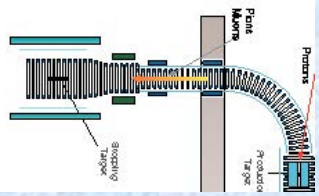


The AlCap Experiment

Progress and Beam Request

Ed Hungerford
Univ. Houston

The Collaboration

COMET

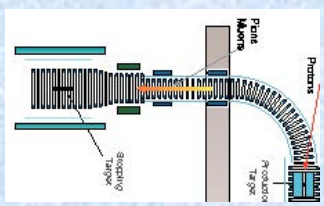
Osaka University, IHEP China
Imperial College London
University College London

Mu2e

Argonne NL
Boston University
Brookhaven NL
INFN Frascati
University of Houston
University of Washington

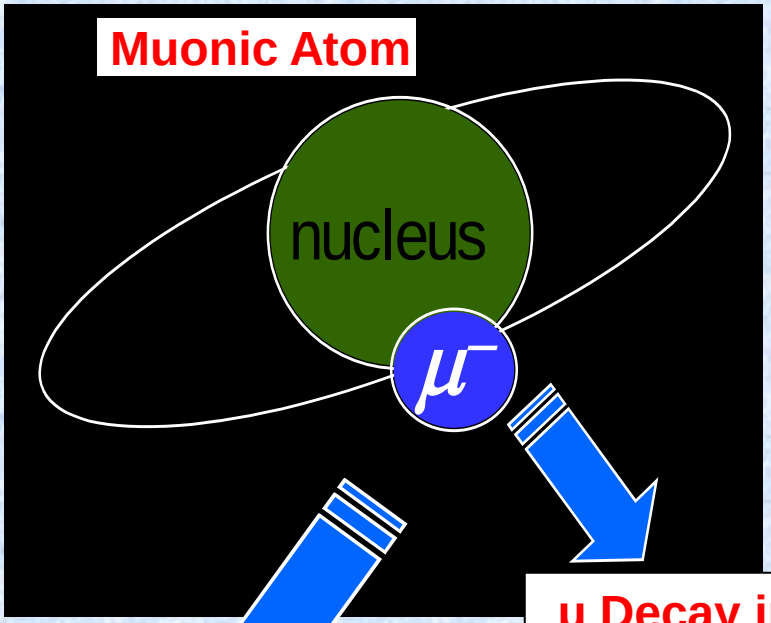
One PhD awarded H. N. Tran

Four others in progress: D. Alexander, A. Edmomds, B. Krikler, J. Quirk



Muon-to-Electron (μ-e) Conversion
Lepton Flavor Violation

Lepton Flavor Changes by one unit
Coherent Conversion
$\mu^- + A \rightarrow e^- + A$



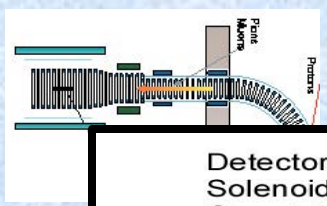
$$R_{\mu\to e} = \frac{\Gamma\left(\mu X \to eX\right)}{\Gamma\left(\mu X \to \nu_\mu X' \ldots\right)}$$

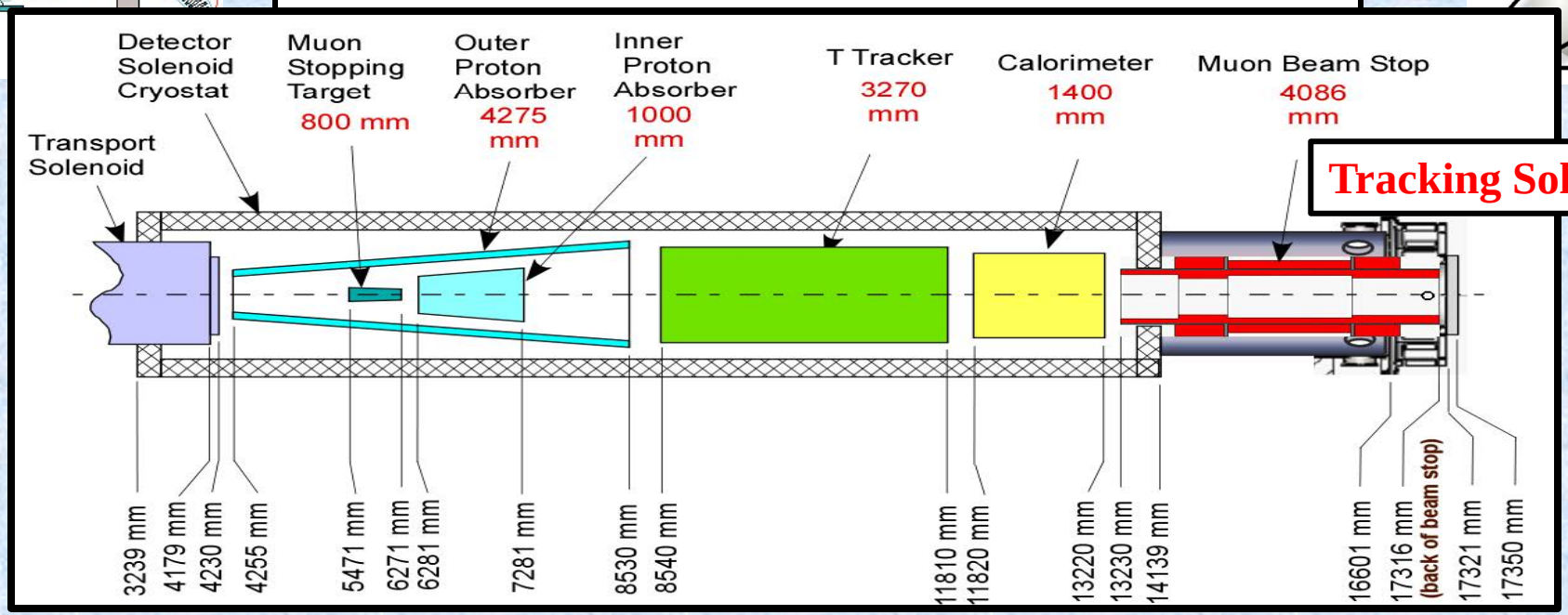
Normalization

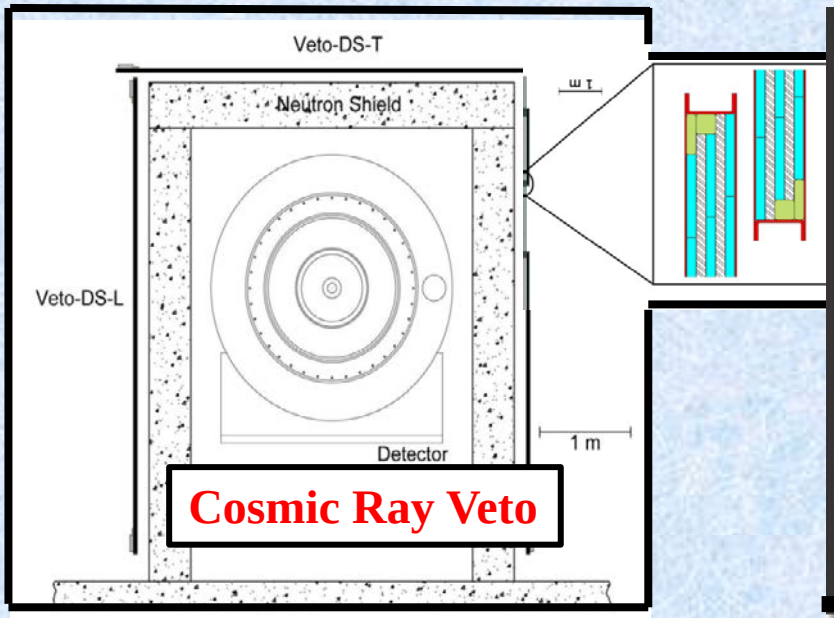
μ Decay in Orbit (DIO)
$\mu^- \rightarrow e^- \nu \nu$

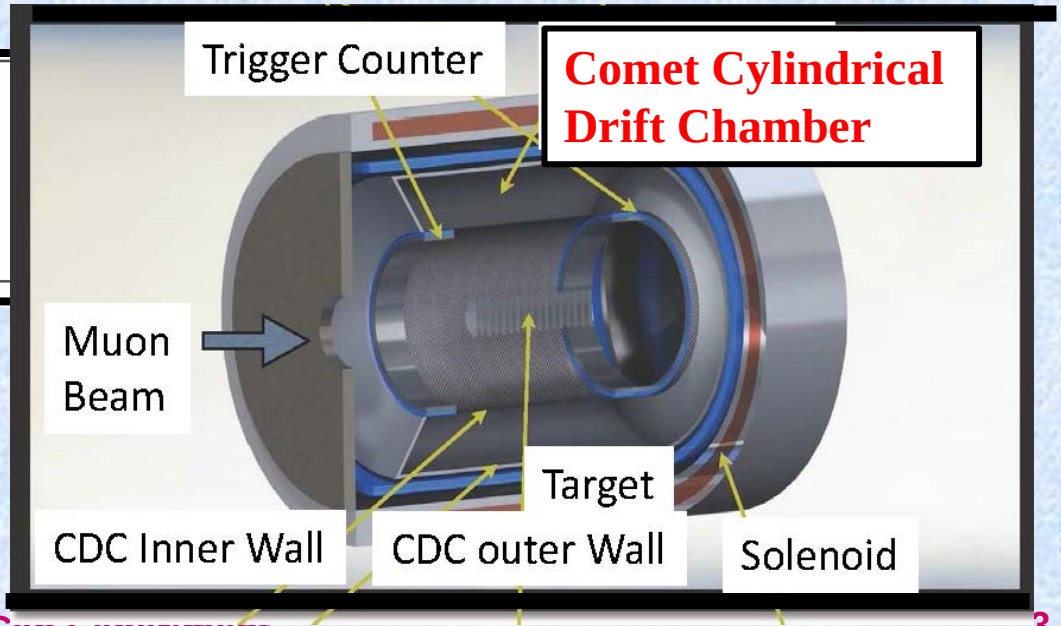
Nuclear Capture
$\mu^- + A \rightarrow \nu + [N + (A-1)]$

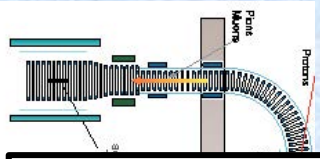
Mu2e/Comet Detector Components











Status

Comet (Phase I)

The cylindrical drift chamber (CDC) is under construction

1) Inner wall to be completed and installed in 2015.

