Research in Experimental Nuclear Astrophysics

Ellen McCleskey

Post Doc TAMU/LLNL

REU Career Day July 25, 2014

Topics

- Master's Work at CSM
- PhD Work at TAMU
- Post Doc in Collaboration with LLNL

Masters Work

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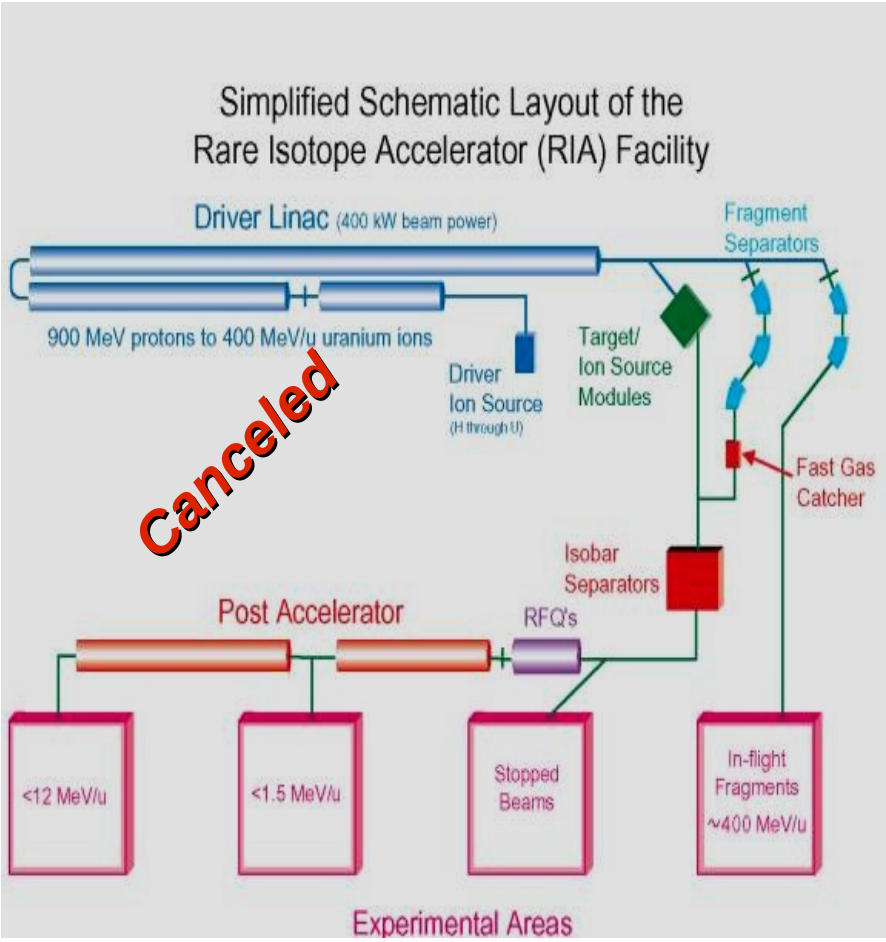
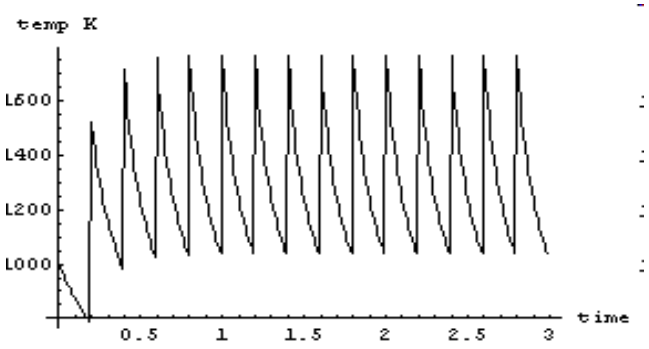
Beam Stripping in the Driver Accelerator at the Rare Isotope Accelerator

- Summary of Project:
  - Investigated the thermodynamics of stripper foils placed in beam
  - Foil Materials
    - C, Be, Al, Ti, V, Cu, Ag and Au
  - Simple Calculations done with ***Mathematica***
  - More complex heat flow simulations done with ***SOLIDWOKS + COSMOSWORKS***



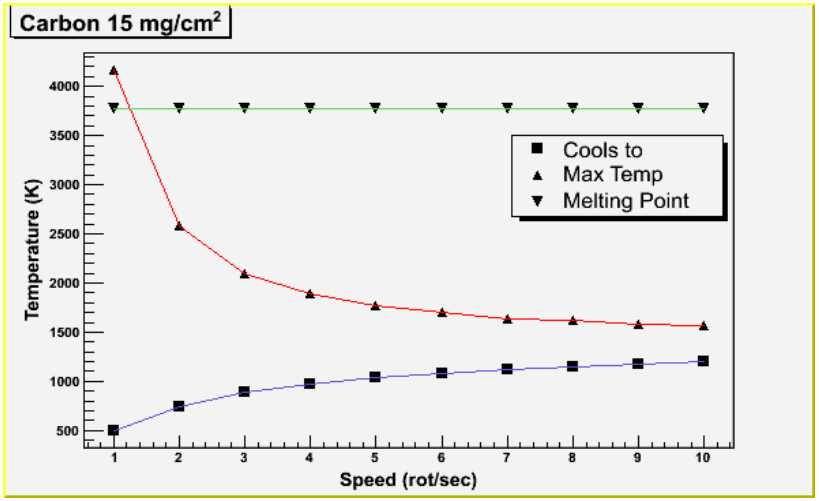


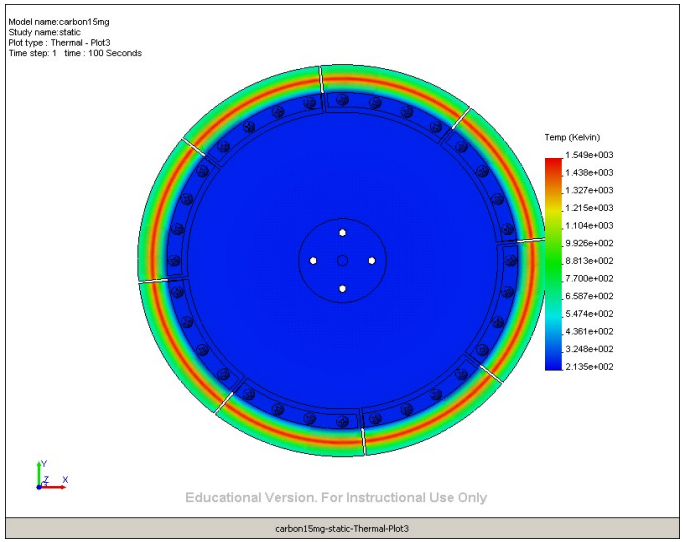
Copper Wheel

Target Foils

Stainless Steel Shaft

Aluminum Clamps





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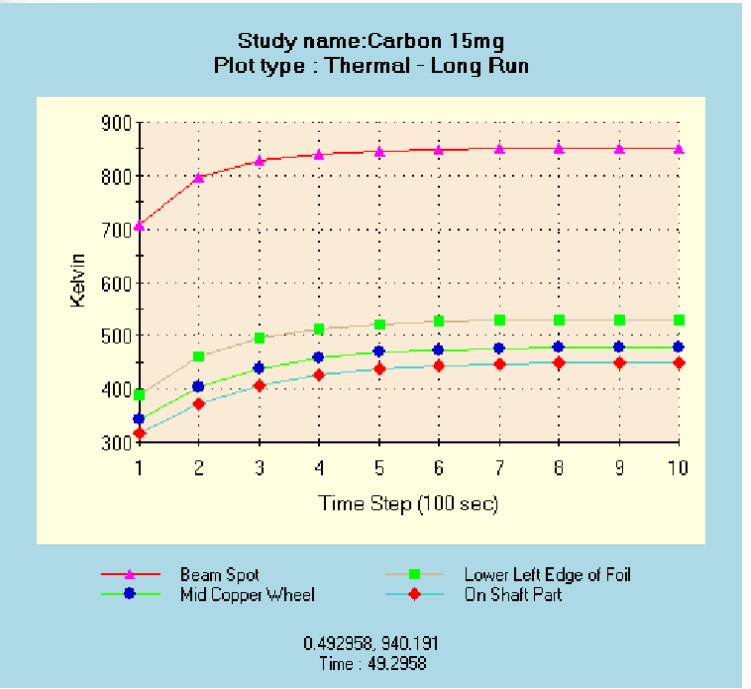
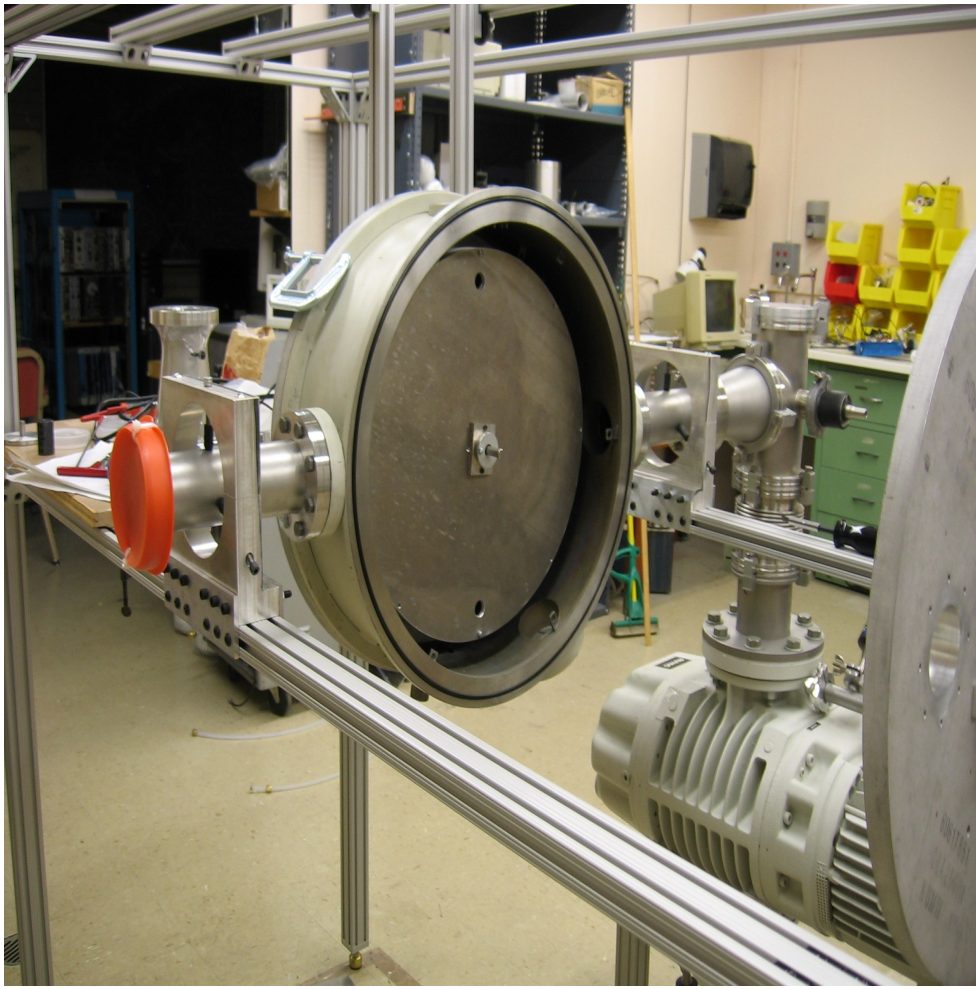


- In Conclusion:
  - CAD Programs:
    - AutoCAD
    - SOLIDWORKS
  - Calculation Tools:
    - Mathematica
    - MATLAB
  - Data Analysis Tools:
    - ROOT



PhD Work

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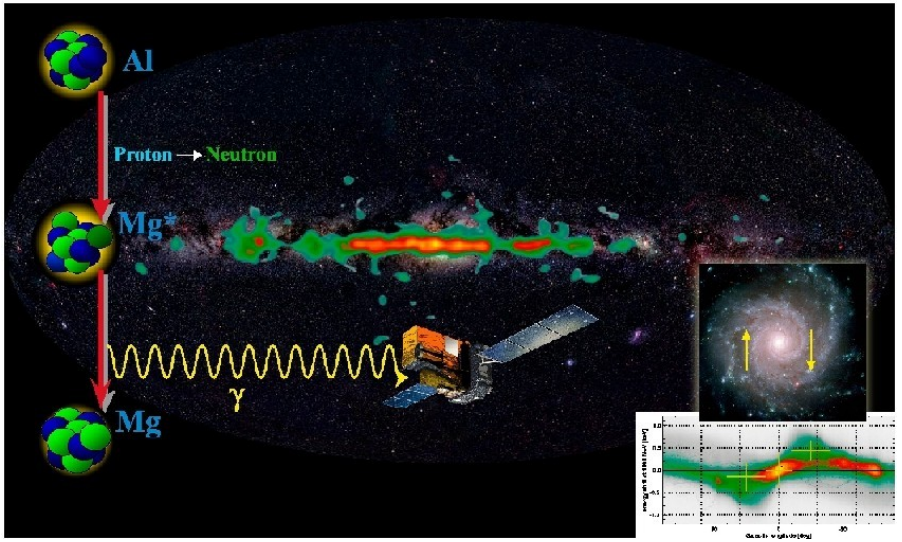
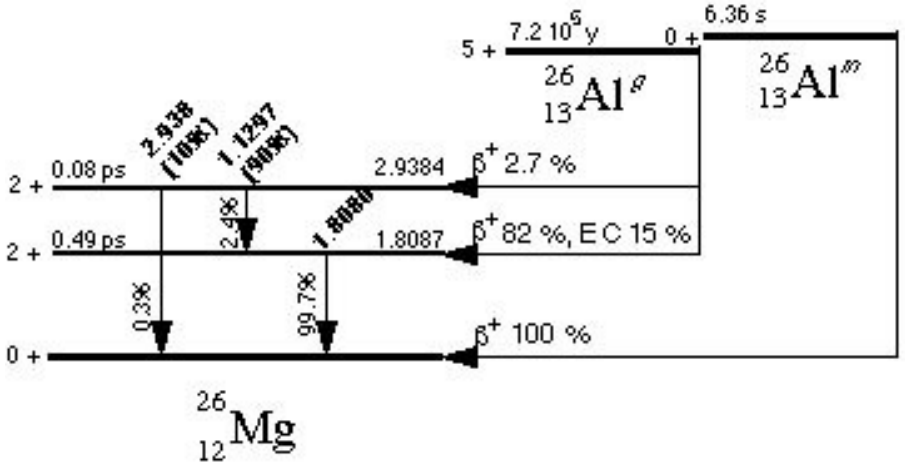
Astrophysical Observation

- First & most well observed gamma ray line from ^{26}Al g
  - First observed in 1982 by the HEAO-C Satellite
  - COMPTEL Sky Map of ^{26}Al (1991 – 2000)
- Ongoing nucleosynthesis
  - Dynamic Universe!
- Excess of ^{26}Mg in carbonaceous chondrites
  - Implications on the age of the solar system

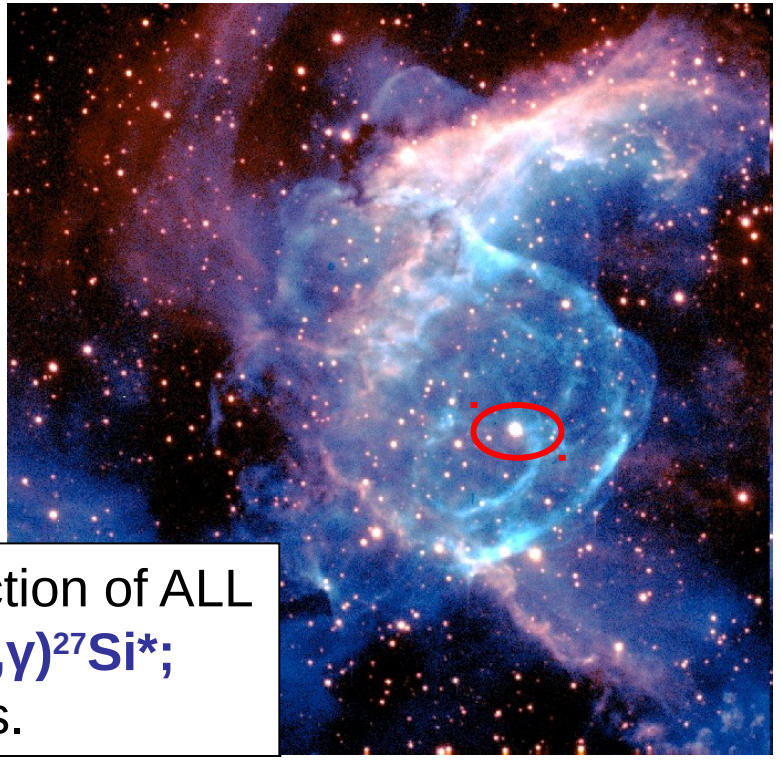


Astrophysical Interest

- Creation site of ^{26}Al is still under debate
  - WR & AGB Stars
  - Classical Novae
  - Core Collapse Supernova

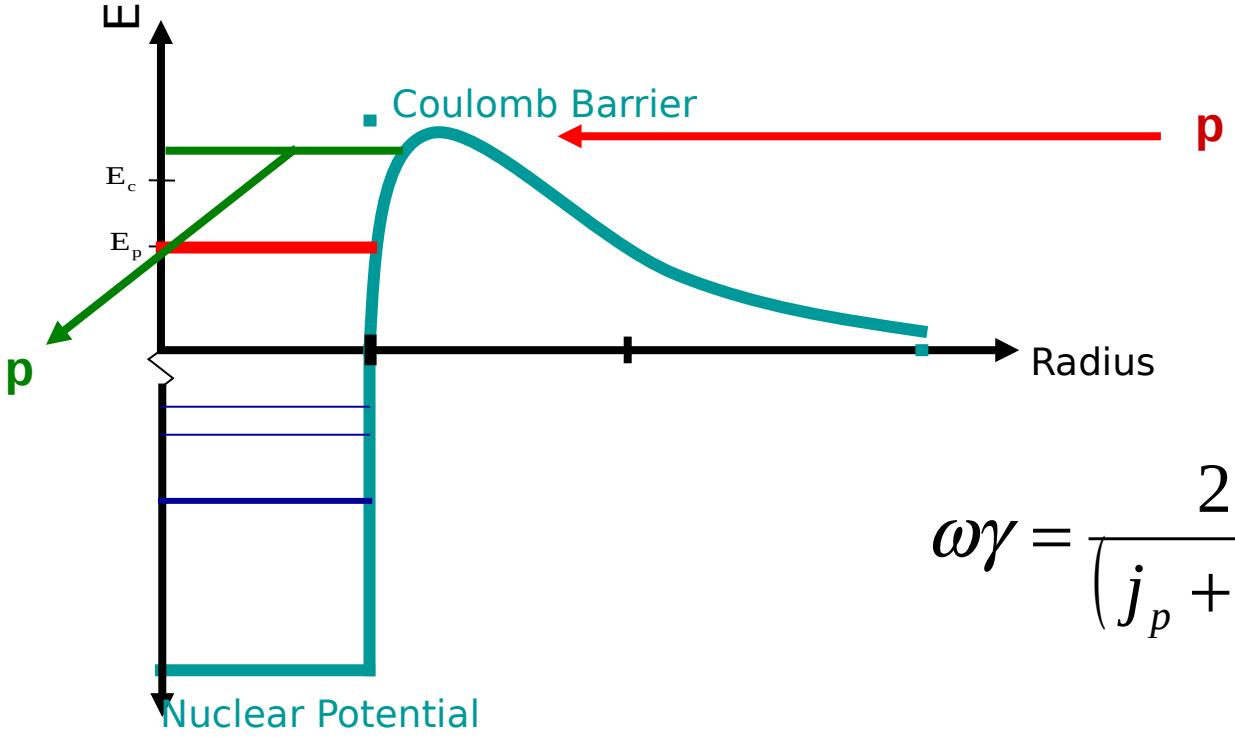


- For ^{26}Al^{g} & ^{26}Al^{m}:
  - Below temps of ~1 GK
    - Separate Species
  - Above these temps
    - Correlated



The study of reactions for production and destruction of ALL ^{26}Al are of high interest. I will focus on **^{26m}Al(p,γ)^{27}Si*;** dominated by resonant capture process.

