The statistical properties of ^{92}Mo and implications for the p-process

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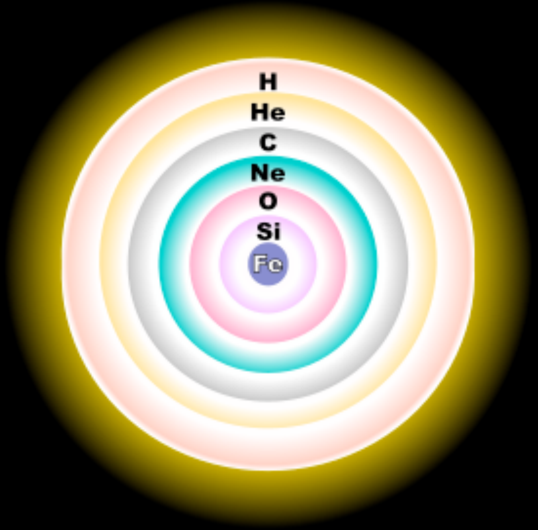
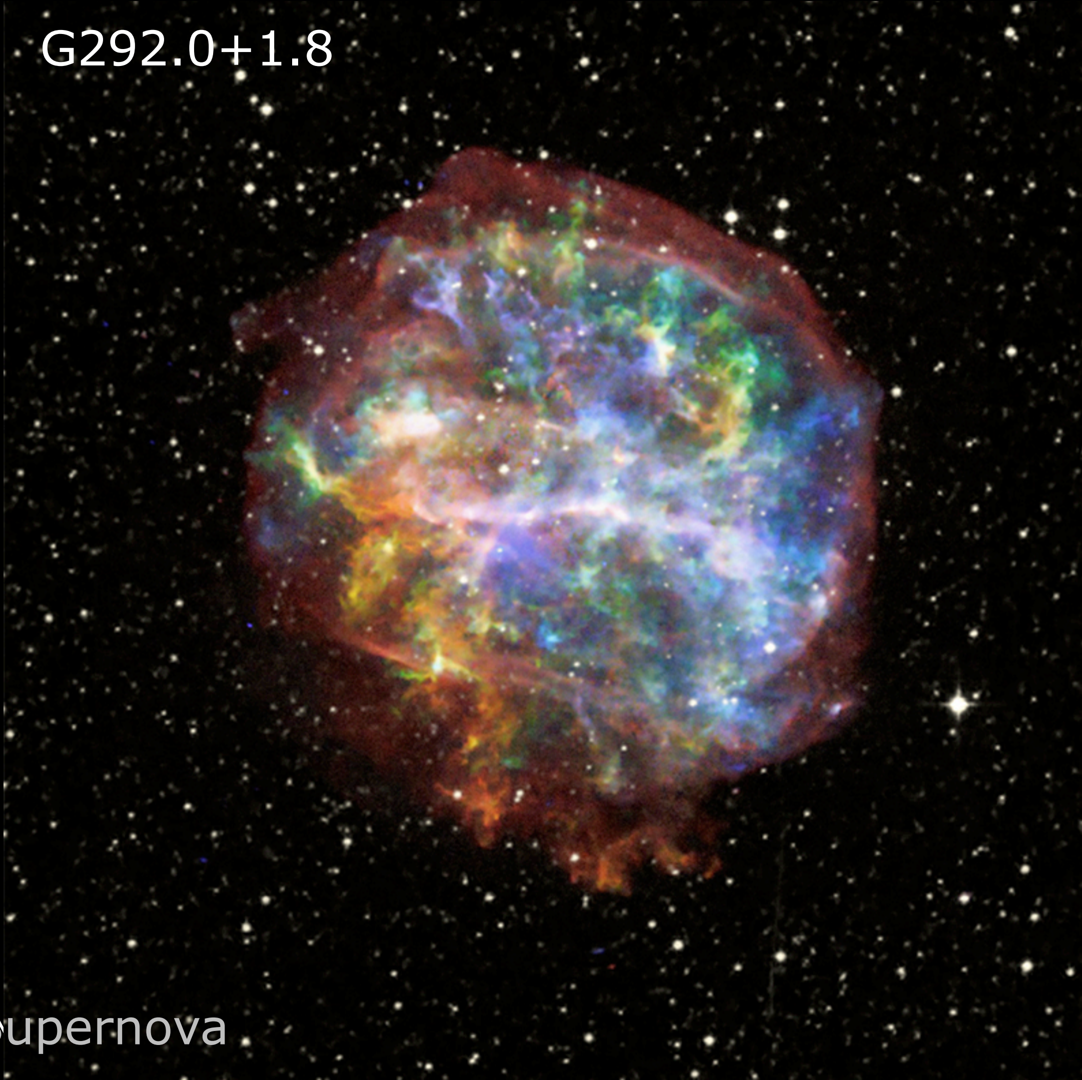
P-nuclei are stable, proton-rich isotopes that are bypassed by the s- and r-process





edit: X-ray: NASA/CXC/Penn State/S.Park et al.; Optical: Pal.Obs. D

Sites of production?
Type 2 Supernova or type 1a Supernova

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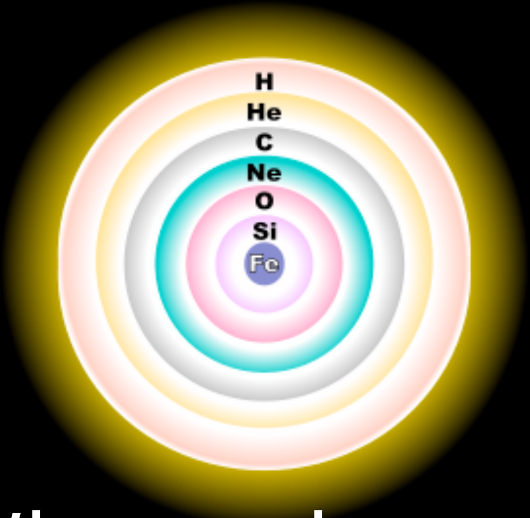
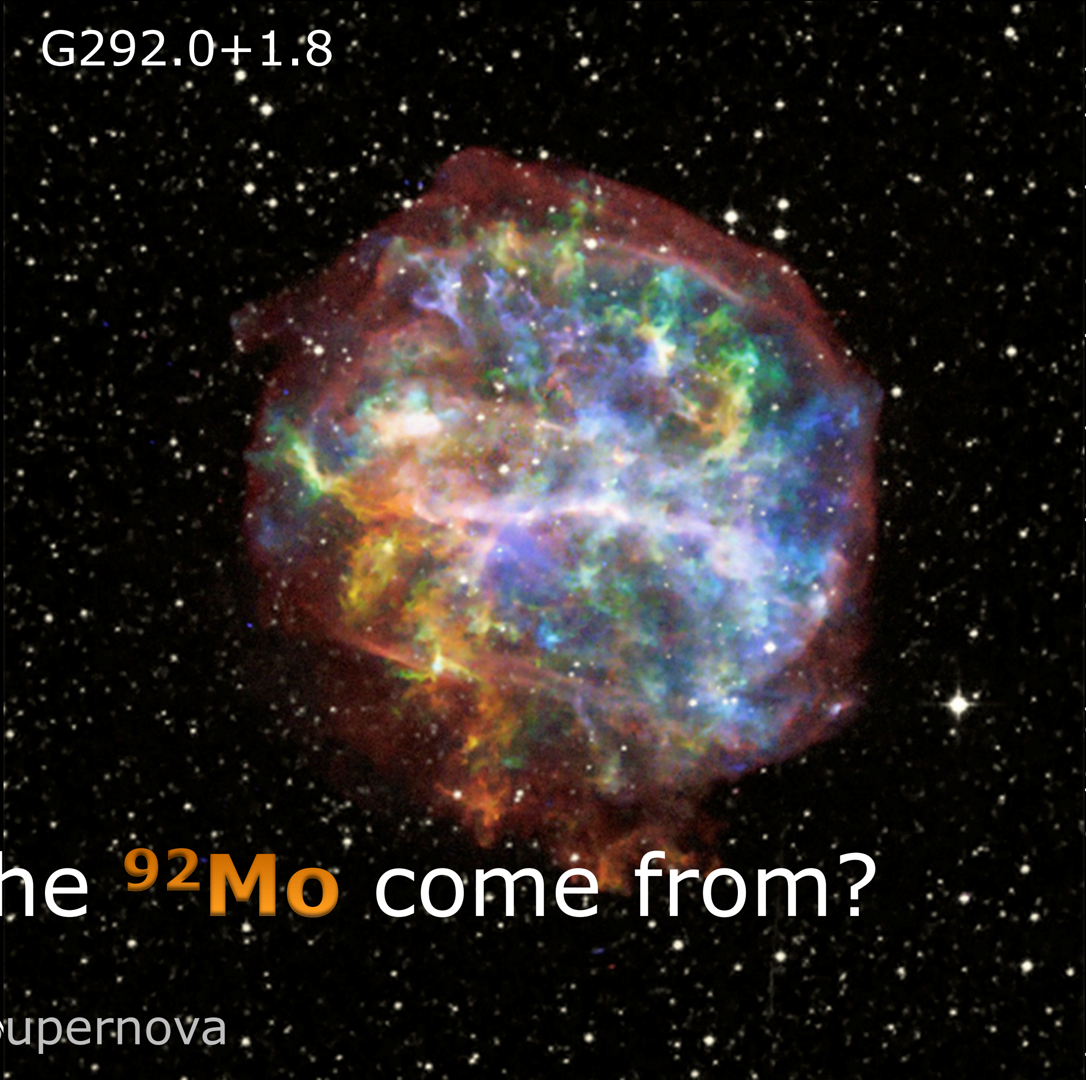




Where does all the ^{92}Mo come from?

