A β-delayed charged particle detector for studies of novae and X-ray bursts

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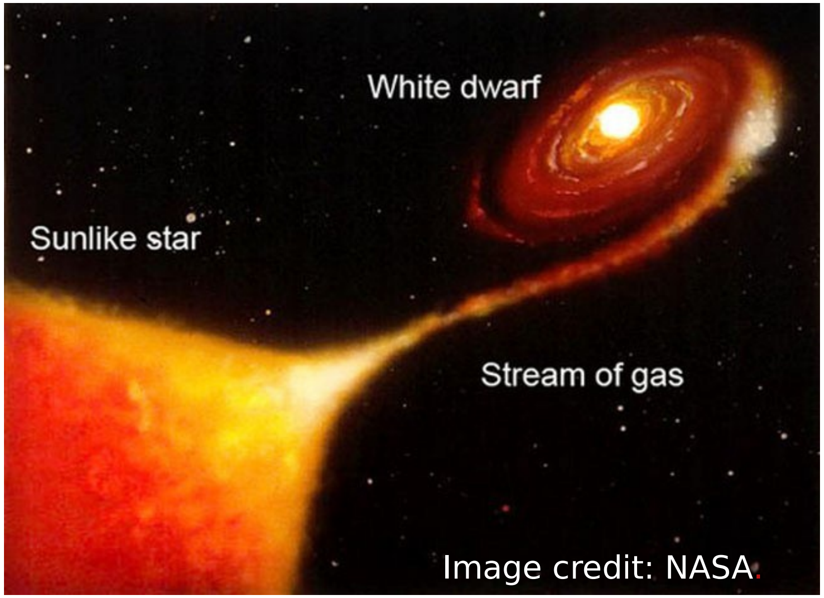
Outline

- Astrophysical motivation - thermonuclear runaways
  - Phase I: $^{31}Cl(\beta p)^{30}P$ decay to probe $^{30}P(p,\gamma)^{31}S$ (Nova)
- Experimental challenges
- The Proton Detector project
  - Principle of operation
  - Detector assembly
  - Performance
- Proposed experiments
  - $^{31}Cl(\beta p)^{30}P$ experiment
  - Future outlook: Time Projection Chamber for Phase II
- Summary

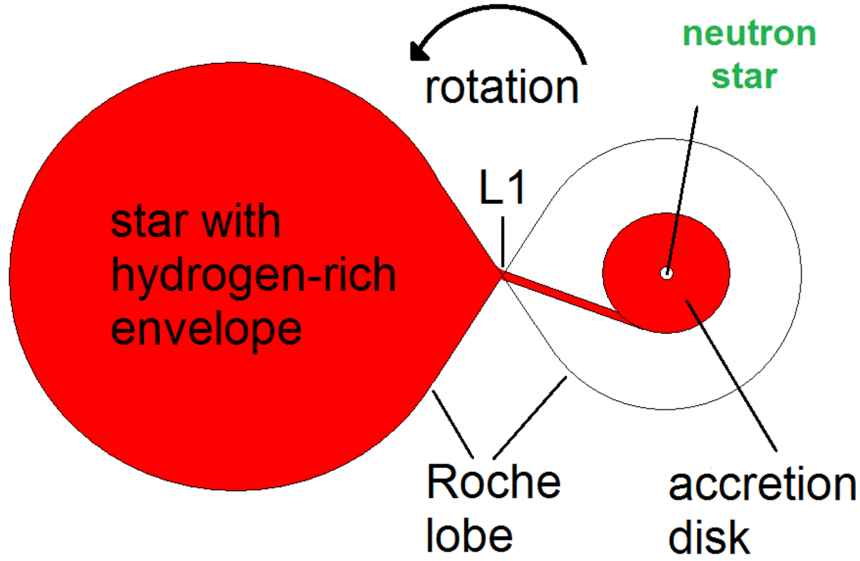
Close Binary Systems

Classical novae



Observables of interest:
Composition of ejected material
- Spectroscopy
- Cosmic γ-ray emission
- Pre-solar grains

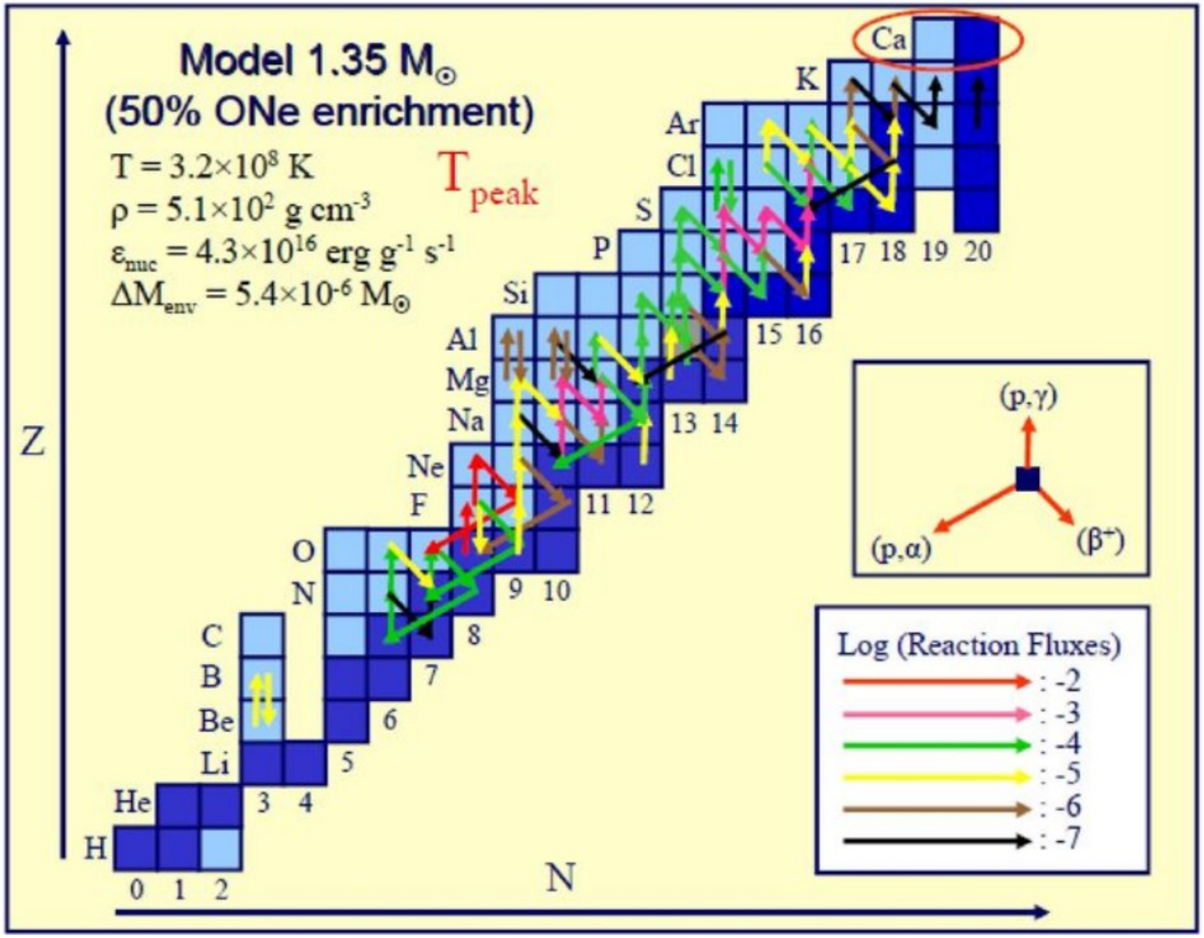
Type I x-ray bursters



Observable of interest:
X-ray light curve

Phase I: $^{31}Cl(\beta p)^{30}P$ decay to probe $^{30}P(p,\gamma)^{31}S$

Nucleosynthesis in novae



J. Jose, Proceedings of Science, NIC XI 050 (2011)

Phase I: ^{31}Cl(βp)^{30}P decay to probe ^{30}P(p,γ)^{31}S

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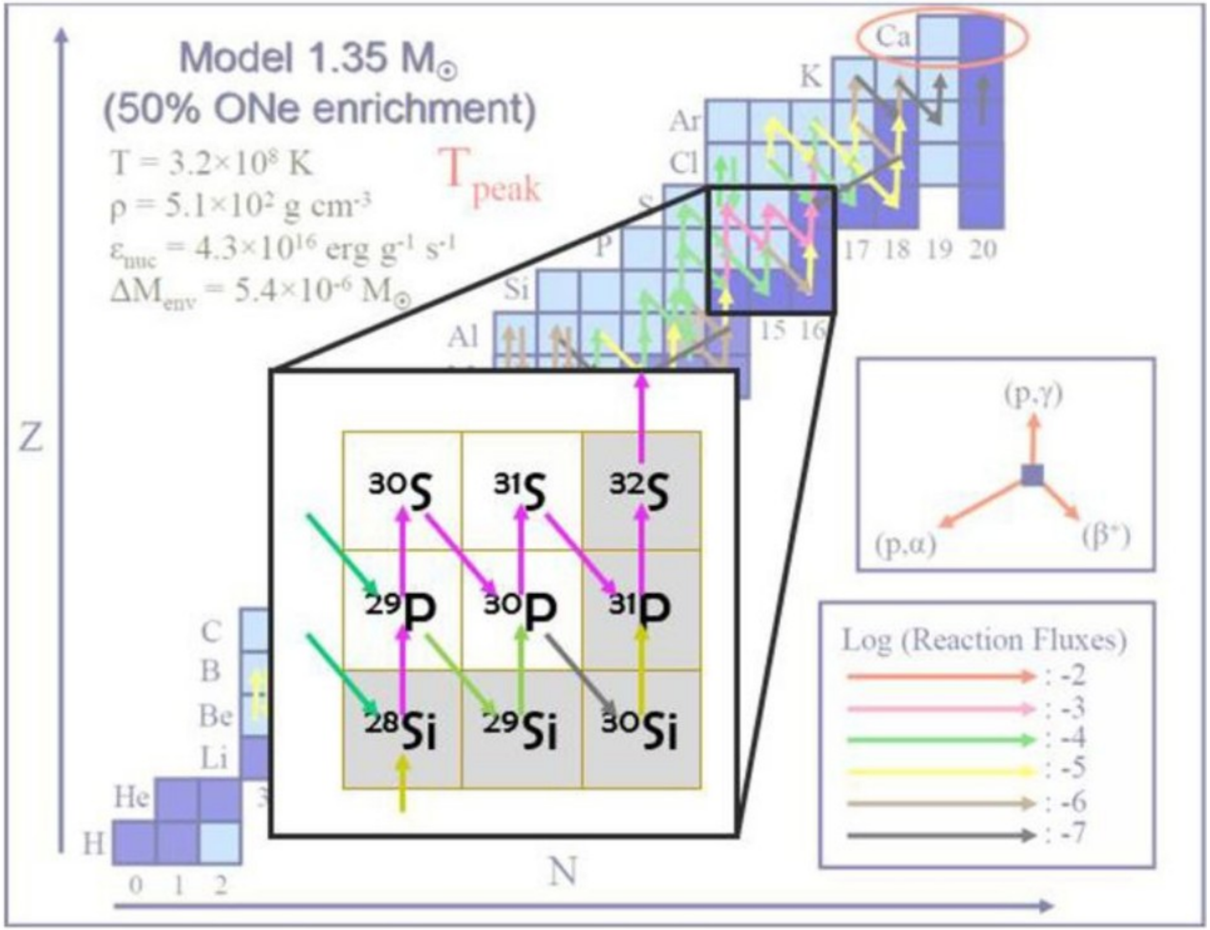

