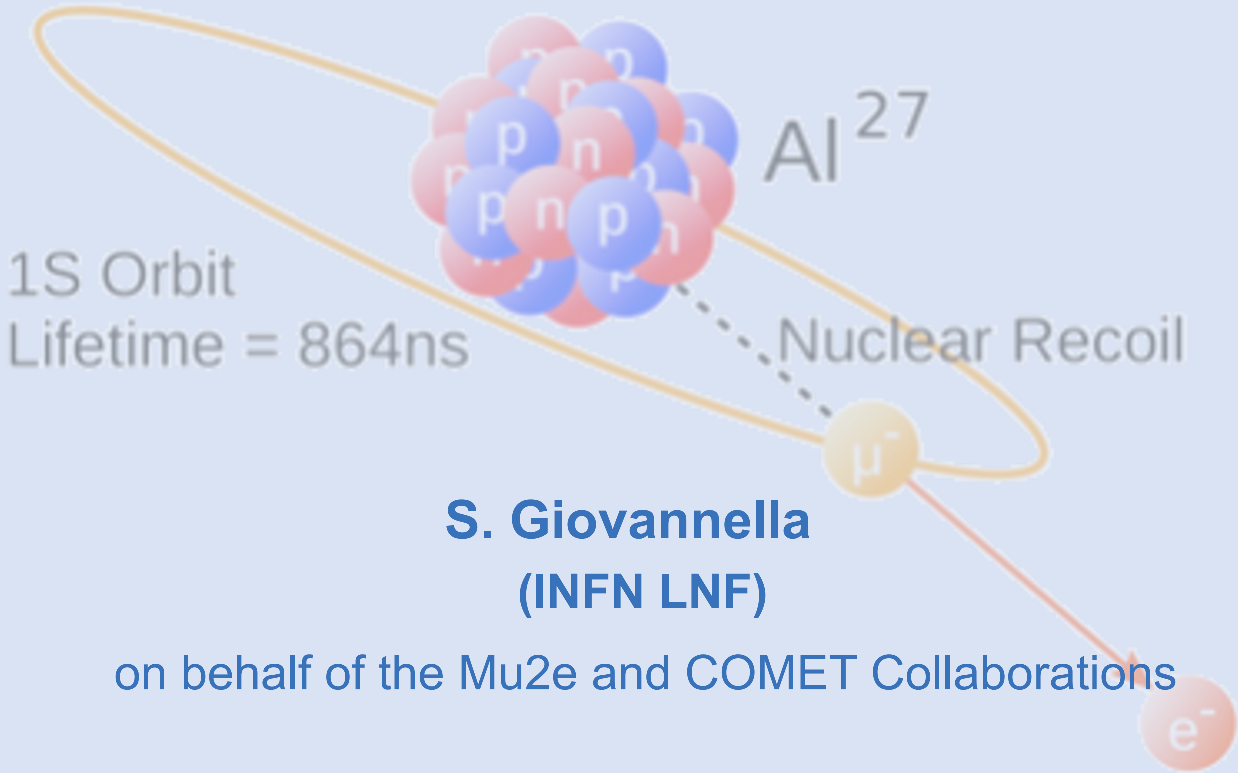
Status of Mu2e and COMET experiments



S. Giovannella

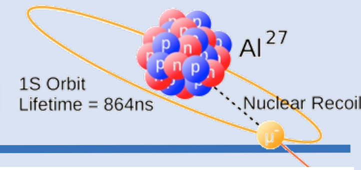
(INFN LNF)

on behalf of the Mu2e and COMET Collaborations

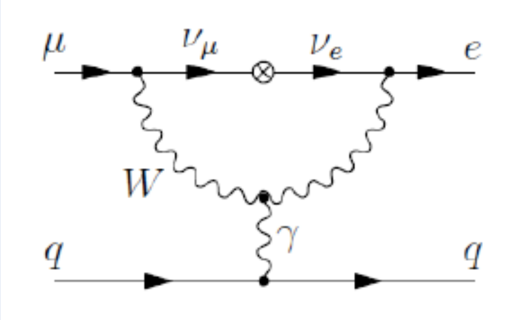
Workshop on flavour changing and conserving processes 2022

22-24 September 2022 – Capri

Charge Lepton Flavour Violation



- **CLFV** processes **strongly suppressed in Standard Model**
  - ✓ in principle, not forbidden due to neutrino oscillation
  - ✓ in practice, negligible (rate ~ $\Delta M_\nu^4/M_W^4 < 10^{-50}$)



- Broad array of **New Physics models predict rates observable** at next generation CLFV experiments

➡ any observation of **CLFV** would be **unambiguous evidence of New Physics**

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0-\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B\to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+\to\pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L\to\pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu\to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau\to\mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu+N\to e+N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

W.Altmannshofer er al., Nuclear Physics B 830 (2010)

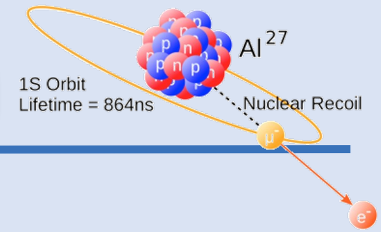
Most promising CLFV measurements use muons:

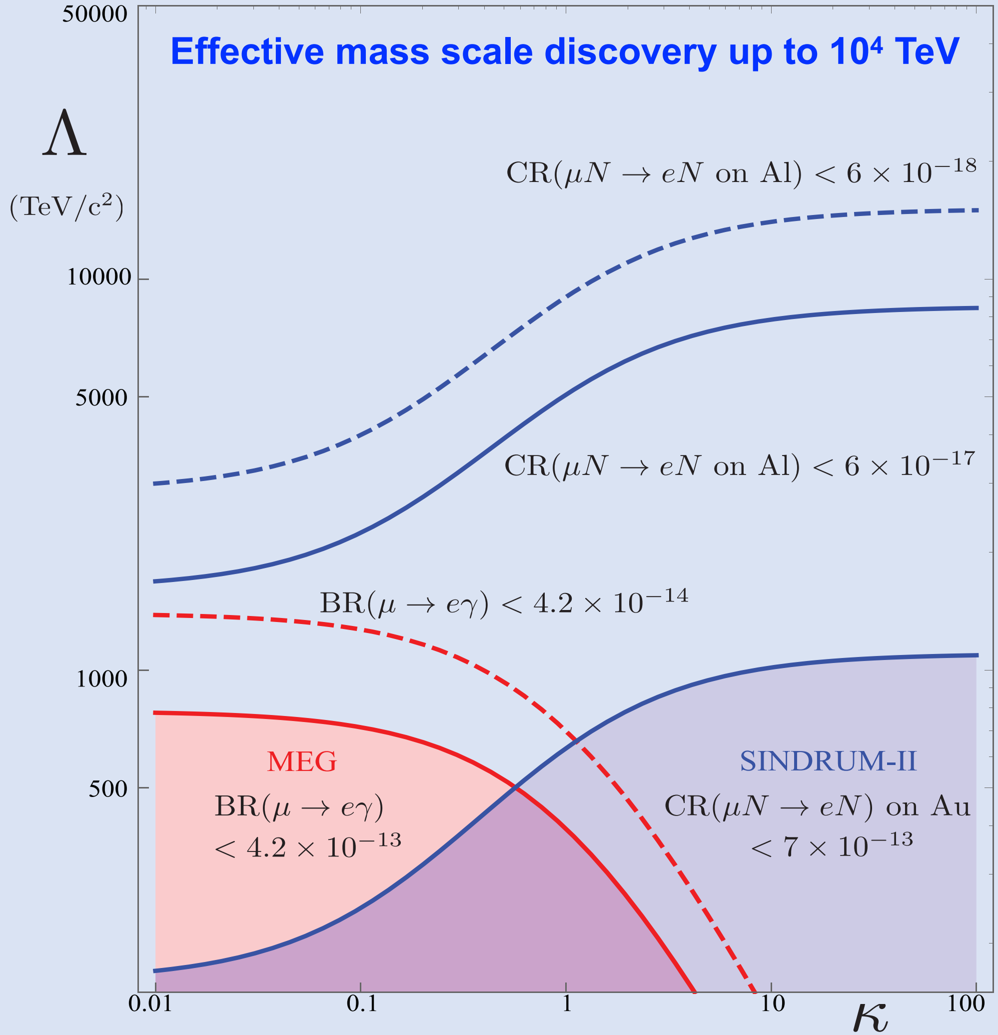
- ➢ clean topologies
- ➢ large rates
- ➢ sensitive to many NP models

CLFV@Mu2e/COMET: coherent neutrinoless conversion of a muon to an electron in the field of a nucleus

★★★ Large effects
★★ Visible but small
★ No sizeable effect

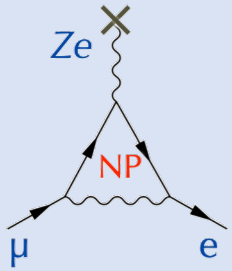
Charge Lepton Flavour Violation



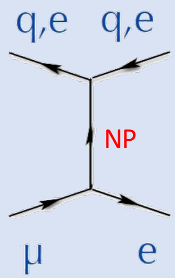


Effective CLFV Lagrangian:

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



Loop dominated

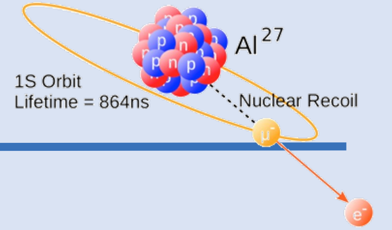


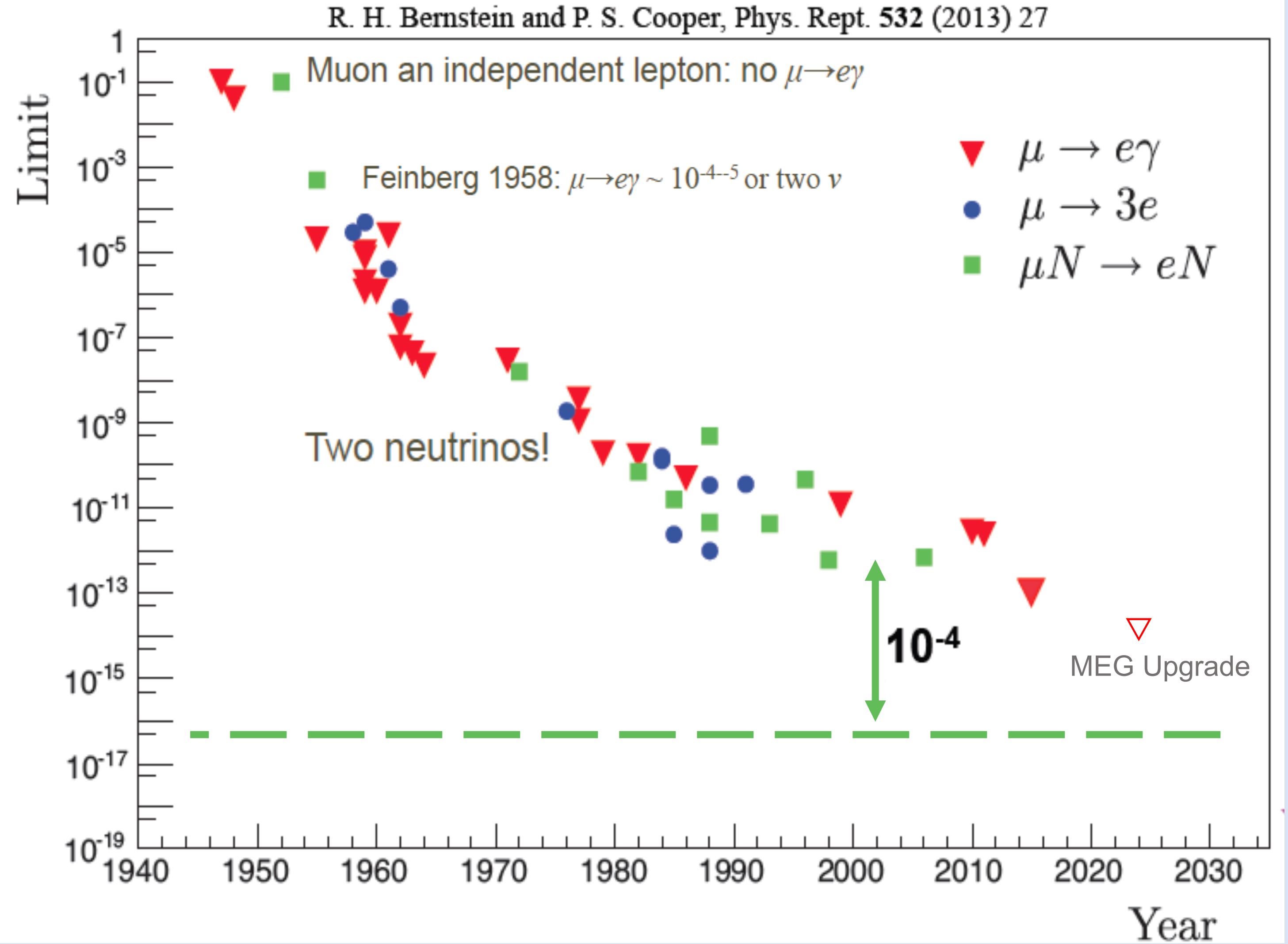
Contact dominated

κ <<1: LOOP DOMINATED

κ >>1: CONTACT DOMINATED

CLFV with muons





Current best limits:

MEG-2016
BR($\mu \rightarrow e\gamma$) < 4.2 x 10^{-13}

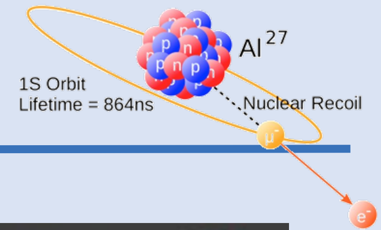
SINDRUM-1988
BR($\mu \rightarrow 3e$) < 1 x 10^{-12}

SINDRUM-II 2006
$R_{\mu e}$ < 6.1 x 10^{-13}

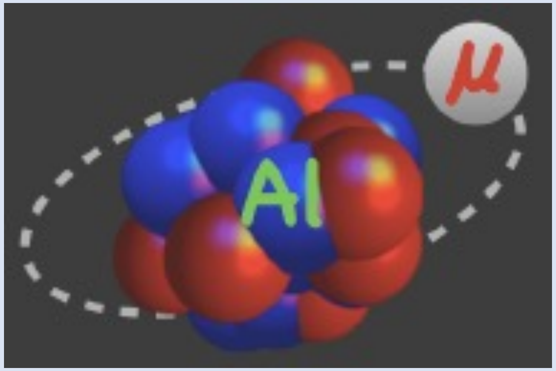
MU2E/COMET GOAL:
$R_{\mu e}$ = 6 x 10^{-17}

Mu2e and COMET aim to improve by a factor 10^4 the present best limit

$\mu N \rightarrow eN$: experimental technique



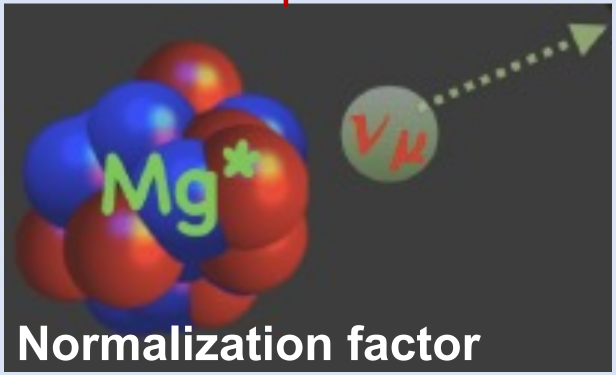
- Beam of low momentum muons
- Muons stopped in Al target
- Muons trapped in orbit around the nucleus
- Look for $\mu^- N(A,Z) \rightarrow e^- N(A,Z)$ events: mono-energetic e^- with $E \sim M_\mu$, produced
- Normalize to muon captures counting emitted muonic X-rays



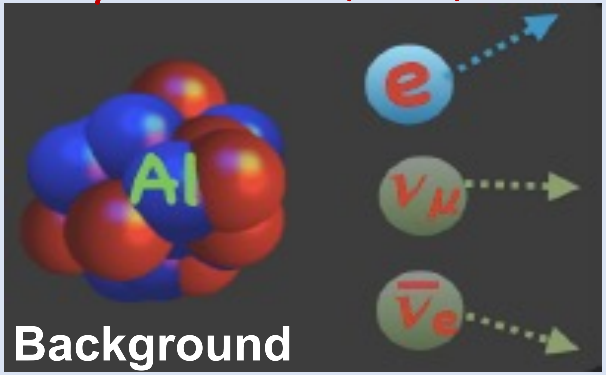
τ_μ^{Al} = 864 ns

Muonic atom at rest can undergo to:

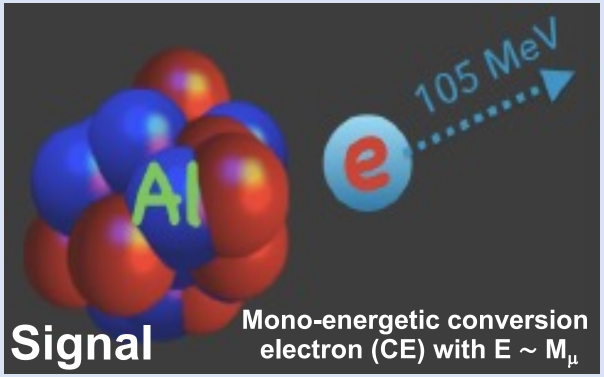
Nuclear capture ~ 61%



Decay In Orbit (DIO) ~ 39%

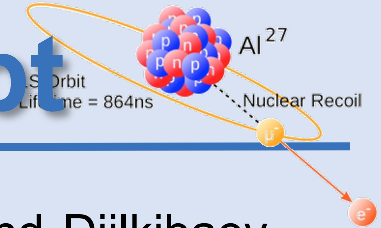


Conversion < 10^{-12}



Slow neutrons and protons + γ's from muon capture create a lot of random hits in the detector

$\mu N \rightarrow eN$: experimental concept

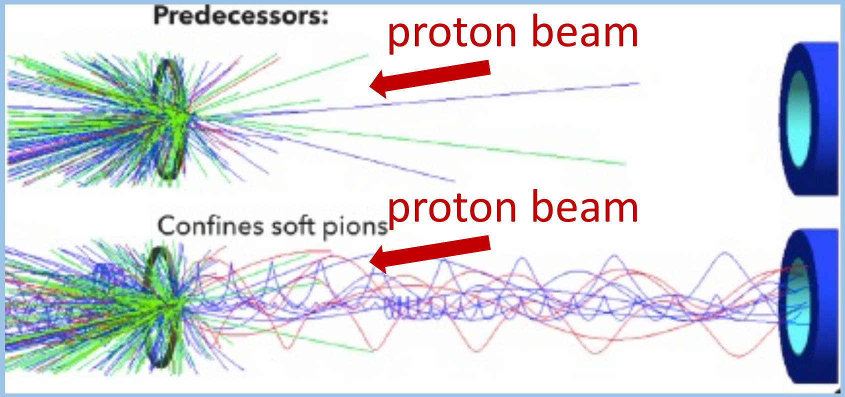


Concept of the Mu2e/COMET experiments proposed by Lobashev and Djilkibaev in 1989 for the MELC experiment at INR, Russia [Sov.J.Nucl.Phys. 49, 384 (1989)]

