Status of the AlCap Experiment

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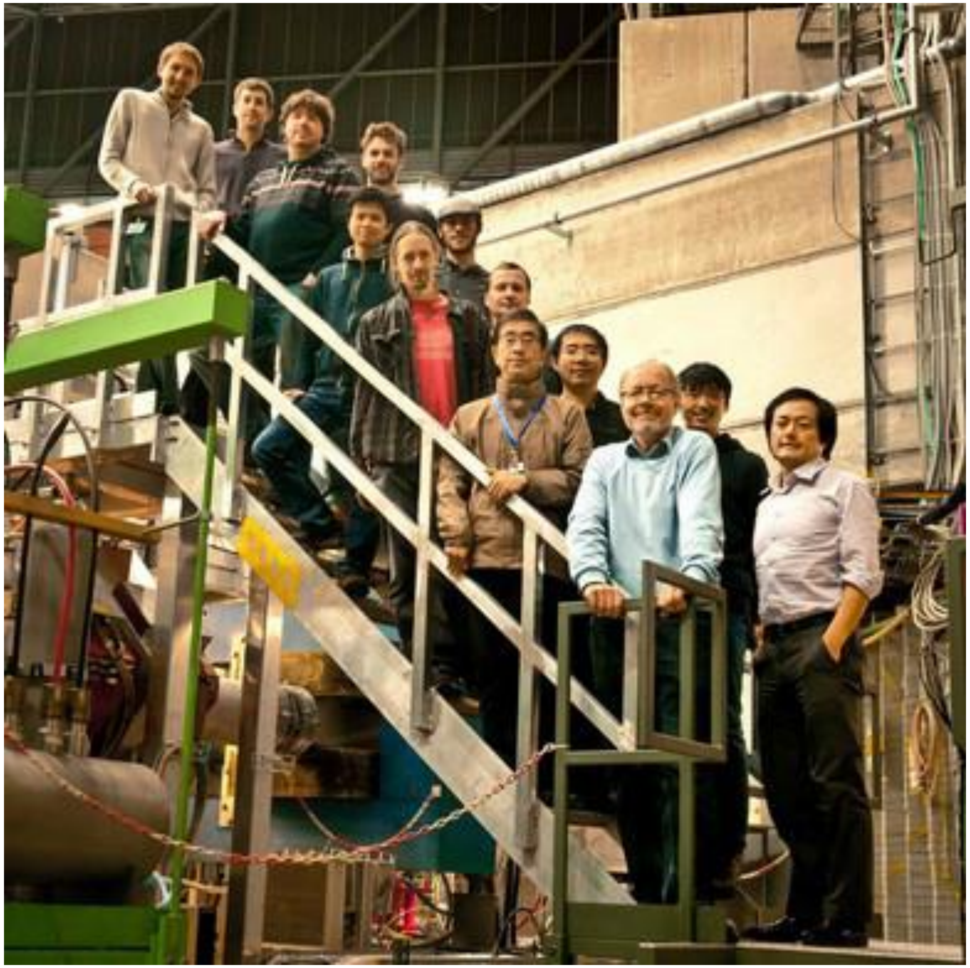
Outline

1. **Who** is AlCap?
2. **Why** do AlCap?
3. **What** is AlCap?
4. **Where** is AlCap?
5. **How** does AlCap work?
6. **What next** for AlCap?

The AlCap Collaboration



from COMET
Osaka University,
IHEP China,
Imperial College London,
University College London,

from Mu2e
Argonne NL,
Boston University,
Brookhaven NL,
University of Houston,
University of Washington,

The AlCap Collaboration

from COMET

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IHEP China,

Imperial College London,

University College London,

from Mu2e

Argonne NL,

Boston University,

Brookhaven NL,

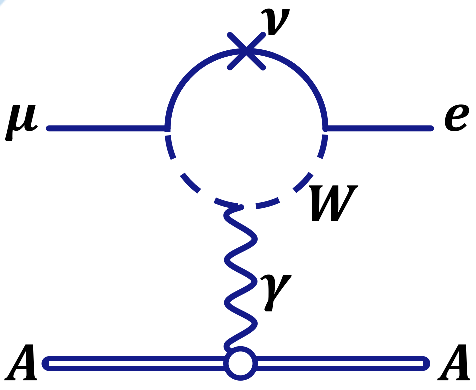
University of Houston,

University of Washington,

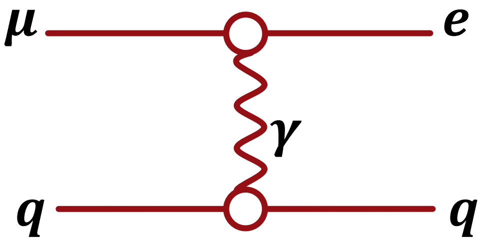
μ to e conversion

In the **SM** $\mu A \rightarrow eA$ is heavily supressed because of the mass disparity between the W and neutrino.

In **new physics** scenarios this does not usually apply, and other diagrams typically give CLFV much higher than the SM.

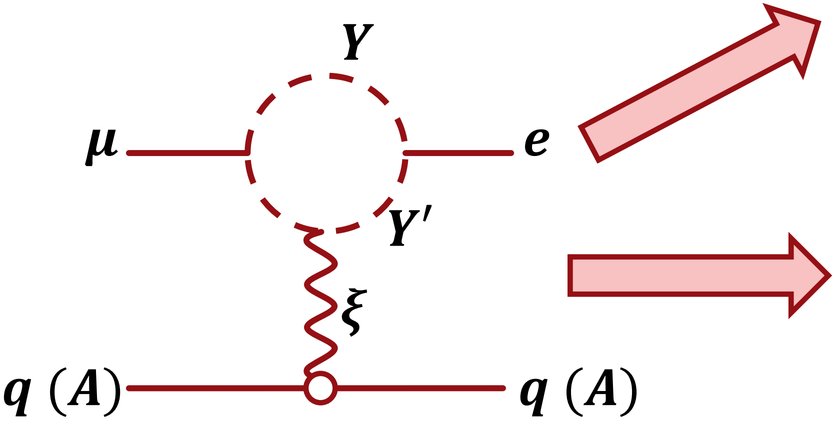


SM $\mu - e$ conversion

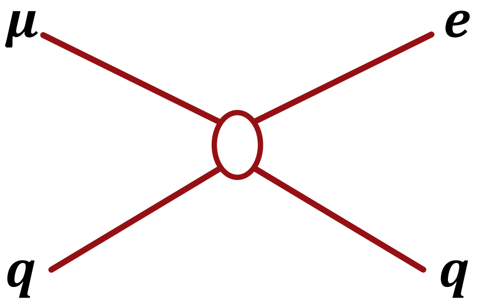


Dipole coupling

$$\mathcal{L}_{\mathrm{d}} \sim \frac{m_\mu}{\Lambda^2}\, \bar{\mu}\sigma_{\mu\nu}e \cdot F^{\mu\nu}$$



