Mu2e
A Rare Opportunity

Doug Glenzinski
Fermilab
For the Mu2e Collaboration

DOE PI Workshop
17 June, 2014

U.S. DEPARTMENT OF ENERGY | Office of Science

Fermilab

Outline

- Physics Motivation
- Concept and Apparatus
- Status and Schedule
- Collaboration
- Closing Remarks

Mu2e Physics Motivation

- Mu2e will measure Charged Lepton Flavor Violation (CLFV) with a single-event sensitivity of 2.5 x 10^{-17} (relative to ordinary muon capture)

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

- This experiment
  - Offers compelling discovery sensitivity over broad array of Beyond the Standard Model (BSM) parameter space
  - Provides unique and incisive probe of BSM physics
  - Has the world's best sensitivity to CLFV

Some CLFV Processes

Process	Current Limit	Next Generation exp
$\tau \to \mu\eta$	BR < 6.5 E-8	10^{-9} - 10^{-10} (Belle II)
$\tau \to \mu\gamma$	BR < 6.8 E-8	
$\tau \to \mu\mu\mu$	BR < 3.2 E-8	
$\tau \to eee$	BR < 3.6 E-8	
$K_L \to e\mu$	BR < 4.7 E-12	NA62
$K^+ \to \pi^+ e^- \mu^+$	BR < 1.3 E-11	
$B^0 \to e\mu$	BR < 7.8 E-8	Belle II, LHCb
$B^+ \to K^+ e\mu$	BR < 9.1 E-8	
$\mu^+ \to e^+\gamma$	BR < 5.7 E-13	10^{-14} (MEG)
$\mu^+ \to e^+e^+e^-$	BR < 1.0 E-12	10^{-16} (PSI)
$\mu N \to eN$	$R_{\mu e}$ < 7.0 E-13	10^{-17} (Mu2e, COMET)

- The most sensitive CLFV probes use muons

CLFV Predictions

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

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$	$0.02\dots 1$	$\sim 6\cdot 10^{-3}$	$\sim 6\cdot 10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.04\dots 0.4$	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau\to \mu\gamma)}$	$0.04\dots 0.4$	$\sim 2\cdot 10^{-3}$	$0.06\dots 0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.04\dots 0.3$	$\sim 2\cdot 10^{-3}$	$0.02\dots 0.04$
$\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau\to \mu\gamma)}$	$0.04\dots 0.3$	$\sim 1\cdot 10^{-2}$	$\sim 1\cdot 10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$0.8\dots 2.0$	~ 5	$0.3\dots 0.5$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau^-\to \mu^-e^+e^-)}$	$0.7\dots 1.6$	~ 0.2	$5\dots 10$
$\frac{R(\mu\mathrm{Ti}\to e\mathrm{Ti})}{Br(\mu\to e\gamma)}$	$10^{-3}\dots 10^{2}$	$\sim 5\cdot 10^{-3}$	$0.08\dots 0.15$

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

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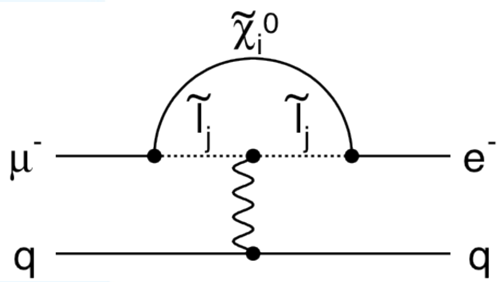
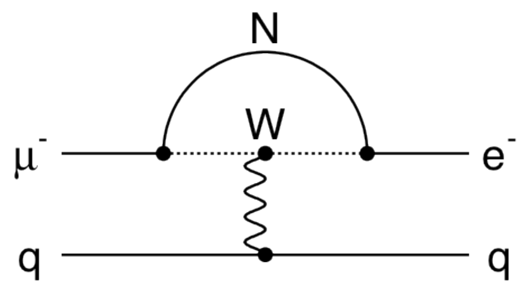
- Measure ratios to pin-down theory details

Mu2e Physics Reach

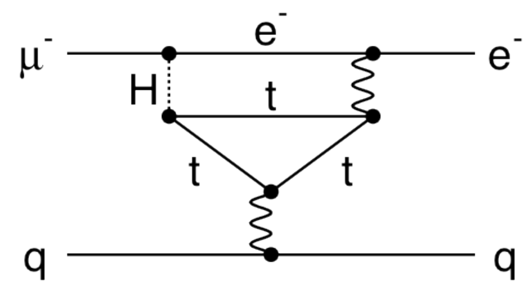
Loops



Supersymmetry

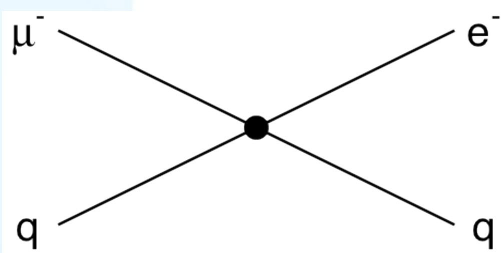


Heavy Neutrinos

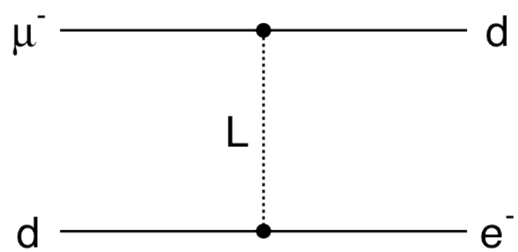


Two Higgs Doublets

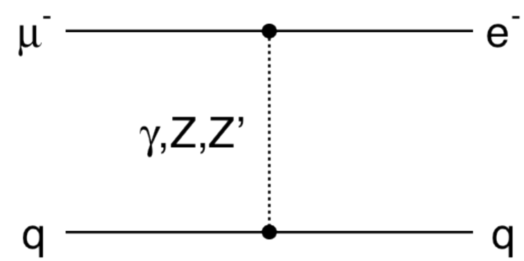
Contact Terms



Compositeness



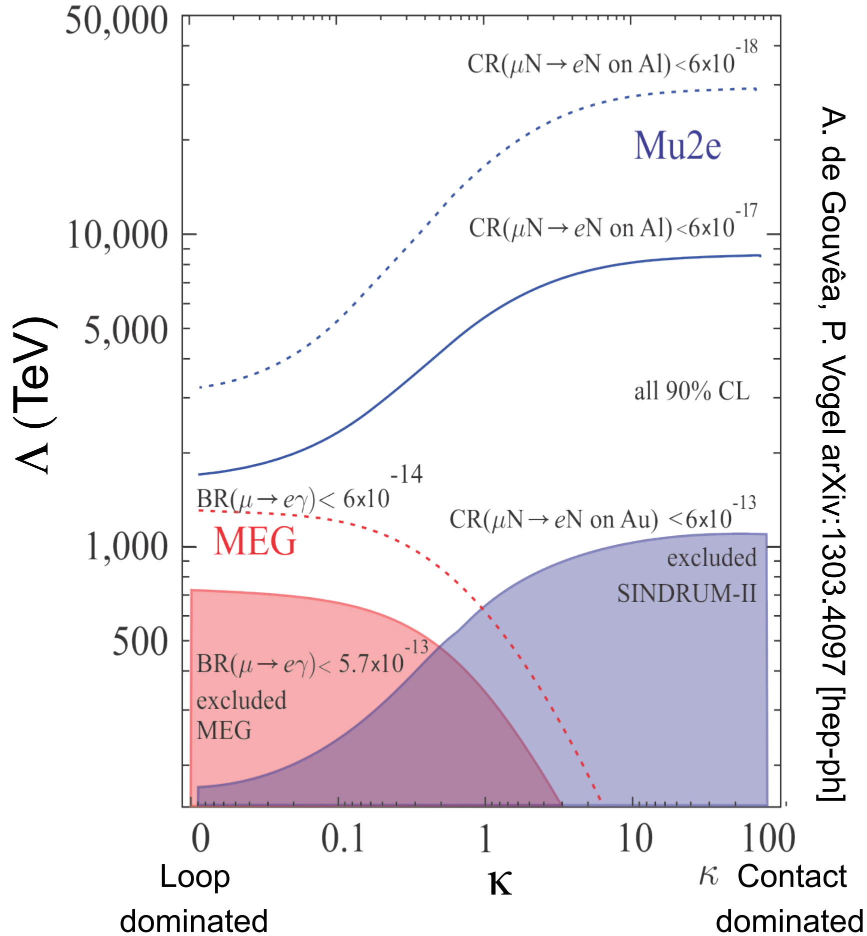
Leptoquarks



New Heavy Bosons / Anomalous Couplings

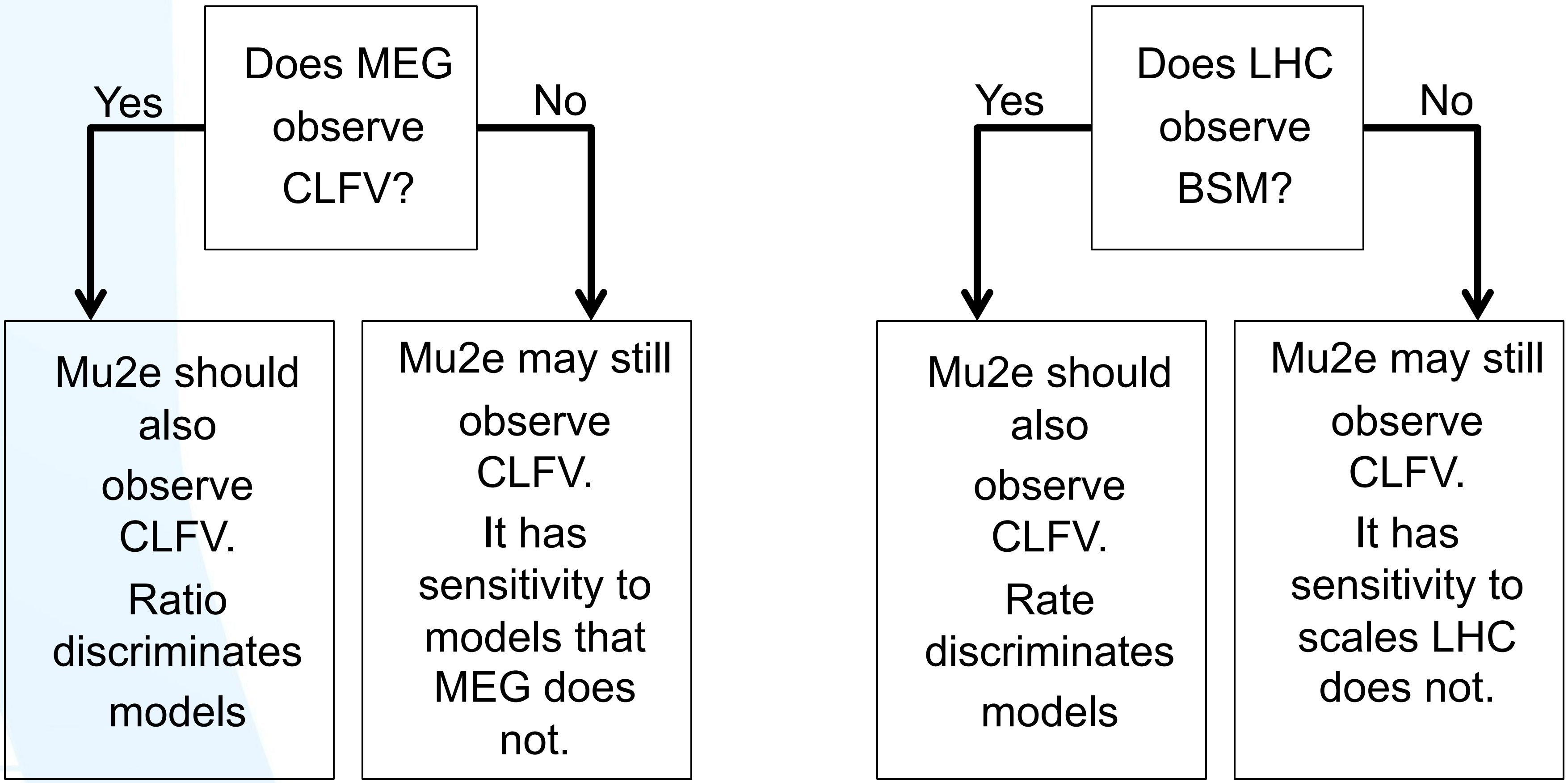
- Enables **discovery** sensitivity over broad swath of BSM parameter space

Mu2e Physics Reach



- Can probe mass scales >> LHC
    - Will eclipse MEG

Mu2e Physics Reach



- Mu2e results are important in all scenarios

Mu2e Physics Reach

W. Altmannshofer, A.J.Buras, S.Gori, P.Paradisi, D.M.Straub

★★★ Discovery Sensitivity

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\rm CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

Table 8: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

arXiv:0909.1333[hep-ph]

Mu2e Physics Reach

W. Altmannshofer, A.J.Buras, S.Gori, P.Paradisi, D.M.Straub

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\rm CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

★★★ Discovery Sensitivity

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Table 8: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

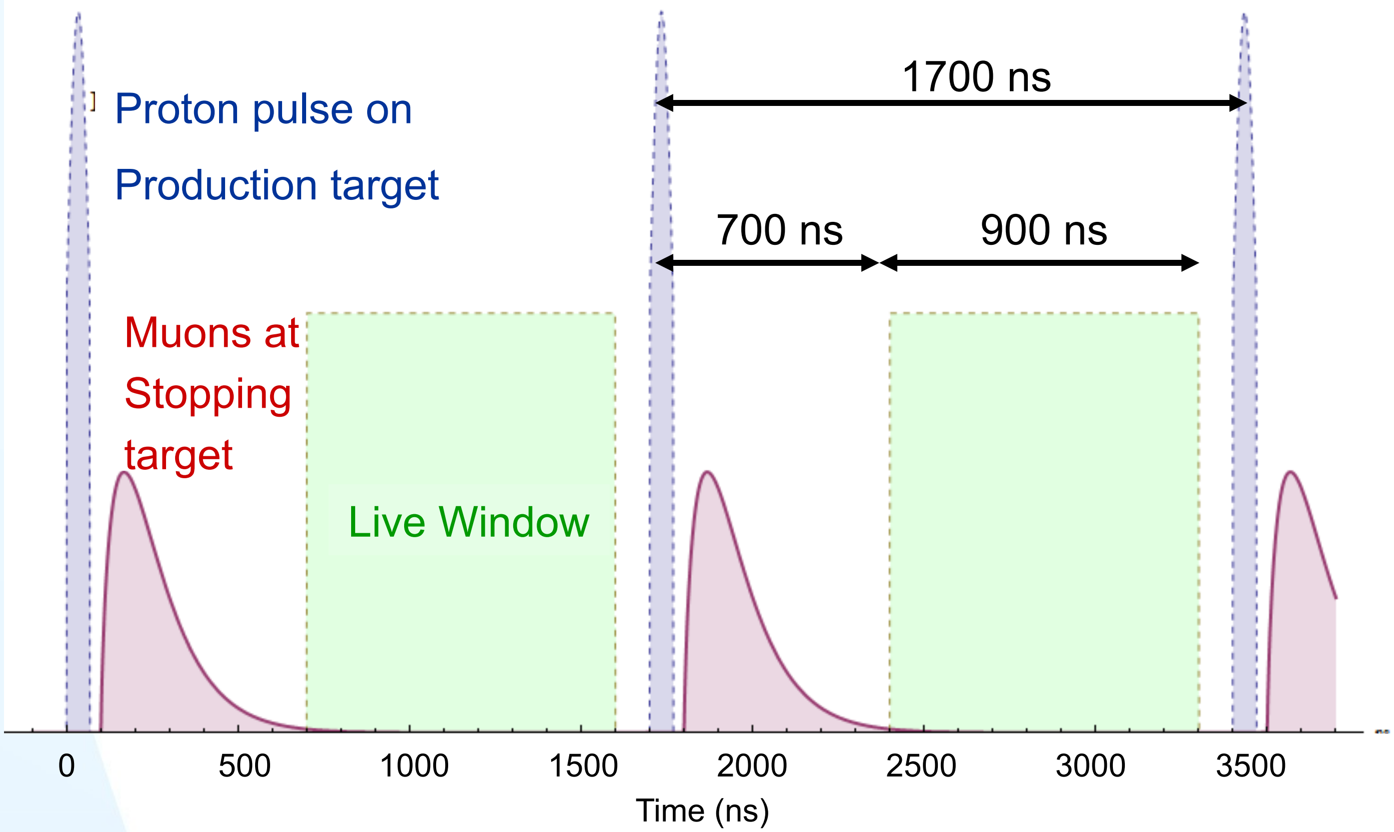
- Mu2e has discovery sensitivity across the board

How does Mu2e work?

