DOE-Review
BNL, 27-28 April 2005

The MECO Experiment at BNL

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Brookhaven National Laboratory

- **LFV: Physics Reach**
- **Experimental Technique**
- **MECO Experiment at BNL**
- **MECO Issues**
- **The BNL-Physics Dept. people (exp.) in MECO**

Muon to Electron COnversion (MECO) Experiment

Boston University

R. Carey, V. Logashenko

J. Miller, B. L. Roberts,

Brookhaven National Laboratory

K. Brown, M. Brennan, G. Greene
L. Jia, W. Marciano, W. Morse,
P. Pile, Y. Semertzidis, P. Yamin

Berkeley

Y. Kolomensky

University of California, Irvine

C. Chen, M. Hebert, P. Huwe,

W. Molzon, J. Popp, V. Tumakov

University of Houston

Y. Cui, N. Elkhayari, E. V. Hungerford,

N. Klantarians, K. A. Lan

University of Massachusetts, Amherst

K. Kumar

Institute for Nuclear Research, Moscow

V. M. Lobashev, V. Matushko

New York University

R. M. Djilkibaev, A. Mincer,
P. Nemethy, J. Sculli

Osaka University

M. Aoki, Y. Kuno, A. Sato

University of Virginia

C. Dukes, K. Nelson, A. Norman

Syracuse University

R. Holmes, P. Souder

College of William and Mary

M. Eckhause, J. Kane, R. Welsh

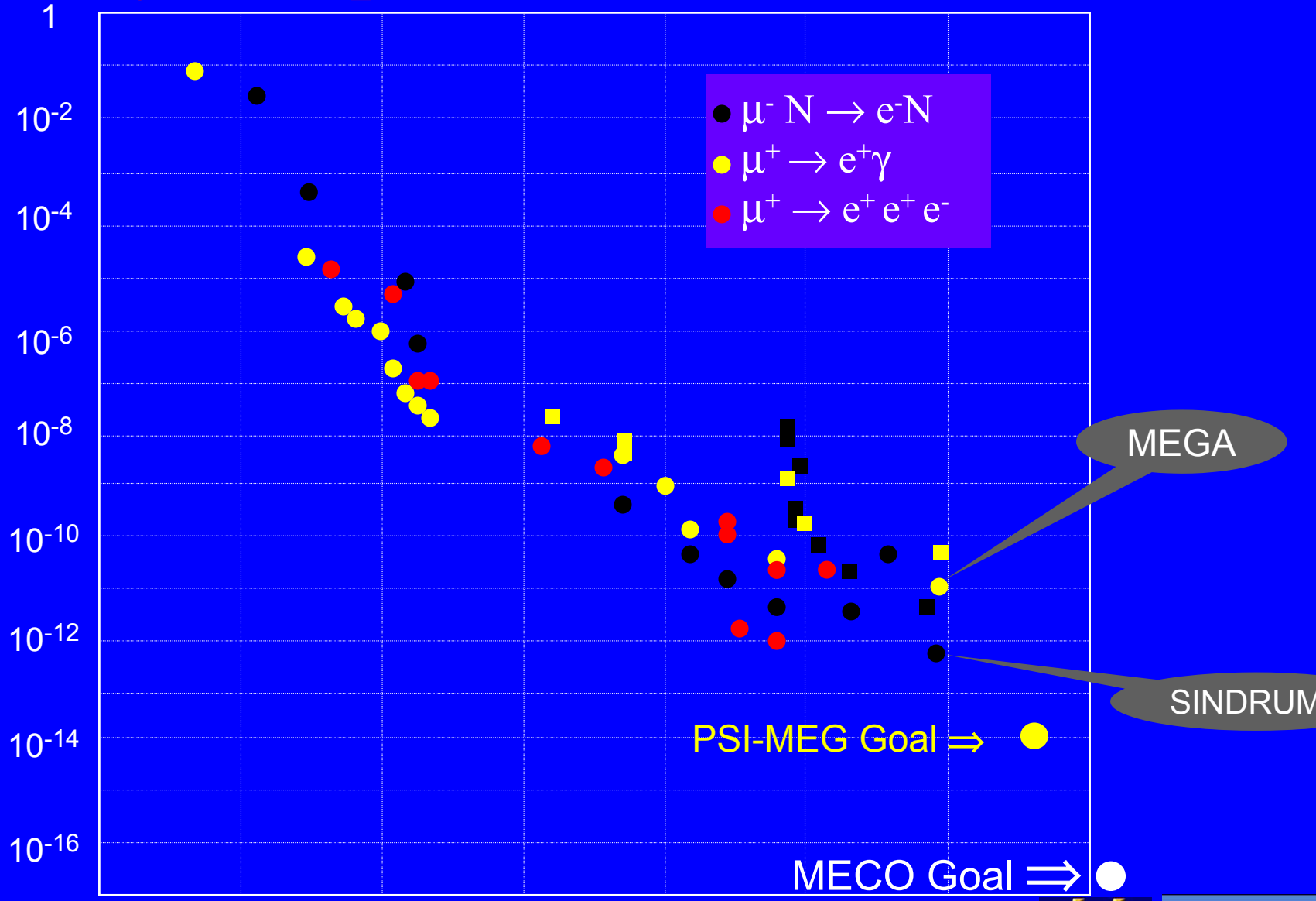
We want to measure $R_{\mu e}$ *with Sensitivity:*

$$R_{\mu e} \equiv \frac{\mu^- N \to e^- N}{\mu^- (N,Z) \to \nu_\mu (N, Z-1)} = 2 \times 10^{-17}$$

Need

- High Proton Flux, High Muon Collection Efficiency, goal: ~10^{11}muon stops/sec
- High Background Rejection, High Extinction

History of Lepton Flavor Violation Searches



MECO

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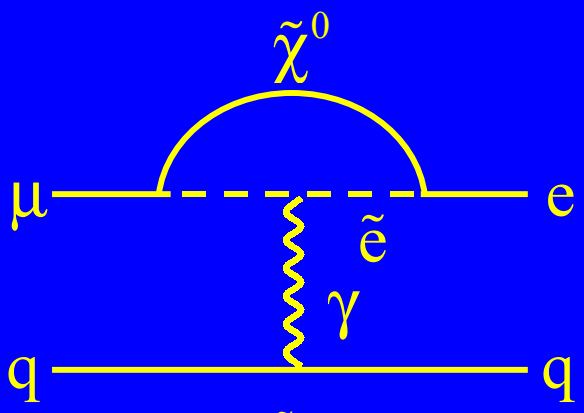
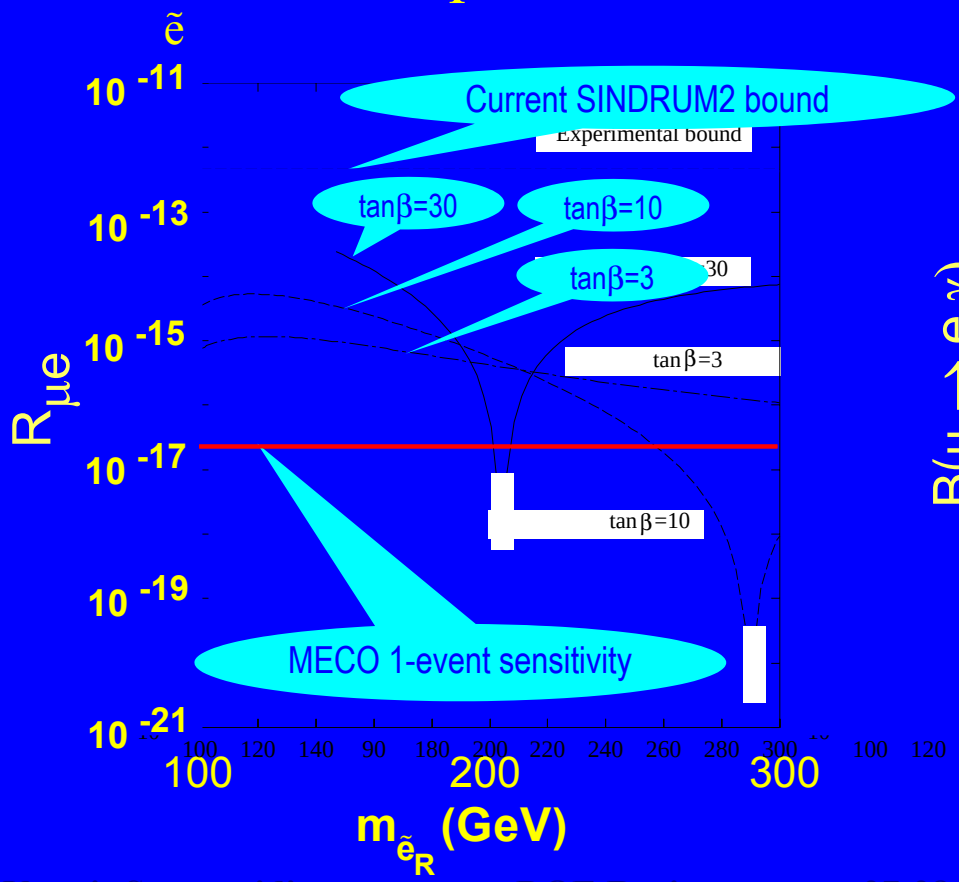
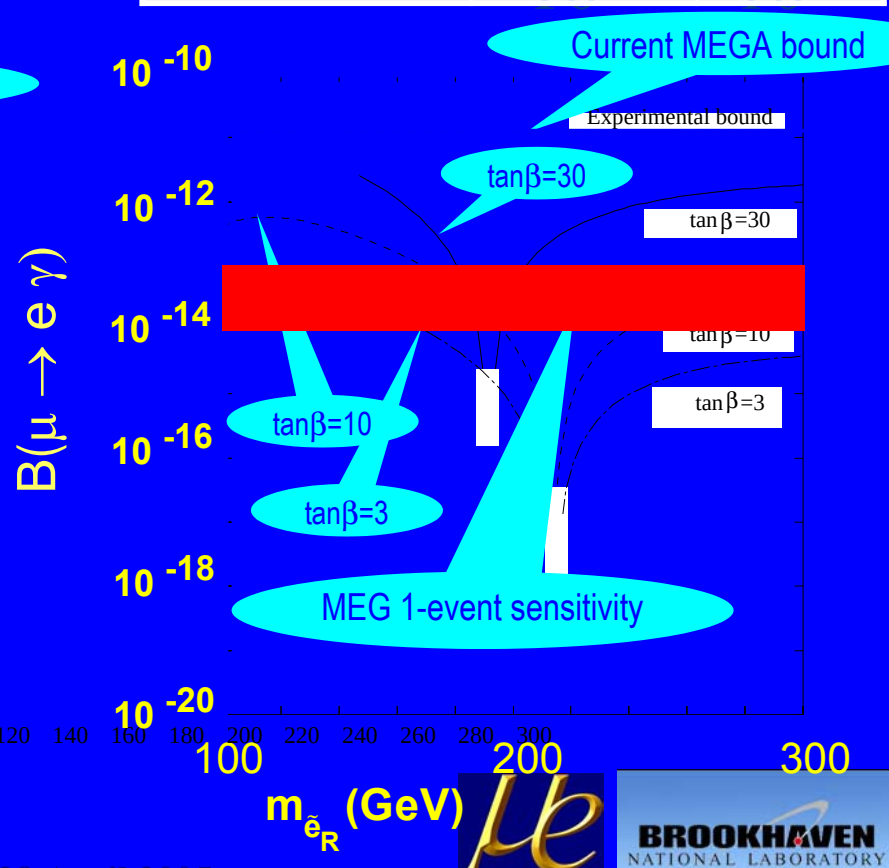
Grand Unified Supersymmetry Predictions for LFV Processes



