Status of the Mu2e experiment at Fermilab

14th International Workshop on e⁺e⁻ collisions from Phi to Psi 2026 (PHIPSI26)

Pisa, 9 June 2026

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on behalf of the Mu2e Collaboration

Istituto Nazionale di Fisica Nucleare

CLFV

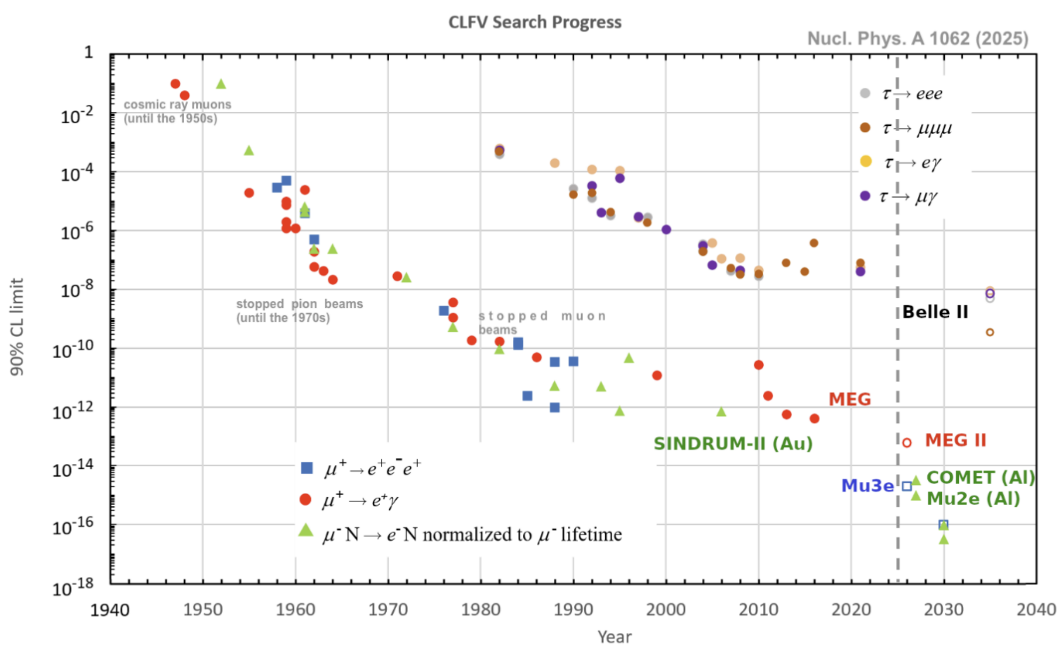
- Neutrino oscillation observed by several experiments
  - Violation of neutral lepton flavor
- Yet, no observed charged lepton flavor violation (CLFV)
- Standard model allows μ→eγ, but:

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{j=1}^{3} U_{ej}U^{*}_{\mu j}\frac{m^2_{\nu j}}{M^2_W}\right| \sim O(10^{-54})$$

- → Any CLFV observation implies BSM physics

DOI: 10.1016/j.nuclphysb.2009.12.019

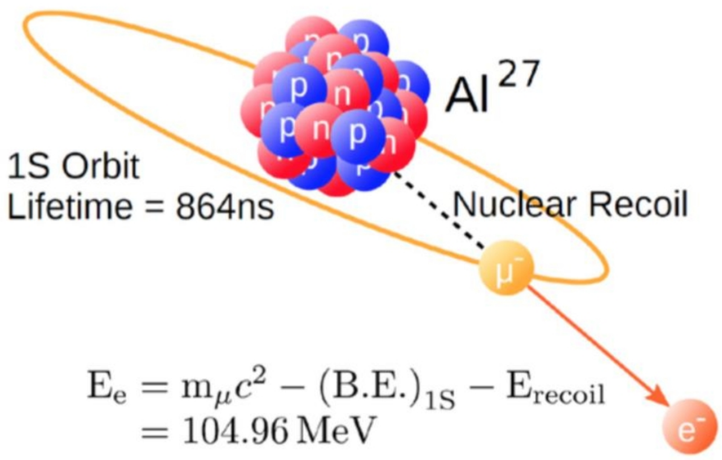
	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

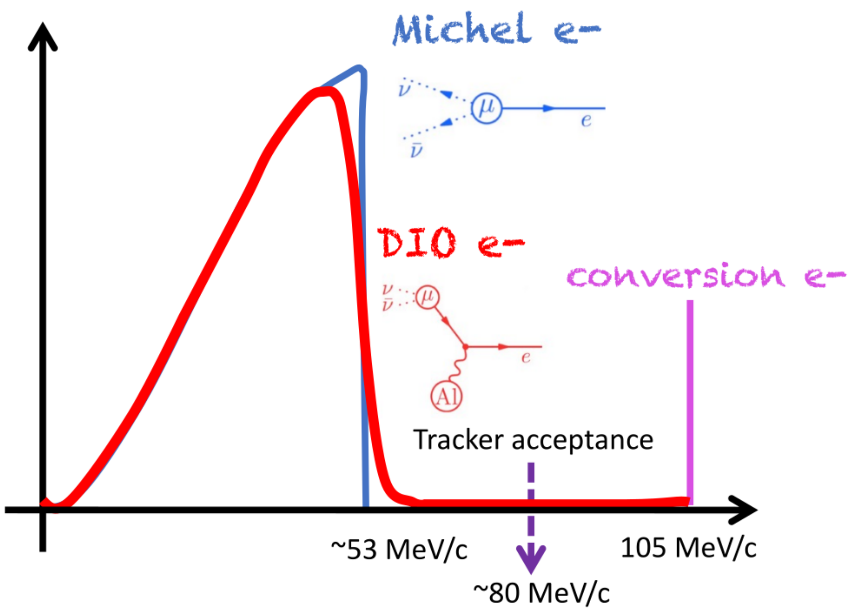


Mu → e

$$R_{\mu e} = \frac{\Gamma(\mu^- + N(Z,A) \rightarrow e^- + N(Z,A))}{\Gamma(\mu^- + N(Z,A) \rightarrow \nu_\mu + N(Z-1,A))}$$

- Search for neutrinoless, coherent muon to electron conversion in the field of Aluminum atoms
- Signal is a monoenergetic 104.96 MeV/c electron
- Physics reach up to 10^4 TeV/c^2 masses
- Current best limit set by SINDRUM II experiment at PSI (Au target):
  - $R_{\mu\rightarrow e} < 7\times10^{-13}$ (90% C.L) Eur.Phys.J. C47, 337 (2006)
- Mu2e Experiment at Fermilab goal: 4 orders of magnitude improvement
  - $R_{\mu\rightarrow e} < 8.4\times10^{-17}$ (90% CL)





The Mu2e Experiment

at the Fermilab Muon Campus

Fermilab

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INFN
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Mu2e

