Strangeness enhancement and light flavor highlights at ALICE

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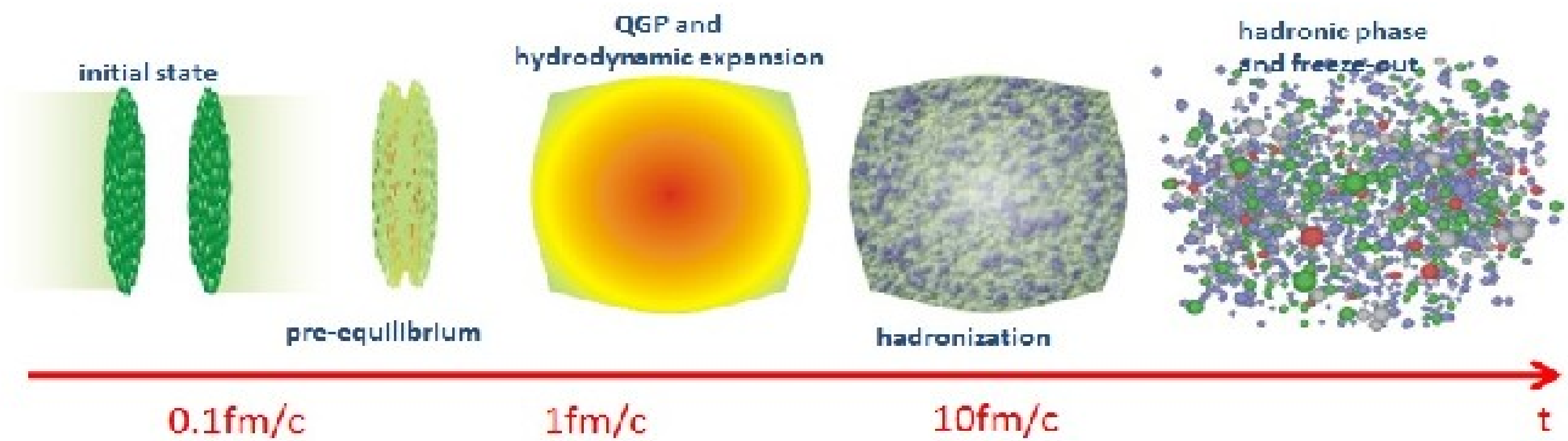
Outline

- Introduction
- ALICE detector
- Results
  --- Strangeness enhancement
  --- Collectivity
  --- Interactions in the hadronic phase
- Summary

Flavour Physics Conference, Vietnam August 13-19, 2017

Introduction: heavy-ion physics

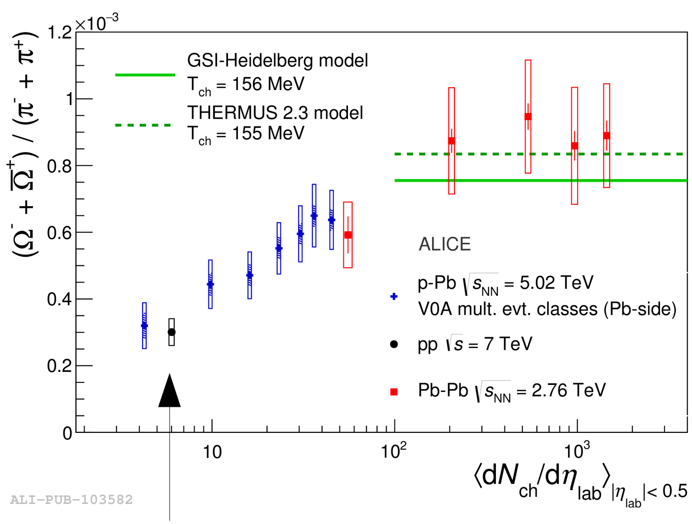


- In ultra-realtivistic heavy-ion (HI) collisions, a Quark Gluon Plasma (QGP) is formed
- After the collision, the QGP fireball expands, developing collective flow and cooling down
- Inelastic processes cease and chemical composition is frozen at T_{chem}
- Elastic interactions continue until the kinetic freeze-out (T_{kin})

Heavy-ion features in small systems:

Recently, several similarities between HI and high multiplicity p-Pb collisions were observed (eg. enhancement in the production of multi-strange baryons)

- **Is it also observed in pp collisions as a function of multiplicity?**
- **Is there any medium formed in pp collisions?**



Minimum bias

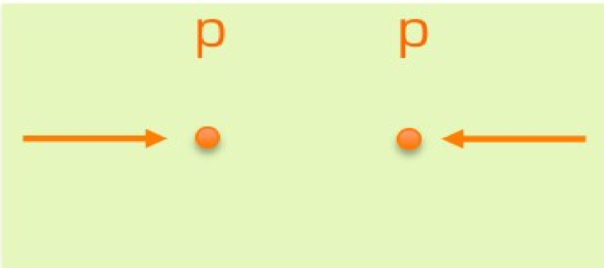
Soft probes in HI collisions:

- Strangeness enhancement
- Collectivity
- Interactions in hadronic phase

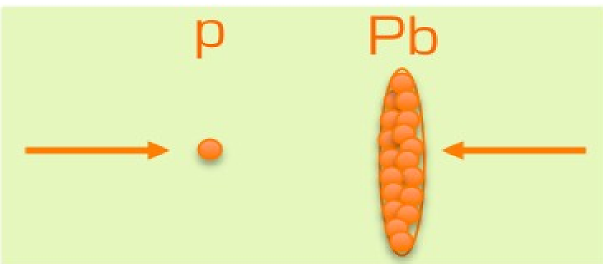
Phys. Lett. B 758 (2016) 389-401

A Large Ion Collider Experiment (ALICE)

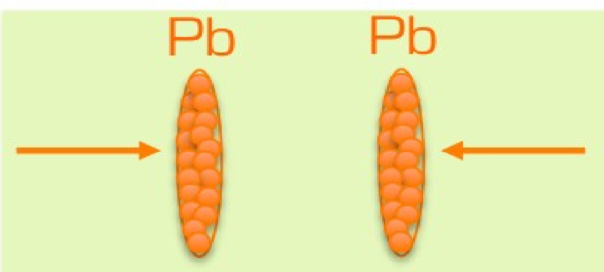
ALICE is designed to study the physics of strongly interacting matter under extremely high temperature and energy densities and to investigate the properties of the quark-gluon plasma



pp (benchmark for heavy-ion physics)
- ✯ Particle production mechanisms at low (soft QCD) and high (pQCD) transverse momentum
- ✔ collected data at $\sqrt{s}$ = 0.9, 2.76, 5.02, 7, 8, 13 TeV



p-Pb (reference as intermediate between pp and Pb-Pb)
- ✯ Initial state effects (shadowing/gluon saturation)
- ✔ collected data at $\sqrt{s_{NN}}$ = 5.02, 8.16 TeV



Pb-Pb
- ✯ QGP study
- ✔ collected data at $\sqrt{s_{\mathrm{NN}}}$ = 2.76, 5.02 TeV

ALICE can probe QCD in a wide range of particle densities

pp, $\sqrt{s}$ = 7 TeV
$\langle dN_{ch}/d\eta \rangle = 21.3 \pm 0.6$ (0-0.95%)
$= 3.9 \pm 0.14$ (48-68%)

p-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
$\langle dN_{ch}/d\eta \rangle = 45 \pm 1$ (0-5%)
$= 9.8 \pm 0.2$ (60-80%)

Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
$\langle dN_{ch}/d\eta \rangle = 1601 \pm 60$ (0-5%)
$= 35 \pm 2$ (70-80%)

