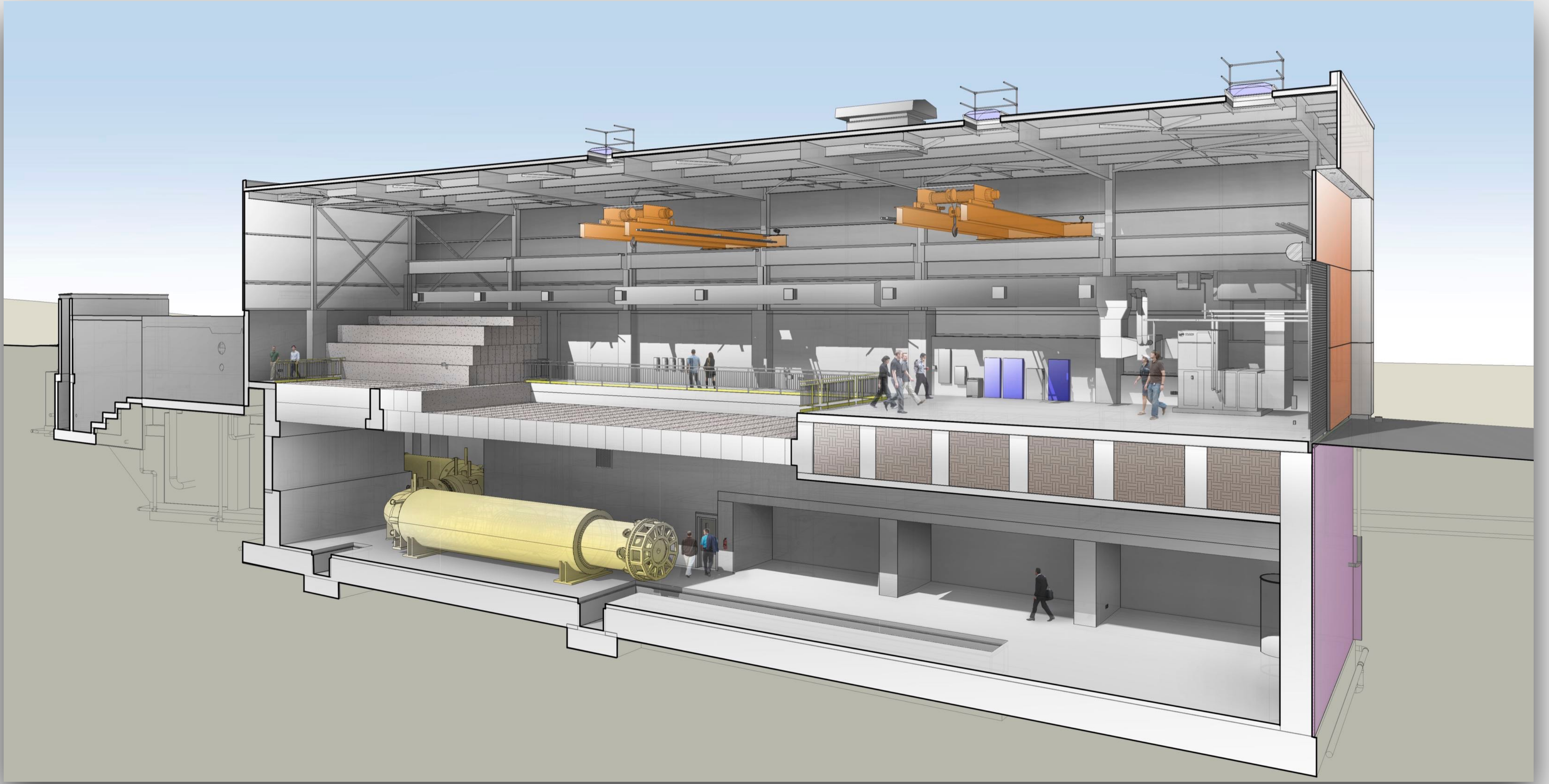
Mu2e Experiment at Fermilab



Steve Boi, Yuri Oksuzian

Newcomers lunch

Mu2e

- Fermilab is actively pursuing the searches with high intensity beams: NOvA, Short-baseline neutrino, DUNE, Muon g-2, Mu2e…
- Mu2e will search for neutrino-less, coherent muon conversion into an electron

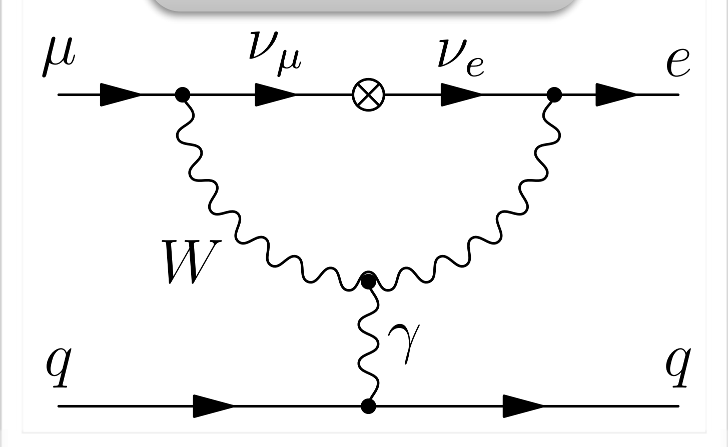
$$\mu^- + N \to e^- + N$$

- Neutrino-less $\mu \to e^-$ conversion is Charged Lepton Flavor Violation (CLFV)

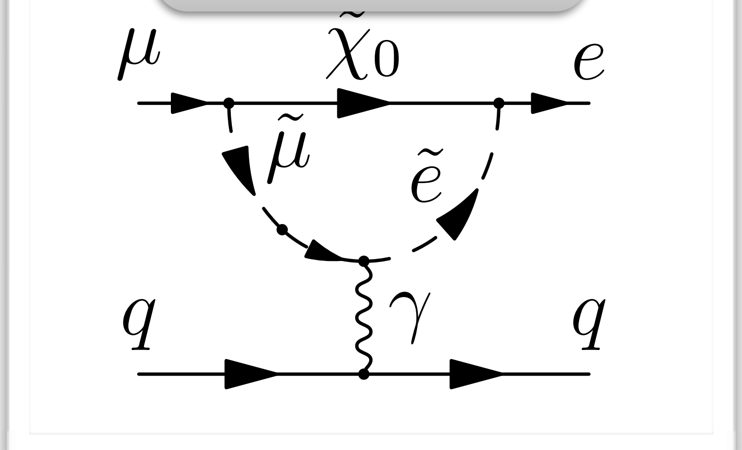
$$\mu \to e\gamma, \;\; \mu \to 3e, \; \tau \to e\gamma, \; \tau \to \mu\gamma \ldots$$

- In the SM, $\mu \to e^-$ occurs at the rate of $<10^{-50}$
  - Signal observation at Mu2e is unambiguous sign of new physics
  - Indirectly probing high mass scales ($>10^4$ TeV)

$\text{Rate}_{\text{SM}} < 10^{-50}$



$\text{Rate}_{\text{BSM}} \sim 10^{-15}$



What do we measure?