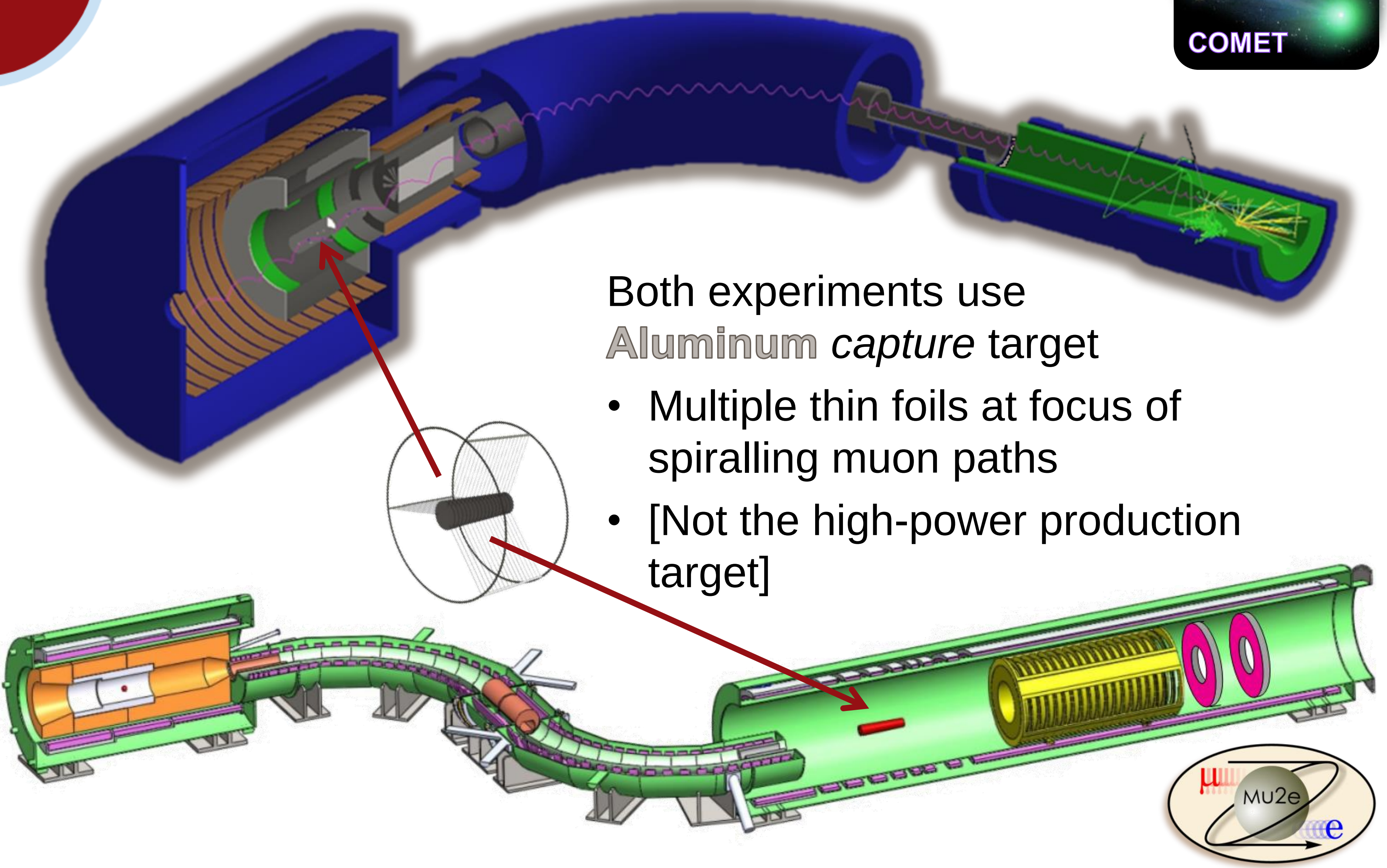
NP $\mu - e$ conversion



Four-fermion coupling

$$\mathcal{L}_4 \sim \frac{1}{\Lambda^2}\, \bar{\mu}\gamma_\mu e \cdot \bar{q}\gamma_\mu q$$

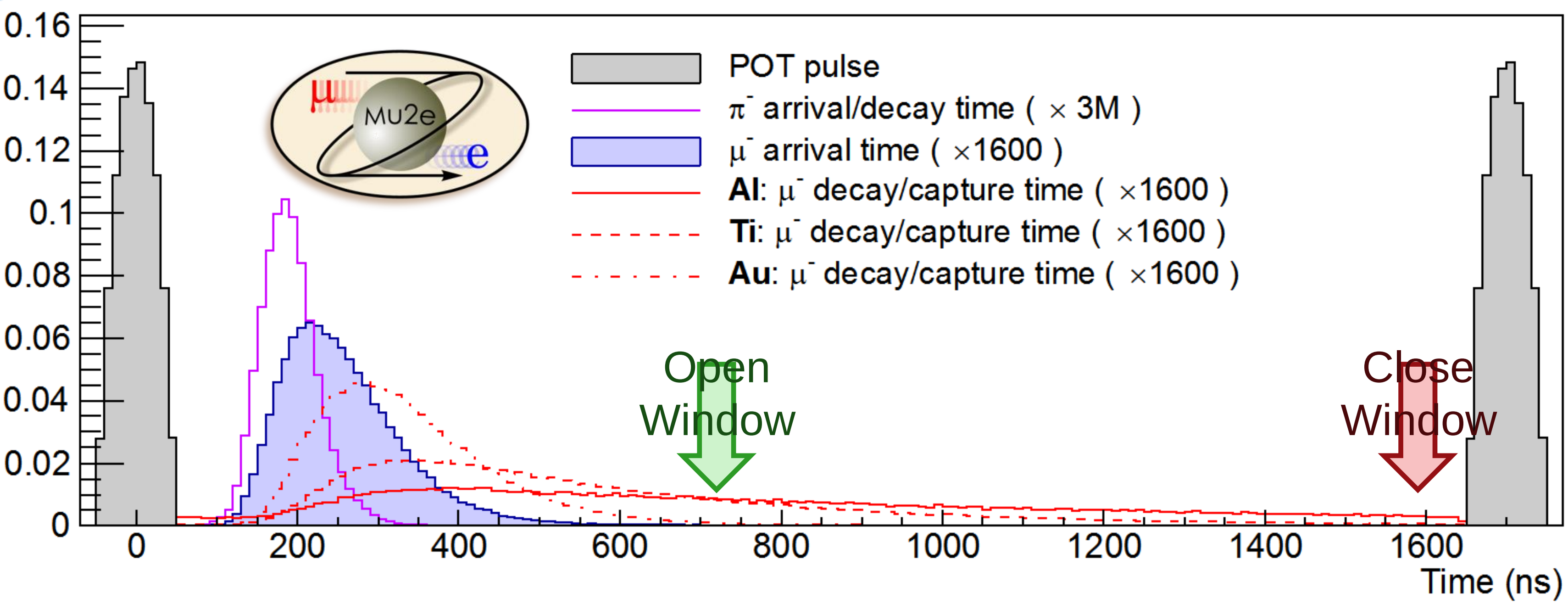
COMET Phase-I and Mu2e



Both experiments use
Aluminum *capture* target

- Multiple thin foils at focus of spiralling muon paths
- [Not the high-power production target]

Why aluminium?



High *Z* materials are good, as it increases capture cross section

- Previous experiment (SINDRUM-II) used gold.

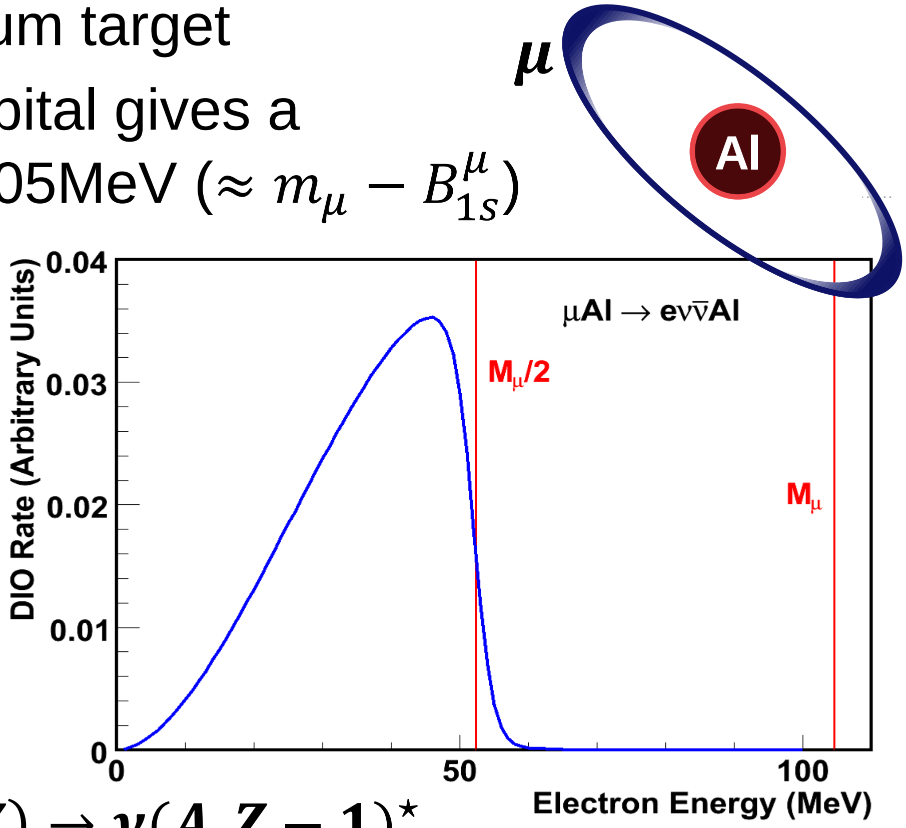
But for prompt BG rejection the new experiments will use pulsed beam and a late ($\gtrsim 700\mathrm{ns}$) window.

