COMET beamline and facility

Satoshi MIHARA

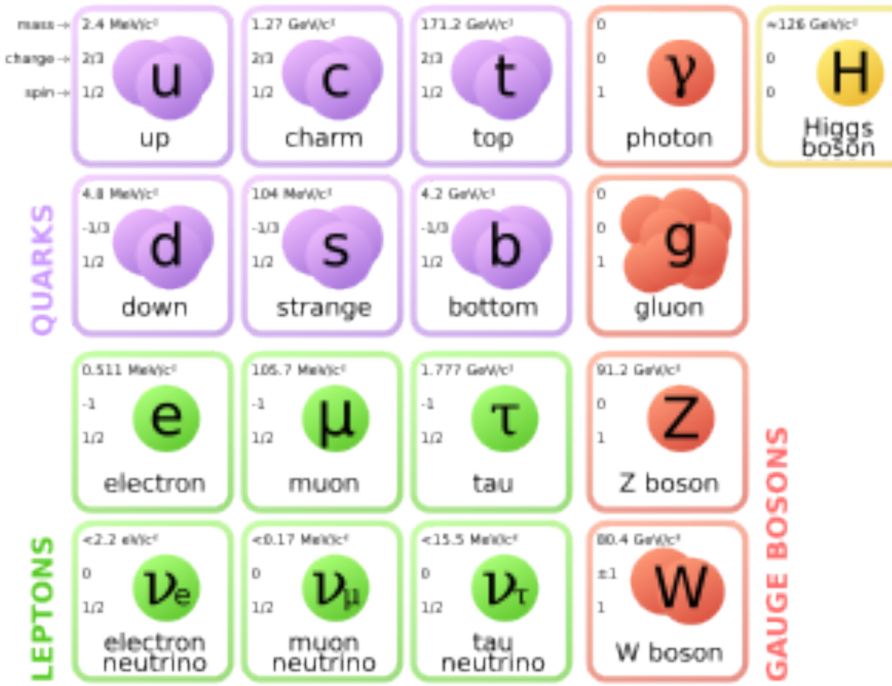
Outline

- COMET physics
- COMET facility & detector
- COMET beam & monitors
- Summary

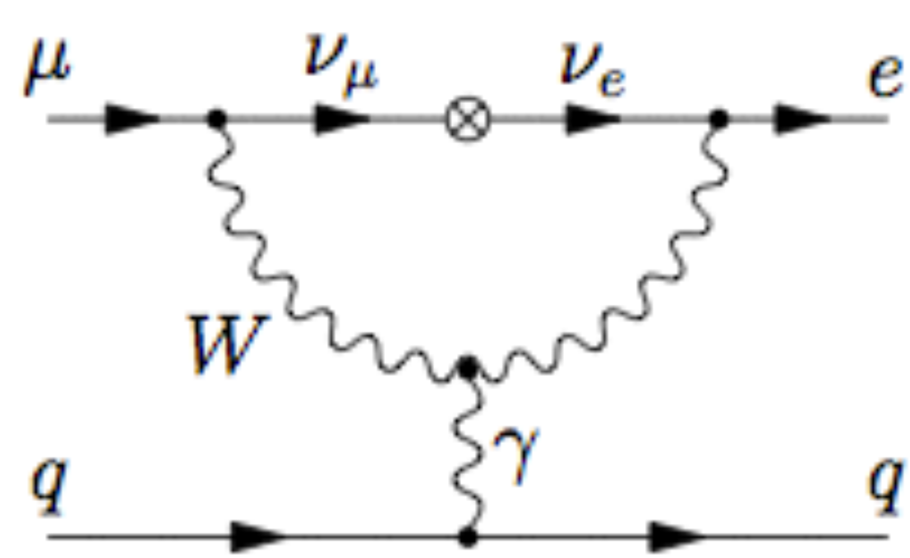
COMET physics

Charged Lepton Flavor in SM

- Precise measurement of charged lepton behavior contributed to establish the SM
- No observation of “exotic decay mode”
    - Concept of Generation (Flavor)
- Lepton flavor transition is strictly forbidden
- Neutrino Oscillation has been observed
    - ν oscillation + SM

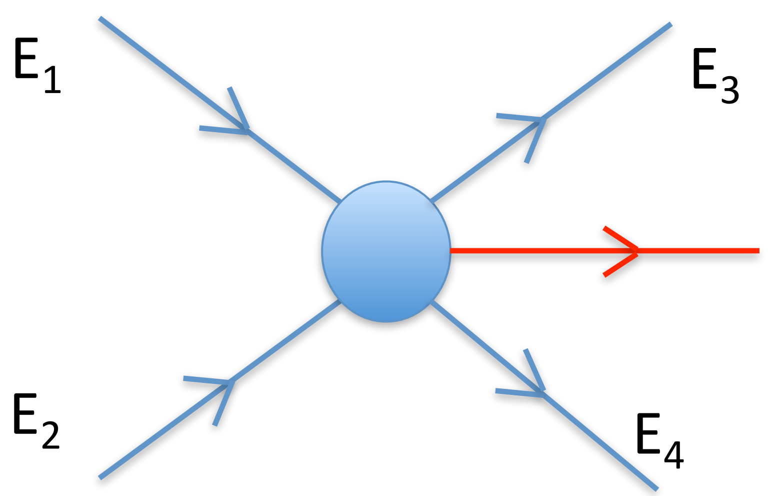


wiki



Role of low-energy charged lepton physics in LHC/ILC era

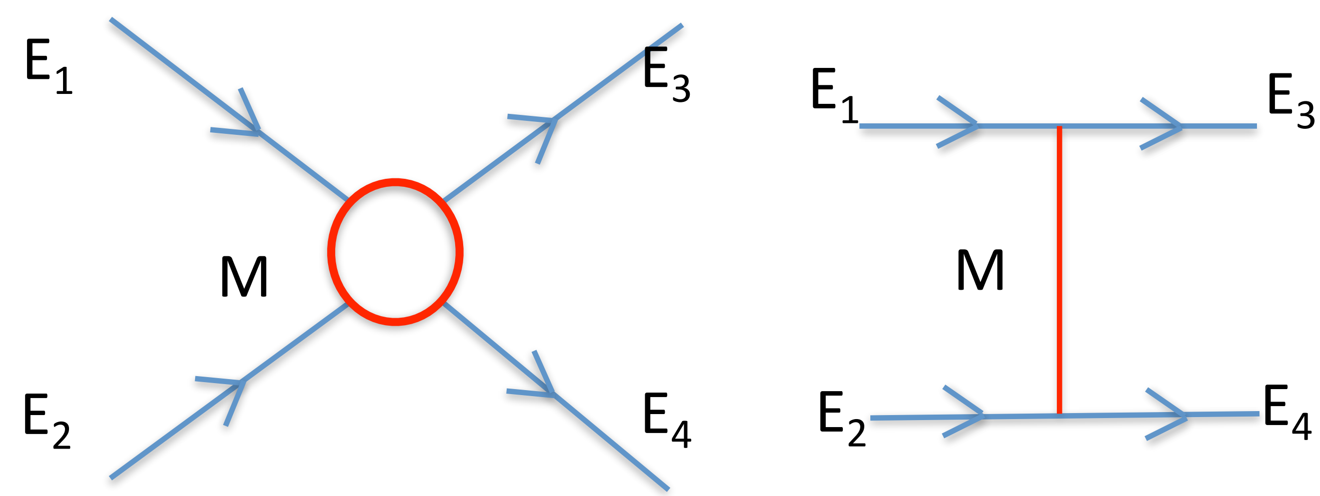
- Direct search
  (Energy Frontier)



$E_1+E_2 > M \sim O(>100\text{GeV})$

- LHC, ILC
  - Higher energy for heavier new particle

- Indirect search
  (Intensity Frontier)



$E_1+E_2=E_3+E_4 <M$

- Charged LFV/g_μ-2

  $L = L_{SM} + L_{BSM}$

  “Slight” difference from SM prediction

New Physics Search in Lepton Flavor

- SM+ν mass+New physics contribution

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda_{\text{LNV}}}\mathcal{O}^{\text{dim-5}} + \frac{1}{\Lambda^2_{\text{LFV}}}\mathcal{O}^{\text{dim-6}} + \cdots.$$

neutrino mass

$$\mathcal{O}^{\text{dim-5}} = (g_\nu)^{ij}(\bar{L}^i\tilde{H})(\tilde{H}^\dagger L^j)^c + \text{h.c.}$$

cLFV ($\mu\to e\gamma$, $\mu\to eee$, $\mu\to e$ conversion)

$$\mathcal{O}^{\text{dim-6}} \ni \bar{\mu}_{\text{R}}\,\sigma^{\mu\nu}\,H\,e_{\text{L}}F_{\mu\nu},\quad (\bar{\mu}_{\text{L}}\gamma^\mu e_{\text{L}})(\bar{f}_{\text{L}}\gamma^\mu f_{\text{L}}),\quad (\bar{\mu}_{\text{R}}e_{\text{L}})(\bar{f}_{\text{R}}f_{\text{L}})$$

Λ: scale of new physics

MEG limit
Br($\mu\to e\gamma$)<5.7×10^{-13}

→ **Λ> O(10^5) TeV**

cLFV & new physics

- Others

$$|A_{SM}+\varepsilon_{NP}|^2 \sim |A_{SM}|^2 + 2Re(A_{SM}\varepsilon_{NP}) + |\varepsilon_{NP}|^2$$

  - Uncertainty of SM prediction

- cLFV

$$|A_{SM}+\varepsilon_{NP}|^2 \sim \cancel{|A_{SM}|^2} + 2Re(\cancel{A_{SM}}\varepsilon_{NP}) + |\varepsilon_{NP}|^2$$

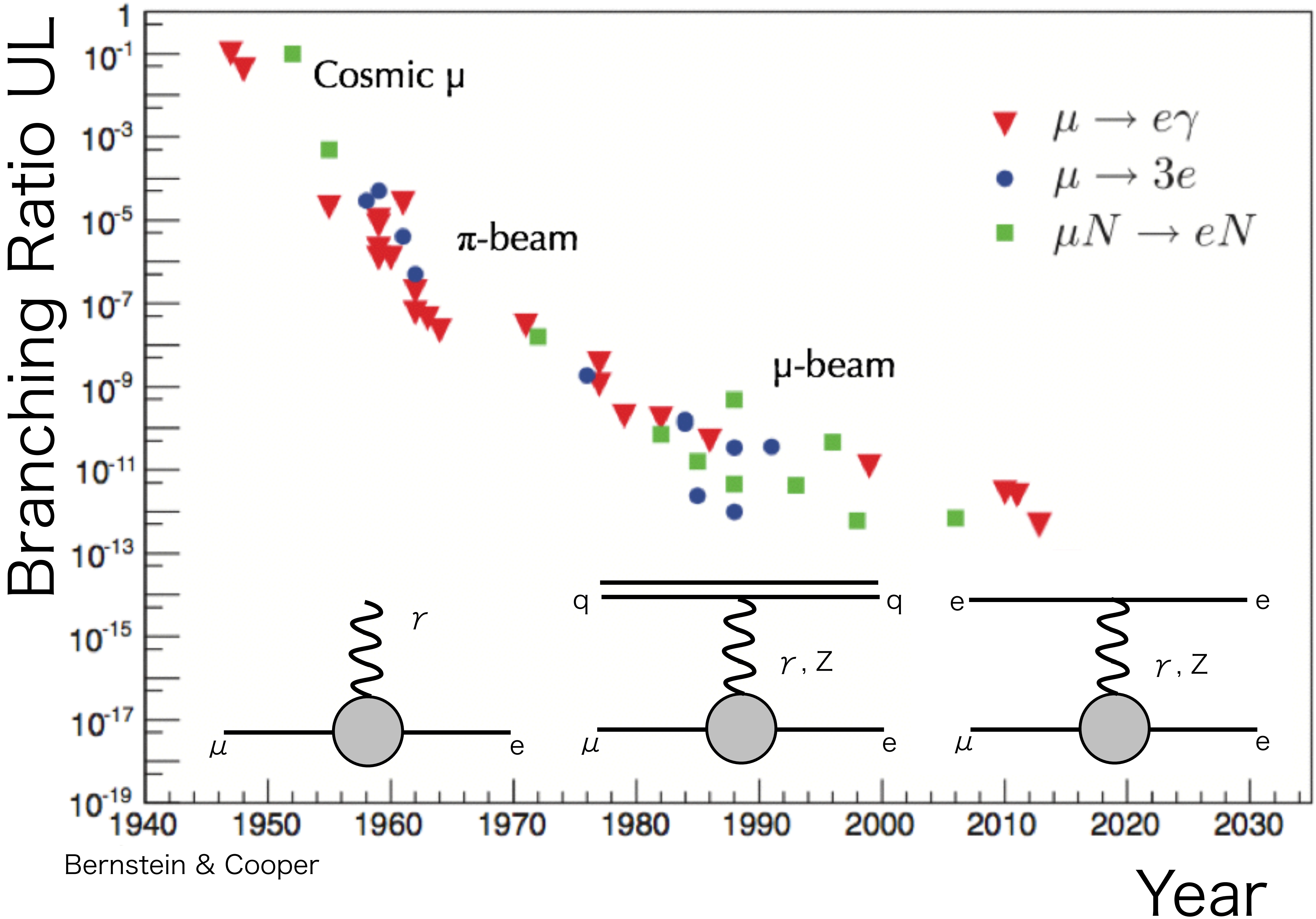
  - Possible to reach higher energy scale

$R \propto 1/\Lambda^4$

10000 higher sensitivity

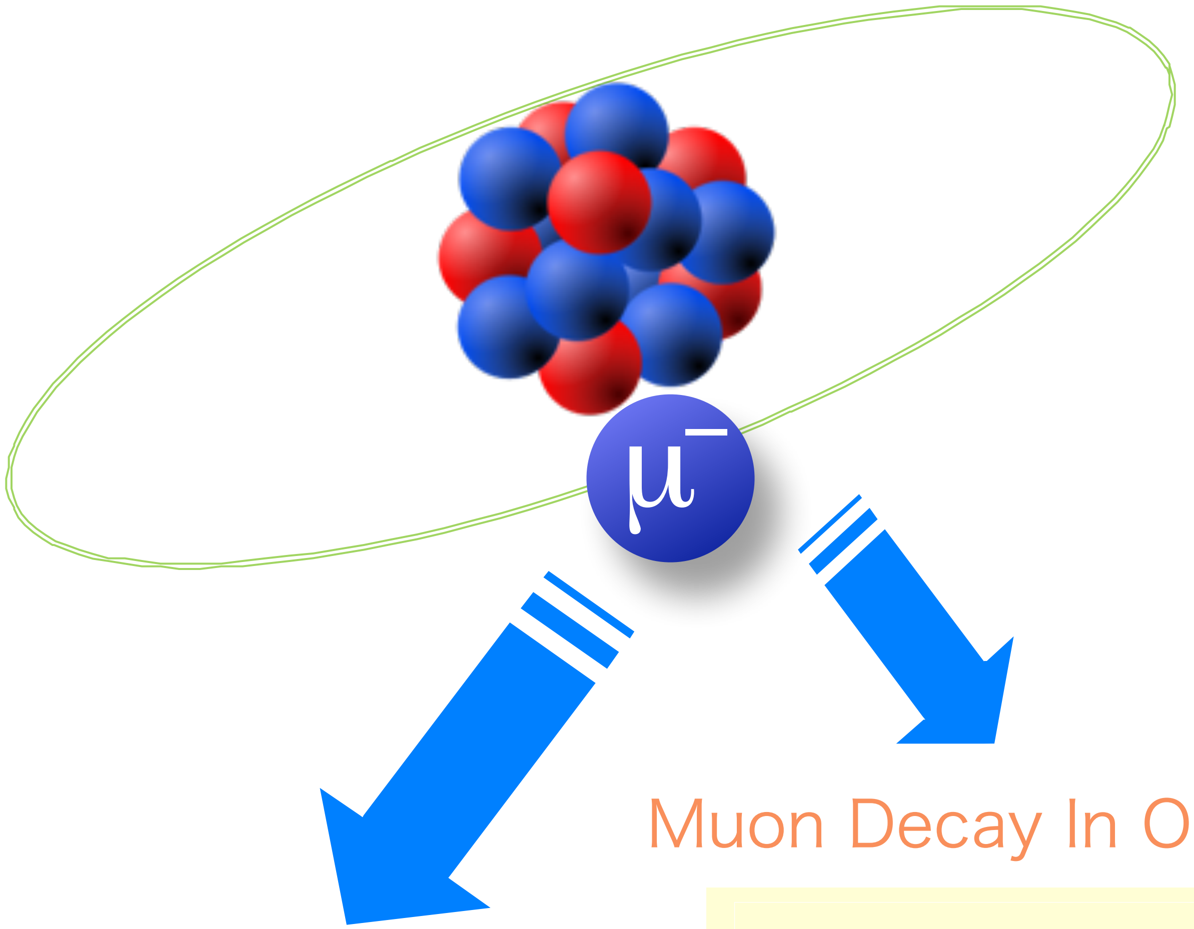
↓

10 times in energy reach



Branching Ratio UL
1
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
10^{-13}
10^{-15}
10^{-17}
10^{-19}
Cosmic μ
π-beam
μ-beam
$\mu \to e\gamma$
$\mu \to 3e$
$\mu N \to eN$
γ
q
q
γ, Z
e
e
γ, Z
μ
e
μ
e
μ
e
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
Bernstein & Cooper
Year

