COMET

mu-e conversion search experiment at J-PARC

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高エネルギー加速器研究機構

Outline

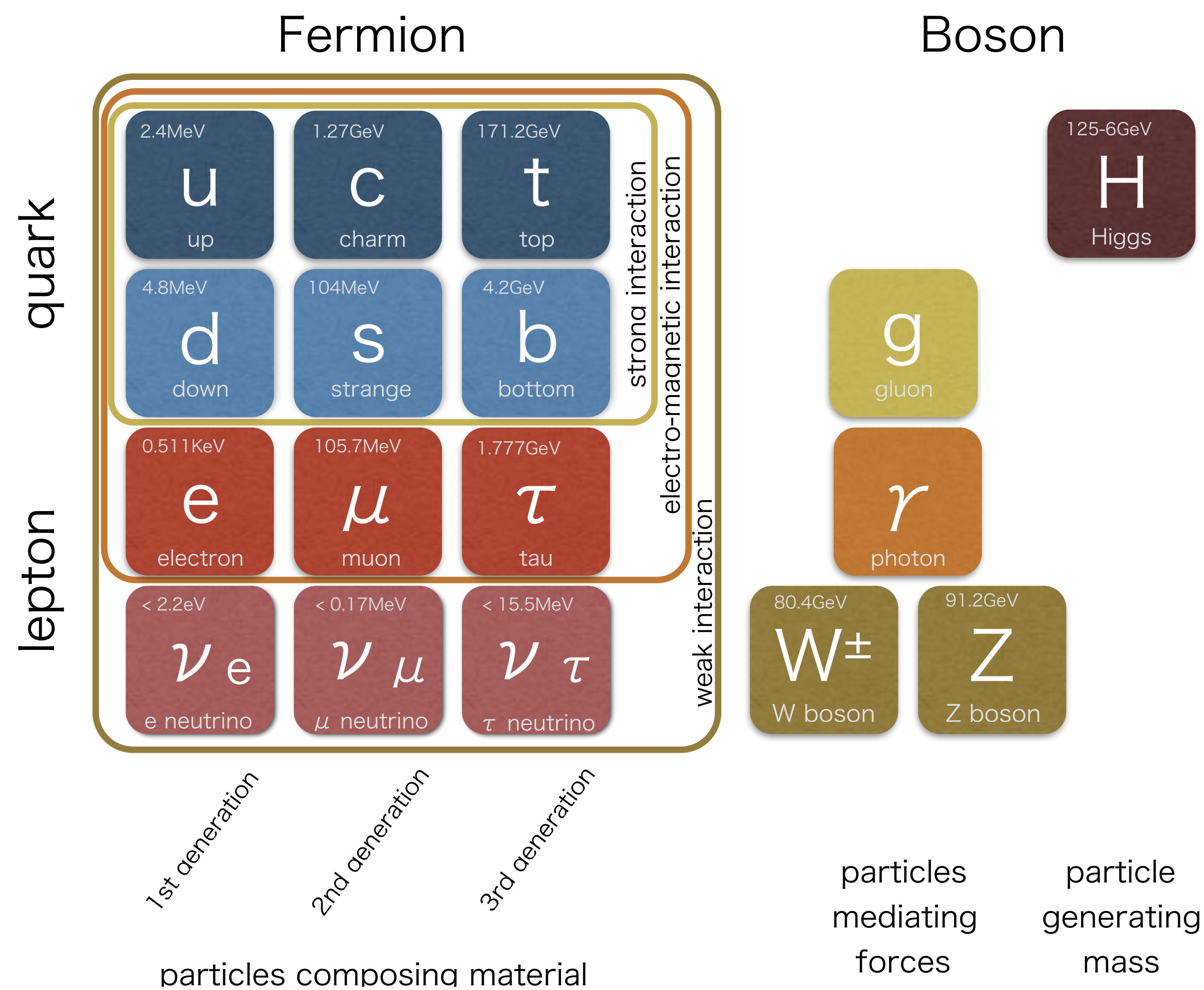
- Introduction
  - Muon particle physics & mu-e conversion
- COMET experiment at J-PARC
  - Status of the experiment
  - Plan of the experiment
- Summary

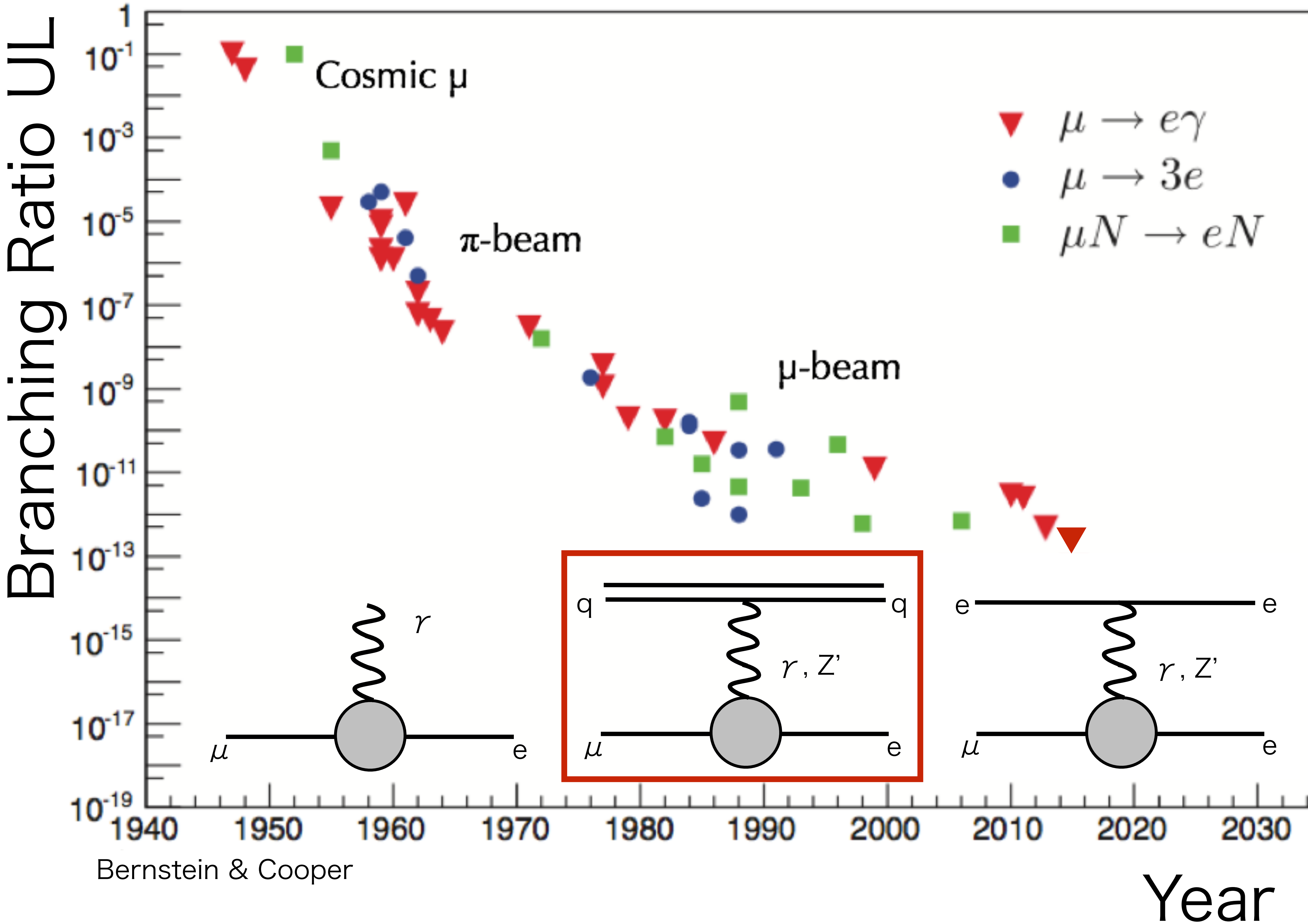
COMET Cyclotron at PSI

Muon particle physics
&
mu-e conversion

Muon Particle Physics

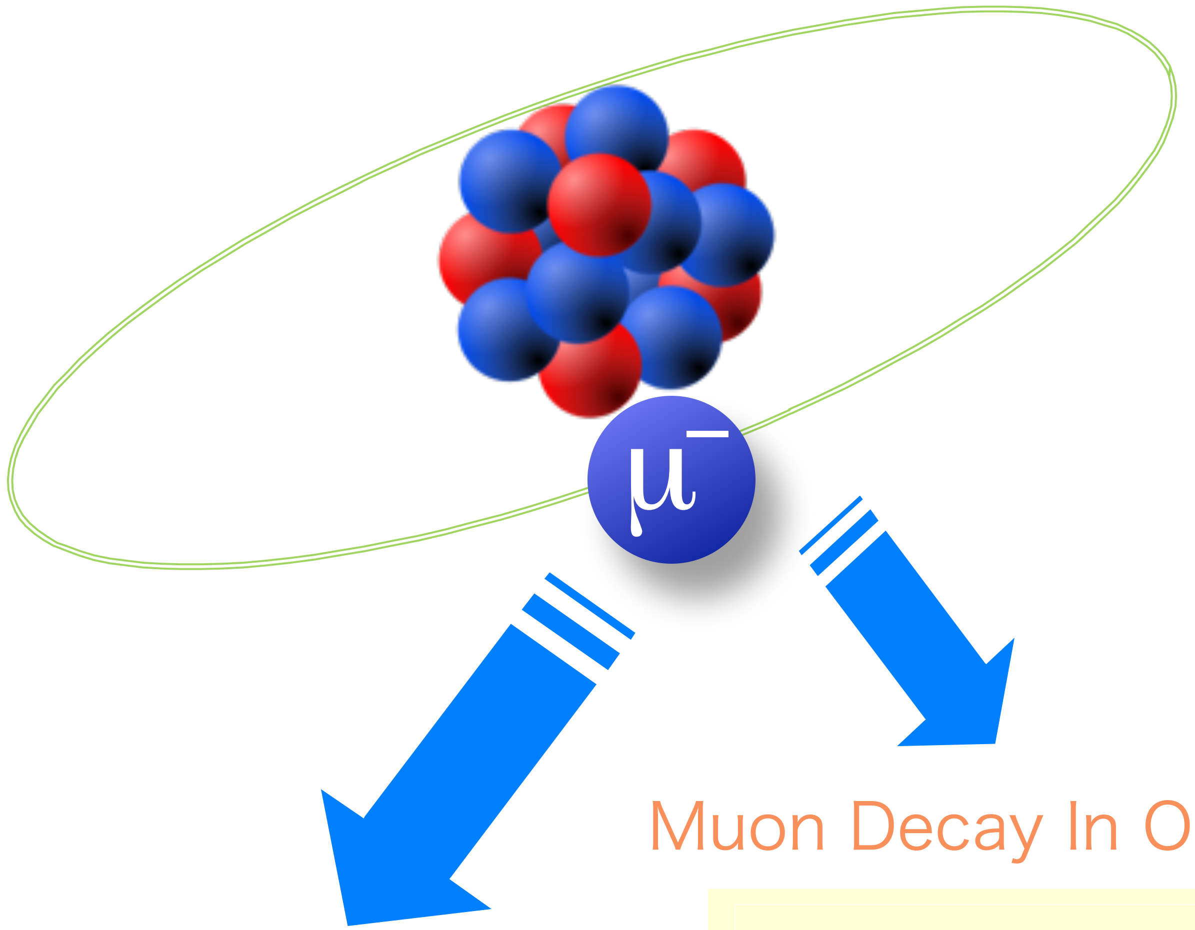
- Muon in the Standard Model
  - Precise measurement of muon properties
  - Establishment of SM
- Indication of BSM related to muon?
  - muon g-2, B leptonic decay …





Bernstein & Cooper

mu-e Conversion



$$\mathcal{L} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_R\sigma^{\mu\nu}e_L F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_L\gamma^\mu e_L)(\bar{q}_L\gamma_\mu q_L)$$

Muon Decay In Orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

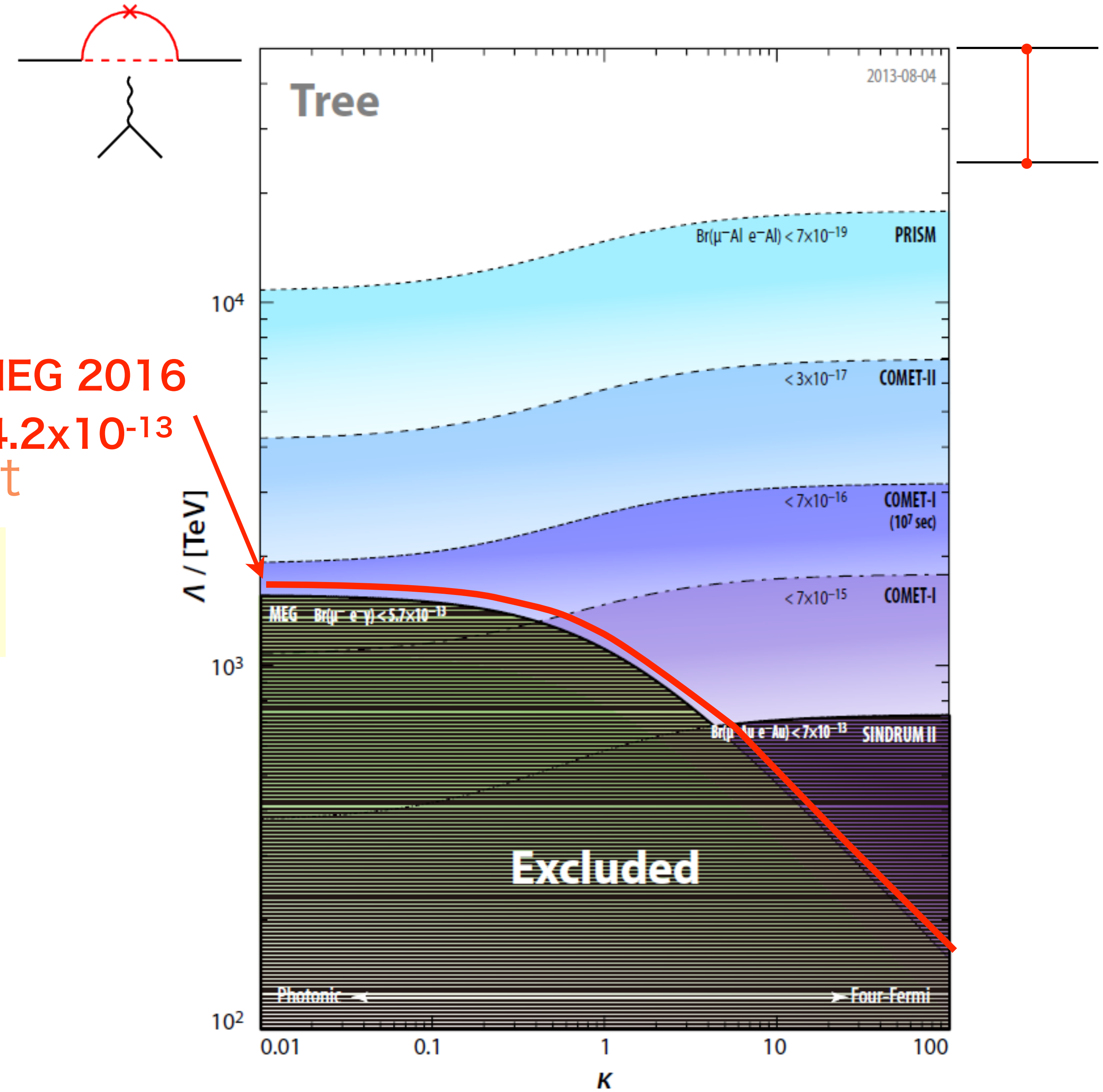
$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

μ-e conversion

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

MEG 2016

4.2×10^{-13}



Andre de Gouvea, W. Molzon, Project-X WS (2008)

