Latest Updates from the AlCap Experiment

Andrew Edmonds
on behalf of the AlCap collaboration

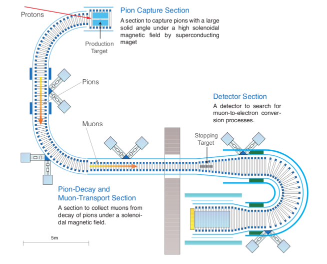
CIPANP2018, 1st June 2018

Lawrence Berkeley National Laboratory

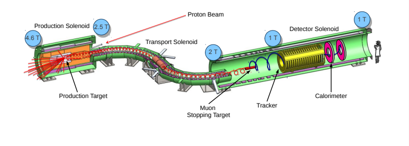
Muon-to-Electron Conversion Searches

The next generation of muon-to-electron conversion experiments will search for the $\mu \to e$ **conversion process**, with a **single event sensitivity** of $\sim 10^{-17}$.

$$R_{\mu \to e} = \frac{\mu^- + N(Z,A) \to e^- + N(Z,A)}{\mu^- + N(Z,A) \to \nu_e + N(Z-1,A)},$$



COMET @ J-PARC



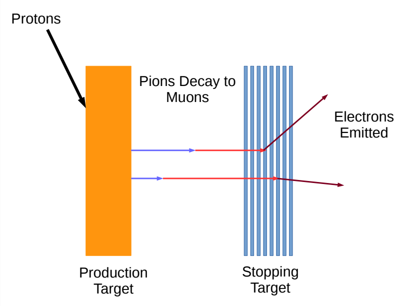
Mu2e @ FNAL

Experimental Method: Stop $O(10^{10})$ muons per second in Al

Muon-to-Electron Conversion Searches

The next generation of muon-to-electron conversion experiments will search for the $\mu \to e$ **conversion process**, with a **single event sensitivity** of $\sim 10^{-17}$.

$$R_{\mu\to e} = \frac{\mu^- + N(Z,A) \to e^- + N(Z,A)}{\mu^- + N(Z,A) \to \nu_e + N(Z-1,A)},$$

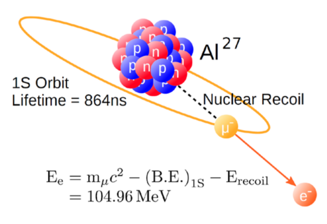


Experimental Method: Stop $O(10^{10})$ muons per second in Al

What happens when a muon is stopped by an atom?

A **muonic atom** is formed:

- the muon instantly falls down to the 1s orbital $\rightarrow$ **X-rays**
- after some time the muon will undergo one of the following processes:
  - $\mu^- \rightarrow e^- \overline{\nu}_e \nu_\mu$ (decay-in-orbit)
  - $\mu^- + N(Z, A) \rightarrow \nu_e + N(Z-1, A)$ (nuclear muon capture) $\rightarrow$ **γ-rays, heavy charged particles, neutrons**



Cartoon of the $\mu - e$ conversion process

Why do we care?

Heavy Charged Particles

- proton with kinetic energy 5 MeV has momentum 100 MeV/c
  - will enter the detectors $\rightarrow$ hit background
  - are highly ionising $\rightarrow$ damage
- need a proton absorber $\rightarrow$ how thin can we make it?

Neutrons

- will leave the experiment and hit the cosmic ray vetos and mimic a cosmic ray $\rightarrow$ additional deadtime

Photons

- can be used to count the number of captured muons

We want to know the rate and spectrum of these emission products!

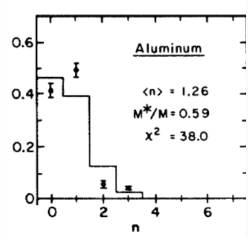
What do we know about the nuclear capture decay products?

Heavy Charged Particles:

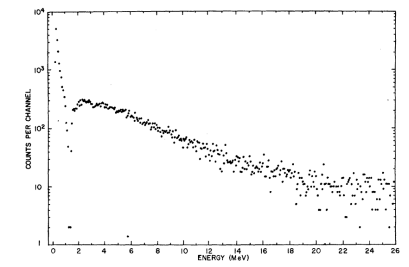
- for Al: only know the high energy region ($>$ 40 MeV)
- for low energy: only known for Si
- composition (p, d, t etc.) not measured

Neutrons:

- rate has been measured



(B. Macdonald et.al. Phys.Rev. 139 (1965) B1253)



(S. E. Sobottka and E. L. Wills Phys.Rev.Lett. 20 (1968) no.12, 596)

Photons:

- X-rays and γ-rays are known
- any background lines? are delayed γ-rays strong enough?