Mu2e will measure the ratio of $\mu \rightarrow e^-$ conversions to the number of muon captures by Al nuclei:

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

Numerator

Mu2e will measure the ratio of $\mu \to e^-$ **conversions** to the number of muon captures by Al nuclei:

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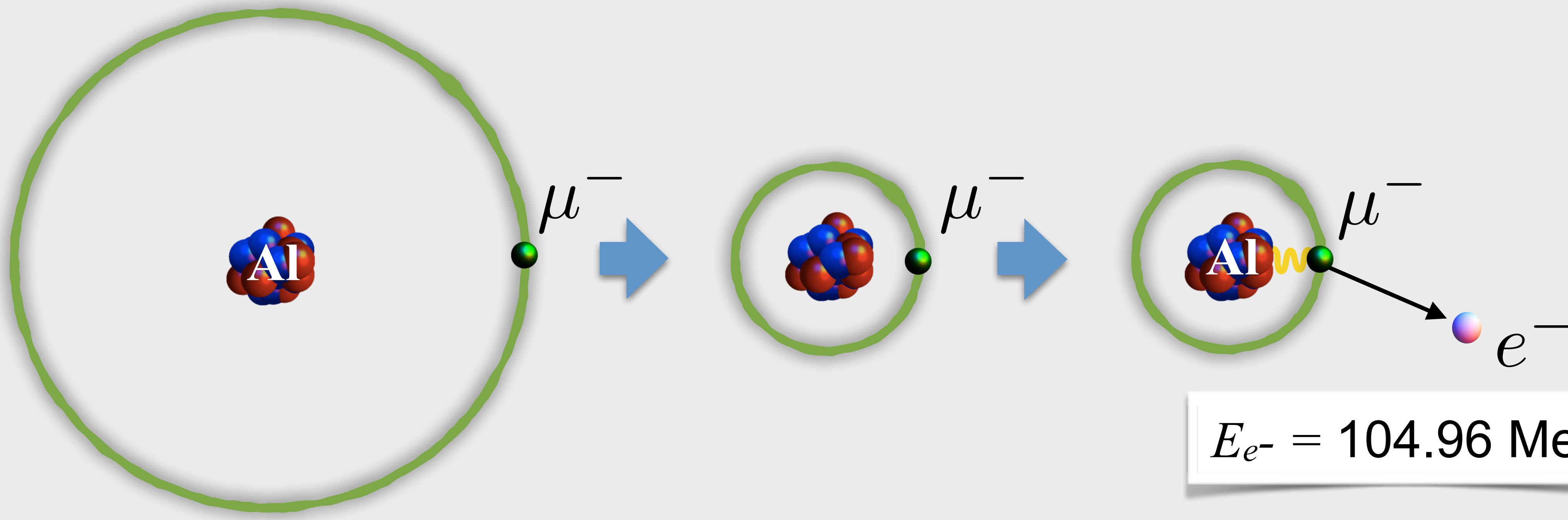
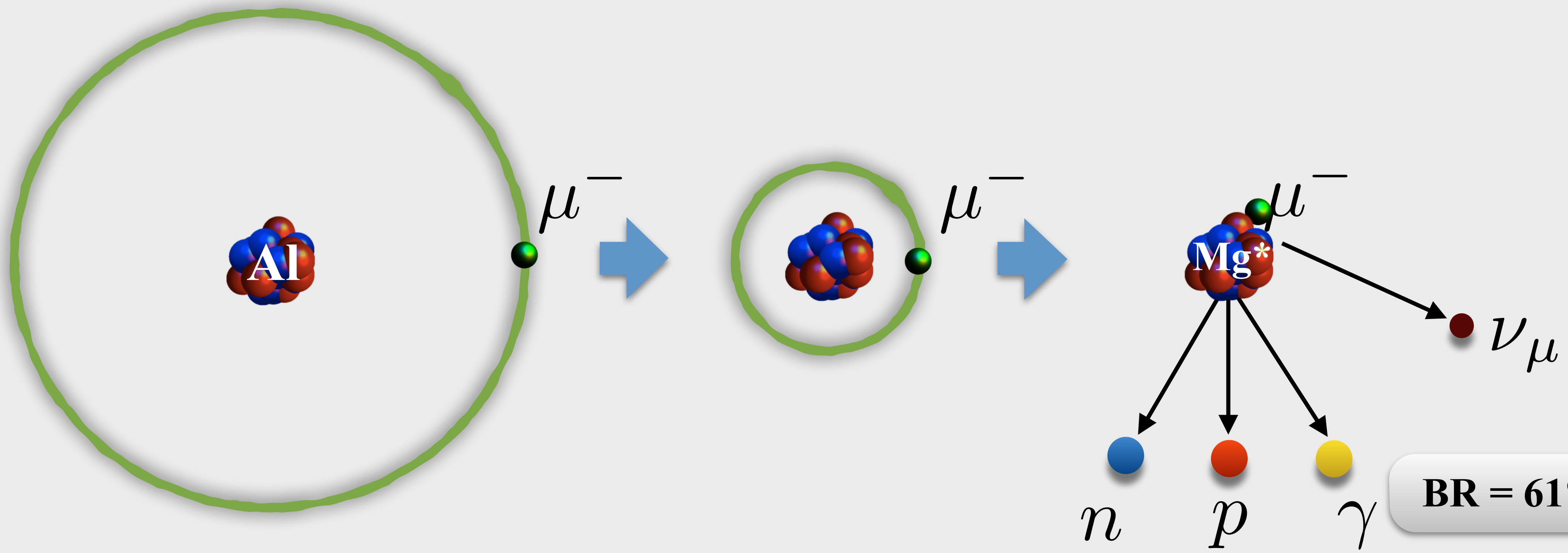


$E_{e^-} = 104.96$ MeV

Denominator

Mu2e will measure the ratio of $\mu \to e^-$ conversions to the number of **muon captures by Al nuclei**:

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



BR = 61%

Dominant background: Decay in orbit

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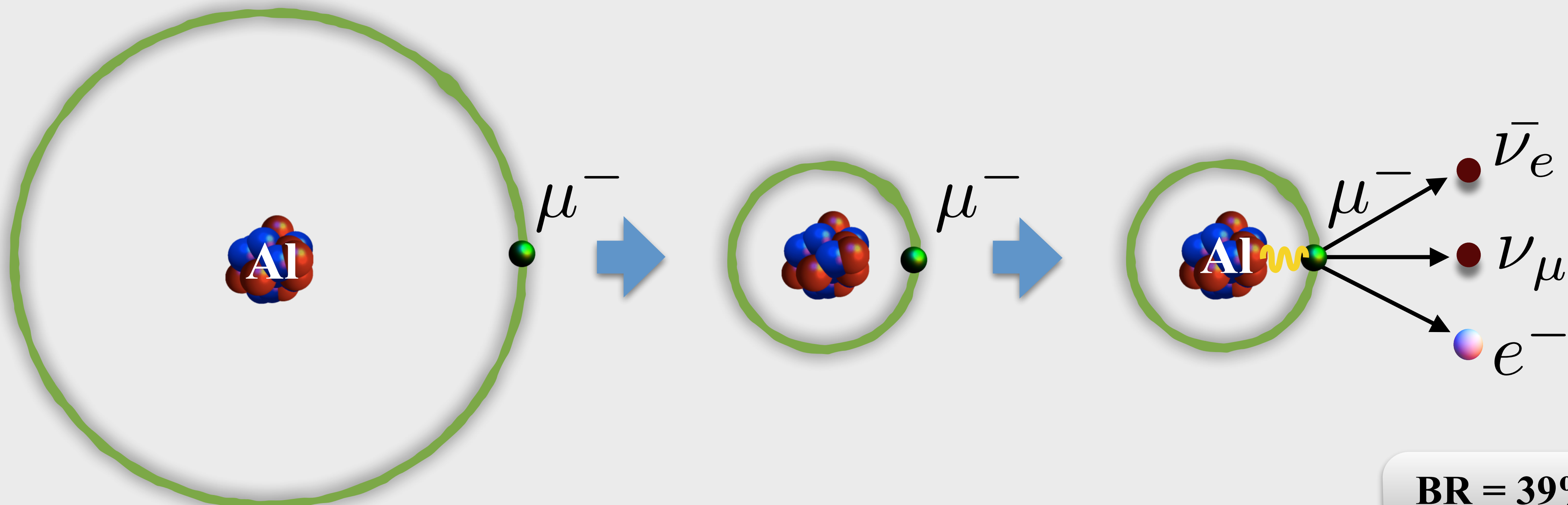


