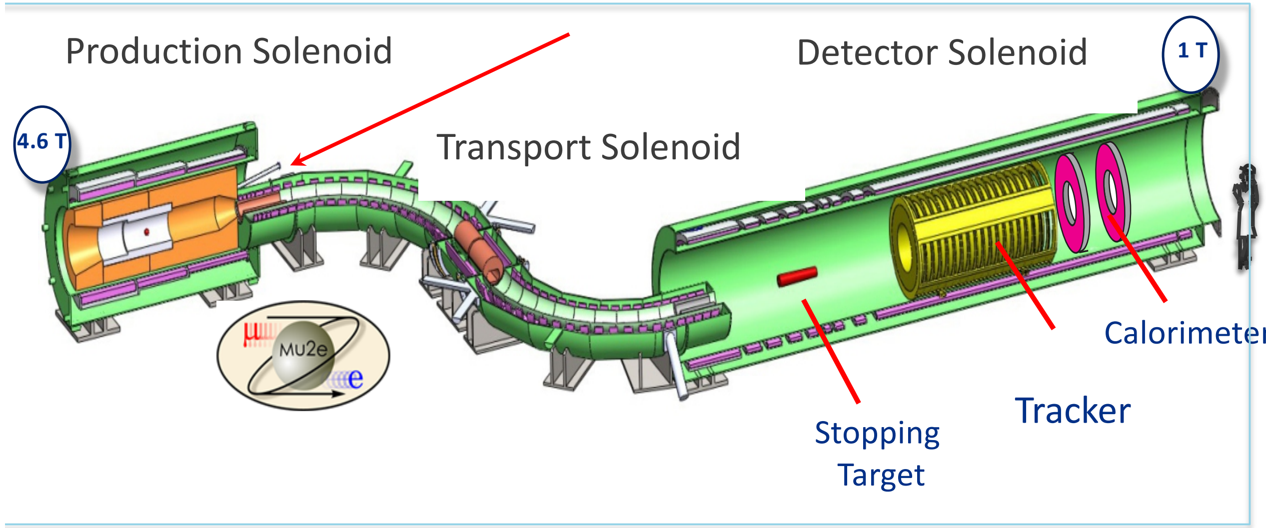
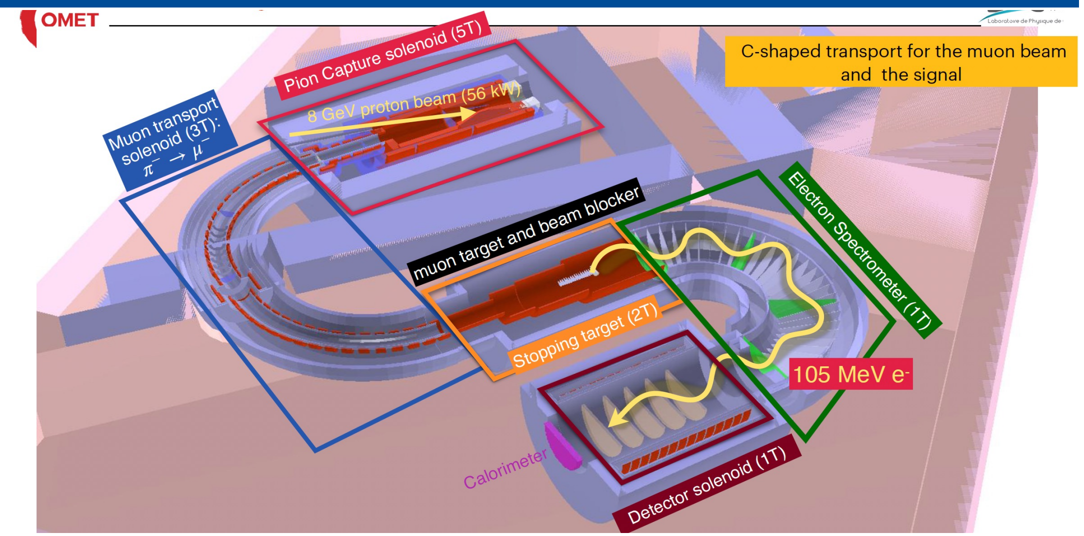




Searching for CLFV with muon to e conversion: Mu2e and COMET status

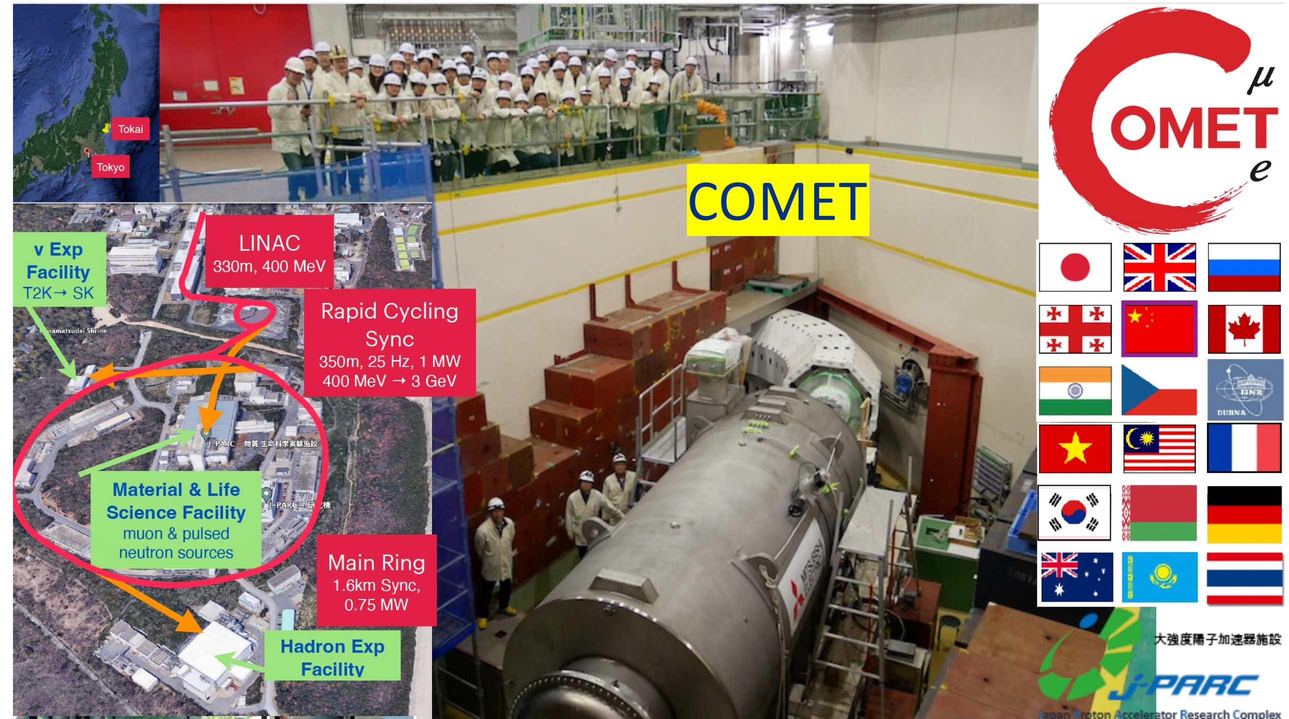
Stefano Miscetti, LNF-INFN Italy

on behalf of the Mu2e and Comet collaborations

FCCP-2025 (Anacapri)

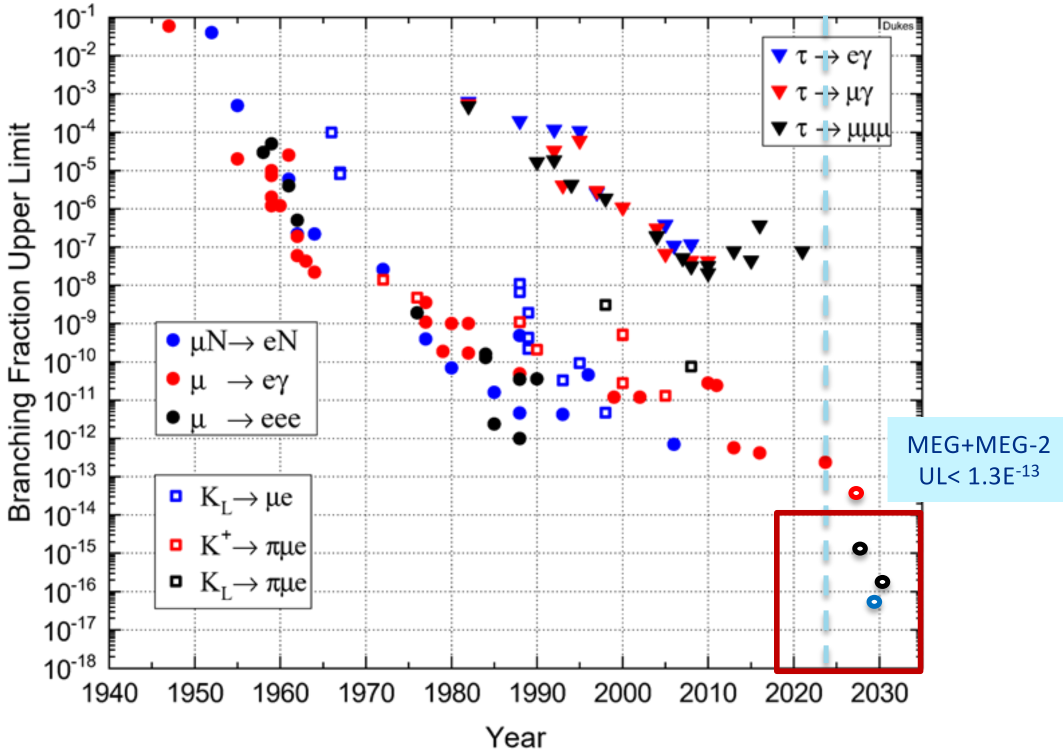
30 September 2025

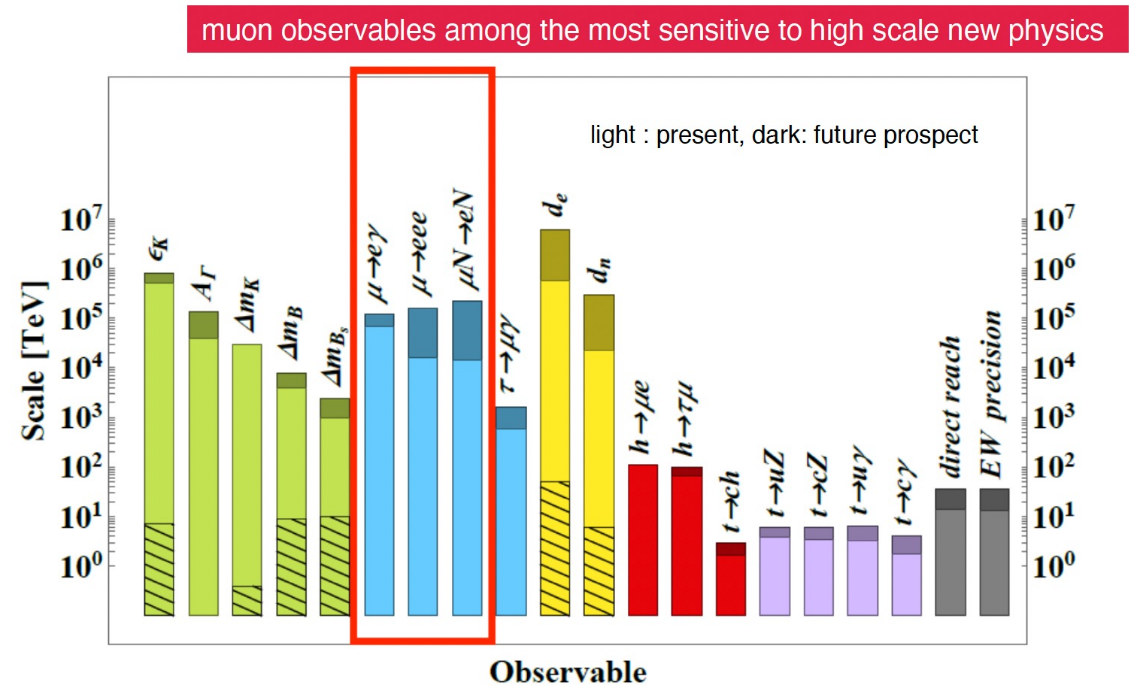
Mu2e and COMET collaborations



More than 290 members,
48 institutions,
18 countries

Current status of CLFV searches and muon sector relevance

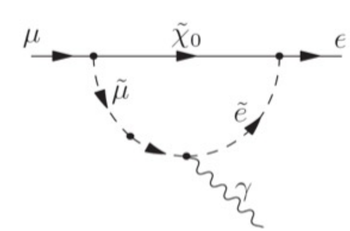


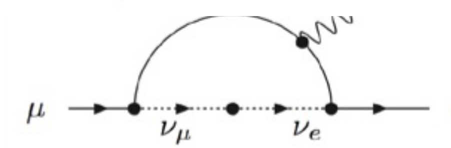


European Particle Physics Strategy Update (1910.11775)

- Only SM background assuming neutrino oscillations has BR~10^{-52}
- Observation of the CLFV events is therefore a clear sign of new physics
- We can explore a range of new masses up to 10^4 TeV/c^2

  → an unaccessible land for current (or foreseen) high-energy colliders
- Muons do better (high rates, good topologies, clean signal)

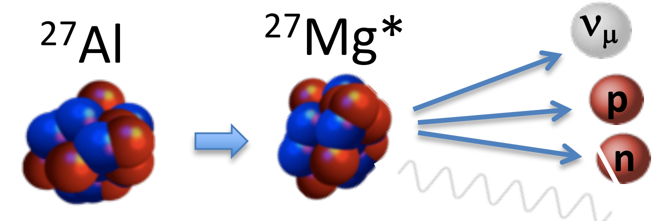


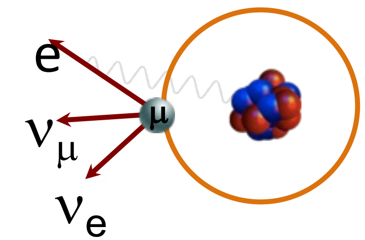


$$BR(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

Mu2e/COMET goal: x10000 improvements in muon conversion

- ✓ Mu2e searches for the cLFV conversion of μ^- to e^- in Al nuclei
  →
  $$\mu^- + {}^{27}_{13}Al \rightarrow e^- + {}^{27}_{13}Al$$
- ✓ When μ^- are stopped in aluminum a muonic atom is formed
  - Prompt cascade to 1s state (0.1 ps)
  - 347 keV X-ray emitted, used for normalization
  - Due to high mass, muons circulate in a very short radius around nucleus (20 fm)
    - → 61% undergo muon nuclear capture, 1.8 MeV normalization line
    - → 39% decay in orbit (DIO)
    - → few (hopefully ☺) undergo conversion

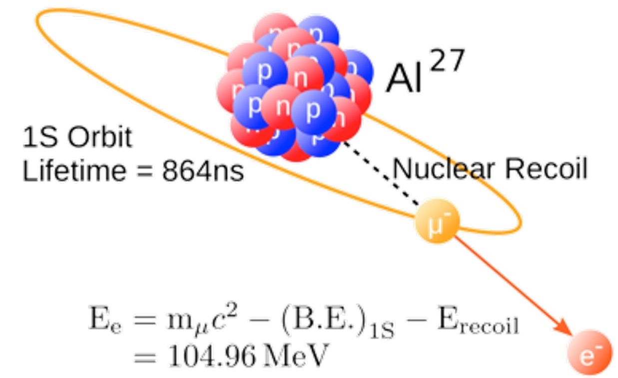




- ✓ Conversion signature is a single monoenergetic electron close to μ mass (105 MeV/c)
- ✓ Mu2e wants to improve the current sensitivity by four orders of magnitude

$$R_{\mu e} = \frac{\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)}{\mu^- + N(A,Z) \rightarrow \nu_\mu + N(A,Z-1)} < 8.4 \times 10^{-17}$$

@ 90% CL



This process is forbidden in SM. Observing a signal is a clear sign of new physics
We can explore new mass scales up to 10^4 TeV/c^2

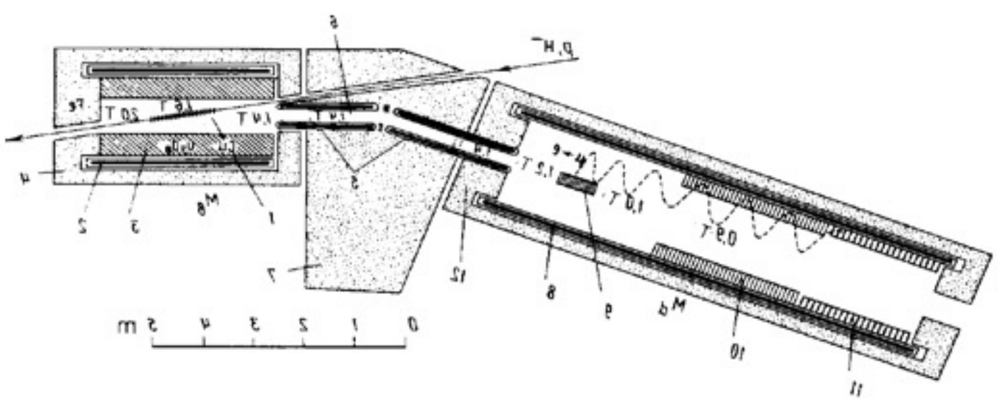
How to: x 10000 improvements (1)

1. High statistics: O(10^{18}) stopped muons needed

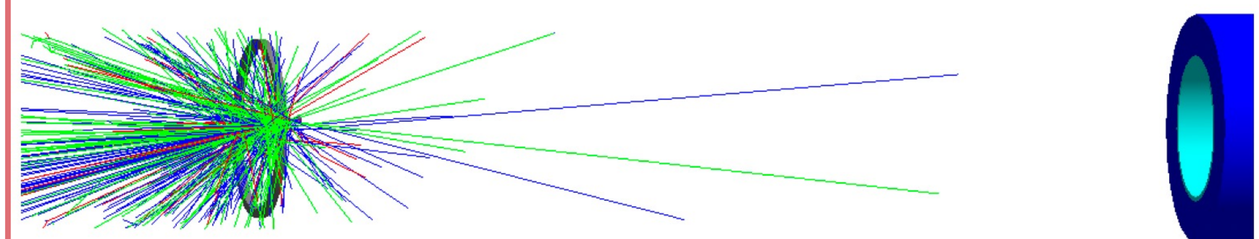
- Highest intensity muon beam in the world (~ 10 GHz on stopping target)
- required x1000 improvement wrt Sindrum-II (PSI, 10^8muon/sec , 1 MW)
- Use multi-gradient solenoidal system to produce, transport, focus the muon beam from pion decays generated by a 8 GeV proton beam on a production target

(first proposed in 1989 for the MELC experiment @ Dubna)

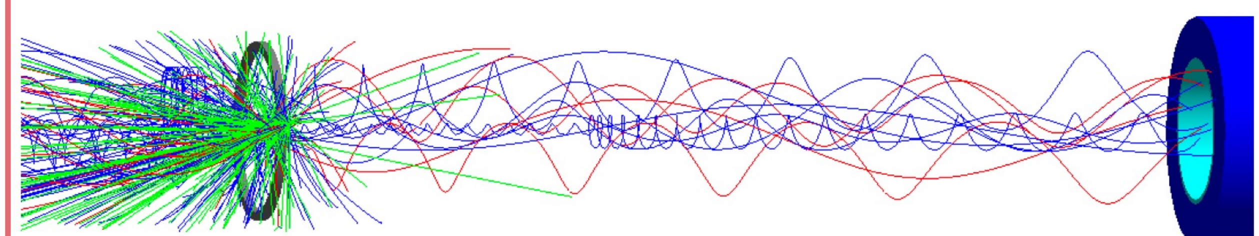
R.M. Dzhilkibaev and V.M. Lobashev
Sov.J.Nucl.Phys. 49, 384 (1989)



Instead of this



Do this



Solenoidal *B* field confines soft pions. Collect their muons.

Mu2e: $> 10^{10}$ μ^-/s from only 8 kW of protons!

how to: x 10000 improvements (2)

2. High background rejection

State of the art detector, TDAQ and reconstruction to isolate signal candidate (105 MeV/c e^-) and reduce backgrounds to < 0.5 events

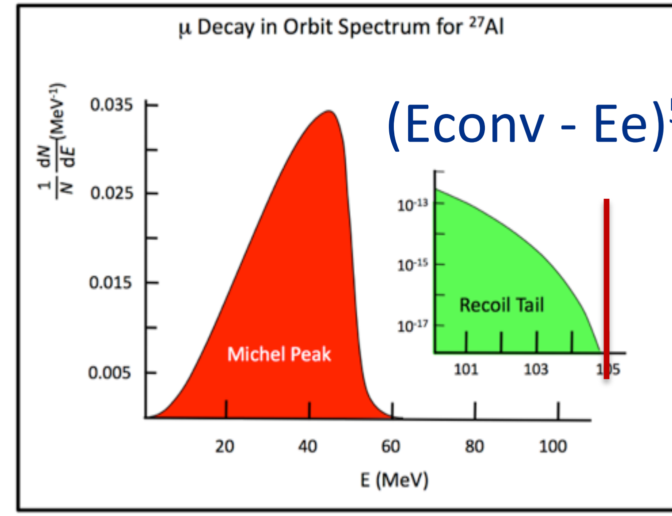
- ✓ **Irreducible bkg - Muon DIO:**
  Free muon decay has maximum energy of = 52.8 MeV, the nucleus distorts the DIO spectrum shape; reconstruction uncertainties and detector energy loss smear out the monoenergetic peak
  ➔ MITIGATION: **High Precision Tracking (< 200 keV @ 100 MeV)**

- ✓ **Cosmic rays interacting with detector material**
  ➔ MITIGATION: **Offline Veto of Cosmic rays , PID (mu/e)**

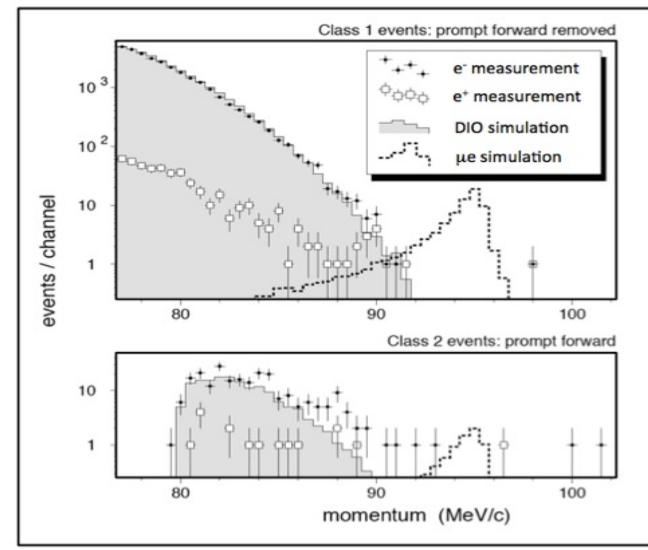
3. Pulsed beam to create a time window for pions to decay

- ○ Need to separate prompt backgrounds, mainly **Radiative pion capture** (RPC, $\pi^- N \to \gamma N', \gamma \to e^+e^-; \pi^- N \to e^+e^- N$)
- ○ Main background for the Sindrum-II experiment at PSI

