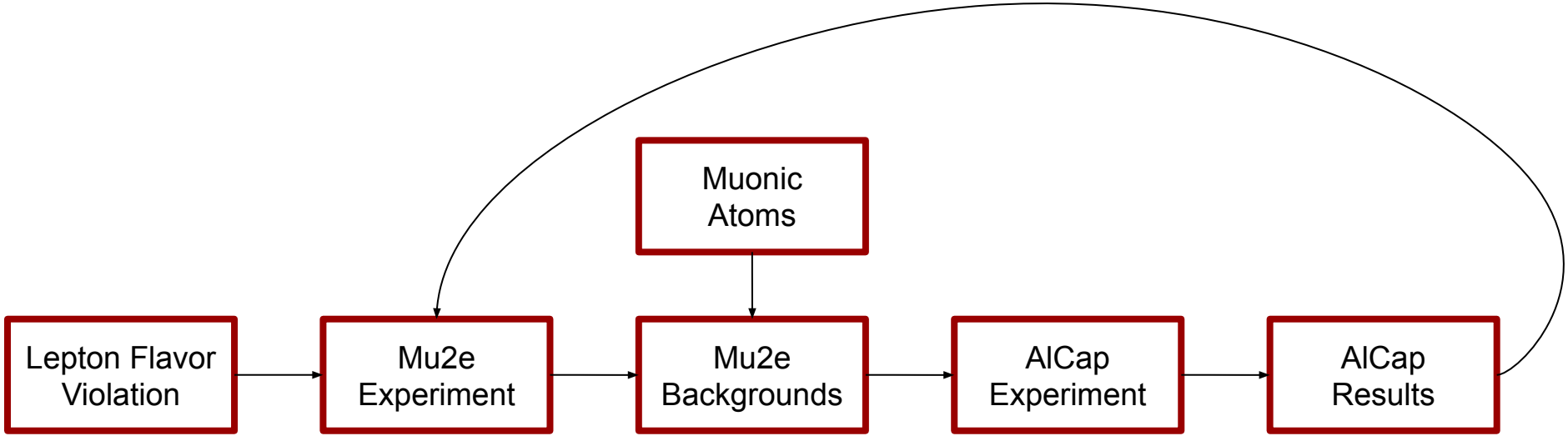
BOSTON UNIVERSITY

Preliminary Results from the AlCap Experiment

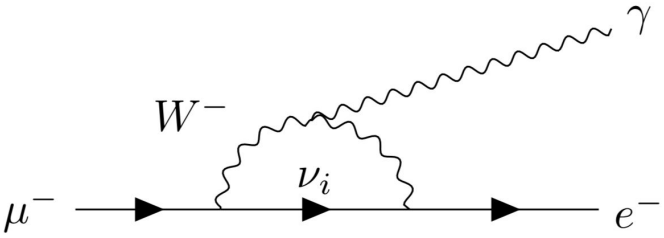
John Quirk
on behalf of AlCap Collaboration
Boston University
DPF 2019

Roadmap for Today

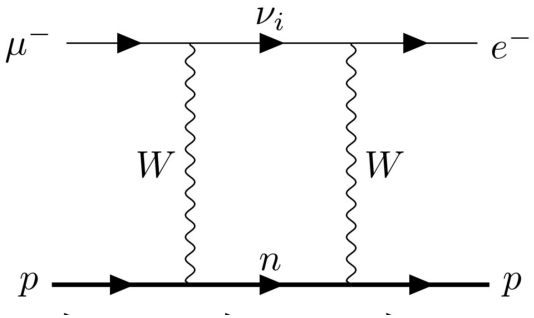


Lepton Flavor Non-Conservation

Lepton number conservation is an accidental symmetry of the SM broken by neutrino mixing. Neutral flavor violation induces *charged* lepton flavor violation, albeit at vanish:



$$Br^{\nu\mathrm{SM}}(\mu \to e\gamma) < 10^{-54}$$

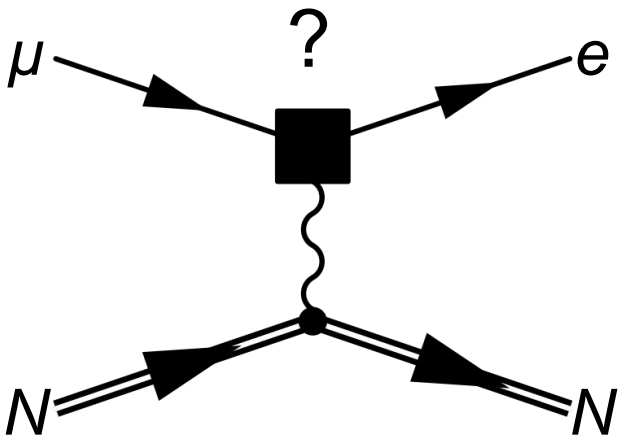


$$R^{\nu\mathrm{SM}}_{\mathrm{Al}}(\mu \to e) < 10^{-52}$$

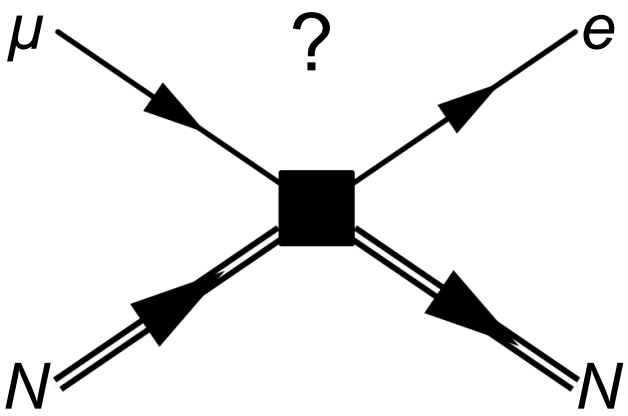
$$R(\mu \to e) = \frac{\Gamma_{\mathrm{conv}}}{\Gamma_{\mathrm{capt}}}$$

Too small to measure. So what would a signal mean?

Charged Lepton Flavor Violation: $\mu \rightarrow e$



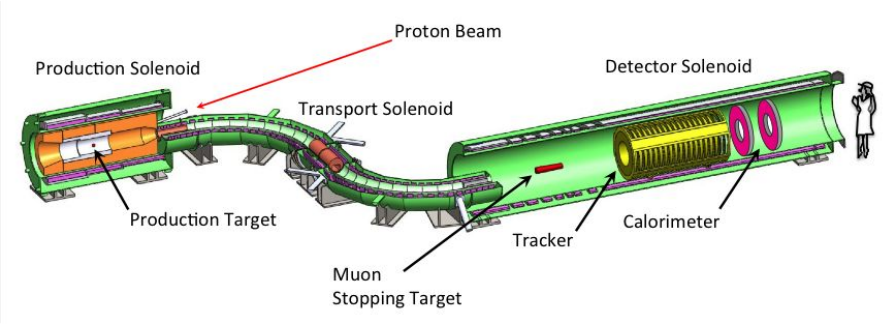
New Physics



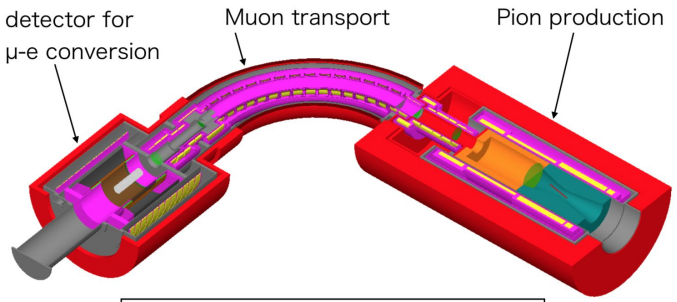
Muon to Electron Conversion Experiments

1. Proton beam incident on muon production target
2. Graded B-field focuses muons downstream
3. Curved section selects negative muons
4. μ- stop in aluminum foil target
5. Monoenergetic 105 MeV conversion electron detected in tracker and calorimeter

Mu2e @ FNAL



COMET @ JPARC [TDR]



