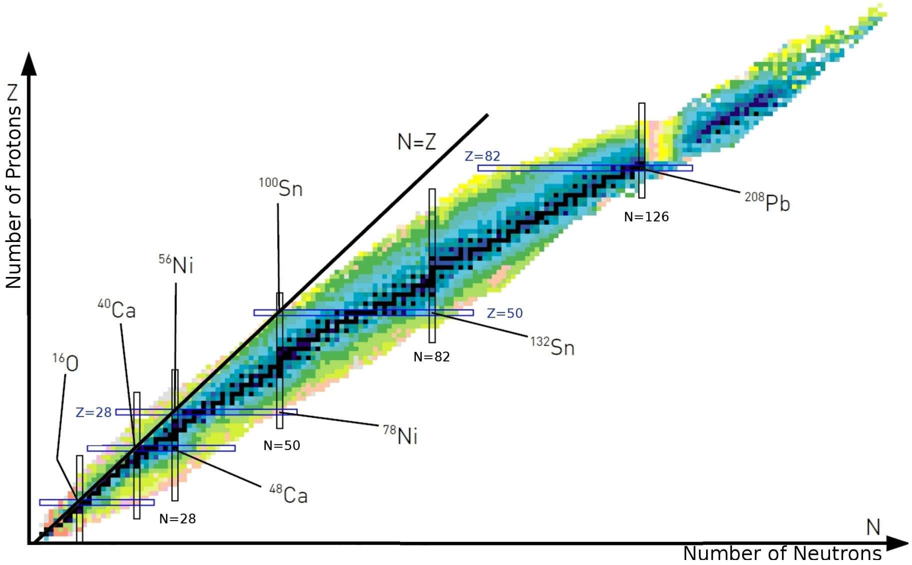
Mirror symmetry in the $f_{7/2}$ shell below ^{56}Ni, excited states and electromagnetic transition rates in ^{55}Ni and ^{55}Co

H. Asch for the TIP/TIGRESS Collaboration

Department of Physics
Simon Fraser University

Structure studies along the N=Z line



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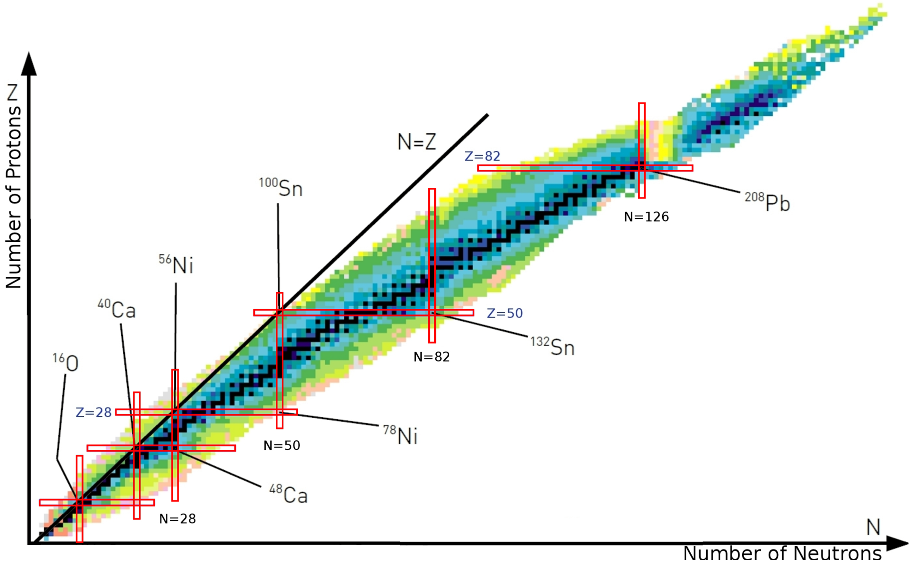

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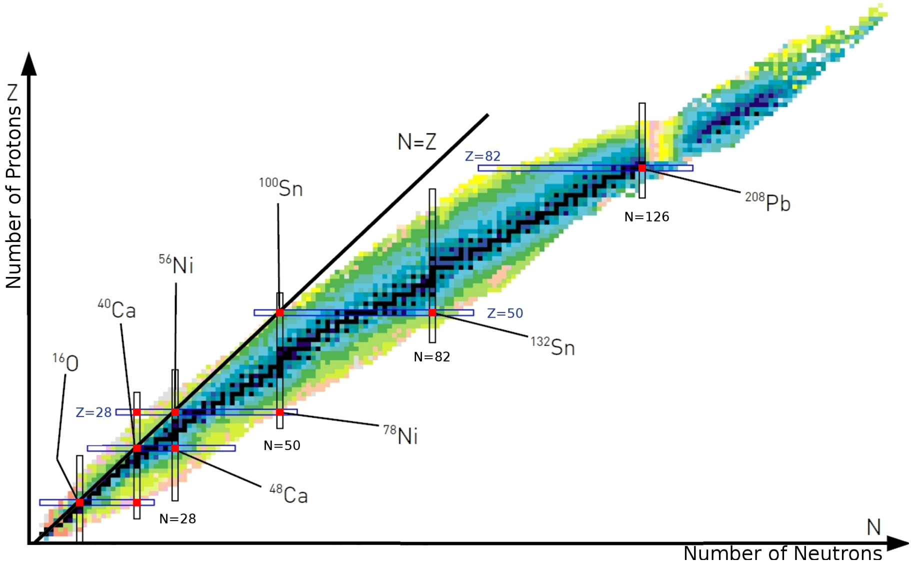

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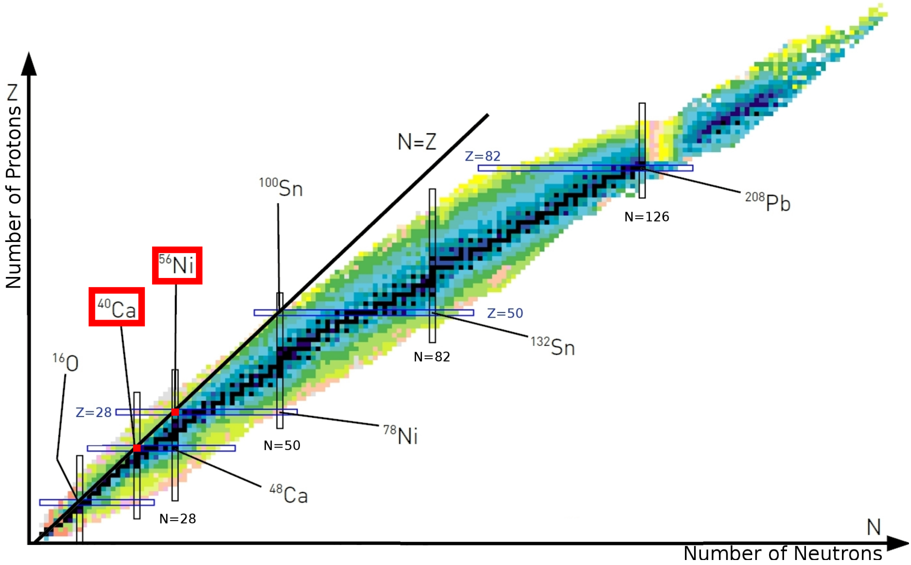

