Mu2e Experiment and Issues

Rick Coleman,   Fermilab

RESMM'12, February 2012

Mu2e talks

- Today
  - Now: Mu2e Experiment and Issues
    - Overview, Status of Project, Production & Transport Solenoids
  - 16:30 Superconducting Magnets of Mu2e- Michael Lamm
  - 17:00 Mu2e Production Solenoid- Vadim Kashikhin
- Tuesday
  - 16:00 Radiation Studies for Mu2e Magnets- Vitaly Pronskikh

Special Thanks to: R. Bernstein, J. Miller, D. Glenzinski, for some material used

Introduction

- Mu2e experiment is a search for Charged Lepton Flavor Violation (CLFV) via the coherent conversion of $\mu^- N \rightarrow e^- N$
- In wide array of New Physics models CLFV processes occur at rates we can observe with next generation experiments
- The proposed experiment uses current proton source at Fermilab with some modifications
- Target sensitivity has great discovery potential

Current limits: $R_{\mu e} = \dfrac{\mu^- Au \rightarrow e^- Au}{\mu^- Au \rightarrow \text{capture}} < 7\text{x}10^{-13}$ (SINDRUM II)

Mu2e goal: $R_{\mu e} = \dfrac{\mu^- Al \rightarrow e^- Al}{\mu^- Al \rightarrow \text{capture}} < 6\text{x}10^{-17}$ (90% c.l.)

Collaboration

Boston University
Brookhaven National Laboratory
University of California, Berkeley
University of California, Irvine
California Institute of Technology
City University of New York
Duke University
Fermilab
University of Houston
University of Illinois, Urbana-Champaign
University of Massachusetts, Amherst
Lawrence Berkeley National Laboratory
Los Alamos National Laboratory
Northwestern University
Rice University
Syracuse University
University of Virginia
University of Washington, Seattle

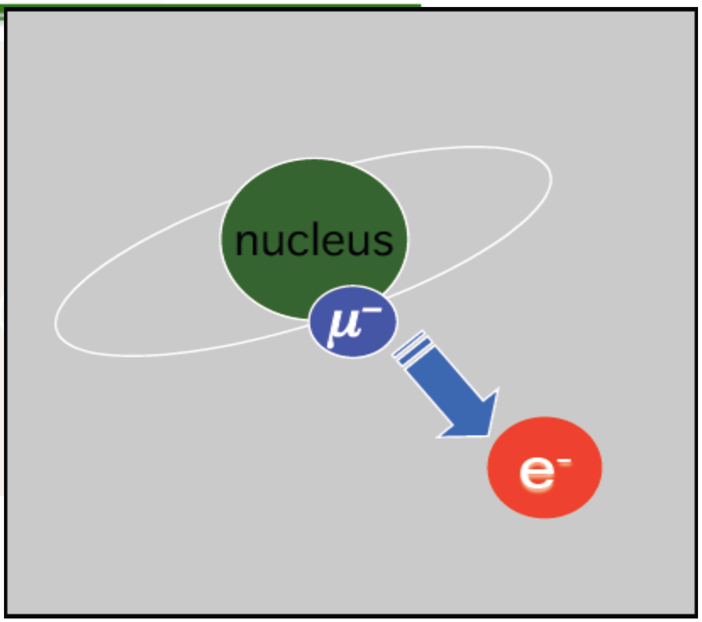
INFN

Istituto G. Marconi Roma
Laboratori Nazionale di Frascati
Università di Pisa, Pisa
Università del Salento
Gruppo Collegato di Udine

Institute for Nuclear Research, Moscow, Russia
JINR, Dubna, Russia

~130 collaborators

The Measurement Method



- Stop negative muons in an aluminum target
- The stopped muons form muonic atoms
  - 207x smaller radius than inner e⁻ in Al–>

  well inside electron orbits →

  muon forms a hydrogen-like atom, unaffected by e's
  - hydrogenic 1S : Bohr radius ~20 fm, BE~500 keV
  - Nuclear radius ~ 4 fm →

    muon and nuclear wavefunctions overlap significantly
- Three main things can happen:
  - Muon decays (40%): $\mu^- \rightarrow e^- + \overline{\nu}_e + \nu_\mu$
  - Muon captures on the nucleus (60%): $\mu^- + {}^{27}_{13}Al \rightarrow X + \nu_\mu$
  - Muon to electron conversion: $\mu^- + {}^{27}_{13}Al \rightarrow {}^{27}_{13}Al + e^-$
- Muon lifetime in 1S orbit of aluminum ~864 ns

  (40% decay, 60% nuclear capture), compared to 2.2 μsec in vacuum
- Look for 105 MeV electron signal

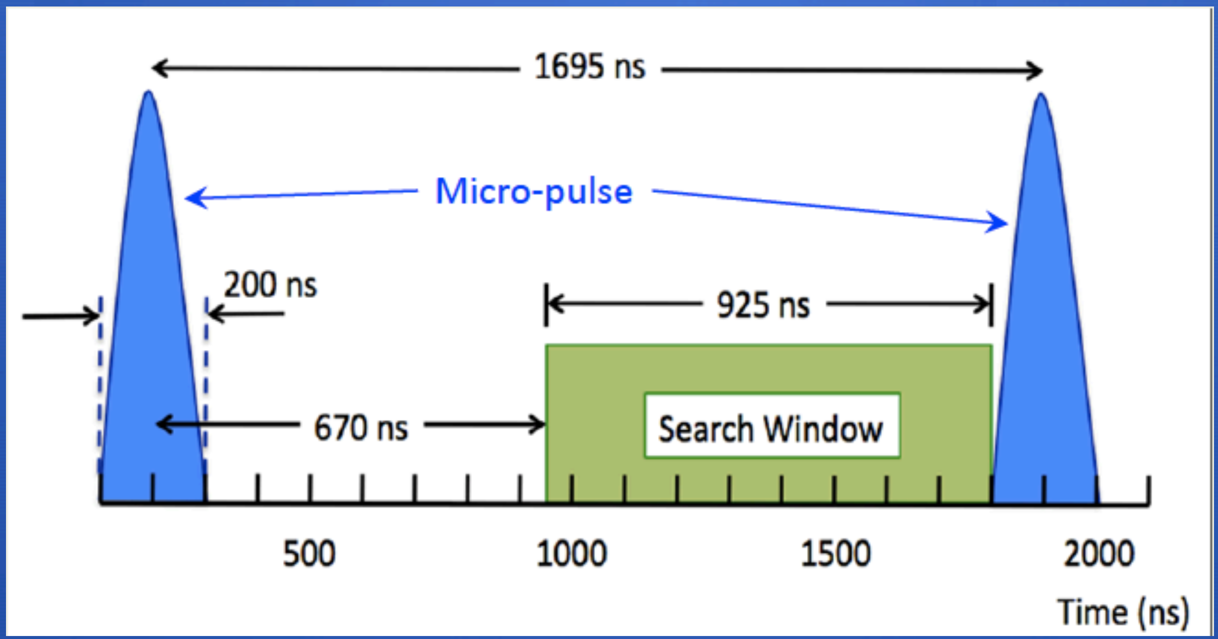
  This energy is well above the most copious sources of backgrounds

Beam Intensity and Pulsed Proton Beam

- Deliver high flux μ^- beam to stopping target
  - proton flux ~6 x 10^{12} /sec at 8 GeV (8 kW)
  - ~2 x 10^{10} Hz μ^- , 10^{18} total, 4 conversion e^- at $R_{\mu e}$~10^{-16}
  - 10^3 more muons than SINDRUM II previous best limt

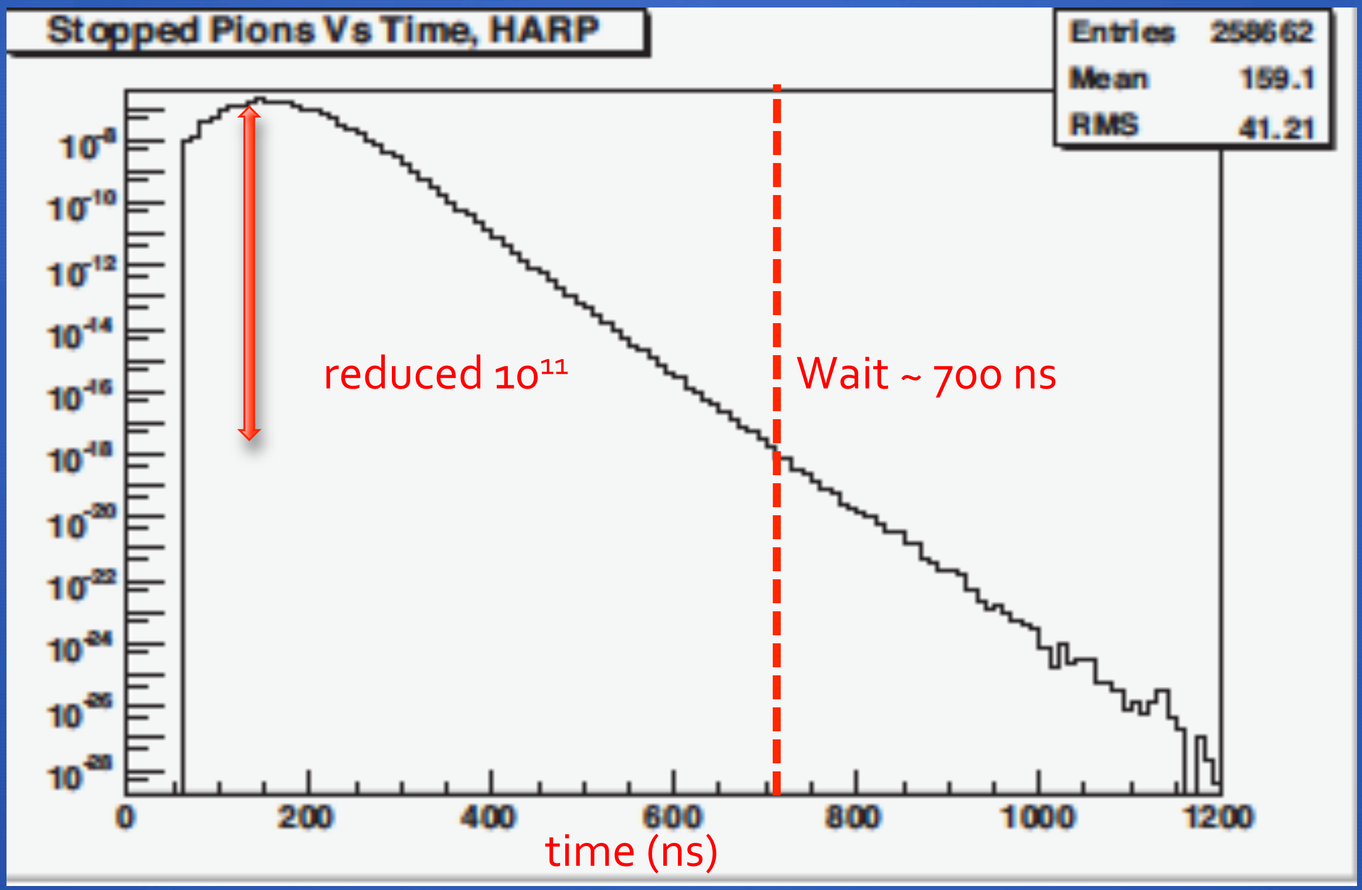
- Pulsed Proton beam – Wait 670 ns to reduce prompt background, extinction = 10^{-10} using Debuncher Ring and oscillating (AC) dipole sweeper in external proton beamline

τ_μ(Al)=864 ns

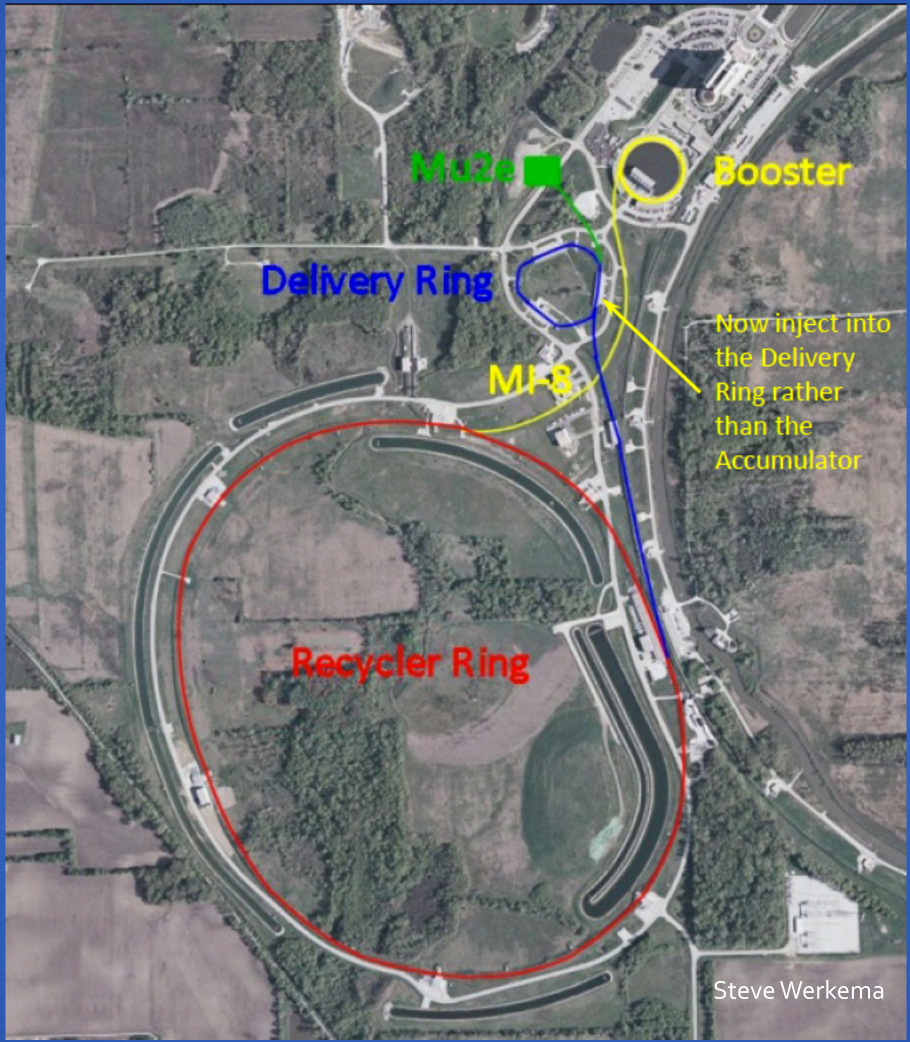


Pulsed Beam and Radiative Pion Capture Background

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



Protons from 8 GeV Booster to Mu2e

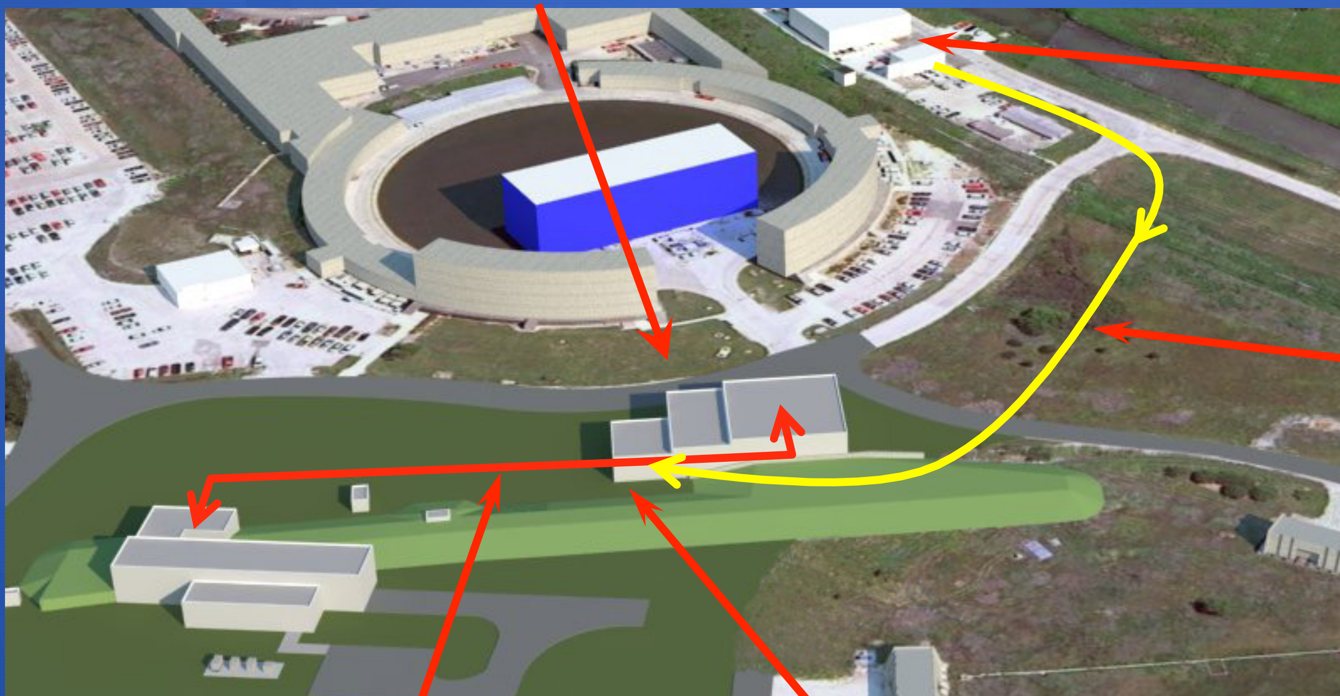


New beamline shared by Mu2e and g-2

Muon Campus for Mu2e and g-2 with Cryo Plant

g-2 building (MC-1) has evolved to support needs of g-2 and Mu2e

- Low bay is Muon Campus Cryo Building
- Medium Bay will house beamline power supplies and equipment.