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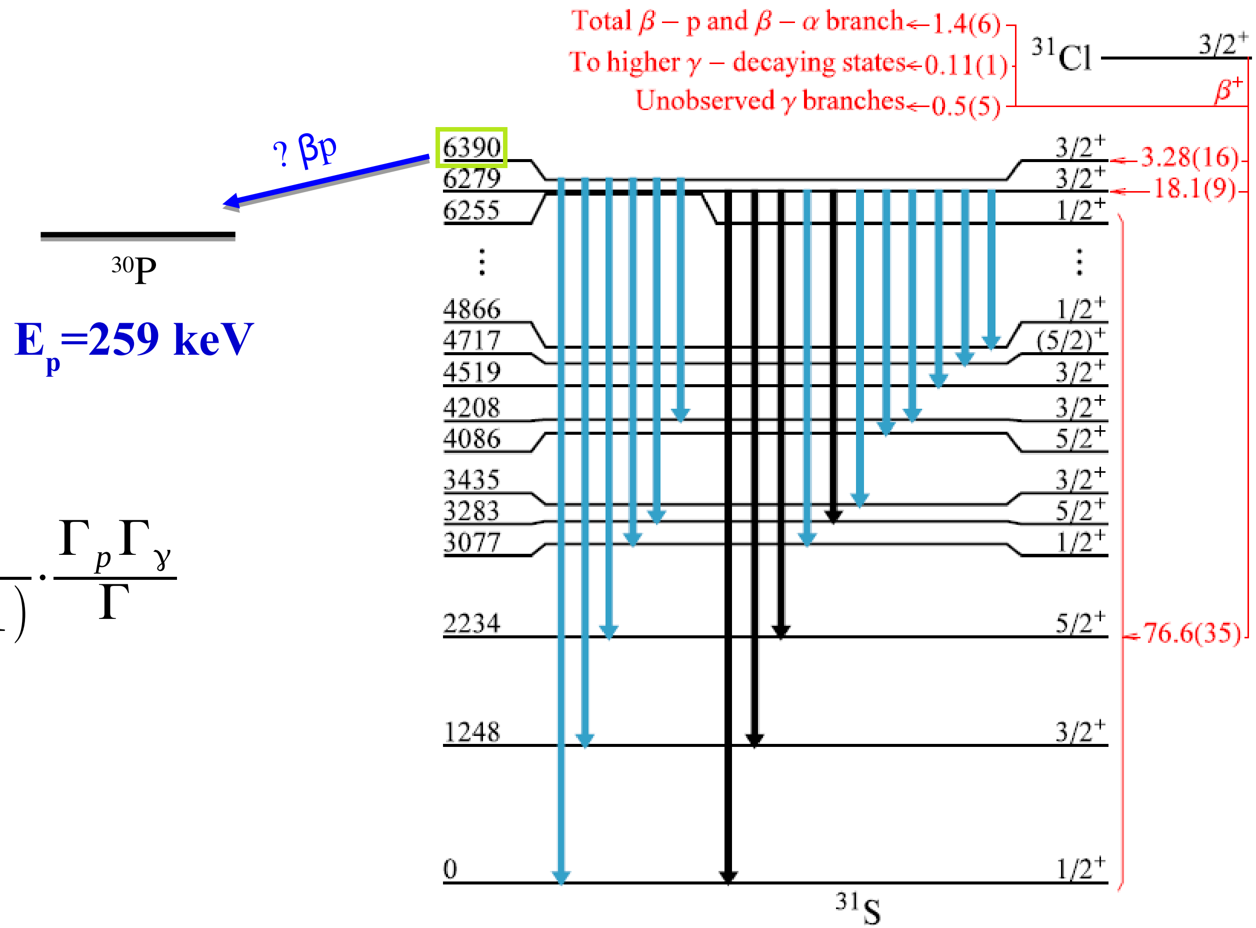


$$\omega\gamma = \frac{2J_{res}+1}{(2J_{reac}+1)(2J_p+1)} \cdot \frac{\Gamma_p \Gamma_\gamma}{\Gamma}$$

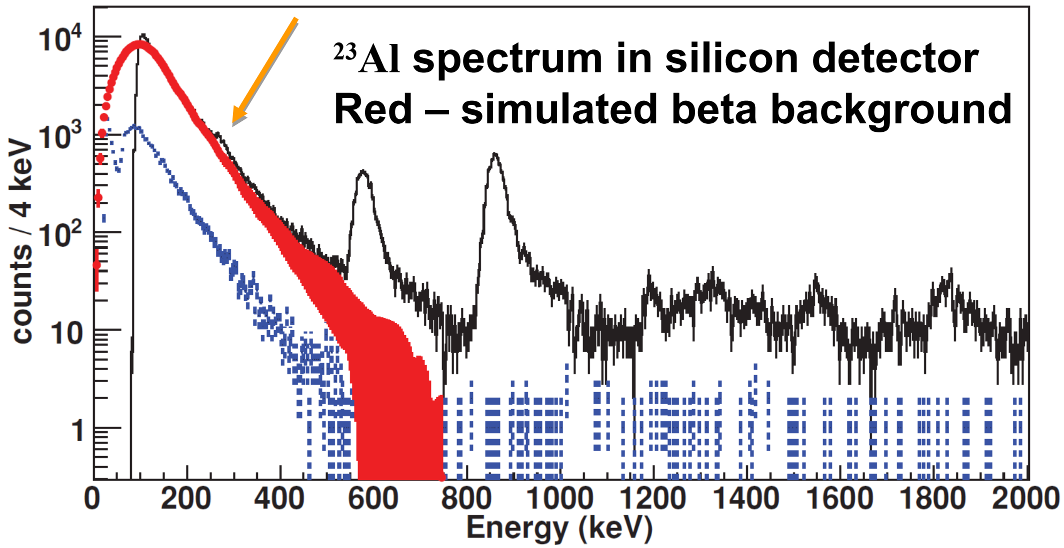
C.Iliadis, Nuclear Physics of Stars (Wiley-VCH, Weinheim, 2007)

Level population measured in our previous experiment: M. B. Bennett *et al.*, Phys. Rev. Lett. 116, 102502 (2016)

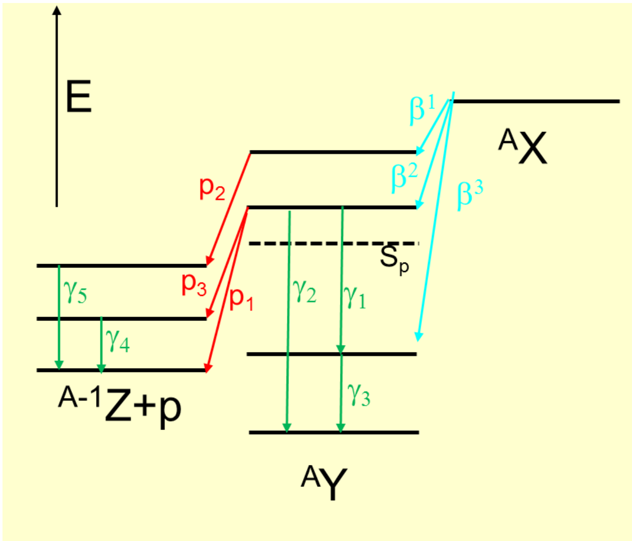
Experimental challenges

- **Detect low energy protons with strong β background**

A. Saastamoinen *et al.*, PRC 83, 045808 (2011)



- **Distinguish between β-p and β-p-γ decays**



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- **Use a gas-filled detector**

