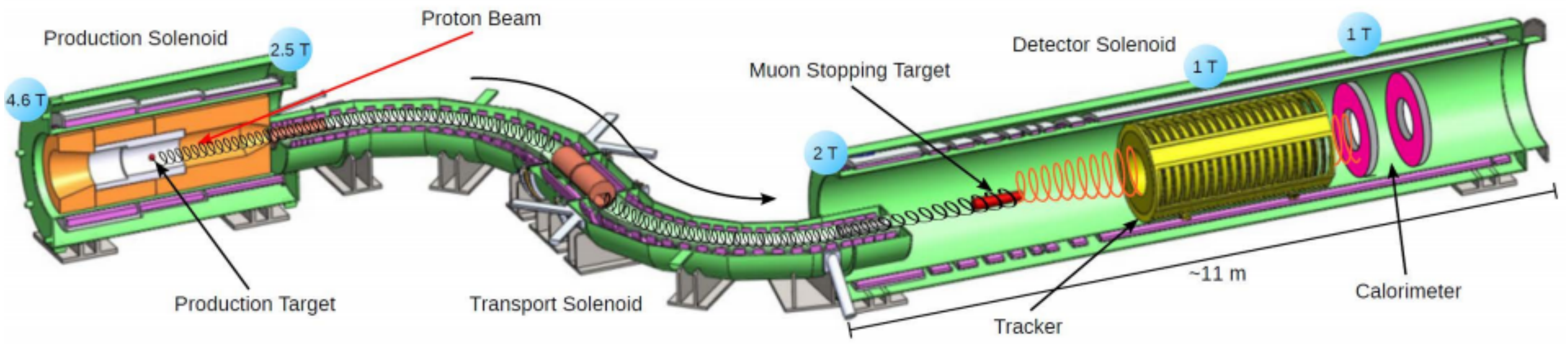

Mu2e :
10 Minutes in Questions

Dan Ambrose
University of Minnesota

New Perspectives

June 14, 2016

What's up with the Muon?

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1936: Anderson and Neddermeyer discover the muon

Rabbi’s famous statement “Who ordered that?”

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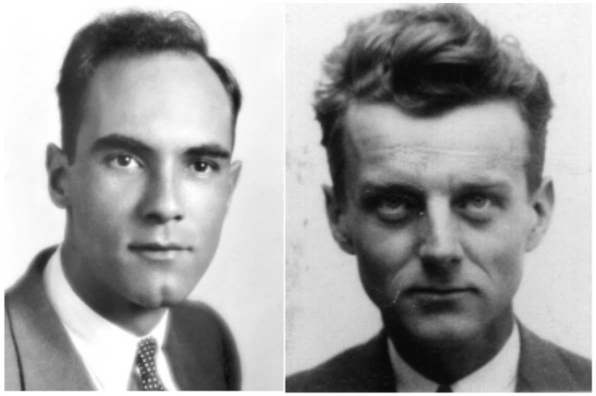

Rabbi’s famous statement “Who ordered that?”

There are still unanswered mysteries surrounding the muon:

- Why are there 3 generations of matter?
- Muon G-2 deviation from theory > 3σ
- Quarks mix and Neutrinos mix. Shouldn’t we expect charged Leptons to mix?

Charge Lepton Flavor Violation (CLFV)

You mentioned CLFV. Does that happen?

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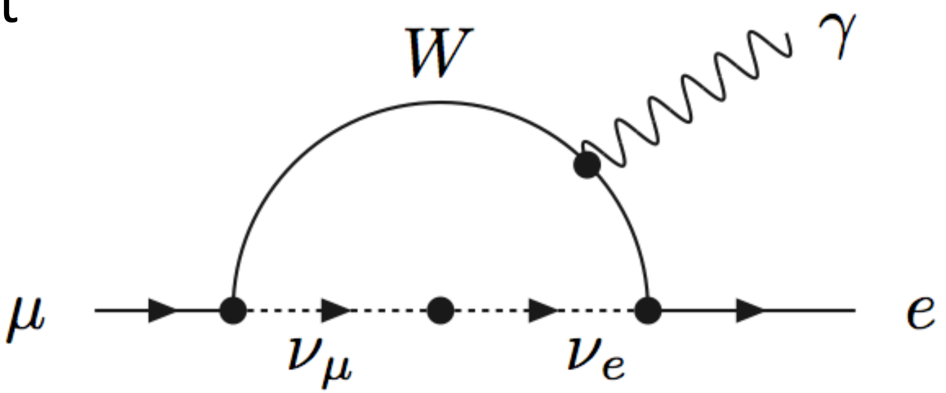

$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

*unmeasurably small

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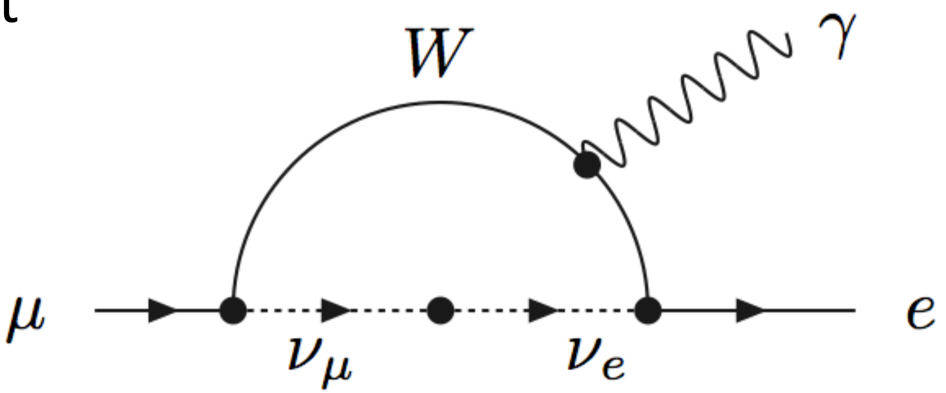

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Any observation of CLFV must be new physics!

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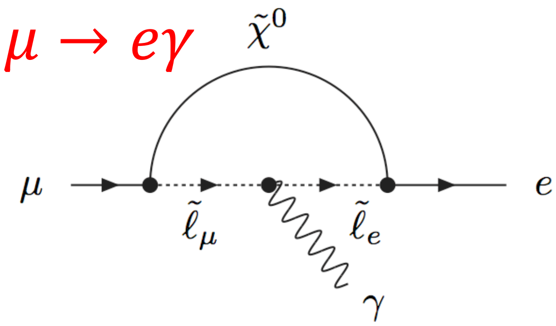
$\mu \to e\gamma$



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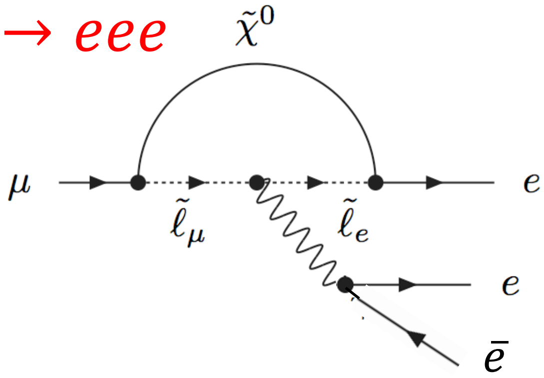
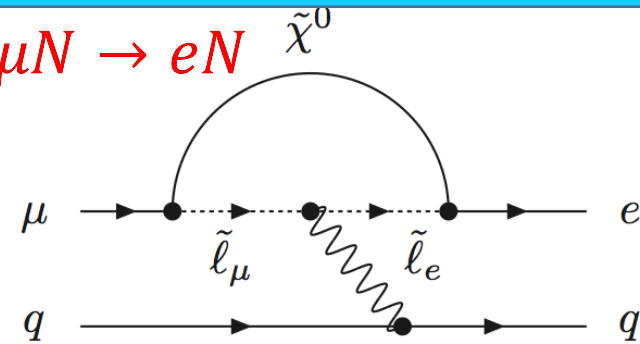


$\mu N \to eN$



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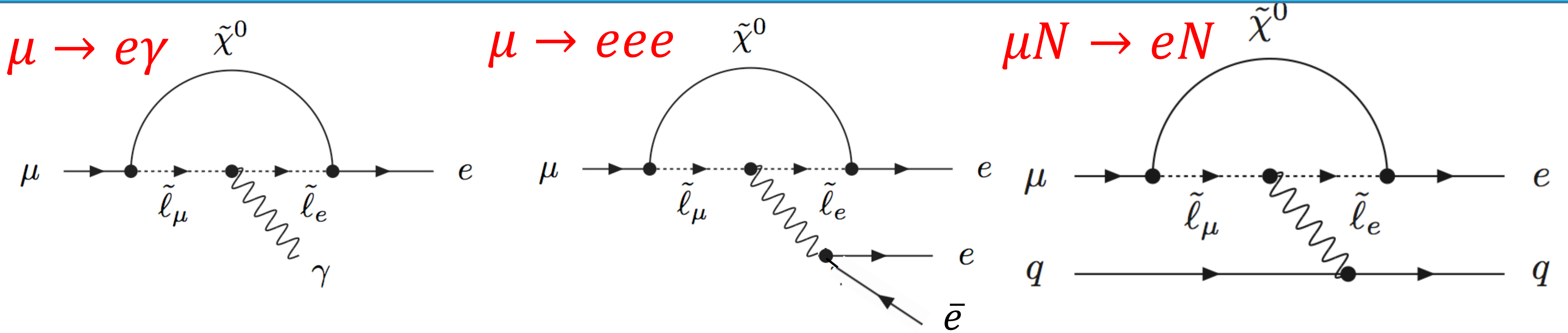
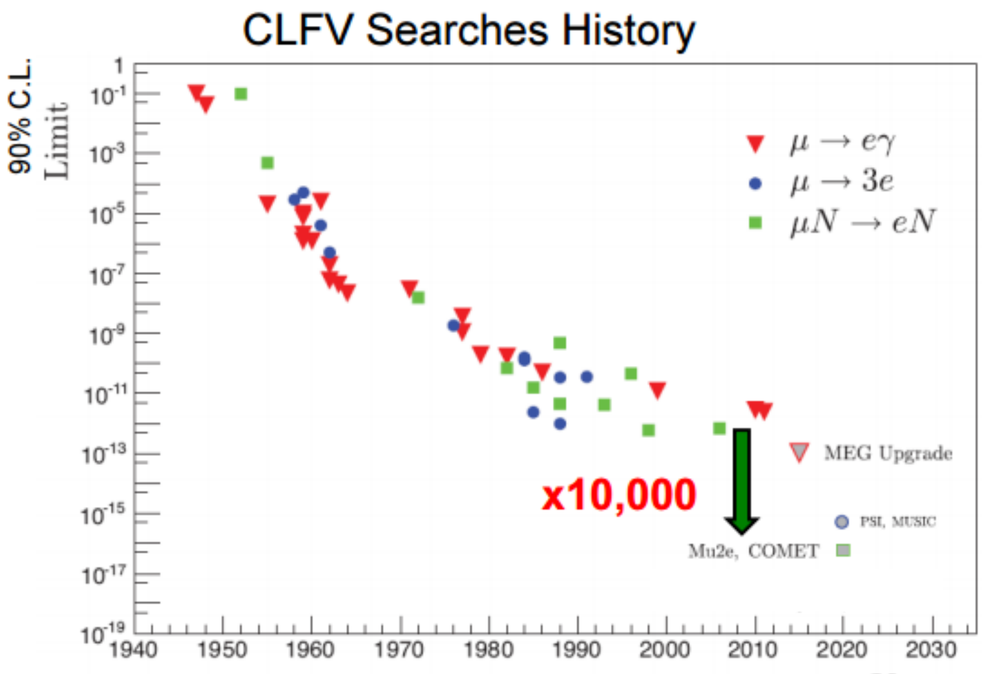




