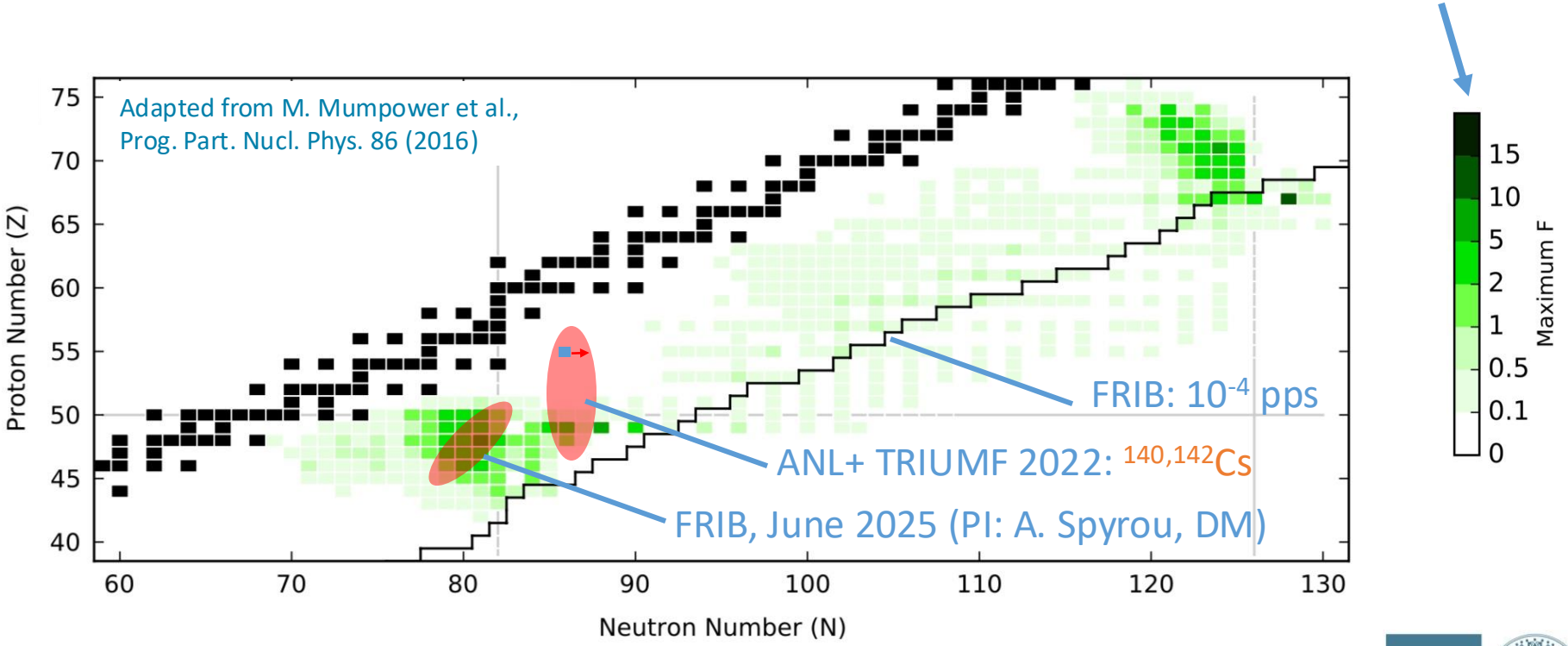
Dennis Mücher (IKP Cologne)

- A. Spyrou, S. Liddick, K. Bosmpotinis, J. Berkman, R. Lubna, S. Uthayakumaar, et. al. (FRIB + MSU)
- A.C. Larssen, M. Guttormsen et al (Oslo)
- M. Wiedeking (LBNL)
- B. Greaves (UoGuelph)
- G. Savard, D. Santiago et. al. (Argonne National Lab.)
- S. Goriely (Univ. Brussels)
- D. Rochman (PSI, Villingen)
- C. Schlaier (IKP Cologne)

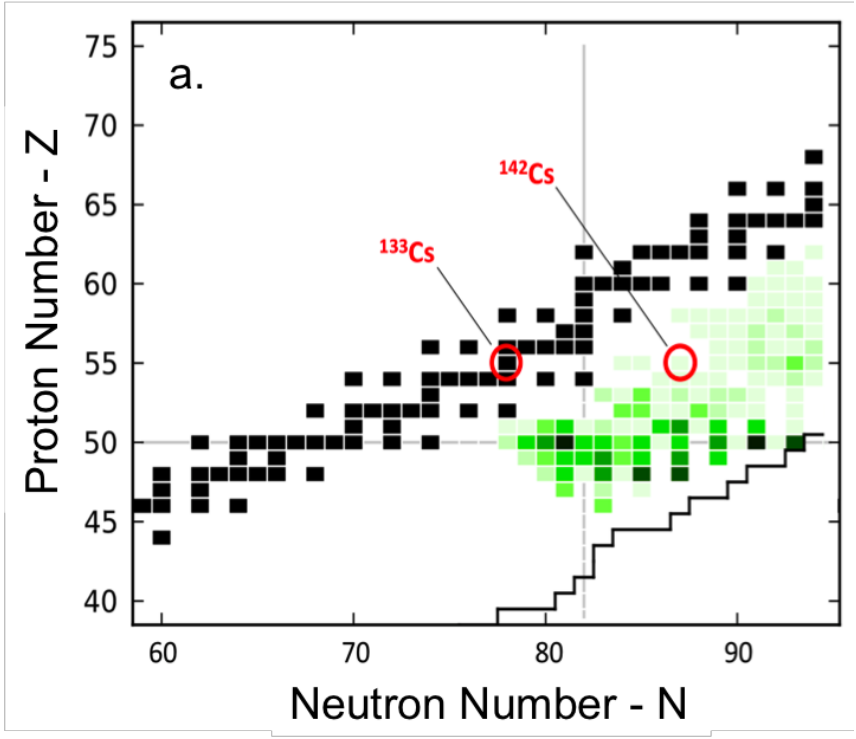
Experimental Neutron Capture Rates for the r Process

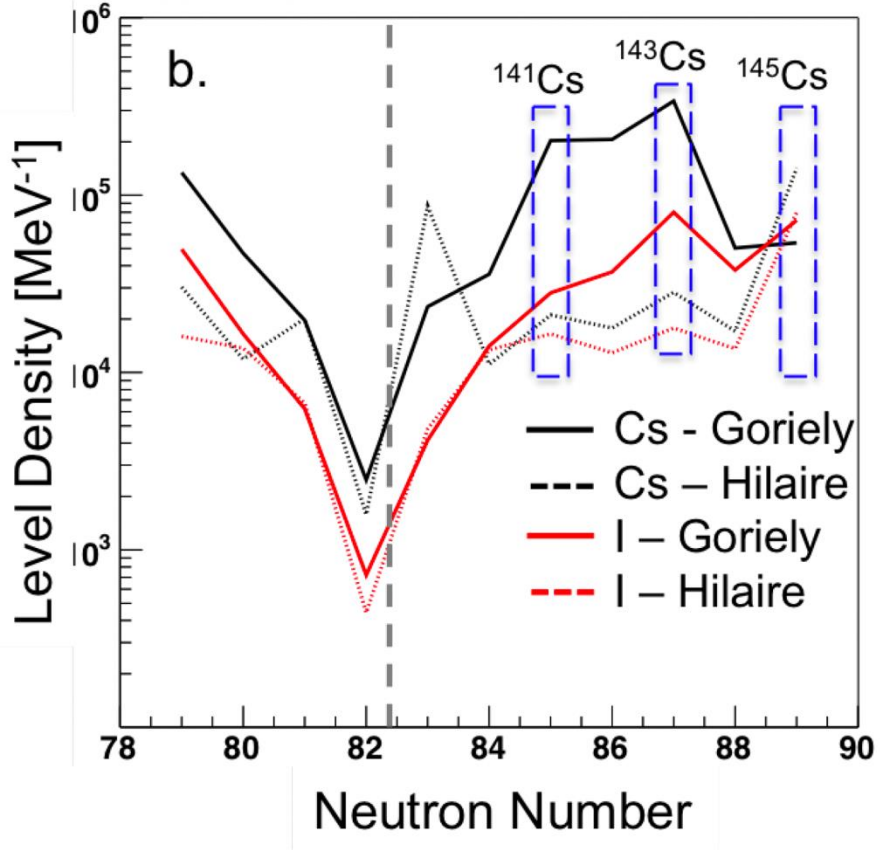
Which Neutron Captures do we want?

Is this realistic?
→ See Stephane's talk



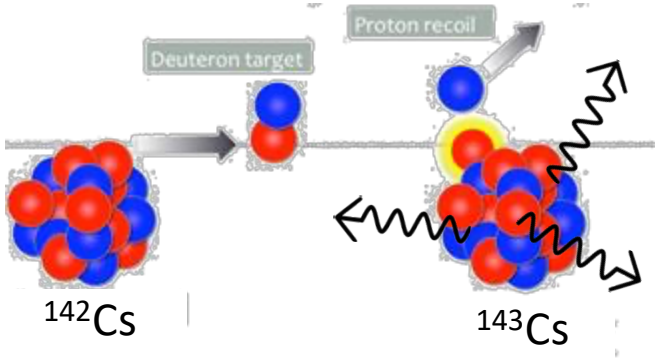
Neutron capture rates in n-rich Cs isotopes (ANL+TRIUMF)



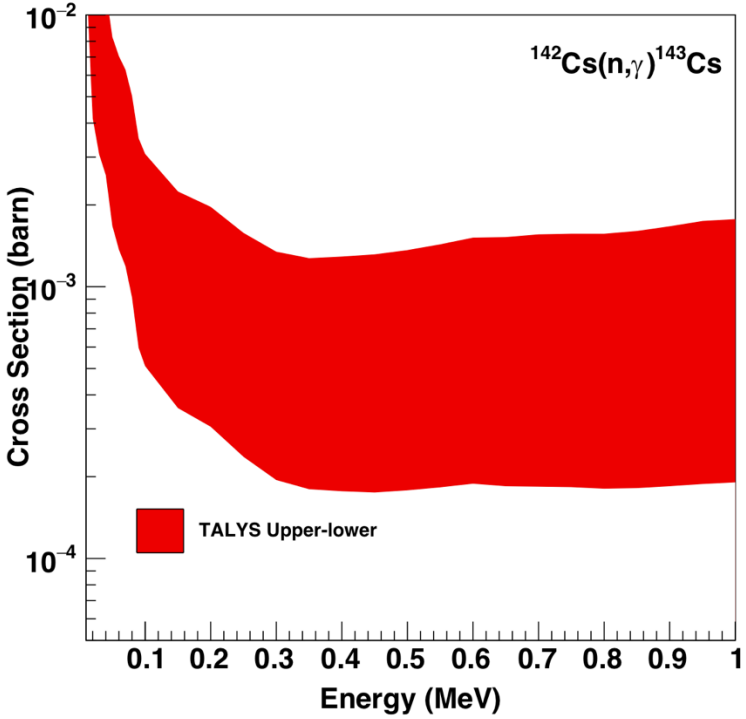


See also talk by Filomena Nunes later today

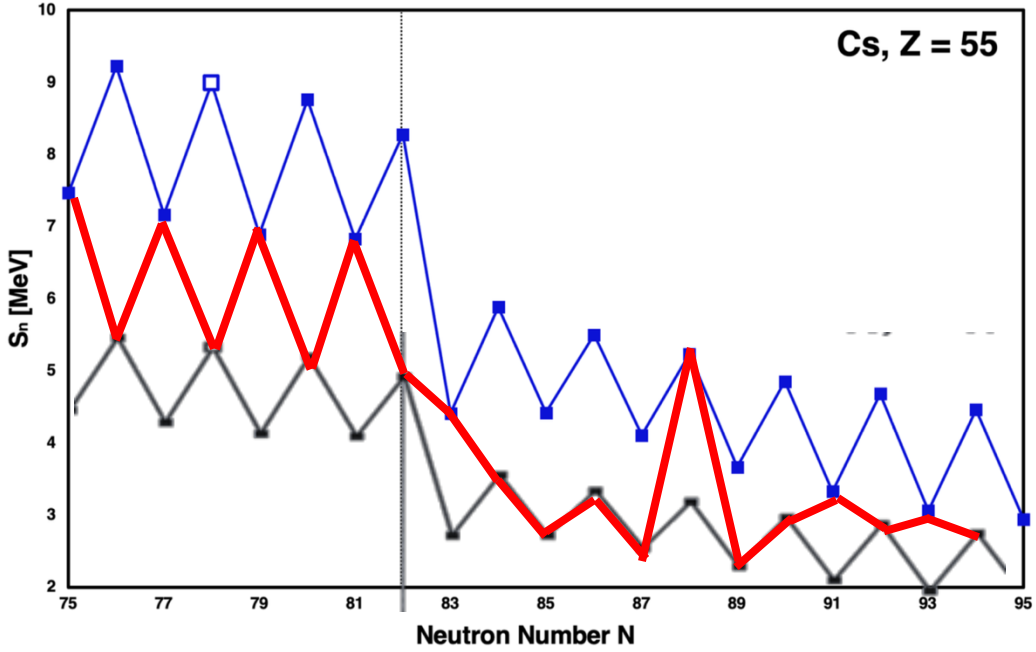
One-neutron transfer reactions (slide from Trento – 2019)