Therefore need a lighter (i.e. low Z) target material for longer muon lifetimes. → aluminium

Muon capture on Aluminium

Muons allowed stop in the Aluminium target

- $\mu A \rightarrow eA$ conversion from 1s orbital gives a ***mono-energetic electron*** at 105MeV ($\approx m_\mu - B^\mu_{1s}$)



'Normal' decays are backgrounds:

- Decay in Orbit [DIO]: $\mu \rightarrow e\nu\bar{\nu}$
  For a free muon, cuts off at $\frac{1}{2}m_\mu$, but bound state has a small tail up to m_μ

- **Nuclear muon capture: $\boldsymbol{\mu(A,Z) \rightarrow \nu(A,Z-1)^\star}$**
  - The resulting nucleus is in an excited state.
  - **De-excitation can emit $\boldsymbol{\gamma, p, n}$, …** (i.e. pretty much anything)
  - Uh-oh…

AlCap goals

Charged particle emission after muon capture.

- Protons are a major component of the single-hit rates in the tracking chambers for both Mu2e and COMET Phase-I.
- Measure both the total rate and the energy spectrum

Gamma and X-ray emission after muon capture.

- Measure X-rays from the muonic atomic cascade, in order to provide the muon-capture normalization.
  - Normalise the charged particle rate measurement
  - Verify method for Mu2e and COMET experiments.

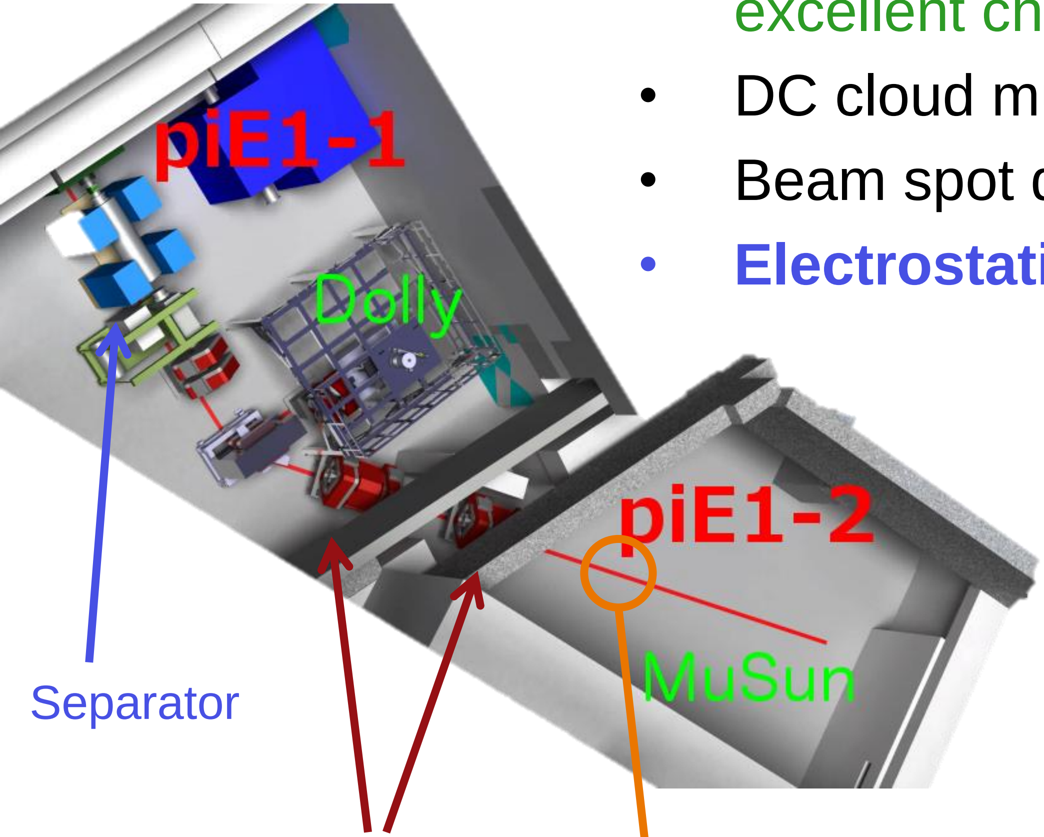
Neutron emission after muon capture.

- Important for determining backgrounds in the Mu2e/COMET detectors and evaluating the radiation damage to electronic components. Also may affect layout of CR veto counters.

AlCap experiment at PSI

The 2013 run used the **πE1** beamline at PSI:

- New beamline, developed by MuSun, with excellent characteristics at low energy.
- DC cloud muon beam
- Beam spot diameter **< 2cm**
- **Electrostatic separator** reduces e^- contamination **< 10%**



Separator

Spot focus Quads

Alcap location

AlCap configuration:

- Momentum ~ **28MeV/c**
- Momentum bite ~ **1%**
- Mainly in **–ive** polarity. (μ *capture* expt!)

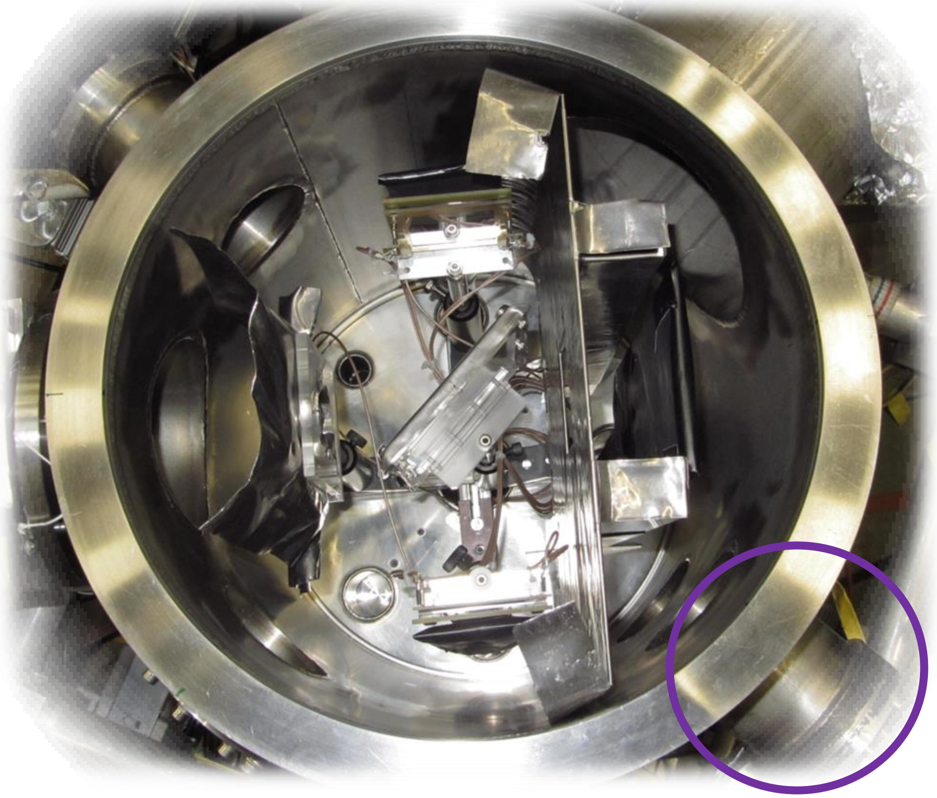
AlCap muon beam

Most of the experiment is housed in a (~ 30cm diameter) vacuum chamber.

- Pump attached to **side port** to reduce pressure to below 10^{-4} mbar to prevent sparking and reduce energy loss in flight.

The **beam** momentum is tuned near 28 MeV/c so that muons stop in the target placed at the centre of the chamber.

