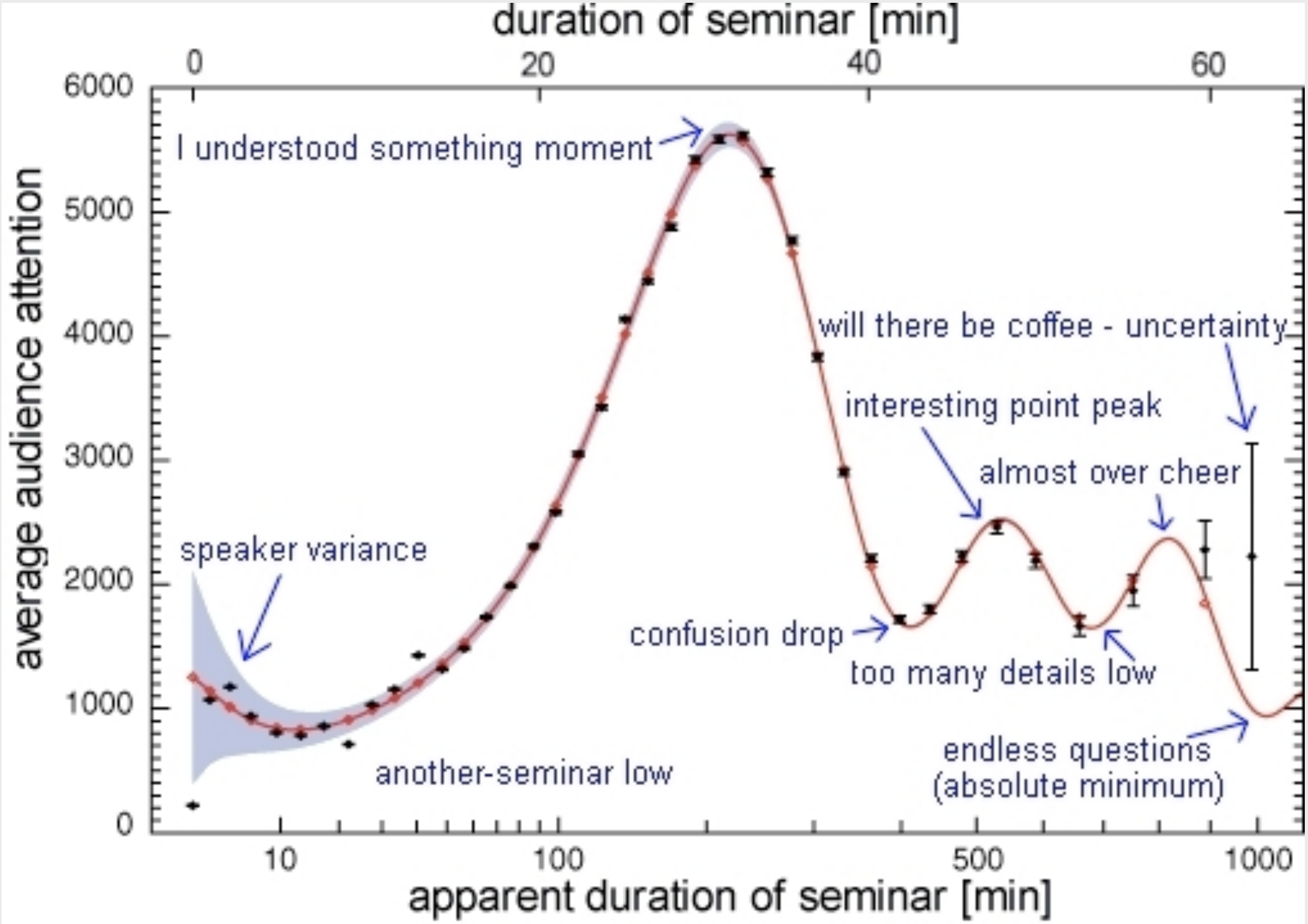
Outline



http://th.physik.uni-frankfurt.de/~hossi/Bilder/BR/powerspectrum.jpg

A New Charged Lepton Flavor Violation Experiment: Muon-Electron Conversion at FNAL

R. Bernstein
Fermilab
for the Mu2e Collaboration
5 April 2010

Collaboration

Boston University
Brookhaven National Laboratory
University of California, Berkeley
University of California, Irvine
City University of New York
Duke University
Fermilab
University of Houston
University of Illinois, Urbana-Champaign
Institute for Nuclear Research, Moscow, Russia
JINR, Dubna, Russia
Lawrence Berkeley National Laboratory
Los Alamos National Laboratory
Northwestern University
INFN Frascati
INFN Pisa, Università di Pisa, Pisa, Italy
INFN Lecce, Università del Salento, Italy
Rice University
Syracuse University
University of Virginia
College of William and Mary
University of Washington, Seattle

~120 collaborators

Outline

- The search for muon-electron conversion
- Experimental Technique
- Fermilab Accelerator
- Project X Upgrades and Mu2e
- Cost and Schedule
- Conclusions

What is μe Conversion?

muon converts to electron in the presence of a nucleus

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

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

- Charged Lepton Flavor Violation (CLFV)
  - will measure $R_{\mu e} < 6 \times 10^{-17}$ @ 90%CL
- Related Processes:

μ or $\tau \rightarrow e\gamma$, e^+e^-e, $K_L \rightarrow \mu e$, and more

Bureaucratic Status

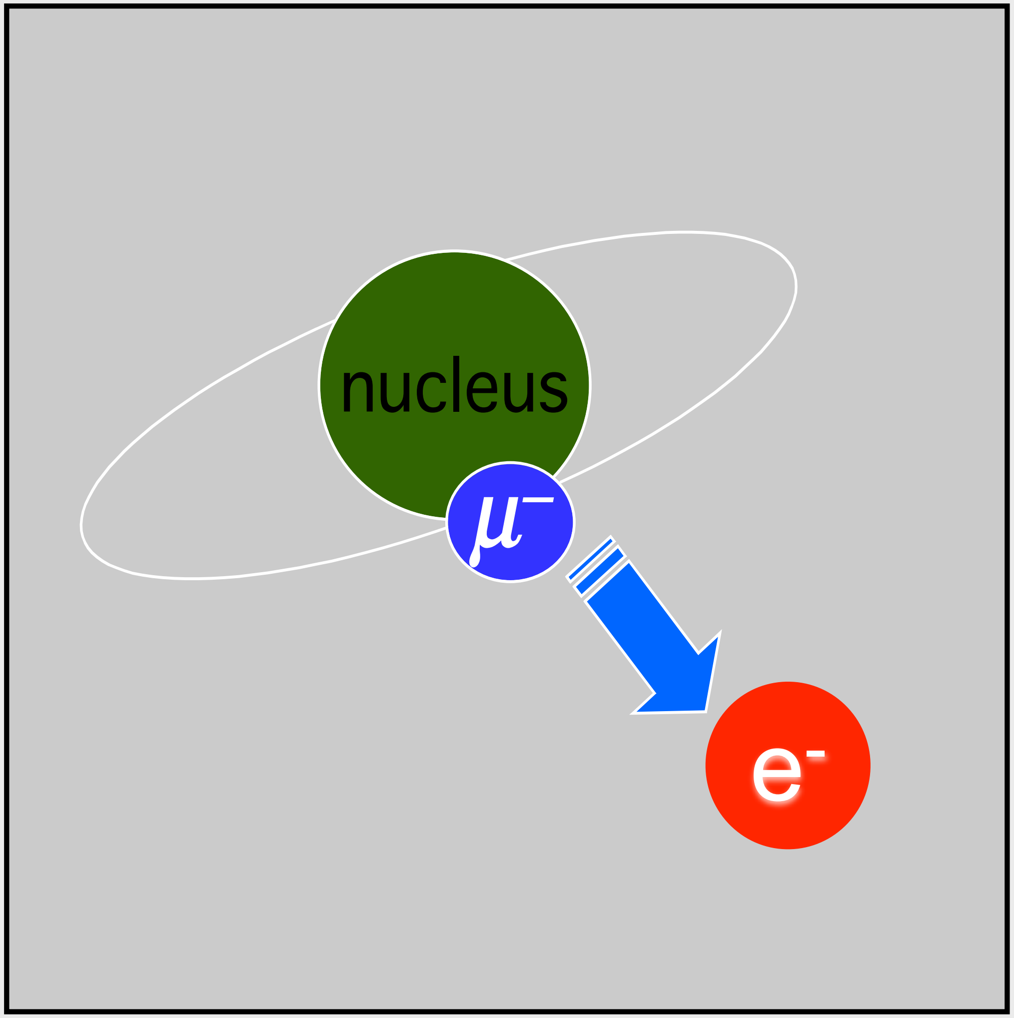
- Strong P5 endorsement:
  - **The panel recommends pursuing the muon-to-electron conversion experiment... under all budget scenarios considered by the panel**"
- Approved by Fermilab
- CD-0! (30 Nov 2009)
- CD-1 Spring/Summer 2011

CD process

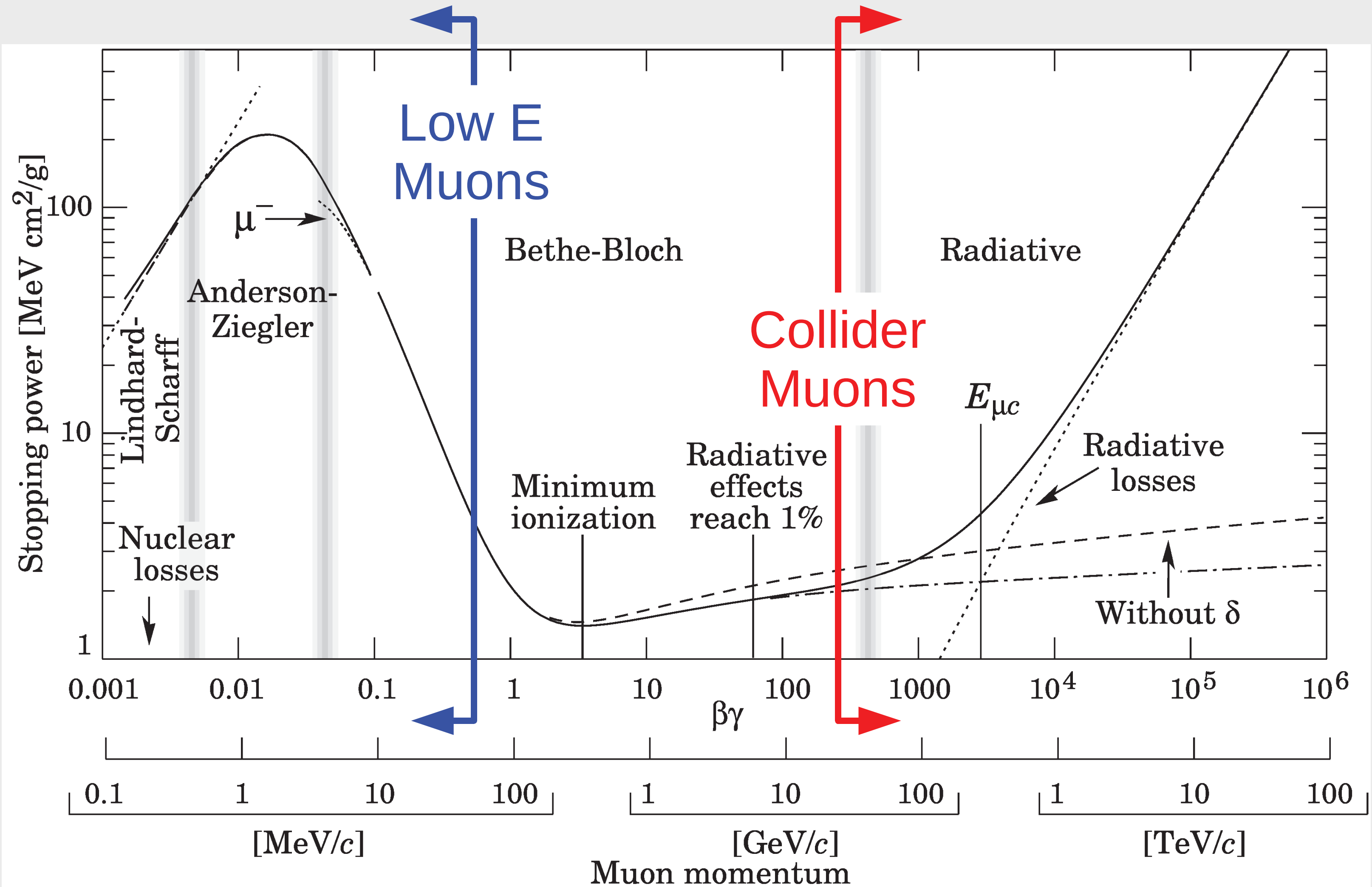
Experimental Signal

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

- A Single Monoenergetic Electron
- If N = Al, E_e = 105. MeV
    - electron energy depends on Z
- Nucleus coherently recoils off outgoing electron, no breakup



Physics is Different at these energies!



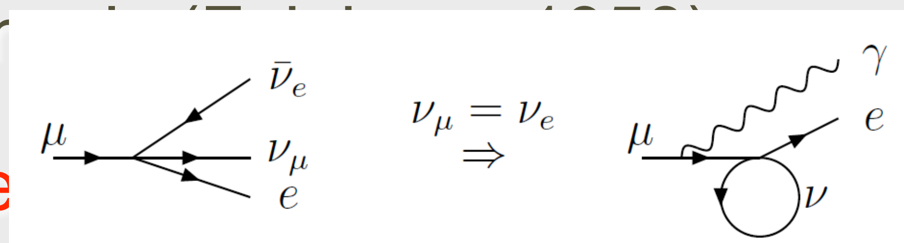
"Who ordered that?"

– I.I. Rabi, 1936

After the μ was discovered, it was logical to think the μ is just an excited electron:

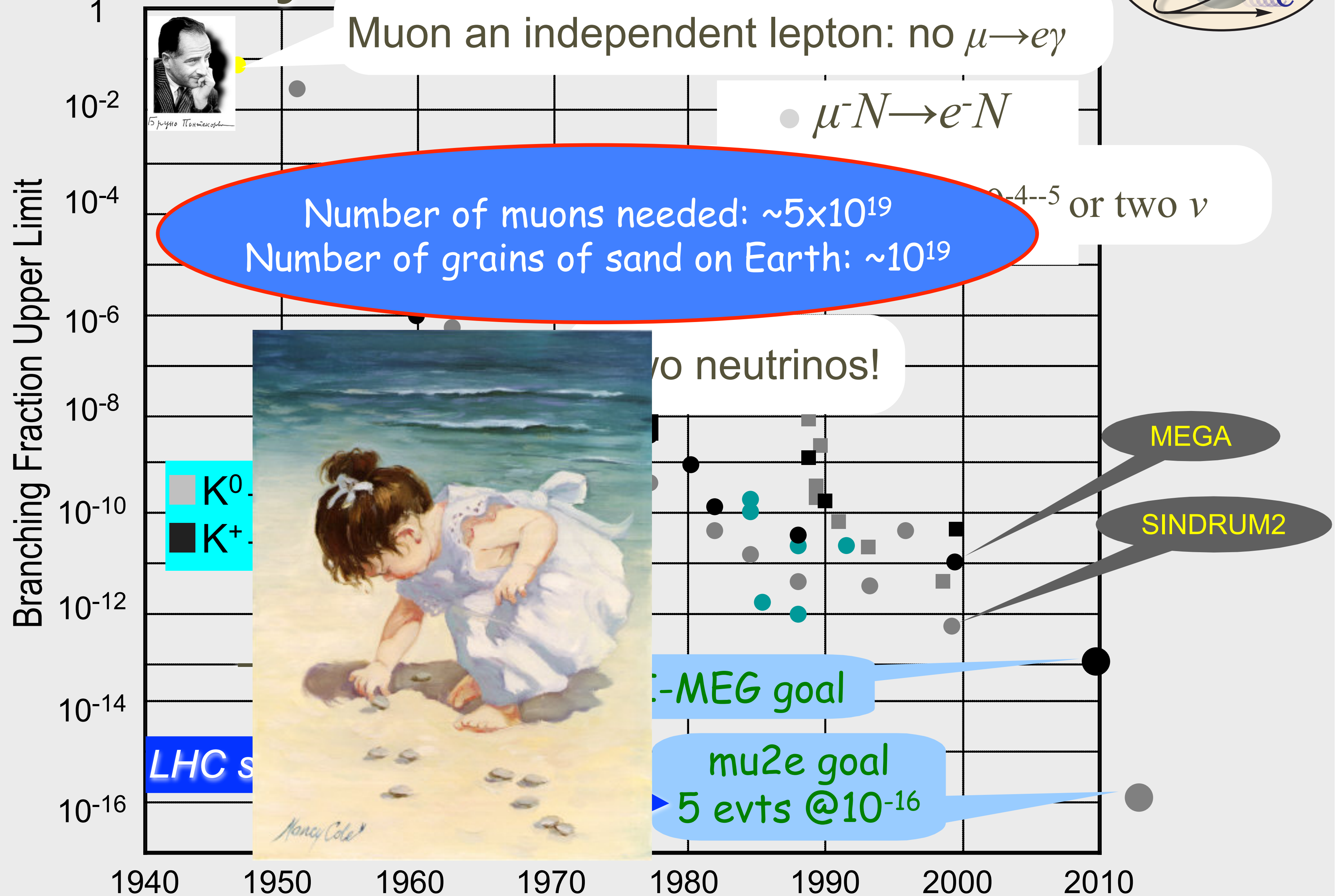
- expect BR($\mu \to e\gamma$) ≈ 10^{-4}
- Unless another ν, in Intermediate Vector Boson Loop, car

➡ same



[1]Unless we are willing to give up the 2-component neutrino theory, we know that $\mu \to e + \nu + \bar{\nu}$.

History of CLFV Searches



Where did that last estimate come from?

http://www.hawaii.edu/suremath/jsand.html

Moral: jobs at Hawaii are more fun than at Pittsburgh

Estimate the number of grains of sand on all the beaches of the earth.

The number of grains of sand will be the volume of sand divided by the the volume per grain.

$$N = \frac{Volume\_of\_sand}{Volume\_of\_grain}$$

The volume of sand is available from the product of the length of all beaches in the world, their average width and average depth.

$$Volume\_of\_sand = (length\_of\_beaches)(width)(depth)$$

We will need to estimate the parameters on the right. To get going we use the idea that the length of beaches is some percentage of the length of shores.

$$length\_of\_beaches = \frac{\%shores}{100} length\_of\_shores$$

The length of shores is related to the size of the earth. We choose to include the size in terms of the circumference.

$$length\_of\_shores = (multiple\_of\_circumference)(earth\_circumference)$$

$$N = \frac{\left(\frac{\%shores}{100}((multiple\_of\_circumference)\ earth\_circumference)\right)(width)(depth)}{Volume\_of\_grain}$$

We use rough but reasonable values for the parameters.

$\%shores = 25$

$multiple\_of\_circumference = 5$

$earth\_circumference = 40000\ km \qquad km = 1000\ m \qquad m = 1000\ mm$

$width = 30\ m$

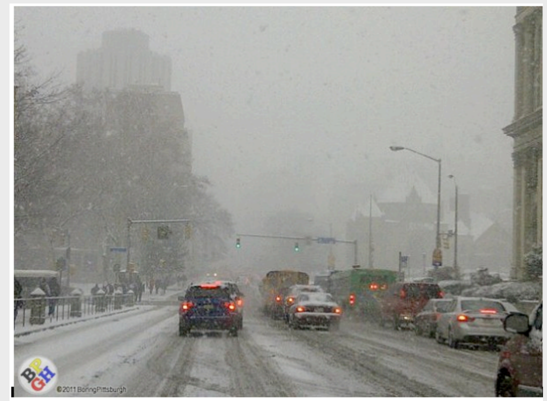
$depth = 5\ m$

$Volume\_of\_grain = 1\ mm^3$

$$N = \frac{\left(\frac{25}{100}((5)(40000(1000(1000\ mm))))\right)(30(1000\ mm))(5(1000\ mm))}{1\ mm^3}$$

$N = 7.5 \times 10^{18}$

The numbers used can readily be varied to introduce more refined estimates of the parameters.

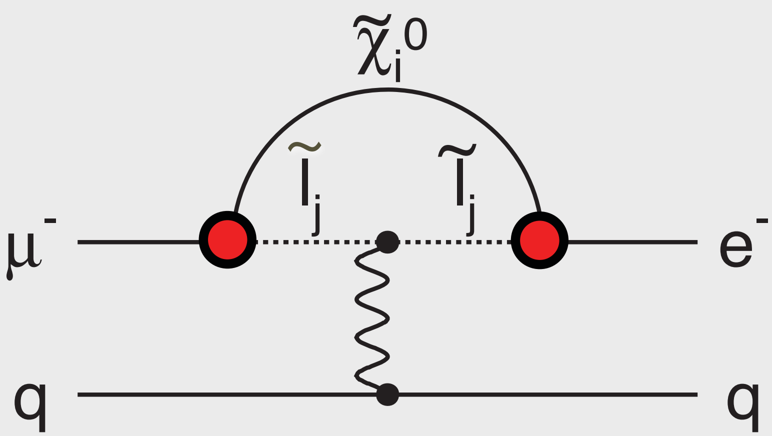


Pittsburgh Snowstorm – January 11, 2011 – Janurary 12, 2011

LFV, SUSY and the LHC

Supersymmetry

rate ~ 10^{-15}

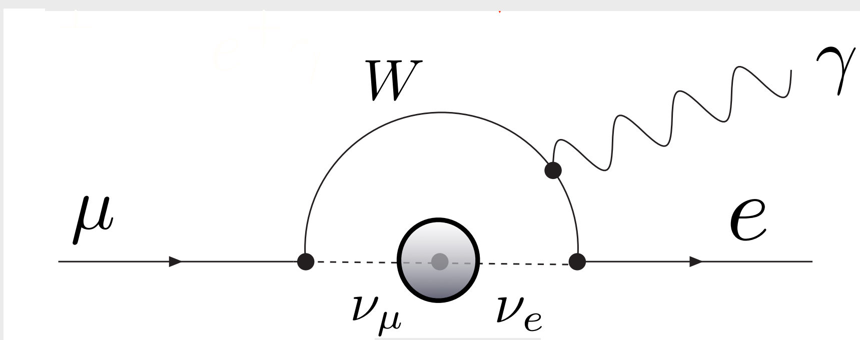


Access SUSY through loops:

signal of Terascale at LHC implies ~40 event signal / 0.4 bkg in this experiment

Neutrino Oscillations and Muon-Electron Conversion

- ν's have mass! *individual lepton numbers are not conserved*
- Therefore Lepton Flavor Violation occurs in Charged Leptons as well



NO STANDARD MODEL BACKGROUND!