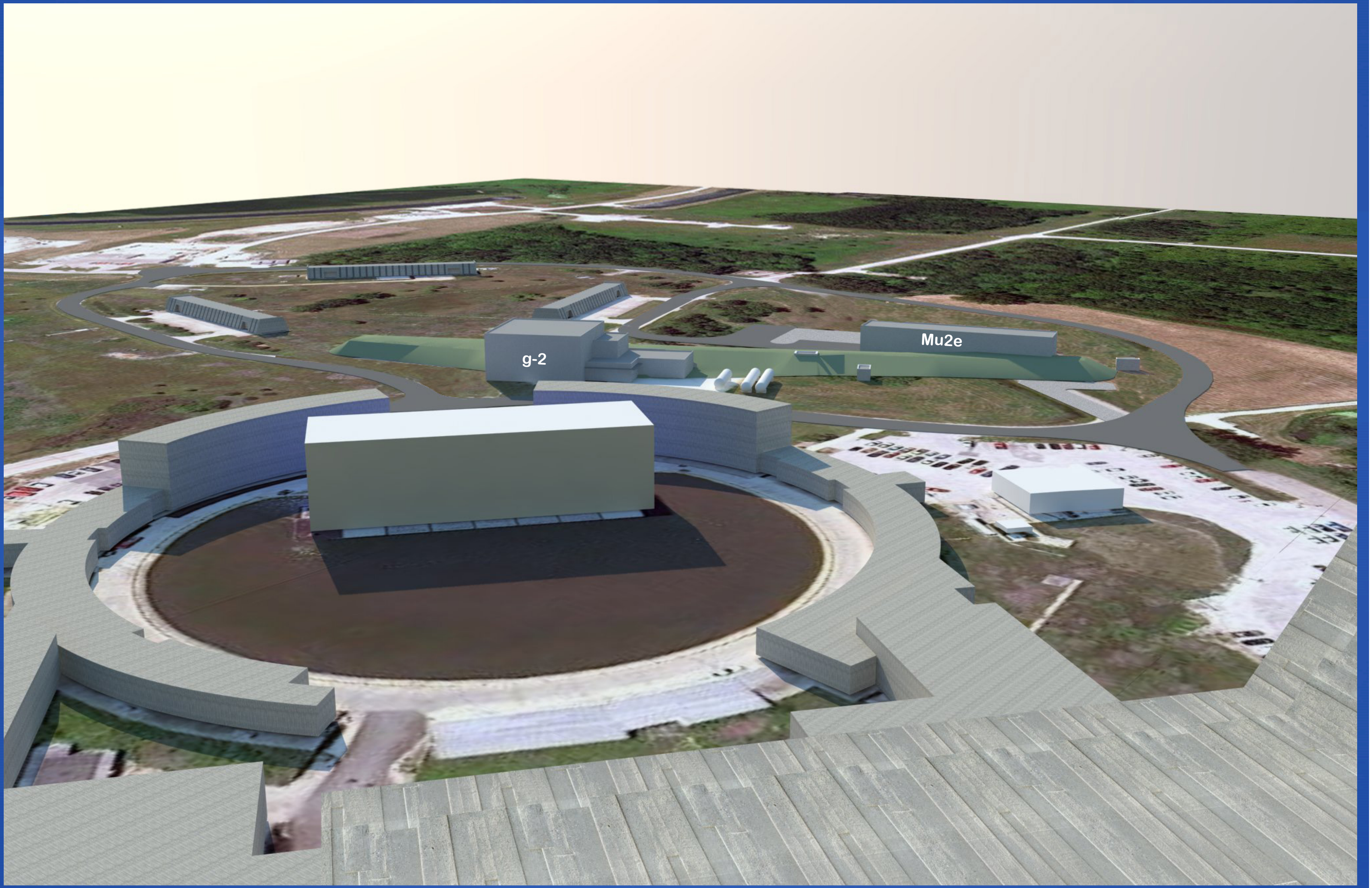


Compressed He from existing TeV compressors

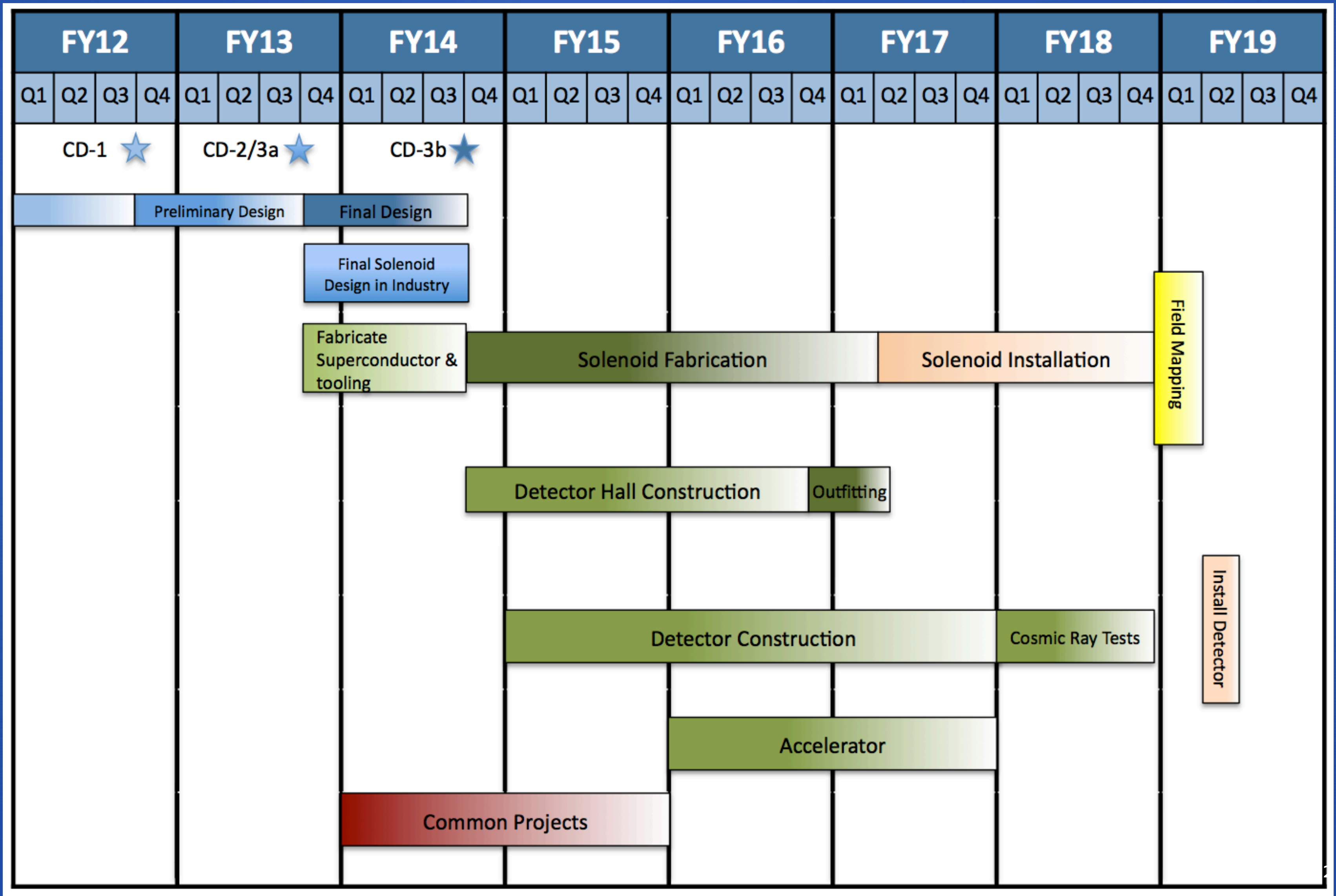
New transfer line for compressed He built from recycled parts

Cold He lines to experiments

Three TeV refrigerators installed in MC-1


g-2
Mu2e

Schedule



FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
Q1
Q2
Q3
Q4
CD-1
CD-2/3a
CD-3b
Preliminary Design
Final Design
Final Solenoid Design in Industry
Fabricate Superconductor & tooling
Solenoid Fabrication
Solenoid Installation
Field Mapping
Detector Hall Construction
Outfitting
Install Detector
Detector Construction
Cosmic Ray Tests
Accelerator
Common Projects

LETTERS TO THE EDITOR

On the search for the $\mu \to e$ conversion process in a nucleus

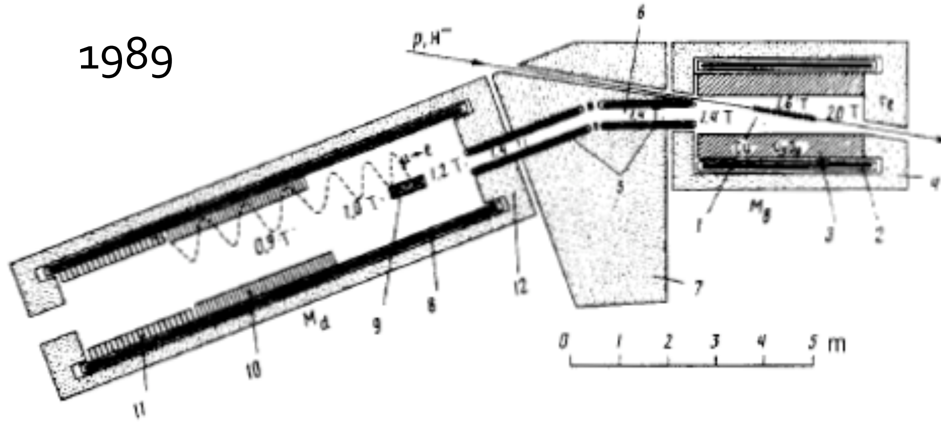
R. M. Dzhilkibaev and V. M. Lobashev

Institute of Nuclear Research, USSR Academy of Sciences

(Submitted 21 June 1988)
Yad. Fiz. **49**, 622–624 (February 1989)

MELC at Moscow

1989

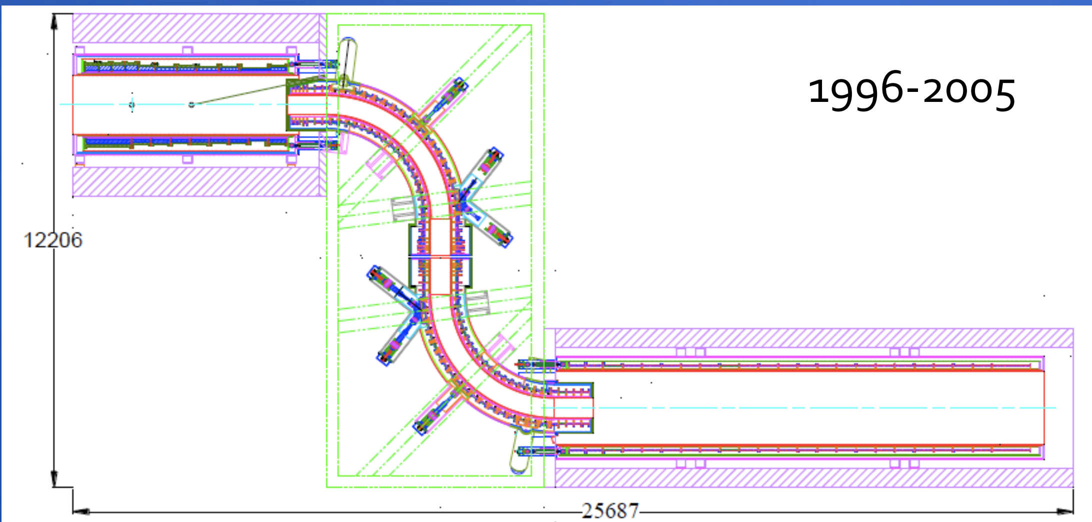


$\mu/p \sim 10^{-4}$ vs

conventional ~10^{-8}

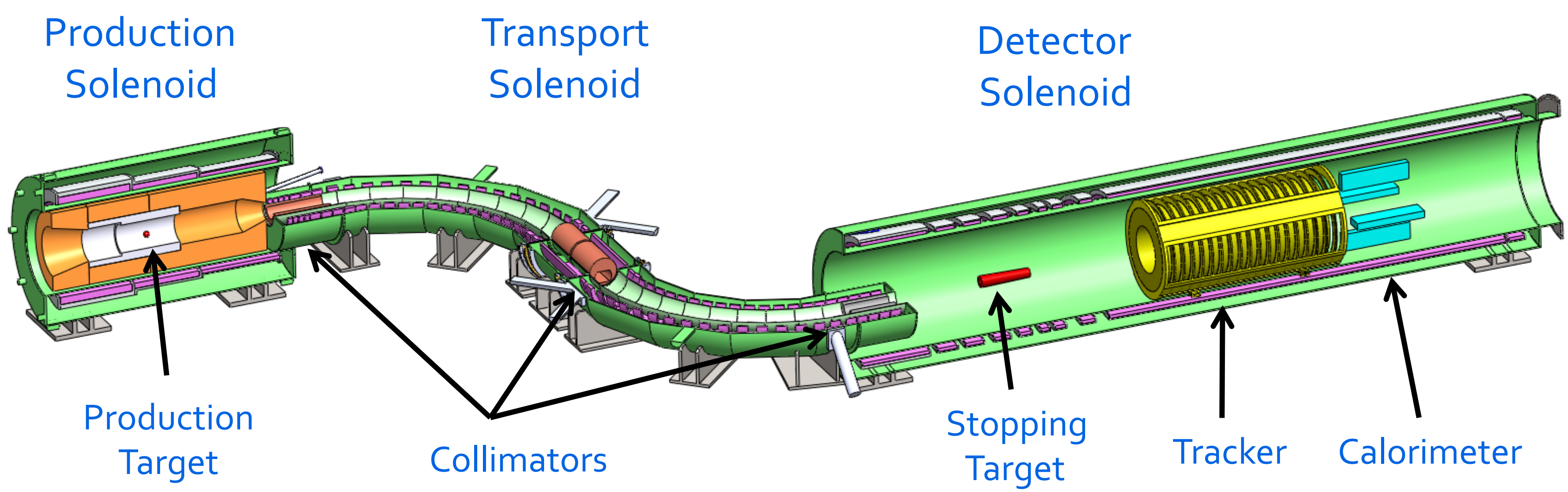
MECO at BNL

1996-2005



COMET at J-PARC: proposal Nov 2007 & Mu2e at FNAL: proposal Oct 2008

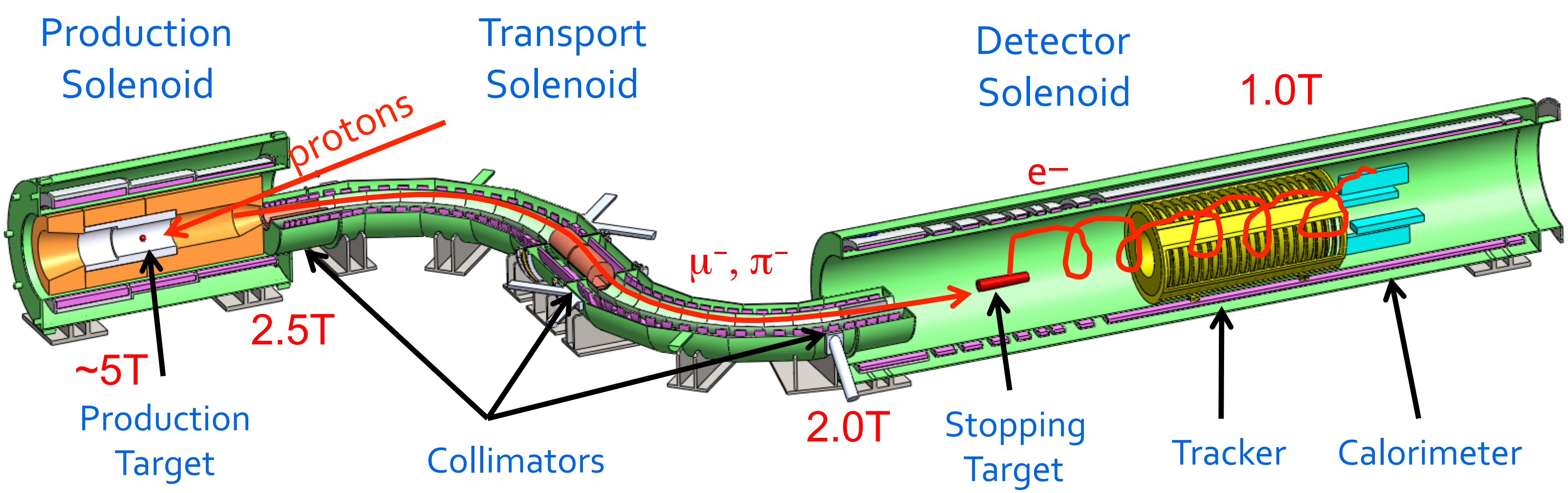
Mu2e Apparatus



(not shown: Cosmic Ray Veto, Proton Dump, Muon Dump, Proton/Neutron absorbers, Extinction Monitor, Stopping Monitor)

