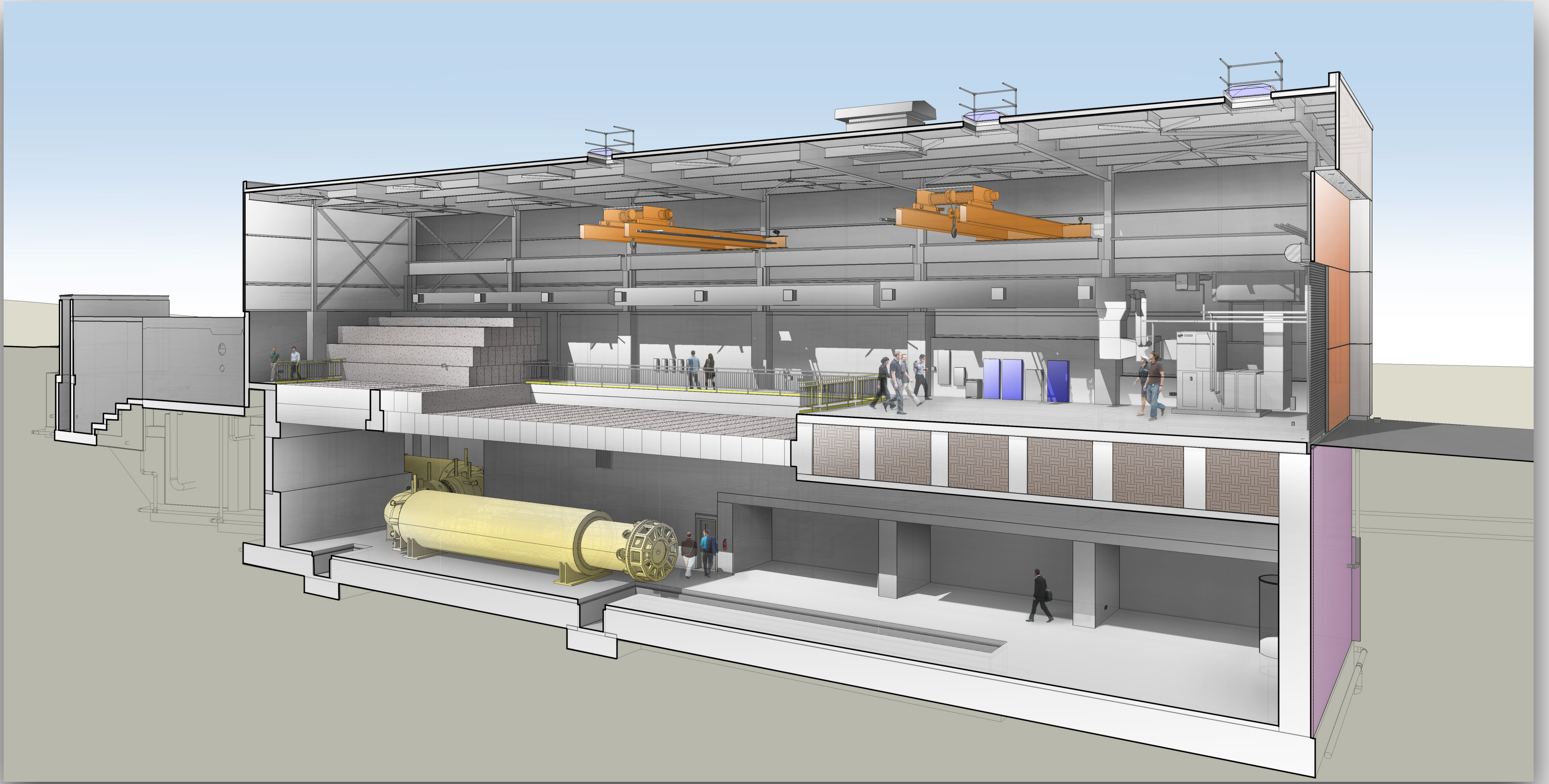
Mu2e Experiment at Fermilab



Yuri Oksuzian on behalf of Mu2e collaboration

Fermilab Users' Meeting, June 11, 2014

Mu2e

- Mu2e will search for neutrino-less, coherent muon conversion into an electron

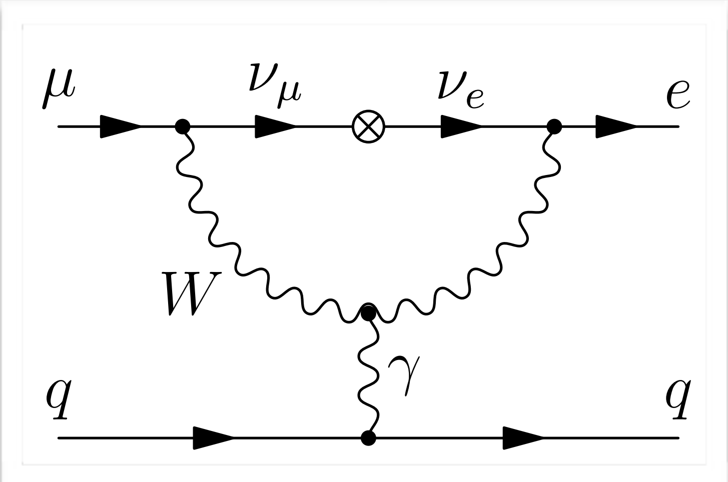
$$\mu^- + N \rightarrow e^- + N$$

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

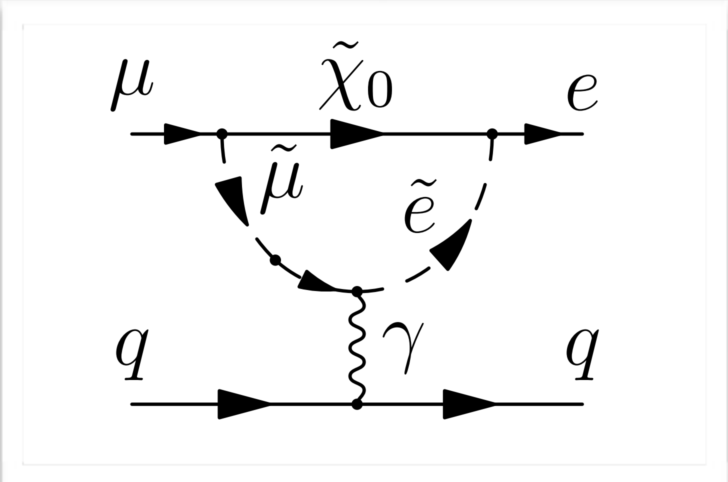
$$\mu \rightarrow e\gamma, \;\; \mu \rightarrow 3e, \; \tau \rightarrow e\gamma, \; \tau \rightarrow \mu\gamma ...$$

- In the SM, $\mu \rightarrow e^-$ occurs at the rate of $<10^{-50}$
  - Signal observation at Mu2e is unambiguous sign of new physics

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



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



What do we measure?

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

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

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

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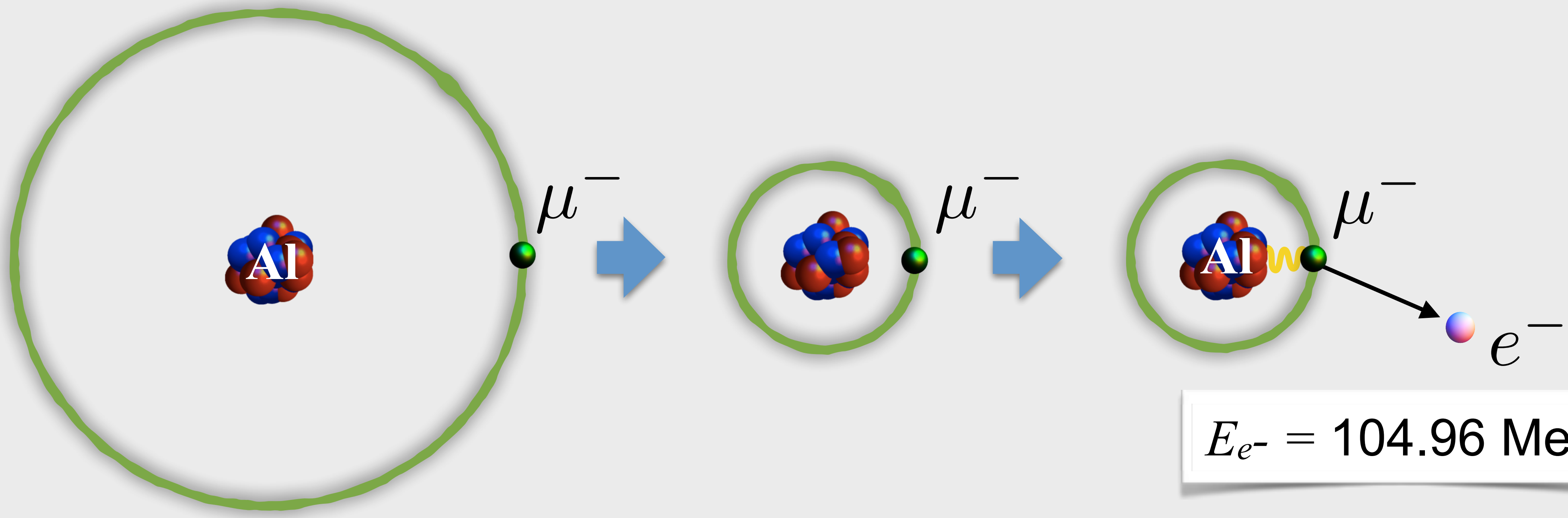