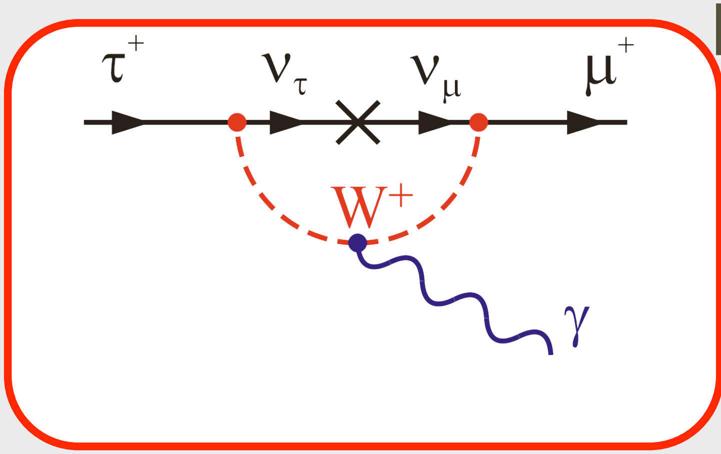
$$\mathrm{BR}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

☹

CLFV and Tau Decays

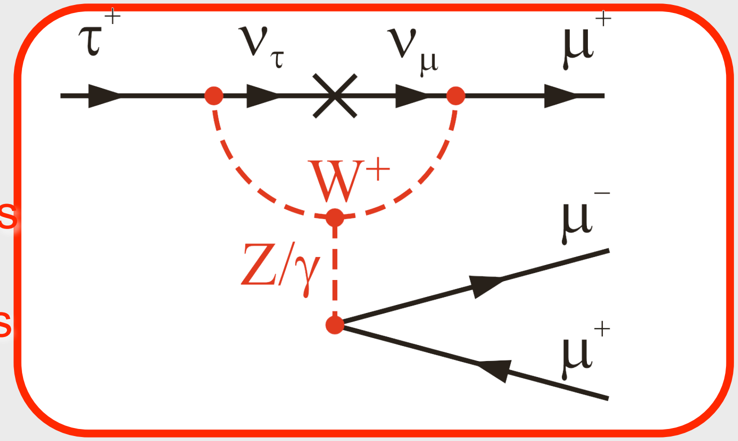
τ processes also suppressed in Standard Model but less:

Lee, Shrock
Phys.Rev.D16:1444,1977



SM ~ 10^{-40}

Smaler GIM Cancellations because of large τ mass



SM ~ 10^{-14}

Pham, hep-ph/9810484

Good News:

Beyond SM rates are several orders of magnitude larger than in associated muon decays

Bad News:

τ's hard to produce: ~10^{10} τ*/yr* vs ~10^{11} μ*/sec* in fixed-target experiments (Mu2e/COMET)

also e$\rightarrow\tau$ at electron-ion collider?

M. Gonderinger, M. Ramsey-Musolf, arXiv:1006.5063v1

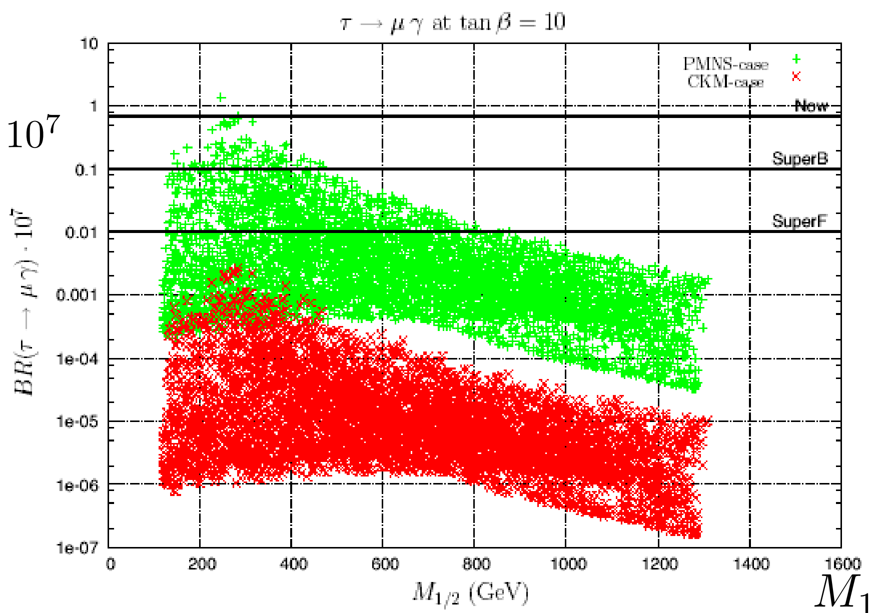
Supersymmetry in Tau LFV

L. Calibbi, A. Faccia, A. Masiero, S. Vempati hep-ph/0605139

Neutrino-Matrix Like (PMNS) Minimal Flavor Violation(CKM)

$\tan\beta = 10$

$\mathrm{BR}(\tau \to \mu\gamma) \times 10^7$



$M_{1/2}$ (GeV)

L. Calibbi, A. Faccia, A. Masiero, S. Vempati, hep-ph/0605139

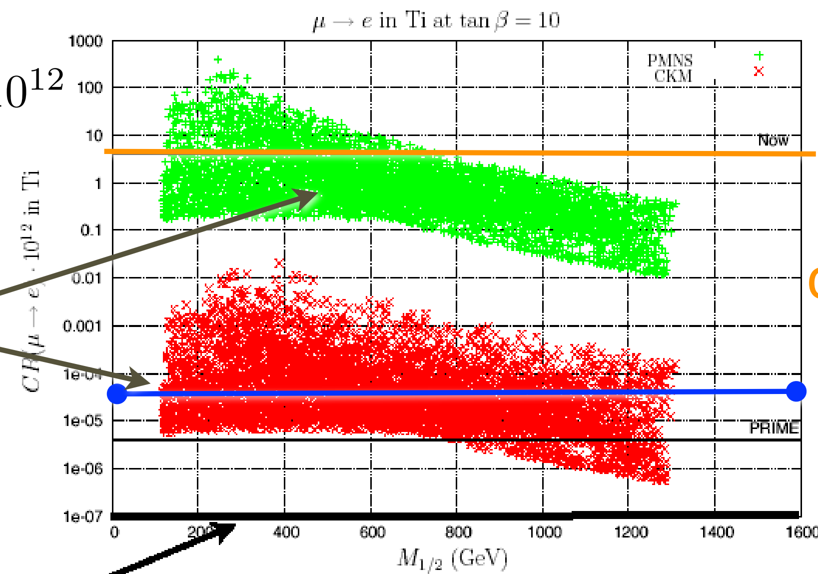
neutrino mass via the see--saw mechanism, analysis is performed in an SO(10) framework

And Muon-Electron Conversion

$\tan\beta = 10$

Neutrino-Matrix Like (PMNS)   Minimal Flavor Violation(CKM)

$\mathrm{BR}(\mu \to e) \times 10^{12}$



Current μe conversion

Mu2e

measurement can distinguish between PMNS and MFV

Project X reach

$M_{1/2}$ (GeV)

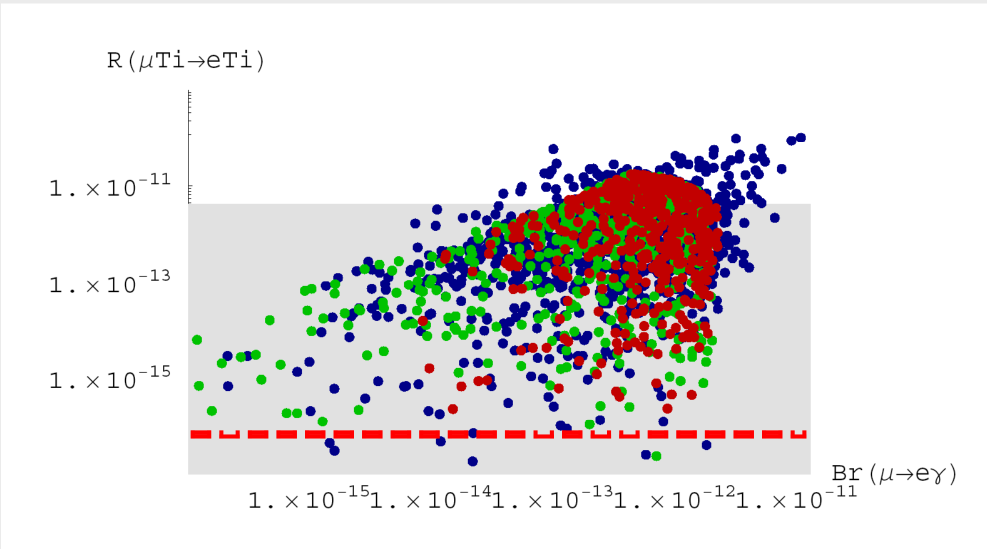
L. Calibbi, A. Faccia, A. Masiero, S. Vempati, hep-ph/0605139

complementarity between Lepton Flavor Violation (LFV) and LHC experiments

Combining μ→eγ with μ→e Conversion

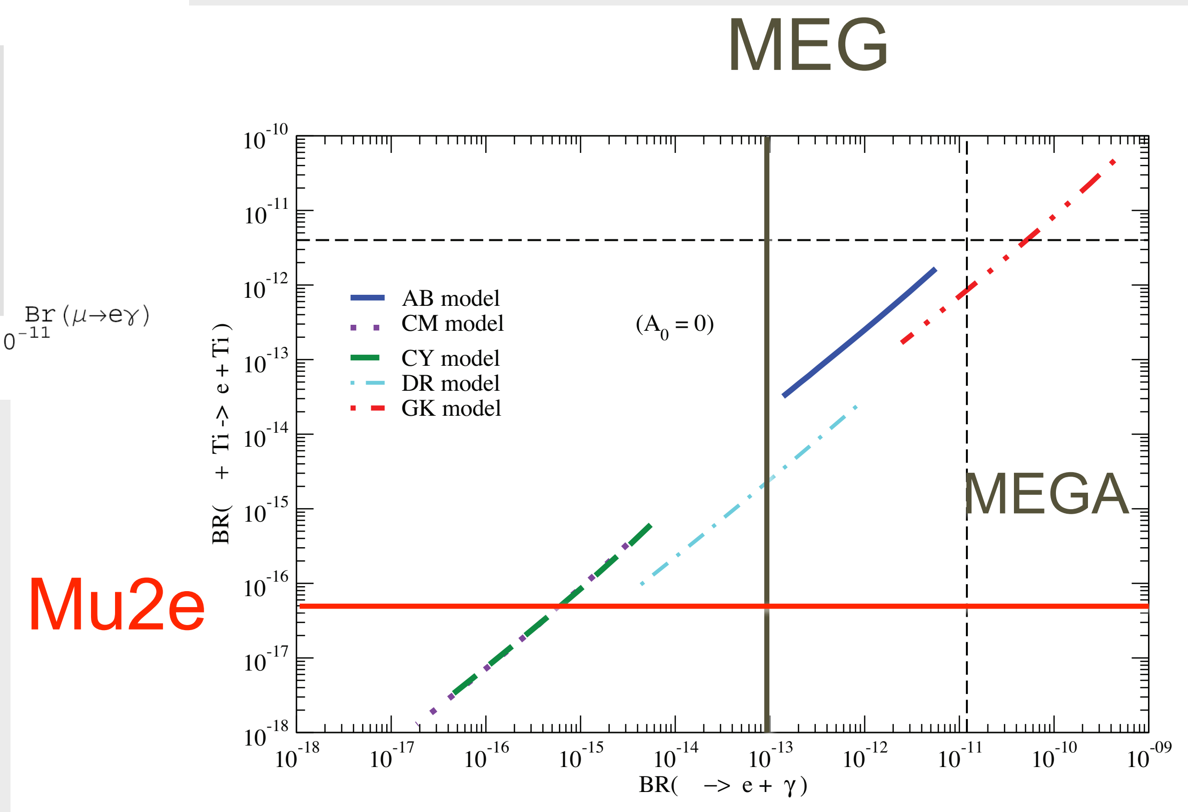
Randall-Sundrum

M. Blanke, A. J. Buras, B. Duling, A. Poschenrieder and C. Tarantino, JHEP 0705, 013 (2007).



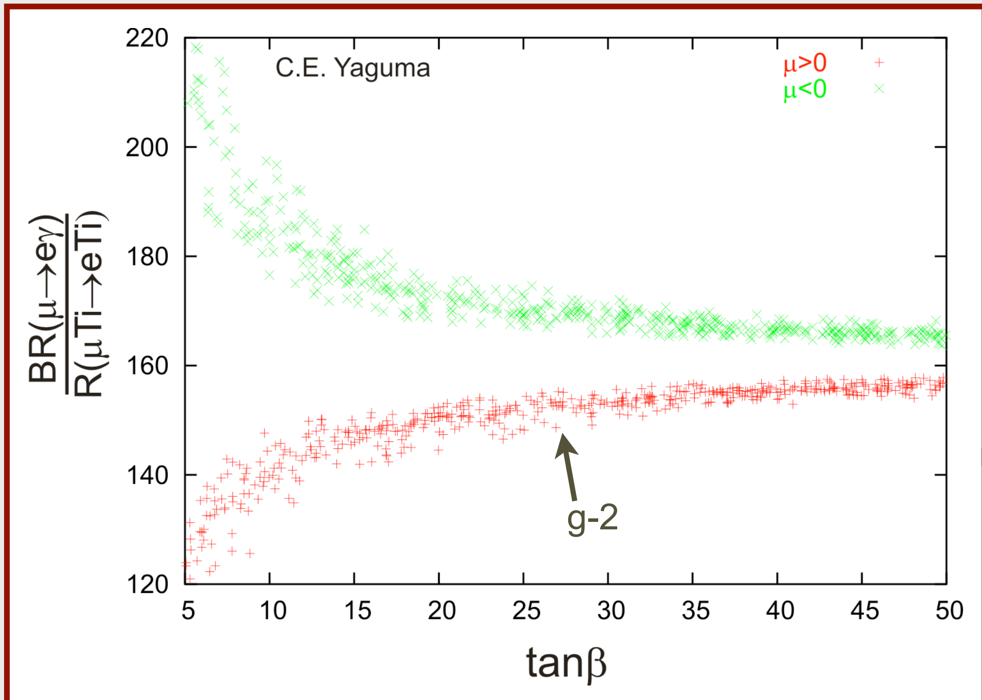
SO(10) models:

C. Albright and M. Chen, arXiv:0802.4228, PRD D77:113010, 2008.



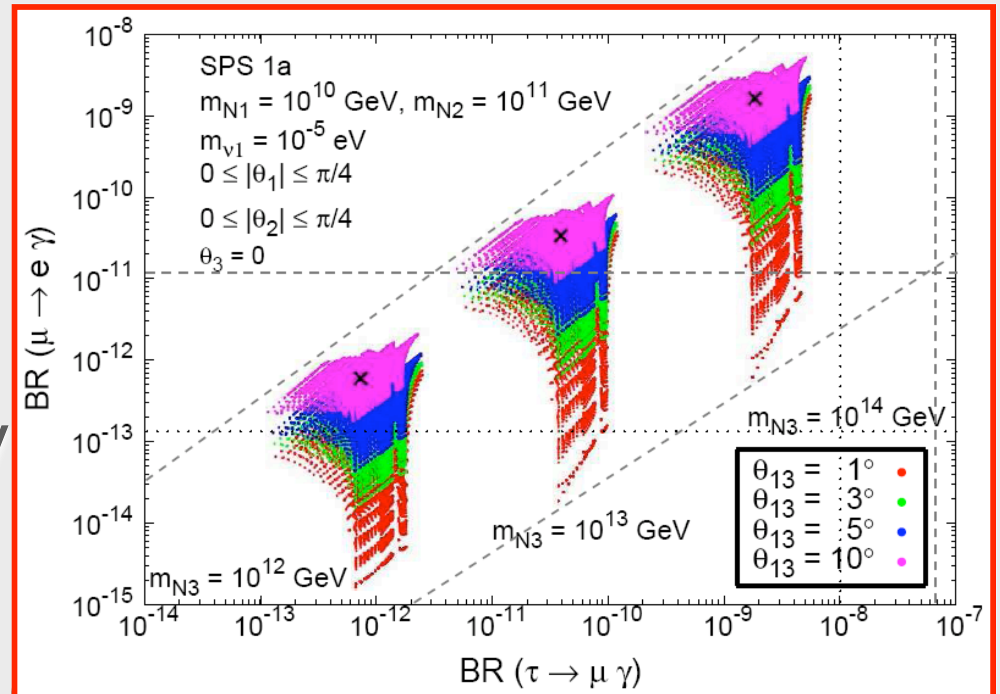
Pinning Down SuperSymmetry

MSSM w mSUGRA



Yaguna, hep-ph/0502014v2

CMSSM - seesaw



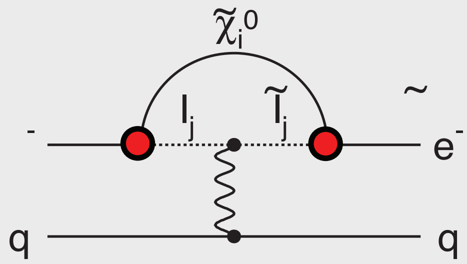
Antusch et al.,hep-ph/0610439

to allow discrimination among different models

Contributions to μe Conversion

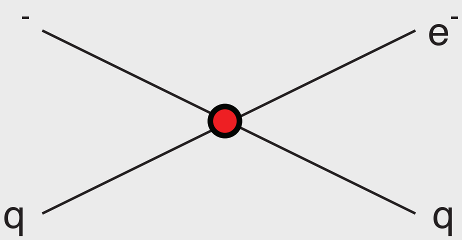
Supersymmetry

rate ~ 10^{-15}



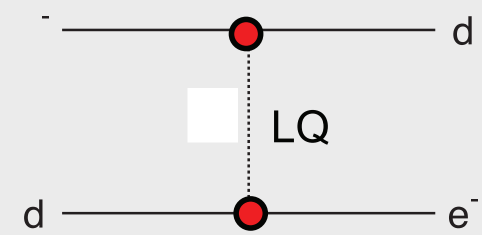
Compositeness

Λ_c ~ 3000 TeV



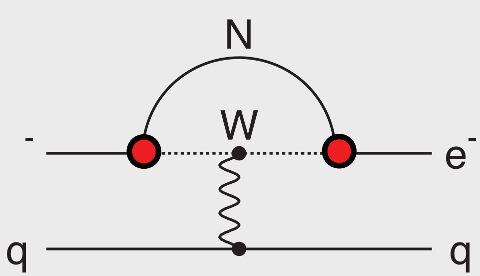
Leptoquark

$M_{LQ} = 3000\ (\lambda_{\mu d}\lambda_{ed})^{1/2}\ \mathrm{TeV}/c^2$



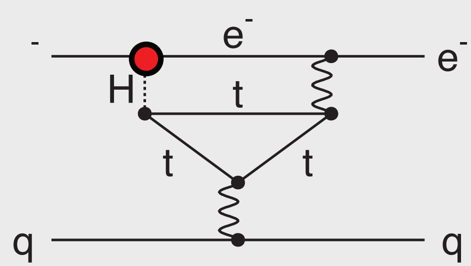
Heavy Neutrinos

$|U_{\mu N}U_{eN}|^2 \sim 8\mathrm{x}10^{-13}$



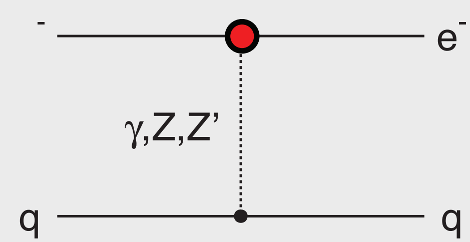
Second Higgs Doublet

$g(H_{\mu e}) \sim 10^{-4} g(H_{\mu\mu})$



Heavy Z' Anomal. Z Coupling

$M_{Z'} = 3000\ \mathrm{TeV}/c^2$



also see Flavour physics of leptons and dipole moments, arXiv:0801.1826
and Marciano, Mori, and Roney, Ann. Rev. Nucl. Sci. 58, doi:10.1146/annurev.nucl.58.110707.171126

“Model-Independent” Form

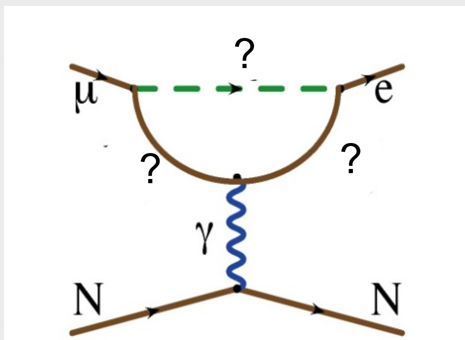
$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{u}_L\gamma_\mu u_L + \bar{d}_L\gamma_\mu d_L)$$

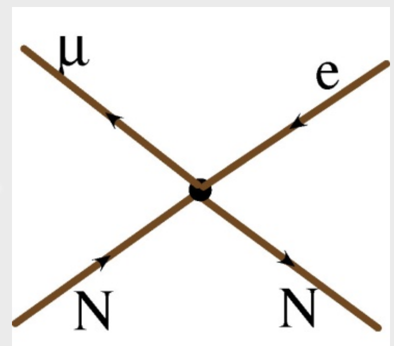
“Loops” **“Contact Terms”**

mass scale Λ

κ

$\kappa=0$





$\kappa=1$

Supersymmetry and Heavy Neutrinos

Contributes to $\mu\rightarrow e\gamma$

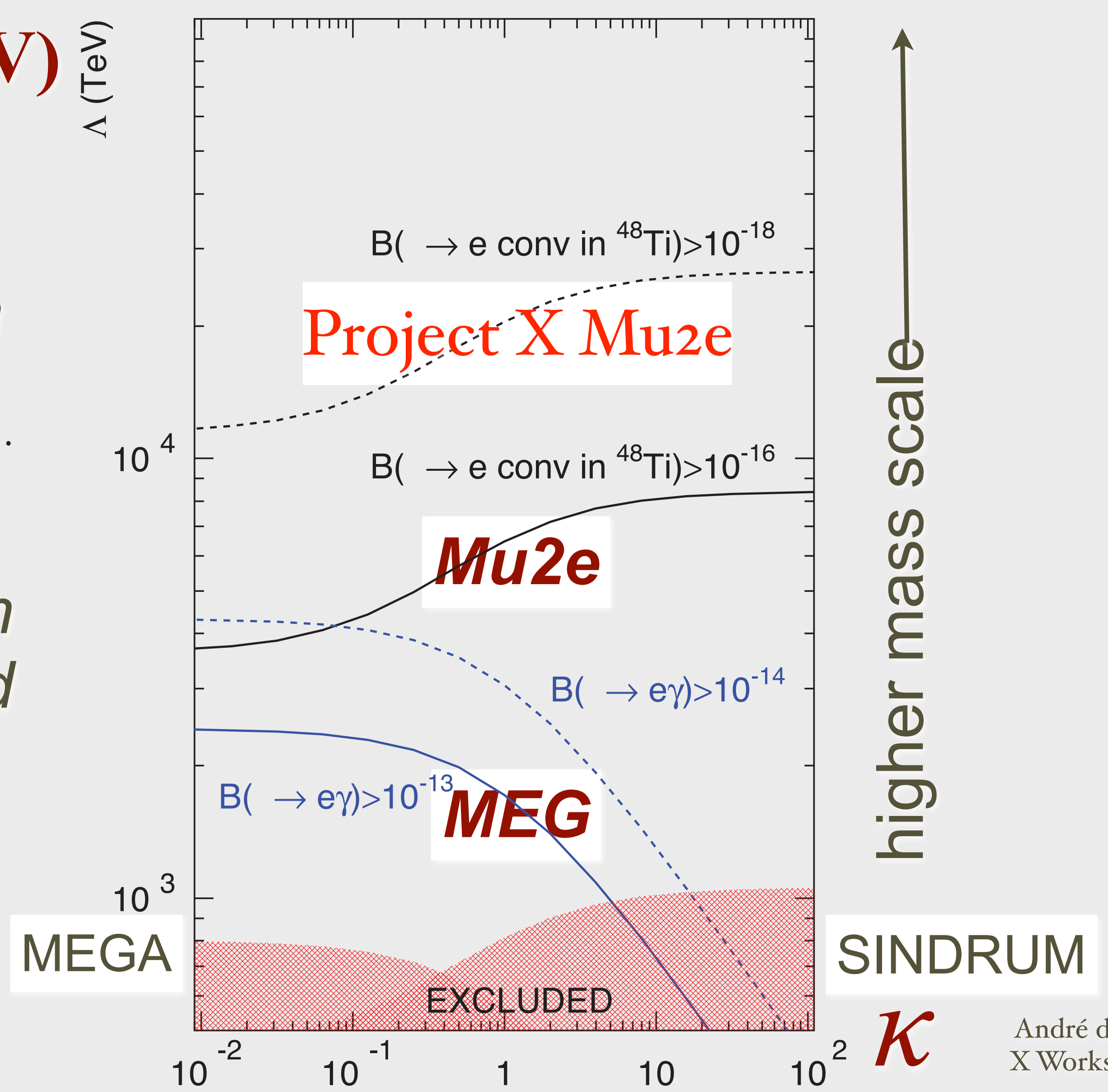
Does not produce $\mu\rightarrow e\gamma$

Quantitative Comparison?

