Search for Muon to Electron Conversion at J-PARC
- the COMET Experiment -

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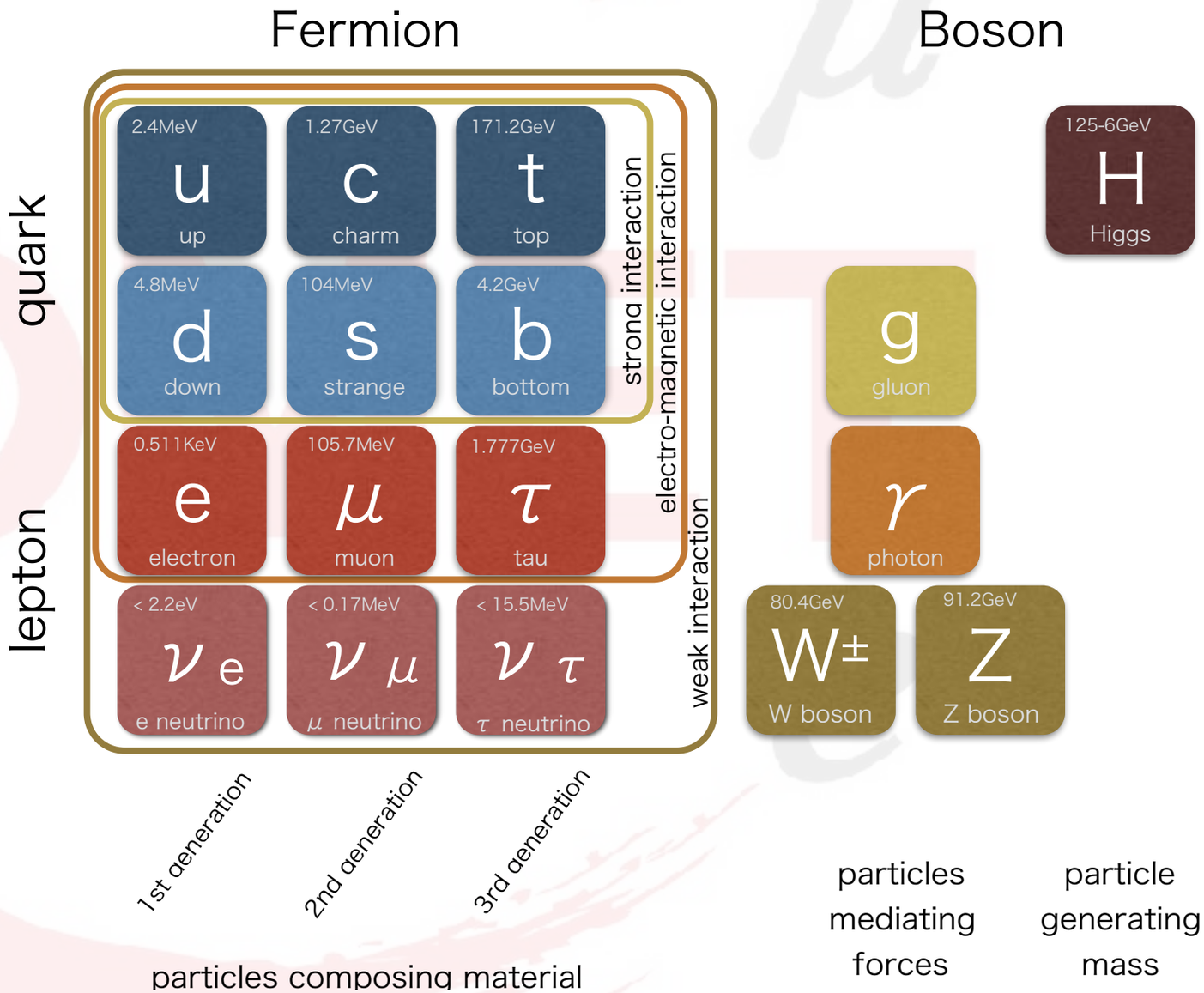
J-PARC

Contents

- Introduction
  - Flavor physics with muons
- COMET Experiment at J-PARC
- Summary

Flavor Physics

- Precise measurement of flavor structure
- Establishment of SM
- Indication of BSM?
  - muon g-2, proton radius, B leptonic decay …



Branching Ratio UL

Cosmic μ

π-beam

μ-beam

$\mu \to e\gamma$

$\mu \to 3e$

$\mu N \to eN$

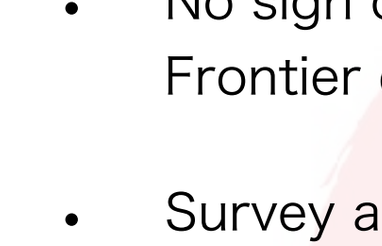
MEG
4.2×10^{-13}

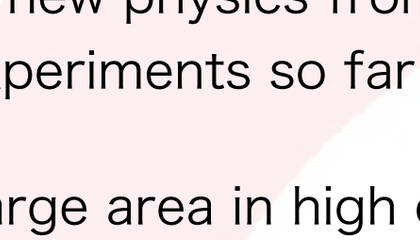
Year

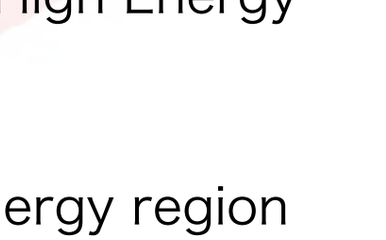
Bernstein & Cooper

cLFV Searches using muon

- No sign of new physics from High Energy Frontier experiments so far
- Survey a large area in high energy region using forbidden process in SM with extremely large statistics
  - Role of Flavor Physics
- No SM background in muon LFV process
- Intense muon beam at high-power proton machines