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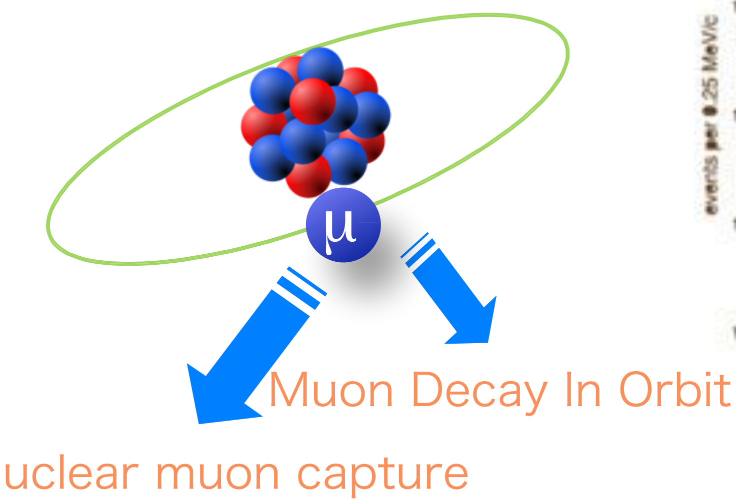
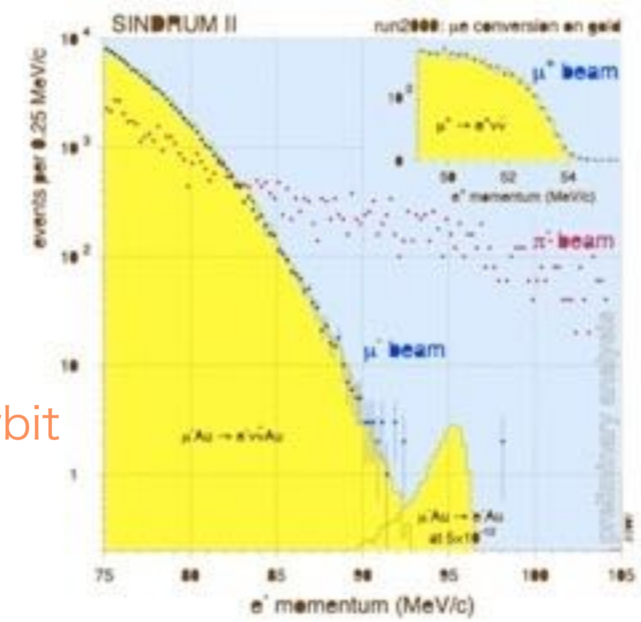
Experimental Techniques

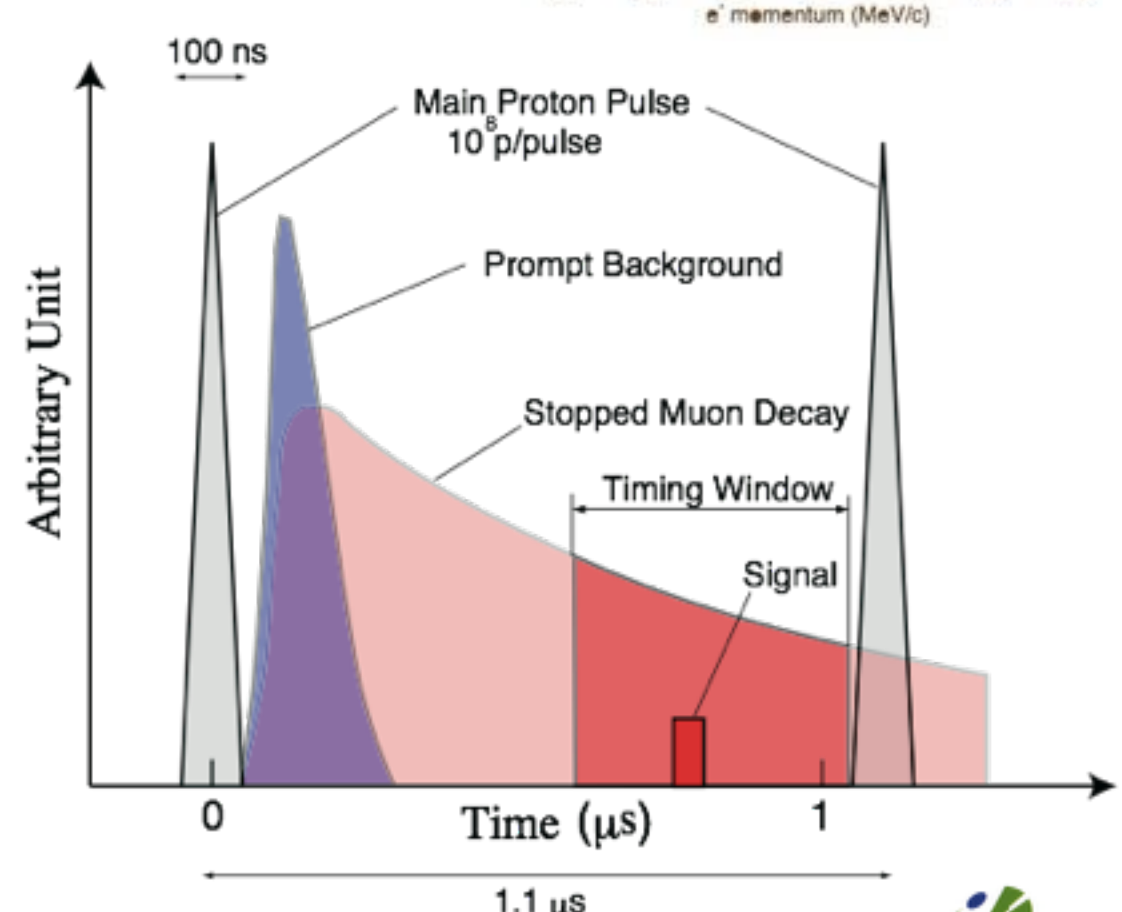
- Process : $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
  - A single mono-energetic electron
    - $E_{\mu e} \sim m_\mu - B_\mu$:105 MeV for Al
  - Delayed : ~1 μS
  - No accidental backgrounds
- Physics backgrounds
  - Muon Decay in Orbit (DIO)
    - E_e > 102.5 MeV (BR:10^{-14})
    - E_e > 103.5 MeV (BR:10^{-16})
  - Beam Pion Capture
  - $\pi^- + (A,Z) \rightarrow (A,Z\text{-}1)^* \rightarrow \gamma + (A,Z\text{-}1)$

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



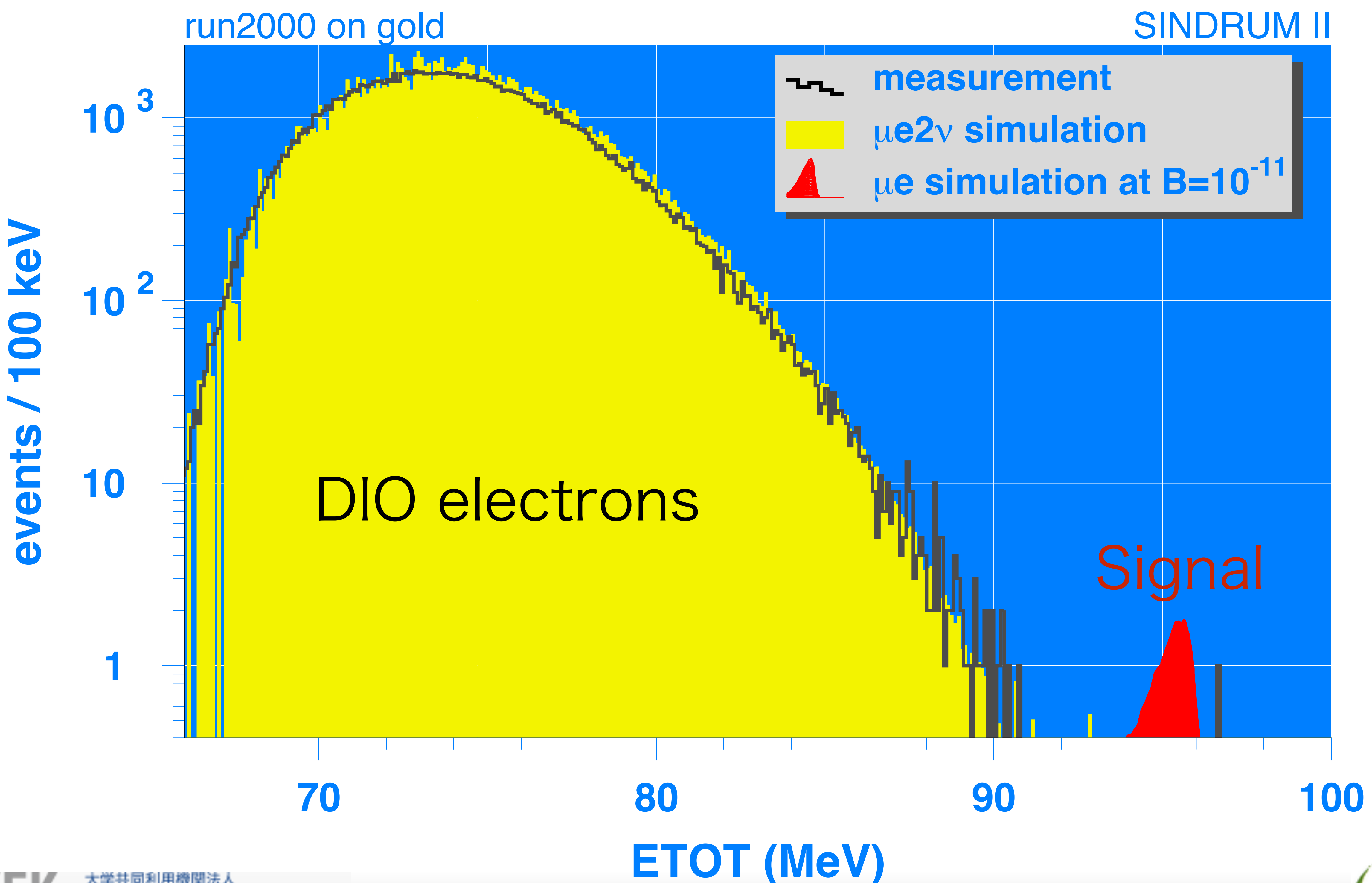
SINDRUM II





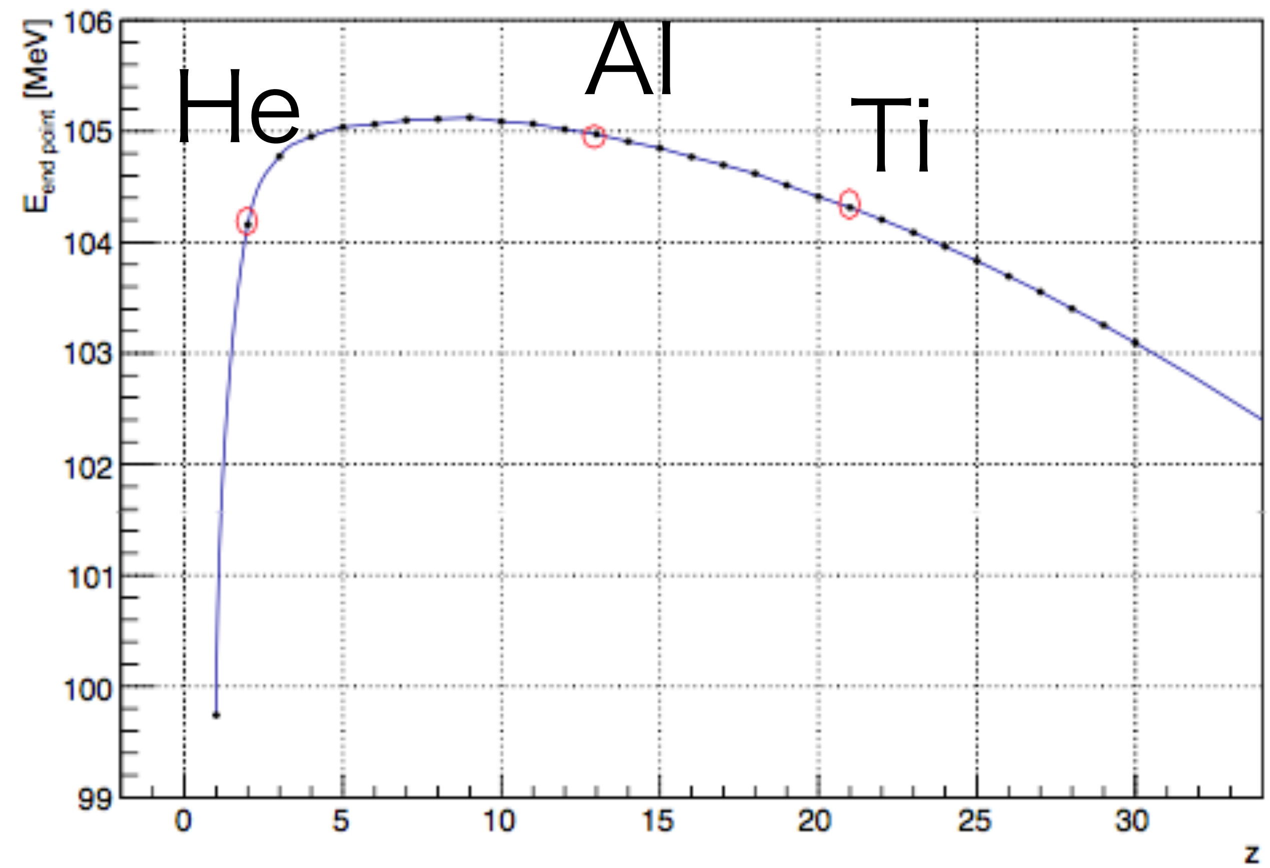
$$R_{ext} = \frac{\text{number of proton between pulses}}{\text{number of proton in a pulse}}$$

Electron Energy



Selection of the Target Material

- DIO $E_{endpoing}$ extends to the $E_{\mu\text{-}e}$
  - Recoil energy
  - Muon binding energy
- Select the target material with high $E_{\mu\text{-}e}$ and avoid using the material with larger $E_{endpoint}$ around the target
  - When the target is made of aluminium, we should avoid using materials from Z=5 to Z=12.
  - He (Z=2) is OK to use around the target
- Lifetime of muon in muonic atoms
  - Shorter in larger Z because of the larger nuclear muon capture rate



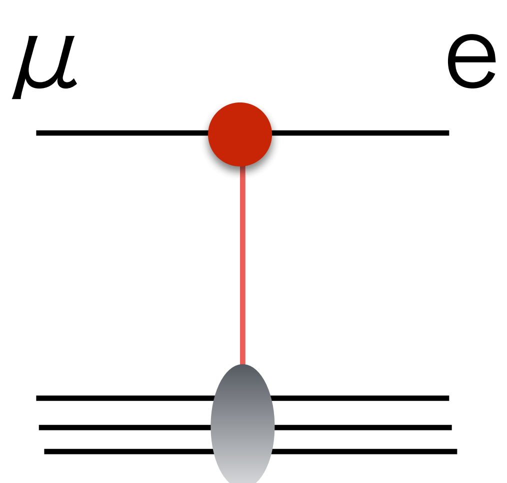
	Al	Ti
lifetime	864 ns	330 ns
time window	0.3	0.2
signal	1	1.5
net	0.3	0.3