Mu2e

Successful DOE review in October 2014

1)Release to purchase long-lead items (Superconductor, Civil Construction to begin)

2)Permission to proceed to CD3 for other items - 2015

Open Questions

1) High Proton emission requires a Proton absorber – what thickness? Degrades resolution/ adds backgrounds

2) **Neutron capture requires redesign of shields, e.g high density concrete for Cosmic Ray Detector**

3) Neutron single event upsets

4) Beam flash impacts choice of normalization detector

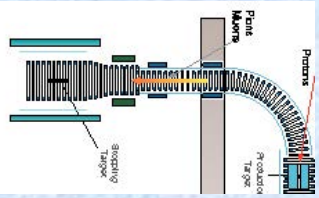
5) Normalization accuracy

Work Packages

1)Proton emission

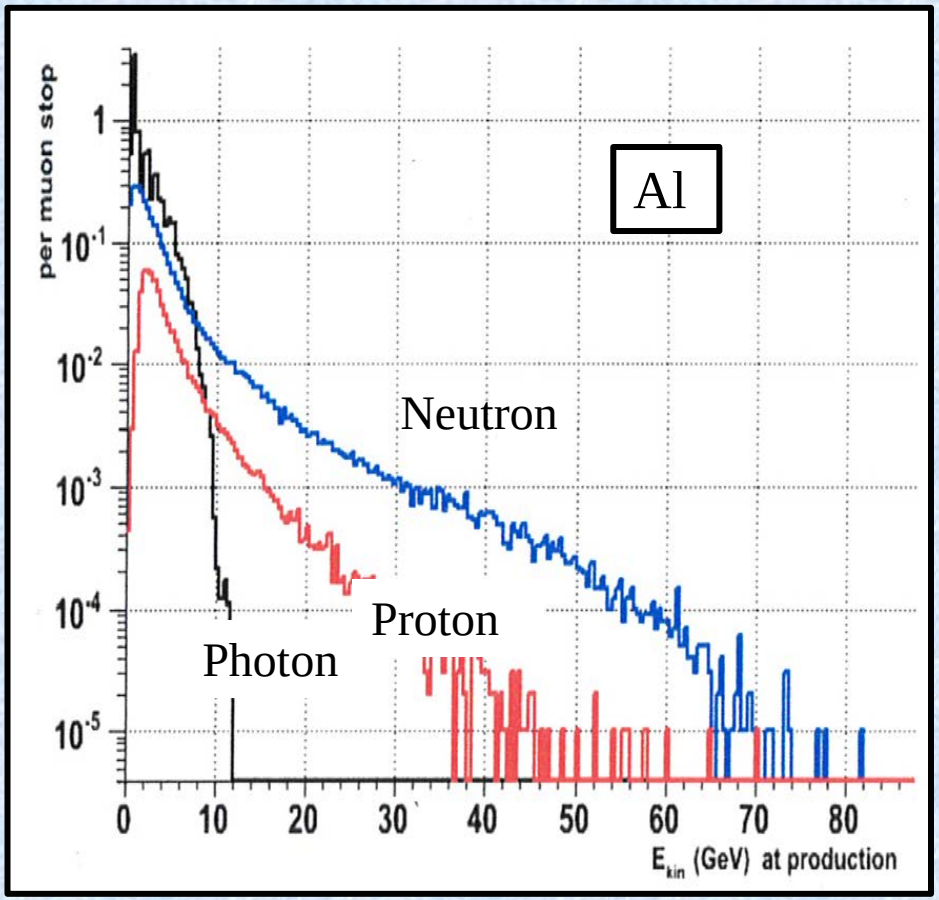
2) Neutron emission

3)X-Ray and Gamma Ray

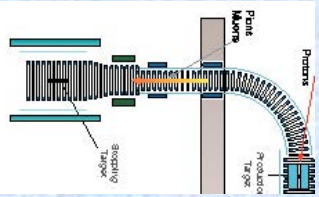


MC Simulation of Particle Emission from Al

FLUKA MC Neutron, Proton, Photon



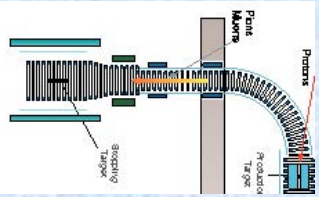
Simulation Statistics Al Target	
Ratio	**Value(%)**
Decay/μ-stop	**26**
Capture/μ-stop	**74**
Proton/Neutron	**24**
0 Neutron/ μ-stop	**29**
1 Neutron/ μ-stop	**39**
2 Neutron/ μ-stop	**4.5**
3 Neutron/ μ-stop	**0.18**
4 Neutron/ μ-stop	**0.00072**
5 Neutron/ μ-stop	**0.00003**
Total Neutron/ μ-stop	**44**
Avg. Neutron/ μ-stop	***1.18**
***Number not %**	



Run 2013
PiE1 Beam Line

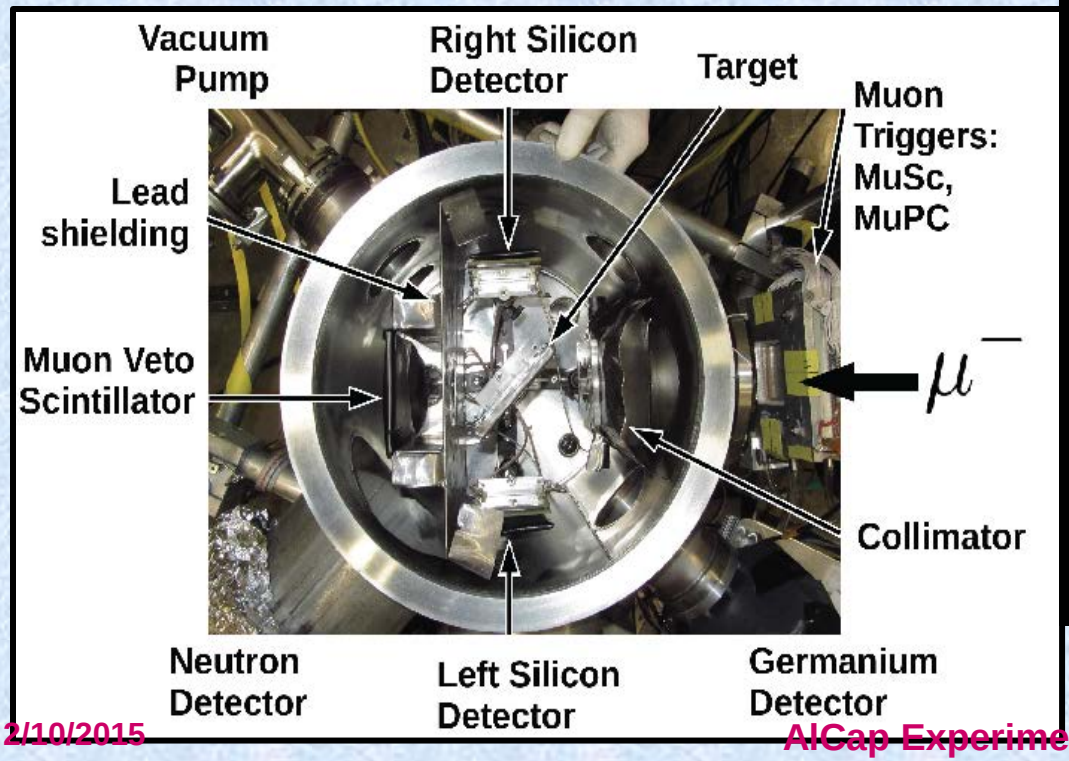
Table 2: Summary of the data that was collected during Run2013.

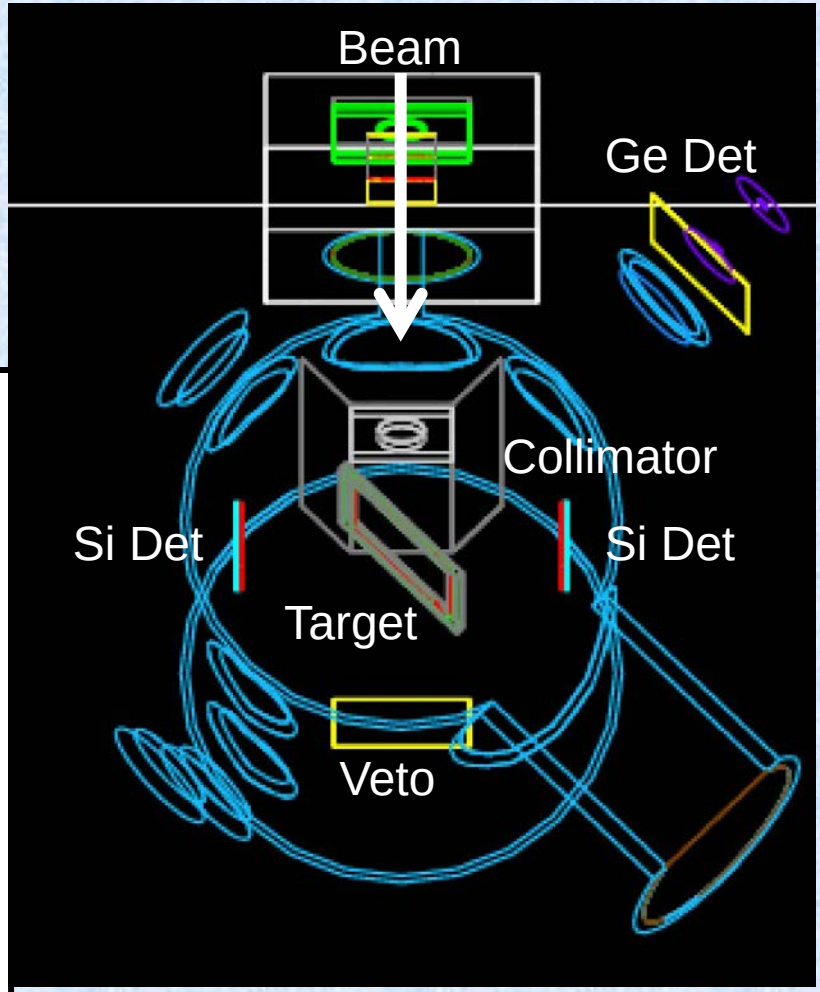
Target	Beam Momentum [$\times 28\,\mathrm{MeV}/c$]	Number of Muons	Comments
Si (1500 μm)	1.32	2.78×10^7	Active Target
	1.30	2.89×10^8	Cross check with
	1.10	1.37×10^8	existing Si data
Si (62 μm)	1.06	1.72×10^7	Passive Target
Al (100 μm)	1.09	2.94×10^8	
	1.07	4.99×10^7	
Al (50 μm)	1.07	8.81×10^8	

