Exploring the Pygmy Dipole Resonance across the Sn mass region with the Oslo method

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NNRC

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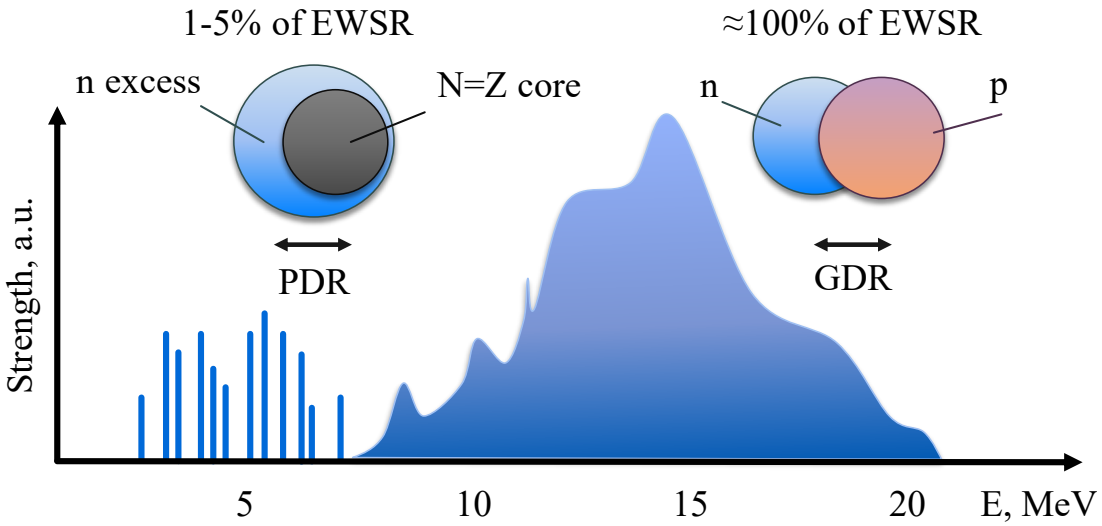
NORWEGIAN NUCLEAR RESEARCH CENTRE

The pygmy dipole resonance in nuclei



- Macroscopic picture: IVGDR originates from collective, out-of-phase oscillations of protons against neutrons.
(enhancement of ≈ 100% of the EWSR).
Isovector mode!

- The PDR is associated with a low-lying E1 strength in the vicinity of the neutron threshold (several % of the EWSR).

- Macroscopic picture: the PDR is generated by oscillations of a neutron excess (skin) against an isospin saturated core (N = Z).

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Both the isovector (out-of-phase, IV) and the isoscalar (in-phase, IS) components are present!

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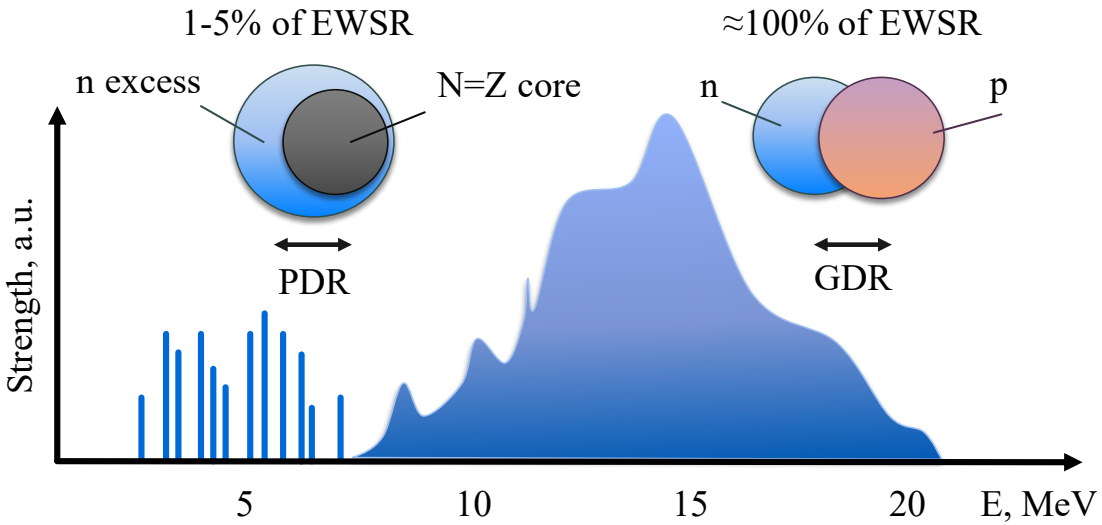

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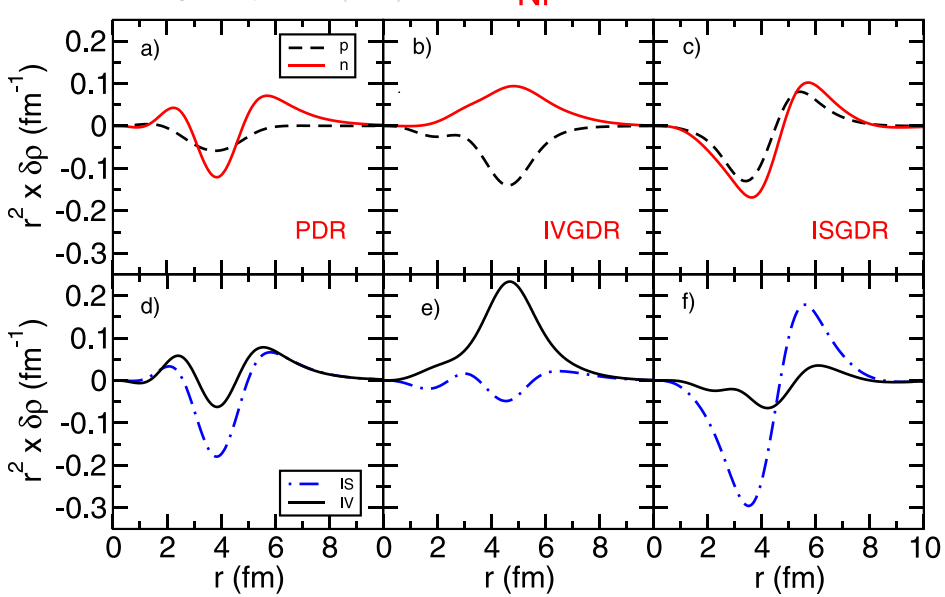

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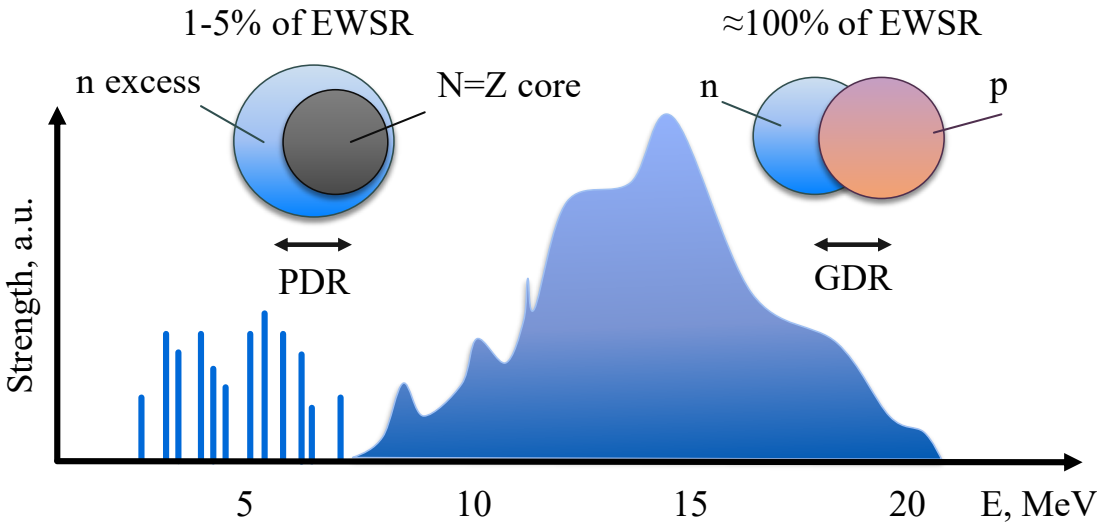

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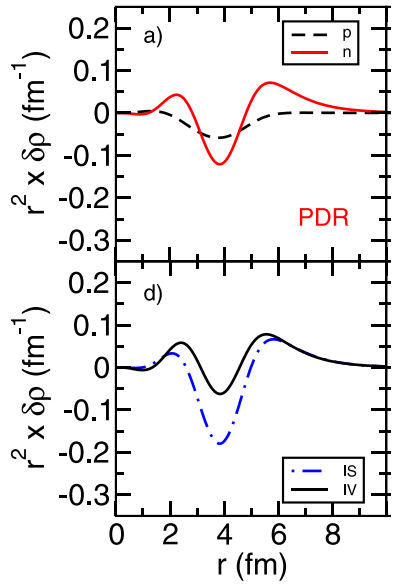