COMET Phase-I Layout

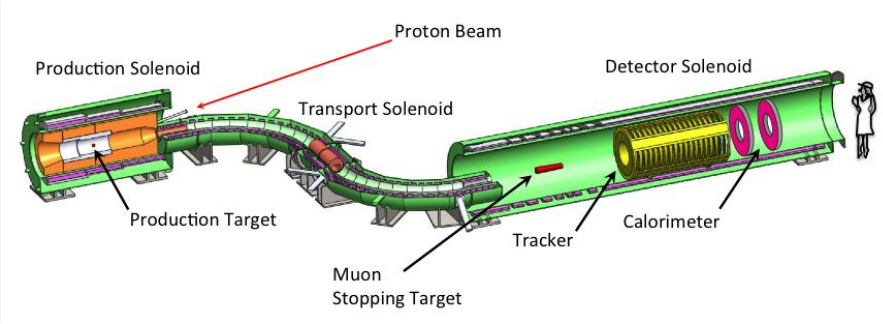
Muon to Electron Conversion Experiments

Mu2e and COMET are looking:

1. For a *rare* μAl interaction ($R_{\mu e}$(Au)<7×10^{-13})[*]
2. Through a *lot* of μAl (>10^{16}) generated noise, background, and damage

Consequently, must understand muon-aluminum interactions

Mu2e @ FNAL



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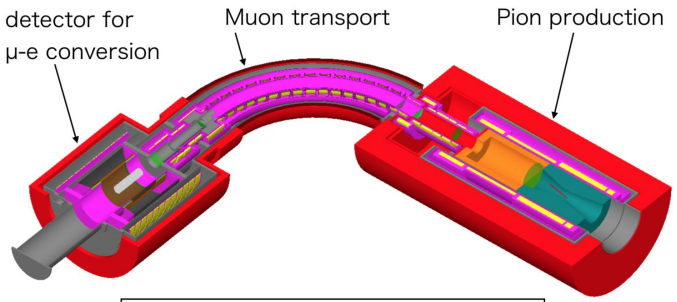
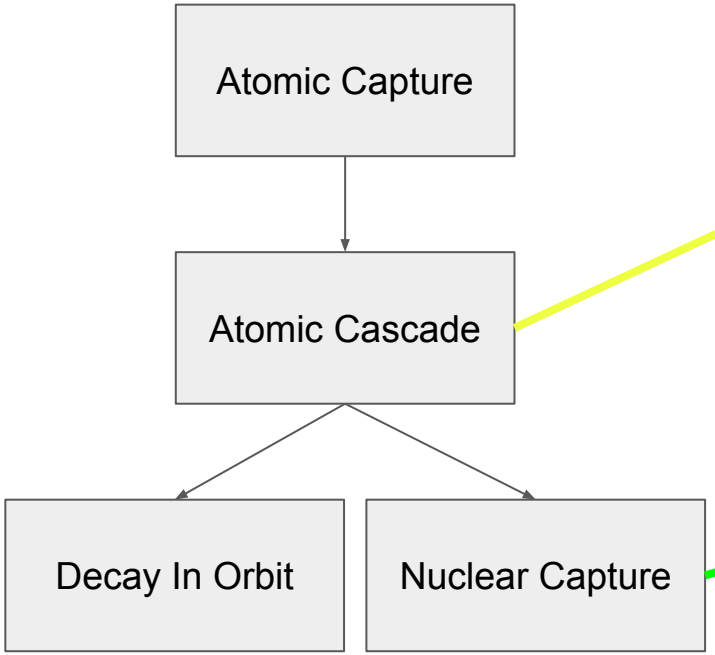


COMET Phase-I Layout

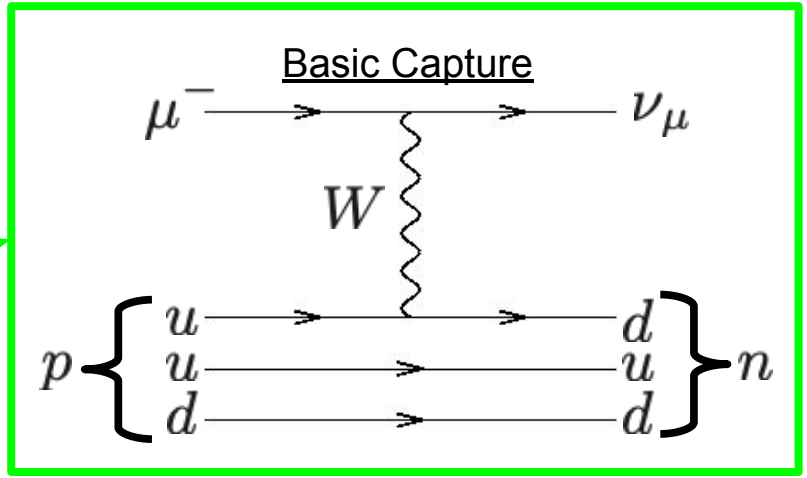
[1] W. H. Bertl *et al.* (SINDRUM II), Eur. Phys. J. **C47**, 337 (2006)

Muonic Atoms

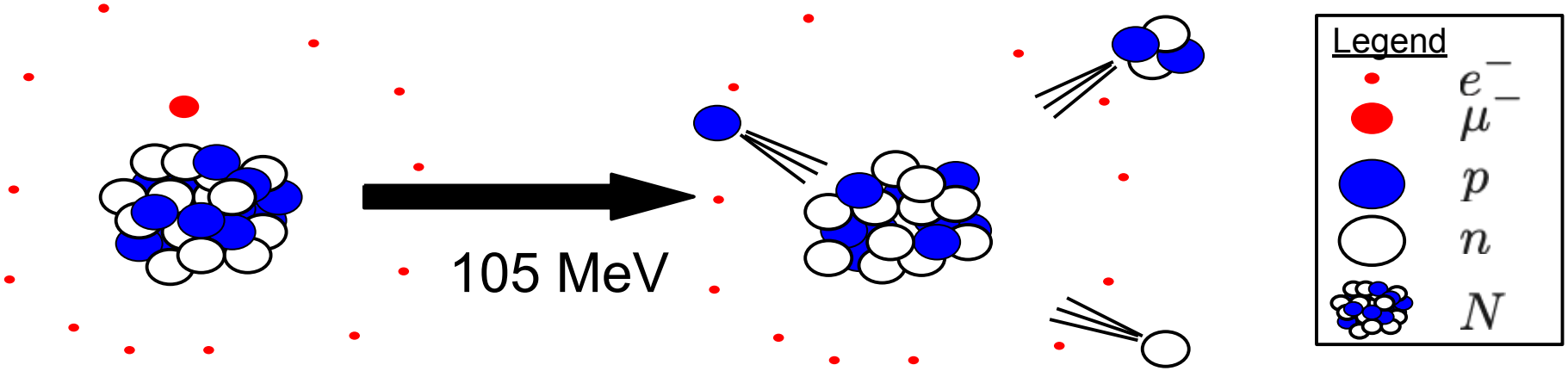


$$\Delta E^{\mathrm{Al}}_{2p\to 1s} \approx 347\mathrm{keV}$$

$$Br^{\mathrm{Al}}_{2p\to 1s} \approx 80\%$$



Nuclear Capture

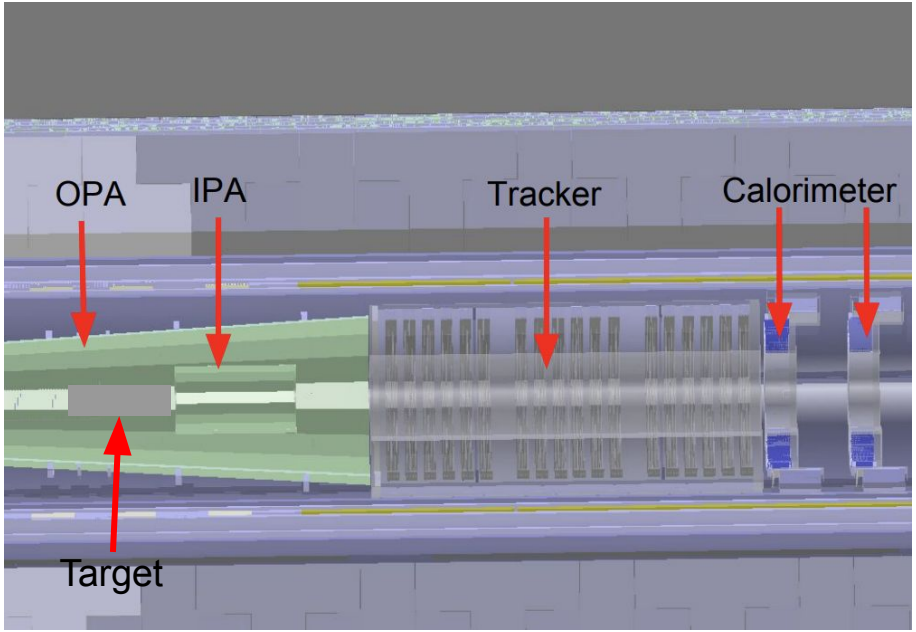


$$\mu^- + {}^{27}_{13}\mathrm{Al} \to \nu_\mu + {}^{A}_{Z}N + \ldots (n, p, \gamma)$$

Issues for Mu2e

Heavy Charged Particles:

- Optimal thickness of inner proton absorber (IPA)?
- Will Mu2e's tracker be capable of recovering quickly after a hit?
- Lifetime of the tracker?



