Constraining the $^{139}Ba(n,\gamma)^{140}Ba$ reaction rate for the astrophysical i process

Artemis Spyrou

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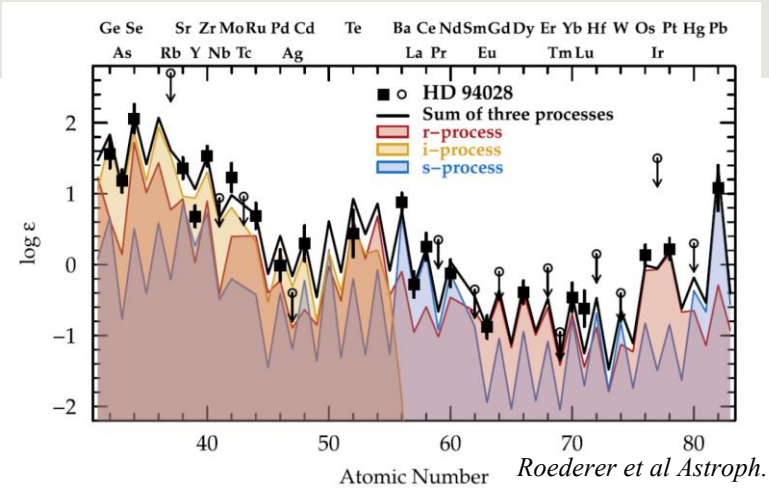
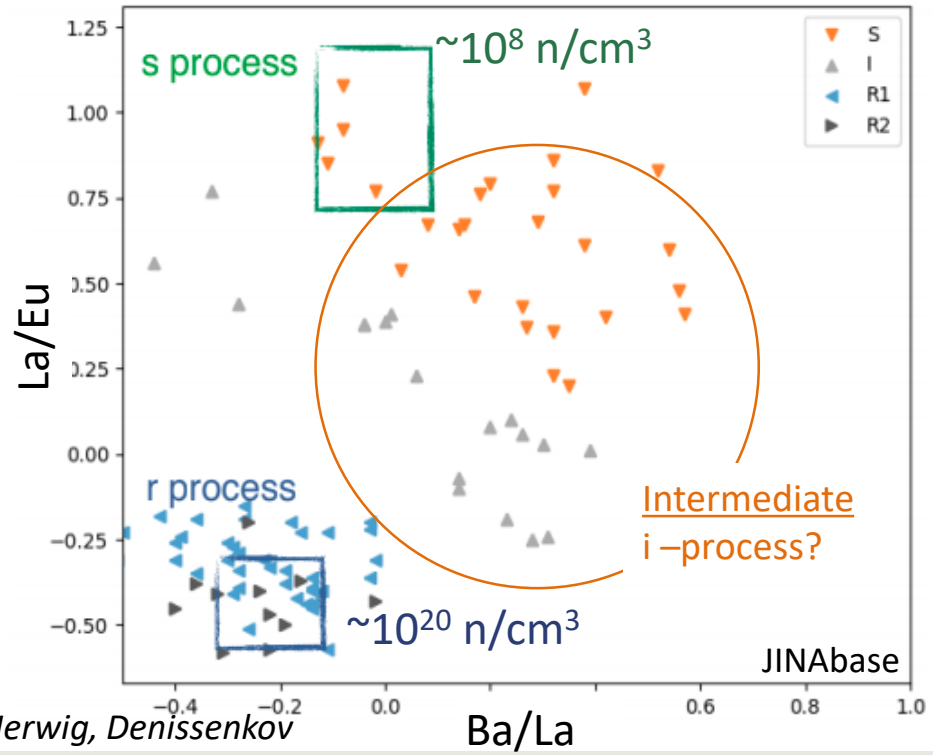
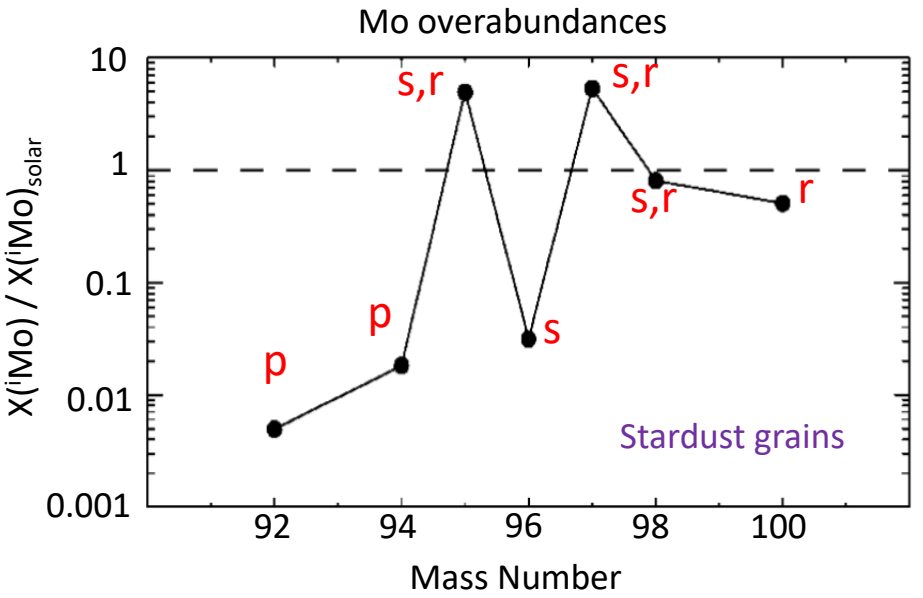
Evidence for additional nucleosynthesis processes



Roederer et al Astroph. J. 2016



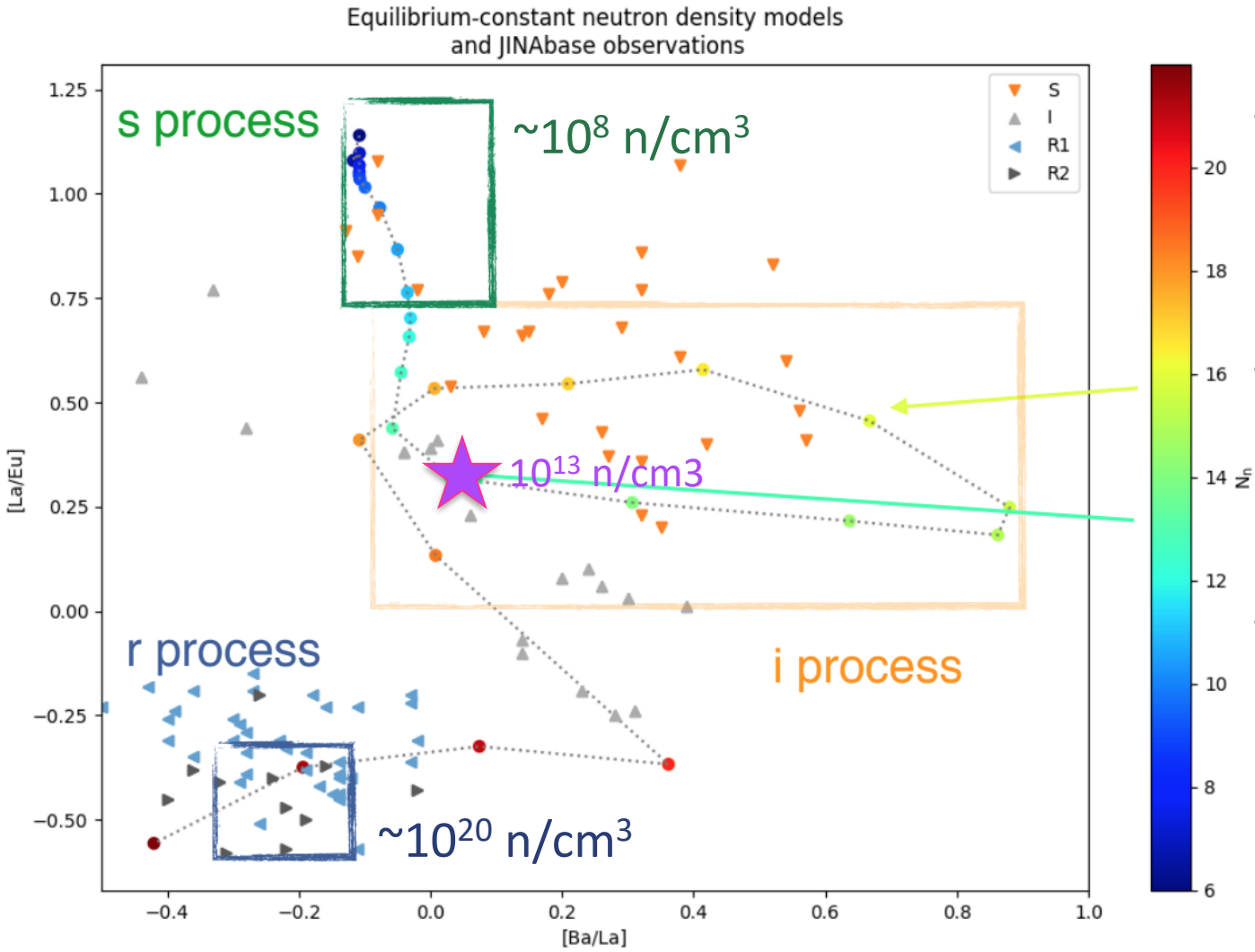
Herwig, Denissenkov



Meyer et al, APJ 2000

- Stellar observations and stardust measurements provide evidence for additional processes
- Models attempt to disentangle the contributions from each process
- Accurate nuclear physics input is necessary with guidance from observations