Key ideas:

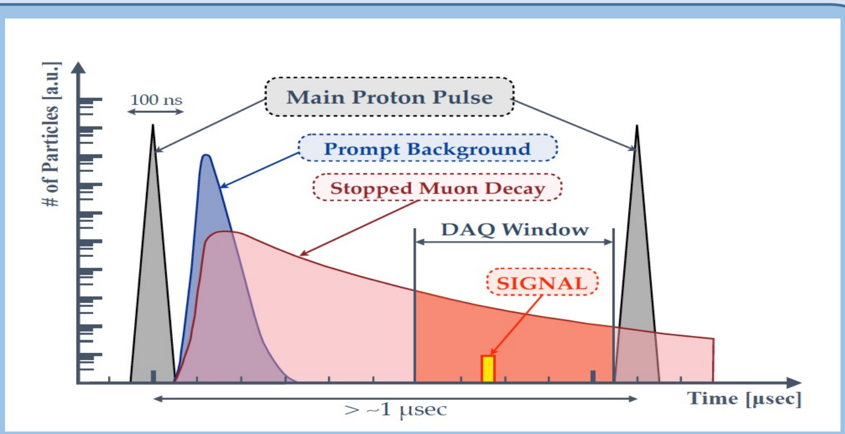
Very intense muon beam

- Soft pions confined with solenoidal B field
- Strong gradient to increase the yield through magnetic reflection

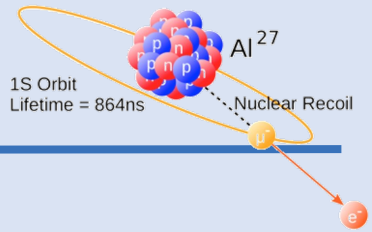


Pulsed beam

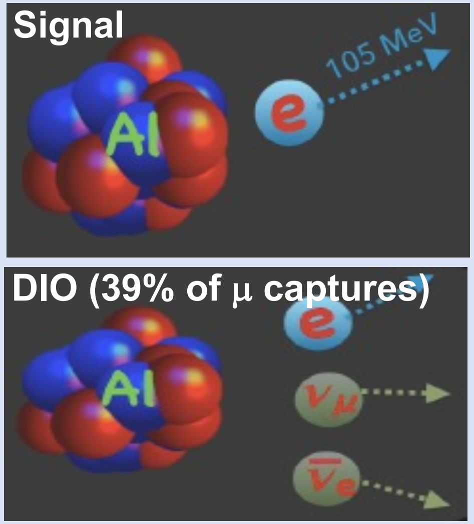
- Delayed live gate to suppress prompt backgrounds
- Narrow proton pulses
- $O(10^{10})$ out-of-time protons suppression

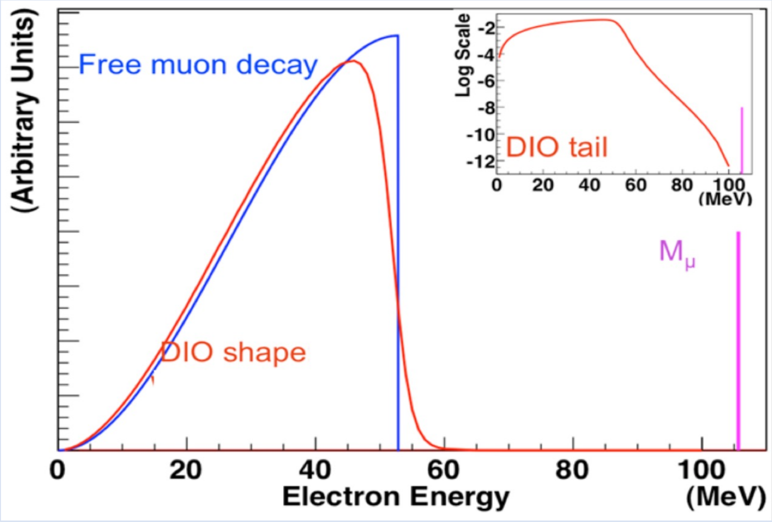


$\mu N \rightarrow eN$: main backgrounds



Muon decays in orbit





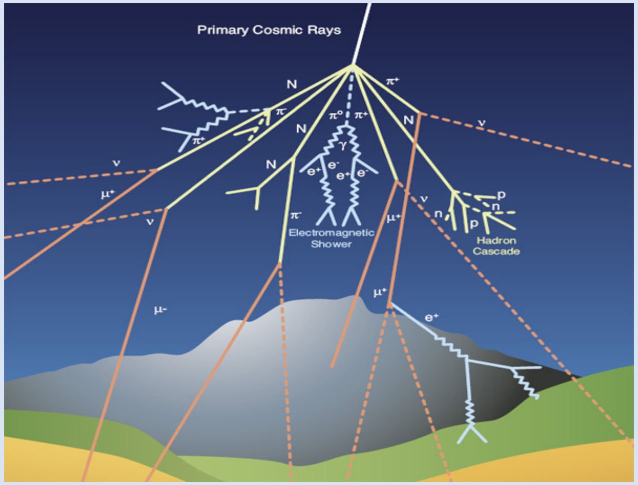
- Nuclear modifications push DIO spectrum near conversion electron (CE)
- DIO and CLFV signal, overlap after energy loss and detector resolution

e^- detection with a momentum resolution $\lesssim$ 0.2% is required

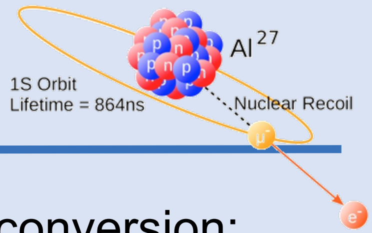
Cosmic Ray events

- Cosmic Ray muons can fake signal events or knock out an electron
- These events are proportional to the running time
  ➡ higher beam intensity is preferrable

Detector region covered by Cosmic Ray Veto counters: 10^{-4} inefficiency required



Mu2e and COMET



Two experiments are under construction to search for coherent muon conversion:

Mu2e (Fermilab, US) **COMET (J-PARC, KEK, JP)**

Medium-size collaborations:

- **> 200 members**
- **~ 40 institutes**

Goal: improvement by a factor of 10^4 on the measurement of

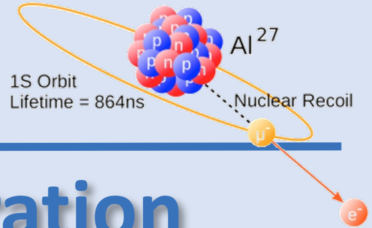
$$R_{\mu e} = \frac{\Gamma\left(\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)\right)}{\Gamma\left(\mu^- + N(A,Z) \rightarrow all\ muon\ captures\right)}$$

Current best limit set by Sindrum-II $R_{\mu e} < 7 \times 10^{-13}$

reaching a final **single-event-sensitivity of 3×10^{-17}** through different running phases

This requires:
- **10^{18} stopped muons**
- high background suppression (**$N_{bckg} \ll 0.5$**)

Mu2e and COMET



Mu2e collaboration

COMET collaboration

Goal: improvement by a factor of 10^4 on the measurement of

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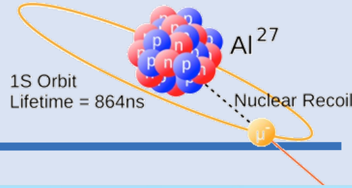
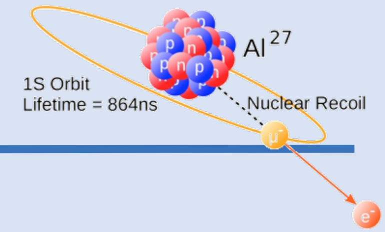
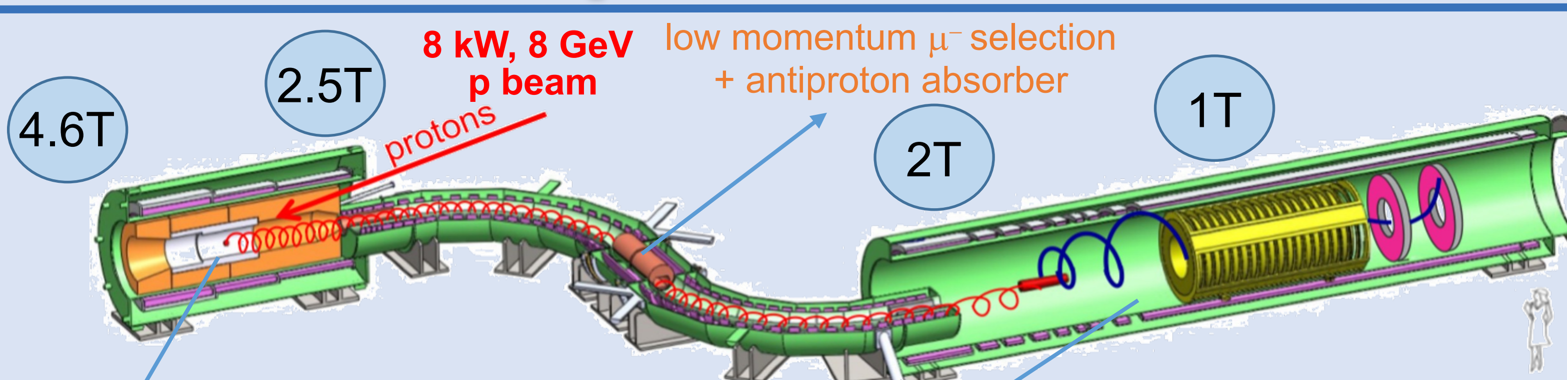
Some perspectives



1,000,000,000,000,000,000
= number of stopped Mu2e muons
= number of grains of sand on earth

The Mu2e Experiment



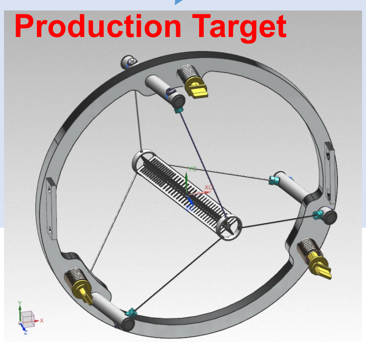


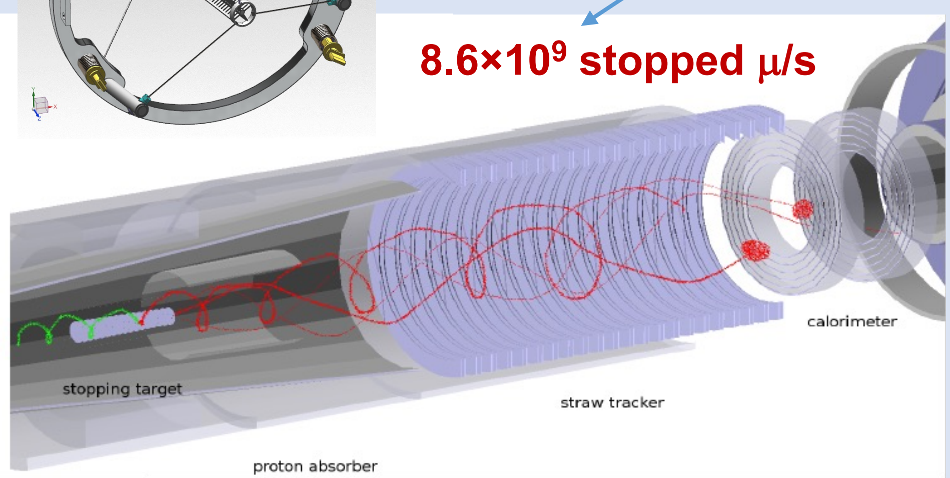
Production and Transport Solenoids

Production, selection and transport of low momentum muon beam

Detector Solenoid

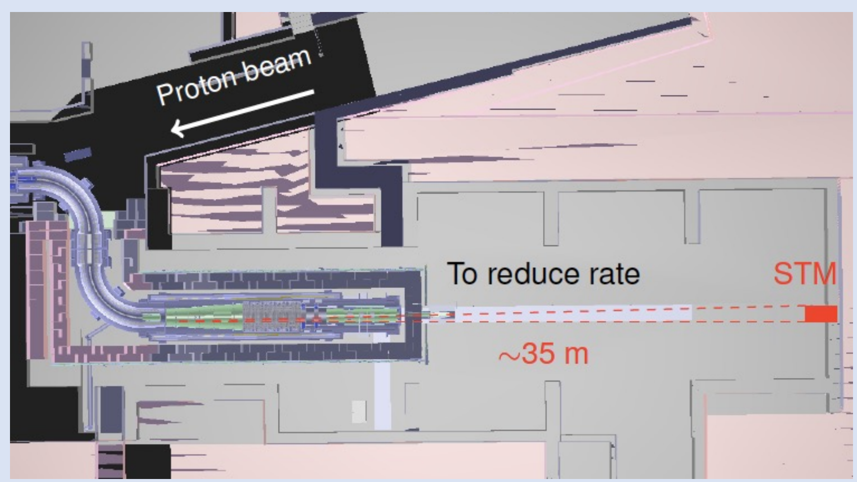
- Muon capture on Al target
- Tracker, EM Calorimeter





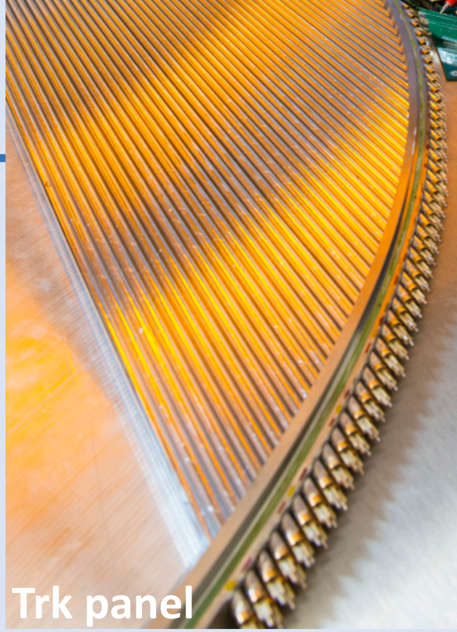
Stopping Target Monitor

- Provides normalization factor
- Detects x-rays emitted from muon capture

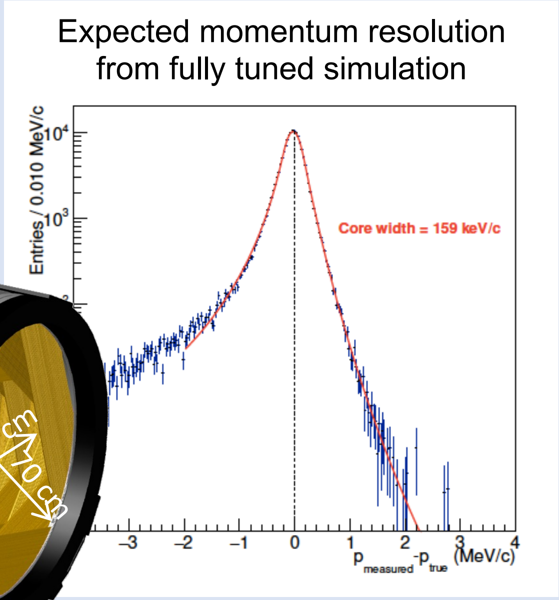


The Mu2e Tracker

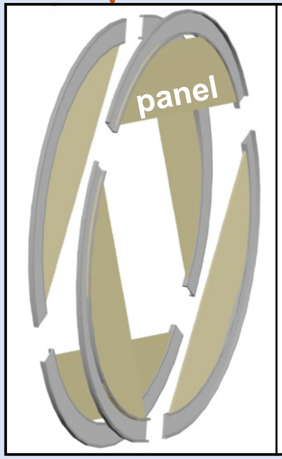
Detector requirements:
- Small X_0
- $\sigma_p < 180$ keV @ 105 MeV
- Good rate capability (20 kHz/cm^2 in live window, beam flash of 3 MHz/cm^2)
- dE/dx capability to distinguish e^-/p



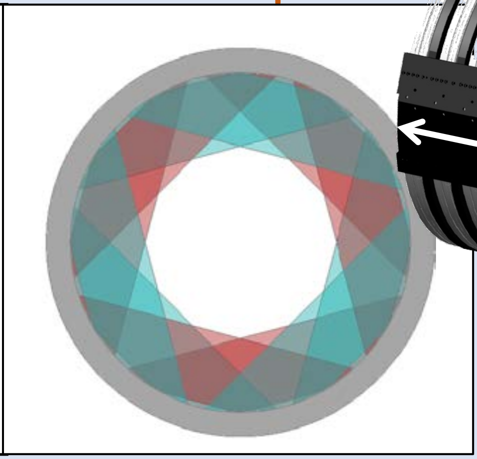
- > 20,000 low-mass straw tubes, 5 mm Ø, 33 – 117 cm length
- 15 μm Mylar wall, 25 μm Au-plated W wire, 80:20 Ar:CO_2 @ 1 atm
- Dual-ended readout ➤ position along wire
- Self-supporting panel consists of 2×48 straws, two staggered layers
- Rotation of panels (stereo reconstruction) arranged in planes on stations