$E_{e^-} = 104.96$ MeV

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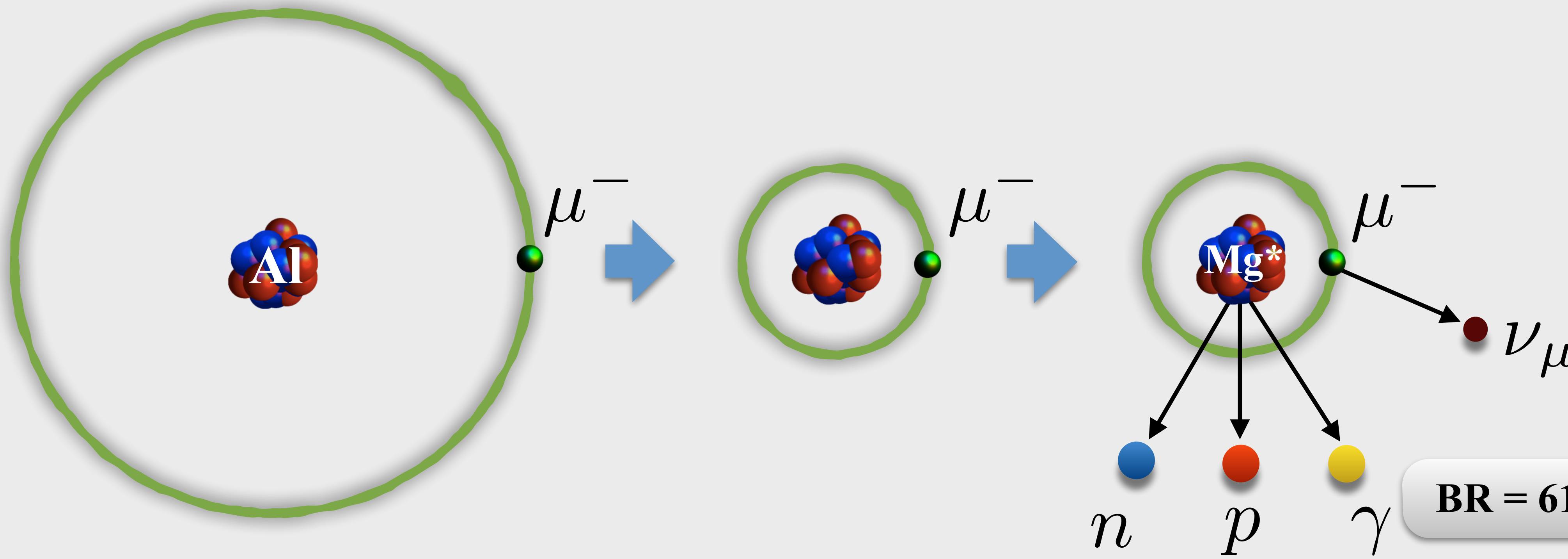

BR = 61%

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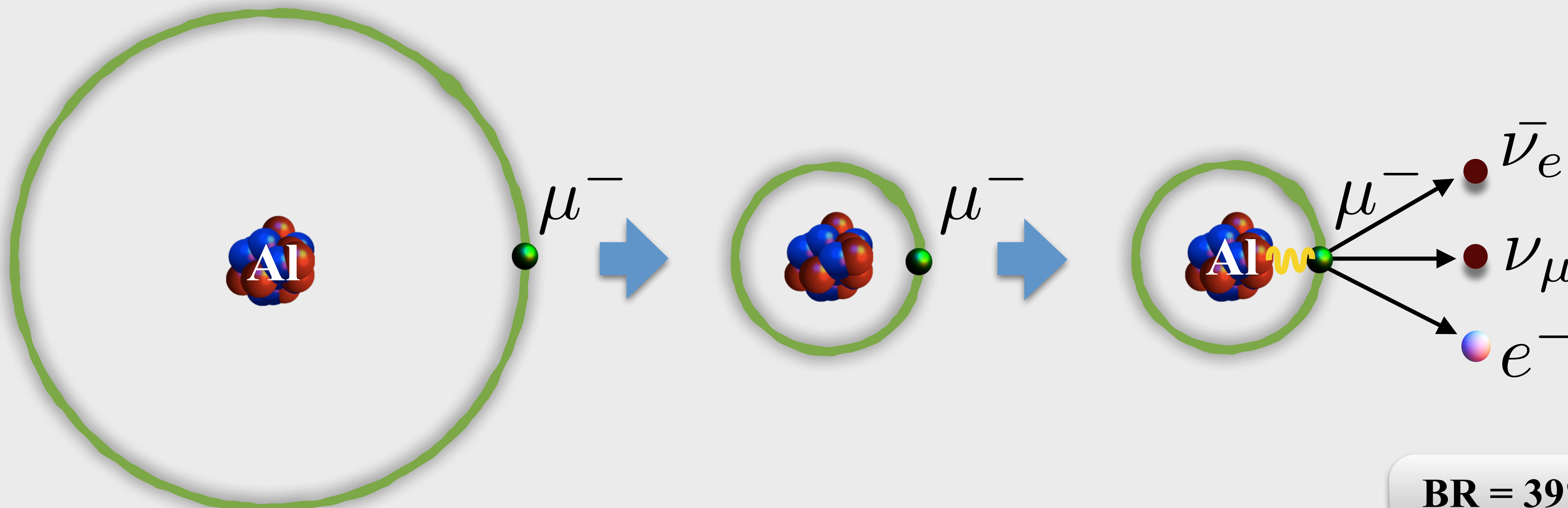


BR = 39%

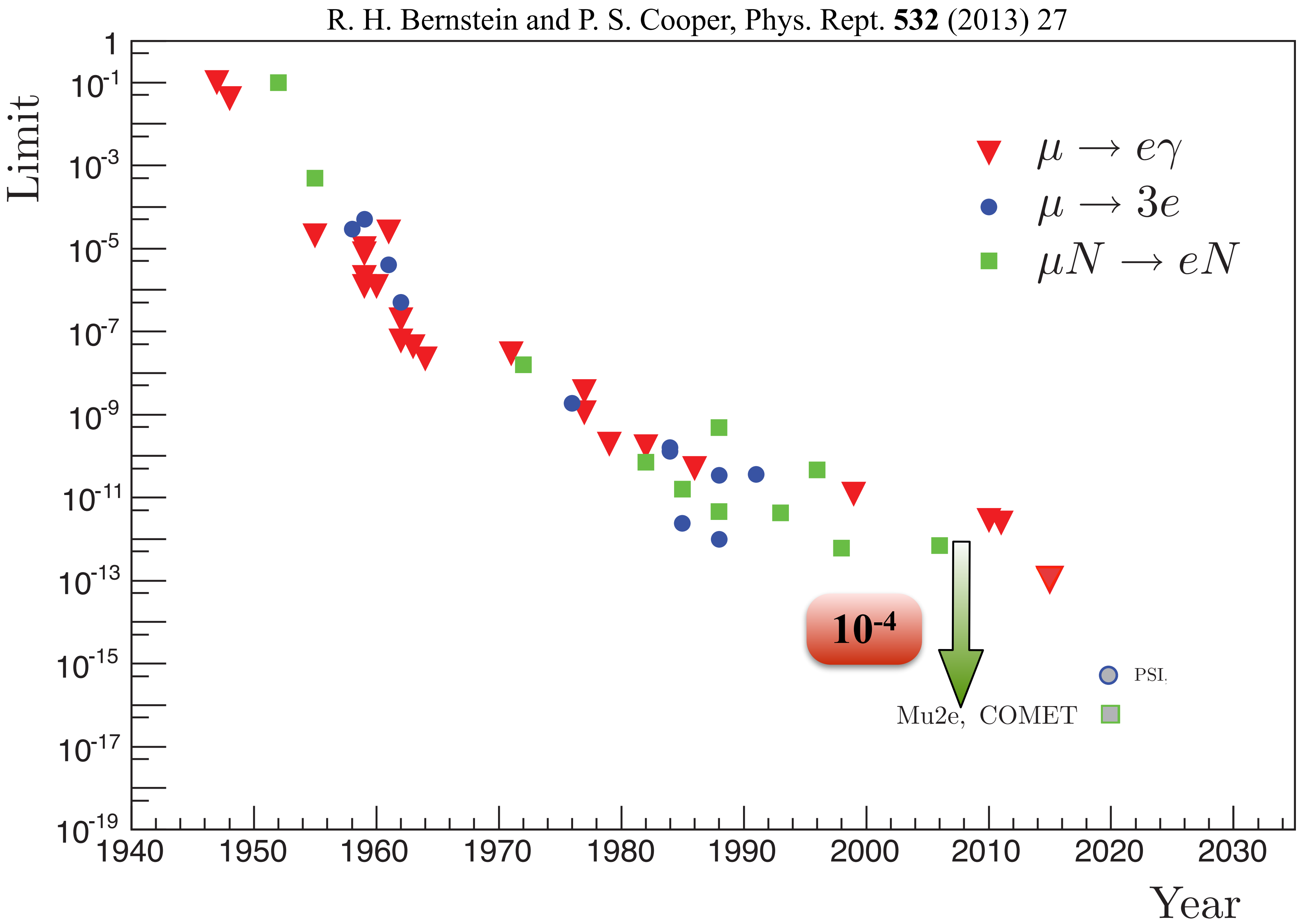
Mu2e Sensitivity

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

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

- Mu2e single event sensitivity: $R_{\mu e} = 2.5\times10^{-17}$
  - Expect 4 events at $R_{\mu e} = 10^{-16}$
  - 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

