Cross Section Measurements for the p-process

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10th Russbach School on Nuclear Astrophysics

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NSCL SuN

- Motivation: the p-process
- Experimental Method
- Results $^{74}Ge(p,\gamma)$ & $^{92}Zr(p,\gamma)$
- Future Plans

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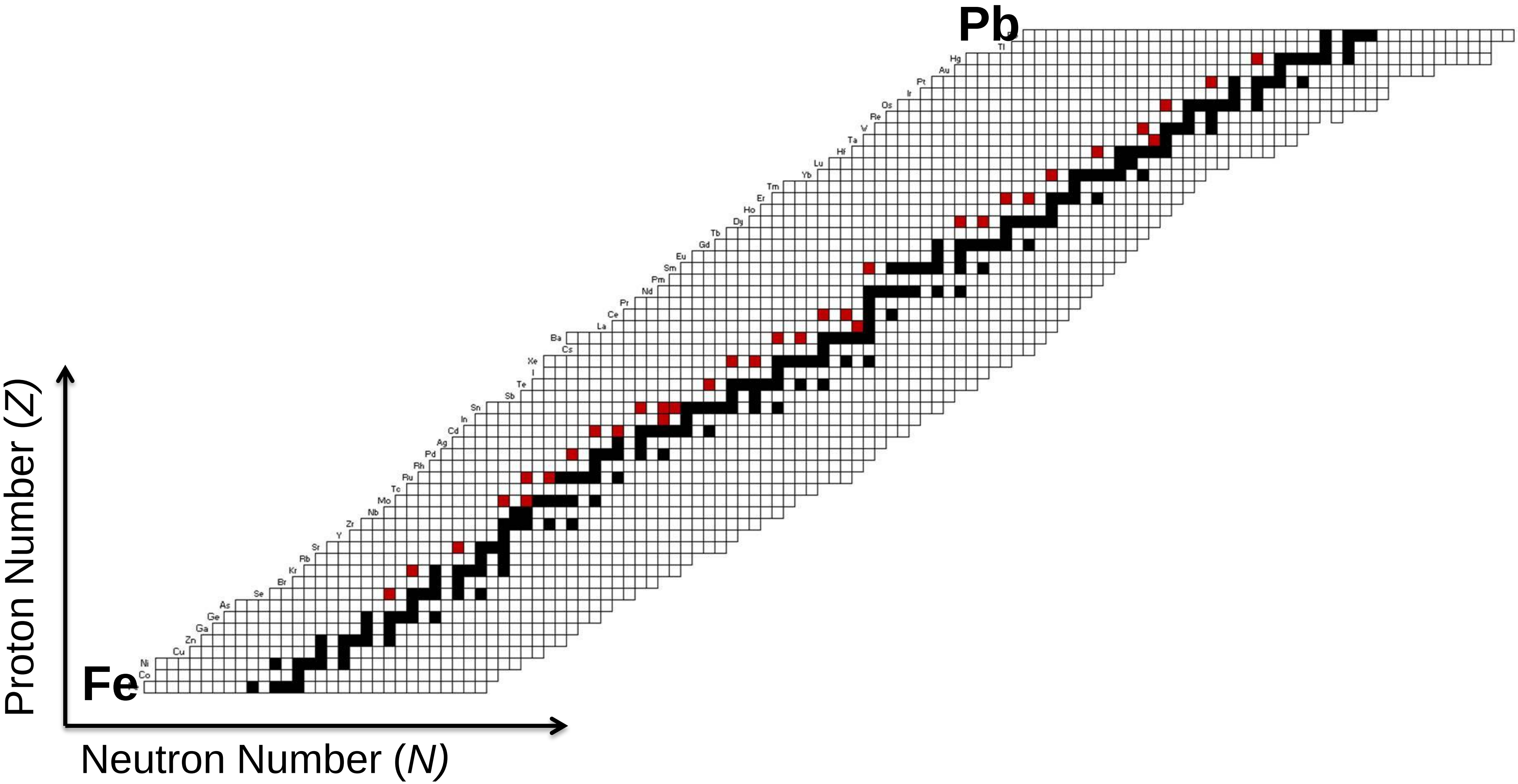
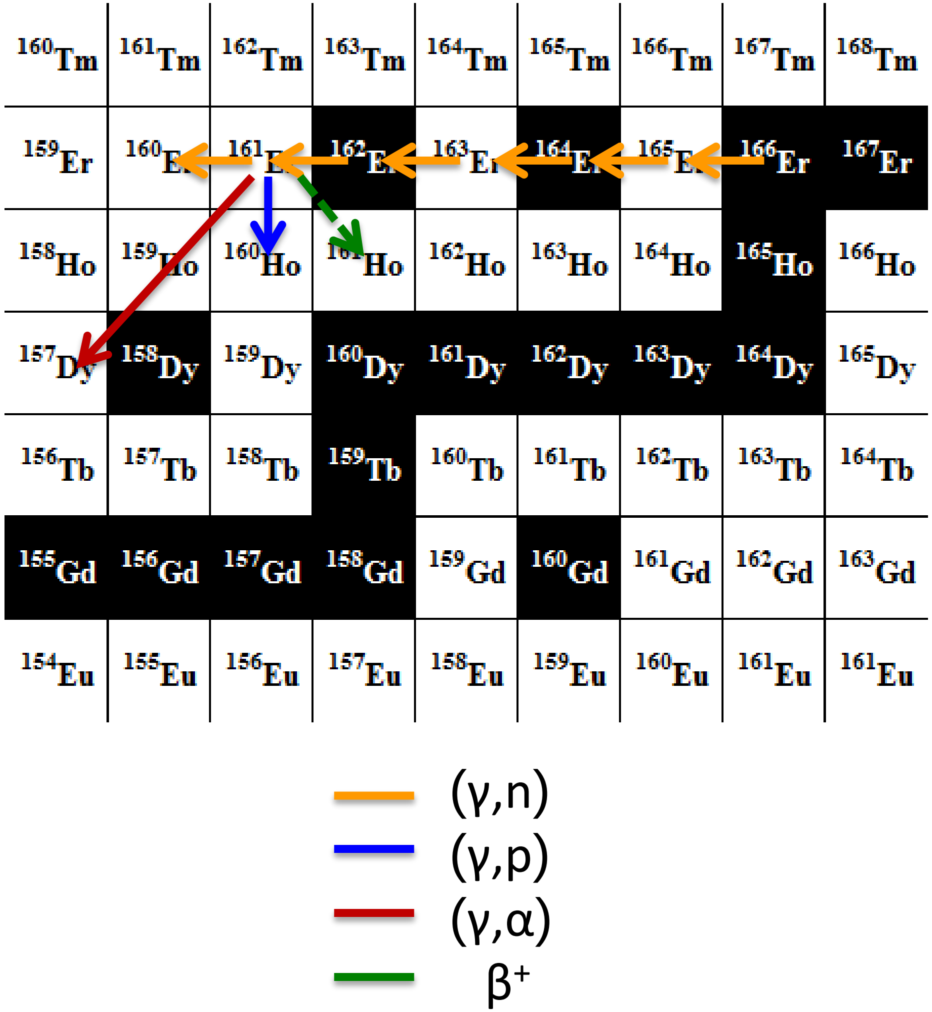
Nucleosynthesis of the p-nuclei



The p-process

- Production of p-nuclei
- Favored scenario is photodisintegrations on seed nuclei in O/Ne layer of Type II SNe
- Competition of (γ,n), (γ,p), and (γ,α) reactions to lighter mass



Reaction Networks

- Assume some initial abundance of seed nuclei in O/Ne layer of pre-supernova star

- Shock front causes a rapid increase in temperature ($1.8<T_9<3.3$) and density

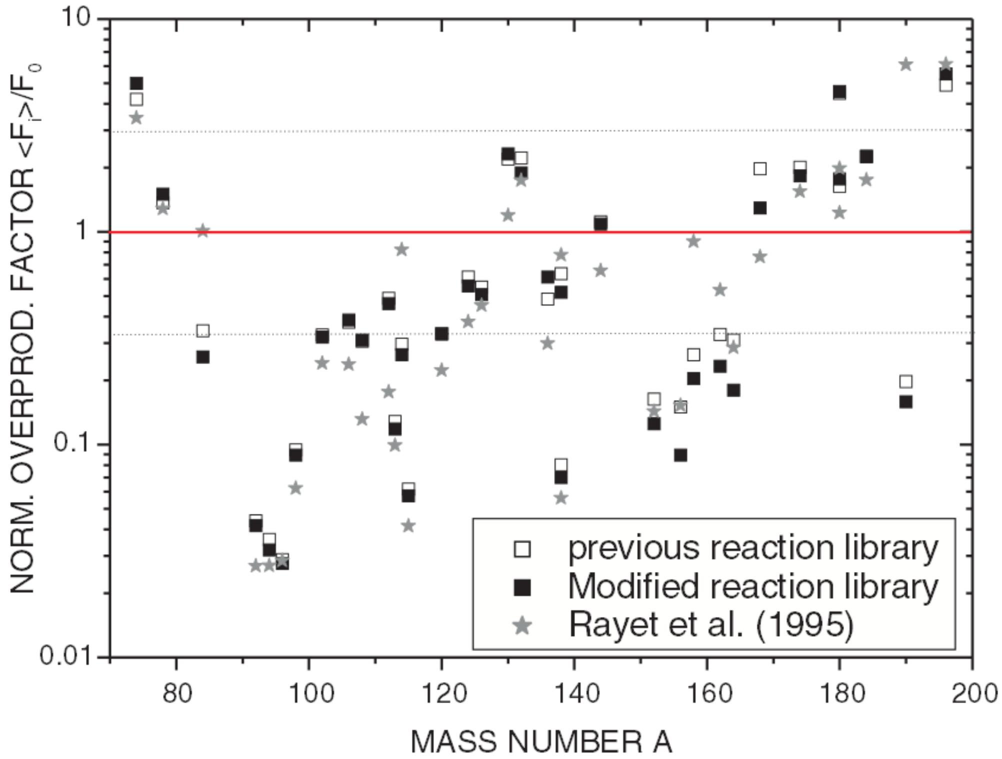
- Reaction network involves thousands of reactions, most calculated by Hauser-Feshbach model