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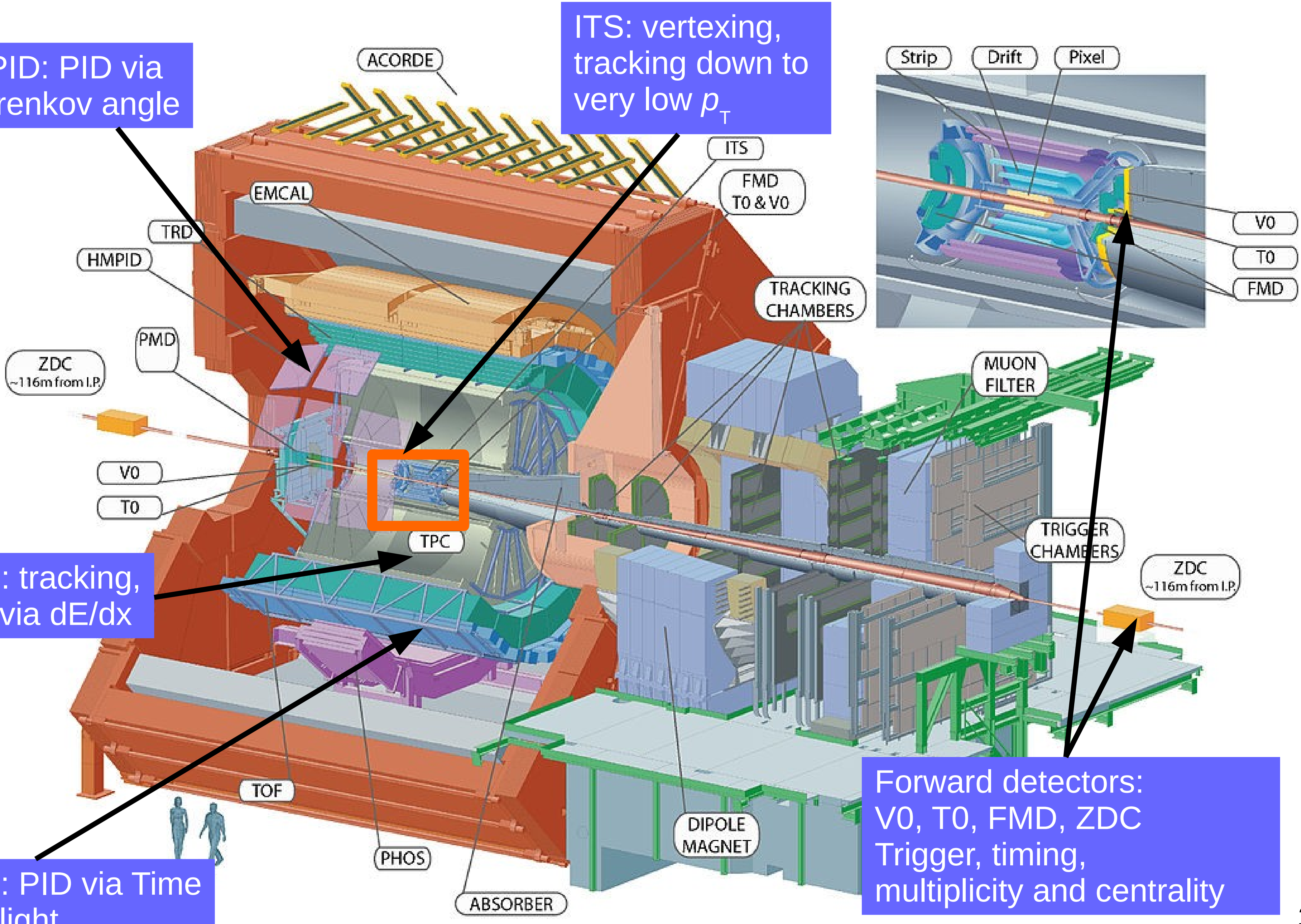


HMPID: PID via Cherenkov angle

ITS: vertexing, tracking down to very low p_T

TPC: tracking, PID via dE/dx

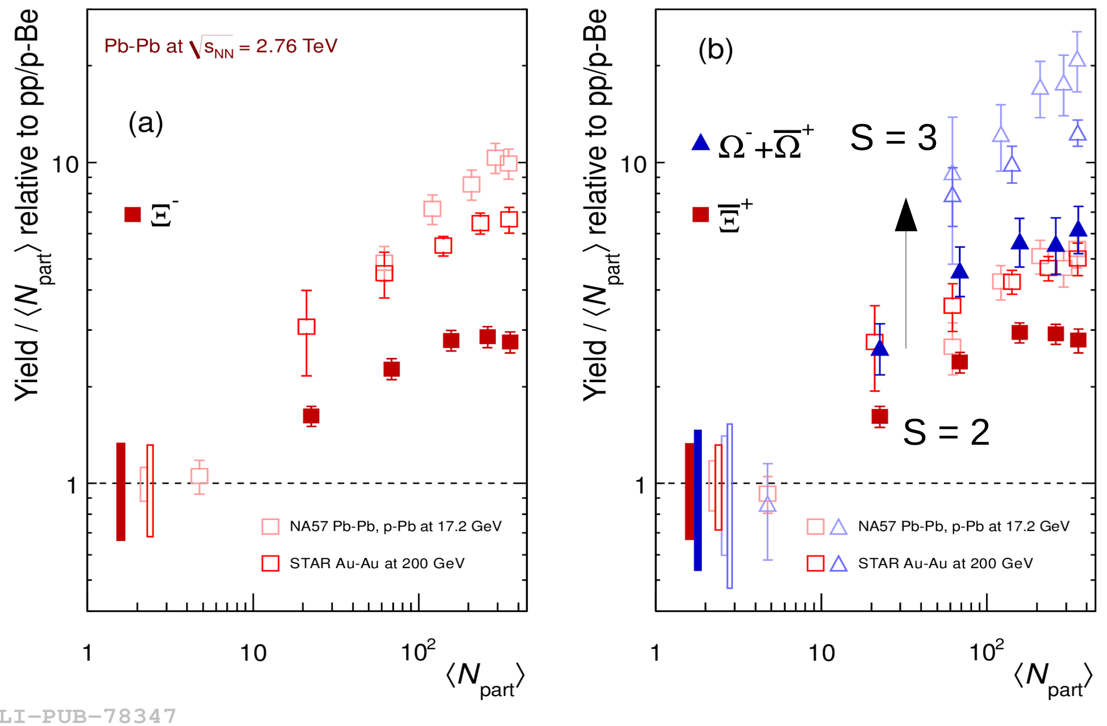
TOF: PID via Time Of Flight

Forward detectors:
V0, T0, FMD, ZDC
Trigger, timing, multiplicity and centrality

Introduction : Strangeness enhancement

- Strangeness enhancement was among the first suggested probes of QGP in heavy-ion collisions
  Phys. Rev. Lett. 48, 1066 (1982)

$$\frac{\text{Yield}_{\text{PbPb}} / < N_{part} >}{\text{Yield}_{\text{pp}} / 2}$$



- Measured at SPS, RHIC and LHC and found to be:

✔ Increasing with strangeness content of the particle

J. Phys. G 32, 427 (2006)
J. Phys. G 37, 045105 (2010)
Phys. Rev. C 77, 044908 (2008)
Phys. Let. B 728 (2014) 216-227

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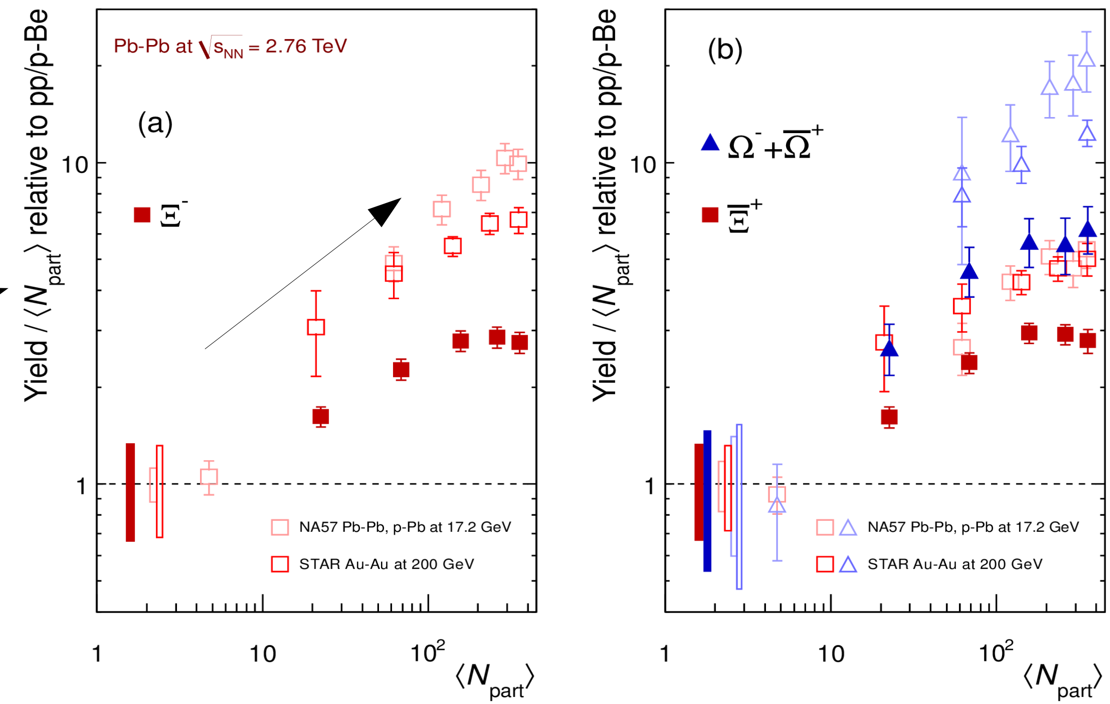