Mu2e Concept

- Generate a beam of low momentum muons
  - Use 8 GeV protons from existing Fermilab complex
- Stop the muons in orbit around a nucleus
  - We plan to use aluminum stopping target
  - In orbit around aluminum τ_{μ}^{Al} = 864 ns
  - Important in discriminating background
- Look for events consistent with the signal

Mu2e Concept



- Mu2e will use a pulsed proton beam and a delayed live gate to suppress prompt background

Mu2e Concept

- Generate a beam of low momentum muons
  - Use 8 GeV protons from existing Fermilab complex
- Stop the muons in orbit around a nucleus
  - We plan to use aluminum stopping target
  - In orbit around aluminum τ_{μ}^{Al} = 864 ns
  - Important in discriminating background
- Look for events consistent with the signal

Mu2e Signal

- The process is coherent
  - The nucleus is left intact
- Experimental signature is an electron and nothing else
  - Energy of electron : $E_e = m_\mu - E_{recoil} - E_{1S\text{-}B.E.}$
  - For aluminum: E_e=104.96 MeV
  - Important for discriminating background

Mu2e Background

Category	Source	Events
	μ Decay in Orbit	0.22
Intrinsic	Radiative μ Capture	<0.01
	Radiative π Capture	0.03
	Beam electrons	<0.01
	μ Decay in Flight	0.01
Late Arriving	π Decay in Flight	<0.01
	Anti-proton induced	0.10
	Cosmic Ray induced	0.05
Miscellaneous	Pat. Recognition Errors	<0.01
Total Background		0.41

(assuming 6E17 stopped muons in 6E7 s of beam time)

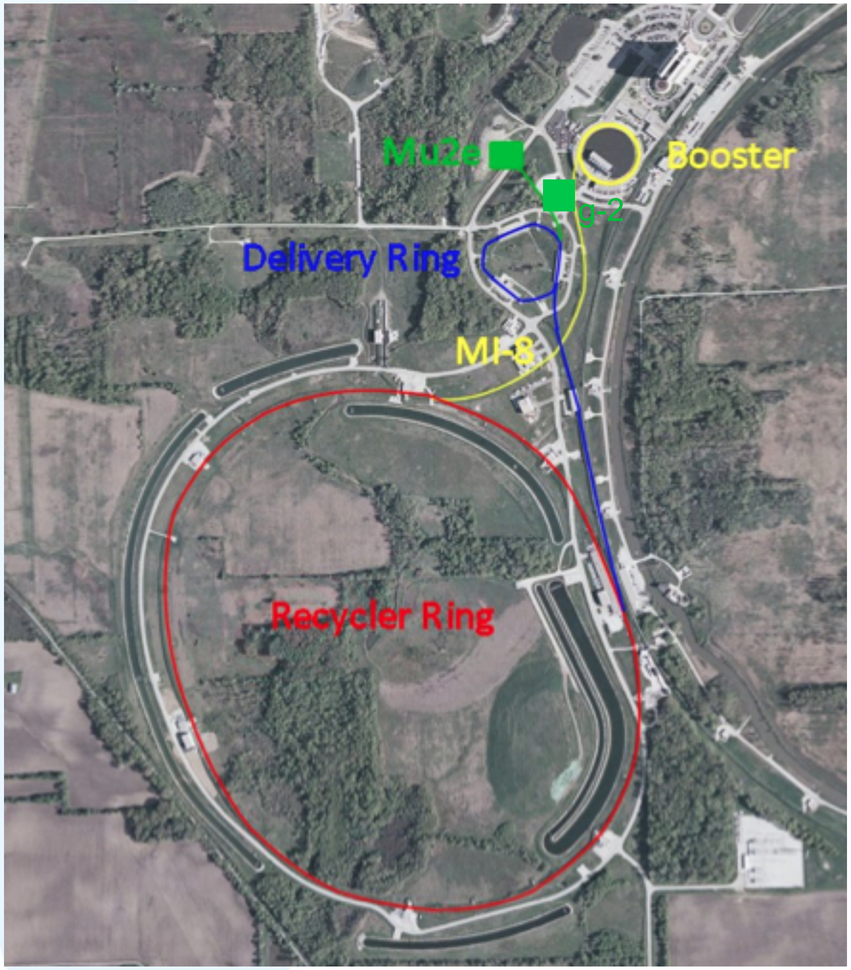
- Discovery sensitivity accomplished by suppressing backgrounds to <1 event total

Mu2e Apparatus

Mu2e Scope

- Beam line capable of delivering 8kW of 8 GeV protons with the necessary time structure
- Experimental apparatus capable of
  - capturing low momentum muons
  - Delivering muons to the stopping target
  - Measuring high energy electrons originating from the stopping target
- An experimental hall to house the experiment

Mu2e Proton Beam



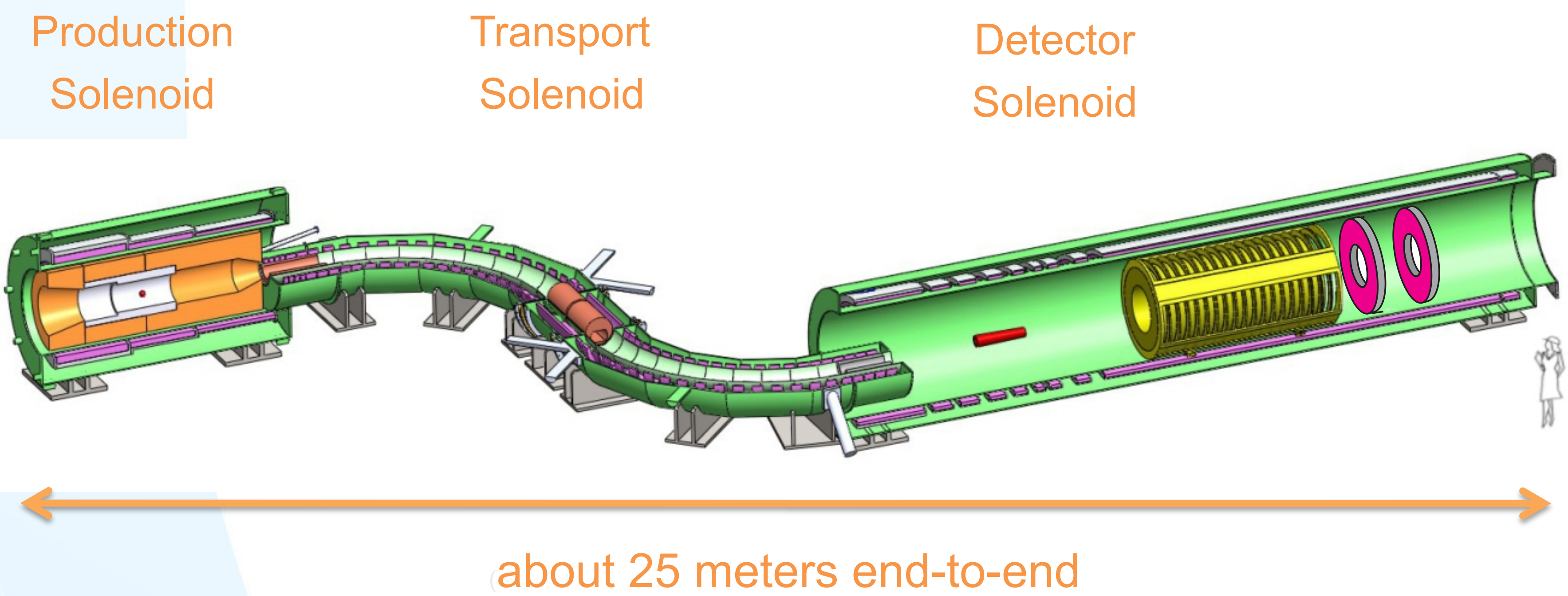
- Mu2e uses 8 GeV protons from Booster
- Mu2e and (g-2) will repurpose much of the Tevatron anti-proton complex to instead deliver muons.
- Mu2e can (and will) run simultaneously with NOvA.

Mu2e Experimental Hall

Graphic of proposed Mu2e Detector Hall

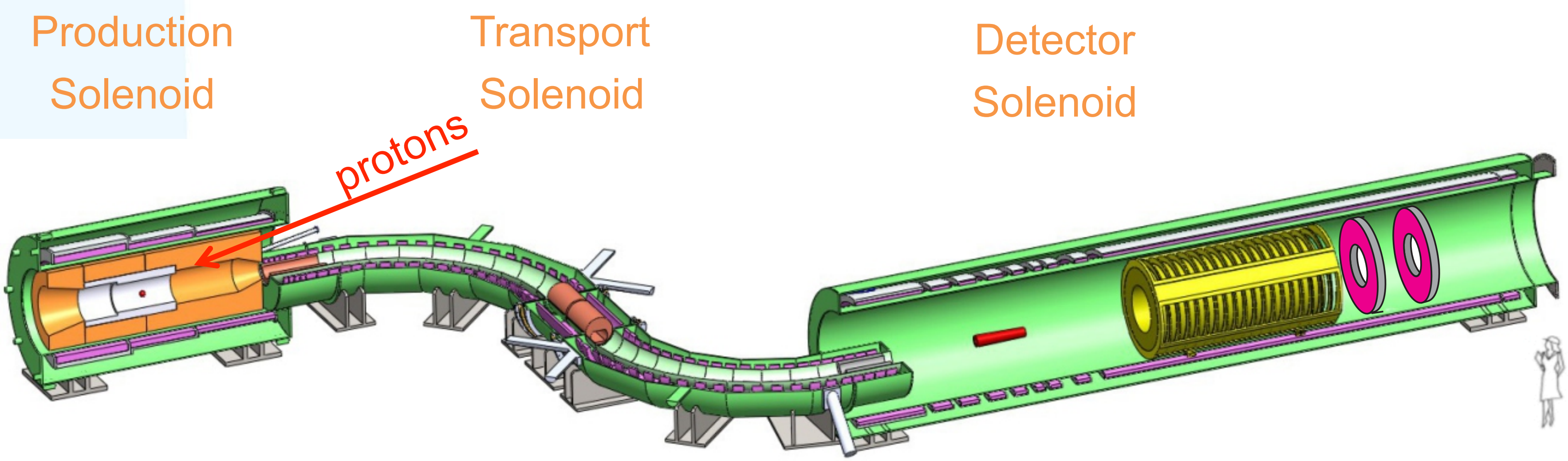
- Design completed
- Scheduled to break ground Fall 2014

Mu2e Experimental Apparatus



- Consists of 3 solenoid systems

Mu2e Experimental Apparatus

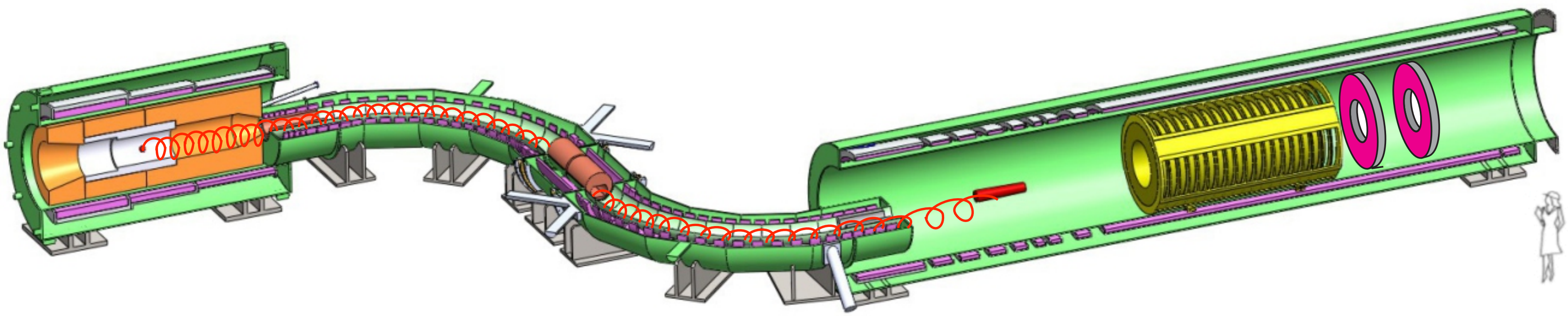


Production Solenoid:

8 GeV protons interact with a tungsten target to produce μ- (from π- decay)

- Consists of 3 solenoid systems

Mu2e Experimental Apparatus



Transport Solenoid:

Captures π- and subsequent μ-; momentum- and sign-selects beam

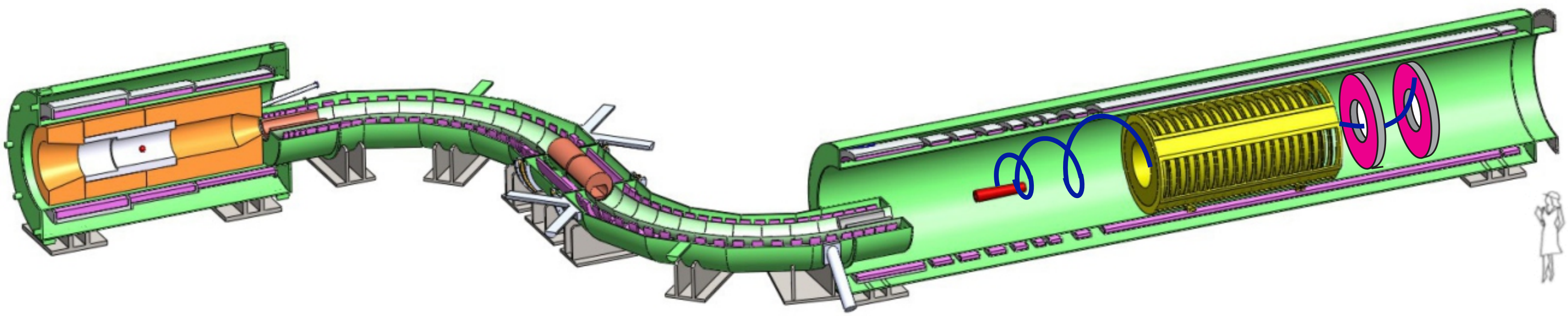
- Consists of 3 solenoid systems

Mu2e Experimental Apparatus

Production Solenoid

Transport Solenoid

Detector Solenoid



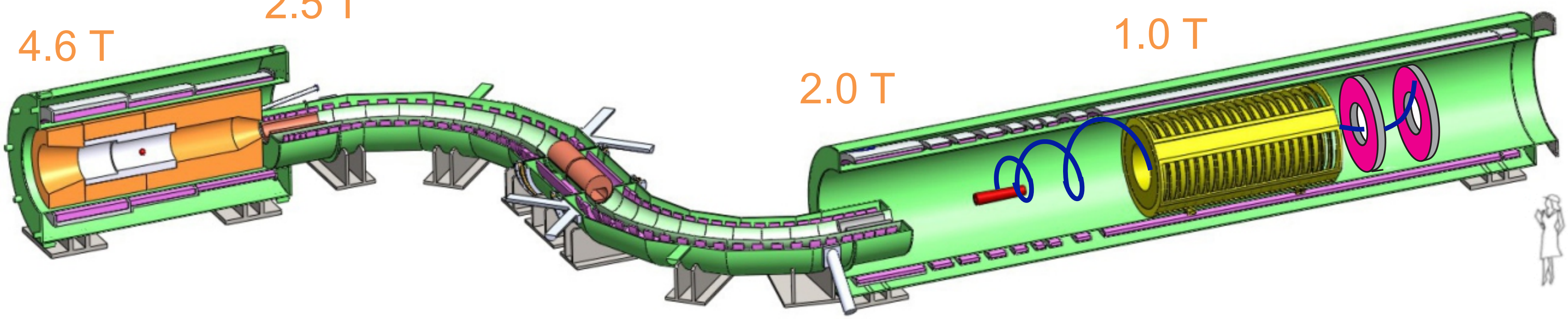
Detector Solenoid:

Upstream – Al. stopping target, Downstream – tracker, calorimeter

(not shown – cosmic ray veto system, extinction monitor, target monitor)

- Consists of 3 solenoid systems

Mu2e Experimental Apparatus



Graded fields important to suppress backgrounds, to increase muon yield, and to improve geometric acceptance for signal electrons

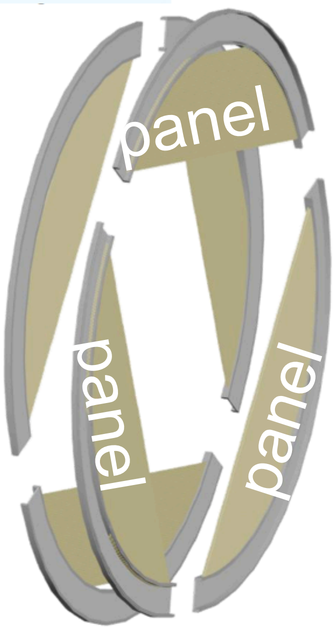
- Consists of 3 solenoid systems

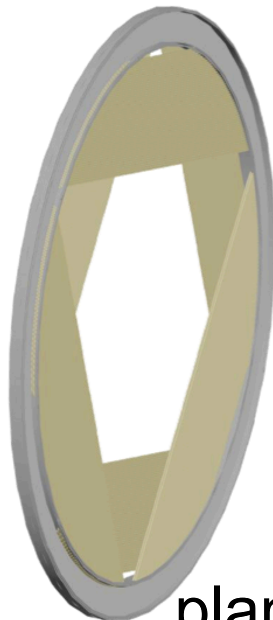
The Mu2e Tracker

- Will employ straw technology
  - Low mass
  - Can reliably operate in vacuum
  - Robust against single-wire failures

