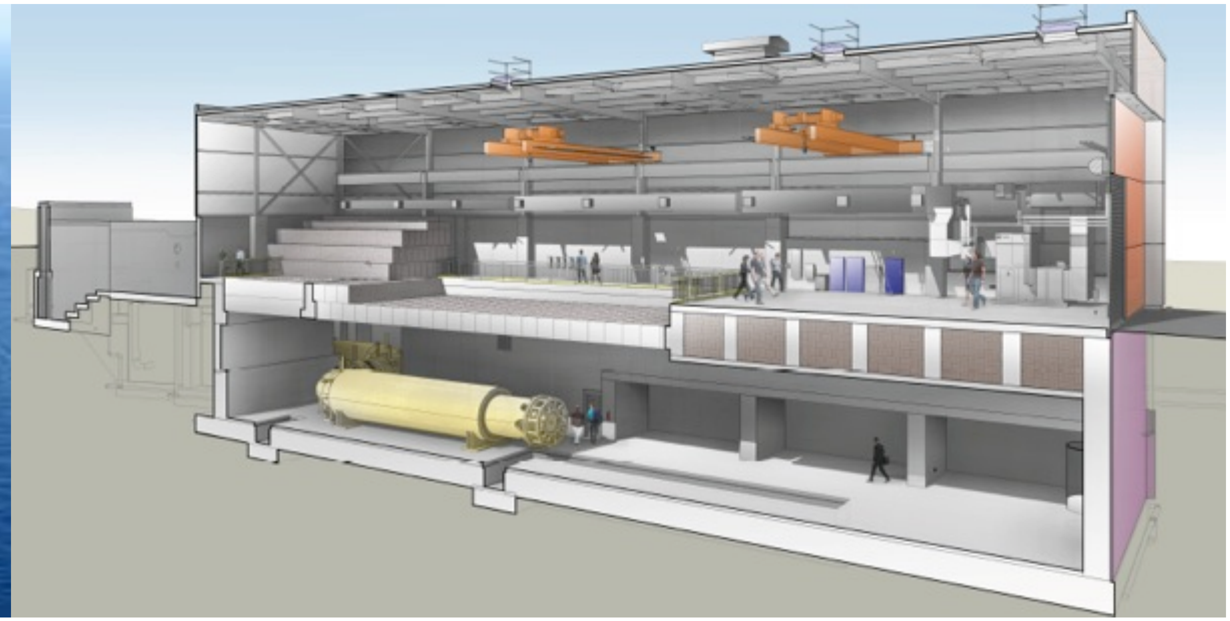
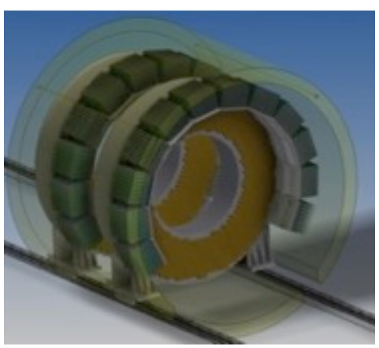
Status of the Mu2e experiment





S. Miscetti

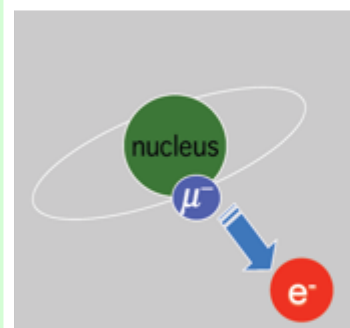
Laboratori Nazionali di Frascati

on behalf of the Mu2e Collaboration

Workshop on

Flavour Changing and Conserving processes 2015

FCCP2015 Capri's Island 12/Sep/2015



Outline

- CLFV and physics reach
- Experimental technique
- Accelerator Complex
- Detector Layout
- Status of Mu2e experiment
- Conclusions

CLFV processes

- Muon-to-electron conversion is a charged lepton flavor violating process (CLFV)

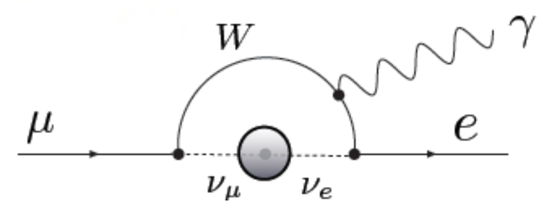
  similar but complementary to other CLFV processes as $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$.

- The Mu2e experiment searches for muon-to-electron conversion in the coulomb field of a nucleus: $\mu^- Al \rightarrow e^- Al$

- CLFV processes are strongly suppressed in the Standard Model

  → In principle, not forbidden due to neutrino oscillations

  → In practice BR($\mu \rightarrow e\gamma$) ~ 10^{-54} is negligible in the SM!

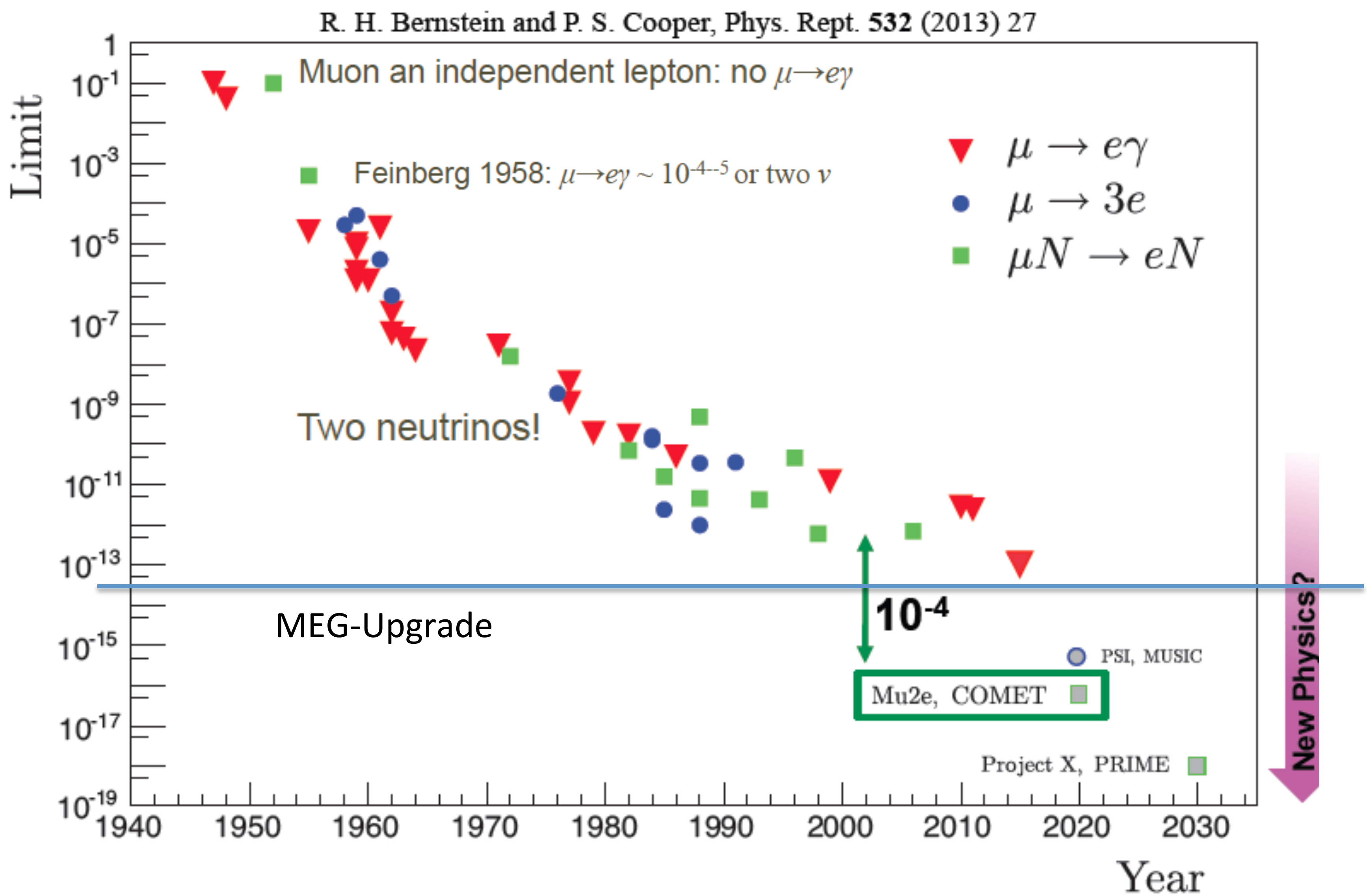


- New Physics could enhance CLFV rates to observable values

- Various NP models allow for it, at levels just beyond current CLFV upper limits.
  - SO(10) SUSY
    - L. Calibbi *et al.*, Phys. Rev. D **74**, 116002 (2006); L. Calibbi *et al.*, JHEP **1211,** 40 (2012).
  - Scalar leptoquarks
    - J.M. Arnold *et al.*, Phys. Rev D **88**, 035009 (2013).
  - Left-right symmetric model
    - C.-H. Lee *et al.*, Phys. ReV D **88**, 093010 (2013).

Observation of CLFV is New Physics

CLFV history

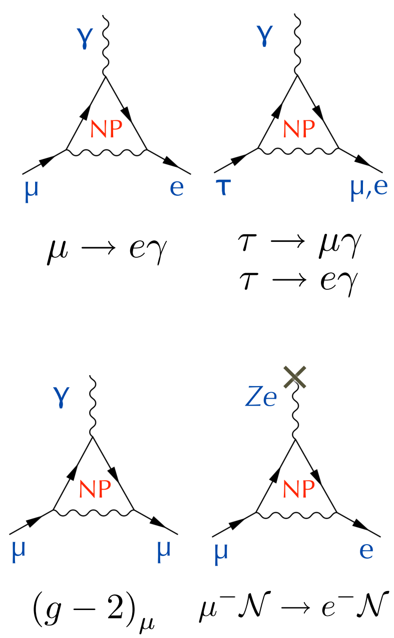


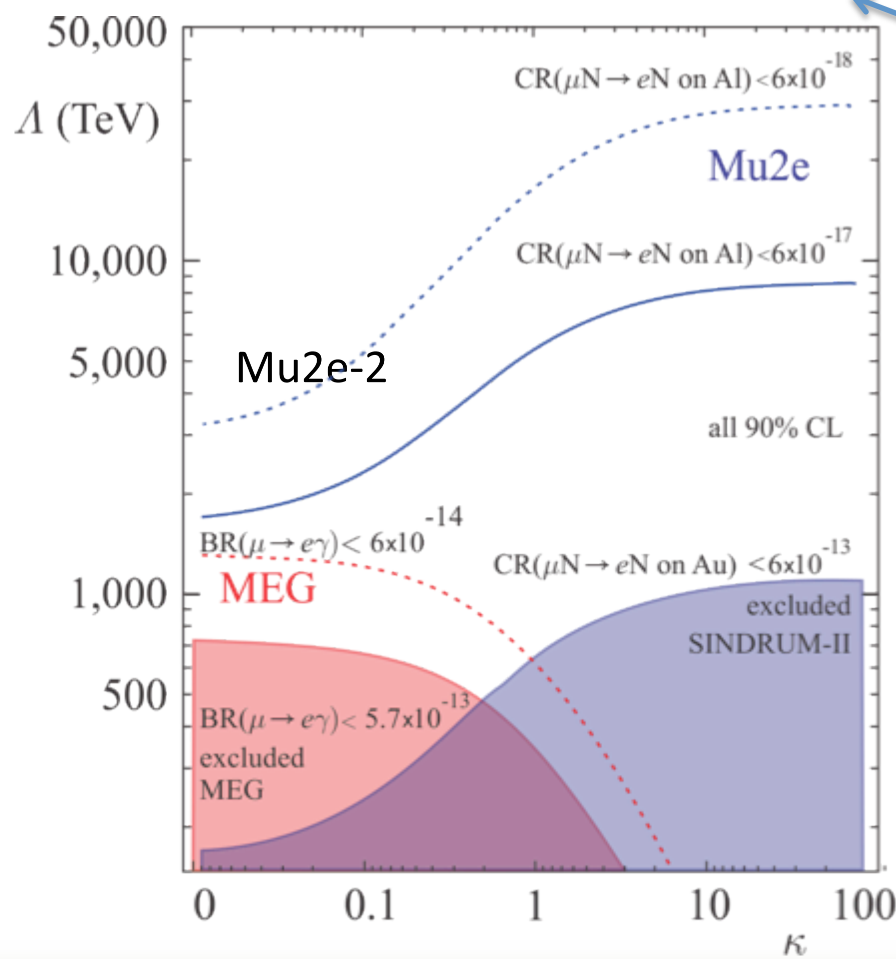
Mu2e vs MEG/MEG upgrade

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

LOOP TERM

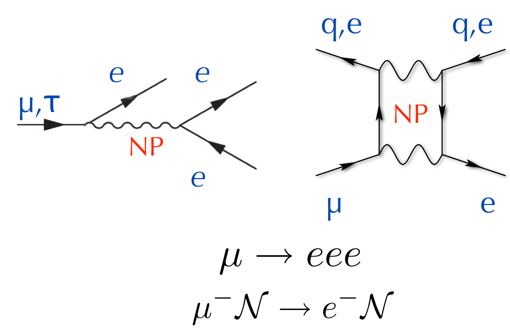
$\kappa \ll 1$





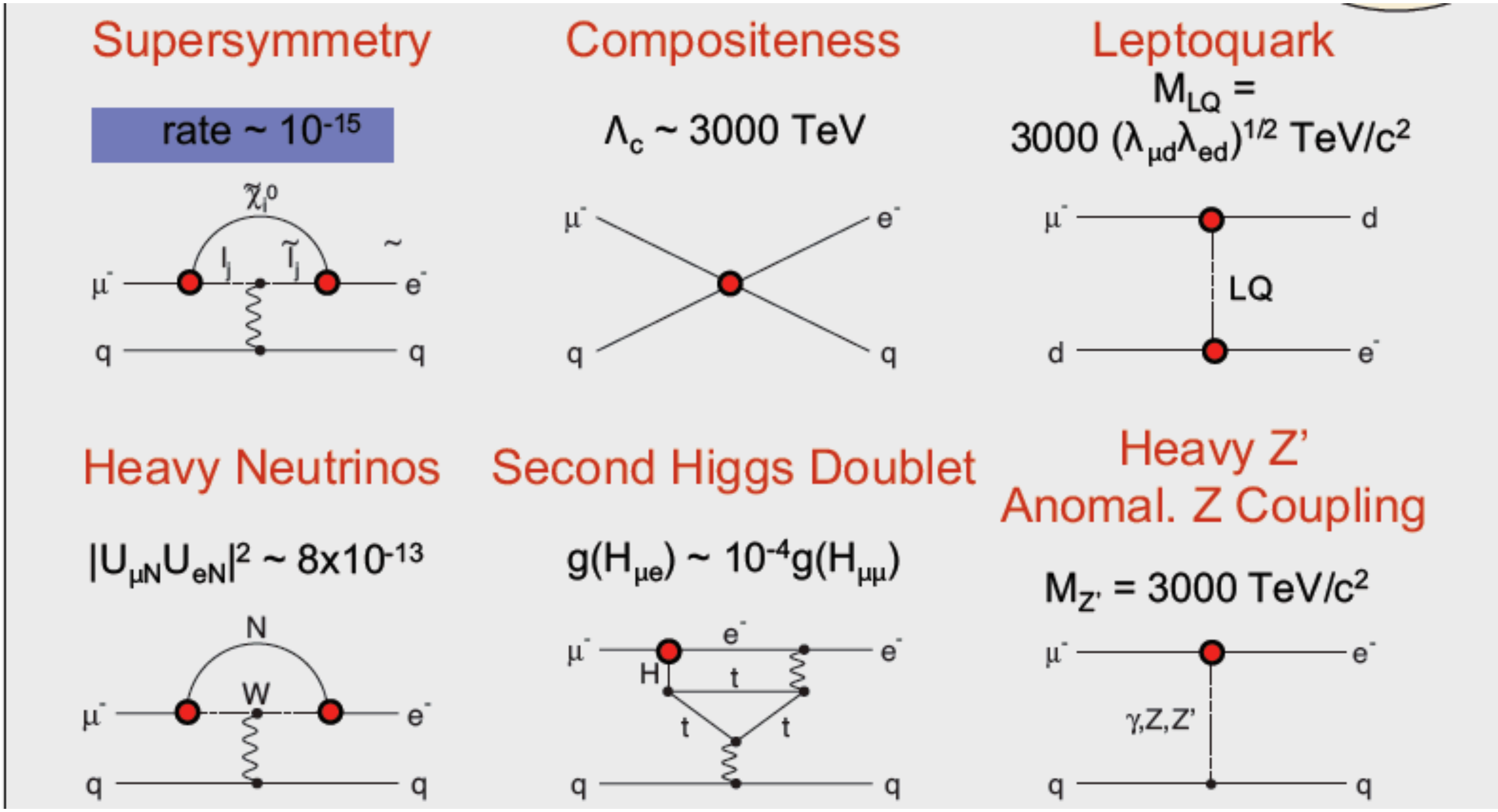
CONTACT TERM

$\kappa \gg 1$



$$R_{\mu e} = \frac{\Gamma(\mu^- + N(A,Z)) \to e^- + N(A,Z)}{\Gamma(\mu^- + N(A,Z) \to \text{ all muon capture})} \leq 6\times 10^{-17}\ (@90\%CL)$$

Mu2e physics reach & goal



Sensitivity reach:
10^4 improvement with respect to previous muon to electron
conversion experiment (Sindrum-II)

Test of Physics BSM:
Marciano, Mori, and Roney, Ann. Rev. Nucl. Sci. 58
M. Raidal *et al*, Eur.Phys.J.C57:13-182,2008
A. de Gouvêa, P. Vogel, arXiv:1303.4097

Why muon conversion is unique?