E. Pollacco *et al.*, NIM A, 723 (2013)
A. Saastamoinen *et al.*, NIM B, 376 (2016)

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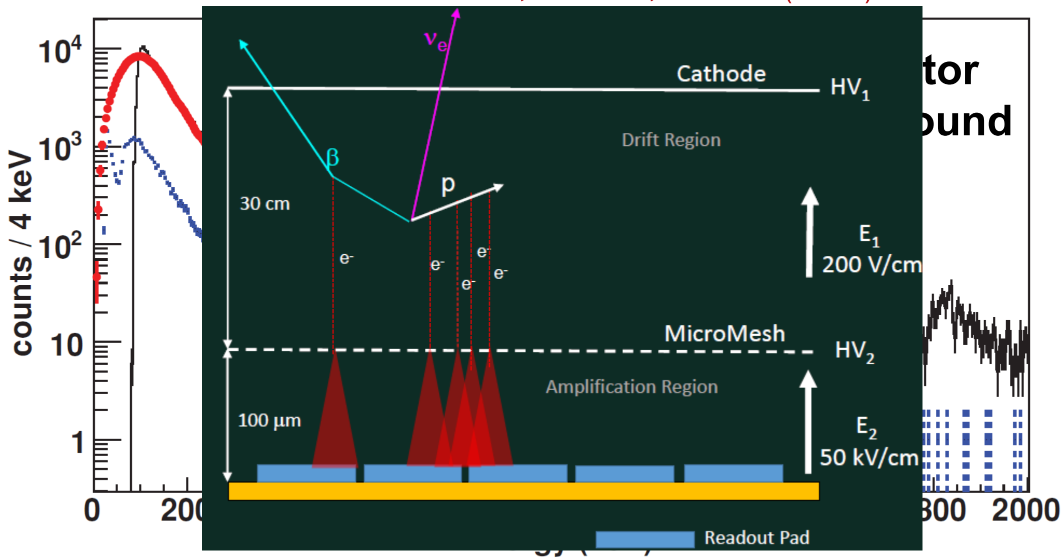

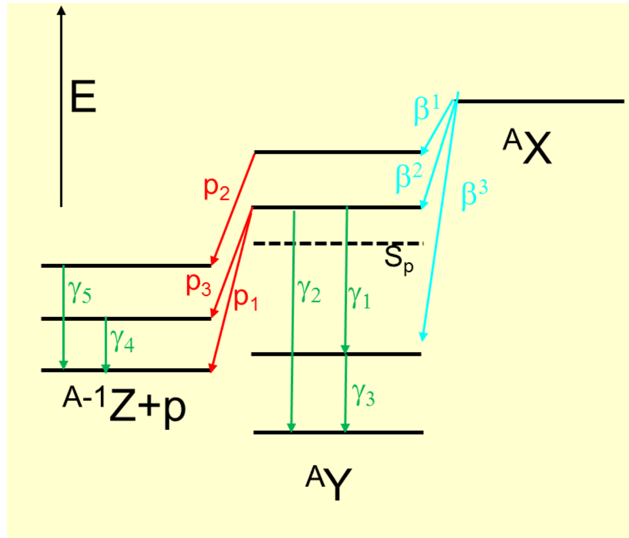

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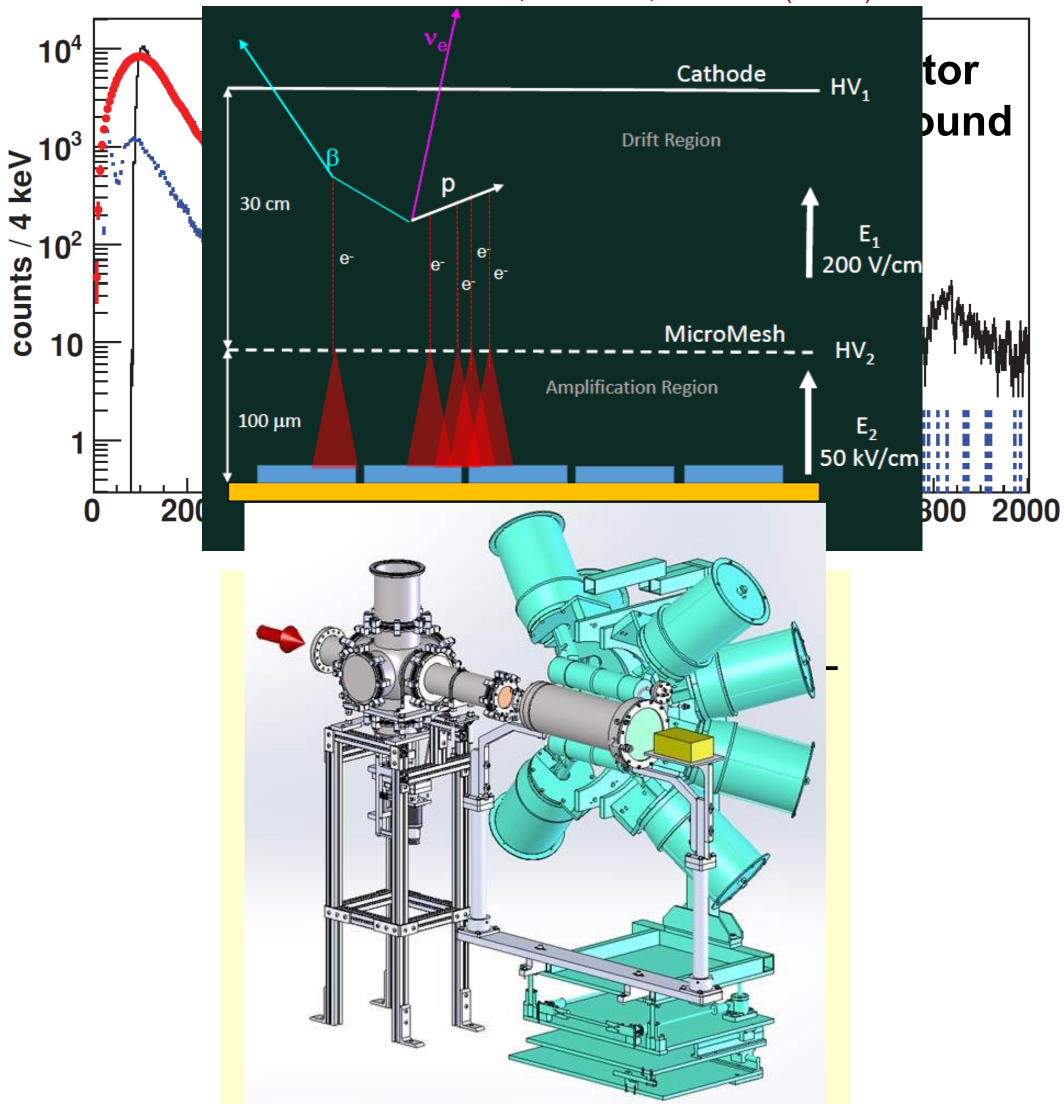

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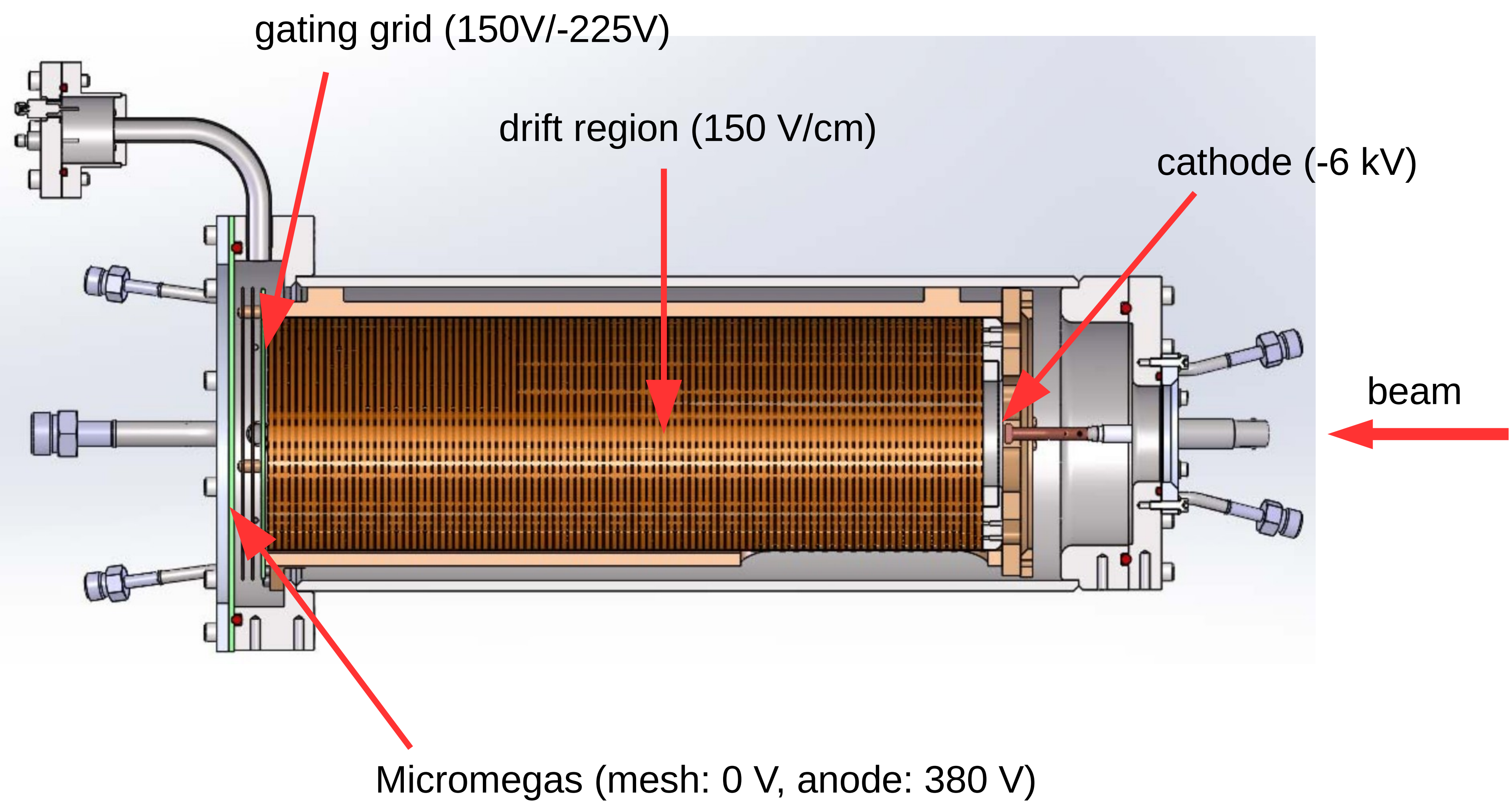
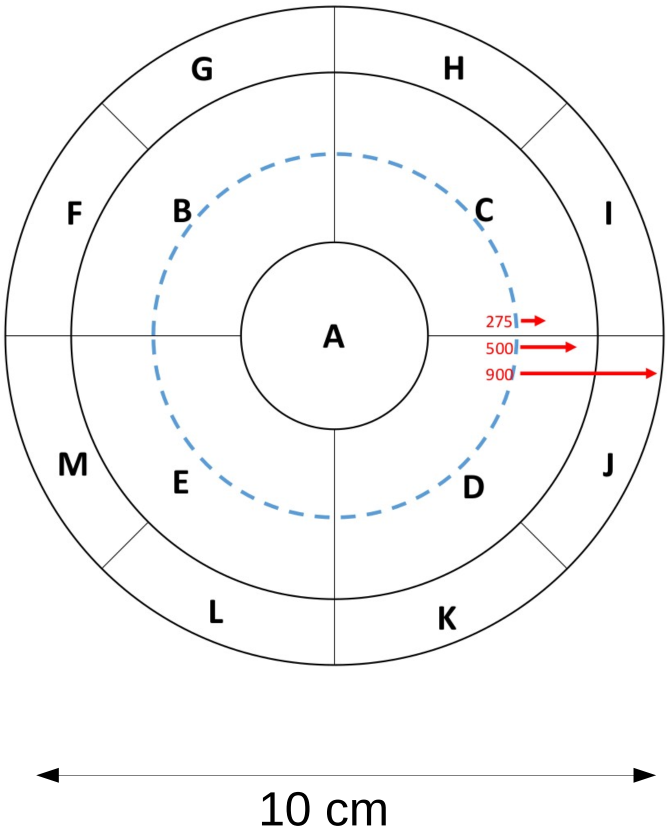
- **Fit detector into SEGA array for coincidence γ detection**

