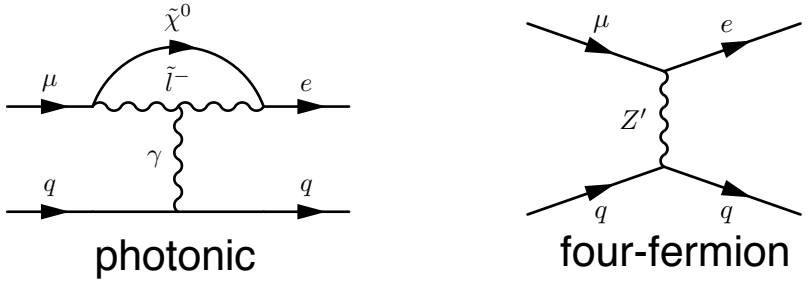
Status of COMET
~μ-e Conversion Search in J-PARC~

Yuki Nakai

(Kyushu University)
on Behalf of the COMET Collaboration

九州大学
KYUSHU UNIVERSITY

CLFV and μ-e Conversion



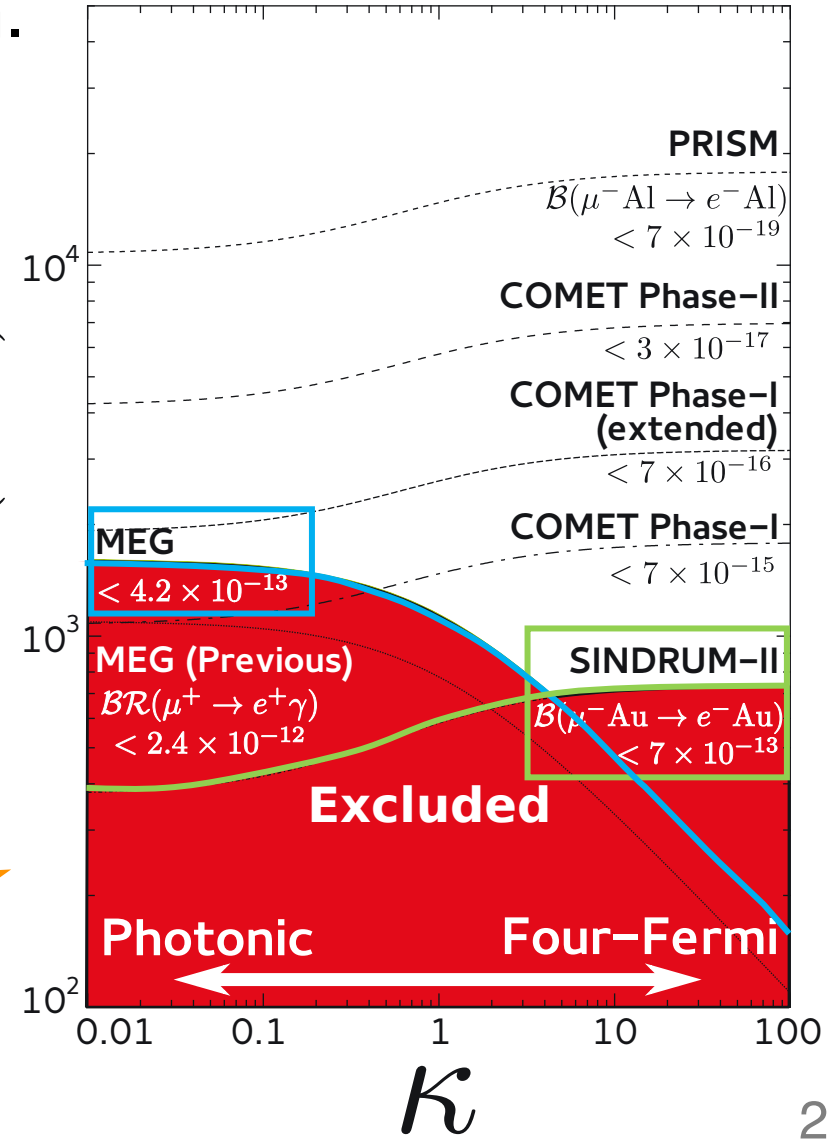
CLFV processes are good probes for BSM search.

BSM : O(**10^{-15}**)
SM : < O(**10^{-50}**)

< Current Limits of CLFV (90% C.L.) >

$\mu \rightarrow e + \gamma$: < 4.2 x 10^{-13} (MEG)

$\mu + N \rightarrow e + N$: < 7 x 10^{-13} (SINDRUM II)

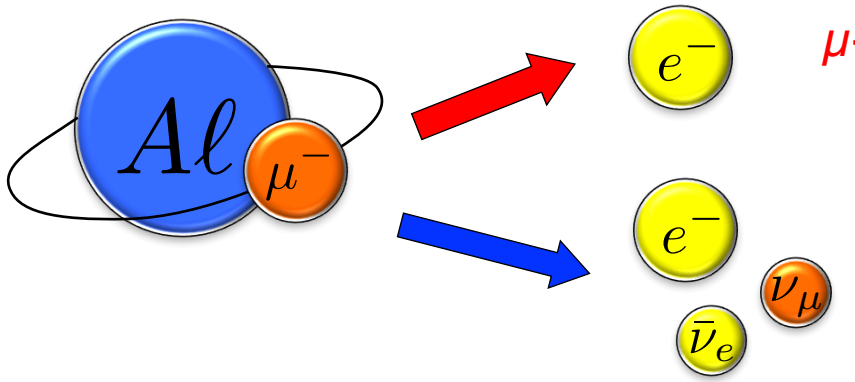


μ -> eγ : photonic

μN -> eN : photonic & four-fermi

➡ **Combined result can distinguish physics models.**

μ-e Conversion Search



μ-e conversion

monochromatic e^- w/ 105 MeV/c

Decay In Orbit (DIO)

endpoint at ~105 MeV/c -> **main physics BG**

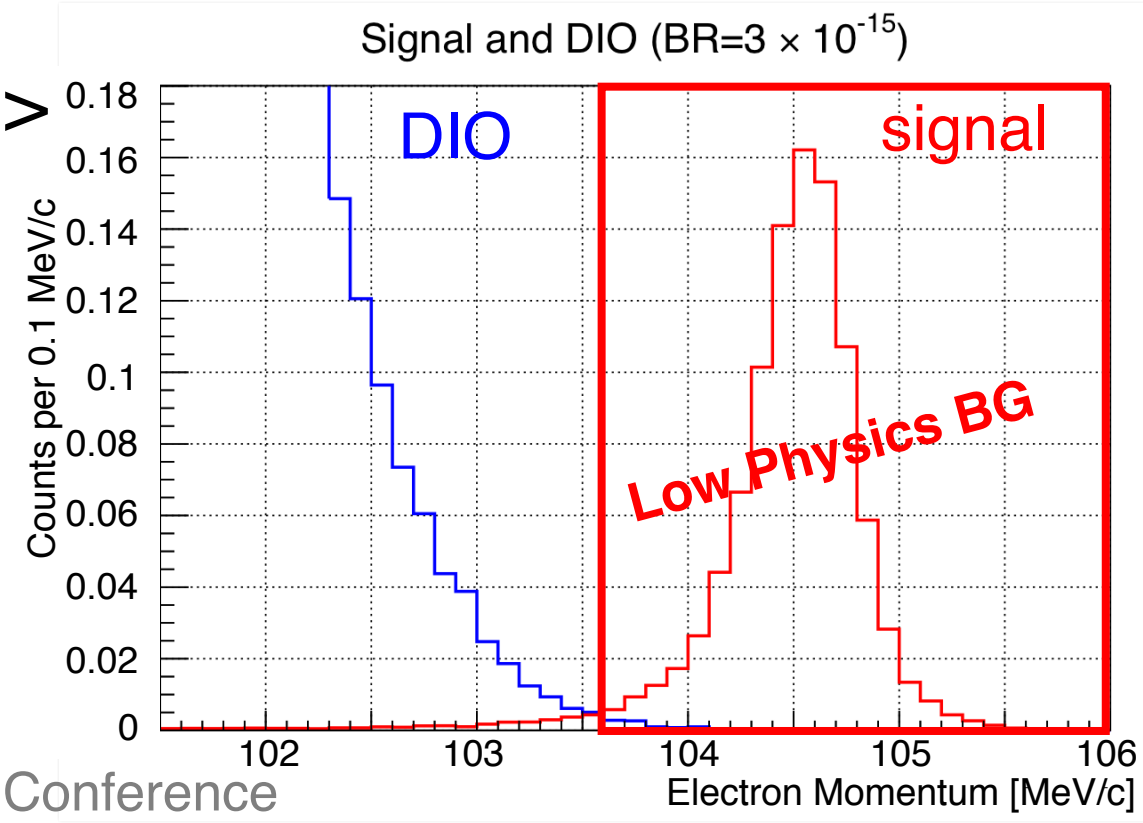
< Experimental Merits of the μ-e conv. >

