Statistical Nuclear Physics and (α,n) Reactions for Applications

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Our mission: To increase the accuracy and predictive powers of statistical descriptions of nuclear reactions.

Our method: Benchmark model calculations against experimental data including nuclear level densities through particle evaporation spectra and direct measurement of (α,n) cross sections

Experimental low-energy nuclear physics done at OU by:

- Faculty: **Zach Meisel***, **Alexander Voinov***, Carl Brune, Steve Grimes, Tom Massey
- Postdoctoral Research Associates: Mansi Saxena, Caleb Marshal, Daniel Odel
- Graduate Students: **K. Brandenburg***, J. Derkin, G. Hamad, Y. Jones-Alberty, N. Singh, D. Soltesz, S. Subedi, J. Warren

*Supported by this grant

2020 Highlights: 8 publications and 5 invited presentations

Recent article: D. Soltesz et al. PRC 103, 015802 (2021)

OHIO UNIVERSITY

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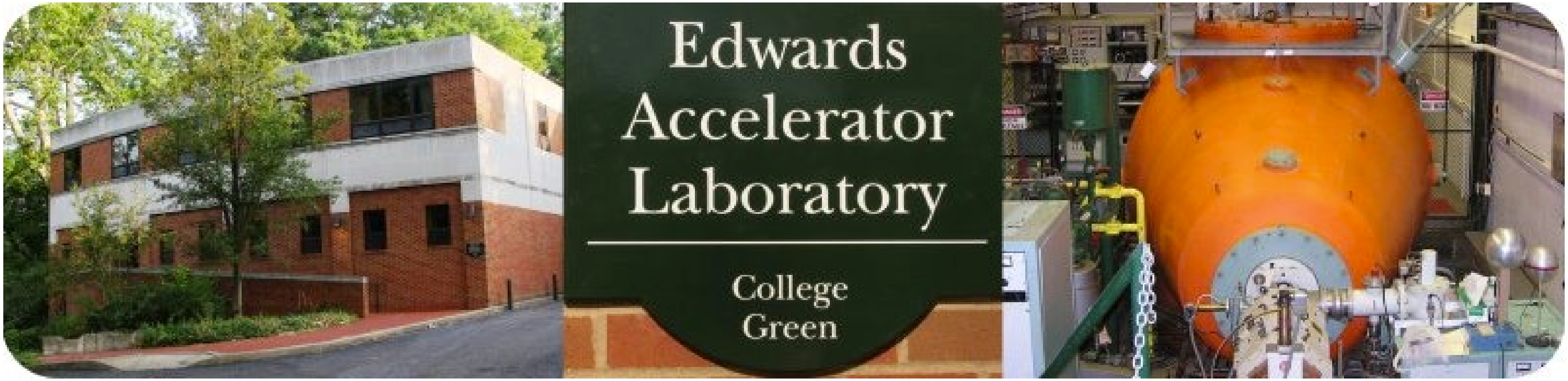
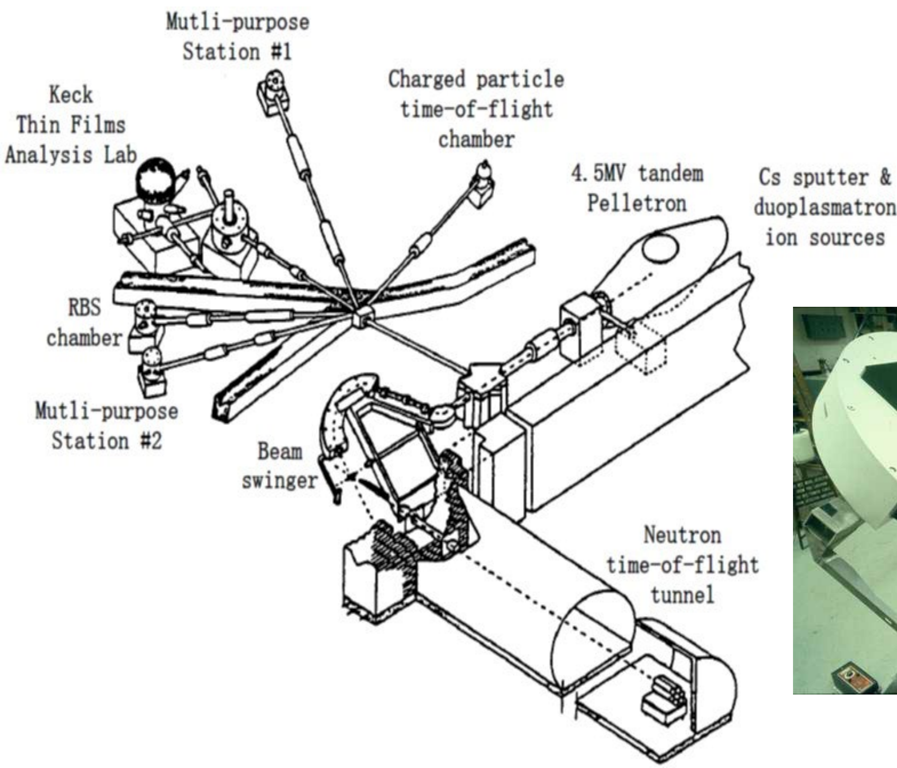
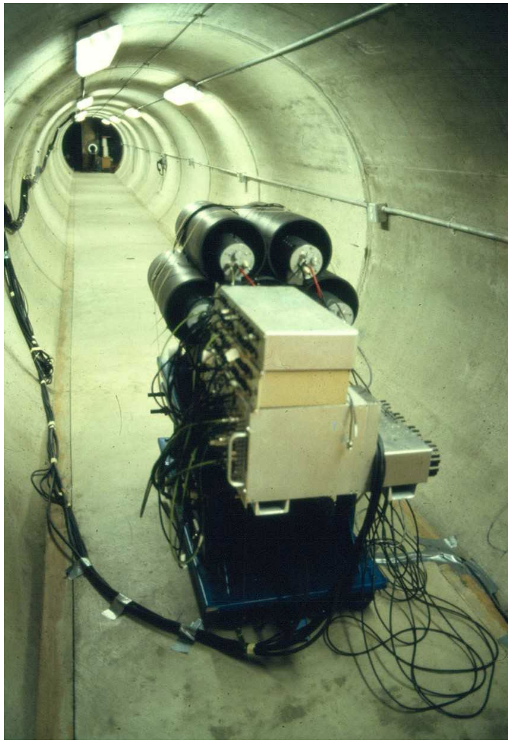
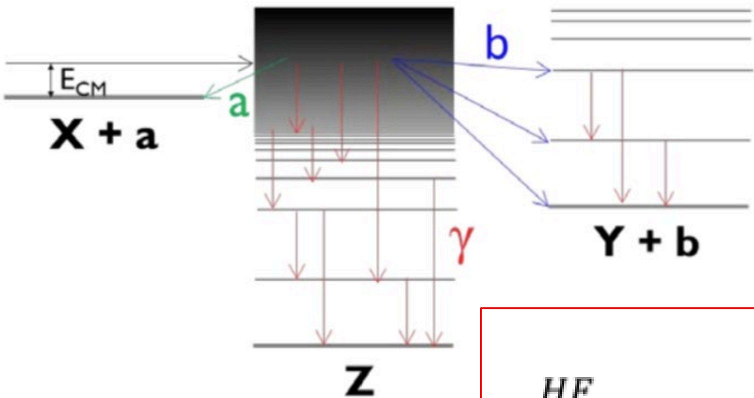
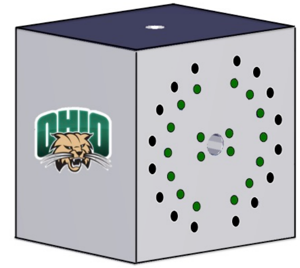

Edwards
Accelerator
Laboratory
College
Green


Mutli-purpose
Station #1
Keck
Thin Films
Analysis Lab
Charged particle
time-of-flight
chamber
4.5MV tandem
Pelletron
Cs sputter &
duoplasmatron
ion sources
RBS
chamber
Mutli-purpose
Station #2
Beam
swinger
Neutron
time-of-flight
tunnel