Muon to electron conversion is a unique probe for BSM:

- **Broad discovery sensitivity across all models:**

  → Sensitivity to the same physics of MEG but with better mass reach

  → Sensitivity to physics that MEG is not

  → If MEG observes a signal, MU2E/COMET do it with improved statistics.
  Ratio of the BR allows to pin-down physics model

  → If MEG does not observe a signal, MU2E/COMET have still a reach to do so.
  In a long run, it can also improve further with the proton improvement plan (PIP-2)

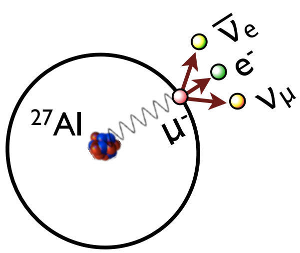
- **Sensitivity to Λ (mass scale) up to hundreds of TeV beyond any current existing accelerator**

Experimental Technique

- ❑ Low momentum μ beam (< 100 MeV/c)
- ❑ High intensity "pulsed" rate
- → 10^{10}/s muon stop on Al. target
- → 1.7 μsec micro-bunch
- ❑ Formation of muonic atoms that can make a:

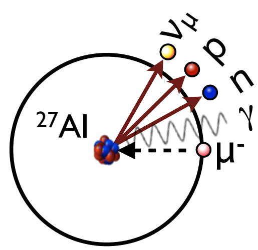
Decay in Orbit (DIO)

(BR=39%)

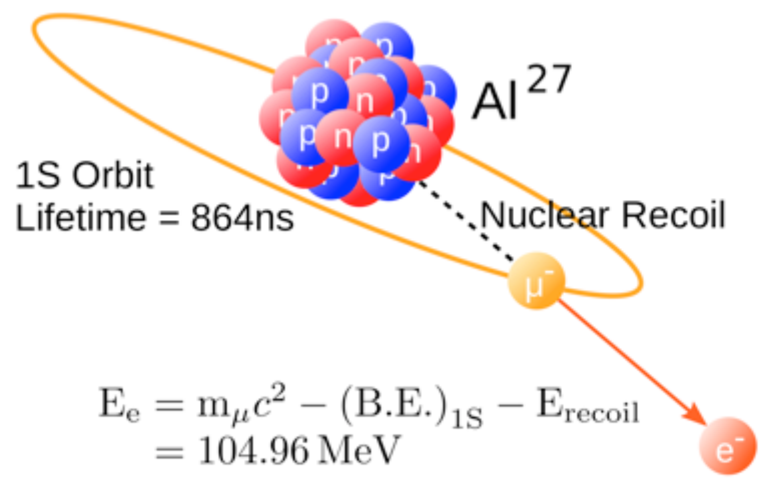


Muon Capture Process

(BR=61%)



Conversion Process



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

The conversion process results in a clear signature of a single electron, CE, with a mono-energetic spectrum close to the muon rest mass

List of Backgrounds to fight

- **Muon decay in orbit (DIO)**
- **Radiative pion capture (RPC)**

  $\pi^- N \rightarrow \gamma N', \gamma \rightarrow e^+e^-$ and $\pi^- N \rightarrow e^+e^- N'$
- Antiprotons: produce pions when they annihilate in the target .. antiprotons are negative and they can be slow!
- Pion/muon decay in flight
- Electrons from beam
- **Cosmic rays**
- …

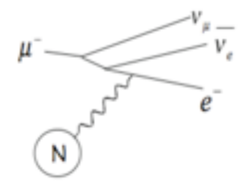
DIO background

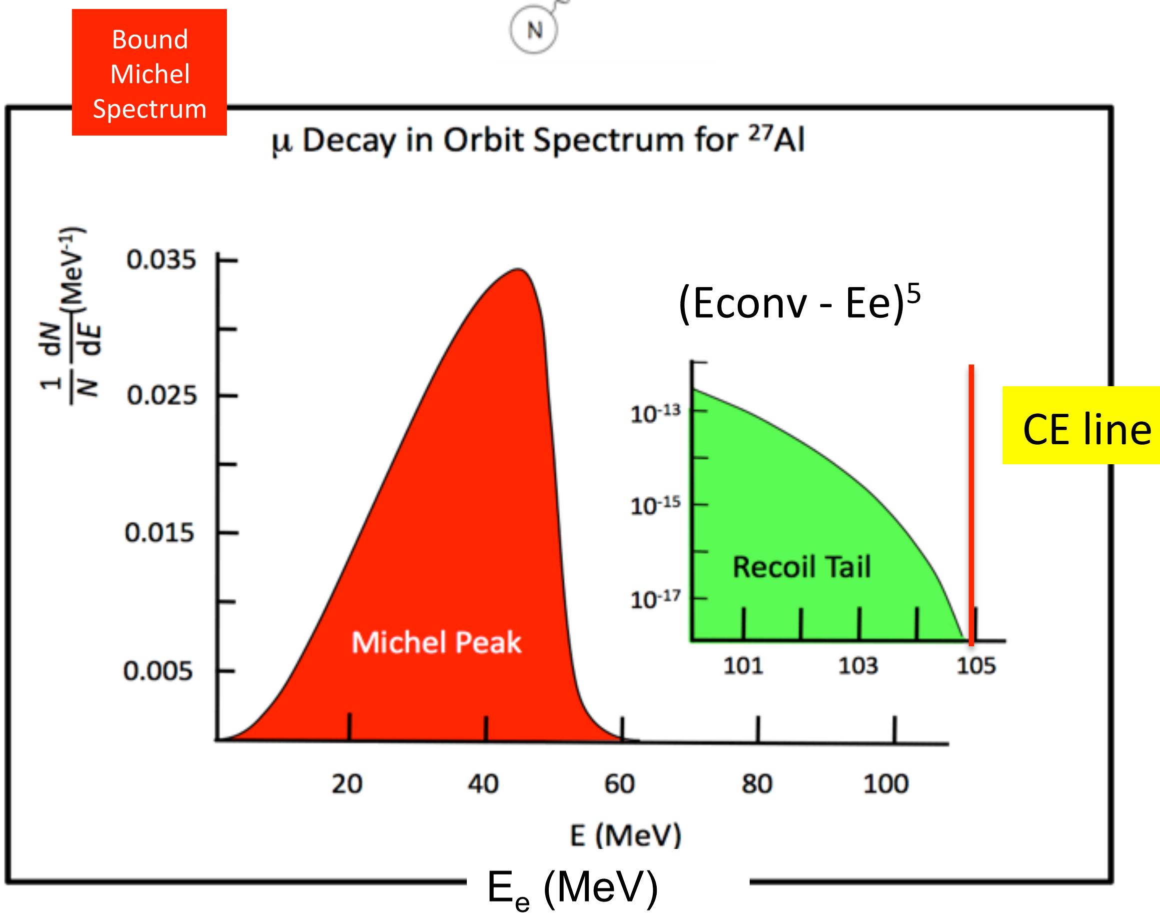
- **The DIO background is the most difficult one.**

- Electron energy distribution from the decay of bound muons is a (modified) Michel spectrum:

→ Presence of atomic nucleus and momentum transfer create a recoil tail with a fast falling slope close to the endpoint

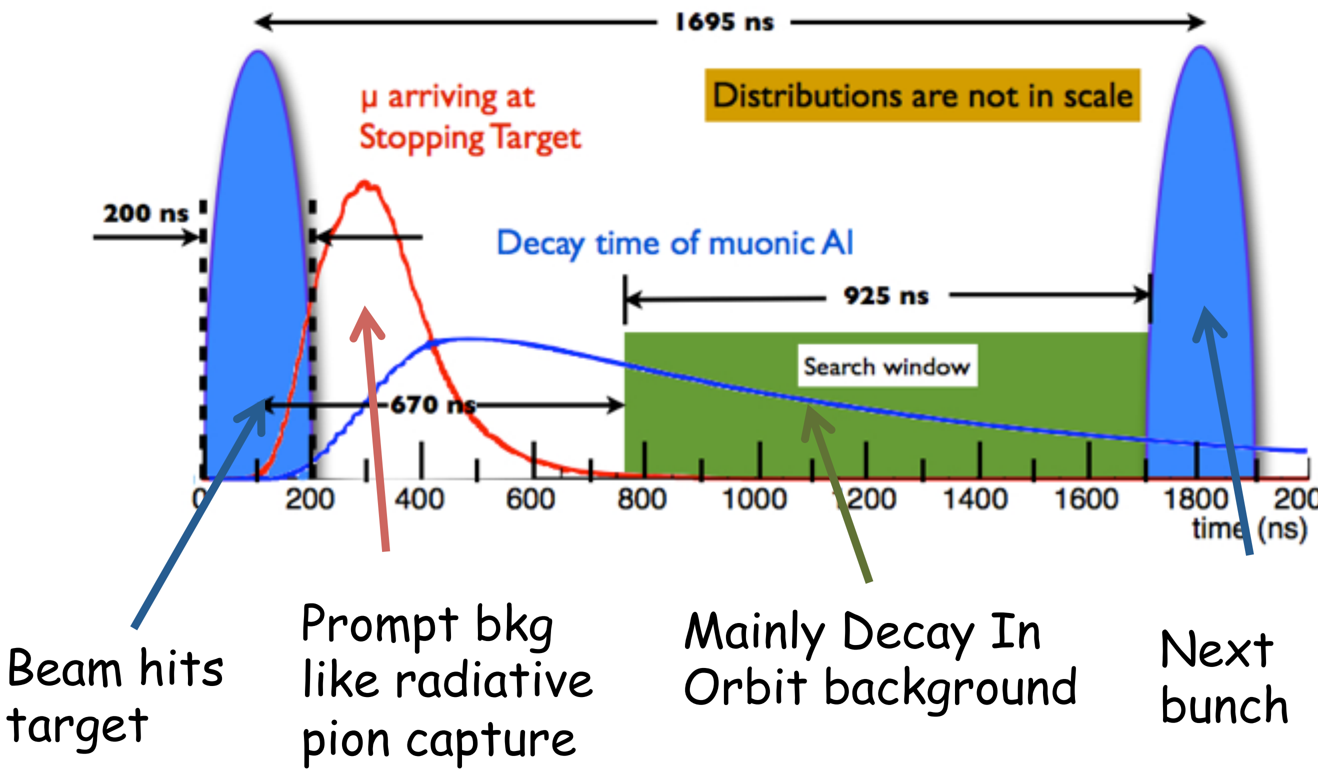
→ To separate DIO endpoint from CE line we need a high Resolution Spectrometer





Czarnecki et al., Phys. Rev. D 84, 013006 (2011) arXiv: 1106.4756v2

Beam structure → prompt background

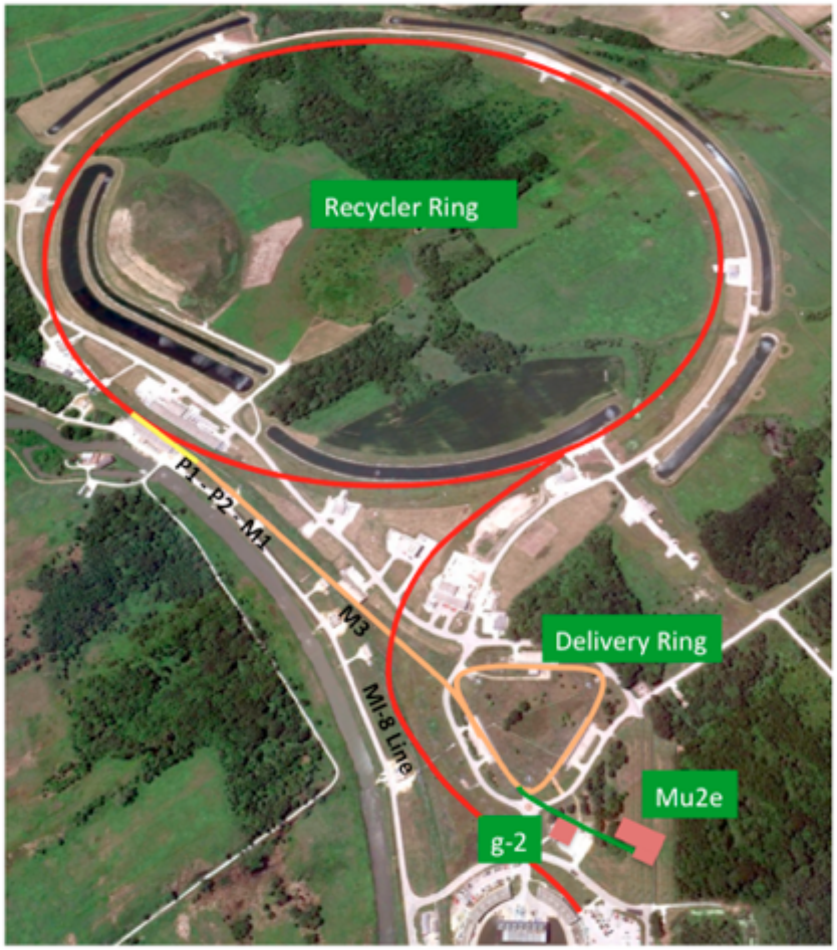


- ❑ **Use the fact that muonic atomic lifetime >> prompt background**
  Need a pulsed beam to wait for prompt background to reach acceptable levels
  → Fermilab provides the beam we need !

- ❑ **OUT of time protons are also a problem.**
  To keep associated background low we need proton extinction of 10^{-10} :
  proton extinction (between pulses) → # protons out of beam/# protons in pulse

Accelerator Scheme & Proton extinction

- Booster: batch of 4×10^{12} protons every 1/15th second
- Booster "batch" is injected into the Recycler ring and re-bunched into 4 bunches
- These are extracted one at a time to the Delivery ring
- As a bunch circulates, protons are extracted to produce the desired beam structure → **bunches of ~3×10^7 protons each, separated by 1.7 μs**



Proton Extinction

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

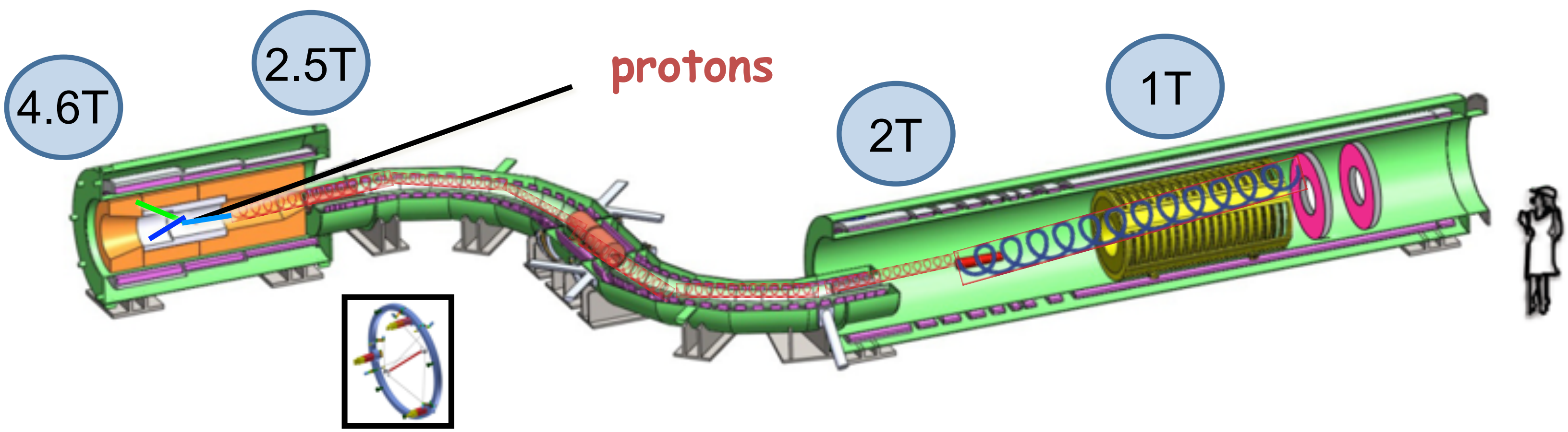
- Internal (momentum scraping) and bunch formation in Accumulator
- External: oscillating (AC) dipole

Calculations based on accelerator models That take into account collective effects Shows that this combination gets ~ 10^{-12}

Muon Beam-line

Production Target / Solenoid (PS)

- 8 GeV Proton beam strikes target, producing mostly pions
- Graded magnetic field contains backwards pions/muons and reflects slow forward pions/muons



→ Heat and radiation shielding
→ Tungsten target.