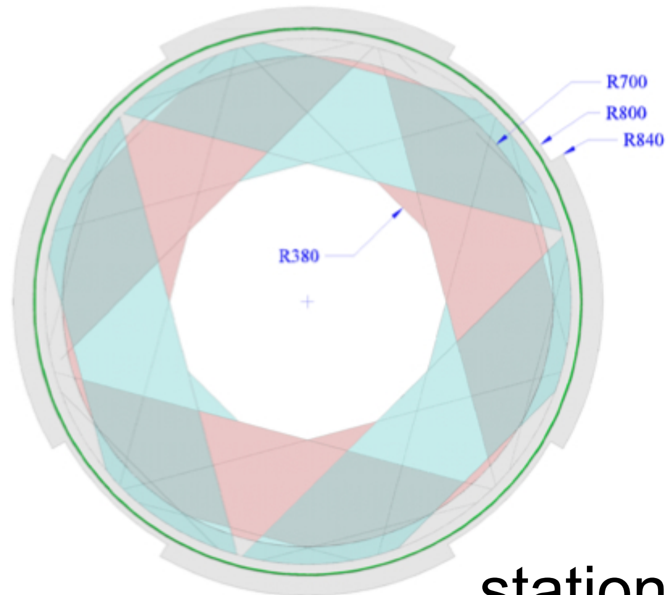
- 5 mm diameter straw
- Spiral wound
- Walls: 12 μm Mylar + 3 μm epoxy
  + 200 Å Au + 500 Å Al
- 25 μm Au-plated W sense wire
- 33 – 117 cm in length
- 80/20 Ar/CO_2 with HV < 1500 V

The Mu2e Tracker





plane

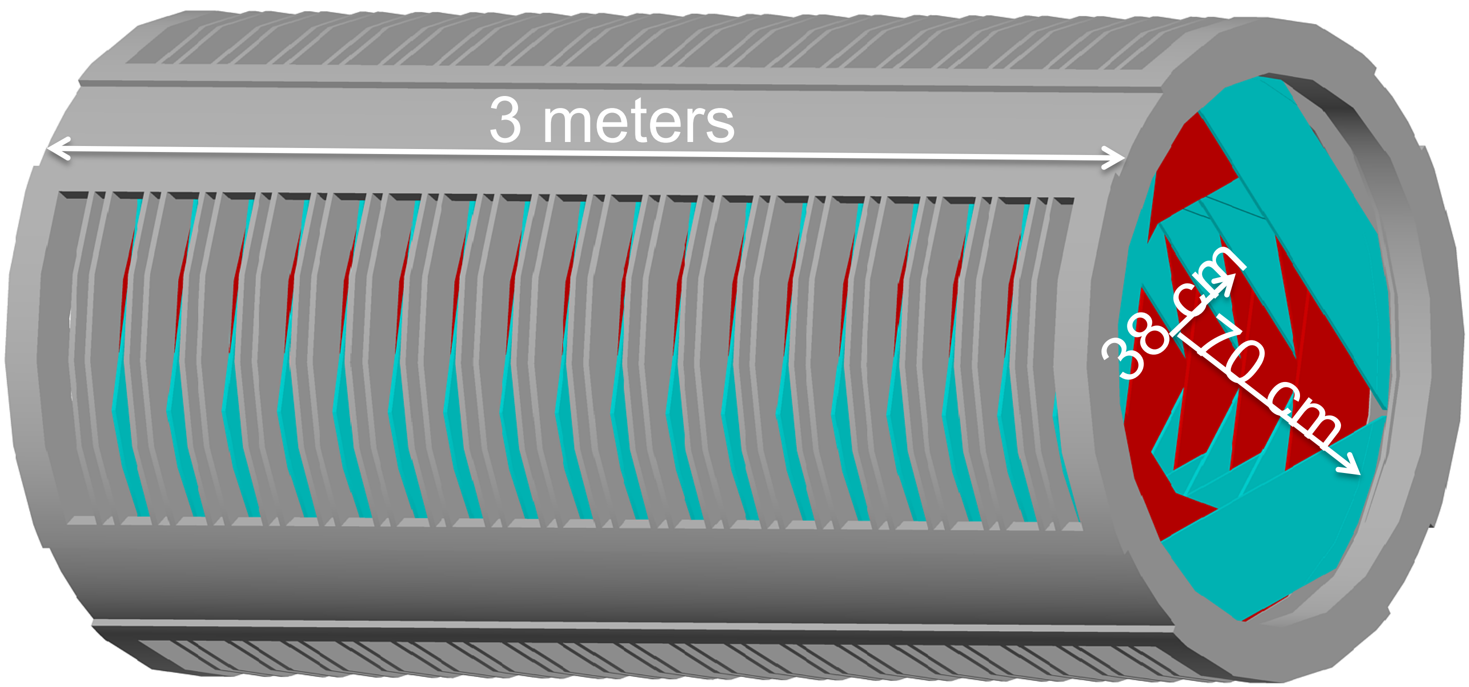


station

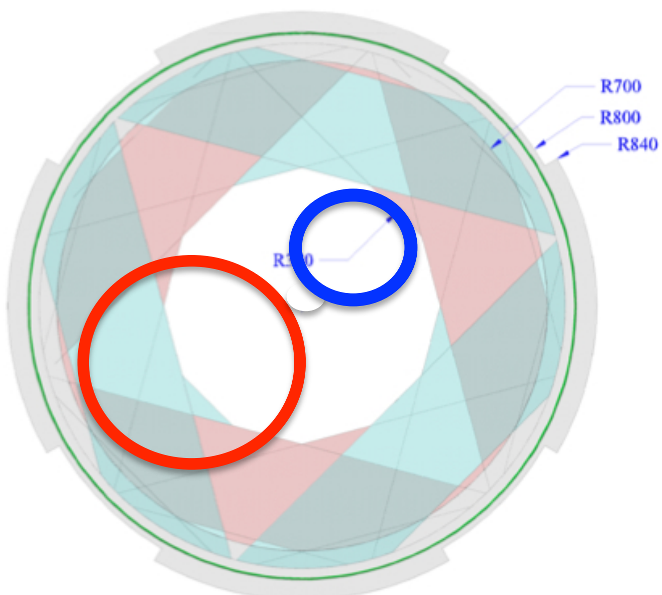
- Self-supporting “panel” consists of ~100 straws
- 6 panels assembled to make a “plane”
- 2 planes assembled to make a “station”
- Rotation of panels and planes improves stereo information
- ~25k straws total

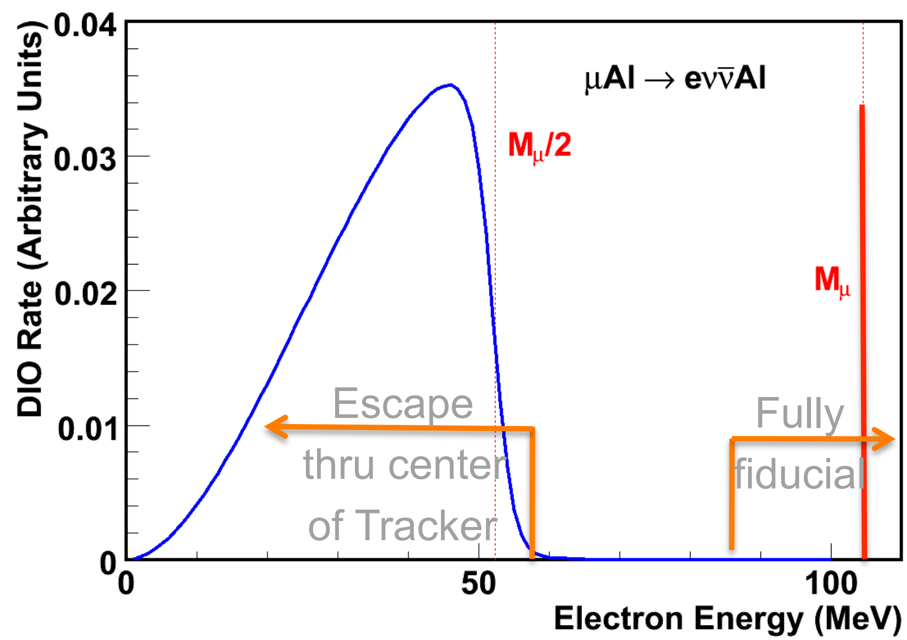
The Mu2e Tracker

- 20 “stations” with straws transverse to beam
- Naturally moves readout and support to large radii, out of active volume



The Mu2e Tracker

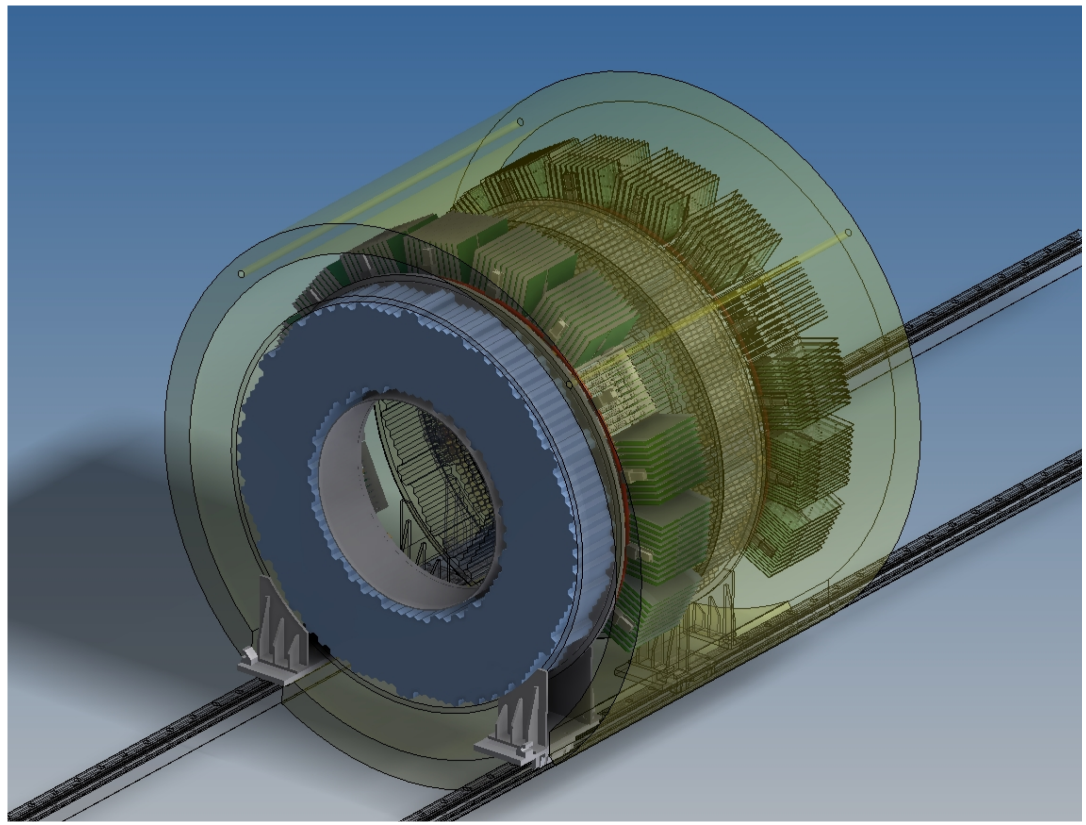




- Inner 38 cm is purposefully un-instrumented
  - Blind to beam flash
  - Blind to >99% of muon decay-in-orbit (DIO) spectrum

Mu2e Calorimeter

- Crystal calorimeter
  - Compact
  - Radiation hard
  - Good timing and energy resolution

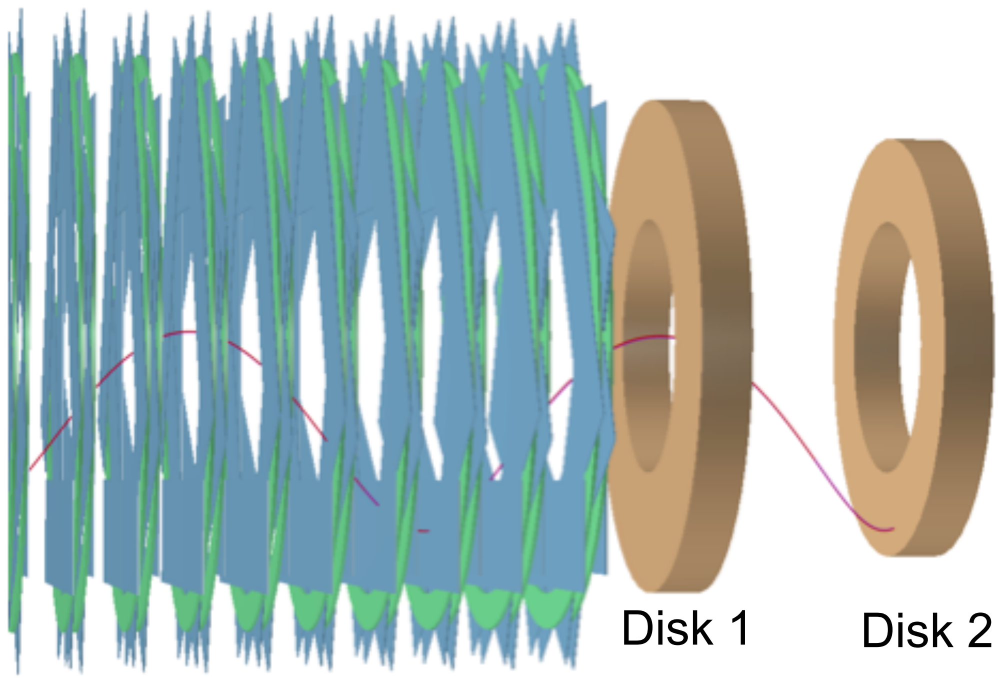


Mu2e Calorimeter

- Baseline design : Barrium Flouride (BaF_2)
  - Radiation hard, very fast (220 nm), non-hygroscopic

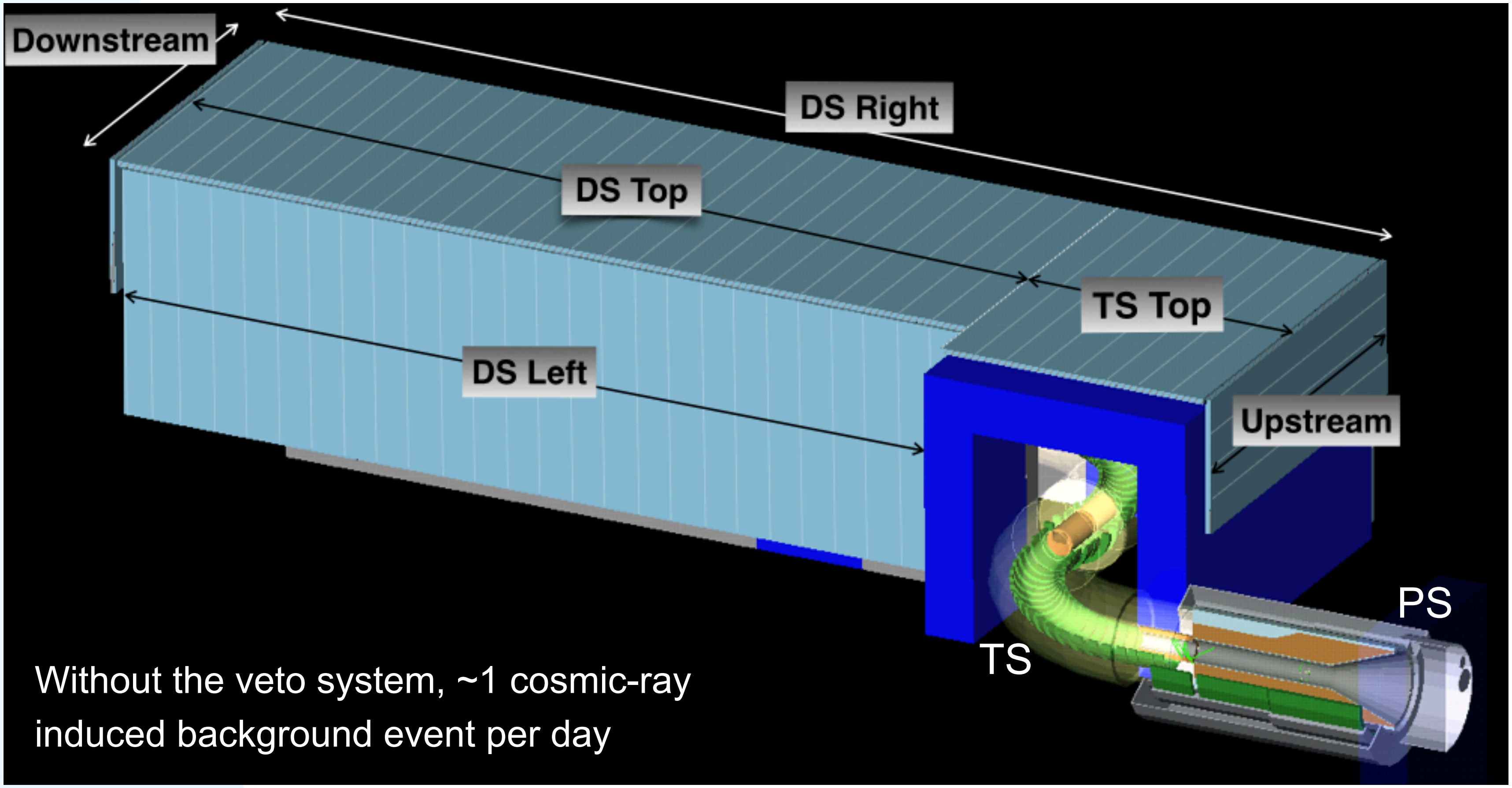
	BaF_2
Density (g/cm3)	4.89
Radiation length (cm)	2.03
Moliere Radius (cm)	3.10
Interaction length (cm)	30.7
dE/dX (MeV/cm)	6.52
Refractive index	1.50
Peak luminescence (nm)	220 (300)
Decay time (ns)	1 (650)
Light yield (rel. to NaI)	5% (42%)
Variation with temperature	0.1% (-1.29)% / deg-C