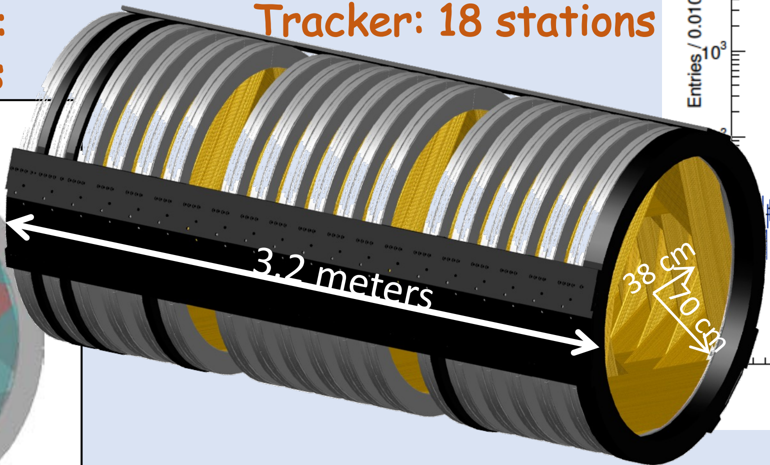
Tracker Plane: 6 panels



Tracker Station: 2 rotated planes

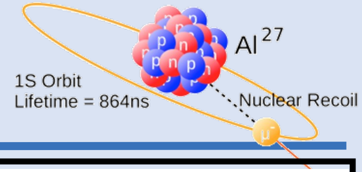


Tracker: 18 stations



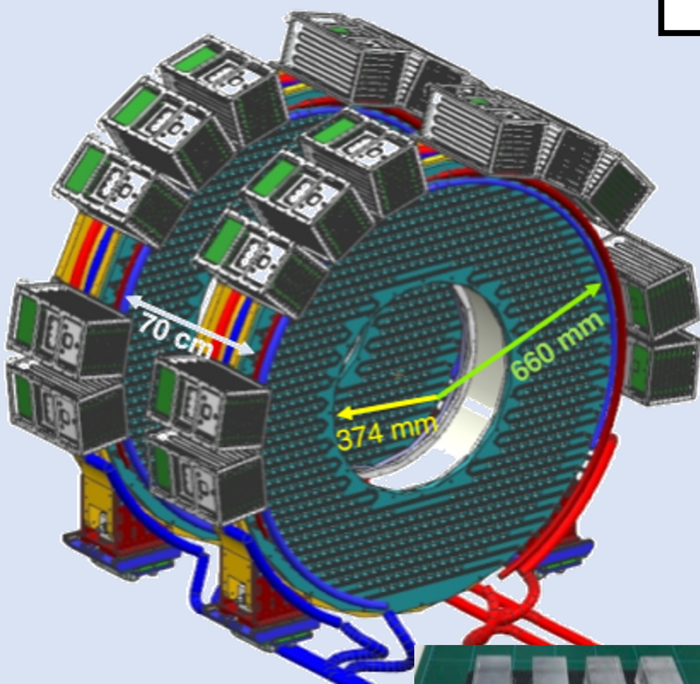
Innermost 38 cm purposely un-instrumented
- ➢ Blind to beam flash (low p_t particles) and >99% of DIOs

The Mu2e Calorimeter

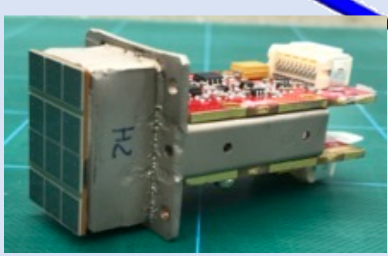


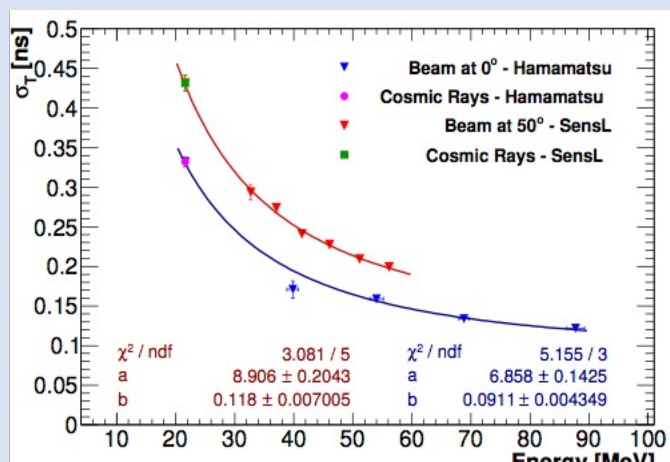
- PID: e/μ separation
- EMC seeded track finder
- Standalone trigger

Requirements:
- $\sigma_E/E = \mathcal{O}(10\%)$ for CE
- σ_T < 500 ps for CE
- $\sigma_{X,Y} \leq 1$ cm
- High acceptance for CE
- Fast (τ<40 ns)
- Operate in 1T and 10^{-4} Torr
- Redundancy in readout
- Radiation hard: 90 krad photons and 3×10^{12} n/cm^2



EMC Design:
- Two annular disks, $10X_0$ length, ~ 75 cm separation
- 2× 674 square x-sec **pure CsI crystals**, (34×34×200) mm^3
- For each crystal, two custom array (2×3 of 6×6 mm^2) **large area UV-extended SiPMs**
- Analog FEE directly mounted on SiPM
- Calibration/Monitoring: 6 MeV radioactive source + laser

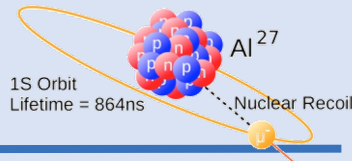




Test beam with 60-120 MeV e^-:

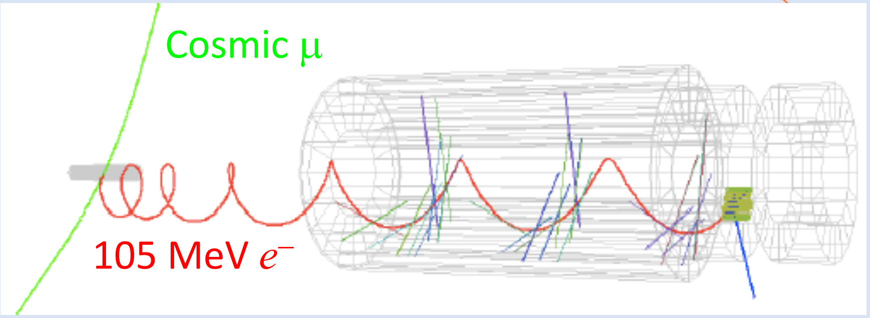
σ_T < 150 ps
σ_E < 10%
@ 100 MeV

The Mu2e Cosmic Ray Veto



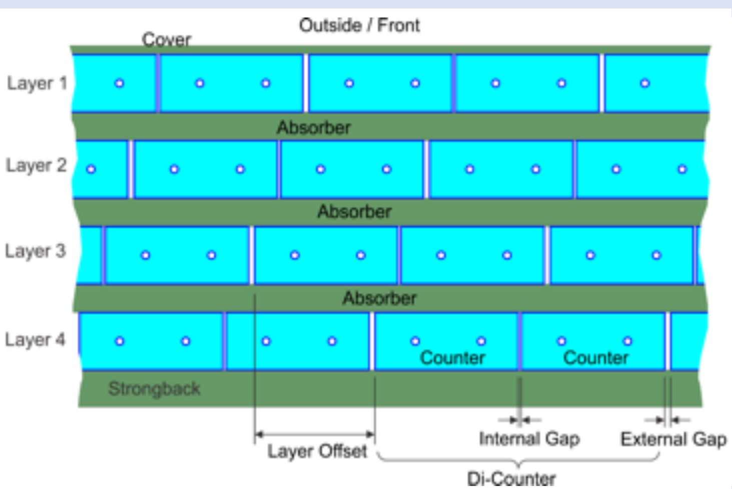
~ 1 event/day from cosmic rays producing a fake signal event per day without a CRV

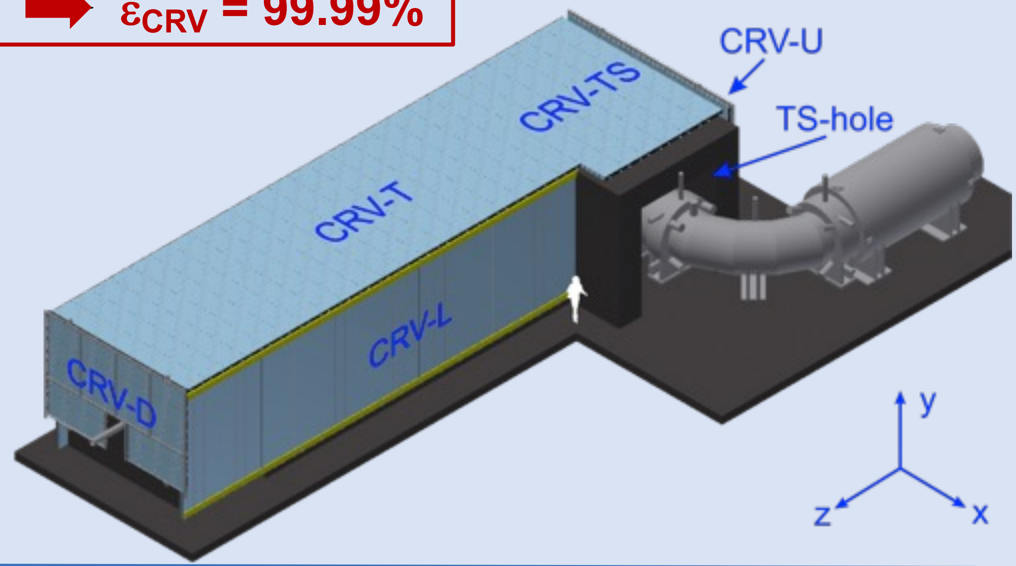
→ **Passive shielding + PID trk/EMC + CRV**



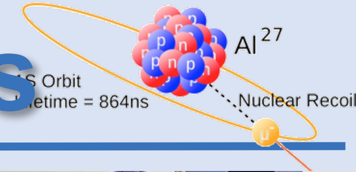
- CRV covers the entire Detector Solenoid and half Transport Solenoid
- Four layers of extruded plastic scintillator (5×2×85÷690) cm^3 + absorber
- 2 WLS fibers (1.4 mm diameter) + (2×2) mm^2 SiPM readout
- 3/4 layers hit: 125 ns veto

$\boldsymbol{\varepsilon_{CRVplane} = 99.6\%}$ ➡ $\boldsymbol{\varepsilon_{CRV} = 99.99\%}$

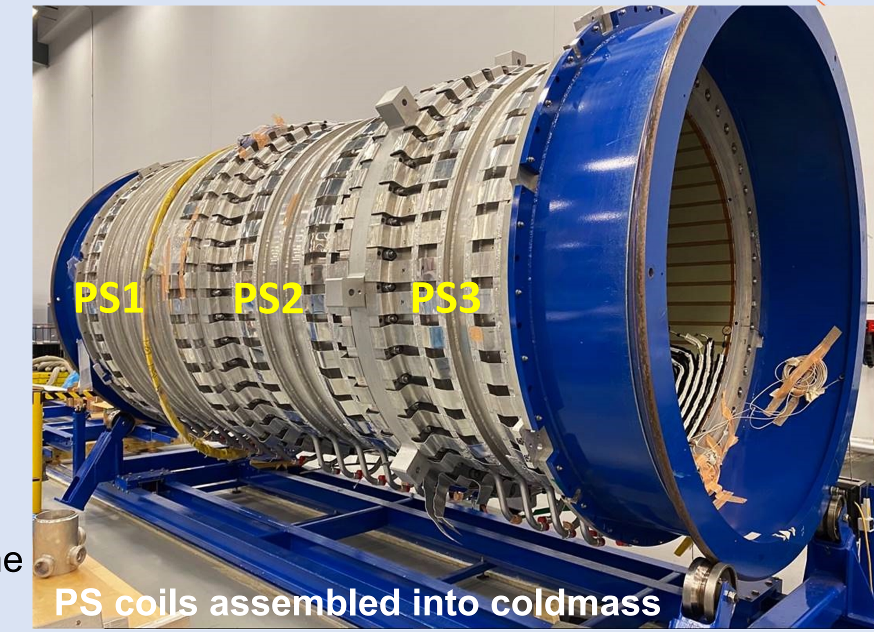




Mu2e construction: solenoids

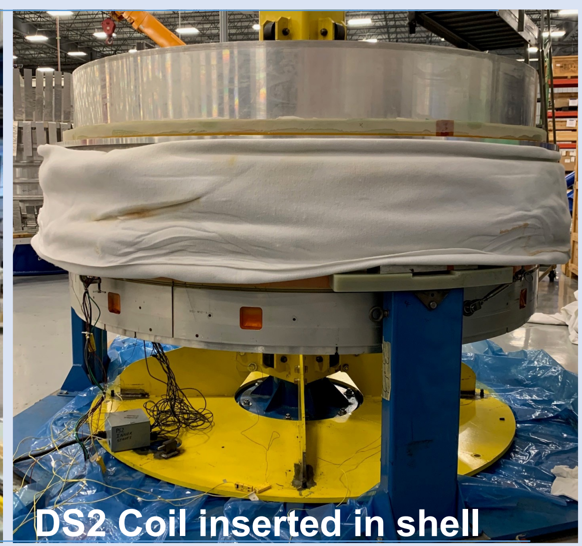


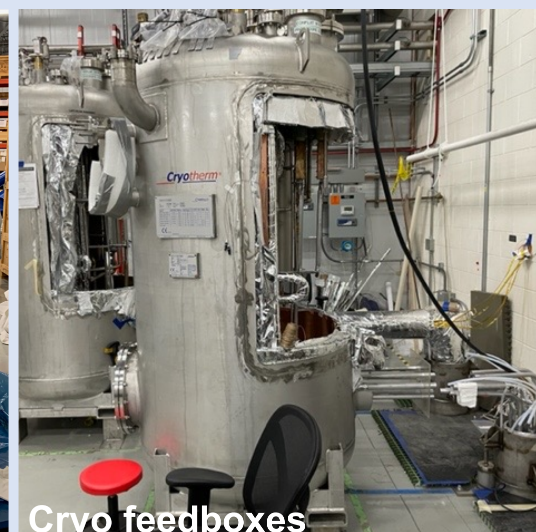
- **Production Solenoid (3 units):**
  - PS coils completed and assembled
  - Cold Mass cryo assembly 75% complete
- **Transport Solenoid (14 units):**
  - TSu cryostat, TSd thermal shield in place
  - Successful TS testing campaign
- **Detector Solenoid (11 units):**
  - 8 coils completed, remaining 3 in fabrication
- **Cryogenics and Quench protection:**
  - PS/TSu cryo feedboxes installed, 8 transfer lines done
  - Quench protection system assembled or in process



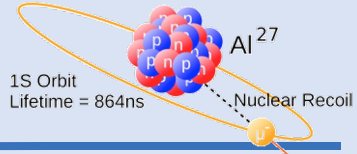
PS coils assembled into coldmass


Upstream TS: outer cryostat in place

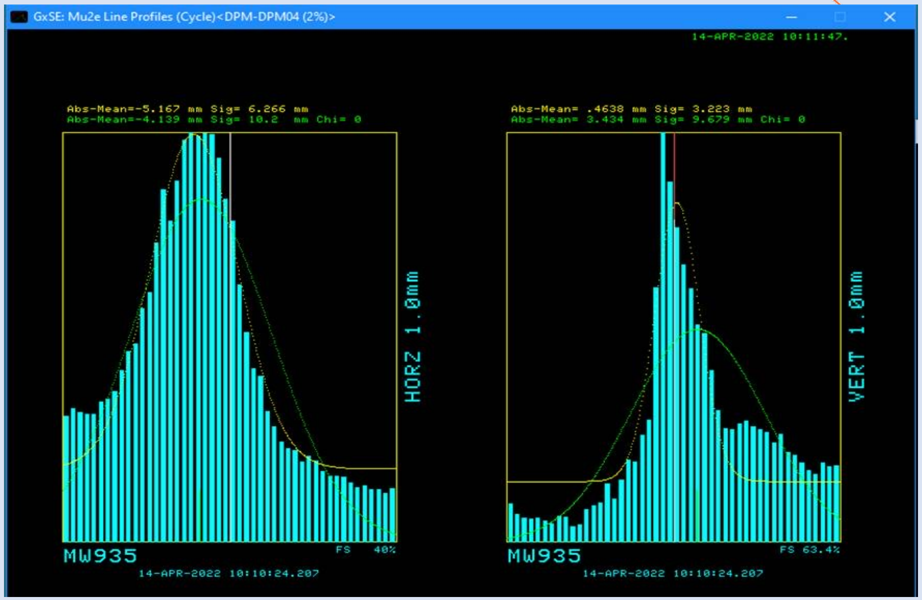

DS2 Coil inserted in shell

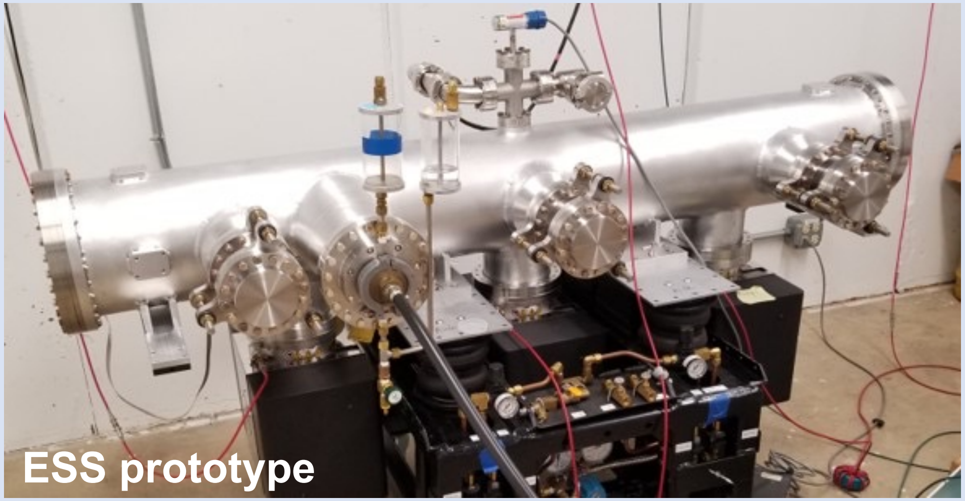

Cryo feedboxes

Mu2e construction: beam



- **Resonant Extraction Magnets installed and tested with beam**
  - Electrostatic Septum (ESS) prototype completed
- **Beamline diagnostic absorber operational**
  - w\ instrumentation, controls and safety system
  - 8 GeV proton beam transported to beamline diagnostic absorber on 14 April 2022, with 90% transmission
- **Production Target assembled**
  - Handling Remote System fabrication completed, ready to be installed into PS
- **Stopping Target assembled**