BR = 39%

Mu2e Sensitivity

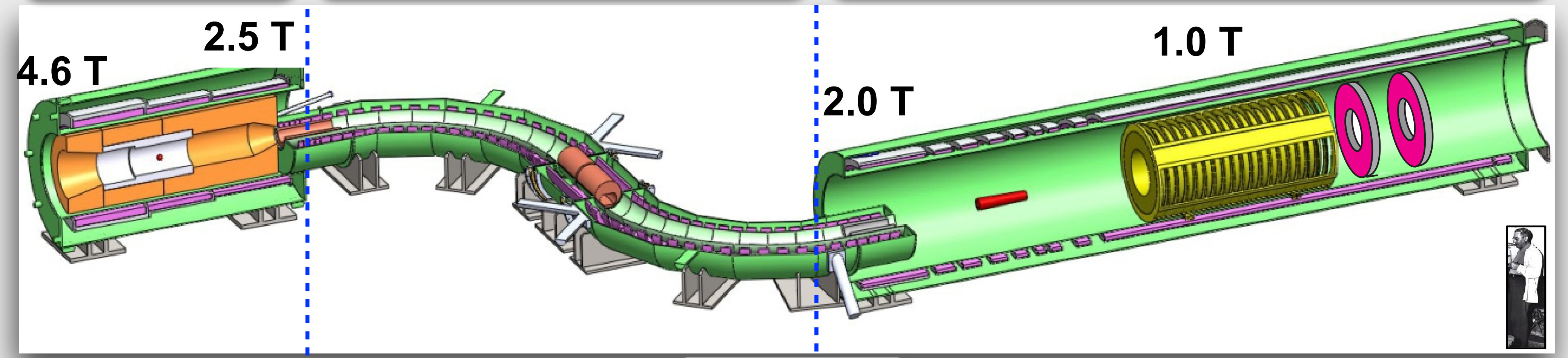
Mu2e will measure the ratio of $\mu \rightarrow e^-$ conversions to the number of muon captures by Al nuclei:

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

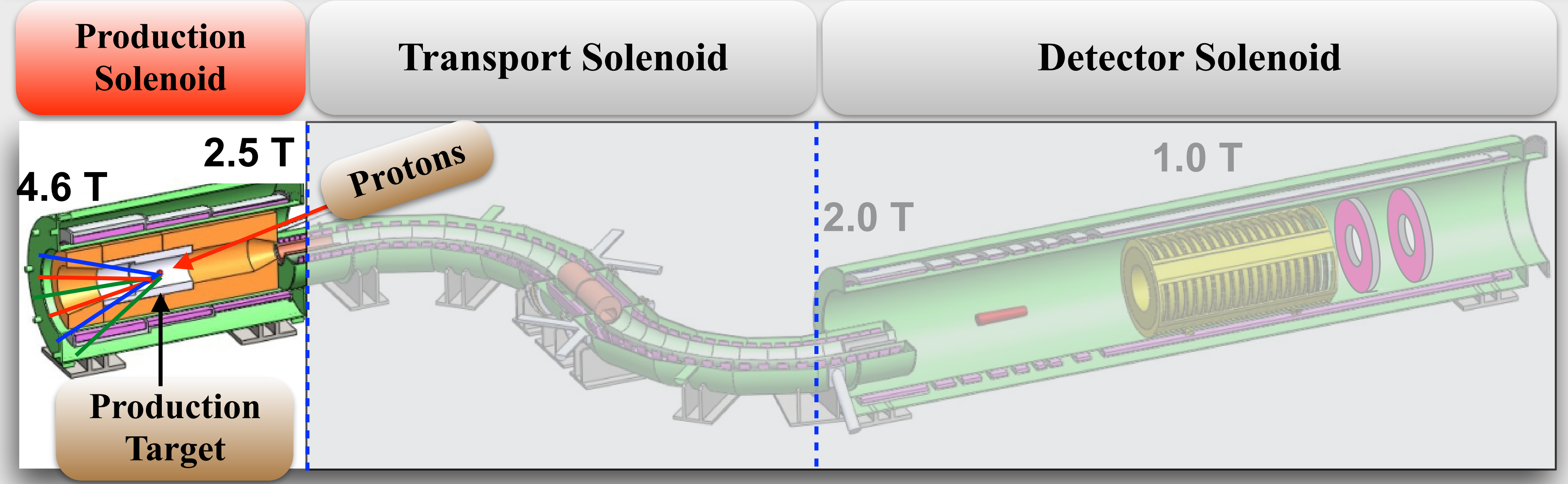
- Mu2e single event sensitivity: $R_{\mu e} = 2.5\times10^{-17}$
  - Expect 40 events at $R_{\mu e} = 10^{-15}$
- Mu2e planned sensitivity: $R_{\mu e} = 7\times10^{-17}$ at 90% CL
- Mu2e needs to stop ~10^{18} muons
  - 3.6×10^{20} protons on target (POT) over 3 years
- Need to keep background small and well understood
  - Total expected background 0.4 events

Mu2e apparatus

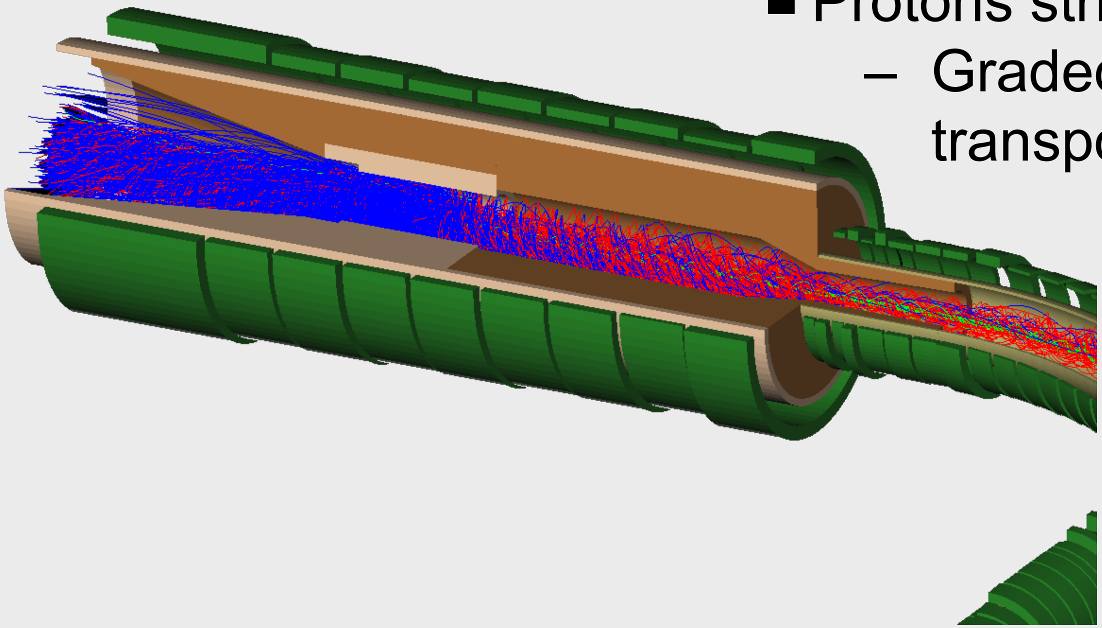
Production Solenoid	Transport Solenoid	Detector Solenoid



