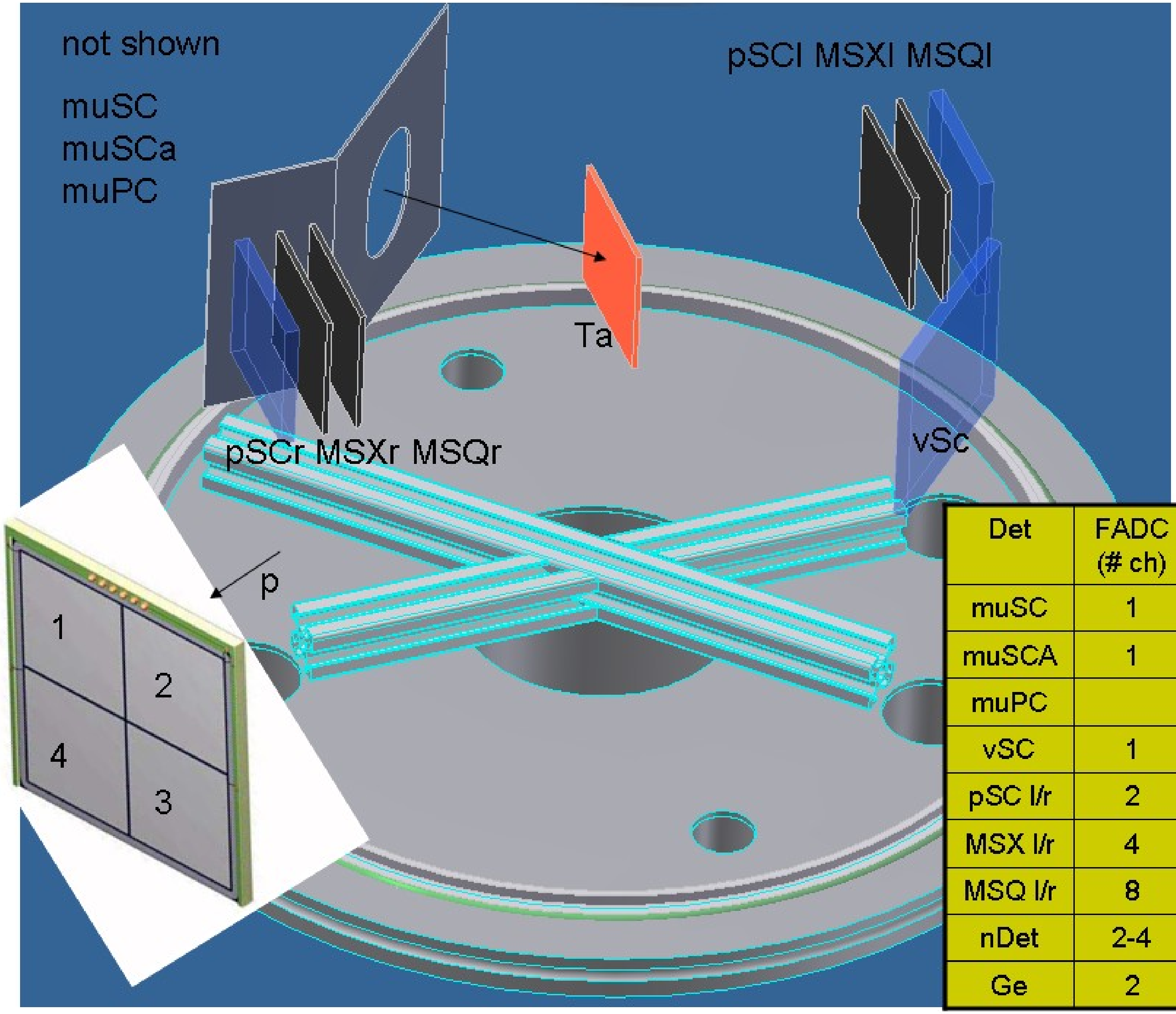
Analysis of 2009 Data

Michael Murray

- **Experiment at PSI** **(July-8 to Aug-3)**
- **Analysis of data jointly performed by Vadim and me**

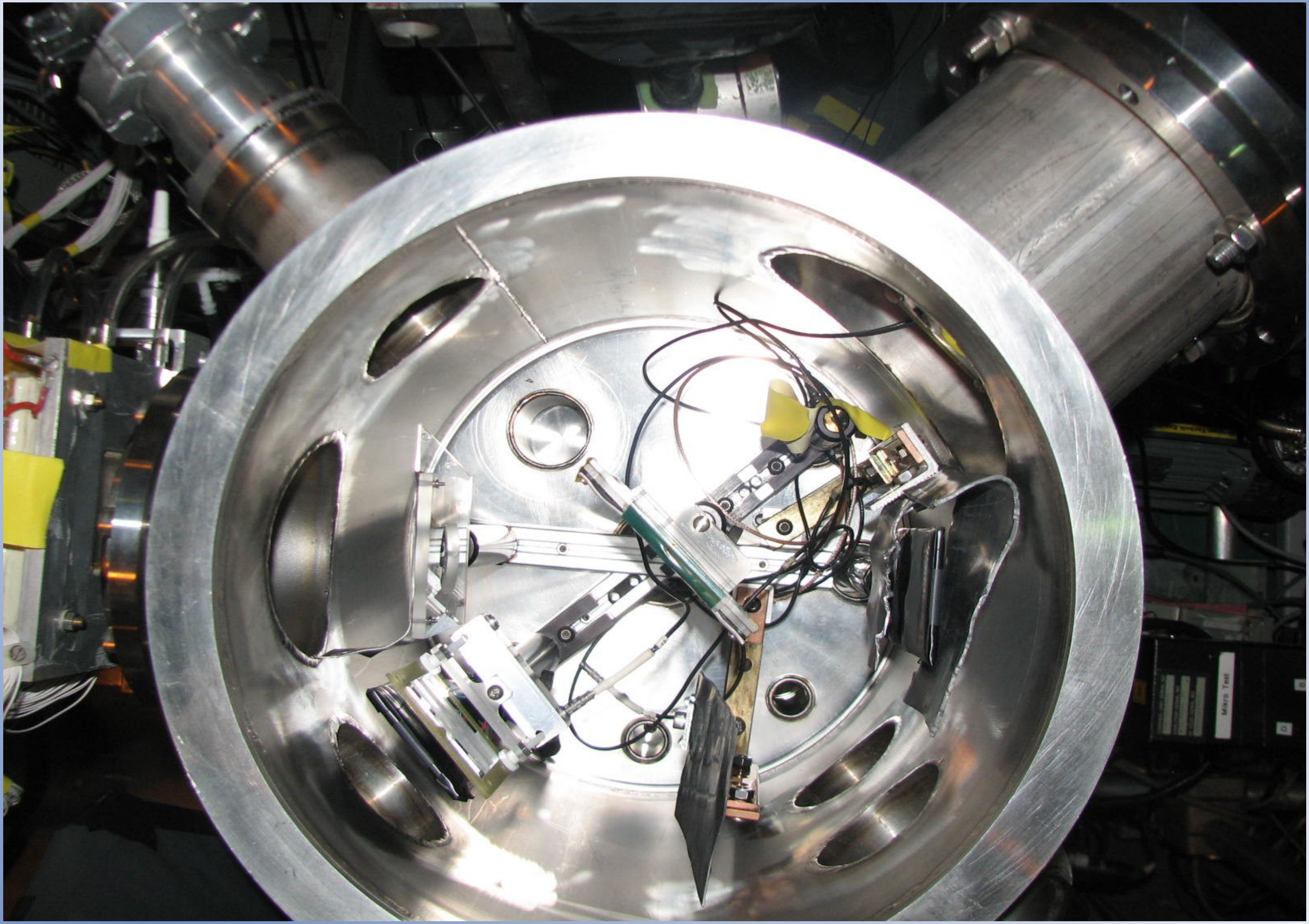
Many slides taken from talks by Peter Kammel and Vadim Rusu, and also from the Mu2e Collaboration documents.

Measurement Setup

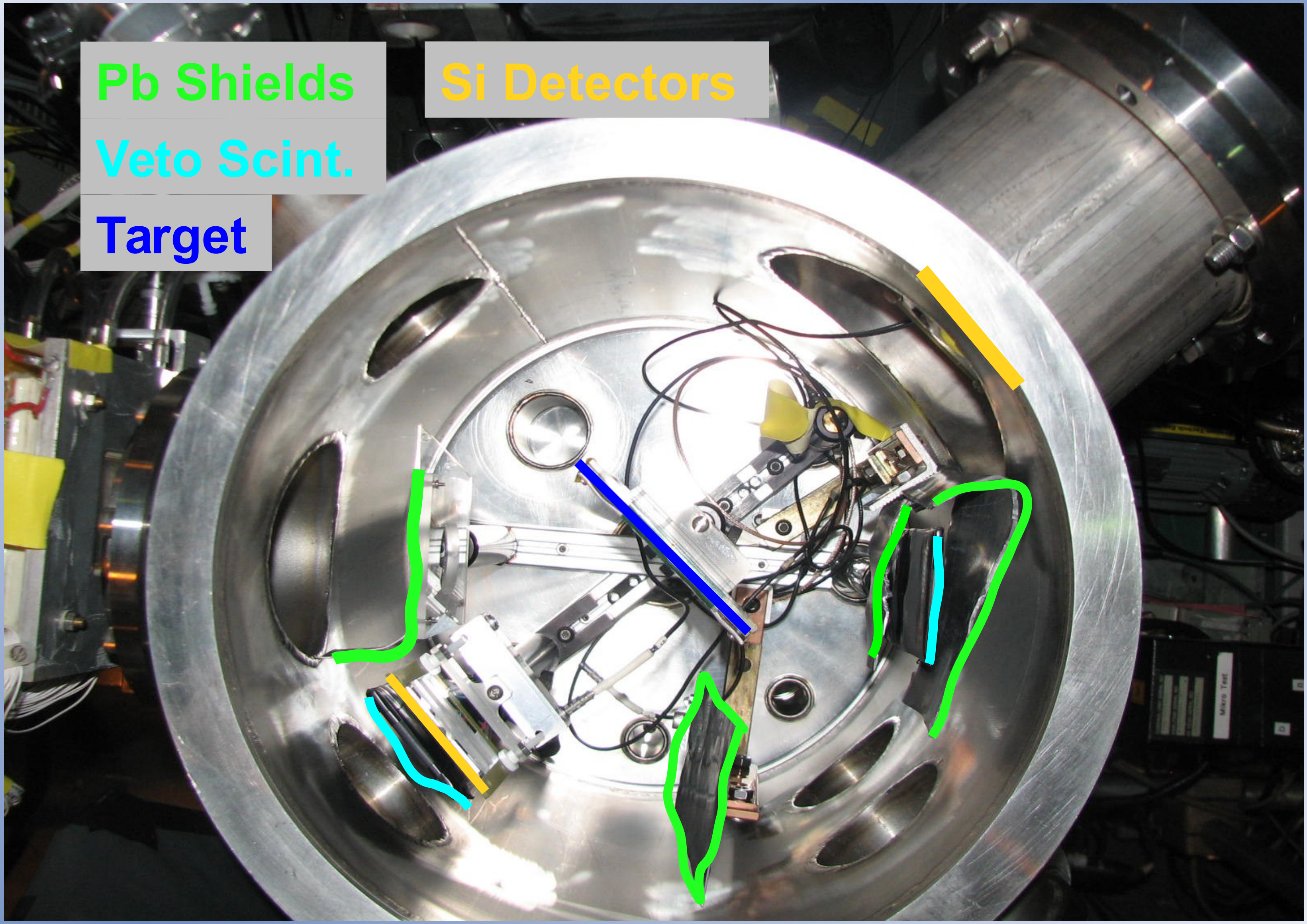


Det	FADC (# ch)	TDC (# ch)
muSC	1	1
muSCA	1	1
muPC		50
vSC	1	1
pSC l/r	2	2
MSX l/r	4	
MSQ l/r	8	
nDet	2-4	
Ge	2	