(1) Signal electron has 105 MeV/c

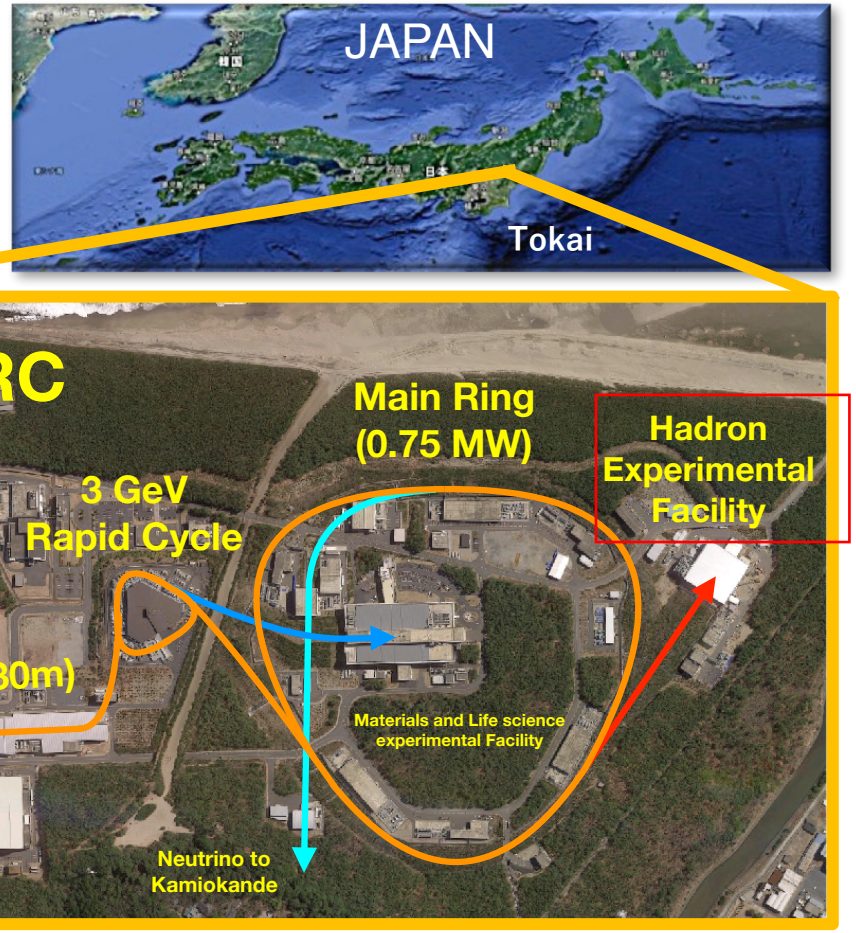
-> **Low physics BG**

(2) No coincidence is required

-> **No accidental BG**



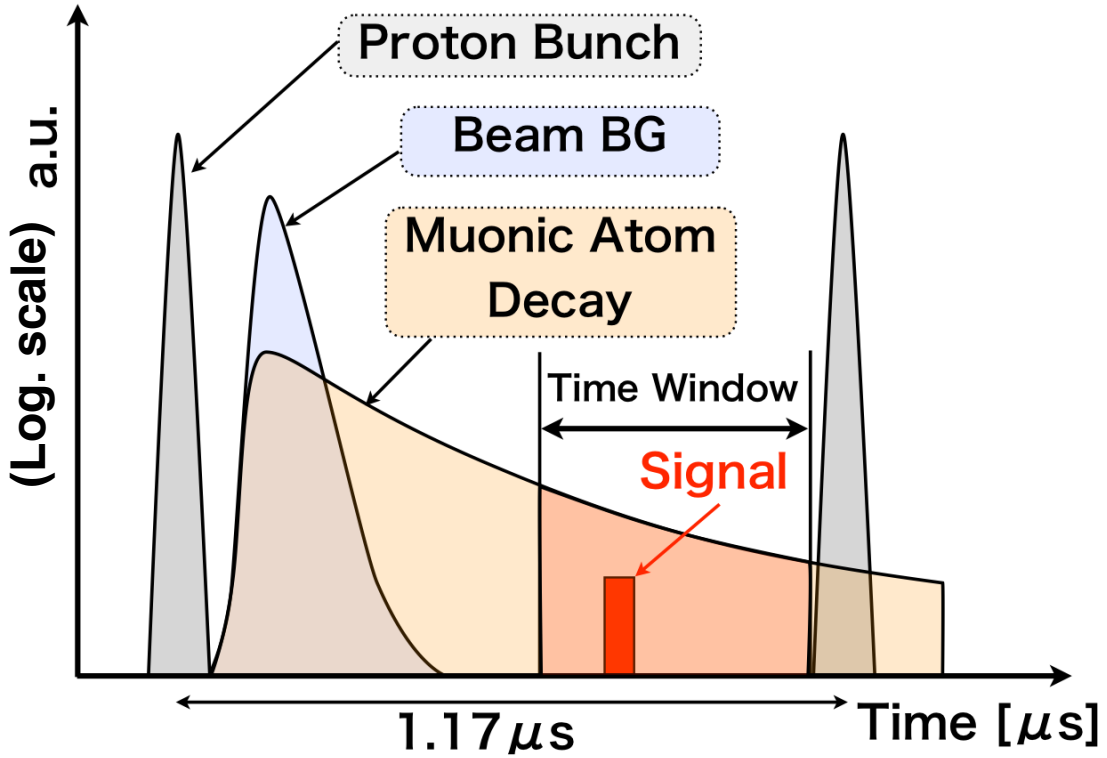
Proton Beam at J-PARC



Proton beam with the highest intensity

Powerful proton beam : 8 GeV, 3.2 kW

↳ **High statistics**



Pulsed beam & time window

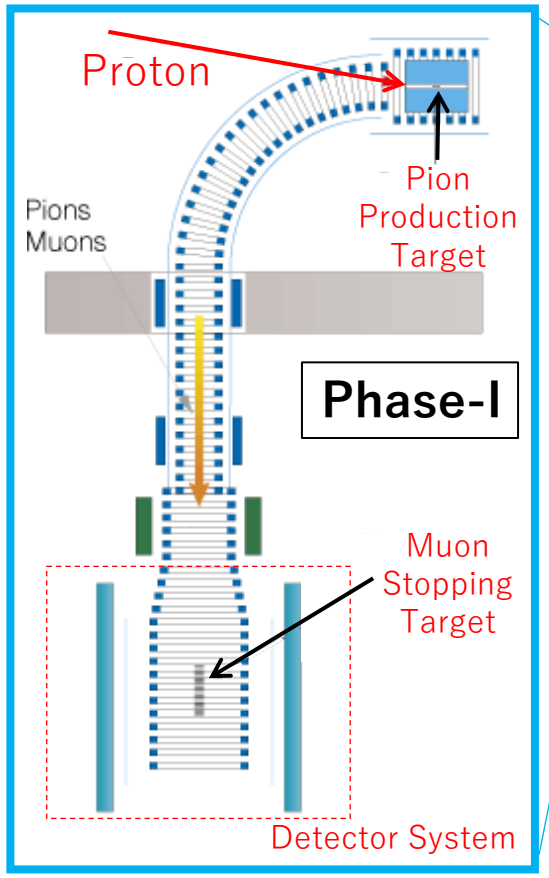
Lifetime of muonic Aluminum : 864 ns

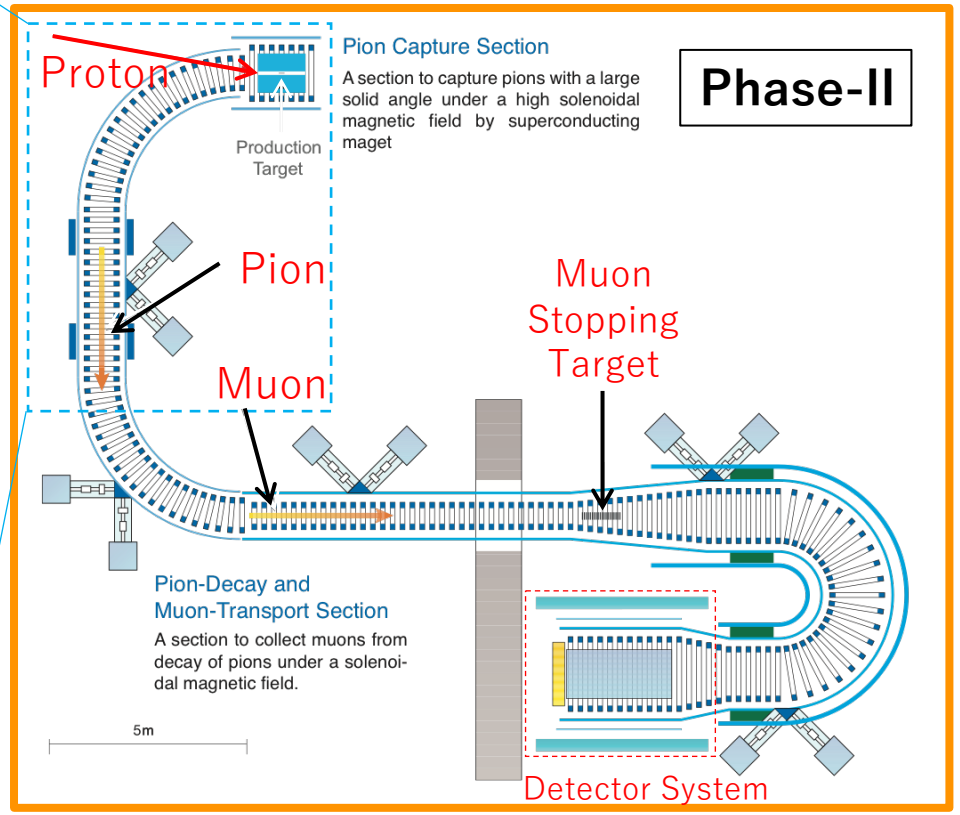
Time window : 700-1170 ns

↳ **Beam related BG free**

COMET Experiment

Staging approach





< Phase-I > start in 2018 or 2019

(1) **Beam measurement** ~1-2 weeks
-> study of the new beam line

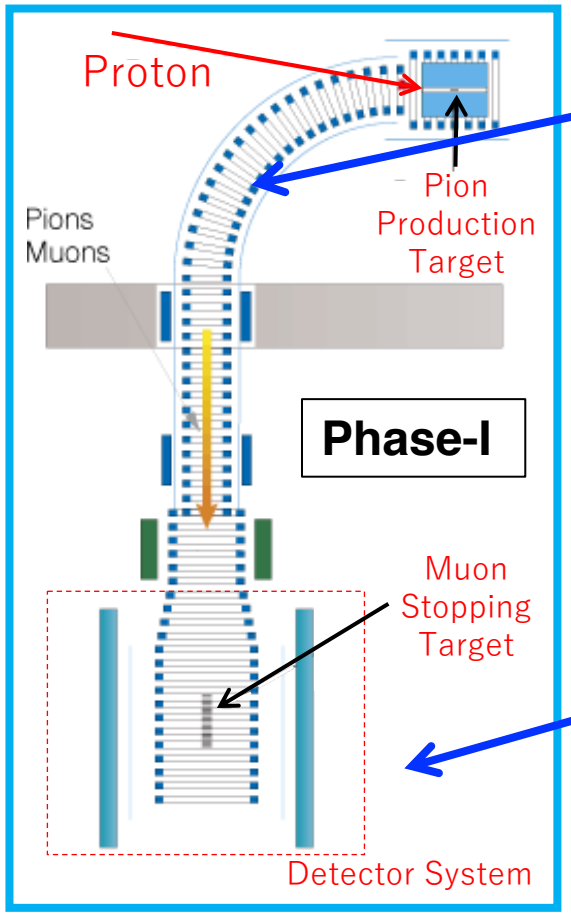
(2) **Physics measurement** ~half year
with sensitivity, **O(10^{-15})**
(improvement of **~100**)

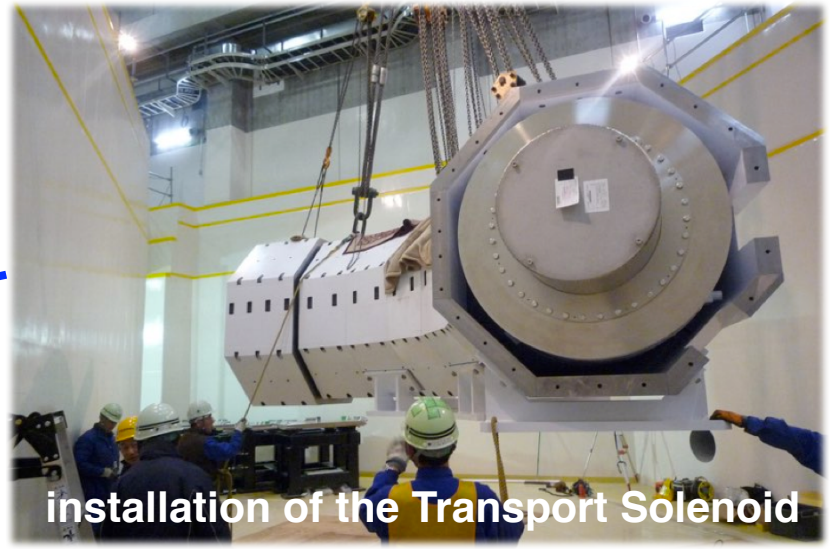
< Phase-II > start in 202X

Physics measurement
with the highest sensitivity, **O(10^{-17})**
(improvement of **10,000**)

Preparation of the
COMET Phase-I is on going!