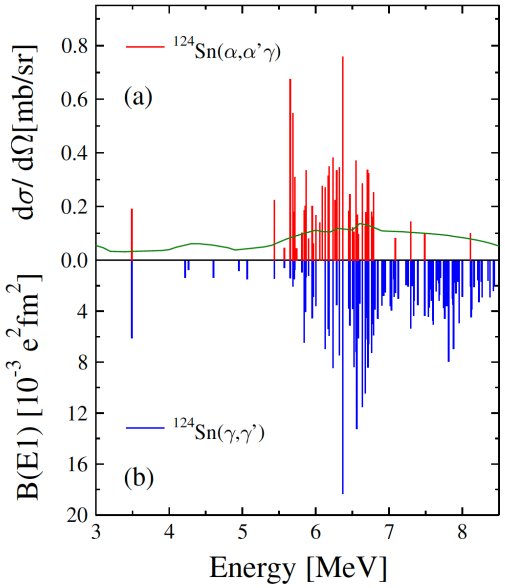

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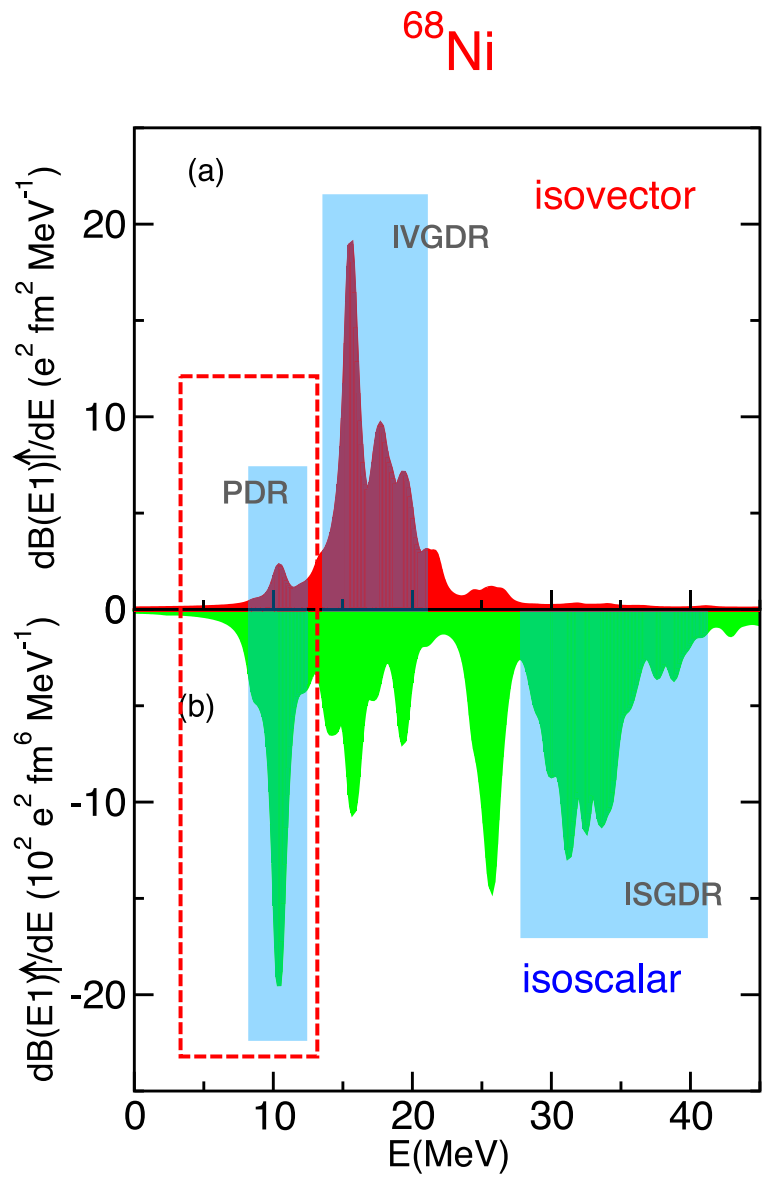

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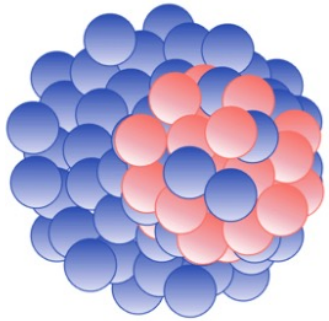
- Mixed isovector/isoscalar nature of the PDR.
- How "collective" is it?

  Collective IS component + Non-collective IV component
- To make things even more complicated:
- The toroidal dipole mode?
- Single-particle content of the low-lying E1 states?
- Impact of deformation?
- Pygmies of other multipolarities?



neutron skin picture

and many more...

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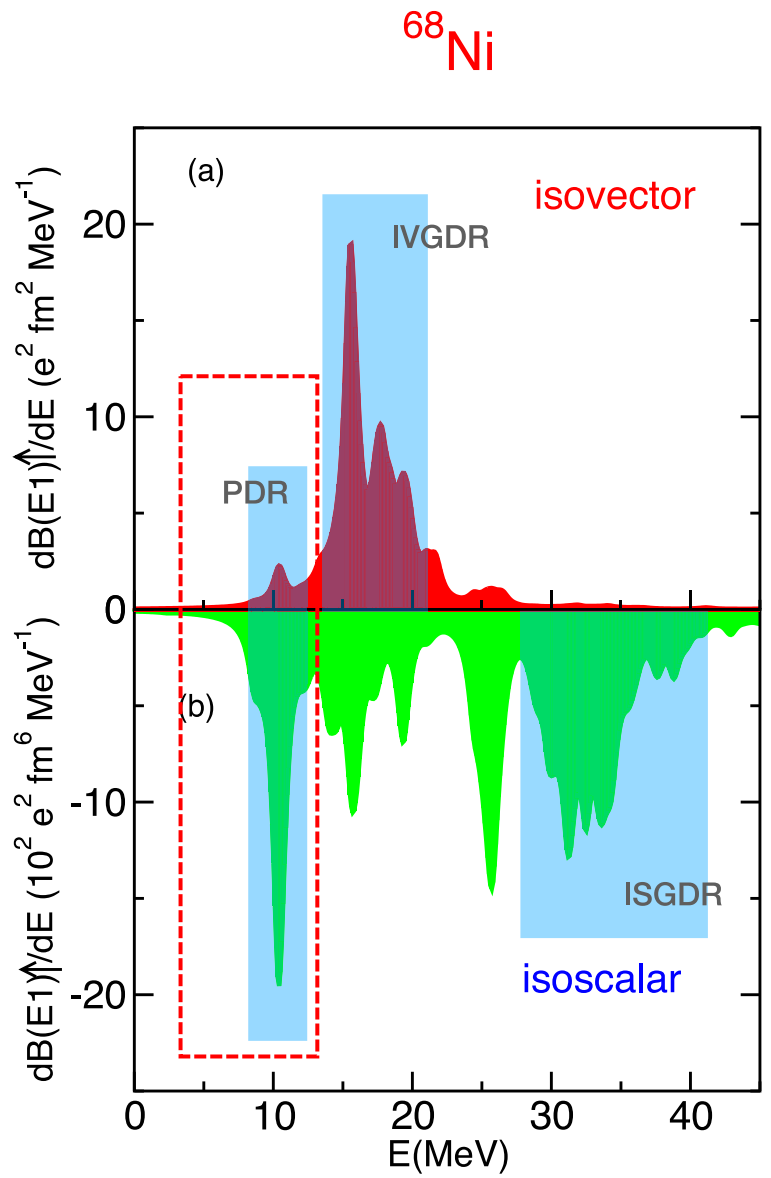

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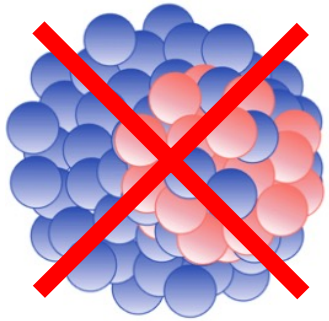

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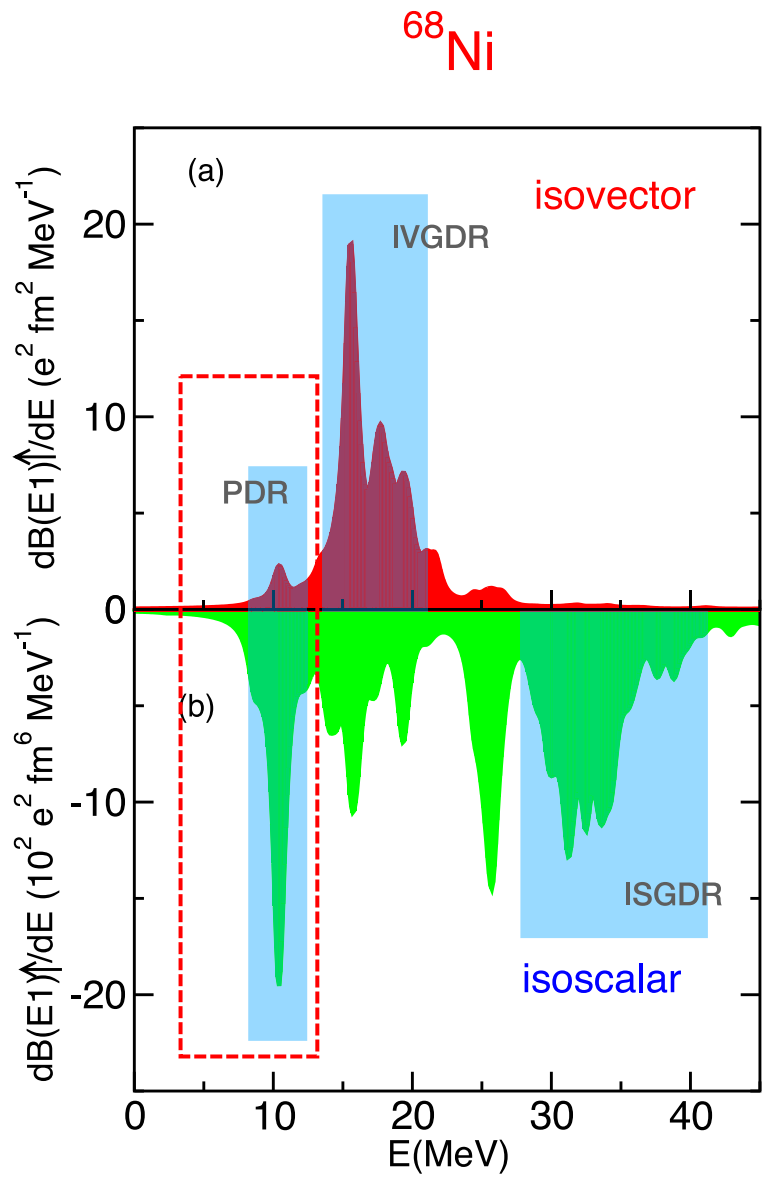

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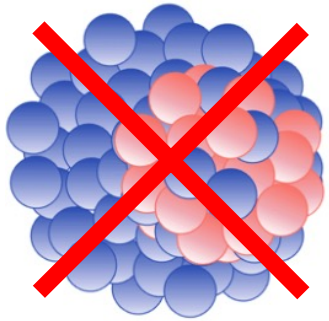

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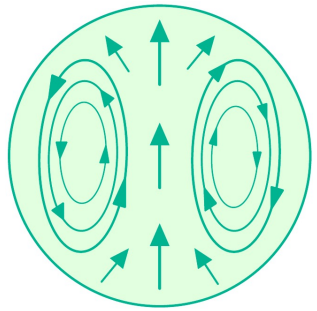

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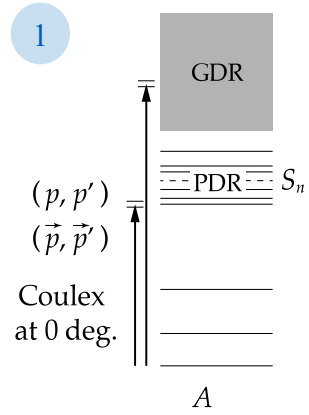
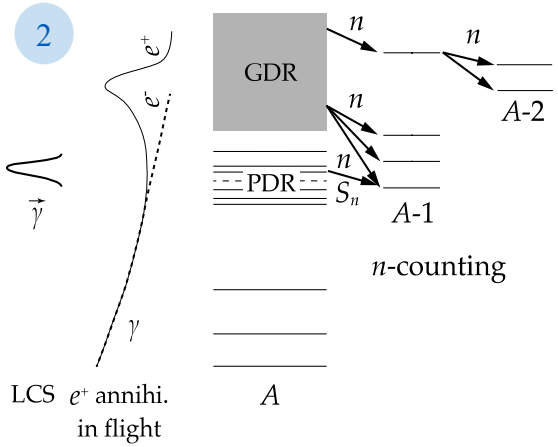
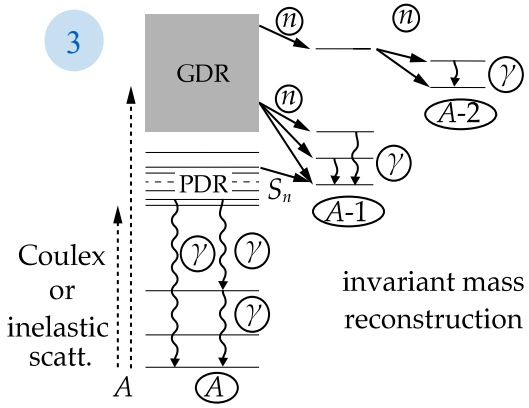


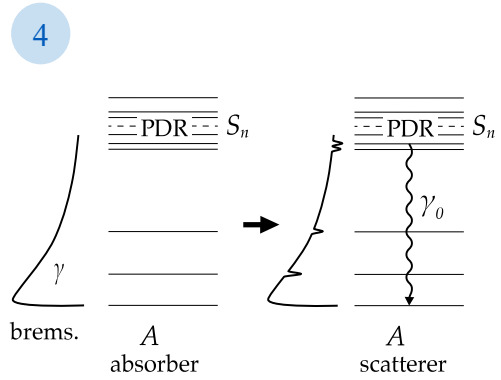
proton Coulex at 0 deg.