Top of the Barrier



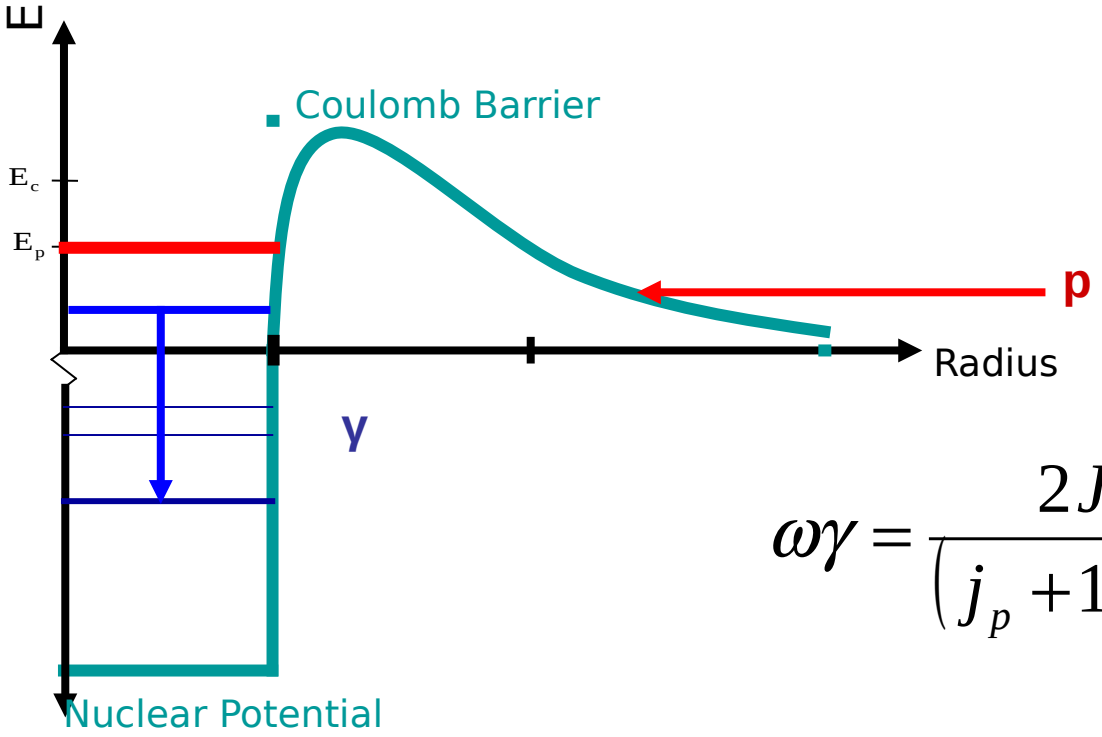
$$\omega\gamma = \frac{2J+1}{(j_p+1)(j_t+1)} \frac{\Gamma_{proton}\Gamma_\gamma}{\Gamma_{proton}+\Gamma_\gamma}$$

At the top of the barrier : $\Gamma_{proton} >> \Gamma_\gamma$

Mostly Protons!

$$\omega\gamma \approx \omega\Gamma_\gamma$$

Bottom of the Barrier



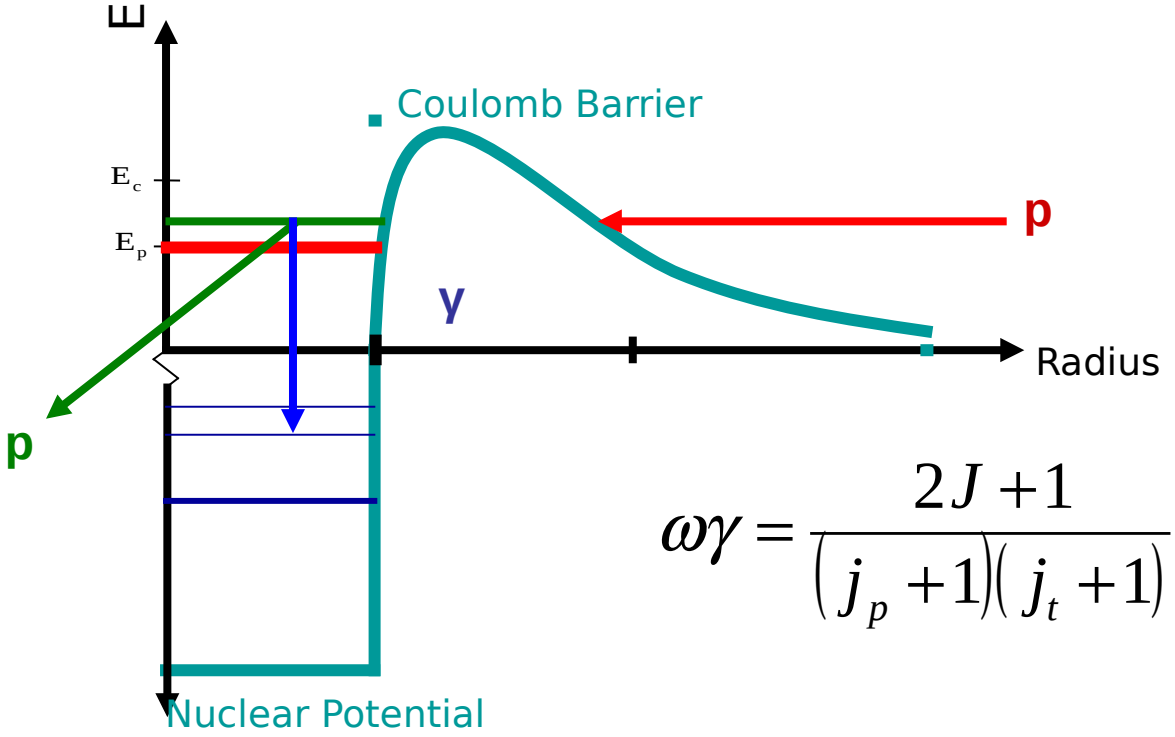
$$\omega\gamma = \frac{2J+1}{(j_p+1)(j_t+1)} \frac{\Gamma_{proton}\Gamma_\gamma}{\Gamma_{proton}+\Gamma_\gamma}$$

At the bottom of the barrier : $\Gamma_{proton} << \Gamma_\gamma$

Mostly Gammas!

$$\omega\gamma \approx \omega\,\Gamma_{proton}$$

Slightly Above the Proton Threshold



$$\omega\gamma = \frac{2J+1}{(j_p+1)(j_t+1)} \frac{\Gamma_{proton}\Gamma_\gamma}{\Gamma_{proton}+\Gamma_\gamma}$$

Slightly Above the Proton Threshold : $\Gamma_\gamma >> \Gamma_{proton}$

$$\omega\gamma \approx \omega \frac{\Gamma_{proton}}{\Gamma_\gamma}\Gamma_\gamma \approx \omega \frac{b_{proton}}{b_\gamma}\left(\frac{\hbar}{\tau}\right)$$

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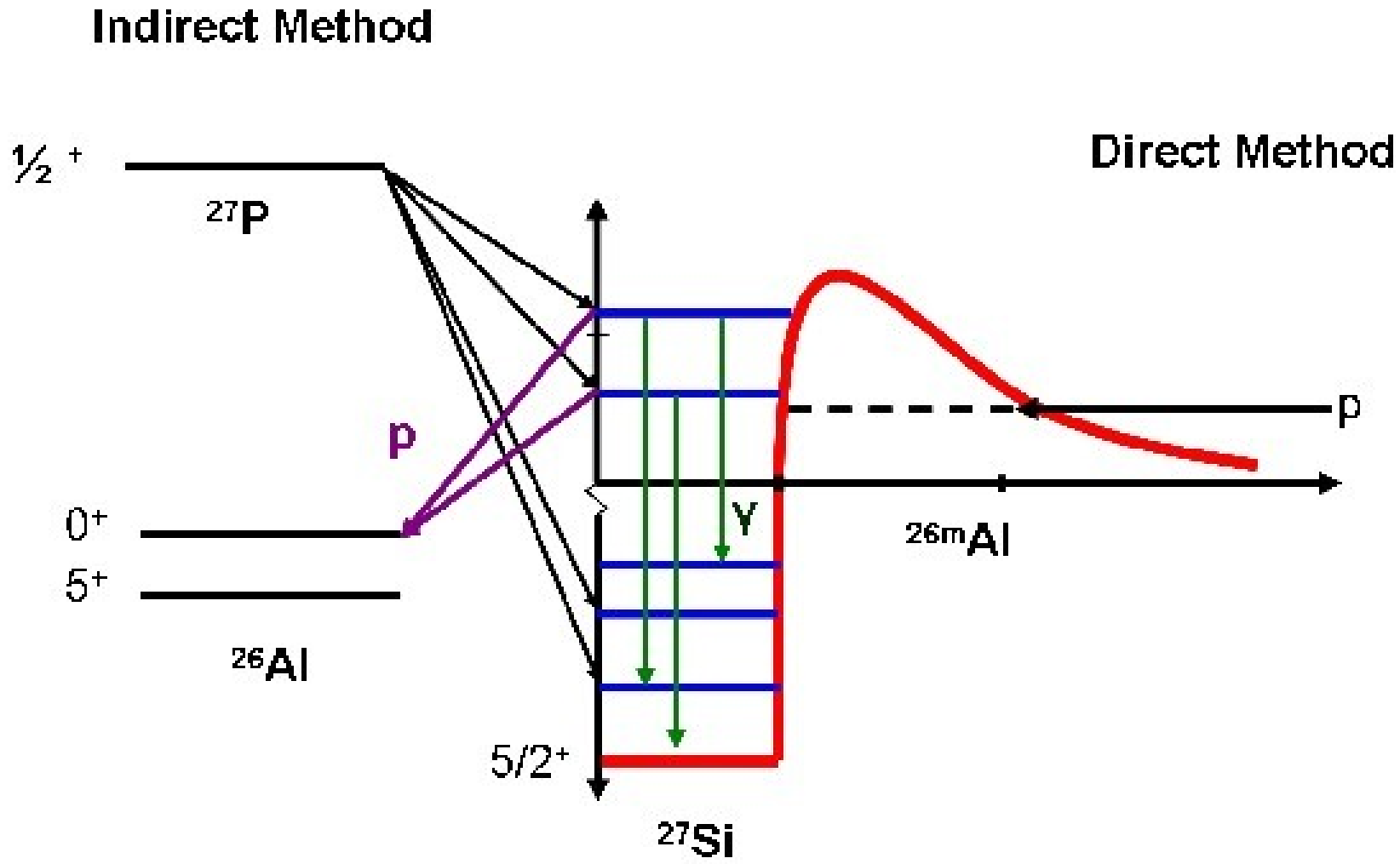
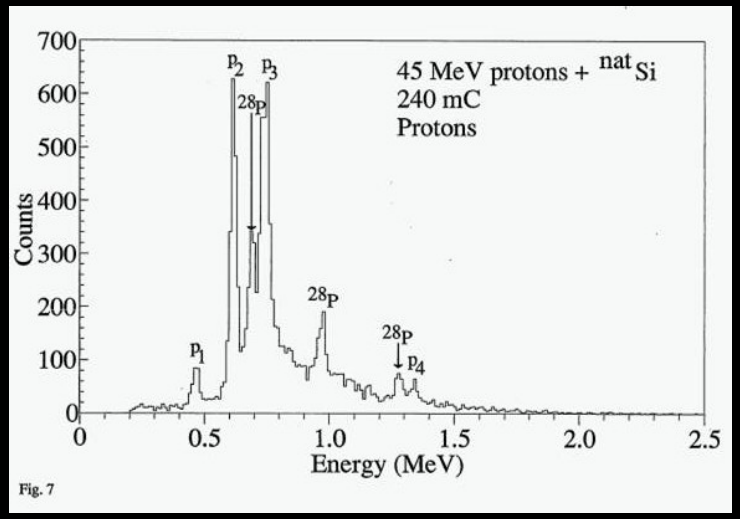


The ***Beta-Delayed*** Proton Decay Study of ^{27}P

Previous Work on ^{27}P



Total ^{27}P β-delayed proton branch of 0.07% was estimated

TABLE II. ^{27}P β-delayed proton groups.

Peak[a]	E_p[b]	$E^*(^{27}Si)$[c]	Relative intensity This work	Ref. [13]
$p1$	466±3	8176±3	9±2	
$p2$	612±2	8328±2	97±3	
$p3$	731±2	8451±2	100[d]	100[d]
$p4$	1324±4	9067±4	7±2	6±3

[a]Refer to Fig. 7.
[b]Energies are reported in keV in the lab system.
[c]Based on 7.692 MeV proton separation energy to the 0^+ isomeric state in ^{26}Al.
[d]Defined.

Ognibene et al, Phys. Rev. C **54**, 1098 (1996)

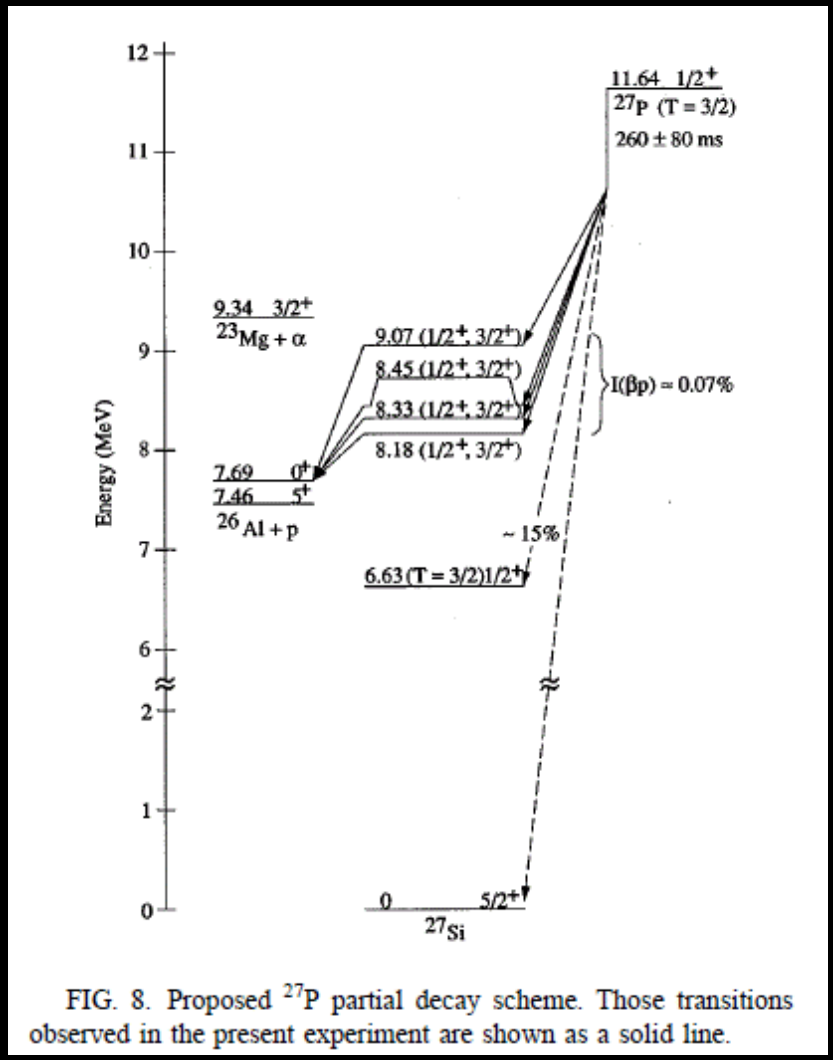


FIG. 8. Proposed ^{27}P partial decay scheme. Those transitions observed in the present experiment are shown as a solid line.