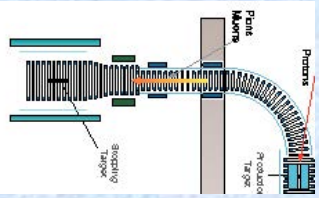


AlCap Geometry for Charged Particle Emission

- **Geant4-based Monte Carlo simulation exists**
- **Used to obtain the response matrices of the silicon detectors**

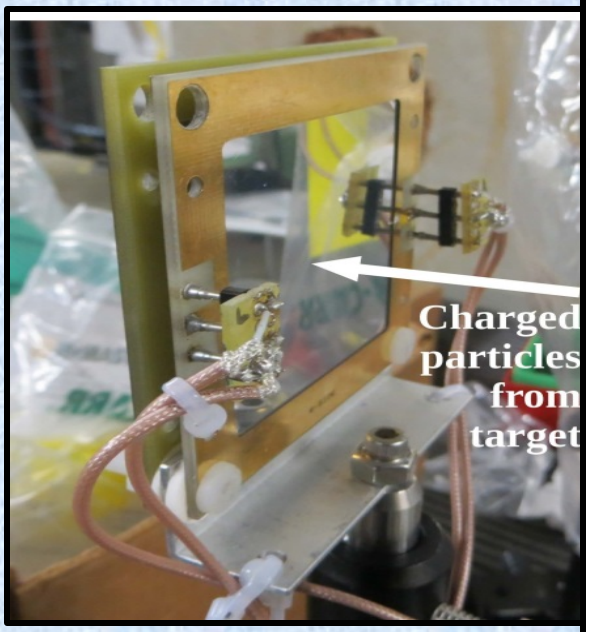


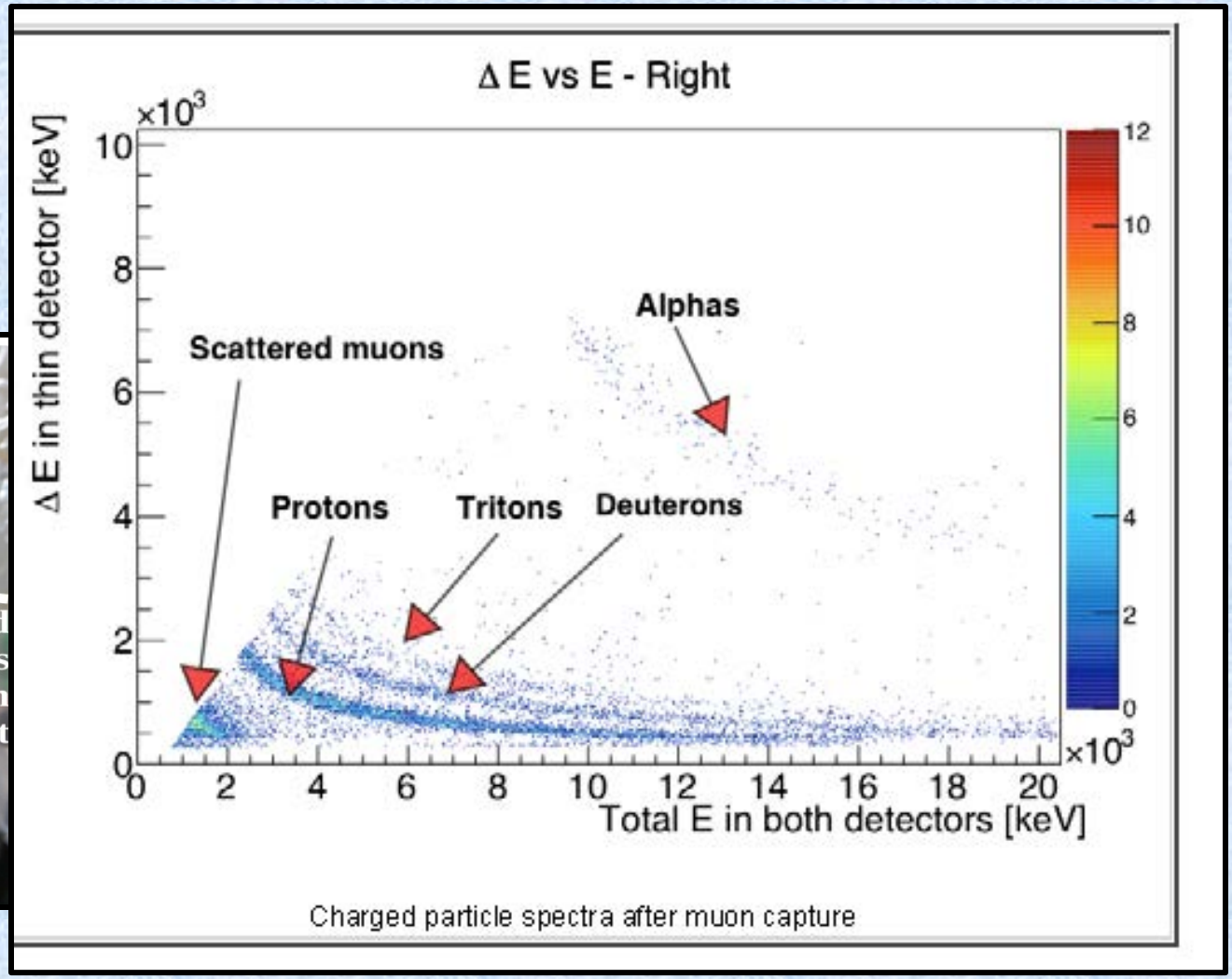


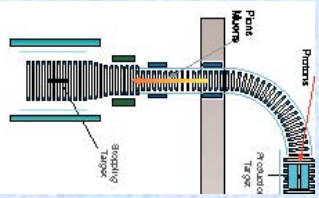


Charged Particle Emission Al-50

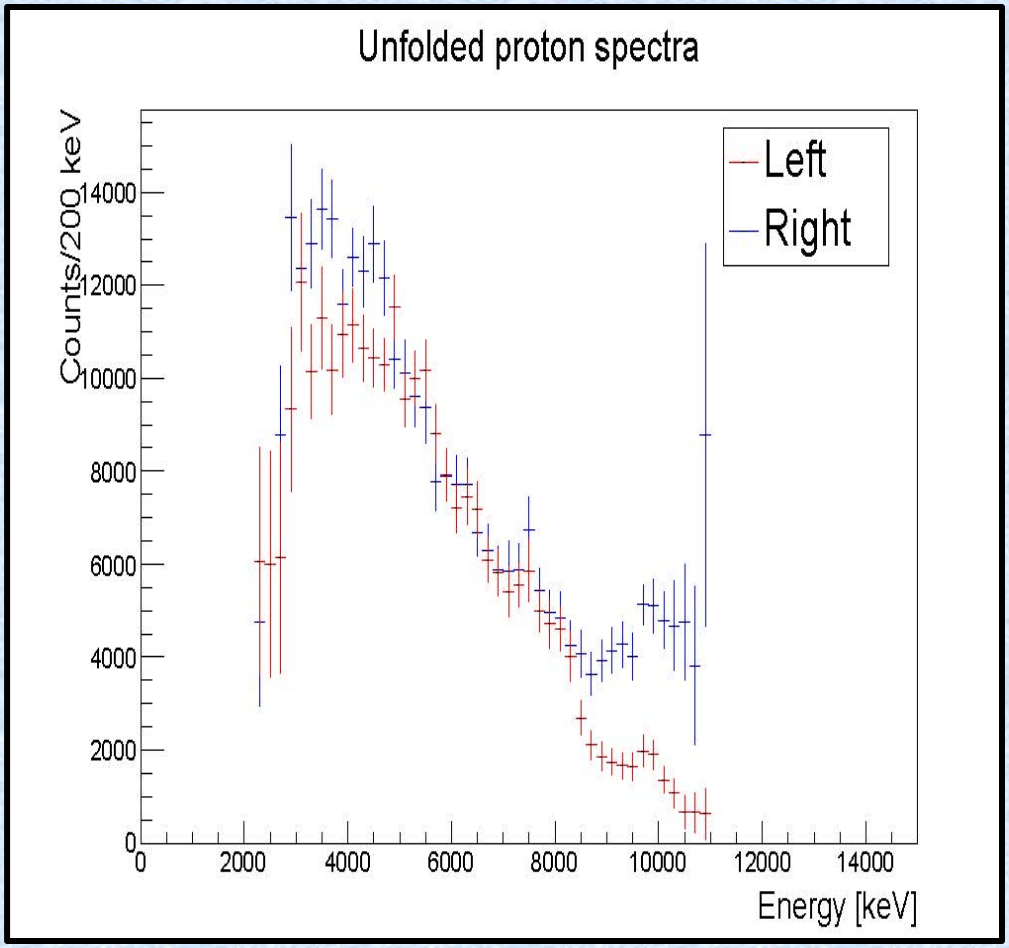
ΔE-E for PID
Time used to cut Pb background







Preliminary Results



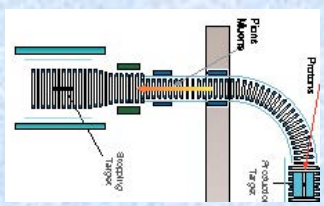
Normalization from recorded X-rays
Number of nuclear captures

N stopped = (1:57± 0:05) x10^7
N cap. = (9:57 ± 0:31) x10^6

Proton Emission 4MeV -8MeV

Rp = 1.7 x 10^{-2} (3.5% total)

Uncertainty 6.1% with dominant sources unfolding process (5%) and number of nuclear captures (3.2%). Consistency between the data sets needs work to understand systematics



Normalization for COMET/Mu2e

$$R_{\mu\to e} = \frac{\Gamma(\mu X \to eX)}{\Gamma(\mu X \to \nu_\mu X' \ldots)}$$