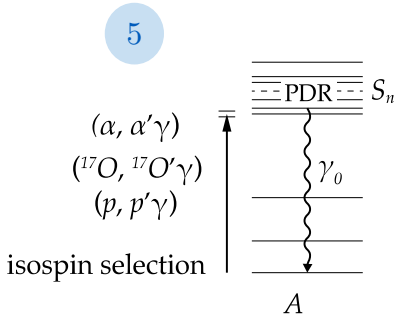
(γ, n), (γ, xn)



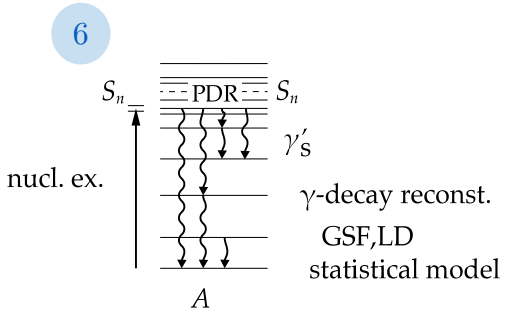
Coulex or inelastic scattering in inverse kinematics



Self-Absorption - NRF



nuclear excitation with γ coincidence



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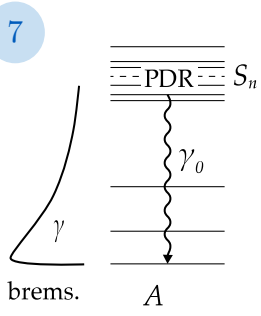
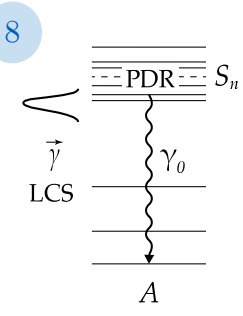
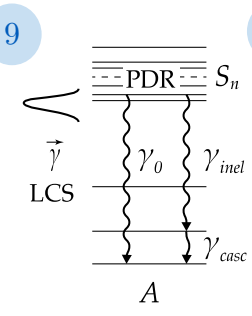


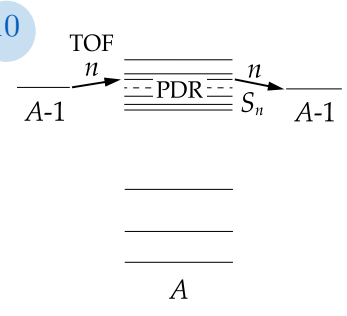
NRF with Brems.



NRF with LCS or tagged-photon



LCS γ^3



n-resonace scattering

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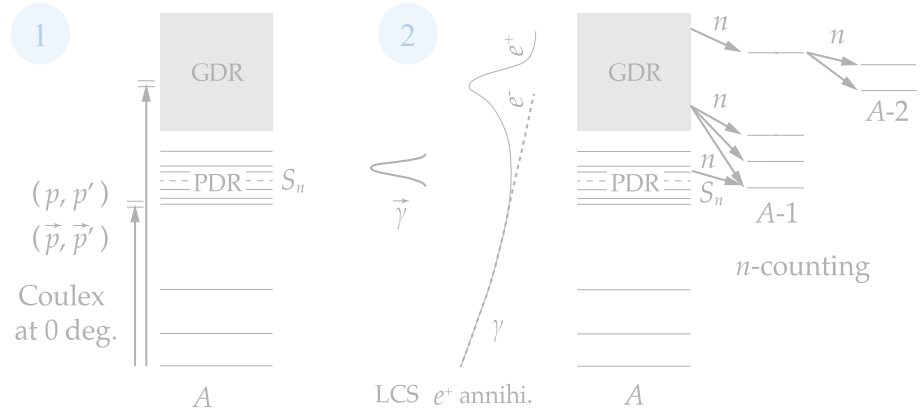

Consistency
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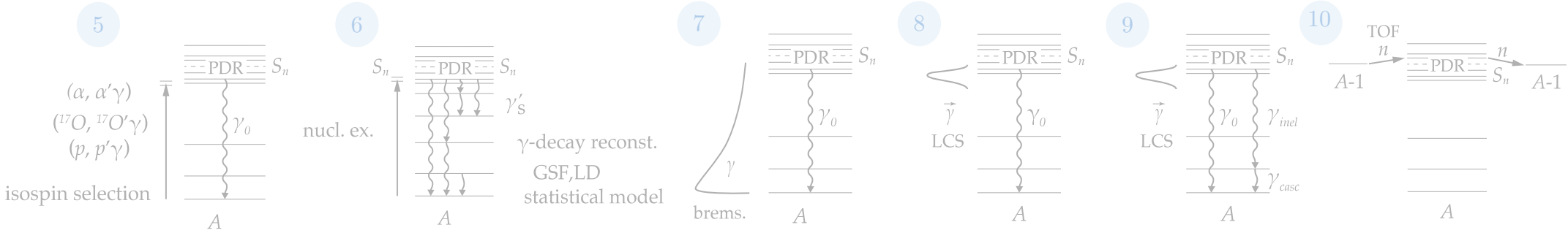

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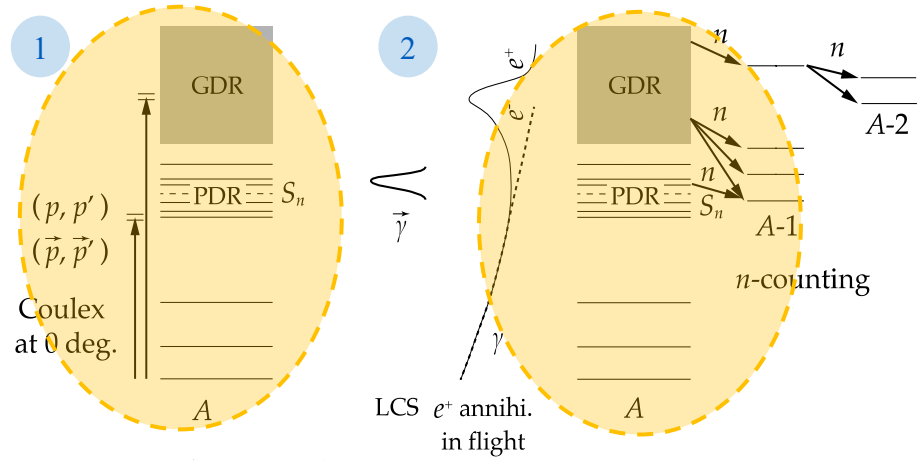

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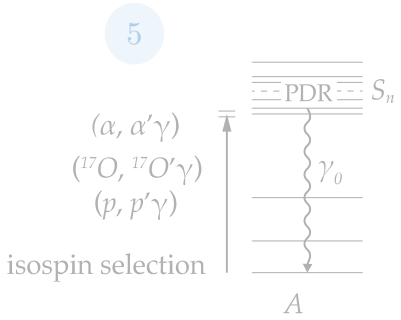

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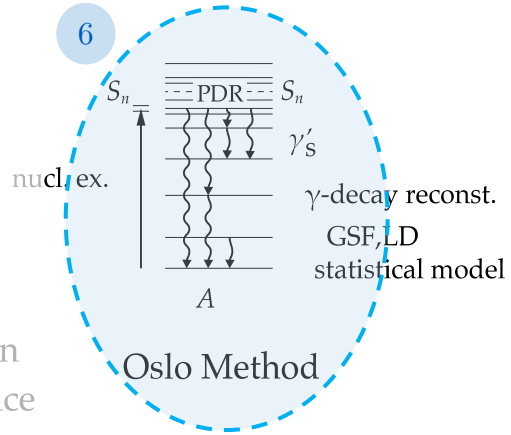

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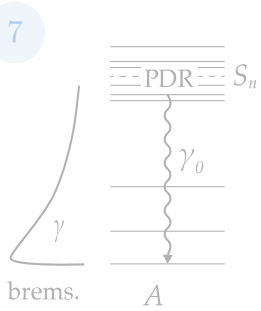

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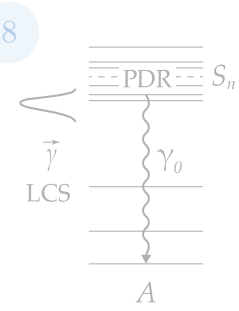

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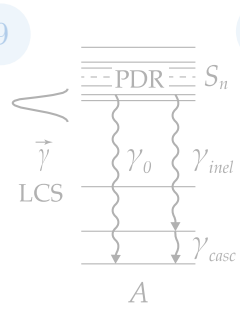

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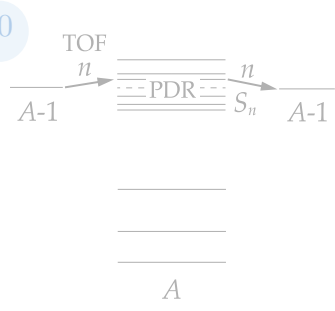

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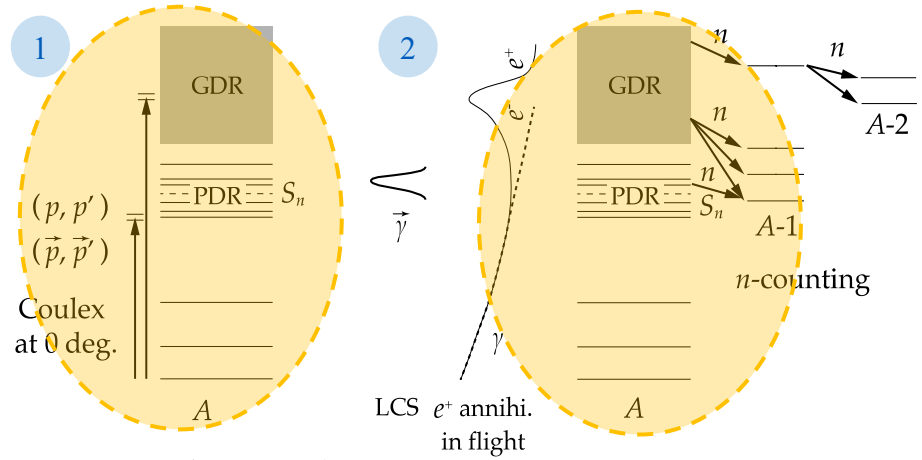