4. Protons outside of pulse must be "extinguished"



Czarnecki et al., Phys. Rev. D 84, 013006 (2011) arXiv:1106.4756v2



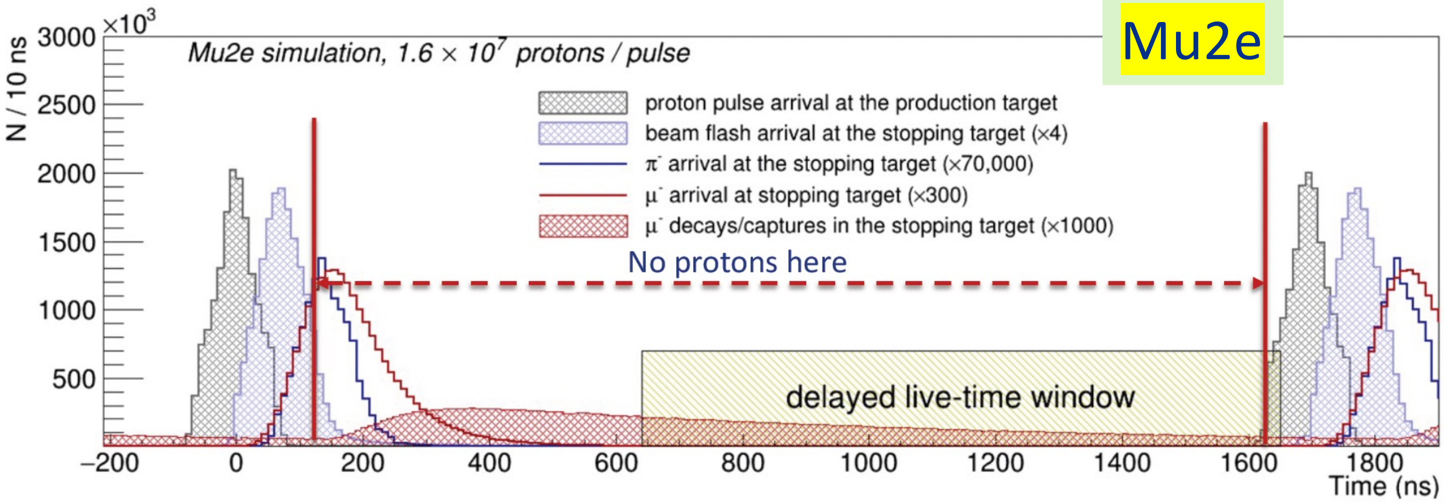
Pulsed proton beam and extinction

- FNAL DR SX pulse period: 1695 ns (~2 τ_{μ}^{Al})
- High intensity (2 batch mode) → 3.9×10^{7} protons
- Low intensity (1 batch mode) → 1.6×10^{7} protons

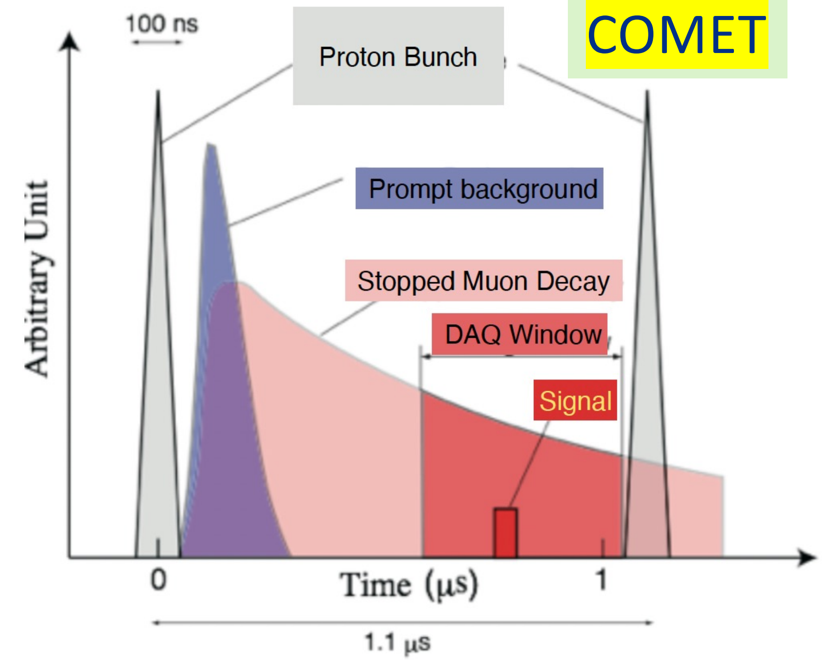
- SX pulse period: 1170 ns (~1.3 τ_{μ}^{Al})

Inter-bunch proton extinction ratio (fraction out of bunch) < 10^{-10}

Mu2e



COMET

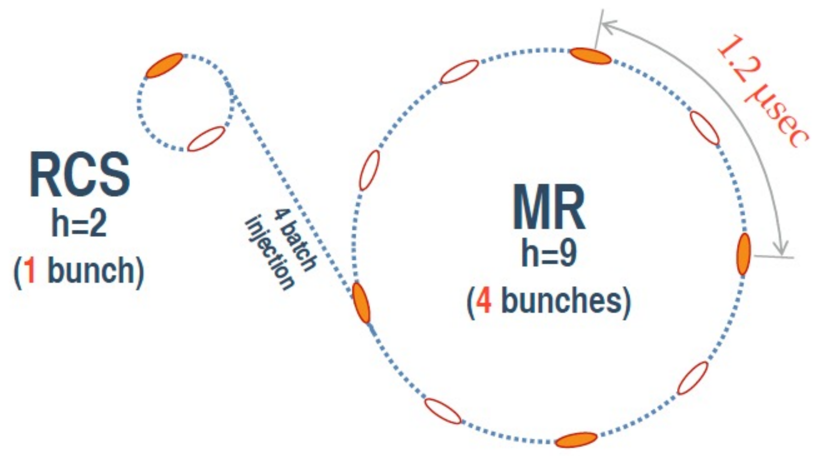


@ FNAL, proton extinction from two sources:
- Bunch formation in recycler (10^{-5})
- AC-dipole sweeping magnets ($10^{-(5\text{-}6)}$)

Delayed DAQ gate (700ns-1,17μs)

Narrow proton pulses

COMET – extinction measurement from T78 exp. in 2021



Bunched beam operation for COMET

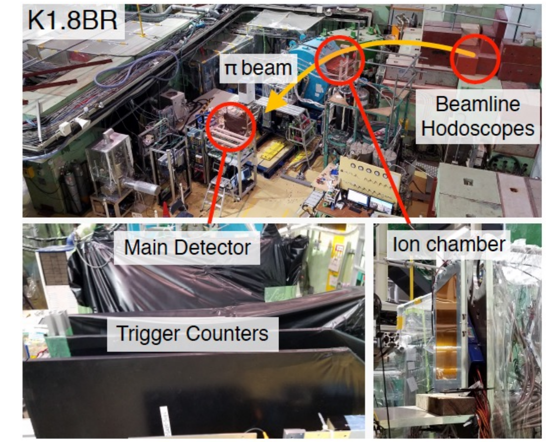
- ✦ Bunched slow extraction for the timing-window measurement
  - ★ 4 out of 9 buckets will be filled.

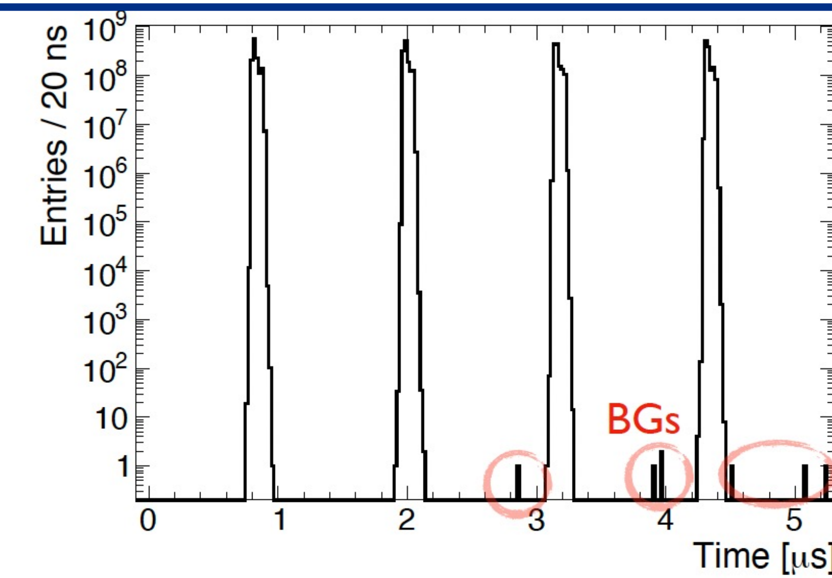
The measured extinction is < 1.0×10^{-10}

- ✦ @ K1.8BR of the Hadron Facility (T78 exp. in 2021)

K. Noguchi, et al., Proc. of Sci., 402 (2022)

- RCS = Rapid Cycling Synchrotron injects 3 GeV proton on MR
- ✓ 4 batches each 40 ms
- ✓ Ext = 10^{-6}
- \+ SBK (single bunch Kicking)
- ✓ Out of time
- MR = Main Ring accelerate
- To 8 GeV
- → SX 8 GeV proton to the experiment



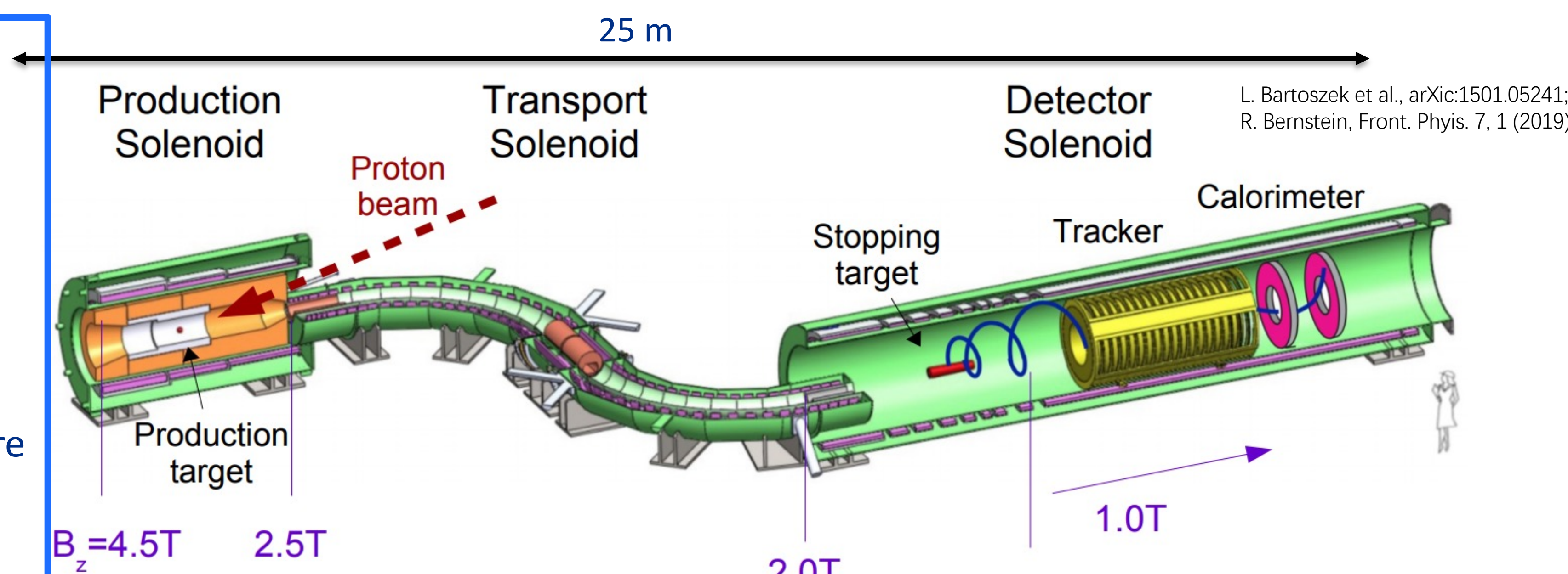


No inter-bunch contaminations in T78 exp.

Mu2e experiment layout

- **Production solenoid (PS)**
  - Contains tungsten production target
  - Gradient magnetic field sweeps pions/muons to transport solenoid
- **Transport solenoid (TS)**
  - S-shaped; collimator in the middle selects sign and momentum
  - Absorbers to remove antiprotons at center of S
- **Detector solenoid (DS)**
  - Al muon stopping target
  - Proton absorber to reduce accidental events
  - Straw tube tracker provides momentum measurement, electromagnetic calorimeter differentiates particles through energy deposition
- Searching for 105 MeV electrons, with a 180 keV/c momentum resolution

- Gradient field from 4.5 to 1 T in beamline
- 1T uniform field in Tracker/Calo region
- Muon charge selection with rotating collimator
- Symmetric detector: measure e^- and e^+ simultaneously ($\Delta L=2$ physics along with an *in situ* measurement of bkgs)



A schematic view of the Mu2e experiment (not including the Cosmic Ray Veto)

Mu2e solenoids status: TS

- **Transport solenoids delivered**: 12/23 (TSU)
  2/24 (TSD) & installed in Mu2e hall

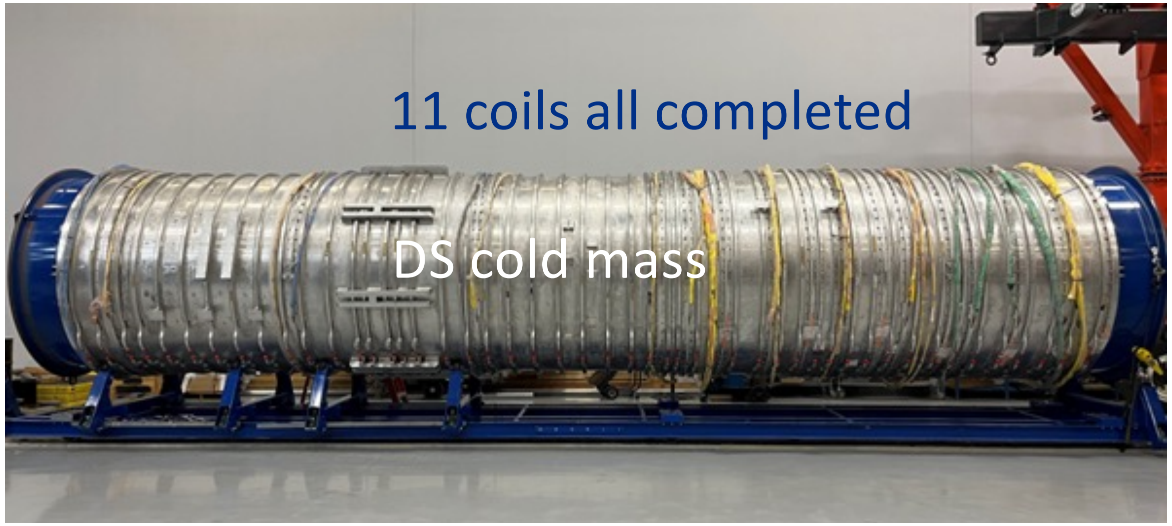
- Rotating collimator COL3 installed and tested
- Installation of AntiProton absorber blade done

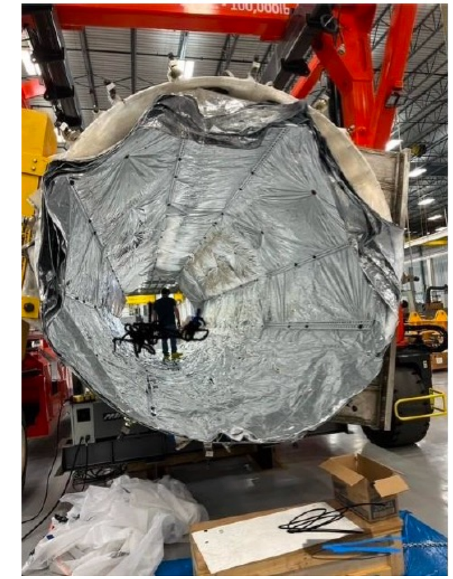
- **Cryogenic system connection well progressed**
  → TSU/TSD pumping down started
  → Quench Protection tests in progress

Mu2e PS – arrival 27 June 2025, in the pit 5 August 2025

- PS ready for transportation @ December 2024, but failed final leak test
- Mu2e team demonstrated leaks to be manageable (30 g/N_2 leak/year)
- Received at Fermilab on **27 June 2025** on MC-2 dock area
- 40 days (out of 60 planned) of extensive tests
  - → all passed. PS moved into the pit **on 5 August 2025**
  - → **30 Ton Bronze HRS installed last week**

Mu2e Solenoid status: DS





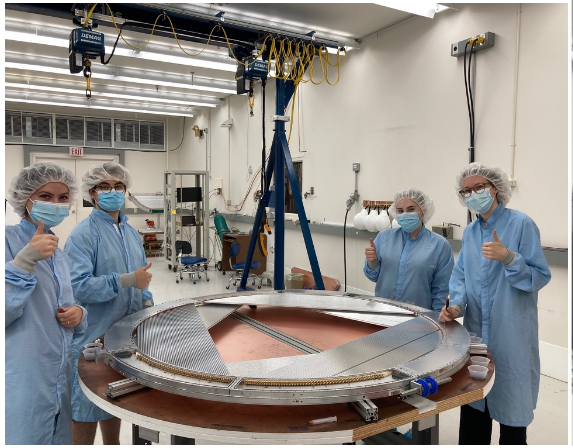
- Dry run of insertion of cold mass into vacuum vessel completed

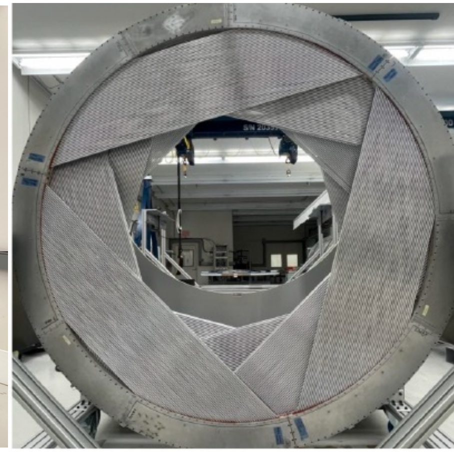
Still to do:

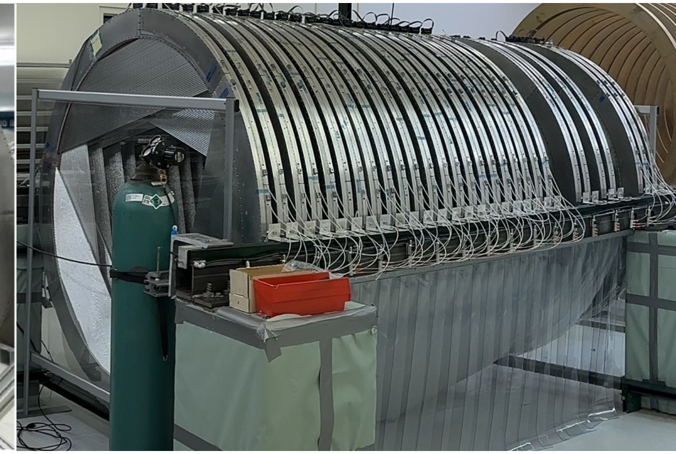
- Build the chimney + Close up vacuum vessel
- Perform cold test, leak tests

  → **Project estimate sets DS delivery for March 2026**

Mu2e Tracker – construction status

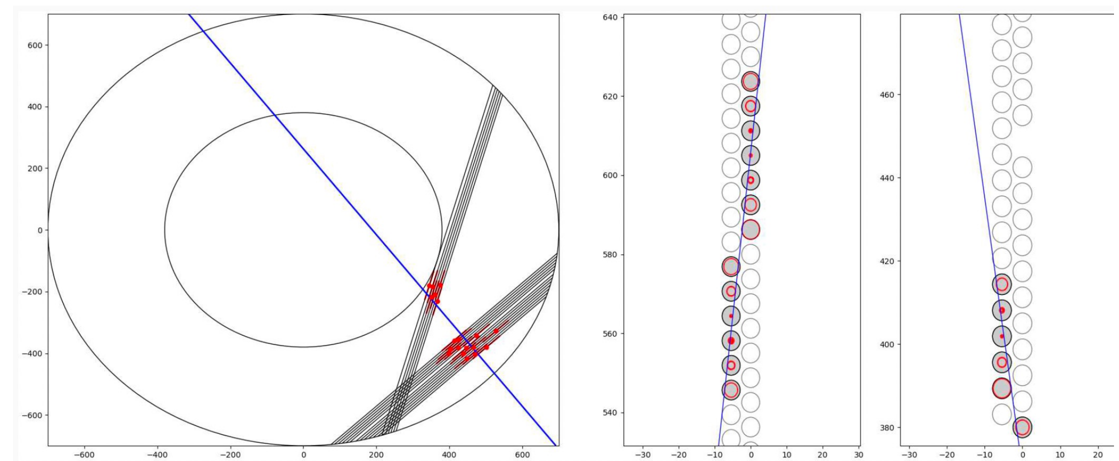






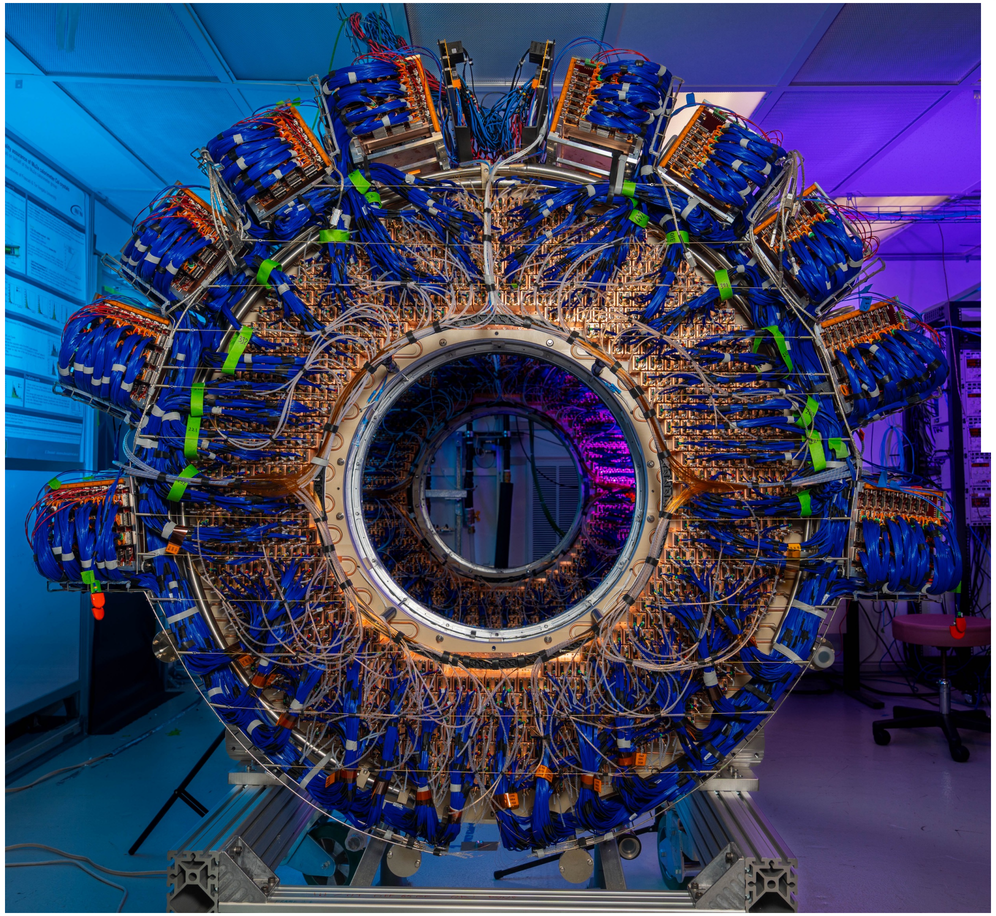
- ✓ 20000 15 um thick, 5 mm diameter's straws
- ✓ Organized in 18 stations, 36 planes
- ✓ 100 % of panels (216) and planes (36) completed.
- ✓ All electronics delivered. Installation of electronics in progress
- ✓ Assembly of stations **(16/18)**