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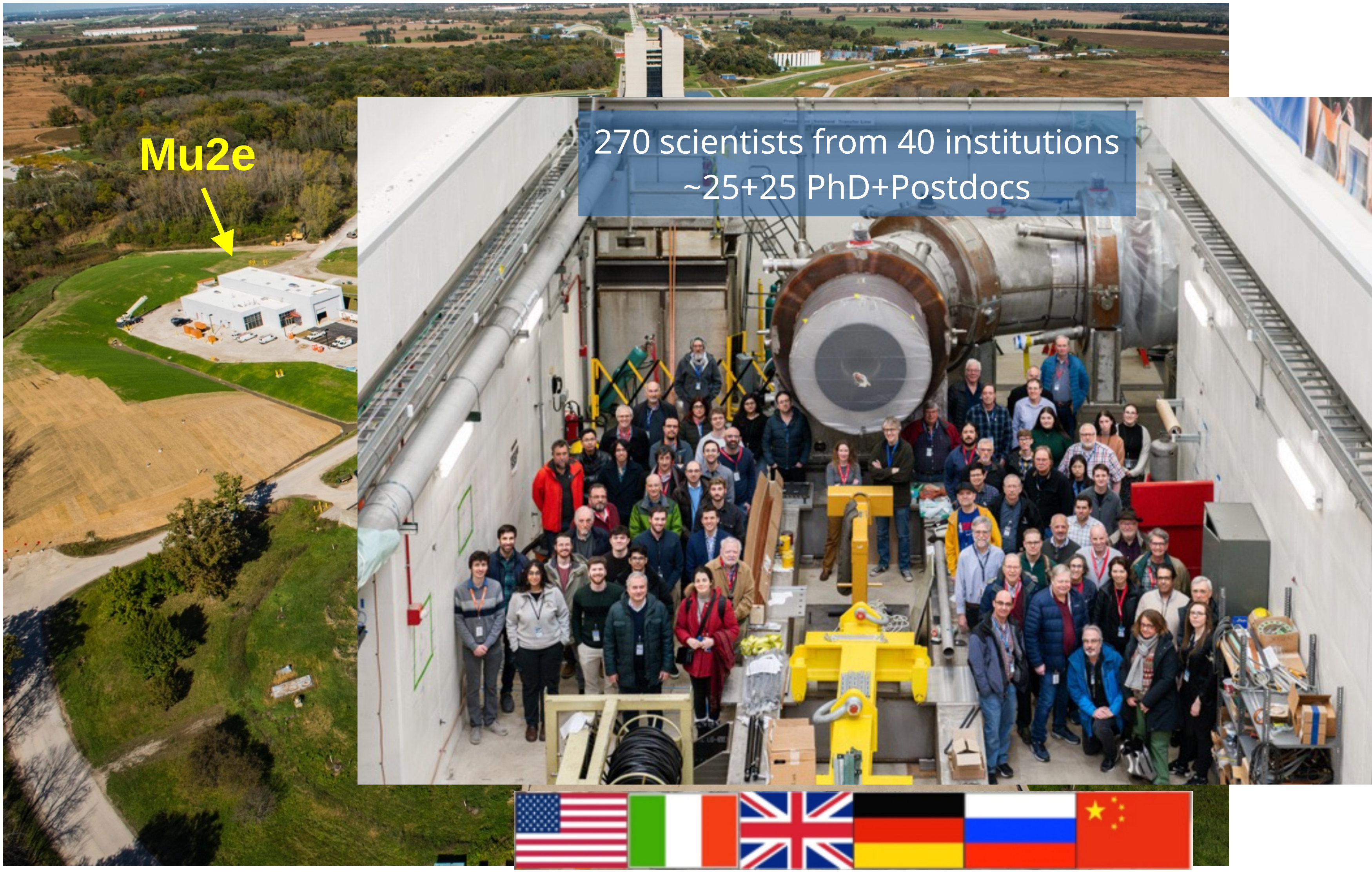
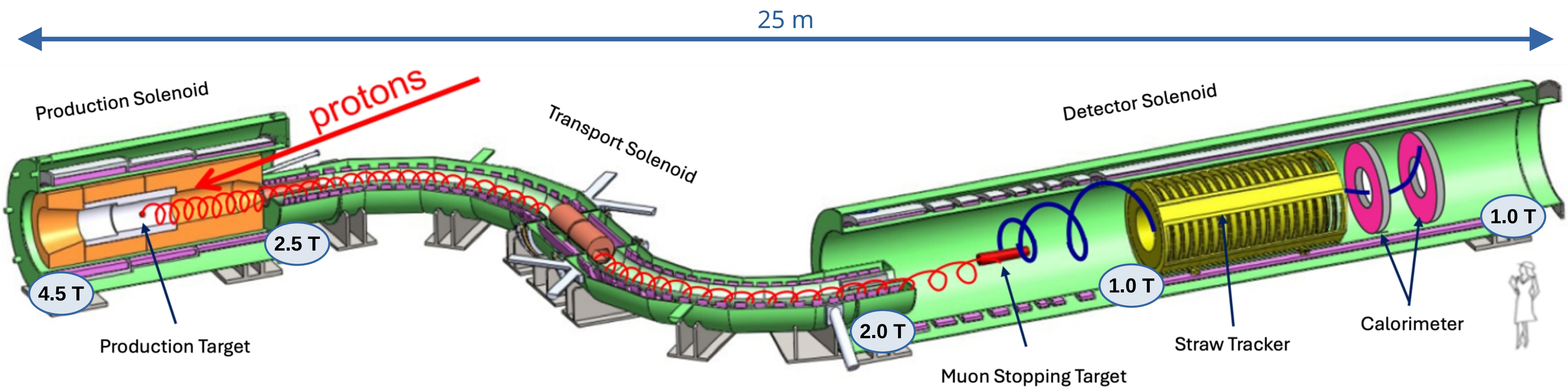


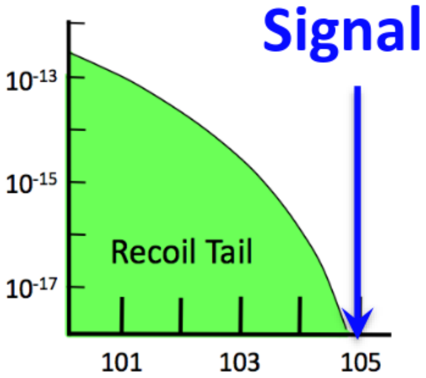
Experiment layout



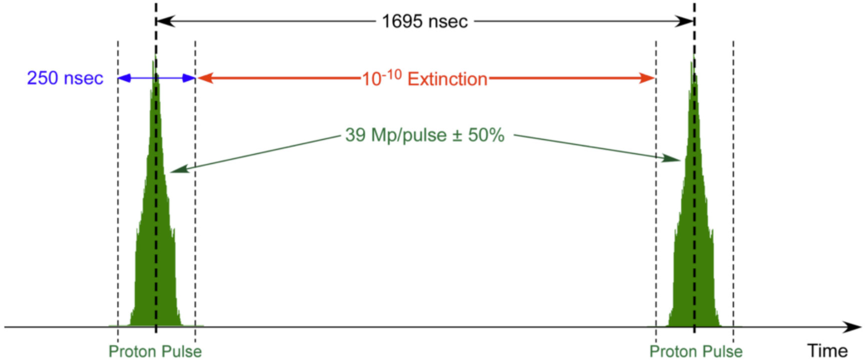
- 8 GeV protons from the accelerator complex with a pulsed structure
- High statistics: O(10^{18}) stopped muons needed in 5 years
- Highest intensity muon beam in the world (~ 10 GHz on stopping target)

Backgrounds

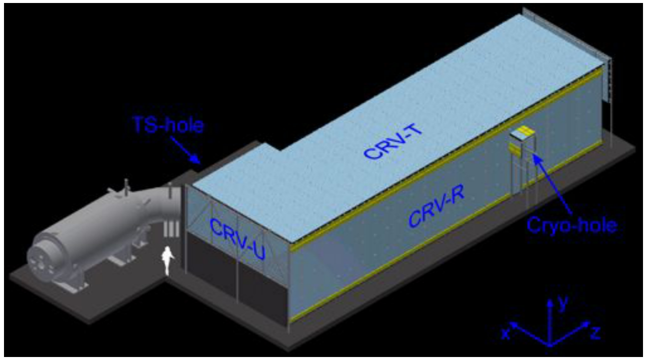
- **Decay in orbit (DIO)**
  - SM process with vanishingly small neutrino energy
  - → Precise momentum resolution from tracker