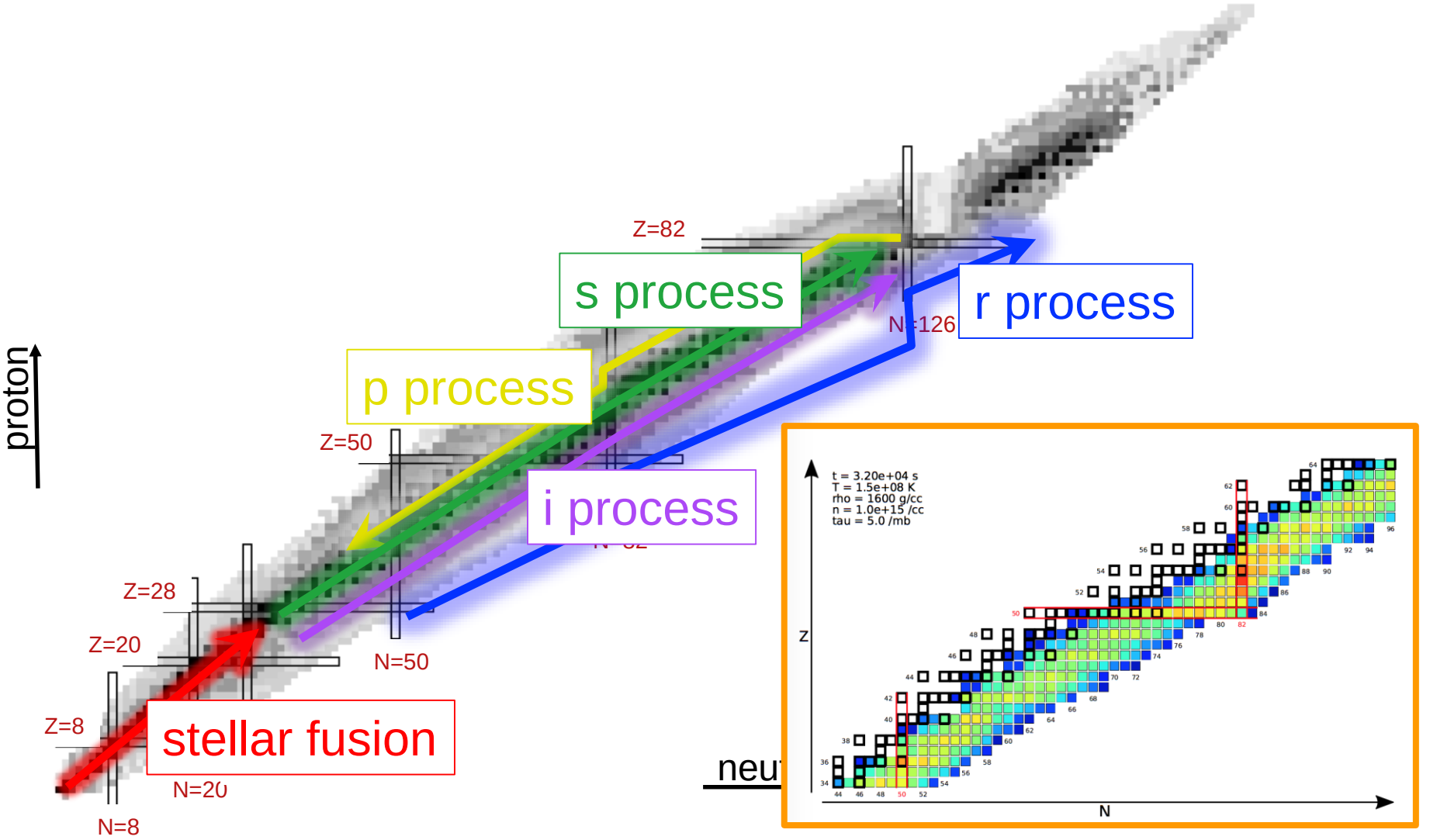
Simple i process calculations



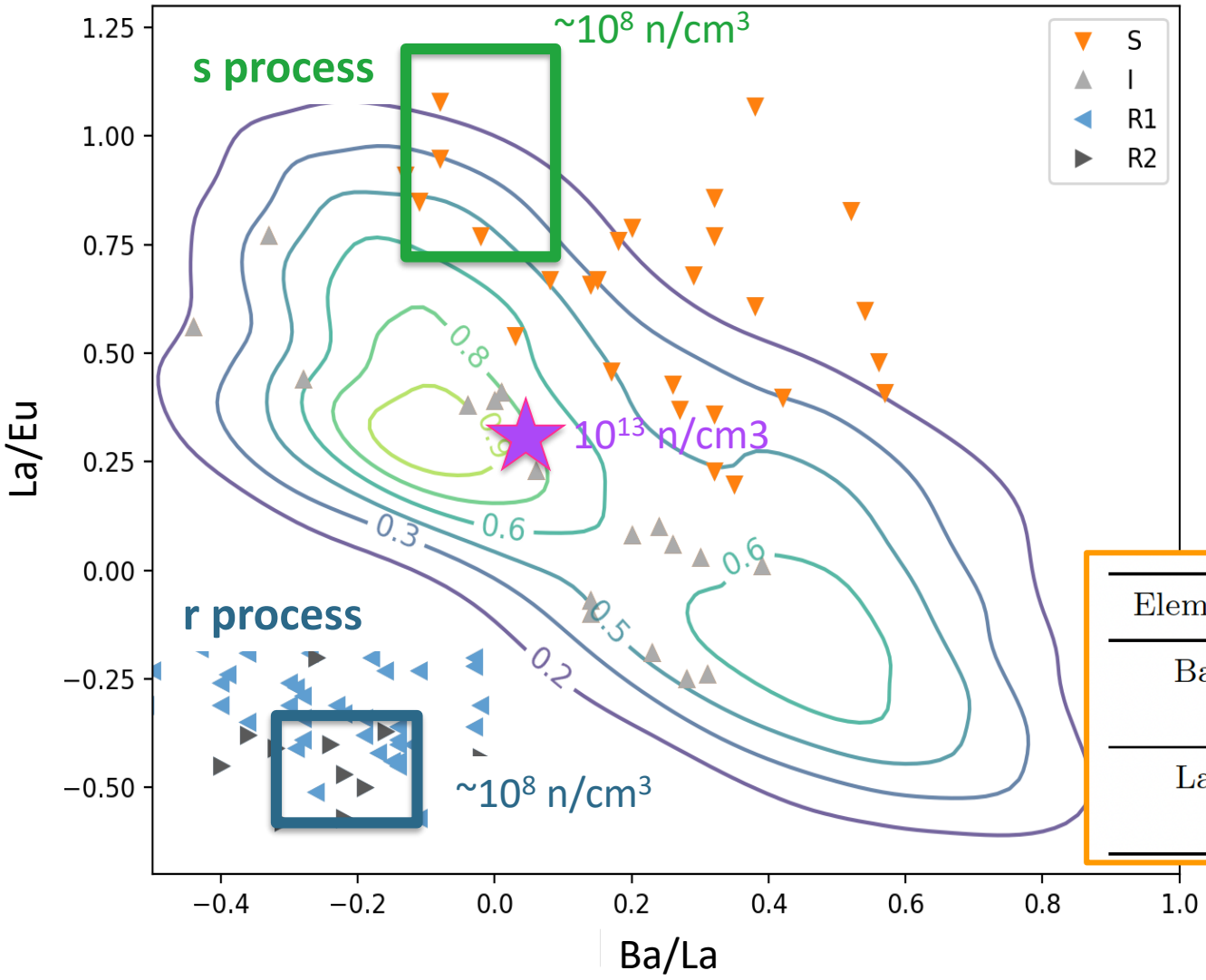
- Simple one zone model changing the neutron density
- s and r process stars exhibit different abundance ratios
- Group of stars not explained by s or r neutron densities

Herwig, Denissenkov

Astrophysical Processes



Sensitivity to neutron-capture rates

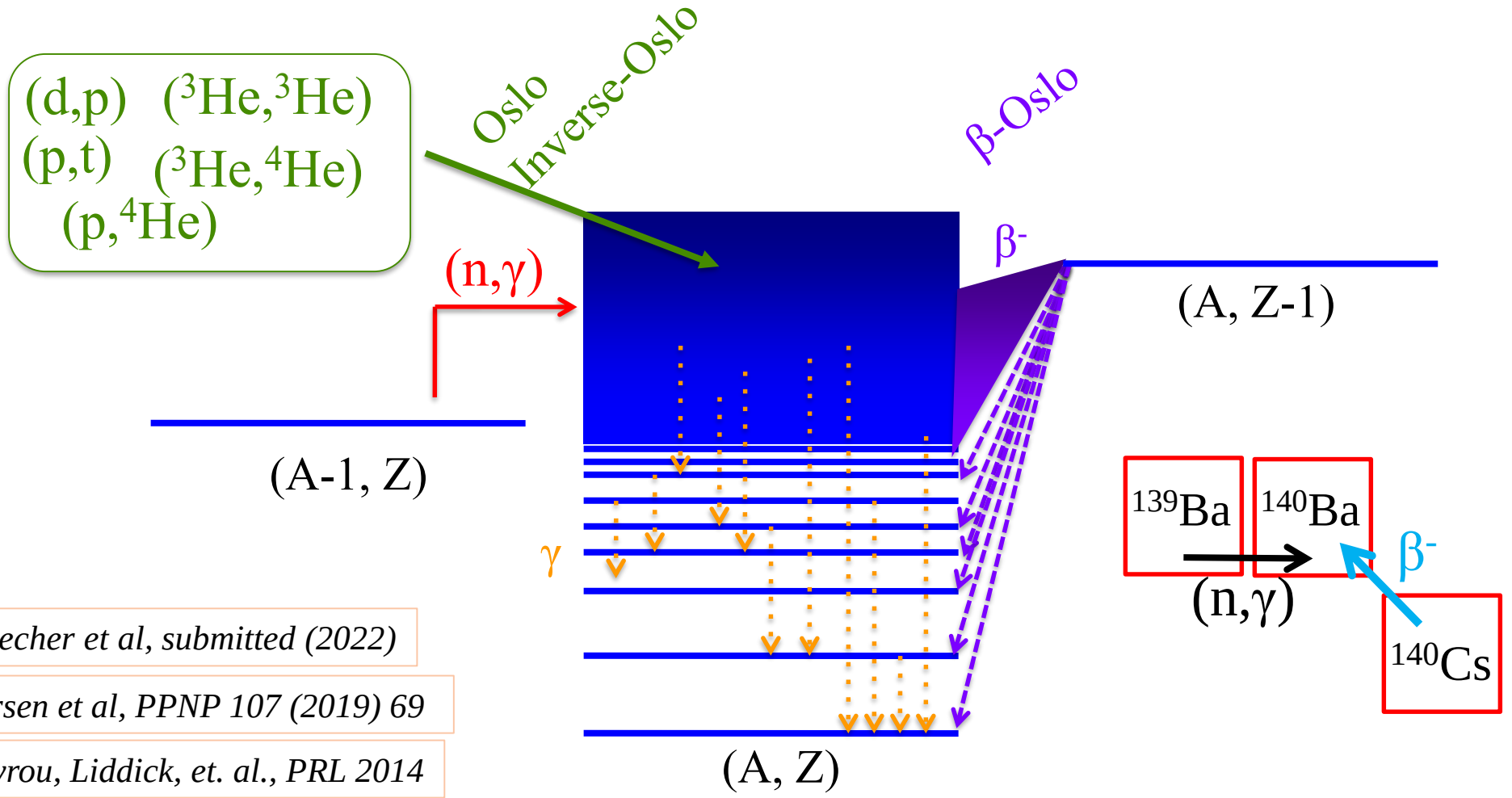


Element	Reaction	$r_{\rm P}(f_i, X_k/X_{k,0})$
Ba	^{134}I	+0.3689
	^{137}Cs	-0.6842
La	^{139}Cs	-0.2558
	^{139}Ba	-0.8651