M. MacKenzie Internal 2018

Work Packages

WP1: Protons

- Determine proton emission rate following muon aluminum nuclear capture to assess tracker noise and damage

WP2: Photons

- Gammas from nuclear capture and activation
- *X*-rays and gammas from other targets
- Noise hits
- Normalization

WP3: Neutrons

- Determine neutron spectra from aluminum and other material used for shielding in Mu2e/COMET
- Cause noise hits, corrupt electronics' memory

Work Packages

Today

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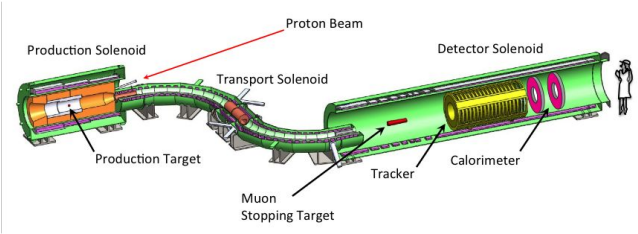
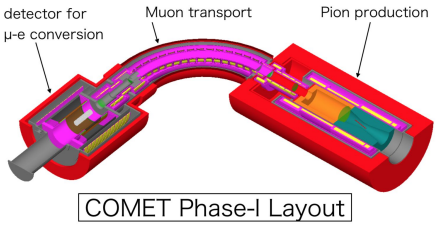
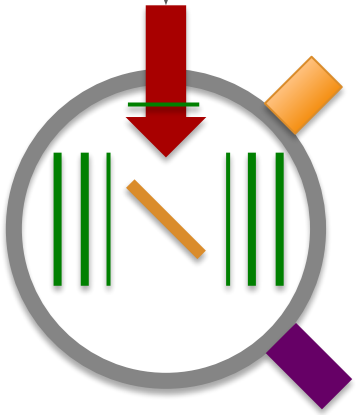
AlCap: The Aluminum Capture Experiment



Mu2e

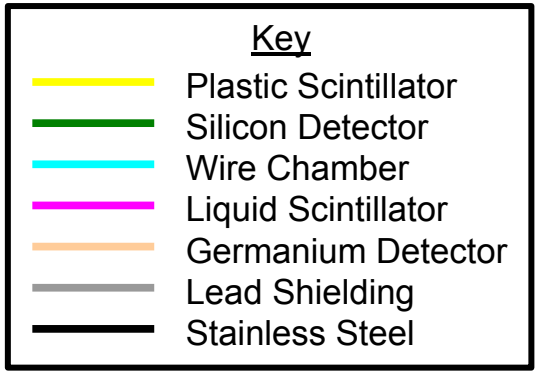


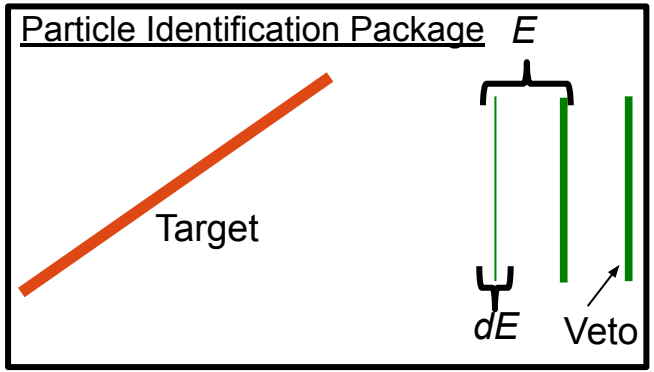
COMET

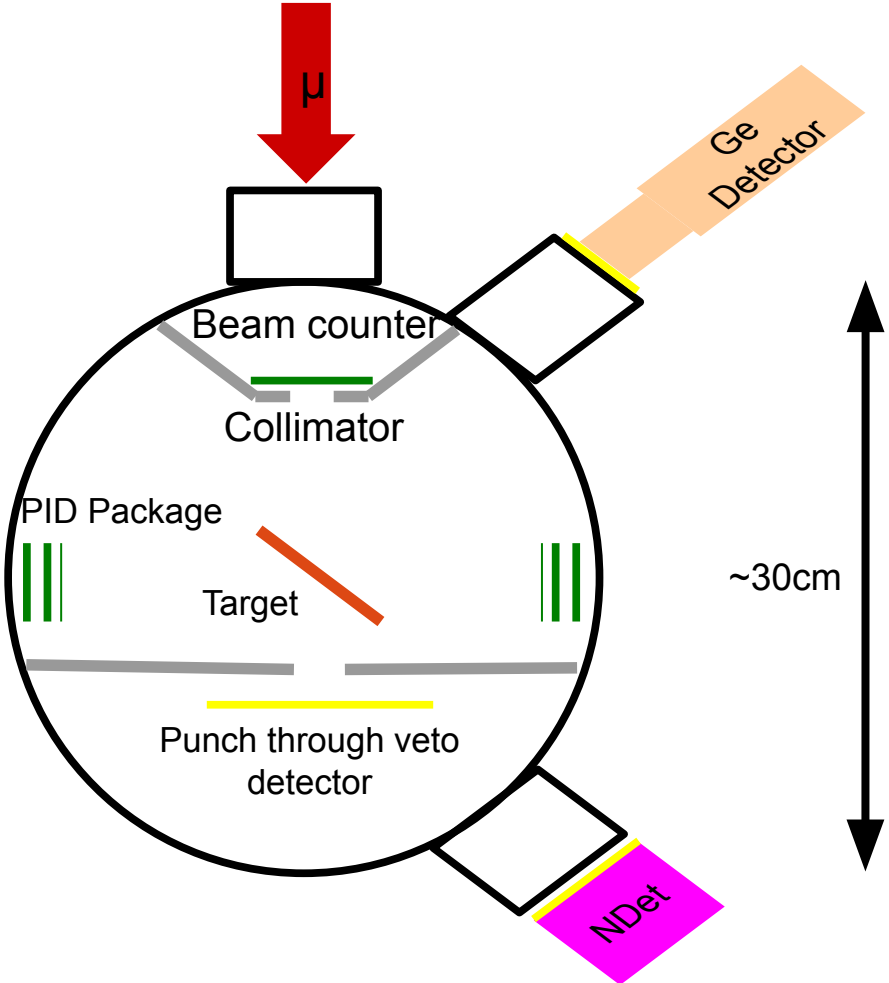


AlCap @ Paul Scherrer Institut (PSI)