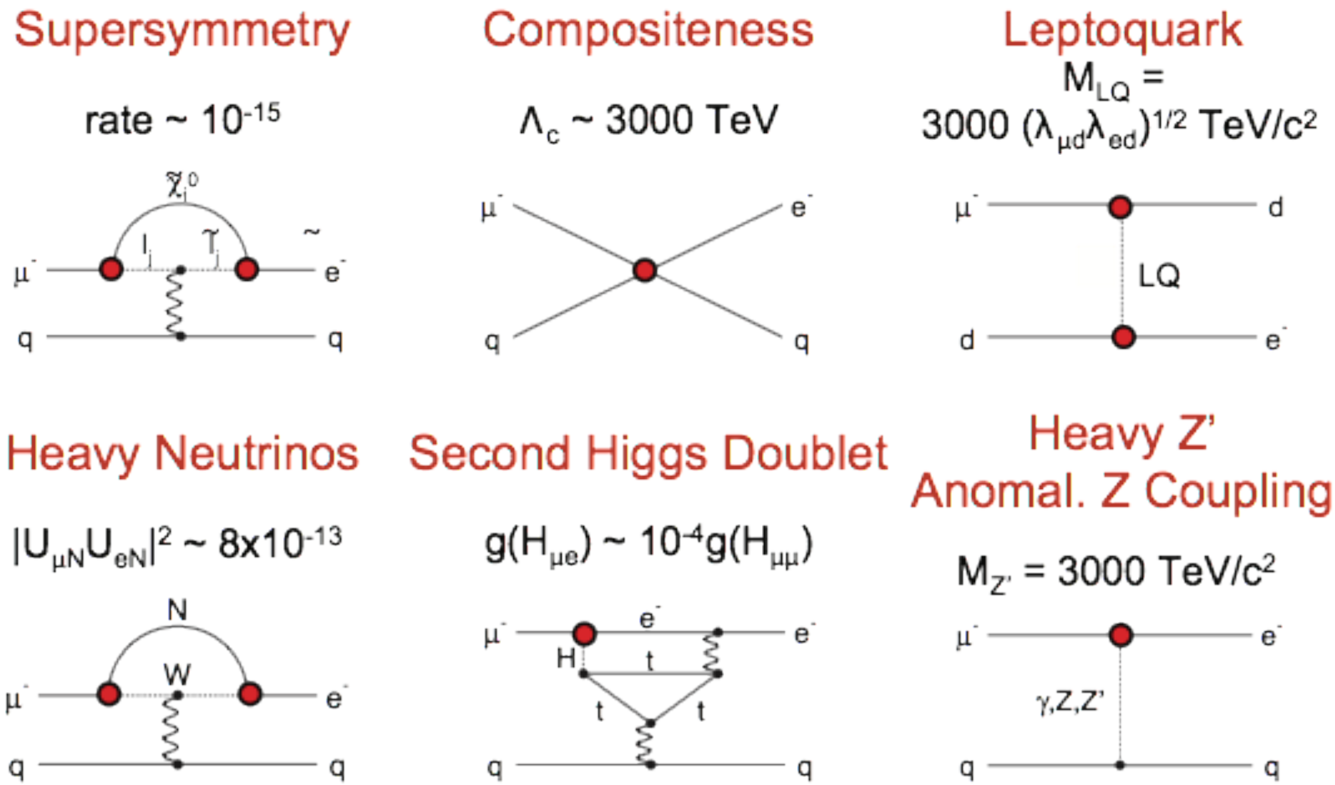
R. H. Bernstein & P. S. Cooper, Phys. Rept. 532 (2013) 27

4 orders of magnitude increased precision is incredible.

Fully operational Mu2e would be able to beat the current world best measurement with about 1 hour of data.

Soooo…Standard model predicts 10^{-54} and Mu2e's substantial increase just gets us to 10^{-17}. I'm not excited, should I be?

Soooo…Standard model predicts 10^{-54} and Mu2e's substantial increase just gets us to 10^{-17}. I'm not excited, should I be? YES!



Estimates from Flavour Physics of Leptons and Dipole Moments, Eur.Phys.J.C57:13-182,2008

Mass Scale up to about 10,000 TeV

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- The stopped muons are trapped in orbit around the nucleus
- Look for events consistent with μN→eN
- We measure : $$R_{\mu e} = \frac{\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)}{\mu^- + N(A,Z) \rightarrow \nu_\mu + N(A,Z-1)}$$

Numerator:

Muon to electron conversion in the presence of a nucleolus

Denominator:

Nuclear captures of muonic Al atoms

What would an event even look like?

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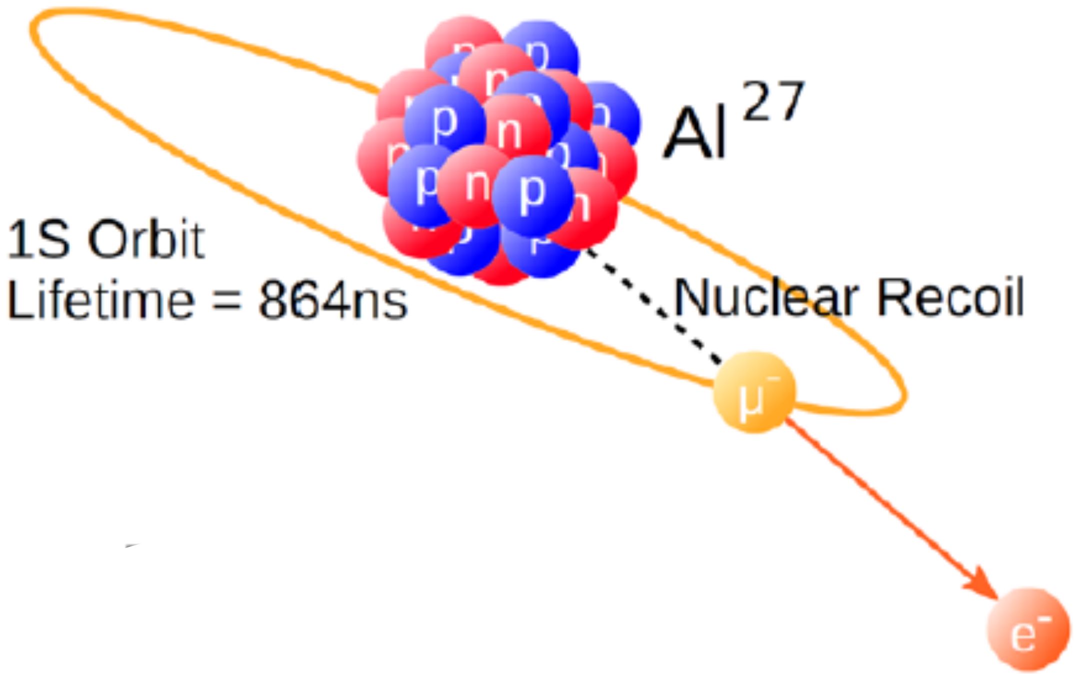

- When captured by a nucleus, a muon will have an enhanced probability of exchanging a virtual particle with the nucleus.

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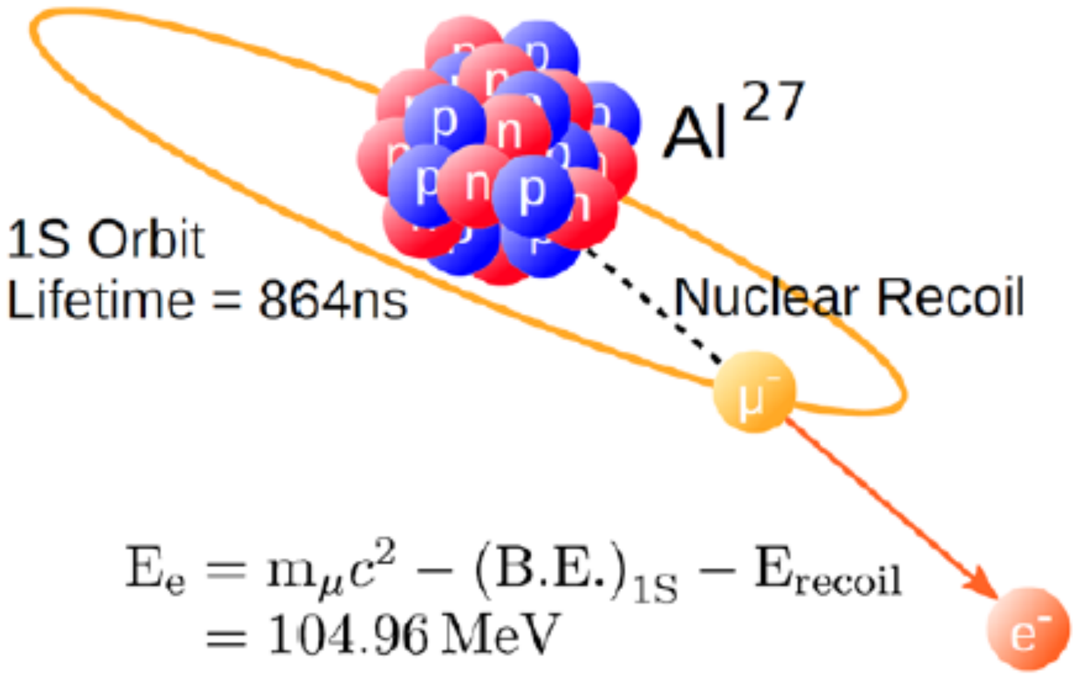

$$E_e = m_\mu c^2 - (B.E.)_{1S} - E_{recoil}$$
$$= 104.96\,\mathrm{MeV}$$

- When captured by a nucleus, a muon will have an enhanced probability of exchanging a virtual particle with the nucleus.
- This reaction recoils against the entire nucleus, producing a *mono-energetic* electron carrying most of the muon rest energy.

This being "crazy rare", what is the muon doing the rest of the time?