Status of the Facility & Magnet

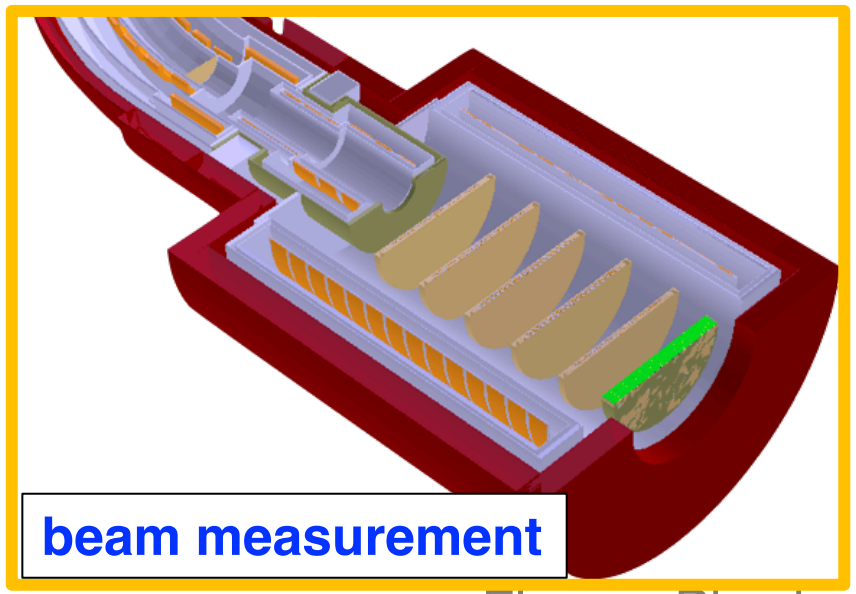


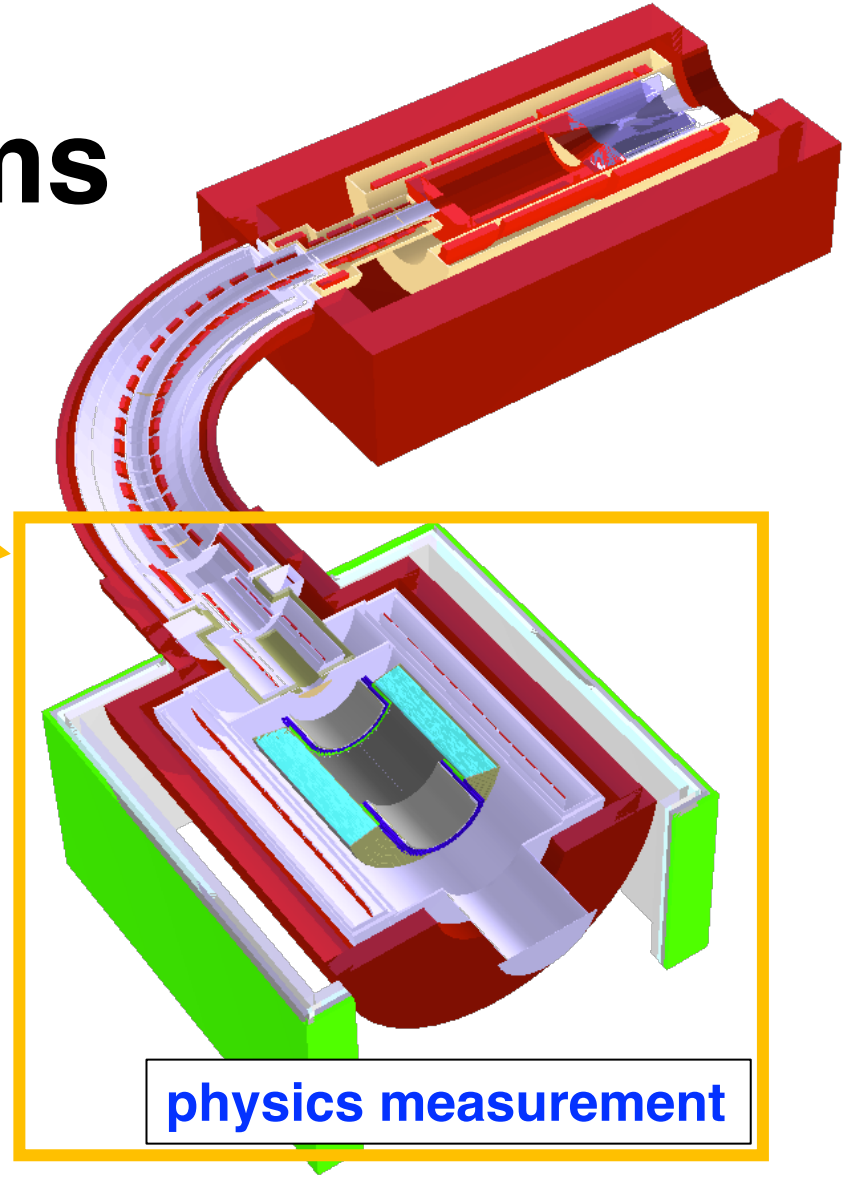


Status of the Detector Systems

There are 2 detector systems in COMET Phase-I

Straw Tube Trackers + ECAL (StrECAL)





Cylindrical Detector System (CyDet)

Detector System (StrECAL)

Beam measurement (in Phase-I)
Physics measurement (in Phase-II)

Straw Tube Tracker

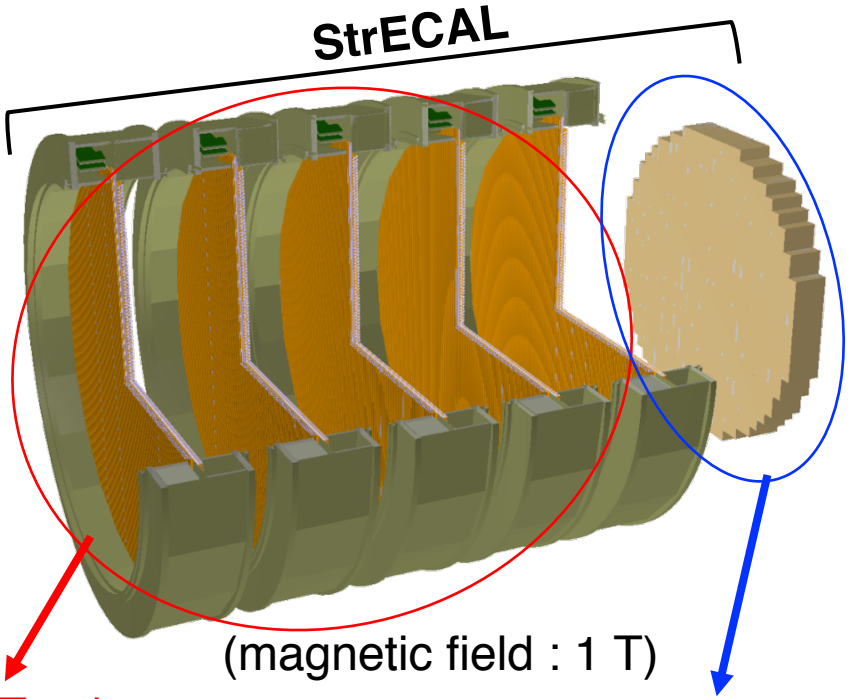
extremely low material tube whose thickness < 20 um
momentum resolution : < 200 keV/c
<Performance for 105 MeV electron>

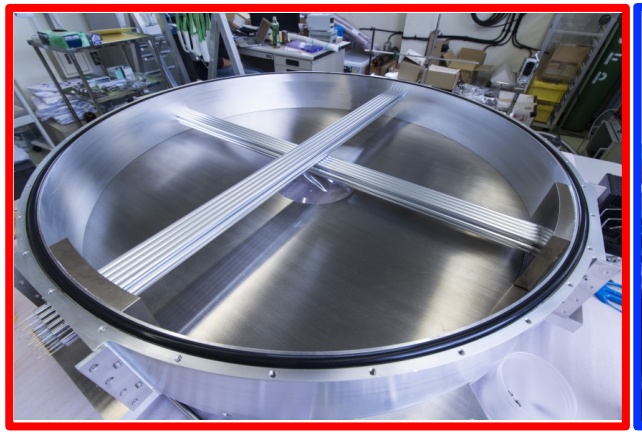
		requirement
Spatial resolution :	**143 um**	200 um

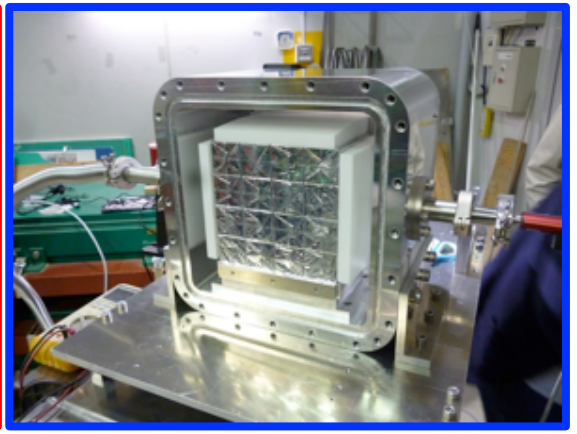
EM Calorimeter (ECAL)

20 x 20 x 120 mm^3 LYSO crystals
measures **energy**, **event timing**, **hit position**
-> **triggers** signal events
<Performance for 105 MeV electron >

		requirements
Energy resolution :	**4.22%**	5%
Position resolution :	**7.6 mm**	10 mm
Time resolution :	**0.4 ns**	1 ns







Final Prototypes

R&D has almost finished ! (including combined test)
Mass production will start in near future

Detector System (CyDet)

Physics measurement (in Phase-I)

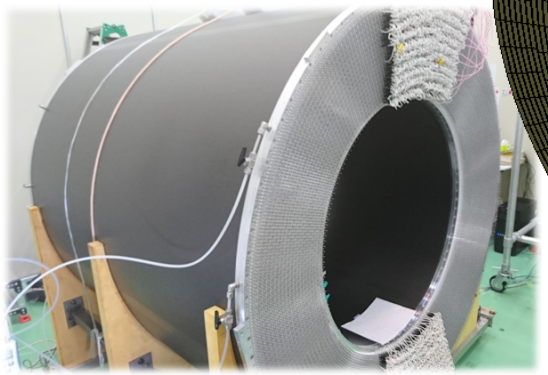
Cylindrical Drift Chamber (CDC)

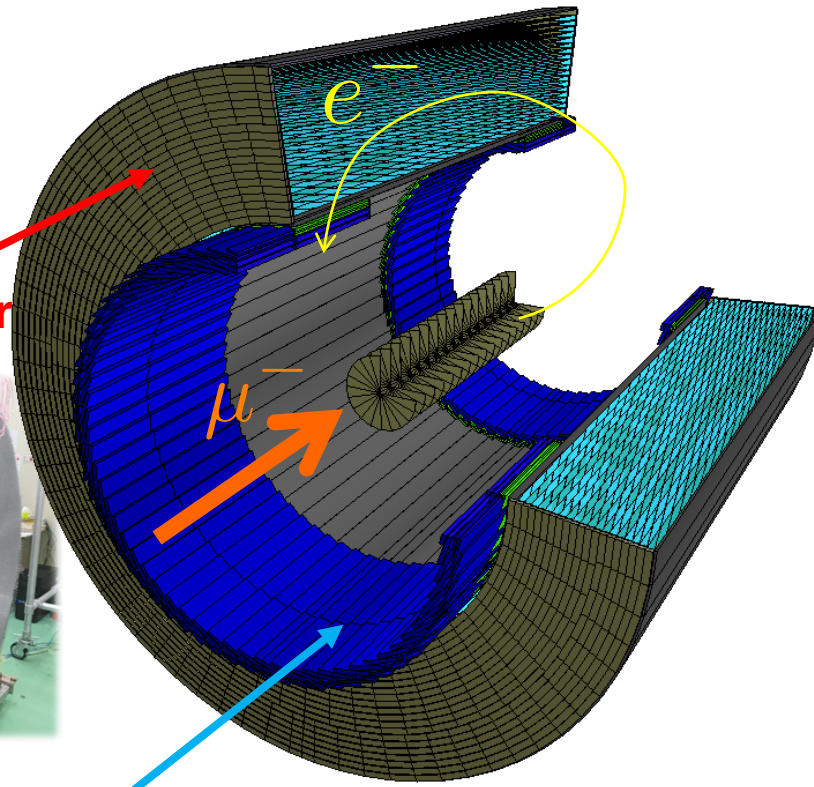
consists of 20 stereo layers
~15,000 field wires, ~5,000 sense wires
momentum resolution : < 200 keV/c
<Performance of the prototype>

	requirement
Spatial resolution : **< 200 um at 1 T**	200 um

Completed construction! (June 2016)

Under Commissioning with cosmic ray



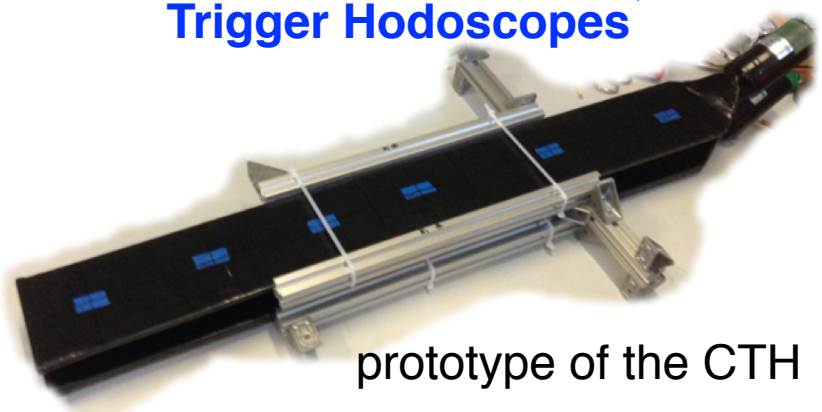


(magnetic field = 1 T)

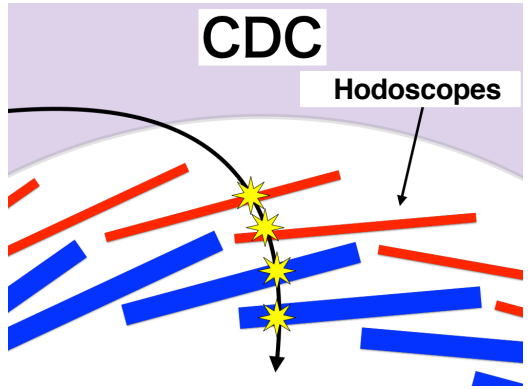
Cylindrical Trigger Hodoscopes (CTH)