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✔ Increasing with strangeness content of the Particle

✔ Increasing with collision centrality and saturate towards central collisions as for a hadron resonance gas in thermal equilibrium

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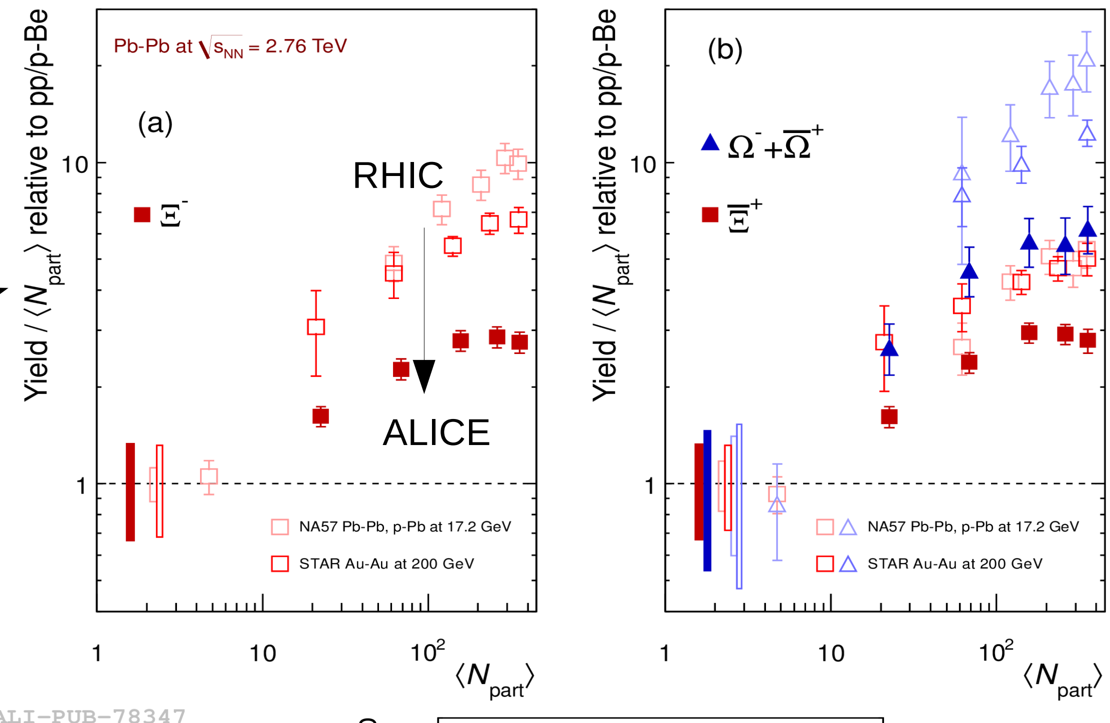
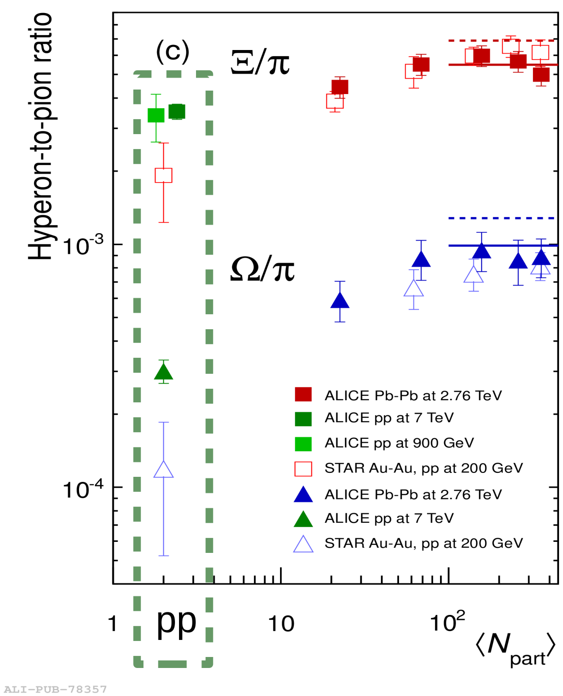


- Measured at SPS, RHIC and LHC and found to be:

✔ Increasing with strangeness content of the Particle
✔ Increasing with collision centrality and saturate towards central collisions as for a hadron resonance gas in thermal equilibrium
✔ Decreasing with collision energy
→ With increasing √s strangeness production in pp increases, whereas in Pb-Pb the production seems to be saturated



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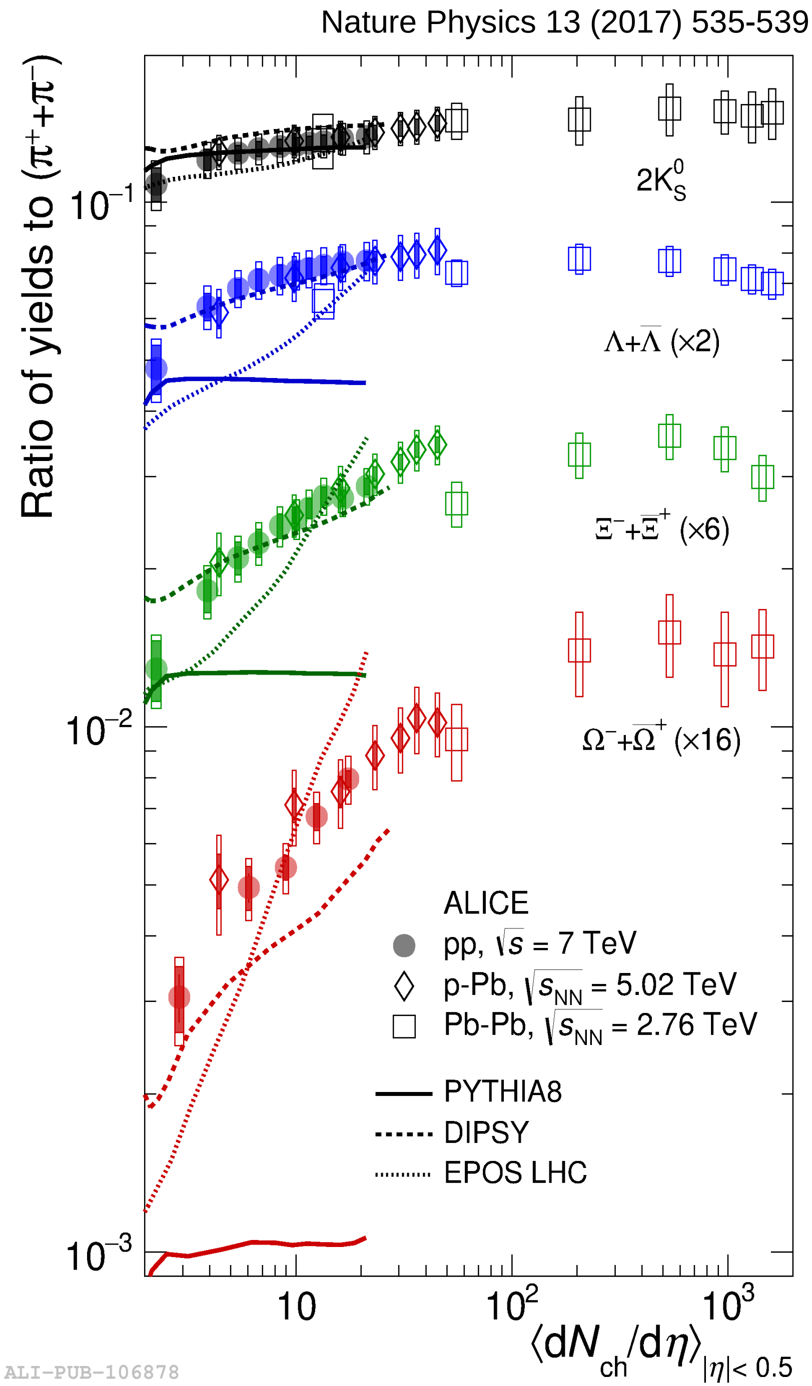
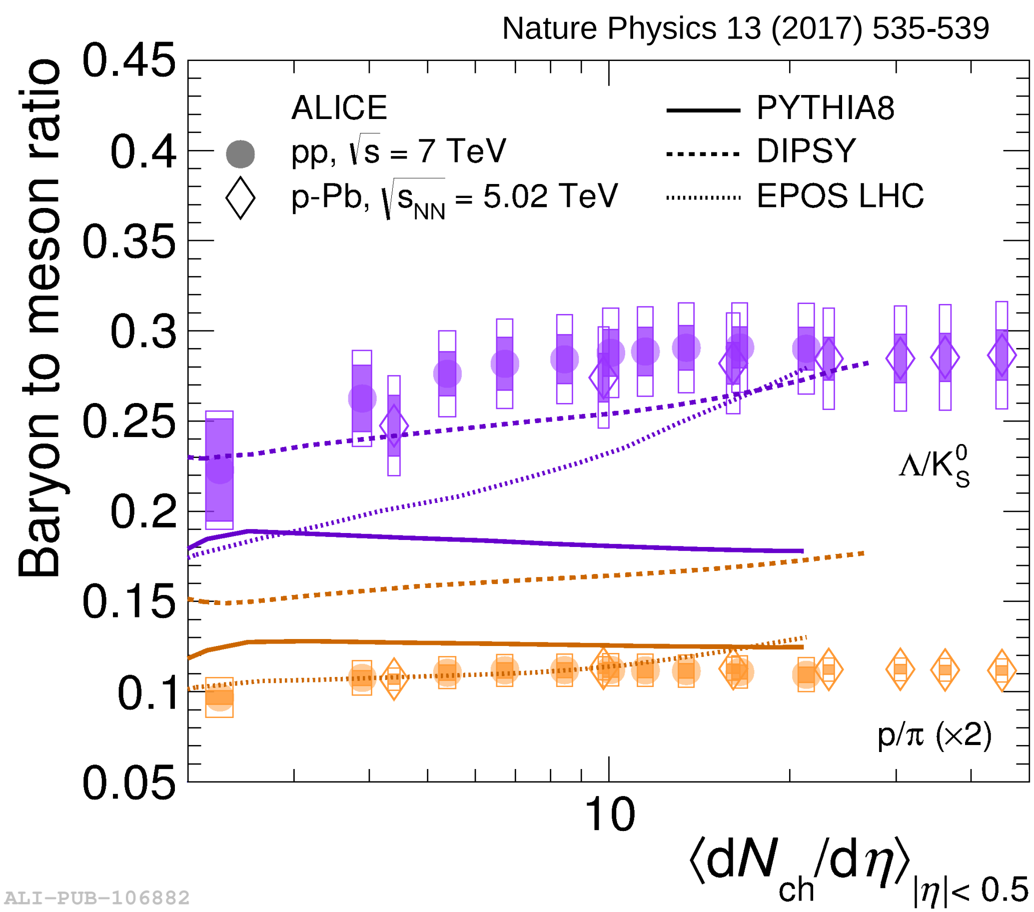
Interesting to study the strangeness production in pp collisions as a function of ⟨dN_{ch}/dη⟩