Transport Solenoid (TS)

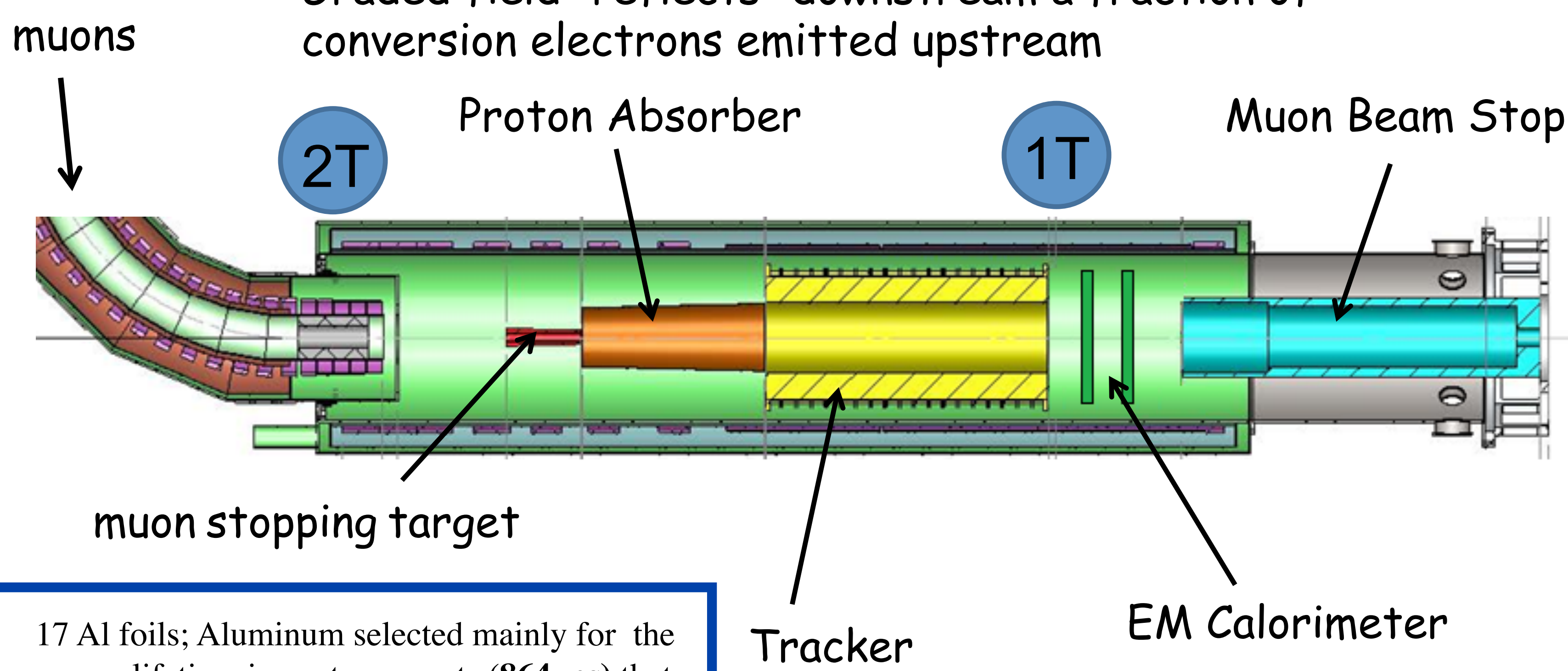
Selects low momentum, negative muons
Antiproton absorber in the mid-section

Target, Detector and Solenoid (DS)

- Capture muons on Al target
- Measure momentum in tracker and energy in calorimeter
- CRV to veto Cosmic Rays event

Detector Solenoid

Graded field "reflects" downstream a fraction of conversion electrons emitted upstream



17 Al foils; Aluminum selected mainly for the muon lifetime in capture events (**864 ns**) that matches nicely the prompt separation in the Mu2e beam structure.

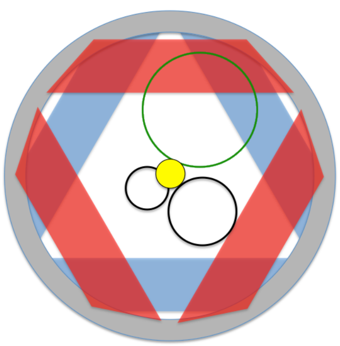
For the sensitivity goal → ~ 6 x 10^{17} stopped muons

For 3 year run , 6 x 10^7 sec → 10^{10} stopped muon/sec

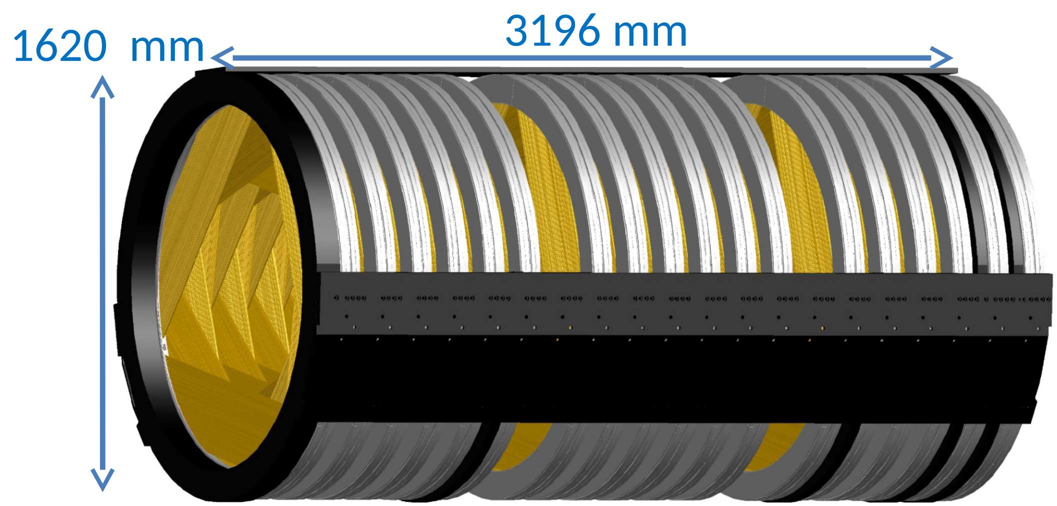
Tracker system

- Tracker is a low mass straw drift tubes design with tubes transverse to secondary beam
- 15 μm thick straw walls, 5 mm diameter, dual-ended readout, length 430 – 1120 mm.
- It must operate in vacuum
- ~ 20000 tubes arranged in planes on stations,
- The tracker has 18 stations.
- Tracking at high radius ensures operability: beam flash produces a lot of low momentum particles, large DIO background. Most of background miss the tracker.

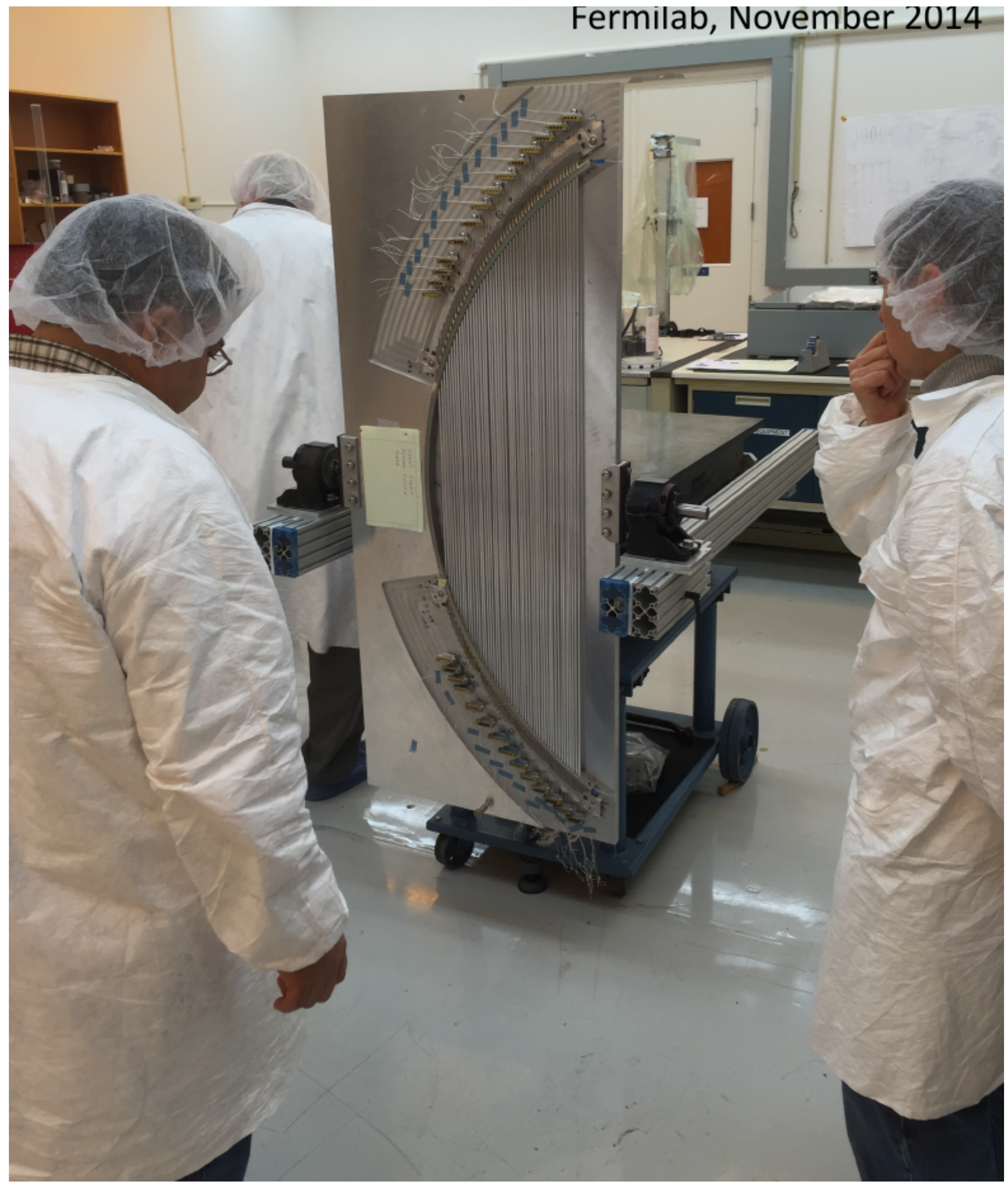
Tracker Plane



Planes rotated



Tracker: Straw panel prototype



- Progressing well.

→ Mechanical properties and gas permeability properties meet Mu2e requirements.

→ Preliminary designs of support and services exist.

Calorimeter System (1)

Calorimeter requirements:

→ Particle Identification to distinguish e/mu
→ Seed for track pattern recognition
→ Tracking independent trigger
→ Work in 1 T field and 10^{-4} Torr vacuum
→ RadHard up to 30 krad, 10^{12} n/cm^2/year

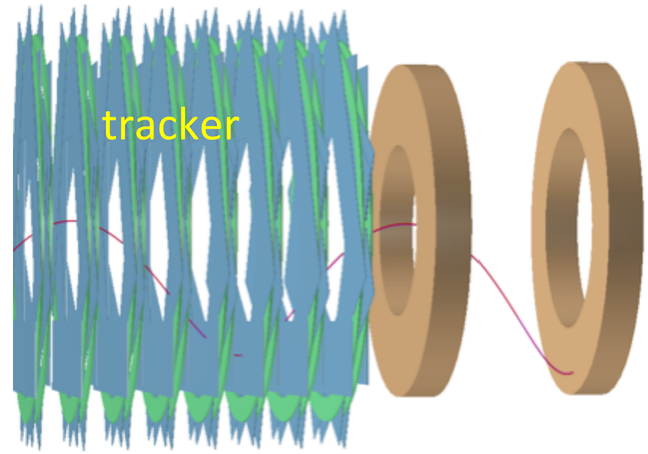
Calorimeter choice:

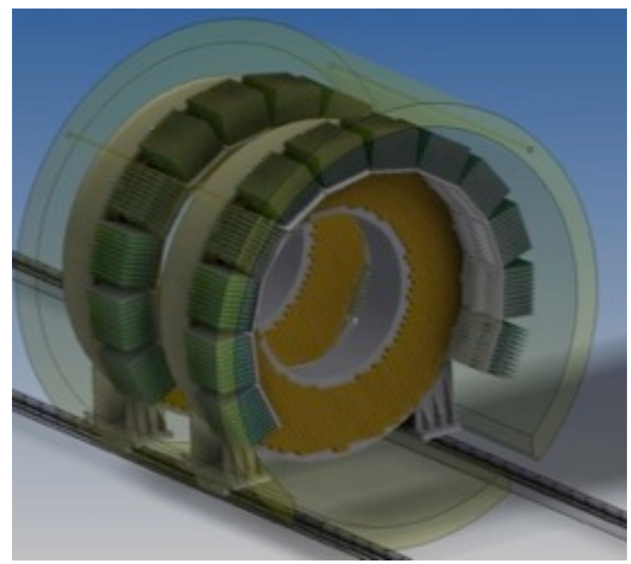
High granularity crystal based calorimeter with:

→ σ/E of O(5%) and Time resolution < 500 ps
→ Position resolution of O(1 cm)
→ almost full acceptance

for CE signal @ 100 MeV

Two disks separated by ½ wavelength (70 cm)





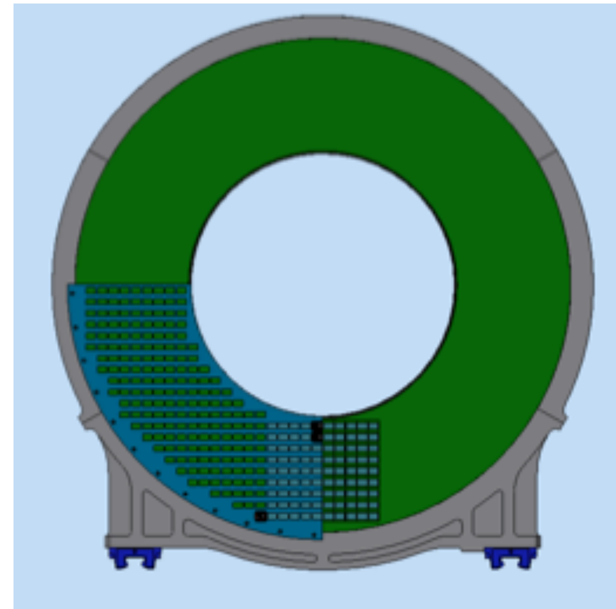
Disk geometry

- Square crystals
- Charge symmetric, can measure $\mu^- N \rightarrow e^+ N$

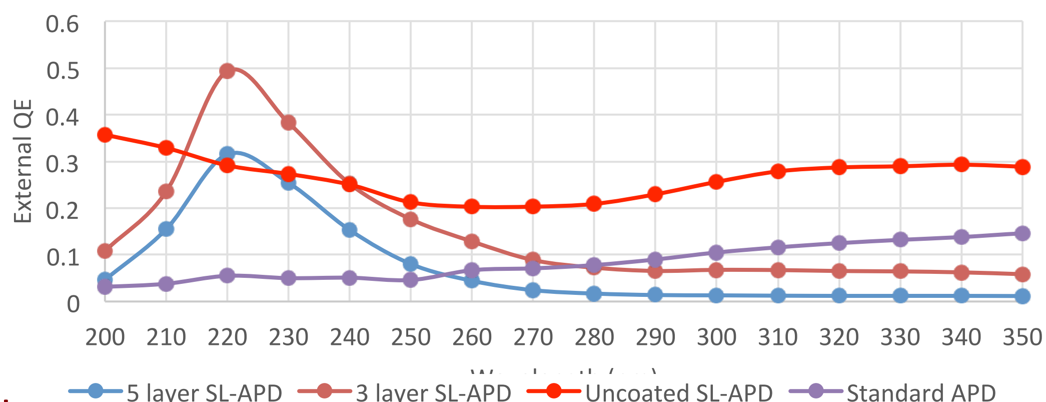
Calorimeter System (2)

The Calorimeter consists of two disks with 1650 BaF_2 square crystals (30x30x200) mm^3

- R_{IN} = 351 mm, R_{OUT} = 660 mm, Depth = 10 X_0 (200 mm)
- Each crystal readout by two SL APDs (9x9 mm^2)
- Analog FEE and digital electronics located on calo
- Radioactive source and laser systems provide absolute calibration and monitoring capability.



To reduce the slow BaF_2 component at higher wavelengths , a Caltech/JPL/RMD consortium formed to develop a RMD APD **into a super-lattice APD with high Q.E. @ 220 nm** that incorporates also **an Atomic Layer Deposition antireflection filter** to reduce efficiency for λ > 300 nm.

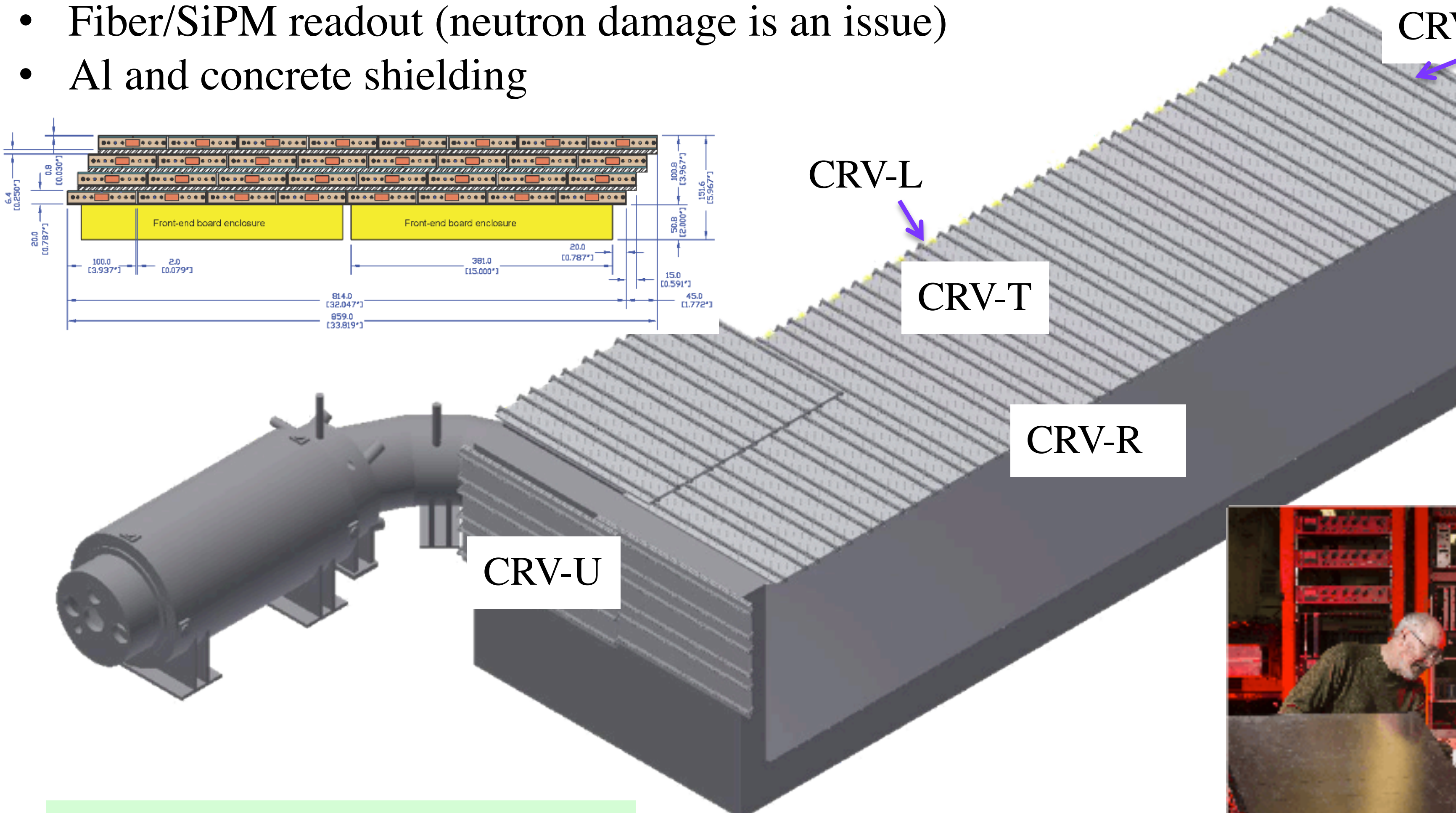


Prototypes with LYSO+APD, CsI+MPPC built
Next one with BaF_2 + SL APDs in progress