- Mu2e experiment consists of 3 solenoid systems

Mu2e Apparatus

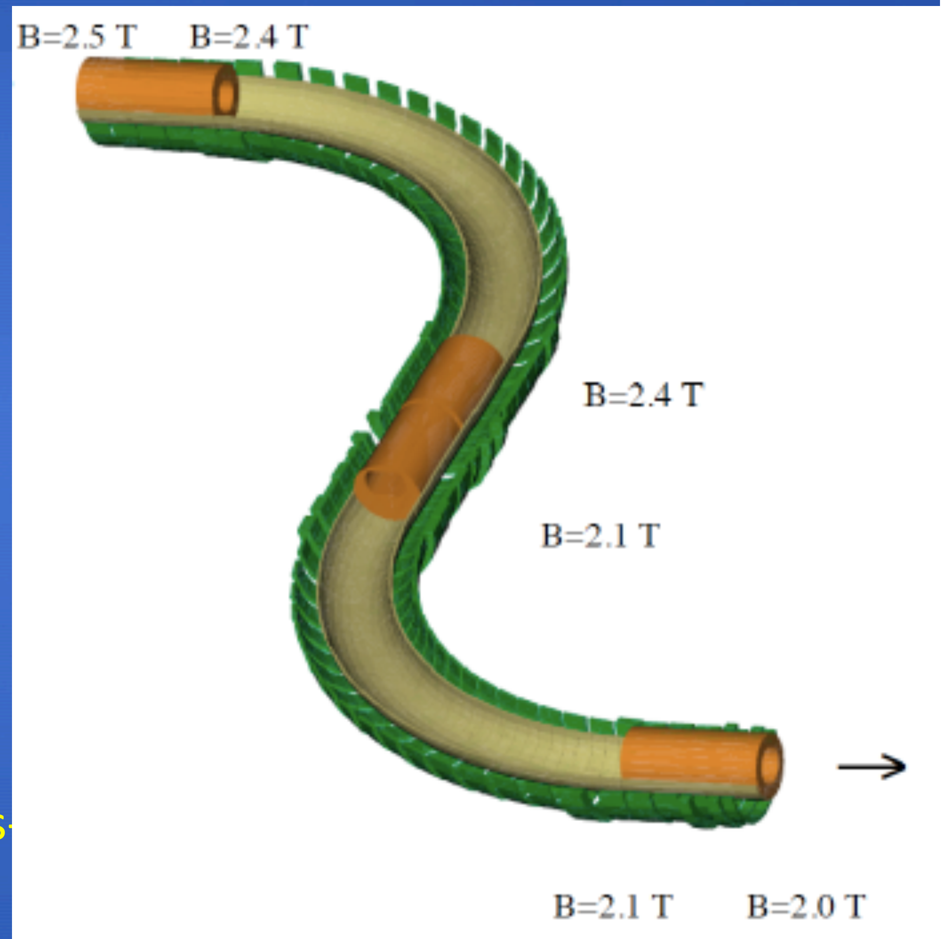


(not shown: Cosmic Ray Veto, Proton Dump, Muon Dump, Proton/Neutron absorbers, Extinction Monitor, Stopping Monitor)

- Mu2e experiment consists of 3 solenoid systems

Transport Solenoid

Inner radius=24 cm
Length=13.11 m
TS1: L=1 m
TS2: R=2.9 m
TS3: L=2 m
TS4: R=2.9 m
TS5: L=1 m



Goals:

—Transport low energy μ^- to the detector solenoid

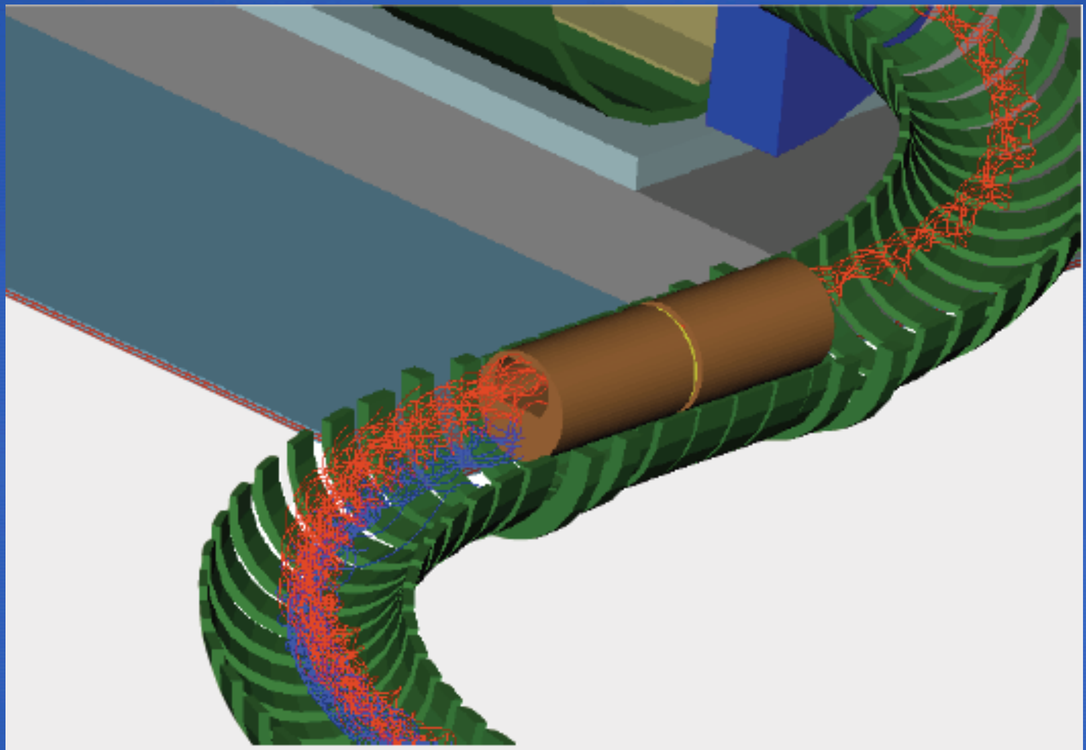
—Minimize transport of positive particles and high energy particles

—Minimize transport of neutral particles

—Absorb antiprotons in a thin window

—Minimize particles with long transit time

Charge, Momentum Selection and Rejection of Long-lived Particles



Vertical Drift Motion in a Toroid

Toroidal Field: B_s=constant x 1/r. This gives a large dB_s/dr

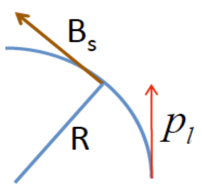
Particle spiral drifts vertically (perpendicular to the plane of the toroid bend):

D= vertical drift distance

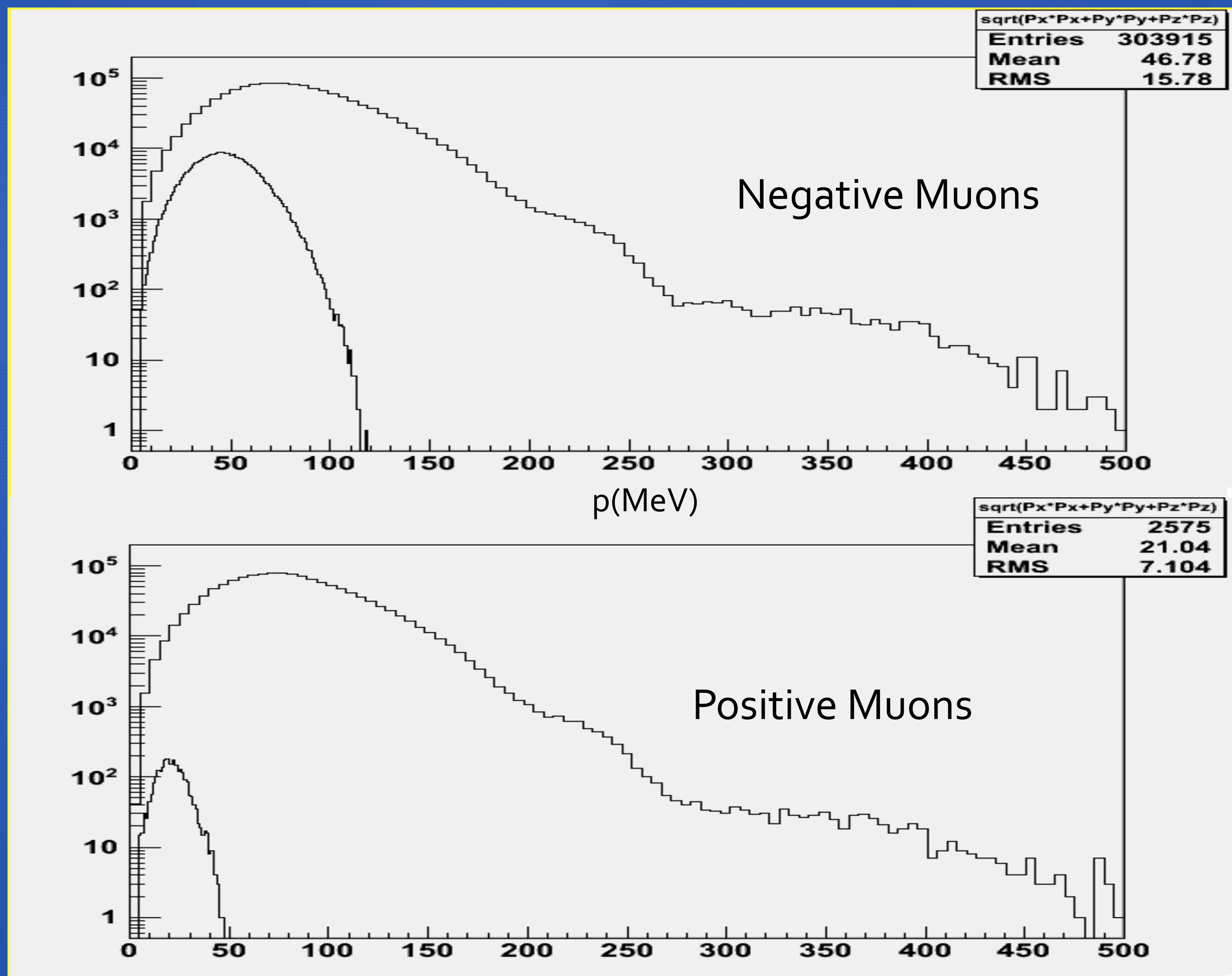
R=major toroid radius,
s/R = toroid angle=90^0
D[m]=distance, B[T], p[GeV/c]

$$\text{Define pitch } = \alpha = \frac{p_l}{p}$$

$$\rightarrow D = \frac{q}{0.3 \times B} \times \frac{s}{R} \times \frac{1}{2} p\left(\frac{1}{\alpha} + \alpha\right).$$

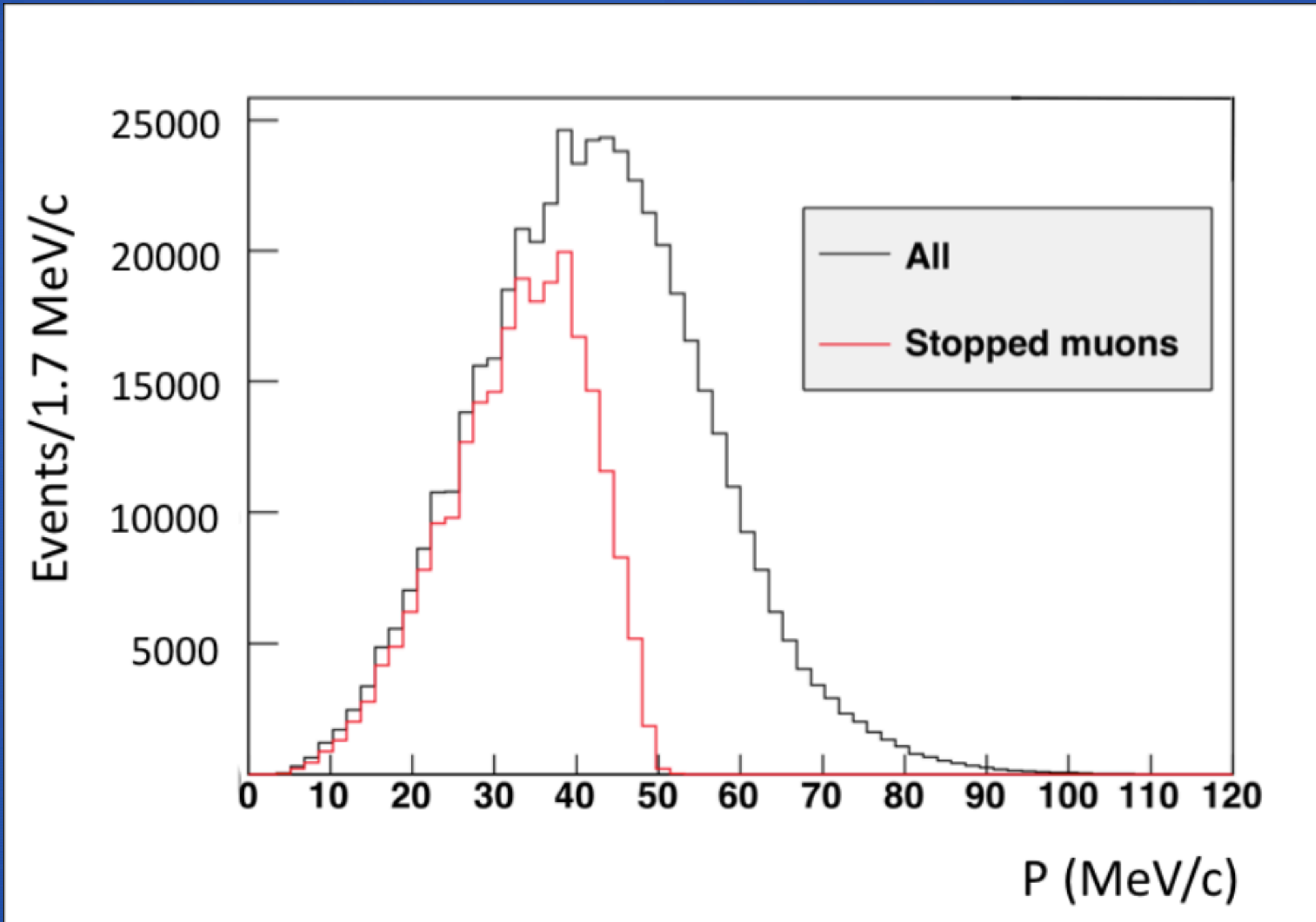


Muon Flux- before and after Transport Solenoid

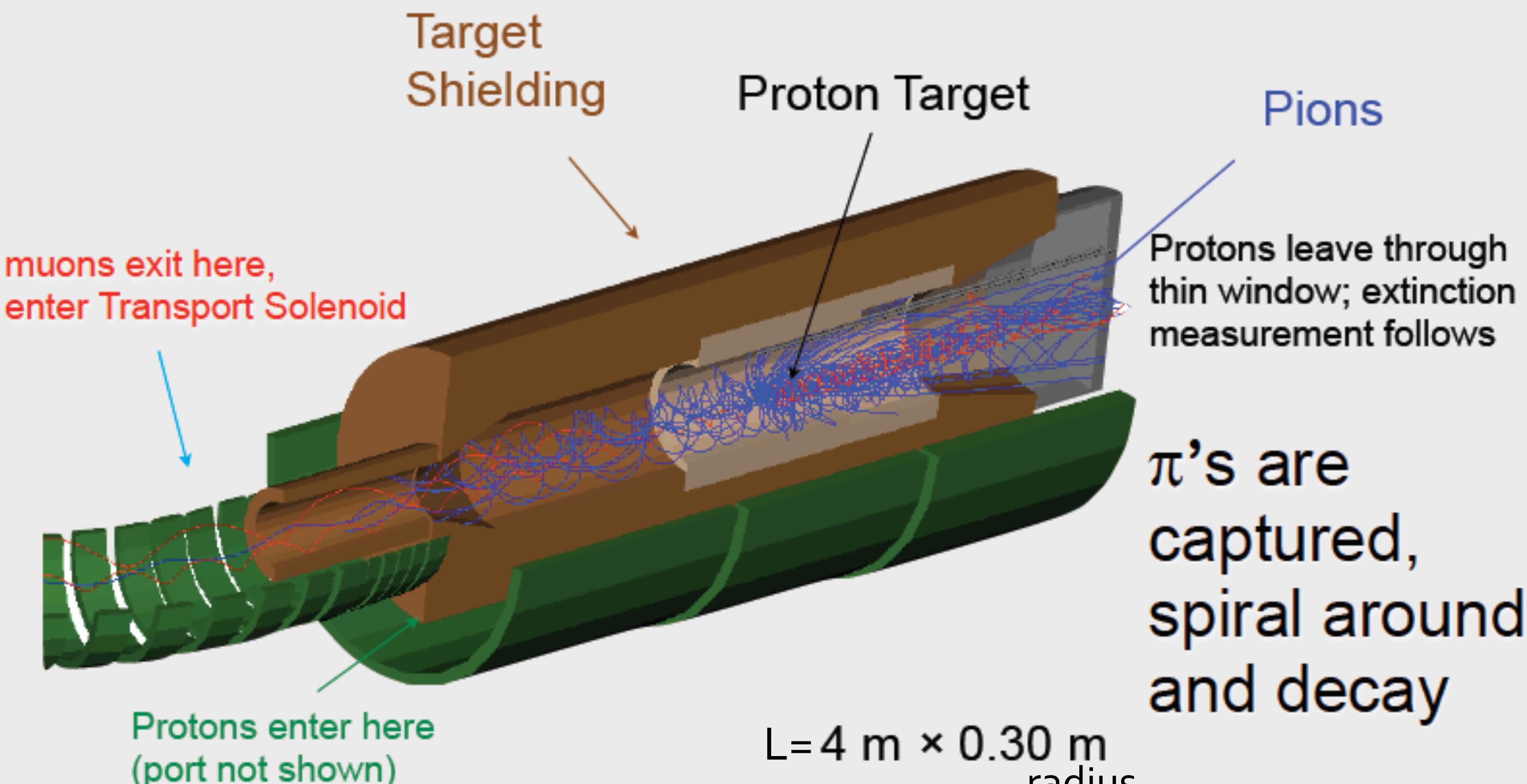


p(MeV)