- Shell evolution
- Neutron capture cross sections



Why we shouldn’t do uncorrelated model uncertainties, anymore…



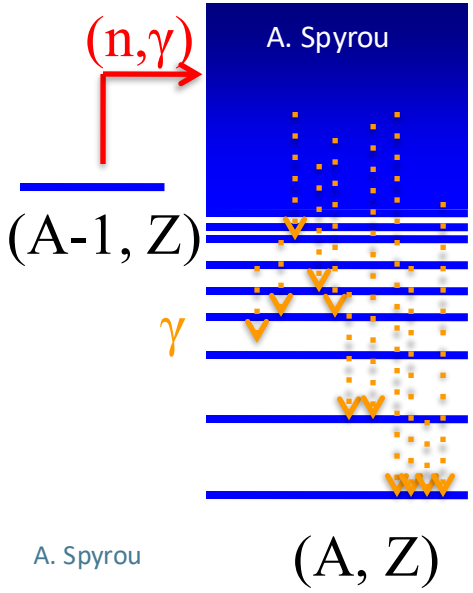
I guess we should

DO

- choose next model
- explore the impact of its parameter uncertainties (uncorrelated), e.g. BFMC
- collect the results

UNTIL Stephane has no more models

Hauser-Feshbach: Statistical Approach to Neutron Captures



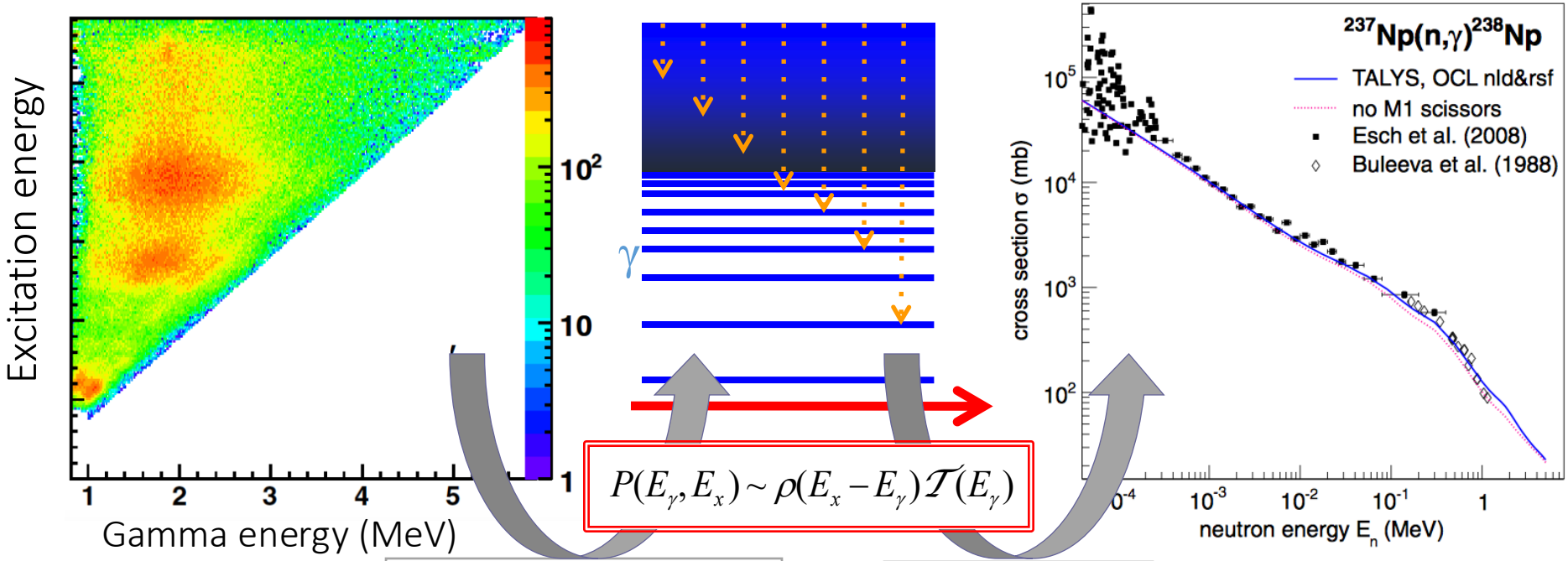
Required input:

- Nuclear Level Density (NLD)
- γ-ray strength function (γSF)
- Optical model potential

+ Direct capture contributions can play a role

- In unstable nuclei the γSF and optical model parameters can in principle be measured or well constrained via inverse kinematics experiment
- First method to directly measure the absolute NLD in short-lived nuclei: "Shape method"

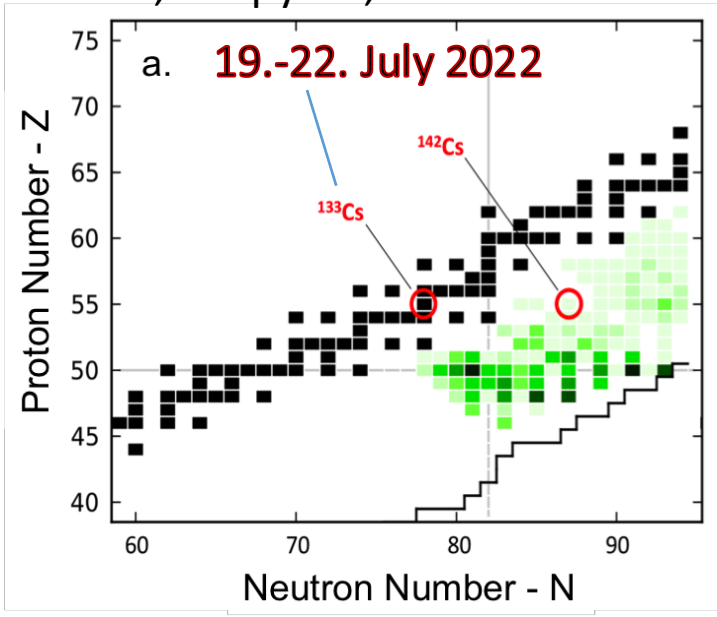
Oslo Method: Constraining neutron capture rates

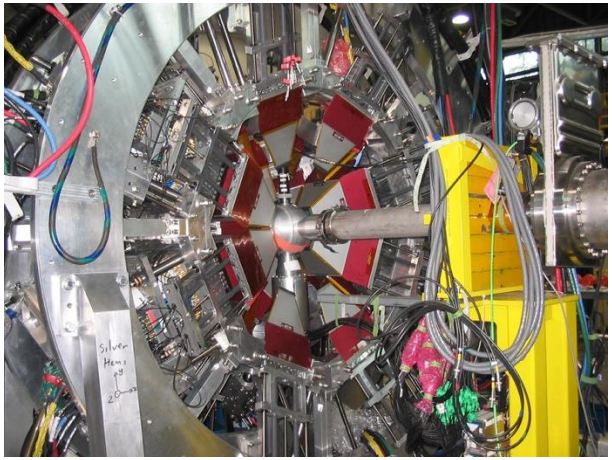


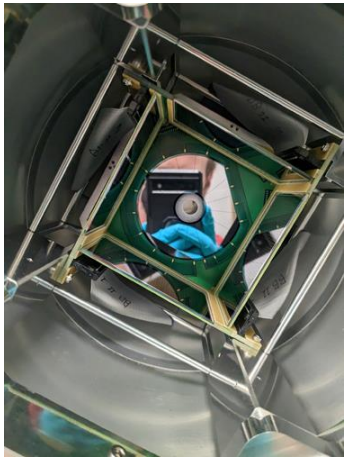
T.G. Tornyi, M. Guttormsen,et al., PRC2014

Reaction-based Oslo in inverse kinematics is hard!

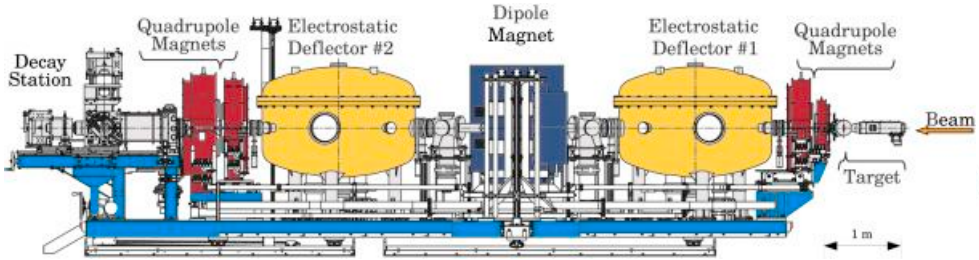
DM, A. Spyrou, I. Dillmann



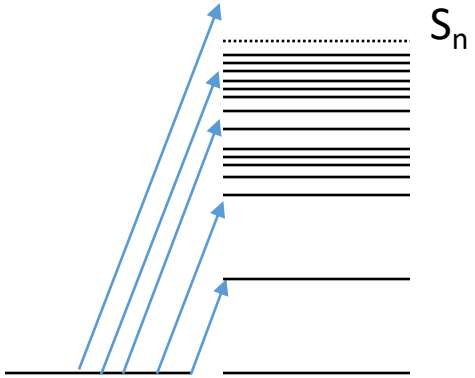




6 MeV/u ^{133}Cs (stable!) on deut. Polyethylen FAILED

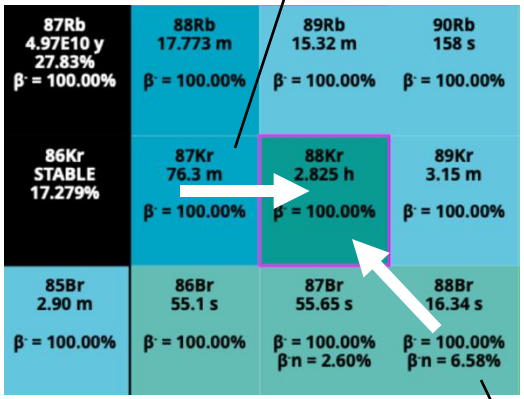


Oslo vs Beta-Oslo

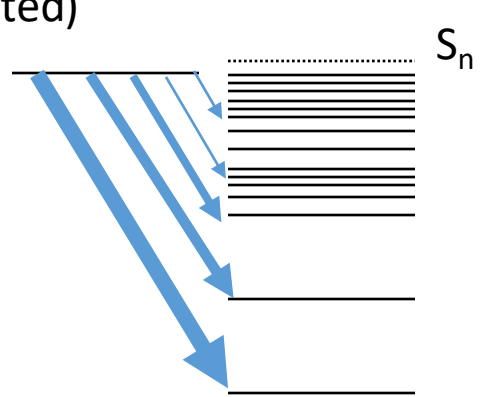


One-neutron transfer (or similar)

3.8· 10^1 pps (reaccelerated)



2.2· 10^3 pps



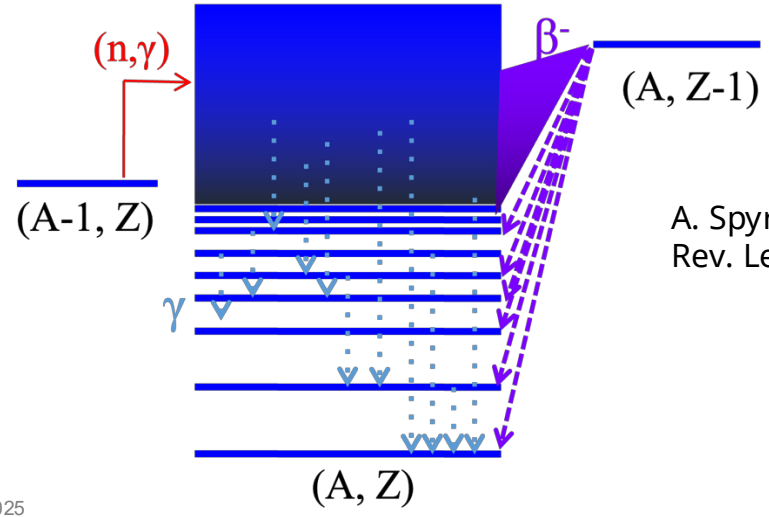
β-decay

- In general, β-Oslo is the (far) more sensitive method in terms of how exotic we can go
- In certain cases, β-Oslo cannot be applied because of Q-value and/or spin restrictions
- It is important to benchmark both methods, **populating the same nucleus**