AlCap Setup

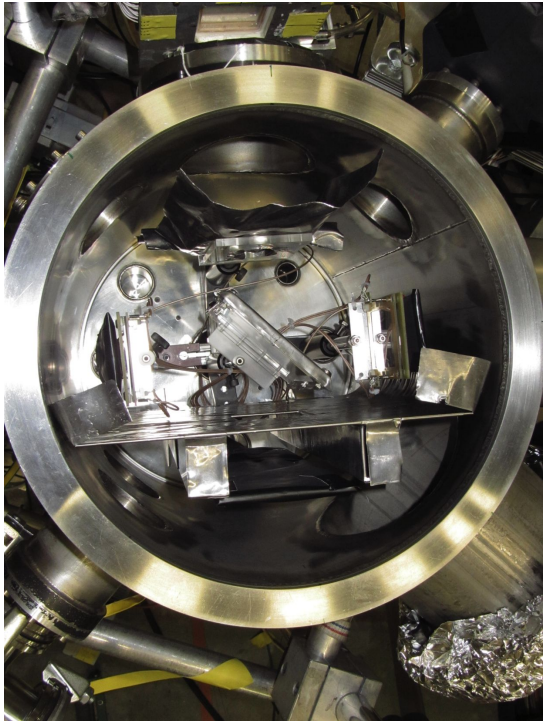


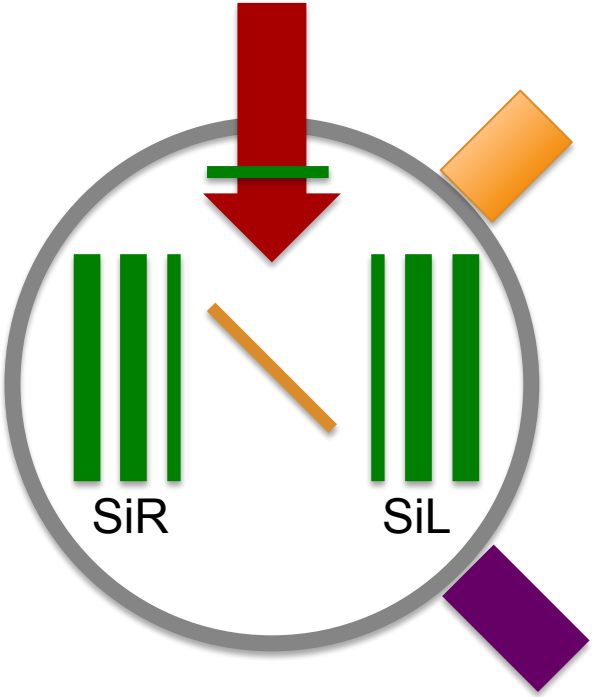




Chamber
- Cylindrical
- Stainless steel
- Under vacuum
- Diameter ~30 cm
- Height ~60cm

AlCap Setup

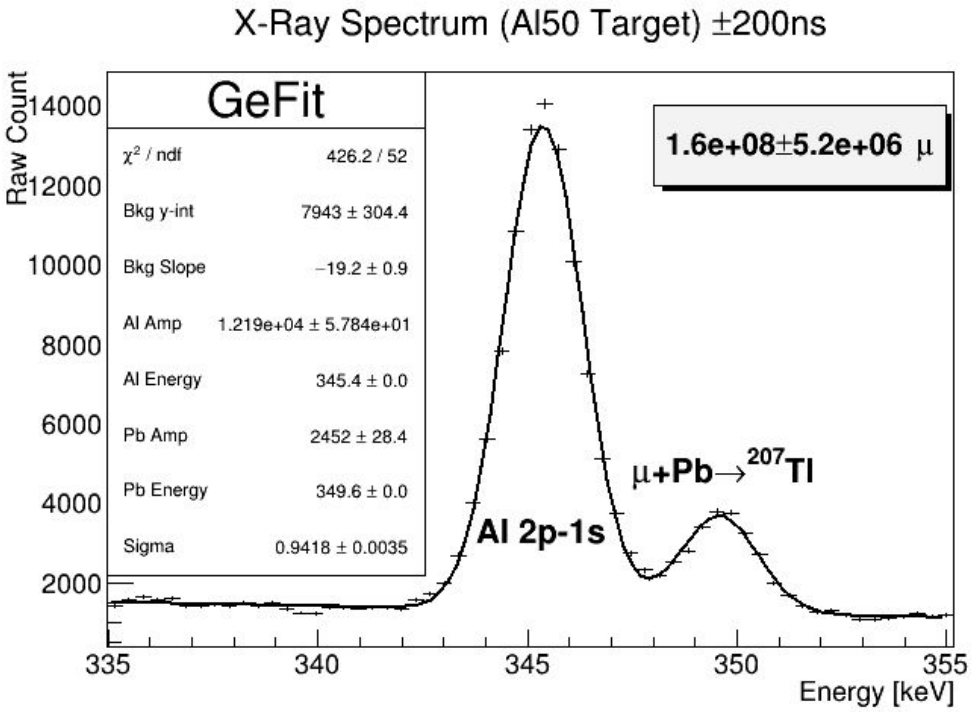




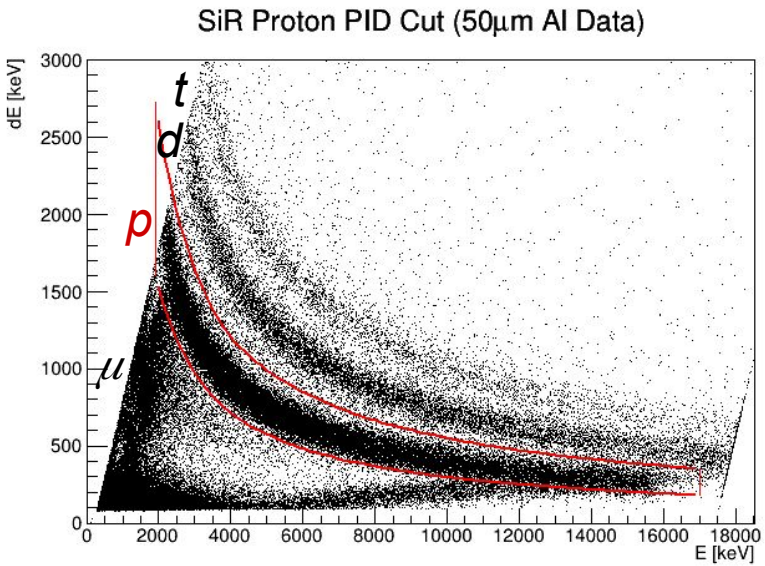
Muon Count from X-rays

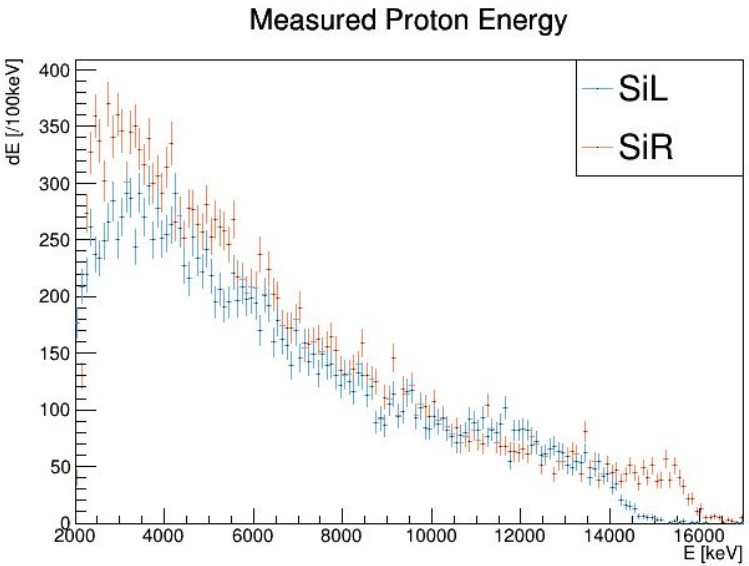
- Count muonic 2p-1s X-rays to determine number of muon stops
- Challenging for Mu2e, but easy for relatively low-background AlCap

2p-1s *X*-rays	84215(510)
Ge Efficiency @ 347 keV	$6.6(2)\times10^{-4}$
X-ray Intensity (/μ-stop)	79.8(8)%
Stopped Muons	160(5)e6