- Track abundances of p-nuclei

- View conditions that form p-nuclei

- Vary reaction rates

I. Dillmann et al. J. Phys. G **35** (2008) 014029



Experimental Details

- University of Notre Dame
- Proton beam
  $E_p = 1.6 – 5.0$ MeV
- SuN detector
- Enriched ^{74}Ge targets made by evaporation onto tantalum backing
- Target thicknesses measured at Hope College using RBS
  ^{74}Ge: 320(40) μg/cm2
  ^{90}Zr: 970(50) μg/cm2

http://physics.nd.edu/

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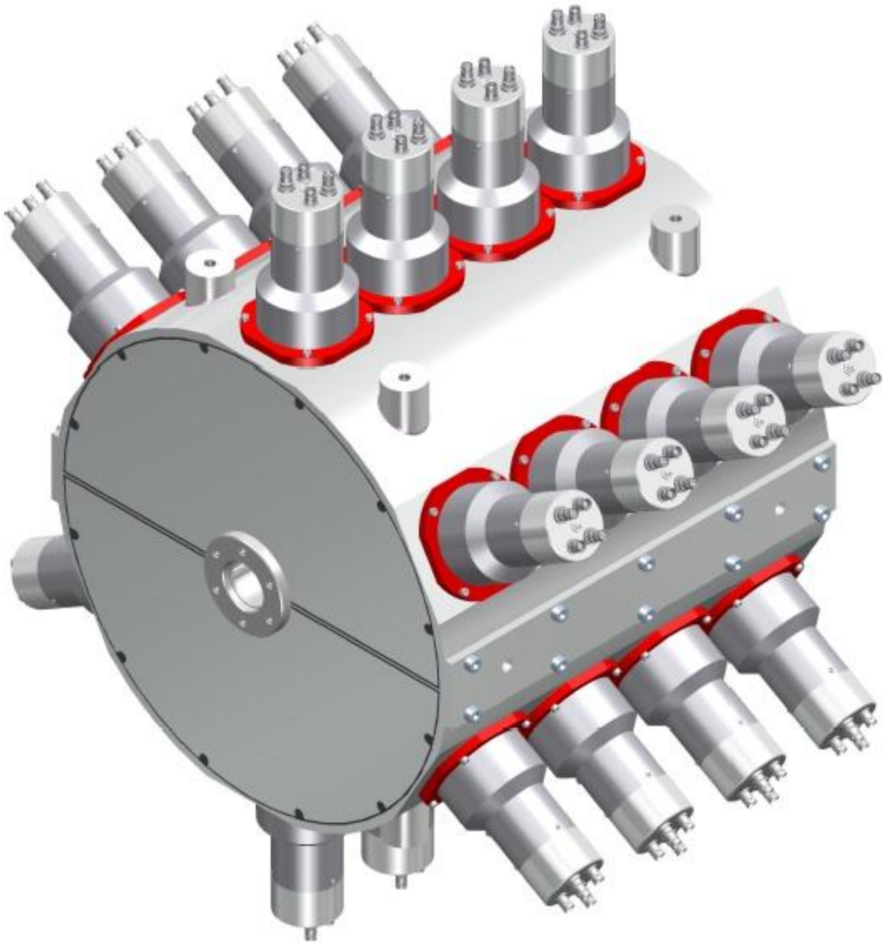
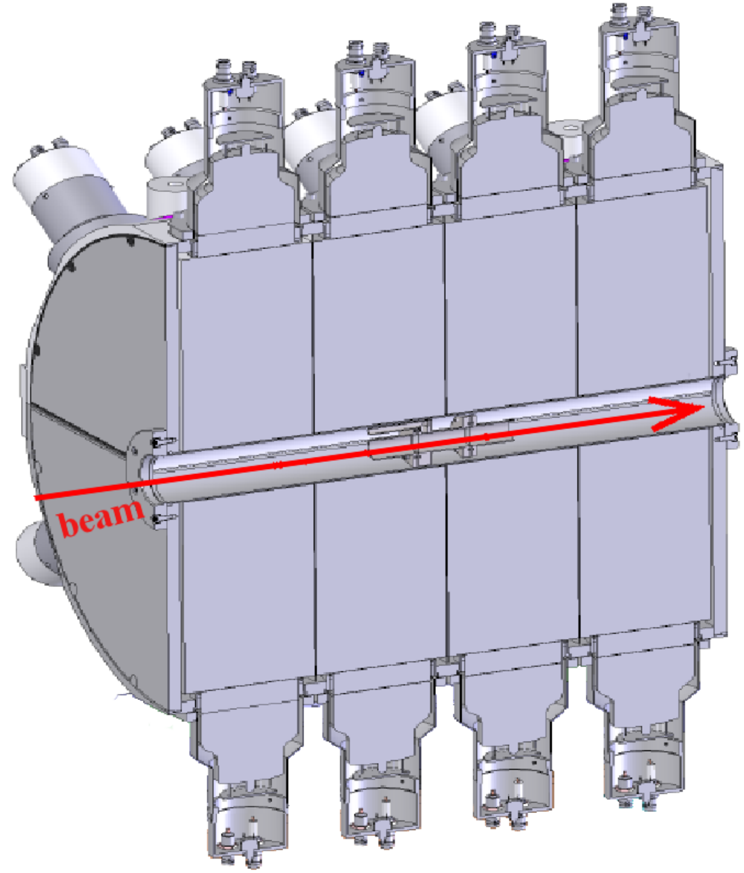
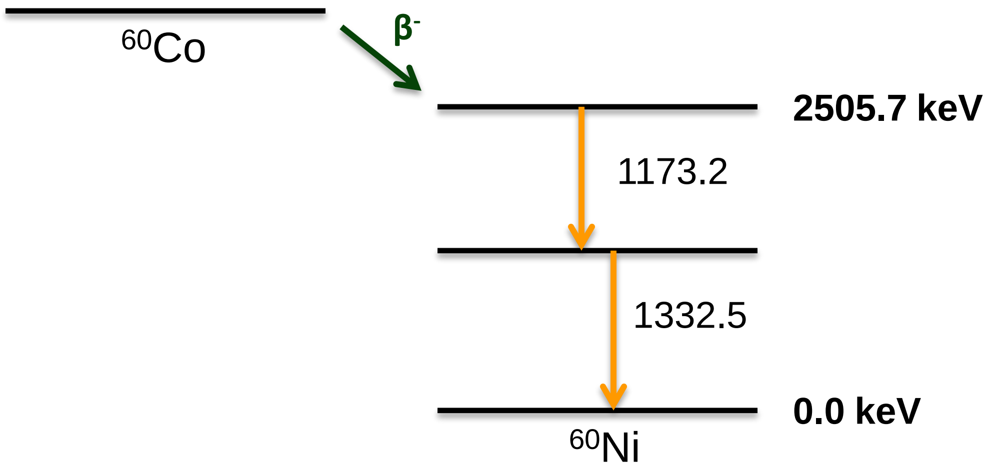
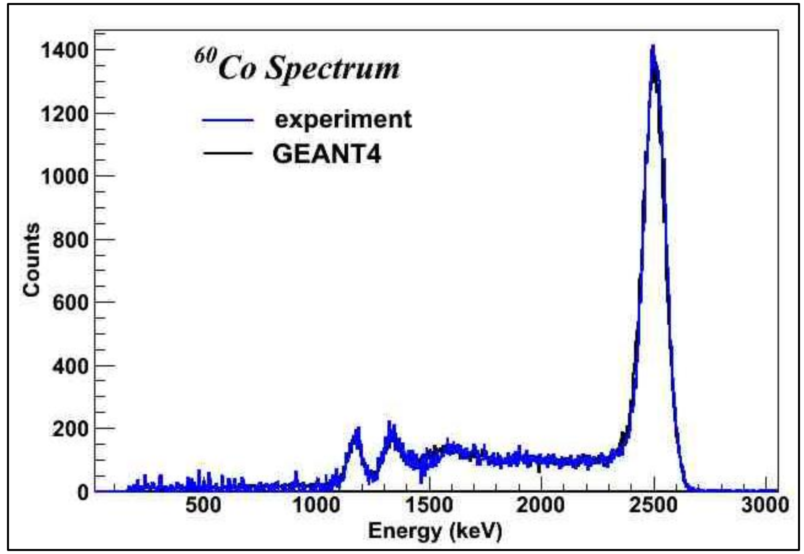
The Summing NaI(Tl) Detector