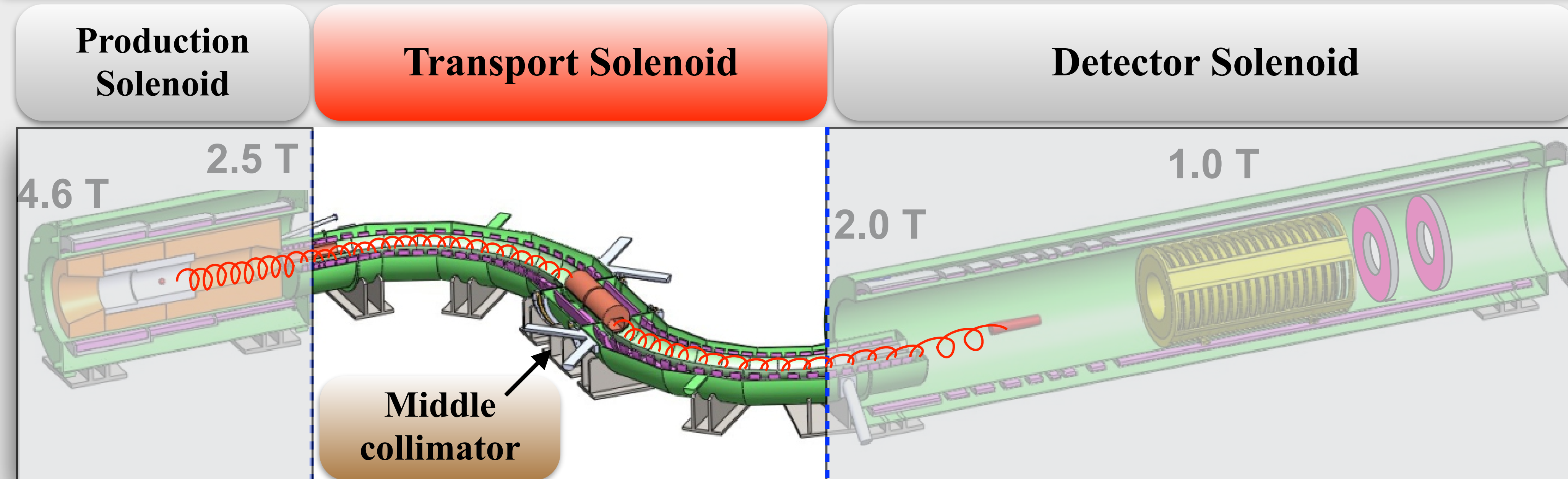
25 meters



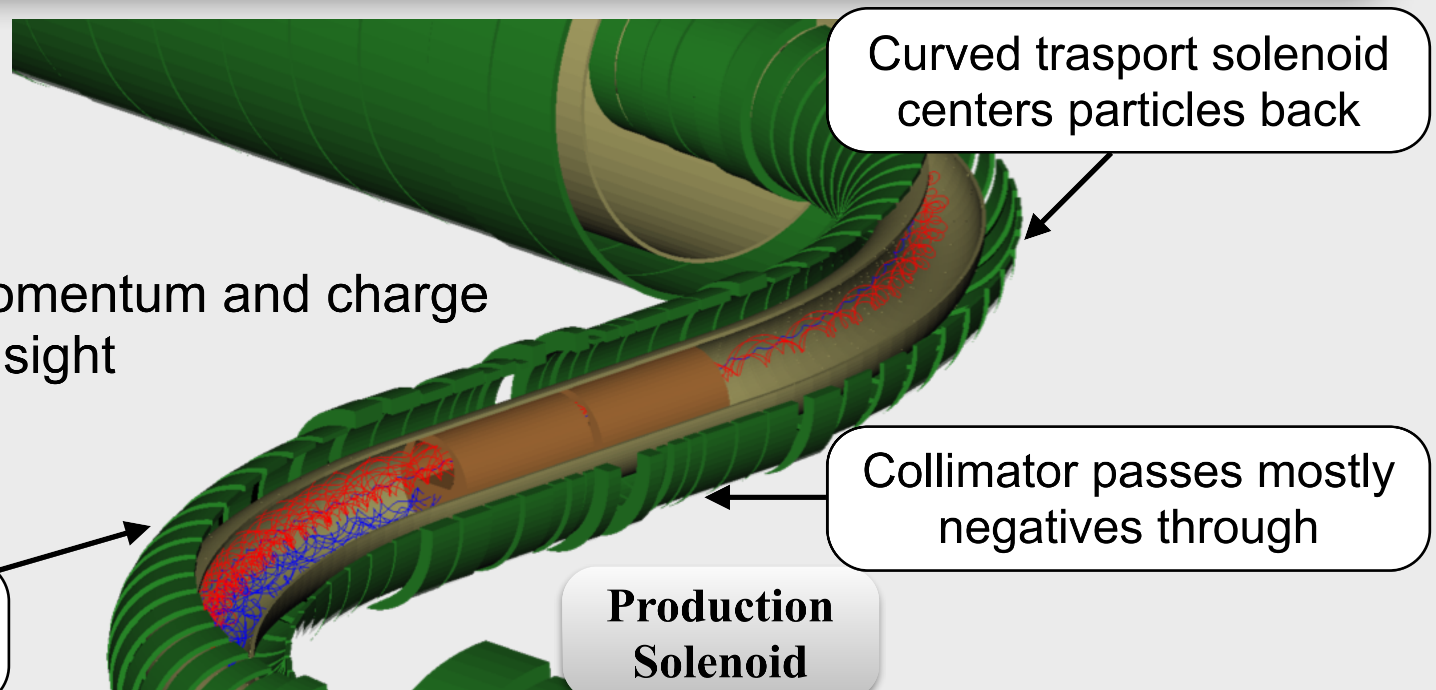
- Protons strike production target to produce π^-
  - Graded B-field reflects pions toward the transport solenoid



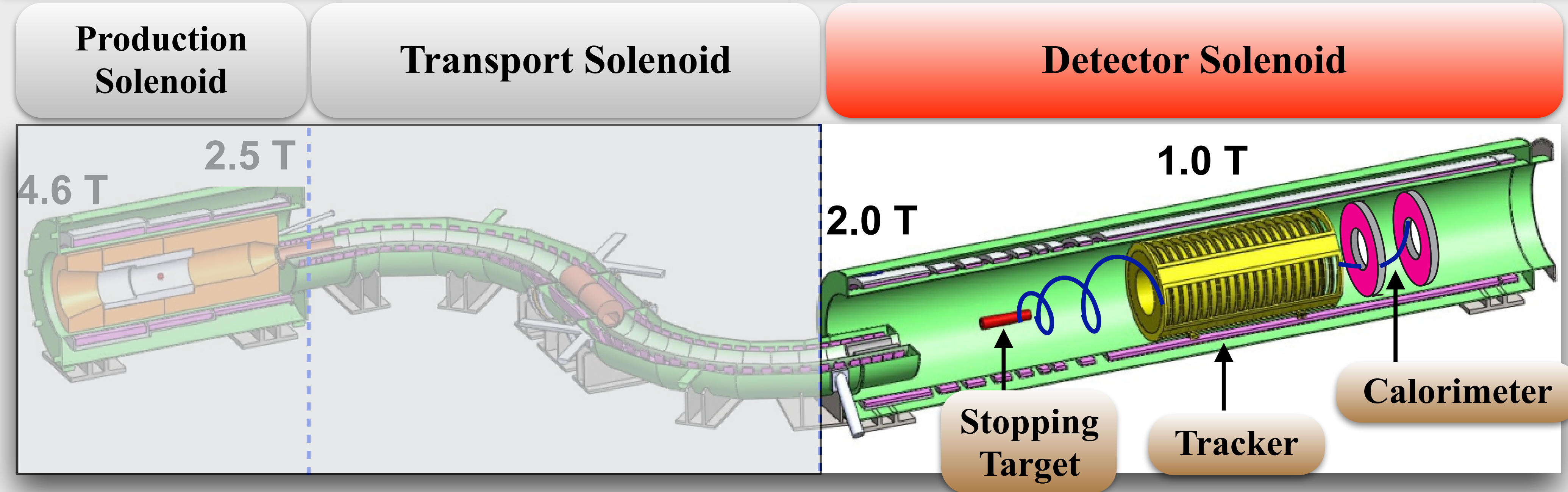
Mu2e apparatus



- Trasport solenoid:
  - Transports π^-/μ^-
  - Selects particle's momentum and charge
  - Avoids direct line of sight