No experiment has been able to produce clean and abundant ^{27}P to study in detail its βp and βγ decays

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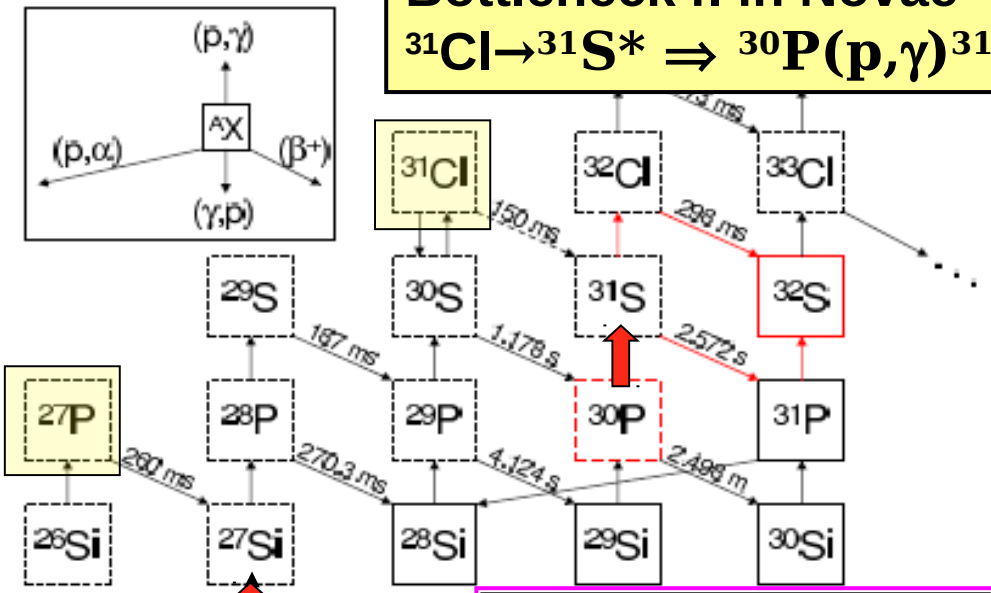
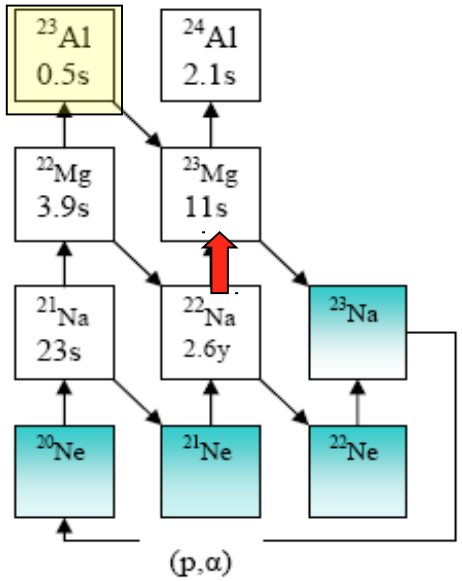
Previous Experiments at TAMU

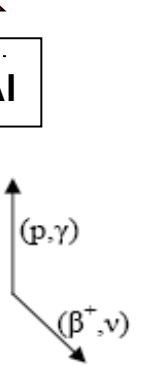
Bottleneck r. in Novae
$^{31}Cl \rightarrow {}^{31}S^* \Rightarrow {}^{30}P(p,\gamma)^{31}S^*$

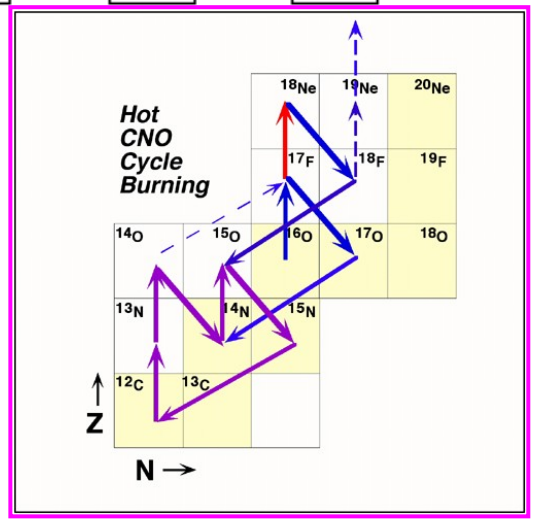
^{26}Al Destruction Rate in Novae
$^{27}P \rightarrow {}^{27}Si^* \Rightarrow {}^{26}Al(p,\gamma)^{27}Si^*$

^{22}Na Depletion in Novae
$^{23}Al \rightarrow {}^{23}Mg^* \Rightarrow {}^{22}Na(p,\gamma)^{23}Mg^*$







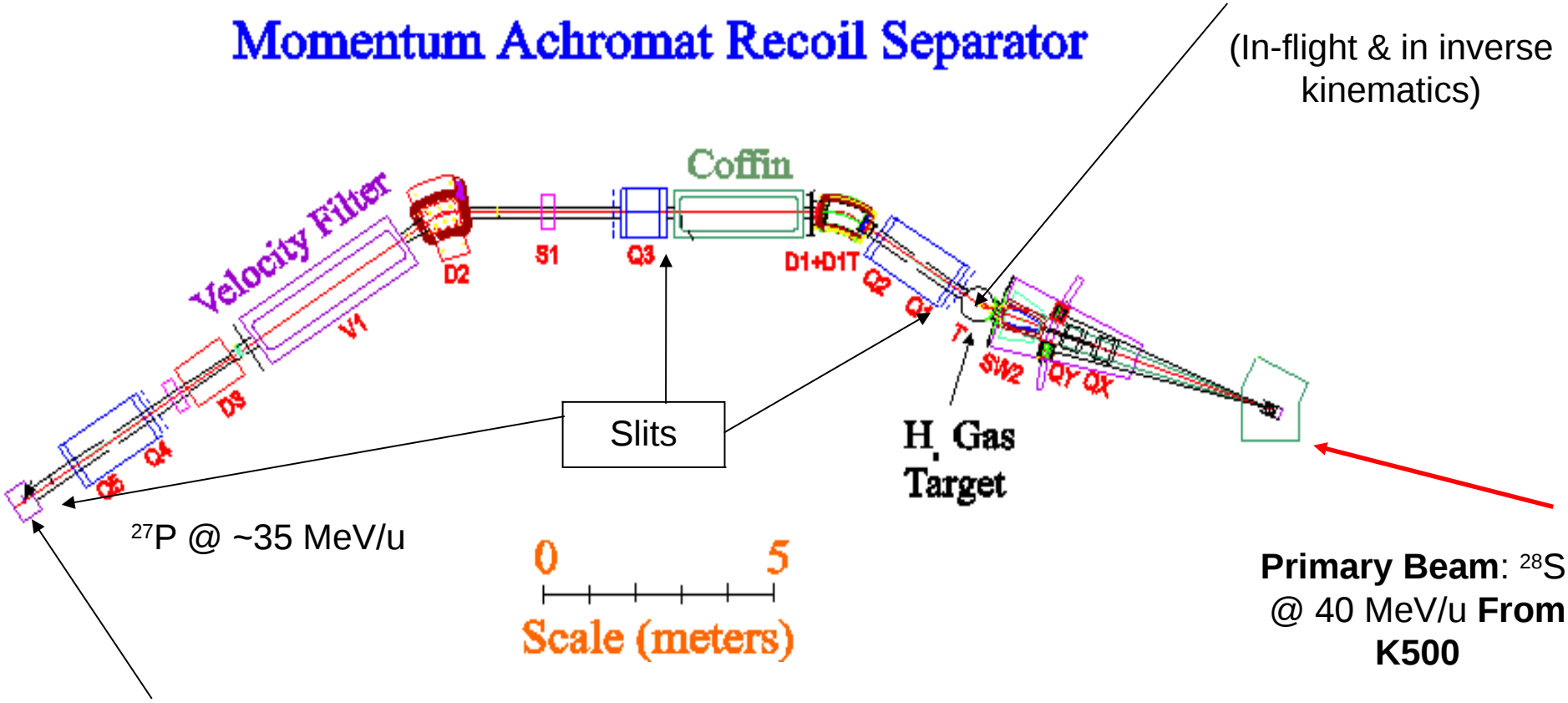


Breakout of HCNO to rp-Process
$^{20}Mg \rightarrow {}^{20}Na^* \Rightarrow {}^{19}Ne(p,\gamma)^{20}Na^*$

Separate the Desired Fragment (^{27}P)

Gas Cell Target Produces Nuclei

(In-flight & in inverse kinematics)



^{27}P @ ~35 MeV/u

Primary Beam: ^{28}Si @ 40 MeV/u **From K500**

The Implantation-Decay Station

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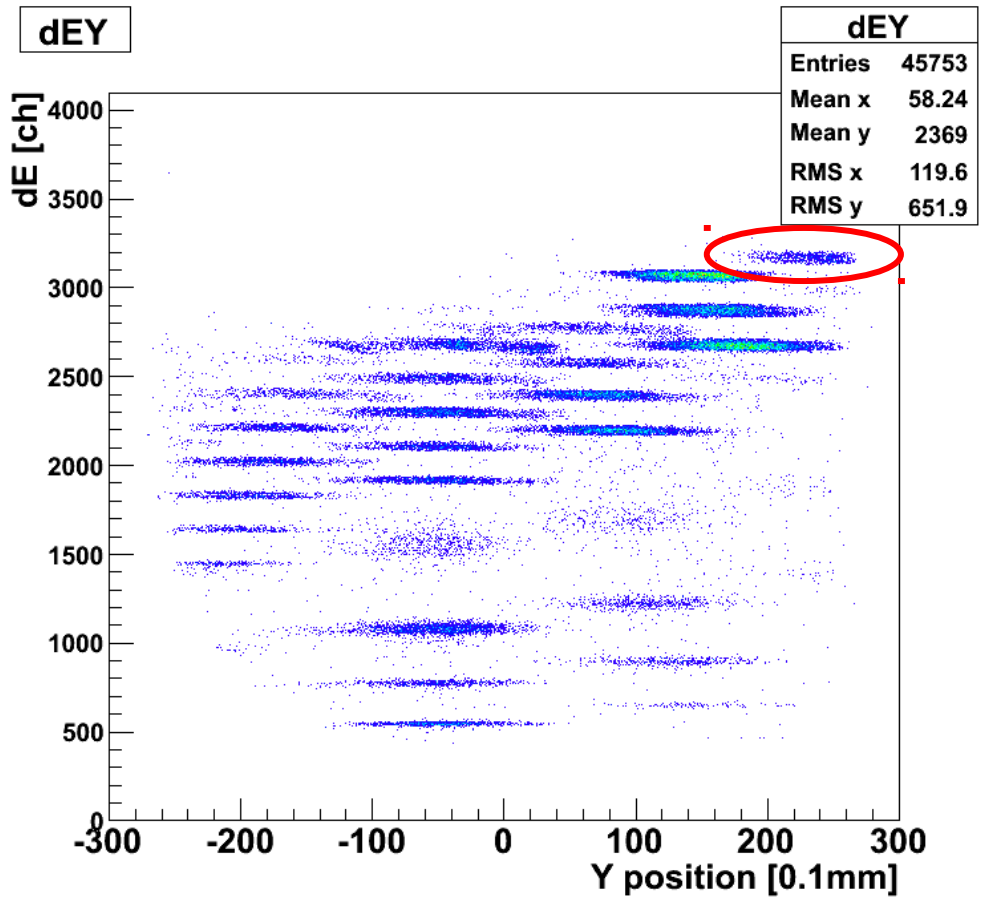
dEY



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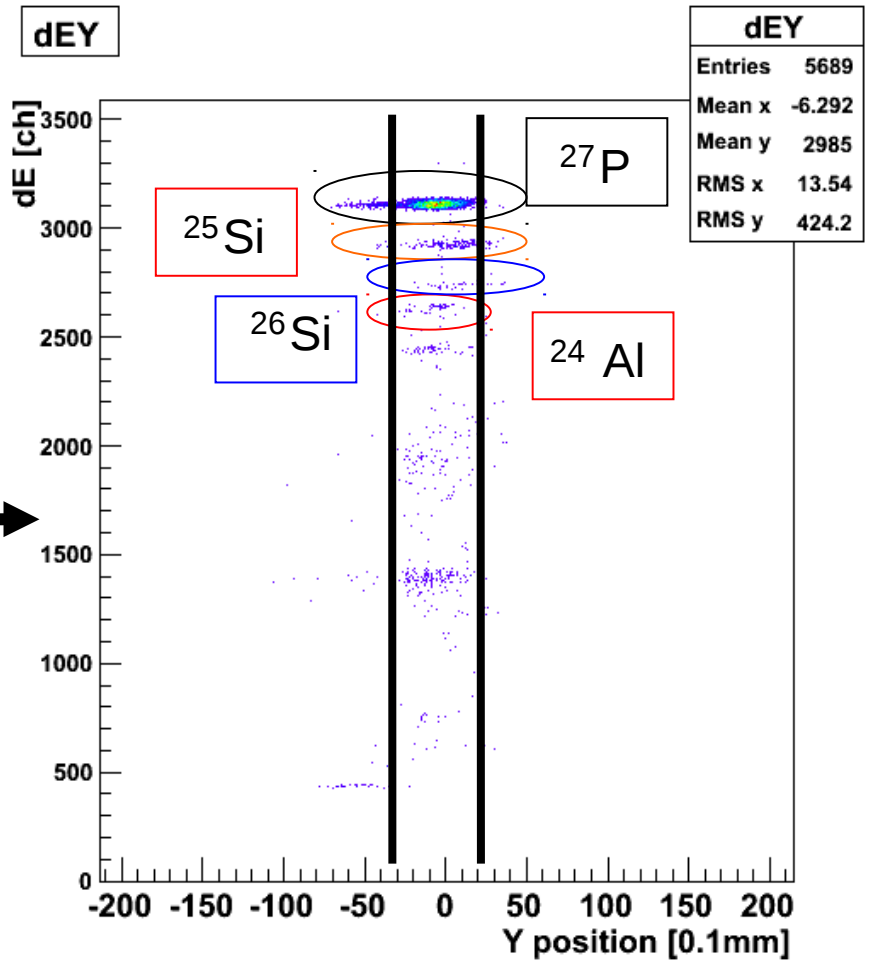
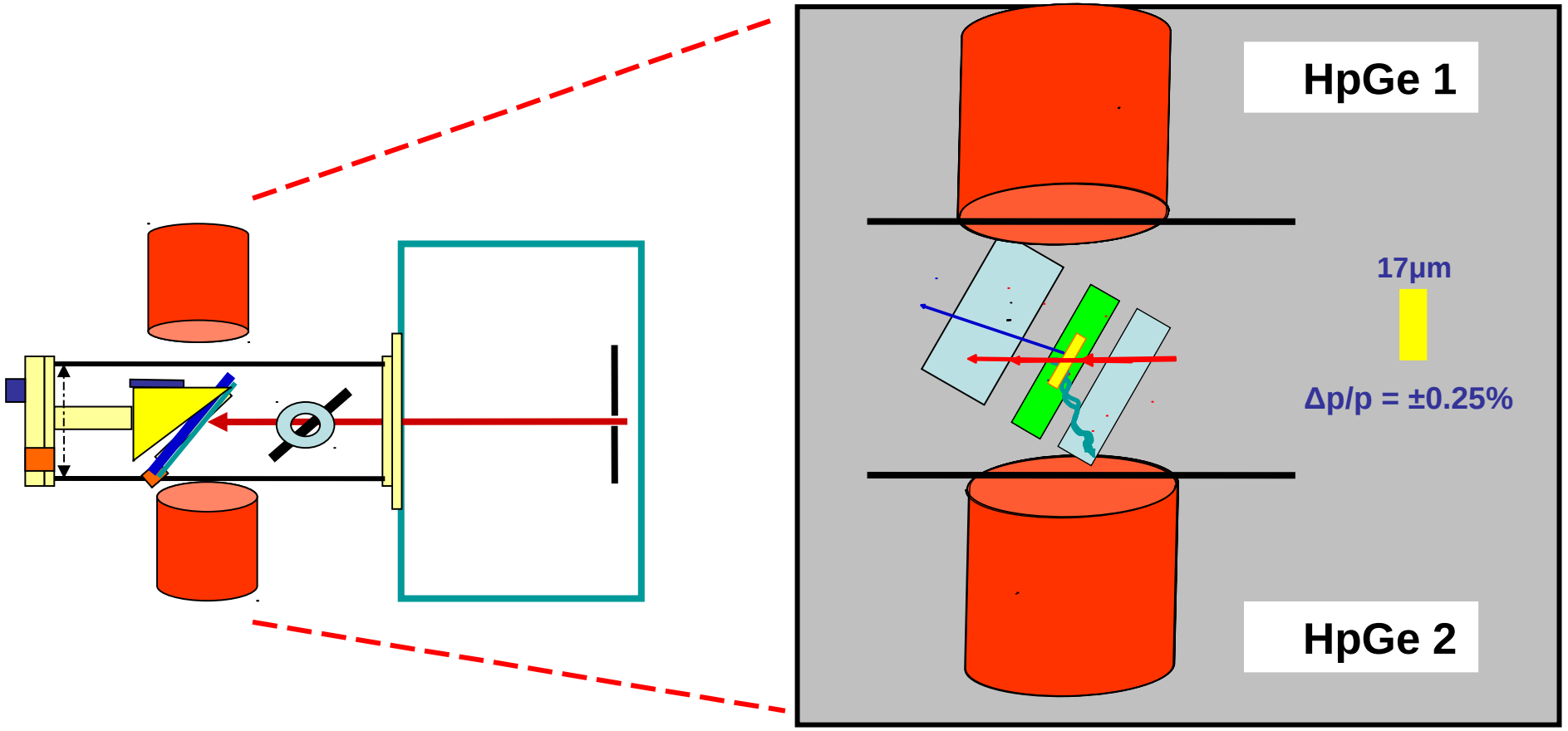
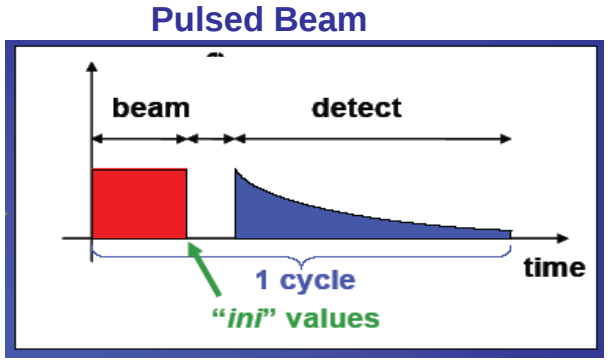


For: ^{27}P: - > 2.9 evts/nC

Total Impurities ~11%

Basic Experimental Procedure





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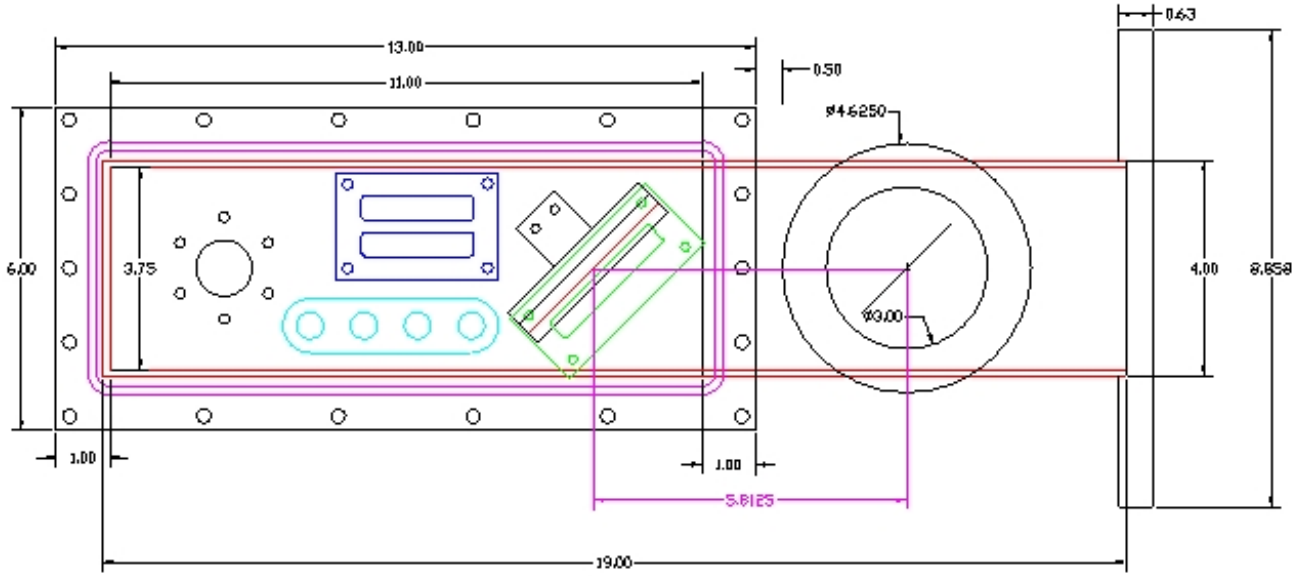

