Status of the COMET Experiment at J-PARC

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on behalf of the COMET collaboration

MELODY2023, CSNS, November 4th, 2023

Outline

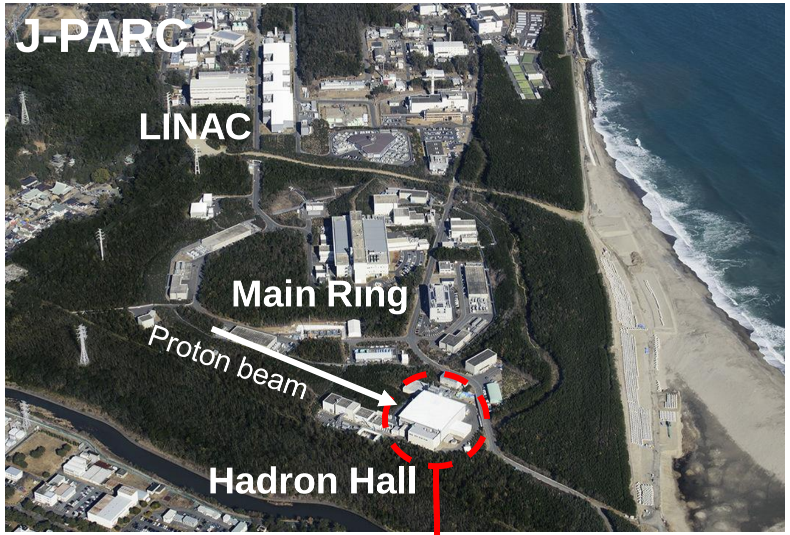
- Introduction
- Design of the COMET Experiment
- Preparation for COMET Phase-I
- COMET Phase-alpha
- Summary

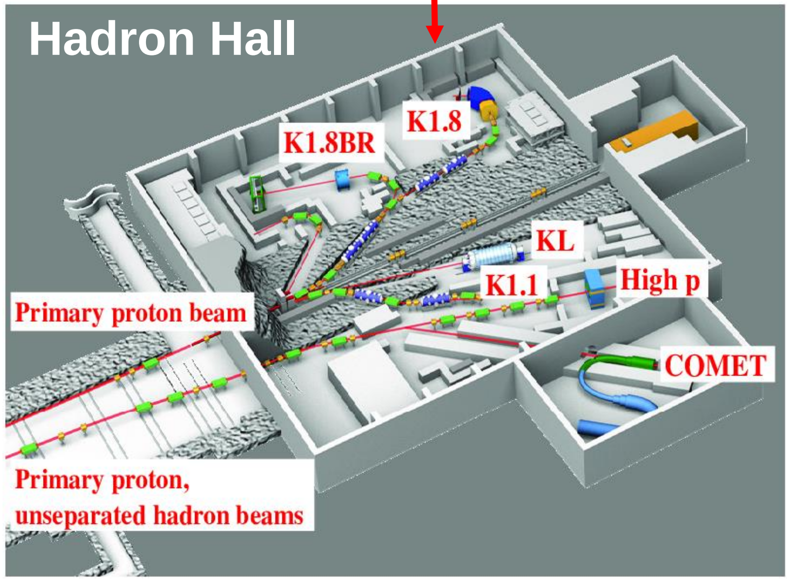
The COMET Experiment

The COMET experiment

- Utilizing the proton beam from the J-PARC main ring, COMET searches for the muon to electron conversion process, which violates charged lepton flavor conservation, with an unprecedent sensitivity.

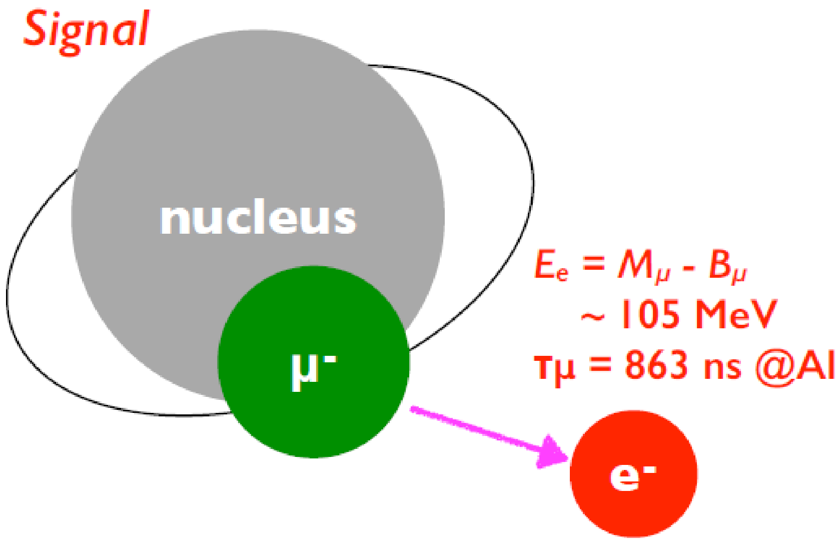
44 Institutes, 17 countries, ~300 collaborators

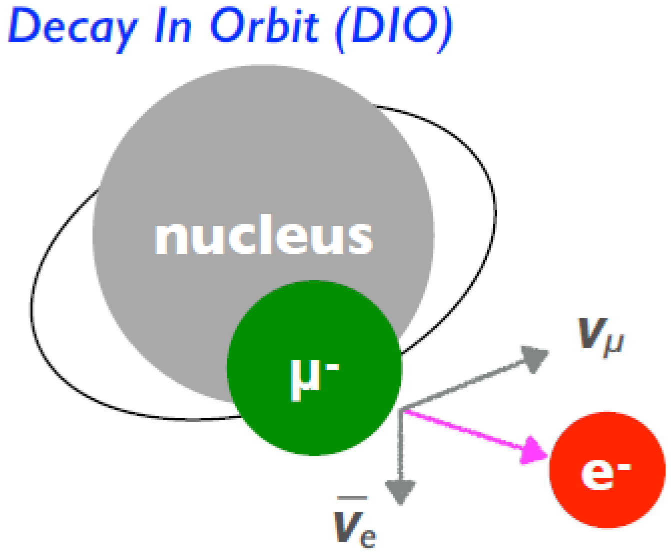


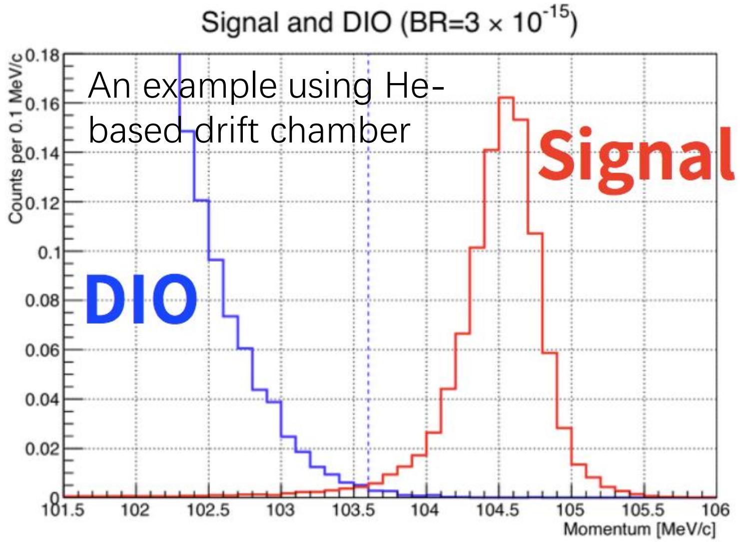


Muon-to-electron conversion ($\mu N \to eN$)

- Muon nuclear capture
  - Coherent process enhanced: the nucleus stays at ground state
- Signal: 1 mono-energetic electron: $E_e = M_\mu - B_\mu - E_{recoil} \sim 105\ MeV$
- Background: intrinsic, beam related, cosmic ray
  - The intrinsic background, from muon Michel decay in orbit, has an end point energy near half muon mass, but







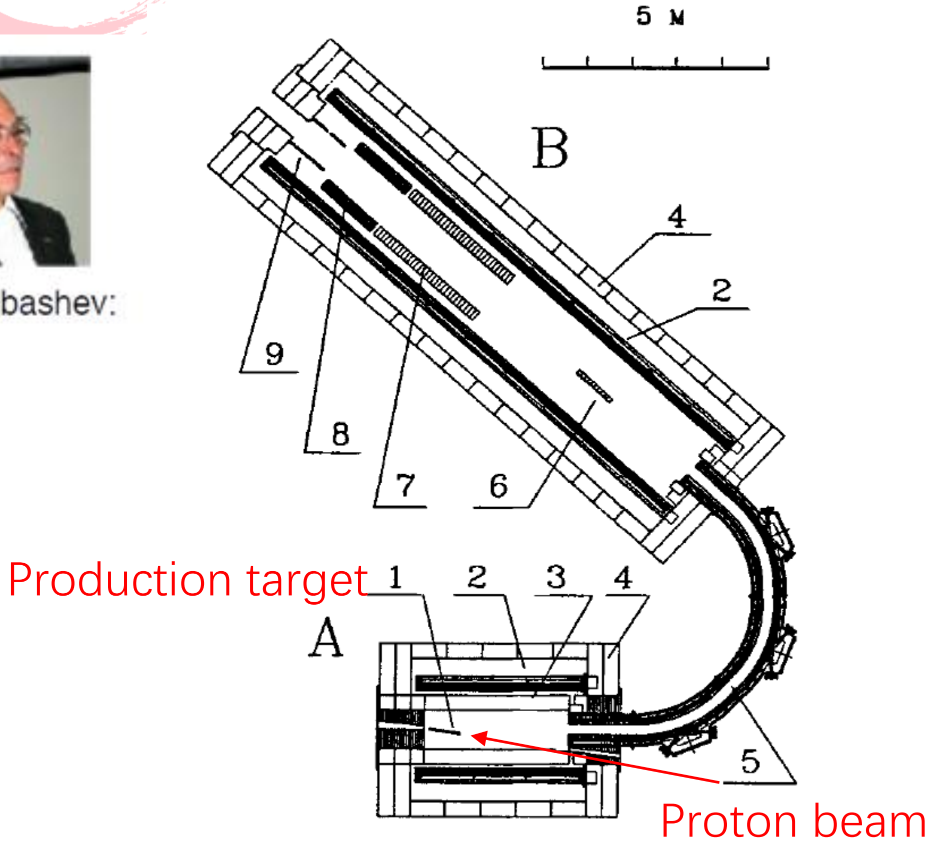
An example using He-based drift chamber

Charged lepton flavor violation (CLFV)!

The Design of COMET

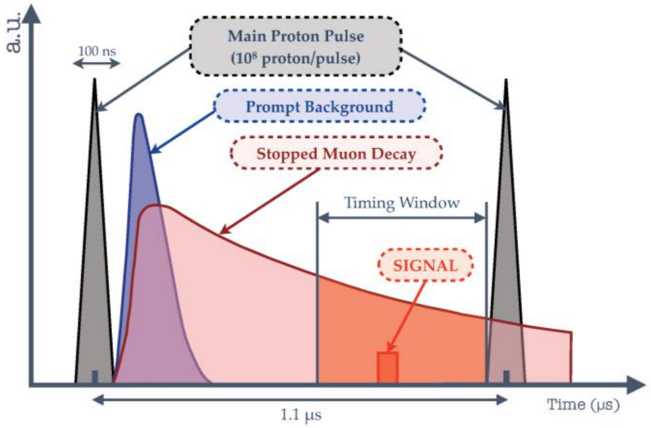
"New muon sources": the Lobashev scheme

V.M. Lobashev:



Djilkibaev R.M. and Lobashev V.M., Sov.J.Nucl.Phys. 49(2), 384, (1989).

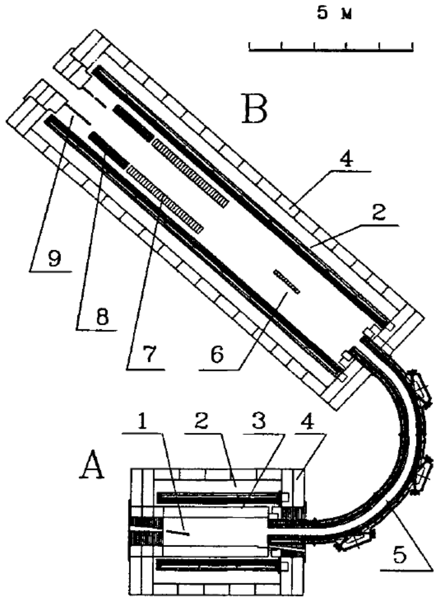
- To get much more muons
  - Thick target:
    ~1 hadron interaction length.
  - Superconducting magnetic field:
    >2.5 T, adiabatically dropping
- To control radiation
  - Accept backward beam
  - Bending solenoid to select low energy beam particles.
- To suppress beam induced background
  - Pulsed beam (MHz).
    Wait for beam flash to pass and pions to decay.



$> 10^{10}$ muons/sec is achievable. Toward $< 10^{-16}$ sensitivity!

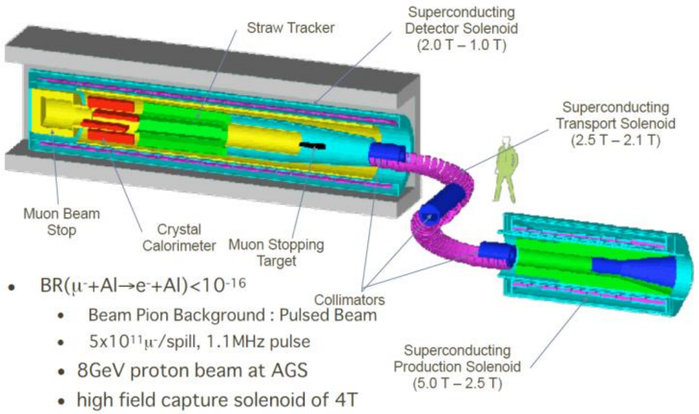
Realizing the Lobashev scheme muon sources

Proposed in 1989.
No budget support.



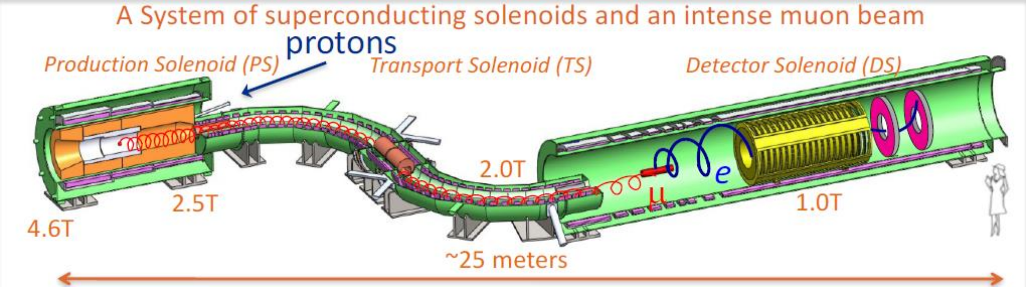
Proposed in 1999.
Canceled in 2005

MECO @BNL/AGS



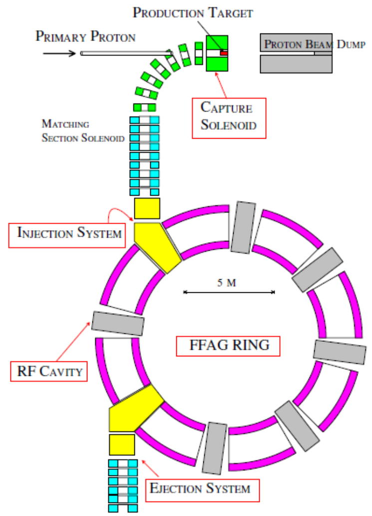
- BR($\mu^- + Al \rightarrow e^- + Al$)<$10^{-16}$
  - Beam Pion Background : Pulsed Beam
  - $5\times10^{11}\mu^-$/spill, 1.1MHz pulse
  - 8GeV proton beam at AGS
  - high field capture solenoid of 4T
- ~ 2005, and cancelled

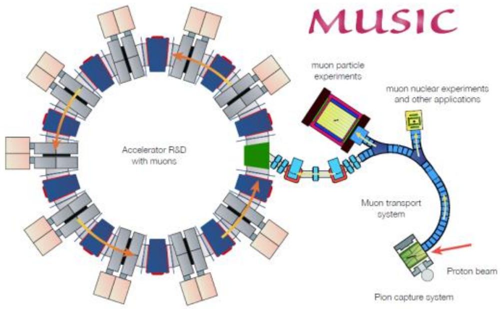
Revived at FermiLab.
Proposed in 2007. Under construction



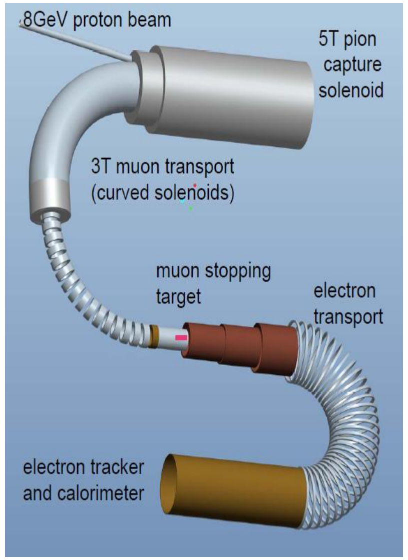
COMET, Phase-I of PRISM/PRIME.
Proposed in 2007. Phase-I Under construction

PRISM/PRIME
Conception started ~ 2003





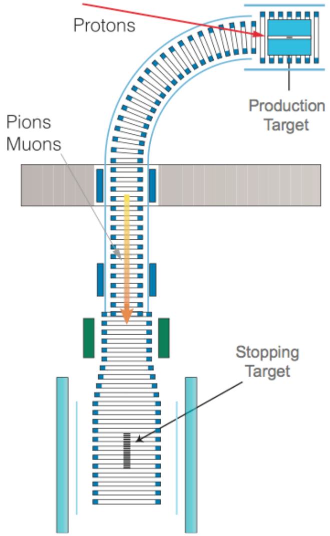
MuSIC, proposed in 2010
Under construction



Phased Approach for COMET

COMET Phase-I

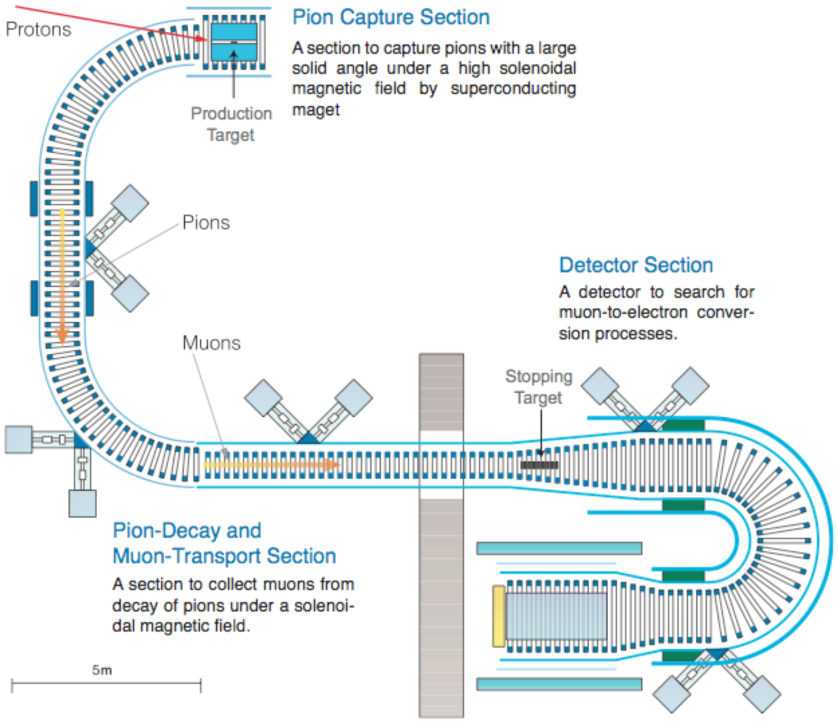
- Directly measure the muon beam with prototypes of Phase-II detector.
- Search for $\mu - e$ conversion with factor of 100 improvement*
- 8 GeV, 3.2 kW, graphite target



- Upstream part same as Phase-II
  - Except production target and part of shielding

COMET Phase-II

- Search for $\mu - e$ conversion with full sensitivity: factor of 10,000 improvement
- CDR submitted in 2009
- 8 GeV, 56 kW, tungsten target



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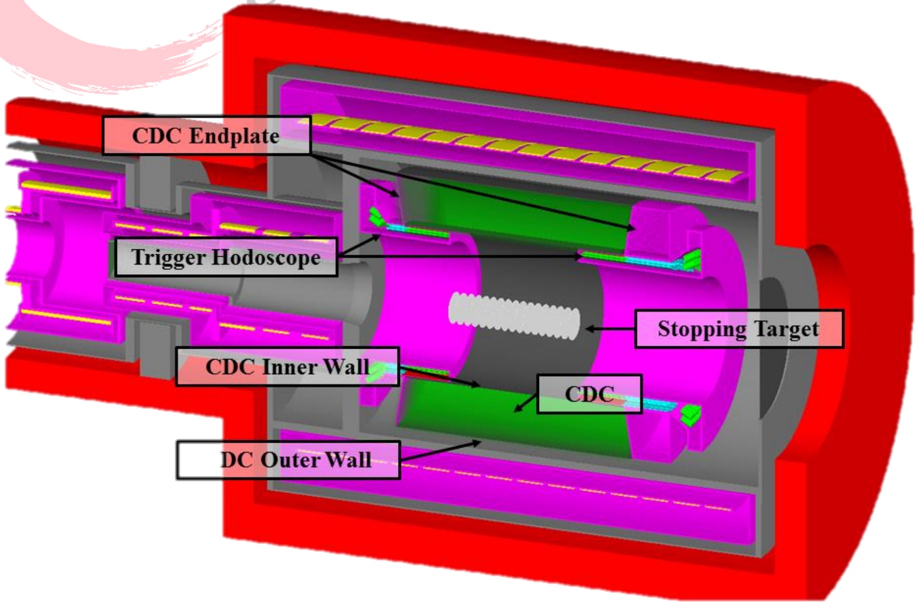
* COMET Phase-I Technical Design Report, DOI:10.1093/ptep/ptz125

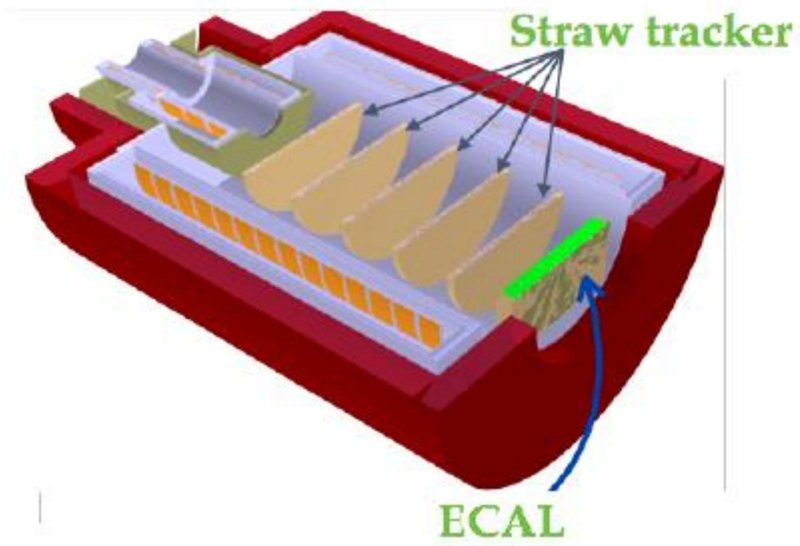
Phase-I Detectors

Main detector: Cylindrical detector (CyDet)



- Specially designed for Phase-I. Consists of:
  - Cylindrical trigger hodoscope:
    - Two layers: plastic scintillator for t0 and Cerenkov counter for PID.
  - Cylindrical drift chamber:
    - All stereo layers: z information for tracks with few layers' hits.
    - Helium based gas: minimize multiple scattering.
    - Large inner bore: to avoid beam flash and DIO electrons.