Error budget
10%

Prompt w/ Stop

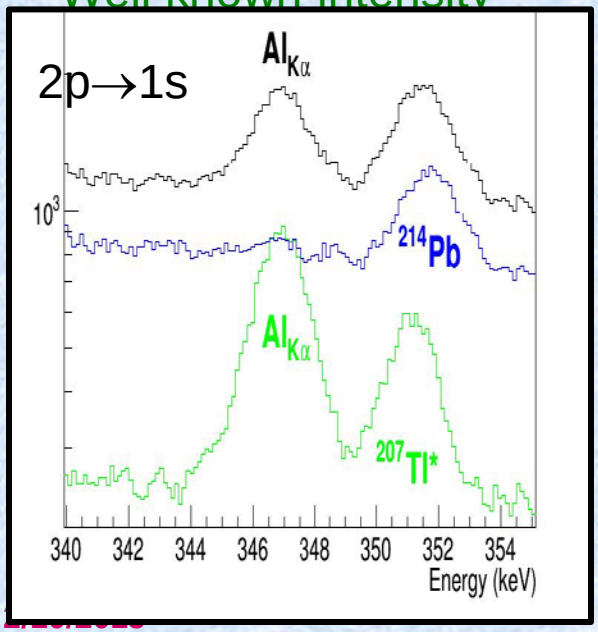
- Instantaneous
- Near beam flash
- Low energy (BG)
- Radiation damage concerns
- High intensity
- Well known intensity

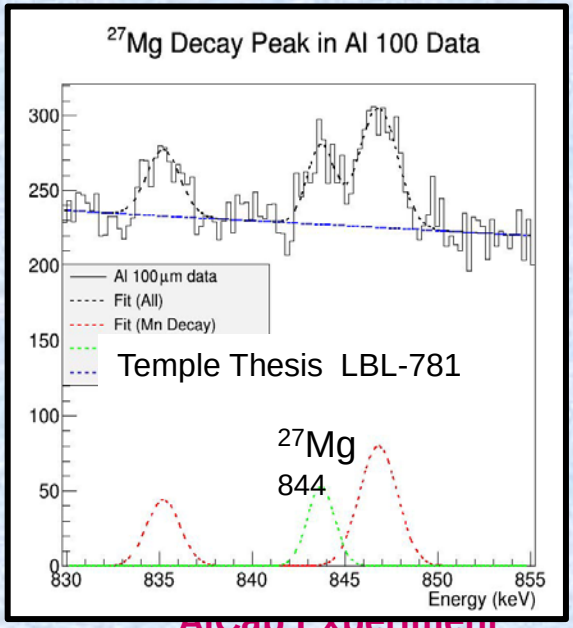
Prompt w/ Capture

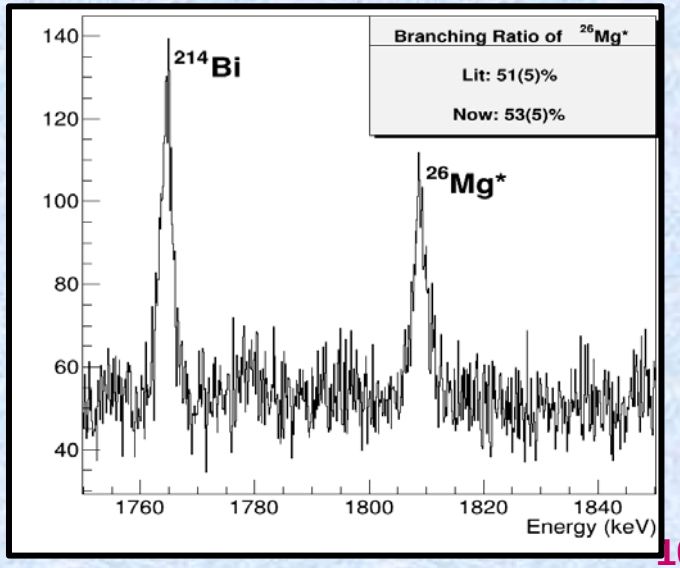
- Time structure same as muon disappearance
- High energy
- Potentially moderate intensity
- Intensities not well known

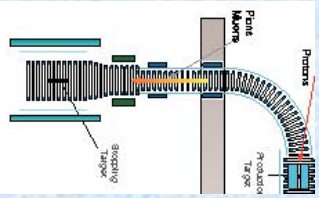
Delayed

- Measurement during beam off
- High energy
- Equilibrium with beam required
- Lower intensity
- Intensities not well
- known





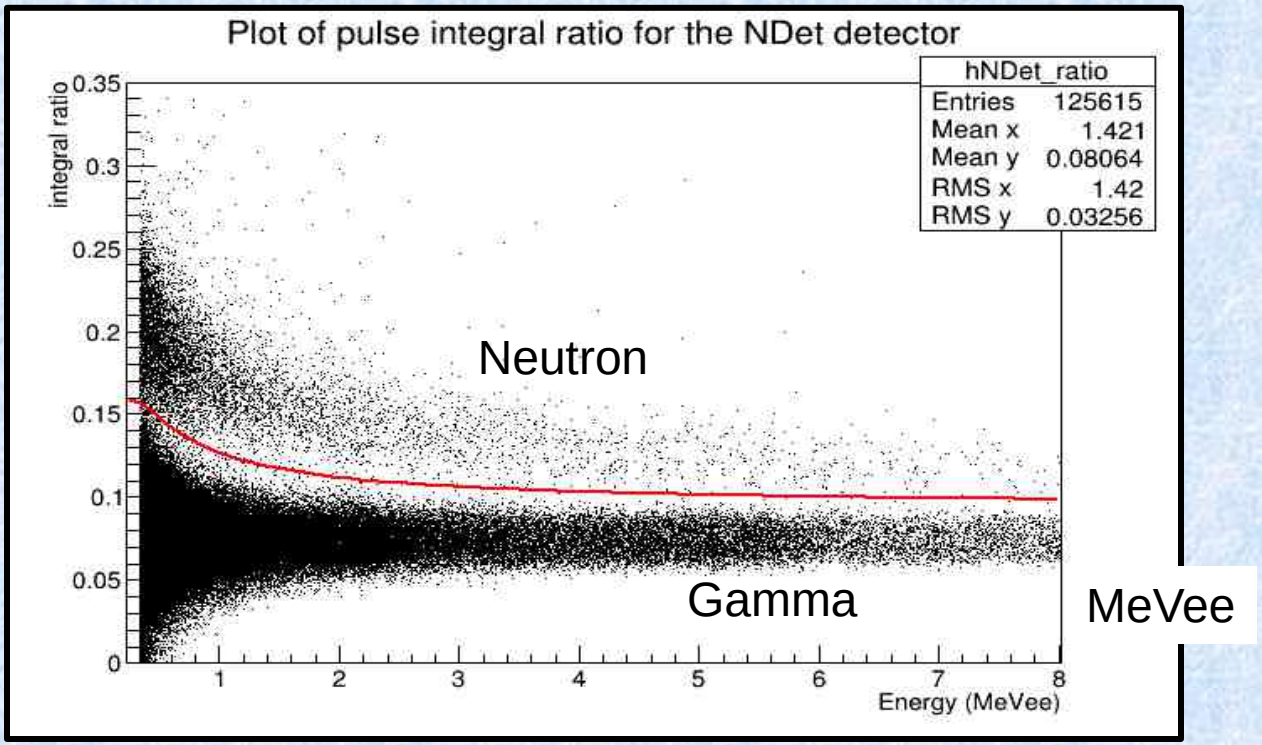


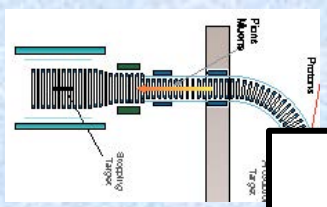


Neutron Emission (Preliminary)

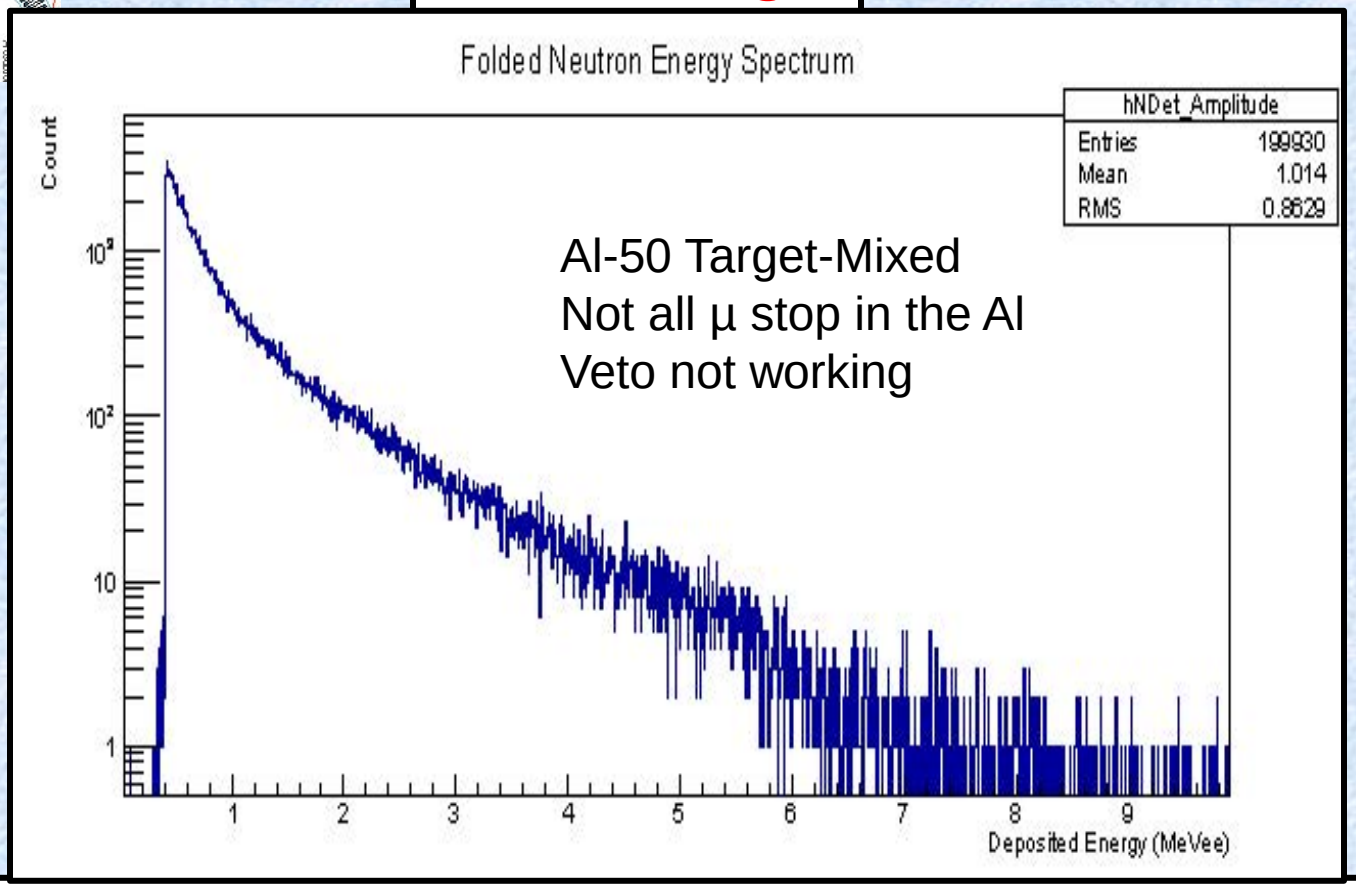
-2 Neutron Detectors Borrowed from MuSun Experiment
5”x5” BC 501