Good progresses on FEE and mechanics

Cosmic Ray Veto

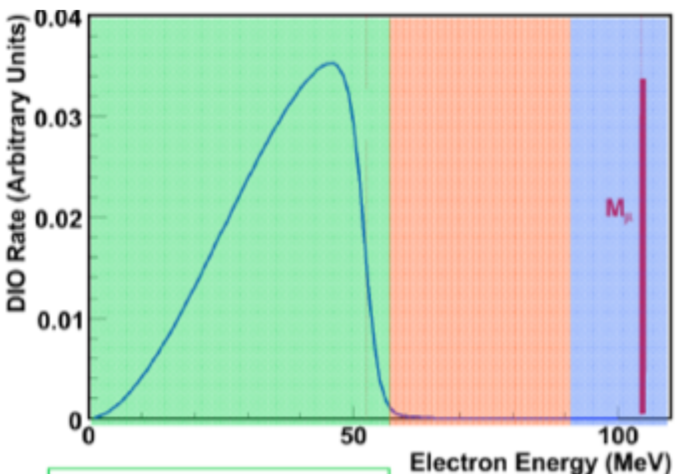
- Four layers of extruded plastic scintillator
- Fiber/SiPM readout (neutron damage is an issue)
- Al and concrete shielding



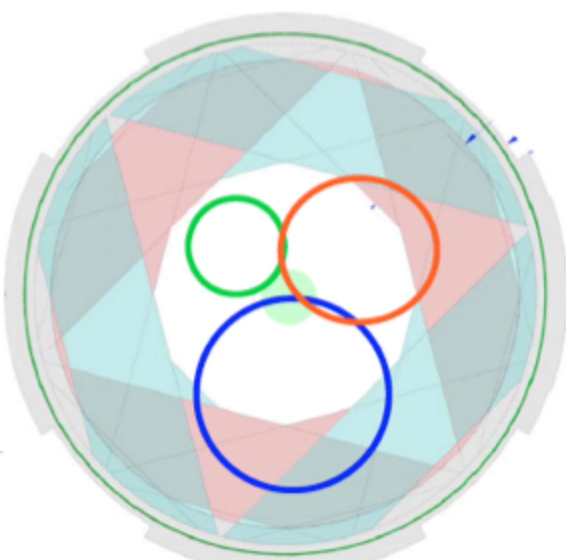
Desired number of bkg: 0.05
Required CR veto inefficiency 10^{-4}

Basic reconstruction scheme

Reconstructable tracks



no hits in tracker



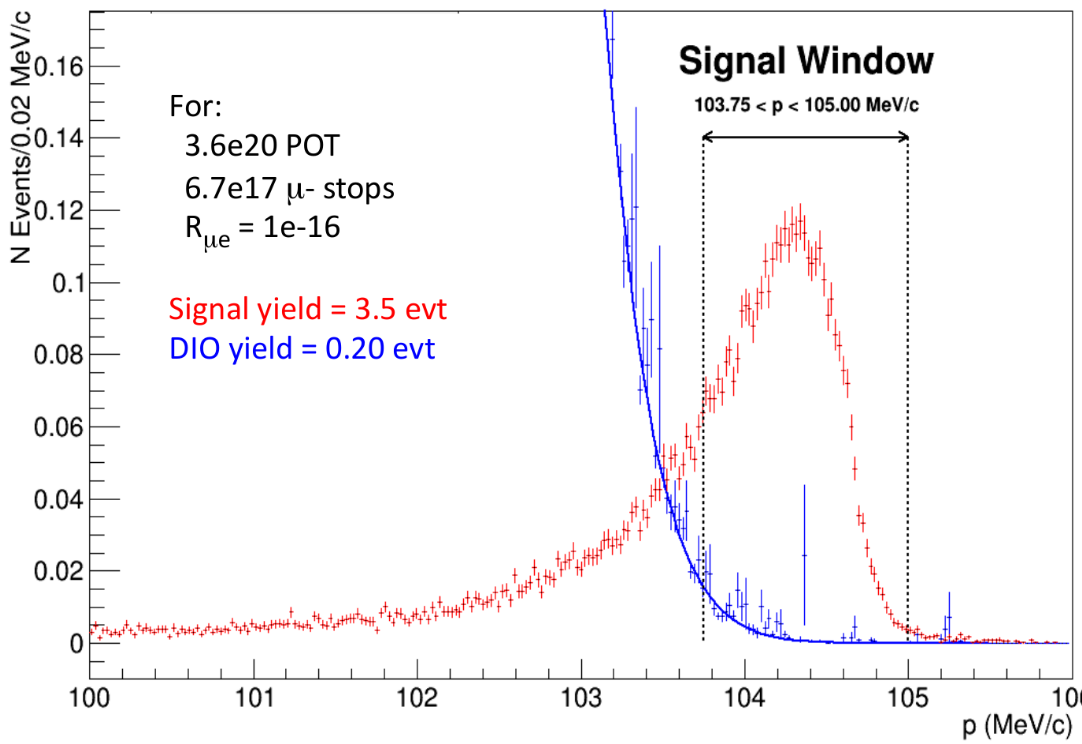
Tracking reconstruction based on
BABAR **Kalman Filter algorithm**

No significant contribution of
mis-reconstructed background

Momentum resolution for CE

core σ~120 keV

tail σ~175 keV (2.5%)



Mu2e Expected Background

(assuming ~ 10 GHz muon stops, $6x10^{17}$ stopped muons in $6x10^7$ s of beam time)

Category	Background process	Estimated yield (events)
Intrinsic	Muon decay-in-orbit (DIO)	0.199 ± 0.092
	Muon capture (RMC)	$0.000^{+0.004}_{-0.000}$
Late Arriving	Pion capture (RPC)	0.023 ± 0.006
	Muon decay-in-flight (μ-DIF)	<0.003
	Pion decay-in-flight (π-DIF)	$0.001 \pm <0.001$
	Beam electrons	0.003 ± 0.001
Miscellaneous	Antiproton induced	0.047 ± 0.024
	Cosmic ray induced	0.092 ± 0.020
	Total	0.37 ± 0.10

Discovery sensitivity accomplished by suppressing backgrounds to < 0.5 event total

Upper Limit < 6×10^{-17} @ 90% C.L.

Mu2e Schedule and plans

- CD2 for detectors (baseline/TDR) obtained on the 5th of March 2015
- CD3b for Civil Construction and start for TS Bid obtained on same date.

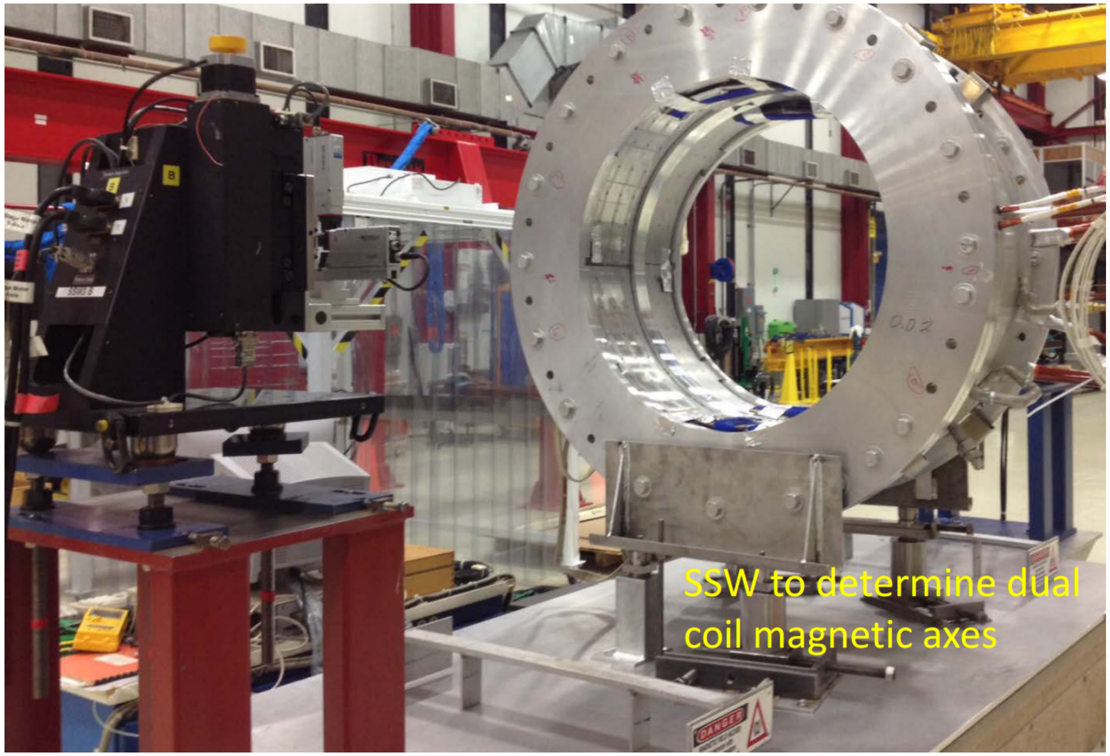
- **Final signatures from DOE done:**
  → Procurement of Superconducting cables in progress
  → Bid for DS/PS assigned to General Atomics
  → Bid for TS completed and assigned.
  → Civil Construction started**: Ground Breaking Cerimony Apr. 18**.

- IDR/CD3 for detectors planned for spring/summer 2016

- **Overall DOE budget secured, 274 M$**.

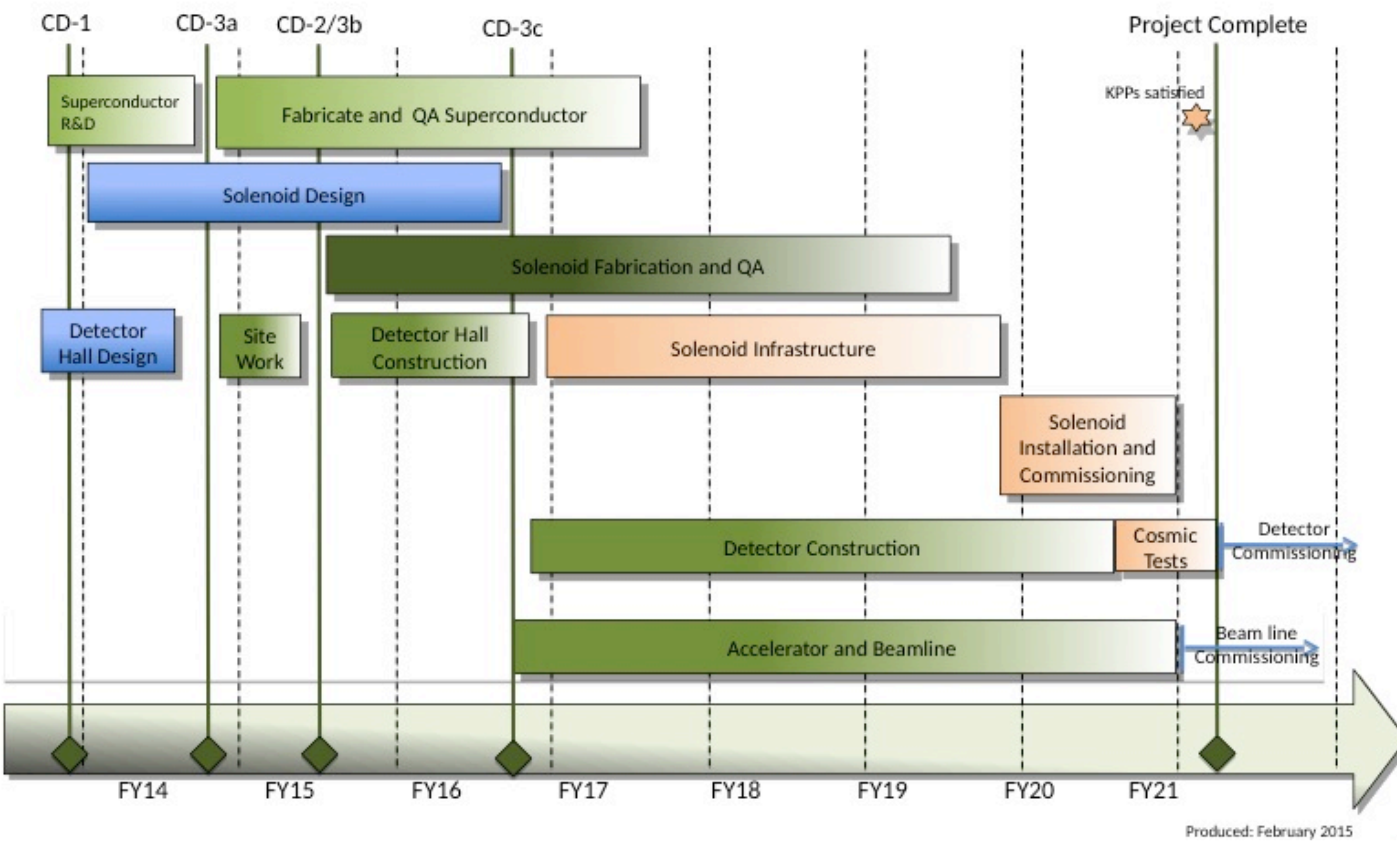

MEL-ROL

Status of Magnetic System



- ❑ **The Super Conducting magnets are the heart of MU2E Apparatus**
- ❑ PS and DS bid is over. **They will be built by General Atomics, USA**
- ❑ TS prototype manufactured by ASG Superconductors, INFN Genova and Fermilab Technical division.
- ❑ **TS proto @ FNAL since December 2014.**
- ❑ Three final tests done in August 2015: alignment, current and temperature
  → Results were really satisfactory …. exceeding expectation

Mu2e project schedule



Conclusions

- **The Mu2e experiment is a CLVF first-class experiment looking for physics BSM with high complementarity to other programs while increasing reach and diversification in models testing.**

- **MU2E will improve previous conversion experiment of 4 orders of magnitude and probe mass scales up to hundreds of TeV.**

- **< 10 years Timeline for completion of first phase.**

- **Mu2e has completed the CD-2 and CD3 for the long lead items**

  → Construction of the solenoids will start next year.

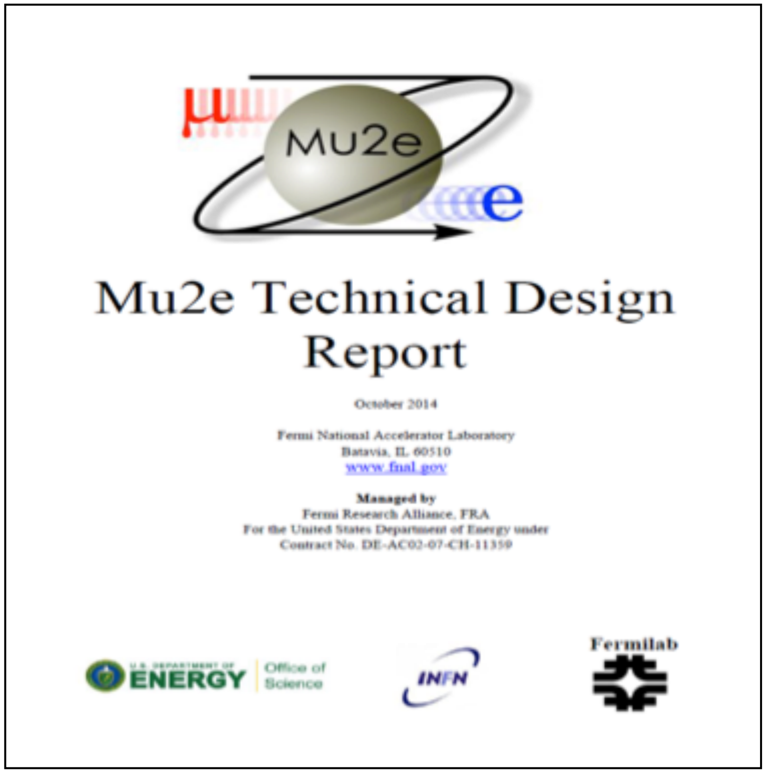
  → Detector Review in spring 2016 to freeze detector with CD3 in summer 2016

  → Construction period 2016-2018 followed by installation in 2019

- **A longer term plan is being discussed.**
- **a Mu2e-2 phase being planned for a (x 10) increase in intensity and sensitivity!**