Straw Tracker & Energy Calorimeter (StrEcal)

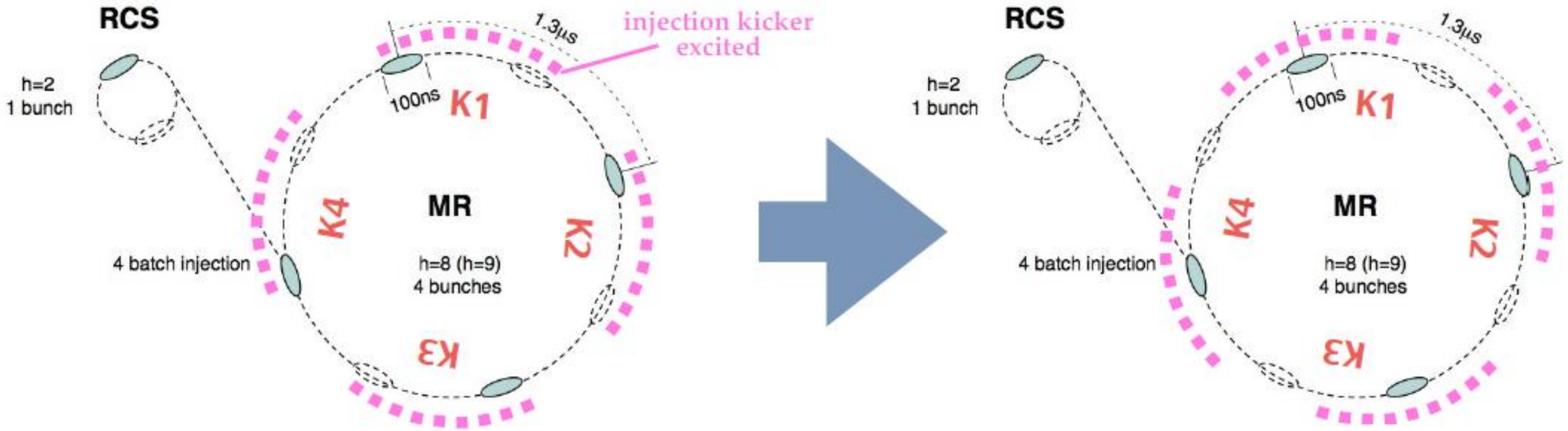


- To measure all delivered beam incl BG, vacuum-compatible tracker and calorimeter is employed
- Straw = Planer/Low-mass, LYSO crystal ECAL = High resolution / High density
- Same concept as Phase-II detector = Prototype of Phase-II Final Detector

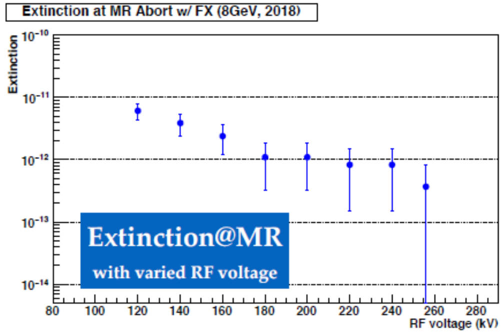
Preparation for Phase-I

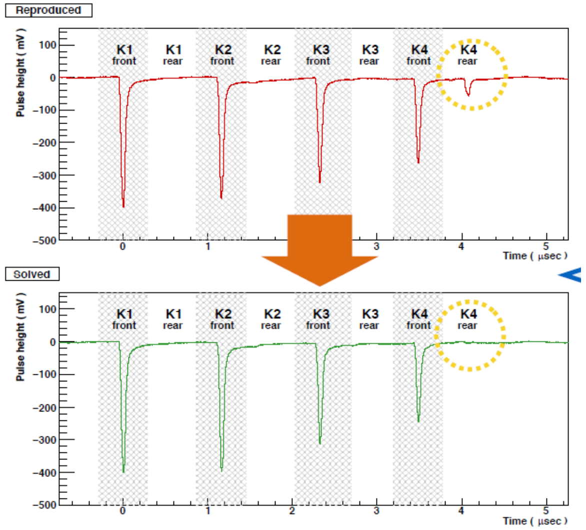
Proton beam from J-PARC

- To make the proton extinction factor: R $(N_{leak}/N_{pulse}) < 10^{-10}$
    - Shift the kicker phase by half period to avoid residual protons in the empty bucket.



Measurement at main ring:
proton leak $< 10^{-12}$

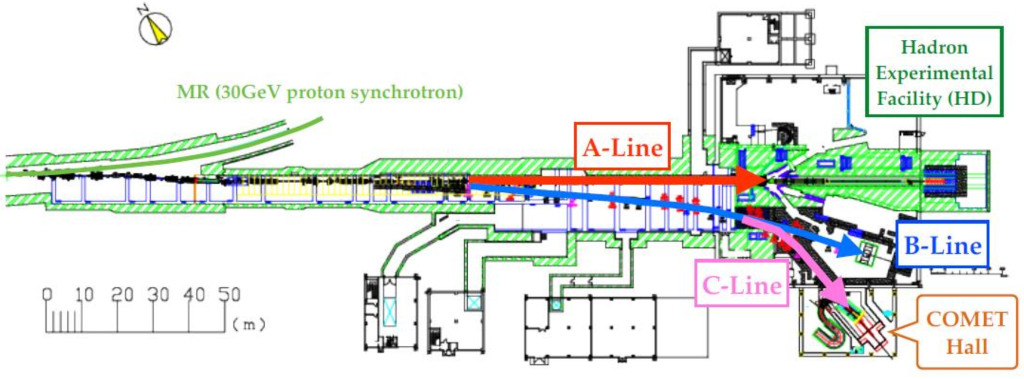




2018: Observed K4 rear leak.
2021: T78 at hadron hall, solved the leak by shifting the kicker further: $< 3.2 \times 10^{-12}$
2023: Confirmed same performance after the power upgrade in the J-PARC main ring.

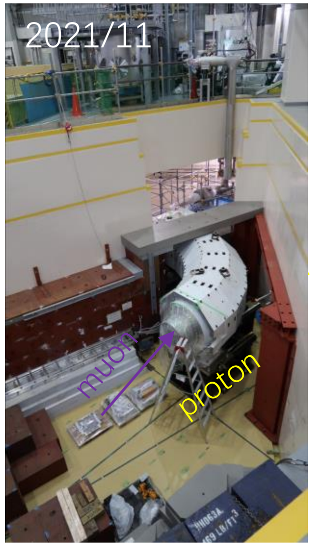
COMET Facility

C-line ready. Proton beam came to COMET for the first time.



Detector area prepared in 2022.

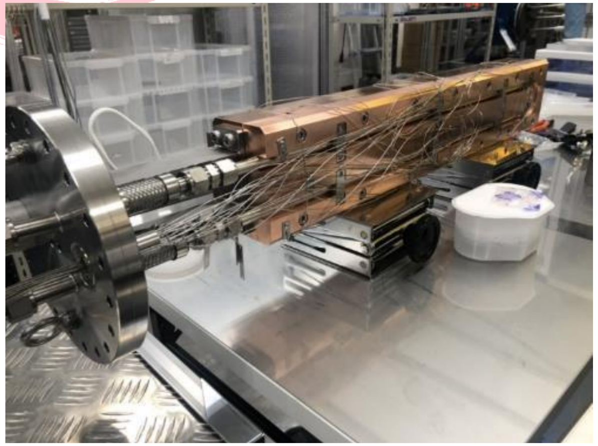
MTS (muon transportation solenoid) in position.



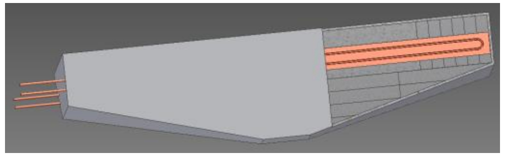
Shielding added last year.

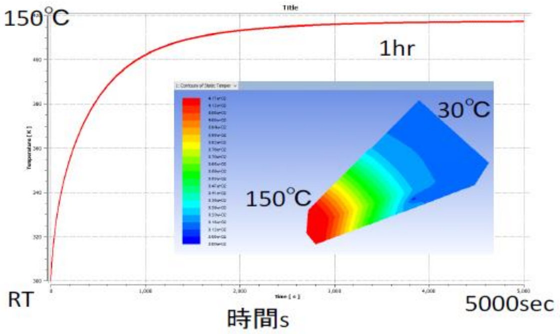
Production Target System

Cooling test of shielding (Cu for Phase-I)

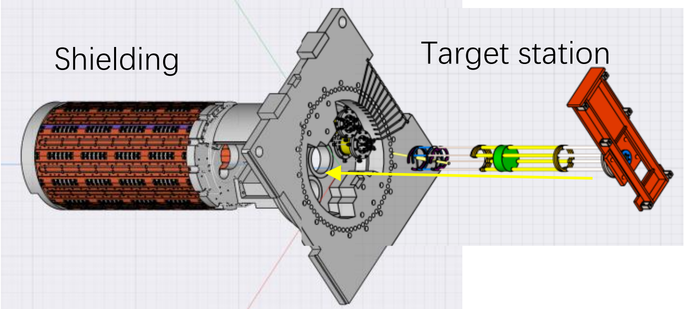


Water cooling for shielding (W for Phase-II): 27 ℃ 3 m/s inlet water is enough to cool the block

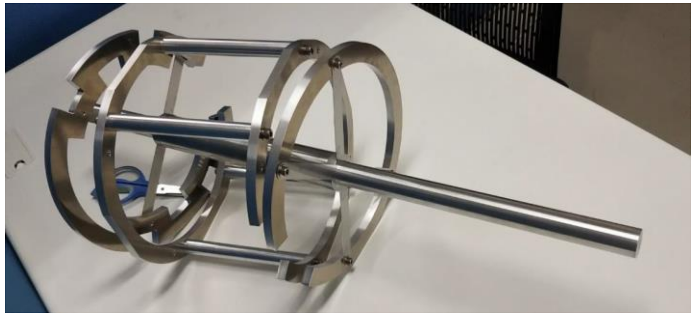




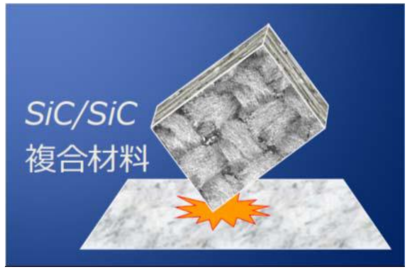
Target station with remote control



Prototype of target station for Phase-I

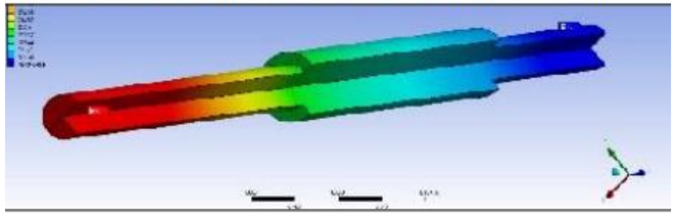


Phase-II target needs water cooling.
Other materials are being considered: W-TiC, SiC/SiC,···



Graphite target for Phase-I: radiation cooling, T<245 degree

Graphite
Diameter: 26 mm and 40 mm, Length: 700 mm

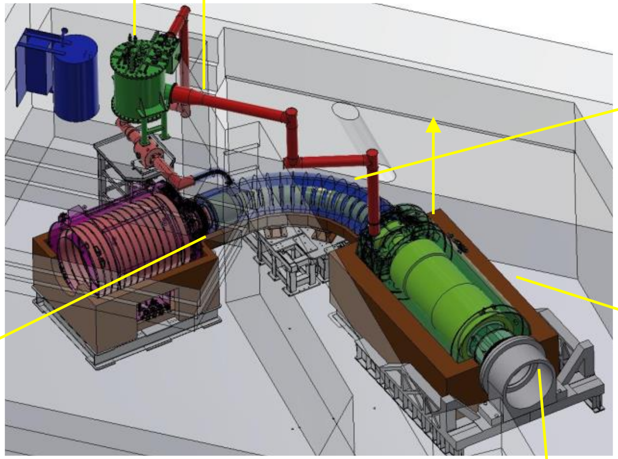


FEM simulation is completed. Max. temp. 245 degC.

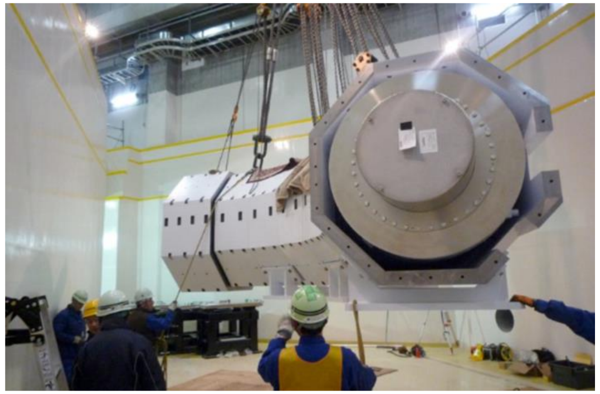
COMET super conducting solenoids

DS coil and peripherals delivered June 2023

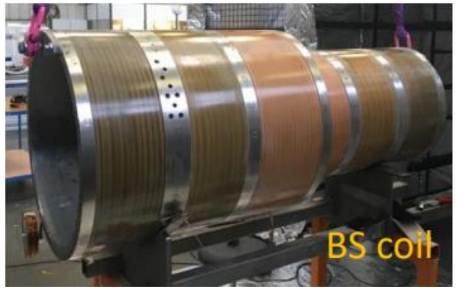
Successfully tested the cooling system with I=3000 A in 2021



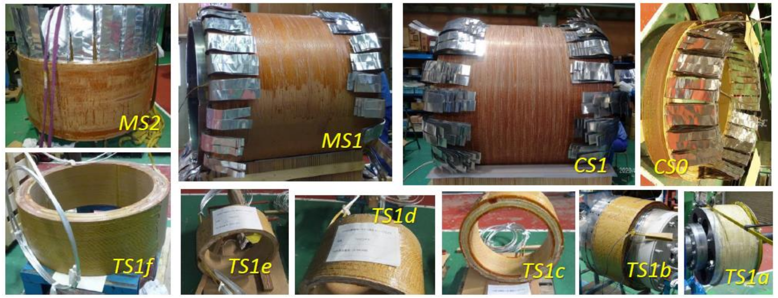
Installed in 2015. Tested in 2022. Field map measured in 2022.



Coils for the bridge solenoid ready in 2018.
BS magnet delivered March 2022.



All coils for the captures solenoid ready in 2020



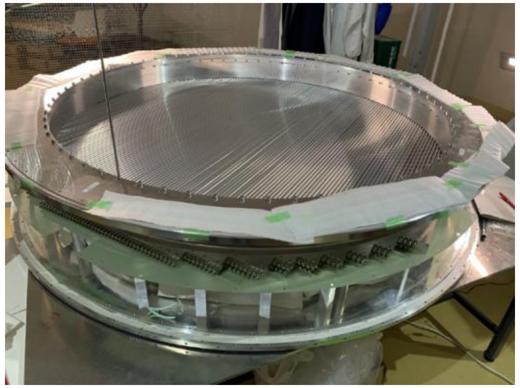
Construction of capture solenoid is in the 3rd year of multi-year construction contract (FY2020-2024)

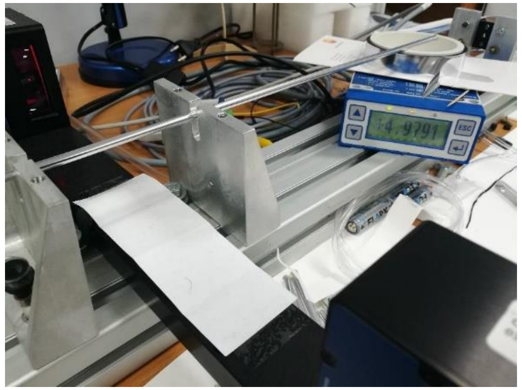
Found degradation of insulation in CS unfortunately:
- Location of electric contact identified.
- However, it needs 3 months to recover and 6 months to be re-constructed…

StrEcal

First station for COMET Phase-I ready. Second station under construction.

- 10 mm diameter, 20 um thickness



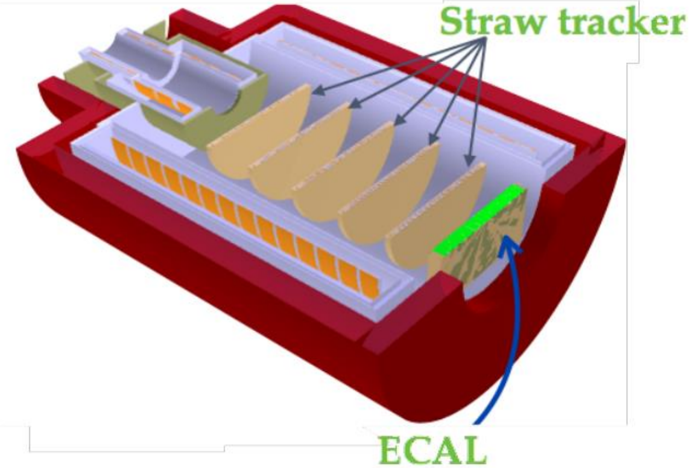


Constructed 5 mm diameter, 12 um thickness straws for Phase-II

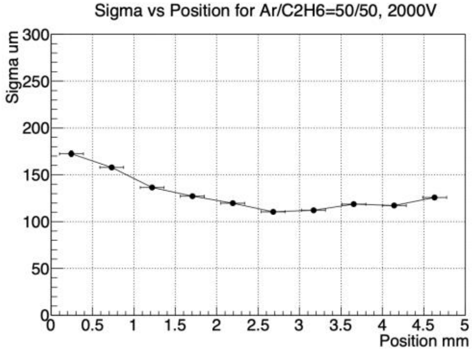
- Pressure tests with 4 bar successful.
- Diameter variation within 120 um
- Further investigations on the way.

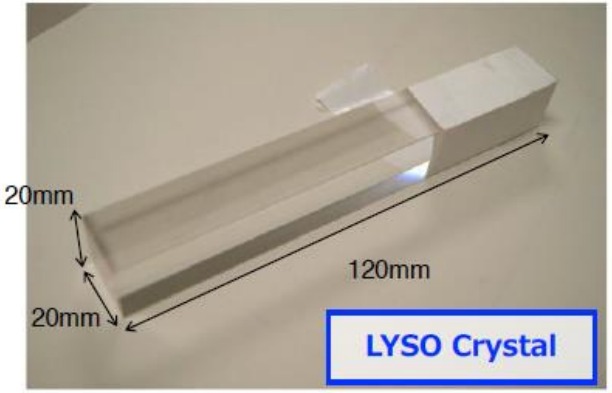
StrEcal system in phase-I: 5 stations and ~500 LYSO crystals.