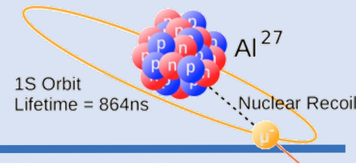



ESS prototype

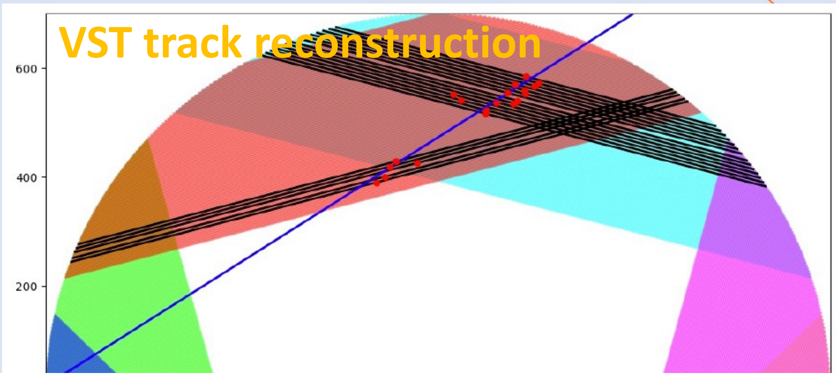

Production target

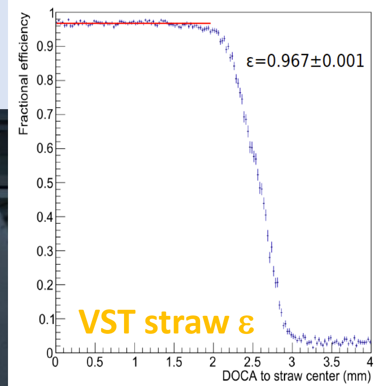

Stopping target

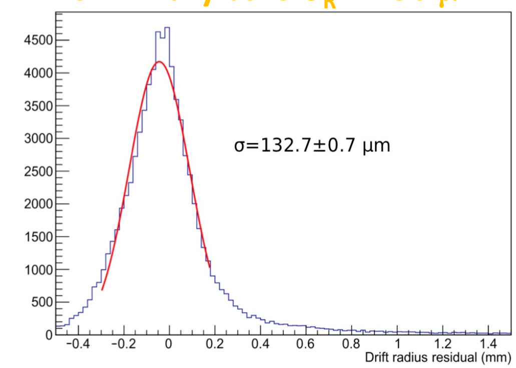
Mu2e construction: tracker

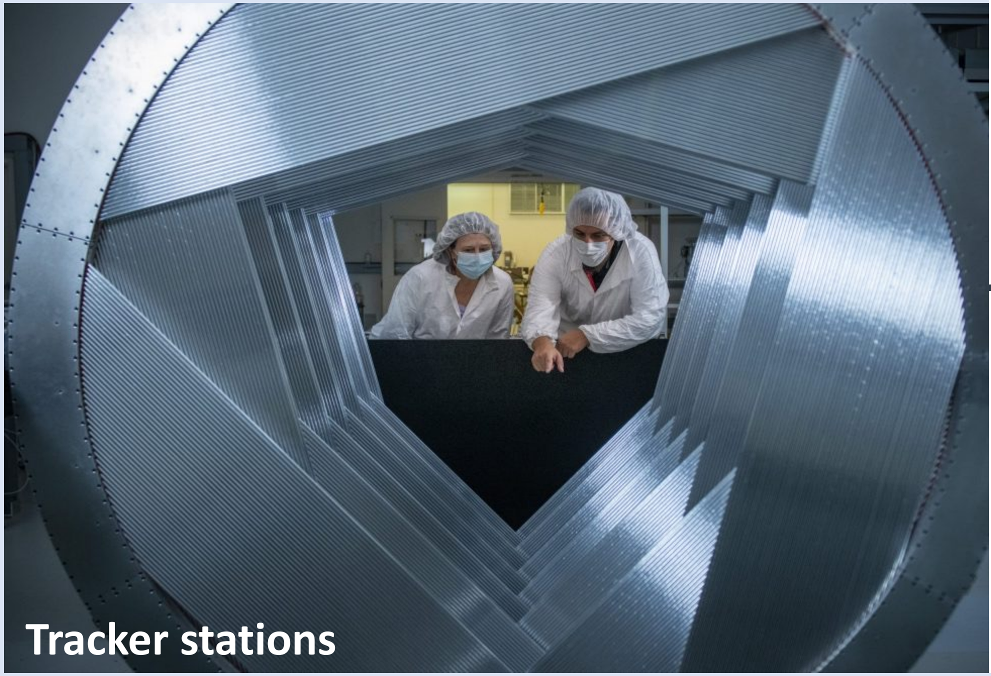


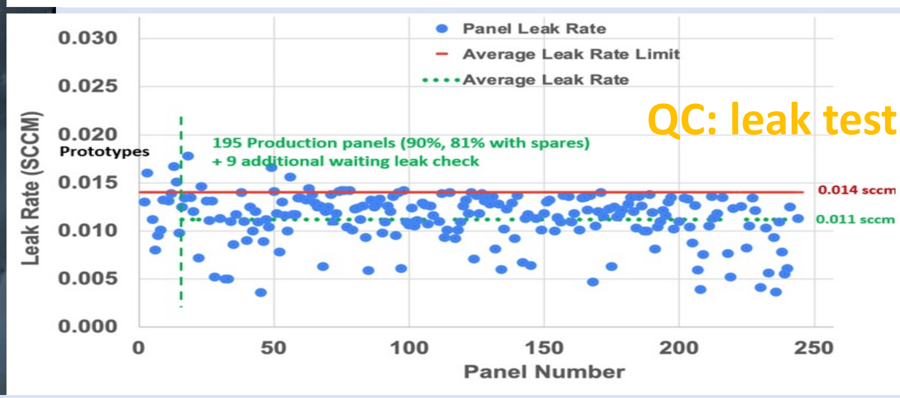
- **Assembling**
  - 92% of panels and 20/36 planes produced
  - Quality Assurance and Control follow closely
- **Electronics**
  - Pre-production performance validation completed
- **Vertical Slice Test**
  - Low noise rate and high efficiency
  - Successful track reconstruction w/ time and drift info
  - Resolution and efficiency meet expectations





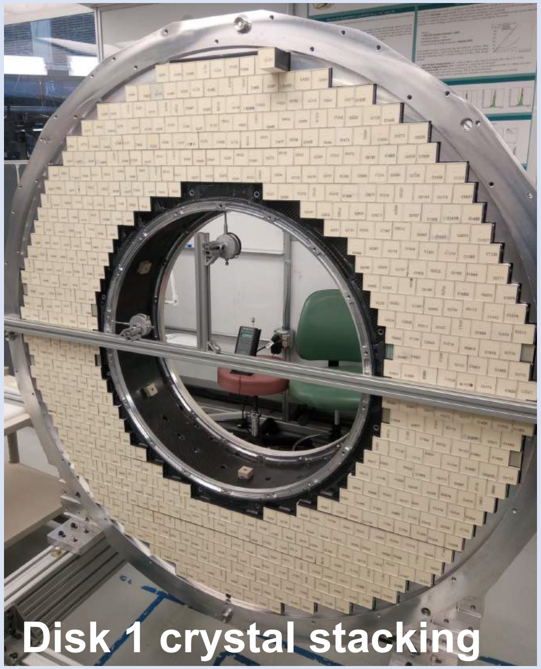


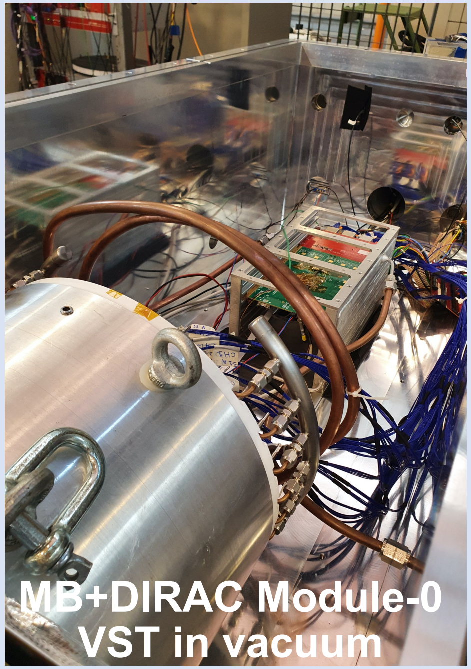




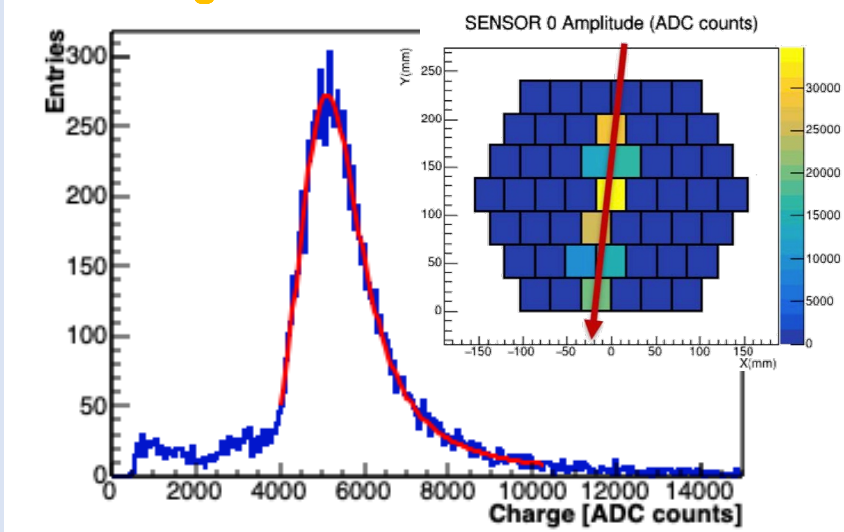
Mu2e construction: calorimeter

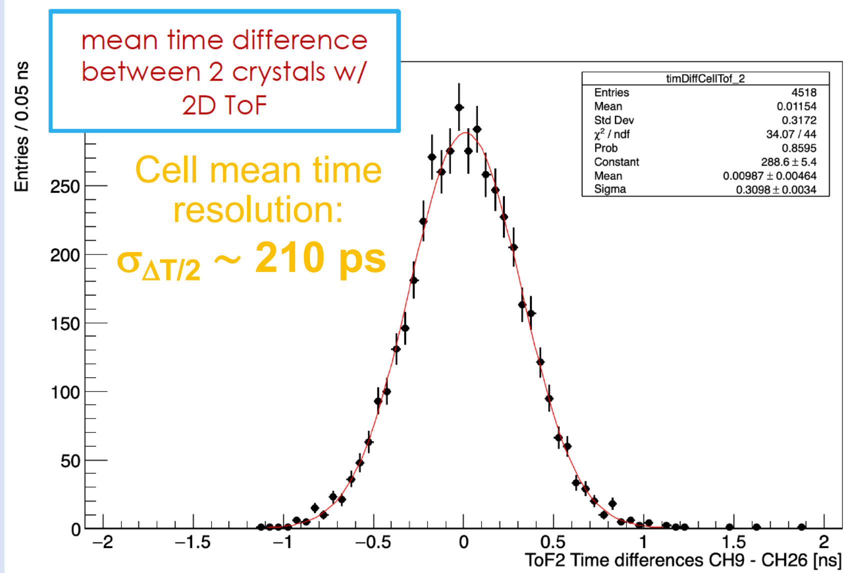
- **Assembling**
  - 1st calorimeter disk fully loaded with crystals
  - Procurements well advanced for source/laser
- **Electronics**
  - Readout units being assembled and tested
  - MB in production, digitizer prototype tested
- **Vertical Slice Test**
  - Runs in vacuum, low temp., irradiated SiPMs
  - E, T calibration algo validated, σ_T exceed requirements



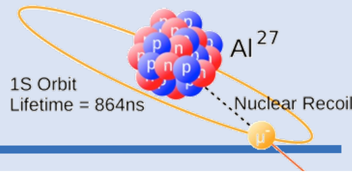


MIP charge distribution

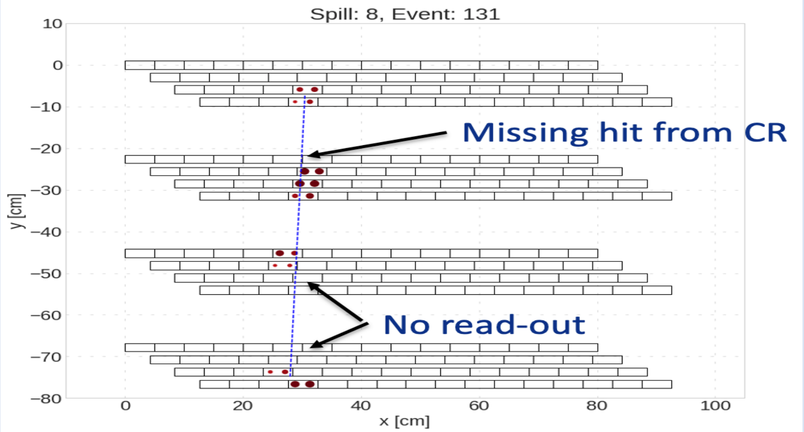


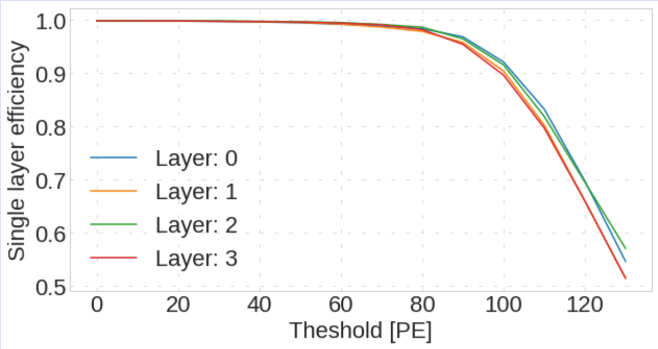


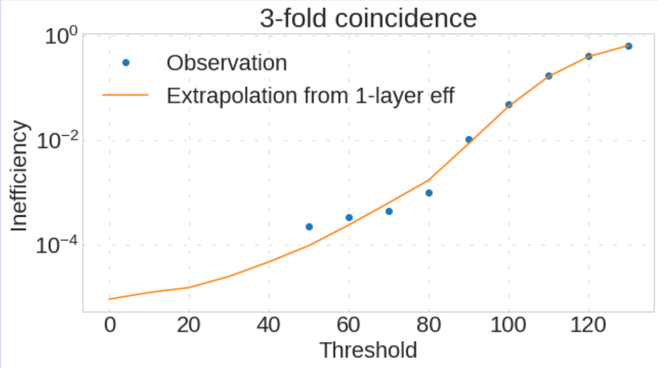
Mu2e construction: CR veto



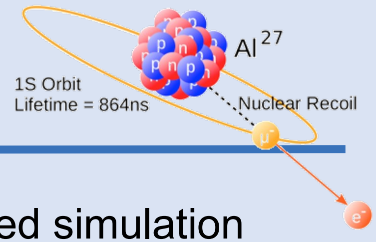
- **Assembling**
  - 69/83 successfully fabricated modules @ FNAL
  - QC: visual inspection and checks for dead channels and light tightness
- **CRV tests @ FNAL**
  - Light yield monitoring, long-term stability
  - Single layer efficiency → CRV module efficiency estimate
  - Practicing calibration algorithms







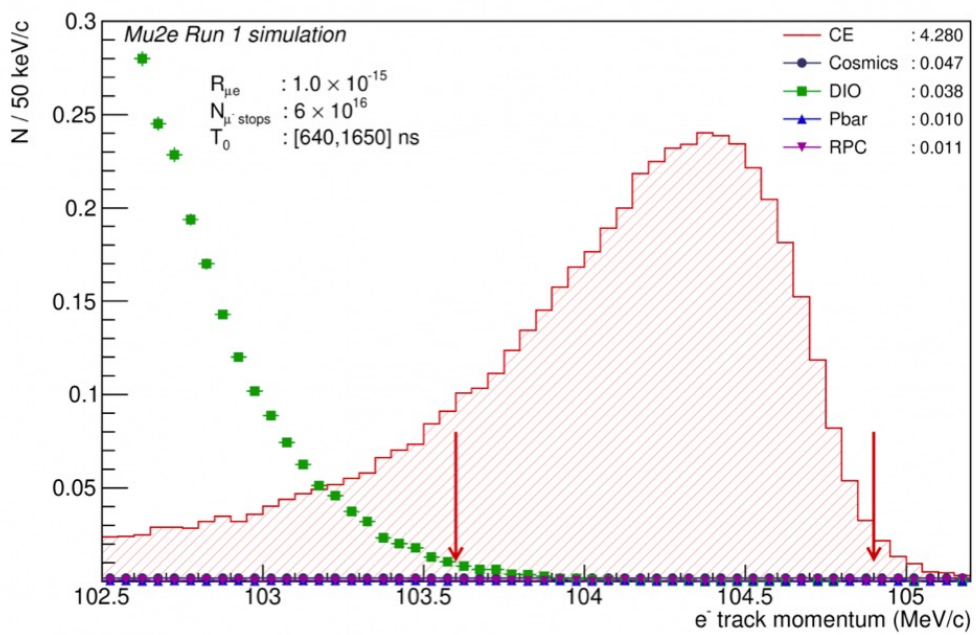
Mu2e Sensitivity Estimate



Recent sensitivity estimate for 3.8×10^{19} POT (first running phase) using detailed simulation

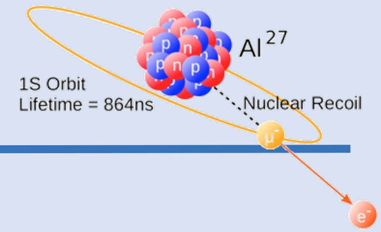
- 5σ discovery **$R_{\mu e} = 1.1 \times 10^{-15}$**
- 90% CL $R_{\mu e} < 5.9 \times 10^{-16}$
- **×1000 better than SINDRUM-II** limit

- **Total background: $0.11 \pm 0.03_{stat.+syst.}$ events**
  - Cosmics = 0.05 ± 0.01 events
  - DIO = 0.04 ± 0.02 events