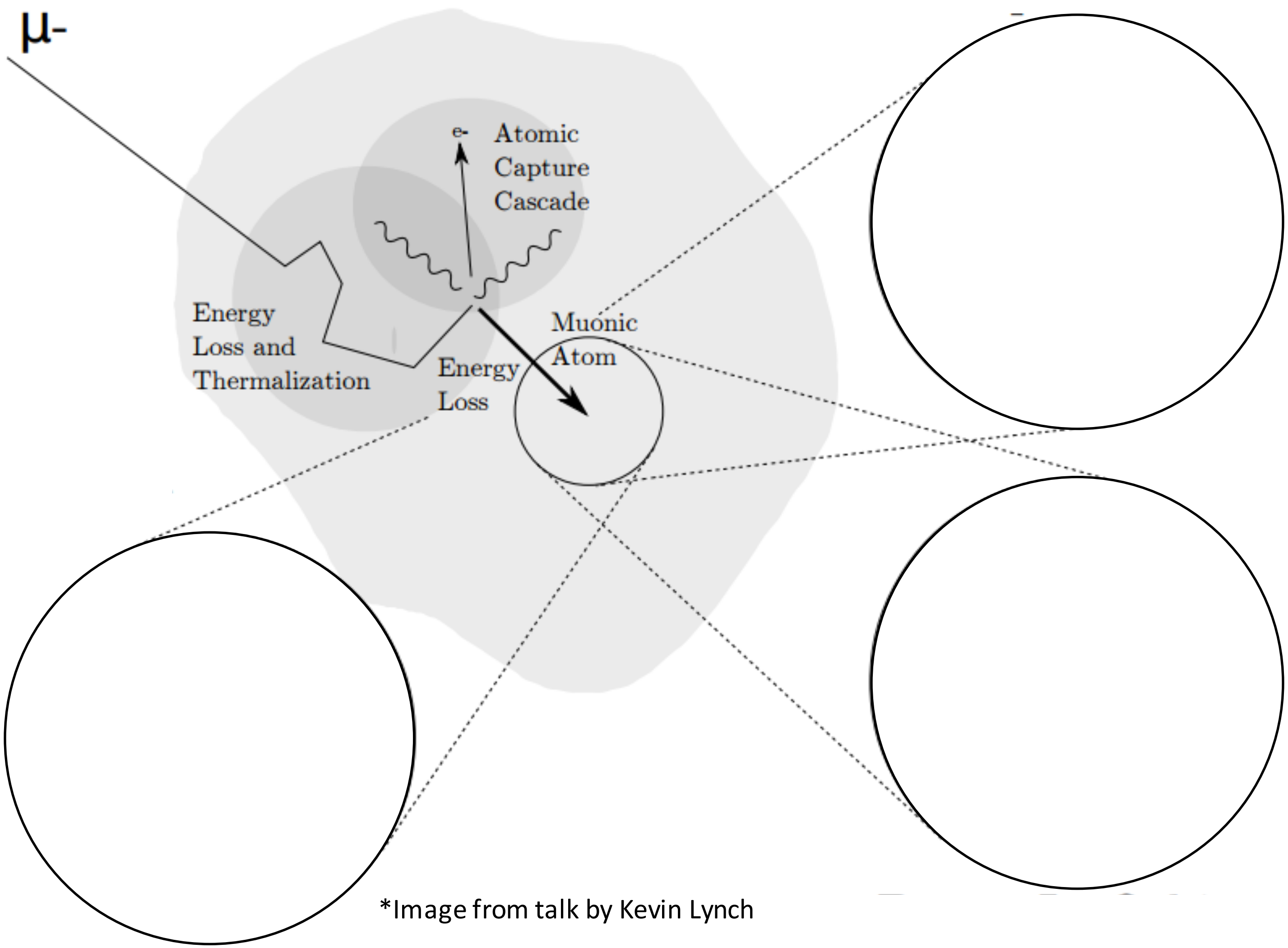

*Image from talk by Kevin Lynch

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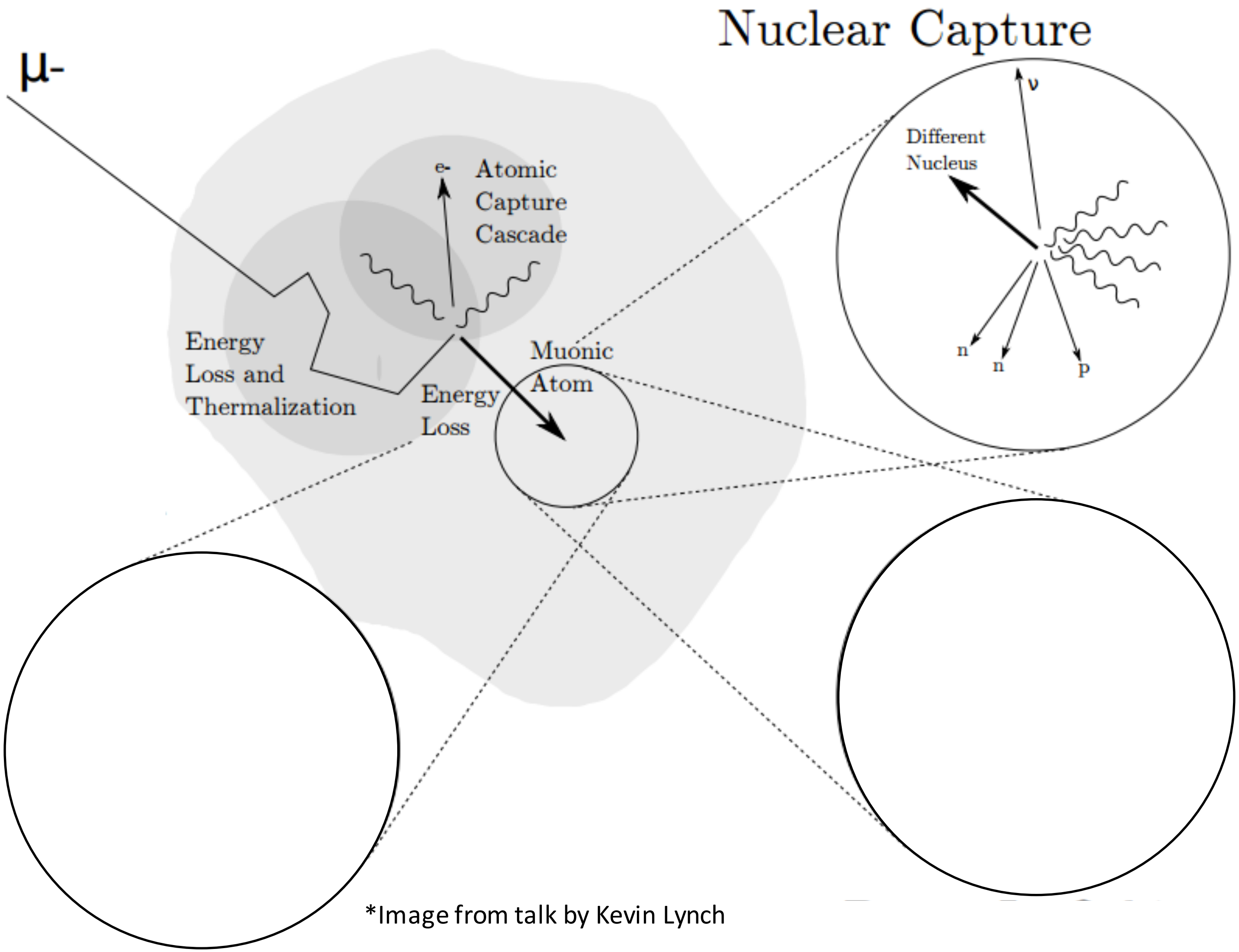

61%

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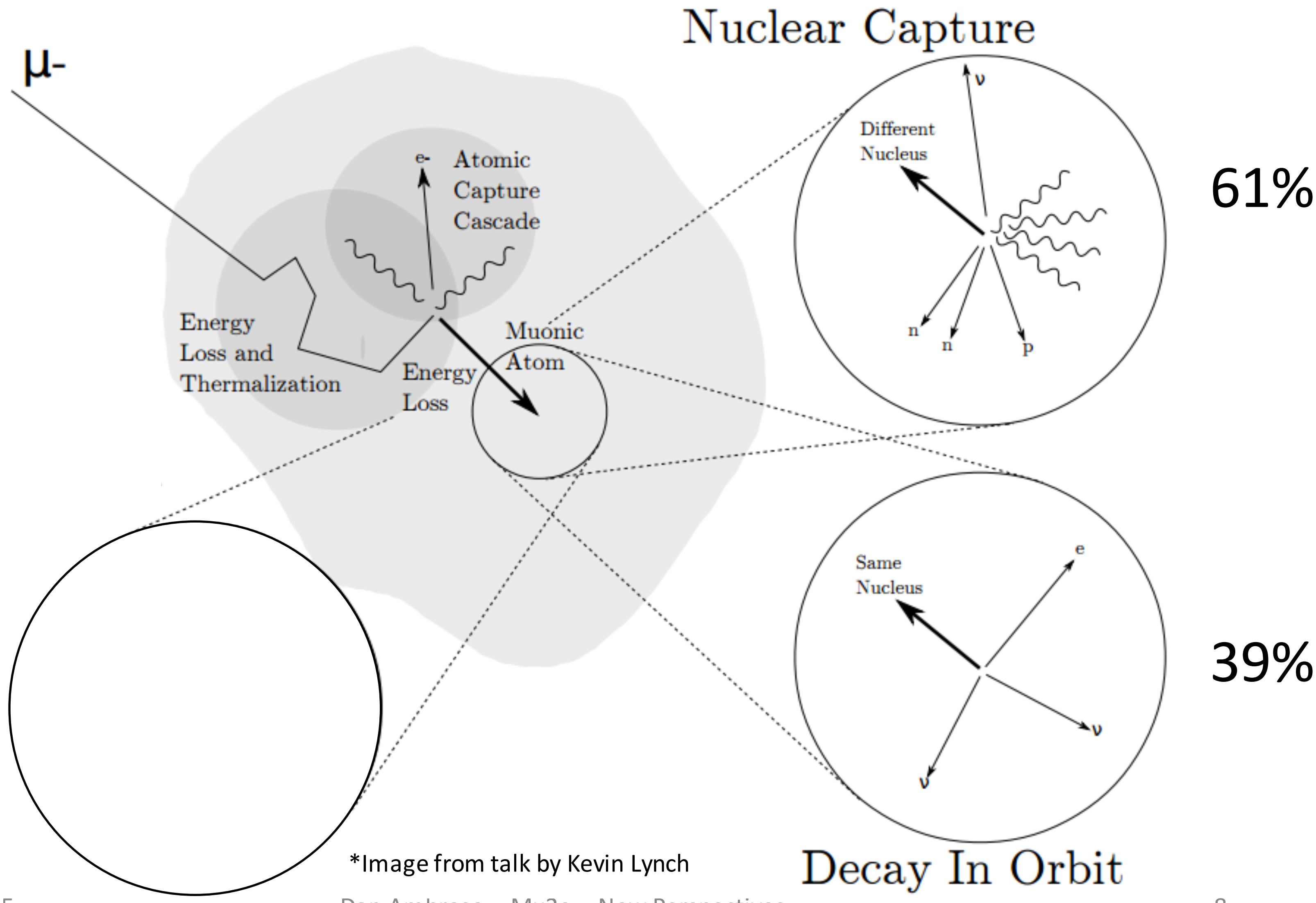

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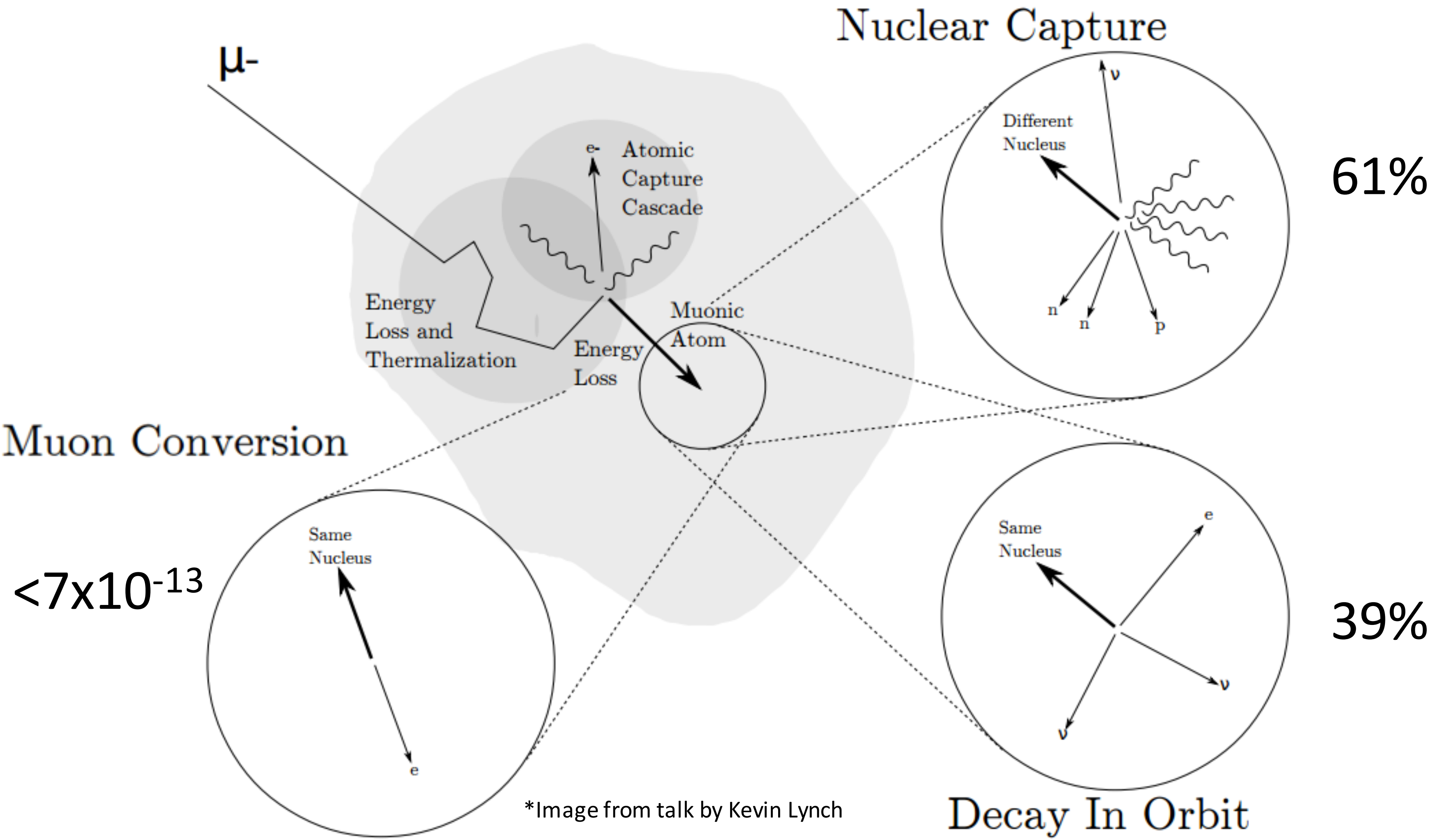

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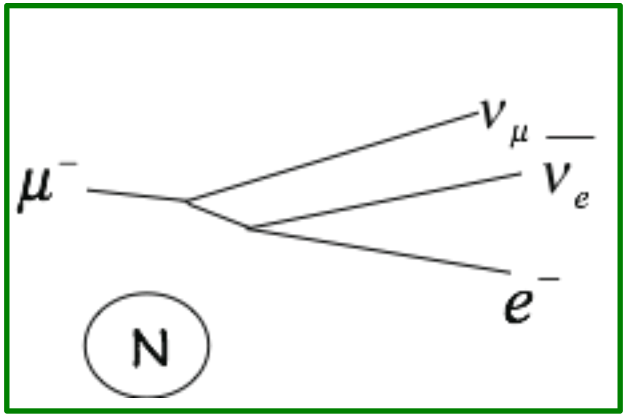