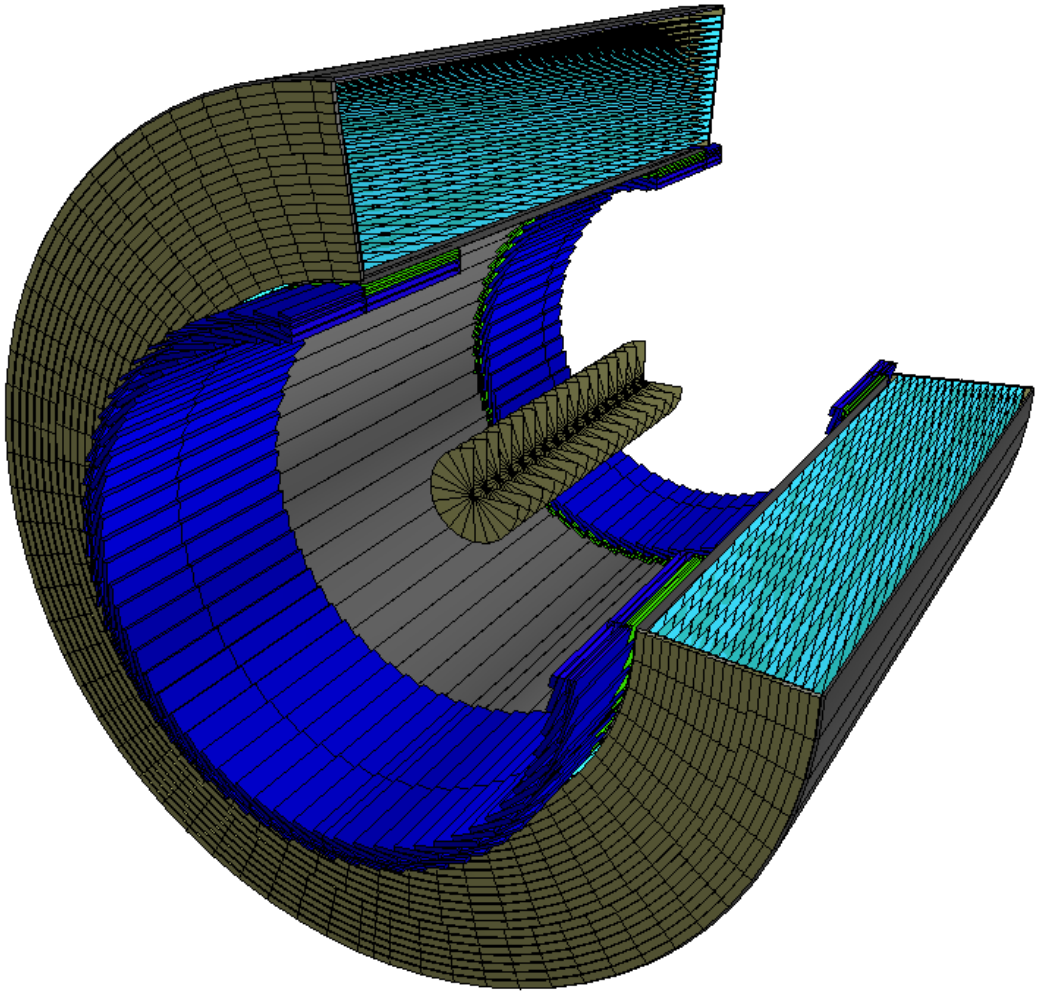
plastic-scintillators and Cherenkov detectors
measures **event time**
identifies electron events
<Performance of the prototype>

	requirement
Time resolution : **< 0.8 ns**	1 ns
S/N ratio : **S/N > 100**	20



prototype of the CTH





Sensitivity and Background Estimation (in COMET Phase-I with CyDet)

Background Estimation

Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	
	All (*) Combined	≤ 0.0038
	Radiative pion capture	0.0028
	Neutrons	$\sim 10^{-9}$
Delayed Beam	Beam electrons	~ 0
	Muon decay in flight	~ 0
	Pion decay in flight	~ 0
	Radiative pion capture	~ 0
	Anti-proton induced backgrounds	0.0012
Others	Cosmic rays†	< 0.01
Total		0.032

† This estimate is currently limited by computing resources.

Single Event Sensitivity

$$B(\mu^- + \mathrm{Al} \to e^- + \mathrm{Al}) = \frac{1}{N_\mu \cdot f_{\mathrm{cap}} \cdot f_{\mathrm{gnd}} \cdot A_{\mu-e}}$$

N_μ : # of total muons stopped in the target (**1.5 x 10^{16}**)

muon yield : 4.7x10^{-4} muons per 8 GeV proton

3.2 kW and 1.26x10^{7} sec operation (~146 days)

f_{cap} : Fraction of captured muons to total muons on target (**0.61**)

f_{gnd} : Fraction of μ-e conversion to the ground state in the final state (**0.9**)

$A_{\mu\text{-e}}$: Net signal acceptance (**0.041**)

Event selection	Value
Online event selection efficiency	0.9
DAQ efficiency	0.9
Track finding efficiency	0.99
Geometrical acceptance + Track quality cuts	0.18
Momentum window ($\varepsilon_{\mathrm{mom}}$)	0.93
Timing window ($\varepsilon_{\mathrm{time}}$)	0.3
Total	0.041

3 x 10^{-15} (S.E.S.)
or
< 7x10^{-15} (90% C.L.)

Summary

μ-e conversion is a good probe for BSM search.

COMET Phase-I searches for μ-e conversion with a sensitivity of $O(10^{-15})$.

The highest intensity proton beam in J-PARC achieves high statistics.

Pulsed beam and time window suppress beam related BG.

Experimental hall and so on have been built and transport solenoid have been installed.

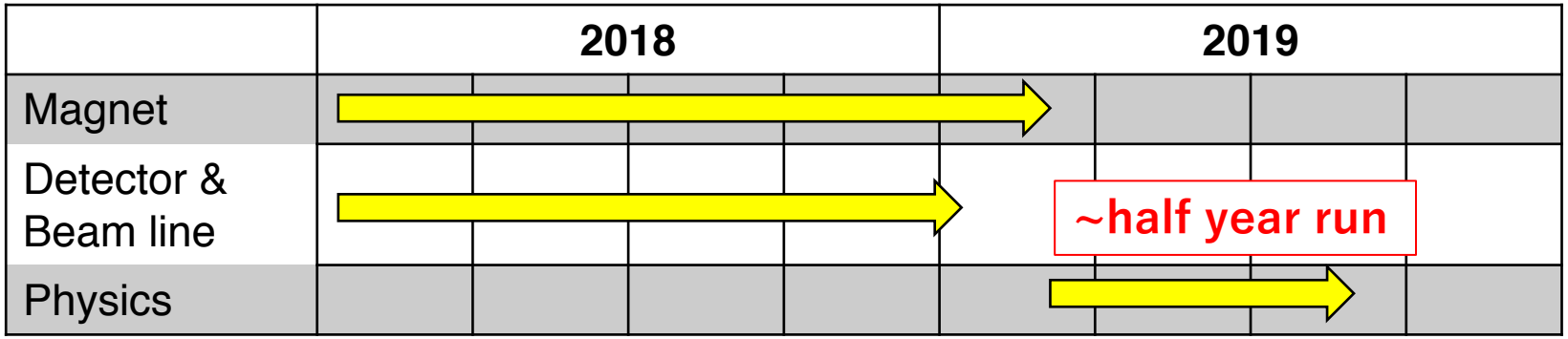
We have 2 detector systems; StrECAL and CyDet.

Both prototypes showed good performances.

Especially, CDC construction completed and commissioning is on going

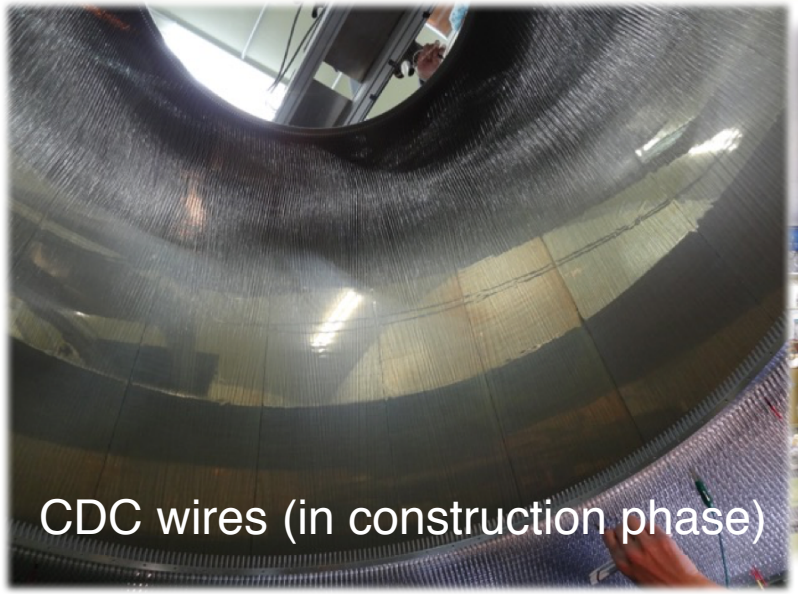
S.E.S : **3×10^{-15}**, which corresponds to **$< 7 \times 10^{-15}$** (90% C.L.)

Estimated BG events : **0.032 events**



Transport Solenoid

COMET Collaborators
(176 collaborators)



CDC wires (in construction phase)

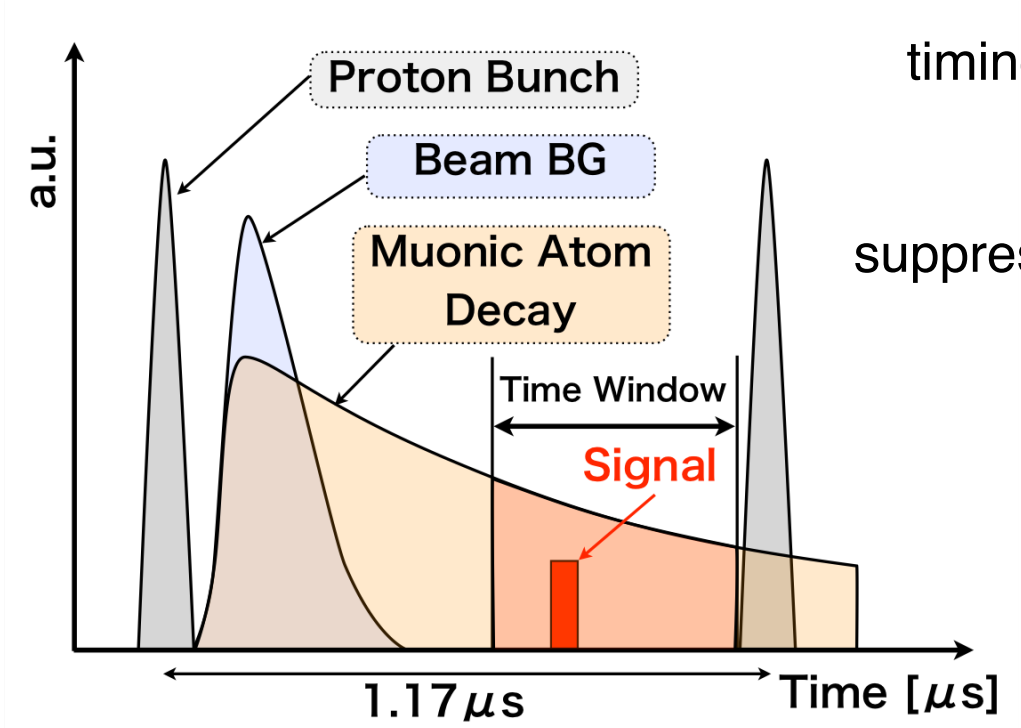
Beam Line

Thank you!

our mascot, COMET-chan

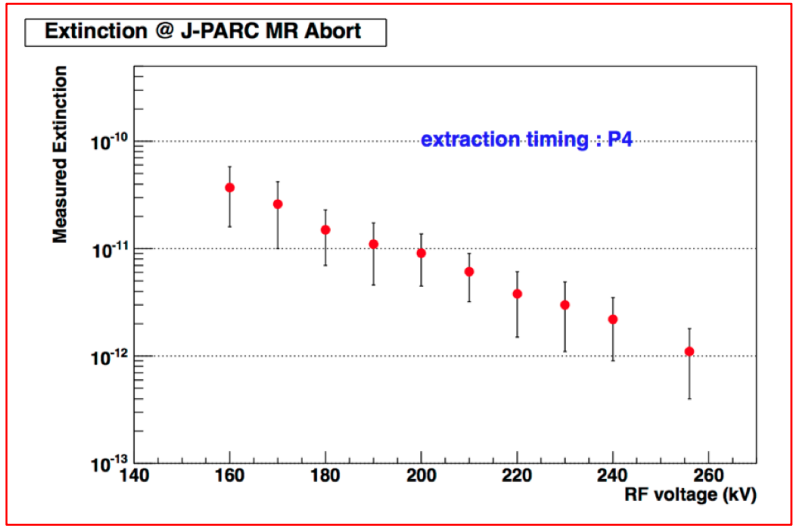
backup slides

Beam Structure



timing window method

suppress beam related BG

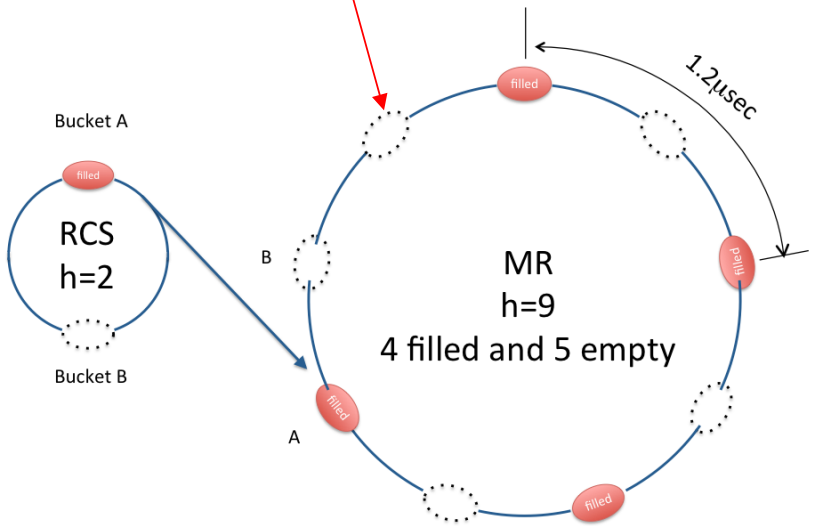


extinction factor
(requirement : < 10^{-9})

good enough!