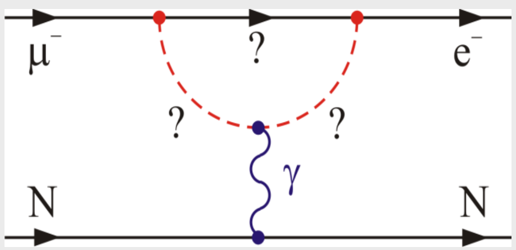
History of CLFV Searches



Mu2e Physics Reach

Effective CLFV Lagrangian

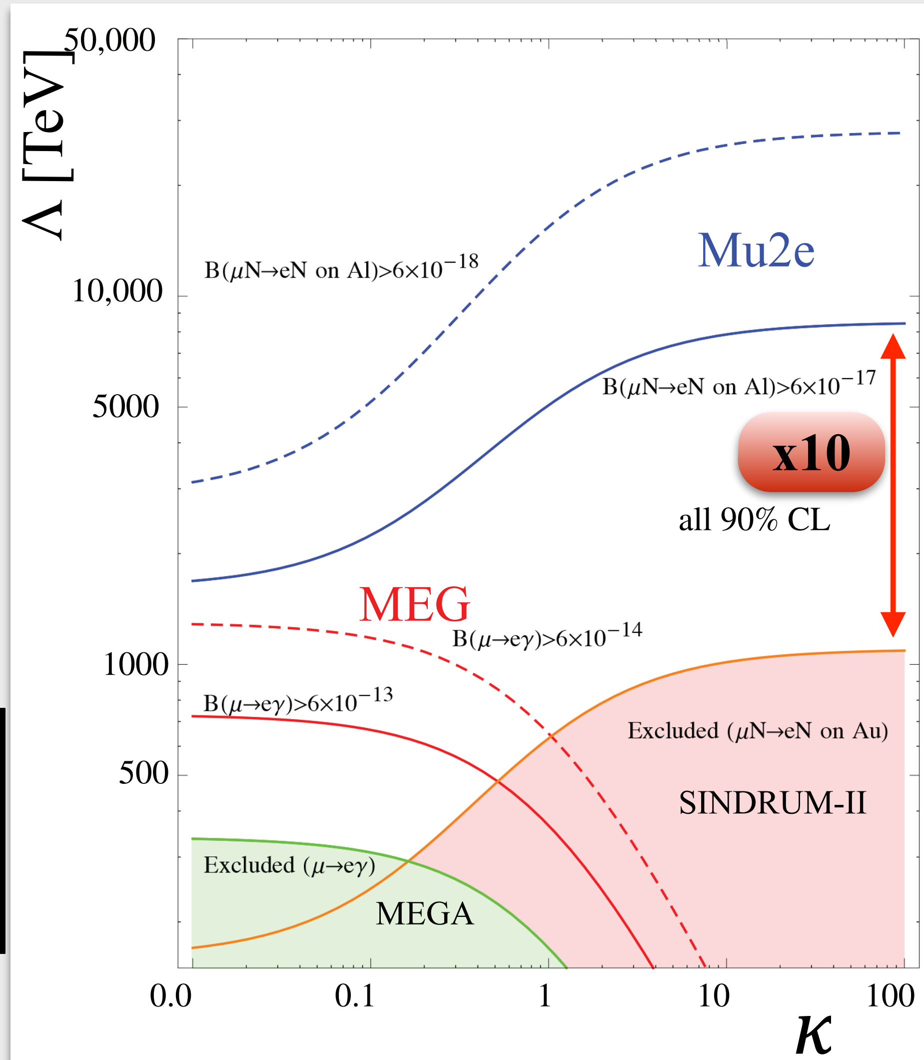
$$L = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}\bar{\mu}_L \gamma_\mu e_L \sum_{q=u,d} \bar{q}_L \gamma_\mu q_L$$

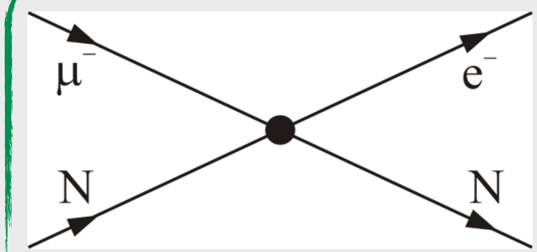


κ << 1

Magnetic moment type operator

State	μ→eγ	μ→e
Sensitive	Yes	Yes





κ >> 1

Contact term operator

State	μ→eγ	μ→e
Sensitive	No	Yes

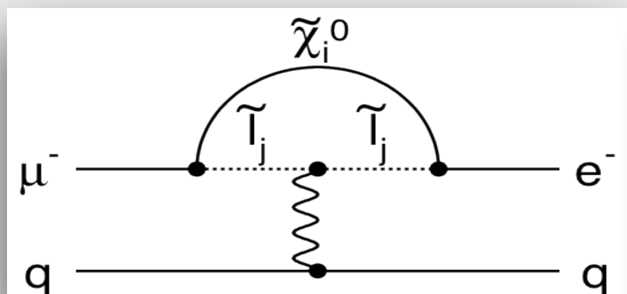
Mu2e Physics Reach

Effective CLFV Lagrangian

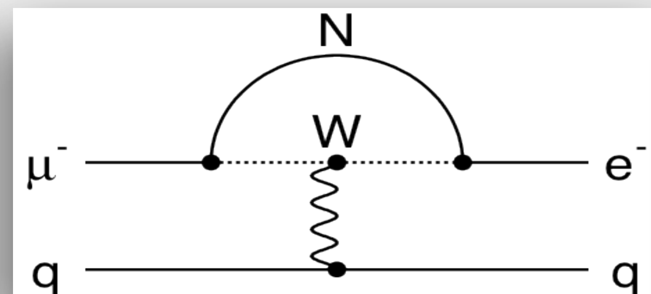
$$L = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L \sum_{q=u,d}\bar{q}_L\gamma_\mu q_L$$