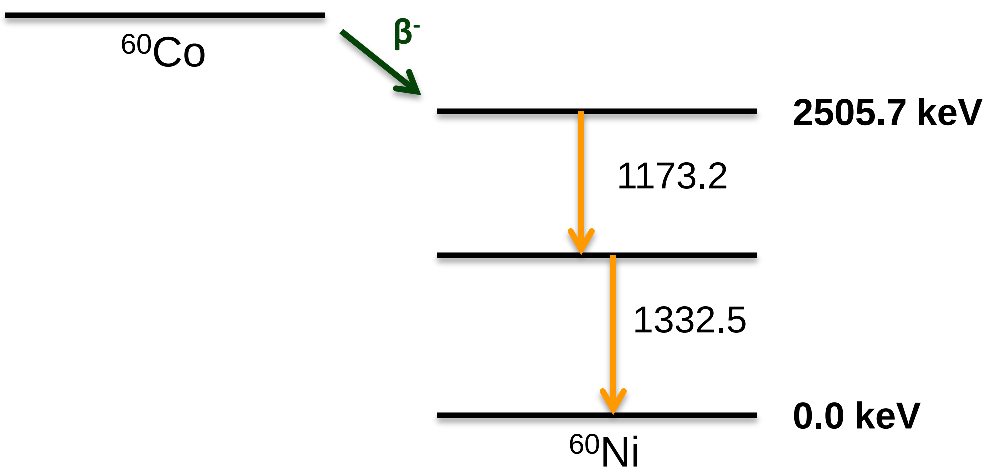


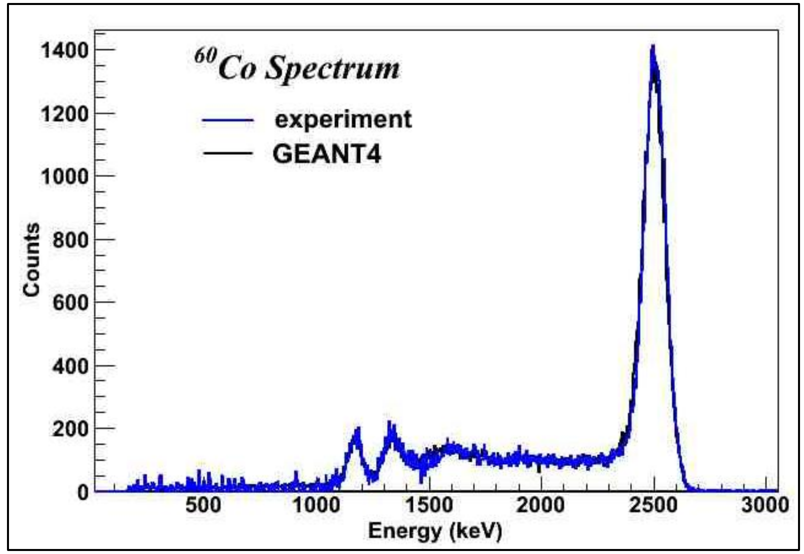
The Summing Technique

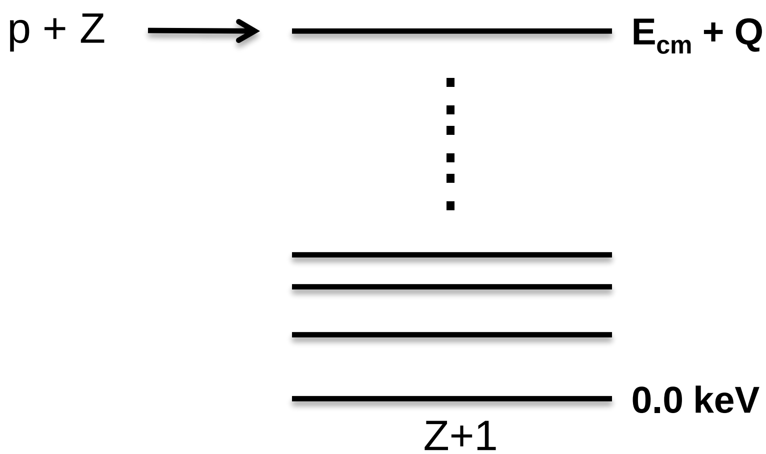


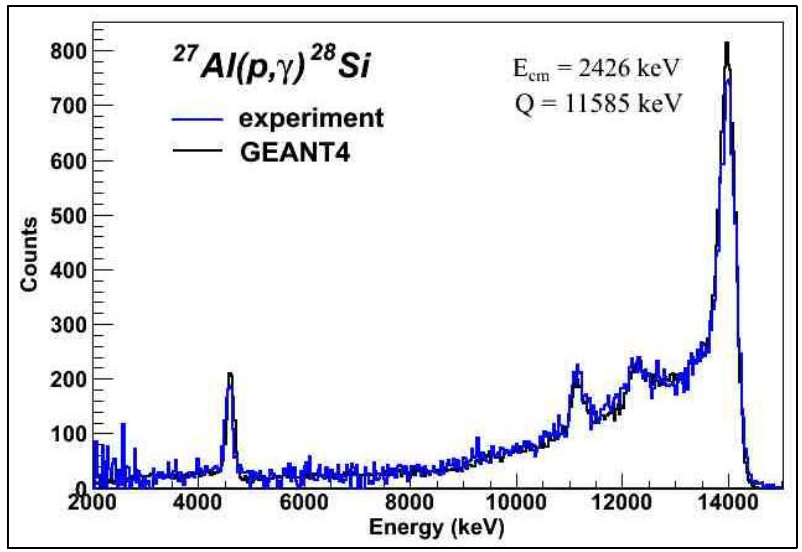


The Summing Technique







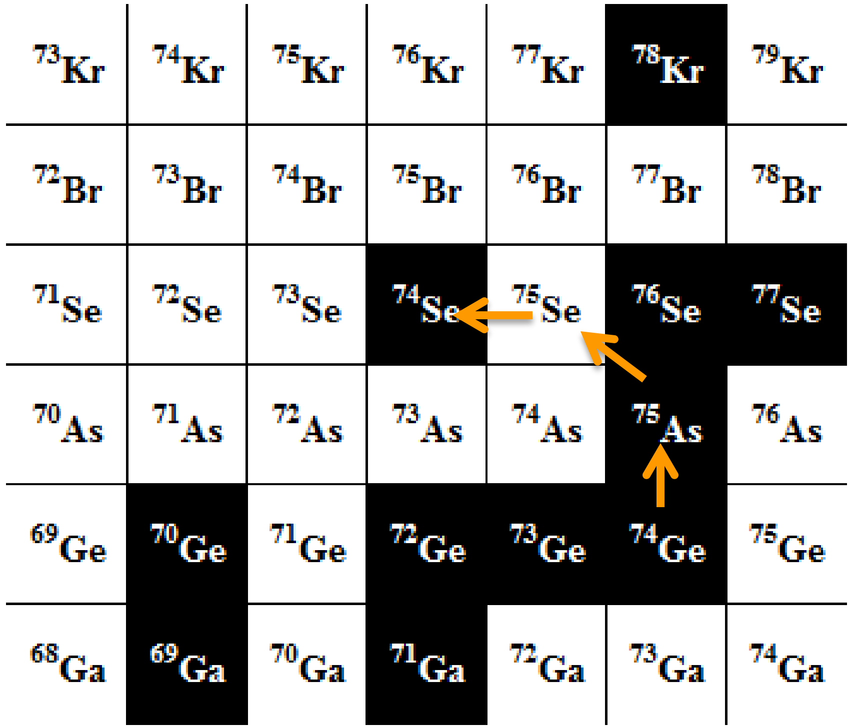


^{74}Ge(p,γ)^{75}As

TABLE 2

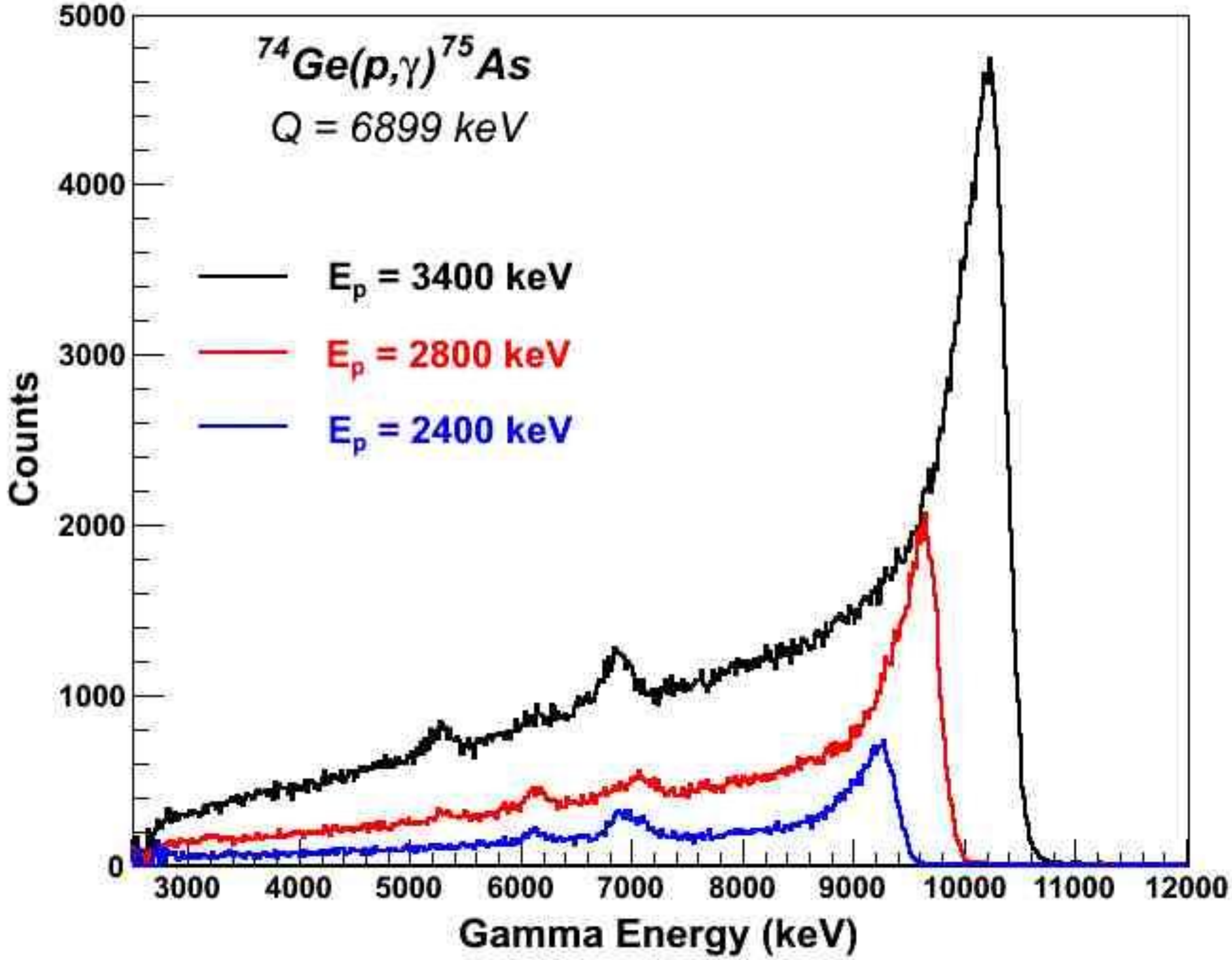
SELECTED (γ, p) OR (n, p) REACTIONS

Reactions		
^{126}Ba(γ, p)^{125}Cs*	^{92}Mo(γ, p)^{91}Nb*	^{75}Se(n, p)^{75}As*
^{110}Sn(γ, p)^{109}In*	^{86}Rb(n, p)^{86}Kr*	^{74}Se(γ, p)^{73}As*
^{106}Cd(γ, p)^{105}Ag	^{85}Sr(n, p)^{85}Rb*	^{76}As(n, p)^{76}Ge*
^{104}Cd(γ, p)^{103}Ag	^{84}Sr(γ, p)^{83}Rb*	^{75}As(γ, p)^{74}Ge*
^{100}Pd(γ, p)^{99}Rh	^{78}Kr(γ, p)^{77}Br*	^{73}As(γ, p)^{72}Ge
^{96}Ru(γ, p)^{95}Tc*	^{77}Se(n, p)^{77}As	^{71}Ge(n, p)^{71}Ga