Main Ring is operated in “COMET mode”

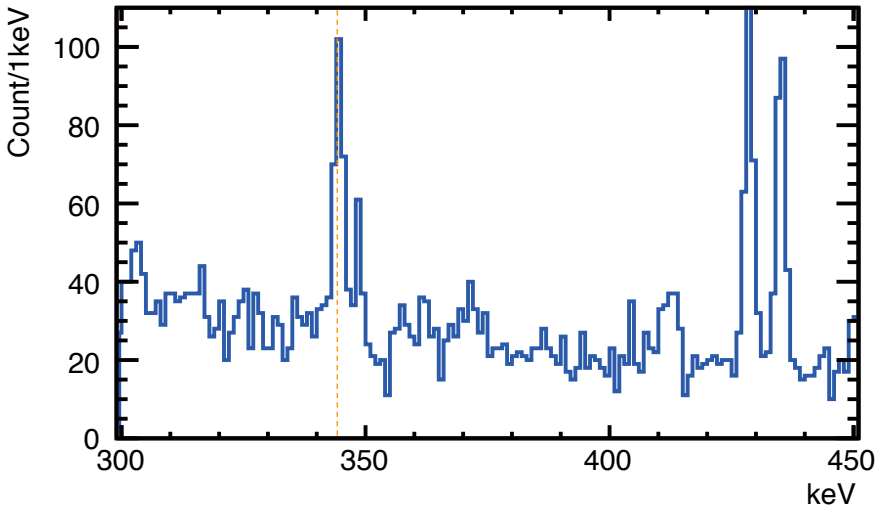
No protons in the time window

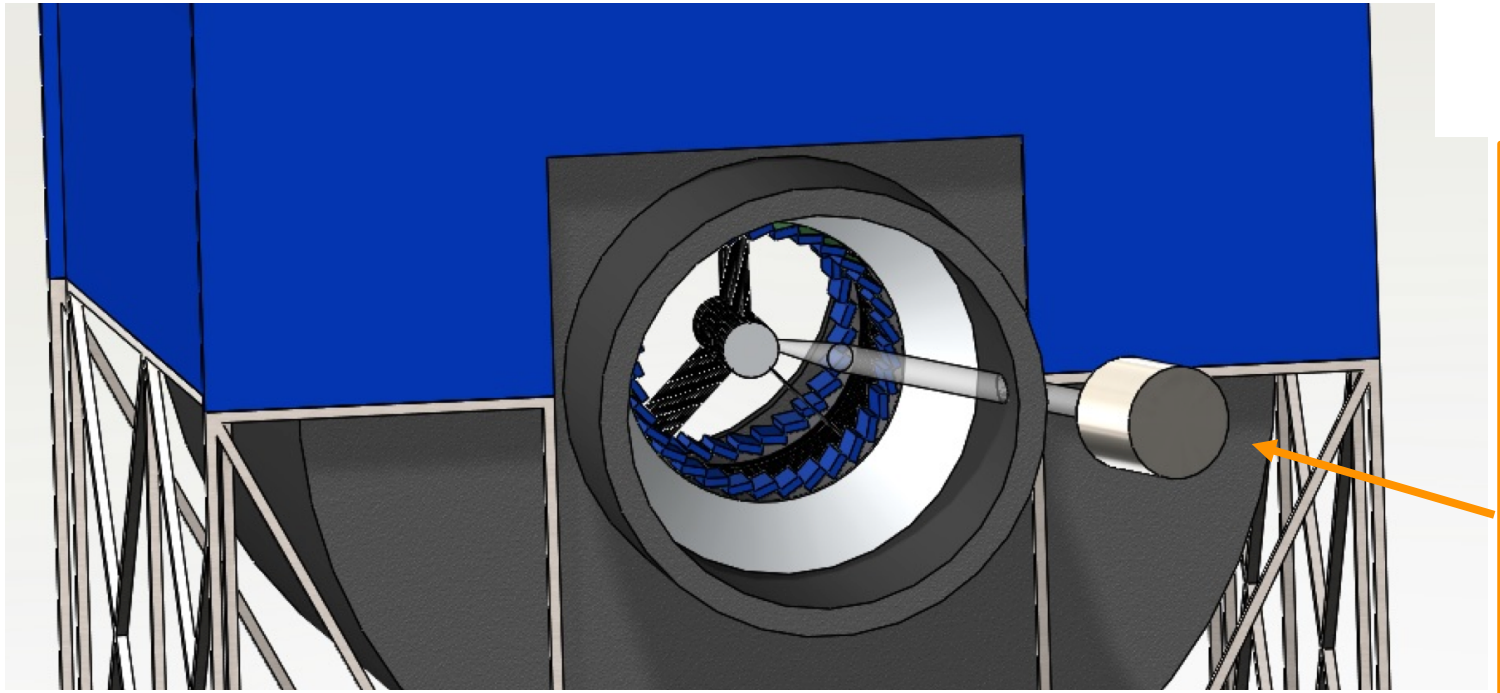


Muonic X-ray Measurement

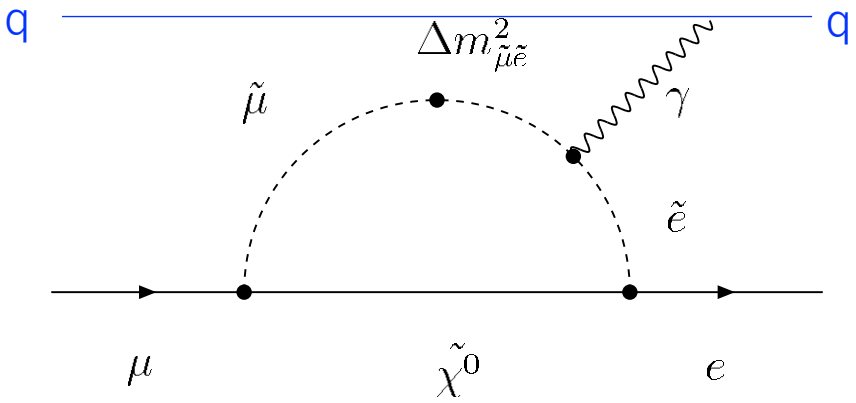
Transition	Energy (keV)	Relative Intensity (%)
2p → 1s	346.828 ± 0.002	79.8 ± 08
3d → 2p	66.11 ± 0.02	67.6 ± 1.7
3p → 1s	412.87 ± 0.05	7.62 ± 0.15
4p → 1s	435.96 ± 0.10	4.87 ± 0.10

# of muonic atoms is estimated by 2p->1s muonic X-ray detected by Germanium detector

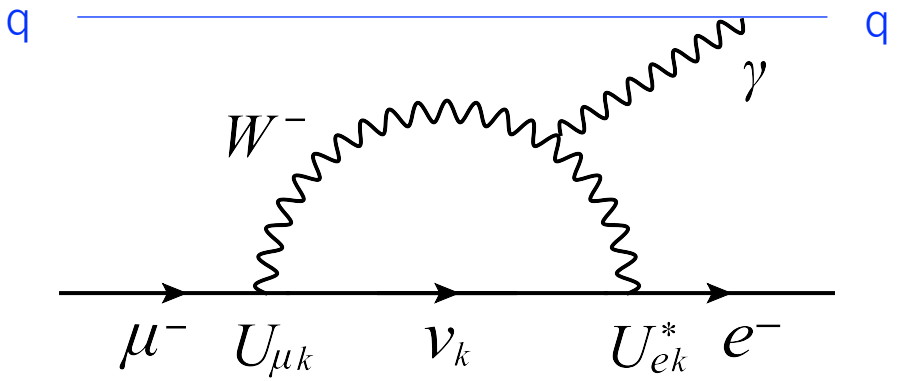




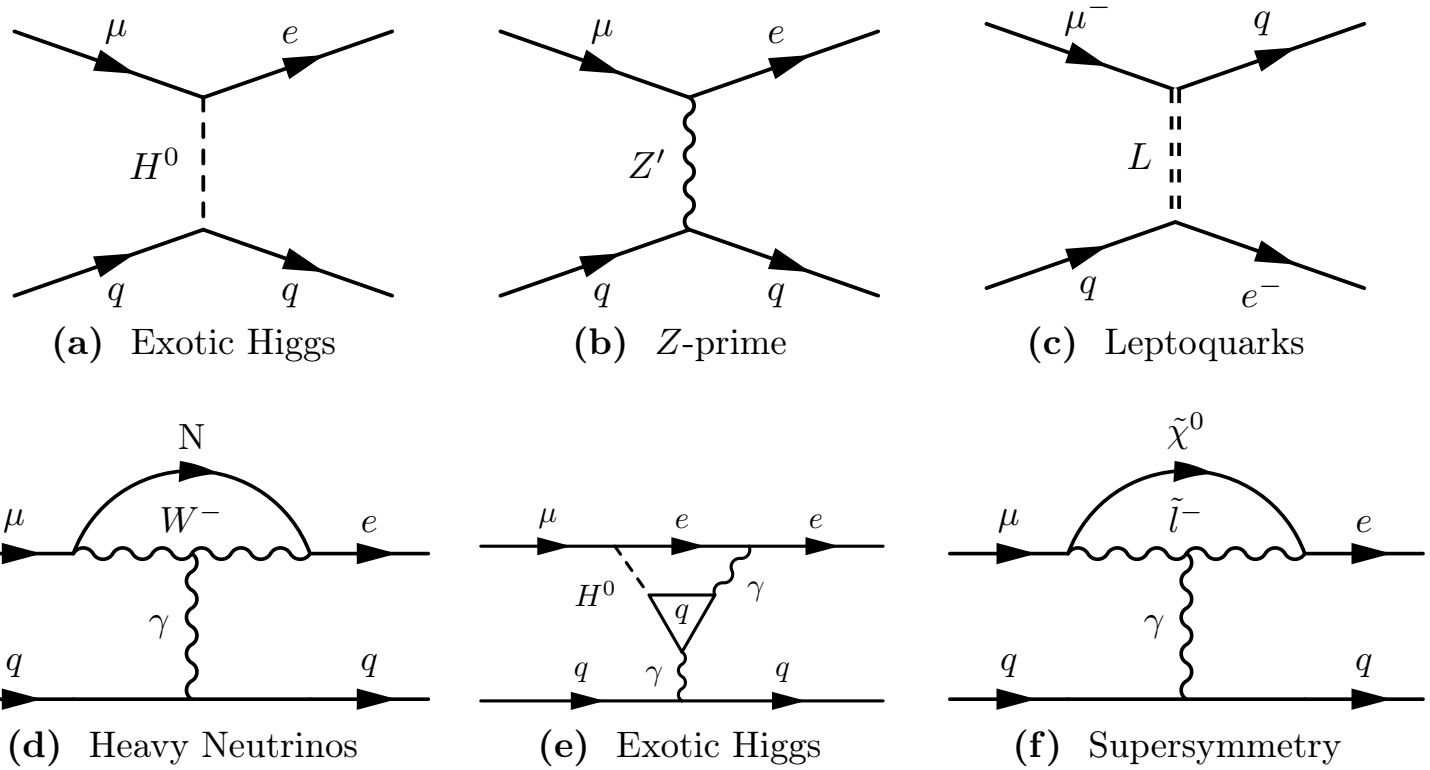
μ->eγ and μN->eN



in BSM (SUSY model)