-Pulse shape discrimination using fast/slow integral ratio.
Slow integral defined as 30 to 200 ns after peak height.
PSD separation good to an energy < 0.5 MeVee



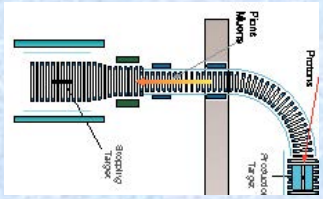


Unfolding

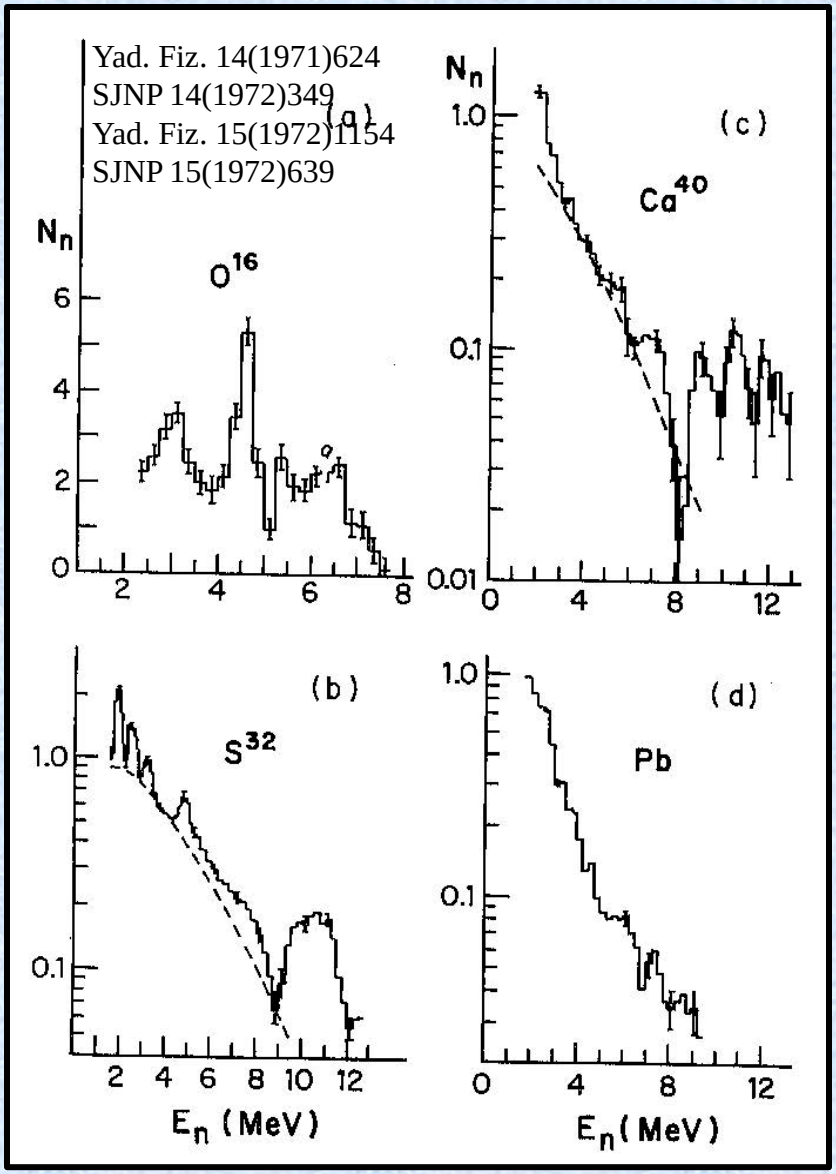


Present folding-unfolding response simulated using RESP7.
Applying software suite HEPROW using Gravel or Max. Entropy

Future will use 2 neutron detectors 5”x2.5” BC 501
500 MHZ Digitizer Readout – Pre-Calibrated at TUNL



More than Background and Rate Studies



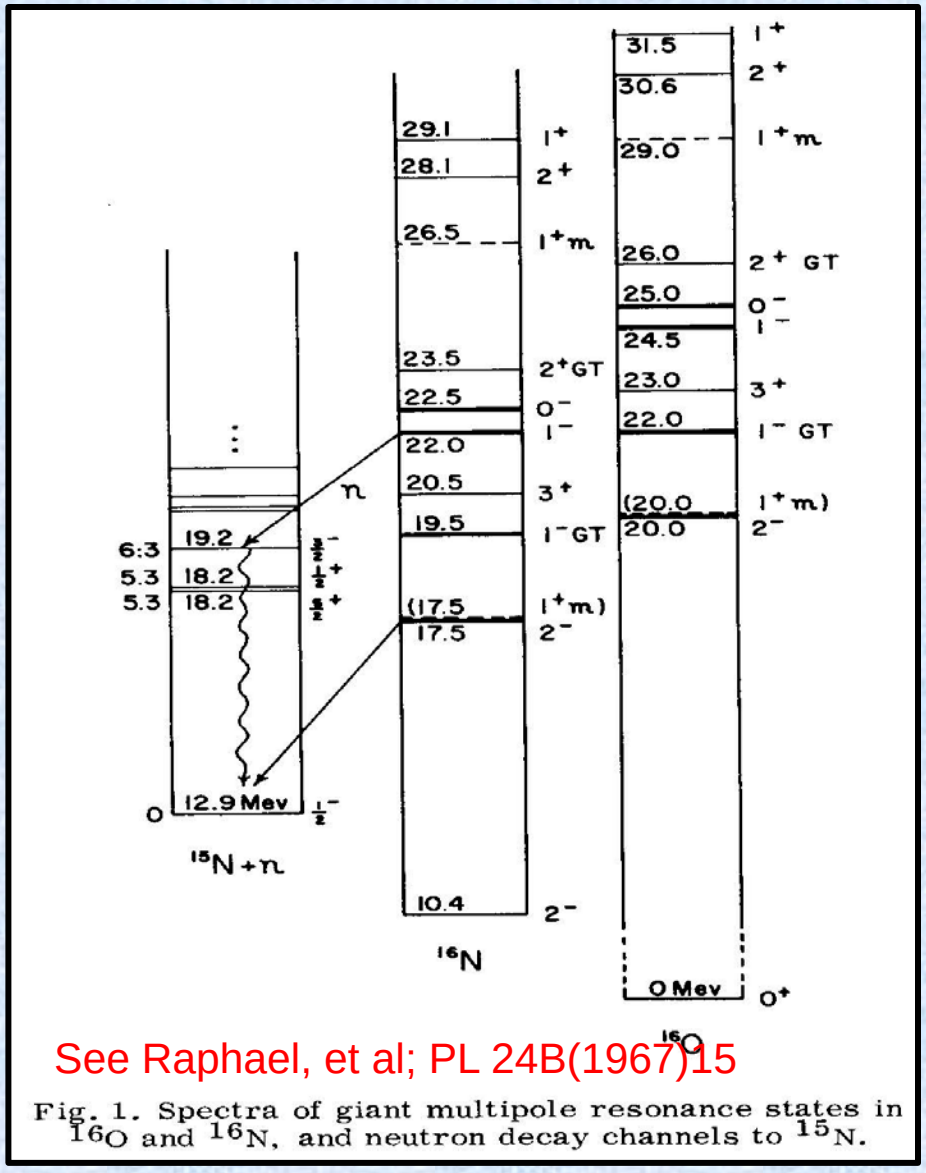
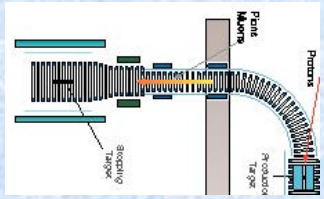
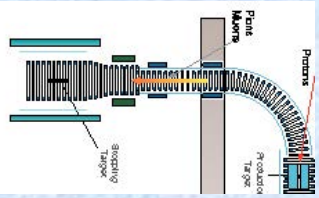


Fig. 1. Spectra of giant multipole resonance states in ^{16}O and ^{16}N, and neutron decay channels to ^{15}N.