Our measurements utilize the Hauser-Feshbach formalism



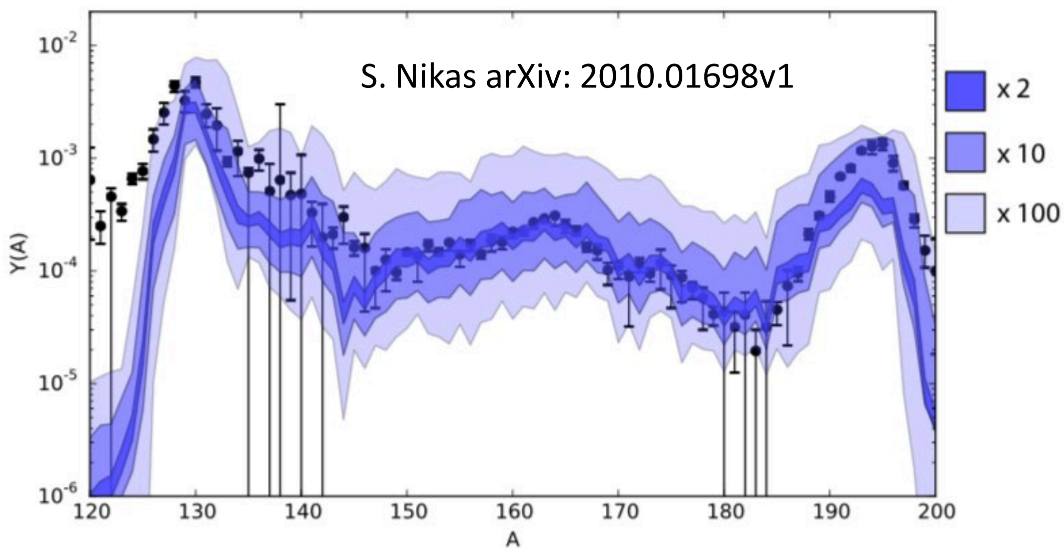


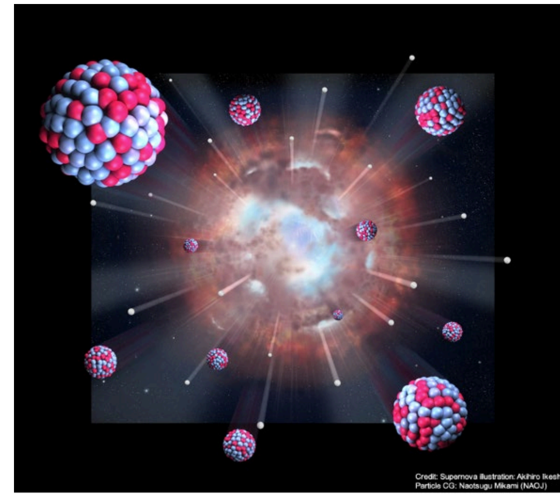
$$\sigma^{HF}_{X(a,b)Y} = \pi \left(\frac{\lambda}{\pi}\right)^2 \sum_J \frac{2J+1}{(2J_a+1)(2J_X+1)} W_{ab} \frac{T_{aX} T_{bY}}{\sum_{chan} T_{chan}}$$

$$\mathcal{T}_\gamma(E,J,\pi) = \sum_{\nu=0}^{\nu_r} \underbrace{\mathcal{T}^\nu_\gamma(E,J,\pi,E^\nu_r,J^\nu_r,\pi^\nu_r)}_{\text{Get from } \gamma\text{-strength function (or, for particles, optical model potential)}} + \int_{E^{\nu_r}_r}^{E} \sum_{J_r,\pi_r} \mathcal{T}^\nu_\gamma(E,J,\pi,E^\nu_r,J^\nu_r,\pi^\nu_r) \cdot \underbrace{\rho(E_r,J_r,\pi_r)}_{\text{Level Density of decay daughter}} \mathrm{d}E_r$$

- Directly measure cross section with HeBGB
- Particle evaporation spectra with charged particle TOF

R-process nucleosynthesis impacted by uncertainties in HF inputs for (n,ϒ) rates





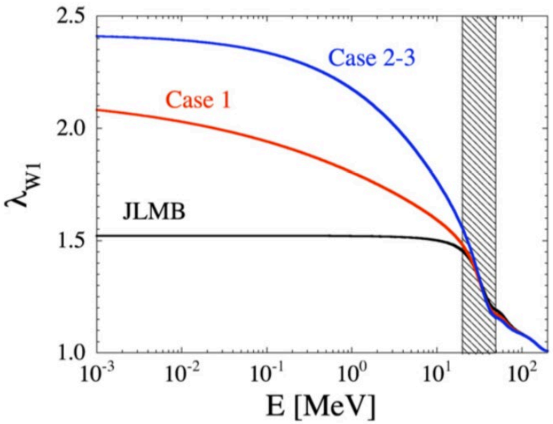
Neutron capture reactions of exotic nuclei off stability are fundamentally important and are evaluated with HF.

- Inputs to HF include: level densities, gamma strength functions and optical model parameters

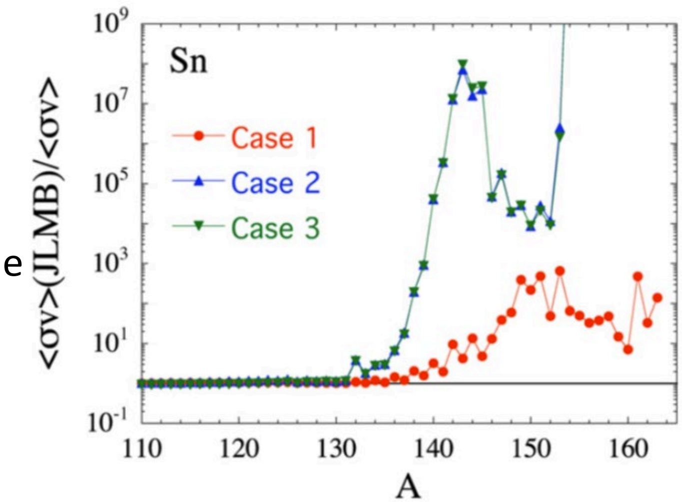
OMP off stability are highly uncertain due to a lack of experimental data

JLM optical potential:

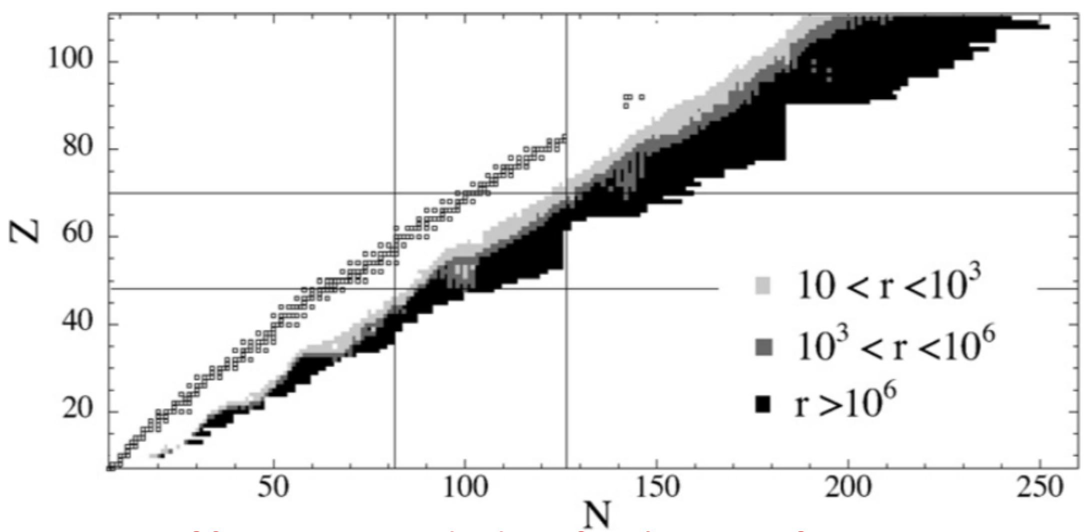
$$U(E) = \lambda_V(E)[V_0 \pm \lambda_{V1}(E)\, \alpha V_1] + i\, \lambda_W(E)[W_0(E) \pm \lambda_{W1}(E)\alpha W_1(E)]$$



Larger λ_{W1} reduces the total imaginary isovector part of the potential and reduce neutron transmission coefficients (i.e. neutron absorption channel)

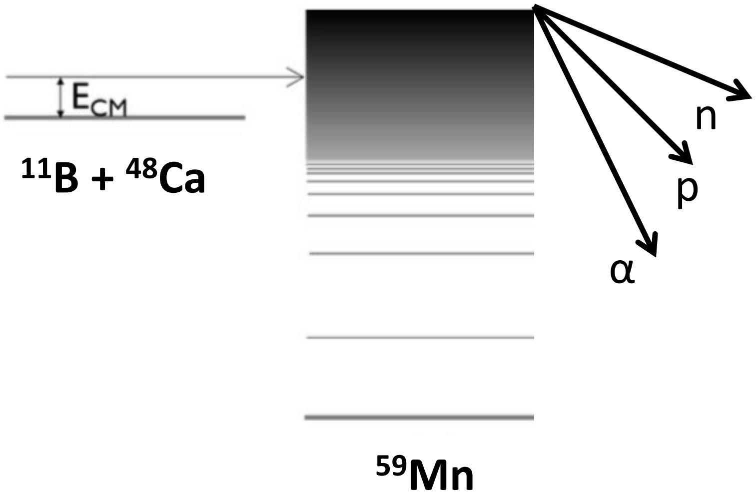


Case 3 results in substantial decreases to currently assumed rates and could mean r-process paths need to be revisited

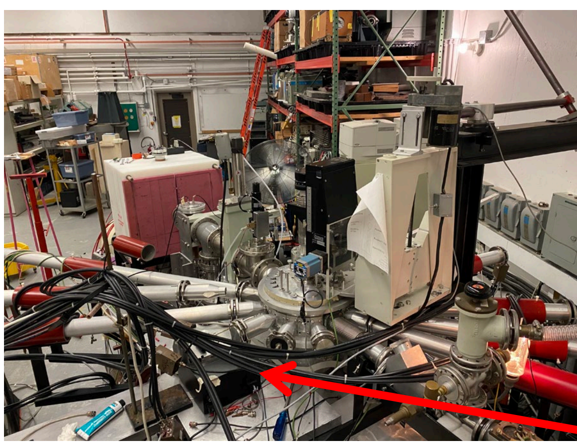


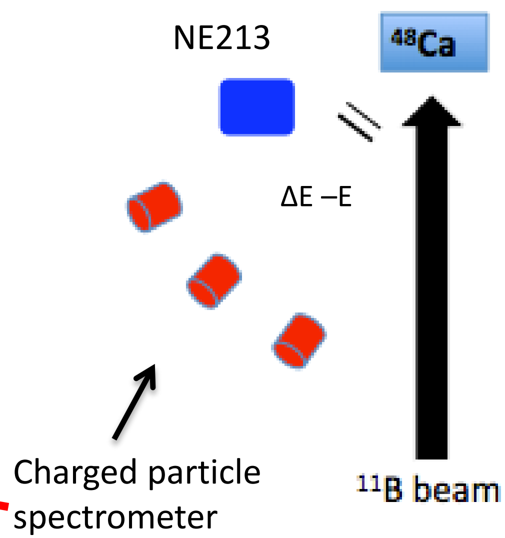
Measurements of λ_{W1} are needed to further confirm