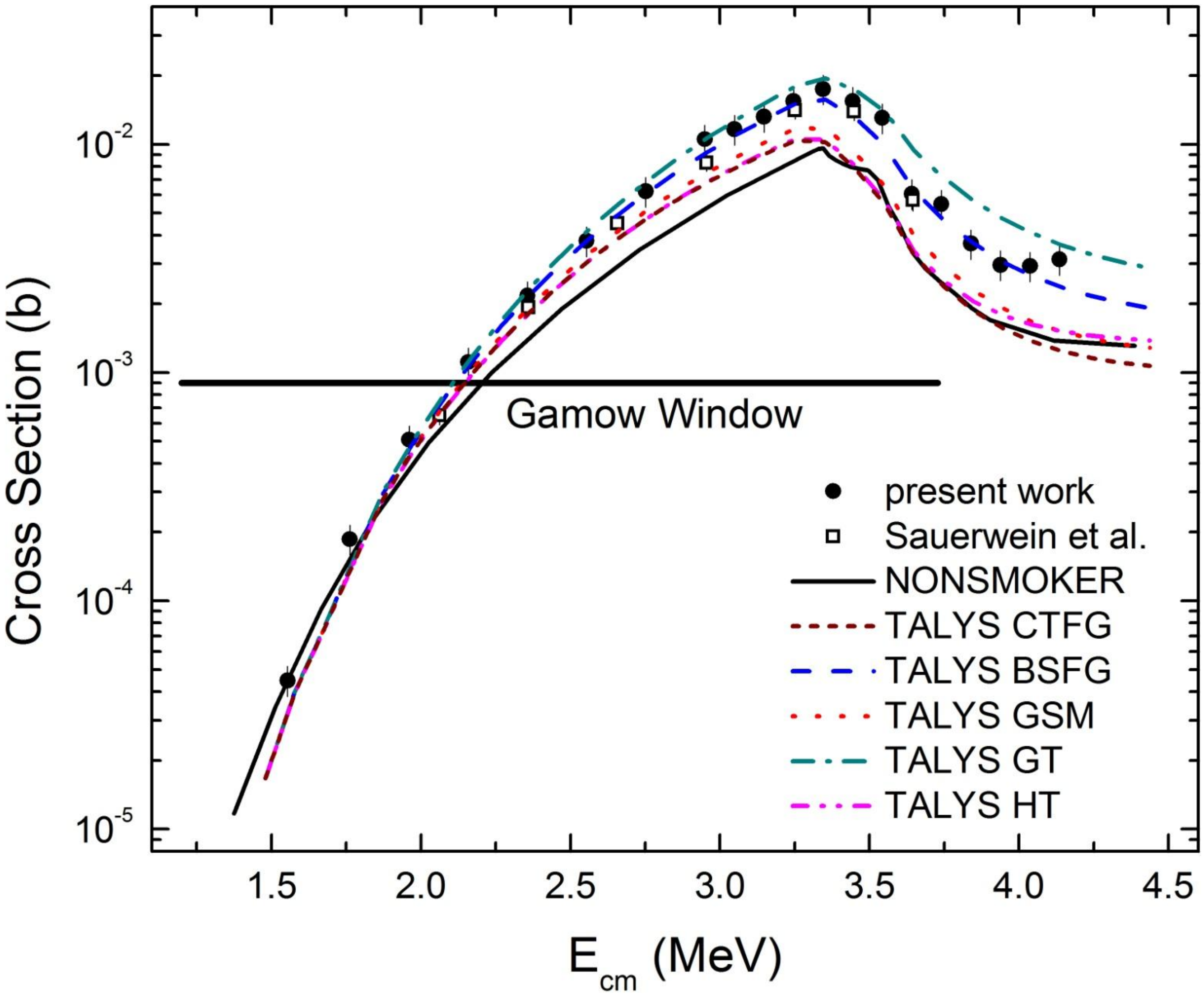


W. Rapp et al, The Astrophysical Journal, 653 (2006) 474-489.

Summed Spectra



Cross Section Results



A. Sauerwein et al, Phys. Rev. C, **86**, 035802 (2012)

Effect on ^{74}Se Production

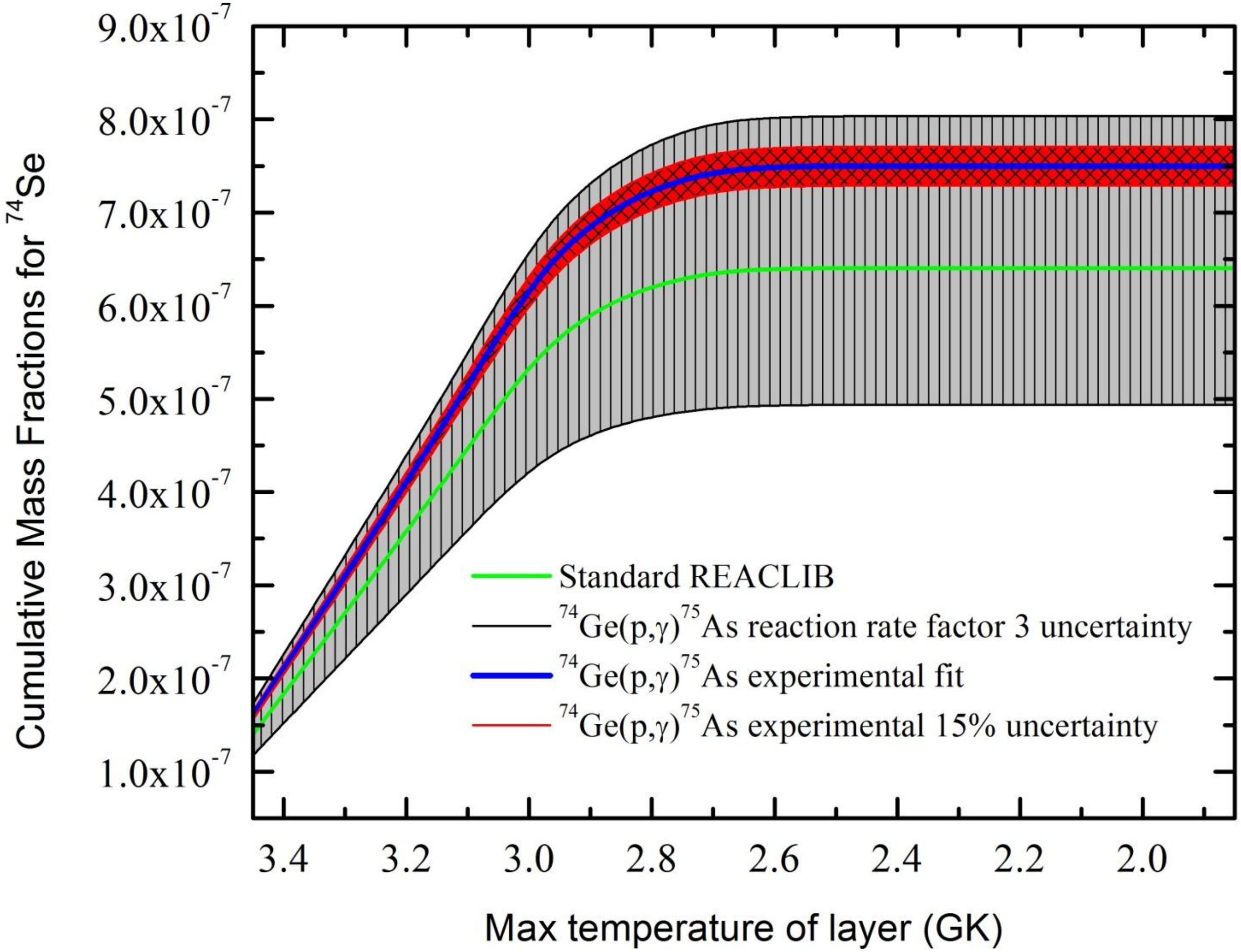
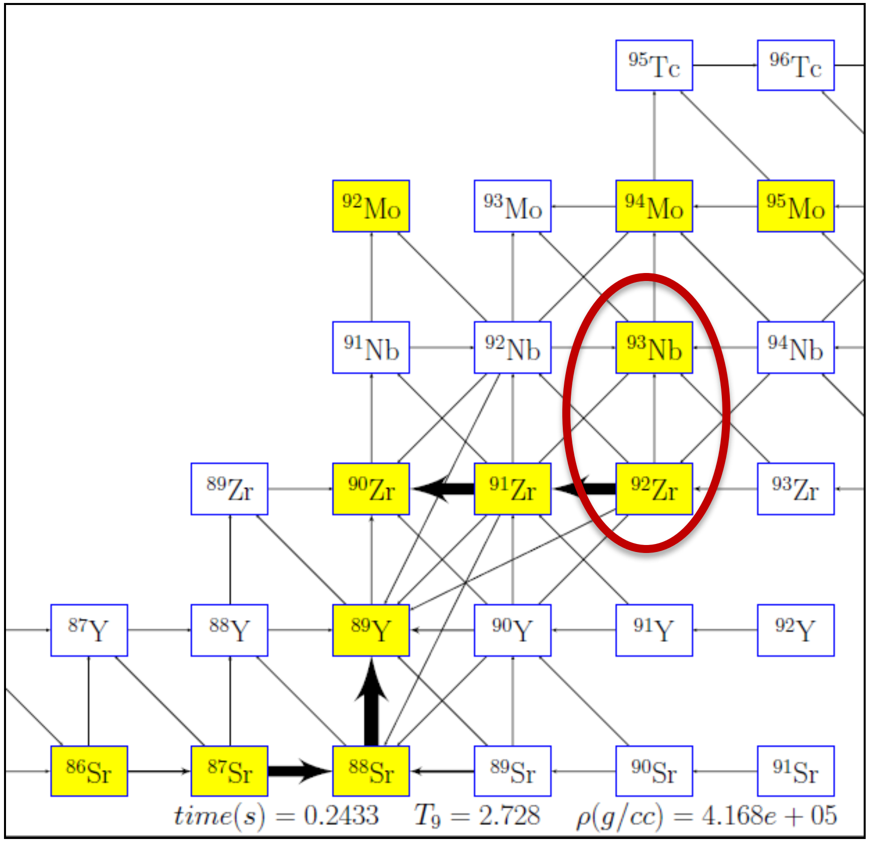