Raw Spectrum and PID



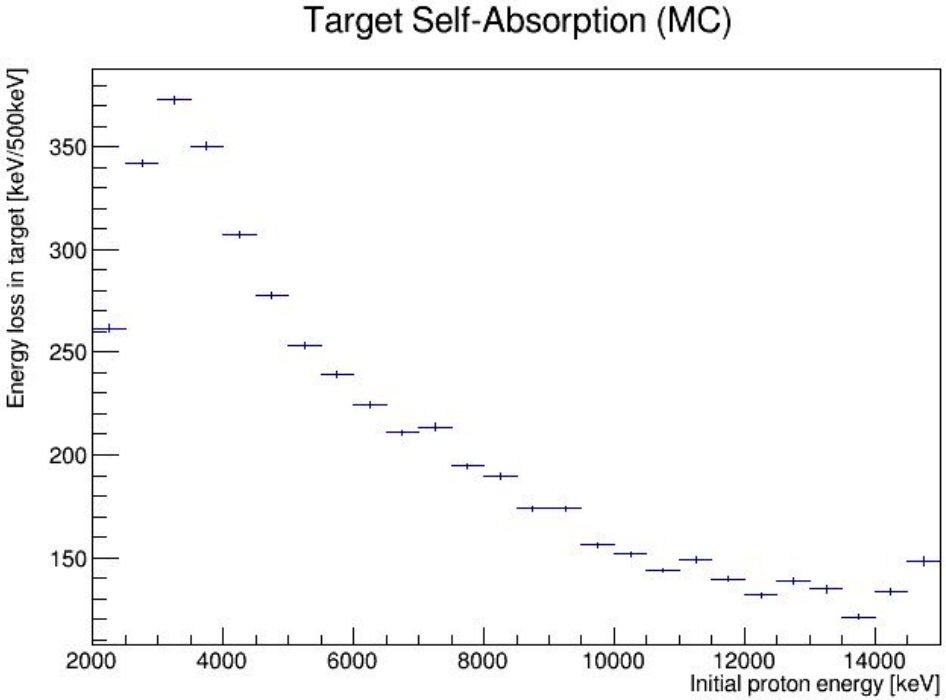


- Plot thin silicon energy vs total energy
- Particles lie in telltale bands
- Distributions fit to data slices and used for selection cut

- Left/Right differences:
  - Target stopping distribution
  - Detector positions
  - Third silicon detector on right increases energy range

Unfolding

- Geometric efficiencies based on target position and stopping distribution
- Target self-absorption based on stopping distribution
- Simulations give us this information



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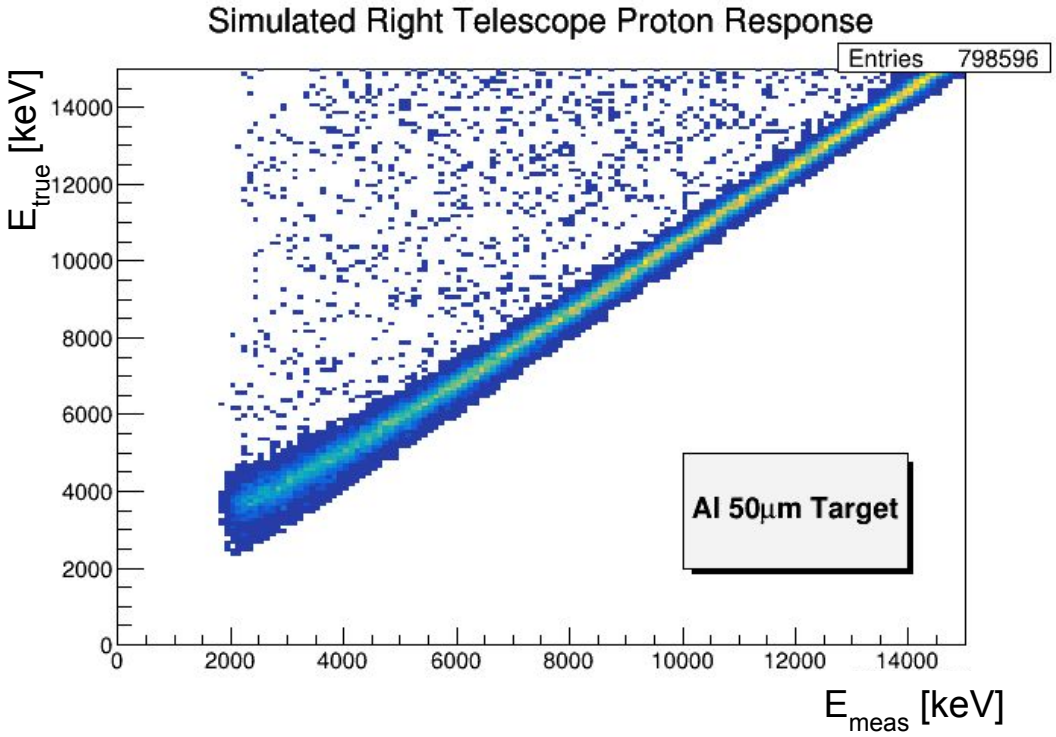


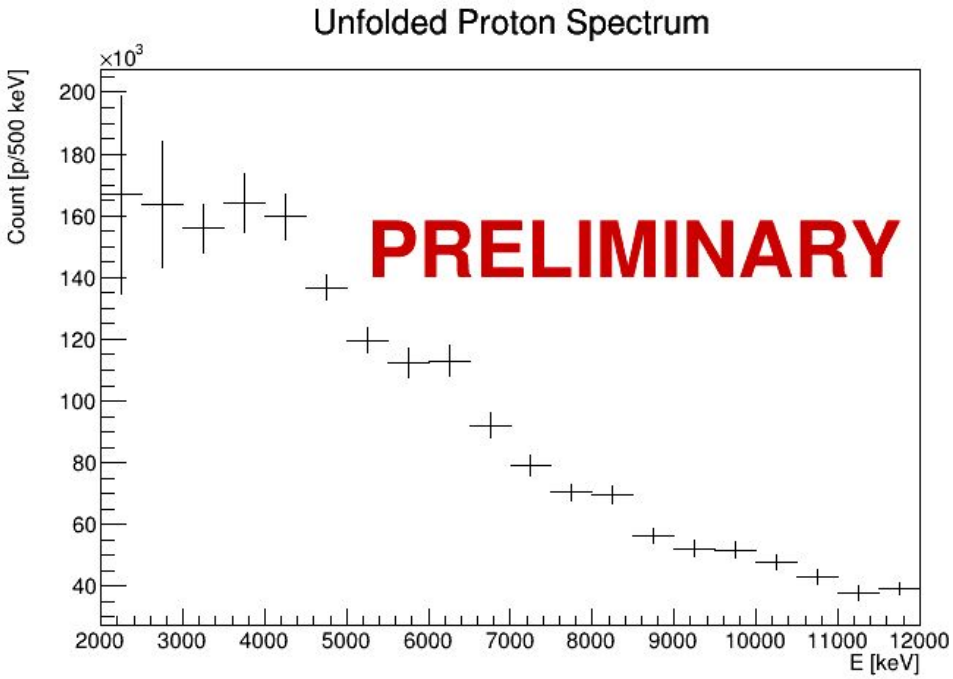
$$E_{meas} = M \times E_{true}$$

Results

Lower rate than expected

Issues:

- Features that are possibly unfolding artifacts
- Unfinished systematic studies
  - Beam characterization, stopping distribution
  - Normalization
- Extend energy range

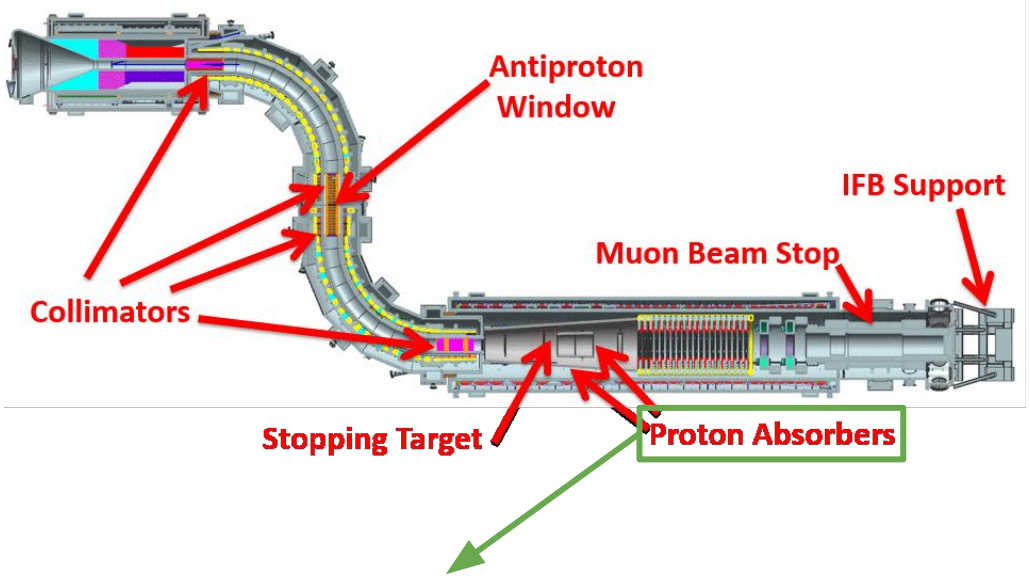


Includes only statistical, unfolding, and PID errors

Impact for Mu2e

Inner proton absorber (IPA):

- Reduces proton detector hit rate
  - Increase lifetime of the straws
  - Decrease noise hit rates
- Degrades conversion e^- signal
  - Degrades signal momentum resolution
  - Reduces signal energy



AlCap has found a (preliminary) reduced rate by a factor of 3, allowing reduction of mass of the IPA and therefore less degradation of signal energy resolution.

