Imperial College London

Flavour Physics

–Perspectives from 2014–

13th Rencontres du Vietnam:
Flavour Physics Conference

Introductory Presentation

Yoshi Uchida

14 August 2017

Rencontres du Vietnam: Flavour Conferences

The meeting is intended to promote fruitful collaboration between experimentalists and theorists, between physicists working in the Heavy Flavour, Neutrino, Charged Leptons and Kaon physics domains and between various institutions, by bringing together a limited number of particle physicists in beautiful and inspiring surroundings. A particular emphasis will be made on the searches for new physics to complement direct studies at the LHC.

- The First Rencontres du Vietnam Flavour Conference was held here in 2014
- Bringing together theorists and experimentalists from across the field of flavour physics

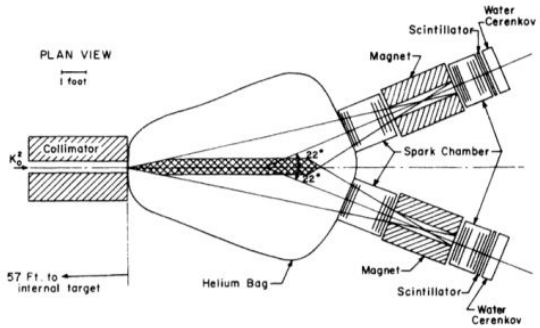
- Today will review the status of the field at the time—looking back, so we can look forwards....
  - only showing a few slides from a subset of the talks from 2014
  - *not* a summary talk!

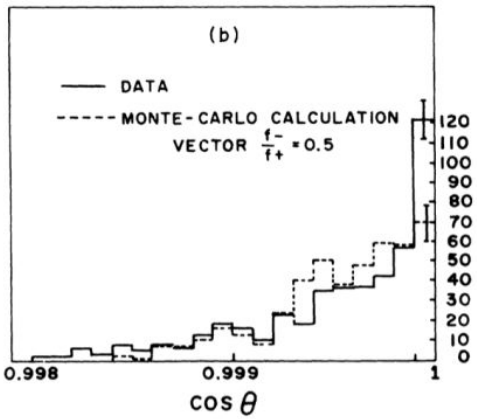
Perspectives from 2014

- 2014 was the 50th anniversary of the discovery of CP violation in the Kaon
- and the Quark Model

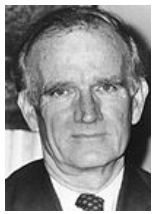
50 years of CP violation

- This year, 50th anniversary of CP violation:
  - In 1964 J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay discovered CPV in the neutral long-lived kaon system: $K_L \to \pi^+\pi^-$





J. Cronin



V. Fitch

1980

Tagir Aushev: *CP Violation: review and perspectives*

Perspectives from 2014

- 2014 was the 50th anniversary of the discovery of CP violation in the Kaon
- and the Quark Model

50 years ago quark was proposed by

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

A formal mathematical model based on field theory can be built up for the quarks exactly as for p, n, Λ in the old Sakata model, for example [3]

(instead of purely mathematical entities as they would be in the limit of infinite mass). Since charge and baryon number are exactly conserved, one of the quarks (presumably $u^{\frac{2}{3}}$ or $d^{-\frac{1}{3}}$) would be absolutely stable *, while the other member of the doublet would go into the first member very slowly by β-decay or K-capture. The isotopic singlet quark would presumably decay into the doublet by weak interactions, much as Λ goes into N. Ordinary

Tatsuya Nakada: *Experimental Summary*

Perspectives from 2014

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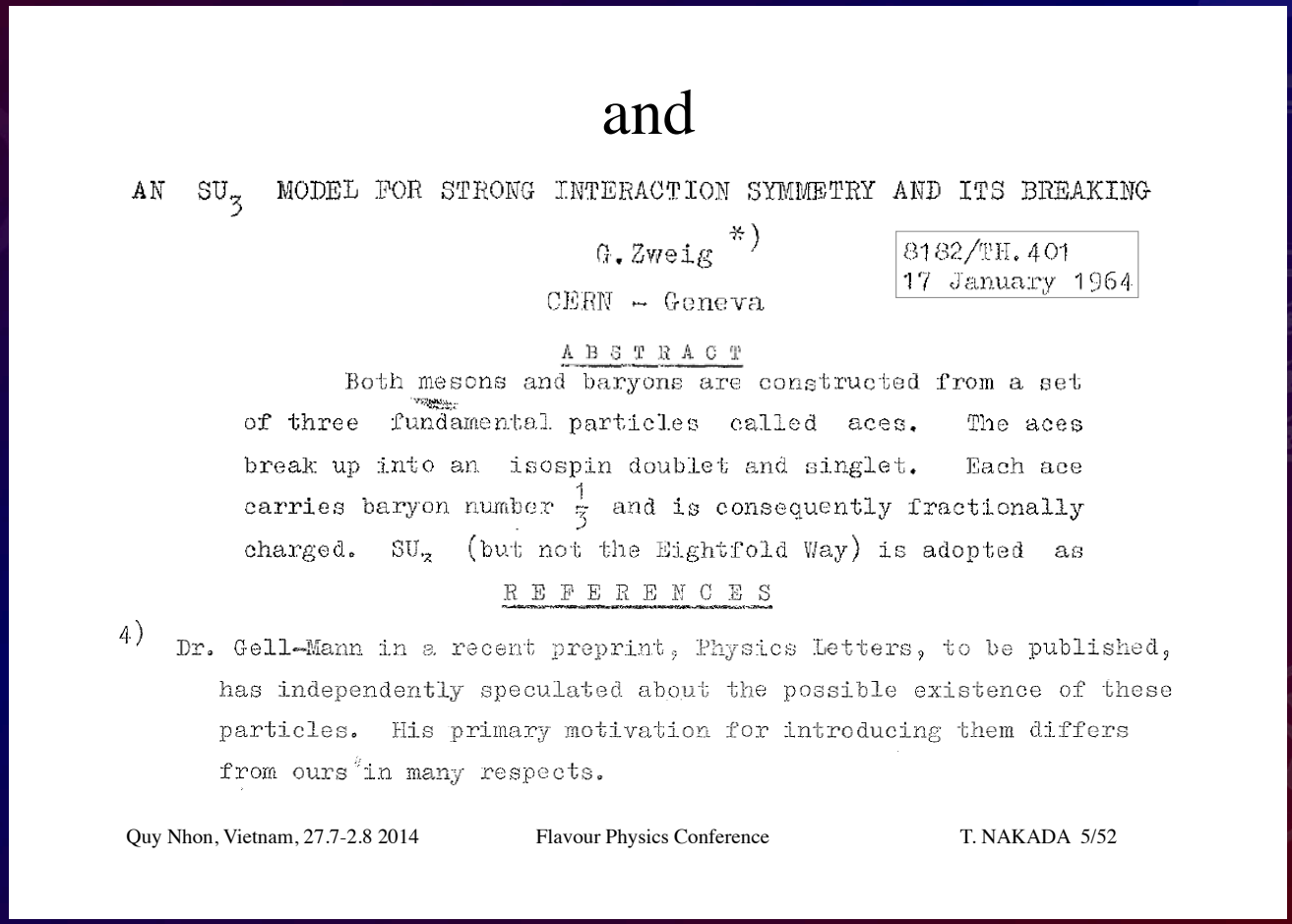

and

AN SU_3 MODEL FOR STRONG INTERACTION SYMMETRY AND ITS BREAKING

G. Zweig *)
CERN - Geneva

8182/TH.401
17 January 1964

ABSTRACT

Both mesons and baryons are constructed from a set of three fundamental particles called aces. The aces break up into an isospin doublet and singlet. Each ace carries baryon number $\frac{1}{3}$ and is consequently fractionally charged. SU_2 (but not the Eightfold Way) is adopted as

REFERENCES

4) Dr. Gell-Mann in a recent preprint, Physics Letters, to be published, has independently speculated about the possible existence of these particles. His primary motivation for introducing them differs from ours in many respects.

Quy Nhon, Vietnam, 27.7-2.8 2014 Flavour Physics Conference T. NAKADA 5/52

Tatsuya Nakada: *Experimental Summary*

Flavour Physics

Perspectives from 2014

Some of the various representations of what it means to study Flavour Physics

This provoked me a question

- Is flavour a quantum number related to internal symmetry?
- Are "charges" (electric, strong and weak) flavour?
- Are isospins flavour?
- etc. etc.
- Let me define like this:
  "Flavour physics is measuring properties of the processes with changing flavours, literally or virtually, **with precision**." ("virtually", since I have EDM or μ(g−2) in my mind)

Quy Nhon, Vietnam, 27.7-2.8 2014 Flavour Physics Conference T. NAKADA 7/52

Tatsuya Nakada: *Experimental Summary*

Flavour Physics

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Standard Model

→ Based on SU(3)xSU(2)xU(1)

→ 3 families of quarks and leptons, in SU(2) doublets

→ QCD sector: quarks and gluons only

→ Flavour changing left-handed charged current explained through the Cabbibo-Kobayashi-Maskawa formalism

→ Brout-Englert-Higgs mechanism: spontaneous breaking of the electroweak symmetry

→ Extremely successful!!

✓ All predicted particles of the Standard Model have been found 

Nazila Mahmoudi Rencontres du Vietnam 2014 – Theoretical summary 4/48

Nazila Mahmoudi: *Theoretical Summary*

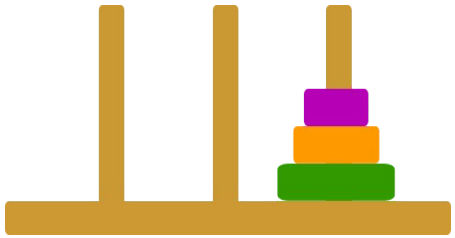
Flavour Physics

Perspectives from 2014

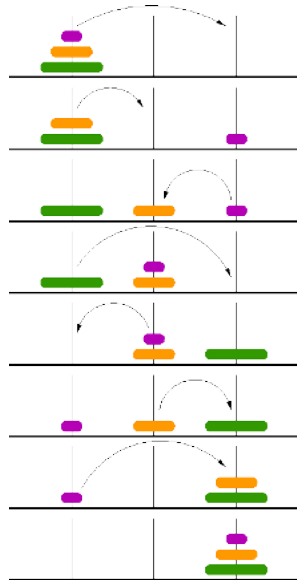
Some of the various representations of what it means to study Flavour Physics

The Standard Model rules!

An easy 3 generation set-up that seems to **rule**!



With well-known and well tested **rules**!



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Nazila Mahmoudi: *Theoretical Summary*

Flavour Physics

Perspectives from 2014

Some of the various representations of what it means to study Flavour Physics

SM parameters

3 gauge couplings

2 Higgs parameters

6 quark masses

3 quark mixing angles + 1 phase

3 charged lepton masses

Flavour Parameters

3 neutrino masses

3 neutrino mixing angles + phases

Extended Neutrino Sector

Flavours are the essence of the SM...

Nazila Mahmoudi Rencontres du Vietnam 2014 – Theoretical summary 6/48

Nazila Mahmoudi: *Theoretical Summary*

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Flavoured questions

Many questions:

→ Hierarchy of quark and lepton masses
→ Absence of flavour changing neutral currents
→ Pattern of mixing angles of quarks and leptons
→ Absence of charged lepton flavour violation
→ Origin of the neutrino masses
→ Existence of right-handed/sterile neutrinos
→ Origin of the baryon asymmetry in the Universe
→ ...

Attempts to answer:

→ Continuous flavour symmetries
→ Discrete flavour symmetries
→ Extra-dimensions
→ Compositeness
→ ...

but no definite answer yet...

Description of the quark sector via the CKM formalism

Nazila Mahmoudi Rencontres du Vietnam 2014 – Theoretical summary 7/48

Nazila Mahmoudi: *Theoretical Summary*

Flavour Physics

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Some of the various representations of what it means to study Flavour Physics

New Physics

No evidence for new particles at the LHC...

Indirect effects in flavour observables?

→ CP violation?

→ Meson mixings?

→ Rare decays?

→ Neutrino sector?

→ Lepton Flavour Violation?

Most of NP scenarios predict deviations in the flavour sector

And flavour physics observables can probe very large NP scales!

Nazila Mahmoudi Rencontres du Vietnam 2014 – Theoretical summary 15/48

Nazila Mahmoudi: *Theoretical Summary*

Flavour Physics

Perspectives from 2017

Some of the various representations of what it means to study Flavour Physics

...and alas, no new 750 GeV states to occupy us

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Nazila Mahmoudi: *Theoretical Summary*

Flavour Physics

Perspectives from 2017

Some of the various representations of what it means to study Flavour Physics

...and alas, no new 750 GeV states to occupy us

Success of SM in describing flavor-changing processes implies that large new sources of flavor symmetry breaking at TeV scale are mostly excluded.

However, NP at TeV scale need not be flavor trivial!

If (properly aligned) new sources of flavor breaking present

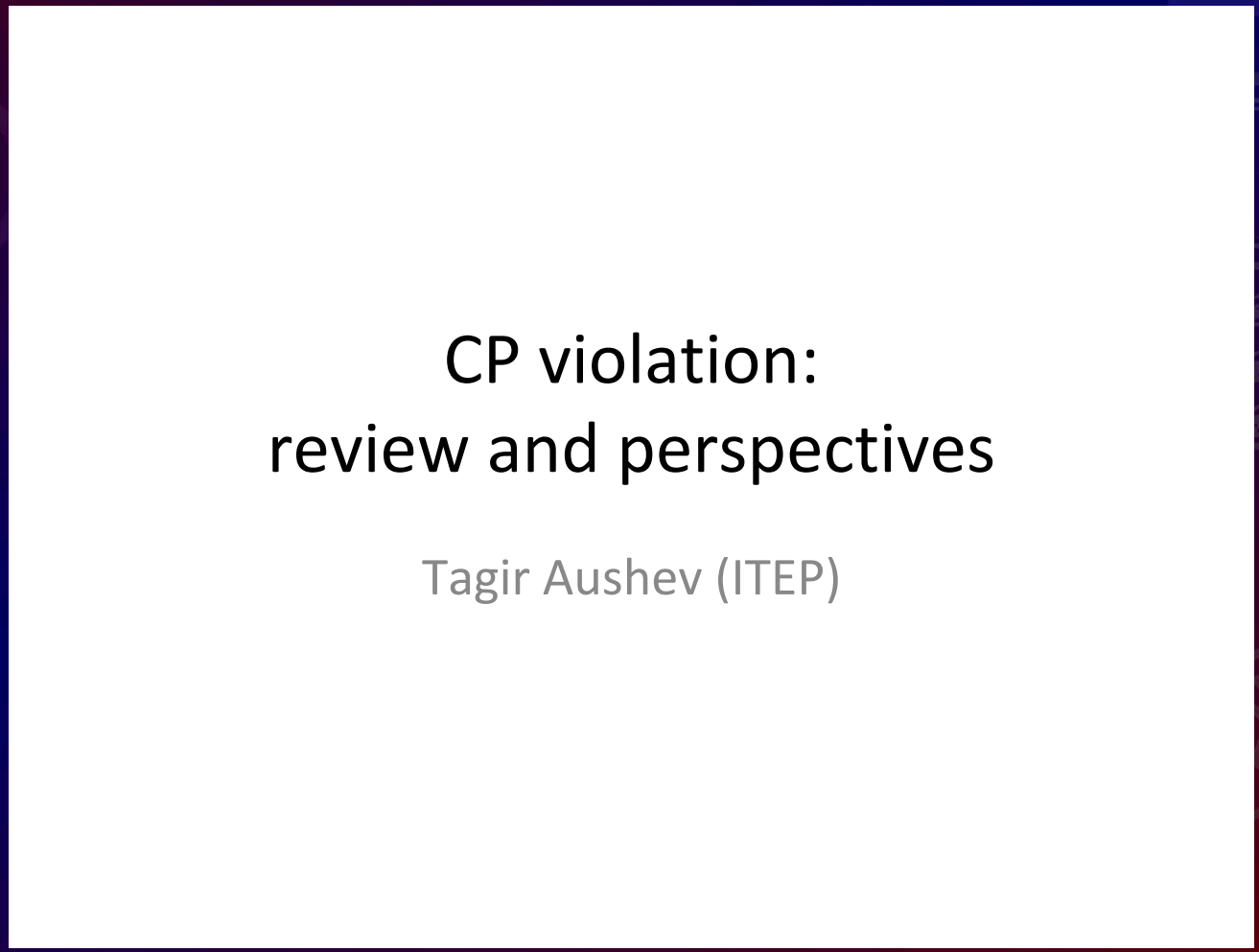
- Precision flavor observables may hide NP signals @10% level in well motivated NP models (natural SUSY)
- can significantly affect & guide NP searches high p_T
- have implications for EW fine-tuning

Jernej Kamenik: *BSM physics driven by a possible solution of hierarchy problem at the electroweak scale*

CP Violation

Perspectives from 2014

CP violation: full review to follow in the afternoon



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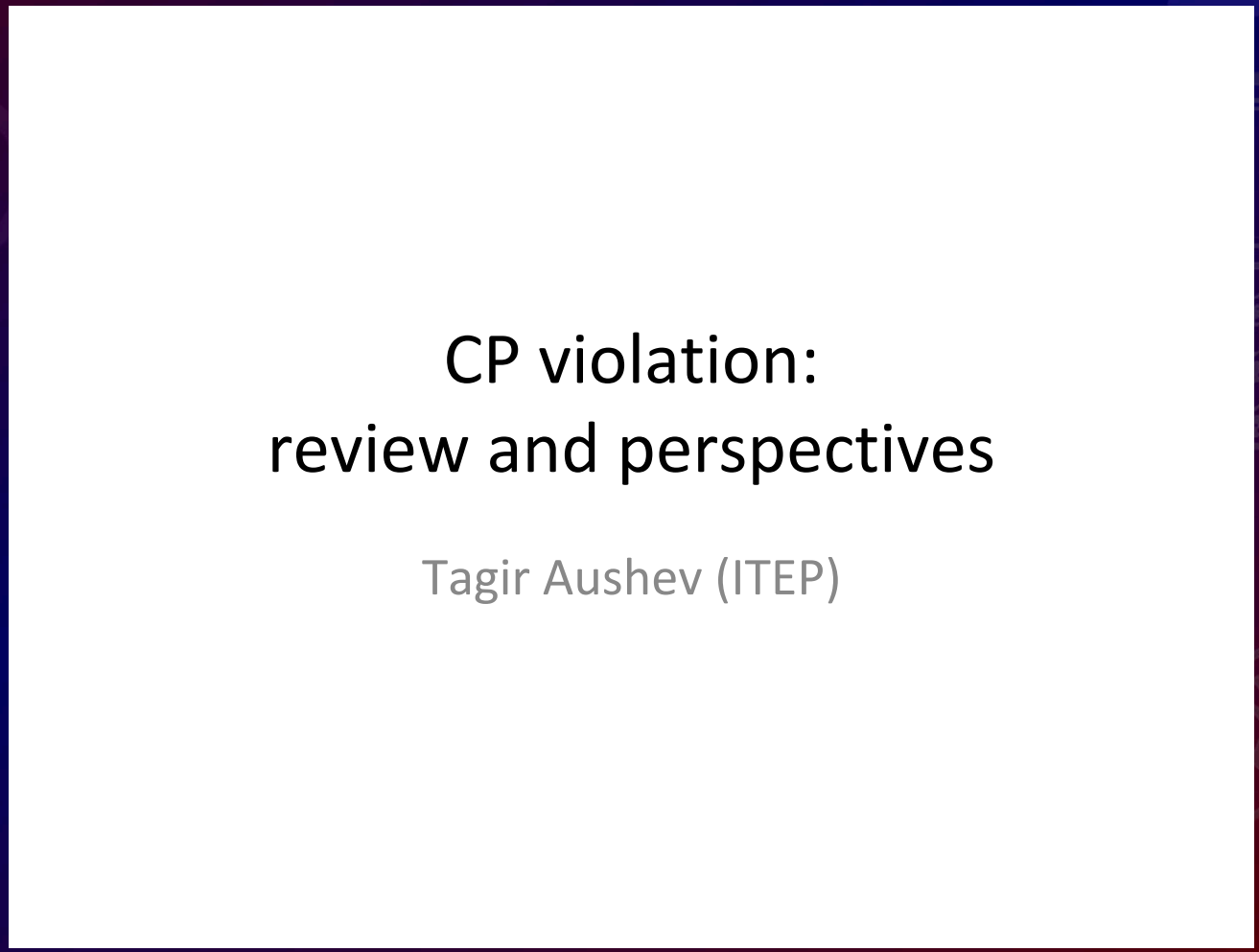

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CP Violation

Perspectives from 2014

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Federer and Nadal are warming up before the game

- If Federer serves faster (more often) than Nadal, sooner or later all balls will be on Nadal's half
  - Q: How much faster Federer should serve to create the existing baryon asymmetry in the Universe?
  - A: Much faster than the current mechanism of CPV

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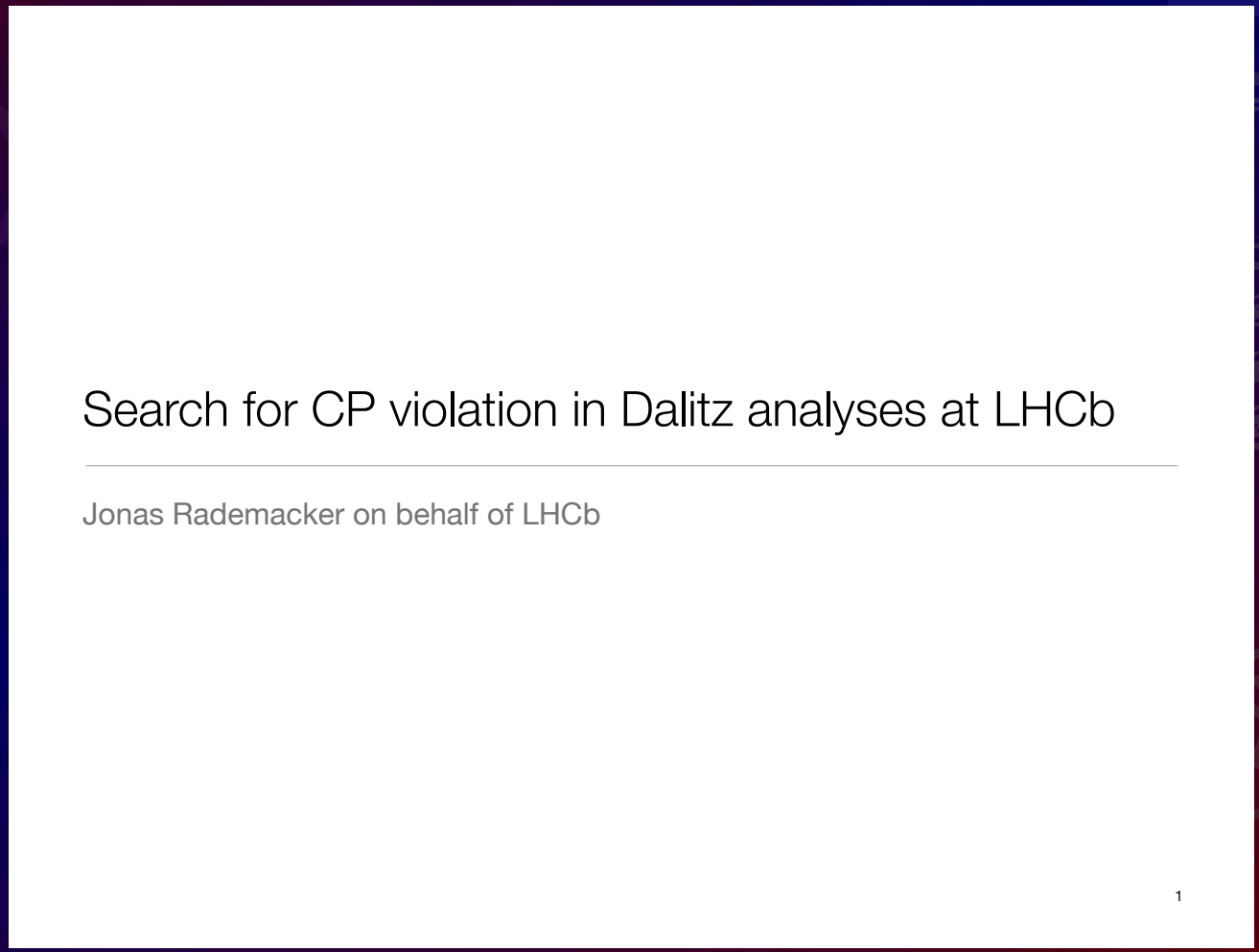
CP Violation

Perspectives from 2014

Use of Dalitz plot methods in three-body decays to extract CPV information



Jonas Rademacker: *Search for CP violation in Dalitz analyses at LHCb*

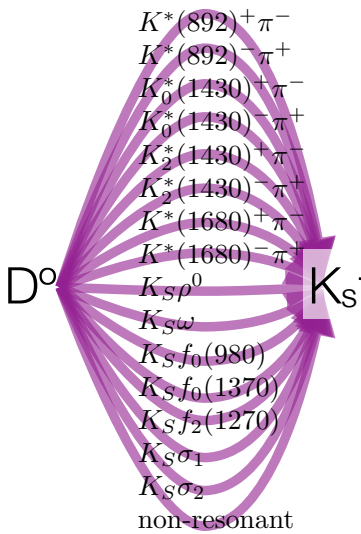
CP Violation

Perspectives from 2014

Use of Dalitz plot methods in three-body decays to extract CPV information

Dalitz plots.

Many interfering decay paths contribute to the same final state



Entire decay kinematics down to two variables. Choose:

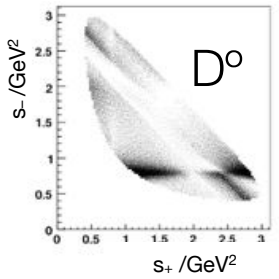
$s_+ = m^2(K_S\pi^+)$,

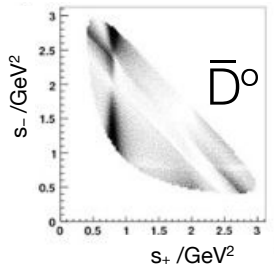
$s_- = m^2(K_S\pi^-)$

Described by a sum of complex amplitudes

$$A(s_+, s_-) = \sum_k a_k(s_+, s_-)\, e^{i\phi_k(s_+, s_-)}$$

$|A(s_+, s_-)|^2$ represented in a Dalitz plot





Jonas Rademacker CP violation in Dalitz analyses at LHCb Xth Rencontres du Vietnam - Flavour Physics Quy Nhon, 28 July 2014 4

Jonas Rademacker: *Search for CP violation in Dalitz analyses at LHCb*

CP Violation

Perspectives from 2014

Use of Dalitz plot methods in three-body decays to extract CPV information

Dalitz plots.

Many interfe… paths cont… the same fi…

$K^*(89…$
$K^*(89…$
$K_0^*(14…$
$K_0^*(14…$
$K_2^*(14…$
$K_2^*(14…$
$K^*(16…$
$K^*(16…$
$K_S\rho^0$
$K_S\omega$
$K_S f_0(980)$
$K_S f_0(1370)$
$K_S f_2(1270)$
$K_S\sigma_1$
$K_S\sigma_2$
non-resonant

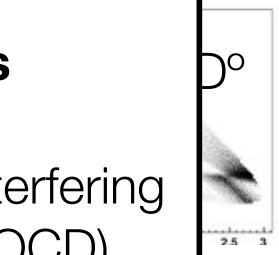
D° → $K_S\pi^+\pi^-$

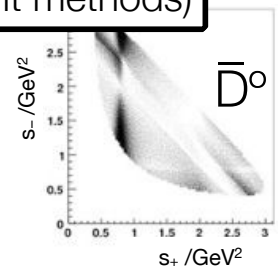
$$A(s_+, s_-) = \sum_k a_k(s_+, s_-)\, e^{i\phi_k(s_+,s_-)}$$

Key advantage of Dalitz plots for CPV:
Sensitivity to **phases**

Key problem: **Modelling** interfering amplitudes is tricky (soft QCD)
(often solved with model-independent methods)

…resented …z plot





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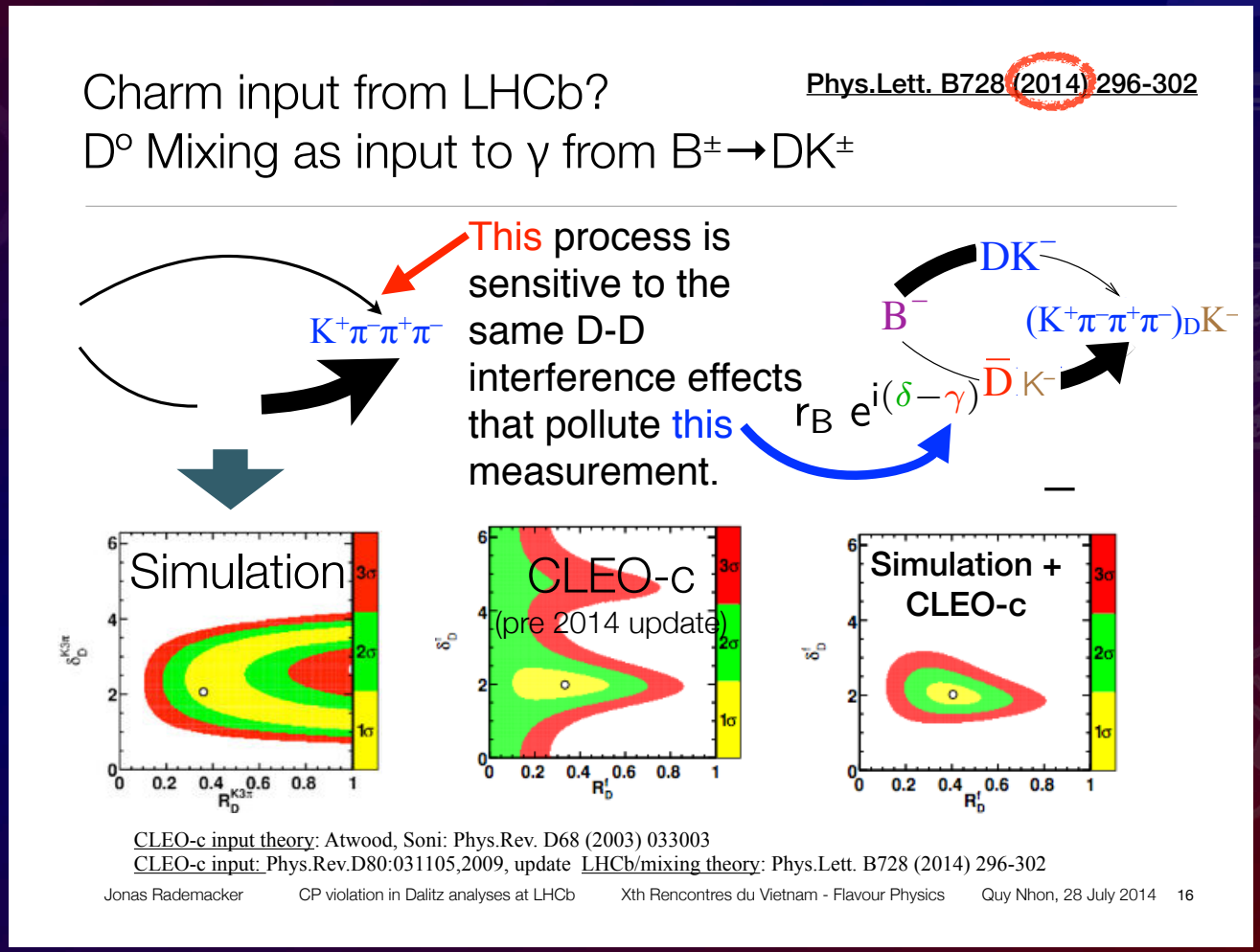
Use of Dalitz plot methods in three-body decays to extract CPV information



Jonas Rademacker: *Search for CP violation in Dalitz analyses at LHCb*

CP Violation

Perspectives from 2014

Use of Dalitz plot methods in three-body decays to extract CPV information

Searches for CPV by comparing binned Dalitz plots

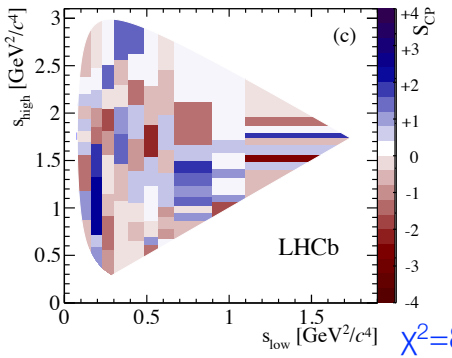
- Compare yields in CP-conjugate bins

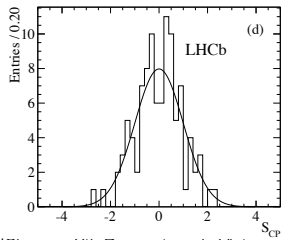
$$\alpha = \frac{N_{\text{total}}}{\bar{N}_{\text{total}}}$$

- Calculate p-value for no-CPV hypothesis based on
- Model independent. Many production and detection effects cancel.

3.1M $D^{\pm} \to \pi\pi\pi$ in 1/fb

Phys.Lett. B728 (2014) 585-595





χ^2=89.1 for 100 bins - compatible with CP conservation at

p=75%

(other binning schemes lead to similar result)

Jonas Rademacker CP violation in Dalitz analyses at LHCb Xth Rencontres du Vietnam - Flavour Physics Quy Nhon, 28 July 2014 20

Jonas Rademacker: *Search for CP violation in Dalitz analyses at LHCb*

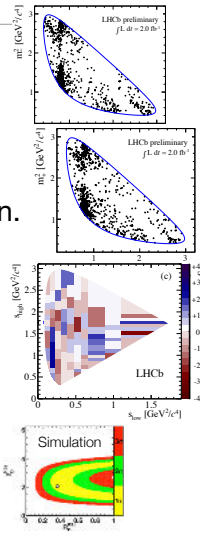
CP Violation

Perspectives from 2014

Use of Dalitz plot methods in three-body decays to extract CPV information

Conclusion

- Amplitude analyses applied to LHCb's very large, very clean heavy flavour data provide powerful precision tests of the SM description of CPV. This includes
  - Most precise measurement of γ - with new channels to maximise precision.
  - Observation large local CPV in $B^{\pm} \to 3$ hadron Dalitz plots.
  - CPV tests in LHCb's truly enormous charm samples.
- Experimental precision possible at LHCb beats theoretical precision of Dalitz plot analyses in many cases. Benefit from model-independent methods, with input from CLEO-c, BES III, and even LHCb itself.
- We only just got started. The LHCb upgrade provides the opportunity towards sub-1° precision on γ and precision in charm CPV reaching down to the SM values.

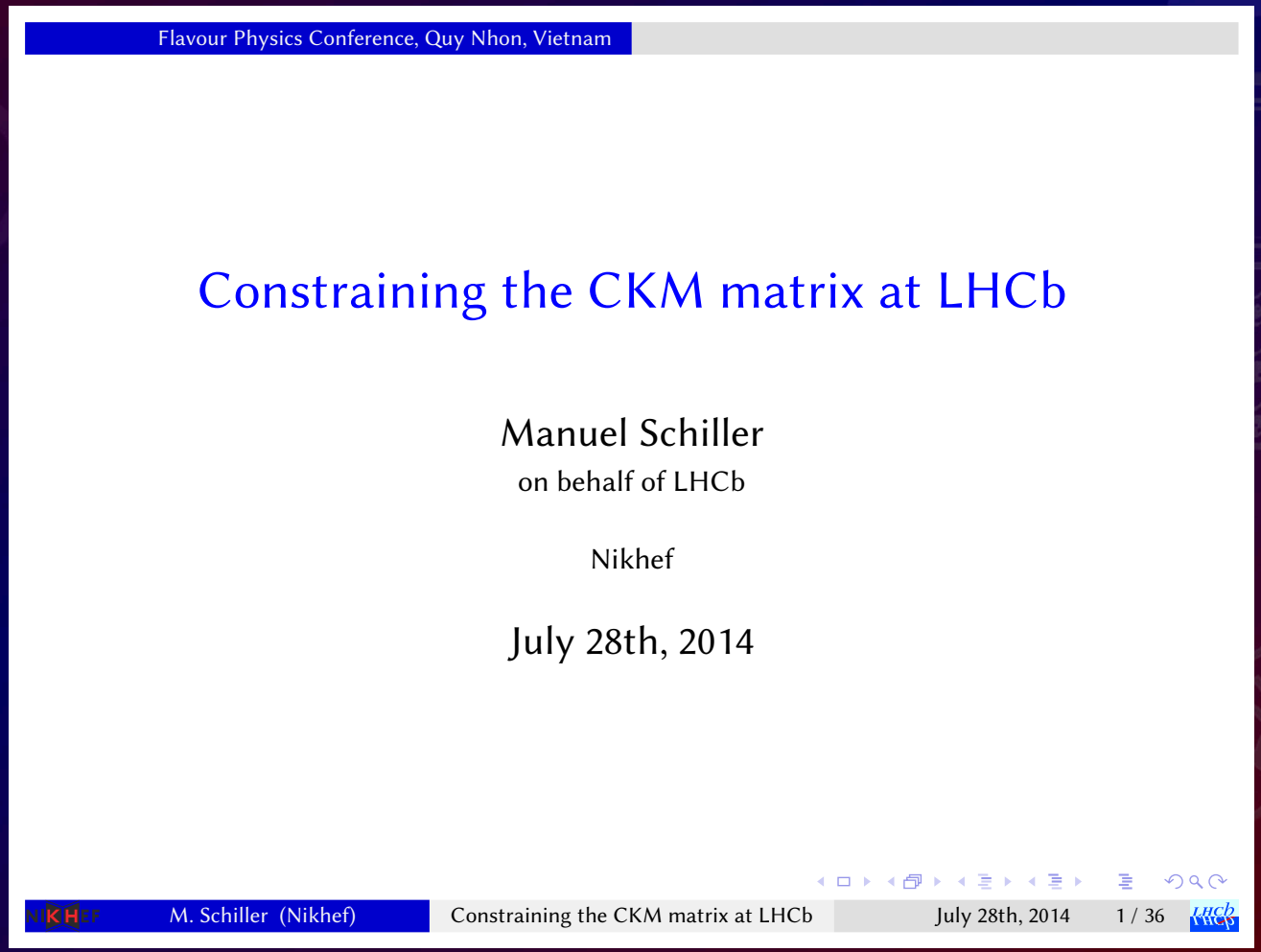


See Wander Baldini, Tuesday

Jonas Rademacker: *Search for CP violation in Dalitz analyses at LHCb*

CP Violation

Perspectives from 2014



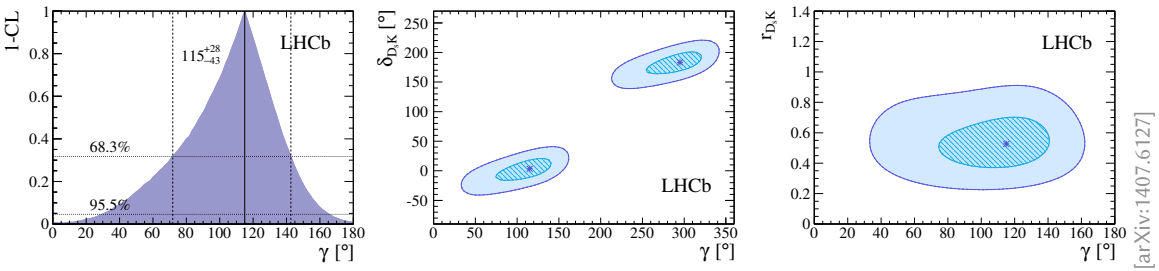
Manuel Schiller: *Constraining the CKM matrix at LHCb*

CP Violation

Perspectives from 2014

time-dependent γ

improving $B_s \to D_s K$



- extract γ based on cFit results

$$\gamma = (115^{+28}_{-43})^\circ \quad \delta = (3^{+19}_{-20})^\circ \quad r_{D_sK} = 0.53^{+0.17}_{-0.16}$$

- sensitivity: $\sigma(\gamma) \approx 36^\circ \sqrt{\text{fb}^{-1}}$

$\to$ competitive!

- plan to add more final states for 3fb^{-1}, also with neutrals like $B_s^0 \to D_s^*(D_s\gamma)K$

Manuel Schiller: *Constraining the CKM matrix at LHCb*

CP Violation

Perspectives from 2014

D^0-mixing and CP Violation in Charm at Belle

Marko Starič

Belle collaboration Jožef Stefan Institute, Ljubljana

Xth Rencontres du Vietnam

Marko Staric: *D0-mixing and CP Violation in Charm at Belle*

CP Violation

Perspectives from 2014

Conclusions

- D^0-mixing measurements in the three most sensitive decay modes were updated with the Belle final data set ($\sim 1\ \mathrm{ab}^{-1}$)
  - $D^0 \to K^+\pi^-$: 5.1σ observation
  - $D^0 \to K^+K^-, \pi^+\pi^-$: 4.5σ evidence in y_{CP}
  - $D^0 \to K^0_s\pi^+\pi^-$: most stringent limits on x
- No evidence for indirect CP violation.
- CP violation was searched in many decay modes using time-integrated approach
  - no evidence found for CPV in the charm sector
  - can see CPV due to K^0-mixing in $D^+ \to K^0_S\pi^+$ decay

Marko Staric: *D0-mixing and CP Violation in Charm at Belle*

CP Violation

Perspectives from 2014

Studies of CP violation with the ATLAS detector in the decay $B_s \rightarrow J/\psi\,\phi$

James Walder
On behalf of the ATLAS Collaboration

Flavour tagged time dependent angular analysis of $B_s \rightarrow J/\psi(\mu\mu)\,\phi(KK)$ using 2011 4.9 fb^{-1} data.
Recently submitted to PRD: arXiv:1407.1796
Update to untagged analysis: JHEP 12 (2012) 072

LANCASTER UNIVERSITY

James Walder: *Studies of CP violation with the ATLAS detector in the decay $B_s \rightarrow J/\psi\phi$*

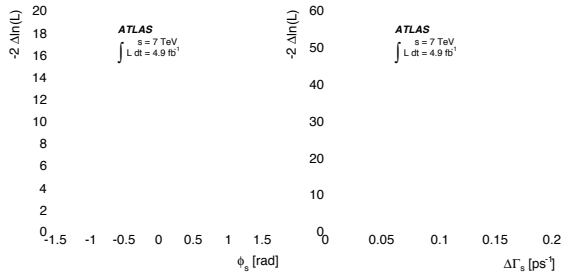
CP Violation

Perspectives from 2014

Results

- From the fit the parameters ϕ_s, Γ_s $\Delta\Gamma_s$, amplitudes and strong phases are extracted.
  - Ambiguity in sign of $\Delta\Gamma_s$
  - Constrain $\Delta\Gamma_s > 0$

PRL 108 (2012) 241801



- The contribution of $B_s^0 \to J/\psi K^+ K^-$ and $B_s^0 \to J/\psi f_0$ is consistent with zero, within the uncertainties
- Measurements are compatible with theory and other experiments.

21

James Walder: *Studies of CP violation with the ATLAS detector in the decay $B_s \to J/\psi\phi$*

CP Violation

Perspectives from 2014

Conclusions

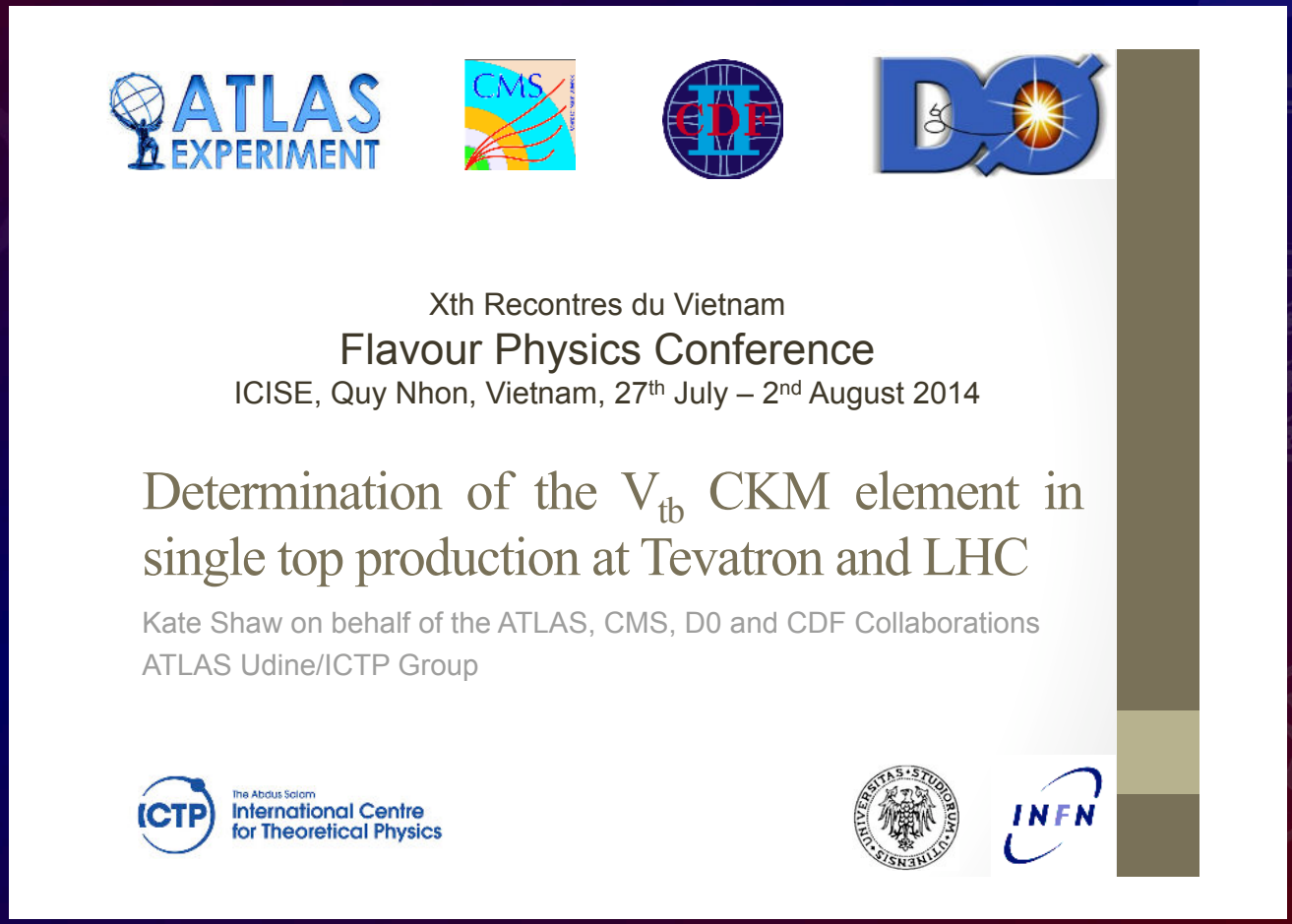
- Time-dependent Flavour-tagged angular measurement performed in the decay $B_s^0 \to J/\psi\phi$, using data from 2011
  - The weak phase ϕ_s, and $\Delta\Gamma_s$ are found to be:
  -
  - Within the uncertainties, no S-wave contribution is reported.
- The results are in good agreement with SM expectations and other experimental results
- This result improves on previously (untagged) published result
  - JHEP 12 (2012) 072 using the same dataset,
  - and is submitted to PRD: CERN-PH-EP-2014-043, arXiv:1407.1796
- With 2012 data from run-I of LHC to be included, with significant increase in statistics, precision will be improved.
- Run-II data-taking (and beyond) will be exciting time to produce precision measurements.

24

James Walder: *Studies of CP violation with the ATLAS detector in the decay $B_s \to J/\psi\phi$*

CP Violation

Perspectives from 2014



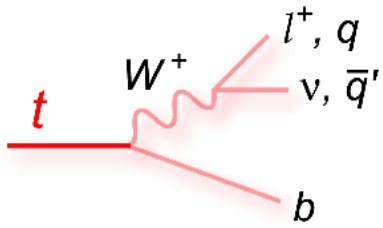
Kate Shaw: *Determination of the Vtb CKM element in single top production at Tevatron and LHC*

CP Violation

Perspectives from 2014

Top Quark

- Top-quark is the most massive known fundamental particle
- It was discovered in 1995 at the Tevatron by CDF and D0
- Its mass is of the order of the electroweak symmetry breaking scale - probe for new physics



Lifetime of the top is shorter than the timescale of hadronisation

Top-quarks decay almost 100% to W-boson and Bottom-quark $|V_{tb}| \sim 1$

Final state topology is dictated by the leptonic or hadronic decay of the W-boson

Flavour Physics Conference 28th July 2014

3

Kate Shaw: *Determination of the Vtb CKM element in single top production at Tevatron and LHC*

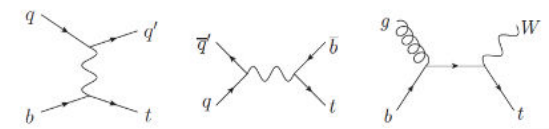
CP Violation

Perspectives from 2014

Directly Measuring $|V_{tb}|$

- The single top cross-section is directly proportional to the square of the coupling at the production vertex, thus proportional to $|V_{tb}|^2$
  - Assuming $|V_{tb}| >> V_{ts}$ and $|V_{tb}| >> V_{td}$
  - Assuming Wtb interaction is a SM-like left-handed weak coupling

$$|V_{tb}| = \sqrt{\sigma_{meas.}/\sigma_{theory}},$$



σ_{theory} assumes $|V_{tb}| = 1$

- No dependence on unitarity of CKM matrix, thus a good test for unitarity and probe for fourth quark generation or BSM physics

Flavour Physics Conference 28th July 2014

7

Kate Shaw: *Determination of the Vtb CKM element in single top production at Tevatron and LHC*

CP Violation

Perspectives from 2014

Summary

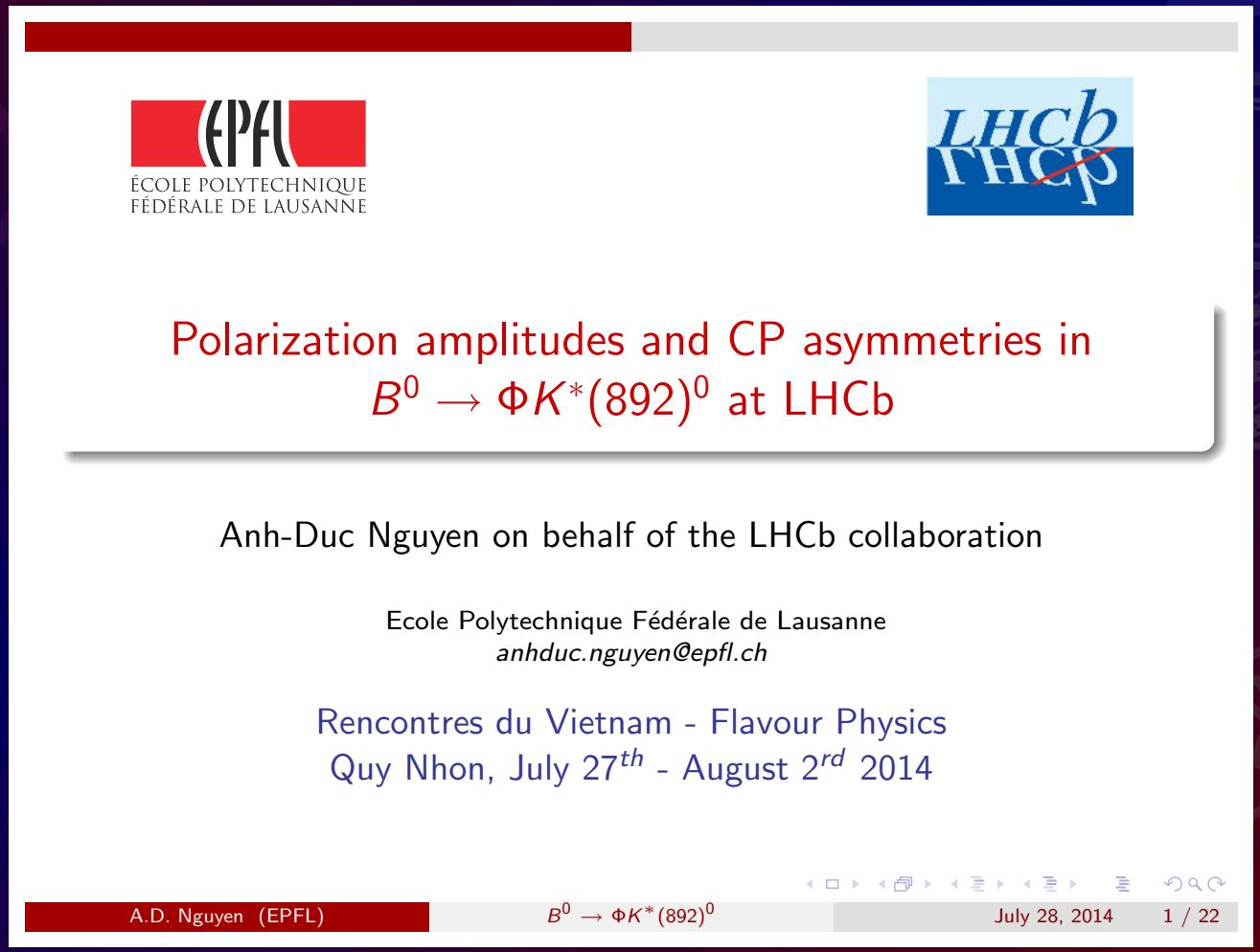
$|V_{tb}|$ determination in single top production without unitarity constraint

	ch.	< $\|V_{tb}\|$	|Vtb| measured value
CDF (1.96 TeV)	s+t	0.84	
D0 (1.96 TeV)	s+t	0.92	1.12 +0.09 – 0.08
CMS (7+8 TeV)	t	0.92	0.998 ± 0.038 (exp.) ± 0.016 (th.)
ATLAS (7 (8) TeV)	t	0.88 (0.78)	1.02 ± 0.07 (0.97 +0.09 – 0.10)
CMS	Wt	0.78	1.03 ± 0.12 (exp.) ± 0.04 (th.)
ATLAS	Wt	0.72	1.10 ± 0.12 (exp.) ± 0.03 (th.)

Kate Shaw: *Determination of the Vtb CKM element in single top production at Tevatron and LHC*

CP Violation

Perspectives from 2014



ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

LHCb

Polarization amplitudes and CP asymmetries in $B^0 \to \Phi K^*(892)^0$ at LHCb

Anh-Duc Nguyen on behalf of the LHCb collaboration

Ecole Polytechnique Fédérale de Lausanne
anhduc.nguyen@epfl.ch

Rencontres du Vietnam - Flavour Physics
Quy Nhon, July 27^{th} - August 2^{rd} 2014

A.D. Nguyen (EPFL) | $B^0 \to \Phi K^*(892)^0$ | July 28, 2014 | 1 / 22

A.D. Nguyen: *Polarization amplitudes and CP asymmetries in $B^0 \to \phi K^*(892)^0$ at LHCb*

CP Violation

Perspectives from 2014

Conclusion

- The results for the P-wave parameters for the decay mode $B^0 \to \phi K^{*0}$ are consistent with, but more precise than previous measurements
- The CP asymmetries are consistent with no direct CP violation.
- The difference in direct CP asymmetries between the $B^0 \to \phi K^{*0}$ and $B^0 \to J/\psi K^{*0}$ where CP violation is predicted to be very small ($\sim 10^{-3}$) is also measured,

$$\Delta A_{CP} = (+1.5 \pm 3.2 \pm 0.5)\,\% \,,$$

This is a factor of two more precise than previous values reported by BaBar and Belle and is found to be consistent with zero

A.D. Nguyen: *Polarization amplitudes and CP asymmetries in $B^0 \to \phi K^*(892)^0$ at LHCb*

CP Violation

Perspectives from 2014

Conclusion

- This analysis was done with 2011 data ($1.0\,\text{fb}^{-1}$ at $\sqrt{s} = 7$ TeV)
  New results and measurements with full 2011 and 2012 data ($2.0\,\text{fb}^{-1}$ at $\sqrt{s} = 8$ TeV) will come soon

Parameter	Fitted value 2011 data	Lausanne (not yet approved) 2012 data
f_{L}	$0.497 \pm 0.019 \pm 0.015$	0.498 ± 0.011
$f_{\perp}$	$0.221 \pm 0.016 \pm 0.013$	0.214 ± 0.009
$f_{\mathrm{S}}(K\pi)$	$0.143 \pm 0.013 \pm 0.012$	0.129 ± 0.007
$f_{\mathrm{S}}(KK)$	$0.122 \pm 0.013 \pm 0.008$	0.090 ± 0.007
$\delta_{\perp}$	$2.633 \pm 0.062 \pm 0.037$	2.557 ± 0.036
$\delta_{\parallel}$	$2.562 \pm 0.069 \pm 0.040$	2.456 ± 0.036
$\delta_{\mathrm{S}}(K\pi)$	$2.222 \pm 0.063 \pm 0.081$	2.971 ± 0.037
$\delta_{\mathrm{S}}(KK)$	$2.481 \pm 0.072 \pm 0.048$	2.131 ± 0.045
$\mathcal{A}_0^{CP}$	$-0.003 \pm 0.038 \pm 0.005$	-0.034 ± 0.022
$\mathcal{A}_{\perp}^{CP}$	$+0.047 \pm 0.074 \pm 0.009$	-0.053 ± 0.042
$\mathcal{A}_S(K\pi)^{CP}$	$+0.073 \pm 0.091 \pm 0.035$	$+0.124 \pm 0.052$
$\mathcal{A}_S(KK)^{CP}$	$-0.209 \pm 0.105 \pm 0.012$	$+0.005 \pm 0.074$
$\delta_{\perp}^{CP}$	$+0.062 \pm 0.062 \pm 0.005$	$+0.045 \pm 0.036$
$\delta_{\parallel}^{CP}$	$+0.045 \pm 0.069 \pm 0.015$	$+0.017 \pm 0.036$
$\delta_S(K\pi)^{CP}$	$+0.062 \pm 0.062 \pm 0.022$	$+0.056 \pm 0.036$
$\delta_S(KK)^{CP}$	$+0.022 \pm 0.072 \pm 0.004$	$+0.031 \pm 0.045$

A.D. Nguyen: *Polarization amplitudes and CP asymmetries in $B^0 \to \phi K^*(892)^0$ at LHCb*

CP Violation

Perspectives from 2014

Interpreting CP Violation in Hadronic Heavy Meson Decays

Martin Jung

technische universität dortmund

Bundesministerium für Bildung und Forschung

Talk at Xth Rencontres du Vietnam, Flavour Physics
ICISE, Quy Nhon, Vietnam
28th of July 2014

Martin Jung: *Interpreting CP Violation in Hadronic Heavy Meson Decays*

CP Violation

Perspectives from 2014

Power counting

SU(3) breaking typically $\mathcal{O}(30\%)$

Several other suppression mechanisms involved:

- CKM structure (λ, but also $R_u \sim 1/3$)
- Topologial suppression: penguins and annihilation
- $1/N_C$ counting

All these effects should be considered!

- Combined power counting in $\delta \sim 30\%$ for all effects
- Neglect/Constrain only multiply suppressed contributions

Yields predictive frameworks with weaker assumptions!

- Uses full set of observables for related decays
- Assumptions can be checked within the analysis

Martin Jung: *Interpreting CP Violation in Hadronic Heavy Meson Decays*

Global fits to CKM data

Phillip Urquijo (The University of Melbourne)
On behalf of the CKMfitter Group

Rencontres du Vietnam
July 2014

CKM fitter

THE UNIVERSITY OF MELBOURNE

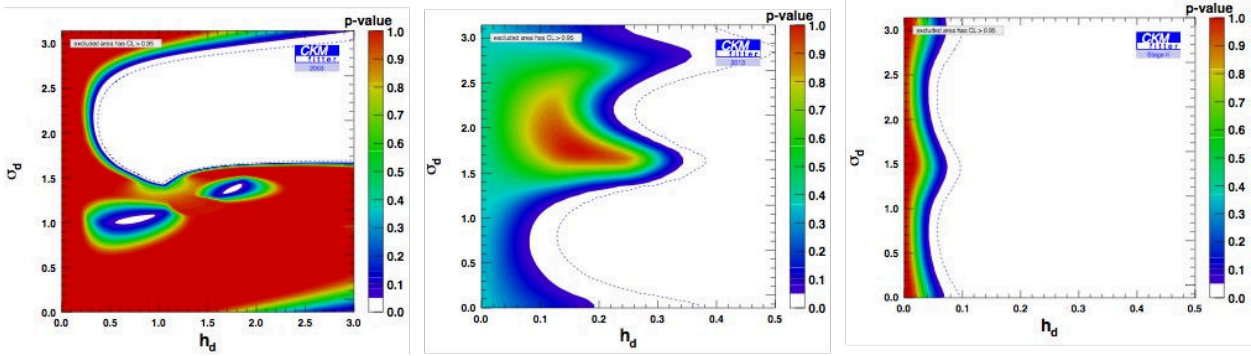
CP Violation

Perspectives from 2014

NP in B_d mixing: Fit results

PRD 89, 033016 (2014)

2003 2013 LHCb Upg.+ Belle II



- at 95% NP≲(many × SM) ⟹ NP≲(0.3 × SM) ⟹ NP≲(0.05 × SM)

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \left(\frac{4.5 \text{ TeV}}{\Lambda} \right)^2$$

$$\lambda_{ij}^t = V_{ti} V_{tj}^* \qquad \sigma = \arg(C_{ij} \lambda_{ij}^{t*})$$

By Stage II,
Λ ~ 20 TeV (**tree**)
Λ ~ 2 TeV (**loop**)

- Stage II: similar sensitivity to gluino masses explored at LHC 14TeV

July 2014, Rencontres du Vietnam, CKMfitter fits Phillip URQUIJO 22 THE UNIVERSITY OF MELBOURNE

Phillip Urquijo: *Globa fits to CKM data*

Research On Event Search Technologies

Perspectives from 2014

Andrey Ustyuzhanin: *Research on Event Search*

Research On Event Search Technologies

Perspectives from 2014

Sources of better sensitivity

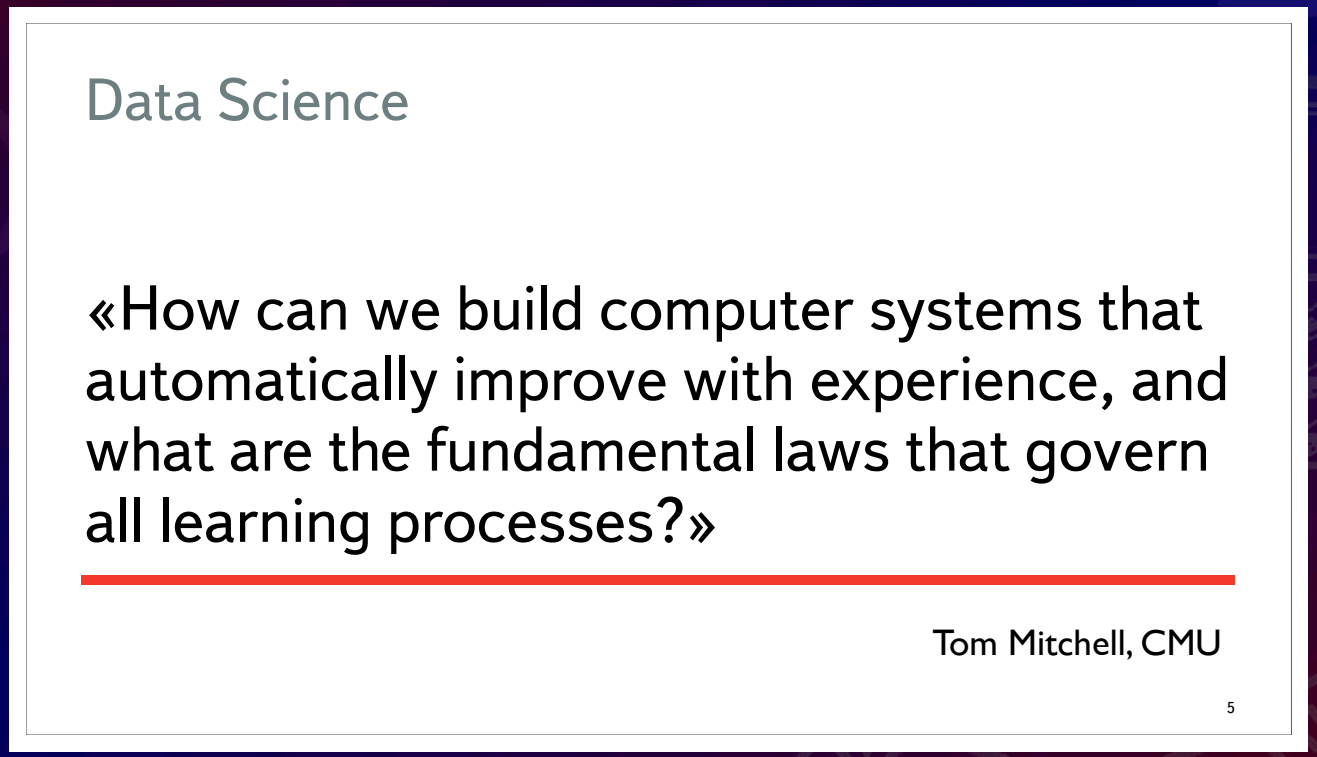
1. more powerful algorithms (e.g. BDT, Deep Neural Networks)
2. improved features (e.g. «isolation» variables or particle identification)
3. complex training schemes (e.g. n-folding, ensembling, blending, cascading)

4

Andrey Ustyuzhanin: *Research on Event Search*

Research On Event Search Technologies

Perspectives from 2014



Andrey Ustyuzhanin: *Research on Event Search*

Research On Event Search Technologies

Perspectives from 2014

Research reproducibility

- By yourself
- By your team members
- By member of another team in the same domain (HEP, Cosmology, ...)
- By someone else

Requires dedicated framework!