Material	Transition	Intensity [%]	Energy [keV]
Al	$2p-1s$	79.8 ± 0.8	346.828 ± 0.002
	$3p-1s$	7.62 ± 0.15	412.87 ± 0.05
Si	$2p-1s$	80.3 ± 0.8	400.177 ± 0.005
	$3p-1s$	7.40 ± 0.20	476.80 ± 0.05

(D. F. Measday et al. Phys.Rev. C76 (2007) 035504)

AlCap

The AlCap experiment is a joint venture between the Mu2e and COMET collaborations **to measure the rate and spectrum** of **individual charged particles, neutrons and photons** after nuclear muon capture.

Three runs at PSI:

- 2013: charged particles and photons (Al, Si (passive))
- 2015a: neutrons and photons (Al, Ti, Pb, SS, Water and Mylar)
- 2015b: charged particles and photons (Al, Si (active), Ti)

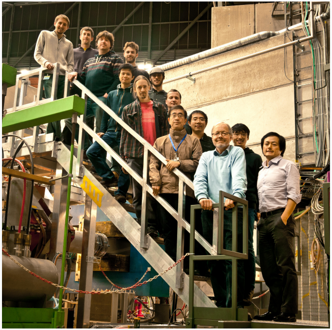
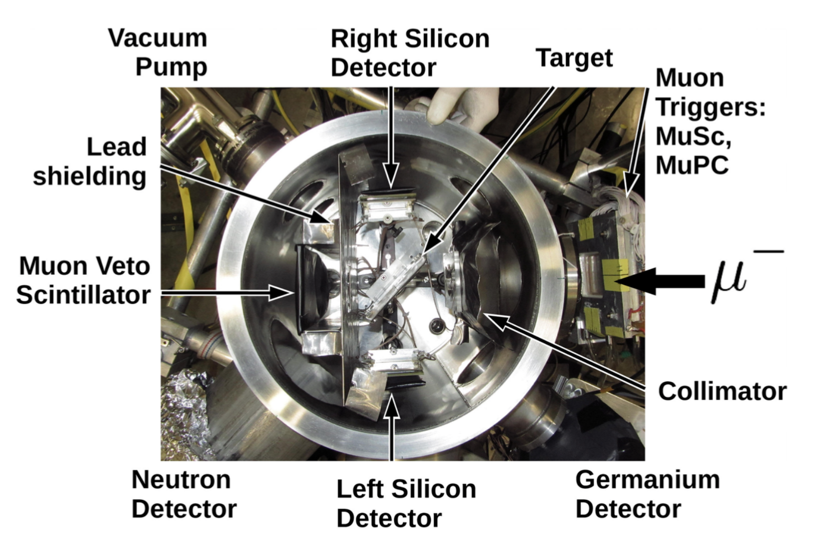


Photo from 2013 Run

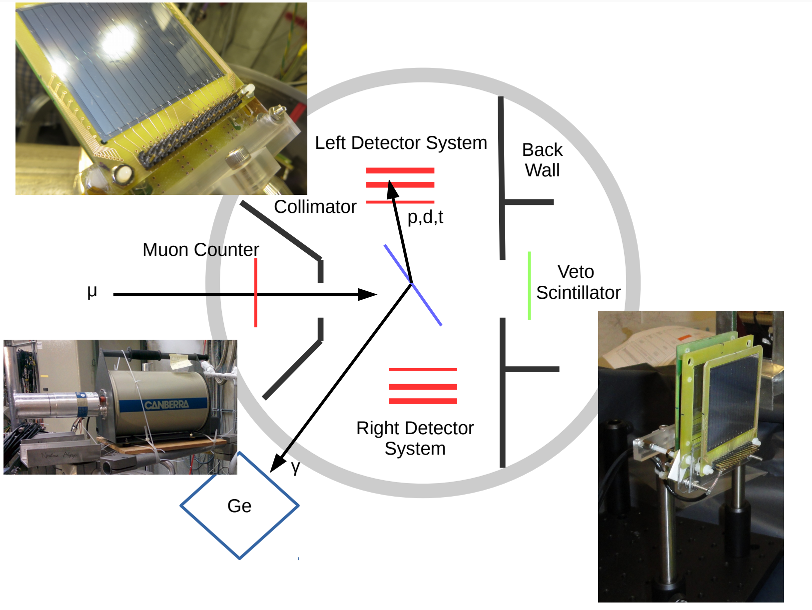
I will focus on the charged particle analysis