Figure by A. Spyrou and A. Simon

$^{92}Zr(p,\gamma)^{93}Nb$



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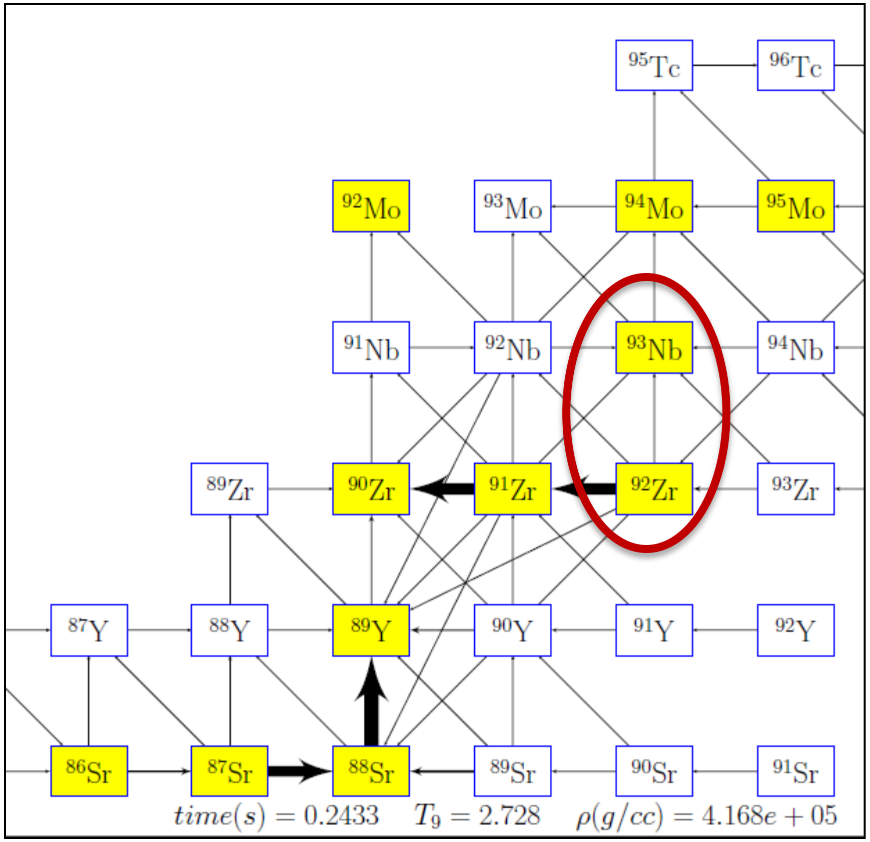
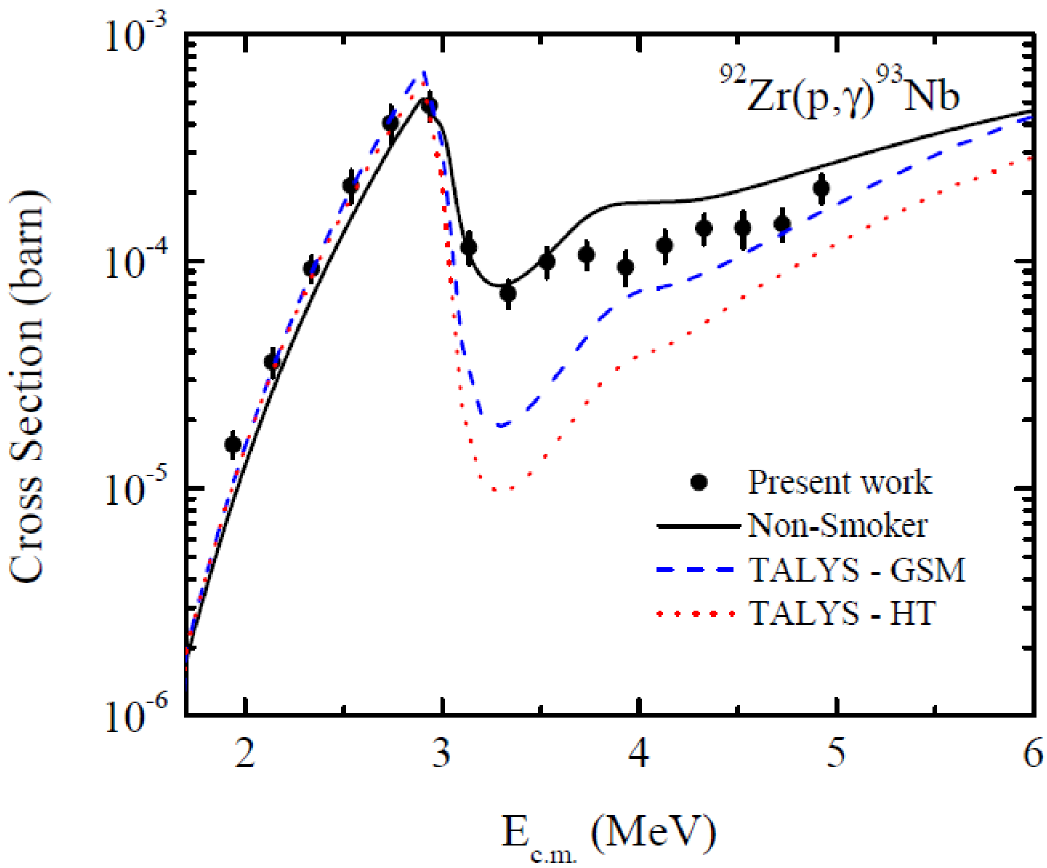
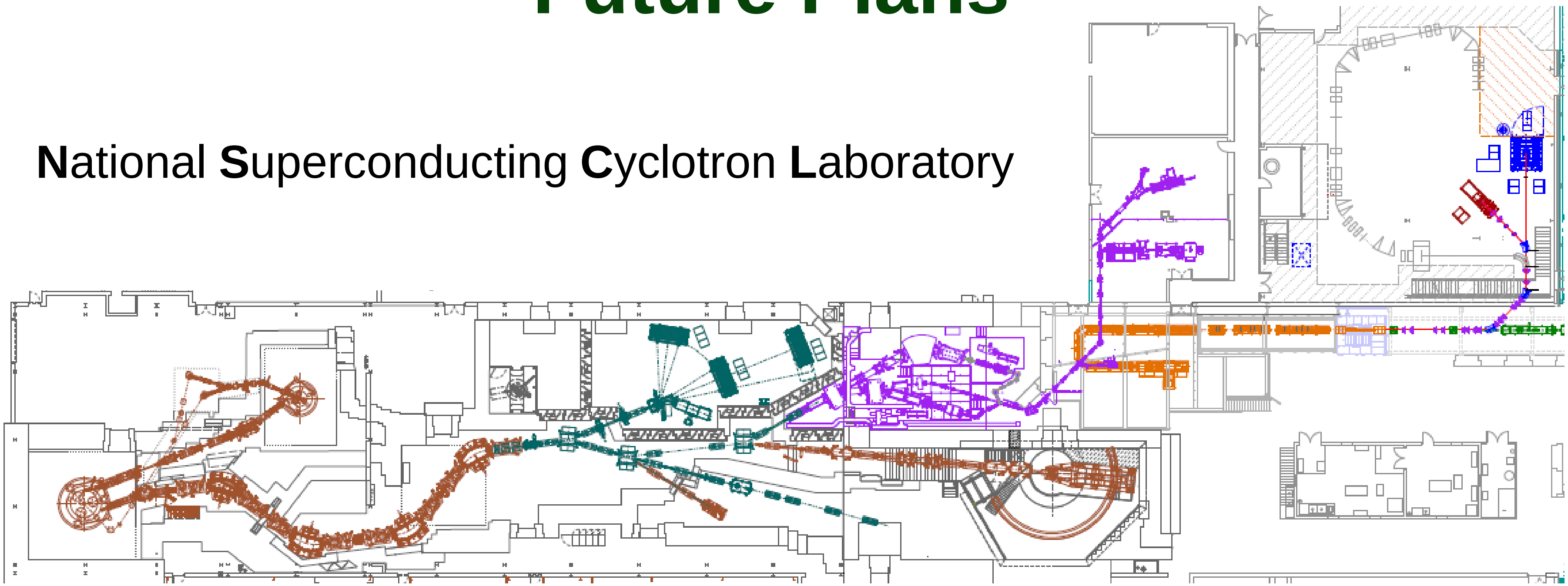




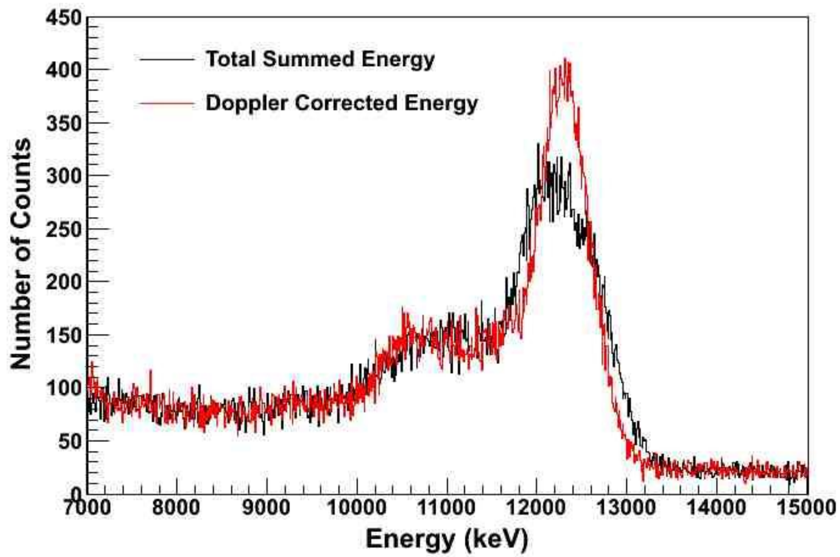
Future Plans

National **S**uperconducting **C**yclotron **L**aboratory



Extend measurements to radioactive isotopes provided by ReA3.

Proof of principle: p(^{27}Al,γ)^{28}Si
p(^{58}Ni,γ)^{59}Cu



Conclusions

- The production of the p-nuclei is not fully understood.

- The recently developed SuN detector is ideally suited for measuring the cross section of important (p,γ) and (α,γ) reactions relevant to the p-process.

- The ^{74}Ge(p,γ) and ^{92}Zr(p,γ) reactions were recently measured at the University of Notre Dame, and results were presented.

- In the future this work will be extended to reactions involving unstable isotopes in inverse kinematics.

Acknowledgements

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- University of Notre Dame

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- Hope College

  Paul DeYoung, Graham Peaslee, Kiley Spirito

Thank You!

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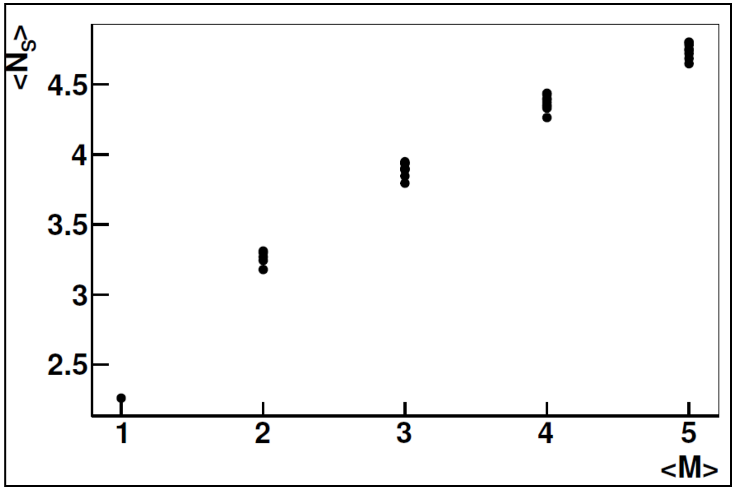
Michigan State University