Mu2e Calorimeter



- Will employ 2 disks (radius = 36-70 cm)
- ~2000 crystals with hexagonal cross-section
  - 3 cm diameter, 20 cm long (~10 X_0)
- Two photo-sensors/crystal on back (APDs)
  - R&D program (CalTech, RMD, JPL)

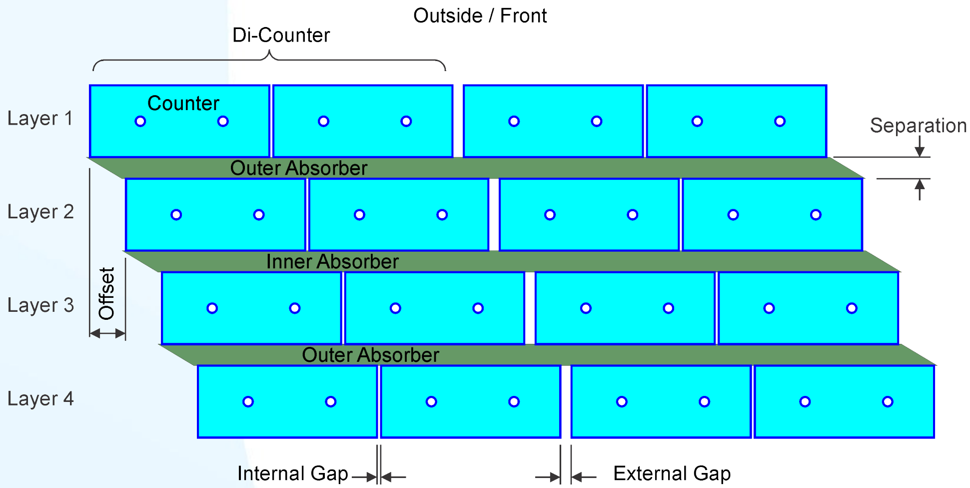
Mu2e Cosmic Ray Veto

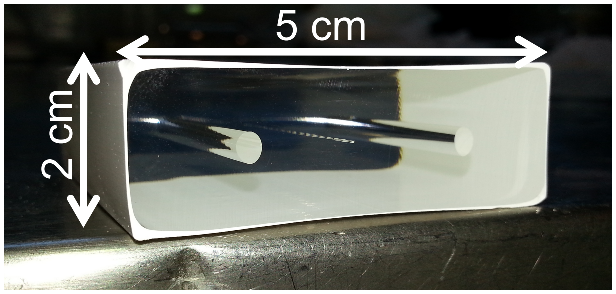


- CR-Veto system covers entire DS and half the TS

Fermilab

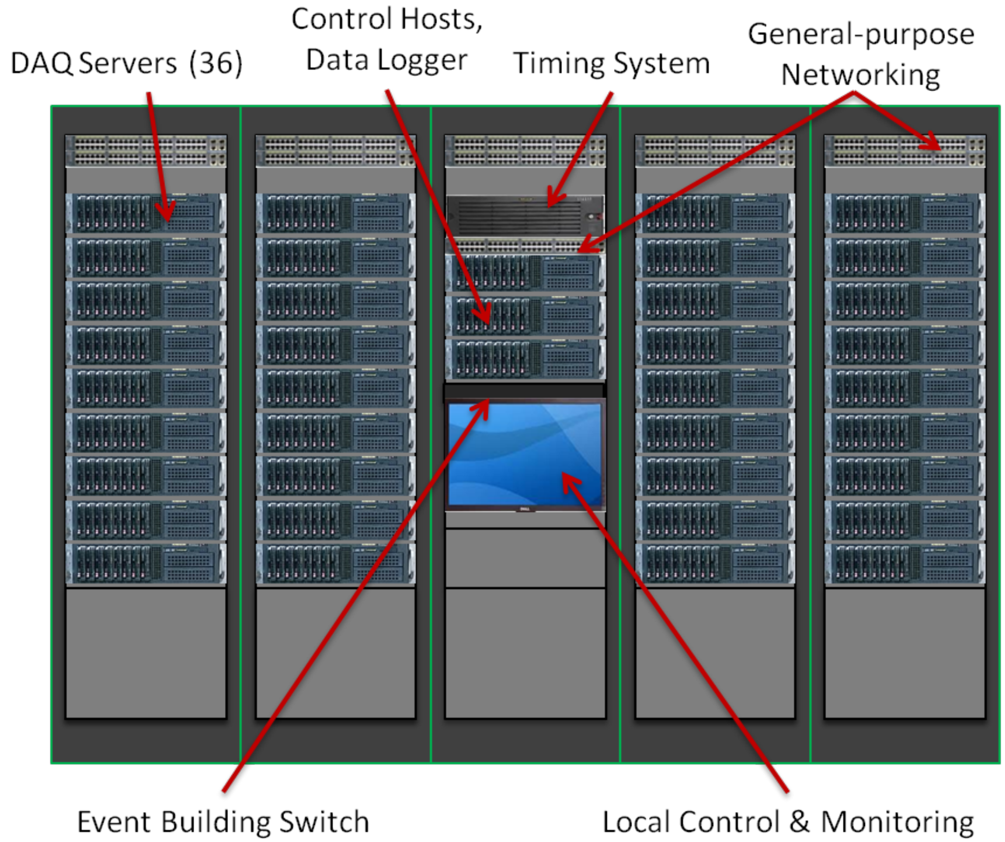
Mu2e Cosmic Ray Veto





- Four layer, (scintillator + WLS-fiber)-based system
- SiPM readout – 2 at each end
- 4-choose-3 veto condition achieves 99.99% veto efficiency (demonstrated in test beam)

Mu2e Trigger and DAQ



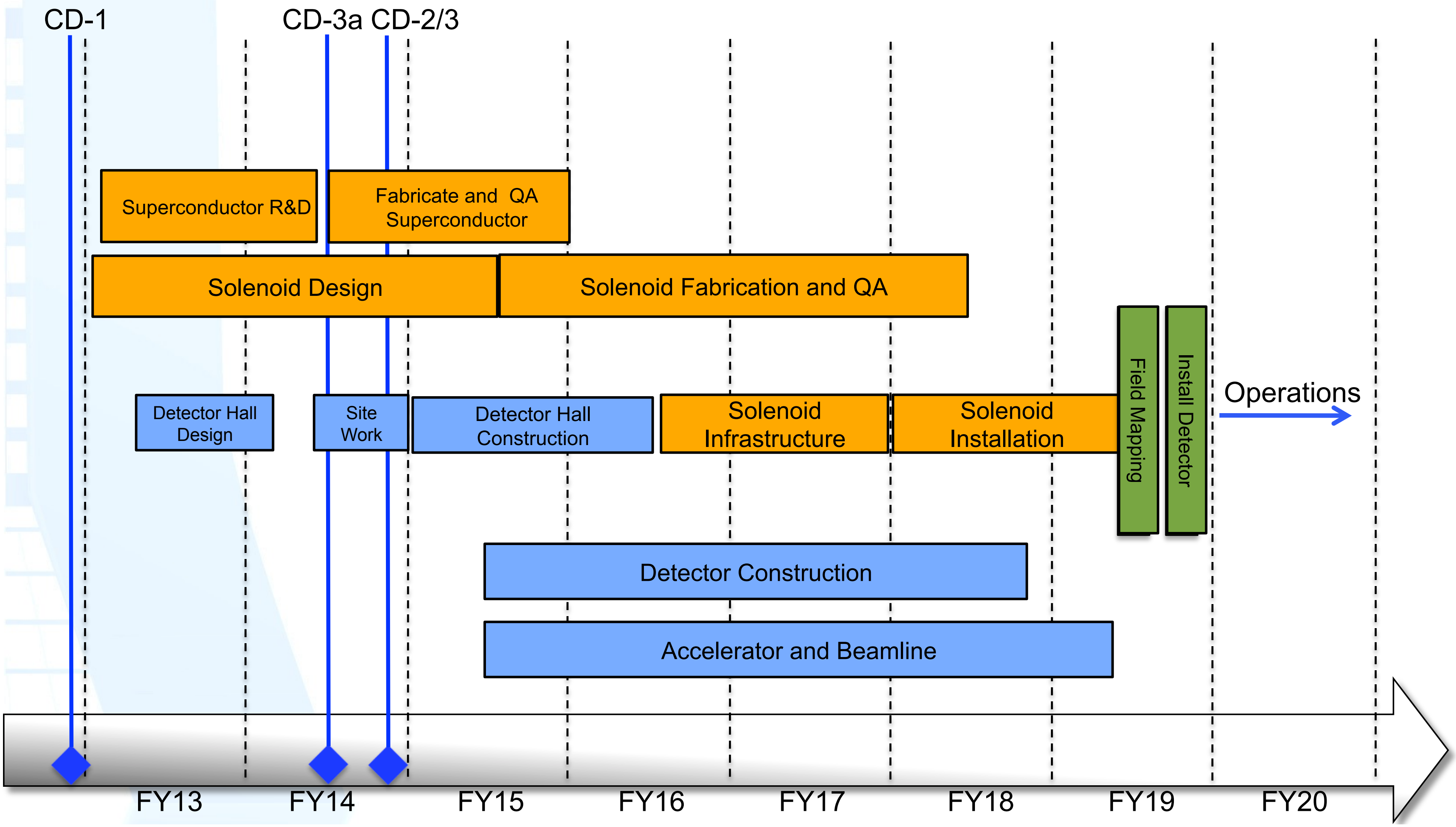
- We will employ a streaming architecture and software filters to reduce data accept rate to about 2 kHz average.

Mu2e Status and Schedule

Mu2e Status

- CD-0 in November 2009
- CD-1 in July 2012
- CD-3a review completed June 2014
  - Order production lengths of solenoid superconductor (long lead item)
- Scheduled CD-2/3 in August 2014
  - Start on building, proceed expeditiously with solenoid final design and fabrication, complete detector designs

Mu2e Schedule



- Critical path: Solenoid conductor, design, fabrication and QA

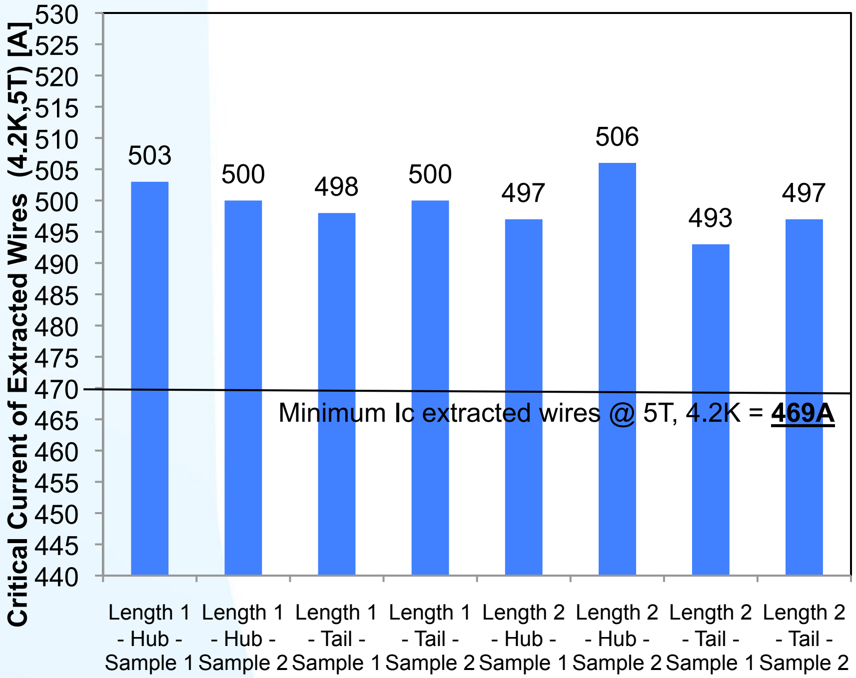
Mu2e Conductor R&D

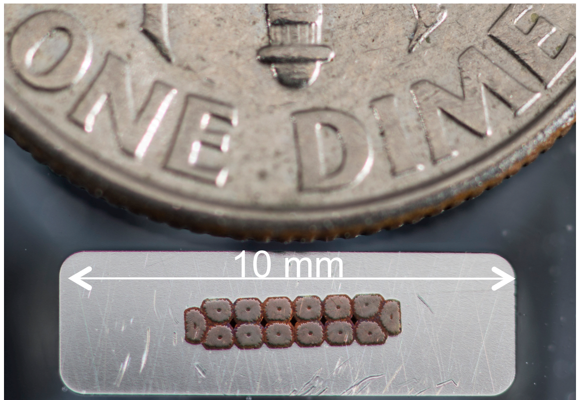
- Vendors made excellent progress.
- Conductor R&D campaign nearly complete.

Conductor Type	Strand	Cable	Final extrusion	Production ready?
PS	meets spec	meets spec	meets spec*	Yes
TS	meets spec	meets spec	meets spec	Yes
DS-1	meets spec	meets spec	meets spec	Yes
DS-2	meets spec	meets spec	meets spec	Yes

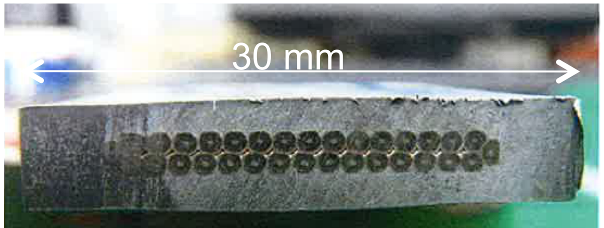
* Evaluating trade-off between bonding strength and RRR

Mu2e Conductor R&D





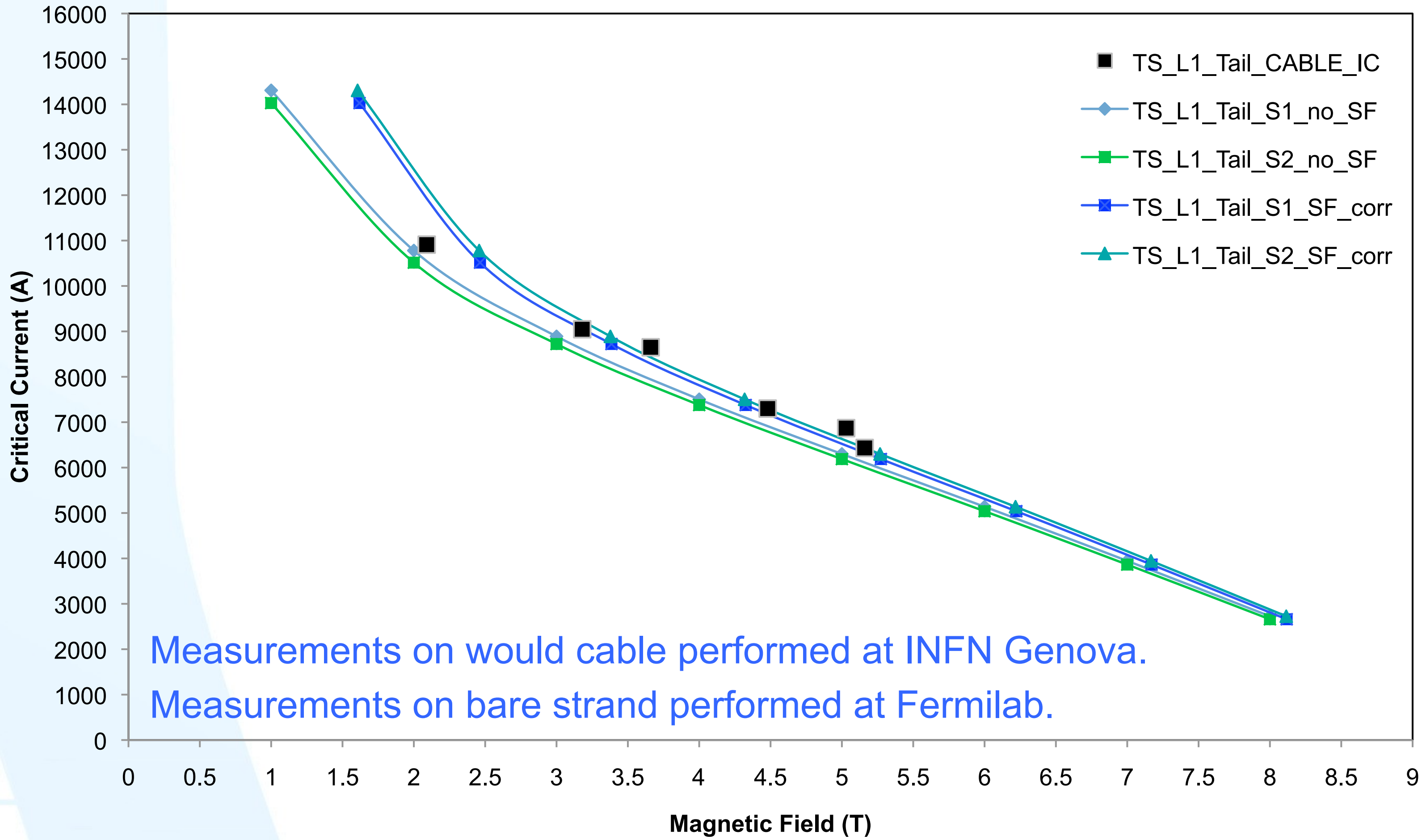
Cross-section of Extruded TS Conductor



Cross-section of Extruded PS Conductor

- We are in the process of placing orders for the production lengths.
- First delivery expected to coincide with completion of solenoid Final Designs

Mu2e Conductor R&D



- Performance of wound conductor matches bench top measurements.