Experimental Setup

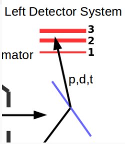


Run 2013 Setup

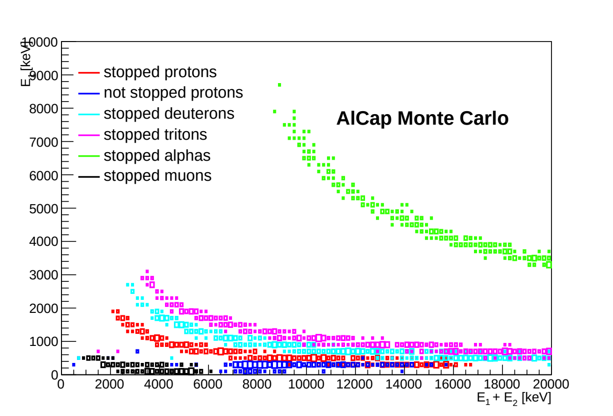
Experimental Setup



Particle ID



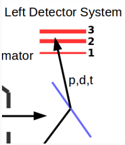
With the layered silicon detectors, we can **identify the different particle types** because dE/dx rises sharply when going to lower energies:

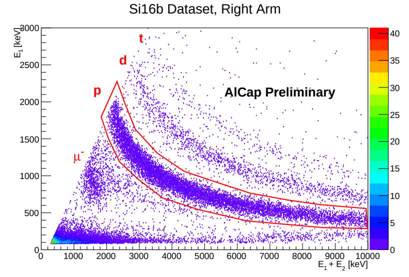


Particle ID

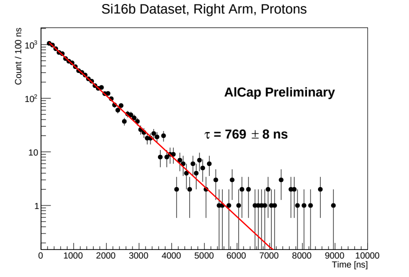
Easy to **extract individual emission products** using simple cuts and check the arrival times are **consistent with the muonic atom lifetime**

- Si: 767 ns





EvdE Plot for Si dataset with cut to select protons

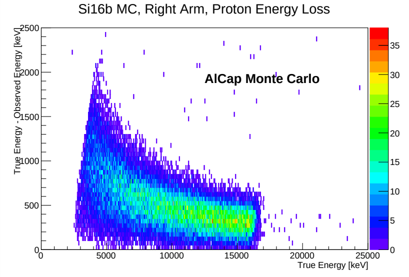


Arrival times for the selected protons

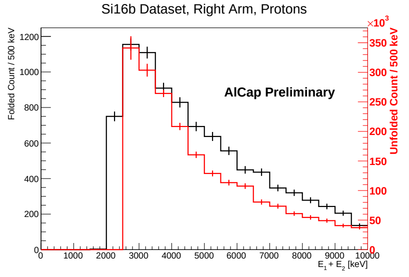
Currently **evaluating efficiency and purity of cuts using MC**.

Unfolding

Once we've extracted the particle band, we need to correct for energy lost in the target $\rightarrow$ **unfolding**.



Energy Loss of Protons in Target

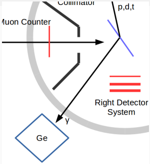


Folded and Unfolded Spectra

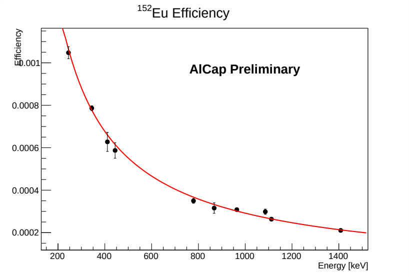
Currently **investigating systematic effects of unfolding** (e.g. assumed stopping depth)

Normalisation

When muon **stops** it emits X-rays as it transitions between atomic energy levels. Specifically we look for the $2p - 1s$ **transition**.