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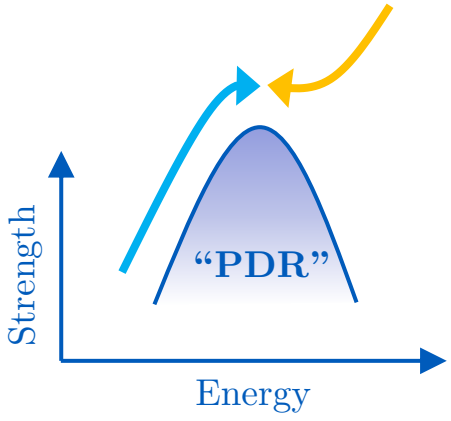

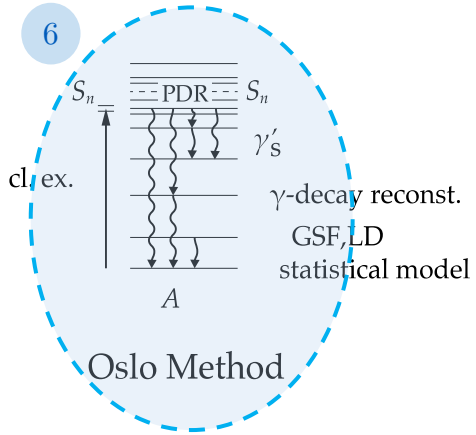

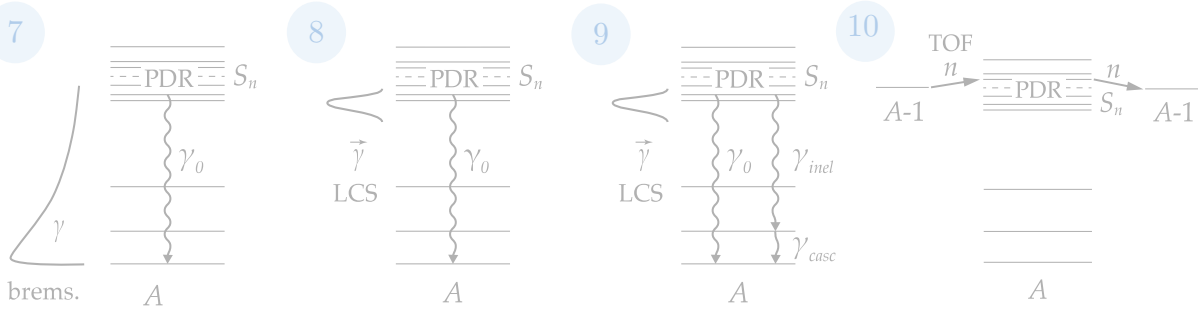

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Main ingredients of our study: NLD and GSF

- Gamma-ray strength function (GSF) and nuclear level density (NLD) are average properties of excited nuclei.

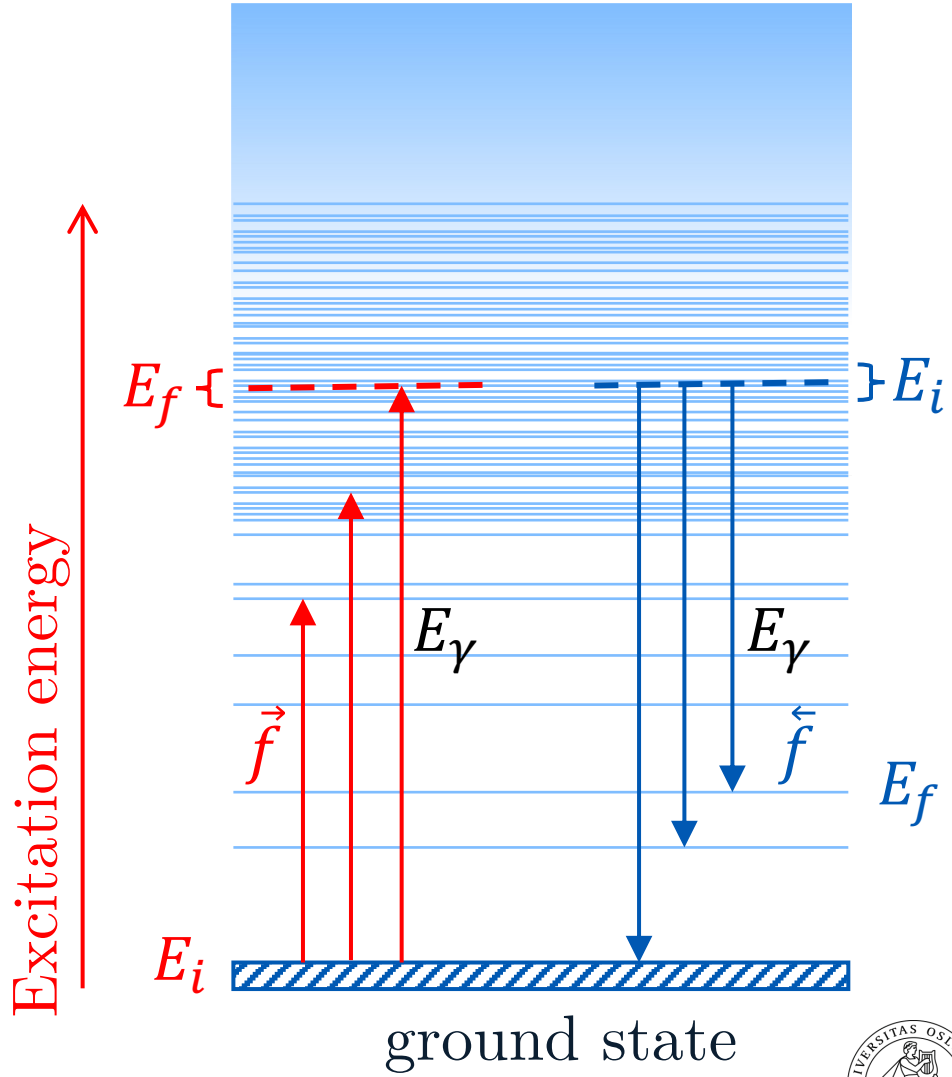
Averaged partial radiative width

$$f^{XL}_{i\to f} = \frac{\overline{\Gamma}_\gamma(i \to f, XL)}{E_\gamma^{2L+1}} \rho(E_f)$$

γ-ray energy — Density of final states

- Tells us about the distribution of γ–transition probability.

γ-decay: Downward strength $\overleftarrow{f}$



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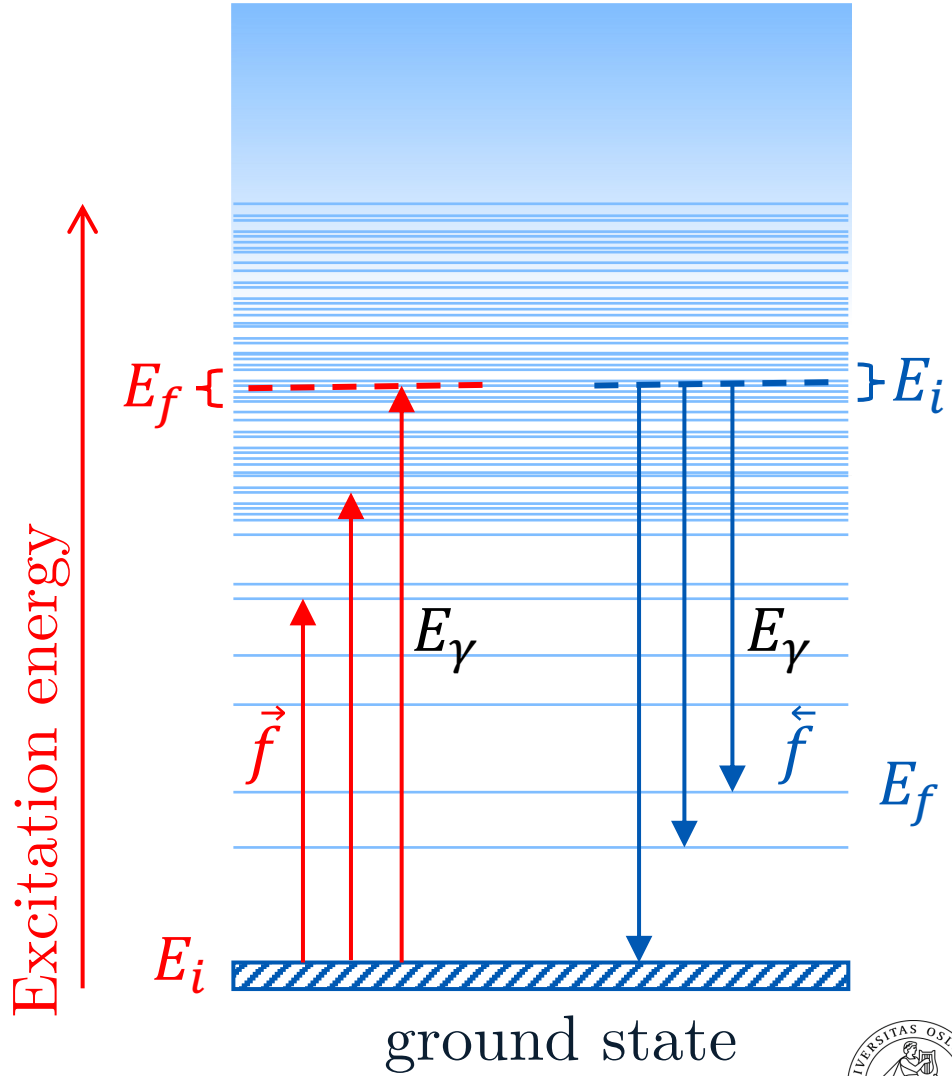
NLD, GSF → Statistical-model calculations → (n,γ) rates