$\mu \rightarrow$e search using pulsed muon beam



Muon Decay In Orbit

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

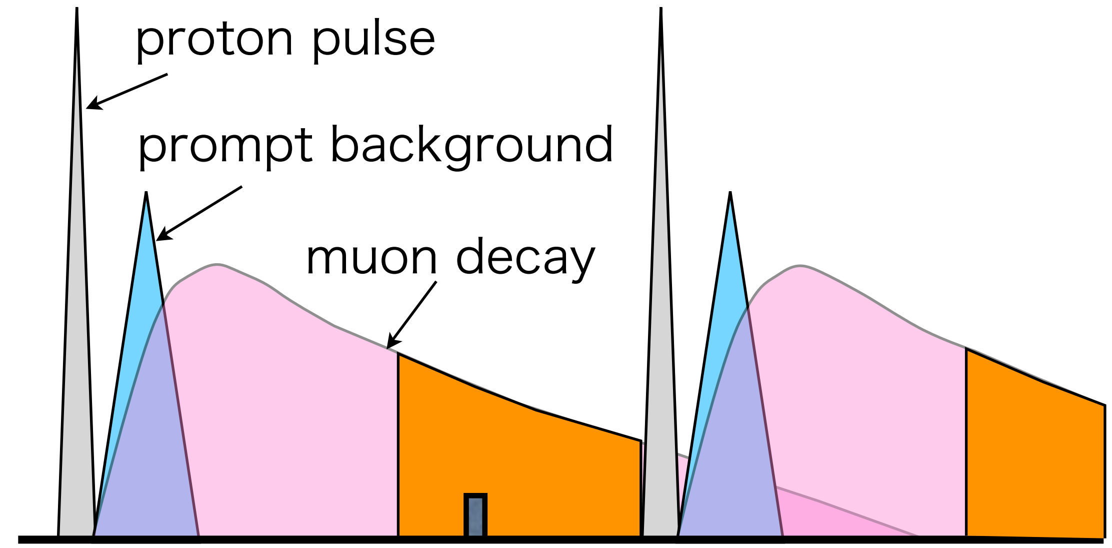
nuclear muon capture

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

μ-e conversion

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

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



$\pi^- + (A,Z) \rightarrow (A,Z-1)^*$, $(A,Z-1)^* \rightarrow \gamma + (A,Z-1)$, $\gamma \rightarrow e^+e^-$

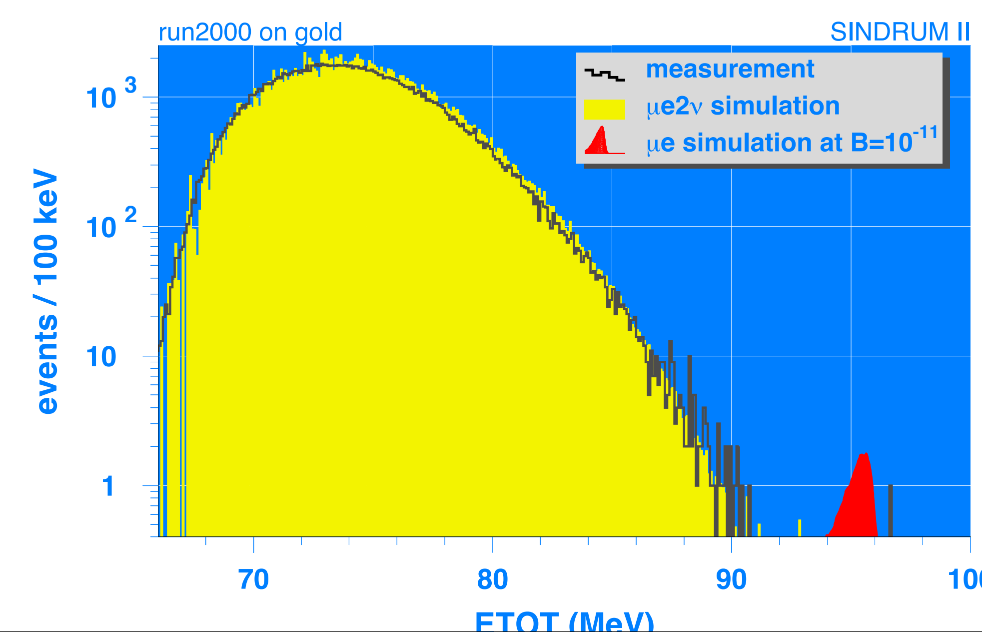
Prompt timing

Other sources

μ^- decay-in-flight, e^- scattering, neutron streaming

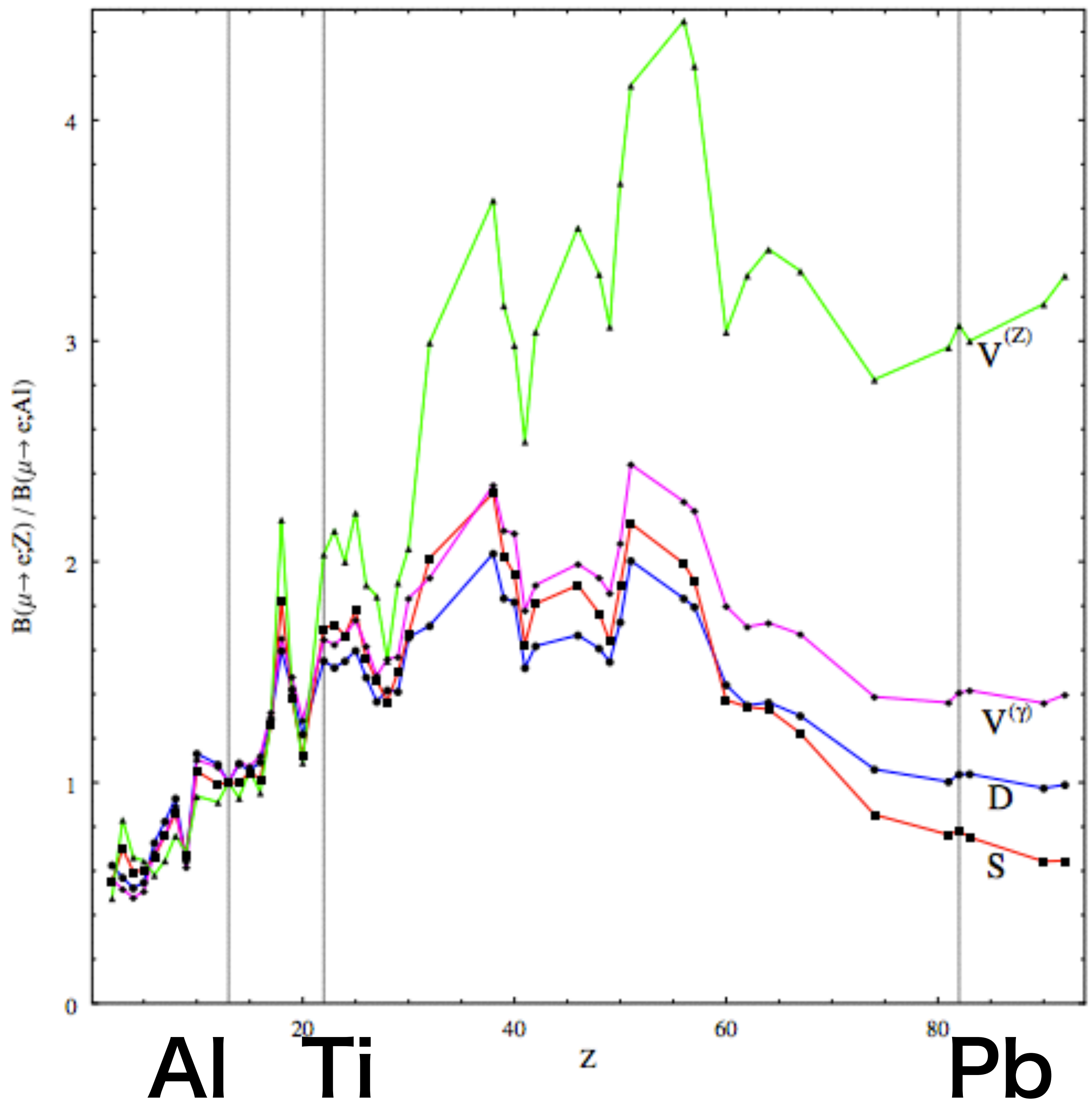
$$R_{ext} = \frac{\text{number of proton between pulses}}{\text{number of proton in a pulse}}$$

SINDRUM II BR[μ^- + Au $\rightarrow e^-$ + Au] < 7×10^{-13}



μ-e conversion with different Z

Even without μ->eγ signal

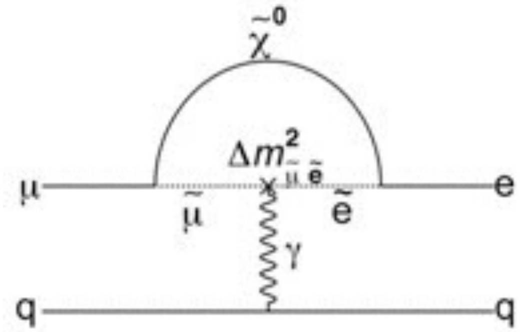


CIRIGLIANO, KITANO, OKADA, AND TUZON PHYSICAL REVIEW D 80, 013002 (2009)

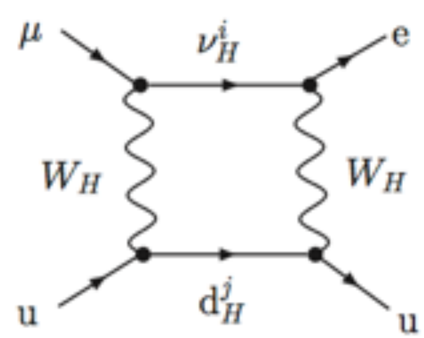
Theory Models

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

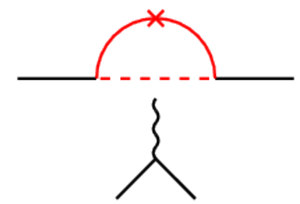
- SUSY-GUT, SUSY-seesaw (Gauge Mediated process
  - BR = 10^{-14} = BR($\mu \to e\gamma$) × O(α)
  - $\tau \to l\gamma$

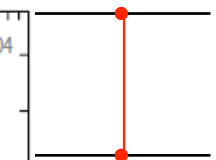


- Little Higgs Model with T parity
  - BR = 10^{-9}~10^{-15}
  - Penguin or Box

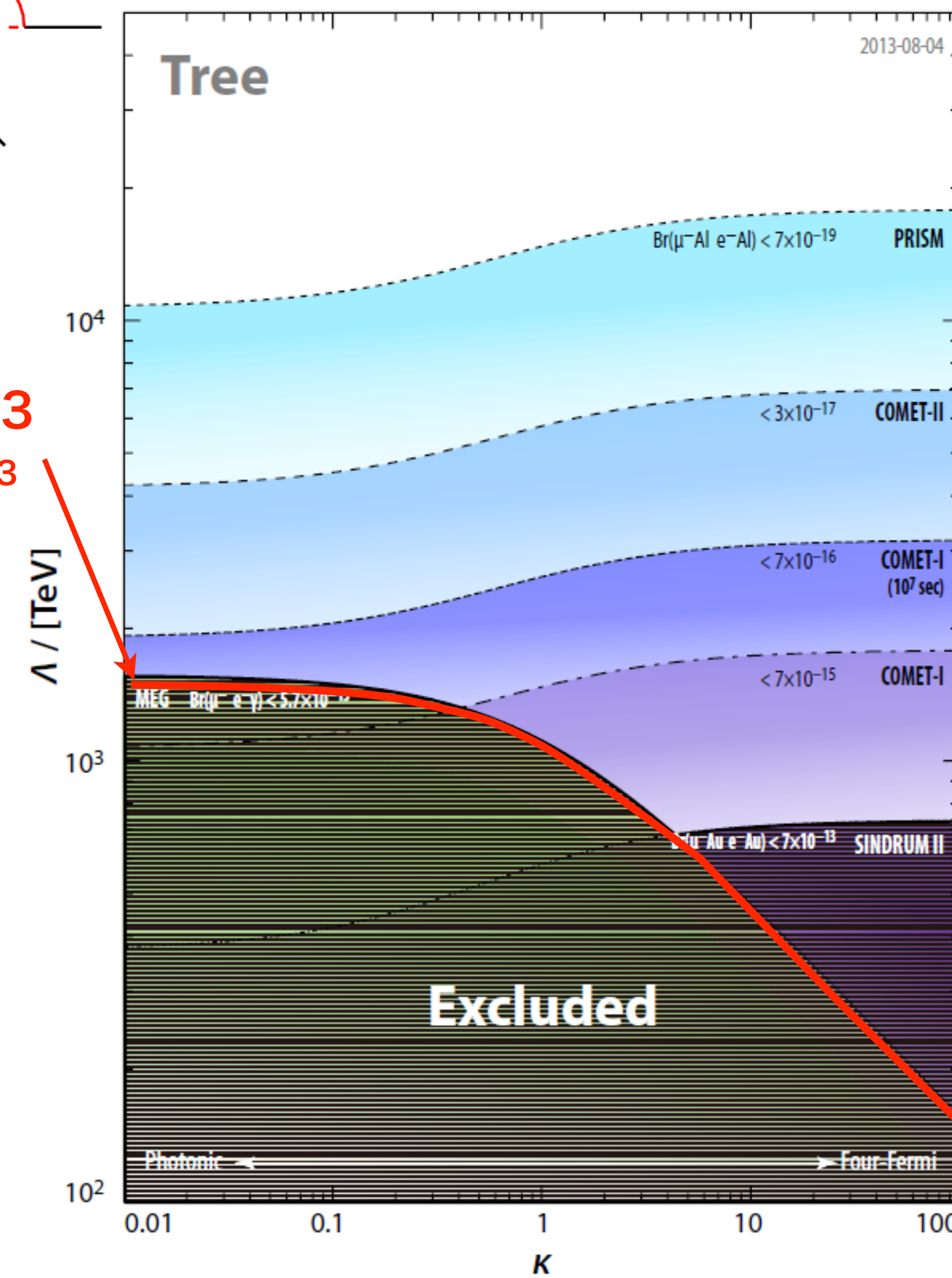


- Fourth Generation of Leptons
  - A new heavy charged lepton & a (Dirac) neutrino
  - Buras AJ, et al. J. High Energy Phys. 1009:104 (2010)
- and many others