Status

- Hammering down systematics
  - Beam characterizations/stopping distribution (how sensitive are we?)
  - PID efficiency
  - Normalization
- Plans to extend the energy range using veto silicon detector
- Other targets (Al 100μm, Ti 50μm) for charged particle analysis
- Photon and neutron measurements coming along
- Current results already impactful for Mu2e and COMET
- Public results planned for PSI2019 (@ PSI 20 Oct)

COMET

Mu2e

Imperial College London

BERKELEY LAB

BROOKHAVEN NATIONAL LABORATORY

大阪大学 OSAKA UNIVERSITY

UCL

Institute of High Energy Physics
Chinese Academy of Sciences

Fermilab

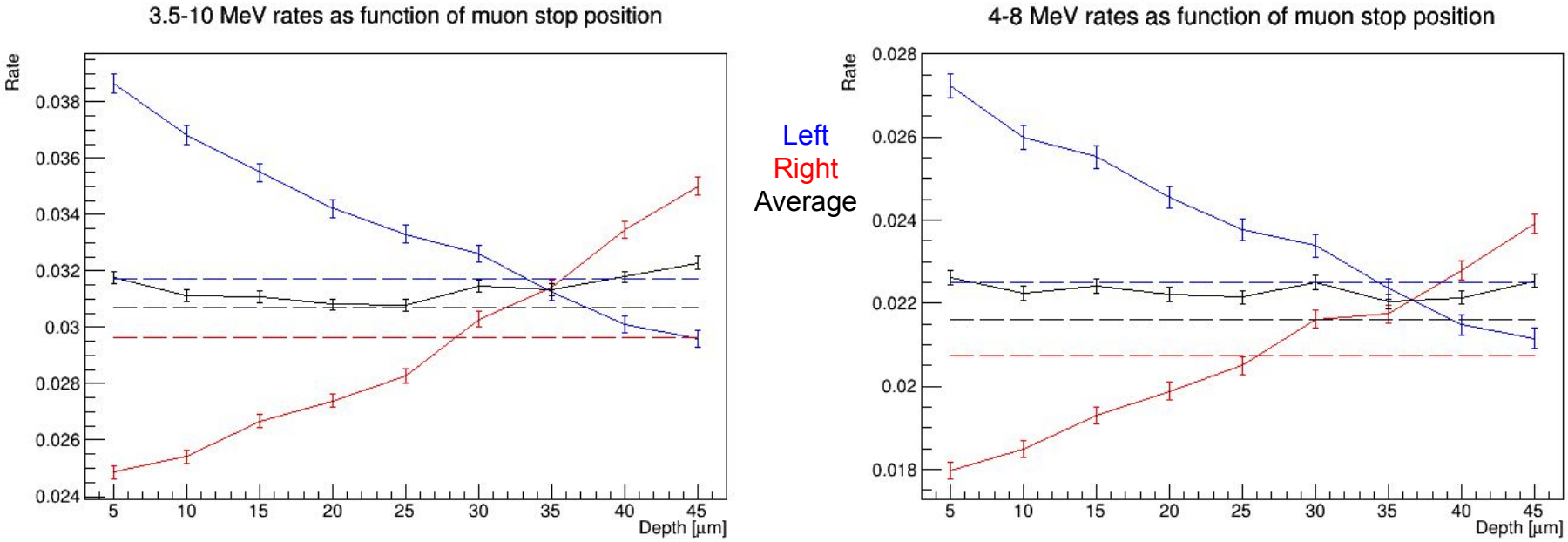
Argonne NATIONAL LABORATORY

INFN

BOSTON UNIVERSITY

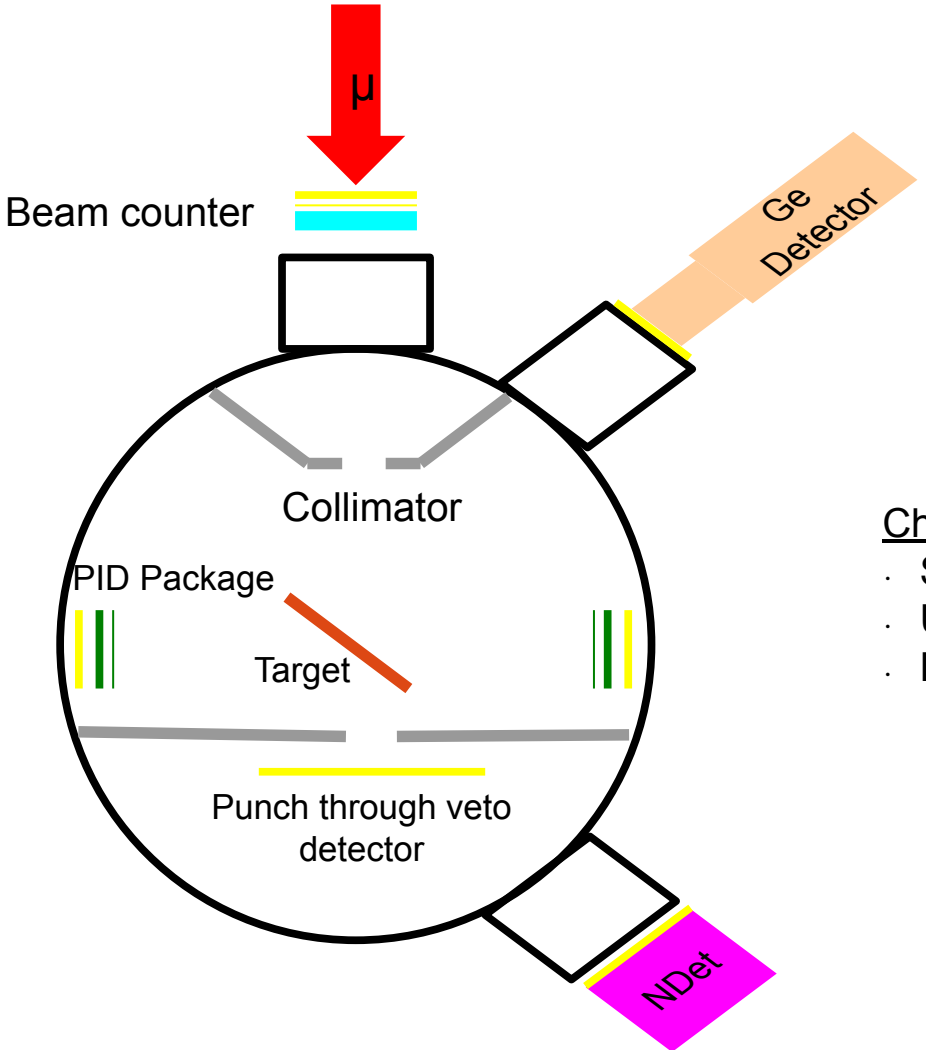
Funding provided in part by DOE

Stopping Depth in Target



While the effects on the individual detector arms is significant, averaging them cancels this out. Ideally, the unfolded rates would agree in the left and right arms.