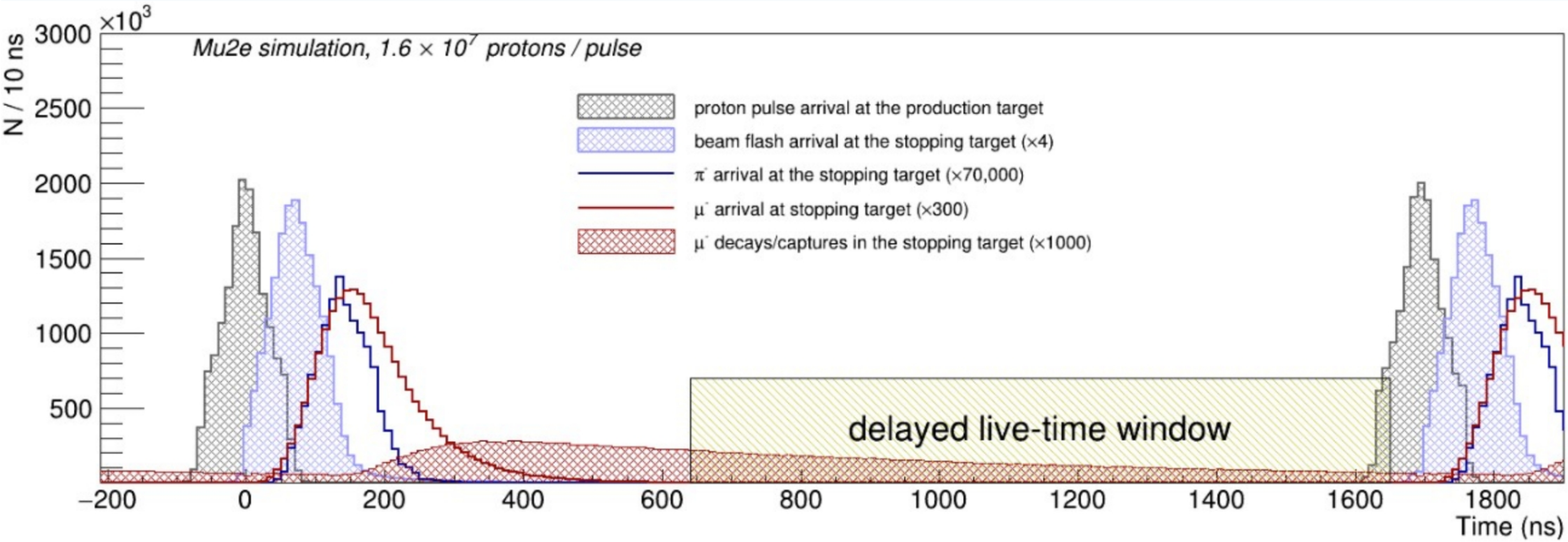
- **Radiative pion capture (RPC)**
  - π- N → γ N*; e+e- pair production
  - → Suppressed with pulsed proton beam (pion lifetime 26 ns) with high extinction



- **Cosmic rays**
  - Cosmic rays can intersect material (stopping target) and can break free an electron at the signal energy
  - → Detector surrounded by efficient cosmic ray veto

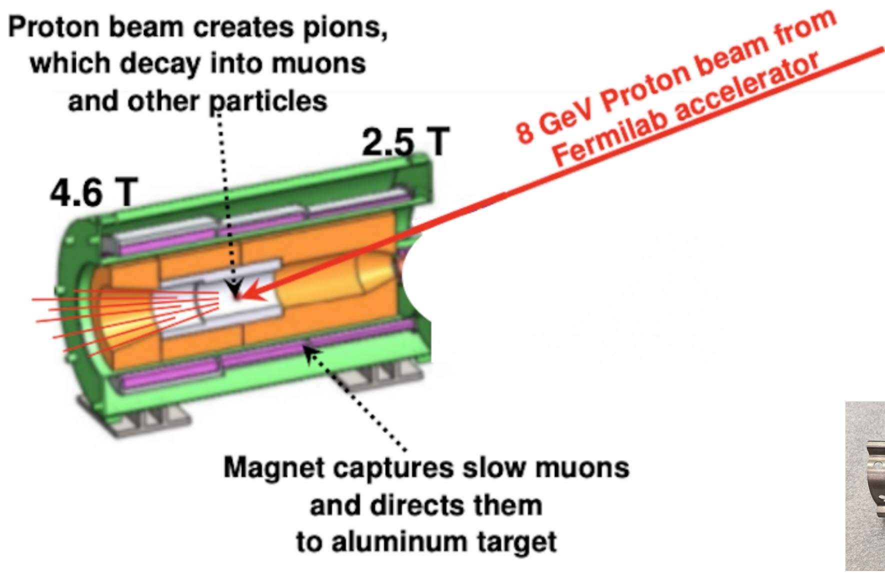


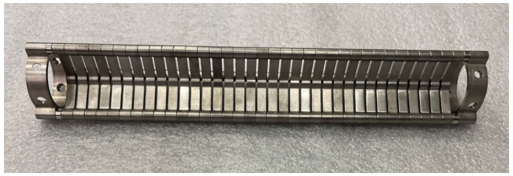
Beam



- Pulsed proton beam with period = 1695 ns (~2x τ_{μ}^{Al})
- Analysis window delayed to avoid prompt RPC and other backgrounds
- Proton extinction between bunches better than 10^{-10}
  - Bunch formation in recycler (10^{-5})
  - AC-dipole sweeping magnets ($10^{-(5-6)}$)