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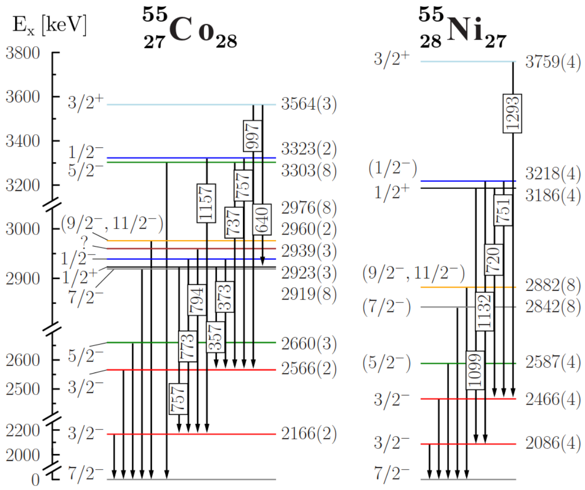
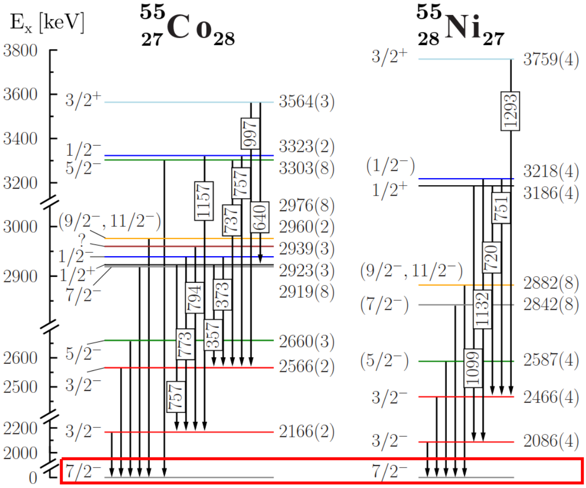
- This arises from the charge dependence of the strong interaction.
- Best viewed in mirror nuclei which are identical under the exchange of proton and neutron counts.

Mirror Asymmetry



Spieker et al., 2019, PhysRevC.99.051304



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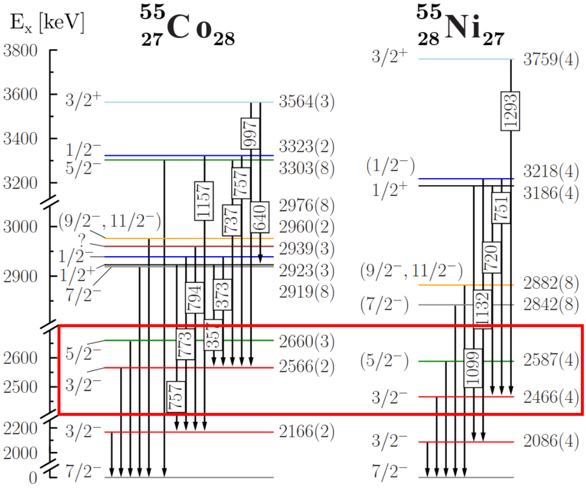

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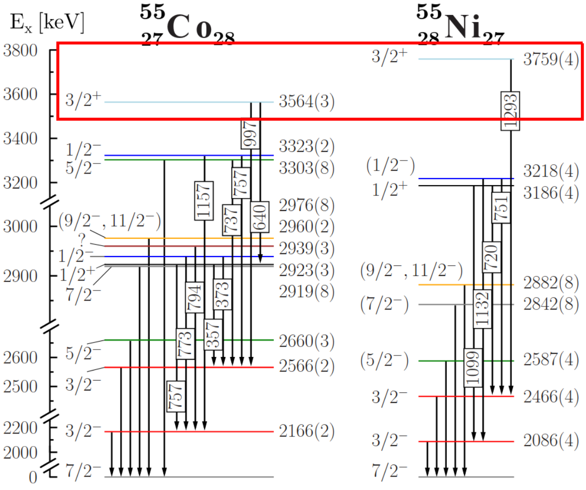

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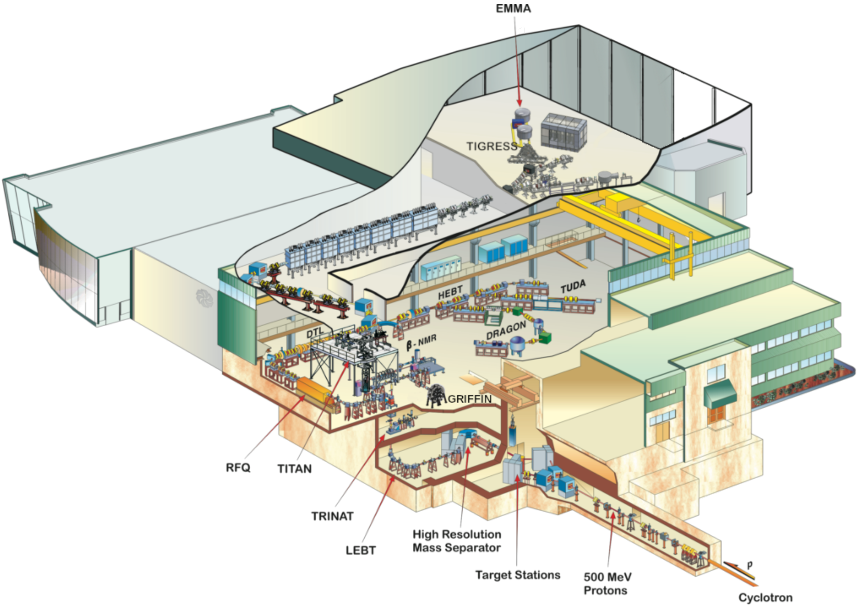
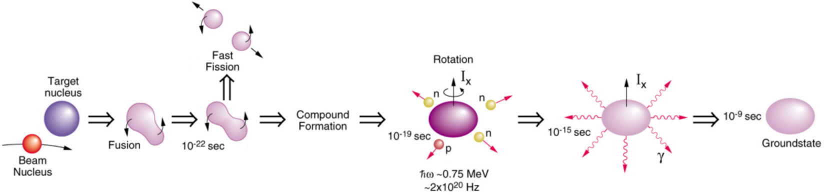
Isotope Separator and ACcelerator II (ISAC-II)