- In phase-II: more stations, 1920 LYSO crystals



Straw filled with Ar:Ethane=50:50 gas.
Beam test shows spatial resolution~150 um

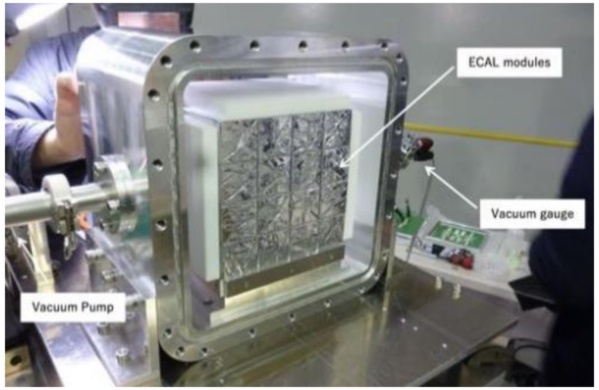




Successful prototype test for LYSO in vacuum.

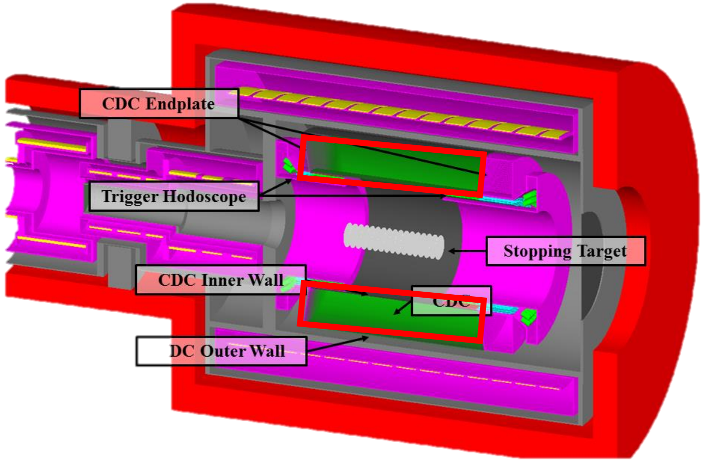
- σ_E/E=4%, $\sigma_{x/y}$=6 mm, σ_t=0.5 ns

Phase-I support structure completed. ~500 LYSO crystals mounted.

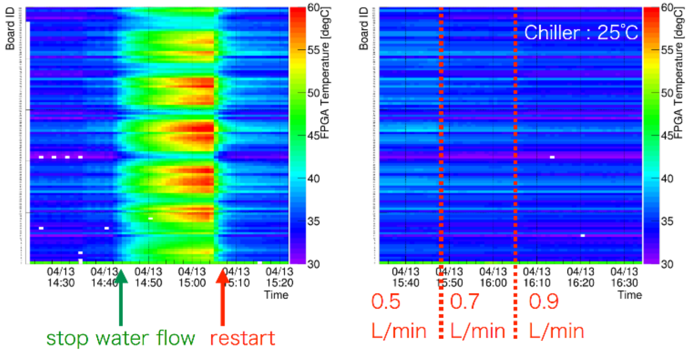


CyDet: CDC

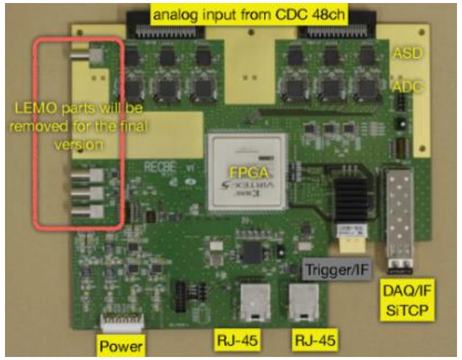
CDC was constructed in 2016 and still working stably. Moved to J-PARC last year. Now ready to take cosmic ray data for calibration



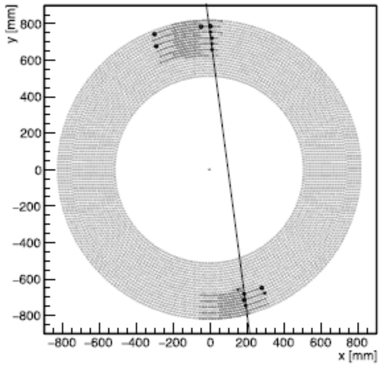
Water cooling system designed for the frontend electronics.
Mounted and tested successfully.

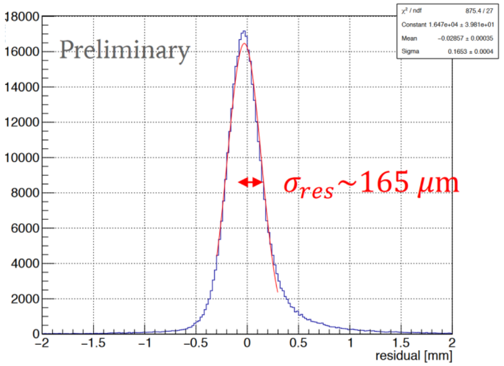


All the 128 boards produced by IHEP group before 2015. All mounted in 2019.



Filled with He:isobutane=90:10 gas.
Cosmic ray test shows spatial resolution~165 um



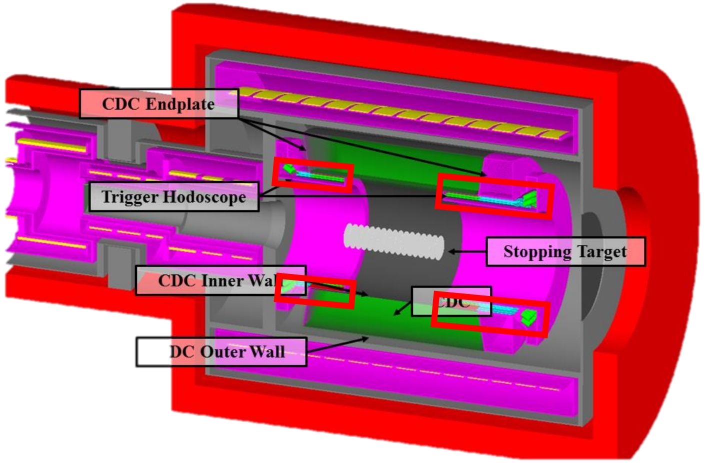


Supporting cradle delivered March 2023

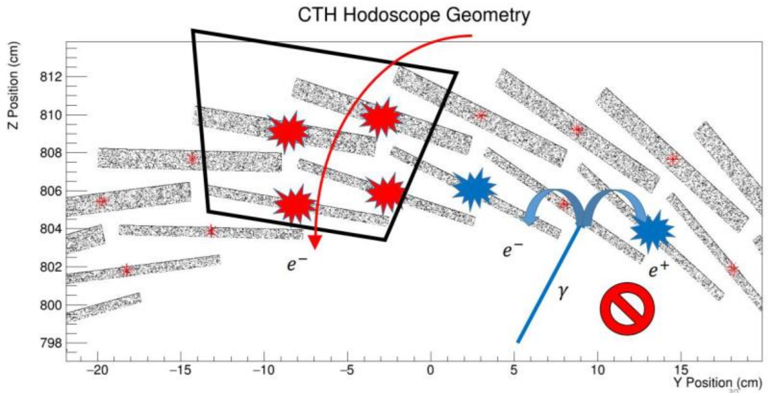
CyDet: CTH

64 scintillators, x2 layers, x2hodoscopes

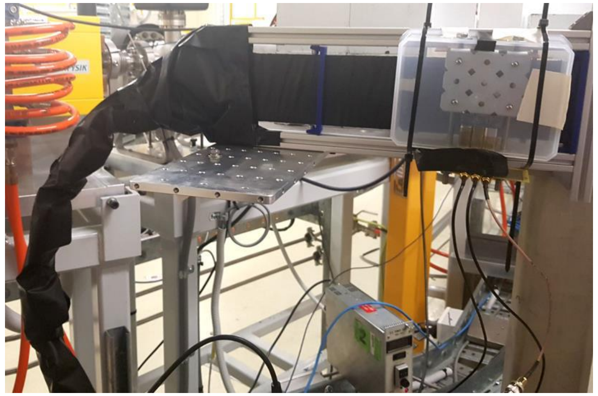
- Stage-I plan. For stage-II, one layer will be replaced by Cherenkov counters.
- Now prototypes are being tested with 100 MeV electron beam
- The readout is SiPM
  - Vulnerable to neutrons.
  - Need extra cooling system to suppress the noise.
  - 5~10 m of optic fibers leading to SiPM outside of the high radiation area



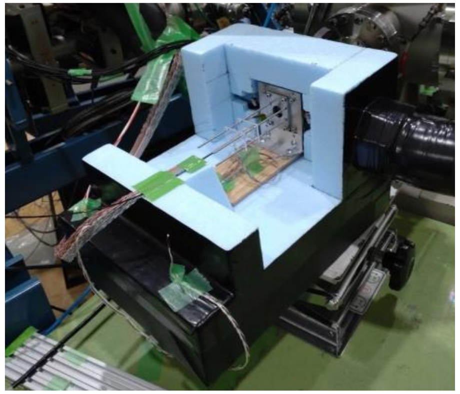
Trigger pattern design



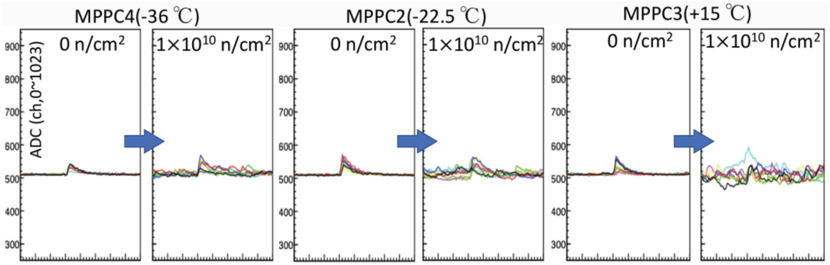
CTH prototype



Readout cooled by N2



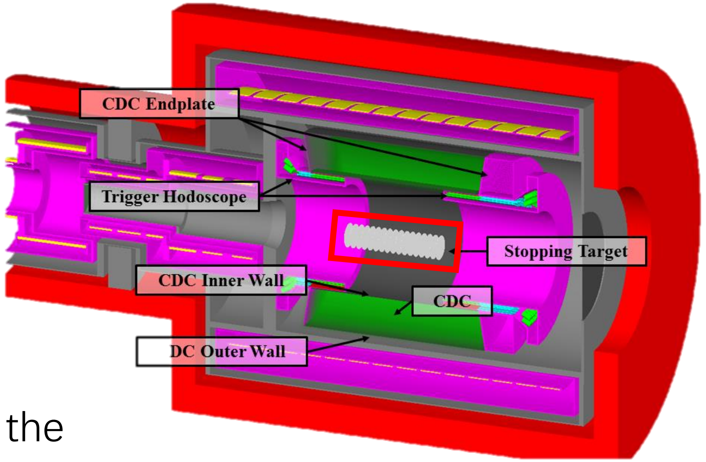
cooling and irradiation test last year:
Successfully reduced the noise by cooling



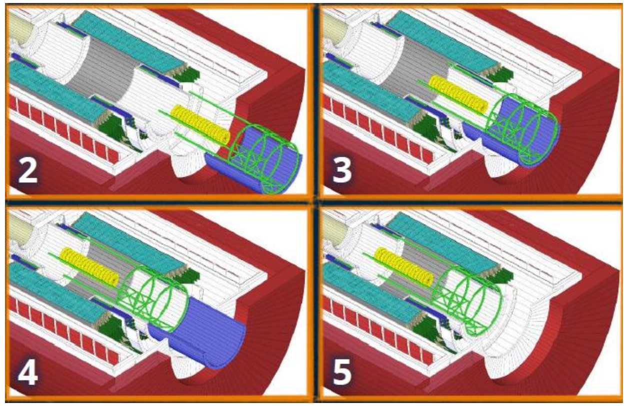
CyDet: stopping target

The stopping target system is under optimization by the Dresden group.

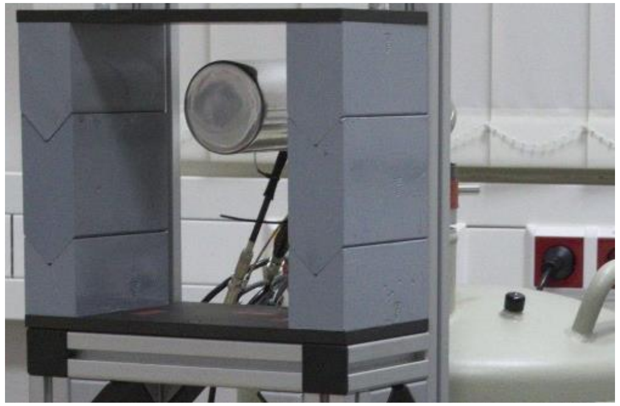
- Number of plates, thickness, etc.
- Prototypes including supporting system produced.



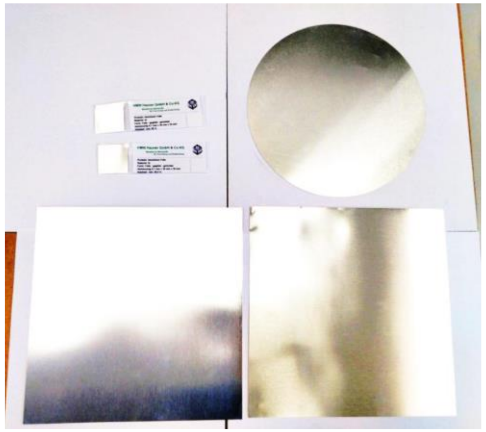
Procedure to install the target system designed.



HPGe detector (to calibrate # stopped muons) placed a few meters away from the target. Dresden group is optimizing the shielding design.

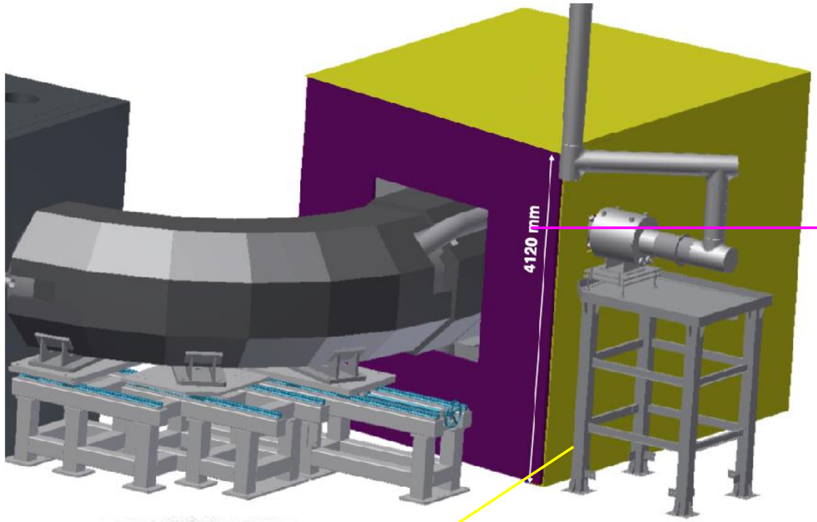


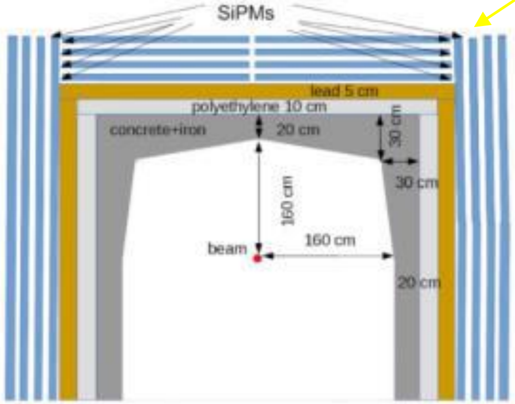
Ongoing tests to choose specific material

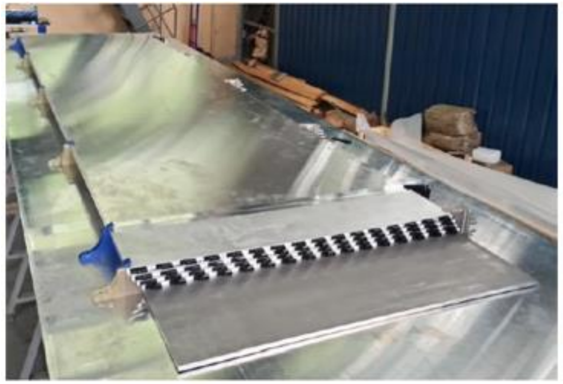


Cosmic ray Veto (CRV)

Design of COMET Phase-I CRV.
Yellow: plastic scintillators (4 layers)
Purple: GRPC detector

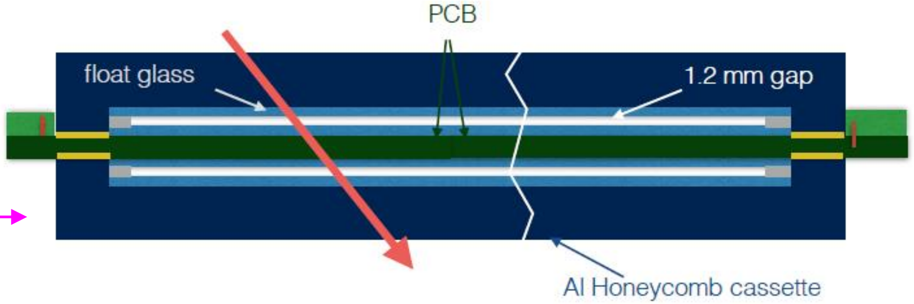




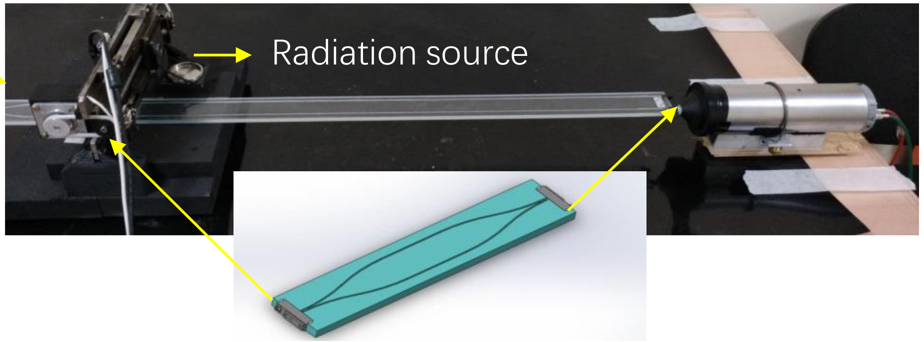


The GRPC design from Clemont.

- Unfortunately the study cannot be continued due to budget issue. Electronics will be contributed to an alternative plan. Other GRPC group? Use straw?



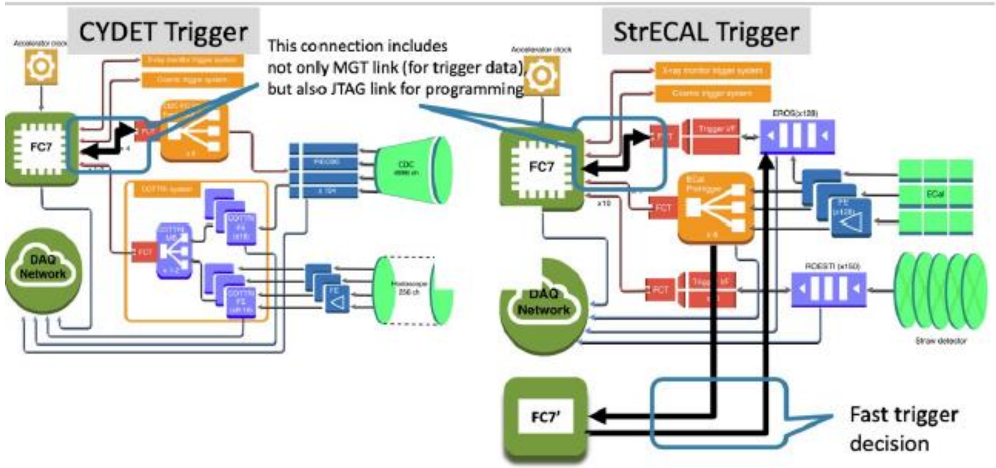
- Testing with radiation source using SiPM as readout.
  - Preliminary: ¾ coincidence veto ratio ~99.86%



Full size modules produced: 16 strips * 4 layers. Will be shipped to J-PARC soon for further studies.

Trigger &DAQ system for COMET Phase-I

- High trigger rate (20-30 kHz) for DAQ
    - Mostly background hits
    - Beam electron, secondary from capture neutron/gamma
    - Online trigger suppress BG hits
- A configurable and flexible Trigger system
    - Central system based on commercial CERN product and a custom interface board
    - Ensuring commonality in interfacing with different systems.
- Online BG hit/event classification using charge and layer features
    - Trigger board implementation to the LUT of FPGA
    - Trigger rate reduced from 91 kHz to 13 kHz, 96% efficiency and 3.2μs latency.