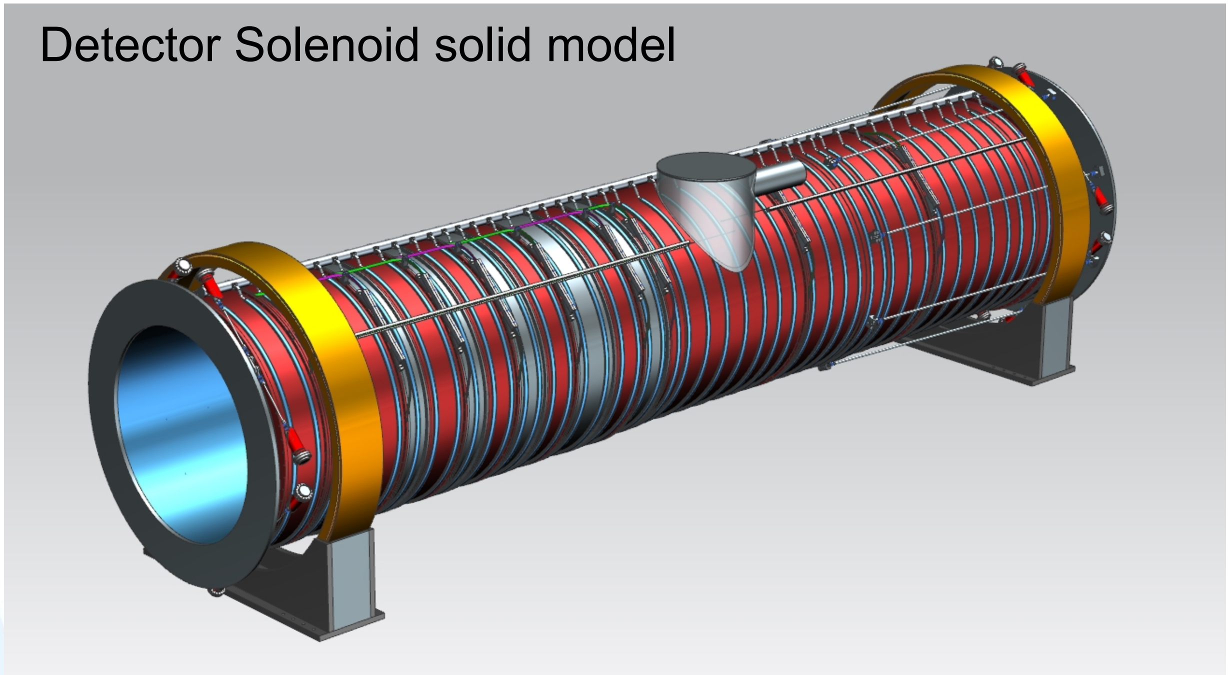
Mu2e Solenoid Designs

	PS	TS	DS
Length (m)	4	13	11
Diameter (m)	1.7	0.4	1.9
Field @ start (T)	4.6	2.5	2.0
Field @ end (T)	2.5	2.0	1.0
Number of coils	3	52	11
Conductor (km)	10	44	15
Operating current (kA)	10	3	6
Stored energy (MJ)	80	20	30
Cold mass (tons)	11	26	8

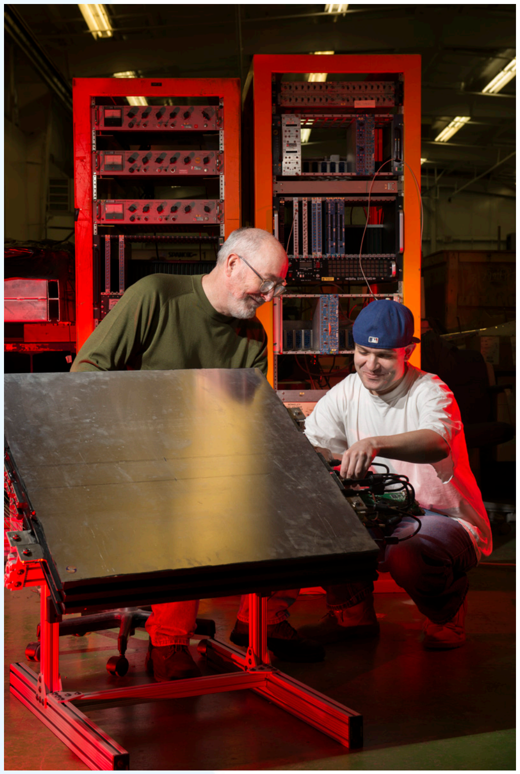
- Detailed reference designs have been produced.
- Design performance quantified using a variety of simulation and modeling tools – including effects from fabrication and installation tolerances.

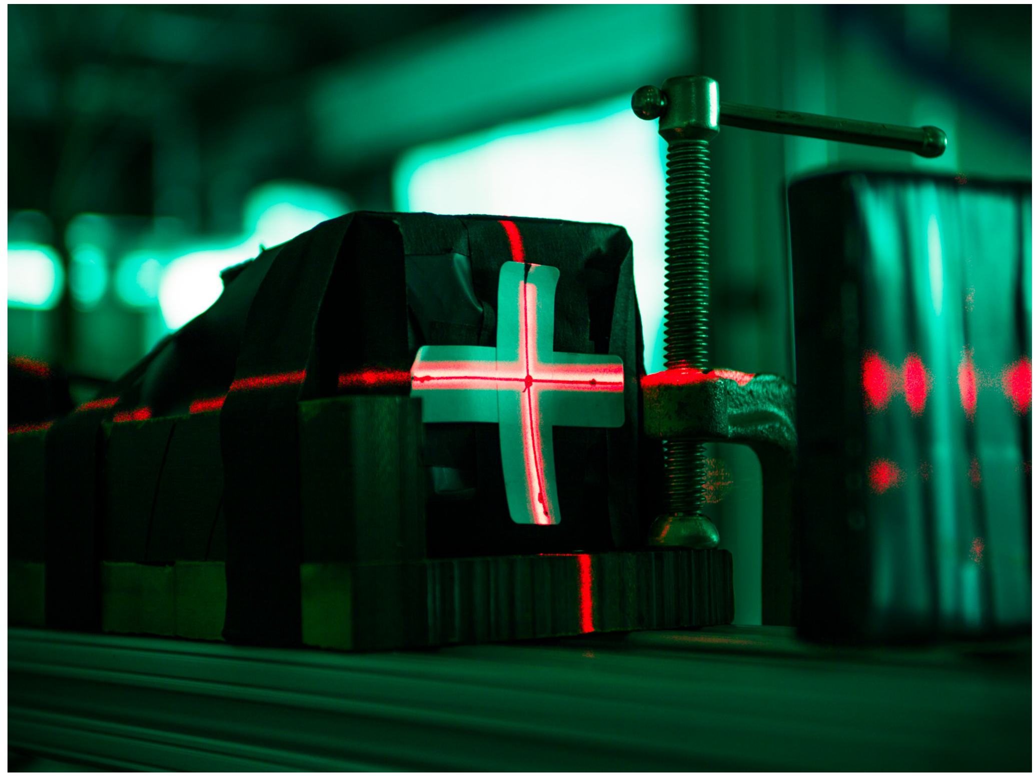
Mu2e Solenoid Designs

- Evaluating bids from industry
  - Initial responses from 5 world-class vendors
  - Have visited all 5 vendors
  - Preparing to make awards for DS and PS



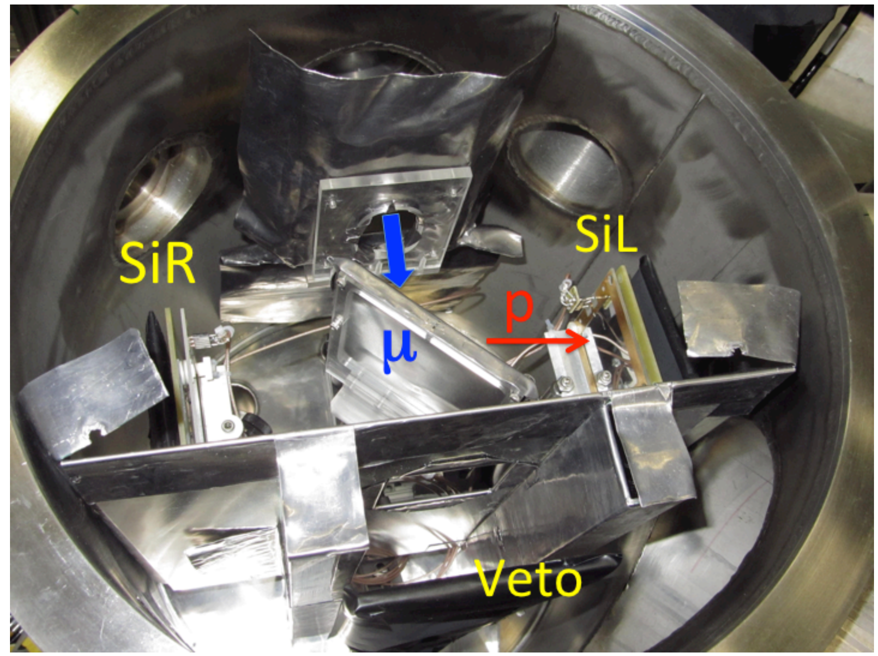
Test Beam – September 2013





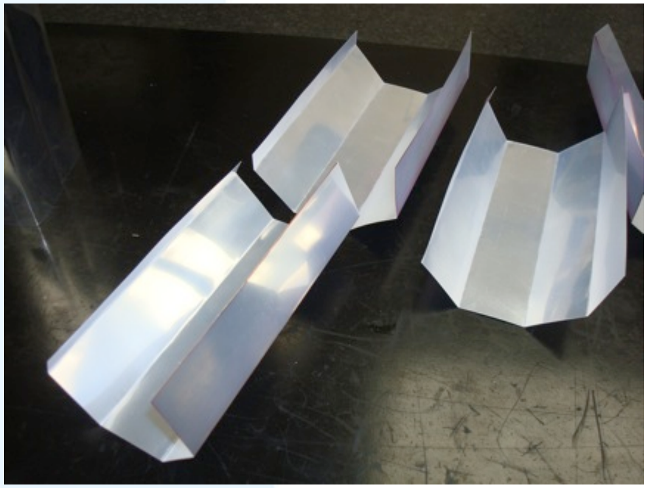
- Cosmic Ray Veto – SiPM, WLS, and component prototype tests
- Upstream Extinction Monitor – conceptual demonstration

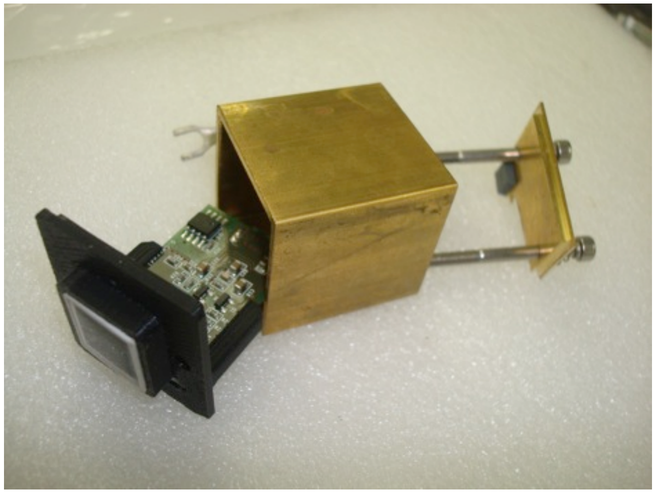
Test Beam – December 2013

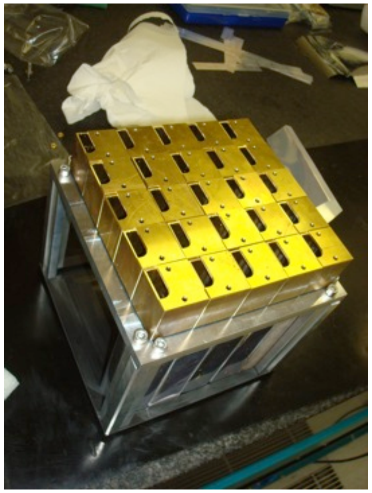


- AlCap – measurement of products of muon captures on aluminum
  - Joint Mu2e/COMET effort
  - Took data at PSI 26Nov – 23Dec

Test Beam – Fall 2014 Preparations

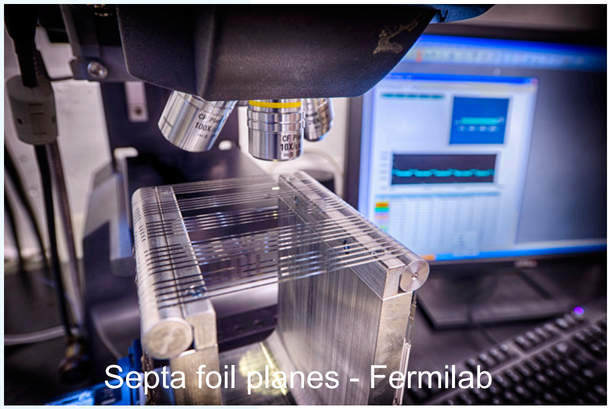






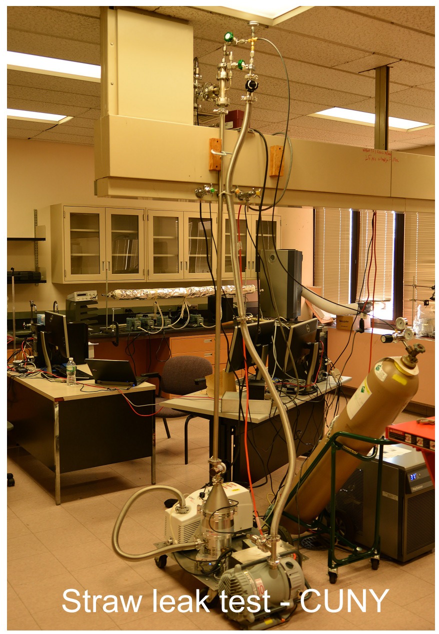
- Test beam (5 -500 MeV e-) in Frascati

Mu2e Other R&D


Septa foil planes - Fermilab


CRV Manifolds – U.Virginia


2x4 Straw test - Fermilab


Straw leak test - CUNY

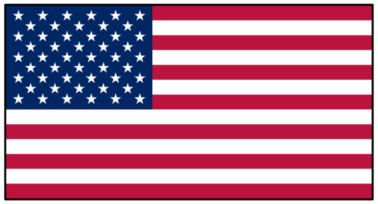
Custom pulsed power supply for fatigue tests on prototype production target - RAL