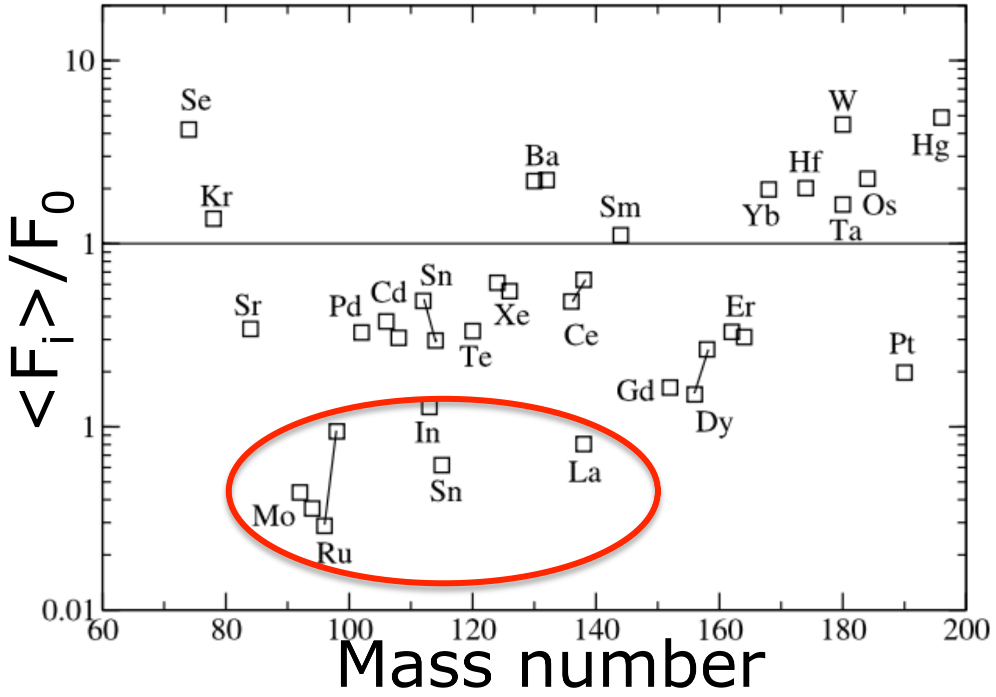
Sites of production?

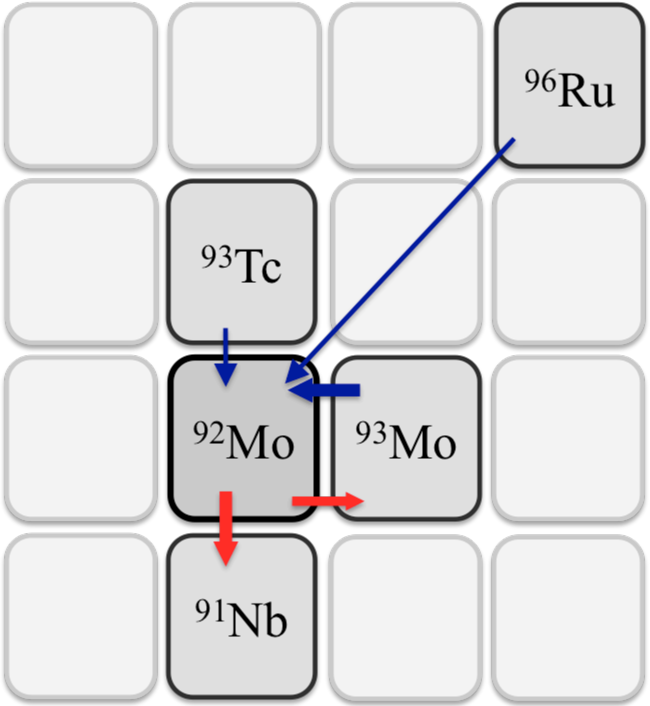
Type 2 Supernova or type 1a Supernova

edit: X-ray: NASA/CXC/Penn State/S.Park et al.; Optical: Pal.Obs. D

^{92}Mo is underproduced in calculations compared to solar abundances

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





If $<F_i>/F_0 = 1$ the value matches solar abundance

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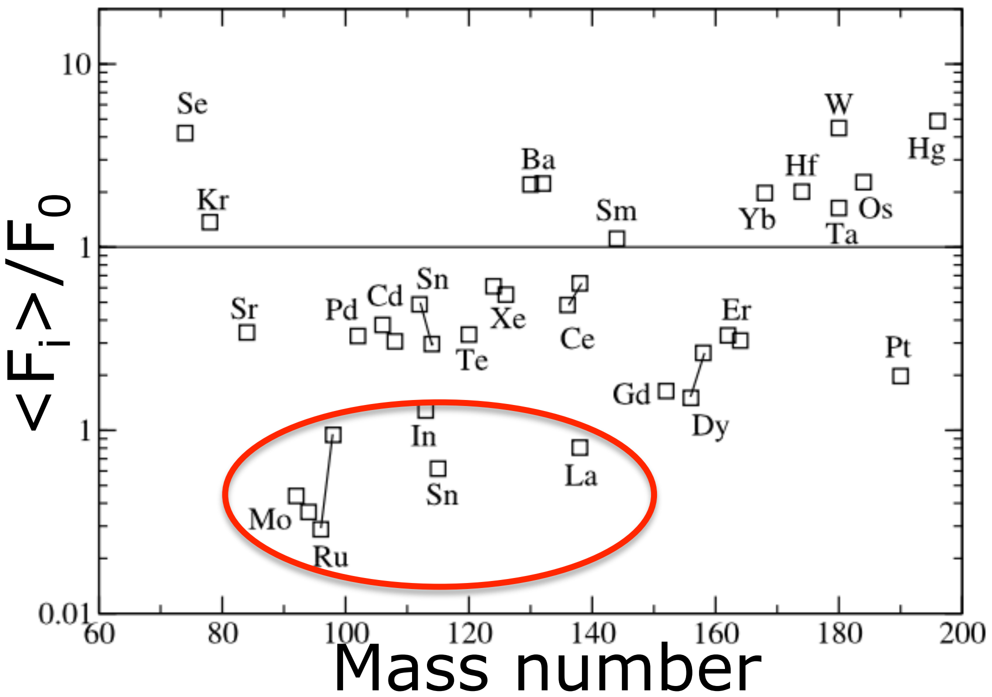
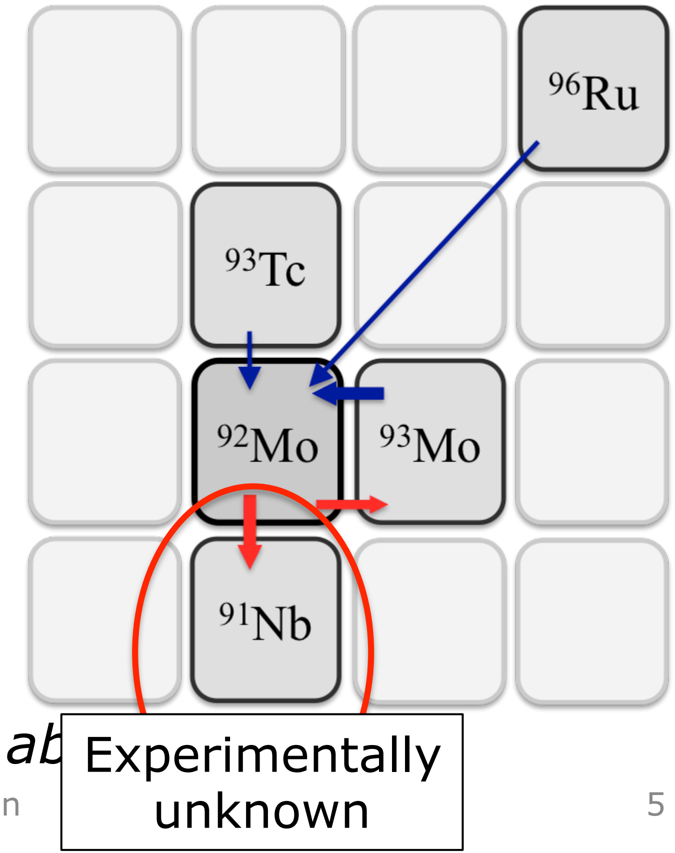
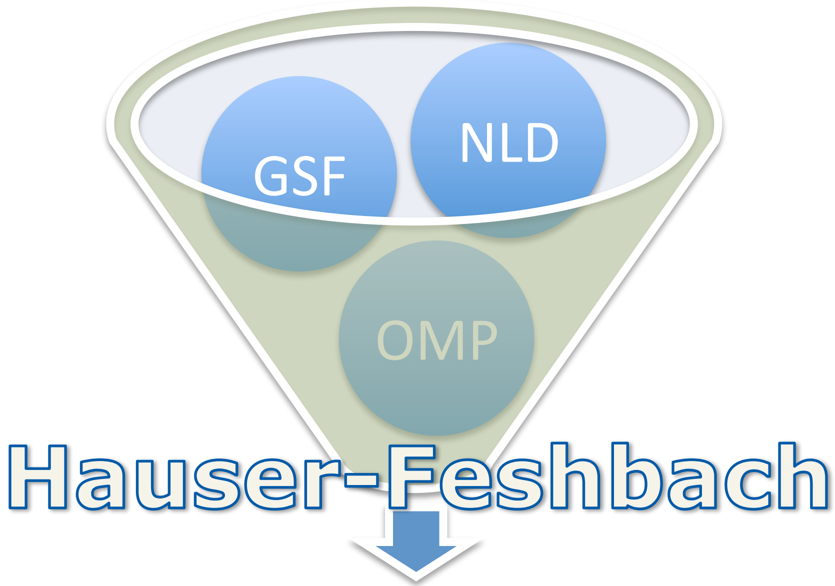




If $\langle F_i \rangle / F_0 = 1$ the value matches solar ab

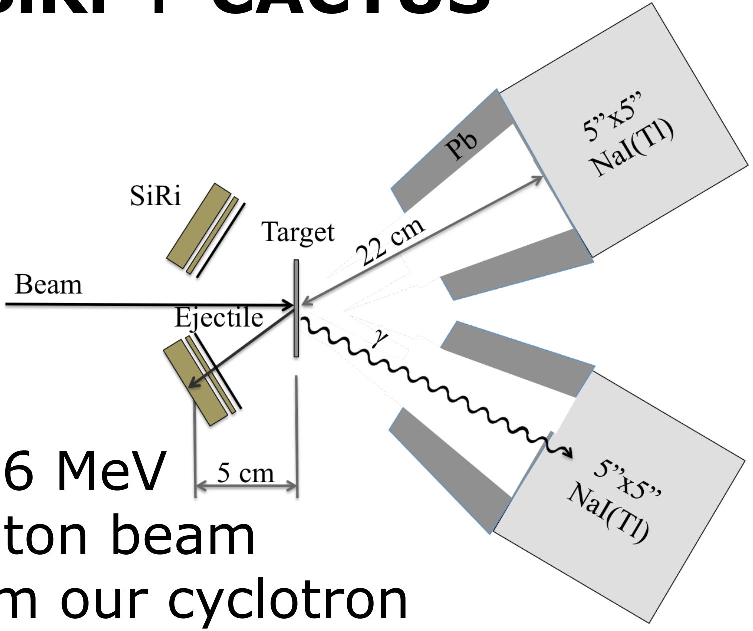
Idea: Use γ strength function (GSF) and nuclear level density (NLD) to constrain cross section