Production solenoid



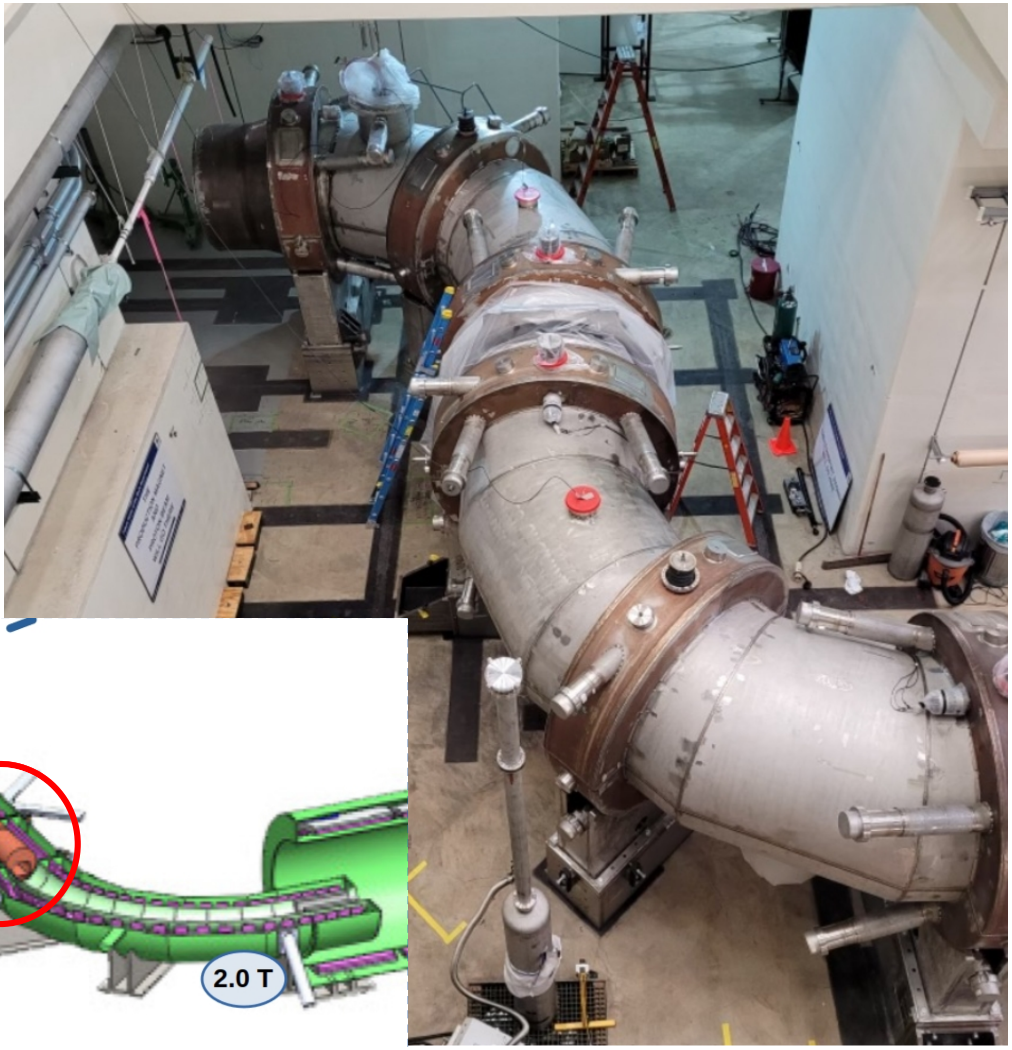


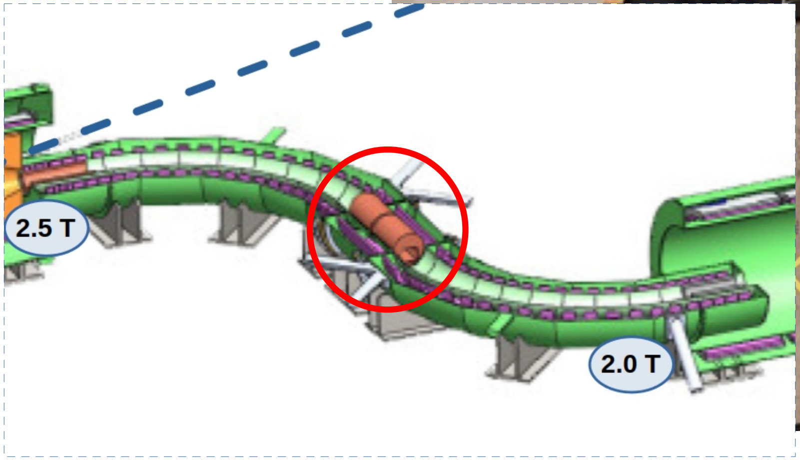
- Inconel target
- Must resist 6x10^12 protons per second (7.3 kW beam)
- Radiation hardness to last for 1 year → robotic replacement

- The 8 GeV proton beam directed to the target inside the Production Solenoid
- Resulting pions are guided toward the transport solenoid with strong magnetic gradient while they decay into muons
- Delivered in June 2025, first cooldown and powerup expected this October

Transport solenoid

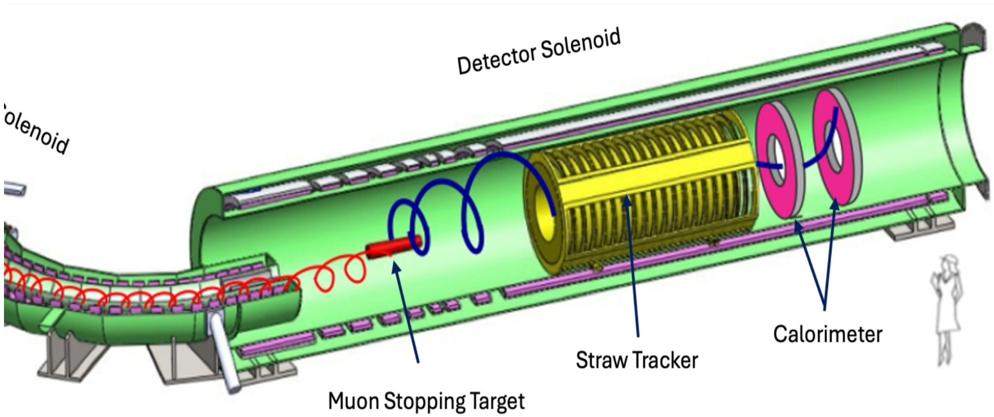
- Small magnetic field gradient to avoid trapped particles
- Thin absorber window to remove antiprotons at the center of the "S"
- Internal rotating collimators to select charge sign and momentum of μ^+/μ^-
- Delivered in early 2024 and now fully installed in Mu2e hall
- First cooldown and powerup expected this August





Detector solenoid

- Muon stopping target, tracker and calorimeter
- Critical equipment in terms of Run-1 timeline
- Fabrication essentially complete, preparing for cold and leak tests
- Delivery expected end of July
- Then, ~12 months for installation at FNAL, cooling and powering up before beam