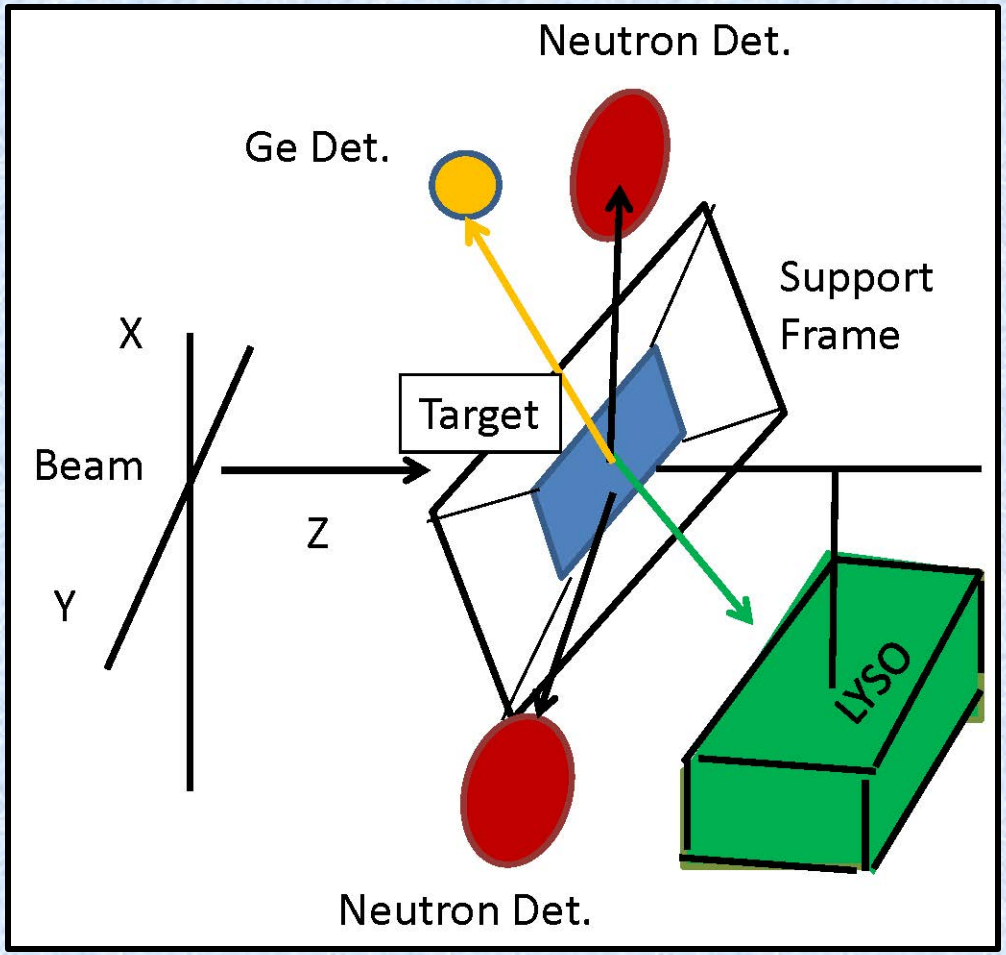


Experimental Up-Grades

1)Beam probe measurements at target location to better align beam on target
2)Improvements for measuring target position and target-detector geometry
3)Improved silicon detector preamp connections, shaping, and power to reduce noise
4)New commercial waveform Digitizer purchased to replace FADCs
5)Time resolution for Ge detector under investigation
6)Better Neutron detectors pre-calibrated and tested at TUNL
7)Gamma and Neutron runs using free standing target
8) Gamma and Neutron runs using higher momentum muons
9) Addition of a gamma LYSO detector for higher energy gammas

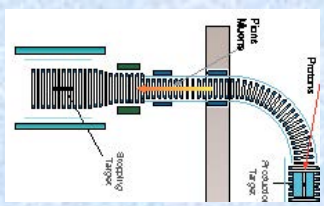


Sketch of Target Geometry



Free Standing Target

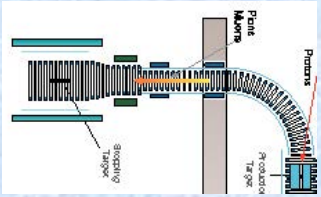
1)~2mm thickness (all μ stop)
2)~40 MeV/c beam
3) ~10 rate increase
3)Ge, Neutron Det in (y,z) plane
4)LYSO below target
5)Target rotated ~45° around y and x axis



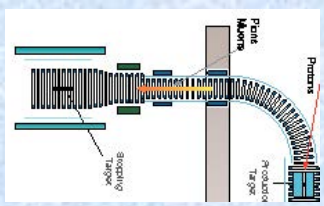
Run Request

Task	Days
Beam Tuning	**2.5**
Commissioning	**3.0**
Proton Studies	**10**
Neutron/Gamma Studies	**7.5**

1)Proton paper needs confirmation before submission
2}Gamma and neutron work needs more studies
3}High energy gamma studies just beginning



Backup Slides



Titanium

Prompt w/ Stop *X*-rays

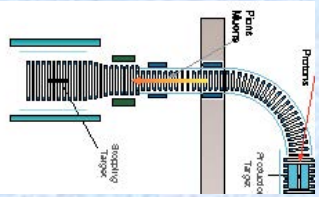
Transition	Energy (keV)	Relative Intensity
2*p*-1*s*	942	100%
3*p*-1*s*	1122	10.2%
4*p*-1*s*	1189	3.1%
5*p*-1*s*	1220	3.6%
6*p*-1*s*	1236	4.1%

Absolute intensities not known

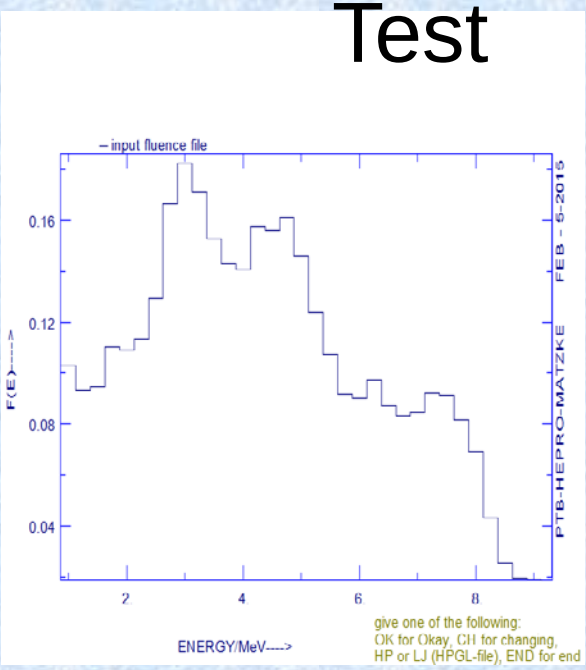
Prompt w/ Capture Gamma-rays

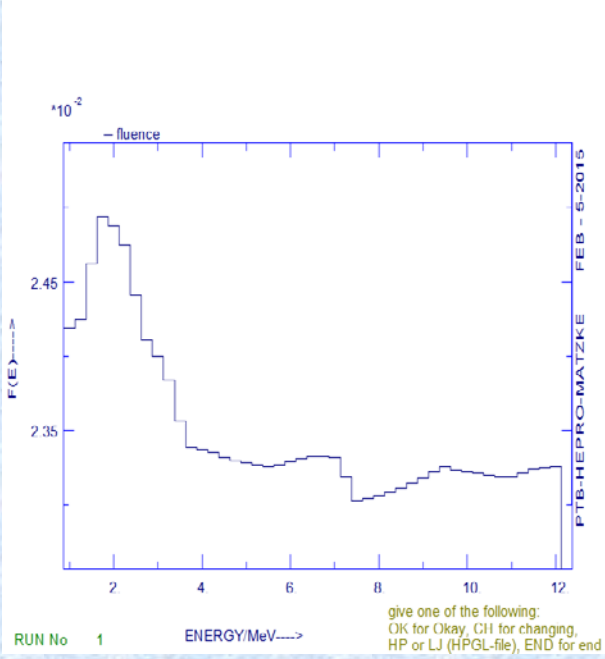
Resultat Isotope	Energy (keV)	Intensity
^{48}Sc	121.4	10.5(9)%
^{48}Sc	130.9	10.4(9)%
^{48}Sc	370.3	12.2(8)%
^{47}Sc	807.8	13.0(15)%

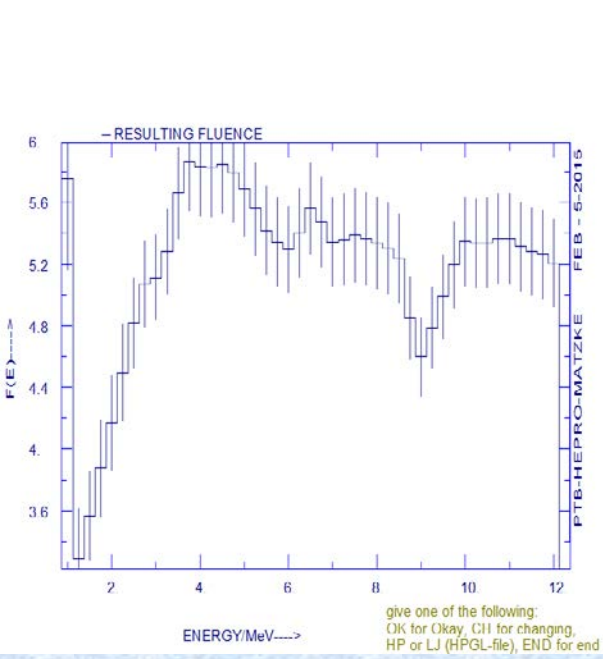
- Initial step to learn absolute *X*-ray intensities
- With same setup improvement as required for Al data, simulations indicate the Prompt w/ Capture signal intensities can be measured better in < 2 days
- According to literature, all Delayed signals are too long lived to be measured by AlCap
- The literature is sparse, and other signals may be identified



ISO AmBe Spectrum Unfolding Test





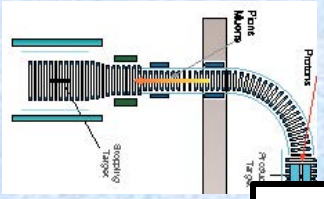


Input spectra (ISO 8529-2 standard)

Unfolding using Gravel algorithm after convolution

Improving the unfolding using Maximum Entropy method

The results are preliminary, but do give us a good start. Data runs still need to be unfolded.



Neutron Rates

An estimate of the SEU in various FPGA's using information of the test in the **iRoC report transmitted**

1 Neutron Background at the standard NYC latitude 40.7^0 N (Sea-Level)→ 14 n/hr/cm^2 → 3.9 x10^{-3} n/s/cm^2

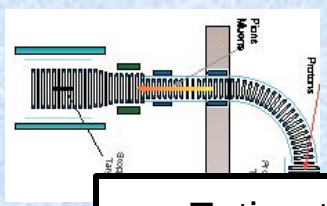
2 1 FIT = 1 failure in 10^9 hrs → 2.4 x 10^{-8} failure/day

3 Neutron Rate in the Tracker → 5 x 10^4 n/s/cm^2

4 Neutron Rate/Sea-Level Rate → 1.3 x 10^{-7}

The above assumes no error correction, but this may take a number of clock cycles. Also note that the iRoC report does not include functional interrupts and transients due to ionizations or radiation damage.