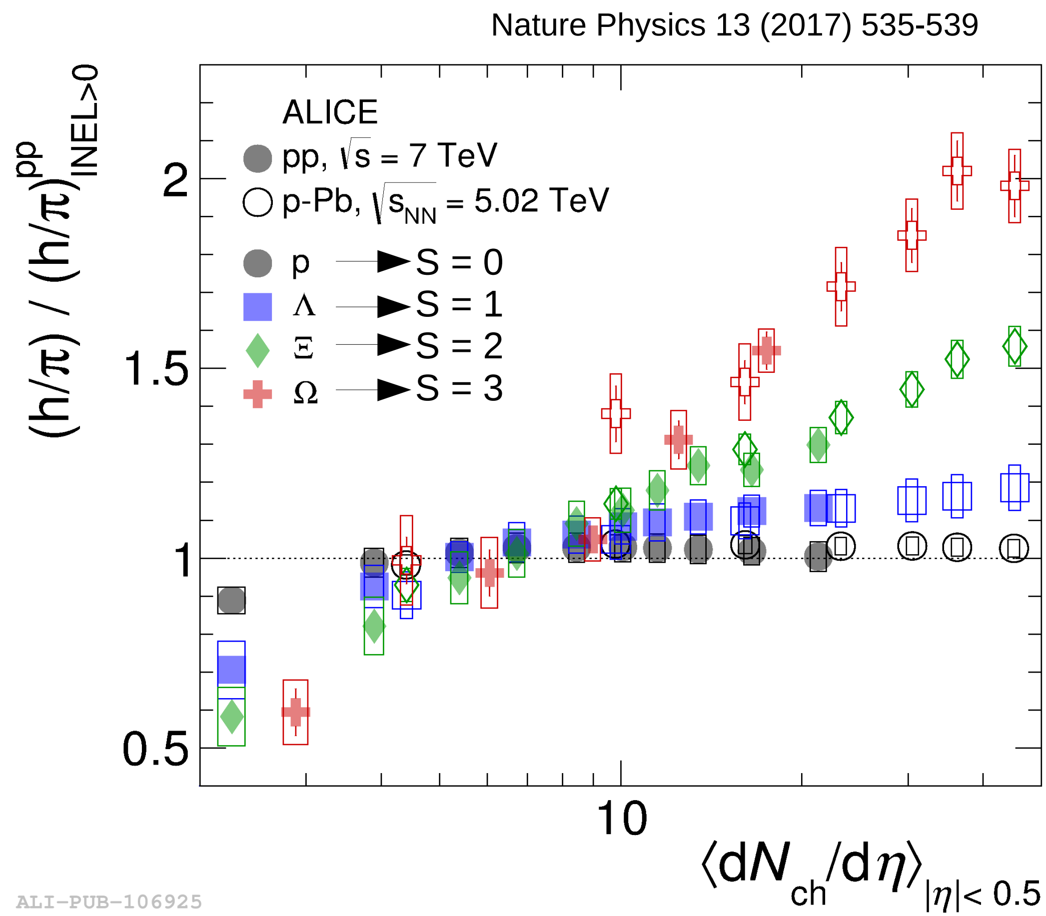
Results : Strangeness enhancement



- Strange to non-strange ratios in the three systems
  - Enhancement of strange to non-strange hadron production from low multiplicity pp to central Pb-Pb collisions
  - Smooth evolution between pp, p-Pb and Pb-Pb collisions
  - Strange to non-strange ratios are saturated in central Pb-Pb collisions for all particles
- MC prediction for pp and p-Pb collisions
  - PYTHIA8 (color reconnection) completely misses the behavior of the data
  - DIPSY (color ropes) gives a decent qualitative description but underestimates the Ω/π ratio and overestimates the p/π ratio
  - EPOS LHC (core-corona approach) only qualitatively describes the trend

Results : Strangeness enhancement





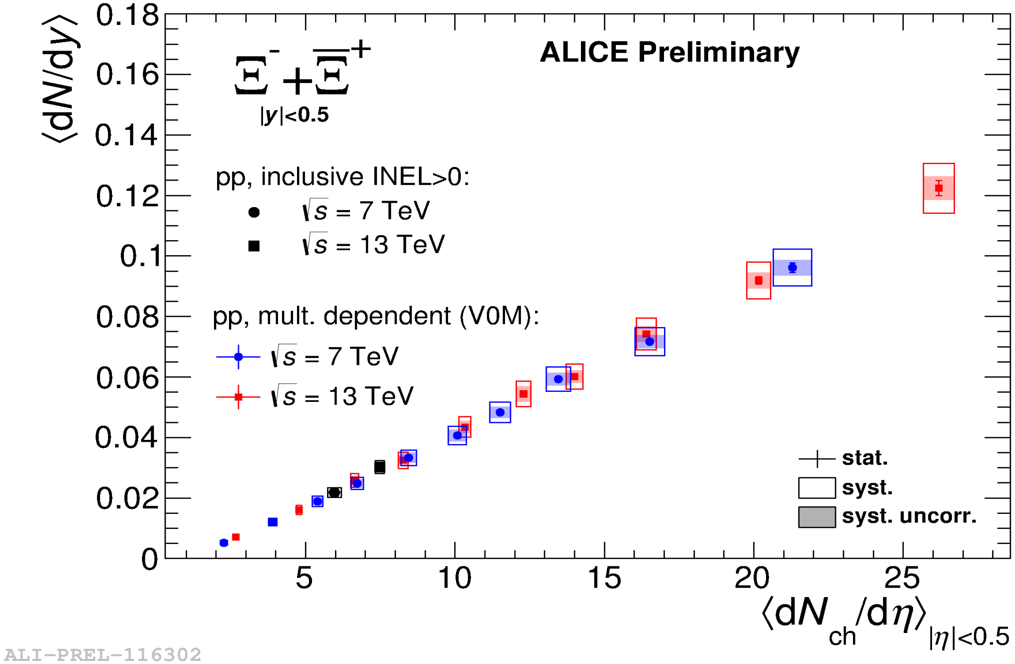
- Baryon-to-meson ratios (with same strangeness content) but different masses