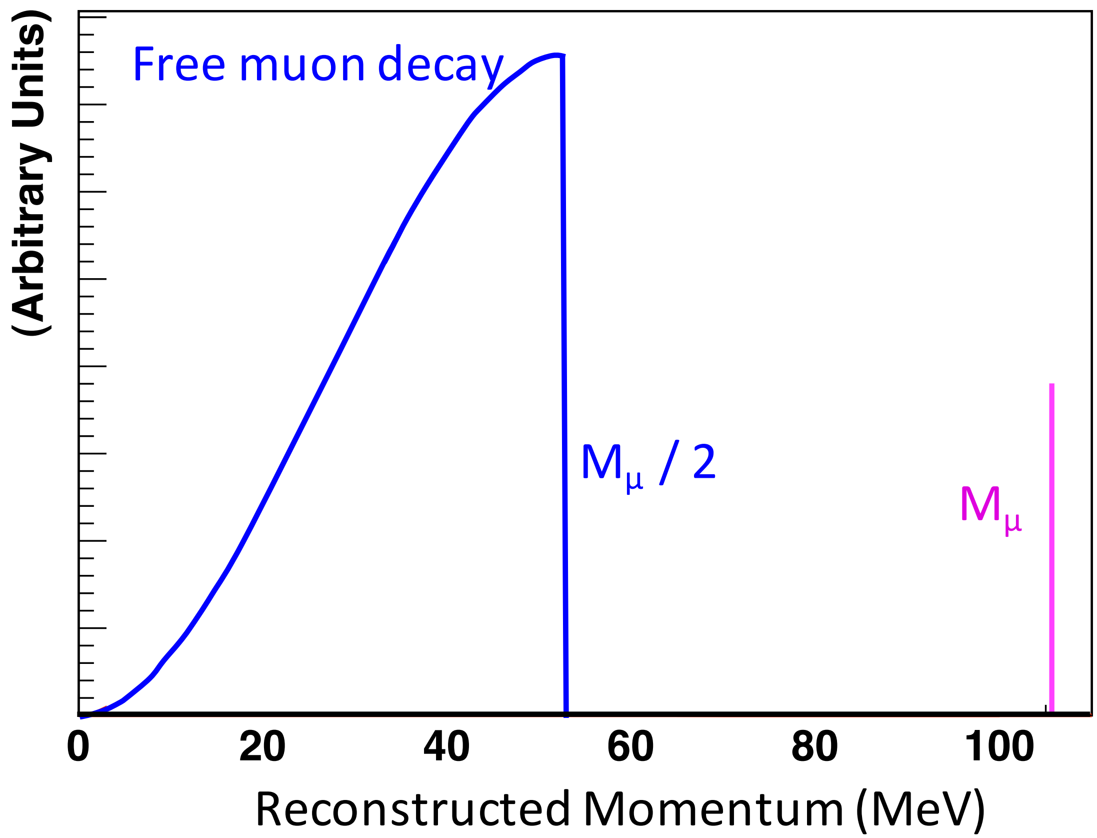

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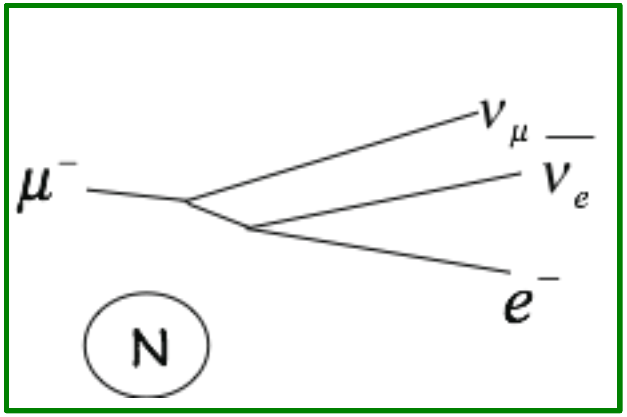

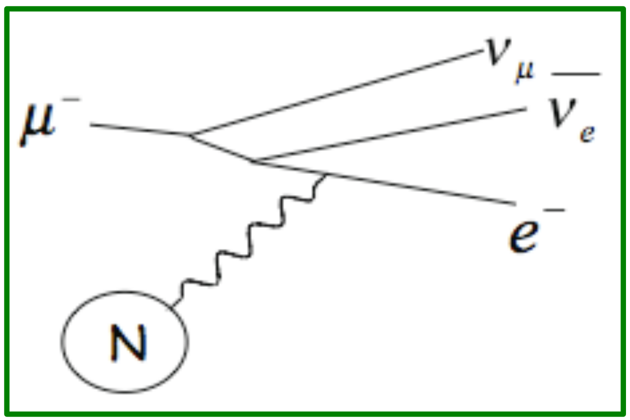

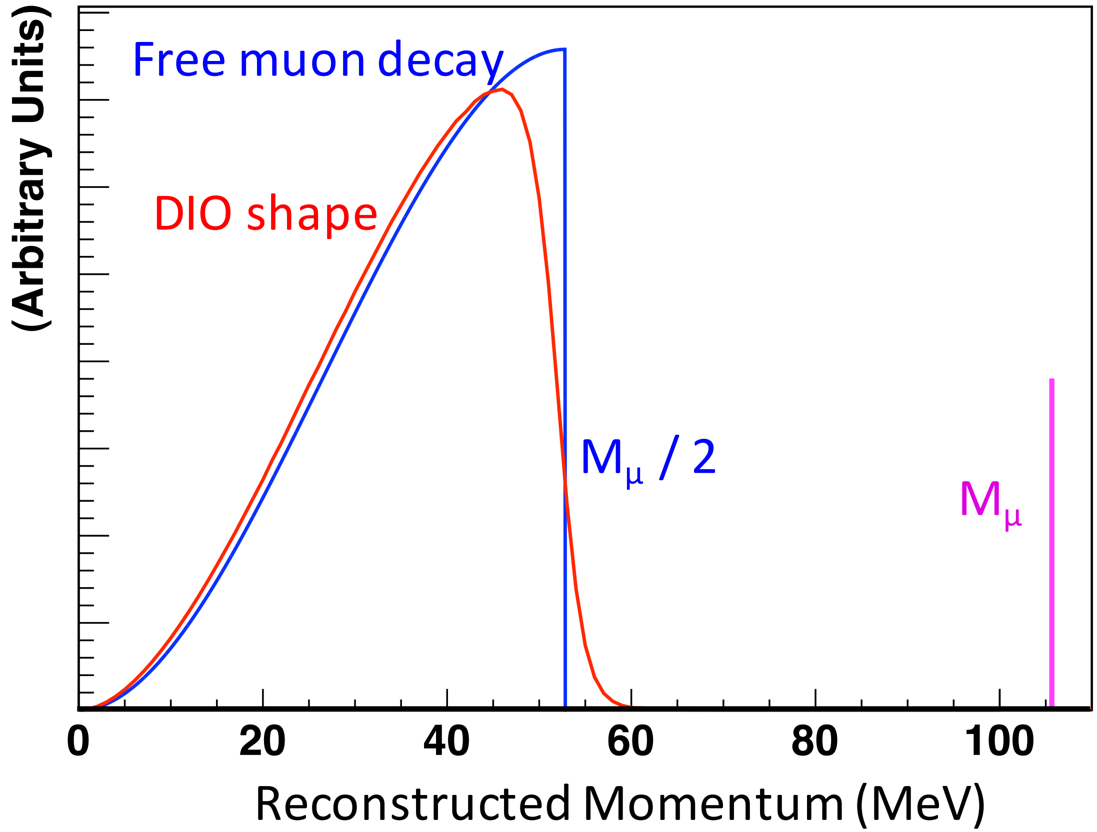

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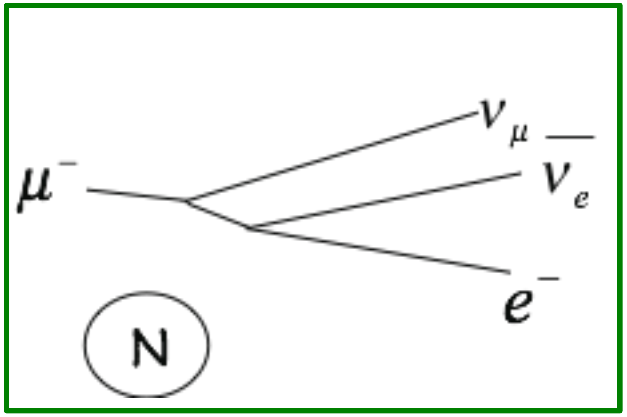

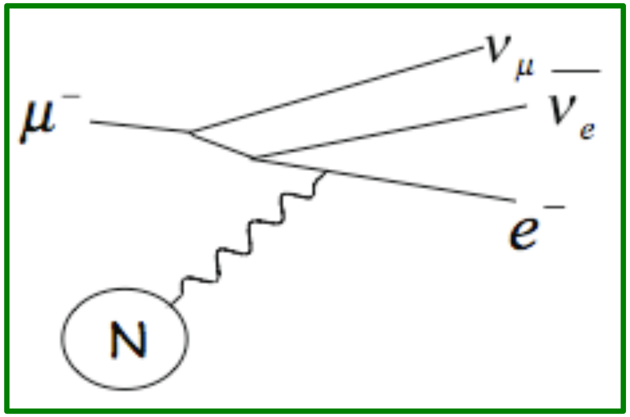

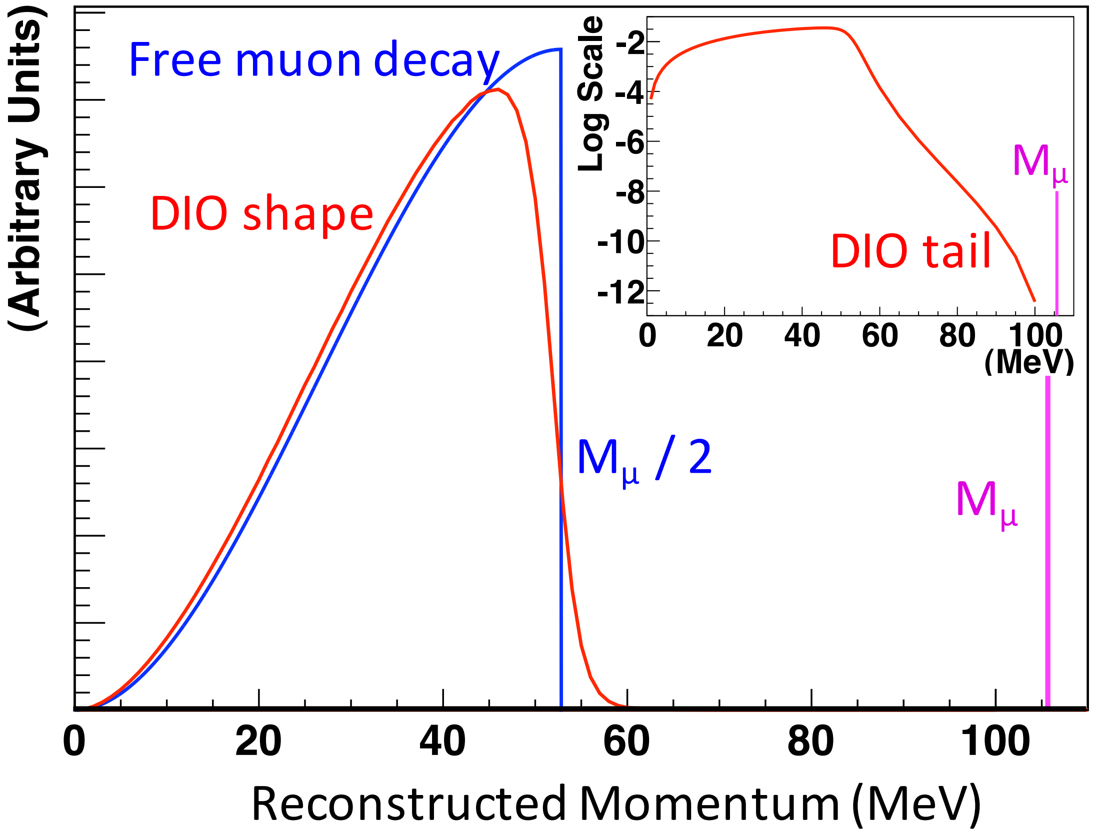

That tail seemed to be getting close to the signal. You sure that isn't a problem?