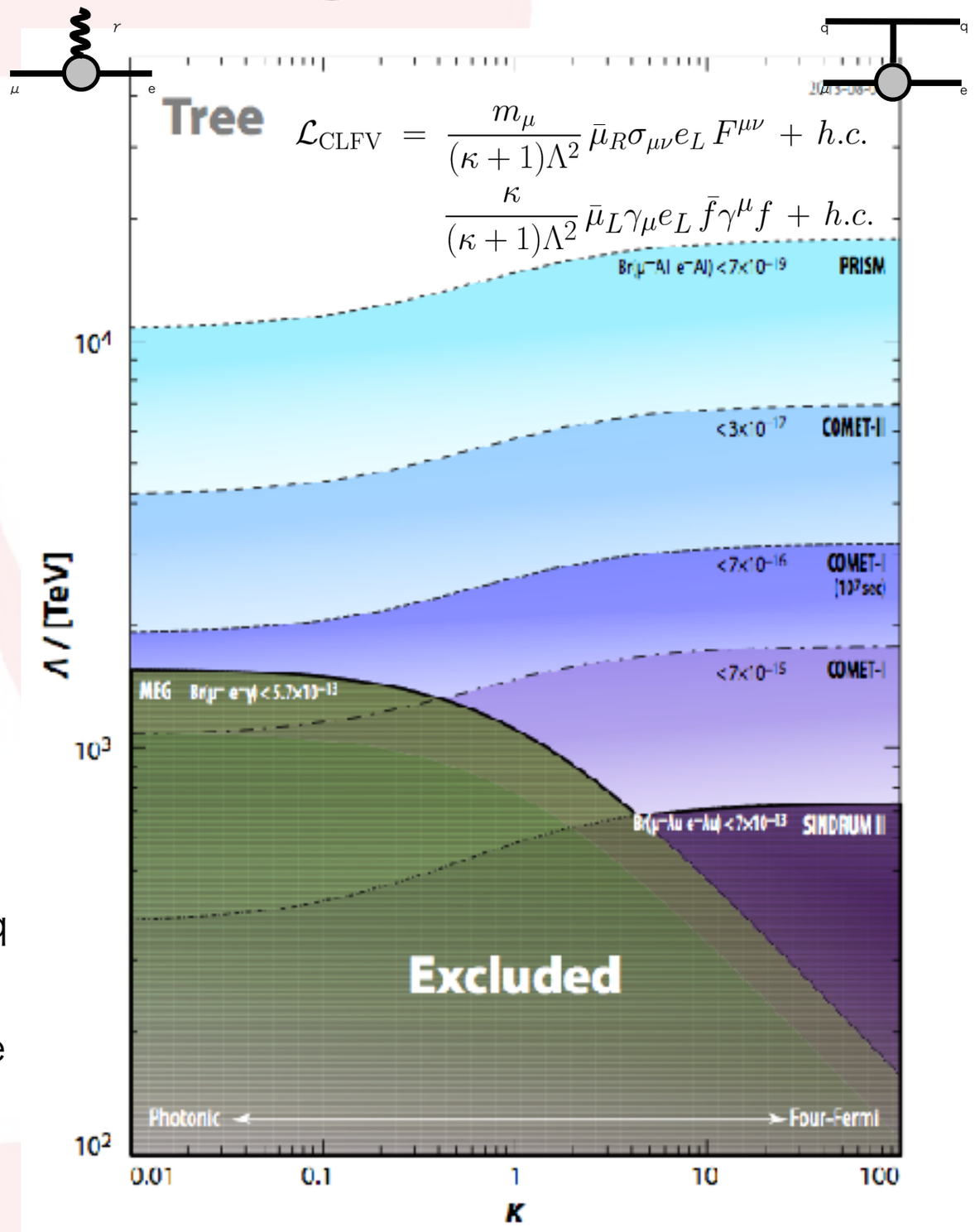






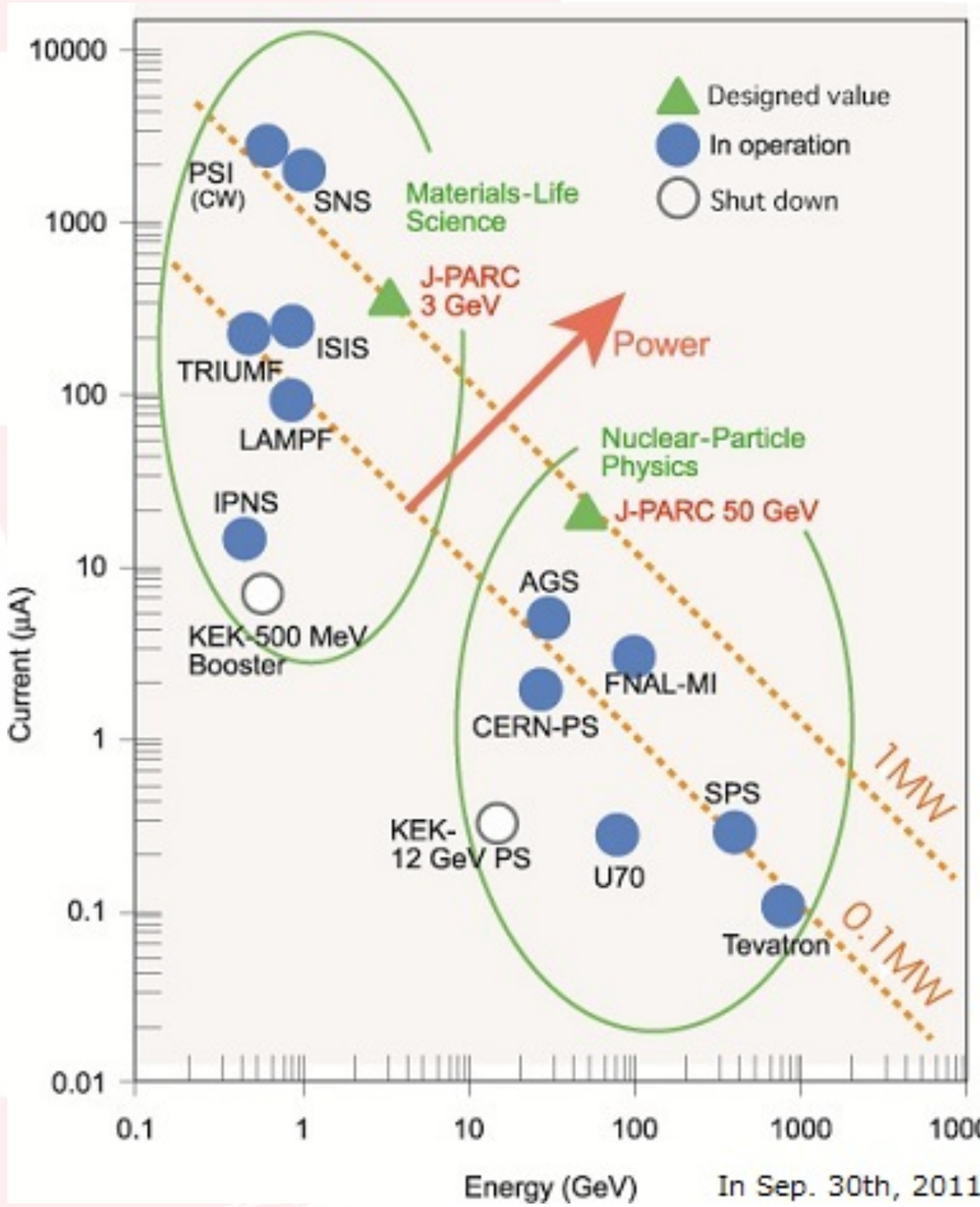
Final States

$e\gamma$ eee e



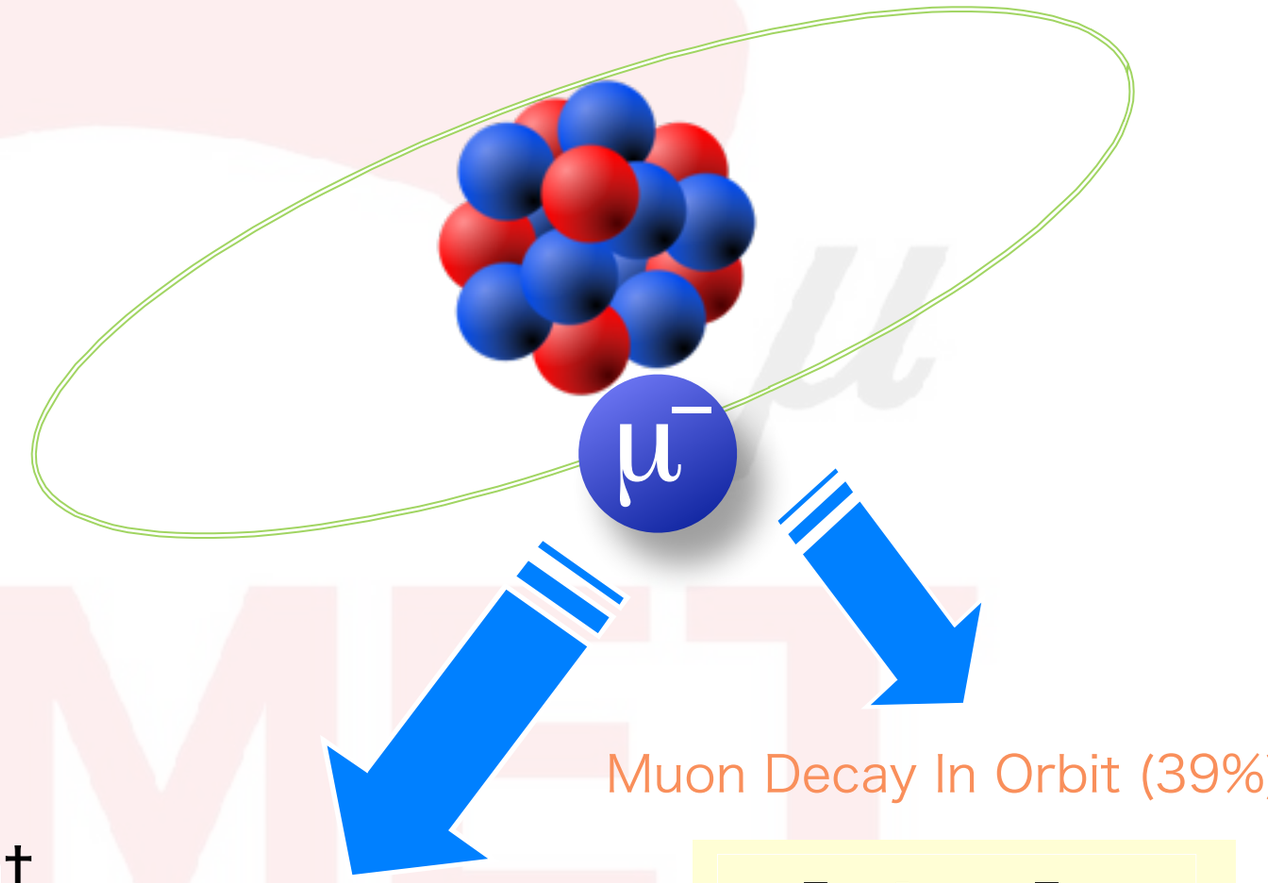
More Muons!

- Muons are produced from pion decays
- More muons produced in more pion decays
- Pion production yield depends on the power the proton driver
  - High-Power machine rather than High-Energy machine
  - Proton current



μ-e conversion search

- **Atomic capture of μ^-**
  - Decay in orbit (DIO)
    - electron gets recoil energy
  - Capture by nucleus
    - resultant nucleus is different



- $\tau_{\mu^N} < \tau_{\mu^{free}}$ ($\tau_{\mu^{Al}}$ = 860 nsec)

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

- $E_{\mu e}(Al) \sim m_\mu - B_\mu = 105MeV$
  - B_μ: binding energy of the 1s muonic atom

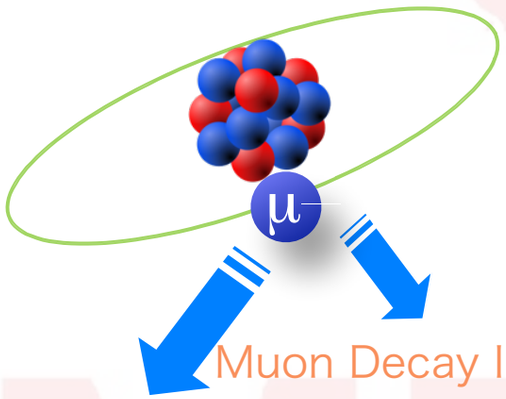
- **μ-e conversion**

μ-e conversion

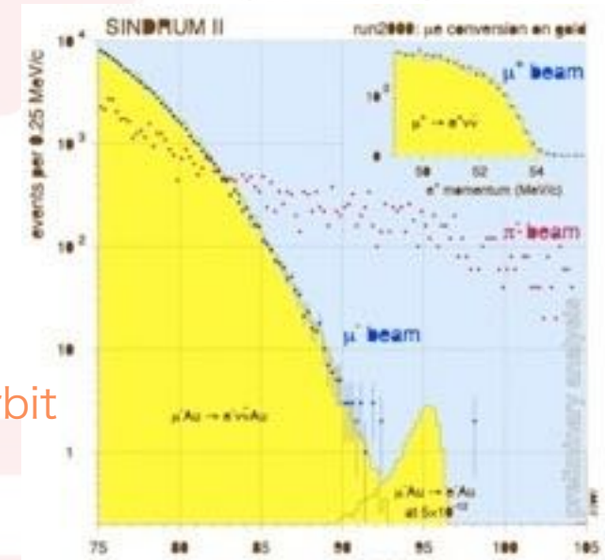
$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

Experimental Techniques

- Process : $\mu^-+(A,Z) \rightarrow e^-+(A,Z)$
  - A single mono-energetic electron
    - $E_{\mu e} \sim m_\mu - B_\mu$:105 MeV for Al
  - Delayed : ~1 μS
  - No accidental backgrounds



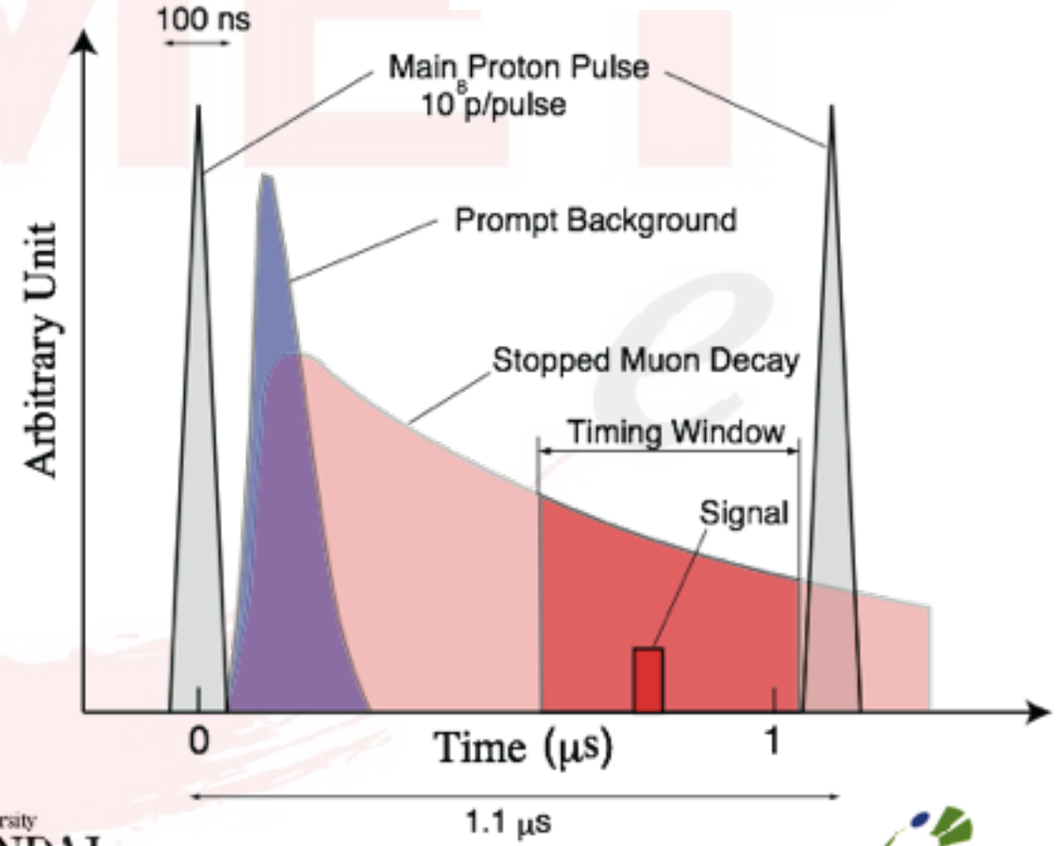
SINDRUM II



- Physics backgrounds
  - Muon Decay in Orbit (DIO)
    - E_e > 102.5 MeV (BR:10^{-14})
    - E_e > 103.5 MeV (BR:10^{-16})
  - Beam Pion Capture
    - $\pi^-+(A,Z) \rightarrow (A,Z\text{-}1)^* \rightarrow \gamma+(A,Z\text{-}1)$

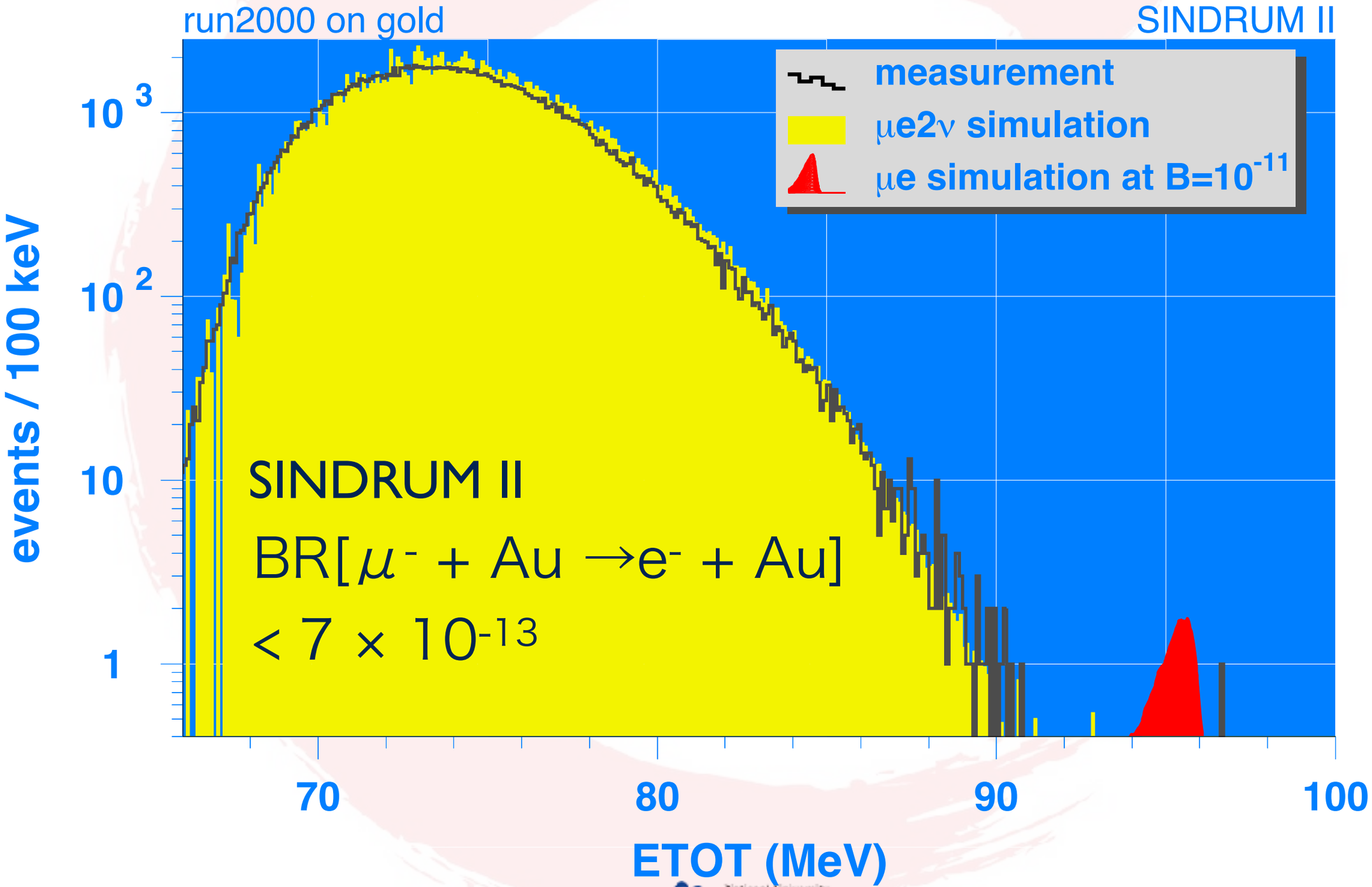
$$\gamma \rightarrow e^+ e^-$$

$$R_{ext} = \frac{\text{number of proton between pulses}}{\text{number of proton in a pulse}}$$