Fusion Evaporation for ^{40}Ca(^{21}Na,αpn)^{55}Ni



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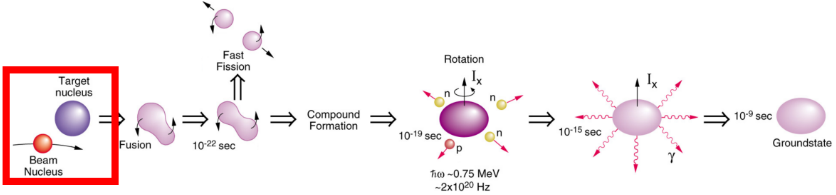

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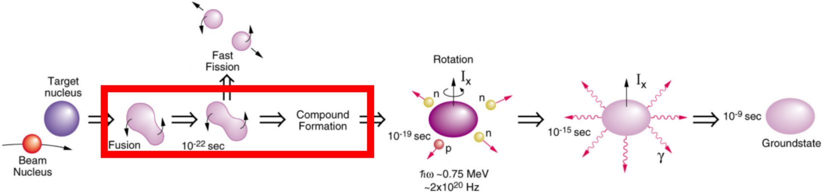

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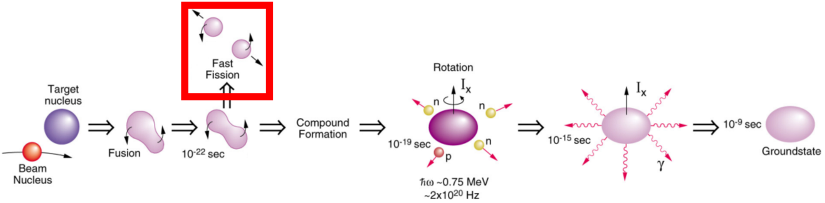

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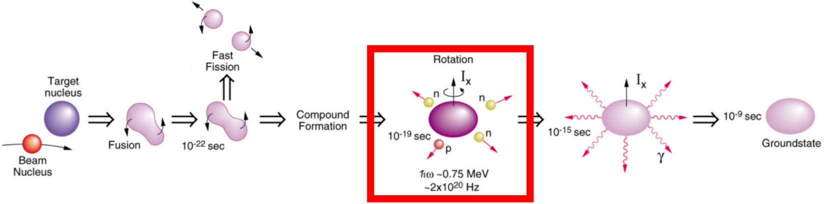

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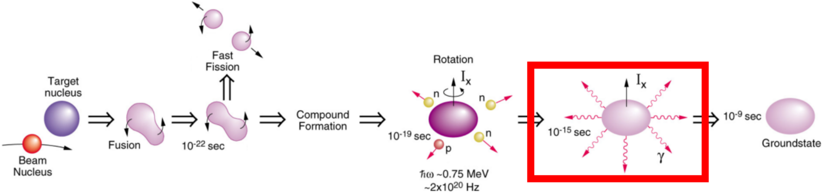

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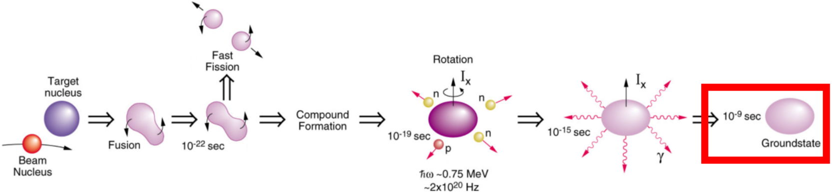

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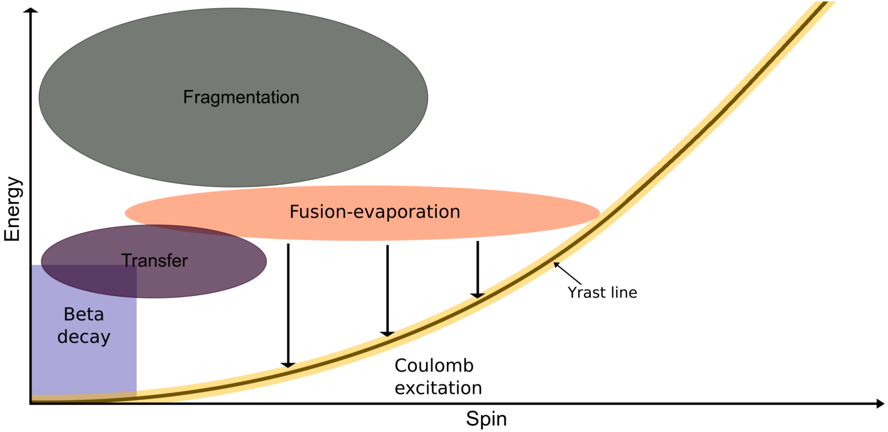
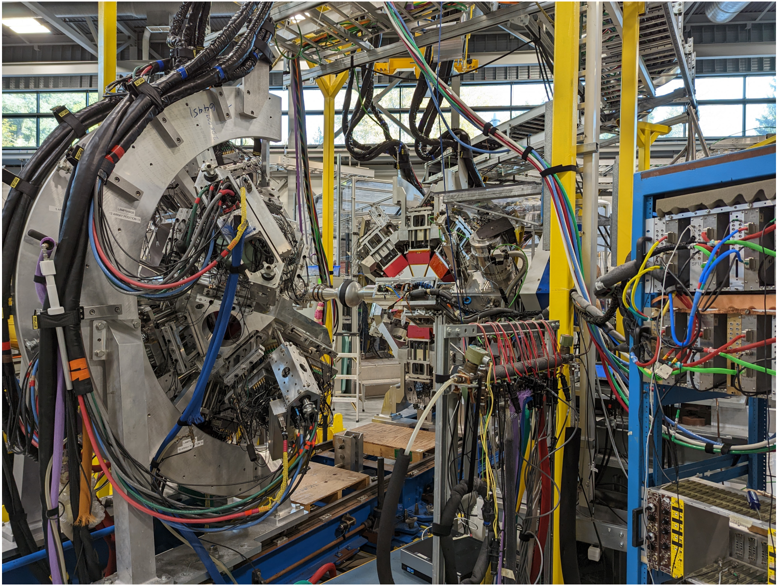
Comparison of Reaction Mechanisms



TRIUMF-ISAC Gamma-Ray Escape Supp. Spec.