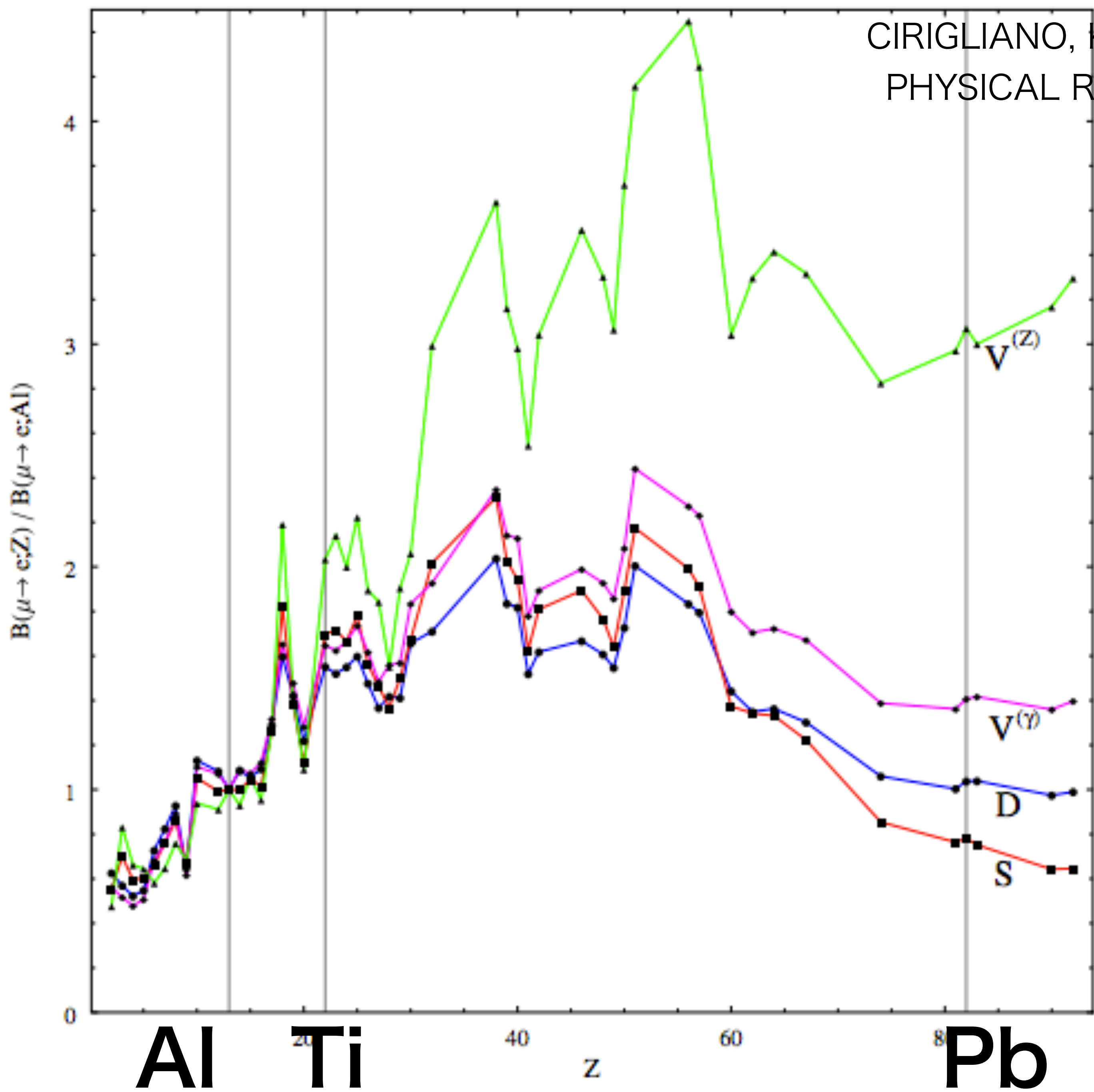
Once the signal is observed…

Even without $\mu \to e\gamma$ signal !

On the model discriminating power of $\mu \to e$ conversion in nuclei

CIRIGLIANO, KITANO, OKADA, AND TUZON
PHYSICAL REVIEW D 80, 013002 (2009)





Vector 2

Vector 1

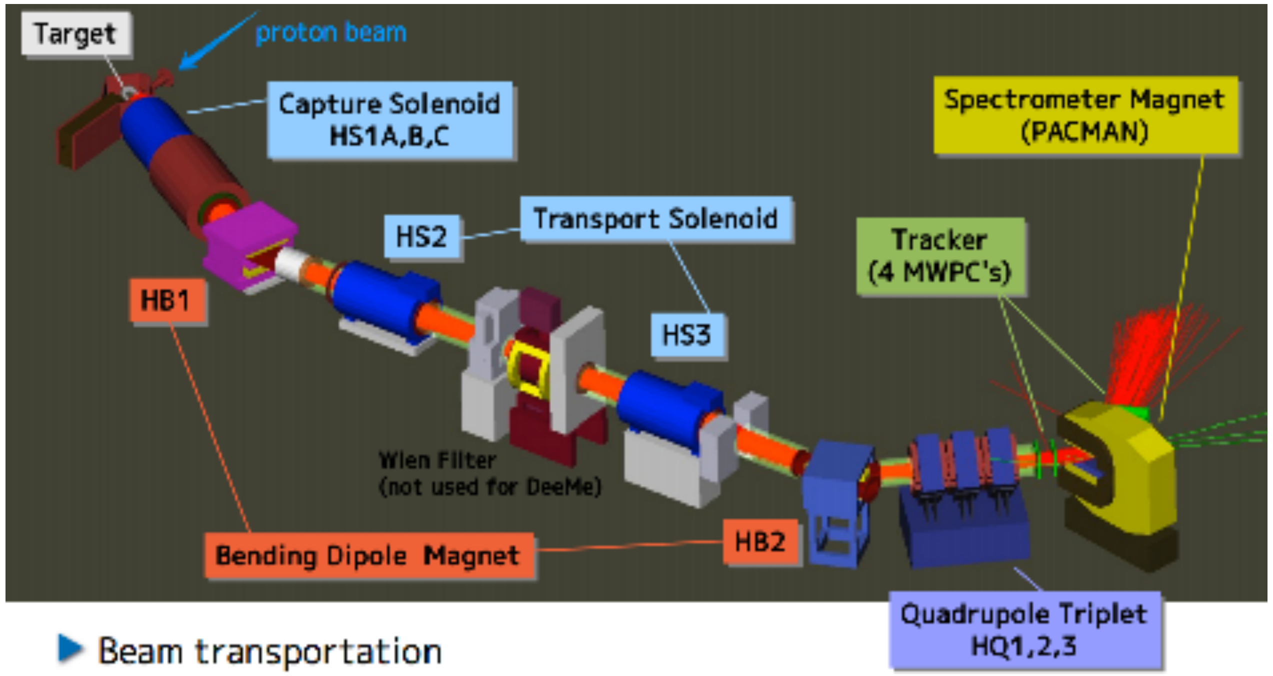
Dipole

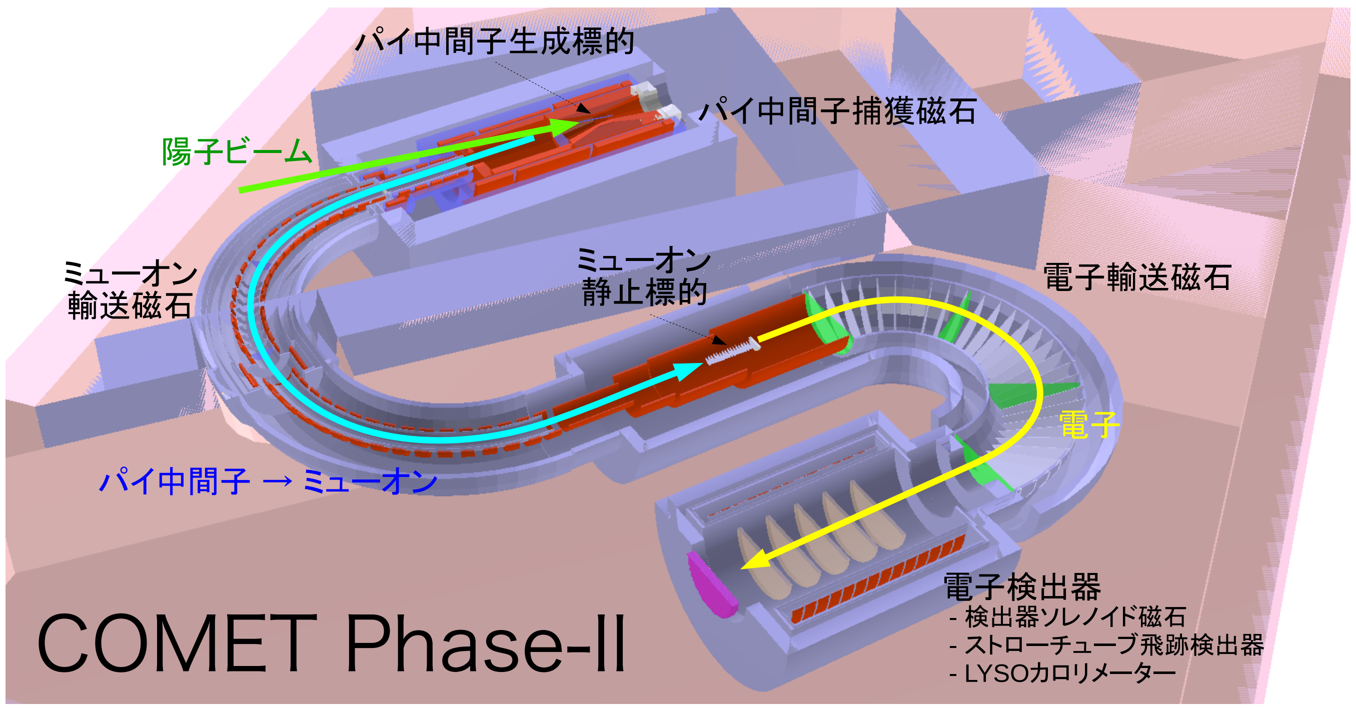
Scalar

μ-e Conversion Search Experiments

- J-PARC
  - DeeMe
  - COMET Phase-I & II
- FNAL
  - Mu2e (A. GAPONENKO's presentation)

$10^{-14} \sim 10^{-16}$ sensitivity

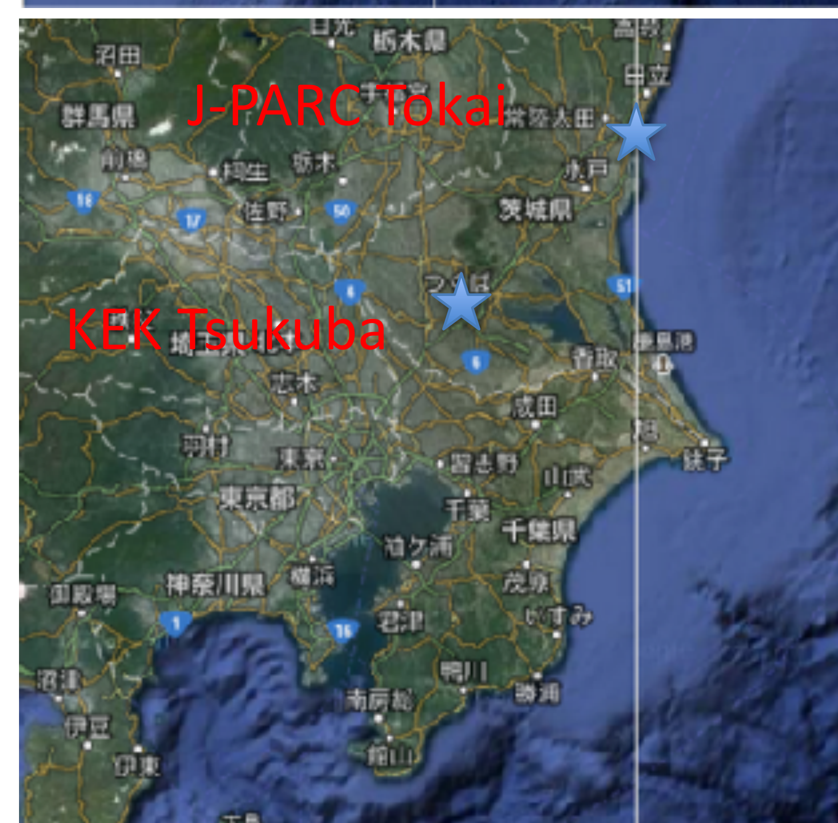




J-PARC

Japan Proton acceleration research complex

- Joint project between JAEA and KEK
- **New and accelerator research facility**, using MW-class high power proton beams at both 3 GeV and 30 GeV.
- Various secondary particle beams
  - neutrons, muons, kaons, neutrinos, etc. produced in proton-nucleus reactions
- Three major scientific goals using these secondary beams
  - Particle and Nuclear physics
  - Materials and life sciences
  - R&D for nuclear transformation (in Phase 2)
- The anticipated goal is 1 MW



J-PARC Facility
(KEK/JAEA)
LINAC
400 MeV
Neutrino beam to Kamioka
Rapid Cycle Synchrotron
Energy : 3 GeV
Repetition : 25 Hz
Design Power : 1 MW
Material and Life
Science Facility
Nuclear and Particle
Physics Exp. Hall
Main Ring
Max Energy : 30 GeV
Design Power for FX : 0.75 MW
Expected Power for SX : > 0.1 MW

COMET

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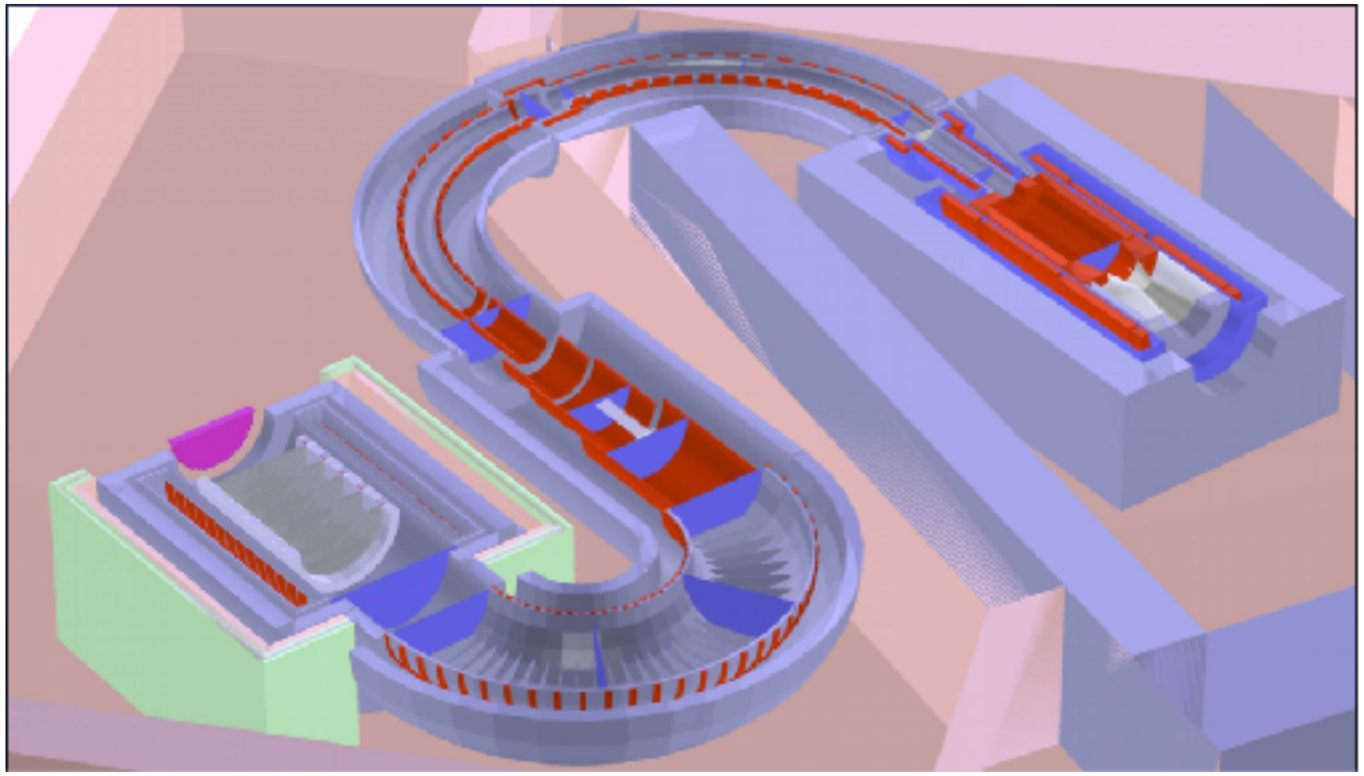
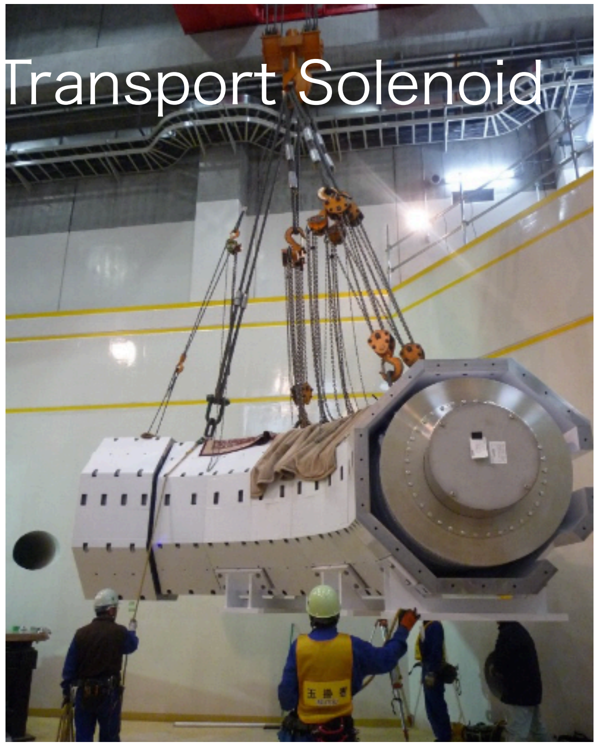
J-PARC