Denissenkov, et al, MNRAS (2019)

Neutron Captures

- Direct measurement of (n,γ) reactions on short-lived isotopes: challenging
- Indirect techniques to provide constraints



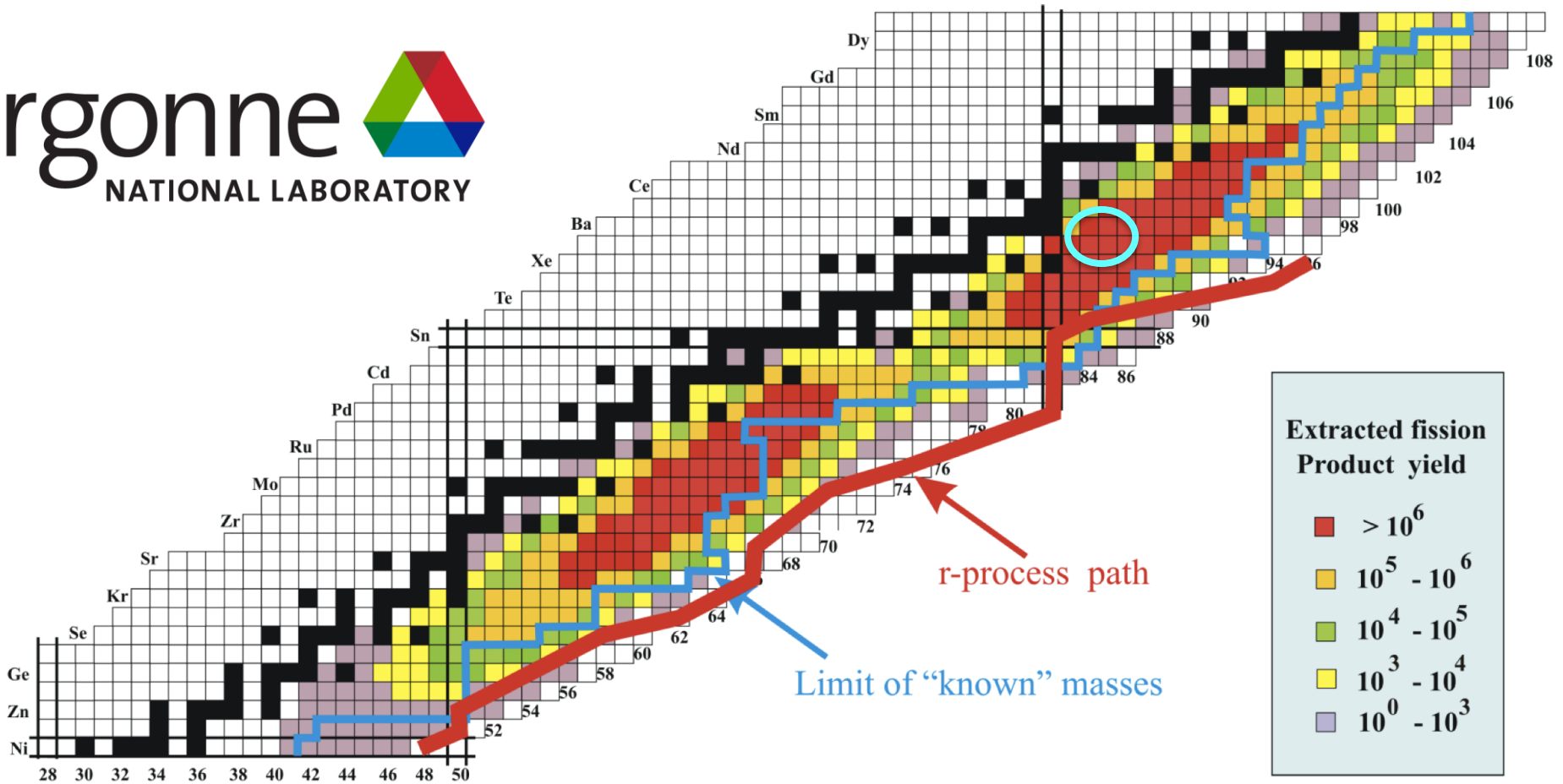
Muecher et al, submitted (2022)