Constraining (n,γ) Rates for Exotic Nuclei via Beta-Decay

- 1. RIB Beam delivery
  here: ^{60}Mn

- 2. population of compound nucleus via β-decay
  here: ^{60}Mn→^{60}Fe

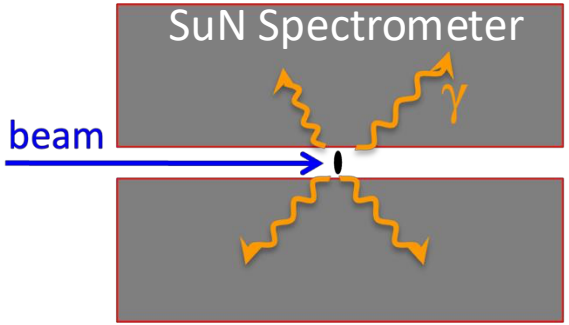


A. Spyrou et. al, Phys. Rev. Lett. **113**, 232502

Constraining (n,γ) Rates for Exotic Nuclei

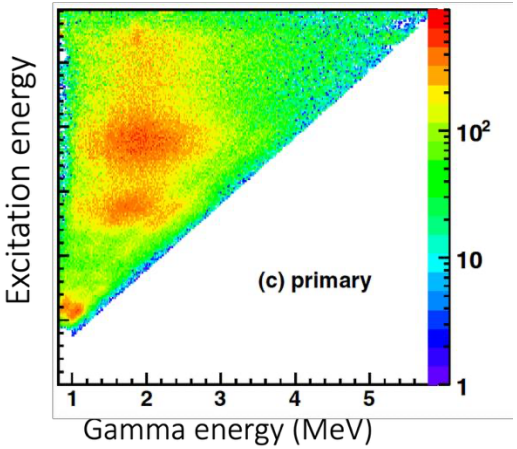
- 3. statistical decay of compound

SuN- Total Absorption Spectrometer: A. Simon et al., NIM B 703 (2013) 16-21

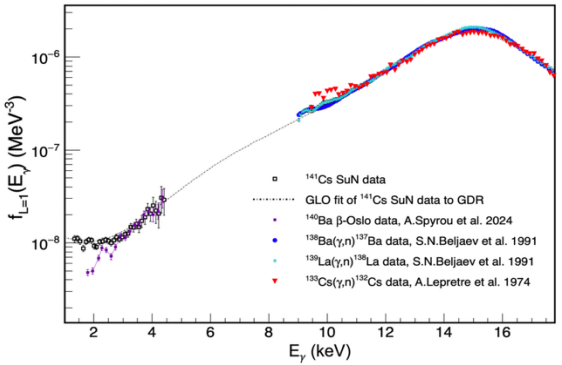


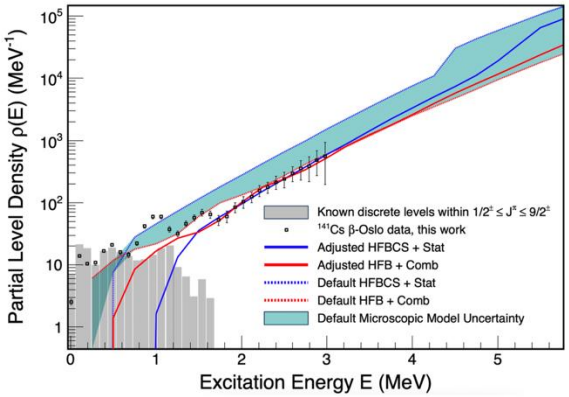
$$E_x = E_{\gamma 1} + E_{\gamma 2} + E_{\gamma 3} + E_{\gamma 4} + \ldots$$

$$P(E_\gamma, E_x) \sim \rho(E_x - E_\gamma)\mathcal{T}(E_\gamma)$$

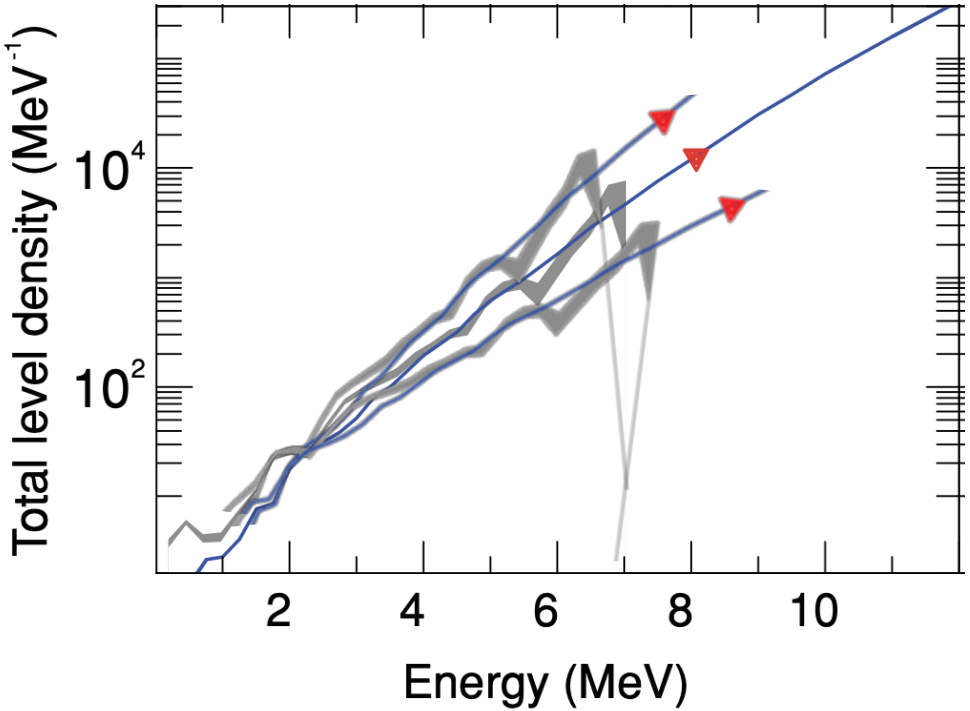


- 4. Extract γSF and NLD





R- Process: Normalizations and the Oslo Method



from discrete levels

$$\tilde{\varrho}(E_i - E_\gamma) = \varrho(E_i - E_\gamma) A \exp(\alpha(E_i - E_\gamma))$$

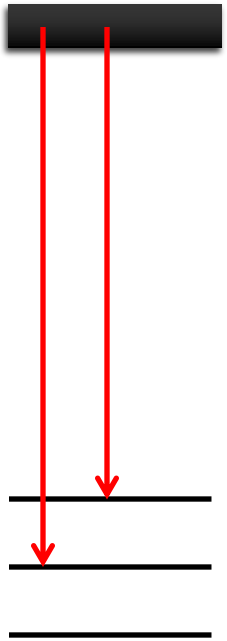
$$\tilde{F}(E_\gamma) = F(E_\gamma) B \exp(\alpha E_\gamma).$$

In exotic nuclei: we don't know D_0

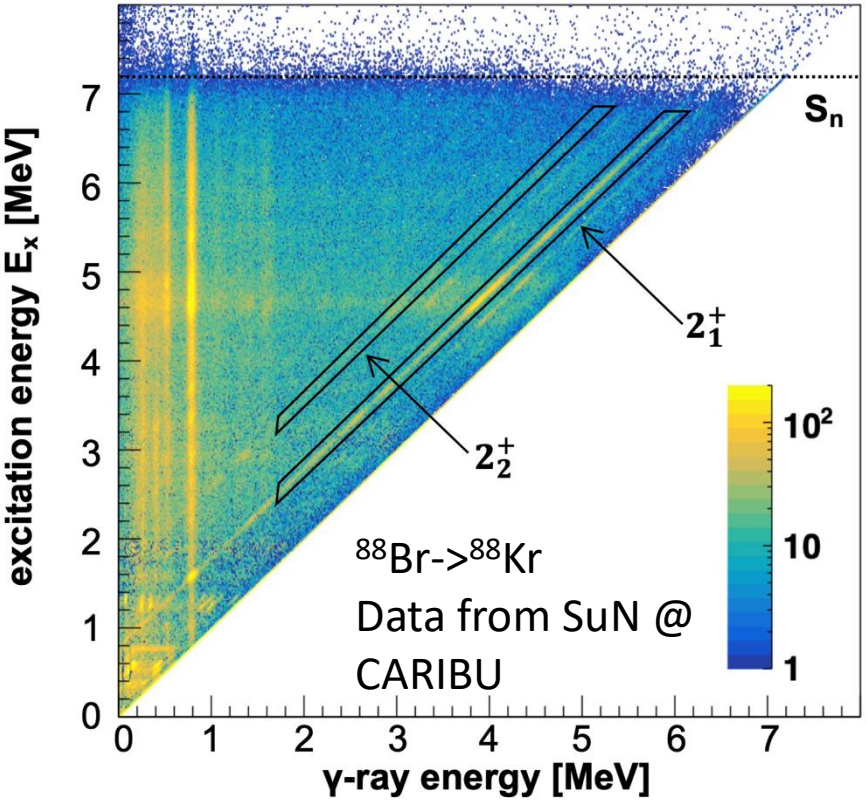
→ We can't determine the "slope" α
→ use level density model to calculate $\rho(Sn)$?

Also: we don't know the absolute gSF strength (i.e. "B")

The Shape Method



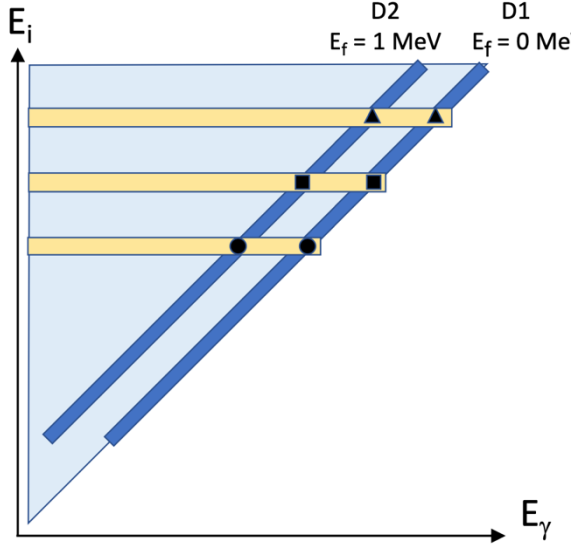
Integration bin with sufficient number of states

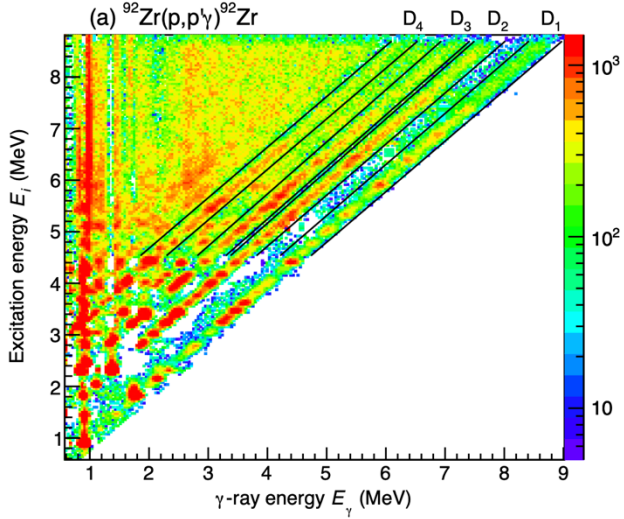


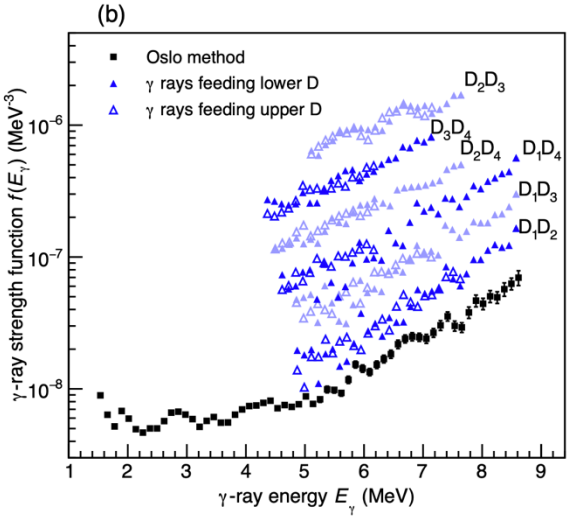
$$R = \frac{f(E_{x,i} - E_{L_1})}{f(E_{x,i} - E_{L_2})} = \frac{N_{L_1}(E_{x,i})(E_{x,i} - E_{L_2})^3}{N_{L_2}(E_{x,i})(E_{x,i} - E_{L_1})^3}$$