In SU(5), SO(10), mixing is through τ lepton under assumption that t-quark and τ are in same multiplet (Hall and Barbieri, Hisano et al.)

Process	Current Limit	SUSY level
$\mu^- N \rightarrow e^- N$	10^{-12}	10^{-15}
$\mu^+ \rightarrow e^+ \gamma$	10^{-11}	10^{-13}
$\tau \rightarrow \mu \gamma$	10^{-6}	10^{-9}





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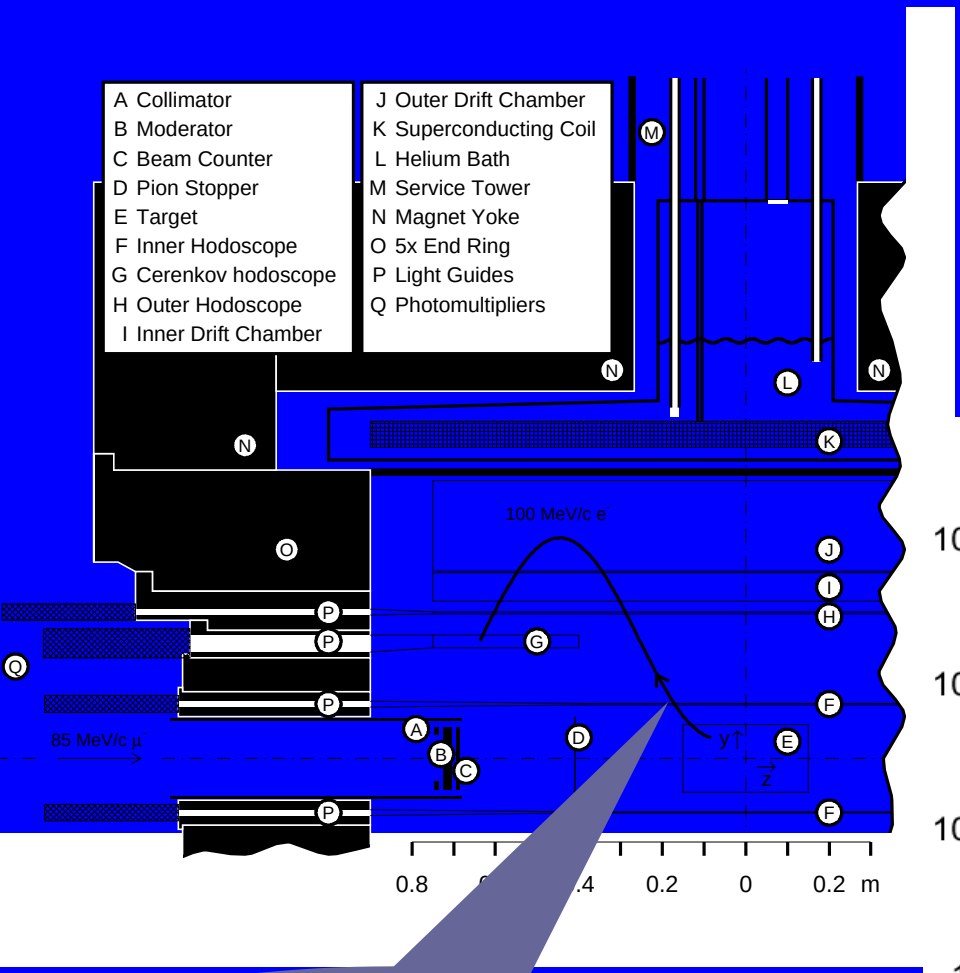
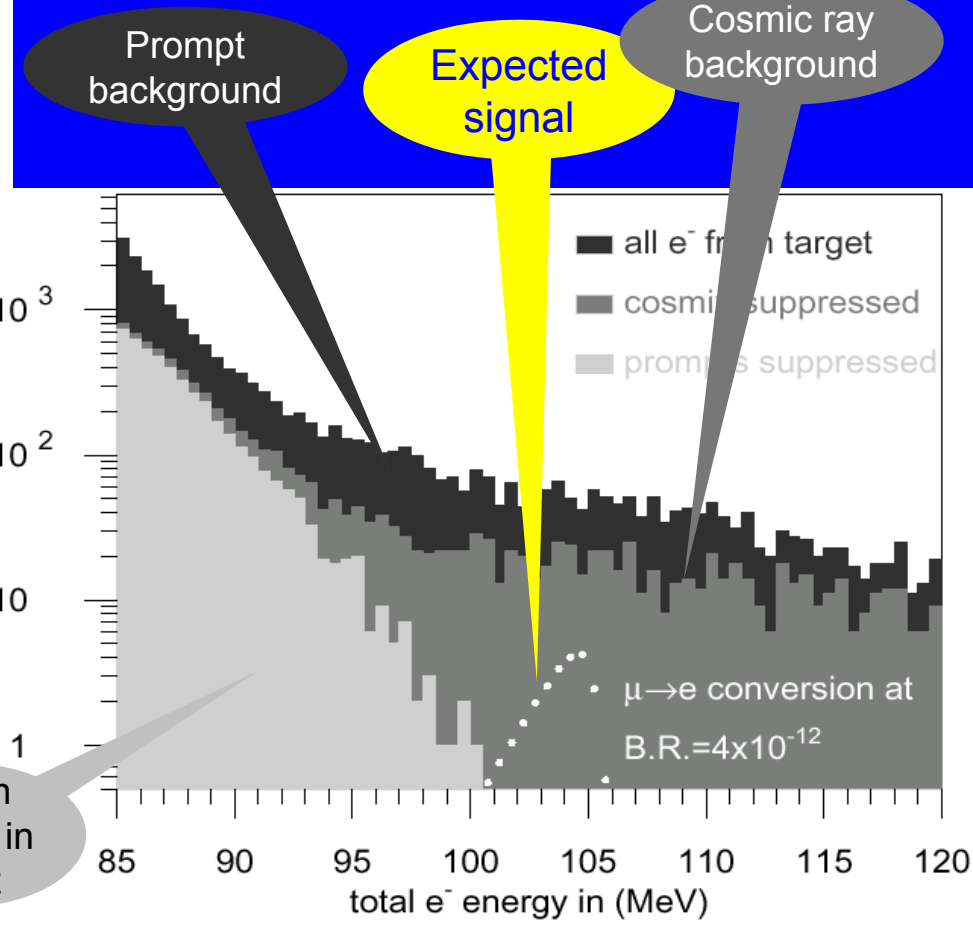
SINDRUM 2





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

Muon decay in orbit

Experimental Method

- Low energy muons are captured by a target nucleus. They cascade to 1s state rapidly.