Cross section of $^{91}Nb(p,\gamma)^{92}Mo$

Setup at the Oslo cyclotron laboratory

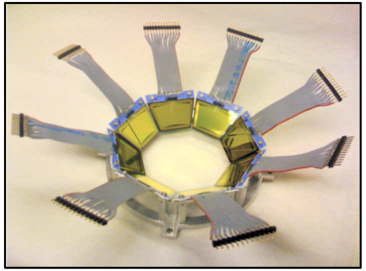
SiRi + CACTUS



16.6 MeV proton beam from our cyclotron

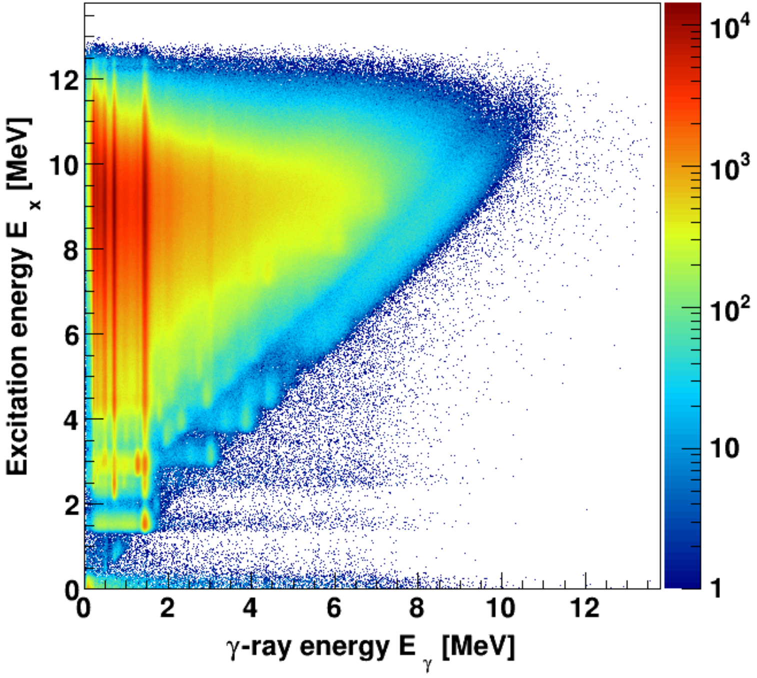
Details

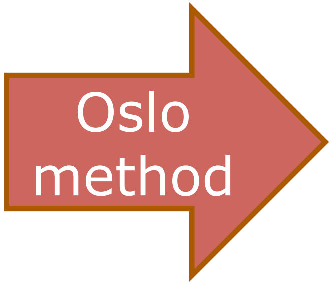
- 8x8 segmented Si-array at backwards angles 124°-140°
- 5"x5" 24 NaI(Tl) collimated scintillator detectors



SiRi: Guttormsen et al. arXiv:1104.1289 [nucl-ex]

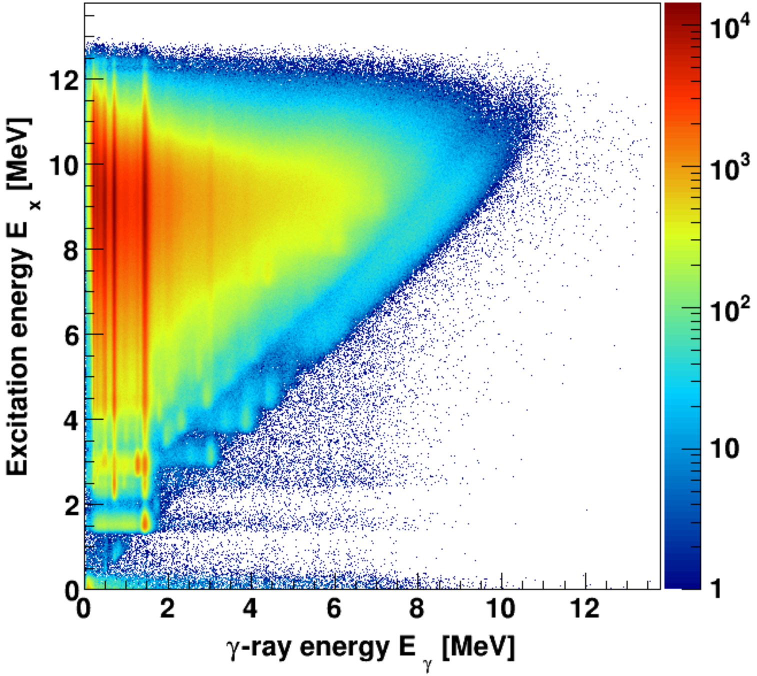
The Oslo method





Particle-γ coincidences from ^{92}Mo(p,p'γ)

The Oslo method



Oslo method

1. Unfolding

Particle-γ coincidences from ^{92}Mo(p,p'γ)

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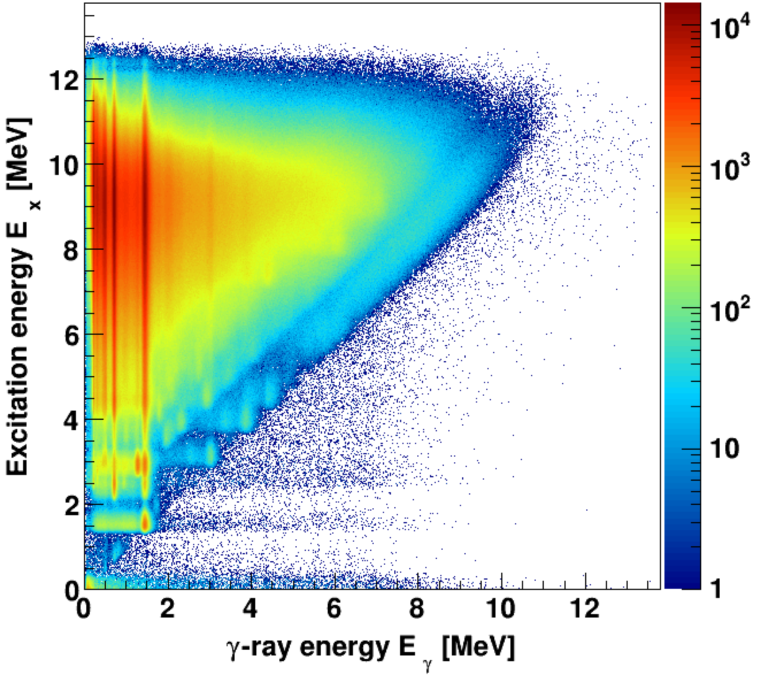
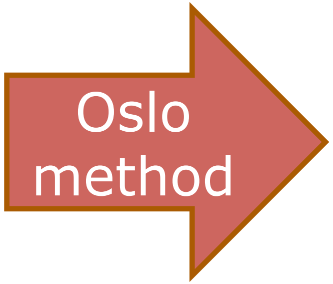
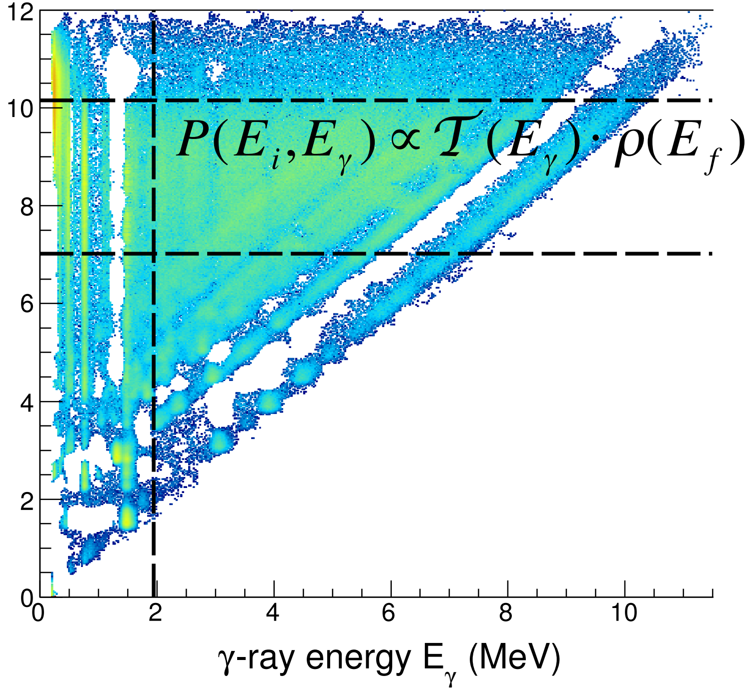




1. Unfolding
2. Extract primary γ's



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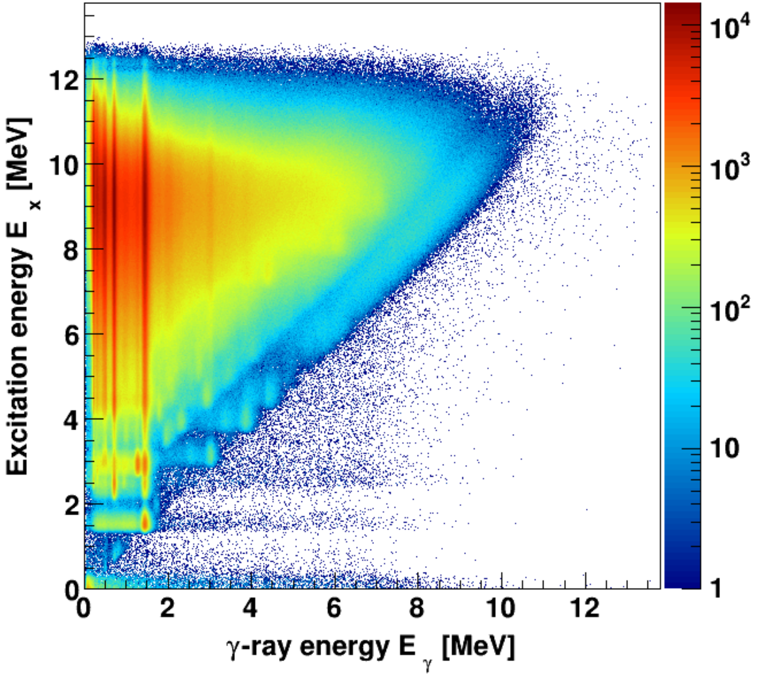