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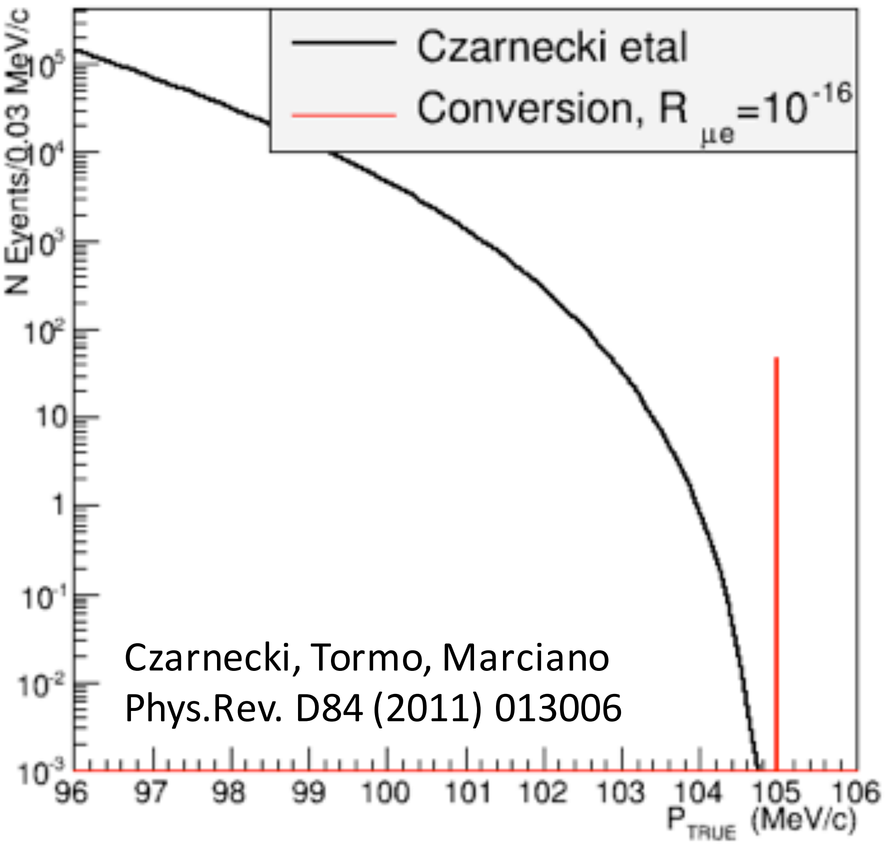
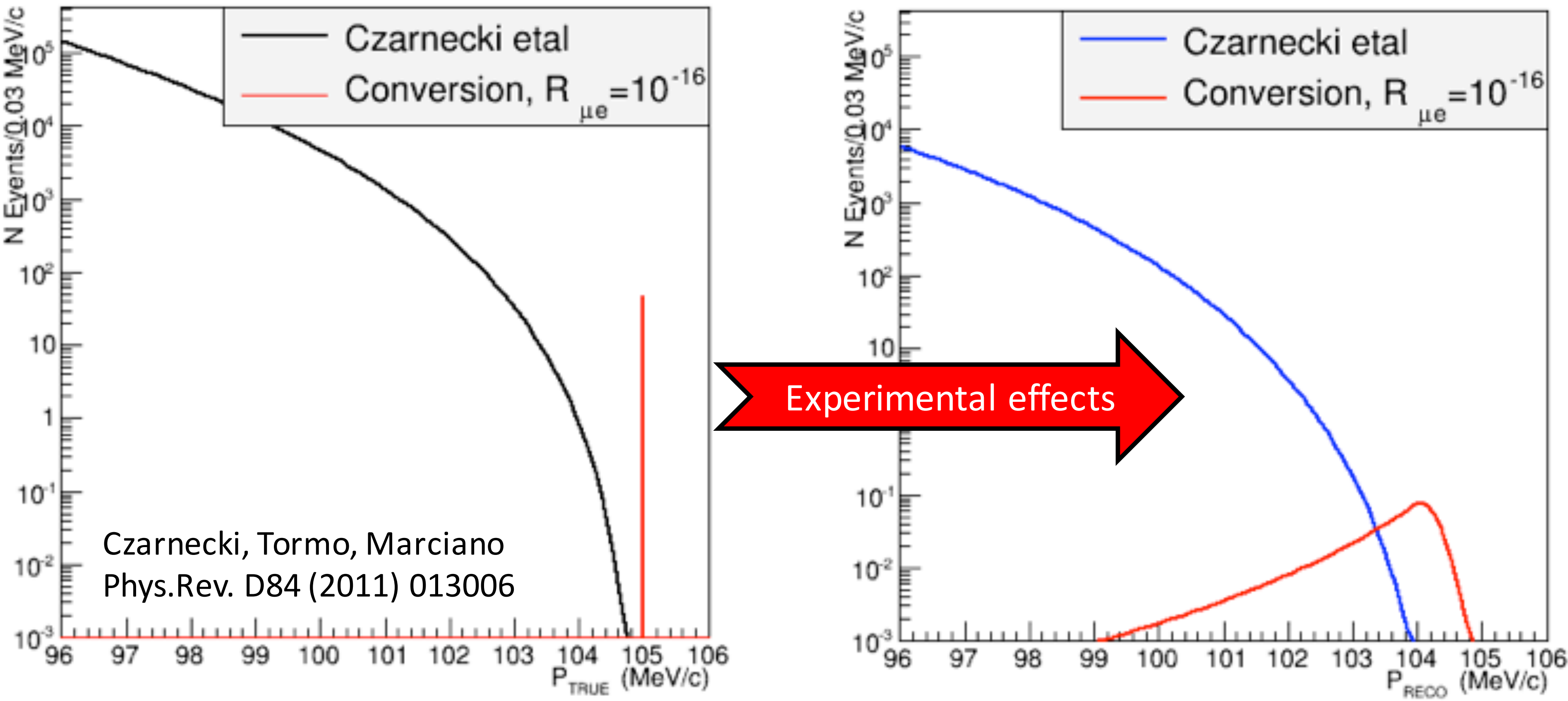
- Tail of DIO falls as $(E_{Endpoint} - E_e)^5$



Czarnecki, Tormo, Marciano
Phys.Rev. D84 (2011) 013006

That tail seemed to be getting close to the signal. You sure that isn't a problem?

- Tail of DIO falls as $(E_{Endpoint} - E_e)^5$
- Separation of ~few 100 keV for $R_{\mu e} = 10^{-16}$



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Tall tasks, but the accelerator and Mu2e have been designed to accomplish this.

What will the experiment look like?

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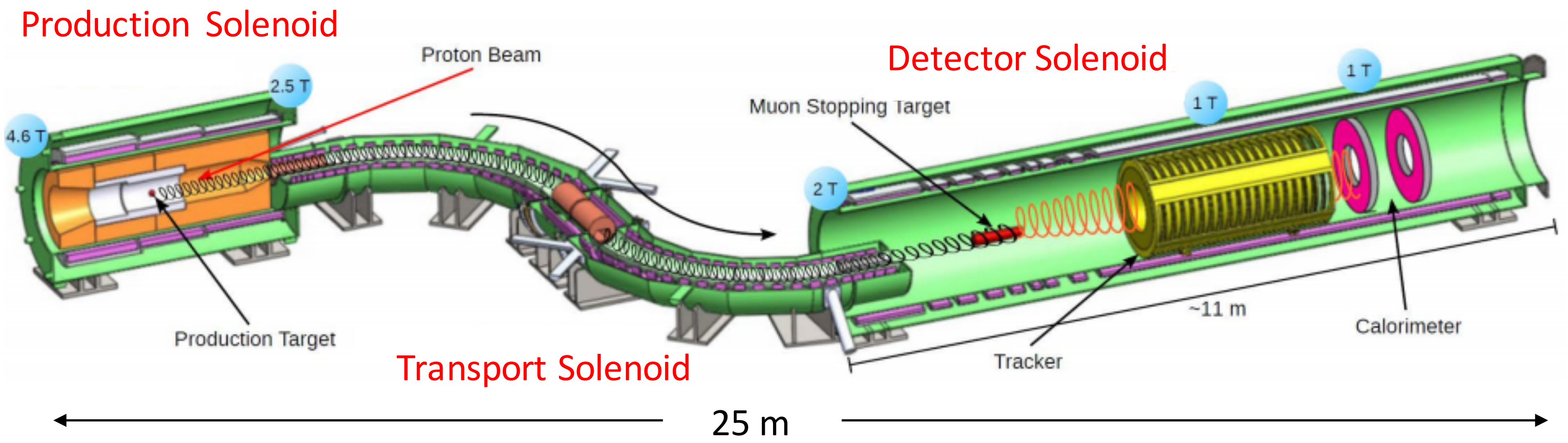

3 main components: Production Solenoid (PS), Transport Solenoid (TS), and Detector Solenoid (DS)
Experimental setup contained within vacuum space
Gradient magnetic field (4.6 T → 1 T) moves charged particles downstream
Step 1:
  8 GeV proton beam hits tungsten target and produces Pions in PS
  Pions decaying into muons are pushed downstream towards TS
Step 2:
  TS selects particles based on charge and momentum
  TS collimators eliminate backgrounds
Step 3:
  Muons are captured in Aluminum target foils
  Conversion electron trajectories measured and validated in tracker and calorimeter

Do other beam particles create background?

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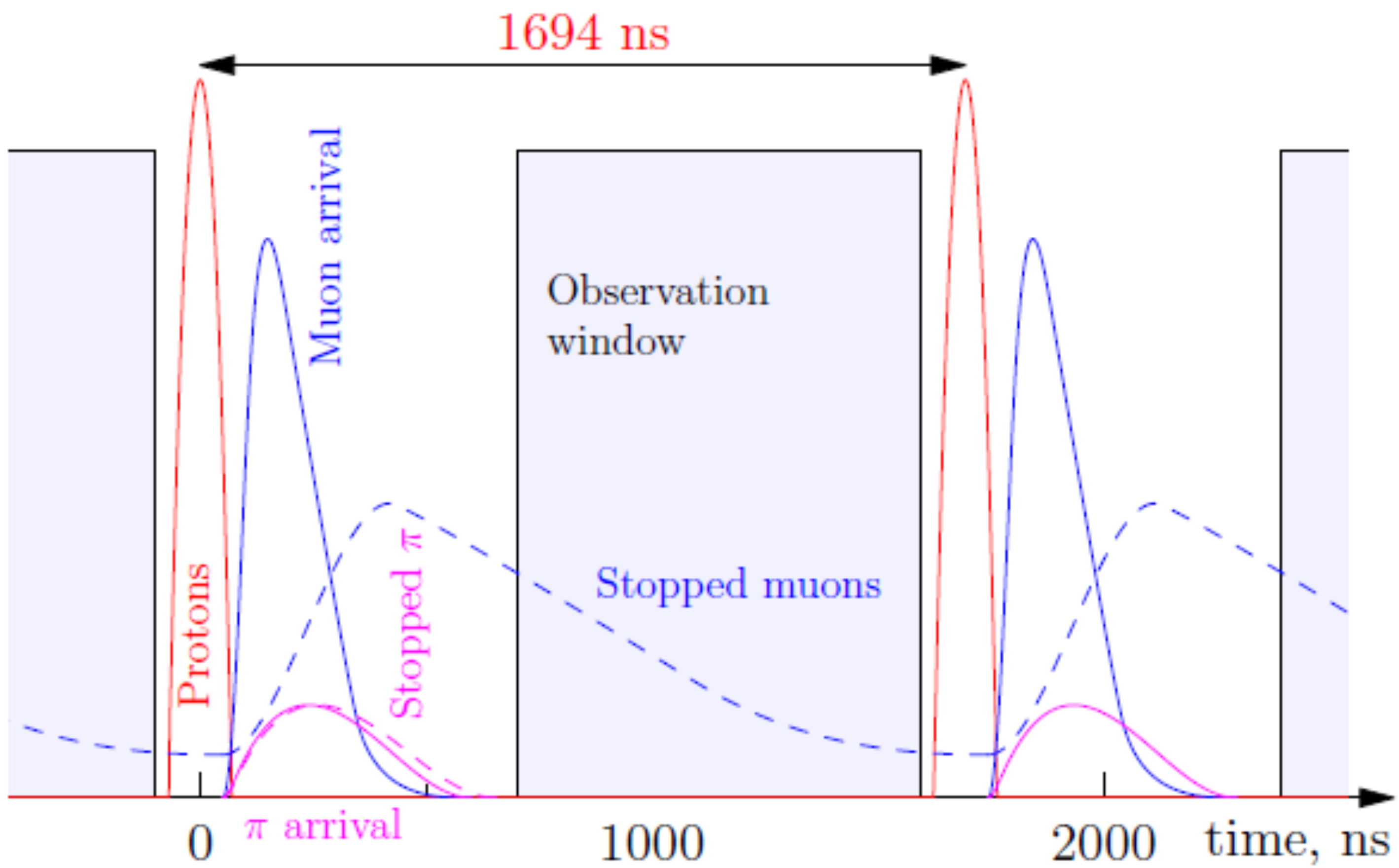

- ~20,000 muons per bunch
- 10^{10} muons per second

Almost all protons, unstopped muons, stopped and unstopped pions will be through the detector before observation window.

Your tracker is shaped like a long doughnut, that’s weird.