Larsen et al, PPNP 107 (2019) 69

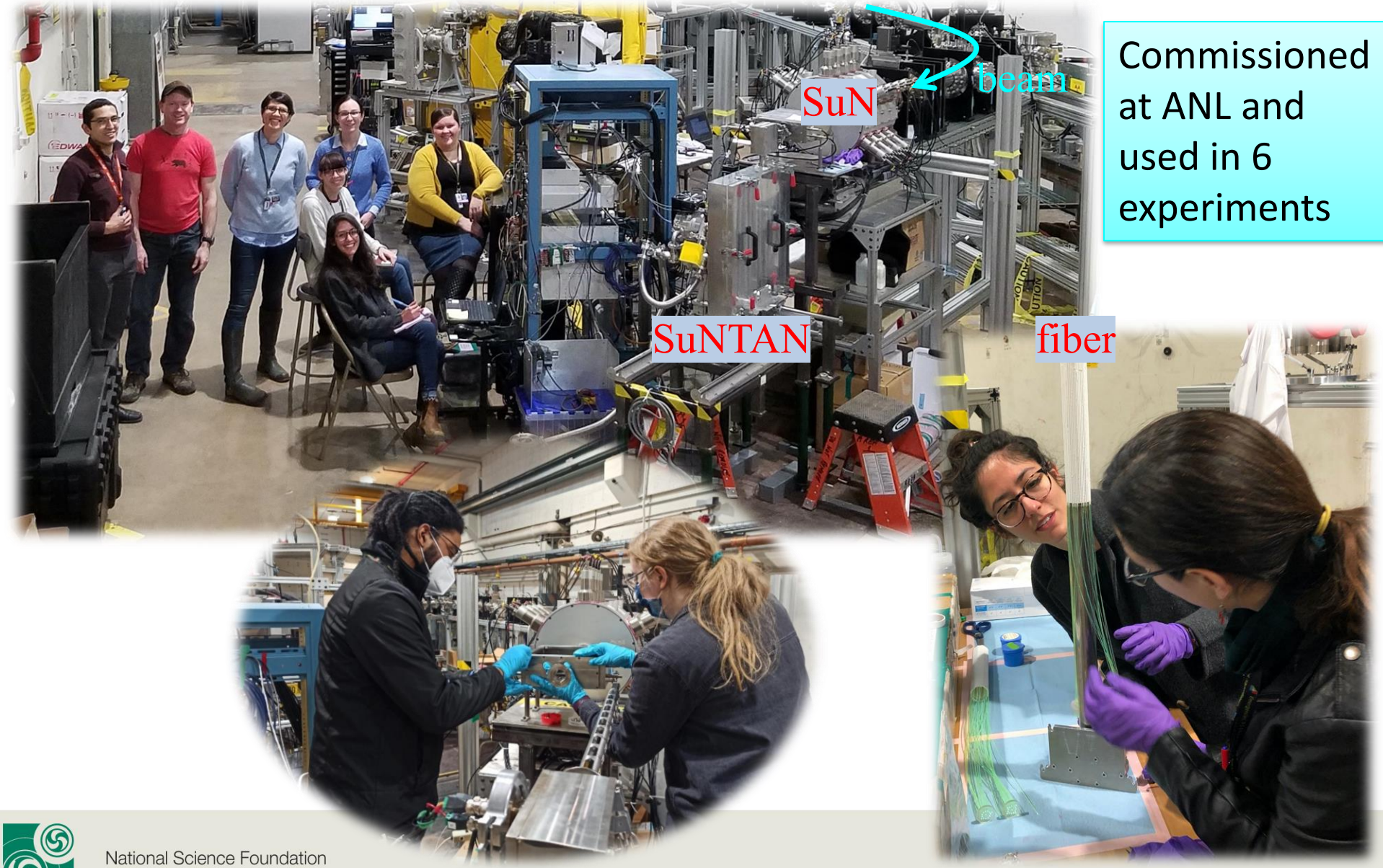
Spyrou, Liddick, et. al., PRL 2014

^{252}Cf spontaneous fission yield from 1 Ci source

Argonne NATIONAL LABORATORY

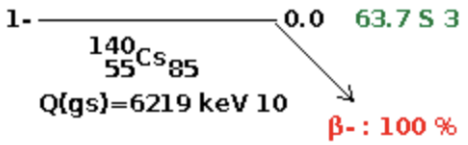


SuN at ANL



Commissioned at ANL and used in 6 experiments

^{140}Cs – β decay – Oslo + Shape methods

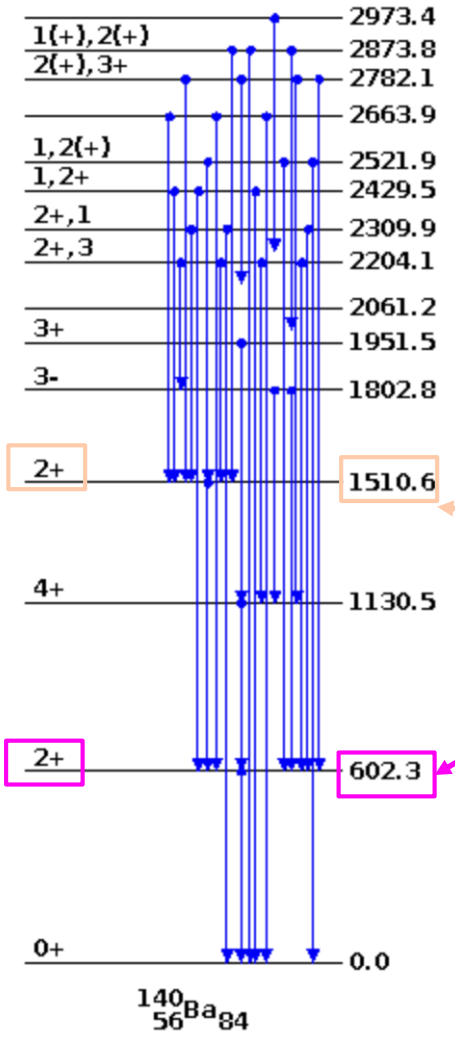


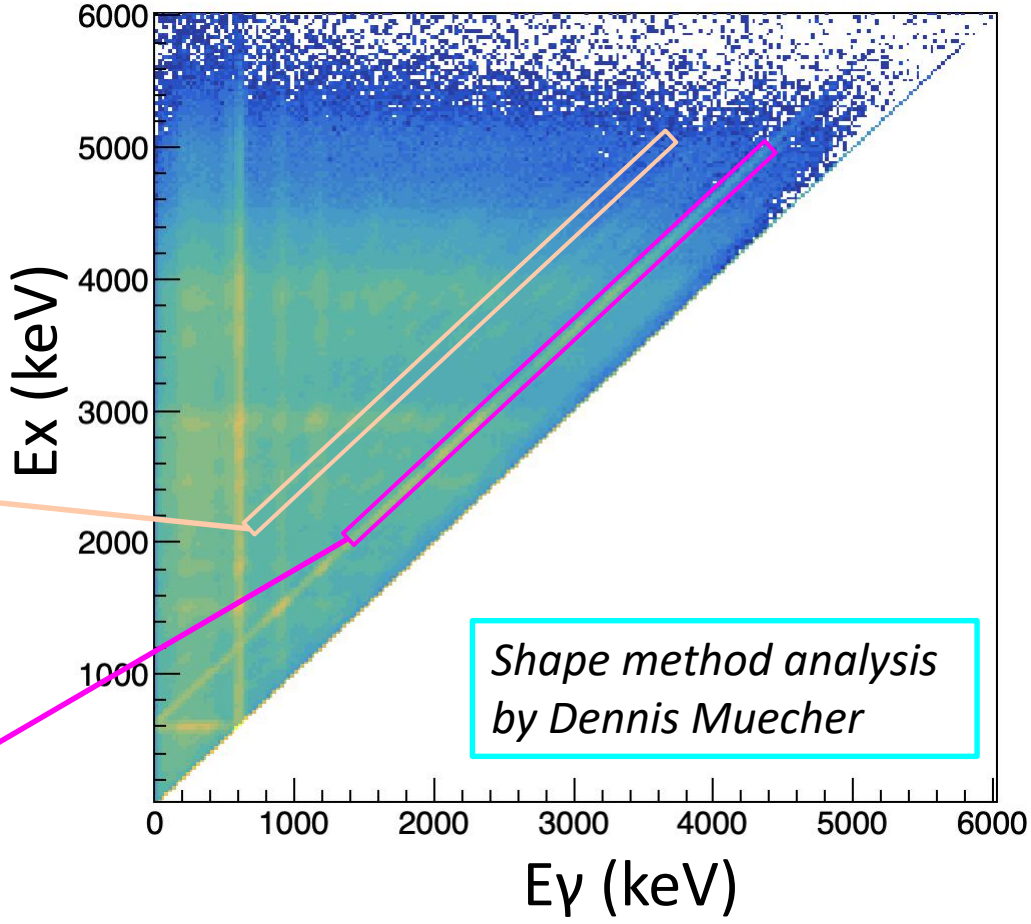
$Q_\beta(^{140}Cs)$ = 6.2 MeV

$S_n(^{140}Ba)$= 6.4 MeV

$T_{1/2}(^{140}Cs)$ = 63.7 s

$T_{1/2}(^{140}Ba)$ = 12.7 d

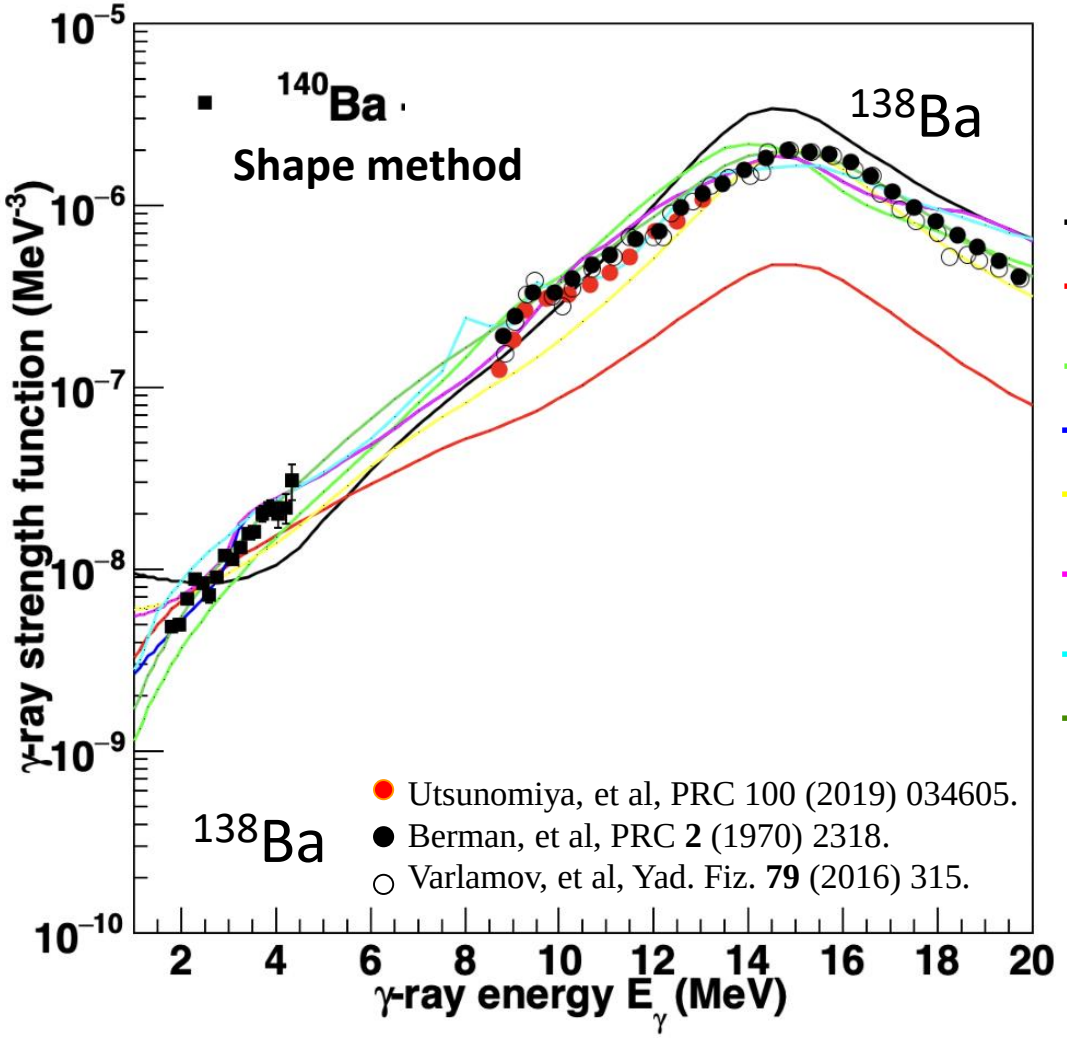




Shape method analysis by Dennis Muecher

Wiedeking et al, PRC 2021
Muecher, Spyrou et al, submitted 2022

Shape method - γSF



γSF models available in TALYS

- Strength 1: Kopecky-Uhl generalized Lorentzian
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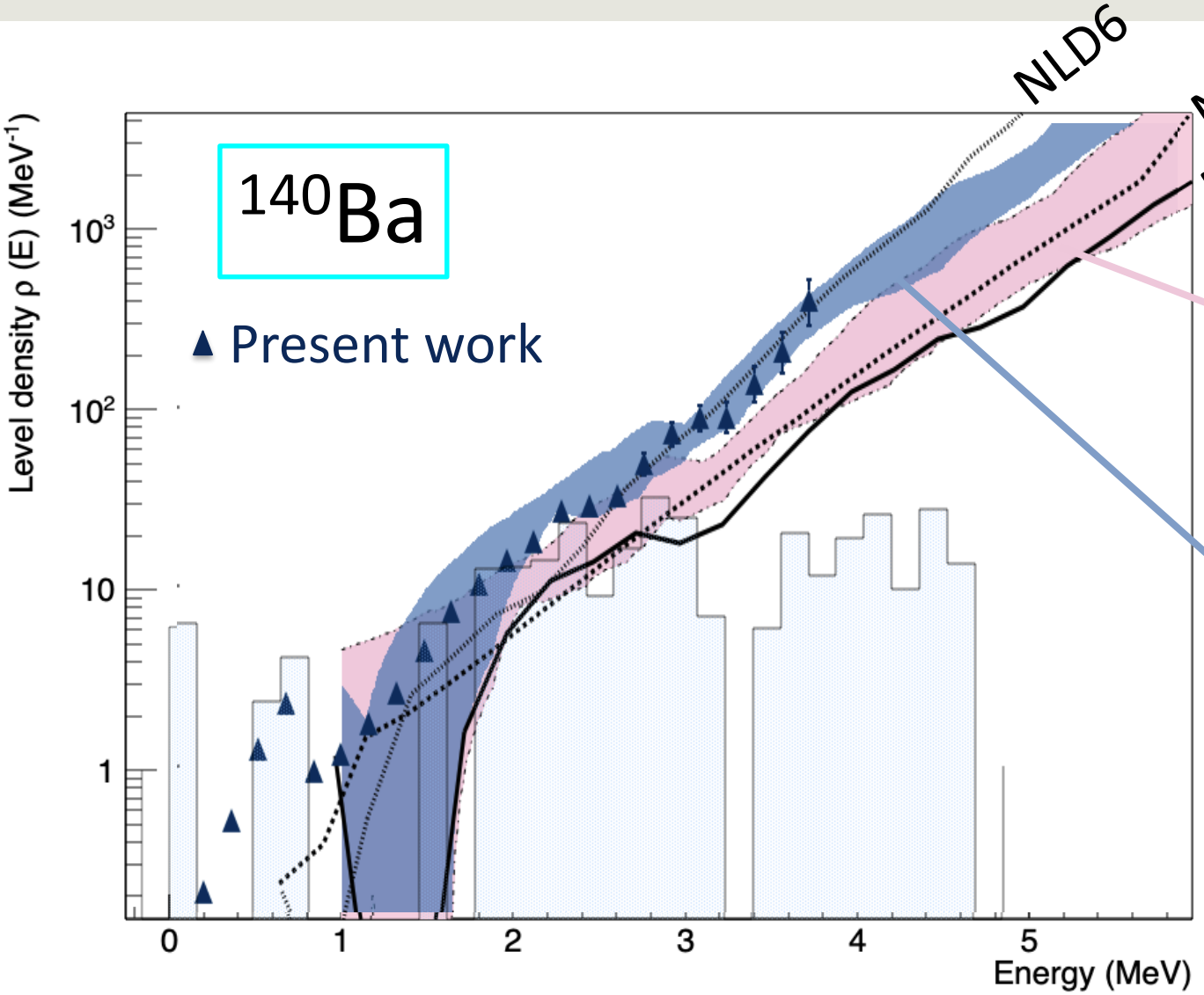
- Strength 6: Goriely's T-dependent HFB
- Strength 7: T-dependent RMF
- Strength 8: Gogny D1M HFB+QRPA