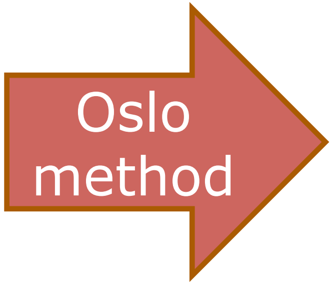

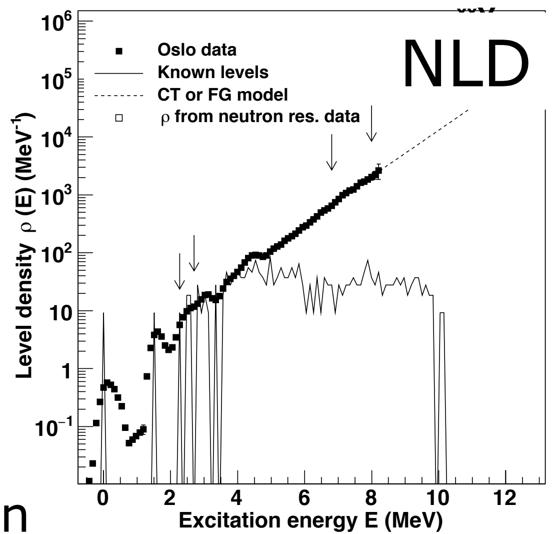

1. Unfolding
2. First generation method
3. Simultaneous extraction of NLD

Particle-γ coincidences from ^{92}Mo(p,p'γ)

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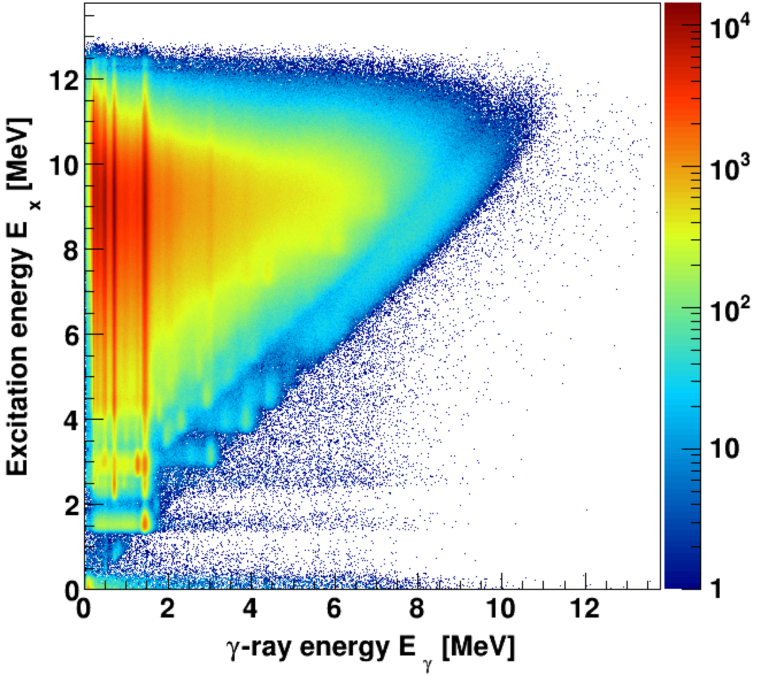

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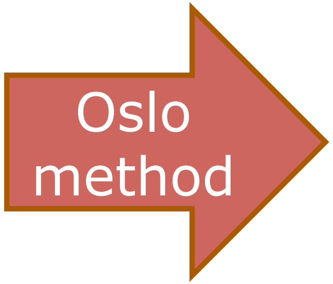

1. Unfolding
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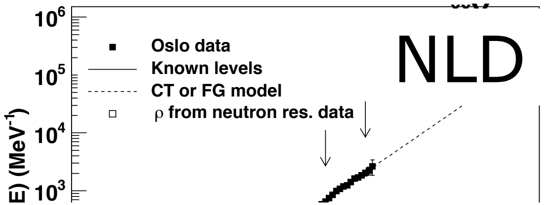
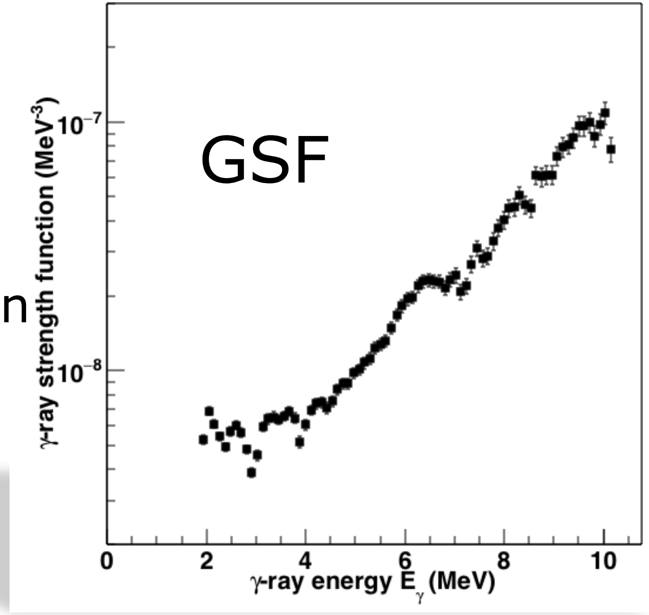
3. Simultaneous extraction of NLD and GSF





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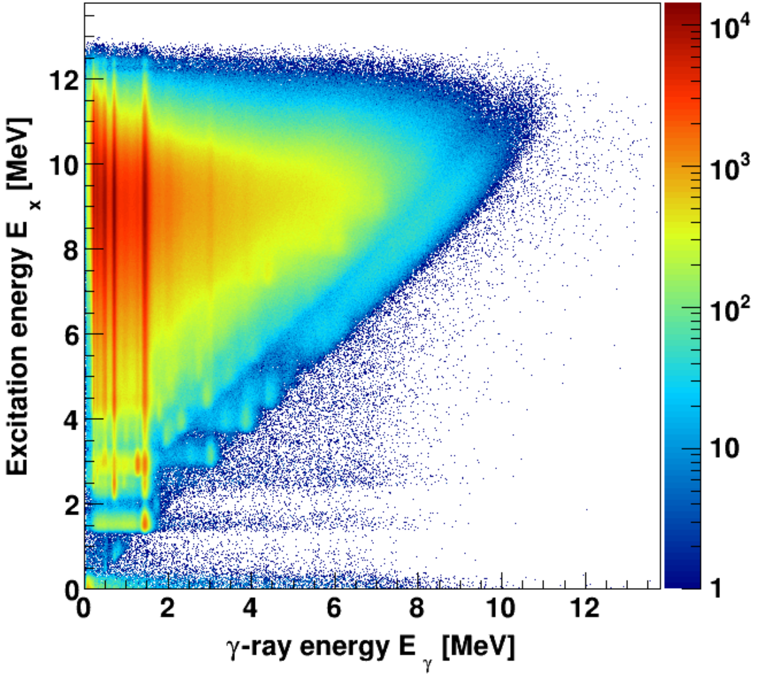