- Muon lifetime ~0.9μs for Al. They either decay in orbit: $\mu^- \rightarrow \nu_\mu e^- \bar{\nu}_e$

  or get captured by the nucleus:

  $\mu^- N \rightarrow \nu_\mu N'(Z-1)$ $[\mu^- p \rightarrow \nu_\mu n]$

- or …they convert to electrons: $\mu^- N \rightarrow e^- N$

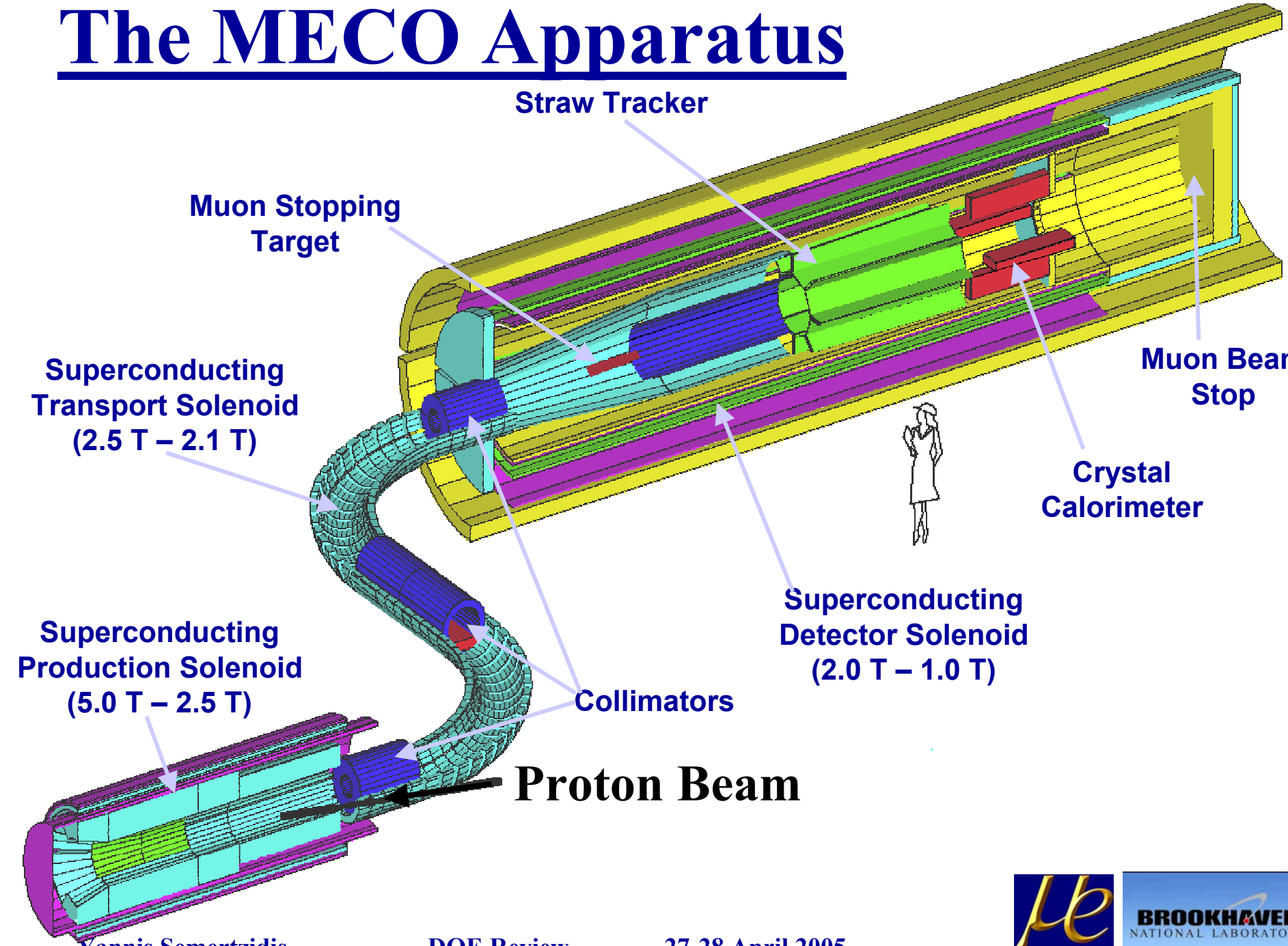
$E_e = m_\mu c^2 - E_{binding} - E_{recoil}$

$= 105.6 - 0.25 - 0.25$ MeV

MECO Requirements

- Increase the muon flux ×1000 (graded solenoid, MELC–MMF design), collect ~10^{-2} muons/proton
- Use pulsed beam with <10^{-9} extinction in between for prompt background rejection
- Detect …only promising events → defines detector geometry; resolution requirements
- Use Cosmic Ray veto

The MECO Apparatus



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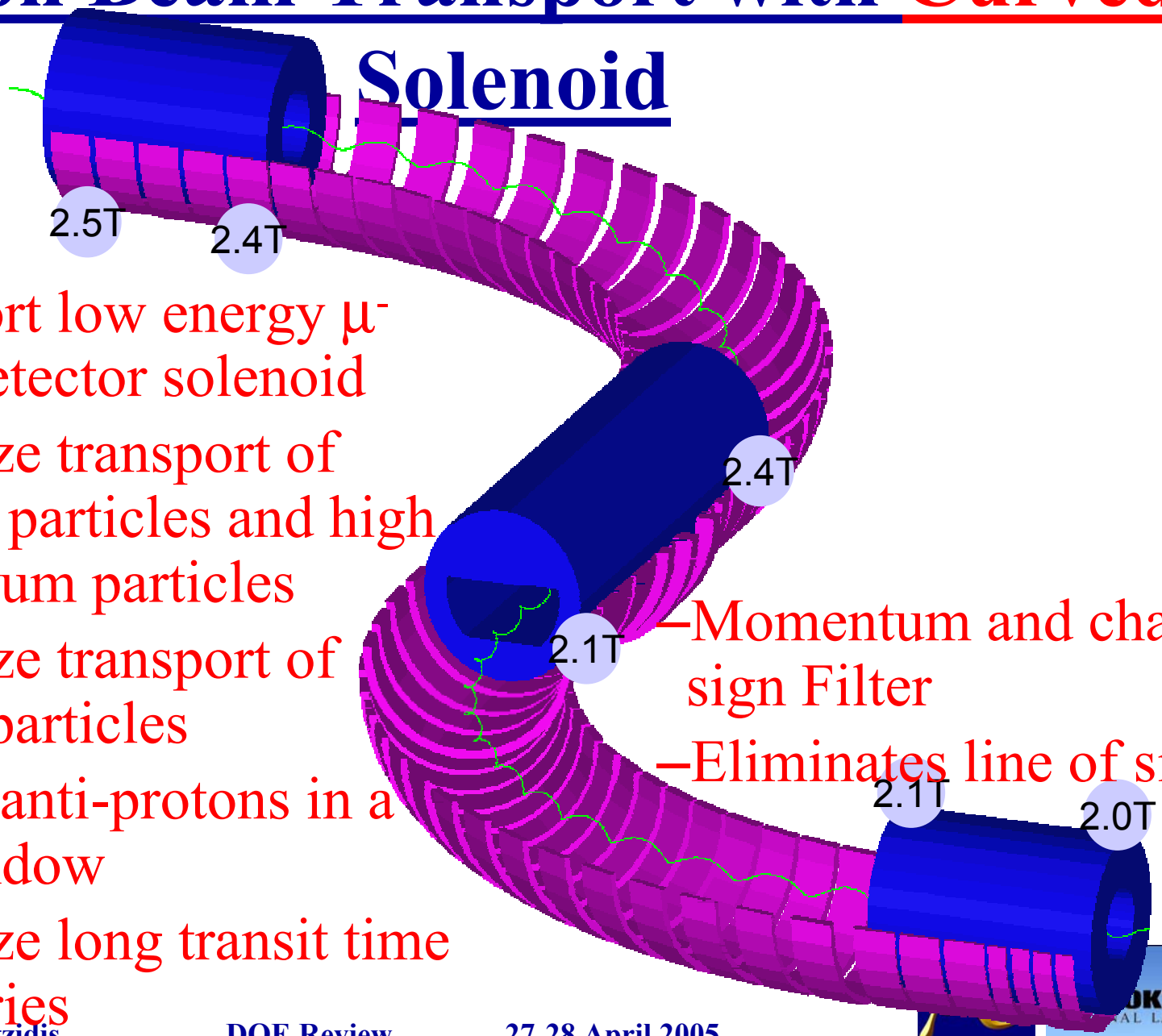
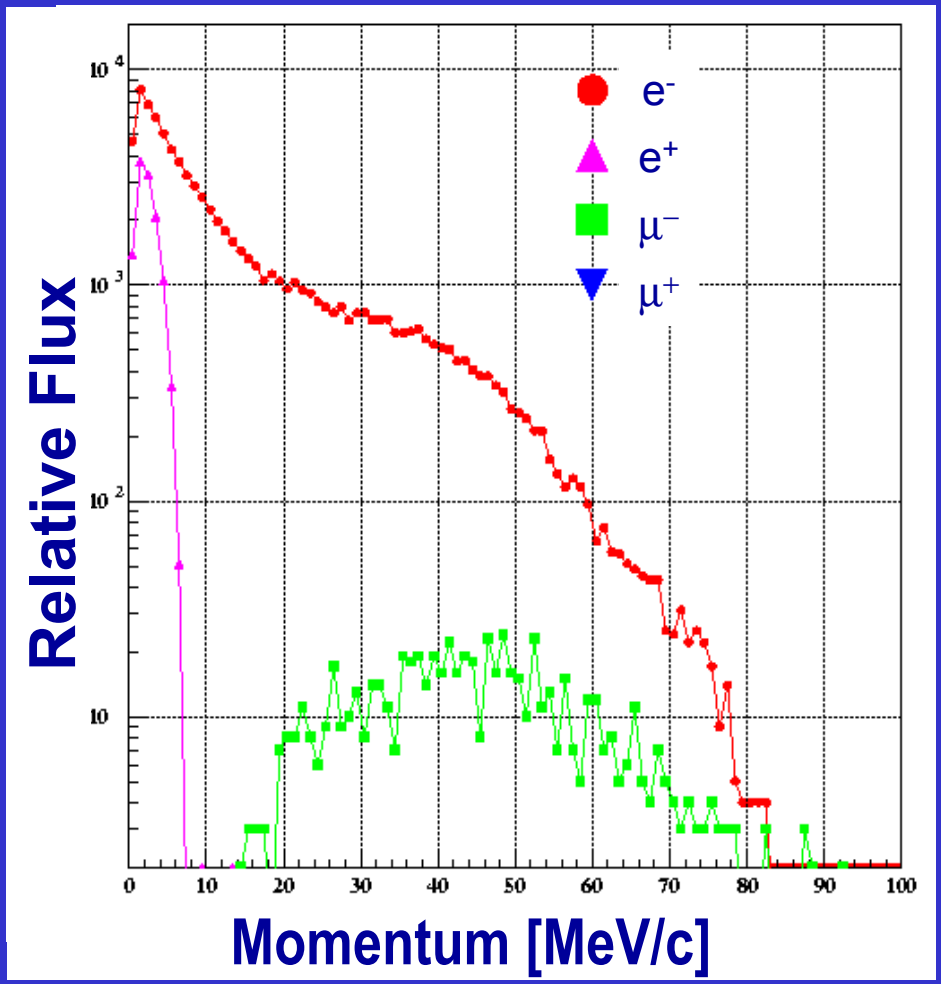
Muon Beam Transport with Curved Solenoid