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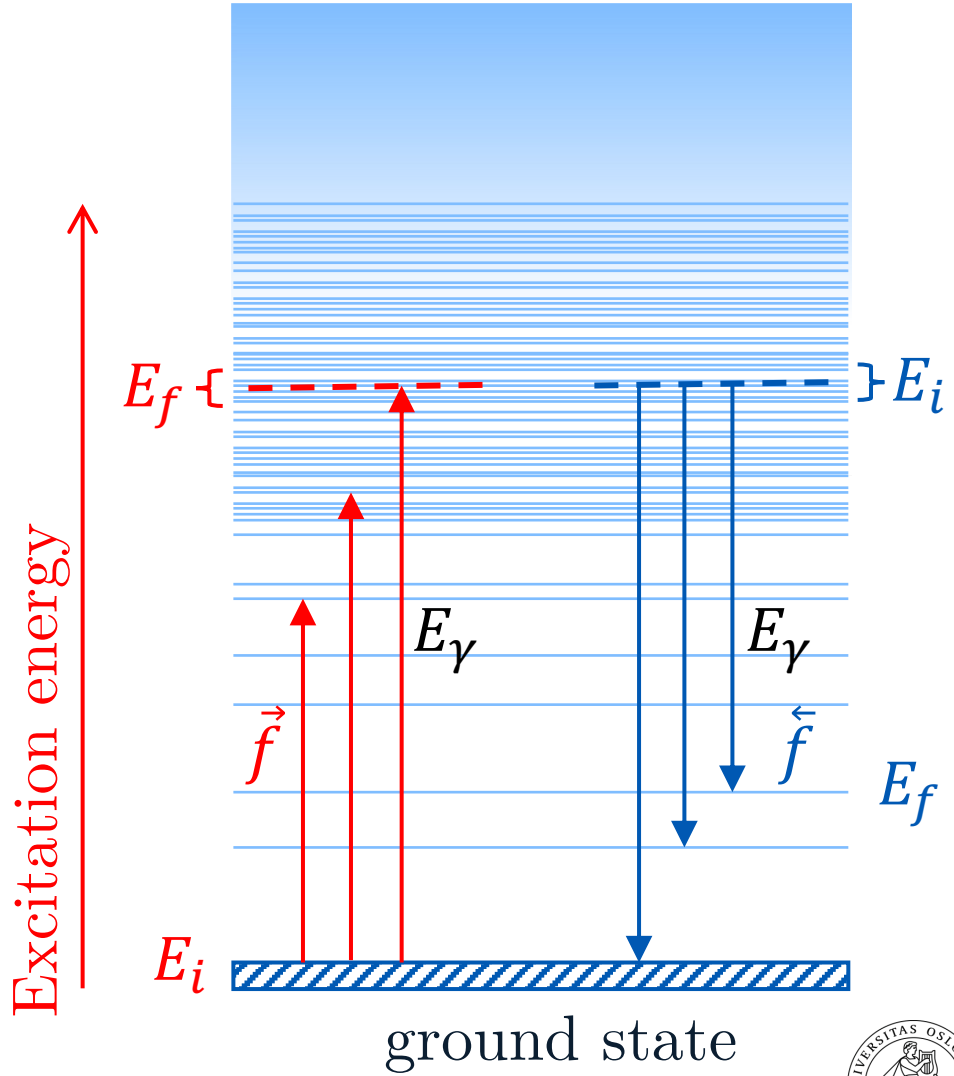
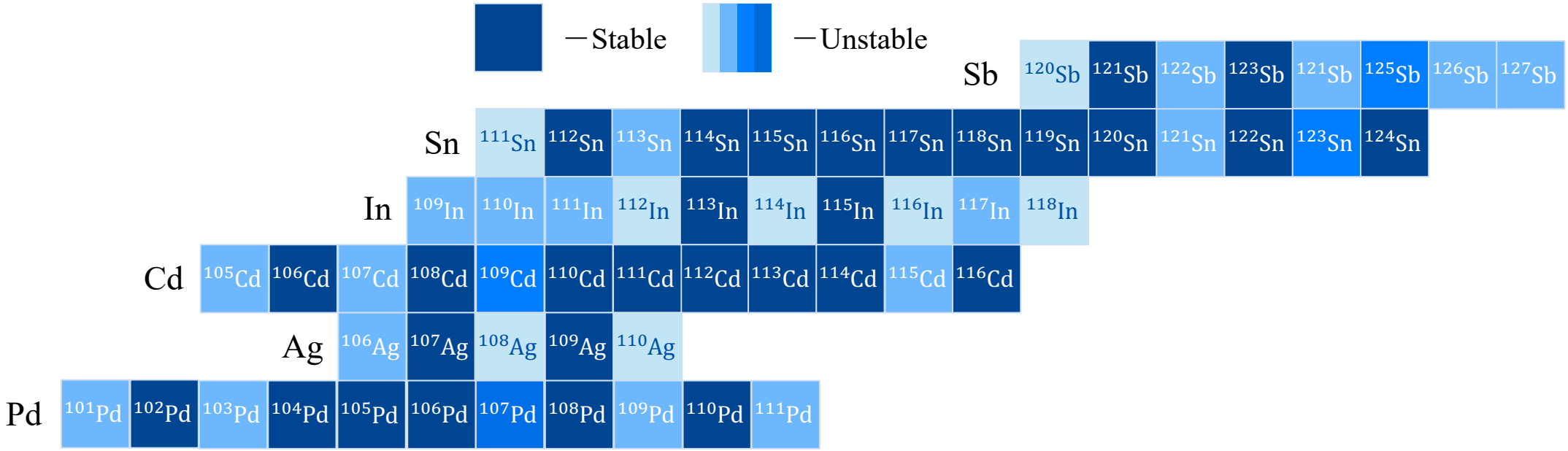


Isotopes studied at the OCL



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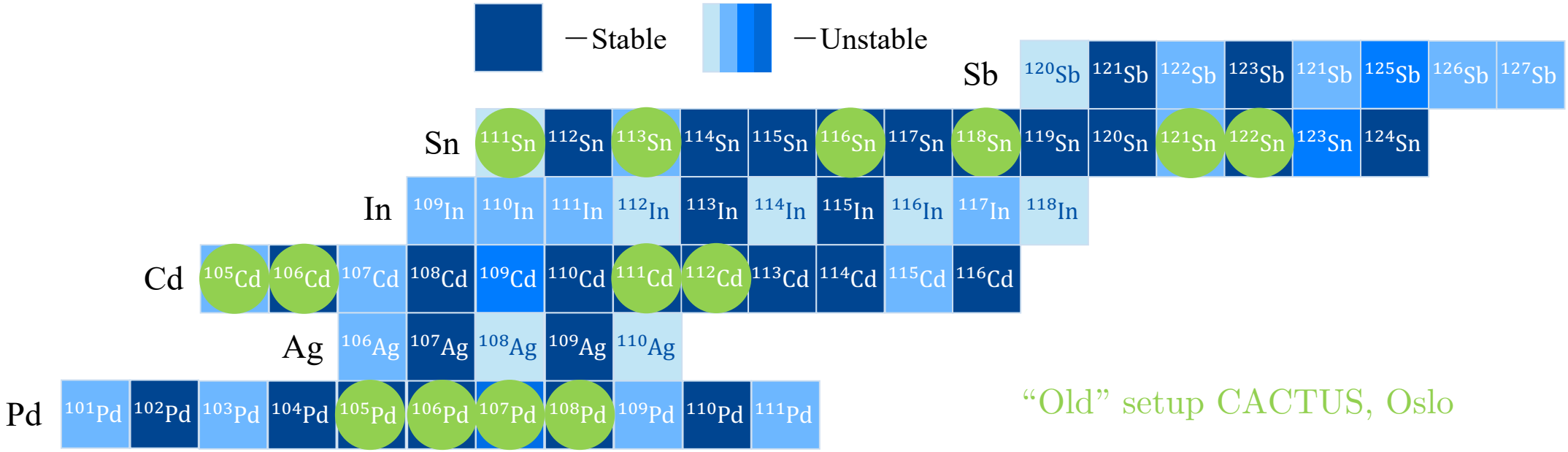

"Old" setup CACTUS, Oslo

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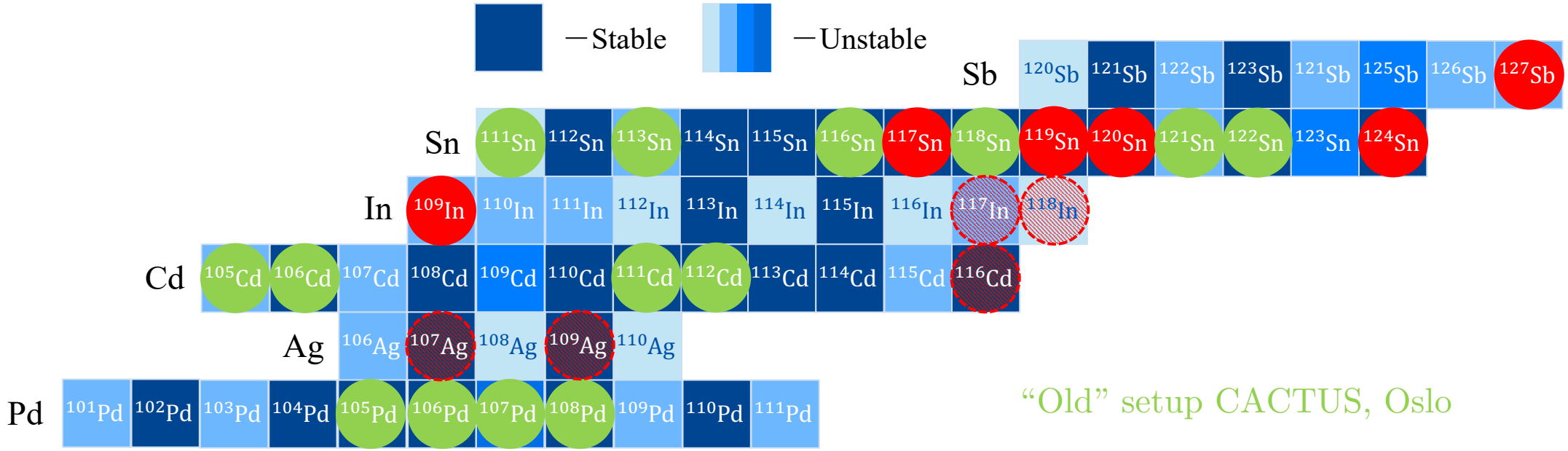