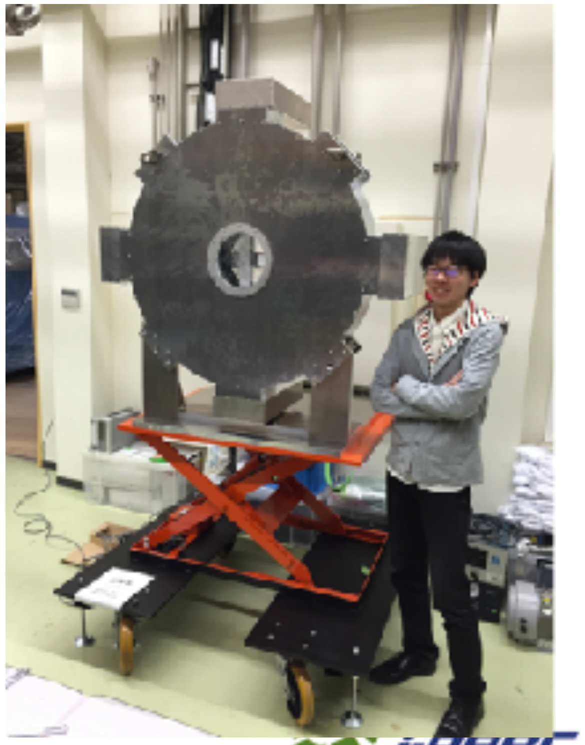
COMET at J-PARC

- **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.

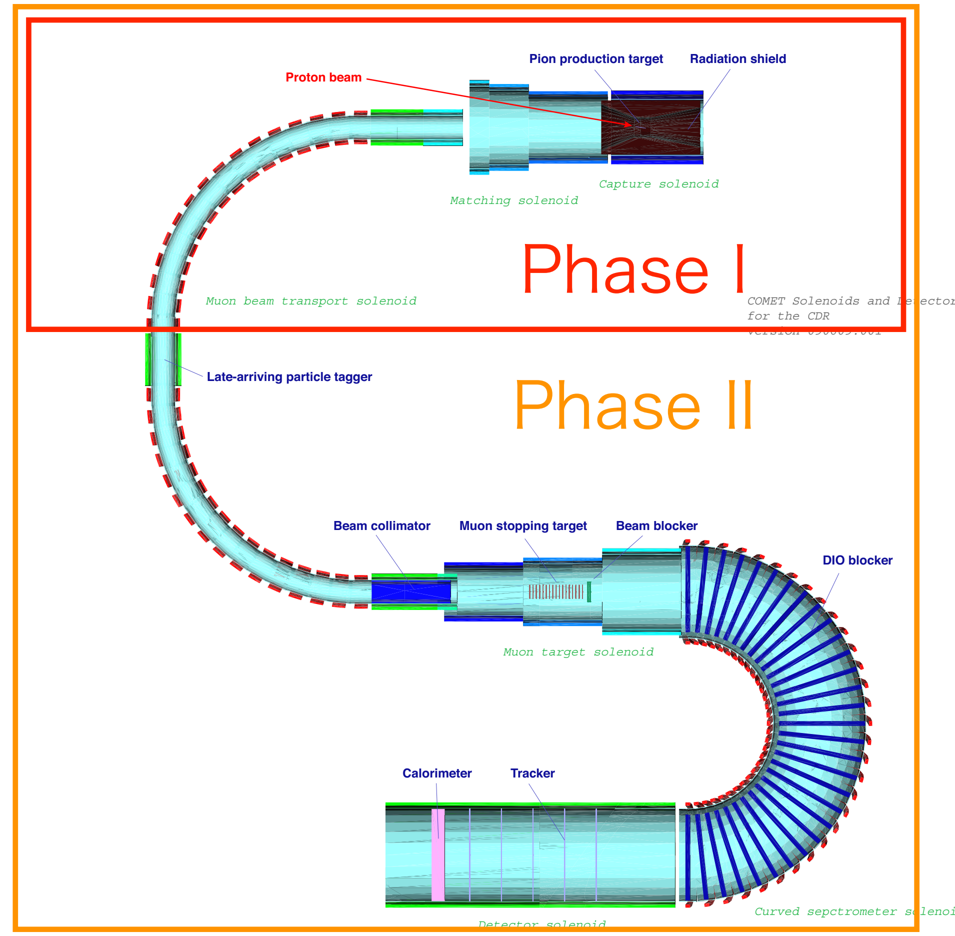






COMET Phase I & II

- Phase I
  - **Beam background study**
  - **Achieve an intermediate sensitivity of < 10^{-14}**
  - 8GeV, 3.2kW, 110 days of DAQ
- Phase II
  - 8GeV, 56kW, 1 year DAQ to achieve the COMET final goal of < 10^{-16} sensitivity



Phase I

2013-2018

Facility construction

2013-2019

Magnet construction & installation

2018-2020

Eng. run & Physics run

Phase II

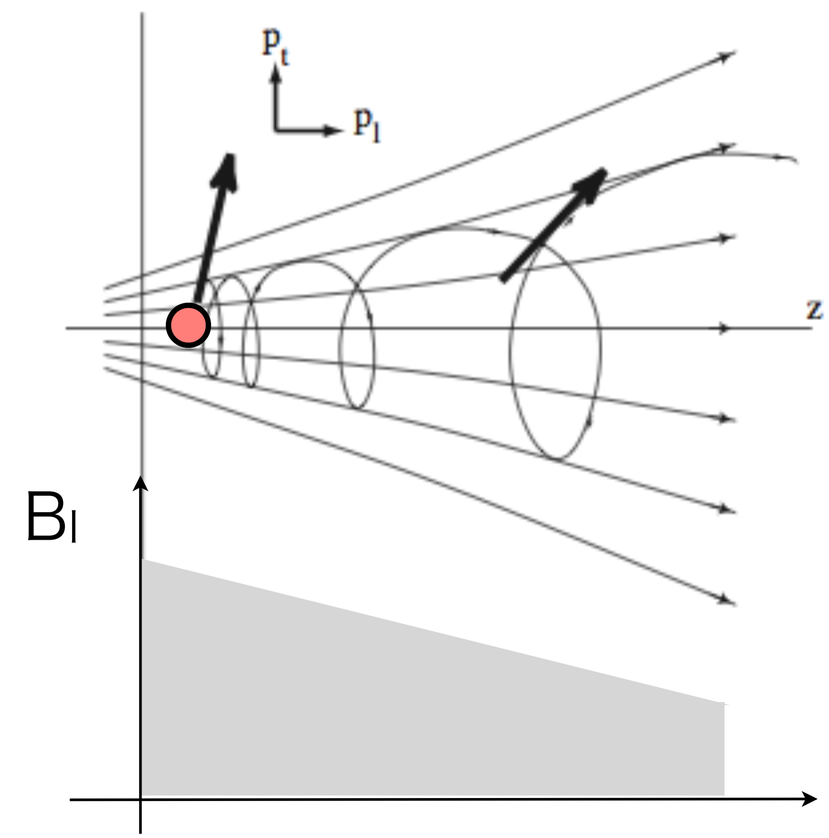
Eng. run in 2022(?)

Pion Capture

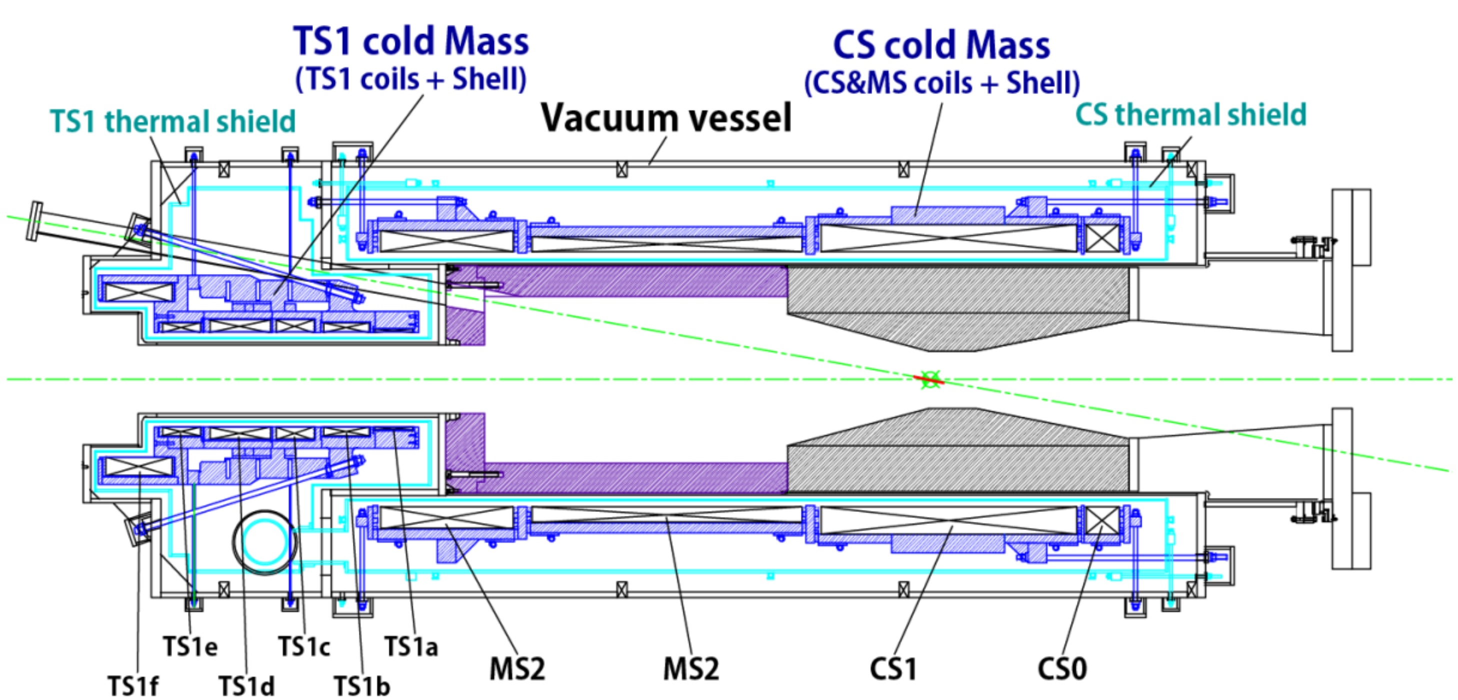
- Adiabatic transition of Muon beam

$$p_T \times R \propto \frac{p_T^2}{B} = \text{constant}$$

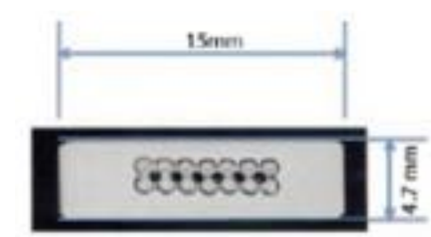
- As B decreases, p_T decreases and R increases
  - more parallel beam at a cost of the increased beam size



Strong Magnetic field in high radiation environment



Aluminum stabilized SC
Collaborative R&D between
COMET & Mu2e



Al/Cu/NbTi : 7.3/0.9/1.0

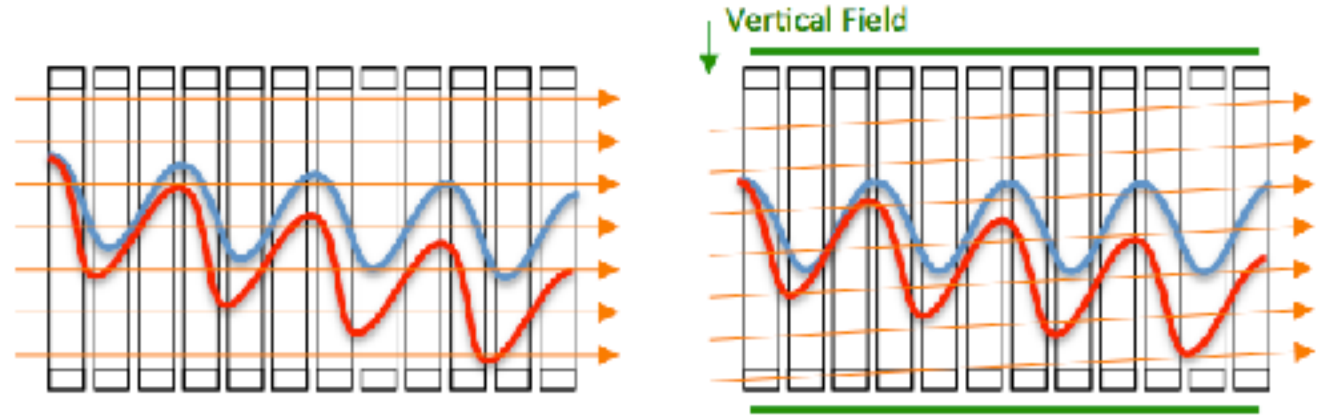
Muon Transport

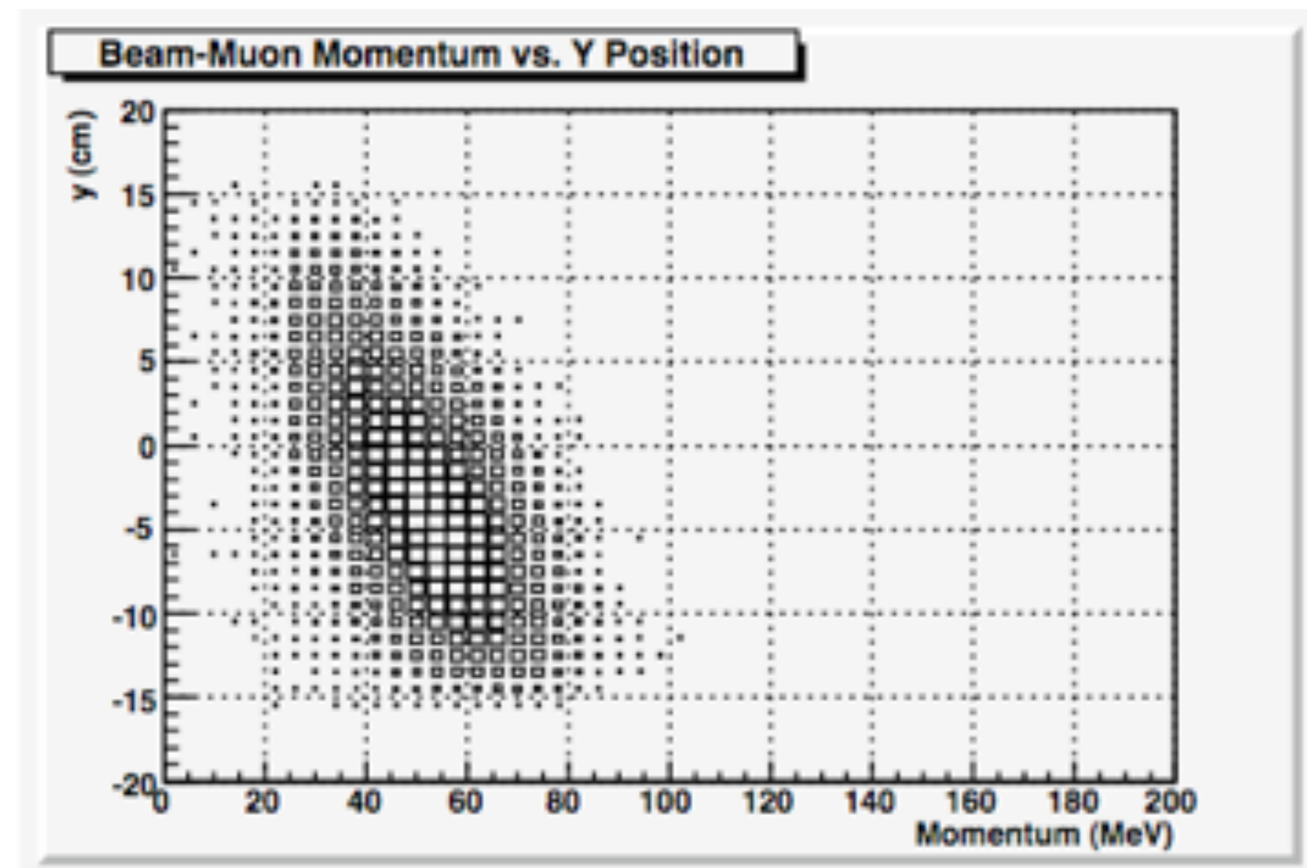
- A center of helical trajectory of charged particles in a curved solenoidal field is drifted by

$$D[m] = \frac{1}{0.3 \times B[T]} \times \frac{s}{R} \times \frac{p_l^2 + \frac{1}{2}p_t^2}{p_l}$$

  - This effect can be used for charge and momentum selection.