13

Andrey Ustyuzhanin: *Research on Event Search*

Research On Event Search Technologies

Perspectives from 2014

Conclusion

- New source of tools & metrics: **data science**
  - ...as well as source of complexity
- **Reproducibility as indicator of mastering complexity**
  - Environment (http://bit.ly/1fCjEqg, ~10th April, LHCb Analysis week@CERN)
  - New research methodology emerging

20

Andrey Ustyuzhanin: *Research on Event Search*

Charged Lepton Flavour Violation

Perspectives from 2014

Searching for flavour violation in charged leptons has unique properties:

- zero rate within SM, because of accidental symmetry
- effectively zero when BSM physics of massive neutrinos inserted
- but this is only due to very specific cancellations (tiny and *similar* neutrino masses)

Yoshi Kuno: *Charged Lepton Flavour Violation: An Introduction*

Charged Lepton Flavour Violation

Perspectives from 2014

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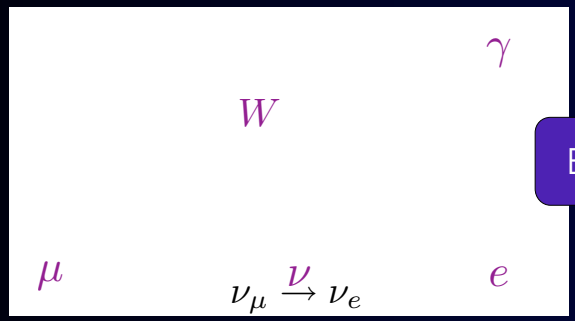
- zero rate within SM, because of accidental symmetry
- effectively zero when BSM physics of massive neutrinos inserted
- but this is only due to very specific cancellations (tiny and *similar* neutrino masses)

SM Contribution is forbidden in CLFV

Osaka University

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_l (V_{MNS})^*_{\mu l}(V_{MNS})_{el}\frac{m^2_{\nu_l}}{M^2_W}\right|^2$$



BR~O(10^{-54})

Observation of CLFV would indicate a clear signal of physics beyond the SM with massive neutrinos.

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Charged Lepton Flavour Violation

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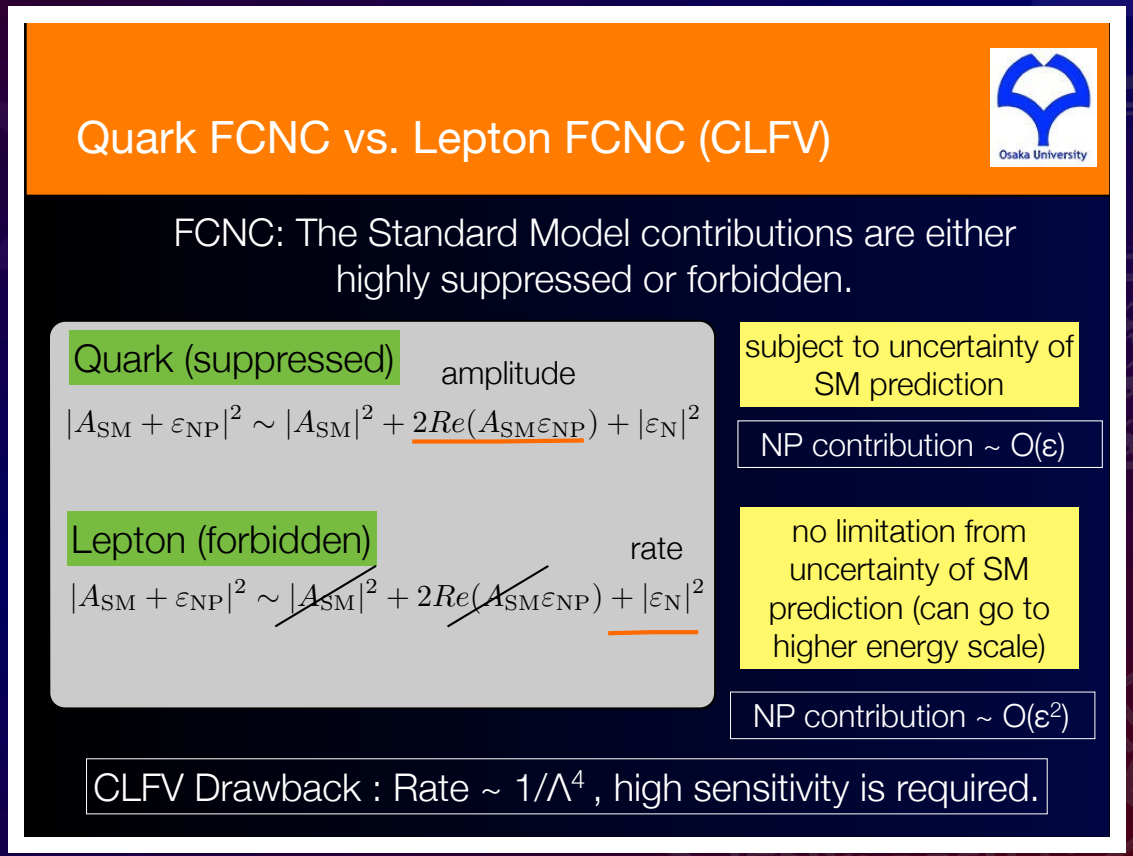

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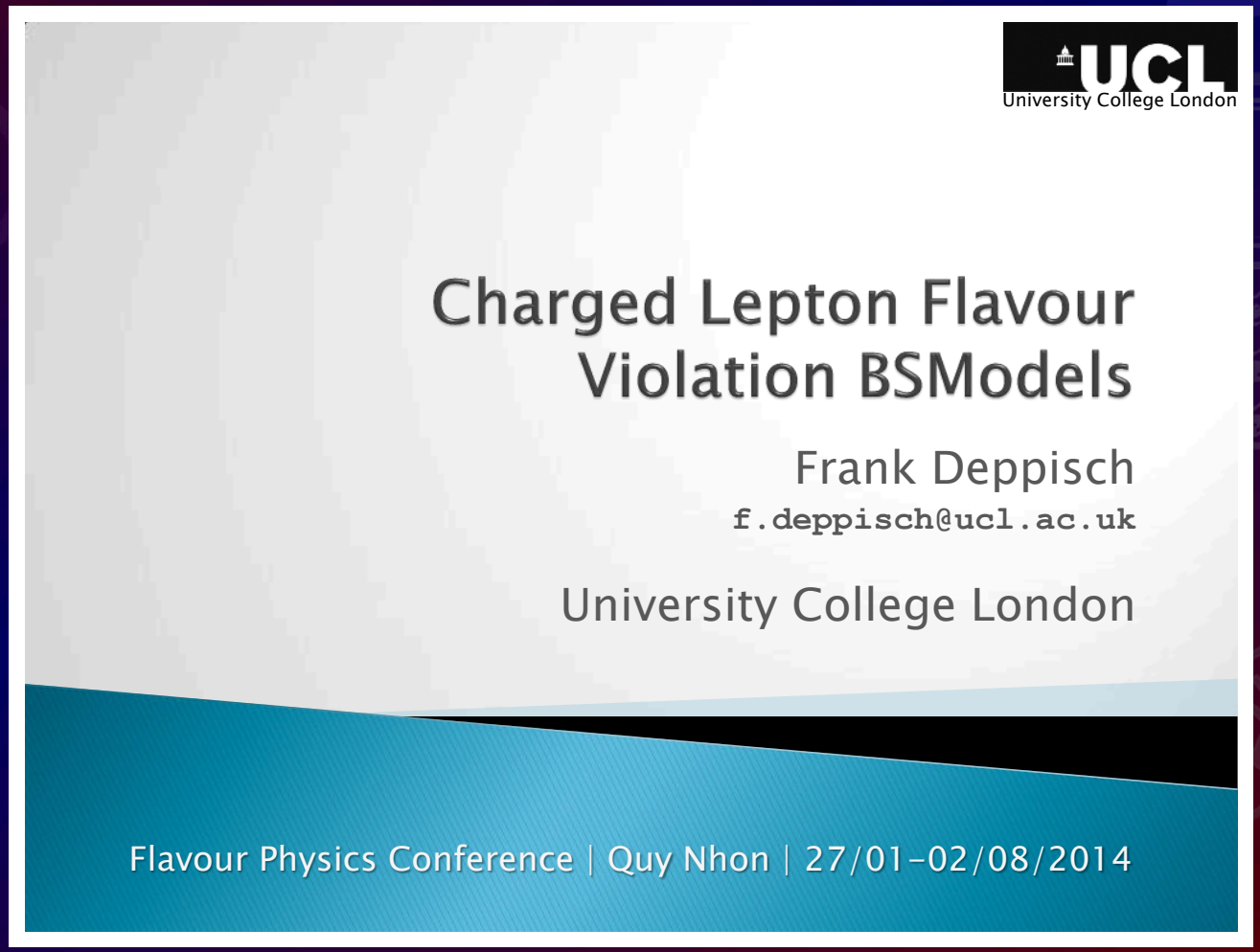
Charged Lepton Flavour Violation

Perspectives from 2014

- Specific links between CLFV and the BSM Flavour Problem
- And observability at the LHC



Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

Perspectives from 2014

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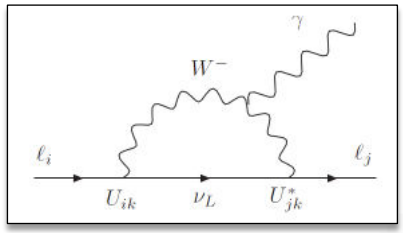
Charged Lepton Flavour Violation

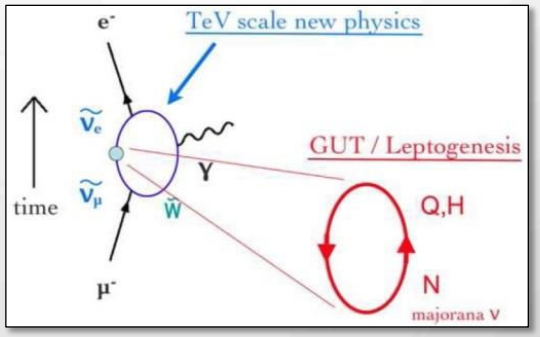
UCL University College London

- Charged Lepton Flavour (practically) conserved in the SM (+ light ν)
  - LFV is clear sign for BSM physics

$$Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_i U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{m^2_W}\right|^2 \approx 10^{-56}$$



- Flavour violation in the quark and neutrino sector
  - Strong case to look for CLFV
- Generic BSModels at TeV scale with couplings to leptons lead to large CLFV
- CLFV can shed light on
  - Grand Unification models
  - Flavour symmetries
  - Origin of flavour



3 / 14

Frank Deppisch | Charged LFV BSModels | 31/07/2014

Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

Perspectives from 2014

- Specific links between CLFV and the BSM Flavour Problem
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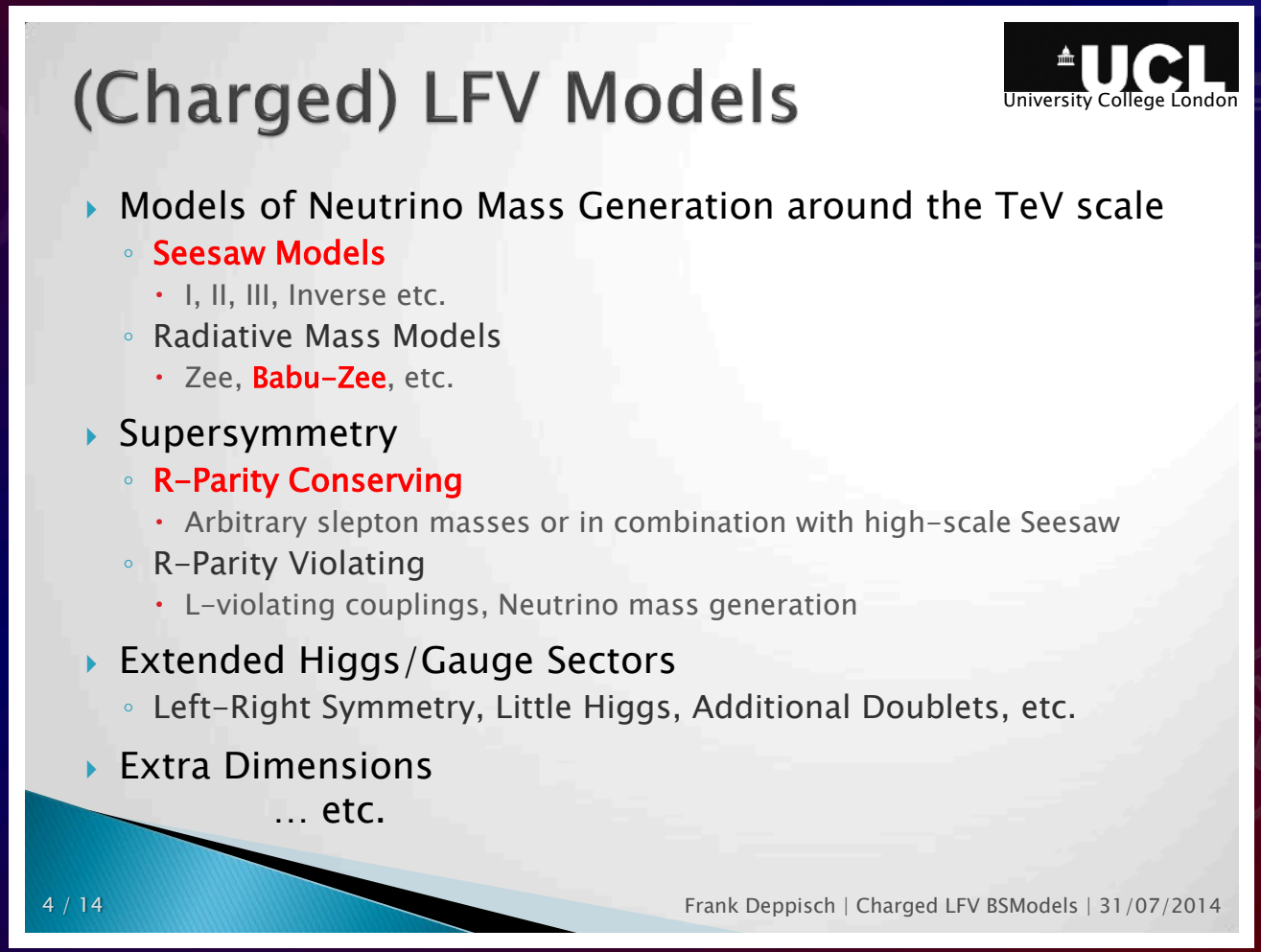

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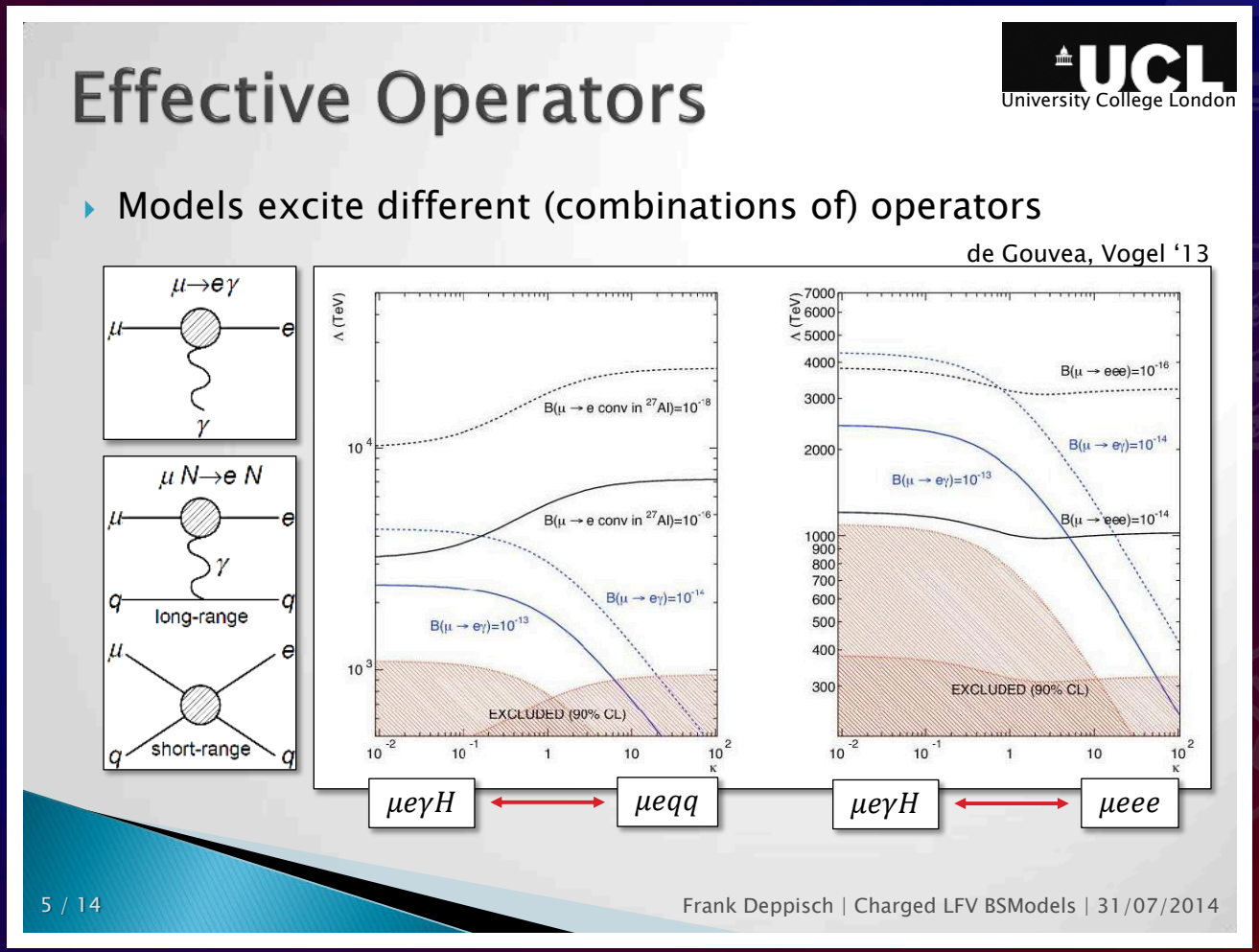

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BSM Flavour Problem

University College London

- Stringent limits on NP operators, e.g.

$$Br(l_i \to l_j \gamma) \approx \frac{24\sqrt{2}\pi^3 \alpha}{G_F^3 m_{l_i}^2 M_{NP}^4} |C_{ij}|^2$$

  - $Br(\mu \to e\gamma) < 5.7 \times 10^{-13} \quad \Rightarrow \quad |C_{\mu e}| < 5 \times 10^{-9} \left(\frac{M_{NP}}{\text{TeV}}\right)^2$
  - $Br(\tau \to l\gamma) < 4.0 \times 10^{-8} \quad \Rightarrow \quad |C_{\tau l}| < 6 \times 10^{-7} \left(\frac{M_{NP}}{\text{TeV}}\right)^2, \; l = e, \mu$
- LFV couplings must be suppressed and/or New Physics scale is larger $\approx 10^3$ TeV
- Solutions
  - No New Physics at the TeV scale
  - Specific flavour structure of New Physics
    - Degeneracy
    - Symmetry (e.g. Minimal Flavour Violation)

6 / 14 Frank Deppisch | Charged LFV BSModels | 31/07/2014

Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

Perspectives from 2014

- Specific links between CLFV and the BSM Flavour Problem
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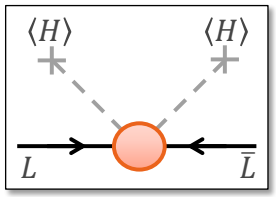
Neutrino Mass Models

UCL University College London

- Effective operator for Majorana neutrino mass
  - Only dimension-5 operator beyond SM

$$\mathcal{L} \supset \frac{1}{2}\frac{h_{ij}}{\Lambda_{LNV}}(\bar{L}_i^c \cdot H)(H^T \cdot L_j) \xrightarrow[\langle H\rangle]{} \frac{1}{2}(m_\nu)_{ij}\bar{\nu}_i^c \nu_j$$

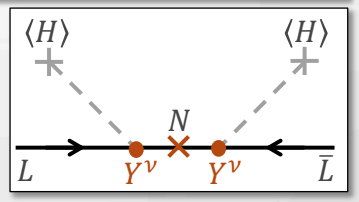


- Seesaw Mechanism
  - Add right-handed neutrinos N_i to SM

$$\mathcal{L} \supset Y_{ij}^\nu \bar{N}_i L_j \cdot H - \frac{1}{2}M_{ij}\bar{N}_i N_j^c \xrightarrow[\mu \ll M_N]{} \frac{1}{2}(Y_{ki}^\nu M_{kl}^{-1} Y_{lj}^\nu)(\bar{L}_i^c \cdot H)(H^T \cdot L_j)$$

- Light neutrino mass

$$m_\nu \approx 0.1\ \text{eV}\left(\frac{Y_\nu \langle H\rangle}{100\ \text{GeV}}\right)^2\left(\frac{10^{14}\ \text{GeV}}{M}\right)$$



7 / 14 Frank Deppisch | Charged LFV BSModels | 31/07/2014

Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

Perspectives from 2014

- Specific links between CLFV and the BSM Flavour Problem
- And observability at the LHC

Neutrino Mass Models

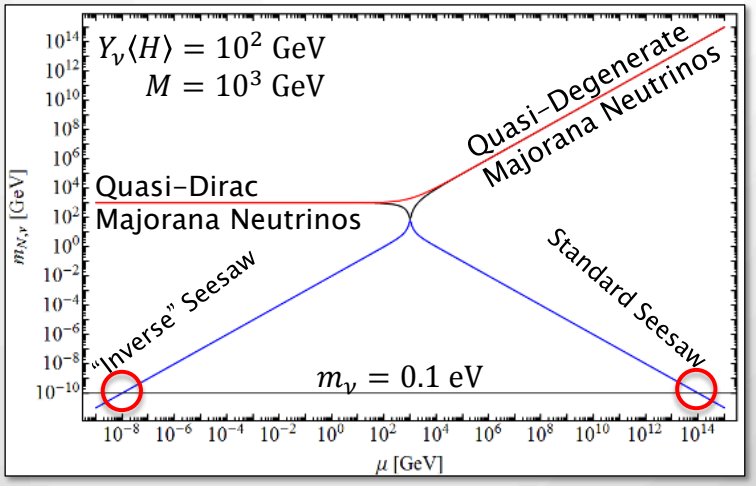
UCL University College London

- Correct light neutrino masses for TeV scale heavy neutrinos
  - Seesaw Mechanism with TeV scale heavy neutrinos
    - Standard Seesaw with small Yukawa couplings
    - CLFV remains small
  - "Bent" Seesaw mechanisms
    - Decouple $\Lambda_{\rm LNV}$ from heavy neutrino mass
    - Example

$$V^{LR} \approx Y_\nu \approx 10^{-6}\sqrt{M_N/\text{TeV}}$$

$$\mathcal{M} = \begin{pmatrix} 0 & Y_\nu\langle H\rangle & 0 \\ Y_\nu\langle H\rangle & \mu & M \\ 0 & M & \mu \end{pmatrix}$$

    - Potentially large CLFV
    - In the limit $\mu \to 0$, no LNV but CLFV



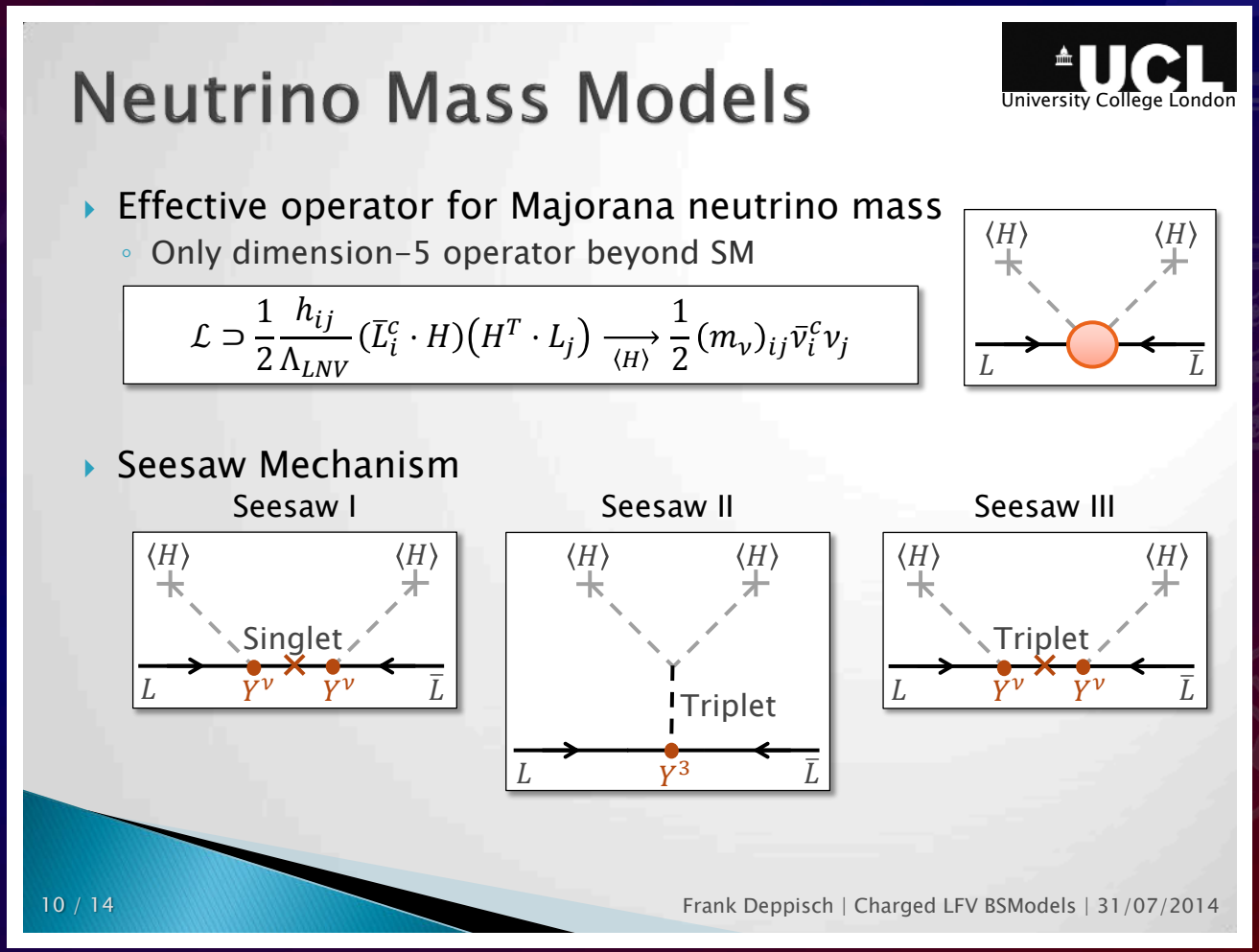
9 / 14 Frank Deppisch | Charged LFV BSModels | 31/07/2014

Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

Perspectives from 2014

- Specific links between CLFV and the BSM Flavour Problem
- And observability at the LHC



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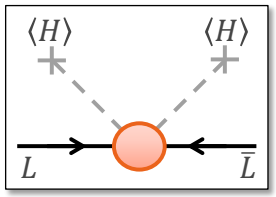
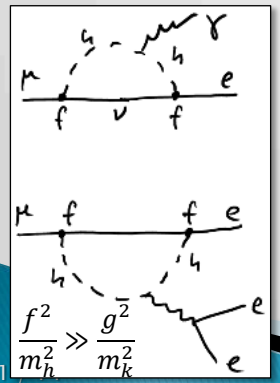
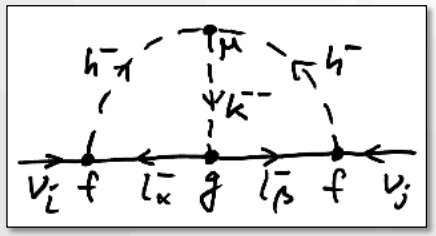
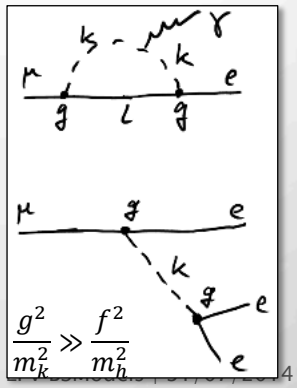


- Radiative Generation via Loops
  - Alternative to Seesaw, e.g. Babu-Zee model (Zee '85, Babu '88)





Neutrino masses suppressed at 2-loop



Frank Deppisch | Charged

Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

Perspectives from 2014

- Specific links between CLFV and the BSM Flavour Problem
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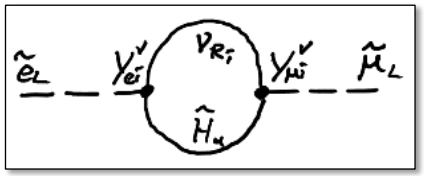
SUSY Seesaw

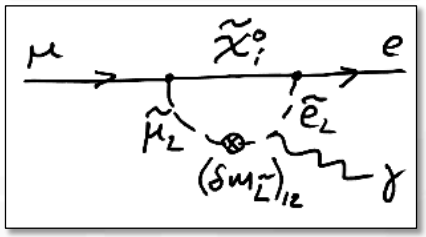
UCL University College London

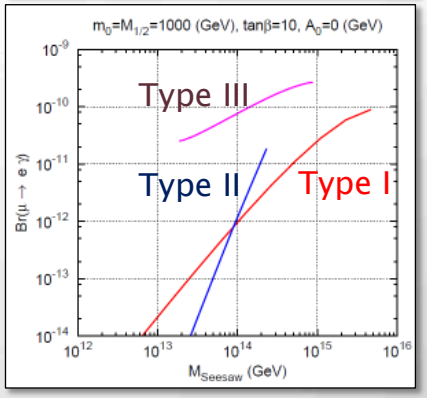
- Neutrino flavour mixing radiatively induces slepton flavour mixing
  (Borzumati, Masiero '86)
- Correlation between slepton and neutrino flavour mixing (Type I)

$$\left(\delta m_{\tilde{L}}^2\right) = \begin{pmatrix} \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{12}^* & \delta_{22} & \delta_{23} \\ \delta_{13}^* & \delta_{23}^* & \delta_{33} \end{pmatrix} \propto \left(Y^{\nu\dagger} \cdot Y^{\nu}\right) \log(M_X/M_{\nu_R})$$

- Induces observable charged LFV rates despite high scale Seesaw $M_{\nu_R} \approx 10^{14}\text{GeV}$







Esteves et al. '11

12 / 14

Frank Deppisch | Charged LFV BSModels | 31/07/2014

Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

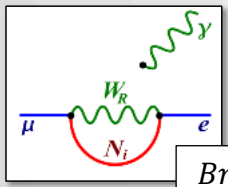
Perspectives from 2014

- Specific links between CLFV and the BSM Flavour Problem
- And observability at the LHC

Observable High Energy CLFV at LHC?

University College London

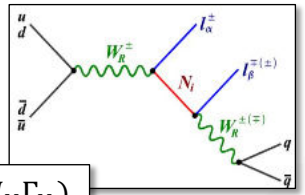
- $\tau\mu/\tau e$ flavour transitions less constrained ($h \to \mu\tau$ observed?)
- Small CLFV messenger mass splitting



Off-shell GIM mechanism

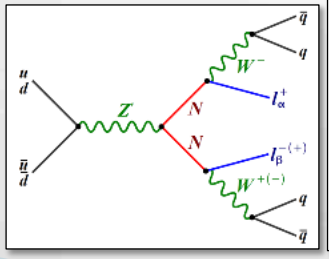
$Br(\mu \to e\gamma) \propto \Delta M_N^2 / M_{W_R}^2$

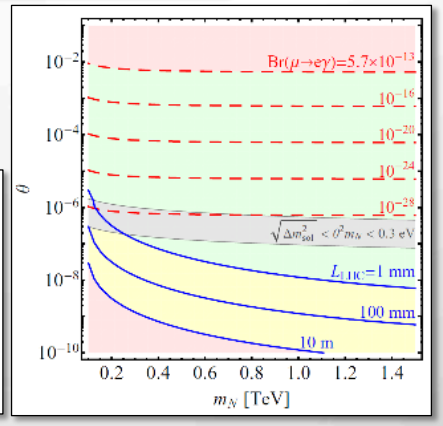
On-shell (resonant) GIM mechanism



$\sigma_{LHC} \propto \Delta M_N^2 / (M_N \Gamma_N)$

- CLFV through heavy portal
  (FFD, Desai, Valle, Phys. Rev. D89 051302)
  - N can only decay through heavy-light suppressed coupling $\theta = Y_\nu \langle H \rangle / m_N$





13 / 14

Frank Deppisch | Charged LFV BSModels | 31/07/2014

Frank Deppisch: *Charged Lepton Flavour Violation BSModels*

Charged Lepton Flavour Violation

Perspectives from 2014

- Currently the only experimental programme taking data in the muon CLFV area
- MEG searches for the canonical CLFV process, from Pontecorvo's time in the late '40s

Experimental search for $\mu^+ \rightarrow e^+\gamma$ present and future

Dmitry Grigoriev
Budker Institute of Nuclear Physics
Novosibirsk State University
Novosibirsk, Russia
On behalf of MEG and MEG-2 collaborations

RENCONTRES DU VIETNAM
Quy Nhon, 31.07.2014

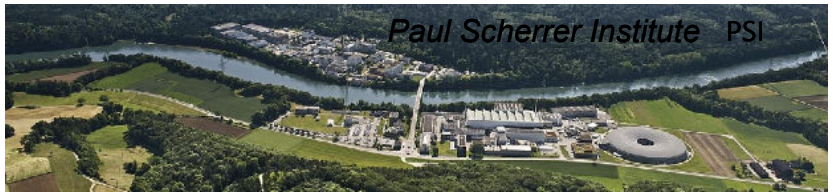
Dmitry Grigoriev: *Experimental search for $\mu^+ \rightarrow e^+ + \gamma$ present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

- Currently the only experimental programme taking data in the muon CLFV area
- MEG searches for the canonical CLFV process, from Pontecorvo's time in the late '40s

MEG HOME



MEG Collaboration

some 65 Physicists

5 Countries, 14 Institutes

Switzerland

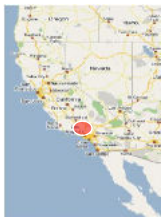
PSI, ETH-Z

Italy

INFN + Univ. : Pisa, Genova, Pavia, Roma I & Lecce

USA

University of California Irvine UCI



Russia

BINP, Novosibirsk, JiNR, Dubna

Japan

Univ.Tokyo, KEK Waseda Univ., Kyushu Univ.

Dmitry Grigoriev: *Experimental search for* $\mu^+ \to e^+ + \gamma$ *present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

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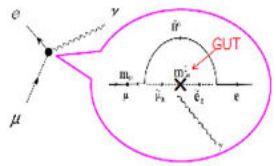
Why $\mu^+ \rightarrow e^+\gamma$



- CLFV Forbidden in SM (background: $Br(\mu^+ \rightarrow e^+\gamma) < 10^{-45}$)
- So far, no CLFV signal has been observed.
- Many new physics beyond SM (e.g. SUSY, Extra dimensions etc.) predict observable Br (10^{-14} — 10^{-11})
- Discovery will be an unambiguous evidence of new physics.

- Complementary search of new physics,
  - LHC Run 2
  - New experiments to search for other muon channels ($\mu \rightarrow e$ convertion, $\mu \rightarrow eee$)

Dmitry Grigoriev: *Experimental search for $\mu^+ \rightarrow e^+ + \gamma$ present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

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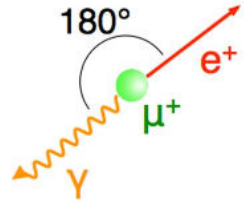
Signal and backgrounds

Signal μ+ decay at rest

52.8 MeV (half of M_μ) (E_γ,E_e)

Back-to-back ($\theta_{e\gamma}$,$\varphi_{e\gamma}$)

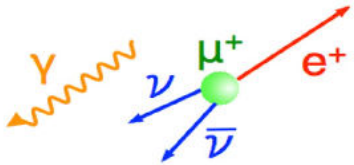
Timing coincidence ($T_{e\gamma}$)



Accidental background (dominant)

Michel decay e^+ + random γ

Random timing, angle, E < 52.8MeV

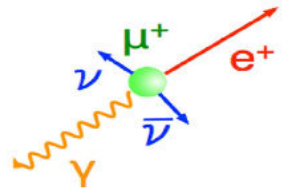


Radiative muon decay

$\mu^+ \rightarrow e^+\nu\bar{\nu}\gamma$

Timing coincident, not back-to back,

E <52.8MeV



Dmitry Grigoriev: *Experimental search for $\mu^+ \rightarrow e^+ + \gamma$ present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

- Currently the only experimental programme taking data in the muon CLFV area
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Key points of the experiment

- high quality & rate stopped μ-beam ⇨ surface muon beam (10^8/s), ($\overline{E} \times \overline{B}$) Wien filter, SC-solenoid+degrador
- e^+ magnetic spectrometer with excellent tracking & timing capabilities ⇨ COBRA magnet, DCs & TCs
- photon detector with excellent spatial, tming & energy resolutions ⇨ 900 litre LXe detector (largest in world)
- Stable and well monitored & calibrated detector ⇨ Arsenal of calibration & monitoring tools

Dmitry Grigoriev: *Experimental search for* $\mu^+ \to e^+ + \gamma$ *present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

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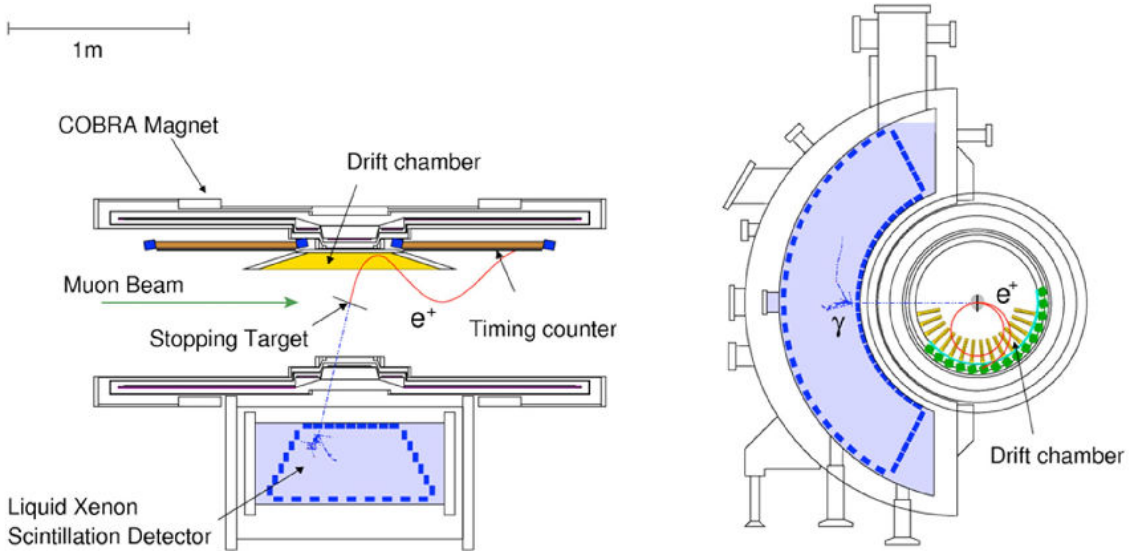
Layout of the detector



The important part – gradient field COBRA magnet:
tracks radius is independent on incident angle at 52.8 MeV/c

Dmitry Grigoriev: *Experimental search for* $\mu^+ \to e^+ + \gamma$ *present and future*

Charged Lepton Flavour Violation

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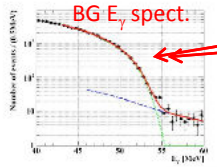
Analysis Principle

Analysis Region shown in 2D
(No Selection)

Blind likelihood Analysis:

Data Sample defined by 5 Observables:

E_{e^+}, E_γ, $\theta_{e\gamma}$, $\phi_{e\gamma}$, $T_{e\gamma}$

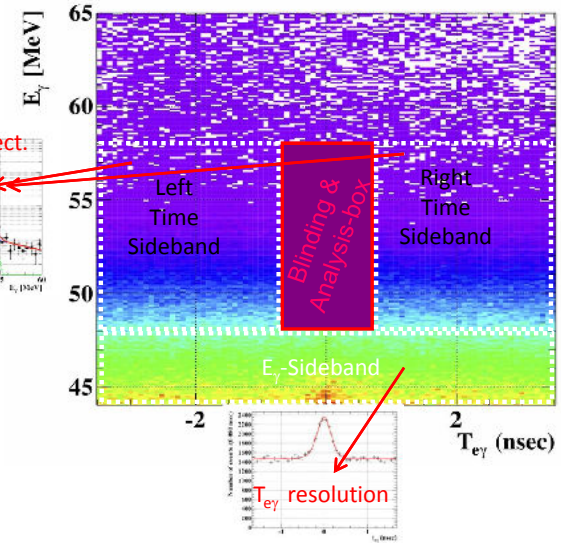


Analysis-box for Likelihood fit
Defined in 5D-space as:

Analysis Box vs 5 Observables

(~10σ wide windows cf. res.)
48 ≤ E_γ ≤ 58 MeV
50 ≤ E_e ≤ 56 MeV
| $T_{e\gamma}$ | ≤ 0.7 ns
| $\phi_{e\gamma}$ |, | $\theta_{e\gamma}$ | ≤ 50 mrad
(angles between e^+ & flipped γ vec.)

Analysis box "Blinded" in the E_γ vs $T_{e\gamma}$ plane during calibration and optimization of physics analysis



!!! Time and E_γ sidebands Important Ingredient to Analysis also angular sidebands introduced
⇨ Since our background is dominated by "accidentals" the side bands can be used to estimate the background in the signal region, check of experimental sensitivity & measure the timing resolution using RMD in the E_γ-sideband

Dmitry Grigoriev: *Experimental search for* $\mu^+ \to e^+ + \gamma$ *present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

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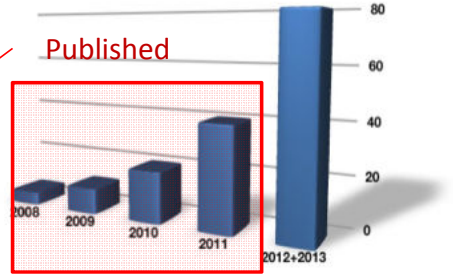
Results



Phy. Rev. Lett. 110, 201801 (2013)

Data taking finished at 31.08.2013
Statistics is doubled compare to published

year	Nstop μ, x10^{13}	Sensitivity, x10^{-13}	Br, Upper limit (CL 90%), x10^{-13}
2009+2010	17.5	13	13
2011	18.5	11	6,7
2009+2010+2011	36.0	7.7	**5.7** (20 times better
All data (expected)	~80	~5	than MEGA)

Final result of analysis is expected by the end of 2014

Dmitry Grigoriev: *Experimental search for* $\mu^+ \to e^+ + \gamma$ *present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

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- MEG searches for the canonical CLFV process, from Pontecorvo's time in the late '40s

MEG-2

- **Goal to reach sensitivity in order of magnitude better than MEG:**
  - **More statistics (double beam rate)**
  - **Improve efficiency ~2 and background rejection ~30 (*upgrade of LXe calorimeter, new cylindrical Drift Chamber, new Timing counters*).**

Dmitry Grigoriev: *Experimental search for* $\mu^+ \to e^+ + \gamma$ *present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

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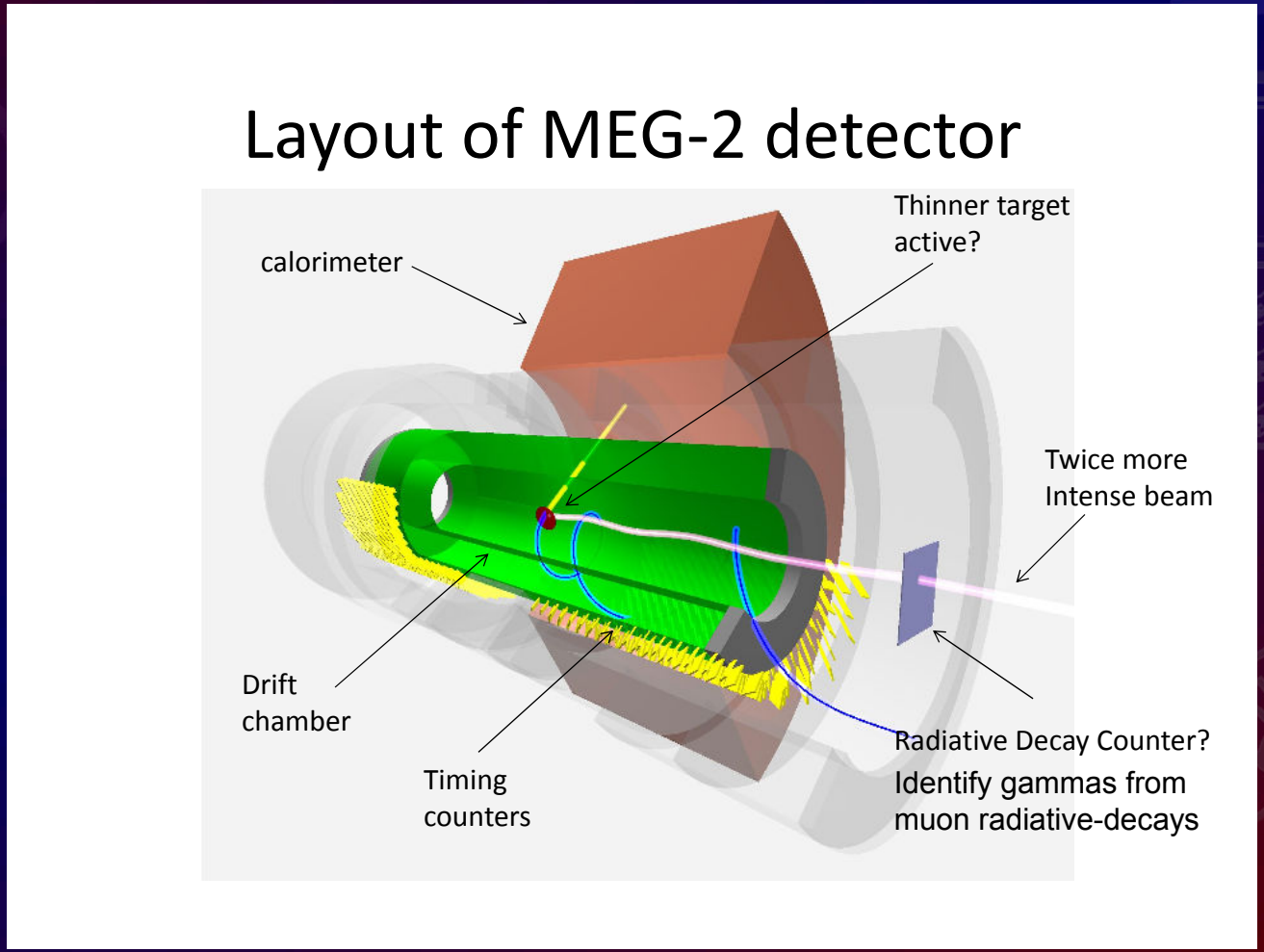
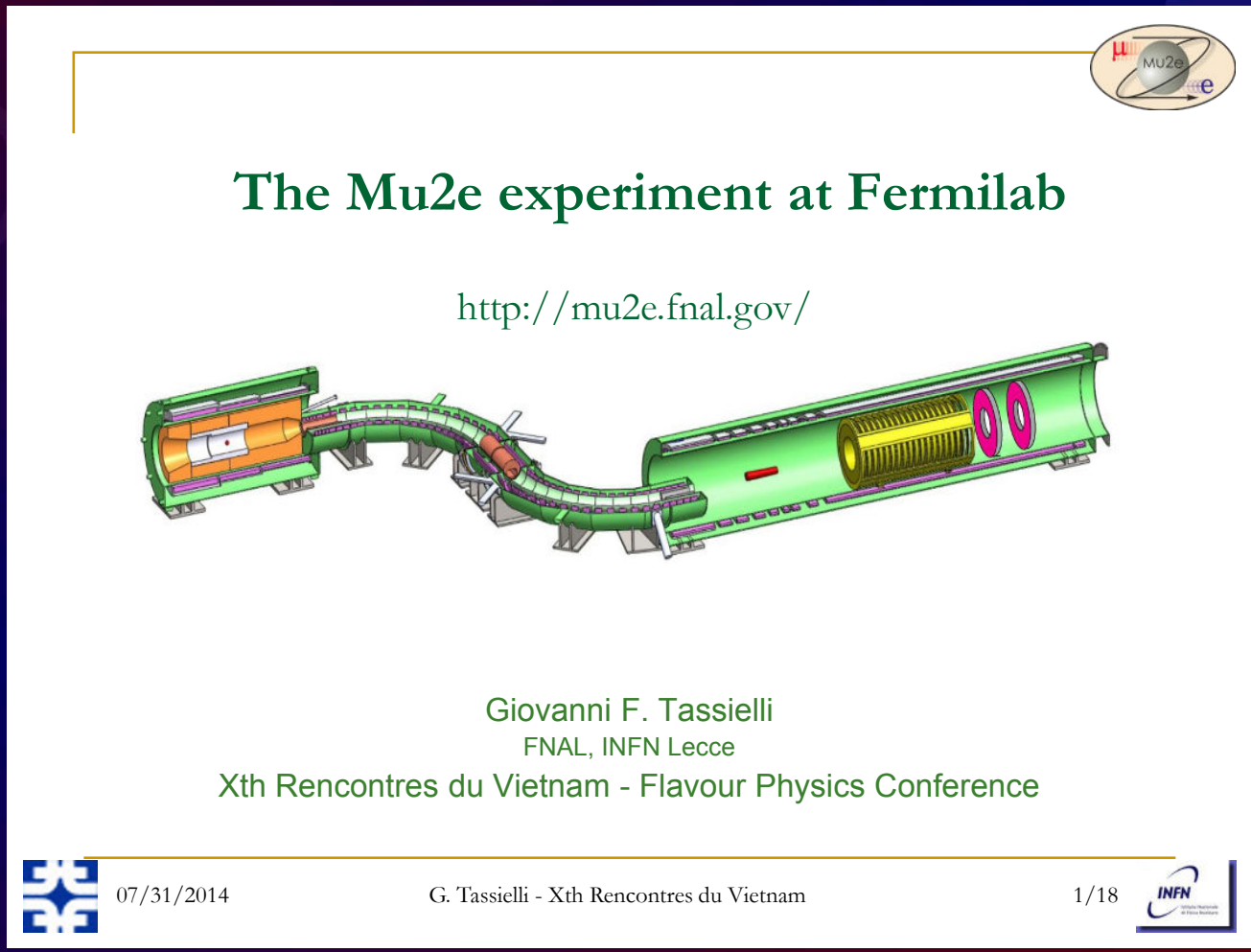


Dmitry Grigoriev: *Experimental search for* $\mu^+ \to e^+ + \gamma$ *present and future*

Charged Lepton Flavour Violation

Perspectives from 2014

Mu2e was making strong headway in 2014 with experimental designs being finalised and R&D progressing



Giovanni Tassielli: *The Mu2e experiment at Fermilab*

Charged Lepton Flavour Violation

Perspectives from 2014

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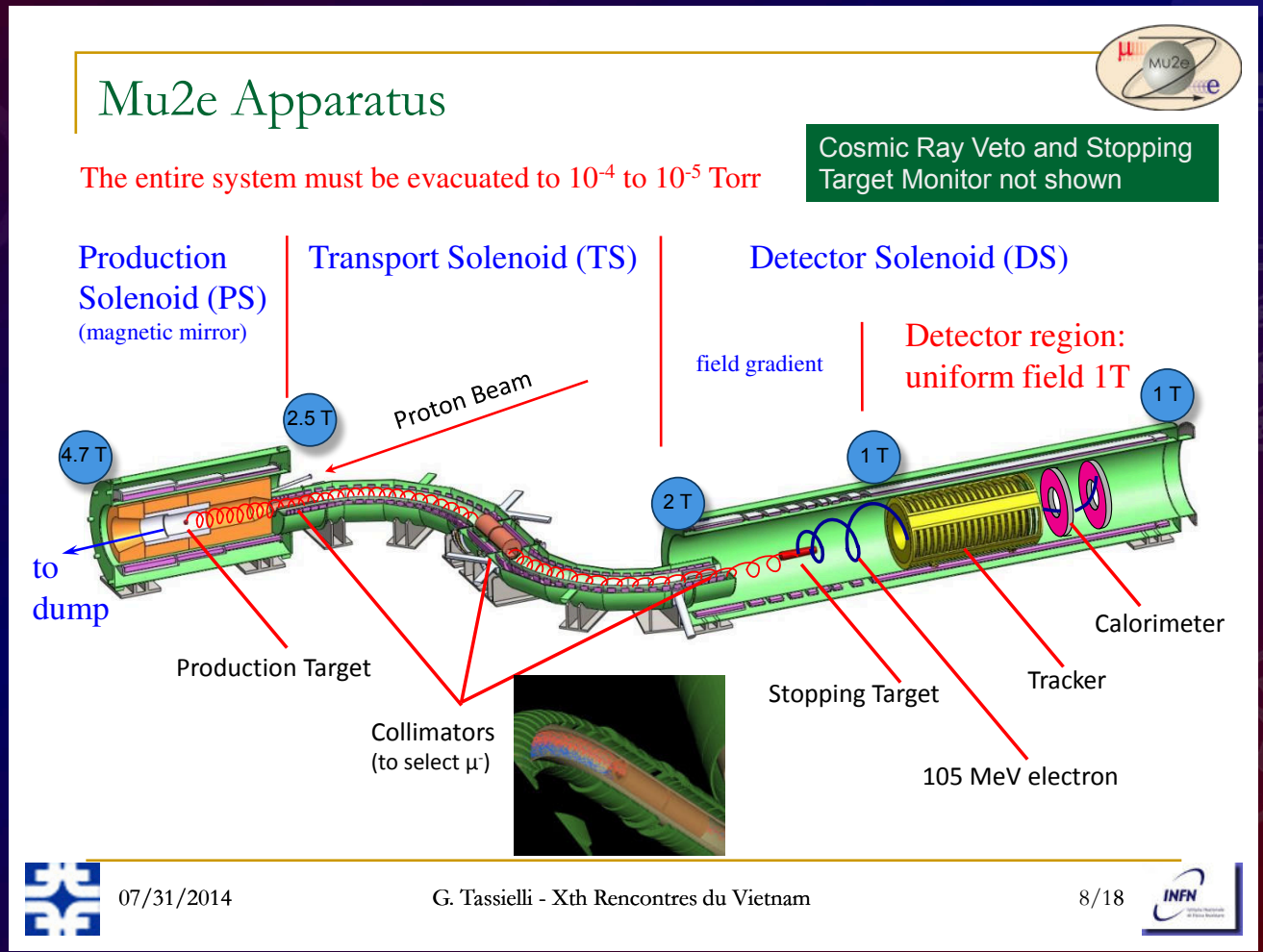

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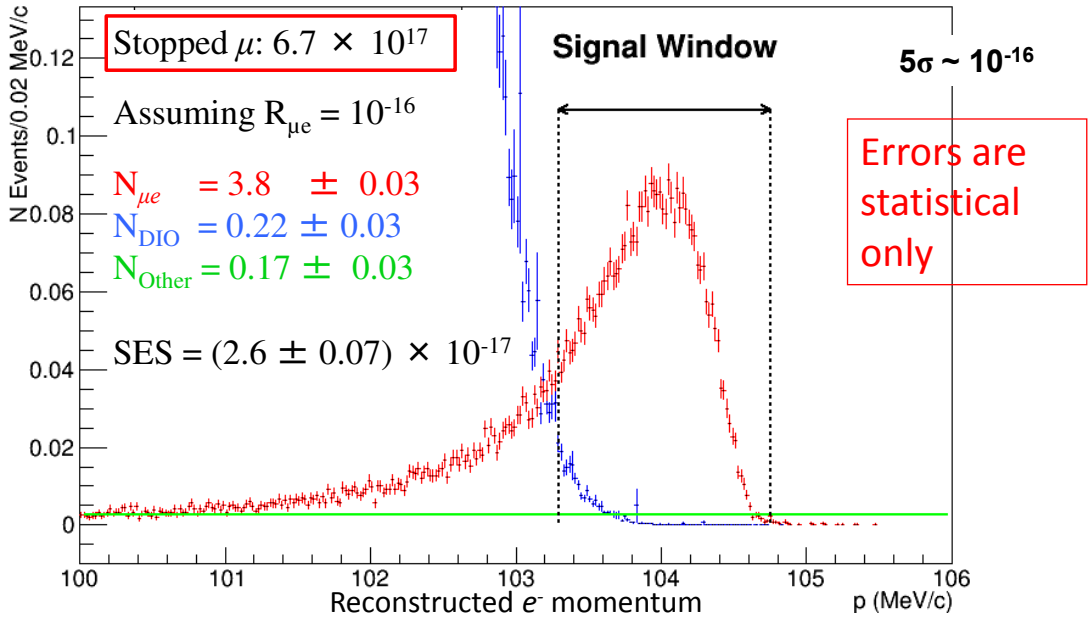
Charged Lepton Flavour Violation

Perspectives from 2014

Mu2e was making strong headway in 2014 with experimental designs being finalised and R&D progressing

Signal sensitivity for a 3 Year Run

Full Geant4 modeling and reconstruction without any truth input (tracker only)



typical SUSY at 10^{-15}: 40 events vs 0.4 backgrounds

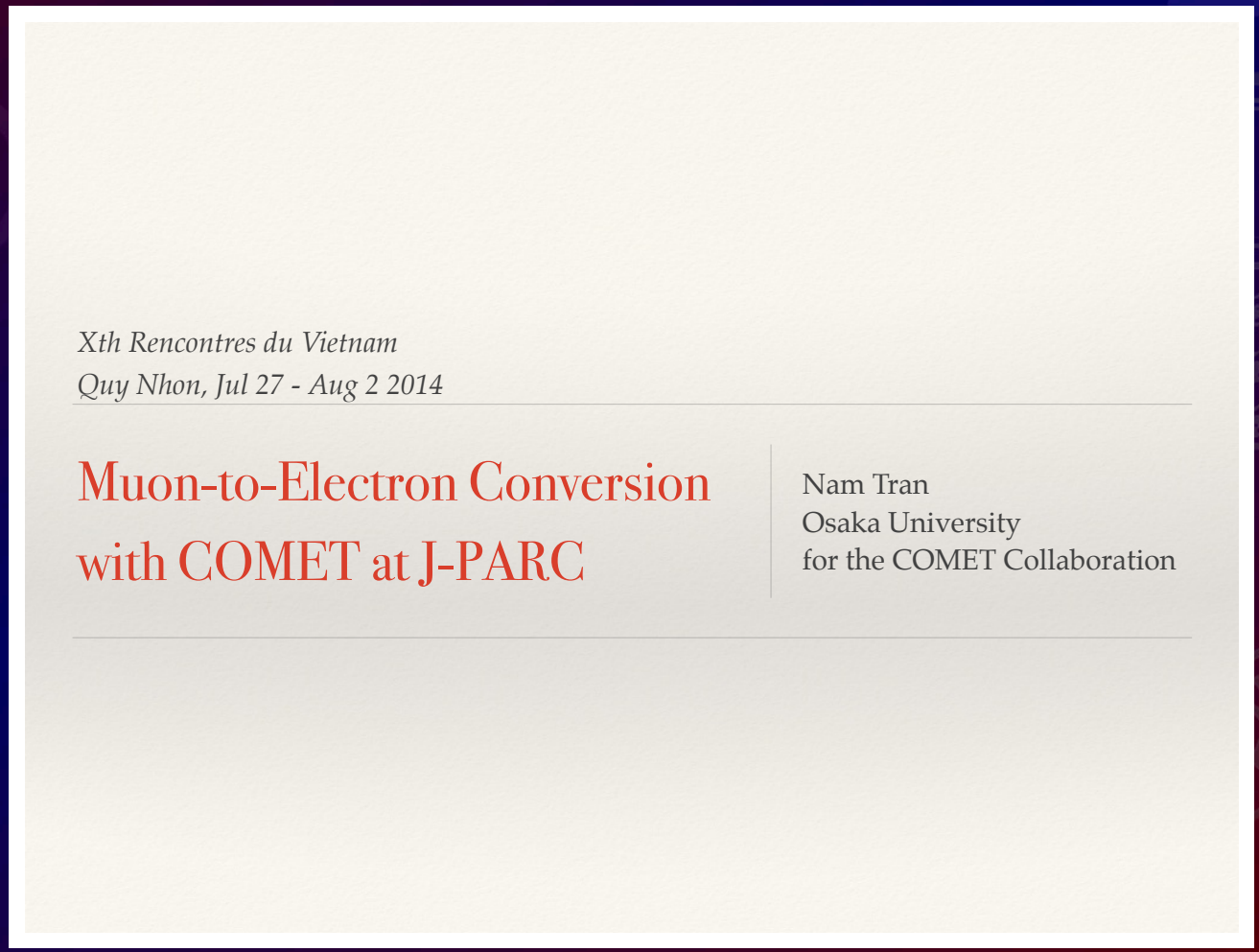
07/31/2014 G. Tassielli - Xth Rencontres du Vietnam 14/18

Giovanni Tassielli: *The Mu2e experiment at Fermilab*

Charged Lepton Flavour Violation

Perspectives from 2014

COMET was also making good progress in 2014, with early detector prototypes for Phase-I and the experimental hall being under construction



Xth Rencontres du Vietnam
Quy Nhon, Jul 27 - Aug 2 2014

Muon-to-Electron Conversion with COMET at J-PARC

Nam Tran
Osaka University
for the COMET Collaboration

Nam Tran: *Muon-to-Electron Conversion with COMET at J-PARC*

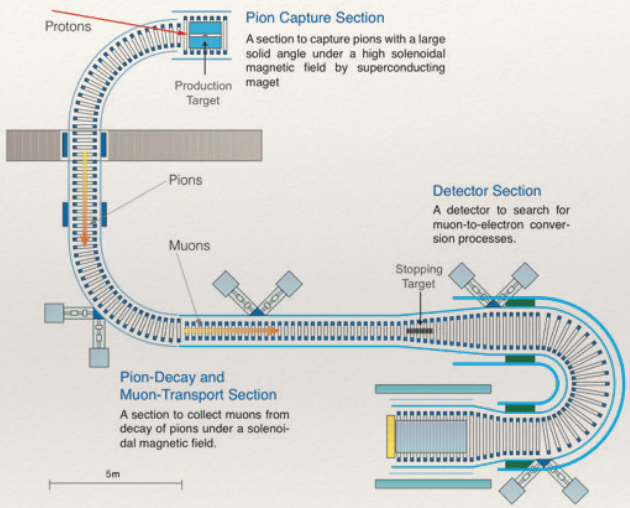
Charged Lepton Flavour Violation

Perspectives from 2014

COMET was also making good progress in 2014, with early detector prototypes for Phase-I and the experimental hall being under construction

The COMET experiment

- COherent Muon to Electron Transition
- Backward pions/muons
  - lower yield compare to forward ones
  - tighter time and momentum distribution, eliminate high momentum pions/muons
- 2 C-shape solenoids:
  - a dedicated curved solenoid for electron measurement: reject protons, quieter environment
  - additional dipole field to compensate vertical drift



$$\mathcal{B}(\mu^- Al \to e^- Al) < 6 \times 10^{-17}$$

6

Nam Tran: *Muon-to-Electron Conversion with COMET at J-PARC*

Charged Lepton Flavour Violation

Perspectives from 2014

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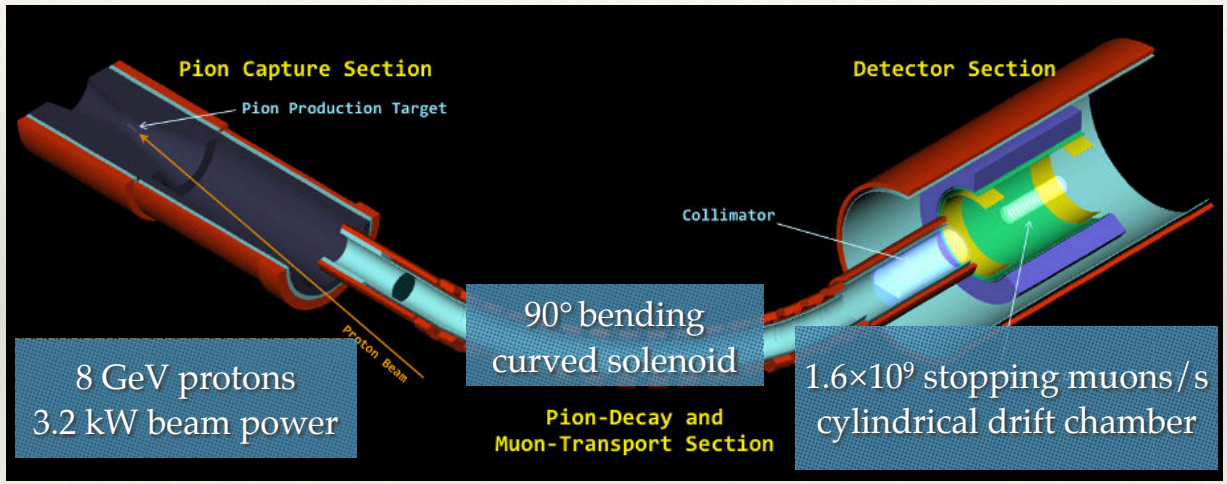
μ-e conversion search in the Phase I



8

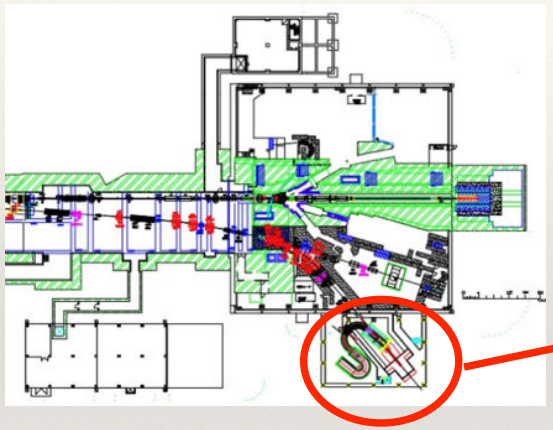
Nam Tran: *Muon-to-Electron Conversion with COMET at J-PARC*

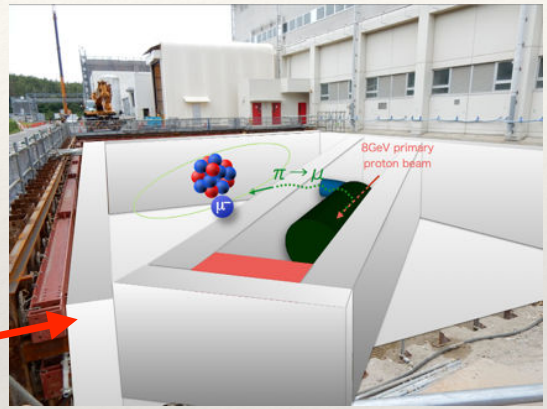
Charged Lepton Flavour Violation

Perspectives from 2014

COMET was also making good progress in 2014, with early detector prototypes for Phase-I and the experimental hall being under construction

Facility and beam line





- Budget for constructions is secured
- Under construction, finish by the end of JFY 2015

15

Nam Tran: *Muon-to-Electron Conversion with COMET at J-PARC*

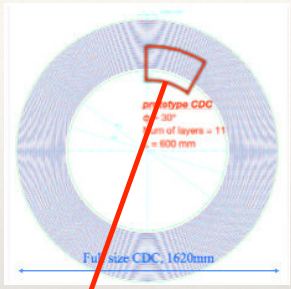
Charged Lepton Flavour Violation

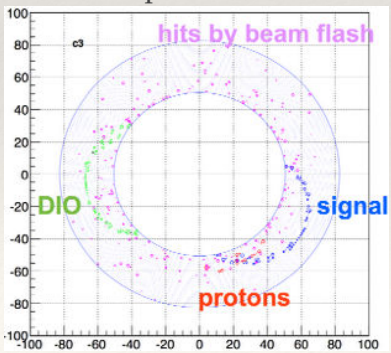
Perspectives from 2014

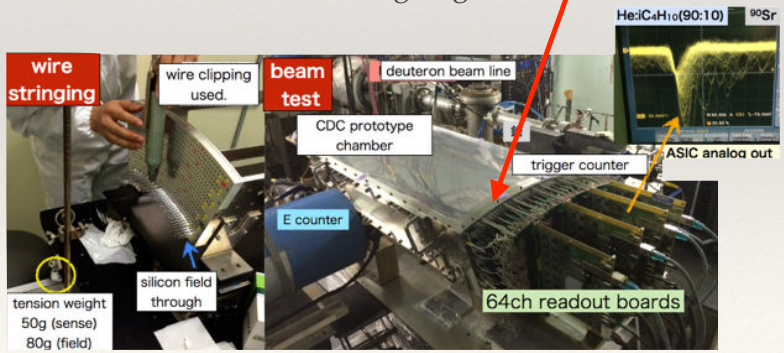
COMET was also making good progress in 2014, with early detector prototypes for Phase-I and the experimental hall being under construction

Detector R&D - Drift chamber

- Cylindrical drift chamber (CDC) for μ-e search:
  - finalise the design
  - test chamber, electronics, and reconstruction tested in several beam tests
  - a dedicated test chamber for ageing test
  - comprehensive MC and reconstruction studies are ongoing







18

Nam Tran: *Muon-to-Electron Conversion with COMET at J-PARC*

Heavy Flavour Physics

Perspectives from 2014

LHCb had just reported the 13.9σ measurement of $Z(4430)^-$

Xth Rencontres du Vietnam

Flavour Physics Conference

Heavy flavor spectroscopy and production at LHCb

Victor Egorychev

On behalf of the LHCb collaboration

1

Victor Egorychev: *Heavy flavor spectroscopy and production at LHCb*

Heavy Flavour Physics

Perspectives from 2014

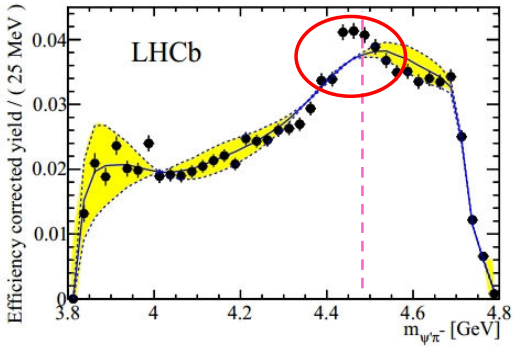
LHCb had just reported the 13.9σ measurement of $Z(4430)^-$

$Z(4430)^-$ state in LHCb

LHCb uses both approaches

LHCb-PAPER-2014-014
arXiv: 1404.1903

Belle 4D



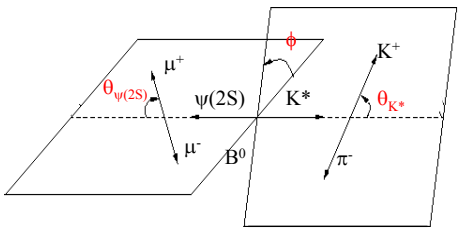
Moments analysis

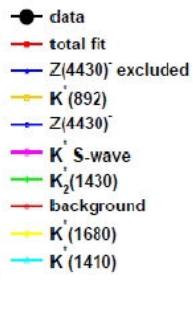
No assumptions about K* contributions except for the maximal J

K* reflection do not describe the $Z(4430)^-$ region

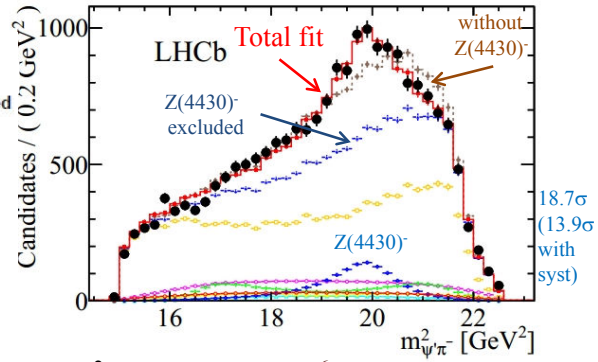
This approach does not allow to define $Z(4430)^-$ parameters

4D model dependent amplitude analysis





4D fit method



The χ^2 p-value < 2 x10^{-6} (Z excluded)
The χ^2 p-value = 12% (with $Z(4430)^-$)

10

Victor Egorychev: *Heavy flavor spectroscopy and production at LHCb*

Heavy Flavour Physics

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Victor Egorychev: *Heavy flavor spectroscopy and production at LHCb*

Heavy Flavour Physics

Perspectives from 2014

LHCb had just reported the 13.9σ measurement of $Z(4430)^-$

✓$X(3872) \to \psi(2S)\gamma$ decay now established at 4.4 σ

LHCb-PAPER-2014-008, Nucl.Phys B 886 (2014) 665

- BR($X(3872) \to \psi(2S)\gamma$)/BR($X(3872) \to J/\psi\gamma$) inconsistent with pure molecular interpretation of X(3872)

✓Existence confirmation of $Z(4430)^-$ with >13.9σ

- quantum numbers determination $J^P = 1^+$
- resonant behaviour observed
- the charge and spin-party make $Z(4430)^-$ unambiguous four-quark candidate

LHCb-PAPER-2014-014 arXiv: 1404.1903

✓No evidence for $f_0(980)$ in $B_d \to J/\psi\pi^+\pi^-$ decays

- resonance production $f_0(980)$ as a tetraquark state ruled out at 8σ

LHCb-PAPER-2014-012 arXiv 1404.5673

✓New interesting results on $\chi_b(3P)$ production rate:

- $\chi_b(3P)$ to $\Upsilon(3S)$ feed-down is large

LHCb-PAPER-2014-031

✓The kinematic dependences of the relative production rates f_{Λ_b}/f_d of Λ_b baryons and B_d mesons are measured

LHCb-PAPER-2014-004, arXiv 1405.6842

✓Looking forward for new exciting results!