MEG 2013
5.4x10^{-13}

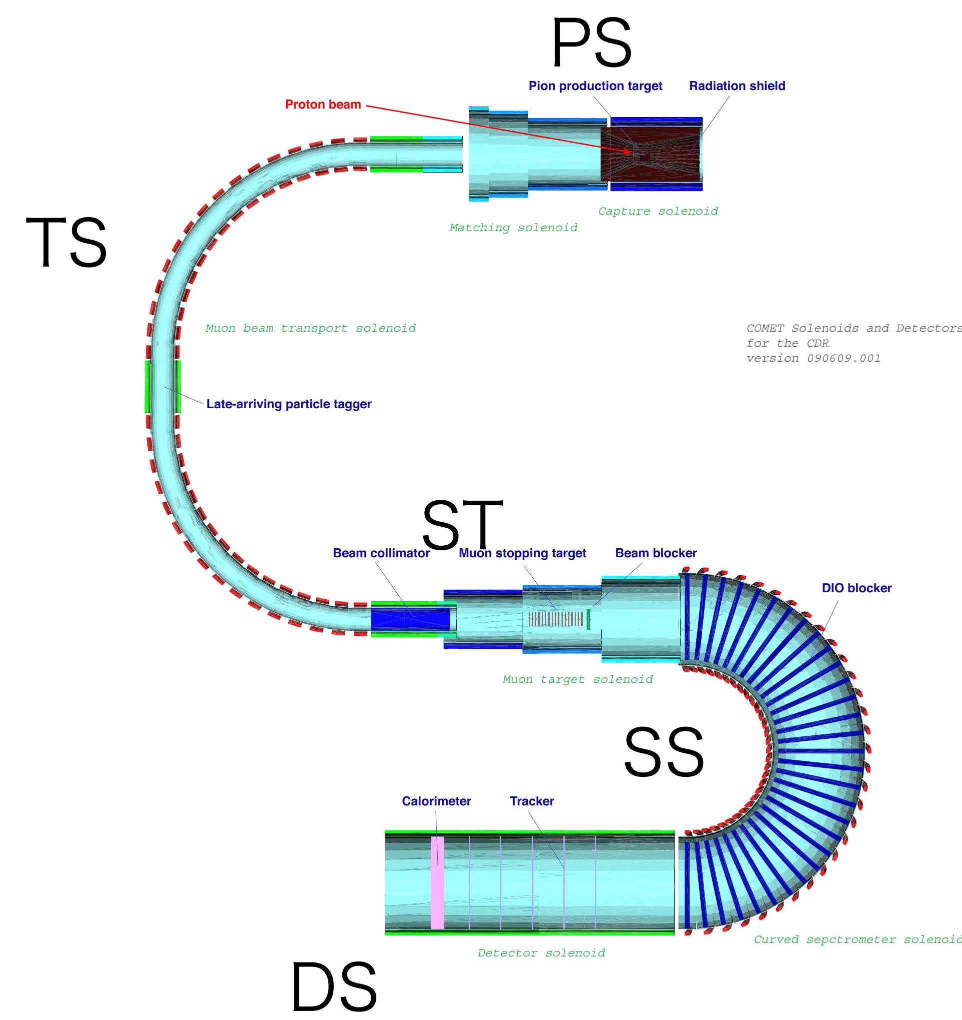


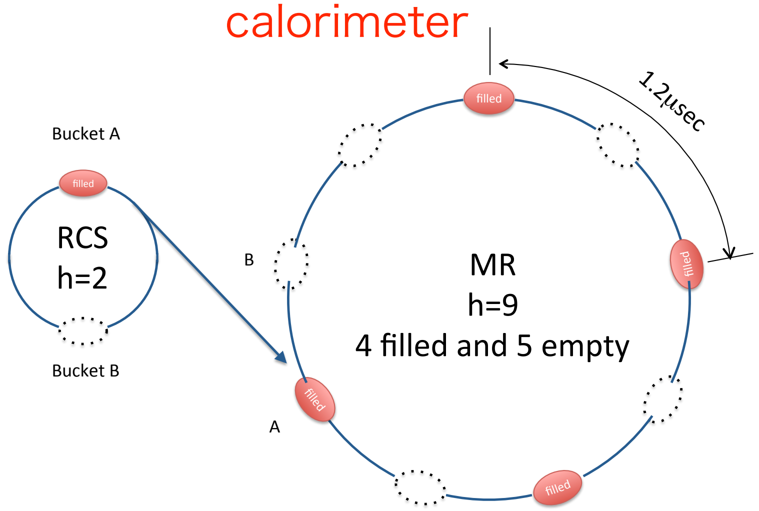
Andre de Gouvea, W. Molzon, Project-X WS (2008)

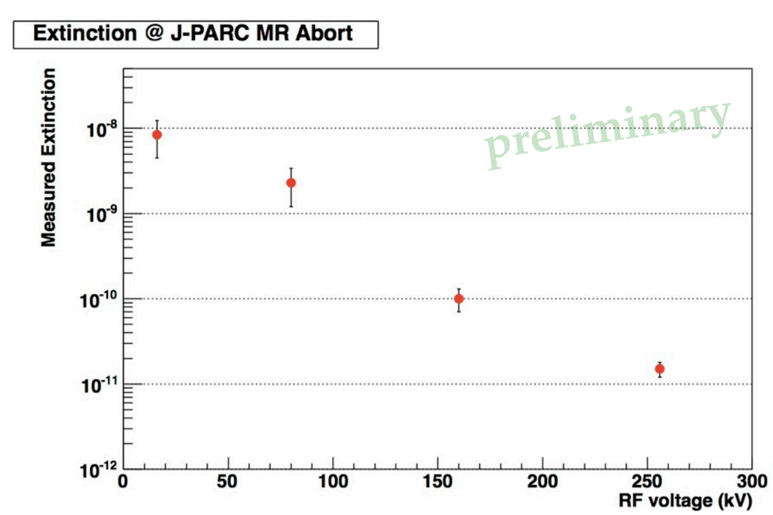
COMET facility & detector

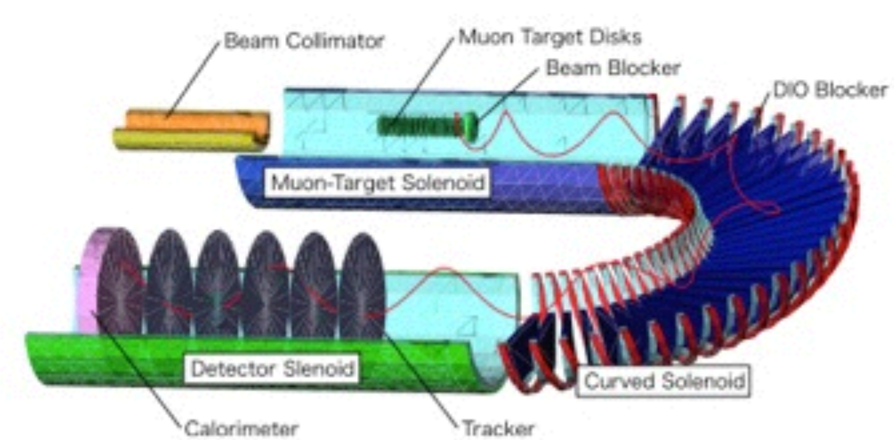
COMET at J-PARC

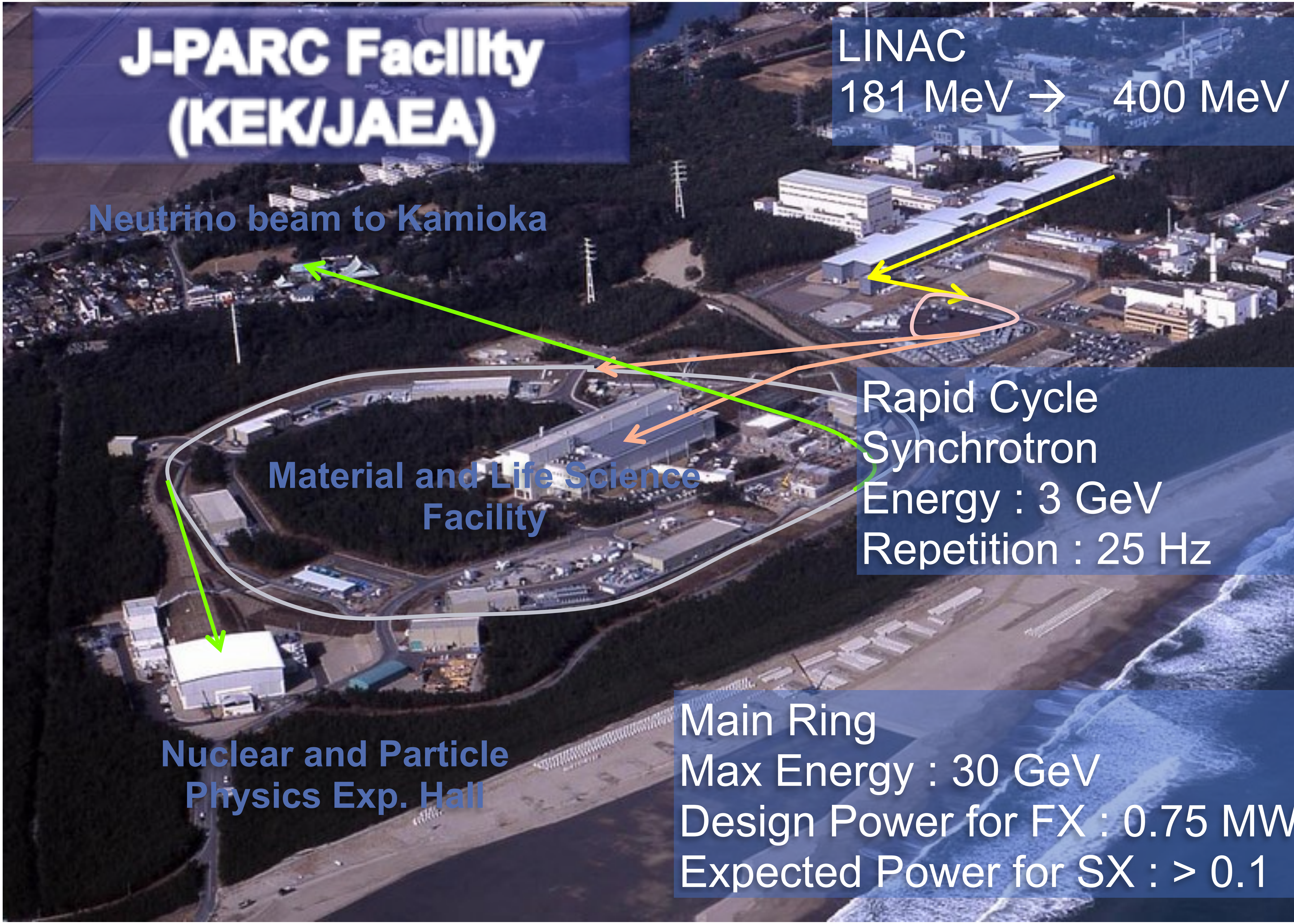
- J-PARC pulsed proton beam to produce pulsed muon beam
  - 8GeV, 3kW-56kW
  - Beam extinction factor study
    - 30GeV w/o extraction, Rext < 1.5×10^{-11}
- 32m long chain of SC solenoid magnets
  - pion collection (PS)
  - muon transport (TS)
  - muon focusing on the stopping target (ST)
  - electron momentum selection (SS)
  - electron spectrometer (DS)
- Electron spectrometer
  - 1T solenoidal field, Multi-layer straw tube tracker, crystal calorimeter



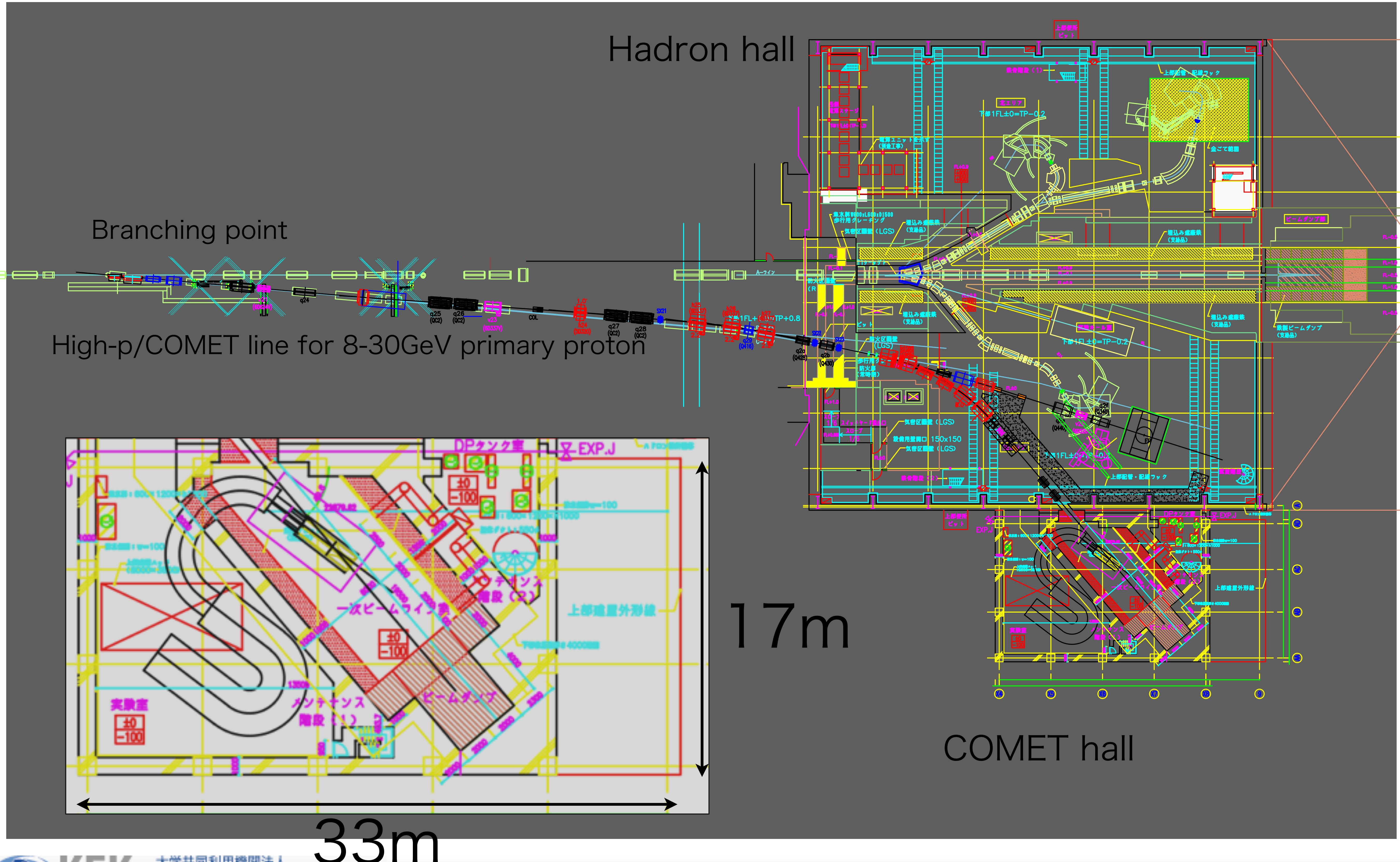




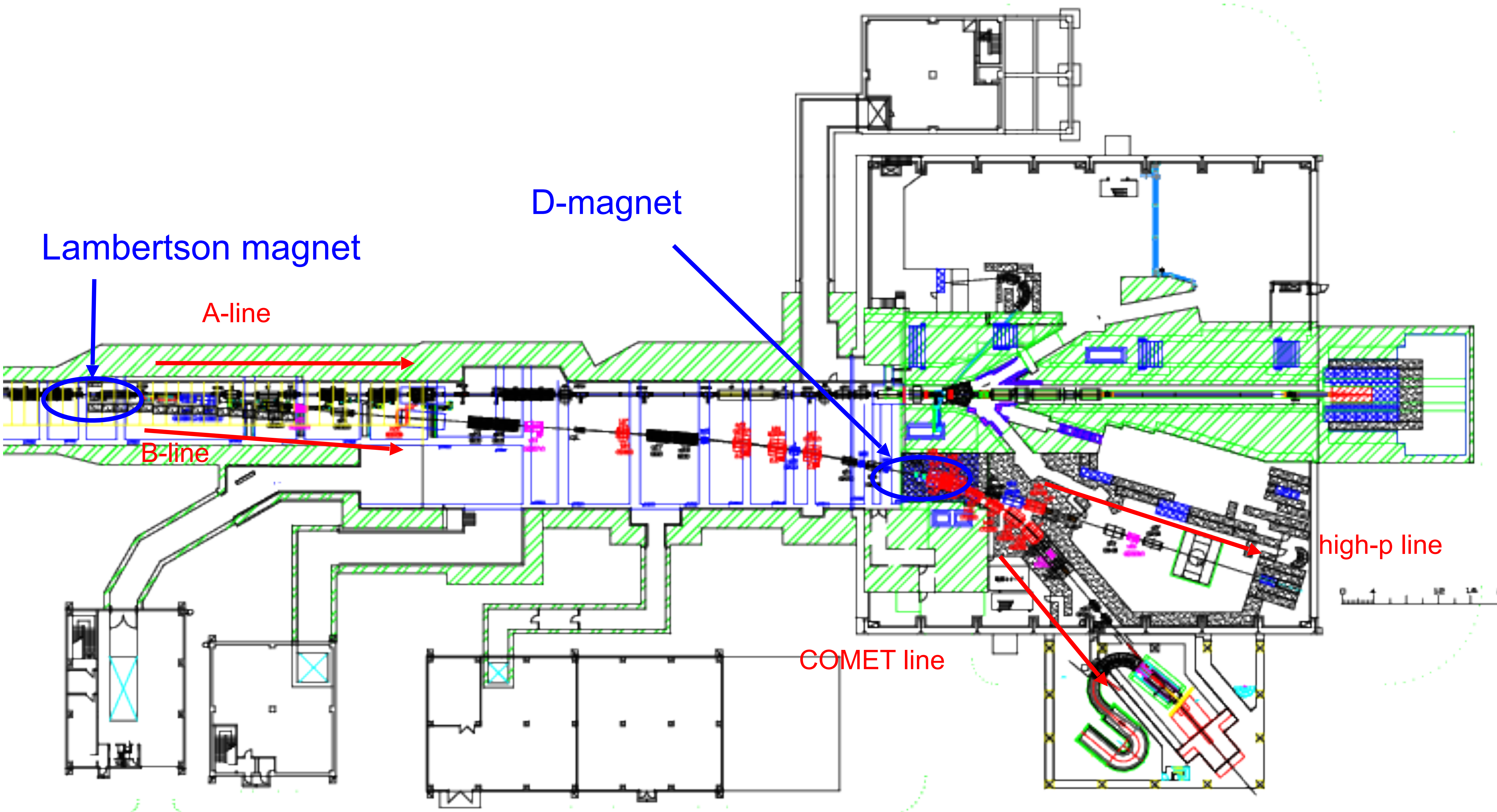



J-PARC Facility
(KEK/JAEA)
LINAC
181 MeV → 400 MeV
Neutrino beam to Kamioka
Rapid Cycle
Synchrotron
Energy : 3 GeV
Repetition : 25 Hz
Material and Life Science
Facility
Main Ring
Max Energy : 30 GeV
Design Power for FX : 0.75 MW
Expected Power for SX : > 0.1
Nuclear and Particle
Physics Exp. Hall