The Shape Method

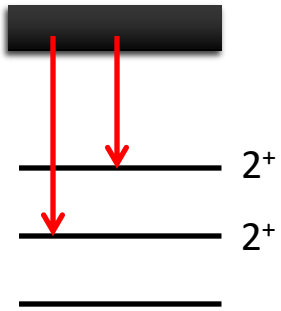
M. Wiedeking, M. Guttormsen, A. C. Larsen, F. Zeiser, A. Görgen, S. N. Liddick, D. Mücher, S. Siem, and A. Spyrou
Phys. Rev. C **104**, 014311 – Published 12 July 2021

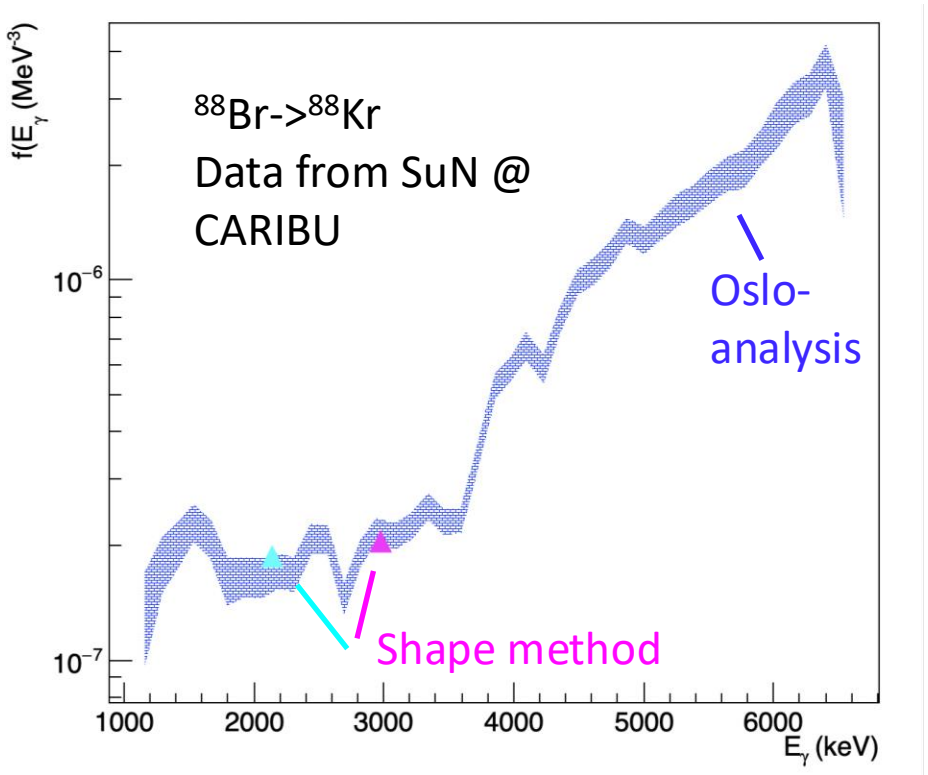




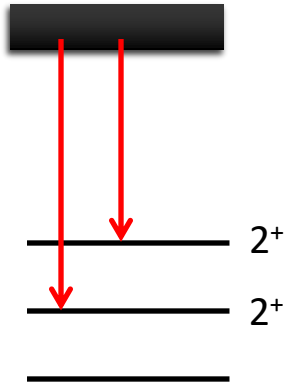


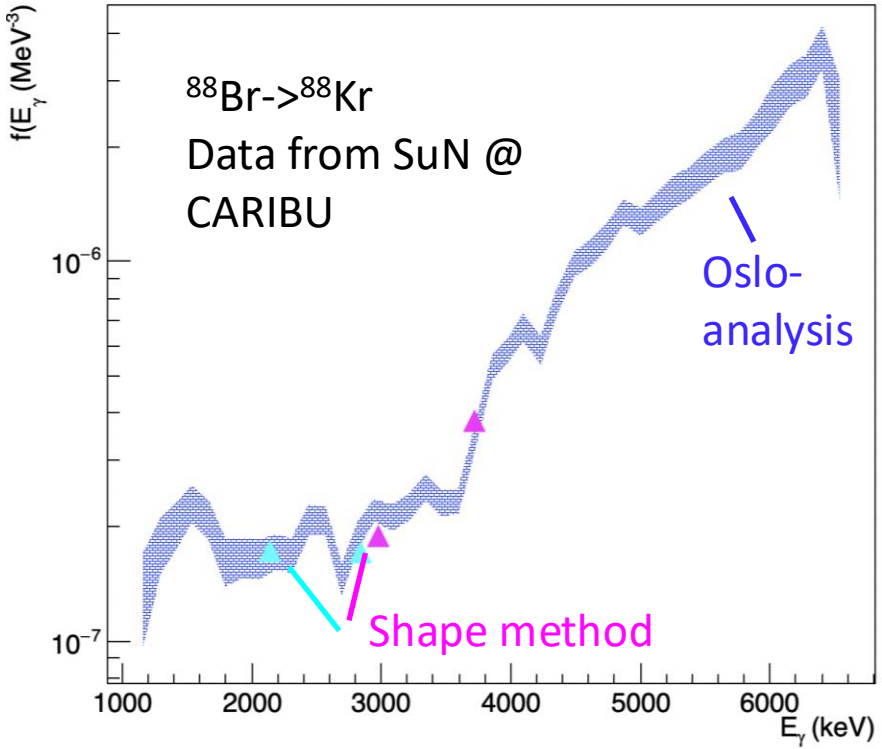
Constraining neutron capture rates



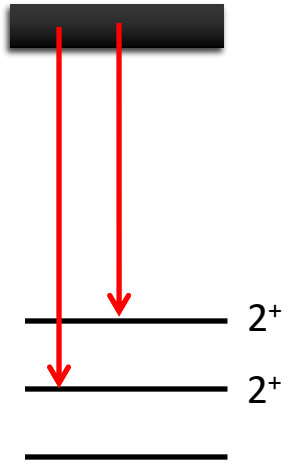


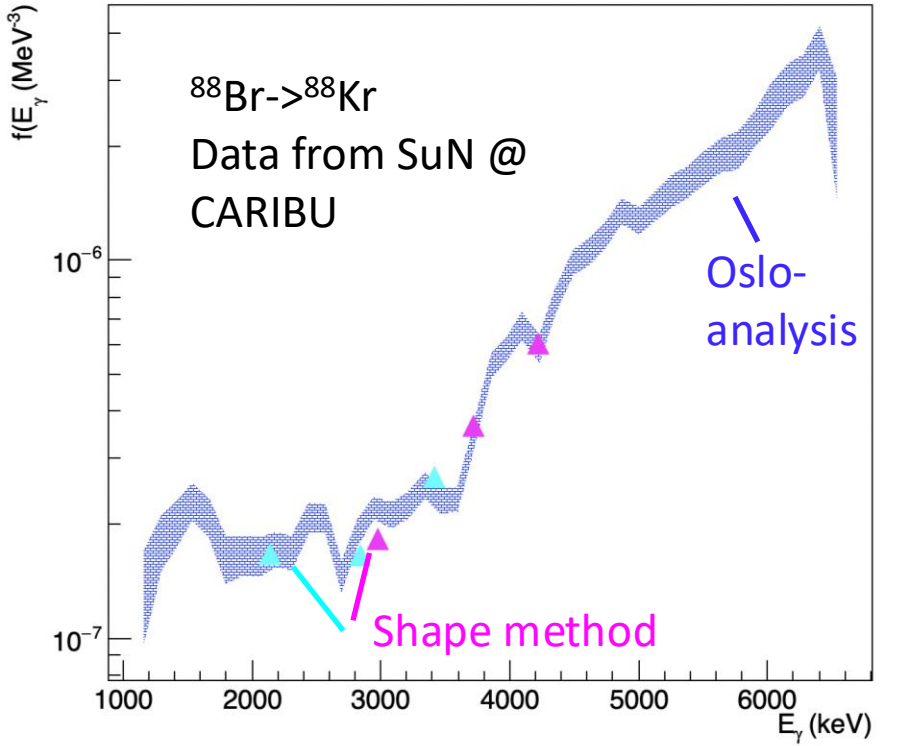
Constraining neutron capture rates



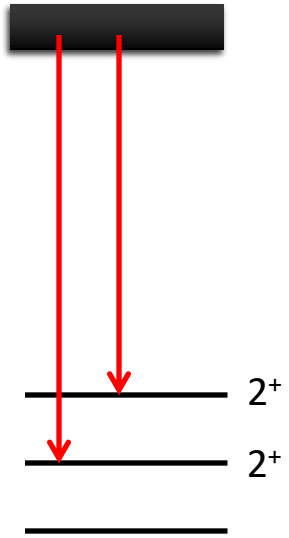


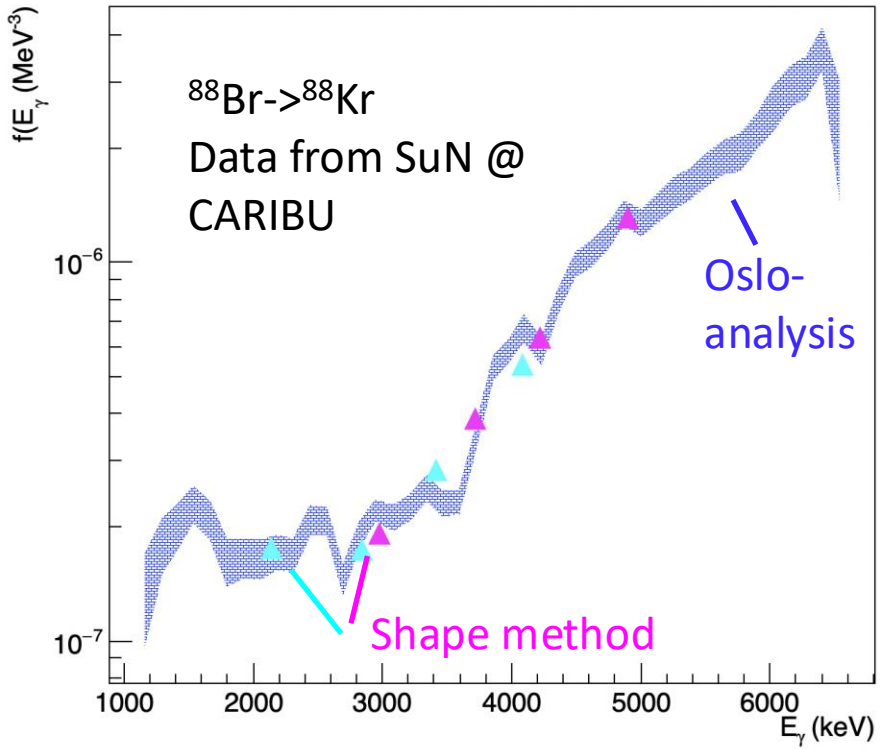
Constraining neutron capture rates



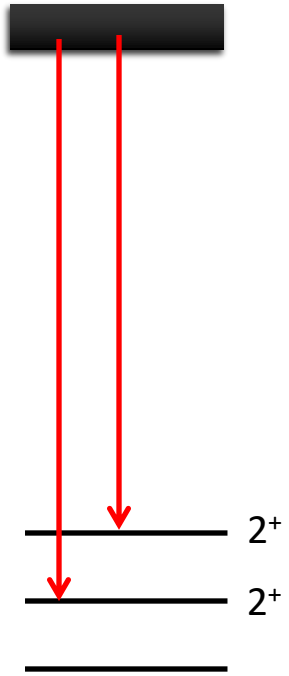


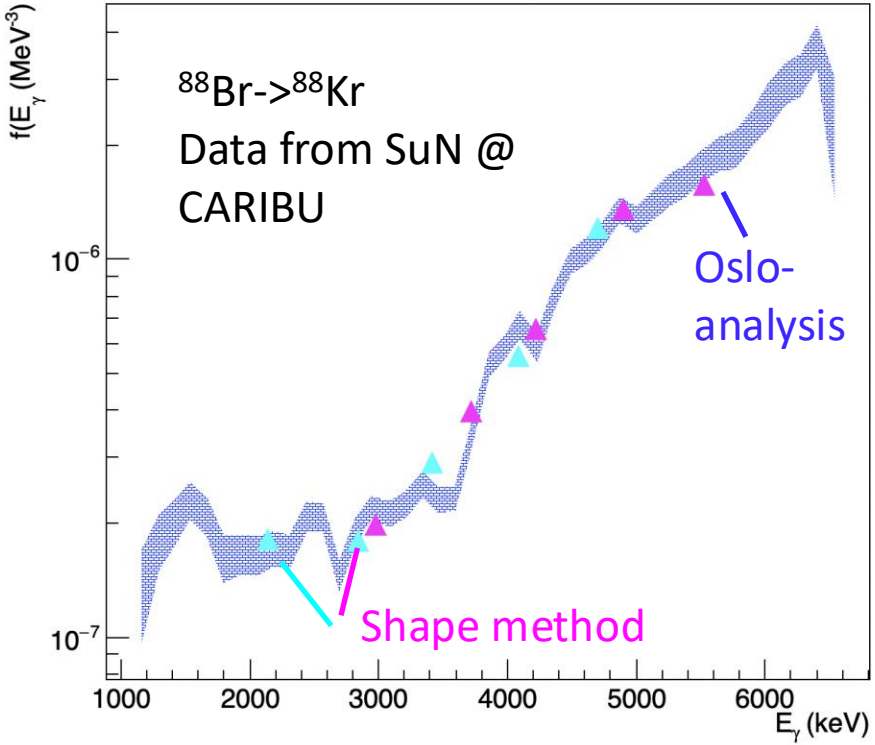
Constraining neutron capture rates



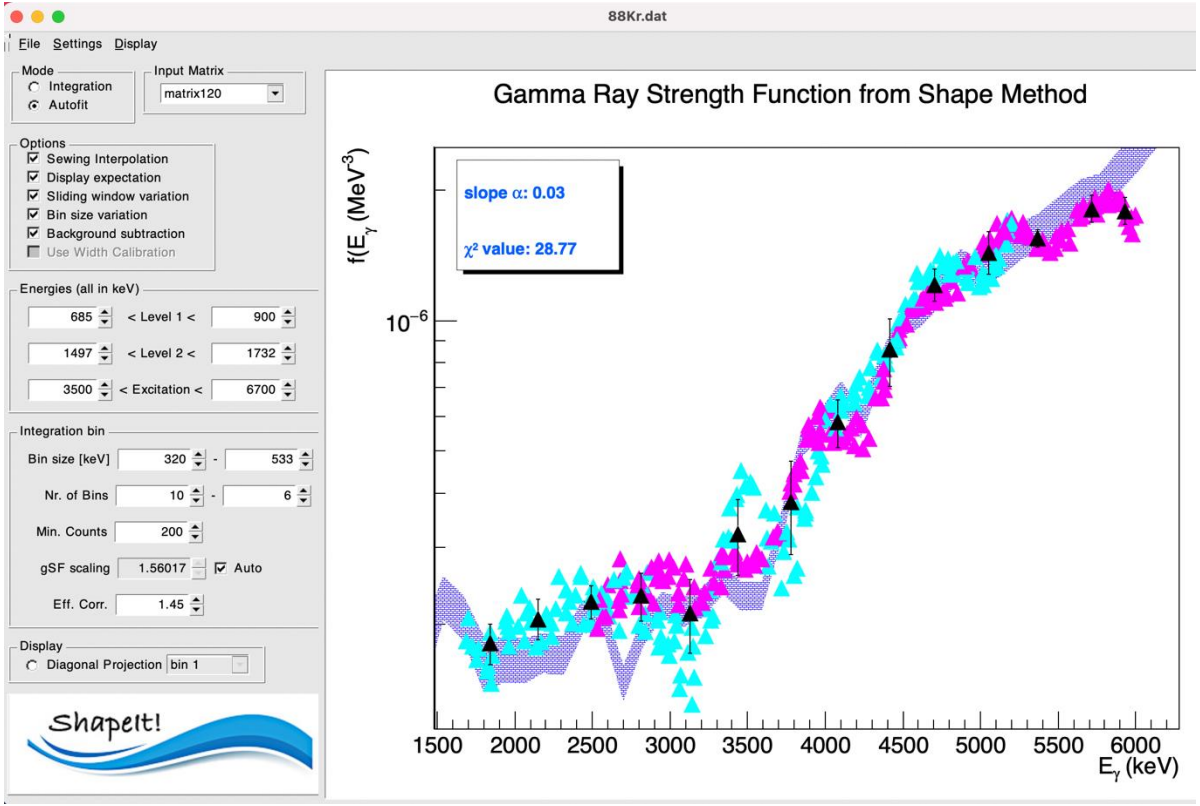


Constraining neutron capture rates

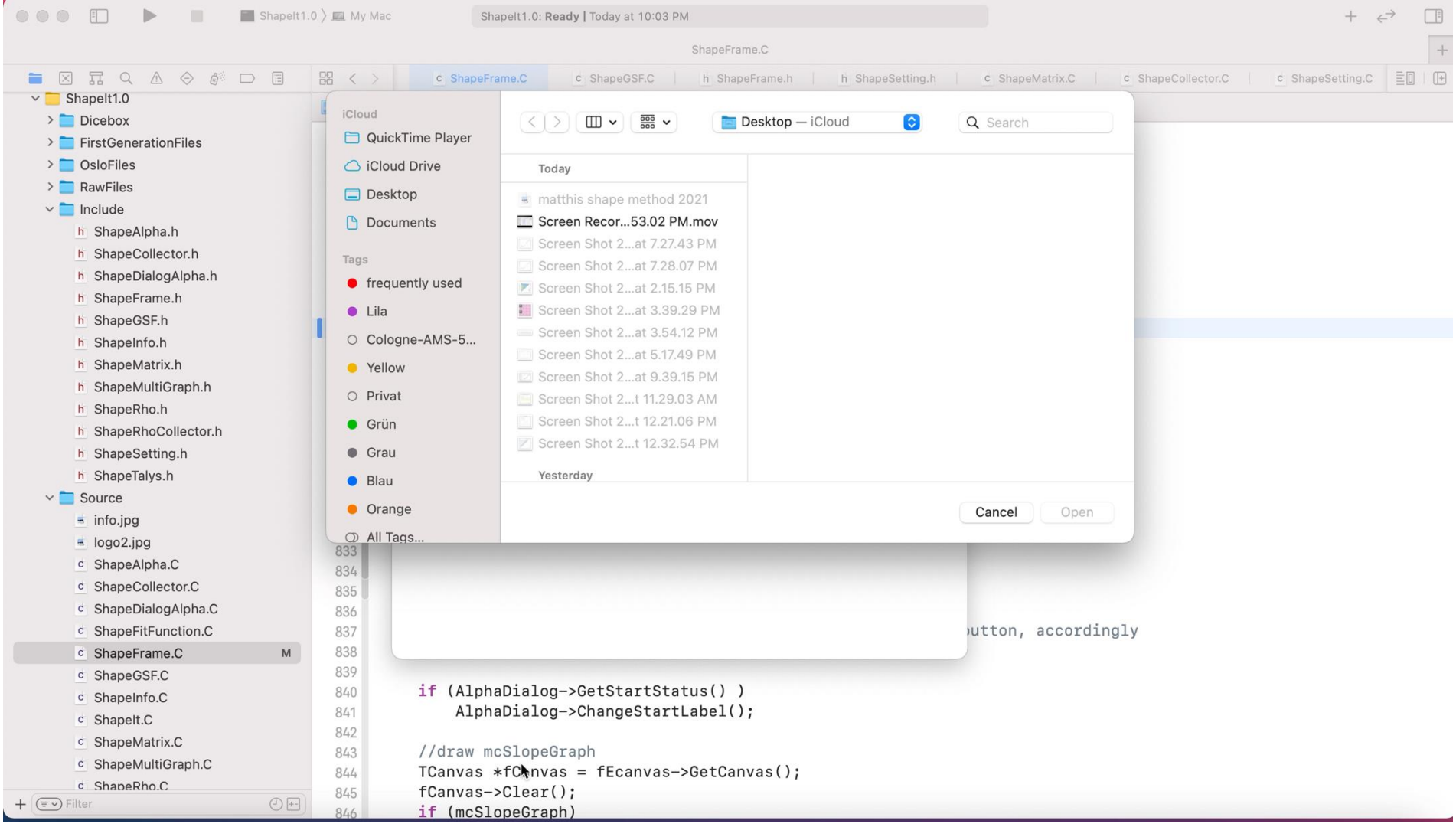




ShapeIt!



- Open source: https://github.com/dennismuecher/ShapeIt
- C++, based on ROOT framework
- platform independent
- Autofit & integration mode w/o background subtraction
- Quantifies robustness of results due to fluctuations
- Monte-Carlo-based uncertainty analysis of “slope” of gSF
- Extraction of absolute partial level densities
- TALYS intgeration


ShapeIt1.0 〉 My Mac
ShapeIt1.0: Ready | Today at 10:03 PM
ShapeFrame.C
ShapeFrame.C
ShapeGSF.C
ShapeFrame.h
ShapeSetting.h
ShapeMatrix.C