in SM



diagrams of μ-e conv. process

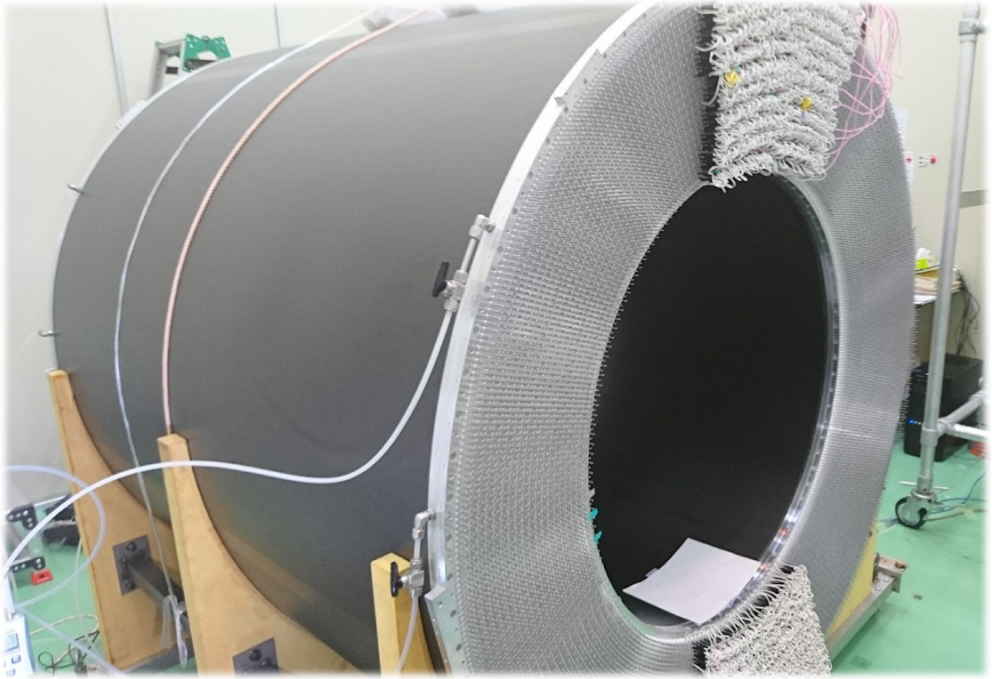
Status of the CDC

Prototype study has finished.

Construction of the CDC already completed. (June 2016)

Now under commissioning with cosmic ray

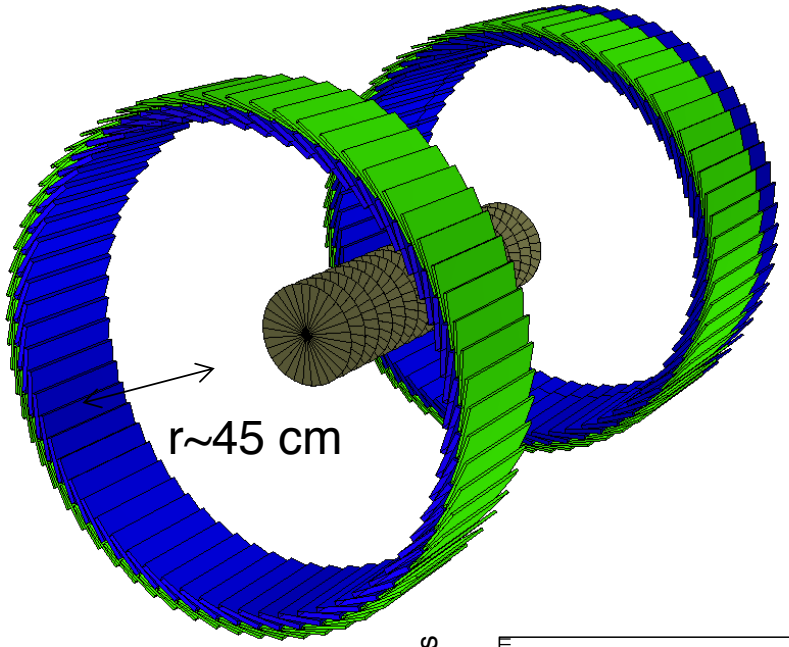
from upstream

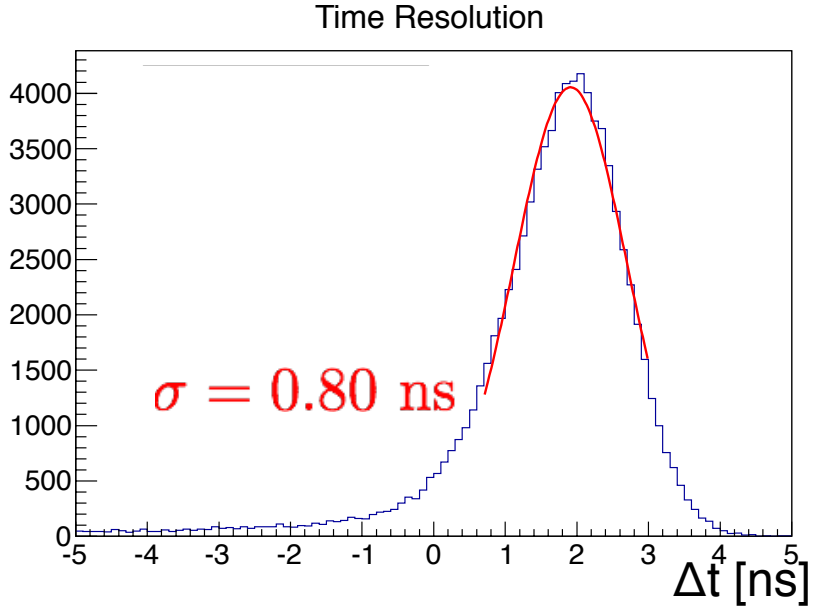


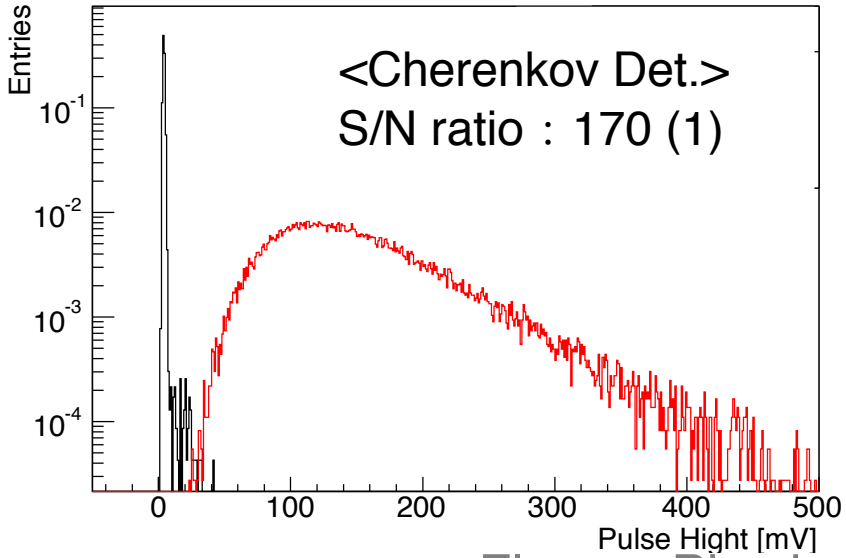
CDC (under cosmic ray test)

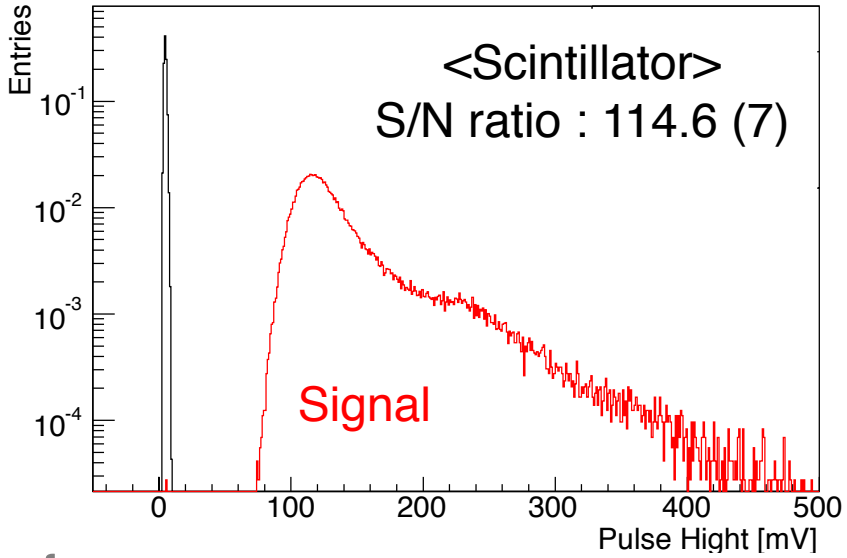
CDC wires (in construction phase)