Hadron Hall & COMET Facility



COMET Hall & Beamline

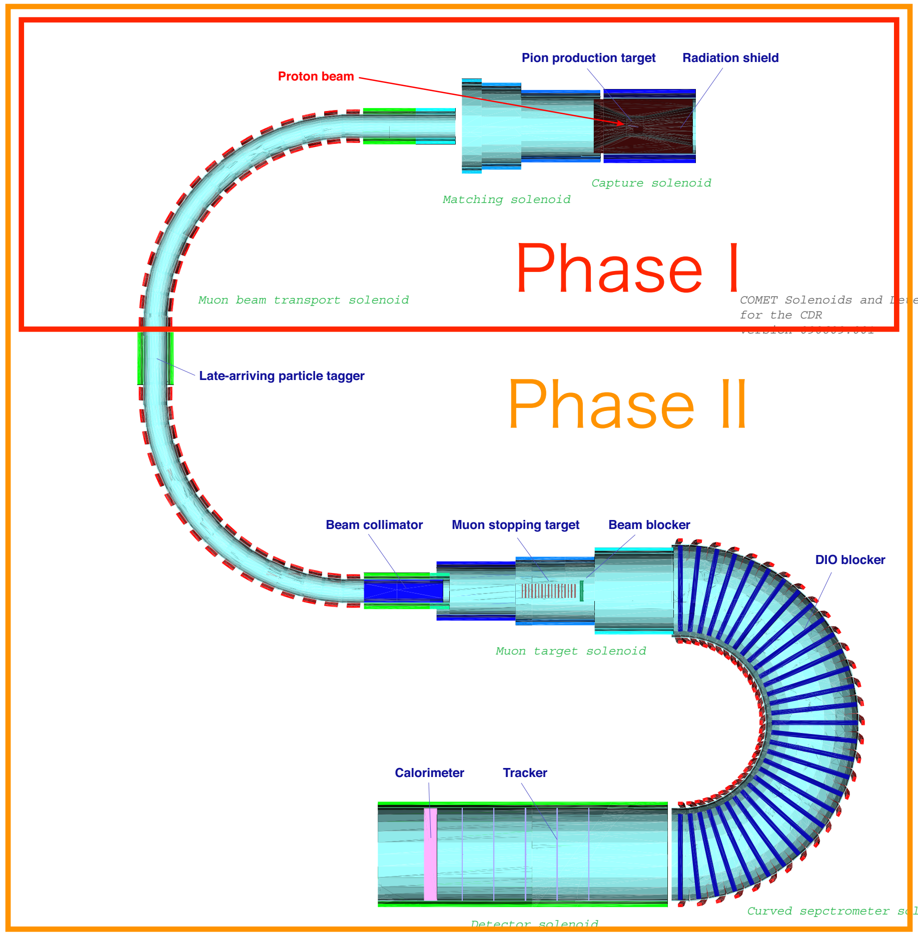


Branch for COMET and high-p is realized by normal dipole magnets.
(No simultaneous operation of COMET and other hadron-hall experiments)

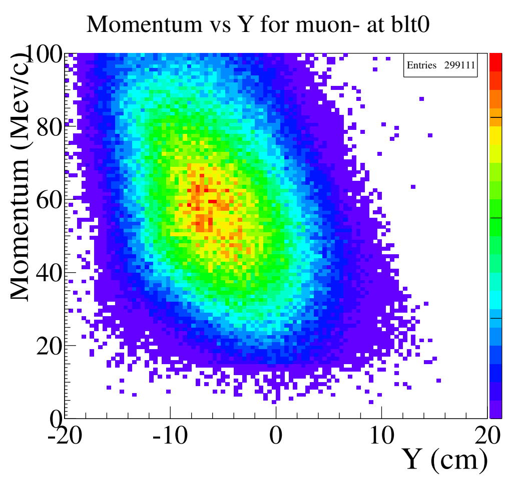

05/Feb/2014

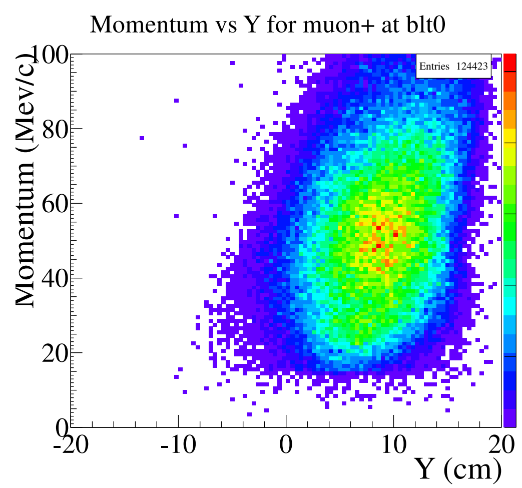
COMET Phase I & II

- Phase I
  - Beam background study and achieving an intermediate sensitivity of $<10^{-14}$
    - 8GeV, ~3.2kW, ~90 days of DAQ
- Phase II
  - 8GeV, ~56 kW, 1 year DAQ to achieve the COMET final goal of $< 10^{-16}$ sensitivity



μ^-

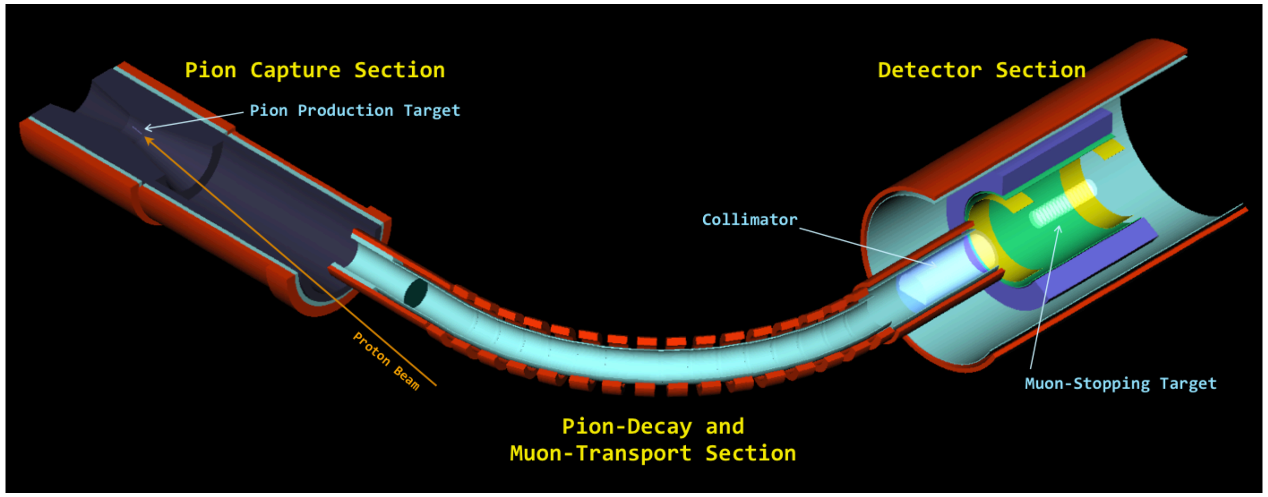


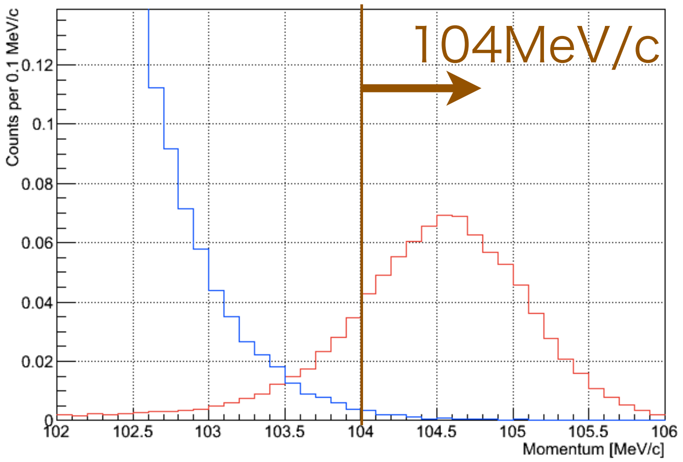


μ^+

Phase I

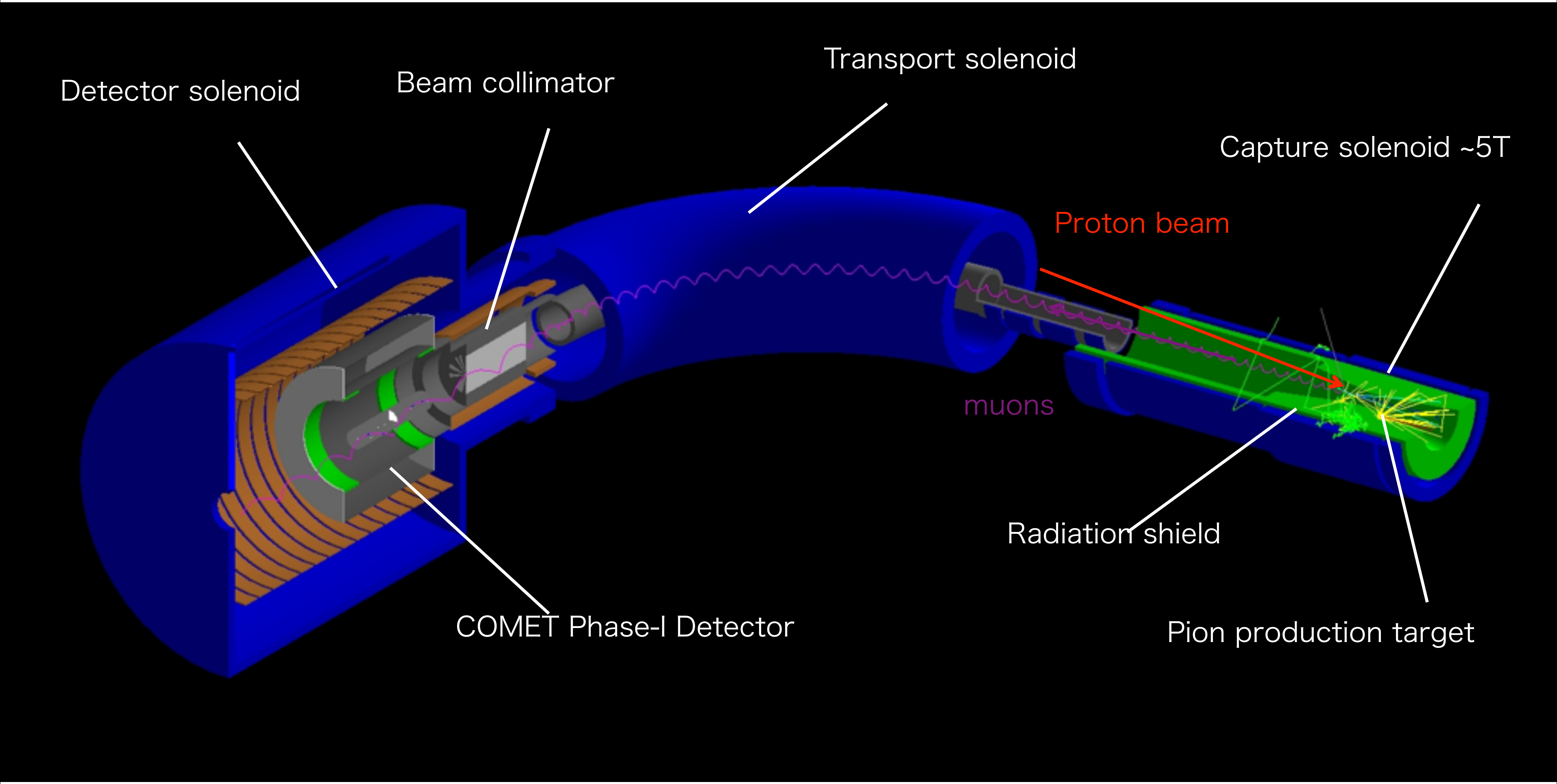
0.03 BG expected in 1.5×10^6 sec running time





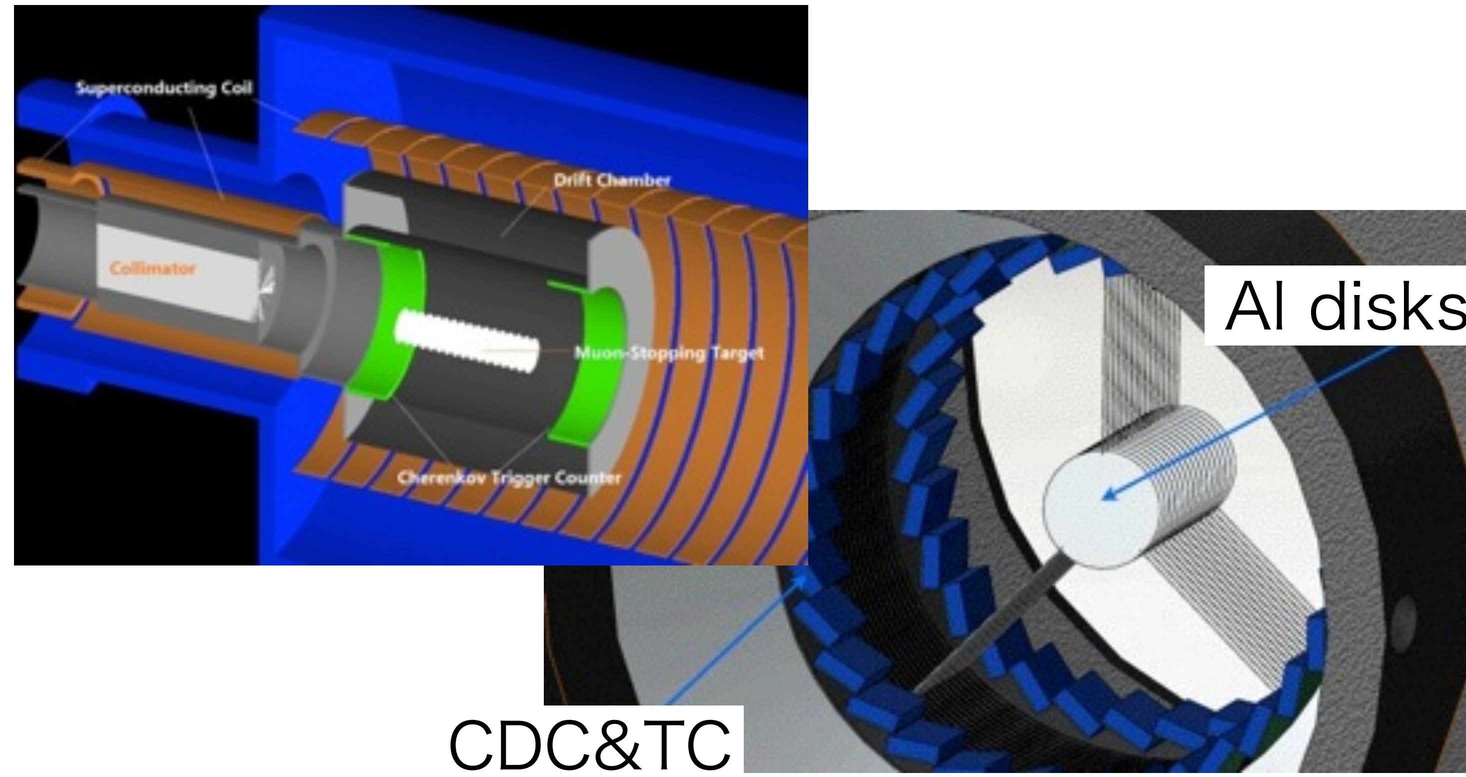
Phase I
2013-2015
Facility construction
2013-2016
Magnet construction & installation
2016
Eng. run & Physics run
Phase II
Eng. run in 2020(?)