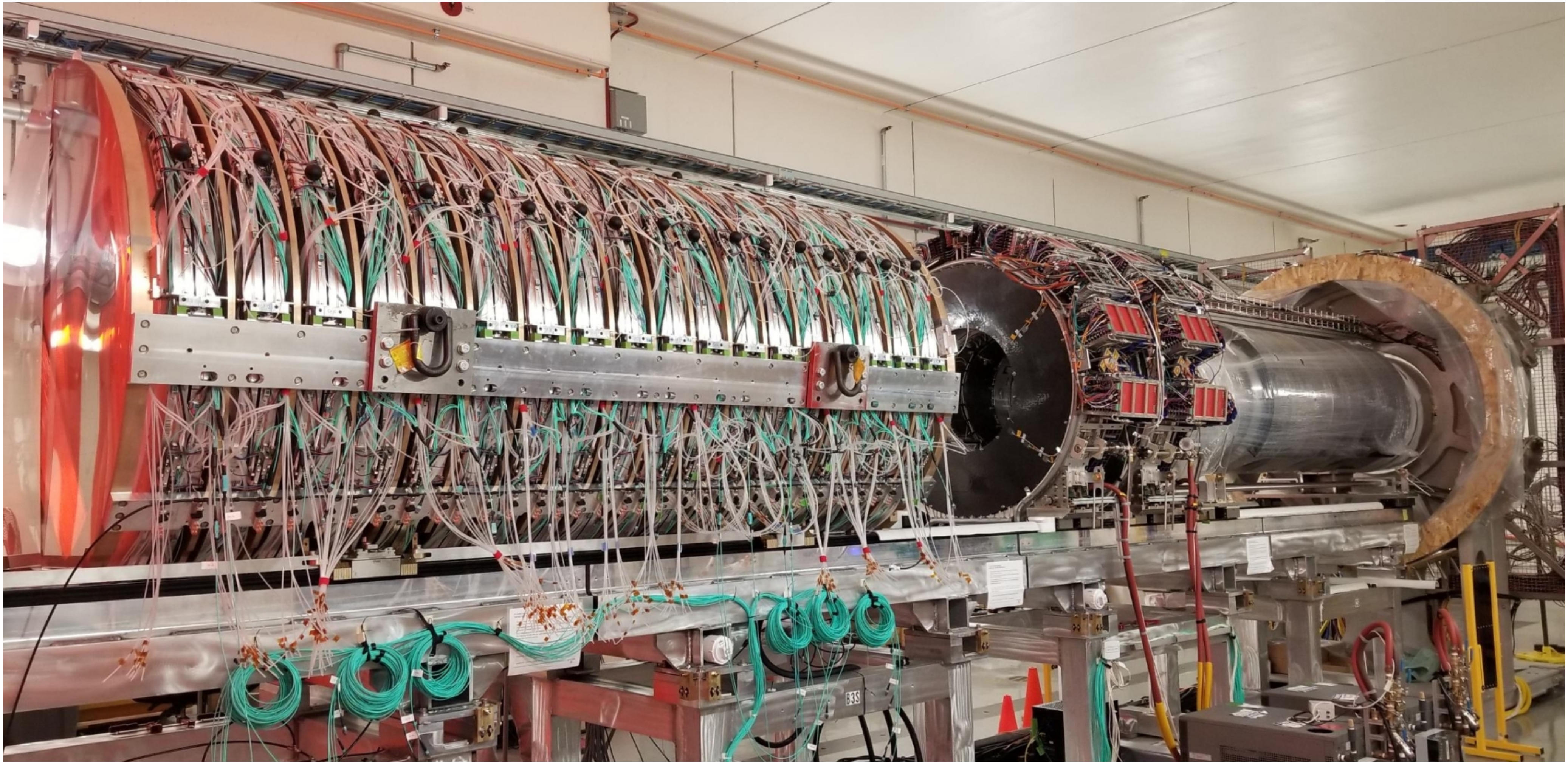


Muon stopping target

- 37 foils of ^{27}Al, each 105 μm thick
- Segmented to reduce electron energy losses

Detector train

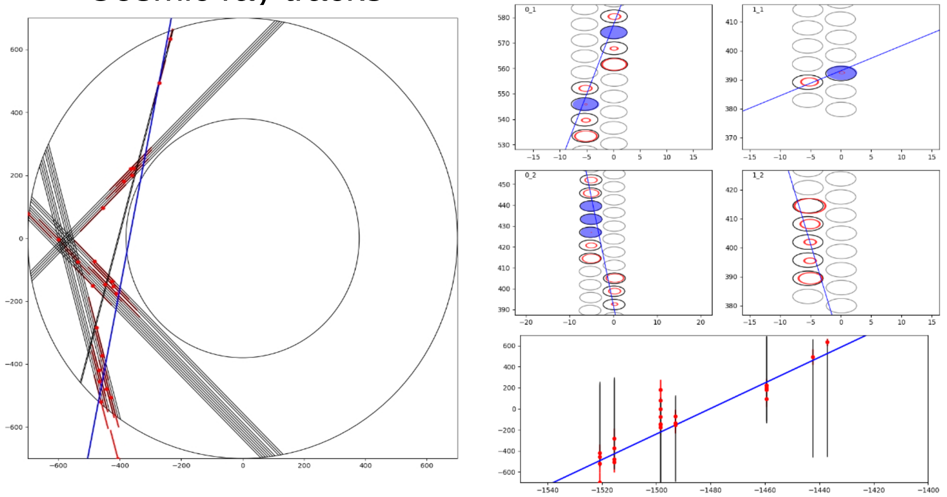
- Tracker, Calorimeter, and muon beam stop on rails to be inserted and extracted in/from detector solenoid



Tracker

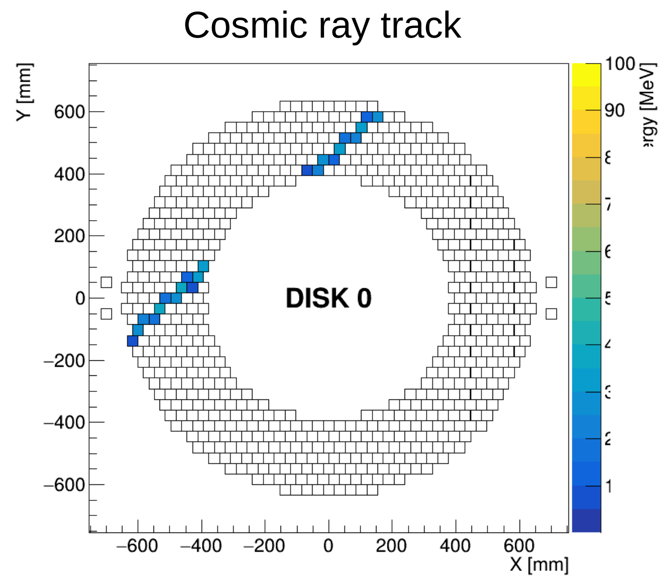
- Straw-tube detector to measure the momentum of conversion electrons
- Annular geometry to reject most of the decay-in-orbit electron tracks
- Momentum resolution of 180 keV/c
- 36 planes for a total of 20736 total straws
- Straws:
  - 25 μm gold plated tungsten wire
  - 5 mm diameter, 15 μm thick, aluminized mylar tubes
  - filled with Ar:Co2 (80:20)
- Installed in the Mu2e hall in November 2025, full commissioning in progress

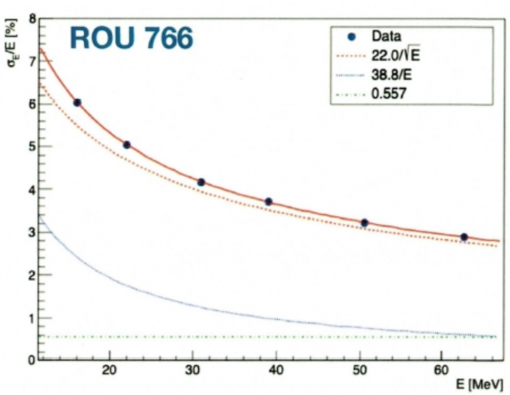
Cosmic ray tracks

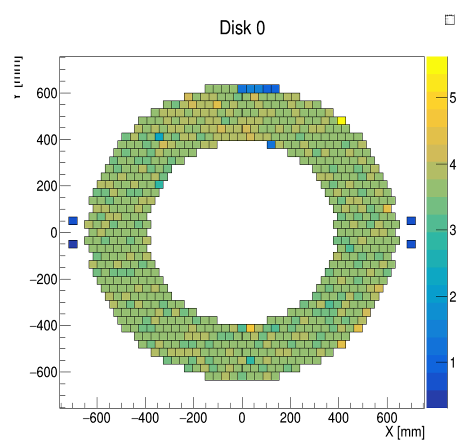


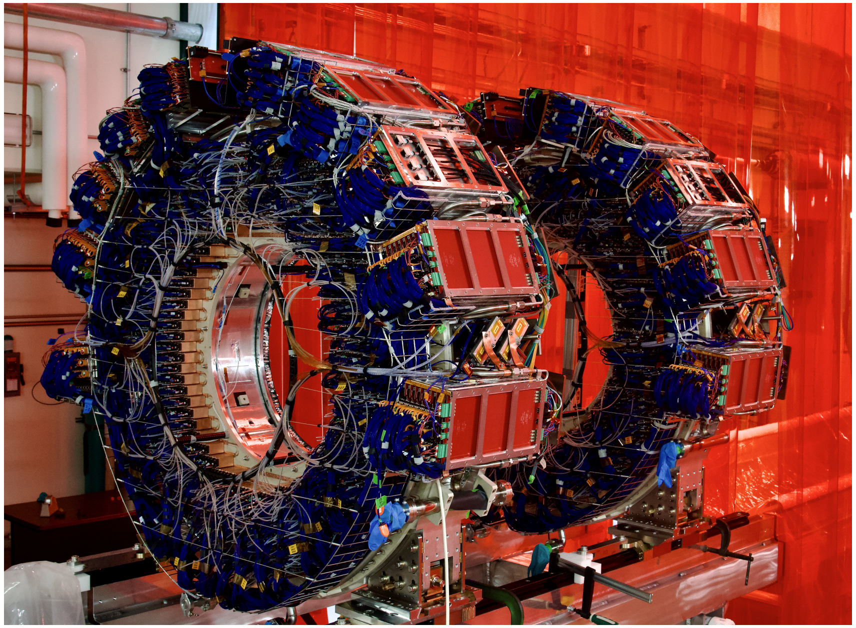
Calorimeter

- 2 disks, each composed of 674 undoped CsI crystals with 2 SiPM readout/crystal for particle identification and seeding for track finding
  - < 10% energy resolution at 105 MeV/c
  - < 500 ps timing resolution at 105 MeV/c
  - Keep performances in vacuum and in a high radiation environment
- Transported to Mu2e hall in Sep 2025 → full commissioning in progress
- Main contribution from INFN