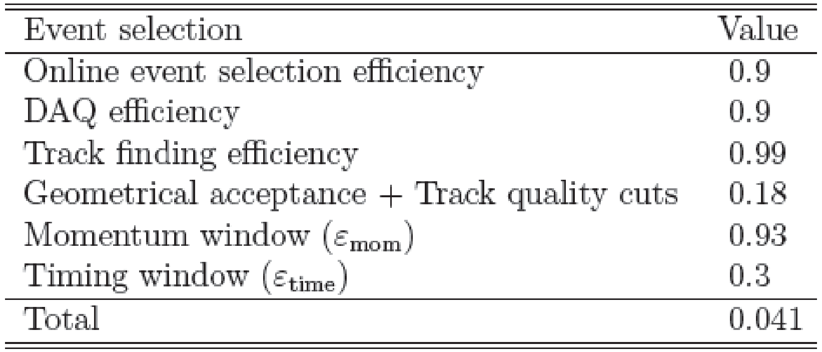
FC7 (CMS)

FCT

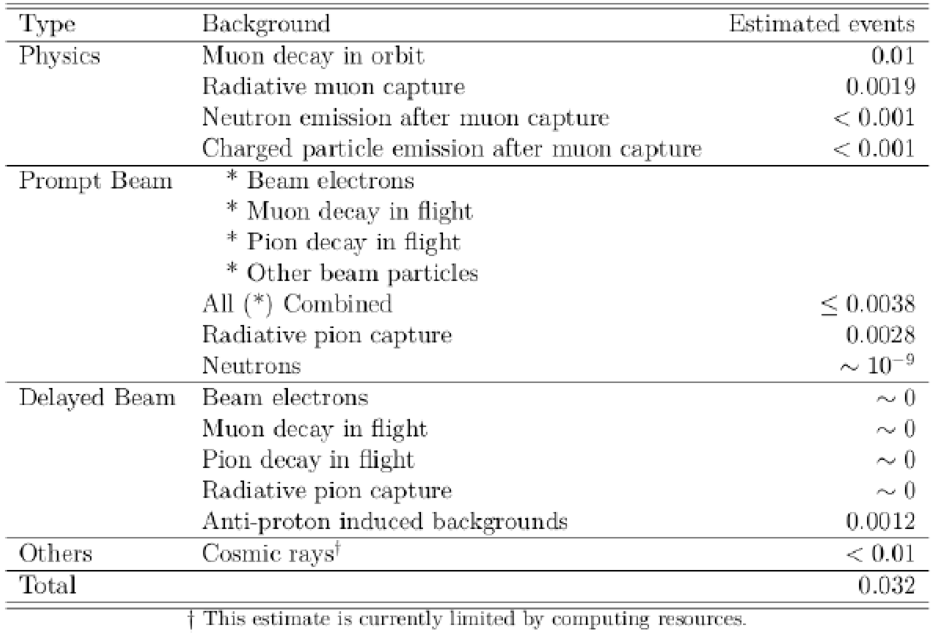
COTTRI

Monte Carlo study of COMET Phase-I

- The optimization of COMET Phase I is finished. Detailed performance is estimated with Monte Carlo studies. TDR was published in 2021.
  - Sensitivity:
    - Total acceptance of signal is 0.041
    - Can reach 3×10^{-15} SES in 150 days, 90% C.L. u.l. 8×10^{-15}
  - Background:
    - With 99.99% CRV veto ratio, total expected background is 0.032
  - Trigger rate:
    - Average trigger rate ~10kHz (after trigger with drift chamber hits)



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 (ε_{mom})	0.93
Timing window ($\varepsilon_{\text{time}}$)	0.3
Total	0.041



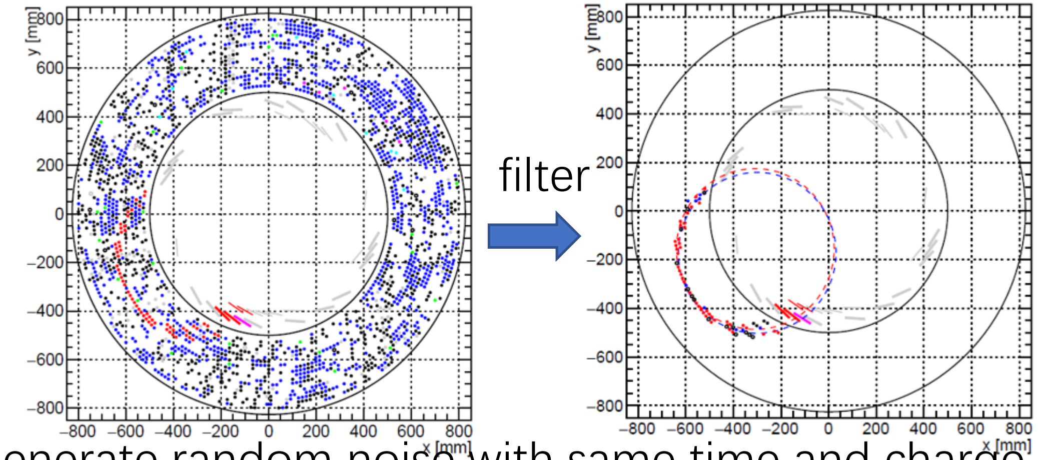
Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	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

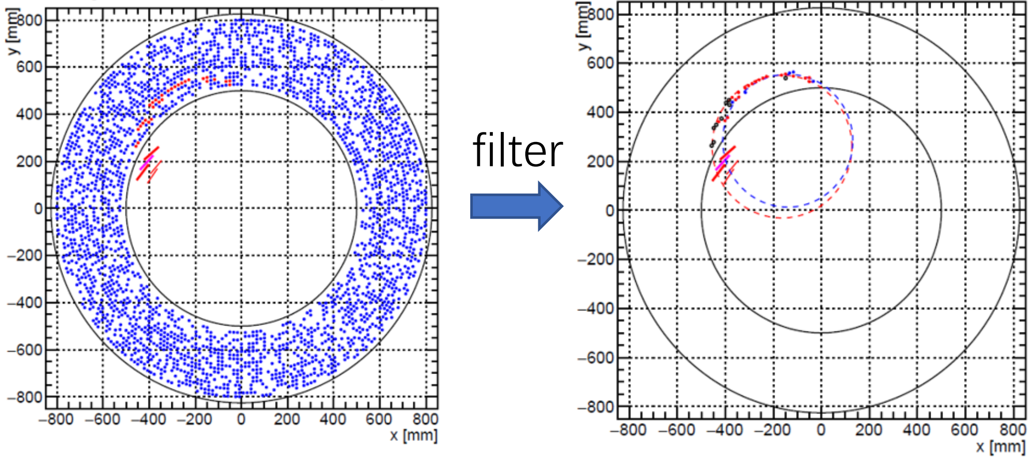
Progress of Theoretical and Experimental Physics, 2020, 2020(3)

Mock data challenge

Using Geant4 based beam simulation to study background hits distribution: ~300 bunches generated.
Machine learning based filter algorithm tested:

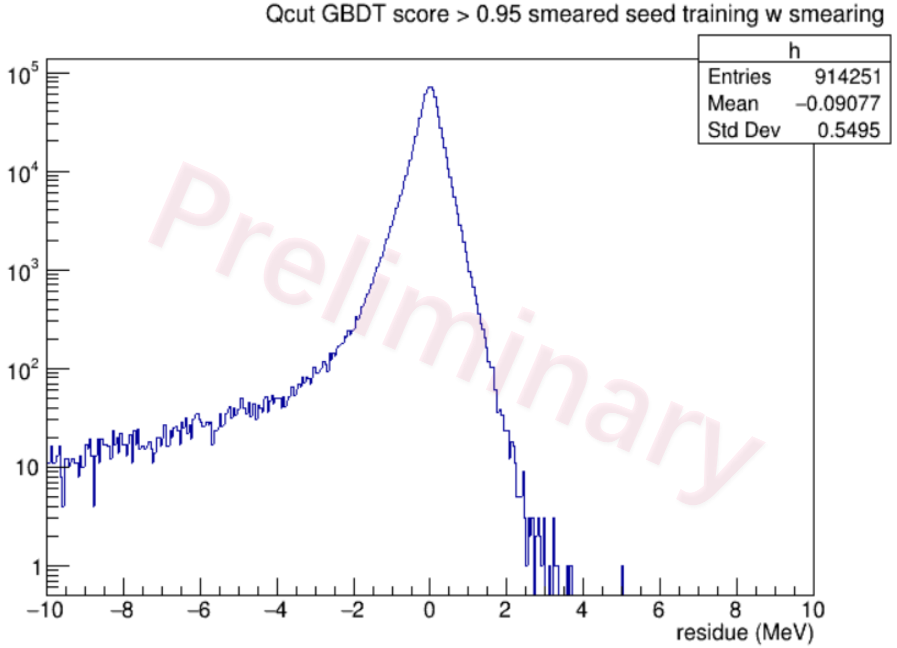


Generate random noise with same time and charge distribution, and provide similar challenge.



After generating random noise on top of 20M signal events from MC, we started the challenge in tracking

- Using machine learning for filter.
- Using Genfit2 for fitting
- Starting from single turn events
- After using Gradient Boosted Decision Tree (GBDT) to require the quality, satisfying resolution achieved


Qcut GBDT score > 0.95 smeared seed training w smearing

COMET Phase-alpha

COMET’s Novel Muon Beamline

Complete the muon beamline with a thin graphite target and some vacuum ducts: COMET Phase-α

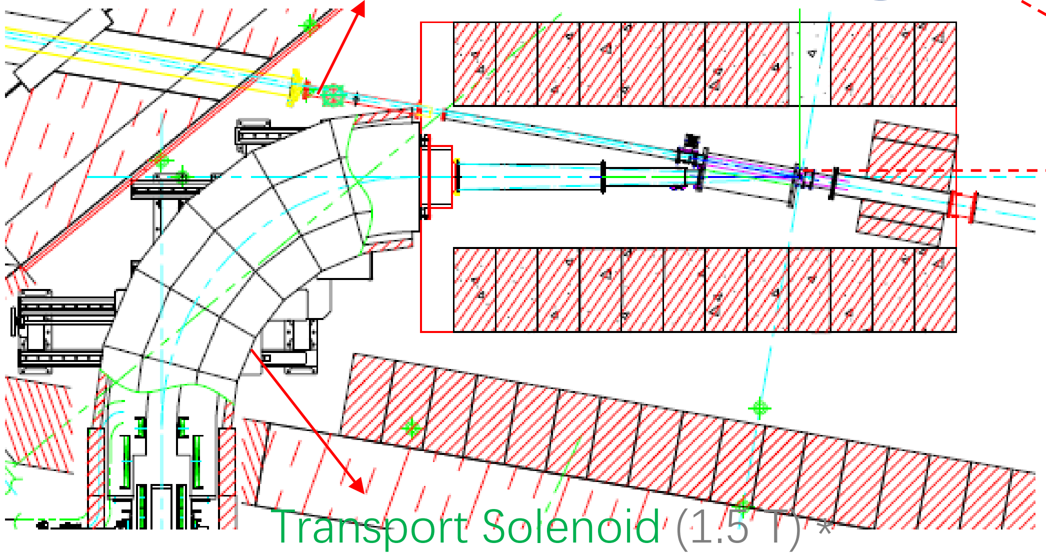
- Commissioning for both the proton beamline and the transport solenoid
- Study pion production process by 8 GeV protons on a graphite target.
- Study the performance of the transport solenoid.

Thin target system

- 2×2 cm^2, 1.1 mm thick C/C composite pion production target
- Beam-loss measuring stainless target for beam profile measurement

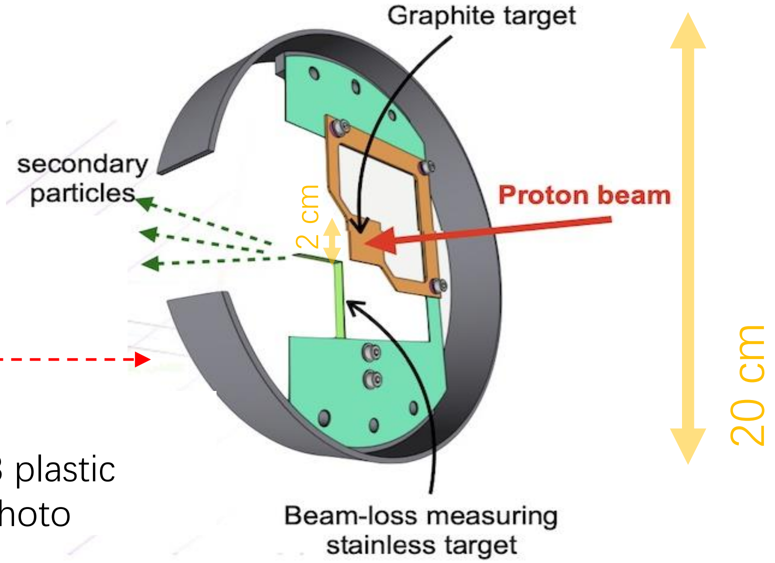
8 GeV Proton Beamline

Target Monitor



Transport Solenoid (1.5 T)*

Target monitor: 3 plastic scintillator with photo multipliers



** Due to the concern with the force by Eddy current, extra support rods need to be mounted to operate at 3 T.*

COMET Phase-α Run Summary

Commissioning Run (10th − 14th February)

- First proton beam commissioning succeeded.
- Tested the detectors, checked signal timings, and checked trigger logics.

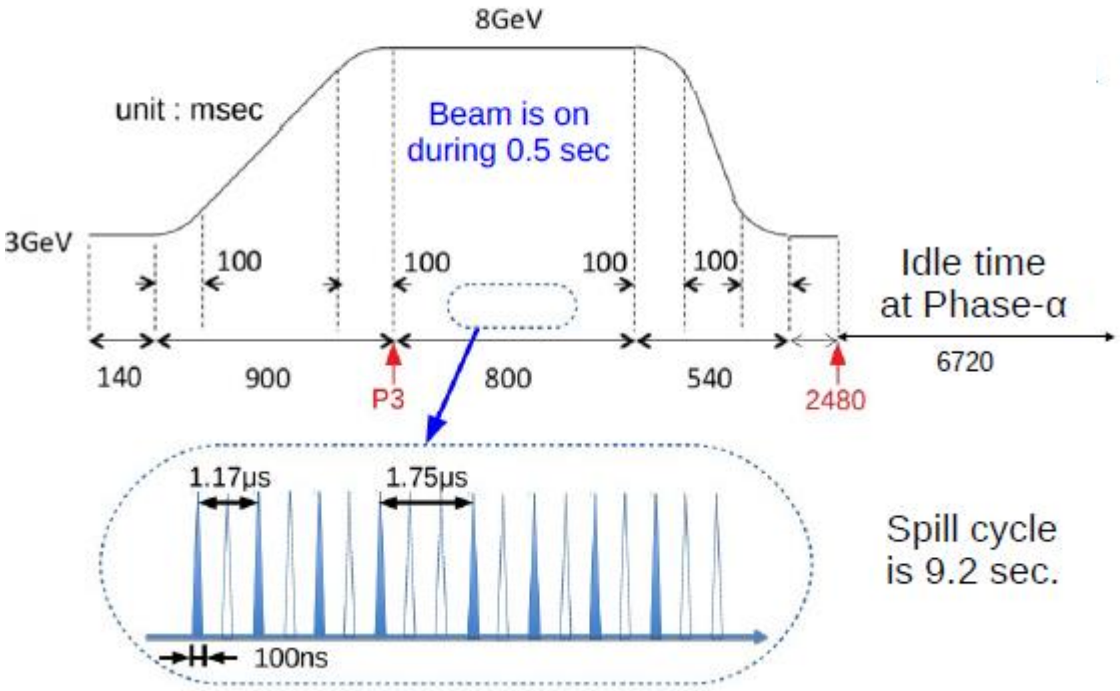
Measurement Run (~ a week in 3rd – 15th March)

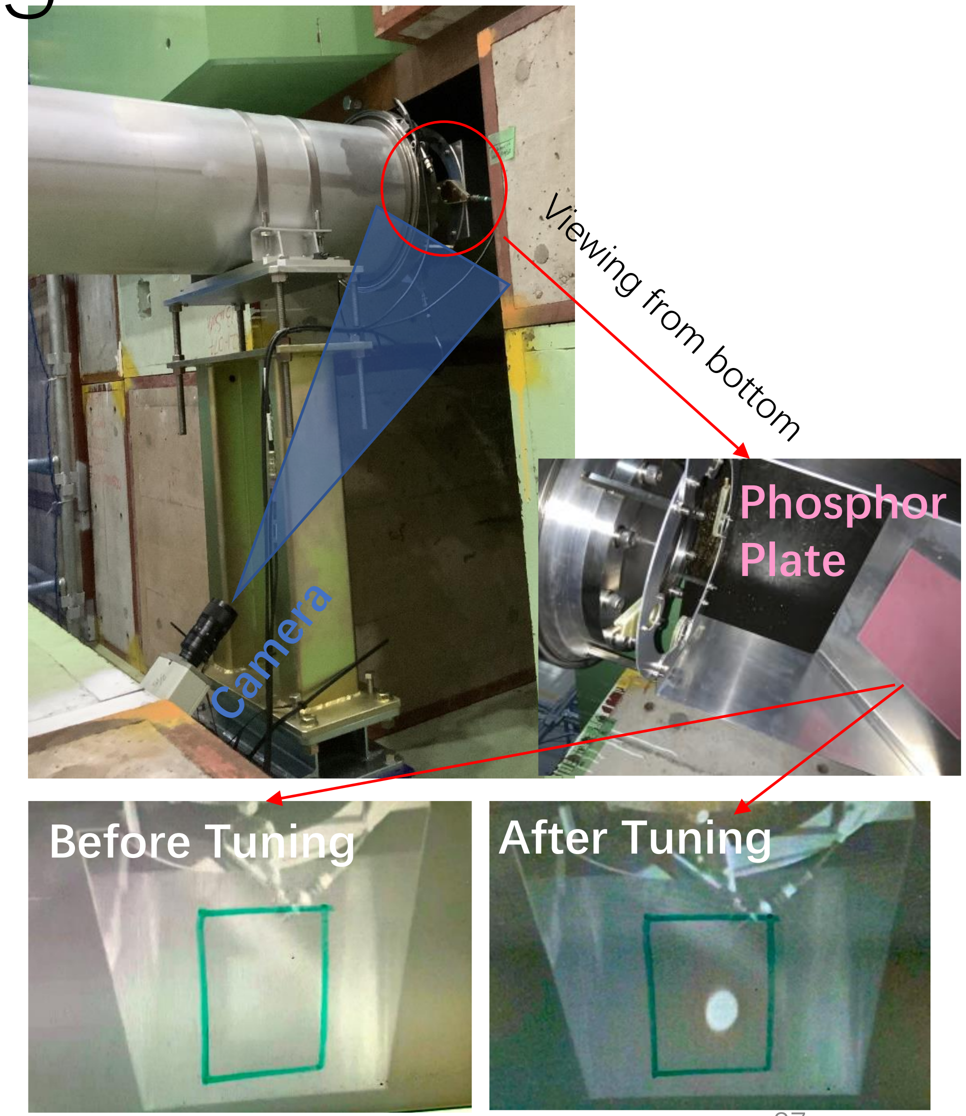
- **3rd − 4th: Principal check of beam muons**
  - Checked if the muon's copper-induced short lifetime disappears w/o the copper absorber.
- **9th − 13th: Muon momentum spectrum measurement**
  - Changed the Range Counter's configuration.
    - Degrader thicknesses to change the momentum range to measure
    - Range Counter's position to see the beam profile wider.
- **13th − 15th: Positive-charged beam measurement**
  - Inverted the dipole magnet's polarity
  - Took data for beam kinematics studies using positive pions and the beam-masking system.

Muon beam in the COMET experimental hall for the first time!