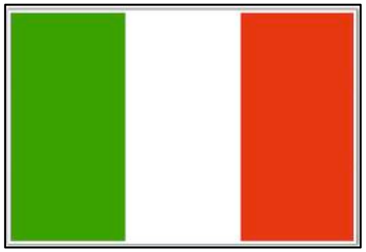
- Active R&D campaign across project

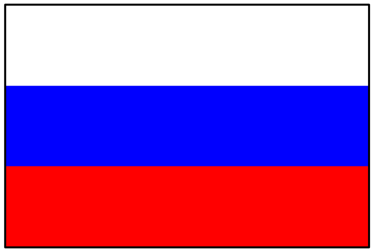
Mu2e Collaboration

Mu2e Membership


Mu2e Collaboration 2013

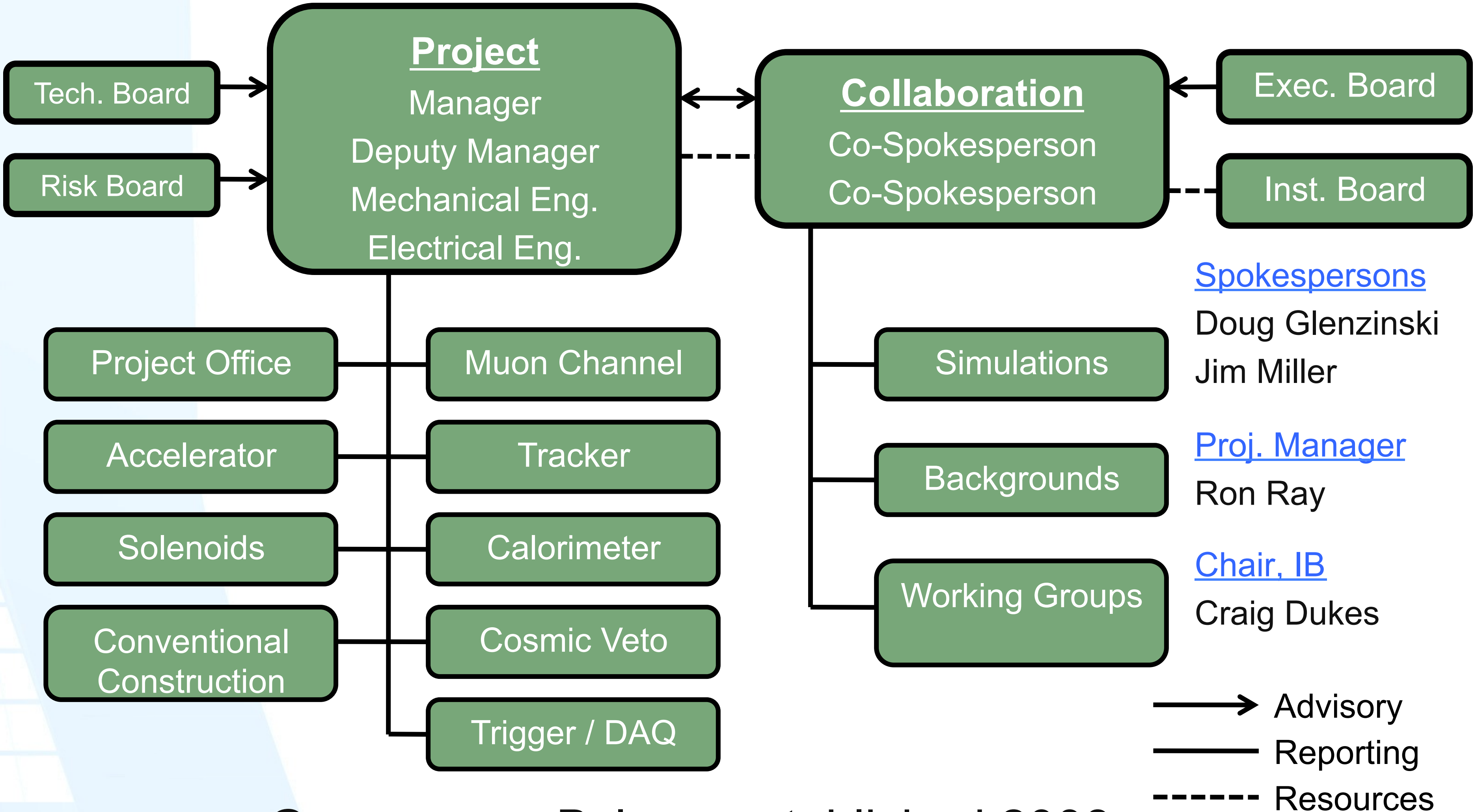






- ~140 Collaborators, 26 Institutions, 3 Countries

Mu2e Organization



- Governance Bylaws established 2008
- Institutional Board meets 3-4 times/year

Mu2e – New Members

- +2 Institutions, +20 members in last year

  (currently in discussion with 4 additional groups)

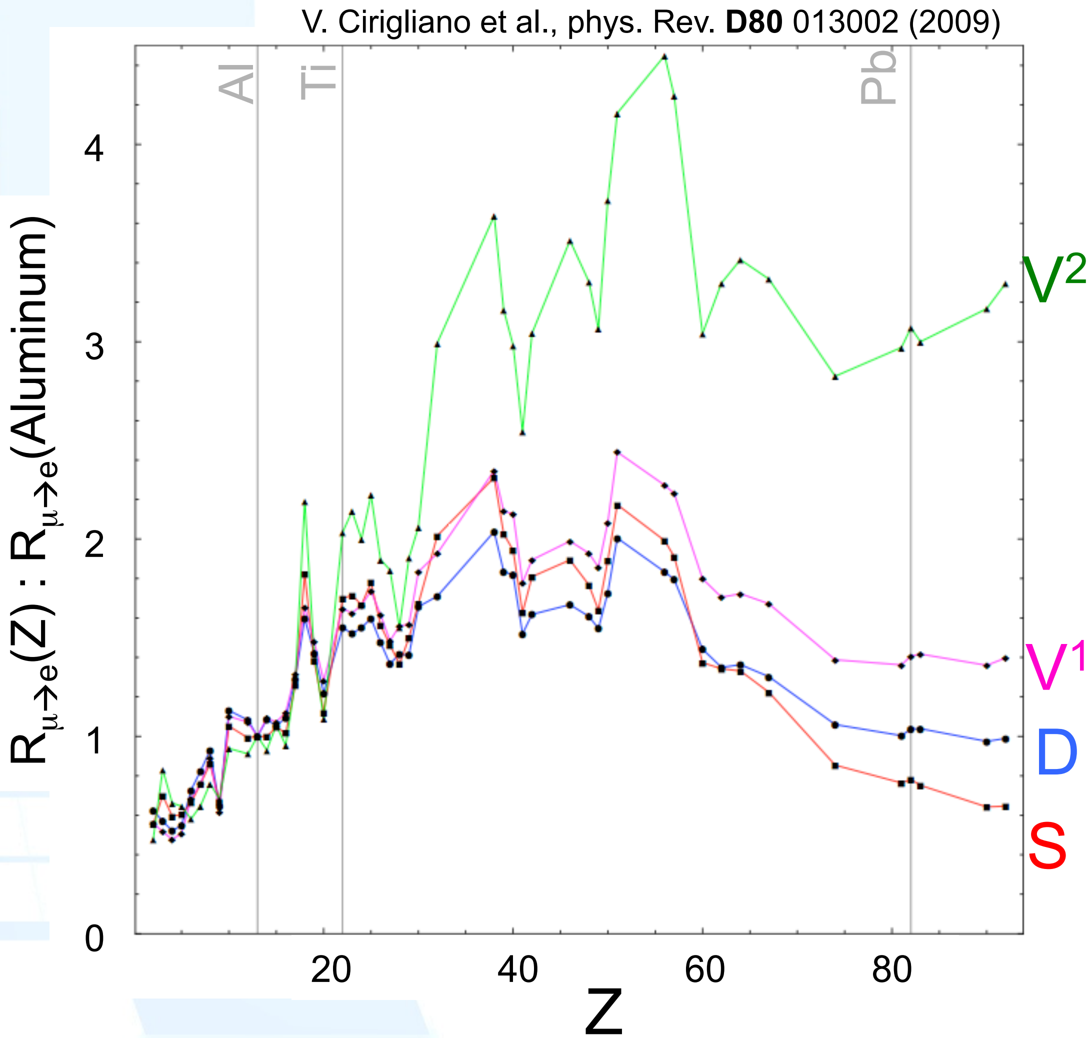
- Procedure
  1) Contact Spokespersons
     mu2e-spokespersons@fnal.gov
  2) Submit Application
  3) Make presentation to Collaboration
  4) Institutional Board votes

Mu2e Opportunities

- Although we've completed a preliminary design for CD-2 – there are opportunities for new groups to make significant contributions
  - Final design, fabrication, installation, commissioning of some electronics boards
  - Participation in final design and fabrication of tracker panels and subsequent commissioning
  - Development of trigger filters, final trigger strategy, testing and commissioning of HLT
  - Magnetic Field mapping
  - Prototype beam tests – fabrication, data taking, analysis
  - Software development – reconstruction, validation algorithms, online monitoring

Mu2e Future

Mu2e upgrades (Mu2e-II)



- PIP-II offers path for an upgraded Mu2e
  - x10 sensitivity with modest upgrades
  - Explore different stopping target materials
  - Snowmass study – arXiv:1311.5278, 1307.1138

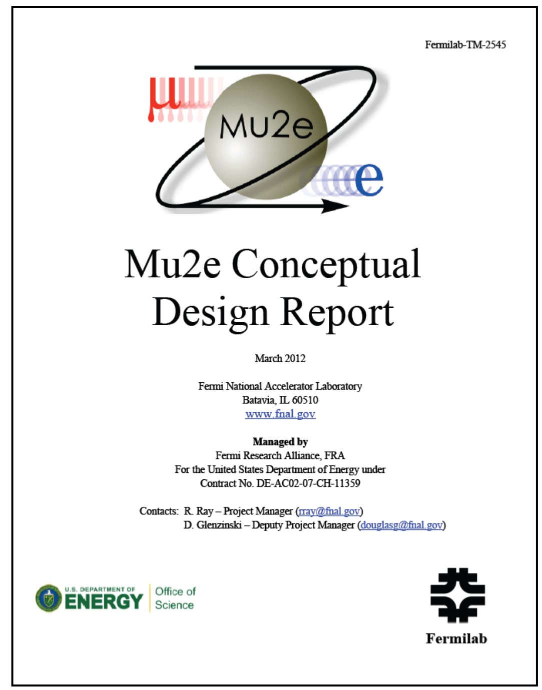
In Closing

Closing remarks

- Mu2e offers compelling discovery sensitivity across a broad swath of BSM parameter space.
  - A unique incisive probe of BSM physics
- Mu2e will begin commissioning at the end of this decade
  - DOE CD-2/3 review scheduled for this August
- A plausible upgrade path exists
- Opportunities available for new groups
  - mu2e-spokespersons@fnal.gov

More Information about Mu2e

- Conceptual Design Report
  - http://arXiv.org/abs/1211.7019
- Experiment web site:
  - http://mu2e.fnal.gov


Fermilab-TM-2545

Mu2e

Mu2e Conceptual Design Report

March 2012

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

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Contract No. DE-AC02-07-CH-11359

Contacts: R. Ray – Project Manager (rray@fnal.gov)
D. Glenzinski – Deputy Project Manager (douglasg@fnal.gov)

U.S. DEPARTMENT OF ENERGY Office of Science

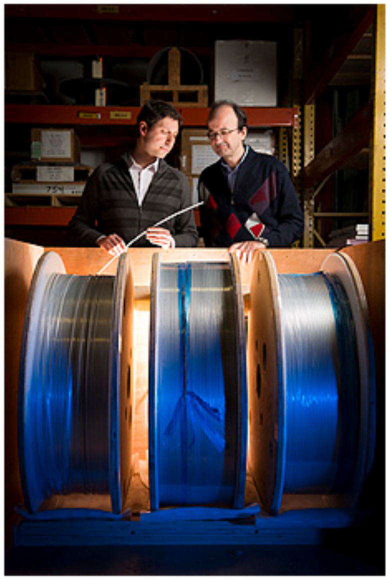
Fermilab

Backup Slides

Mu2e in the news

Feature

Mu2e superconducting cable prototype successful



Vito Lombardo and Giorgio Ambrosio lead the development of the Mu2e transport solenoid. In a recent test, the prototype superconducting cable for the solenoid met every benchmark. *Photo: Reidar Hahn*

Last month, members of the Technical Division conducted final tests on the first batch of prototype

December 16, 2013

Mu2e attracts magnet experts

By tapping into specialized knowledge around the world, the Mu2e collaboration will undertake a first-of-its-kind experiment.

By Andre Salles

PDF download

Related symmetry content

Feature: The muon guys: On the hunt for new physics

Feature: Through a muon's eyes

Elsewhere on the web

Mu2e experiment

Fermilab's Mu2e experiment is unlike anything ever attempted. So when the collaboration needed a first-of-its-kind magnet prototype built, they turned to an institution known for its magnet expertise: the Genoa section of the Italian Institute for Nuclear Physics, or INFN, located in the University of Genoa in Italy.

Earlier this year, INFN-Genoa became the sixth Italian institution to join the Mu2e collaboration, which now sports more than 150 members from 28 labs and universities in the United States, Italy and Russia. The team of magnet experts there has decades of experience working on high-energy physics experiments—they helped design and build magnets for BaBar at SLAC and, more recently, the CMS detector at CERN.

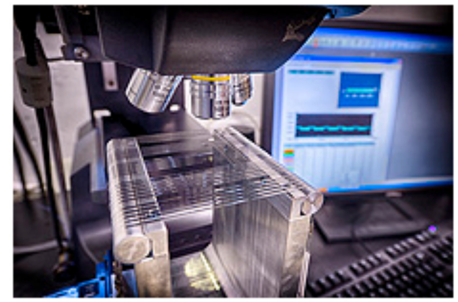
Now they're putting that knowledge toward building prototypes of the years-in-development magnets that will be used for for Mu2e, an experiment intended to study whether charged particles called leptons can change from one type to another. According to Doug Glenzinzki, the deputy project manager for Mu2e, the experiment's goal is to narrow down the possibilities for completing physicists' picture of the universe, by amassing evidence for one theory over others.

"We know the Standard Model is incomplete," Glenzinski says. "The number one goal of particle physics is to elucidate what a more complete model looks like. There are a lot of theories, and we are looking for data that tells us which is right."

It turns out, Glenzinski says, "charged lepton flavor violation"—the phenomenon Mu2e is being built to study—is a powerful way of

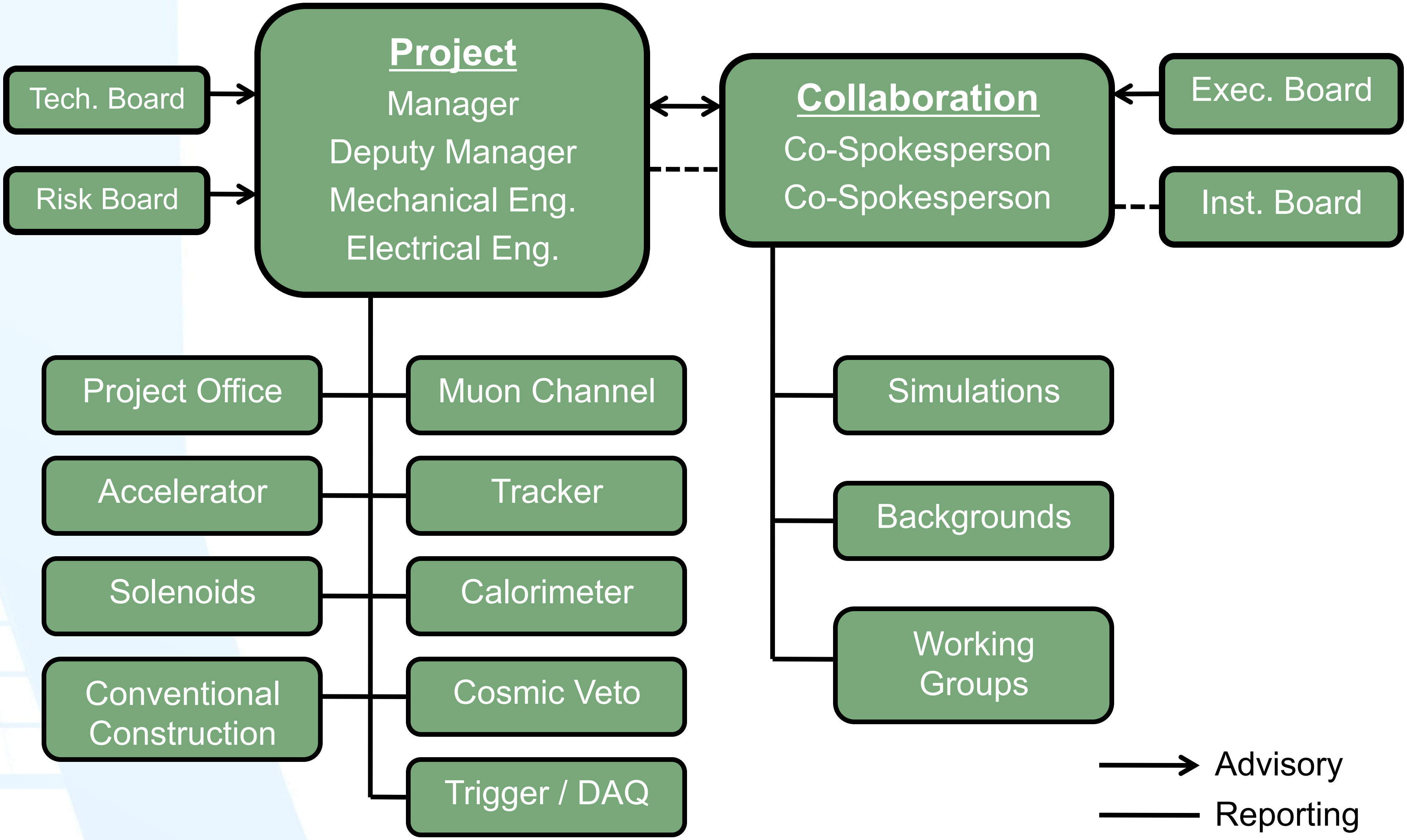
Photo of the Day

Toward better beam extraction



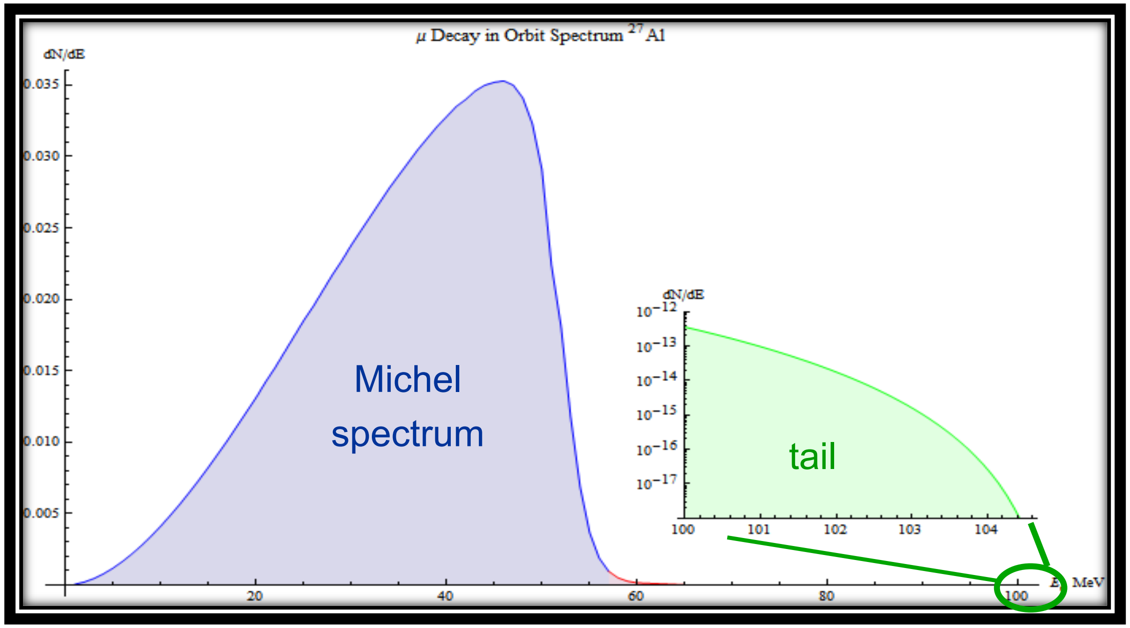
New projects bring to Fermilab new technological challenges and new solutions. One of those new technologies is the electrostatic septum made with very thin tungsten foils. Electrostatic septa are used in slow beam extraction to separate the circulating and extracted beams. At Fermilab, slow extraction has traditionally taken place as the beam is sent from the Main Injector to the Switchyard. In the standard technology, the septum plane is made as a layer of 100-micrometer tungsten wires. A challenge of the Mu2e project is slow extraction of protons with