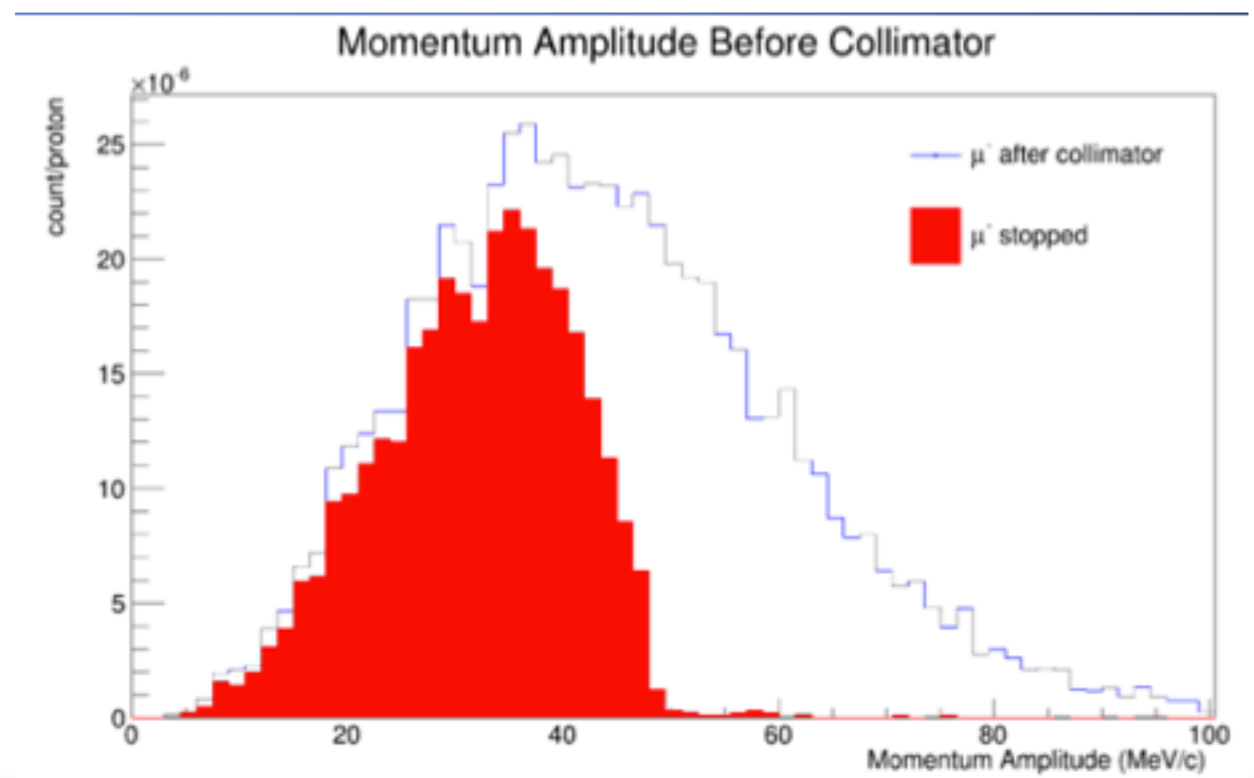
COMET Phase I Setup



Muon Beam and Stopping Target

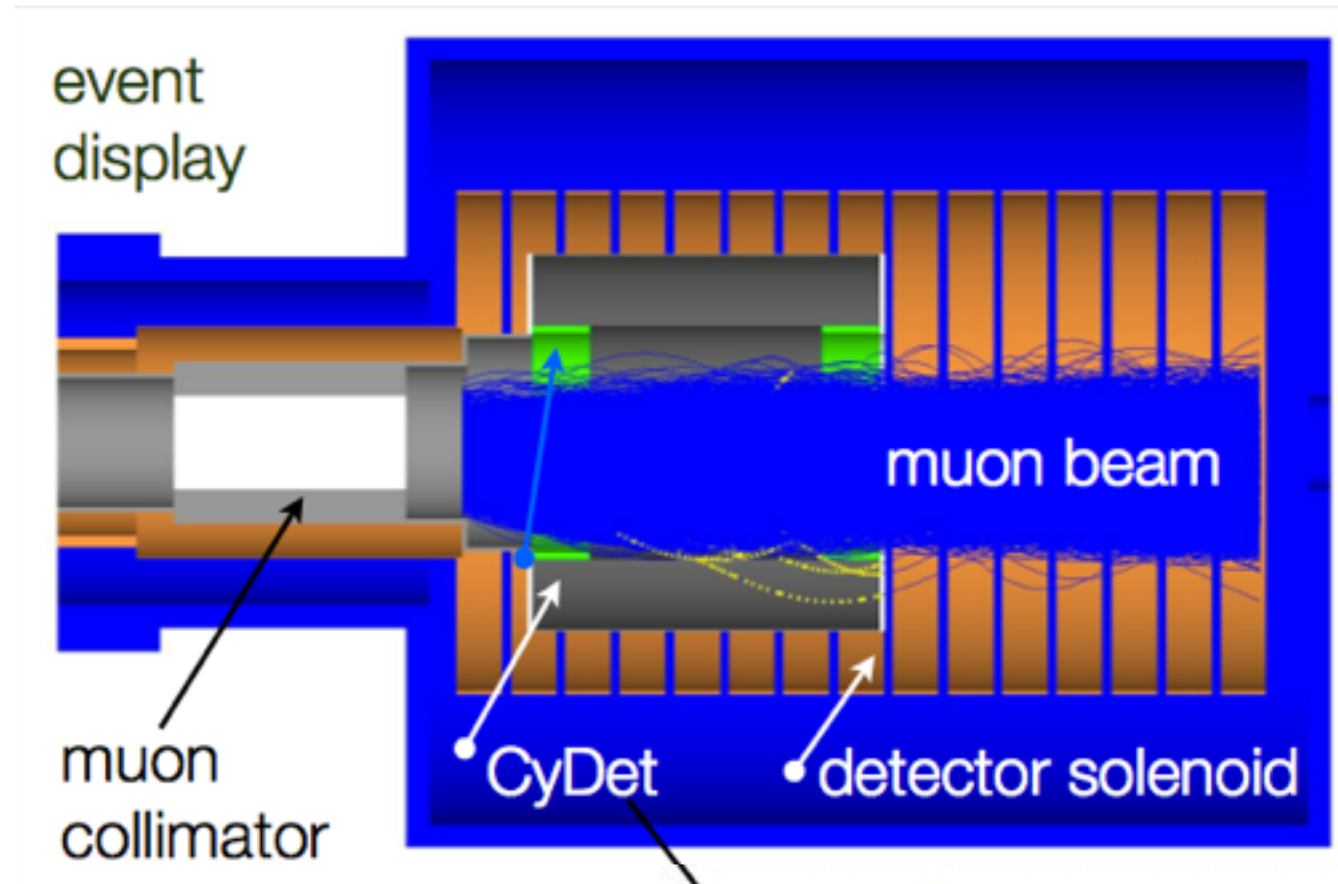
- Search for muon conversion in muonic aluminum (different material in future)
- Stop as many muons as possible on target disks
    - Correct (only) low momentum pion/muon and transport to the experiment setup
    - Stop muons on Al disks
        - Diam.: 100 mm
        - Thickness: 100 μm
        - Number of disks: 17



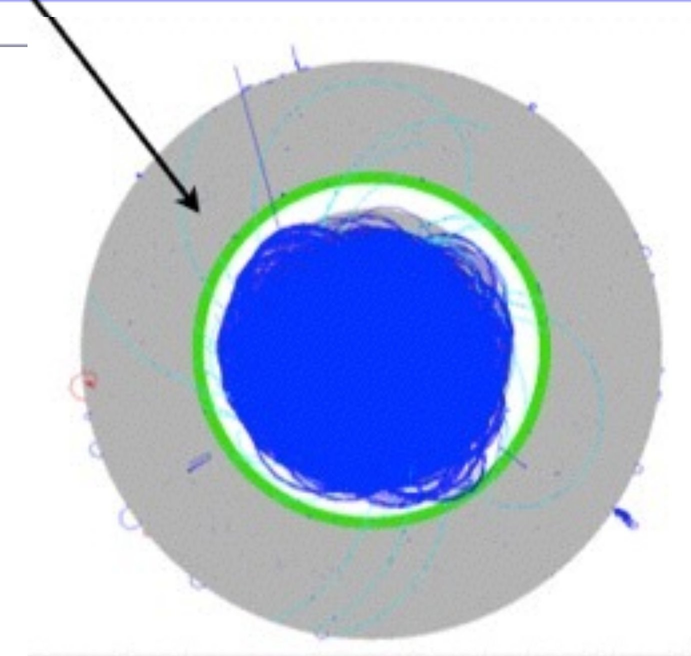


Why CDC (CyDet) in Phase I ?

- Why CyDet?
- No curved solenoid to select momentum and charge is available in phase I
- No beam particle hits the detector in CyDet geometry

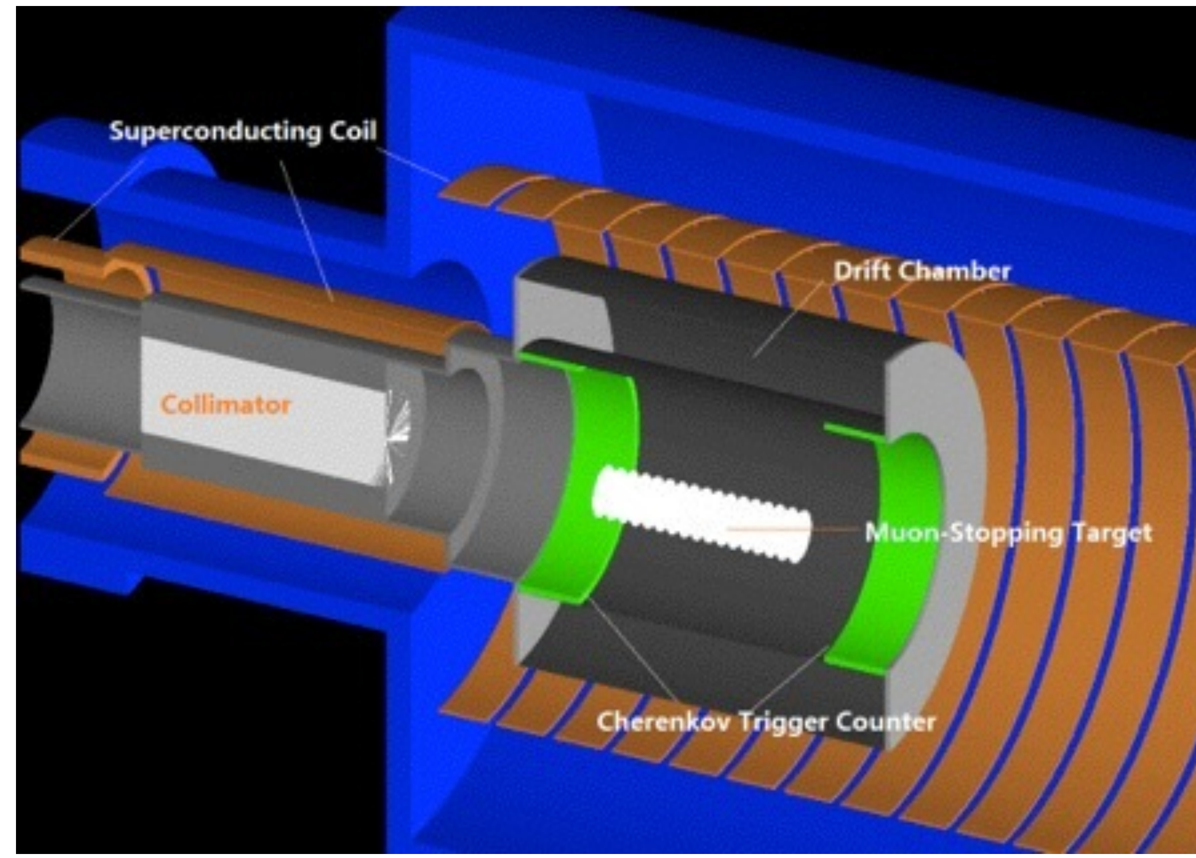


Prompt Timing

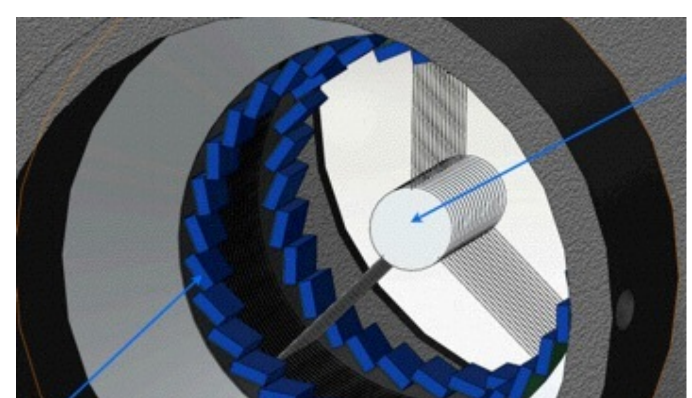


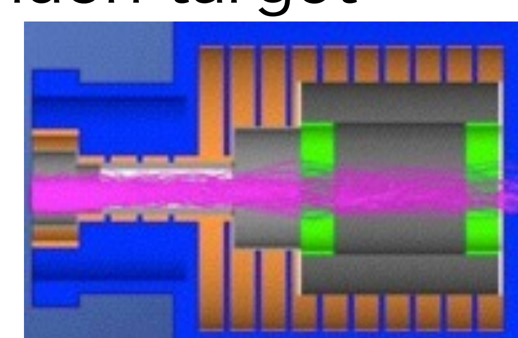
COMET Phase I Detector Design

- CDC
  - Belle II CDC design
    - He-based low mass gas mixture
  - large inner bore with a 0.5mm thick CFRP inner wall
    - proton emission from muon captures
  - construction starts in JFY 2013 in parallel to prototype study
- Cherenkov Trigger counter
  - segmented
  - SiPM readout
- Collimator/target disk optimization as well