FPGA	Measured FIT Sea-Level	Scaled FIT Tracker	Failure/Day	Failure//Day 300 FPGA	Failure/hr 300 FPGA
Actel	<0.04	<5.2x10^5	<0.01	<3.6	--
Xilinx XC3S1000	320	4.2x10^9	100	3.0x10^4	1300
Altera	460	6.0x10^9	144	4.3x10^4	1800



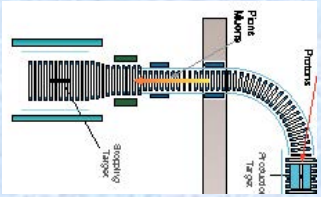
MyeongJae Lee
(LBNL) Mu2e Soft/Sim meeting, Jan 10, 2012

- Estimating Neutron flux is important to the Tracker electronics radiation hardness.
  - Fast neutron is an important source of Single Electron Upset (and subsequent failure) in the real time operation of electronics system.
- Target Tolerance level

  = 1 [reset of all electronics] / day

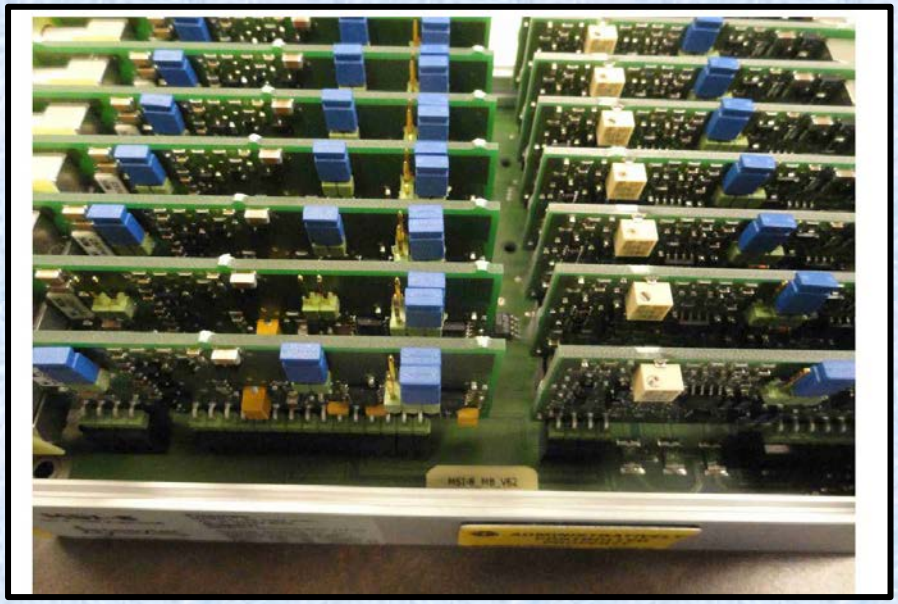
  = 64 / 21600 reset/day/chip = 3×10^{-8} reset/sec/chip
  - This means we can endure DAQ recycling once a day. Channel/chip ratio not decided yet.
- Lifetime of exp (including duty rate) = 4×10^{7} sec
- Life time neutron dose (all energy) = 2×10^{12} n/cm^2
  - Obtained from Mu2eG4. Muon capture neutron is dominant and considered only.

($\times10^{10}$ n/cm2)	Thermal (KE <1eV)	Epithermal (1eV<KE<1MeV)	Fast (KE>1MeV)
Muon capture	15.9	76.9	**103**
MBS	0.198	1.56	0.785
Beam Flash	0.240	1.28	1.56
Production Solenoid	0.561	0.087	0.00

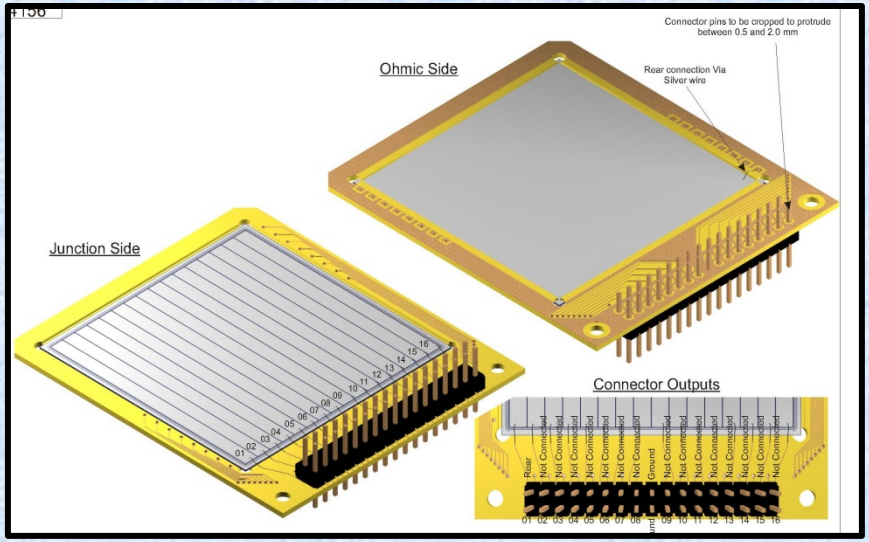


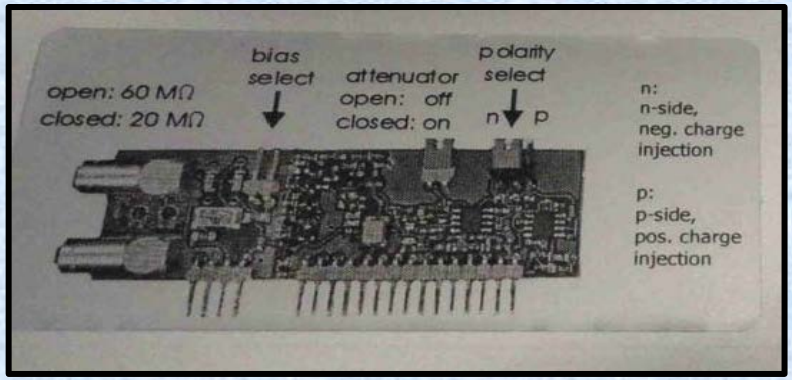
Experimental Upgrades

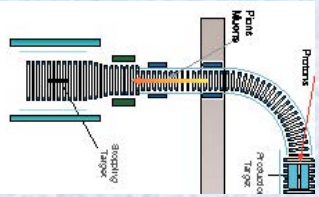
Mesytec MSI-8 16 Channel Preamp/shaper



Micron 65 μm 16 strip ΔE Silicon Detector

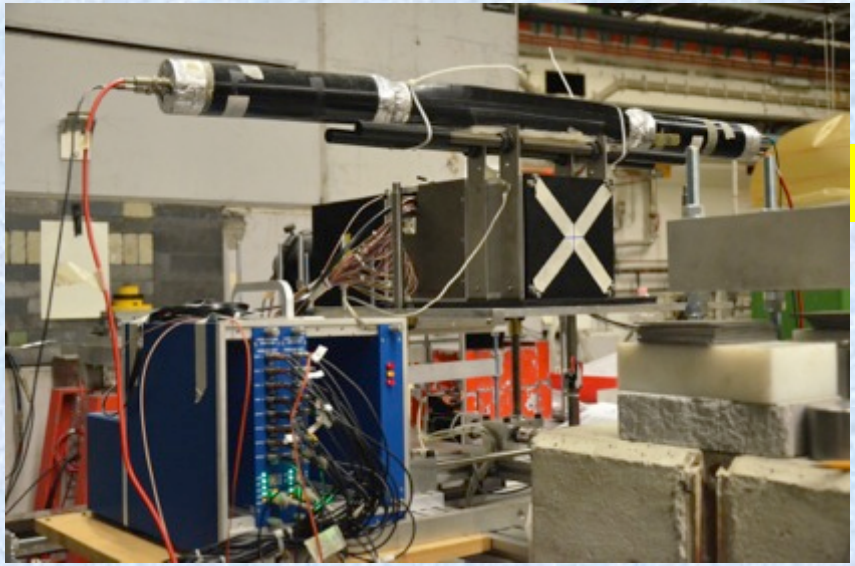




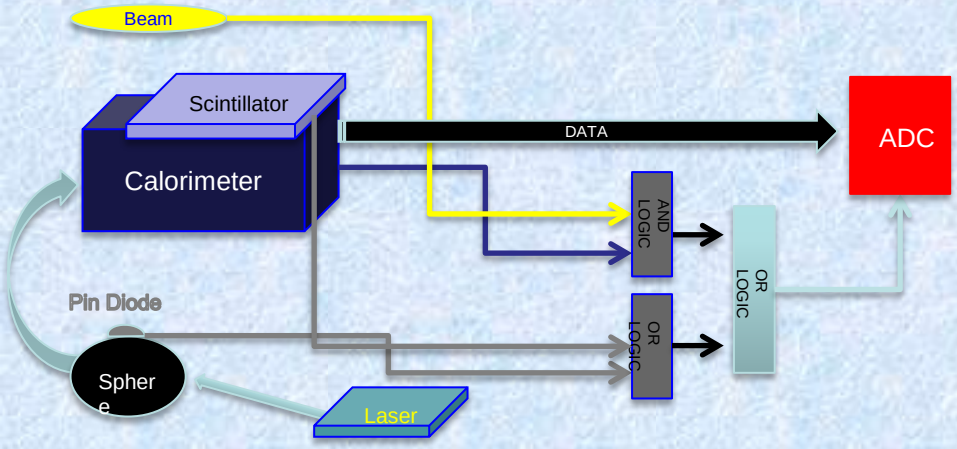


Experimental Setup

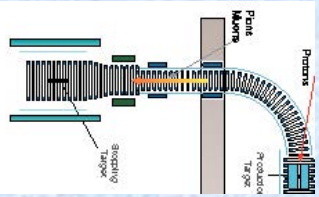
- The calorimeter prototype was installed over a movable table in front to the photon's beam
- We have triggered using a coincidence between the OR of the discriminated signal from the sum of the central crystals (threshold on the sum ~ 5 MeV) and the reference tagging signal from the scintillating spectrometer.