Victor Egorychev: *Heavy flavor spectroscopy and production at LHCb*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS

Production and Decays of Heavy Flavours in ATLAS

Vincenzo Canale
Università di Napoli "Federico II" and INFN

Alessandro Cerri
University of Sussex

Xth Rencontres du Vietnam – Flavour Physics Conference

ICISE, Quy Nhon,VN, July 27 – August 2, 2014

Vincenzo Canale: *Production and Decays of Heavy Flavours in ATLAS*

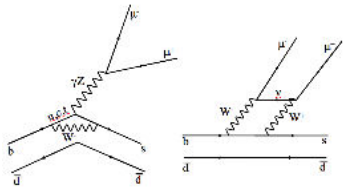
Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS

C.4 Study of $B_d \to K^{*0}(K\pi)\ \mu^+\mu^-$

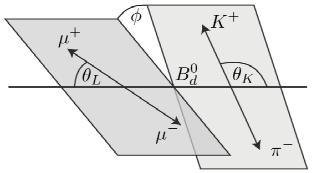
- $b \to s\ l^+\ l^-$ transition
- loop-mediated in SM $\Rightarrow$ BR$\approx 1.1\ 10^{-6}$
- sensitive to BSM contribution



- lepton forward-backward asymmetry A_{FB}
- K^{*0} longitudinal polarisation fraction F_L

3 angles (θ_L, θ_K, φ) and q^2

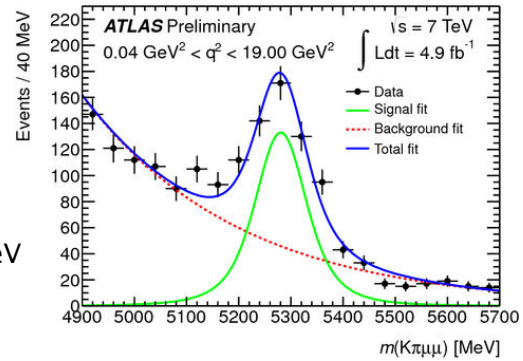
- φ symmetry, then integrate on φ
- alternative integration on θ_L or θ_K



fit to angular distribution $\Rightarrow$ (A_{FB},F_L) in q^2-intervals

- $q^2 < 2\text{GeV}^2$ limited statistics
- Veto:
  - $q^2 = (m^2_{J/\psi}, m^2_{\psi(2S)}) \pm 3\sigma$
  - radiative J/ψ and $\psi(2S)$ decays
  - $K^{*0}(K\pi)$ mass range [846,946] MeV
- maximum likelihood fit

$\Rightarrow N_{sig} = 466 \pm 34$ and $N_{bkg} = 1132 \pm 43$



Vincenzo Canale: *Production and Decays of Heavy Flavours in ATLAS*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS

- High precision production measurements
  - quarkonium ($J/\psi, \psi_{2s}, \chi_{cj}, \Upsilon_{ms}$,)
  - open state (B^+)
  - LHC: new kinematical regions (e.g. high p_T) ⇒ test predictions of different QCD tools
- ATLAS →
  - → evidence for new states
  - → decay properties of heavy flavour
- Expect to exploit full run-I and future run-II to probe new interesting phenomena in heavy flavour production
  - polarization
  - double quarkonium
  - associated production with W, Z etc…
  - decays to test SM and look for BSM effects (e.g. rare or suppressed decays)

Vincenzo Canale: *Production and Decays of Heavy Flavours in ATLAS*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS

Sarmad Masood Shaheen: *Production and Decays of Heavy Flavors at CMS*

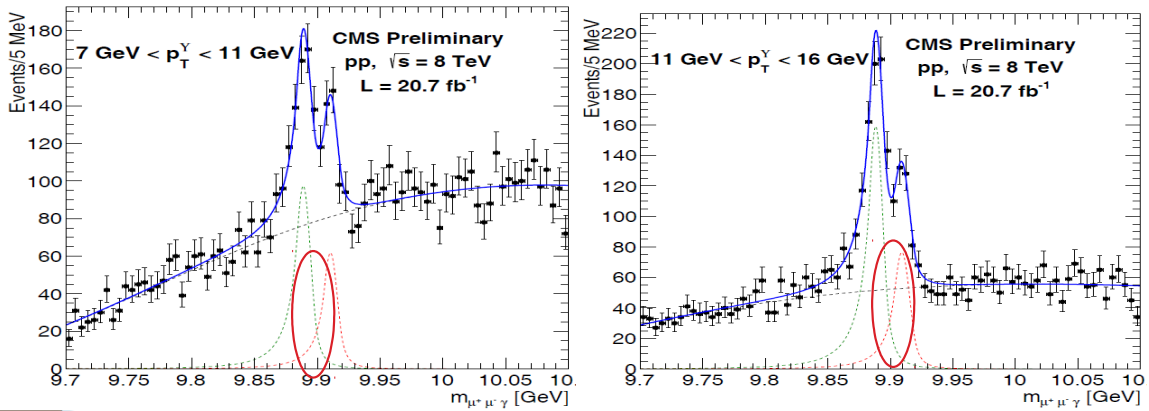
Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS

Measurement of the $\sigma(\chi_{b2}(1P)) / \sigma(\chi_{b1}(1P))$

- Promptly produced states studied for integrated luminosity 20.7fb^{-1} at $\sqrt{s} = 8$ TeV
- Detecting through radiative decays $\chi_{b1,2}(1P) \to \Upsilon(1S) + \gamma$
- Measured in the phase space $|\eta^{\gamma}| < 1.0,\ 7 < p_T^{\Upsilon} < 40$ GeV and $|y^{\Upsilon}| < 1.5$ in four Υ(1s) p_T bins ranging from 7 to 40 GeV and the ratio is 0.90



CMS

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13

Sarmad Masood Shaheen: *Production and Decays of Heavy Flavors at CMS*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS

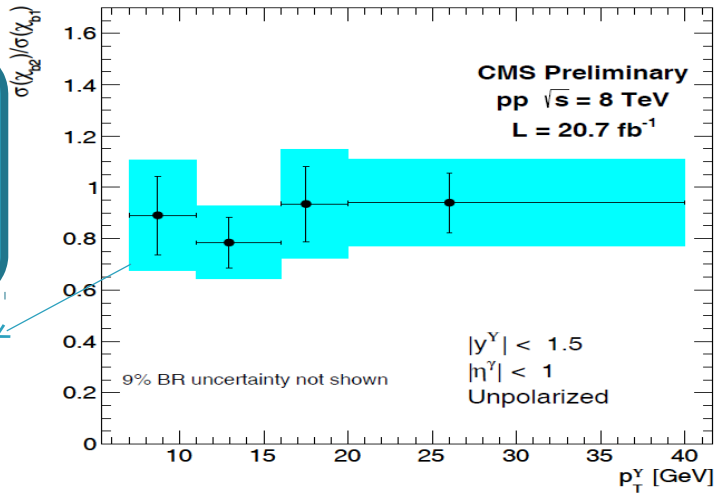
Measurement of the $\sigma(\chi_{b2}(1P)) / \sigma(\chi_{b1}(1P))$

p_T^{Υ} [GeV]	$\sigma(\chi_{b2}) / \sigma(\chi_{b1})$
7 – 11	0.89±0.15(stat.)±0.12(syst.)±0.08(BR)
11 – 16	0.78±0.10(stat.)±0.11(syst.)±0.07(BR)
16 – 20	0.94±0.15(stat.)±0.14(syst.)±0.08(BR)
20 – 40	0.94±0.12(stat.)±0.12(syst.)±0.08(BR)

Shows the uncertainty because of Branching fractions.

A comparison to theoretical calculations made by correcting the ratios for the branching fractions

Includes systematic and statistical error (no BR)



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Sarmad Masood Shaheen: *Production and Decays of Heavy Flavors at CMS*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS

- rich and competitive heavy flavor program
- Results found to be consistent with previous measurements.
- Precise Differential cross section measurement of Υ(nS) for the p_T range 10-100GeV
- The transition from exponential to power law at high pT challenges the theoretical models.
- There is no measurement of the cross section of Bc Meson yet and this ratio measurement would be remarkable step to understand the behavior of Bc Meson and further measurements.
- The result of the ratio in a good agreement with LHCb (only estimation)
- The cross ratio measured for χ_{b2} to χ_{b1} is 0.90 with no significant dependence upon transverse momentum of Υ(1S).
- The ratio of $\sigma(\chi_{b2})$ and $\sigma(\chi_{b1})$ is the first measurement and would be helpful as an inputs to constrain studies in future .

CMS

7/29/2014

Sarmad Masood Shaheen IHEP, Beijing

Sarmad Masood Shaheen: *Production and Decays of Heavy Flavors at CMS*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS, Belle

Leptonic and Semileptonic B Decays at Belle

César Beleño
On behalf of the Belle Collaboration.

July 29, 2014
Flavor Physics Conference 2014
10^{th} Rencontres du Vietnam
Quy Nhon, Vietnam

C. Beleño $B \to (X)\ell\nu$ decays at Belle 10^{th} Rencontres du Vietnam 1/16

César Beleno: *Leptonic and Semileptonic B Decays at Belle*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS, Belle

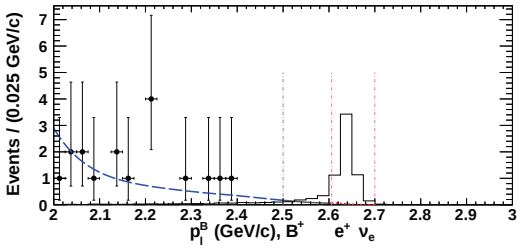
Search for $B \to (e, \mu)\nu$ preliminary [arXiv:1406.6356]

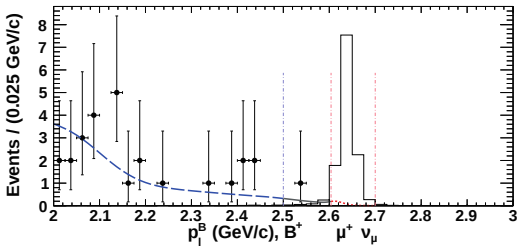
- $\mathcal{B}(B \to \ell\nu)^{\text{theory}} = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$
- SM predictions for $\mathcal{B}(B \to \ell\nu)$: $\tau \sim 10^{-4} \gg \mu \sim 10^{-7} \gg e \sim 10^{-11}$
- Data set 711 fb^{-1}
- Hadronic tag
- Unbinned fit to p_ℓ^B
- $\mathcal{B}(B \to \ell\nu)^{\text{experiment}} = \frac{N_{\text{obs}} - N_{\text{exp}}^{\text{bkg}}}{2\epsilon_s N_{B^+B^-}}$
- No evidence of signal
- U.L. at 90% C.L.
- Untagged measurement U.L.

  [PLB 647, 67-63 (2007)]:

  $\mathcal{B}(B^+ \to e^+\nu) < 9.8 \times 10^{-7}$

  $\mathcal{B}(B^+ \to \mu^+\nu) < 1.7 \times 10^{-6}$





Results

ℓ	ϵ_s[%]	N_{obs}	$N_{\text{exp}}^{\text{bkg}}$	U.L. $\mathcal{B}[10^{-6}]$
e	0.086	0	0.10 ± 0.04	3.4
μ	0.102	0	$0.26^{+0.09}_{-0.08}$	2.7

César Beleno: *Leptonic and Semileptonic B Decays at Belle*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS, Belle

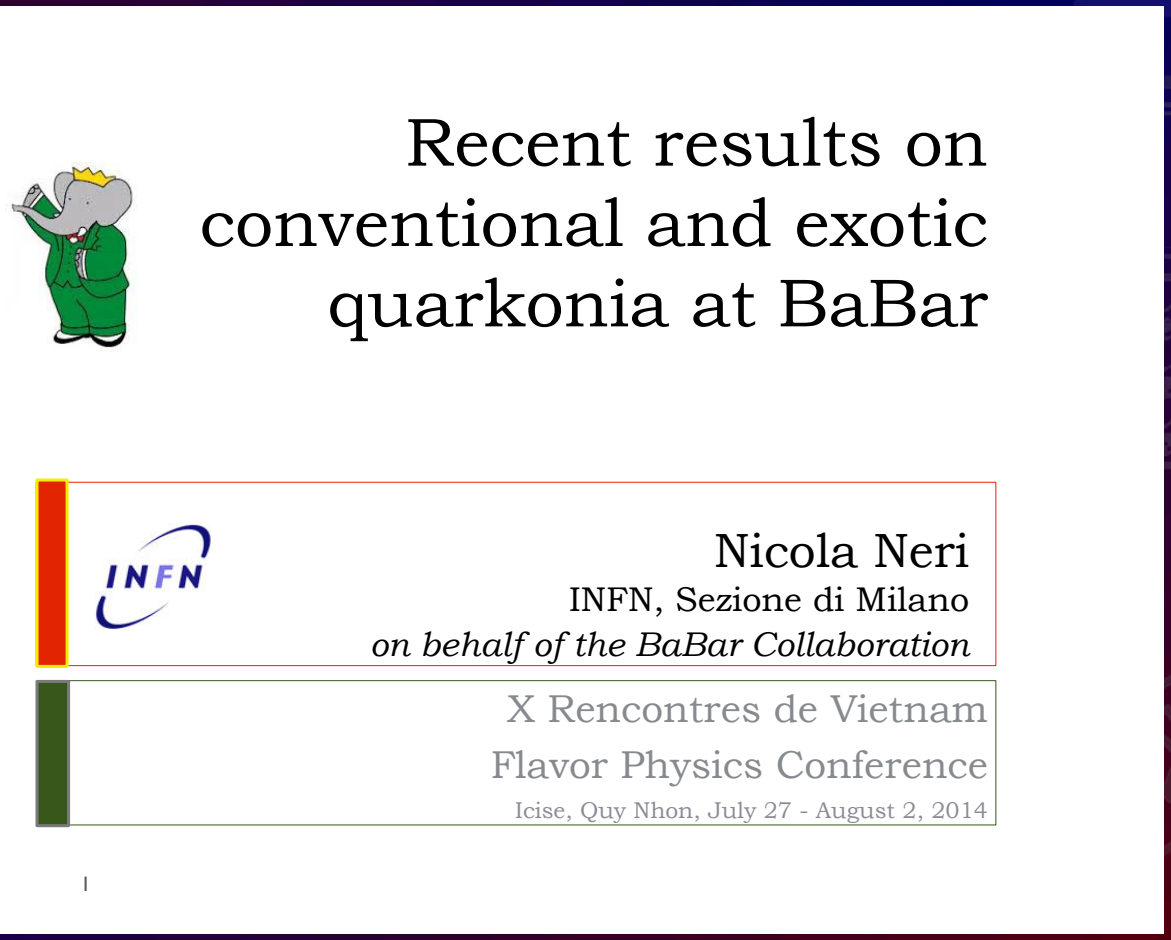
- Measurement of $\eta_{EW}\mathcal{G}(1)|V_{cb}|$ and ρ^2 from $B \to D\ell\nu$ consistent with HFAG average
- Branching ratios normalized with the inclusive rate are given for $B \to D^{(*)}X\ell\nu$ decays
- New measurements of $\mathcal{B}(B_s^0 \to D_s^{(*)}X\ell\nu)$: $\mathcal{B}(B_s \to D_s X\ell\nu) = (8.2 \pm 0.2 \pm 0.8 \pm 1.5)\%$ and $\mathcal{B}(B_s \to D_s^* X\ell\nu) = (5.4 \pm 0.4 \pm 0.5 \pm 1.0)\%$
- Meausurements of $|V_{ub}|$ from $(B \to (\pi, \rho, \omega)\ell\nu)$
- Evidence of SL dacays with baryon-antibaryon system.
- No evidence for $B^+ \to e^+\nu_e$ and $B^+ \to \mu^+\nu_\mu$ with hadronic tag.

César Beleno: *Leptonic and Semileptonic B Decays at Belle*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS, Belle, BaBar



Nicola Neri: *Recent results on conventional and exotic quarkonia at BaBar*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS, Belle, BaBar

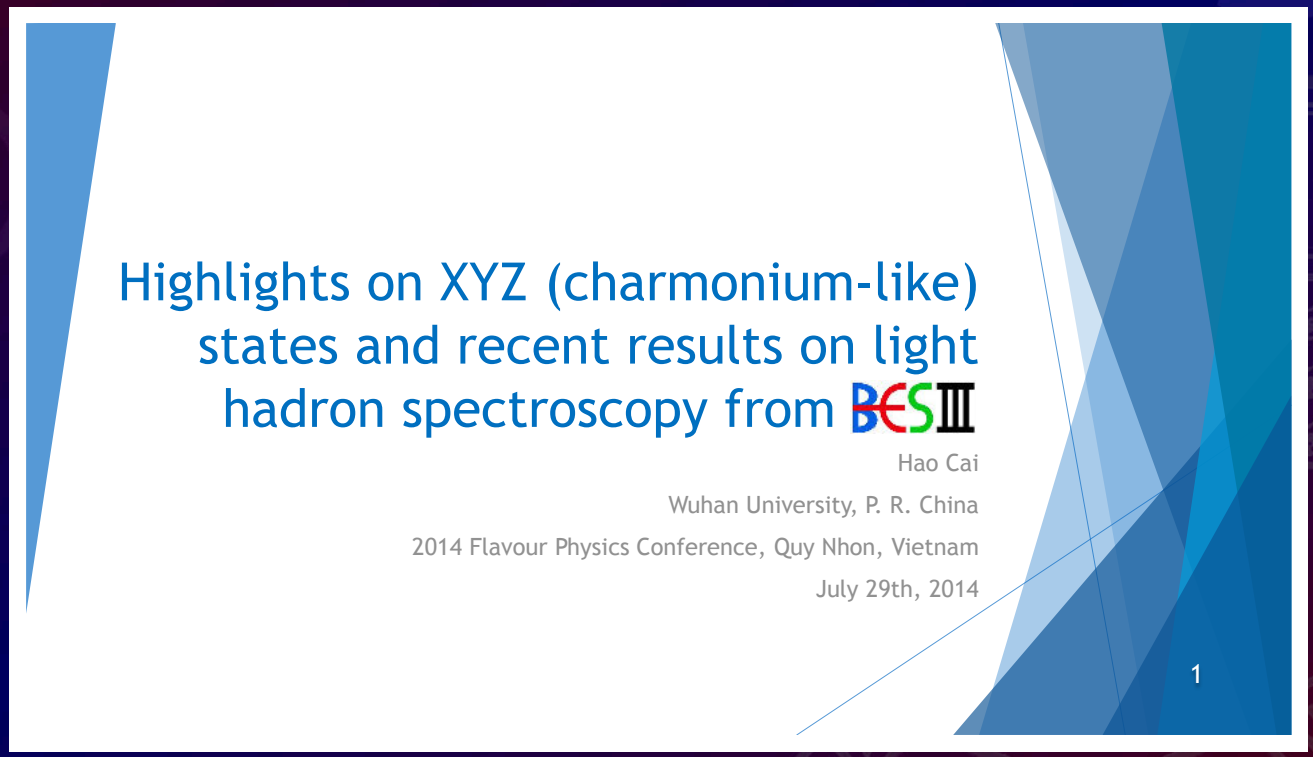
- We performed a study of the $B^0 \to J/\psi K^+ K^- K^0_S$ and $B^\pm \to J/\psi K^+ K^- K^\pm$ decays *Paper in preparation*
  - obtained new branching fraction measurements
  - significance below 2σ for both $X(4140)$ and $X(4270)$ exotic resonances in the $J/\psi\phi$ mass spectrum.
  - search for the suppressed decay $B^0 \to J/\psi\phi$ and derive an UL for the branching fraction
- Comprehensive study of electric dipole transitions $\Upsilon(1S, 2S, 3S)$ and $\chi_{bJ}(1P, 2P)$ *Paper in preparation*
  - Used two unique and complementary techniques: a) 2 calorimeter photons b) 1 calorimeter photon + 1 converted photon in e^+e^-
  - achieved best observation significance for $\chi_{b0}(2P) \to \gamma\Upsilon(2S)$ and for $\chi_{b0}(1P) \to \gamma\Upsilon(1S)$

Nicola Neri: *Recent results on conventional and exotic quarkonia at BaBar*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS, Belle, BaBar, and BESIII



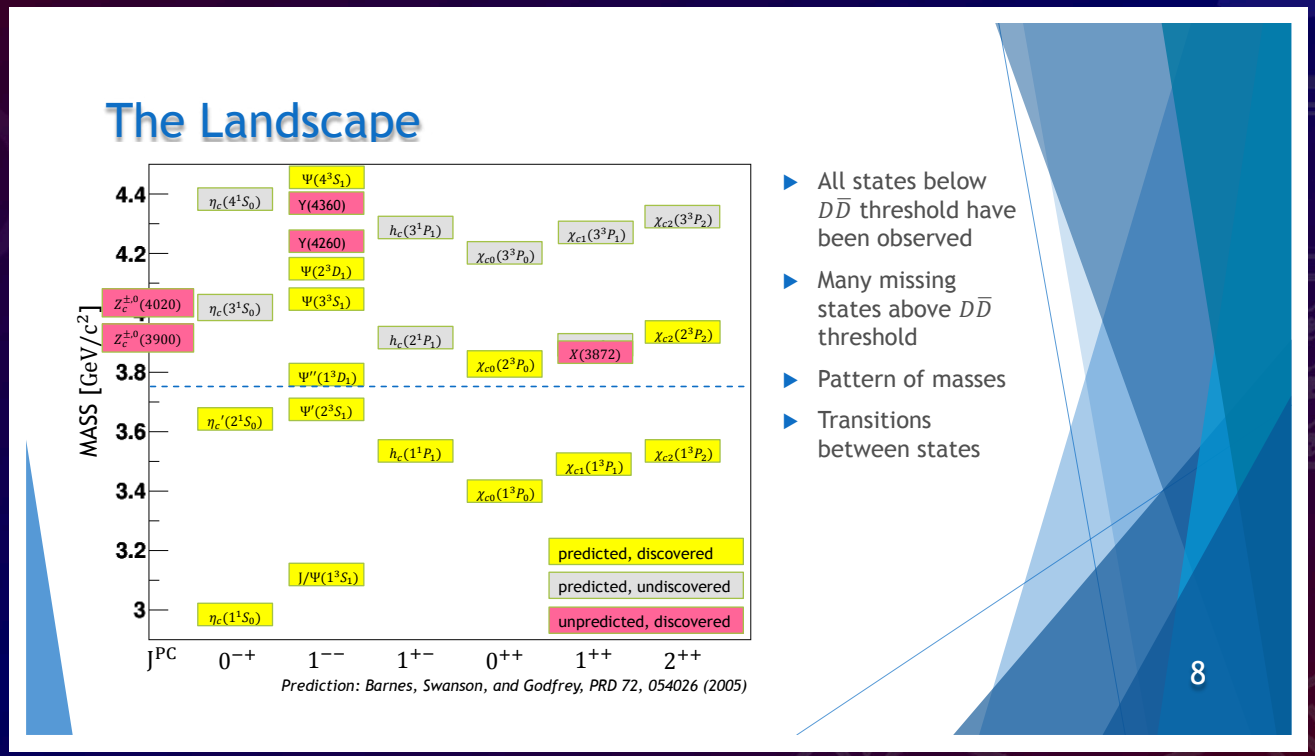
Hao Cai: *Highlights on XYZ (charmonium-like) states and recent results on light hadron spectroscopy from BESIII*

Heavy Flavour Physics

Perspectives from 2014

Precision measurements of heavy flavour states from ATLAS, CMS, Belle, BaBar, and BESIII

Further updates on Tuesday



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Heavy Flavour Physics

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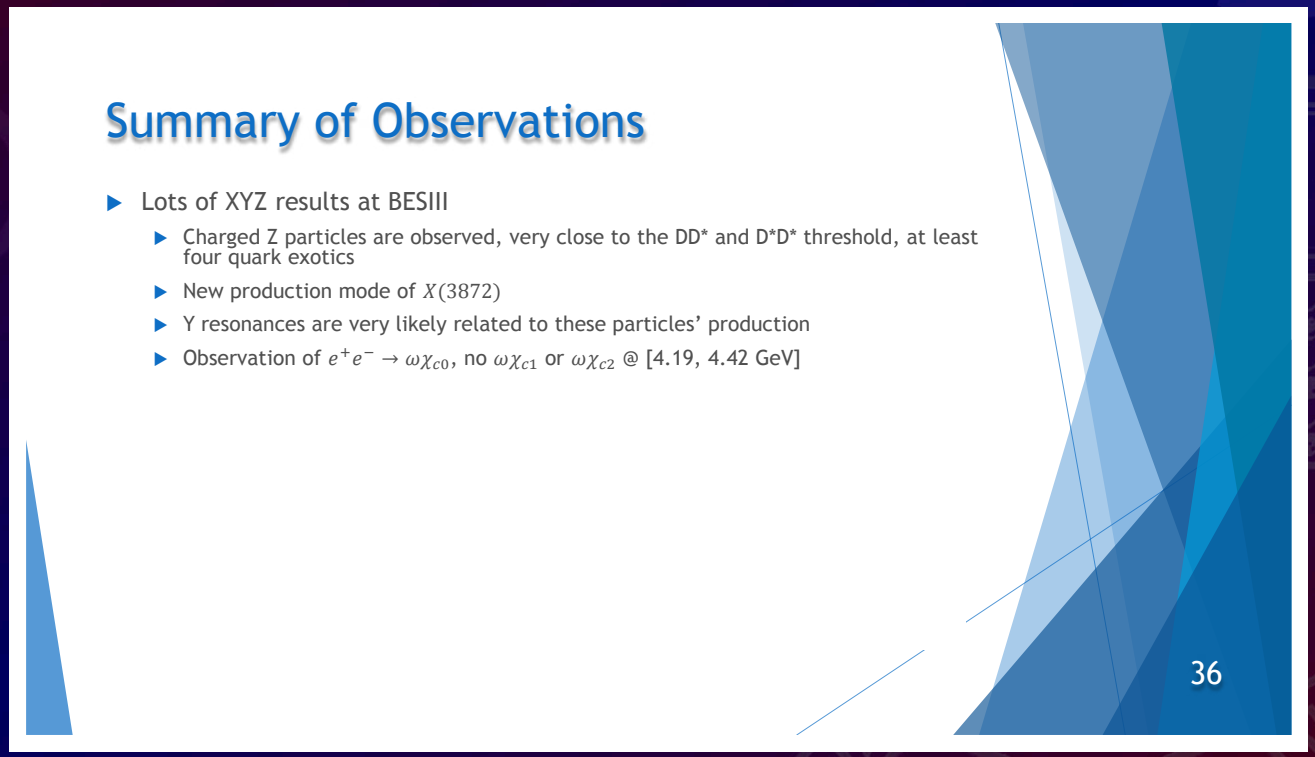

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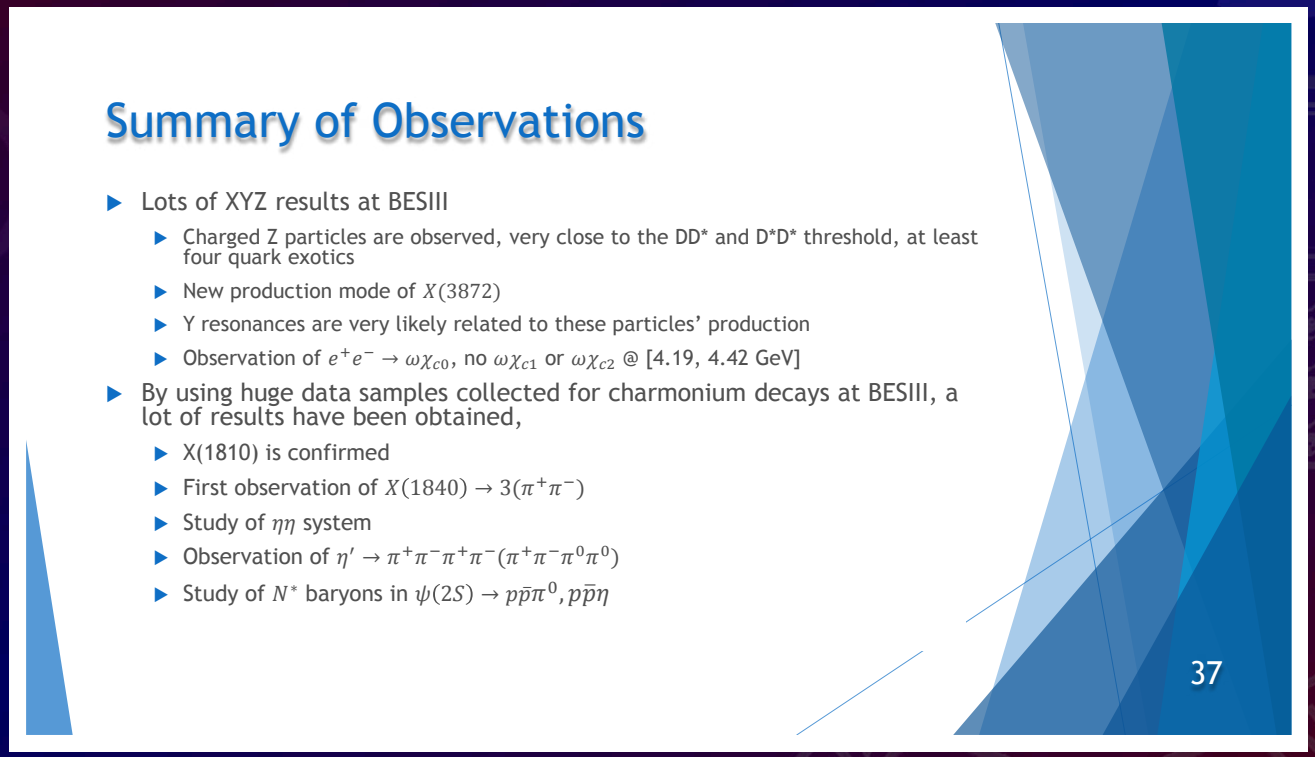

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Heavy Flavour Physics

Perspectives from 2014

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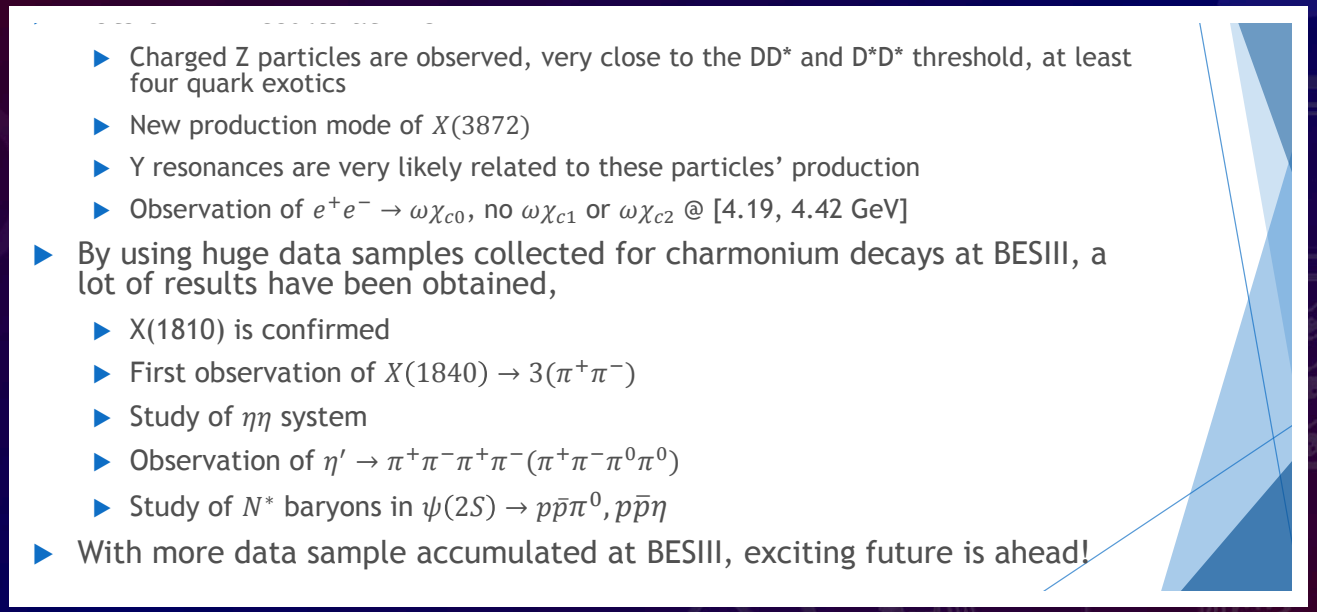

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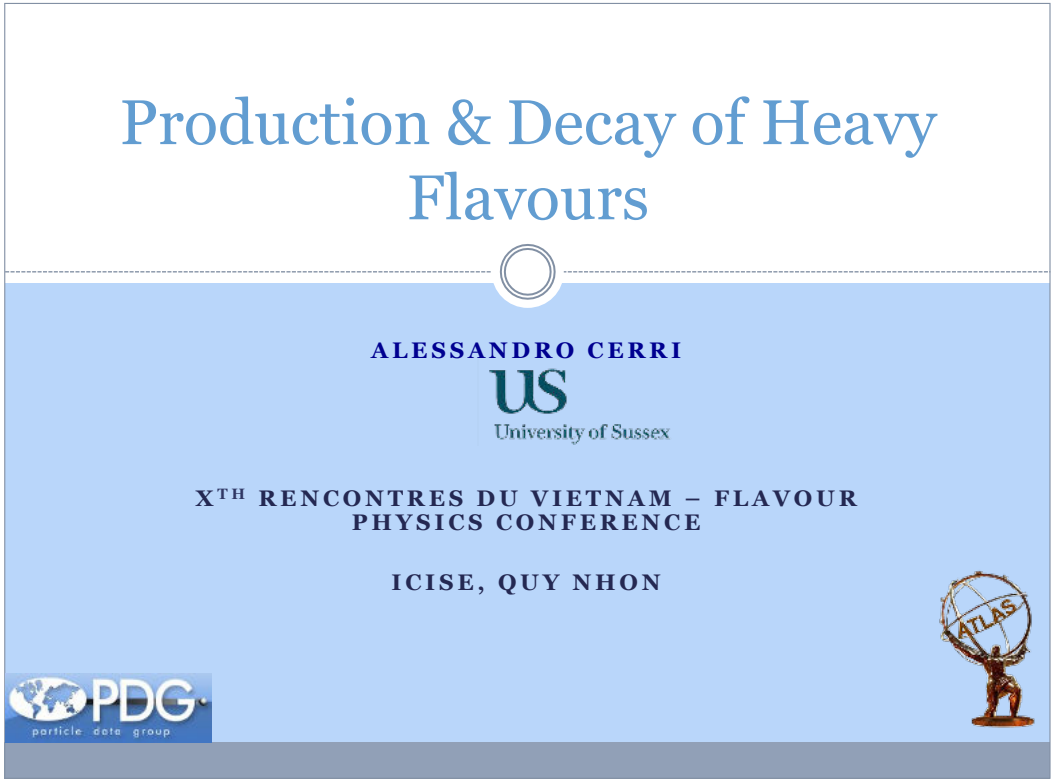
Heavy Flavour Physics

Perspectives from 2014

Comparisons of QCD calculations and numerous experimental inputs

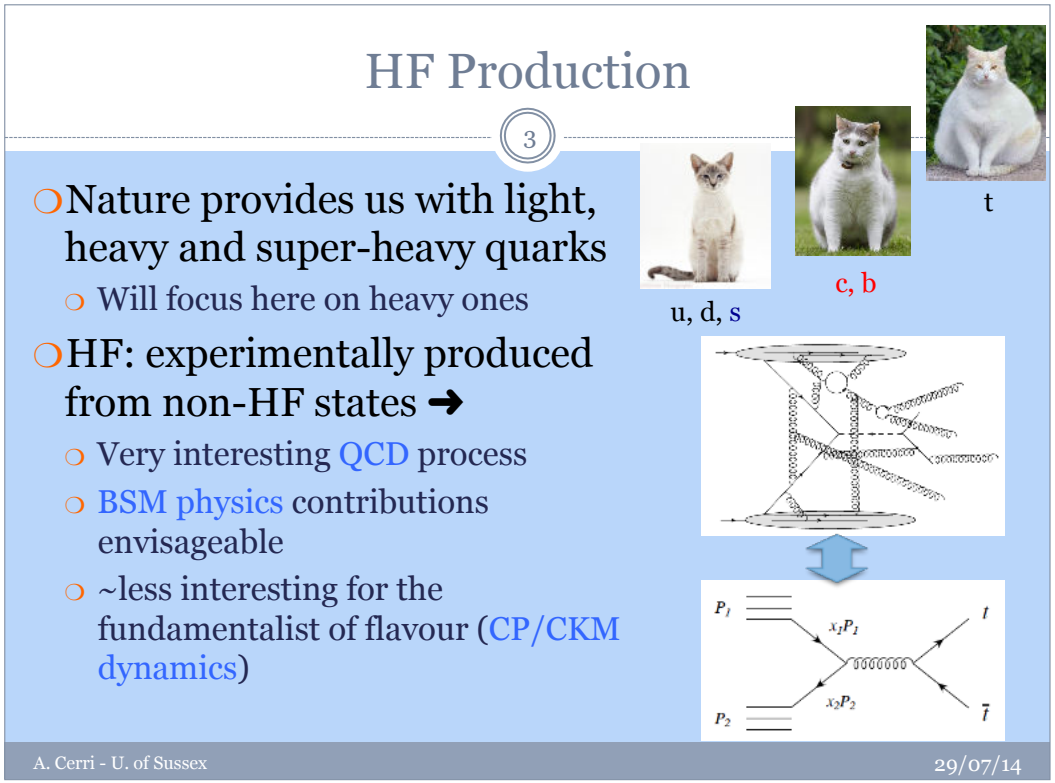


Alessandro Cerri: *Production & Decay of Heavy Flavours*

Heavy Flavour Physics

Perspectives from 2014

Comparisons of QCD calculations and numerous experimental inputs

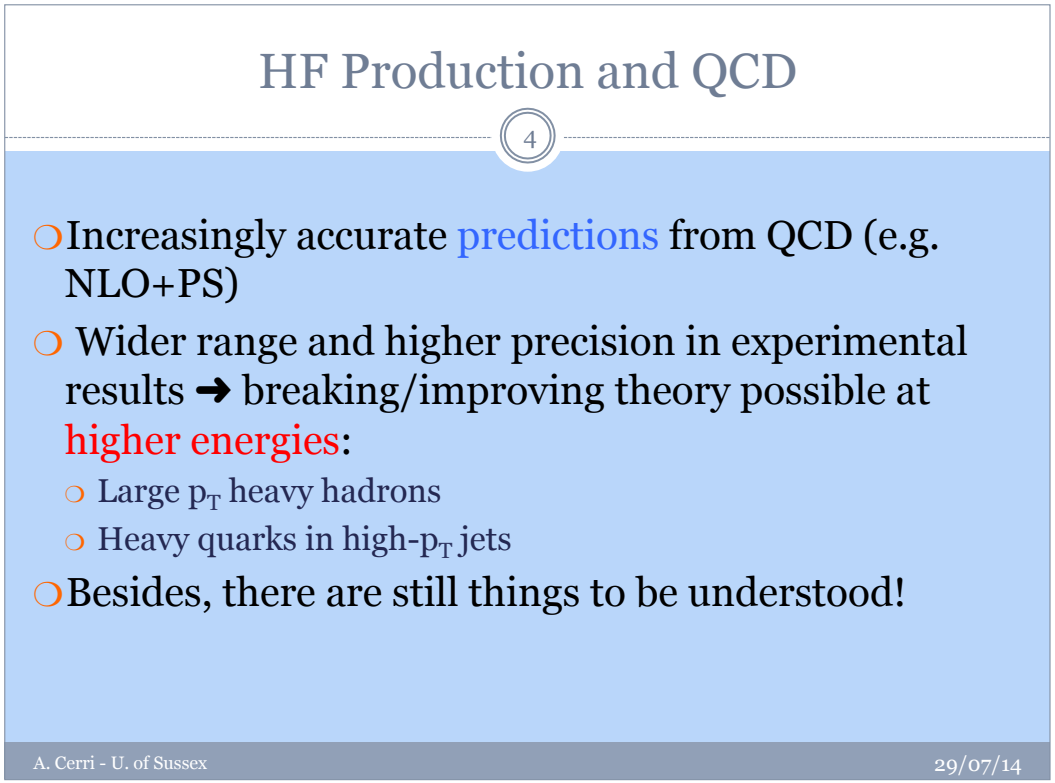


Alessandro Cerri: *Production & Decay of Heavy Flavours*

Heavy Flavour Physics

Perspectives from 2014

Comparisons of QCD calculations and numerous experimental inputs



Alessandro Cerri: *Production & Decay of Heavy Flavours*

Heavy Flavour Physics

Perspectives from 2014

Comparisons of QCD calculations and numerous experimental inputs

- QCD works pretty well!
- Our predictive tools (NLO+PS, FONLL, CEM, CSM, COM...) aren't perfect
- Our experimental data isn't fully consistent with them

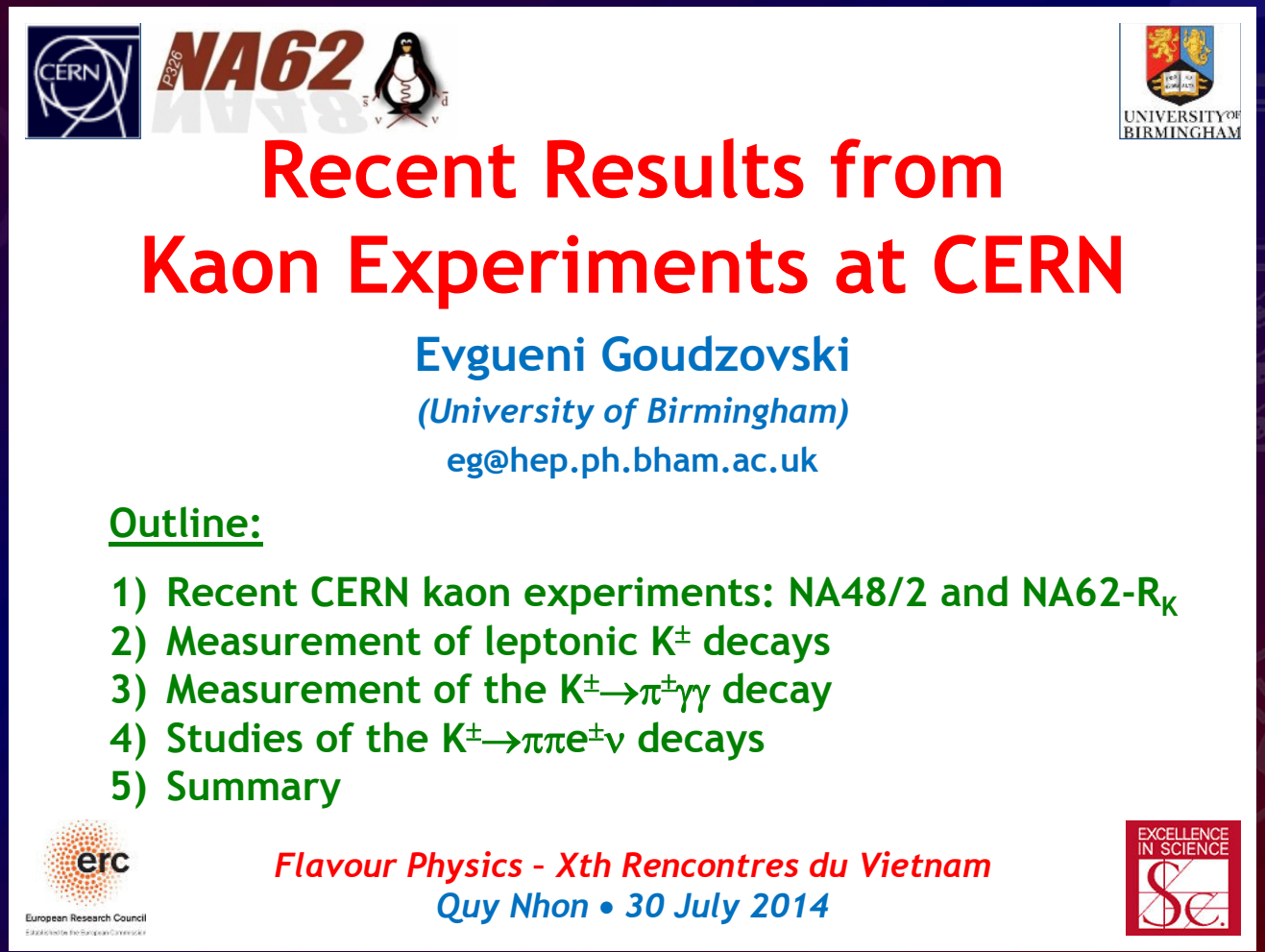
- Measure more and better!
- Predict more and better!

"If it ain't broke don't fix it"
- ...but it is
- "If it ain't broke, break it first"

Alessandro Cerri: *Production & Decay of Heavy Flavours*

Kaon Physics

Perspectives from 2014

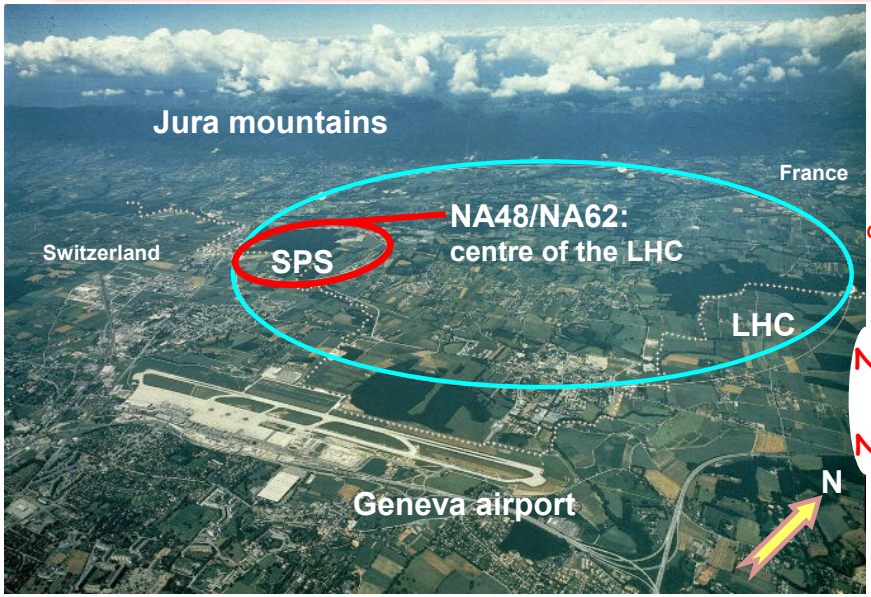


Evgueni Goudzovski: *Recent Results from Kaon Experiments at CERN*

Kaon Physics

Perspectives from 2014

CERN NA48/NA62 experiments



Earlier: NA31

NA48 discovery of direct CPV	1997: ε'/ε: K_L+K_S	
	1998: K_L+K_S	
	1999: K_L+K_S	K_S HI
	2000: K_L only	K_S HI
	2001: K_L+K_S	K_S HI
NA48/1	2002: K_S/hyperons	
NA48/2	2003: K^+/K^-	
	2004: K^+/K^-	
NA62 R_K phase	2007: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$	tests
	2008: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$	tests
NA62	2012: technical run	
	2014: 1st $K^+\to\pi^+\nu\bar{\nu}$ run	

Kaon decay in flight experiments.
NA62: currently ~200 participants, 29 institutions

E. Goudzovski / Quy Nhon, 30 July 2014

1

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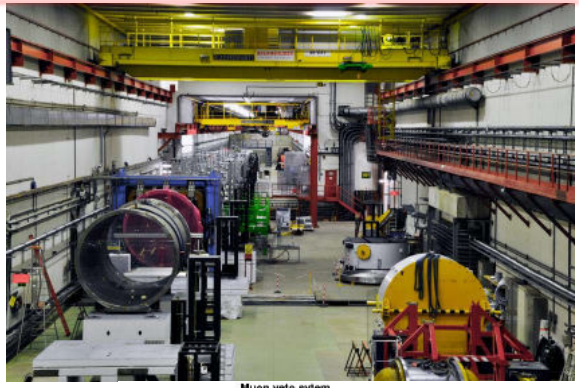
Kaon Physics

Perspectives from 2014

NA48/2 and NA62-R_K detector

2003–2008: charged kaon beams, the NA48 detector

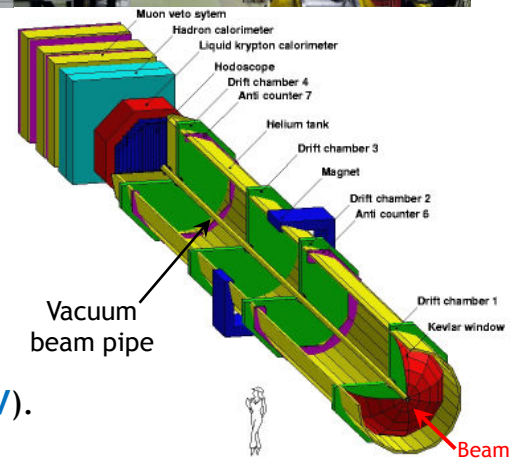


Narrow momentum band $K^{\pm}$ beams:
P_K= 60 (74) GeV/c, $\delta P_K/P_K$ ~ 1% (rms).

- Maximum $K^{\pm}$ decay rate ~100 kHz;
- **NA48/2:** six months in 2003–04;
- **NA62-R_K:** four months in 2007.

Principal subdetectors:

- Magnetic spectrometer (4 DCHs)
  4 views/DCH: redundancy ⇒ efficiency;
  $\delta p/p = 0.48\% \oplus 0.009\% p$ [GeV/c] (in 2007)
- Scintillator hodoscope
  Fast trigger, time measurement (150ps).
- Liquid Krypton EM calorimeter (LKr)
  High granularity, quasi-homogeneous;
  $\sigma_E/E = 3.2\%/E^{1/2} \oplus 9\%/E \oplus 0.42\%$ [GeV];
  $\sigma_x=\sigma_y=4.2\text{mm}/E^{1/2} \oplus 0.6\text{mm}$ (1.5mm@10GeV).



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Kaon Physics

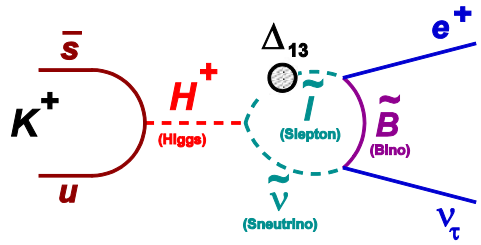
Perspectives from 2014

$R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ beyond the SM

2HDM - tree level

$K^{\pm} \to l^{\pm}\nu$ can proceed via charged Higgs $H^{\pm}$ (in addition to $W^{\pm}$) exchange

→ Does not affect the ratio R_K



2HDM - one-loop level

Dominant contribution to R_K: $H^{\pm}$ mediated LFV (rather than LFC) with emission of ν_τ

→ R_K enhancement can be experimentally accessible

Masiero, Paradisi and Petronzio, PRD 74 (2006) 011701, JHEP 0811 (2008) 042

$$R_K^{LFV} \approx R_K^{SM}\left[1 + \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right)|\Delta_{13}|^2 \tan^6\beta\right] \Longrightarrow$$

sensitive to slepton mixing

- ❖ MSSM: ~1% effect possible
  Girrbach and Nierste, arXiv:1202.4906
- ❖ However limited by $B_{(S)} \to \mu^+\mu^-$ measurements
  Fonseca, Romão and Teixeira, EPJC 72 (2012) 2228
- ❖ Sensitive to SM extensions with 4th generation, sterile neutrinos
  Lacker and Menzel, JHEP 1007 (2010) 006; Abada et al., JHEP 1302 (2013) 048

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5

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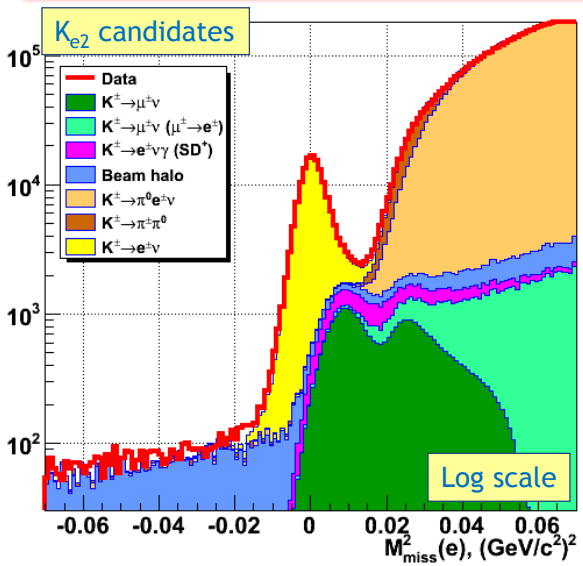
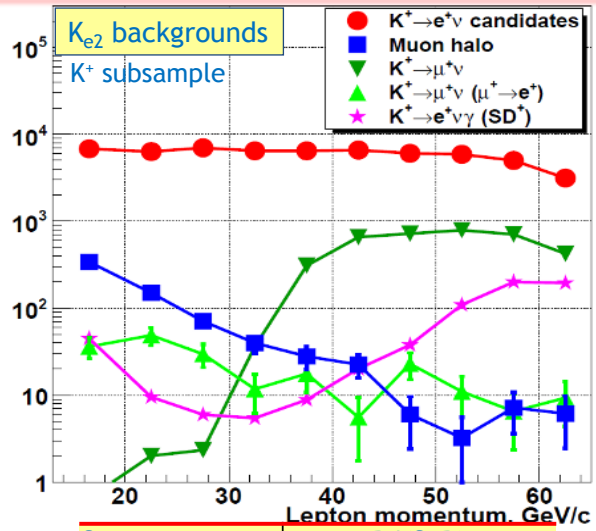
Perspectives from 2014

NA62-R_K data: K_{e2} sample





145,958 $K^{\pm}\to e^{\pm}\nu$ candidates.
Background: B/(S+B)=(10.95±0.27)%.
Electron ID efficiency: (99.28±0.05)%.

Source	B/(S+B)
$K_{\mu 2}$	(5.64±0.20)%
$K_{\mu 2}$ ($\mu\to e$)	(0.26±0.03)%
$K_{e2\gamma}$ (SD)	(2.60±0.11)%
$K_{e3(D)}$	(0.18±0.09)%
$K_{2\pi(D)}$	(0.12±0.06)%
Opposite sign K	(0.04±0.02)%
Beam halo	(2.11±0.09)%
Total	(10.95±0.27)%

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6

Evgueni Goudzovski: *Recent Results from Kaon Experiments at CERN*

Kaon Physics

Perspectives from 2014

Summary

- **NA48/2** (2003–2004): a multi-purpose $K^{\pm}$ experiment.
  - ✓ $K^{\pm}$ physics at a new precision level (17 peer-reviewed papers so far);
  - ✓ Further analyses of rare/forbidden $K^{\pm}$, π^0 decays in progress.
- **NA62-R_K** (2007–2008): minimum bias electron trigger.
  - ✓ Lepton Universality test at record **0.4%** precision:
    $BR(K^{\pm}\to e^{\pm}\nu)/BR(K^{\pm}\to\mu^{\pm}\nu) = (2.488\pm0.010)\times10^{-5}$;
  - ✓ further rare decay analyses completed or in progress.
- **Recent results presented:**
  lepton universality test, $K^{\pm}\to\pi^{\pm}\gamma\gamma$ and $K^{\pm}\to\pi\pi e^{\pm}\nu$ decays.
  More results are coming soon.