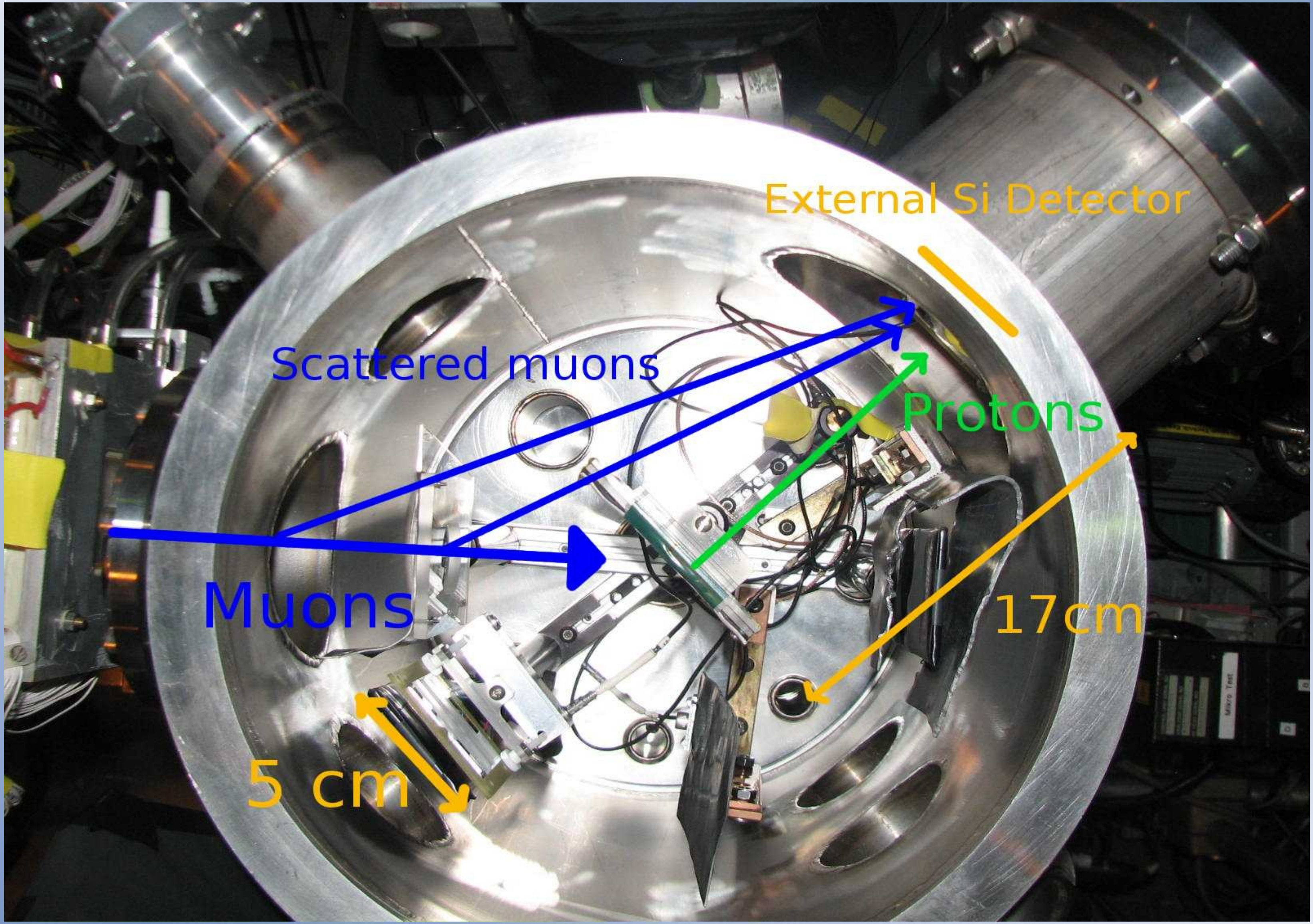
Measurement Setup



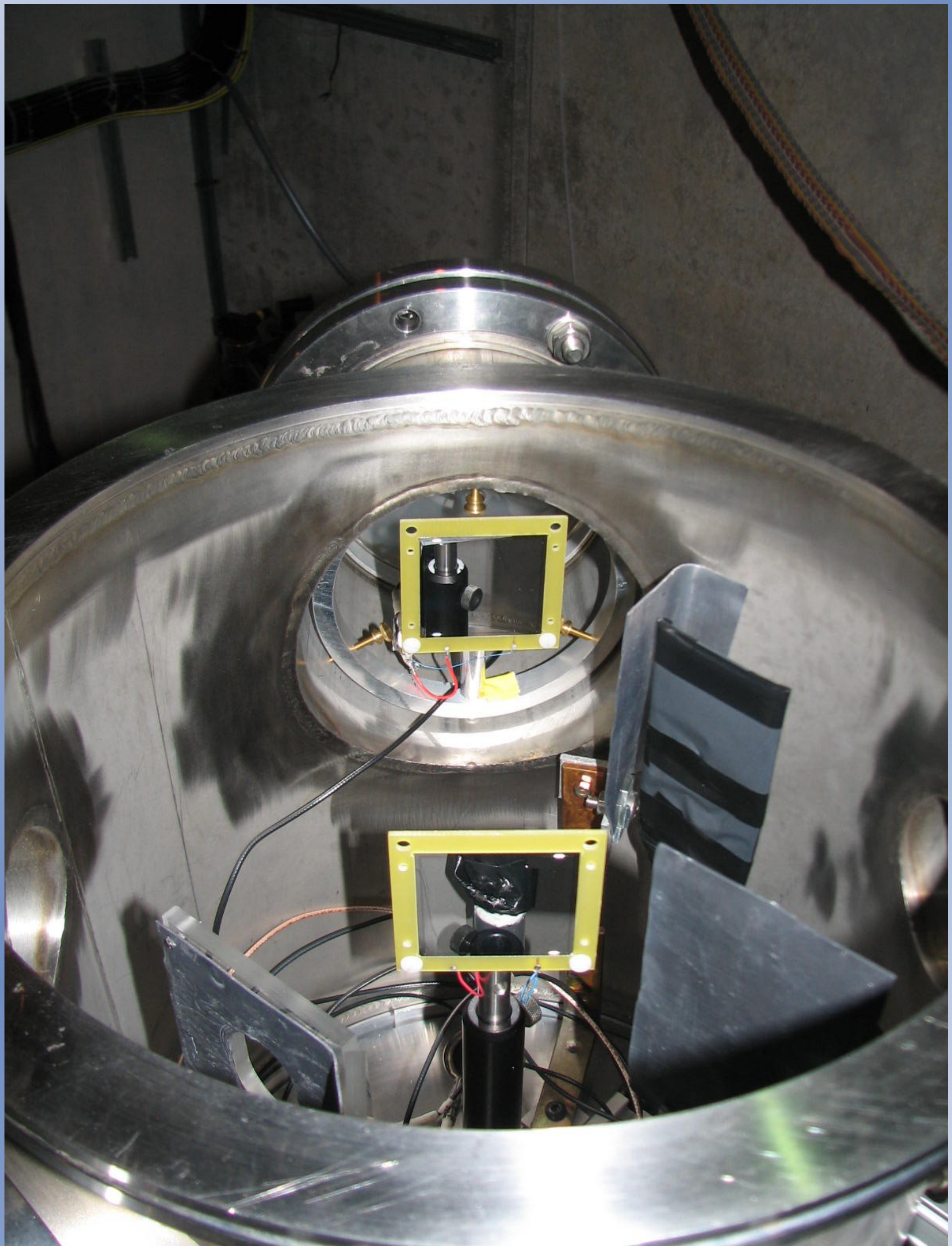
Measurement Setup

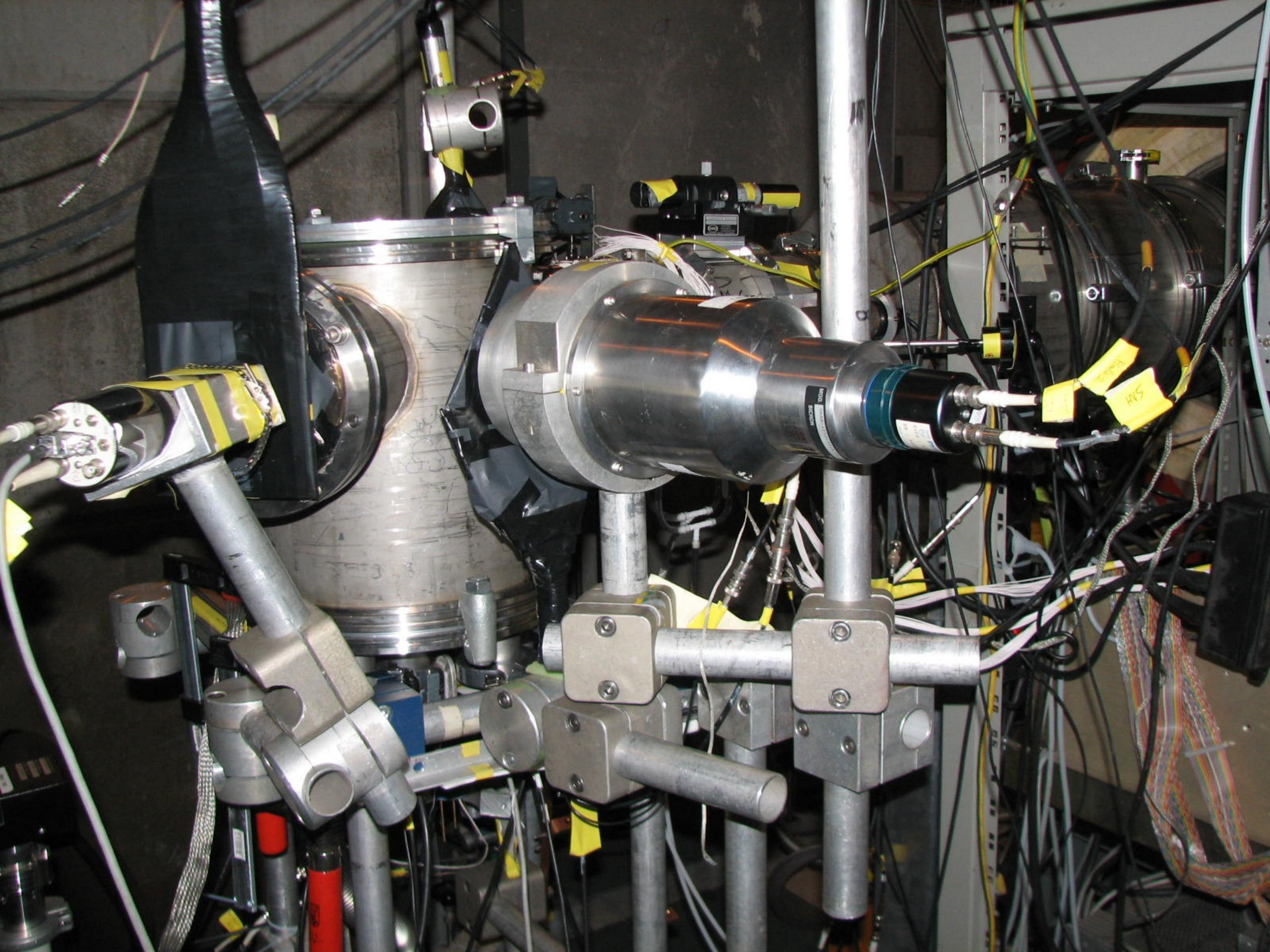


Measurement Setup



Si Calibration Setup




MOD.
BICRON

Proton Measurement Summary

- Interested in number of protons per muon stopped in the target
- Total flux and energy spectrum of protons
- Two analyses to perform
  - Numerator – number of protons and proton spectrum
    - Si detectors
    - Calibration with Am 241 source
  - Denominator – total number of muon stops
    - Muon cascade x-rays
    - Electron lifetime fit

Background

- **Target**
  - Michel electrons: E (MIPS 40 KeV/100u), antiCoinc, mu+
  - Neutrons: ESi*dESi, measurement with absorber, MC, Si target

- **Wall + Windows**
  - low or high Z materials (competing capture and p emission)
    - High Z not too much of a problem – wait ~500ns for all activity to decay.
    - Low Z contributes long lifetimes that make it difficult to extract the Si lifetime. Low Z materials need to be avoided.
  - Careful collimation is required. Shield detectors carefully from unwanted stray particles.
  - Si active target setup for calibration and efficiency calculations

How many muons do we stop?

X-ray method

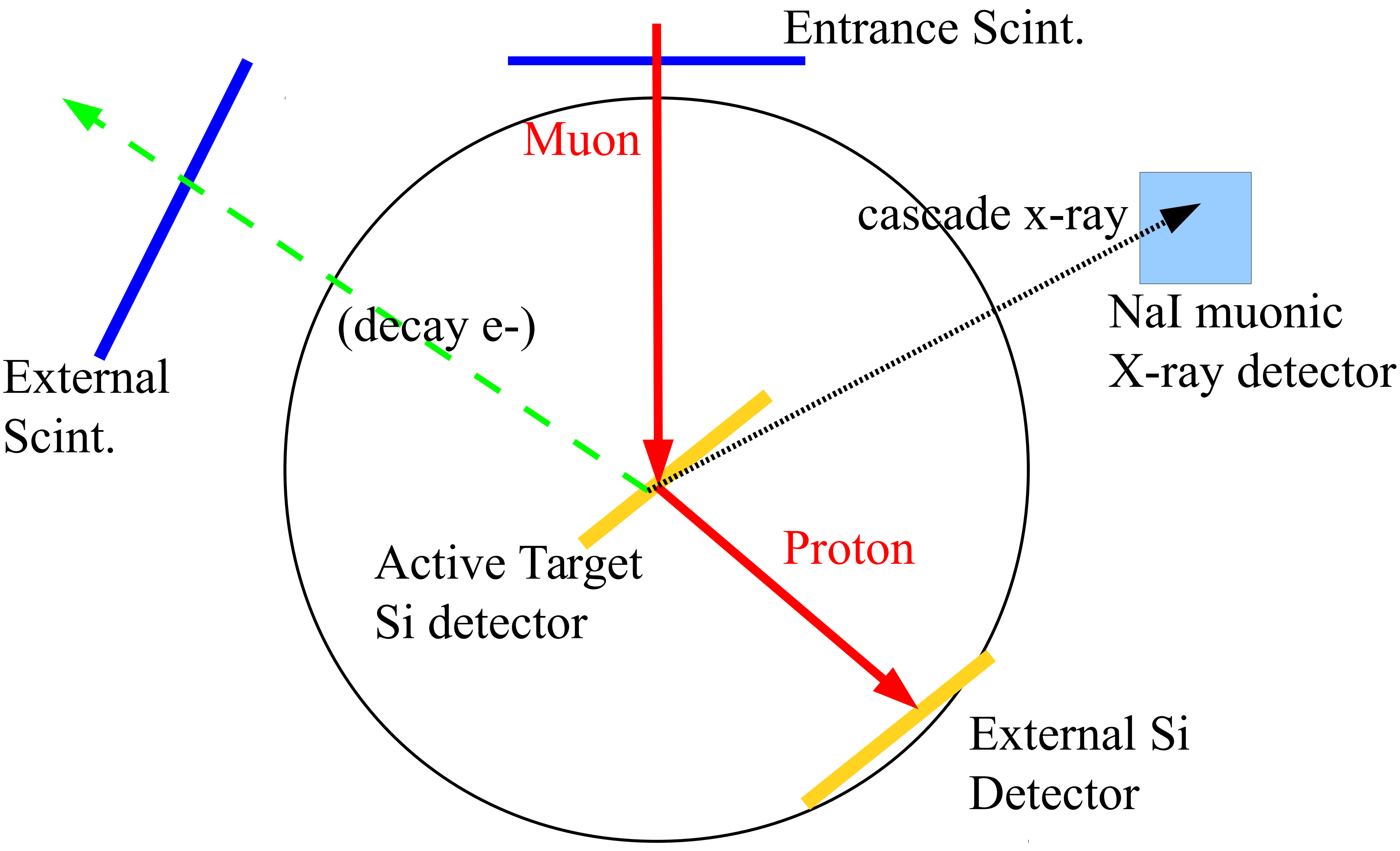
- K_alpha transition in muonic atom.
- Prompt to muon stop
- Characteristic signature of target nucleus