Mu-e Conversion

Electron Energy Spectrum

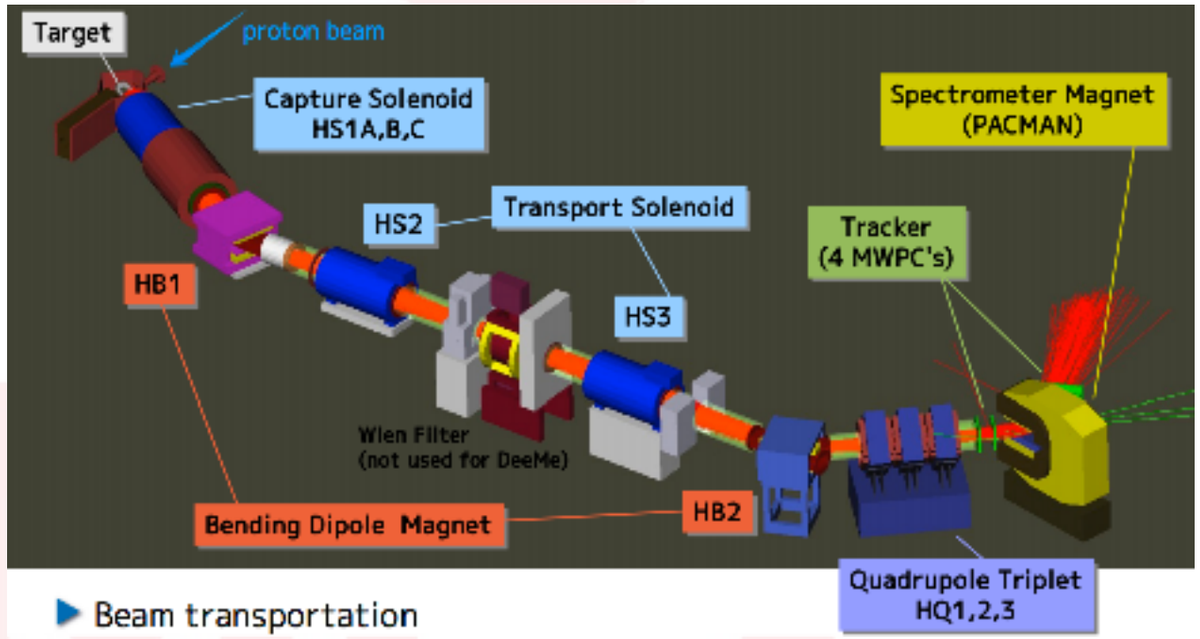


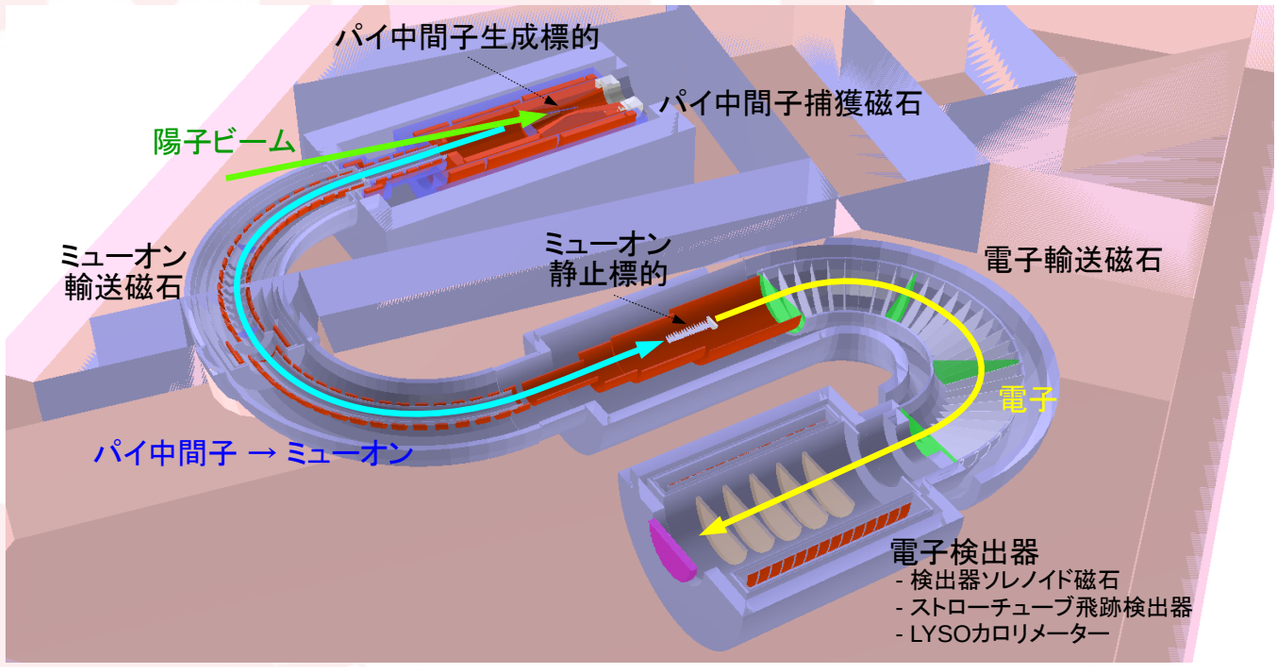
Mu-e Conversion Search Experiments

- **DeeMe**
  - ~$10^{-13\text{-}14}$ using C or SiC for muonic atom formation

- **COMET Phase-I & II**
  - Al target to reach the 10^{-14} sensitivity in Phase-I and 10^{-16} in Phase-II

- **Mu2e**
  - Al target to reach the 10^{-16} sensitivity





J-PARC Facility (KEK/JAEA)

LINAC
400 MeV

Rapid Cycle Synchrotron
Energy : 3 GeV
Repetition : 25 Hz
Design Power : 1 MW

Main Ring
Max Energy : 30 GeV
Design Power for FX : 0.75 MW
Expected Power for SX : > 0.1 MW

J-PARC Facility (KEK/JAEA)

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Neutrino beam to Kamioka

Material and Life Science Facility

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Nuclear and Particle Physics Exp. Hall

Main Ring
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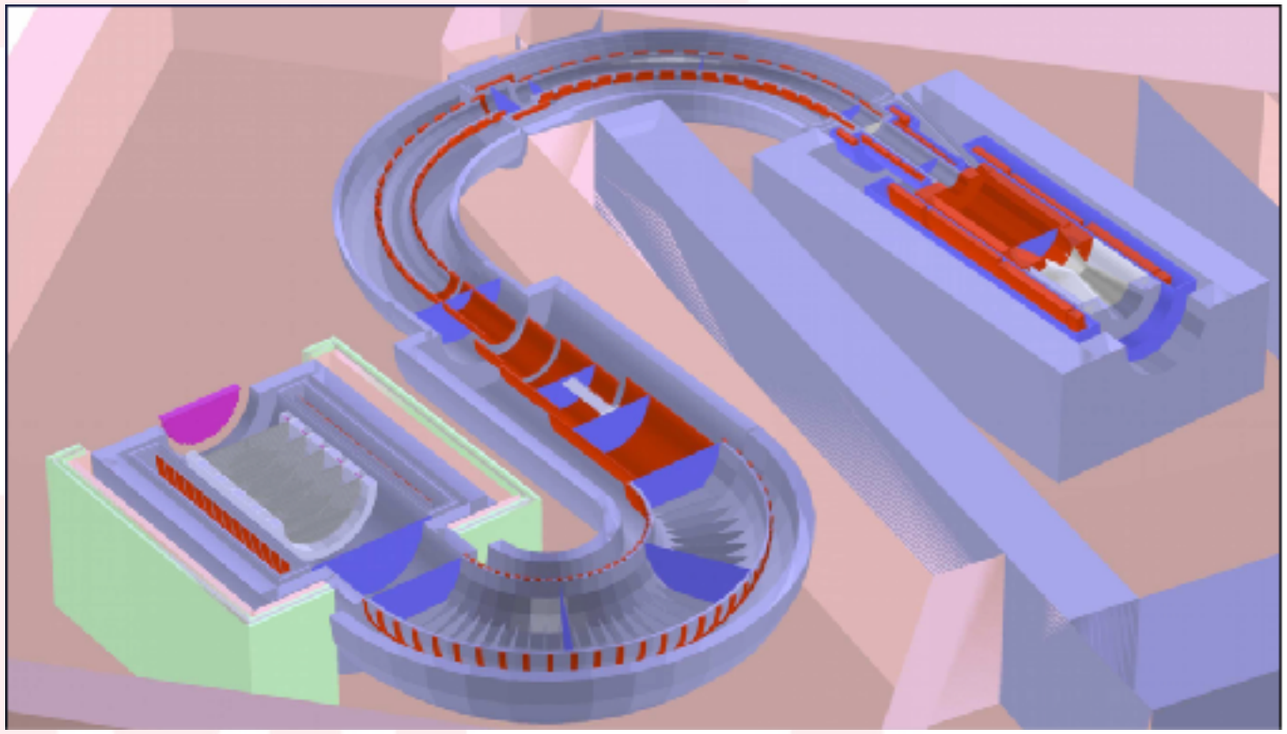
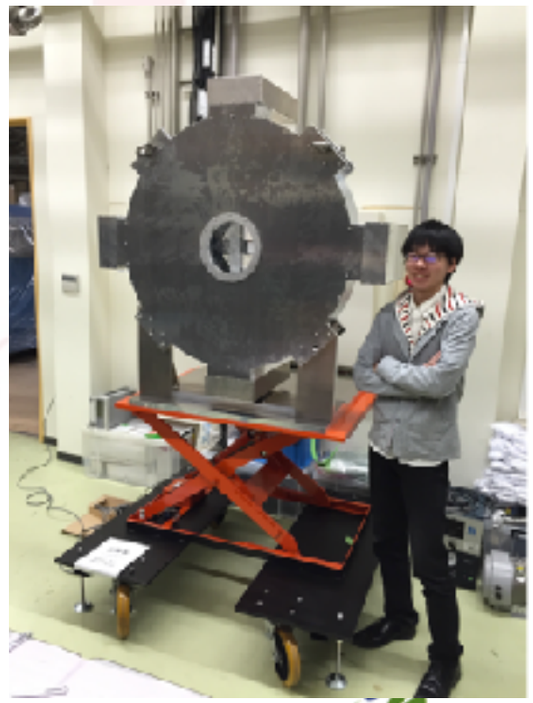
COMET at J-PARC

- **Target S.E.S. 2.6×10^{-17}**

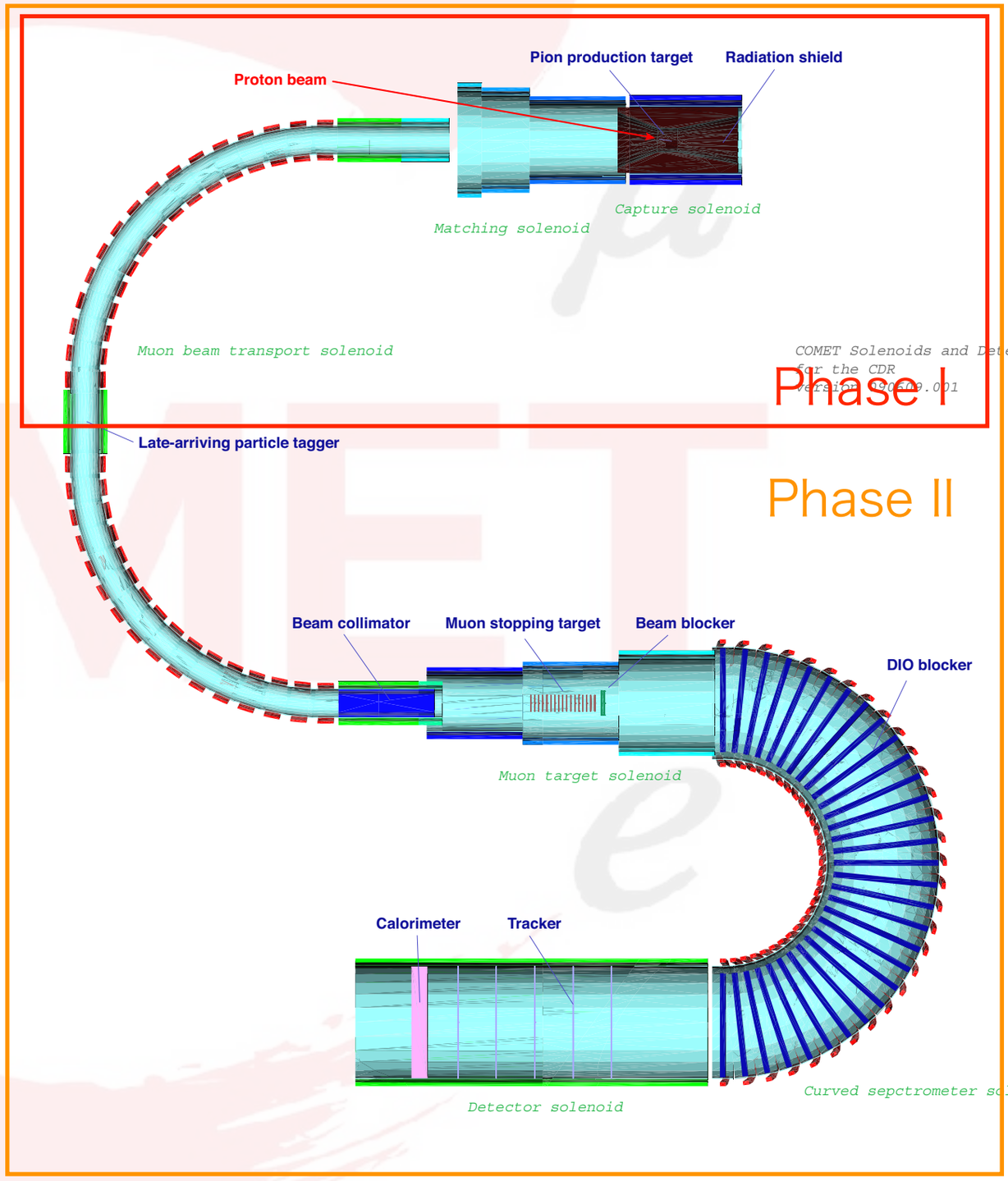
- Pulsed proton beam at J-PARC
  - Insert empty buckets for necessary pulse-pulse width
  - bunched-slow extraction
- pion production target in a solenoid magnet
- Muon transport & electron momentum analysis using C-shape solenoids
  - smaller detector hit rate
  - need compensating vertical field
- Tracker and calorimeter to measure electrons
- Recently staging plan showed up. The collaboration is making an effort to start physics DAQ as early as possible under this.
  - **Phase-I 8GeV-3.2kW, < 10^{-14}**
  - **Phase-II 8GeV-56kW, < 10^{-16}**