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16

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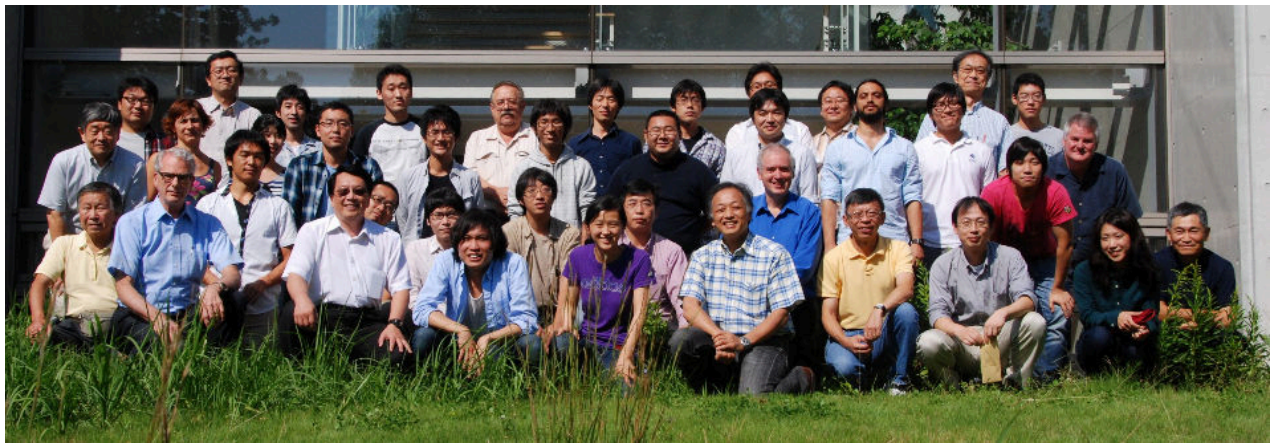
Kaon Physics

Perspectives from 2014

Results of the KOTO experiment at J-PARC

Flavor Physics Conference July 30th 2014
Hajime NANJO (Kyoto Univ.)
for the KOTO collaboration



Arizona State, Chicago, Chonbuk, Jeju, JINR, KEK, Kyoto, Kyungpook, Michigan, NDA, NTU, Okayama, Osaka, Pusan, Saga, Yamagata

Hajime Nanjo: *Results of the KOTO experiment at J-PARC*

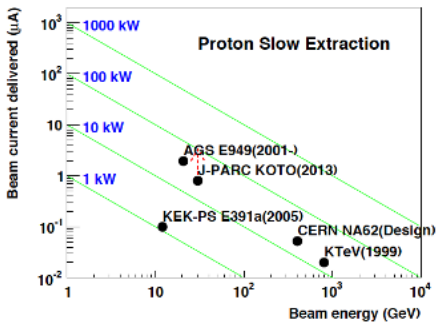
Kaon Physics

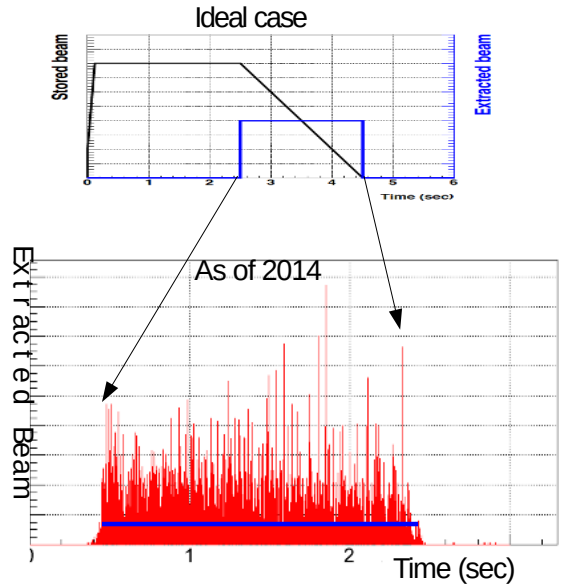
Perspectives from 2014

J-PARC Slow Extraction

- Power in 2013 : 24kW → 100kW planed in 2017
- Duty : 2sec/6sec
- Duty in spill : ½
  - High accidental rate (x2)

  → trying to reduce

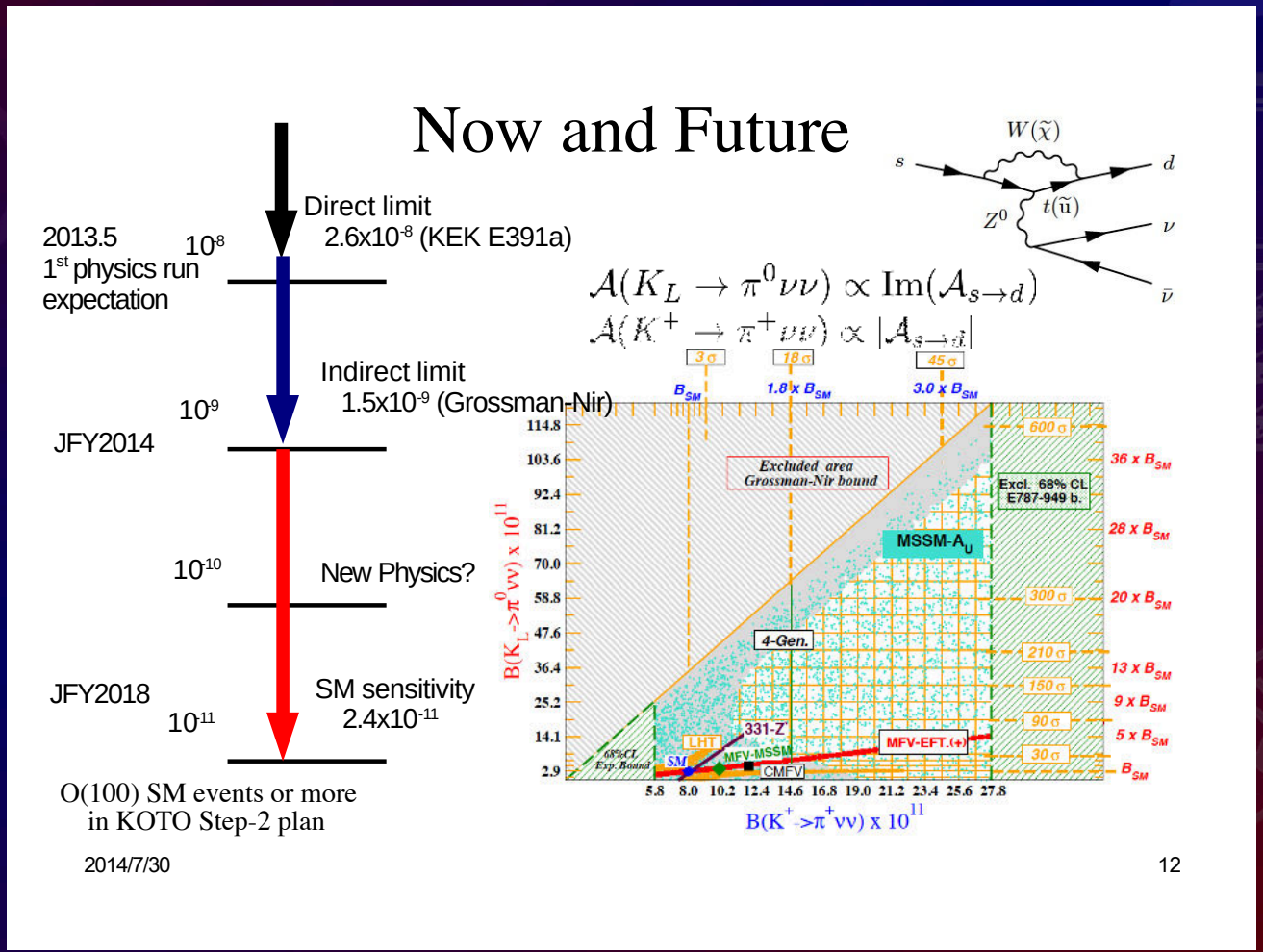




Hajime Nanjo: *Results of the KOTO experiment at J-PARC*

Kaon Physics

Perspectives from 2014



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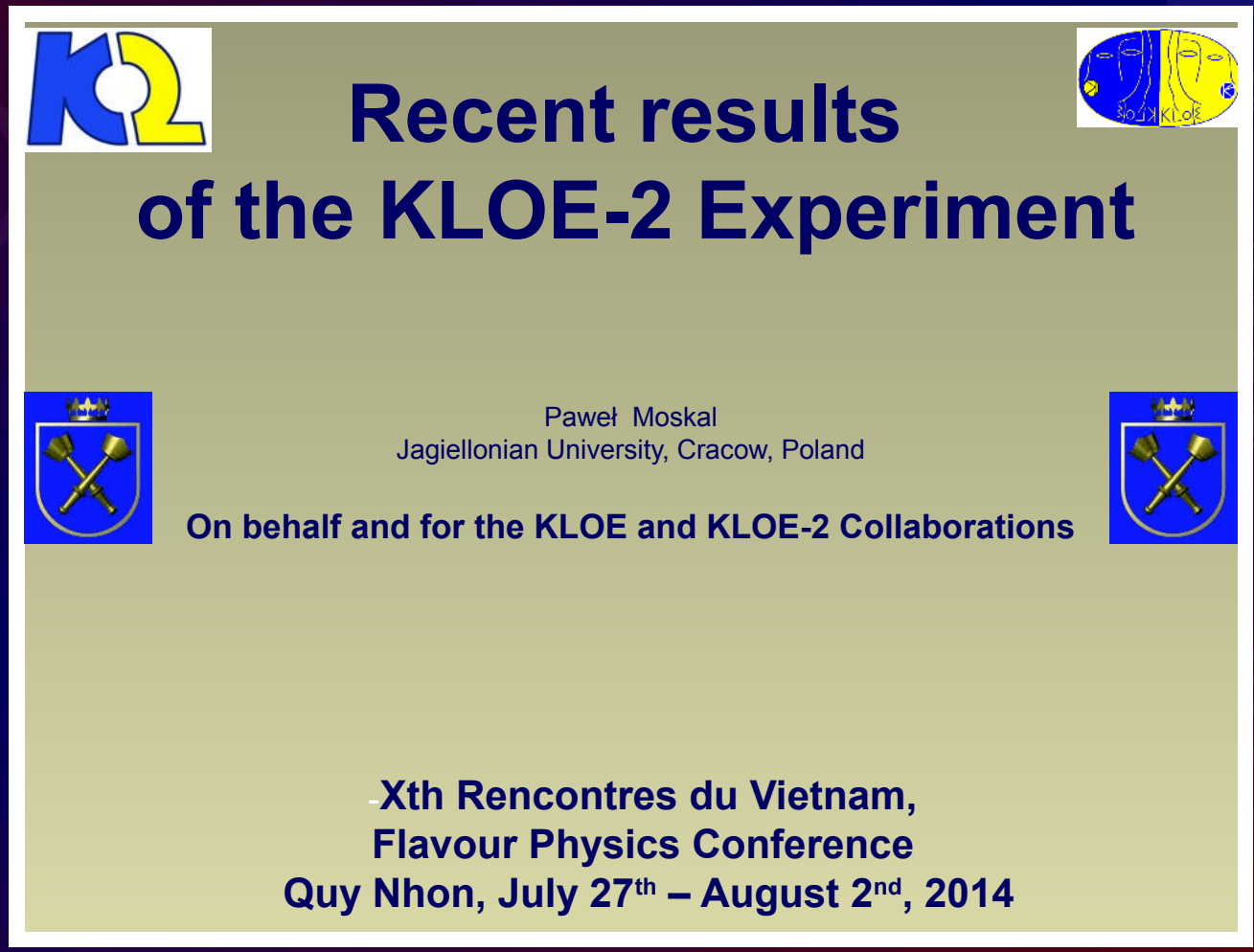
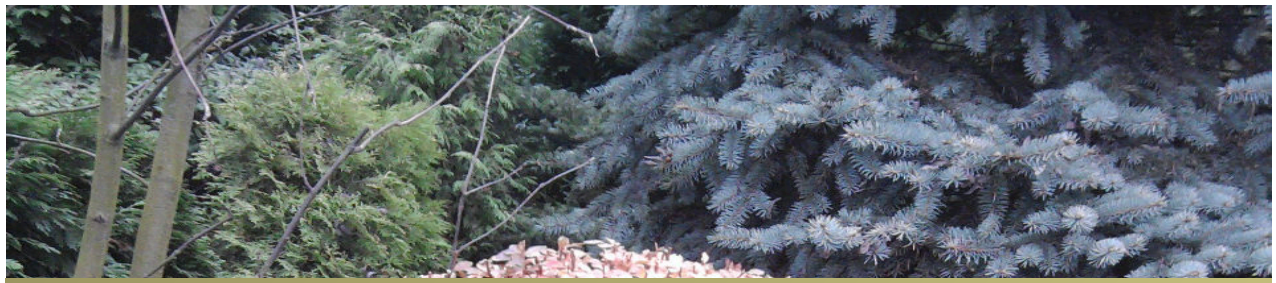


Paweł Moskal: *Recent results of the KLOE-2 Experiment*

Kaon Physics

Perspectives from 2014



KLOE

completed data taking with 2.5 fb^{-1}

$\sim 8 \cdot 10^9$ ϕ

$\sim 2.5\ 10^9$ $K^0\overline{K^0}$ entangled pairs

$\sim 3.6\ 10^9$ K^+K^- pairs

Paweł Moskal: *Recent results of the KLOE-2 Experiment*

Kaon Physics

Perspectives from 2014

50th anniversary of the discovery of CP violation

J. H. Christenson, J. W. Cronin, V. L. Fitch, R. Turlay
"Evidence for the 2π Decay of the K^0_2 Meson System".
Physical Review Letters **13** (1964) 138

CP allowed: $K_L \to \pi\pi\pi$ **CP violating: $K_L \to \pi\pi$**

CP allowed: $K_S \to \pi\pi$ **CP violating: $K_S \to \pi^0\pi^0\pi^0$**

CP violating: $K_S \to \pi^0\pi^0\pi^0$
never observed so far !

SM $\Gamma(K_S \to 3\pi^0) = \Gamma(K_L \to 3\pi^0)\,|\eta_{000}|^2 \Rightarrow BR(K_S \to 3\pi^0) \sim 2\times10^{-9}$

KLOE/KLOE-2: Phys. Lett. B 723 (2013) 54

$$BR(K_S \to 3\pi^0) \leq 2.6 \times 10^{-8} \quad \text{at} \quad 90\% \quad \text{C.L.}$$

Factor of five better than previous results

$$\epsilon + \epsilon'_{000} = |\eta_{000}| = \left|\frac{A(K_S \to 3\pi^0)}{A(K_L \to 3\pi^0)}\right| = \sqrt{\frac{\tau_L}{\tau_S}\frac{BR(K_S \to 3\pi^0)}{BR(K_L \to 3\pi^0)}} \leq 0.0088 \quad \text{at} \quad 90\% \quad \text{C.L.}$$

KLOE-2 has a chance to observe K_S - -> $\pi^0\pi^0\pi^0$ decay for the first time in the near future

Paweł Moskal: *Recent results of the KLOE-2 Experiment*

Kaon Physics

Perspectives from 2014

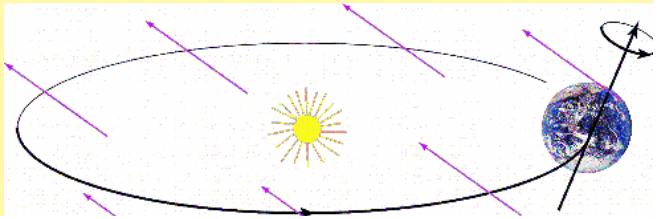
$|K_S(t)\rangle = e^{-\lambda_S t}|K_S\rangle$

$|K_L(t)\rangle = e^{-\lambda_L t}|K_L\rangle$

$|K_S\rangle \approx (1+\varepsilon_s)|K^0\rangle + (1-\varepsilon_s)|\overline{K^0}\rangle$

$|K_L\rangle \approx (1+\varepsilon_L)|K^0\rangle - (1-\varepsilon_L)|K^0\rangle$

$\delta = (\varepsilon_s - \varepsilon_L)/2$



δ is the CPT violation parameter in the Kaon system.

PRD64,076001
PRL89,231602

According to the SME (Kostelecky) and anti-CPT theorem,
CPT violation should appear together with Lorentz Invariance breaking (Greenberg),
and thus implying a direction dependent modulation.

$$\delta \simeq i \sin\phi_{SW} e^{i\phi_{SW}} \gamma_K (\Delta a_0 - \vec{\beta}_K \Delta\vec{a})/\Delta m$$

$$I_{f_1 f_2}(\Delta\tau) \propto e^{-\Gamma|\Delta\tau|}\left[|\eta_1|^2 e^{\frac{\Delta\Gamma}{2}\Delta\tau} + |\eta_2|^2 e^{-\frac{\Delta\Gamma}{2}\Delta\tau} - 2\Re e\left(\eta_1\eta_2^* e^{-i\Delta m\Delta\tau}\right)\right]$$

$$\eta_1 = \eta_\pm = \varepsilon_K - \delta(\vec{p}_{K^1}) \qquad \eta_2 = \varepsilon_K - \delta(\vec{p}_{K^2})$$

Paweł Moskal: *Recent results of the KLOE-2 Experiment*

Kaon Physics

Perspectives from 2014

ORKA technology for future $K^+ \to \pi^+ \nu\bar{\nu}$ experimental searches

Zhe Wang (Tsinghua University)

On behalf of ORKA collaboration

July 30, 2014

at Flavour Physics Conference at Vietnam

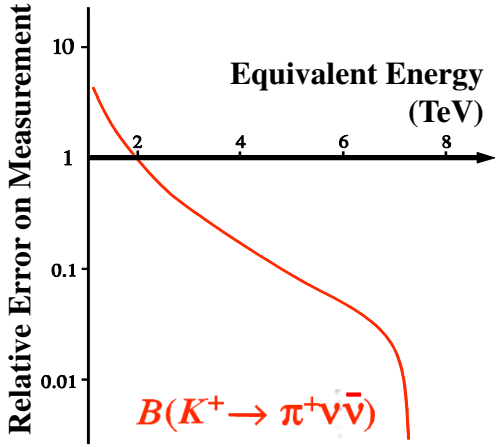
Zhe Wang: *ORKA technology*

Kaon Physics

Perspectives from 2014

Where to look for new physics?

- Direct search after the era of the LHC might be difficult
- Experimental research on kaon decay will present unprecedented sensitivities on new physics
- ORKA, the Golden Kaon Experiment with primary goal of ~1000 of $K^+ \to \pi^+ \nu\nu$



Curve assumes a Minimal Flavor Violation (MFV) model

IJMPA **21**, 487 (2006)

2014/07/30 ORKA 2

Zhe Wang: *ORKA technology*

Kaon Physics

Perspectives from 2014

Results from NA48/2, NA62-R_K, KOTO and KLOE presented–review talk on Thursday

KAON PHYSICS

Augusto Ceccucci / CERN

Xth Rencontres du Vietnam
Flavour Physics Conference
ICISE, Quy Nhon,VN, July 27 - August 2, 2014

Augusto Ceccucci: *Kaon Physics: An Introduction*

Kaon Physics

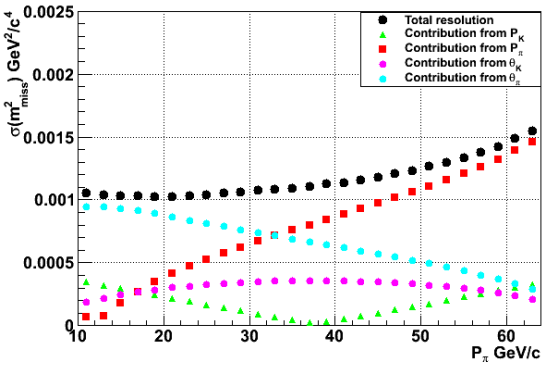
Perspectives from 2014

Results from NA48/2, NA62-R_K, KOTO and KLOE presented–review talk on Thursday

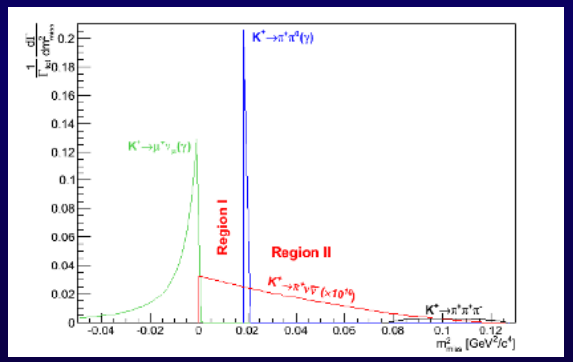
Future: NA62: $K^+ \to \pi^+ \nu\nu$ in-flight decays

General Theme: Maintain a good signal/background ratio preserving the signal acceptance as much as possible

1. **Kinematic rejection**
2. **Charged particle rejection**
3. **Photon rejection**
4. **π/μ separation and μ suppression**



Missing Mass Resolution



Augusto Ceccucci: *Kaon Physics: An Introduction*

Kaon Physics

Perspectives from 2014

Results from NA48/2, NA62-R_K, KOTO and KLOE presented—review talk on Thursday

NOT A SUMMARY

- Kaon physics is a broad subject and I focused only on those aspects most related to flavour
- The future is bright: KLOE2, KOTO, LHCb, NA62, OKA and possible future experiments are poised to significantly improve the state of the art
- Compelling questions are being addressed
- A clear research line that adds flavour to a beautiful subject

Augusto Ceccucci: *Kaon Physics: An Introduction*

Neutrino Physics

Neutrino Physics

Perspectives from 2014

- Are there *more* than 3 mass eigenstates?
  - Are there non-weakly-interacting "sterile" neutrinos?

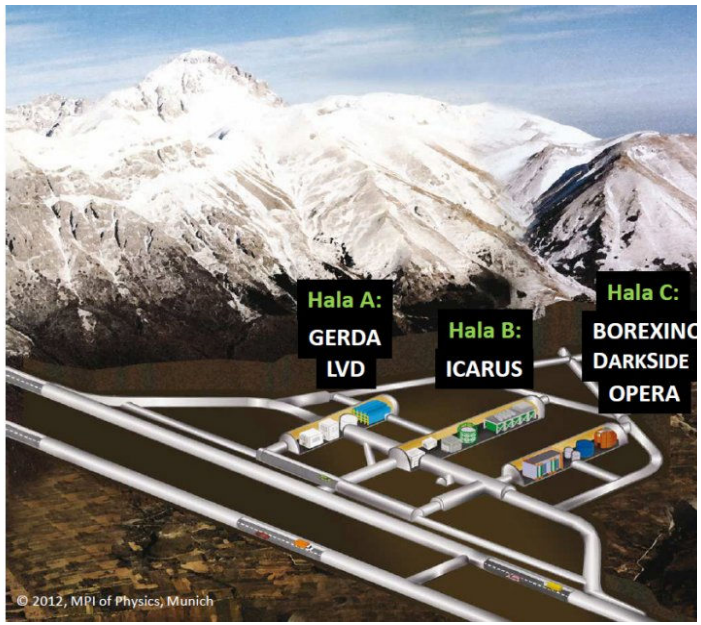
- Do neutrinos break the rules?
  - Non-Standard-Model interactions?
  - Violation of Lorentz invariance?
  - Violation of CPT invariance?
  - Departures from quantum mechanics?

21

Boris Kayser: *Neutrino Physics: An Introduction to the Current Scene*

Neutrino Physics

Perspectives from 2014



Are Neutrino Masses Different?

22

Boris Kayser: *Neutrino Physics: An Introduction to the Current Scene*

Neutrino Physics

Perspectives from 2014

Perhaps, neutrino masses have the same source as the quark and charged lepton masses:

The Standard Model (SM) Brout – Englert – Higgs mechanism for fermion masses.

Coupling constant — Must add to the SM

$$\mathcal{L}_{SM} = y\overline{H}^0\overline{\nu}_L\nu_R \Rightarrow y\left\langle\overline{H}^0\right\rangle_0\overline{\nu}_L\nu_R \equiv m_\nu\overline{\nu}_L\nu_R$$

SM Higgs field — Vacuum expectation value

$$\left\langle\overline{H}^0\right\rangle_0 \equiv v = 174\ \text{GeV}\ ,\ \text{so}\ \ y = \frac{m_\nu}{v} \sim \frac{0.1\,\text{eV}}{174\ \text{GeV}} \sim 10^{-12}$$

A coupling constant this much smaller than unity leaves many theorists skeptical.

23

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Neutrino Physics

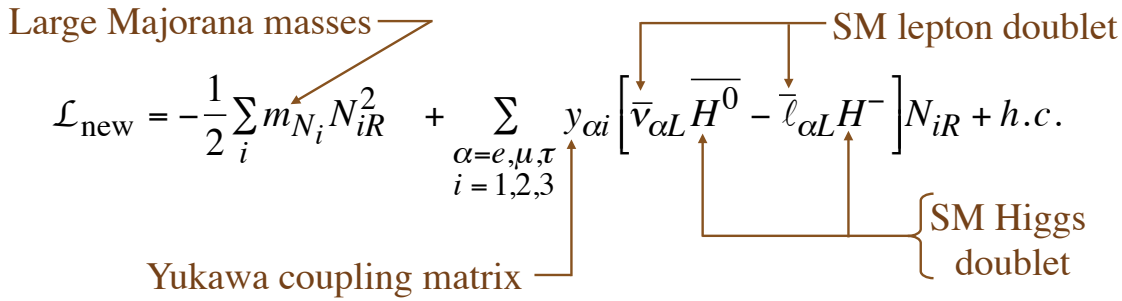
Perspectives from 2014

— An alternative possibility —

Majorana masses and the **See-Saw** picture

The See-Saw model is the most popular theory of why neutrinos are so light.

The straightforward (type-I) See-Saw model adds to the SM 3 heavy neutrinos N_i, with —



24

Boris Kayser: *Neutrino Physics: An Introduction to the Current Scene*

Neutrino Physics

Perspectives from 2014

- T2K had just made unambiguous the first signs of ν_e appearance that were announced in 2011
- Now there were some tantalising hints of sensitivity to CP violation parameters emerging, from only neutrino-mode running

T2K Recent Results From T2K

Xth Rencontres du Vietnam
Flavour Physics Conference
ICISE, Quy Nhon,VN
July 27 - August 2, 2014

Vittorio Paolone
University of Pittsburgh
(Representing the T2K collaboration)

Vittorio Paolone: *Recent Results from T2K*

Neutrino Physics

Perspectives from 2014

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The T2K Experiment
(Tokai to Kamioka)

Goals:

- Study electron neutrino appearance ($\nu_\mu \rightarrow \nu_e$): Explore δ_{CP} and $\theta_{13,\,23}$
- Precision measurement of ν_μ disappearance: Explore θ_{23}

$$P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \sin^2 2\theta_{23} \sin^2 \frac{\Delta m^2_{32} L}{E}$$

Xth R du VN, July 27-August 2, 2014 V. Paolone, University of Pittsburgh 5

Vittorio Paolone: *Recent Results from T2K*

Neutrino Physics

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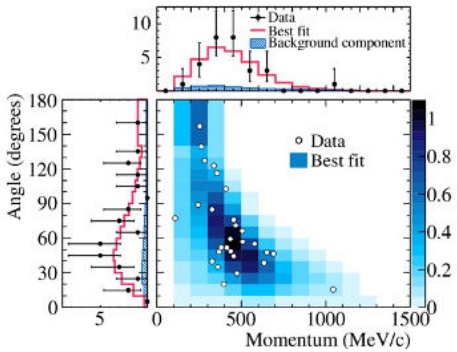
Results: Observation of ν_e Appearance

Using Maximum likelihood fit in (p_e, θ_e):



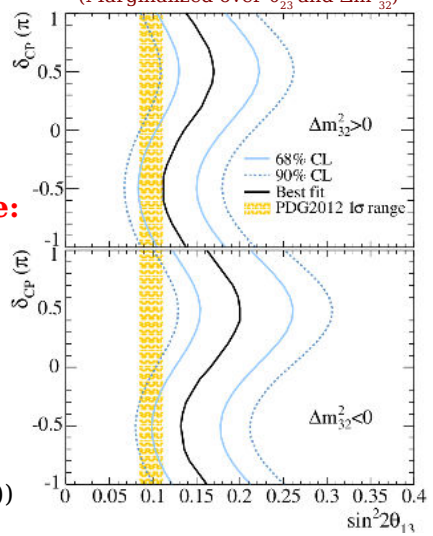
7.3σ significance: $\theta_{13} \neq 0$!

Best-fit value	
NH	$\sin^2 2\theta_{13} = 0.140^{+0.038}_{-0.032}$
IH	$\sin^2 2\theta_{13} = 0.170^{+0.045}_{-0.037}$

for $\sin^2\theta_{23} = 0.5$, $|\Delta m^2_{32}| = 2.4 \times 10^{-3}$ eV^2, $\delta_{CP} = 0$

(Result Published: PRL 112, 061802 (2014))

(Marginalized over θ_{23} and Δm^2_{32})



When combining T2K with reactor results, some values of δ_{CP} are disfavored

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Vittorio Paolone: *Recent Results from T2K*

Neutrino Physics

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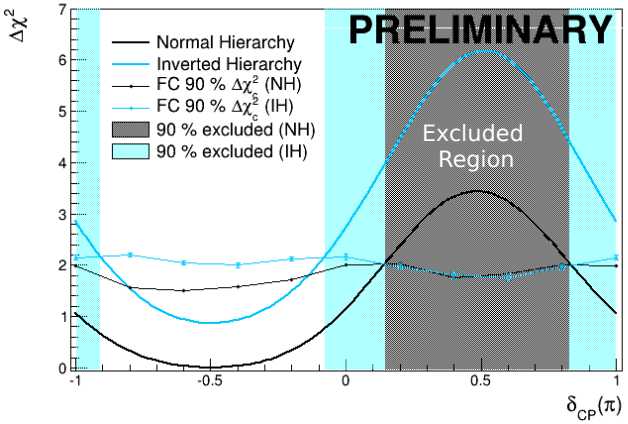
Joint $\nu_\mu + \nu_e$ Analysis Fit: Preliminary

- **Likelihood ratio fit of ν_μ and ν_e events from T2K**
  - Confidence interval performed with Feldman-Cousins
  - Include constraint from reactor experiments



- **Preference for Normal Hierarchy and a value of δ_{CP} around $-\pi/2$**

Using a Markov Chain Monte Carlo (MCMC):

(%)	NH	IH	Sum
$\sin^2\theta_{23} \leq 0.5$	18	8	26%
$\sin^2\theta_{23} > 0.5$	50	24	74%
Sum	68%	32%	

PRELIMINARY

- Comparing the probabilities for each Mass Hierarchy (MH) and θ_{23} octant combination in the posterior probabilities.

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Vittorio Paolone: *Recent Results from T2K*

Neutrino Physics

Perspectives from 2014

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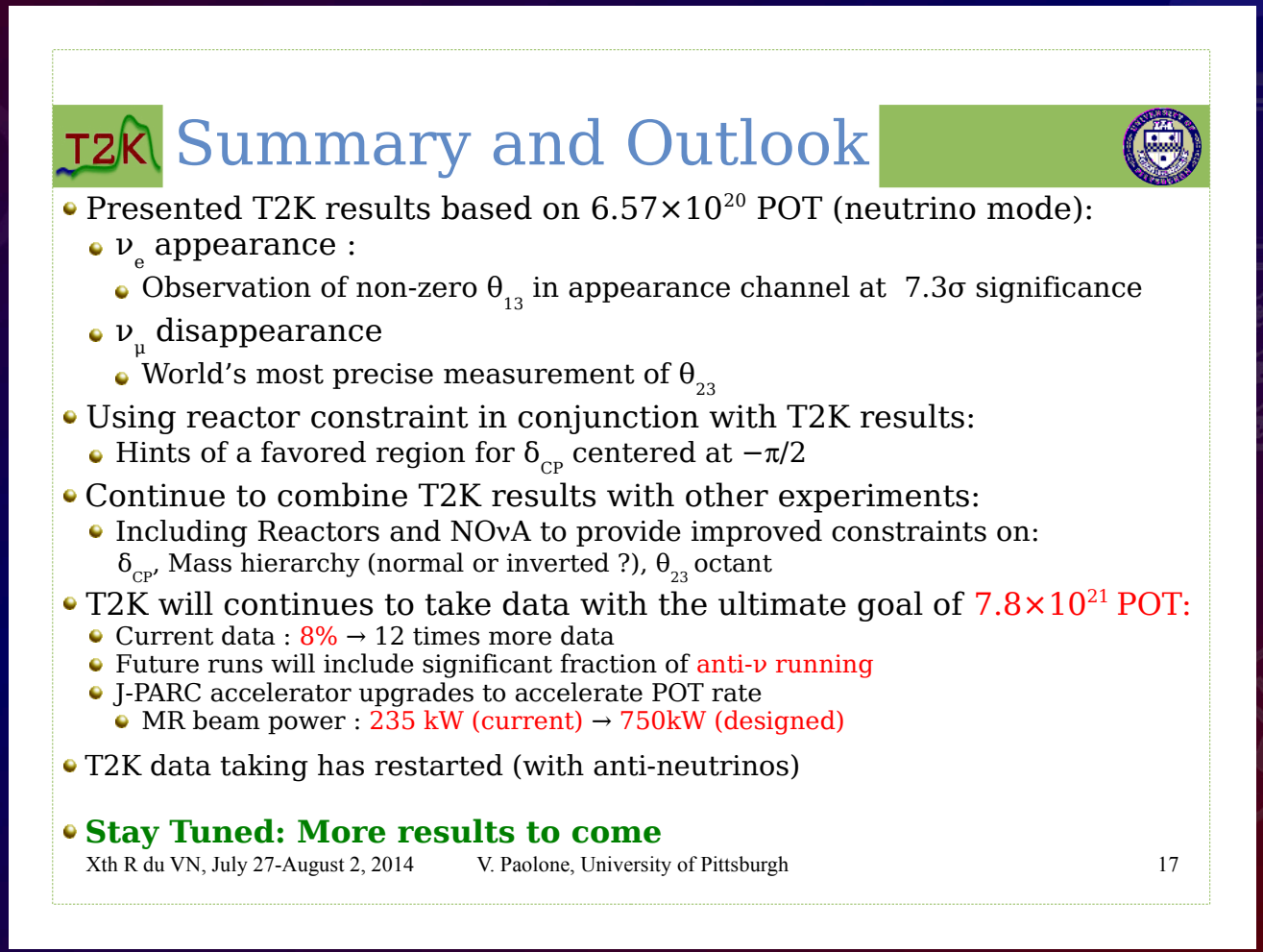

T2K Summary and Outlook

- Presented T2K results based on 6.57×10^{20} POT (neutrino mode):
  - ν_e appearance :
    - Observation of non-zero θ_{13} in appearance channel at 7.3σ significance
  - ν_μ disappearance
    - World's most precise measurement of θ_{23}
- Using reactor constraint in conjunction with T2K results:
  - Hints of a favored region for δ_{CP} centered at $-\pi/2$
- Continue to combine T2K results with other experiments:
  - Including Reactors and NOνA to provide improved constraints on: δ_{CP}, Mass hierarchy (normal or inverted ?), θ_{23} octant
- T2K will continues to take data with the ultimate goal of 7.8×10^{21} POT:
  - Current data : 8% → 12 times more data
  - Future runs will include significant fraction of anti-ν running
  - J-PARC accelerator upgrades to accelerate POT rate
    - MR beam power : 235 kW (current) → 750kW (designed)
- T2K data taking has restarted (with anti-neutrinos)
- **Stay Tuned: More results to come**

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Vittorio Paolone: *Recent Results from T2K*

Neutrino Physics

Perspectives from 2014

The understanding (and reduction) of systematics is more and more important–and NA61 has contributed significantly to understanding T2K

Alexis Haesler: *Results from the NA61/SHINE experiment*

Neutrino Physics

Perspectives from 2014

The understanding (and reduction) of systematics is more and more important–and NA61 has contributed significantly to understanding T2K

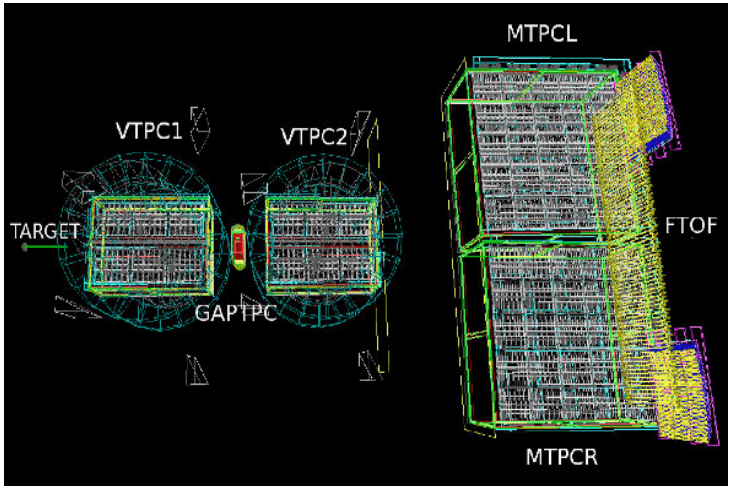
The NA61/SHINE experiment

NA61/SHINE : hadron production experiment at SPS CERN
Rich physics program covering:

- heavy ion physics
- hadron-production measurements for cosmic ray experiments
- hadron-production measurements for accelerator neutrino experiments

Large acceptance spectrometer:

- 5 TPCs
- 2 dipole magnets
- $\sigma(p)/p^2 \sim 10^{-4}(GeV/c)^{-1}$ (at 9Tm)
- $\sigma(dE/dx)/ < dE/dx > \sim 0.04$
- 3 ToF
- $\sigma(FTOF) \sim 120ps$
- $\sigma(TOF\ L/R) \sim 80ps$



Data taken for the Neutrino Physics Program:

Beam	(GeV/c)	graphite target	year	Nx10^6
p	31	2cm	2007	0.7
p	31	2cm	2009	5.4
p	31	90cm "T2K replica"	2007	0.2
p	31	90cm "T2K replica"	2009	4
p	31	90cm "T2K replica"	2010	10

Alexis Haesler: *Results from the NA61/SHINE experiment*

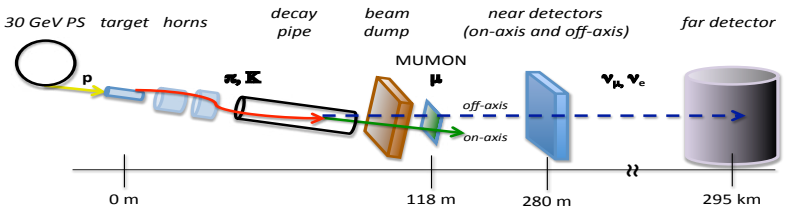
Neutrino Physics

Perspectives from 2014

The understanding (and reduction) of systematics is more and more important–and NA61 has contributed significantly to understanding T2K

Hadron Production measurements for the T2K neutrino flux prediction

- Conventional ν beams produced by interactions of protons on fixed target
- Neutrino beam predictions rely on modeling the proton interactions and hadron production in the target
- Precise hadron production measurements allow to reduce uncertainties on neutrino flux prediction



Examples:

HARP, CERN-PS 1.5 - 15 GeV Beam	Mini- Sci- Micro- BooNE at Fermilab K2K (KEK to Super-Kamiokande)
NA20 & SPY/NA56, SPS 400 - 450 GeV Beam	WANF (NOMAD, CHORUS) CNGS (OPERA, ICARUS)
NA49, CERN-SPS 160 GeV Beam MIPP, FNAL-E907 120 GeV beam	NuMi Beam Line in Fermilab MINOS, MINERvA, NOvA
NA61/SHINE, CERN-SPS 13-400 GeV Beam	T2K (Tokai to Super-Kamiokande) NuMI (MINOS+,MINERvA, NOvA) Future Long Base Line Experiments (LBNE, LBNO, T2HK)

Alexis Häsler (University of Geneva) Flavour Physics Conference / ICISE Vietnam July 31, 2014 4 / 13

Alexis Haesler: *Results from the NA61/SHINE experiment*

Neutrino Physics

Perspectives from 2014

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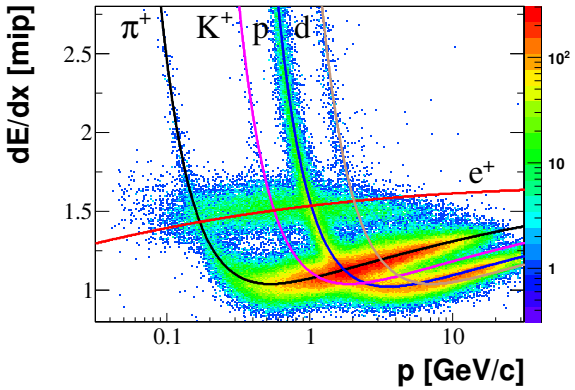
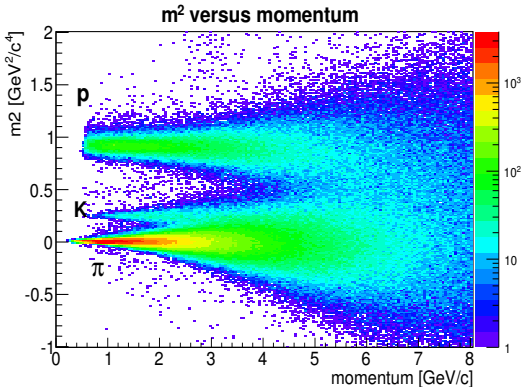
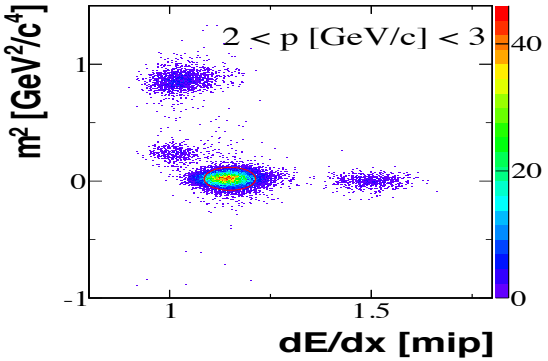
Analysis Techniques in NA61/SHINE

Three analysis techniques:

- h^- analysis: analysis of π^- via measurements of negatively charged particles
- dE/dx analysis at $p \leq 1 GeV/c$: $\pi^\pm$ and protons were identified via energy loss in TPC
- $ToF - dE/dx$ analysis at $p \geq 1 GeV/c$: information from dE/dx and ToF is combined to identify $\pi^\pm$, $K^\pm$ and protons







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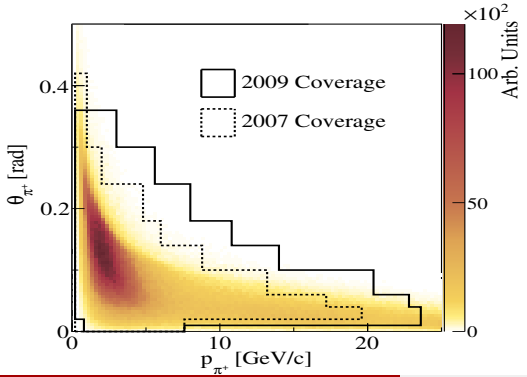
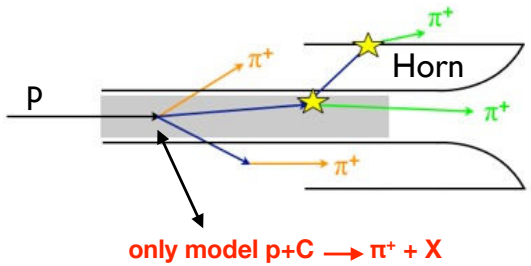
The T2K Beam Tuning with NA61/SHINE Measurements

p+C at 31 GeV/c data in T2K

- Major part of the T2K phase space is covered by NA61/SHINE data
- Interaction chain is stored at the simulation level to be tuned later with measurements
- Tuning of tertiary particles requires extrapolation from NA61/SHINE data:
  - Extrapolation to different incident nucleon momenta
  - Extrapolation to different material (carbon to aluminum)
- Larger uncertainty to the flux due to tertiary particle production





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Alexis Haesler: *Results from the NA61/SHINE experiment*

Neutrino Physics

Perspectives from 2014

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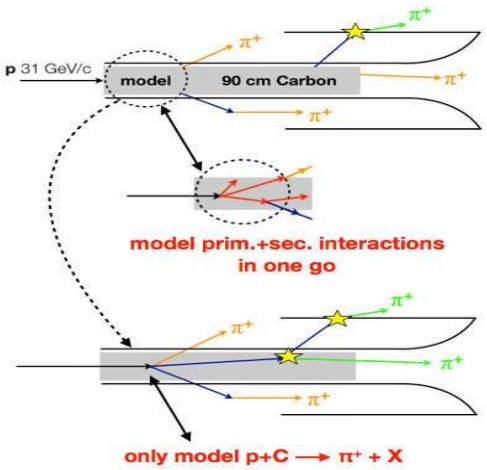
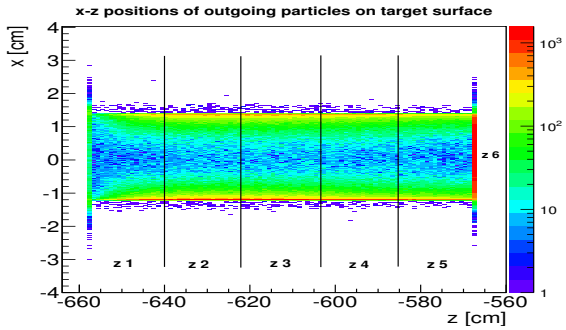
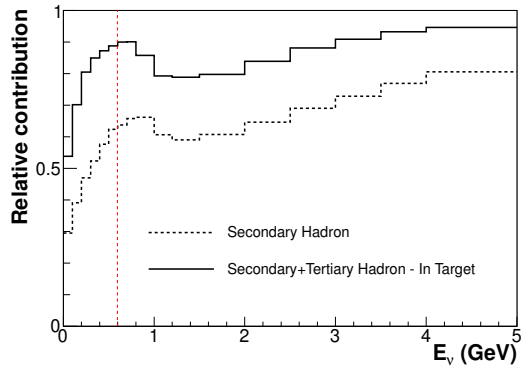
The T2K Beam Tuning with NA61/SHINE Measurements

Alternative approach to the neutrino flux prediction:

- Measurement of hadron multiplicities at the surface of a T2K replica target placed in the NA61/SHINE experimental set-up
- Analysis in (p, θ, z) bins (6 "longitudinal" z bins)
- Re-weighting multiplicities of hadrons exiting the target in the T2K beam simulation
- Re-weighting up to 90% as compared to 60% in the standard approach







Alexis Häsler (University of Geneva) | Flavour Physics Conference / ICISE Vietnam | July 31, 2014 | 10 / 13

Alexis Haesler: *Results from the NA61/SHINE experiment*

Neutrino Physics

Perspectives from 2014

The understanding (and reduction) of systematics is more and more important–and NA61 has contributed significantly to understanding T2K

Summary

- The NA61/SHINE experiment has proved it's ability to deliver high quality data used for Neutrino Physics programs
- All data requested by the T2K long baseline experiment have been recorded
- 7 particle species are extracted for p+C at 31 GeV/c:
  - $\pi^{\pm}$, $K^{\pm}$, K^{0}_{s}, *protons and* Λ released
- 3 articles have been published from p+C at 31 GeV/c
  - Measurement of Production Properties of Positively Charged Kaons in Proton-Carbon Interactions at 31 GeV/c; Phys.Rev. C85 (2012)
  - Measurements of Cross Sections and Charged Pion Spectra in Proton-Carbon Interactions at 31 GeV/c; Phys.Rev. C84 (2011)
  - Pion emission from the T2K replica target: method, results and application; Nuclear Inst. and Methods in Physics Research, A (2013)
- NA61/SHINE published results have been extensively used and have contributed to the recent achievements of the T2K experiment. Detailed explanations have been published in an article by the T2K collaboration (T2K neutrino flux prediction; Phys. Rev. D 87,(2013)). Future results with the thin (2cm) and T2K replica graphite target analyses will allow to further improve the T2K neutrino flux prediction.
- NA61/SHINE plans to continue taking hadron production measurements for future neutrino program at Fermilab and for long base line neutrino experiments

Alexis Häsler (University of Geneva) Flavour Physics Conference / ICISE Vietnam July 31, 2014 13 / 13

Alexis Haesler: *Results from the NA61/SHINE experiment*

Neutrino Physics

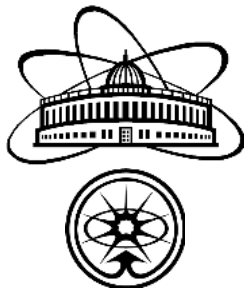
Perspectives from 2014

Some of the issues with modelling neutrino interaction cross-sections were highlighted–an area with much intense activity in recent years

The effective nucleon axial mass approach and quasielastic neutrino event rates in NOνA and Super-Kamiokande

K. Kuzmin[ab], V. Naumov[a], O. Petrova[a], I. Shandrov[a], A. Sheshukov[a]

[a] Joint Institute for Nuclear Research,
[b] Institute for Theoretical and Experimental Physics



Olga Petrova: *The effective nucleon axial mass approach and quasielastic neutrino event rates*

Neutrino Physics

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QES of neutrino on the nucleon

QES section:

$$\boxed{d\sigma = \frac{G_F^2 M}{16\pi^2 (kp)} \left(1 + \frac{Q^2}{M_W^2}\right)^{-2} L^{\alpha\beta} W_{\alpha\beta} \frac{d^3\vec{k}'}{2k'_0}.}$$

Lepton tensor:

$$L^{\alpha\beta}(k,k') = \begin{cases} j^{\alpha}(k,k') j^{*\beta}(k,k') & \text{for } \nu; \\ \bar{j}^{\alpha}(k,k') \bar{j}^{*\beta}(k,k') & \text{for } \bar{\nu}. \end{cases}$$

Weak lepton currents:

$$j^{\alpha}(k,k') = \bar{u}(k')\gamma^{\alpha}\frac{1-\gamma_5}{2}u(k), \qquad \bar{j}^{\alpha}(k,k') = \bar{v}(k)\gamma^{\alpha}\frac{1-\gamma_5}{2}v(k').$$

Hadron tensor:

$$W_{\alpha\beta}(p,q) = \frac{1}{4}\int J_{\alpha}(p,p') J^{*}_{\beta}(p,p') \delta^4(k'+p'-k-p)\frac{d^3\vec{p'}}{2p'_0}.$$

Olga Petrova: *The effective nucleon axial mass approach and quasielastic neutrino event rates*

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Weak form factors of the nucleon

Weak hadron current is given by

$$J_\alpha(p,p') = V_{ud}^{\mathrm{CKM}} \bar{u}_p(p') \Gamma_\alpha(p,q) u_n(p).$$

Basis expansion of $\Gamma_\alpha(p,q)$ comes to

$$\Gamma_\alpha(p,q) = \gamma_\alpha F_V + i\sigma_{\alpha\beta}\frac{q^\beta}{2M}F_M + \frac{q_\alpha}{M}F_S + \\ + \left(\gamma_\alpha F_A + \frac{p_\alpha + p'_\alpha}{M}F_T + \frac{q_\alpha}{M}F_P\right)\gamma_5.$$

Standard dipole parametrization of the axial form factor is

$$F_A(Q^2) = g_A\left(1 + \frac{Q^2}{{M_A}^2}\right)^{-2}, \qquad g_A = -1.2695.$$

PCAC gives the formula for pseudoscalar form factor:

$$F_P(Q^2) = \frac{2M^2}{m_\pi^2 + Q^2}F_A(Q^2).$$

Olga Petrova: *The effective nucleon axial mass approach and quasielastic neutrino event rates*

Neutrino Physics

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Some of the issues with modelling neutrino interaction cross-sections were highlighted–an area with much intense activity in recent years

World survey of M_A

The current best-fit value (with 1σ and 2σ st. deviations) derived on hydrogen, deyterium and high-energy data[1]:

$$M_A = 1.012 \pm 0.031 \left(^{+0.061}_{-0.06}\right) \text{GeV}.$$

Experimental results:

NOMAD (with stat. and syst. errors)[2]: $M_A = 1.05 \pm 0.02 \pm 0.06$ GeV.

K2K[3]: $M_A = 1.2 \pm 0.12$ GeV.

MiniBooNE[4]: $M_A = 1.35 \pm 0.17$ GeV.

T2K shape-fit[5]: $M_A = 1.38 \left(^{+0.39}_{-0.27}\right)$ GeV.

[1] Kuzmin, Lyubushkin & Naumov, 2008; Kuzmin & Naumov, in preparation.
[2] Lyubushkin (NOMAD Collaboration), 2009.
[3] Gran (The K2K Collaboration), 2006.
[4] Aguilar-Arevalo *et al.* (The MiniBooNE Collaboration), 2010.
[5] Hadley (The T2K Collaboration), 2013.

Olga Petrova: *The effective nucleon axial mass approach and quasielastic neutrino event rates*

Neutrino Physics

Perspectives from 2014

Some of the issues with modelling neutrino interaction cross-sections were highlighted–an area with much intense activity in recent years

Conclusions

- The M_A value essentially affects the predicted count rates.
- The effect should be taken into account.
- Using the effective axial mass instead of the constant values like:
  - 1.35 GeV (MiniBooNE)[1] or 1.38 GeV (T2K)[2]
  - 1.05 GeV (NOMAD)[3]

  should improve the validity of the mixing parameter values.
- The estimations presented herein are preliminary.

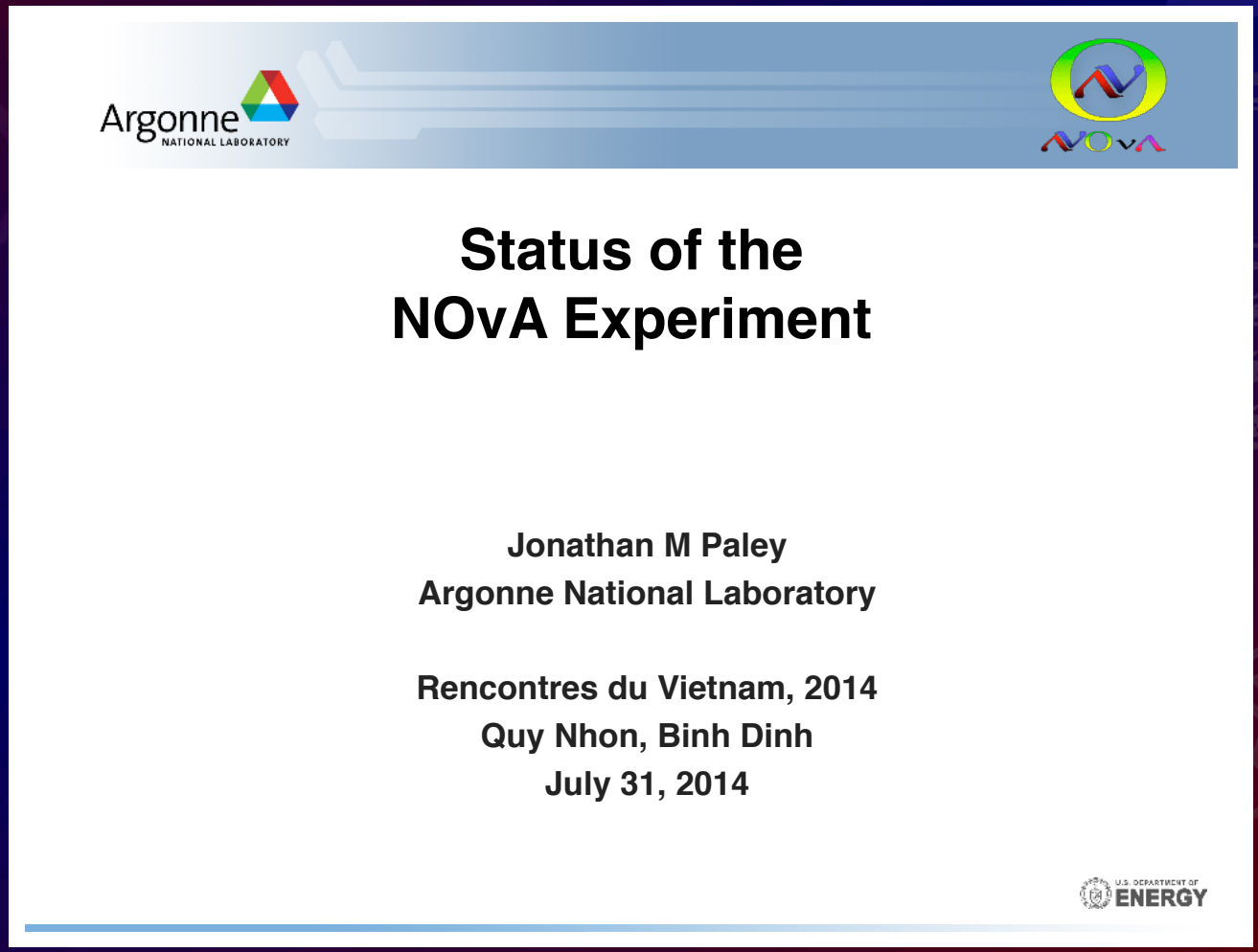
[1] Aguilar-Arevalo *et al.* (The MiniBooNE Collaboration), 2010.
[2] Hadley (The T2K Collaboration), 2013.
[3] Lyubushkin (NOMAD Collaboration), 2009.

Olga Petrova: *The effective nucleon axial mass approach and quasielastic neutrino event rates*

Neutrino Physics

Perspectives from 2014

NOνA, setting out to observe neutrino appearance and disappearance at the "atmospheric" Δm^2 as does T2K, was approaching completion



Jonathan Paley: *Status of the NOvA Experiment*

Neutrino Physics

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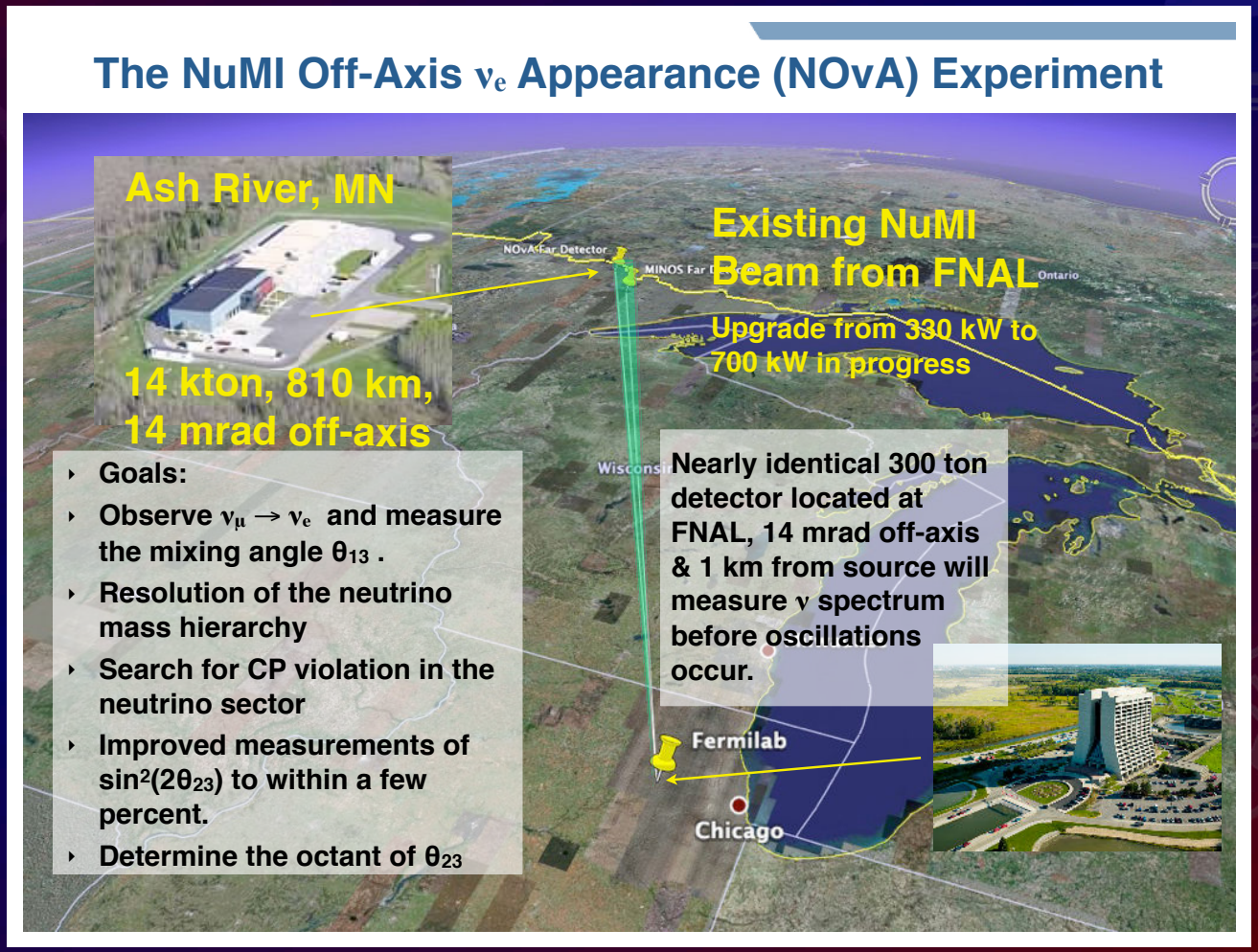

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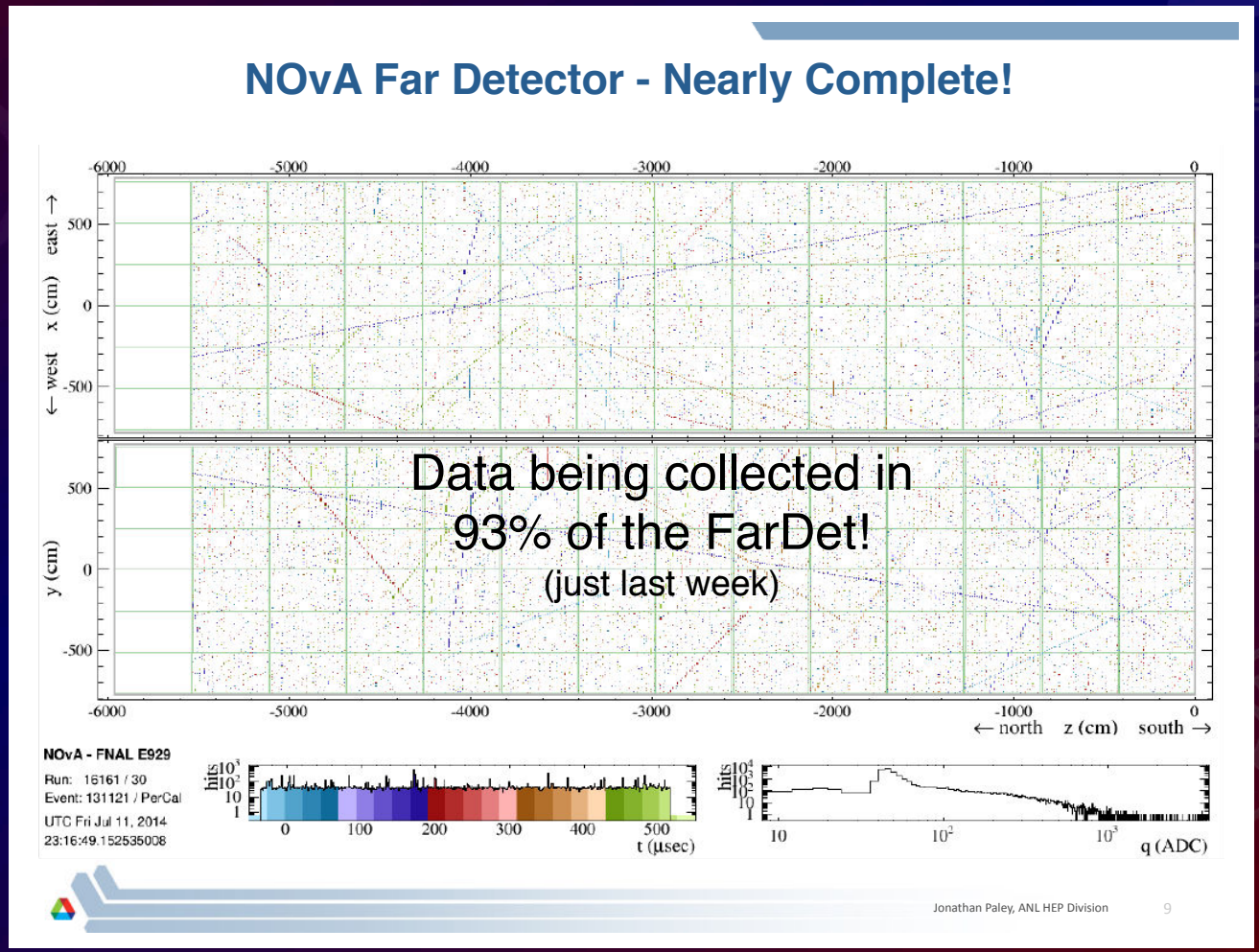

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Neutrino Physics

Perspectives from 2014

NOνA, setting out to observe neutrino appearance and disappearance at the "atmospheric" Δm^2 as does T2K, was approaching completion

Summary

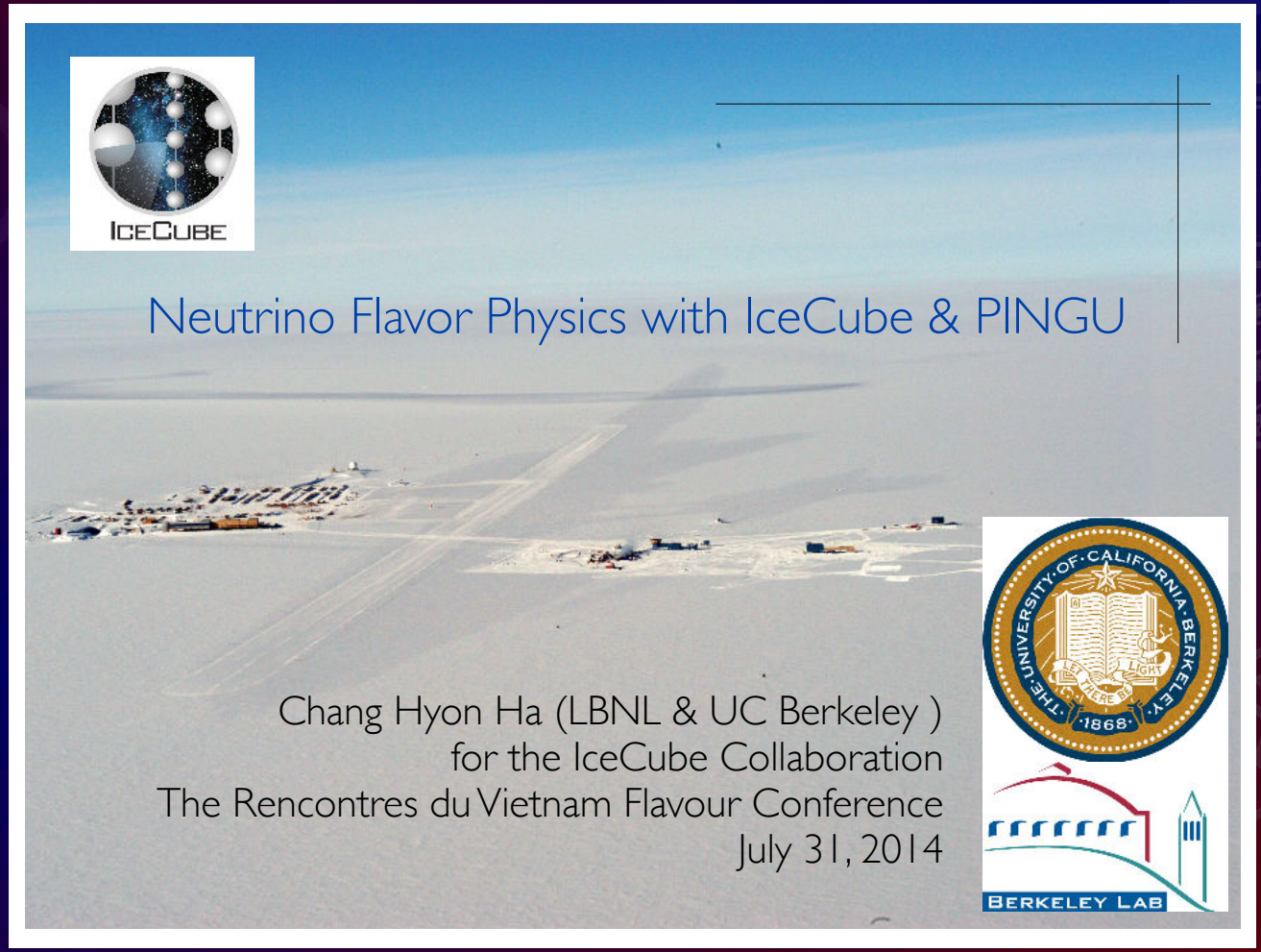
- NOvA will make many important contributions to neutrino physics:
  - Measurement of θ_{13}
  - Important first information on the neutrino mass hierarchy and CP violating phase
  - More precise measurement of $\sin^2(2\theta_{23})$ and determination of the θ_{23} octant
- Both Far and Near detectors are nearly complete
- First neutrinos have been observed in both detectors!
- Collaboration is very focused on commissioning of both detectors
- NuMI beam will be down for upgrades between September and October; when beam returns, we will have fully instrumented, commissioned and calibrated detectors
- Reconstruction and analysis tools are in place for first results in early 2015
- Stay tuned!