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Oslo method

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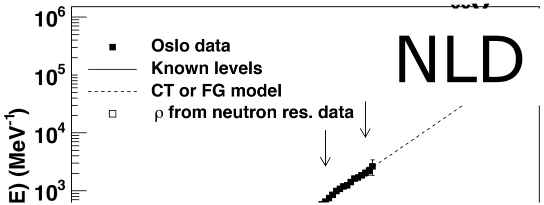
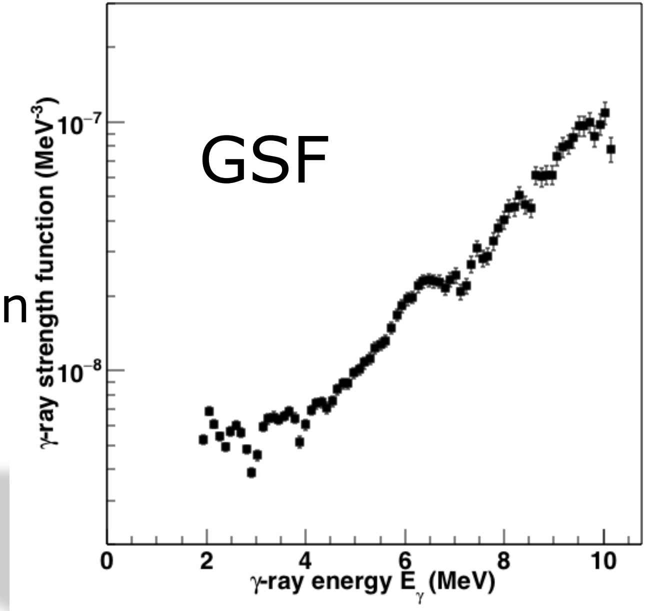
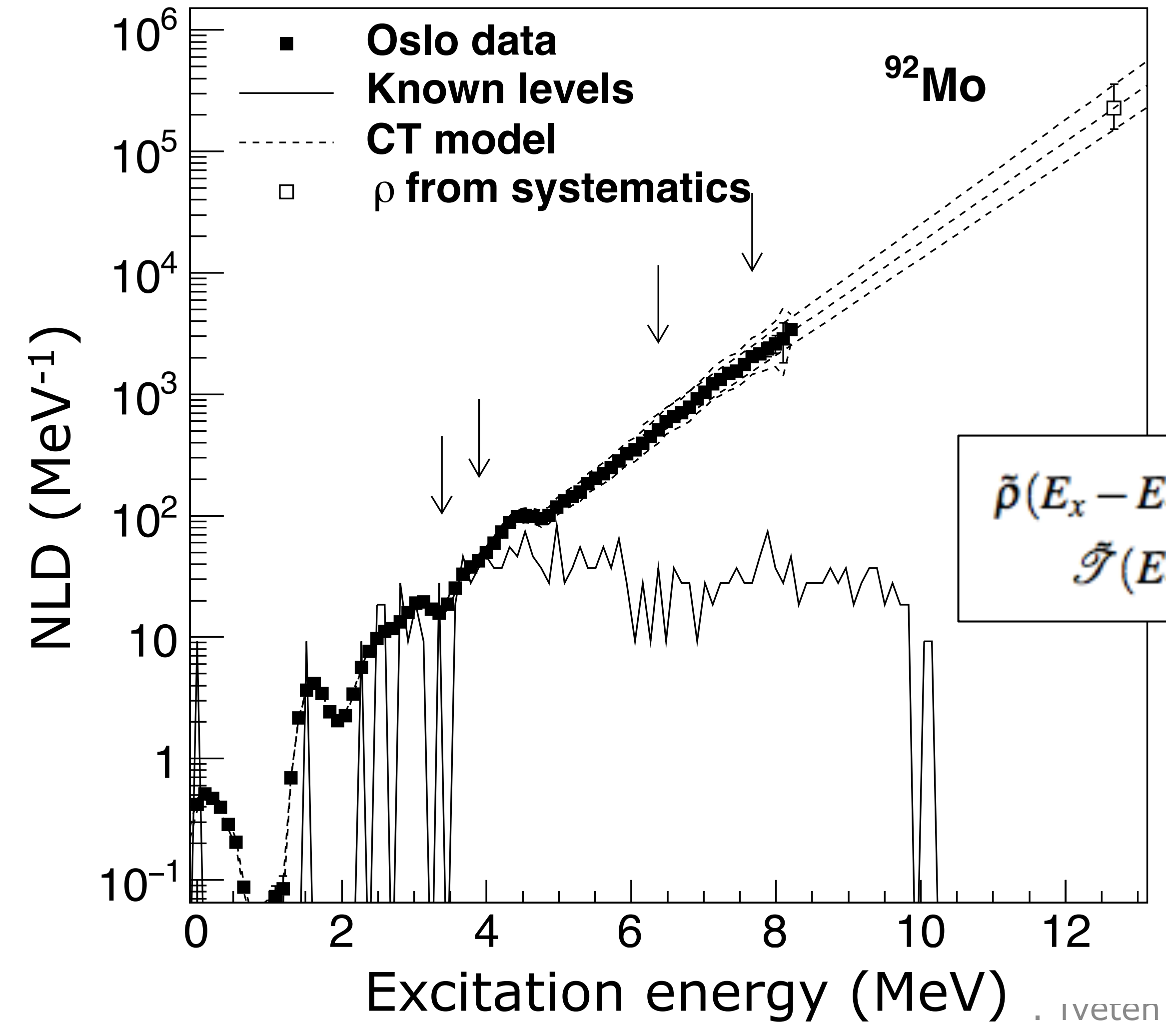
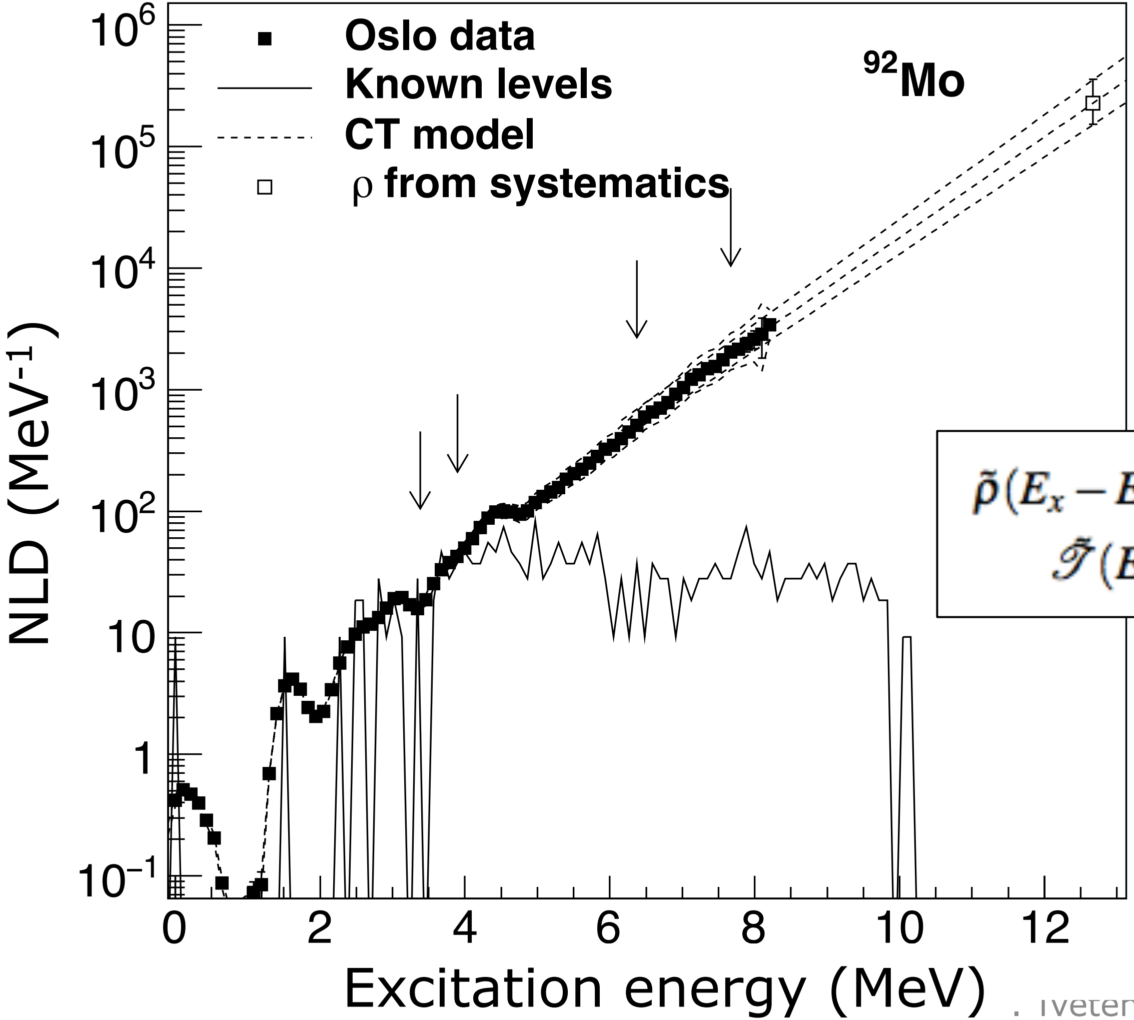




4. Normalization!



$$\tilde{\rho}(E_x - E_\gamma) = \mathscr{A} \exp[\alpha(E_x - E_\gamma)]\, \rho(E_x - E_\gamma),$$
$$\tilde{\mathscr{T}}(E_\gamma) = \mathscr{B} \exp(\alpha E_\gamma)\, \mathscr{T}(E_\gamma).$$



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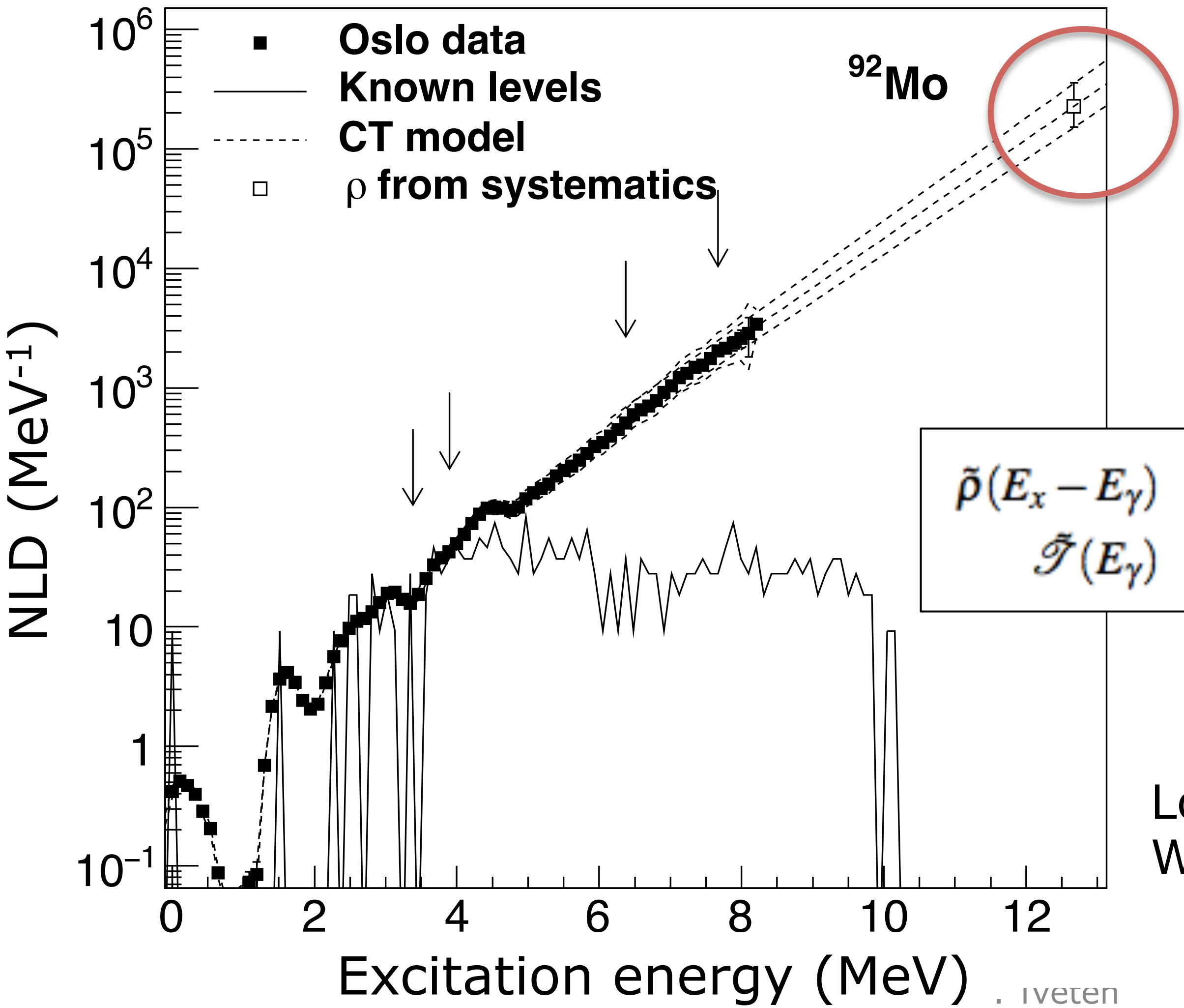
Low excitation:
We count known levels