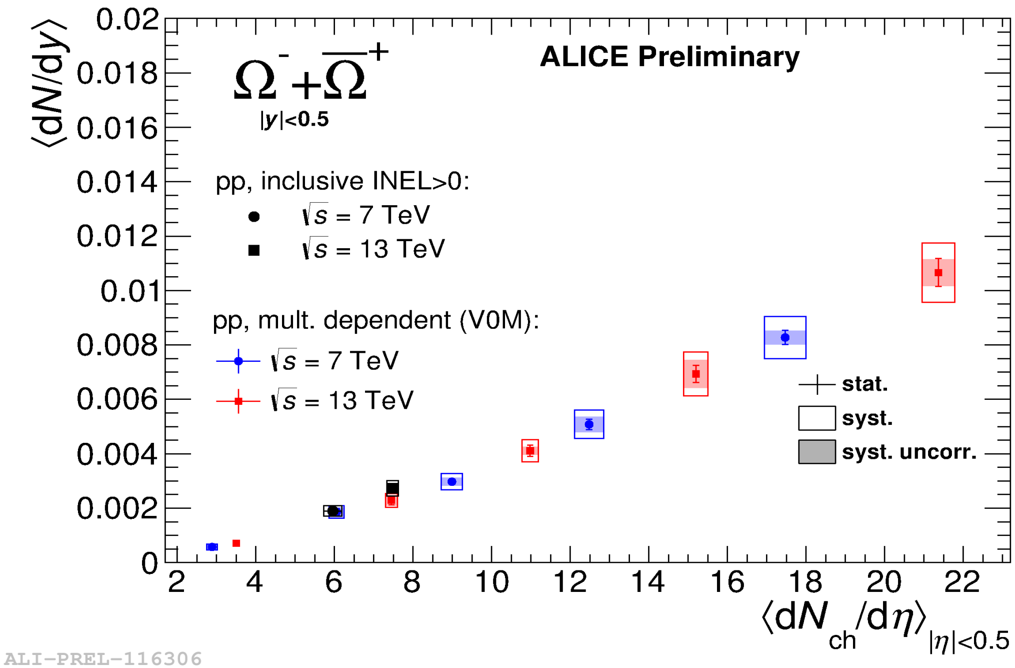
✔ No significant change with multiplicity
→ Strangeness enhancement is not driven by mass nor it is a baryon/meson effect

✔ Slope increases with increasing strangeness content in pp and p-Pb collisions

✔ Enhancement in hyperon-to-pion ratios is driven by strangeness content

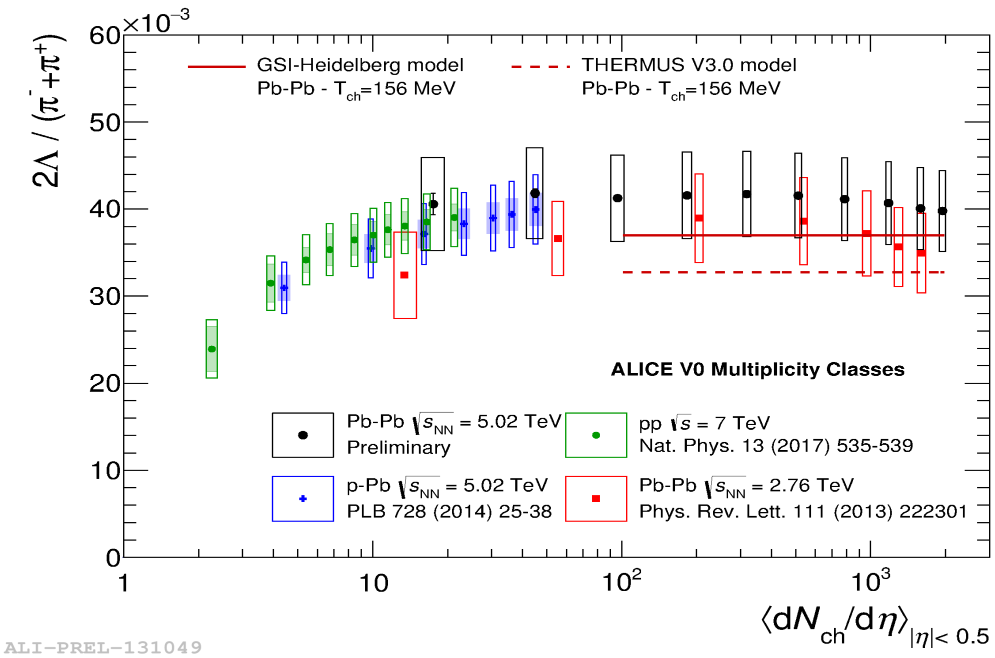
Collision energy dependence of strangeness production

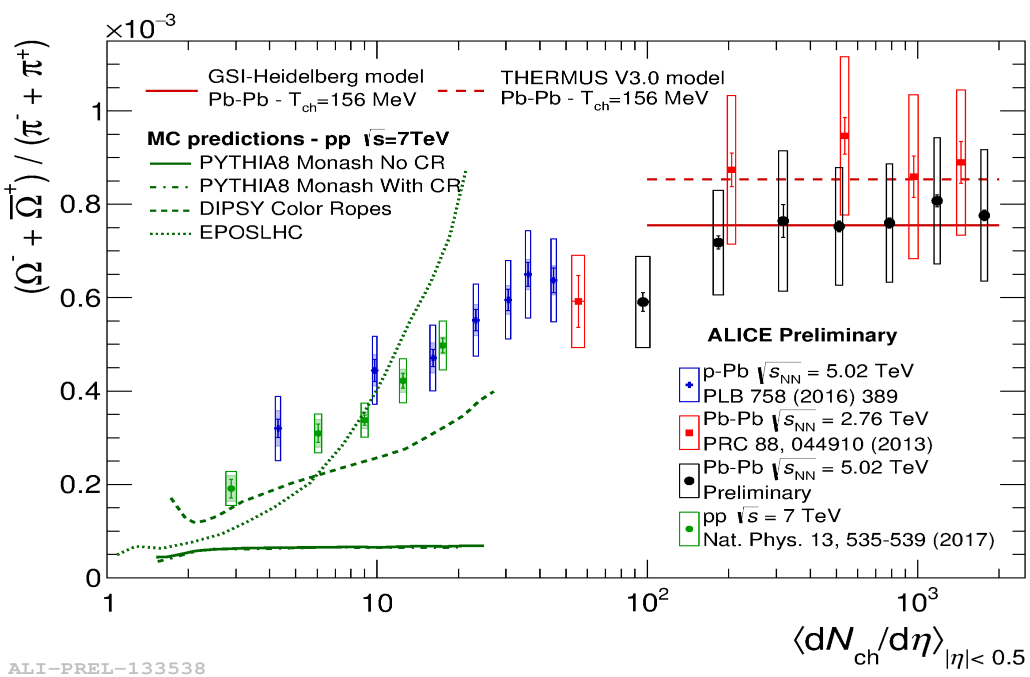




- Yields of (multi-)strange particles measured in pp 13 TeV as a function of multiplicity lie on the same trend as the 7 TeV data
- ✔ Yields in minimum bias pp collisions at different energies follow the same trend
- ✔ Particle production is driven by $\langle dN_{ch}/d\eta \rangle$ irrespective of the collision energy