Electron Lifetimes

- Delayed
- Multi-parameter fitting
- Lifetimes characteristic of material

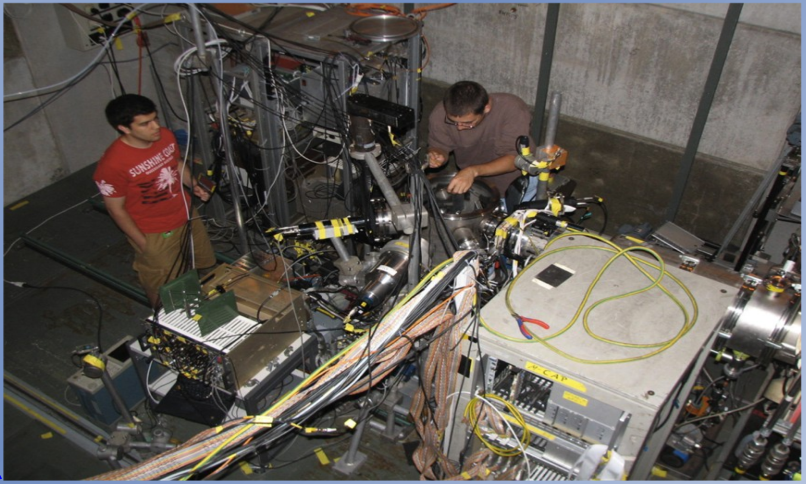
	2p-1s(keV)	Lifetime(ns)
Al^{27}	346.8	864
Si^{28}	400.1	758
Ti^{47}	932.5	329
Pb^{208}	5778	75
C^{12}		2040

Easy Setup: Active Si Target

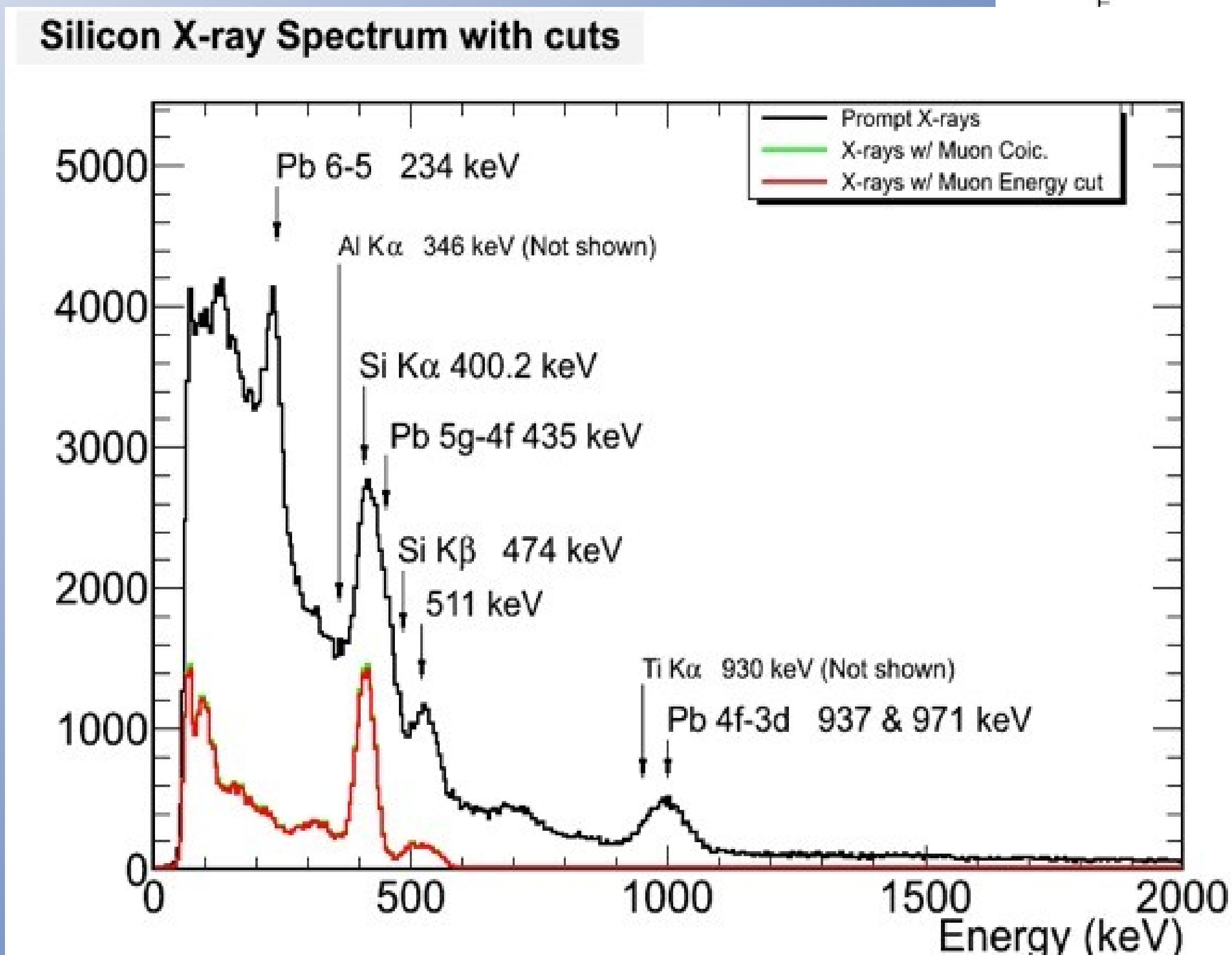


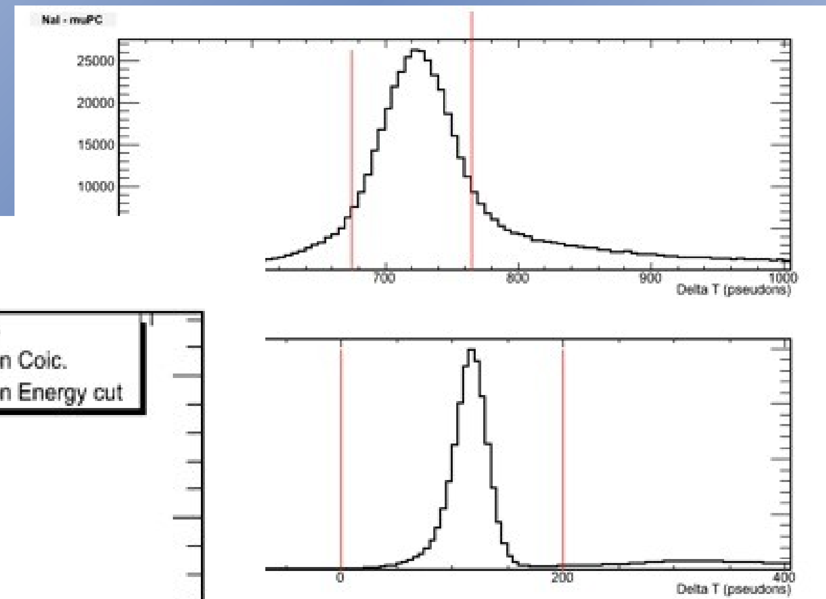
Xray Method

- NaI detector downstream and to the left of beam
- $N_{stops} = N_{xray}/\varepsilon$
  - First, measure ε
  - Si detector at the target position provides the normalization : # of stops directly detected.



X Rays in Si

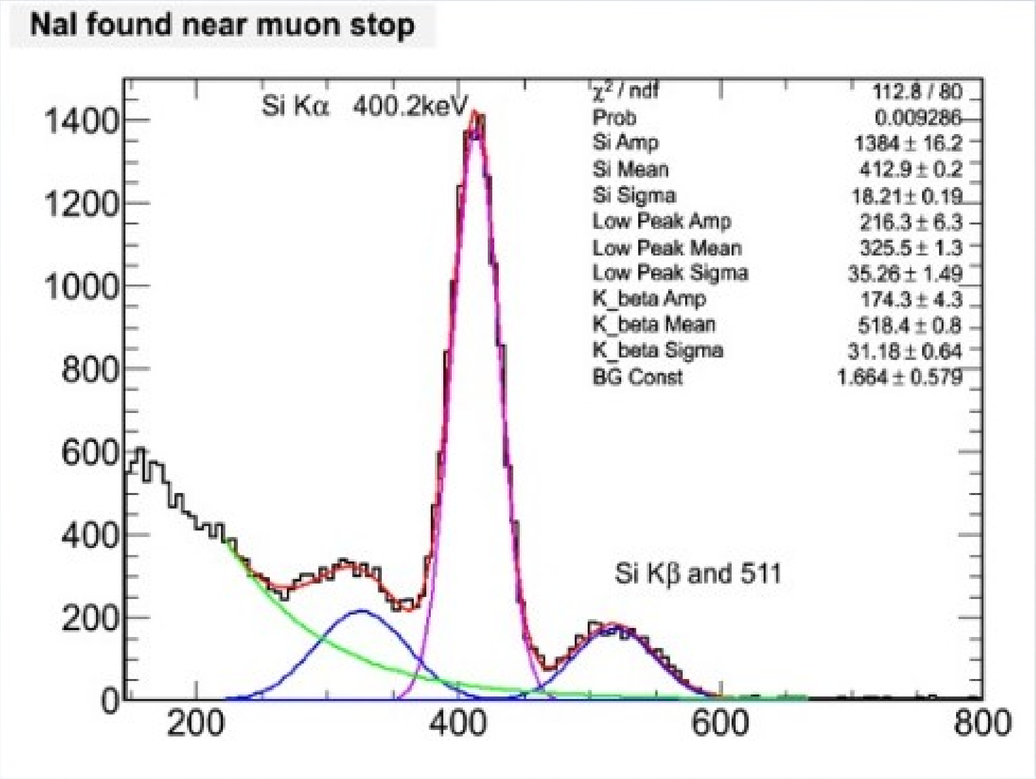




Prompt X-rays:
In coincidence with muon entrance counters.