Probing exotic matter at the Edwards Lab



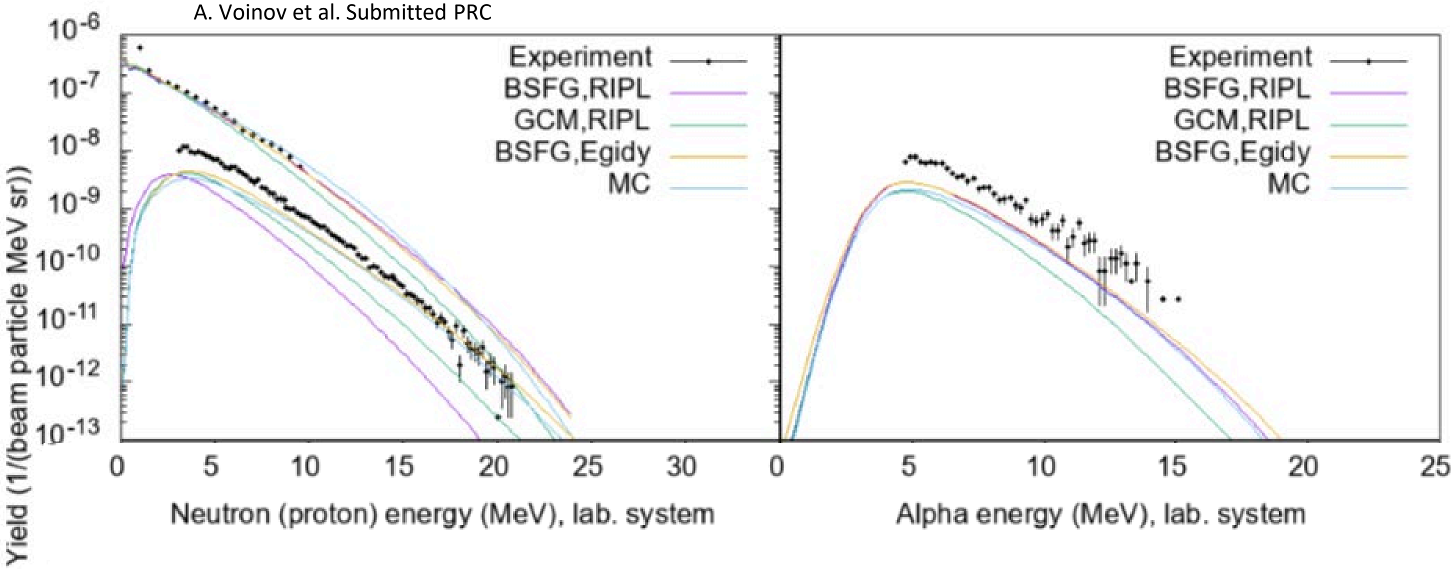
Ratio of the yields of outgoing channels is sensitive to transmission coefficients and therefore λ_{W1}





Current models underestimate proton and α yields

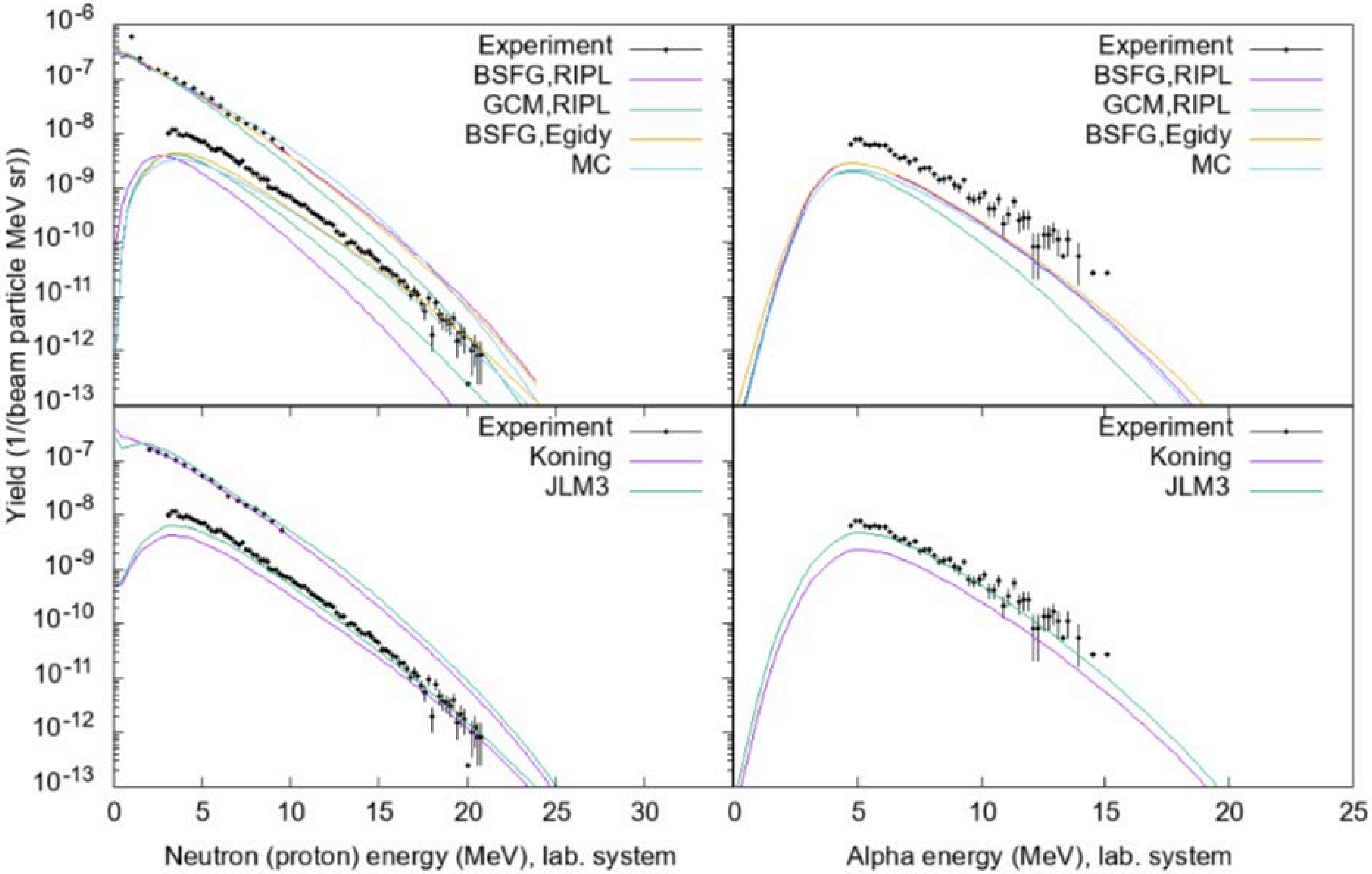
A. Voinov et al. Submitted PRC



Better agreement to our data is found by increasing λ_{W1}

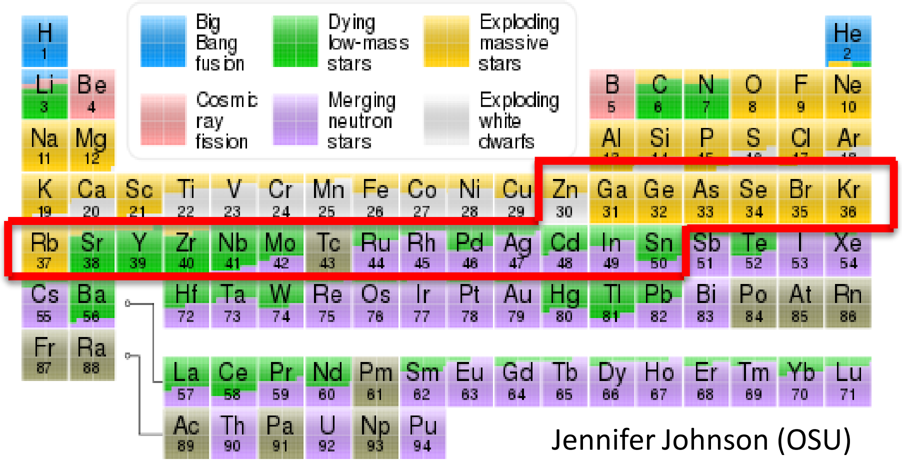
Isovector part of imaginary potential in JLM3 is set to 4 (larger than suggested)