Collision energy dependence of strangeness production



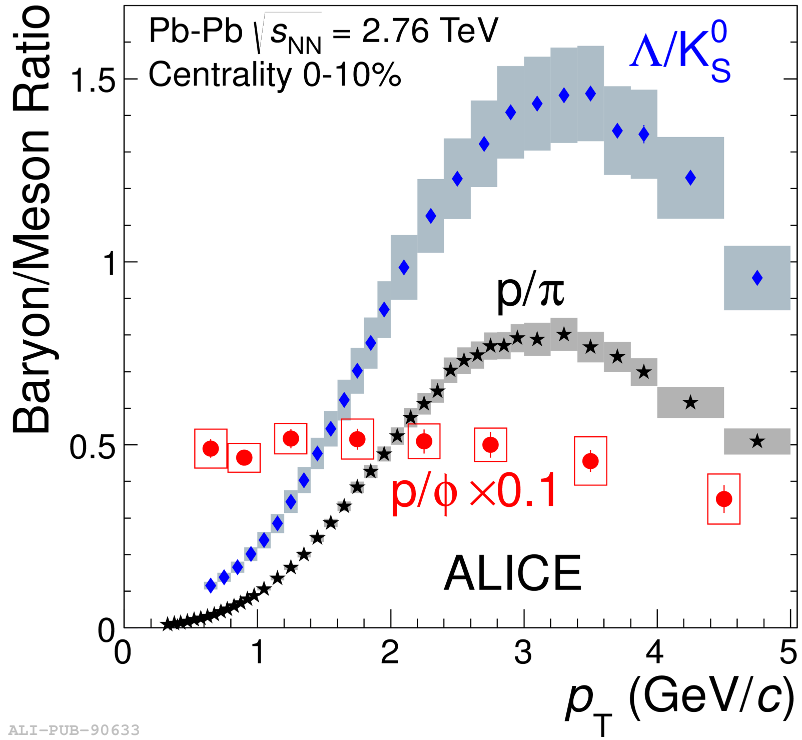


Pb-Pb at √s = 2.76 TeV
Pb-Pb at √s = 5.02 TeV

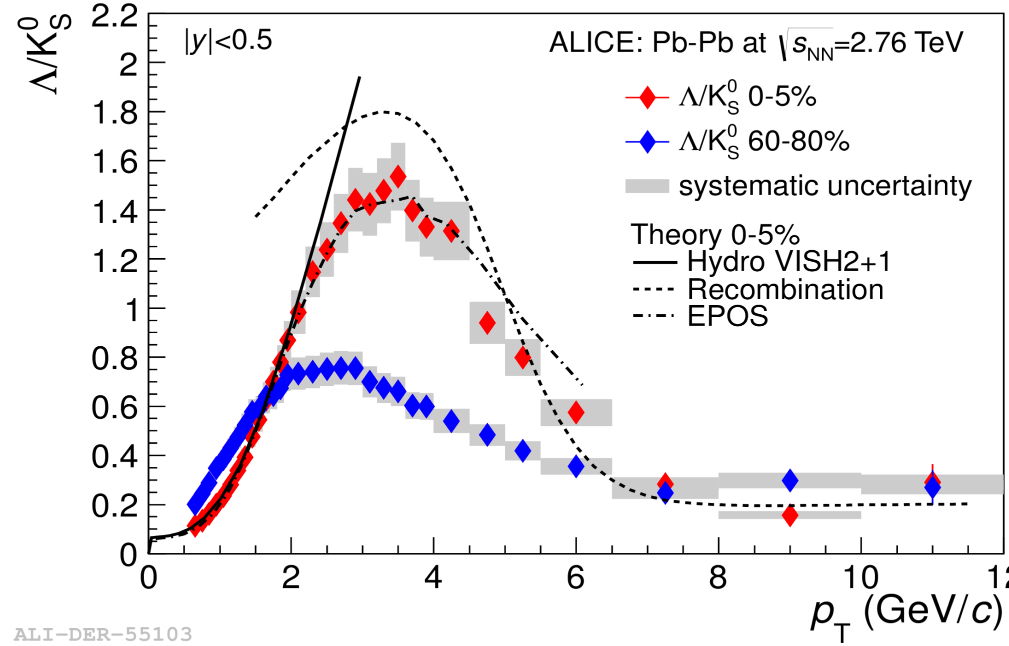
- ✔ In Pb-Pb collisions the relative production of strange particles has no significant dependence on collision energy

Results : effect of radial flow on baryon/meson ratios

Phys. Rev. C 91 (2015) 024609



Phys. Rev. Lett. 111 (2013) 22301

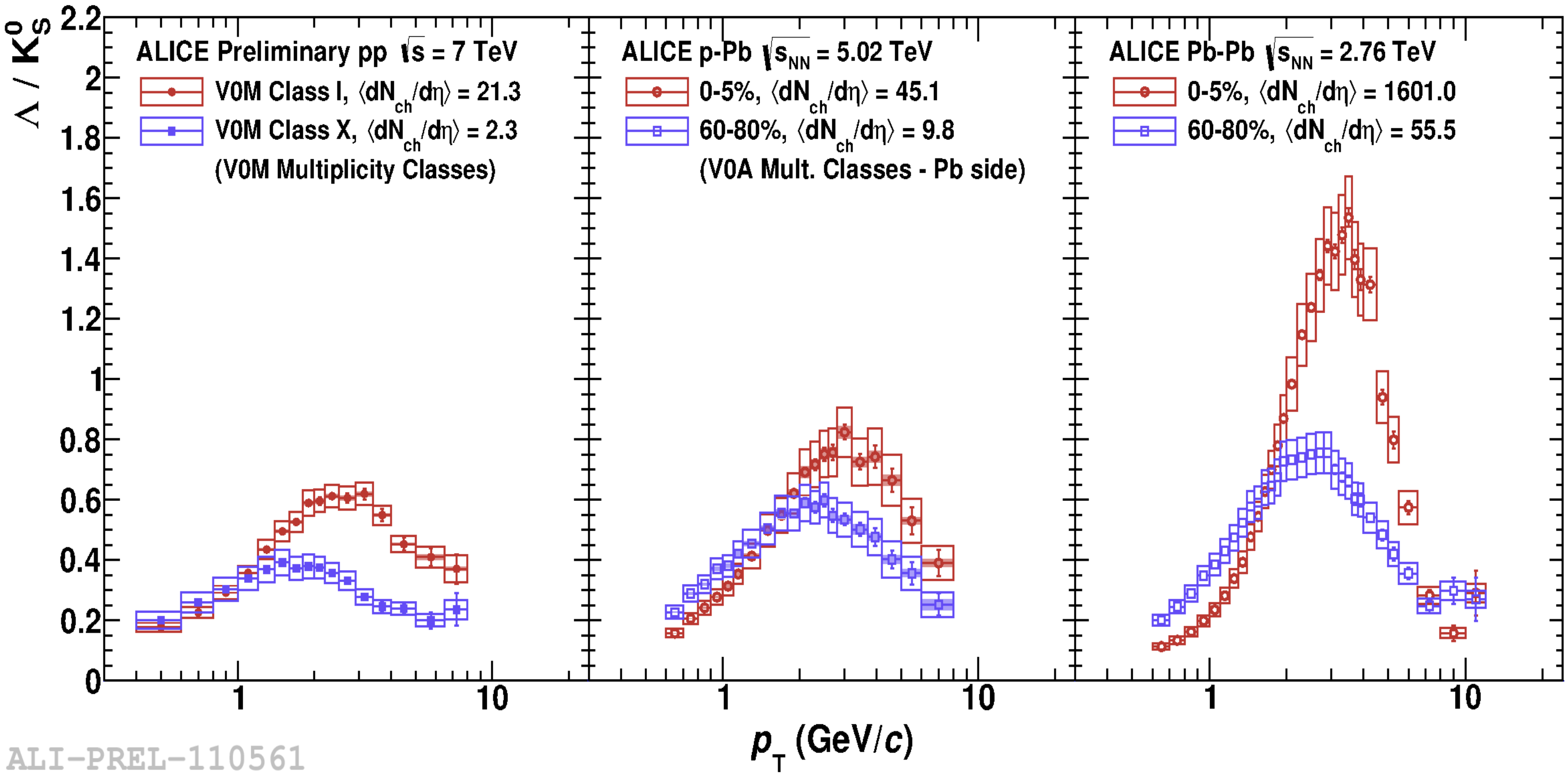


- The shape of baryon to meson ratio is driven by mass.
- ✔ Λ/K^0_S ratio increases up to $p_T \approx$ 3 GeV/c and then decreases
- ✔ p/ϕ ratio is independent of p_T: similar mass causes similar spectral shapes
  - ⟶ Can be explained by hydro but also hydro+recombination model

- **Central vs. Peripheral collisions for Λ/K^0_S ratio:**
- ✔ peripheral Pb-Pb collisons > central Pb-Pb collisions for p_T < 1.5 GeV/c
- ✔ central Pb-Pb collisons > peripheral Pb-Pb collisions for 1.5 < p_T < 7 GeV/c
- ✔ central Pb-Pb collisons = peripheral Pb- Pb collisions for p_T > 7 GeV/c
- **Models**
- ✔ Hydro describes only the rise < 2 GeV/c
- ✔ Recombination reproduces effect but overestimates at low p_T
- ✔ EPOS gives good description of data