Additional Material

Mu2e TDR

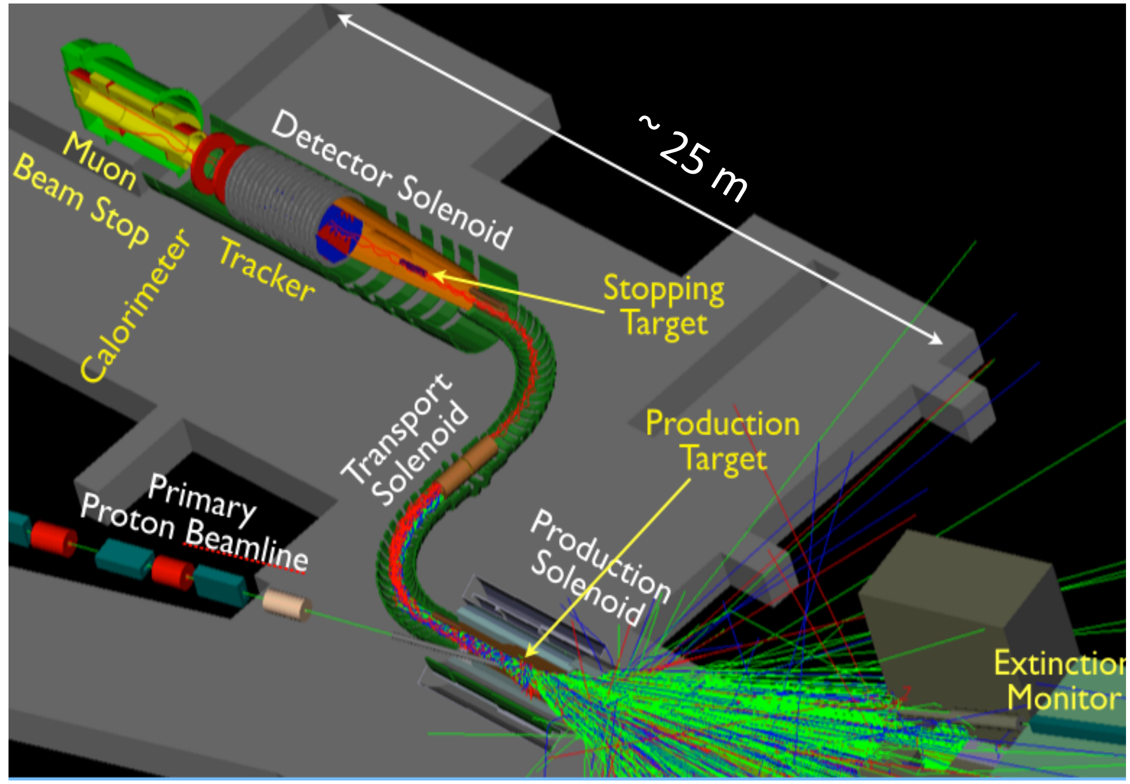

Mu2e Technical Design Report

October 2014

Fermi National Accelerator Laboratory
Batavia, IL 60510
www.fnal.gov

Managed by
Fermi Research Alliance, FRA
For the United States Department of Energy under
Contract No. DE-AC02-07-CH-11359

Fermilab



http://mu2e.fnal.gov/

TDR available at http://arxiv.org/abs/1501.05241

(WhatNext?) Mu2e → Mu2e-2

Project-X re-imagined to match Budget constraints:

1) PIP-2 plans:

→ 1 MW at LNBF at start (2025)
→ 2 MW at regime at LNBF
→ **x 10 at Mu2e**

Projectx-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1232
CLVF-snowmass →Arxiv.1311.5278
Mu2e-2 → Arxiv.1307.1168v2.pdf

2) **Depending on the beam Structure available:**
→ study Z dependence
if signal is observed

3) If no signal is observed
Use x 10 events in Mu2e-2

Minor modifications of the detector → **BR < 6 x 10^{-18}**

V. Cirigliano, R. Kitano, Y. Okada, P. Tuzon., arXiv:0904.0957 [hep-ph]
Phys.Rev. D80 (2009) 013002

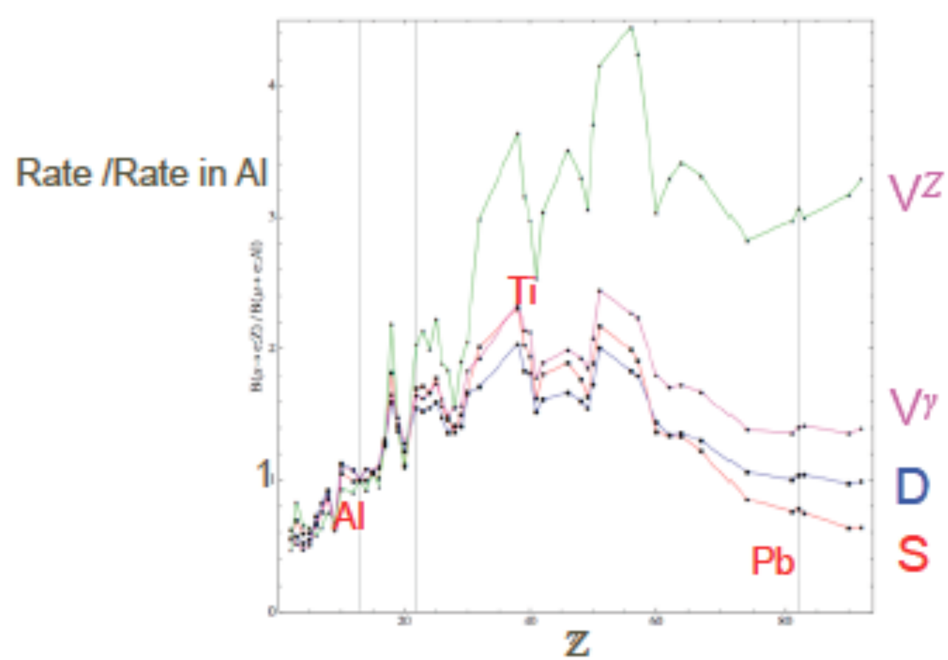


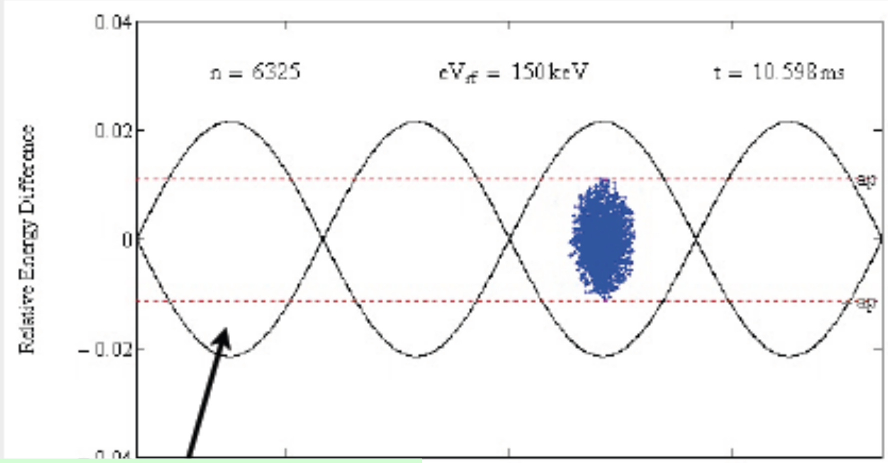
Figure 3: Target dependence of the $\mu \to e$ conversion rate in different single-operator dominance models. We plot the conversion rates normalized to the rate in Aluminum ($Z = 13$) versus the atomic number Z for the four theoretical models described in the text: D (blue), S (red), $V^{(\gamma)}$ (magenta), $V^{(Z)}$ (green). The vertical lines correspond to $Z = 13$ (Al), $Z = 22$ (Ti), and $Z = 83$ (Pb).

Out of Time proton → Extinction Method

Proton extinction between pulses → # protons out of beam/# protons in pulse

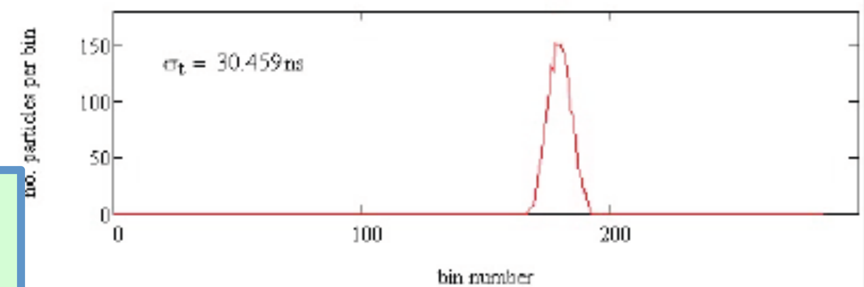
achieving 10^{-10} is hard; normally get $10^{-2} – 10^{-3}$

- Internal (momentum scraping) and bunch formation in Accumulator
- External: oscillating (AC) dipole
  - high frequency (300 KHz) dipole with smaller admixture of 17th harmonic (5.1 MHz)
  - Sweep Unwanted Beam into collimators



Momentum Scrape

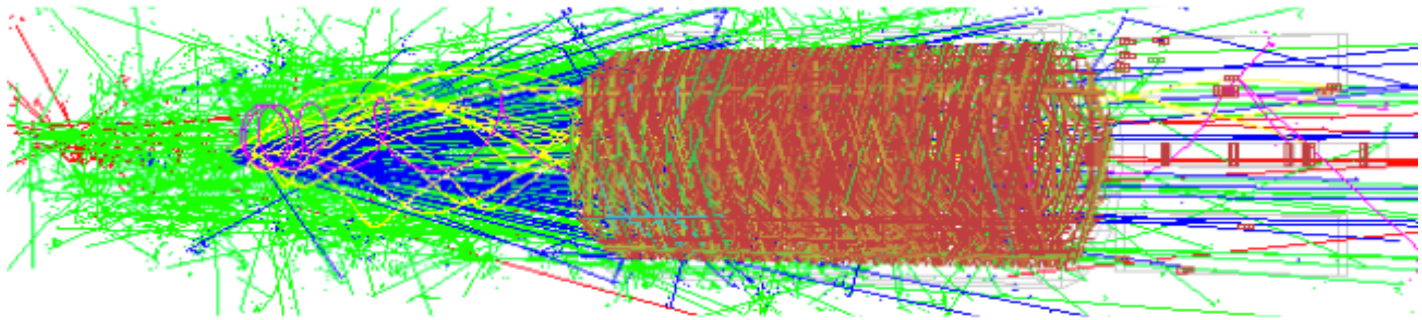
$$|dE/E| = x_{max}/D$$



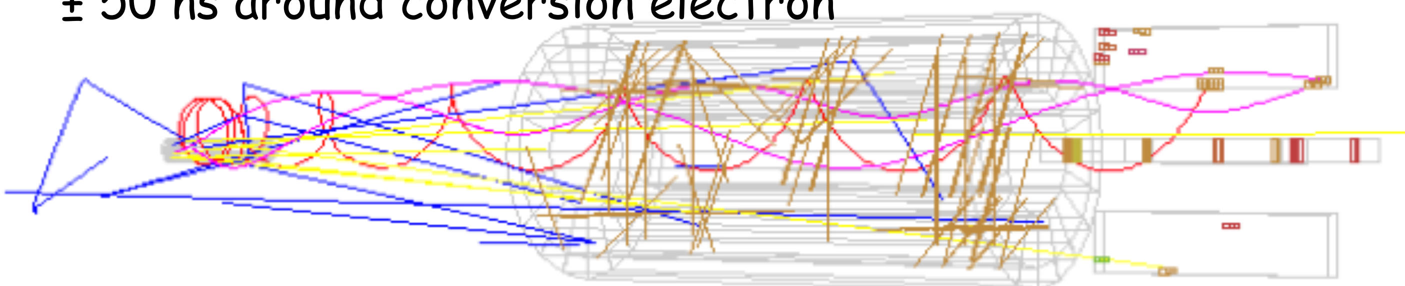
Calculations based on accelerator models That take into account collective effects Shows that this combination gets ~ 10^{-12}

A typical Mu2e event: Calo track seeding

500 – 1695 ns window

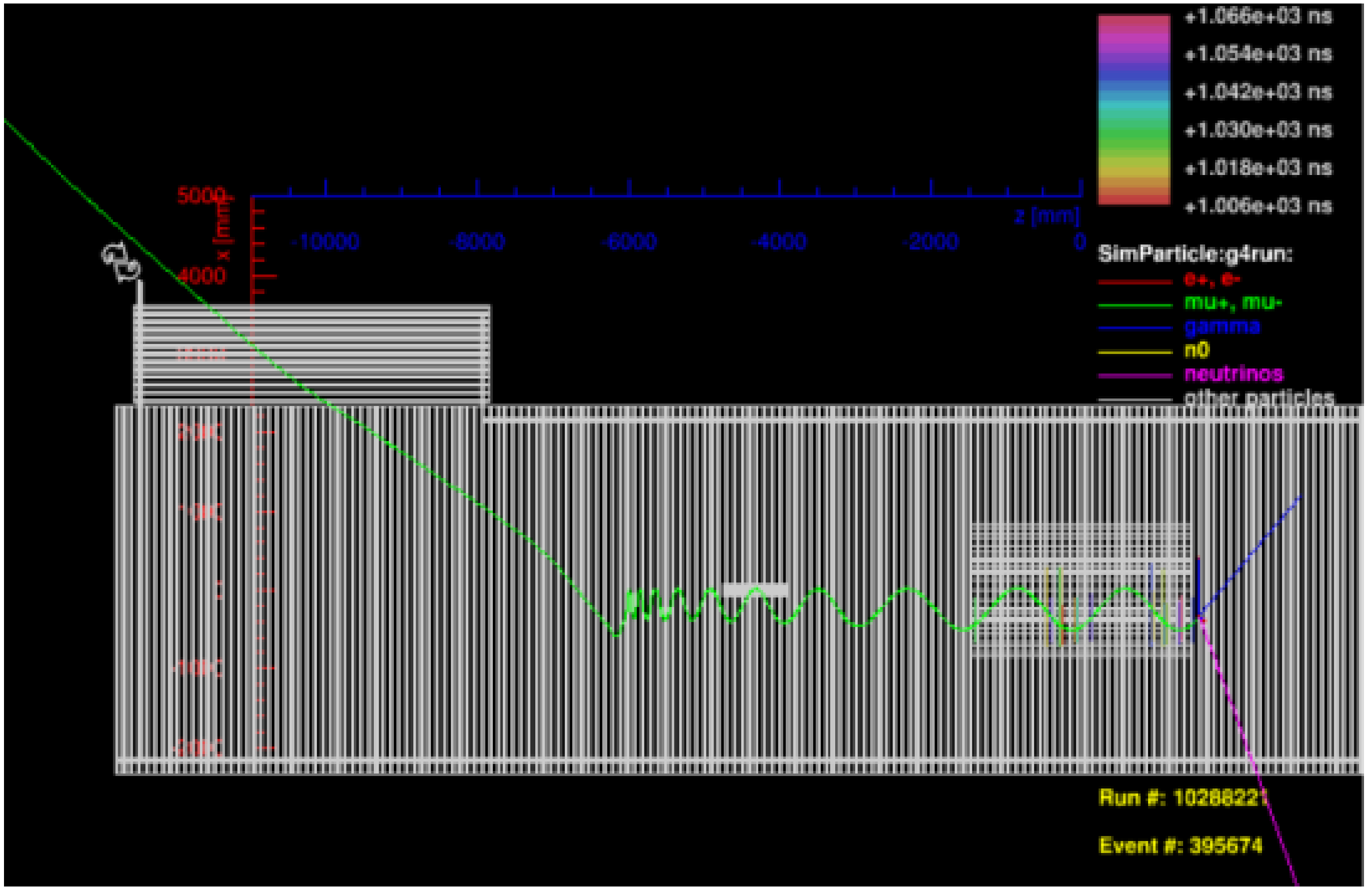


± 50 ns around conversion electron



- ❑ Search for tracking hits with time and azimuthal angle compatible with the calorimeter clusters ($|\Delta T| < 50$ ns) → simplification of pattern recognition
- ❑ Add search of an Helix passing through cluster and selected hits + use calorimeter time to calculate tracking Hit drift times.
  → Reduce the wrong drift sign assignments i.e. **smaller positive momentum tail**

"fake" CE from CR events



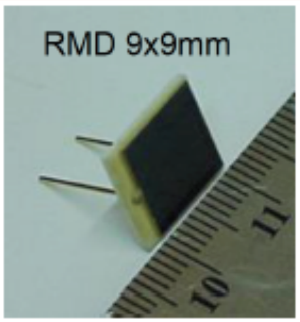
- ❑ A long MC production used to optimize the CRV geometry by generating the same amount of cosmics that will cross the detector in MU2E running period.
- ❑ **few events evaded the CRV**, passing closely enough to the target, were tracked by the tracker and passed all reconstruction tracking criteria. They were all μ^- → **rejected due to the combination of Calorimeter and tracking information : timing and *E*/*p***

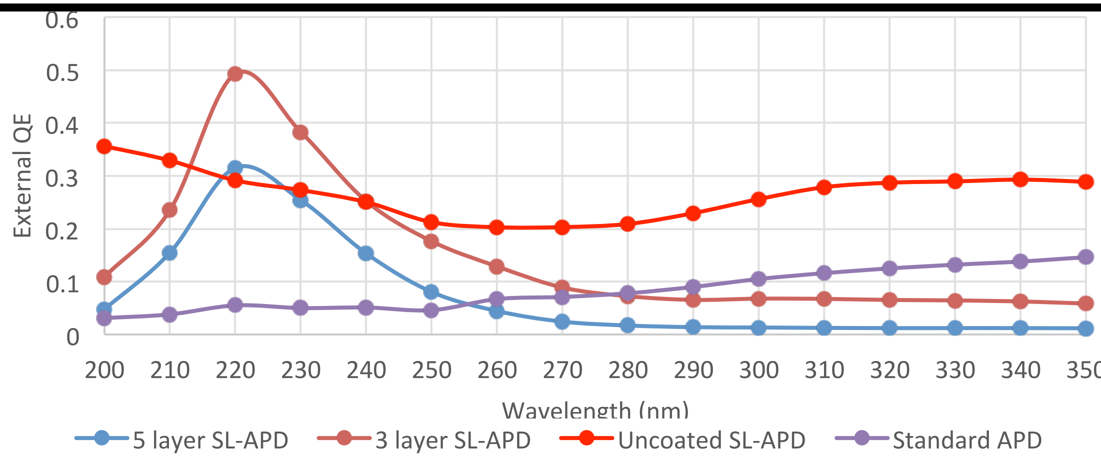
Photosensors Choice

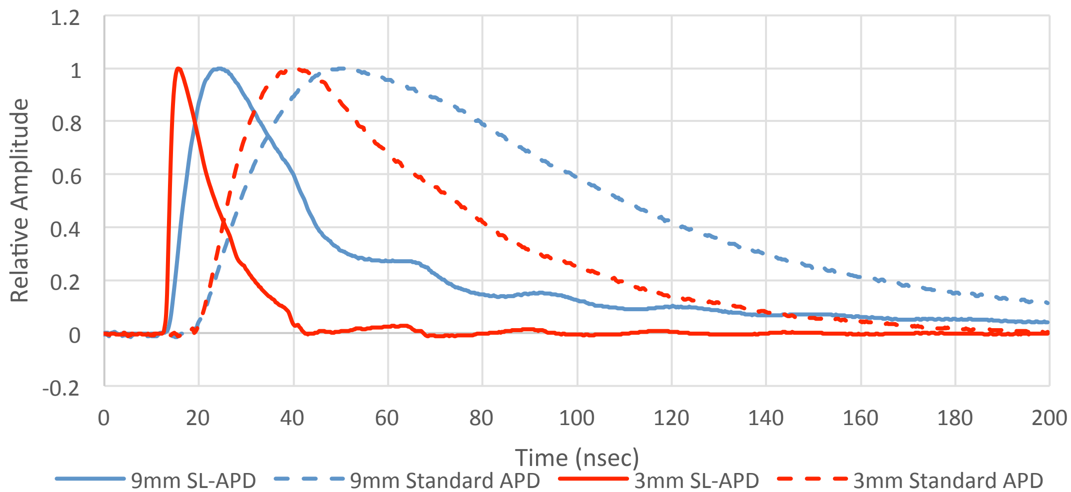
A Caltech/JPL/RMD consortium formed to develop a Large area RMD APD **into a super-lattice APD with high Q.E. @ 220 nm** incorporating also **an Atomic Layer Deposition antireflection filter** to reduce efficiency for wavelength > 300 nm.