High excitation energy:
We calculate from average level spacings at S_n

For ^{92}Mo we estimated from systematics

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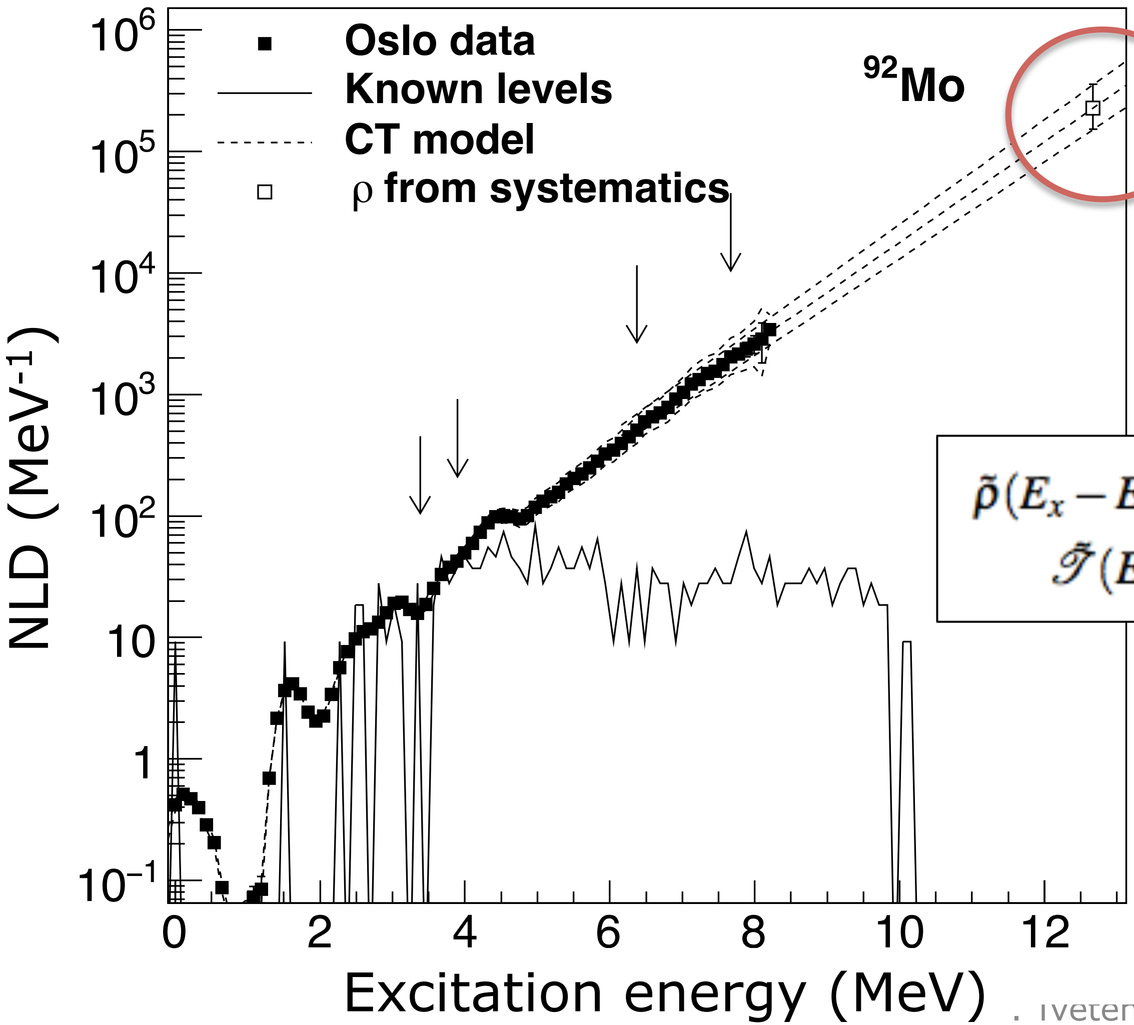

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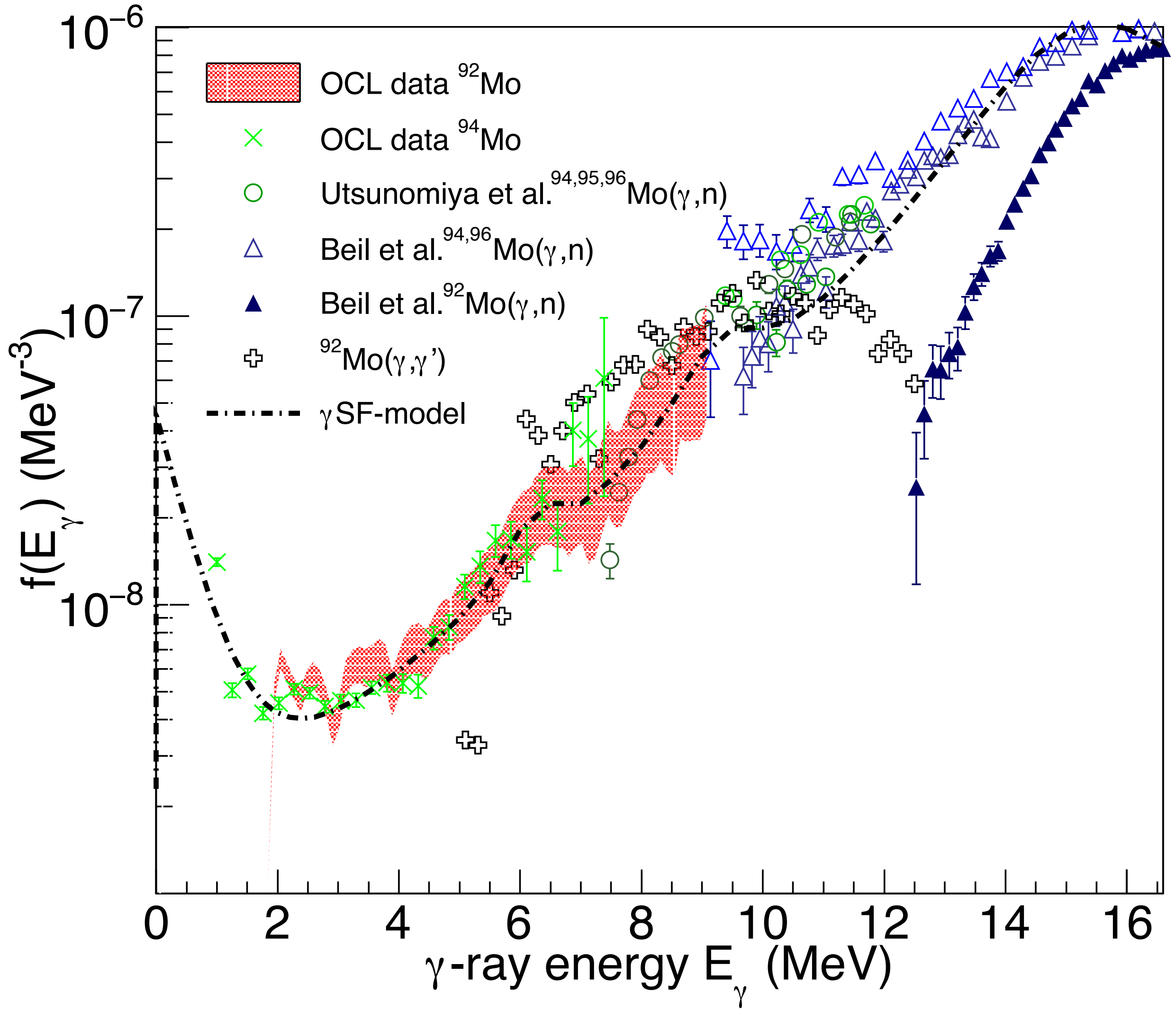
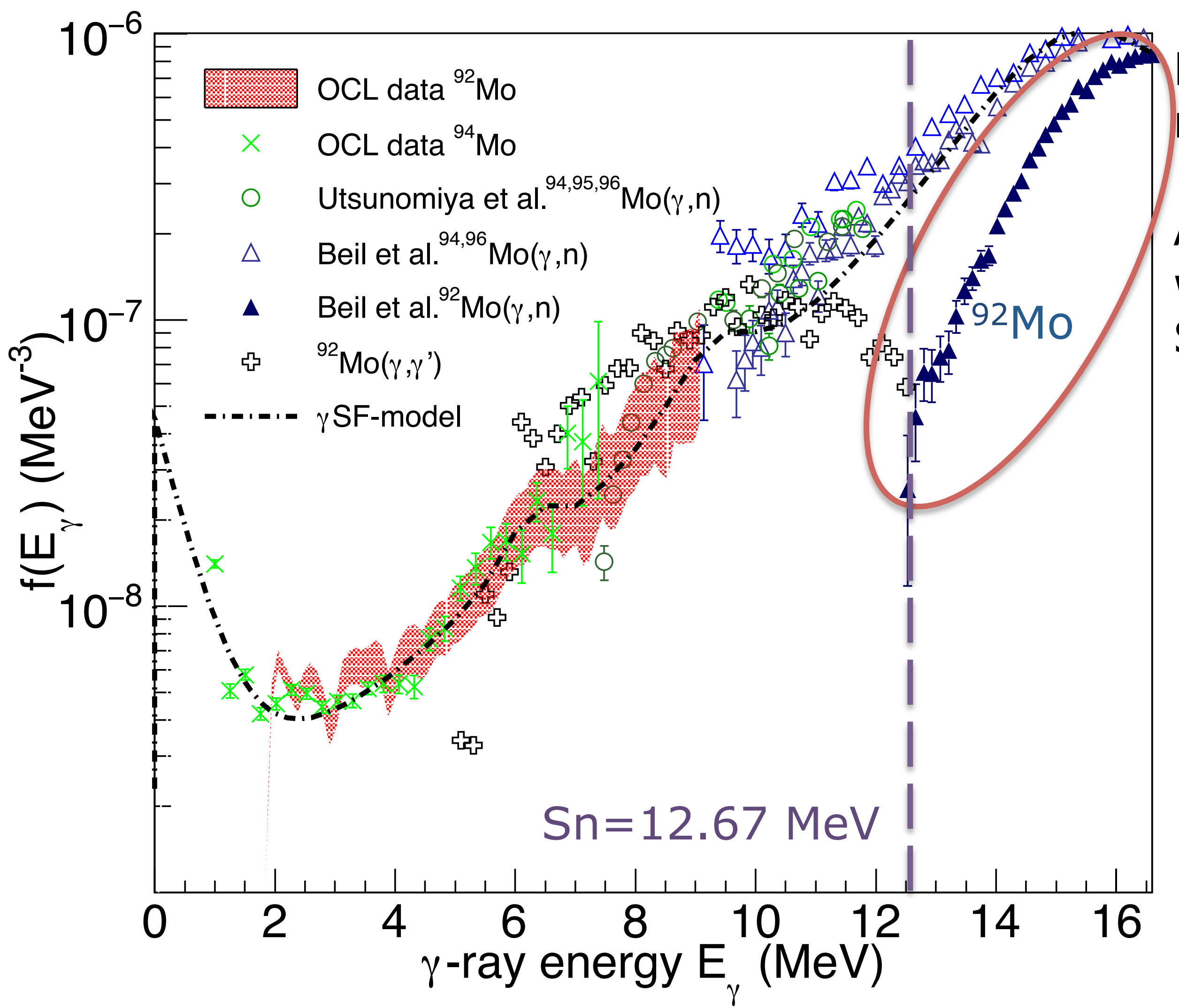


Here too, we needed to rely on systematics.