Performance of the Trigger Hodoscopes



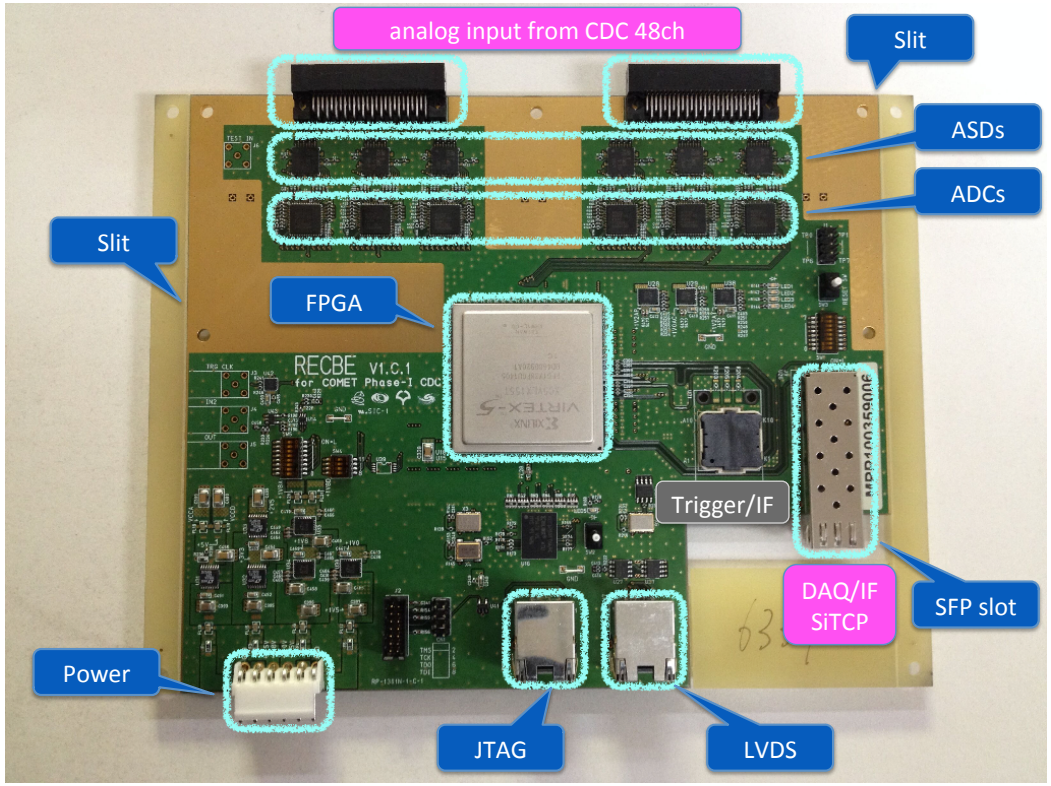




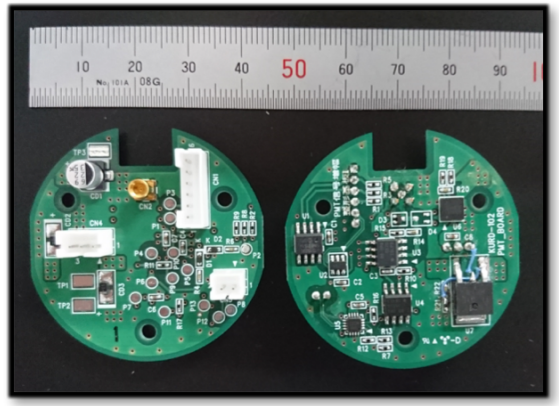


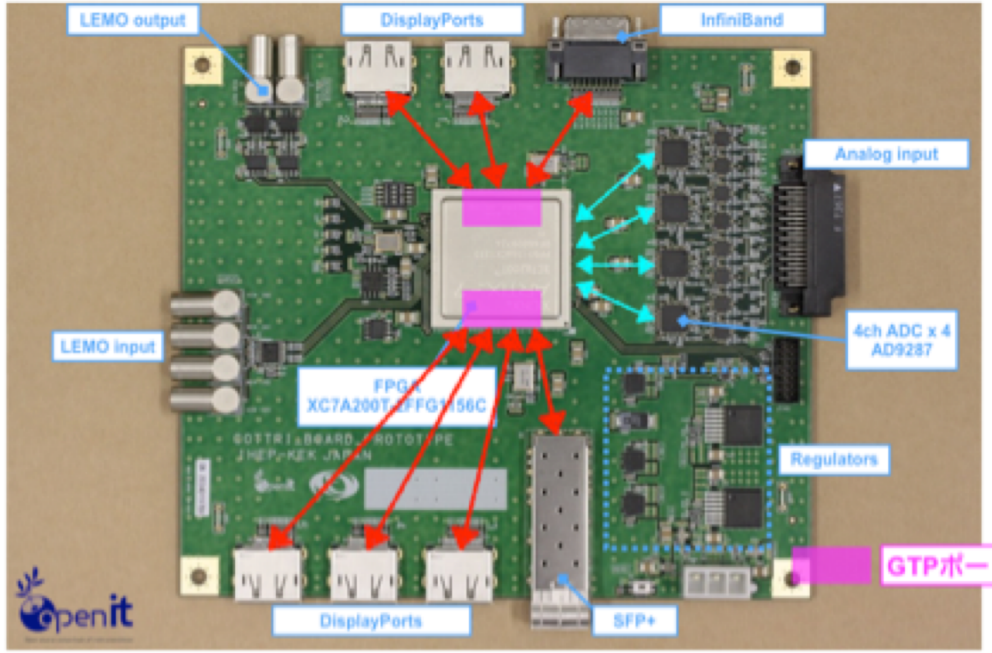
Electronics of the CyDet

Front-end board for CDC



Front-end board for CTH

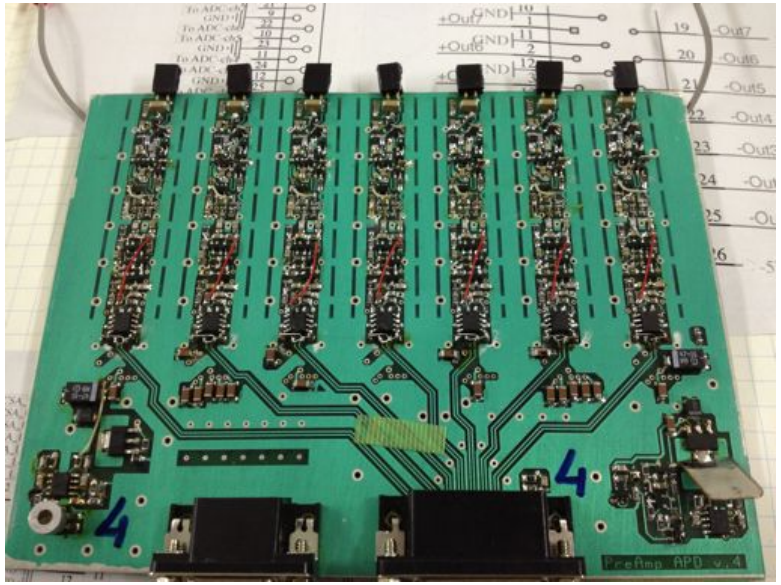




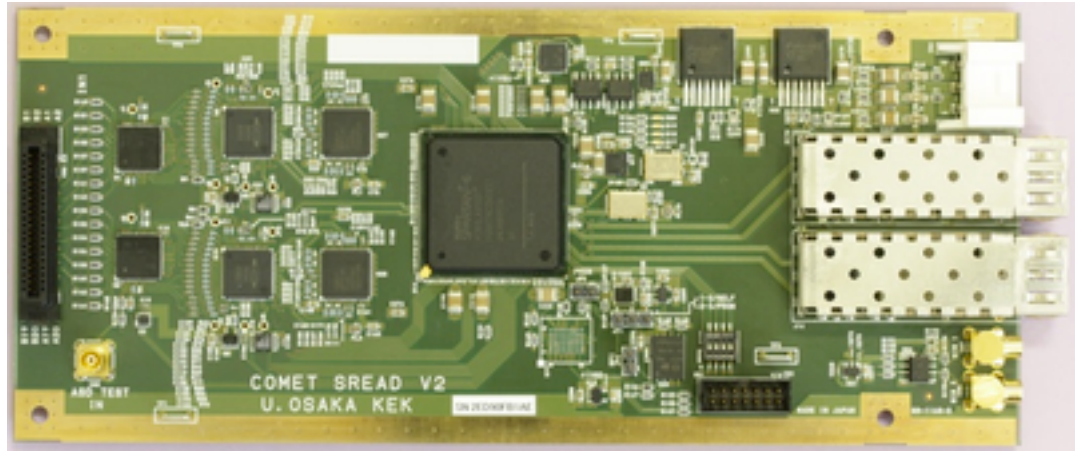
Trigger board (prototype)

Electronics of the StrECAL

ECAL Preamplifier



Mezzanine board + WFD board for ECAL (E-ROS)

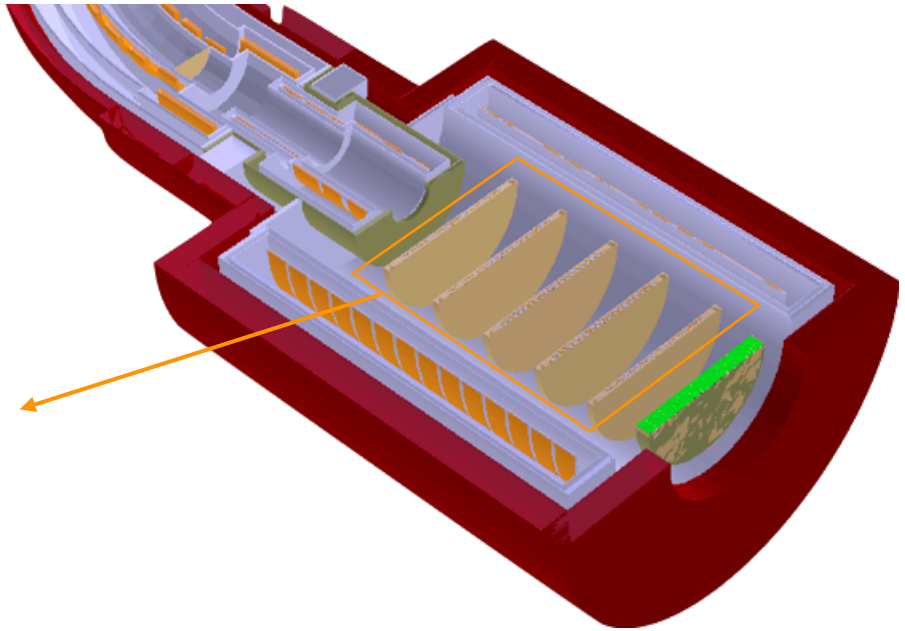


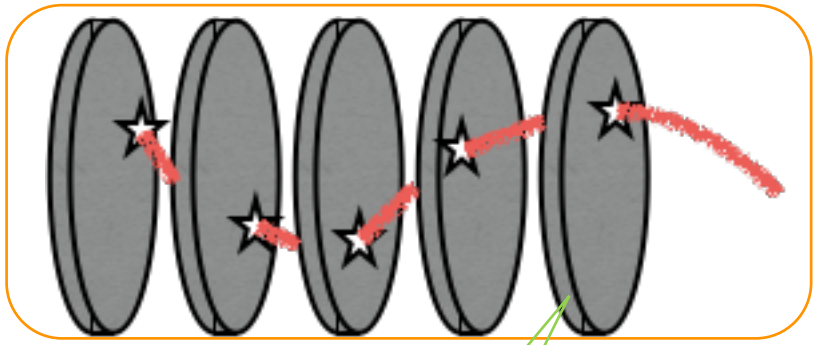
WFD board for the straw tube tracker (ROESTI)

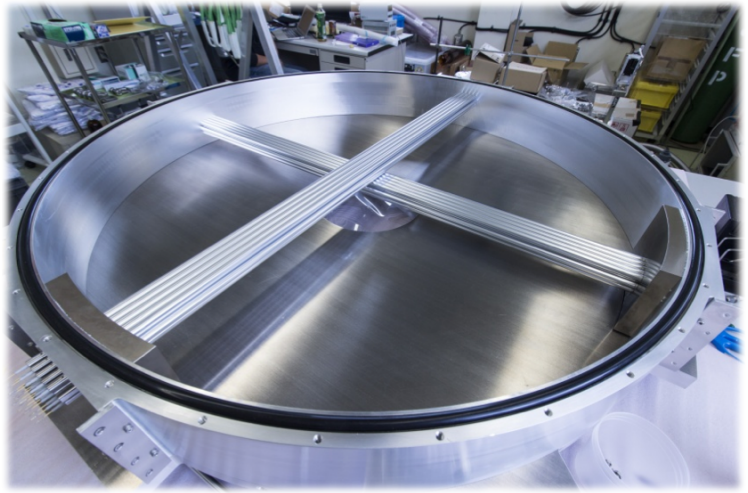
Straw Tube Tracker

Align straw tube trackers along X&Y axis. (= a “station”)
5 stations measure a track of incident charged particle.
→ Reconstruct momentum of the charged particle.

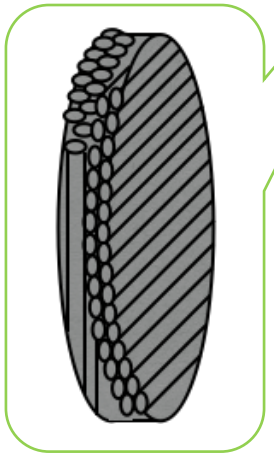
Readout waveforms with 1 GSPS by a Front-end board.
→ Can distinguish pileup events.