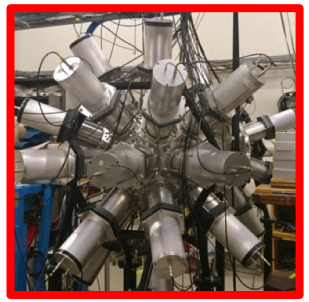

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"New" setup OSCAR, Oslo

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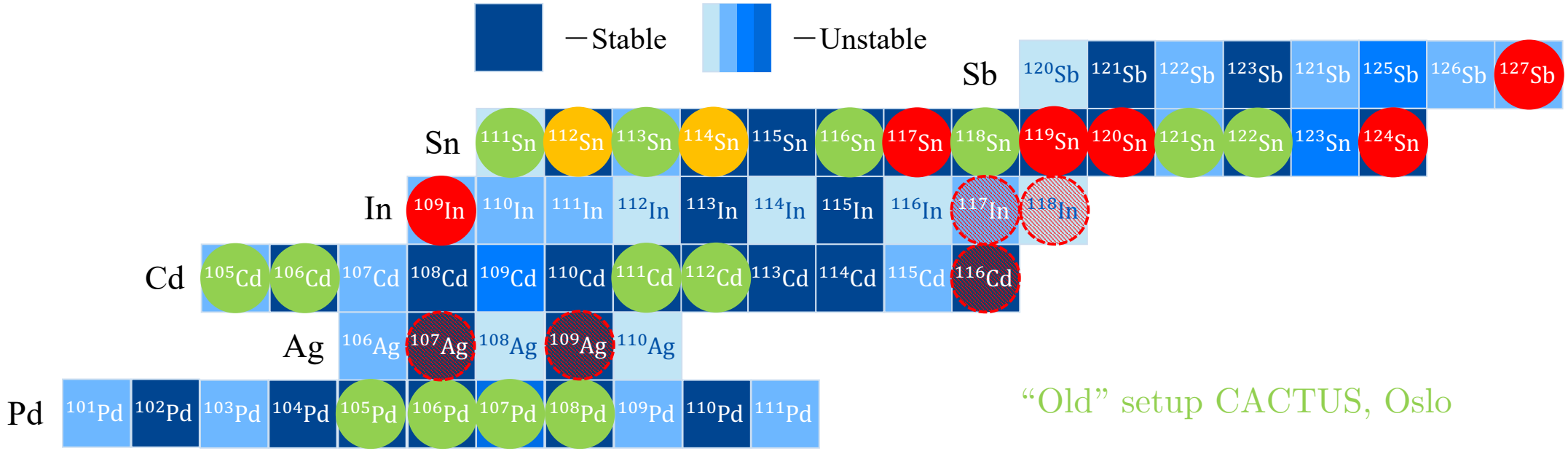
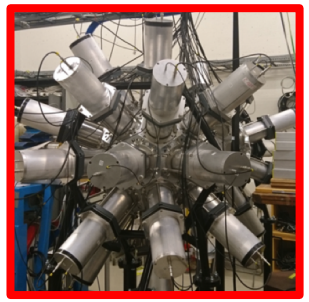
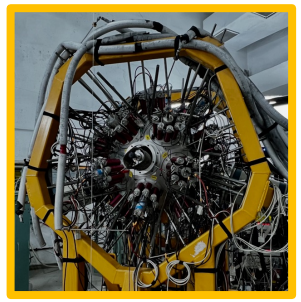




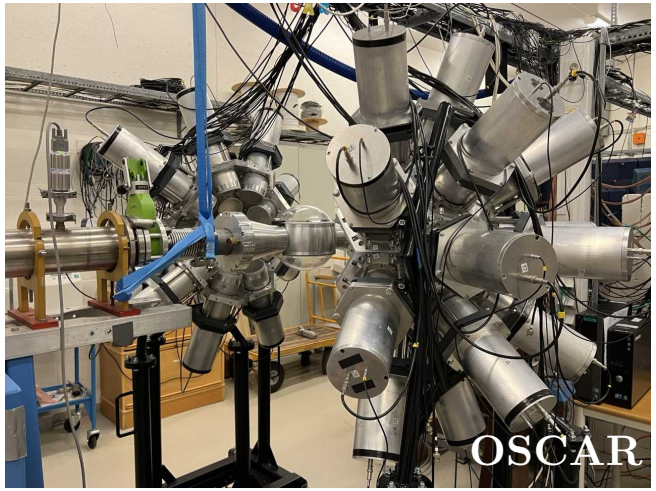


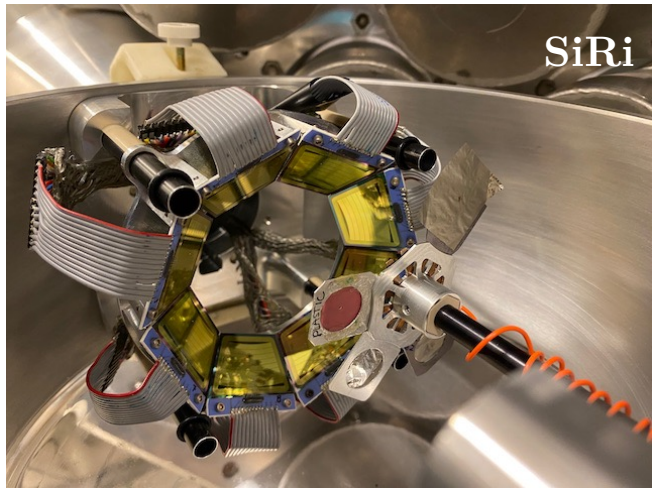
"Old" setup CACTUS, Oslo

"New" setup OSCAR, Oslo

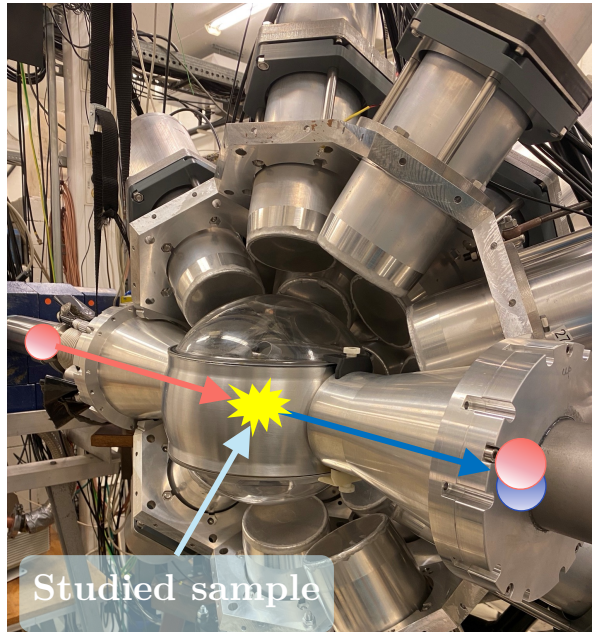
"New" setup, ELI-NP/IFIN-HH

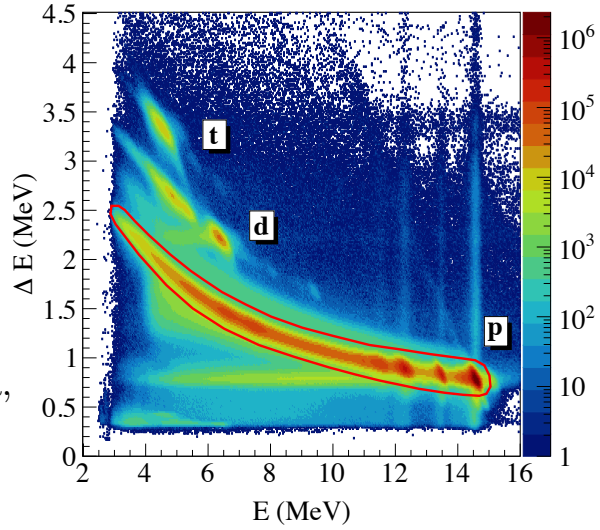
Experiments at the OCL

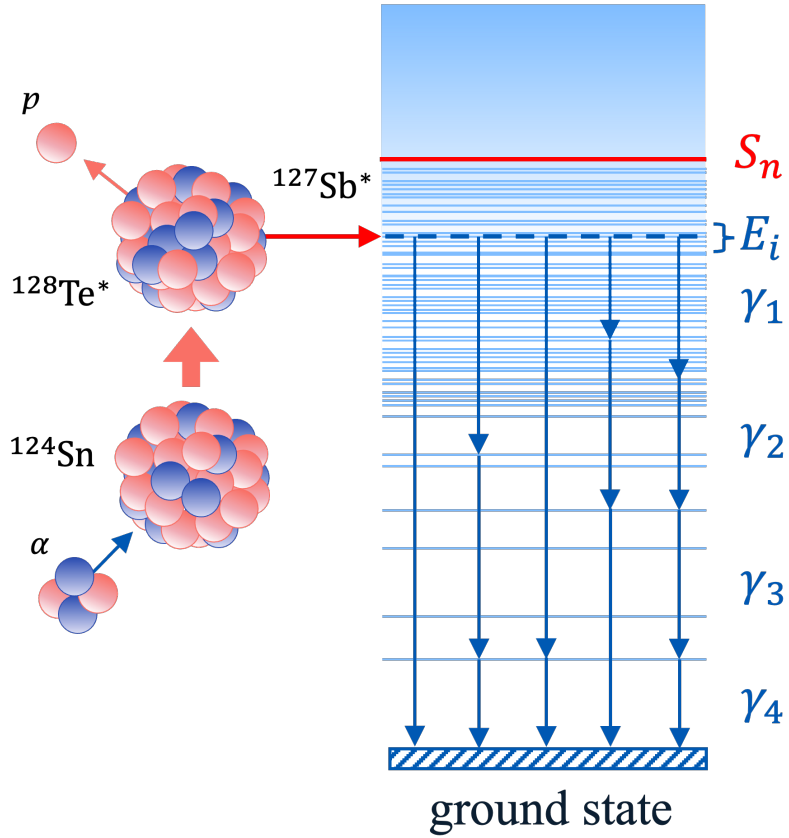




SiRi Si particle telescope + NaI(Tl) (CACTUS, older)/ LaBr3(Ce) (OSCAR, new) detector array.
126°-140° or 40°-54° particle angles are covered.