μ beam



Mylar beam window is of standard PSI design

AlCap muon beam

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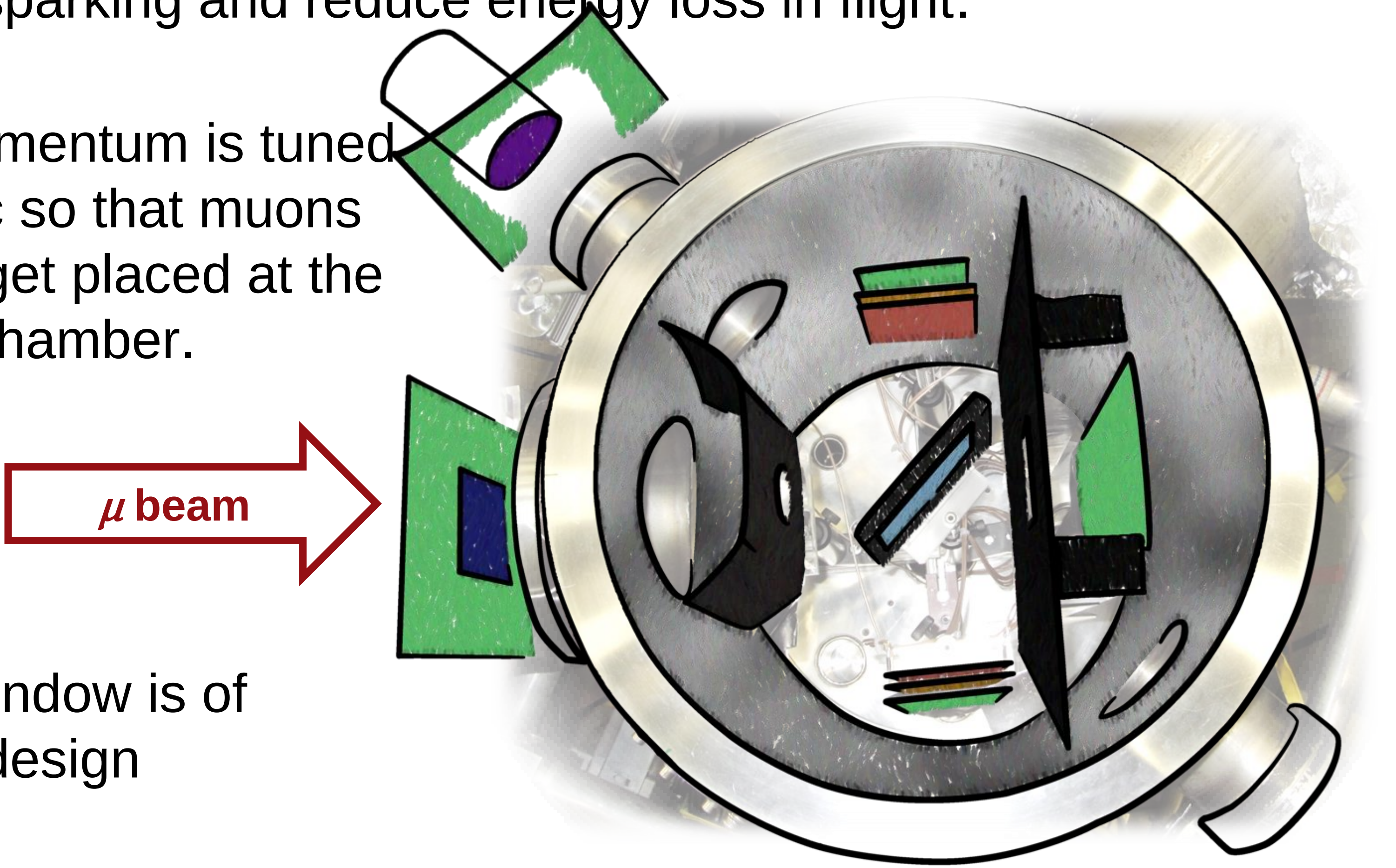
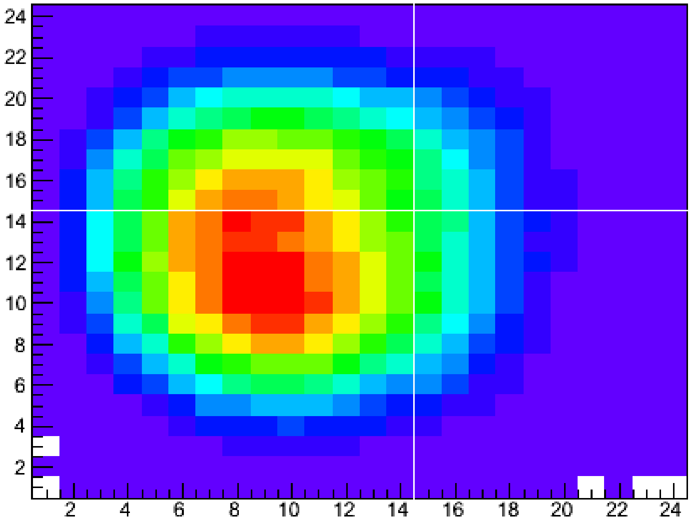
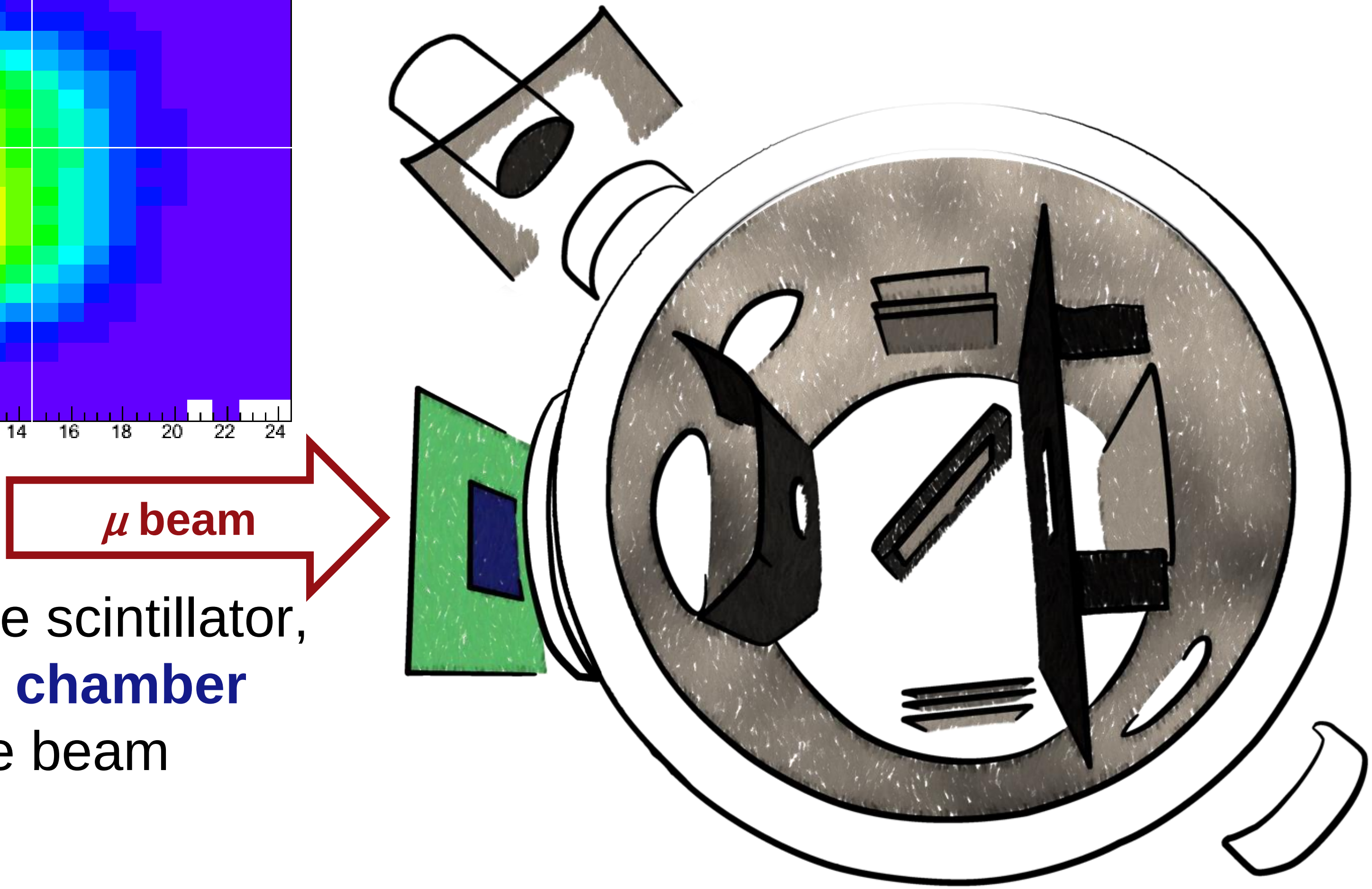


Mylar beam window is of standard PSI design

Beam monitoring

Upstream of the beam window, a **scintillator** paddle is used to tag charged particles in the beam. This is also used in the offline analysis.