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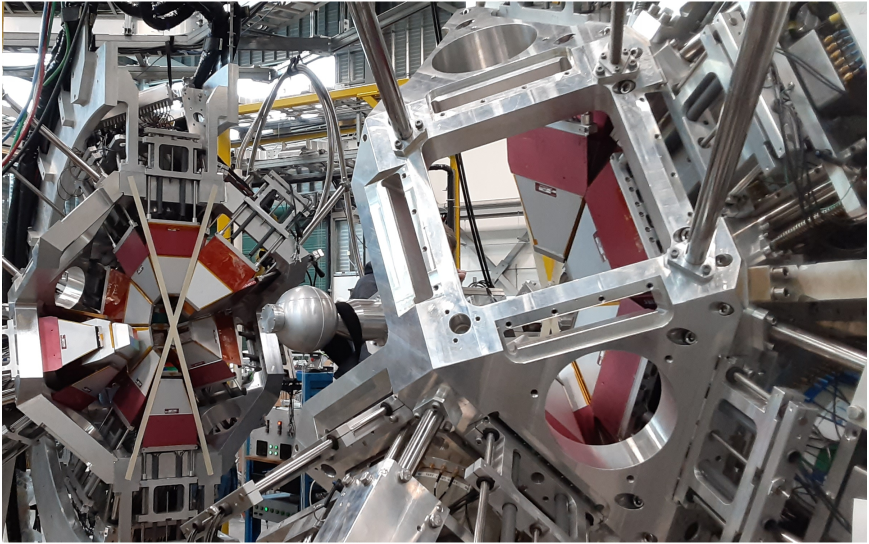
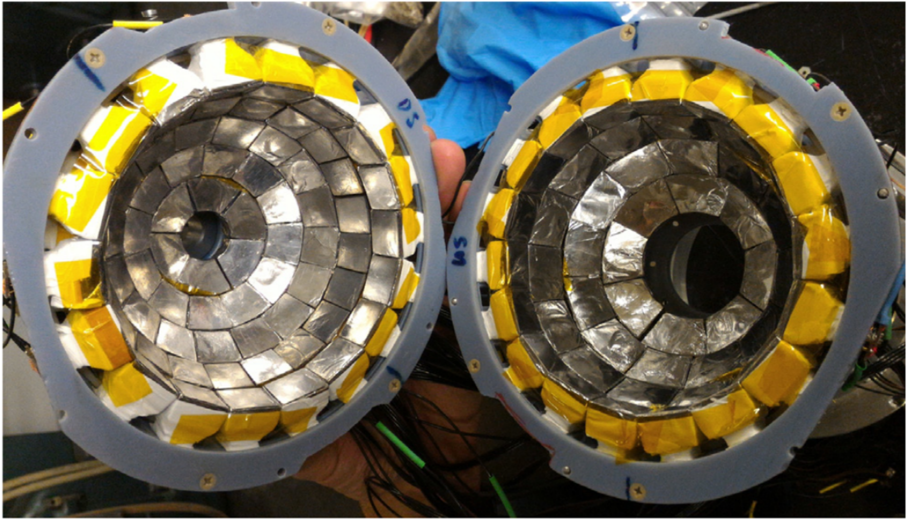


Cesium Iodide Ball



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- Progress is being made toward quantitative analysis.

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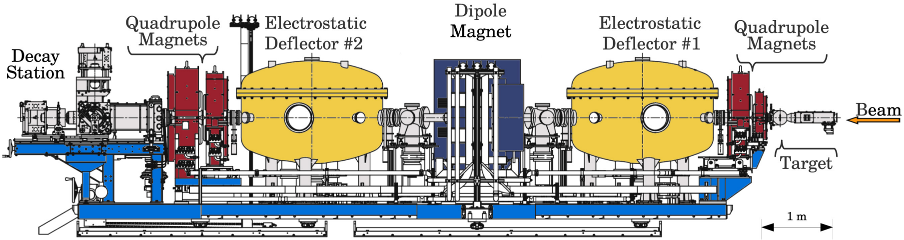
- Will collect two data streams gated on ^{55}Ni's 2882 keV transition:
  - TIP+TIGRESS: $2\gamma\alpha$p gate: $\sim$ 1400 events/hour
  - TIP+TIGRESS+EMMA: $\gamma\alpha$p with mass gating: $\sim$ 320 events/hour
  - State of the art is 200 total counts.

ElectroMagnetic Mass Analyzer



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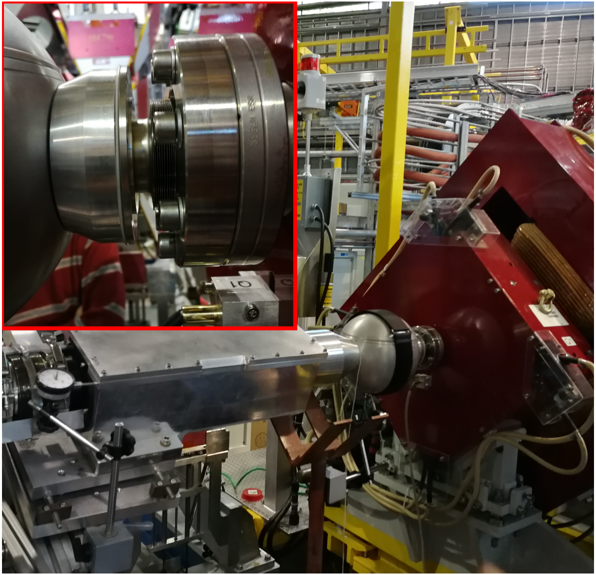
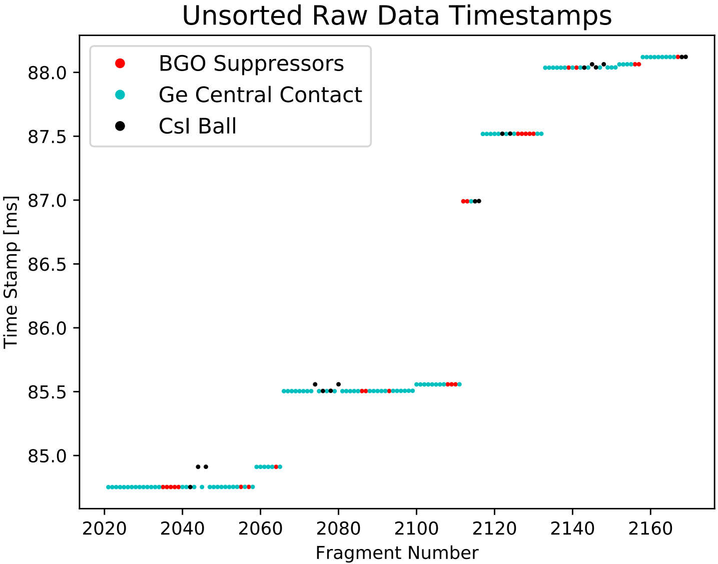
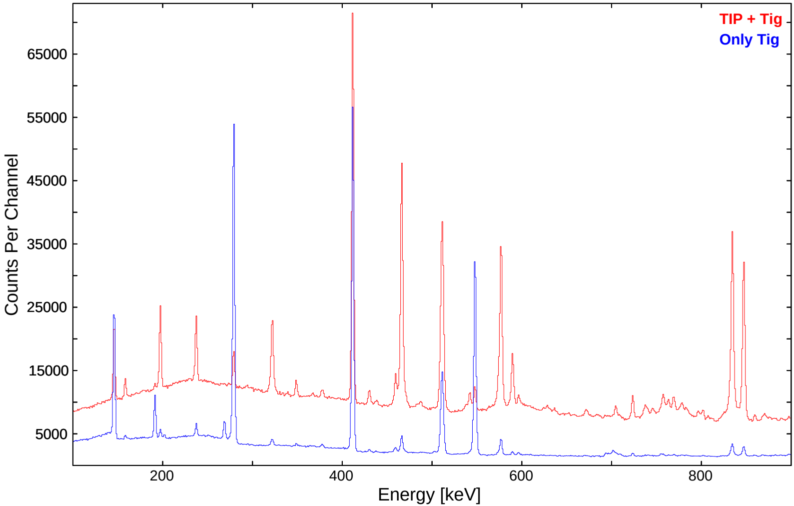