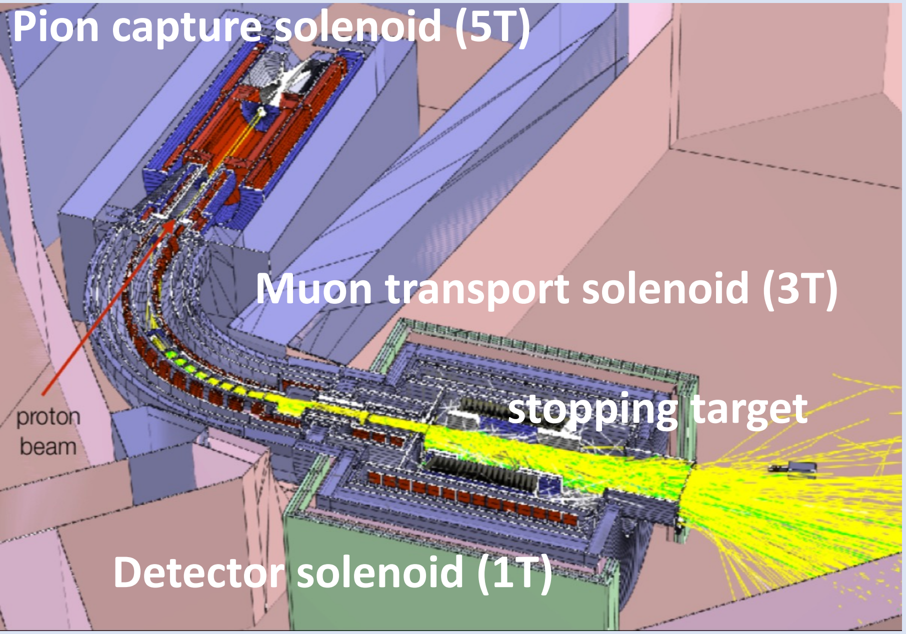


Signal and Background PDFs for $R_{\mu \to e} = 10^{-15}$

The COMET Experiment



Phase-I

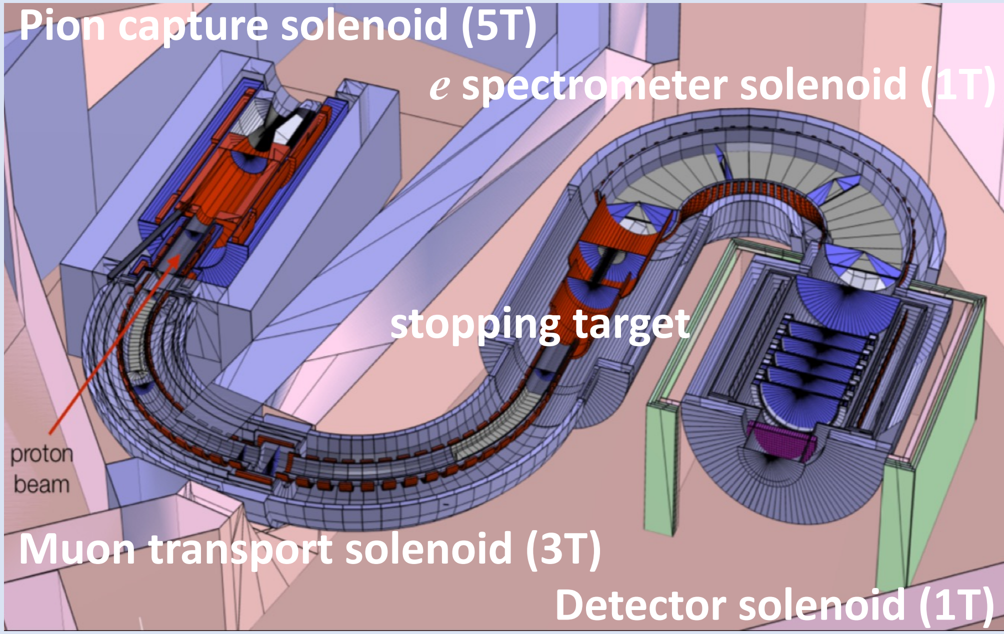


- 3.2 kW, 8 GeV p beam, graphite p target
- 1.2×10^{9} stopped μ/s
- 5 months data taking

➢ CLFV search: **SES = 3.1×10^{-15}**

➢ **Direct measurement of the muon beam** with prototypes of Phase-II detectors

Phase-II

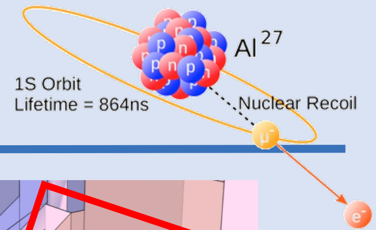


- 56 kW, 8 GeV p beam, tungsten p target
- 2×10^{11} stopped μ/s
- 1 year data taking
- Vertical B field to steer desired charge and momentum along beam centre

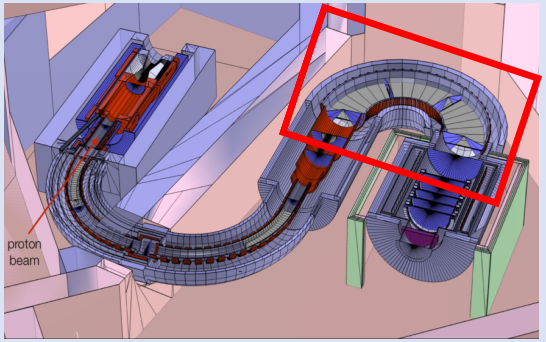
➢ CLFV search: **SES = 2.7×10^{-17}**

Studies underway to further improve sensitivity

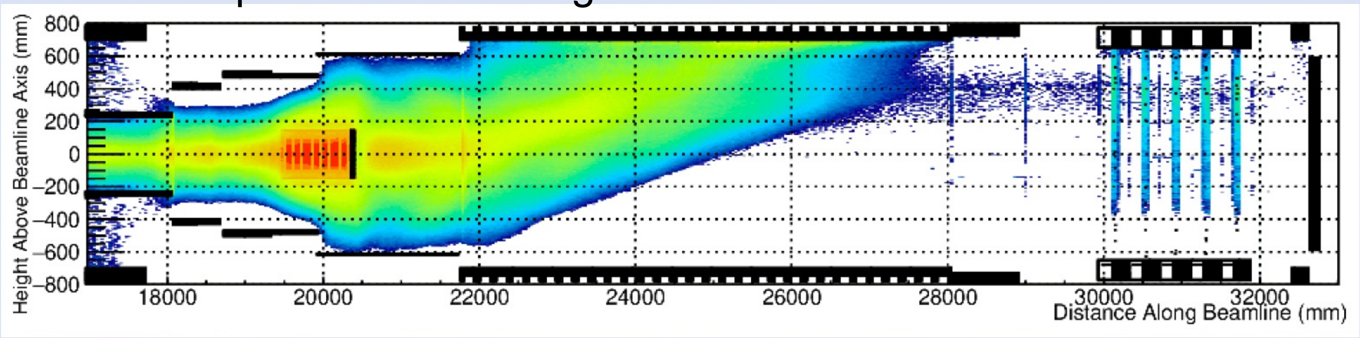
COMET Phase-II



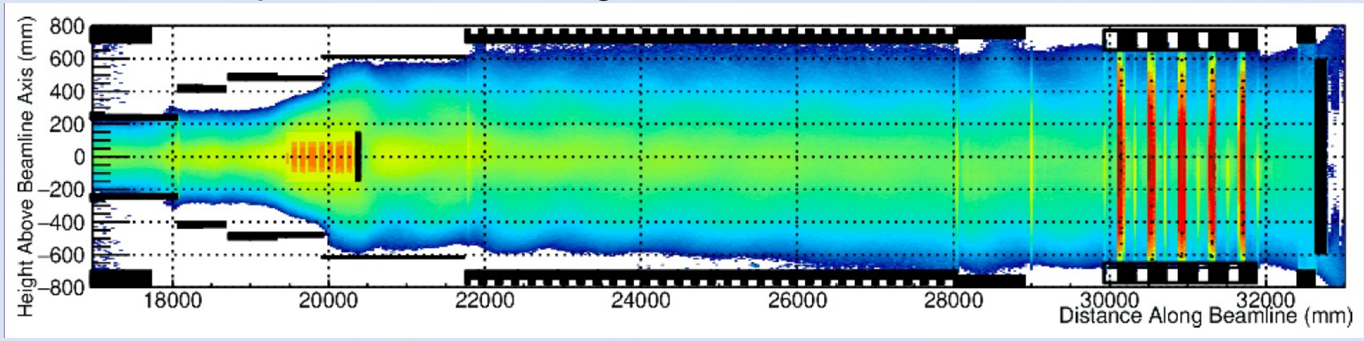
- Beam gradually disperses in C-shaped curved solenoids
- Vertical dipole field used to pull back the beam
- Example: steering of signal electrons (105 MeV/c)



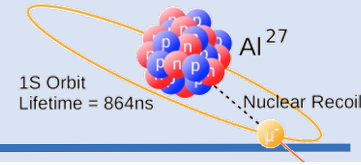
Vertical compensation: steering field OFF



Vertical compensation: steering field ON

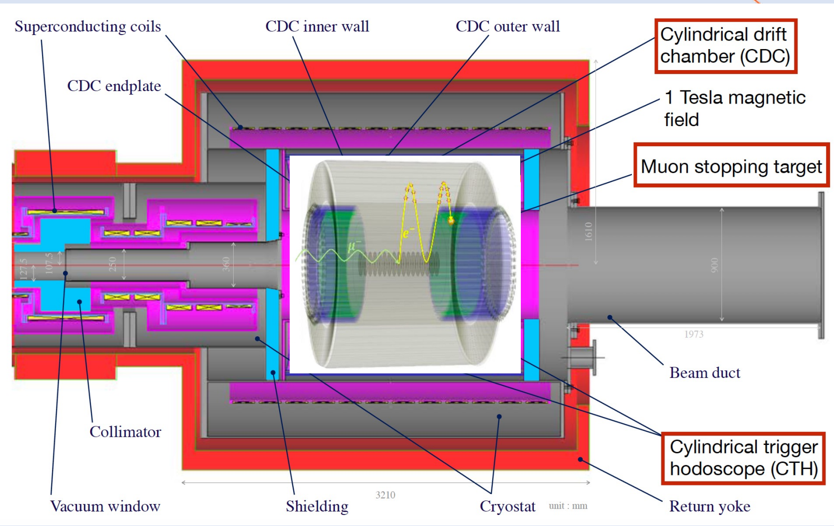


COMET: the CyDet detector

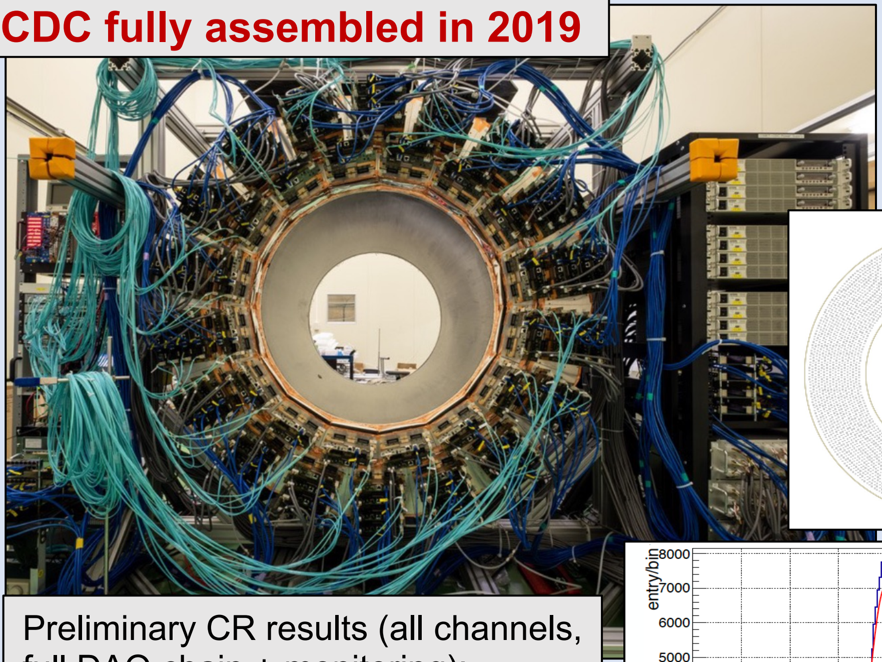


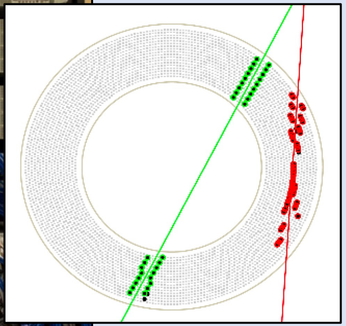
CyDet designed for Phase-I CLFV physics:

- **Cylindrical Drift Chamber (CDC)**
  - All-stereo layers → z information
  - He-based gas minimizing multiple scattering
  - Large inner bore: no beam flash and DIO e^-



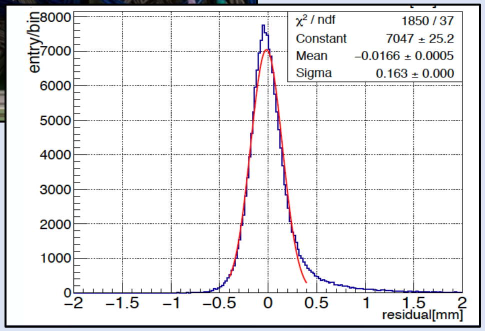
CDC fully assembled in 2019

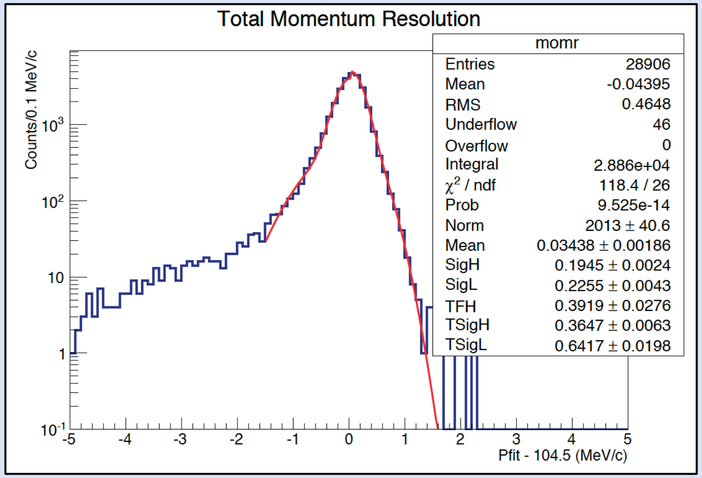




Preliminary CR results (all channels, full DAQ chain + monitoring):

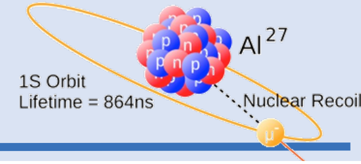
- Good stability after > 2 years
- 170 μm spatial resolution
- 98% hit efficiency





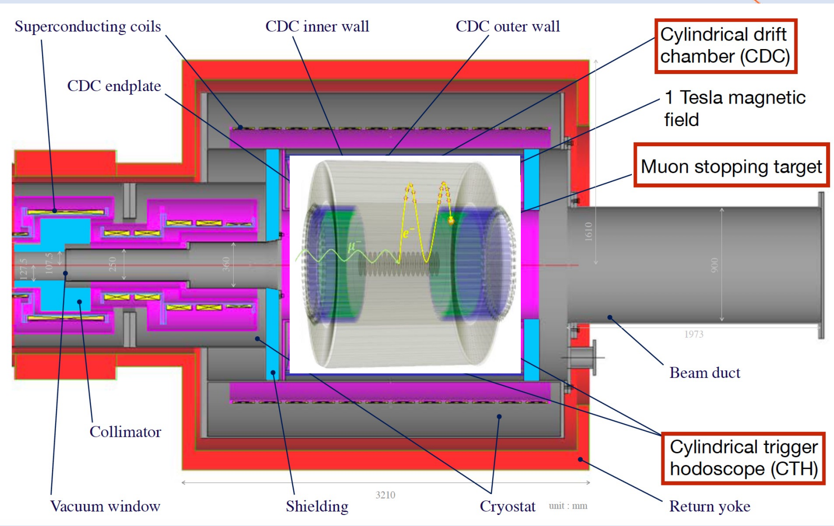
MC: high side momentum resolution **~ 200 keV/c**

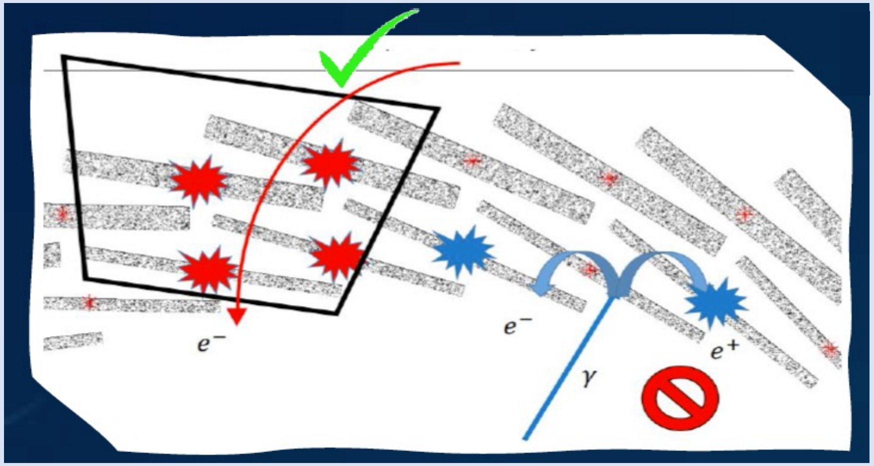
COMET: the CyDet detector



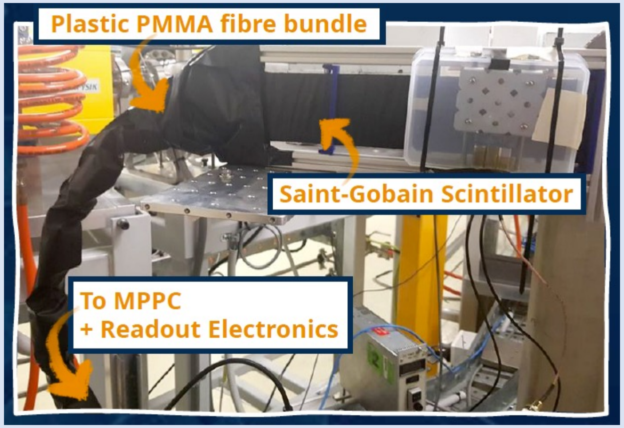
CyDet designed for Phase-I CLFV physics:

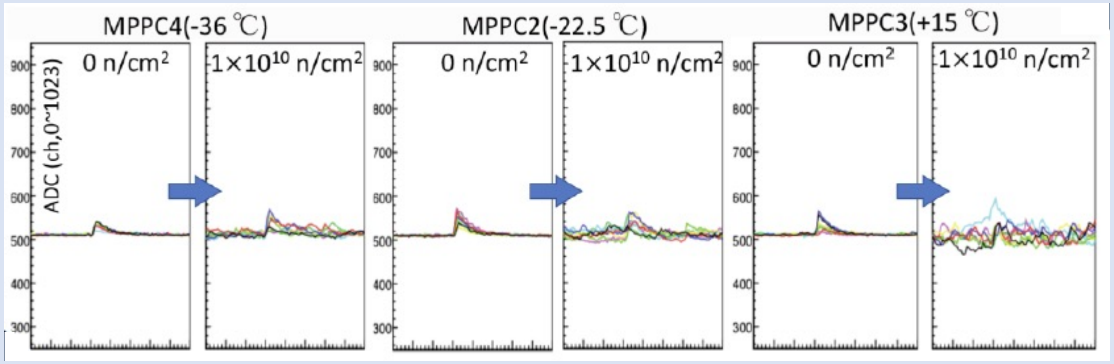
- **Cylindrical Trigger Hodoscope (CTH)**
  - 2x64 plastic scintillator rings for timing ($\sigma_T \sim 0.8$ ns)
  - Tilted support structure to optimize signal acceptance
  - 5-10 m optical fiber readout coupled to MPPCs (outside high radiation detector region)