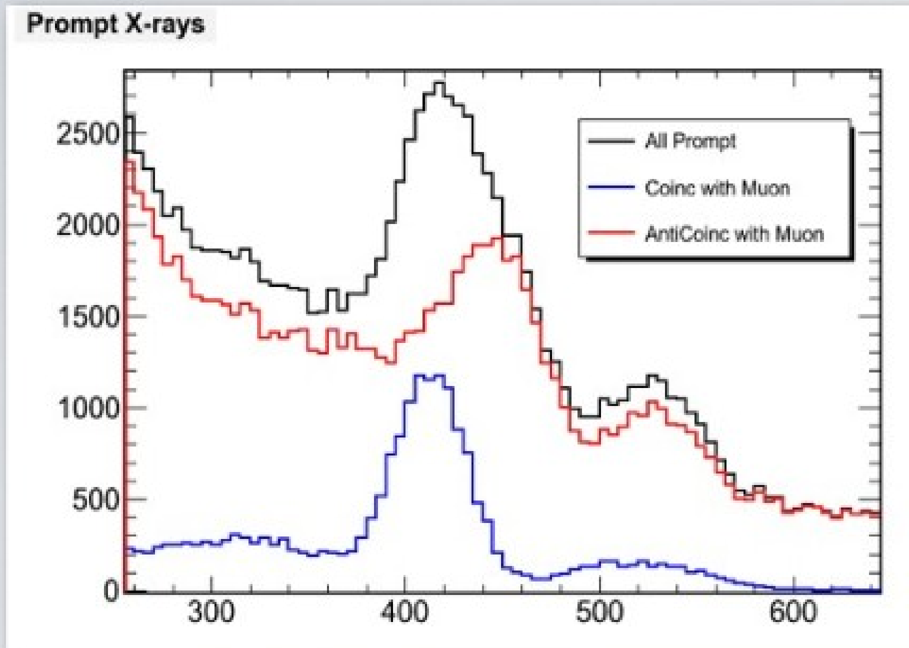
NaI EFFICIENCY FOR SI XRAYS

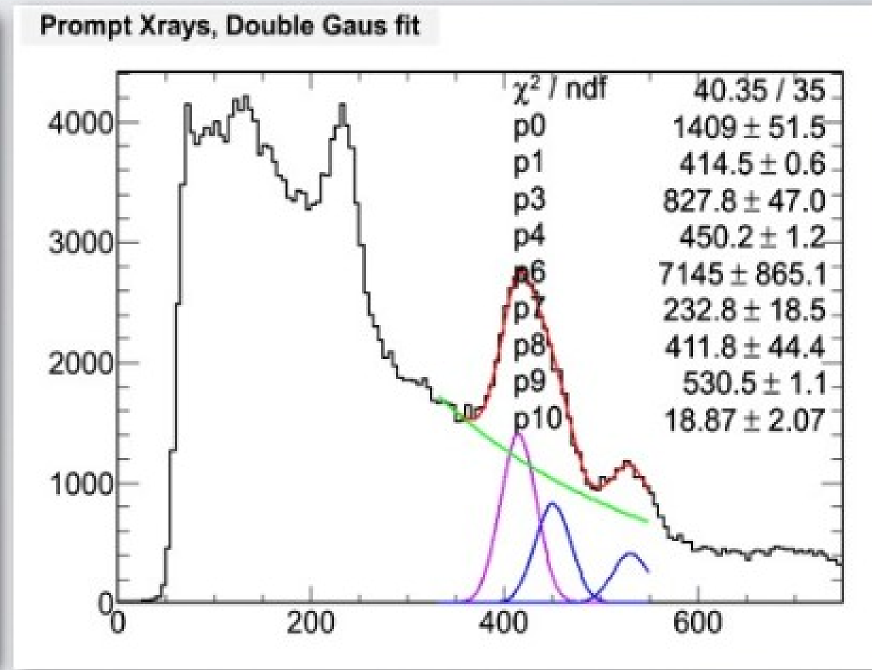
- $\varepsilon = N_{peak}/N_{total}$
- $\varepsilon = (429 \pm 5) \times 10^{-6}$



TOTAL NUMBER OF STOPS

- Complicated by other lines around
- Need to disentangle different contributions

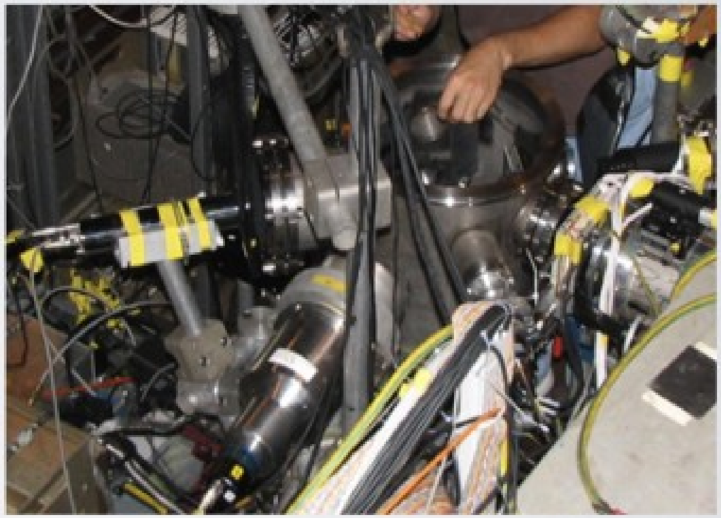




- **$N_{stops} = N_{xray}/\varepsilon$**
- **$N_{stops} = 30.6+1.2M$**

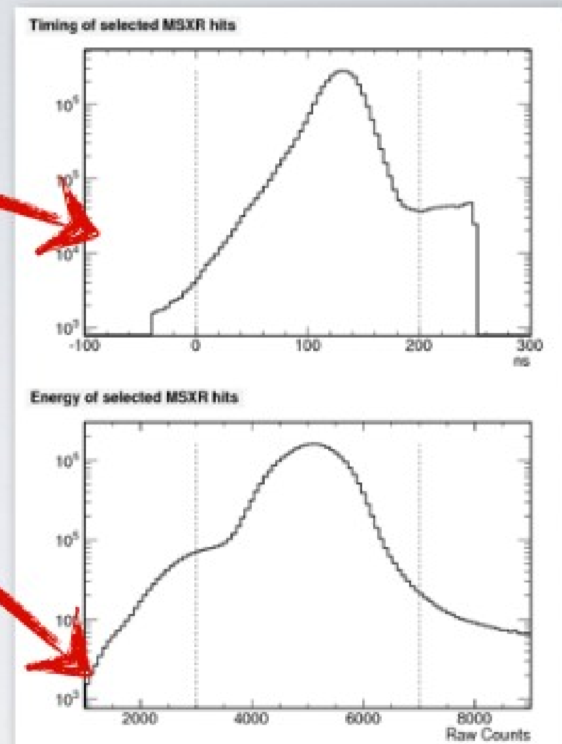
LIFETIME METHOD

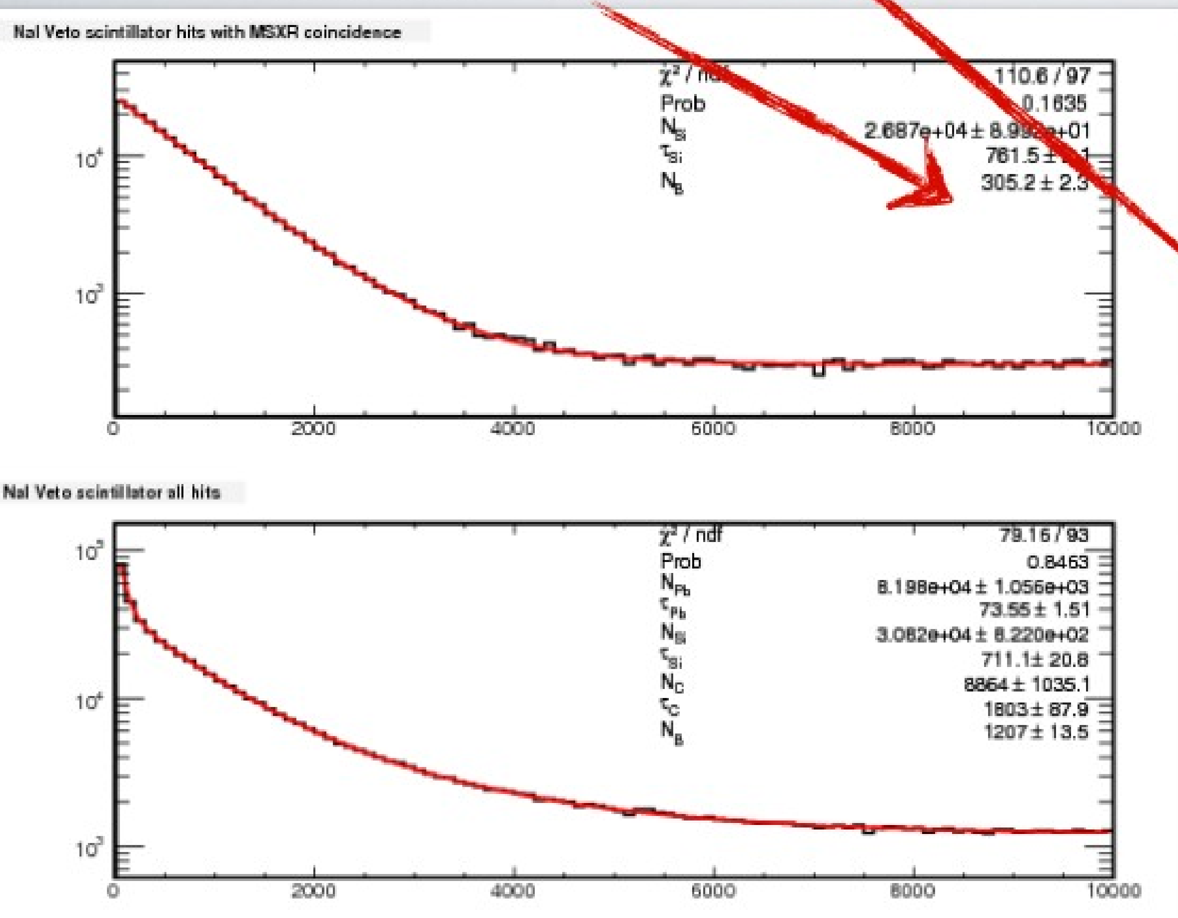
- collect the electrons from the muon decays with scintillators
  - ➡ multiple scintillators in the setup
  - ➡ NaI, LANL, KY
    - ~ns resolution CAEN TDC for readout



EFFICIENCY CALCULATION

- Prompt MSXR hits
- consistent with muon stops
- Si lifetime = 758ns



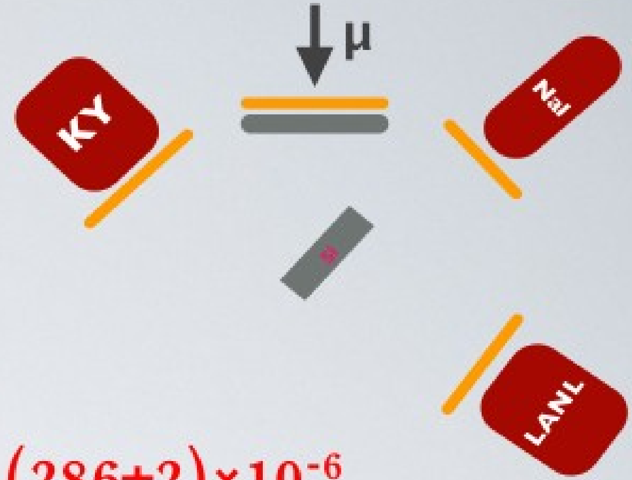


- $\varepsilon = N_{NaI+MSXR}/N_{nmsxr}$
- Typical $\varepsilon = (909 \pm 3) \times 10^{-6}$
- $N_{stops} = N_{NaI}/\varepsilon = 33.8 \pm 0.9M$