Muons Reaching the Stopping Target in the Detector Solenoid



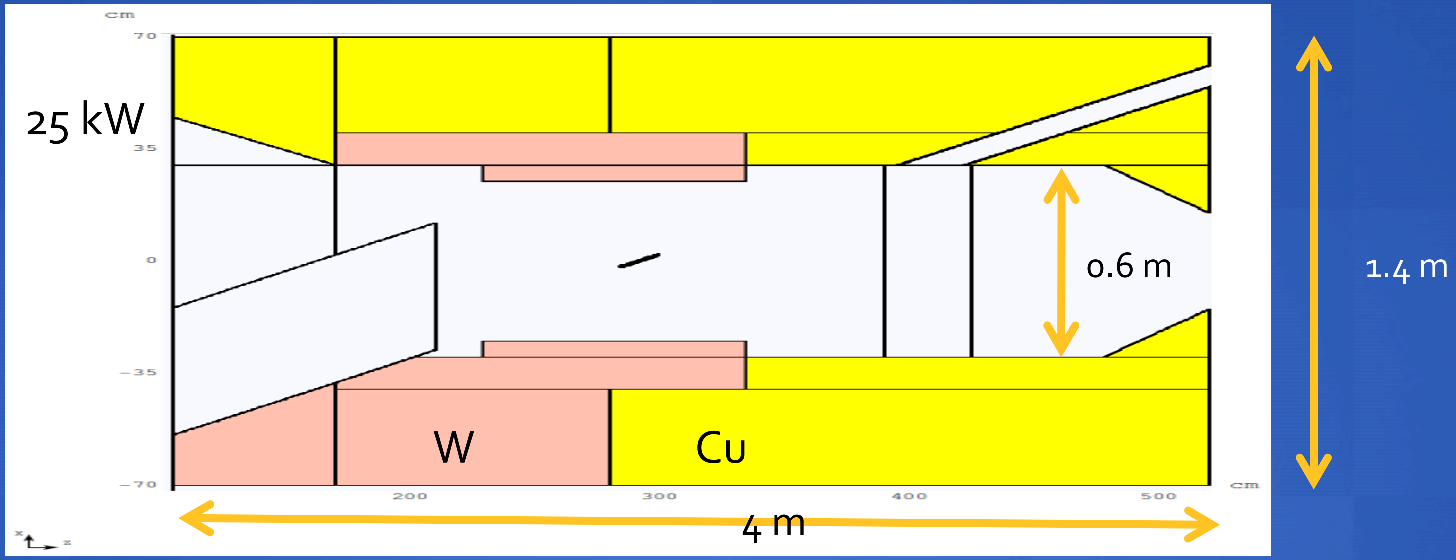
Production Solenoid

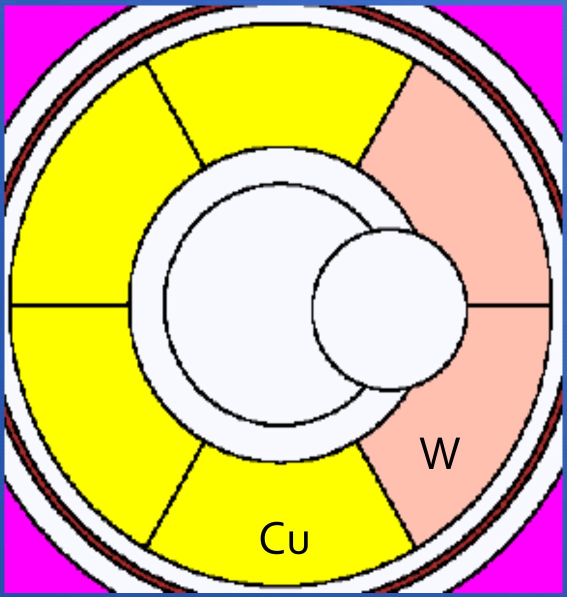


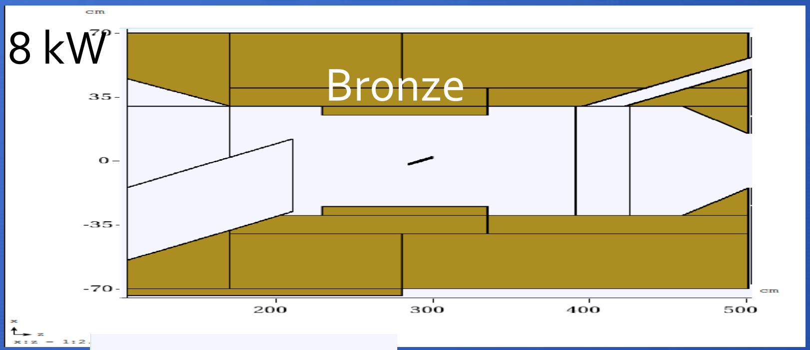
π's are captured, spiral around and decay

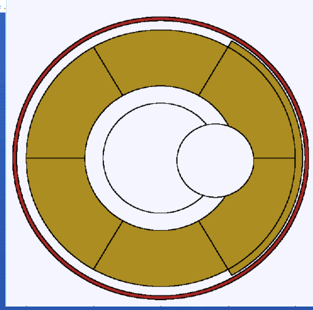
L = 4 m × 0.30 m radius

Heat and Radiation Shield Dimensions from Simulation





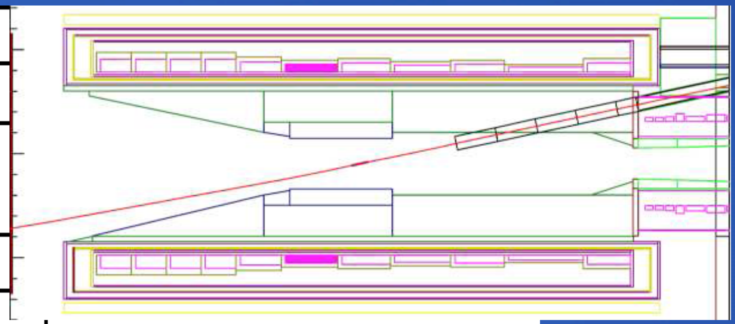




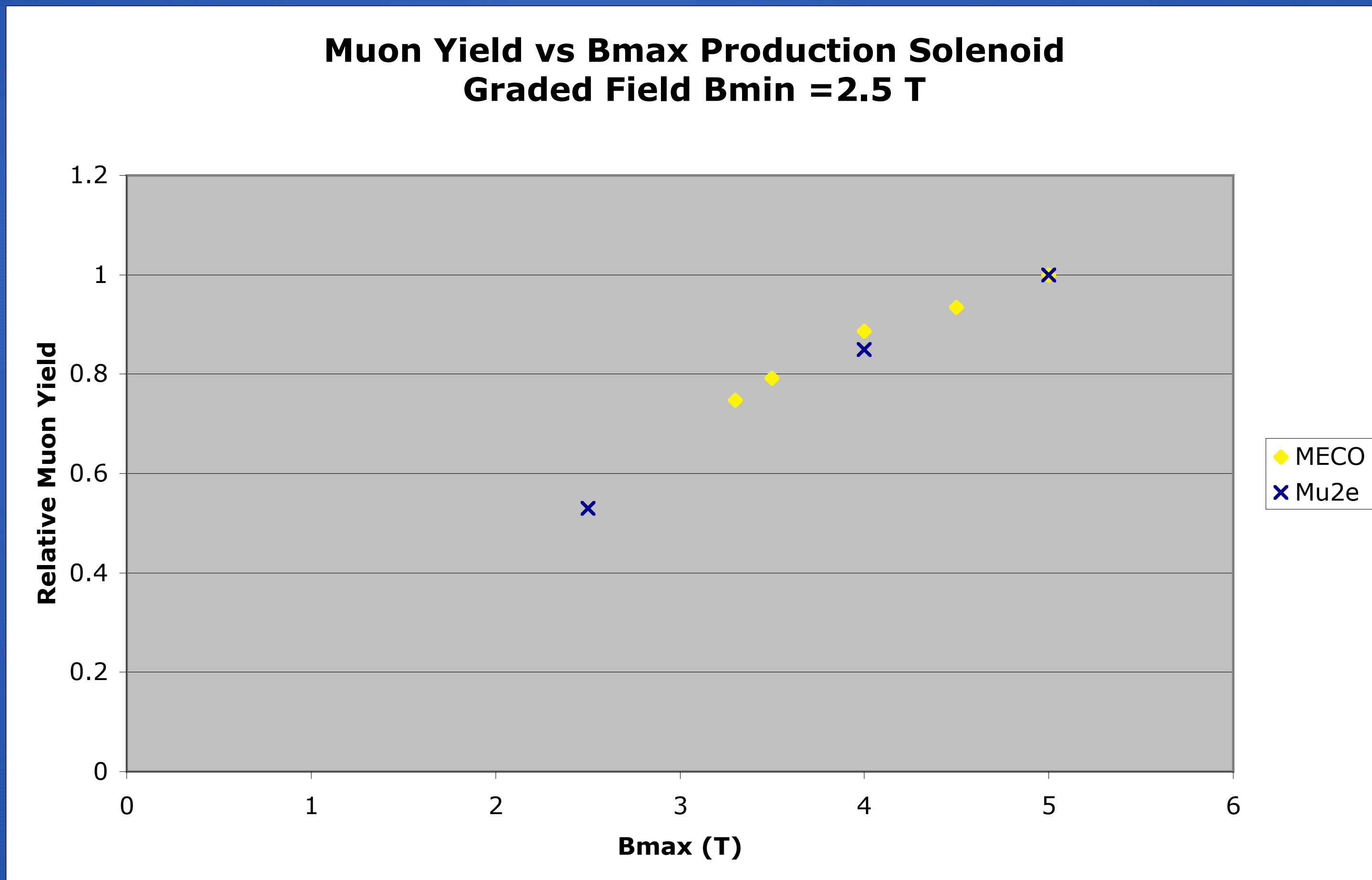
See Vitaly Pronskikh's talk tomorrow

Some Early Comparisons to MECO (2009)

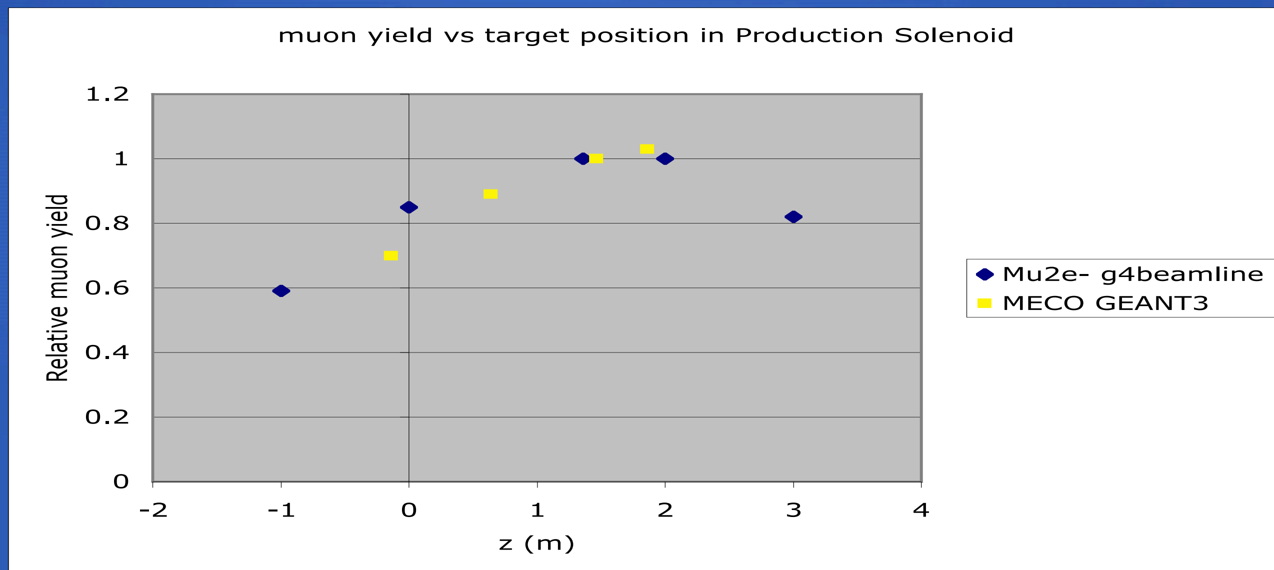
	MECO	G4beamline
Stopped muon yield per proton incident	0.0022-0.0025	0.0022
PS mirror removed	~0.7	0.79
PS bore radius 25 cm to 20 cm	0.96	0.92
Proton beam angle 12 - > 5 deg	0.98	0.98
Target radius 3 mm-> 6mm	0.65	0.64
Target L= 16 to 12 cm	0.91	0.92
Target L=16 to 20	0.99	0.96
Target z position in PS	See next plot	
PS max field	See next plot	

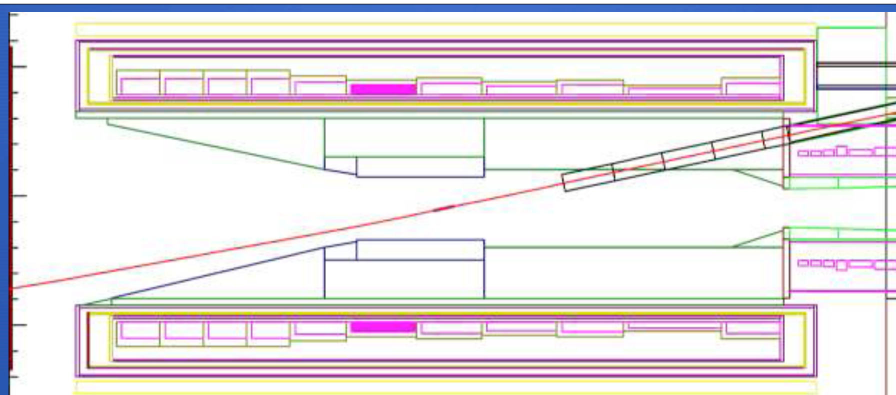


Study of Muon Yield vs Maximum Field in Production Solenoid

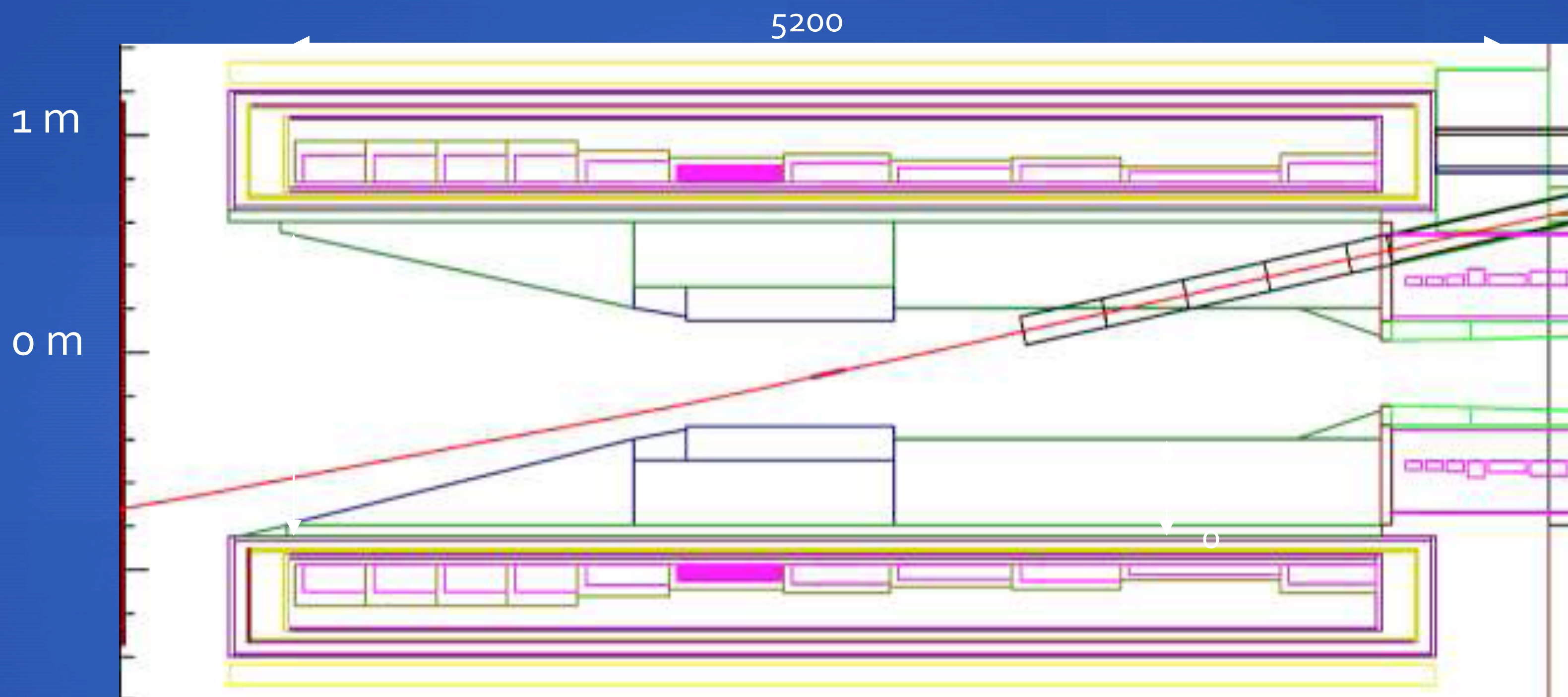


Target z position Study (2009)

