Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

Mu2e in 10 Minutes: an Overview of the Mu2e Experiment

Rose Powers on behalf of the Mu2e Collaboration

New Perspectives

27 June 2023

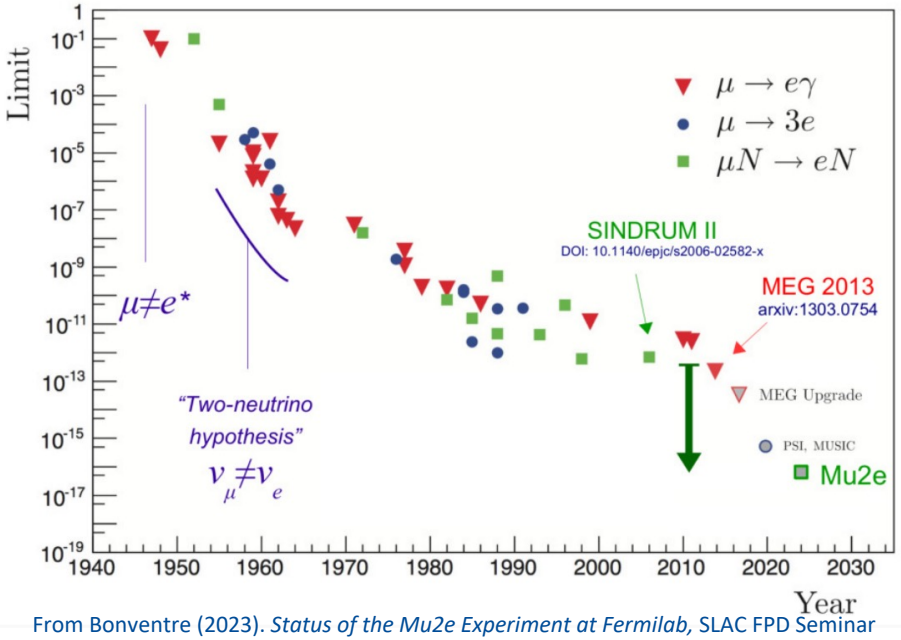
In partnership with:

FERMILAB-SLIDES-23-137-PPD

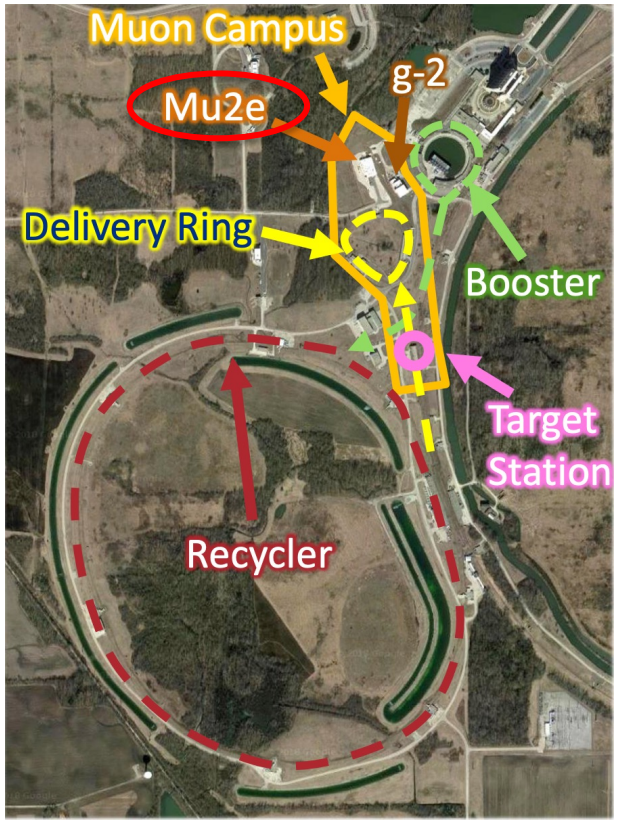
Contents

Introduction to Mu2e

- Search for neutrinoless muon-to-electron conversion in the field of an Al nucleus
- Monochromatic signal ~105 MeV (rest mass of muon)
- Testing the Standard Model
- Probing several unobserved physics processes
- Run-I set to begin taking data in 2025