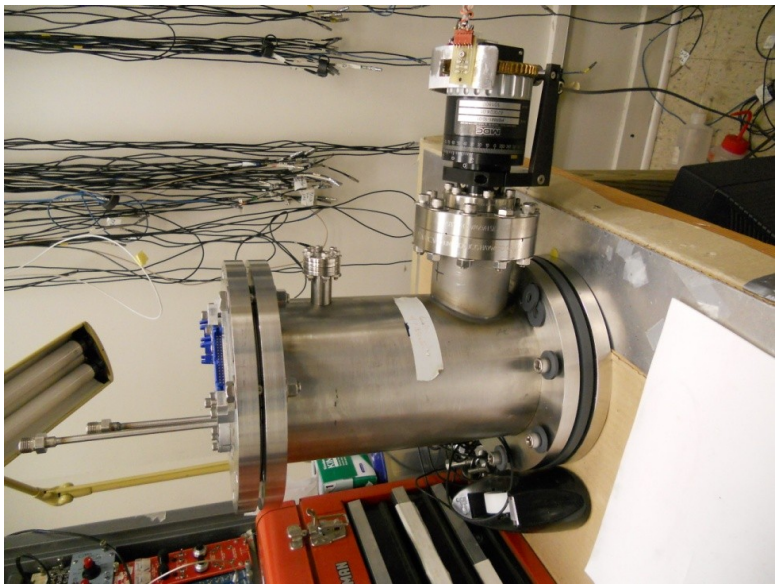

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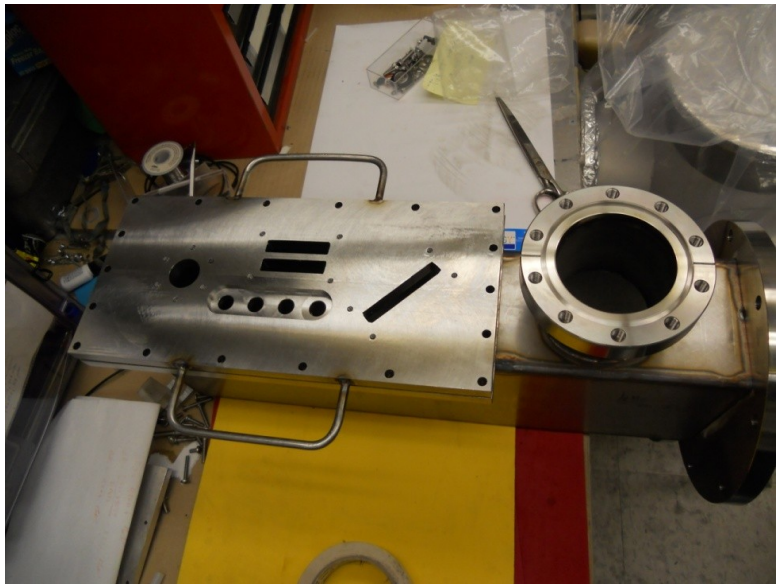
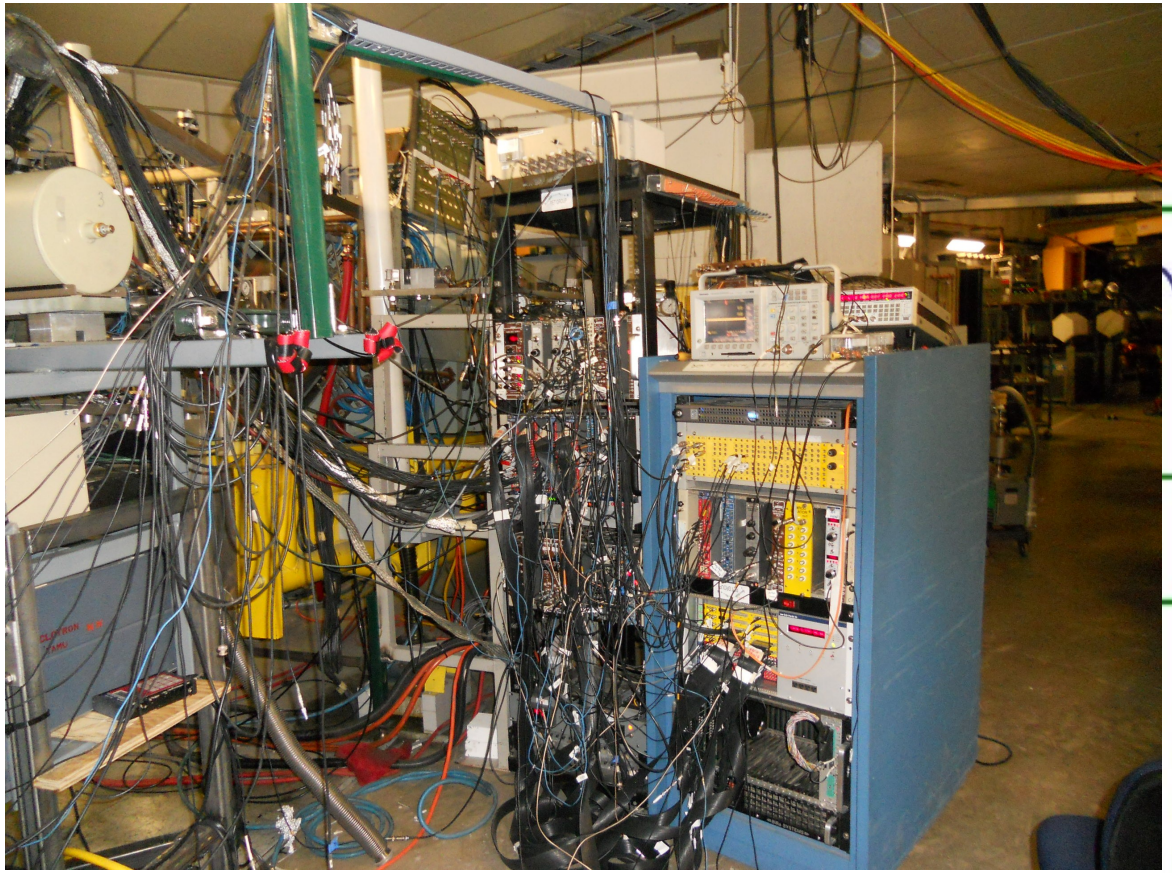
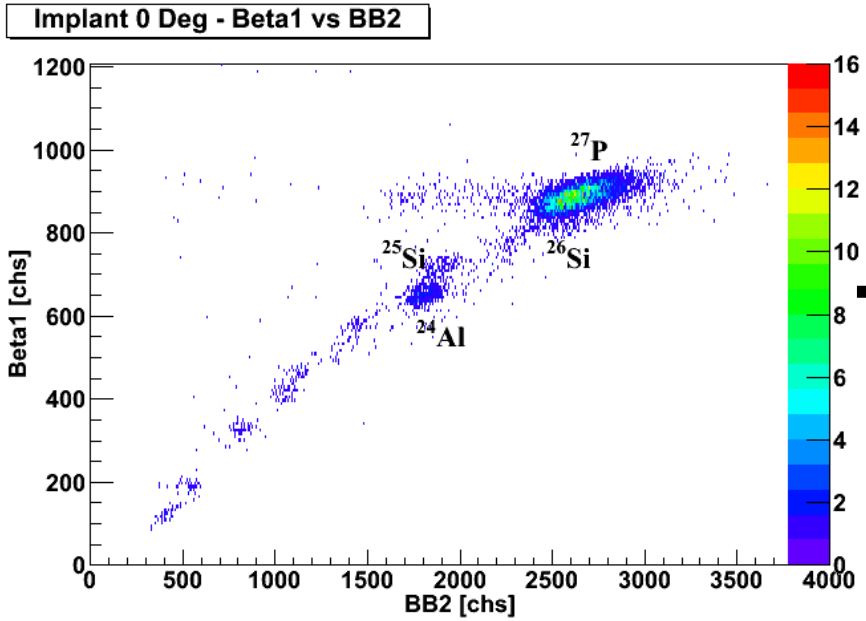
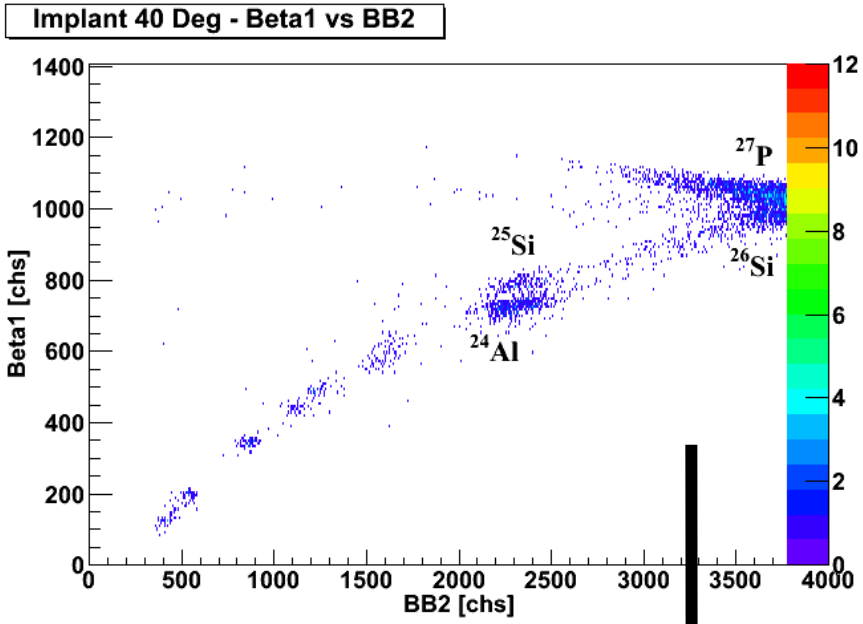


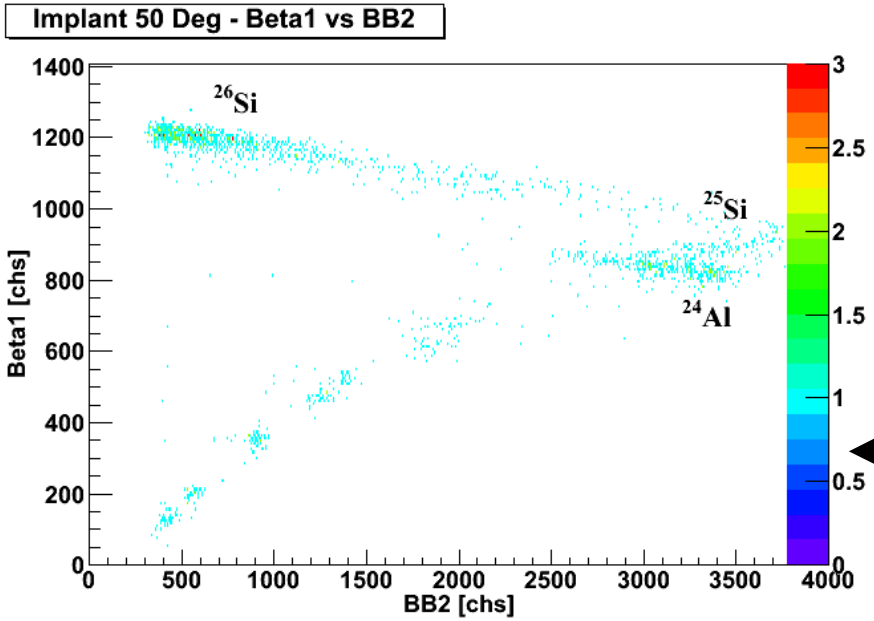
Electronics!

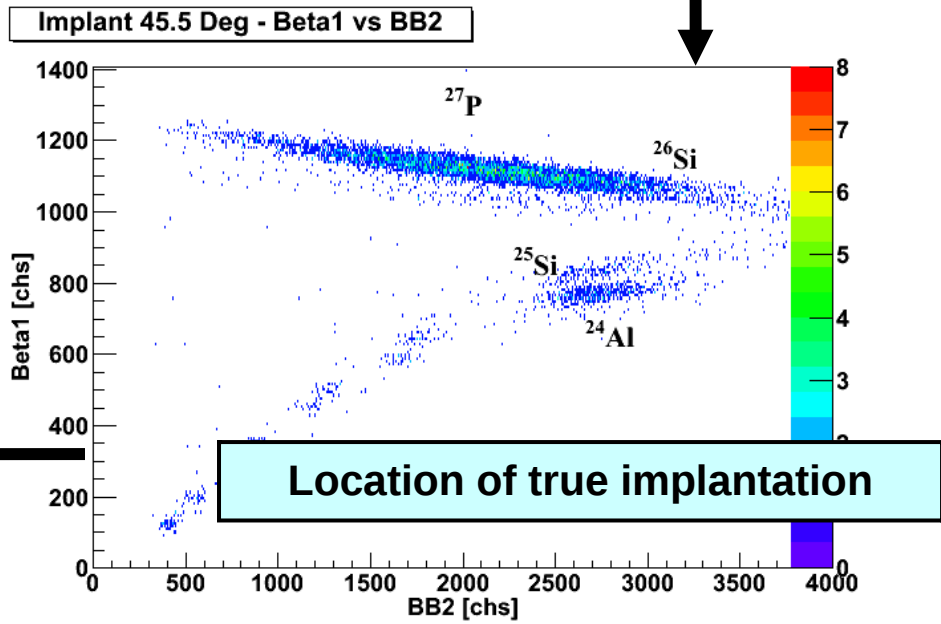


Implantation









Location of true implantation

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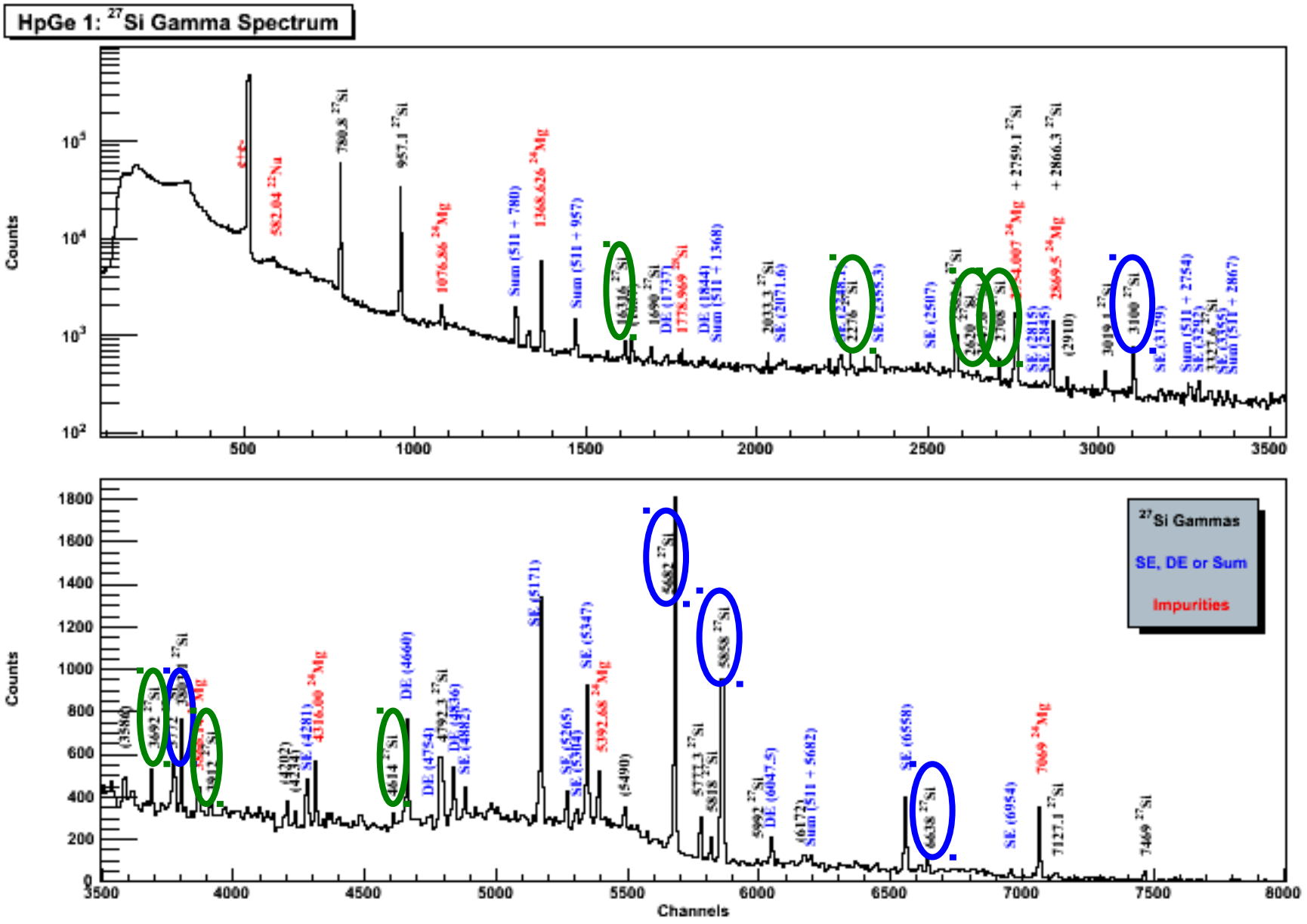
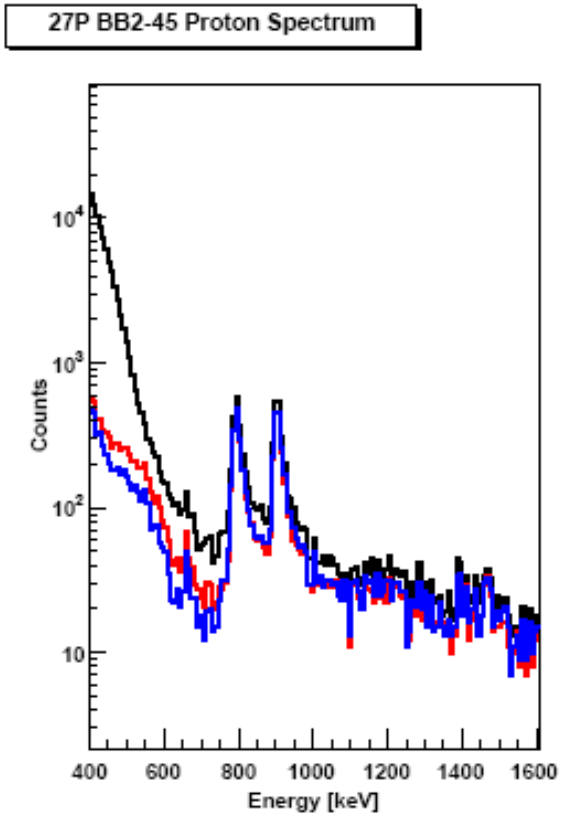
Gamma Analysis