Nuclear Level Density



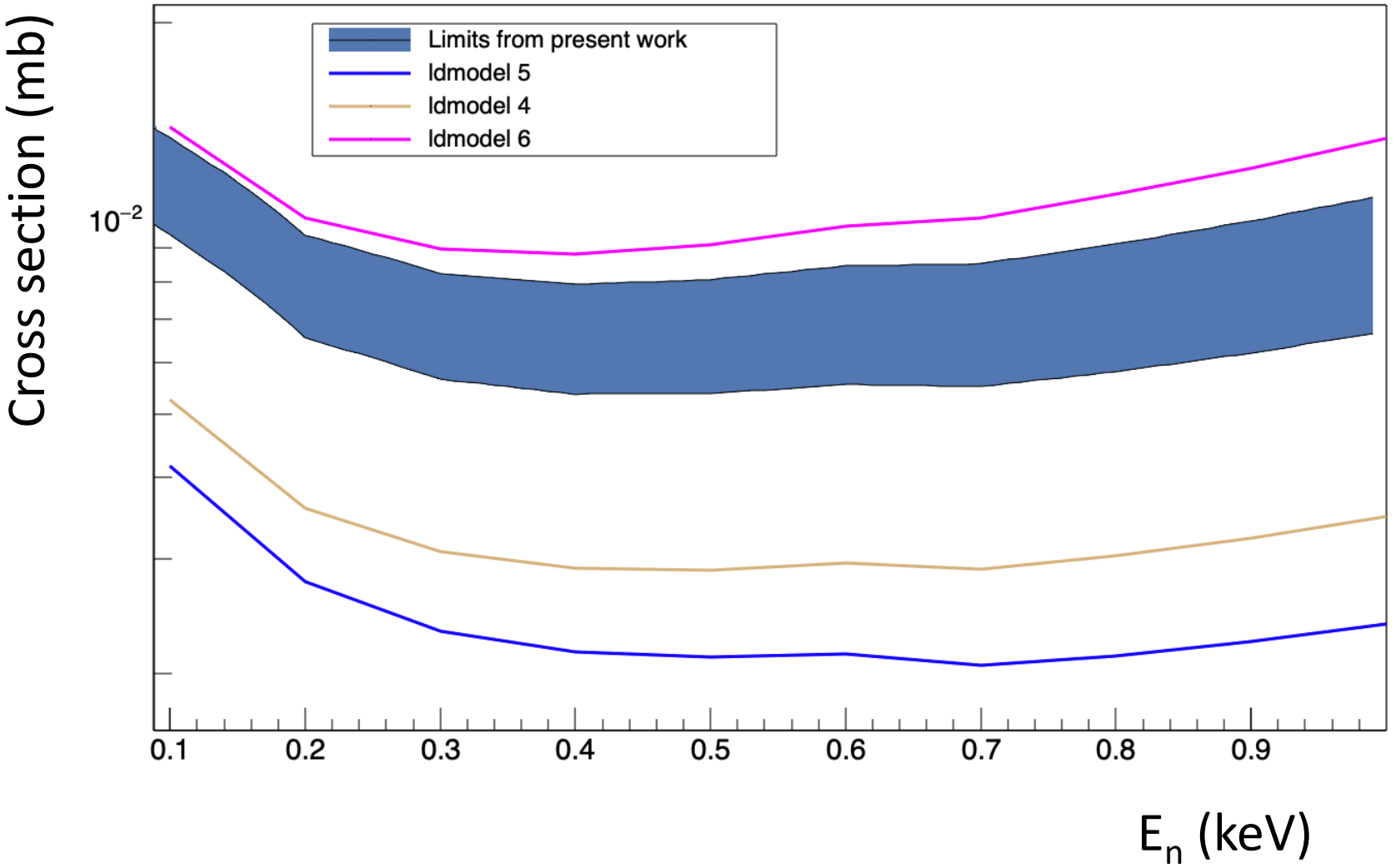
Semi-microscopic models

Fit to discrete levels

Fit to our data using NLD5

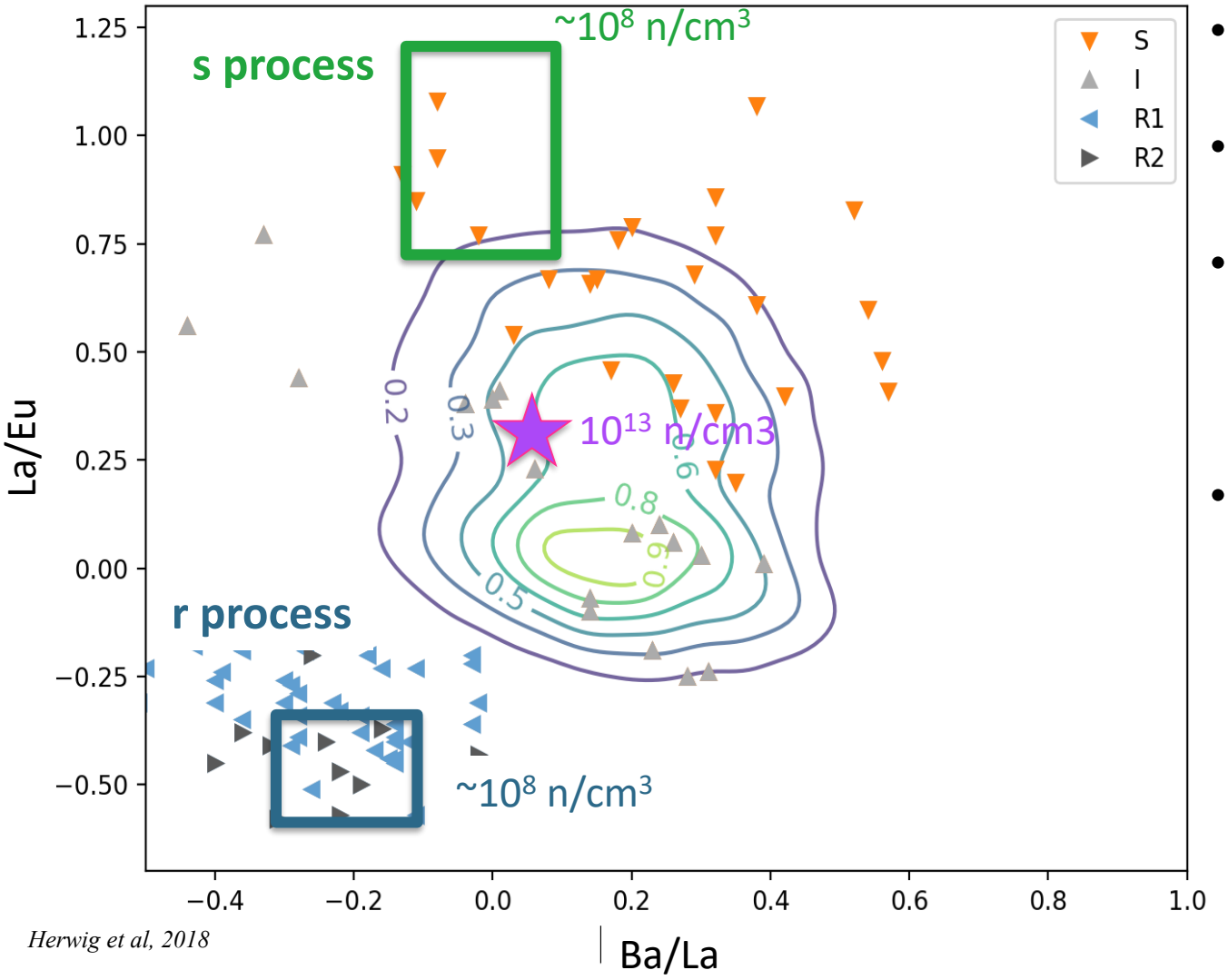
Goriely et al, 2001
Goriely et al 2008
Hillaire et al 2012