Jonathan Paley: *Status of the NOvA Experiment*

Neutrino Physics

Perspectives from 2014

ICECUBE had successfully discovered extraterrestrial neutrinos, and were looking towards the lower energy range of their acceptance, to be able to make atmospheric neutrino measurement



Chang Hyon Ha: *Neutrino Flavour Physics with IceCube & PINGU*

Neutrino Physics

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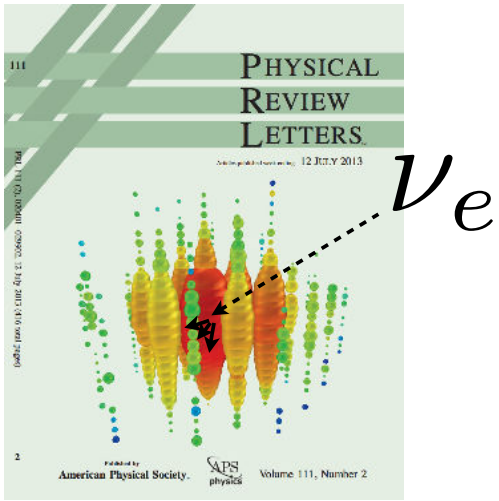
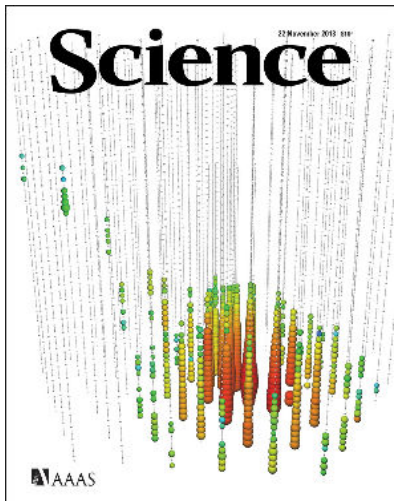
Two Covers



Observation of PeV-Energy Neutrinos

Physical Review Letters 111 (2013) 021103 [arXiv:1304.5356]



Evidence for High-Energy Extraterrestrial Neutrinos

Science 342, 1242856 (2013) [arxiv:1311.5238]

5

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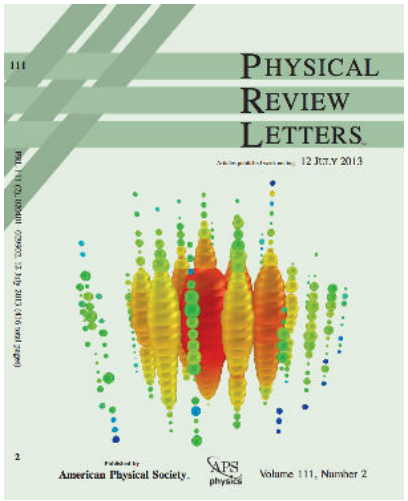

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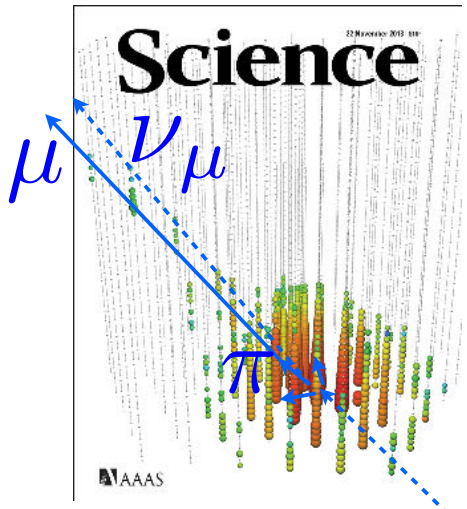

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9

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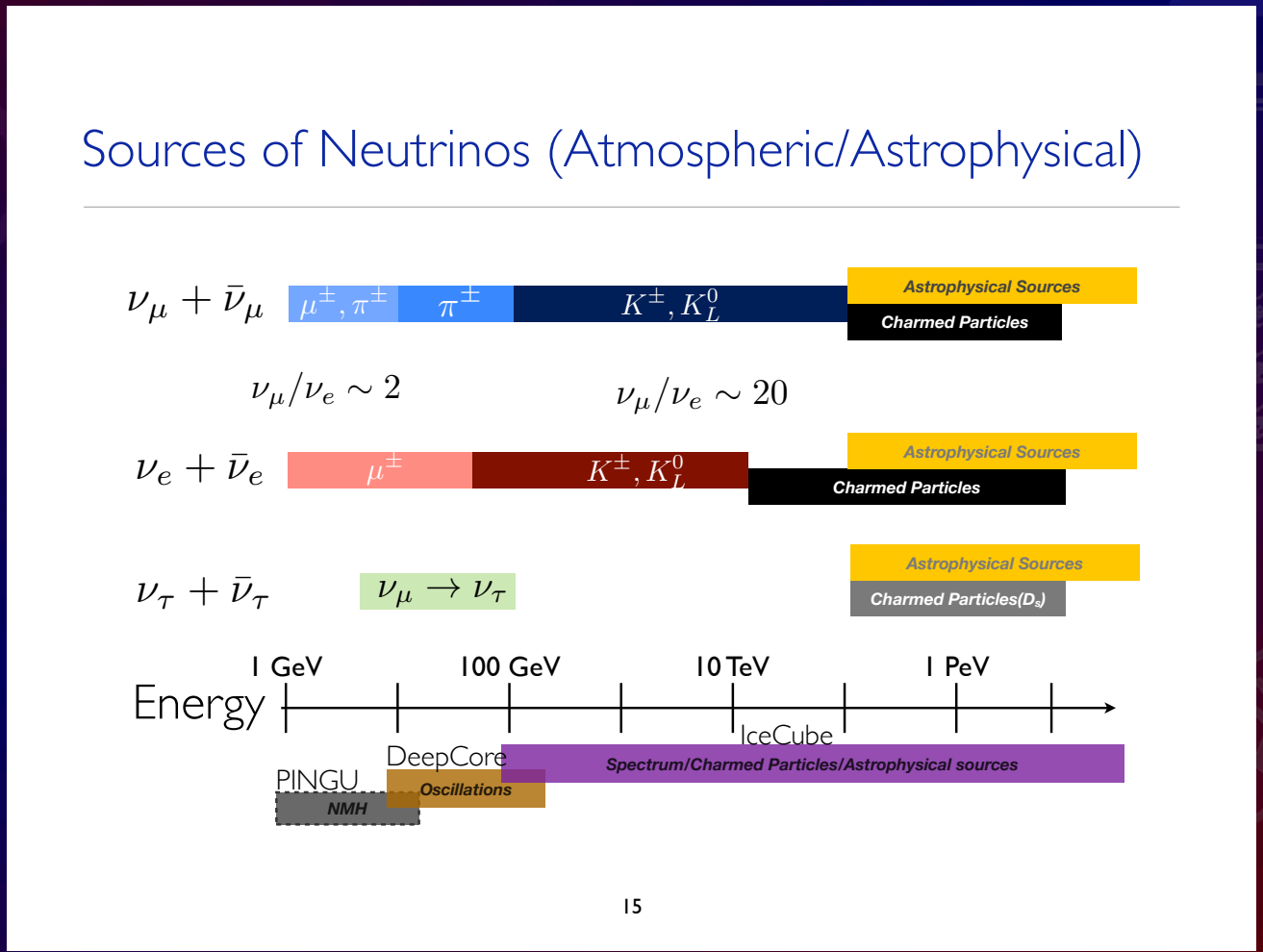

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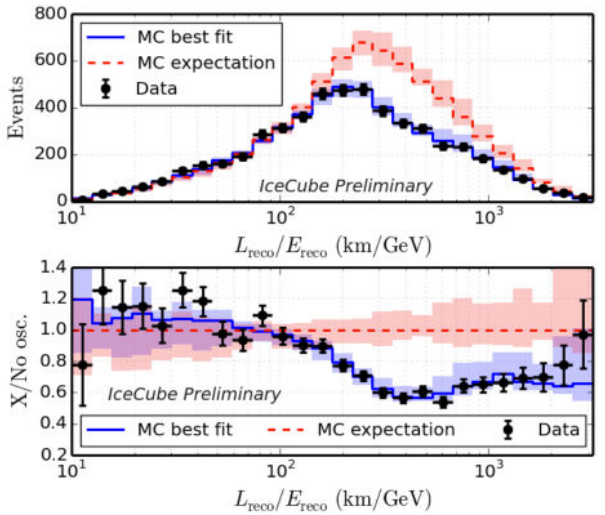
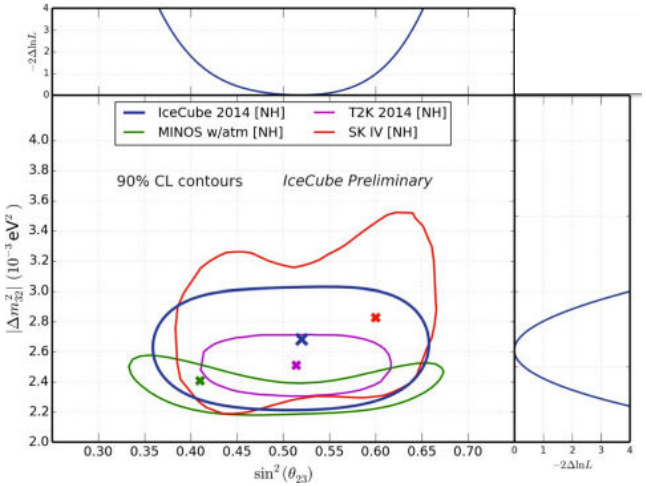
Neutrino Oscillations : ν_μ Disappearance

Zenith Angle and Energy with 3 year DeepCore (953 days)

Bands: variations allowed by the systematic uncertainties ***assumed***





3-flavor oscillations measured with the high energy atmospheric neutrinos
Measurements are consistent with other results
We continue to improve the systematic uncertainties.

17

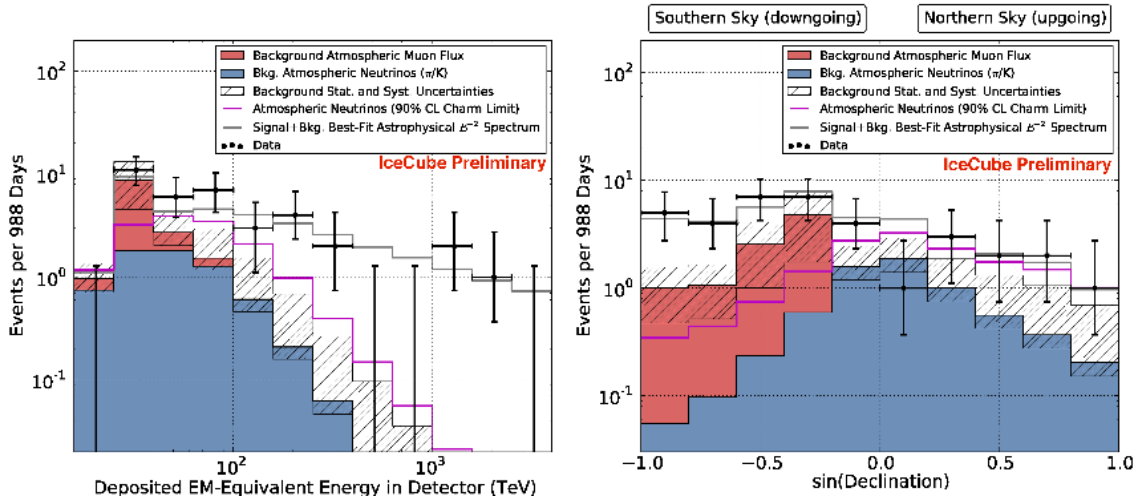
Chang Hyon Ha: *Neutrino Flavour Physics with IceCube & PINGU*

Neutrino Physics

Perspectives from 2014

ICECUBE had successfully discovered extraterrestrial neutrinos, and were looking towards the lower energy range of their acceptance, to be able to make atmospheric neutrino measurement

Astrophysical Neutrinos



Arxiv:1405.5305

37 events in three years of data
- 8.4 +/- 4.2 atmospheric muons (background)
- 6.6+5.9-1.6 atmospheric neutrinos (background)

High confidence of non-atmospheric source of neutrinos
(5.7 sigma rejection of atmospheric-only hypothesis)

21

Chang Hyon Ha: *Neutrino Flavour Physics with IceCube & PINGU*

Neutrino Physics

Perspectives from 2014

ICECUBE had successfully discovered extraterrestrial neutrinos, and were looking towards the lower energy range of their acceptance, to be able to make atmospheric neutrino measurement

Summary

- The IceCube detector is running at full strength
  - Three years of 86-string data are being analyzed while taking the fourth year of 86-string data
  - The detector runs very smoothly (~99% uptime)
- IceCube is a multi-purpose detector
  - Measurement of Atmospheric neutrino flux
  - Observation of astrophysical neutrinos and active prompt neutrino search program
  - Particle physics with DeepCore low energy extension, or possibly with PINGU
  - Other projects : Indirect Dark Matter searches, Exotic particle searches, Follow-up programs, Air shower physics, and so on.
- Highlights from Recent Results
  - The High Energy Starting Event search found 37 events (3 events above PeV) inconsistent with atmospheric backgrounds at ~5.7 σ.
  - Atmospheric neutrino oscillations & neutrino flux measurements (ν_μ and ν_e) agree well with models of atmospheric neutrinos and world average.
  - More data with improved analyses coming soon and PINGU can help determine NMH.

26

Chang Hyon Ha: *Neutrino Flavour Physics with IceCube & PINGU*

Neutrino Physics

Perspectives from 2014

More Daya Bay measurements following their discovery of the disappearance of reactor $\overline{\nu_e}$, at about 1 km, to the several-percent level in 2012

Zhe Wang: *The Latest Results from Daya Bay*

Neutrino Physics

Perspectives from 2014

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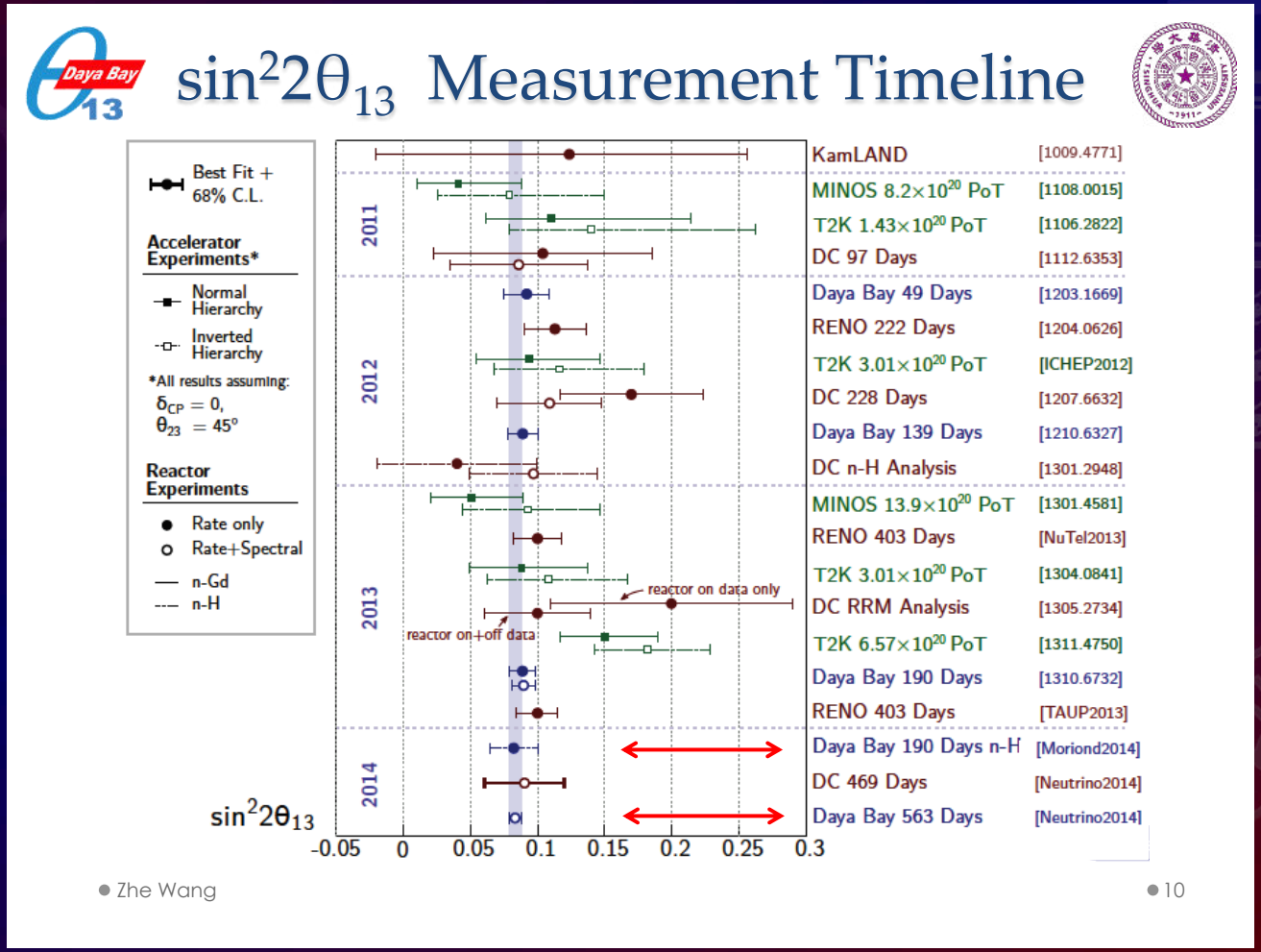

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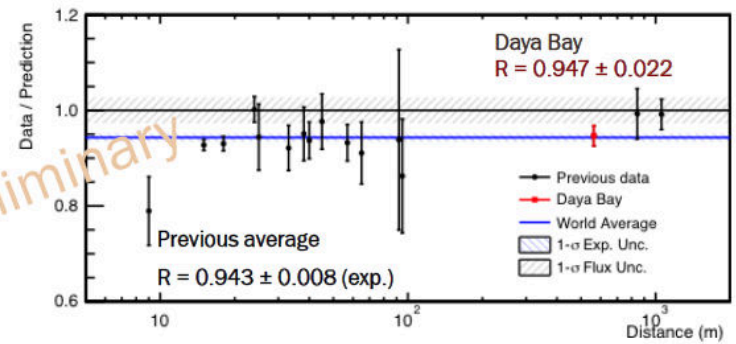
Absolute Flux Measurement

Daya Bay's reactor antineutrino flux measurement is consistent with previous short baseline experiments.

- Global comparison of measurement and prediction (Huber+Mueller):



- Effective baseline of Daya Bay: L_{eff} = 573m
  - Flux weighted detector-reactor distances of 3 ADs in near sites only.
- Effective fission fractions α_k of Daya Bay ^{235}U: ^{238}U: ^{239}Pu: ^{241}Pu = 0.586: 0.076: 0.288: 0.050
  - Mean fission fractions from 3 ADs in near sites only.

Zhe Wang 12

Zhe Wang: *The Latest Results from Daya Bay*

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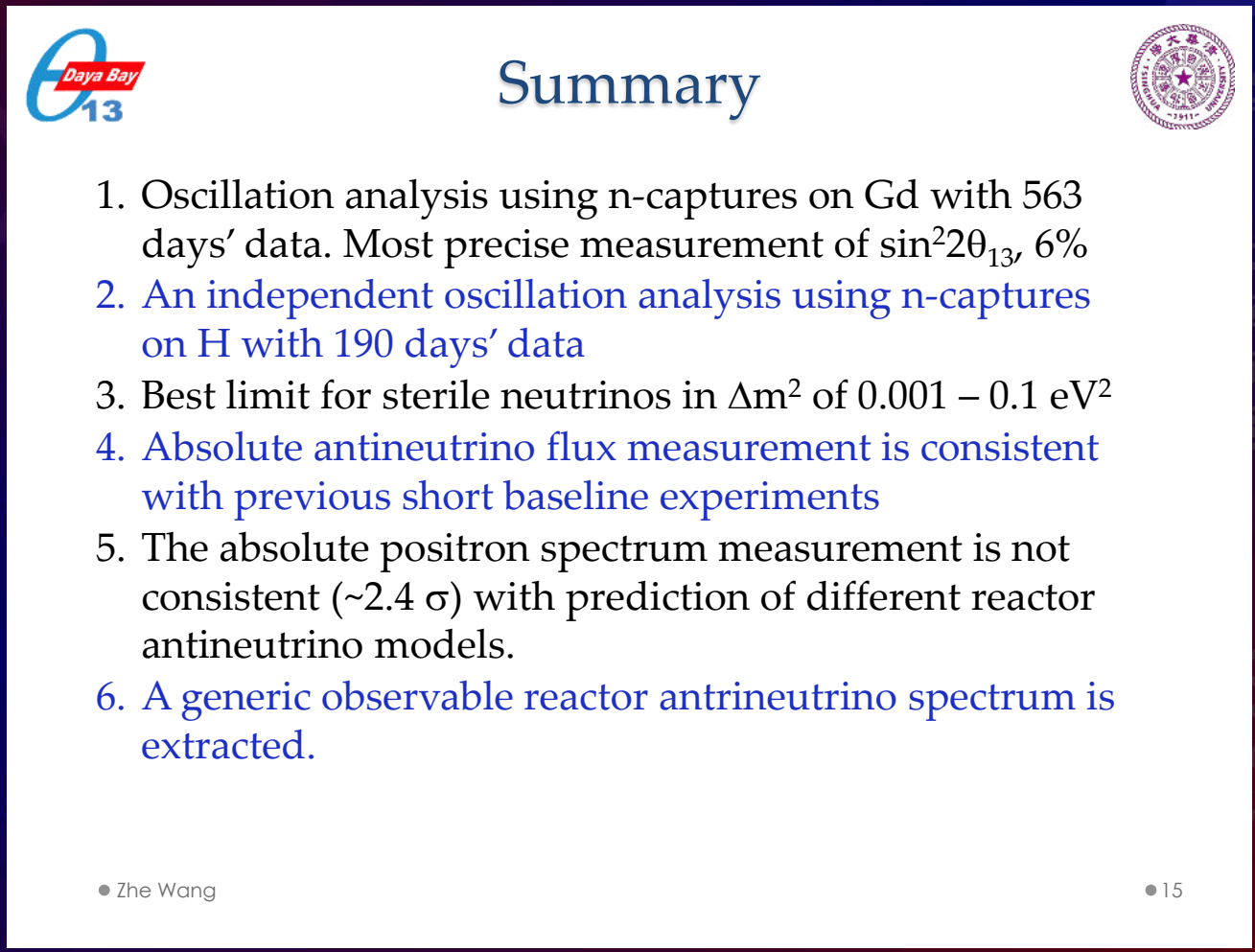
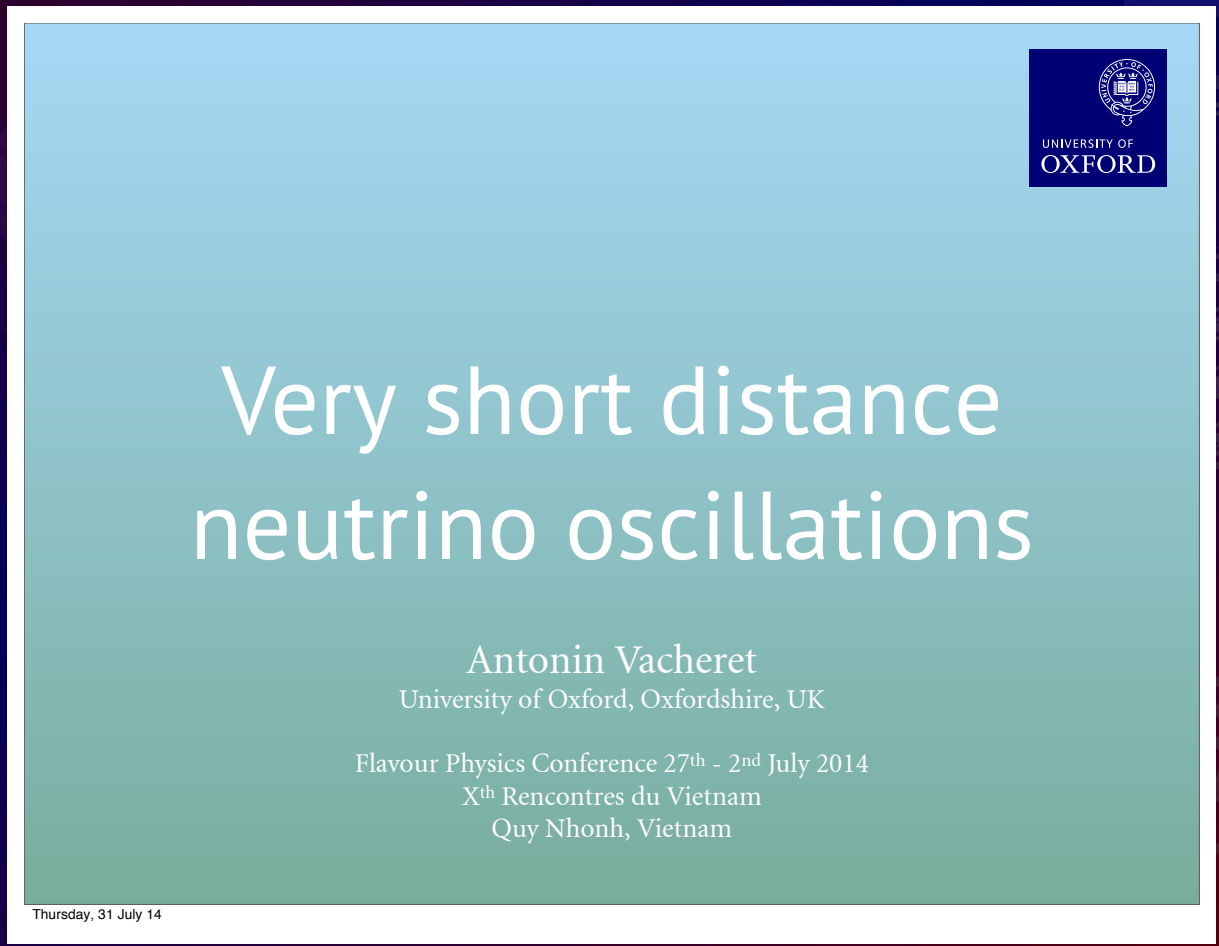


Zhe Wang: *The Latest Results from Daya Bay*

Neutrino Physics

Perspectives from 2014

- Pursing the precise understanding of reactor neutrino fluxes, and possible oscillations, through measurements at much shorter baselines than 1 km
- Several competing groups across the world working in this area



Antonin Vacheret: *Very short-distance neutrino oscillations*

Neutrino Physics

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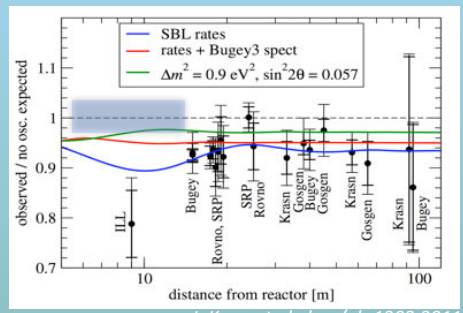
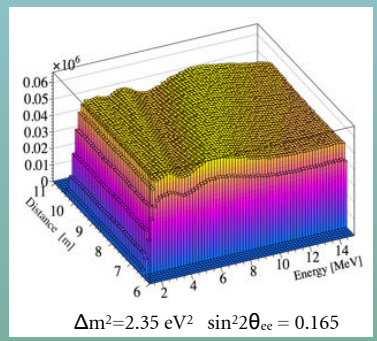
New experiment at short distance

- $\Delta m^2 \sim 1$ eV^2 ~ 1-3 m oscillation length
  - require compact reactor core
- remeasure at very short distance using two distance measurement ratio
  - no assumption on shape of spectrum
- similar precision to θ_{13} search needed
- challenging above ground / near reactor measurement
  - large gamma-ray and neutron backgrounds expected



J. Kopp et al., hep/ph:1303.3011



Δm^2=2.35 eV^2 sin^{2}2θ_{ee} = 0.165

Thursday, 31 July 14

Antonin Vacheret: *Very short-distance neutrino oscillations*

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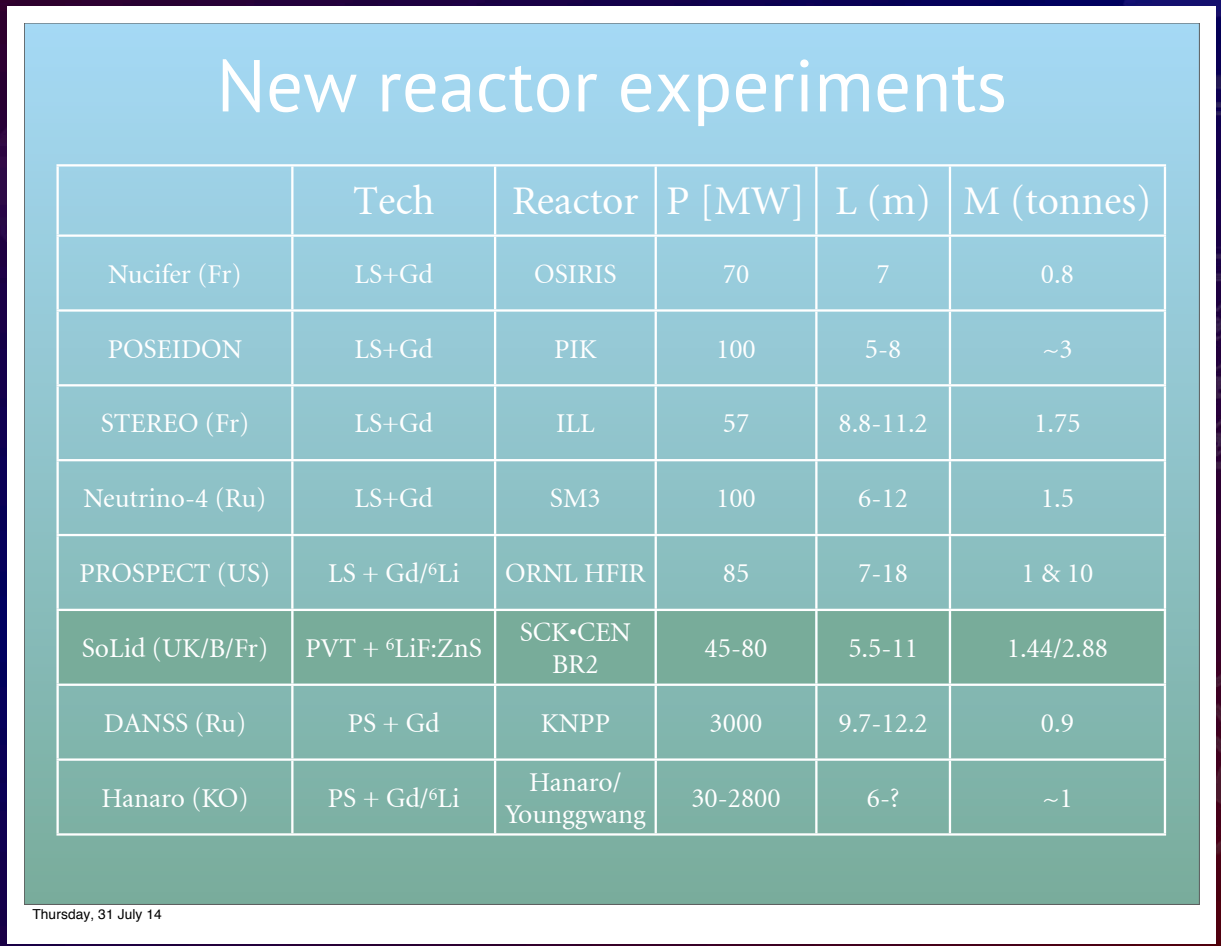

	Tech	Reactor	P [MW]	L (m)	M (tonnes)
Nucifer (Fr)	LS+Gd	OSIRIS	70	7	0.8
POSEIDON	LS+Gd	PIK	100	5-8	~3
STEREO (Fr)	LS+Gd	ILL	57	8.8-11.2	1.75
Neutrino-4 (Ru)	LS+Gd	SM3	100	6-12	1.5
PROSPECT (US)	LS + Gd/^{6}Li	ORNL HFIR	85	7-18	1 & 10
SoLid (UK/B/Fr)	PVT + ^{6}LiF:ZnS	SCK•CEN BR2	45-80	5.5-11	1.44/2.88
DANSS (Ru)	PS + Gd	KNPP	3000	9.7-12.2	0.9
Hanaro (KO)	PS + Gd/^{6}Li	Hanaro/ Younggwang	30-2800	6-?	~1

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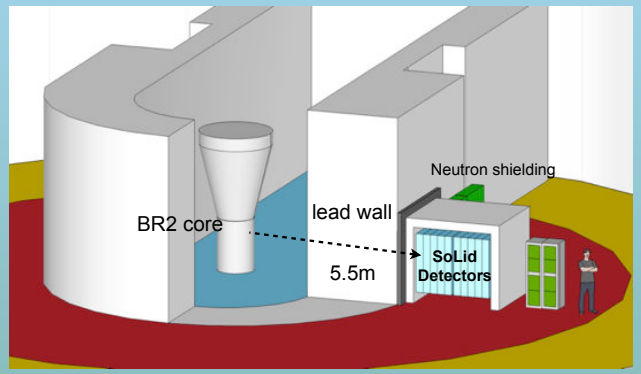
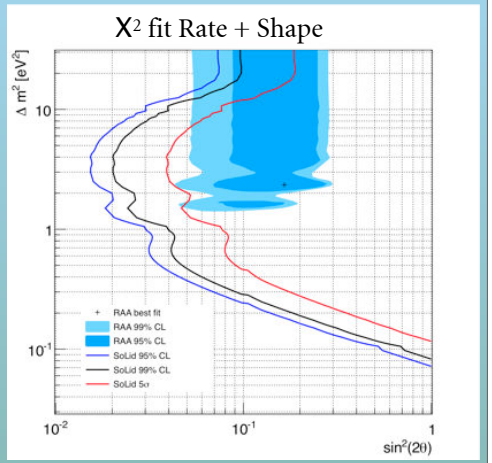
SoLid experiment overview





- Source: SCK-CEN BR2 MTR reactor
  - 45-70 MWth power, 150 days/year
  - Relatively low level of reactor background
- Baseline L = 5.5-11 m
- 2.88 tonnes fiducial mass
- Modest passive shielding
- Data taking in early 2016

• IBD efficiency 41% (416ν/day/tonne)
• 300 days running at 6.8m baseline
• flux normalisation (4.1%), detector efficiency (2%) systematics and backgrounds (S:B ~ 5-6)
• large bins to account for energy smearing effects

Thursday, 31 July 14

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Thank you

Thursday, 31 July 14

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Neutrino Physics

Perspectives from 2014

- Phase-I of the GERDA experiment was able to test the early-2000's claim of a $0\nu\beta\beta$ peak in the Ge spectrum

Andrea Kirsch: *Search for Neutrinoless Double Beta Decay in the GERDA Experiment*

Neutrino Physics

Perspectives from 2014

- Phase-I of the GERDA experiment was able to test the early-2000's claim of a $0\nu\beta\beta$ peak in the Ge spectrum

Open questions from neutrino oscillations...

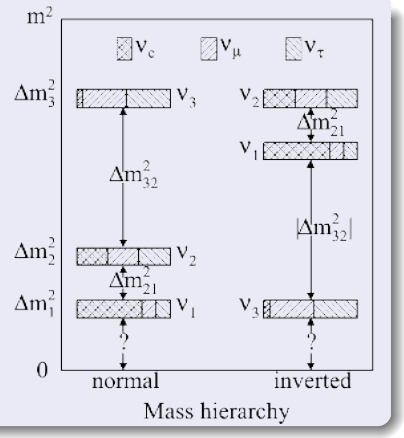
Flavour eigenstates ν_α (with $\alpha = e, \mu, \tau$) as linear superposition of mass eigenstates ν_i

$|\nu_\alpha\rangle = \sum_{i=1}^{3} U_{\alpha i} |\nu_i\rangle$

Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}s_{23}s_{13}e^{i\delta} & -c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

where $s_{ij} = \sin\theta_{ij}$ and $c_{ij} = \cos\theta_{ij}$



What we know

- squared mass differences Δm^2_{12} and $|\Delta m^2_{23}|$
- mixing angles θ_{12}, θ_{23} and θ_{13}

from e.g. solar neutrino + long baseline reactor, atmospheric neutrino + long baseline accelerator or short baseline reactor/accelerator experiments

What we do not know

- nature of the neutrino (Dirac or Majorana?)
- new physics behind SM
- absolute mass scale
- mass hierarchy

Andrea Kirsch: *Search for Neutrinoless Double Beta Decay in the GERDA Experiment*

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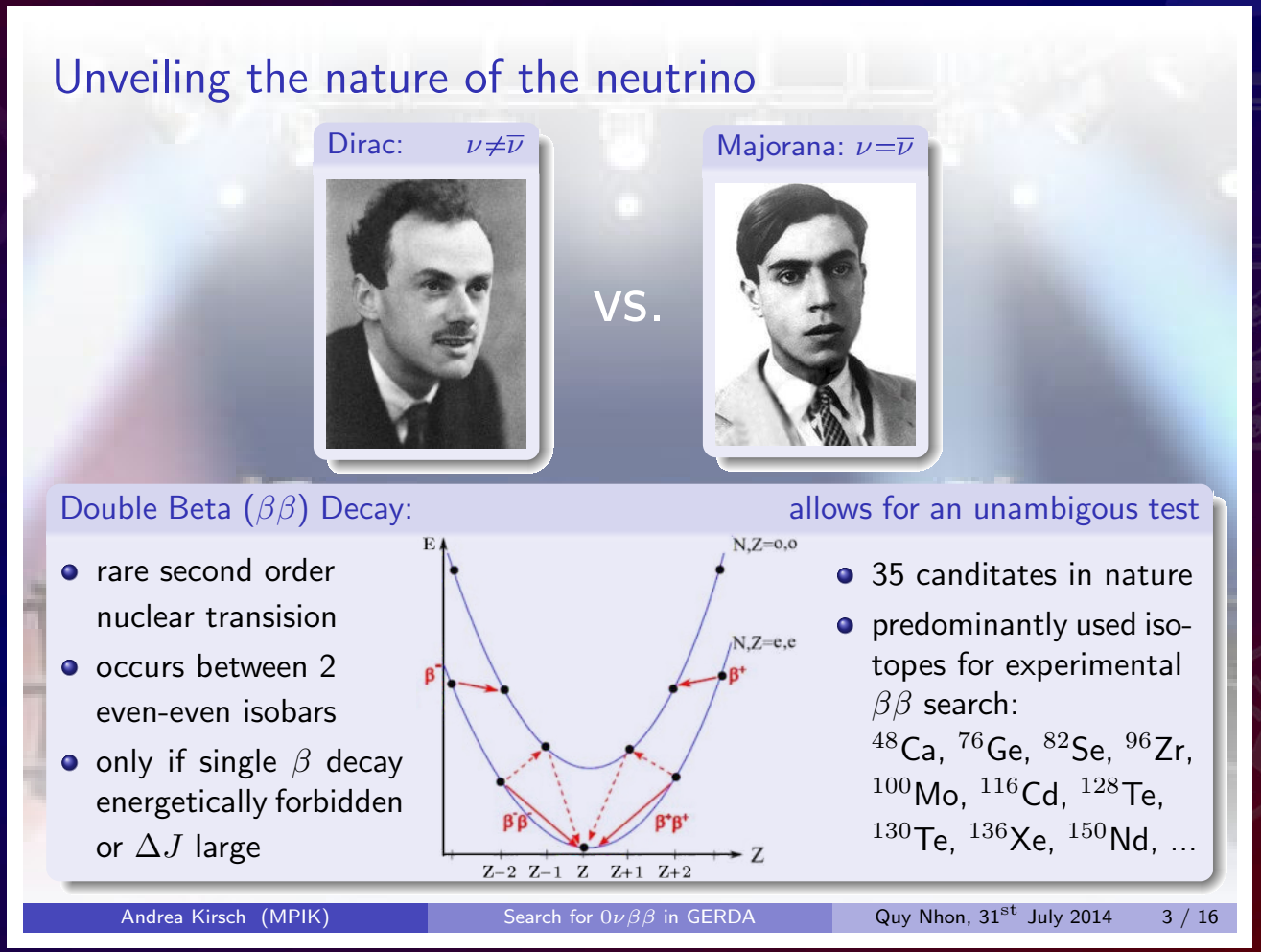

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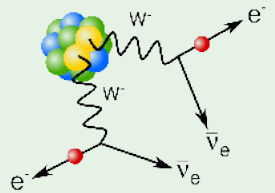
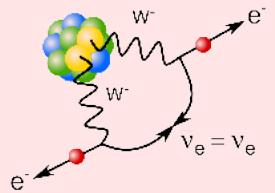
Double Beta Decay

$2\nu\beta\beta$: $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\overline{\nu}_e$



- so far observed in 12 nuclei
- half lifes in the range of $10^{18} - 10^{24}$yr with $T^{2\nu}_{1/2}(^{76}\mathrm{Ge}) = 1.84^{+0.14}_{-0.10} \cdot 10^{21}$yr
  J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110
- $\Delta L = 0$: Lepton-number conserved
- allowed by Standard Model

$0\nu\beta\beta$: $(A, Z) \rightarrow (A, Z+2) + 2e^-$

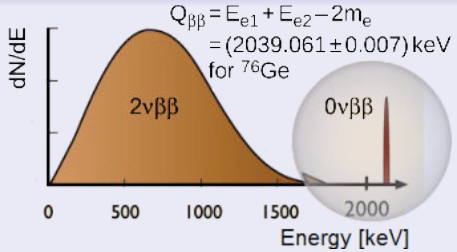


- only if ν has Majorana mass component
- still hunted process
- note: one claim by subgroup of HdM with $T^{0\nu}_{1/2}(^{76}\mathrm{Ge}) = 1.19^{+0.37}_{-0.23} \cdot 10^{25}$yr
  Phys. Rev. Lett. B 586, 198-212 (2004)

can be mediated by e.g. light Majorana ν, R-handed weak currents, SUSY particles, ...

Experimental signatures

- measure the electrons sum energy spectrum
- distribution sensitive to the underlying process



Phys. Rev. 401 C81 (2010) 032501

- continuum → $2\nu\beta\beta$ or $0\nu\beta\beta$ + Majoron(s)
- monoenergetic peak @ $Q_{\beta\beta}$-value → $0\nu\beta\beta$

Andrea Kirsch: *Search for Neutrinoless Double Beta Decay in the GERDA Experiment*

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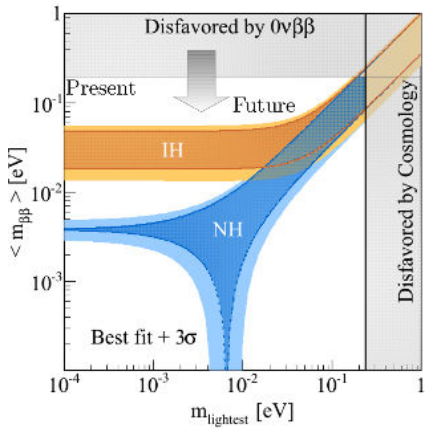
Neutrinoless Double Beta Decay

Expected decay rate: assuming light Majorana ν exchange to be dominating process

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\,|M^{0\nu}|^2\,\langle m_{\beta\beta}\rangle^2$$

where:

- $G^{0\nu}(Q_{\beta\beta}, Z) \propto Q^5_{\beta\beta}$ = phase space integral
- $|M^{0\nu}|$ = nuclear matrix element
- $\langle m_{\beta\beta}\rangle = |\sum_{i=1}^{3} U_{ei} m_i|$ = effective ν mass



Values taken from:
Phys. Rev. D86 (2012) 013012;
JCAP 07 (2012) 053

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Neutrino Physics

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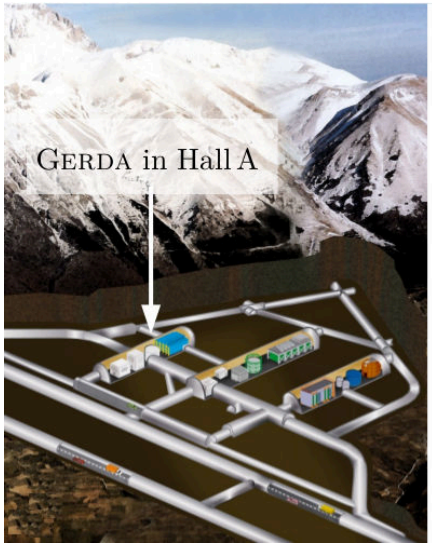
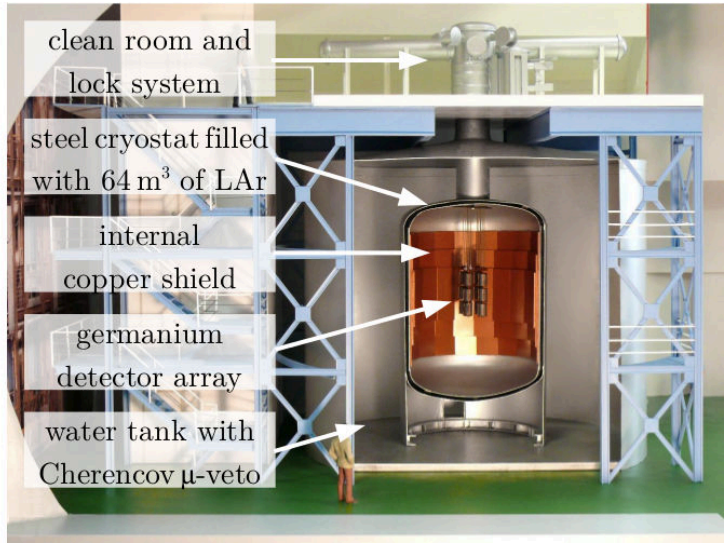
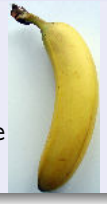
GERmanium Detector Array Eur. J. Phys. C73 (2013) 2330





Background reduction techniques from construction of setup:

- located in Hall A of LNGS underground laboratory, Italy → cosmic μ flux reduced by 10^6
- novel idea: Ge detectors are operated bare in LAr as coolant
- only minimal amount of (screened) material close to detectors



component/ det. support	^{40}K [μBq]	^{226}Rn [μBq]	^{228}Th [μBq]
copper (80g)	<7.0	<1.3	<1.5
PTFE (10g)	6.0	0.25	0.31
Banana (125g)	$1.5{\cdot}10^7$	–	–

Andrea Kirsch (MPIK) | Search for $0\nu\beta\beta$ in GERDA | Quy Nhon, 31st July 2014 | 6 / 16

Andrea Kirsch: *Search for Neutrinoless Double Beta Decay in the GERDA Experiment*

Neutrino Physics

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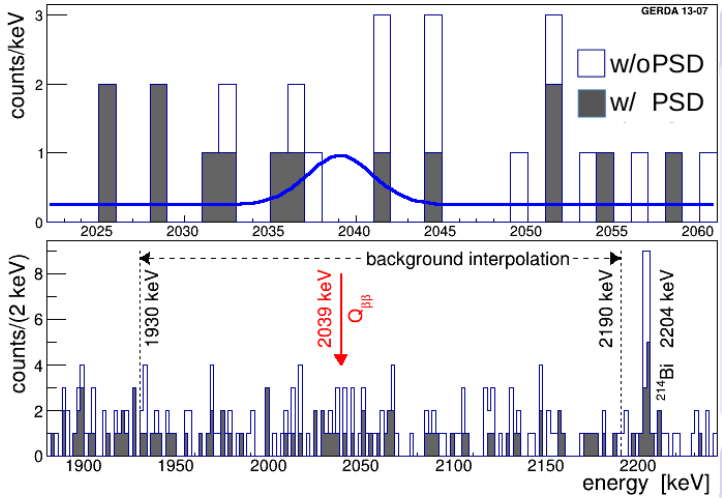
- Phase-I of the GERDA experiment was able to test the early-2000's claim of a $0\nu\beta\beta$ peak in the Ge spectrum

Unblinding @ $Q_{\beta\beta} \pm 5$ keV

Phys. Rev. Let. 111 (2013) 122503



$$T^{0\nu}_{1/2} = \frac{\ln(2)\cdot N_A}{m_A \cdot N^{0\nu}} \cdot M \cdot t \cdot f_{76} \cdot f_{av} \cdot \epsilon_{fep} \cdot \epsilon_{psd}$$

- fit in $[1930 - 2190]$ keV with 4 free parameters: $3\times$ constant background plus $1\times$ gauss with $T^{0\nu}_{1/2} > 0$
- fixed gaussian parameters: μ=(2039.06±0.2) keV, σ=(2.0±0.1) kev for semi-coaxial, σ=(1.4±0.1) kev for BEGe
- systematic uncertainties on f, ϵ, μ, σ: MC sampling & averaging

data set	PSD	Exposure [kg·yr]	FWHM @ $Q_{\beta\beta}$ [keV]	Efficiency $f_{76}\cdot f_{av}\cdot\epsilon_{fep}\cdot\epsilon_{psd}$
golden	w/o	17.9	4.8±0.2	0.688
	w/			0.619
silver	w/o	1.3	4.8±0.2	0.688
	w/			0.619
BEGe	w/o	2.4	3.2±0.2	0.720
	w/			0.663

Results on $T^{0\nu}_{1/2}$ limit

- Frequentist: profile likelihood fit
  → best fit $N^{0\nu} = 0$
  → $T^{0\nu}_{1/2}(90\%\text{C.L.}) > 2.1 \cdot 10^{25}$ yr
  → median sensitivity: $2.4 \cdot 10^{25}$ yr
- Bayes: flat $1/T$ prior $0-10^{-24}$ yr
  → best fit $N^{0\nu} = 0$
  → $T^{0\nu}_{1/2}(90\%\text{C.L.}) > 1.9 \cdot 10^{25}$ yr
  → median sensitivity: $2.0 \cdot 10^{25}$ yr

Andrea Kirsch (MPIK) | Search for $0\nu\beta\beta$ in GERDA | Quy Nhon, 31st July 2014 | 13 / 16

Andrea Kirsch: *Search for Neutrinoless Double Beta Decay in the GERDA Experiment*

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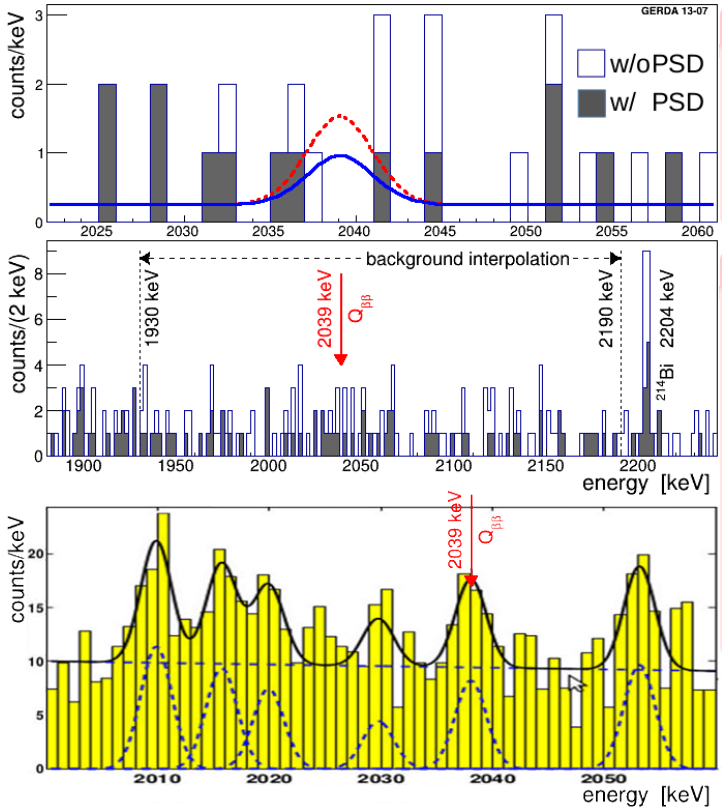

Claim by subgroup of HdM (2004)

- total exposure: $M \cdot t = 71.7$ kg·yr
- 28.75 ± 6.86 signal events observed
- $T^{0\nu}_{1/2} = 1.19^{+0.37}_{-0.23} \cdot 10^{25}$ yr

Phys. Rev. Lett. B 586, 198-212 (2004)

Comparison with Phase I result

- assuming the claimed signal GERDA should see 5.9 ± 1.4 $0\nu\beta\beta$ events in $\pm 2\sigma$ interval above background of 2.0 ± 0.3
- probability from profile likelihood: $p(N^{0\nu}=0|H1=\text{signal+bkg})=0.01$ → claim ruled out @ 99% level
- Bayes factor: $p(H1=\text{signal+bkg})/p(H0=\text{bkg})$ gives 0.024

→ search for $0\nu\beta\beta$ "open" again, many proposals to push sensitivity

Andrea Kirsch (MPIK) | Search for $0\nu\beta\beta$ in GERDA | Quy Nhon, 31st July 2014 | 13 / 16

Andrea Kirsch: *Search for Neutrinoless Double Beta Decay in the GERDA Experiment*

Neutrino Physics

Perspectives from 2014

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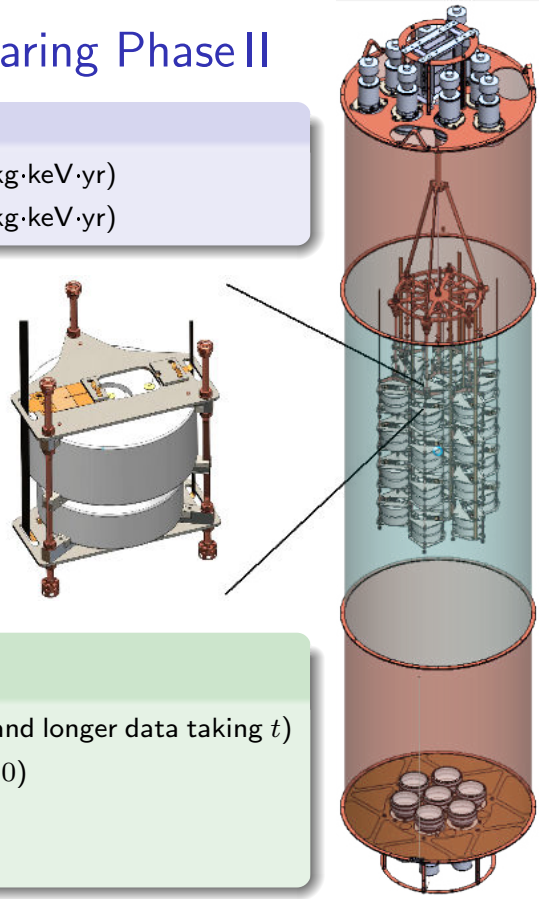
Phase I finished → currently preparing Phase II

Goal:

- Phase I: 20 kg·yr with a BI of $\sim 10^{-2}$ cts/(kg·keV·yr)
- Phase II: 100 kg·yr with a BI of $\sim 10^{-3}$ cts/(kg·keV·yr)

Upgrade:

- 2× detector mass (~20 kg BEGe + ~15 kg semi-coax)
- liquid argon veto instrumented with PMTs
- optimized readout electronics
- low mass detector suspension + wedge bond contact (made of clean material)



$T_{1/2}^{0\nu} \propto f_{76} \cdot \epsilon \cdot \sqrt{\frac{M \cdot t}{BI \cdot \Delta E}}$ (if background is present)

- increased statistic (higher $\beta\beta$ emitter mass M and longer data taking t)
- lower background index BI (by about factor 10)
- better energy resolution ΔE

→ expected sensitivity $\simeq 1.4 \cdot 10^{26}$ yr (90% C.L.)

Andrea Kirsch (MPIK) | Search for $0\nu\beta\beta$ in GERDA | Quy Nhon, 31st July 2014 | 14 / 16

Andrea Kirsch: *Search for Neutrinoless Double Beta Decay in the GERDA Experiment*

Neutrino Physics

Perspectives from 2014

- MICE had made initial measurements of its muon beam, and was moving towards taking data with absorbers (needed for cooling) and tracking detectors etc.
- nuSTORM, proposed as the next step for using the unique properties of neutrinos from decays of a stored muon beam, and studies for Fermilab and CERN were ongoing

Melissa Uchida: *MICE and nuSTORM*

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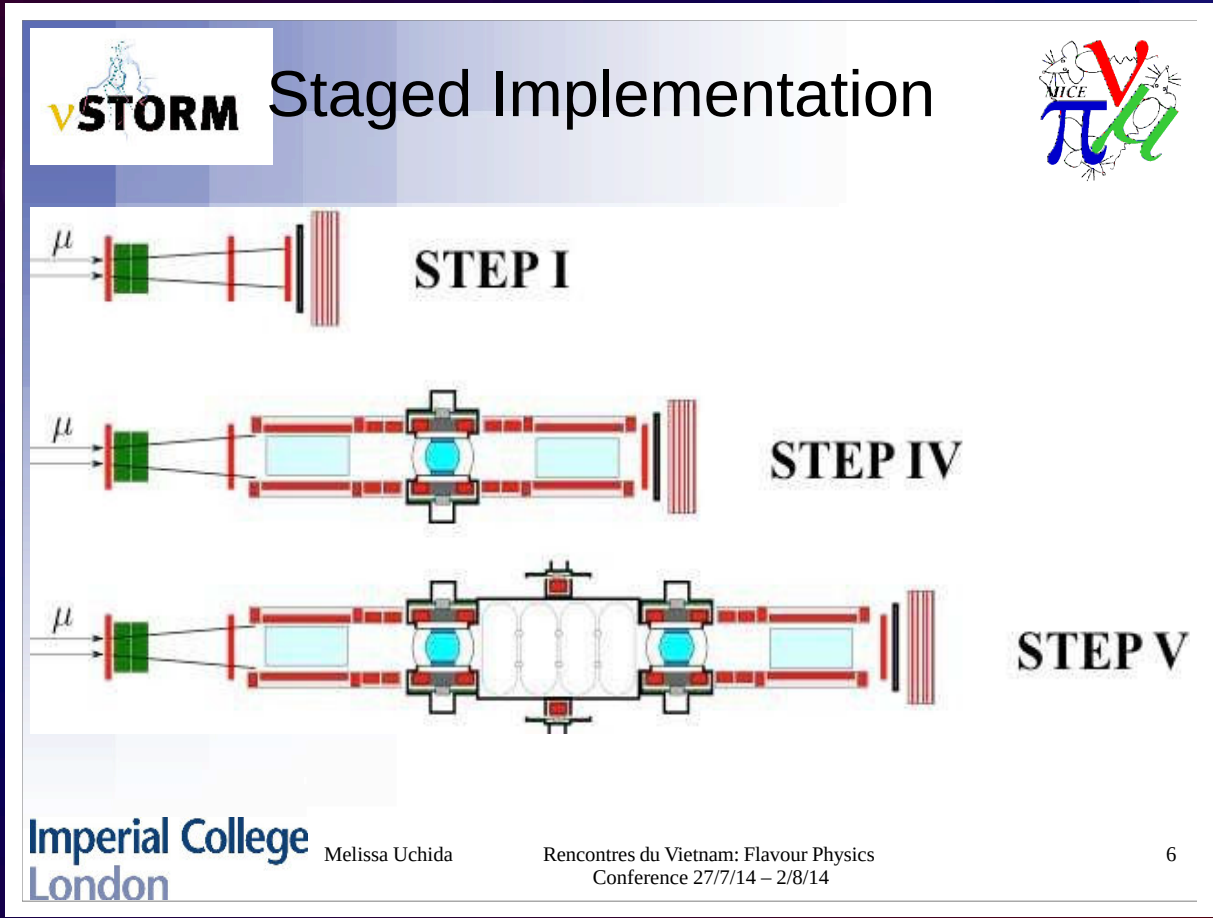

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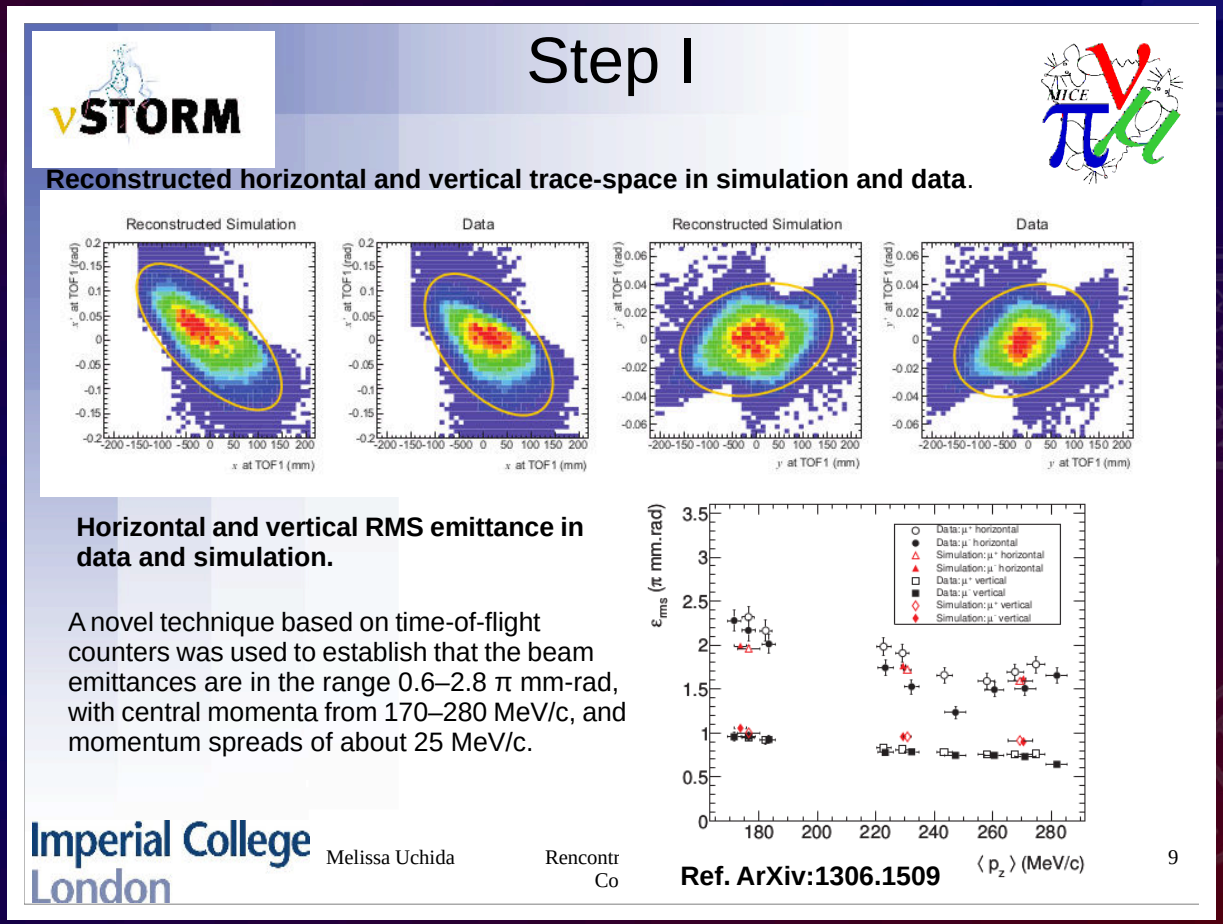

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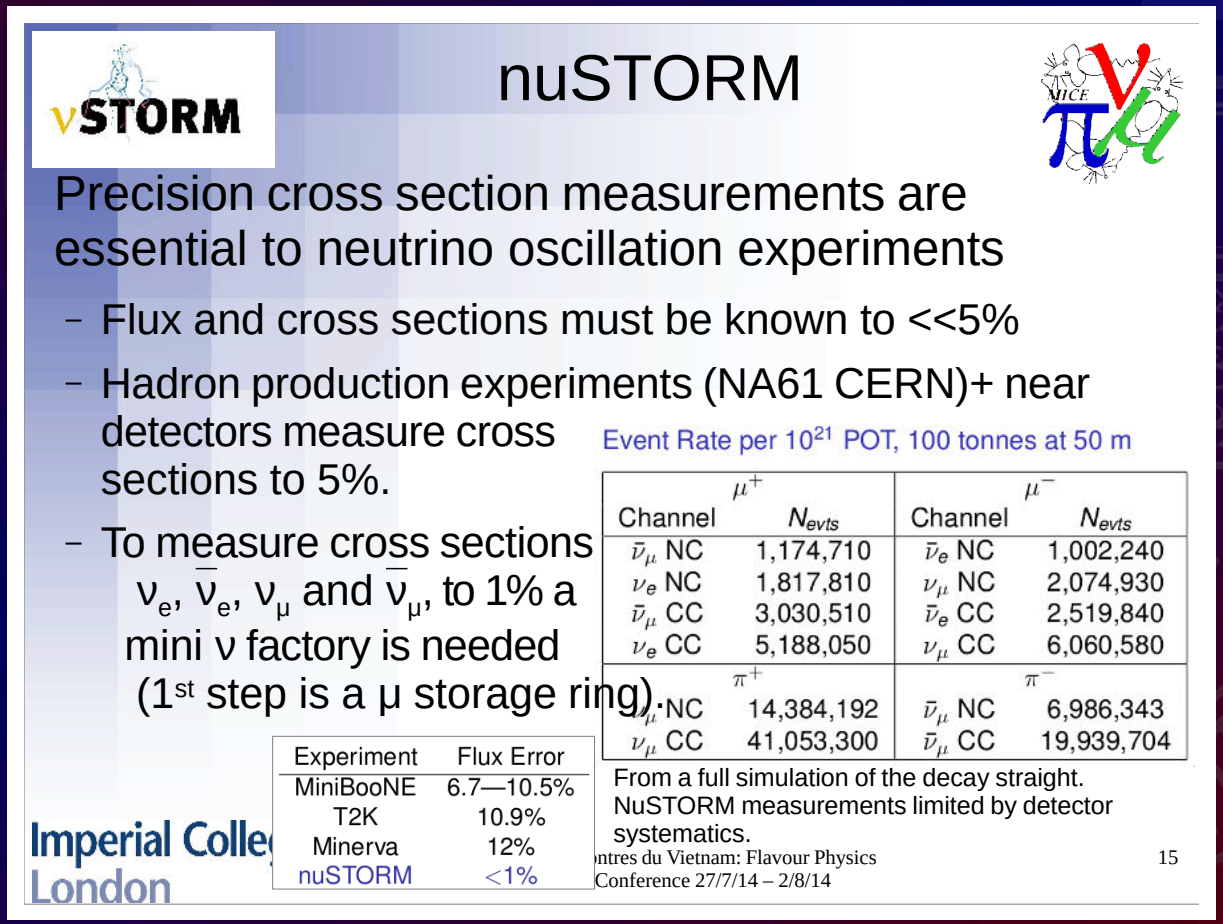

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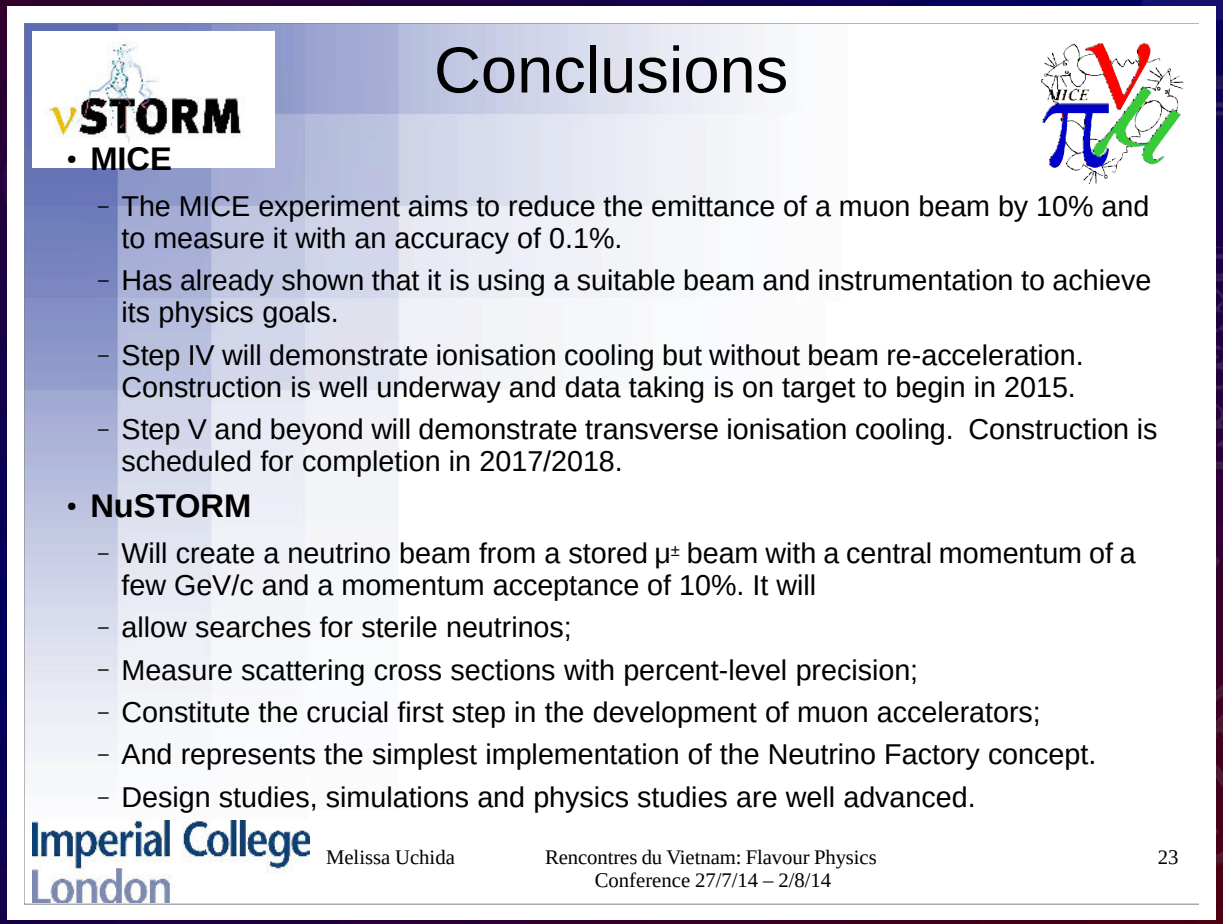

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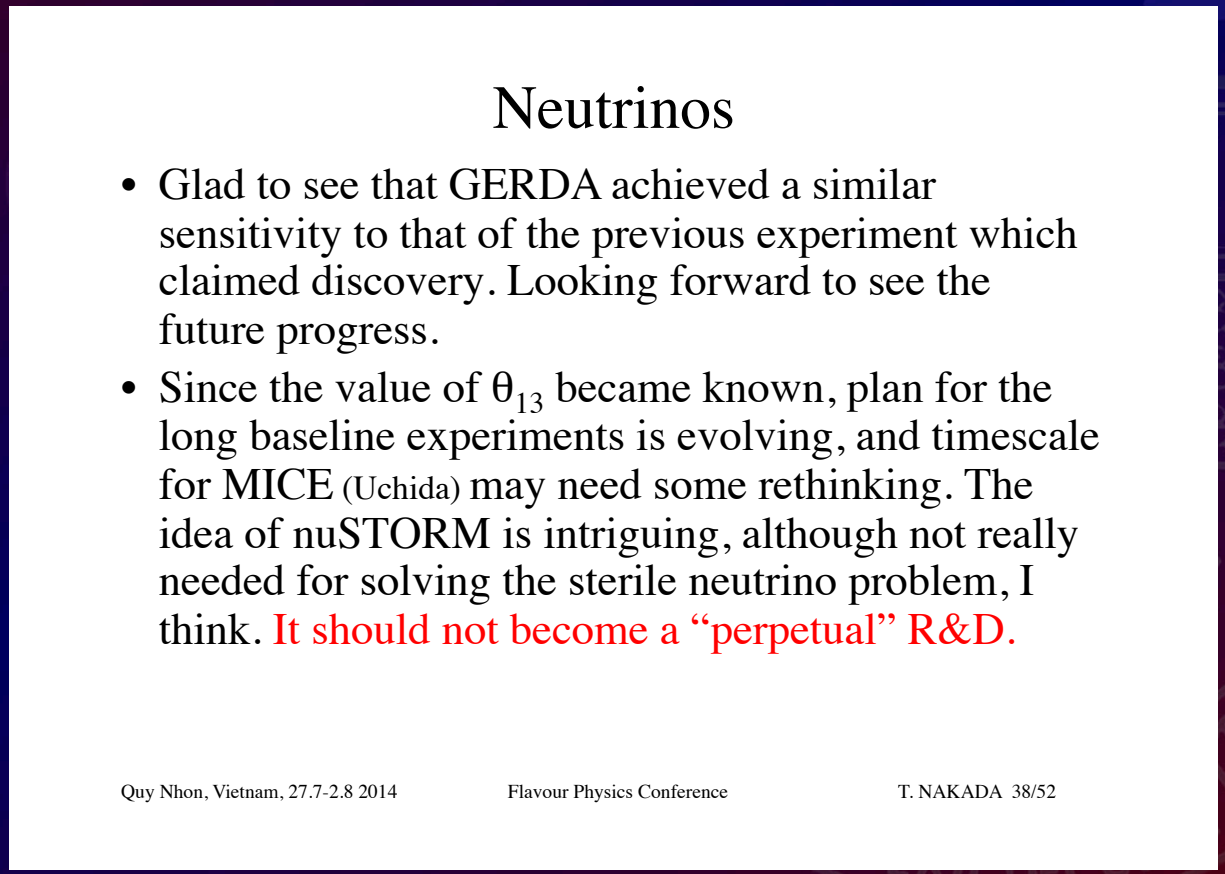


Neutrinos

- Glad to see that GERDA achieved a similar sensitivity to that of the previous experiment which claimed discovery. Looking forward to see the future progress.
- Since the value of θ_{13} became known, plan for the long baseline experiments is evolving, and timescale for MICE (Uchida) may need some rethinking. The idea of nuSTORM is intriguing, although not really needed for solving the sterile neutrino problem, I think. It should not become a "perpetual" R&D.