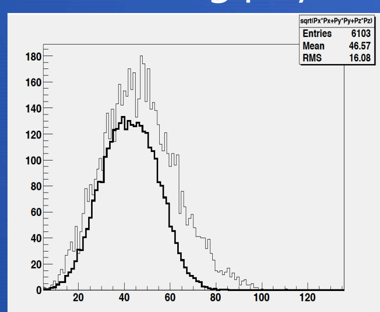


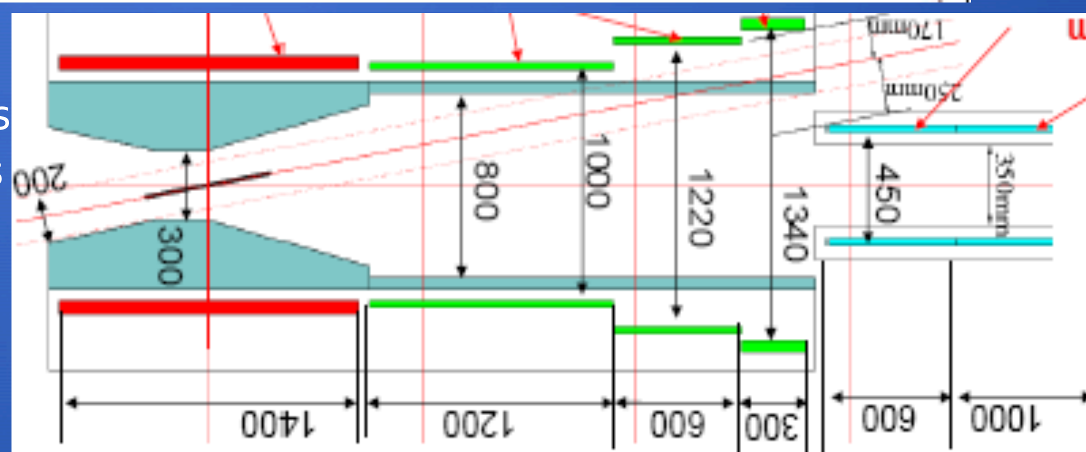


MECO

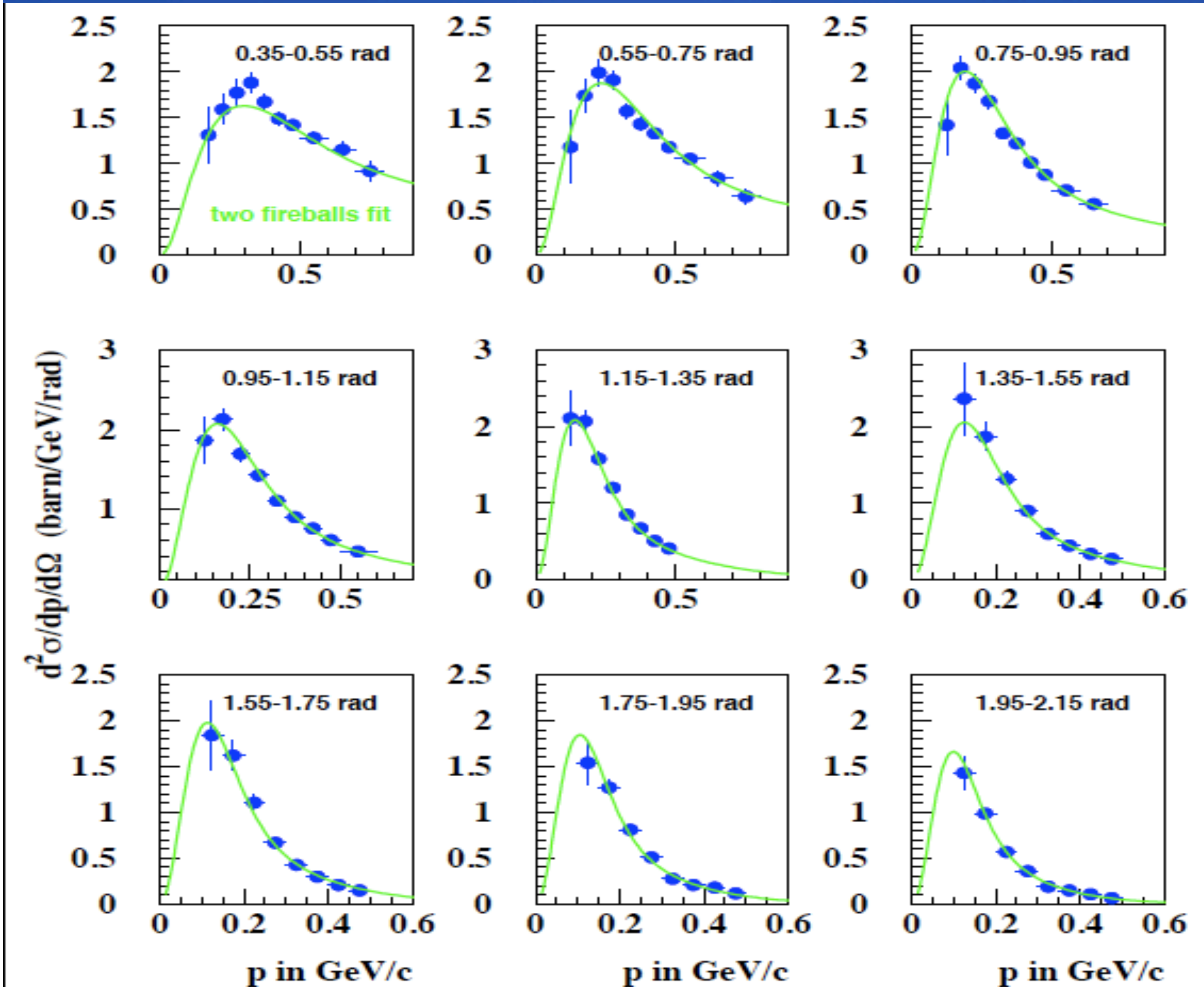


Joint Meeting in Berkeley Jan 2009 with COMET group- direct comparisons difficult due to differing physics models





COMET

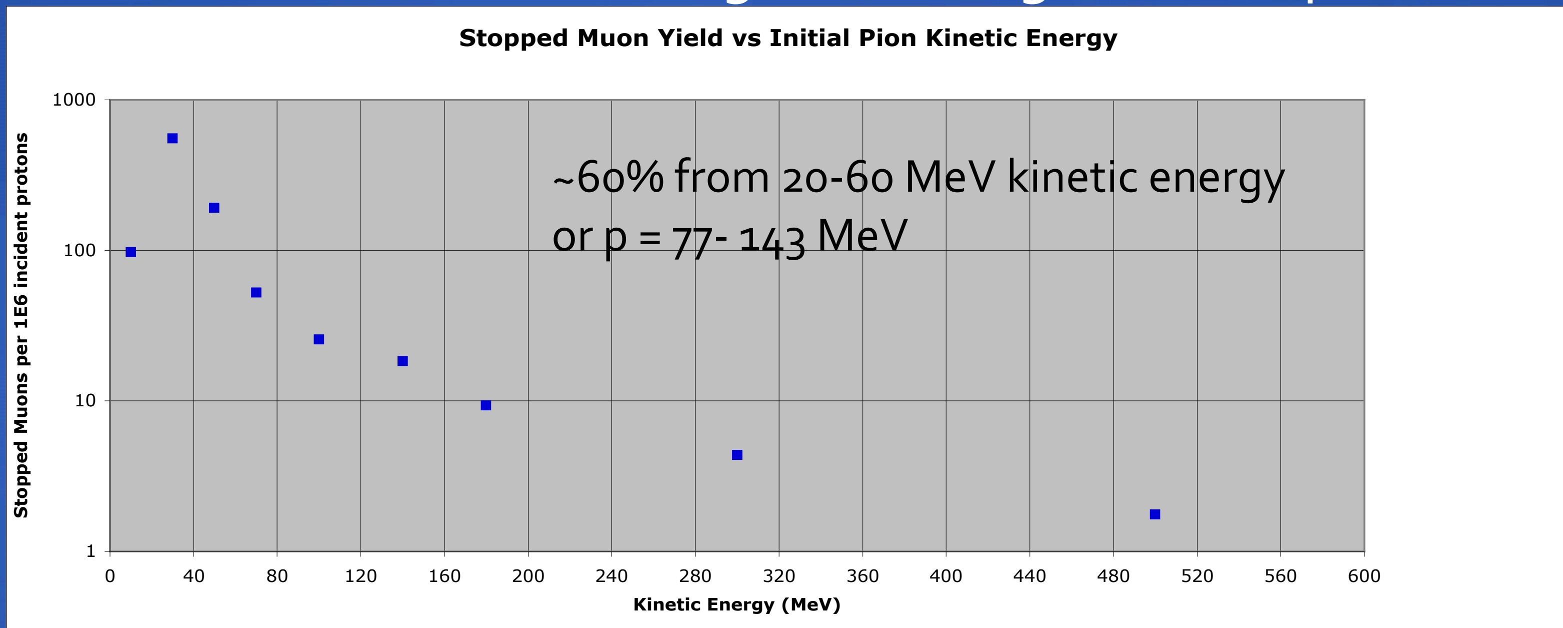


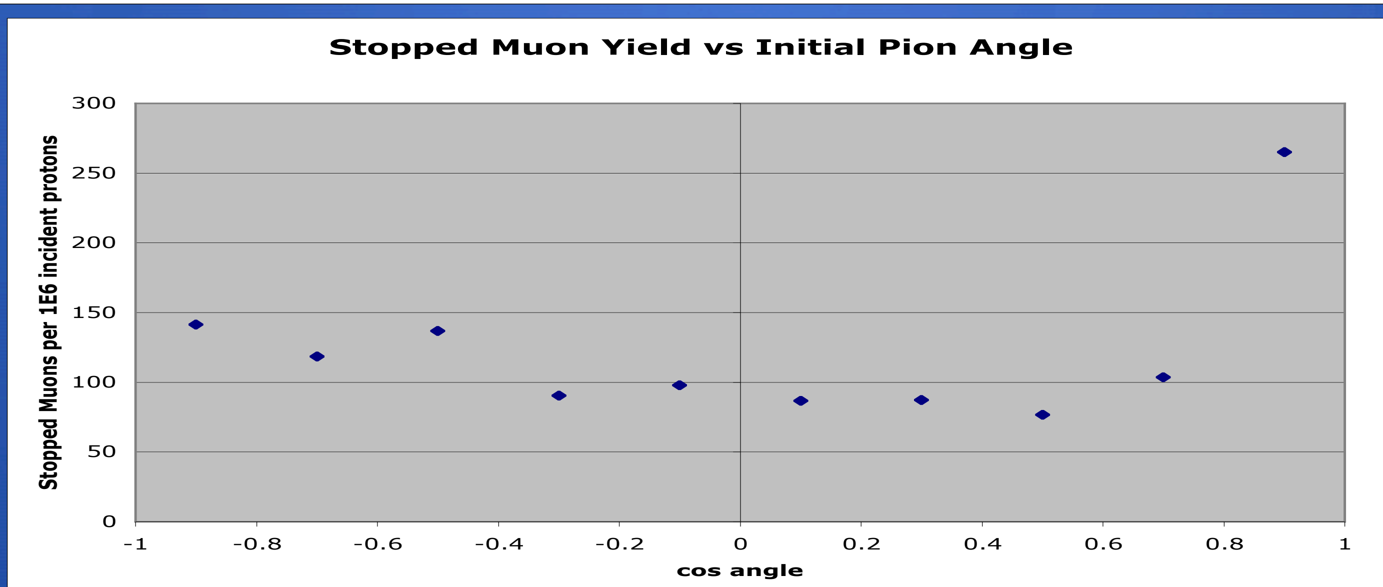
π^- production in proton tantalum interaction at 8 GeV/c. HARP data.

Sergei Striganov improved fit for Mu2e 2009, similar fits by Bob Bernstein

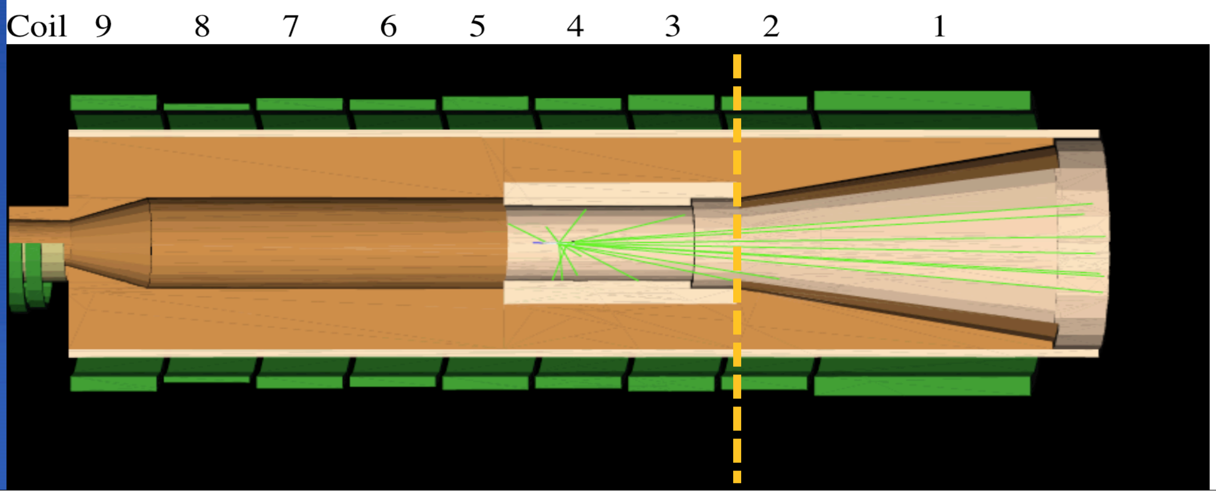
File of pions weighted by HARP data used

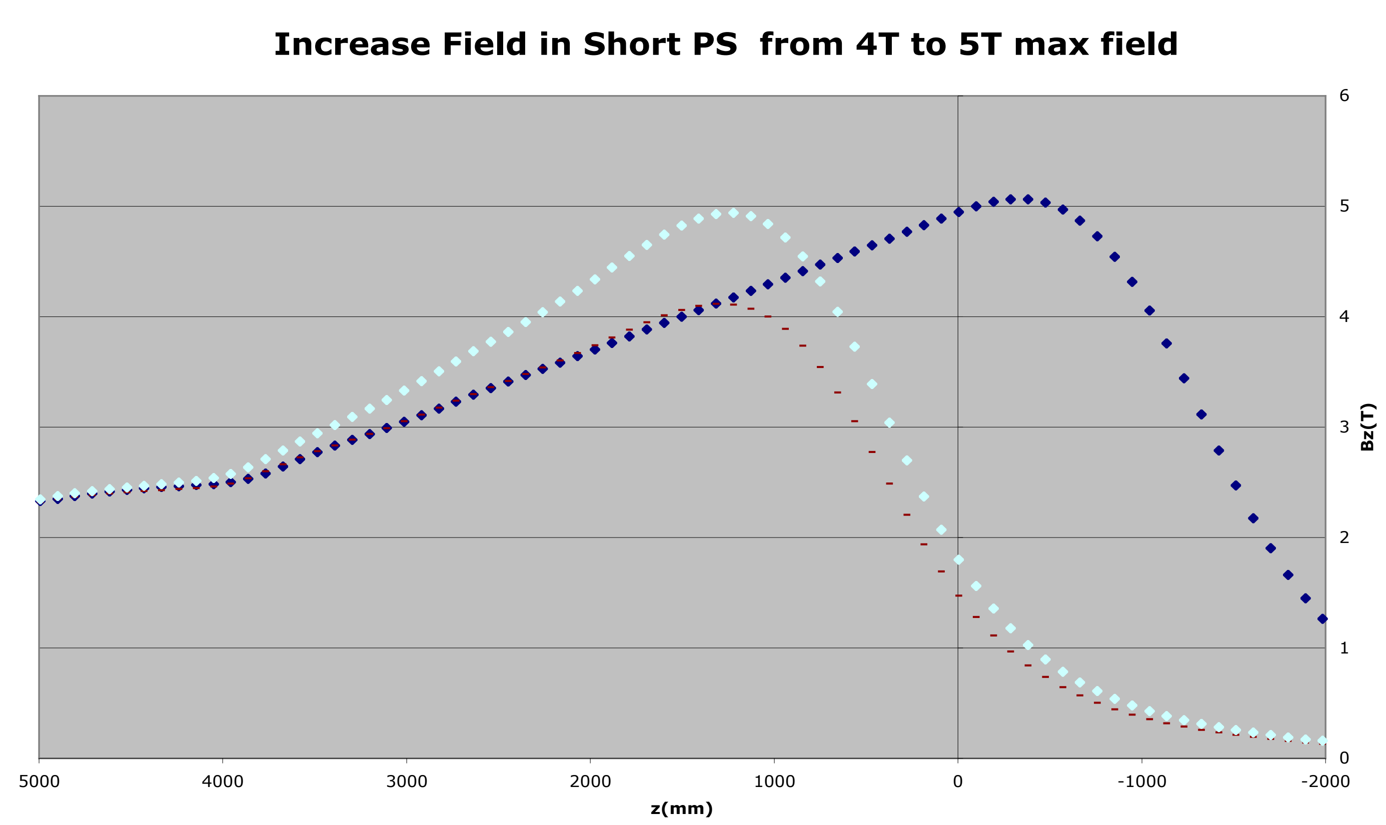
Pion Production- what energies and angles are important?