Proton Beam Commissioning

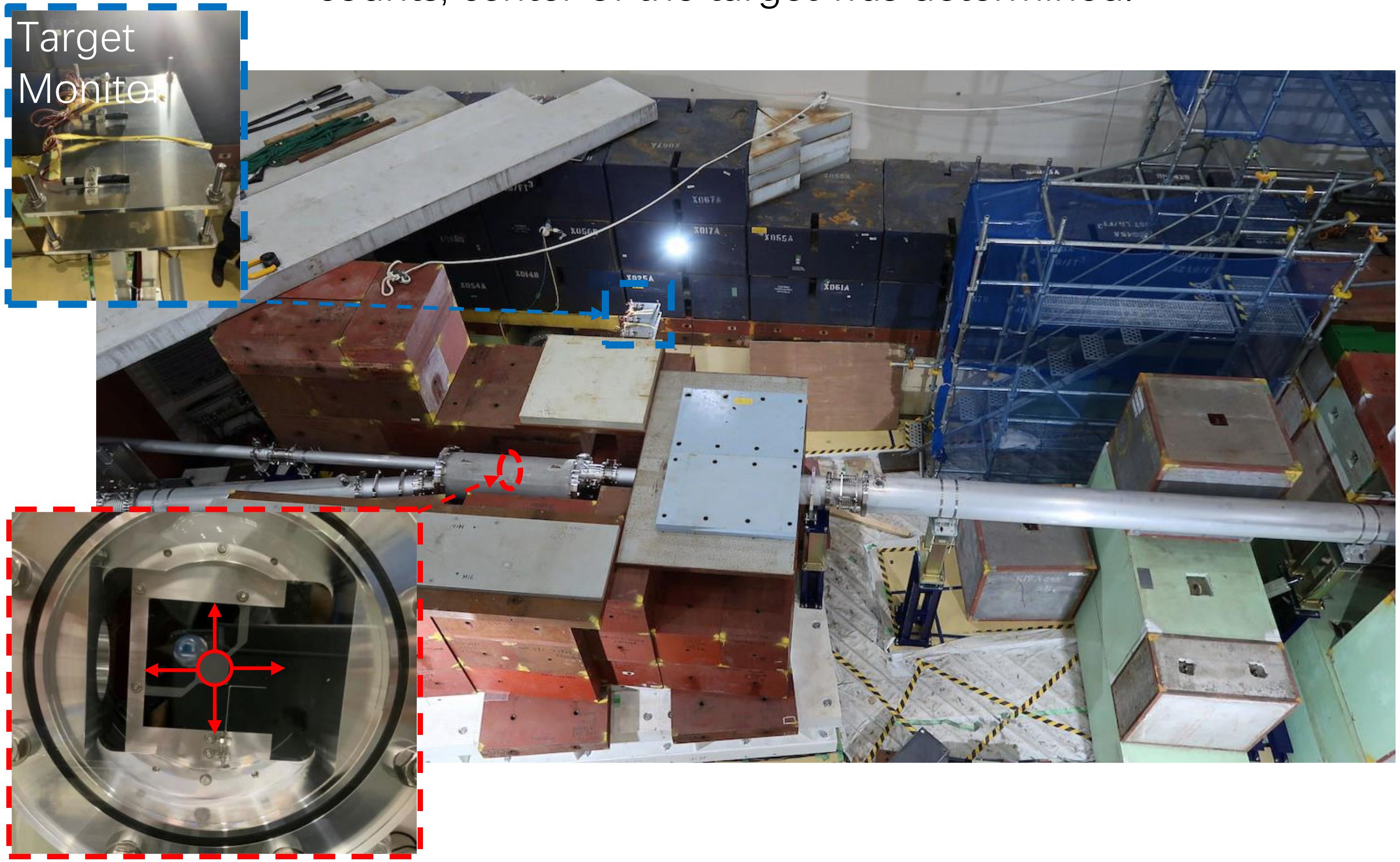
- Slow extraction with the COMET proton beamline (C-Line) was commissioned for the first time!
  - Same bunch filling structure as COMET Phase-I, but longer accelerator cycle
  - Lower beam power: 260 W (3.2 kW in Phase-I)

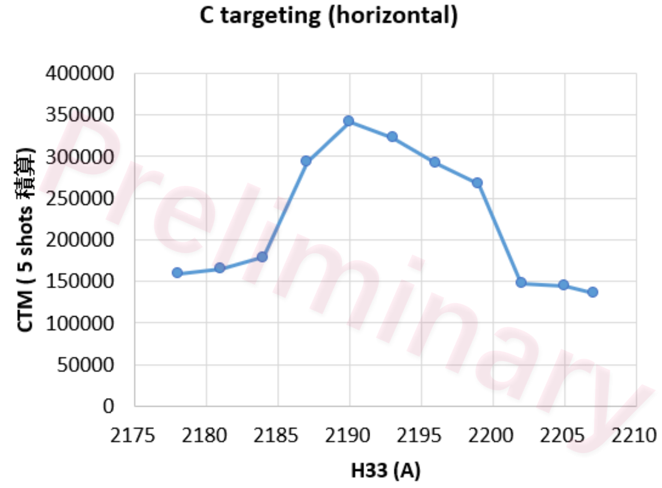


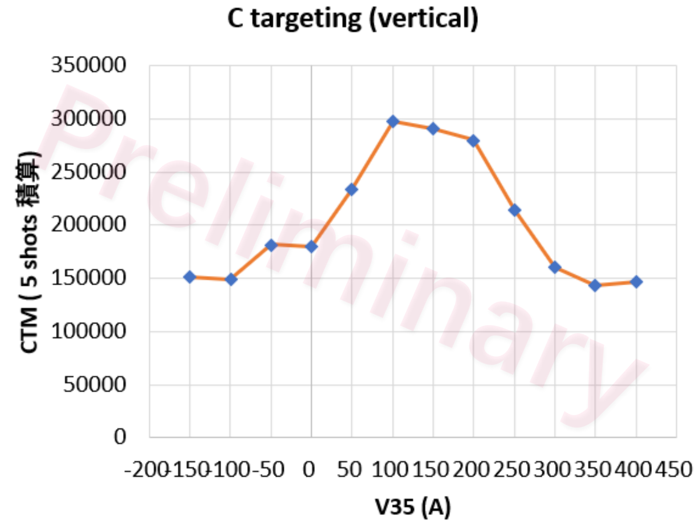


Proton Beam Commissioning

Sweeping bending magnet and measuring target monitor counts, center of the target was determined.

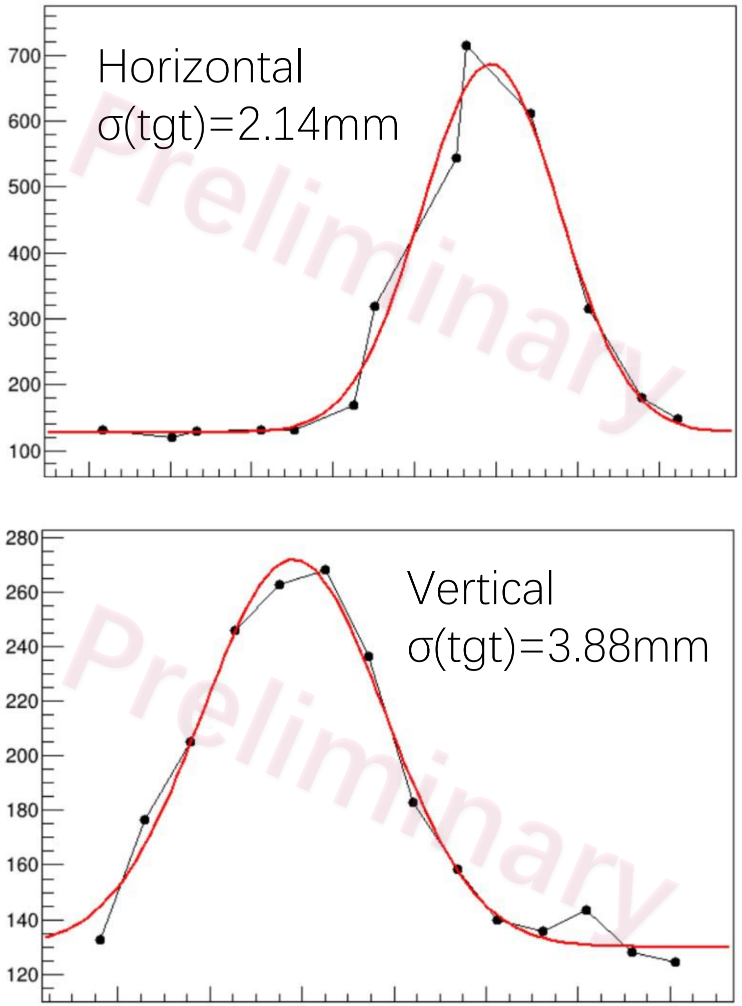



C targeting (horizontal)


C targeting (vertical)

Proton Beam Commissioning

Sweeping bending magnet and measuring target monitor counts, profile at the target was measured.



Measured beam dimensions

Muon Beam Measurement

Muon decay spectrum

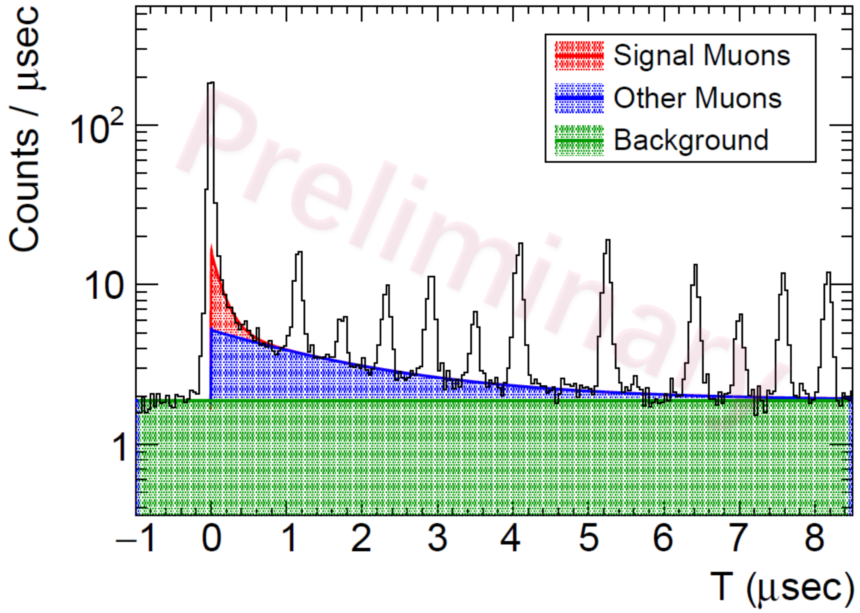
- The signal ‘short’ muon decay component was observed.
    - Negative muons transported via the 90°-curved Transport Solenoid!

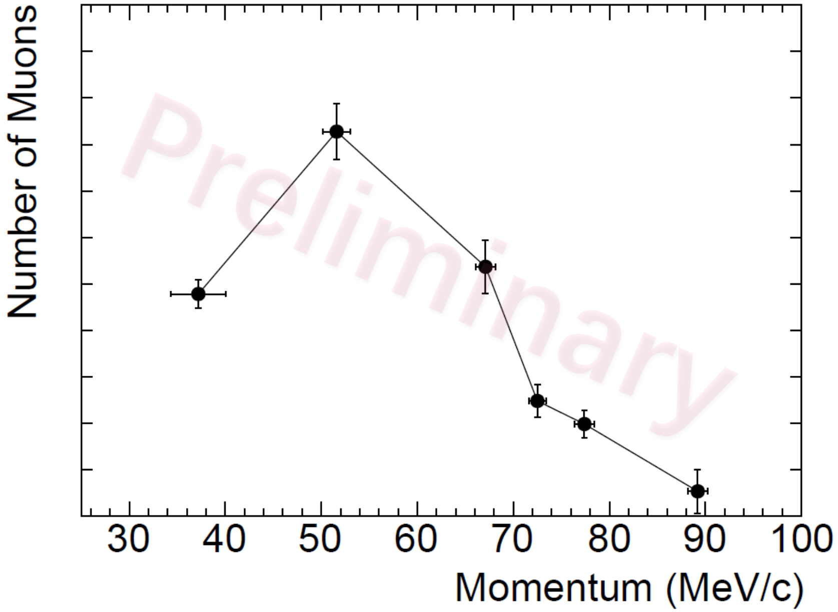
Muon momentum spectrum

- Reconstructed the number of negative muons stopped in the muon stopper from the fitted value.
    - Only statistical uncertainties plotted.
- The spectrum shape is close to our expectation from the design.

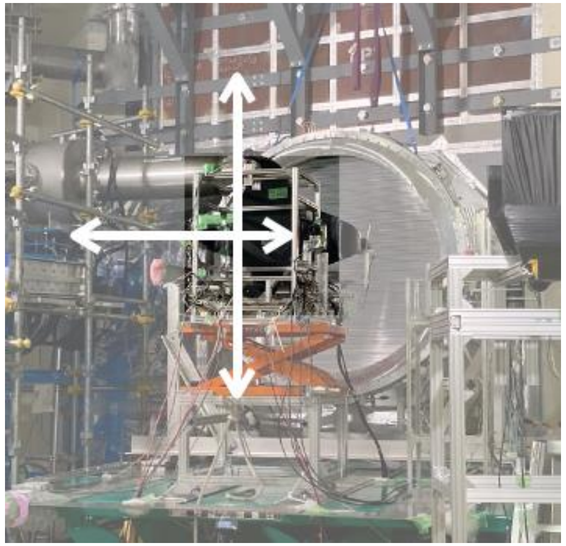
Comparison with simulation

- These measurements contribute to our hadron production model studies.
    - The model reproducing the data will be chosen for simulation studies for Phase-I & -II.



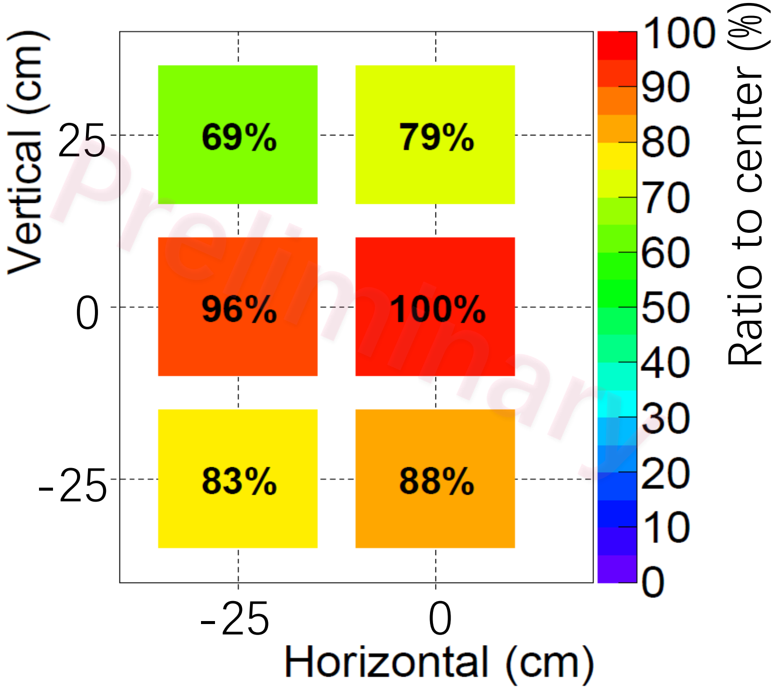


Muon Beam Measurement

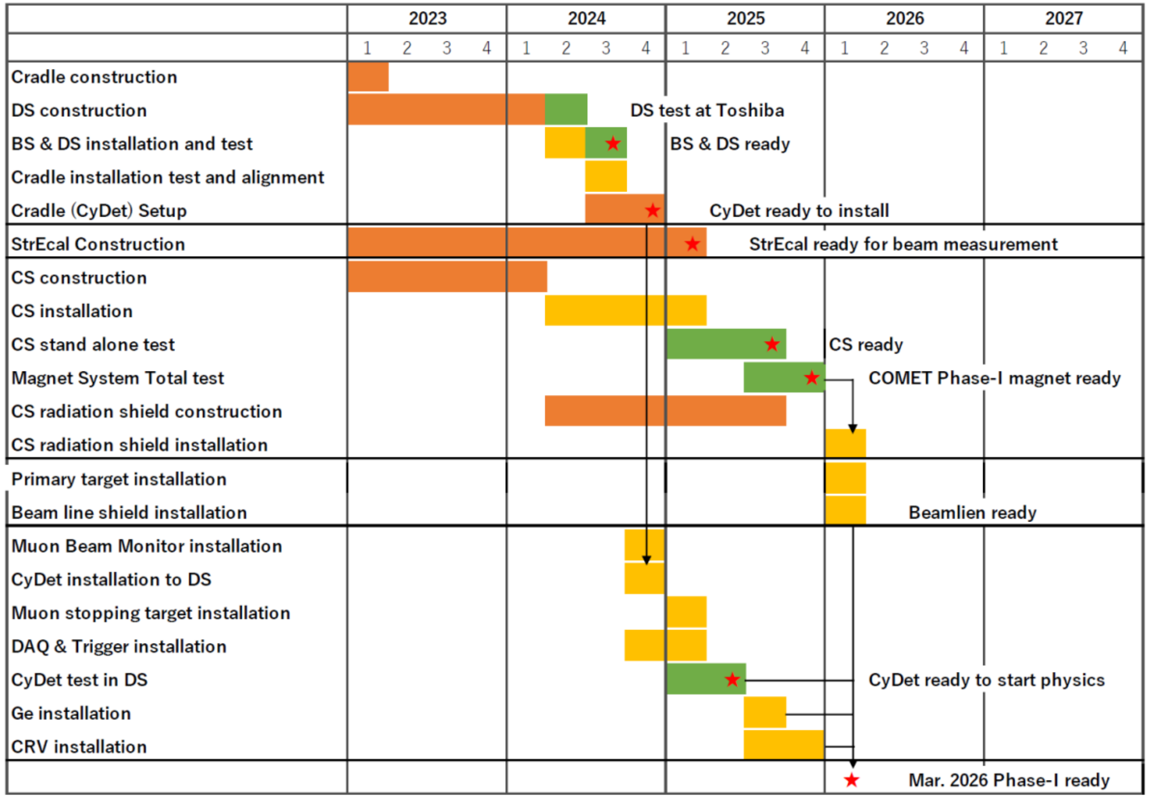


Muon beam 2D profile

- Moved the Range Counter two-dimensionally by 25 cm step.
- Muons with a momentum of around 40 MeV/c were measured.
- Muons in this momentum range are expected to concentrate around the center in the vertical direction.



Timeline for COMET



- COMET Phase-II will start construction afterward. MC studies are on the way, aiming to improve the sensitivity by x10,000 or even x100,000

	Phase-I	Phase-II	(Phase-II)+
proton beam	8 GeV, 3.2 kW	8 GeV, 56 kW	8 GeV, 56 kW
proton target	graphite	tungsten	tungsten
transport	90° bend	180° bend	180° bend
muons stop	1.2×10^{9}/s	1×10^{18}	2×10^{11}/s
run time	150 days	200 days	300 days
detector	CyDet	StrECAL	StrECAL
90% CL	$<7\times10^{-15}$	$<4.6\times10^{-17}$	$<7\times10^{-18}$
backgrounds	0.03 events	0.32 events	0.6 events

- Mu2e Updates since then
  - Mu2e run1: 2026, 6 months, x1,000 improvement
  - Mu2e run2: 2029~2033, x10,000 improvement
  - Mu2e-II: somewhere after 2030, x100,000 improvement.

Summary

- COMET is an experiment at J-PARC searching for muon to electron process.
  - Aims at single event sensitivity (S.E.S) = 2.6×10^{-17} (4 orders of magnitude improvement) with 1 year beam time using 56 kW 8 GeV proton beam.
  - With the same beam power, **10** times better sensitivity ($\mathcal{O}(10^{-18})$) is likely and optimization is about to be finalized.
- COMET will be carried out in two phases and Phase-I is under construction.
  - Aims at S.E.S = 3×10^{-15} (2 orders of magnitude improvement) with 150 days beam time using 3.2 kW 8 GeV proton beam.
  - Will directly measure the muon beam.
- COMET Phase-α carried out in February and March
  - Proton beam was successfully extracted into the COMET beam hall.
  - Achieved the first observation of beam particles (muons) successfully transported via a 90°-curved Muon Transport Solenoid.
  - Expected muon momentum spectrum and beam profile were observed.
- COMET Phase-I is expecting its beamtime in 2026
  - COMET Phase-II's construction will follow afterward

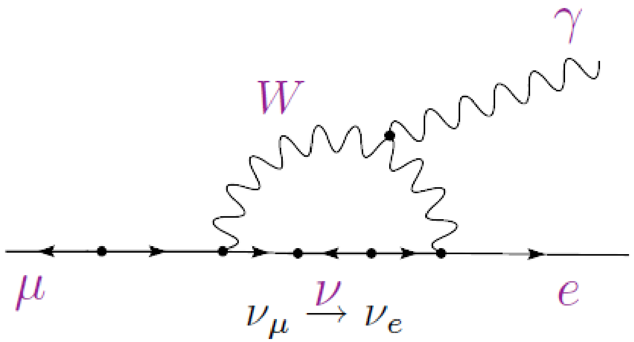
Thank You!

COMETちゃん
by higgstan.com

Charged Lepton Flavor Violation (CLFV)

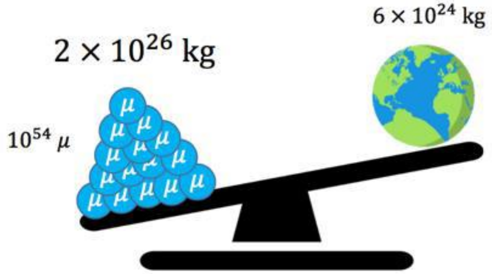
- Since 1940s, μ started to be considered as a heavy version of electron. The quest of CLFV started from searching for $\mu \to e\gamma$.
  - The null result led to the concept of flavor conservation.
- Neutrino oscillations demonstrates that neutrinos are massive, and lepton flavor conservation is violated (PMNS matrix).
- However, CLFV is still practically forbidden in SM+m_ν due to GIM
  - 40 orders of magnitude lower than current limit: Clean field to search for new physics!