A. Voinov et al. Submitted PRC

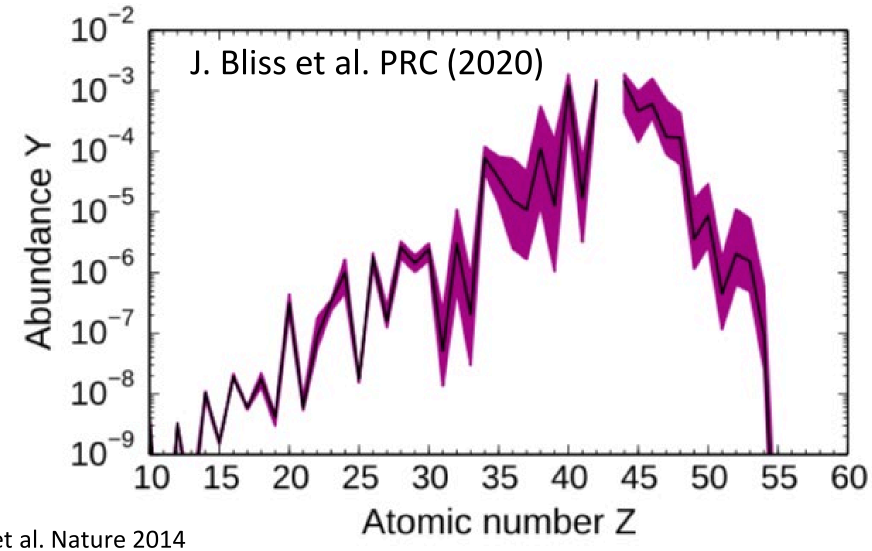


^{58}Mn(n,ϒ) reaction rate would be reduced by 2x

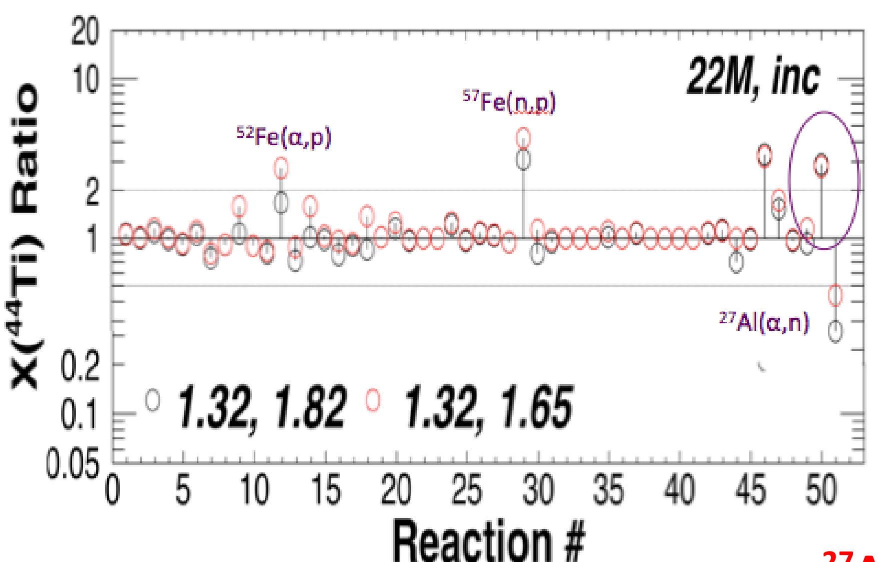
(α,n) measurements needed for many fields



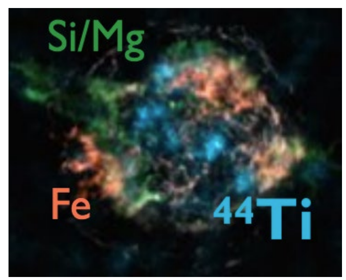
Jennifer Johnson (OSU)



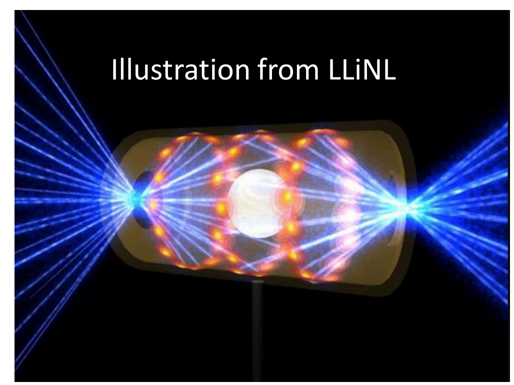
S. Subedi et al. ApJ (2020)



B. Grefenstette et al. Nature 2014

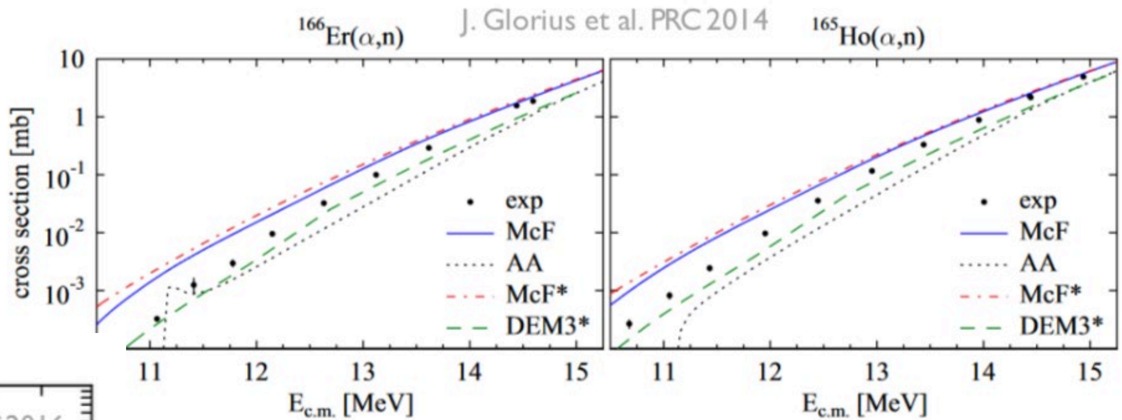


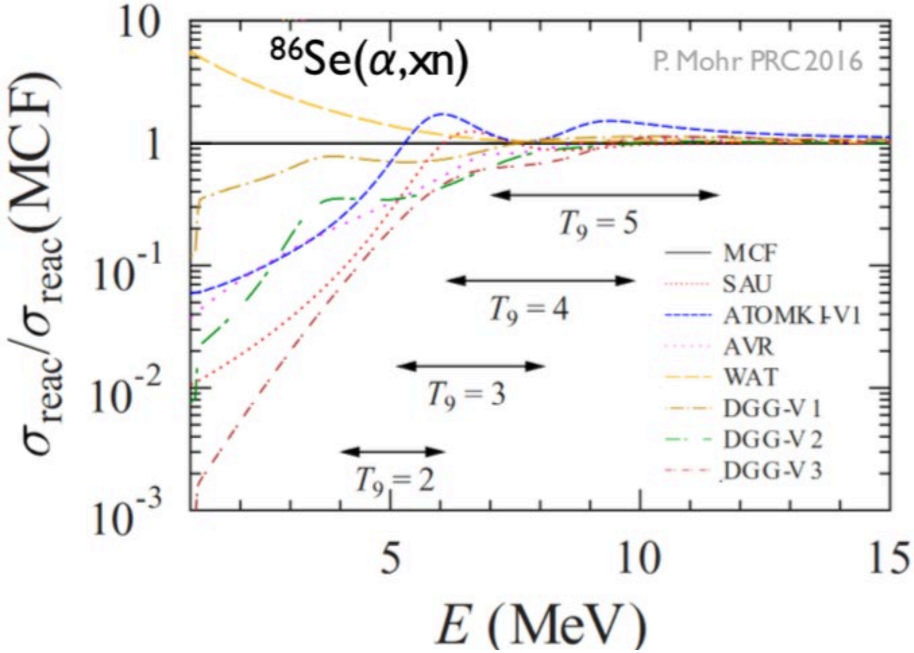
α diagnostic for ICF via d(t,n)α



^{27}Al(α,n) data needed!

αOMP and level densities for (α,n) can be constrained through direct measurement

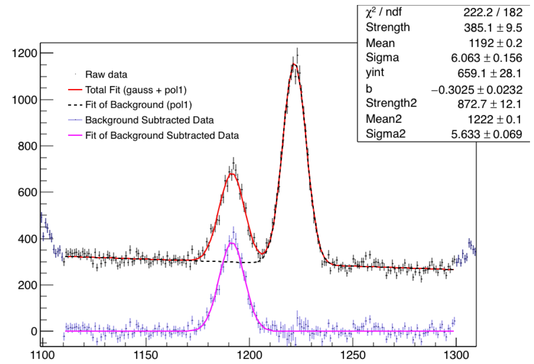


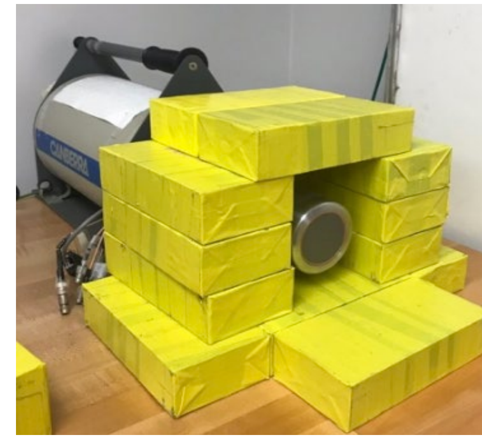


Modifications to theory inputs can be done to better match existing data and give better estimates for reactions with no data

(α,n) measurements techniques at OU

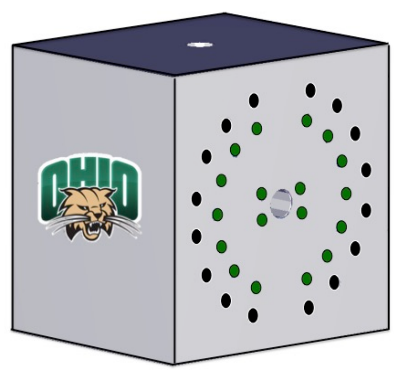
- Activation
  - $^{96}Zr(\alpha,n)^{99}Mo$