Phys. Lett. B 658 (2008) 279
Ann. Rev. Nucl. Part. Sci. 58 (2008) 177
Phys. Rev. Lett. 109 (2012) 102301
Phys.Rev. C 92 (2015) 054904

Results : Collectivity in small system

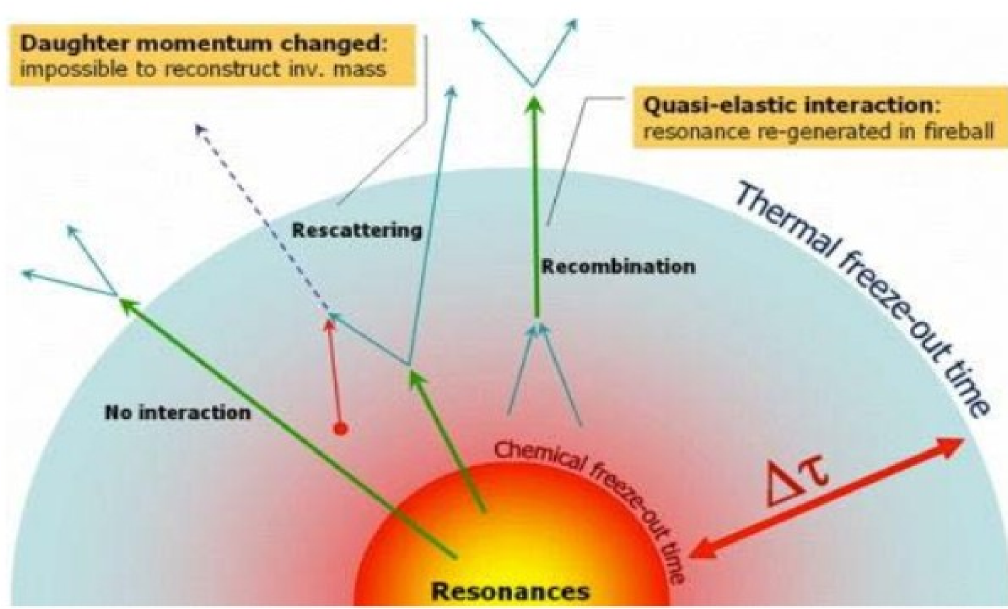


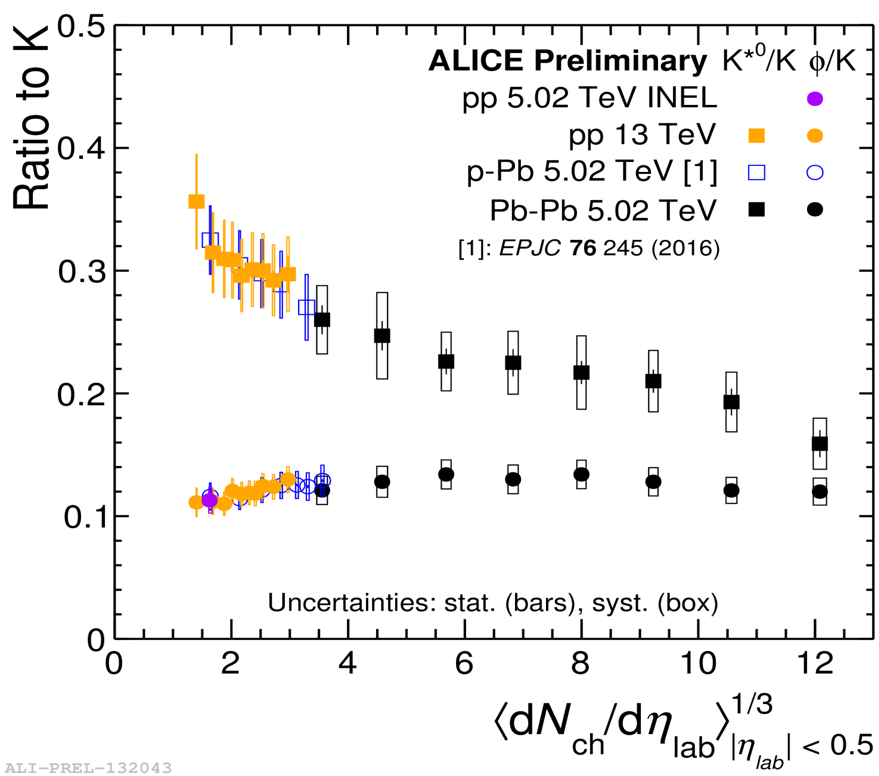
- Across the three systems Λ/K_S^0 evolves with multiplicity in qualitatively similar way:
- ✔ Depletion at low p_T , enhancement at intermediate p_T

---->**Hint of collective behaviour in small systems**

Phys. Rev. Lett. (2013) 222301
Phys. Lett. B 728 (2014) 25-38

Results : Interactions in the hadronic phase





- Regeneration and rescattering can cause modification of hadronic resonance's yield and their ratios to stable hadrons
- The level of modification depends on timescale between chemical and kinetic freeze-out along with interaction cross section of the decay products and the resonance lifetime

- K^{*0}/K shows a suppression, going from pp, p-Pb to central Pb-Pb collisions
  → Rescattering of K^{*0} decay daughters
- ϕ/K shows no suppression
  → Rescattering is not significant for the decay daughters of ϕ

$\tau(\phi) = 46.2$ fm/c >> $\tau(K^{*0}) = 4.2$ fm/c

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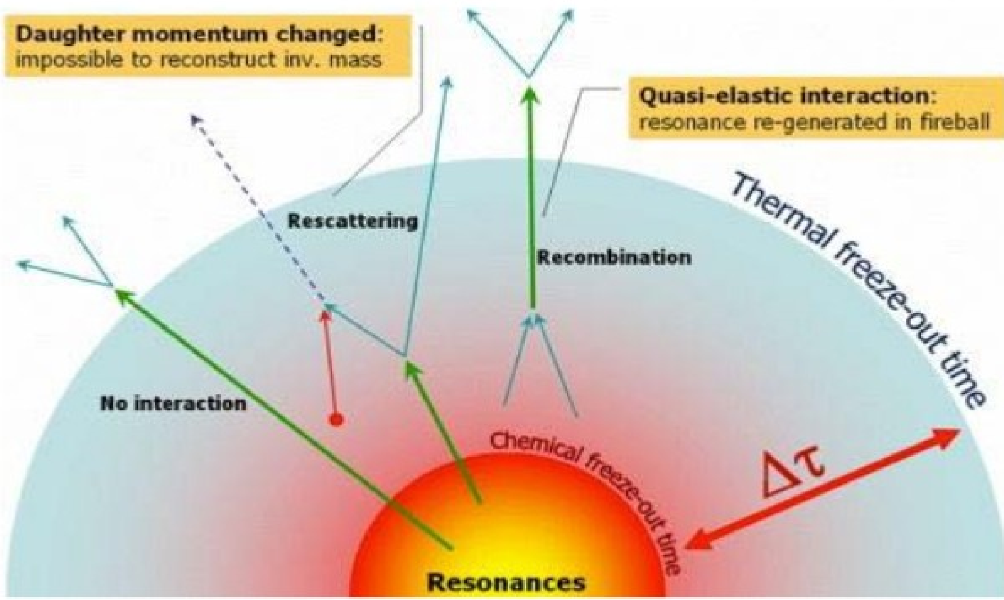