ShapeCollector.C
ShapeSetting.C
ShapeIt1.0
Dicebox
FirstGenerationFiles
OsloFiles
RawFiles
Include
ShapeAlpha.h
ShapeCollector.h
ShapeDialogAlpha.h
ShapeFrame.h
ShapeGSF.h
ShapeInfo.h
ShapeMatrix.h
ShapeMultiGraph.h
ShapeRho.h
ShapeRhoCollector.h
ShapeSetting.h
ShapeTalys.h
Source
info.jpg
logo2.jpg
ShapeAlpha.C
ShapeCollector.C
ShapeDialogAlpha.C
ShapeFitFunction.C
ShapeFrame.C M
ShapeGSF.C
ShapeInfo.C
ShapeIt.C
ShapeMatrix.C
ShapeMultiGraph.C
ShapeRho.C
Filter
iCloud
QuickTime Player
iCloud Drive
Desktop
Documents
Tags
frequently used
Lila
Cologne-AMS-5...
Yellow
Privat
Grün
Grau
Blau
Orange
All Tags...
Desktop — iCloud
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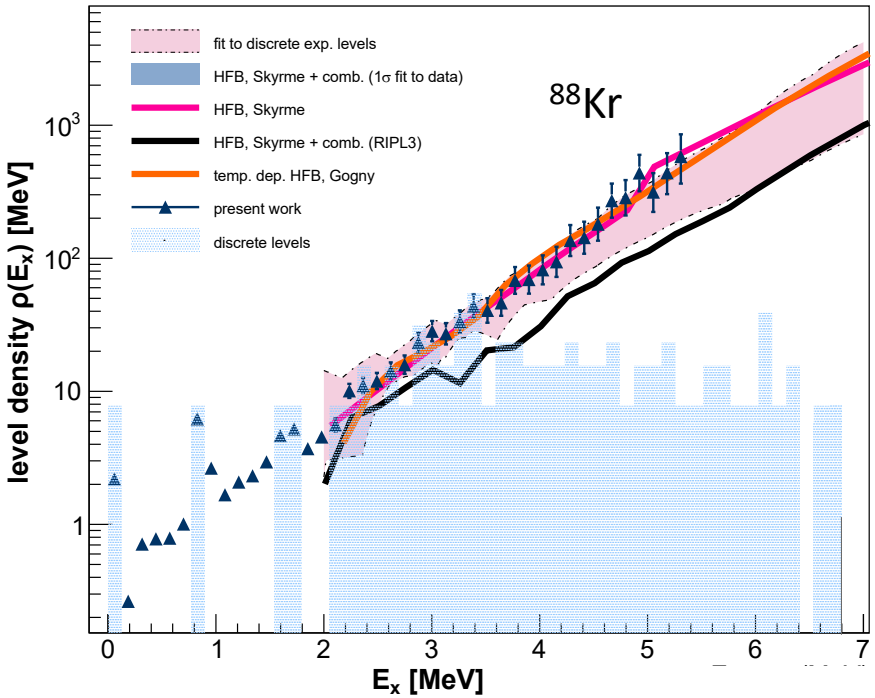
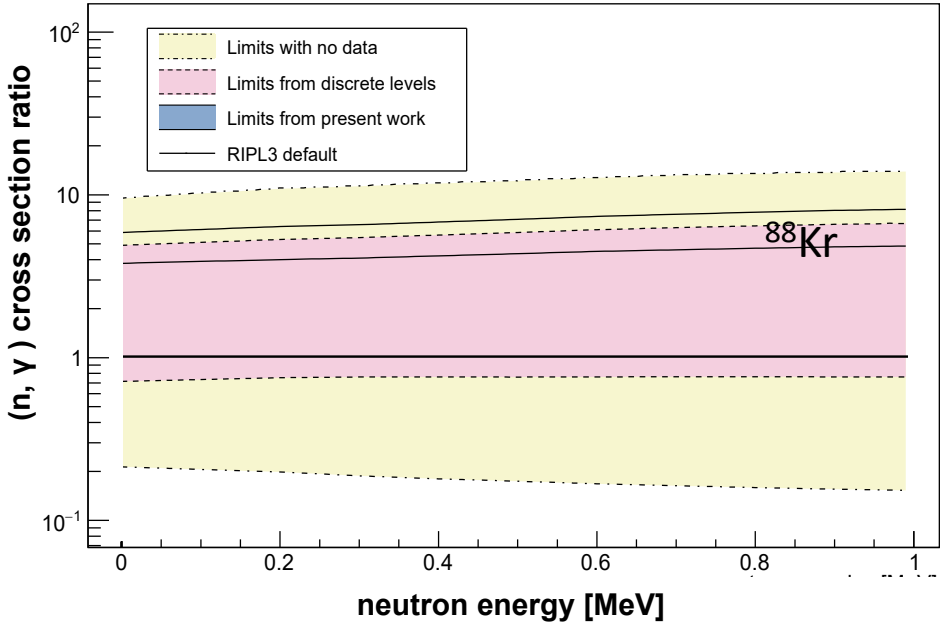
Today
matthis shape method 2021
Screen Recor...53.02 PM.mov
Screen Shot 2...at 7.27.43 PM
Screen Shot 2...at 7.28.07 PM
Screen Shot 2...at 2.15.15 PM
Screen Shot 2...at 3.39.29 PM
Screen Shot 2...at 3.54.12 PM
Screen Shot 2...at 5.17.49 PM
Screen Shot 2...at 9.39.15 PM
Screen Shot 2...t 11.29.03 AM
Screen Shot 2...t 12.21.06 PM
Screen Shot 2...t 12.32.54 PM
Yesterday
Cancel
Open
833
834
835
836
837
838
839
840
841
842
843
844
845
846
utton, accordingly
if (AlphaDialog->GetStartStatus())
AlphaDialog->ChangeStartLabel();
//draw mcSlopeGraph
TCanvas *fCanvas = fEcanvas->GetCanvas();
fCanvas->Clear();
if (mcSlopeGraph)