COMET Phase I & II

- Phase I
  - Beam background study, achieve an intermediate sensitivity of < 10^{-14}
    - 8GeV, 3.2kW, 150 days of DAQ
- Phase II
  - 8GeV, 56kW, 1 year DAQ to achieve the COMET final goal of < 10^{-16} sensitivity



COMET Phase-I

Status

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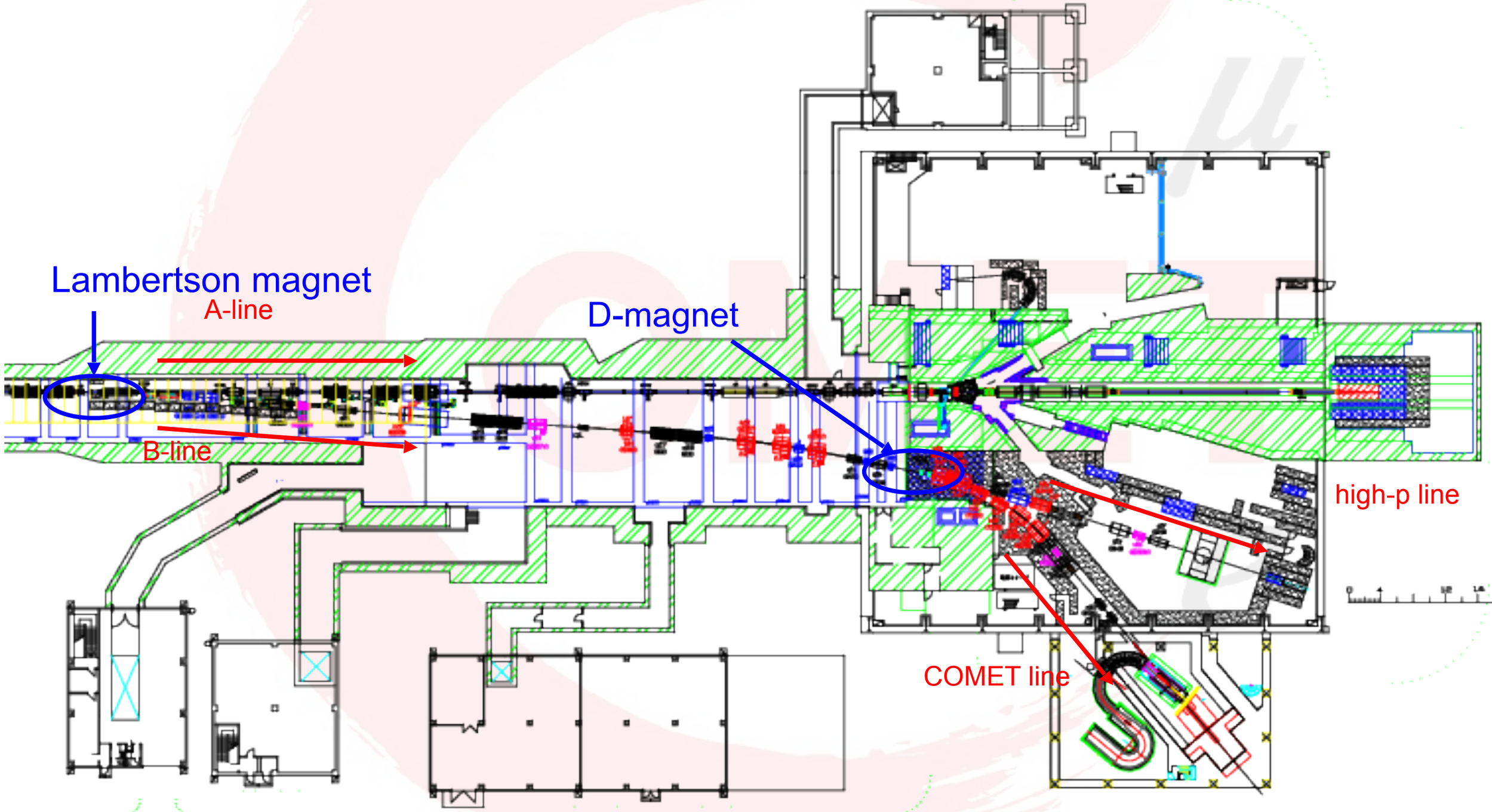
COMET Primary Beamline