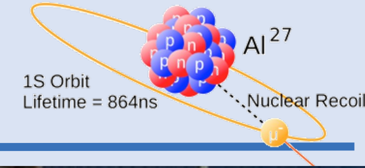
CTH prototype: 100 MeV e⁻ test beam to evaluate photon yield, timing, resolution





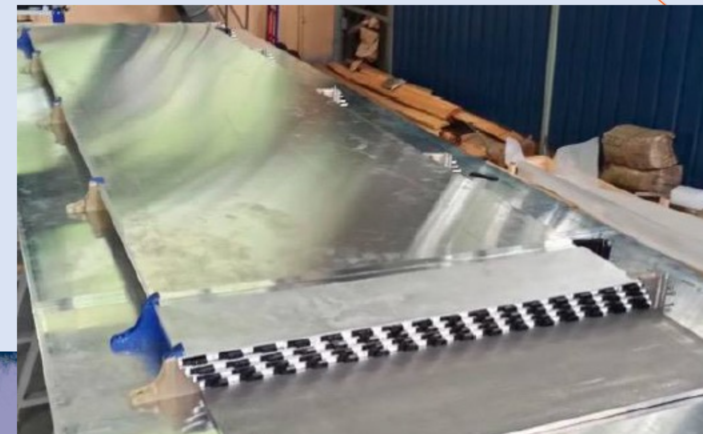
MPPC cooling and irradiation test successfully carried out in May 2022

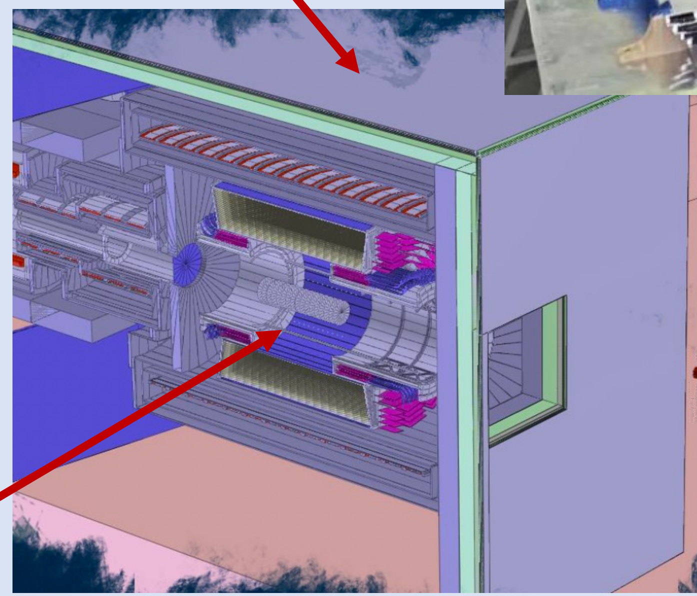
COMET: the CyDet detector

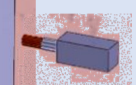


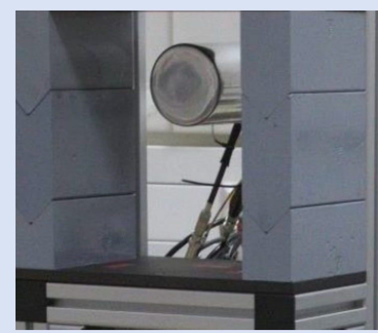
CyDet designed for Phase-I CLFV physics:

- **Cosmic Ray Veto**
  - CR background rejection with ε = 99.99%
  - 4 layers of plastic scintillators with optical fibers and SiPM readout, triple coincidence
  - First full-scale module completed





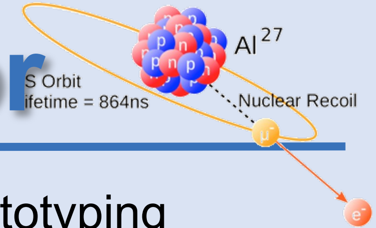




- **Muon Stopping Target**
  - Ongoing target optimization: Ndisks and thickness vs stability and background
  - Prototype currently underway, including holder

- **Germanium detector**
  - Measurement of muonic X-rays for muon stop normalization
  - DAQ under development
  - MC studies for position and shielding

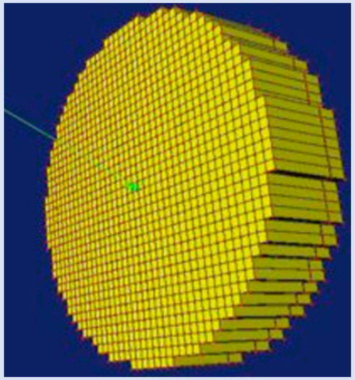
COMET: the StrECAL detector

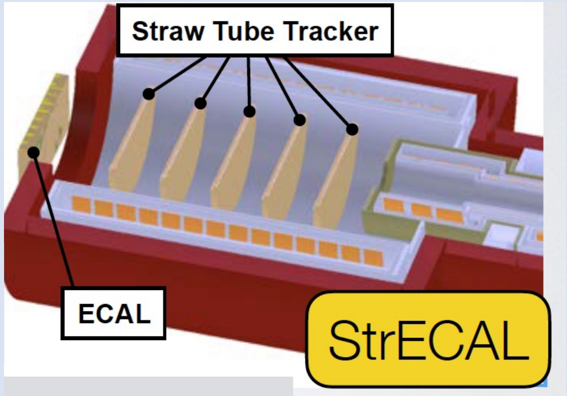


StrECAL designed for Phase-I beam measurements and Phase-II prototyping

Electromagnetic calorimeter

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

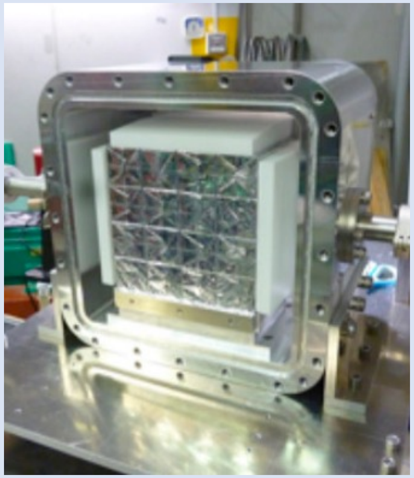


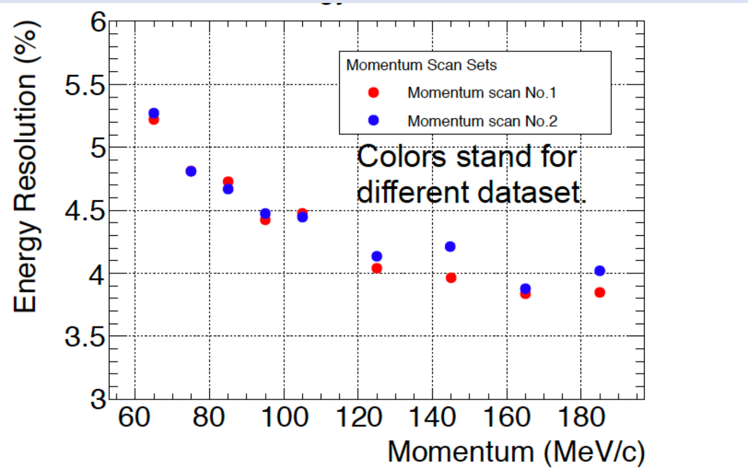


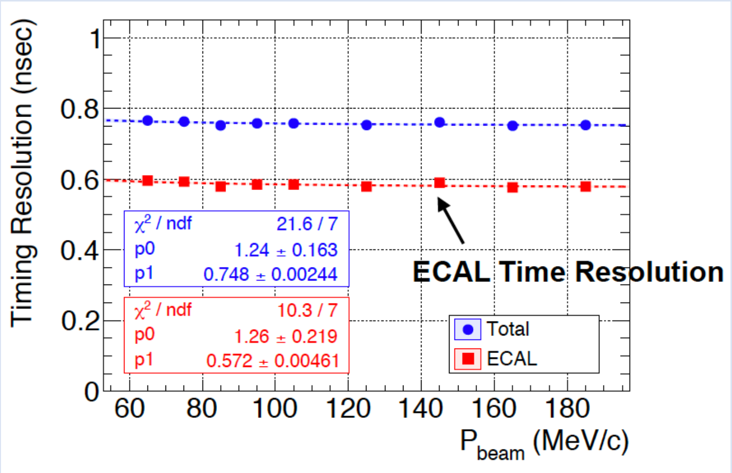
Test of ECAL prototype

- Results for 105 MeV electrons

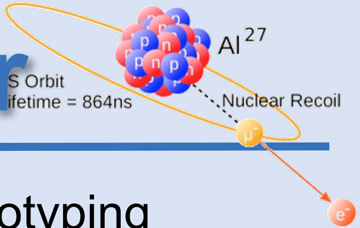
> **energy resolution < 4.5%**
>
> **position resolution < 10 mm**
>
> **timing resolution < 1 ns**







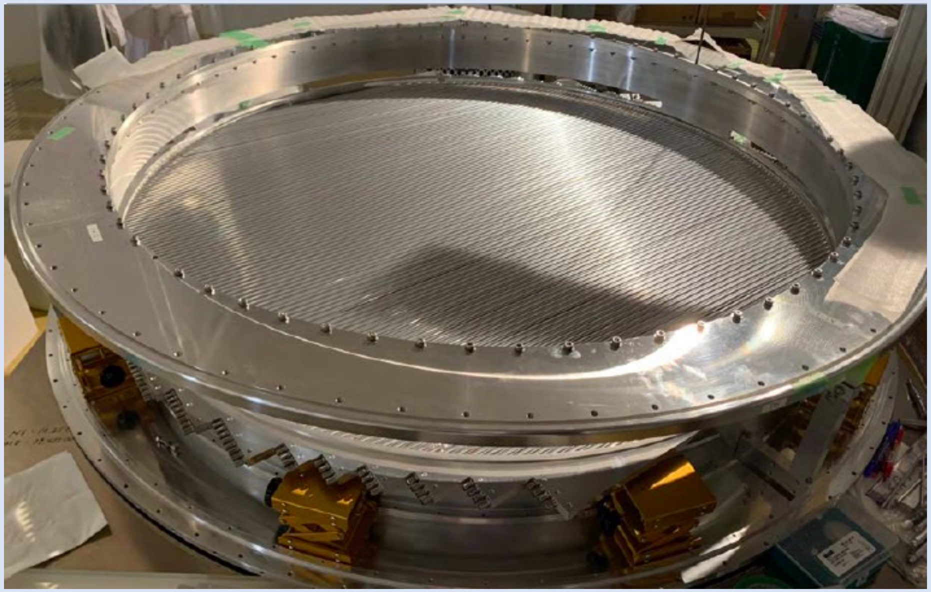
COMET: the StrECAL detector



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
- First layer assembled
- Assembly of all five stations expected by March 2023

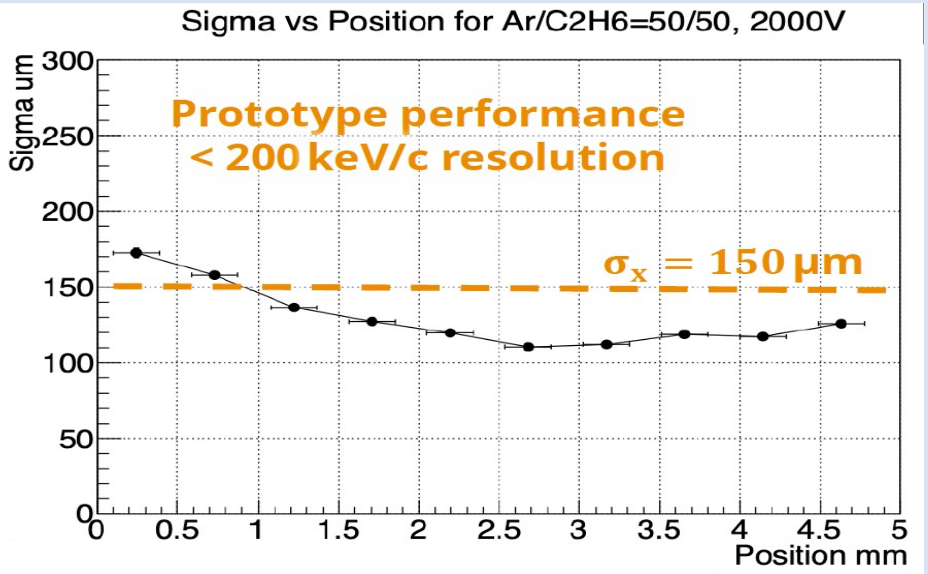


Test of prototype in vacuum, 100 MeV e^- :

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

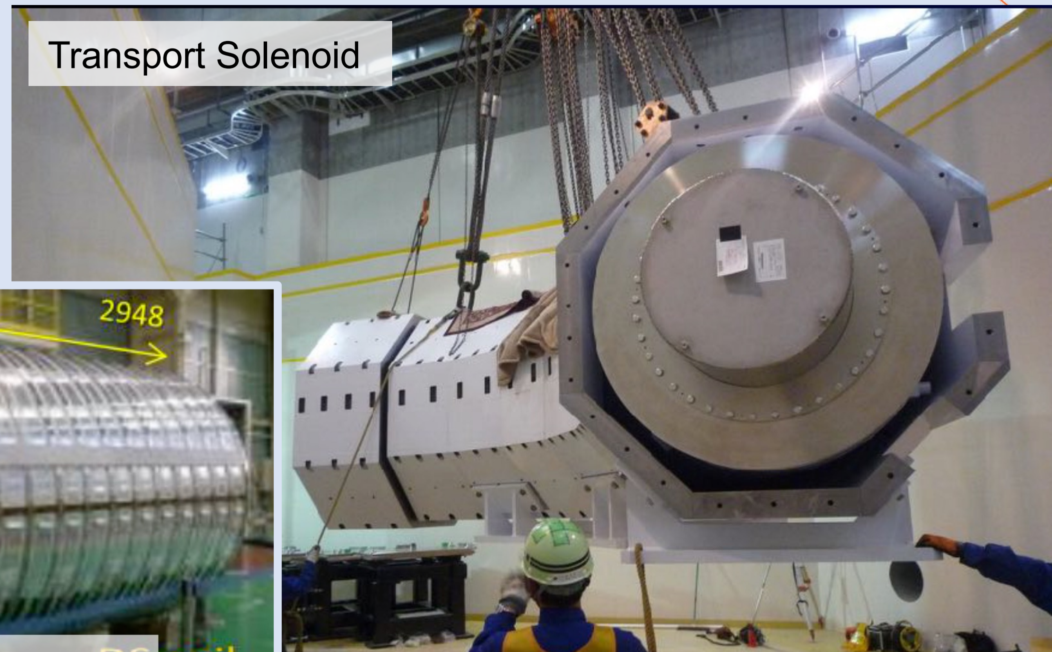
➢ **position resolution <200 μm** for 50:50 Argon/Ethane

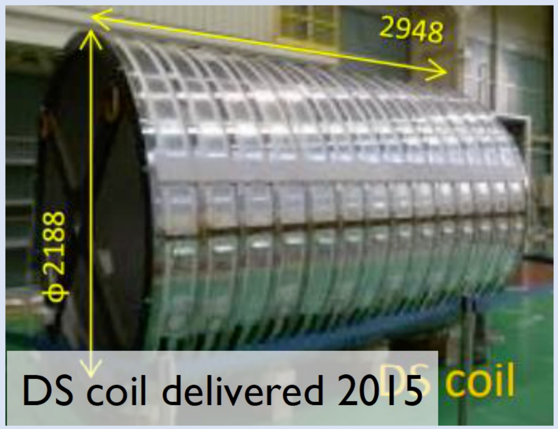
➢ momentum resolution ~180-200 keV/c (straw track fitting based on Genfit2)

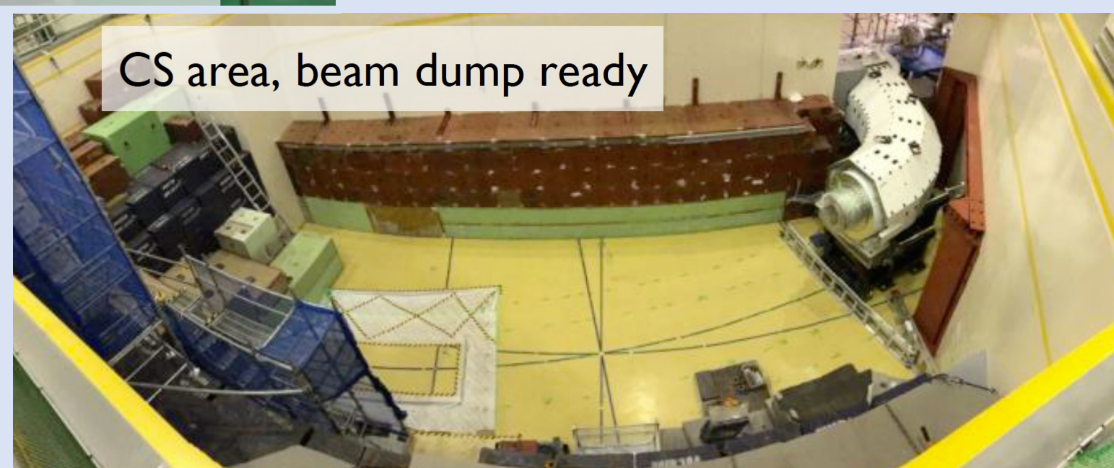


COMET construction: solenoids

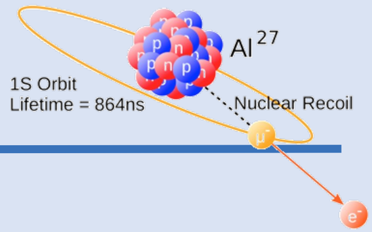
- Pion Capture Solenoid (CS): cold masses into cryostat in 2022, delivery in 2023
- Transport Solenoid (TS): installed and ready for cryogenics tests
- Detector Solenoid (DS): coil and cryostat ready