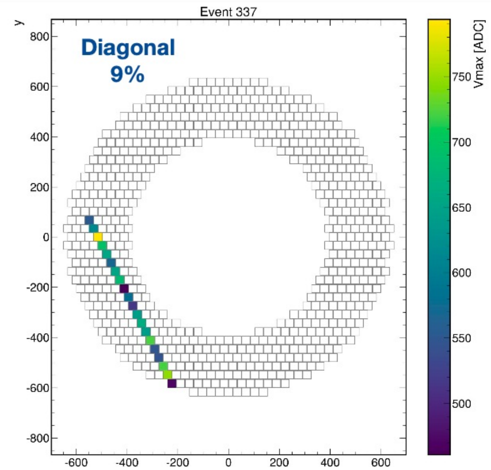
→ Move in the pit in November 2025

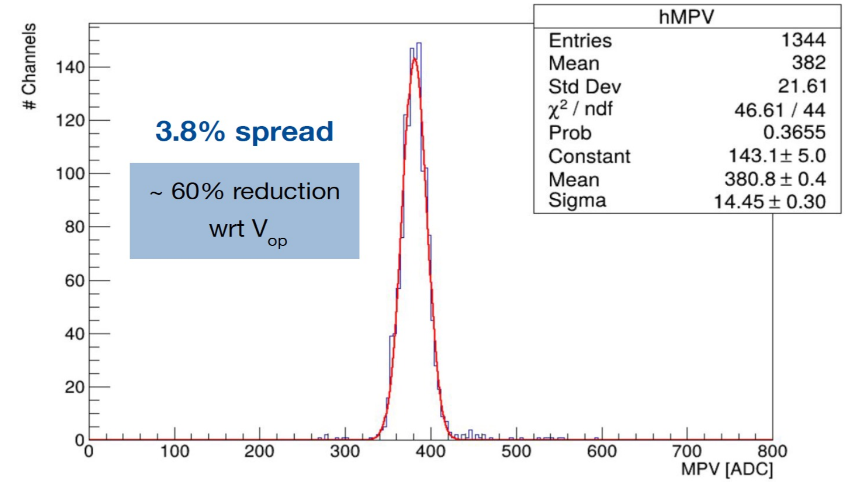


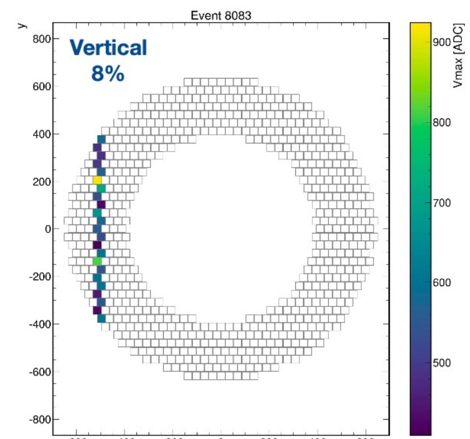
Cosmic Ray track as reconstructed at the Tracker VST of the station

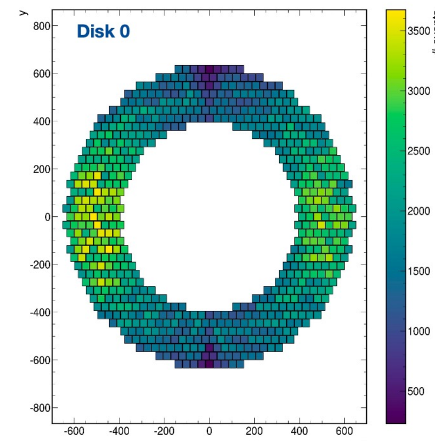
Mu2e Calorimeter → construction completed

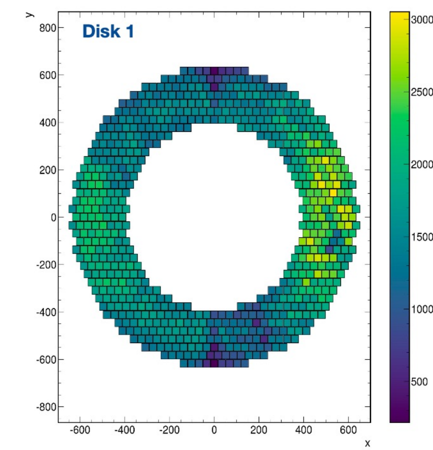






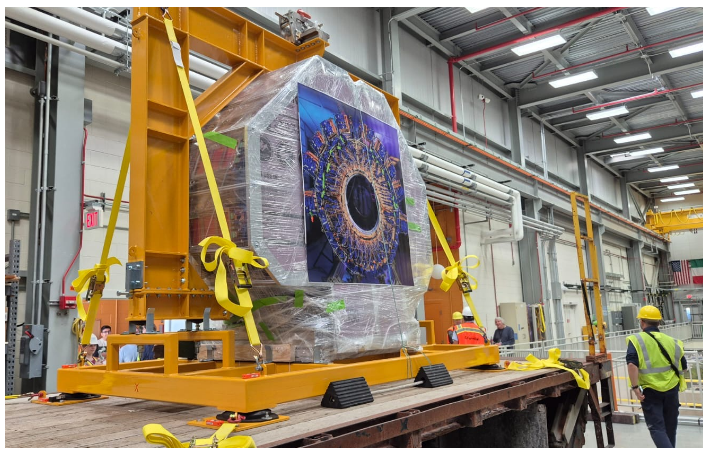


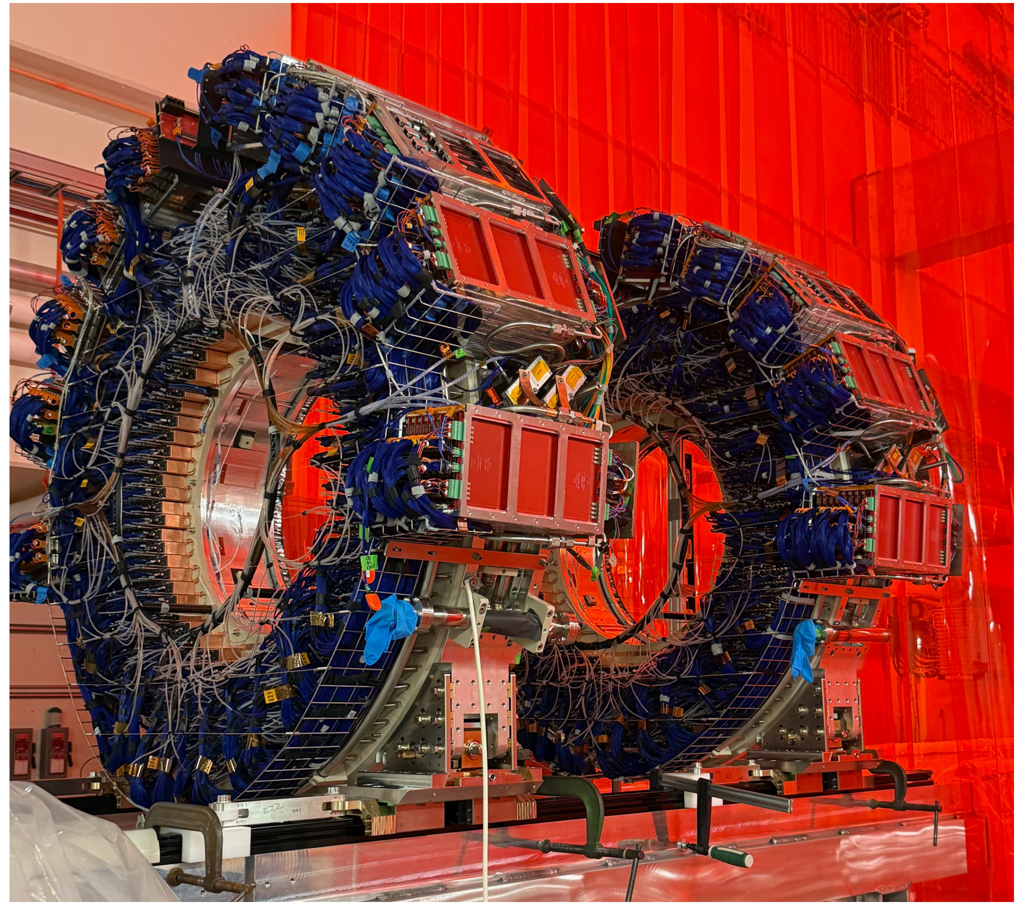


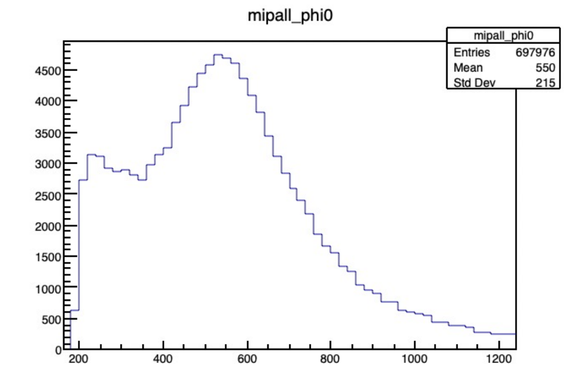


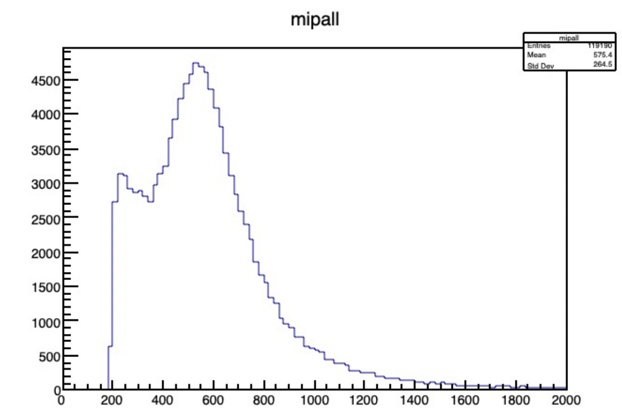
- Disk-0 and Disk-1 fully assembled including all digital electronics and cables from FEE to Digital boards
- TDAQ readout of Disk1/Disk-0 carried out from September 2024 to April 2025
- Final commissioning runs in May/June 2025**. Disk ready to go, all channels calibrated at the end of June 2025**

Mu2e Calorimeter → disks installed on detector rails





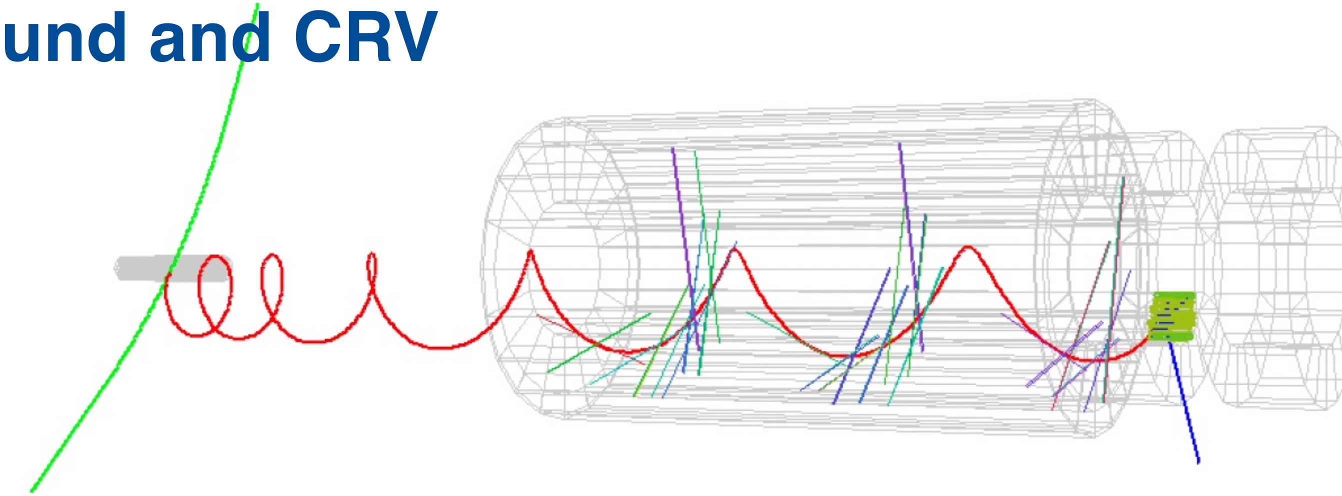




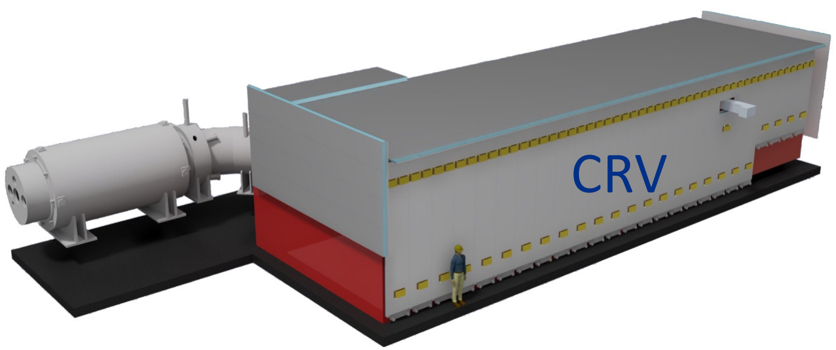
- ✓ Disk 1/Disk0 mved to Mu2e hall and installed over the insertion rails on 11/17 September 2025.
- ✓ Service test of the calorimeter in the hall completed. 2696/2696 channels tested OK

Mu2e Cosmic Ray background and CRV

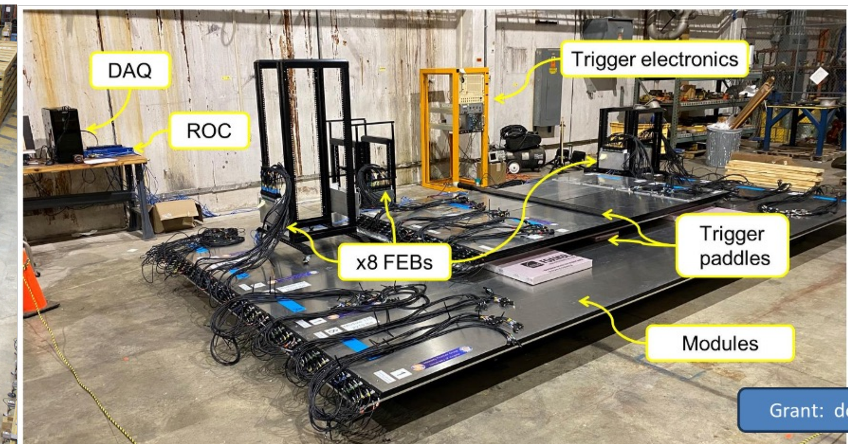
- ❑ Cosmic ray tracks can mimic a 105 MeV/c electron track
- ❑ A cosmic muon can decay or knock out electrons from detector material



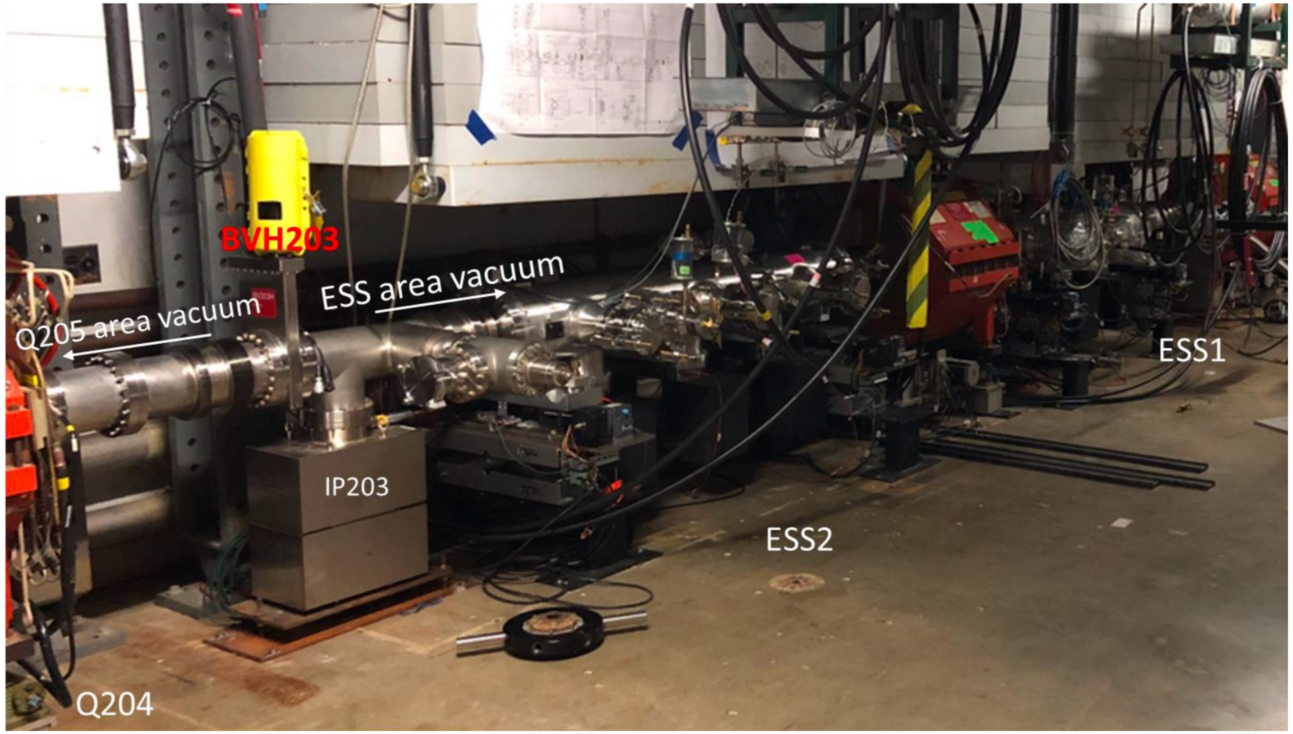
➔ Expect 1 CR-related background event/day to produce tracks in the signal momentum region
➔ Need "offline" VETO (> 99.99%) for incoming cosmic muons with high efficiency and high coverage
➔ Need PID (tracker+calo) to discriminate muons from electrons

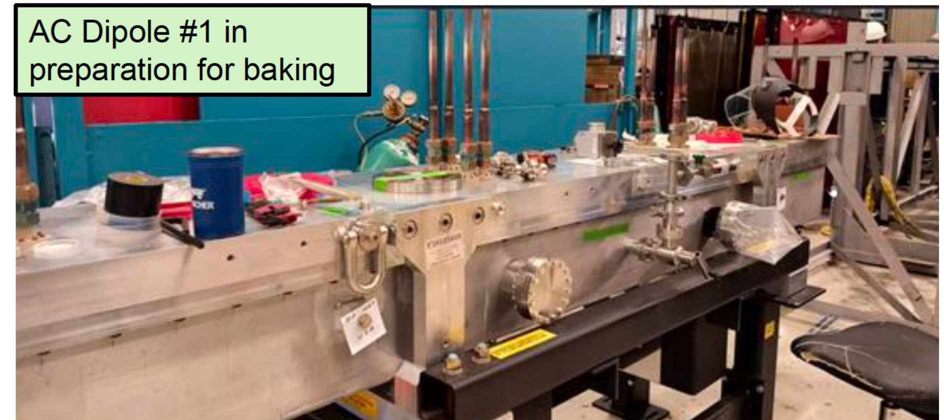


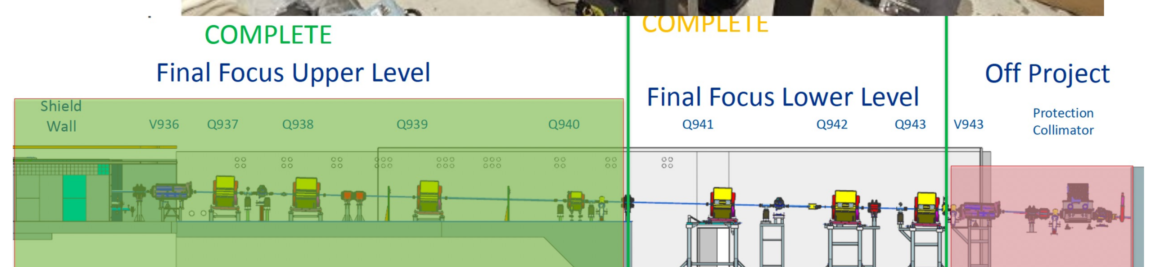
✓ Four layers of scintillators with embedded WLS fiber and SIPM readout



Mu2e Accelerator achievements: ESS, AC, and final focus







- ✓ Two electrostatic septa (ESS) for Slow Extraction inserted in the beam line and operated at full voltage
- ✓ Two 3m-long AC dipoles needed for protons' extinction assembled and power tested. Being installed in beamline.
- ✓ Final focus on M4 beamline installed: operation of turnon power supplies still to be completed.