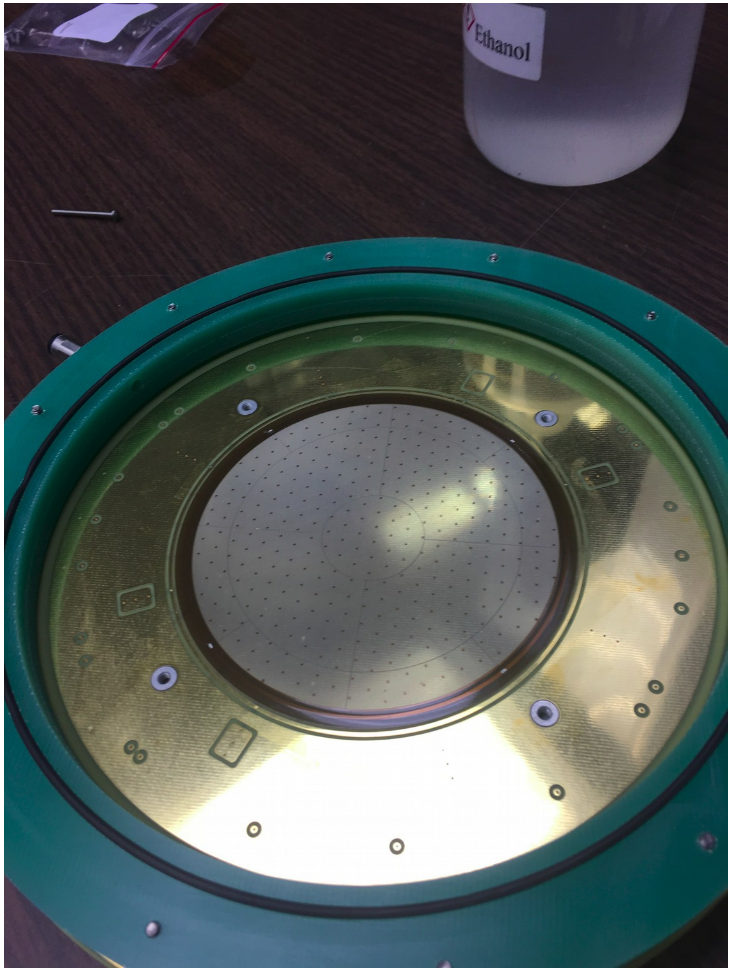
The Proton Detector



The Proton Detector

pad plane geometry





Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

- Commissioning experiment run between May 2-6.
- ^{25}Si beam with strong and clean 401 keV proton line used for tuning and calibration purposes.
- Long (~11 hours) run with ^{23}Al beam for low energy (215 keV) beta-delayed proton detection.
- Same decays used to successfully commission ASTROBOX detectors at Texas A&M.
- An additional measurement of ^{11}Be decay was done few weeks later

Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

The Segmented Germanium Array (SeGA)

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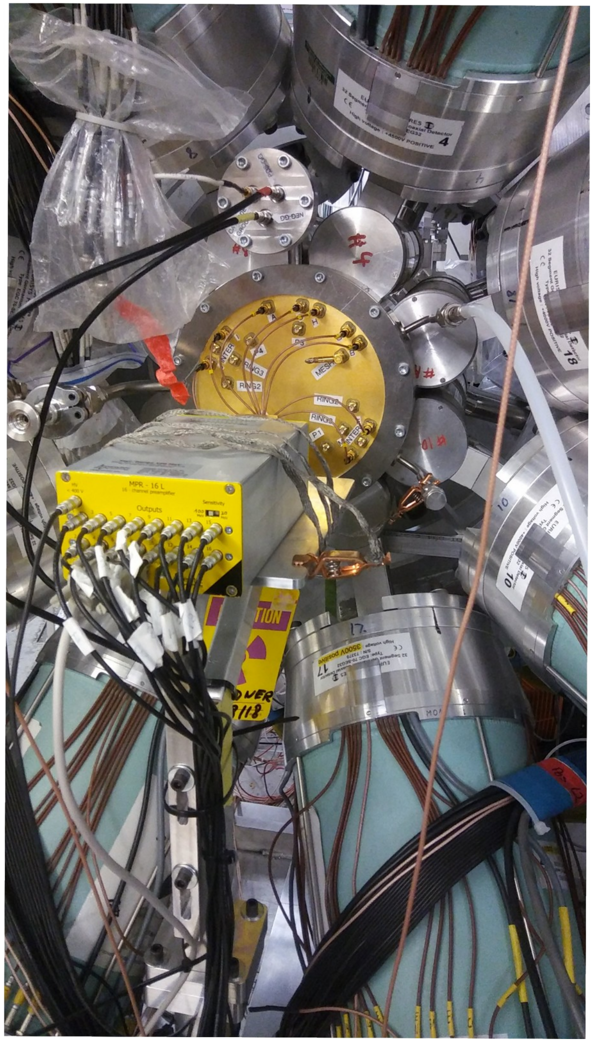
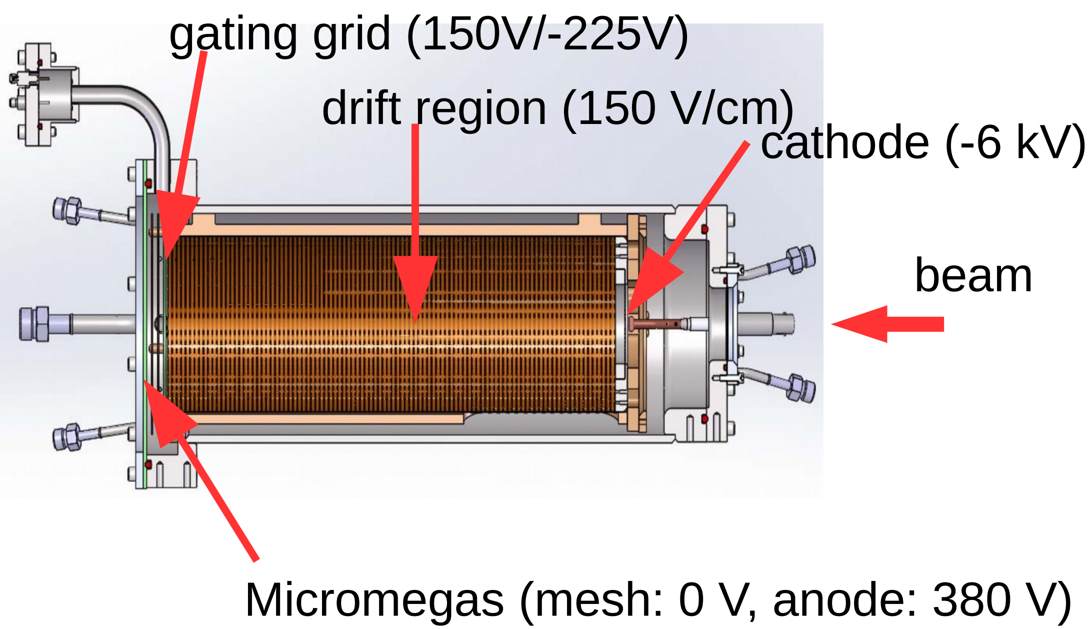
Data Acquisition