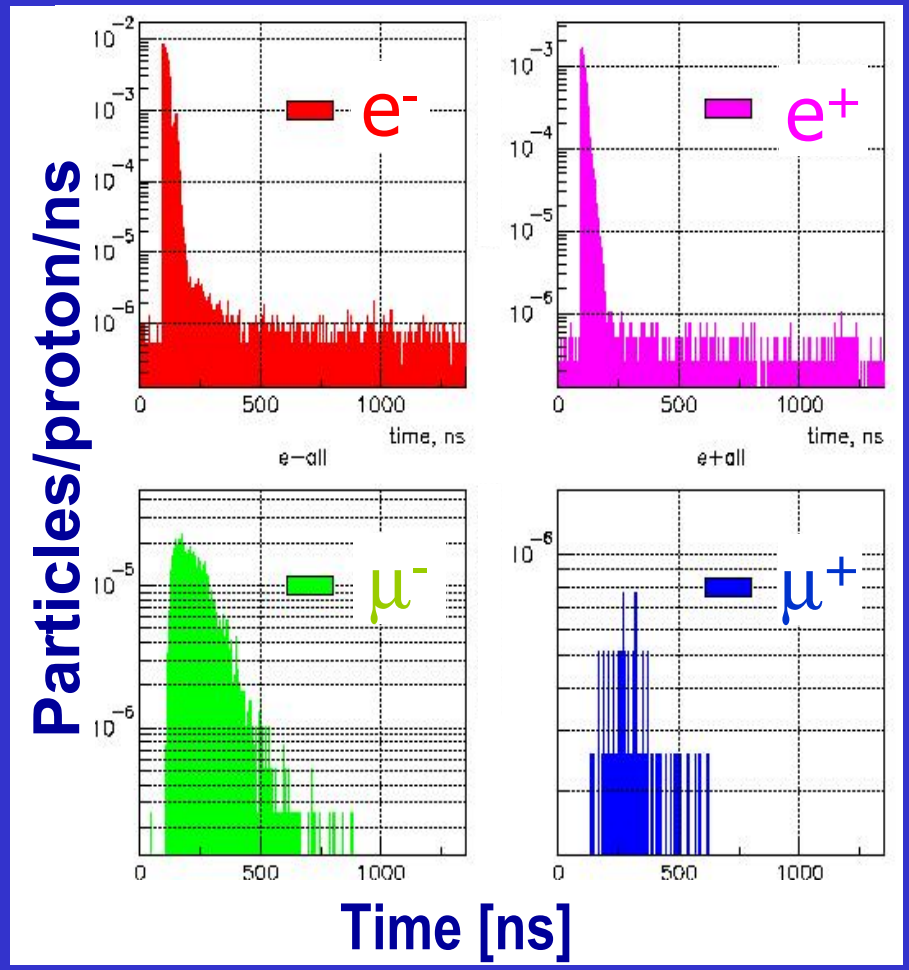


Goals:

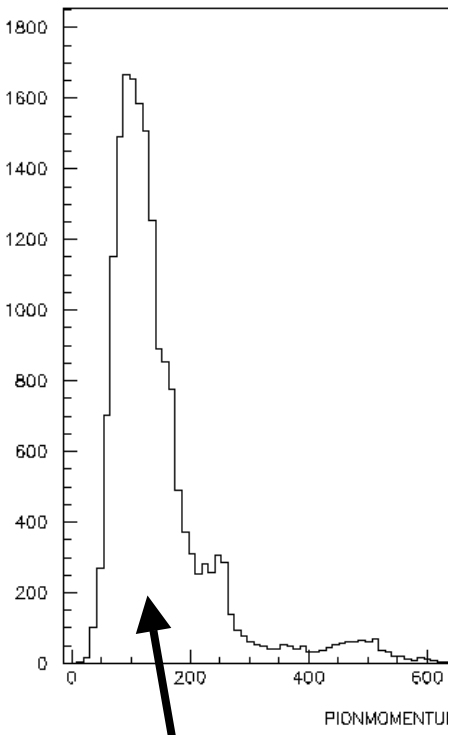
- Transport low energy μ^- to the detector solenoid
- Minimize transport of positive particles and high momentum particles
- Minimize transport of neutral particles
- Absorb anti-protons in a thin window
- Minimize long transit time trajectories
- Momentum and charge sign Filter
- Eliminates line of sight