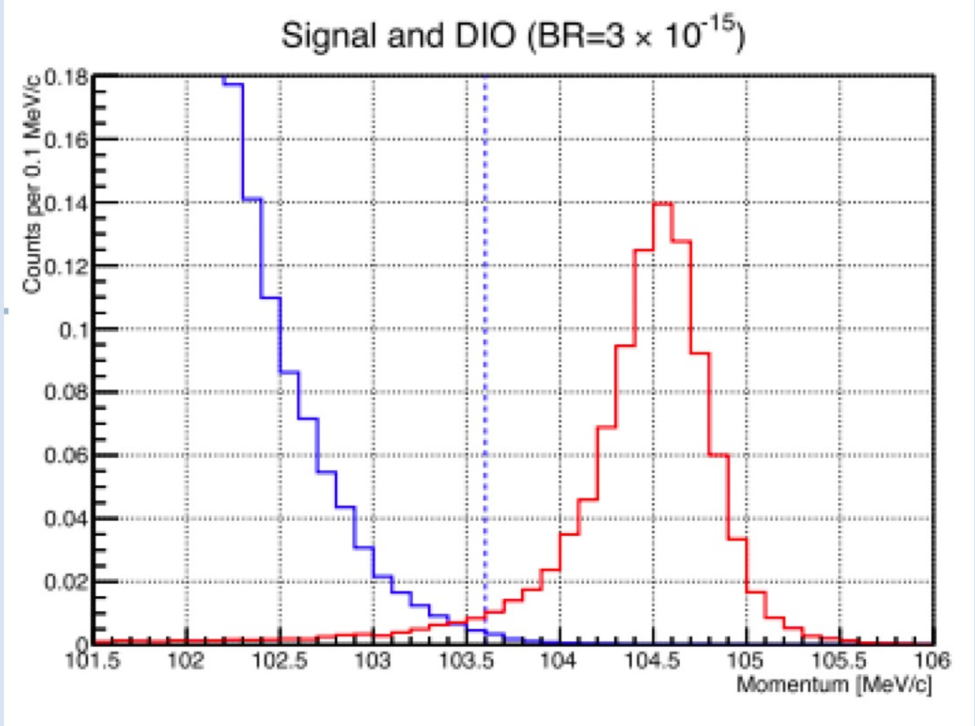




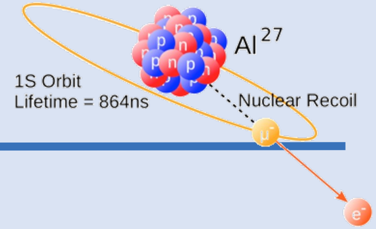
COMET sensitivity estimate



- COMET Phase-I Target single event sensitivity : **3x10^{-15}**
  - 100 times improvement from SINDRUM-II
  - Phase-II : $2.5 \times 10^{-17} \sim 10^{-18}$
- Net acceptance = **4.1%**
  - Geometric acceptance + track quality ~ 0.18
  - 103.6 MeV < p < 106MeV : 0.93
  - 700 ns < t < 1170 ns : 0.3
- Background = **0.032**
  - DIO ~ 0.01 (dominant)
  - RPC ~ 0.003, Cosmic < 0.01

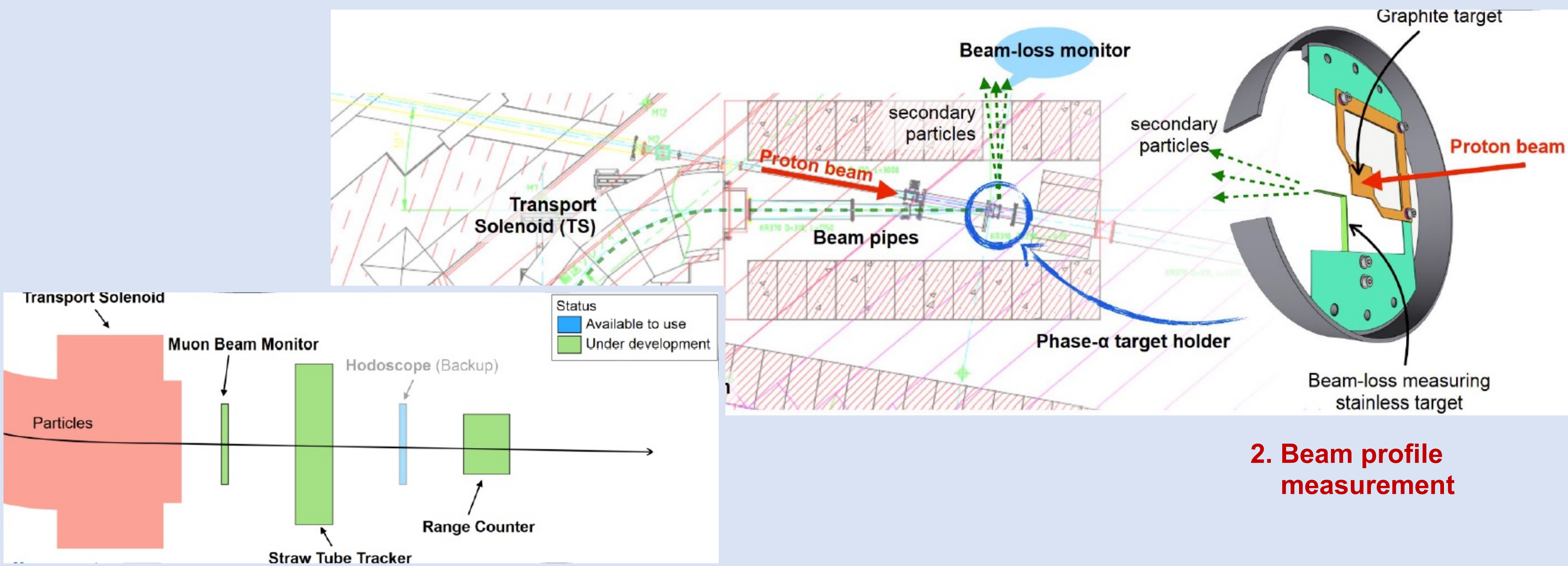


COMET: phase-α



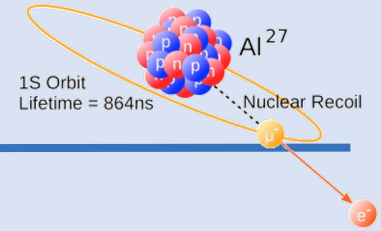
- 8-GeV low-intensity (260 W) proton beam delivery to COMET
- 15-day run in April 2023
  - Proton beam line commissioning
  - Direct extinction measurements at the COMET area
  - Demonstration of the muon transport system
  - Estimation of backward pions/muons production yields
  - Measurement of yields of secondary particles, others

1. Beam loss on target



2. Beam profile measurement

Run schedule



COMET

- **Phase-α planned for end of JFY2022**
- Phase-I detector ready by end 2023
- **Facility ready for Phase-I on April 2024**
  - ➢ 10^2 improvement over SINDRUM-II
- **No official Phase-II schedule from KEK**

Mu2e

- **Beam on target late 2024**
- **Run1: 2025-2026** (from half to full intensity)
  - ➢ $4.5\times10^9 \rightarrow 8.57\times10^9$ stopped μ/s
  - ➢ 10^3 improvement over SINDRUM-II
- **PIP-II/LBNF shutdown**: end of 2026
- **Run2: early 2029**
  - ➢ 10^4 improvement over SINDRUM-II by the end of the decade

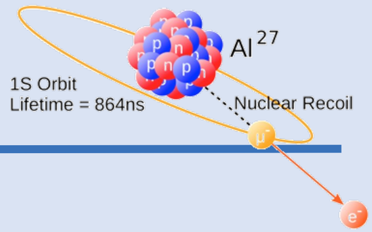
Current schedule for experiment's startup:

	2023	2024	2025	2026
	COMET Phase-α	COMET Phase-I	Mu2e Run1	

SES 3×10^{-15}

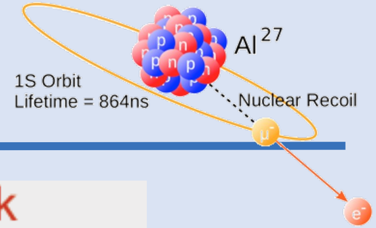
SES 3×10^{-16}

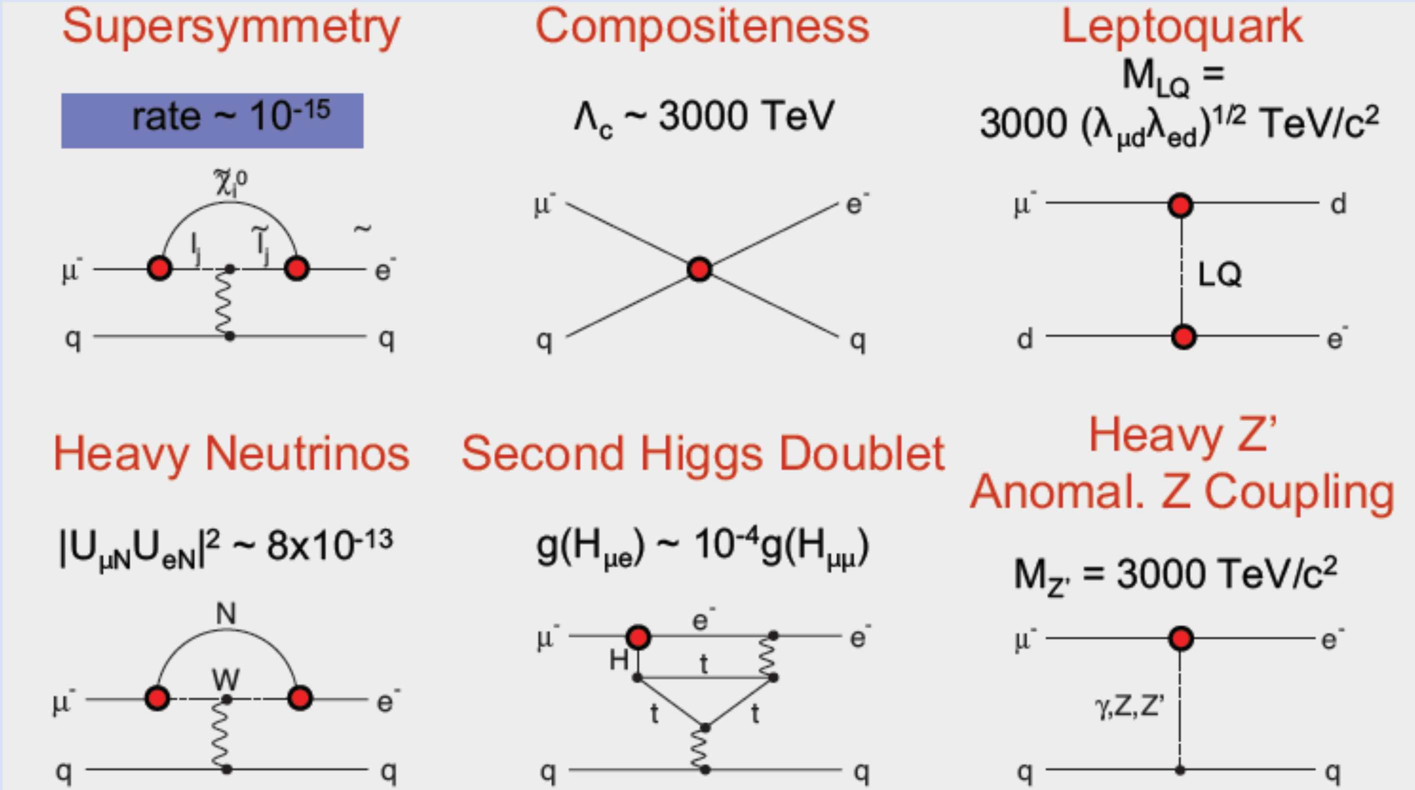
Conclusions



- MU2E@FNAL and COMET@KEK will search for CLFV in muon-to-electron conversion
  - ➢ discovery capability over a wide range of New Physics models
  - ➢ Final goal: 10^4 improvement w.r.t. current measurement (SES 10^{-17})
- Design phase completed
- Construction phase in full swing
- Installation, commissioning and data taking will follow

CLFV and New Physics



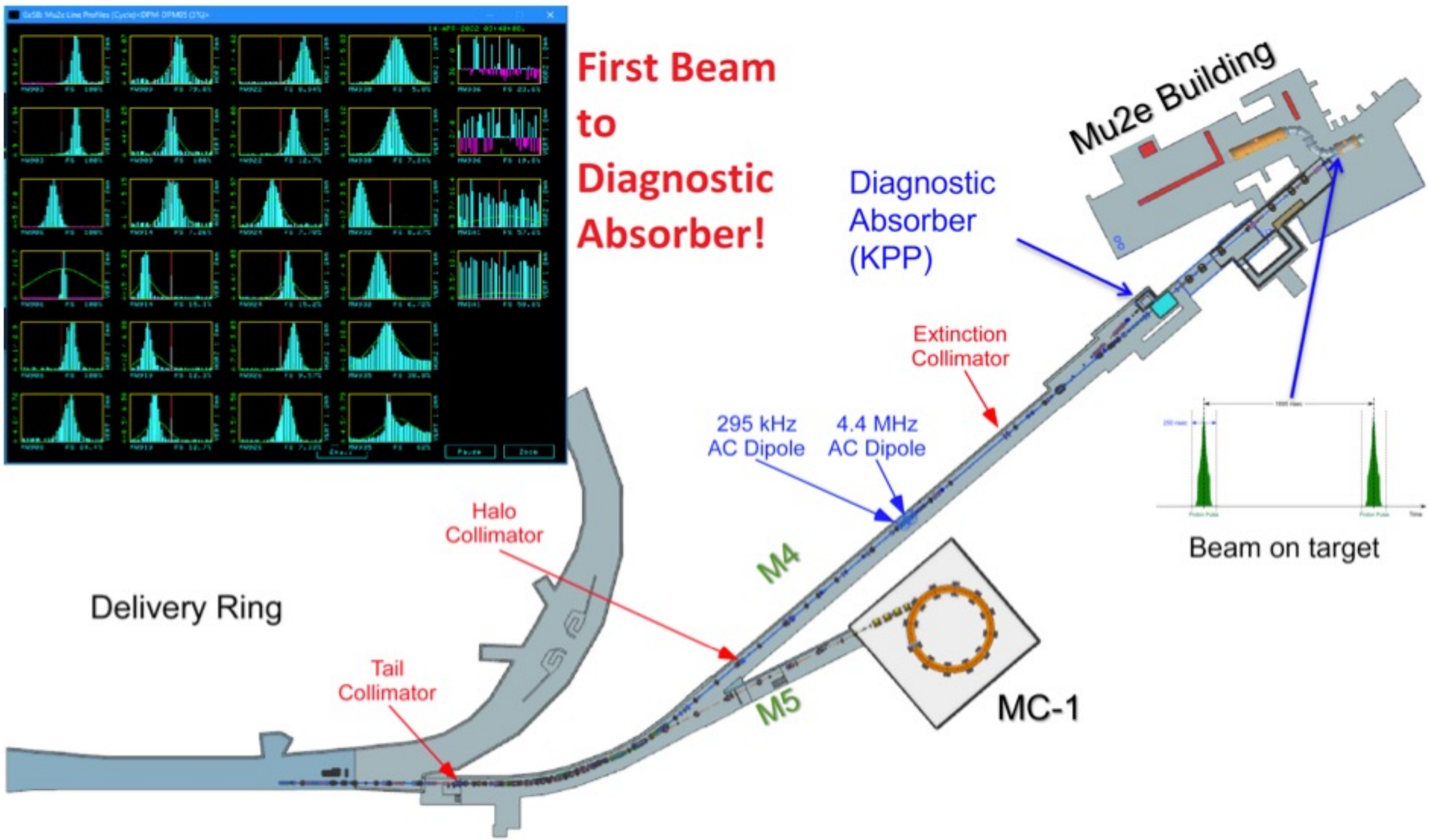


If SUSY seen at LHC → rate ~10^{-15}

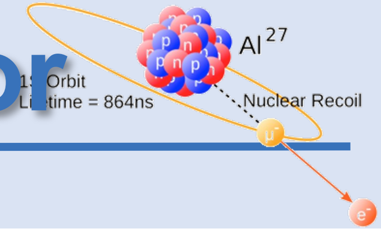
Implies O(40) reconstructed signal events with negligible background in Mu2e for many SUSY models.

Mu2e keeps discovery sensitivity for all SUSY benchmark point for LHC Phase2

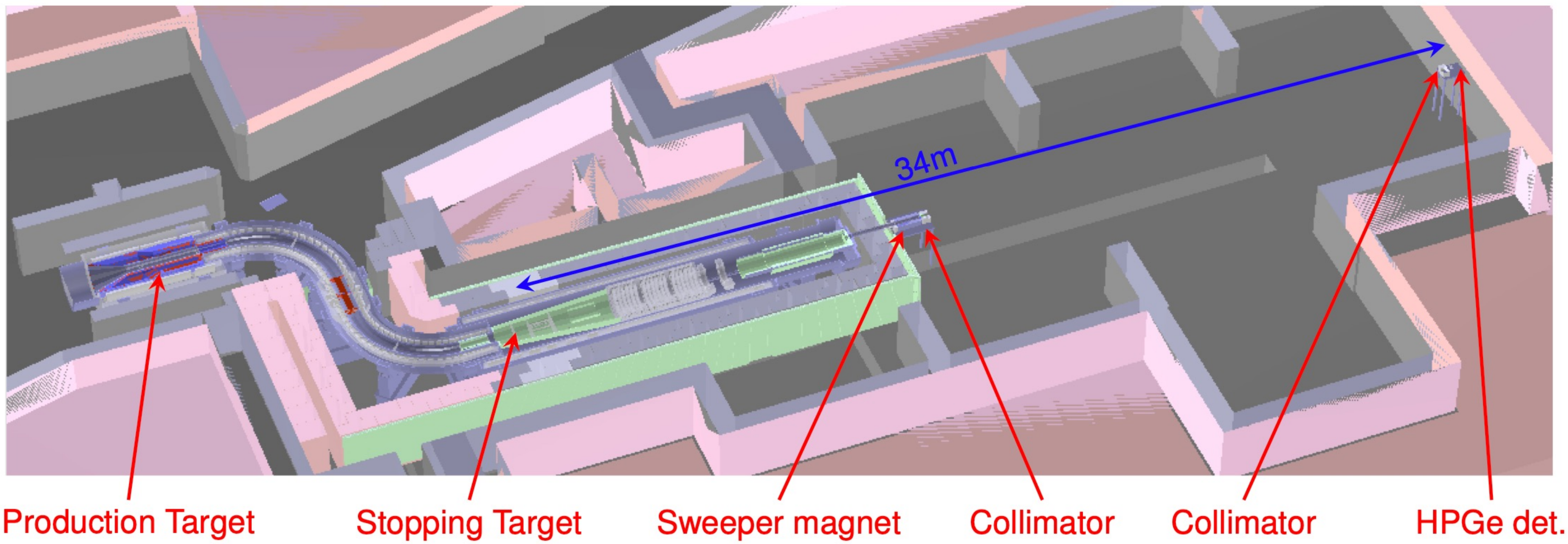
Mu2e Diagnostic absorber



Mu2e Stopping Target Monitor

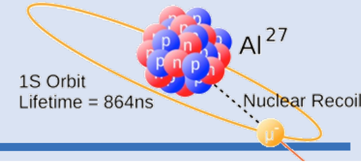


High-purity Germanium detector to determine overall muon-capture rate on Al to the level of 10%