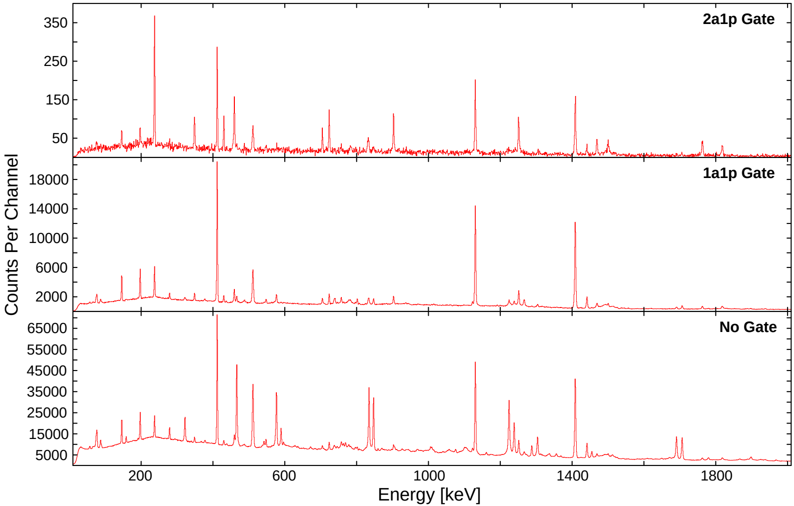
Event Reconstruction



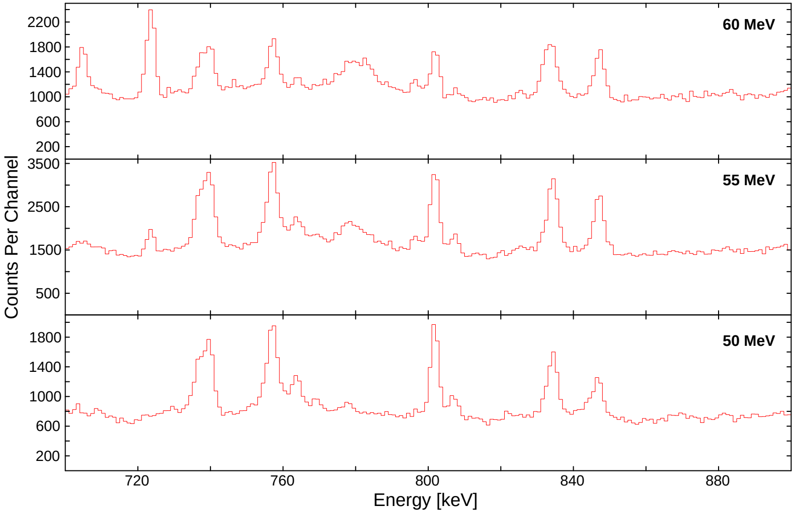
^{55}Co Preliminary Analysis: Event Composition



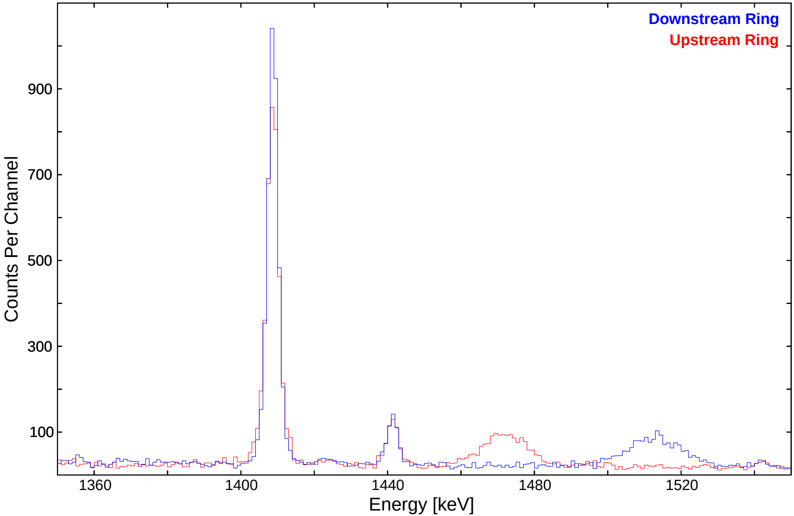
^{55}Co Preliminary Analysis: Particle Gates



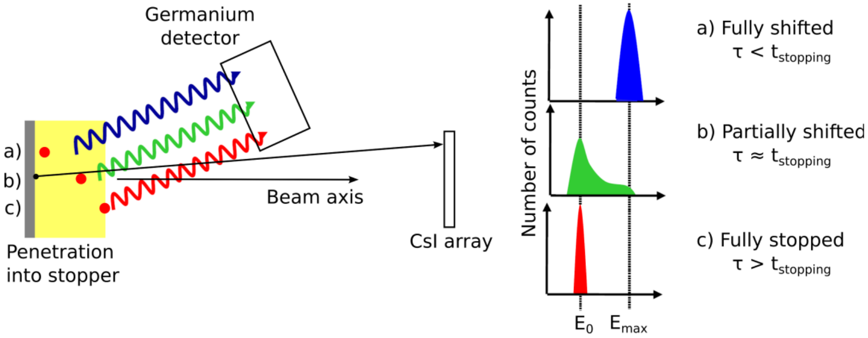
^{55}Co Preliminary Analysis: Beam Energy