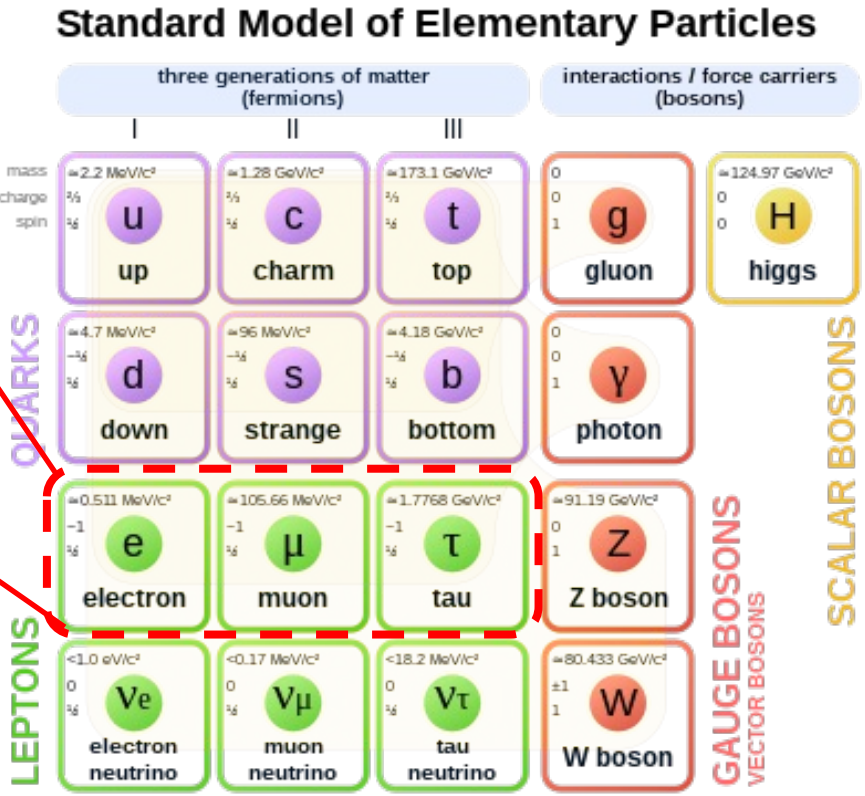
Sensitivity limit set by various $\mu \to e$ searches by year (left); the Fermilab muon campus, where Mu2e will run (right)



From Bonventre (2023). *Status of the Mu2e Experiment at Fermilab,* SLAC FPD Seminar

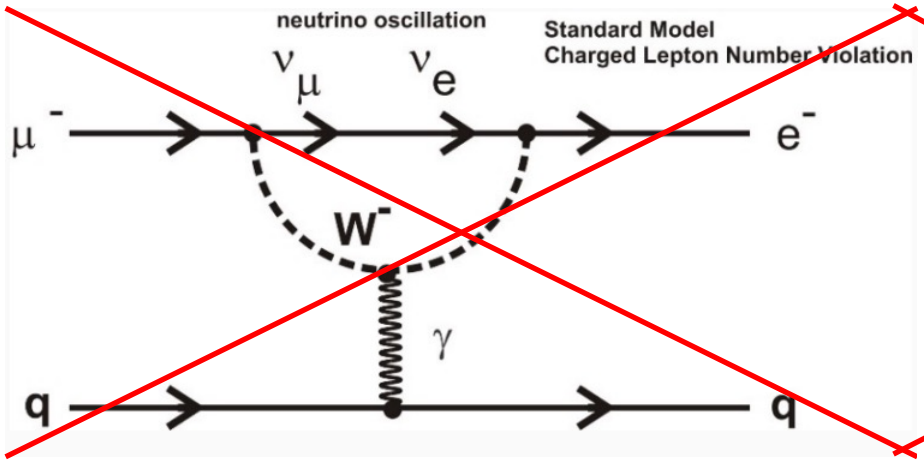
Beyond the Standard Model: Physics of Mu2e

- Standard Model: fundamental particles and their interactions
- Lepton number, lepton flavor are conserved quantities
- Neutrino flavor oscillation observed
- Charged lepton flavor violation?