Beam commissioning run: 2025/2026

Beam established on Muon campus at the beginning of May 2025, with 2 months run completed in July

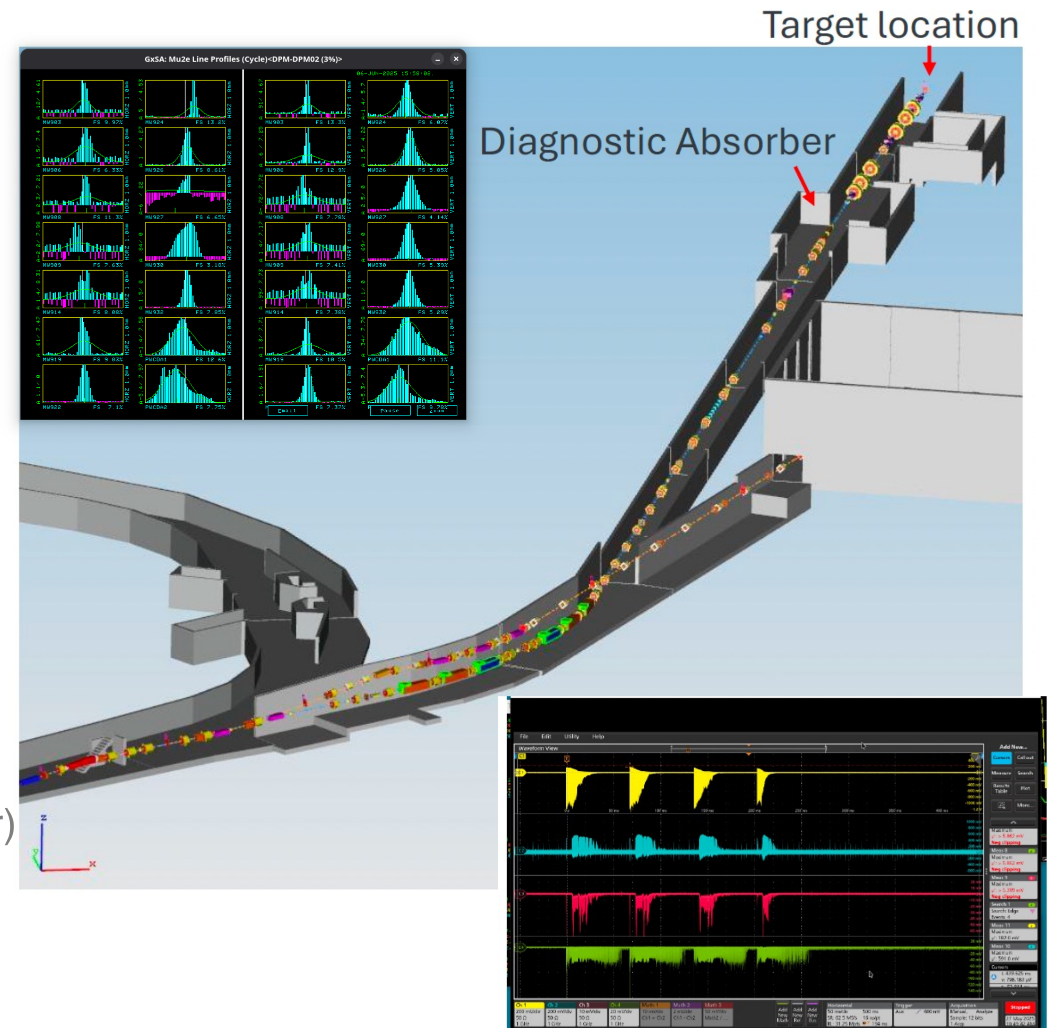
→ A very successful run. Ready for startup a 7 months commissioning in 2026

Done in 2025:

- → Injection understood and improved
- → Profile monitors in M4 beamline are commissioned
- → Extraction frequency improved
- → Spill regulation system was commissioned
- → Resonant Extracted beam with full ESS splitting voltage to the M4 diagnostic absorber established

To do in 2026

- Improve machine acceptance, center the orbits
- Identify and reduce the beam losses (direct and indirect).
- Improve beam line matching to Delivery Ring
- Commission the Extinction system
- Commission the new RF system
- Commission fast and slow regulation
- Developments in instrumentation (e.g. new Extraction Profilometer)
- Developments in controls' applications
- General machine development (e.g. vacuum system)

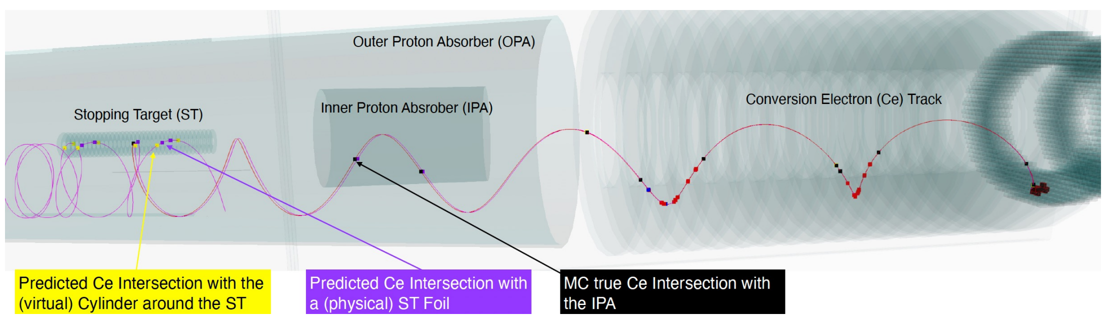


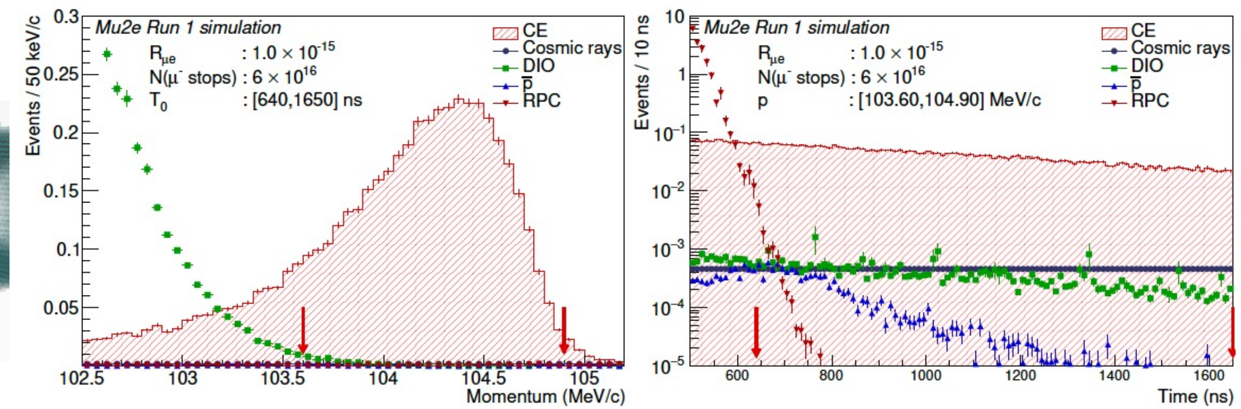
Mu2e Run-1 physics goals

Universe **2023**, *9*(1), 54; https://doi.org/10.3390/universe9010054

- Run-1 plan assumes running with a low intensity beam, followed by a slow ramp-up at high intensity for ~ 4 months running time.
- Full detector simulation & reconstruction of Run-1 (SU2020) proved that collecting 10% of POT corresponds to x1000 sensitivity increase wrt Sindrum-II
- ❑ Trigger + Offline + Reconstruction + Analysis improved wrt SU2020. For instance, tracking now performs Kinematic fitting, including calo hits, and is able to determine crossing points on OPA, IPA and ST

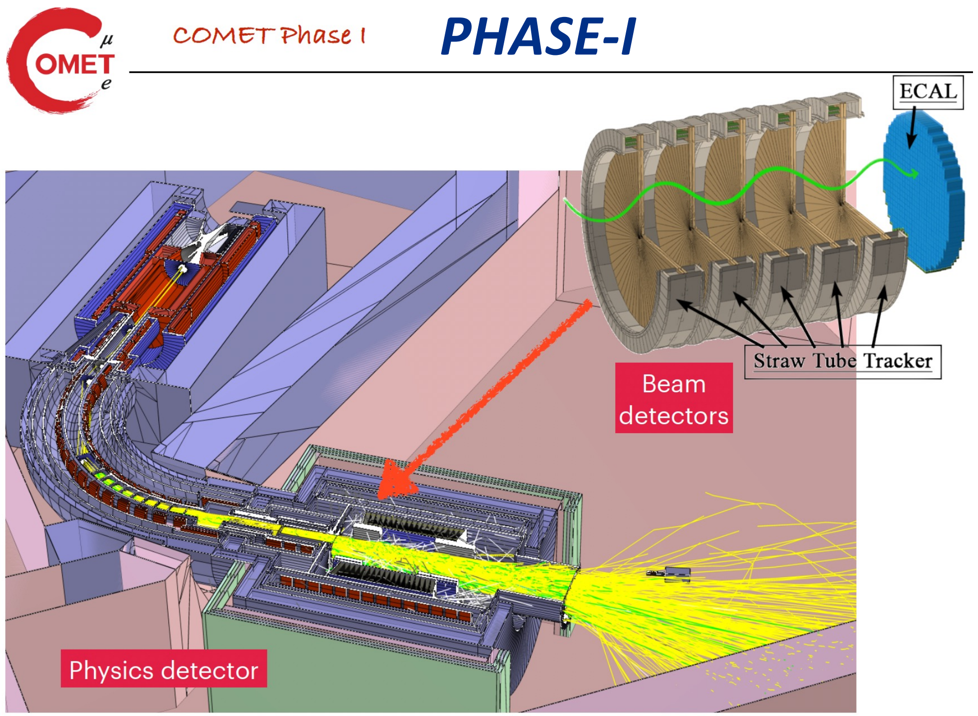
Channel	Mu2e Run I
SES	2.4×10^{-16}
Cosmic rays	0.046 ± 0.010 (stat) ± 0.009 (syst)
DIO	0.038 ± 0.002 (stat) $^{+0.025}_{-0.015}$ (syst)
Antiprotons	0.010 ± 0.003 (stat) ± 0.010 (syst)
RPC in-time	0.010 ± 0.002 (stat) $^{+0.001}_{-0.003}$ (syst)
RPC out-of-time ($\zeta = 10^{-10}$)	$(1.2 \pm 0.1$ (stat) $^{+0.1}_{-0.3}$ (syst)$) \times 10^{-3}$
RMC	$< 2.4 \times 10^{-3}$
Decays in flight	$< 2 \times 10^{-3}$
Beam electrons	$< 1 \times 10^{-3}$
Total	0.105 ± 0.032

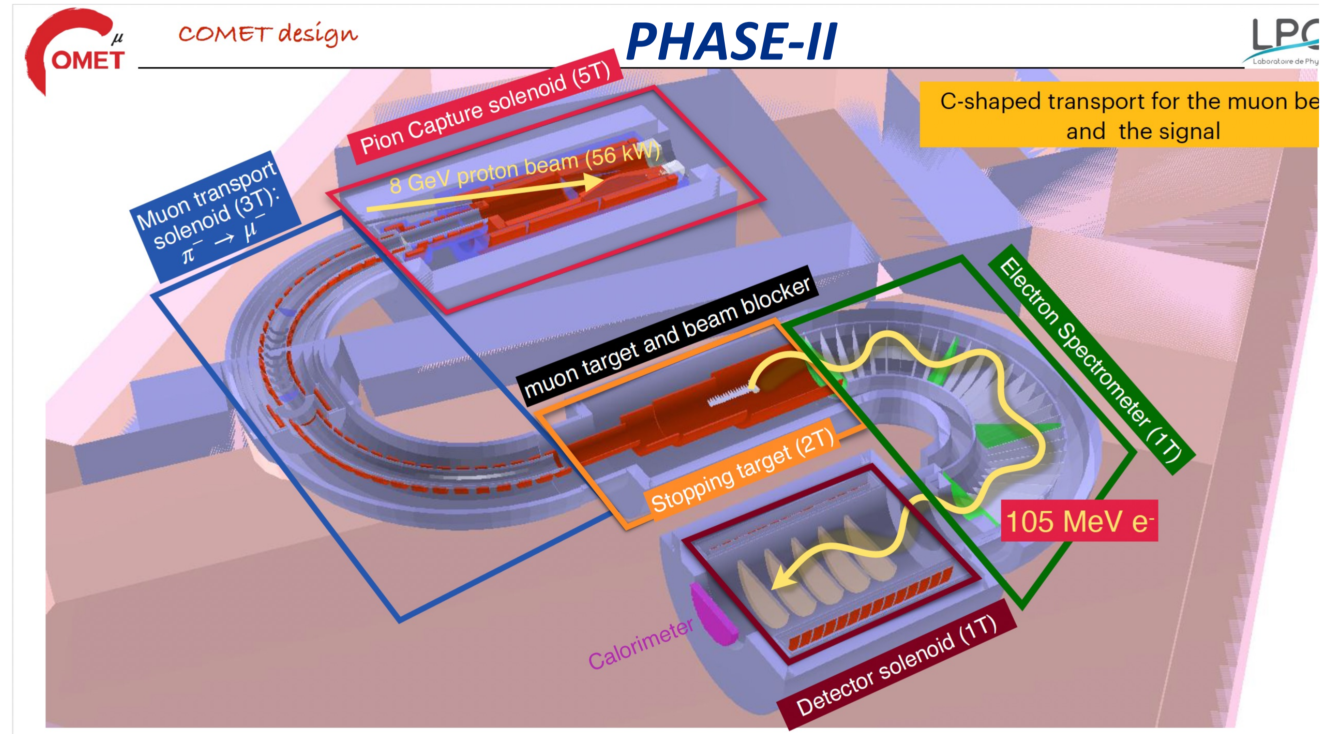




If DS preparation slips of few months: minimize CRV installation .. reach x 100 sensitivity

Layouts of the COMET experiment in two phases





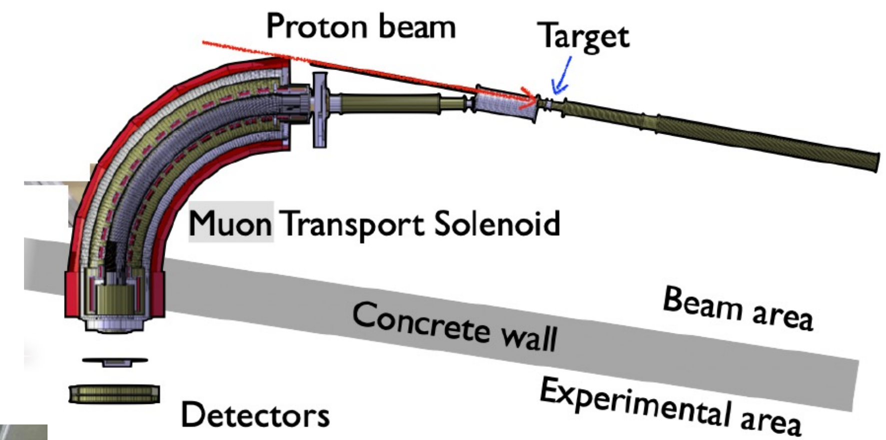
- **Only ½ C-transport. No electron spectrometer**
- 3.2 kW, 8 GeV p beam, **graphite production target**
- 1.2×10^{9} stopped μ/s for 5 months data taking
- ➢ CLFV search: **SES = 3.1×10^{-15} 100 x SINDRUM-II**
- ➢ **Muon beam bcks** with Phase-II detectors'protos
- ➢ ΔL=2 e^+e^- symmetric

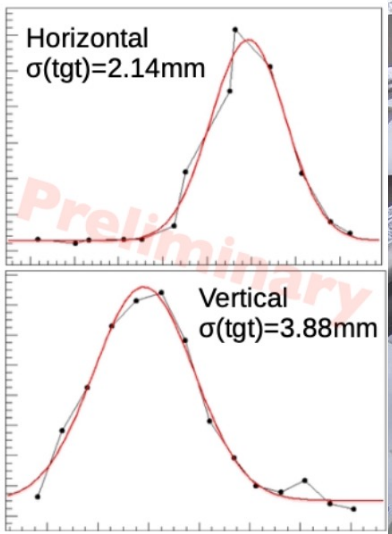
- **Full solenoids' suite, including an electron spectrometer**
- 56 kW, 8 GeV p beam, **tungsten production target**
- 2×10^{11} stopped μ/s for **one year of data taking**
- Vertical B field to steer desired charge/momentum along beam centre
- ➢ CLFV search: **SES = 2.7×10^{-17} ➔ 10000 x Sindrum-II**
- ➢ Only e^-

Not yet financially approved

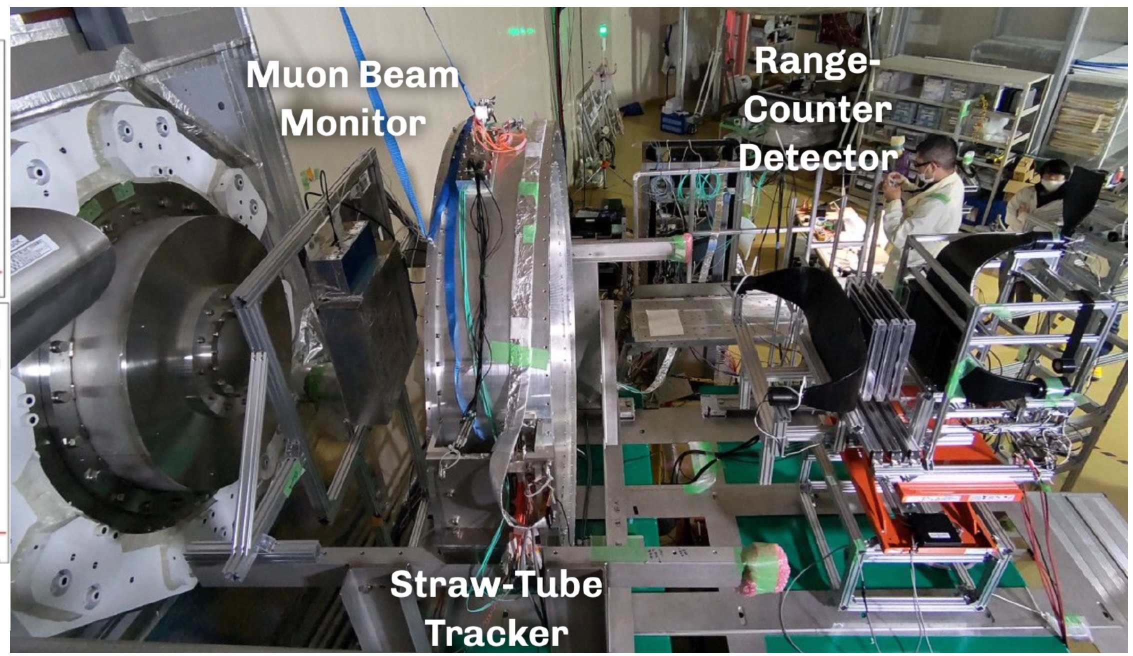
COMET Phase-I alpha (Feb-March 2022)

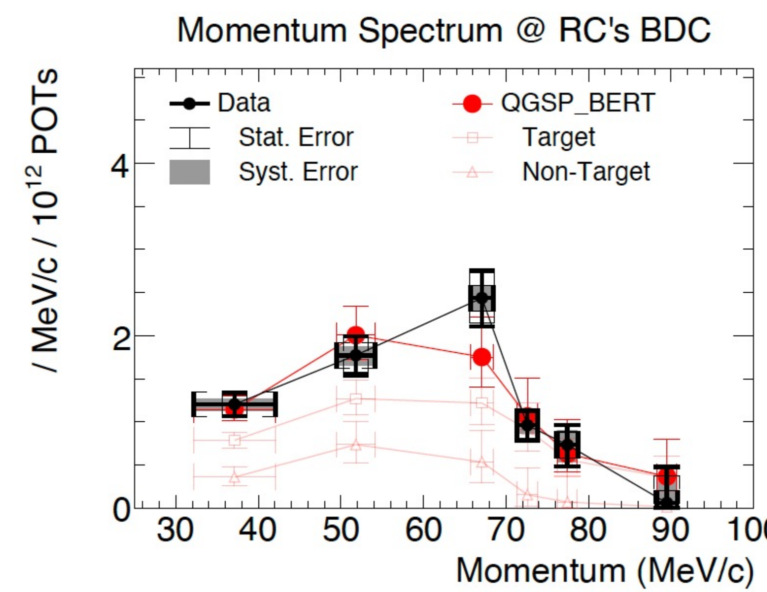
- ✓ SX pulsed 8 GeV protons **@ 260 W (1/10 of Phase-I)**
- ✓ 1 mm graphite production target
- ✓ Proton beam diagnostic detectors (t,Ib, x-y)
- ✓ Secondary particle detectors





Measured beam size





Adapted from: C. Carloganu/Kaon2025

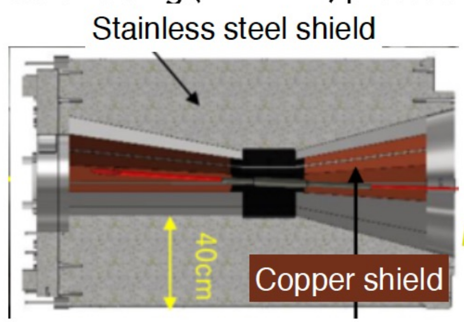
COMET SOLENOIDS: Pion Capture solenoid

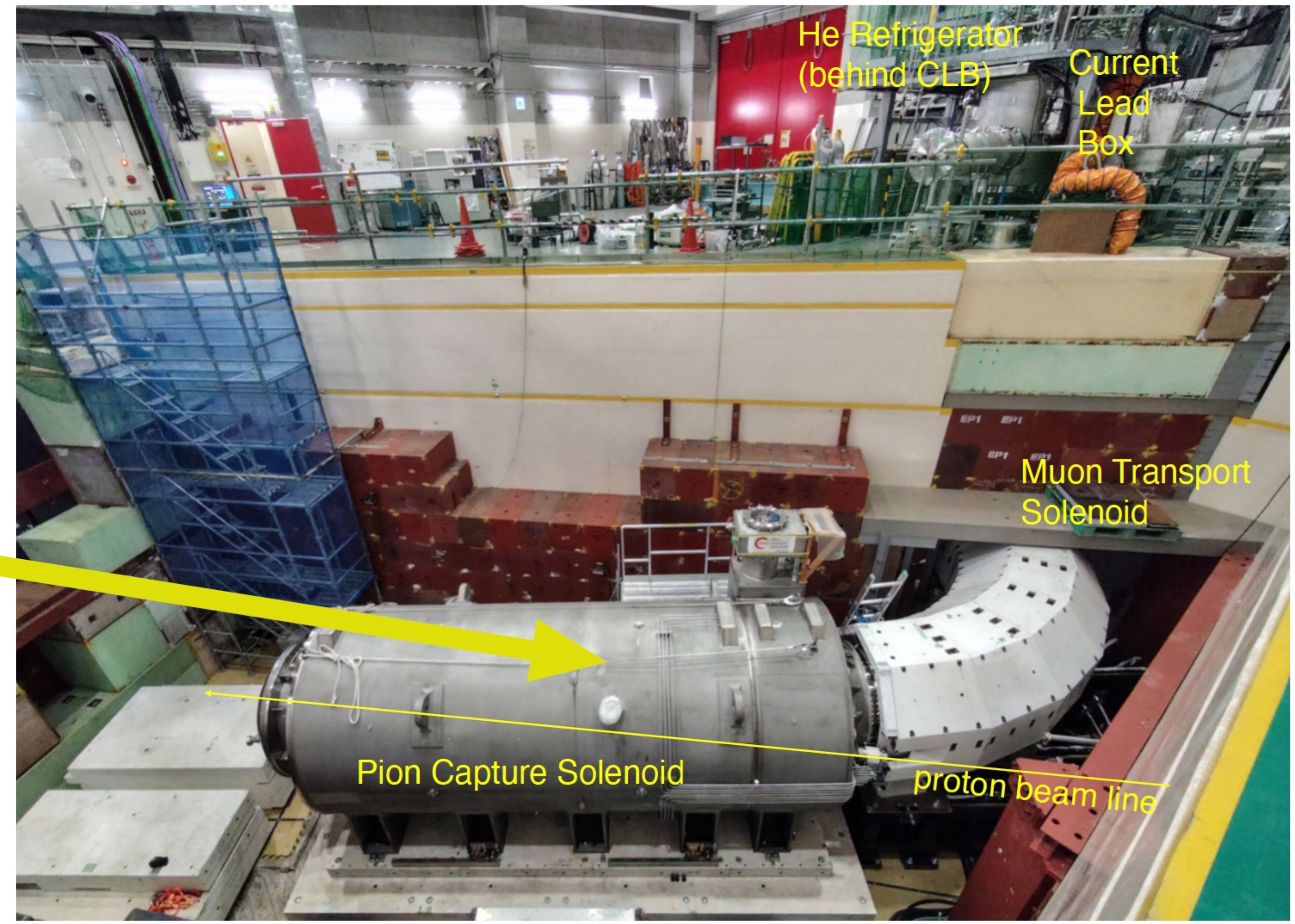
Facility ...s :: Pion Capture Solenoid

Credits: C. Carloganu/Kaon2025

Needs to stand hard conditions in Phase I:

- Heat deposition: $\sim 2\,\mathrm{mW/kg} \rightarrow \sim 26\,\mathrm{kGy}$ / 150 days
- Neutron flux: $3 \times 10^{13}\,\mathrm{n/m^2/s} \rightarrow 4 \times 10^{20}\,\mathrm{n/m^2}$ / 150 days
- Thick stainless shielding ($\sim 40\,\mathrm{cm}$) protects coil





Installed and connected with MTS in Dec. 2024

- Coil resistance & voltage withstand up to 500 V
- Leak tests of LHe- & water-cooling pipes successful