- ✓ 60% QE @ 220 nm
- ✓ ~ 0.1 % QE @ 300 nm
- ✓ capacitance ~ 60 pF (1/5 of Ham S8664)
- ✓ HV ~ 1800 V
- ✓ Operation Gain ~ 500
- ✓ Decay time ~ 25 ns.

deltadoped APD from RMD

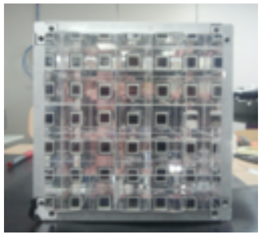


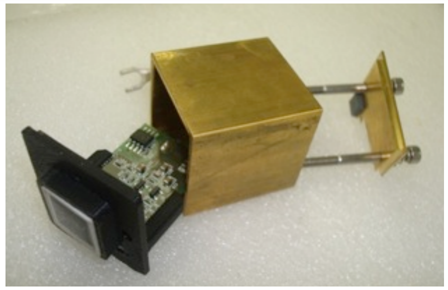


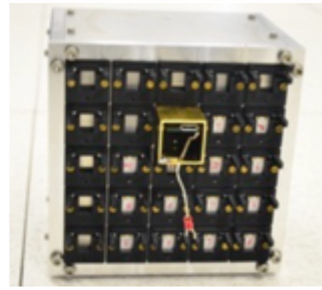


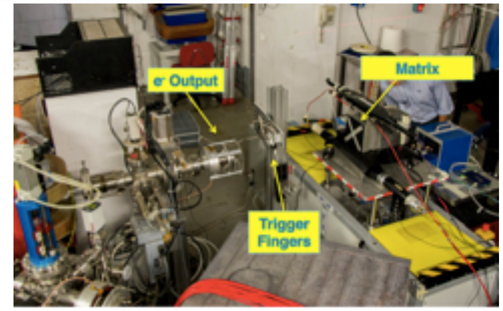
32

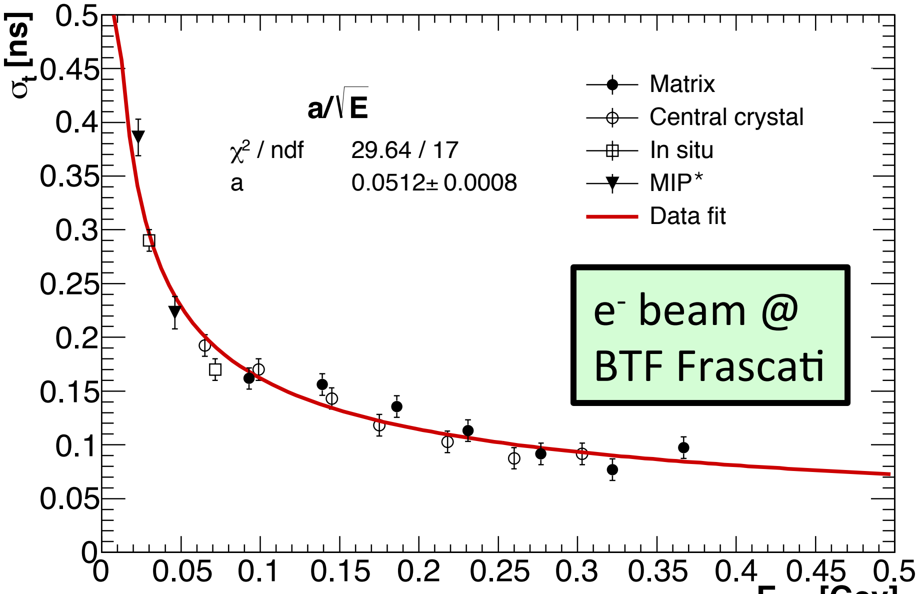
LYSO Legacy



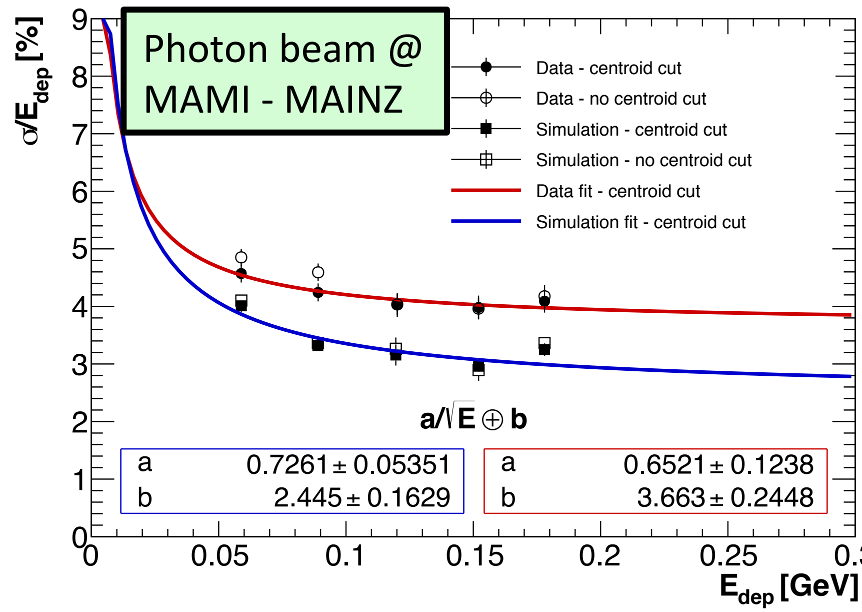








*Time resolution with MIPs from Mu2e DocDB 4409



σ_T = 51 ps/sqrt(E/GeV)
compare with KLOE
~ 55 ps/sqrt(E/GeV)

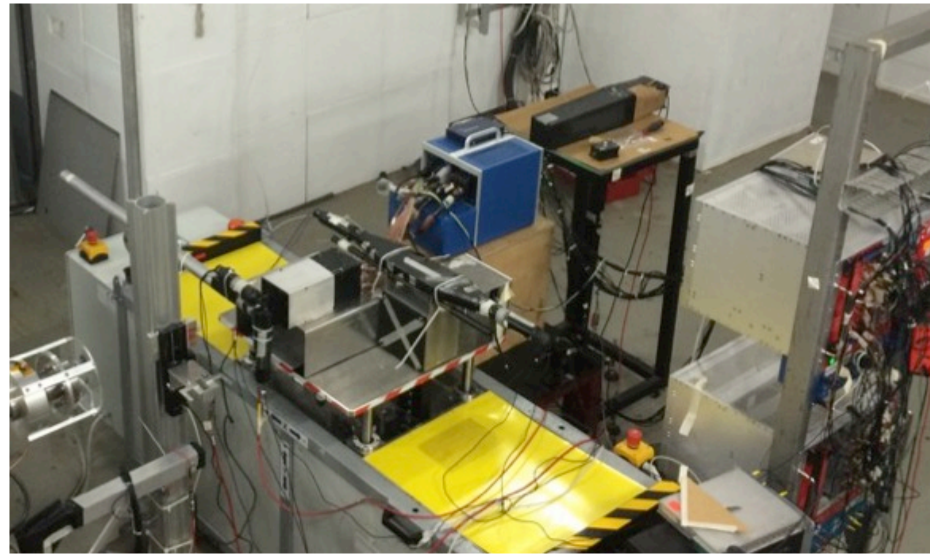
Energy resolution as a function of the energy deposition fitted with the function:

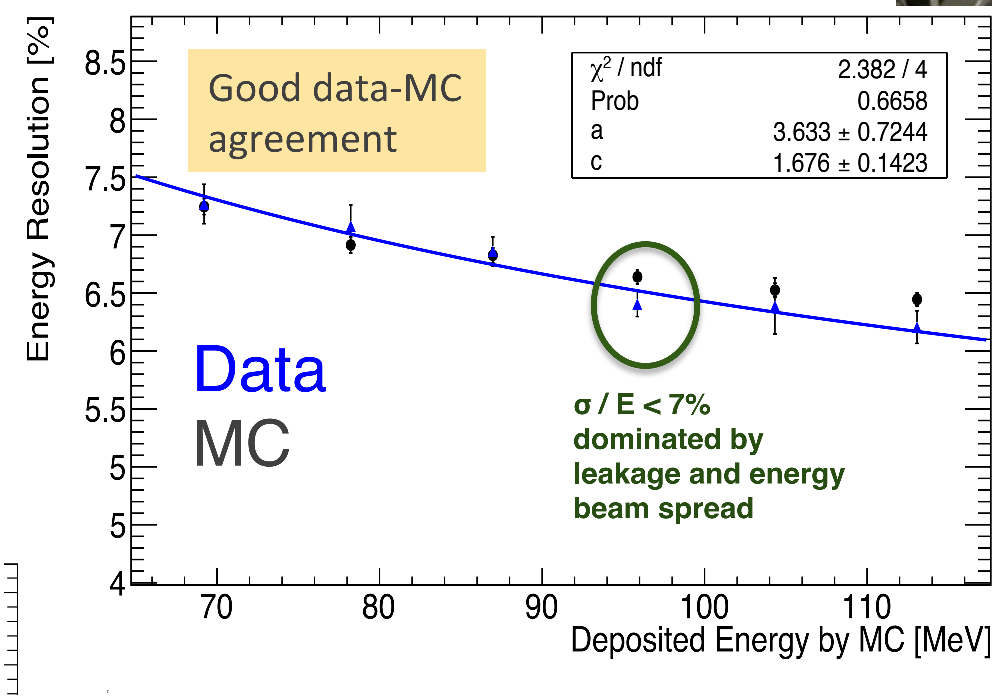
~ 4% @ 100 MeV

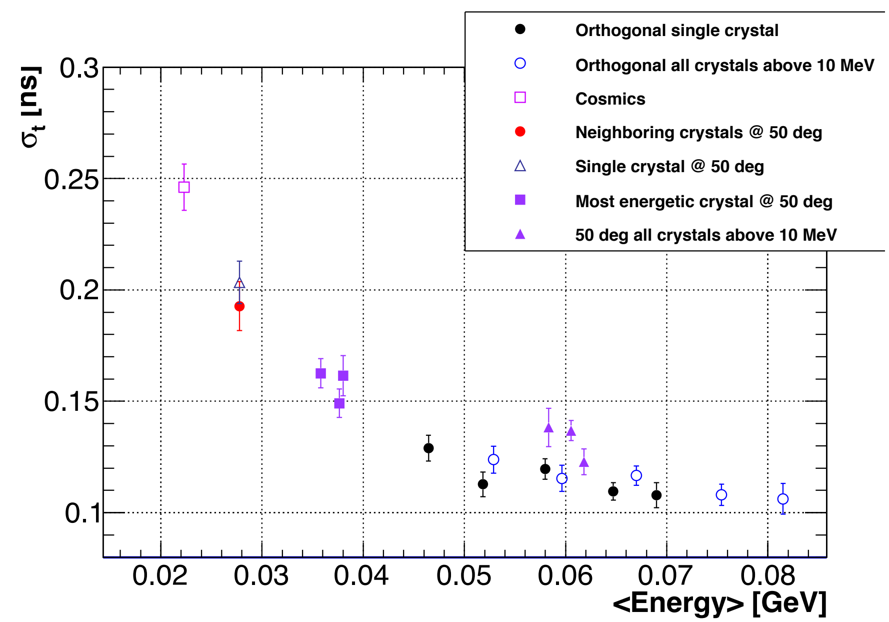
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

Noise term *b* considered negligible (~0.1% in quadrature).

CsI+MPPC backup option

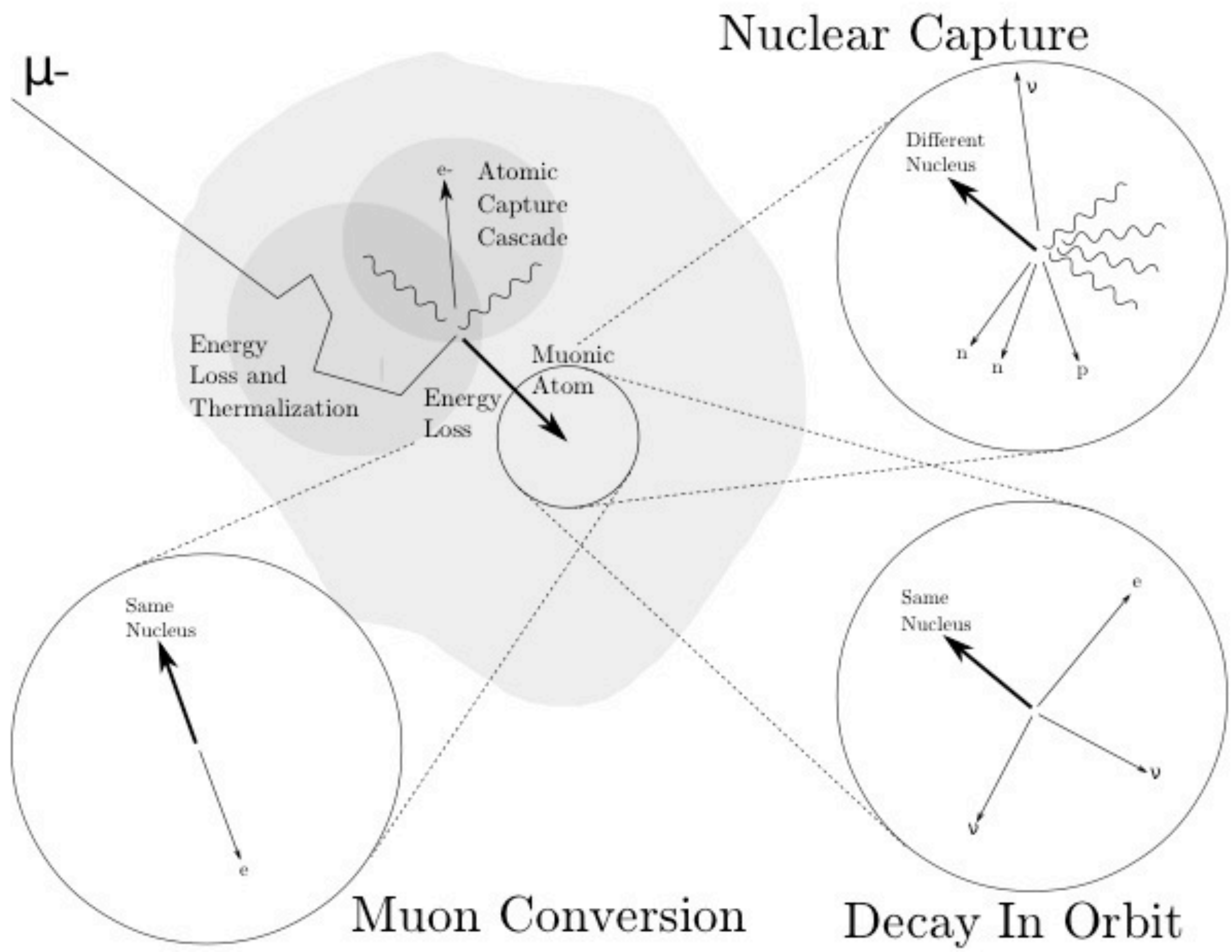






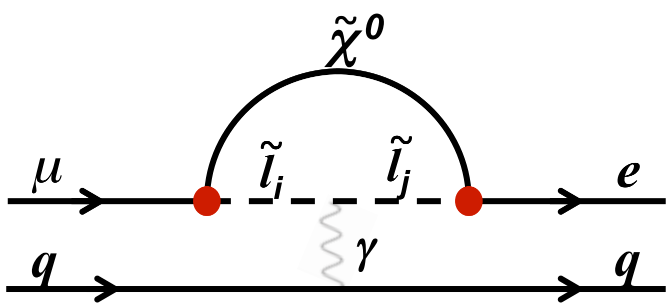
Muon Processes

The atomic, nuclear, and particle physics of μ^- drive the design of the experiment



Specific Example: SUSY

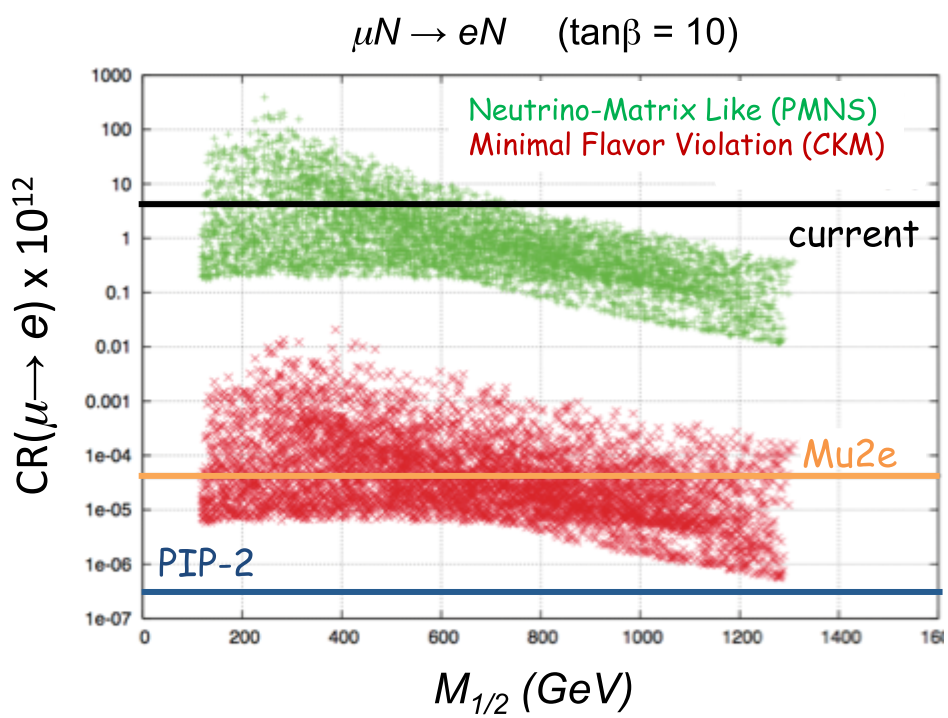
Probe SUSY through loops



If SUSY seen at LHC → rate ~10^{-15}

Implies ~ 40-50 signal events with negligible background in Mu2e for many SUSY models.