Magnetic moment type operator

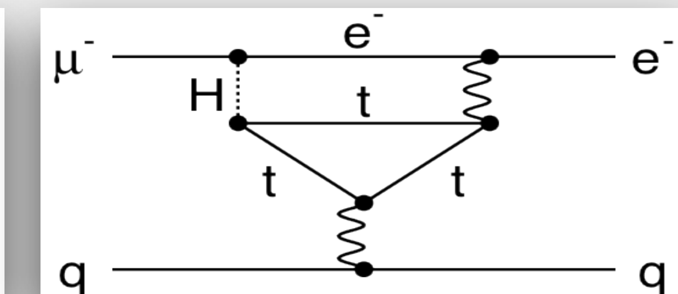
Supersymmetry



Heavy neutrinos

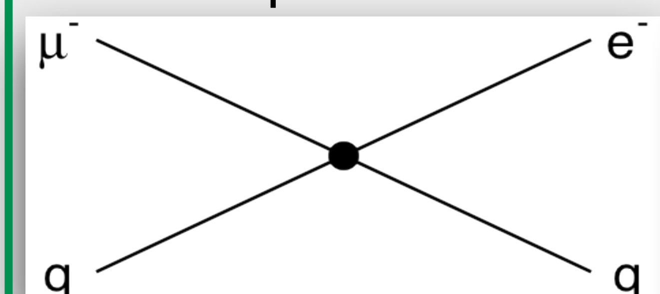


Two Higgs Doublets

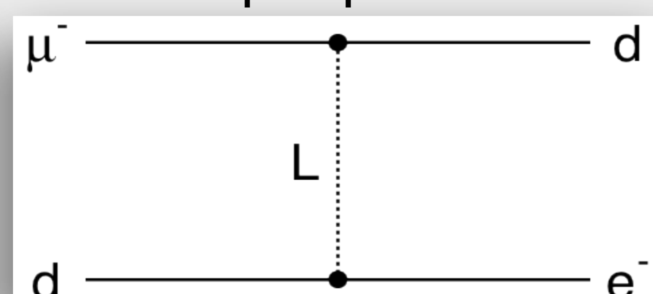


Contact term operator

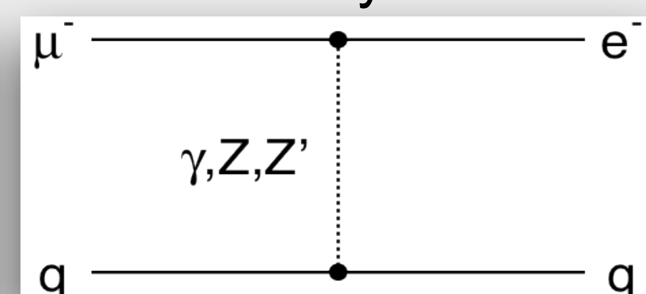
Compositeness



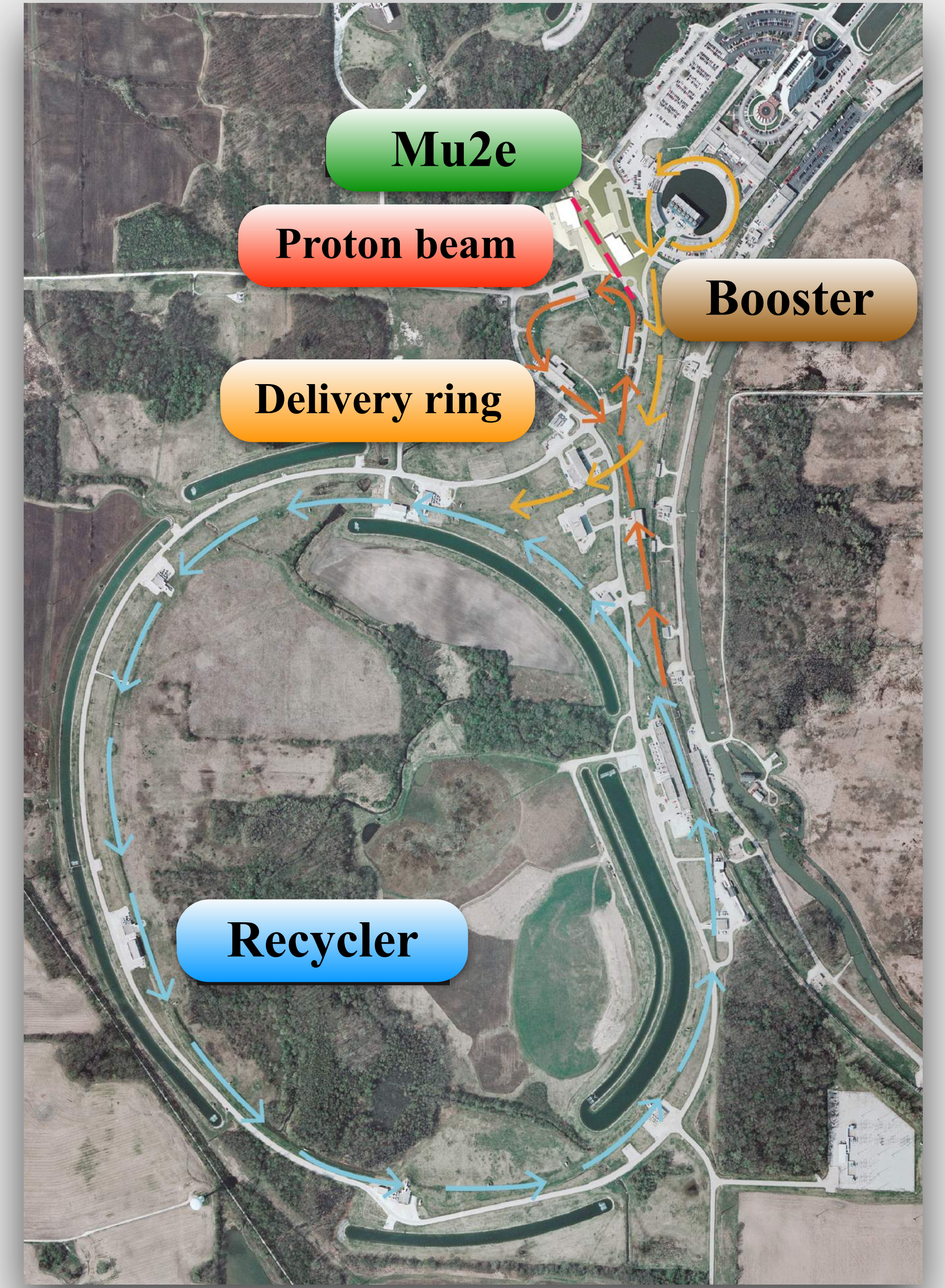
Leptoquarks



Heavy Z'

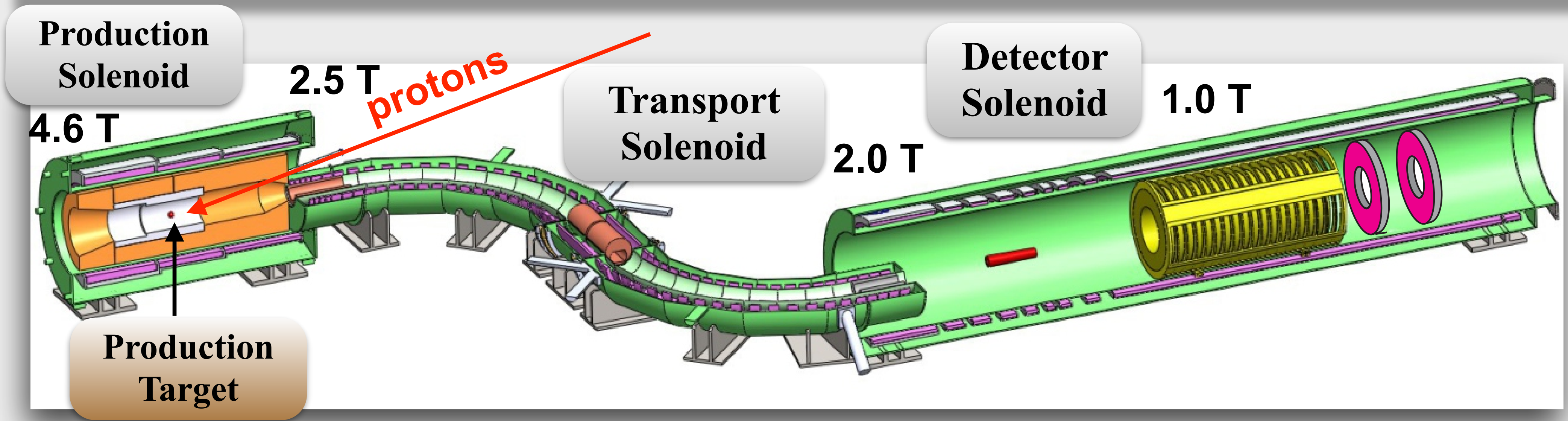


Mu2e proton beam



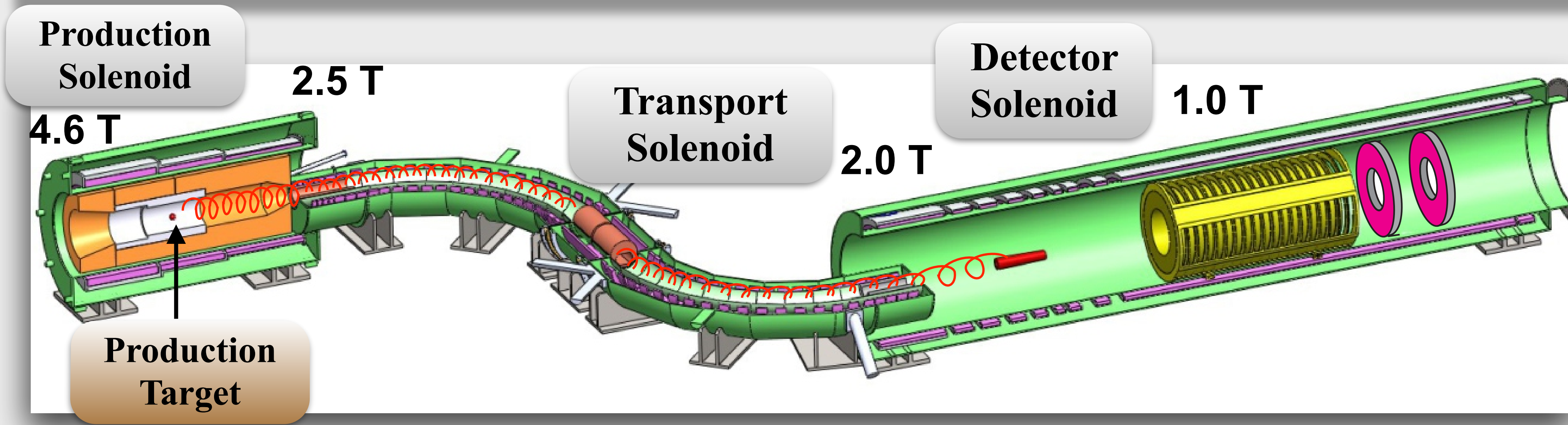
- Mu2e will recycle the existing accelerator infrastructure
- **Booster** provides batches of 8 GeV protons to recycler
- **Recycler** divides proton batches into 4 smaller bunches
- **Delivery ring** gets 1 out of 4 bunches from recycler
- **Mu2e** gets the **proton beam** pulses from delivery ring every 1695 ns
- Mu2e runs simultaneously with NOvA
  - Using spare Booster batches
  - NOvA POT is unaffected by Mu2e

Mu2e apparatus



- Proton beam hits production target in Production Solenoid to produce π^-
  - Pions are reflected toward the transport solenoid