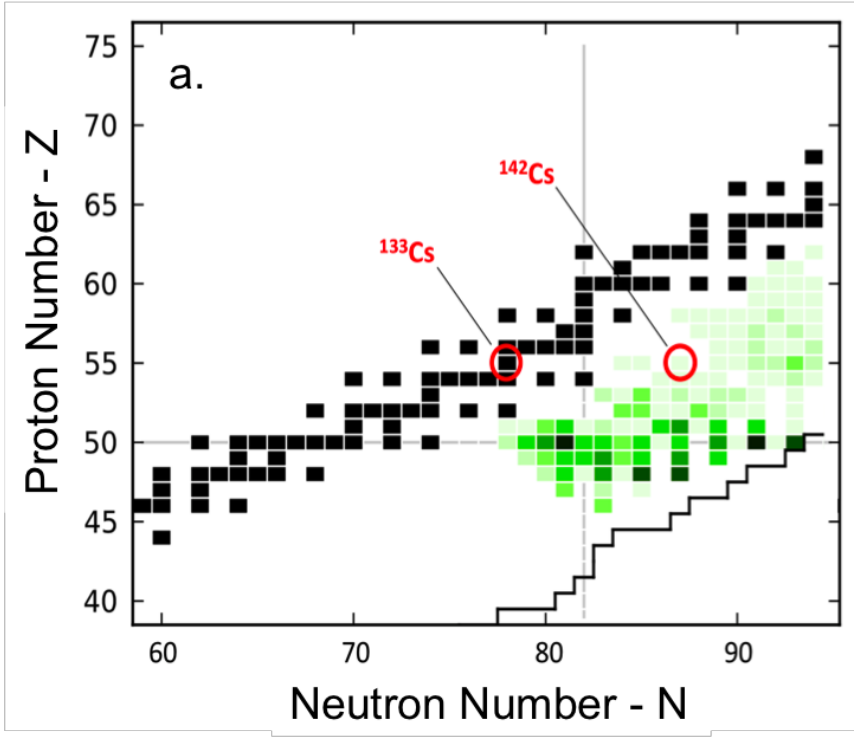
absolute partial NLD in an unstable nucleus

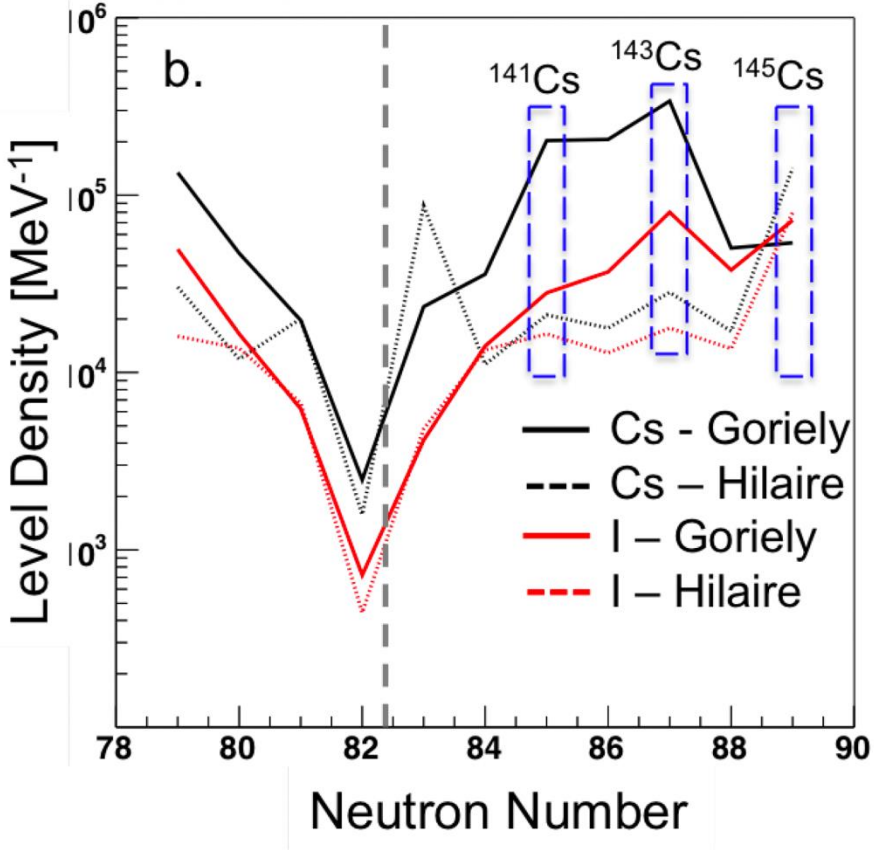




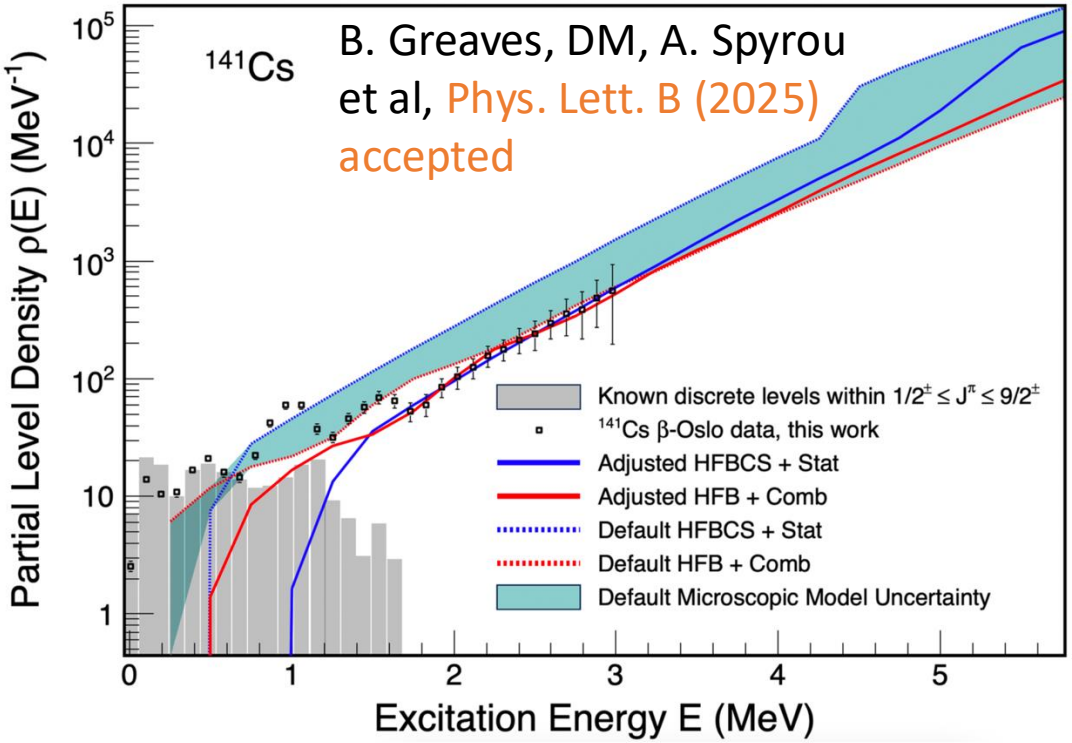
DM, A. Spyrou et al, PRC Letters 2023

Neutron capture rates in n-rich Cs isotopes (ANL+TRIUMF)



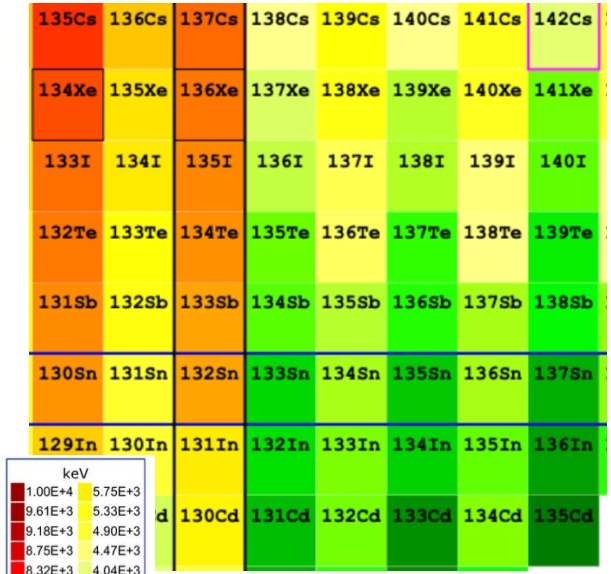


Guiding NLD Models Far Away From Stability



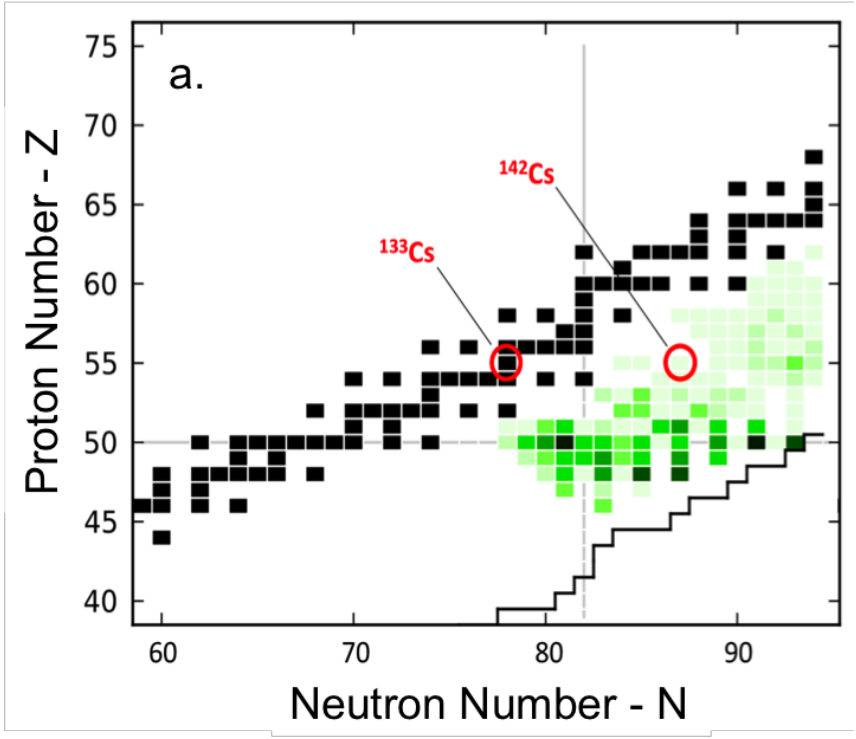
- Our data suggest that NLDs in the A=140 region tend to be smaller than expected by some models