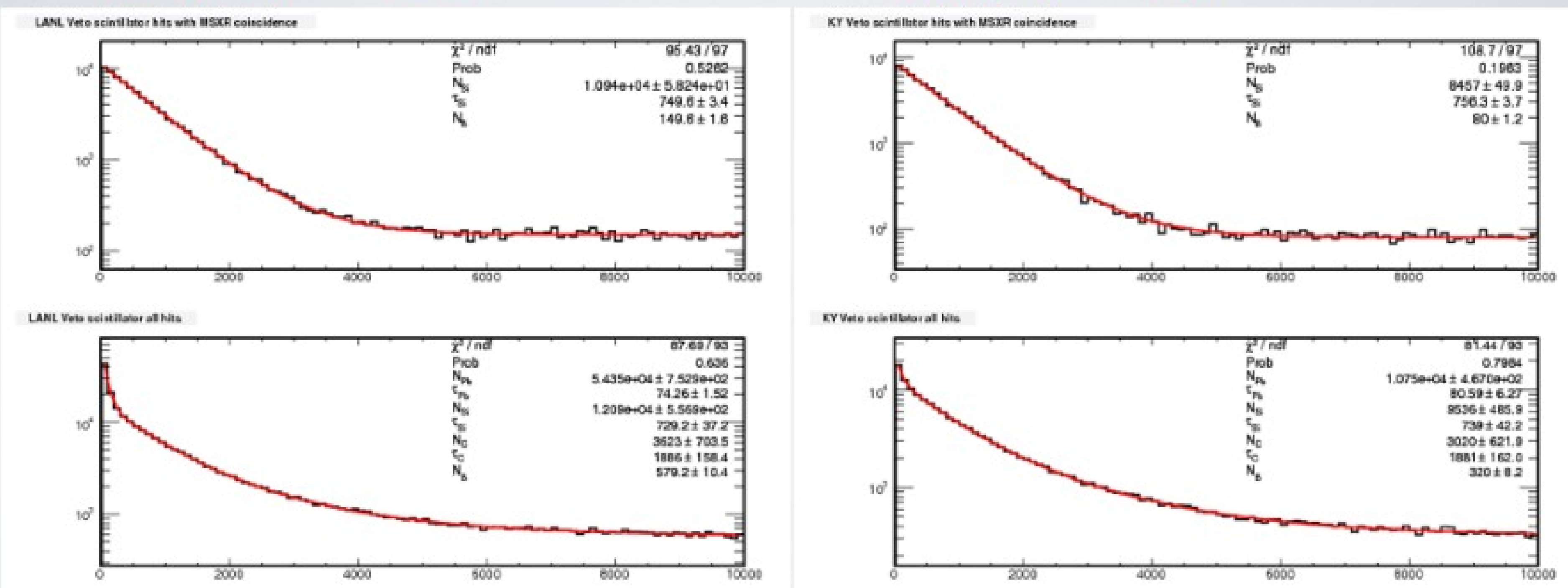
Stops by x-rays = 30.6±1.2M

CONSISTENCY

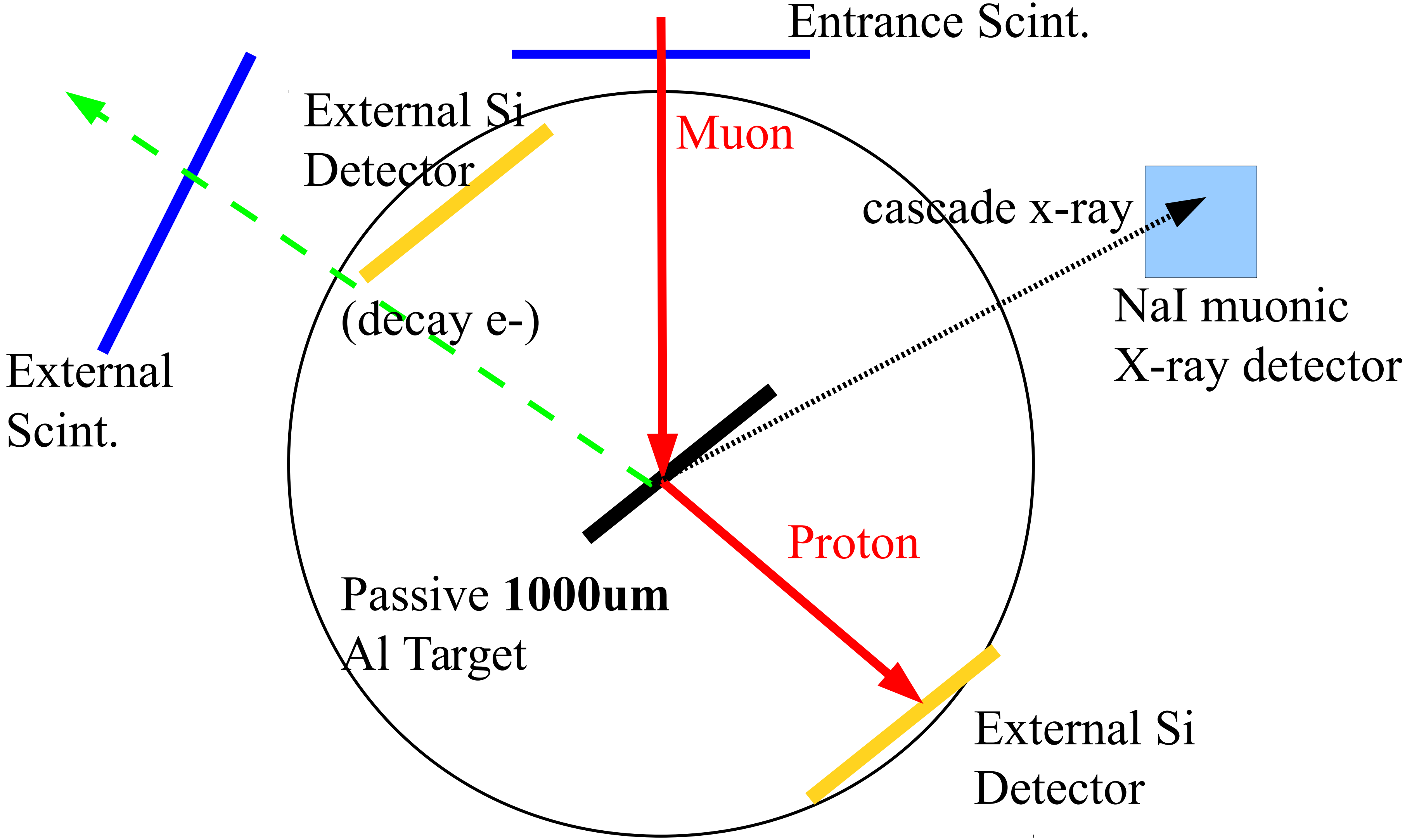
between different detectors



- $\varepsilon_{LANL} = (370 \pm 2) \times 10^{-6}$
- $N_{stops(LANL)} = N_{LANL} / \varepsilon = 32.6 \pm 1.5M$
- $\varepsilon_{KY} = (286 \pm 2) \times 10^{-6}$
- $N_{stops(KY)} = N_{KY} / \varepsilon = 33.3 \pm 1.7M$

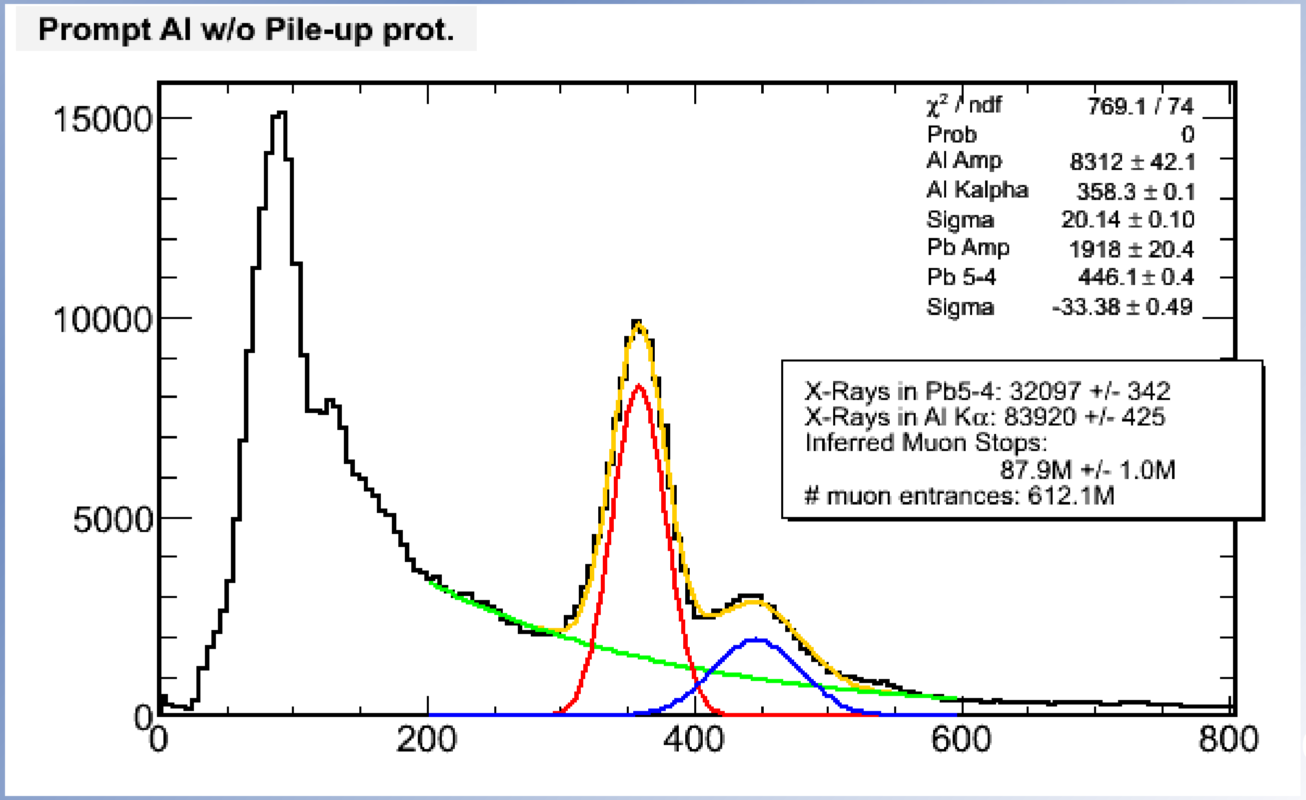


Hard Setup: 1000um Al Target



1000um Al Target

- Factor of 3 discrepancy for thinner 100um target
- Try to achieve consistency with a thick target – large statistics, simple stopping situation
- Measured muon stops: 87.9M +/- 1.0M

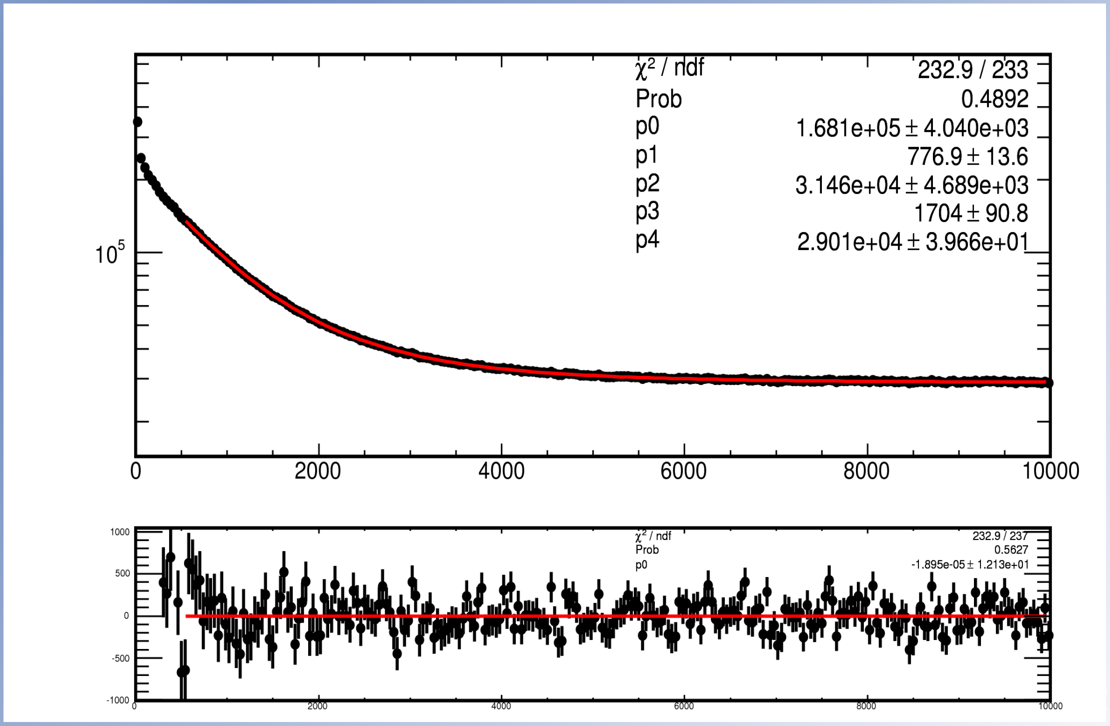


Lifetime fit for 1000um Al

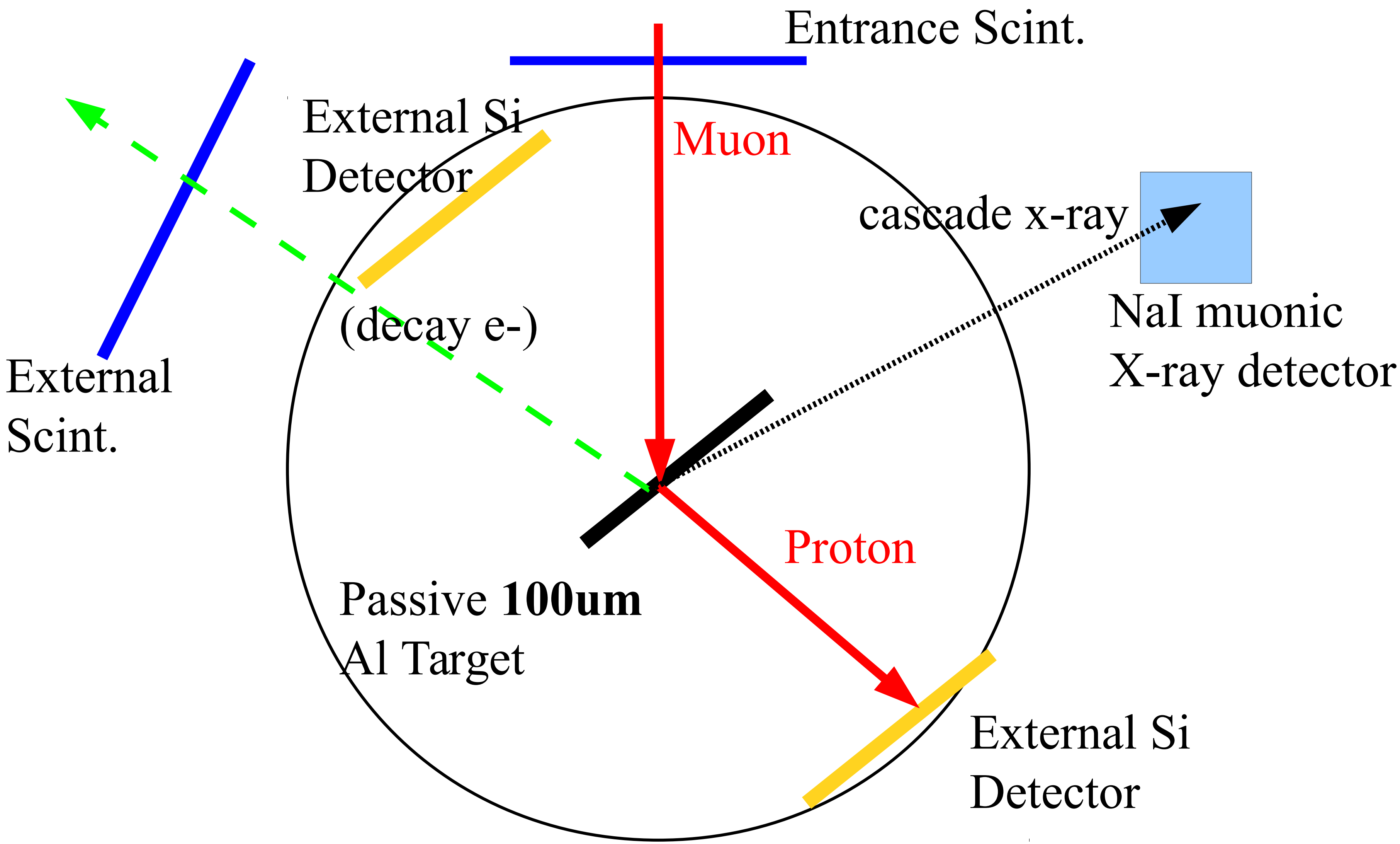
- Excellent fit
- Calculated muon stops: 122M +/- 3M.
- Discrepancy of 50% with X-ray method: 87.9M +/- 1.0M
- Denominator calculation may be unfeasible.