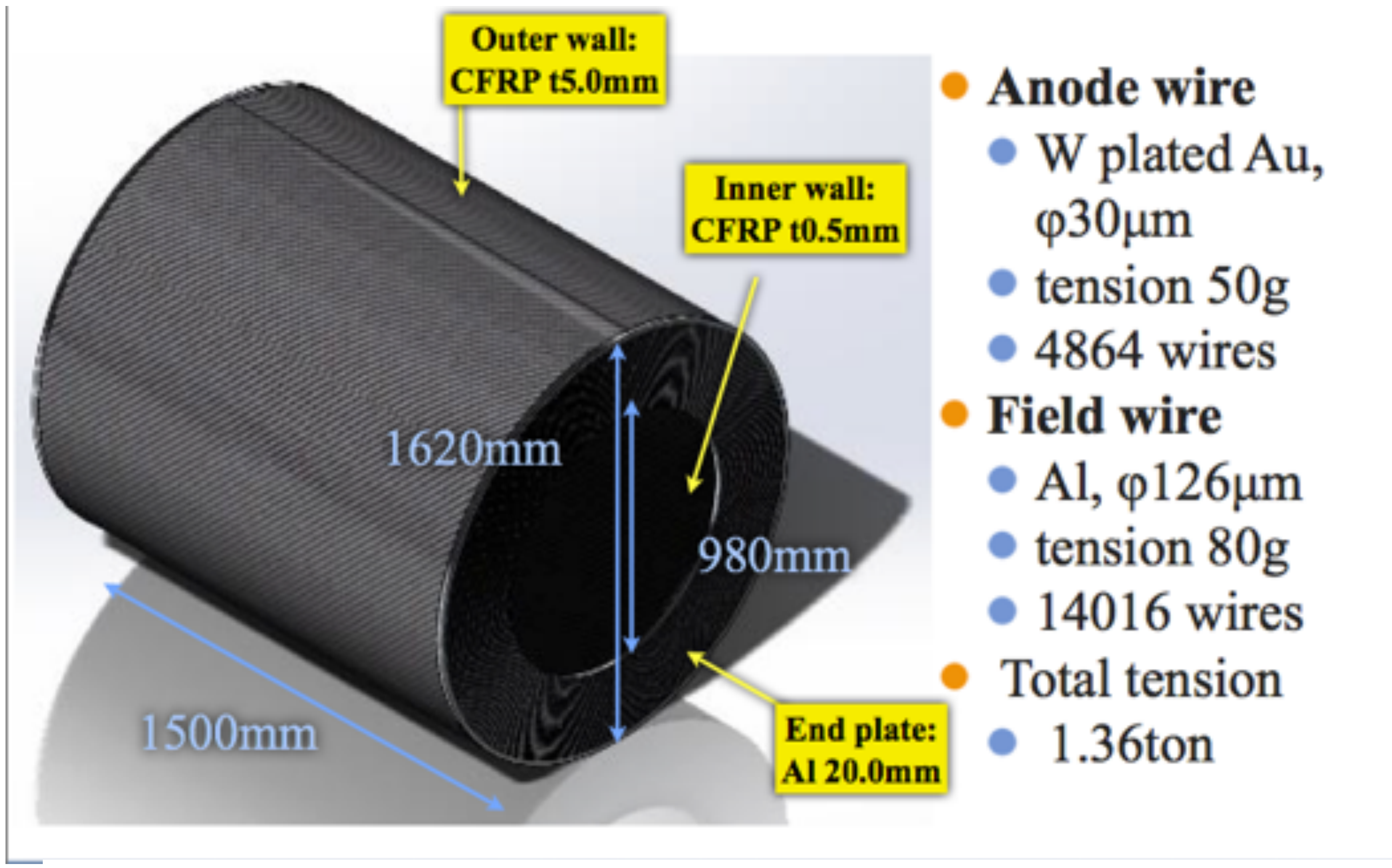
muon target



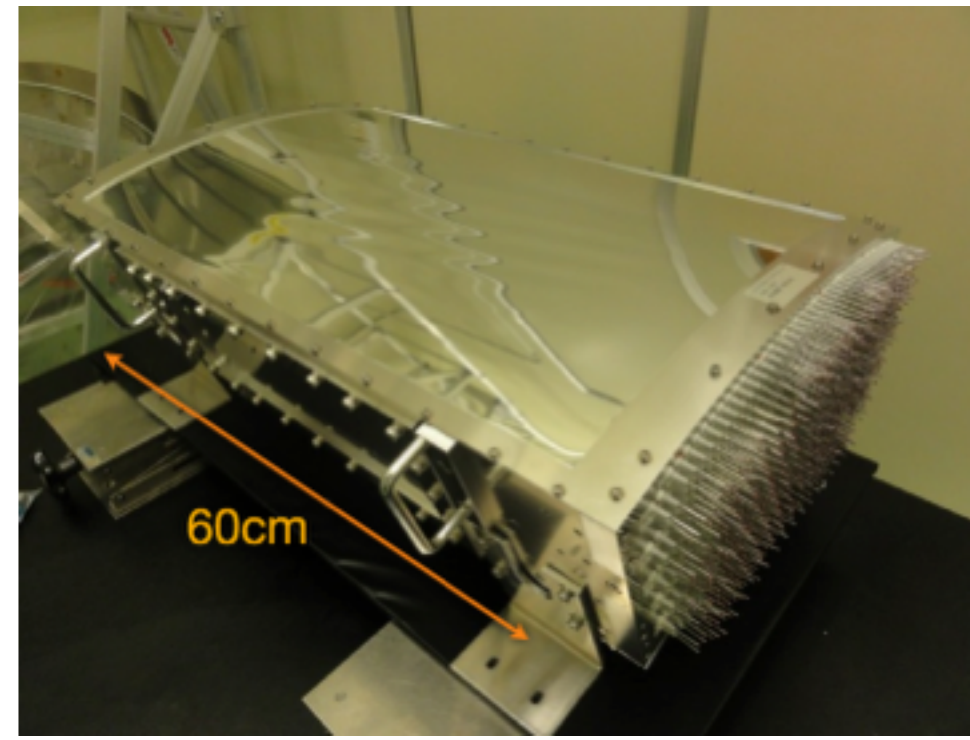


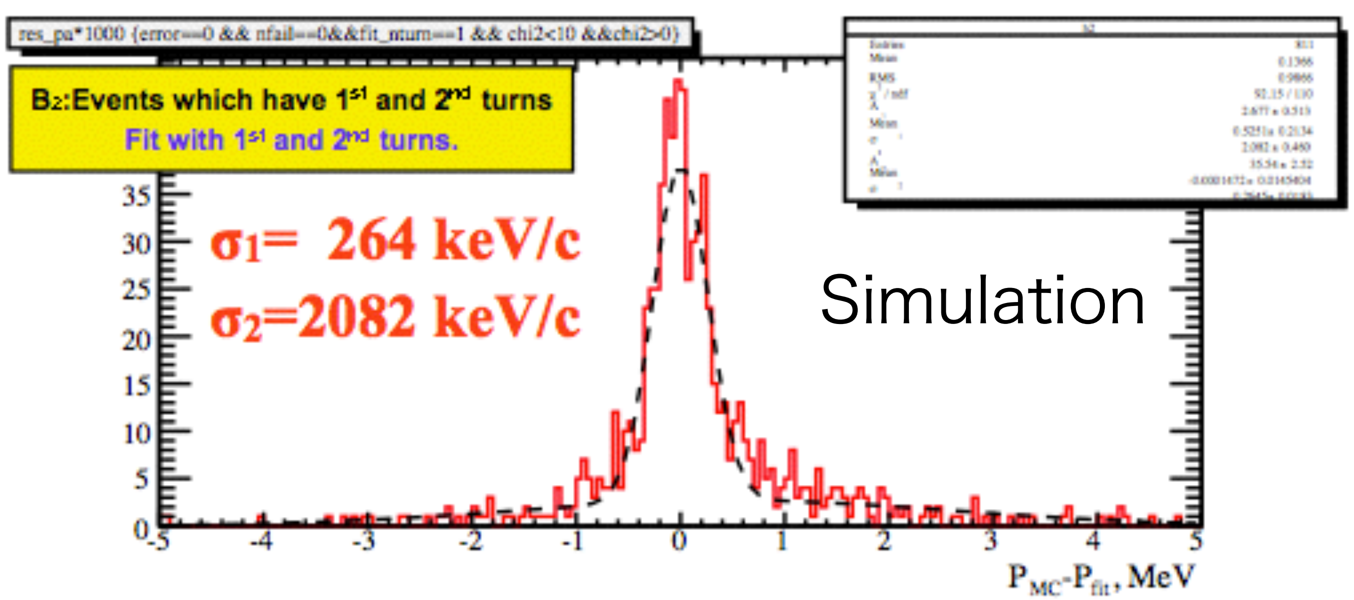
trigger counter

CDC Design and R&D



prototype



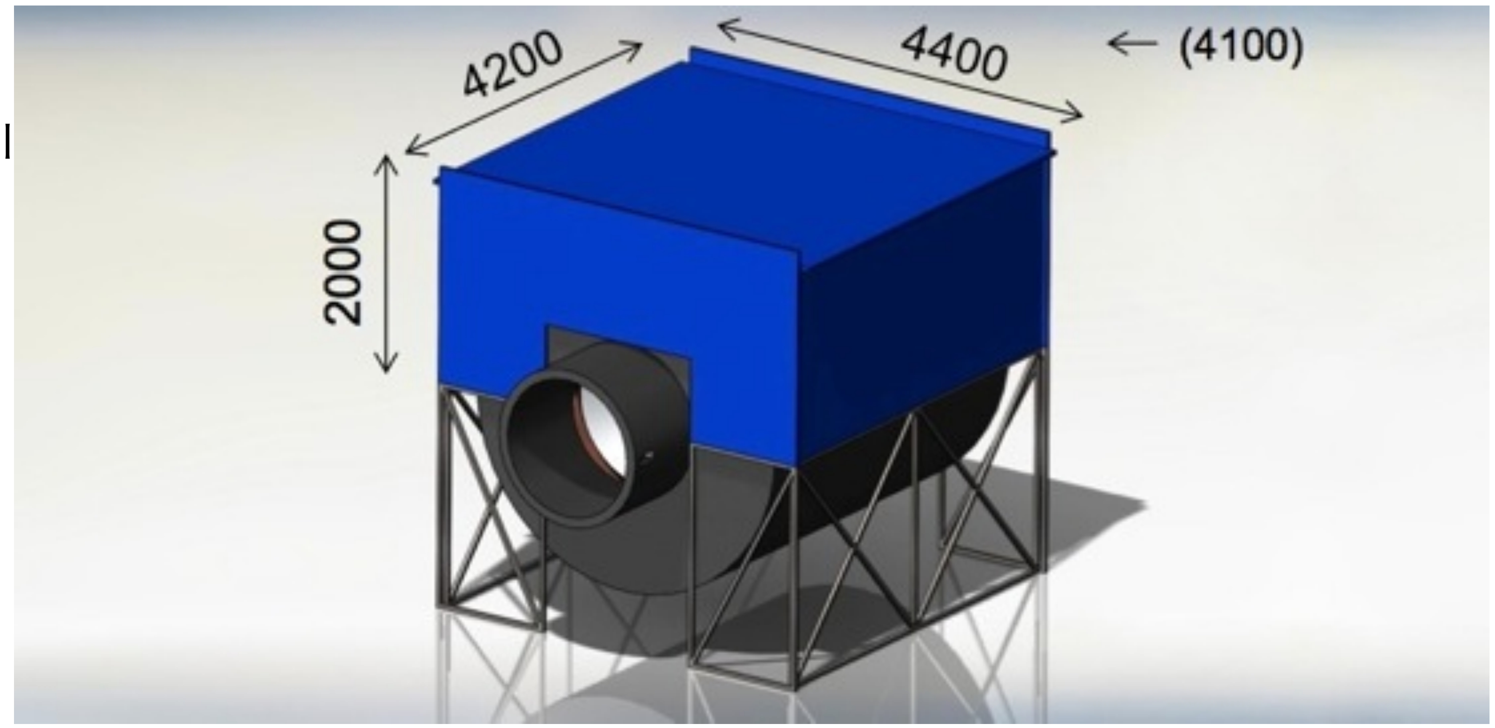


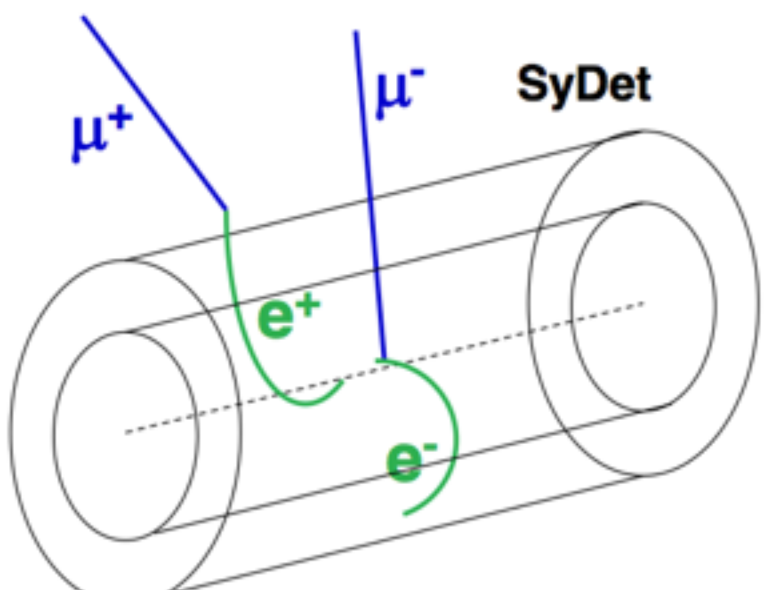
Belle II CDC technology

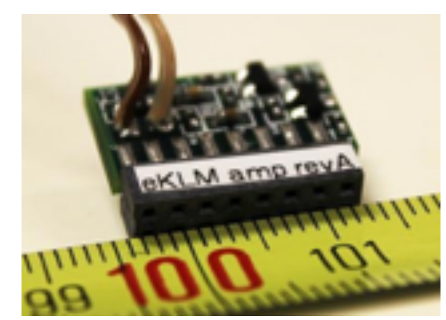
- All stereo layers
- He based low mass gas
- large inner bore with a 0.5μm thick CFRP inner wall

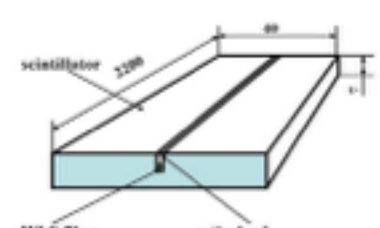
Cosmic Ray Veto Counter

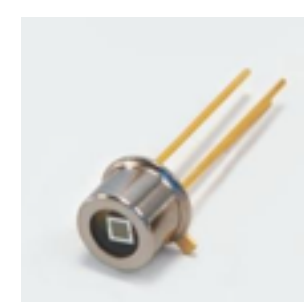
- Cosmic-ray veto counter production based on the technology developed for the Belle II muon system
  - Efficient rejection is mandatory for COMET
  - Necessary to cover the detector solenoid
  - Scintillator bars with WLS fibers ready by SiPM
- Infrastructure for the Belle II system will be reused for COMET











Sensitivity & background in Phase I

- Sensitivity
  - Acceptance=0.056
    - 0.20 (geometrical) x 0.80(mom. sel.) x 0.39 (timing sel.) x 0.90 (trigger)
  - Atomic capture rate f_{cap}=0.6
  - N_{μ}=9.4x10^{15} muons (83days)
  - S.E.S.=3.2x10^{-15}, 90% U.L. = 7.2x10^{-15}

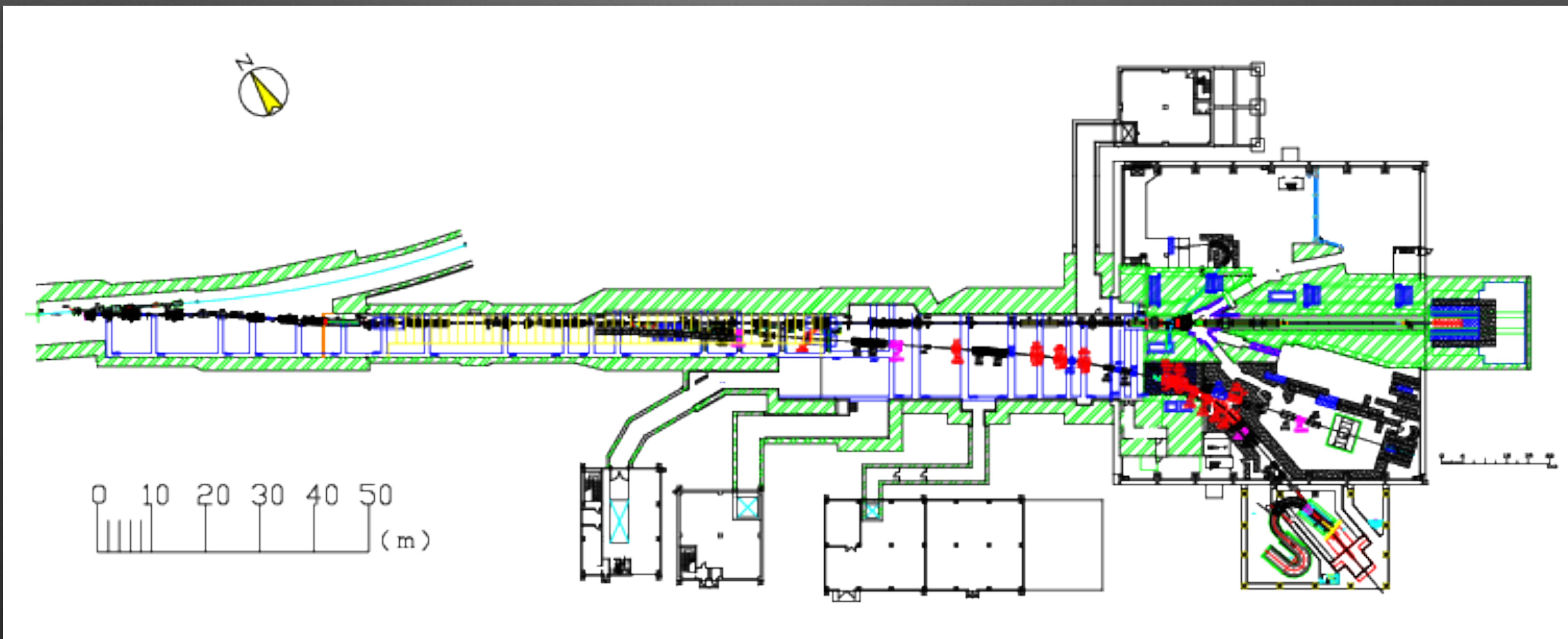
- Background

Background	estimated events
Muon decay in orbit	0.01
Radiative muon capture	1.38×10^{-4}
Neutron emission after muon capture	< 0.001
Charged particle emission after muon capture	< 0.001
Beam electrons (prompt)	7.5×10^{-3}
Beam electrons (delayed)	~ 0
Muon decay in flight (prompt)	$< 1.9 \times 10^{-4}$
Muon decay in flight (delayed)	~ 0
Pion decay in flight (prompt)	$< 2.2 \times 10^{-3}$
Pion decay in flight (delayed)	~ 0
Neutron induced background	$\sim 0^*$
Radiative pion capture (prompt)	1.4×10^{-3}
Radiative pion capture (delayed)	1.1×10^{-2}
Anti-proton induced backgrounds	0.007
Electrons from cosmic ray muons	< 0.0001
Total	0.0285