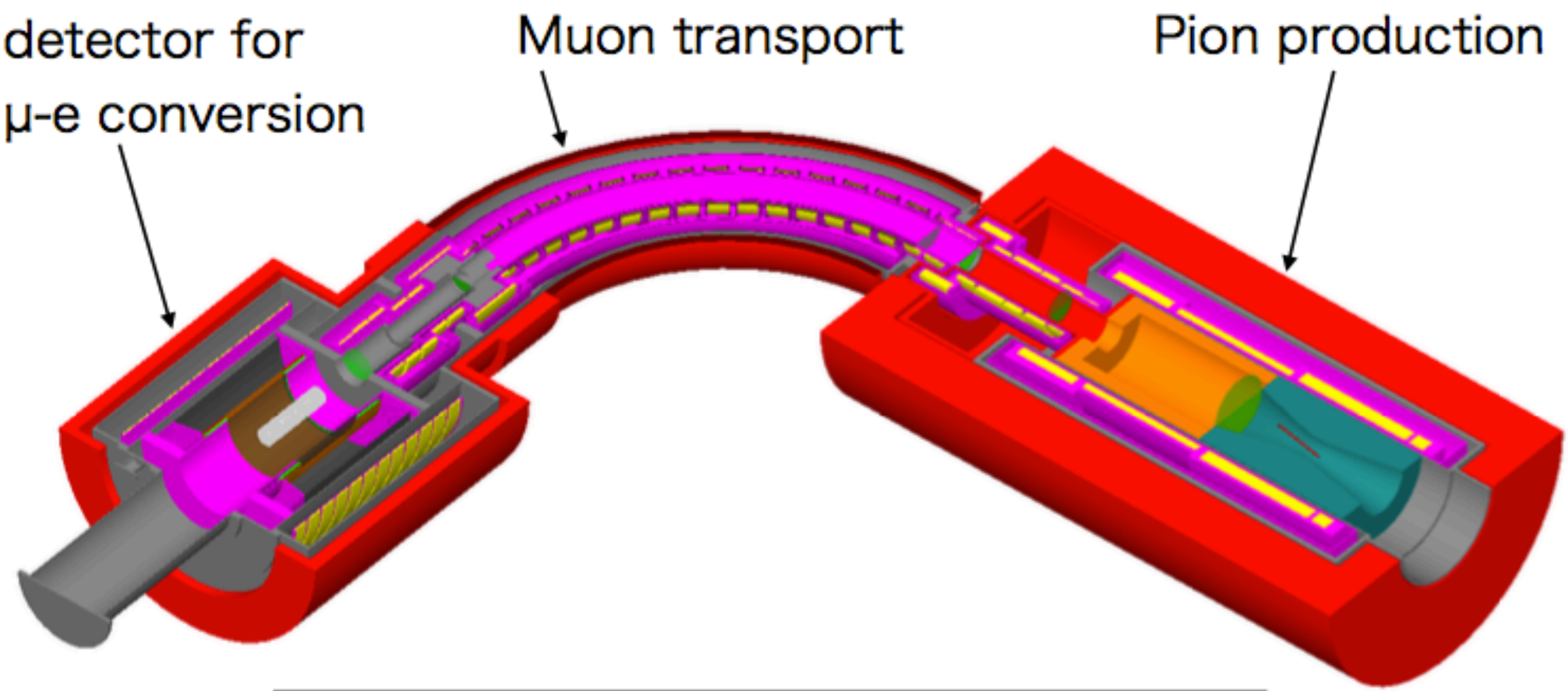
- This drift can be compensated by an auxiliary field parallel to the drift direction





$\delta p/\delta x$ = 1 MeV/c/cm

COMET Phase-I

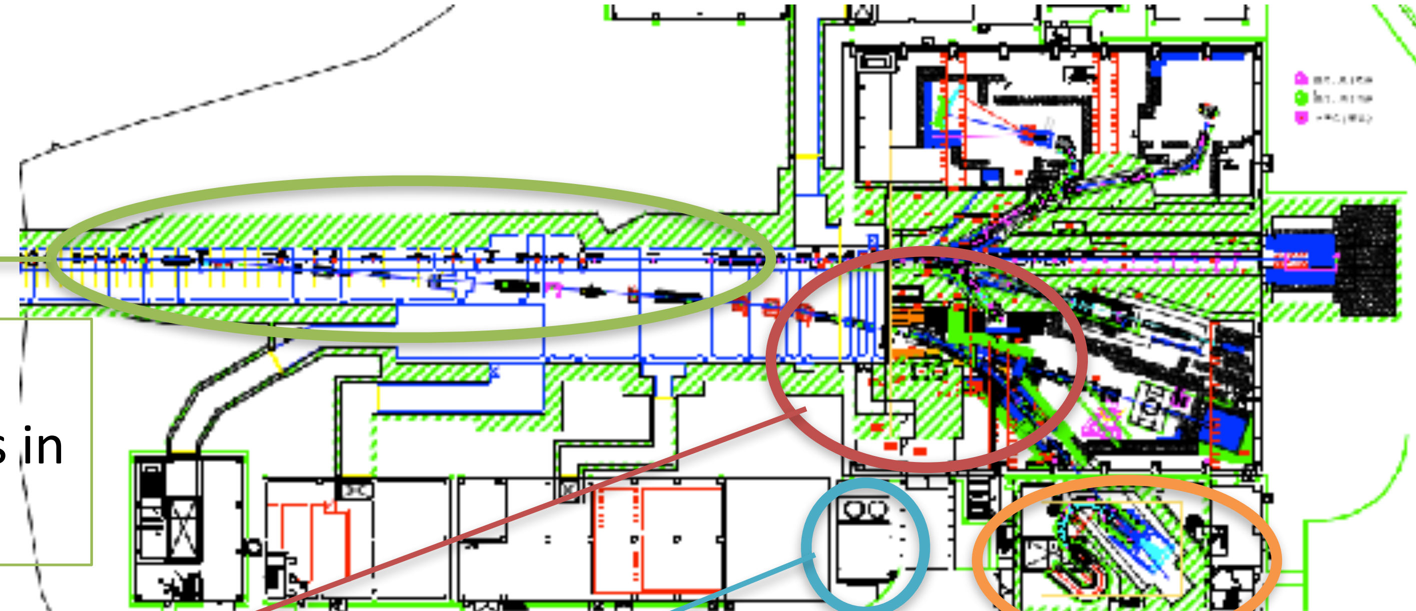


COMET Phase-I Layout

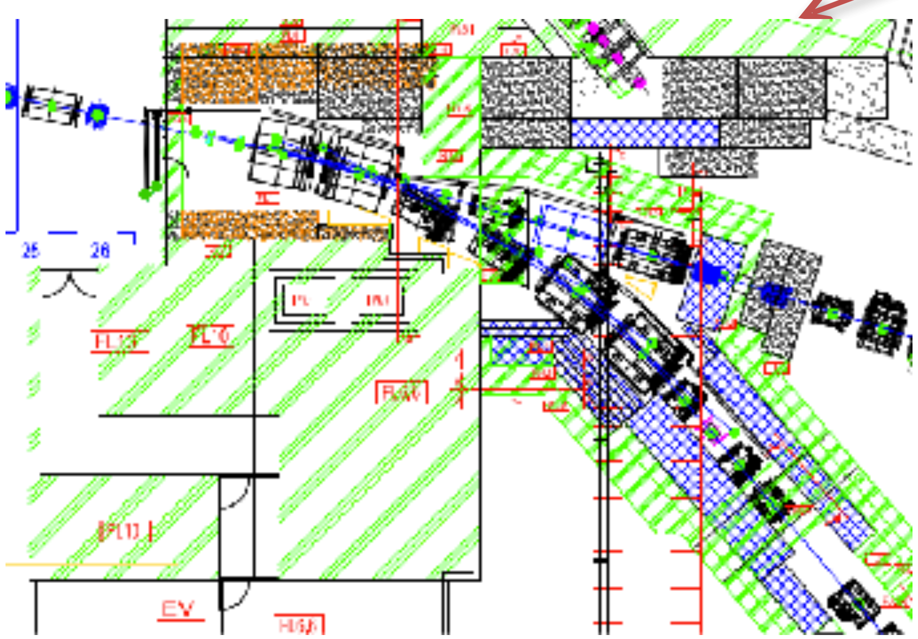
Status of COMET Experiment Facility

Switch Yard Beamline Elements

Beam line component installation in progress in SY since 2014



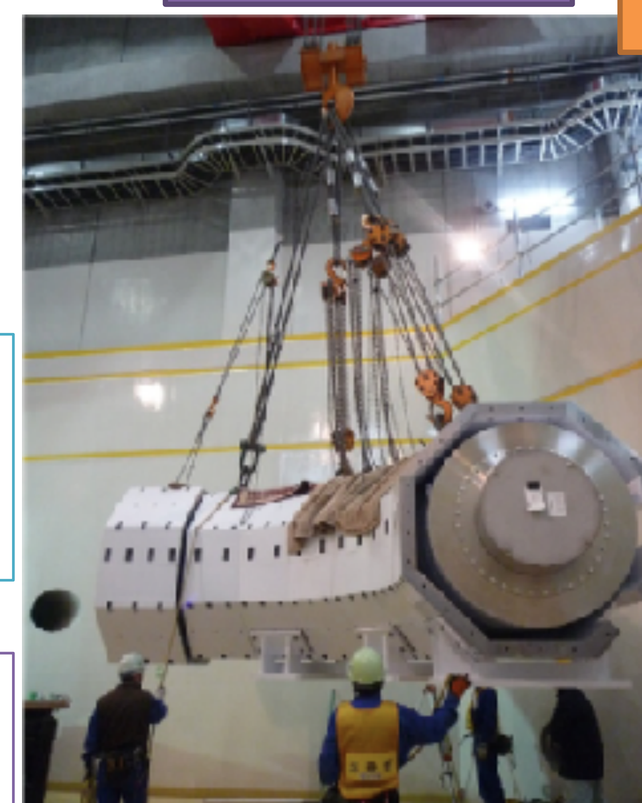
Beam transport line in HD hall



Significant construction work 2016 Summer to connect SY and Hall along the B-Line

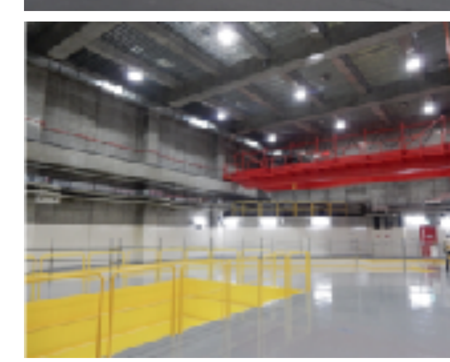
He compressor used for E36 will be reused for COMET