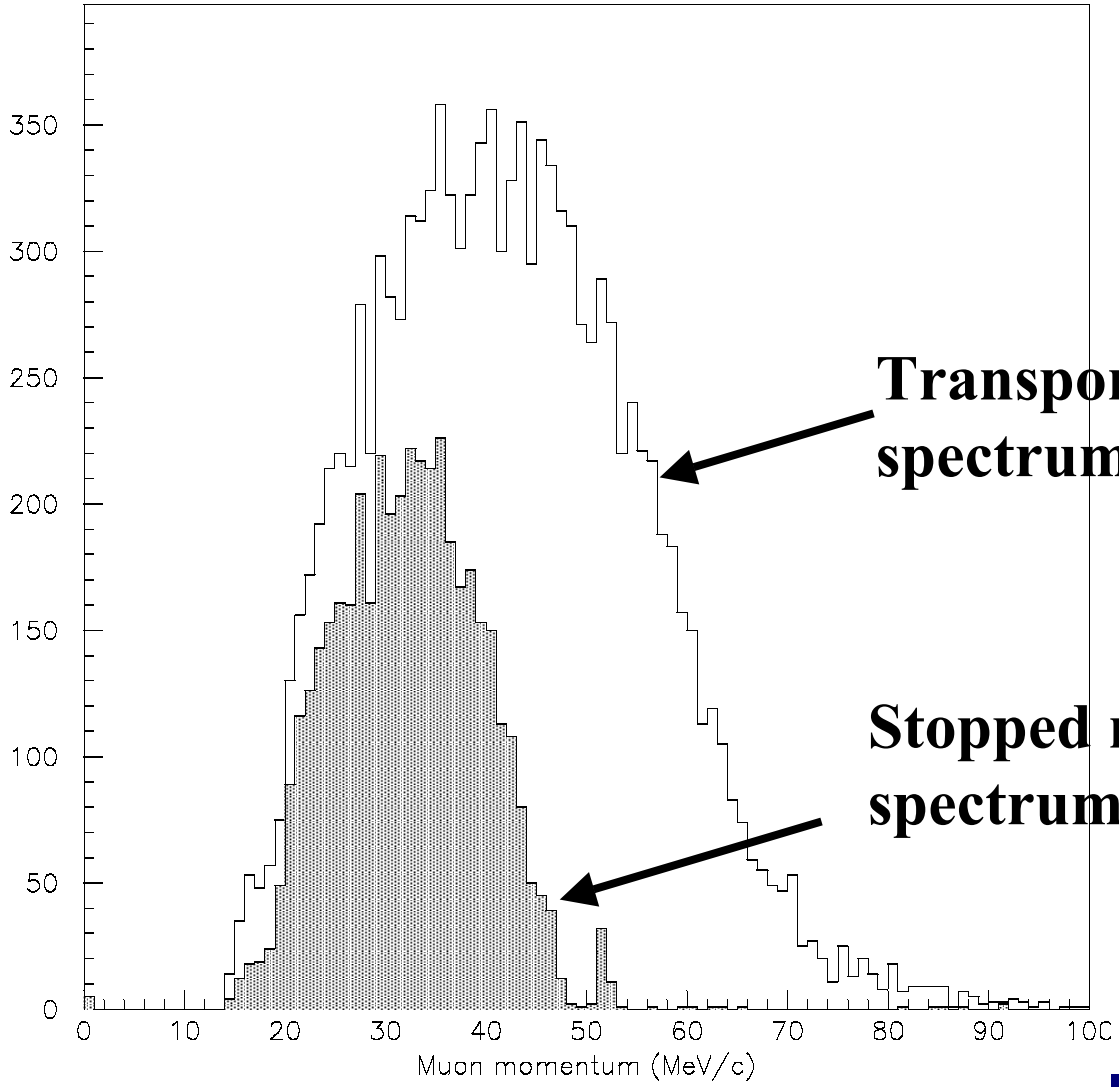
Momentum and Time Distributions in MECO Muon Beam





Transported and stopped muons





Transported muon spectrum

Stopped muon spectrum

Pion spectrum at Entrance of Transport Sol.

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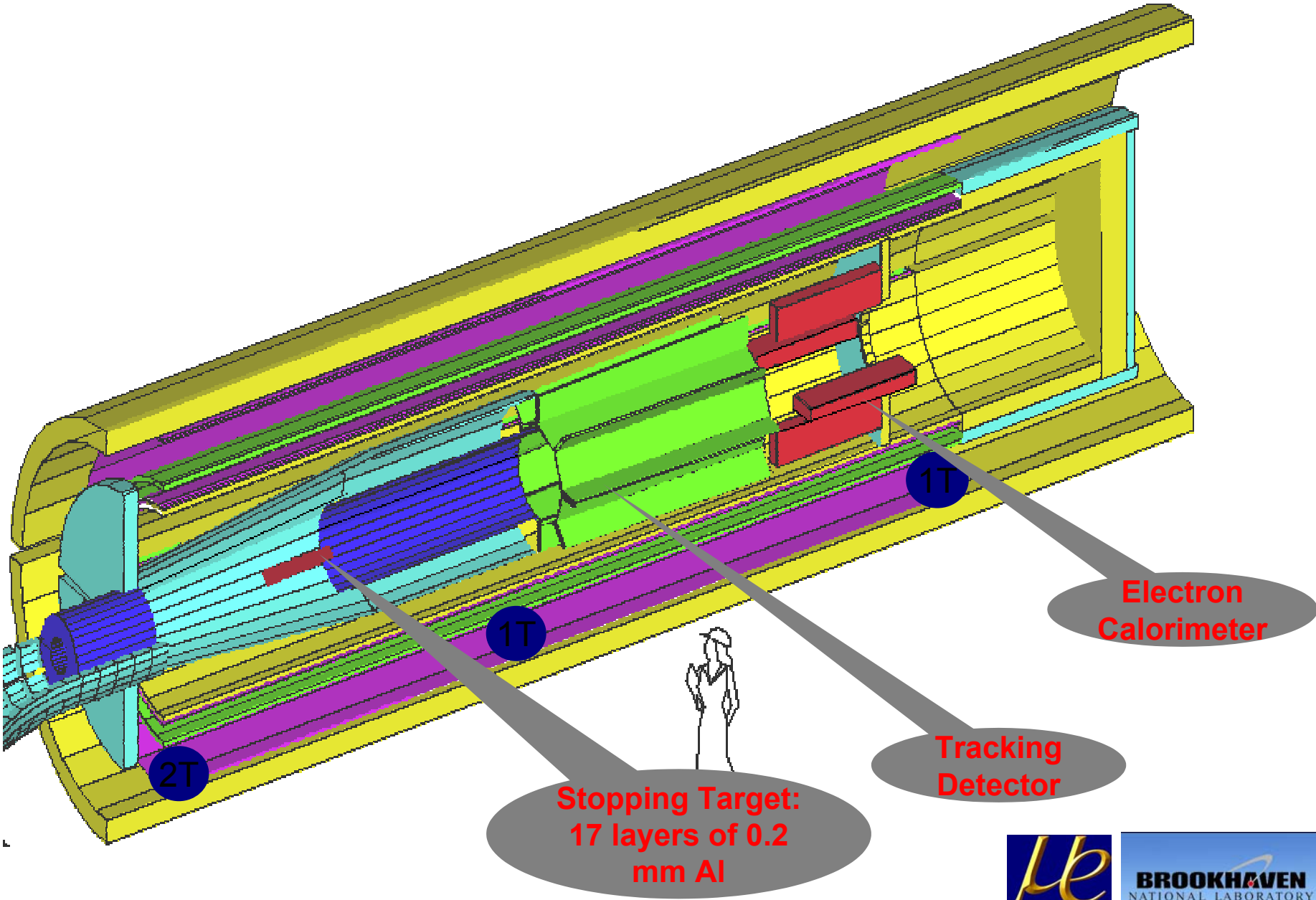
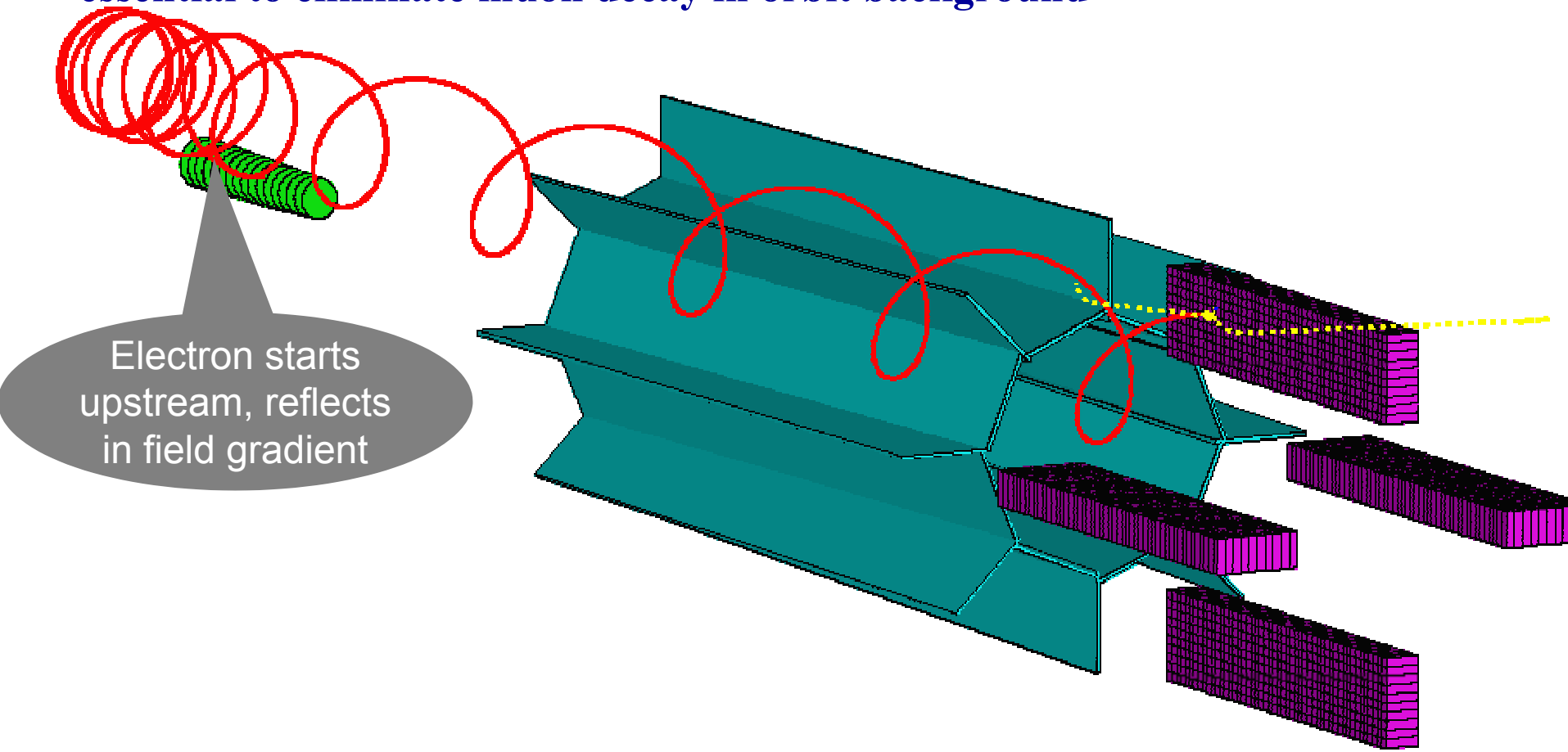
Stopping Target and Experiment in Detector Solenoid