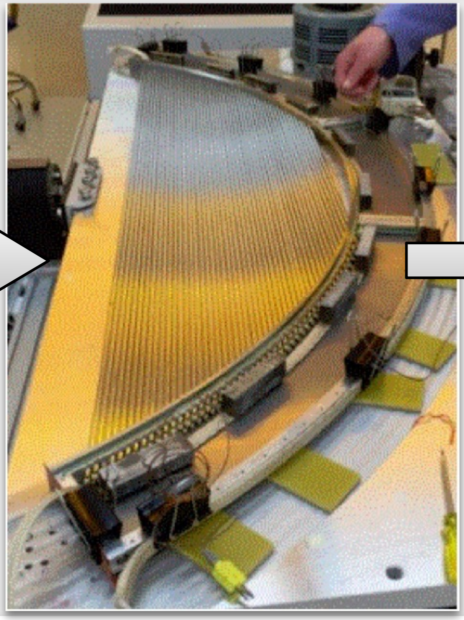


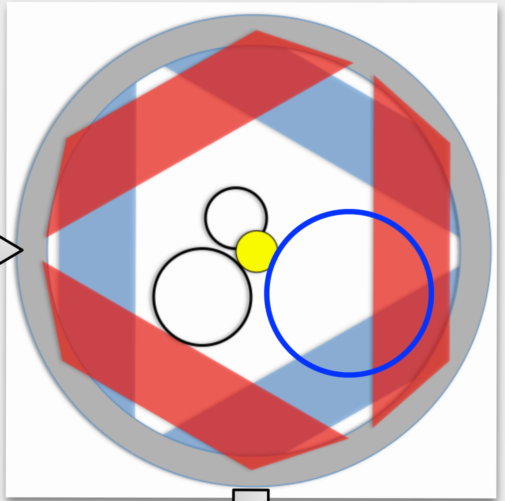
Mu2e apparatus

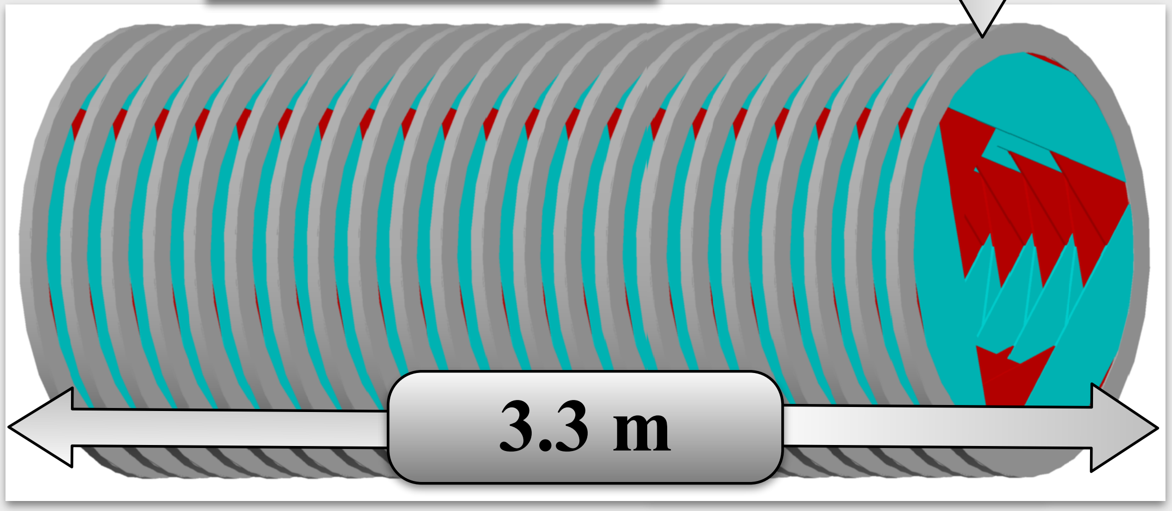


- Muons stop on Al stopping target
  - 50% of μ^- stop on the target
  - 1,000 POT → 2 stopped muons
  - Graded magnetic field reflects conversion electrons toward the tracker
- Conversion electron momentum and energy are measured in the tracker and calorimeter

Tracker



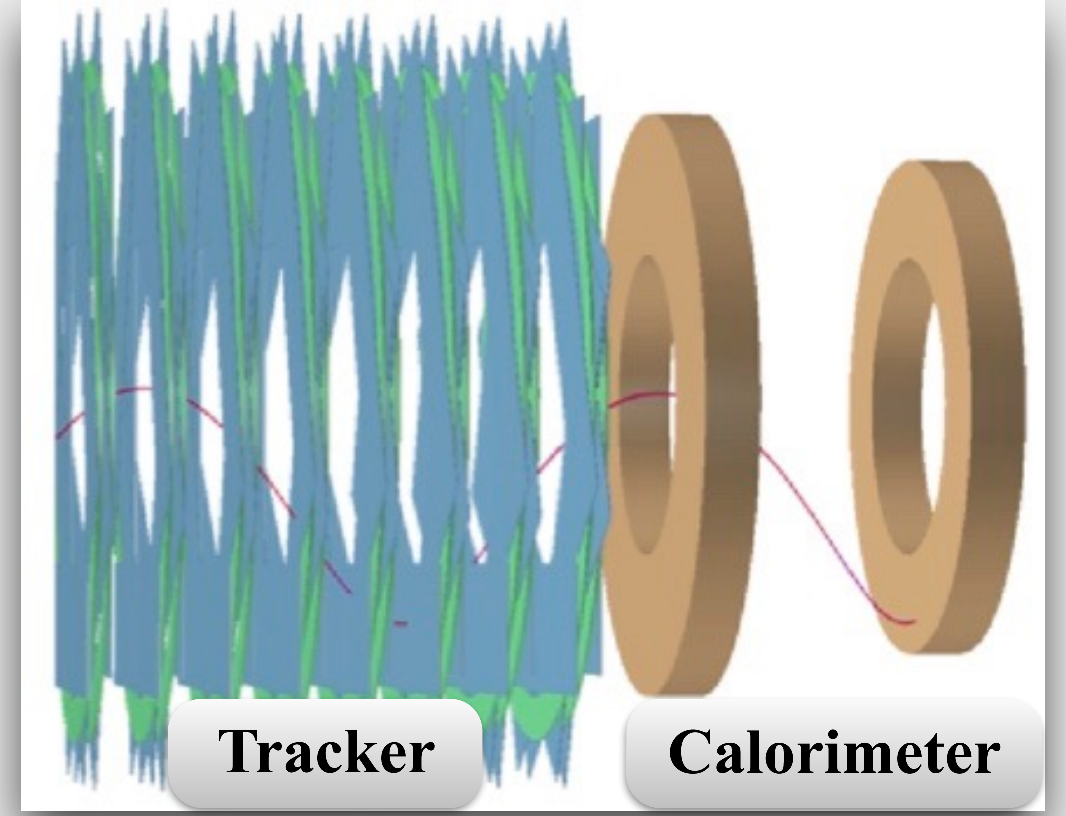


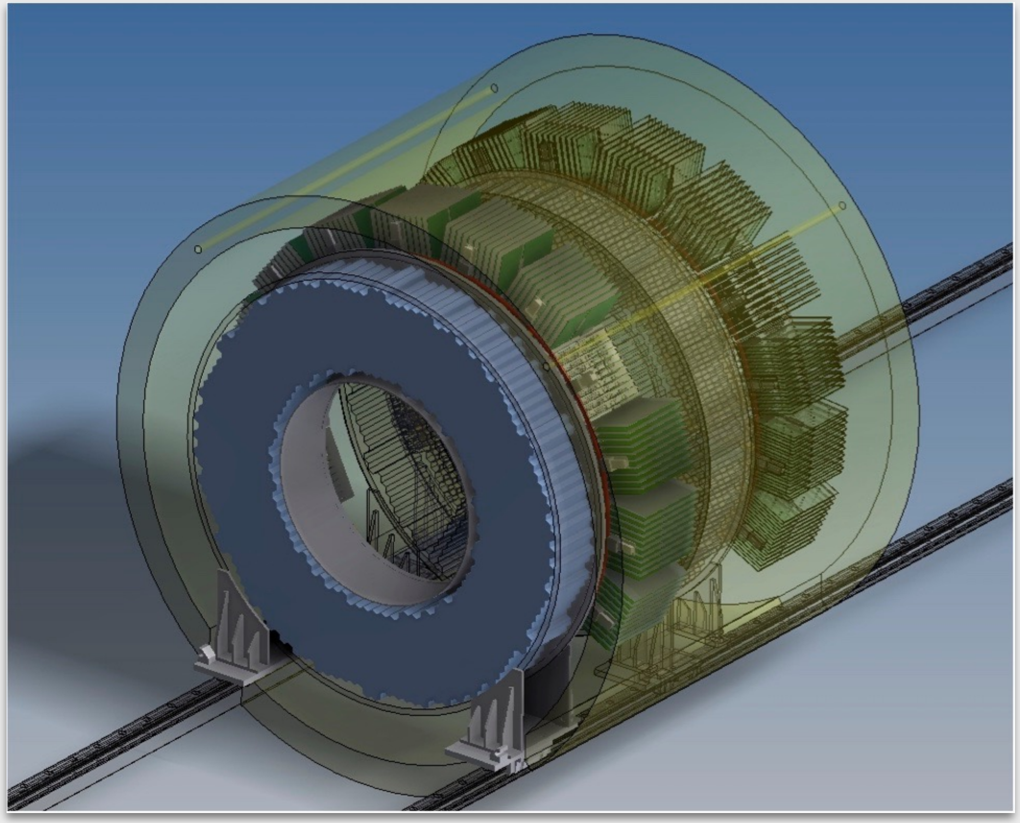


- Low mass straw drift tubes
- 5 mm diameter straws
  - 15 μm Mylar walls
  - Filled with 80/20 Ar/CO_2
- 25 μm gold-plated tungsten sense wires
- 100 Straws = Panel; 6 Panel = Plane; 2 Planes = Station; Tracker = 18 Station