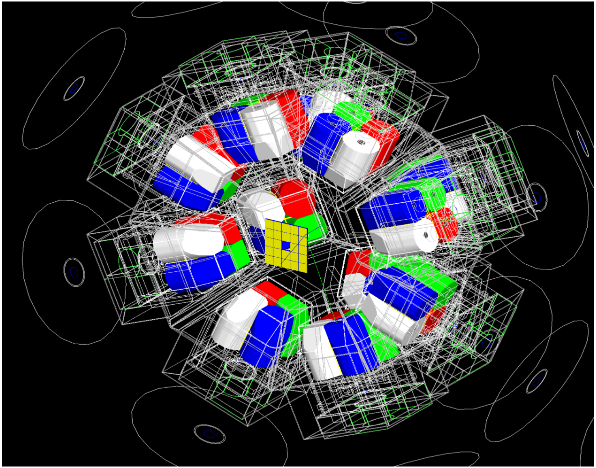
^{55}Co Preliminary Analysis: Doppler Shifts

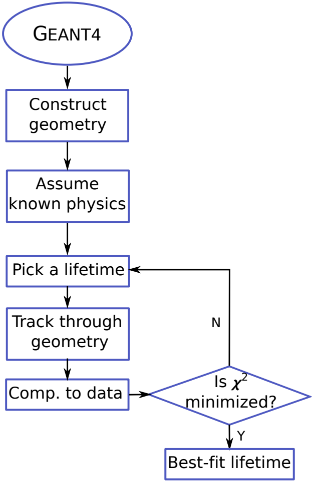


Doppler-Shift Attenuation Method



GEANT4 simulation framework





Acknowledgements

From Simon Fraser University:

- C. Andreoiu[1], D. Annen[2], M.D.H.K.G. Badanage[1], M.S. Martin[2], J.S. Dodge[2], K. Ortner[1], A. Redey[3], P. Spagnoletti[1], K. Starosta[1], D. Tam[2], K. van Wieren[4], F.T. Wu[1]

From TRIUMF:

- B. Davids[5], S. Georges[5], G. Hackman[5], J.D. Holt[5], V. Karayonchev[5], P. Machule[5], C. R. Natzke[5], D. Rhodes[5], E.J. Williams[5], D. Yates[5]

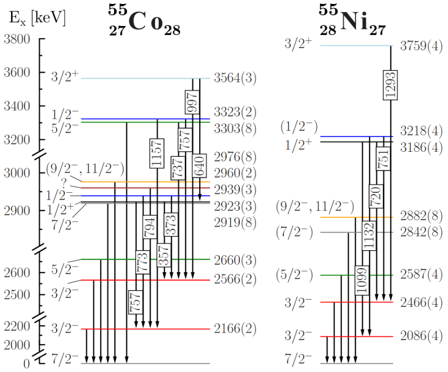
From the University of Guelph:

- R.J. Coleman[6], P.E. Garret[6], E. Kasanda[6], L. Schmidt[6], C.E. Svensson[6]

[1] Department of Chemistry, Simon Fraser University
[2] Department of Physics, Simon Fraser University
[3] School of Engineering Science, Simon Fraser University
[4] Science Technical Centre, Simon Fraser University
[5] TRIUMF
[6] Department of Physics, University of Guelph

Summary

- Calculating ^{55}Ni and ^{55}Co mirror energy differences.
- Fusion evaporation at TRIUMF:
  - ^{40}Ca(^{21}Na,αpn)^{55}Ni
  - ^{40}Ca(^{20}Ne,αp)^{55}Co
- Using the ISAC-II, TIGRESS, TIP and EMMA apparatus.
- Measuring energies of excited states, angular correlations and polarization of γ-rays and lifetimes.
- Comparing isospin dependent parts of both wave functions and operators.



Spieker et al., 2019, PhysRevC.99.051304

Yields for ^{40}Ca(^{21}Na,αpn)^{55}Ni detection

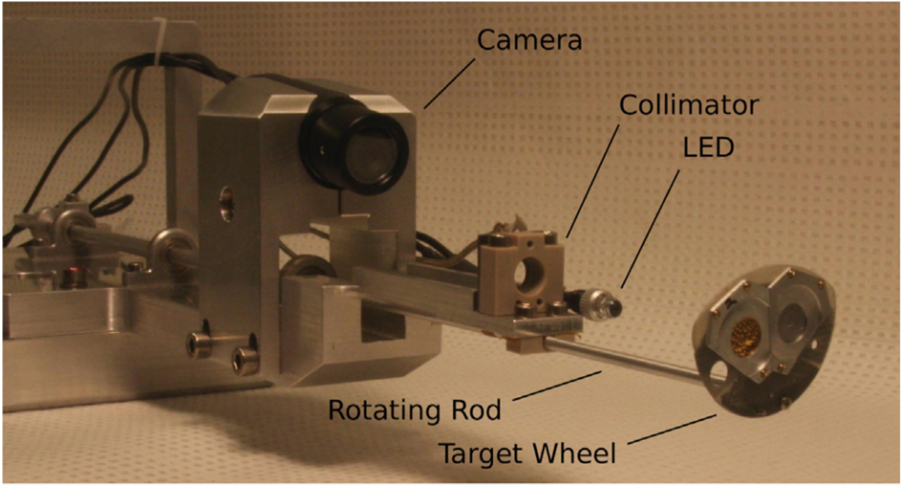
- Rates are predicted using the following:
  - PACE4-predicted cross-section is 4.41 mb,
  - 1.6 mg/cm^2 Calcium target in a thin Silver envelope,
  - 10 % beam yield delivered at 79 MeV with 9.2×10^8 part./sec on target,
  - TIP efficiencies $\varepsilon^{\alpha} = 56\%$ and $\varepsilon^{\mathrm{p}} = 70\%$,
  - TIGRESS CLOVER add-back efficiency of $\varepsilon^{\gamma} = 6.3\%$ at 2882-keV in the high-efficiency mode,
  - EMMA efficiency of $\varepsilon^{\mathrm{EMMA}} = 5\%$.
- αpγ with EMMA mass gating:
  - 2600 counts in the 2882-keV transition per shift,
  - Factor of $\sim$13 per shift over the current state of the art at 200 total counts in the 2882-keV transition.
- With EMMA gating replaced with γ-γ coincidence:
  - 22000 counts in the 2882-keV transition per shift,
  - Factor of $\sim$110 per shift over the current state of the art at 200 total counts in the 2882-keV transition.