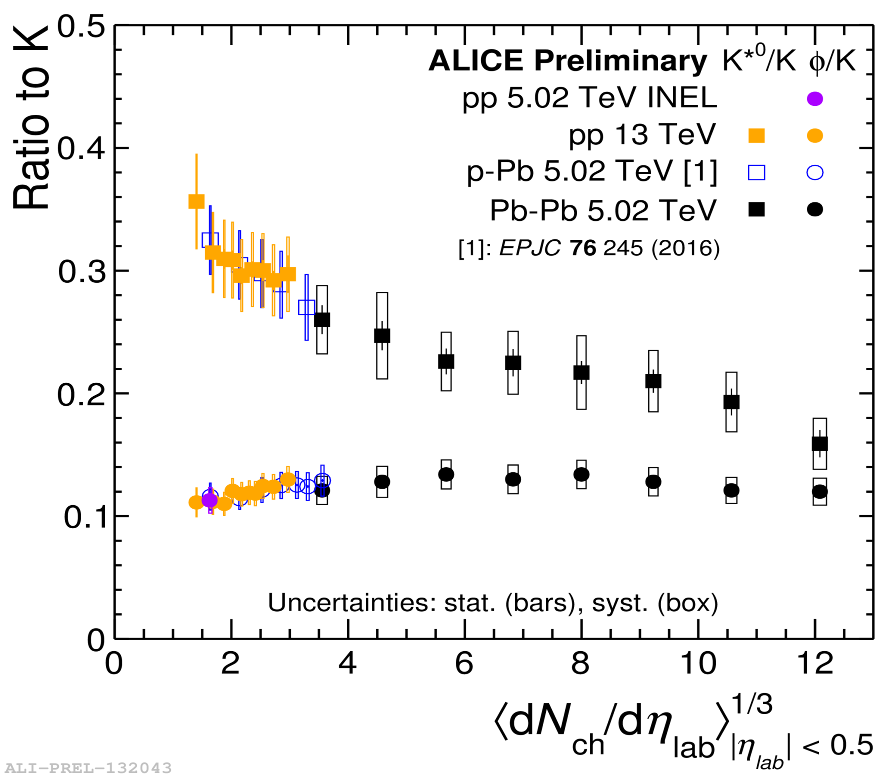

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$\tau(\phi)$ = 46.2 fm/c >> $\tau(K^{*0})$ = 4.2 fm/c

- It is important to understand the hadronic phase because processes such as baryon annihilation might affect the measurable relative abundances of baryons (e.g. protons or multistrange baryons)
- ϕ contains a pair of strange and antistrange quarks. Does it behave like a S = 0 or like a S = 2 particle in terms of enhancement?

Summary

- Enhancement of strange hadron production is observed in pp and p-Pb collisions as a function of ⟨dN_{ch}/dη⟩
- ✓ Smooth evolution across pp, p-Pb and Pb-Pb with ⟨dN_{ch}/dη⟩

- Relative production of strange particles do not depend on collision energy but is driven by ⟨dN_{ch}/dη⟩

- Shape of baryon to meson ratio as a function of p_T is driven by mass and similar trends in pp, p-Pb and Pb-Pb collisions suggest the presence of collective phenomena in small systems (among other observables)

- Suppression of K^{*0}/K ratio from low multiplicity pp, p-Pb to central Pb-Pb collisions suggests the rescattering of K^{*0} decay daughters and thus the presence of interactions in a hadronic phase in large systems, which can affect the measurable yields

THANK **YOU**

BACK UP

Event classes in Pb-Pb

Event **multiplicity/centrality** classes are defined based on the amplitude measured in the **V0 scintillators**, placed at $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C)

$\langle dN_{ch}/d\eta \rangle$ is measured in $|\eta|<0.5$
→ avoid "auto-biases" in multiplicity determination

In **Pb-Pb** the Glauber model is used to relate the V0A&V0C ("V0M") amplitude* distribution to the geometry of the collision.

At $\sqrt{s_{NN}}$ = 2.76 TeV
0-5%: $\langle dN_{ch}/d\eta \rangle = 1601 \pm 60$
$\langle N_{part} \rangle = 328.8 \pm 3.1$
70-80%: $\langle dN_{ch}/d\eta \rangle = 35 \pm 2$
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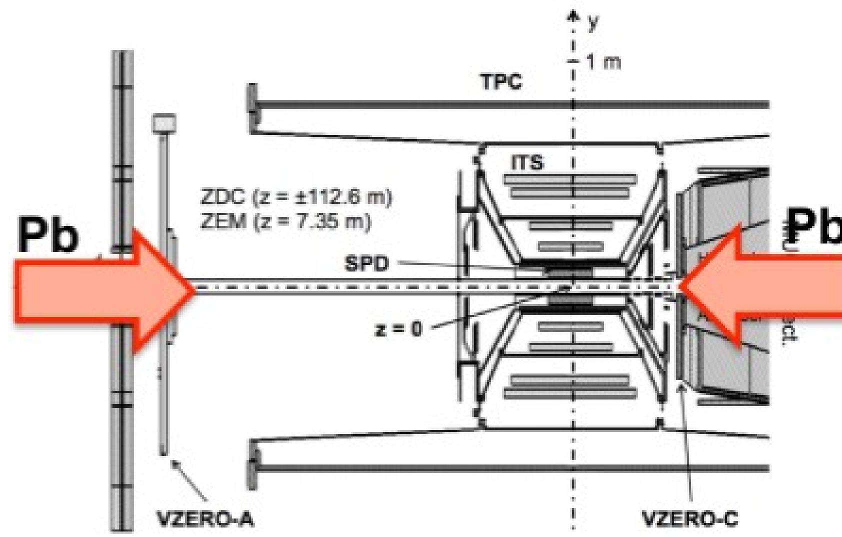
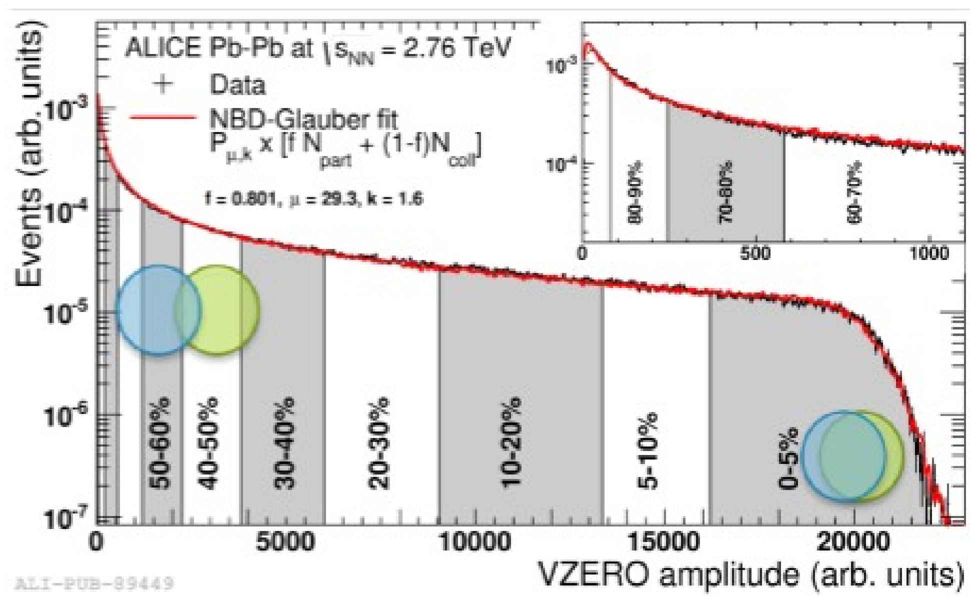
(*alternatively, multiplicity of spectators in the Zero Degree Calorimeters or number of tracks in the Silicon Pixel Detector or the Time Projection Chamber)





Phys. Rev. Lett. 106 (2011) 032301

Event classes in Pb-Pb, p-Pb and pp

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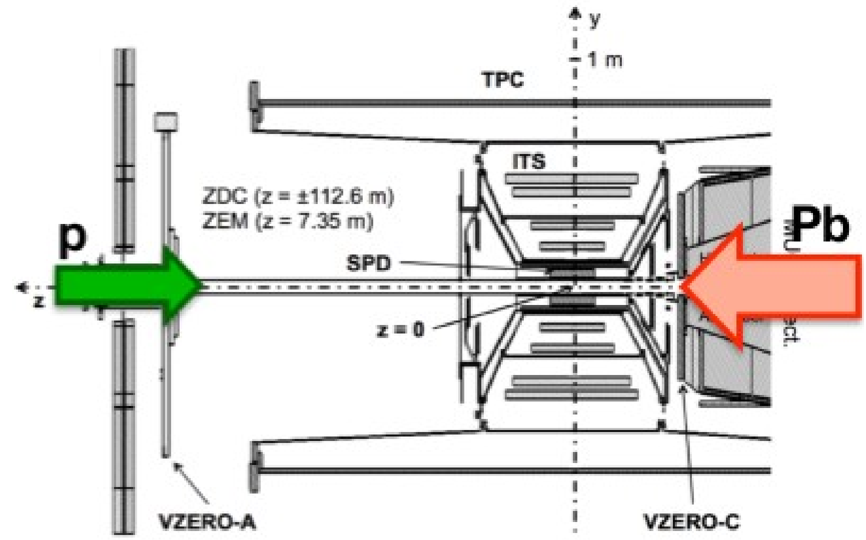

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Phys. Rev. Lett. 106 (2011) 032301
Phys. Rev. C 91 (2015) 064905