SUSY GUT in an SO(10) framework



L. Calibbi et al., hep-ph/0605139

Complementary with the LHC experiments while providing models' discrimination

Other CLFV Predictions

M.Blanke, A.J.Buras, B.Duling, S.Recksiegel, C.Tarantino

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$	$0.02\ldots1$	$\sim 6\cdot10^{-3}$	$\sim 6\cdot10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.4$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.4$	$\sim 2\cdot10^{-3}$	$0.06\ldots0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.3$	$\sim 2\cdot10^{-3}$	$0.02\ldots0.04$
$\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$0.8\ldots2.0$	~ 5	$0.3\ldots0.5$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau^-\to \mu^-e^+e^-)}$	$0.7\ldots1.6$	~ 0.2	$5\ldots10$
$\frac{R(\mu\mathrm{Ti}\to e\mathrm{Ti})}{Br(\mu\to e\gamma)}$	$10^{-3}\ldots10^{2}$	$\sim 5\cdot10^{-3}$	$0.08\ldots0.15$

arXiv:0909.5454v2[hep-ph]

Table 3: *Comparison of various ratios of branching ratios in the LHT model ($f = 1\,\mathrm{TeV}$) and in the MSSM without [92, 93] and with [96, 97] significant Higgs contributions.*

- **Relative rates are model dependent**
- **Measure ratios to pin-down theory details**

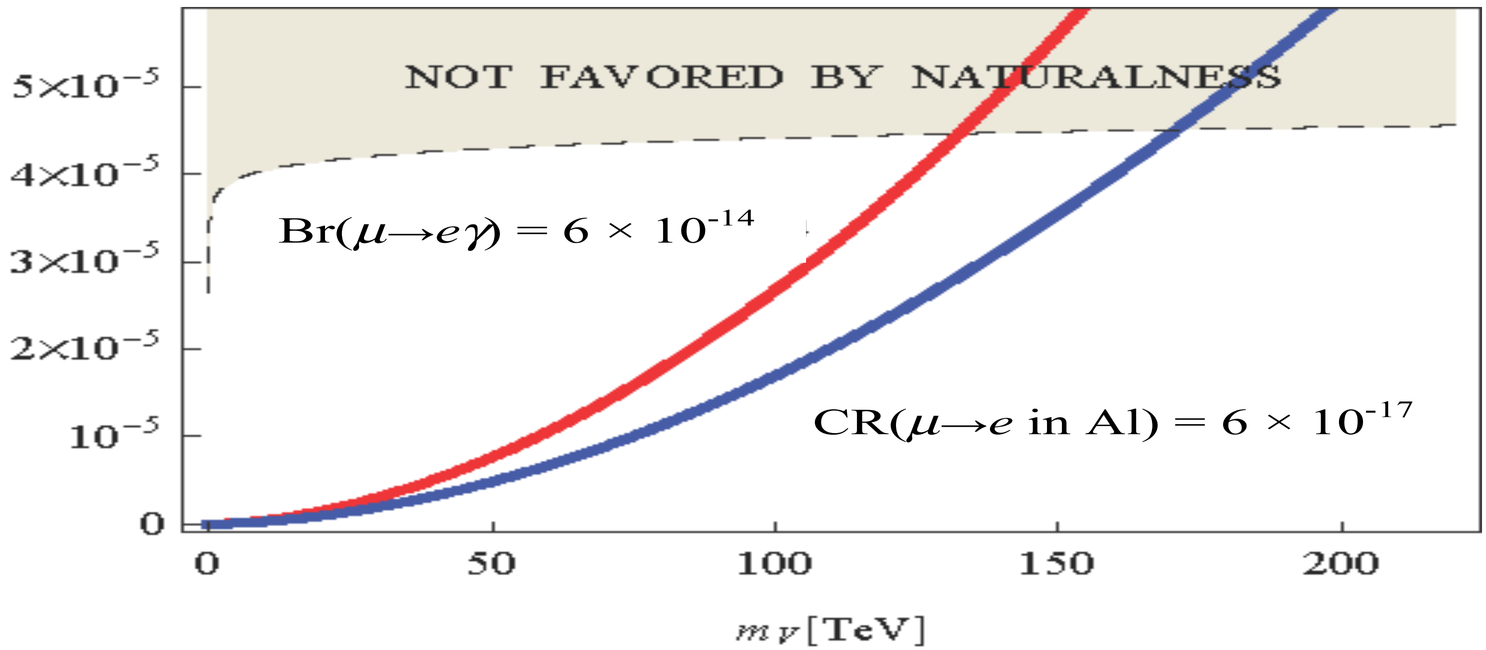
SUSY benchmark points vs LHC

TABLE XII: LFV rates for points **SPS 1a** and **SPS 1b** in the CKM case and in the $U_{e3} = 0$ PMNS case. The processes that are within reach of the future experiments (MEG, SuperKEKB) have been highlighted in boldface. Those within reach of post–LHC era planned/discussed experiments (PRISM/PRIME, Super Flavour factory) highlighted in italics.

	SPS 1a		SPS 1b		SPS 2		SPS 3		Future
Process	CKM	$U_{e3}=0$	CKM	$U_{e3}=0$	CKM	$U_{e3}=0$	CKM	$U_{e3}=0$	Sensitivity
$\mathrm{BR}(\mu \to e\,\gamma)$	$\mathbf{3.2 \cdot 10^{-14}}$	$\mathbf{3.8 \cdot 10^{-13}}$	$\mathbf{4.0 \cdot 10^{-13}}$	$\mathbf{1.2 \cdot 10^{-12}}$	$1.3 \cdot 10^{-15}$	$8.6 \cdot 10^{-15}$	$1.4 \cdot 10^{-15}$	$1.2 \cdot 10^{-14}$	$\mathcal{O}(10^{-14})$
$\mathrm{BR}(\mu \to e\,e\,e\,)$	$2.3 \cdot 10^{-16}$	$2.7 \cdot 10^{-15}$	$2.9 \cdot 10^{-16}$	$8.6 \cdot 10^{-15}$	$9.4 \cdot 10^{-18}$	$6.2 \cdot 10^{-17}$	$1.0 \cdot 10^{-17}$	$8.9 \cdot 10^{-17}$	$\mathcal{O}(10^{-14})$
$\mathrm{CR}(\mu \to e \text{ in Ti})$	$\mathit{2.0 \cdot 10^{-15}}$	$\mathit{2.4 \cdot 10^{-14}}$	$\mathit{2.6 \cdot 10^{-15}}$	$\mathit{7.6 \cdot 10^{-14}}$	$\mathit{1.0 \cdot 10^{-16}}$	$\mathit{6.7 \cdot 10^{-16}}$	$\mathit{1.0 \cdot 10^{-16}}$	$\mathit{8.4 \cdot 10^{-16}}$	$\mathcal{O}(10^{-18})$
$\mathrm{BR}(\tau \to e\,\gamma)$	$2.3 \cdot 10^{-12}$	$6.0 \cdot 10^{-13}$	$3.5 \cdot 10^{-12}$	$1.7 \cdot 10^{-12}$	$1.4 \cdot 10^{-13}$	$4.8 \cdot 10^{-15}$	$1.2 \cdot 10^{-13}$	$4.1 \cdot 10^{-14}$	$\mathcal{O}(10^{-8})$
$\mathrm{BR}(\tau \to e\,e\,e)$	$2.7 \cdot 10^{-14}$	$7.1 \cdot 10^{-15}$	$4.2 \cdot 10^{-14}$	$2.0 \cdot 10^{-14}$	$1.7 \cdot 10^{-15}$	$5.7 \cdot 10^{-17}$	$1.5 \cdot 10^{-15}$	$4.9 \cdot 10^{-16}$	$\mathcal{O}(10^{-8})$
$\mathrm{BR}(\tau \to \mu\,\gamma)$	$5.0 \cdot 10^{-11}$	$\mathbf{1.1 \cdot 10^{-8}}$	$7.3 \cdot 10^{-11}$	$\mathbf{1.3 \cdot 10^{-8}}$	$2.9 \cdot 10^{-12}$	$\mathit{7.8 \cdot 10^{-10}}$	$2.7 \cdot 10^{-12}$	$\mathit{6.0 \cdot 10^{-10}}$	$\mathcal{O}(10^{-9})$
$\mathrm{BR}(\tau \to \mu\,\mu\,\mu)$	$1.6 \cdot 10^{-13}$	$3.4 \cdot 10^{-11}$	$2.2 \cdot 10^{-13}$	$3.9 \cdot 10^{-11}$	$8.9 \cdot 10^{-15}$	$2.4 \cdot 10^{-12}$	$8.7 \cdot 10^{-15}$	$1.9 \cdot 10^{-12}$	$\mathcal{O}(10^{-8})$

- These are SuSy benchmark points for which LHC has discovery sensitivity
- Some of these will be observable by MEG/Belle-2
- All of these will be observable by Mu2e

Specific example: Leptoquarks



Leptoquarks

Presenza di leptoquarks alla scala del TeV potreb
indurre processi CLFV con una costante di accoppiamento λ.