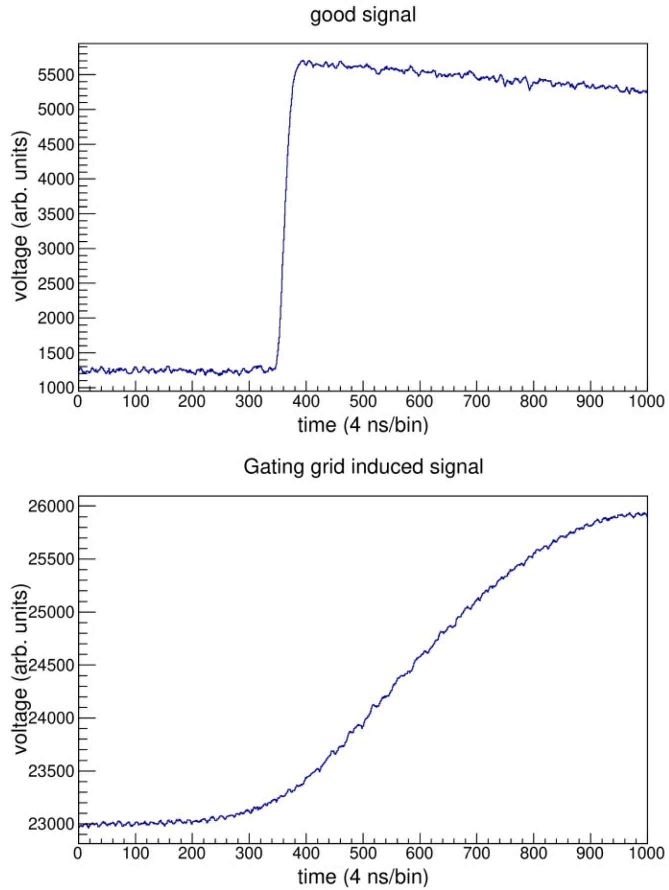


- Mesytec 16 channels charge sensitive preamp.
- 2 NSCL Digital Data Acquisition modules, 16 channels each (one for SeGA).
- Sampling frequency 250 MHz.
- Each channel trigger independently with single clock timestamps, no common trigger required.

Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

Gating Grid Modes
Unipolar mode



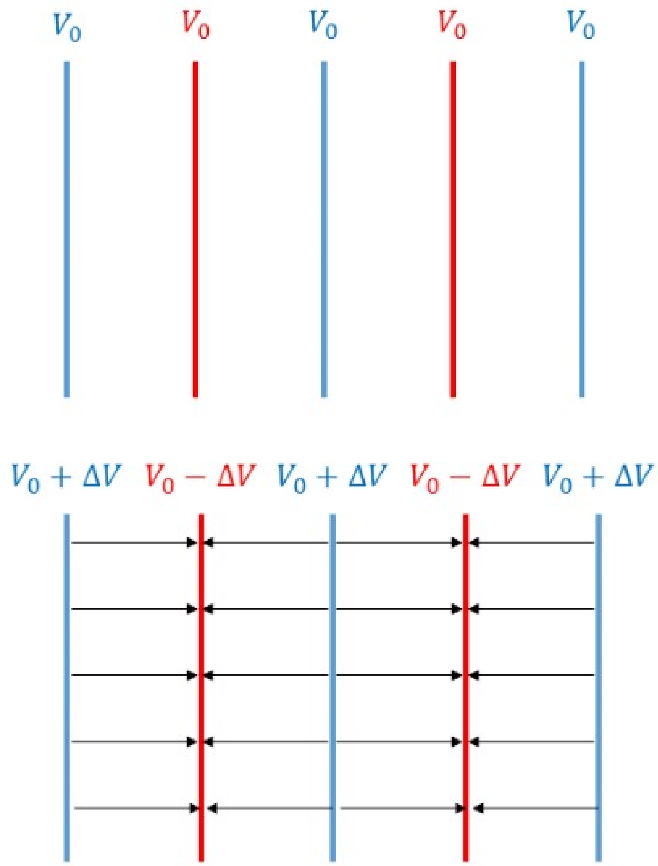


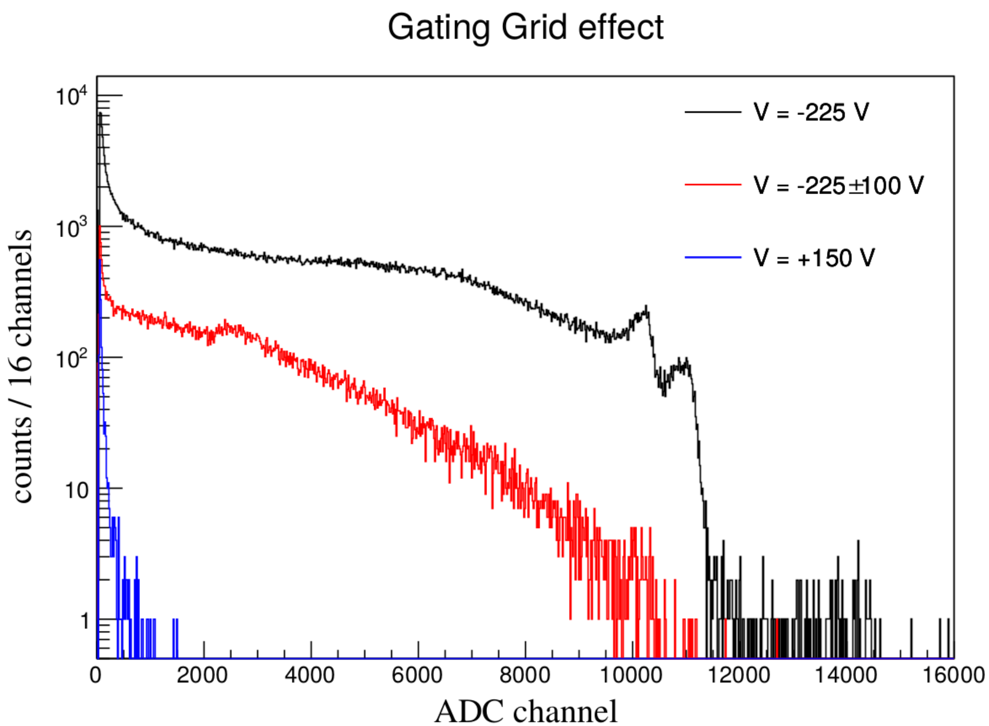
Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