Are we able to connect with existing data above S_n?

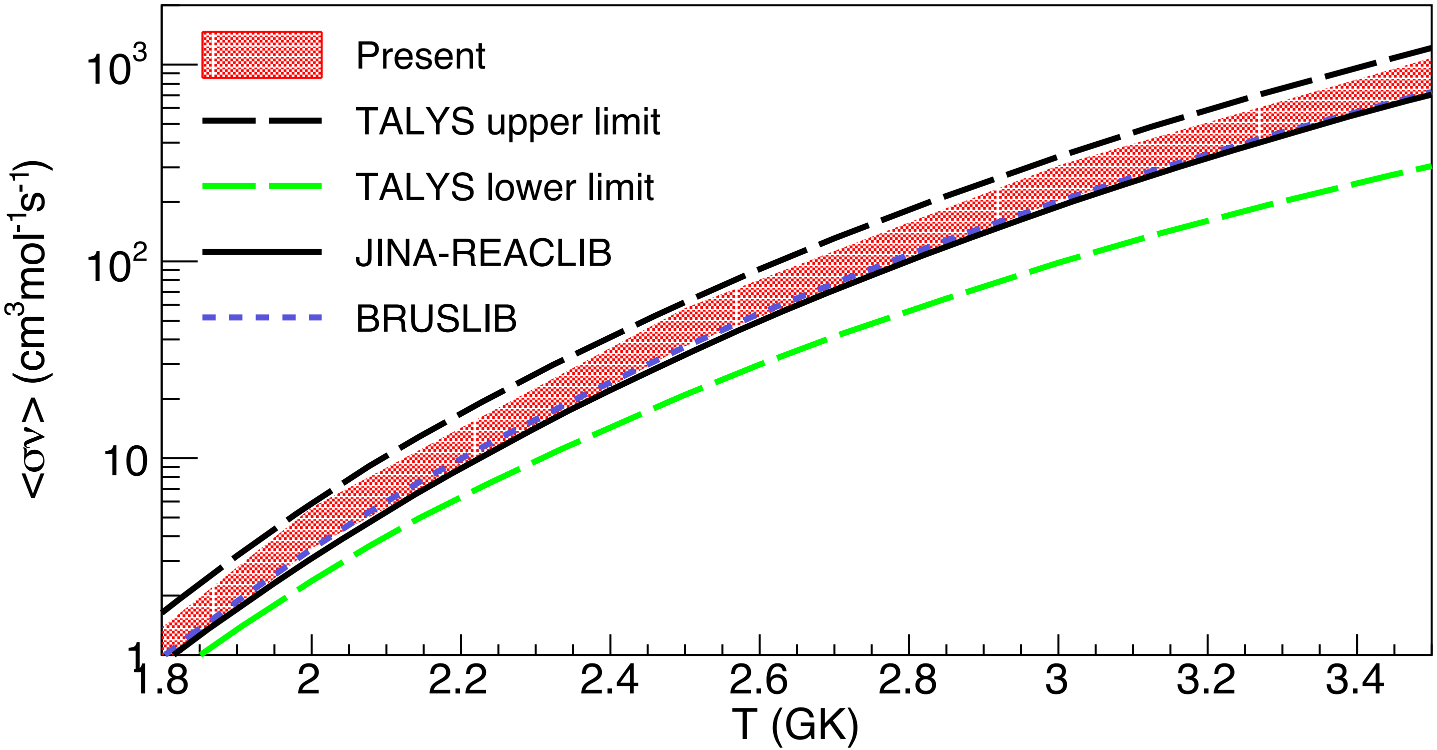


Here too, we needed to rely on systematics.

Are we able to connect with existing data above S_n?

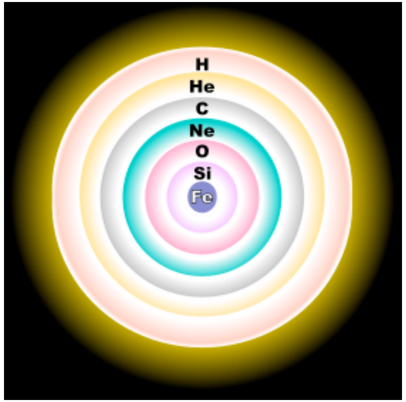
The (p,g) cross section and (p,g) and (g,p) Maxwellian averaged reaction rates were calculated using TALYS

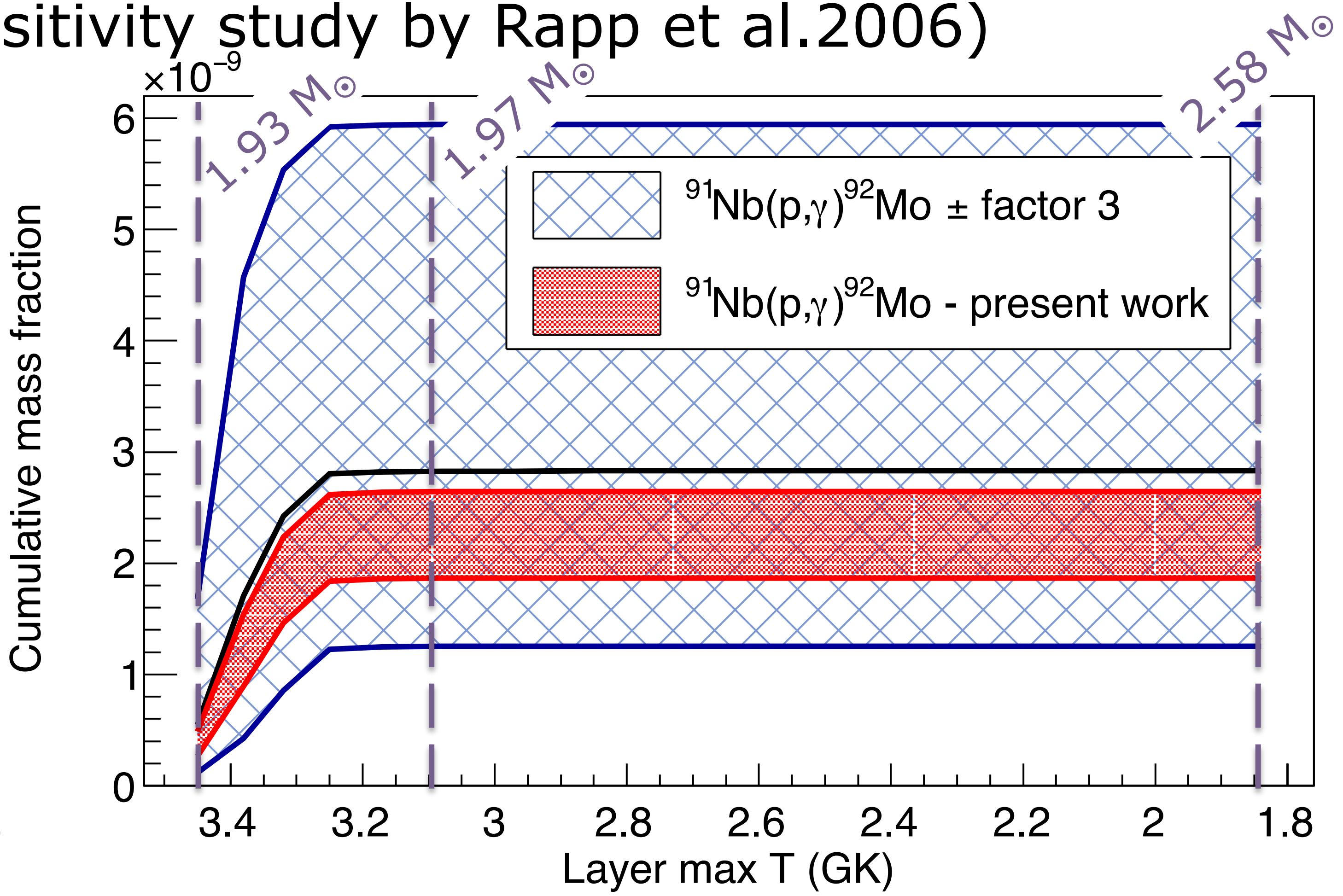
Input:
NLD and GSF models based on the experimental results



Nuclear reaction network calculations for 14 layers (as in the sensitivity study by Rapp et al.2006)

25 M$_\odot$ star
O-Ne layers
NucNet Tools





Tveten et al.
PRC 94, 025804 (2016)
arXiv:1605.07012

Collaborators, thanks!
Questions?