Quy Nhon, Vietnam, 27.7-2.8 2014 Flavour Physics Conference T. NAKADA 38/52

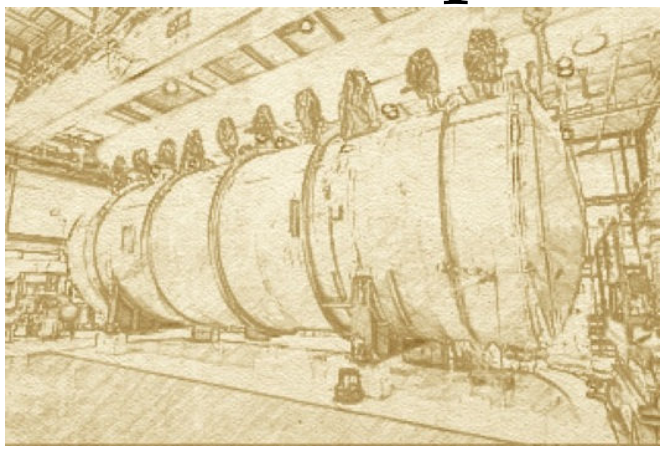
Tatsuya Nakada: *Experimental Summary*

Neutrino Physics

Perspectives from 2014

- ArgoNeut was the first of the recent Liquid Argon neutrino detector experiments at Fermilab
- It had just started seeing data
- The much larger MicroBooNE was being built at the time

Status of the ArgoNeuT and MicroBooNE Experiments



Mitch Soderberg
on behalf of the ArgoNeuT and MicroBooNE collaborations
Recontres du Vietnam Flavour Conference

Mitch Soderberg: *Status of the ArgoNeuT and MicroBooNE Experiments*

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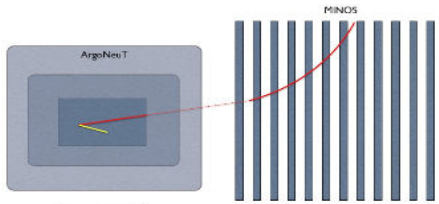
ArgoNeuT

- LArTPC operated in Fermilab's NuMI neutrino beam.
- Located upstream of MINOS near detector, which provides muon reconstruction and sign selection.
- Collected 1.35×10^{20} Protons on Target (POT).

Cryostat Volume	500 Liters
TPC Volume	175 Liters (90cm x 40cm x 47.5cm)
# Electronic Channels	480
Electronics Style (Temp.)	JFET (293 K)
Wire Pitch (Plane Separation)	4 mm (4 mm)
Electric Field	500 V/cm
Max. Drift Length (Time)	0.5 m (330 μs)
Wire Properties	0.15mm diameter BeCu



ArgoNeuT in the NuMI Tunnel

Refs:

1.) *The ArgoNeuT detector in the NuMI low-energy beam line at Fermilab*, C. Anderson et al., JINST 7 P10019, Oct. 2012, arXiv:1205.6747

7

Mitch Soderberg: *Status of the ArgoNeuT and MicroBooNE Experiments*

Neutrino Physics

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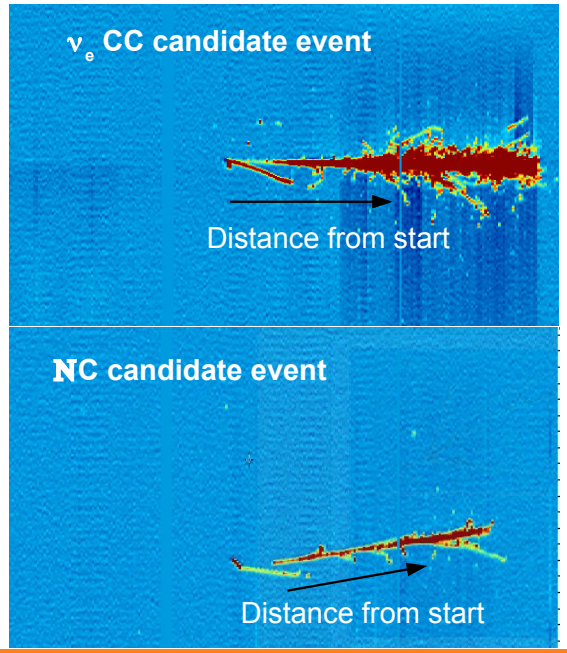
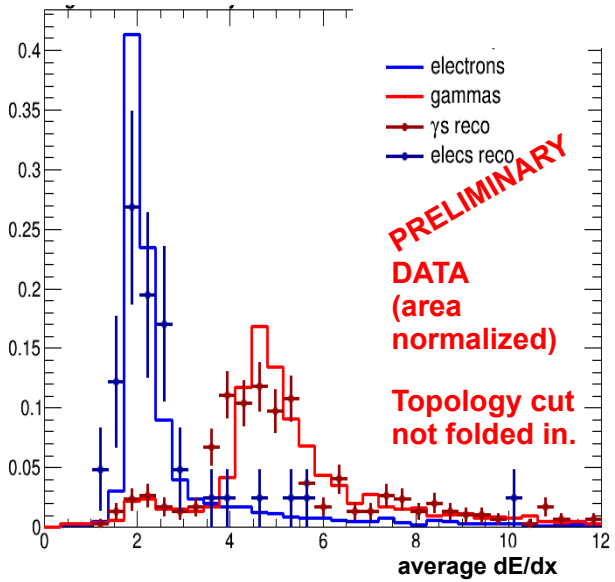
ArgoNeuT: Physics

- Particle ID of electrons vs. photons relies on ability to see displaced vertices, and to reconstruct energy at beginning of shower.
- ArgoNeuT is developing this technique using a small data sample.





10

Mitch Soderberg: *Status of the ArgoNeuT and MicroBooNE Experiments*

Neutrino Physics

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MicroBooNE Installation: June 2014

14

Mitch Soderberg: *Status of the ArgoNeuT and MicroBooNE Experiments*

Neutrino Physics

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Conclusions

- LArTPCs are powerful detectors for studying neutrinos.
- Tremendous ongoing progress in development of LArTPC technology, driven by "small" efforts like ArgoNeuT and MicroBooNE.
- Next few years should be very exciting as MicroBooNE come online.
- Informed by these ongoing activities, future massive (~kiloTon) LArTPCs offer potential for discovering CP-violation in neutrino sector, and short-baseline experiments will search for sterile neutrinos.

17

Mitch Soderberg: *Status of the ArgoNeuT and MicroBooNE Experiments*

Rare Decays

Perspectives from 2014

Rare Decays

Rencontres du Vietnam – Flavour Physics, 28th July 2014

Mitesh Patel (Imperial College London)

Imperial College London

LHCb

Mitesh Patel: *Rare Decays*

Theoretical Basis II

- At LHC measure exclusive processes – operators involve hadronic form factors
- Have to use observables where the uncertainties on the operators cancel out – measuring the Wilson Coefficients tells us about the heavy degrees of freedom – *independent of model*
- One of key concepts: QCD factorisation – try to handle QCD and EW penguin parts separately insofar as is possible
- Can try and avoid form factor uncertainties by making inclusive measurements – difficult in hadronic environment of LHC, possible at B-factory experiments

6

Mitesh Patel: *Rare Decays*

Rare Decays

Perspectives from 2014

Outline

- Theoretical basis of rare decays studies
- The decays $B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$
- The decay $B_d^0 \to K^{*0}\mu^+\mu^-$ and other $b \to sll$ processes
- Theory issues around interpretation of data
- Search for Majorana neutrinos

11

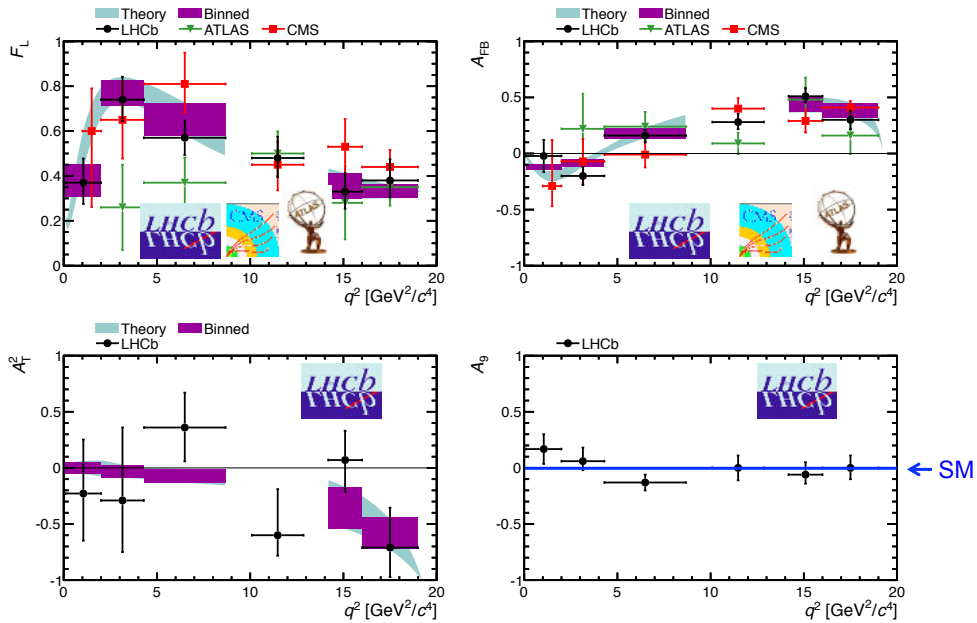
Mitesh Patel: *Rare Decays*

Rare Decays

Perspectives from 2014

- Range of $B_d^0 \to K^{*0}\mu^+\mu^-$ angular observables in excellent agreement with SM (see talk of M. Tresch)

ATLAS (prelim.) [ATLAS-CONF-2013-038] , CMS 5.2 fb^{-1} [PLB 727 (2013) 77] , LHCb 1 fb^{-1} [JHEP 08 (2013) 131]



Theory prediction from Bobeth et al. [JHEP 07 (2011)] and references therein.

13

Lepton Universality – R_K

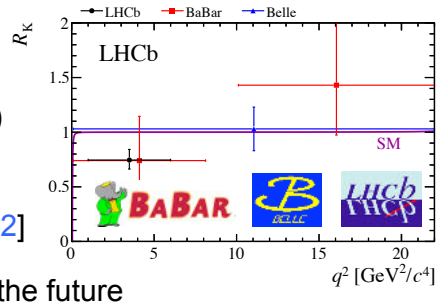
- Some Z' models have differing couplings to the different generations of leptons – see e.g. [arXiv:1403.1269]
  - Would then expect $B(B^+ \to K^+\mu^+\mu^-) < B(B^+ \to K^+e^+e^-)$
  - Interesting to test lepton universality in $b \to sll$
  - Z' couplings would have to be such as to avoid effect in $R_{K \to l\nu} = (2.488 \pm 0.009) \times 10^{-5}$ [PLB 698 (2011) 105]

- LHCb measures $R_K = B(B^+ \to K^+\mu^+\mu^-) / B(B^+ \to K^+e^+e^-)$

- In 3fb^{-1}, $1 < q^2 < 6$ GeV^2,

  $R_K = 0.745^{+0.090}_{-0.074}(\text{stat})^{+0.036}_{-0.036}(\text{syst})$

  → Consistent with SM at 2.6σ
  [arXiv:1406.6482]



- R_{K^*} measurement clearly of interest for the future

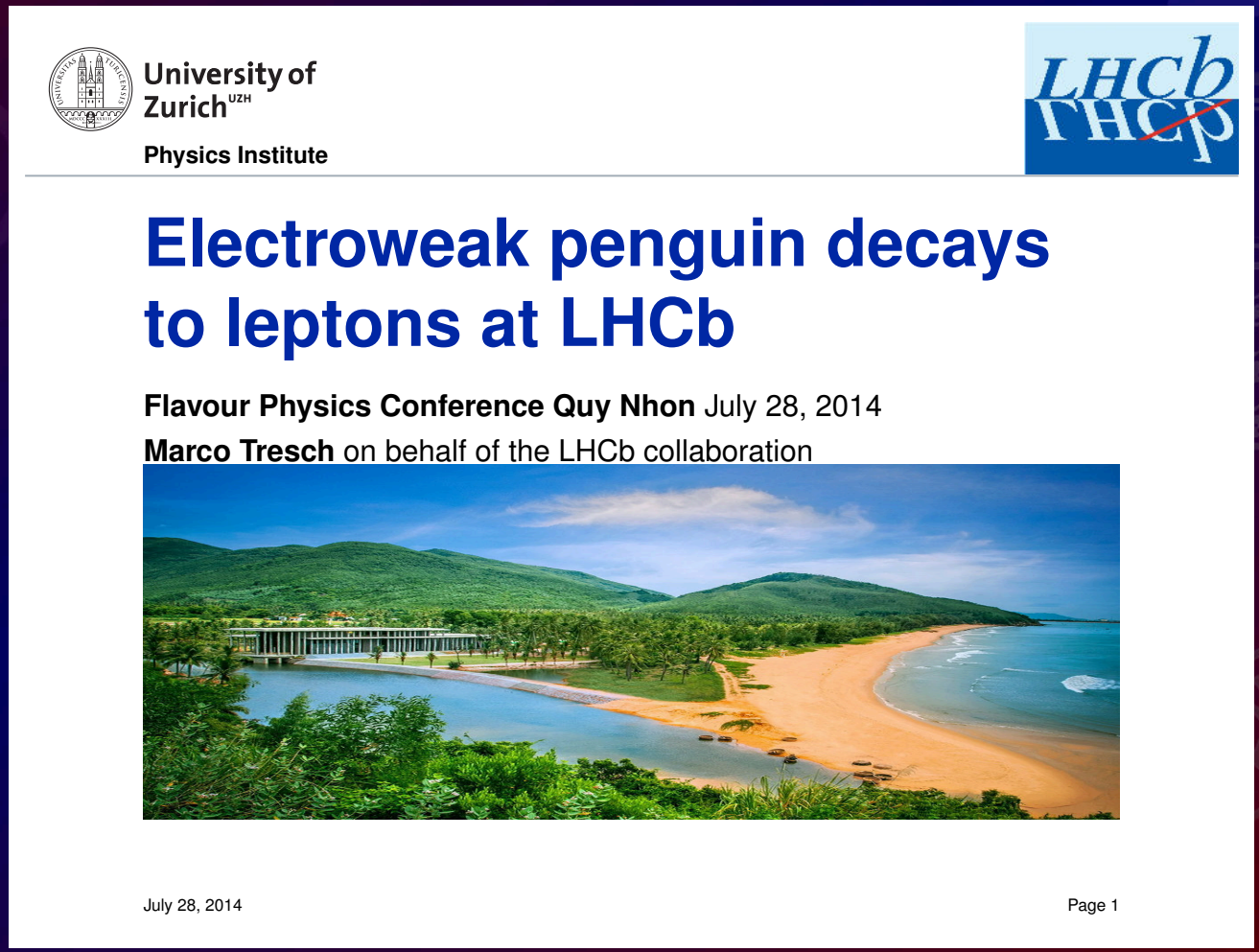
20

Mitesh Patel: *Rare Decays*

Rare Decays

Perspectives from 2014

Angular analyses of $b \to s$ processes reported



Marco Tresch: *Electroweak penguin decays to leptons at LHCb*

Rare Decays

Perspectives from 2014

Angular analyses of $b \to s$ processes reported

University of Zurich[UZH]

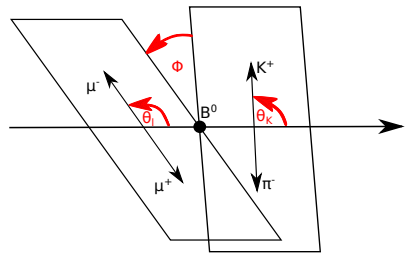
Physics Institute

LHCb

$B^0 \to K^{*0}\mu^+\mu^-$

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_\mathrm{K} + F_\mathrm{L}\cos^2\theta_\mathrm{K} + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_\mathrm{K}\cos 2\theta_\ell$$
$$-F_\mathrm{L}\cos^2\theta_\mathrm{K}\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+S_4\sin 2\theta_\mathrm{K}\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_\mathrm{K}\sin\theta_\ell\cos\phi$$
$$+S_6\sin^2\theta_\mathrm{K}\cos\theta_\ell + S_7\sin 2\theta_\mathrm{K}\sin\theta_\ell\sin\phi$$
$$+S_8\sin 2\theta_\mathrm{K}\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_\mathrm{K}\sin^2\theta_\ell\sin 2\phi\Big]$$

- Neglect lepton masses, average B^0 and $\bar{B}^0$
- Angular terms can be measured in bins of q^2
- Theory uncertainties are dominated by the $B^0 \to K^{*0}$ form-factors
- Analysed in two steps (JHEP08(2013)131) and (PhysRevLett.111.191801) with different foldings to reduce the number of coefficients



July 28, 2014 Electroweak penguin decays to leptons at LHCb Page 3

Marco Tresch: *Electroweak penguin decays to leptons at LHCb*

Rare Decays

Perspectives from 2014

Angular analyses of $b \to s$ processes reported

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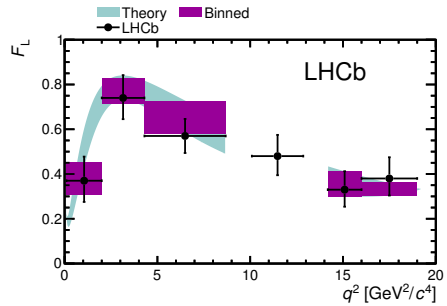
Physics Institute

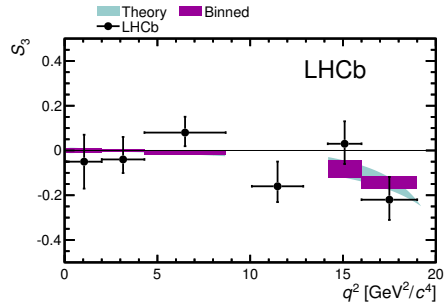
LHCb

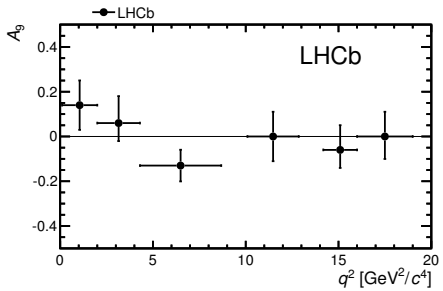
JHEP08(2013)131
with 1 fb^{-1}

$B^0 \to K^{*0}\mu^+\mu^-$, Observables



– All results are compatible with SM





July 28, 2014 Electroweak penguin decays to leptons at LHCb Page 5

Marco Tresch: *Electroweak penguin decays to leptons at LHCb*

Rare Decays

Perspectives from 2014

Angular analyses of $b \to s$ processes reported

and lepton universality tests

University of Zurich[UZH]

Physics Institute

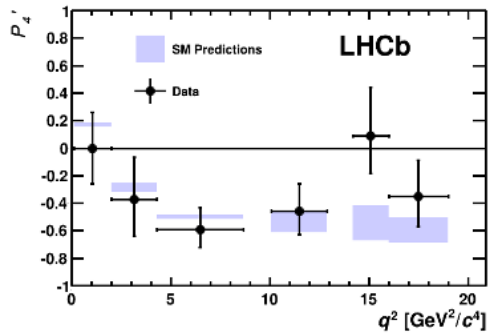
LHCb

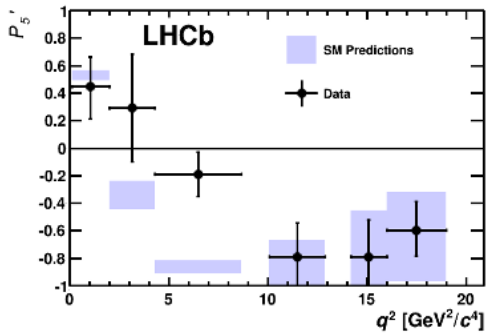
$B^0 \to K^{*0}\mu^+\mu^-$, form-factor independent observables

PhysRevLett.111.191801
with 1 fb^{-1}

– Change of basis, form-factor cancels at leading order

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$





– P'_5 shows a local deviation of 3.7σ in one q^2 bin ($4.30 - 8.68\,\mathrm{GeV}^2/c^4$), as discussed by M. Patel.

Theory prediction: (Decotes-Genon et al. JHEP 05 (2013) 137)

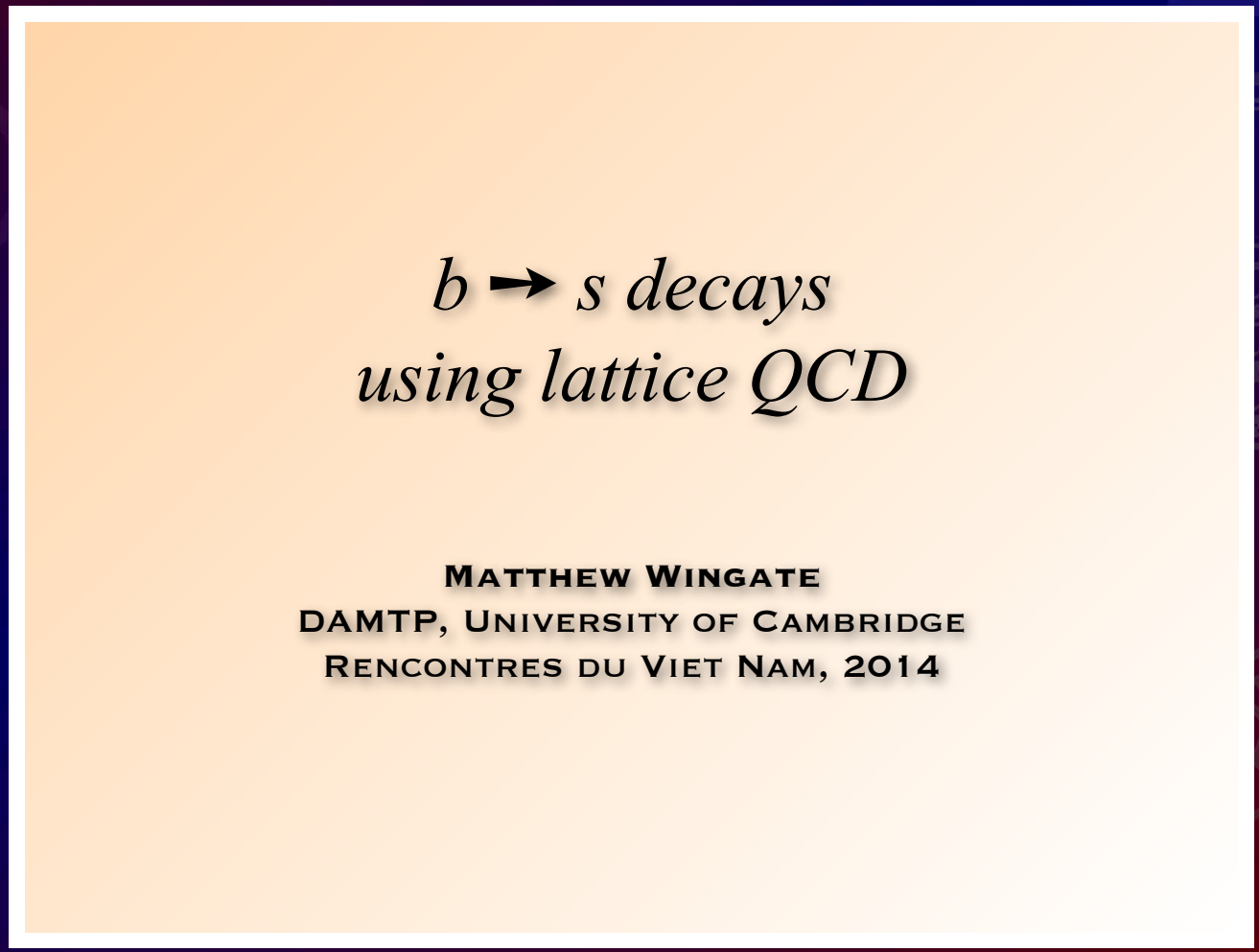
July 28, 2014 Electroweak penguin decays to leptons at LHCb Page 6

Marco Tresch: *Electroweak penguin decays to leptons at LHCb*

Rare Decays

Perspectives from 2014

Important contributions from Lattice QCD calculations to the form factors, and ongoing improvements

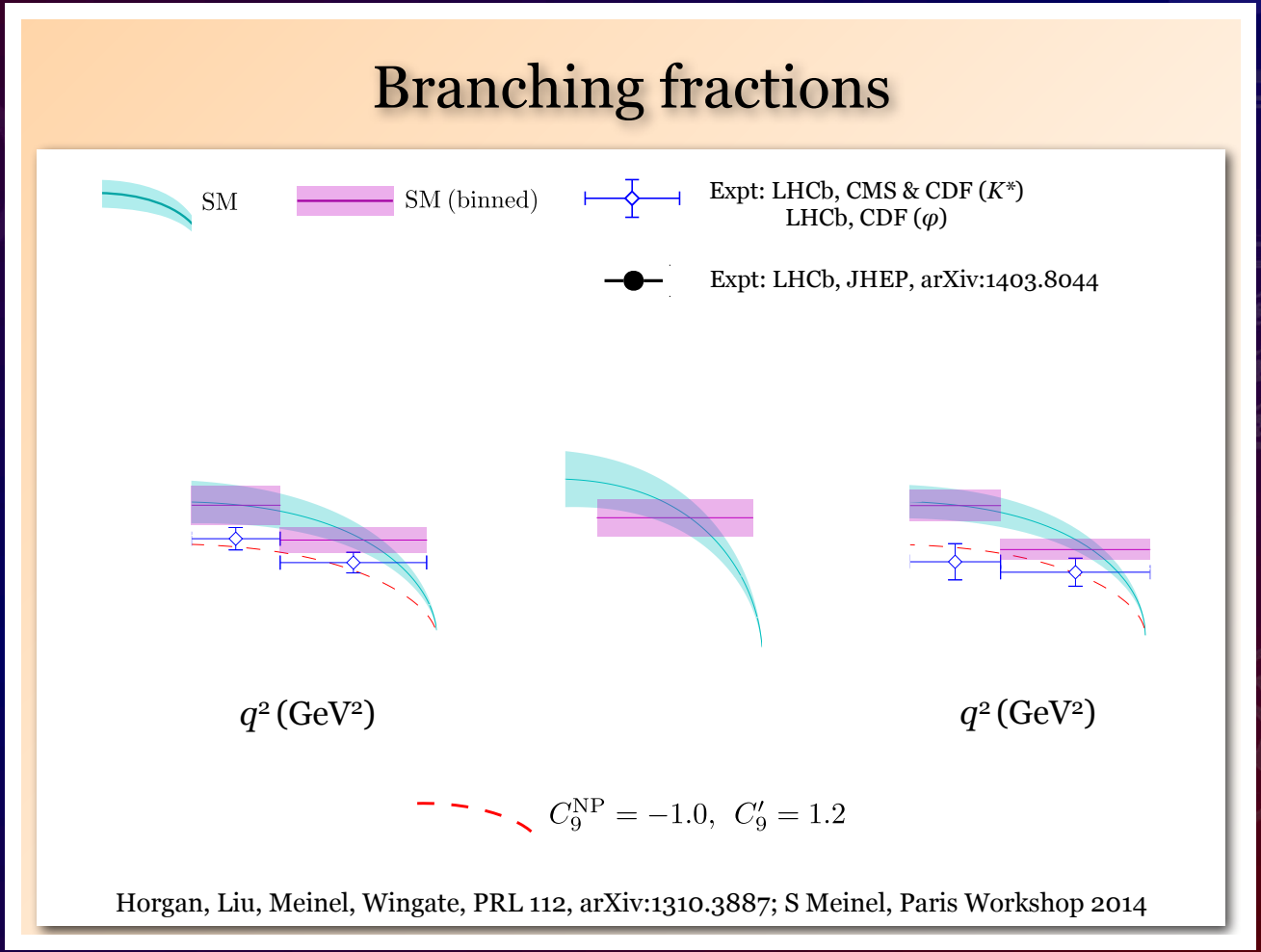


Matthew Wingate: $b \to s$ *decays using lattice QCD*

Rare Decays

Perspectives from 2014

Important contributions from Lattice QCD calculations to the form factors, and ongoing improvements



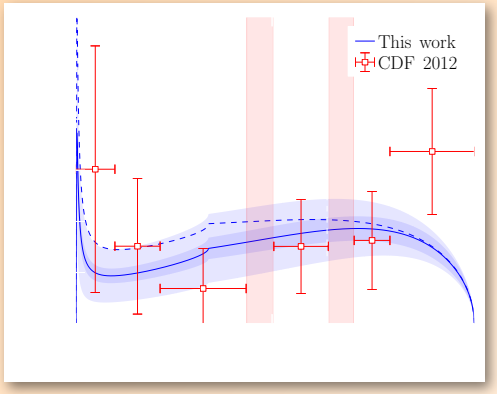
Matthew Wingate: *$b \to s$ decays using lattice QCD*

Rare Decays

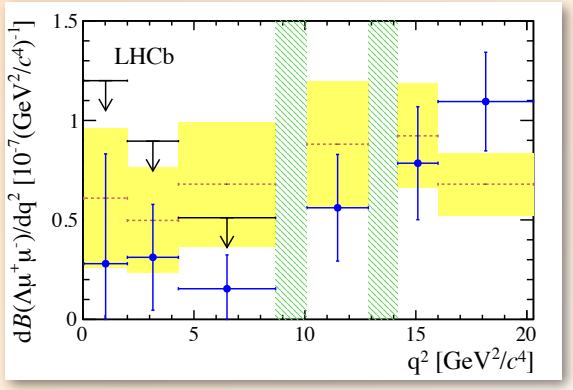
Perspectives from 2014

Important contributions from Lattice QCD calculations to the form factors, and ongoing improvements

$\Lambda_b \to \Lambda\, l^+ l^-$



CDF: red; LQCD: blue



LHCb: blue; binned LQCD: red/yellow

Dominant theory error due to use of LO HQET (static action)
Improved calculation (w/ RHQ) underway (Meinel, Lattice 2013)

Detmold, Lin, Meinel, Wingate, Phys Rev D87 (2013)
CDF, public note 108xx, v0.1, http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
LHC*b*, R Aaij, Phys. Lett. B 725 (2013) [arXiv:1306.2577]

Matthew Wingate: *b → s decays using lattice QCD*

Rare Decays

Perspectives from 2014

Important contributions from Lattice QCD calculations to the form factors, and ongoing improvements

Summary

- First unquenched LQCD calculations of $b \to s$ form factors
- These reduce uncertainties in f.f., especially at large q^2
- $B_{(s)} \to K^*, \varphi$: complement sum rule calculations, many observables, caveat: $K^* \to K\pi$ threshold effects not included
  (ambitious proposal: Briceño, Hansen, Walker-Loud, arXiv:1406.5965)
  - Expt b.f. *suppressed* relative to SM
  - Best fit coincides with Altmannshofer-Straub, compatible w/ others
- $B \to K$: Precise short distance, expt. b.f. seems *suppressed* relative to SM, prominent $\psi(4160)$ resonance
- $\Lambda_b \to \Lambda$: static limit done, hint of high q^2 *enhancement* in b.f., calculation with physical m_b underway

Matthew Wingate: $b \to s$ *decays using lattice QCD*

Rare Decays

Perspectives from 2014

The measurement of the polarisation of the photon in radiative decays ($b \to s + \gamma$)

Francesco Polci: *Radiative Decays at LHCb*

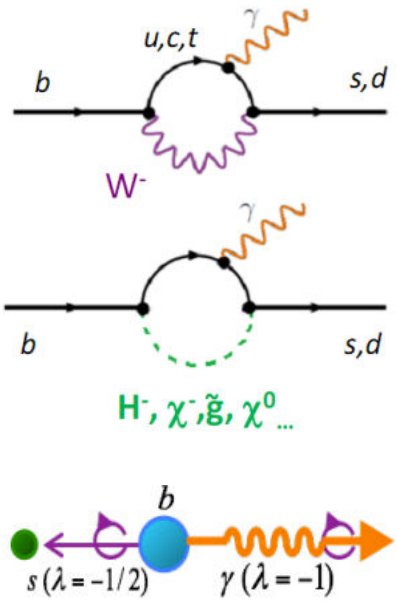
Rare Decays

Perspectives from 2014

The measurement of the polarisation of the photon in radiative decays ($b \to s + \gamma$)

THE RADIATIVE DECAY *b->sγ*

- *b->sγ* transitions are FCNC proceeding via electroweak loop (*penguin*) diagrams
- They are sensitive to new physics via new particles in the loop
- In the SM, since the *W* boson couples only to left-handed fermions, the emitted photon is dominantly left-handed:
  maximal parity violation
  (right-handed at level of m_s/m_b)
- Extensions of the SM predict right-handed polarization [PRL79(1997)185]
- The measured rates of *b->sγ* transitions are in agreement with the SM
- What about the photon polarization?



Francesco Polci 2 FPC 2014 - Quy Nhon, Vietnam

Francesco Polci: *Radiative Decays at LHCb*

Rare Decays

Perspectives from 2014

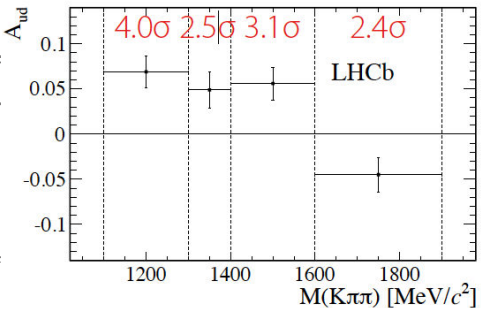
The measurement of the polarisation of the photon in radiative decays ($b \to s + \gamma$)

ANGULAR FIT RESULTS

- Coefficients are obtained for each of the four $K\pi\pi$ mass regions
- They allow to determine four independent up-down asymmetries
- Statistical and systematic uncertainties are combined
- Correlation matrices are also provided

[PRL 112, 161801 (2014)] (x10^{-2})

	[1.1,1.3]	[1.3,1.4]	[1.4,1.6]	[1.6,1.9]
c_1	6.3 ± 1.7	5.4 ± 2.0	4.3 ± 1.9	-4.6 ± 1.8
c_2	31.6 ± 2.2	27.0 ± 2.6	43.1 ± 2.3	28.0 ± 2.3
c_3	-2.1 ± 2.6	2.0 ± 3.1	-5.2 ± 2.8	-0.6 ± 2.7
c_4	3.0 ± 3.0	6.8 ± 3.6	8.1 ± 3.1	-6.2 ± 3.2
$\mathcal{A}_{ud}$	6.9 ± 1.7	4.9 ± 2.0	5.6 ± 1.8	-4.5 ± 1.9



Combining the four measurements, the up-down asymmetry is found to be different from 0 at 5.2 σ

FIRST OBSERVATION OF THE PHOTON POLARIZATION IN b->sγ

Francesco Polci **15** **FPC 2014 - Quy Nhon, Vietnam**

Francesco Polci: *Radiative Decays at LHCb*

Rare Decays

Perspectives from 2014

The measurement of the polarisation of the photon in radiative decays ($b \to s + \gamma$)

CONCLUSIONS

- The photon polarization measurement in radiative *b->sγ* transitions is a powerful test of the Standard Model
- LHCb has provided, via the angular analysis of the *B->Kππγ* decays, the first evidence for the photon being polarized in *b->sγ* transitions
- The quest for new physics via the γ polarization measurement in *b->sγ* transitions continues in LHCb:
  - *Full amplitude analysis of* $B \to K\pi\pi\gamma$
  - *Angular analysis of* $B^0 \to K^* l^+ l^-$ *and* $B^+ \to \phi K^+ \gamma$
  - *Proper time distribution of* $B_s \to \phi\gamma$
  - *Radiative b-baryons decays:* $\Lambda_b \to \Lambda^* \gamma$ *and* $\Xi_b \to \Xi^* \gamma$
- Let's hope for new physics to show up!

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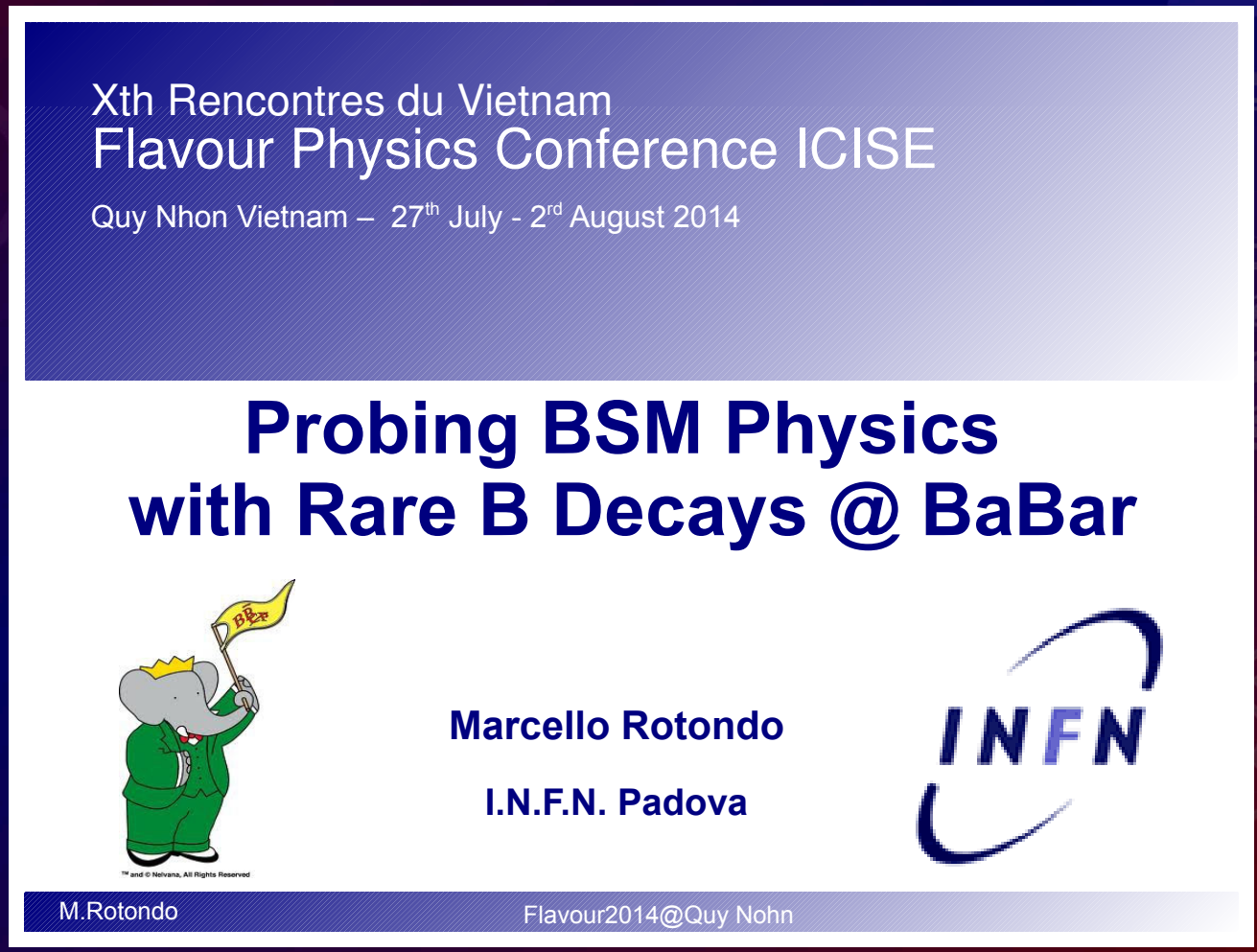
Francesco Polci: *Radiative Decays at LHCb*

Rare Decays

Perspectives from 2014

A survey of rare decay results from BaBar was given



Marcello Rotondo: *Probing BSM Physics with Rare B Decays @ BaBar*

Rare Decays

Perspectives from 2014

A survey of rare decay results from BaBar was given

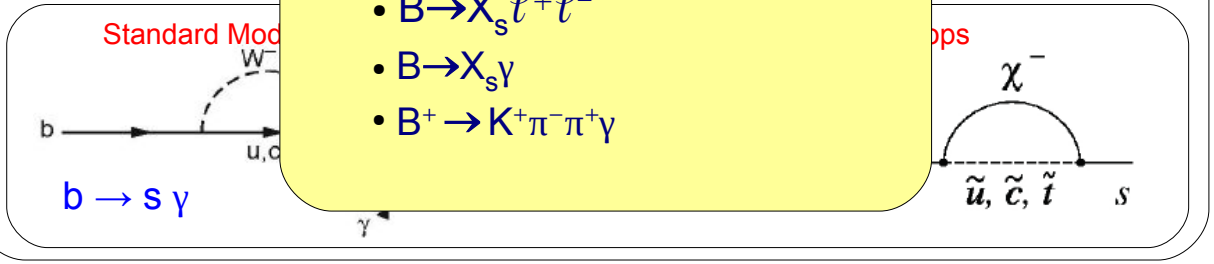
Rare B decays: New Physics probes

- CMS and ATLAS search for direct production of new particles predicted in many extensions of the Standard Model (SM)
- New particles also contribute to heavy mesons decays
  - Search for deviations from SM predictions due to virtual contributions of new heavy particles in loop processes
  - Complementa
- The most intere … y suppressed in the SM: FCNC … ng...)
  - NP could incr
  - Rare B decay … ach of LHC

Outline

I will focus on recent measurements on radiative & EW penguin decays

- $B \to X_s \ell^+ \ell^-$
- $B \to X_s \gamma$
- $B^+ \to K^+ \pi^- \pi^+ \gamma$



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Marcello Rotondo: *Probing BSM Physics with Rare B Decays @ BaBar*

Rare Decays

Perspectives from 2014

A survey of rare decay results from BaBar was given

Conclusions

- BaBar still produces exciting physics results using new analysis techniques to access new interesting observables
  - $B \to X_s \ell^+ \ell^-$ from a sum of exclusive final decays
  - $B \to X_s \gamma$ search for CP viol. and first measurement of ΔA_{CP}
  - TD analysis of $B^0 \to K_s \pi\pi\gamma$ and study of $B^+ \to K\pi\pi\gamma$ decay
- No evidence of New Physics so far!
- Larger statistics are needed to tell wether or not there are indications of NP in these decays
- Search for indirect signal of NP is continuing with much high statistical samples @LHC (LHCb, CMS, ATLAS) and in near future at Belle-II

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Marcello Rotondo: *Probing BSM Physics with Rare B Decays @ BaBar*

Rare Decays

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INFN

Università degli Studi di Padova

Rare B decays at CMS

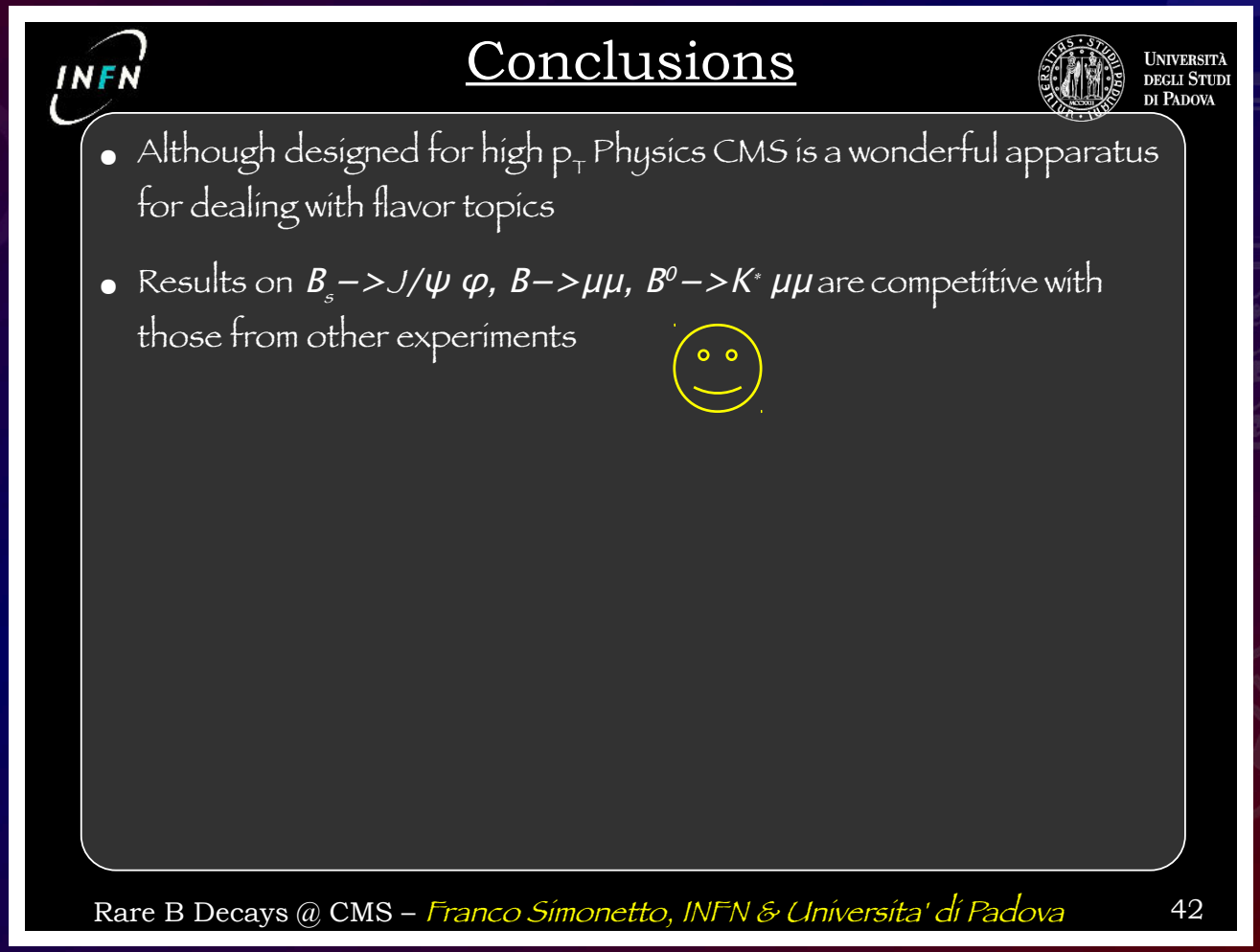
X Rencontres du Vietnam

Franco Simonetto
Universita' & INFN Padova

Franco Simonetto: *Rare B decays at CMS*

Rare Decays

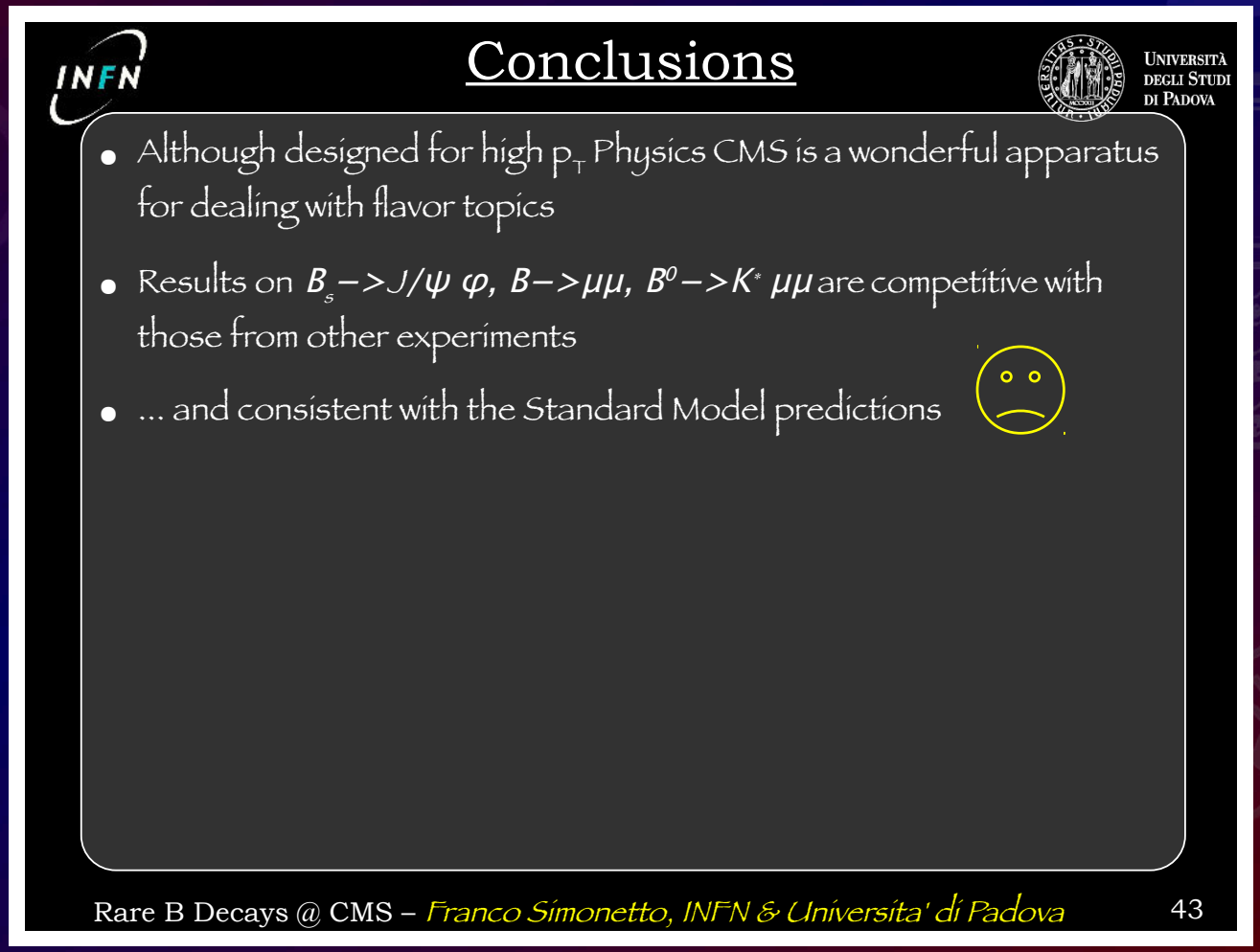
Perspectives from 2014



Franco Simonetto: *Rare B decays at CMS*

Rare Decays

Perspectives from 2014



Franco Simonetto: *Rare B decays at CMS*

Rare Decays

Perspectives from 2014

Rare Decays

Rencontres du Vietnam – Flavour Physics, 28th July 2014

Mitesh Patel (Imperial College London)

Imperial College London

LHCb

Mitesh Patel: *Rare Decays*

Rare Decays

Perspectives from 2014

Outline

- Theoretical basis of rare decays studies
- The decays $B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$
- The decay $B_d^0 \to K^{*0}\mu^+\mu^-$ and other $b \to sll$ processes
- Theory issues around interpretation of data
- Search for Majorana neutrinos

11

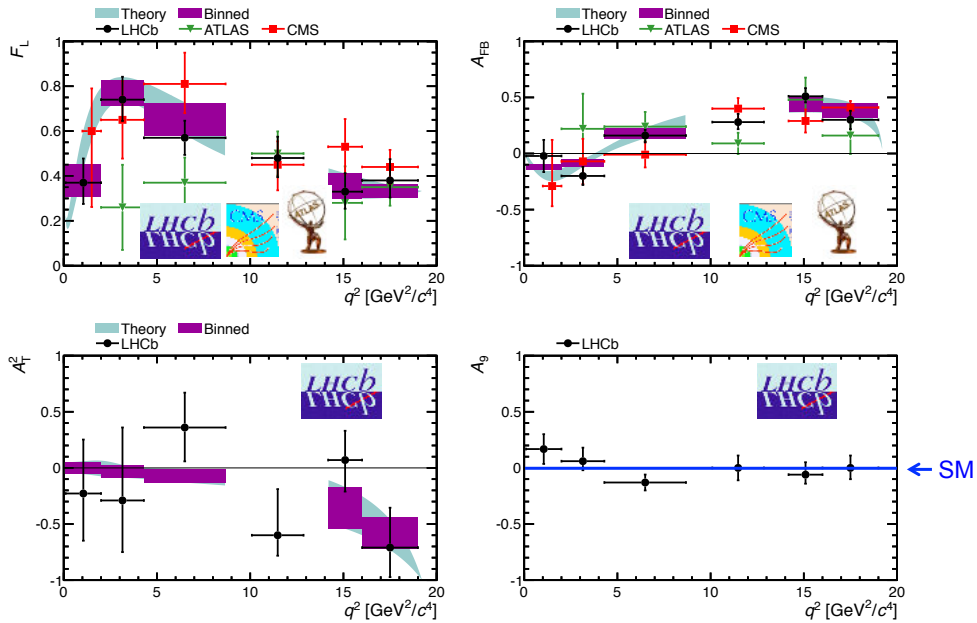
Mitesh Patel: *Rare Decays*

Rare Decays

Perspectives from 2014

- Range of $B_d^0 \to K^{*0}\mu^+\mu^-$ angular observables in excellent agreement with SM (see talk of M. Tresch)

ATLAS (prelim.) [ATLAS-CONF-2013-038] , CMS 5.2 fb^{-1} [PLB 727 (2013) 77] , LHCb 1 fb^{-1} [JHEP 08 (2013) 131]



Theory prediction from Bobeth et al. [JHEP 07 (2011)] and references therein.