MECO

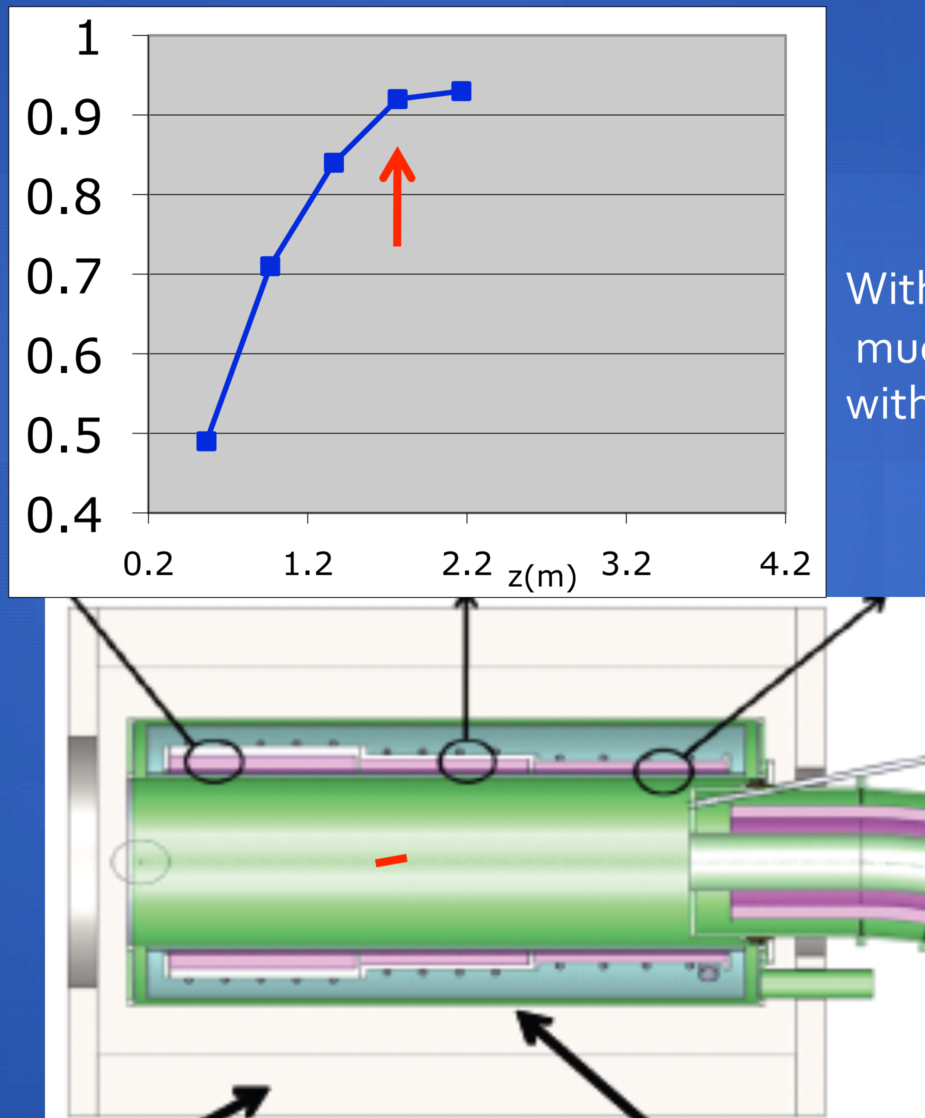




Use HARP

	Standard PS-5T max	Short PS- 4T max	Short PS- 5T max
Mu- hitting stopping target	1955	1603	1917
Mu- stopping	1280	970	1109
Relative stopped yield	=1.00	0.76	0.87

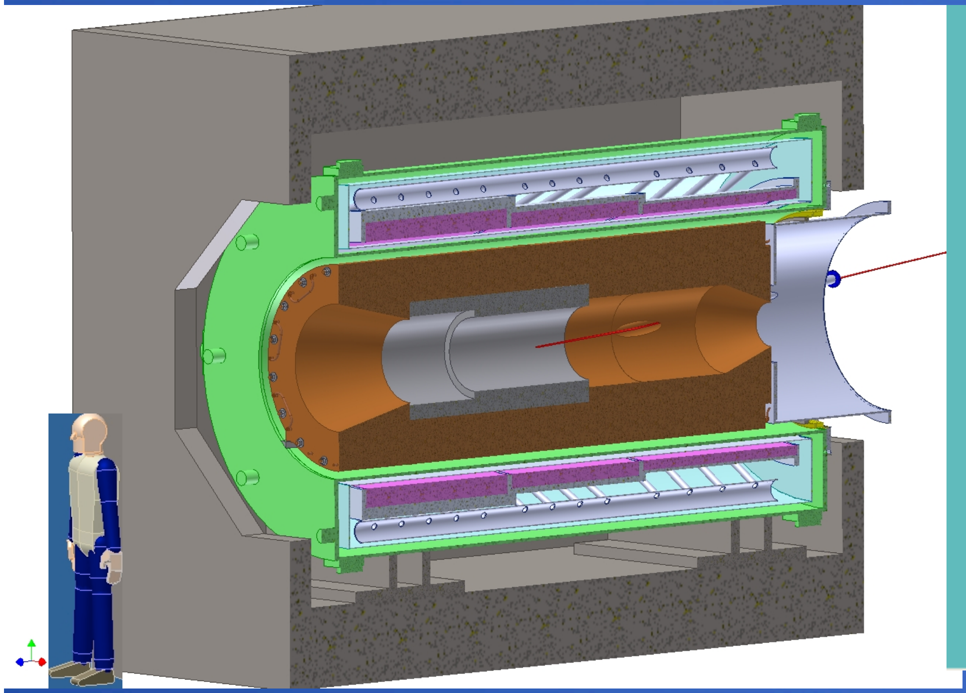
Optimize target z position for Stopped muon yield for L= 4m Mu2e PS

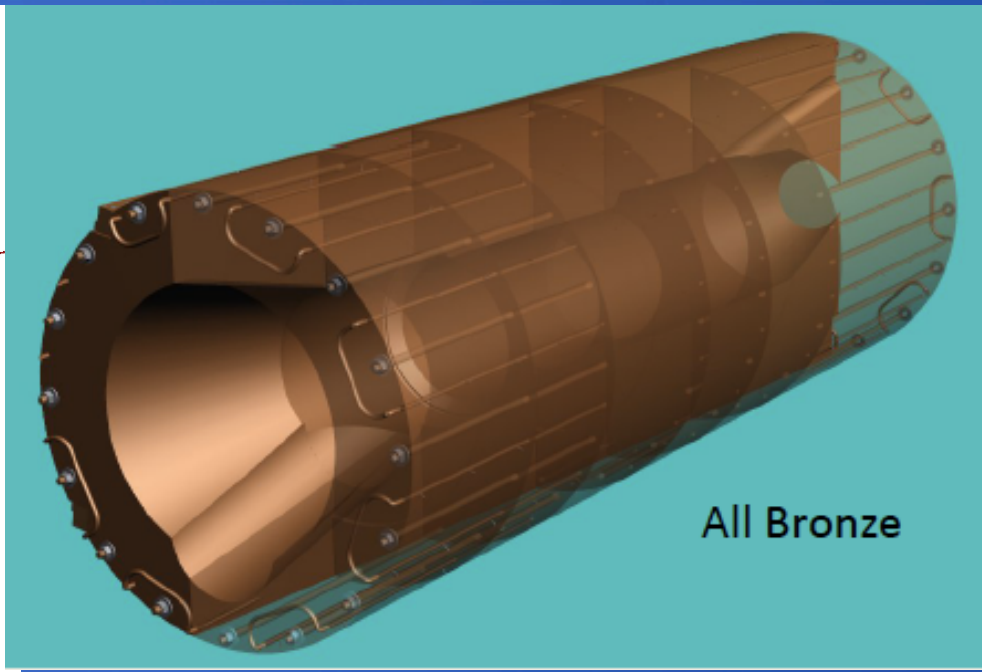


With this target location
muon yield is down ~ 7%
with L=4 m vs L=5.2 m (MECO)

Some cost savings reducing L, but most important feature is DPA requirements can be satisfied in region where proton beam exits PS- see Vitaly's talk tomorrow

Production Solenoid- Some Engineering Aspects – Heat Shield



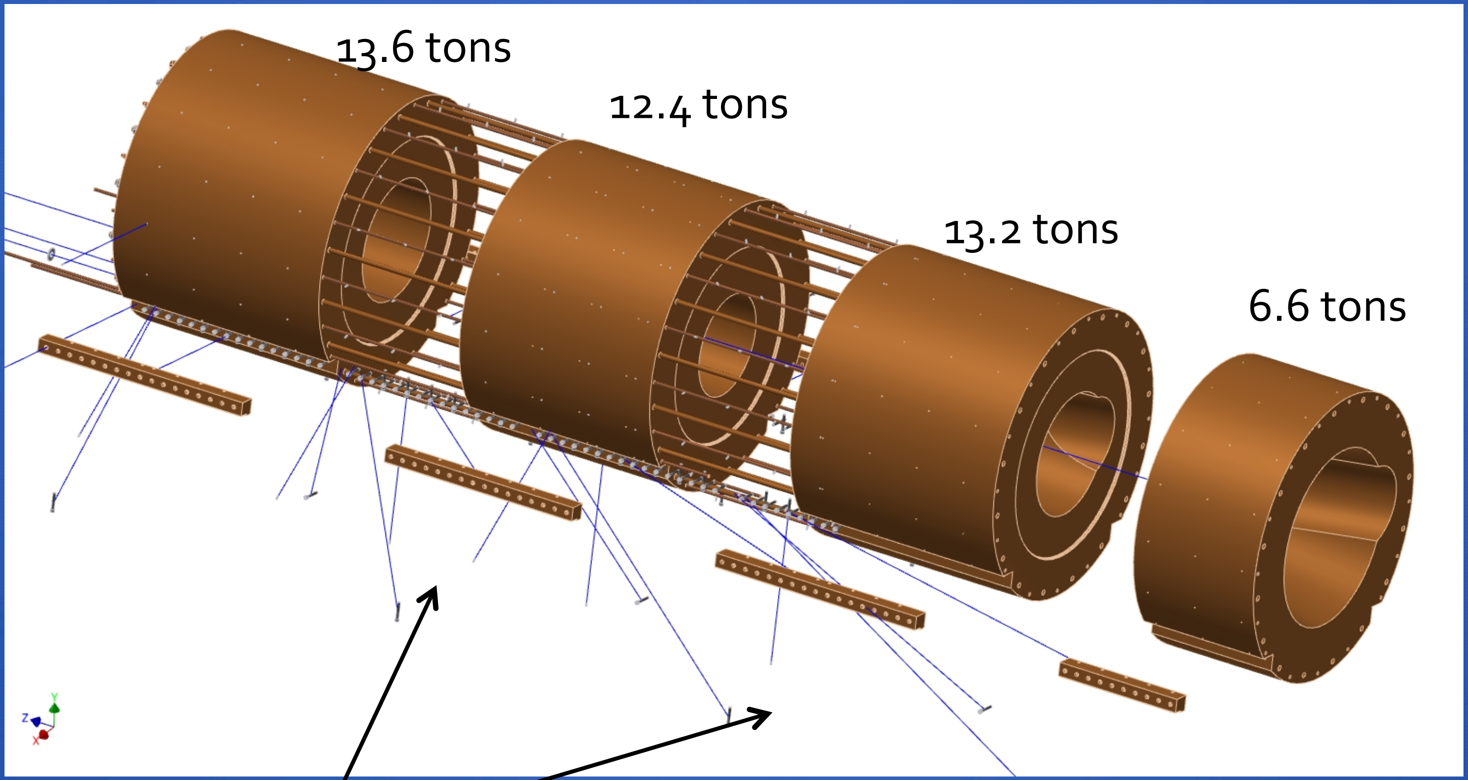


25 kW version
Requires Tungsten → $$$
Heat Transfer issues

8.3 kW current version

The Mu2e All-Bronze Heat and Radiation Shield Design

Exploded view showing radiation labyrinths and all parts



Bolt-on rails

46 tons total

L. Bartoszek

BARTOSZEK ENGINEERING

Status of Heat Shield Engineering

- We have to build drawings on all-bronze 8.3 kW
- 3 cost estimates, very consistent, significant savings in 8.3 kW version over 25 kW version which uses tungsten
- Thermal analysis in progress, not expected to be a problem
- Need to explore other materials (Copper, Copper/Nickel)
- Continue simulations to optimize design

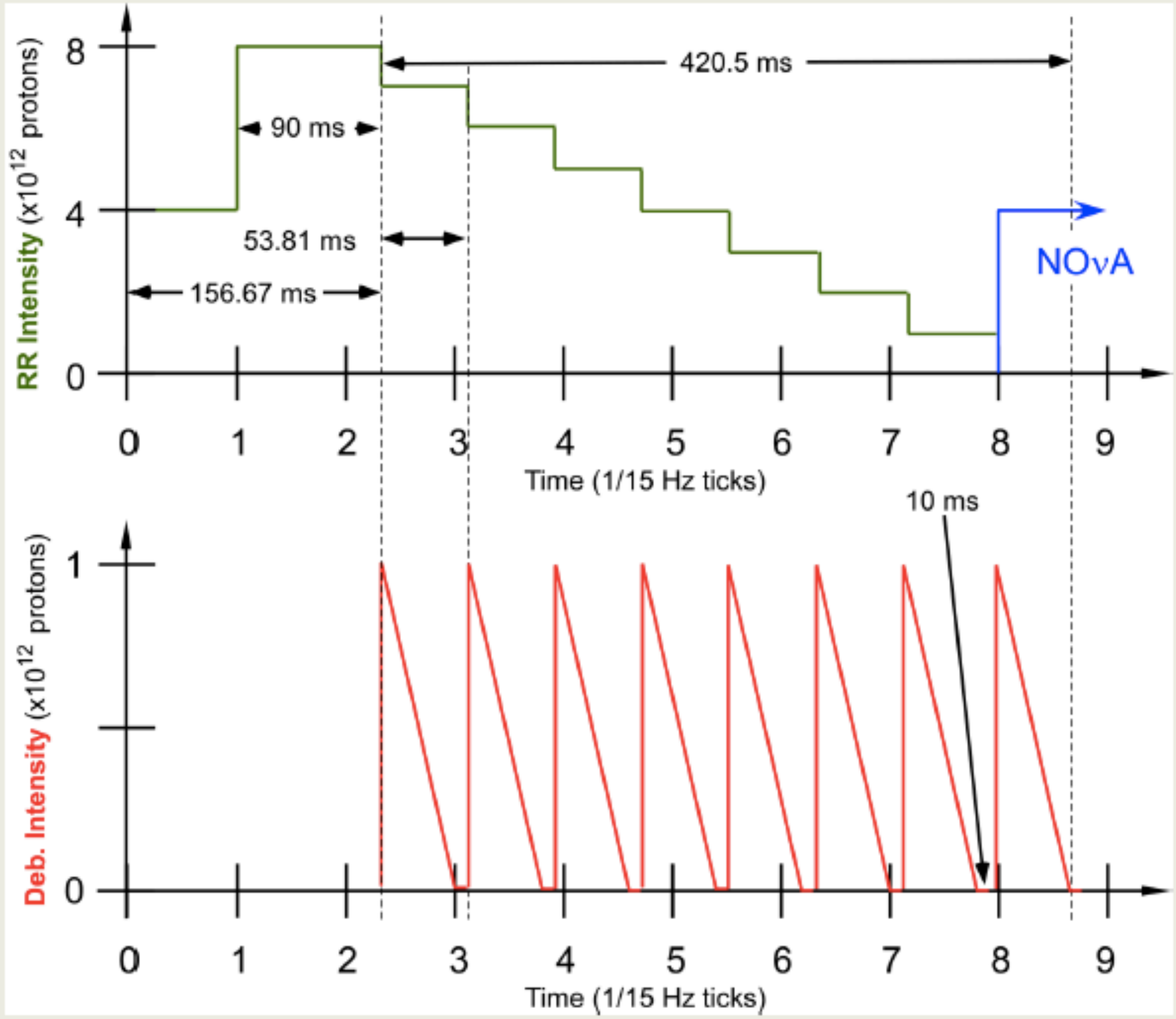
Backup Slides

2 Batch Spill Structure
Mu2e Part of Timeline

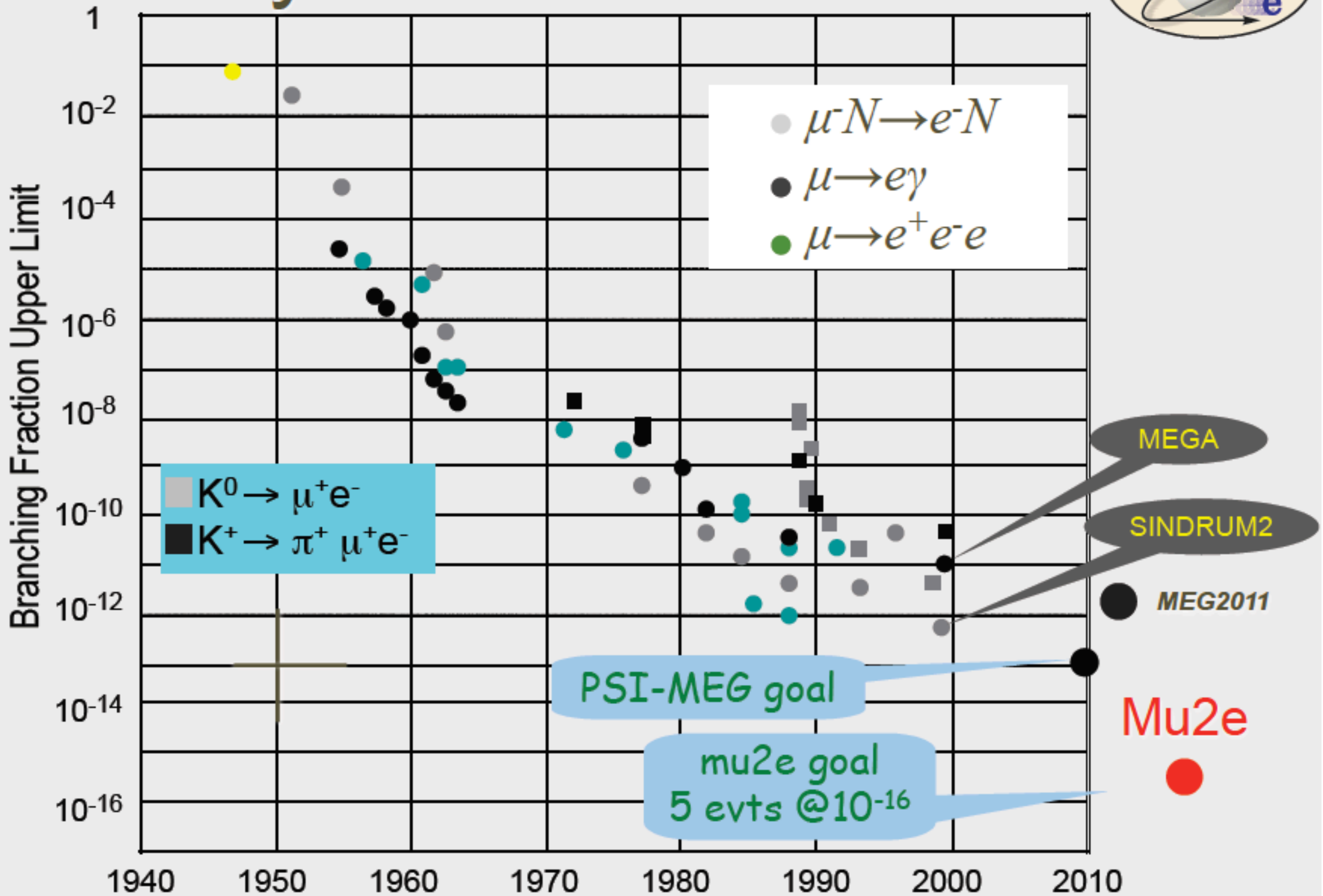
2 Batch Scenario

Timing of proton extractions from the Recycler Ring (RR) to the Debuncher Ring (Deb.)