Calorimeter

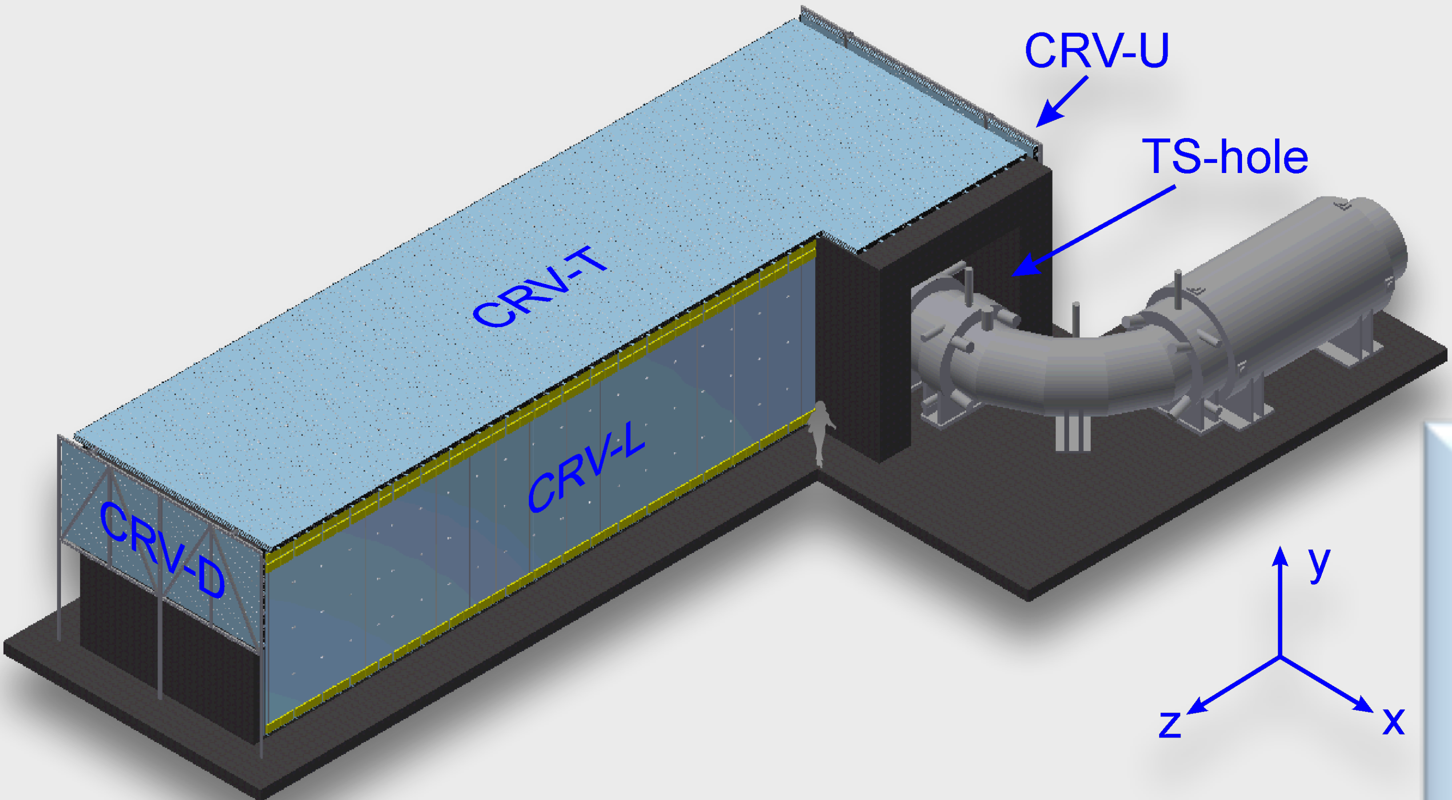
- Two disks of BaF_2 scintillating crystals
  - BaF_2 fast (<1 ns) time component and good energy resolution (5%)
- Provides precise timing, PID, seed for tracking and triggering
- Complementary energy measurement





Cosmic Ray Veto

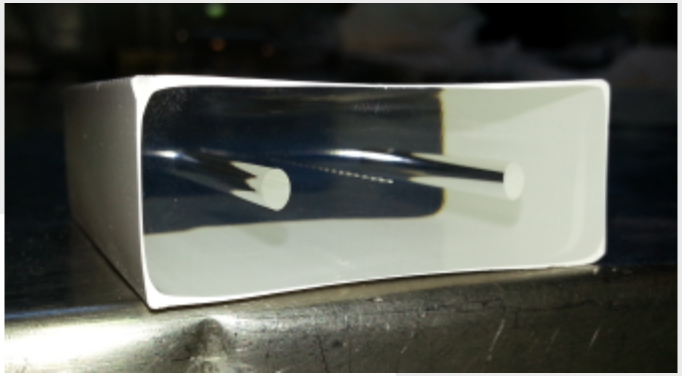
- Mu2e expects 1 signal-like event per day induced by cosmic rays
- Cosmic Ray Veto(CRV) consists of 4-layer scintillating
- We require hits in at least 3 out of 4 layers for a valid cosmic ray muon background track

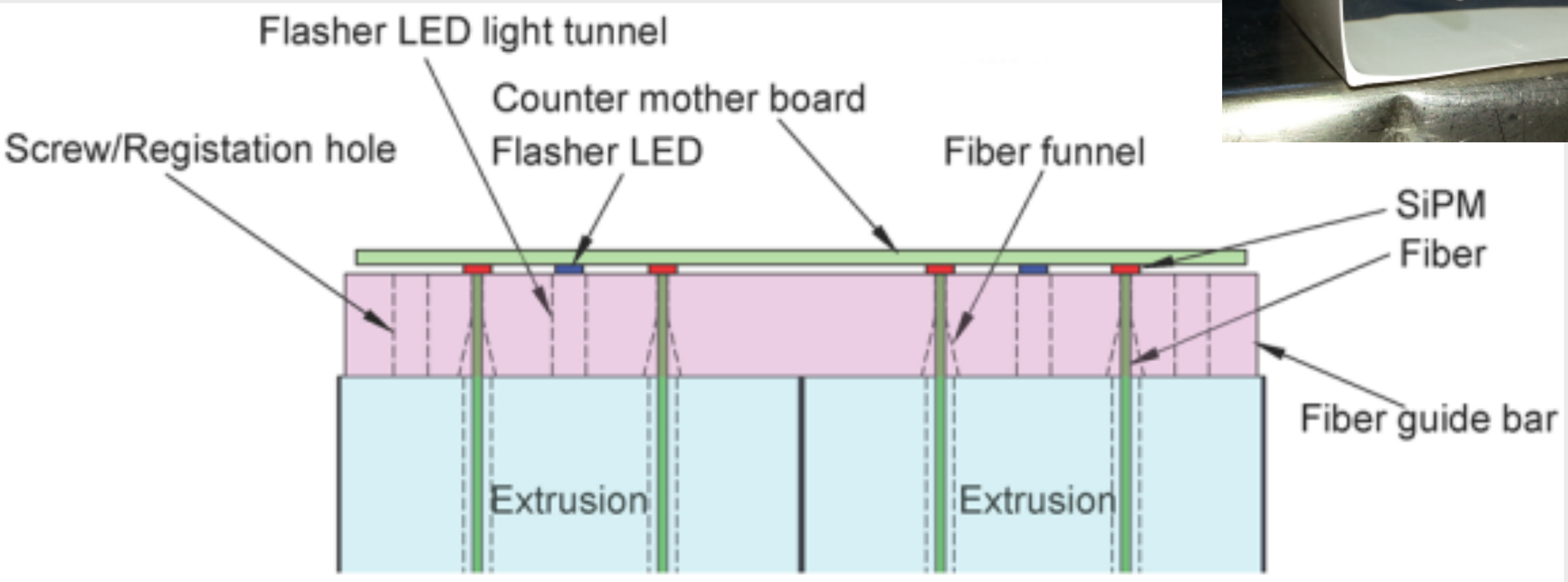


Details:
- Area: 323 m^2
- 82 modules 7 sizes
- 5,152 counters
- 10,254 fibers
- 18,944 SiPMs