Cross Section



TALYS

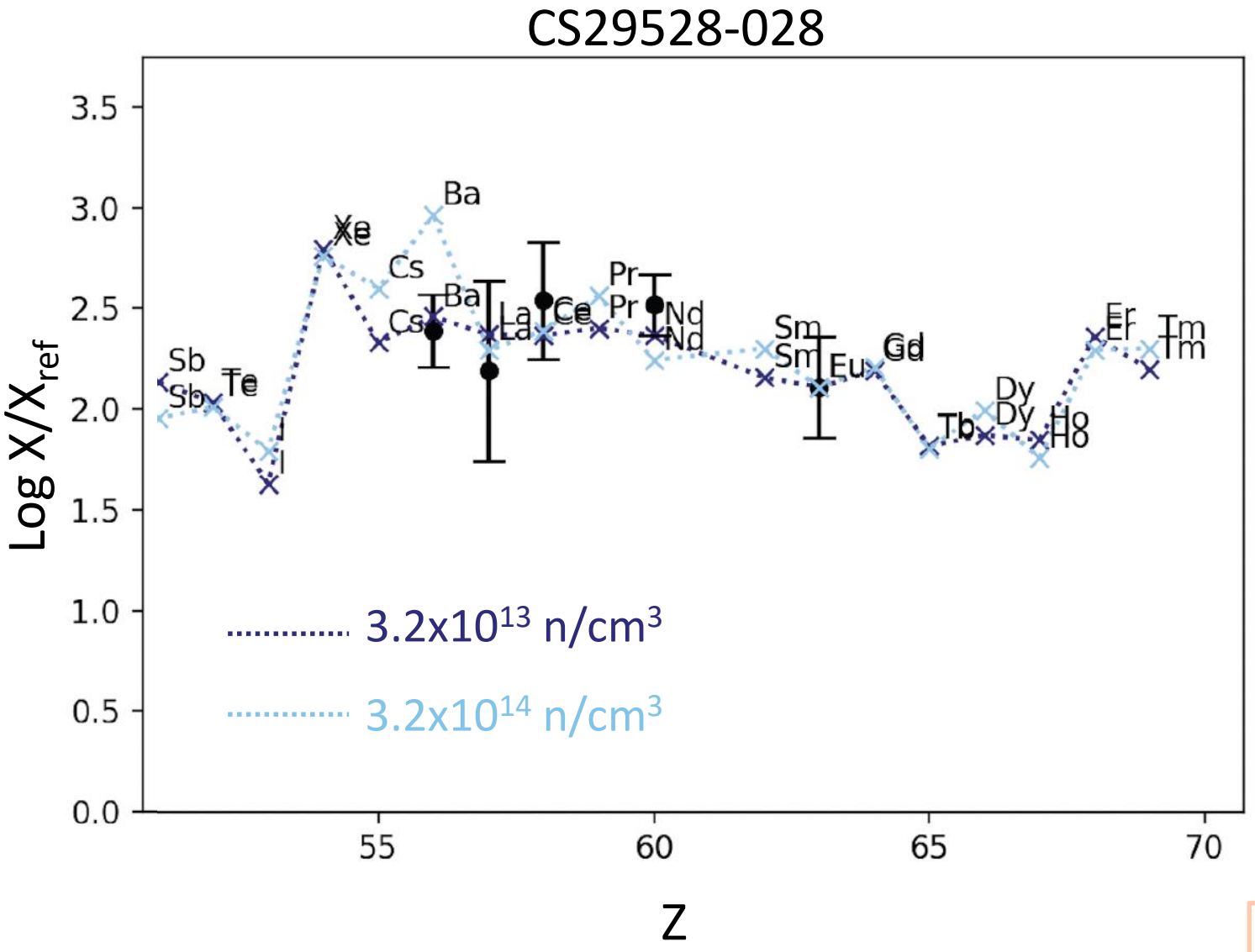
Sensitivity to neutron-capture rates



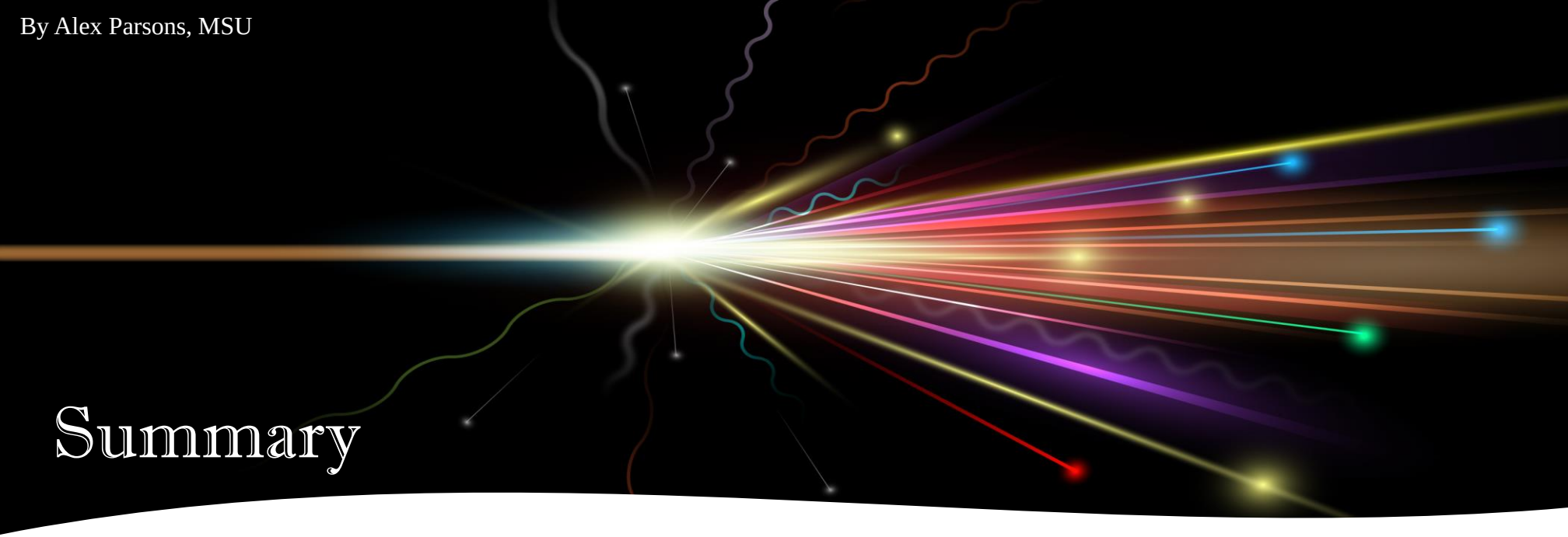
Herwig et al, 2018

- Constraints on the $^{139}Ba(n,\gamma)^{140}Ba$
- Uncertainties in 10^{13} n/cm^3 greatly reduced
- Verified that within the specific model, 10^{13}n/cm^3 is a viable neutron density to reproduce observations
- Can be used to identify conditions that could reproduce specific stars

Single-star comparisons



Denissenkov



Summary

- Studies of the astrophysical i process
- Neutron-capture reactions are the main nuclear uncertainty
- Used Shape and Oslo methods to constrain the reaction

  $^{139}Ba(n,\gamma)^{140}Ba$: main uncertainty at neutron densities 10^{13} n/cm^3
- Single reaction used to determine astrophysical conditions

Collaboration

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M. K. Smith
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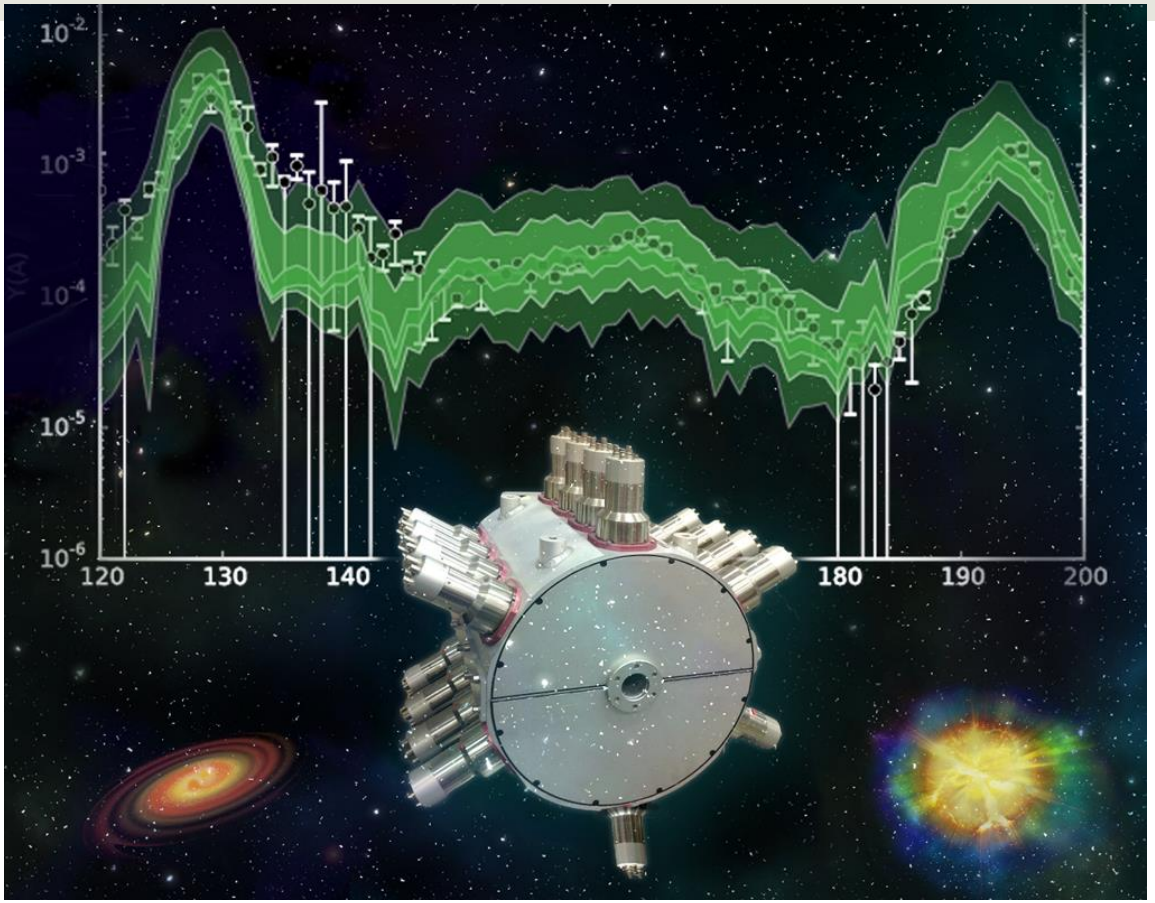