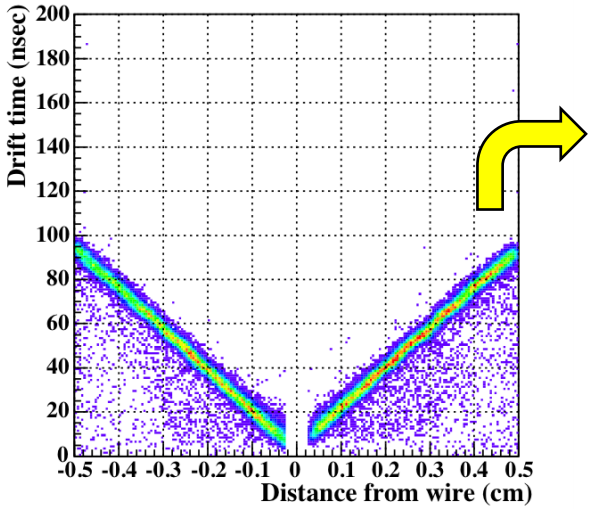


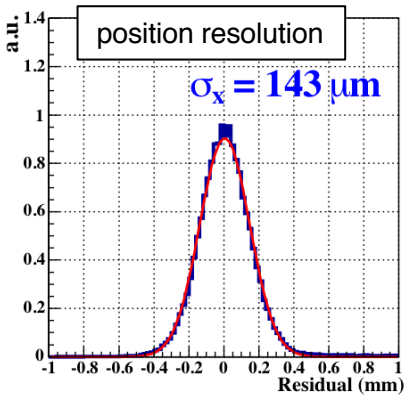




prototype







X-T plot

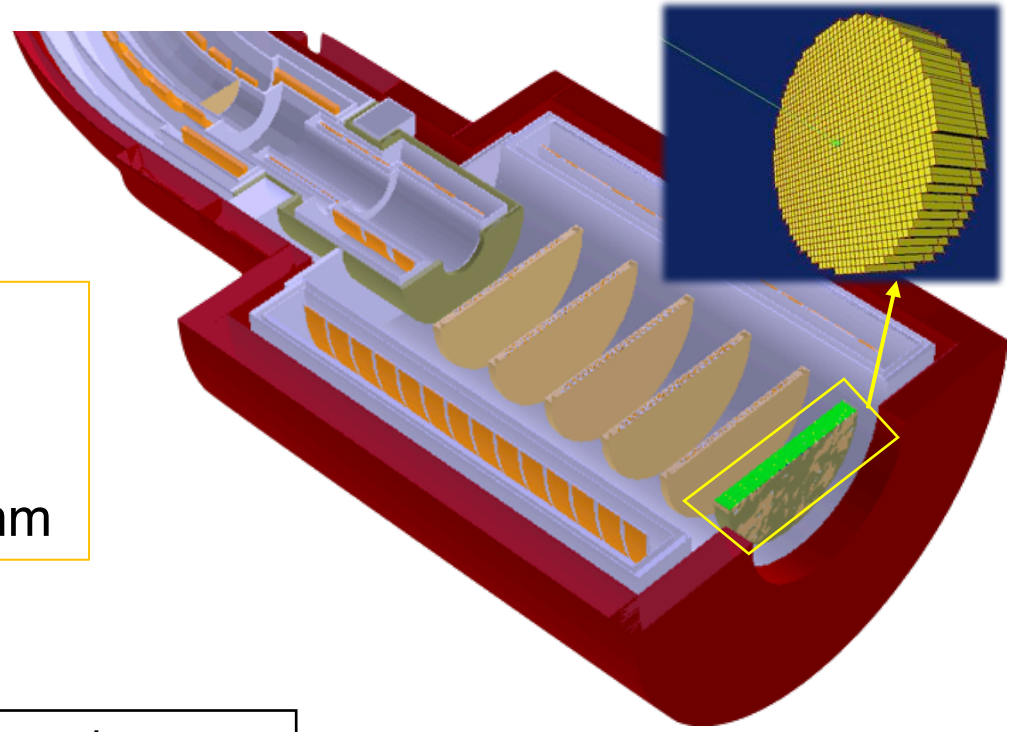
ECAL

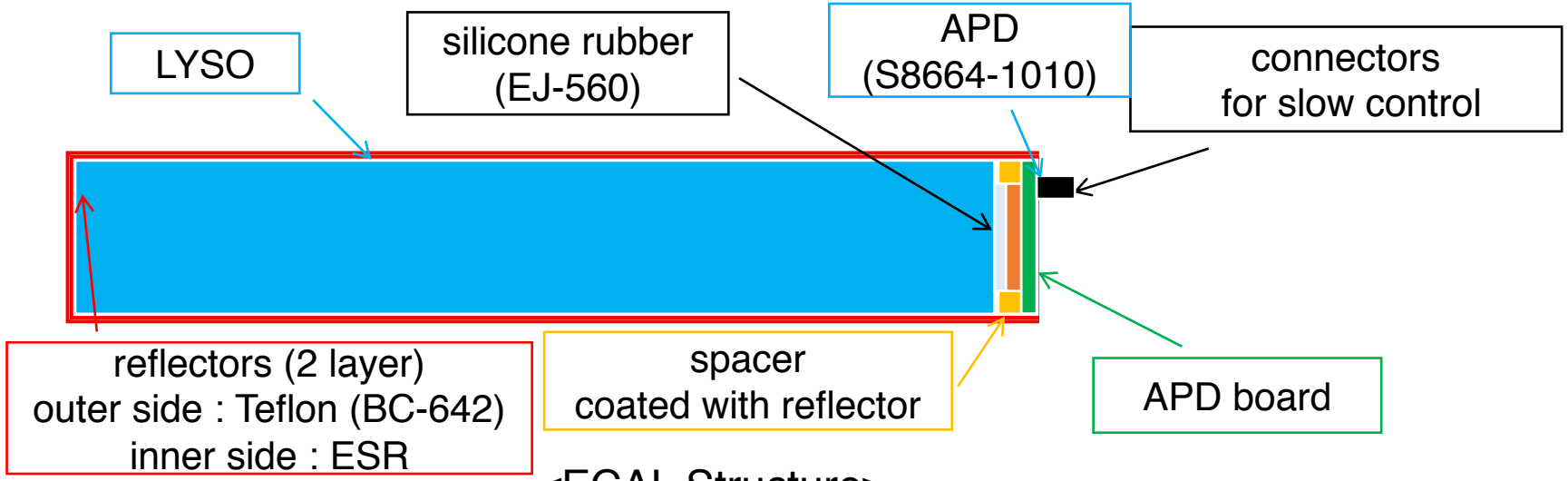
LYSO crystals（20 x 20 x 120 mm^3） + APD
-> placed cylindrically

(1) energy
(2) event timing
(3) hit position on ECAL
(4) supplying trigger
(5) particle ID
（use **momentum** measured by straw tube tracker）

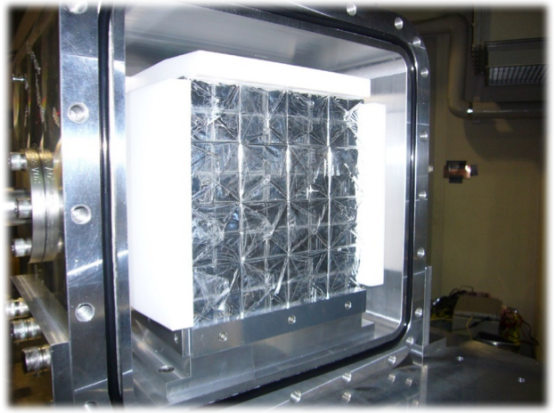
requirements
energy resolution : 5%
time resolution : 1 ns
position resolution : 10 mm

Record waveforms with 1 GSPS





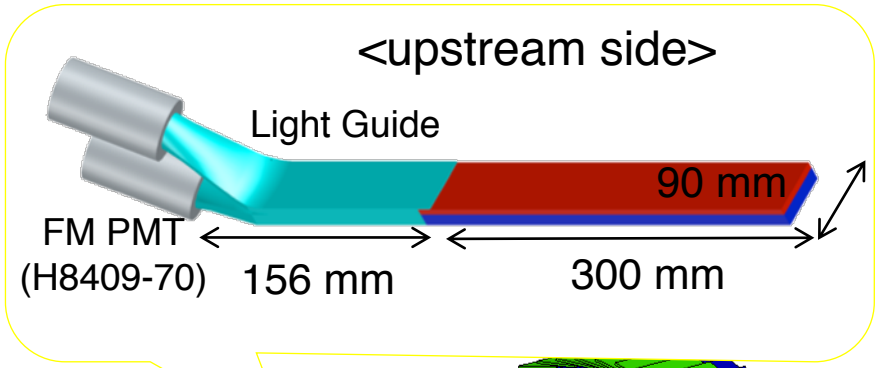
<ECAL Structure>

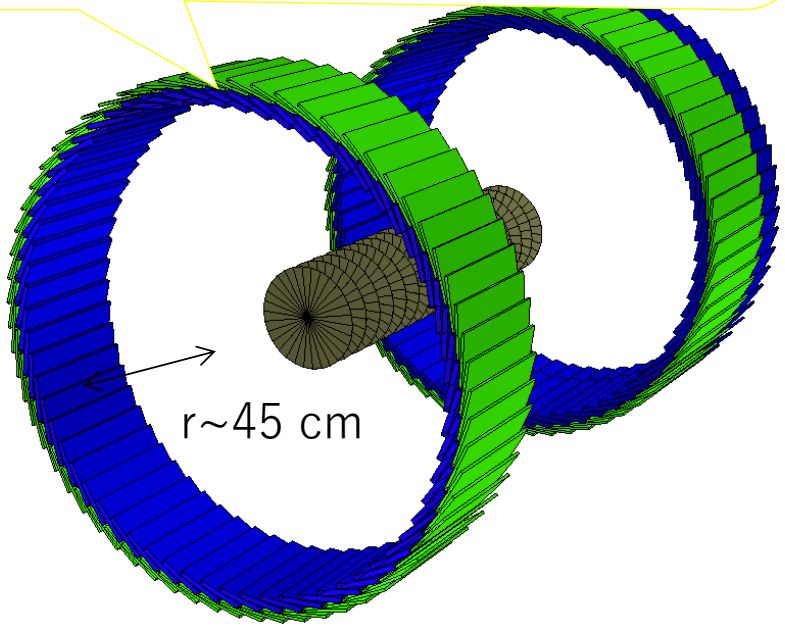


Prototype

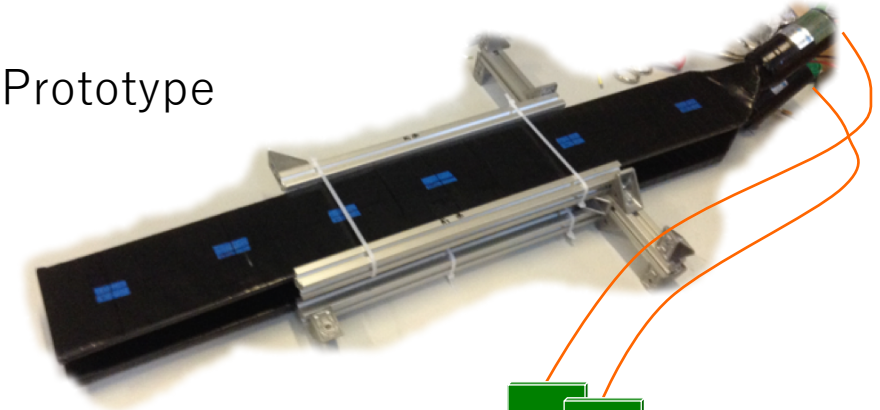
Trigger Hodoscopes

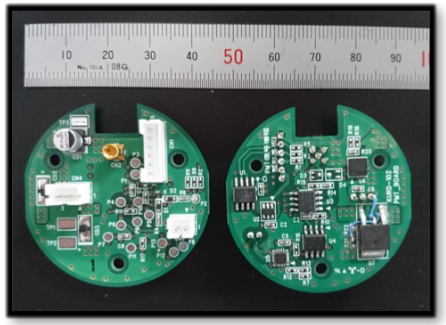
triggers only electrons with high momentum

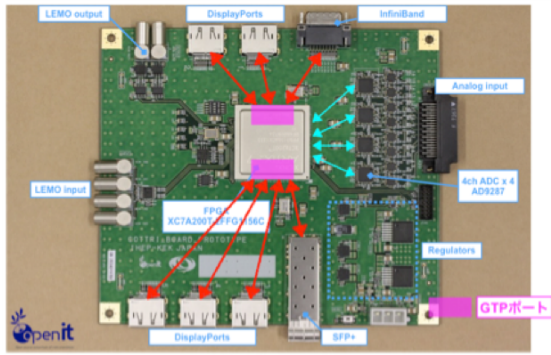


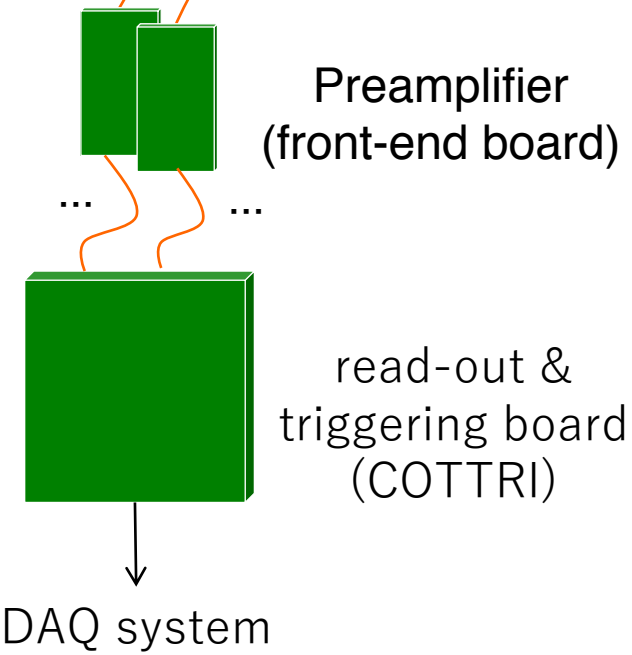


Prototype









COMET Phase-II

- Spectrometer transports electrons with high momentum to the detector system.
- measure momentum and energy with the tracker and ECAL respectively.