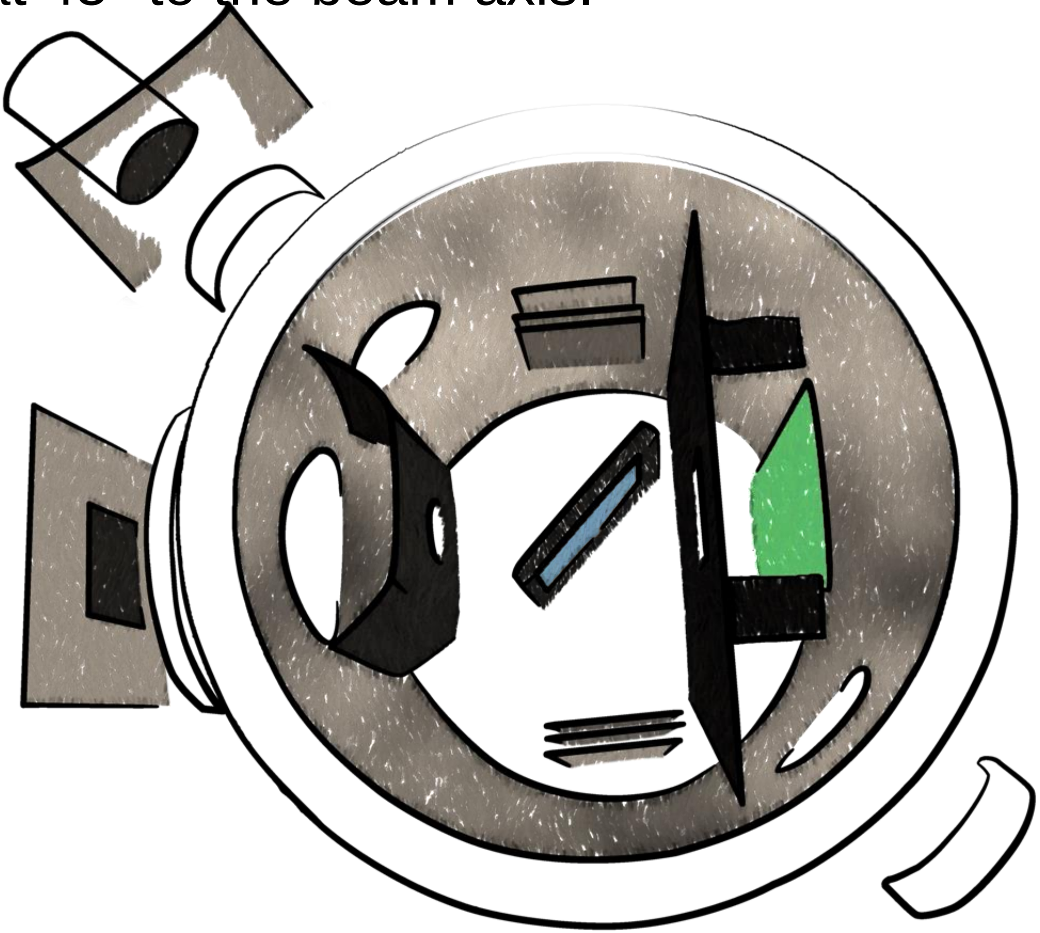
▲ Just after the scintillator, there is a **wire chamber** to measure the beam profile in x & y

Target and veto

Behind the target is a veto scintillator for **electrons**, which are more penetrating at this energy.

The target sits at the centre, at 45° to the beam axis.
Several targets were used:

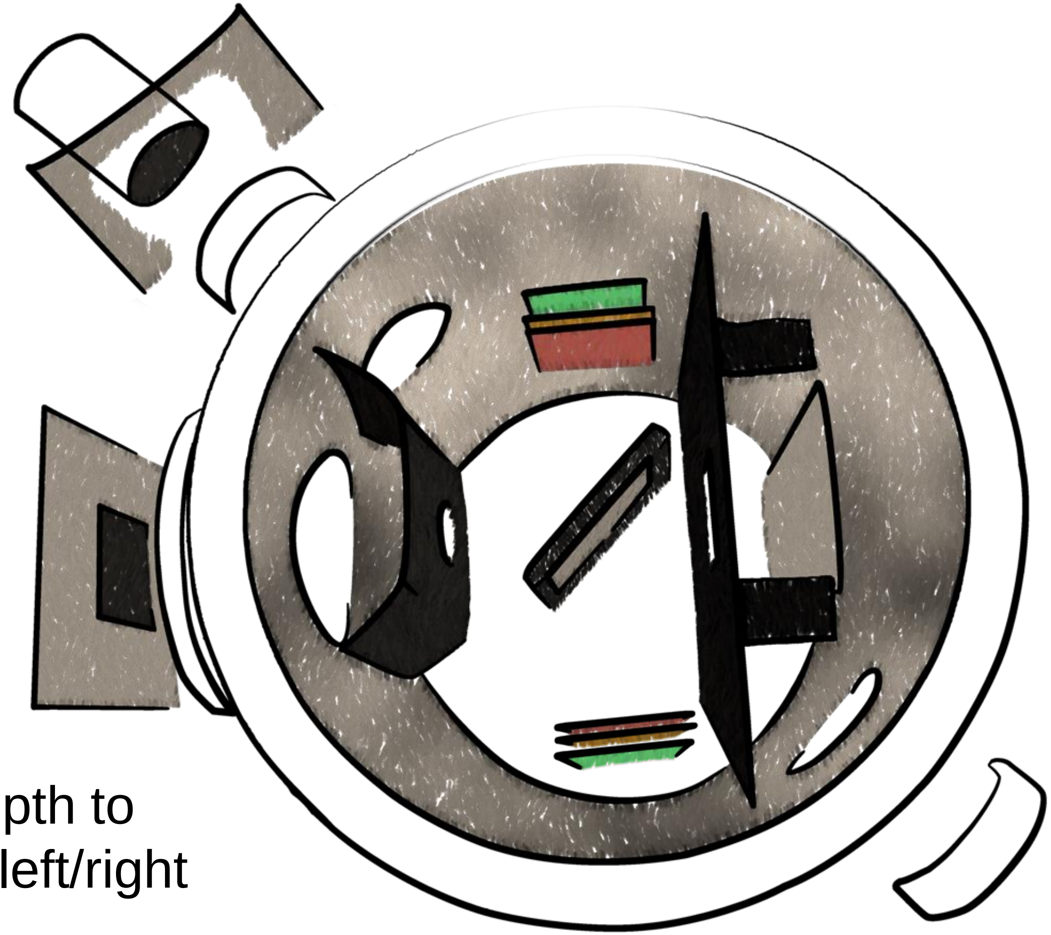
Material	Thickness	Notes
Si	1500µm	‘Right arm’
Si	65µm	Mostly passive (*)
Al	100µm	
Al	50µm	



Detector arms

At ±90° to the beam axis are two detector arms, consisting of:

- **Thin ‘transmission’ silicon**, 65μm, with 2×2 segmentation to measure δE of emitted particles
- **Thick silicon** 1.5mm, to measure overall energy
- **Scintillator** paddles to tag escaping particles