R13 Setup



- Plastic Scintillator
- Silicon Detector
- Wire Chamber
- Liquid Scintillator
- Germanium Detector
- Lead Shielding
- Stainless Steel

Chamber

- Stainless steel
- Under vacuum
- Diameter ~30 cm

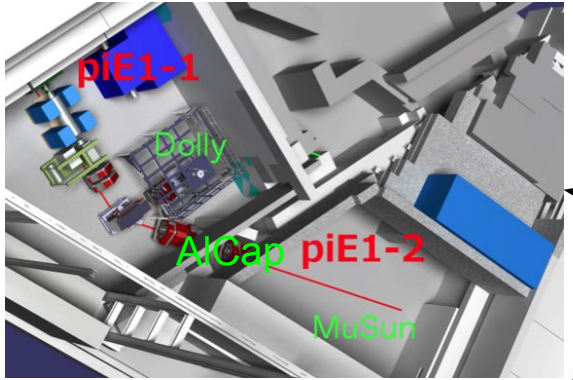
Campaigns

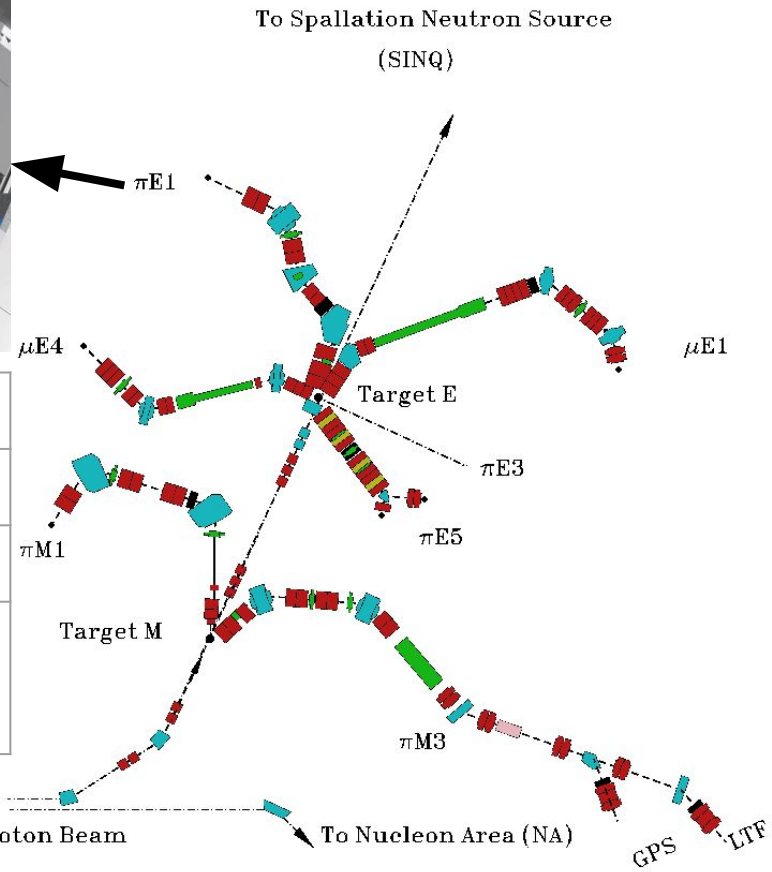
Campaign	R13	R15a	R15b
Dates	Nov 28-Dec 23 2013	Jun 8-21 2015	Nov 5-22 2015
Work Packages	WP 1, 2, 3	WP 2, 3 (Neutral particles)	WP 1 (Charged particles)
Beamline	πE1	πE5	πE1
Targets	Al, Ti, Si (Passive)	Al, Ti, H2O, Pb, Steel	Al, Ti, Si

Paul Scherrer Institut (PSI)

- Highest current, highest power proton accelerator (2.2mA, 590MeV cyclotron)
- Most intense muon beam
- Number of DC muon beamlines to choose from to balance rate and momentum bite

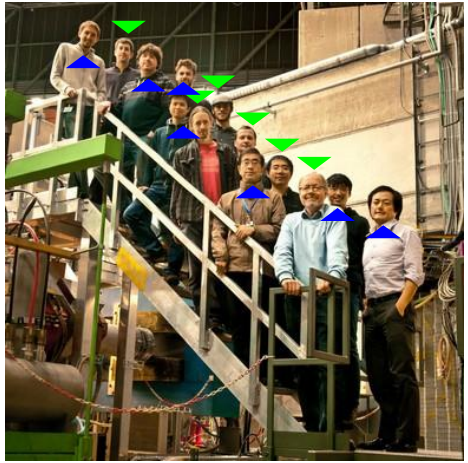
Beamlines at PSI





Beamline	πE1	πE5
Campaign	R13, R15b	R15a
Ω (msr)	13	150
Momentum Resolution (FWHM)	0.26%	2%