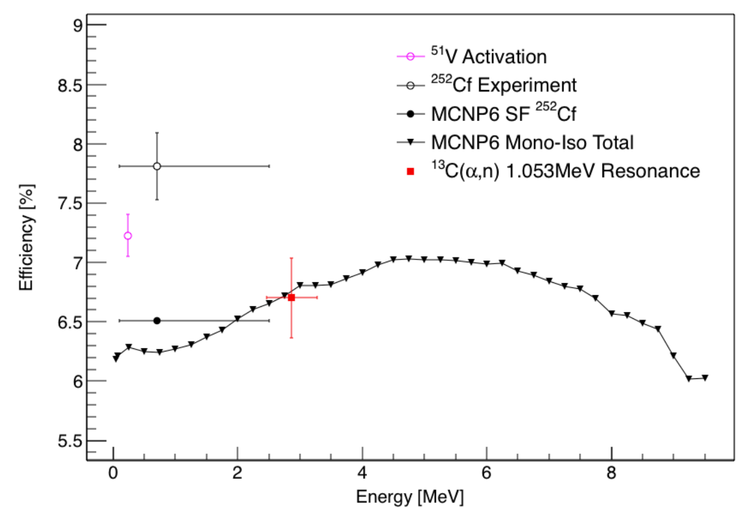




- Direct neutron measurement with custom built detector

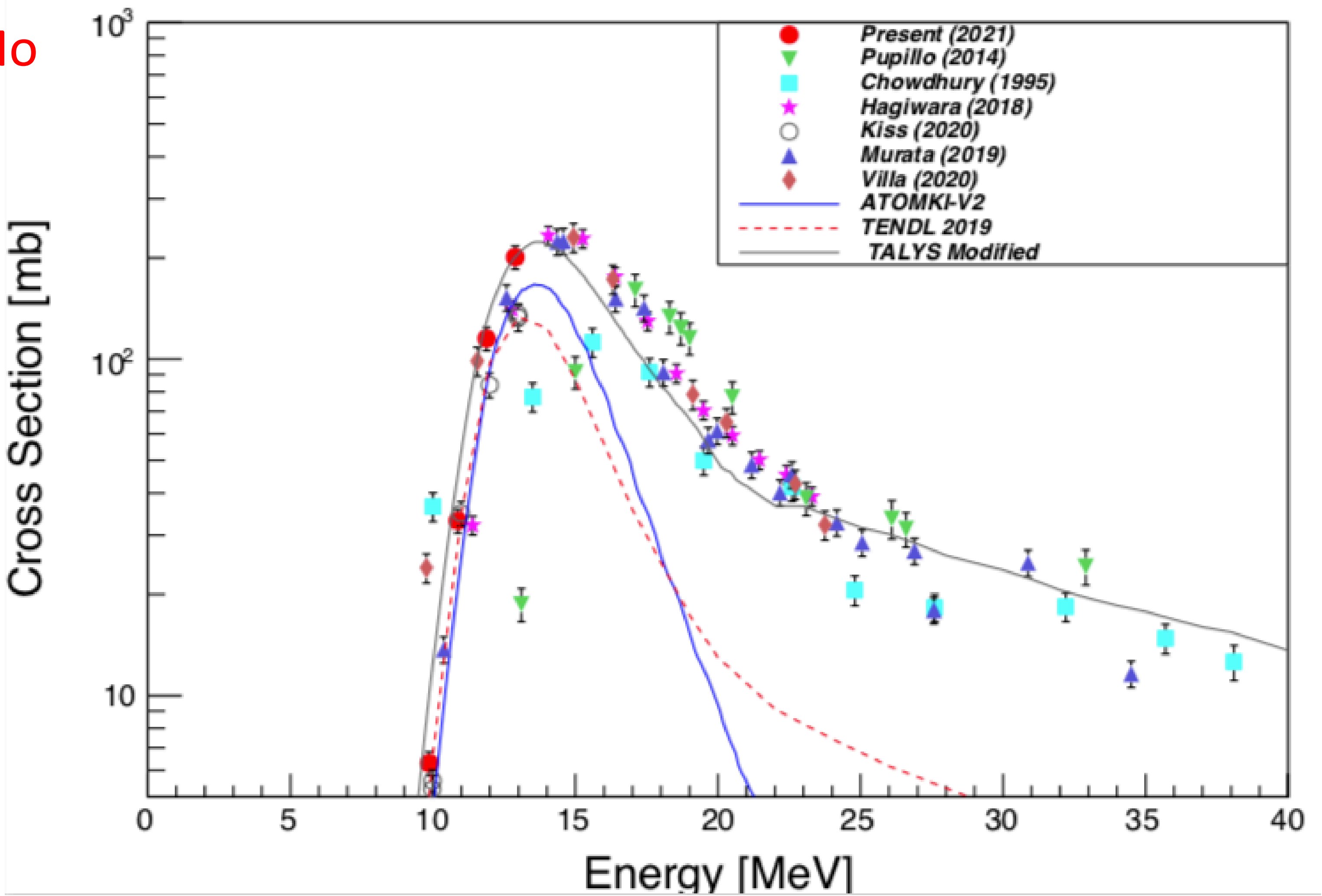
HeBGB





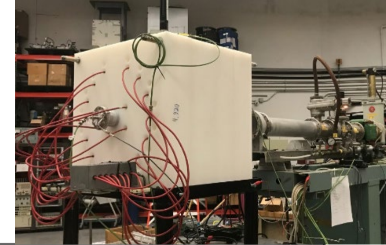
Adjustments to AOMP and level density parameters give better agreement to world data

$^{96}Zr(\alpha,n)^{99}Mo$

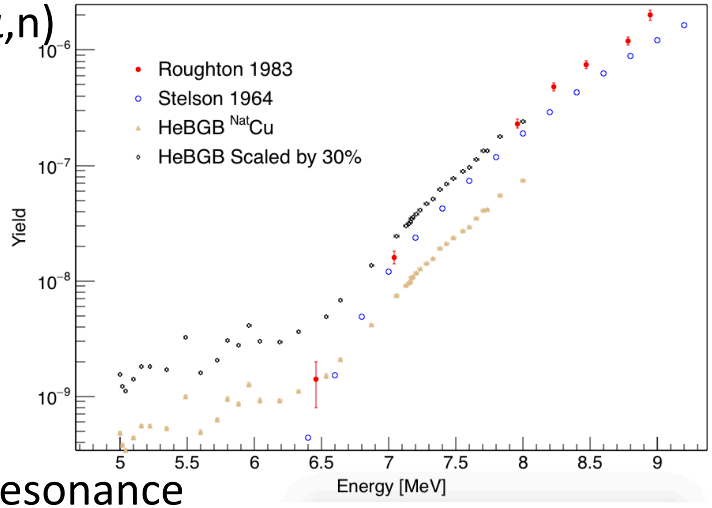


Measurements at more energies are ongoing

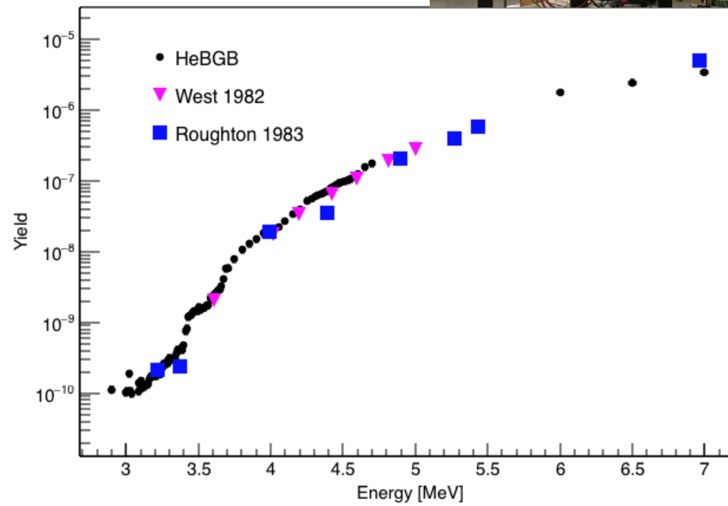
Campaign of direct (α,n) measurements with HeBGB