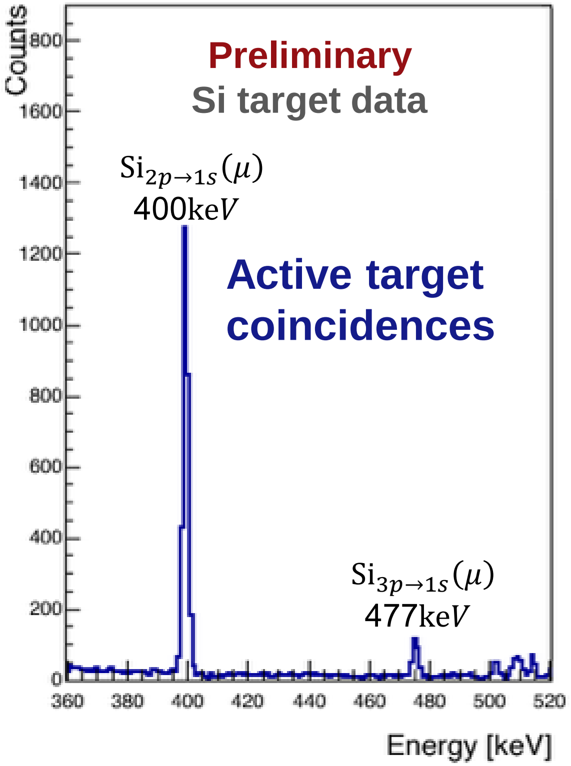
The arms are:

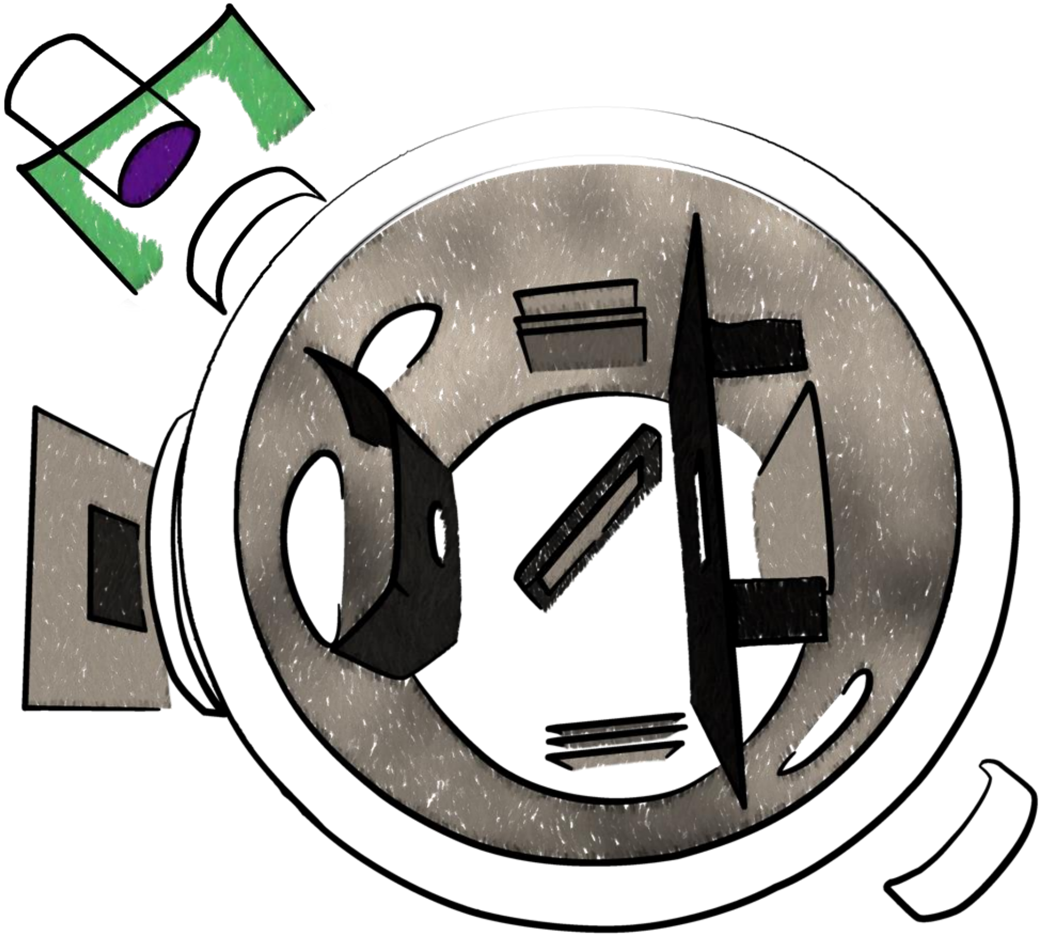
- Symmetric to the beam
  - Equalises BG
- At 45° to opposite faces of target
  - Allows beam penetration depth to be estimated by comparing left/right

Germanium detector

At one port is a **HP-Ge detector**, and associated **scintillator** paddle

- Used to measure the capture rate by looking for the muonic 2p→1s at 347keV (Al) or 400keV (Si)