Mu2e apparatus



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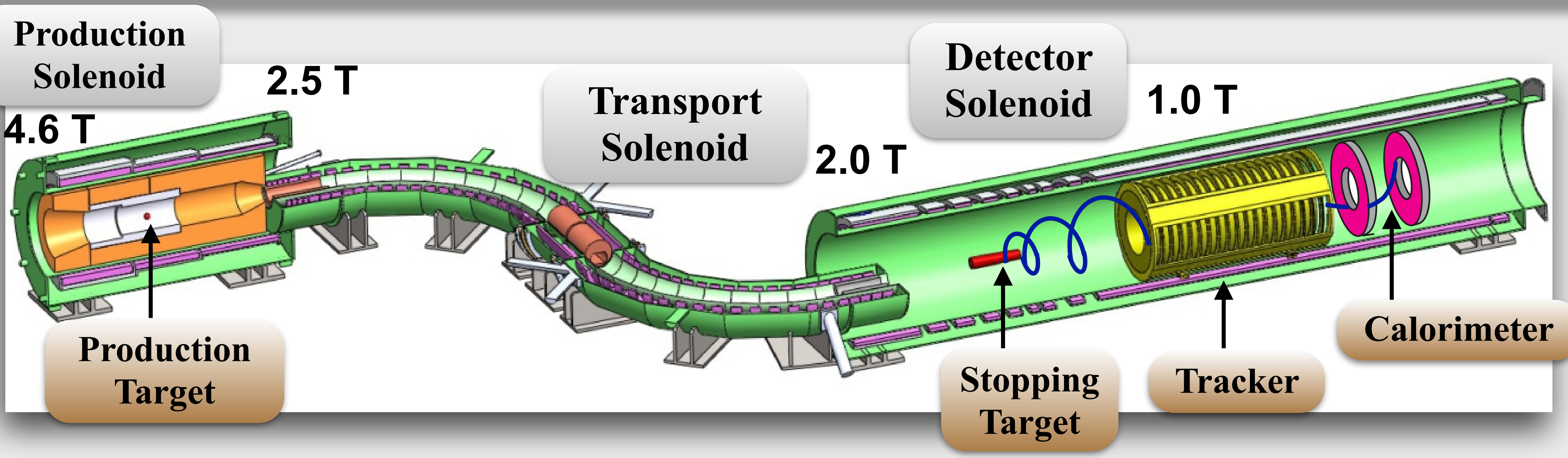
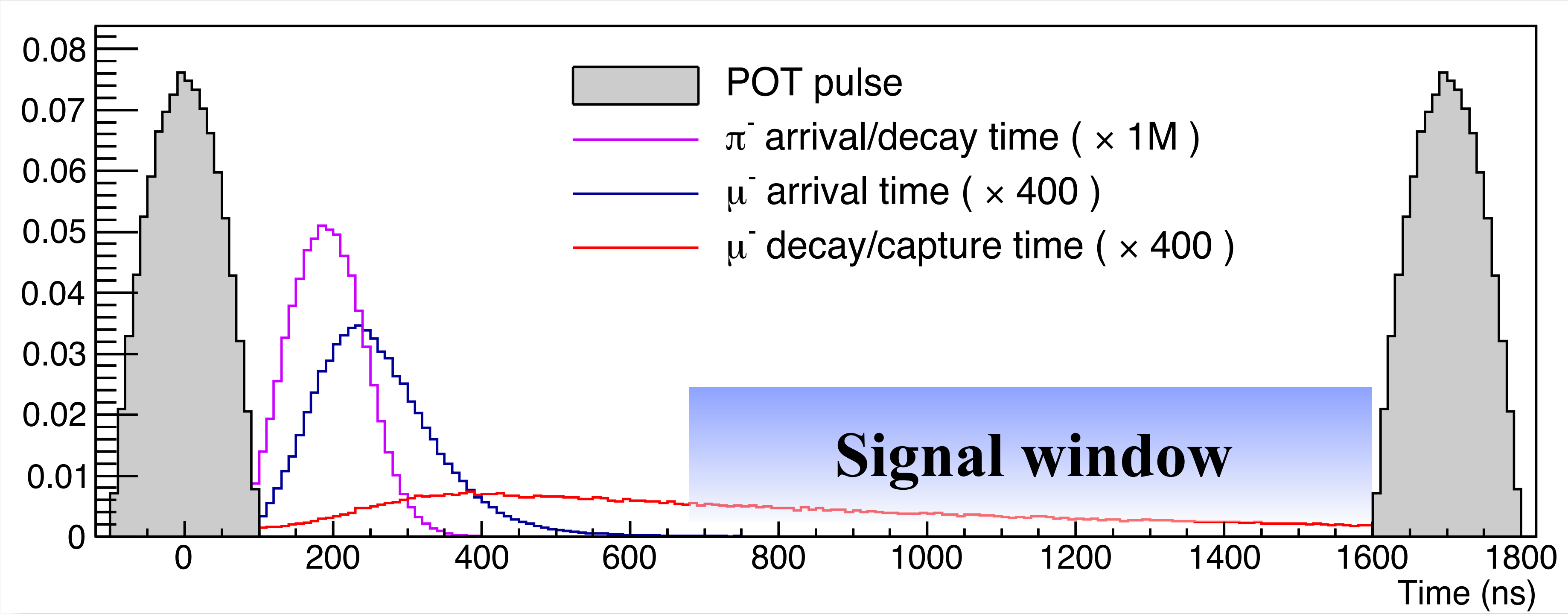
- Trasport solenoid:
  - Transports π^-/μ^-
  - Selects particle's momentum and charge
  - Avoids direct line of sight

Mu2e apparatus



- Proton beam hits production target in Production Solenoid to produce π^-
  - Pions are reflected toward the transport solenoid
- Trasport solenoid:
  - Transports π^-/μ^-
  - Selects particle's momentum and charge
  - Avoids direct line of sight
- Muons stop on Al stopping target
  - 50% of μ^- stop on the target
  - 1,000 POT → 2 stopped muons
  - Conversion electron momentum and energy are measured in the tracker and calorimeter

Pulsed beam

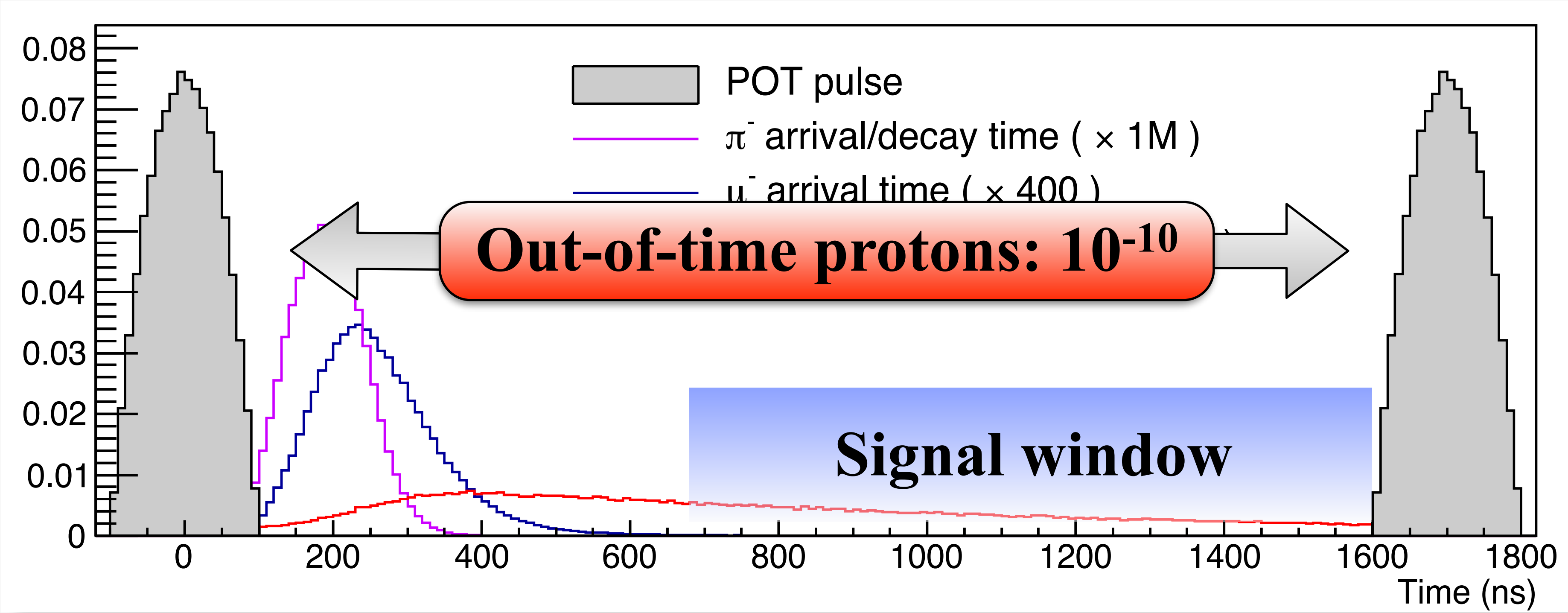


- Prompt background: particles produced by proton pulse which interact almost immediately when they enter the detector
- Muons travel with pions. Pions produce background when captured on target

$$\pi^- N \to \gamma N^* \to e^+ e^- N^*$$

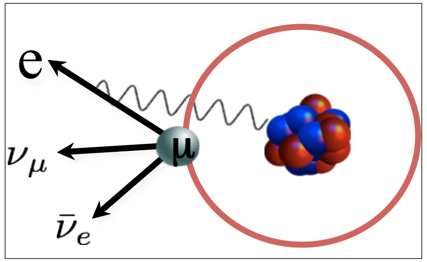
- Other examples of prompt backgrounds: beam electrons, μ/π decay in flight
- Solution: Suppress prompt backgrounds by employing a delayed signal window
- Delivery ring revolution period of 1695 ns is well matched for τ^{Al} = 864 ns
  - 50% of muons decay/captured in the signal window