What did we learn?

- Ge detector for x-ray resolution
- Carefully avoid low Z lifetimes

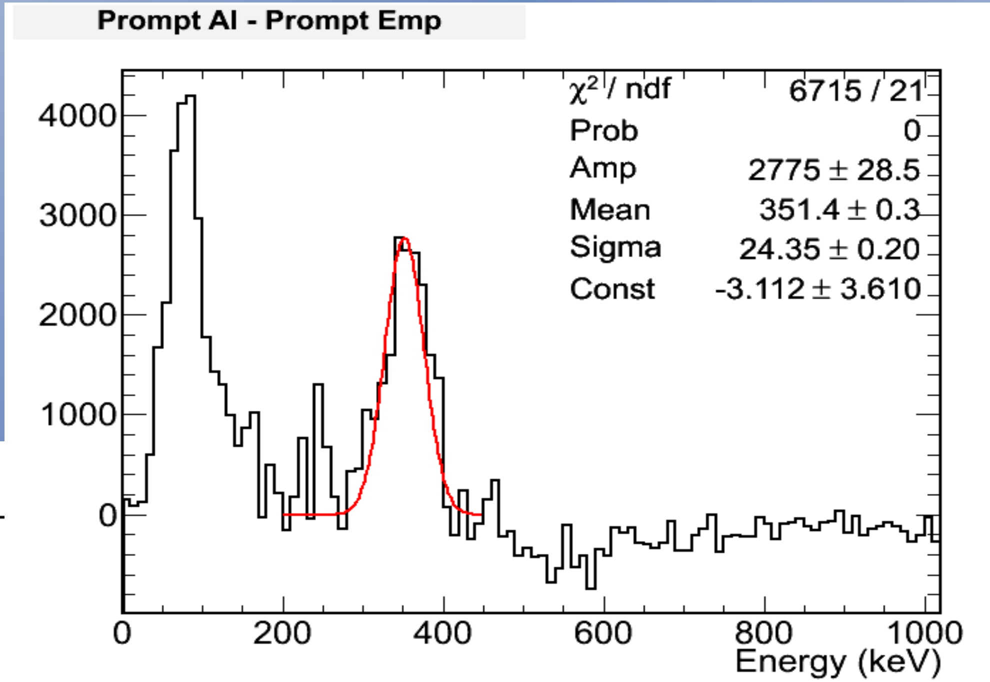


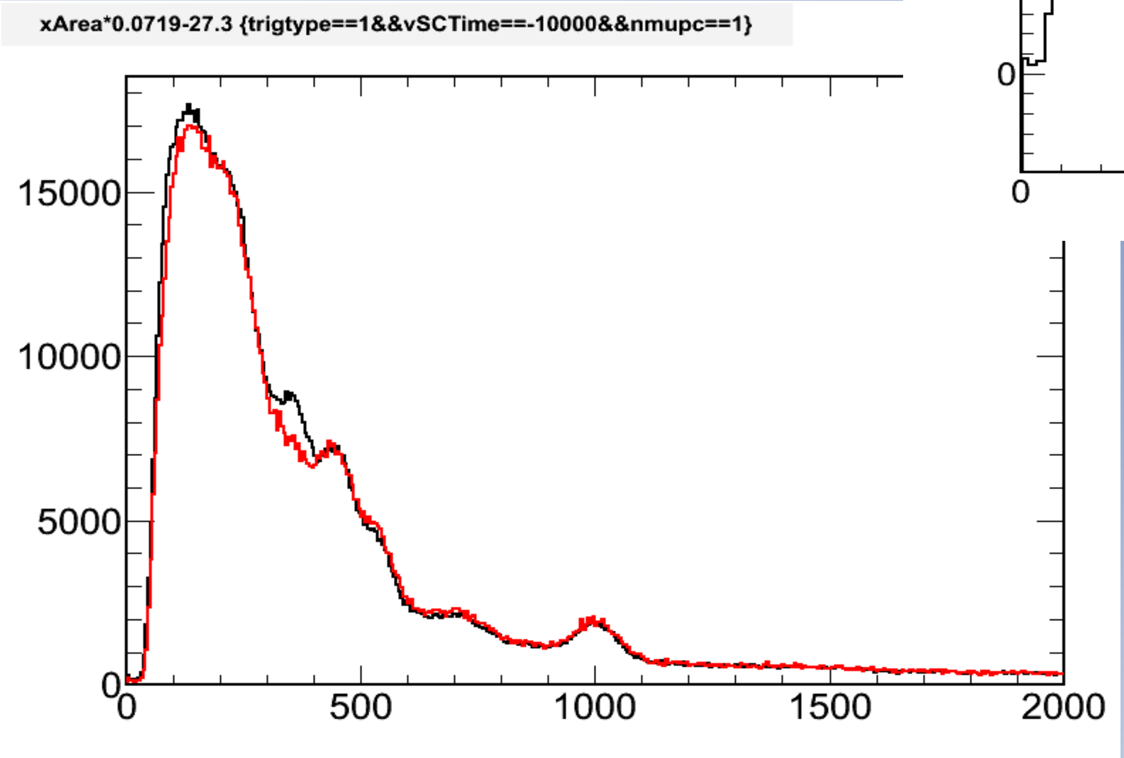
Hardest Setup: 100um Al Target



Stops in 100um Al Target

X-Rays in peak = 18900
#Stops = 18900/(0.000429)
= 44M

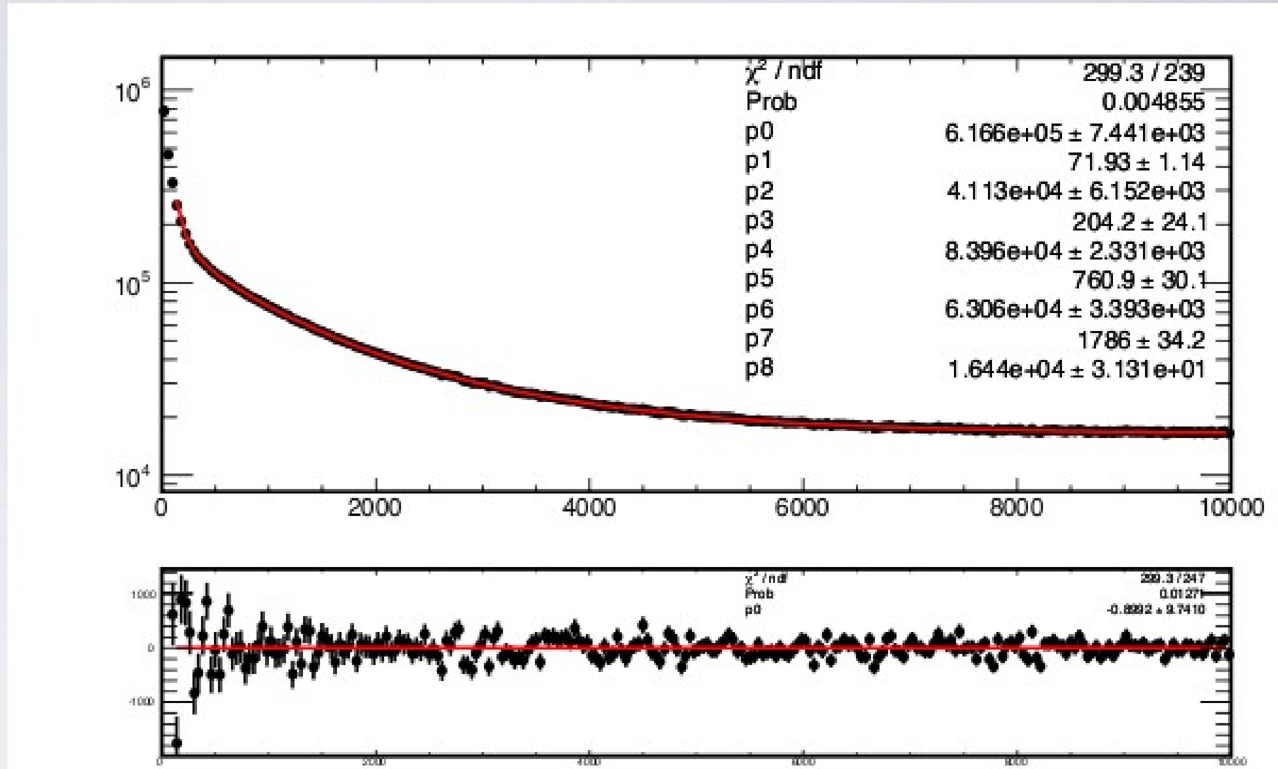




Subtraction of runs w/ empty target from runs with 100um target

ALUMINUM TARGET

100 um thick



- Thinner target
  - ➡ fewer stops
- other components may show up
  - ➡ Stainless steel

Using the efficiency form before and the fit above

N_{stops} = 135.7+3.2M

Stops from x-rays = 44M

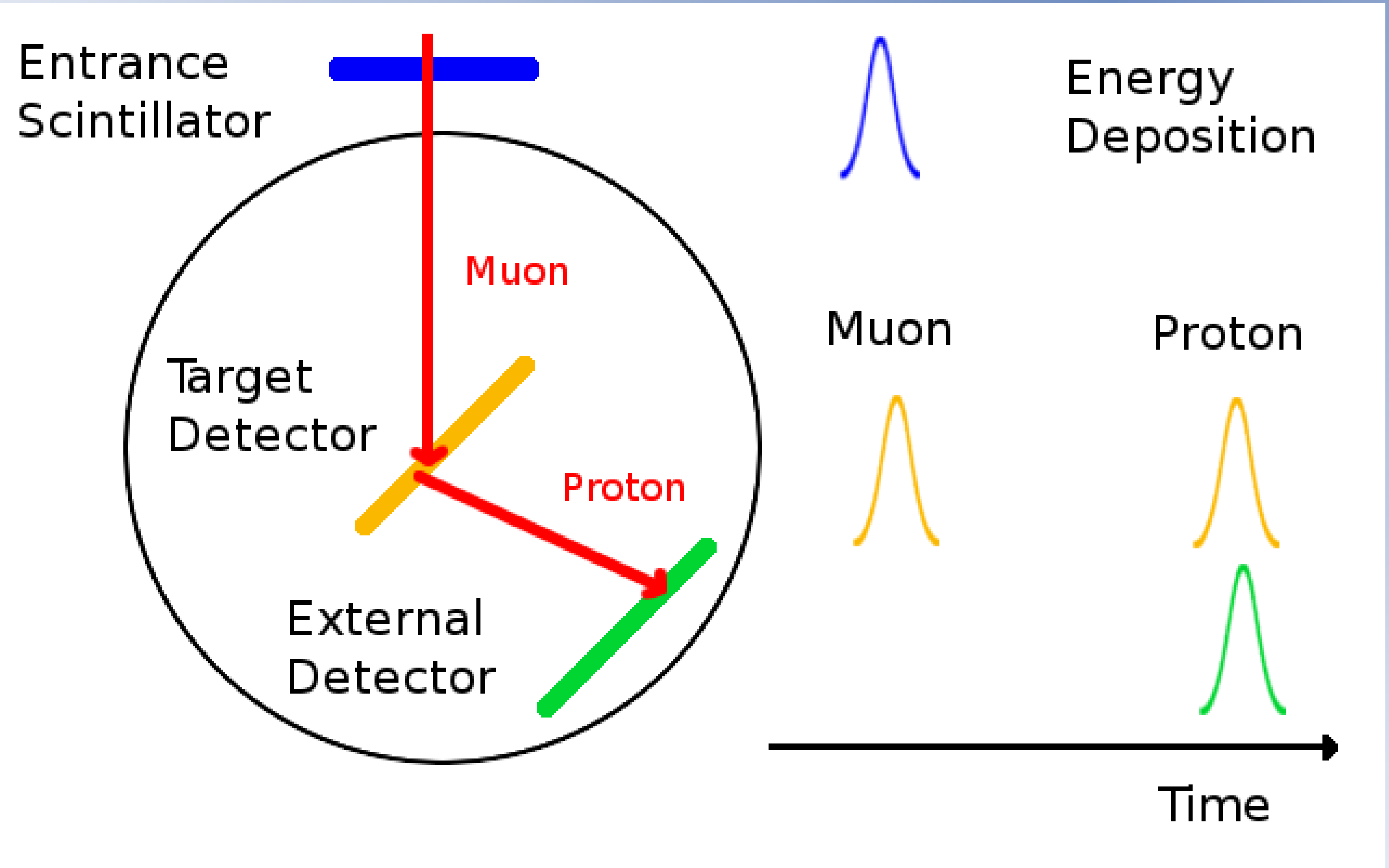
Factor of 3 discrepancy!