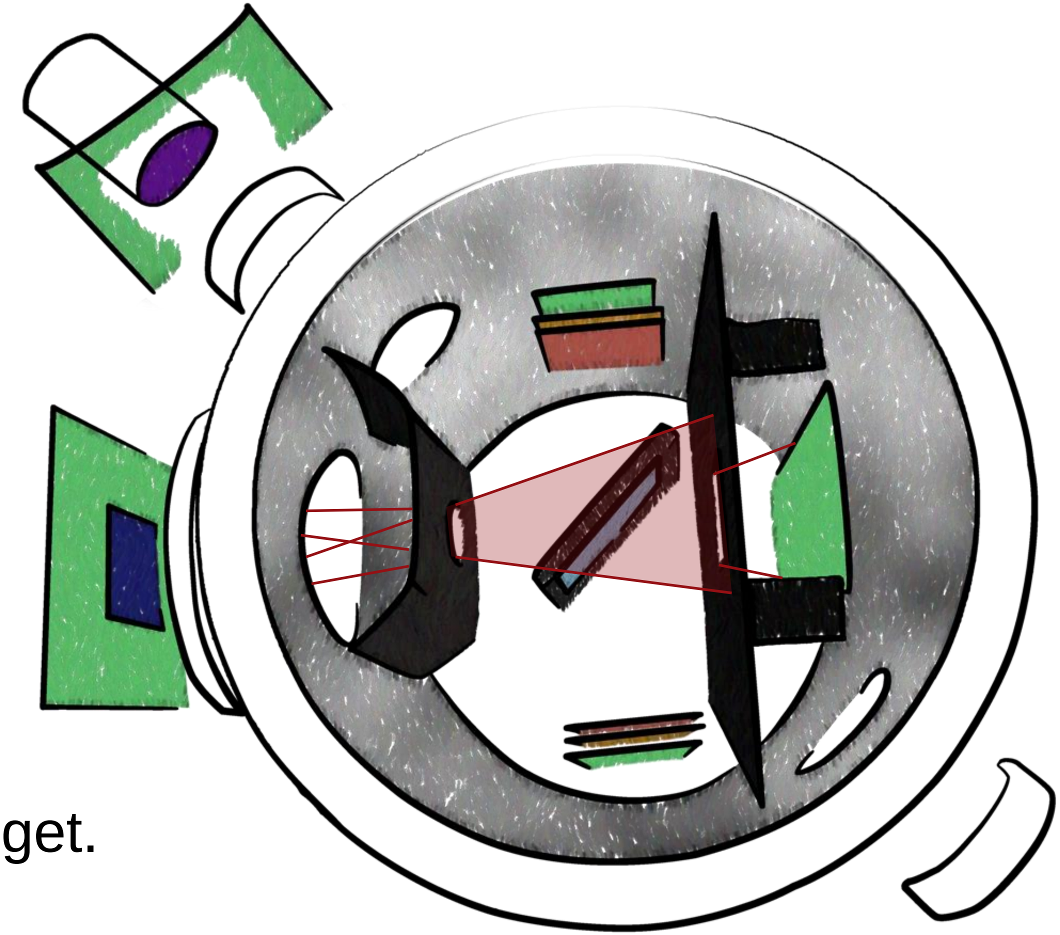




Shielding

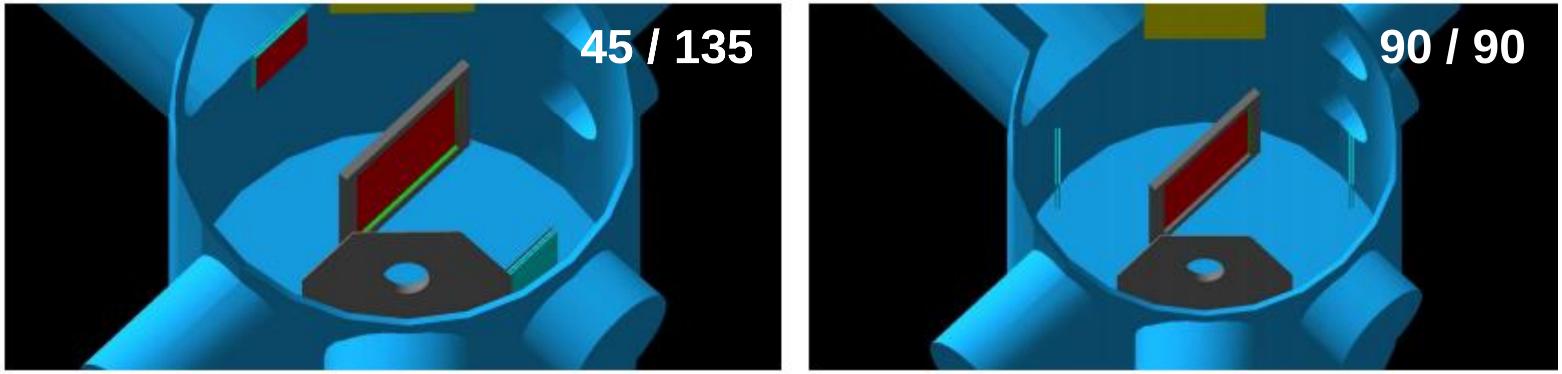
Shielding and geometry received careful consideration, based on experience from 2009 run:

- We added lead ($\tau \sim 82\text{ns}$) shielding **upstream** and **downstream** of the target, and on the **target mount** ▶



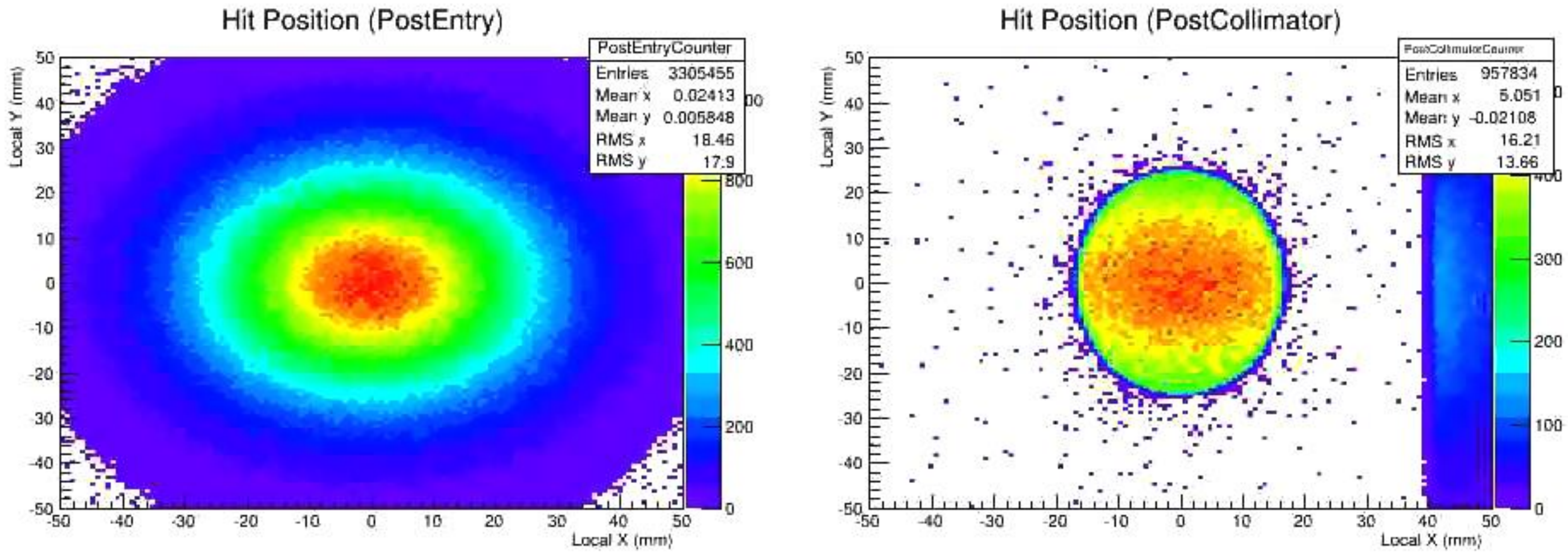
- Goal is that the only beam-irradiated areas visible to detectors are made of lead, or are the target.

GEANT4 Simulation

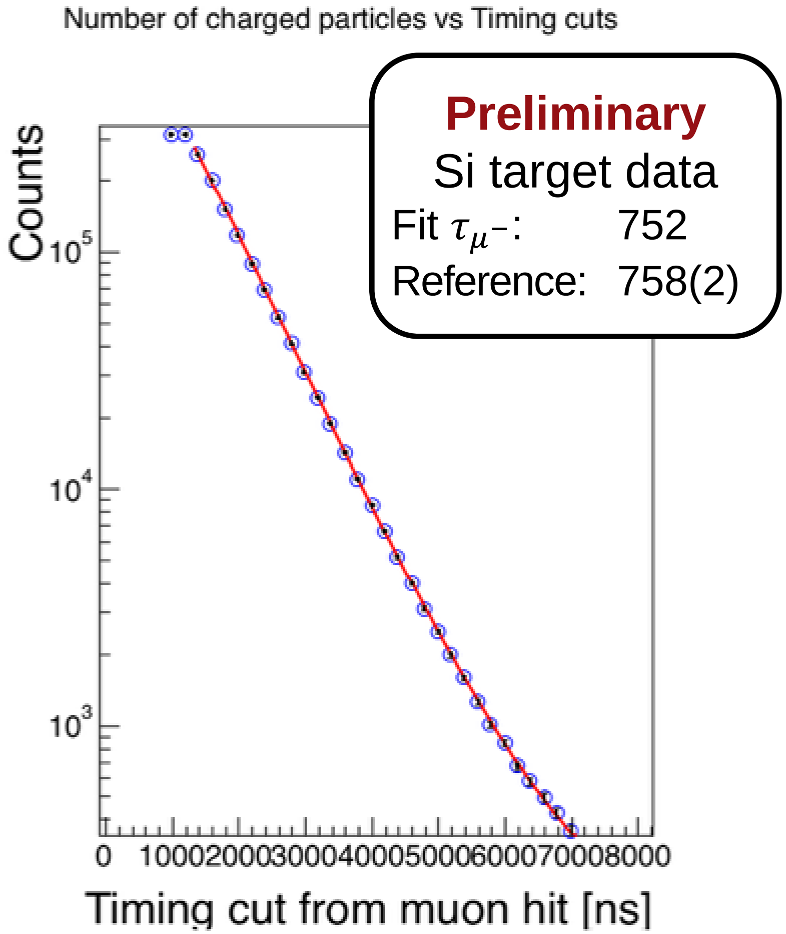


▲ Comparison of detector orientations

Simulation of upstream shield/collimator ▼



Initial analysis



Preliminary

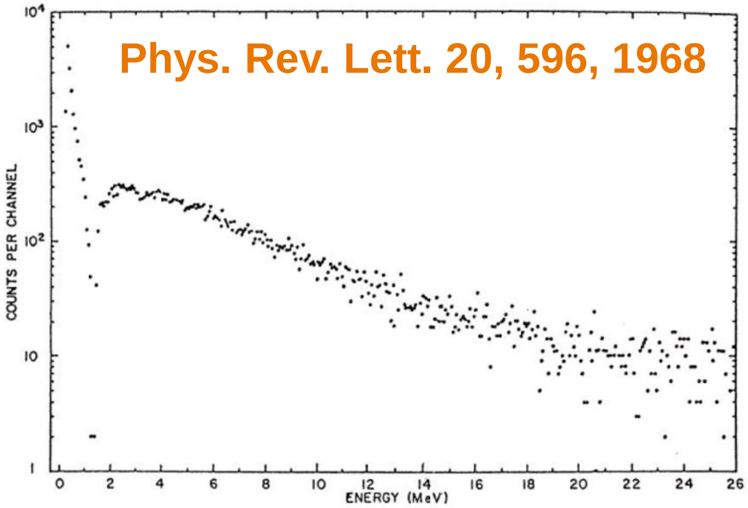
Si target data

Fit τ_{μ^-}: 752

Reference: 758(2)

Analysis is currently focussing on data taken with the active targets.