μe Conversion and μ→eγ

1) *Mass Reach to ~10⁴ TeV*

2) *about x2 beyond MEG in loop-dominated physics*

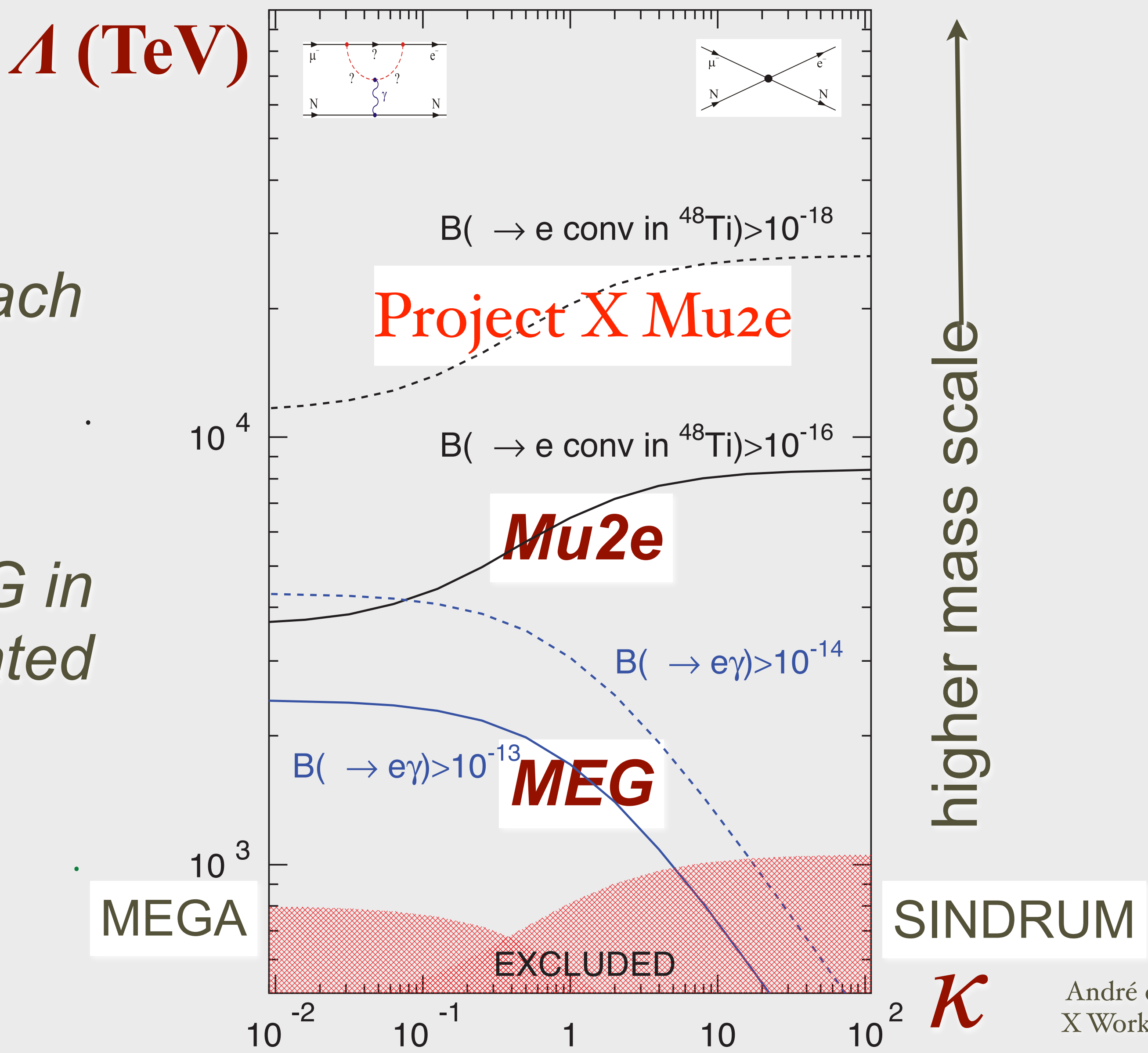


André de Gouvêa, Project X Workshop Golden Book

μe Conversion and μ→eγ

1) *Mass Reach to ~10⁴ TeV*

2) *about x2 beyond MEG in loop-dominated physics*



André de Gouvêa, Project X Workshop Golden Book

Outline

- The search for muon-electron conversion
- *Experimental Technique*
- Fermilab Accelerator
- Project X Upgrades and Mu2e
- Cost and Schedule
- Conclusions

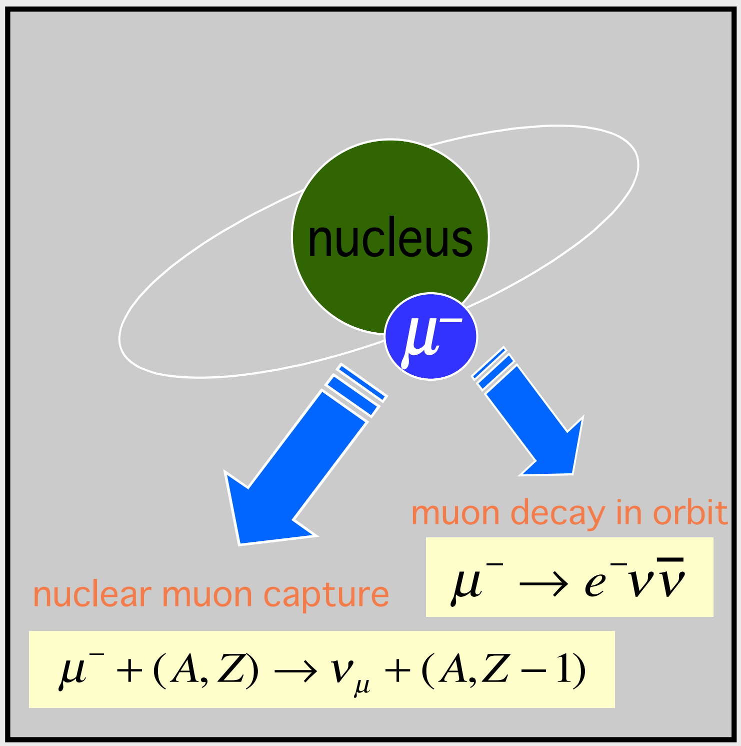
Overview Of Processes

μ^- stops in thin Al foil

the Bohr radius is ~ 20 fm,
so the μ^- sees the nucleus

μ^- in 1s state

Al Nucleus
~4 fm



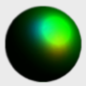
60% capture
40% decay

muon capture,
muon "falls into"
nucleus:
normalization

Decay in Orbit:
background

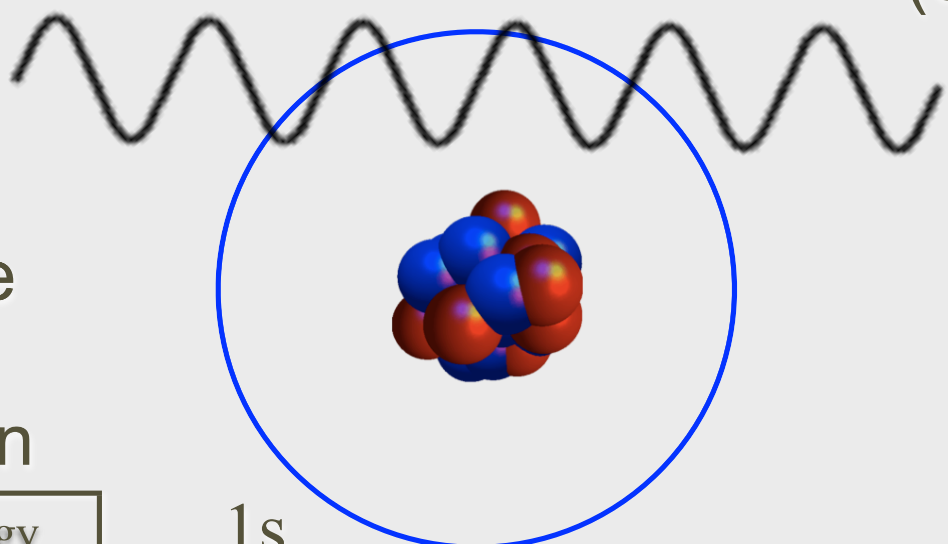
Three Possibilities: Normalization

muon stops



μ

X-Rays from cascade (occurs in psec)



1s

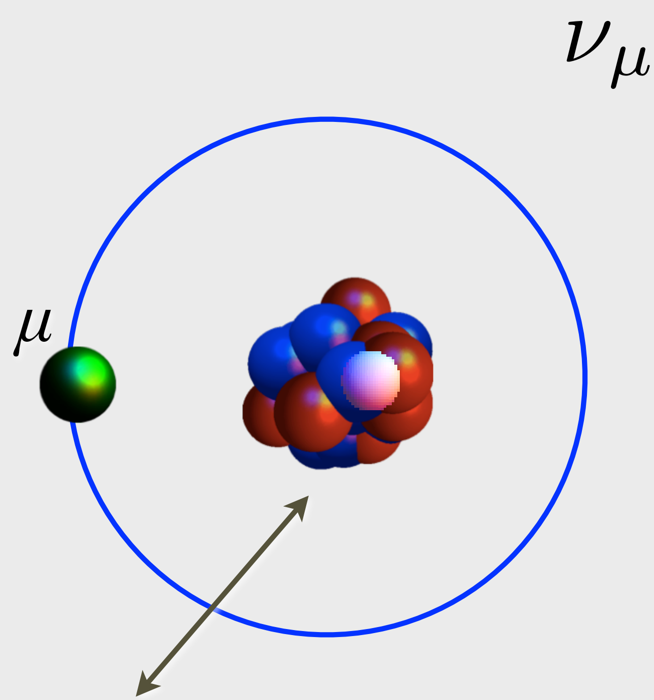
detect these for normalization

Transition	Energy
3d→ 2p	66 keV
2p→ 1s	356 keV
3d→ 1s	423 keV
4p→ 1s	446 keV

Normalization to Nuclear Capture

1) measure stop rate 2) calculate capture rate/stop

Kitano et al. ,Phys.Rev.D66:096002,2002, Erratum-ibid.D76:059902,2007. e-Print: hep-ph/0203110

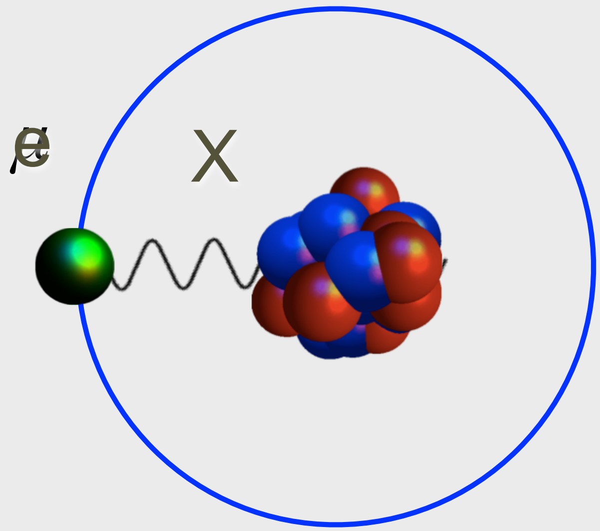


$$\mathrm{Al}(27,13) \rightarrow \mathrm{Mg}(27,12)$$

$$\text{then compute } R_{\mu e} \quad = \quad \frac{\mu N \rightarrow eN}{\mu \ \mathrm{Al}(27,13) \rightarrow \nu_\mu \ \mathrm{Mg}(27,12)}$$

Three Possibilities: Signal

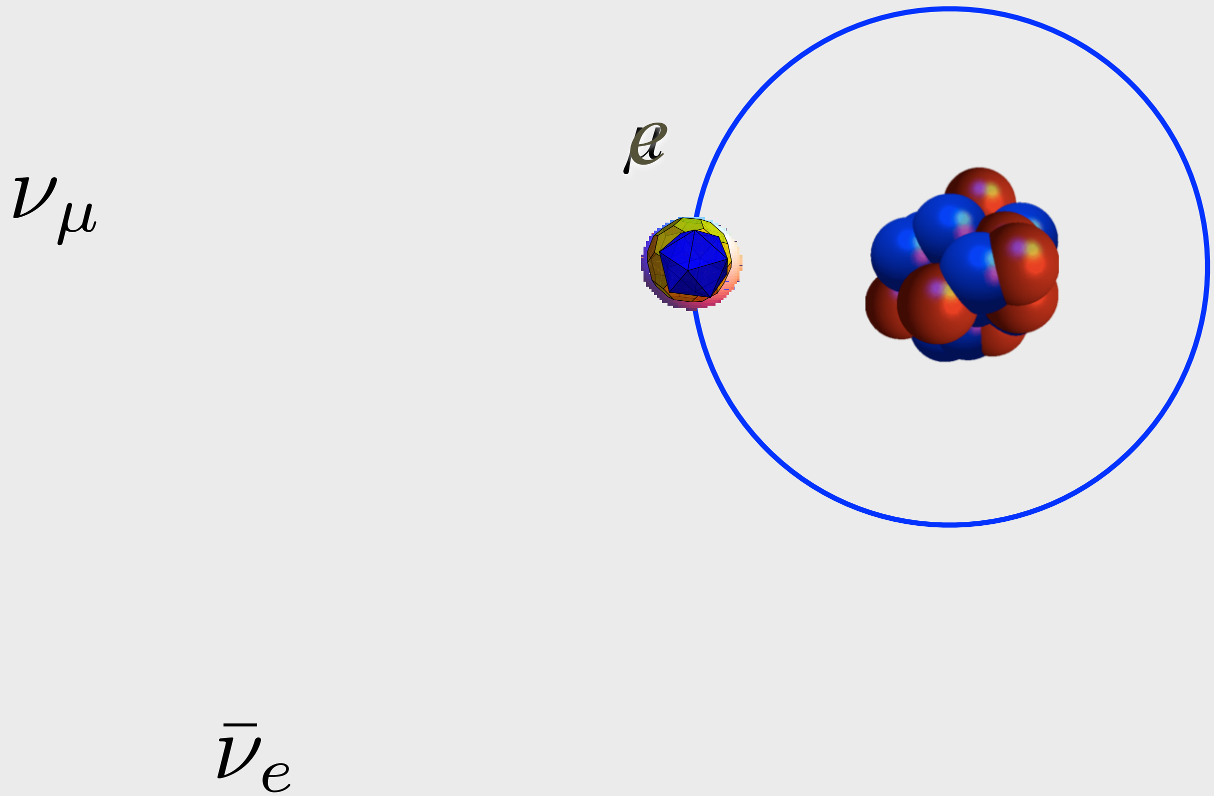
off to detector!



coherent recoil of nucleus

Three Possibilities: Background

this electron can be background; let’s see how

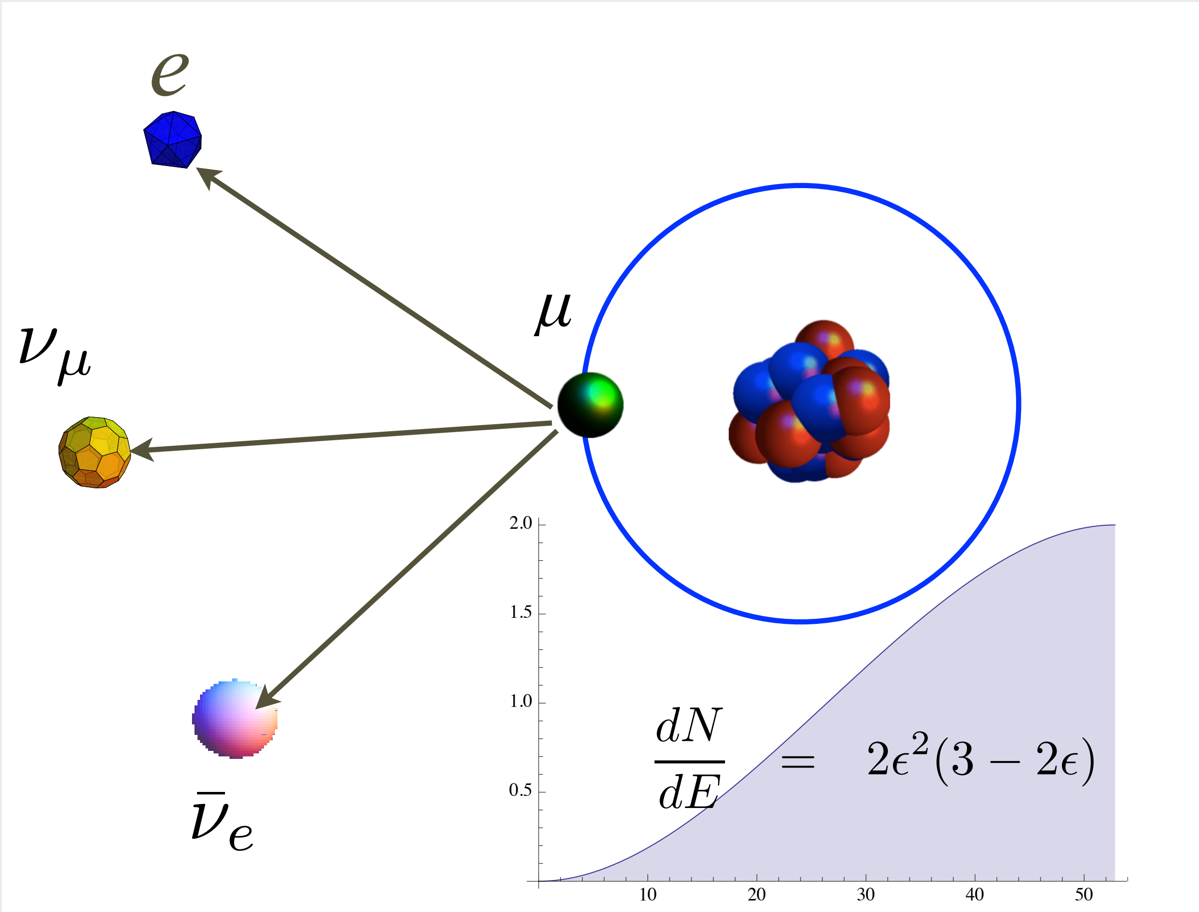


Decay-In-Orbit: Not always Background

- Peak and Endpoint of Michel Spectrum is at

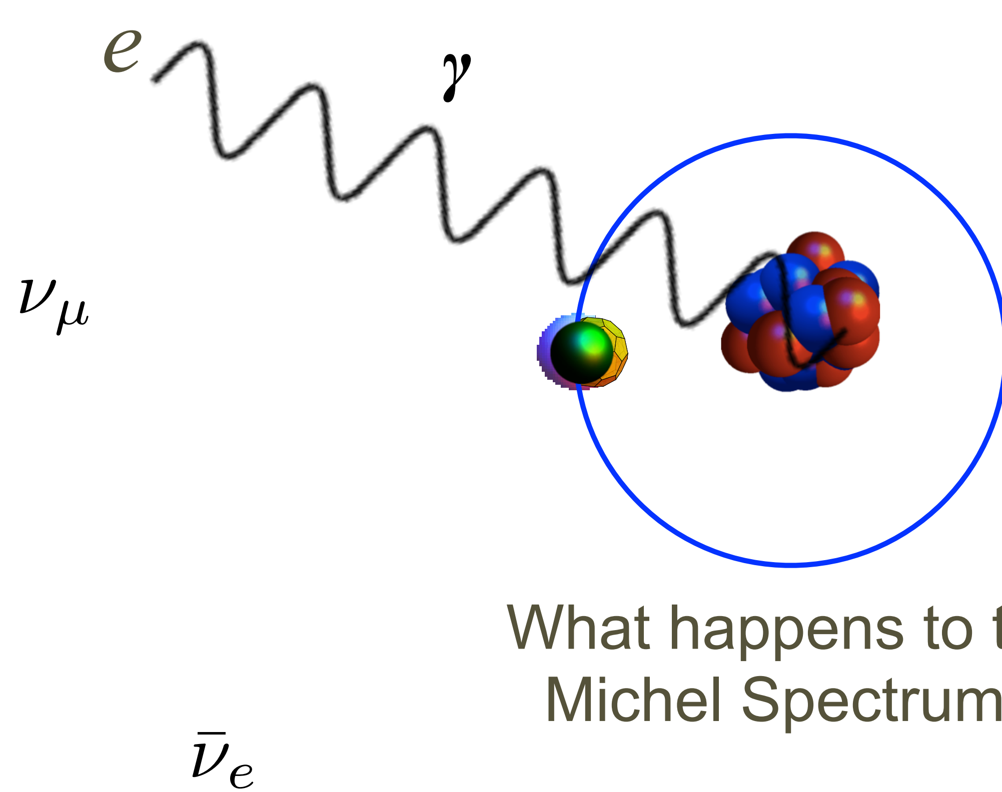
$$E_{\max} = \frac{m_\mu^2 + m_e^2}{2m_\mu} \approx 52.8 \text{ MeV}$$