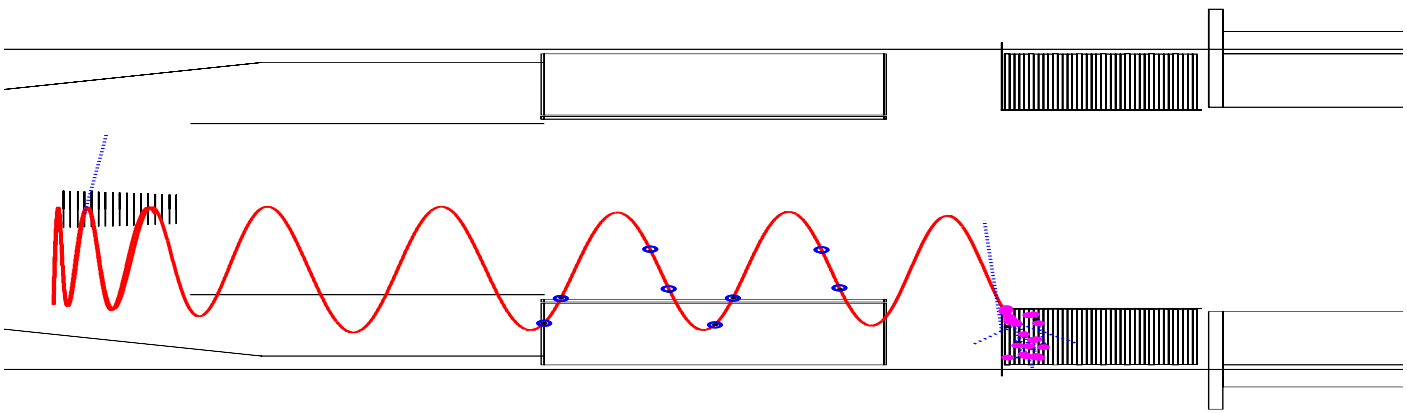


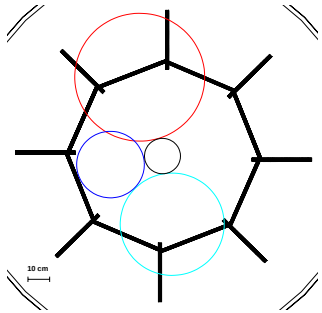
Magnetic Spectrometer for Conversion Electron Momentum Measurement

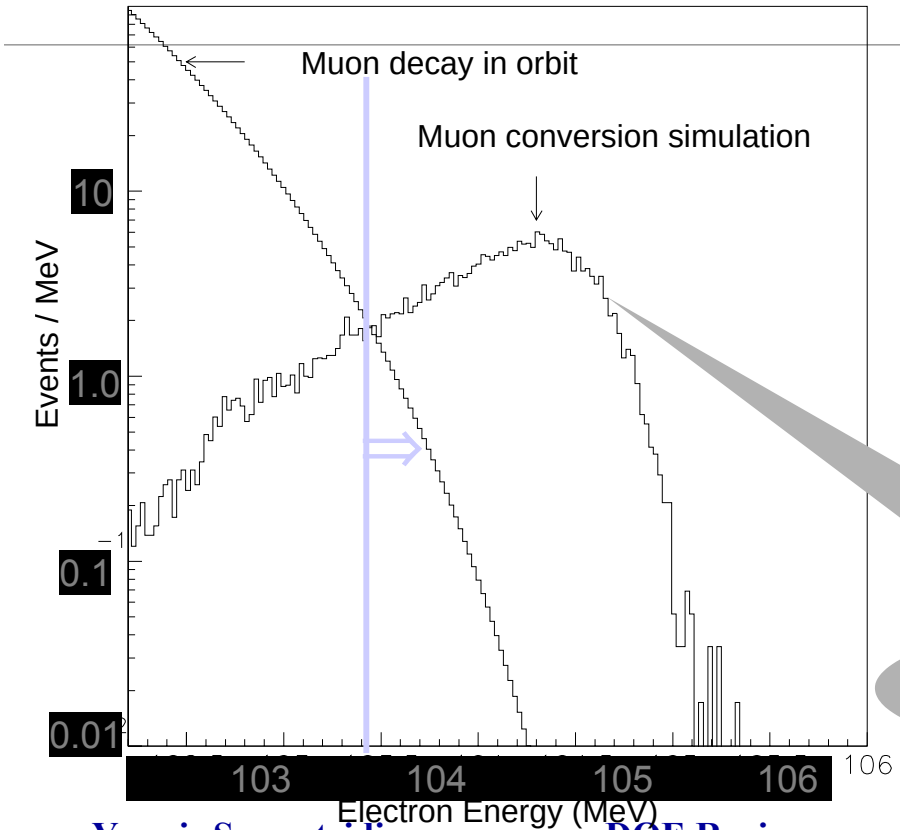
- **Measures electron momentum with precision of about 0.2% (RMS) – essential to eliminate muon decay in orbit background**



Spectrometer Performance Calculations







Aiming for ~200 KeV resolution

FWHM ~900 keV

Expected Sensitivity of the MECO Experiment

MECO expects ~ 5 signal events for 10^7 s running for $R_{\mu e} = 10^{-16}$

Contributions to the Signal Rate	Factor	
Running time (s)	10^7	
Proton flux (Hz) (50% duty factor, 740 kHz micropulse)	4×10^{13}	*
μ entering transport solenoid / incident proton	0.0043	*
μ stopping probability	0.58	*
μ capture probability	0.60	
Fraction of μ capture in detection time window	0.49	*
Electron trigger efficiency	0.90	
Fitting and selection criteria efficiency	0.19	
Detected events for $R_{\mu e} = 10^{-16}$	**5.0**	

*** BNL Involved**

Expected Background in MECO Experiment

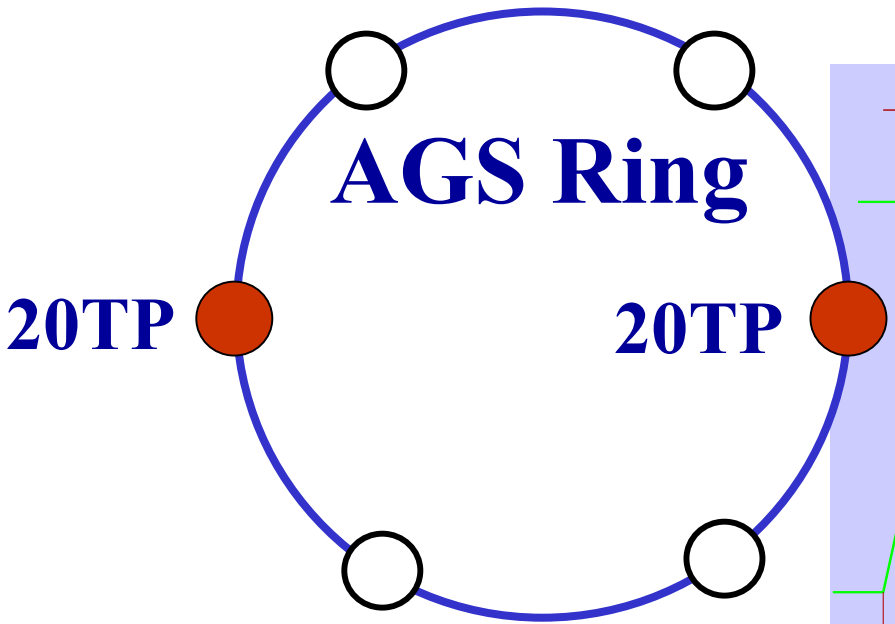
MECO expects ~0.45 background events for 10^7 s with ~ 5 signal events for $R_{\mu e} = 10^{-16}$