- 8 spills for each 1.33sec super-cycle (20 ticks)
- Spill length: 53.81 ms
- 10 msec gap between spills
- 38.7×10^{6} protons/μ-pulse
- After last spill: no beam for 912.9 ms



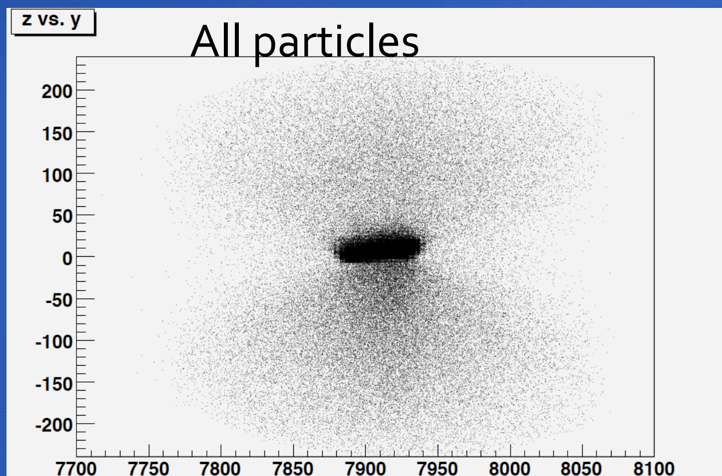
History of CLFV Searches

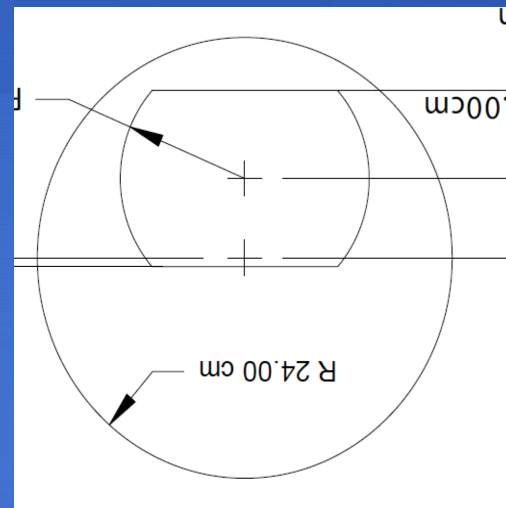


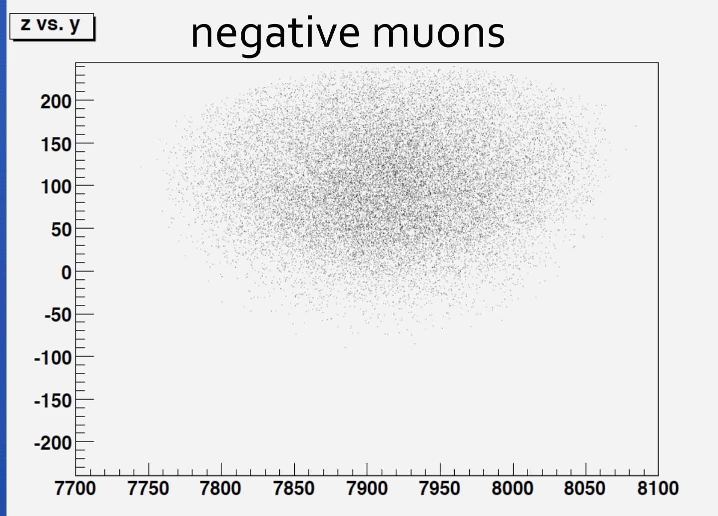
MEG 2011: arXiv:1107.5547 [hep-ex]