Experimental Goals

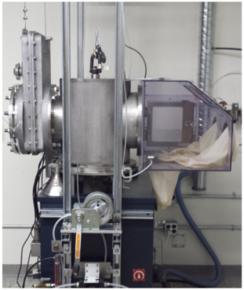
- To be investigated:
  - Energies of excited states,
  - Angular correlations/polarization of γ-rays for spin/parity assignment,
  - Doppler-shift (DSAM) lifetimes.

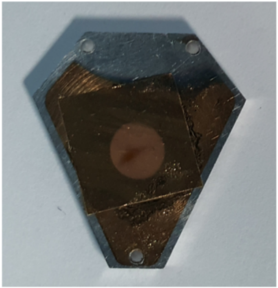
- Scientific goals:
  1. Identification of energy, spins, and parities of excited states in ^{55}Ni beyond current state of the art. Establishing Mirror Energy Differences for new states observed in ^{55}Ni from a comparison to corresponding states in ^{55}Co,
  2. Providing reliable data for Shell Model calculations for $f_{7/2}$ neutron hole states near ^{56}Ni,
  3. Investigating mirror symmetry via measurements and comparison of electromagnetic transition rates for excited states in ^{55}Ni and ^{55}Co.

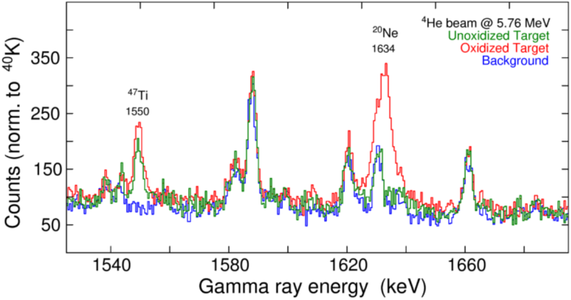
Target Wheel Assembly



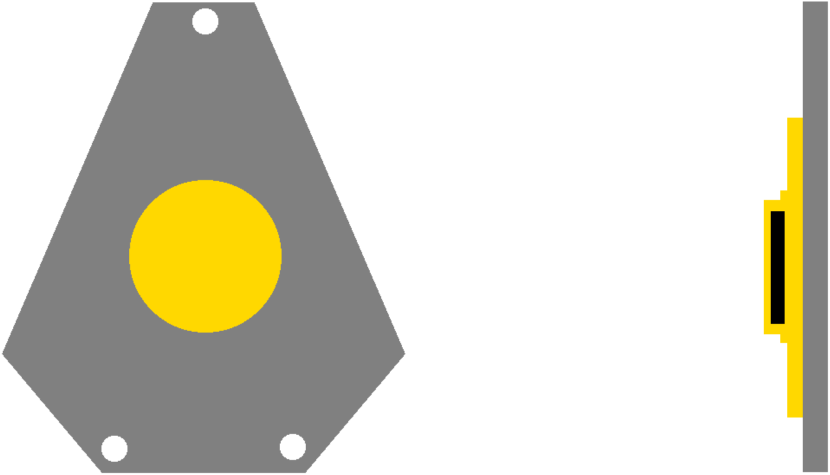
Calcium Targetry for TIP







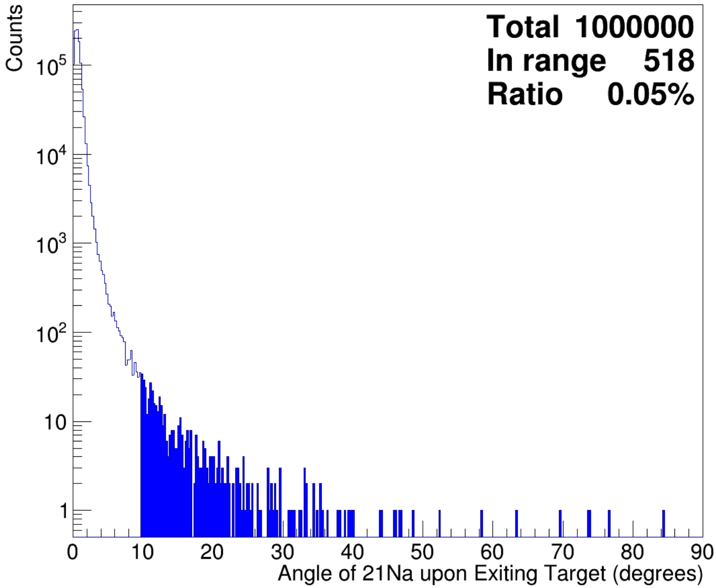
Target Schematic



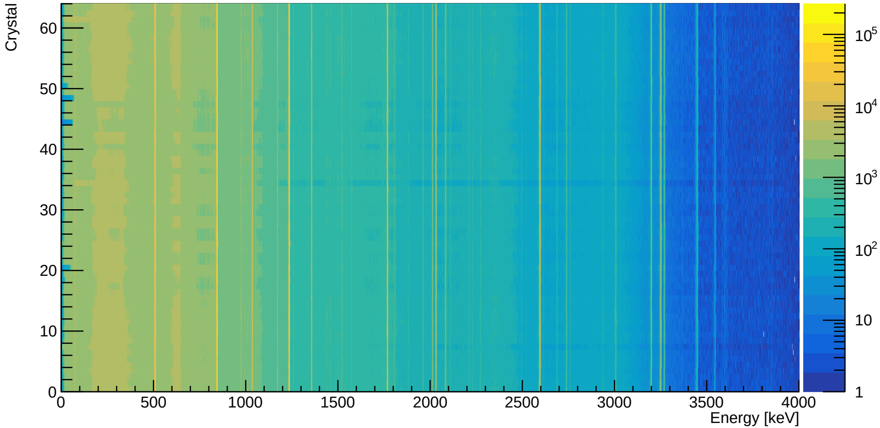
^{21}Na beam scattering into TIP chamber

- At the total fusion cross section of 675 mb the number of fusion-evaporation reactions is 15000 per second,
- With 22.5 s half life of ^{21}Na, 9.2×10^{8} part./sec. beam current and 0.05% scattering probability the steady-state rate of the decaying scattered beam is $\sim$500 kBq; this is $\sim$30 times higher than the fusion reaction rate,
- ^{21}Na β^{+} decays to ^{21}Ne, at the Q-value of 3.5 MeV, 95% will decay directly to the ground state with the remaining 5% dominated by emission of a 350.7 keV γ-ray,
- The decays will be separated from fusion by:
  - TIP 2-particle trigger combined with the energy threshold optimized for each of 128 individual CsI detectors,
  - Timing with respect to the LINAC RF,
  - CsI pulse shape discrimination.