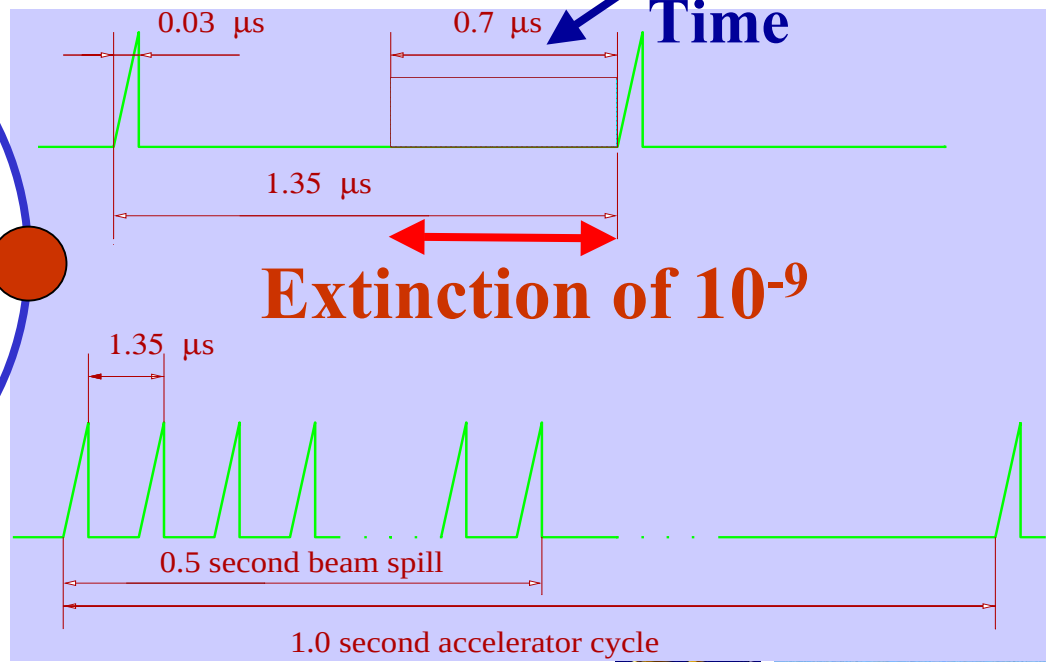
Source	Events	Comments	
μ decay in orbit	0.25	Dominant background; resolution	*
Tracking errors	< 0.006		
Radiative μ decay	< 0.005		
Beam e^-	< 0.04		
μ decay in flight	< 0.03	Without scattering in stopping target	
μ decay in flight	0.04	With scattering in stopping target	
π decay in flight	< 0.001		
Radiative π capture	0.07	From out of time protons; 10^{-9} extinction	*
Radiative π capture	0.001	From late arriving pions	
Anti-proton induced	0.007	Mostly from π^-	
Cosmic ray induced	0.004	Assuming 10^{-4} CR veto inefficiency	*
Total Background	0.45	Assuming 10^{-9} inter-bunch extinction	

10^{-9} Extinction at the AGS

Use E-O effect to measure it in the AGS to help achieve this challenging goal!

Use 6 buckets, only two of them filled with beam. Time between filled buckets: 1.35 μs

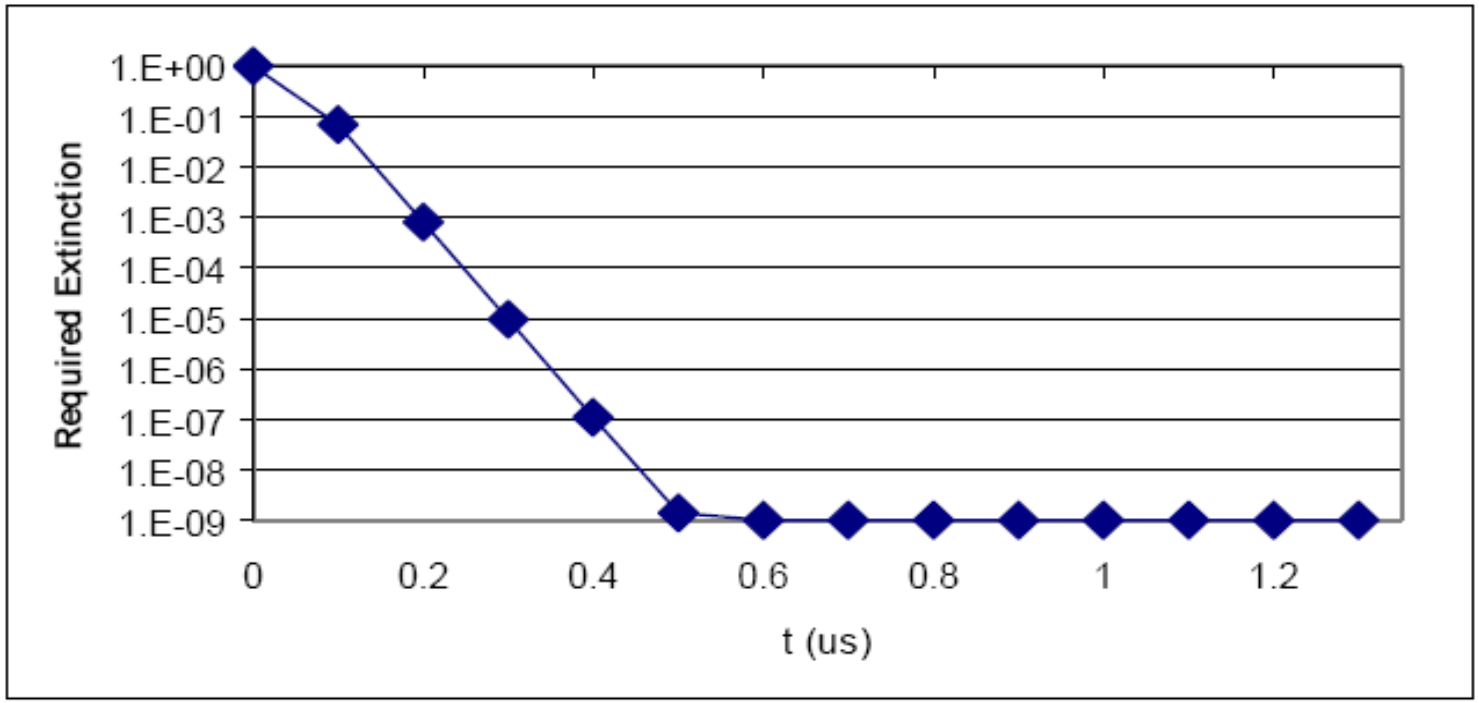




Required Extinction vs Time

W. Morse, Y. Semertzidis, MECO note #140.

Fig. 1. Required extinction level vs. time between proton bunches for radiative pion background (see text for discussion).



The Physics dept. exp. Physicists in MECO

- **Peter Yamin (1/2 FTE):** Neutron background studies using MARS code; Target and Heat Shield Teamleader.

- **William Morse:** Muon Beamline (WBS 1.3.3) Teamleader, Extinction, C.R. Shield.

- **Yannis Semertzidis:** Extinction, Background, Target Optimization.

MARS Simulations

Peter Yamin has studied neutrons produced by muon capture in the region of the CR Shield as a source of background rates in the scintillators.