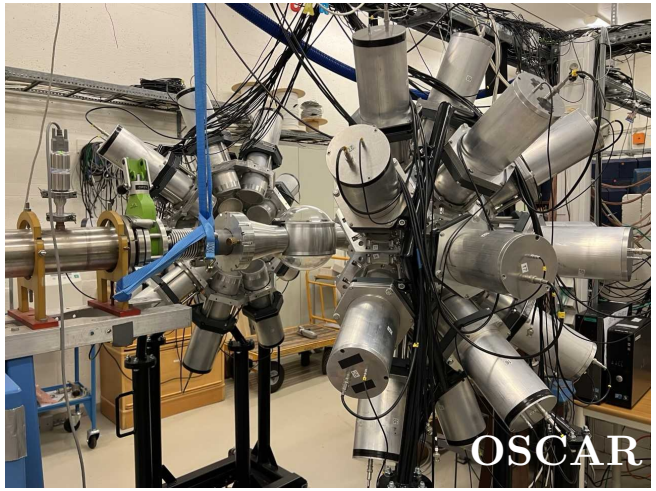


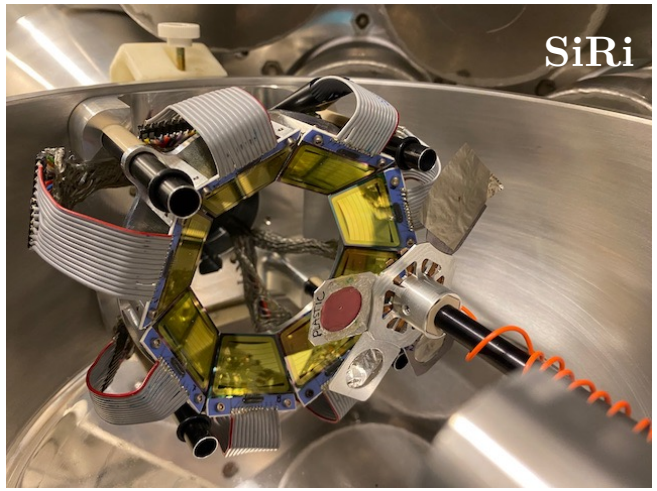




$(p, p'\gamma)$, $(p, d\gamma)$ with 16 and 25 MeV protons
$(d, p\gamma)$ with 11.5 MeV deuterons
$(^3\mathrm{He}, ^3\mathrm{He}\ \gamma)$, $(^3\mathrm{He}, \alpha\gamma)$ with 38 MeV ^{3}He
$(\alpha, p\gamma)$ with 23 and 24 MeV α

Experiments at the OCL





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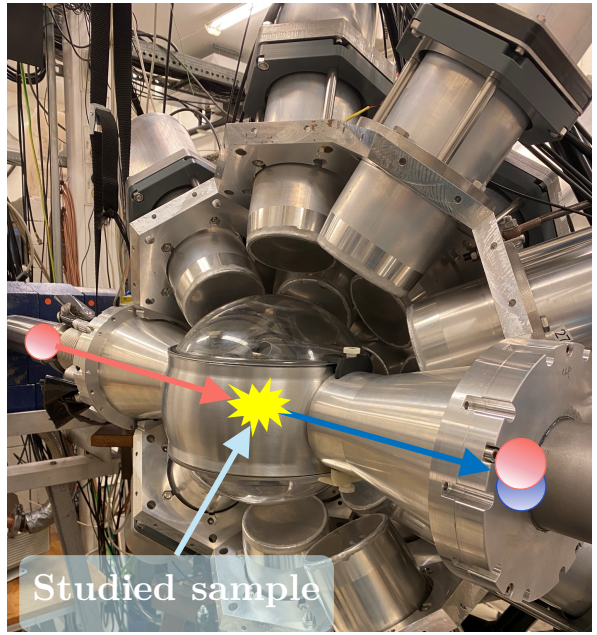

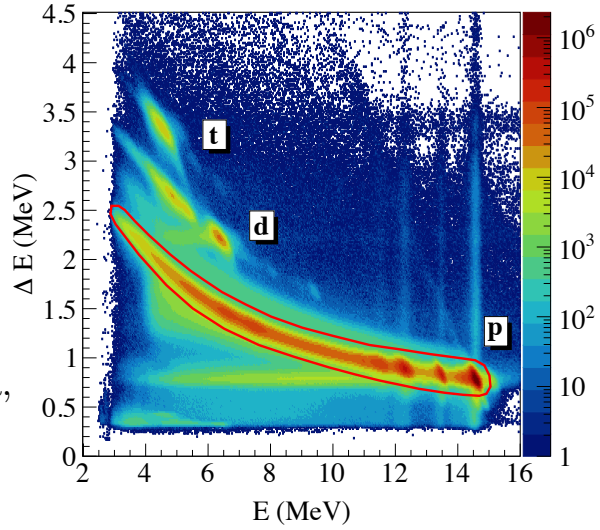

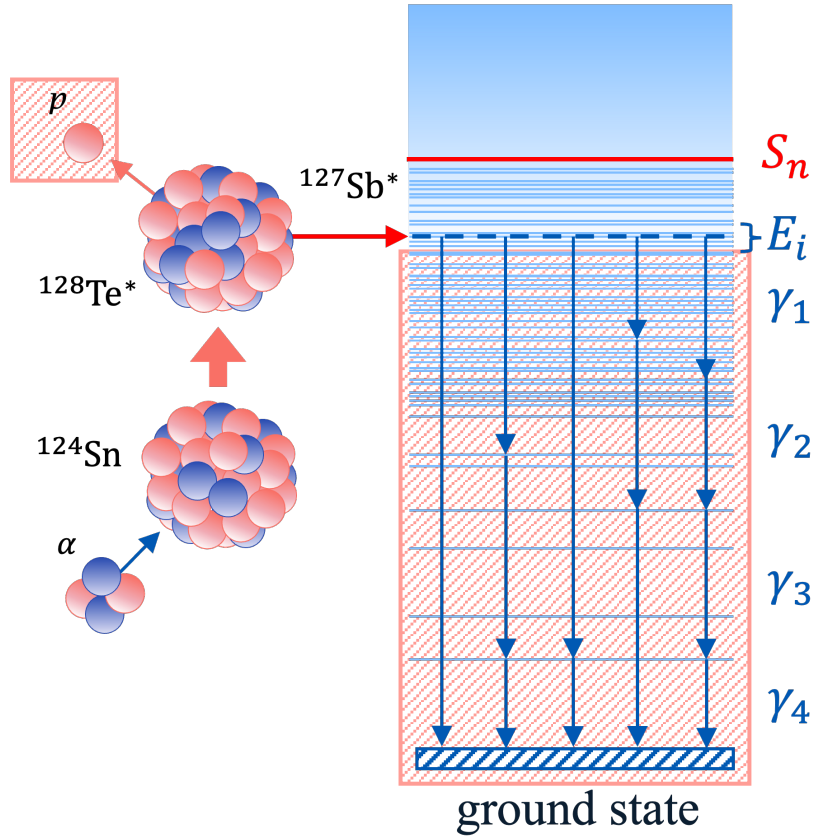

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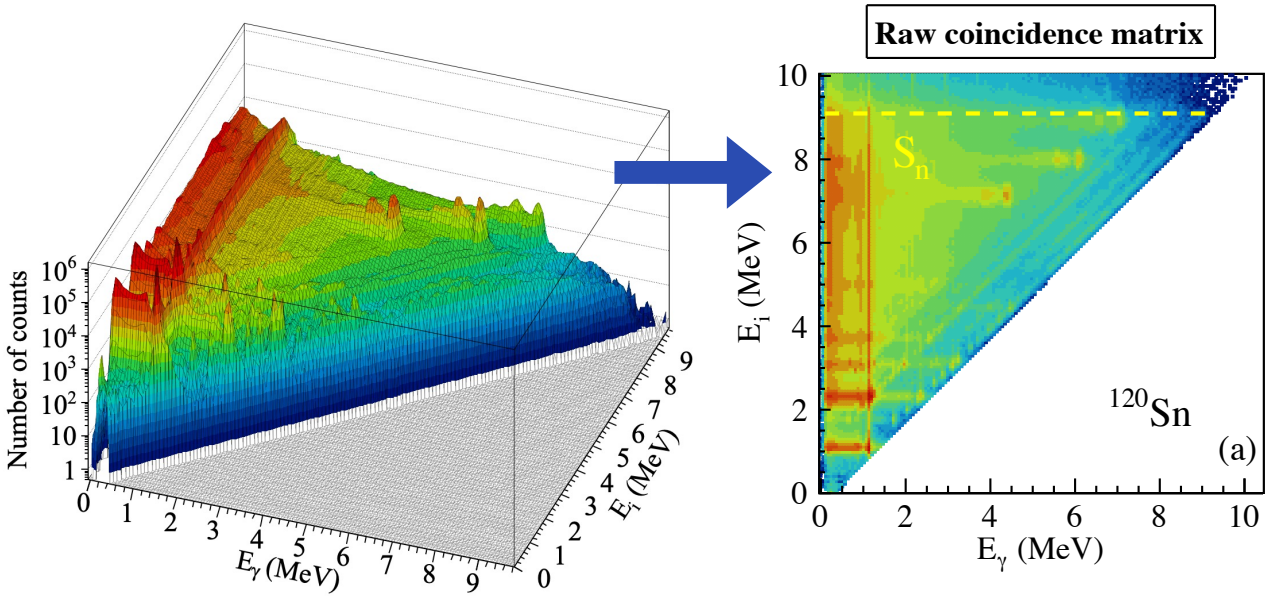
The Oslo method: step-by-step



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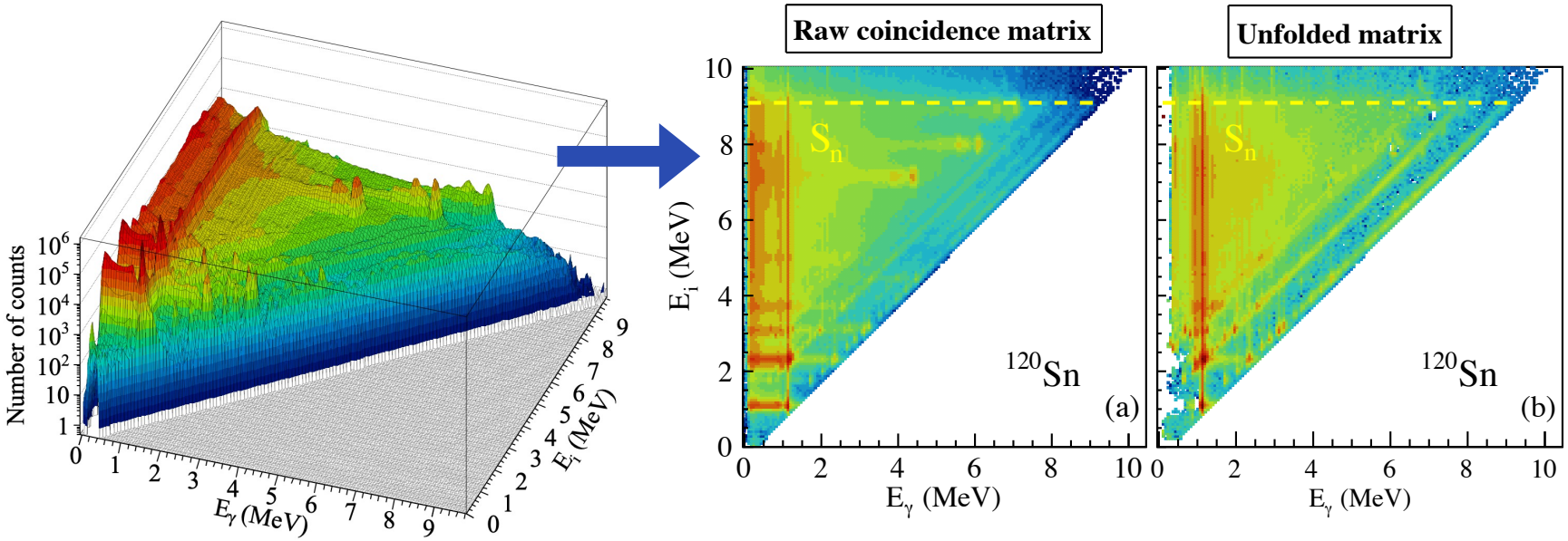