BEAM

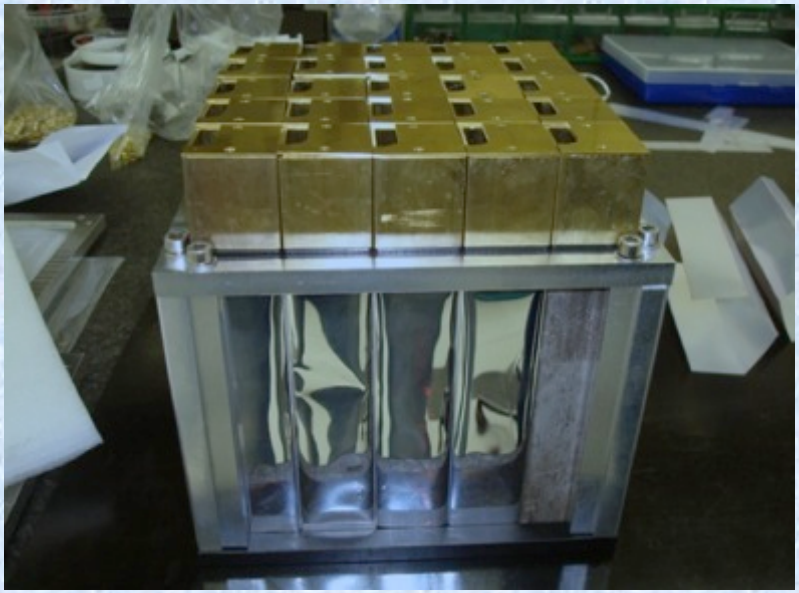


Simplified Trigger Scheme



Matrix assembly: cabling FEE

- The project and the development of the FEE have been done at LNF by the SEA electronic department
- The Amp-HV is a multi-layer double-sided discrete component board that carries out the two tasks of amplifying the signal and providing a locally regulated bias voltage, thus significantly reducing the noise loop-area.

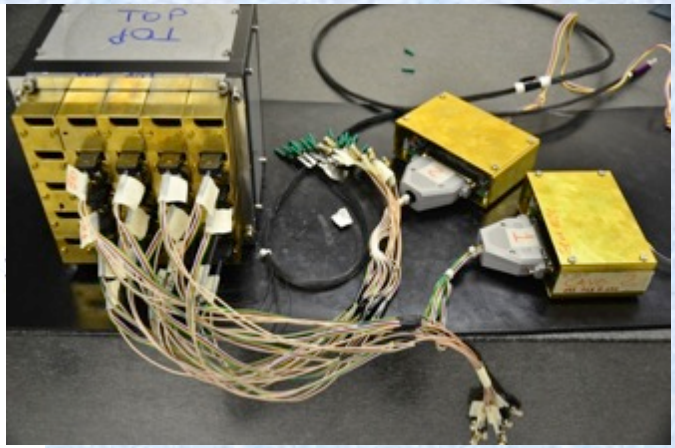


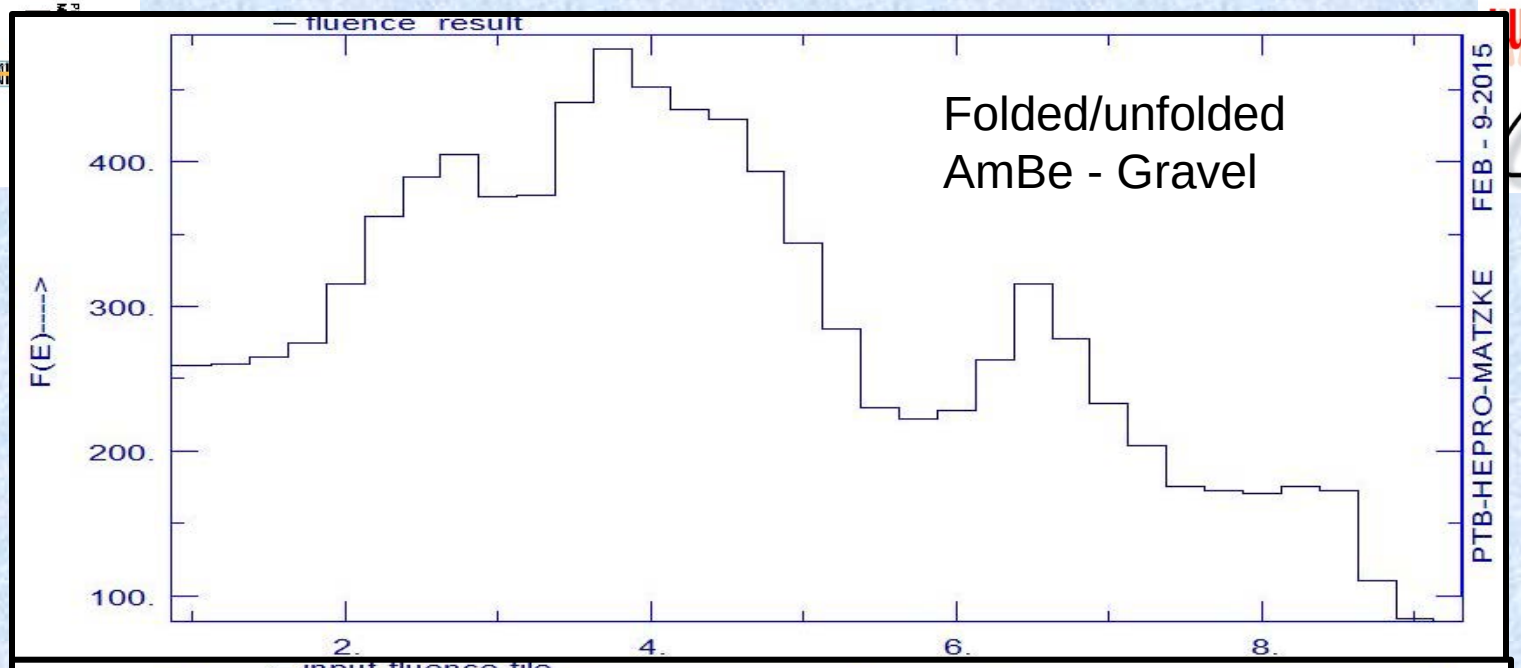
Amp.

Dynamic		2.5V
Bandwidth		70Mhz
Rise time		6ns
Polarity		Reversed
Output impedance		50 Ω
Stability with source capacity	max	300pf
Coupling output end source		AC
Noise, with source capacity 1pf		1000 enc
Power dissipation		14mW
Power supply		6V
Input Protector over-Voltage		10mJ

HV

Adjustment range Vout	250V to 500V
Accuracy, reading and writing, Vout	16 bit
Current limiter can be adjusted	tpv. 300uA
Noise tot.	2mVpp
Long-term stability	100ppm
Settling Time	<500 us $\rho <$
Typical power dissipation	135mW
Double filter high Voltage, attenuation	56db




— fluence result
Folded/unfolded
AmBe - Gravel
F(E)---->
400.
300.
200.
100.
2.
4.
6.
8.
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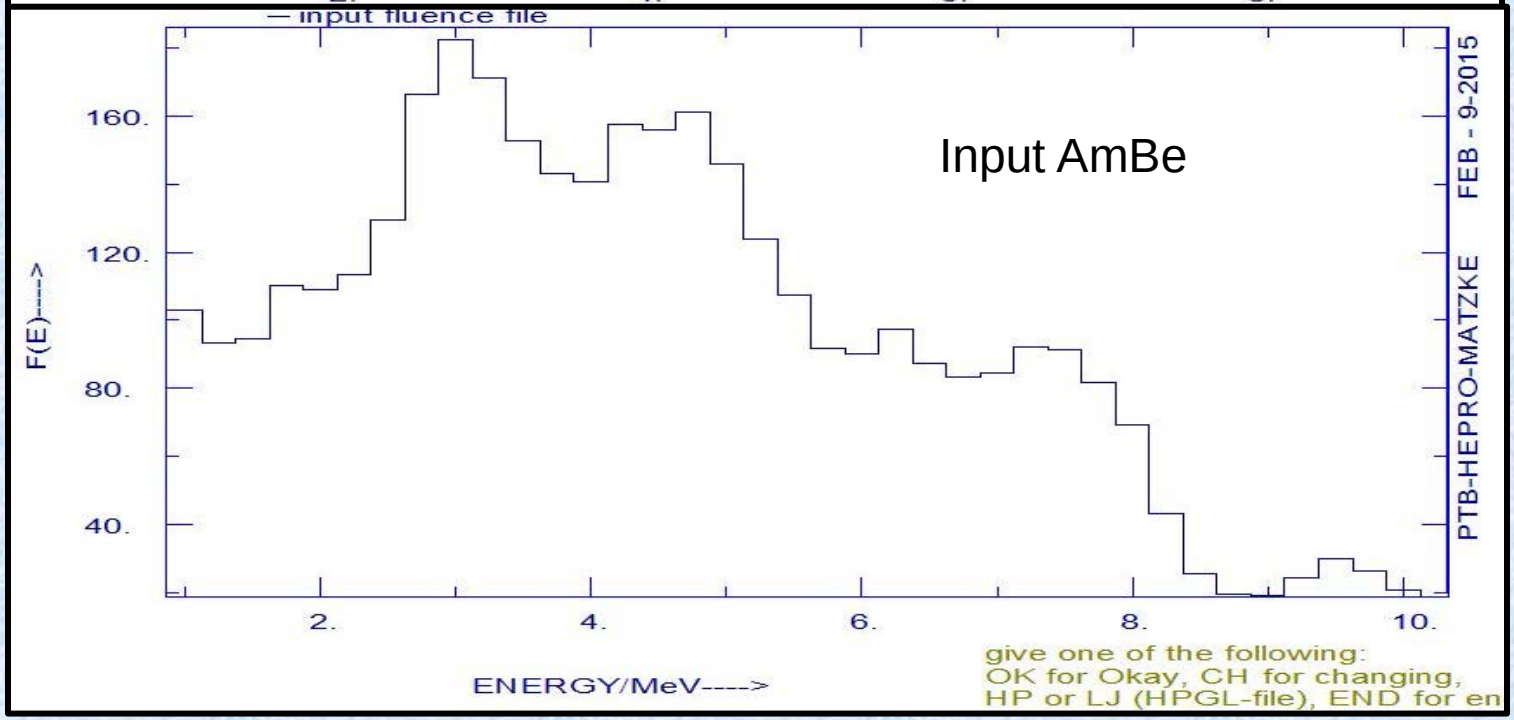
— input fluence file
Input AmBe
F(E)---->
160.
120.
80.
40.
2.
4.
6.
8.
10.
ENERGY/MeV---->
give one of the following:
OK for Okay, CH for changing,
HP or LJ (HPGL-file), END for en
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