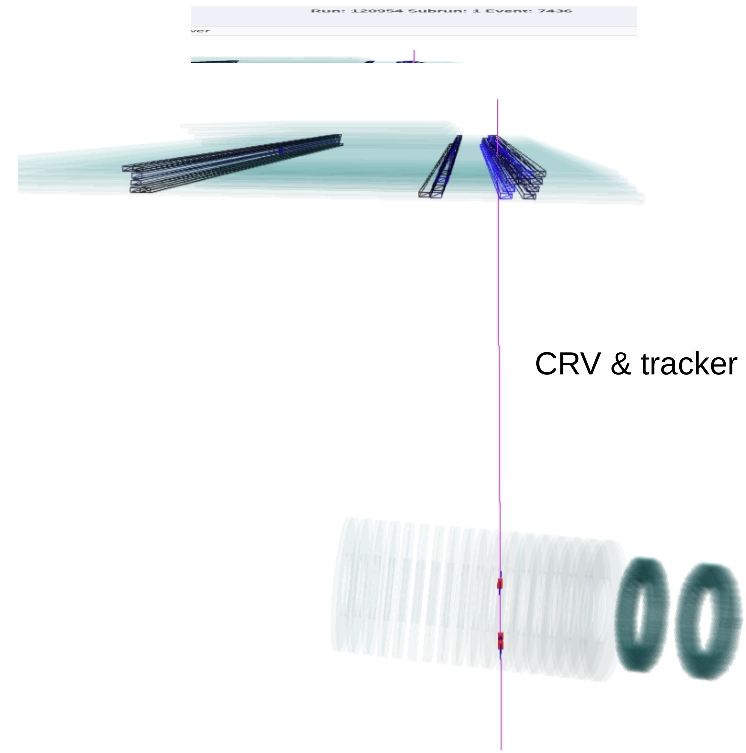






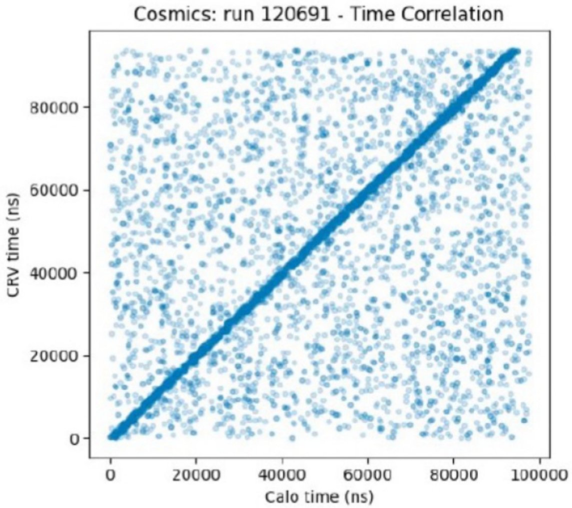
Cosmic Ray Veto

- Cosmic-ray muons can initiate 105 MeV electrons that appear to emanate from the stopping target → 1 signal-like event per day
  - >99.99% efficient cosmic ray veto
- Four layers of extruded polystyrene scintillators with embedded WLS fiber and SIPM readout, separated by aluminum absorbers
- All modules built. Small fraction of CRV system installed over the detectors for cosmic ray run, fully working



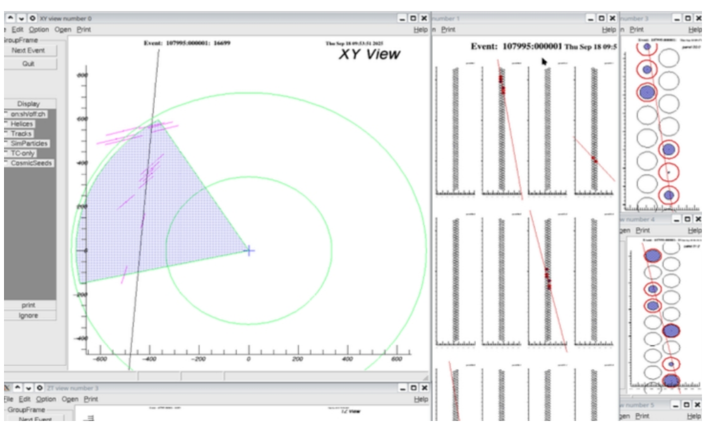
CRV & tracker

CRV & calo



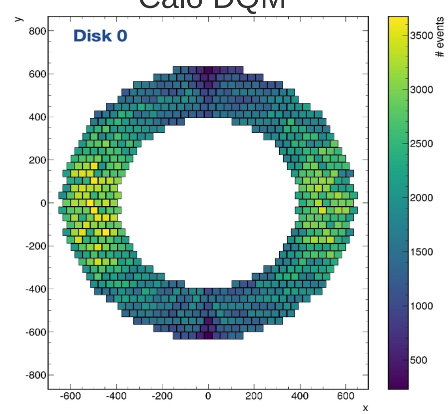
Commissioning phase

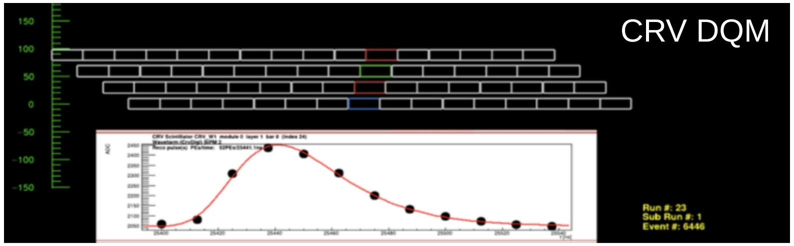
- All detectors are now in their commissioning phase
- Using cosmic rays to test the DAQ and develop all needed infrastructure
- Periodic “shifter” runs where multiple detector take data together with unified DAQ with a shifter in control room
- Fall 2026: cosmic ray run with all subdetectors