Proton Detectors

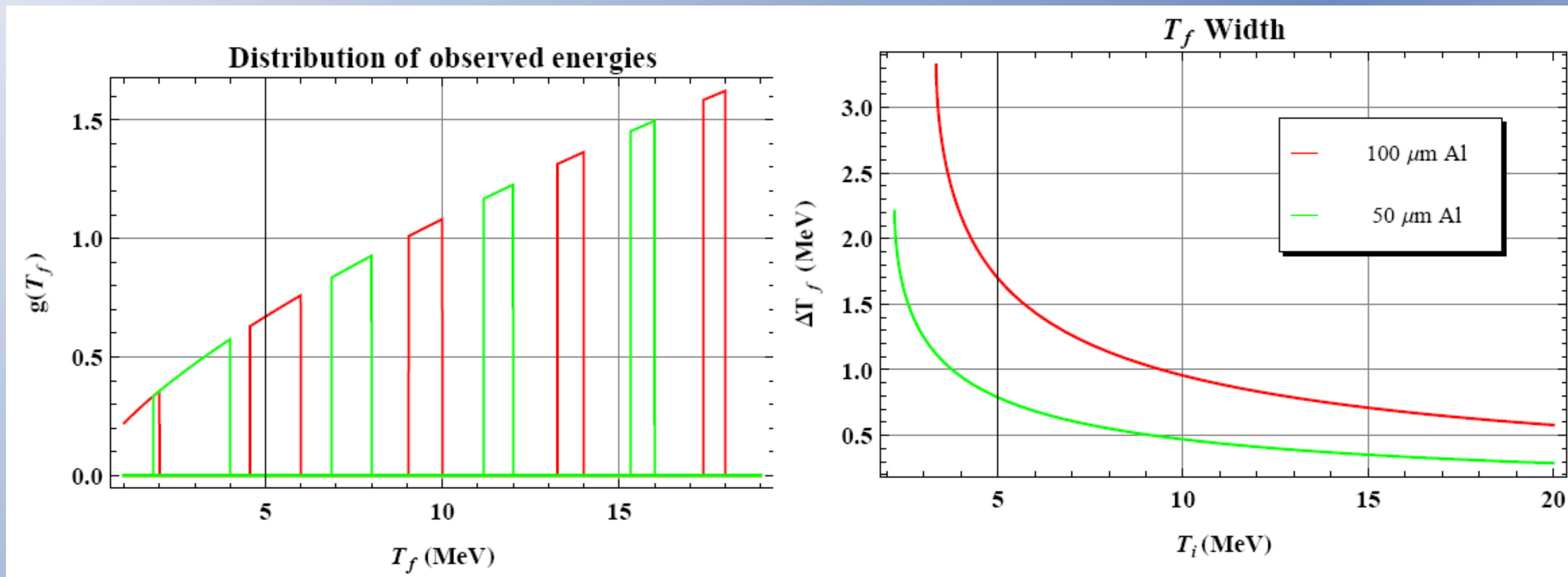
- So we don't understand how to determine the number of stops. What can we learn from the (unnormalized) proton emission spectrum?

- Interesting problem
  - Deconvolution and reconstruction of original energy function
  - Particle ID : deuterons, alphas
- Summary of progress
  - Data checks on proton data
  - Some attempts at the energy spectrum

Proton Energy Deposition

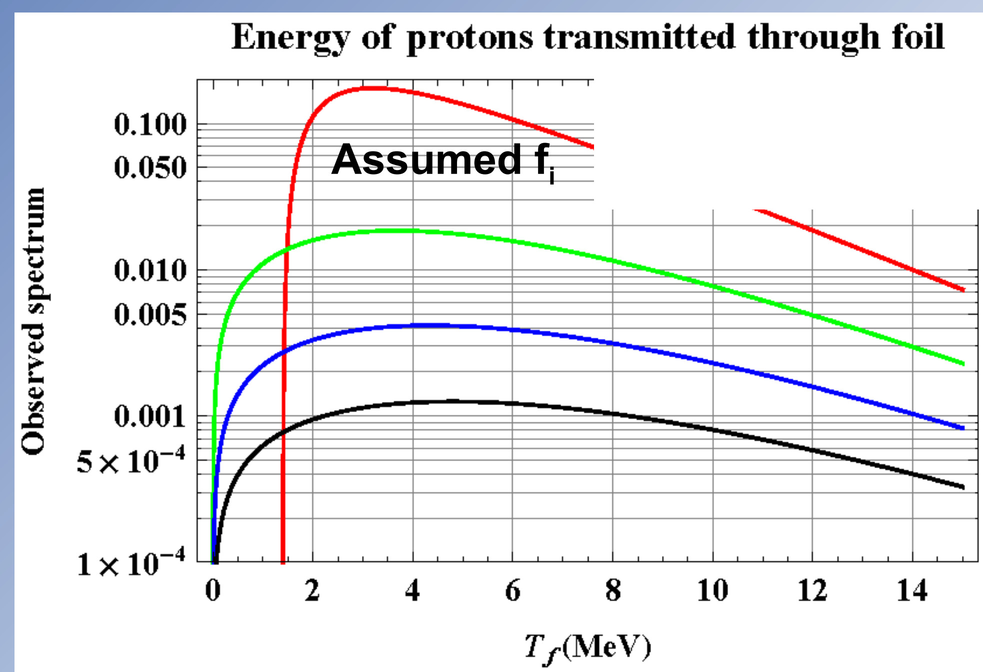


Deconvolution



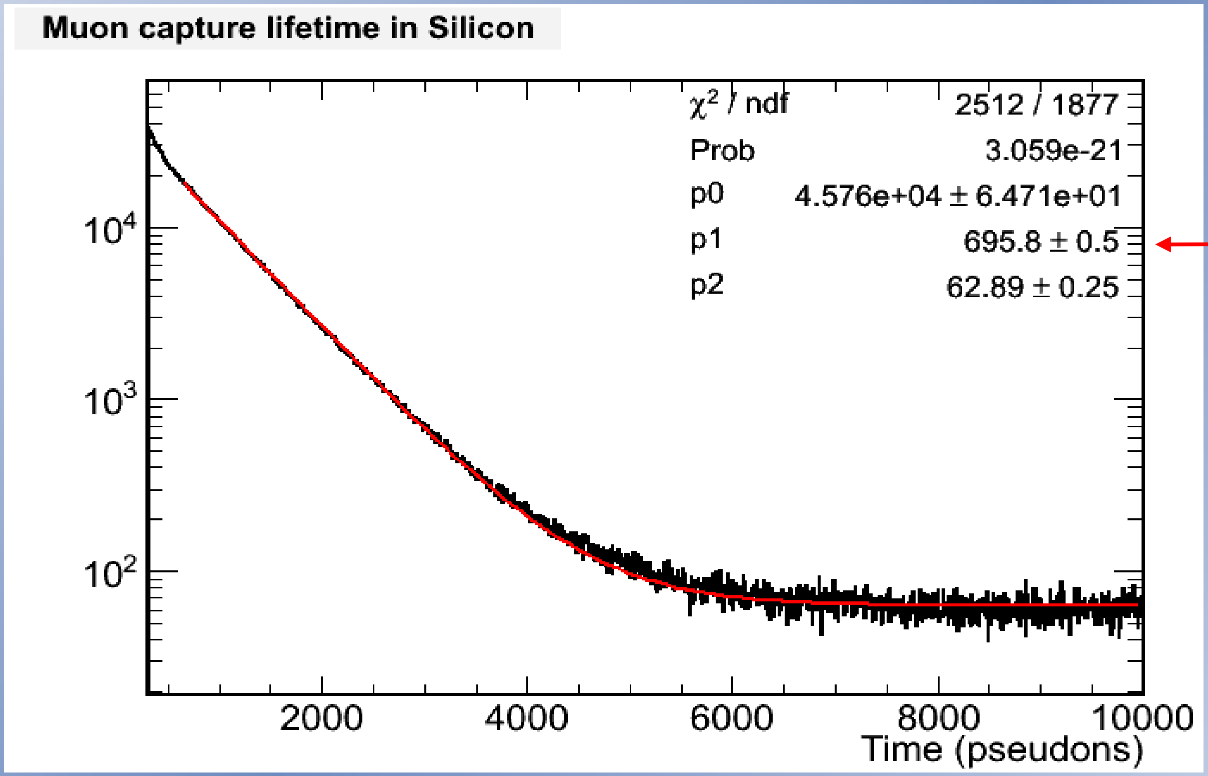
Response function from MC and experiment

- range distribution
- different thickness
- active Si target



Data Quality

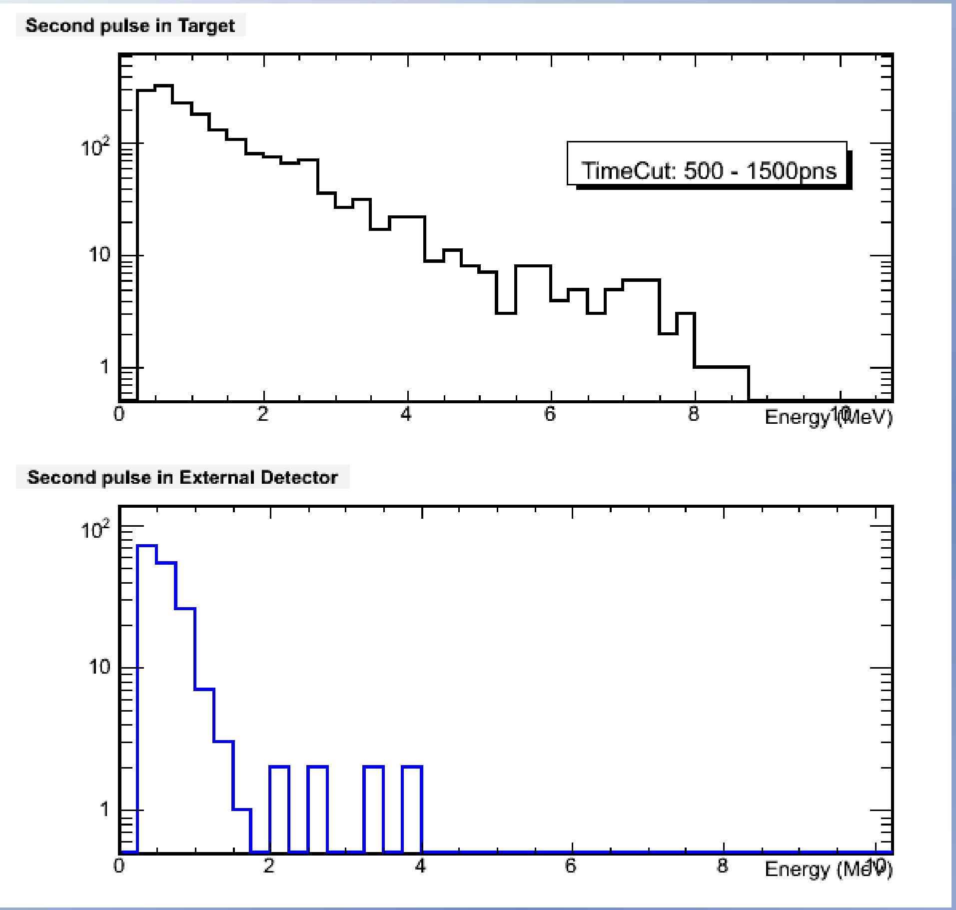
- Using active Si target, measure the muon capture lifetime in the delayed proton spectrum.
  - Look for prompt muon hit in the target
  - Count the time of the next pulse (outgoing proton)



In real ns, this comes out to **τ = 770ns**.

The actual capture lifetime in silicon is **τ = 758ns**

Spectra in Each Detector



Look after a muon hits the Si detector in the delayed window 500pns-1500pns and record the energy of the next pulse found (outgoing proton).

The external detector (lower plot) does actually see prompt muons, though far fewer than the target detector (factor of 200).

The dynamic range in energy deposition for the Si detectors is 10 MeV. This is limited electronically, as the maximum energy deposition in 1.5mm Si is ~15 MeV for a proton.