Gating Grid Modes
Bipolar mode

transparent

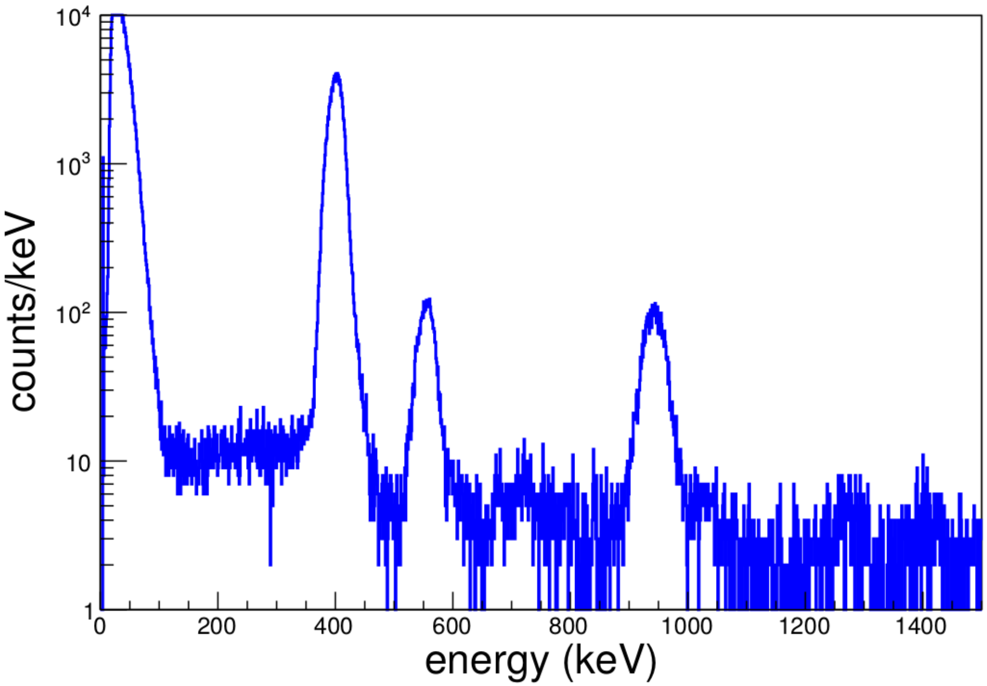
intermediate

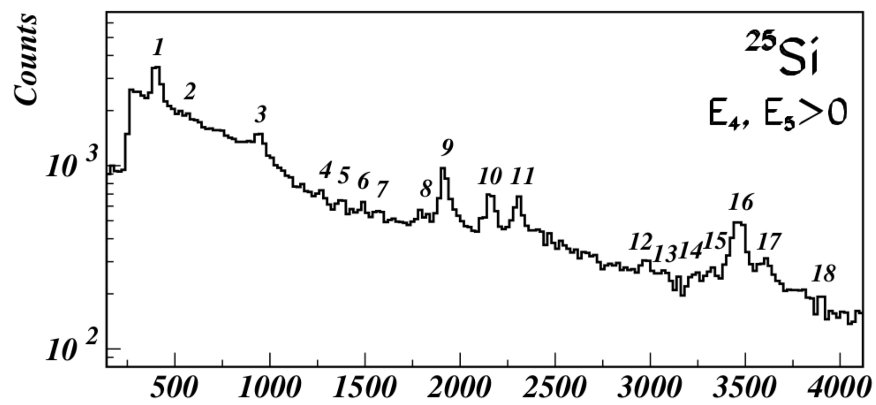




Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

^{25}Si data

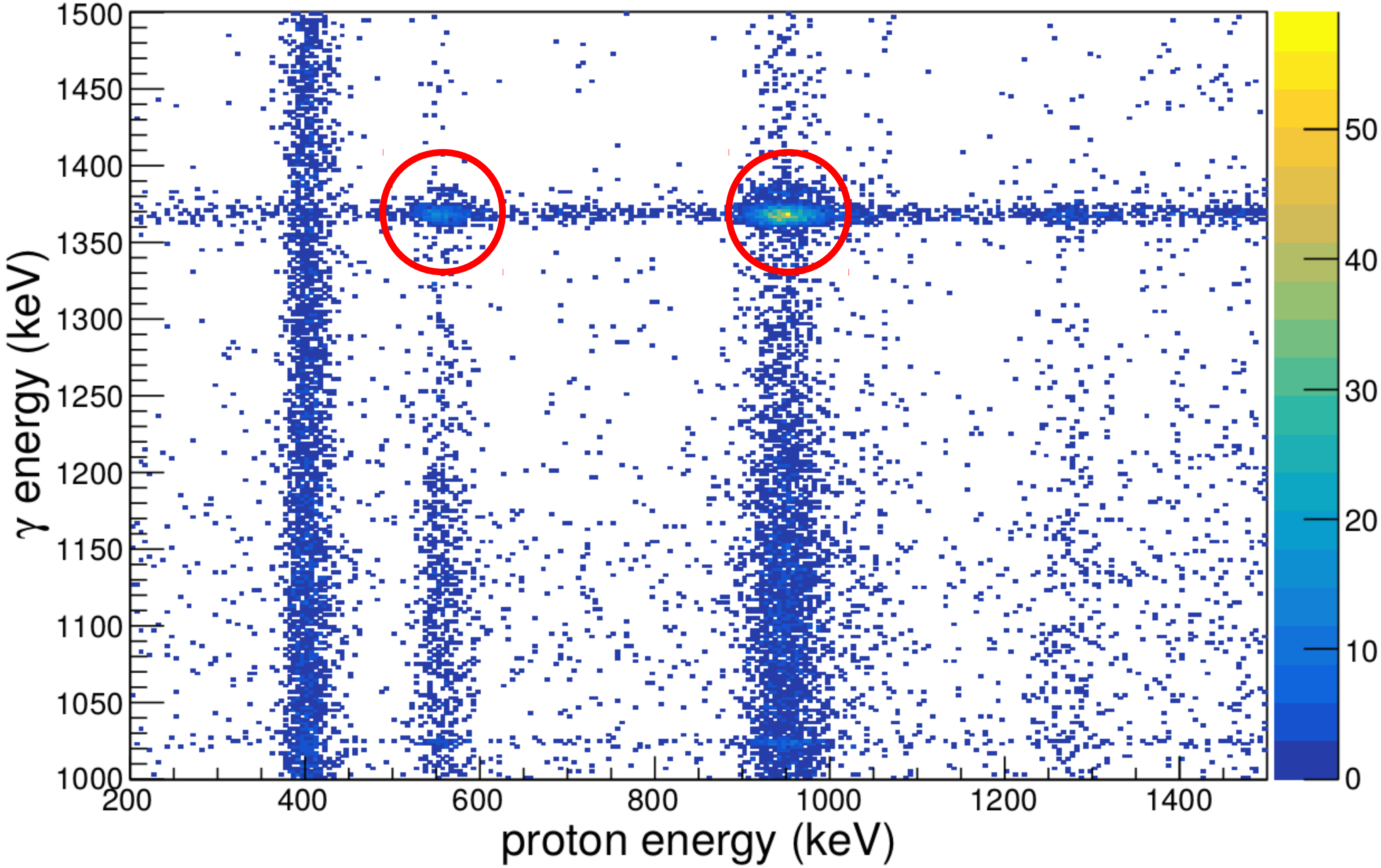




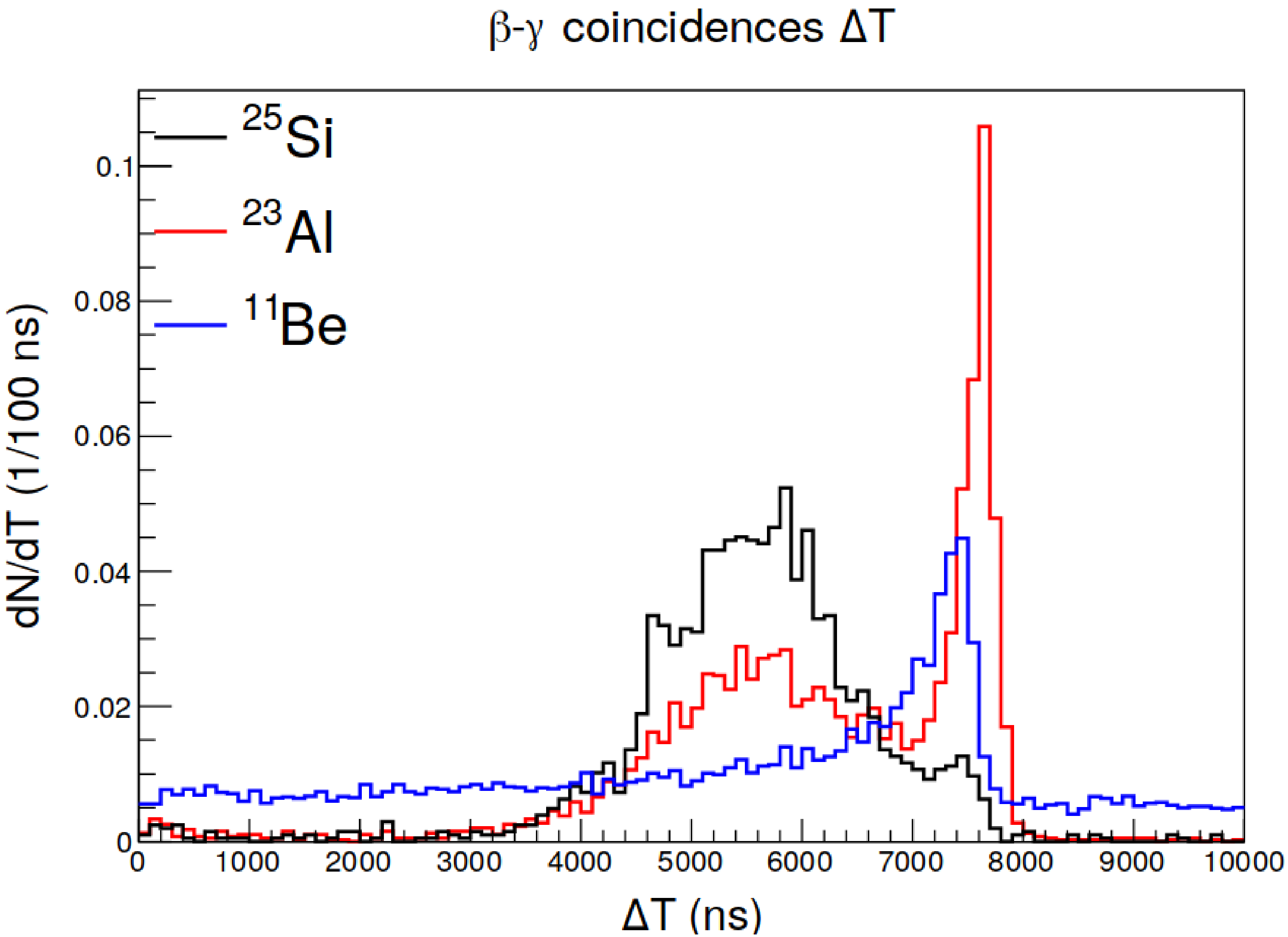
J.C. Thomas *et al.*, EPJ A 21 (2004)

Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

γ-p coincidences



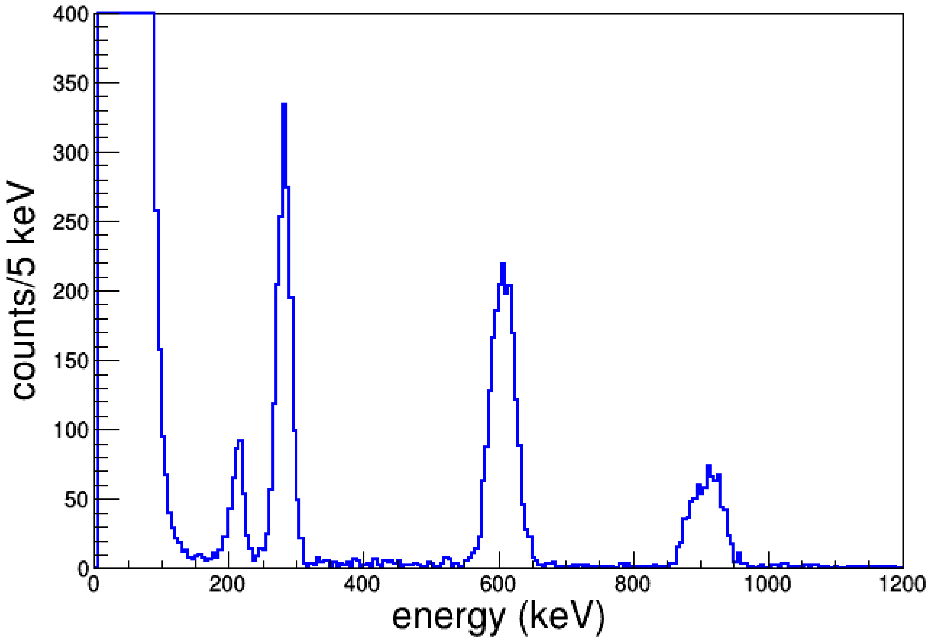
Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