Mu2e Organization



Mu2e Dominant Background Sources

- Decay-in-Orbit (DIO)
  - Intrinsic physics background from stopped muons decaying while in orbit around Al nucleus



Electron energy in MeV

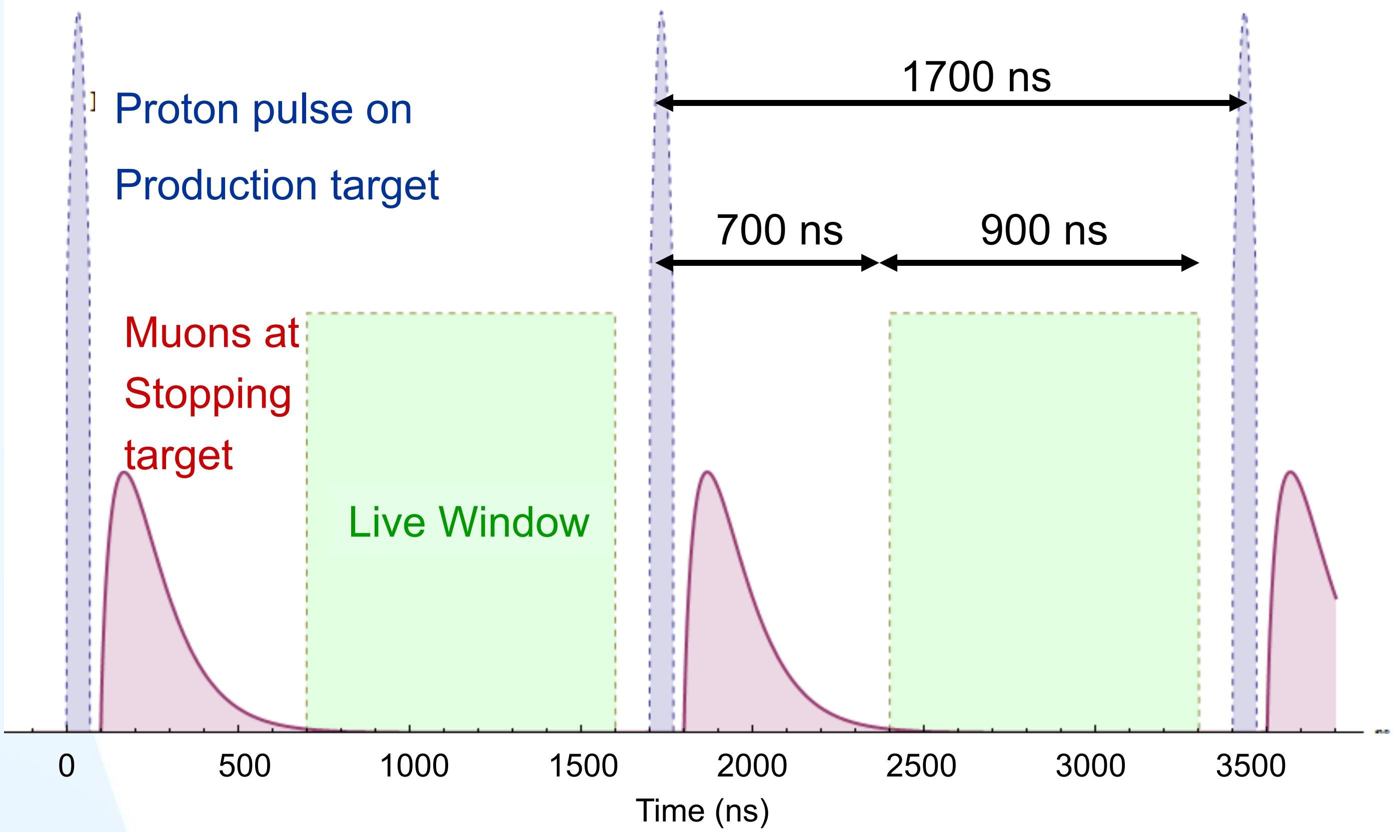
- Requires an excellent spectrometer resolution with small non-Gaussian tails

Mu2e Dominant Background Sources

- Radiative pion Capture (RPC)
  - Pions at Al target are promptly captured on nucleus
  - About 2% of the time a photon is radiated with a maximum energy ~ M_{π}
  - Main sources of pions at stopping target t >700 ns
    - Tails in proton distribution
    - Out-of-time protons
    - Anti-protons annihilating near Al target

- Requires narrow proton pulses, suppression of out-of-time protons, anti-proton absorber

Mu2e Pulsed Proton Beam



- Mu2e will use a pulsed proton beam and a delayed live gate to suppress prompt background

Mitigating Out-Of-Time Protons

- The RF structure of the Recycler provides some "internal" extinction:
  - Extinction (Intrinsic) = few 10^{-5}
- A custom-made AC dipole placed just upstream of the production target provides additional "external" extinction:
  - Extinction (AC dipole) = $10^{-6} – 10^{-7}$
- Together they provide a total extinction:
  - Extinction (Total) = few $10^{-11} – 10^{-12}$

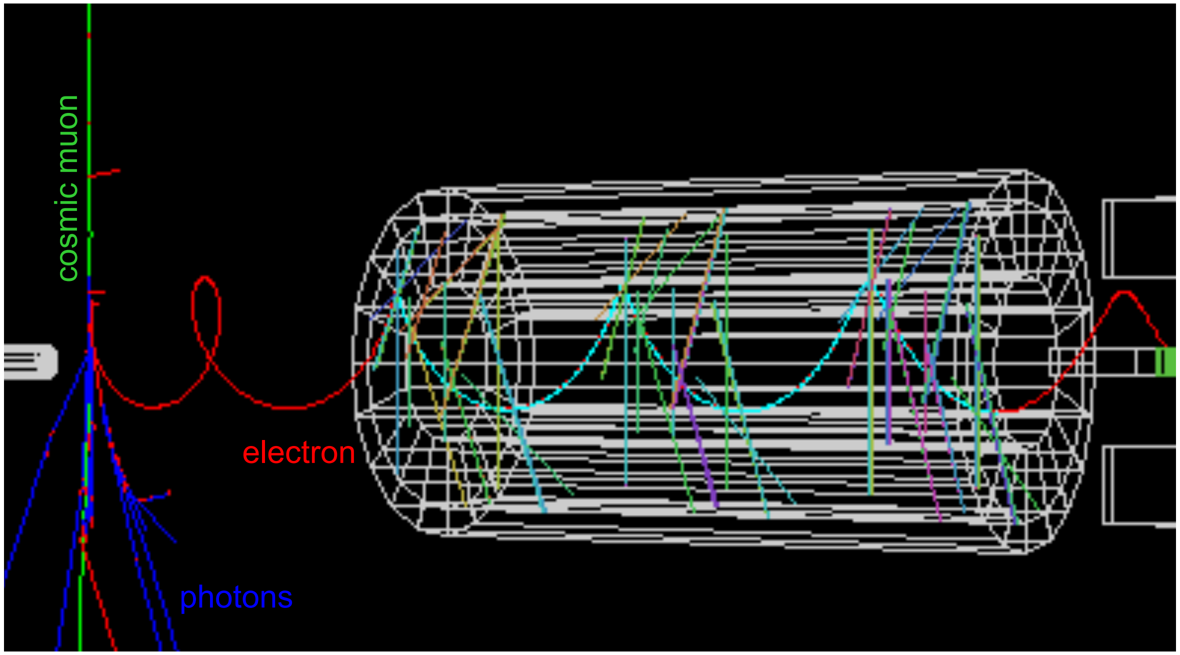
Mu2e Dominant Background Sources

- Radiative pion Capture (RPC)
  - Pions at Al target are promptly captured on nucleus
  - About 2% of the time a photon is radiated with a maximum energy ~ M_{π}
  - Main sources of pions at stopping target t >700 ns
    - Tails in proton distribution
    - Out-of-time protons
    - Anti-protons annihilating near Al target

- Requires narrow proton pulses, suppression of out-of-time protons, anti-proton absorber

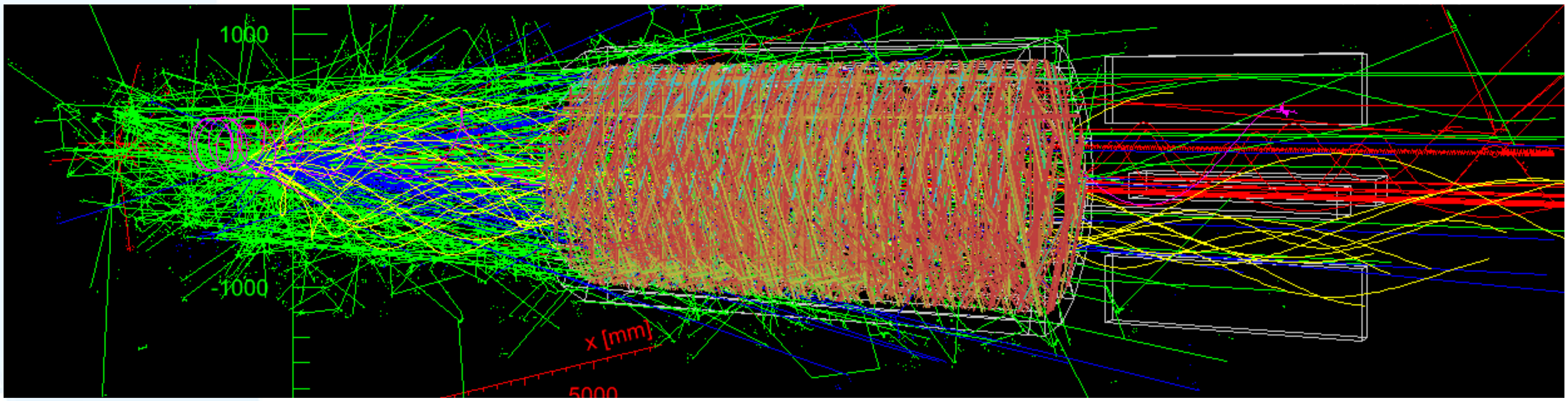
Mu2e Dominant Background Sources

- Cosmic-Ray Induced
  - CR can create background events via scattering, decay, or material interactions
  - Get about one such event per day



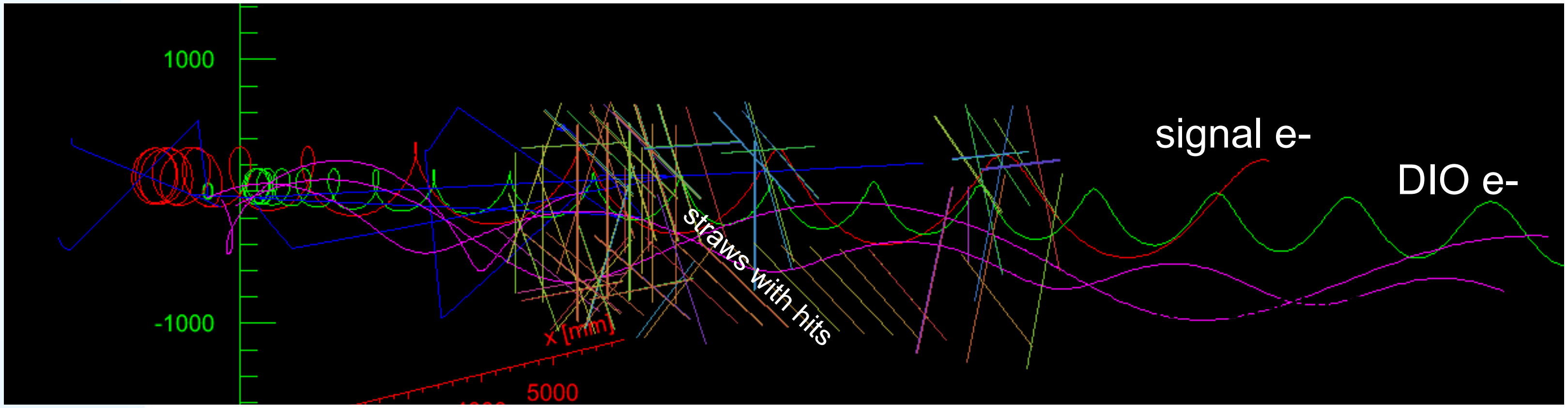
- Requires high efficiency CR-veto system, PID

Mu2e Pattern Recognition



- A signal electron together with all the other “stuff” occurring simultaneously integrated over 500-1695 ns window

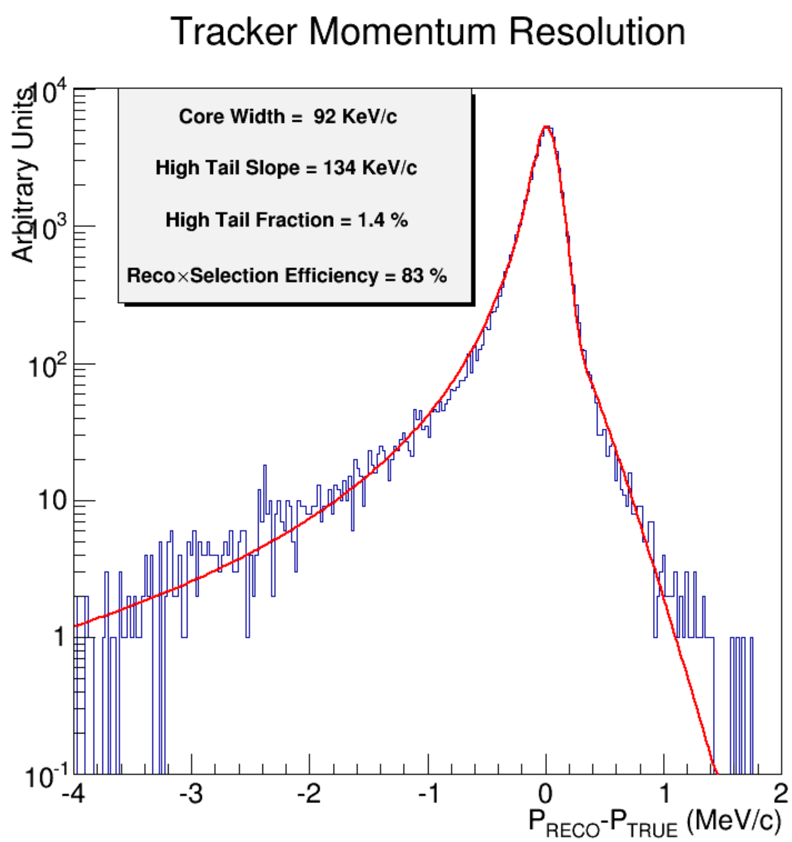
Mu2e Pattern Recognition



(particles with hits within +/-50 ns of signal electron t_{mean})