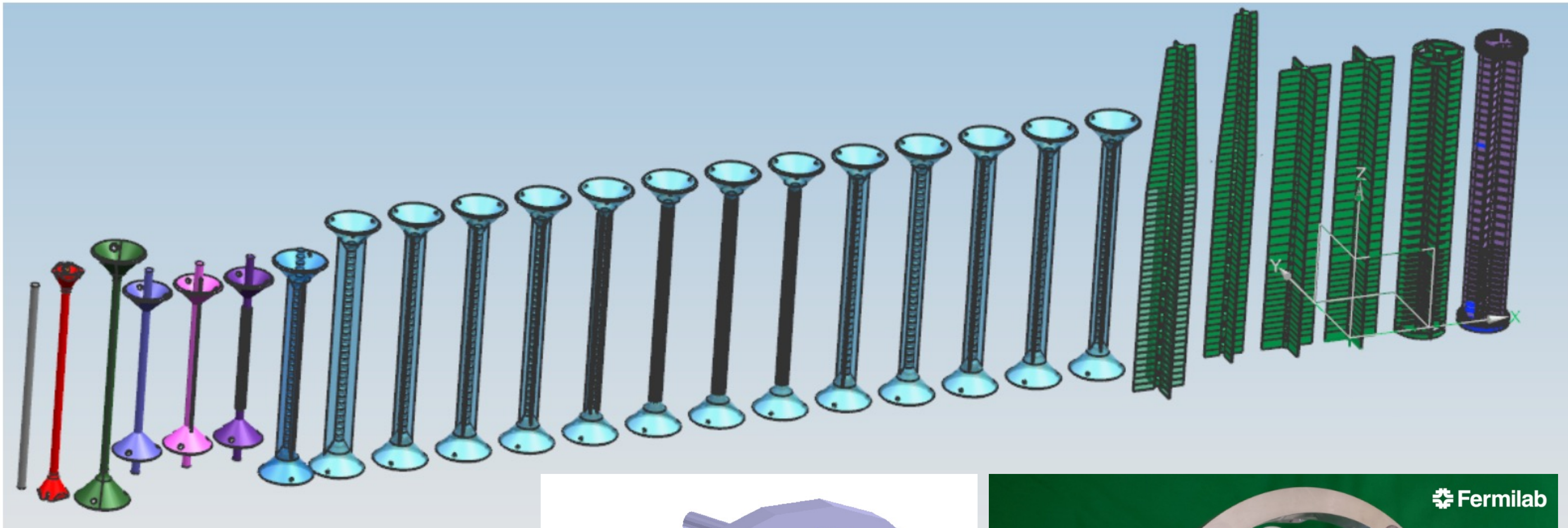


- measure X- and γ-rays from muonic Aluminum
  - 347 keV 2p-1s X-ray (80% of muon stops)
  - 844 keV delayed γ-ray (5% of muon stops)
  - **1809 keV** γ-ray (30% of muon stops)
- line-of-sight view of Muon Stopping Target
- sweeper magnet to reduce charged particle background and radiation damage to detector
- It was decided to accompany the HPGe detector with a $LaBr_3$ detector (worse energy resolution, but can take higher rates)

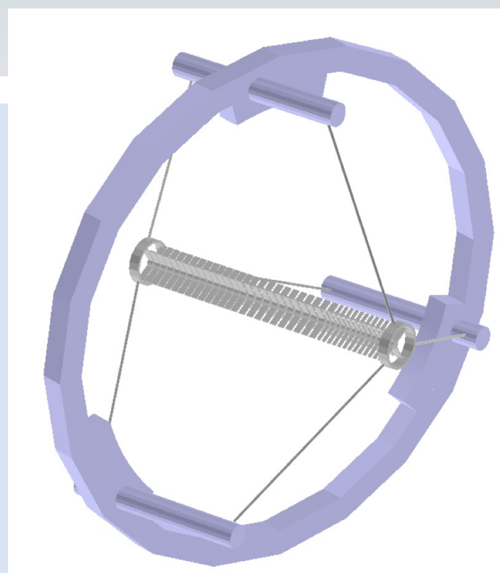
HZDR



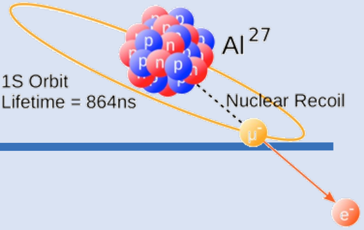
The Mu2e proton target



After several iterations, the final design was chosen, which preserves the number of muons per POT, while increasing the capability to radiate away the energy

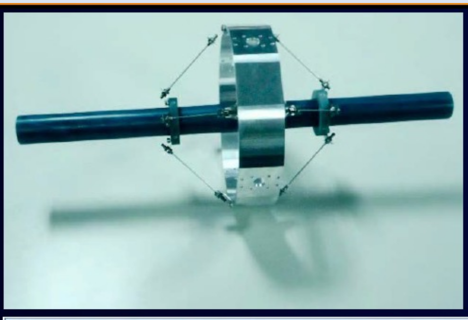


The COMET proton target



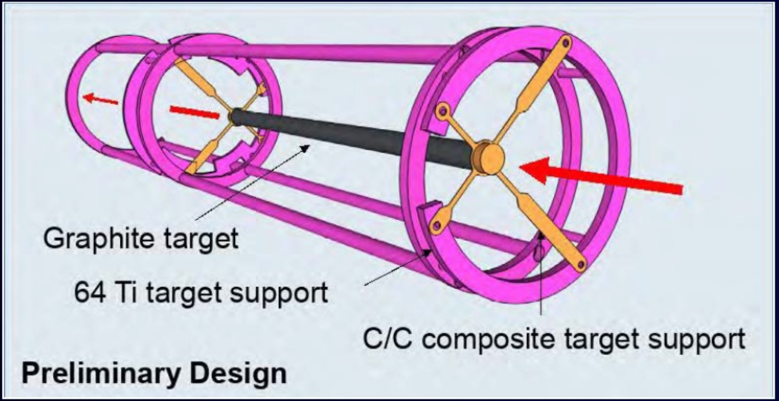
- Proton target for Phase-I
  - Graphite rod with radiation cooling
  - Proton beam power 3.2 kW
  - Radius 13 mm, length 700 mm
  - Design of support underway
- Proton target for Phase-II
  - Tungsten rod with water/He cooling
  - Radius 5 mm, length 250 mm
  - Proton beam power, 56 kW
  - graphite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

(1)

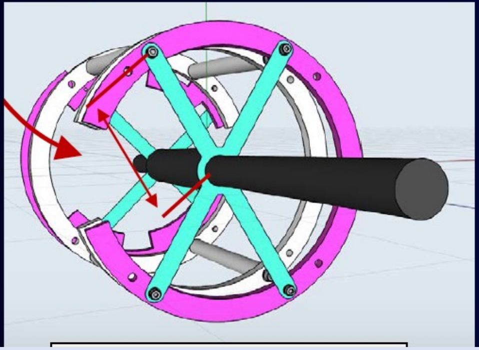


from COMET Phase-I Technical Design Report (2016)

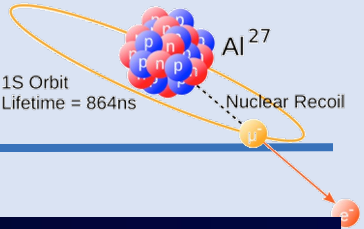
(2)



(3)

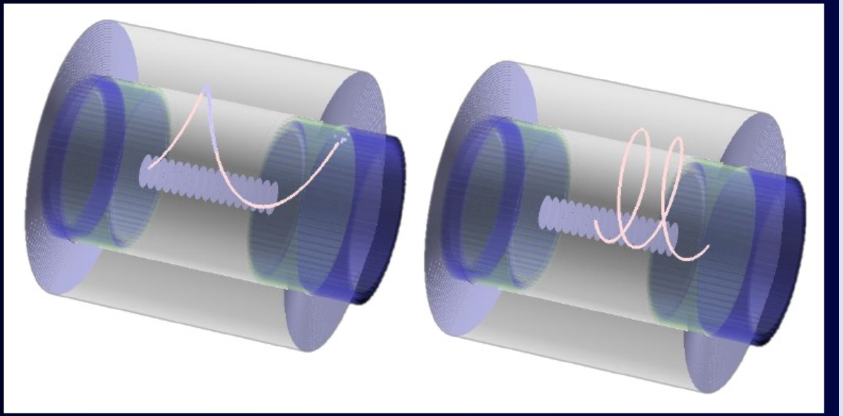


The COMET CDC



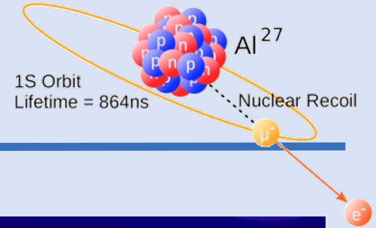
- 20 concentric sense layers (including 2 guard layers)
- All stereo layers: ±70 mrad (alternate)
  - z information
- Helium based gas:
  - minimize multiple scattering
- Large inner bore: ~ 500 mm radius
  - avoid beam flash and DIO
  - momentum cut > 80 MeV/c

sense wire	25 μm, gold-plated tungsten
field wire	126 μm, pure Aluminium
inner wall	0.5 mm, CFRP
outer wall	5.0 mm, CFRP



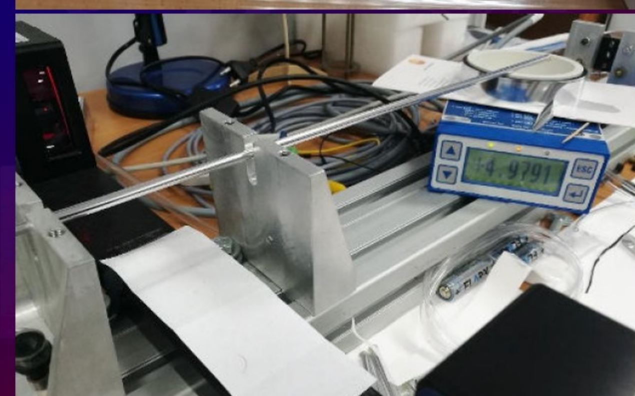
- Signal tracks (~105 MeV/c) contained inside the CDC
  - better momentum resolution
- 60 % for single turn tracks and 40 % for multiple turn tracks (for triggered events)

COMET: Phase-II R&D

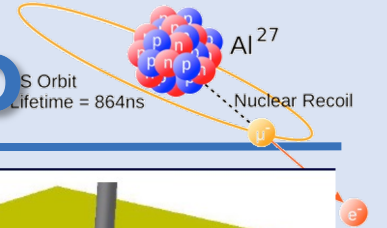


Successfully developed tubes with ***12 micron-thick walls***

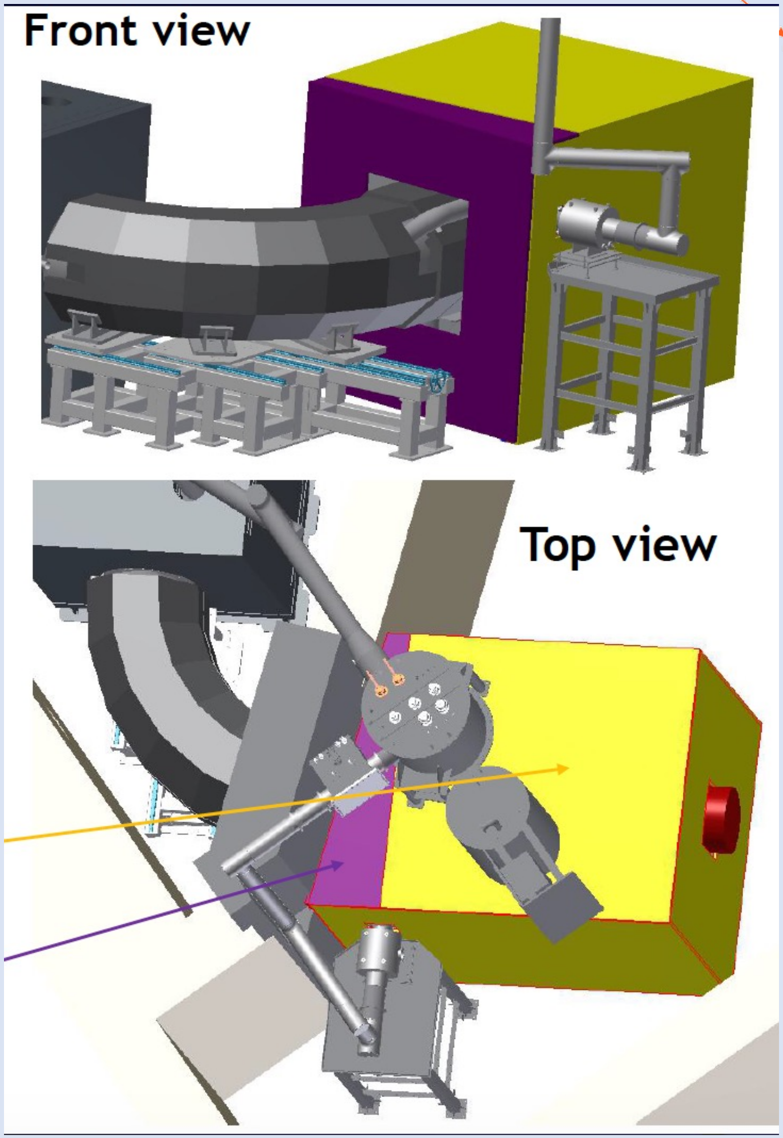
- Diameter 5 mm (half of Phase-I)
- Overpressure of 1 bar: 0.1 micron-level accuracy
- Tested at more than 4 bar overpressure



The COMET Cosmic Ray Veto

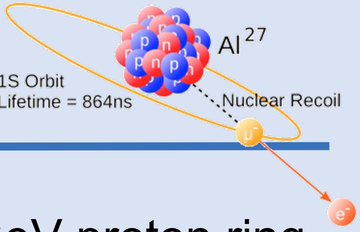


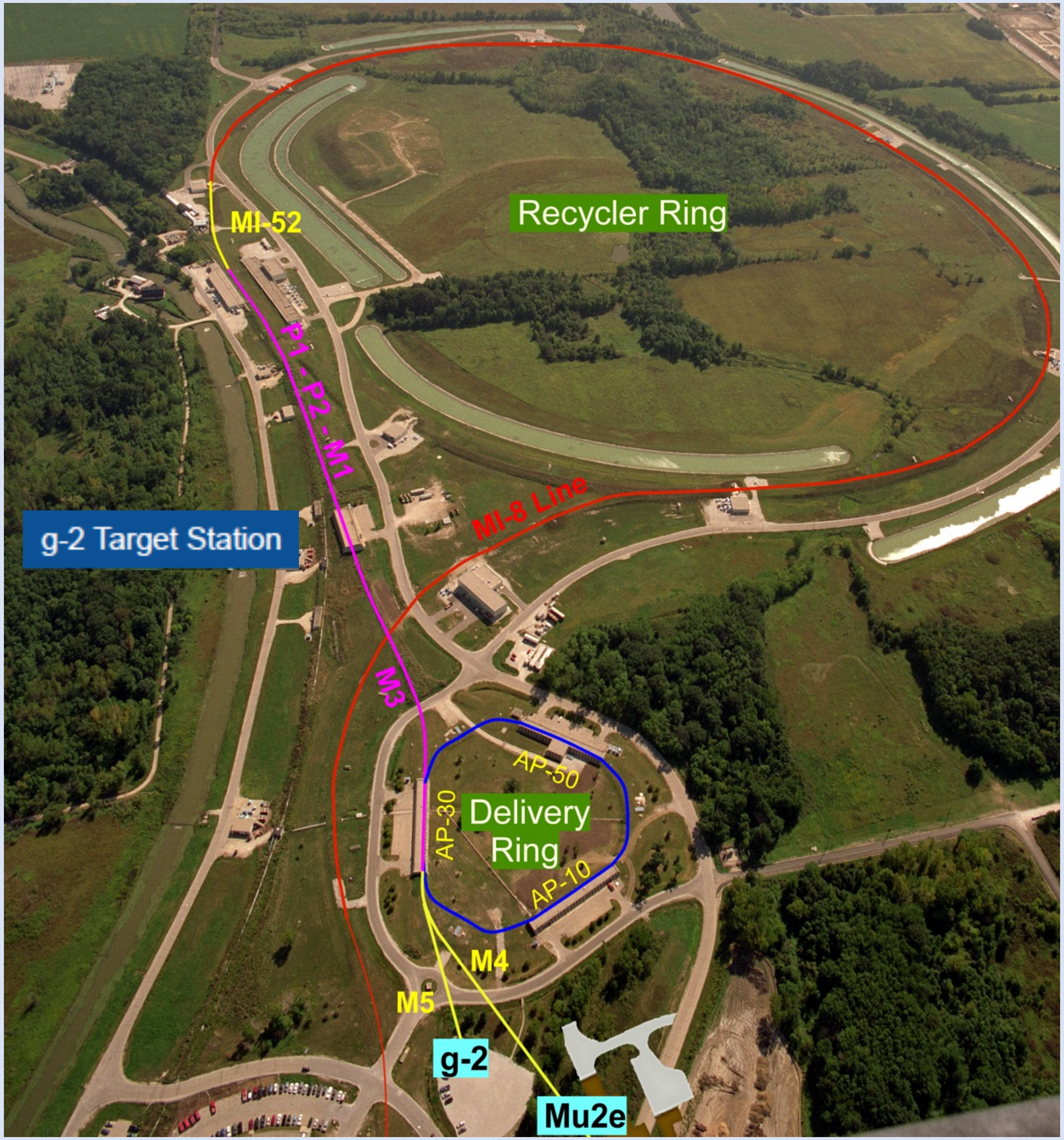
- Requirements:
  - Reject CR-backgrounds with efficiency of 99.99%
- Passive CRV
  - concrete, HDPE, and lead
- Active CRV
  - 4 layers of plastic scintillators with optical fibers and SiPM readout
    - triple coincidence
  - Glass resistive plate chambers (GRPC) in high neutron flux areas
    - under preparation
  - 5 walls, each wall composed of panels



scintillators (yellow) and GRPC (purple)

Beam for Muon Campus





Recycler: fixed 8 GeV proton ring

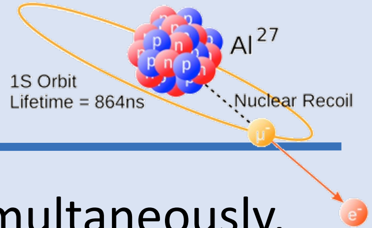
Beams both to Muon Campus and neutrino experiments

Separate runs for g-2 and Mu2e

g-2: target before the delivery ring, 3.1 GeV π^+ selected, clean, polarized μ^+ beam

Mu2e: 8 GeV protons to Mu2e hall

A typical Mu2e signal event



Signal electron, together with all the other hits/tracks occurring simultaneously, integrated over 500-1695 ns window