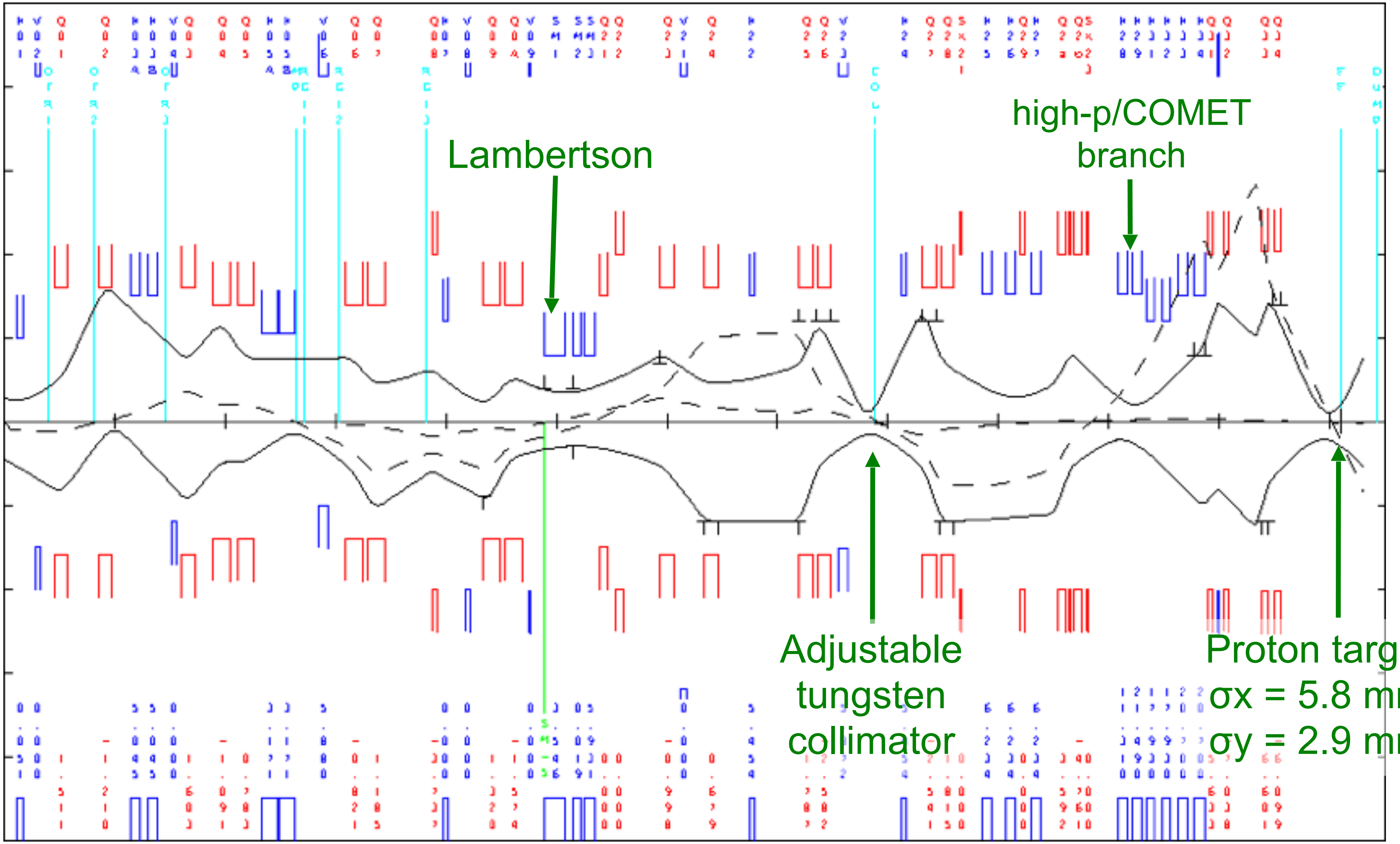
- Intrinsic & beam related
  - Measured in Phase I
  - Straw & Ecal for Beam related BG study

COMET beam

Proton Beam

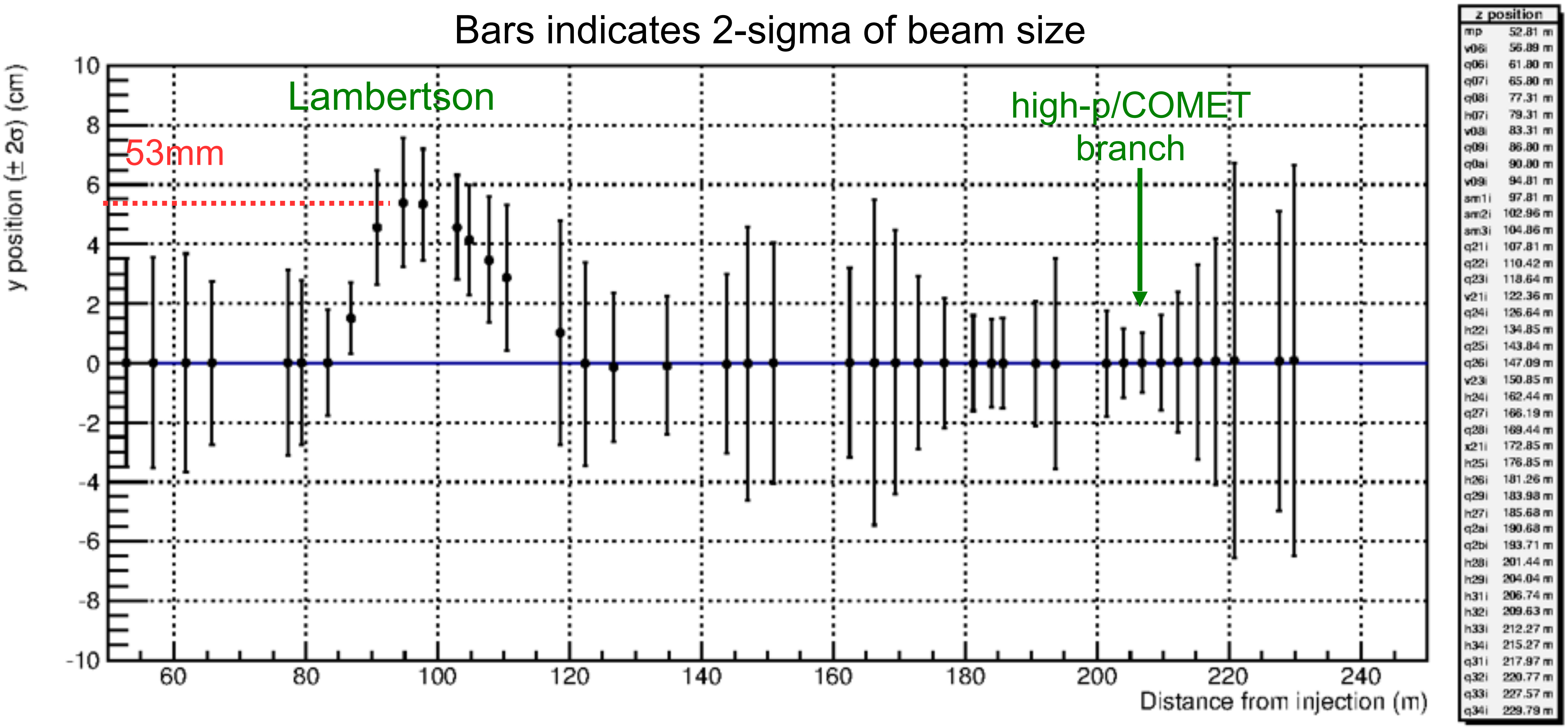


Beam Optics (TRANSPORT)



Beam size at 8 GeV is estimated by 3.5-times emittance at 30 GeV beam.

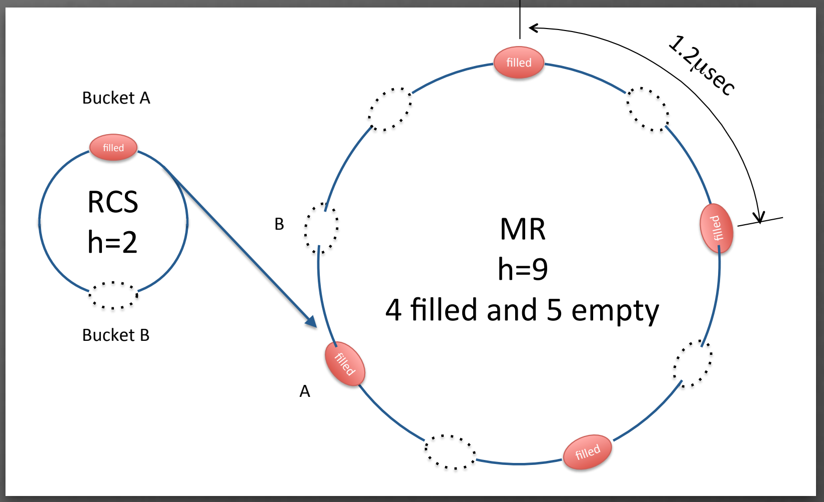
Beam Shift for Lambertson Magnet



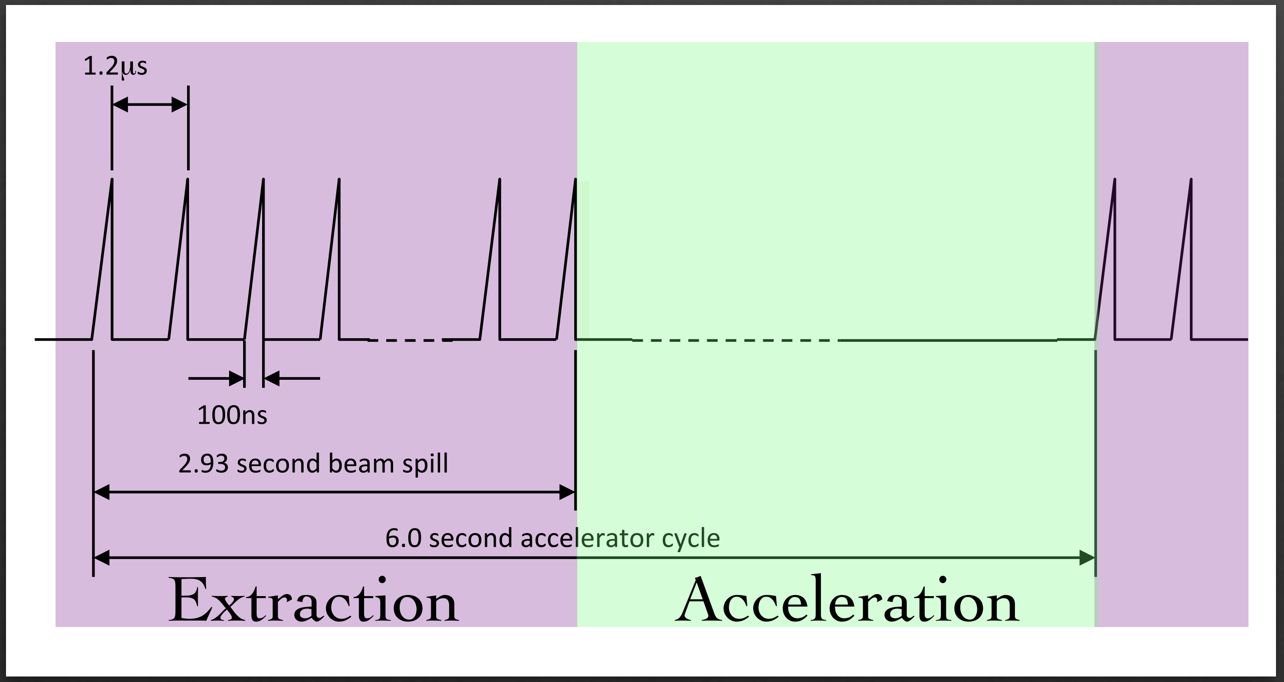
Beam shift of 53 mm was achieved at the entrance of the Lambertson magnet. (with beam loss of 0.36%)

→ Beam shift at A-line operation can be ~30mm.
We obtained 83mm shift in total between
COMET operation and A-line operation (76mm required)

COMET Beam Parameters (proton)



- Phase I beam intensity 3.2kW
- Acceleration (in MR)
  - 3.8×10^{12} protons / backet, 1.5×10^{13} protons in total in one Acc cycle
- After extraction
  - 2.5×10^{12} protons/sec (normalized)
    - 6 sec repetition period, 2.93 beam on, pulsed



Beam Extinction

$N_{bg} = NP \times R_{ext} \times Y_\pi/P \times A_\pi \times P_\gamma \times A$

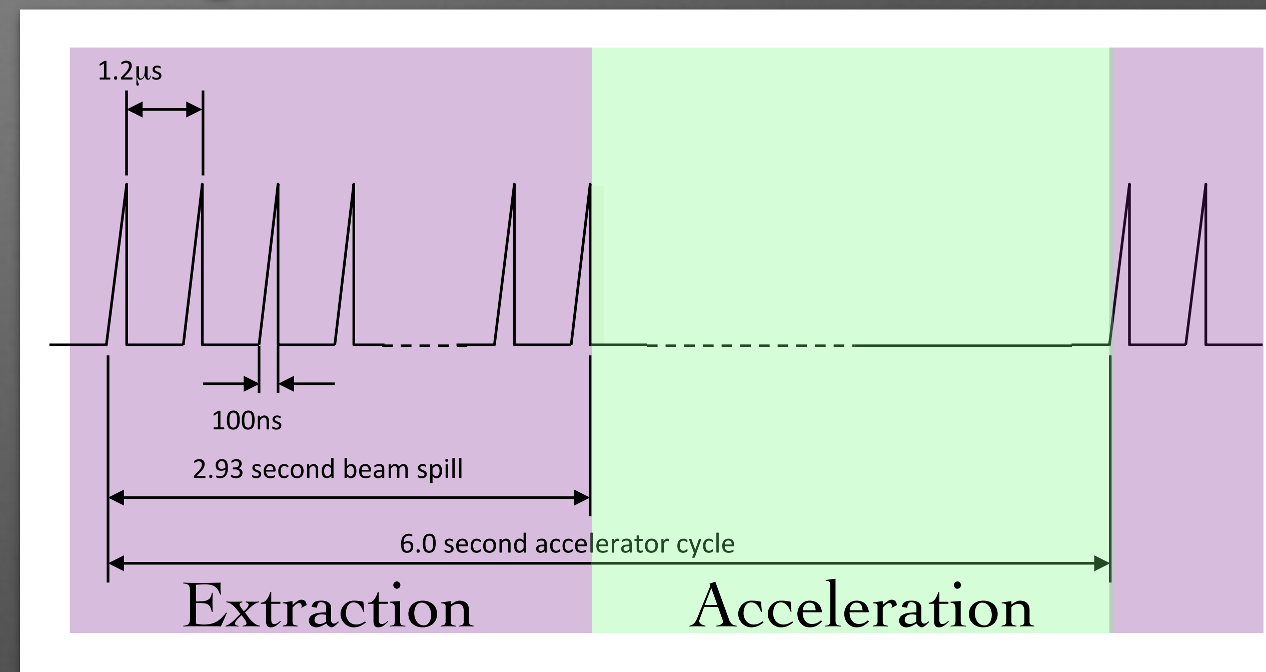
NP : total # of protons ($\sim 10^{21}$)
R_{ext} : Extinction Ratio (10^{-9})
Y_π/P : π yield per proton (0.015)
A_π : π acceptance (1.5×10^{-6})
P_γ : Probability of γ from π (3.5×10^{-5})
A : detector acceptance (0.18)