y Beamline

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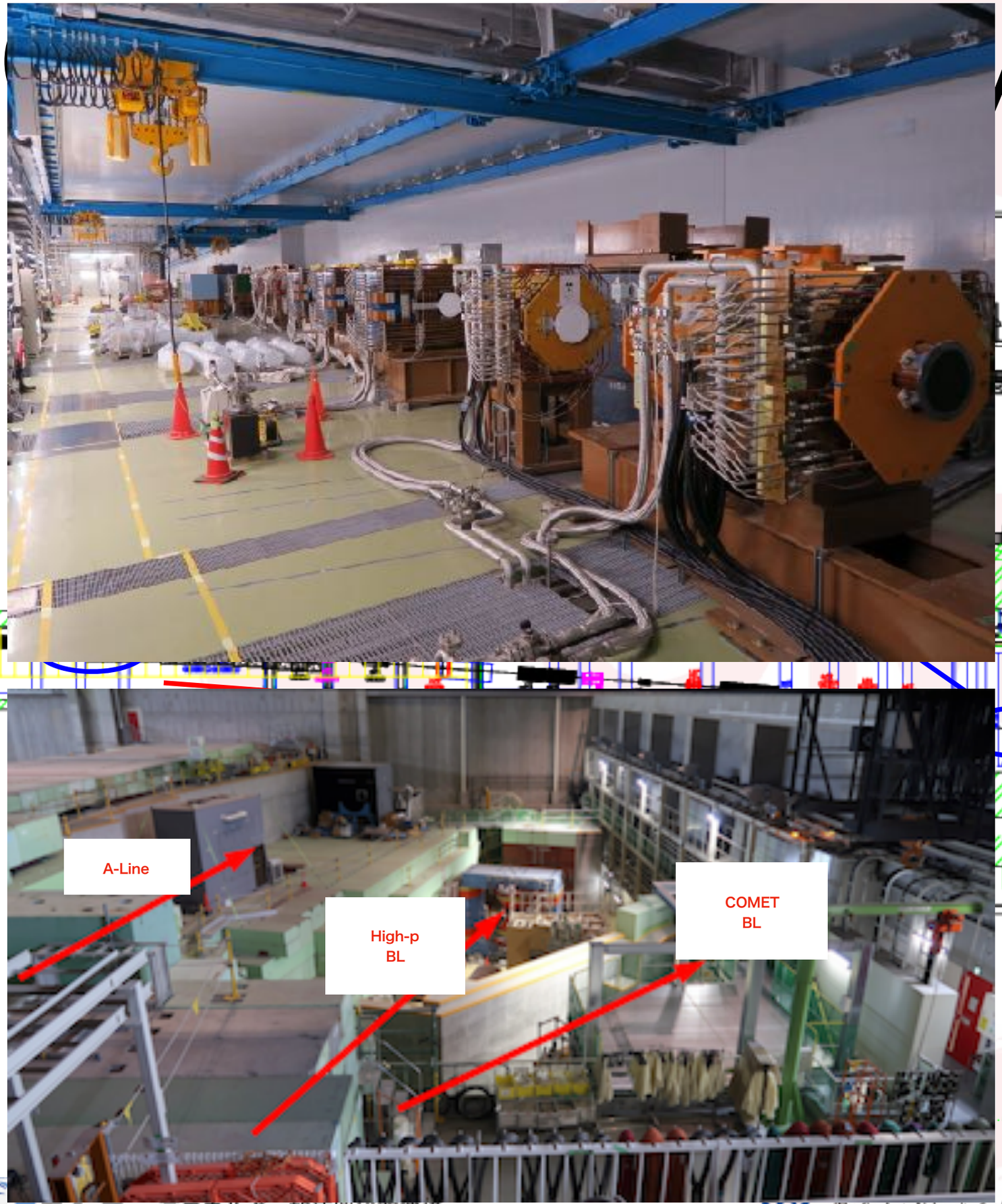
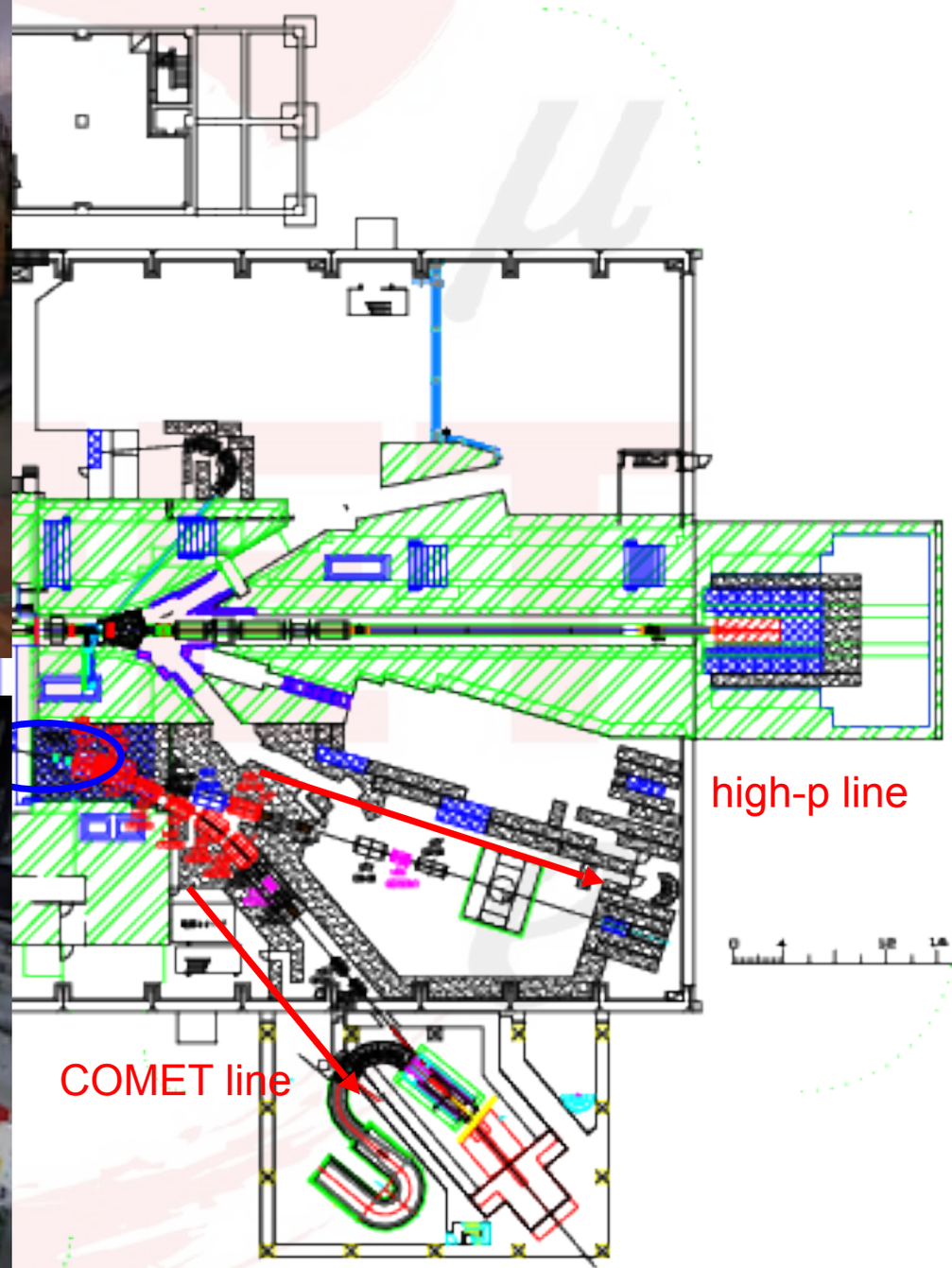
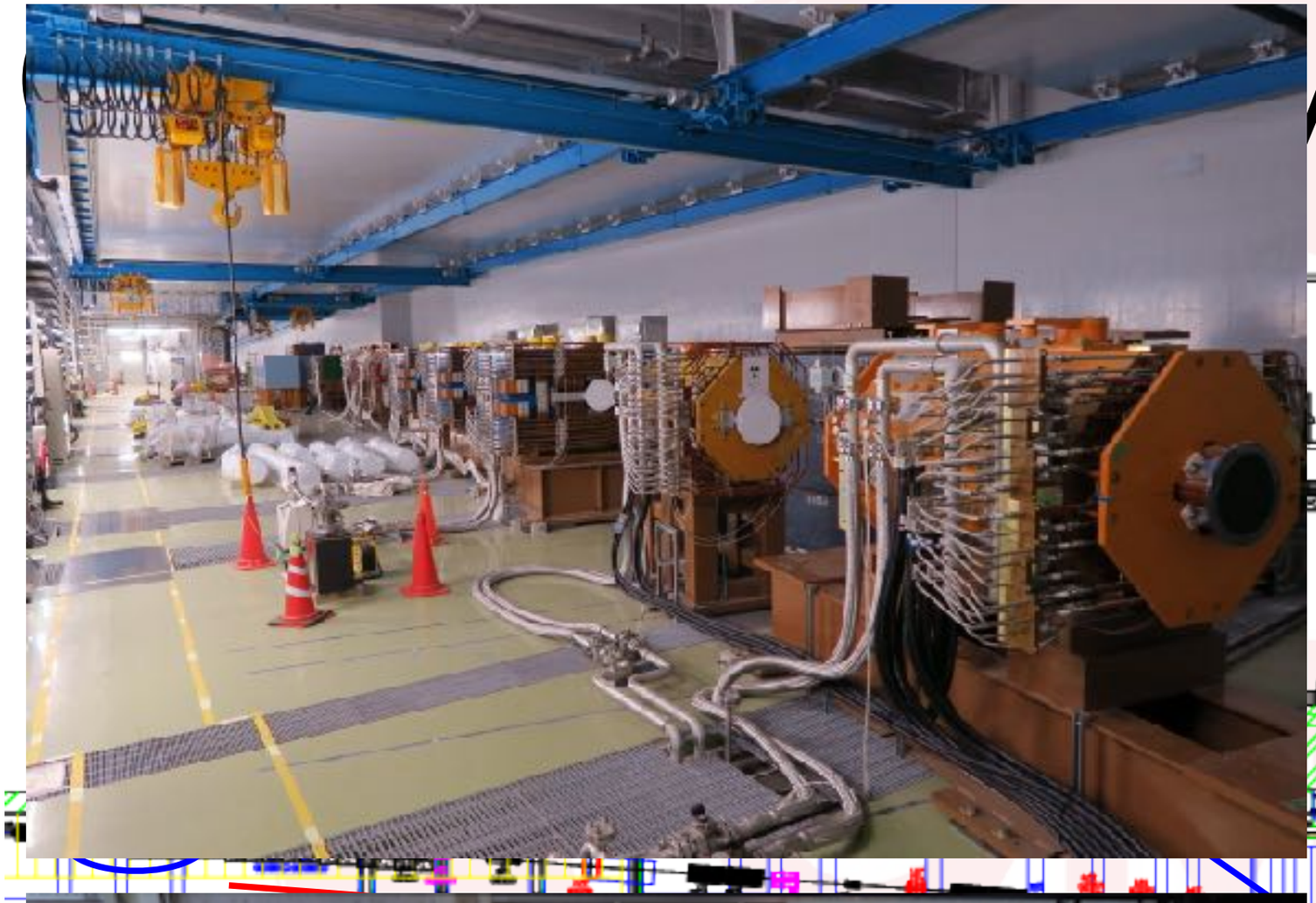
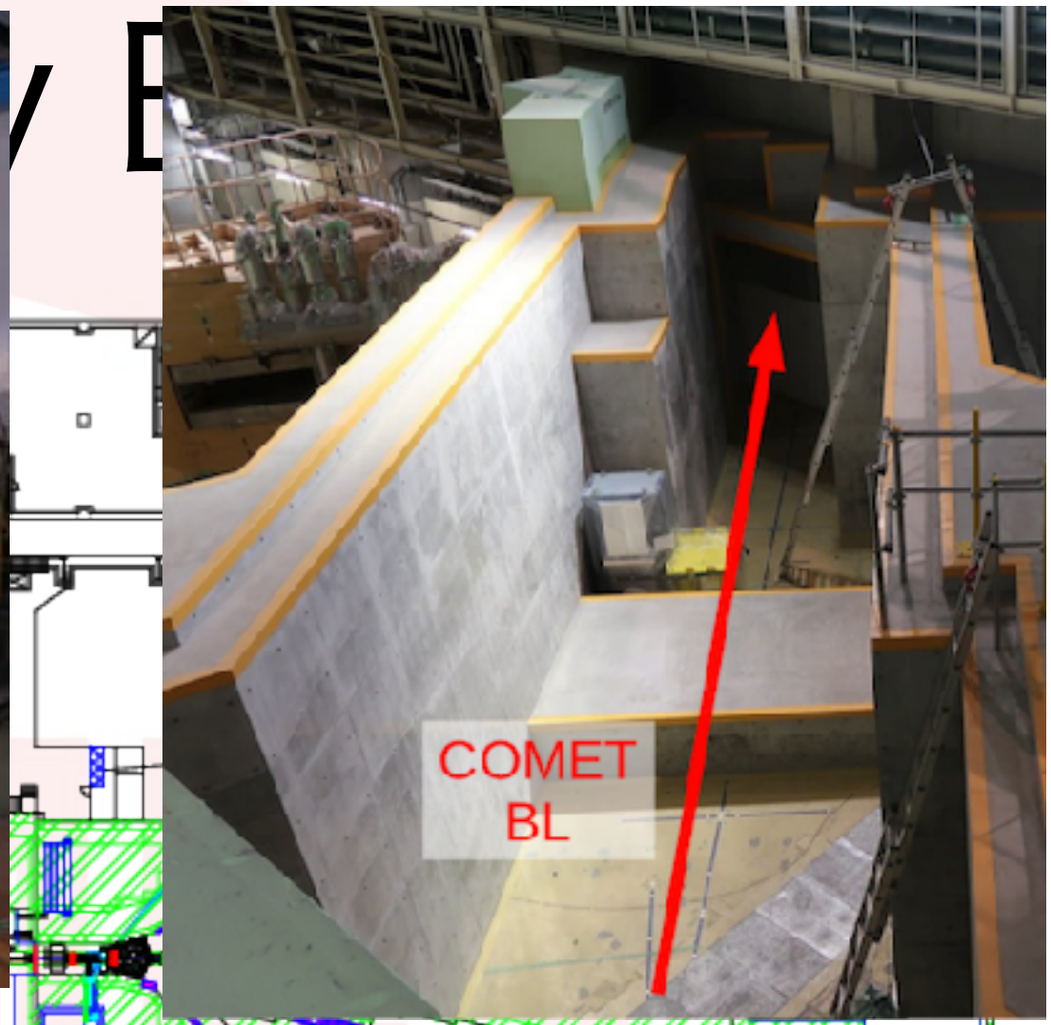
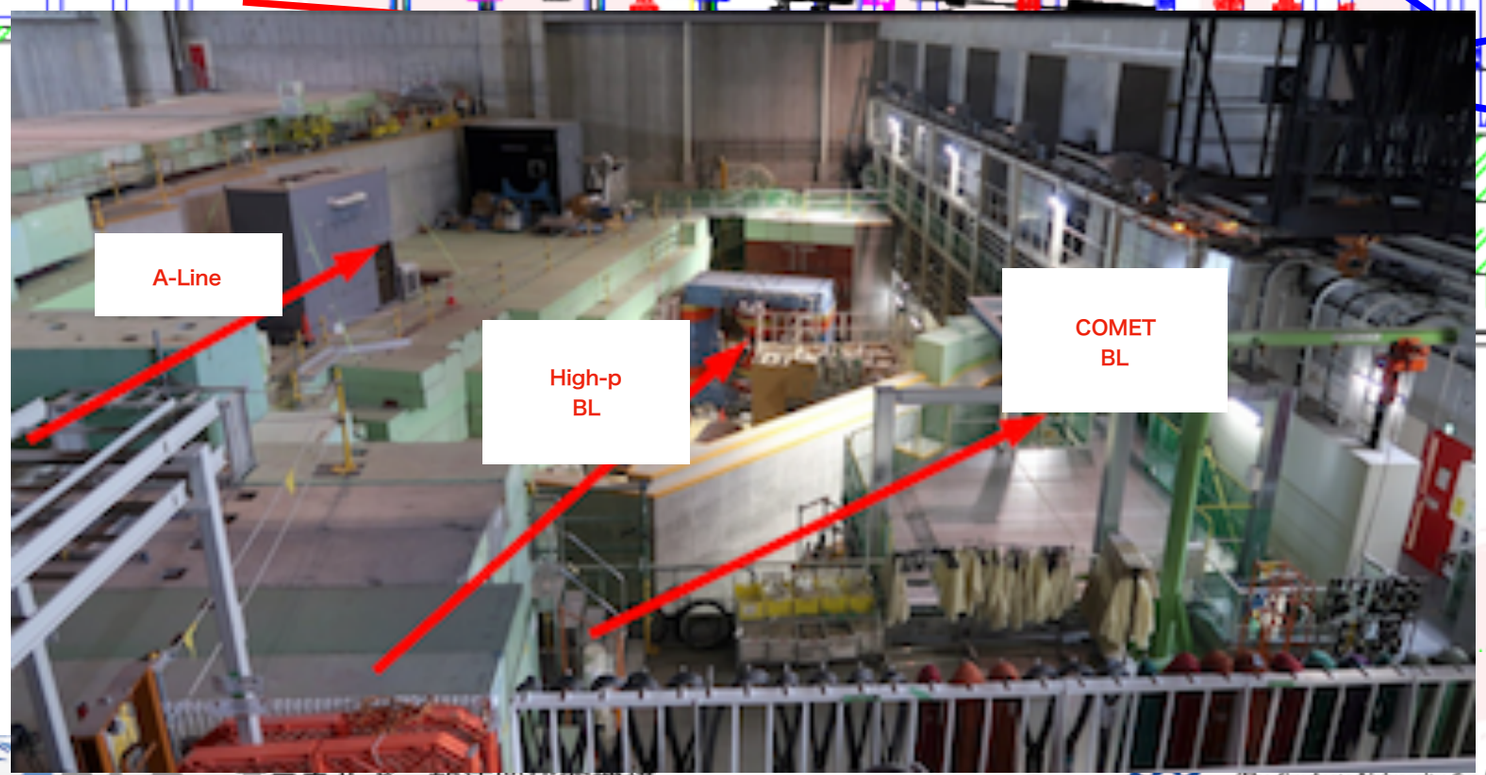
y Beamline