$^{Nat}Cu(\alpha,n)$

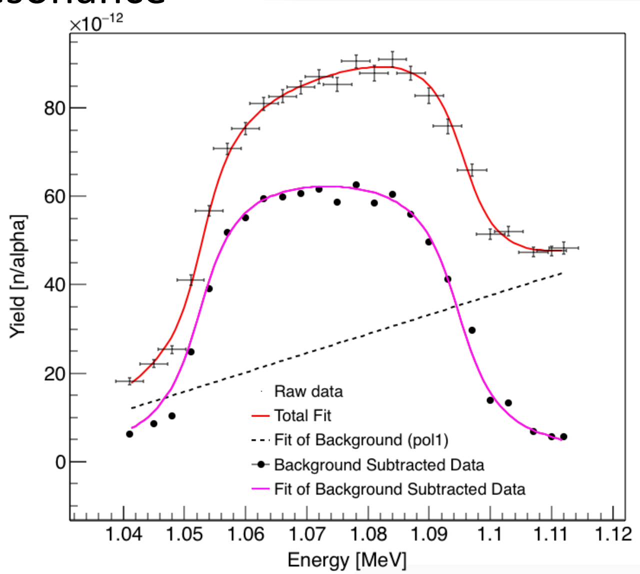


$^{27}Al(\alpha,n)$

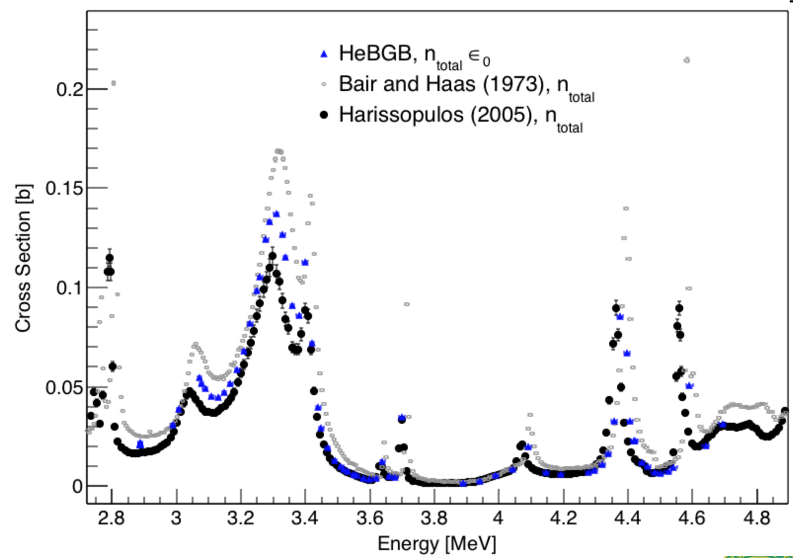


1.05 MeV resonance

$^{13}C(\alpha,n)$

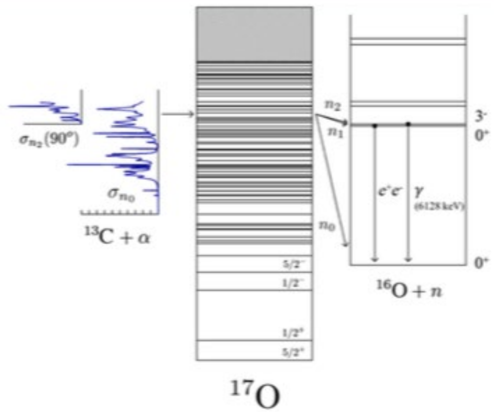


$^{13}C(\alpha,n)$

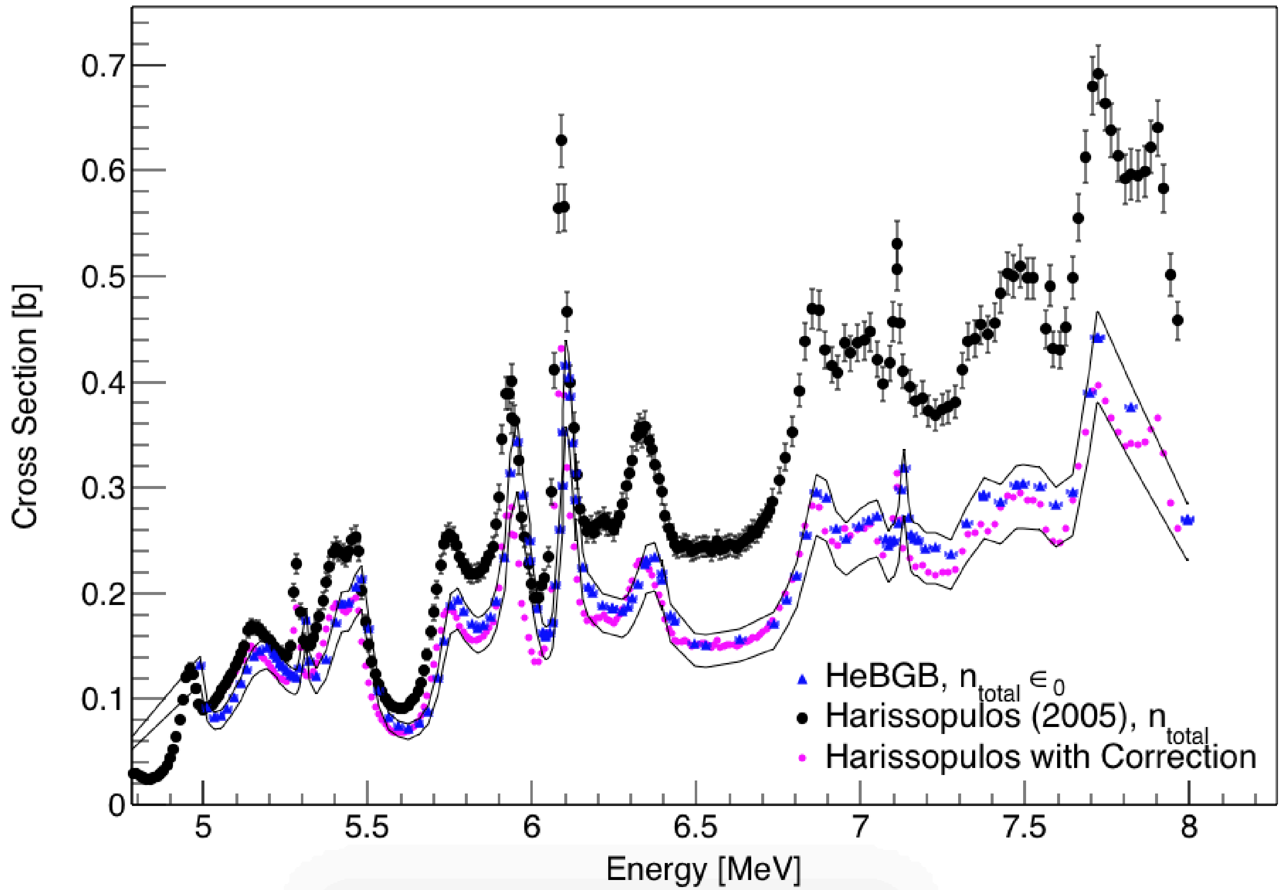


HF based method predicts cross section for light nucleus

$^{13}C(\alpha,n)$



$$\eta_{\rm eff} = \sum_{j=0}^{4} b_j(E_\alpha)\,\eta_j(E_{n,j})$$



*Citation for correction and level scheme

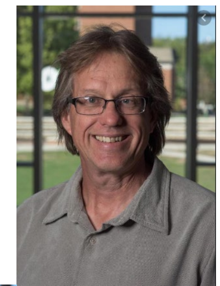
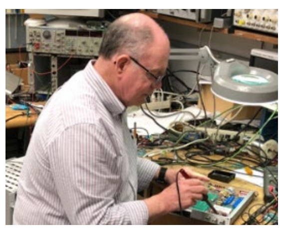
Thank you to my collaborators and to NNSA



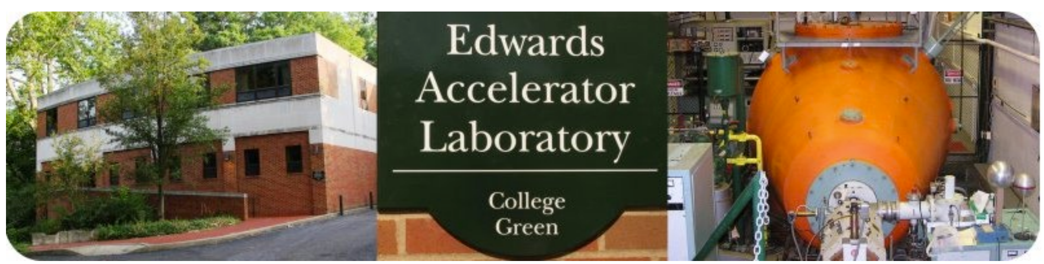






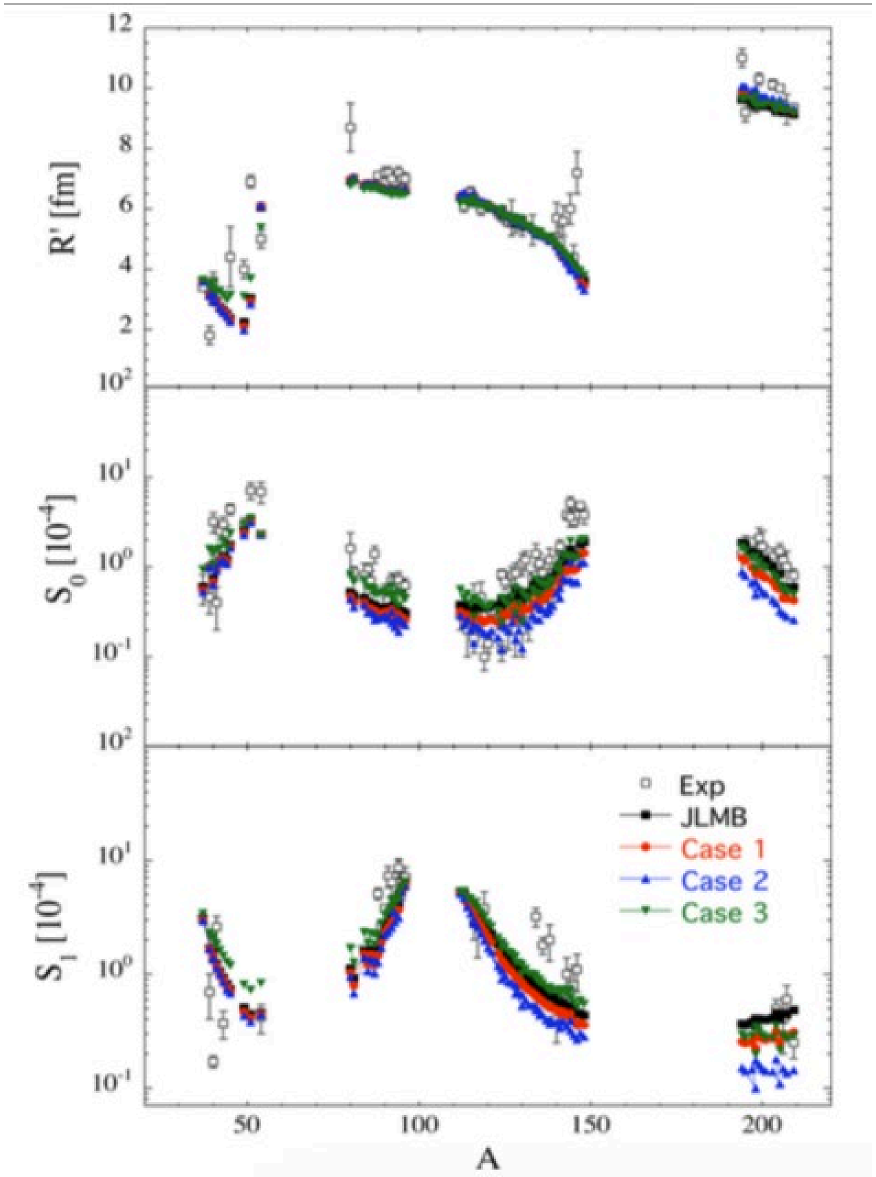




And thank you for listening!