Beyond the Standard Model: Physics of Mu2e

- With neutrino mass extension, SM predicts CLFV ~10^{-52}



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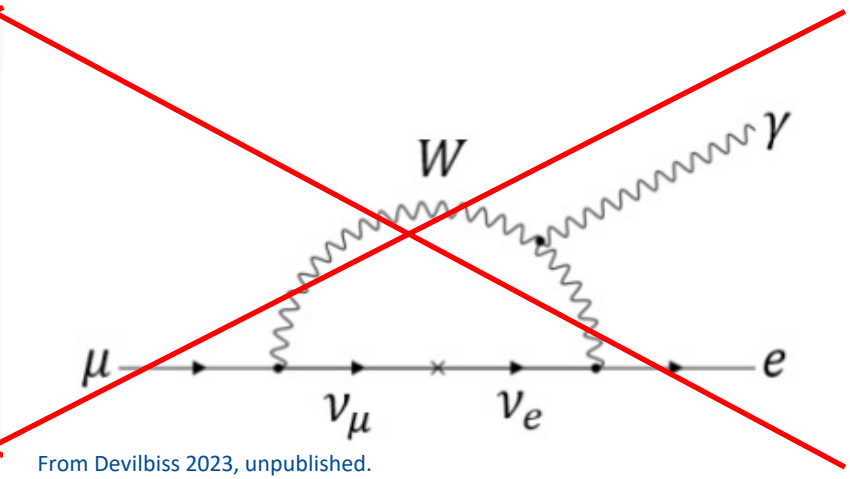
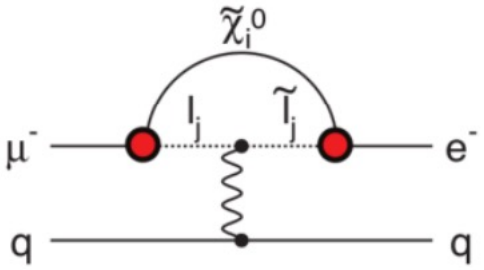


From Devilbiss 2023, unpublished.

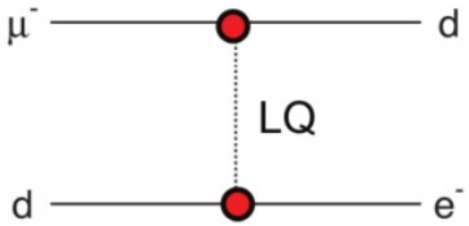
- Mu2e sensitivity: 10^{-17}
- If we detect conversion, NOT due to SM processes
- What else could cause neutrinoless muon-to-electron conversion?

Beyond the Standard Model: Physics of Mu2e

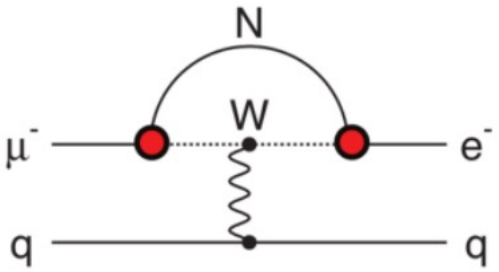
Supersymmetry



Leptoquark



Heavy Neutrinos

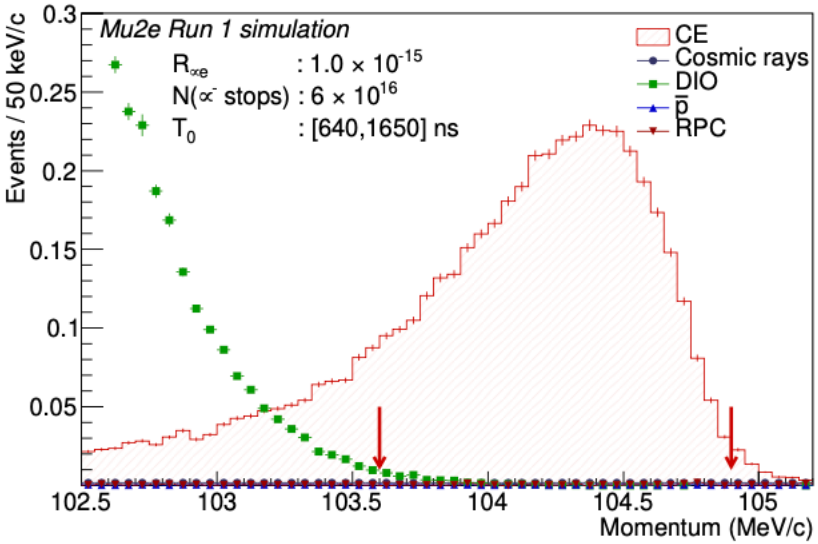


Feynman diagrams illustrating three possible BSM $\mu N \rightarrow eN$ conversion scenarios