SC magnets



90 deg. Transport Solenoid installed in Spring 2015

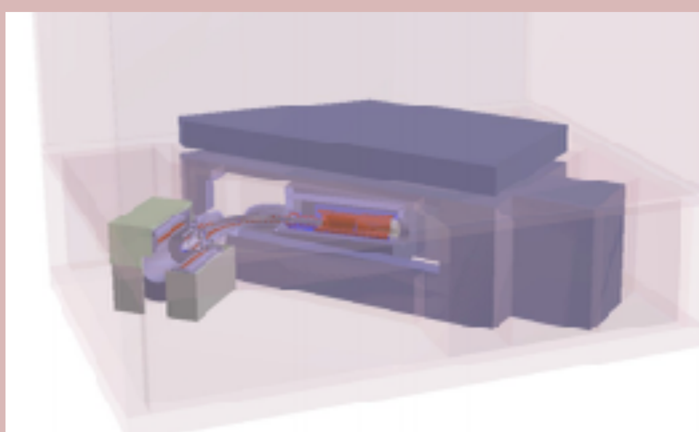
Hall construction



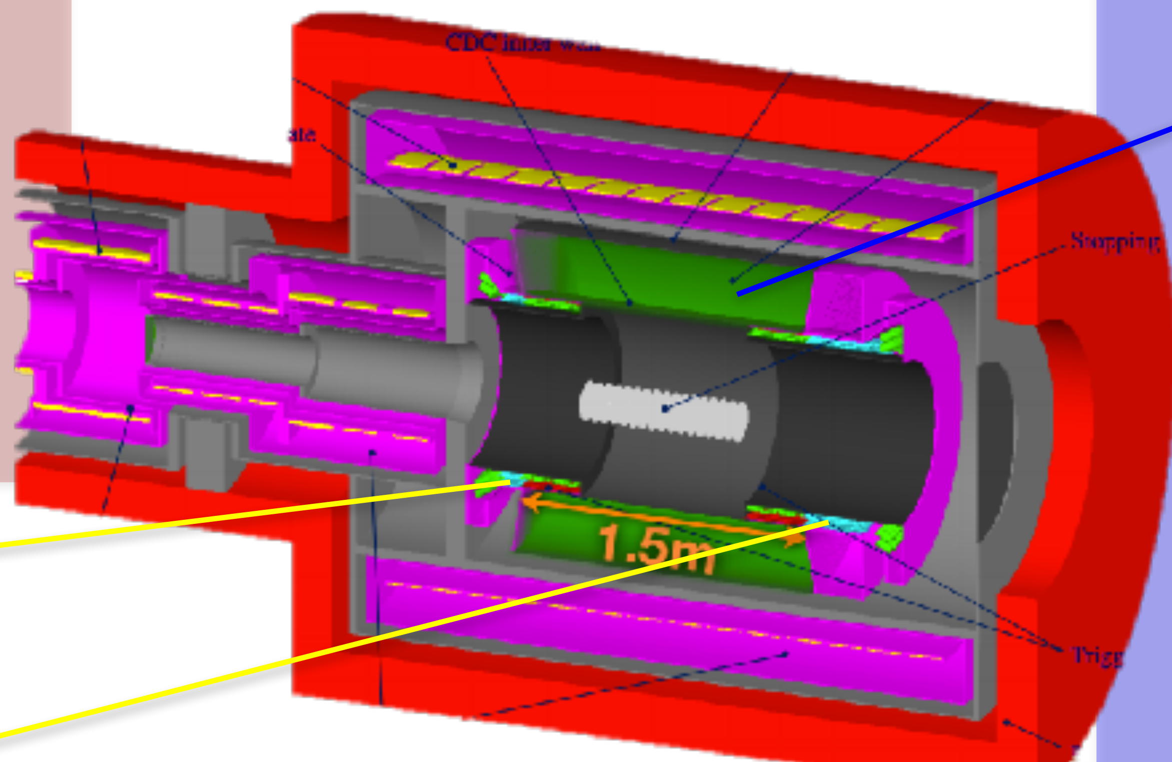
COMET Hall ready in Spring 2015

COMET:Status of Detector Preparation

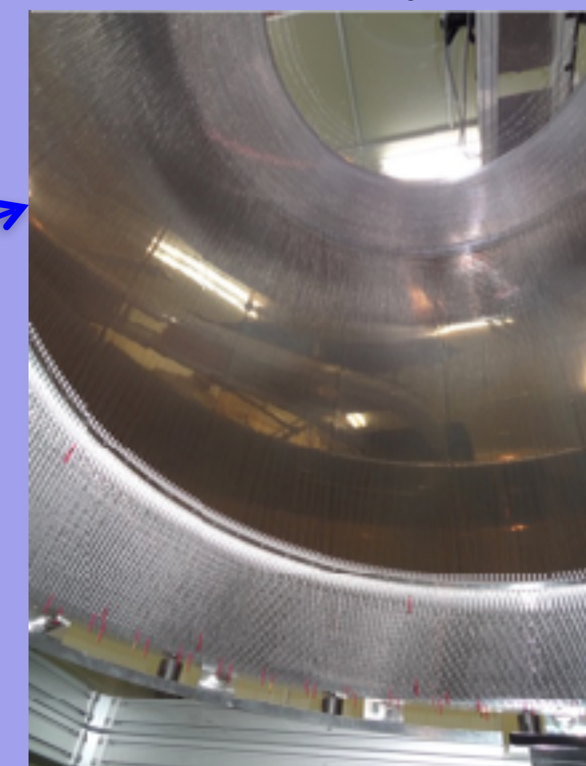
All geometry implemented in the full simulation: ICEDUST



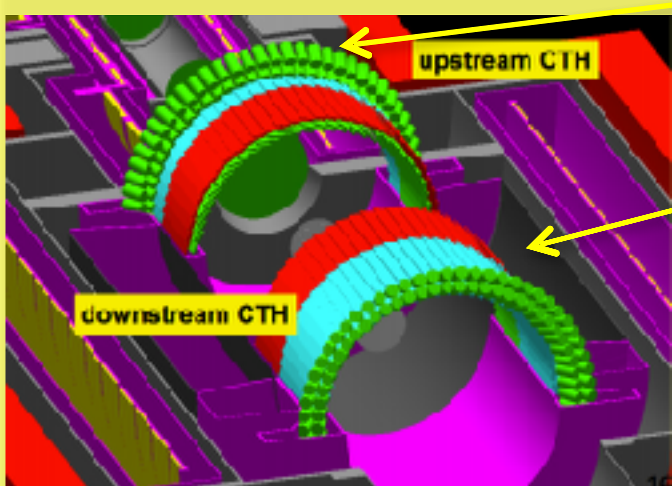
Detector for physics measurement in Phase I

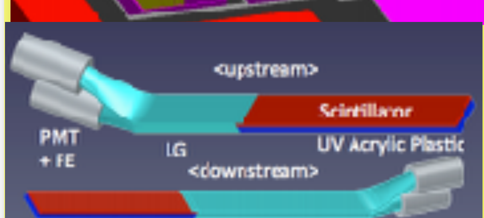


CDC : the main detector of COMET Phase-I Physics



Wire stringing completed in July 2016 at KEK

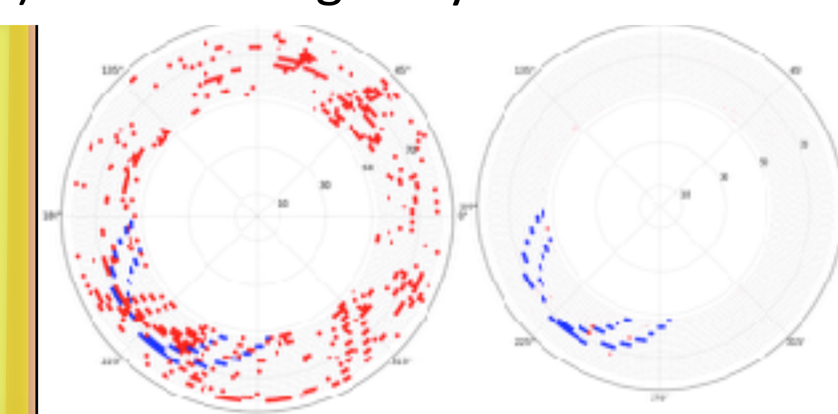




Beam test @ PSI 2015

Trigger Hodoscope Counter
Scintillator + Cerenkov

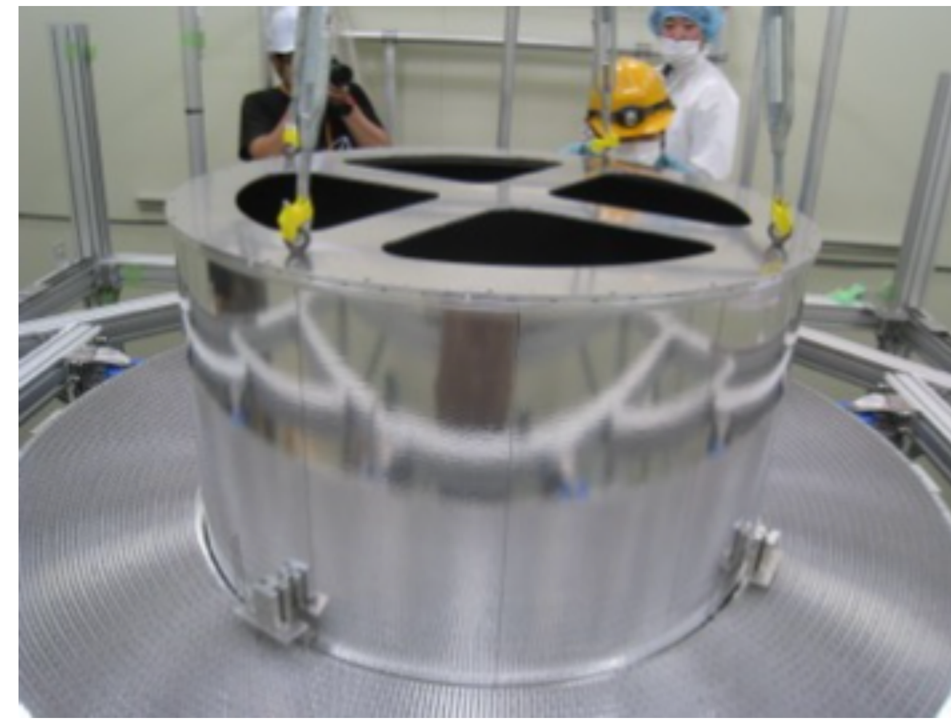
Analysis algorithm development in progress using simulation data.
ex) track finding in CyDET

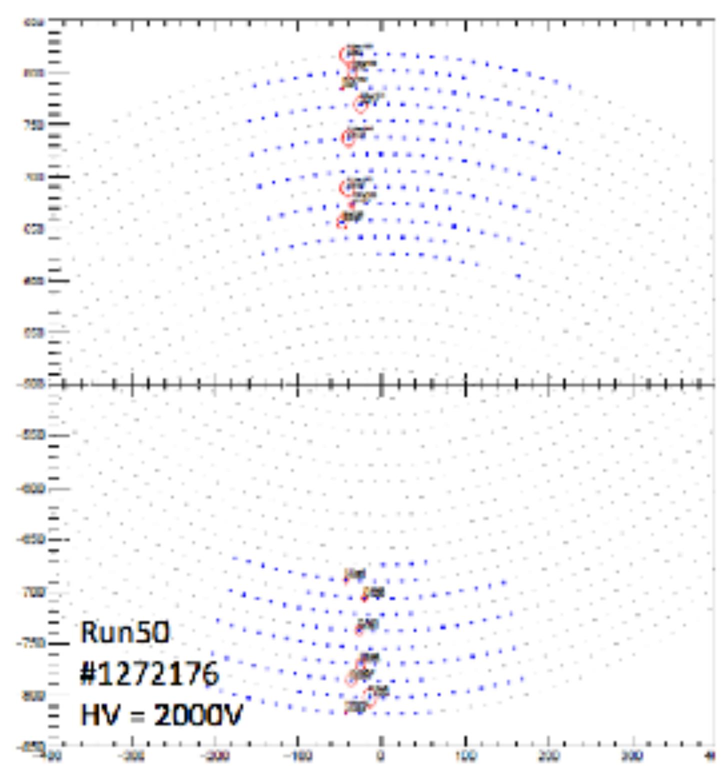


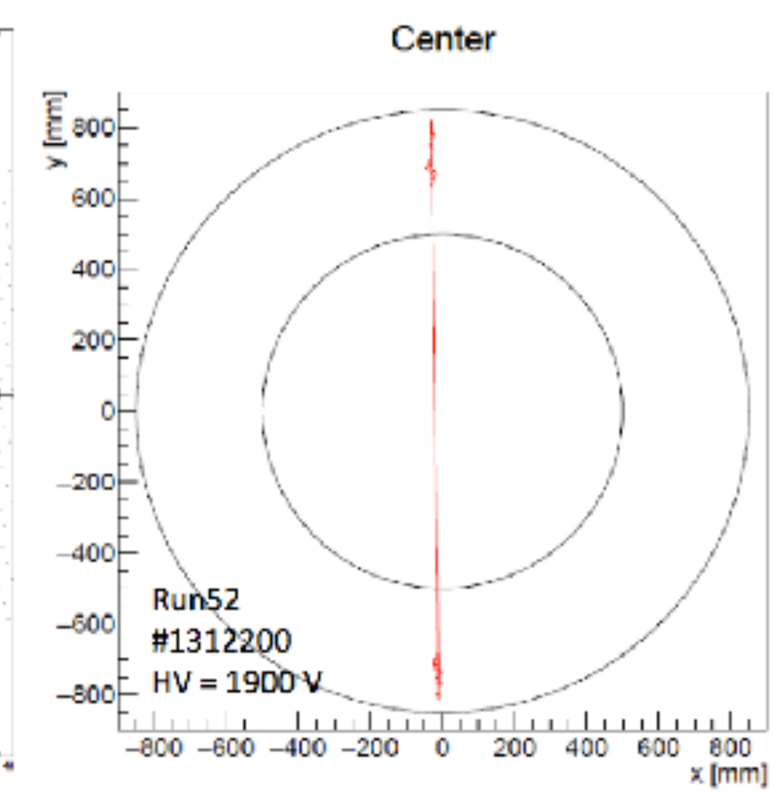
CDC Read Out Electronics RECBE production at IHEP

CDC Construction

- COMET Phase-I Physics Main Detector
- Wire stringing completed in July 2016
- 1st cosmic-ray event observed in Sep. 2016

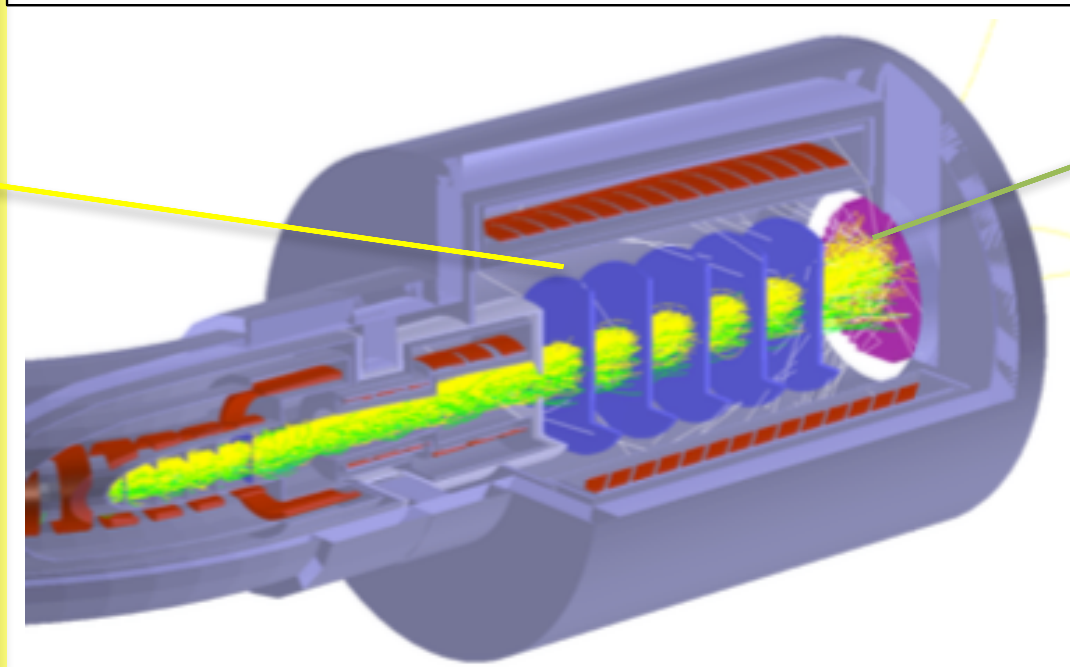




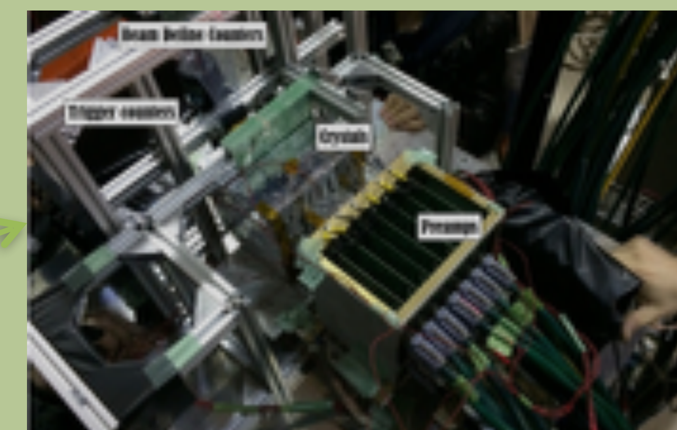
COMET: Detector Preparation Cont'd

Straw tracker (operational in vacuum) prototype

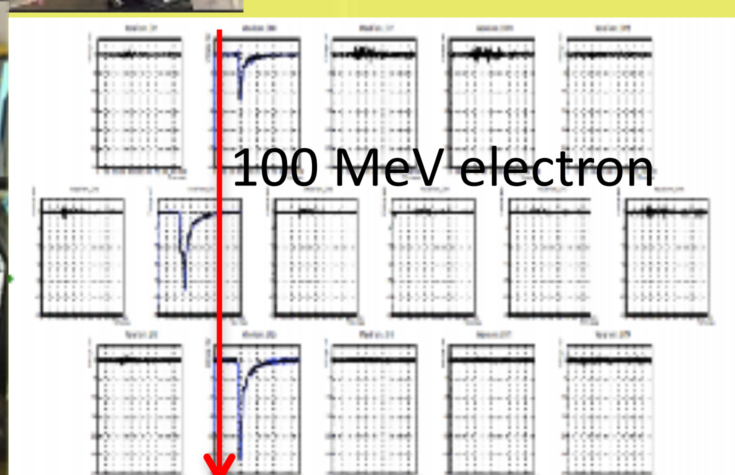
Detector for beam BG measurement in Phase I and physics measurement in Phase II