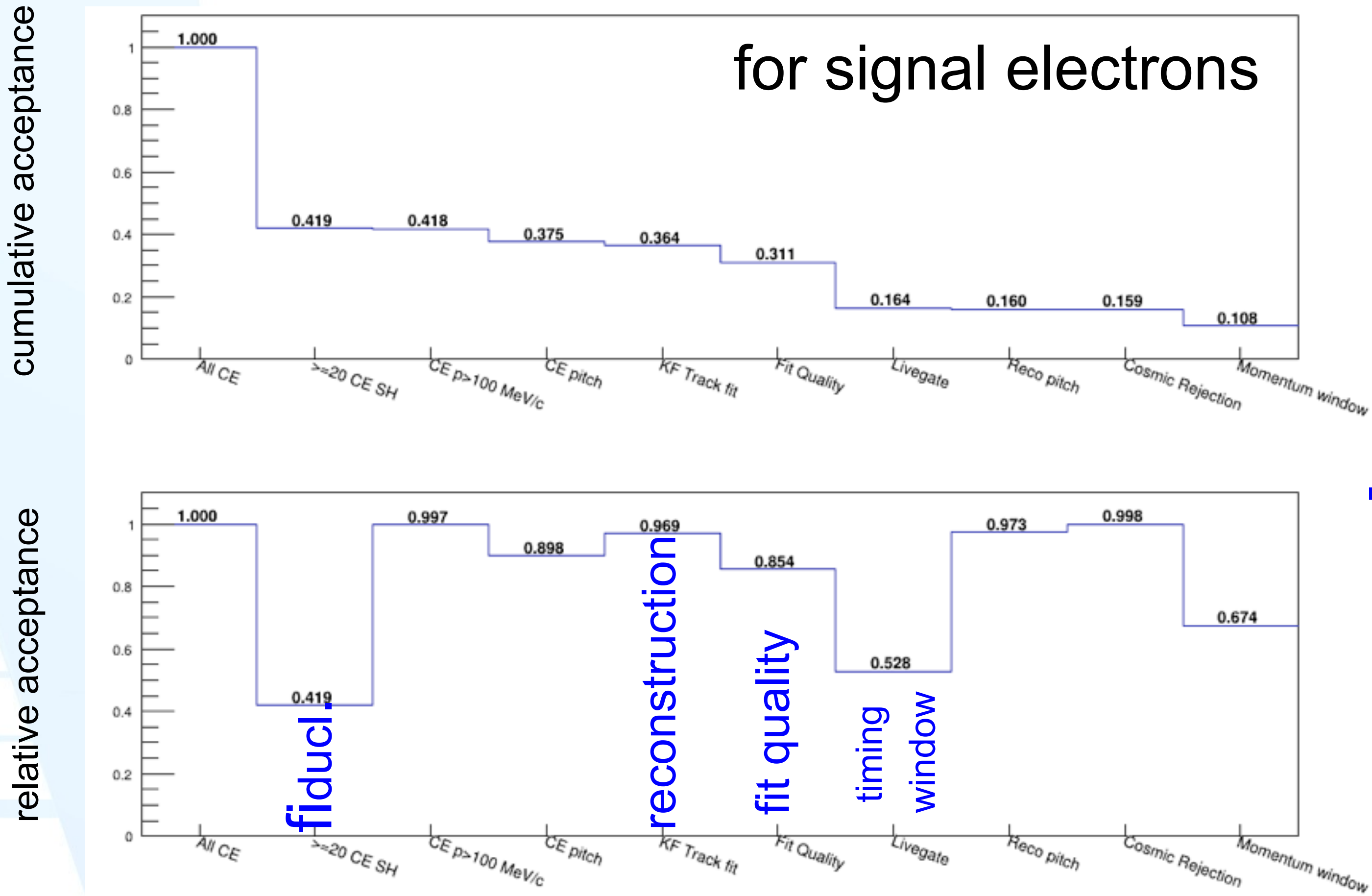
- We use timing information to look in +/- 50 ns windows – significant reduction in occupancy and significant simplification for Patt. Rec.

Mu2e Spectrometer Performance



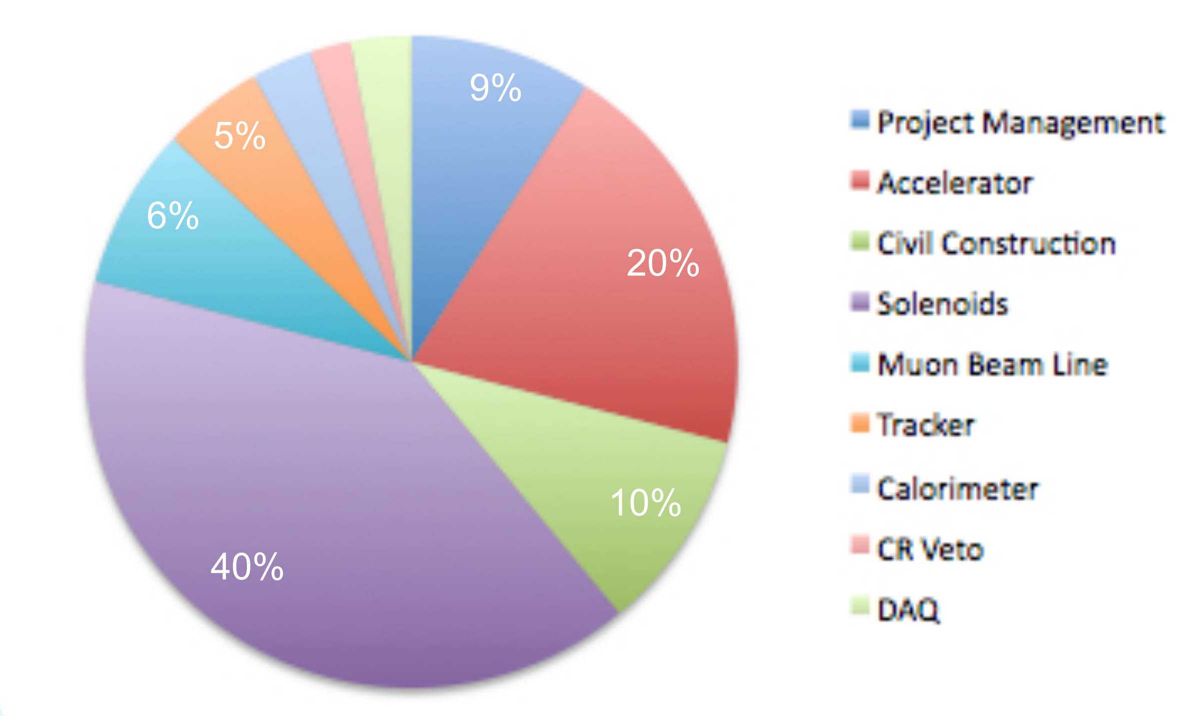
- Performance well within physics requirements

Reconstruction and Selection Efficiencies



- Inefficiency dominated by geometric acceptance and delayed signal-timing window

Mu2e Cost Breakdown

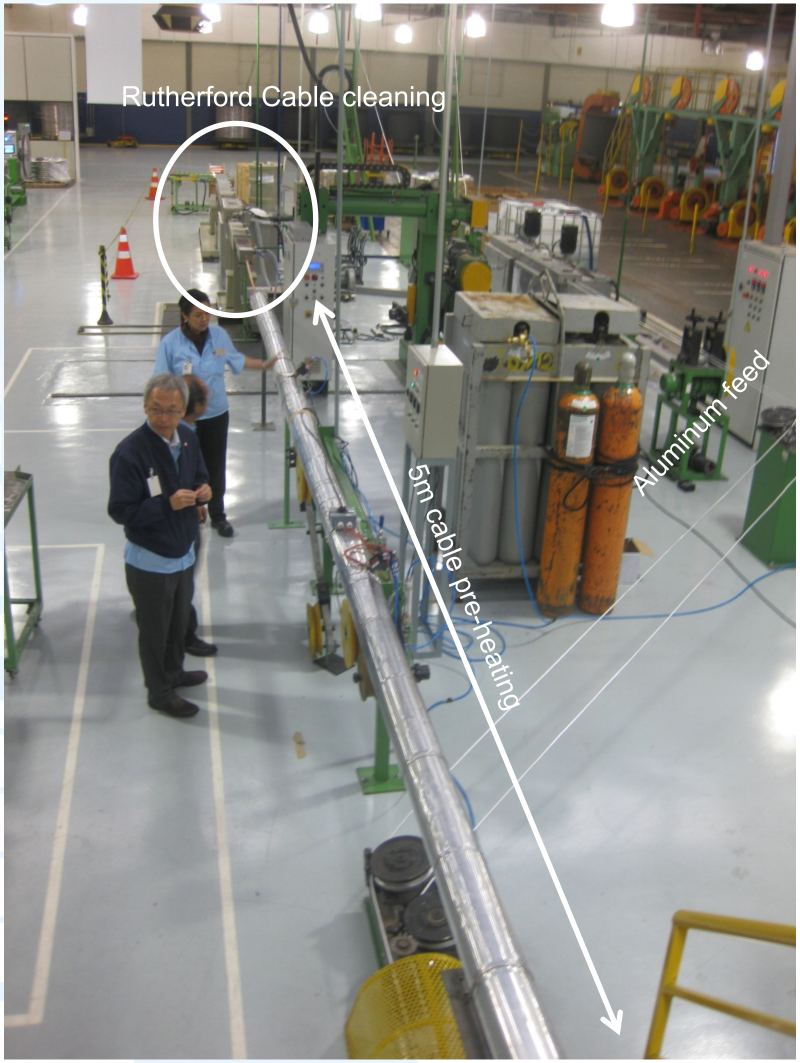


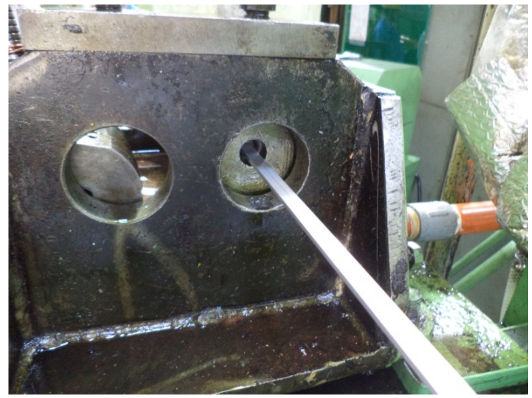
- Solenoid costs : Coils/Infrastructure ~ 65/35

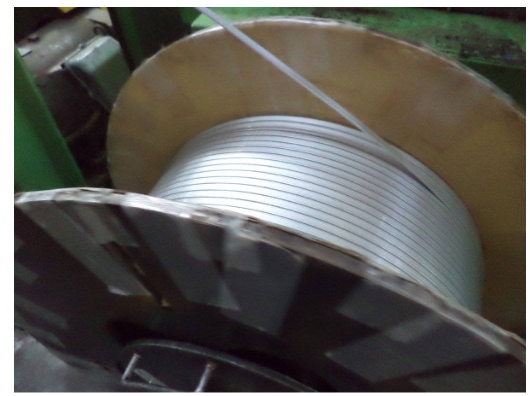
Mu2e Sensitivity for TDR

- Background Working Group
  - Established March 2013
    (led by A. Gaponenko, FNAL)
  - Significant contributions from collaboration
    (D. Brown (LBNL), R. Ehrlich (U. Virginia), K. Knoepfel (FNAL), R. Kutchke (FNAL), Z. You (UC Irvine), V. Logoshenko (Boston))
- Staged approach
  - Factorizes work and facilitates detector optimizations and systematic studies
  - 2600M POT generated → 1M micro-pulses
  - 3 x 10^5 CPU-days, 10 TB of disk
- Studies completed, preparing TDR

Mu2e Conductor R&D



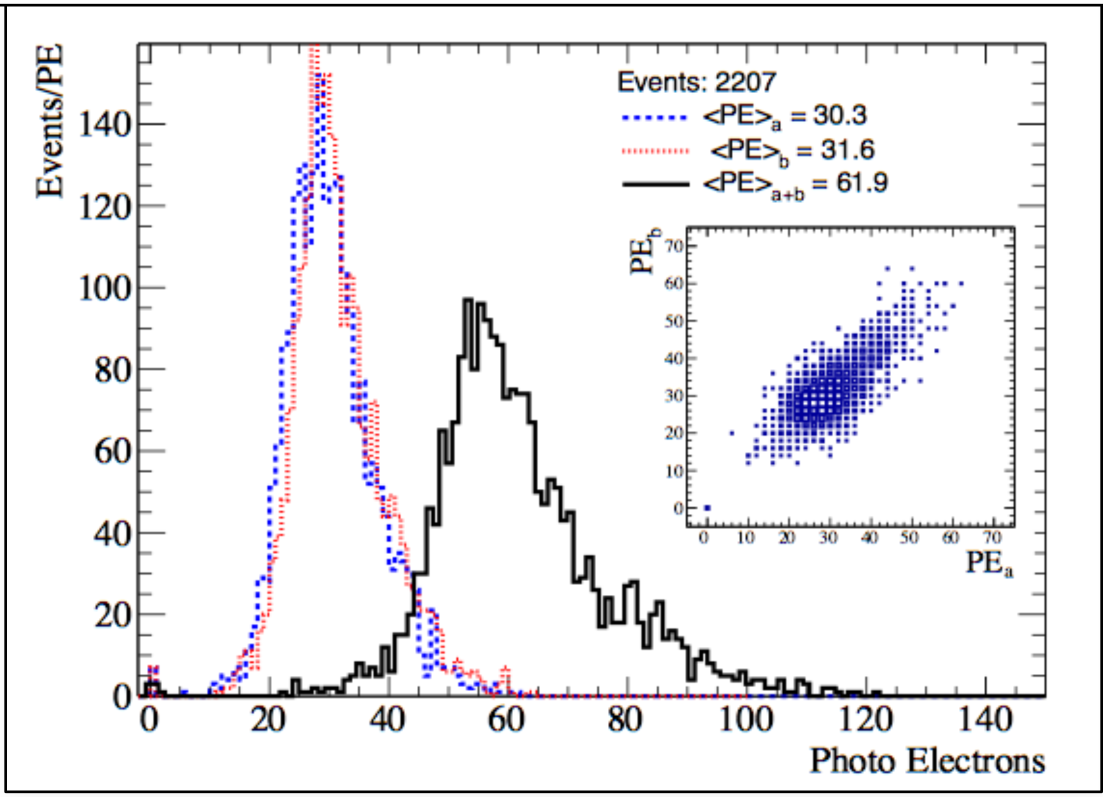




- Have established a good relationship with the vendors

Test Beam – September 2013 Results

Typical light yield from CRV counter prototype – 20 cm from RO end



- Achieves veto efficiency >99% at 2.5m from RO
  - want more light to allow for SiPM failure, 8y lifetime
  - will move from 1mm WLS fiber to 1.4 mm

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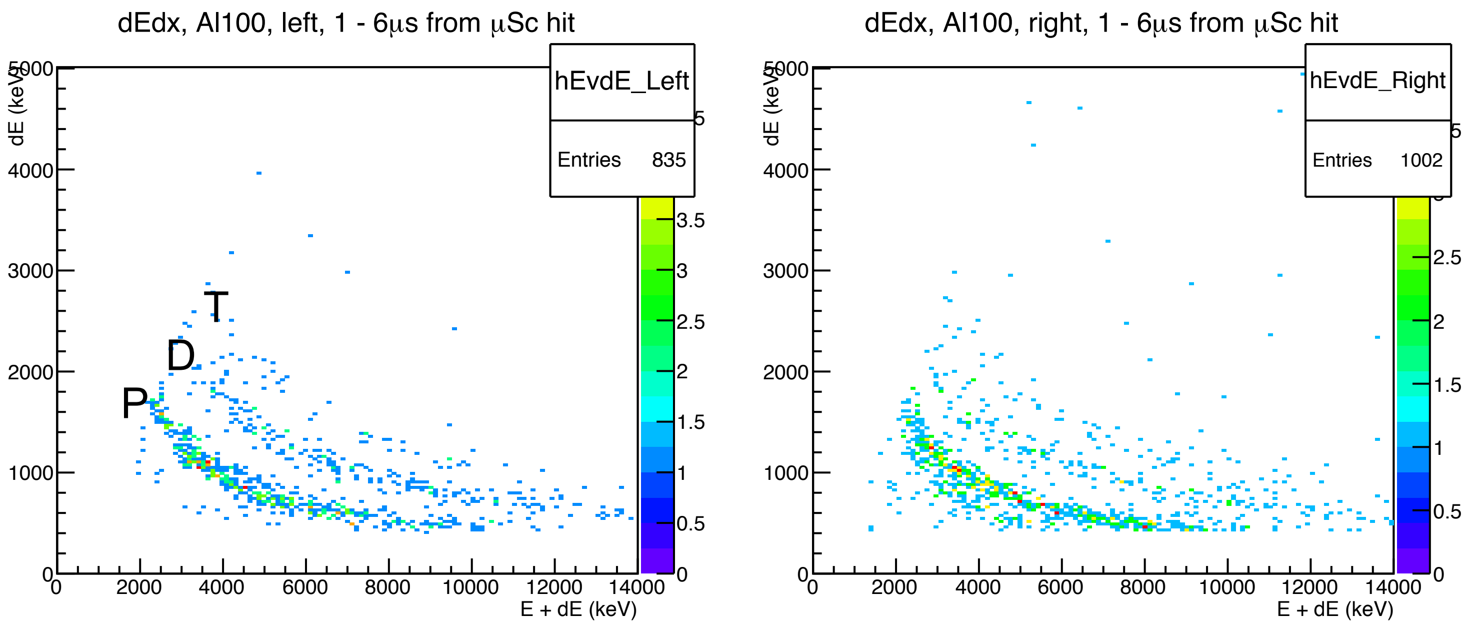
Test Beam – December 2013 Results



- Preliminary AlCap results
  - Analysis ongoing, but proton, deuteron lines clear