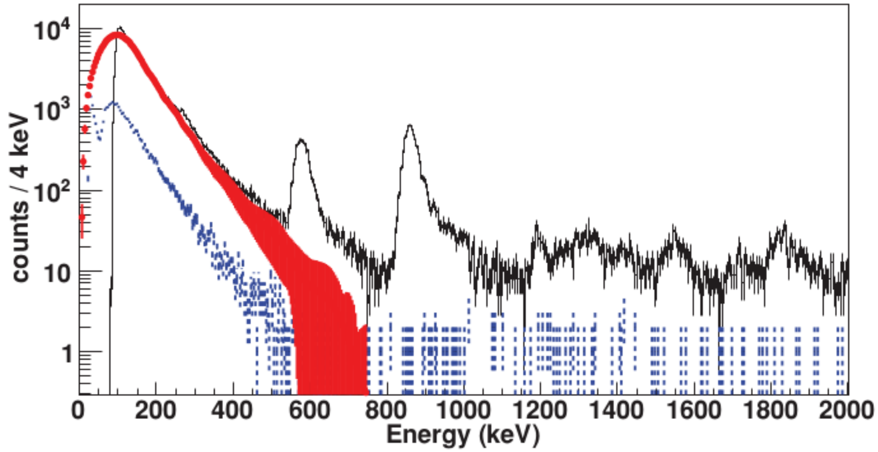


Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

^{23}Al data

pad A



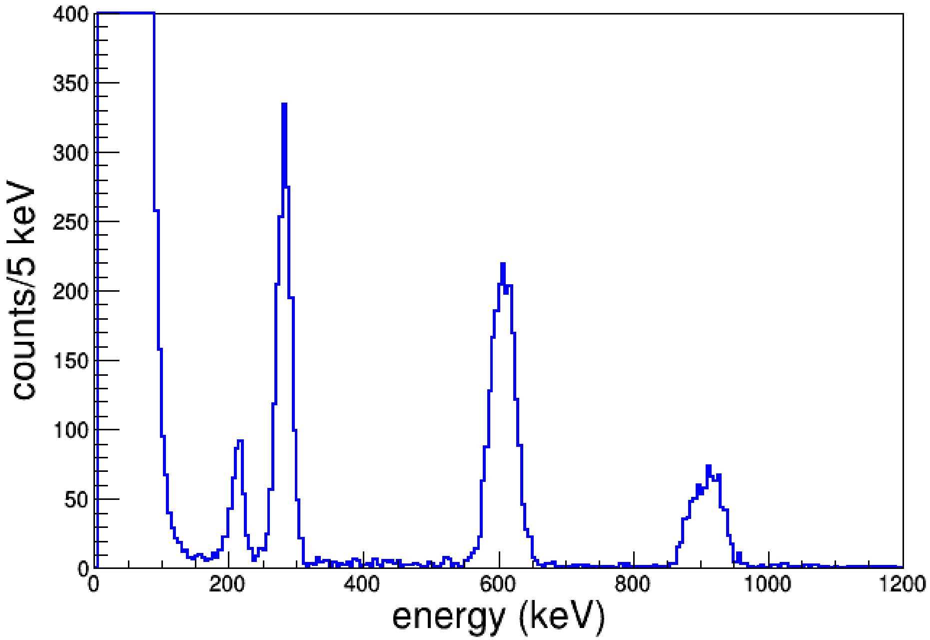


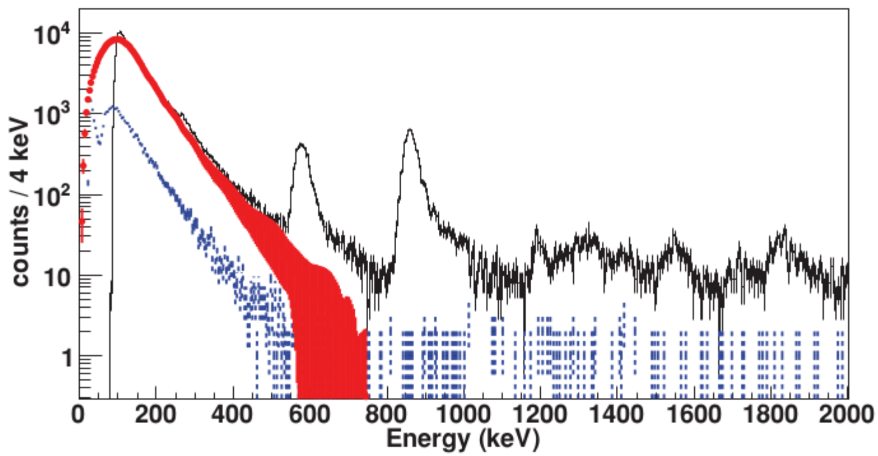
A. Saastamoinen *et al.*, PRC 83, 045808 (2011)

Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

Normalization

pad A





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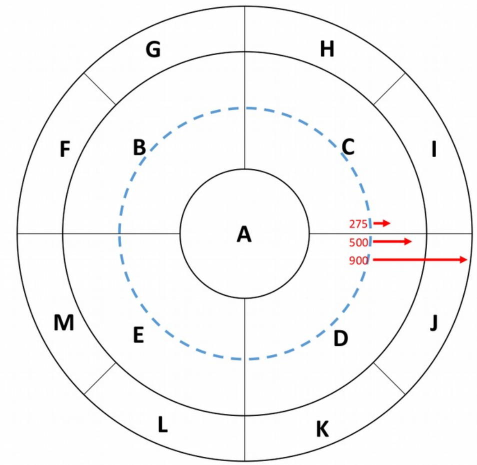
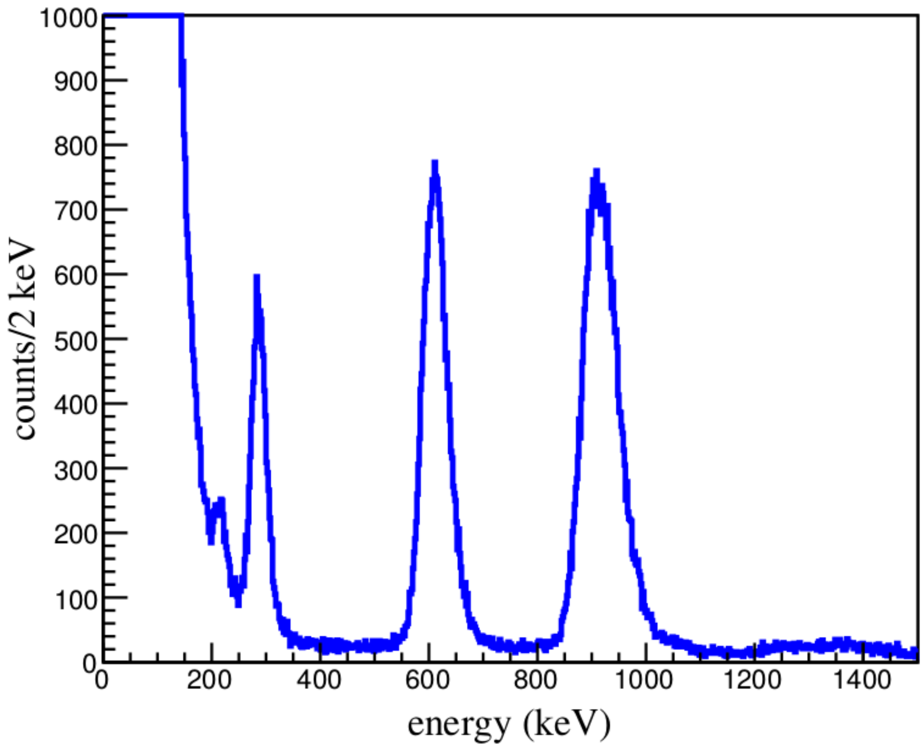
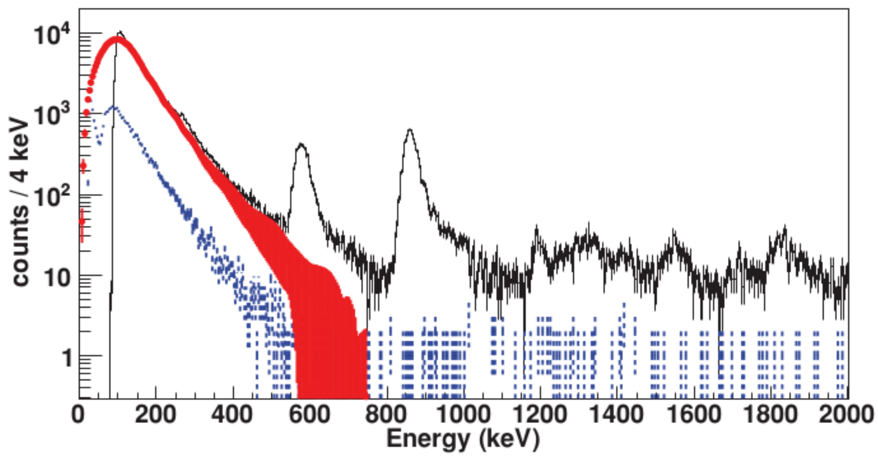


Commissioning with $^{23}Al(\beta p)^{22}Na$ and $^{25}Si(\beta p)^{24}Mg$ decays