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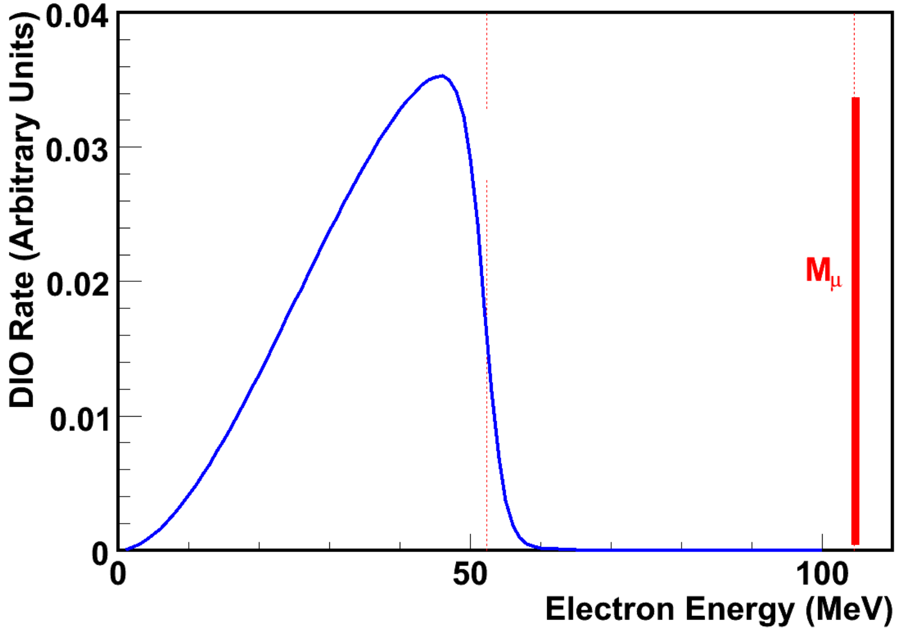

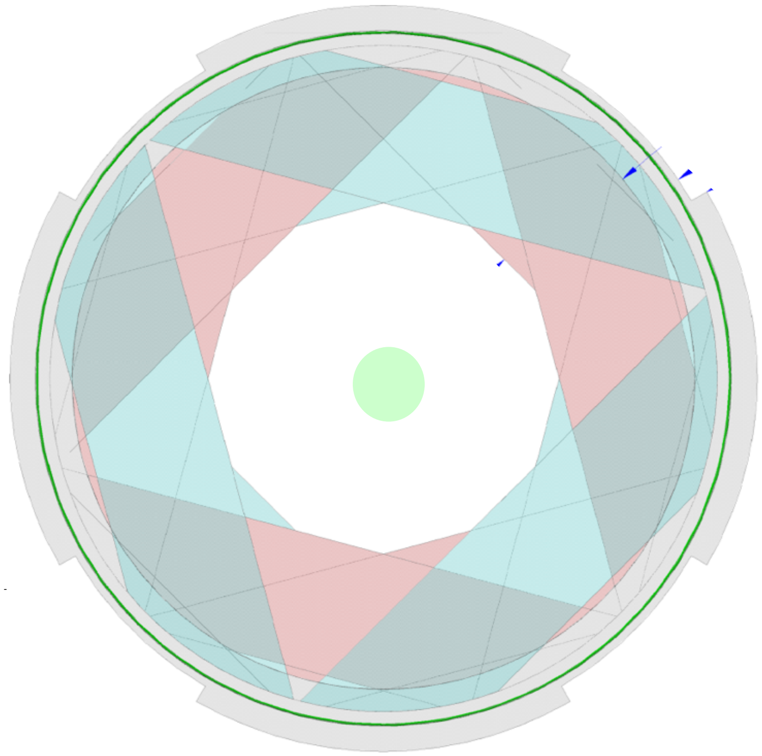

Beam's-eye view of Tracker

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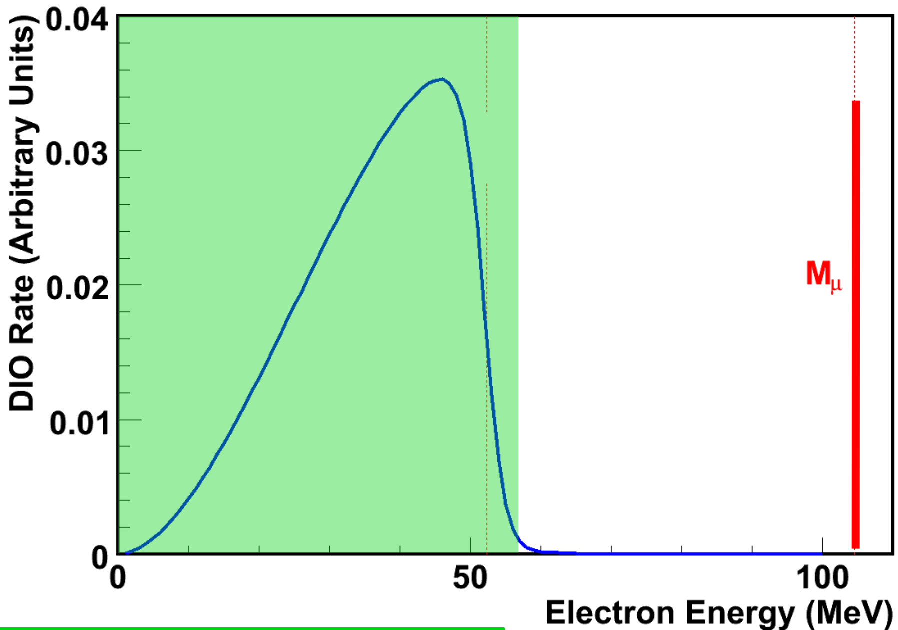
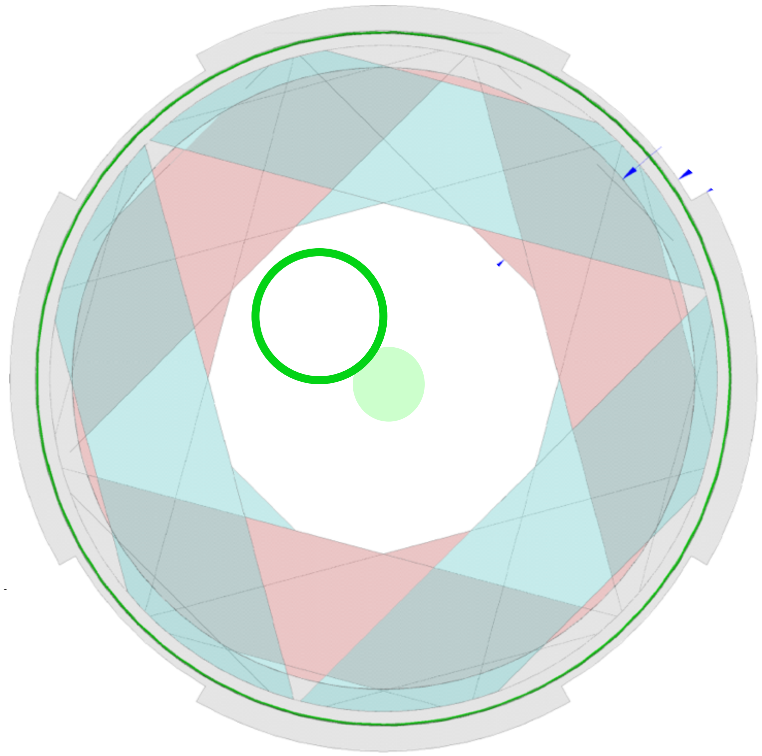


No hits in detector



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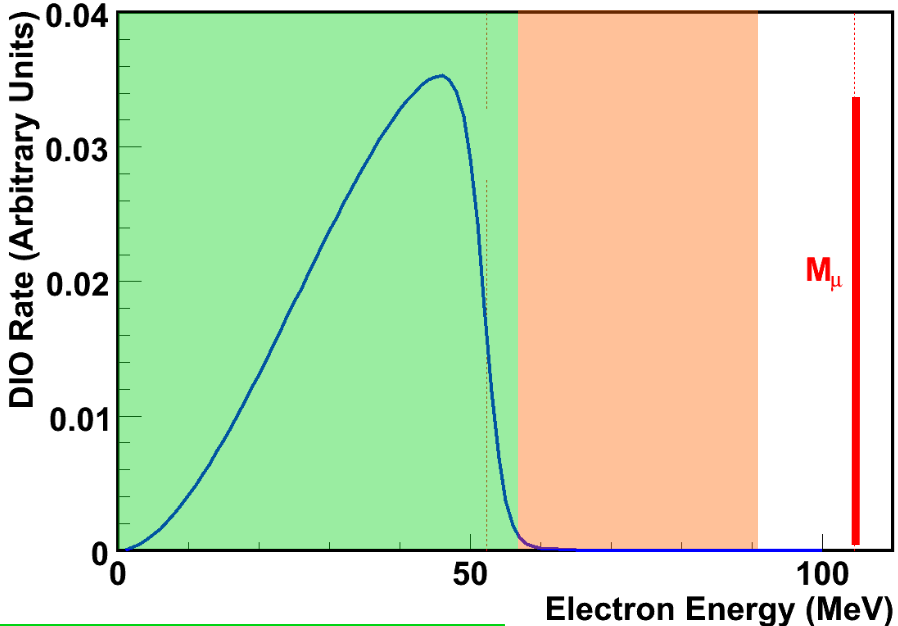

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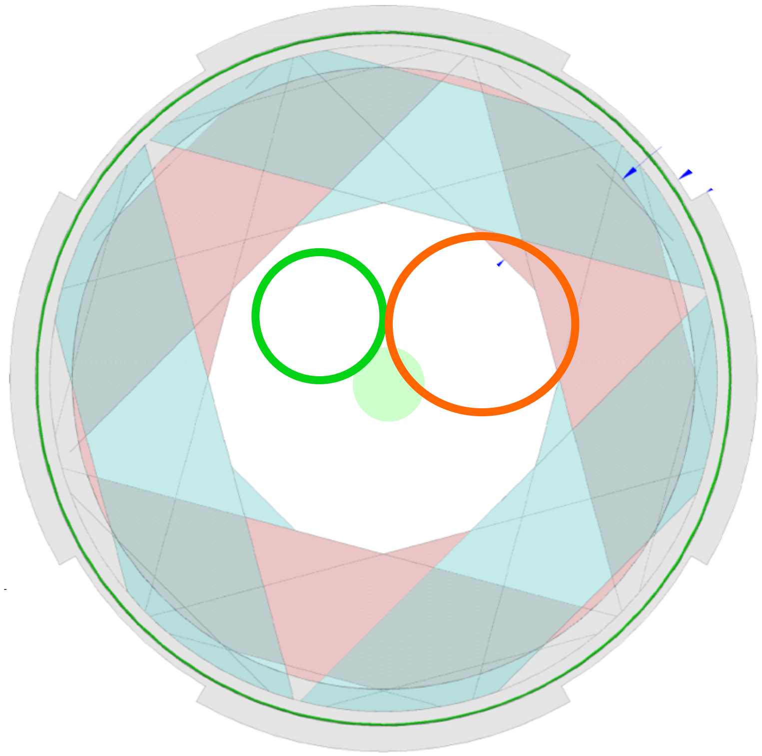
Tracks not reconstructable.



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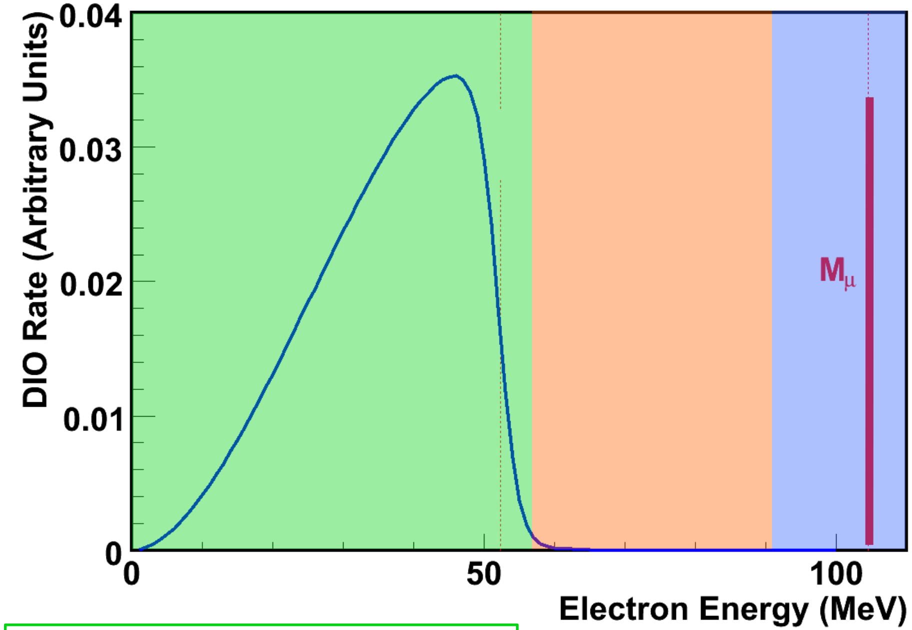