Highly suppressed in SM+m_ν by GIM due to the smallness of m_ν



$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M_W^2}\right|^2 \sim 10^{-54}$$

S.T. Petcov, Sov.J. Nucl. Phys. 25 (1977) 340

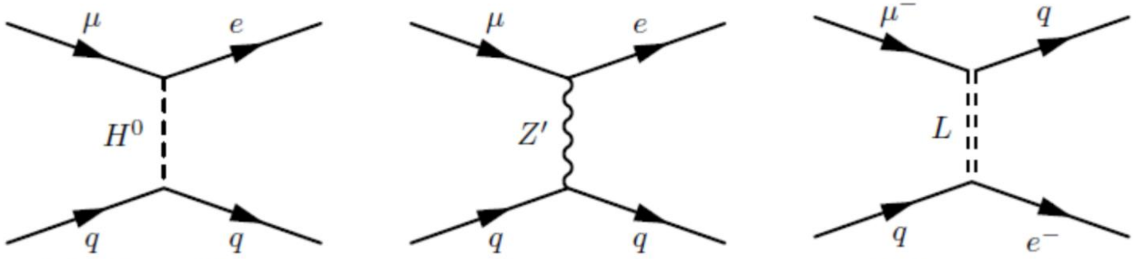


M.J.Lee, MELODY2023

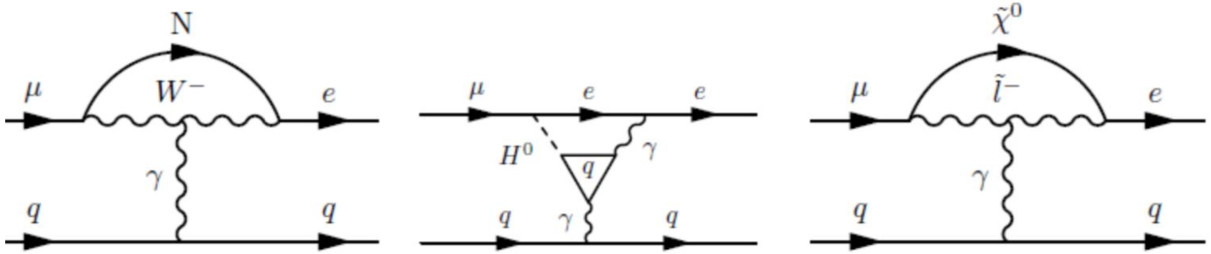
Charged Lepton Flavor Violation (CLFV)

- Neutrino mass requires new physics: scale is unknown.
- There is no fundamental law to prevent CLFV.
  - Naturally exists in new physics
- CLFV is closely related to important questions:
  - neutrino mass origin, baryogenesis, flavor origin…
- Hints from anomalies: g-2, LFU

CLFV Widely predicted in NP models



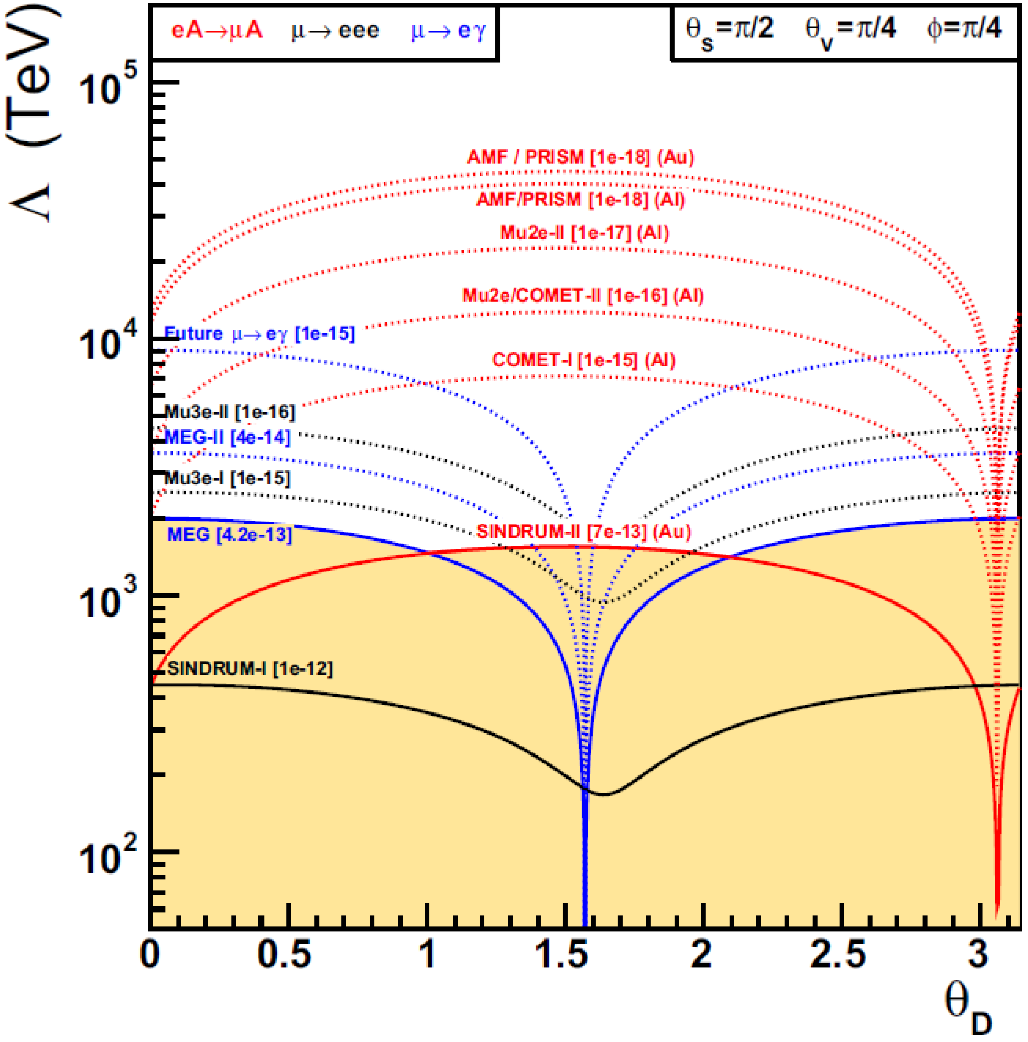
(a) Exotic Higgs (b) Z-prime (c) Leptoquarks



(d) Heavy Neutrinos (e) Exotic Higgs (f) Supersymmetry

Model independent approach: EFT

- Extend SM in effective field theory with higher dimension operators:
  $$\mathcal{L} = \mathcal{L}_{SM} + \sum_{n\geq 1} \frac{{C_{ij}}^{4+n}}{\Lambda^n} \mathcal{O}^{4+n}$$
- CLFV can be introduced from dim-6:
  $$Br \sim \frac{1}{\Lambda^4}$$
- Λ can reach $\mathcal{O}(10^3 \sim 10^4)$ TeV!
  - Good complementation to direct searches for new physics.

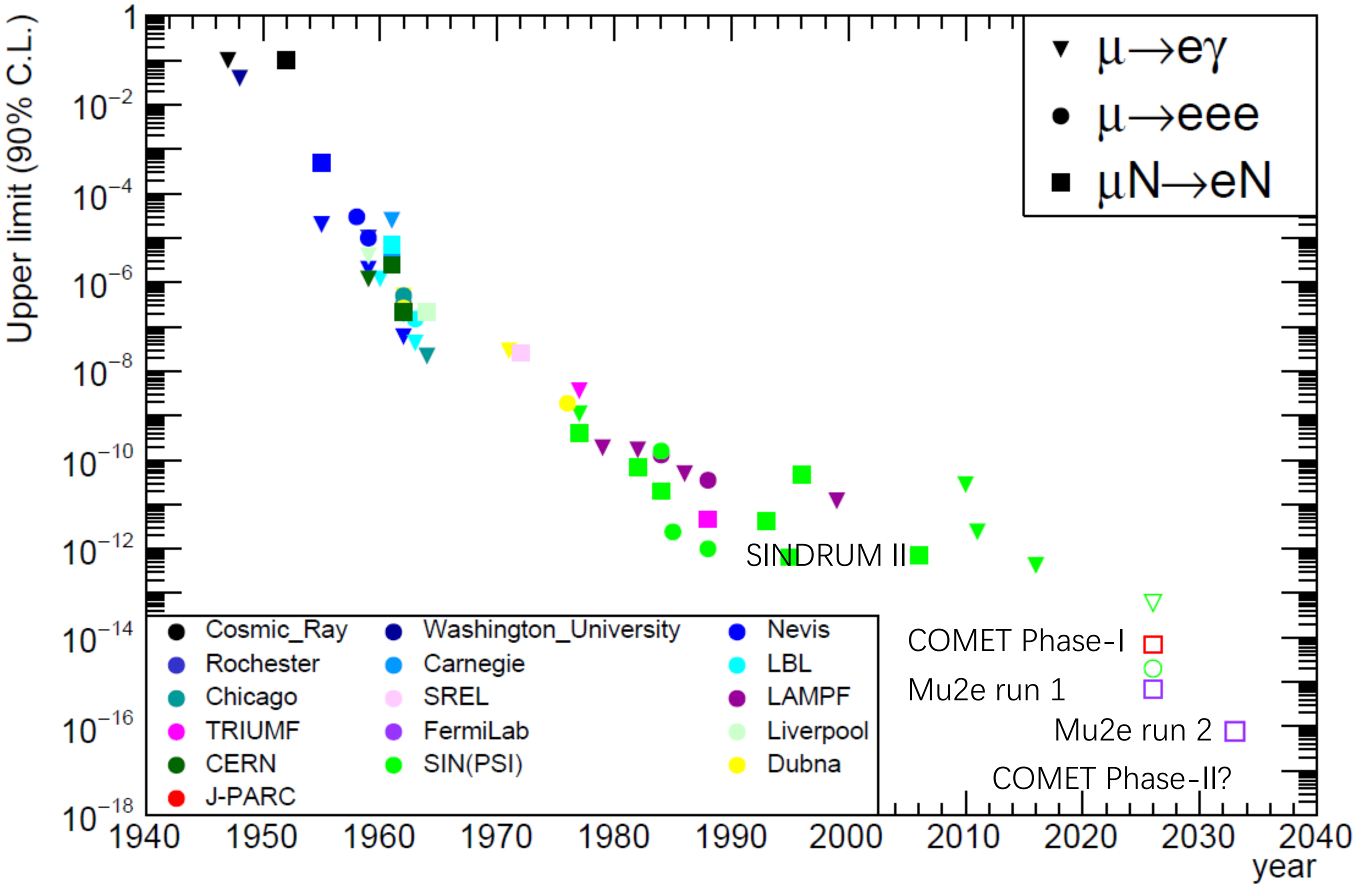


θ_D parameterizes the relative magnitude of dipole and four-fermion coefficients

Eur. Phys. J. C (2022) 82:836

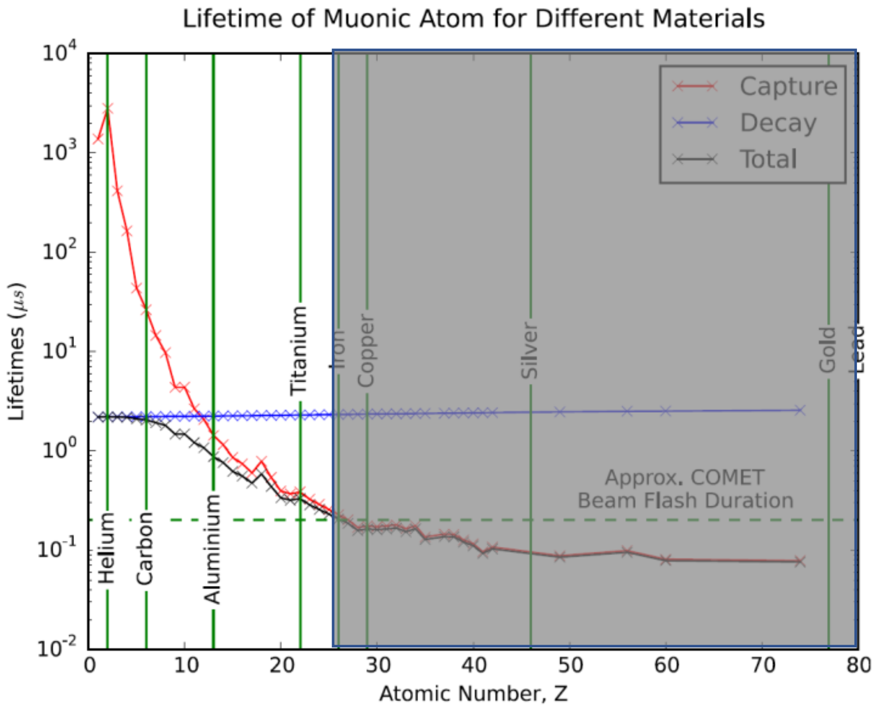
History of CLFV experiments

- In the near future
  - Already data taking: MEG-II
  - Under construction: COMET Phase-I, Mu2e, Mu3e
- In the far future
  - PSI muon facility upgrade plan (HiMB) will make Mu3e Phase-II and next stage $\mu \to e\gamma$ possible to improve by x10.
  - COMET Phase-II and Mu2e-II are seeking to be approved: aiming at 10^{-18}, an improvement by x10 .
  - In the far future, AMF/PRISM may bring the sensitivity to $< 10^{-19}$

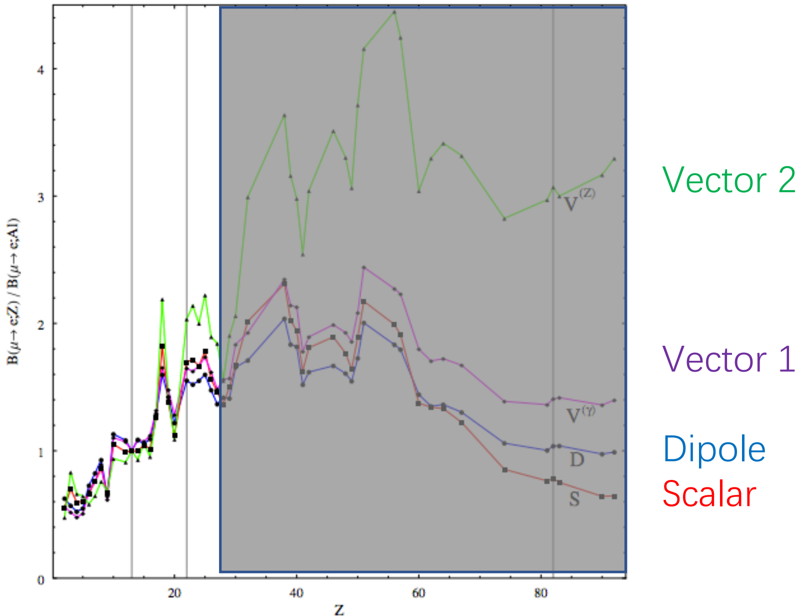


Trade off in Lobashev scheme can be recovered in PRISM scheme

- In high-Z target, muons immediately got absorbed by the nuclear
  - The muonic atom's lifetime can be shorter than the beam flash duration itself.
  - There is no way to wait for the beam flash to vanish…
- High-Z target is of particular interests:
  - Higher capture ratio means larger Cr and smaller DIO background.
  - Z scanning can tell apart new physics model.

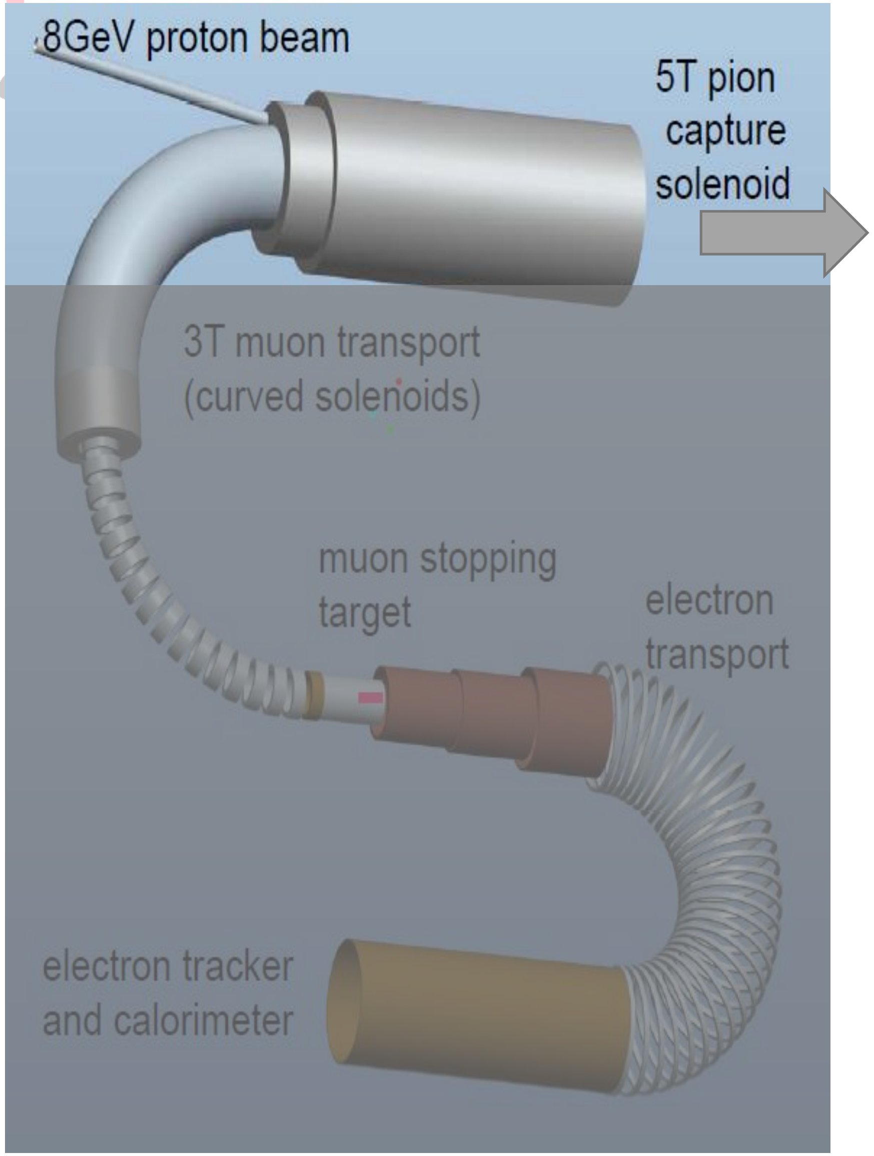


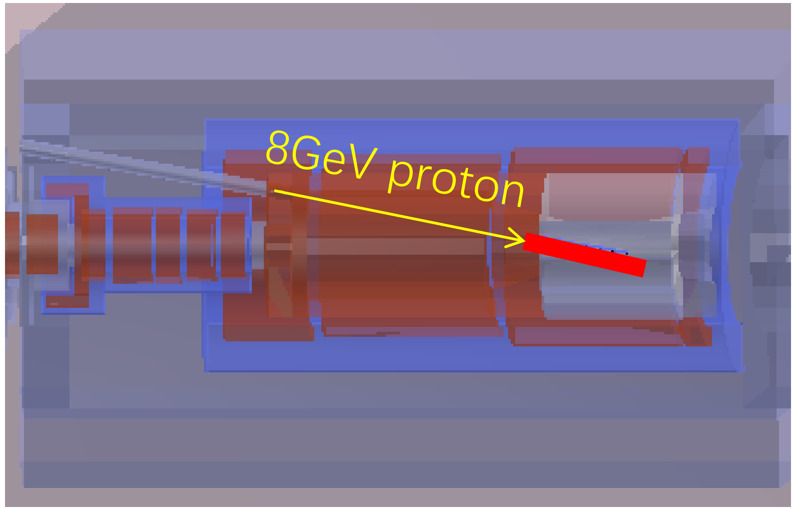
Area in gray: Impossible in Lobashev's scheme, but possible in PRISM



V. Cirigliano et al., phys. Rev. D80 013002 (2009)

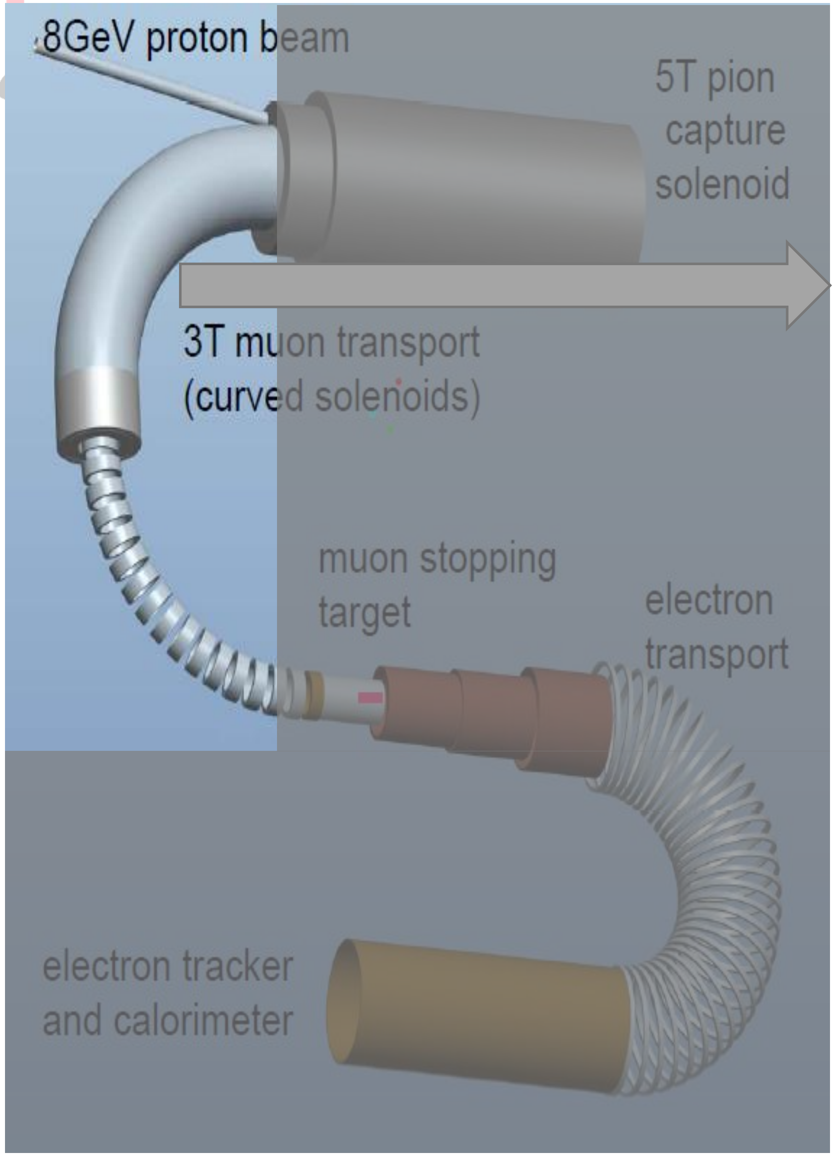
Production target and the capture magnet