Normalization

all pads





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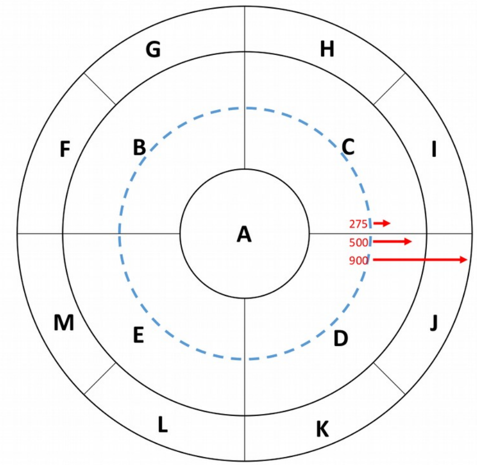
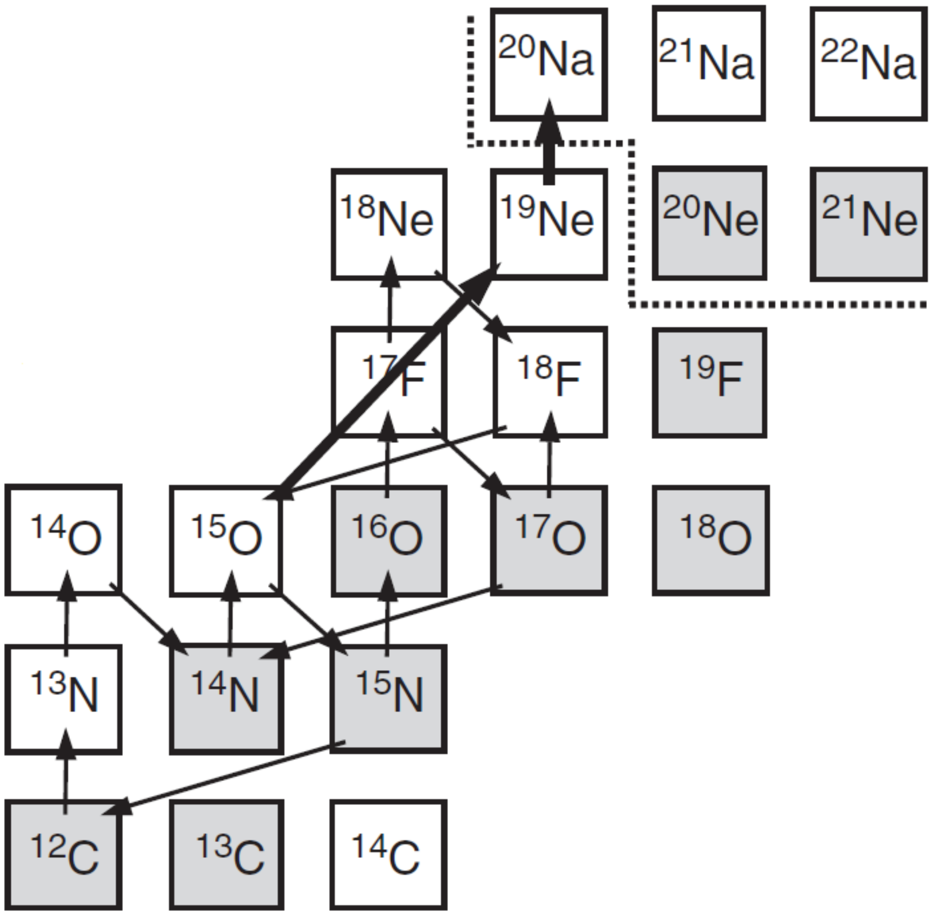


$^{31}Cl(\beta p)^{30}P$ experiment

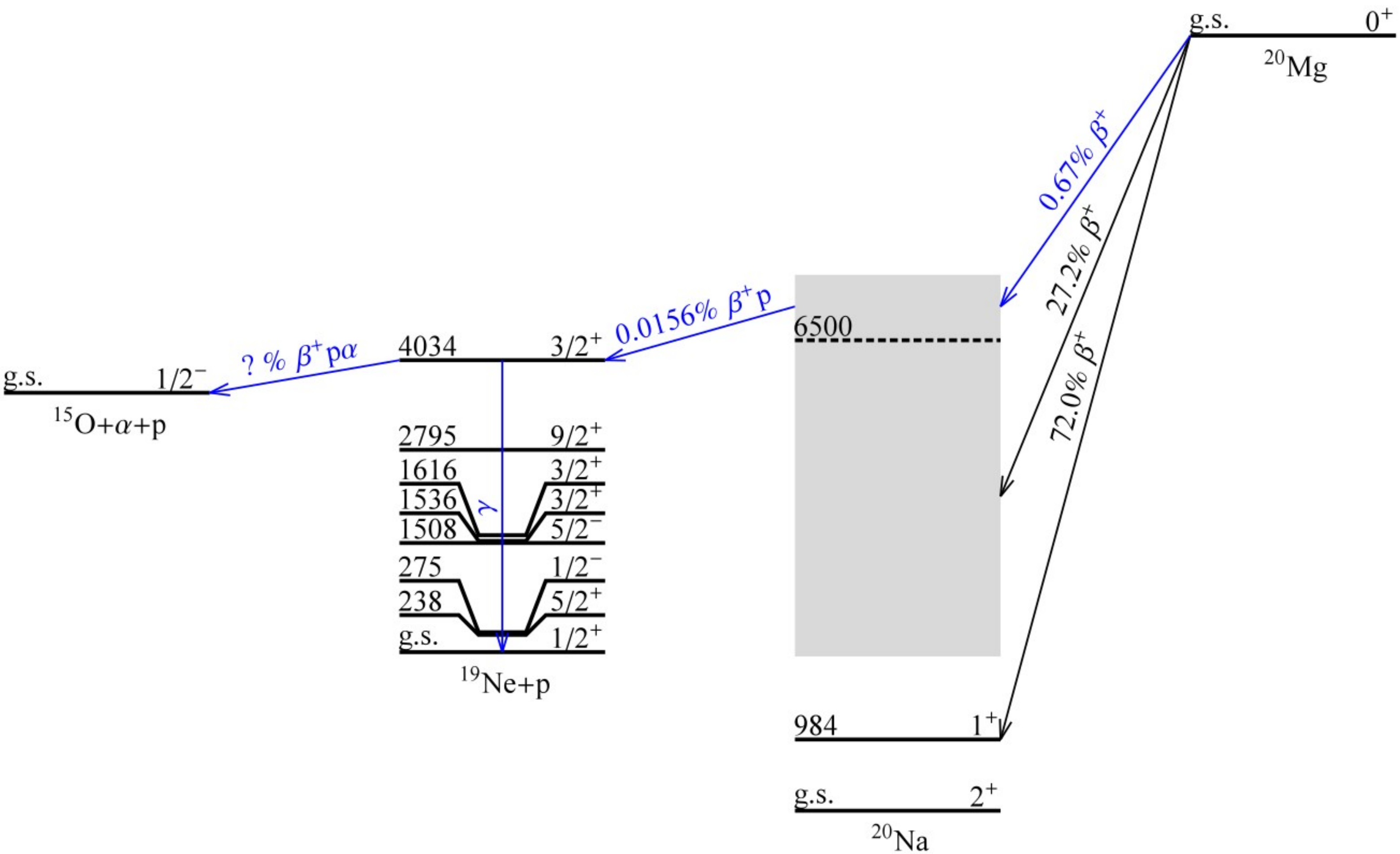
- $^{31}Cl(\beta p)^{30}P$ experiment conditionally approved.
- Based on Geant4 simulation, and assuming absolute intensity of 10^{-5} we expect ~7000 counts in the relevant 259 keV proton line for 140 hours of measurement time.

Phase II: $^{20}Mg(\beta p\alpha)^{15}O$ decay to probe $^{15}O(\alpha,\gamma)^{19}Ne$

Break out from hot CNO cycles



Phase II: ^{20}Mg($\beta p\alpha$)^{15}O decay to probe ^{15}O(α,γ)^{19}Ne

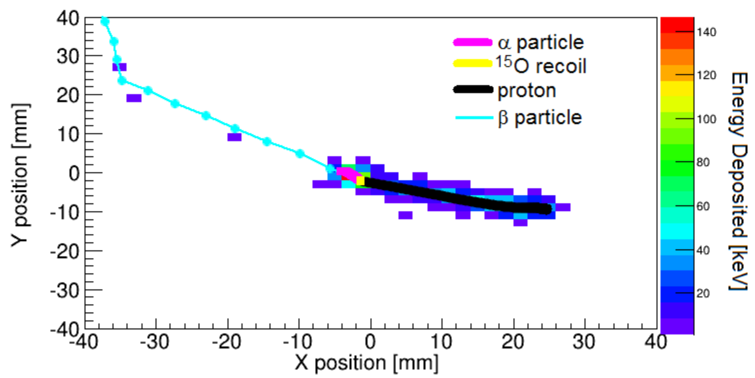


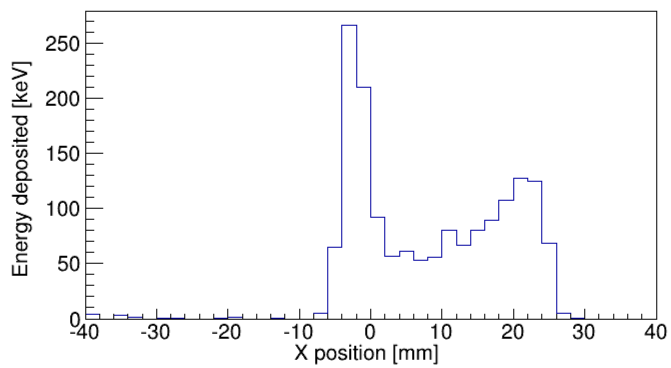
C. Wrede *et al.*, PRC 96, 032801(R) (2017)

Future outlook: Time Projection Chamber for Phase II

Phase II: upgrade to time projection chamber, by increasing Micromegas granularity to ~1800, 2X2 mm^2 pads. We intend to use GET data acquisition.

Geant4 simulation





Summary

- $^{30}P(p,\gamma)^{31}S$ and $^{15}O(\alpha,\gamma)^{19}Ne$ are key reactions to understand classical novae and type I x-ray bursts nucleosynthesis, respectively.
- Due to the lack of intense low-energy rare-isotope beams, direct measurements of the cross sections are not feasible. As an alternative, we measure decay products branching ratios to calculate resonance strengths.
- The Proton Detector group at NSCL is developed a β-delayed charged particle detector to study these reactions.
- The detector is coupled with the **Se**gmented **G**ermanium **A**rray.
- The detector is was successfully commissioned, first physics experiment is planned for November 2018.
- An upgrade to a TPC is planned. The upgrade will require ~1800 Micromegas pads, and changing to GET DAQ.

Our contributors

Collaborators:

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CEA – Saclay

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Texas A&M

A. Saastamoinen

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