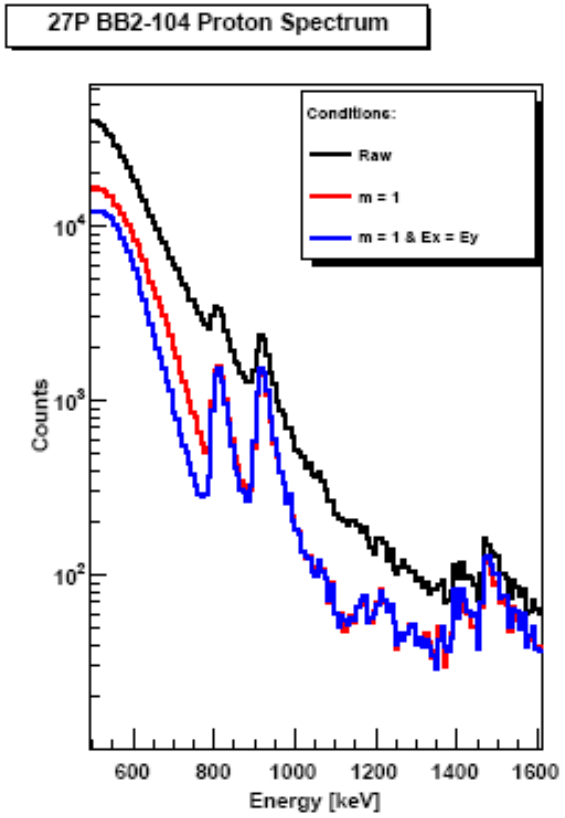
Peak ID in ^{27}Si Spectrum

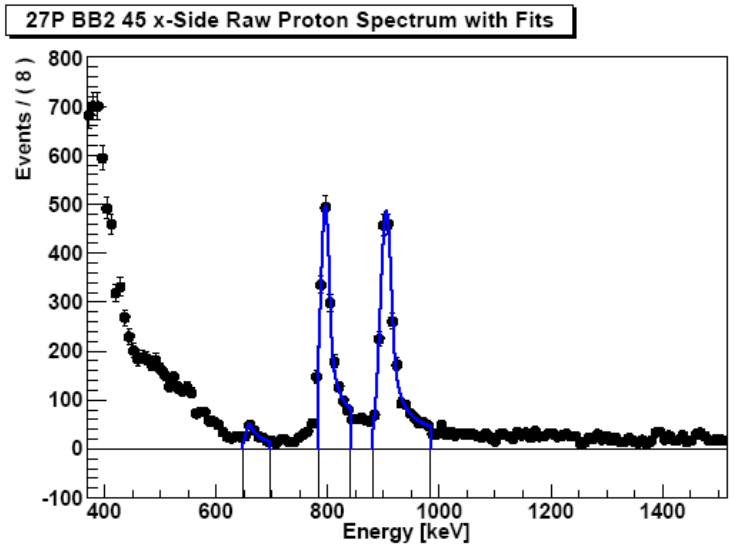


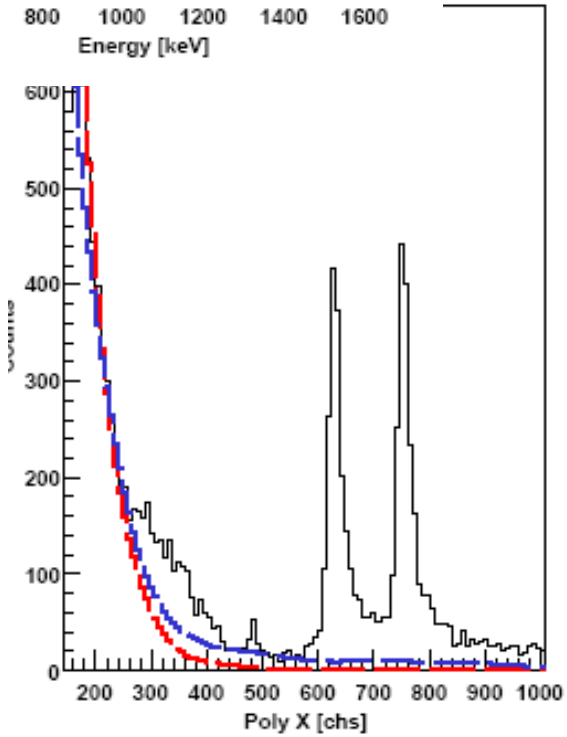
Proton Analysis

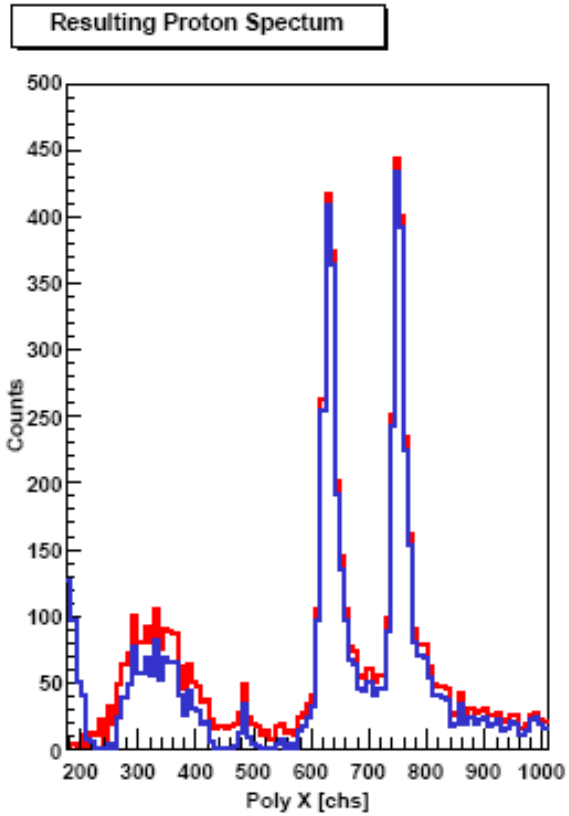
Peak ID











Future Outlook
The AstroBox Prototype

Designed and built in collaboration with CEA Saclay (Dr. E Pollacco) and CERN

- **Goals for New Detector**:
  - Less sensitive to β-particles
  - Good Resolution
    - 10-20 keV (FWHM) at 200 keV
  - Uniform Efficiencies
    - About 10-20%

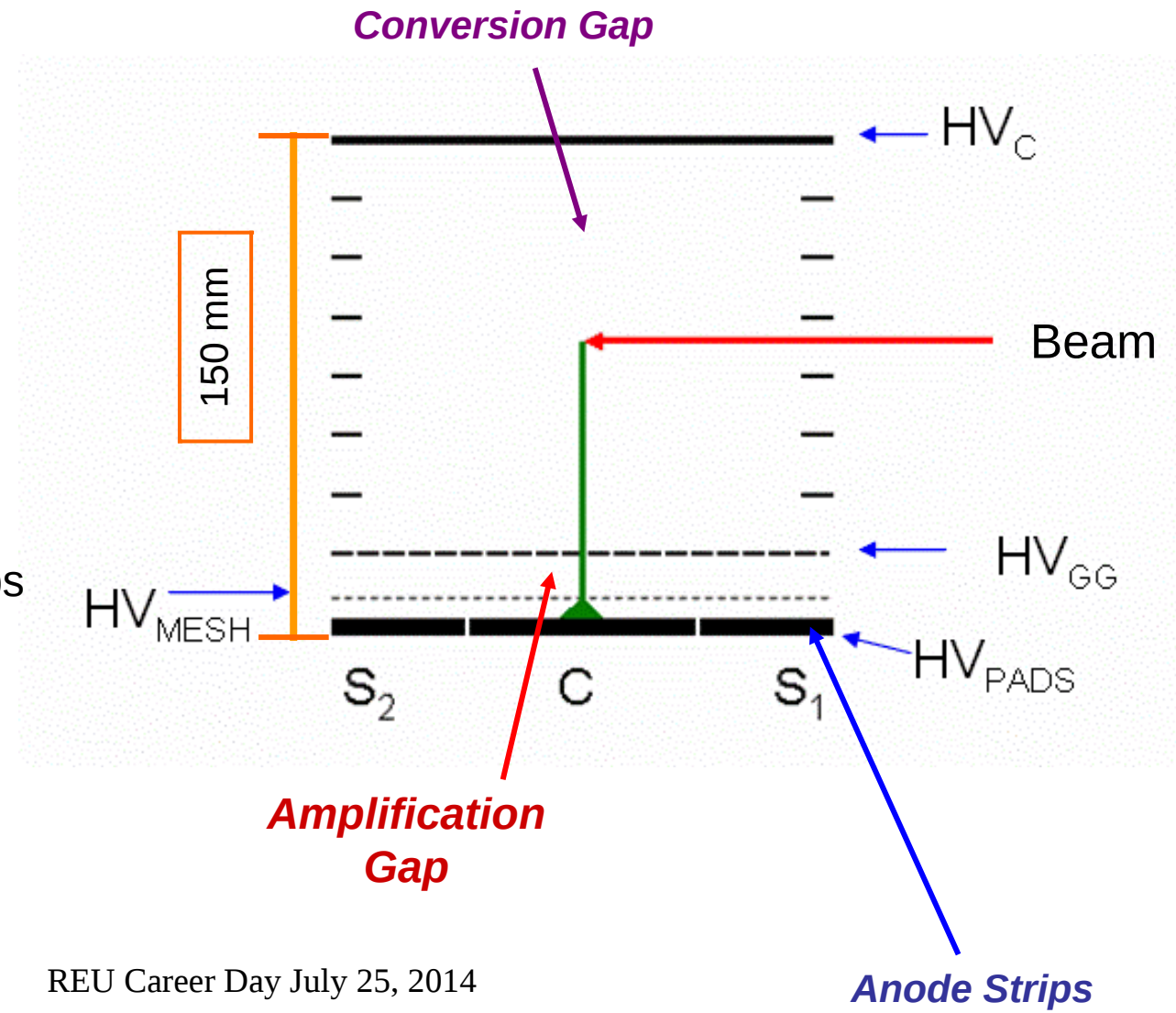
- **Less Sensitive to Betas**:
  - Active gas volume
    - Very little energy loss for the betas

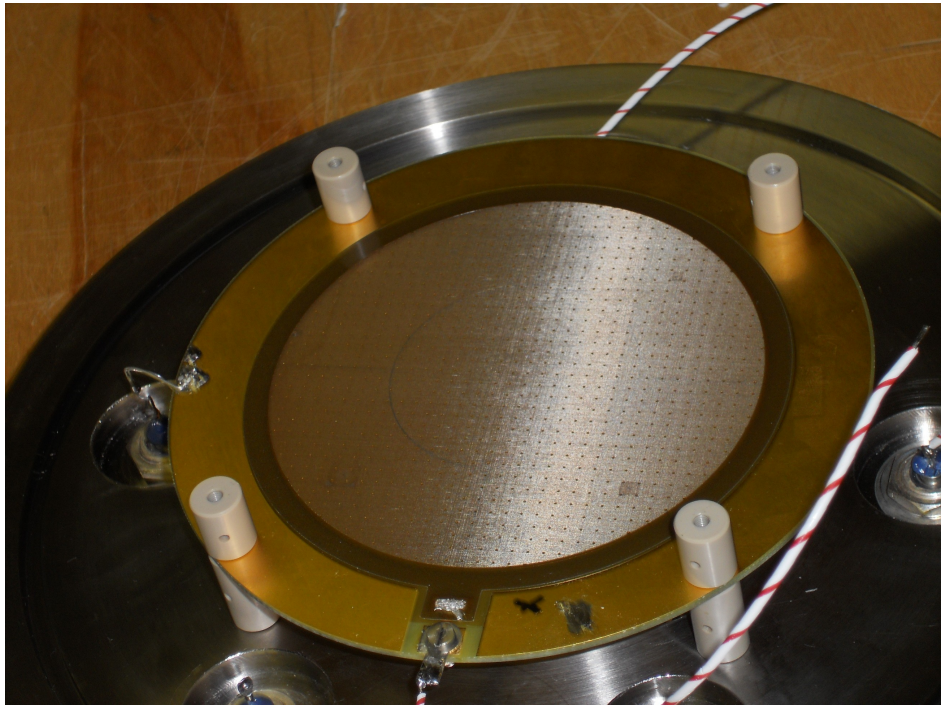
- **Good Resolution & Efficiency**:
  - Solved by the use of a new detector design
    - MICROMEGAS (MICRO-MEsh-GAseous Structure)

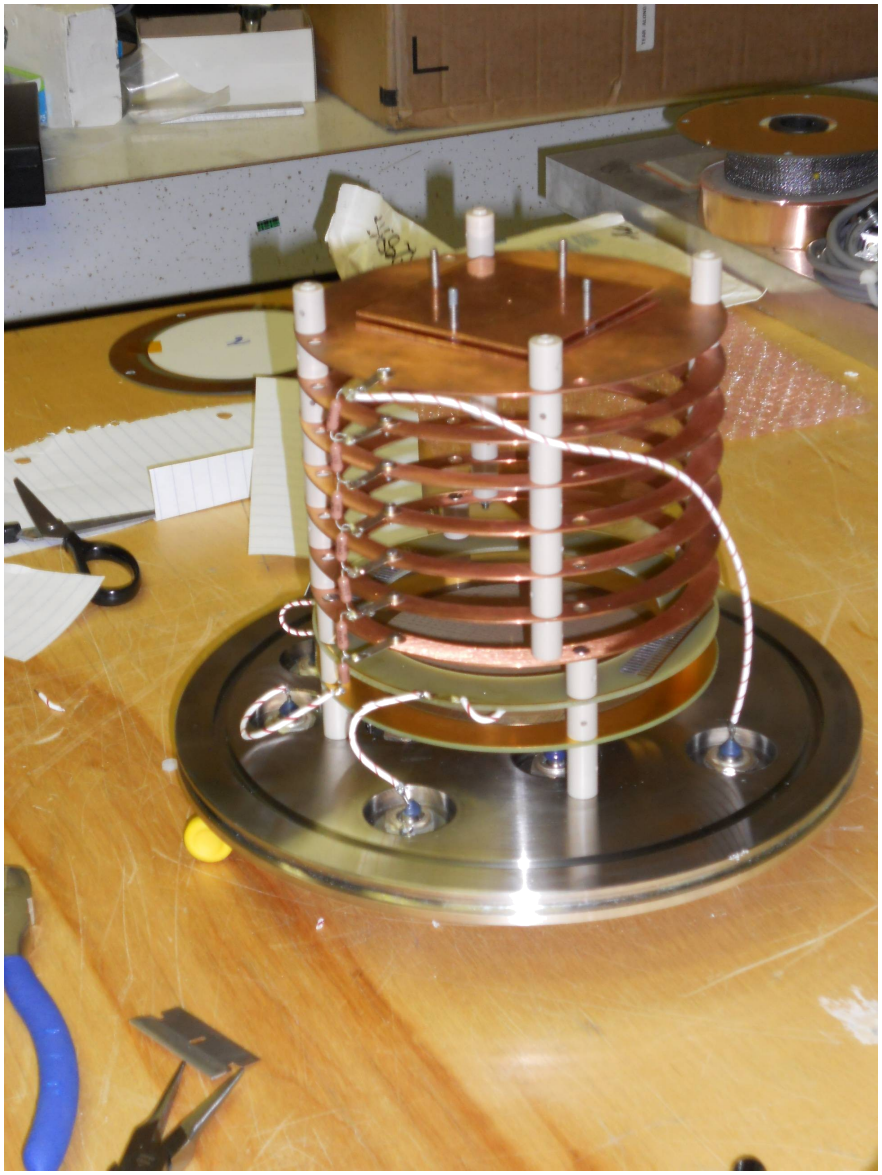
AstroBox-1 Detector Design

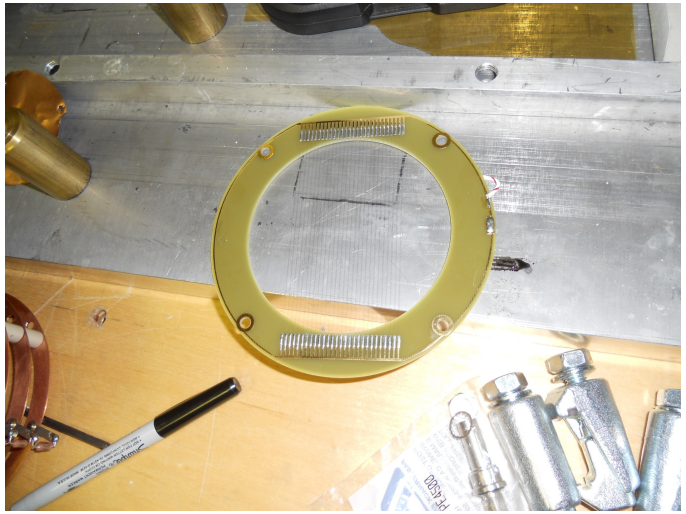
MICROMEGAS Basics

- **Two Main Regions**:
  - The ***Conversion Gap***
  - The ***Amplification Gap***
- **Applying Voltages**:
  - A very high E-Field in the amplification region
  - A low E-Field in the drift region
  - Ratio between the two gaps can be large
    - Required for an optimal functioning of the device