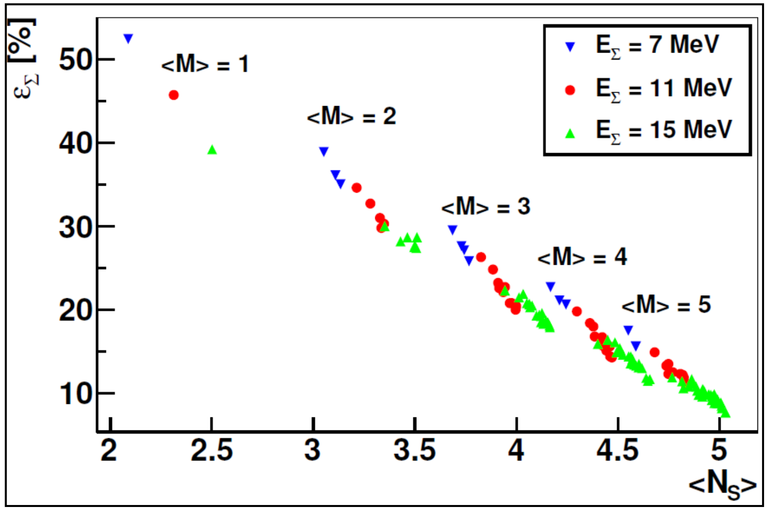
Extra Slides

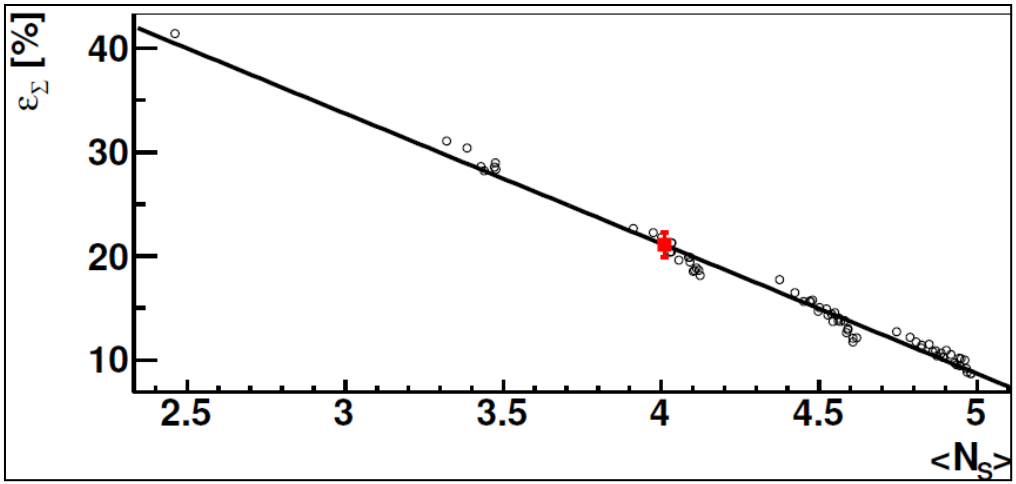
SuN's Efficiency

Number of segments firing is directly related to average multiplicity of cascade



Efficiency depends on both energy and average multiplicity

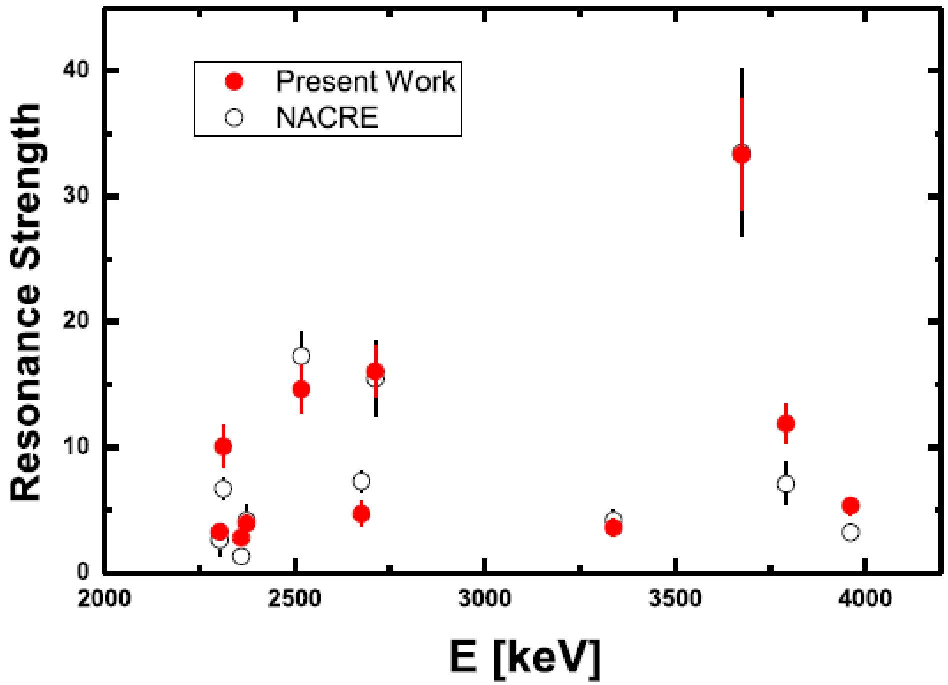




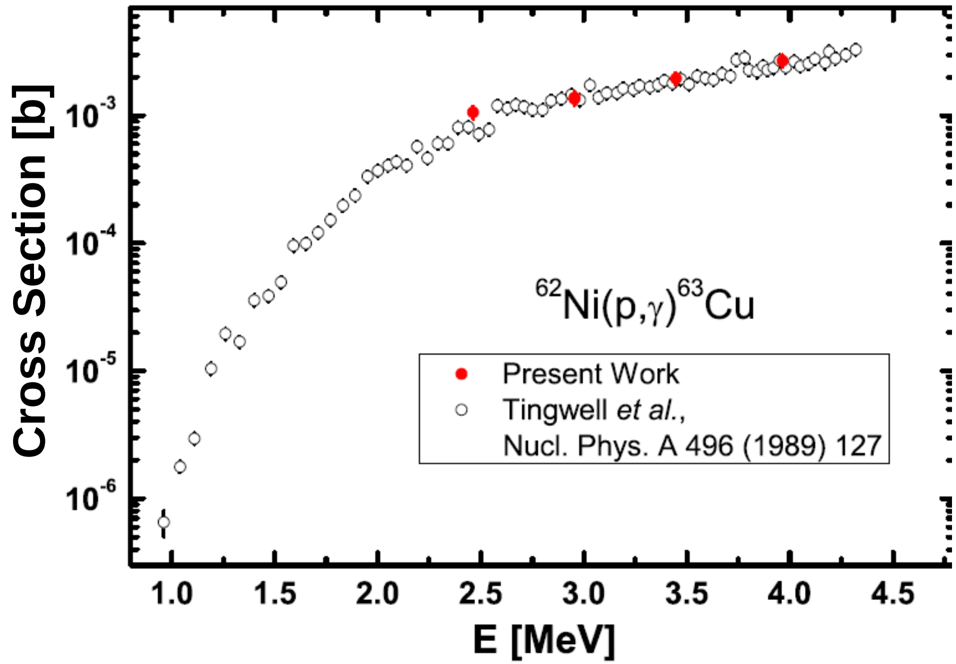
Figures by A. Simon

Testing the SuN Detector

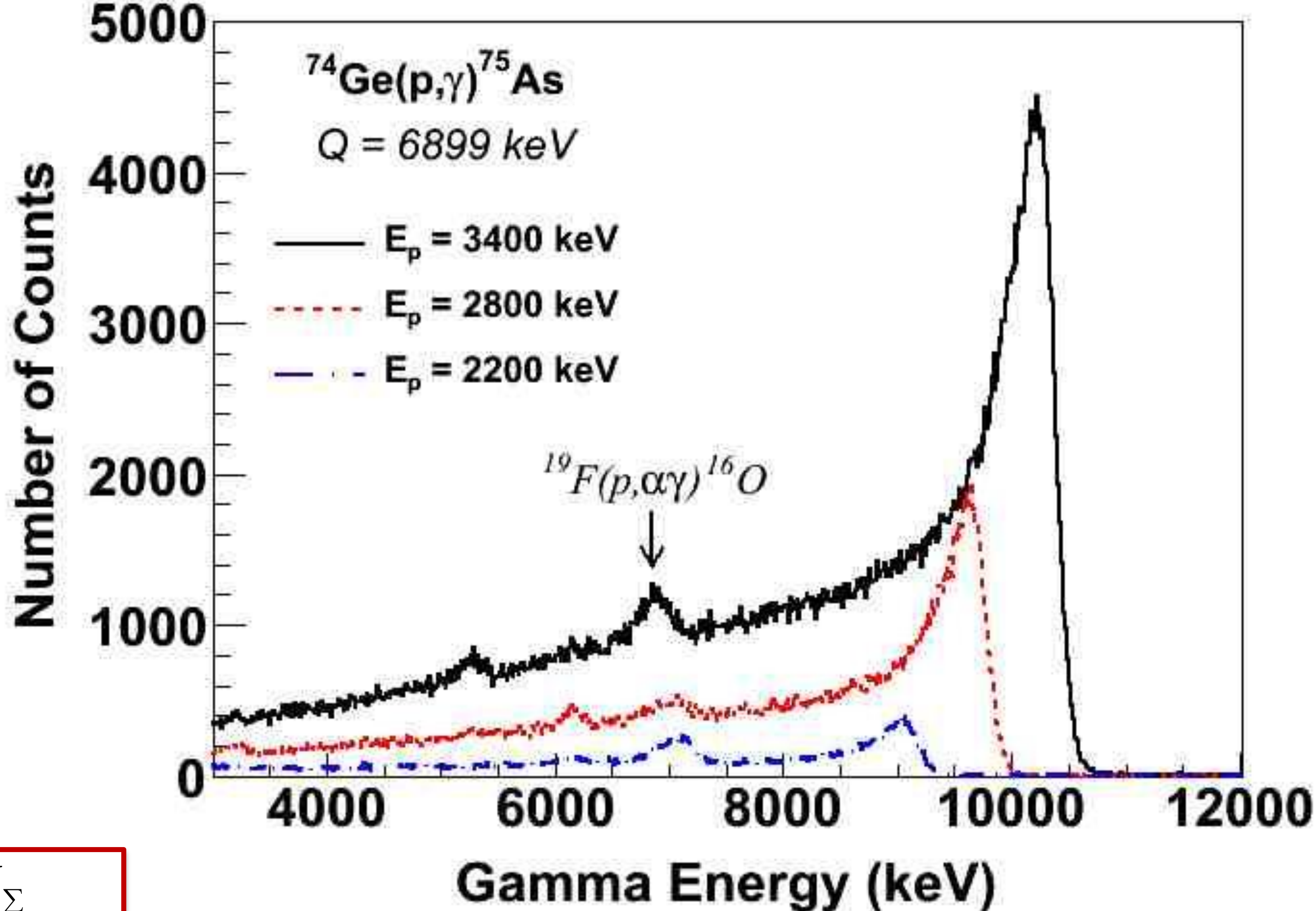