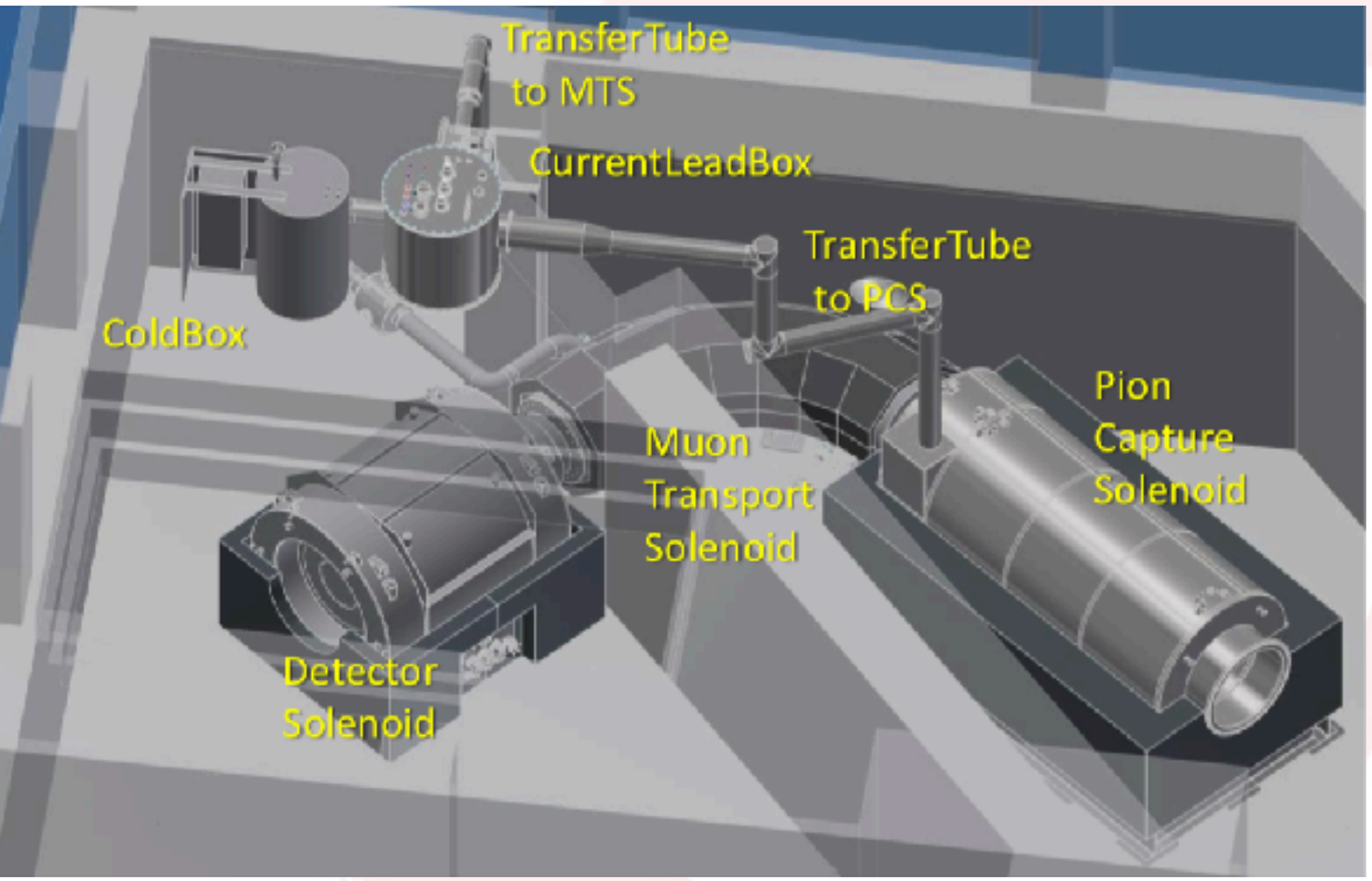


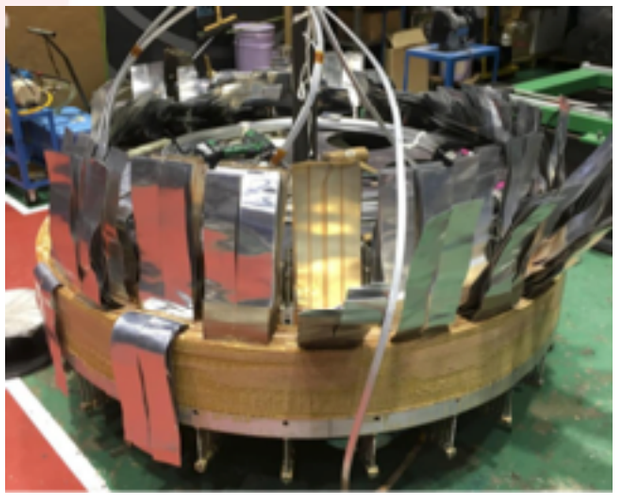

COMET
BL

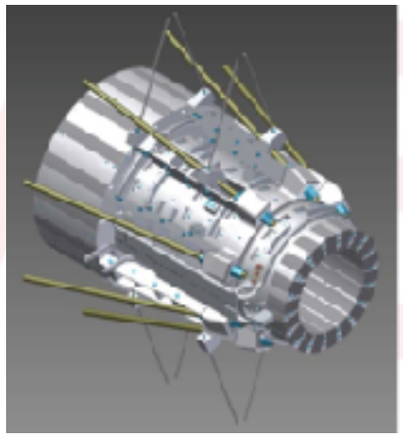

A-Line
High-p
BL
COMET
BL

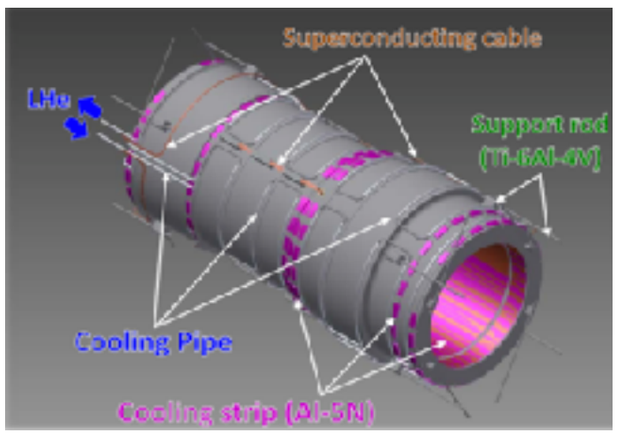
high-p line
COMET line

Solenoid Magnet System



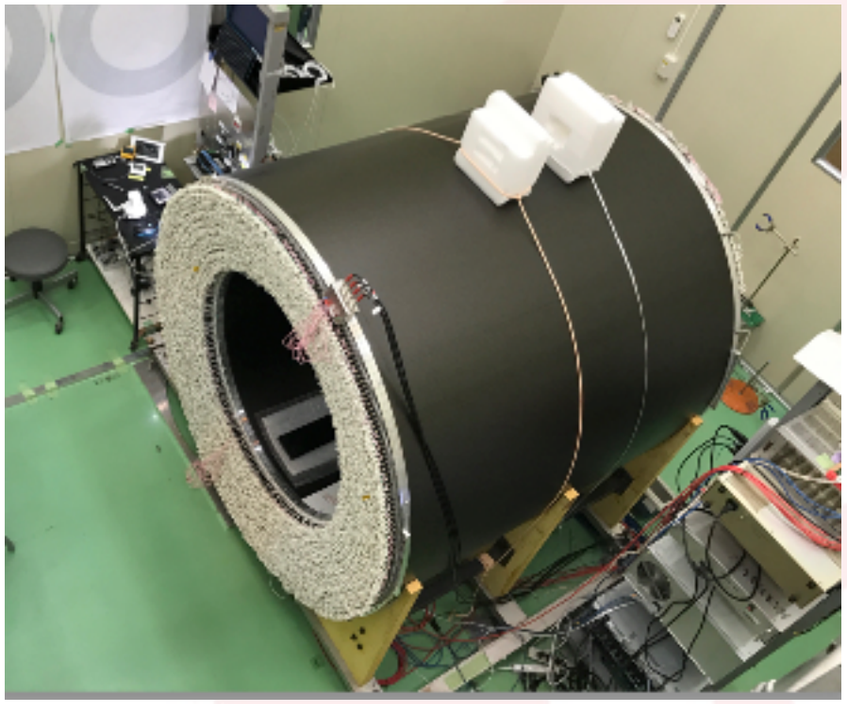


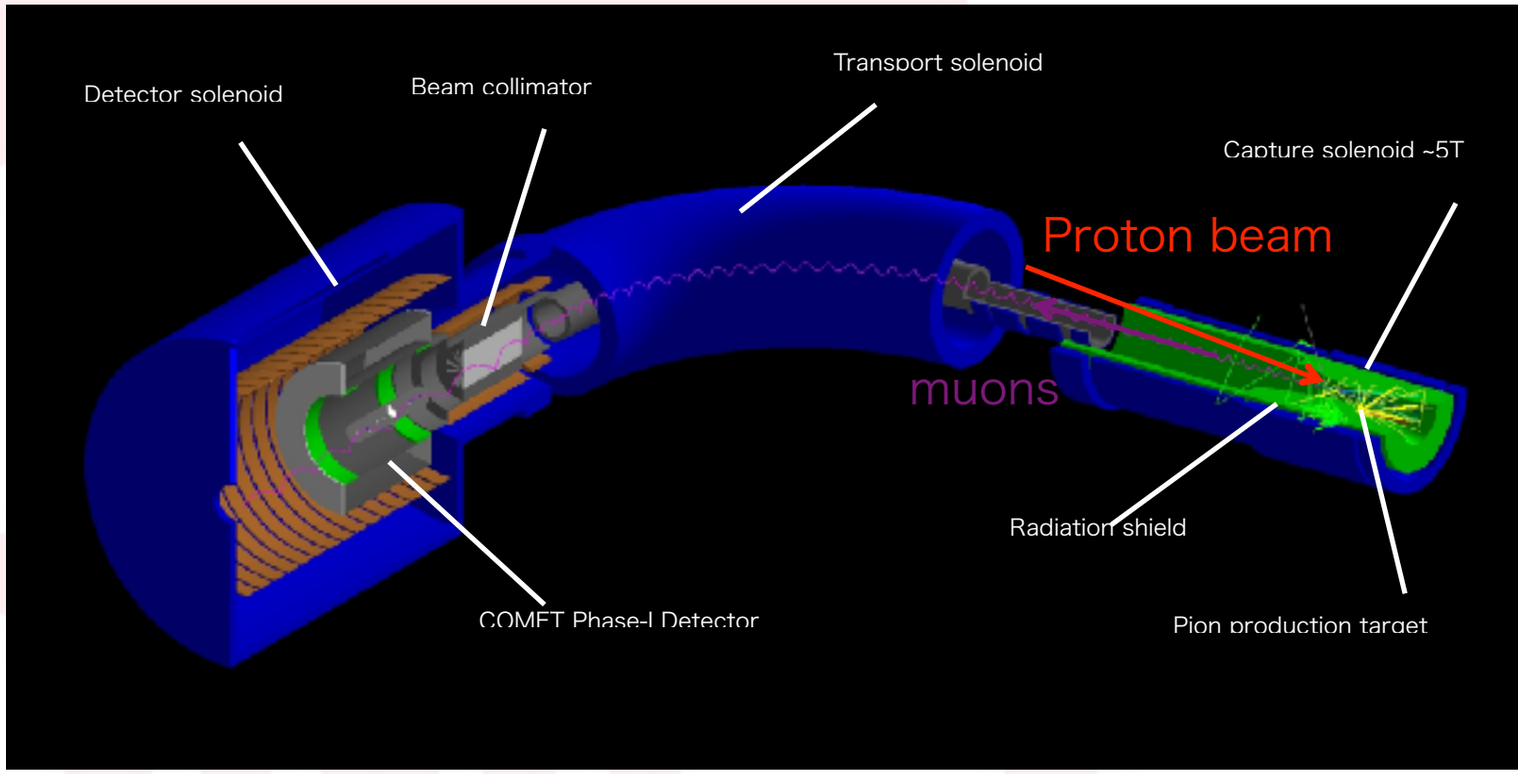


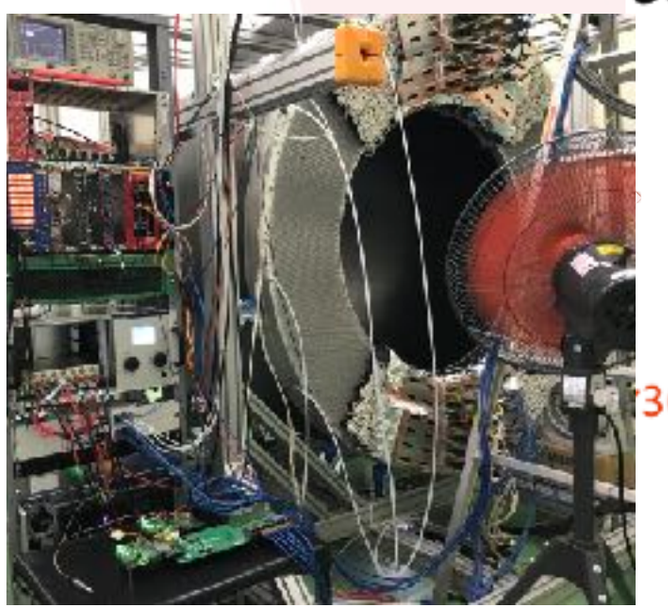


- Capture solenoid: Coil winding & cold mass assembly in progress. Cryostat design ongoing
- Transport solenoid: Installed and ready for cryogenic test
- Bridge & detector solenoids: design in progress.
- Cryogenic System: Refrigerator test completed. Helium transfer tube in production