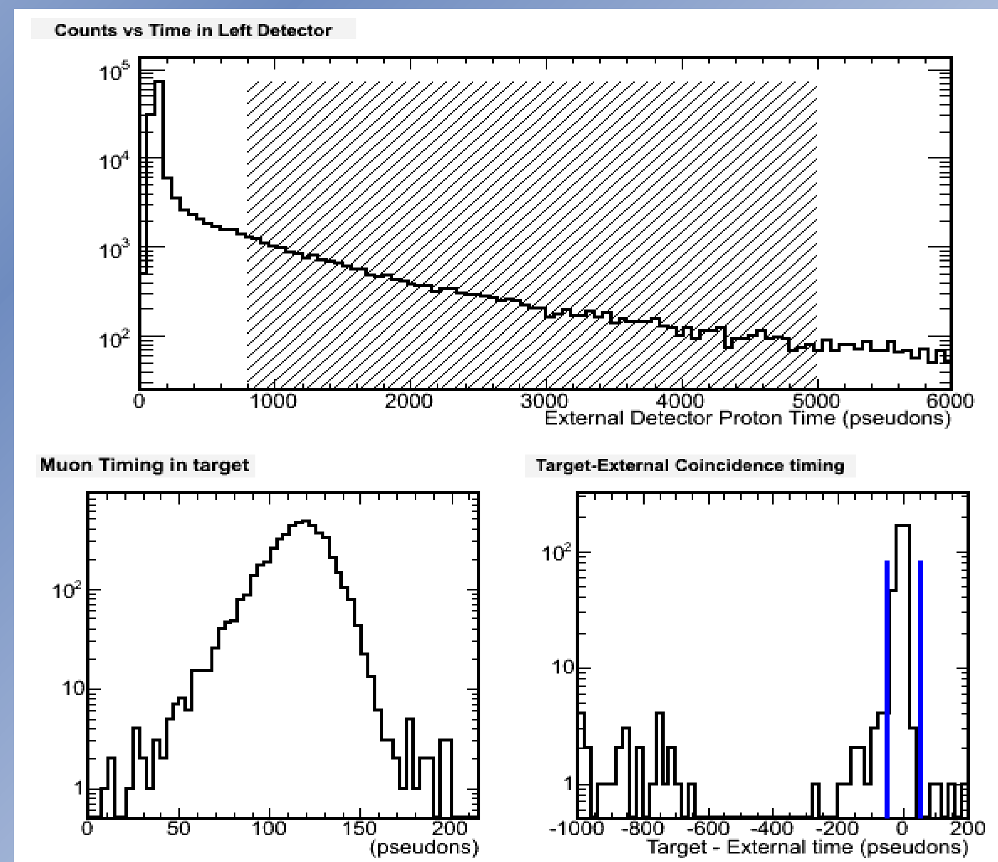
Protons hit both detectors

Coincidence between pulses in both Si detectors indicate a proton. The proton originating in the target Si detector will deposit energy as it exits the material.

If the proton hits the external Si detector, its remaining kinetic energy is seen as a pulse coincident with the target detector.

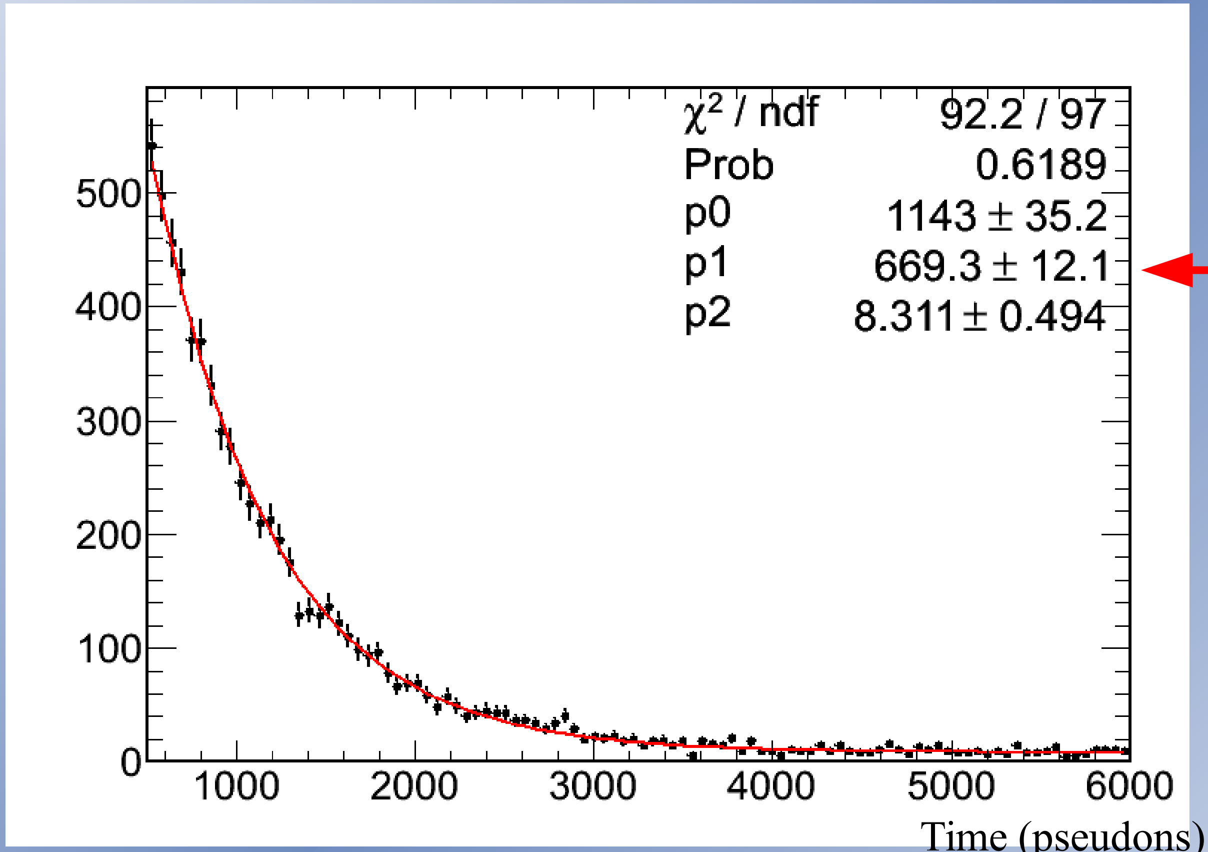
The shaded region is the time window used for the next few plots.

Times are relative to entrance counter



Si Lifetime in External Det.

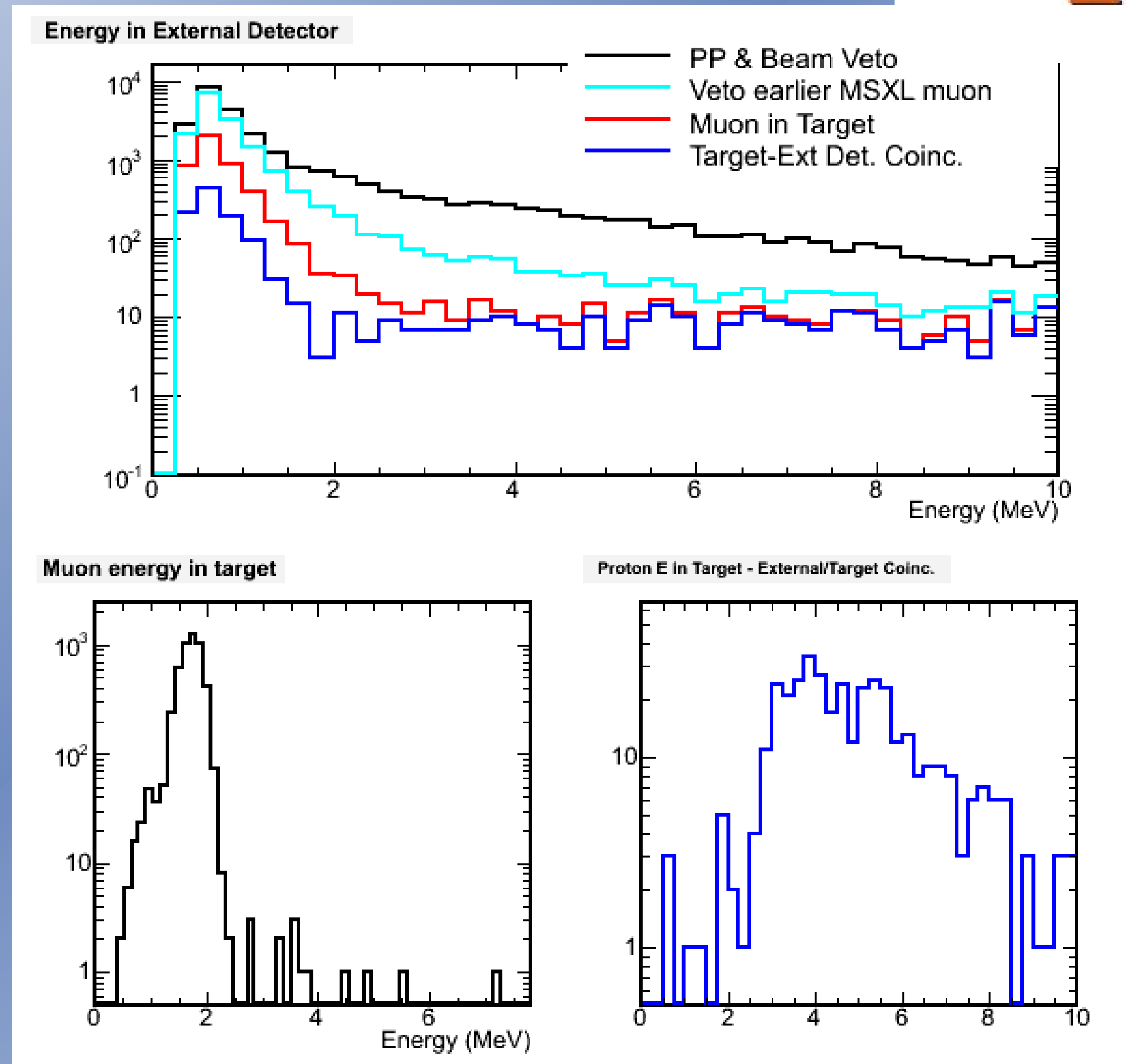
- As long as we see a muon hit the target Si detector plot the time distribution of following hits in the external Si detector.
- Don't need two components to the lifetime because of the active target.



Si lifetime in literature is 684 pseudo ns. (1pns = 1.1 ns)

Energy in the External Si

Cuts are cumulative
Black:
- Pileup protection
- Beam veto
- Time cut
Teal:
- no muon in external
Red:
- Prompt muon in target
Blue:
- Coincidence between pulse in target and pulse in external Si



(see cartoon a few slides back)

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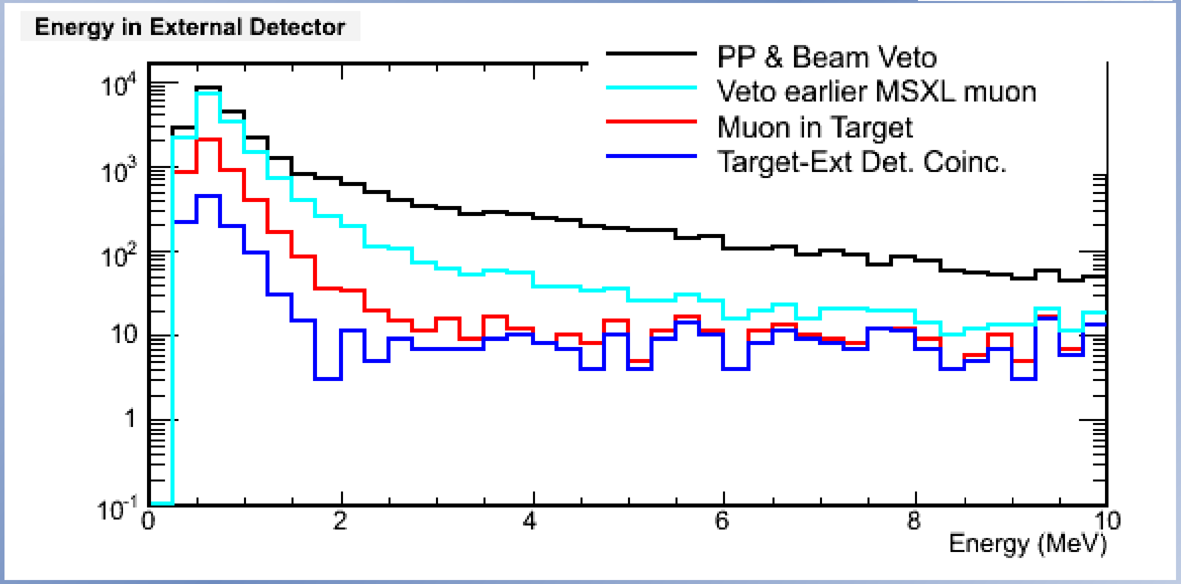

- Al target: we only see Black and Teal
- Why is there a factor of 3-4 between
  – Teal and Red?
  – Red and Blue?
- The external Si detector sees many hits from unknown background sources that are cleaned up by making coincidences.

Additional ideas/plans

- **Si calibration setup**
  - We could use just the one silicon detector, measuring the energy spectrum up to the point where protons escape the 1.5mm silicon. (10MeV proton ranges out in 700um of Si).
  - Response matrix for different momenta
  - BG in the teal curve
- **Measurement setup**
  - Different targets (thickness, material) with Si dets. In measuring position
  - BG run (empty target), compare left – right target energy spectrum.

References

- https://www.npl.uiuc.edu/cgi-bin/twiki/bin/view/Main/MuEGroup
- http://www.npl.illinois.edu/elog/mu2e/capture/