COMET SOLENOIDS: Detector solenoids

Facili[illegible]tus :: Bridge and Detector Solenoids

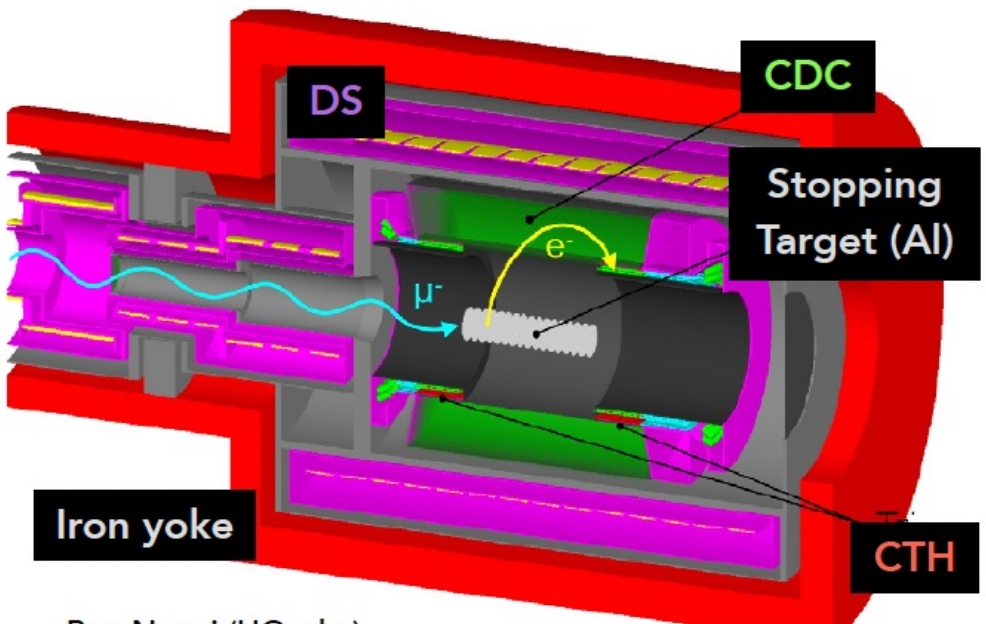
Credits: C. Carloganu/Kaon2025

BS magnet is at NU1 in J-PARC, stand-alone commissioning has been completed

- DS magnet tested successfully in 2024 in North Counter Hall in Tsukuba
- Currently is being installed in the COMET Hall
- The field measurement will follow shortly

COMET Phase-I (CLFV detectors):

- ✓ Stopping Target (Al)
- ✓ CDC = Cylindrical Drift Chamber
- ✓ CTH = Cylindrical Trigger Hodoscope

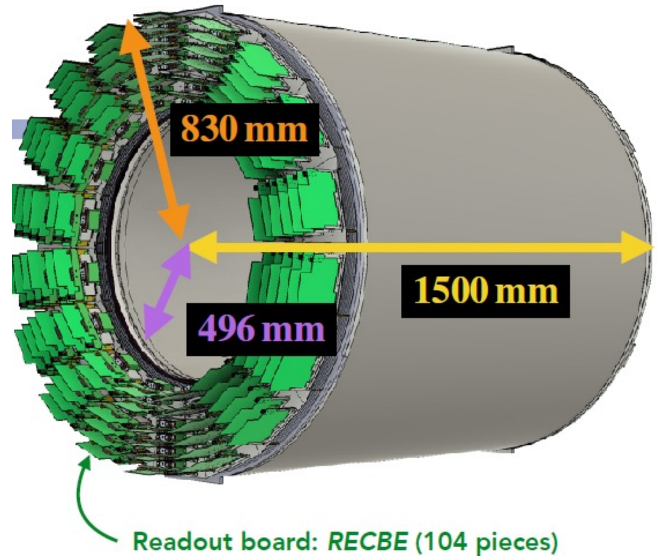


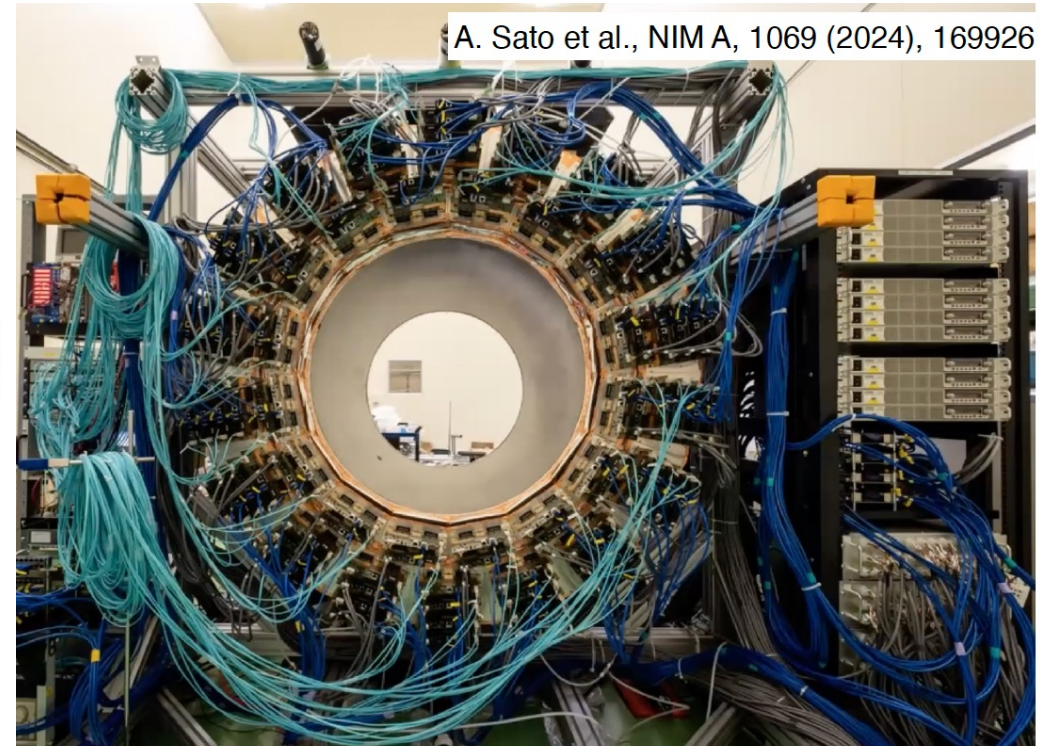
- CDC makes the momentum Reconstruction inside 1 T field With < 200 keV/C
- CTH provides a trigger and a TOF measurement withPID
- All embedded in shieldings + iron yoke + CRV
- Germanium for STM

- Muon stopping target in Al formed by 17 aluminium disks, 10 cm diameter 200 um thick
- *Similar to Mu2e stopping target which has 37 aluminum disks, 100 um thick, 7 cm diameter*

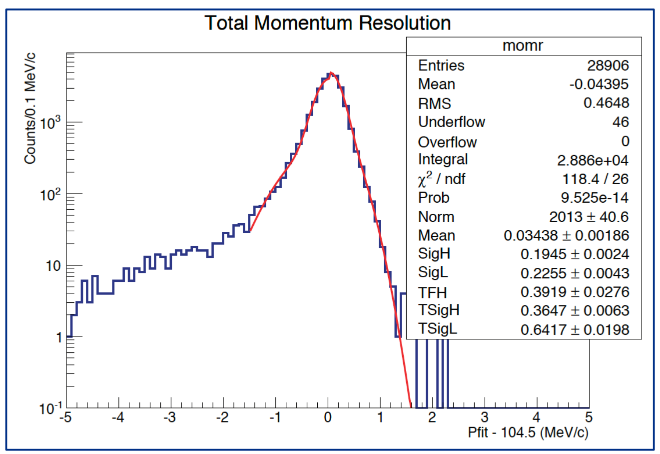
COMET Phase-I : CDC

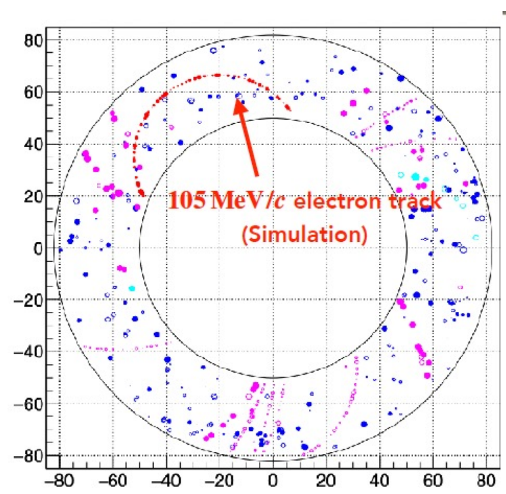
- ✓ 5000 sense wires organized in 20 concentric layers. All stereo.
- ✓ Mechanics similar to Belle-2 CDC
- ✓ Helium based gas mixture to avoid MS
- ✓ Large inner bore to avoid flash and DIO high rate
- ✓ Mom. Resolution < 200 keV/c
- ✓ Completed in 2019
- ✓ CR test completed
- ✓ Insertion in DS in 2026

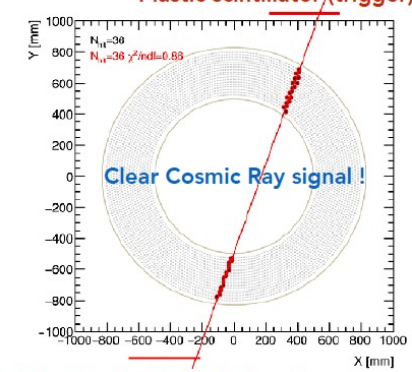


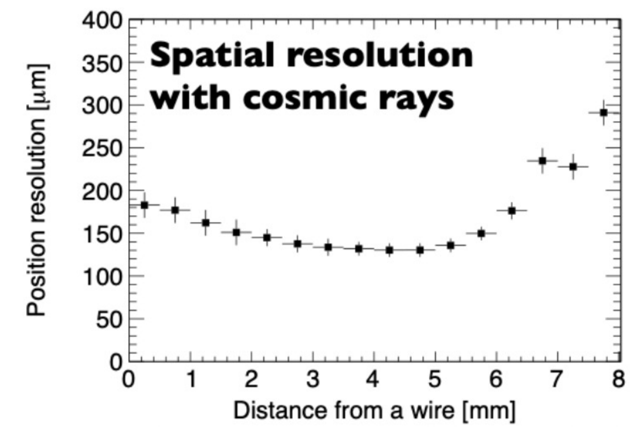


Basic performance test using CRs has been completed

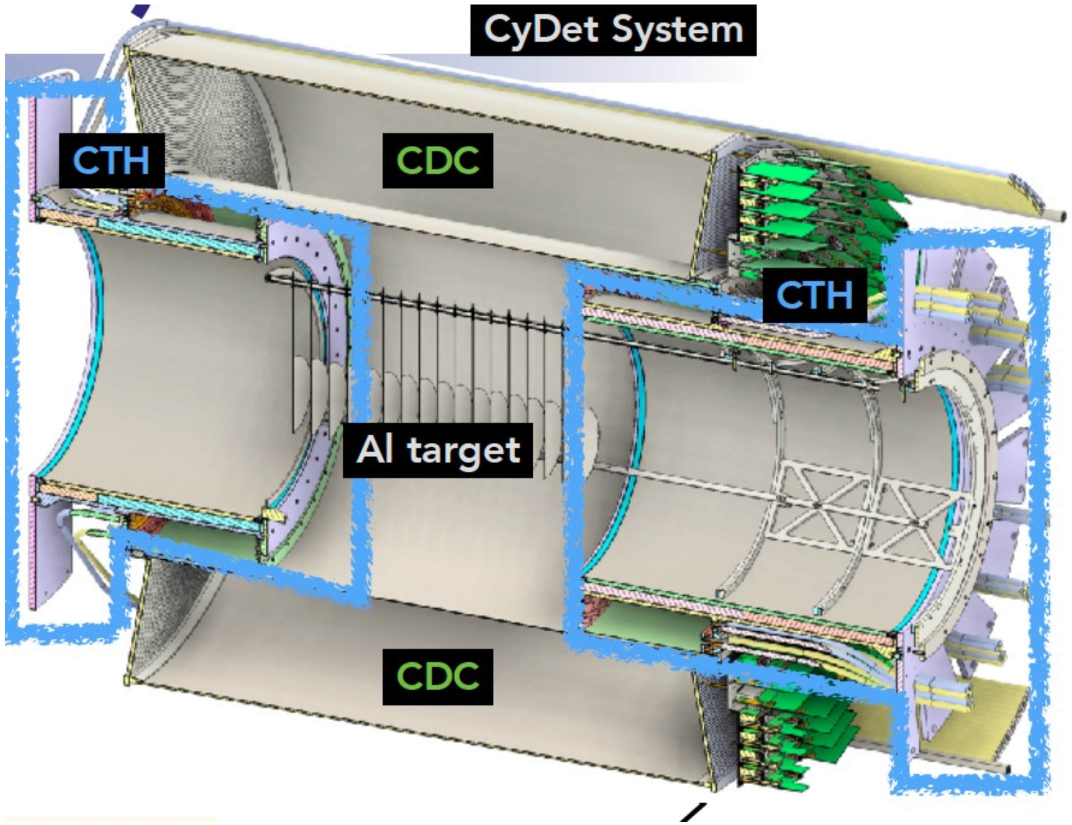


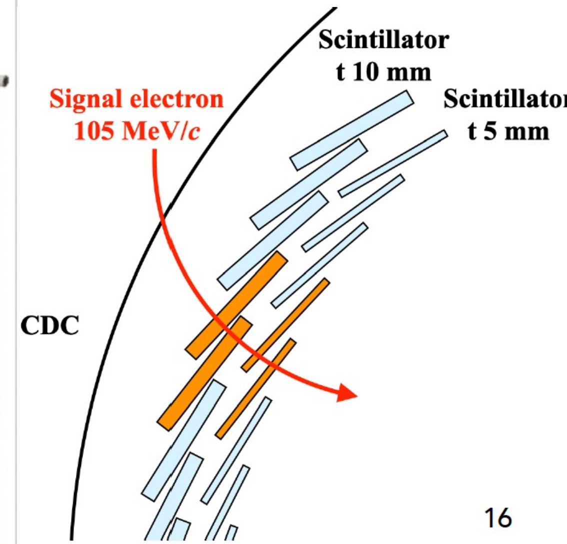


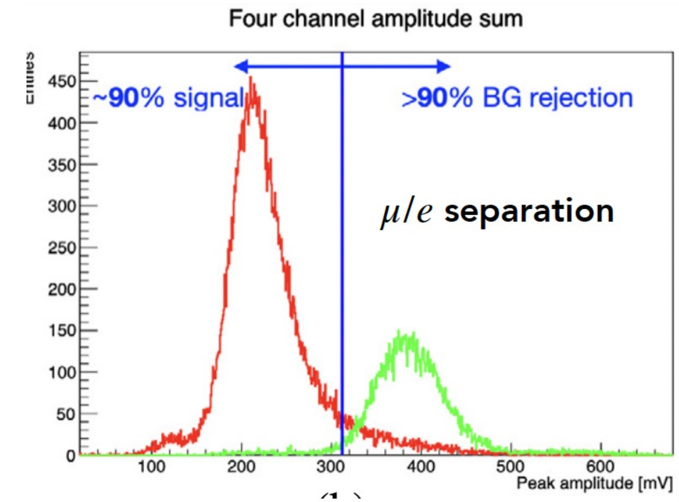




COMET Phase-I : CTH







Ryo Nagai (UOsaka)

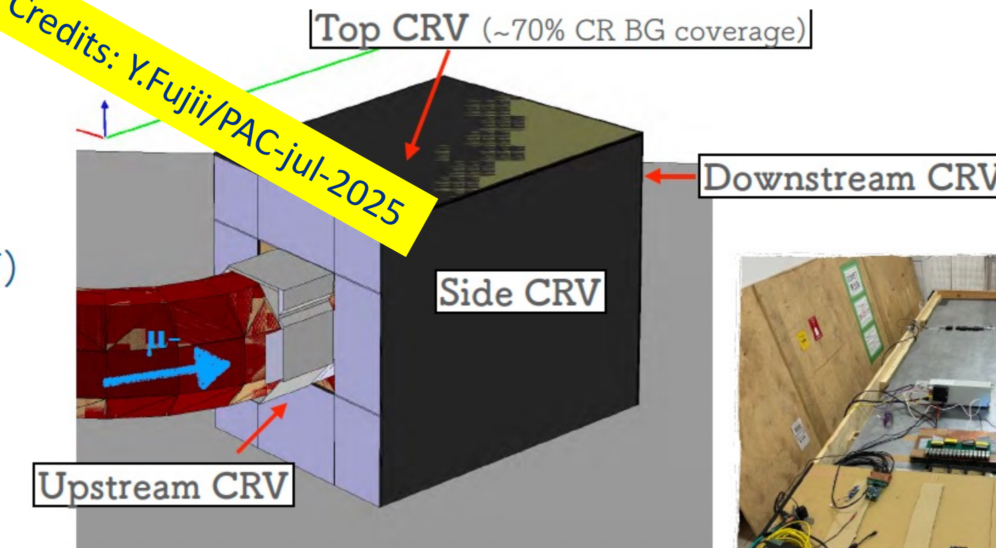
NIM A 1067 (2024)169665

- ✓ 10 mm/5mm plastic scintillators with MPPC readout at both ends of CDC
- ✓ 256 total counters (1/2 ready)
- ✓ Trigger signal by four-fold coincidence of fired counters
- ✓ Good mu/e separation

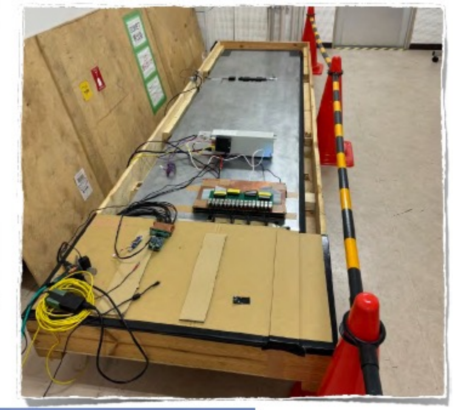
COMET Phase-I: CRV detectors

- Agreed on the partial installation with different technologies in the Phase-I low-intensity
  - Top CRV (full coverage): plastic scintillator (JINR/GTU)
  - Side CRV: ARGO-RPC (IHEP)
  - Upstream/downstream CRV: iRPC (IP2I/LPCA)
- Both RPCs will be tested at GIF++ @ CERN this year

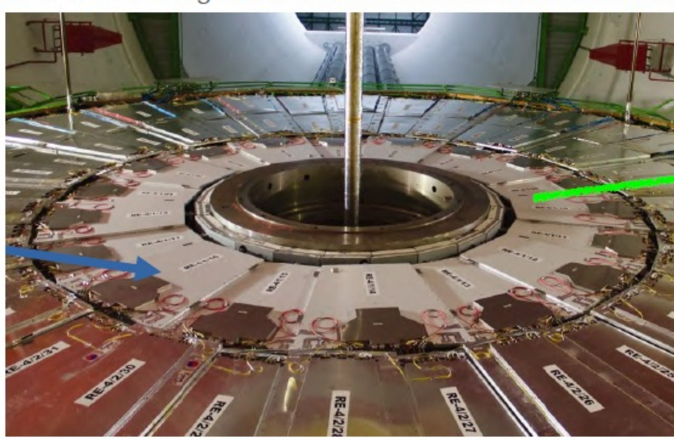
Credits: Y.Fujii/PAC-jul-2025



4 layers of Plastic scintillators for Top CRV to ensure **99.99%** efficiency



CMS iRPC for the highest radiation area near the end of MTS



Repurpose ARG-YBJ experiment's RPC modules for the side RPC in Phase-I low-intensity

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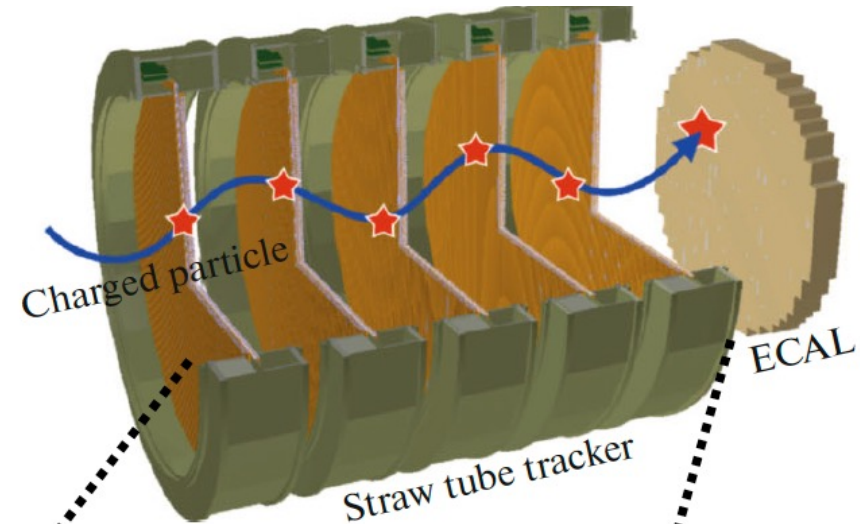
Y. Fujii, July 2025, 40th J-PARC PAC

COMET Phase-I beam measurement/Phase-II protos

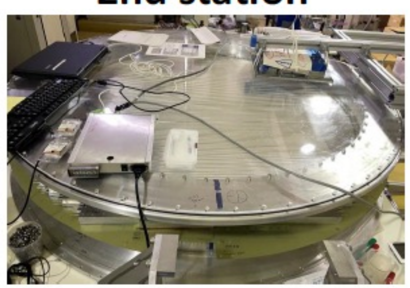
Credits: R. Nagai/nufact2025

- **Straw tracker**:
  - 2,400 straws ($\phi 10\,\mathrm{mm}$, $20\,\mu\mathrm{m}$ aluminized Mylar)
  - Gas mixture: Ar/C_2H_6 (5:5)
  - **3rd station completed**, 4th/5th under construction
  - Spatial resolution achieved $\sim 110\,\mu\mathrm{m}$ (prototype; req: $< 200\,\mu\mathrm{m}$)
  - Momentum resolution: $< 200\,\mathrm{keV}/c$
- **Calorimeter**:
  - Structure has been built: ready
  - LYSO crystal (**485**/512) QC/QA ongoing (light yield, irradiation)
  - APDs: **all delivered**; QA on dark current & gain curve in progress
  - Electronics: final version under refinement and validation (digitizer: completed)