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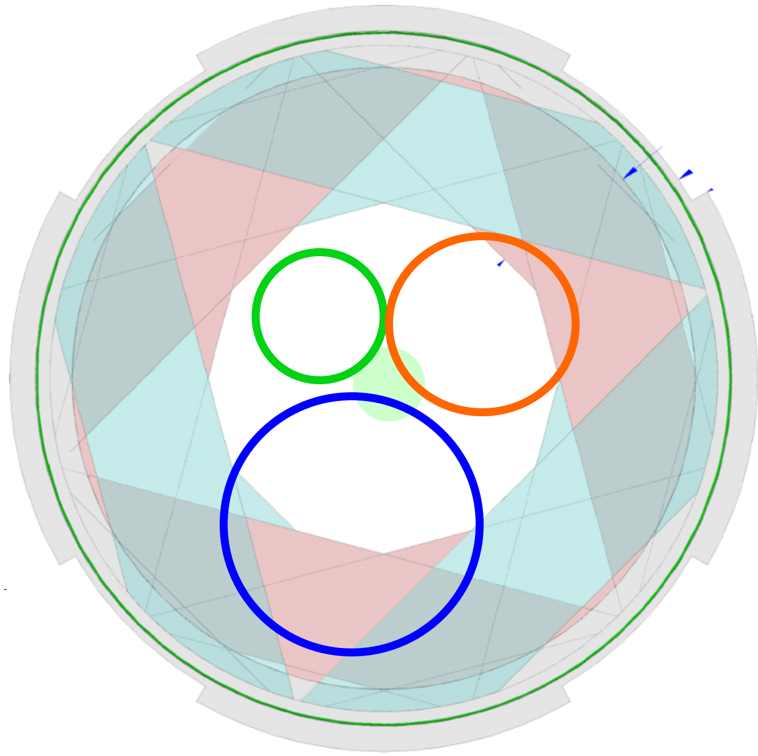
Reconstructable tracks
Momentum resolution σ < 180 keV/c



Beam's-eye view of Tracker

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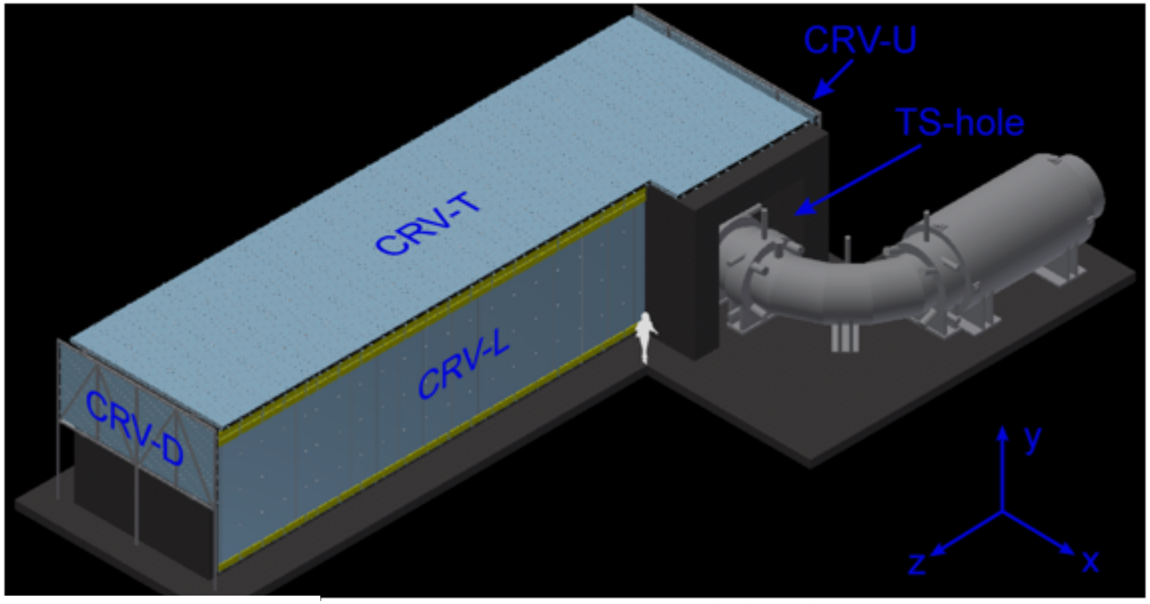
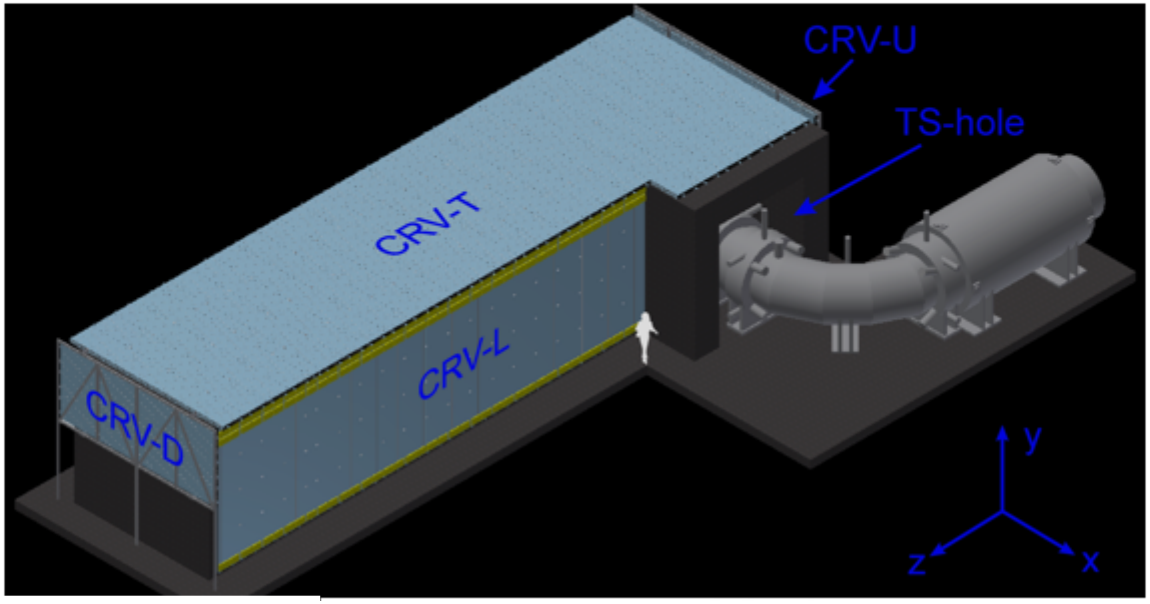
- The CRV covers all of DS and half of TS



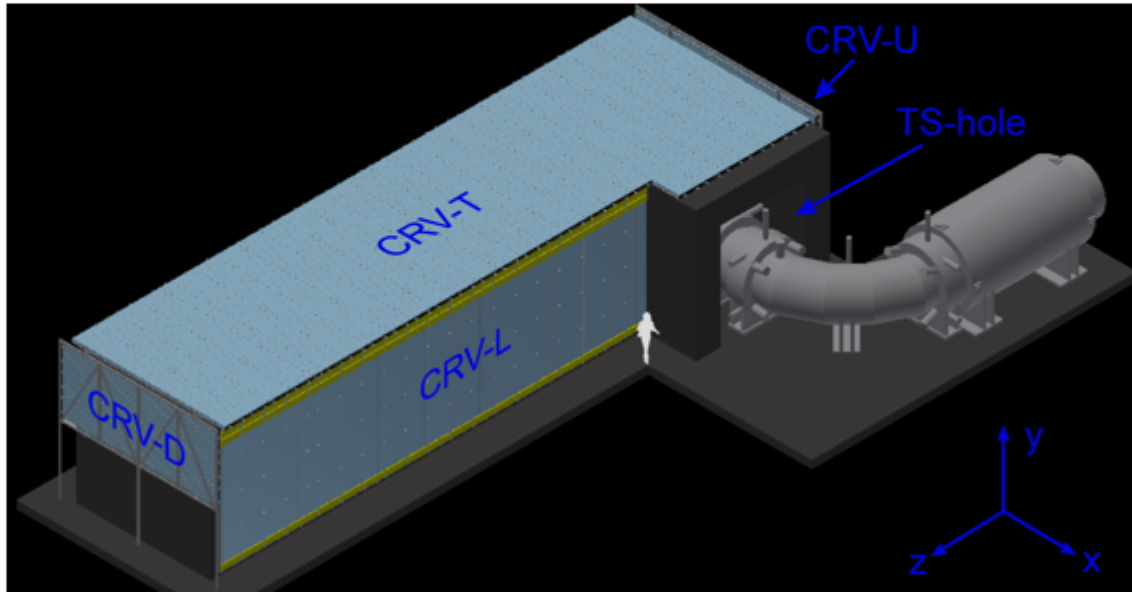
Don't you have to worry about cosmic rays?

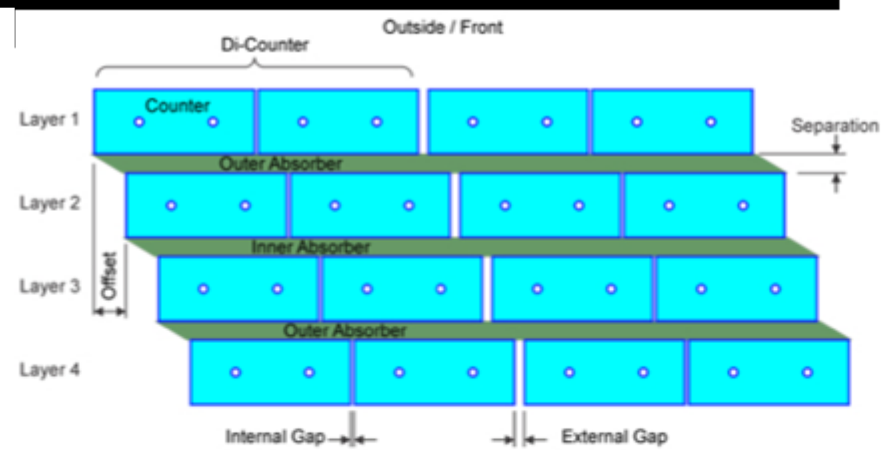
- The CRV covers all of DS and half of TS
- Without CRV, expect ~1 cosmic-ray-induced background event per day (99.99% net efficiency)



Don’t you have to worry about cosmic rays?

- The CRV covers all of DS and half of TS
- Without CRV, expect ~1 cosmic-ray-induced background event per day (99.99% net efficiency)
- The CRV consists of 4 layers of scintillator strips with wavelength shifter and aluminum absorber
-





What do you hope to see after the 3 Year Run?

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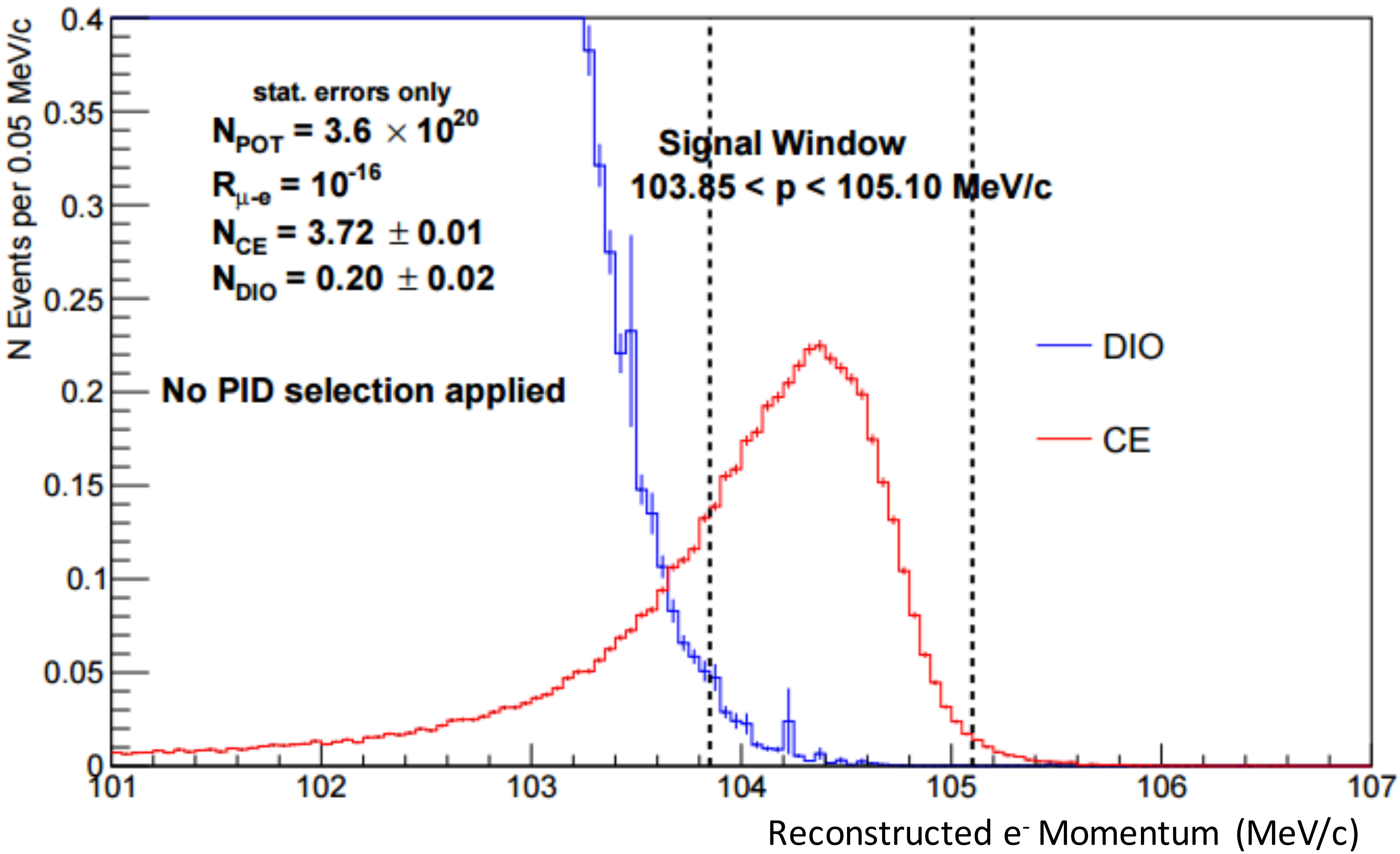

When is this all going to happen?