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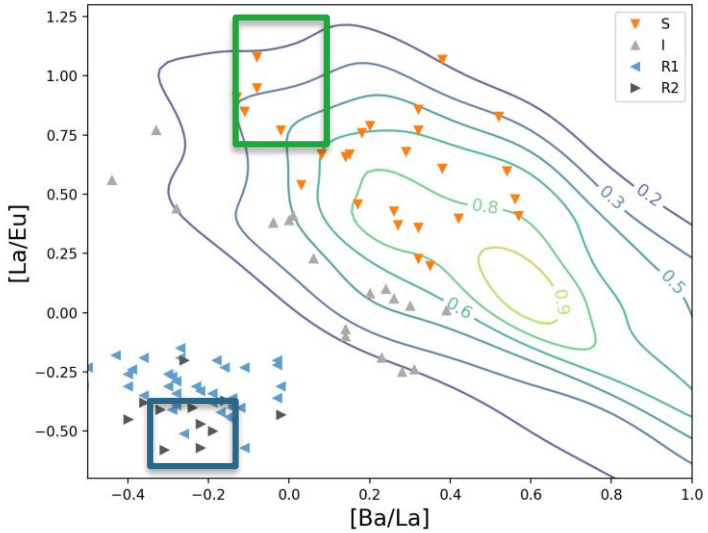
University of Cologne

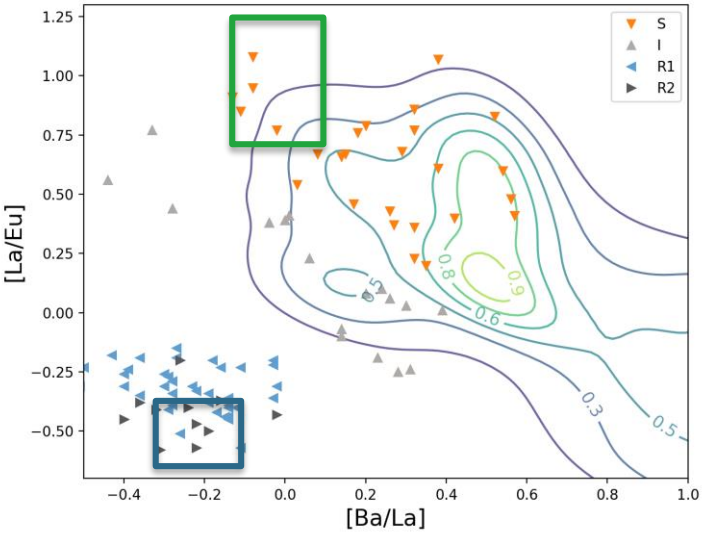
NSCL FRIB
U.S. Department of Energy Office of Science
National Science Foundation
Michigan State University