- Detector will be insensitive to electrons at this energy
- Recall *signal* at 105 MeV>>52.8 MeV



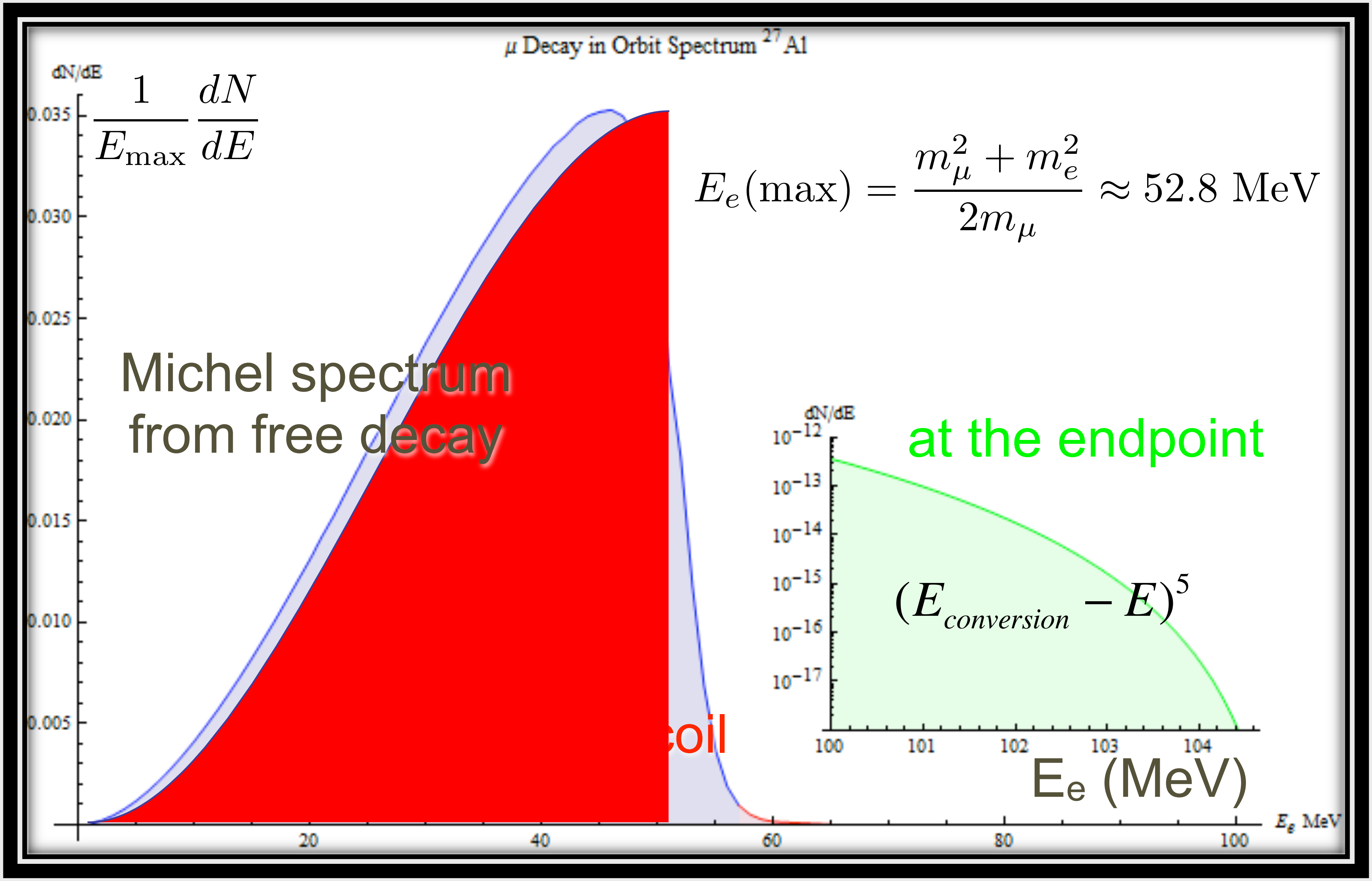
Decay-In-Orbit Background

- Same process as before
- But this time, include electron recoil off nucleus
- If neutrinos are at rest, the DIO electron can be exactly at conversion energy (up to neutrino mass)



What happens to the Michel Spectrum?

Decay-in-Orbit Shape



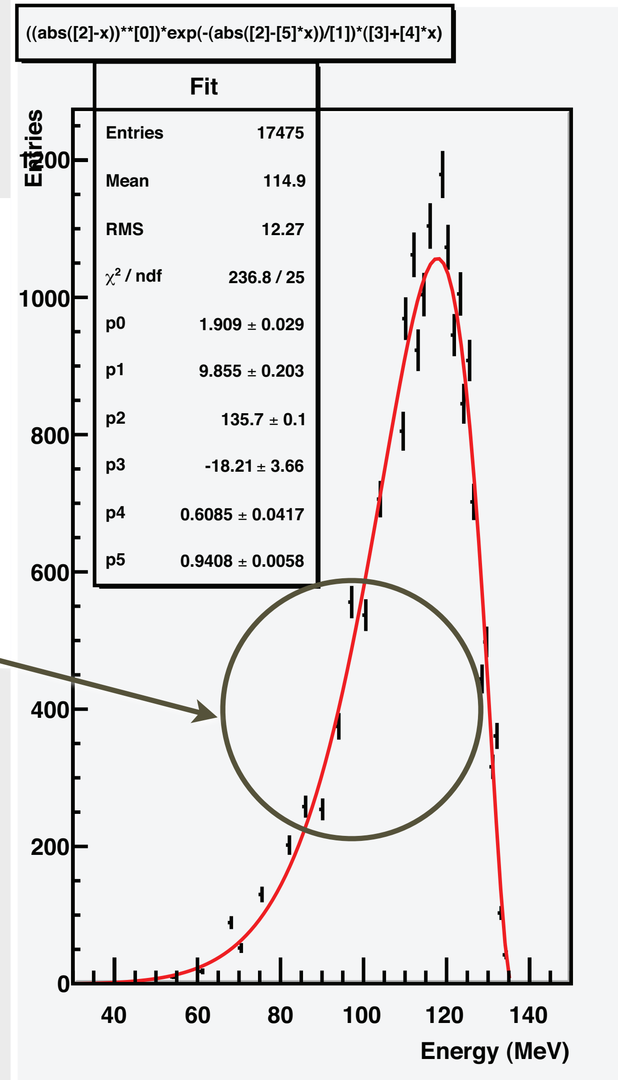
DIO Background Calculation

- Two Ingredients: Shape and Normalization
  - Very hard to calculate 10^{-17} portion of the spectrum; Marciano, Czarnecki are doing this
- Real DIO background is from these near-to-endpoint events combining with spurious or extra hits from other events to form catastrophically mis-reconstructed signal events
  - one advantage of FNAL over BNL is x 3 lower instantaneous rate, lowering this background

Prompt Backgrounds

Particles produced by proton pulse which interact almost immediately when they enter the detector: π, neutrons, pbars

- **Radiative pion capture**, π-+A(N,Z) $\rightarrow \gamma$ +X.
  - γ up to m$_\pi$, peak at 110 MeV; $\gamma \rightarrow$ e+e- ; if one electron ~ 100 MeV in the target, looks like signal: ***limitation in best existing experiment, SINDRUM II?***



energy spectrum of γ measured on Mg
J.A. Bistirlich, K.M. Crowe et al., Phys Rev C5, 1867 (1972)

also included internal conversion, $\pi^- N \rightarrow e^+ e^- X$

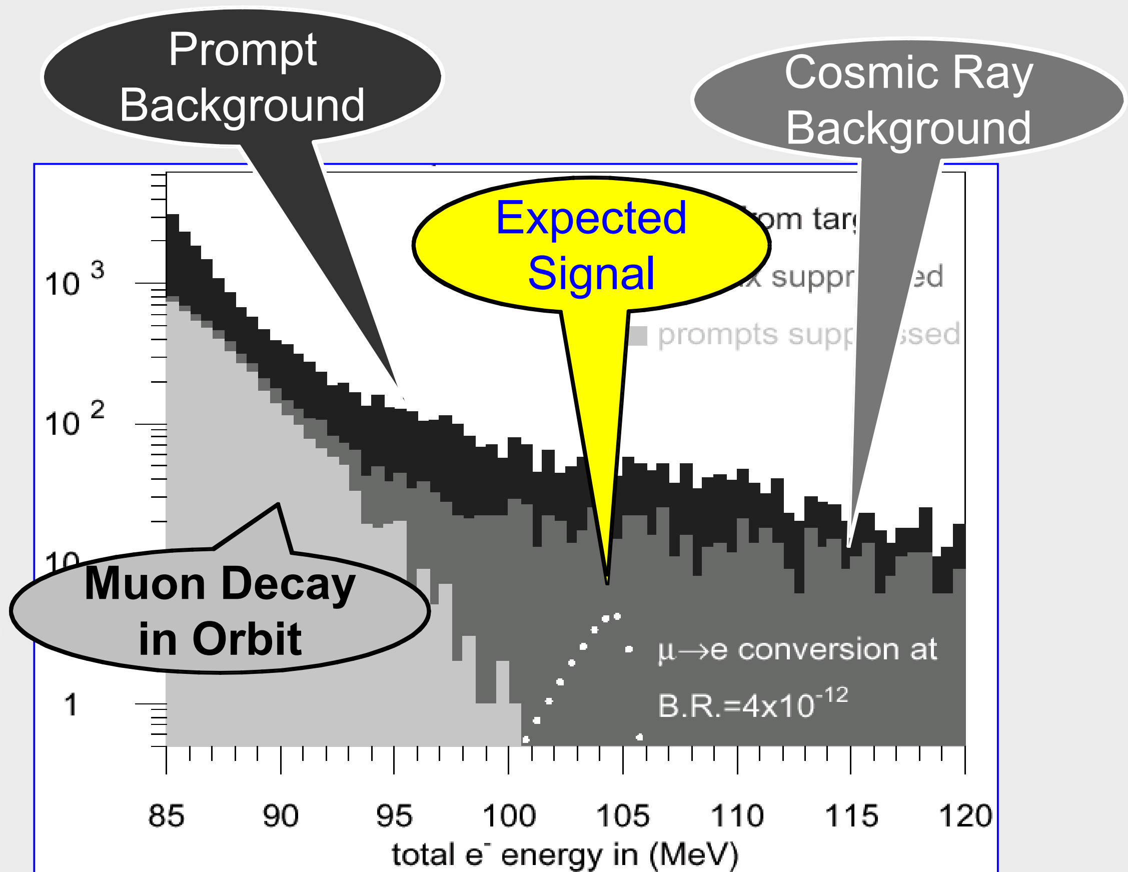
Review: Two Classes of Backgrounds

	Decay-In-Orbit	Prompt
Source	Intrinsic Physics Background	Radiative π Capture: Mostly π's produced in production target
Solution	Spectrometer Design: resolution and pattern recognition	Design of Muon Beam, formation, transport, and time structure

Previous Best Experiment

SINDRUM-II

- $R_{\mu e} < 6.1 \times 10^{-13}$ in Au
- Want to probe to 6×10^{-17}
- $\approx 10^4$ improvement



Experimental signature is 105 MeV e⁻ originating in a thin Ti stopping target

SINDRUM-II Results

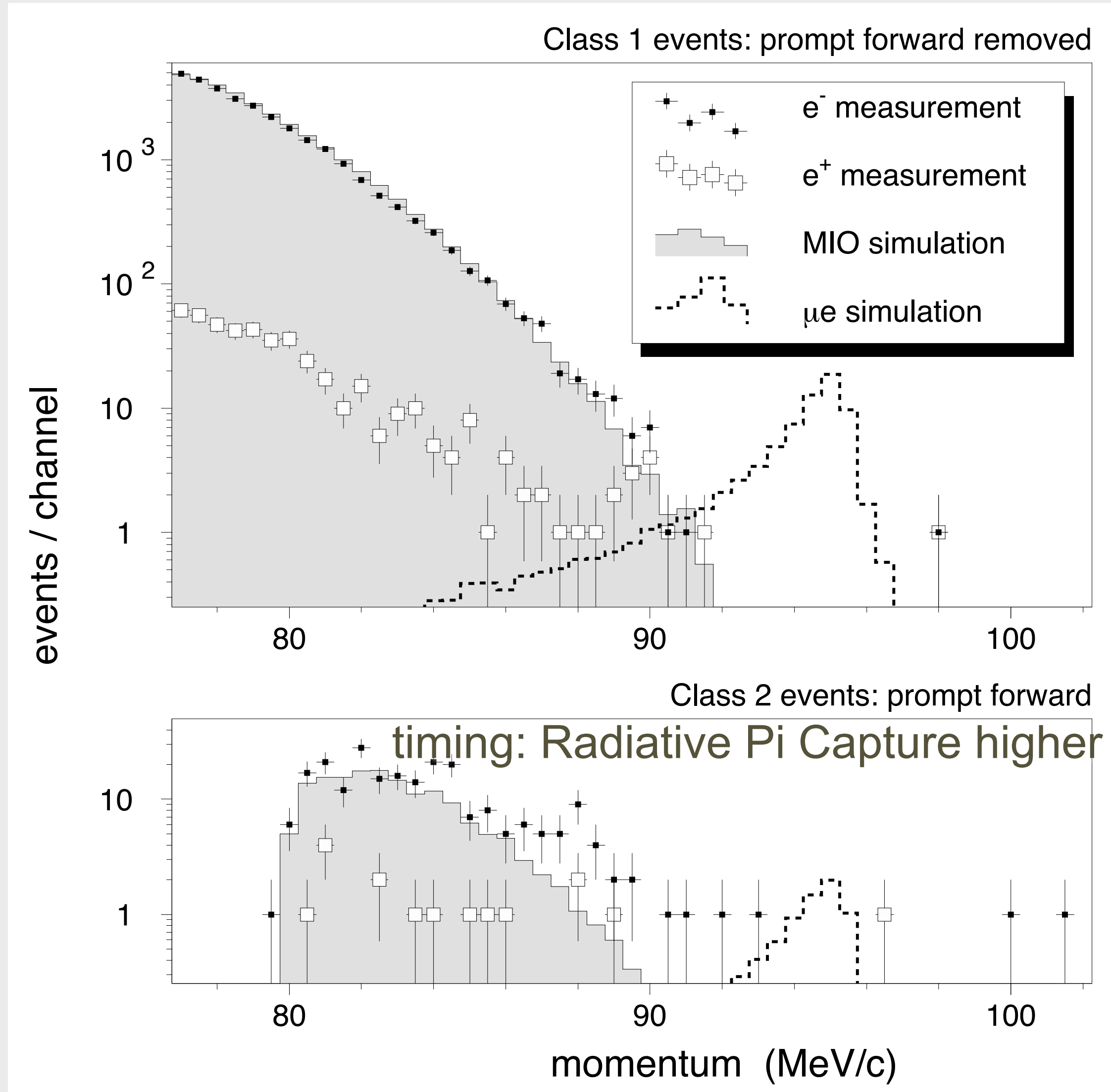
W. Bertl et al., Eur. Phys. J. C 47, 337–346 (2006)

- Final Results on Au:

$$B_{\mu e}^{\mathrm{Au}} \quad < \quad 7 \times 10^{-13} \text{ @ } 90\% \text{ CL}$$

51 MHz (20 nsec) repetition rate, width of pulse ~0.3 nsec

little time separation between signal and prompt background



How Can We Do Better?

>10^3 increase in muon intensity from SINDRUM

Requiring

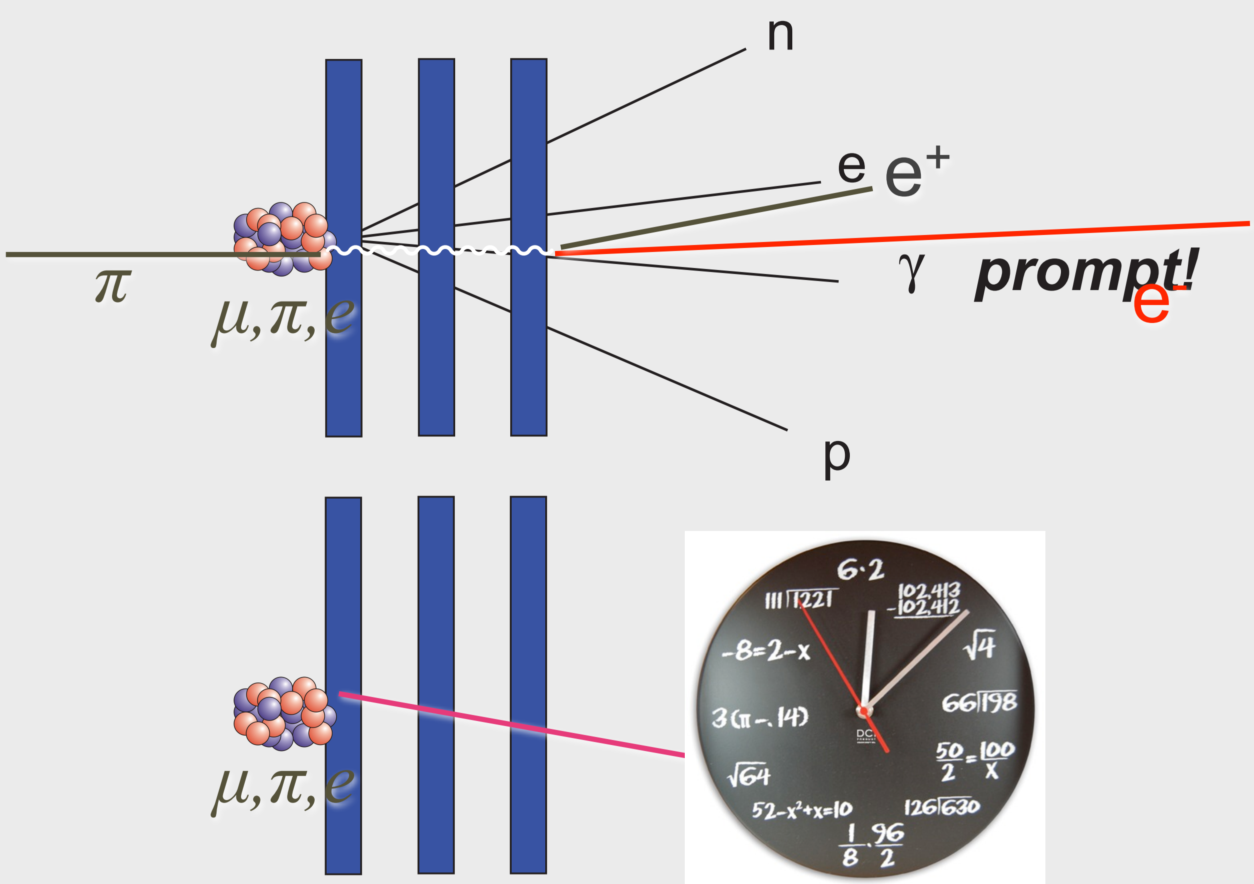
Pulsed Beam to Eliminate prompt backgrounds like radiative π capture and CR

protons out of beam pulse/ protons in beam-pulse < 10^{-10}
and we must measure it

Advantage of Pulsed Beam

target foils: muon converts here

= muons, electrons, pions



delayed 105 MeV electron

pulsed beam lets us wait until after prompt backgrounds disappear and rate lowered

RPC:

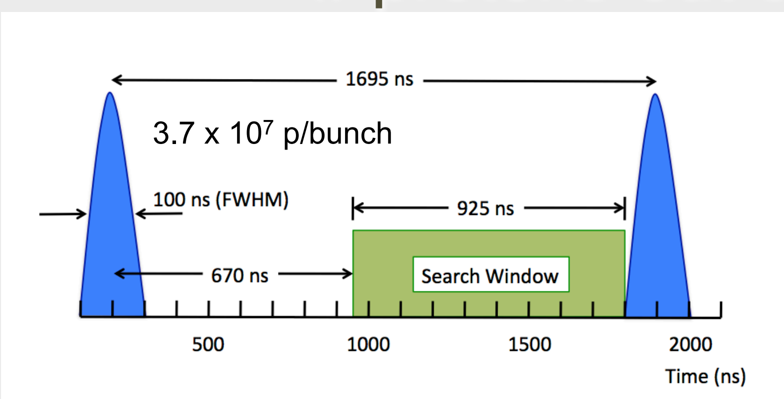
$\pi N \rightarrow \gamma N$

$\gamma \rightarrow e^+ e^-$ *in foils*

Pulsed Beam Structure

- Tied to prompt rate and machine: FNAL "perfect"
- Want pulse duration << $\tau_{\mu}^{\rm Al}$, pulse separation ≈ $\tau_{\mu}^{\rm Al}$
  - FNAL Debuncher has circumference 1.7μsec , ~x2 $\tau_{\mu}^{\rm Al}$
- Extinction between pulses < 10^{-10} needed