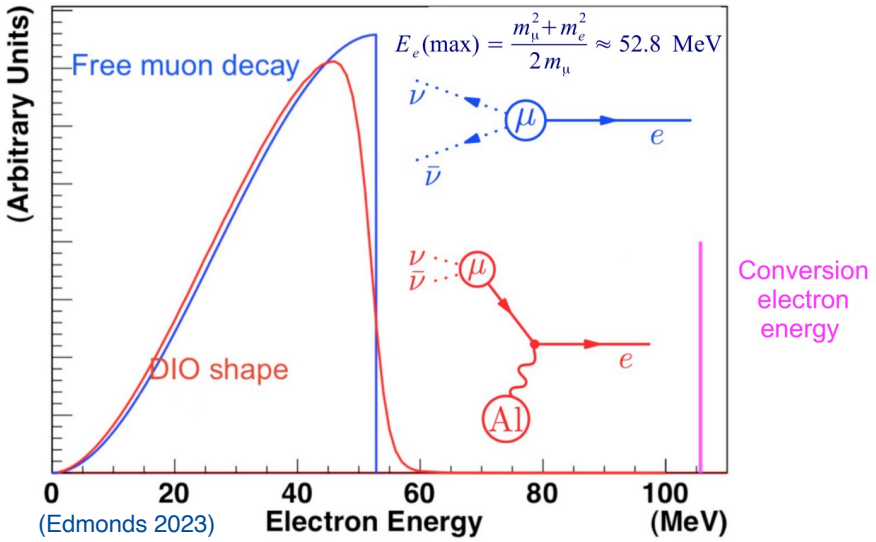
Bottom Line: One rare signal → A whole new era of particle physics

Feynman diagrams from Bonventre (2023)

Signal and Background



Momentum spectrum of signal and background (Edmonds 2023)



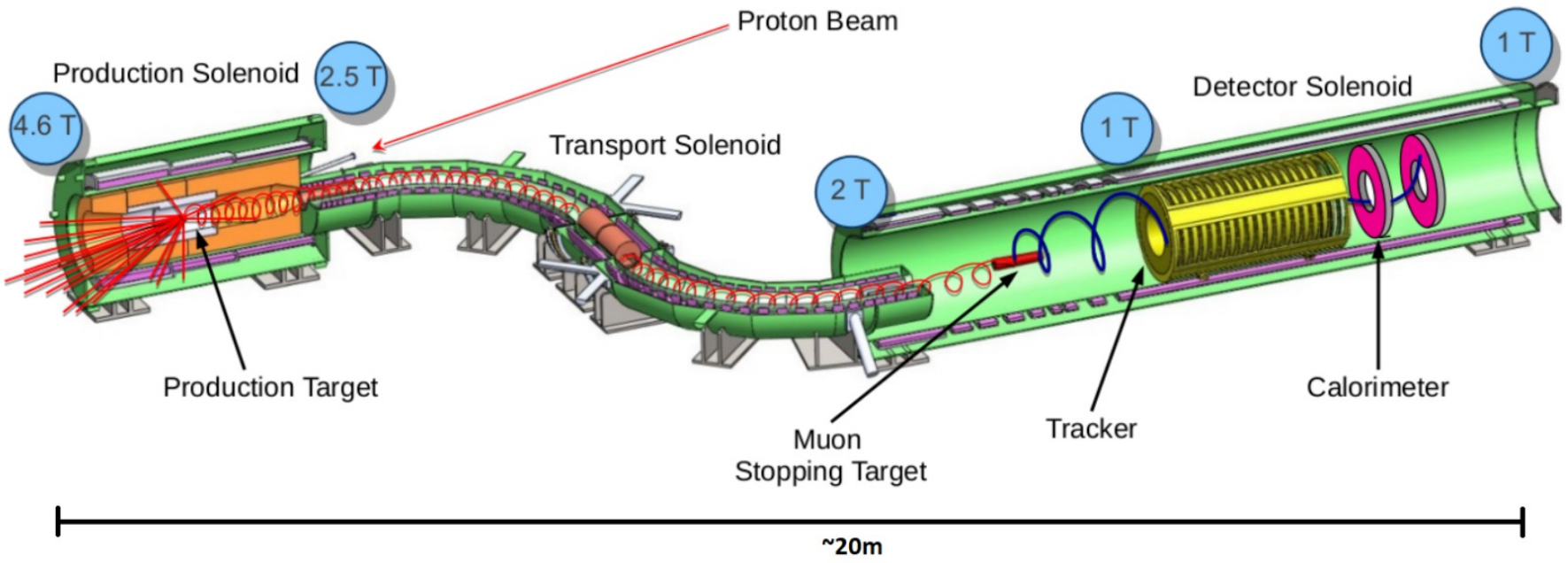
Signal:

105 MeV negative conversion electron

Background:

- ***Cosmic rays***
- ***Decays in orbit***
- ***Antiproton annihilation***
- ***Radiative pion capture (RPC)***
- ***Radiative muon capture (RMC)***
- ***Decays in flight***

Layout and Detectors



Edmonds (2023)

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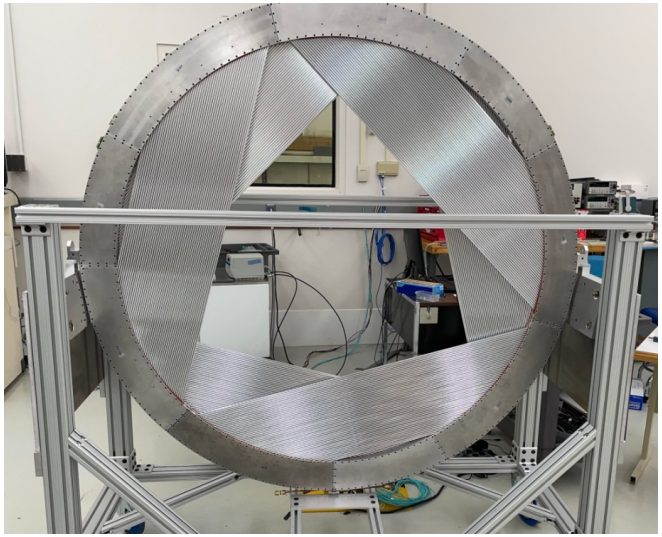
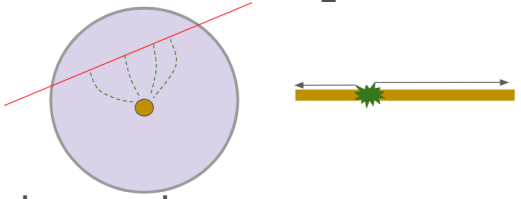
Layout and Detectors

The Tracker



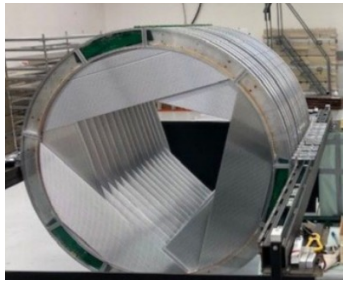
A single tracker plane composed of six panels

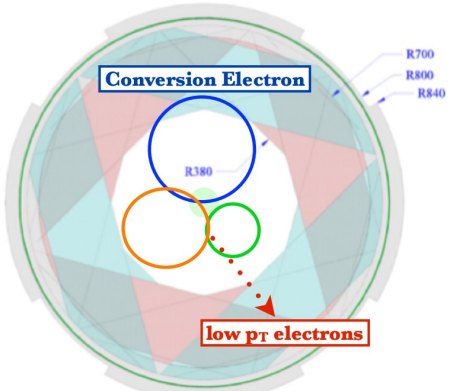
- >20k straw tubes filled with Ar/CO_2 mixture
- Voltage ~1.5kV
- Au sense wire
- 36 planes, 6 panels per plane
- Central gap to optimize signal acceptance, suppress bkg



For electrons ~E_{CE}, intrinsic momentum resolution expected to be:

$$\Delta p_{trk}/p_{trk} < 0.003$$





Assembled tracker planes (bottom left); single straw tube with a pencil for scale (top left); acceptance of tracker (right).