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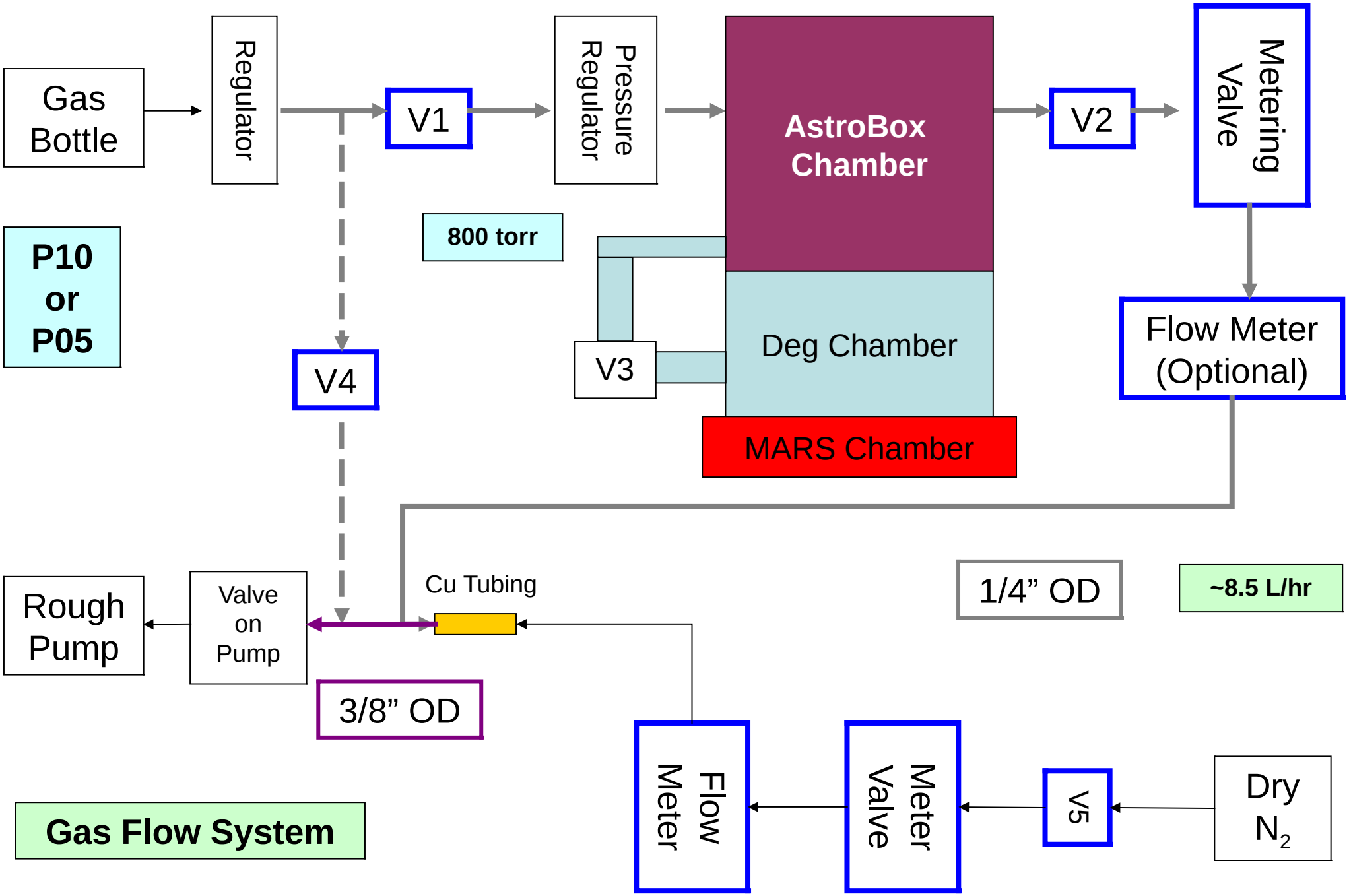
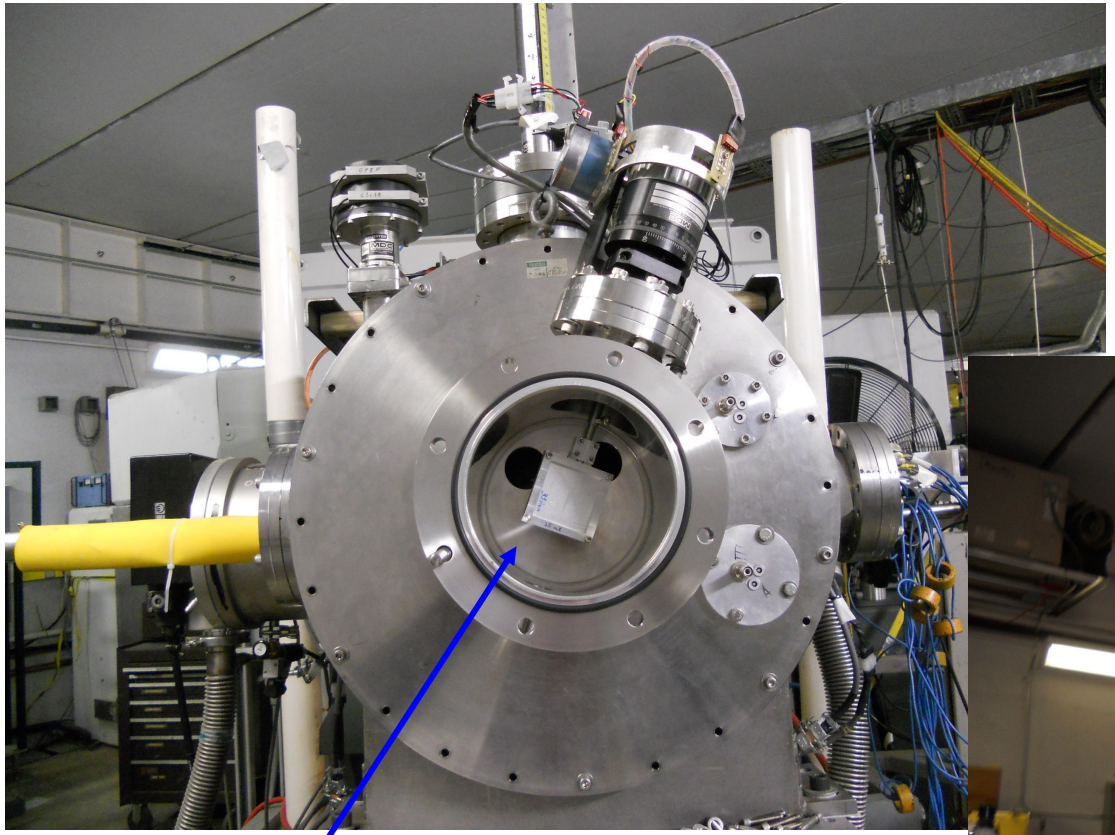
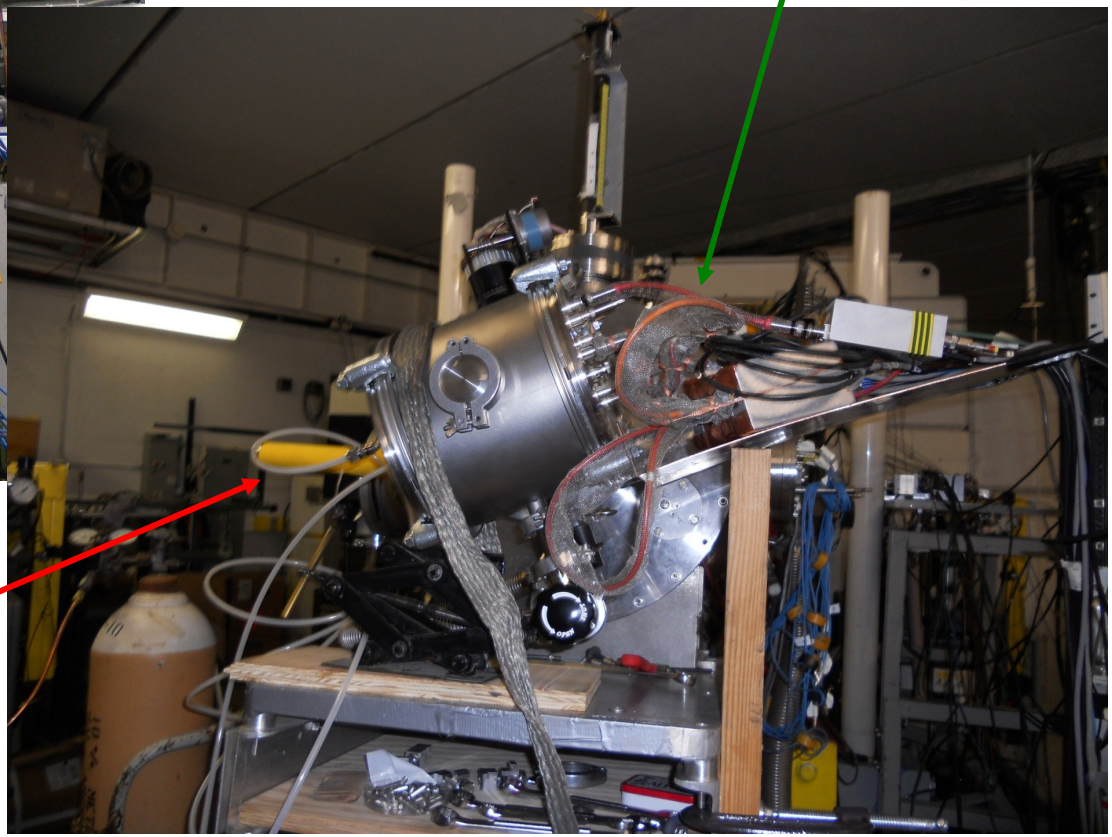

Gas Bottle
Regulator
V1
Pressure Regulator
AstroBox Chamber
V2
Metering Valve
800 torr
P10 or P05
V4
V3
Deg Chamber
Flow Meter (Optional)
MARS Chamber
Rough Pump
Valve on Pump
Cu Tubing
1/4” OD
~8.5 L/hr
3/8” OD
Flow Meter
Meter Valve
V5
Dry N_2
Gas Flow System