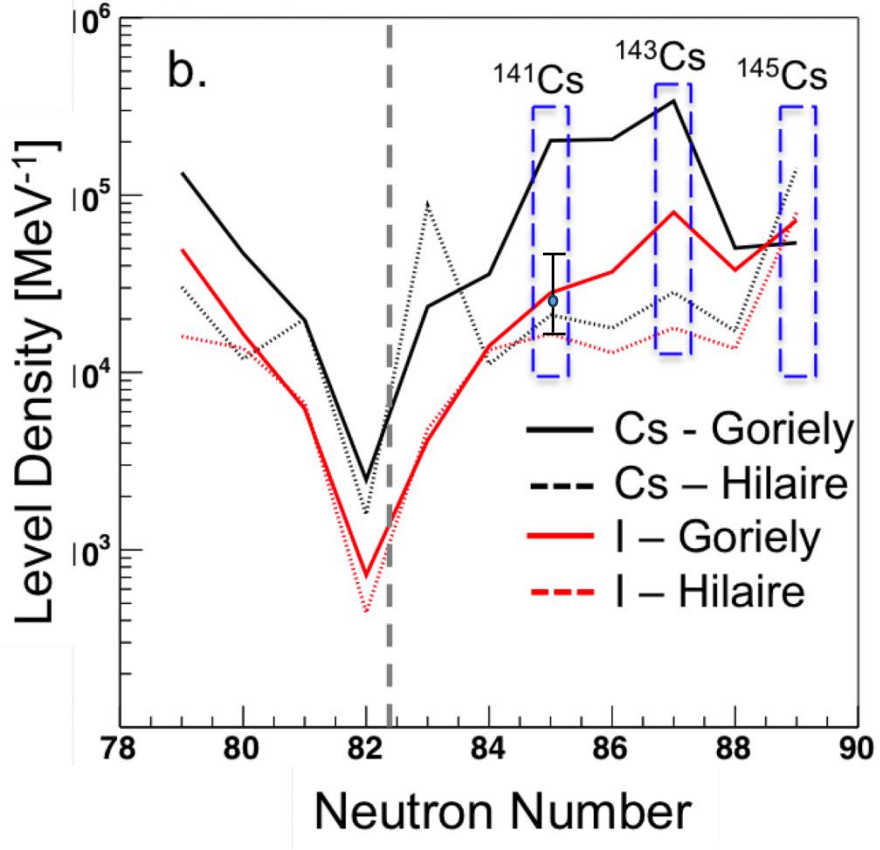
Lower NLD has impact on validity of Hauser-Feshbach model



Universität zu Köln

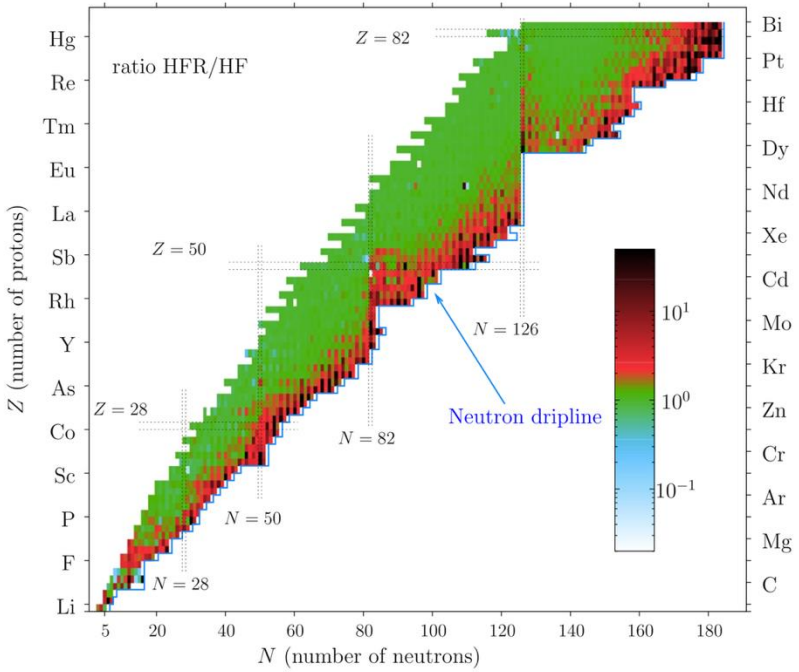
Neutron capture rates in n-rich Cs isotopes (ANL+TRIUMF)

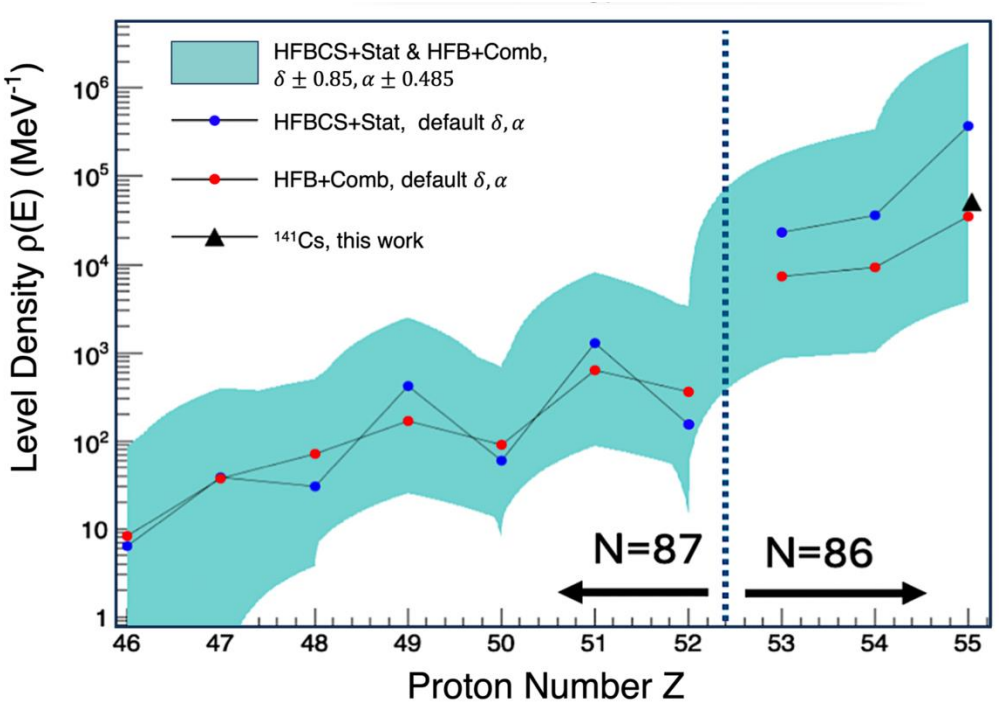




B. Greaves, DM, A. Spyrou et al, PLB 2025 (accepted)

Probing the Limit of the Statistical Regime: The High-Fidelity Resonance Model

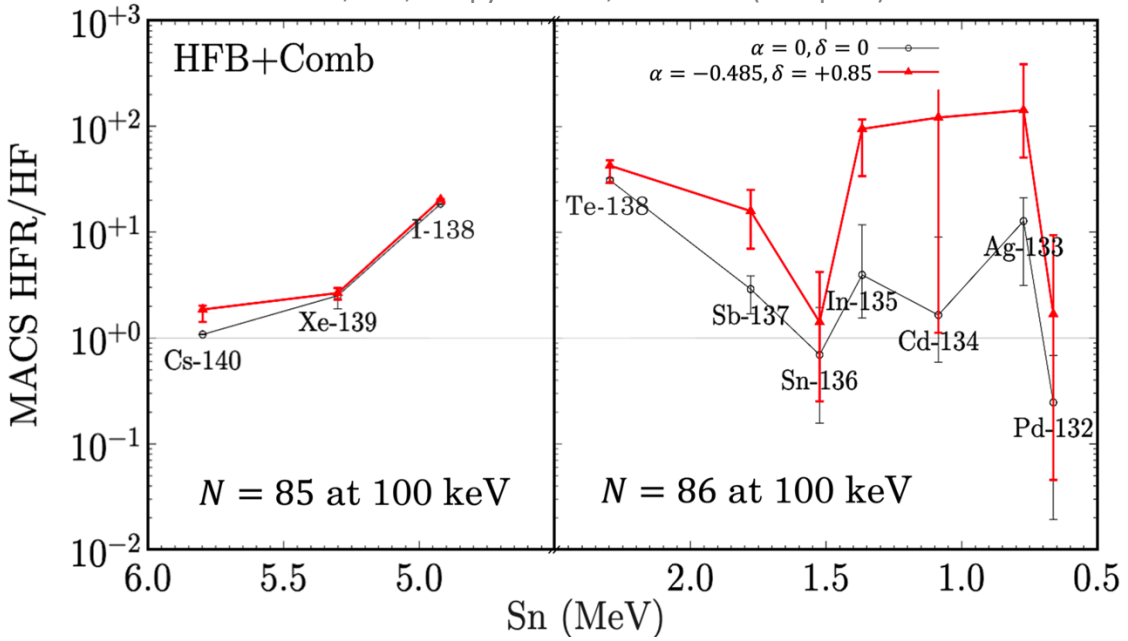




D. Rochman, S. Goriely et al,
Physics Letters B 764 (2017)

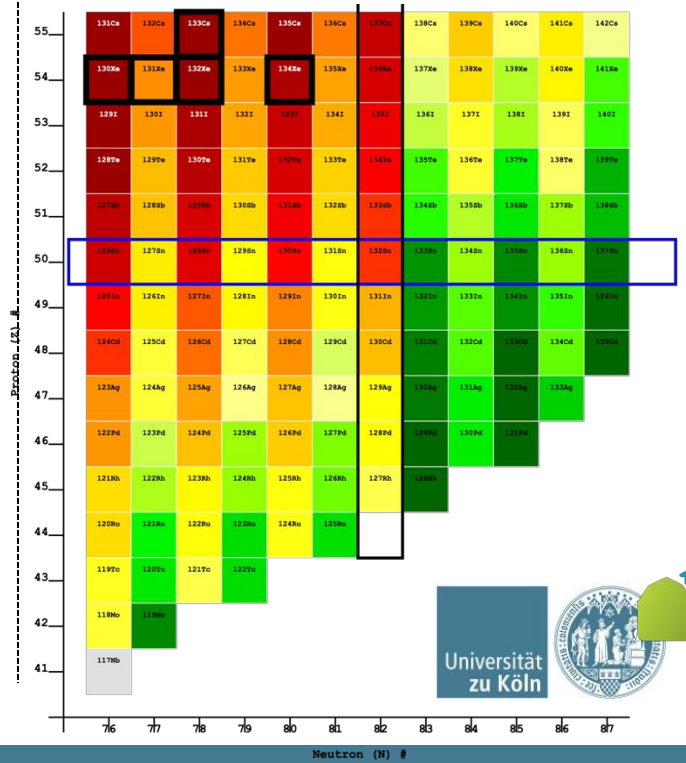
Hauser-Feshbach vs. Individual Resonances