Pictures from Bonventre (2023), Pezzullo (2018)
The Mu2e Collaboration, *Universe* 9(1):54 (2023)

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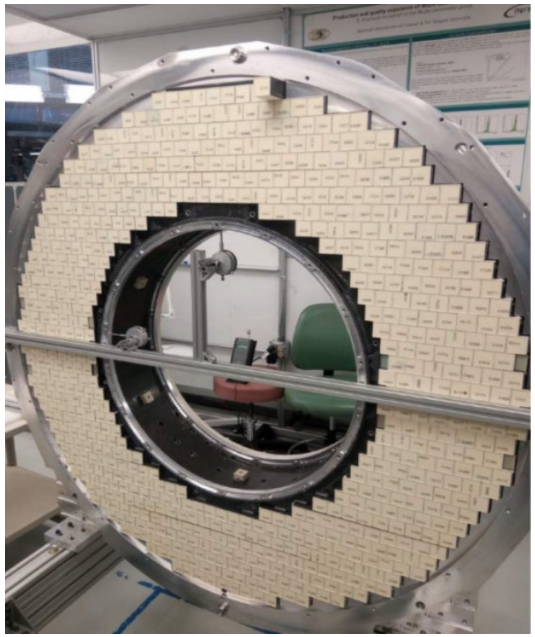
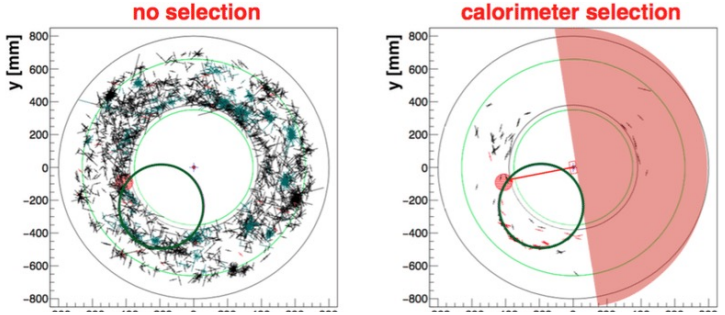
Layout and Detectors

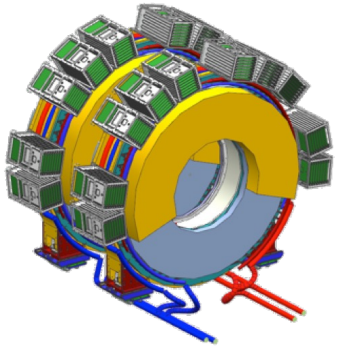
The Calorimeter

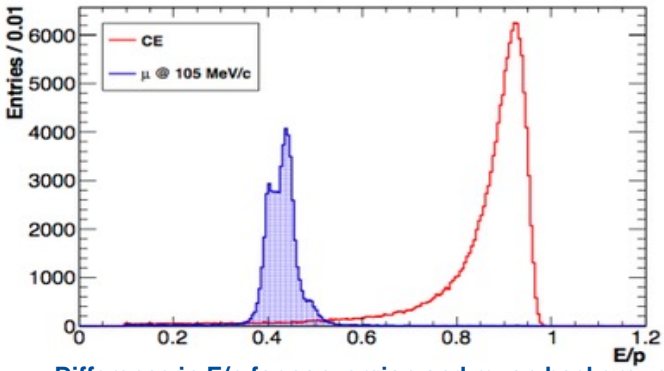


- ~1300 CsI crystals, each with 2 SiPM readouts
  - 20 x 3.4 x 3.4 cm^3 in volume
- Fast energy measurement, track pre-selection
- Energy + momentum → particle identification



Event displays showing background mitigation achieved by calorimeter track selection.





The Mu2e Collaboration, *Universe* 9(1):54 (2023); Pezzullo 2018

Difference in E/p for conversion and muon backgrounds at signal energy.