  = # protons out of pulse/# protons in pulse

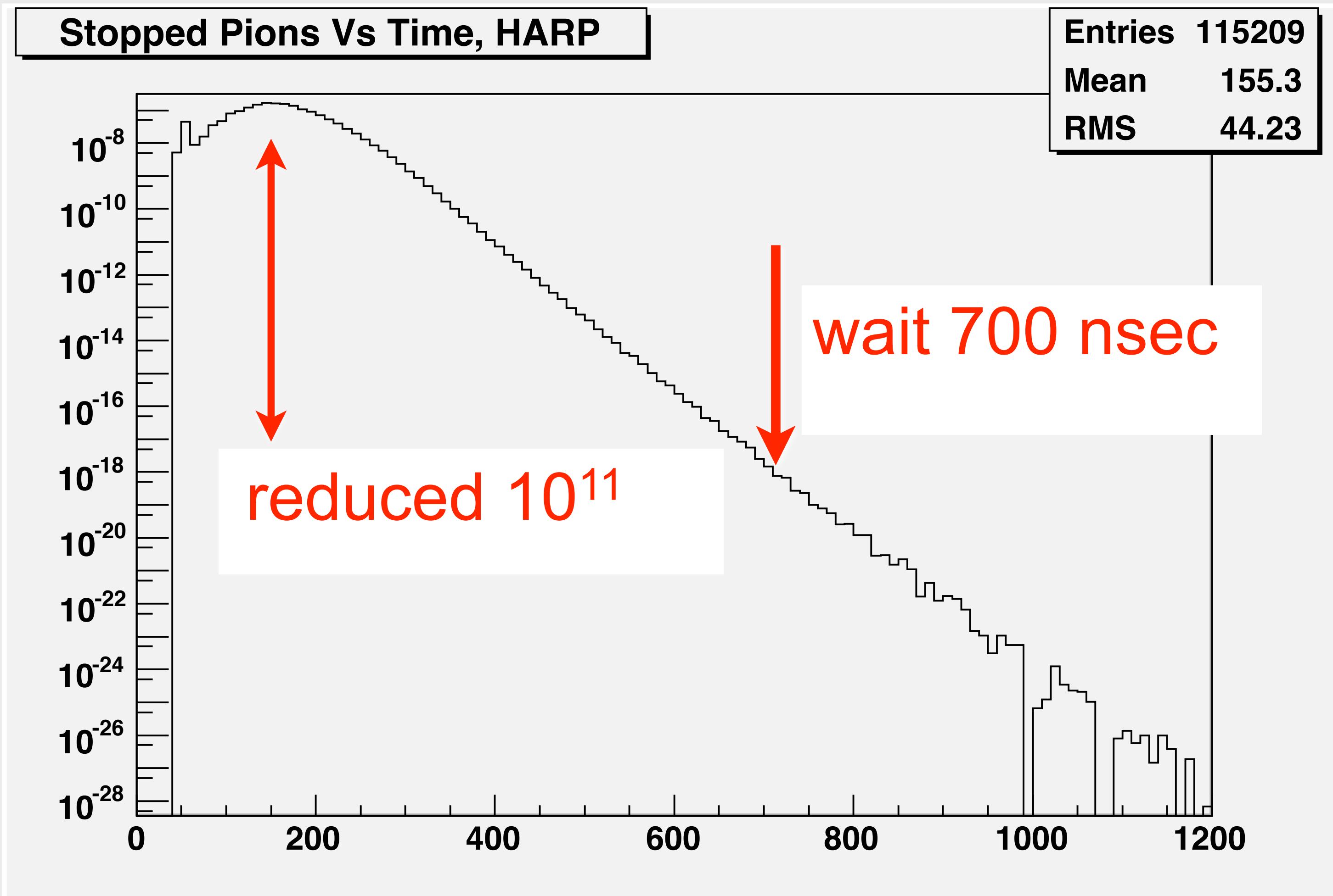


- 10^{-10} based on simulation of prompt backgrounds and beamline

Extinction ~ 10^{-10}

Pulsed Beam Structure and Radiative π Capture

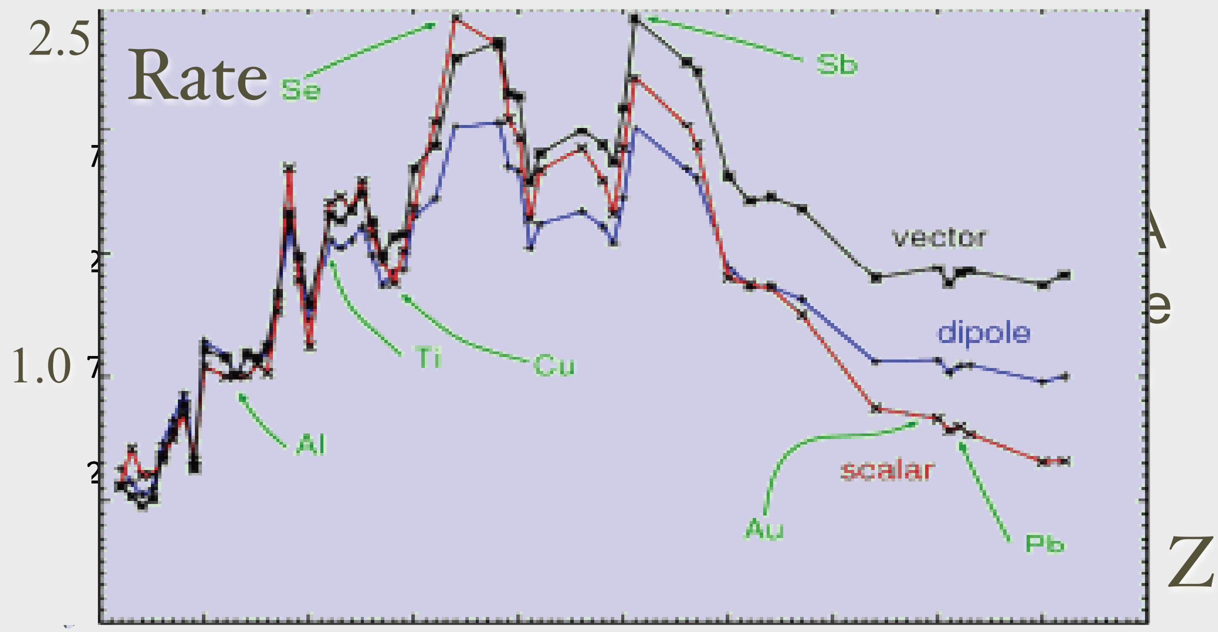
$$\pi N \to \gamma N, \gamma \to e^+ e^-$$



Choice of Stopping Material: rate vs wait

rate normalized to Al

- Stop muons in target (Z,A)
- Physics sensitive to Z: with signal, can switch target to probe source of new physics
- Why start with Al?



V. Cirigliano, B. Grinstein, G. Isidori, M. Wise **Nucl.Phys.B728:121-134,2005**. e-Print: **hep-ph/0507001**

Kitano, et al, PRD 66, 096002 (2002)

shape governed by relative conversion/capture rate, form factors, ...

Prompt Background and Choice of Z

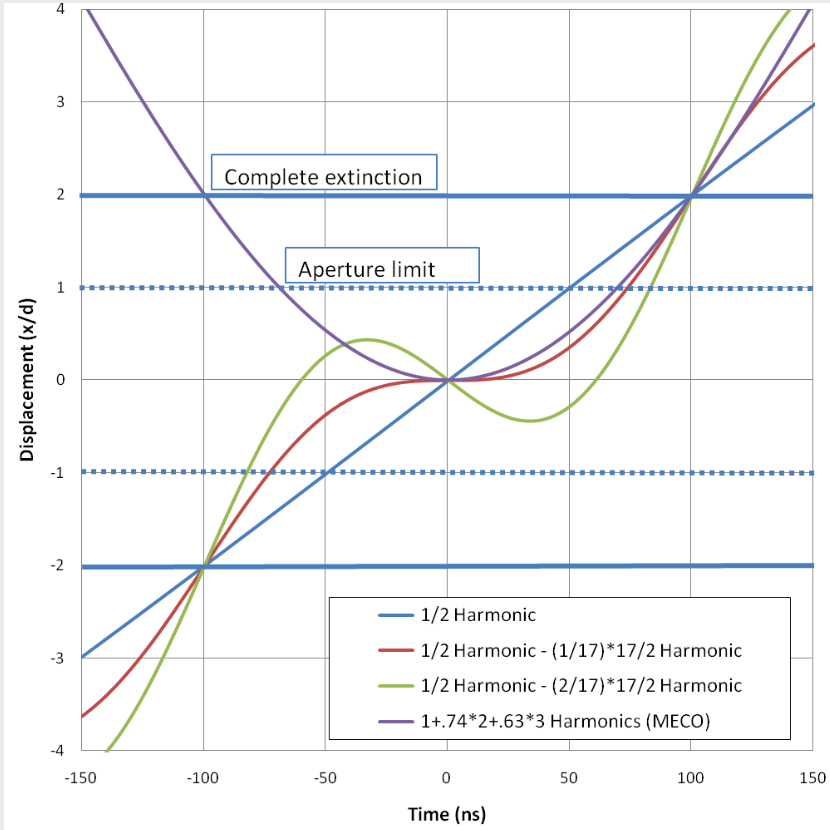
choose Z based on tradeoff between rate and lifetime: longer lived reduces prompt backgrounds

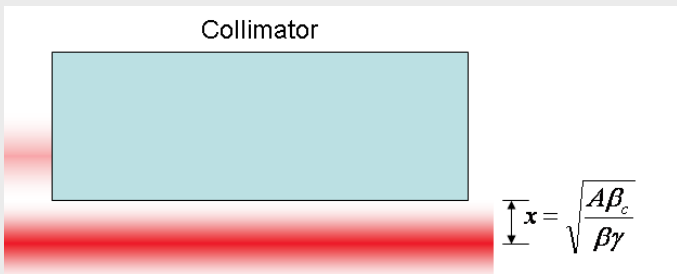
Nucleus	$R_{\mu e}(Z)$ / $R_{\mu e}(Al)$	Bound Lifetime	Conversion Energy	Fraction >700 ns
Al(13,27)	1.0	864 nsec	104.96 MeV	0.45
Ti(22,~48)	1.7	328 nsec	104.18 MeV	0.16
Au(79,~197)	~0.8-1.5	72.6 nsec	95.56 MeV	negligible

Extinction Scheme

achieving 10^{-10} is hard; normally get $10^{-2} – 10^{-3}$

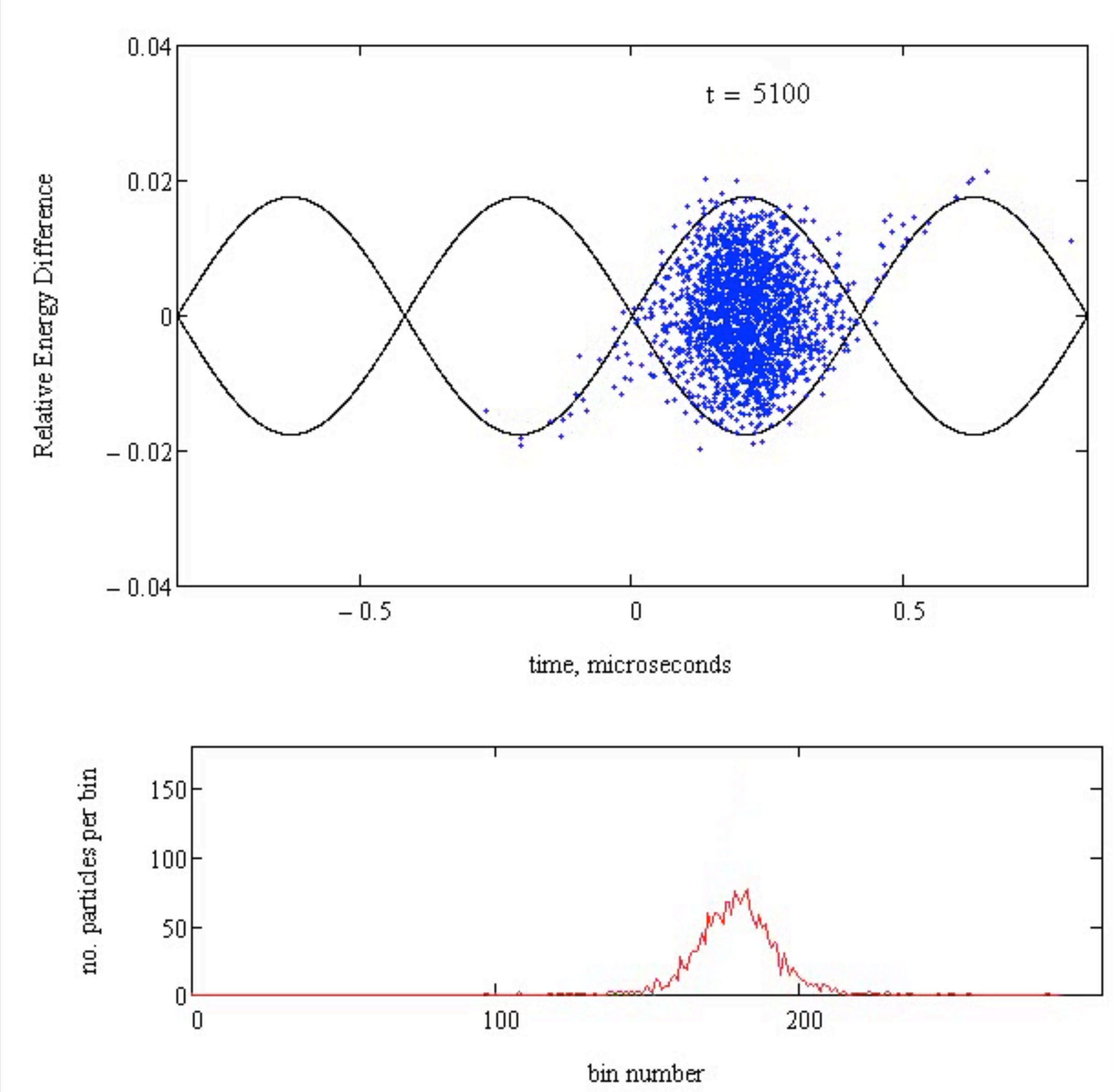
- Two methods, Internal and External:
- External:
  - high frequency (300 KHz) dipole with smaller admixture of 17th harmonic (5.1 MHz)
  - Sweep Unwanted Beam into collimator
  - Calcs show this sufficient





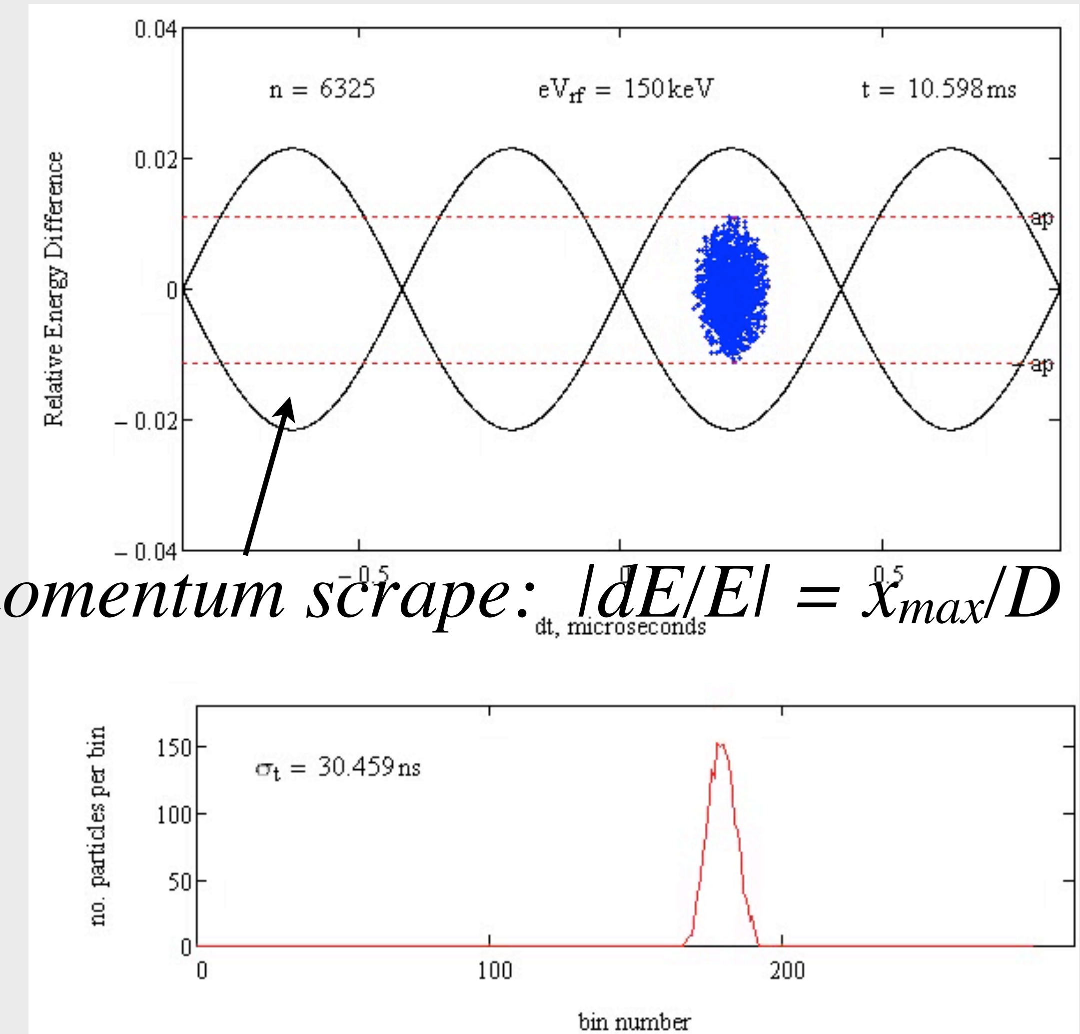
Extinction (Internal)

- RF jitter, scattering, etc can cause protons to wander out of their bucket



Extinction (internal)

- *Internal*:“momentum scraping”: wait for beam to be wide, then use collimators
- Perform in Debuncher
- Have also modified beam transfer scheme from Accumulator to Debuncher to improve cleanliness



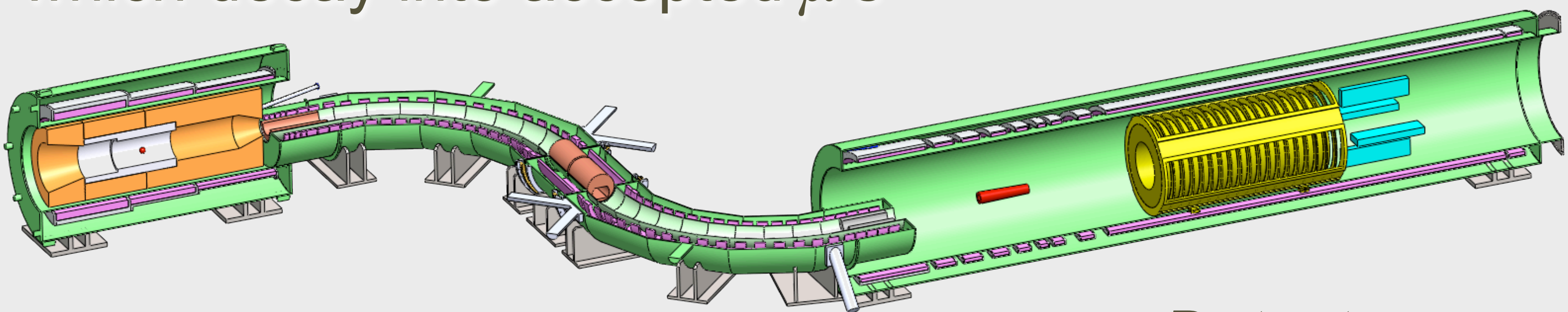
momentum scrape: $|dE/E| = x_{max}/D$

Extinction Measurement

- Continuous Extinction monitoring techniques under study
  - Can we count protons directly?
    - dynamic range: 3e7 in-spill to 1 out-of-spill
  - Statistical:
    - count diffracted protons from target
    - see 1 event/hr or so for 10^{-10} , ~10 in spill

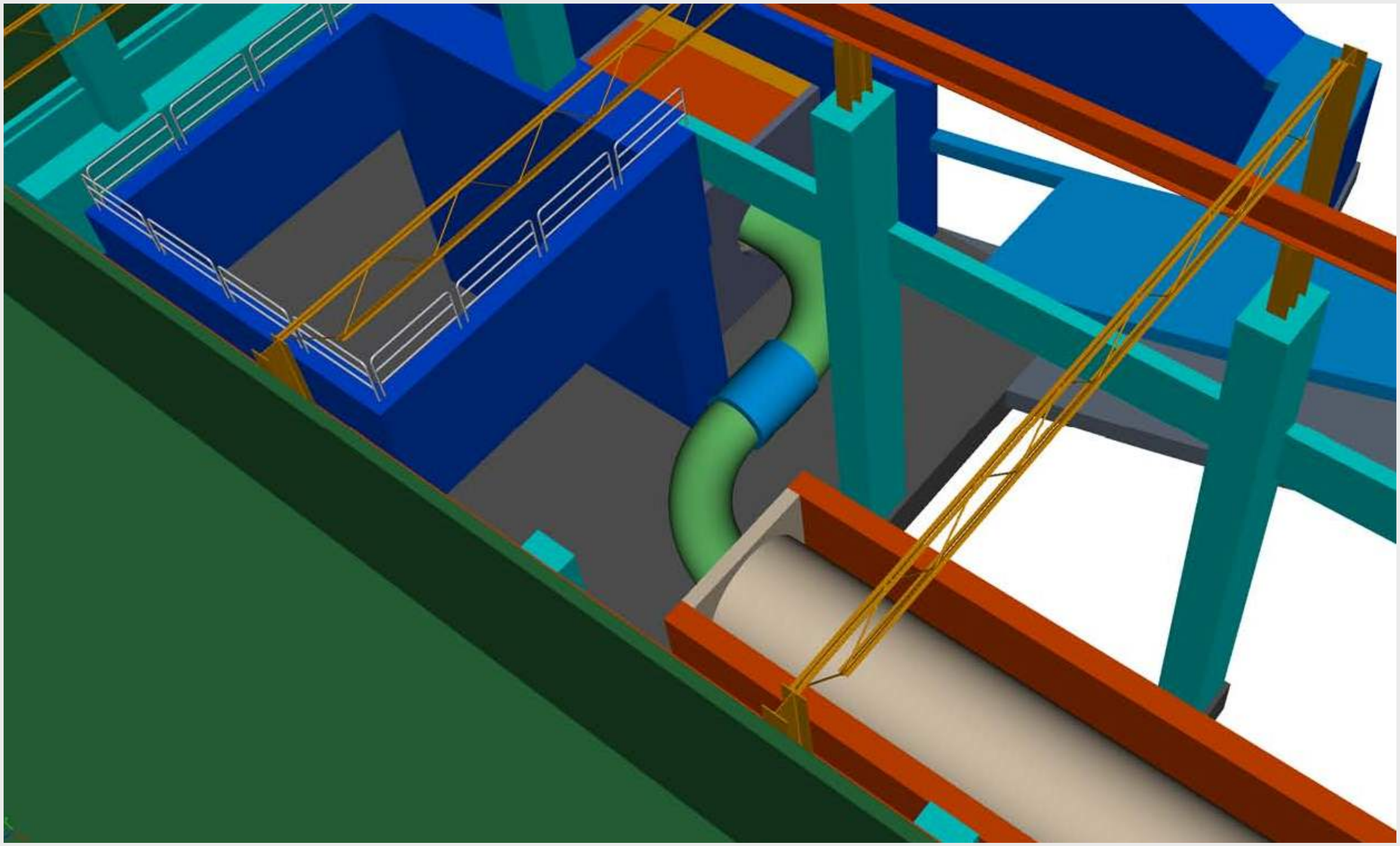
Mu2e Overview

- *Production*: Magnetic bottle traps π's, which decay into accepted μ's



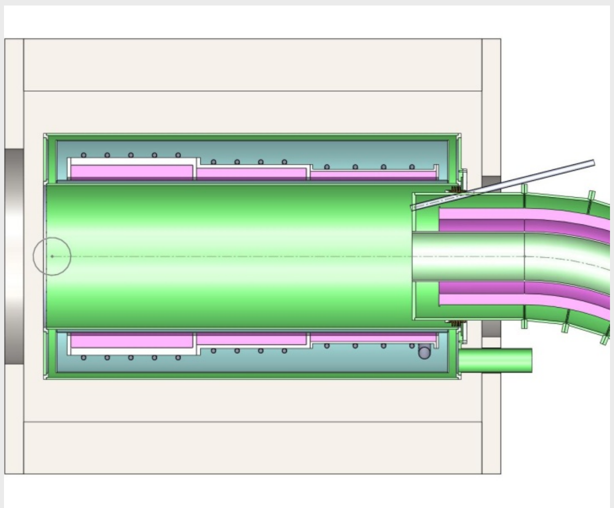
- *Transport:* S-curve eliminates backgrounds and sign-selects
- *Detector:* Stopping Target, Tracking and Calorimeter