CRV counter

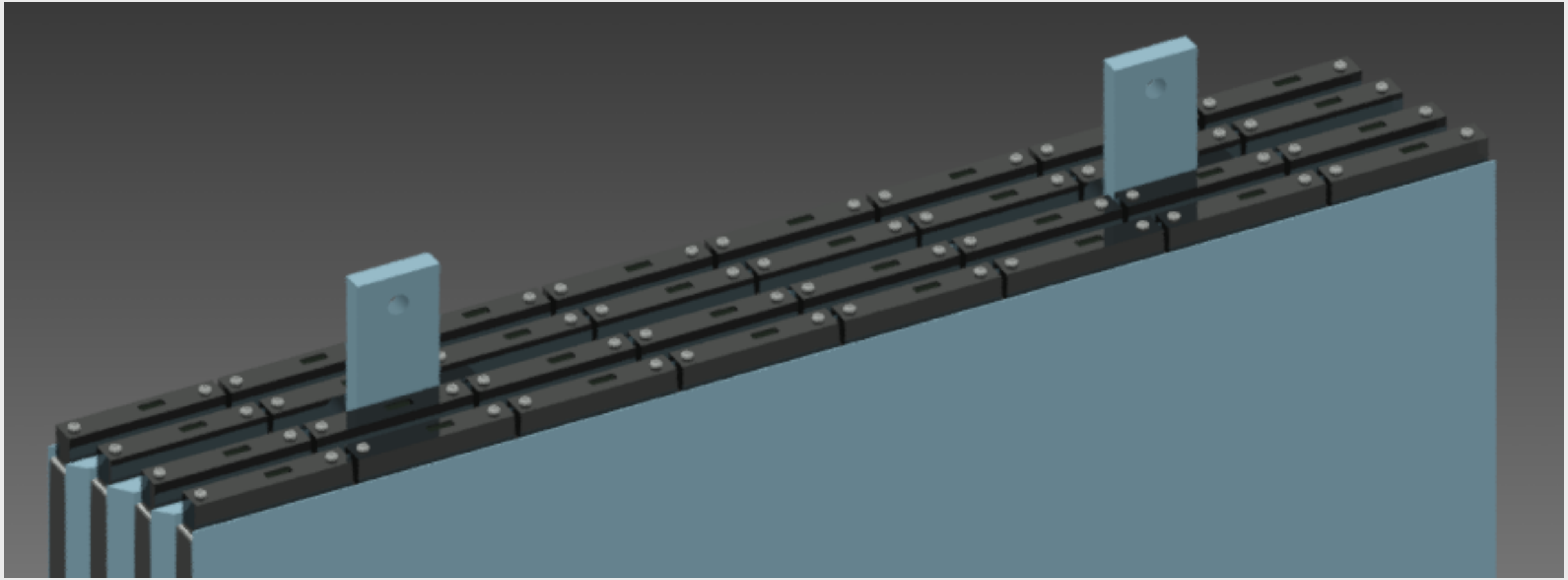
- Extruded plastic scintillator counters: 50 x 20 x 900-6600 mm^3
- Two 1.4-mm diameter wavelength shifting fibers
- Readout: 2x2 mm^2 SiPMs on each fiber end
  - Two fibers per extrusion, up to four SiPMs for readout
- Glue two extrusions together to form di-counters





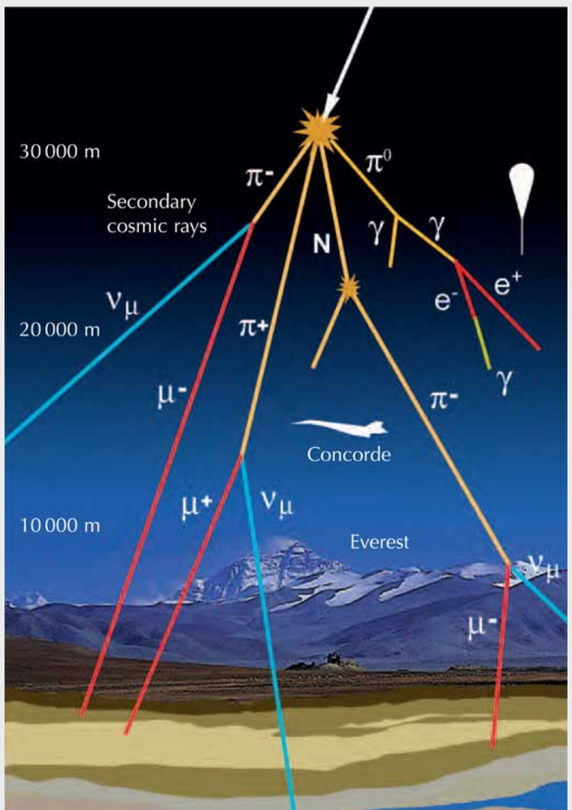
CRV Modules

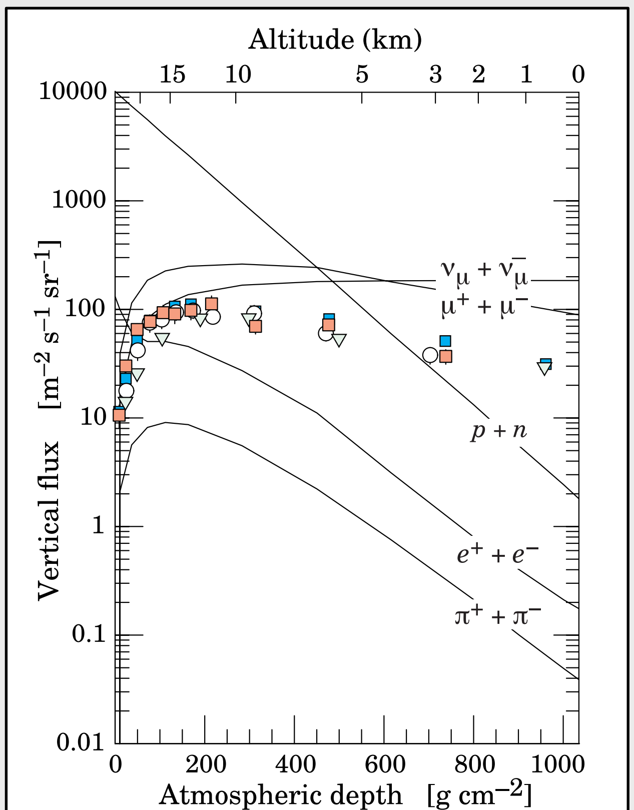
- 4 layers of counters with 3 layers of Al absorbers sandwiched between them: 16 counters/layer
- Layers are offset to avoid projective gaps between counters
- Total: 82 modules; two widths, five different lengths

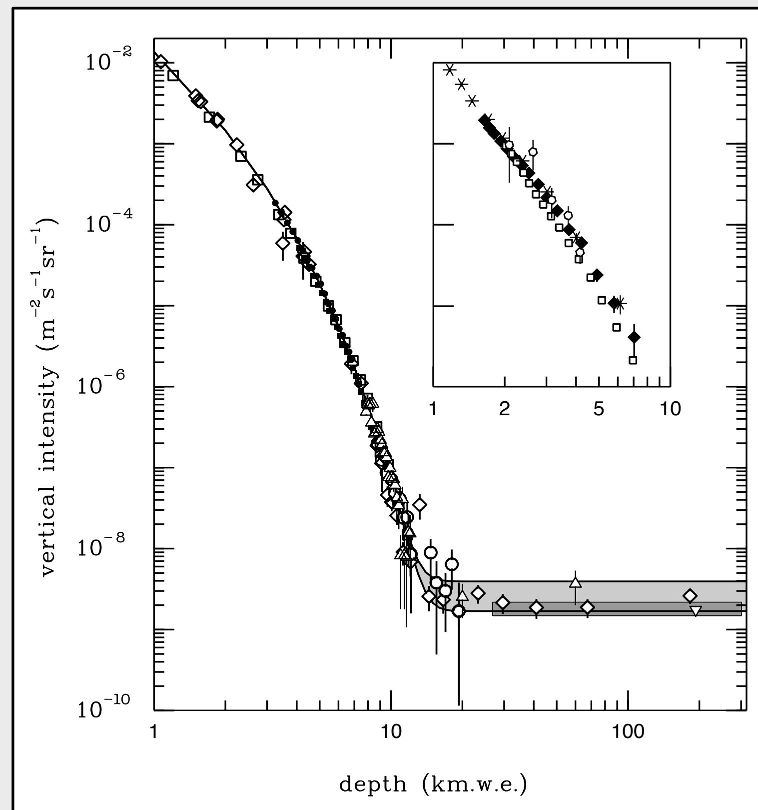


Cosmic Ray Background

- The majority of cosmic ray muons are produced from galactic cosmic proton interactions in Earth's atmosphere
- Cosmic ray muon rate at the surface is 100 Hz/m2
- The rate is at maximum for vertical muons, and decreases with the angle as $\cos^2\theta$
- In order to shield against cosmic muons we need to build the detector several km under the ground
- …or cover Mu2e experiment with active shielding - CRV