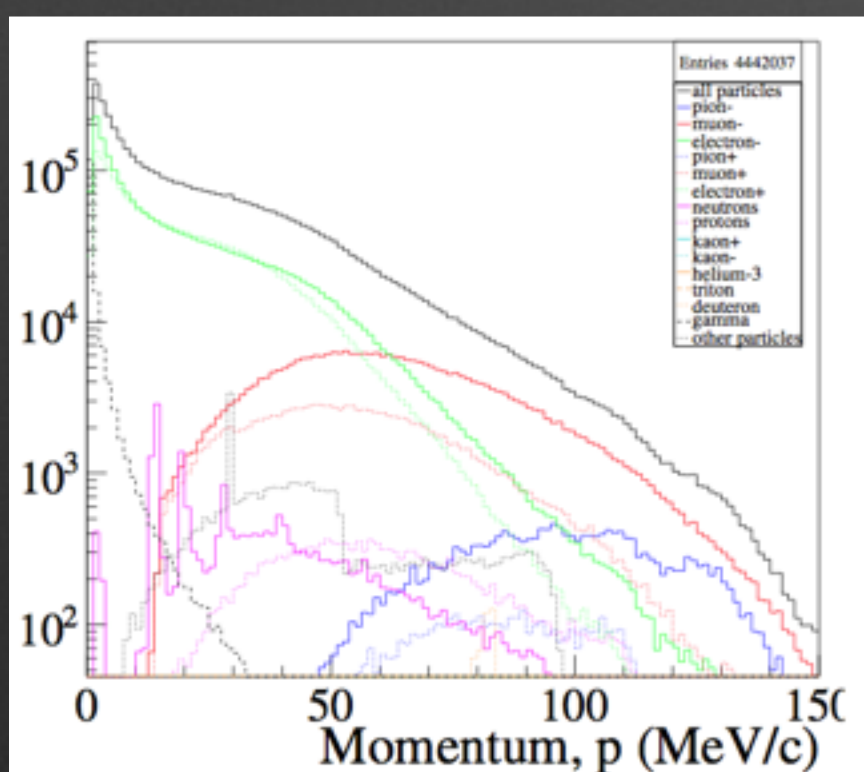
BR=10^{-16}, $N_{bg} \sim 0.1$ →

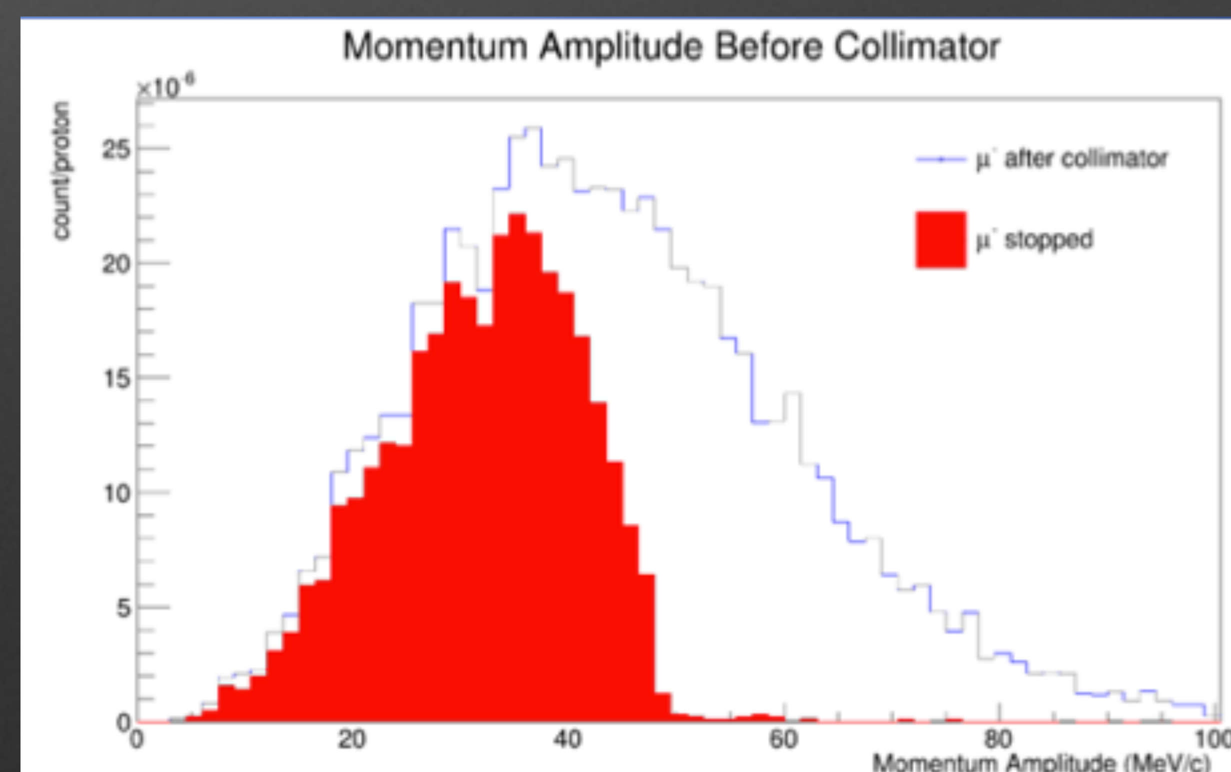
Extinction < 10^{-9}

COMET Beam Parameters (muon)

- 5×10^{-4} muons / proton on target
- 2.5×10^{4} muons/sec , 1.5×10^{3} muons / pulse
- Same time structure with protons in principle
- More electrons and pions



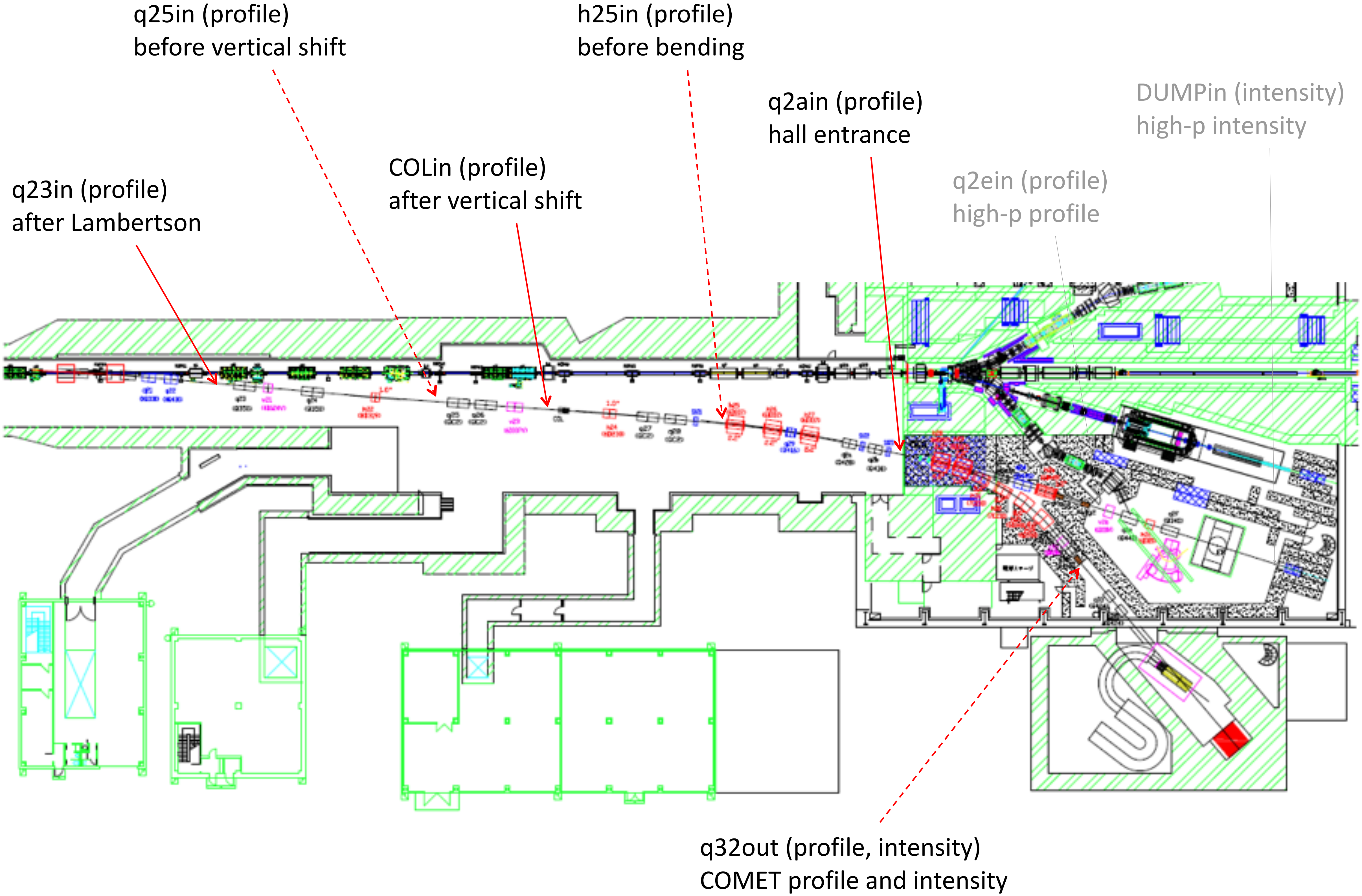




Monitors using Silicon Detector

- Proton monitor
  - Beam intensity monitor
  - Profile monitor
  - Extinction monitor, spill by spill or pulse by pulse (Switching?)
- Muon monitor
  - Profile monitor
  - Extinction monitor, spill by spill or pulse by puse (Switching?)
  - (Active target -> Kyushu & Wilfrid's presentation tomorrow)

Beam Monitor Location

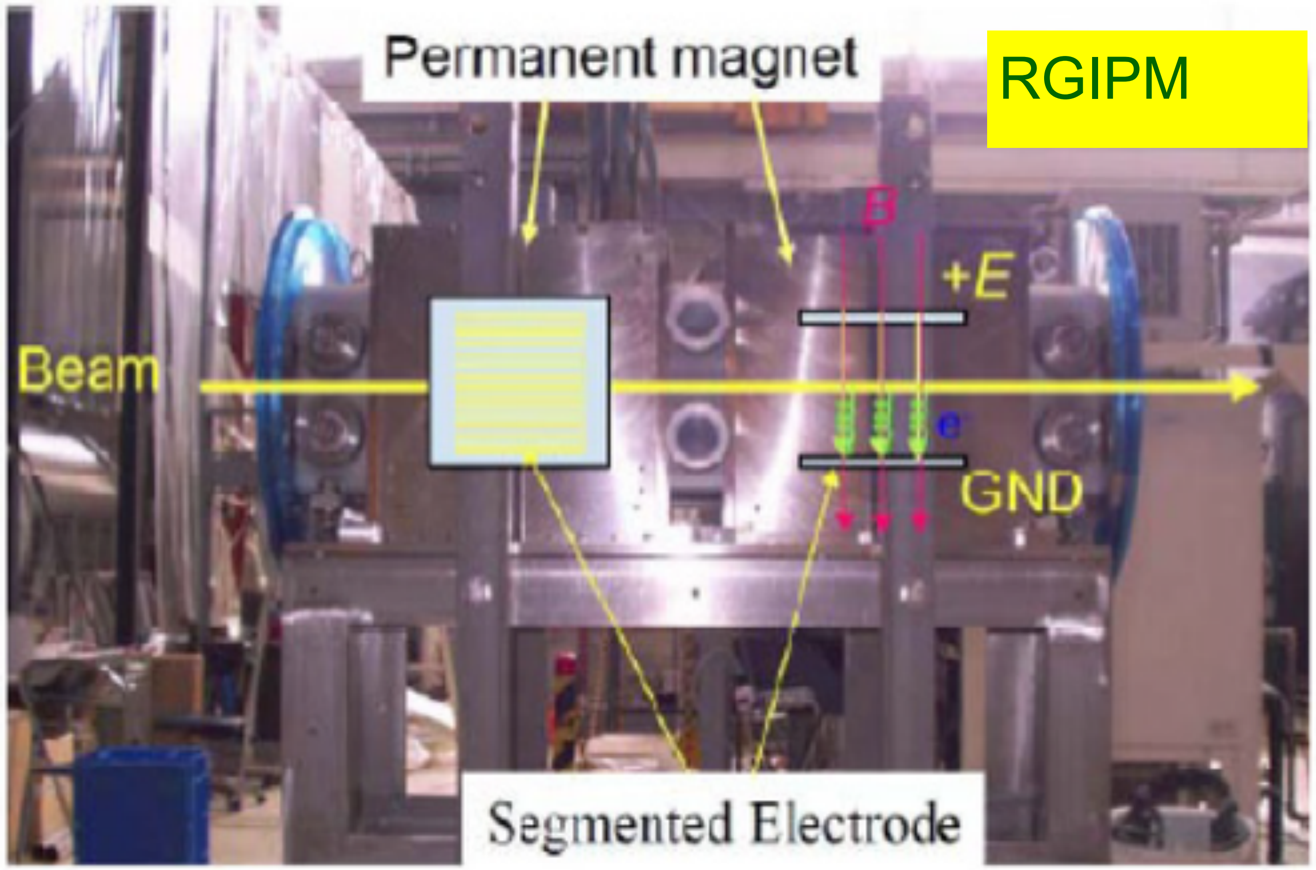


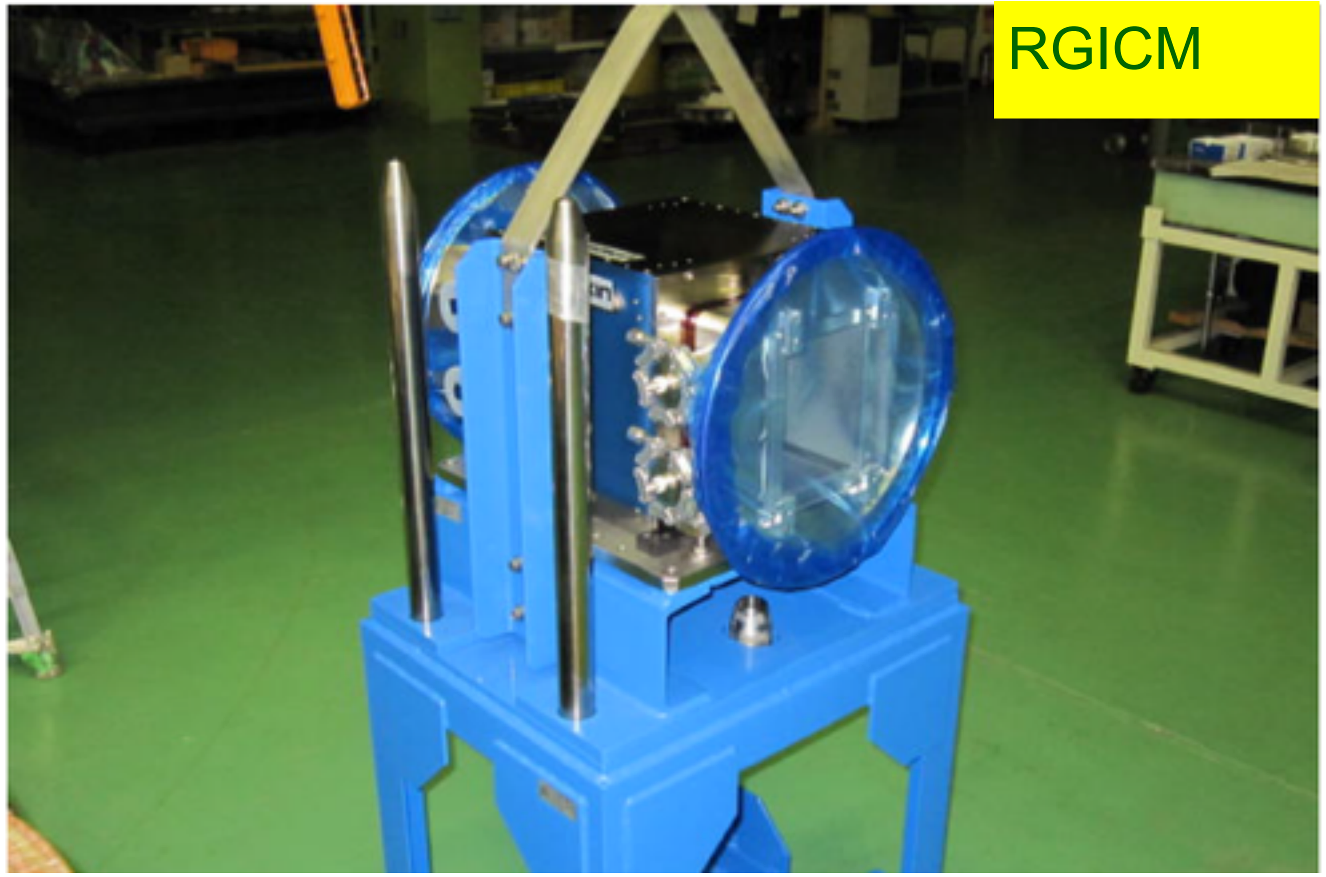
By Toyoda-san

Beam Monitor : RGIPM / RGICM

RGIPM : Residual Gas Ionization Profile Monitor
RGICM : Residual Gas Ionization Current Monitor

Readout ionized electrons (profile / current) from beam interaction with residual gas





Both horizontal and vertical beam profile are measured.

Stability of degree of vacuum is important for precise measurement.

Summary

- COMET Phase I starts in 2016-2017
- Facility and detector constructions in progress
- Accelerator study dedicated for COMET will startein 2014
- Proton beam monitor / Muon beam monitor
  - Spill-by-spill or bunch-by-bunch Extinction level monitor
  - Any idea / proposal is welcome