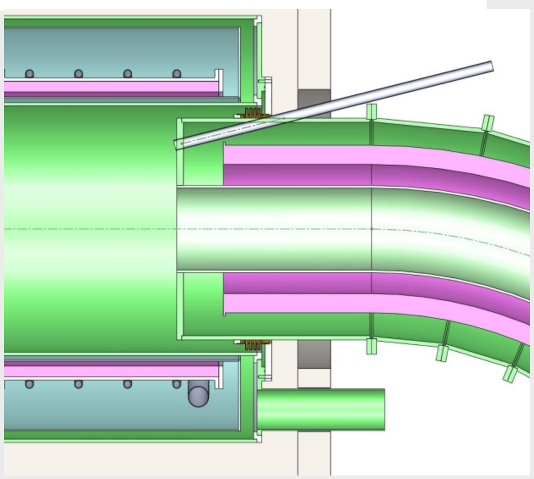
Solenoid in the Hall

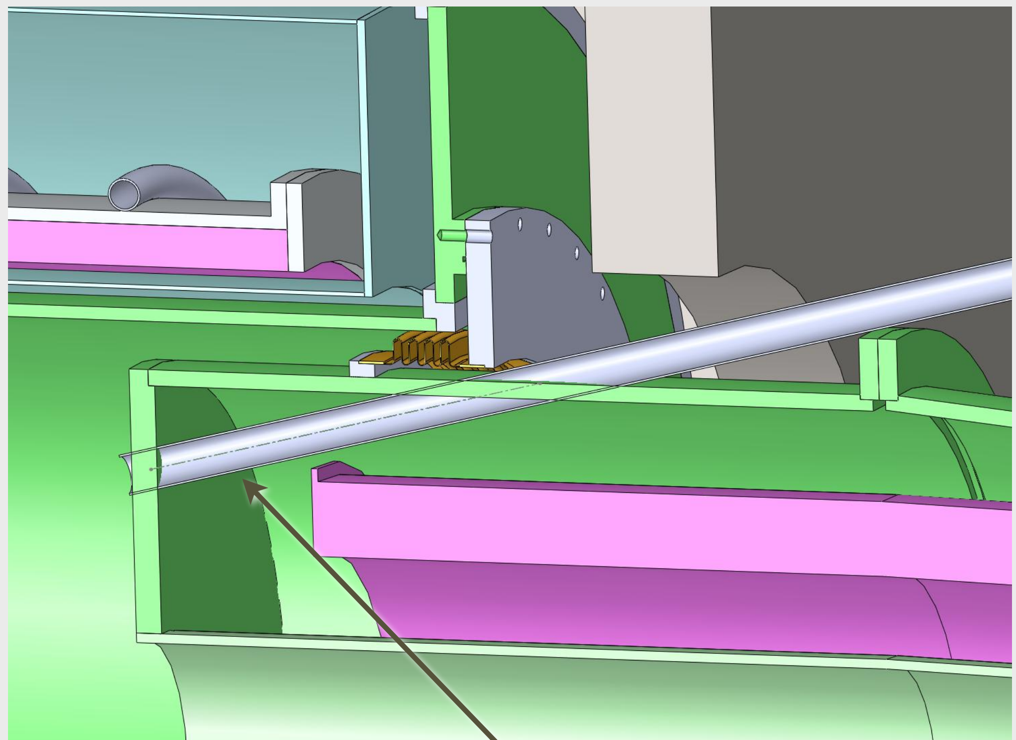


Much Progress in Solenoid Design

- Starting to talk with vendors about construction of solenoids; much interest in bids







incident proton beam pipe

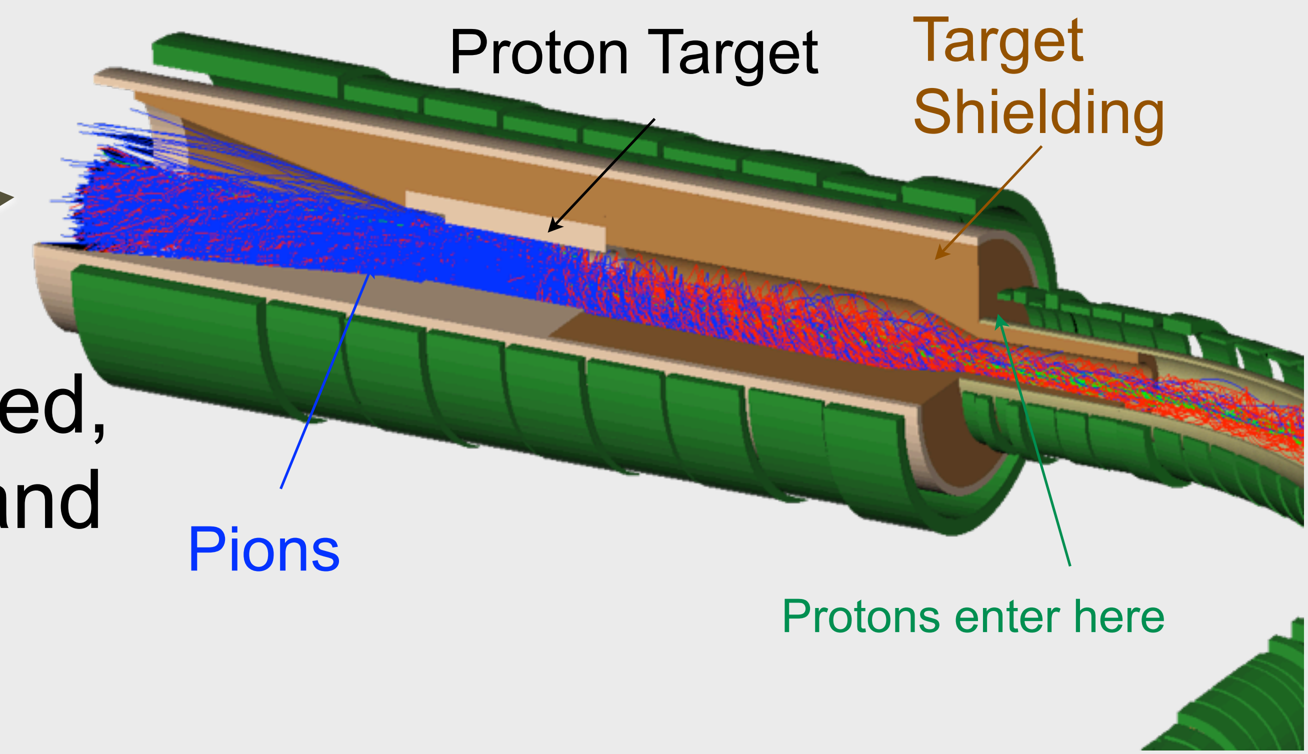
Production Solenoid:

Protons enter opposite to outgoing muons

Protons leave through thin window

π's are captured, spiral around and decay

muons exit to right

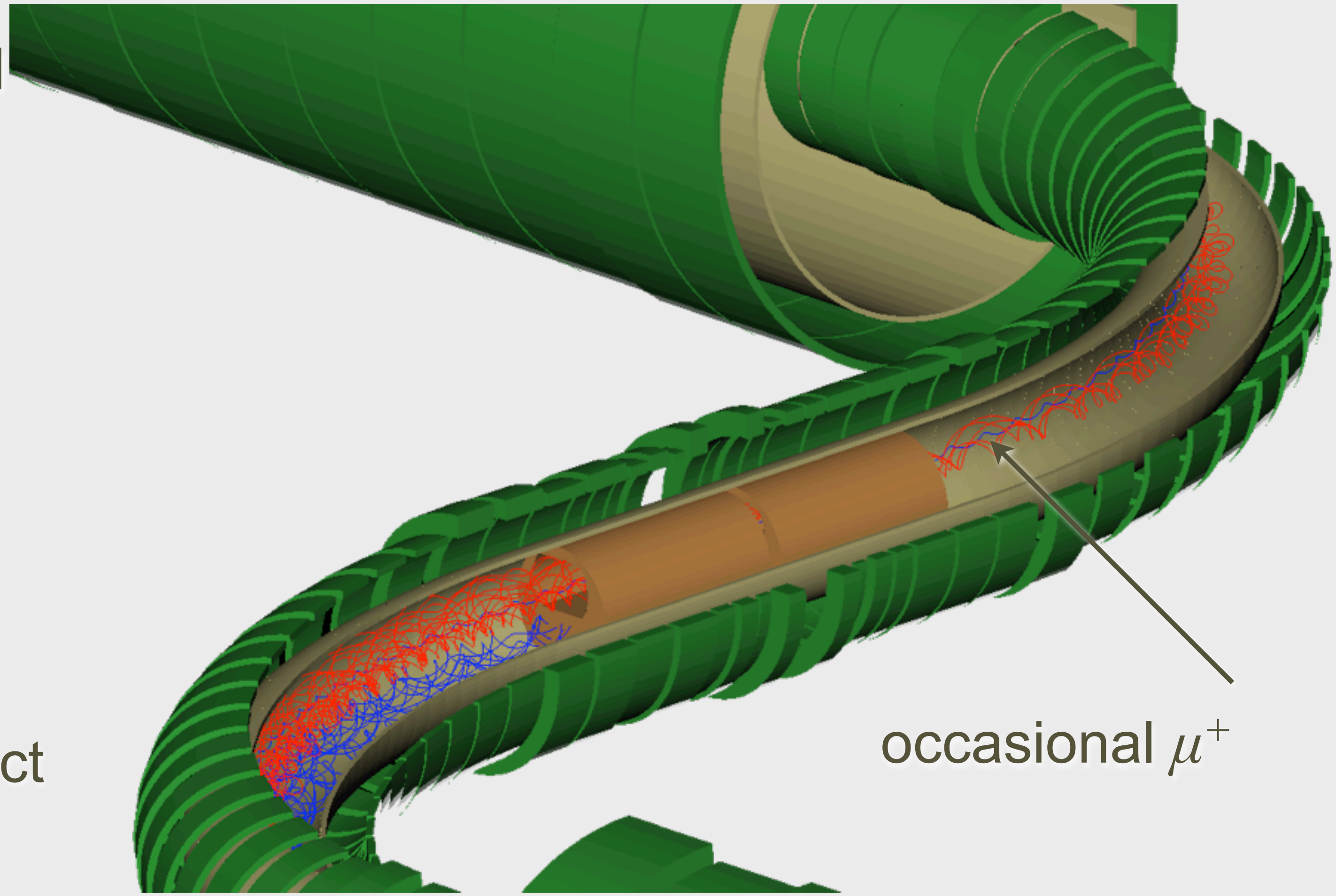


4 m × 0.30 m

Transport Solenoid

- Curved solenoid eliminates line-of-sight transport of photons and neutrons

- Curvature drift and collimators sign and momentum select beam

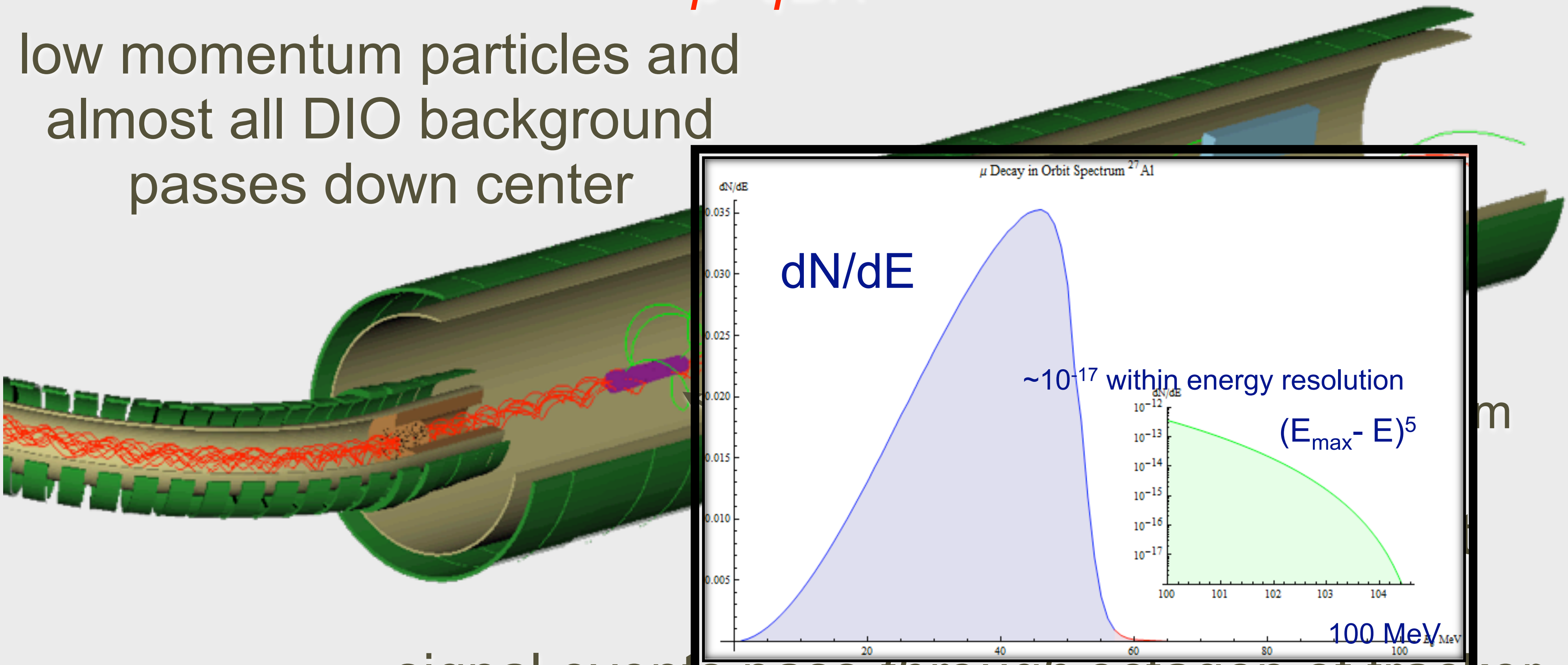


13.1 m along axis × ~0.25 m

Detector Solenoid

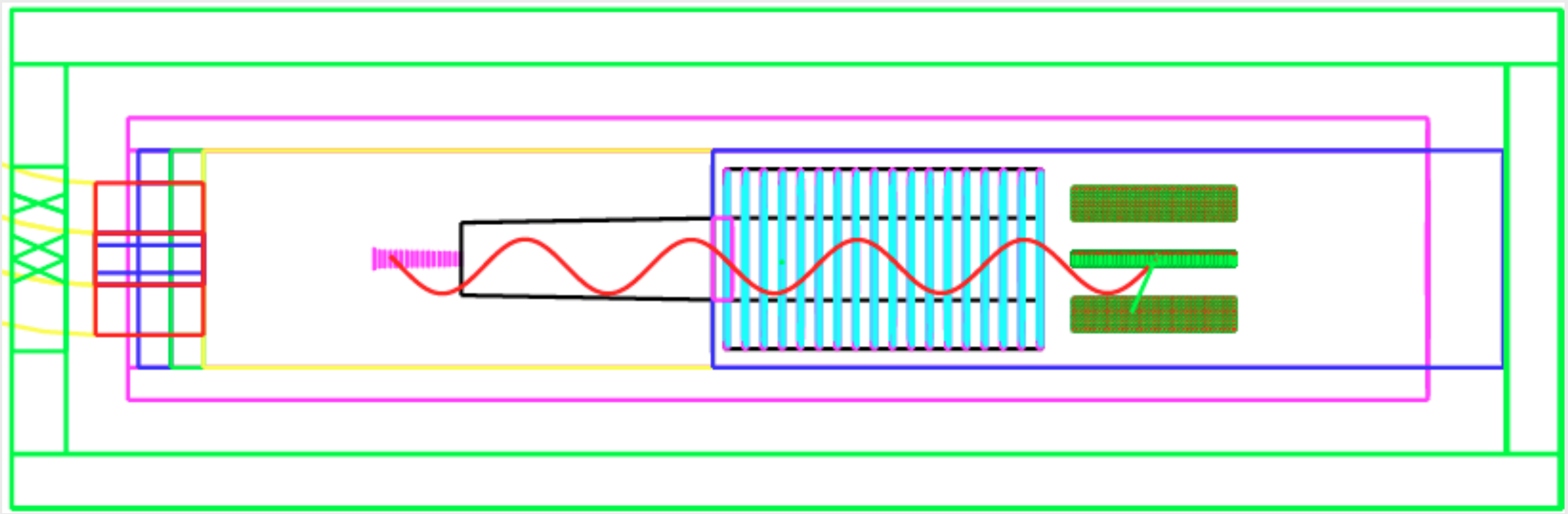
octagonal tracker surrounding central region: radius of helix proportional to momentum, p=qBR

low momentum particles and almost all DIO background passes down center



signal events pass *through* octagon of tracker and produce hits

Detector

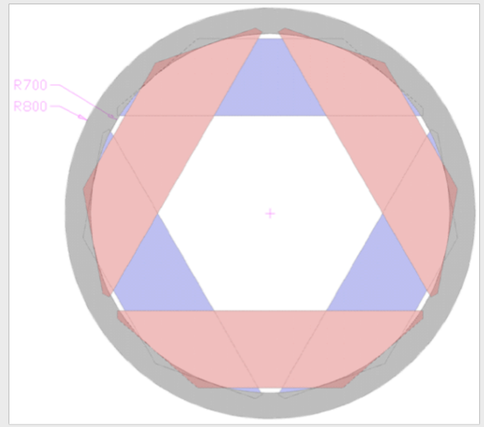


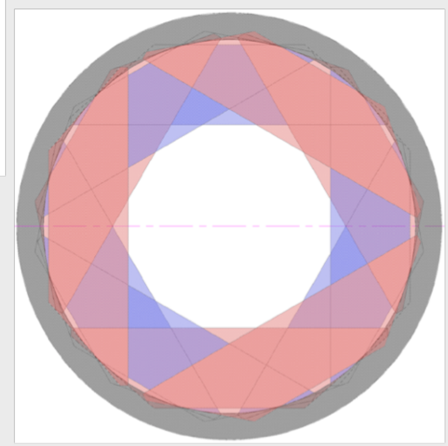
- Immersed in solenoidal field, so electrons follow near-helical path
- Conversion Electron born in Stopping Target
- Tracker followed by Calorimeter

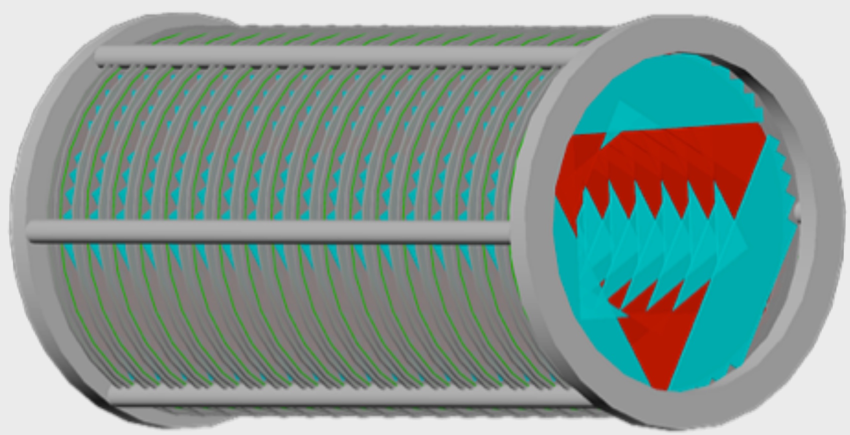
- Tracker: (straw tubes with axes transverse to beam)
  - 216 sub-planes
    - sixty 5 mm diameter conducting straws
    - length from 70-130 cm
    - total of 13,000 channels
- Calorimeter:
  - 1024 3.5 × 3.5 × 12 cm $PbWO_4$ or LYSO
  - 4--5% resolution

T-Tracker Details

- This “windowframe” is repeated, rotated each time
- Just know which straw is hit
  - Makes PR complicated!
  - Have preliminary and encouraging results
- Are investigating time or charge division to provide 3rd coordinate