Future Plans

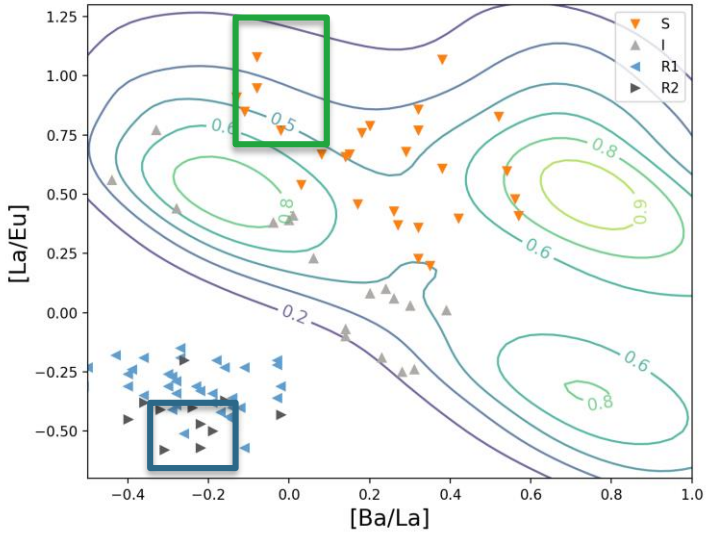
All (n,γ) reactions

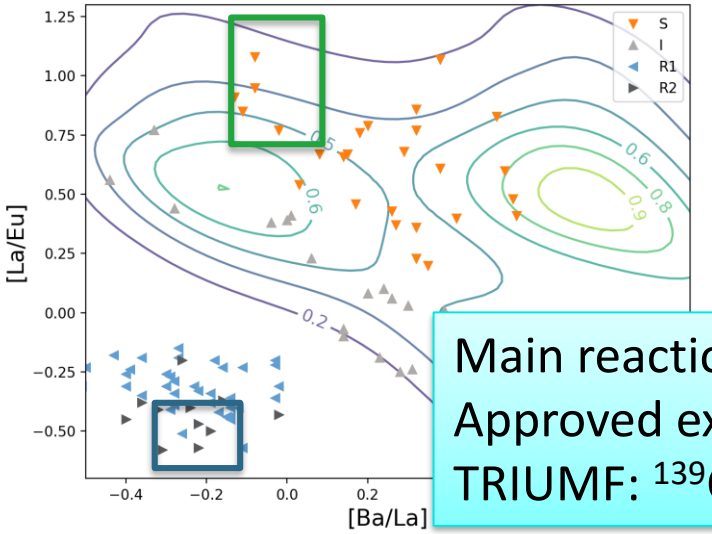
Experimental ^{139}Ba(n,γ)^{140}Ba





10^{14} n/cm3





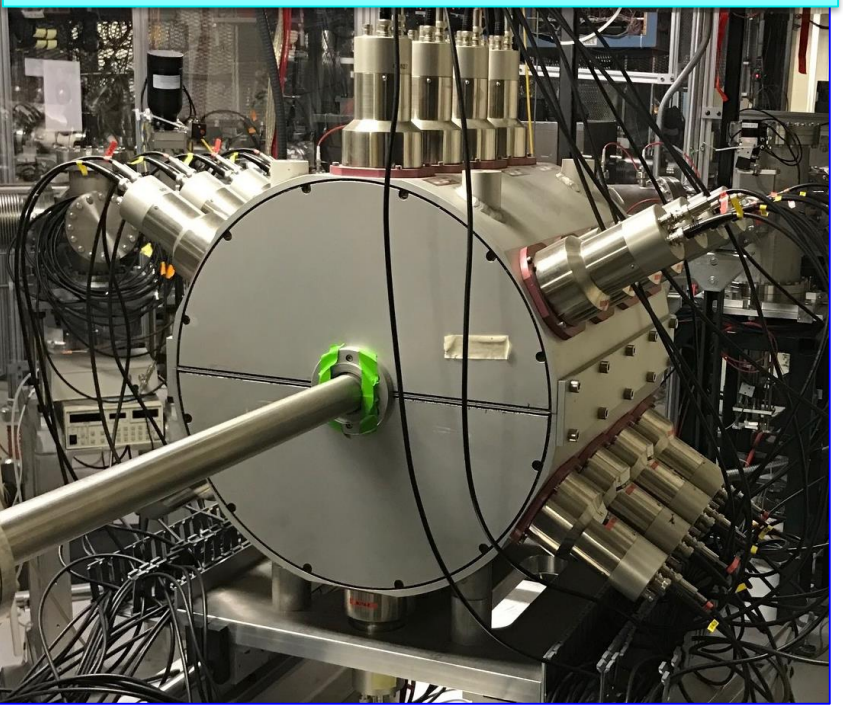
10^{15} n/cm3

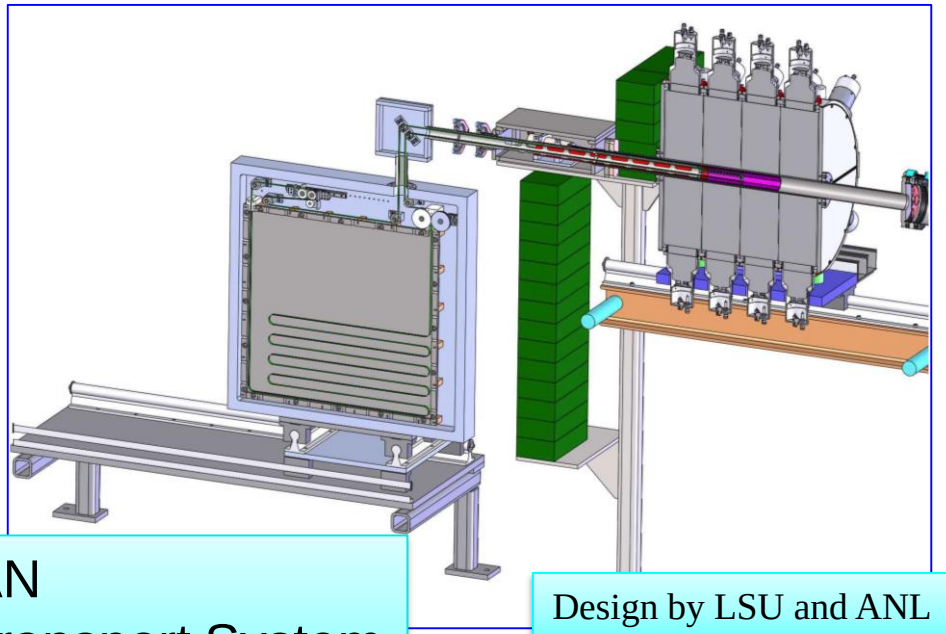
Main reaction: ^{139}Cs(n,γ)^{140}Cs

Approved experiment at TRIUMF: ^{139}Cs(d,p)^{140}Cs

Summing NaI – SuN and friends

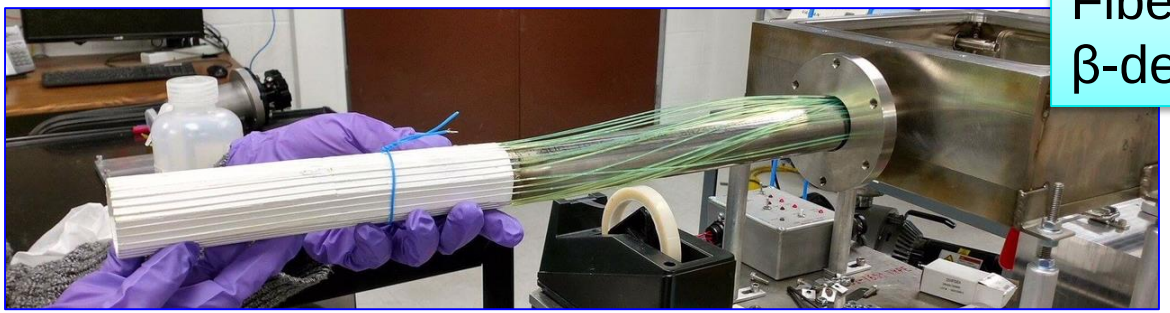
SuN
γ-Total Absorption Spectrometer





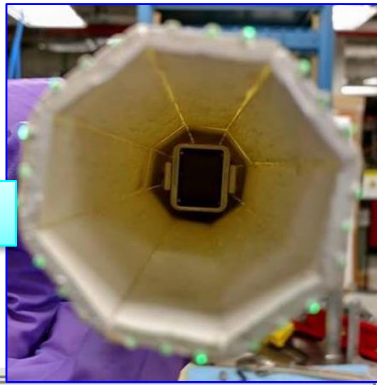
SuNTAN
Tape Transport System

Design by LSU and ANL



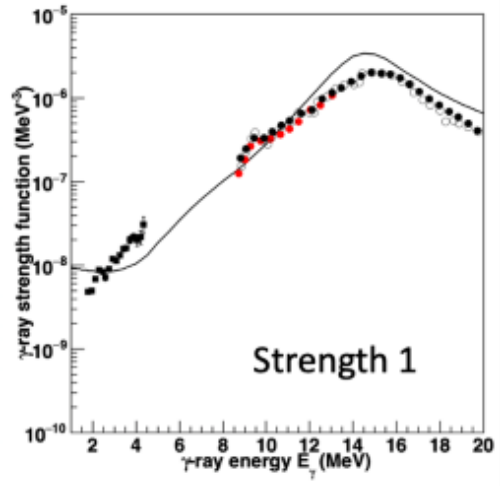
Fiber Detector
β-detection

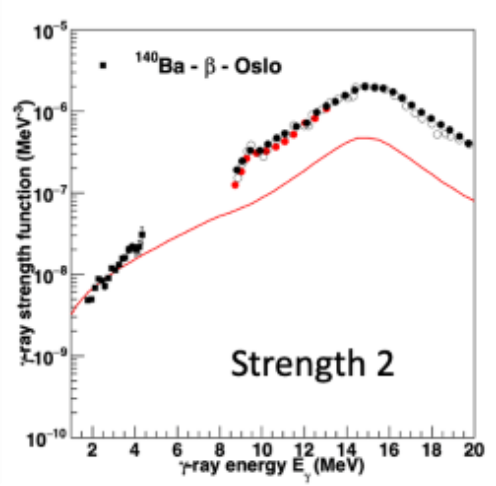
Hope College

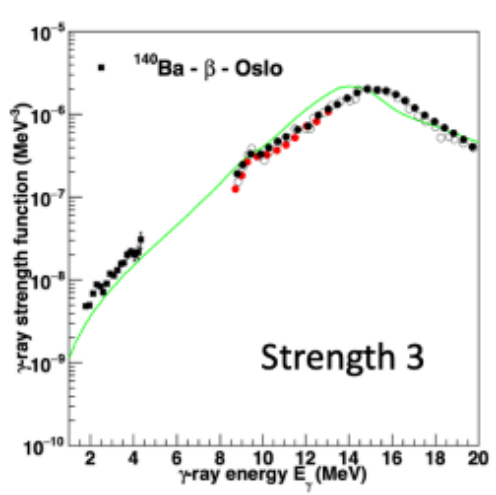


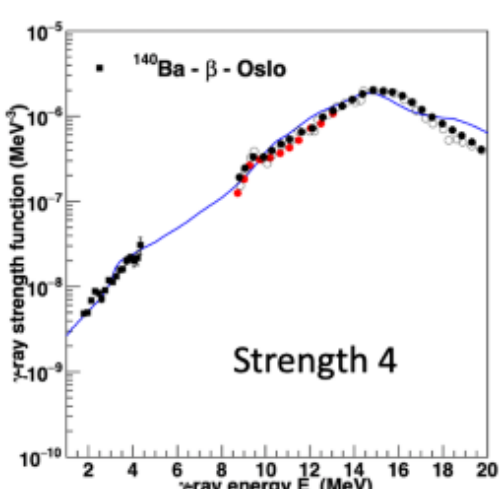
A. Simon, S.J. Quinn, A.S., et al., Nucl. Instr. Meth A 703, 16 (2013)

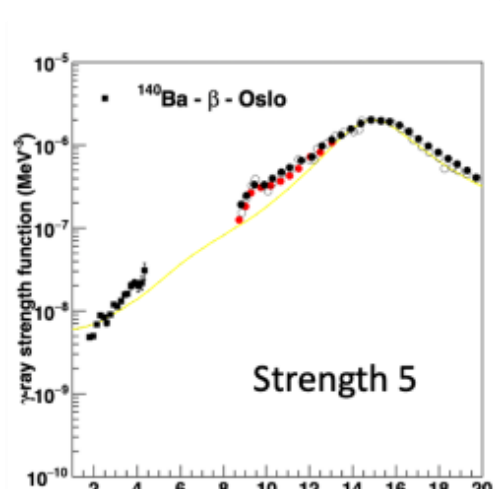
Shape method - γSF

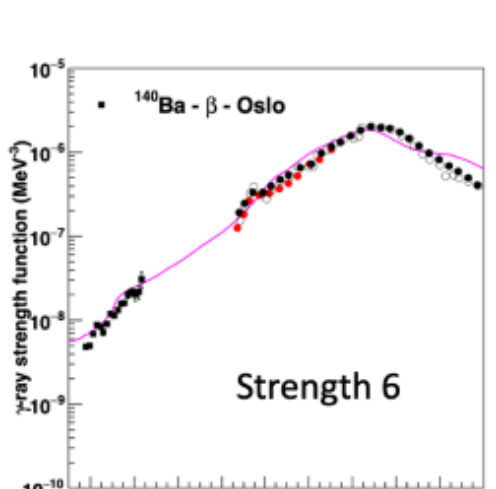


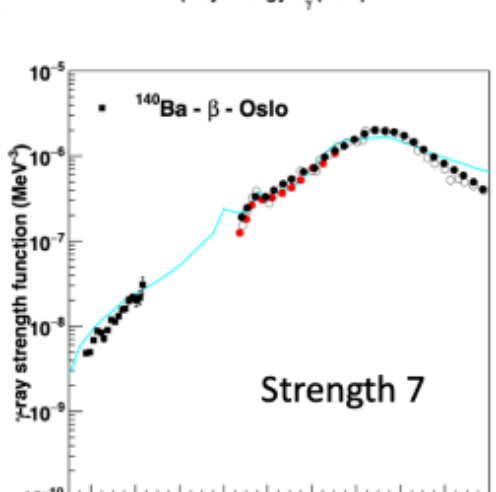


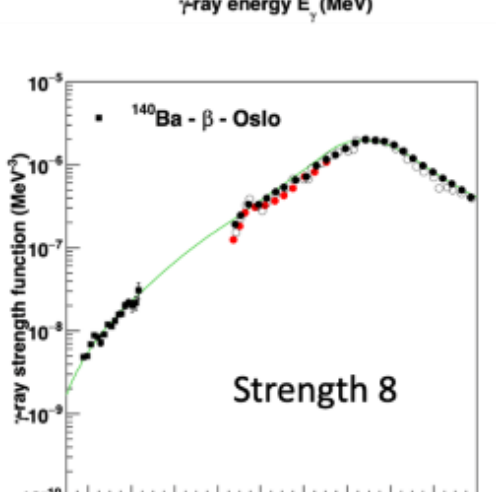




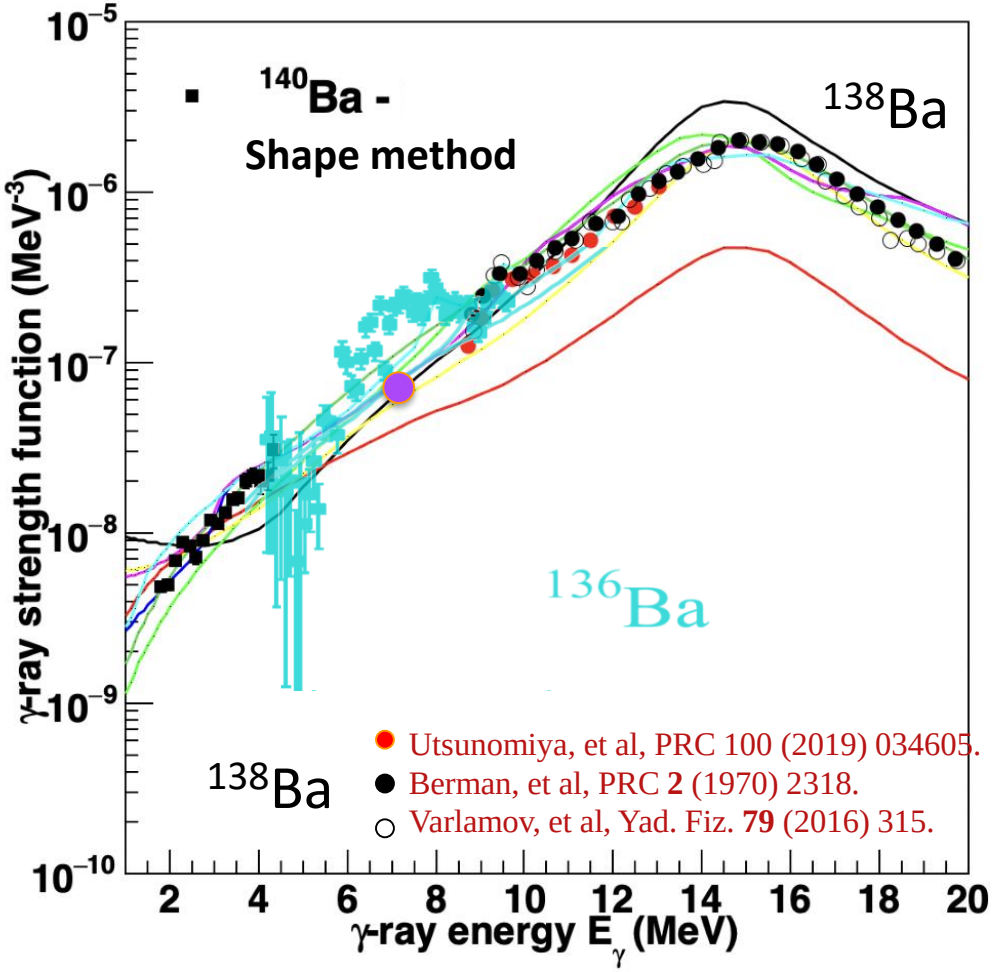








Shape method - γSF



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