13

Lepton Universality – R_K

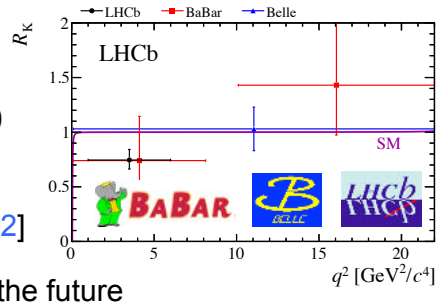
- Some Z' models have differing couplings to the different generations of leptons – see e.g. [arXiv:1403.1269]
  - Would then expect $B(B^+ \to K^+\mu^+\mu^-) < B(B^+ \to K^+e^+e^-)$
  - Interesting to test lepton universality in $b \to sll$
  - Z' couplings would have to be such as to avoid effect in $R_{K \to l\nu} = (2.488 \pm 0.009) \times 10^{-5}$ [PLB 698 (2011) 105]

- LHCb measures $R_K = B(B^+ \to K^+\mu^+\mu^-) / B(B^+ \to K^+e^+e^-)$

- In 3fb^{-1}, $1 < q^2 < 6$ GeV^2,

  $R_K = 0.745^{+0.090}_{-0.074}(\text{stat})^{+0.036}_{-0.036}(\text{syst})$

  → Consistent with SM at 2.6σ
  [arXiv:1406.6482]



- R_{K^*} measurement clearly of interest for the future

20

Rare Decays

Perspectives from 2014

- Successful exploitation of rare decays requires **interplay** :
  - **Experimental and theoretical communities** – e.g. angular observables in $B_d^0 \to K^{*0}\mu^+\mu^-$, lattice predictions for $b \to sll$ BFs
  - **Different measurements** – expect effects in $B_d^0 \to K^{*0}\mu^+\mu^-$ and $B \to H\mu^+\mu^-$ that must be compatible with mixing / CKM measurements
  - **Different facilities** – LHC for exclusive, B-factories for inclusive, dedicated K experiments
- Some interesting effects to study further with run II data at LHC and entire suite of new/complimentary measurements coming from Belle2 and then from the LHCb-upgrade
- In the absence of evidence for NP from direct searches in Run II, rare decays will be one of the best ways to extend our searches

Mitesh Patel: *Rare Decays*

Flavour dynamics of leptogenesis

Stéphane Lavignac (IPhT Saclay)

- introduction
- review of standard leptogenesis
- lepton flavour effects
- flavour-dependent scalar triplet leptogenesis
- a predictive scheme for scalar triplet leptogenesis
- conclusions

Flavour Physics Conference – Xth Rencontres du Vietnam
ICISE, Quy Nhon, 31 July 2014

Stéphane Lavignac: *Flavour dynamics of Leptogenesis*

Introduction

The baryon asymmetry of the universe (BAU)

$$\frac{n_B - n_{\bar{B}}}{n_\gamma} \simeq \frac{n_B}{n_\gamma} = (6.04 \pm 0.08) \times 10^{-10} \qquad \text{(Planck)}$$

must be explained by some dynamical mechanism ⇒ baryogenesis

Sakharov's conditions:
(1) B violation
(2) C and CP violation
(3) departure from thermal equilibrium

(1) and (2) are present in the SM

(1) B+L anomaly ⇒ transitions between vacua with different (B+L) possible at $T \gtrsim M_{weak}$, where nonperturbative (B+L)-violating processes (electroweak sphalerons) are in equilibrium

Electroweak baryogenesis fails in the SM because (3) is not satisfied [also CP violation is too weak] ⇒ need either new physics at M_{weak} to modify the dynamics of the EWPT, or generate a (B-L) asymmetry at $T > T_{EW}$

Stéphane Lavignac: *Flavour dynamics of Leptogenesis*

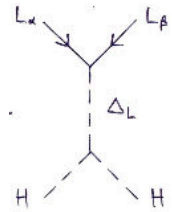
Neutrino Physics

Perspectives from 2014

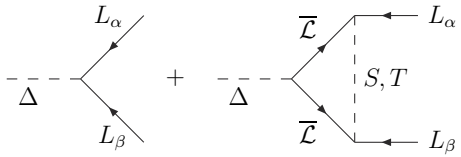
A predictive scheme for scalar triplet leptogenesis

Some non-standard SO(10) models lead to pure type II seesaw mechanism ⇒ neutrinos masses proportional to triplet couplings to leptons:

$$(M_\nu)_{\alpha\beta} = \frac{\lambda_H f_{\alpha\beta}}{2M_\Delta} v^2$$



These models also contain heavy (non-standard) leptons that induce a CP asymmetry in the heavy triplet decays



The SM and heavy lepton couplings are related by the SO(10) gauge symmetry, implying that the CP asymmetry in triplet decays can be expressed in terms of (measurable) neutrino parameters

→ important difference with other triplet leptogenesis scenarios

[Frigerio, Hosteins, SL, Romanino '08]

Stéphane Lavignac: *Flavour dynamics of Leptogenesis*

Conclusions

Leptogenesis is an attractive mechanism for generating the baryon asymmetry of the Universe

In its minimal version with heavy Majorana neutrinos, the only required ingredients are the ones needed to generate small neutrino masses via the seesaw mechanism

Lepton flavour dynamics can significantly affect the baryon asymmetry generated by leptogenesis

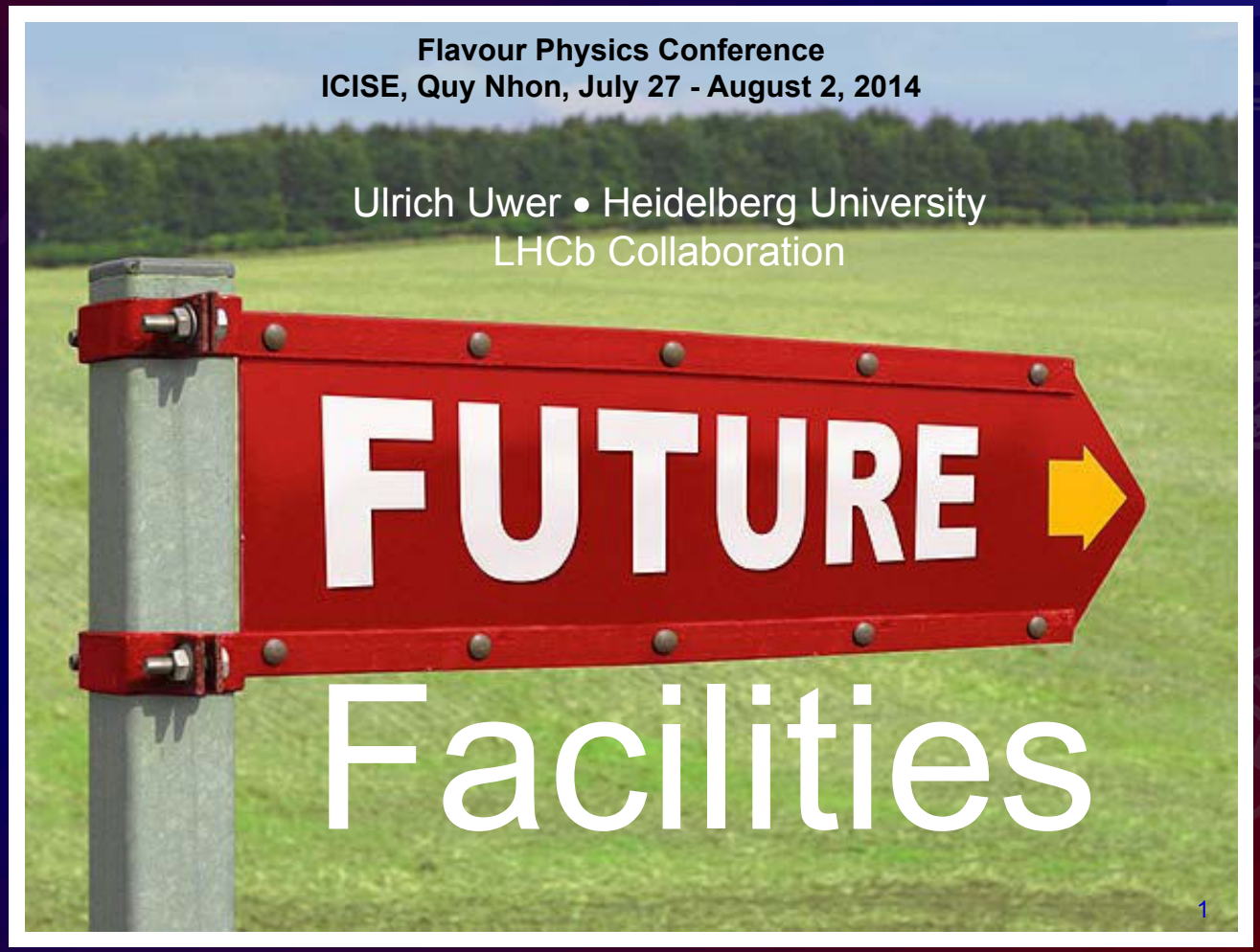
Recent progress in scalar triplet leptogenesis: inclusion of flavour effects, flavour-covariant Boltzmann equations (density matrix formalism), application to a predictive model providing a link between leptogenesis and low-energy parameters

Stéphane Lavignac: *Flavour dynamics of Leptogenesis*

Future Facilities

Future Facilities

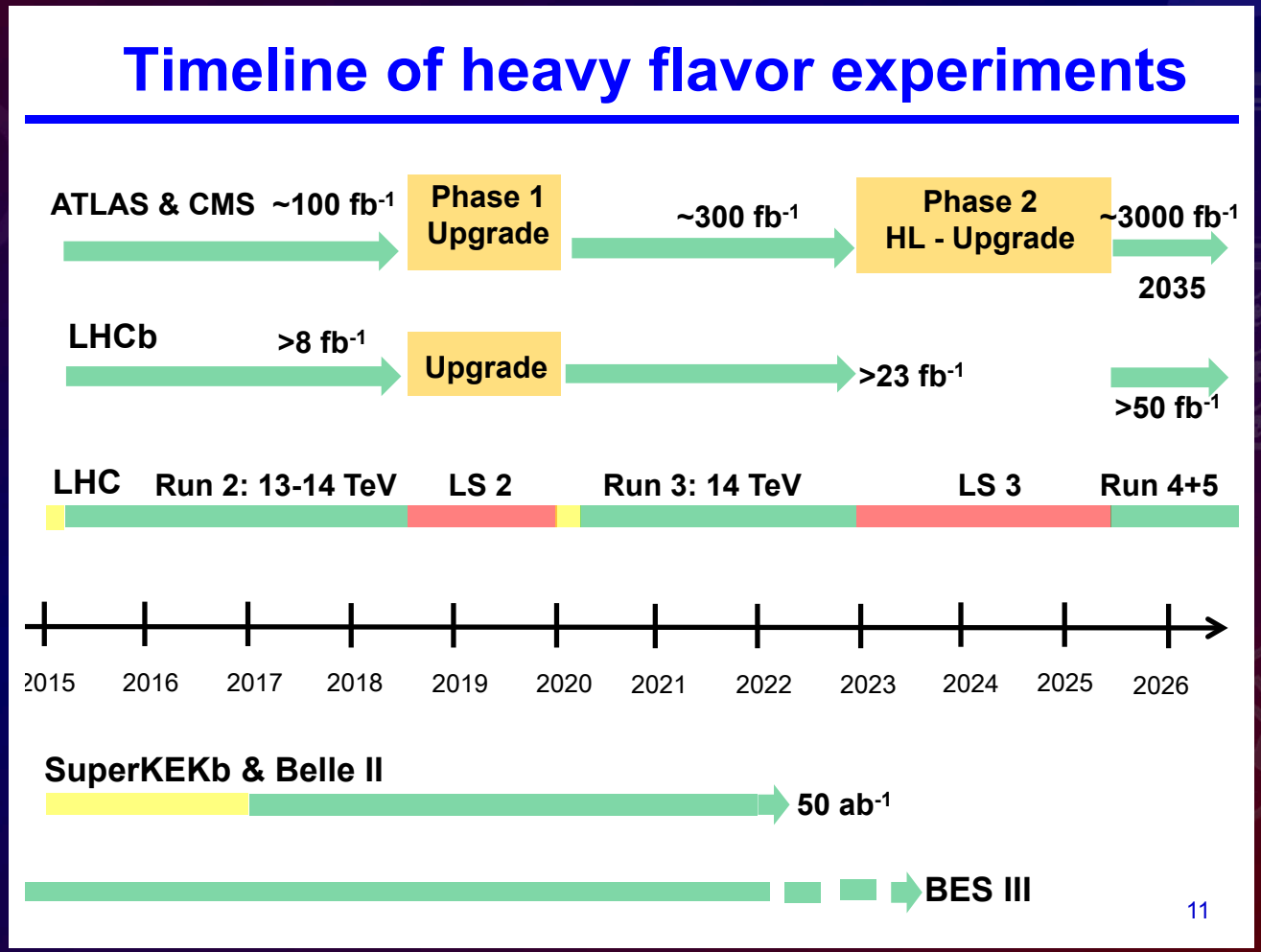
Perspectives from 2014



Ulrich Uwer: *Future B Physics Facilities*

Future Facilities

Perspectives from 2014

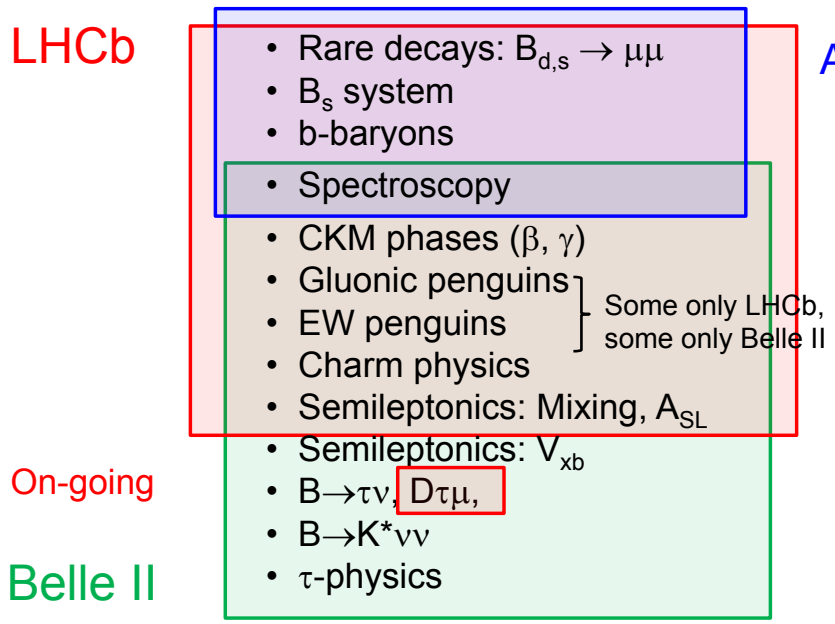


Ulrich Uwer: *Future B Physics Facilities*

Future Facilities

Perspectives from 2014

Physics Complementarity*)



*) Caveat: I am probably missing "your" favored channel/field

13

Ulrich Uwer: *Future B Physics Facilities*

Future Facilities

Perspectives from 2014

Wander Baldini: *The LHCb Upgrade*

Future Facilities

Perspectives from 2014

Conclusions

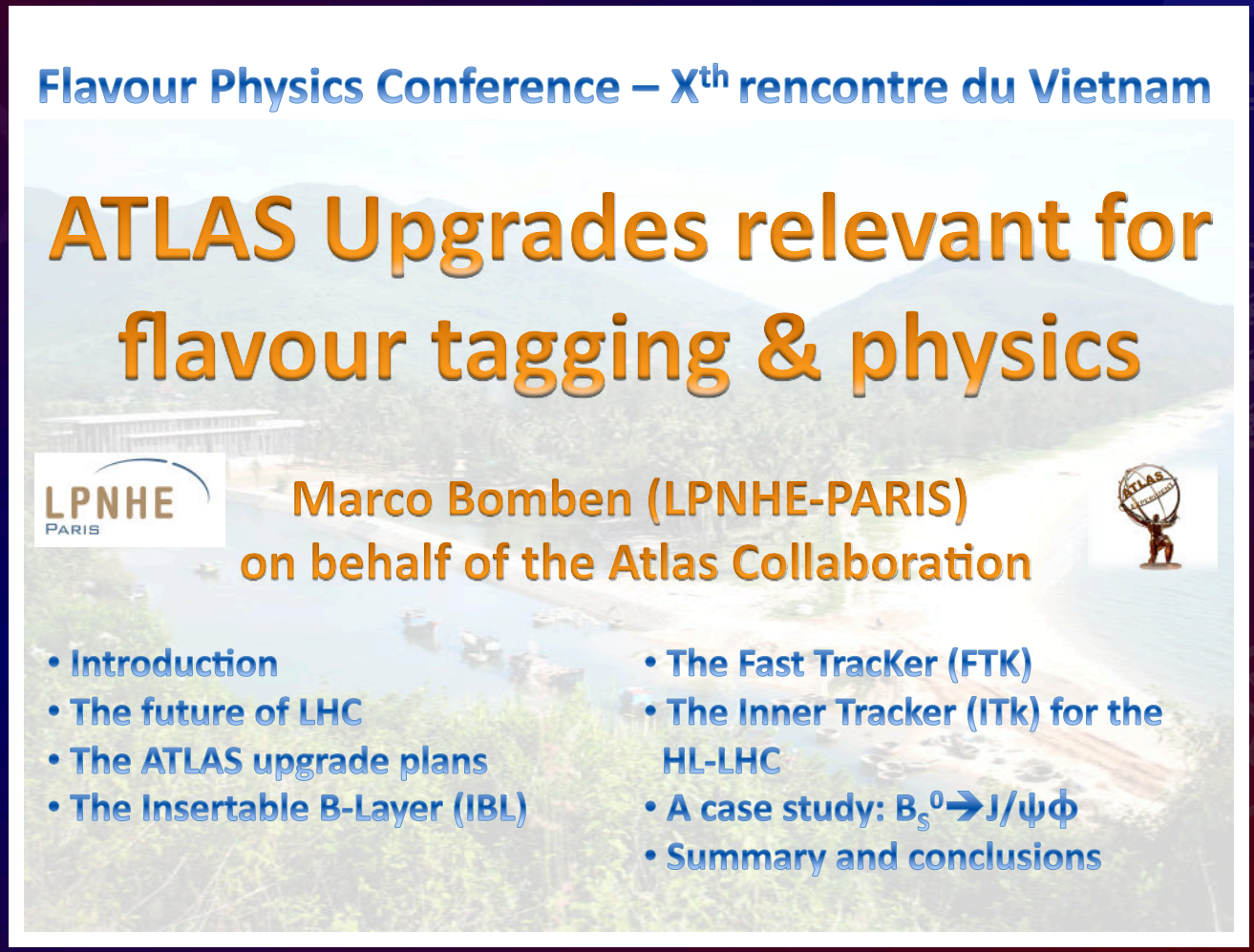
- Thanks to its excellent performance LHCb is producing world best measurements in the beauty and charm sector
- The Upgraded LHCb trigger-less scheme with event processing at 40 MHz, will allow to collect 5 fb^{-1} per year
- The upgrade will be performed during LS2 (2018-19) data taking will start in 2020
- The LHCb upgrade is mandatory to reach experimental precision of the order of theoretical uncertainties
- The LHCb upgrade is fully approved

Flavour Physics Conf., July 29th 2014 W. Baldini, INFN Ferrara 26

Wander Baldini: *The LHCb Upgrade*

Future Facilities

Perspectives from 2014

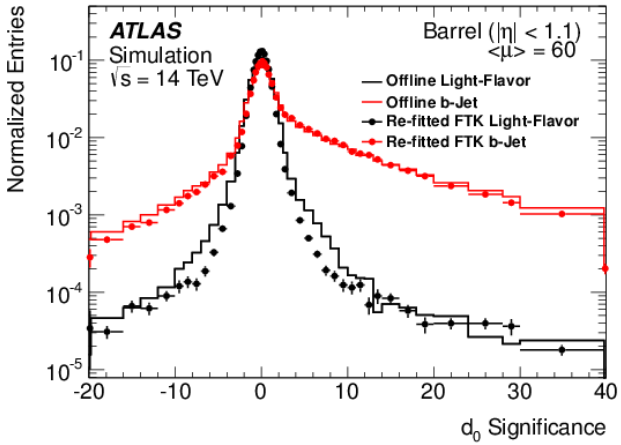


Marco Bomben: *ATLAS Upgrades Relevant for flavour tagging and physics*

Future Facilities

Perspectives from 2014

B-tagging with FastTrack



Updates since the TDR:

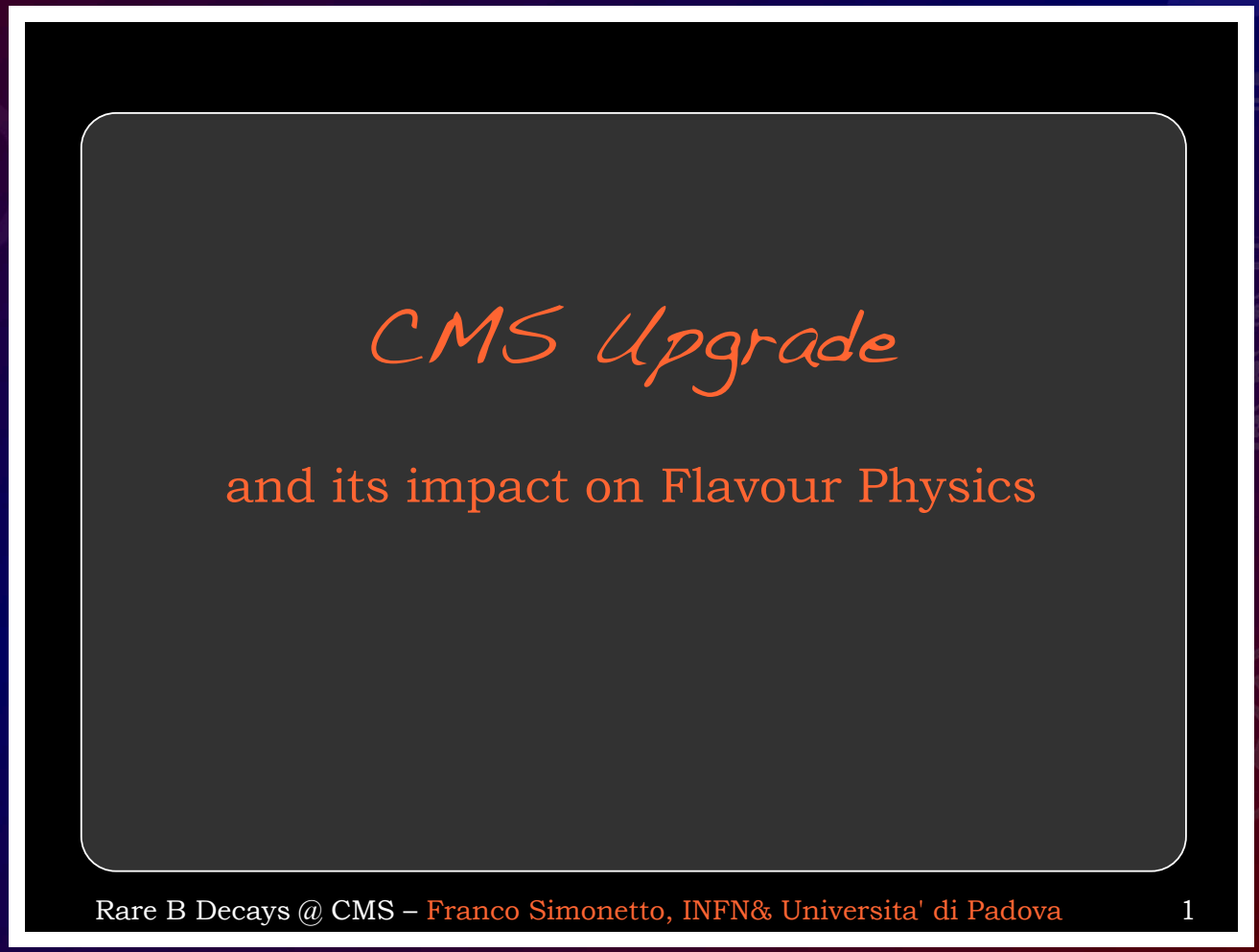
- IBL included in the performance simulation
- FTK clusters are re-fitted to FTK tracks using offline algorithm

M. Bomben, LPNHE-Paris - Flavour Physics Conference 2014 20

Marco Bomben: *ATLAS Upgrades Relevant for flavour tagging and physics*

Future Facilities

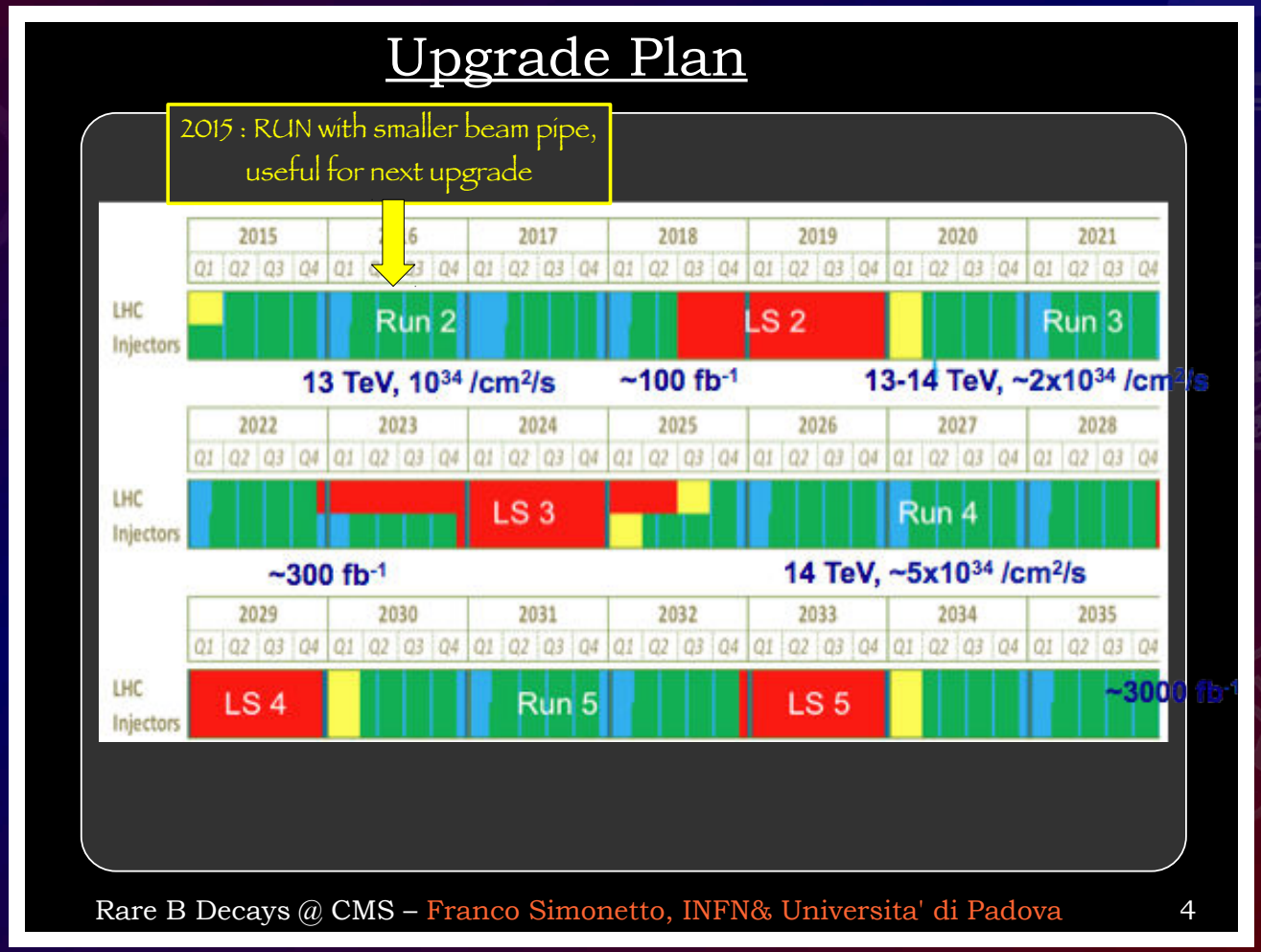
Perspectives from 2014



Franco Simonetto: *CMS Upgrade and its impact on Flavour Physics*

Future Facilities

Perspectives from 2014



Franco Simonetto: *CMS Upgrade and its impact on Flavour Physics*

Future Facilities

Perspectives from 2014

Benchmark : B−>μμ

Hypothesis :

- L1 track-Trigger allows same L1 thresholds as now ($p_T(\mu) > 3$ GeV)
- Efficiency :
  - pileup : ε(μμ) ↓ 30% (isolation)
  - μ reco & trigger : ε(μμ) ↓ 2 x 5%
- σ(syst) :
  - f_s/f_u : 5% (now) → 3%
  - Normalization ($B^+ -> \psi K^+$) : $3\%^{(BR)} \oplus 5\% / \sqrt{\mathcal{L}_{INT}/20\ fb^{-1}}$ (Rate)
  - Peaking Backround : $10\%^{(BR)} \oplus 50\% / \sqrt{\mathcal{L}_{INT}/20\ fb^{-1}}$ (Control Sample)
  - Semileptonic Background : $20\%^{(BR)} \oplus 50\% / \sqrt{\mathcal{L}_{INT}/20\ fb^{-1}}$ (Control Sample)
- Resolution:
  - ↓ 1.6 (Barrell) ↓ 1.2 (Forward)
  - ignore improvement due to 1st pixel layer

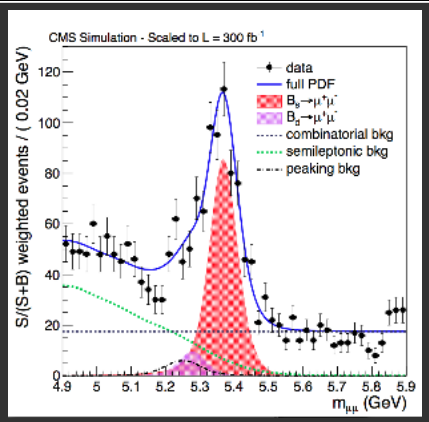
Rare B Decays @ CMS – Franco Simonetto, INFN& Universita' di Padova 12

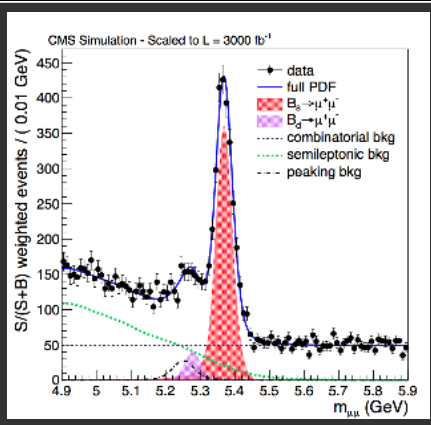
Franco Simonetto: *CMS Upgrade and its impact on Flavour Physics*

Future Facilities

Perspectives from 2014

B->μμ : expectations





L (fb^{-1})	No. of B_s^0	No. of B^0	$\delta\mathcal{B}/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$\delta\mathcal{B}/\mathcal{B}(B^0 \to \mu^+\mu^-)$	B^0 sign.	$\delta\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s^0\to\mu^+\mu^-)}$
20	16.5	2.0	35%	>100%	0.0–1.5 σ	>100%
100	144	18	15%	66%	0.5–2.4 σ	71%
300	433	54	12%	45%	1.3–3.3 σ	47%
3000	2096	256	12%	18%	5.4–7.6 σ	21%

- 3000 fb^{-1} : statistic is not an issue
- Use just barrel events, resolution is enough to separate B_d/B_s/B->hh'
- $\mathcal{B}r$ (B_d) > 5 σ

Rare B Decays @ CMS – Franco Simonetto, INFN& Universita' di Padova 13

Franco Simonetto: *CMS Upgrade and its impact on Flavour Physics*

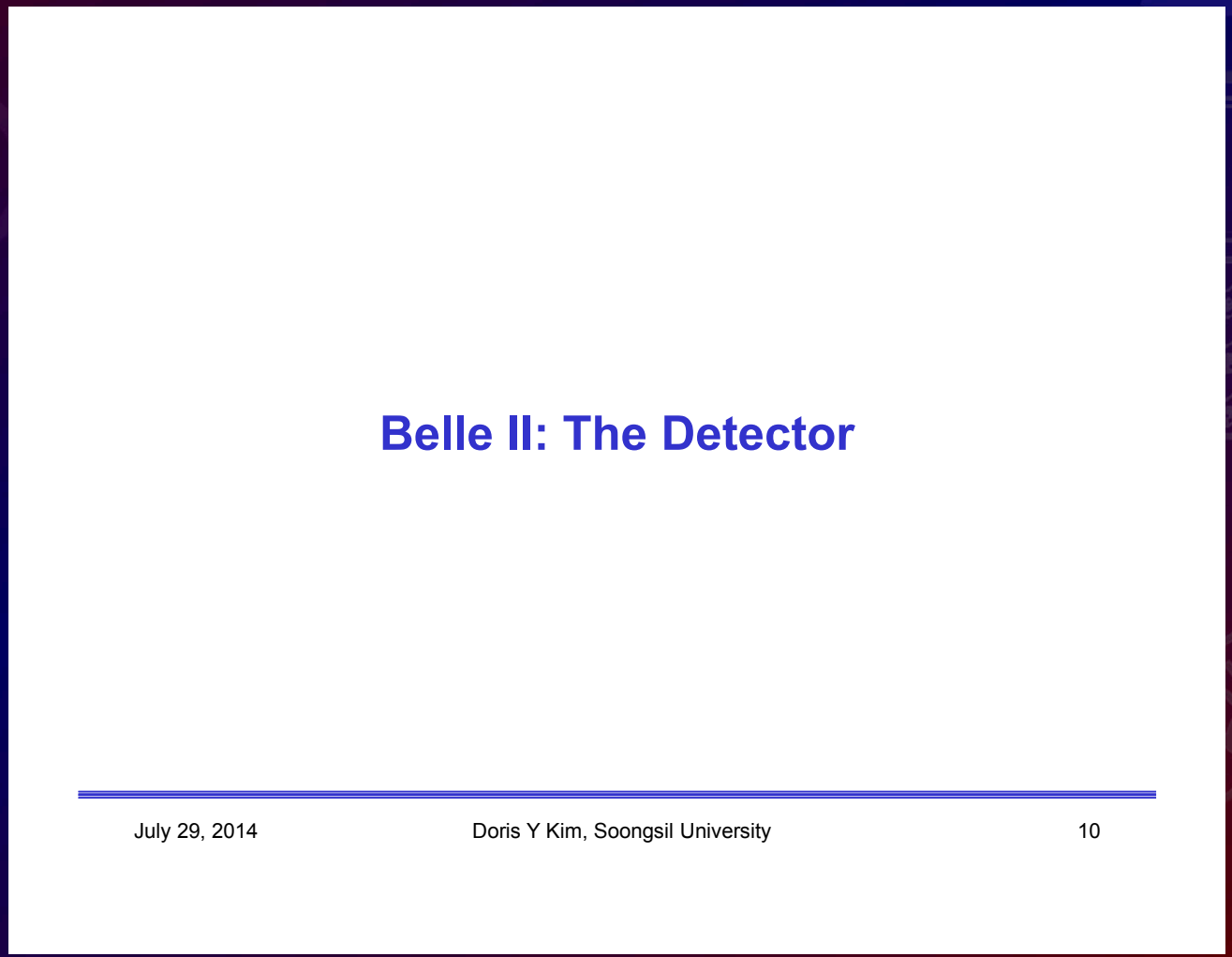
Future Facilities

Perspectives from 2014

Doris Kim: *The Belle II Experiment*

Future Facilities

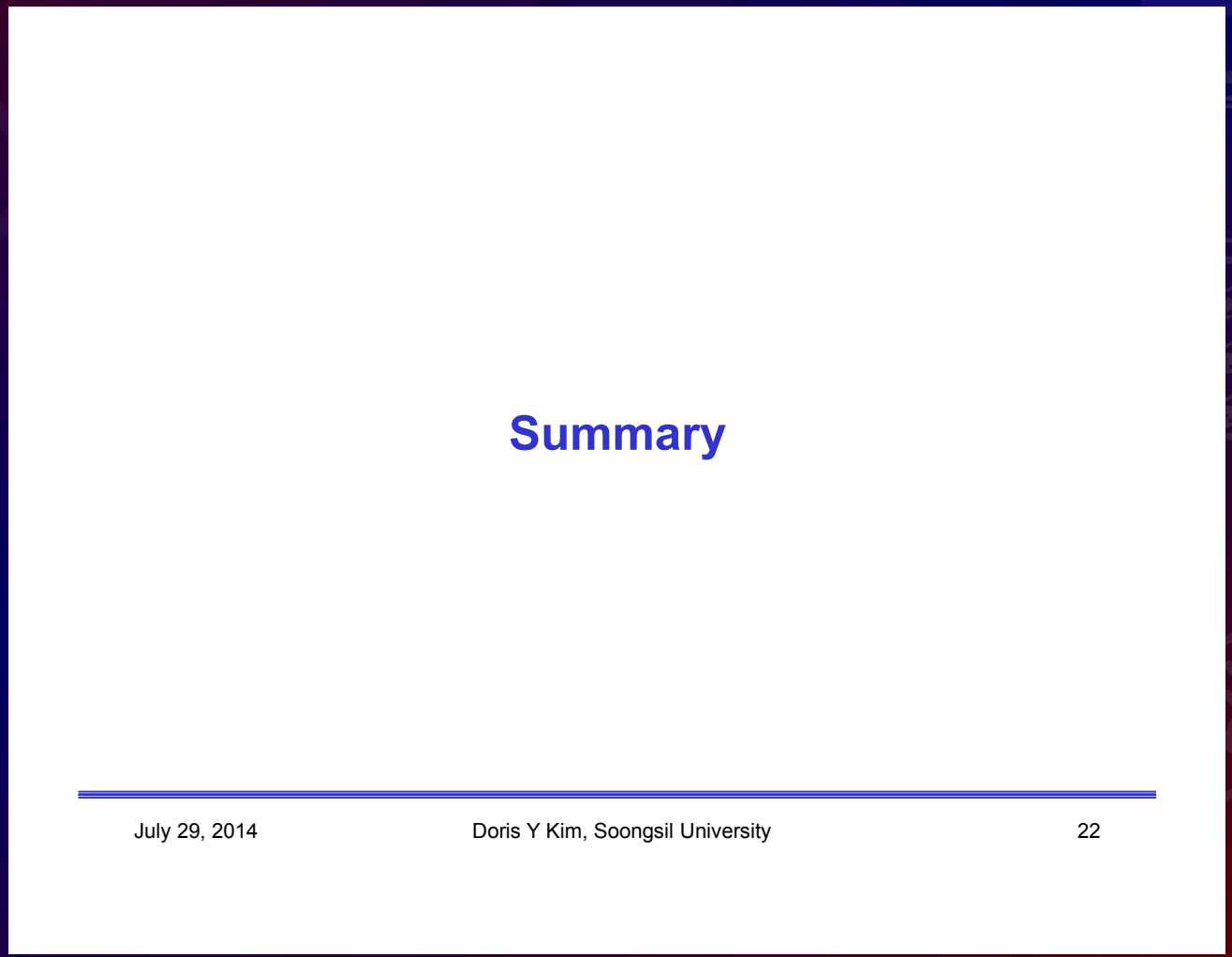
Perspectives from 2014



Doris Kim: *The Belle II Experiment*

Future Facilities

Perspectives from 2014



Doris Kim: *The Belle II Experiment*

Beyond the Standard Model

Perspectives from 2014

Xth Rencontres du Vietnam

Flavour Physics Conference

BSM physics driven by a possible solution of hierarchy problem at the electroweak scale

Jernej F. Kamenik

Univerza *v Ljubljani*

Institut "Jožef Stefan"

01/08/2014, Quy Nhon

Jernej Kamenik: *BSM physics driven by a possible solution of hierarchy problem at the electroweak scale*

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Beyond the Standard Model

Perspectives from 2014

Conclusions

Success of SM in describing flavor-changing processes implies that large new sources of flavor symmetry breaking at TeV scale are mostly excluded.

However, NP at TeV scale need not be flavor trivial!

If (properly aligned) new sources of flavor breaking present

- Precision flavor observables may hide NP signals @10% level in well motivated NP models (natural SUSY)
- can significantly affect & guide NP searches high p_T
- have implications for EW fine-tuning

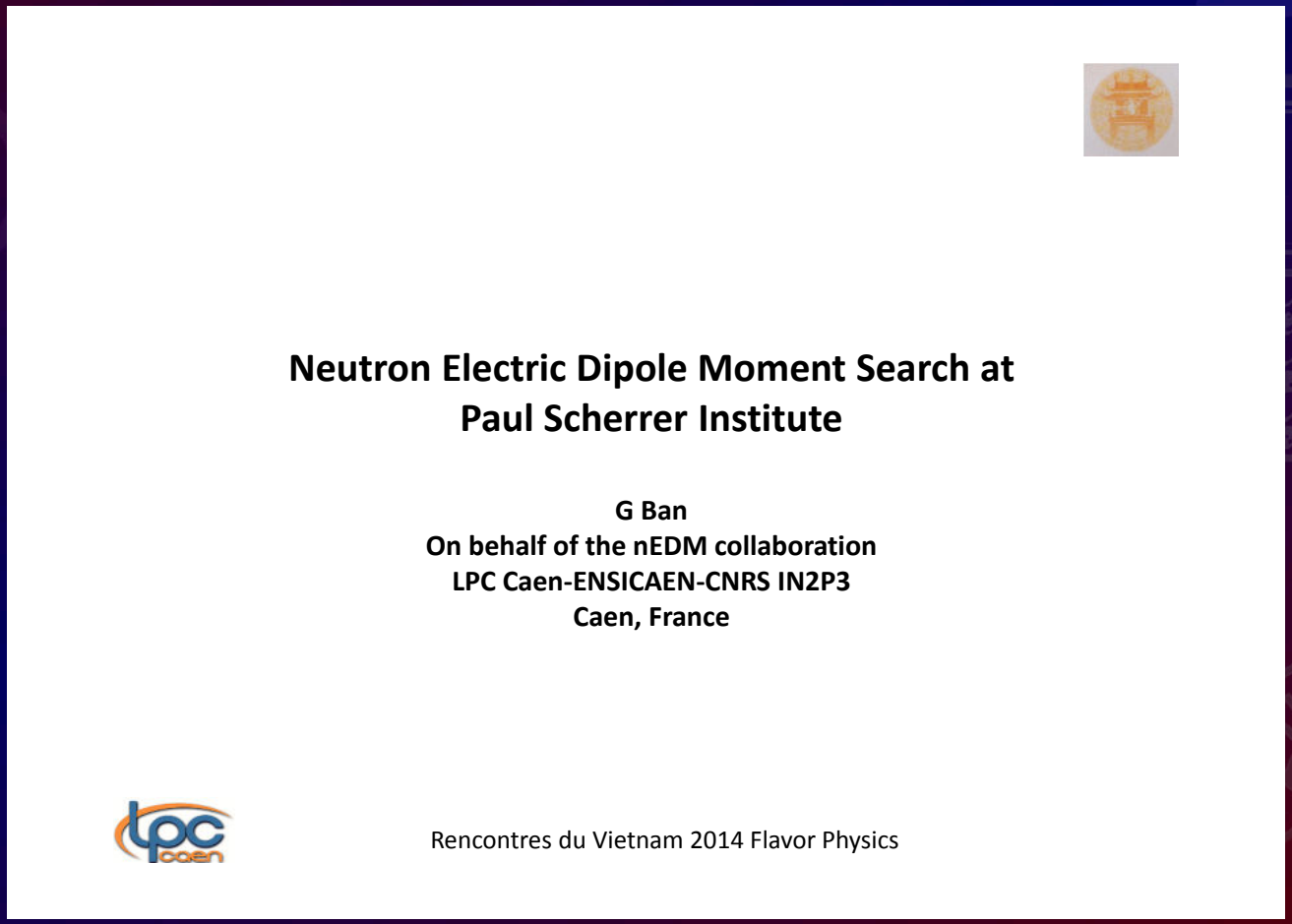
37

Jernej Kamenik: *BSM physics driven by a possible solution of hierarchy problem at the electroweak scale*

Beyond the Standard Model

Perspectives from 2014

nEDM experiments making progress towards the 10^{-27} e·cm range

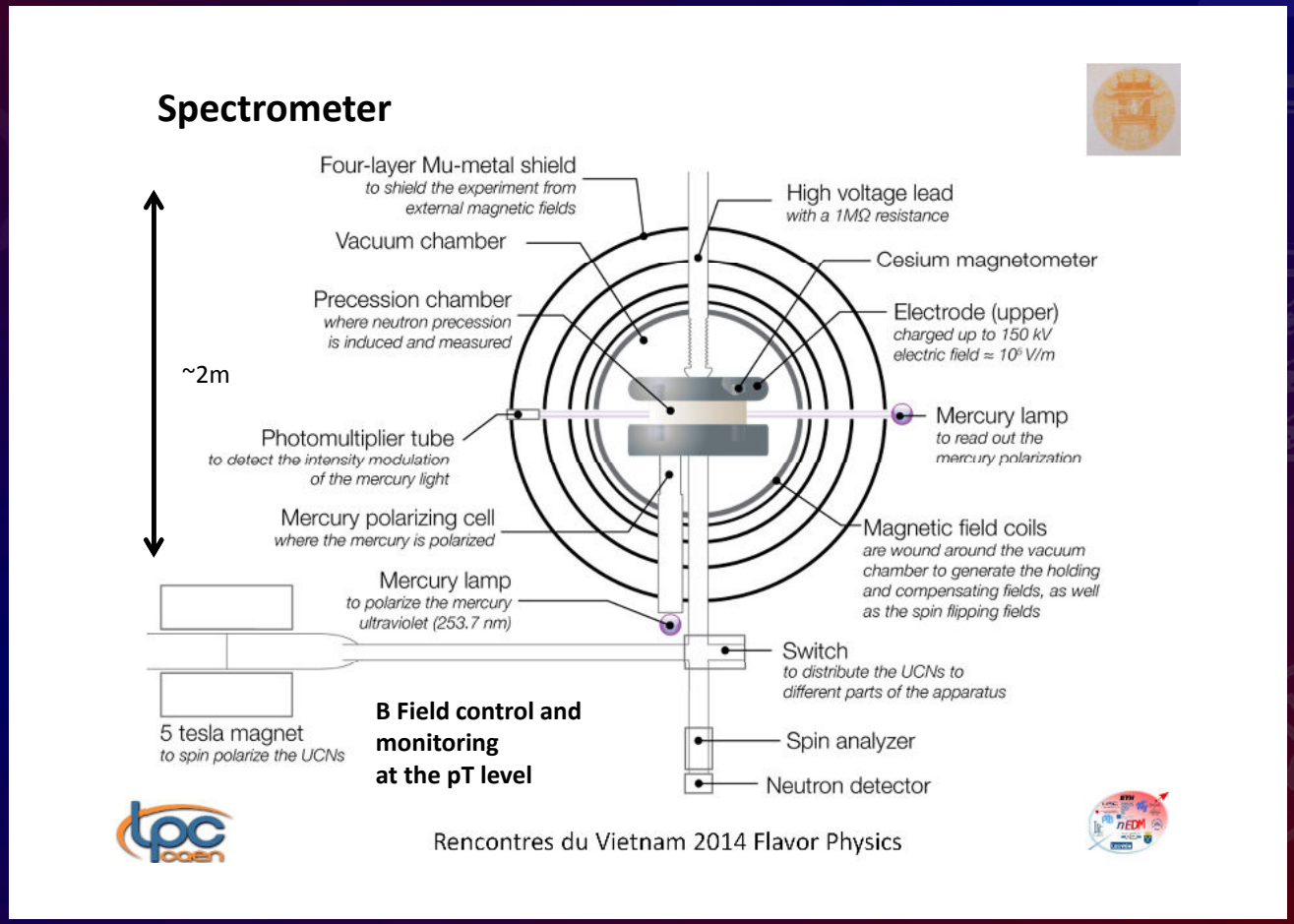


Gilles Ban: *Neutron Electric Dipole Moment Search at PSI*

Beyond the Standard Model

Perspectives from 2014

nEDM experiments making progress towards the 10^{-27} e·cm range



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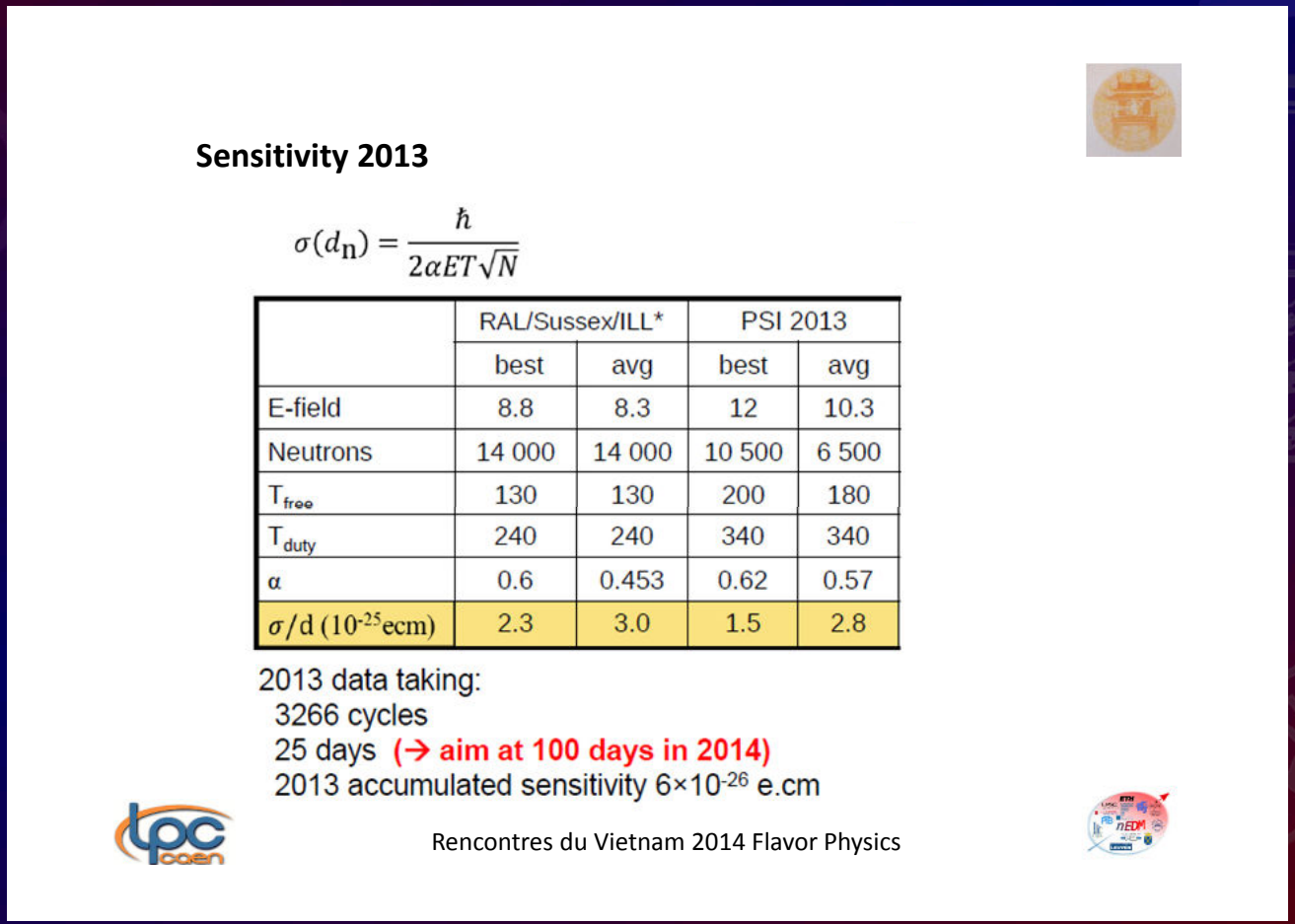
Beyond the Standard Model

Perspectives from 2014

nEDM experiments making progress towards the 10^{-27} e·cm range



Gilles Ban: *Neutron Electric Dipole Moment Search at PSI*

Beyond the Standard Model

Perspectives from 2014

nEDM experiments making progress towards the 10^{-27} e·cm range

SYSTEMATICS

Effects	Status
Direct Effects	
Uncompensated B-Drifts	0.5 ± 1.2
Leakage Current	0.00 ± 0.05
$V \times E$ UCN	0 ± 0.1
Electric Forces	0 ± 0.4
Hg EDM	0.02 ± 0.06
Hg Direct Light Shift	0 ± 0.008
Indirect Effects	
Hg Light Shift	0 ± 0.05
Quadrupole Difference	1.3 ± 2.4
Dipoles	
At the surface	0 ± 0.4
Other Dipoles	0 ± 3
Total	1.8 ± 4.1

With present apparatus
Goal ~ 10^{-26} ecm in 3 years

In 10^{-27} ecm

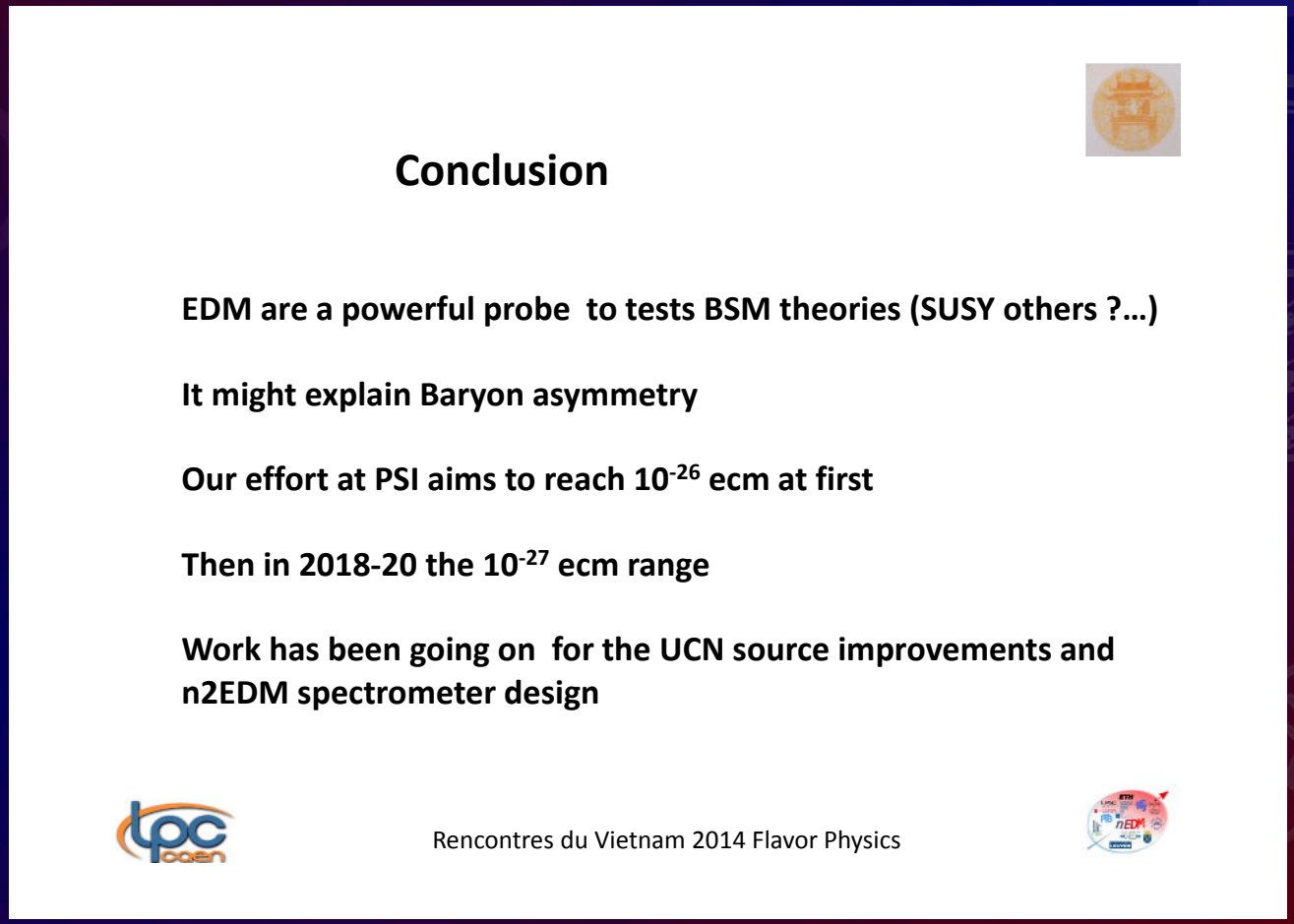
Rencontres du Vietnam 2014 Flavor Physics

Gilles Ban: *Neutron Electric Dipole Moment Search at PSI*

Beyond the Standard Model

Perspectives from 2014

nEDM experiments making progress towards the 10^{-27} e·cm range



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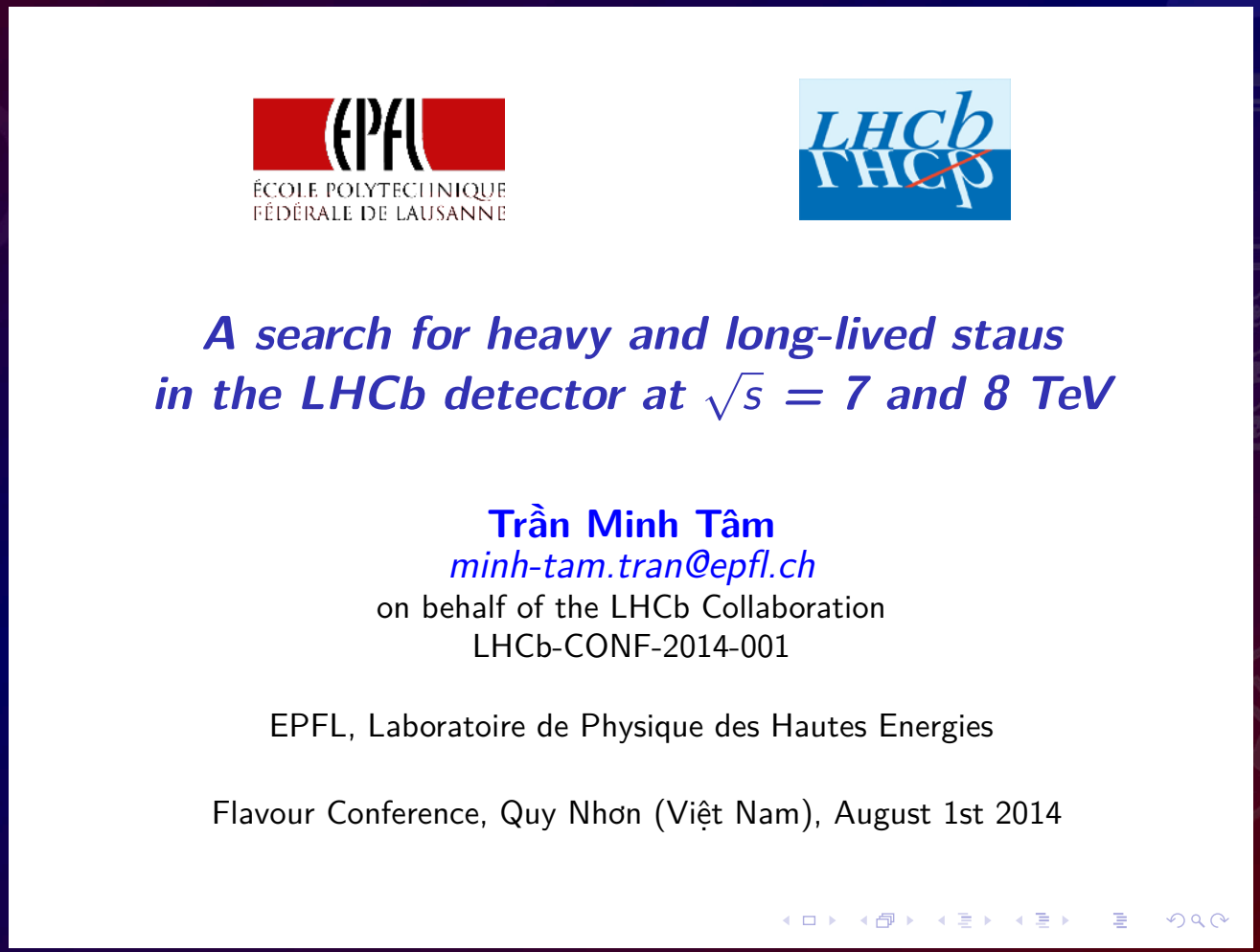
Beyond the Standard Model

Perspectives from 2014



Trán Minh Tâm: *A search for heavy and long-lived staus in the LHCb detector at s = 7 and 8 TeV*

Beyond the Standard Model

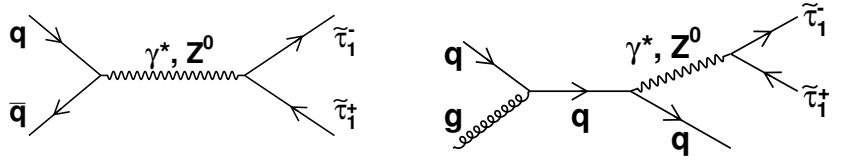
Perspectives from 2014

1.2. The staus

To get long-lived staus, SPS7 benchmark sets (arXiv:hep-ph/0202233v1 25 Feb 2002):

- $\Lambda \simeq 40 - 100$ TeV, $M_m = 2\Lambda$, $N_5 = 3$, $\tan\beta = 15$ and $\mathrm{sgn}\mu = +1$.
- The $\tilde{\tau}$ lifetime is ~ 100 ns for $C_{grav} \sim 4000$.

- Their mass is ≤ 1 TeV (John Ellis, hep-phy/0211168, 12 Nov 2002)
- They are charged (± 1), massive and can be long lived (i.e they do not decay inside the detector).
- Staus only have the electromagnetic interaction,
  $\Rightarrow$ they look like muons.
- We look for pairs produced in: $q + \bar{q} \rightarrow \tilde{\tau}_1^- + \tilde{\tau}_1^+$
  $\Rightarrow$ x-sections limits can be stated as function of the staus masses only

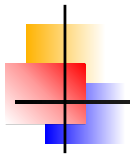


4 / 28

Trán Minh Tâm: *A search for heavy and long-lived staus in the LHCb detector at $s = 7$ and 8 TeV*

Beyond the Standard Model

Perspectives from 2014



4.2. Results

Expected numbers of stau and muon pairs in the signal region

$m_{\widetilde{\tau}}$ (GeV/c^2)	$\mathcal{L} = 1.01$ fb^{-1}, 7 TeV		$\mathcal{L} = 2.1$ fb^{-1}, 8 TeV	
	muon pairs	stau pairs	muons pairs	stau pairs
124	0.0082 ± 0.0045	0.7534 ± 0.1379	0.0102 ± 0.0057	2.0298 ± 0.3605
309	0.0013 ± 0.0008	0.0026 ± 0.0005	0.0032 ± 0.0018	0.0090 ± 0.0017

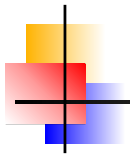
Expected number of μ pairs close to zero,
$\widetilde{\tau}$ pairs almost zero except for the lowest mass hypothesis.

No event found !

Trán Minh Tâm: *A search for heavy and long-lived staus in the LHCb detector at $s = 7$ and 8 TeV*

Beyond the Standard Model

Perspectives from 2014



5. Conclusions and Outlook

- A search for heavy and long-lived staus in the LHCb detector at $\sqrt{s} = 7$ and 8 TeV has been performed for stau masses ranging from 124 to 309 GeV/c^2.
- The 2011 and 2012 data sets corresponding to the luminosities of 1 fb^{-1} and 2 fb^{-1} have been analyzed. No events have been observed.
- The upper limits on the cross section for stau pair production in pp collisions at $\sqrt{s} = 7$ and 8 TeV have been set.
We will try to combine the two periods.
- **Prospect:** The detection of heavy stable particles is limited by the trigger width; a trigger allowing an extra delay of ∼5 ns would allow to detect particles with β down to ~ 0.6 but this would require in addition an *ad hoc* modification of the tracking algorithm.

Trán Minh Tâm: *A search for heavy and long-lived staus in the LHCb detector at s = 7 and 8 TeV*

Walter Bonivento

Perspectives from 2014

The future of Flavor Physics at CERN

Walter M. Bonivento
CERN/INFN-Cagliari

Xth Rencontres du Vietnam
Flavour Physics Conference
ICISE, Quy Nhon,VN, July 27 - August 2, 2014

1

Walter Bonivento: *The Future of Flavor Physics at CERN*

Walter Bonivento

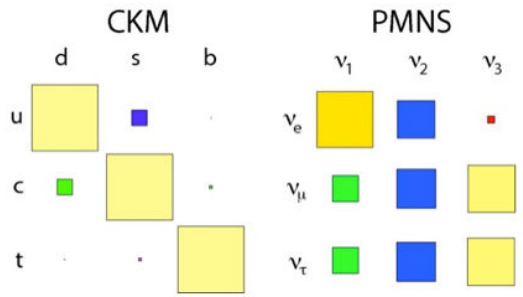
Perspectives from 2014

The SM incompleteness

However, we already know that the SM cannot be a complete theory due to several reasons:

one coming from particle physics experiments:

neutrinos do oscillate and therefore have mass —> 3x3 matrix PMNS (with CPV phase to be determined!); still we don't know the masses (but they are likely in the range 40meV<∑m<230meV), the mass hierarchy and if ν is Dirac or Majorana



Very different from CKM!

Walter Bonivento: *The Future of Flavor Physics at CERN*

Walter Bonivento

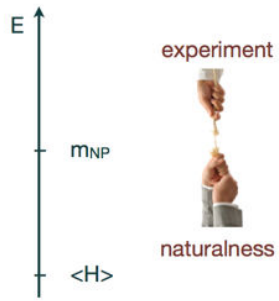
Perspectives from 2014

The hierarchy problem

One other outstanding issue with the SM comes from so called Naturalness arguments (or Hierarchy problem):

if there exists a new scalar particle of mass M between EW scale and Planck scale, then the Higgs mass is not protected against radiative corrections and is brought towards high values —>fine tuning is then needed to explain why m_H=125GeV

(I neglect here for simplicity other issues such as how to solve the strong CP problem, who is the inflaton, what is dark energy,…)

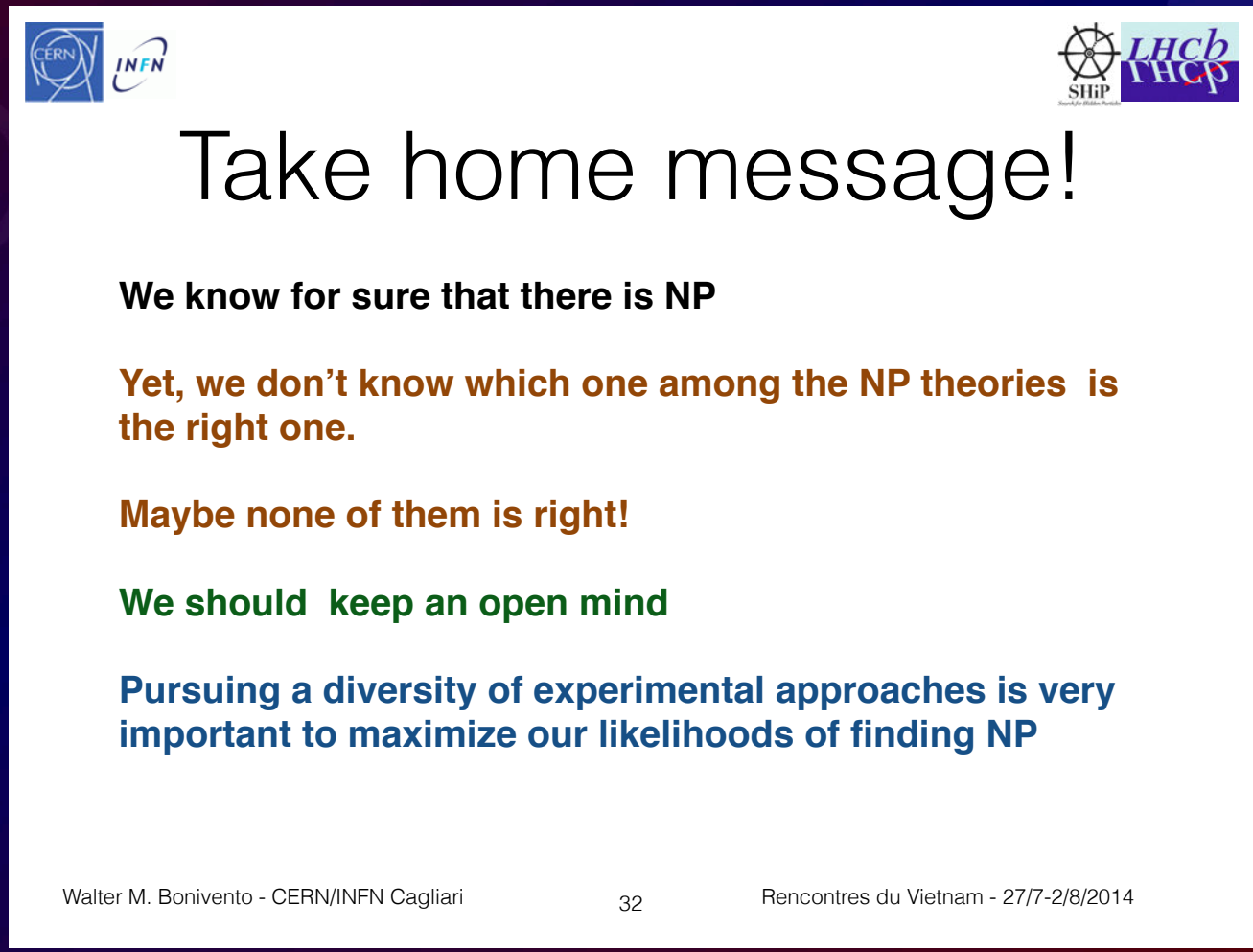


Walter M. Bonivento - CERN/INFN Cagliari 9 Rencontres du Vietnam - 27/7-2/8/2014

Walter Bonivento: *The Future of Flavor Physics at CERN*

Walter Bonivento

Perspectives from 2014



Walter Bonivento: *The Future of Flavor Physics at CERN*

Beyond the Standard Model

Perspectives from 2014

QUEST FOR NEW PHYSICS DRIVEN BY EXPERIMENT AND SIMPLICITY

Oleg Ruchayskiy

EPFL

Xth Rencontres du Vietnam

July 30, 2014

Oleg Ruchayskiy: *Quest for new physics driven by experiment and simplicity*

Beyond the Standard Model

Perspectives from 2014

Is this the end?

- ✓ All predicted particles of the Standard Model have been found 
- ✓ The theory behind these particles and their interactions stays **mathematically consistent** to very high energies 

Did we just had the last Nobel Prize in particle physics?

Oleg Ruchayskiy: *Quest for new physics driven by experiment and simplicity*

Beyond the Standard Model

Perspectives from 2014

All discovered phenomen explained? 

Particle physics: neutrino oscillations

Cosmology and astrophysics: particle physics (coupled to Einstein gravity) applied to the Universe as a whole faces the challenges of

- dynamics of gravitating objects at scales from galactic to cosmological (**dark matter**?)
- absence of primordial asymmetry of the Universe

Possibly

- initial conditions for the Universe (**inflation**?)
- accelerated expansion of the Universe (**dark energy**?)

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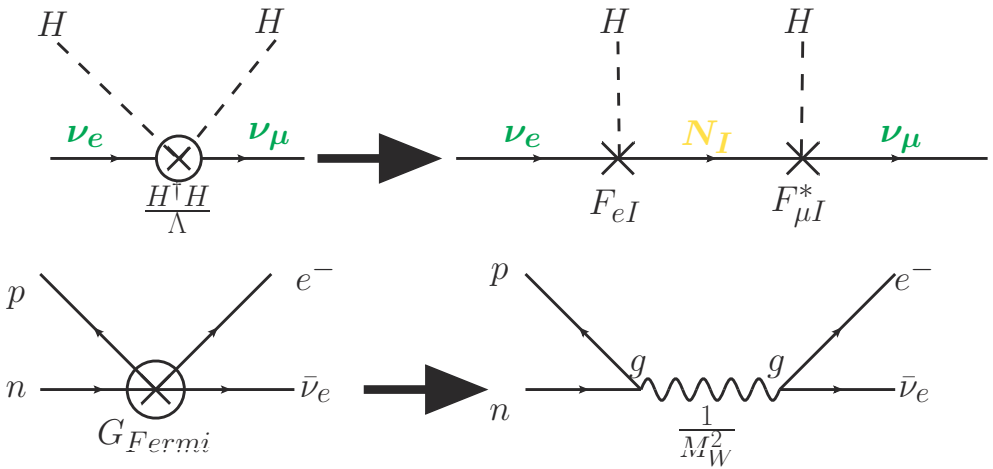
Beyond the Standard Model

Perspectives from 2014

"Resolving" neutrino mass term



Neutrino oscillations mean that there exist new particles!

Oleg Ruchayskiy QUEST FOR NEW PHYSICS DRIVEN BY MINIMALITY... 12

Oleg Ruchayskiy: *Quest for new physics driven by experiment and simplicity*

Beyond the Standard Model

Perspectives from 2014

Unidentified spectral line at $E \sim 3.5$ keV

Boyarsky et al. 2014 [1402.4119]

M31 galaxy	XMM-Newton, center & outskirts
Perseus cluster	XMM-Newton, outskirts only
Blank sky	XMM-Newton

Bulbul et al. 2014 [1402.2301]

73 clusters	XMM-Newton, central regions of clusters only. Up to $z = 0.35$, including Coma, Perseus
Perseus cluster	Chandra, center only
Virgo cluster	Chandra, center only

Position: 3.52 ± 0.02 keV.