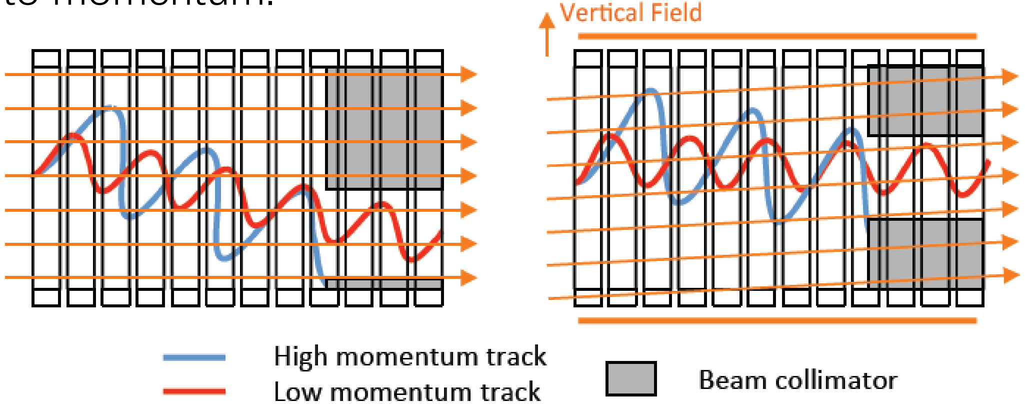




- 8 GeV 56 kW proton beam
- Thick target with 1~2 hadron interaction length
- Powerful capture magnet: 5 T
  - Large inner bore to fit in the shielding
  - Adiabatic decreasing field: focusing and mirroring
- Expected muon yield: 10^{11} muon/sec! $(10^8\ @\ PSI)$

Transportation solenoid

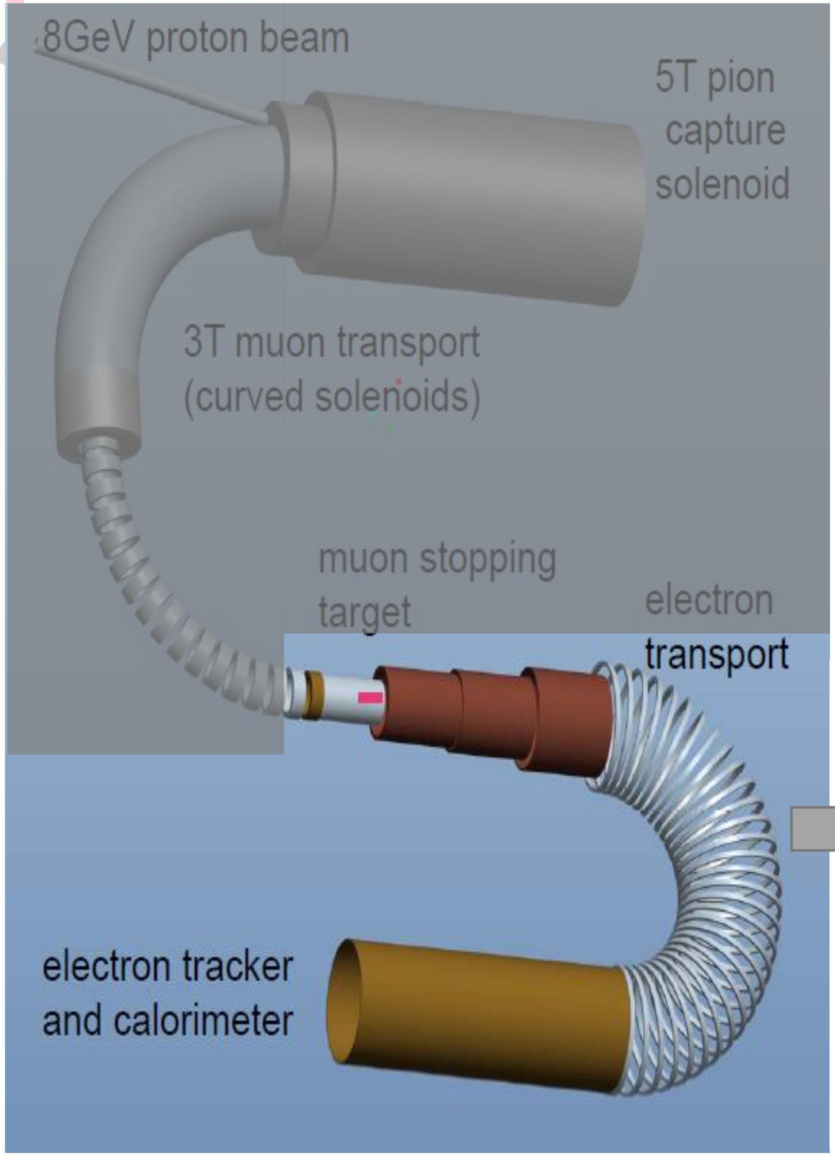



Drift vertically, proportional to momentum.

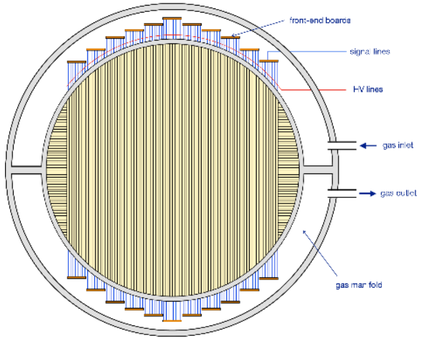
Vertical field as “correction”

- Use C shape curved solenoid
  - Beam gradually disperses
    - Charge & momentum
  - Dipole field to pull back muon beam
    - Can be used to tune the beam
  - Collimator placed in the end
    - Utilize the dispersion in 180 degrees

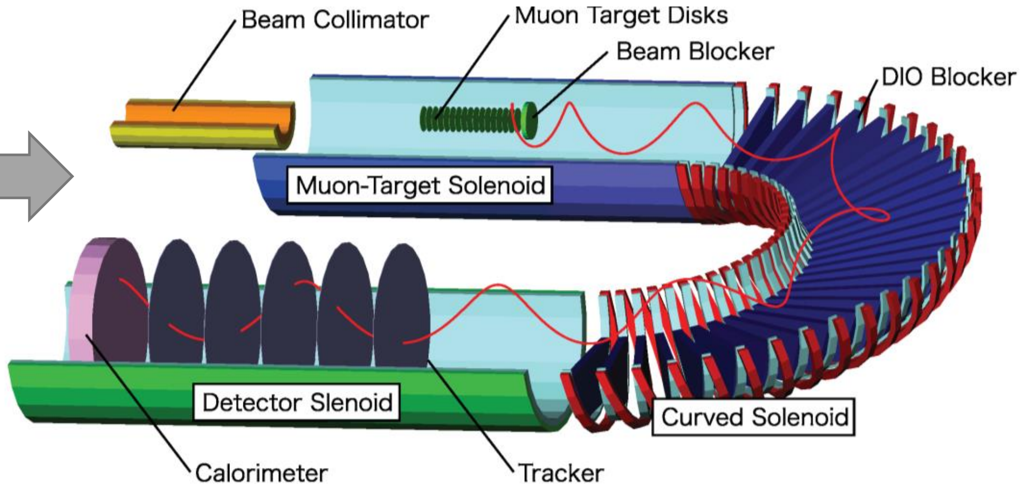
Stopping target and detector system



- Use straw tracker to measure the momentum
  - Really light: put in vacuum, 12 micro meter thin straw

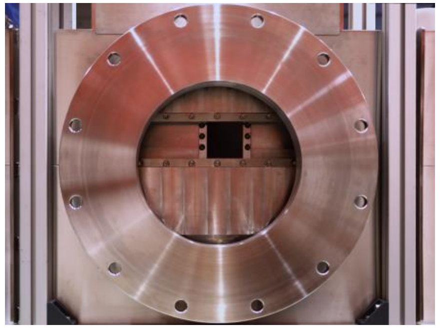


- Electromagnetic calorimeter
  - Providing trigger, TOF and PID



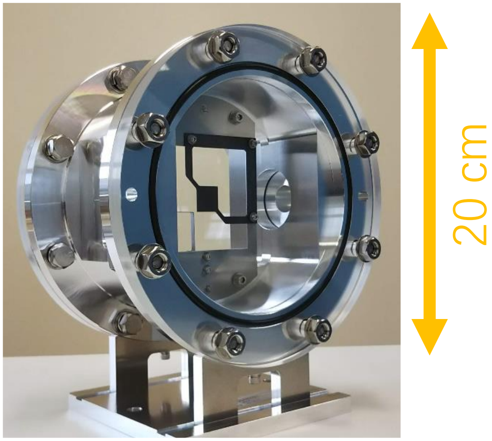
The Construction of the Moun Beamline

The movable slits in the beam-masking system.

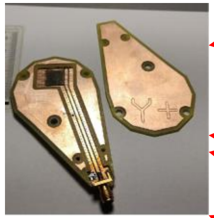


Covered with shielding blocks

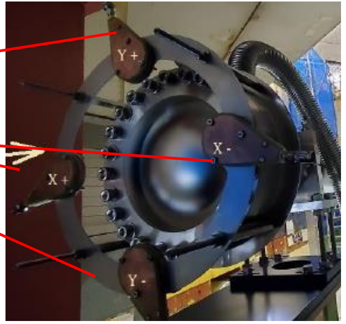
2×2 cm^2, 1.1 mm thick C/C composite pion production target put inside the vacuum chamber.



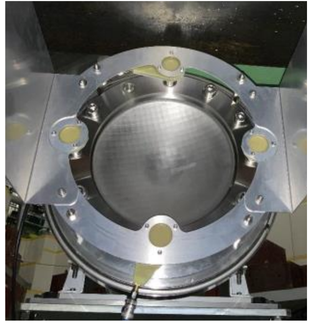
Vacuum ducts mounted with 3-D printed vacuum windows.



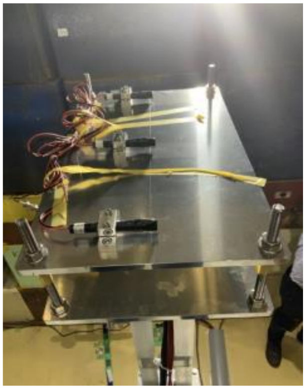
Proton Beam Monitor



4 @ Pre-target



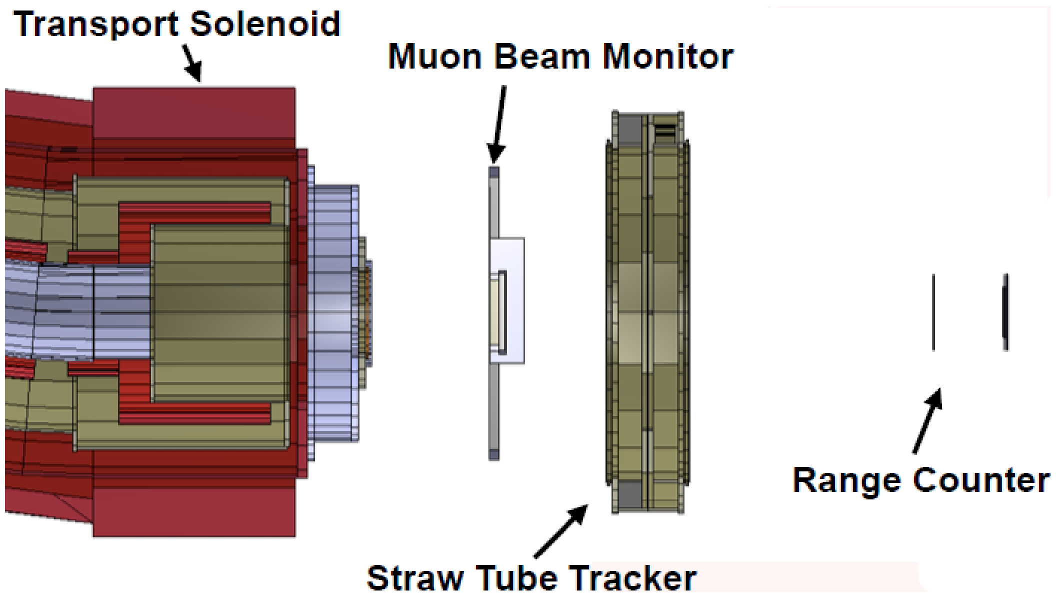
4 @ Post-target

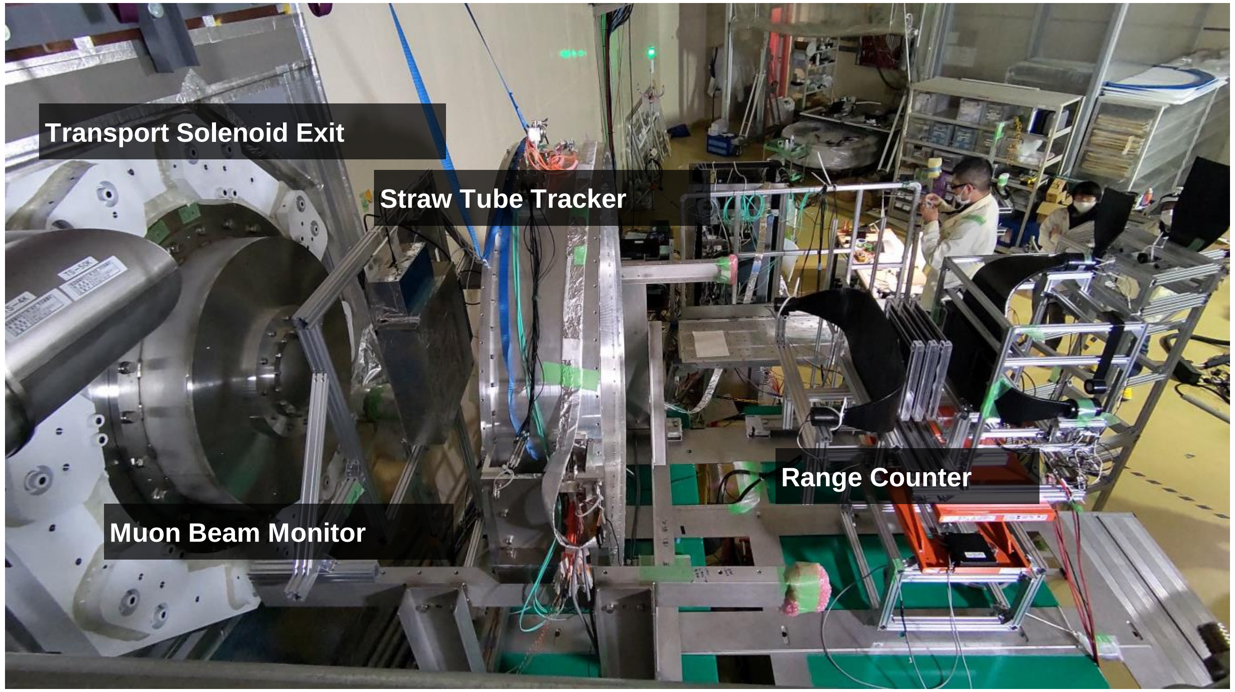


Target monitor: 3 plastic scintillator with photo multipliers

Muon Beam Detectors

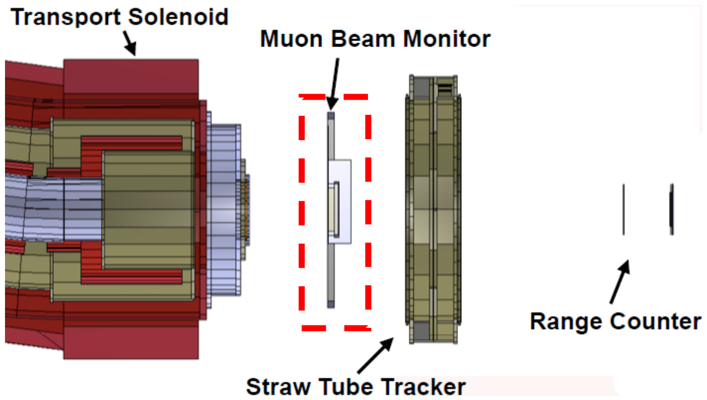
- Muon Beam Monitor
    - Position measurement
- Straw Tube Tracker
    - Position & direction measurement
- Range Counter.
    - For momentum reconstruction and muon identification
    - Also generates trigger signals
- DAQ
    - Based on the MIDAS DAQ framework, officially adopted by COMET.

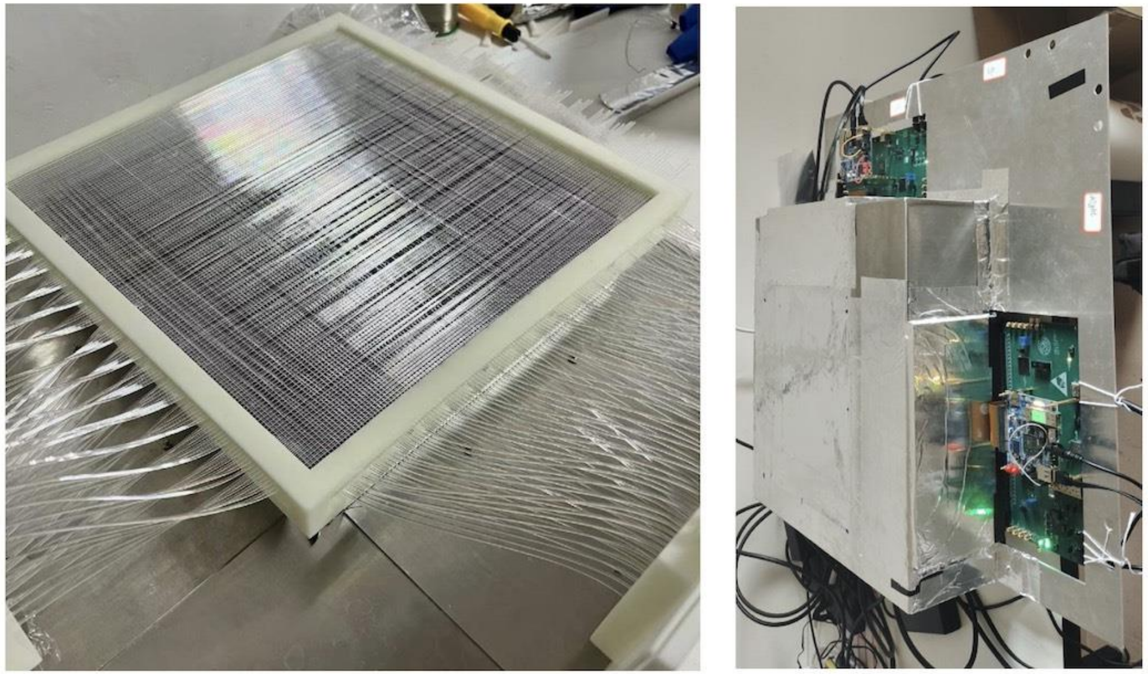




Muon Beam Monitor

- Scintillator fiber hodoscope
  - 1 mm^2 plastic scintillating fibers, readout by SiPMs.
  - 30×30 cm^2 area holds 2D-aligned 128+128 fibers.
- A multi-channel input electronics was developed.
  - ~3 nsec time resolution.
  - Good hit rate tolerance and capability for the experiment.