$^{27}Al(p,\gamma)^{28}Si$



$^{62}Ni(p,\gamma)^{63}Cu$

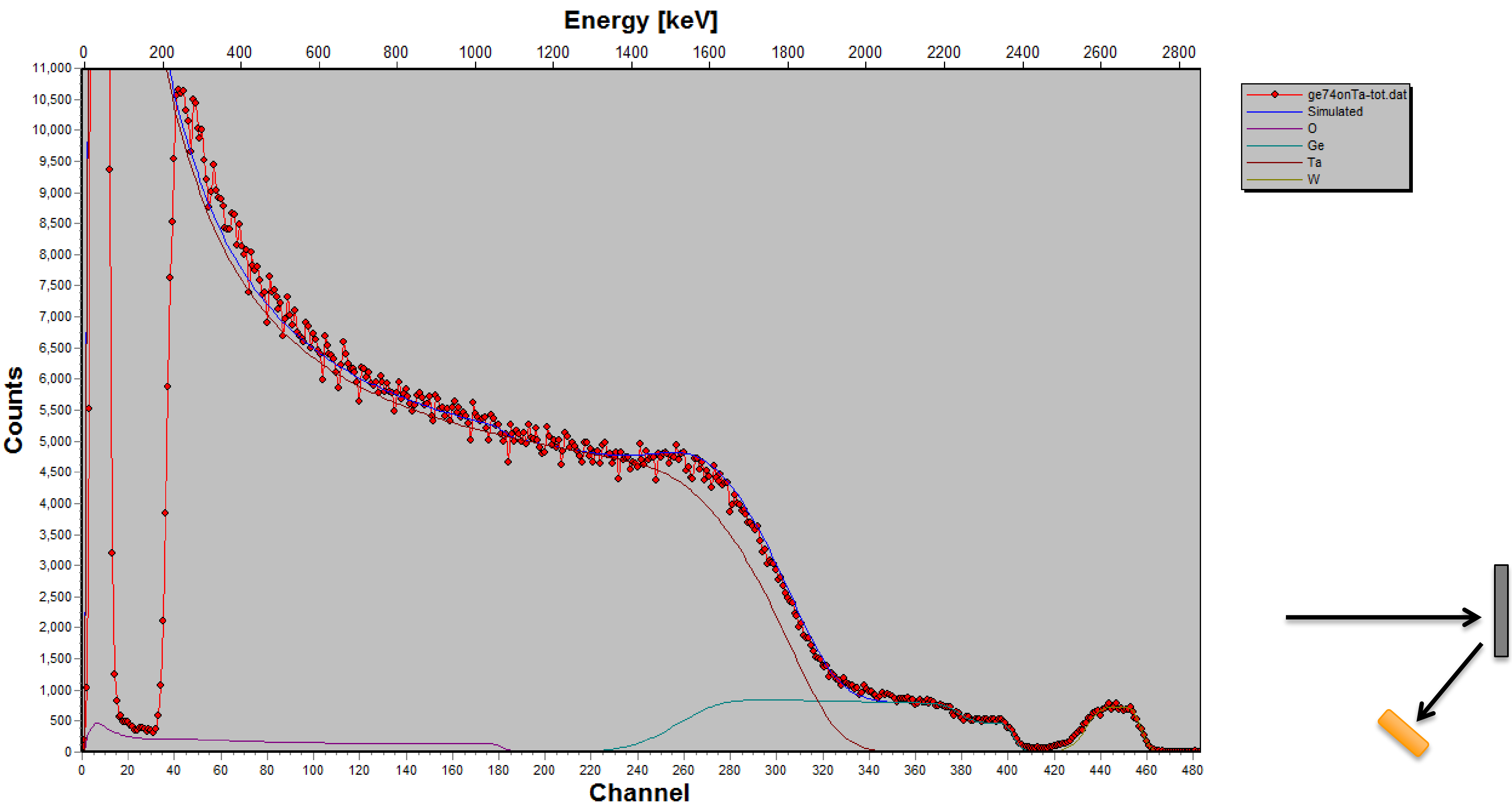


Figures by A. Simon & A. Spyrou

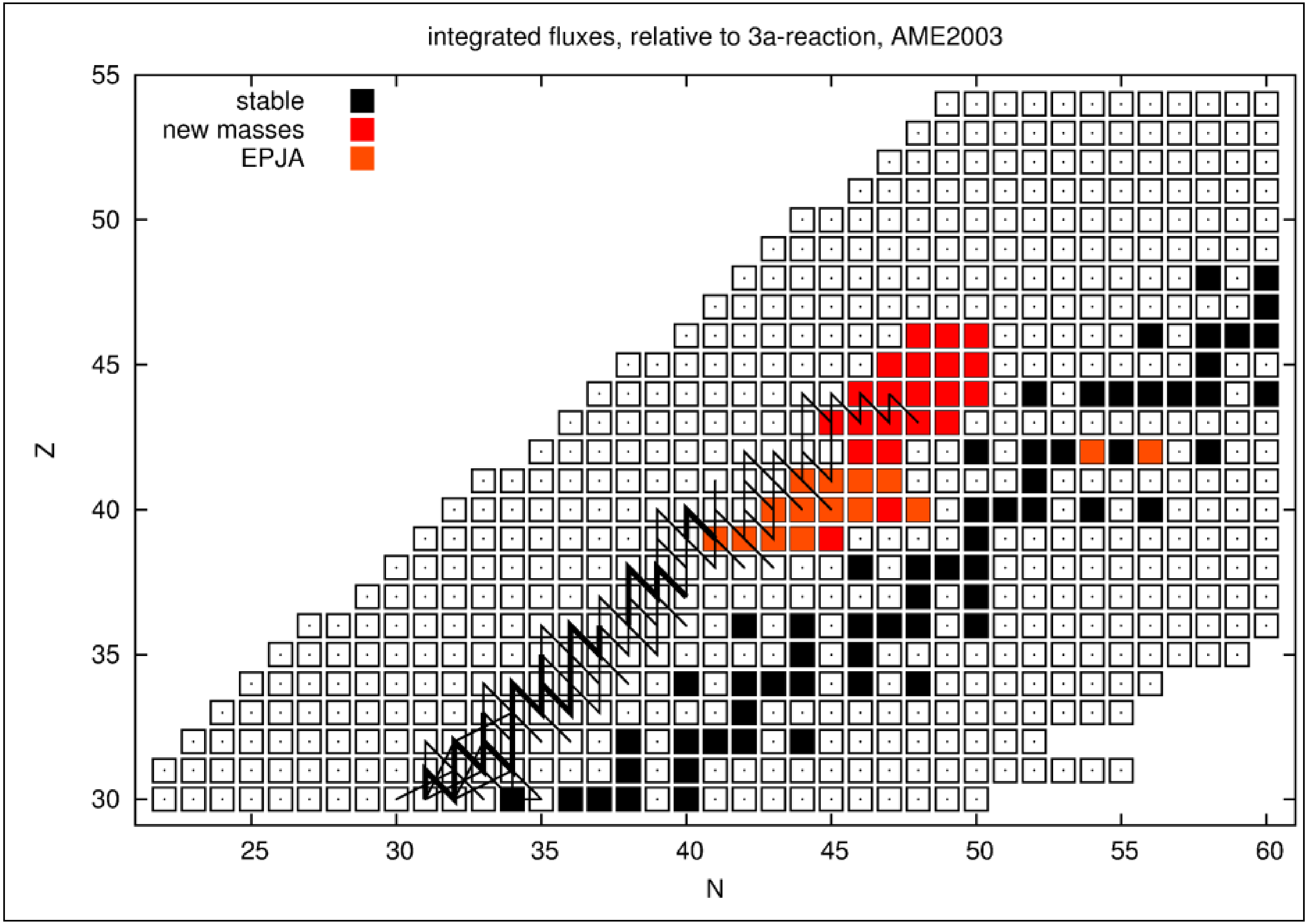


$$\sigma = \frac{N_{\Sigma}}{N_p \cdot \varepsilon_{\Sigma} \cdot n_t}$$

RBS at Hope College



vp-process path



F.K. Thielemann et al, Journal of Physics: Conference Series 202 (2010), 012006.

$^{74}Ge(p,\gamma)^{75}As$