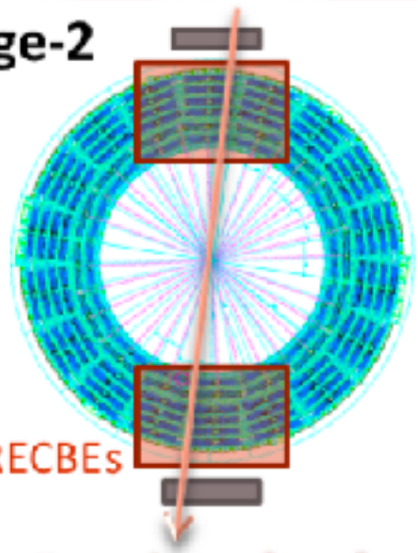
Phase-I Detector







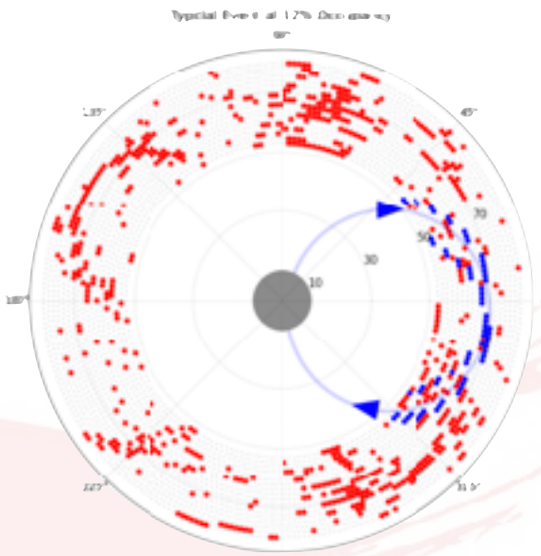
Stage-2

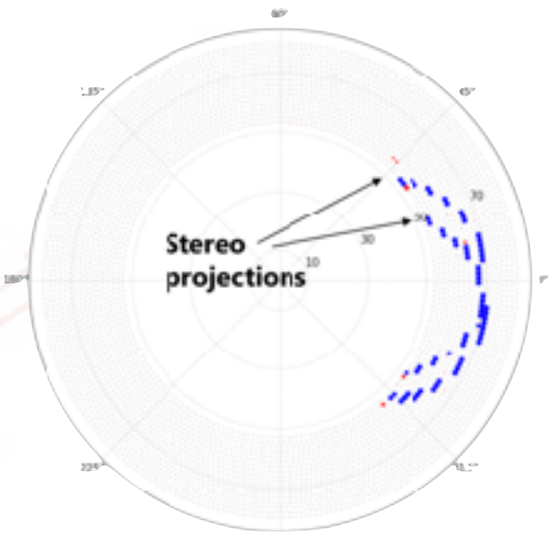


Precise check

Elec. trigger upgrade &
Detail performance check

Track Reconstruction





Hit selection & Hough Transformation

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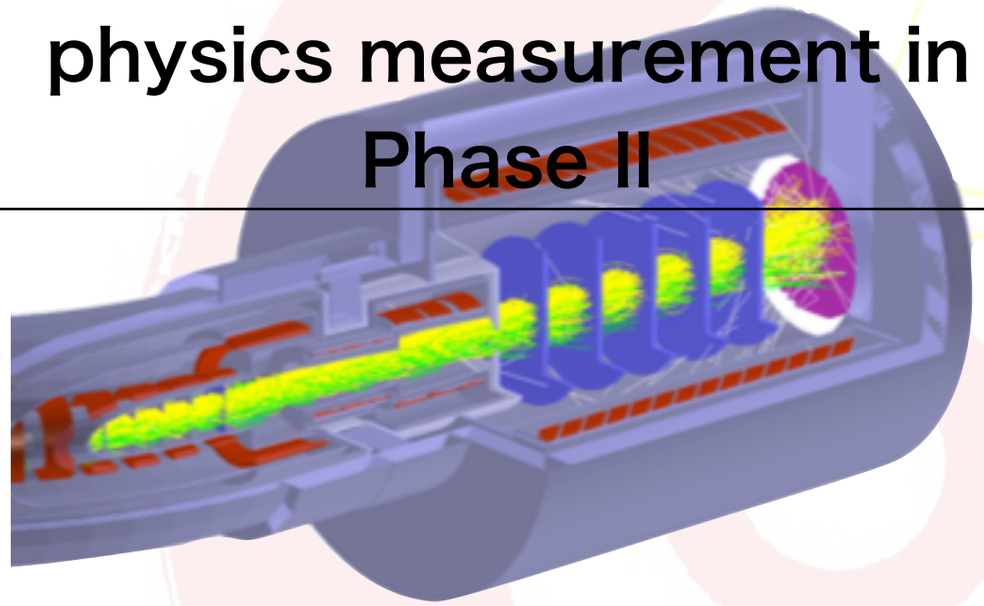
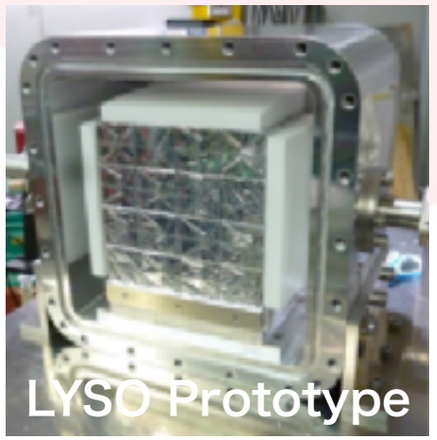
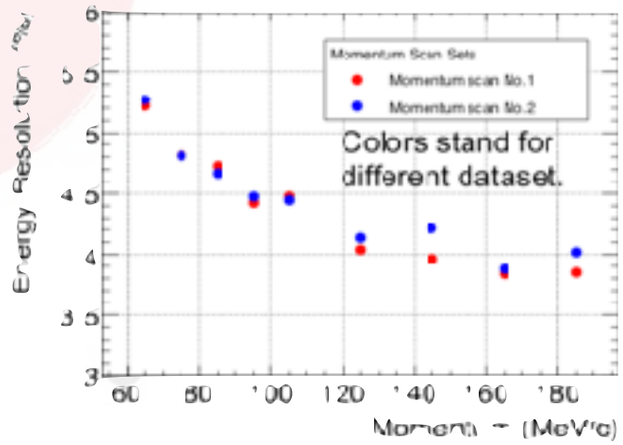
Phase I Detector cont'd

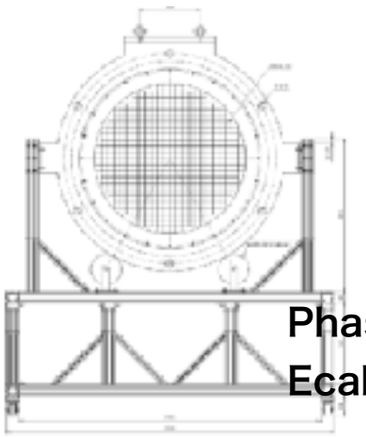
Detector for beam BG measurement in Phase I and physics measurement in Phase II





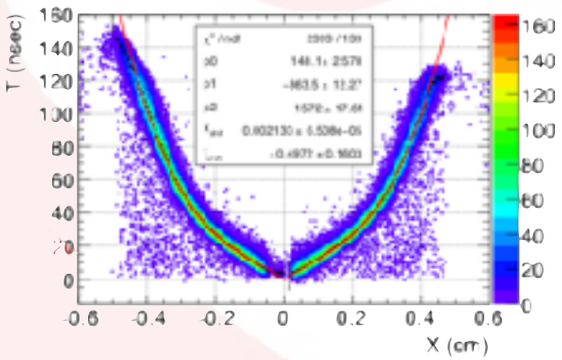


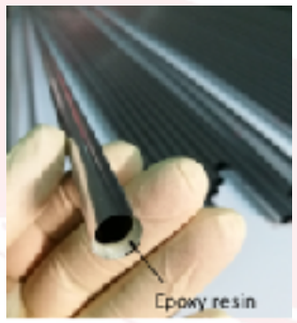
- LYSO cryostat production in progress
- Electronics design (almost) finalized

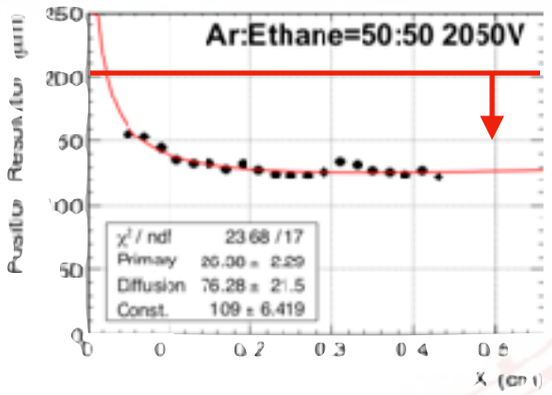


Phase I Ecal Design

Prototype straw tracker for performance evaluation

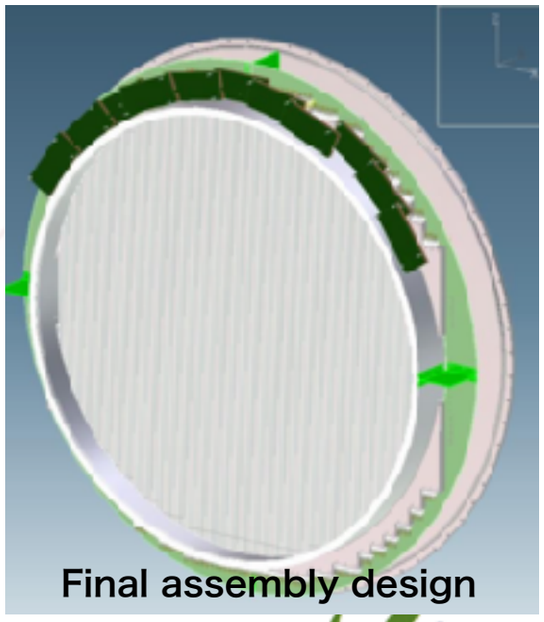






13 tubes broken out of 2700
After two-years storage

- Epoxy crystallization etc.



Final assembly design

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Other R&D

- Intensive studies of radiation hardness
- Aluminum muon stopping target design & X-ray monitoring
- New development of a proton beam monitor
- Cosmic-ray veto system
- Simulation and analysis tool development
- 8GeV acceleration & beam extinction factor measurement

Other R&D

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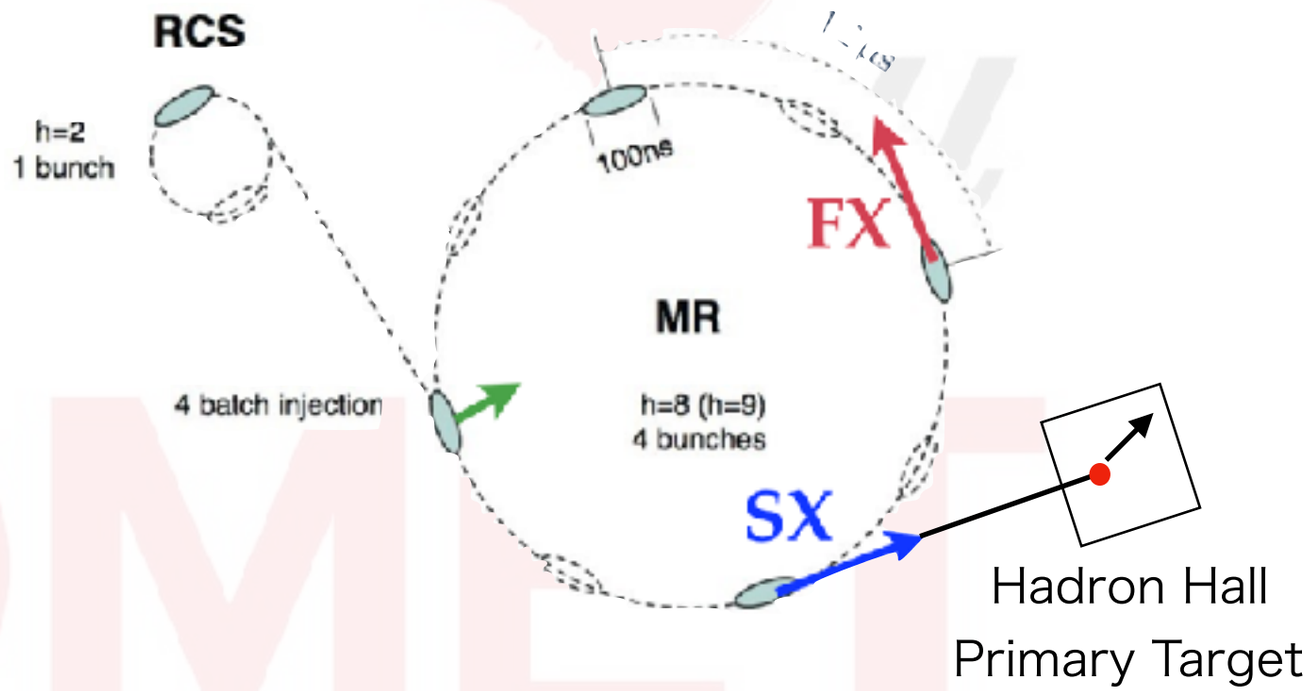
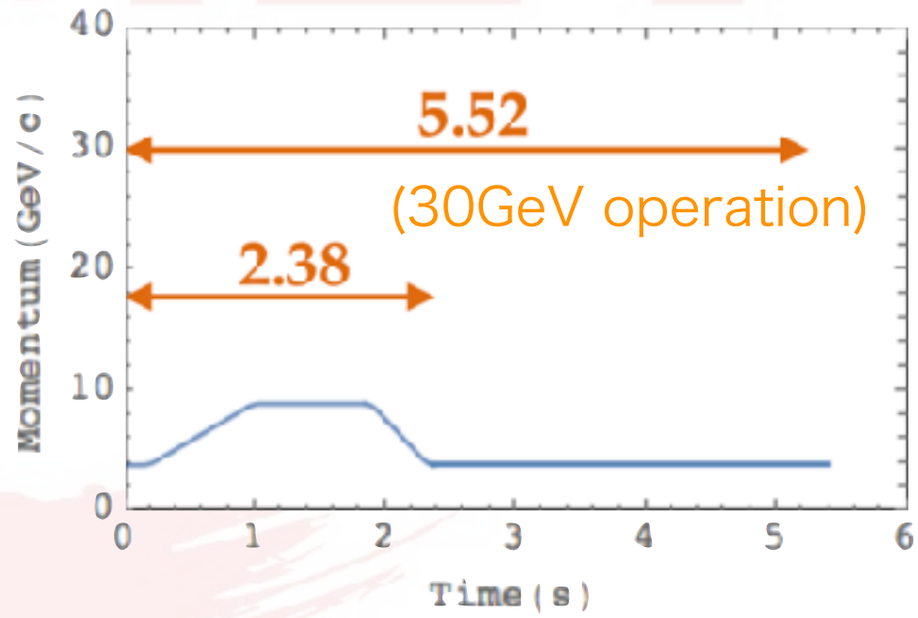
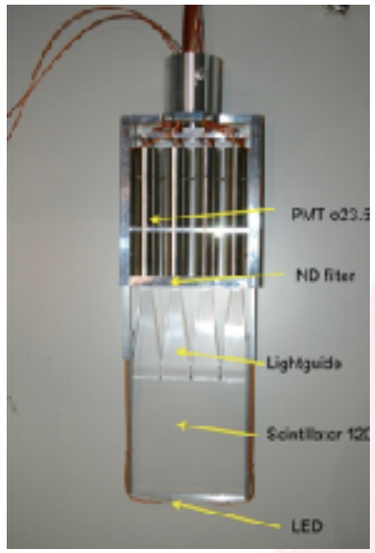
8GeV Acceleration & Extraction