B. Greaves, DM, A. Spyrou et al, PLB 2025 (accepted)

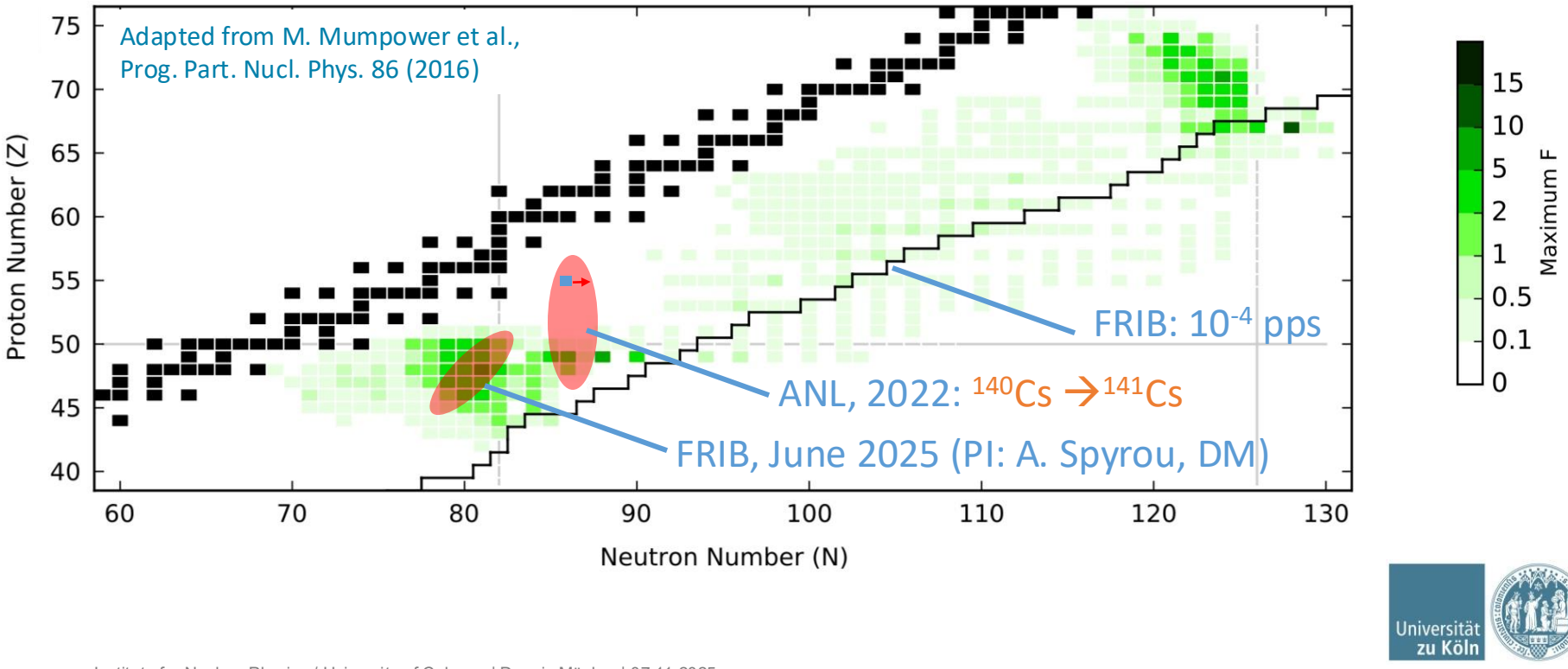


- We have already experimentally reached the limit of the statistical regime
- General trend: Hauser-Feshbach unterpredicts (n,γ) rates

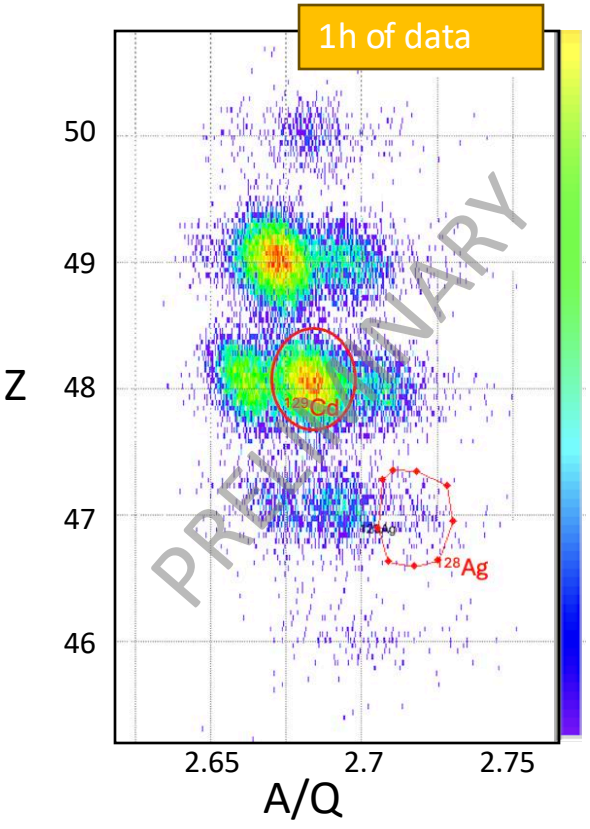
Lower NLD has impact on validity of Hauser-Feshbach model

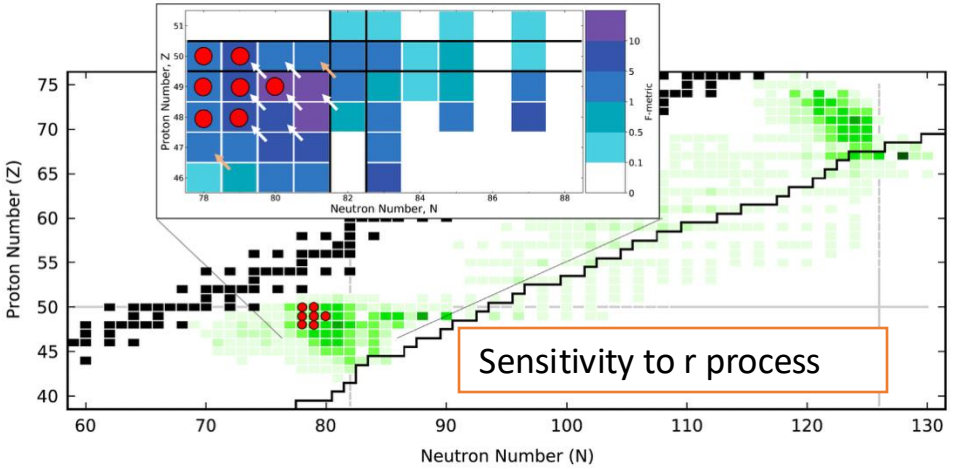


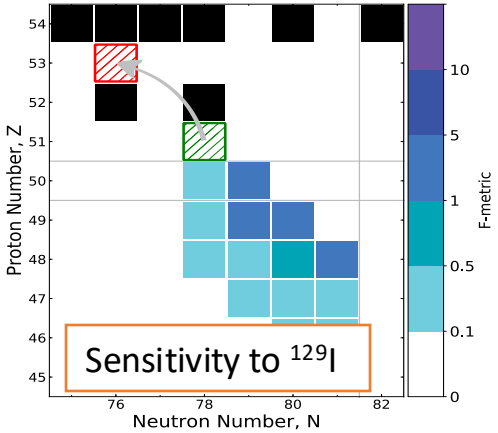
The rapid neutron capture process

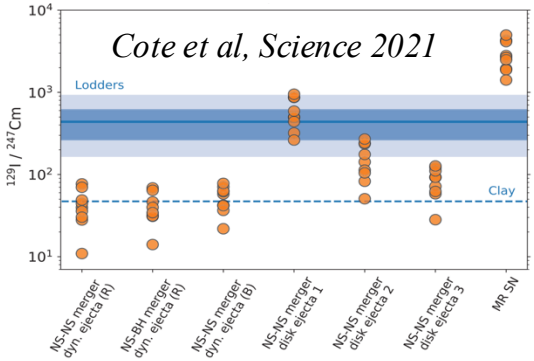


Results from SuN@FRIB, MSU June 2025









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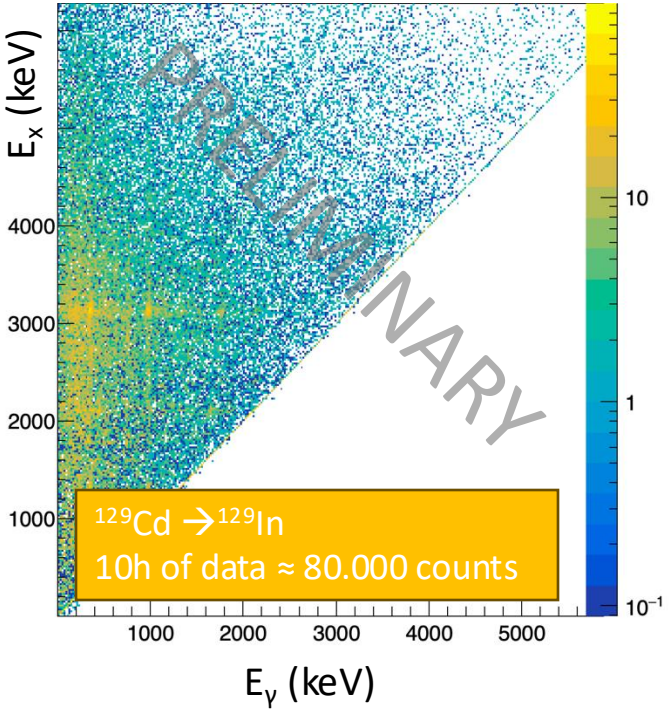
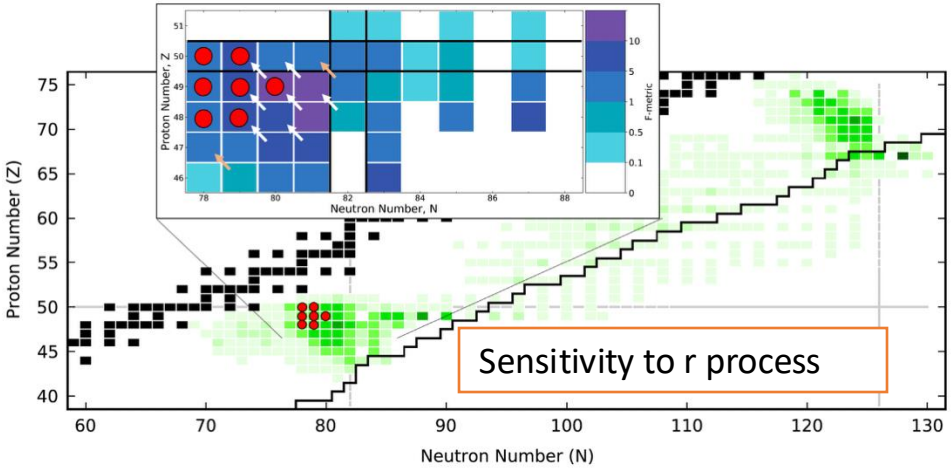
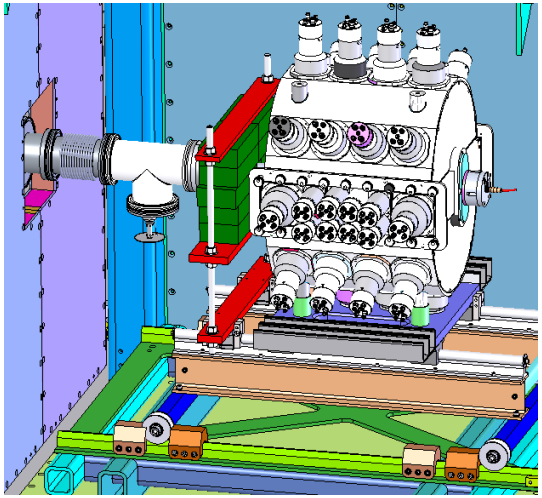


PIs: A. Spyrou, DM
+ S. Lidick + many people





Setup

- SuN++ TAS (12 NaI, 8 $CeBr_3$)
- seg. implantation DSSD detector (both PiD and β-trigger)
- hosted inside MTAS frame

Summary + Thank you

- β-Oslo: powerful technique for constraining n-capture rates in exotic nuclei
- First constraint of the $^{140}Cs(n,\gamma)^{141}Cs$ reaction rate at the limit of statistical behaviour
- Successful first experiment for n-capture rates at FRIB below ^{132}Sn

- A. Spyrou, S. Liddick, K. Bosmpotinis, J. Berkman, R. Lubna, S. Uthayakumaar, et. al. (FRIB + MSU)
- B. Greaves (UoGuelph)
- G. Savard, D. Santiago et. al. (Argonne National Lab.)
- S. Goriely (Univ. Brussels)
- D. Rochman (PSI, Villingen)
- C. Schlaier (IKP Cologne)