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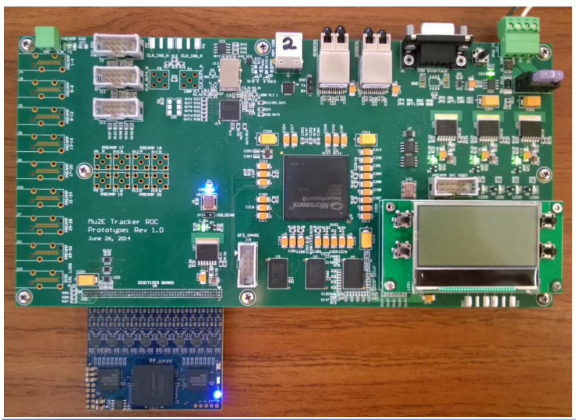
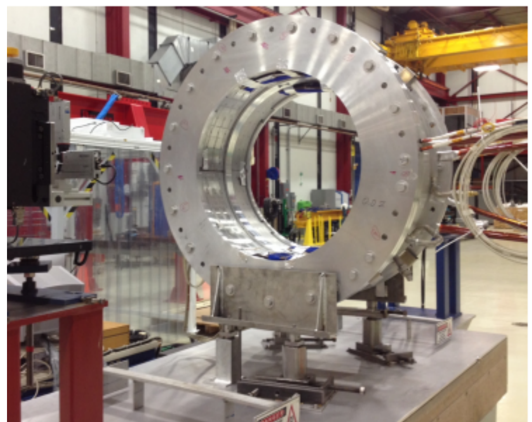
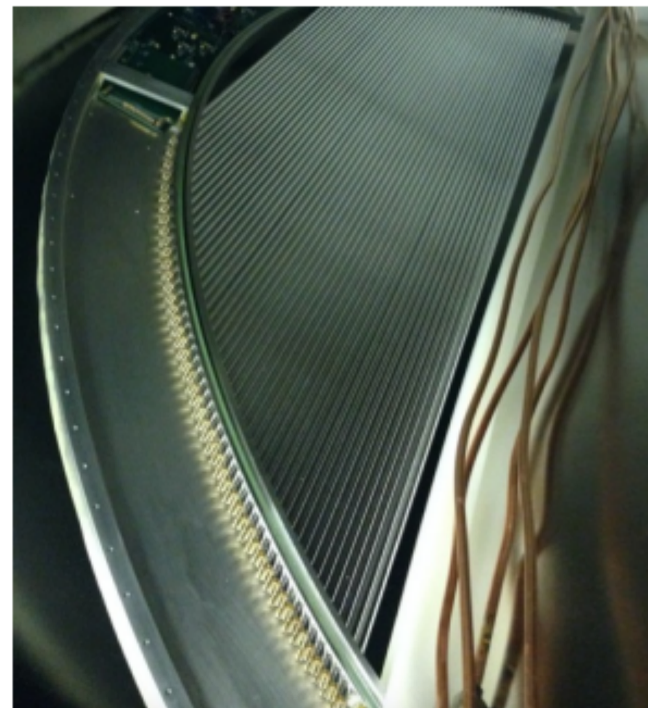
Construction is under way and our last major review is happening right now in the HR.
We expect to be taking data in 2021.







Summary

- Mu2e can lead us to better understand why there are three generations of matter.
- There is a lot of excitement about theoretical model discrimination afforded with a 4 orders of magnitude improvement on muon conversion sensitivity.
- The Mu2e project has a design which will allow for a single event sensitivity of 2.5×10^{-17}.
- Mu2e will be taking data in 2021.

Gee, you sure ask a lot of questions, lets give some else a turn.

Questions?

Thank you

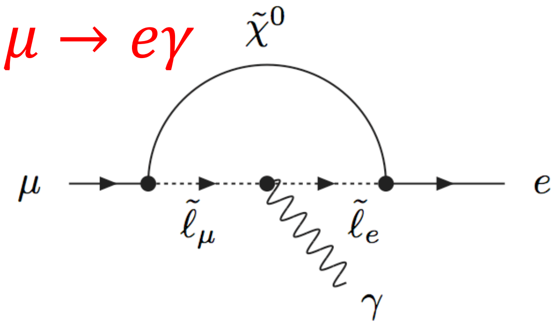
The Mu2e Collaboration

~200 scientists from 35 institutions

Argonne National Laboratory, Boston University, Brookhaven National Laboratory University of California, Berkeley, University of California, Irvine, California Institute of Technology, City University of New York, Joint Institute for Nuclear Research, Dubna, Duke University, Fermi National Accelerator Laboratory, Laboratori Nazionali di Frascati, Helmholtz-Zentrum Dresden-Rossendorf, University of Houston, University of Illinois, INFN Genova, Kansas State University, Lawrence Berkeley National Laboratory, INFN Lecce and Università del Salento, Lewis University, University of Louisville, Laboratori Nazionali di Frascati and Università Marconi Roma, University of Minnesota, Muons Inc., Northern Illinois University, Northwestern University, Novosibirsk State University/Budker Institute of Nuclear Physics, Institute for Nuclear Research, Moscow, INFN Pisa, Purdue University, Rice University, University of South Alabama, Sun Yat Sen University, University of Virginia, University of Washington, Yale University

Current Worlds best measurements

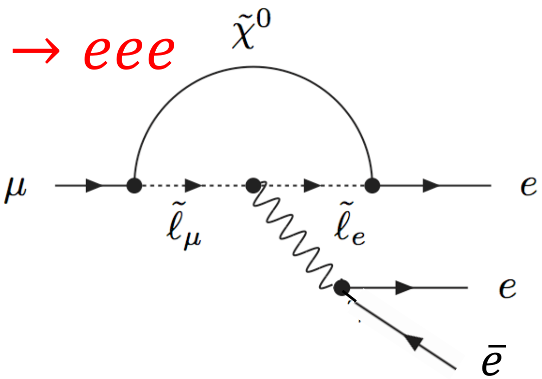
$\mu \to e\gamma$



MEG: $\mathcal{B}(\mu \to e\gamma) < 5.7\times10^{-13}$

PRL **110**, 201801 (2013)

$\mu \to eee$

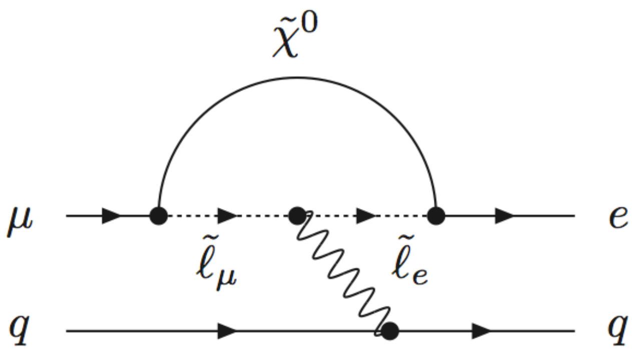


SINDRUM-I: $\mathcal{B}(\mu \to 3e) < 1\times10^{-12}$

Nucl. Phys., B **299**, 1 (1988)

$\mu N \to eN$

Muon conversion in the field of a nucleus



SINDRUM-II:

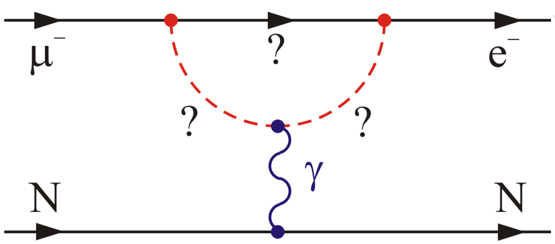
$$R_{\mu e}(\mu N \to eN \text{ on Au}) < 7 \times 10^{-13}$$

EPJ C **47**, 337 (2006)

Sensitivity to High Mass Scales

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

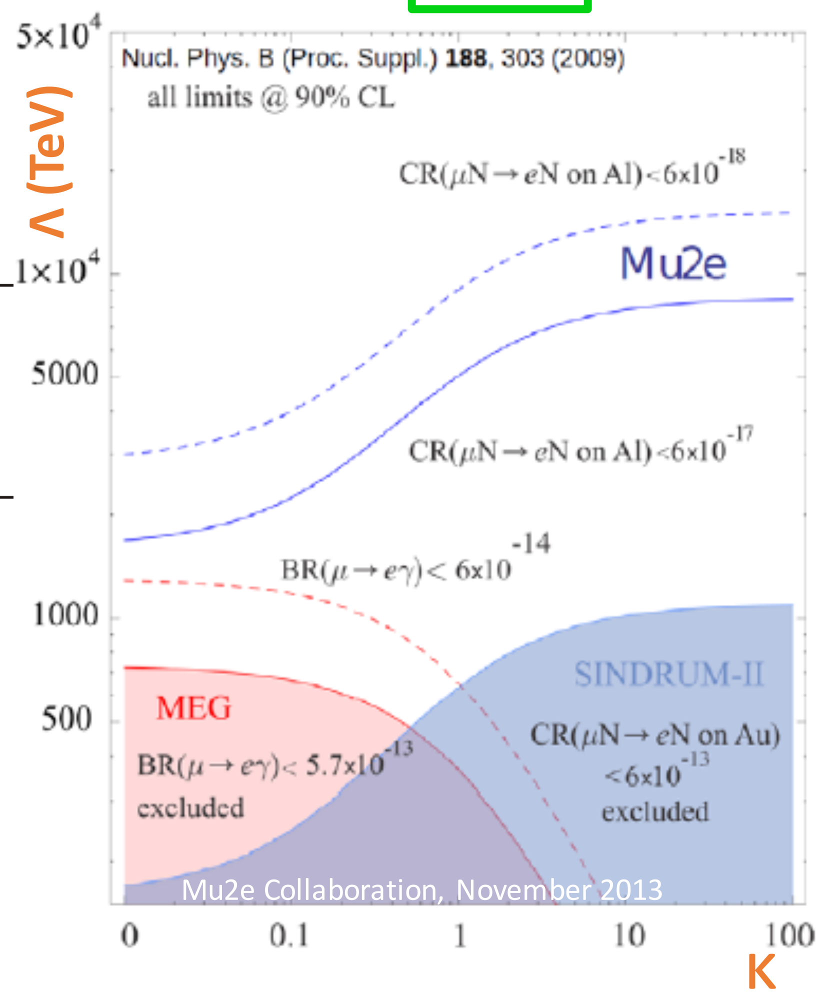
Loops dominate for κ << 1



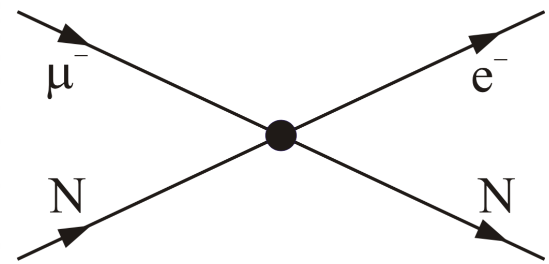
μ→eγ

μN→eN

μ→eee



Contact terms dominate for κ >> 1



μ→eγ

μN→eN

μ→eee

Mu2e backgrounds

Category	Source	Events
μ-Intrinsic	μ Decay in Orbit	0.21± 0.09
	Radiative μ Capture	<0.01
Out-of-Time	Radiative π Capture	0.023±0.006
	Beam electrons	0.003±0.001
	μ Decay in Flight	<0.003
	π Decay in Flight	<0.001
	Antiproton induced	0.047±0.024
Other	Cosmic Ray induced	0.096±0.020
	Pat. Recognition Errors	<0.01
Total Background		**0.37 ± 0.10**

*Assuming 6×10^{17} stopped muons in 6×10^{7} sec of beam time

Less than 1 background event allows us to reach desired single event sensitivity

Mu2e is High Priority for US HEP

- In the 2008 P5 report Mu2e was strongly supported:
  - "Mu2e should be pursued in all budget scenarios considered by the panel"
- In 2010 P5 reiterated their support of the 2008 plan and the priorities specified therein.
- In 2013 the Facilities Panel gave Mu2e the highest endorsement:
  - "The science of Mu2e is *Critical* to the DOE OHEP mission and is *Ready to Construct*."
- In the 2014 P5 report Mu2e is strongly supported:
  - Recommendation 14, "Complete the Muon (g-2) and Mu2e Projects."