G. M. Tveten,[1,*] A. Spyrou,[2,3,4] R. Schwengner,[5] F. Naqvi,[2,4] A. C. Larsen,[1] T. K. Eriksen,[1,6] F. L. Bello Garrote,[1] L. A. Bernstein,[7] D. L. Bleuel,[7] L. Crespo Campo,[1] M. Guttormsen,[1] F. Giacoppo,[1,8,9] A. Görgen,[1] T. W. Hagen,[1] K. Hadynska-Klek,[1,10] M. Klintefjord,[1] B. S. Meyer,[11] H. T. Nyhus,[1] T. Renstrøm,[1] S. J. Rose,[1] E. Sahin,[1] S. Siem,[1] and T. G. Tornyi[6]

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[8] *Helmholtz Institute Mainz, 55099 Mainz, Germany*
[9] *GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany*
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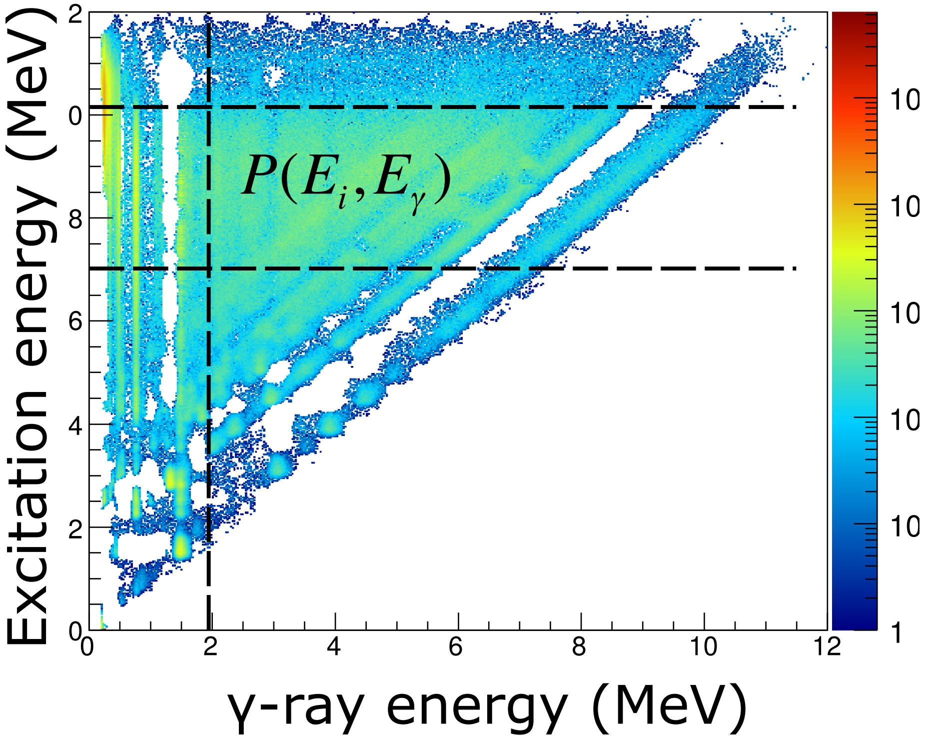
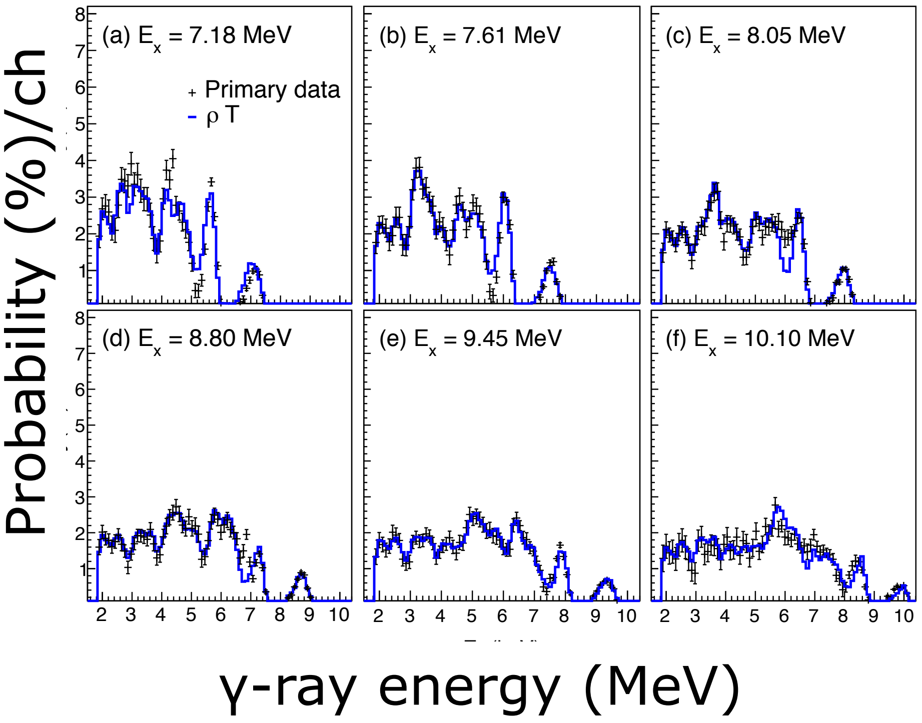
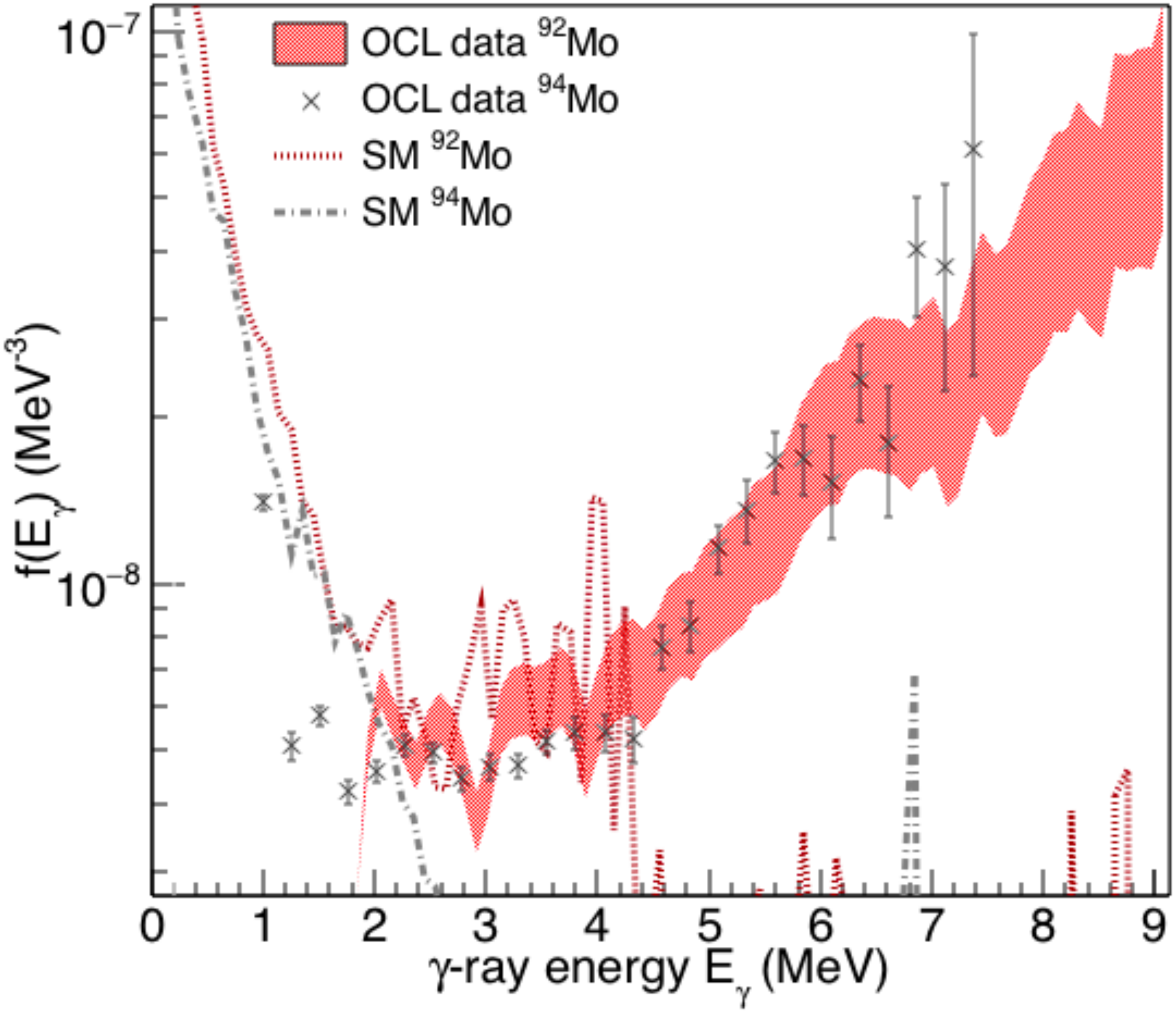
So, does it work?

$$P(E_i, E_\gamma) \propto \mathcal{T}(E_\gamma) \cdot \rho(E_f)$$

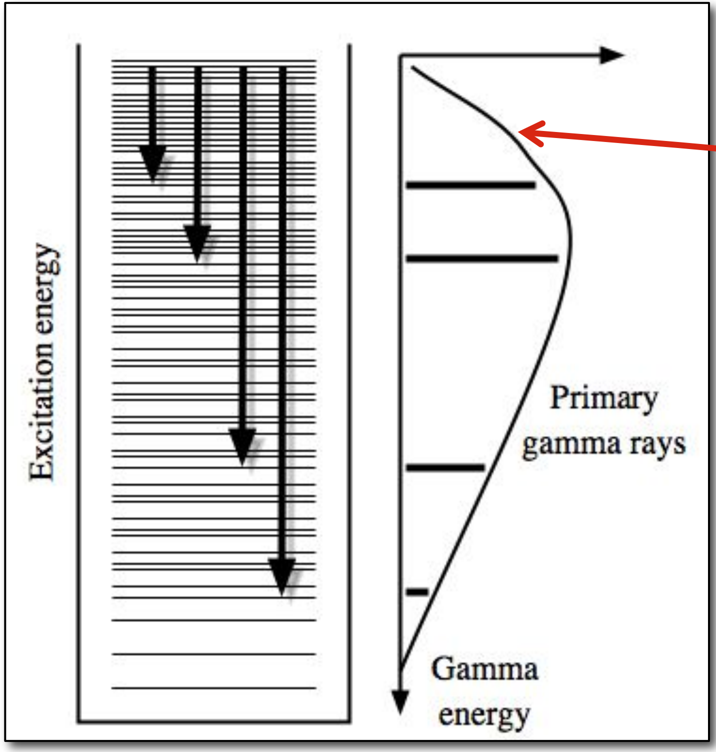






OCL data ^{92}Mo
OCL data ^{94}Mo
SM ^{92}Mo
SM ^{94}Mo
$f(E_\gamma)$ (MeV^{-3})
γ-ray energy E_γ (MeV)
10^{-7}
10^{-8}
0 1 2 3 4 5 6 7 8 9

$$\lambda = \frac{2\pi}{\hbar}\left|M_{if}\right|^2 \cdot \rho(E_f)$$



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