ECal (LYSO) R&D using prototypes



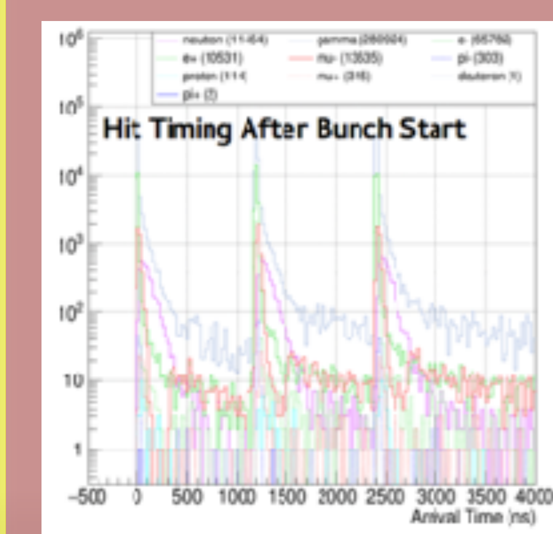
Crystal quality test bench at JINR

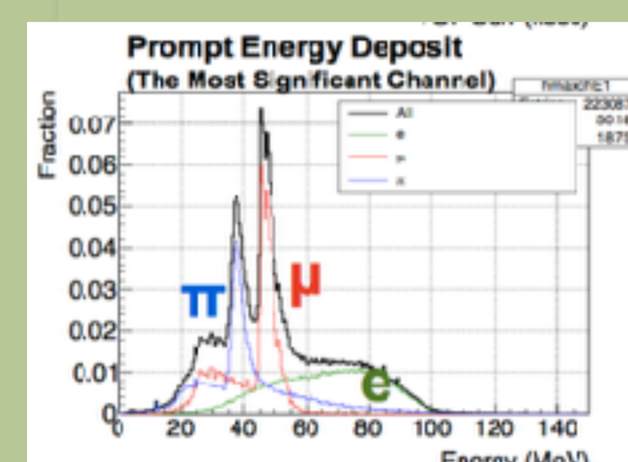


↑Wave form taken in the test

← Electron beam test at ELPH

Ecal Pile-up study using simulation data



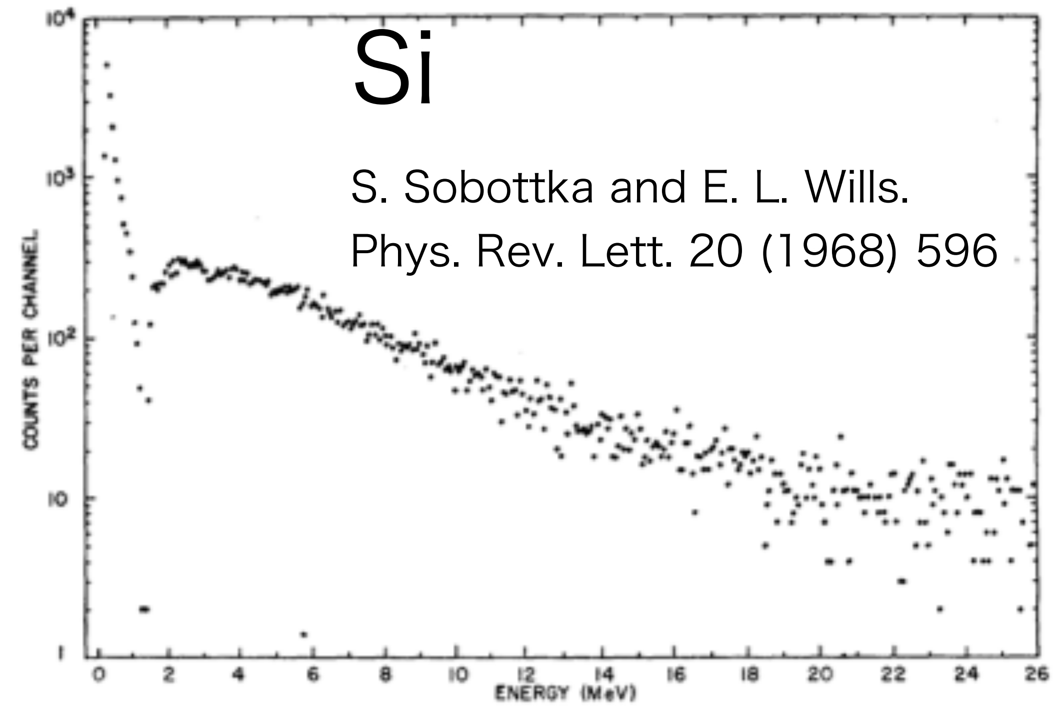


Ecal PID performance evaluation at PSI 2015

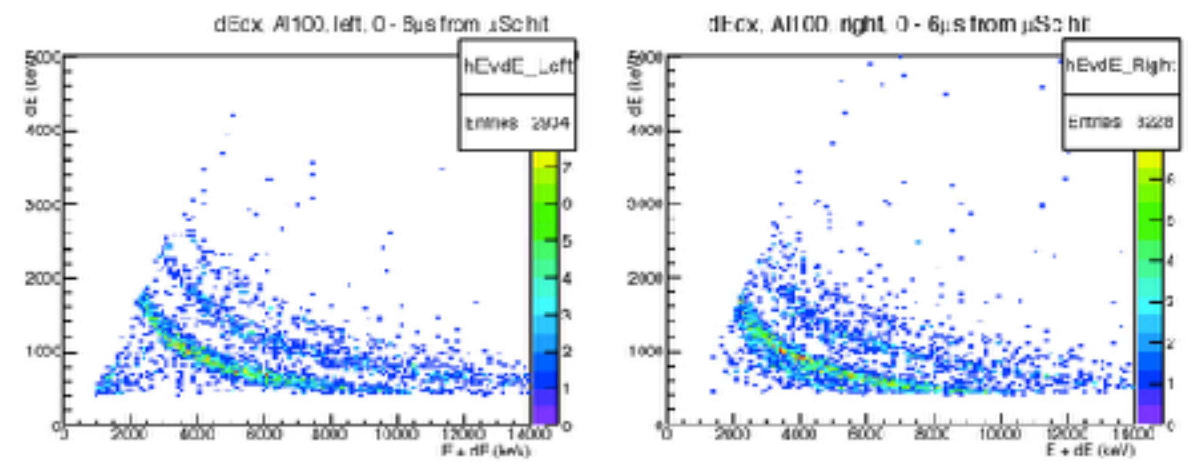
Backgrond Assessment

- Proton emission from muon captures
- No data available for Al
    - Si data only (near Al)
        - 15% proton emission / muon capture on ^{28}Si
        - 50MeV/c < p < 200MeV/c
- Significant contribution to the detector hit rate
- AlCap experiment at PSI
    - **Joint effort between COMET/ Mu2e**

Si

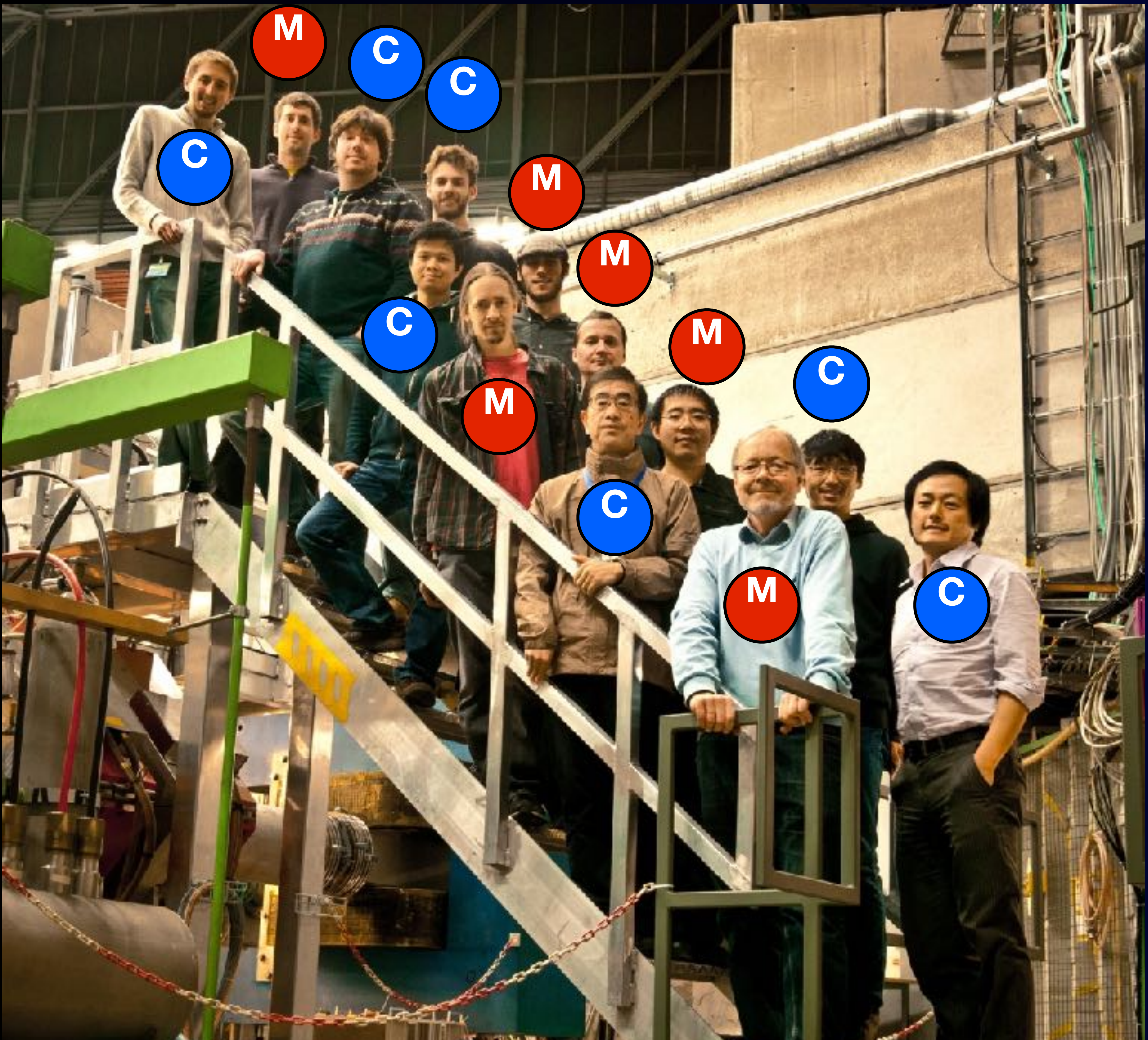


Al



- 0.05 protons/ muon capture
- Tran Hoai Nam (Osaka Univ.) PhD

opportunities for cooperation with Mu2e



AlCap@PSI

Dec. 13

C COMET

M Mu2e

Background Phase-I

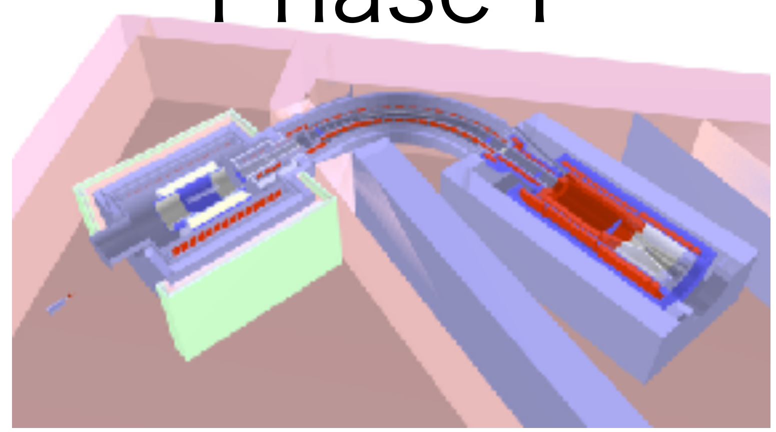
Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	
	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.

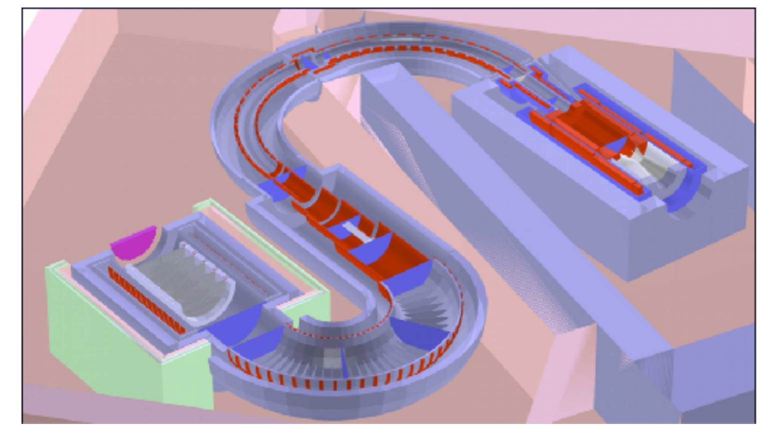
Preparation for Phase-II

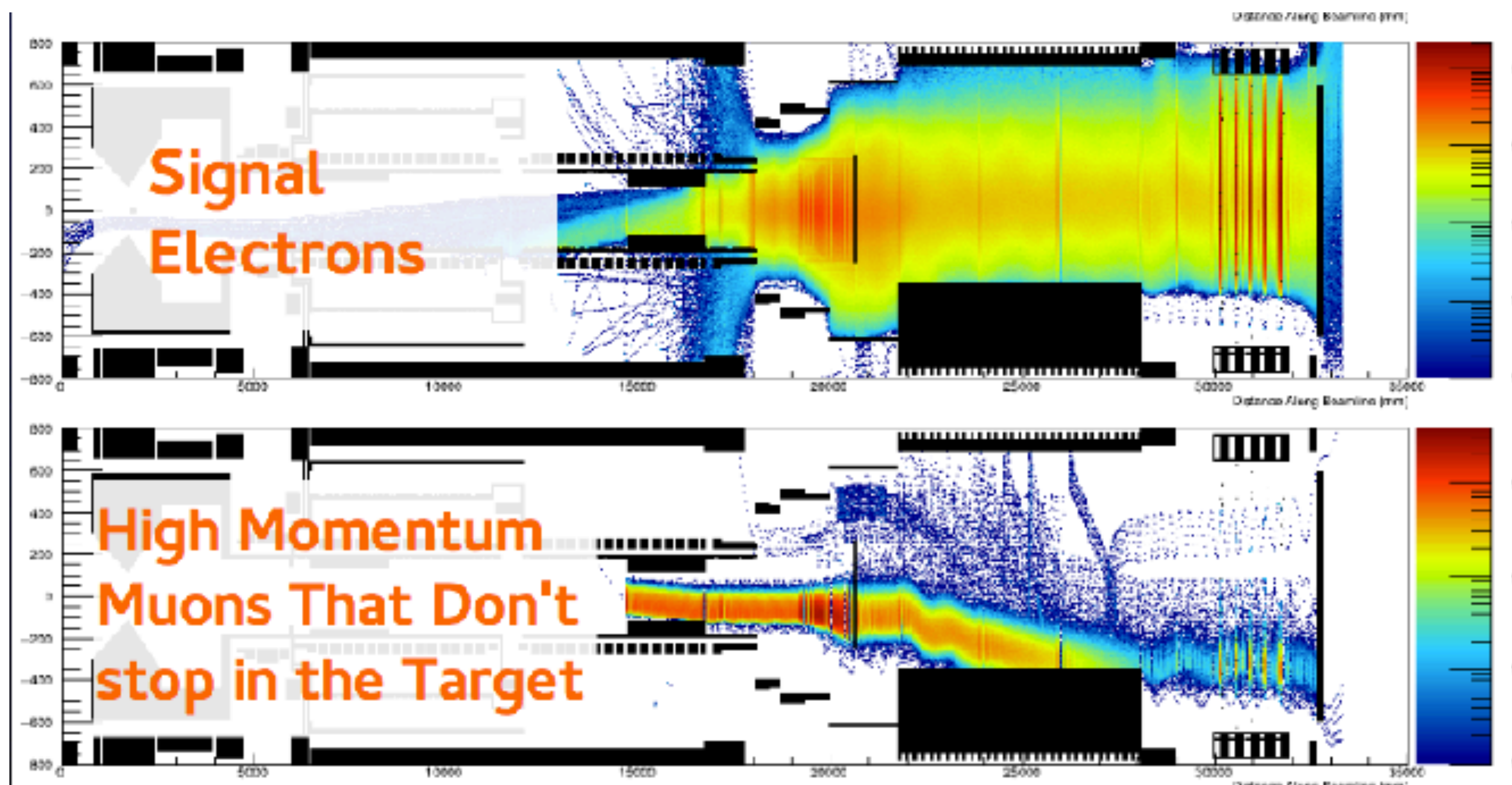
- 180 degree bend in the muon transport section
  - Better pi/mu separation and high-p particle rejection
- 180 degree bend in the electron spectrometer
  - Keep the detector occupancy rate reasonable even with higher primary beam power
  - Optimization of
    - muon stopping target disks
    - collimators in the electron spectrometer
- Detector R&D as a beam measurement detector in Phase-I