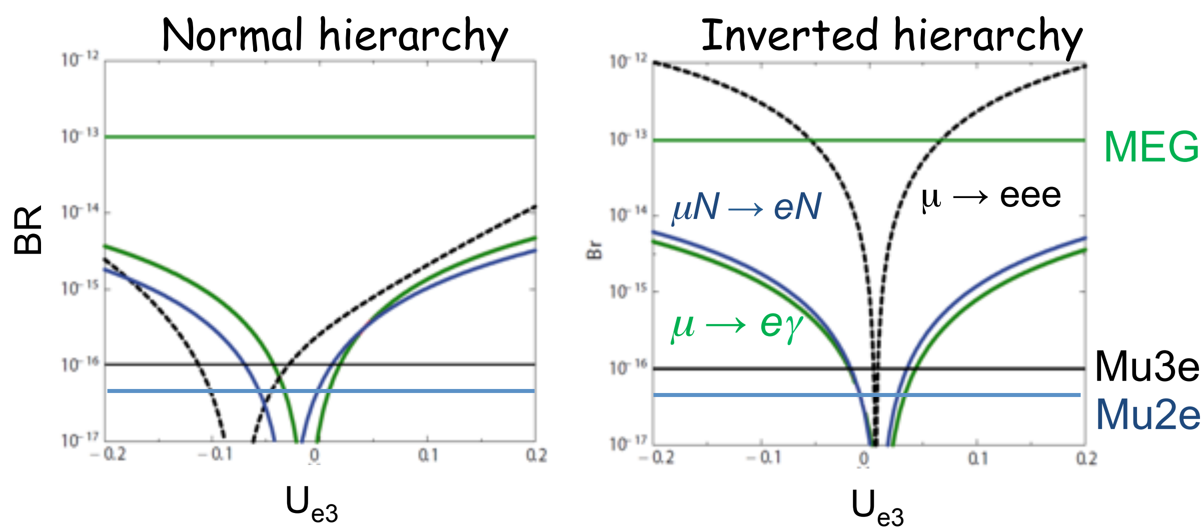
- Rosso: MEG-II
- Blu: Mu2e

Specific example: Higgs Triplet e LHT

M. Kakizaki et al., PLB566 (2003) 210

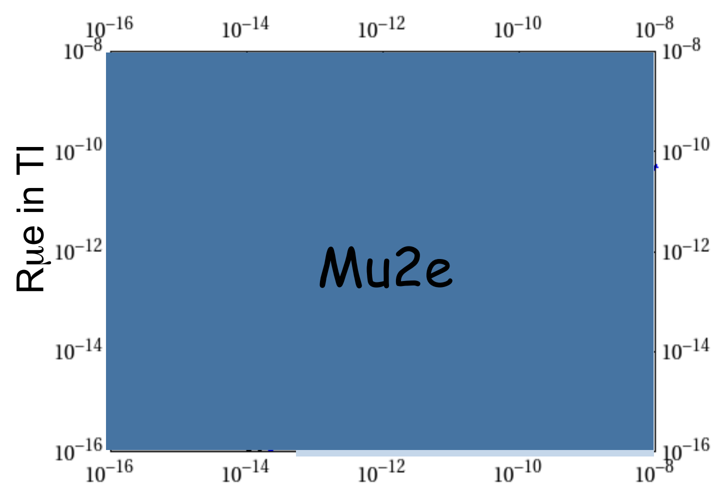
Higgs triplet model

Dependence on neutrino mass hierarchy and θ_{13}



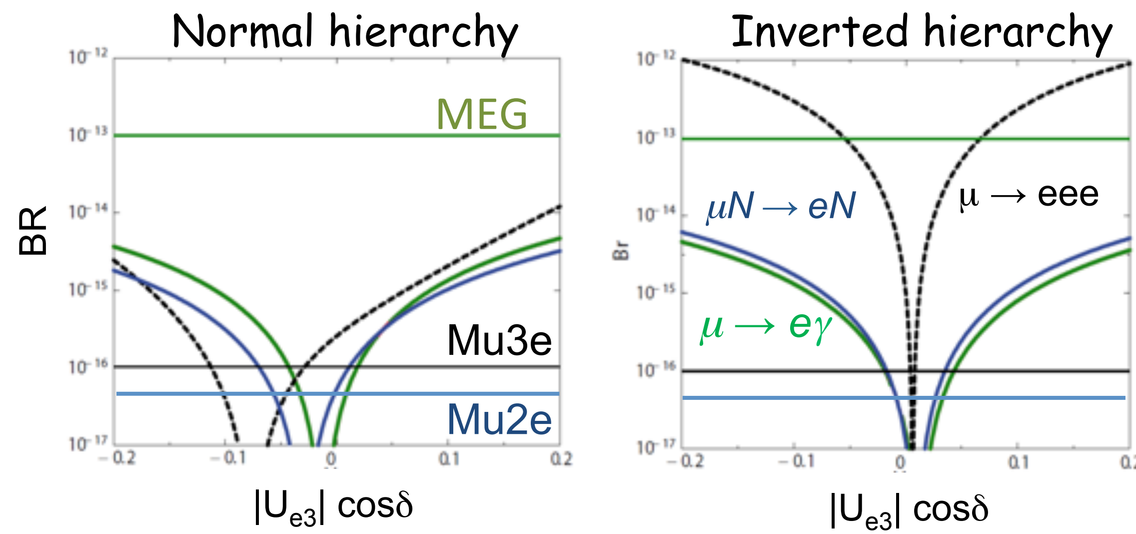
Littlest Higgs with T-parity

M. Blanke et al., Acta Phys.Polon.B41:657,2010

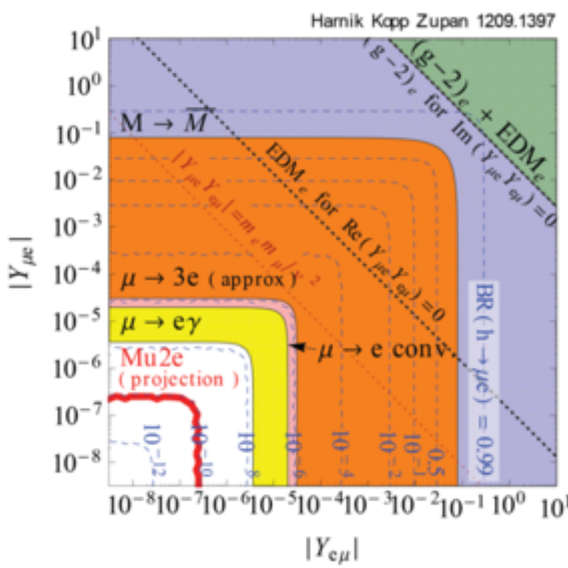


A few more models…

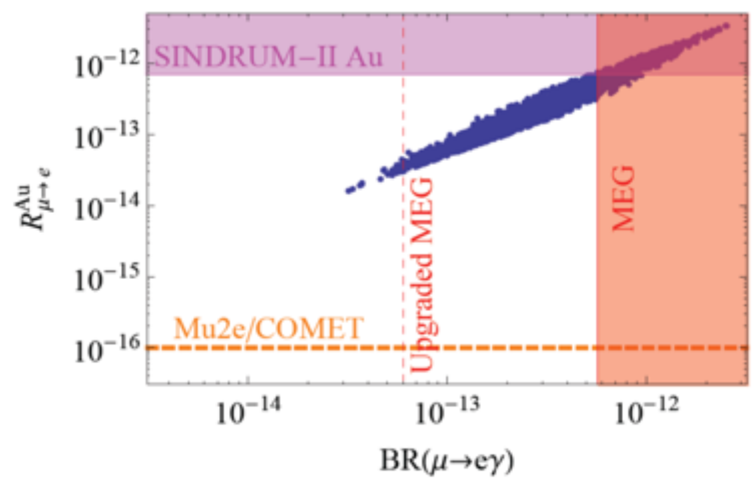
Higgs triplet model



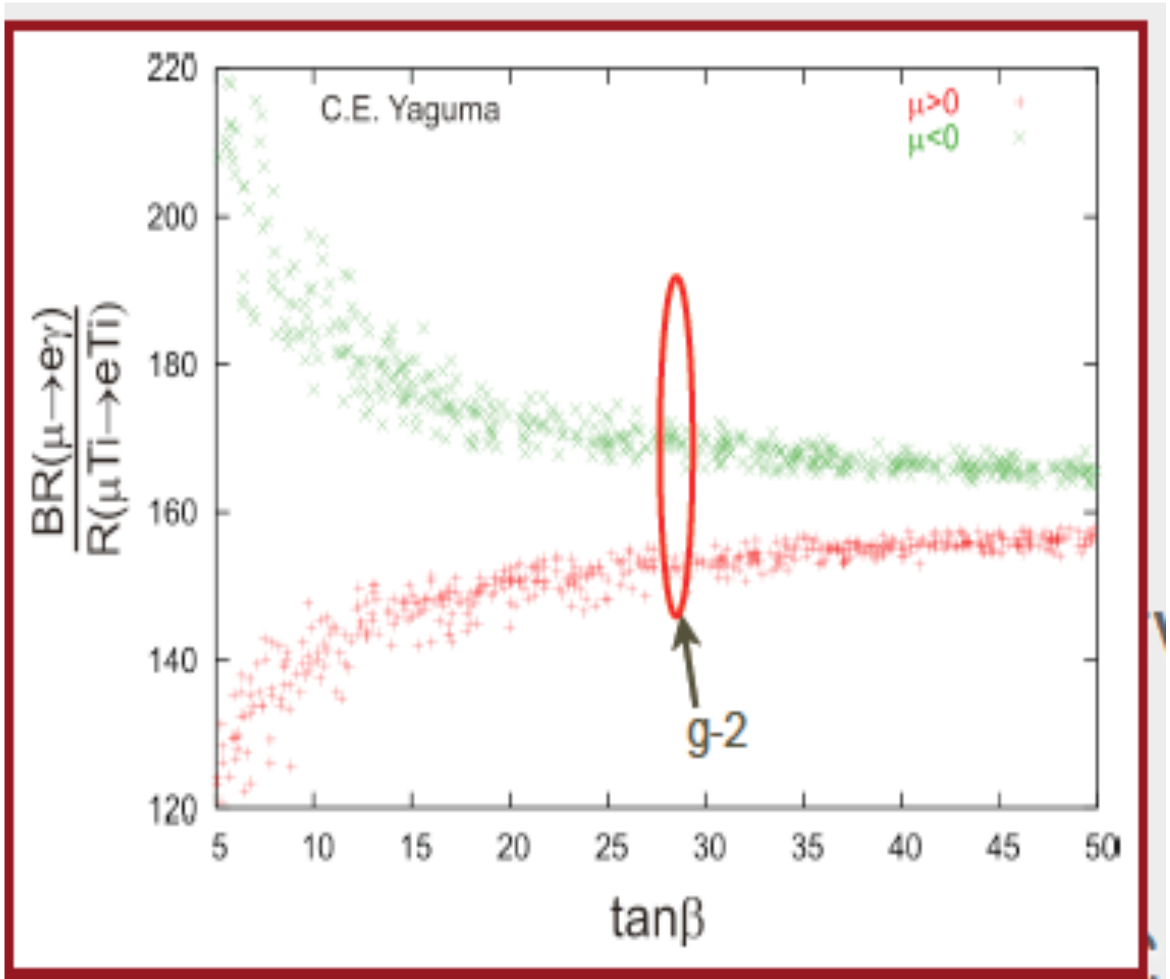
Flavor violating Yukawa couplings



Left-right symmetric models



MSSM- mSugra



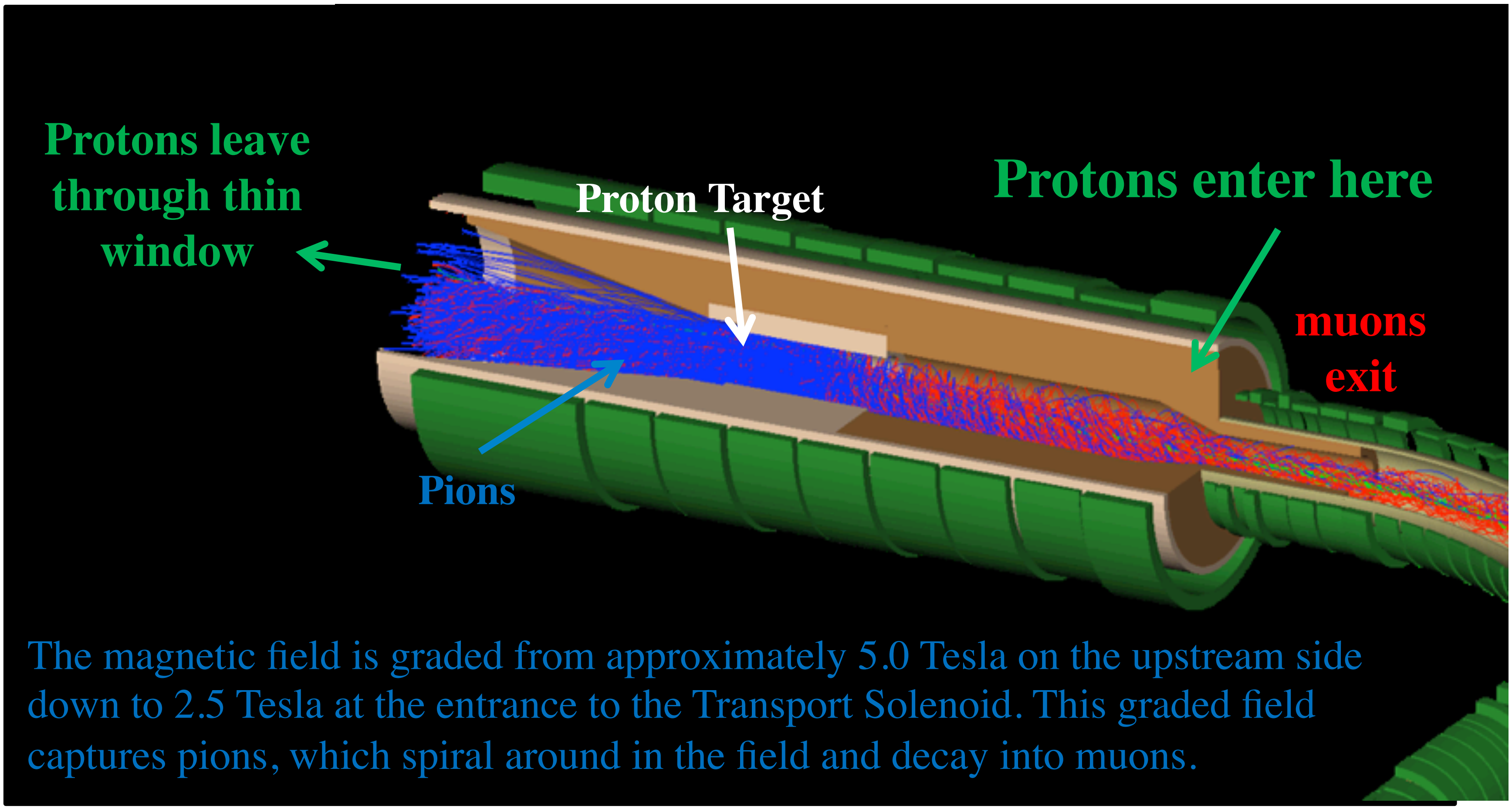
Yaguna, hep-ph/0502014v2

Next Generation Proton Source

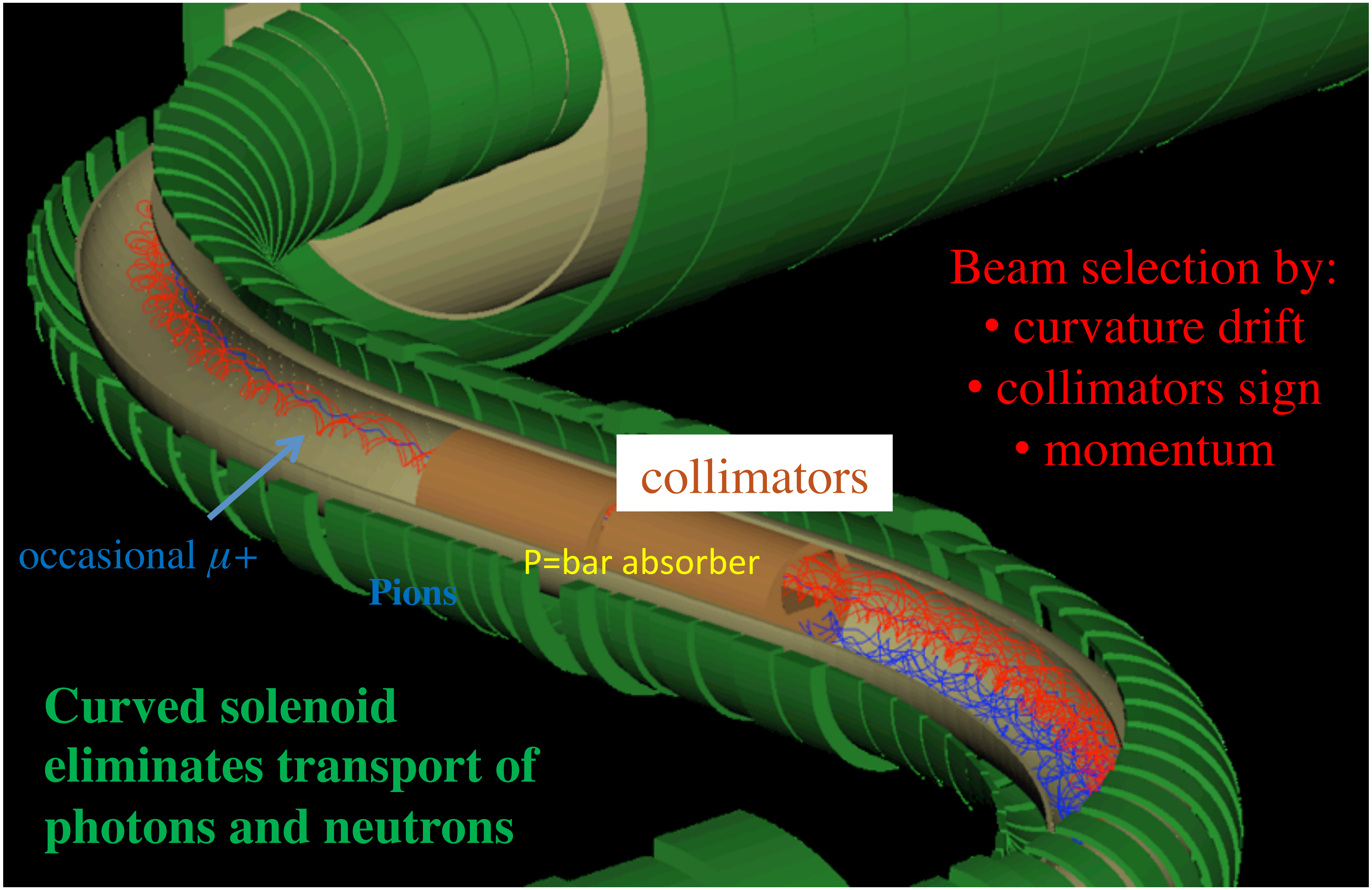
- Proton Improvement Plan (PIP)
  - Improve beam power to meet NOνA requirements
  - Essentially complete.
- PIP-II design underway
  - Project-X reimagined to match funding constraints
  - 1+ MW to LBNE at startup (2025)
  - Flexible design to allow future realization of the full potential of the FNAL accelerator complex
    - ~2 MW to LBNE
    - 10× the protons to Mu2e
    - MW-class, high duty factor beams for rare process experiments

Production Solenoid

Protons enter opposite to outgoing muons:
This is a central idea to remove prompt background



Transport Solenoid



Stopping Target Monitor

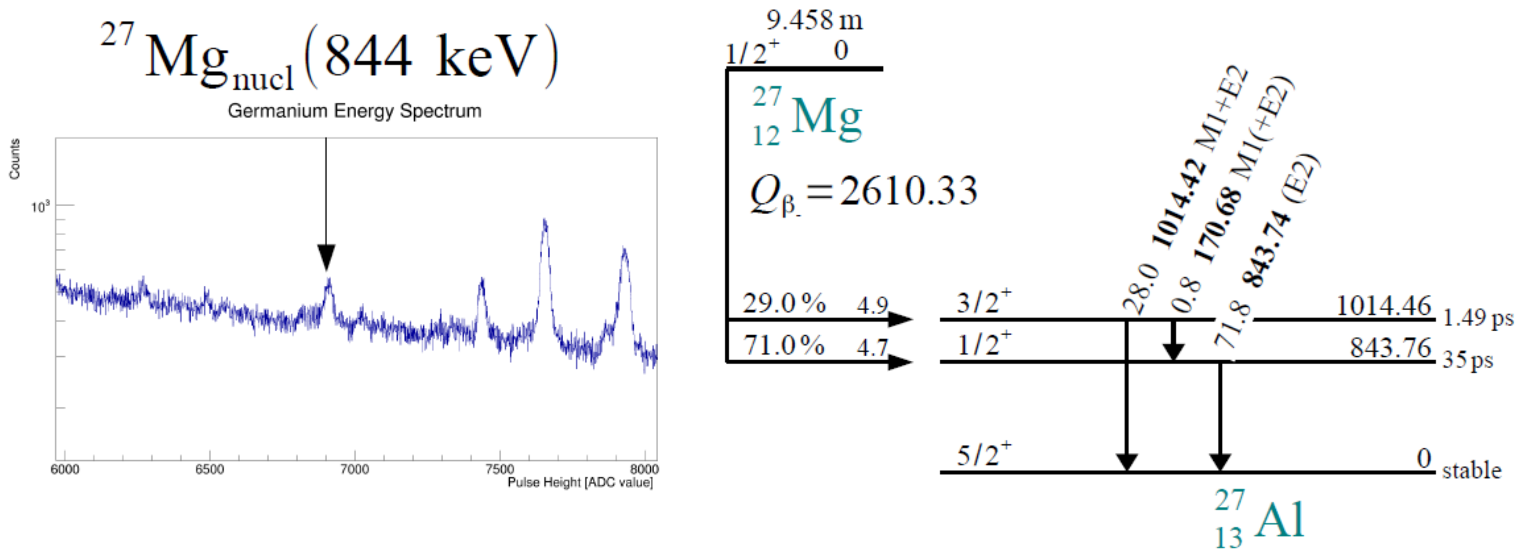
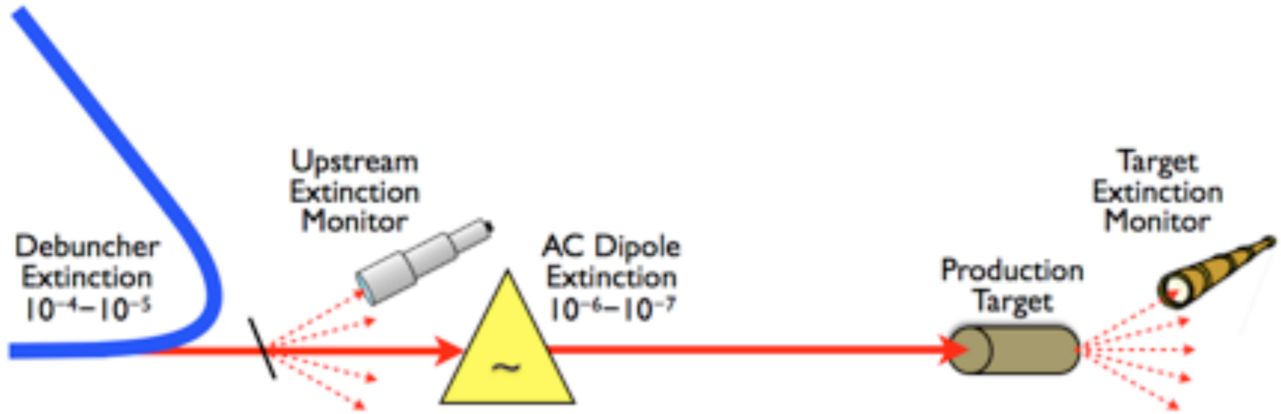


Figure 7.18. Preliminary singles germanium spectrum from the AlCap experiment at PSI. When muons stop in aluminum, they capture on the nucleus 60% of the time. A fraction of the captures produce ^{27}Mg in the ground state, which has a half-life of 9.5 minutes. In the decay, an 844 keV gamma is produced 72% of the time.

- Need a high precise gamma detector (HpGe)
- Energy of gamma ray is unique to the detector
- Detecting the delayed gamma rays eliminate problems related to beam flash
- Proton beam structure is 0.5 s on followed by 0.8 s idle. Gamma spectrum wil be acquired during idle time.
- Hpge should view the target far from the source and beyond DS

Extinction Monitor



- Thin foils in the debuncher → Mu2e production target transport line (fast feedback)
- Off-axis telescope looking at the production target (slow feedback – timescale of hours)

Spectrometer based on ATLAS pixel detector

Reach a 10^{-10} extinction sensitivity in an hour or so