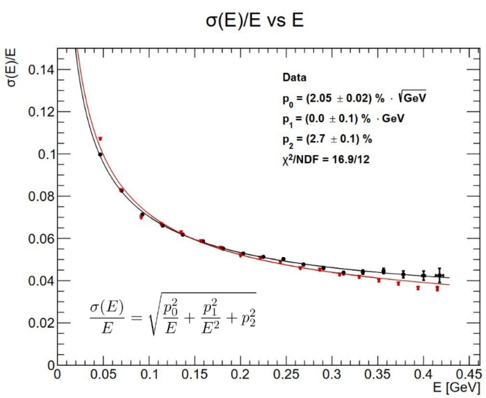


Tracker DQM

Calo DQM



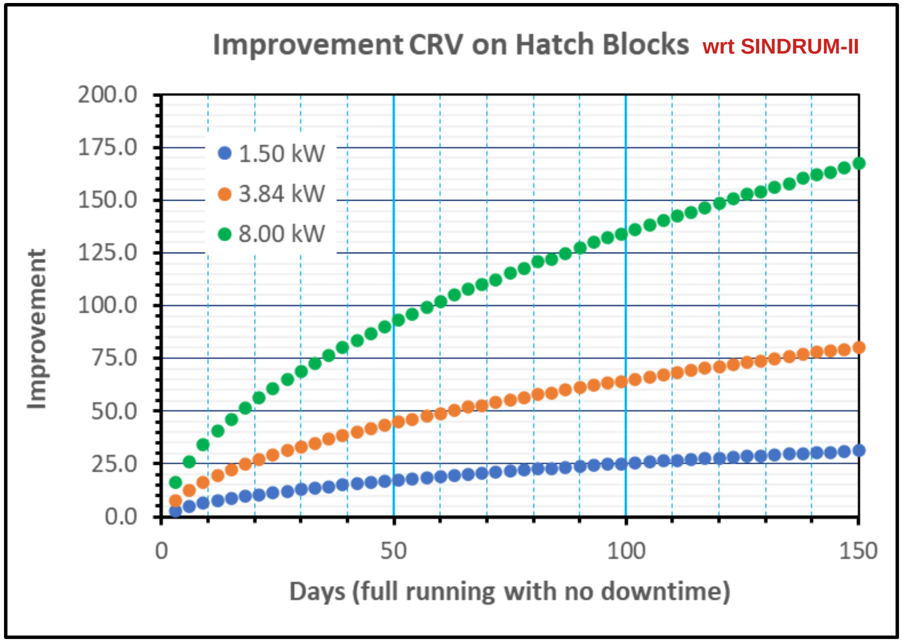


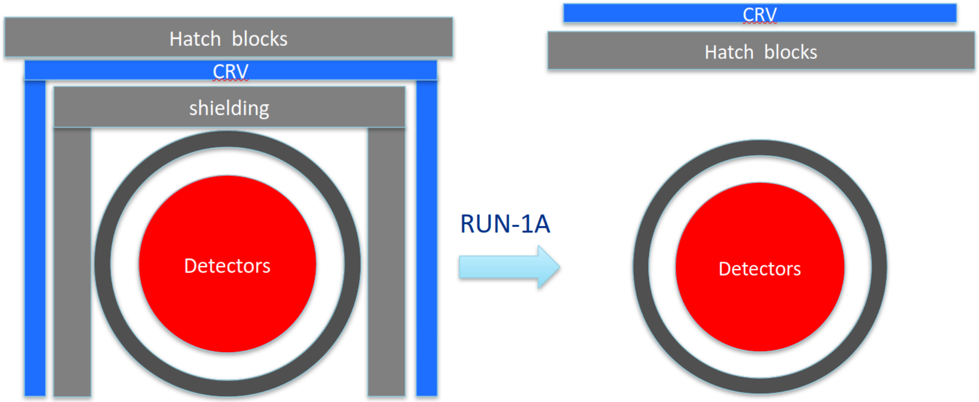


Calo energy resolution

Run-1 timeline

- Run-1A scheduled to start in late 2027 and last few months
  - Long shutdown for PIP-2 installation planned for Jan 1st, 2028
  - Start with low intensity beam and rampup to high intensity in a second phase
- Initial beam date is currently driven by the Detector Solenoid readiness
- Slight difference with TDR Run1 plan to accomodate DS installation
  - No shielding blocks around detector
  - CRV only on top of detector train
- Aiming for x30 improvement wrt SINDRUM-II





Conclusions

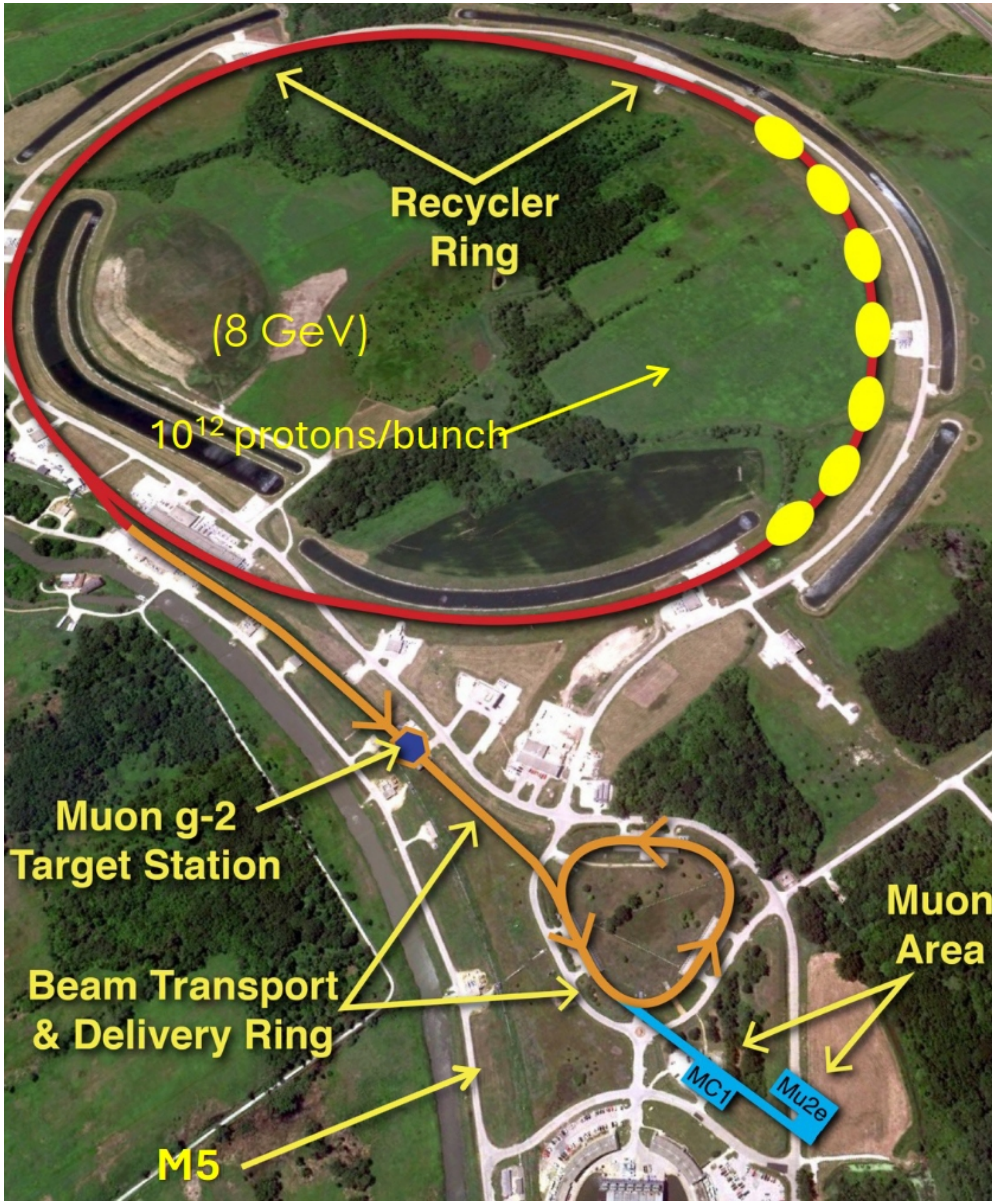
- Mu2e construction is progressing at full speed
- Commissioning of all subsystems in progress and in good shape
- Cosmic ray run with all detectors starting this fall
- Detector solenoid will arrive in ~2 months, and will drive the Run-1 schedule
- Aiming to reach up to 30x Sindrum-II sensitivity in Run-1 by end of 2027!

Thank you for your attention!