Back End of MARS



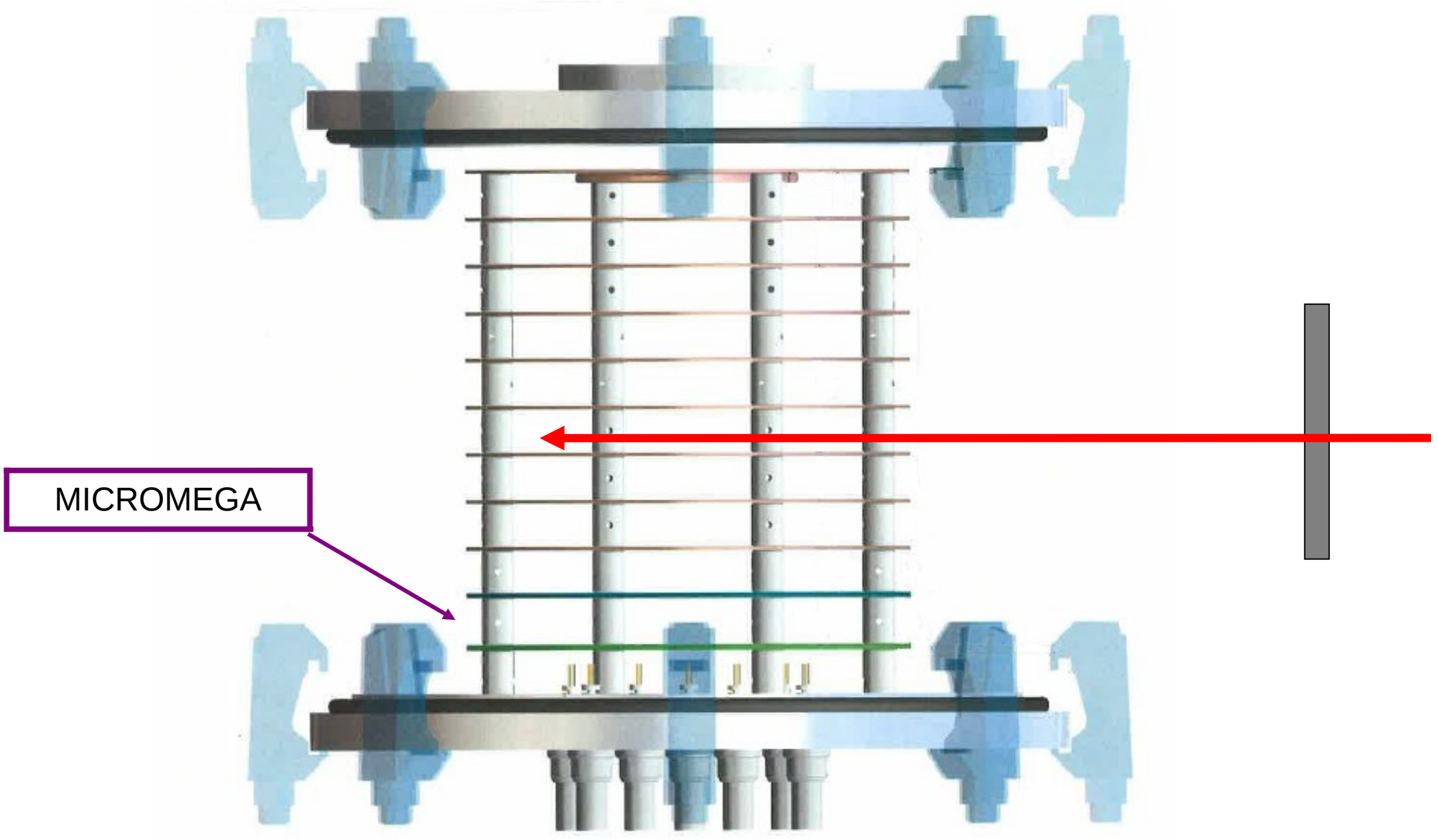


Output Signals and Pre-Amplifier Units

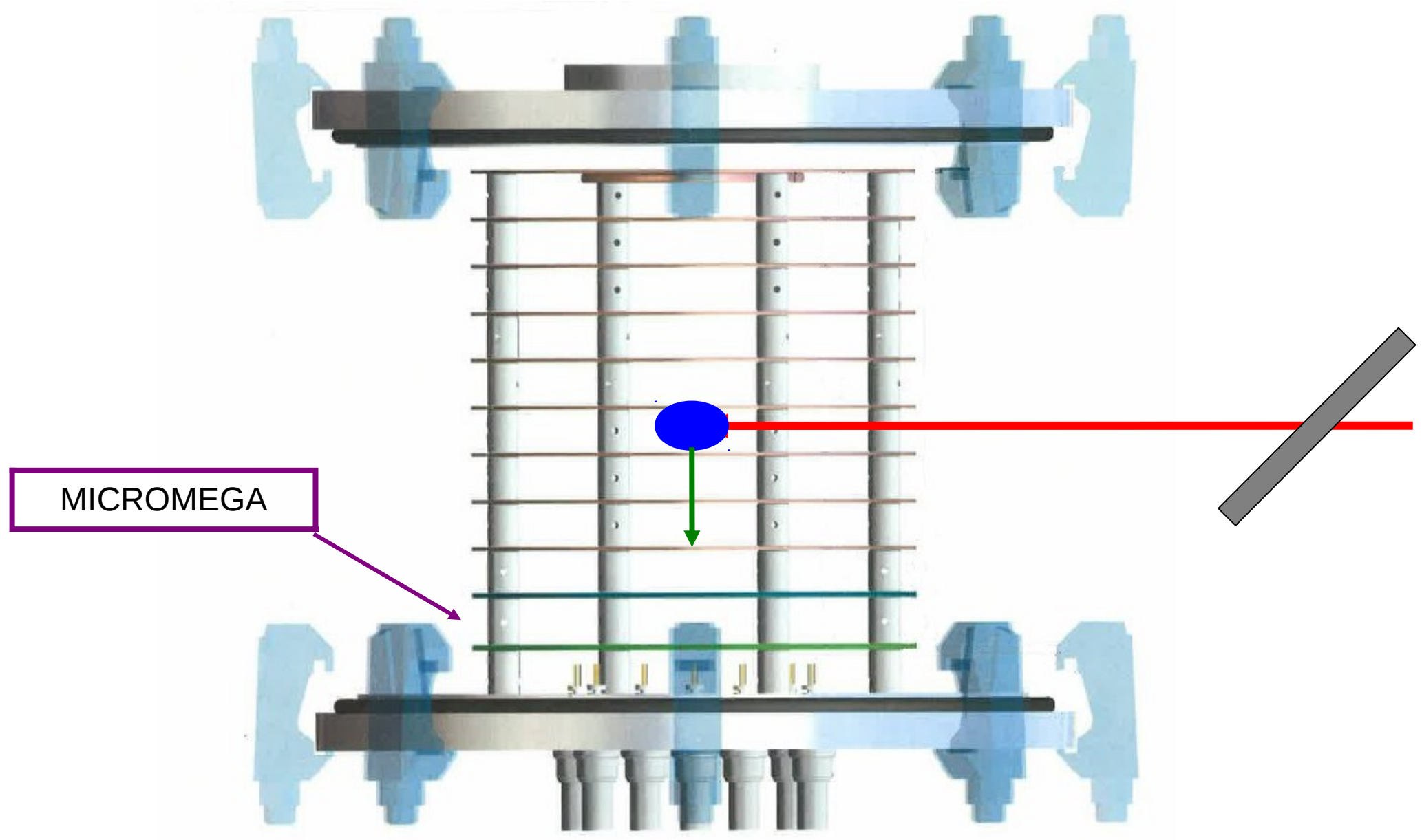
Al Degrader

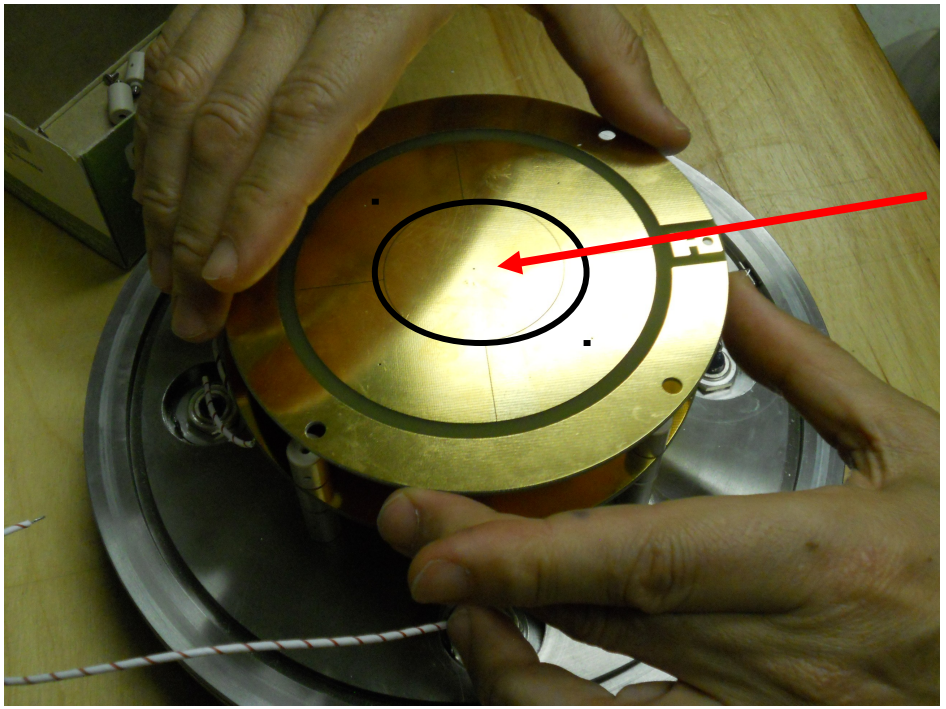
Gas Flow System

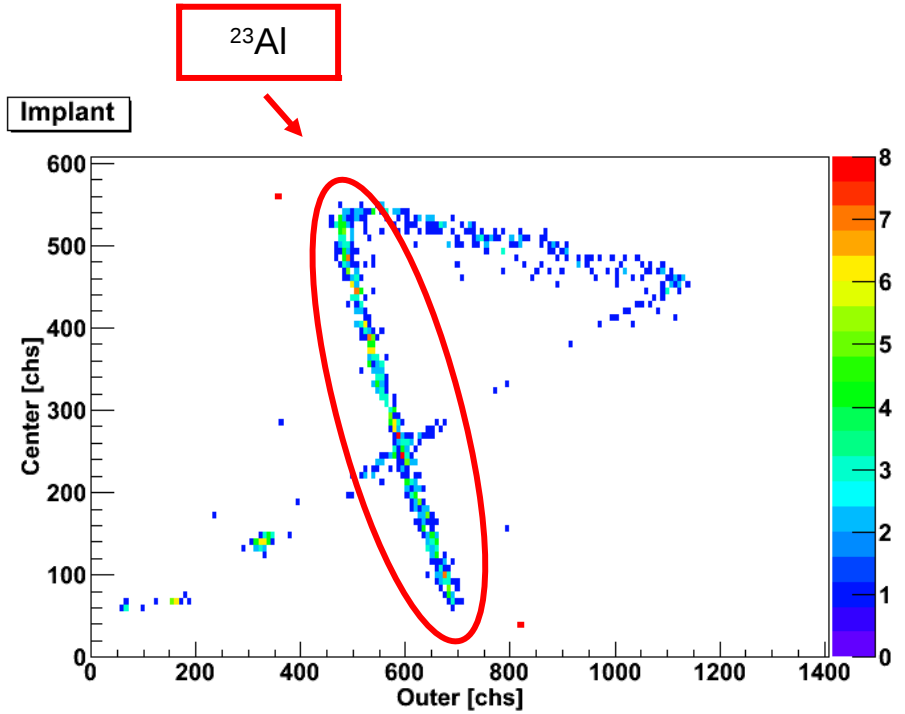
Implantation Method

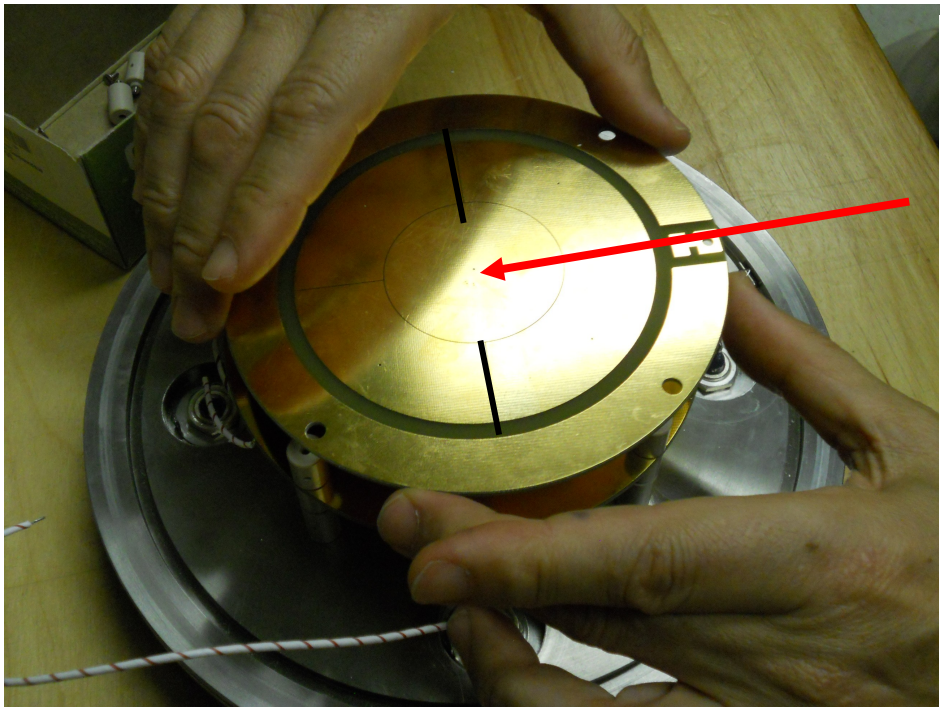


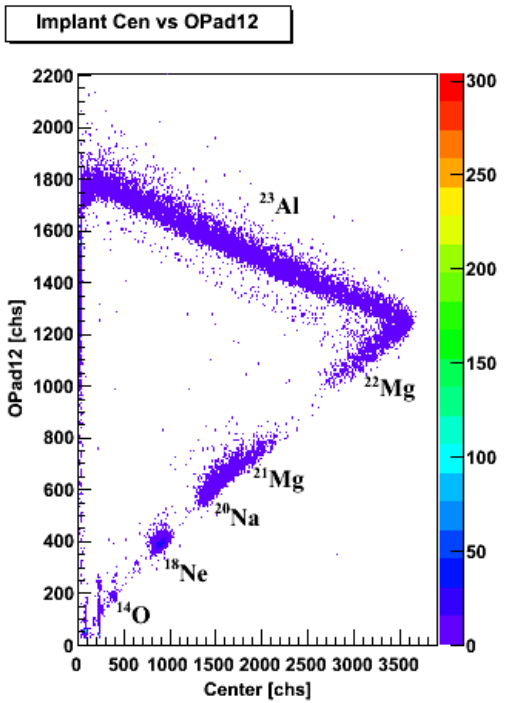
Implantation Method

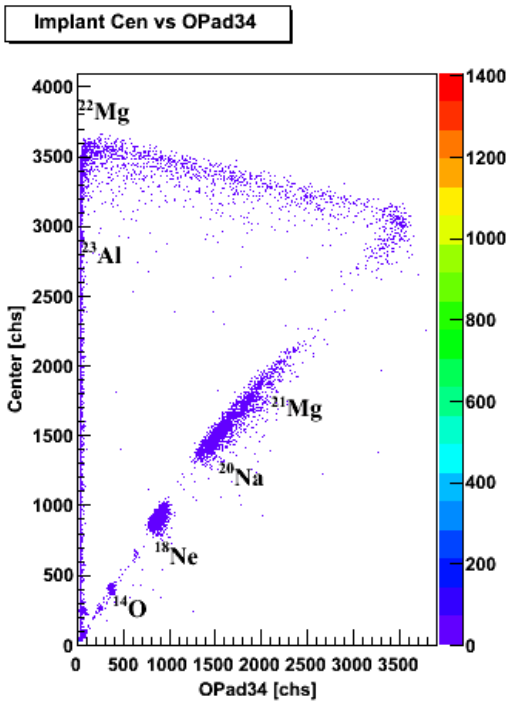





^{23}Al
Implant
Center [chs]
Outer [chs]

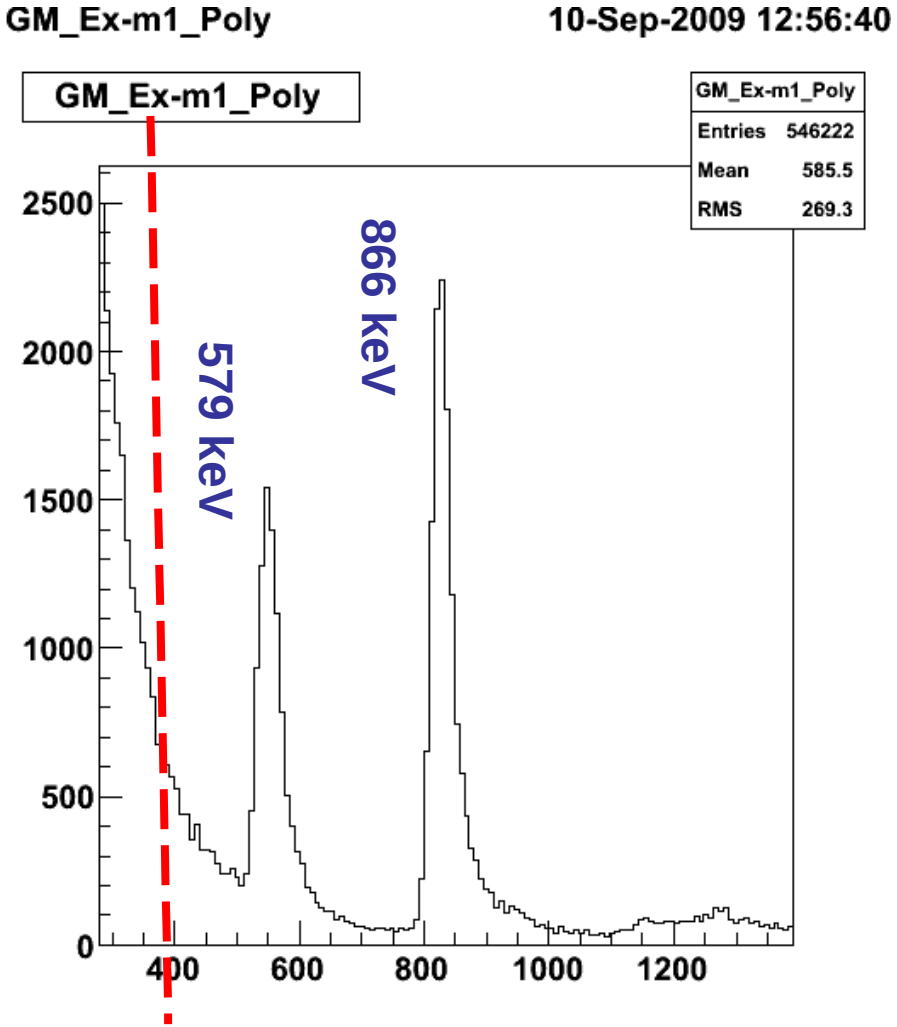



Implant Cen vs OPad12
^{23}Al
^{22}Mg
^{21}Mg
^{20}Na
^{18}Ne
^{14}O
OPad12 [chs]
Center [chs]


Implant Cen vs OPad34
^{22}Mg
^{23}Al
^{21}Mg
^{20}Na
^{18}Ne
^{14}O
Center [chs]
OPad34 [chs]

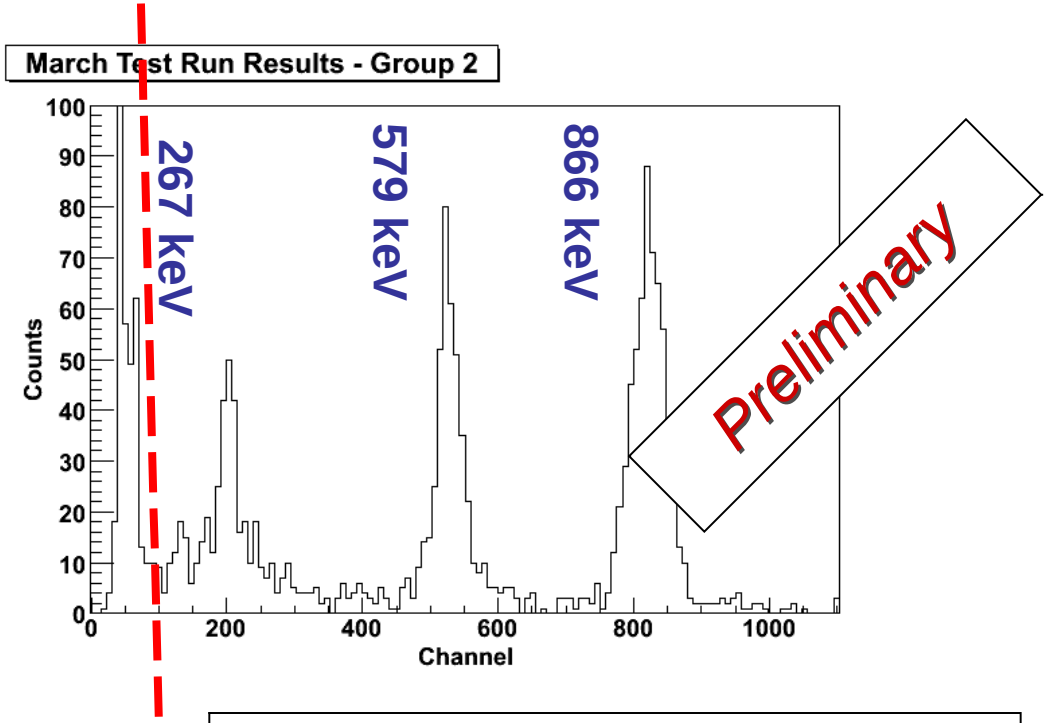
Proton Response

First Test Run (P10)