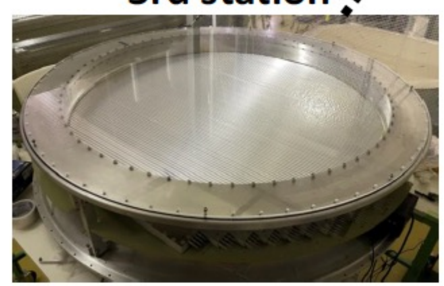


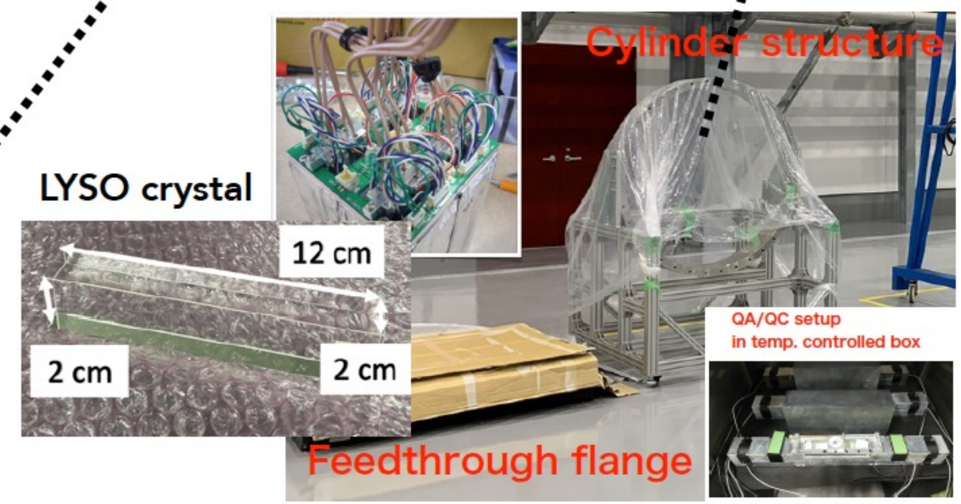
1st station

2nd station



3rd station



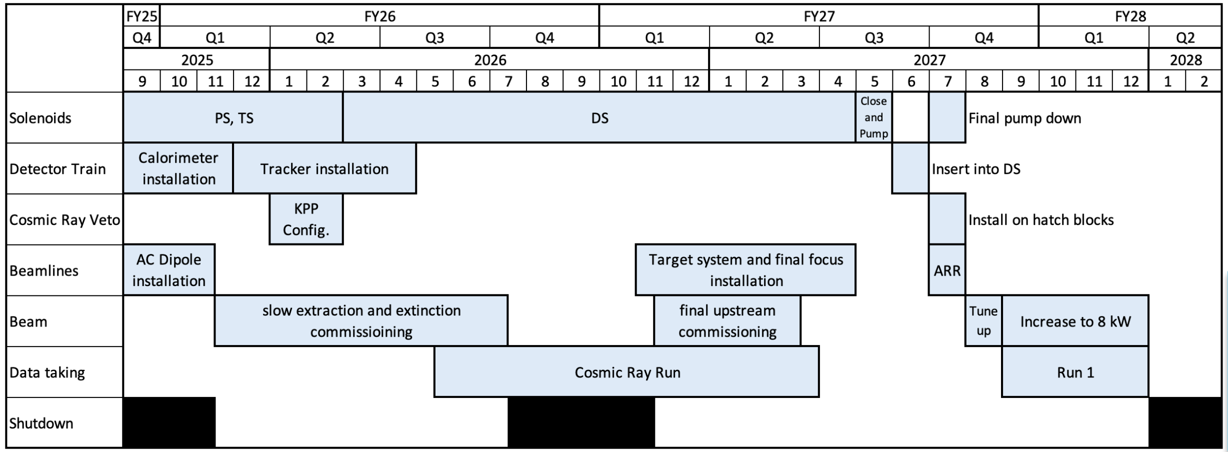


4 September 2025 17

Fermilab

MU2E RUN1 and COMET Phase-I Schedule Updates

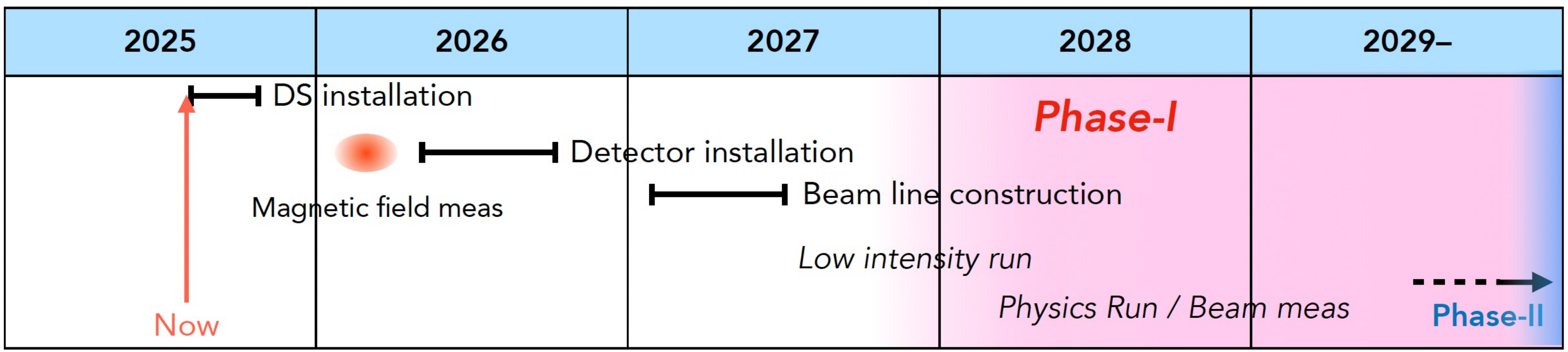
Mu2e



Long Shutdown
2028-1/2 2030

In Mu2e if DS cooldown and energize take too long, contingency option: minimal CRV installatio

COMET



Conclusions

- **Mu2e at Fermilab and Comet at JPARC** will search for the SM forbidden CLFV process of a muon converting to an electron, to largely improve current sensitivity

- **Both experiments are technically challenging**, with their preparation driven by the construction of long, unique superconducting solenoids to improve the muon/POT

- **The detectors and solenoids' construction is well progressed** in both experiments

- CR commissioning and **a startup at lower beam intensity** are **planned for both experiments within the next two/three years.**

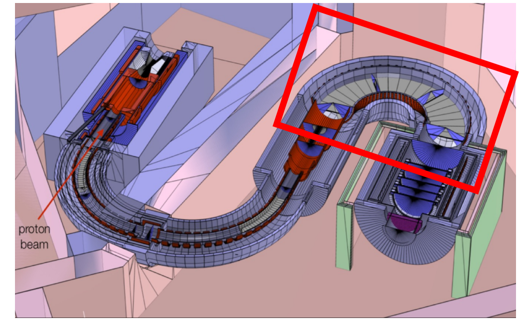
- **Competition and collaboration of both experiments is essential** to improve the sensitivity for the measurement at hand

→ **BE TUNED**

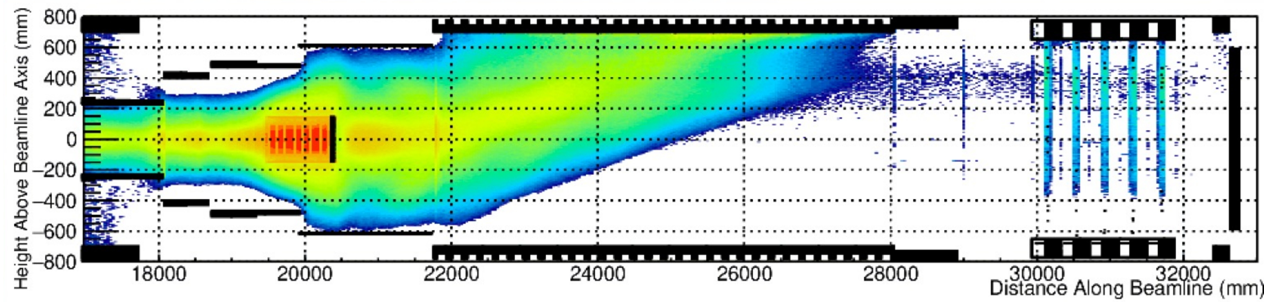
- ADDITIONAL MATERIAL

COMET Phase-II beam in electron solenoid

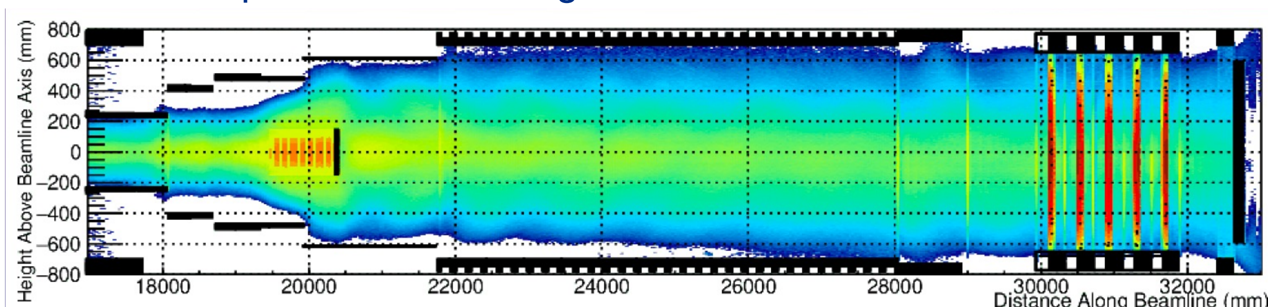
- Beam gradually disperses in C-shaped curved solenoids
- Vertical dipole field used to pull back the beam
- Example: steering of signal electrons (105 MeV/c)



Vertical compensation: steering field OFF

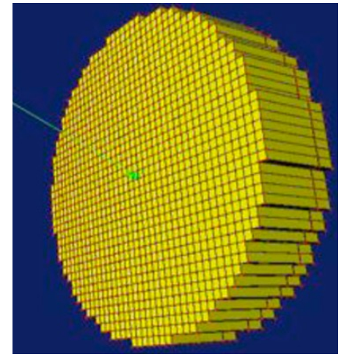


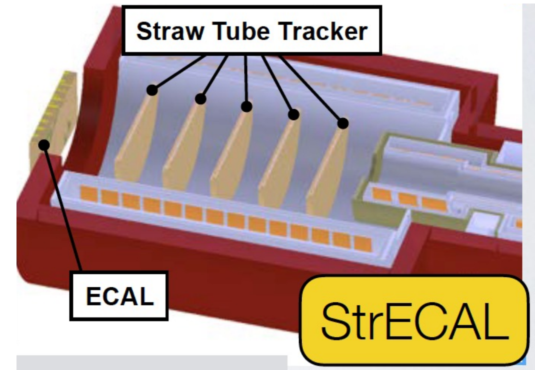
Vertical compensation: steering field ON



COMET: the StrECAL detector, CALO

Electromagnetic calorimeter



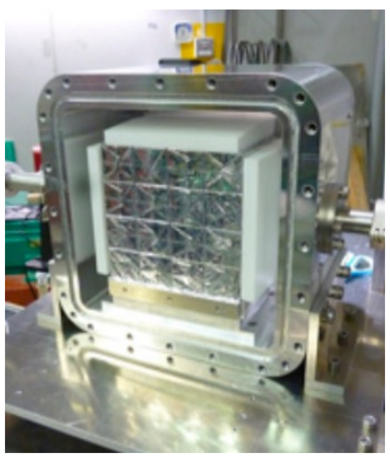


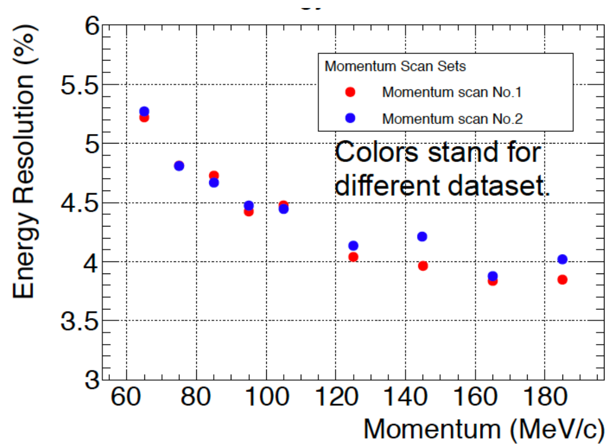
- 2×2 cm^2 LYSO crystals (~ 500)
- 1×1 cm^2 APD readout
- Design completed

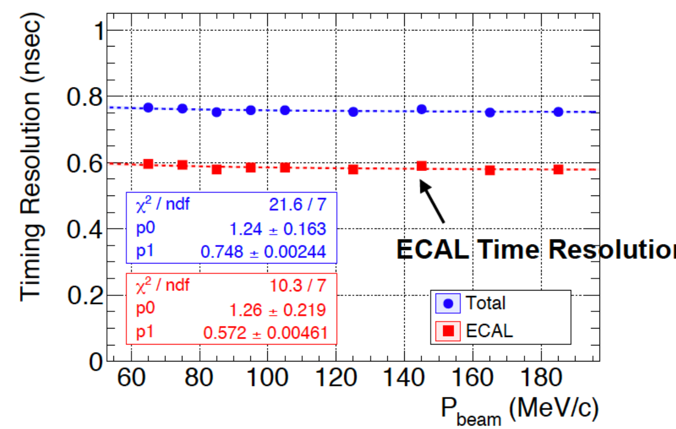
➢ **energy resolution < 4.4%**
➢ **position resolution < 10 mm**
➢ **timing resolution < 1 ns**

Test of ECAL prototype

- Results for 105 MeV electrons







Fermilab

COMET: the StrECAL detector, Straws

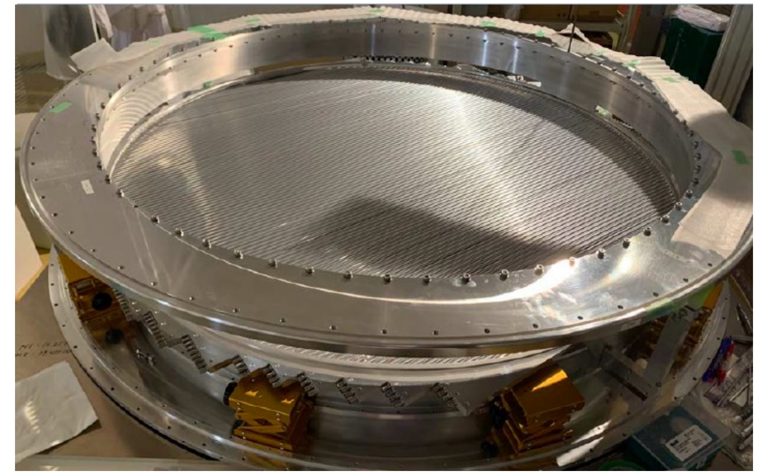
StrECAL designed for Phase-I beam measurements and Phase-II prototyping

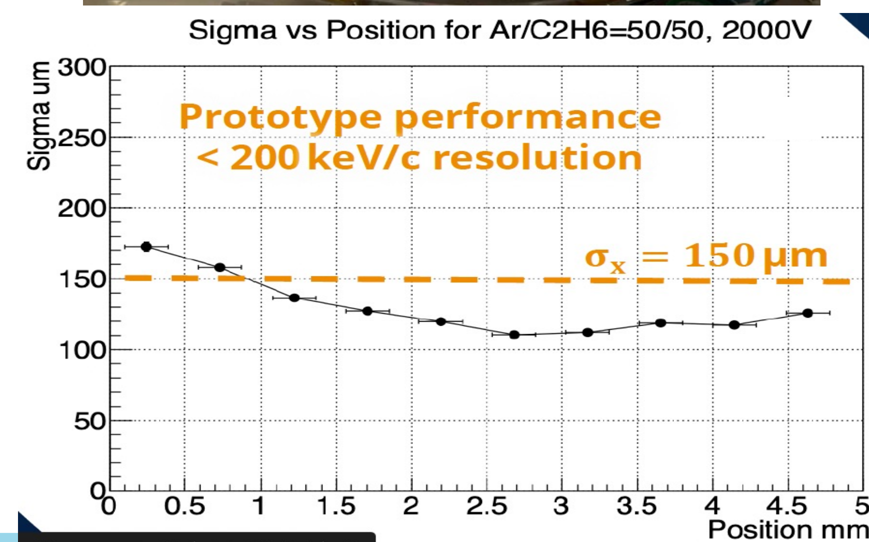
Straw tube detector

- 20 µm thick, 9.75 mm diameter
- Production complete
- Vacuum and deformation tested
- Five stations of 2 staggered x planes and 2 staggered y planes

Test of prototype in vacuum, 100 MeV e^-:

- Ar:Ethane = 50:50 & Ar:CO_2 = 70:30



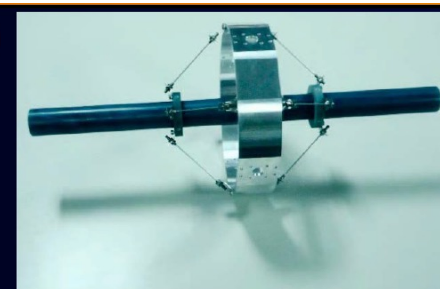


- **position resolution <200 µm** for 50:50 Argon/Ethane
- momentum resolution ~180-200 keV/c (straw track fitting based on Genfit2)

The COMET proton target

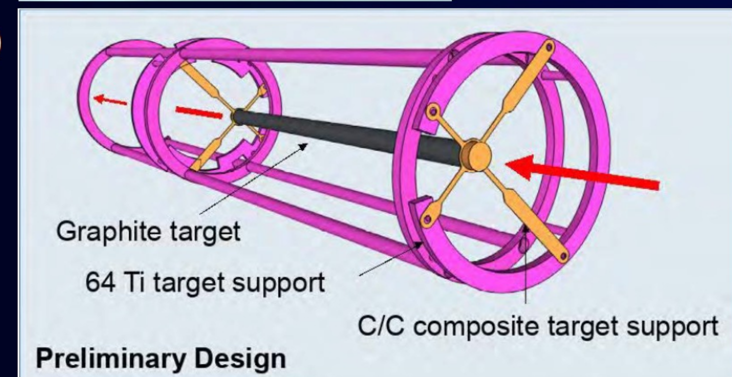
- Proton target for Phase-I
  - Graphite rod with radiation cooling
  - Proton beam power 3.2 kW
  - Radius 13 mm, length 700 mm
  - Design of support underway
- Proton target for Phase-II
  - Tungsten rod with water/He cooling
  - Radius 5 mm, length 250 mm
  - Proton beam power, 56 kW
  - graphite rod with radiation cooling is another option (pion yield is lower)

(1)

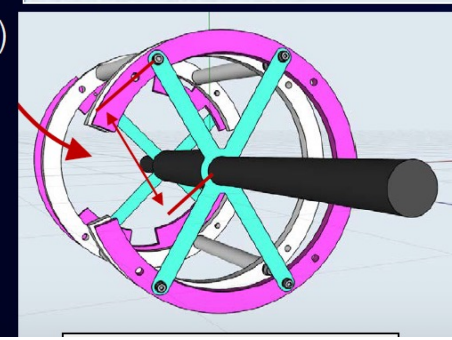


from COMET Phase-I Technical Design Report (2016)

(2)



(3)



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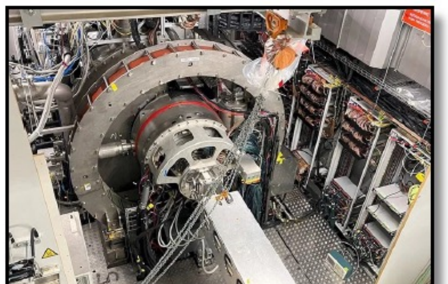
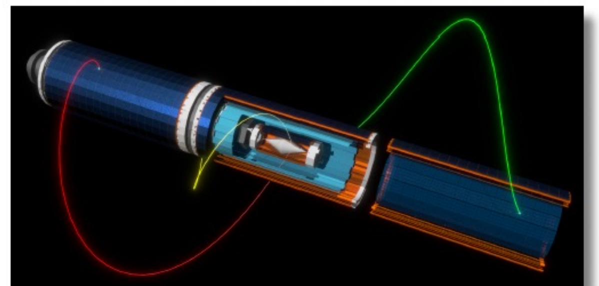
Dedicated CLFV experiments with muon rare decays have been able to measure B.R. limits up to a 90% confidence level.

The next generation of experiments aim to improve the current limits by a few orders of magnitude.

Channel	Current limit (90% C.L.)	Current limit experiment	Next generation expected limit	Next generation experiment
$\mu^+ \rightarrow e^+\gamma$	$< 1.5 \times 10^{-13}$	MEG	$< 1.0 \times 10^{-13}$	MEG-II
$\mu^+ \rightarrow e^+e^-e^+$	$< 1.0 \times 10^{-12}$	SINDRUM	$\sim 10^{-16}$	Mu3e
$\mu^- N \rightarrow e^- N$	$< 7.0 \times 10^{-13}$	SINDRUM II	$\sim 10^{-17}$	Mu2e, COMET