Phase-I

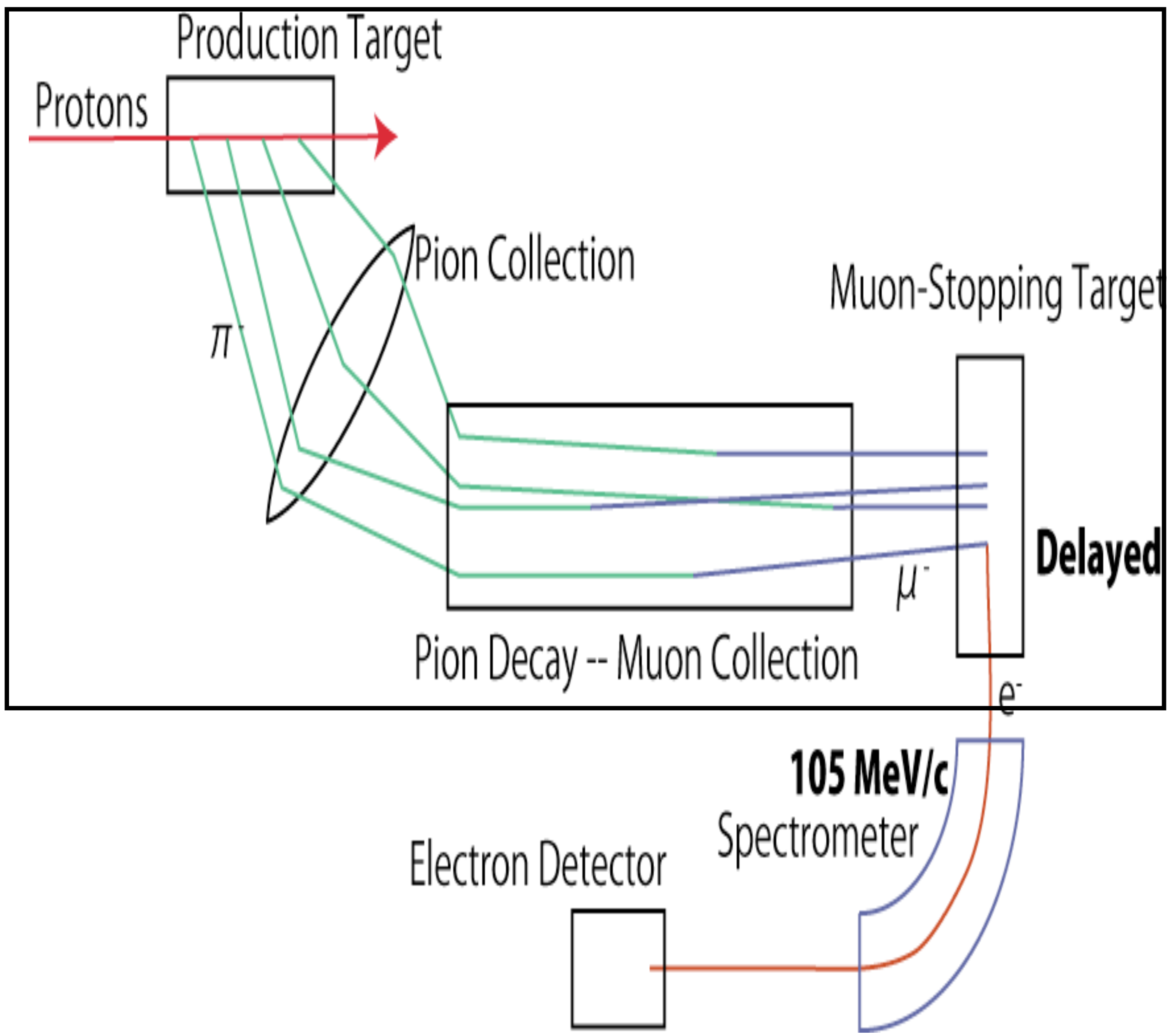


Phase-II



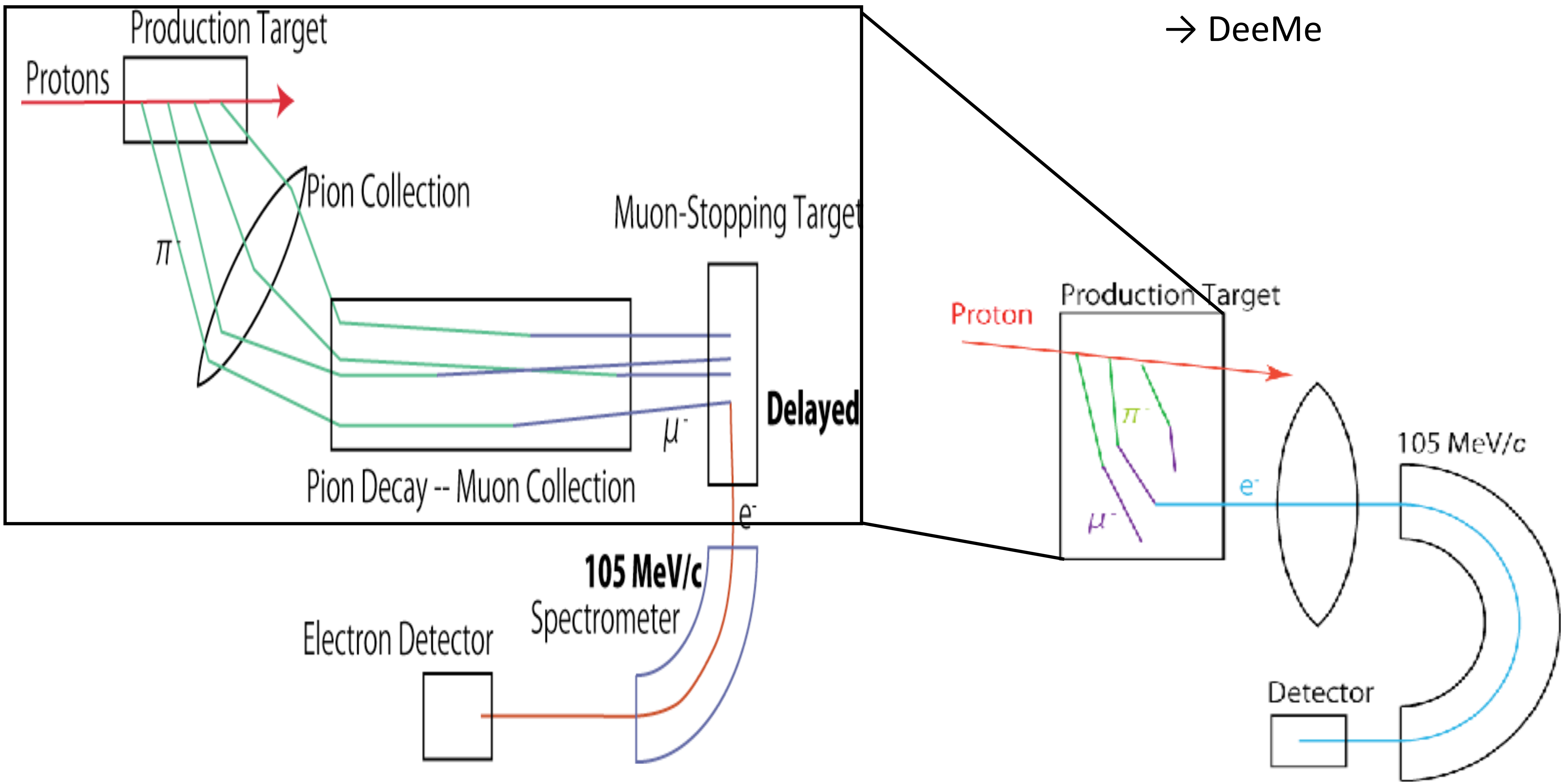


Principle of DeeMe



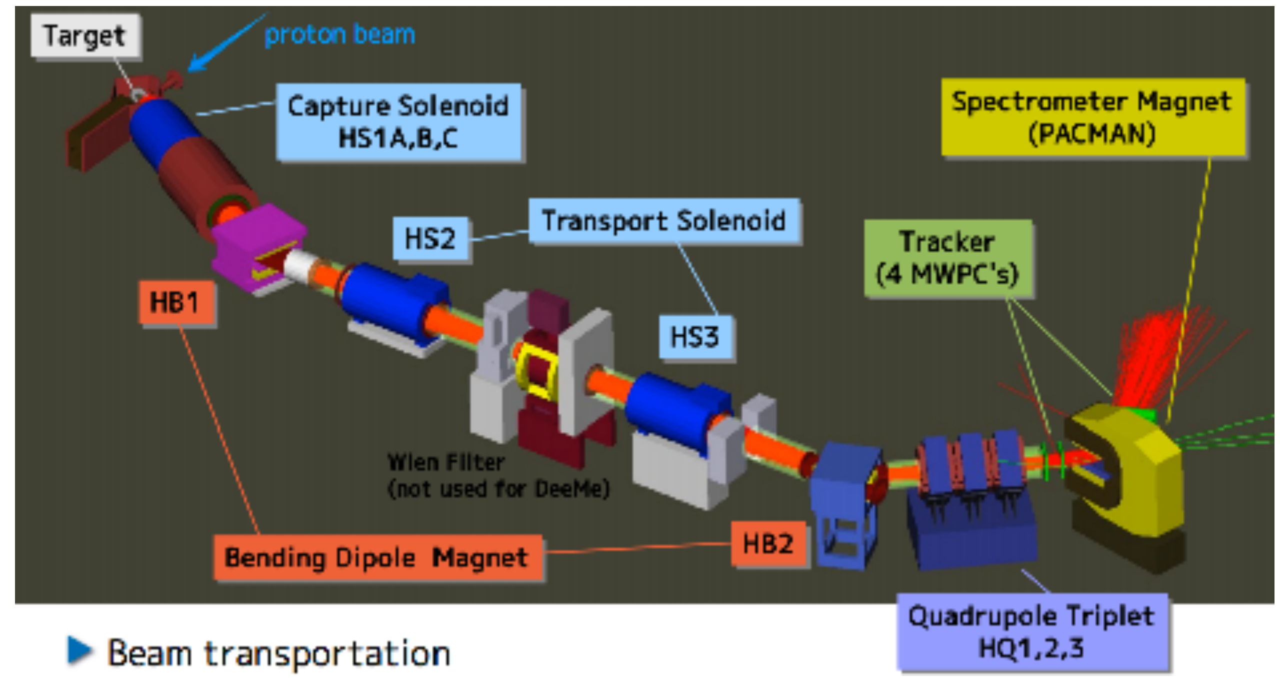
→ DeeMe

Principle of DeeMe

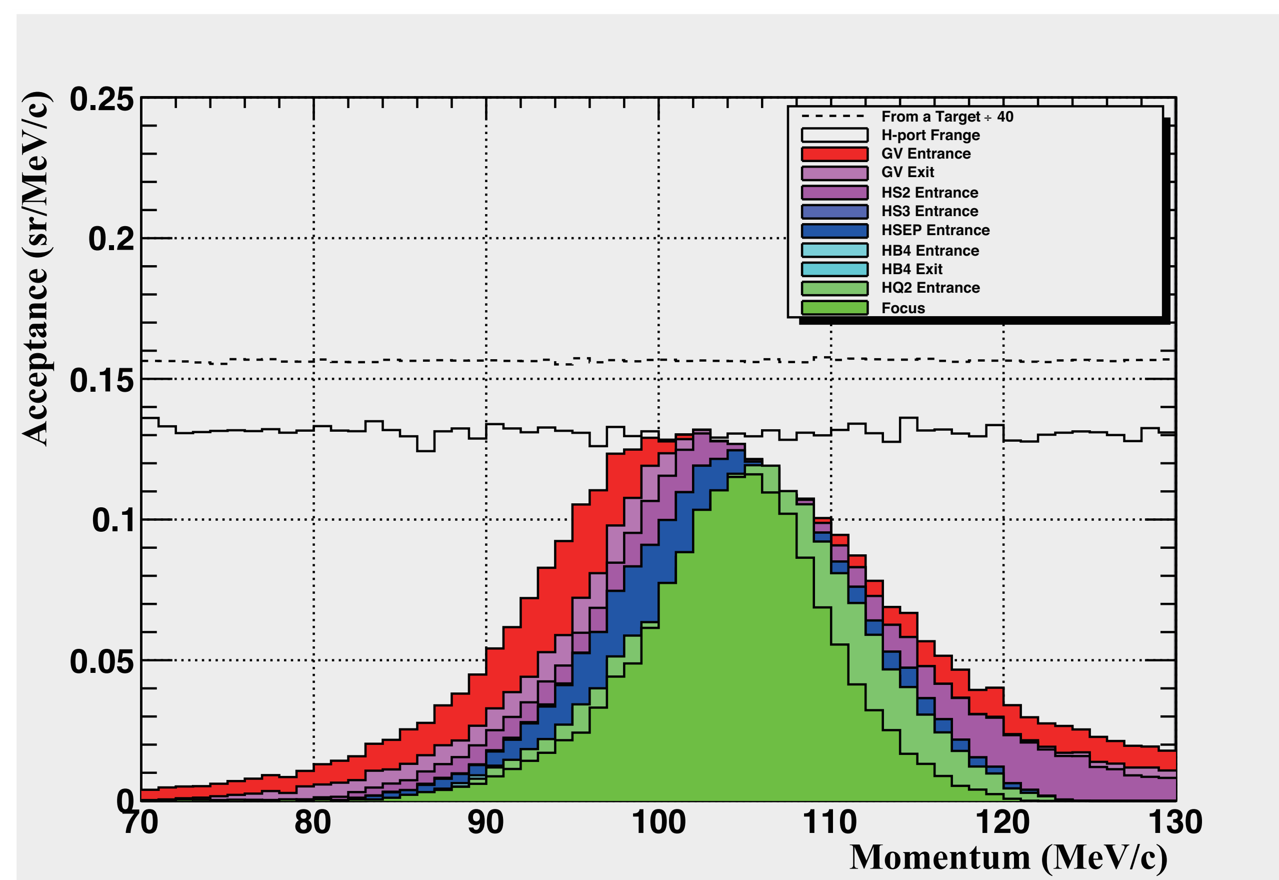


DeeMe at J-PARC

- **mu-e conversion search at J-PARC with a S.E.S. of 10^{-14}**
  - Primary proton beam from RCS
    - 3GeV, 1MW
  - Pion production target as a muon stopping target
  - Beam line as a spectrometer
    - Kicker magnets to remove prompt background
  - Multi-purpose beam line for DeeMe, HFS, g-2/EDM is under construction
  - **Engineering run (DIO electron measurement) in JFY 2016**



Beam transportation



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presented at PSI2013

Bld. construction completed in 2015 spring