Clean Spec Down To ~100 keV

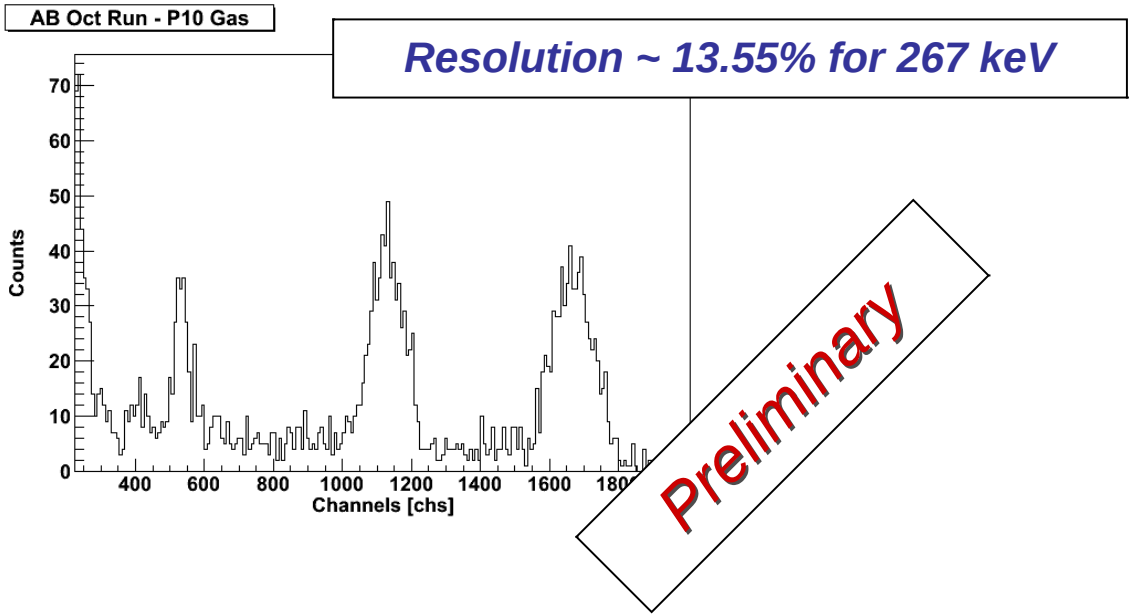
Stats after only 3.5 hrs

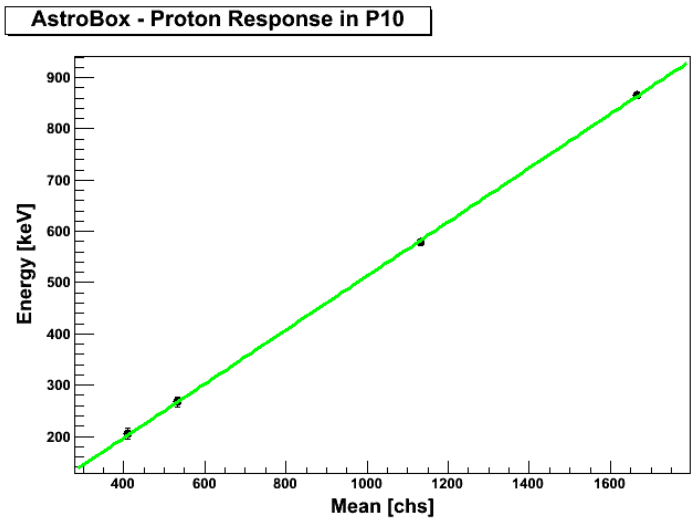


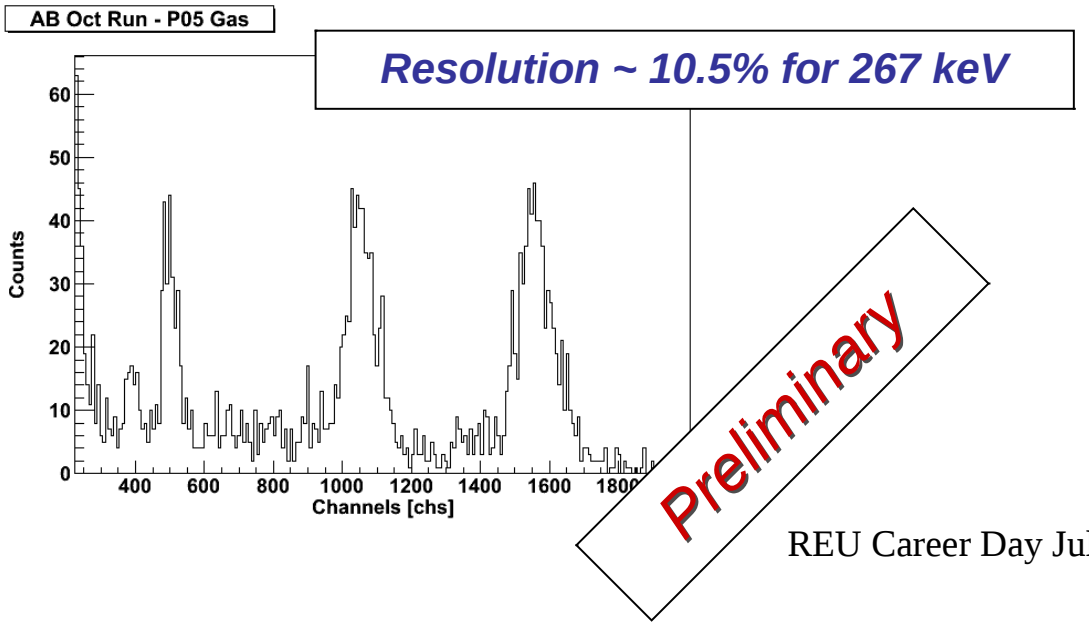
Resolution ~ 13% for 267 keV

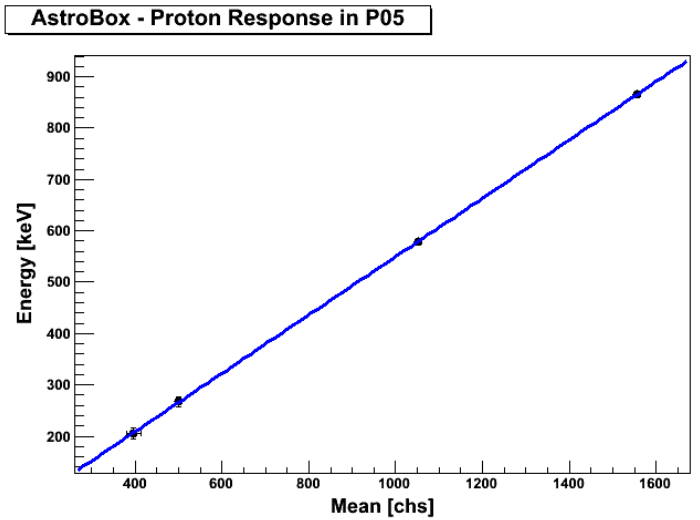
Proton Response

Second Test Run - P10 vs P05

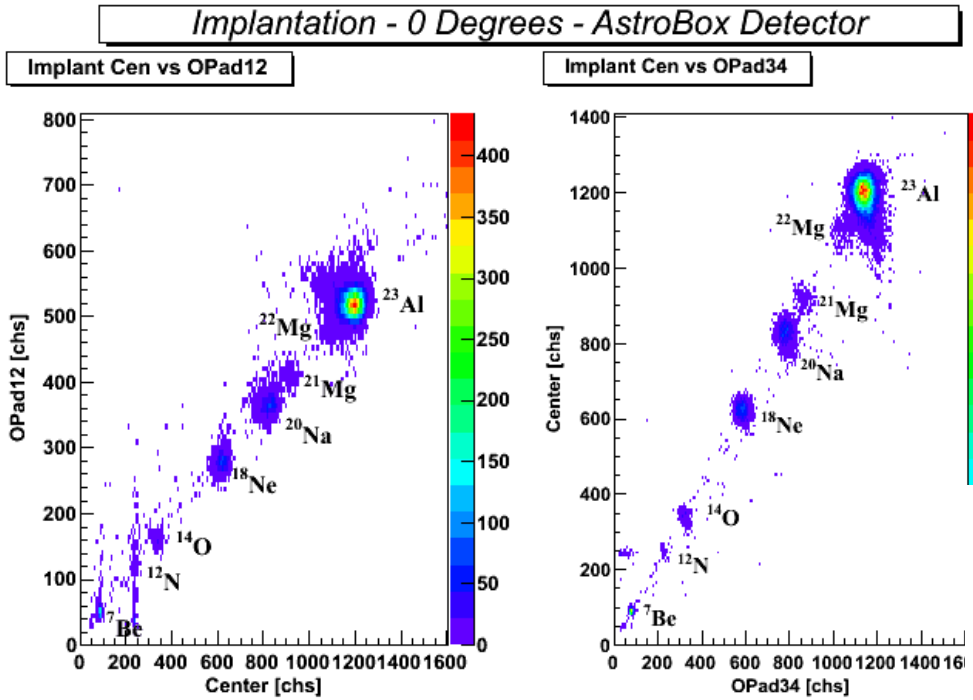




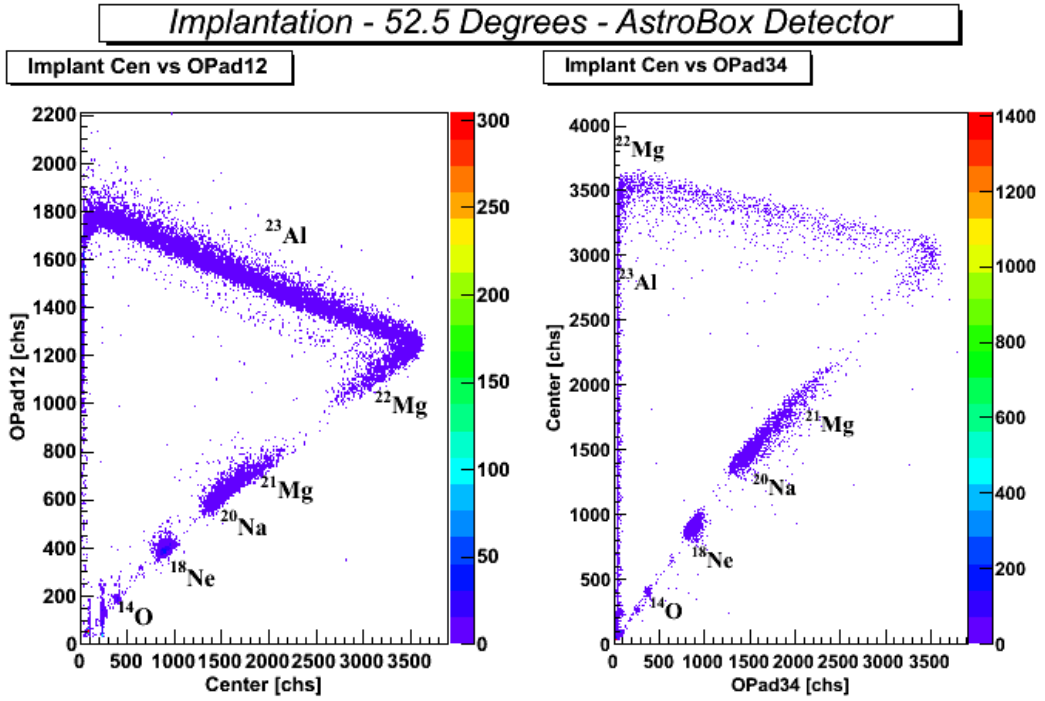


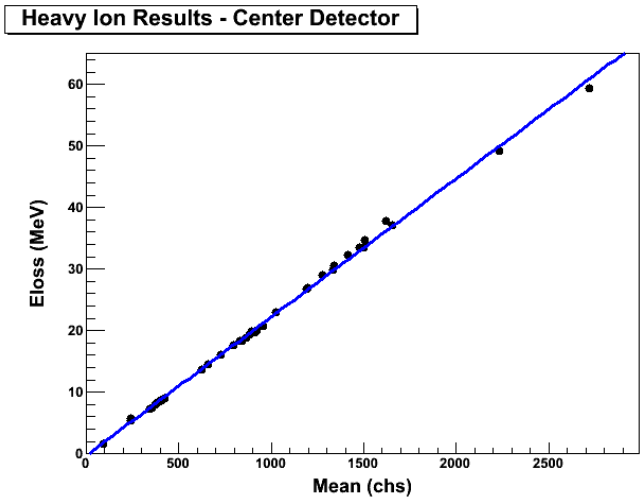


Heavy Ion Response



Resolution ~ 5% for ^{23}Al





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- A. Saastamoinen , A. Banu*, M. McCleskey, and R.E. Tribble
  - *Texas A&M University, (*J Madison University, VA)
- J.C. Hardy, V.E. Iacob, S. Molitor, H. Park, G. Rapisarda*, B. Roeder, R. Chyzh, M. Dag, A. Spiridon, L. Trache**
  - *INFN-Laboratori Nazionali del Sud, Catania, Italy
  - **IFIN-HH, Bucharest, Romania
- T. Davinson, G. Lotay, P.J. Woods, J. Wallace, D. Doherty
  - University of Edinburgh, United Kingdom
- E. Pollacco, G. Pascovici*, M. Riallot, J. P. Mols, M. Kebbiri
  - IRFU, CEA Saclay
  - *Institut fuer Kernphysik der Universitaet zu Koeln

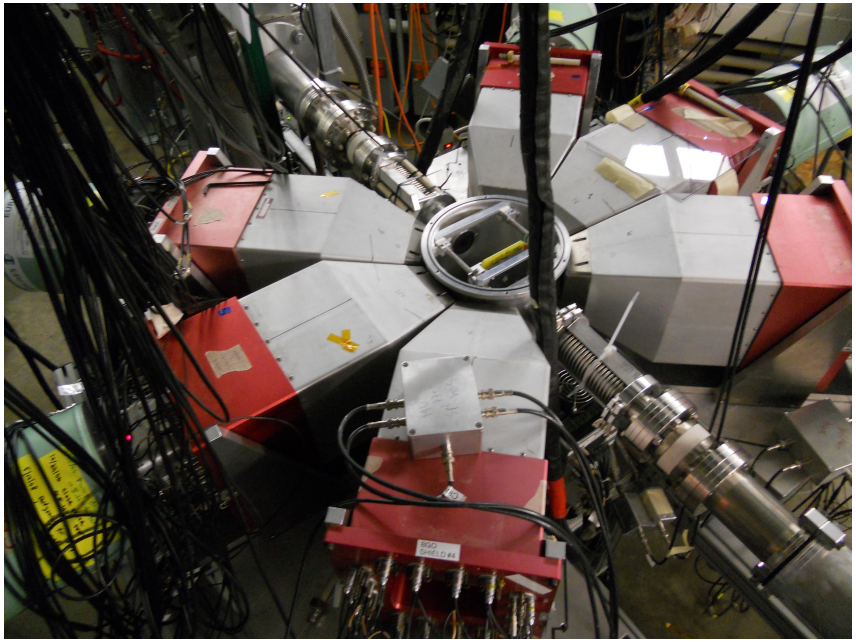
- In Conclusion:
  - CAD Programs:
    - AutoCAD
    - SOLIDWORKS
  - Data Analysis Tools:
    - ROOT
      - C++
    - Simulations
      - Lise++/SRIM
      - Geant4
  - Lab Skills:
    - Detectors
    - Electronics
    - Experimental Procedures

Post Doc Work/Plans

REU Career Day July 25, 2014

Ion Interactions Line (STARLiTeR)

(Silicon Telescope Array for Reaction Studies)

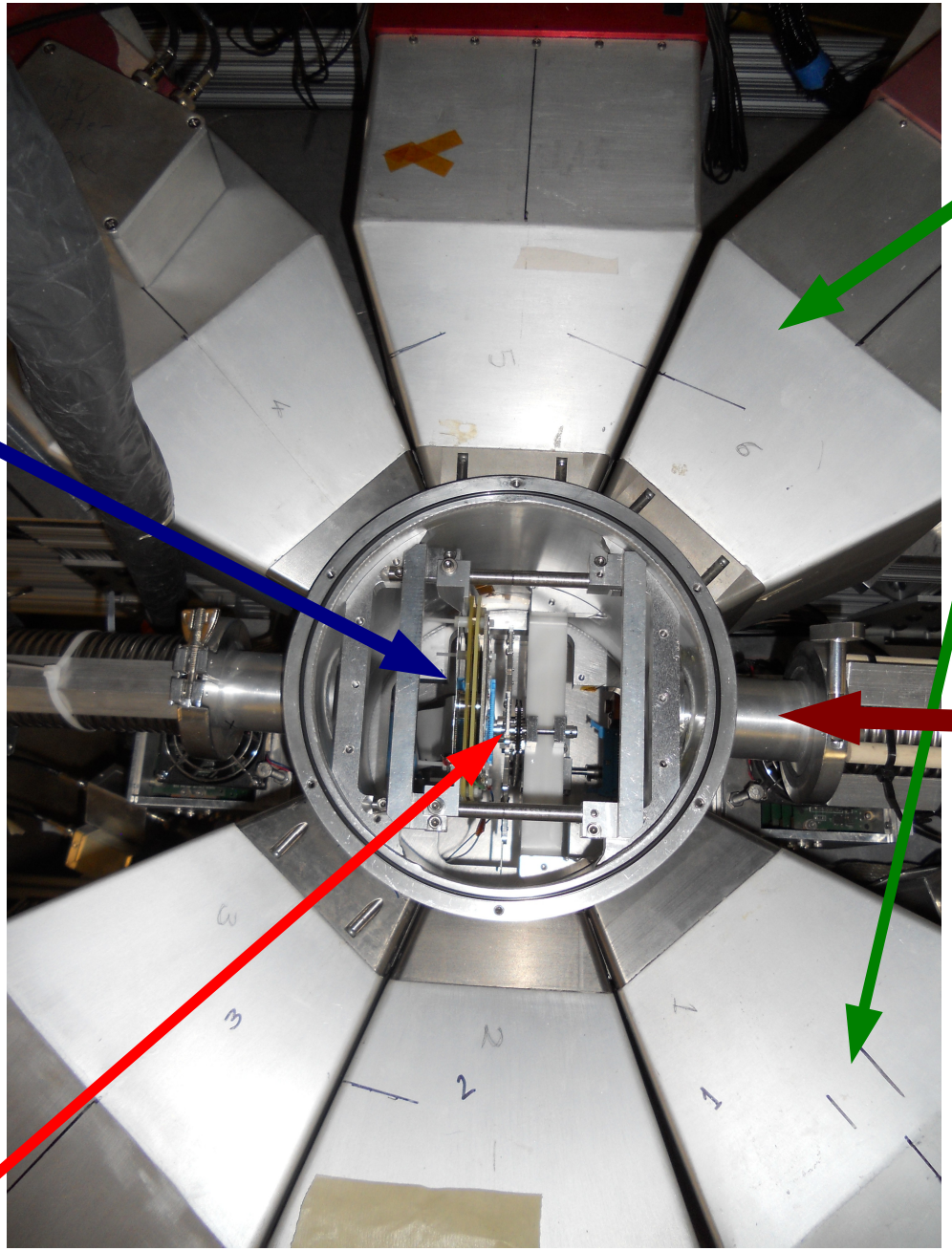


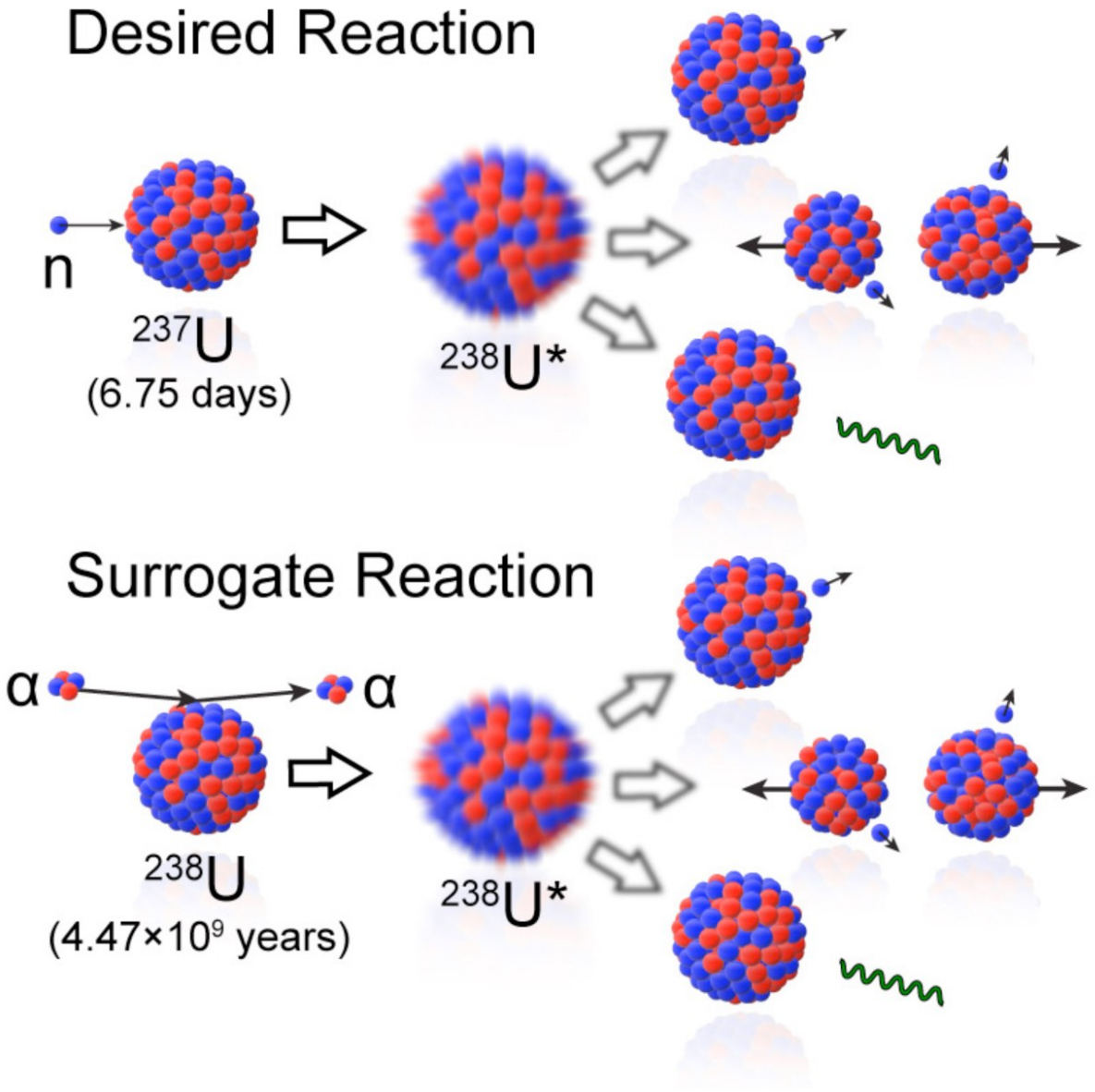
- Large Collaboration:
  - Multiple National Labs and Universities Collaboration
    - Mainly from LLNL
    - People from several countries
  - Originally Set Up at Berkeley

  First In place here in 2012

- Experiments:
  - Tagged Transfer Reaction Study
  - Surrogate Technique to Obtain Cross Sections
    - "Populating the same compound nucleus using a longer-lived target"
    - For Neutron Capture, Neutron Induced Fission and (n,2n) cross sections

- Currently up to 6 Ge Clover Detectors
  - Upgrade for more coming soon
- Up to 4 Si Detectors
  - 2 upstream and 2 down stream of a target placed on a rotating wheel


Silicon Detectors
Clover Germanium Detectors
Beam
Solid Target


Desired Reaction
n
237U
(6.75 days)
238U*
Surrogate Reaction
α
α
238U
(4.47×10^9 years)
238U*

Collaborators

(undergraduate students, graduate students, post-docs)

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