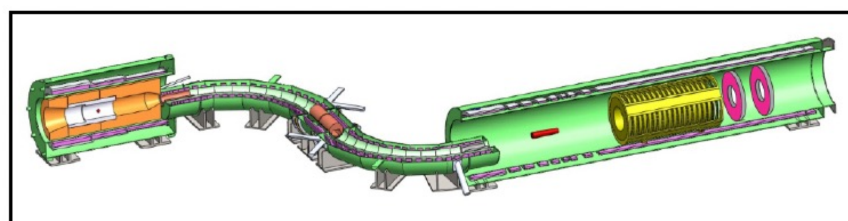


MEG-II



Mu3e

COMET

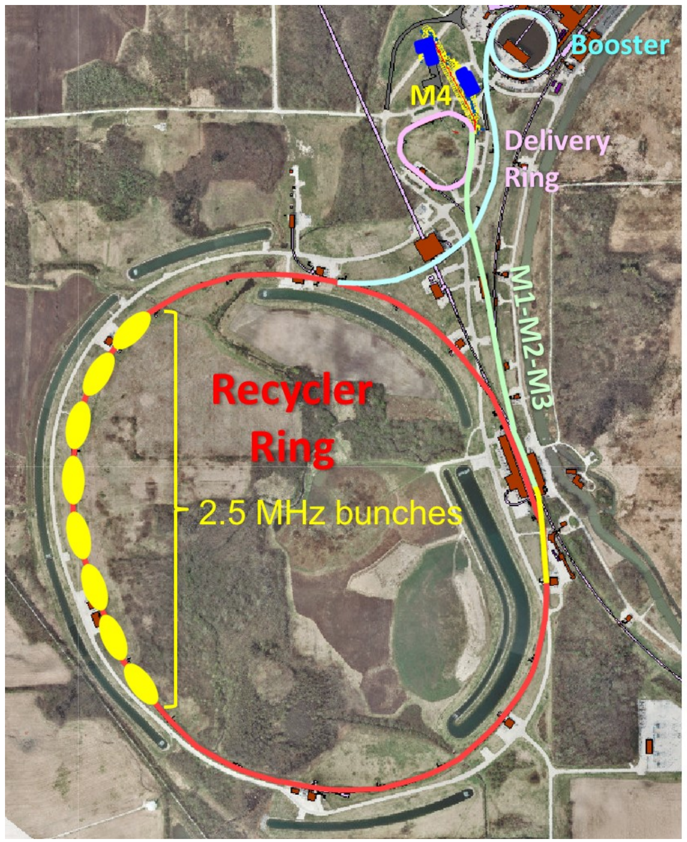


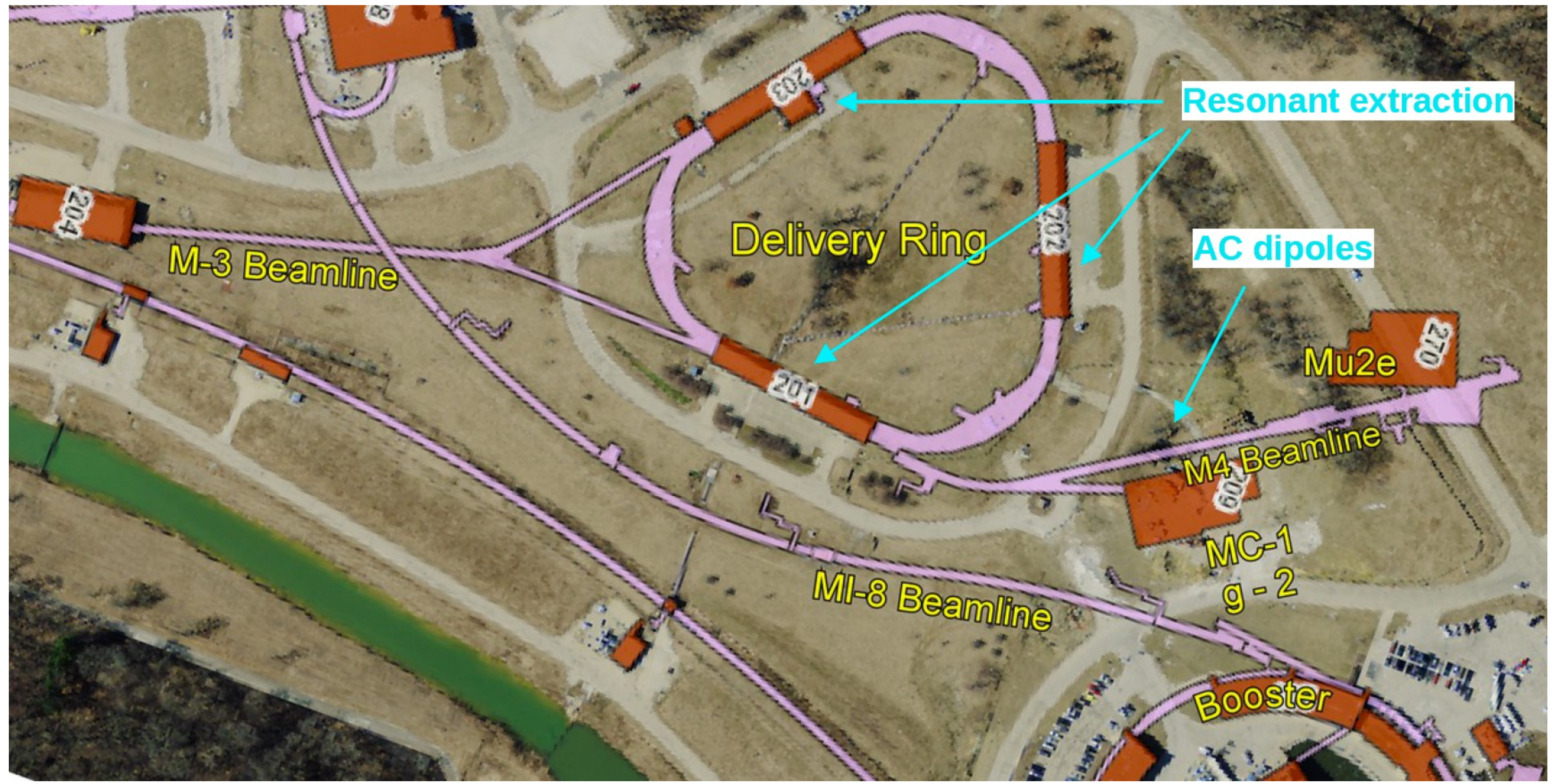
Mu2e

Accelerator Proton beam

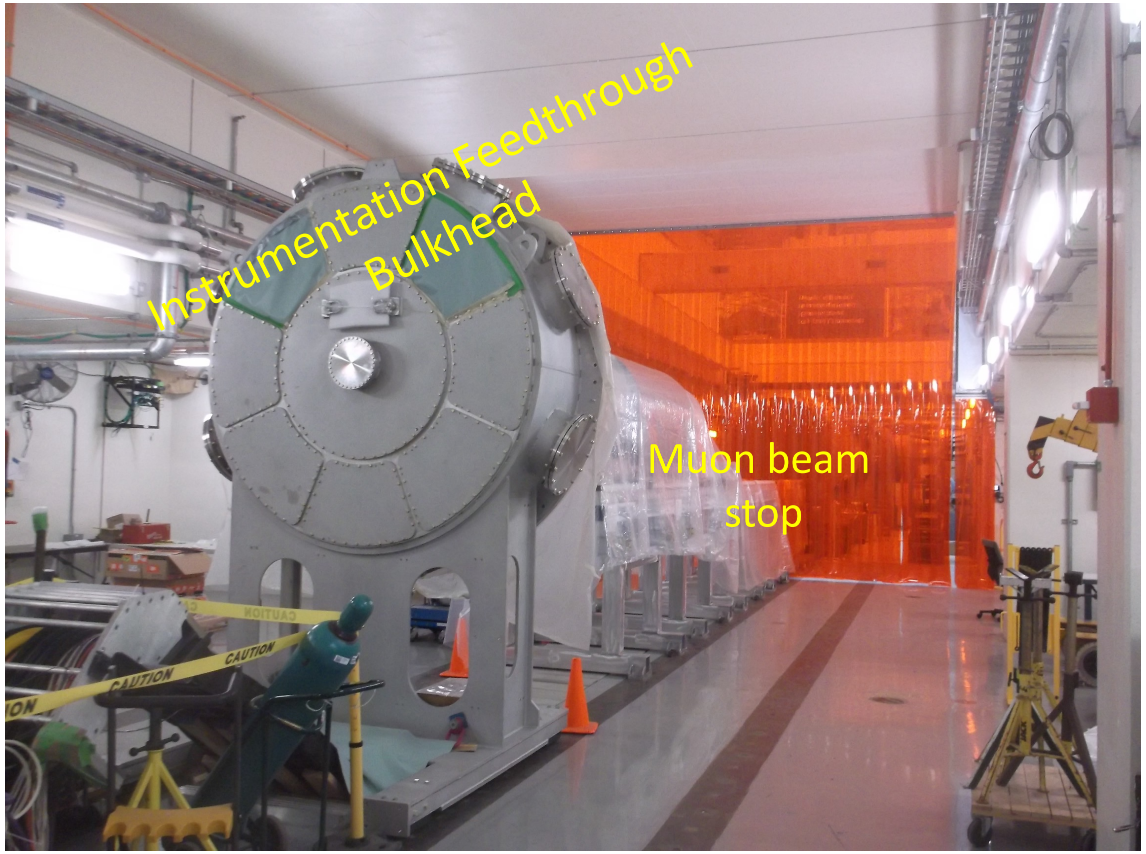
8 GeV protons from the Booster are re-bunched in the Recycler and then stored in the Delivery ring

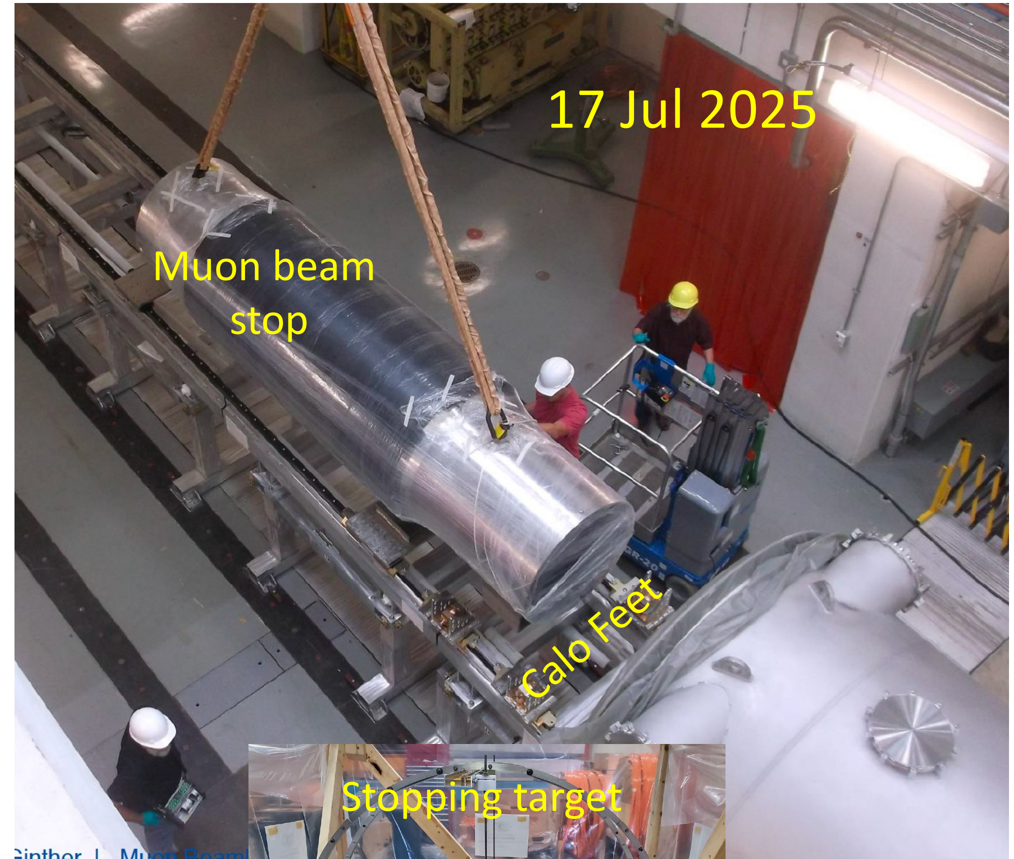
Proton bunches from the Delivery Ring are then slowly extracted to the experiment every 1.7 μs





Muon Beam Line – extracted position outside DS





- Cumulative experiment effort ongoing to integrate all parts and services also for the detectors.
- IFB + Rails and Muon Beam stop already installed. Stopping target is ready.
- Installation sequence well defined.
- Preparation of flanges, cabling and services well underway

Other physics channels

- **$\Delta L=2$ channel $\mu^- \rightarrow e^+$ conversion**
  → It violates both lepton flavour and lepton number
  → Complementary to double-beta decay
  → Main background is RMC, poorly known near the endpoint
  We can determine it with photon-spectrum and theory extrapolation
- **$\mu^- \rightarrow e^- X$**
  → searches for ALP, new bosons, peak in electron spectrum + DIO spectrum near endpoint
- **$\mu^+ \rightarrow e^+ X$**
  → searches for ALP, new bosons
  → require rotating collimators, low intensity, ½ B field
  → Search for a peak in the electrons' momentum spectrum
- **$\pi^+ \rightarrow e^+ X$**
  → searches for heavy neutral leptons in π decay
  → require the same condition of μ^+ search, but more background (especially muon decays in flight)
- RMC, RPC photon spectra
- RMC, RPC bkg shape of electron spectra from positron distribution

Mu+ → e+X, pi+ → e+X from Phys.Rev.D 109, 035025 (2024)

- Exclusion plots for different ALP models (mu+ → e+X) or Heavy neutral leptons (pi+)
- Context: special runs, 1 week low intensity, ½ field, rotated collimator sign, degrader for pions
- Acceptance taken from Mu2e PhD thesis - **Main findings: sensitivy reach comparable with mu3e, Meg-II-X, Comet-X**

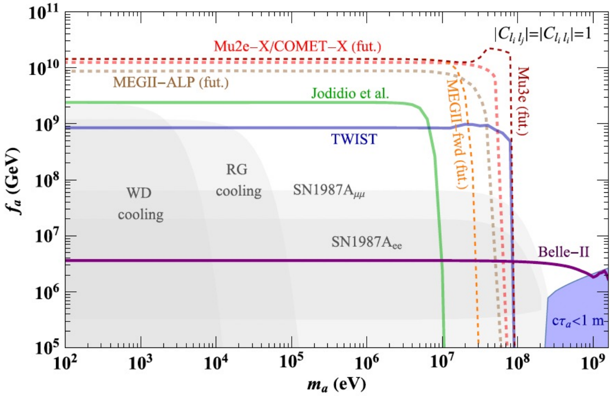


FIG. 1. The 95% C.L. limits on a general ALP with anarchic couplings to all three generations of leptons. The present laboratory

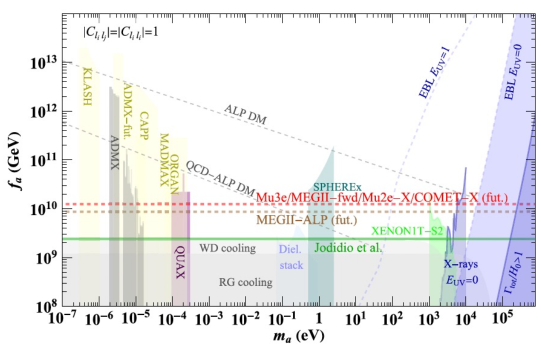


FIG. 2. The 95% C.L. limits on a leptophilic ALP that can be a

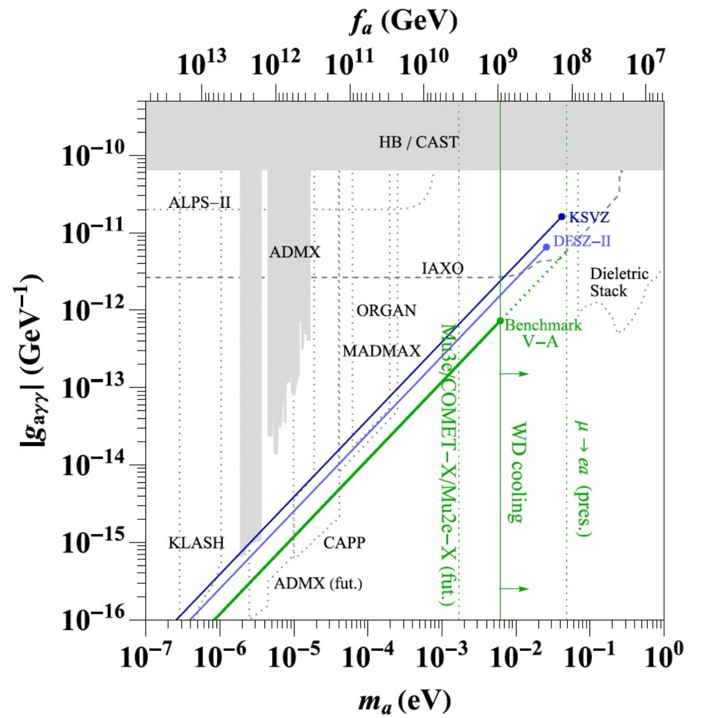


FIG. 3. The 95% C.L. limits on lepton flavor violating QCD axion for the assumed $V - A$ forms of couplings. The mass of the QCD axion, m_a, is inversely proportional to the coupling constant f_a. The vertical axis refers to the axion coupling to photons,

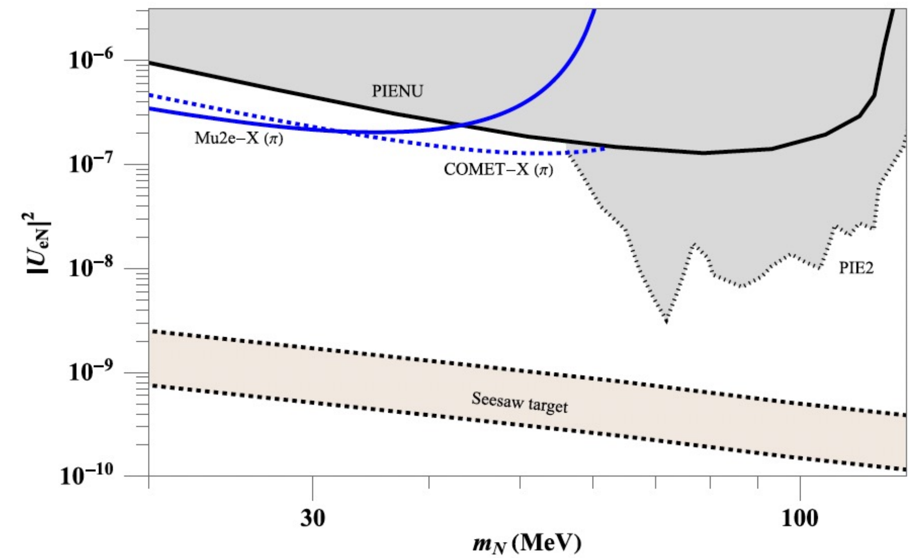
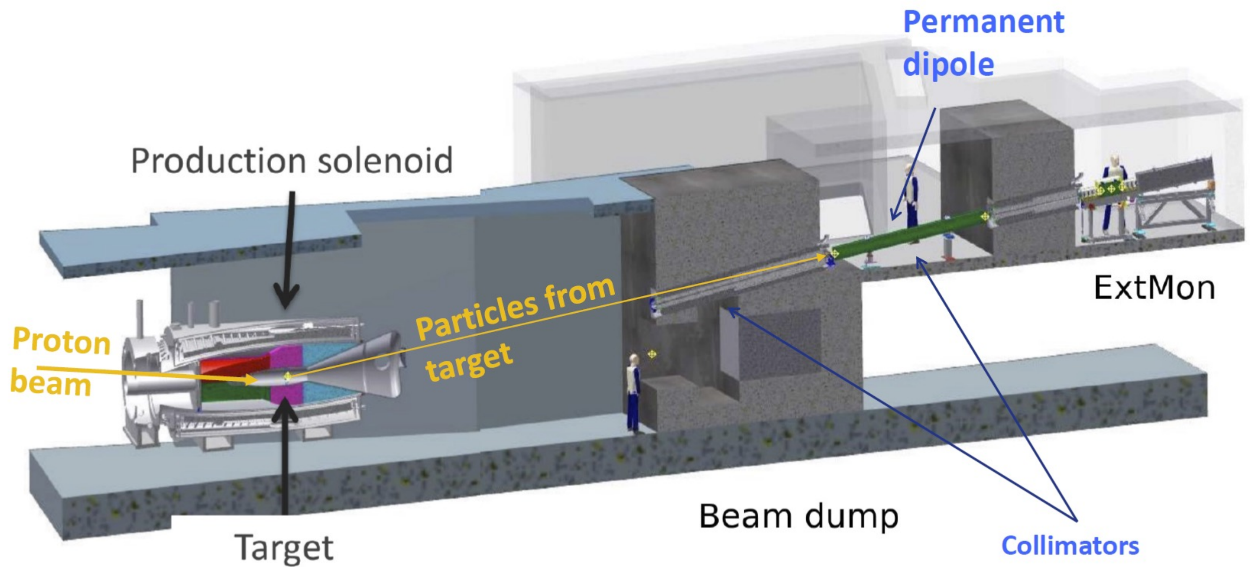


FIG. 4. Projections for mass dependent 90%-C.L. sensitivity to HNL mixing with electron flavor from Mu2e-X in a pion configuration; see Sec. III for details. Existing limits come from

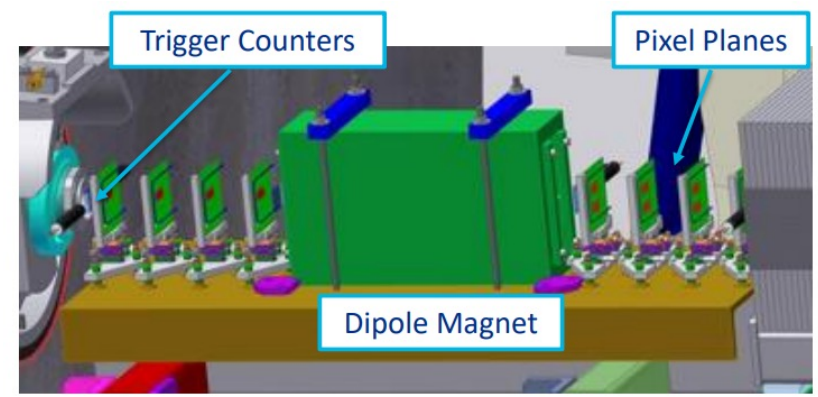
Extinction Monitor (Downstream)



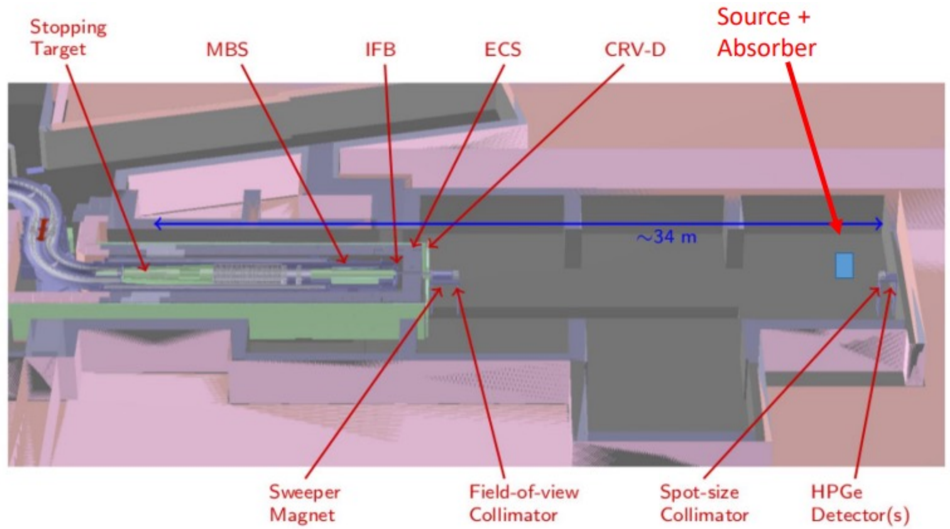
Downstream EXTMON located above and behind the primary beam dump
→ The 2 collimators + 1 dipole select a p/pi beam of ~ 4 GeV/c

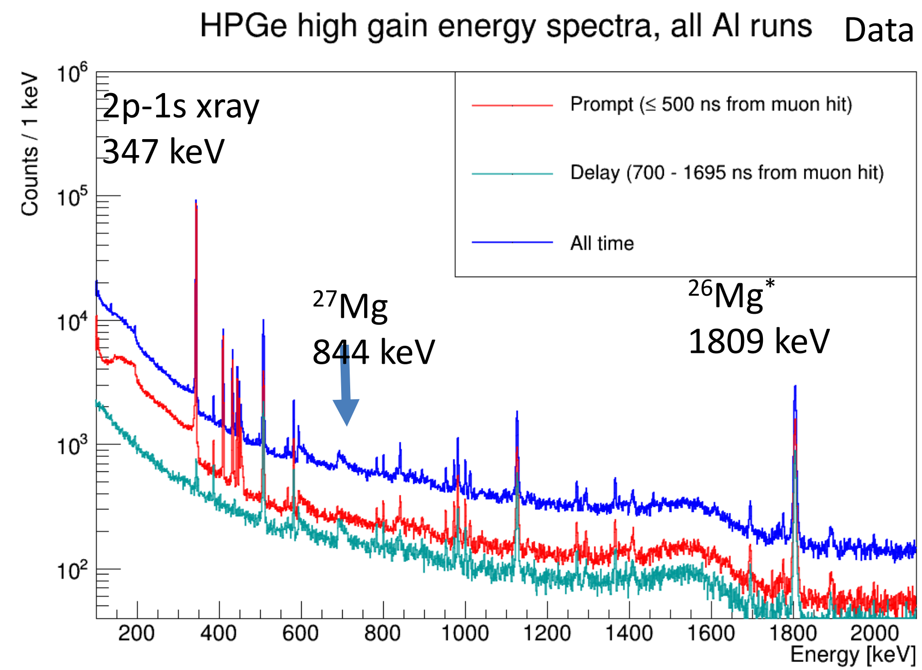
- The detector is based on Trig Scintillators + Pixel Tracker
  → Scintillators : arrival time and between bunch trigger
  → Tracker : reconstruct p, π's + dipole rough momentum determination

- It provides an average extinction value (not pulse by pulse) over ~ 8 hrs



Main normalization detector - STM

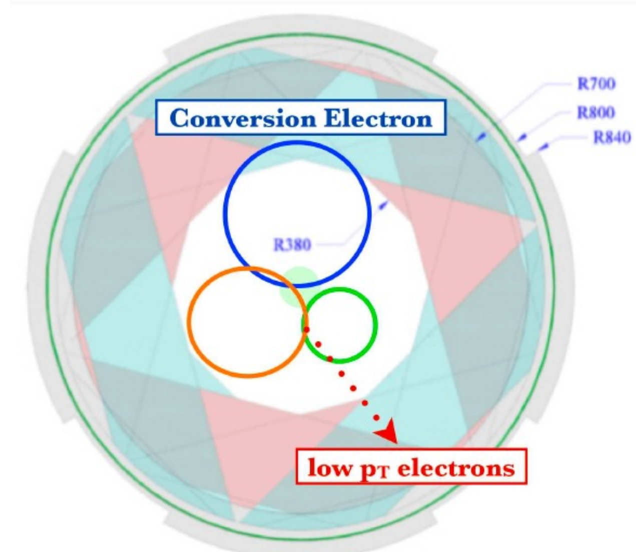


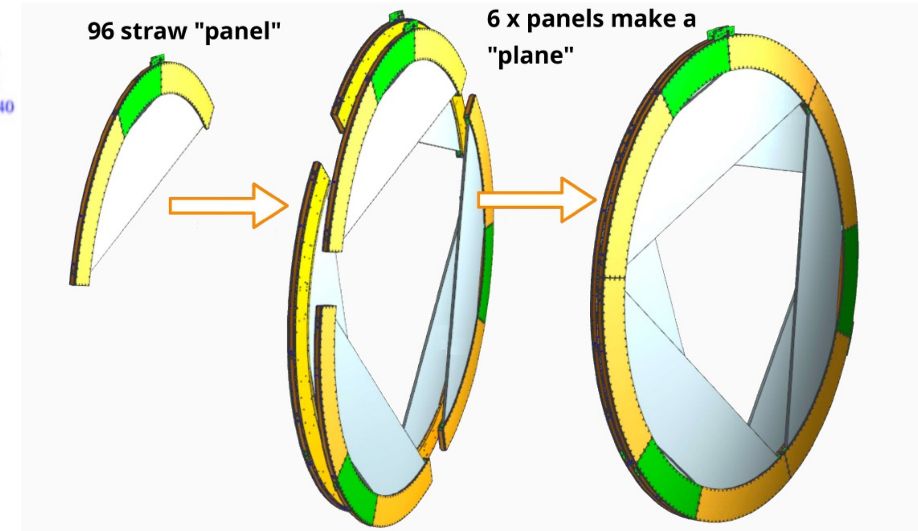


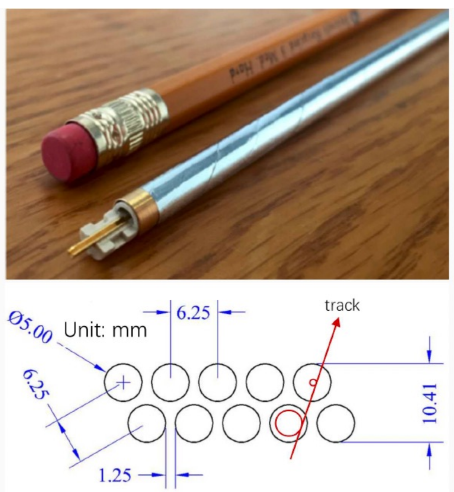
- Measure rates of muonic X and g's lines from Stopping Target using high resolution HPGe and lower resolution (but faster) LaBr3
- 34 m away from the target looking for 3 lines 347 keV "prompt", 844 kev delayed, 1809 keV
- 10 % absolute precision in few minutes of data collection