Backup

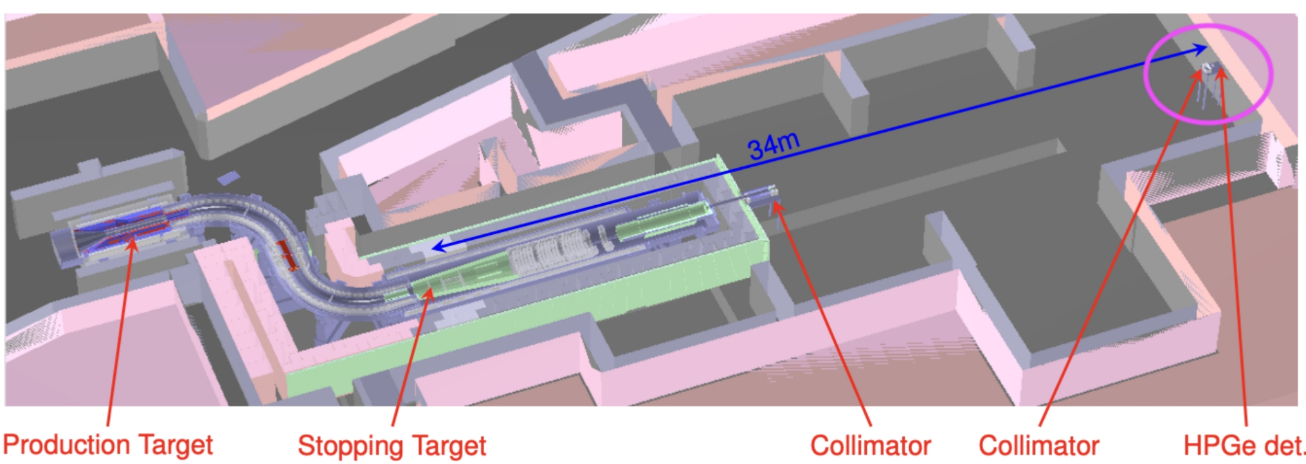
Beam

- LINAC accelerates protons to 400 MeV
- Bunches are accelerated to 8 GeV by the Booster Ring
- Recycler ring accumulates 8 bunches of ~ 10^{12} protons each
- Bunches are sent to the Delivery Ring where they are resonantly extracted each 1695 ns to create the proton pulses to Mu2e (~ $4x10^{7}$ protons/pulse)



Stopping Target Monitor

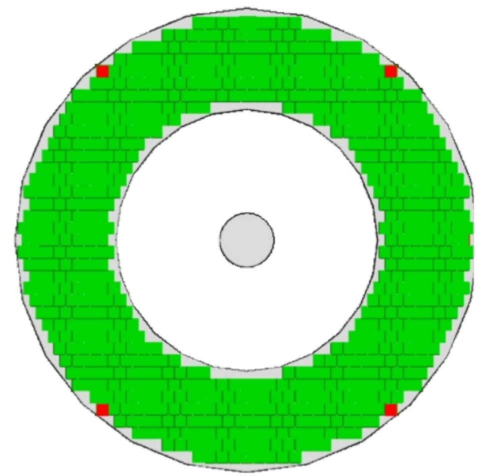
- Detector to count number of muon stops and provide absolute normalization
- Two detectors located 34 m downstream of the muon stopping target:
  - solid state high-purity Germanium detector (high-precision)
  - scintillating LaBr3 detector (high-rate)
- 10 % absolute precision in few minutes of data



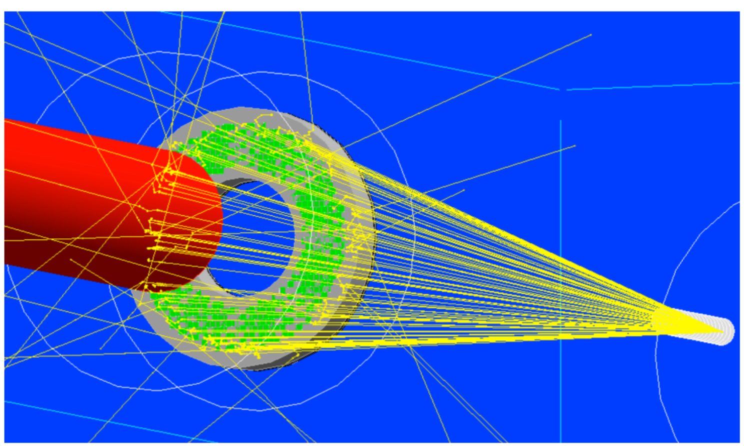
Physics observables:

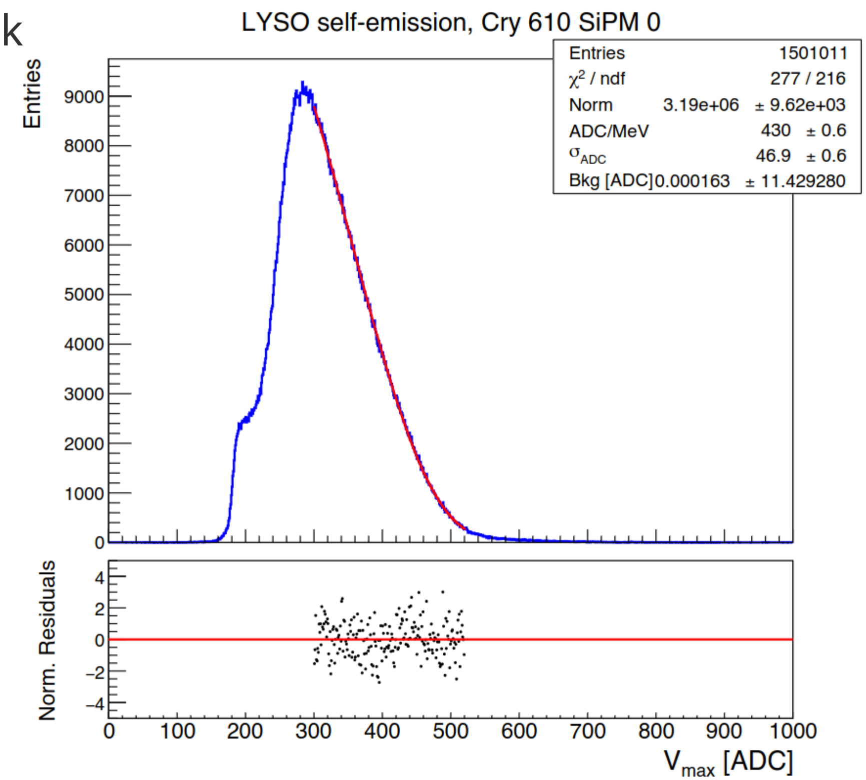
- 347 keV 2p→1s X-ray
  - Absolute normalization anchor
- 1809 keV capture gamma
  - High-rate normalization signal
- 844 keV delayed gamma
  - Delayed normalization channel

CAPHRI



- Calorimeter Precision Hi-Reso Intensity Detector
- 4 CsI crystals replaced with LYSO (~20x higher light yeald)
- Measure the 1.8 MeV gamma line from muon captures
- Very fast response for normalization and AD feedback
- At full beam power, we expect 3% precision each injection cycle (1.4 sec)
- System installed and under commissioning





Extinction Monitor(s)

- Inter-bunch proton extinction ratio (fraction out of bunch) has to be < 10^{-10}
- **Downstream** ExtMon detector placed behind the proton beam dump
  - Two collimators and a dipole select protons and pions of ~4 GeV/c
  - High efficiency tracking with ATLAS IBL silicon pixel sensors and FE-I4b readout chips (8 planes)
  - Scintillators for bunch triggering
  - Average extinction measurement over ~ 8 hrs
- **Upstream** ExtMon detector at end of M4 line
  - Independent Cherenkov counter detector
  - Single pulse extinction from the Recycler by looking at off-axis counts before the AC sweeping dipoles
  - Commissioning in progress