Out-of-time Protons

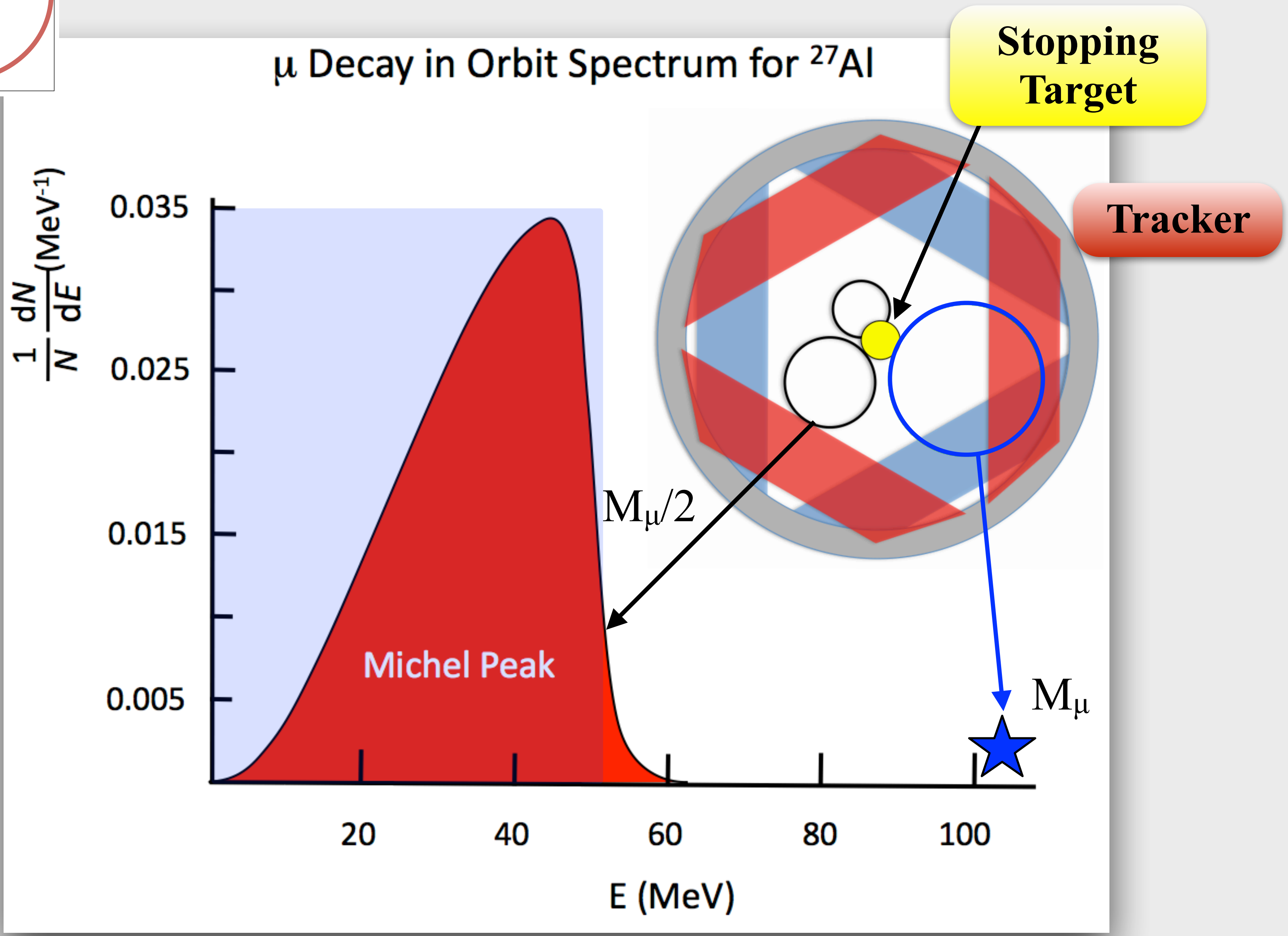


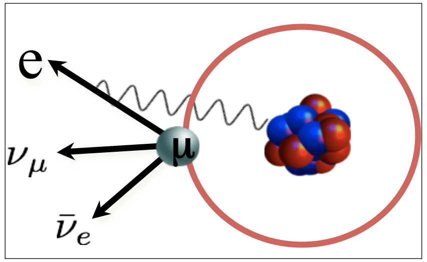
- Out-of-time protons can give rise to prompt backgrounds in the signal window
- RF structure in Delivery ring and sweeping AC dipole in front of PS will suppress out-of-time protons by $>10^{-10}$
- Only 1 in 10 billion POT will be outside of the main pulse

Decay In Orbit (DIO)

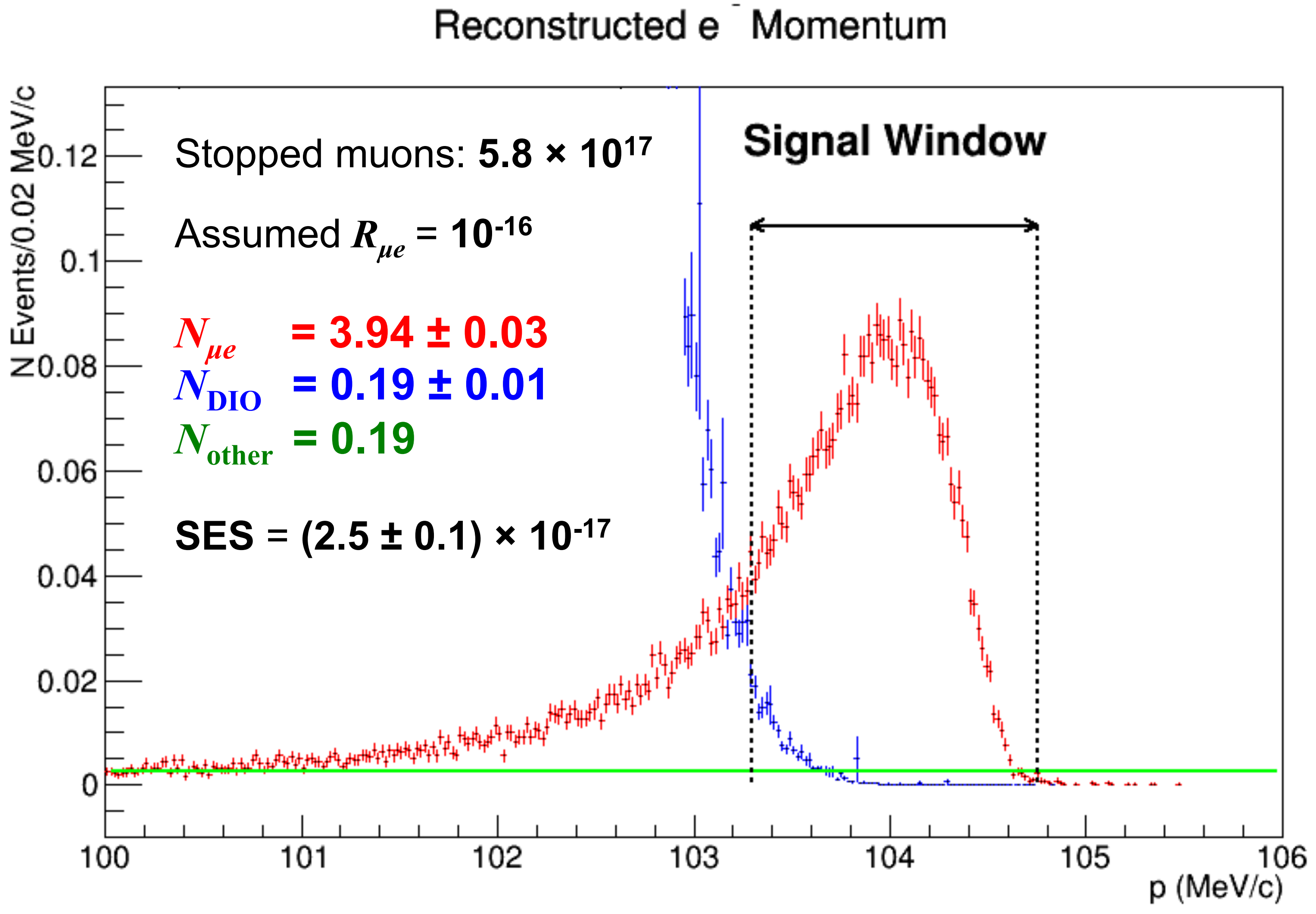


Tracker is “blind” to beam flash and 97% of DIO spectrum

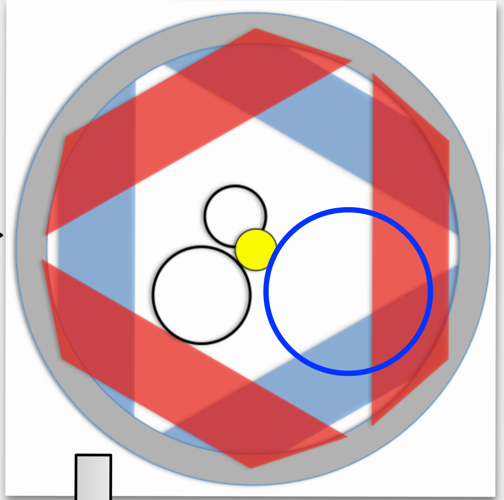


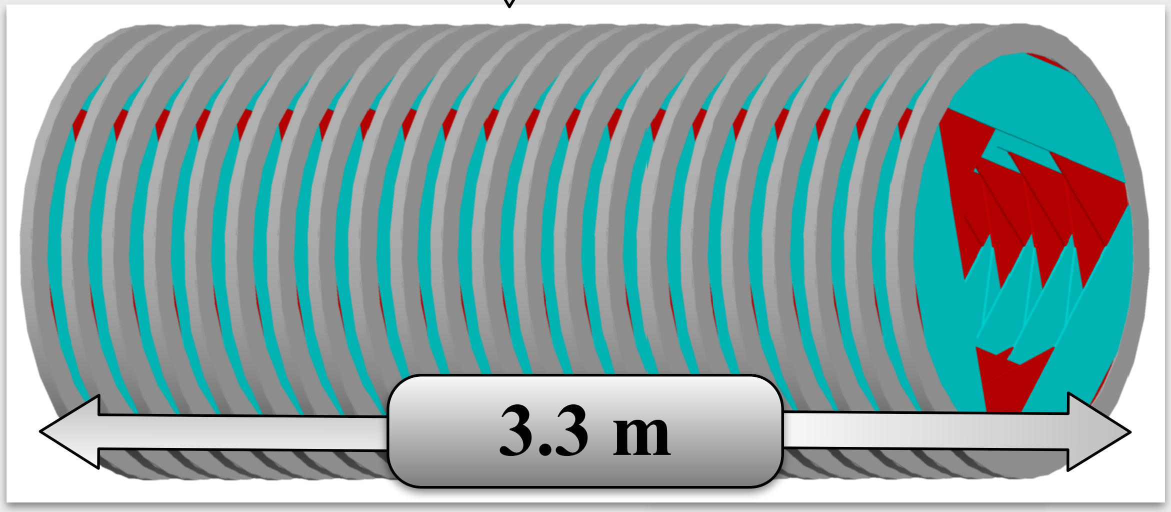


- Long tail from Michel peak. Signal is smeared.
- Need good momentum resolution.
  - 100 KeV momentum resolution is achievable