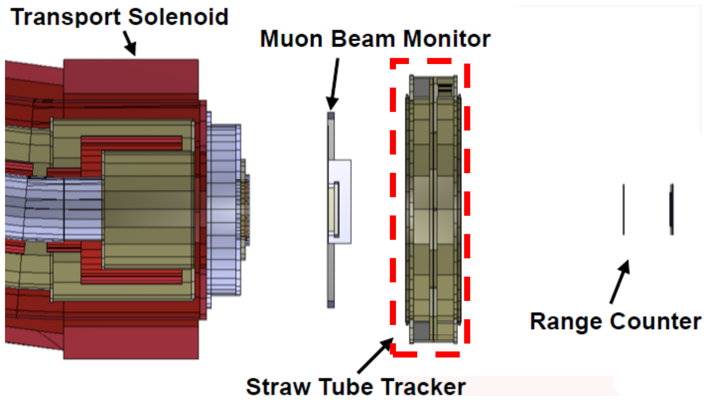


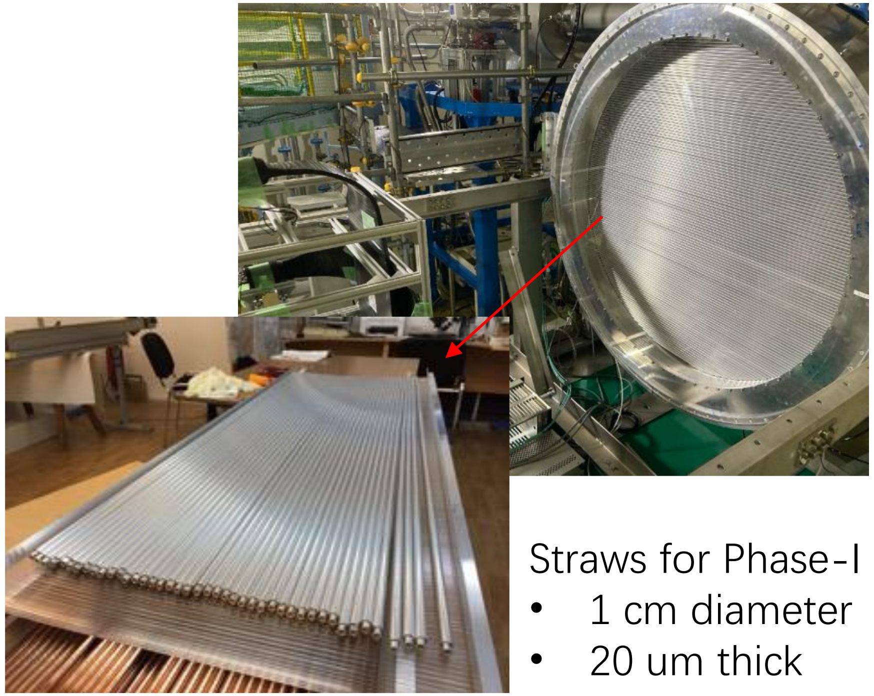


Straw Tube Tracker

A single station of Phase-I straw tube tracker was assembled for Phase-α.

- 480 straw tubes (narrow drift chambers) aligned on the X and Y planes.
  - Ar & C2H6 (50:50) gas mixture
- Phase-α was the first opportunity for commissioning a Phase-I detector!
  - Full readout chain was tested.





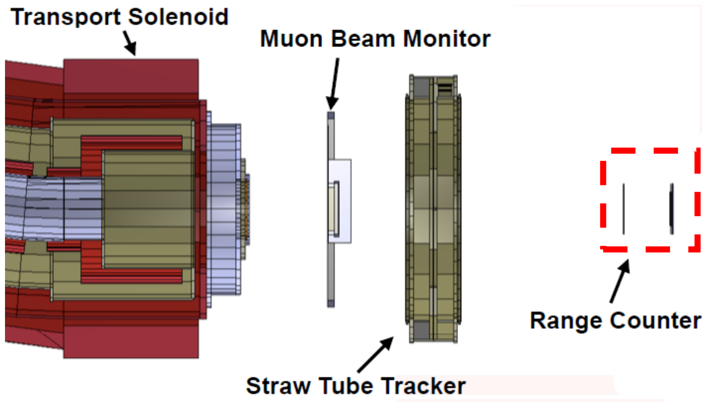
Straws for Phase-I
- 1 cm diameter
- 20 um thick

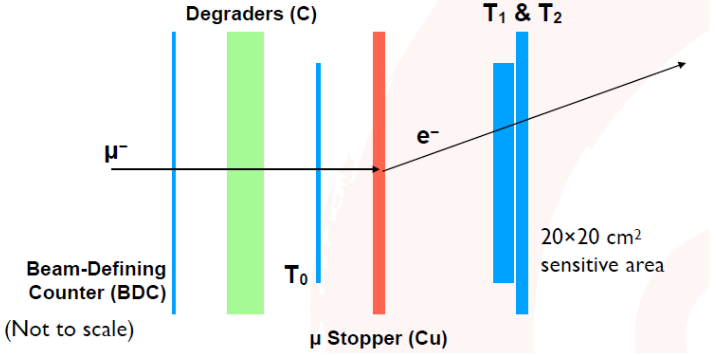
“ROESTI”, front-end electronics for COMET Phase-I/II

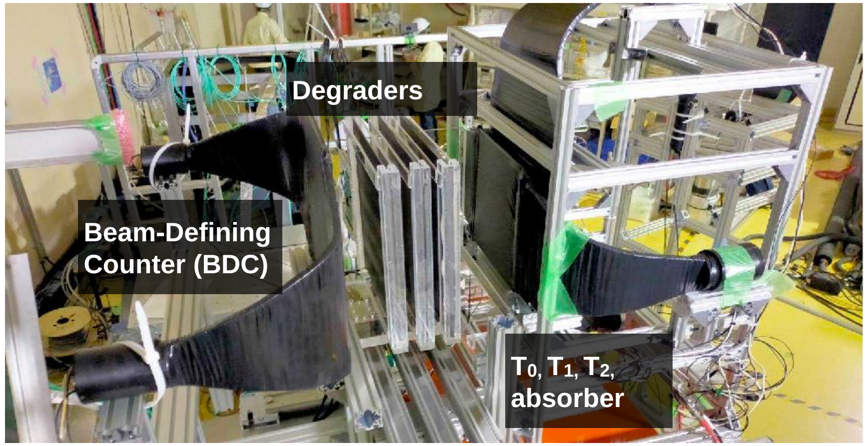
Range Counter

Multi-layered plastic scintillating counters measuring muon decay time

- Change the momentum range to measure with different thicknesses of a graphite degrader.
- Reconstruct the number of muons stopped in a copper muon stopper.
  - Negative muon's life time in copper is about 160 nsec compared to about 2 μsec in lighter materials.
- Generated trigger signals when a particle hits BDC & T0 with no simultaneous hits in T1 / T2.



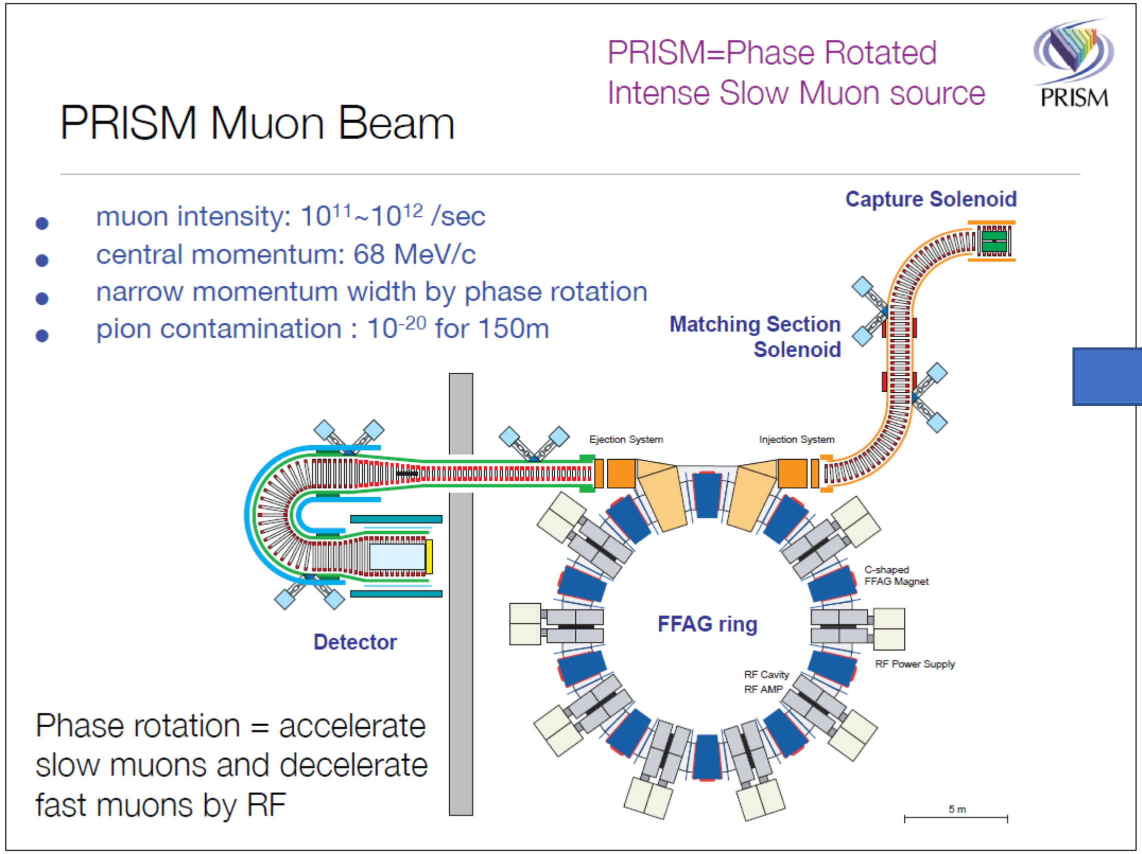




PRISM/PRIME design

The original design before COMET
Started from 2003.

The PRISM group is still updating the design to achieve an ultimate search for $\mu N \rightarrow eN$

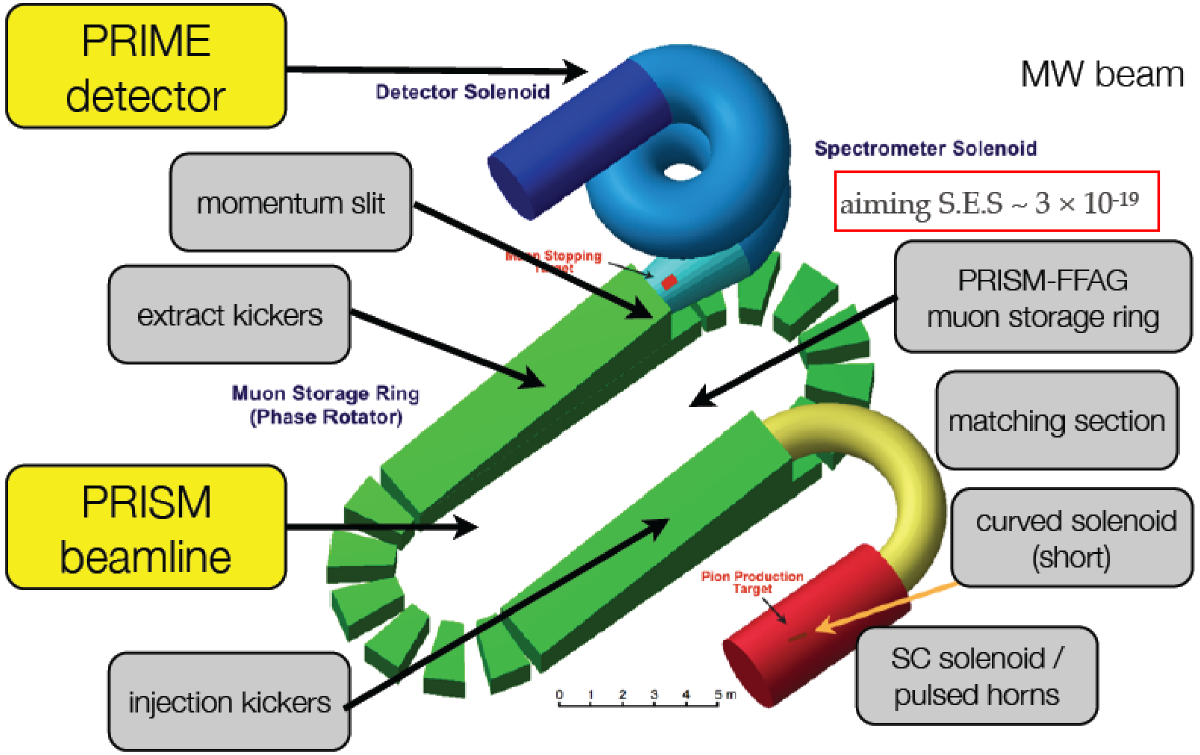


PRISM=Phase Rotated Intense Slow Muon source

PRISM Muon Beam

- muon intensity: 10^{11}~10^{12} /sec
- central momentum: 68 MeV/c
- narrow momentum width by phase rotation
- pion contamination : 10^{-20} for 150m

Phase rotation = accelerate slow muons and decelerate fast muons by RF



PRIME detector

momentum slit

extract kickers

PRISM beamline

injection kickers

MW beam

aiming S.E.S ~ 3×10^{-19}

PRISM-FFAG muon storage ring

matching section

curved solenoid (short)

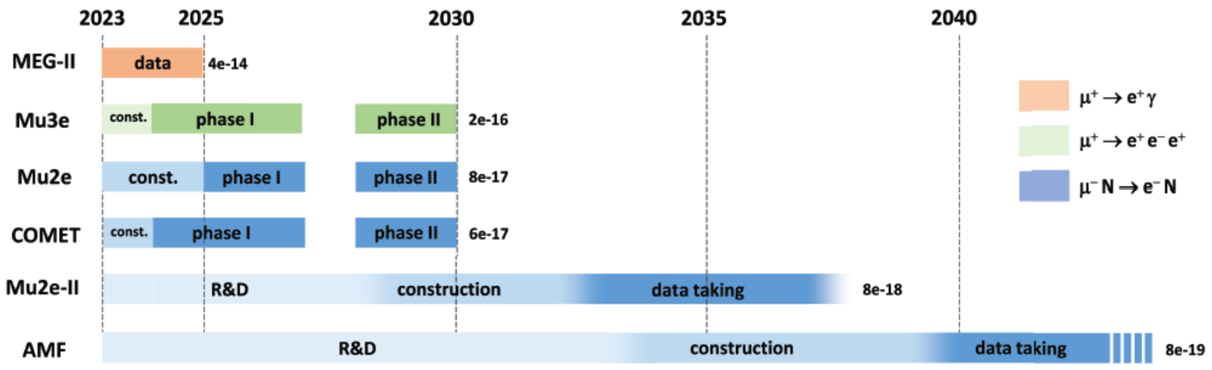
SC solenoid / pulsed horns

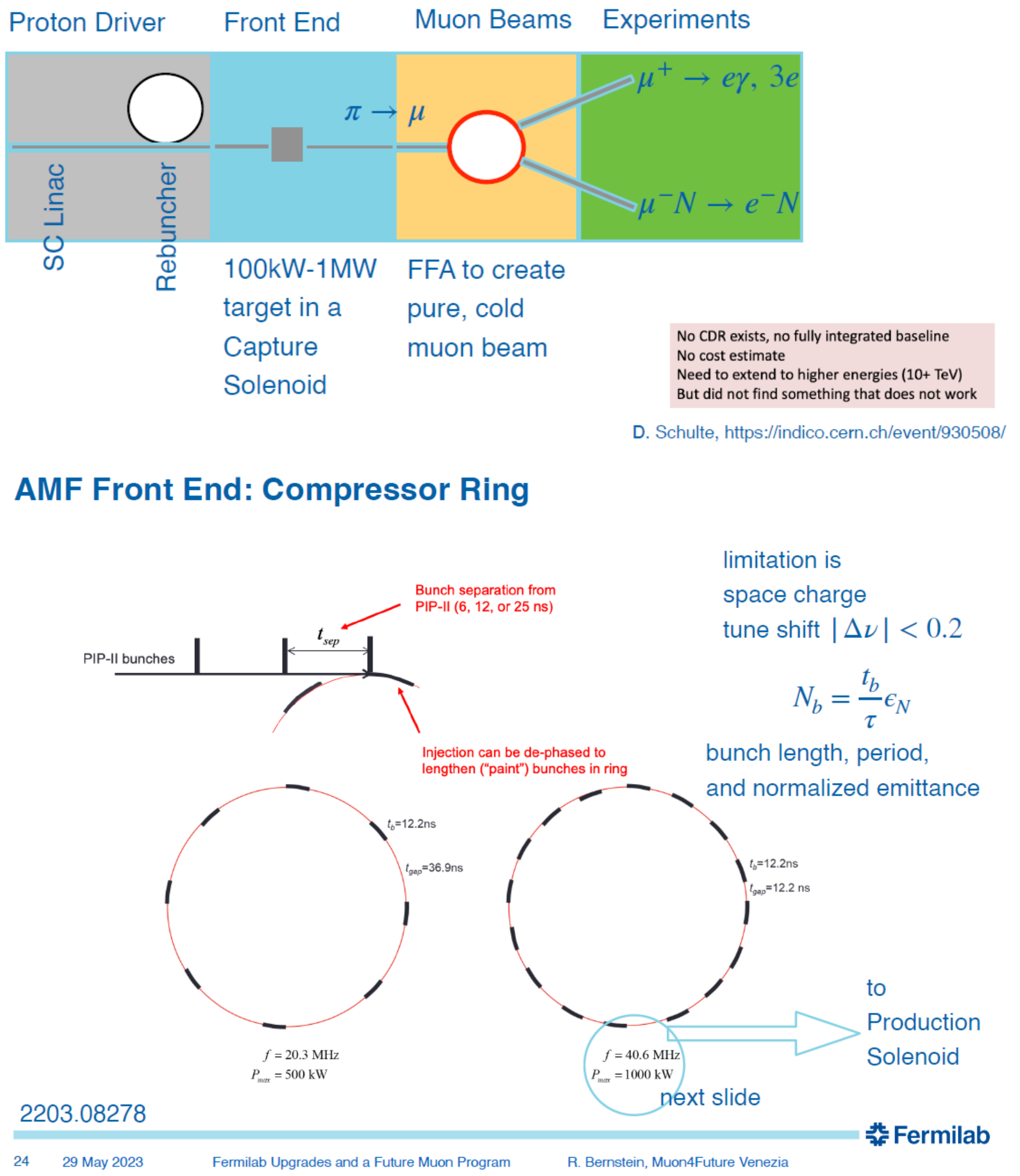
In synergy with muon collider: target, capture, and storage ring. Might be the most intense muon beam before muon collider.

Y.Kuno, NOW2006

AMF proposal

- Advanced Muon Facility (AMF) was proposed to make use of PIP-II for next generation muon physics
- AMF proposed to use compressor ring to make beam structure for FFA
  - 10 ns bunches at 100-1000 Hz
- Pile-up effect will be too much
  - Need PRISM type detector: select electrons.
- May reach 10^{-19} sensitivity in 2040s?





100kW-1MW target in a Capture Solenoid

FFA to create pure, cold muon beam

No CDR exists, no fully integrated baseline
No cost estimate
Need to extend to higher energies (10+ TeV)
But did not find something that does not work

D. Schulte, https://indico.cern.ch/event/930508/

AMF Front End: Compressor Ring

limitation is space charge tune shift $|\Delta\nu| < 0.2$

$$N_b = \frac{t_b}{\tau}\epsilon_N$$

bunch length, period, and normalized emittance

to Production Solenoid

next slide

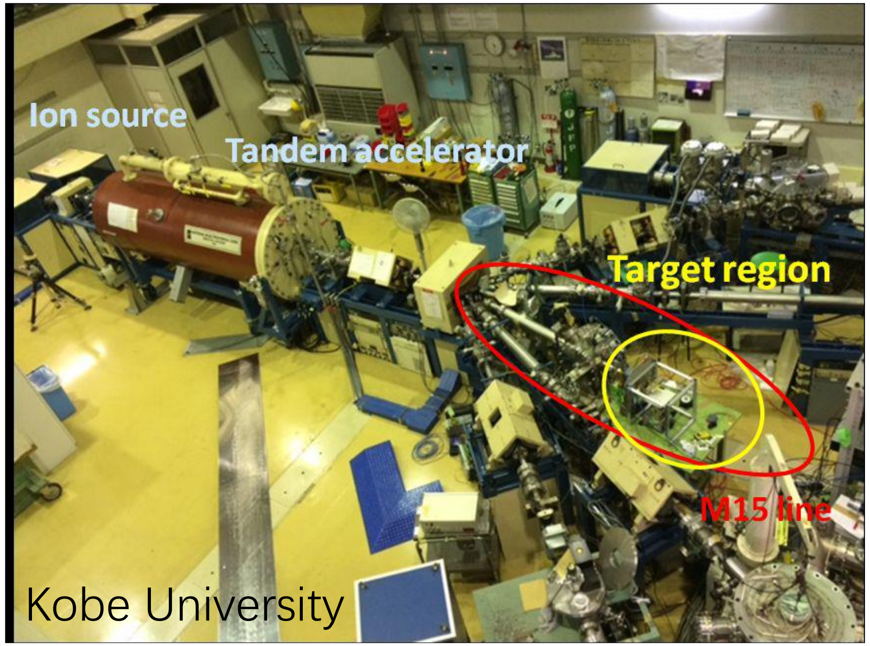
2203.08278

24 29 May 2023 Fermilab Upgrades and a Future Muon Program R. Bernstein, Muon4Future Venezia

AMF: hep-ex 2203.08278

Radiation Studies

- Neutron Tests
  - Tandem accelerator, Kobe, Univ.
  - ^{9}Be(d,n) reaction with 3 MeV ^{9}Be beam
- Gamma-Ray Tests
  - Radioisotope Research Center, Tokyo Institute of Technology
- Publications:
  - K. Ueno et al., IEEE NSS Conf. Rec. (2016) 8069866
  - Y. Nakazawa et al., NIM A 936 (2019) 351
  - Y. Nakazawa et al. NIM A 955 (2020) 163247



Kobe University

Tokyo Institute of Technology