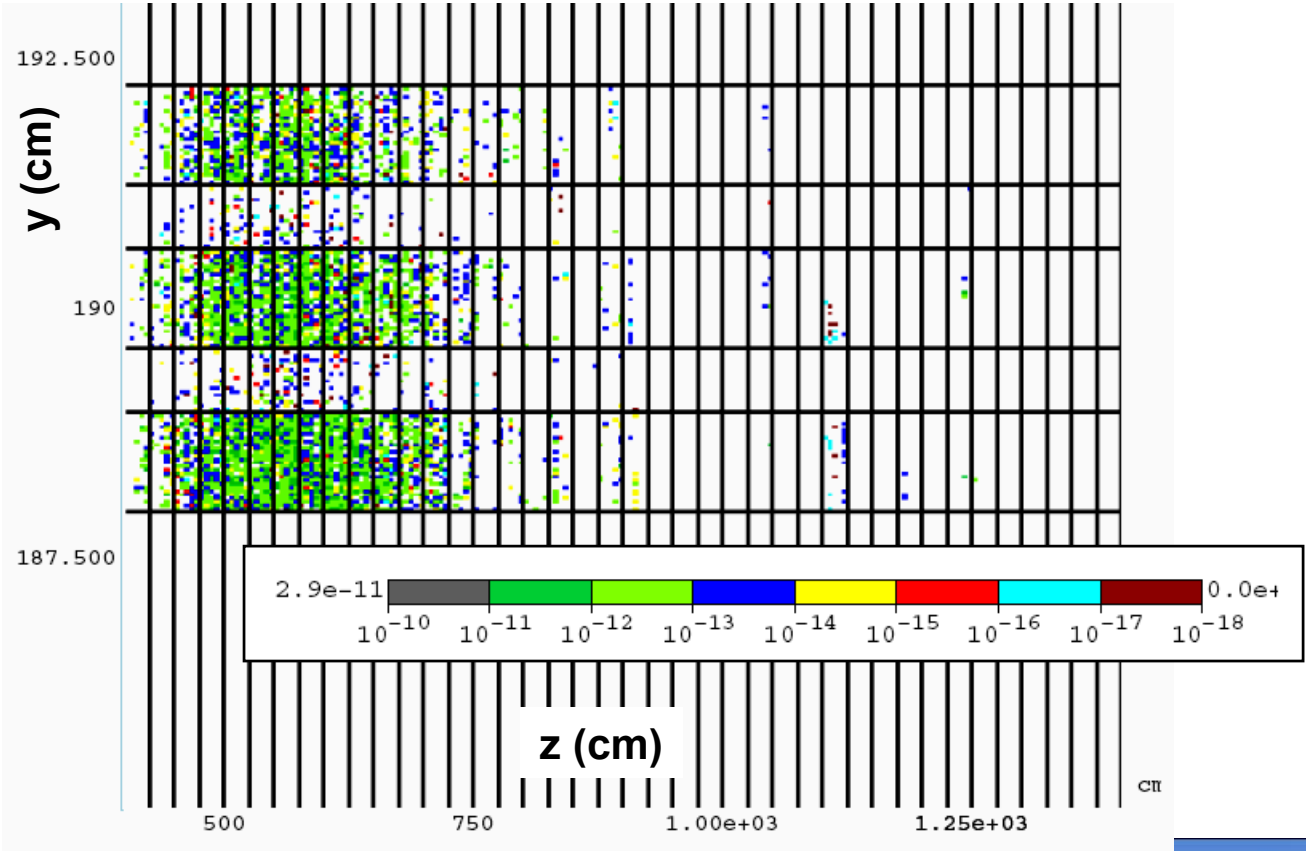
MARS Hadronic Energy Deposition (GeV / gm / stopped μ)

Scintillator Layer

6.3 mm of Aluminum

Scintillator Layer

6.3 mm of Aluminum



MECO Muon Beamline WBS 1.3.3

W. Morse Teamleader

Muon Beamline contains all the stuff inside the TS and DS, except the detectors – would greatly benefit from a BNL junior physicist.

WBS(1.3.3.)	Item	Teamleader
1	Vacuum System	D. Weiss (BNL)
2	Collimators and shielding	Tumakov (UCI)/Semertzidis (BNL)
3	Stopping target	Y. Semertzidis (BNL)
4	Detector shield	V. Tumakov (UCI)
5	Muon beam stop	V. Tumakov (UCI)
6	Pbar stopping window	D. Weiss (BNL)
7	Neutron absorbers	P. Yamin (BNL)
8	Detector support structure	W. Morse (BNL)
9	Stopping target monitor	J. Kane (W & M)

Y. Semertzidis

- Extinction: the combination of internal and external extinction needs to provide 10^{-9}. Use E-O effect to measure it in AGS (LDRD proposal).

- Working with C. Ozben from I.T.U. (visiting BNL for three months) on GEANT based simulations of Extinction, Background reduction and Target optimization.

Need funds to support junior visiting scientists

Our current MECO goals

- Complete neutron background estimations
- Muon beamline (WBS 1.3.3)
- Integrated plan of Extinction
- Reduce experimental backgrounds
- Increase signal rate
- Study collimators/magnetic field requirements

We need help!

- Strong MECO group at BNL to secure the needed studies
- We want to get involved in C.R.S.
- We need a staff position (2012 too long term for a post doc to take data) plus support for a visiting scientist for a total addition of 1.5FTEs

Recent Accomplishments

- Muon g-2: W. Morse resident spokesman, Y. Semertzidis: E. Quadrupole Teamleader, Kicker eddy current measurement, Pileup subtraction…

- EDMs in storage rings concept: Sensitive method of probing the EDM of charged particles in storage rings (stat. error 10^{-29} e·cm for the Deuteron and 10^{-28} e·cm for the proton).

Papers, Talks, Awards (within last 3 Years)

Name	Refereed Journals	Proceedings	Internal Notes	Invited Talks; Awards
P. Yamin + W. Morse + Y. Semertzidis	34	33	57	11; BNL Science & Engineering Award

Other goals

- Muon g-2 Experimental Error to 0.2ppm
  (it will not happen without further support)

- Publish Muon EDM, Muon lifetime,
  Sidereal effects (from E821 data)

Longer Term Goals

- MECO to succeed: Excellent Physics, great science investment. P.Y., W.M., Y.S.

- Muon g-2 to 0.2ppm (with extra support)
  W.M. (resident spokesman), Y.S.

Summary

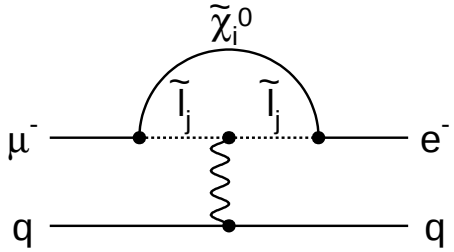
- MECO: Unprecedented sensitivity to LFV and Physics beyond the SM.
- Involved in crucial aspects of the MECO experiment.
- Planning for successful role in MECO in a similar fashion as in g-2. Need to beef up the group by 1.5 FTEs to 4 FTEs from the current 2.5 FTEs for MECO.
- Muon g-2 to 0.2ppm with more extra support.

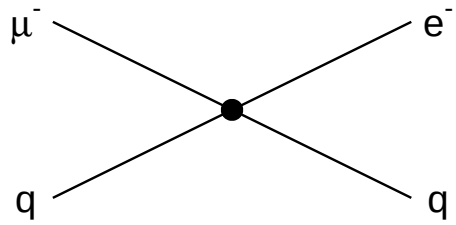
Extra Slides

Sensitivity to Different Muon Conversion Mechanisms

Supersymmetry

Predictions at 10^{-15}



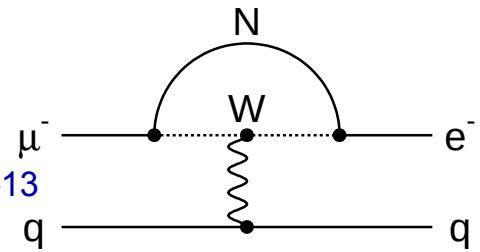


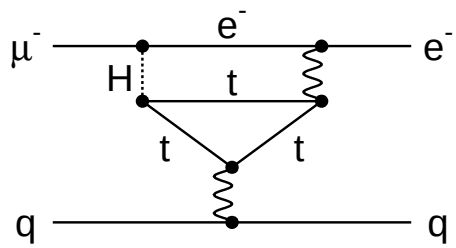
Compositeness

$\Lambda_C = 3000\ \text{TeV}$

Heavy Neutrinos

$\left|U^*_{\mu N}U_{eN}\right|^2 = 8\times10^{-13}$



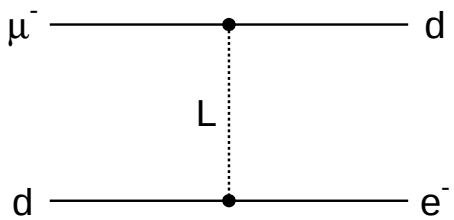


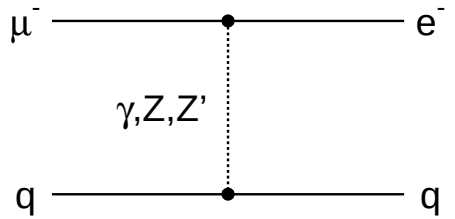
Second Higgs doublet

$g_{H_{\mu e}} = 10^{-4}\times g_{H_{\mu\mu}}$

Leptoquarks

$M_L = 3000\sqrt{\lambda_{\mu d}\lambda_{ed}}\ \text{TeV}/c^2$





Heavy Z', Anomalous Z coupling

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

$B(Z \to \mu e) < 10^{-17}$

After W. Marciano

WBS 1.3.3 Cost Estimate

WBS 1.3.3	Item and Estimator	K$	K$ w cont
1	Vacuum system – Dan Weiss	577	775
2	Collimators and shielding – Dave Phillips/Brad Smith	266	349
3	Stopping target – Dave Phillips	33	47
4	Detector shield – Dave Phillips	22	32
5	Muon beam stop – Dave Phillips/Bill Leonhardt	74	106
6	P-bar stopping window – Dan Weiss	95	124
7	Neutron absorbers – Dave Phillips/Bill Leonhardt	627	823
8	Detector support structure – Dave Phillips/Bill Leonhardt	667	938
9	Stopping monitor – John Kane	52	60
10	Conceptual design and Physics/Engineering interface	59	69
1.3.3	Total	2473	3292