Tracker

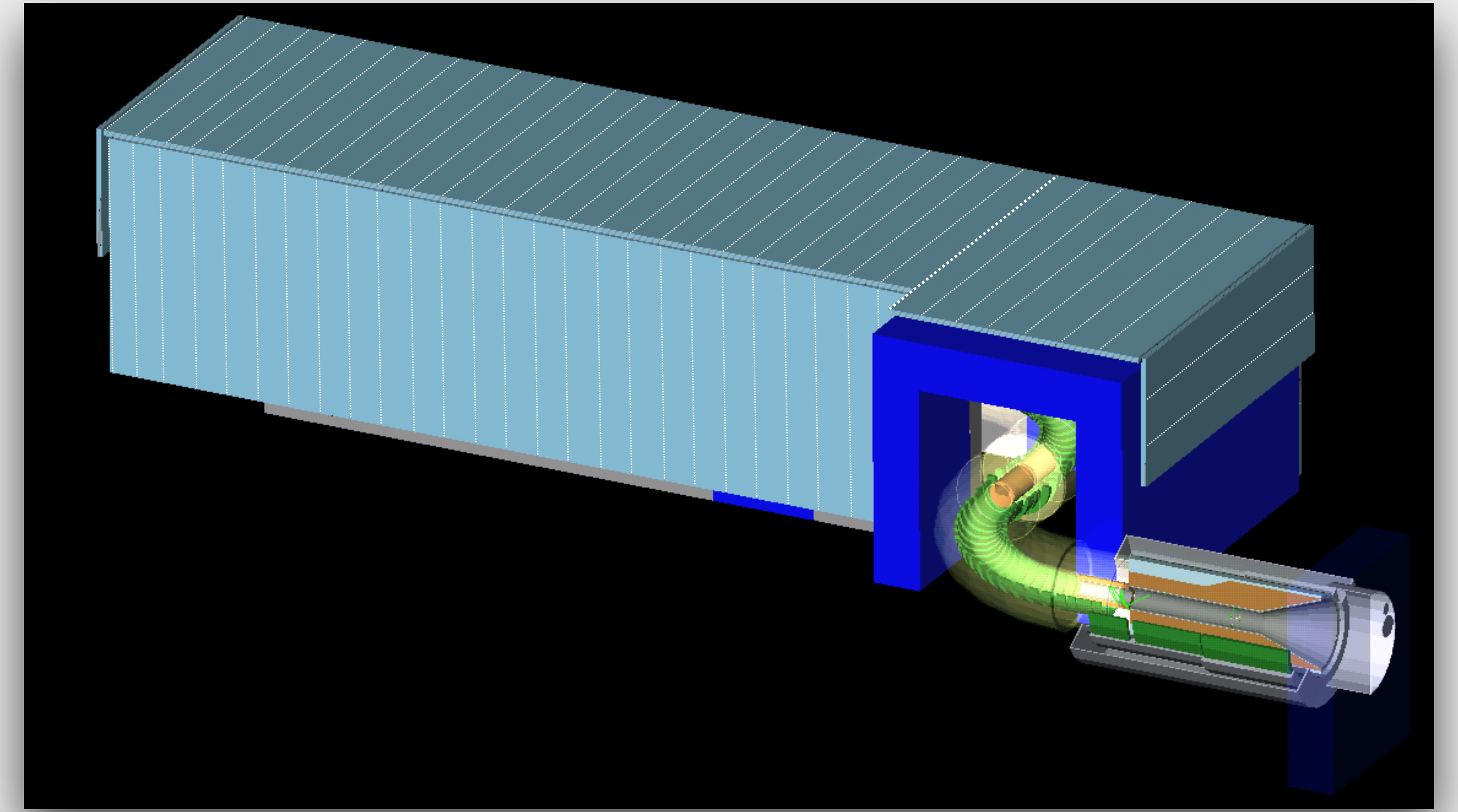




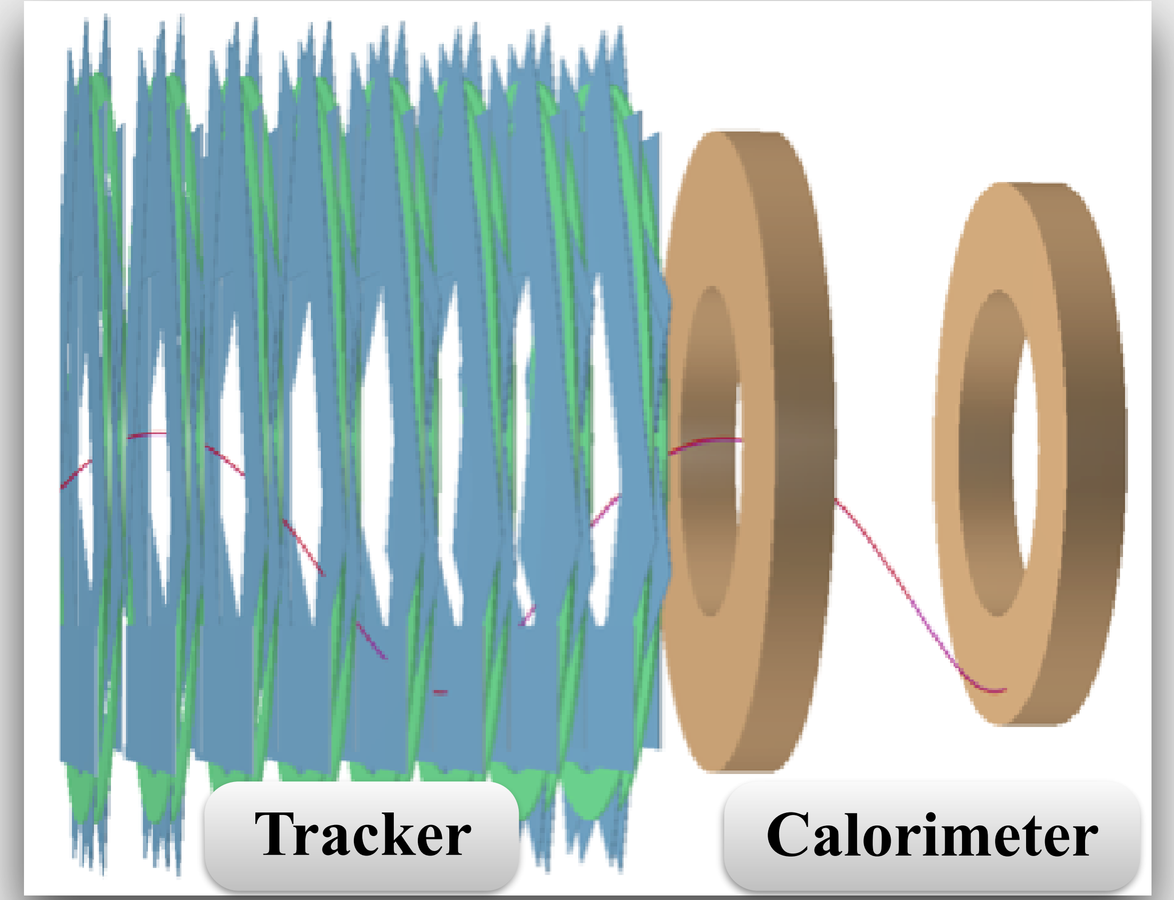
- Low mass straw drift tubes
- 5 mm diameter straws
  - 12 μm Mylar walls
  - Filled with 80/20 Ar/CO_2
- 25 μm gold-plated tungsten sense wires
- 100 Straws = Panel; 6 Panel = Plane; 2 Planes = Station; Tracker = 20 Station

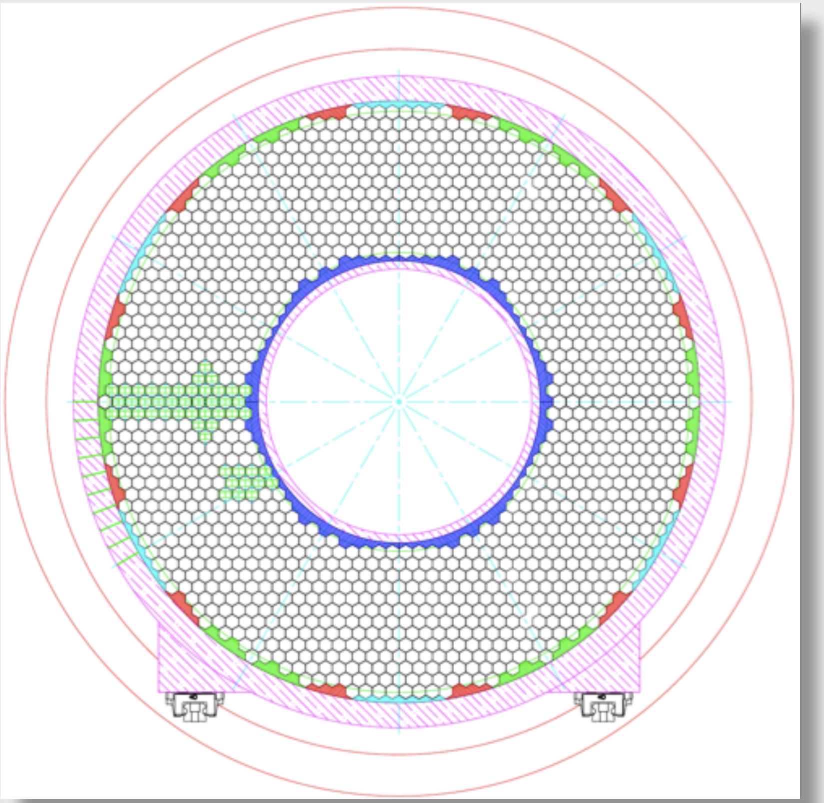
Cosmic Ray Veto

- Mu2e expects 1 signal-like event per day induced by cosmic rays
- Cosmic Ray Veto(CRV) consists of 4-layer scintillating counters
- CRV needs to reject 99.99% of cosmic rays, covering 300 m^2 of detector solenoid
- CRV has to be able to operate in high radiation environment