Questions?

Supplemental

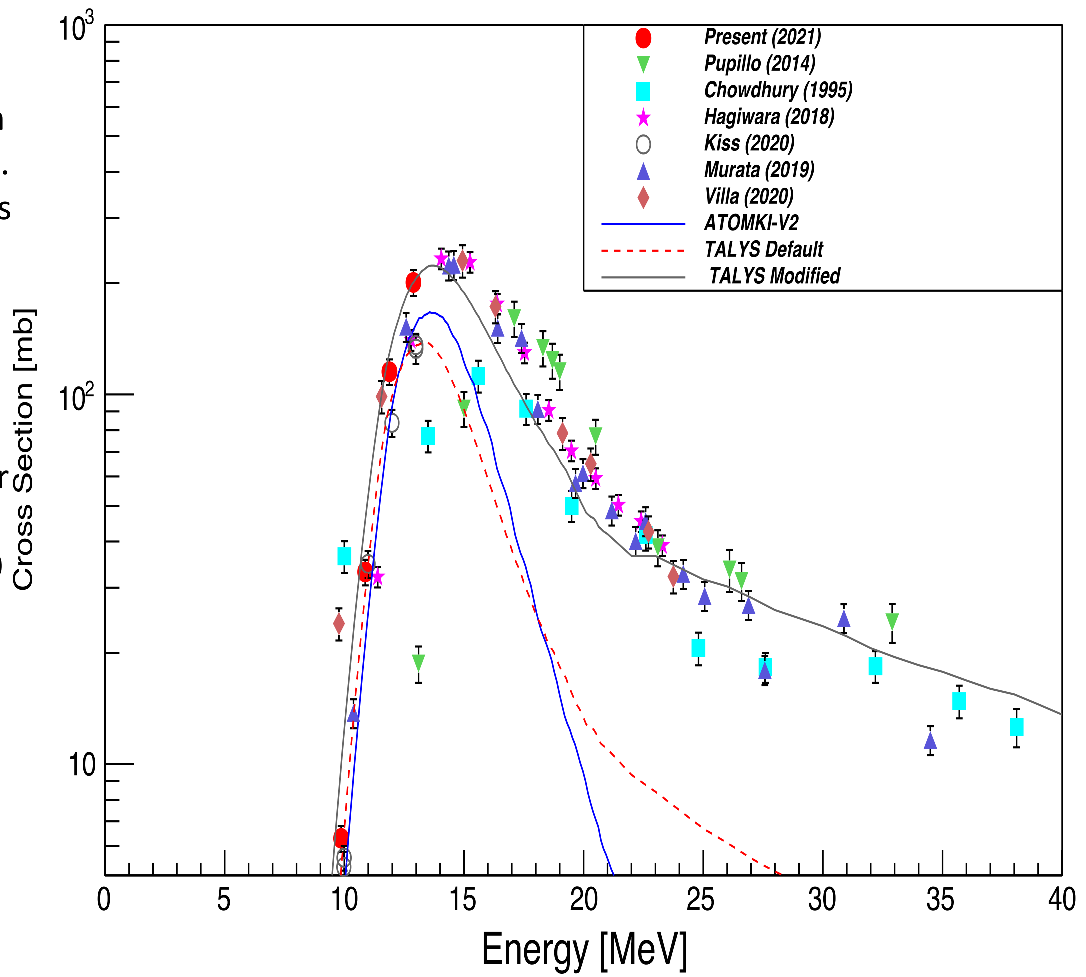


Basis for choice of lambda parameters Scattering Radii and strength functions

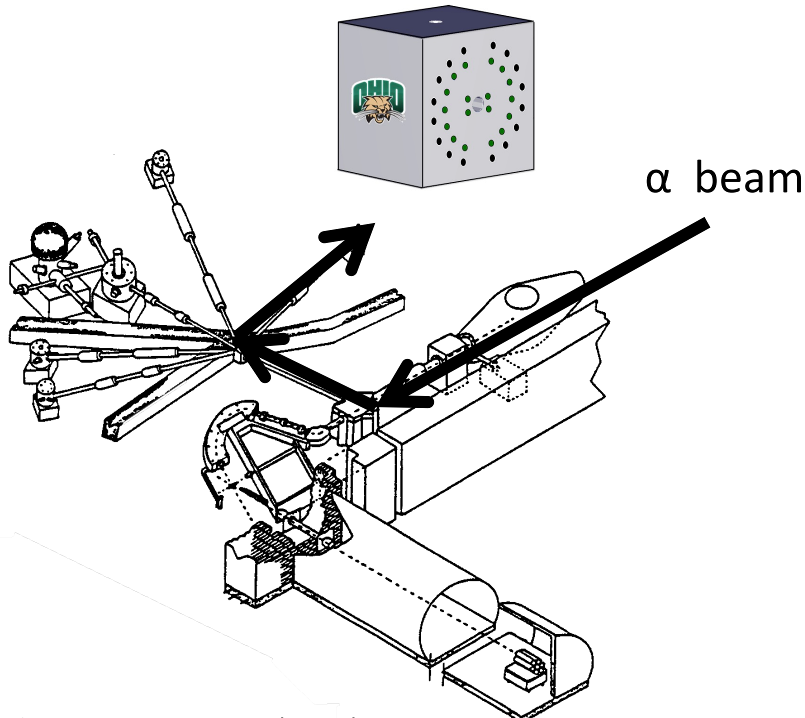
Zr measurement

This is of interest bc the alpha optical potential deviates from what was supposed to be the best model

- Here we compare our results for the96Zr(α,n) cross section to prior results, along with ATOMKI-V2 by Mohr et al. and Hauser-Feshbach results tuned to reproduce experimental results.
- Our experimental results aim to clarify the cross section dependence near the threshold energy.
- Our Hauser-Feshbach calculations aim to achieve a consistent description of the global 96Zr(α,n) data.
- TALYS :
  - Alpha potential of McFadden and Satchler (default = 1)
    - Real part of potential v= 183 ->200
    - Imaginary part of potential w=25 ->27
  - Level density model = Back-shifted Fermi gas model. (default = 1)
    - Level density parameter was adjusted (a =11.43 for 99Mo)
  - S2adjust = spin cut-off parameter = 1.5, default =1)



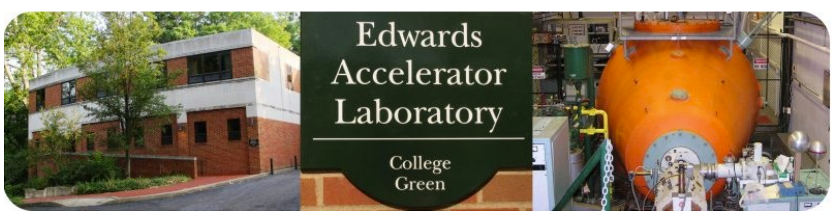
(α,n) measurements can be done near stability at EAL



Nucl. Sci. Eng. 138, 145 (2001)

Neutron detection with long counters:

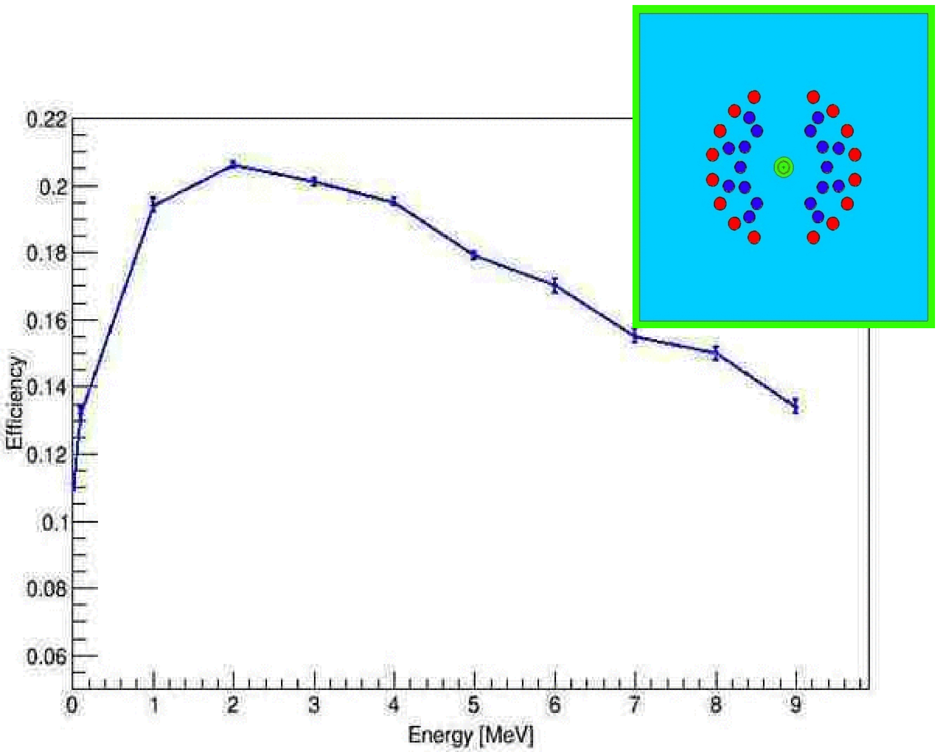
- Provide nearly 4pi coverage
- Generally have large efficiencies
- Quick measurements possible