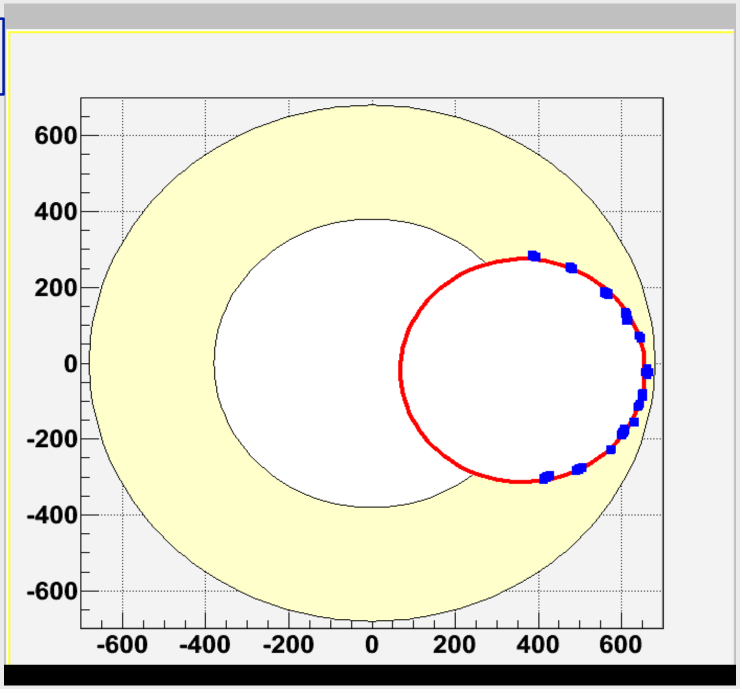




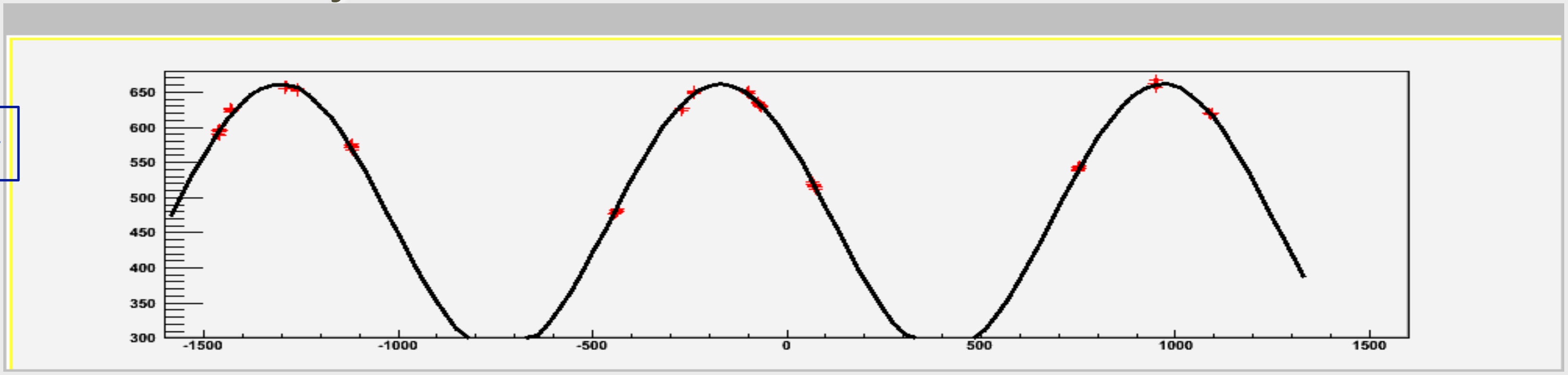
Pattern Recognition and Tracking

- Using Hough Transform for Pattern Recognition
- Have ported BaBar Kalman Filter for Track Fitting
    - robust against noise so far
    - extensive misreconstruction studies underway

X-Y View



R-Z view



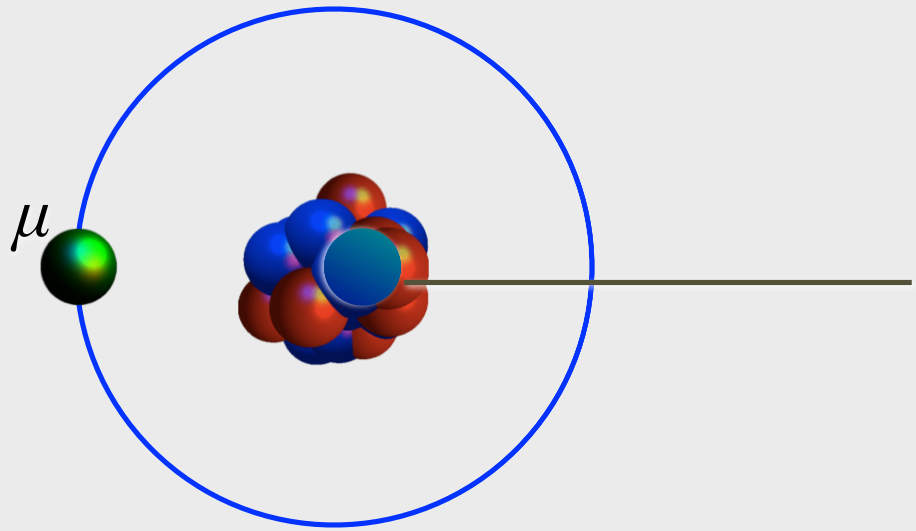
Backgrounds...

Type	Description
e_t	beam electrons
n_t	neutrons from muon capture in muon stopping target
γ_t	photons from muon capture in muon stopping target
p_t	protons from muon capture in muon stopping target
$e(DIO)_t < 55$	DIO from muon capture in muon stopping target, < 55 MeV
$e(DIO)_t > 55$	DIO from muon capture in muon stopping target, > 55 MeV
n_{bd}	neutrons from muon capture in beam stop
γ_{bd}	photons from muon capture in beam stop
$e(DIO)_{bd} < 55$	DIO from muon capture in beam stop, < 55 MeV
$e(DIO)_{bd} > 55$	DIO from muon capture in beam stop, > 55 MeV
$e(DIF)$	DIO between stopping target and beam stop

bd = albedo from beam stop (after calorimeter): splashback, extra hits confusing pattern recognition

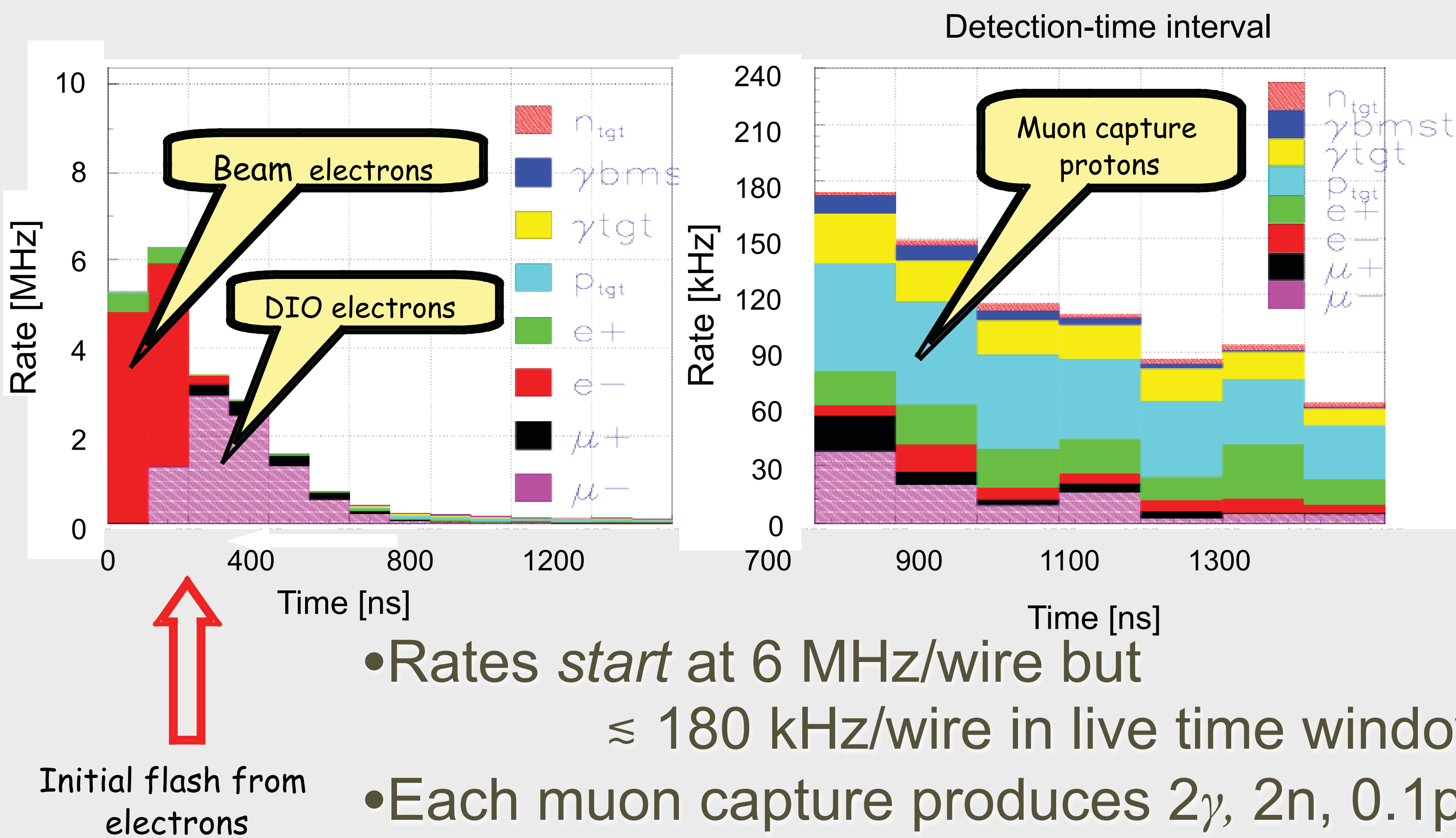
Recall Our Normalization

when a muon stops, about 10% of the time a proton is ejected



these can enter the detector and cause rate problems: slow protons are highly ionizing and can deaden wires

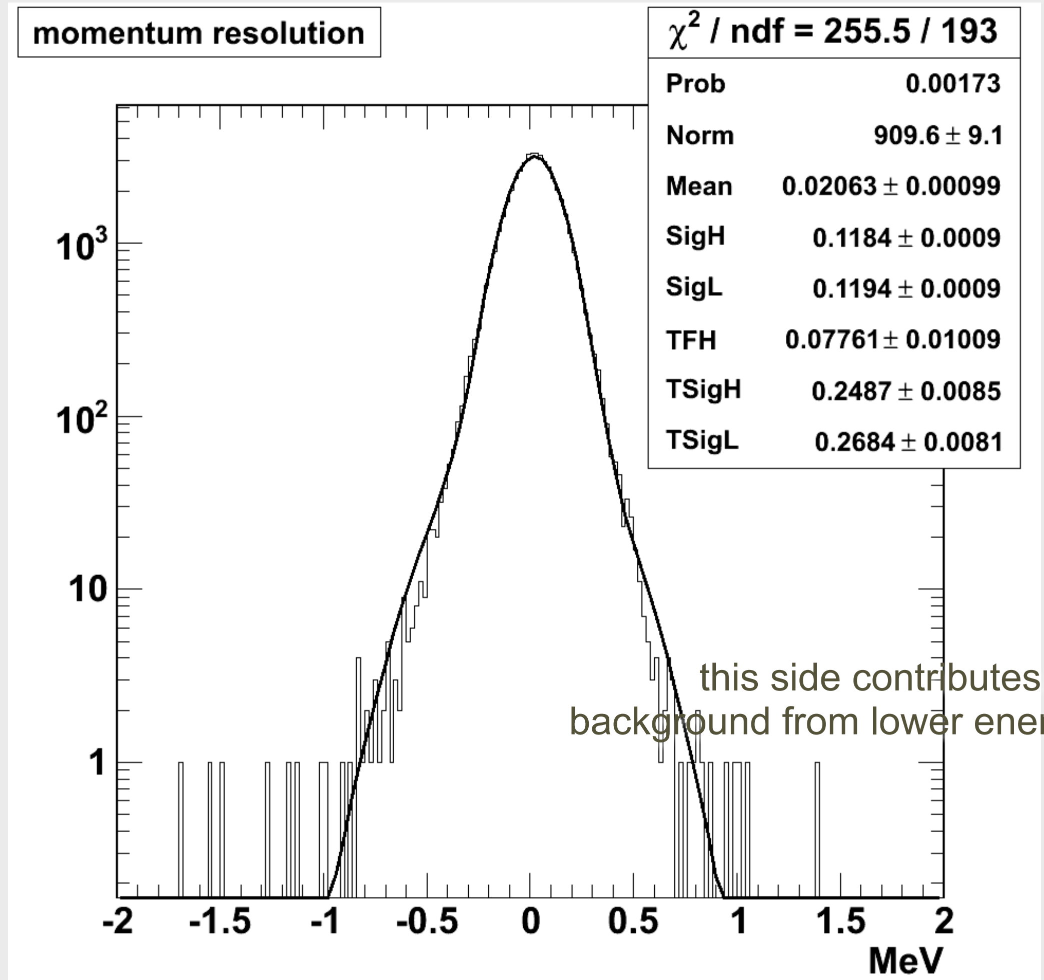
Magnetic Spectrometer: Rates vs. Time



- Rates *start* at 6 MHz/wire but $\lesssim$ 180 kHz/wire in live time window
- Each muon capture produces 2γ, 2n, 0.1p

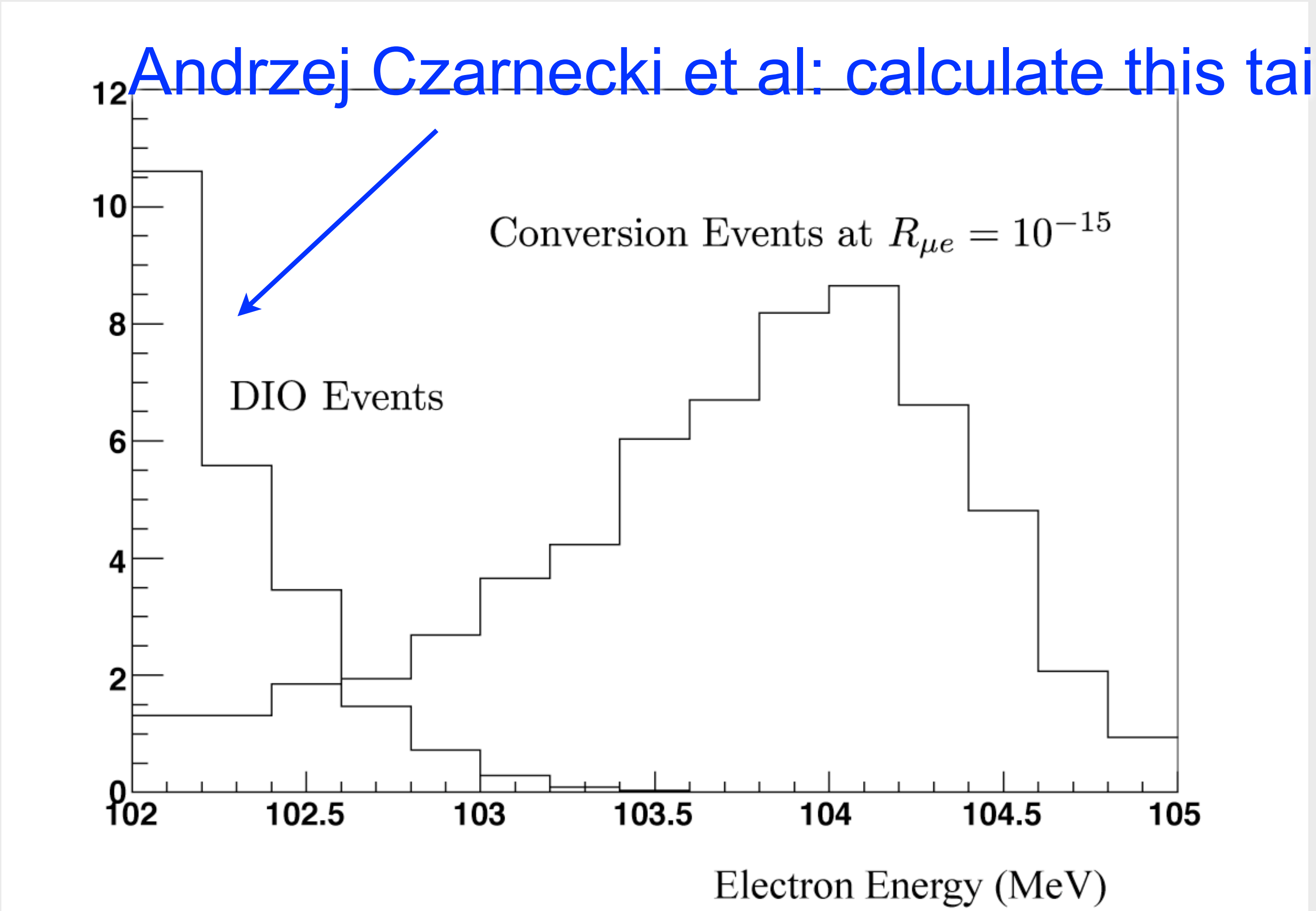
Understanding Resolution

- Measure resolution/ check acceptance:
  - special runs varying target foils, field, location of stopping target
  - Use $\pi^+ \rightarrow e\nu$ decay: monochromatic line at ~70 MeV
  - Gaussian part yield < .01 DIO smeared upwards



core: 92% 120 keV/c
tail: 8% 250 keV/c

Signal and Background



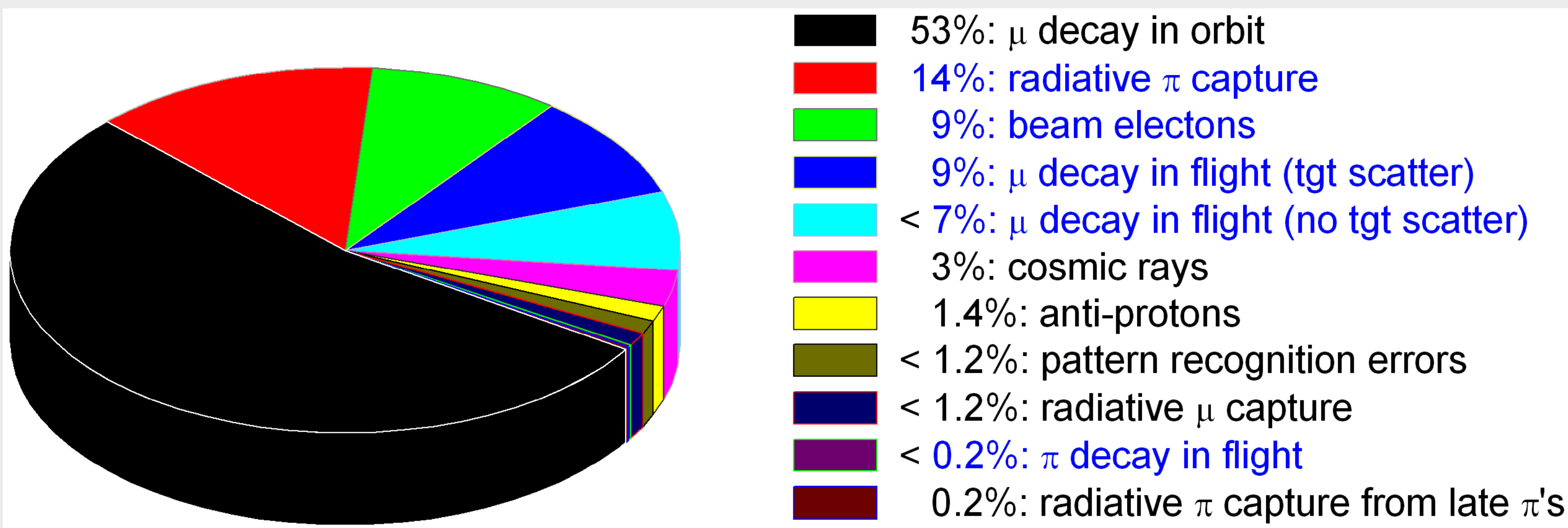
energy loss in stopping target and other material shifts electron down to ~104 MeV

Final Backgrounds

- For $R_{\mu e}$ = 10^{-15}
  ~40 events / 0.4 bkg
  (LHC SUSY?)