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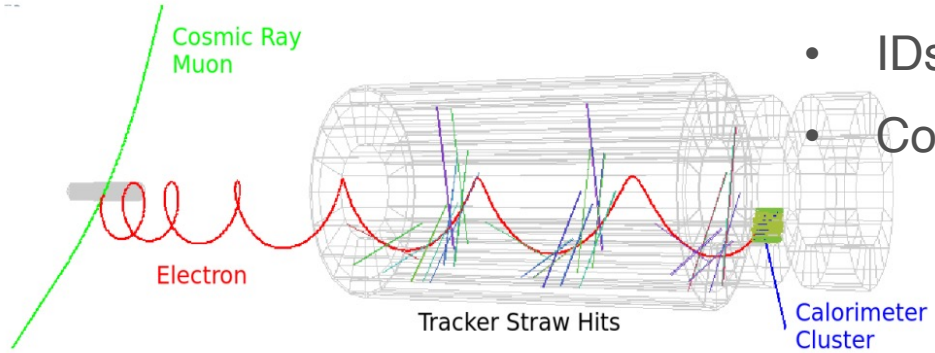
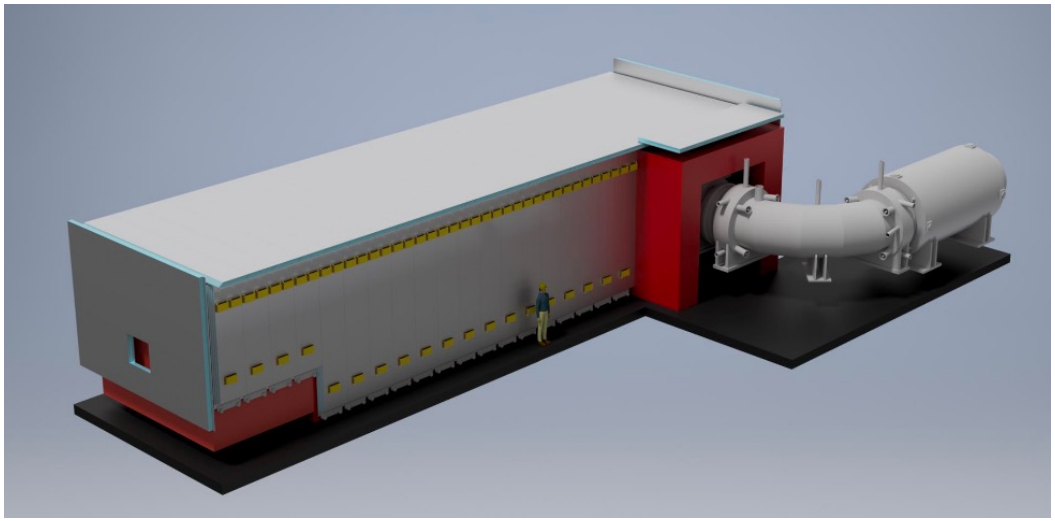
Layout and Detectors

The Cosmic Ray Veto (CRV)

- Encompasses detector solenoid, part of TS
- Extruded scintillator and SiPM readouts
- IDs cosmic track candidates for offline veto
- Cosmic backgrounds must be lifetime <1



Event display of cosmic background (Edmonds 2023)



Outside view of the CRV with human figure to scale (left); CRV modules (below)

Outlook

- Mu2e recently re-baselined
- As of May 2023:
  - Transport solenoids almost complete
  - Other solenoids arriving early fall
  - More than half of tracker planes assembled, frame complete
  - Both calorimeter disks will be assembled by end of summer
  - More than 80% of CRV completed
- On schedule to begin taking data in 2025
- Run-I to be completed before PIP-II shutdown