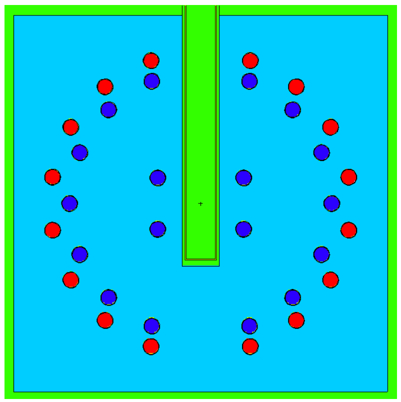


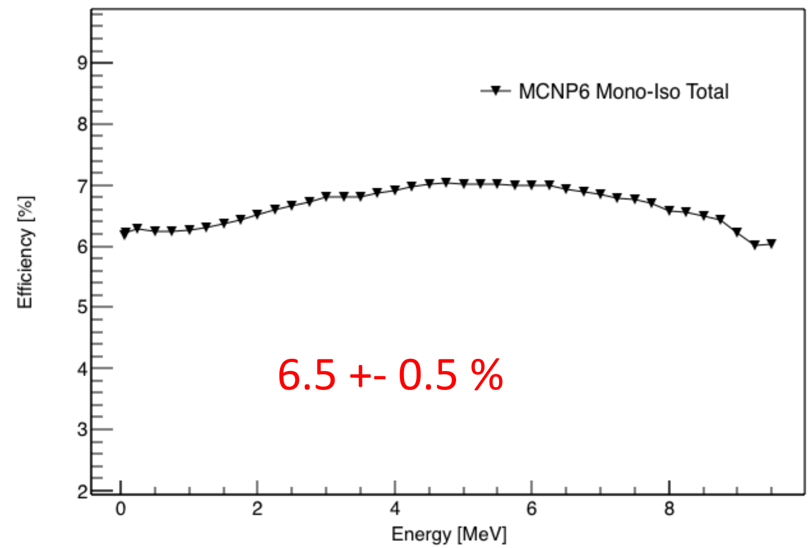
Drawbacks:

- Initial energy of neutron is lost in moderation
- Large systematic errors introduced if efficiency varies with energy

HeBGB was designed for flat efficiency



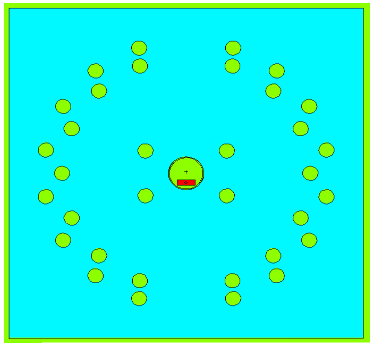
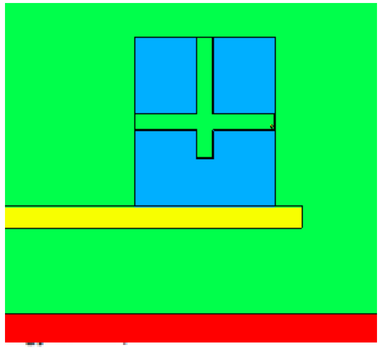


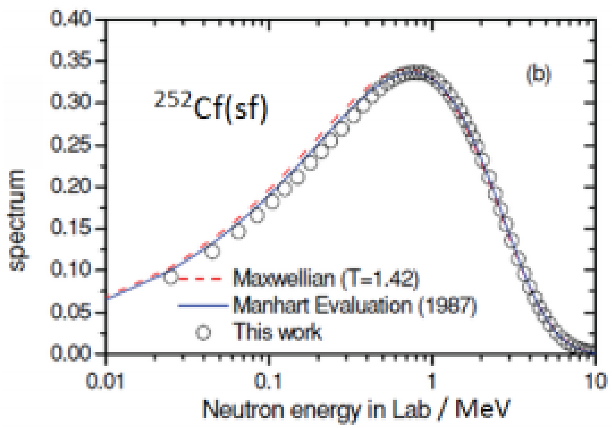


- 18 BF_3 Proportional Counters
- 16 ^{3}He Proportional Counters

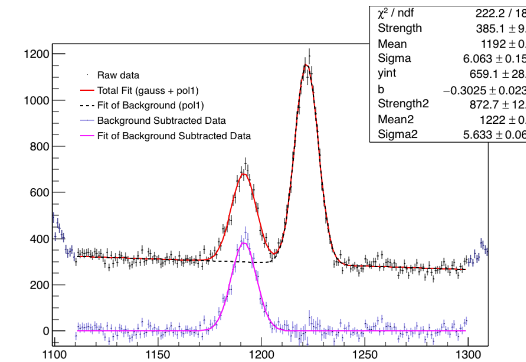
Efficiency Validation:

^{252}Cf Source

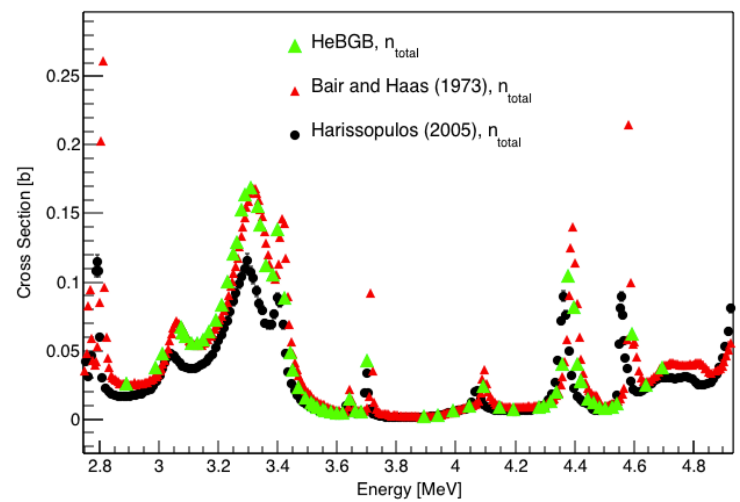





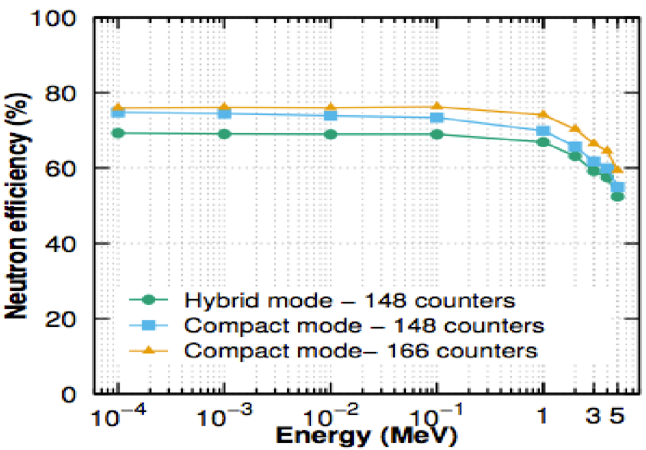
^{51}V(p,n)^{51}Cr Activation



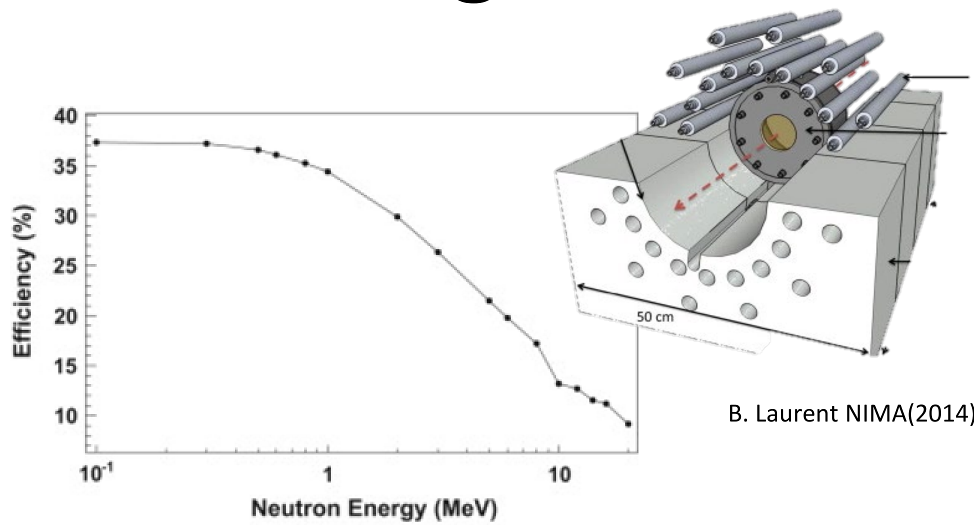
^{13}C(α,n) Cross Section Comparison



Efficiency decreases as neutron energy increases for previous long counters

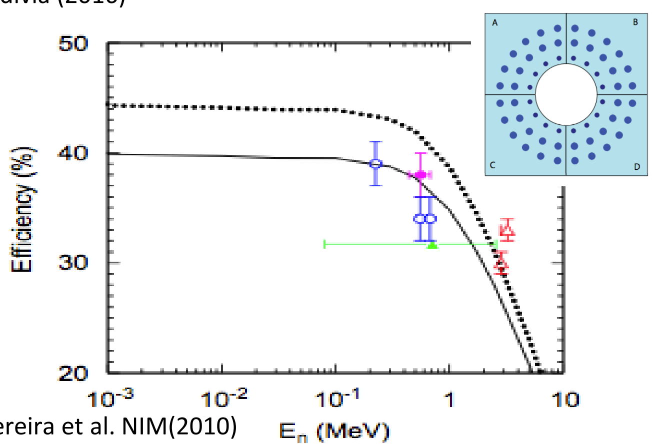


A. Tarifeno-Saldivia (2016)



B. Laurent NIMA(2014)

S. Falahat Nucl. Meth. A (2013)



J. Pereira et al. NIM(2010)