^{21}Na beam scattering into TIP chamber via GEANT4

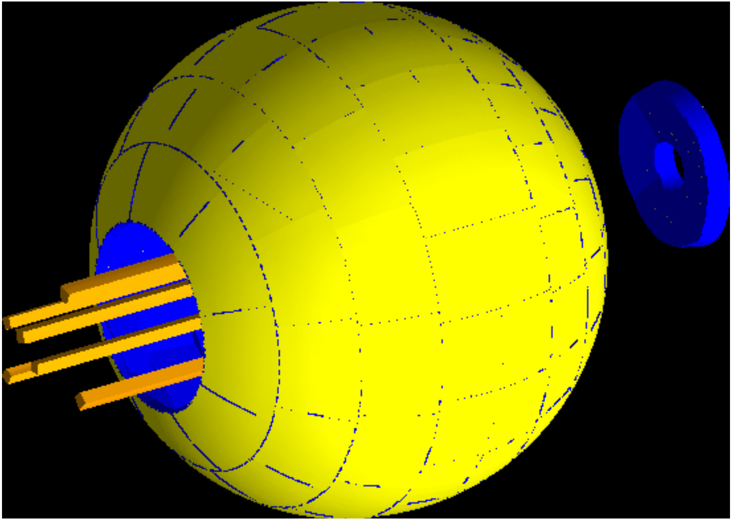


^{55}Co Preliminary Analysis: Energy Calibration

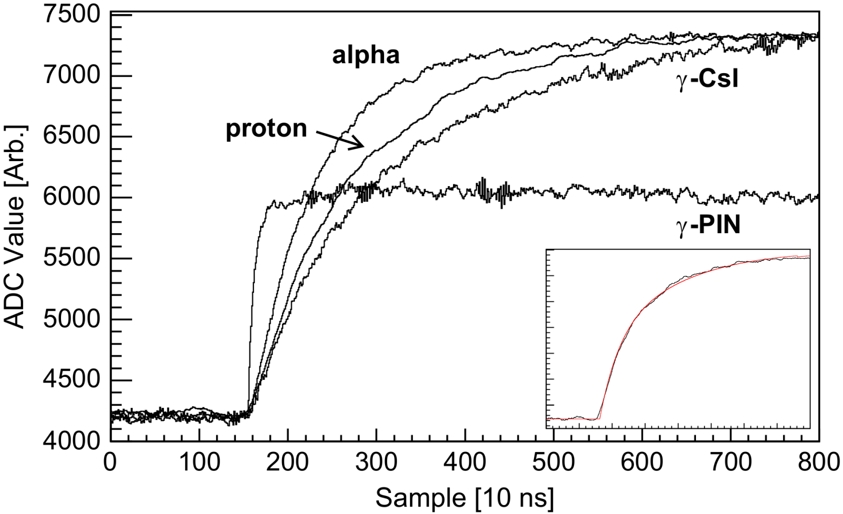


- Calibrated γ-ray energy in each TIGRESS crystal

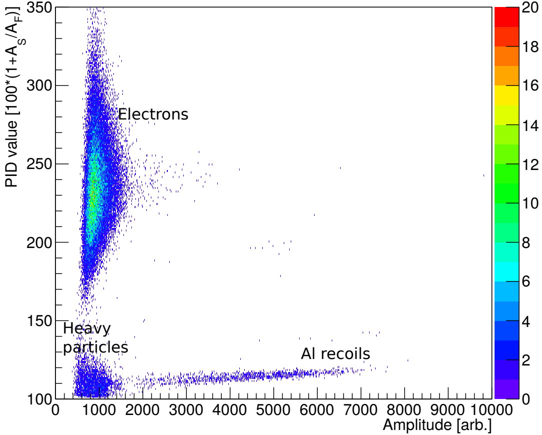
CsI Ball in GEANT4 with Plunger



CsI Pulse Shape Discrimination



P. Voss *et. al.* Nucl. Inst. Meth. **A**746 (2014) 87.

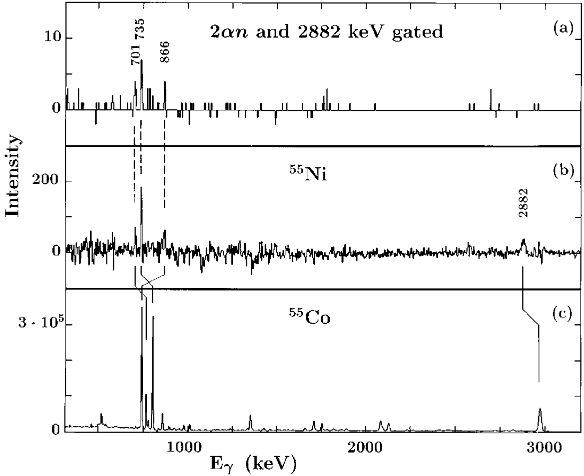


(a) Electrons from β^- decay (b) Al recoils from Coulex reaction

A. Chester *et al.*, Phys. Rev. **C**96, 011302**R** (2017).

Results of the ^{28}Si(^{36}Ar,2αn) GS/MB experiment

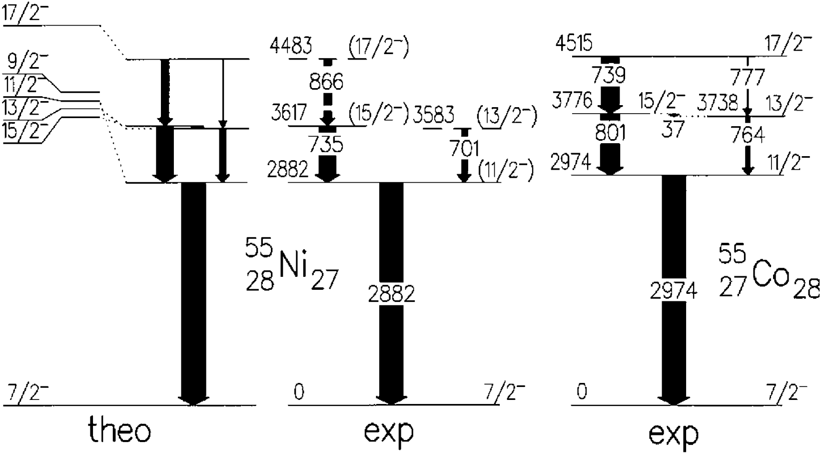
- Reported 200 counts in the 2882-keV peak.



D. Rudolph *et. al.*, Z. Phys. **A** 358 (1997) 379.

Results of the $^{28}Si(^{36}Ar,2\alpha n)$ GS/MB experiment

- Theory places the state of $15/2^-$ below the state of $11/2^-$.



D. Rudolph *et. al.*, Z. Phys. **A** 358 (1997) 379.