Lifetime: $\sim 10^{28}$ sec (uncertainty $\mathcal{O}(10)$)

Significance: Between 4σ and 5σ (global, taking into account trial factors)

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Beyond the Standard Model

Perspectives from 2014

This can be anything

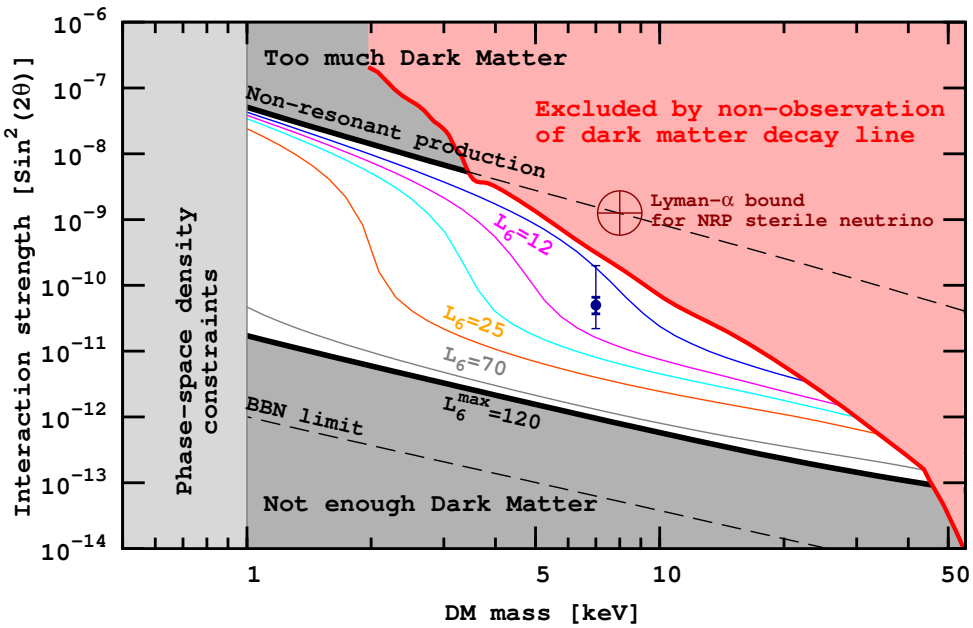
The 3.5 keV X-ray line from decaying **gravitino** dark matter. **Axino** dark matter in light of an anomalous X-ray line. The Quest for an Intermediate-Scale Accidental **Axion** and Further **ALPs**. keV Photon Emission from Light **Nonthermal Dark Matter**. X-ray lines from R-parity violating decays of keV **sparticles**. Neutrino masses, leptogenesis, and **sterile neutrino** dark matter. A Dark Matter Progenitor: **Light Vector Boson Decay** into (Sterile) Neutrinos. A 3.55 keV Photon Line and its Morphology from a 3.55 keV ALP Line. 7 keV Dark Matter as X-ray Line Signal in Radiative Neutrino Model. X-ray line signal from decaying **axino** warm dark matter. The 3.5 keV X-ray line signal from **decaying moduli** with low cutoff scale. X-ray line signal from 7 keV **axino** dark matter decay. Can a **millicharged dark matter** particle emit an observable gamma-ray line?. Effective field theory and keV lines from dark matter. Resonantly-Produced 7 keV **Sterile Neutrino Dark Matter** Models and the Properties of Milky Way Satellites. Cluster X-ray line at $3.5\ \mathrm{keV}$ from axion-like dark matter. Axion Hilltop Inflation in Supergravity. A 3.55 keV hint for decaying axion-like particle dark matter. The 7 keV axion dark matter and the X-ray line signal. An X-Ray Line from **eXciting Dark Matter**. 7 keV sterile neutrino dark matter from split flavor mechanism.

Oleg Ruchayskiy: *Quest for new physics driven by experiment and simplicity*

Beyond the Standard Model

Perspectives from 2014

Sterile neutrino and 3.5 keV line



X-rays: Boyarsky, **O.R** et al.

Production: Laine & Shaposhnikov (2008)

Lyman-α: Boyarsky, Lesgourgues, **O.R.** et al.

Sterile neutrino DM with such parameters is not completely cold and would leave its imprints in the formations of structures

Oleg Ruchayskiy: *Quest for new physics driven by experiment and simplicity*

Beyond the Standard Model

Perspectives from 2014

A dedicated experiment

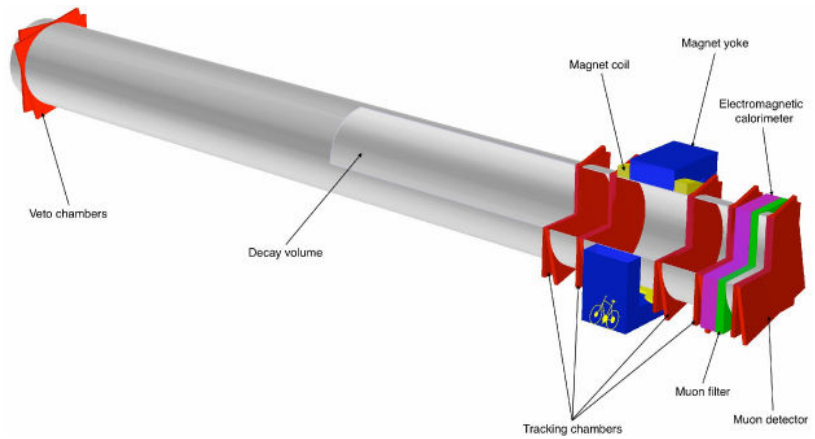
W. Bonivento, A. Boyarsky, H. Dijkstra, U. Egede, M. Ferro-Luzzi, B. Goddard, A. Golutvin, D. Gorbunov, R. Jacobsson, J. Panman, M. Patel, O. Ruchayskiy, T. Ruf, N. Serra, M. Shaposhnikov, D. Treille

[arXiv:1310.17

Proposal to Search for Heavy Neutral Leptons at the SPS

Expression of Interest. Endorsed by the CERN SPS council

Talk by N.Serra on Friday

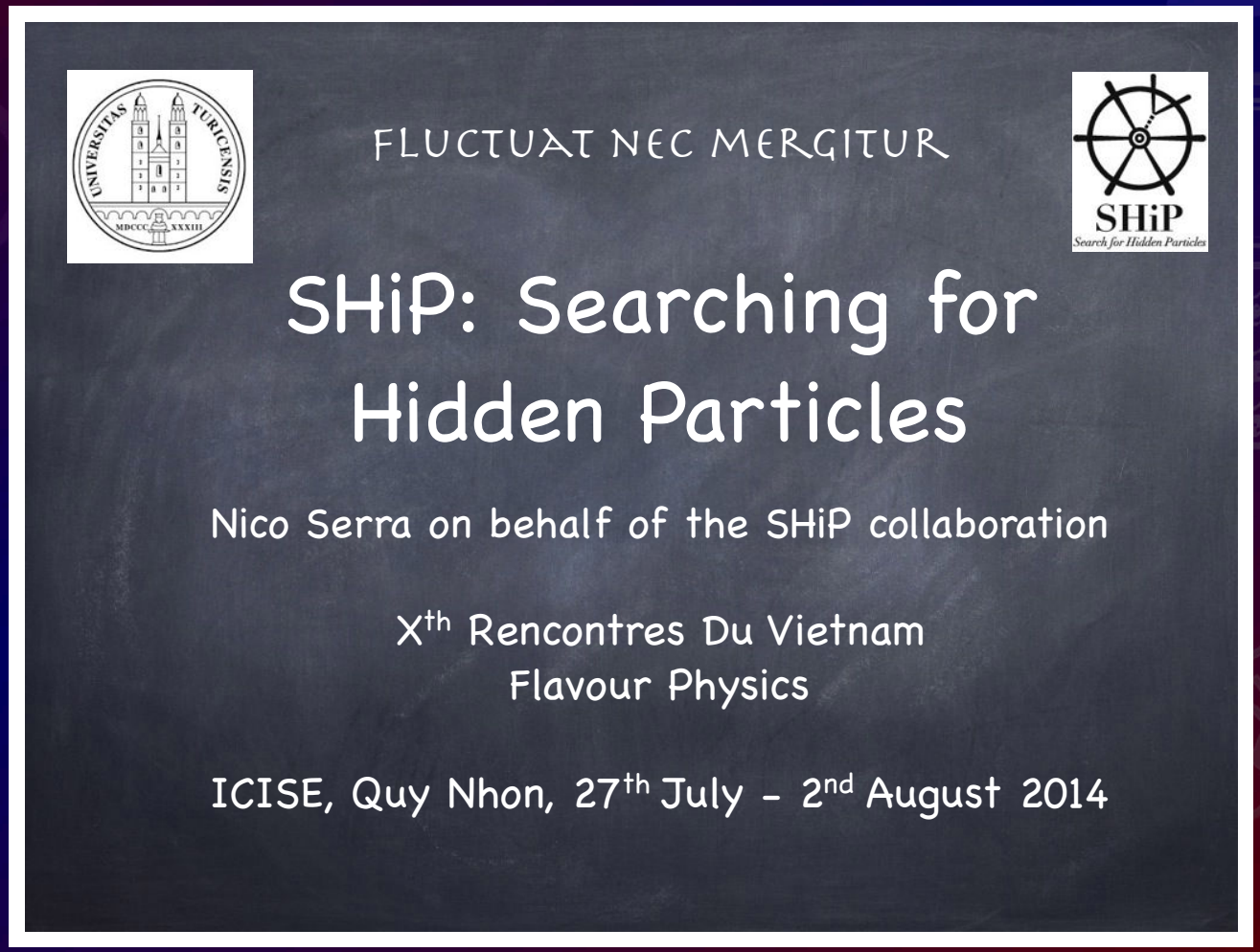


Oleg Ruchayskiy QUEST FOR NEW PHYSICS DRIVEN BY MINIMALITY... 33

Oleg Ruchayskiy: *Quest for new physics driven by experiment and simplicity*

Beyond the Standard Model

Perspectives from 2014

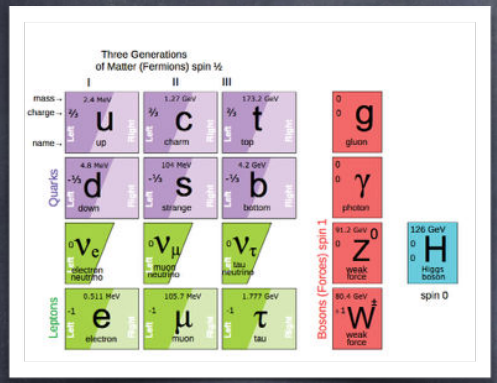


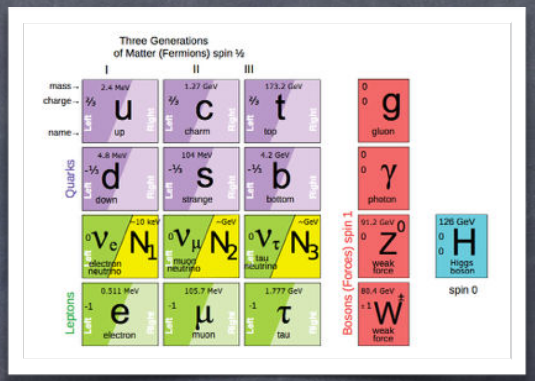
Nico Serra: *SHiP: Searching for Hidden Particles*

Beyond the Standard Model

Perspectives from 2014

The nuMSM





- N_1 with a mass in the KeV region plays the role of Dark Matter
- $N_{2,3}$ have mass in the GeV region, are quasi degenerate, give mass to active neutrinos and produce the baryon-antibaryon asymmetry in the Universe

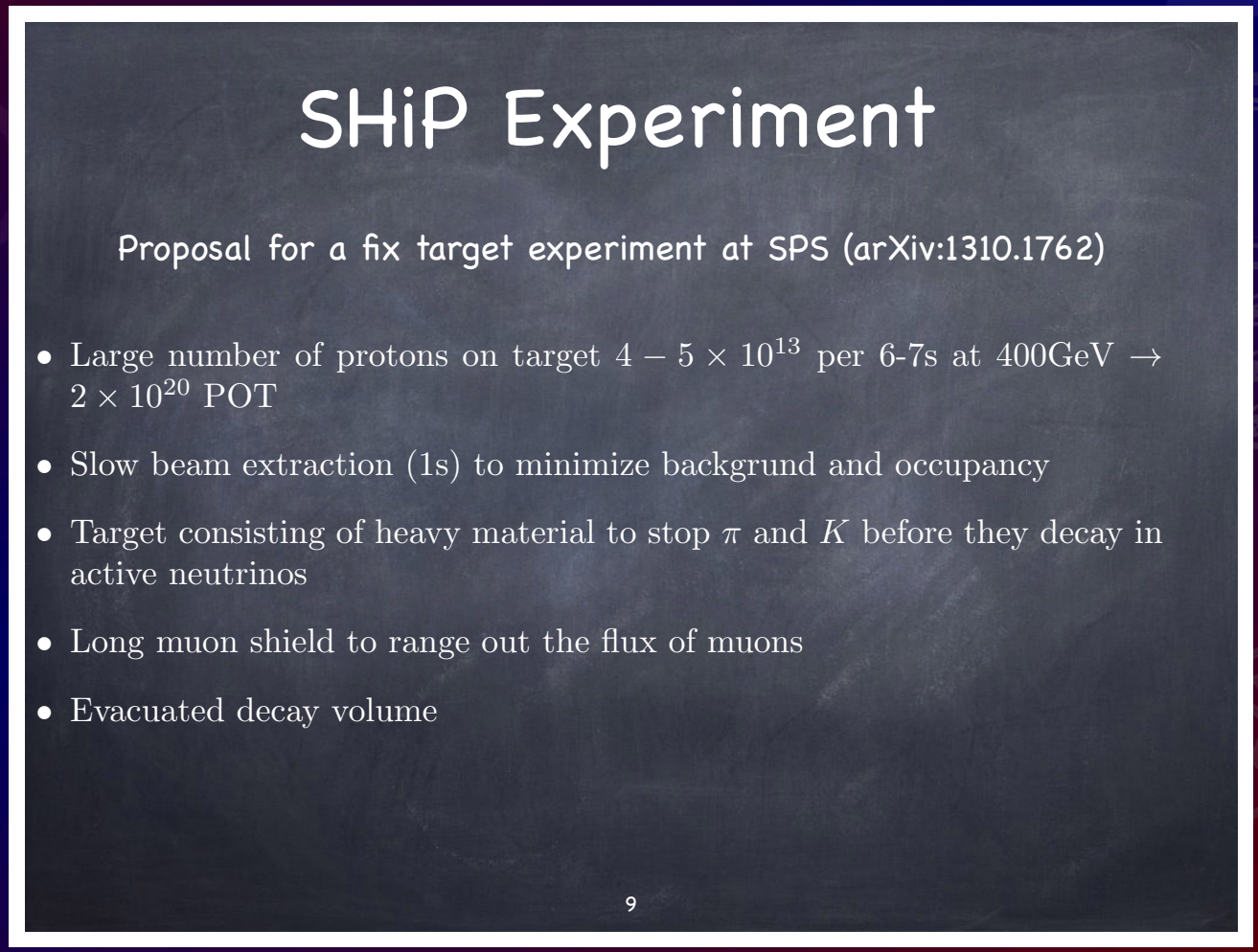
See Oleg's presentation on Wednesday
See Dima's presentation later

6

Nico Serra: *SHiP: Searching for Hidden Particles*

Beyond the Standard Model

Perspectives from 2014



Nico Serra: *SHiP: Searching for Hidden Particles*

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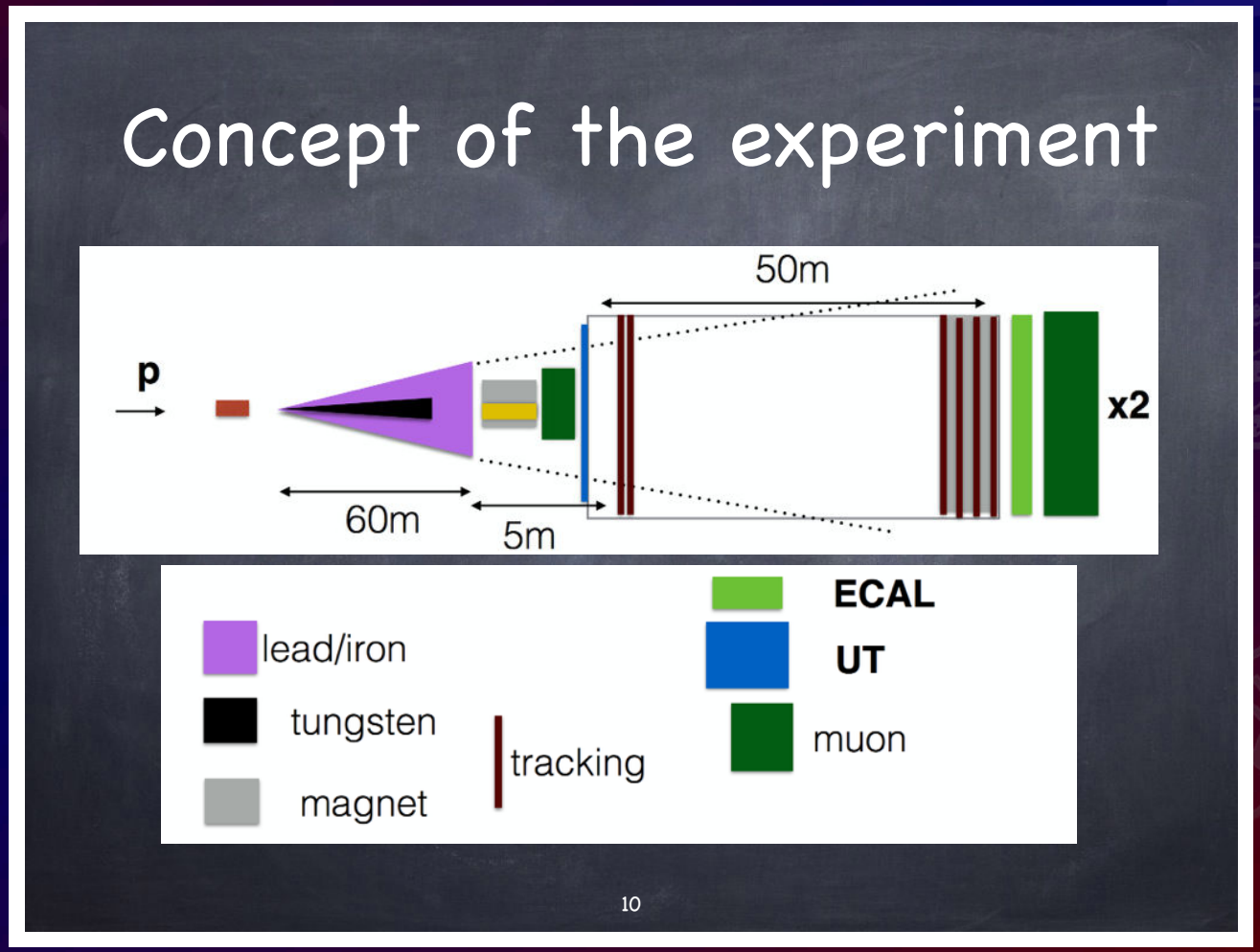
Perspectives from 2014



Nico Serra: *SHiP: Searching for Hidden Particles*

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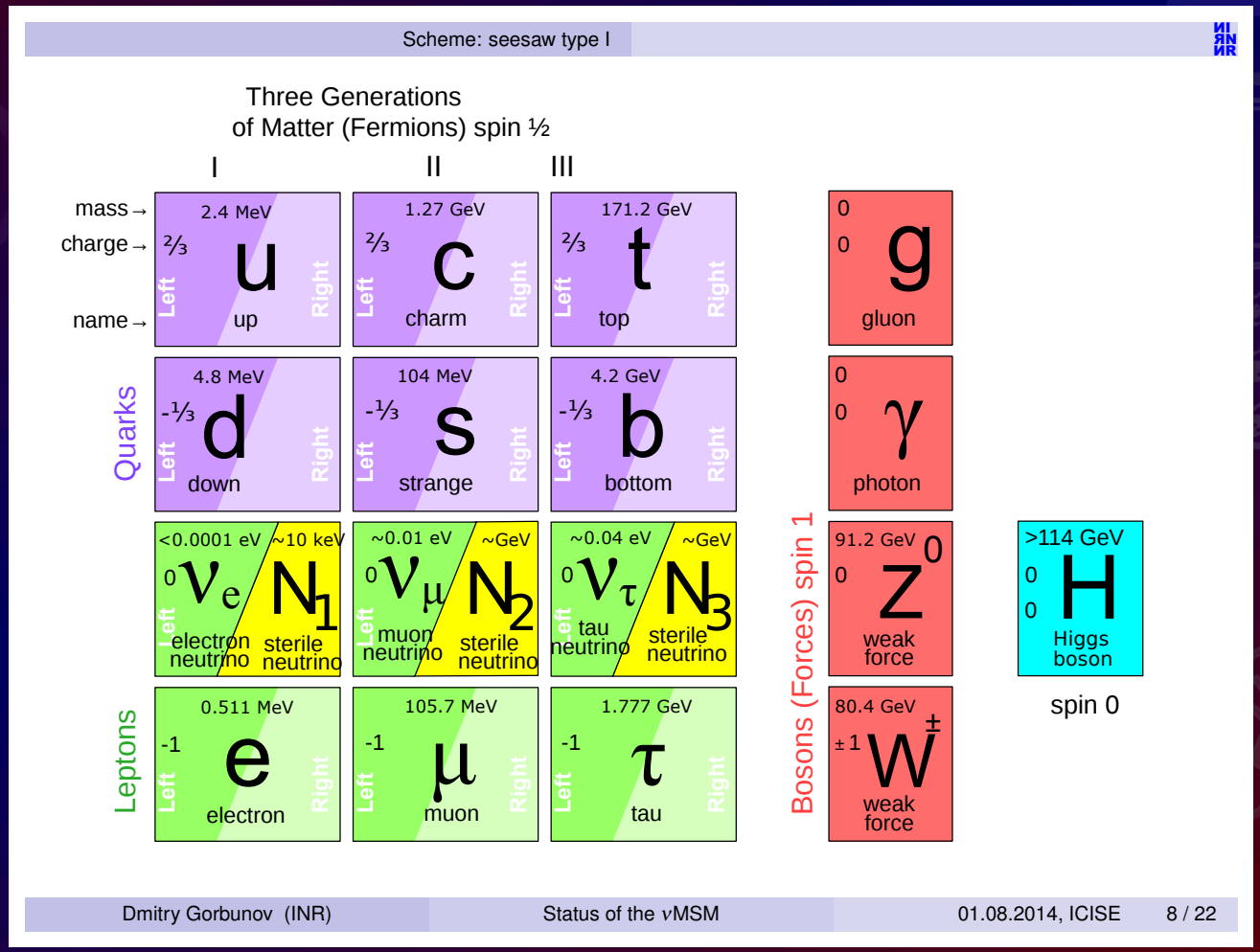
Perspectives from 2014



Dmitry Gorbunov: *Status of the νMSM*

SHiP Experiment Progress

Perspectives from 2017

Brief history and current status of SHiP

- ✓ *Letter Of Intent - October 2013*
- ✓ *Technical Proposal & Physics Paper - April 2015*
- ✓ *Reviewed by the SPSC and CERN RB by March 2016, and recommended to prepare a Comprehensive Design Study (CDS) by 2018*
  - → *Input to the European strategy consultation to take a decision about approval of SHiP in 2019/2020*

***CDS will improve SHiP TP version** respecting cost constraints*

LDMA 2017 13

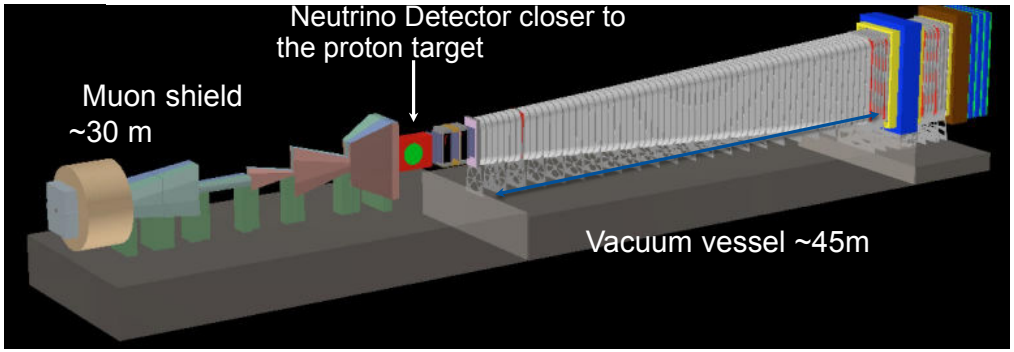
Andrey Golutvin: *Electron and proton beams for Dark Sector Searches at the CERN North Area*

SHiP Experiment Progress

Perspectives from 2017

Main goals of the SHiP optimization for the CDS

- ✓ *Further optimization of the target*
- ✓ *Configuration of the muon shield, including magnetization of the hadron stopper (**MC to be validated with data**)*
- ✓ *Shape, dimension and evacuation of the decay volume*



- ✓ *Optimization of the emulsion detector to search for LDM*
- ✓ *Optimization of physics performance for various sub-detectors*
- ✓ *Revisit detector technologies, including new sub-detectors, to further consolidate background rejection and extend PID*

Updated background estimates and signal sensitivities, and cost

- ✓ *Contribution from the secondary interactions in the target improves signal yield by ~50% (**to be validated with data**)*

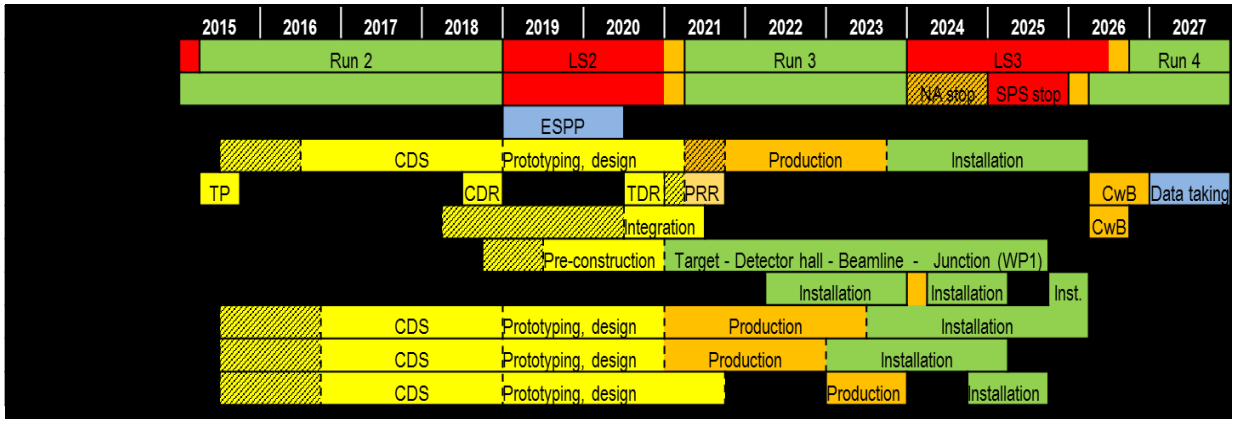
14

Andrey Golutvin: *Electron and proton beams for Dark Sector Searches at the CERN North Area*

SHiP Experiment Progress

Perspectives from 2017

Global SHiP schedule



- ✓ ***Planning very well aligned with***
  - *Update of European strategy 2019/2020*
  - *Accelerator schedule (to be followed closely)*
  - *Production Readiness Reviews (PRR) 2020Q1 →*
  - *Construction / production 2020 →*
  - *Data taking (pilot run) 2026 (start of LHC Run 4)*
- ✓ ***Main current priority: Comprehensive Design Study by 2018***

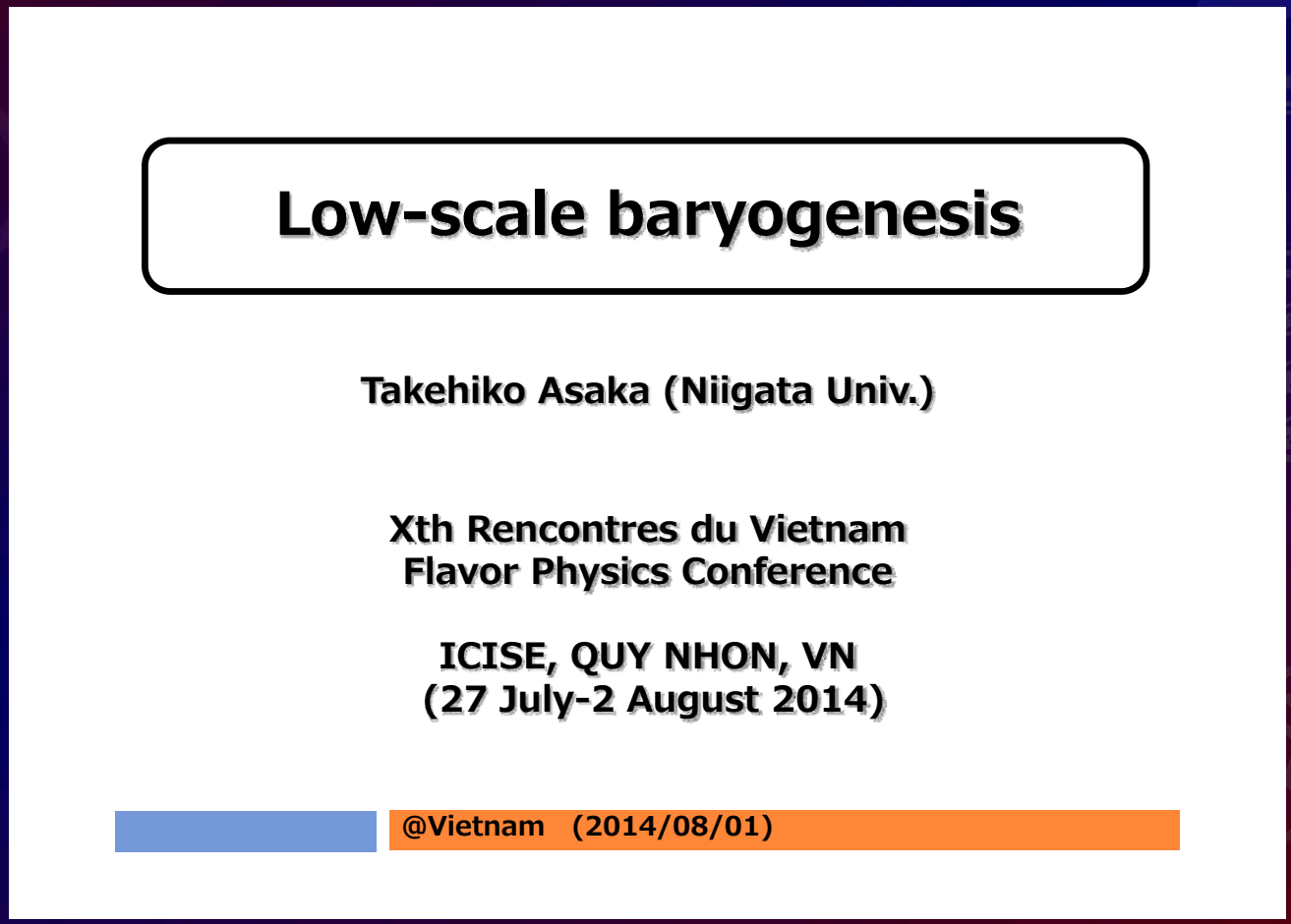
LDMA 2017 15

Andrey Golutvin: *Electron and proton beams for Dark Sector Searches at the CERN North Area*

Beyond the Standard Model

Perspectives from 2014

Phenomenological studies showing at the T2K Near Detector that could have sensitivity to Heavy Neutral Leptons

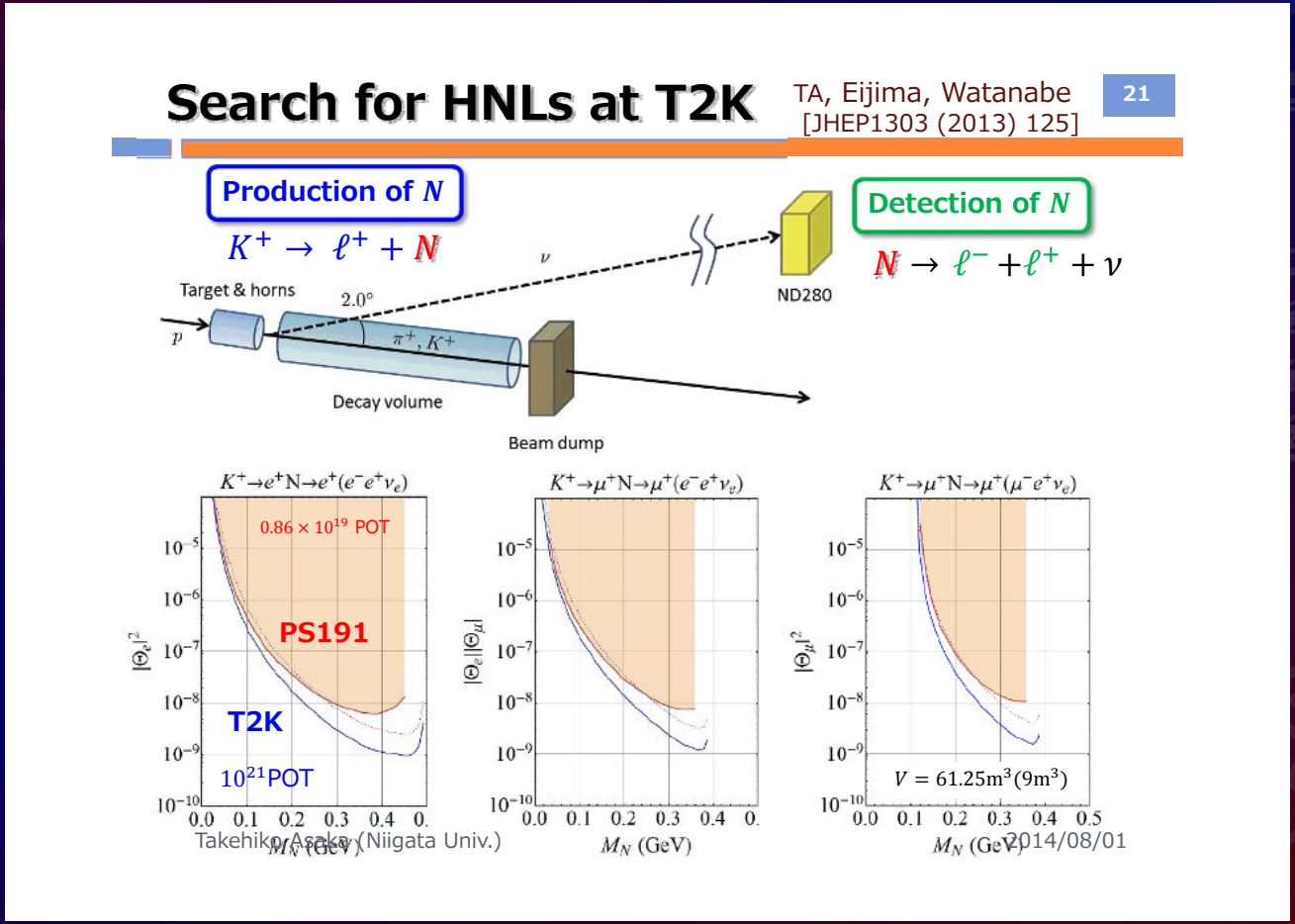


Takehiko Asaka: *Low-scale Baryogenesis*

Beyond the Standard Model

Perspectives from 2014

Phenomenological studies showing at the T2K Near Detector that could have sensitivity to Heavy Neutral Leptons



Takehiko Asaka: *Low-scale Baryogenesis*

Beyond the Standard Model

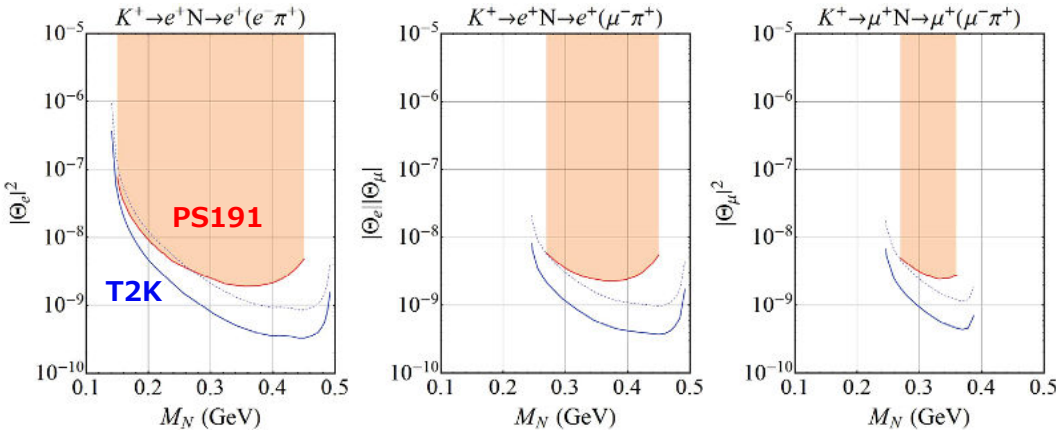
Perspectives from 2014

Phenomenological studies showing at the T2K Near Detector that could have sensitivity to Heavy Neutral Leptons

Sensitivity: PS191 vs T2K

22

TA, Eijima, Watanabe '13



T2K at 10^{21} POT has a better sensitivity than PS191 (0.86×10^{19} POT) !

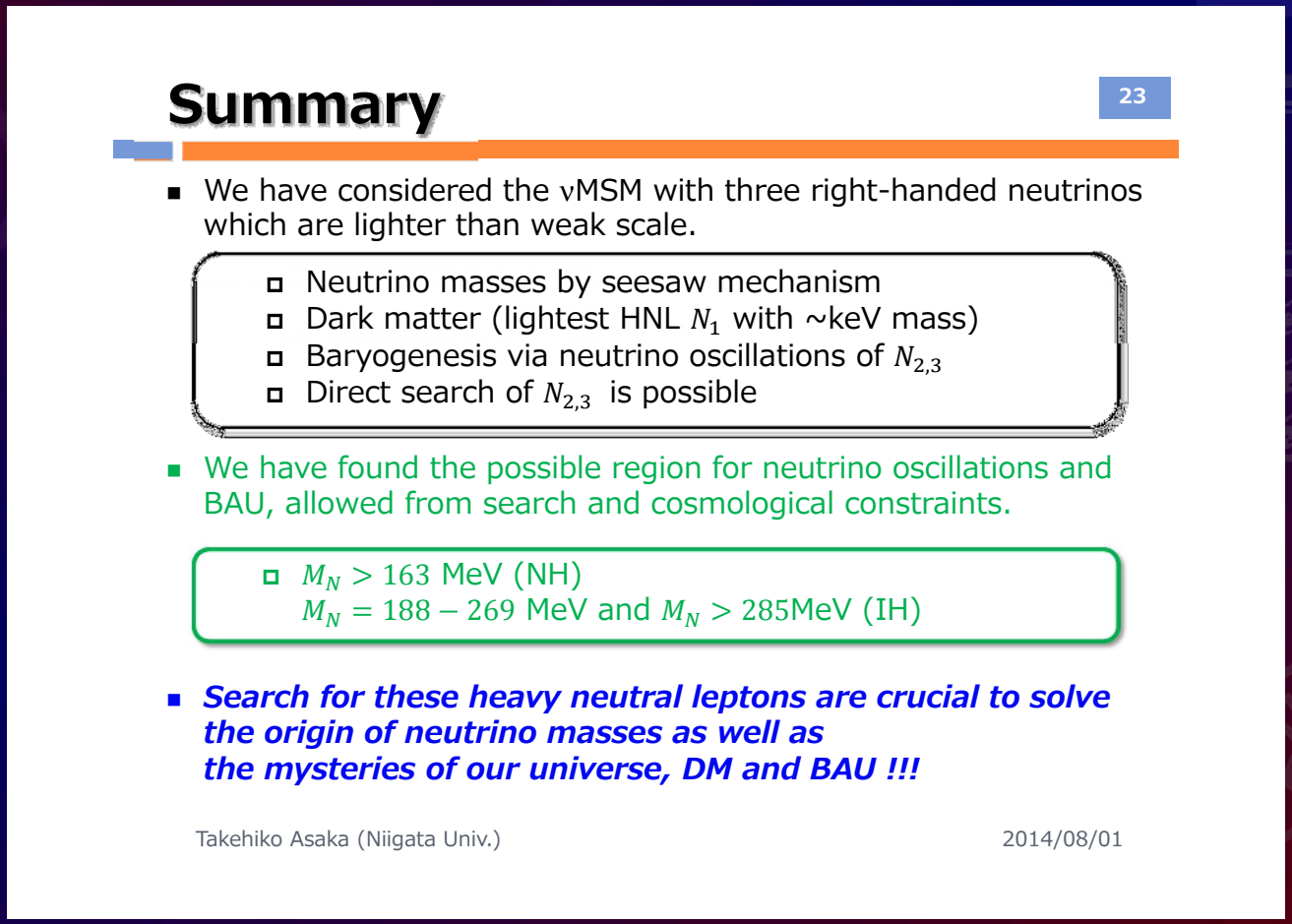
Takehiko Asaka (Niigata Univ.) 02, May/2014

Takehiko Asaka: *Low-scale Baryogenesis*

Beyond the Standard Model

Perspectives from 2014

Phenomenological studies showing at the T2K Near Detector that could have sensitivity to Heavy Neutral Leptons



Summary

23

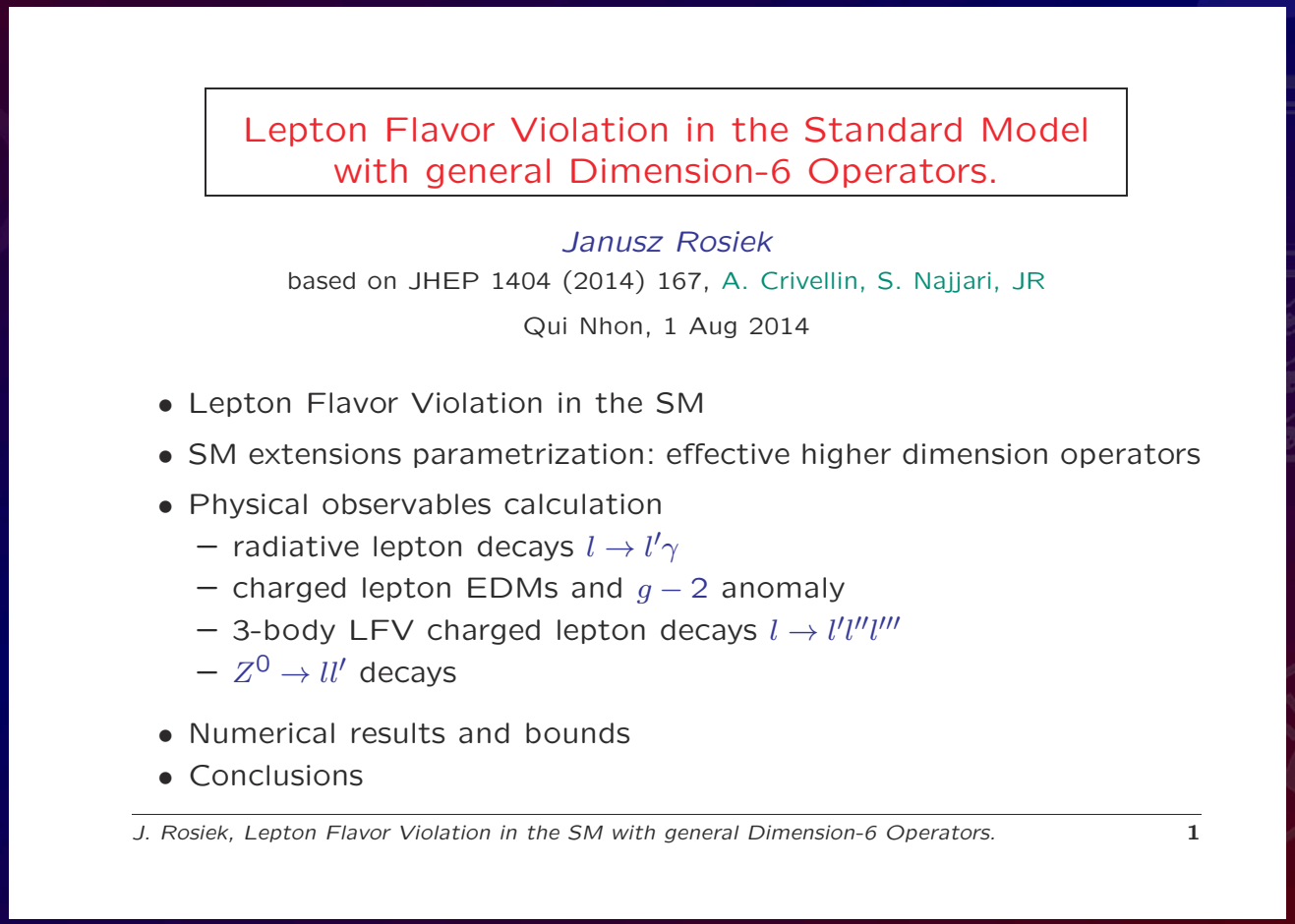
- We have considered the νMSM with three right-handed neutrinos which are lighter than weak scale.
  - Neutrino masses by seesaw mechanism
  - Dark matter (lightest HNL N_1 with ~keV mass)
  - Baryogenesis via neutrino oscillations of $N_{2,3}$
  - Direct search of $N_{2,3}$ is possible
- We have found the possible region for neutrino oscillations and BAU, allowed from search and cosmological constraints.
  - $M_N > 163$ MeV (NH)
    $M_N = 188 - 269$ MeV and $M_N > 285$MeV (IH)
- ***Search for these heavy neutral leptons are crucial to solve the origin of neutrino masses as well as the mysteries of our universe, DM and BAU !!!***

Takehiko Asaka (Niigata Univ.) 2014/08/01

Takehiko Asaka: *Low-scale Baryogenesis*

Beyond the Standard Model

Perspectives from 2014



Lepton Flavor Violation in the Standard Model with general Dimension-6 Operators.

Janusz Rosiek

based on JHEP 1404 (2014) 167, A. Crivellin, S. Najjari, JR

Qui Nhon, 1 Aug 2014

- Lepton Flavor Violation in the SM
- SM extensions parametrization: effective higher dimension operators
- Physical observables calculation
  - radiative lepton decays $l \to l'\gamma$
  - charged lepton EDMs and $g-2$ anomaly
  - 3-body LFV charged lepton decays $l \to l'l''l'''$
  - $Z^0 \to ll'$ decays
- Numerical results and bounds
- Conclusions

J. Rosiek, Lepton Flavor Violation in the SM with general Dimension-6 Operators. 1

Janusz Rosiek: *Lepton Flavor Violation in the Standard Model with general Dimension-6 Operators*

Beyond the Standard Model

Perspectives from 2014

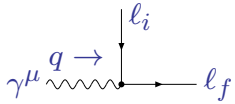
3. Effective lepton-photon coupling

Related observables: radiative lepton decays ($\mu \to e\gamma$), EDMs and AMMs of charged leptons.

The general form of the flavor violating photon-lepton vertex::

$$V_{\ell\ell\gamma}^{fi\,\mu} = \frac{i}{\Lambda^2}\Big[\gamma^\mu(F_{VL}^{fi}P_L + F_{VR}^{fi}P_R) + (F_{SL}^{fi}P_L + F_{SR}^{fi}P_R)q^\mu + (F_{TL}^{fi}i\sigma^{\mu\nu}P_L + F_{TR}^{fi}i\sigma^{\mu\nu}P_R)q_\nu\Big]$$

Most important: " tensor" F_{TL}, F_{TR}. Tree level LFV contribution exist:



$$i\left(e\gamma^\mu\delta^{fi} + i\sigma^{\mu\nu}\left[C_{\gamma L}^{fi}P_L + C_{\gamma R}^{fi}P_R\right]q_\nu\right)$$

$$C_{fi}^{\gamma R} = C_{fi}^{\gamma L\star} = \frac{v\sqrt{2}}{\Lambda^2}\left(c_W C_{eB}^{fi} - s_W C_{eW}^{fi}\right)$$

J. Rosiek, Lepton Flavor Violation in the SM with general Dimension-6 Operators. 7

Janusz Rosiek: *Lepton Flavor Violation in the Standard Model with general Dimension-6 Operators*

Beyond the Standard Model

Perspectives from 2014

4. Tree-level decays: $l \to l'l''l'''$ and $Z^0 \to \ell_f^- \ell_i^+$

3-body charged lepton decays - various final state compositions:

- 3 leptons of the same flavor: $\mu^\pm \to e^\pm e^+ e^-$, $\tau^\pm \to e^\pm e^+ e^-$ and $\tau^\pm \to \mu^\pm \mu^+ \mu^-$.
- 3 distinguishable leptons: $\tau^\pm \to e^\pm \mu^+ \mu^-$ and $\tau^\pm \to \mu^\pm e^+ e^-$.
- 2 lepton of the same flavor and charge and 1 with different flavor and opposite charge: $\tau^\pm \to e^\mp \mu^\pm \mu^\pm$ and $\tau^\pm \to \mu^\mp e^\pm e^\pm$ (exotic, $\Delta L = 2$!).

Tricky phase space integral, photon propagator $1/q^2 \sim 1/m_l^2$ diverges in corners of phase space $\to$ photon contribution enhanced by logarithmic factor $\log(m_l^2/m_{l'}^2)$.

$Z^0 \to \ell_f^- \ell_i^+$ decays - interesting observation: γll and Zll decays depend on "orthogonal" combinations $\left(c_W C_{eB}^{fi} - s_W C_{eW}^{fi}\right)$, $\left(s_W C_{eB}^{fi} + c_W C_{eW}^{fi}\right)$.

J. Rosiek, Lepton Flavor Violation in the SM with general Dimension-6 Operators. 13

Janusz Rosiek: *Lepton Flavor Violation in the Standard Model with general Dimension-6 Operators*

Beyond the Standard Model

Perspectives from 2014

Lepton number conserving observables.

Anomalous magnetic moments: Example: muon $g-2$ anomaly.

$$\Delta a_\mu \;=\; 2.43\times 10^{-4}\ \mathrm{Re}\left[2\times 10^{-5}\, C_{\ell e}^{3223} + C_\gamma^{22}\right]\left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2 ,$$

To be compared with measurement: $\Delta a_\mu^{exp} \approx (2.7 \pm 0.8)\times 10^{-9}$

Electric Dipole Moments (normalized to current exp. bounds):

$$d_e/d_e^{exp} \;=\; -7.9\times 10^{10}\ \mathrm{Im}\left[2\times 10^{-5}\, C_{\ell e}^{3113} + C_\gamma^{11}\right]\left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2$$

$$d_\mu/d_\mu^{exp} \;=\; -36.1\ \mathrm{Im}\left[2\times 10^{-5}\, C_{\ell e}^{3223} + C_\gamma^{22}\right]\left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2$$

$$d_\tau/d_\tau^{exp} \;=\; -0.69\ \mathrm{Im}\left[C_\gamma^{33}\right]\left(\frac{1\ \mathrm{TeV}}{\Lambda}\right)^2$$

J. Rosiek, Lepton Flavor Violation in the SM with general Dimension-6 Operators. **20**

Janusz Rosiek: *Lepton Flavor Violation in the Standard Model with general Dimension-6 Operators*

Beyond the Standard Model

Perspectives from 2014

6. Conclusions

- Several experimentally well constrained LFV processes calculated within the SM extended with all LFV dim-6 operators.
- Predictions in terms of Wilson coefficients - all relevant contributions included, results automatically gauge-invariant.
- Approximate numerical formulae based on current exp. bounds - specific NP models can be tested just calculating Wilson coefficients.
- "Typical" bounds on LFV Wilson coefficients discussed depending on New Physics scale Λ - usually very strong for $\Lambda = \mathcal{O}(1)$ TeV.
- Examples of correlations between various Wilson coefficients shown.

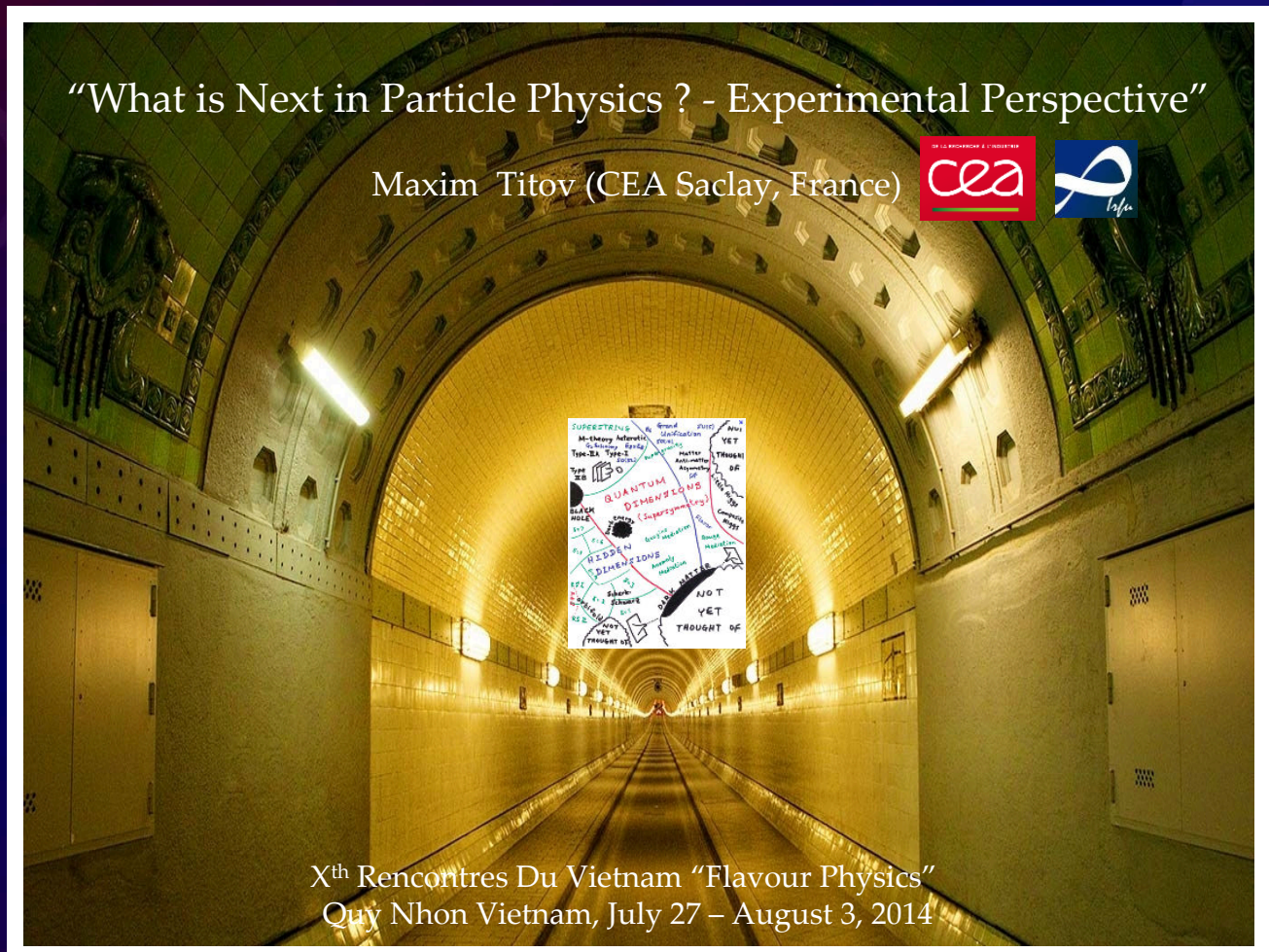
J. Rosiek, Lepton Flavor Violation in the SM with general Dimension-6 Operators. 21

Janusz Rosiek: *Lepton Flavor Violation in the Standard Model with general Dimension-6 Operators*

Experimental Status

Perspectives from 2014

Prospects for direct discoveries in future LHC data, improved flavour measurements where there are tensions



Maxim Titov: *What is Next in Particle Physics? Experimental Perspective*

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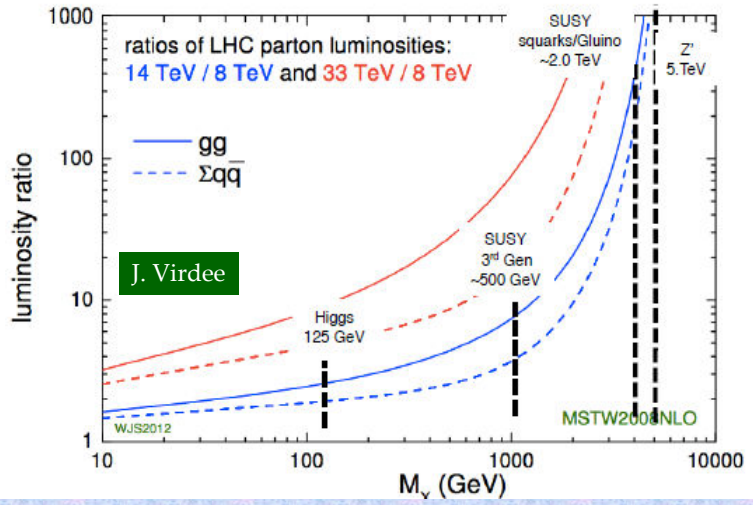
LHC Prospects: Higgs Measurements, SUSY and BSM Searches

- Higgs
  pp → H, H → WW, ZZ, γγ
  mainly gg: Gain factor ~ 2
- SUSY – 3rd Generation:
  Mass scale ~ 500 GeV
  qq and gg: Gain factor ~ 8
- SUSY – Squarks/Gluino:
  Mass scale ~ 2.0 TeV
  qq,gg,qg: Gain factor ~300
- Z′:
  Mass scale ~ 5 TeV
  qq: Gain factor ~1000

Use parton luminosities to illustrate gain factors: 8 → 14 TeV



- Energy is everything: bright prospects for the near future
- → e.g. only with a few fb^{-1} @ 14 TeV new territory will be probed in searches for strongly produced SUSY
- Limits not much increased by luminosity

- At the end of Run II (14 TeV, 100/fb):
  - M_X=1 TeV → statistics x 15
  - M_X=2 TeV → statistics x 50
  - M_X=3 TeV → statistics x 100
- "Natural" limit of LHC ~ few TeV sensitivity (depending on the object)

Maxim Titov: *What is Next in Particle Physics? Experimental Perspective*

Experimental Status

Perspectives from 2014

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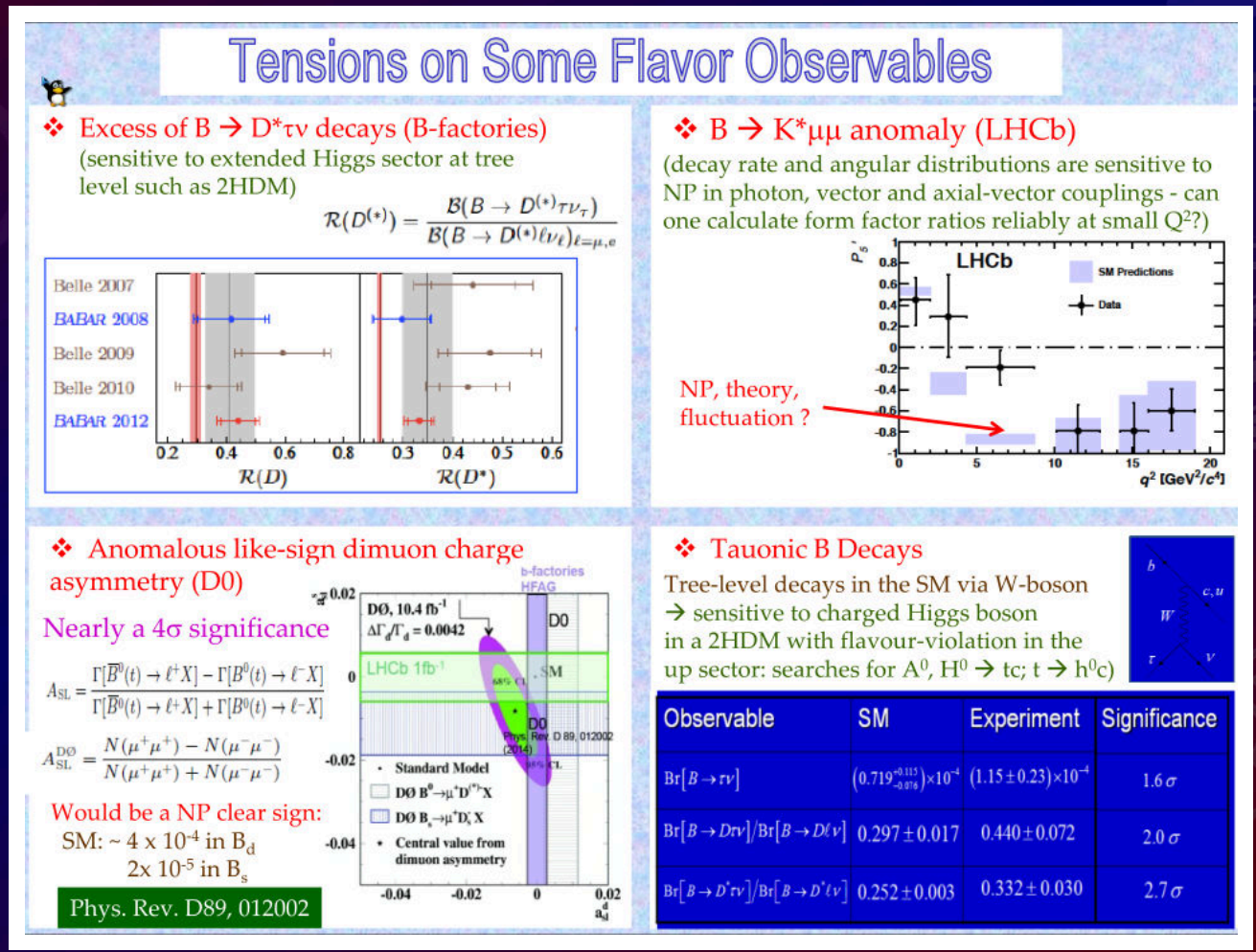


Observable	SM	Experiment	Significance
$\mathrm{Br}[B \to \tau\nu]$	$(0.719^{+0.115}_{-0.076}) \times 10^{-4}$	$(1.15 \pm 0.23) \times 10^{-4}$	$1.6\,\sigma$
$\mathrm{Br}[B \to D\tau\nu]/\mathrm{Br}[B \to D\ell\nu]$	0.297 ± 0.017	0.440 ± 0.072	$2.0\,\sigma$
$\mathrm{Br}[B \to D^*\tau\nu]/\mathrm{Br}[B \to D^*\ell\nu]$	0.252 ± 0.003	0.332 ± 0.030	$2.7\,\sigma$

Maxim Titov: *What is Next in Particle Physics? Experimental Perspective*

Perspectives from 2014

Tatsuya Nakada

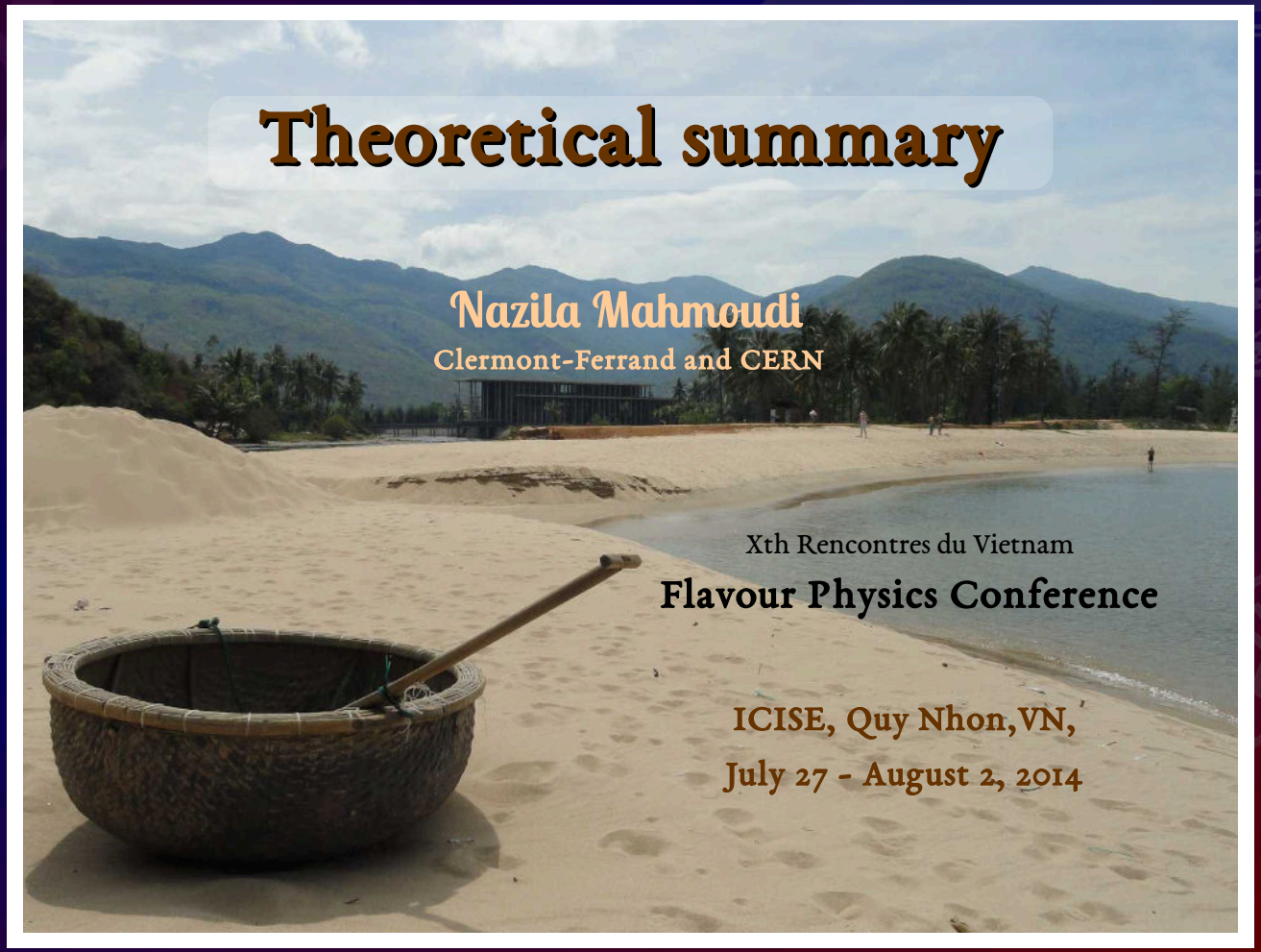
Perspectives from 2014

Tatsuya Nakada: *Experimental Summary*

Perspectives from 2014

Nazila Mahmoudi

Perspectives from 2014



Nazila Mahmoudi: *Theoretical Summary*

Perspectives from 2014

- Precision Heavy-Quark Physics at hadron colliders becoming competitive with e^+e^- colliders
- Results of direct searches at the LHC in Run 2 critical
- However, precision flavour measurements are essential either way
- Neutrino physics making very good headway; need to consider impact on, and balance with, the rest of the field—how would further major discoveries affect the plans for colliders?
- Answers to, e.g., *why* we have three families and what lies behind the structure of the mass matrices, are a long-term problem
- Need to look towards the future and explore options, both incremental and transformational—discussions of future facilities

Perspective from 14 August 2017

- This conference is less specialised than many, but narrower than others—a particular mix of interests
- Experts from all over the broad field of "Flavour Physics"
- Perhaps only one-fifth of the audience is expert in your area
- We will produce an informal summary document of the talks and discussions
  - real-time document that anyone can edit
  - please go to [URL]
  - help us take notes, or edit or correct your own comments etc.
  - recording the identity of people making comments is optional