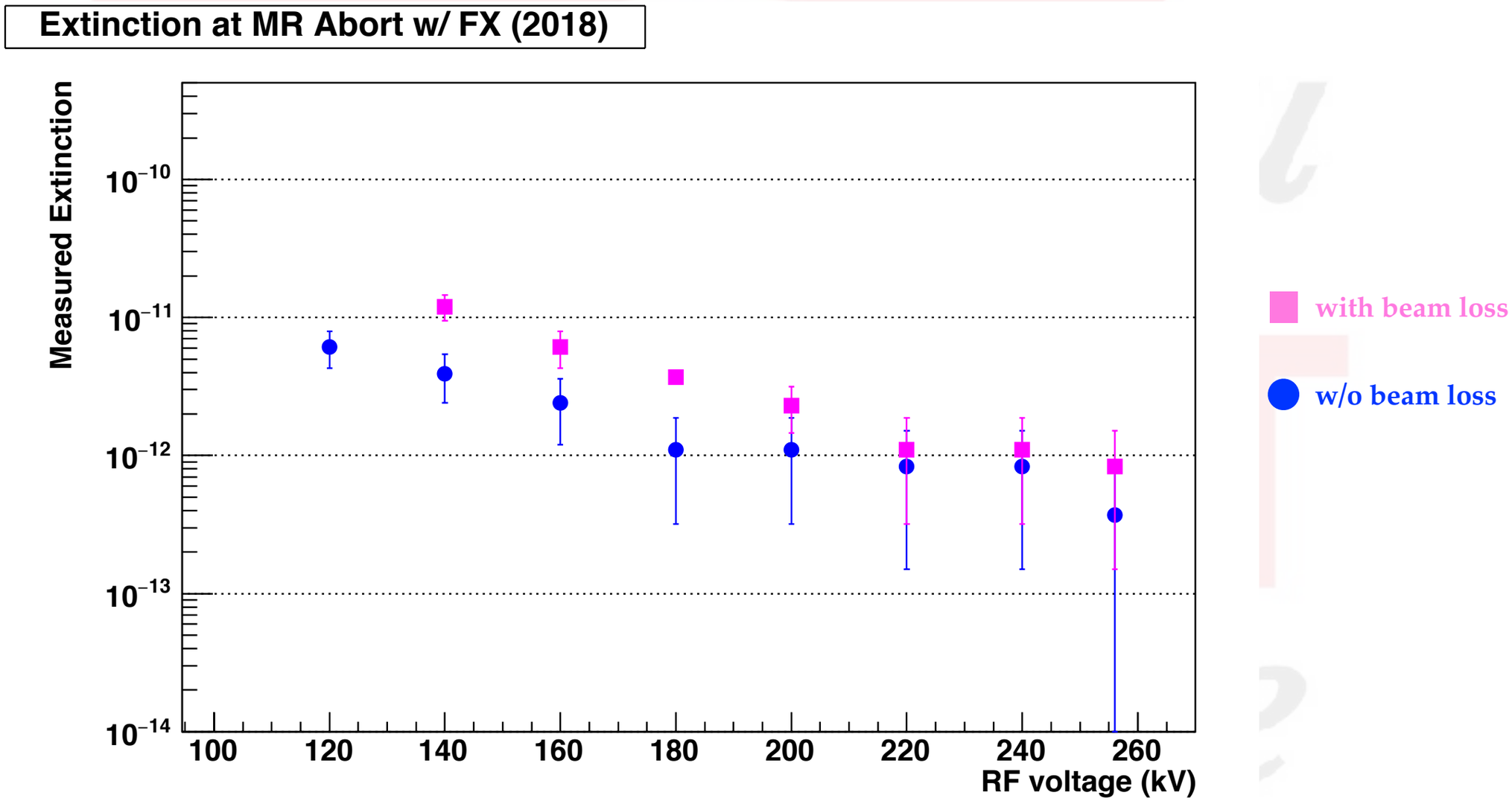
- 8GeV acceleration and extraction to the abort line (FX) and Hadron Hall (SX)
  - 4 bunches out of 9 bunches are filled with protons to realize the COMET beam time structure
    - Same number of protons per bunch with that of Phase I beam
- Injection kicker timing is shifted to kick in only the filled bunch
- SX with RF HV on to keep the bunched time structure





R_{ext} at the abort line (FX)

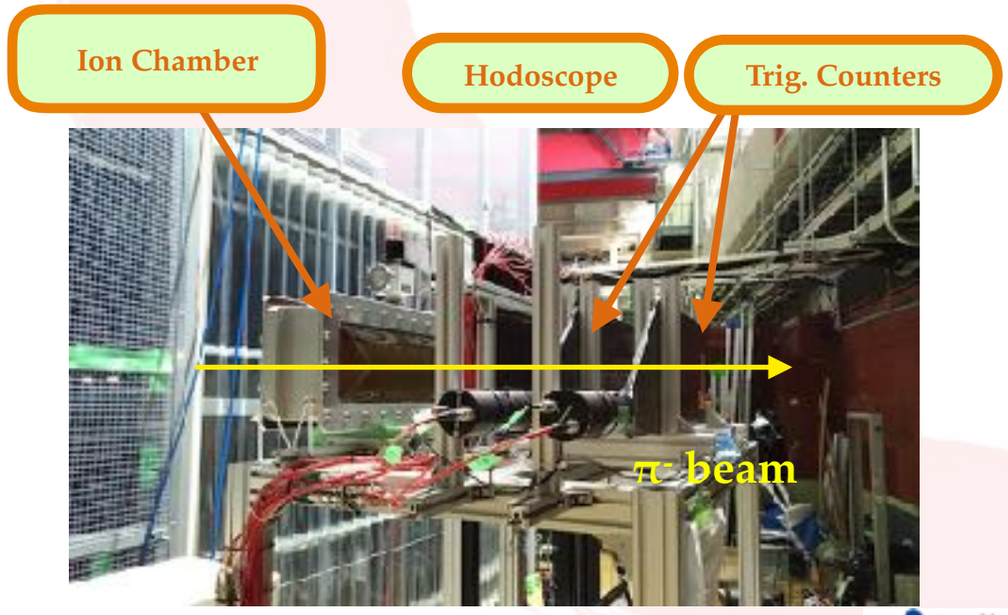




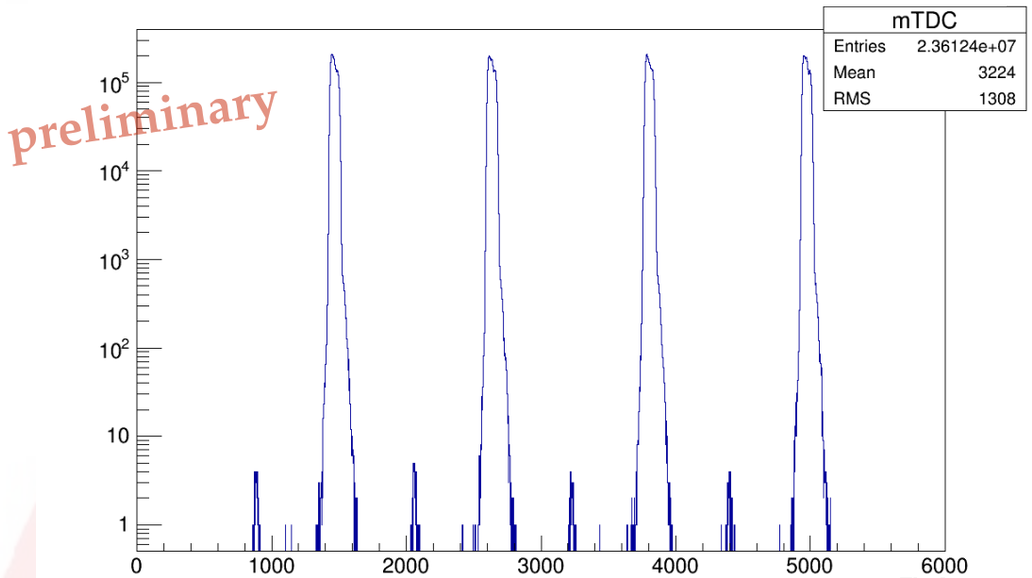
- Excellent extinction of 10^{-12} ~ 10^{-11} is obtained = **Good enough for COMET !!**
- A strong dependence on beam condition (tune, beam loss) is observed.

Rext in Hadron Hall (SX)

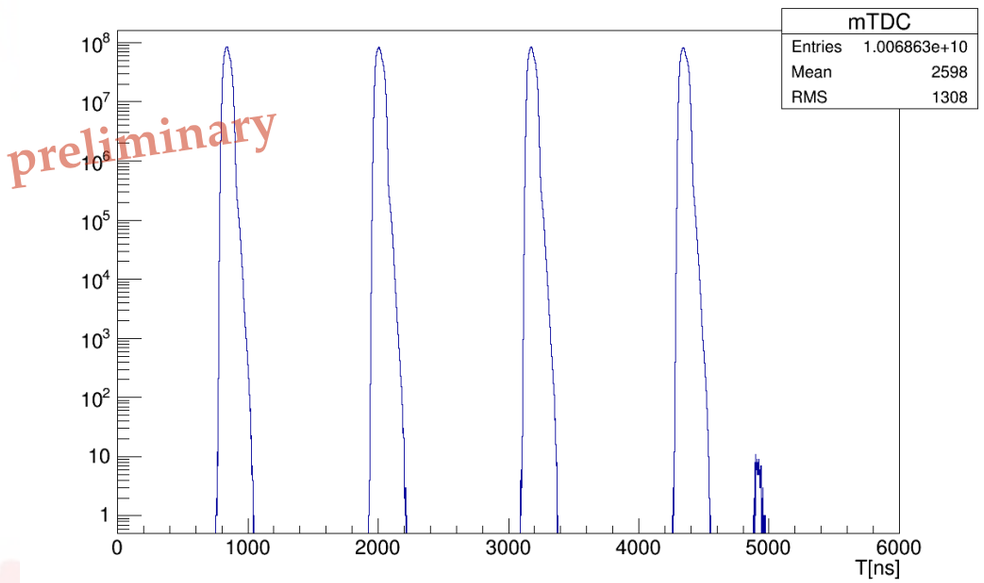
- Extracted pulsed proton beam injected to the Hadron Primary target and produced secondary beam transport to K1.8 area
- Secondary beam time structure measurement with a hodoscope
- Proton leakage is appeared in **K4_rear only** within very early extraction timing (<0.1sec)
- No leakage is appeared in other region
- By rejecting <0.1sec events, upper limit of extinction is obtained: **<6.0 x 10^{-11}**
- Good enough for COMET though we need further studies on K4_rear leakage



w/o kicker shift = initial extinction



w/ kicker shift = improved extinction



Summary

- Muon flavor physics experiment is a clue to investigate new physics BSM
- High-power proton driver to produce high-intensity muon beam
- COMET intends to improve the sensitivity to the mu-e conversion process by more than a factor of 10,000 in two steps;
  - Phase-I sensitivity < 10^{-14}
  - Phase-II sensitivity < 10^{-16}
- J-PARC MR operation at 8GeV to provide the proton beam
  - Proton beam extinction factor as good as 6×10^{-11} confirmed. Need further improvement in collaboration with the J-PARC accelerator group
- Pion/muon capture system, muon transport system as well as the physics detector in preparation
- Collaboration is expanding even now! Any young student and researcher is welcome to join the collaboration!!