(Some) Collaborators

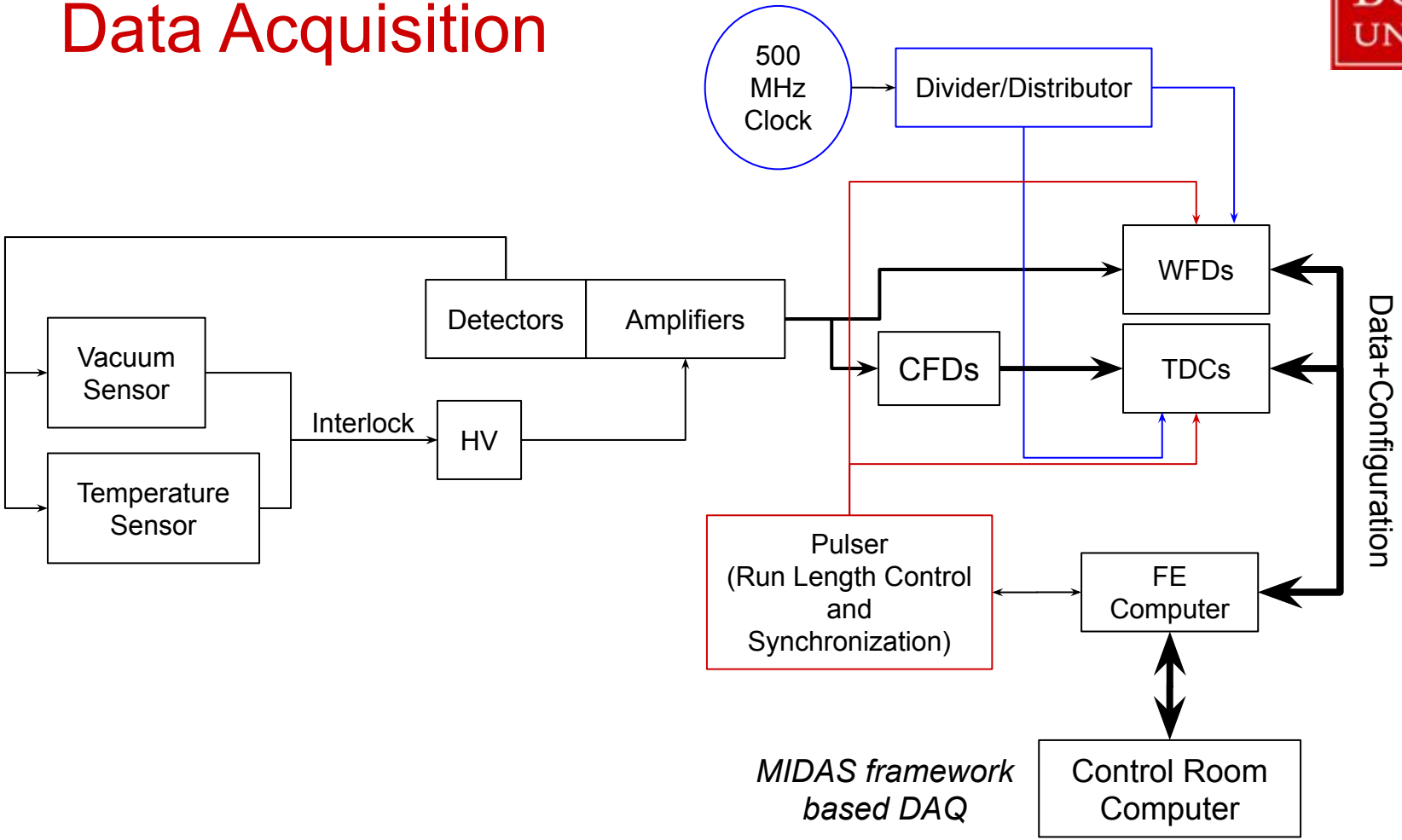


Experiments

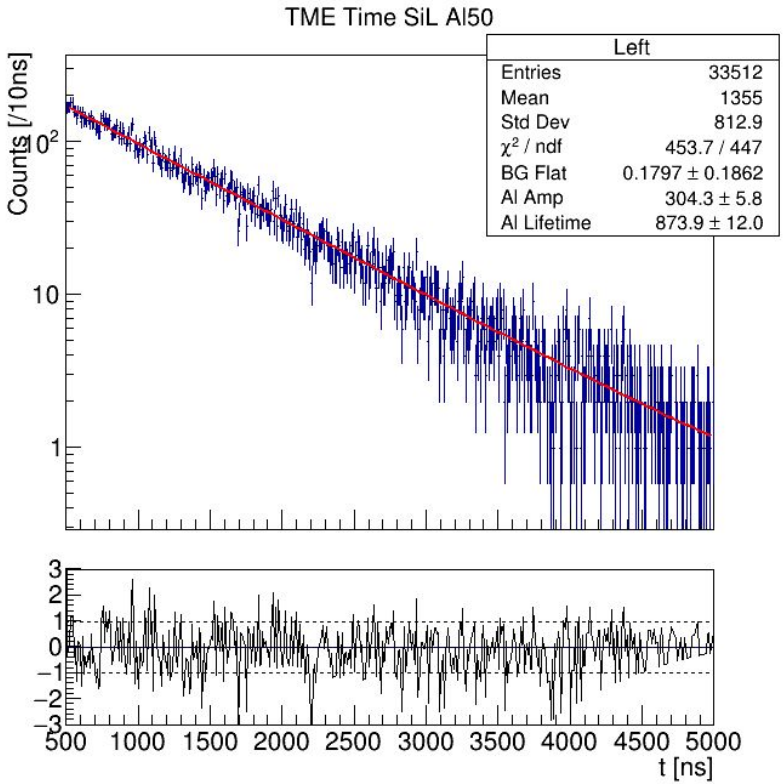
Mu2e

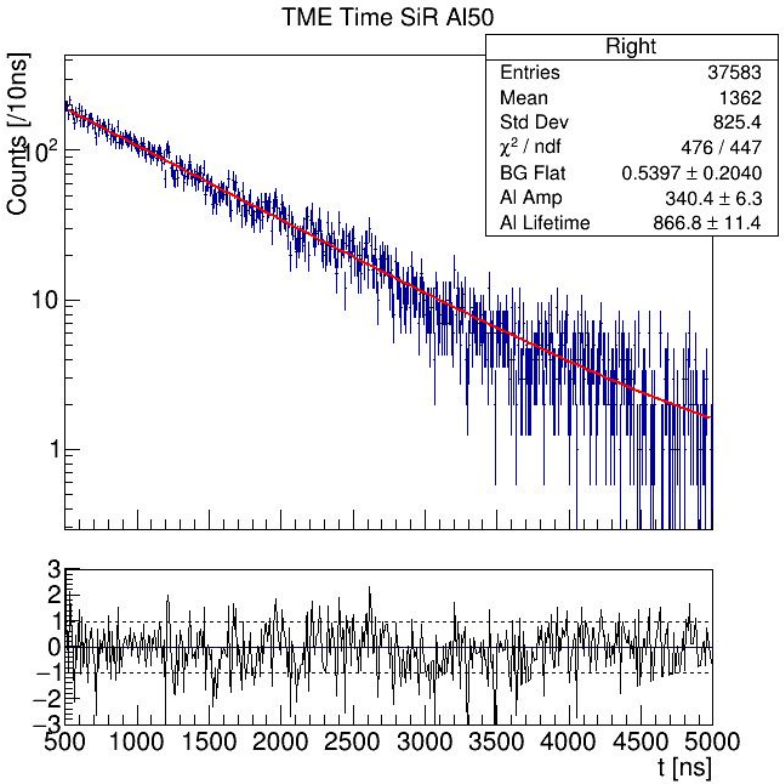
COMET

Data Acquisition

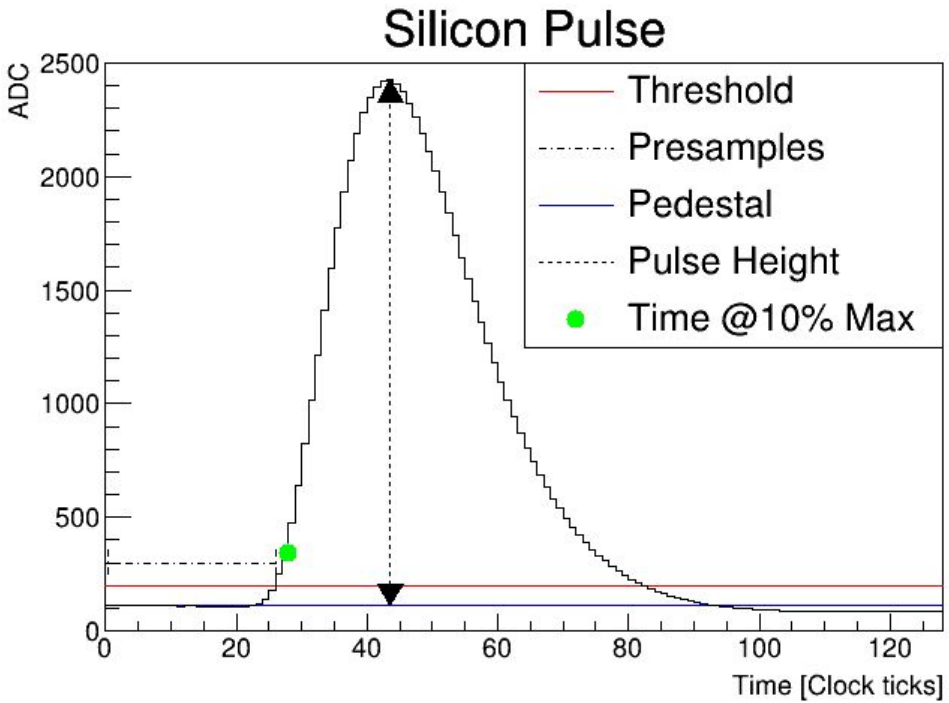


Sanity Check: Lifetime = 864ns



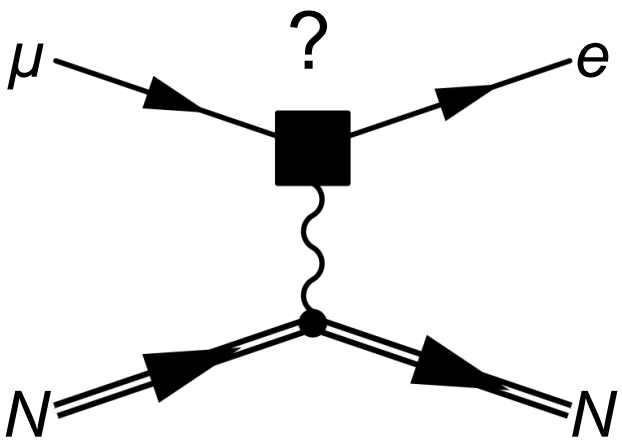


Hit Time and Energy



1. Pulse passes preset threshold, triggering data taking in that channel (each channel is self-triggered)
2. Number of presamples before trigger used to calculate pedestal, preset number of samples taken
3. Maximum height from pedestal taken as energy
4. Interpolated clock tick where pulse hits 10% of maximum taken as time

Charged Lepton Flavor Violation: $\mu \to e$



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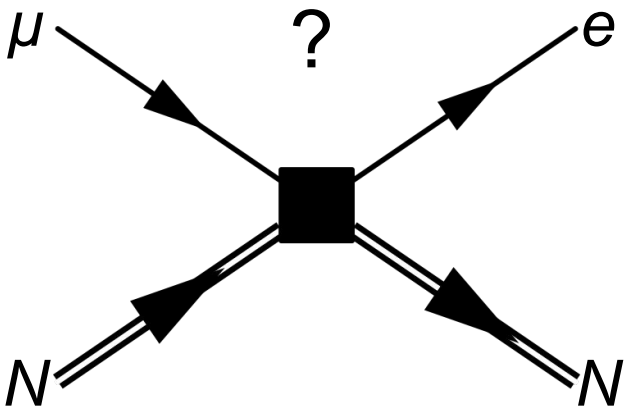

$$R_{\mu e}^{\mathrm{Au}} = \frac{\Gamma_{\mathrm{conv}}(\mu\mathrm{Au} \to e\mathrm{Au})}{\Gamma_{\mathrm{capt}}(\mu\mathrm{Au})} < 7 \times 10^{-13}$$

W. H. Bertl *et al.* (SINDRUM II), Eur. Phys. J. **C47**, 337 (2006)