- Goal is to reproduce known spectra then use what we learn from these to ‘bootstrap’ analyses of the passive targets.



Phys. Rev. Lett. 20, 596, 1968

- More active Si data with thin target would have been preferable… Using thick Si where possible

Initial Analysis II

Silicon packages measure the particle energy twice.

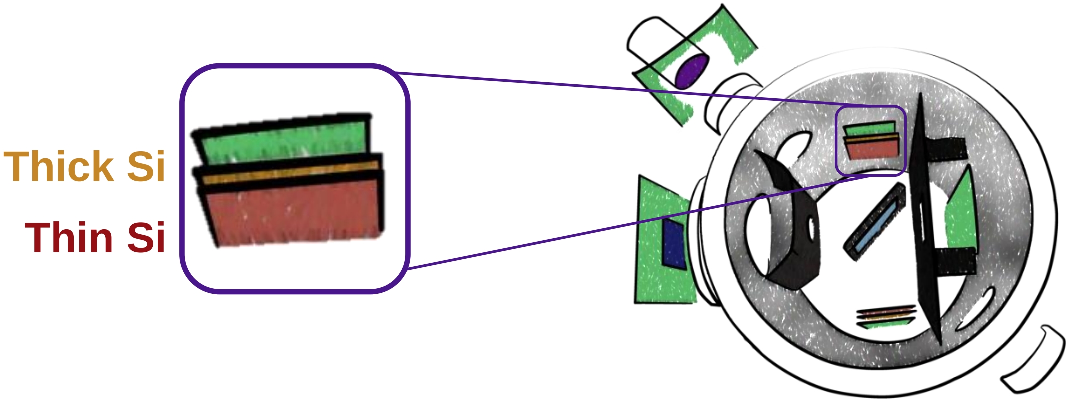
Since first Si is thin, energy deposit is:

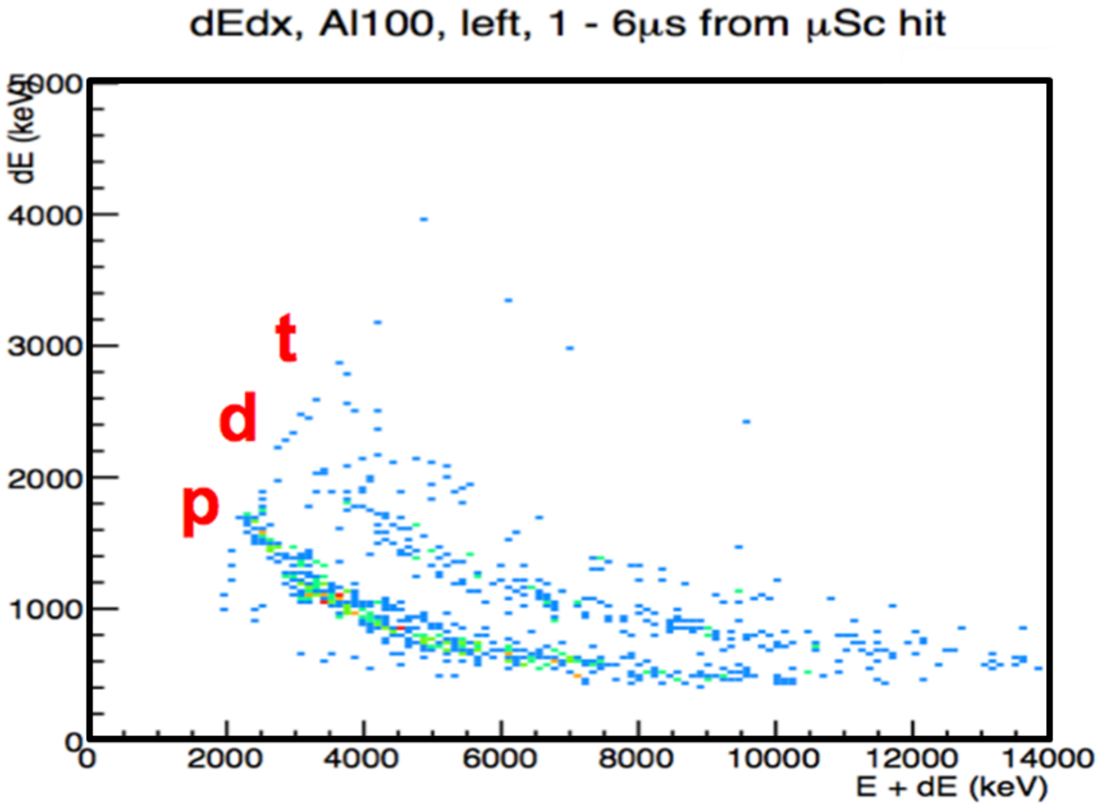
$$\delta E \simeq \frac{dE}{dx} x_{\text{thin}}$$

And since second Si is thick (and no scintillator veto) it measures the remaining energy E. So:

$$\delta E(E + \delta E) \propto \frac{dE}{dx}(E + \delta E)$$

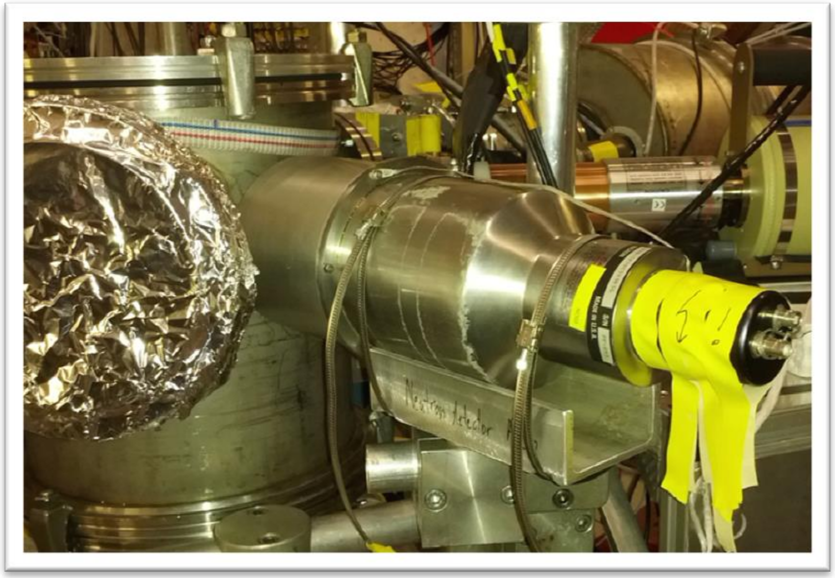
which can be used for charged-particle PID ▶




dEdx, Al100, left, 1 - 6μs from μSc hit

Neutrons

Some preliminary work testing and running with neutron detectors was completed



‘Proof of principle’ analysis is being done on limited data…

…but full data and analysis will come from a later run

Another run?

Run seems to have been successful, and analysis is progressing:

- Problems mostly limited to electronics noise
- Most of the 'Golden' data sets have passed low level quality checks

Should be able to meet goals of **gamma ray normalisation**, and some **charged particle rates/spectra**. But…

- More active Si data would make it possible to do **detailed cross checks**.
- Would like to take more data for serious **neutron studies**.
- Would also like to obtain data with **titanium target** for possible use later in Mu2e and COMET programs

Currently considering making a request for PSI beam in 2015

- It is desirable to take another run before too many students & postdocs move on.

End