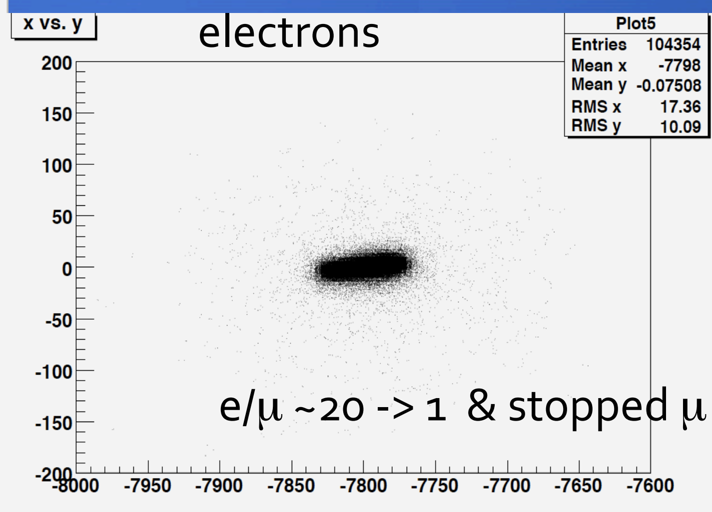
R. Bernstein, FNAL 8 Mu2e SLAC 9/8/2011

Electron Flash and Middle-Collimator



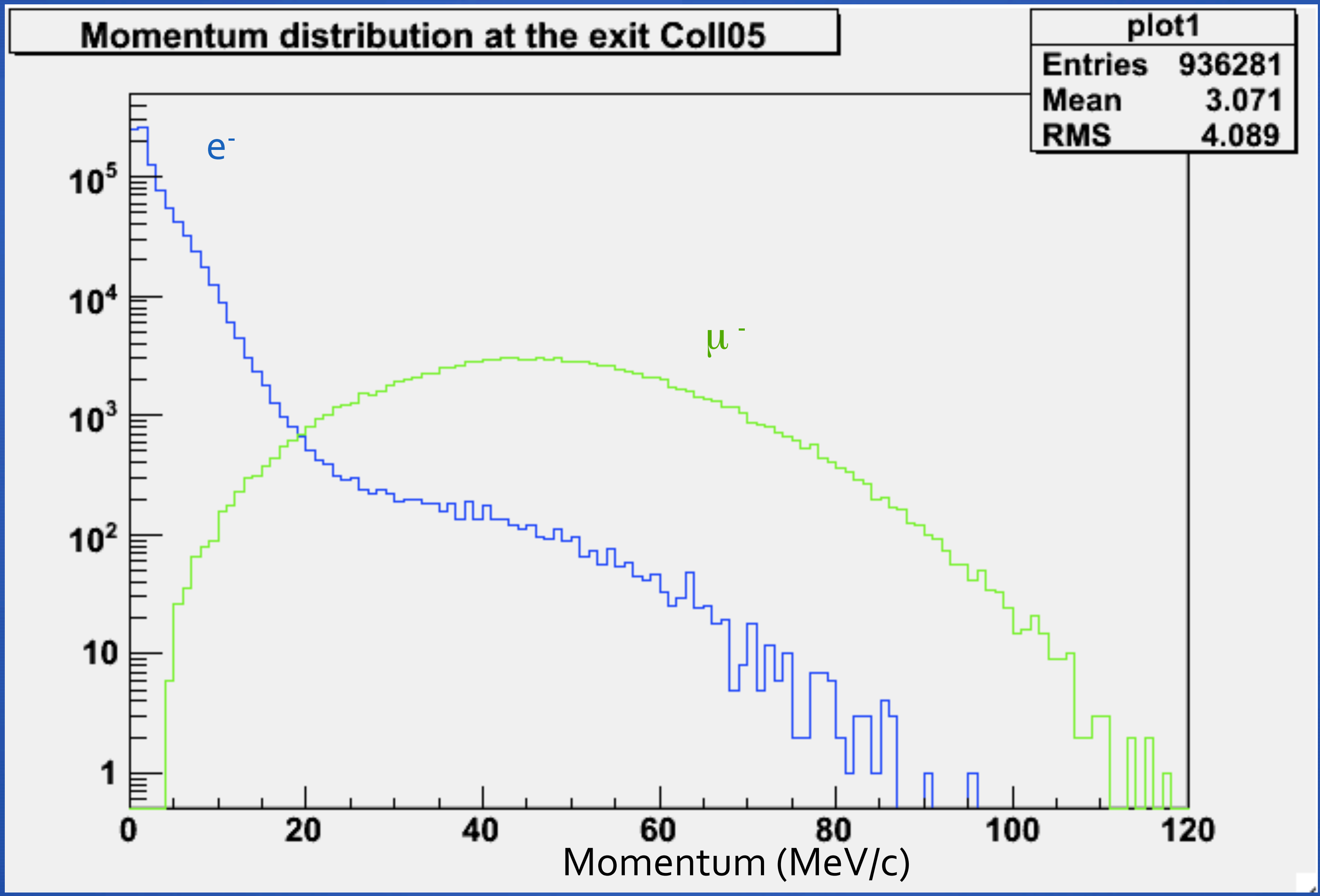




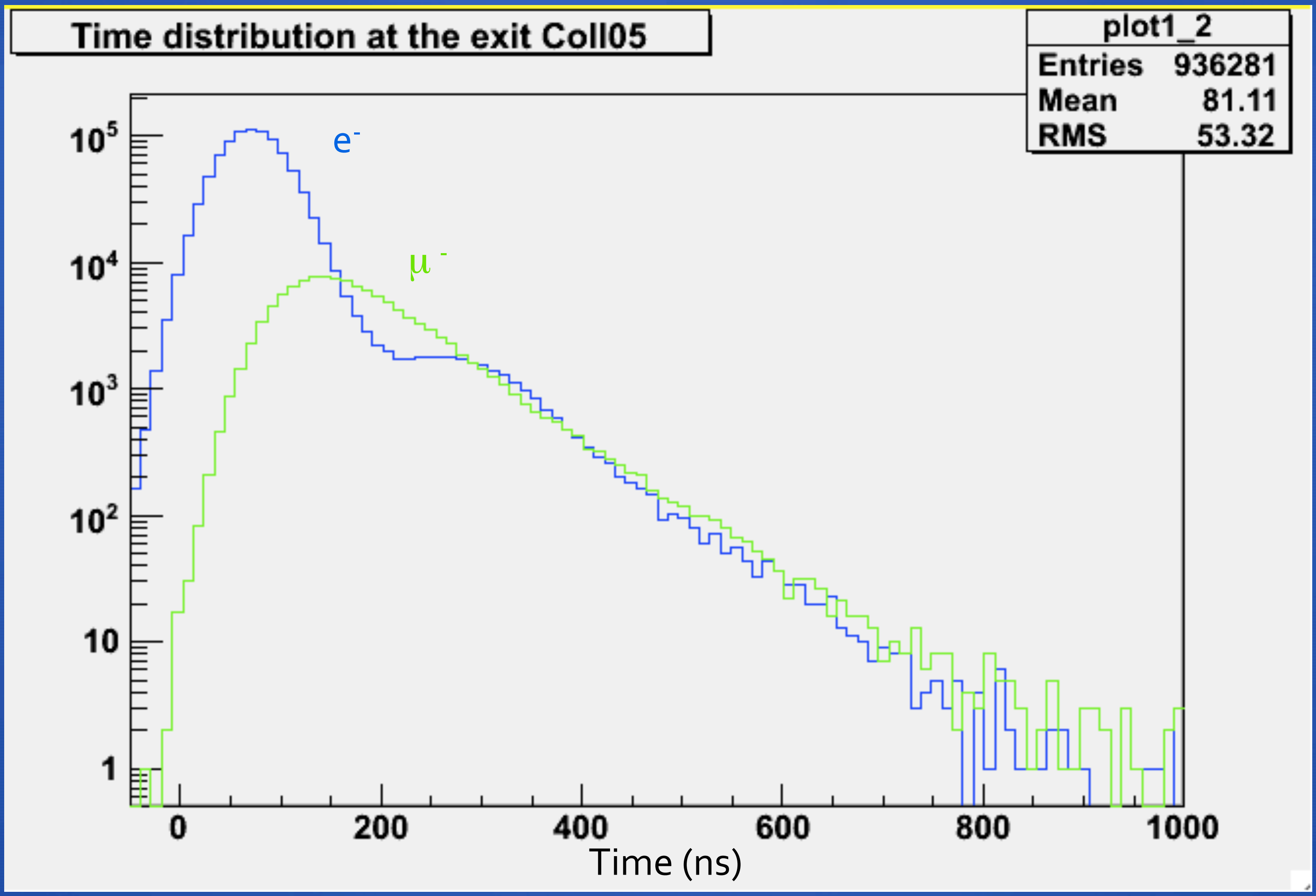


e/μ ~20 -> 1 & stopped μ reduced 20%

e^-/μ^- flux entering the Detector Solenoid

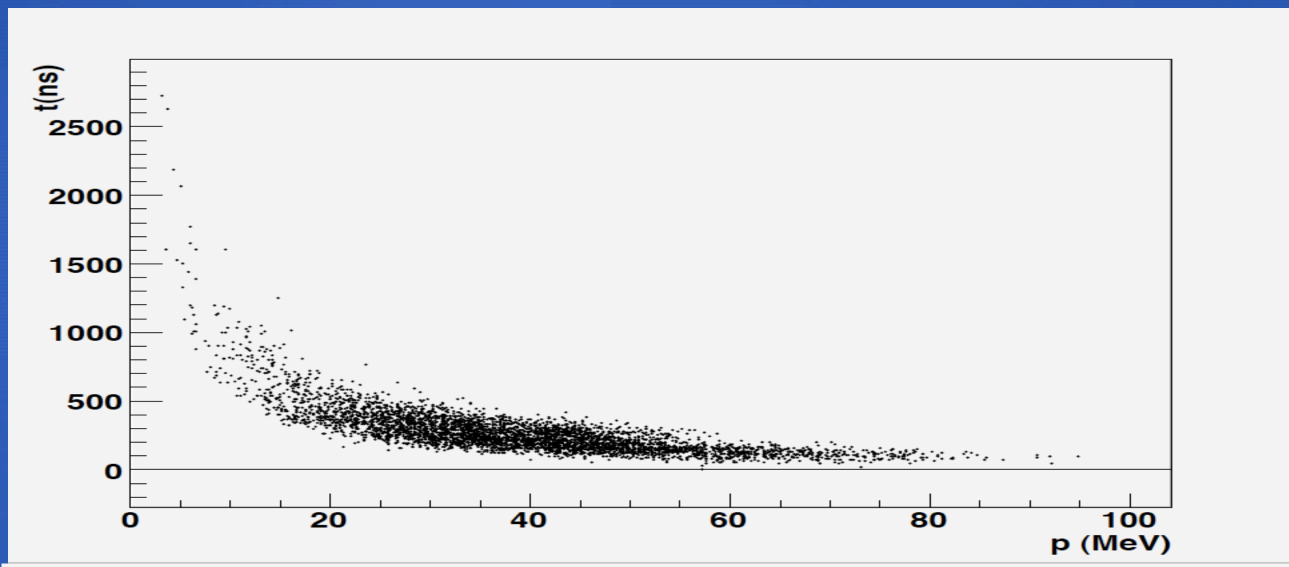


Time distribution entering Detector Solenoid

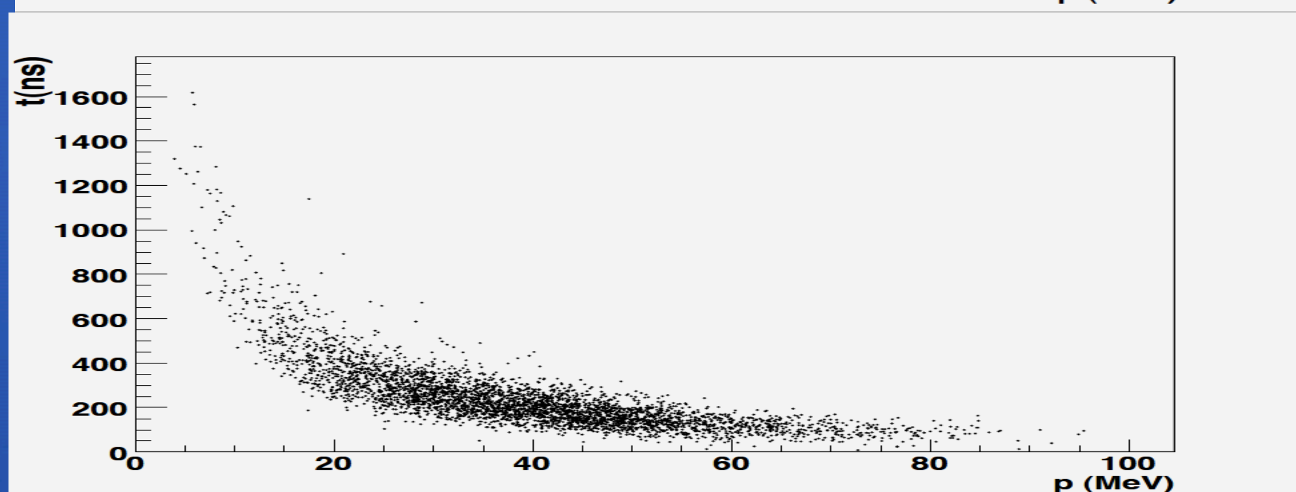


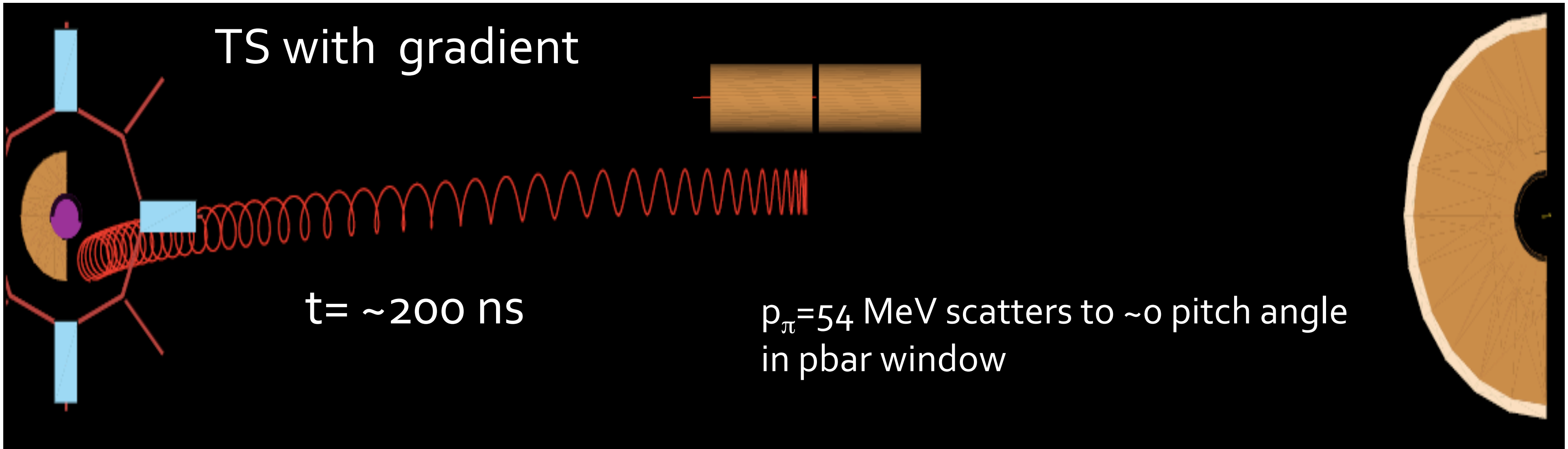
Time vs p - negative muons reaching stopping target

MECO PS

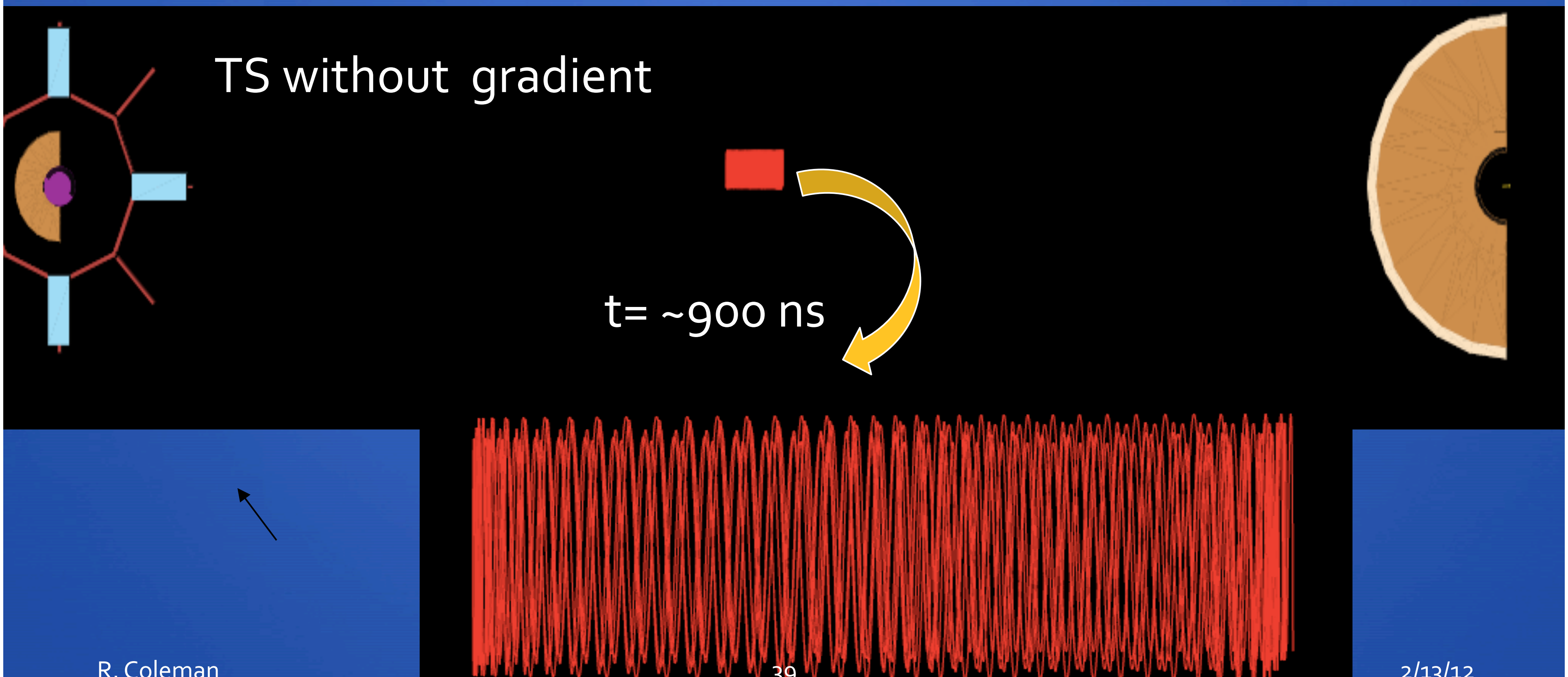


Mu2e PS





TS with gradient
t= ~200 ns
p_{π}=54 MeV scatters to ~0 pitch angle
in pbar window



TS without gradient
t= ~900 ns

Study of the Production Solenoid Gradient vs Muon Yield

Fig 4 Bz(T) vs z for Mu2e(blue) and an alternative shapes(A1-A4)

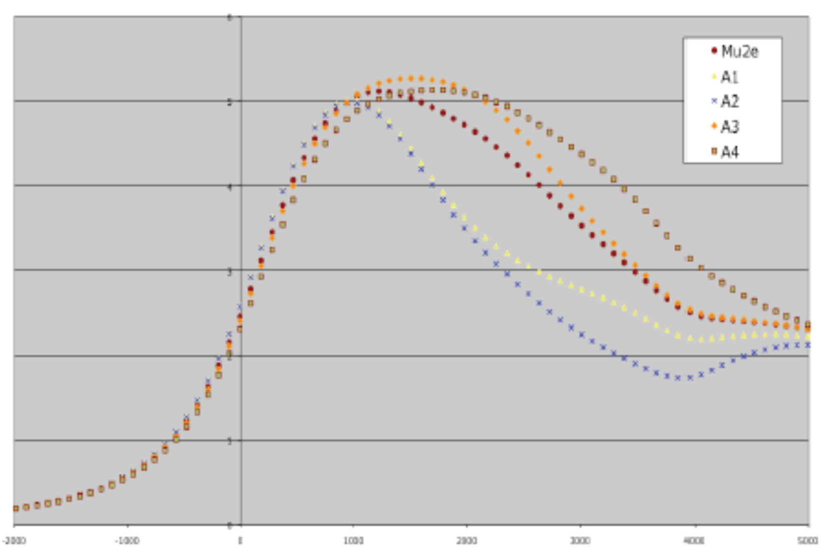
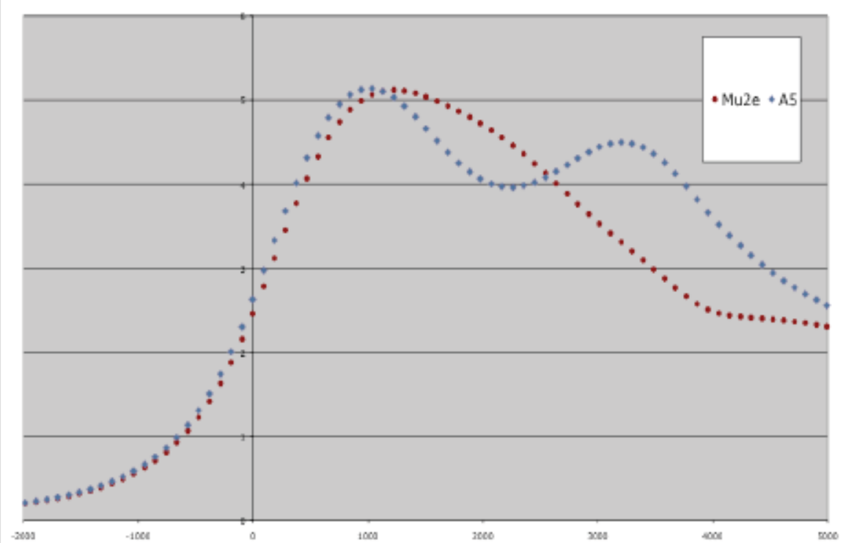
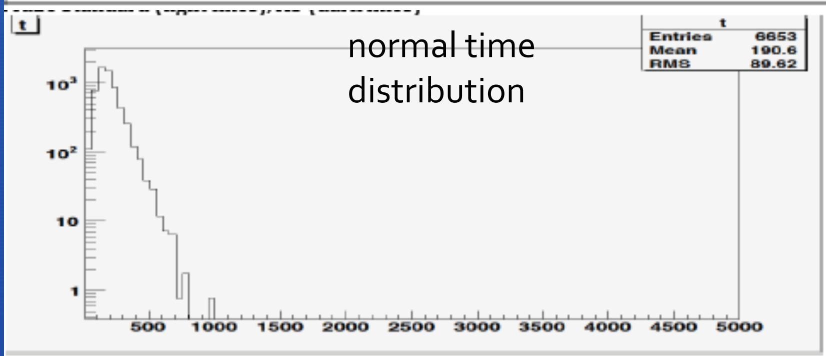


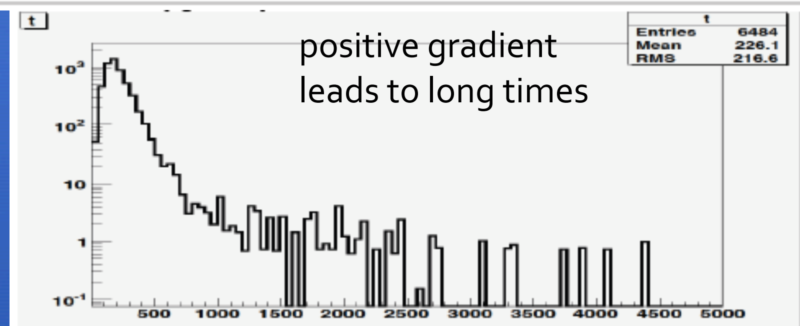
Fig 18 Bz(T) vs z for Mu2e(blue) and an alternative shapes(A5-A?)





normal time distribution

Fig 20 Distribution of Time (ns) for muons passing the last collimator Mu2e Standard (light lines)

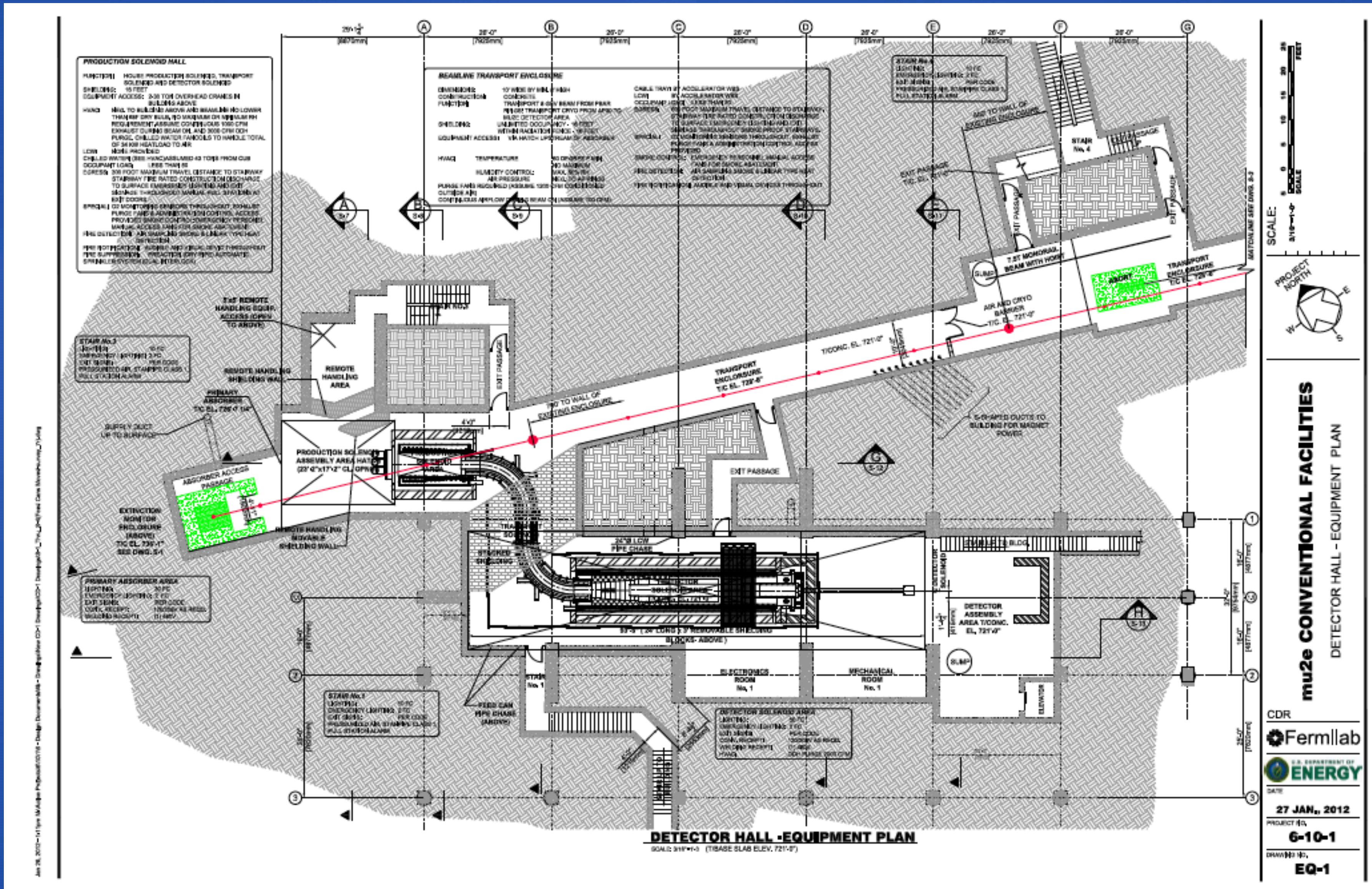


positive gradient leads to long times

Fig 21 Distribution of Time (ns) for muons passing the last collimator A5 (dark lines)

Background	Background Estimate	Error Estimate	Reference	Justification
Radiative Pion Capture	0.04	± 0.02	1087	Acceptance and energy loss modeling
Muon decay in orbit	0.009	± 0.006	387	Acceptance and energy loss modeling and spectrum calculation
Cosmic Rays	0.025	± 0.025	CDR	2 event statistics
Pion decay In-Flight	0.003	± 0.0015	1175	Cross-section, acceptance and modeling
Muon decay In-Flight	0.034	± 0.017	1175	Cross-section, acceptance and modeling
Antiproton Induced	0.06	± 0.06	1366	Cross-section, acceptance and modeling
Beam electrons	0.0006	± 0.0003	1367	Cross-section and acceptance (and this is an upper limit)
Radiative muon capture	$< 2 \times 10^{-6}$	–	1230	Calculation
Reconstruction Errors	< 0.002	± 0.002	CDR	Not all sources of tracker activity evaluated yet.
Total	**0.17**	**± 0.07**	1087	Add in quadrature

Table 3.1. Summary of background estimates and errors.


PRODUCTION SOLENOID HALL
BEAMLINE TRANSPORT ENCLOSURE
TRANSPORT ENCLOSURE
REMOTE HANDLING AREA
DETECTOR ASSEMBLY AREA T/CONC. EL. 721'-0"
ELECTRONICS ROOM No. 1
MECHANICAL ROOM No. 1
EXIT PASSAGE
SUMP
DETECTOR HALL -EQUIPMENT PLAN
mu2e CONVENTIONAL FACILITIES
DETECTOR HALL - EQUIPMENT PLAN
CDR
Fermilab
ENERGY
27 JAN., 2012
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