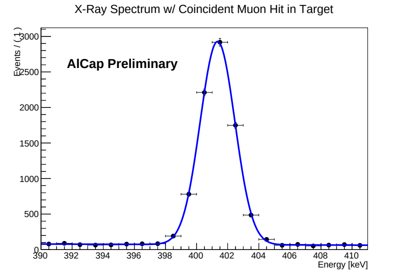


^{152}Eu Source



$\varepsilon(400 \text{ keV}) = (6.67 \pm 0.07) \times 10^{-4}$

Active Target



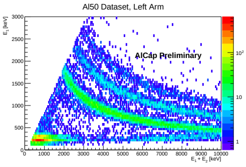
$\varepsilon(400 \text{ keV}) = (5.88 \pm 0.09) \times 10^{-4}$

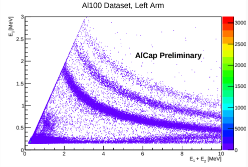
Currently **resolving this** $\sim 10\%$ **discrepancy**

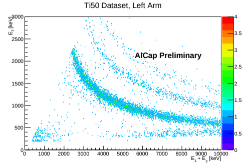
Other Datasets

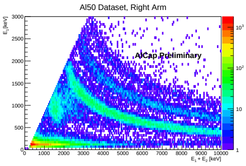
Analysis of other datasets going well:

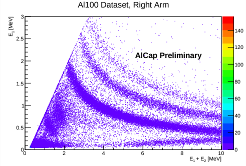
Al 50 μm	Al 100 μm	Ti 50 μm

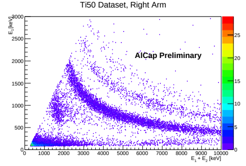












Conclusion

AlCap was formed to determine the **rate and spectrum of charged particles, neutrons and photons after nuclear muon capture** for the next generation of muon-electron conversion experiments

Expect to finish the charged particle analyses in the next few months

- band extraction efficiency and purity
- unfolding systematics
- resolve normalisation discrepancy (or live with it)

Thanks for listening!

COMET

COMET

Mu2e

Mu2e

大阪大学
OSAKA UNIVERSITY

BERKELEY LAB

BROOKHAVEN
NATIONAL LABORATORY

Imperial College
London

UCL

W

Institute of High Energy Physics
Chinese Academy of Sciences

Fermilab

Argonne
NATIONAL LABORATORY

INFN

BOSTON
UNIVERSITY

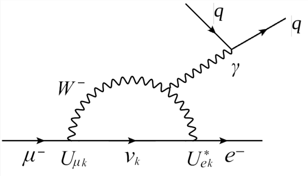
And thanks to our respective funding agencies for their support!

Backup slides

Charged Lepton Flavour Violation

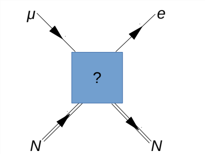
SM Prediction

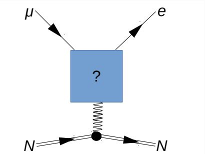
$R_{\mu \to e} \propto (\frac{\Delta m_\nu^2}{M_W^2})^2 < 10^{-52}$



BSM Predictions

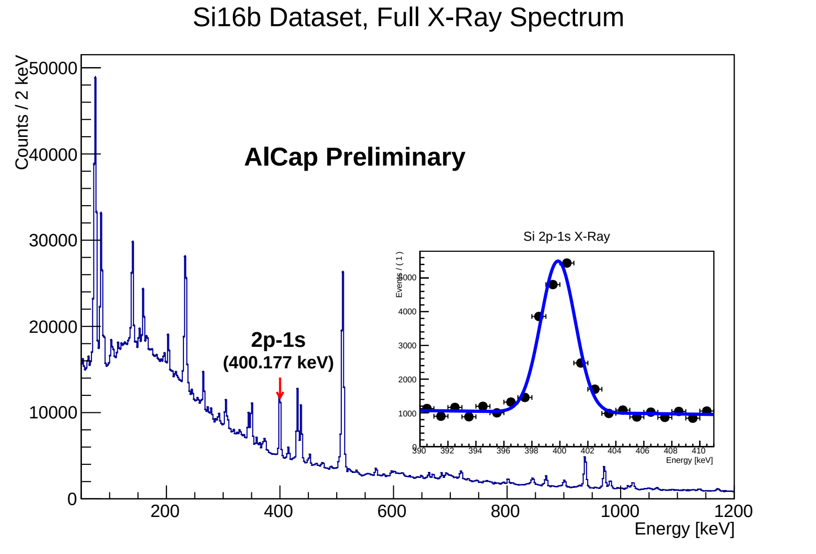
$R_{\mu \to e} \sim 10^{-17} - 10^{-15}$





Current 90% UL: $B(\mu N \to eN \text{ on Au}) < 7 \times 10^{-13}$ (SINDRUM II)

Full X-Ray Spectrum



Response Matrix