- For $R_{\mu e}$ = 10^{-16}
  ~4 events / 0.4 bkg

Source	Number
DIO	0.225
Radiative π capture	0.072
μ decay-in-flight	0.072
Scattered e-	0.035
π decay in flight	<0.0035



Outline

- The search for muon-electron conversion
- Experimental Technique
- *Fermilab Accelerator*
- Project X Upgrades and Mu2e
- Cost and Schedule
- Conclusions

FNAL Beam Delivery

- FNAL has unique, major strength:

Multiple Rings

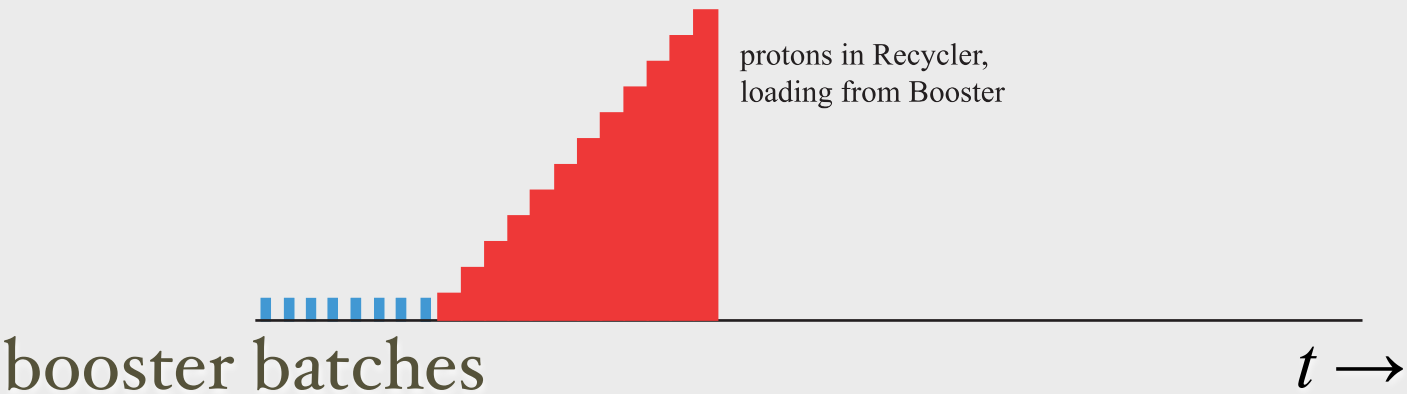
  - *no interference* with NOvA neutrino oscillation experiment
  - reuse existing rings with only minor modifications

Quick Fermilab Glossary

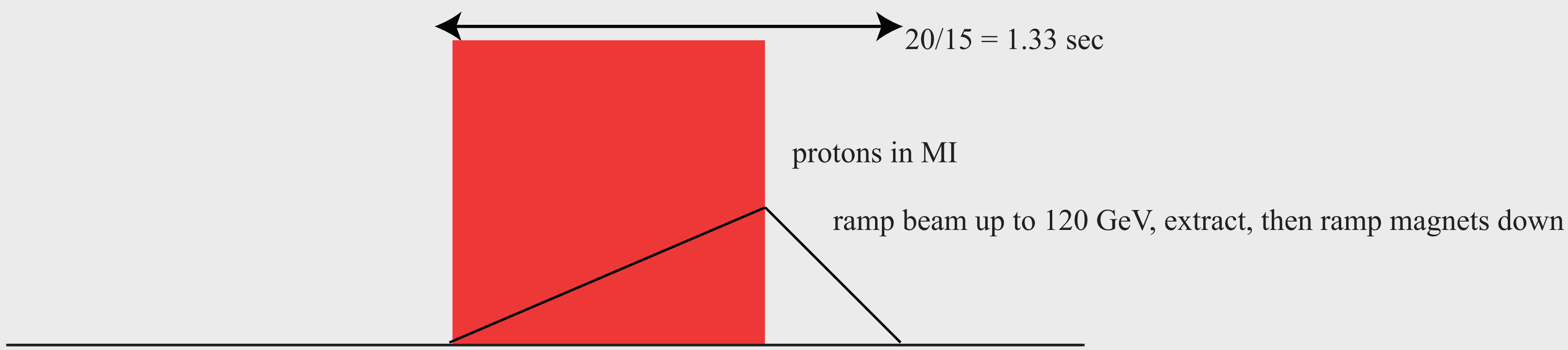
- Booster:
  - The Booster accelerates protons from the 400 MeV Linac to 8 GeV
- Accumulator:
  - momentum stacking successive pulses of antiprotons now, 8 GeV protons for Mu2e
- Debuncher:
  - smooths out bunch structure to stack more $\bar{p}$ now; rebunch for Mu2e
- Recycler:
  - holds more $\bar{p}$ than Accumulator can manage, “store” here; transport line for Mu2e

NovA Era and Mu2e

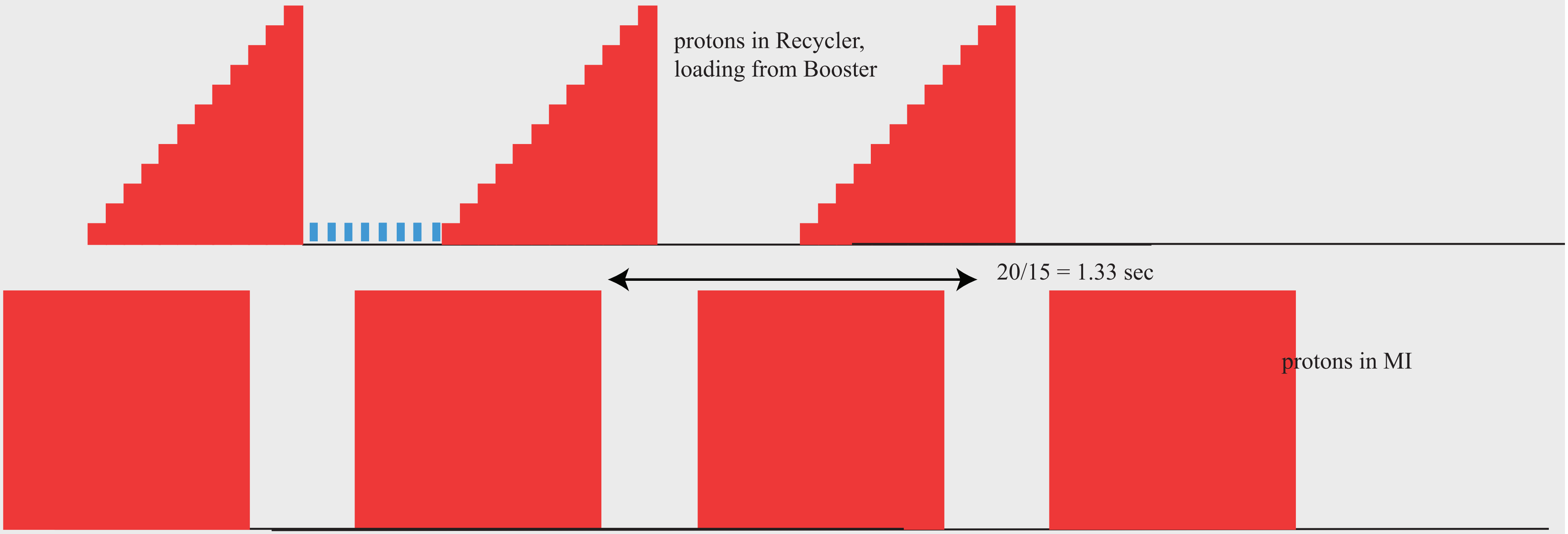
- Load from Booster to Recycler; Booster 'ticks' at 4E12, 15 Hz



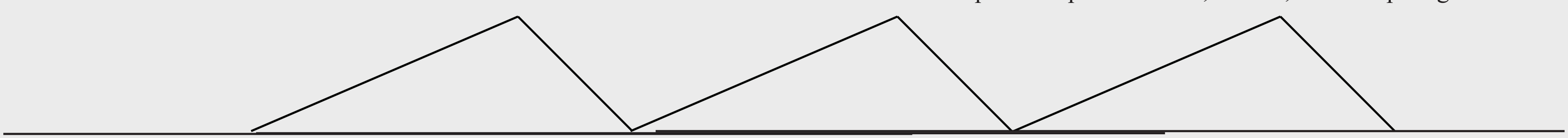
- Single-Turn Transfer to MI



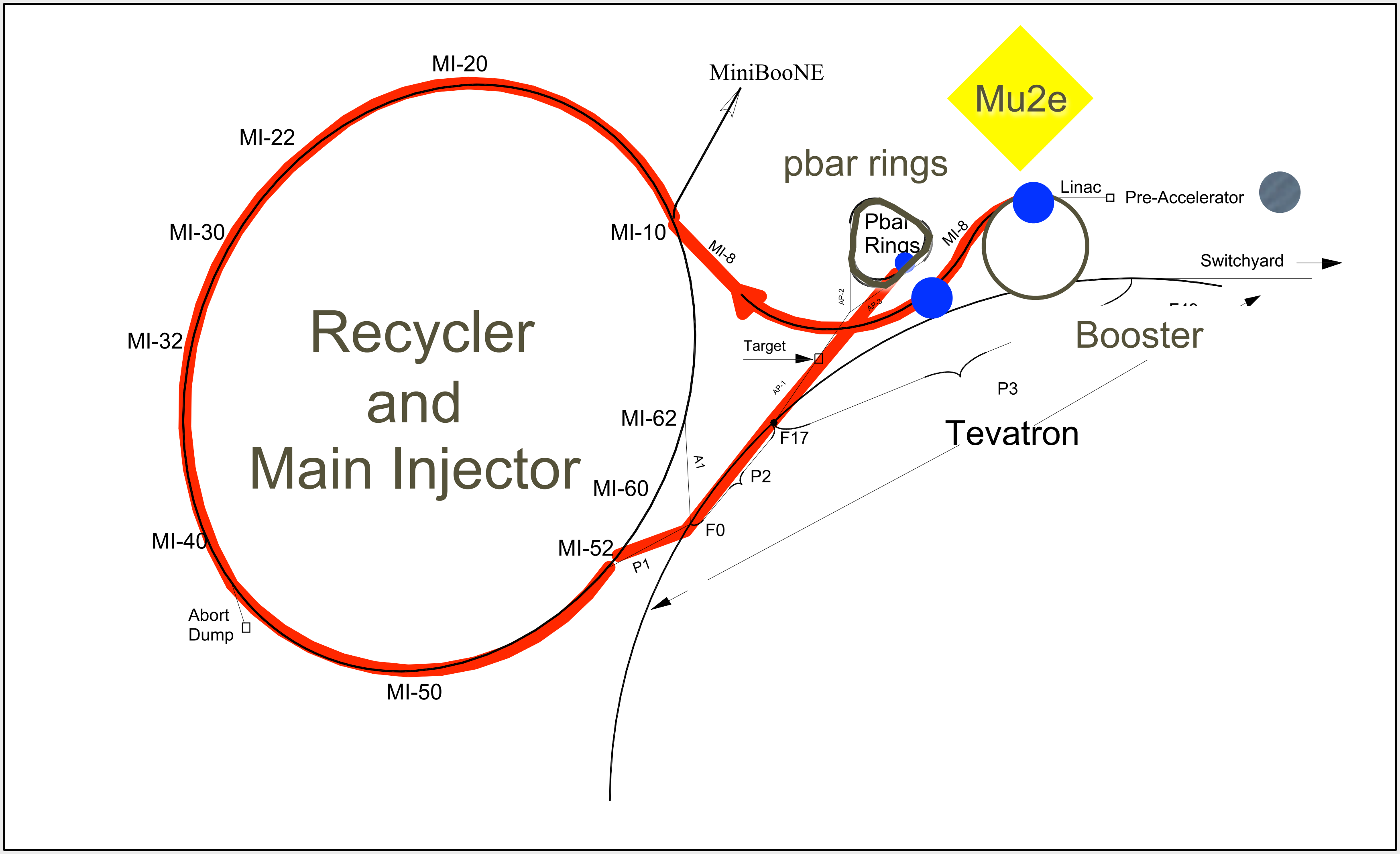
All Together...



time to ramp allows us to fit eight extra Booster batches for Mu2e
(can use 6)



“Boomerang” Scheme



And on the Civil Construction

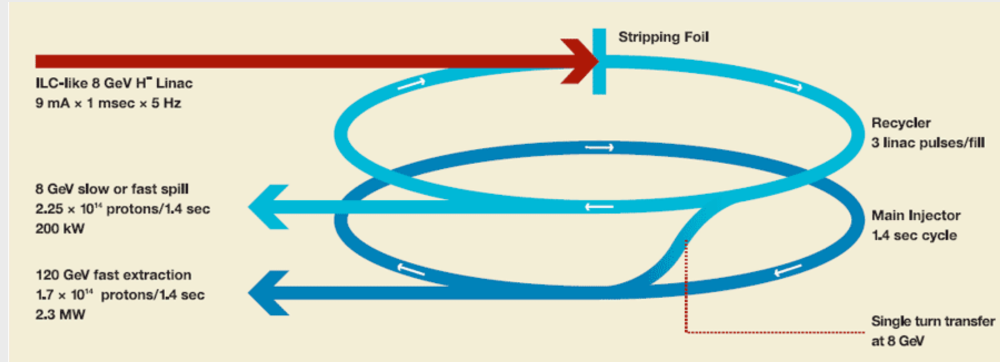
Figure 2 –Site Photo Indicating Location of Proposed mu2e Conventional

Outline

- The search for muon-electron conversion
- Experimental Technique
- Fermilab Accelerator
- *Project X Upgrades and Mu2e*
- Cost and Schedule
- Conclusions

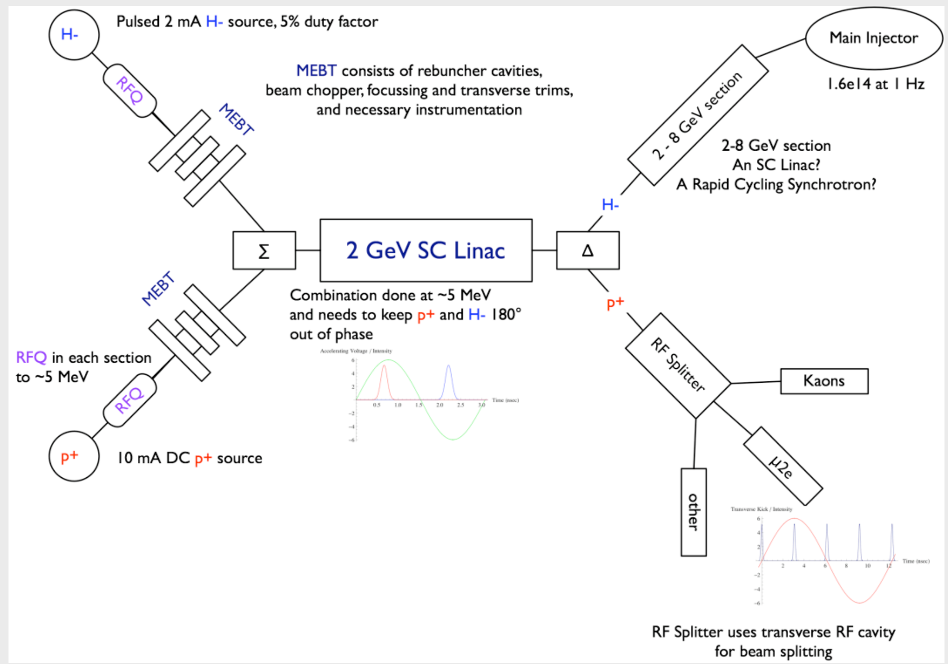
Upgrades at Project X

- Project X is a concept for an intense 8 GeV proton source that provides beam for the Fermilab Main Injector and an 8 GeV physics program.

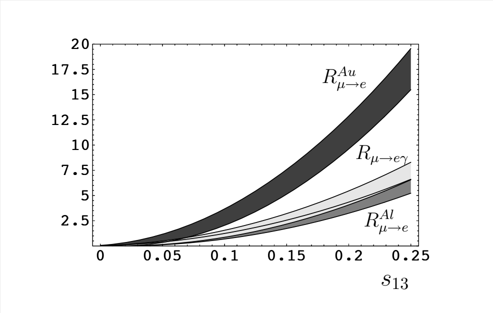


- Can drive next generation experiments in intensity frontier physics: rare processes, neutrinos

- Potential to upgrade Mu2e by *x100*
  - *study new physics*
  - *set stronger limit*



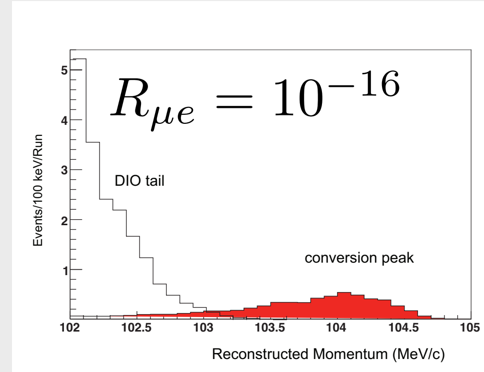
Upgrade Plans...



Signal?

Yes

No



1. Change Z of Target to determine source of new physics

2. Prompt Rates will go up at higher Z, have to redesign detector and muon transport

1. Both Prompt and DIO backgrounds must drop to measure $R_{\mu e} \sim 10^{-18}$

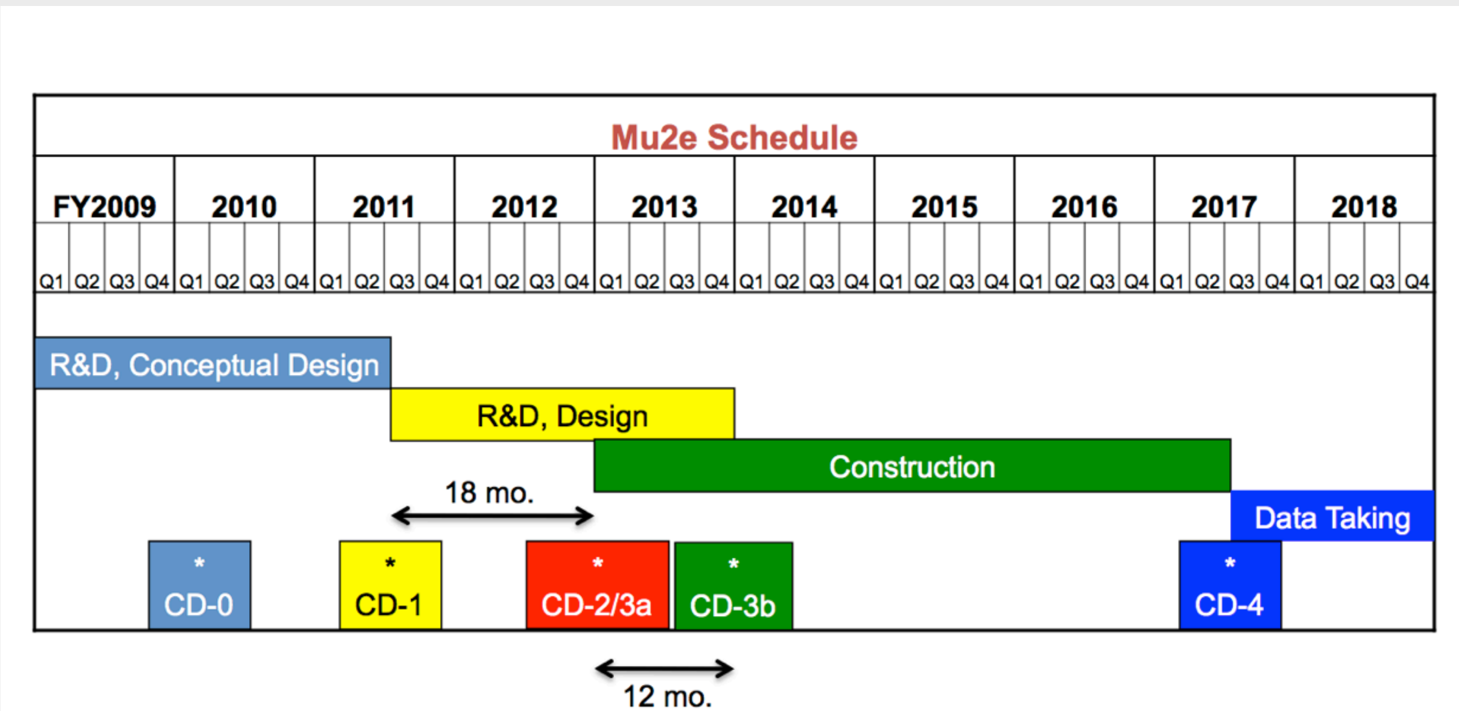
2. Detector, Muon Transport, Cosmic Ray Veto, Calorimeter

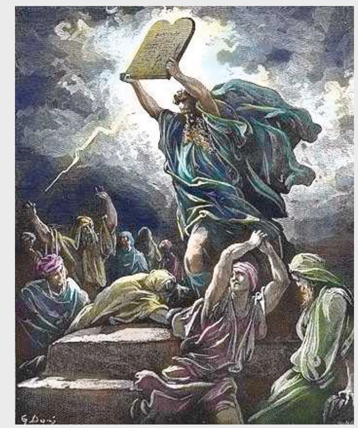
Outline

- The search for muon-electron conversion
- Experimental Technique
- Fermilab Accelerator
- Project X Upgrades and Mu2e
- Cost and Schedule
- Conclusions

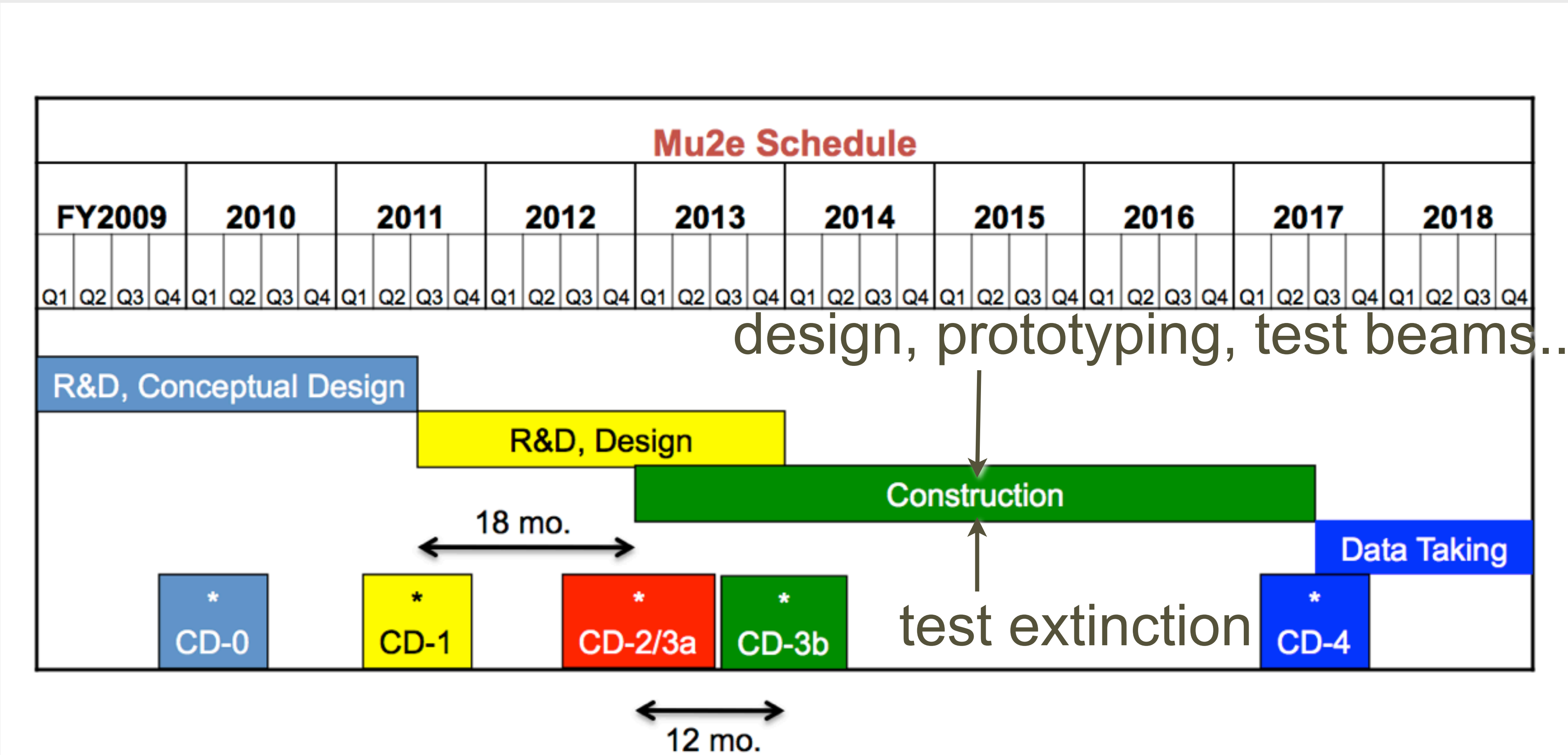
Cost and Schedule

- ***This is a technically limited schedule***
- Critical Path is Superconducting Solenoids
- $200M “fully-loaded” Total Cost





What Does This Mean?



Conclusions

- Mu2e will either:
  - *Reduce the limit for $R_{\mu e}$ by more than four orders of magnitude ($R_{\mu e} < 6 \times 10^{-17}$ @ 90% C.L.)*
  - *Discover unambiguous proof of Beyond Standard Model physics and*
  - *Provide important information either complementing LHC results or probing up to 10^4 TeV mass scales*
- With upgrades, we could extend the limit by up to two orders of magnitude or study the details of new physics

And Perhaps Answer Rabi's Question about the physics of flavor and generations

Who ordered that?