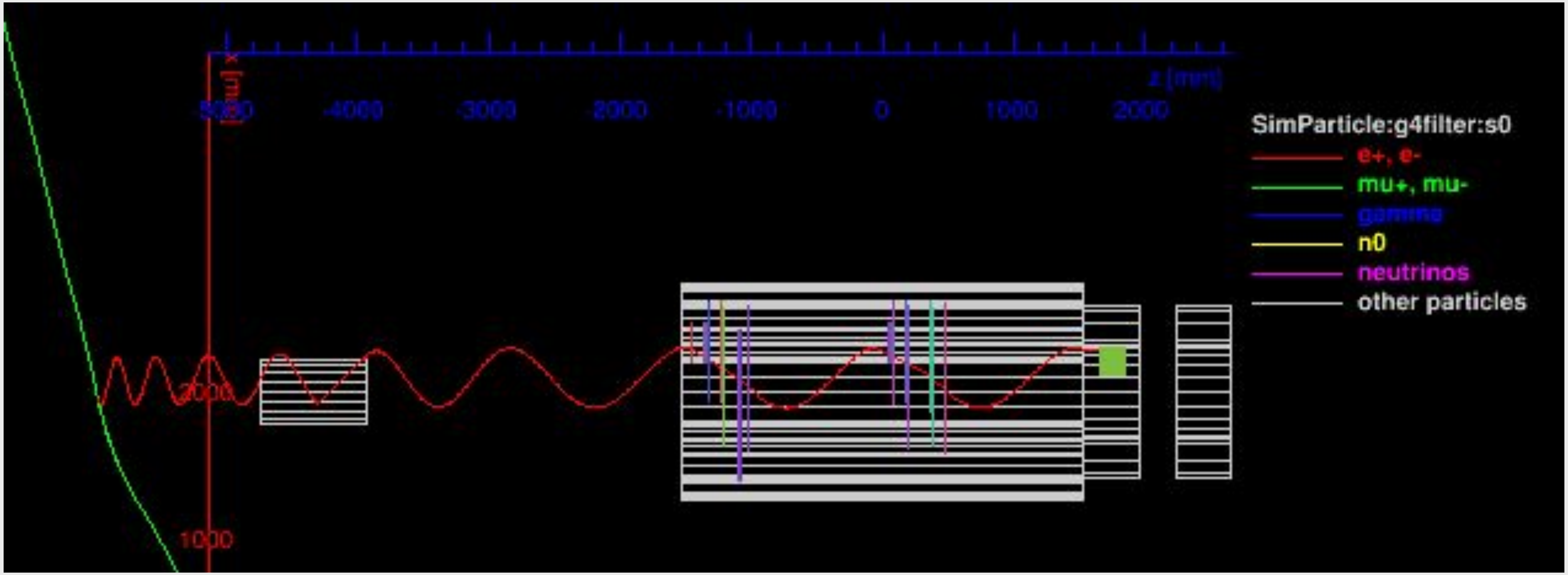






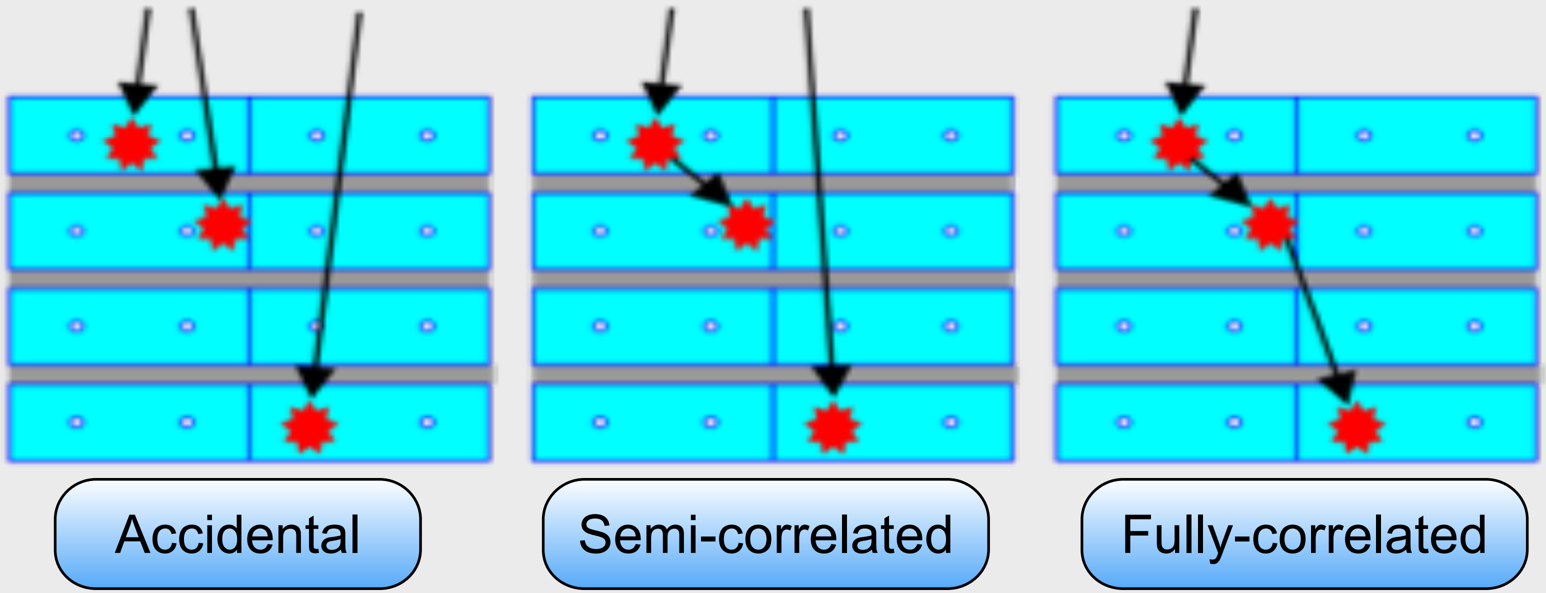
Cosmic Ray Background

- Cosmic rays can interact with detector components producing 105 MeV electron, faking a conversion signal
- To better understand CRV design, simulations are underway
- Currently we simulated 28 billion cosmic ray muons, only 2% of total number expected over experiment lifetime
- To achieve experiment's designed sensitivity, detection inefficiency is required to be no worse than 10^{-4}



Few challenges: radiation noise

- Neutron and gamma fluxes from beam interactions cause problems to CRV operations
  - Produce hits at the CRV, faking cosmic ray muons and hence increasing total Mu2e dead-time



- Total dead-time needs to be small (5-10%)

Summary

- Mu2e has a great discovery potential and can reveal New Physics
- Mu2e will improve over previous conversion experiments by 4 orders of magnitude and will probe new physics mass scales of 10^4 TeV
- Mu2e will provide complimentary information to the LHC and test the existence of new particles that are too heavy to be produced directly at colliders
- Experimental design is mature. Construction has started
- Cosmic ray veto is an essential component for the Mu2e experiment by suppressing the backgrounds by 4 orders of magnitude Potential discovery in the next decade
- Potential discovery within the next decade…