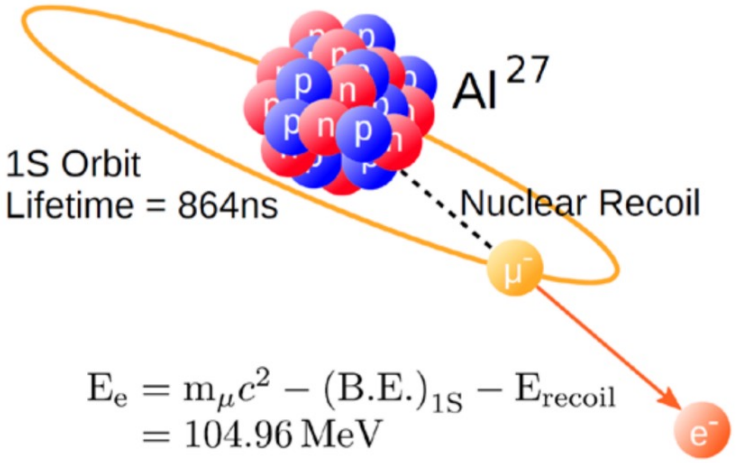
The Mu2e Collaboration

Backup Slides

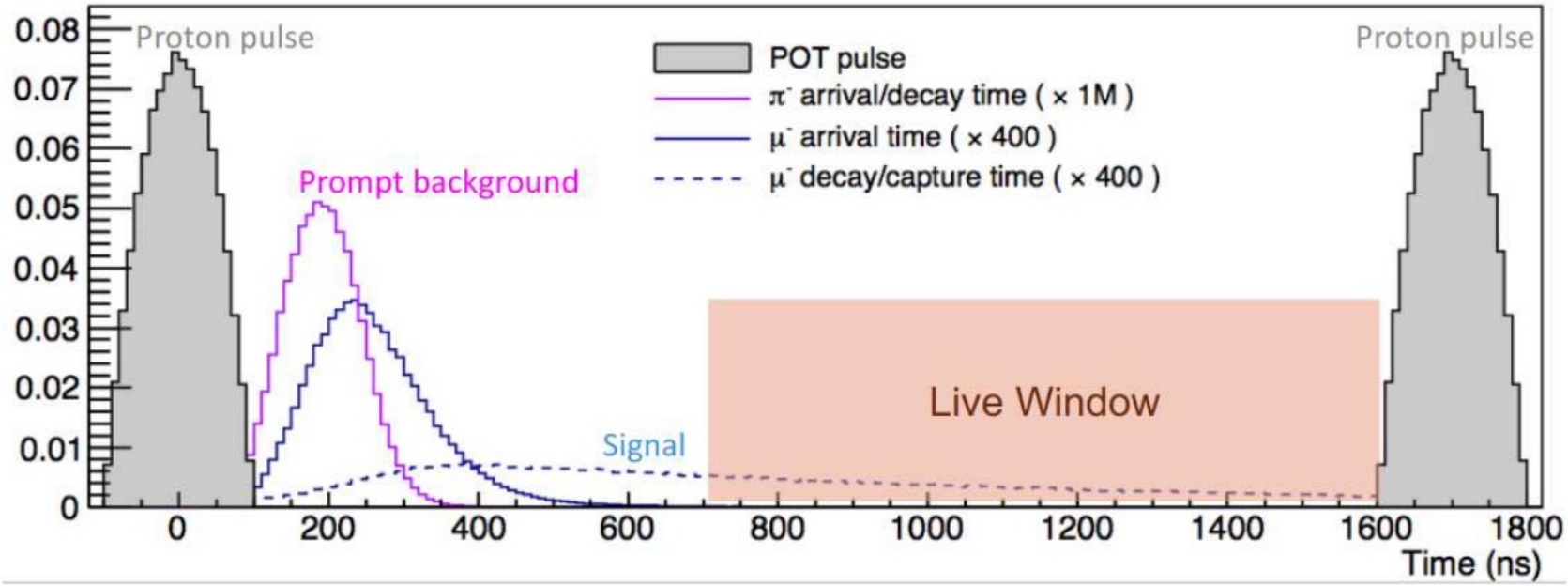
- Mu2e fast facts
- Beam timing
- BSM

Mu2e Fast Facts

- Run-I: 2025-2027, 2 years at reduced intensity
  - Sensitivity → 10^{-16}
- Run-II: 2029-2032, 3 years at full intensity
  - Sensitivity → 10^{-17}
- Will stop *O(10^{18})* muons
- Will discover CLFV at 5σ if $R_{\mu\to e}\sim10^{-16}$



Beam Timing



From S. Di Falco (2022)

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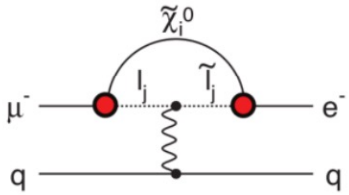
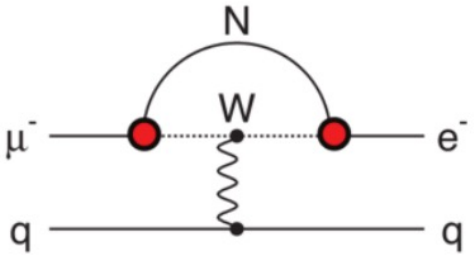
BSM Processes

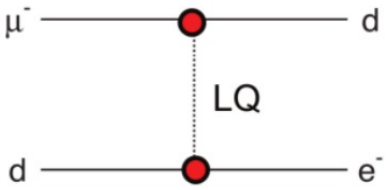
- Supersymmetry
  - Each SM particle theorized to have a superpartner
  - Sleptons, Squarks, Neutralinos…
  - A neutralino (neutral superboson) and sleptons mediate CLFV in the field of a nucleus



- Heavy neutrinos
  - Unobserved υ with quark-like Yukawa couplings
  - Allows mediation of $\mu^- N \rightarrow e^- N$



- Leptoquarks
  - Color-triplet bosons carrying both lepton and baryon number
  - Have different interaction strengths with different lepton flavors



Devilbiss (2023) Unpublished