- Two disks of BaF_2 scintillating crystals
  - BaF_2 fast time component
- Provides precise timing, PID, seed for tracking and triggering
- Complementary energy measurement





Background processes

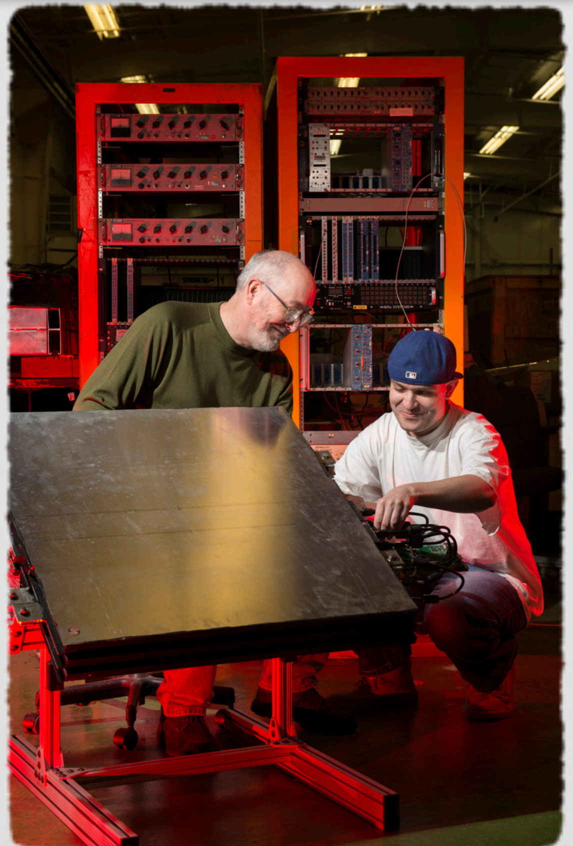
Category	Source	Events		
Intrinsic	μ decay in orbit	0.20	$\pm$	0.06
Late-arriving	Radiative π capture	0.04	$\pm$	0.02
	Beam electrons	0.001	$\pm$	0.001
	μ decay in flight	0.010	$\pm$	0.005
	π decay in flight	0.003	$\pm$	0.002
Miscellaneous	Antiproton capture	0.10	$\pm$	0.06
	Cosmic ray	0.050	$\pm$	0.013
Total Background		0.4	$\pm$	0.1

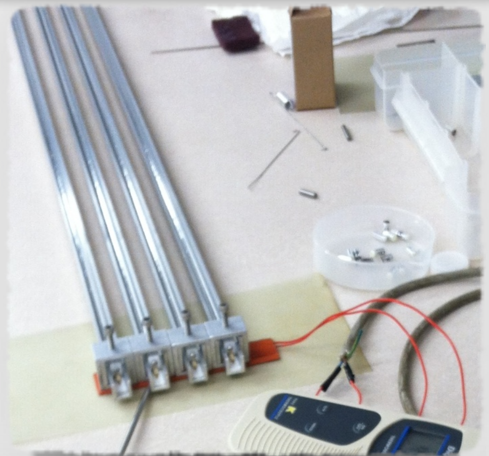
- All these backgrounds can be controlled to the level of <1 event

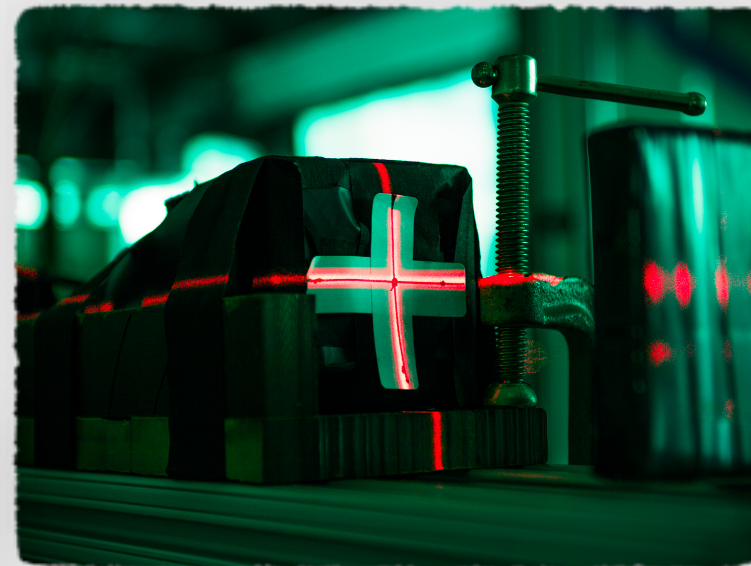
Mu2e Status

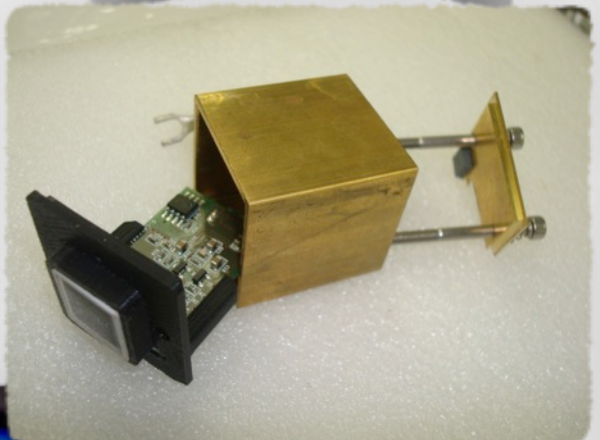
- CD-0 in 2009
- CD-1 in 2012
- Currently working on TDR, scheduled CD2/3 review this year
- Expect to start data taking ~2020
- Experiment was strongly supported by P5
  - Recommendation 22: "Complete the Mu2e and muon g-2 projects."
  - Fully funded in all budget scenarios

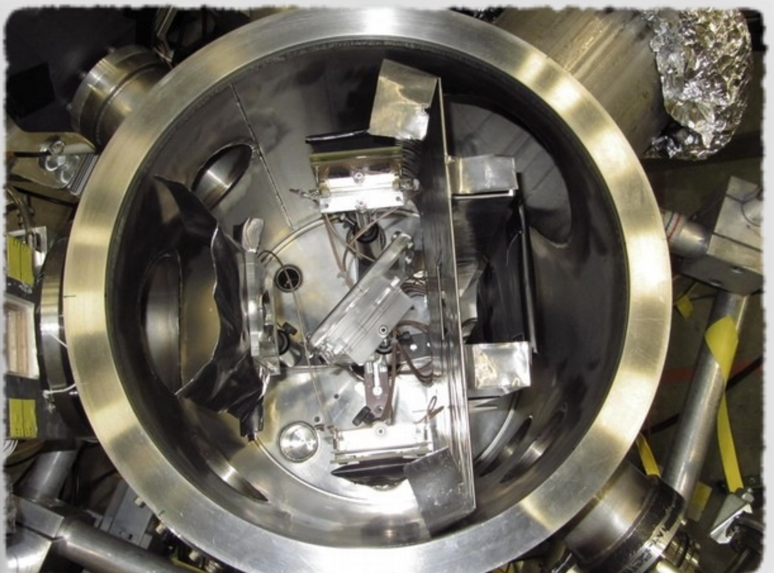
Mu2e R&D/Prototypes Efforts

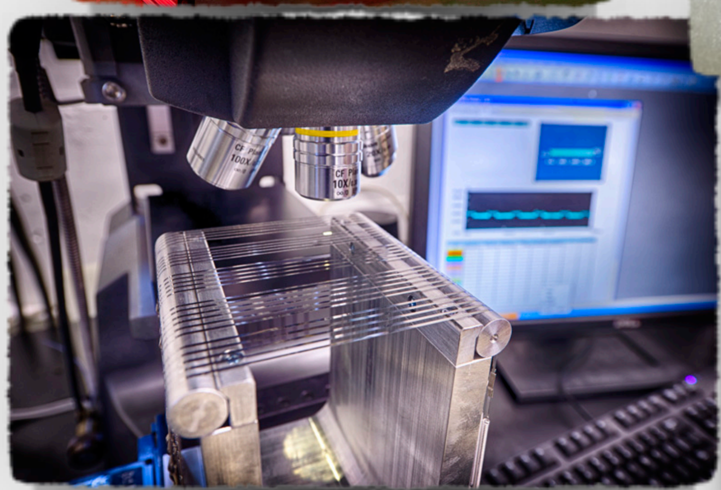


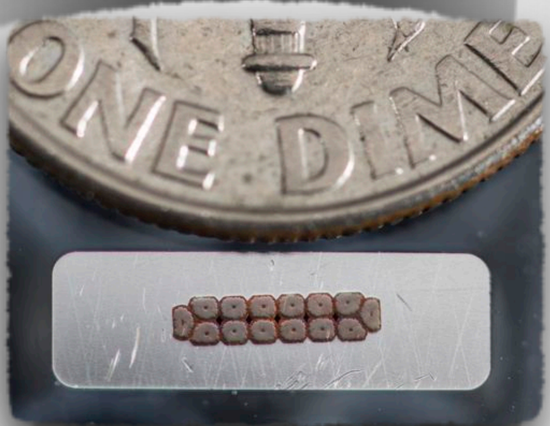












Mu2e Collaboration

160 members from 28 institutions

Join us: mu2e-spokespersons@fnal.gov

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
- "The existence of new particles that are too heavy to be produced directly at high-energy colliders can be inferred by looking for quantum influences in lower energy phenomena … Some notable examples are a **revolutionary** increase in sensitivity for the transition of a muon to an electron in the presence of a nucleus Mu2e (Fermilab)" - P5 report
- Experimental design is mature - break ground this fall
- Lots of interesting projects to work on
  - You can help make a discovery!