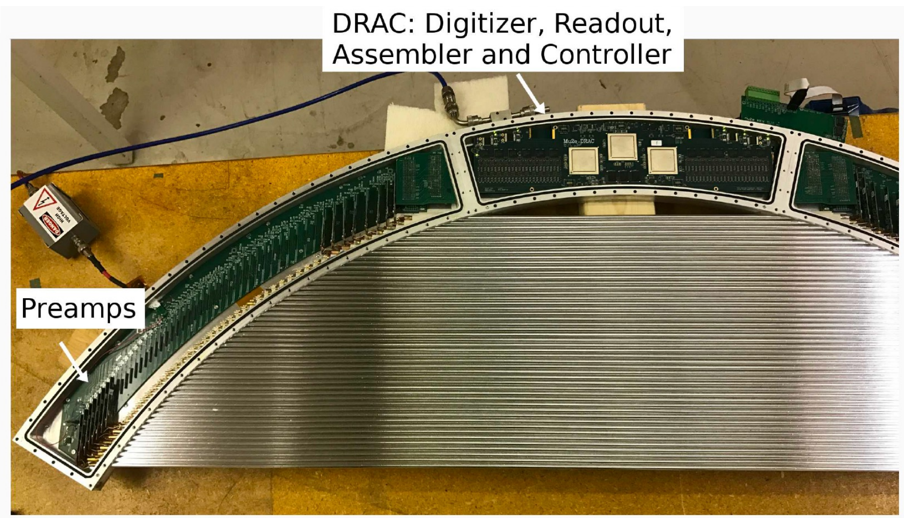
Tracker - design

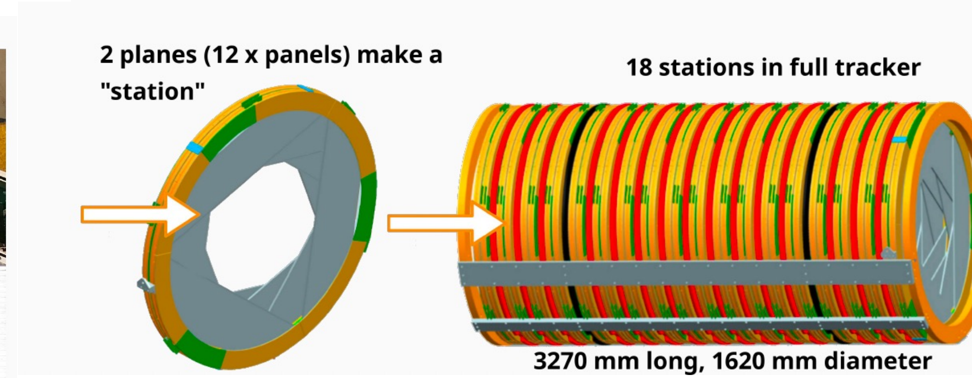
- Very high precision detector
  (~ 180 keV for 105 MeV/c CE)
- ~ 21000 mylar straws
  96/panel x12(panels) x 18(stations)
- Each straw, 5 mm ϕ, 15 um thick
  Mylar walls, 25 um W wire
- 1 Atm of 80/20 Ar/CO_2
- Blind to most of low momentum
  tracks ➔ Annular design



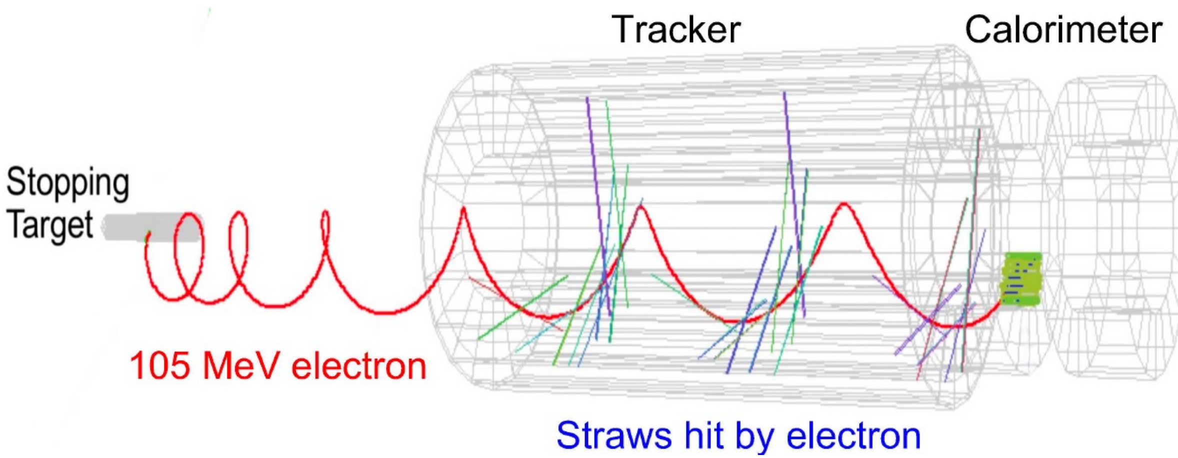


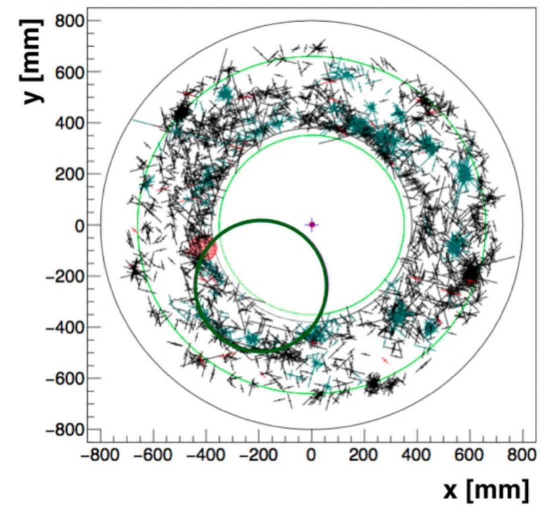


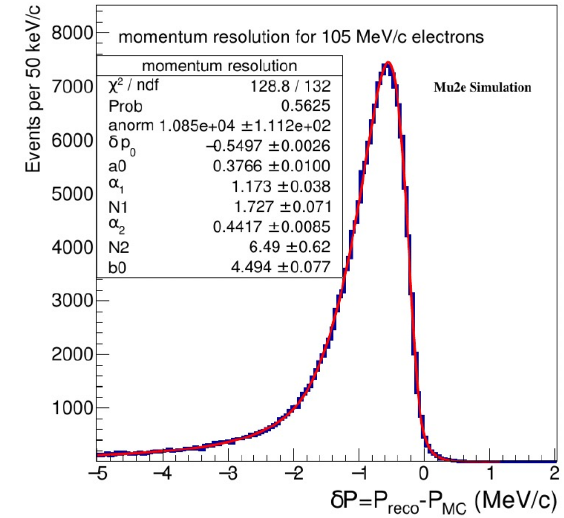




Tracker - performance

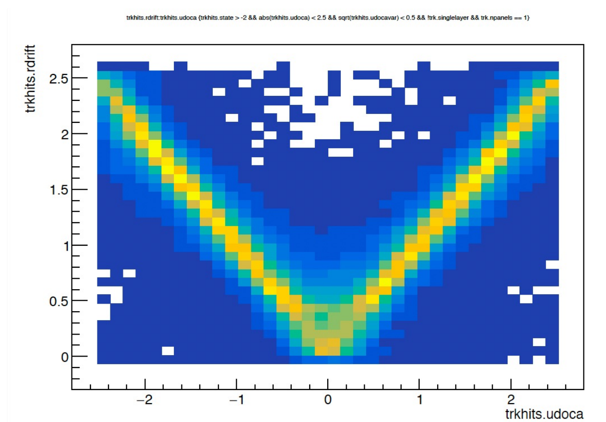


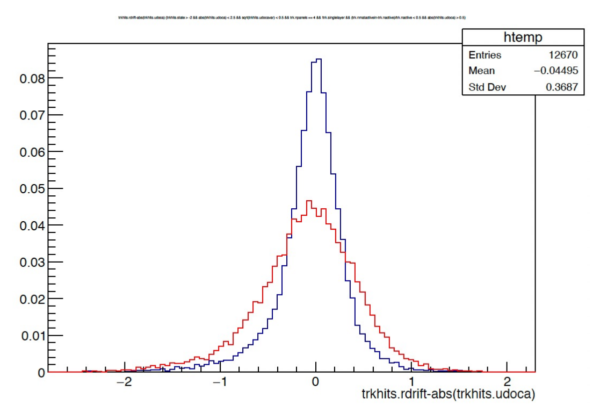


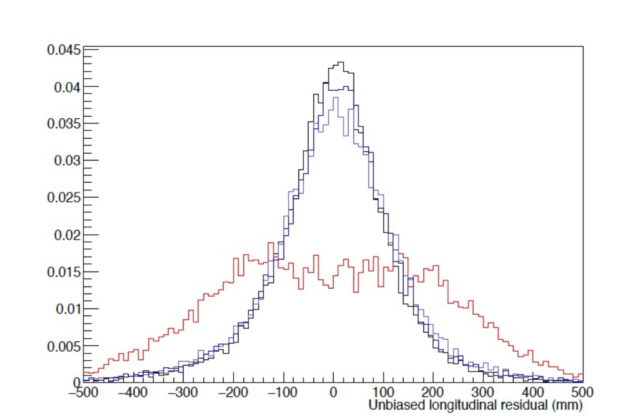


- 105 MeV signal makes 1.5-3 turns, around 40 straw hits/track
- High pileup rate (100 kHz/straw). No external T0 constraint, but can fit from track or use calo
- Intrinsic momentum resolution < 180 keV/c

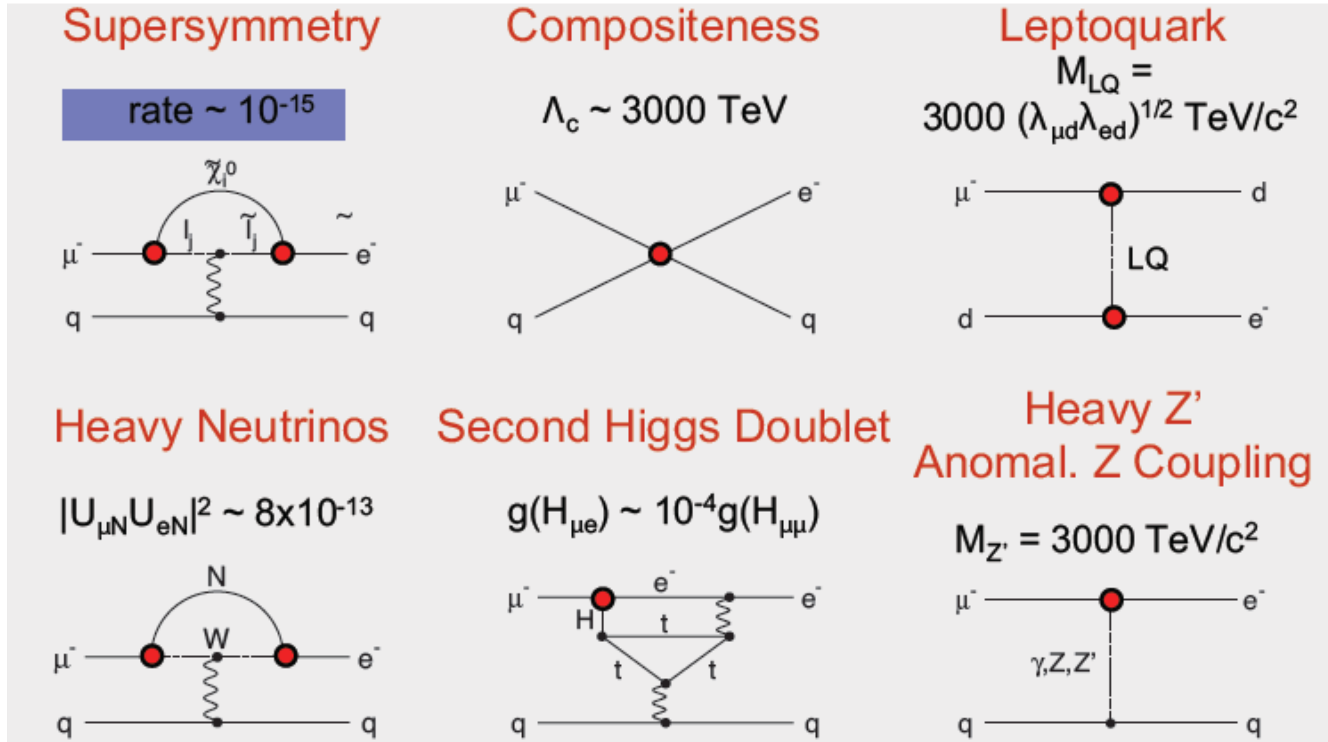
Full 10 hours VST with station and Offline Quality data







CLFV and New Physics

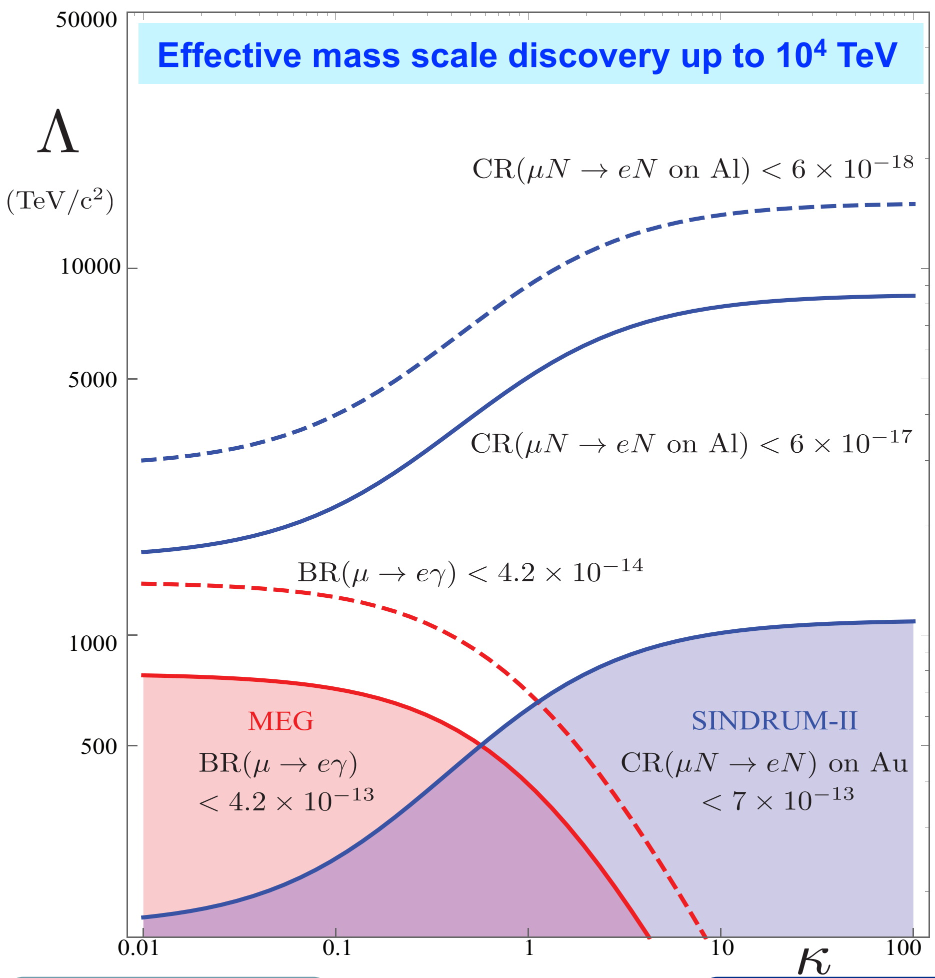


If SUSY seen at LHC → rate ~10^{-15}

O(40) reconstructed signal events with negligible background for many SUSY models.

Mu2e/COMET keep discovery sensitivity for all SUSY benchmark point for LHC Phase2

Charge Lepton Flavour Violation

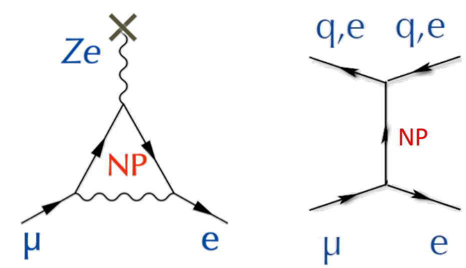


κ <<1: LOOP DOMINATED

κ >>1: CONTACT DOMINATED

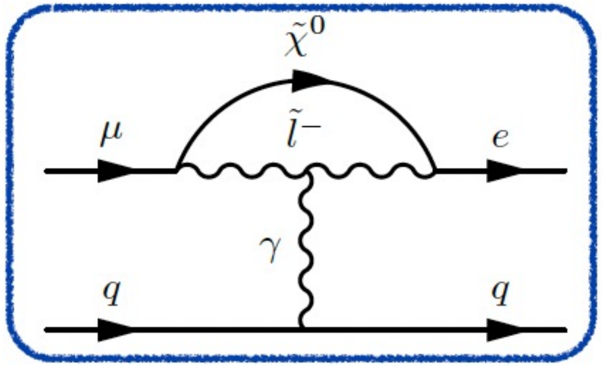
Effective CLFV Lagrangian:

$$L_{CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L)$$

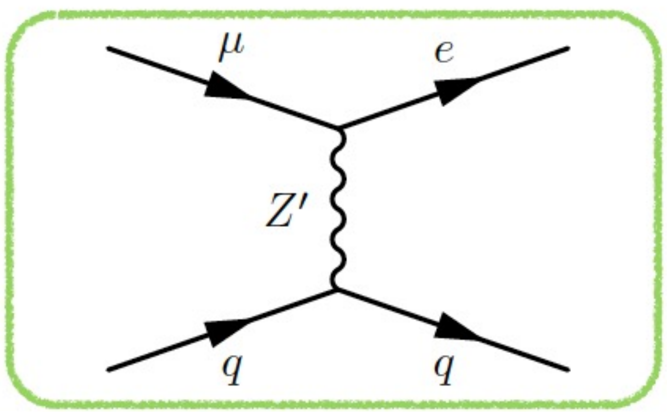


Loop dominated

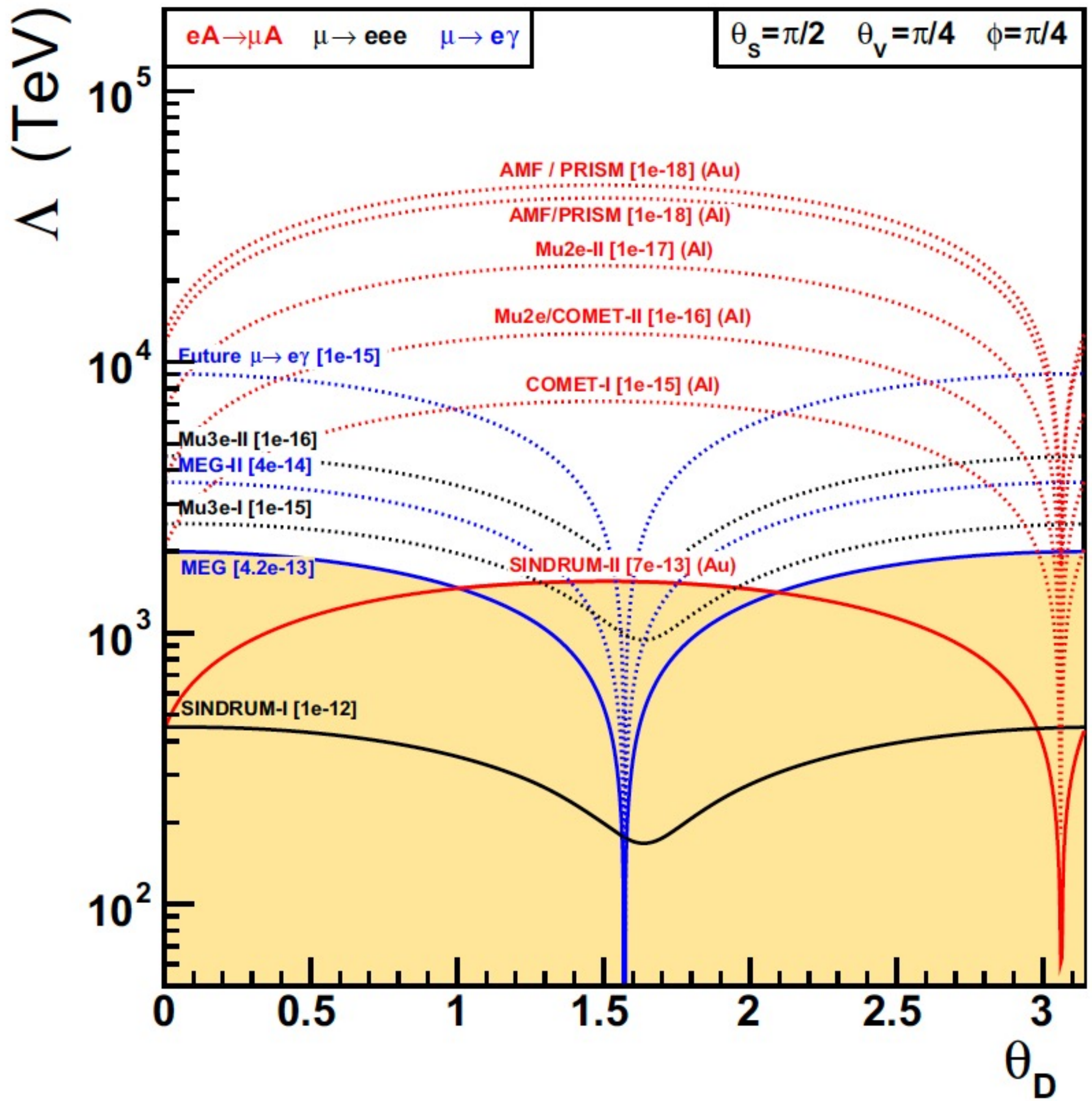
Contact dominated



Photonic process



Four-fermion process



Davidson, S., Eur. Phys. J. C 82, 836 (2022).