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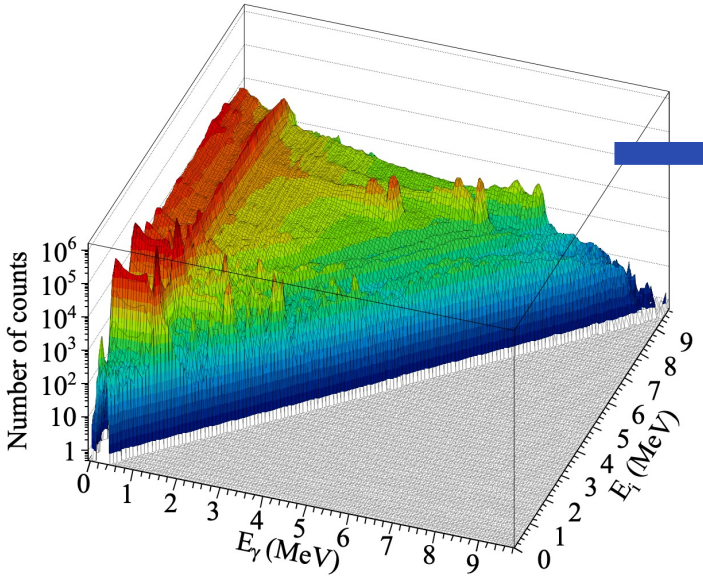

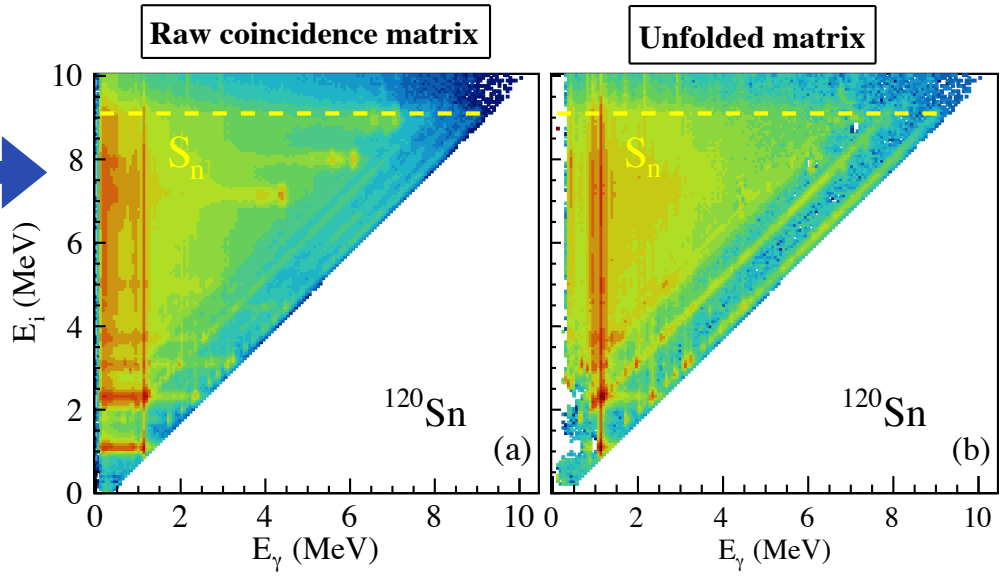

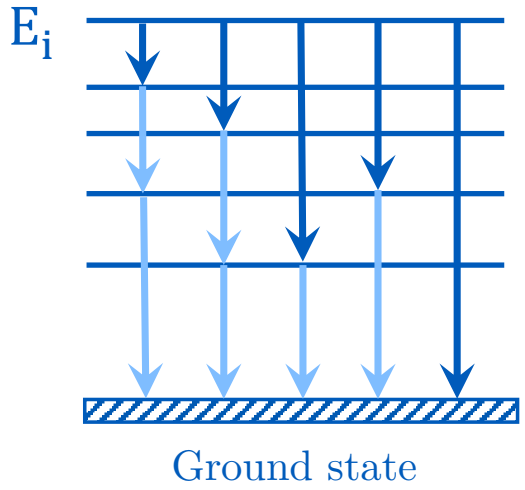

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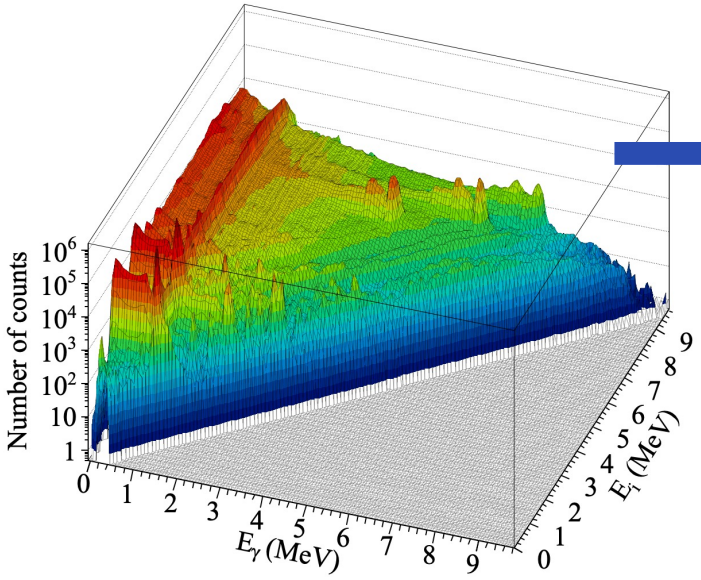

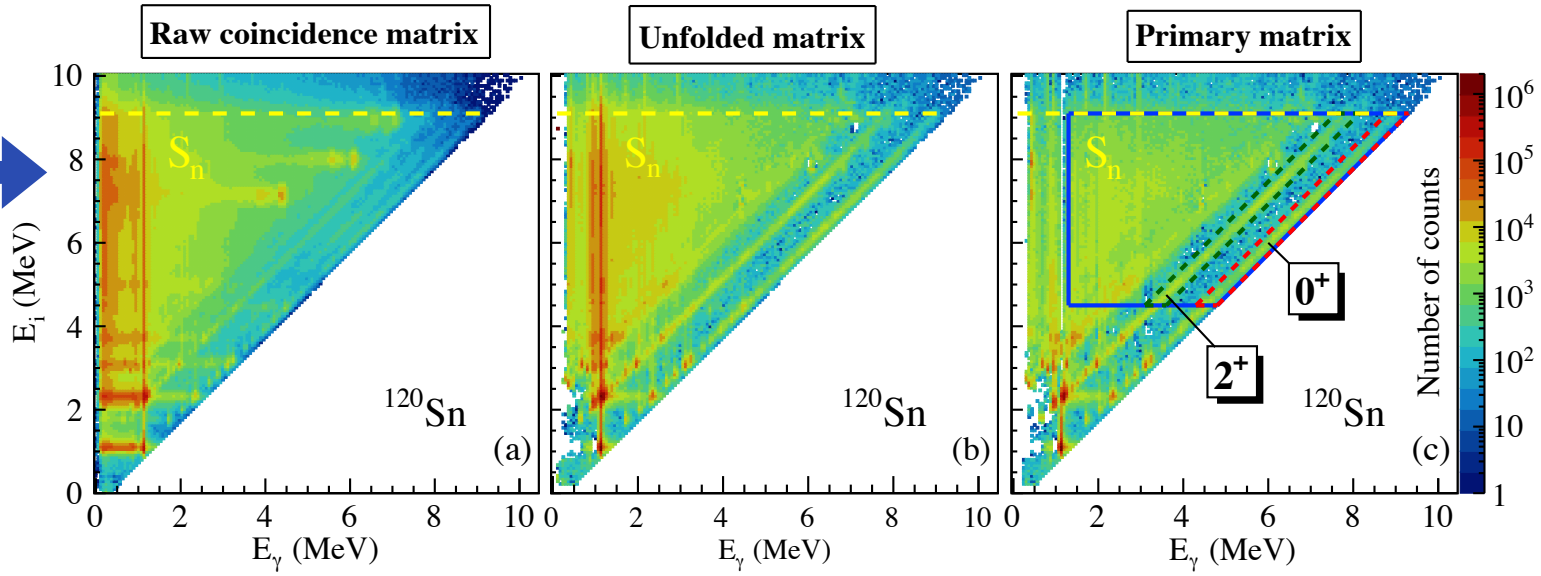

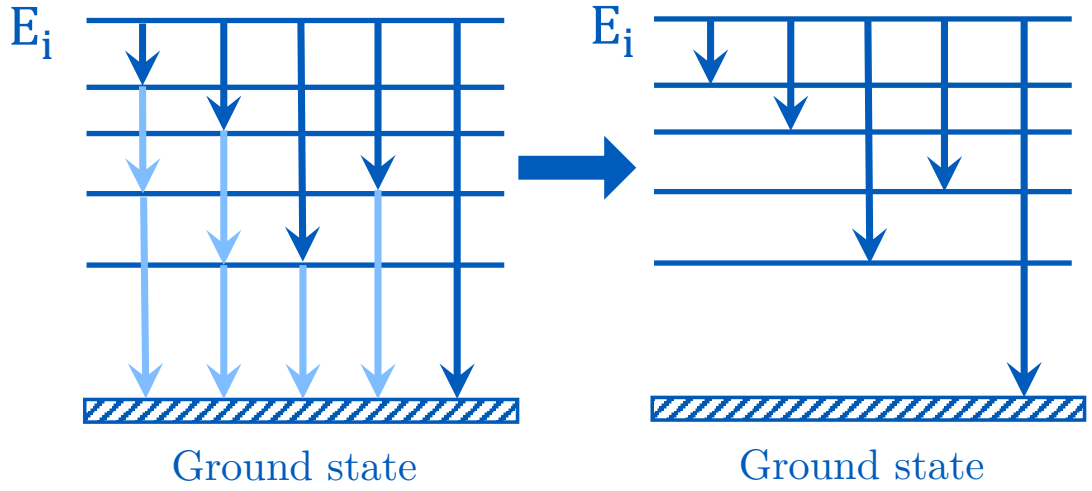

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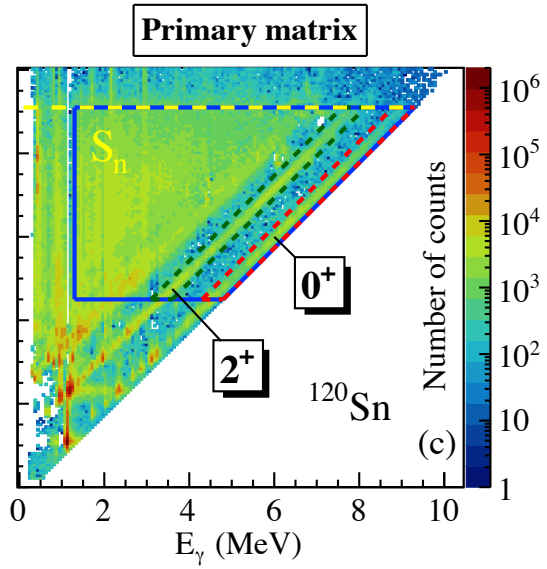

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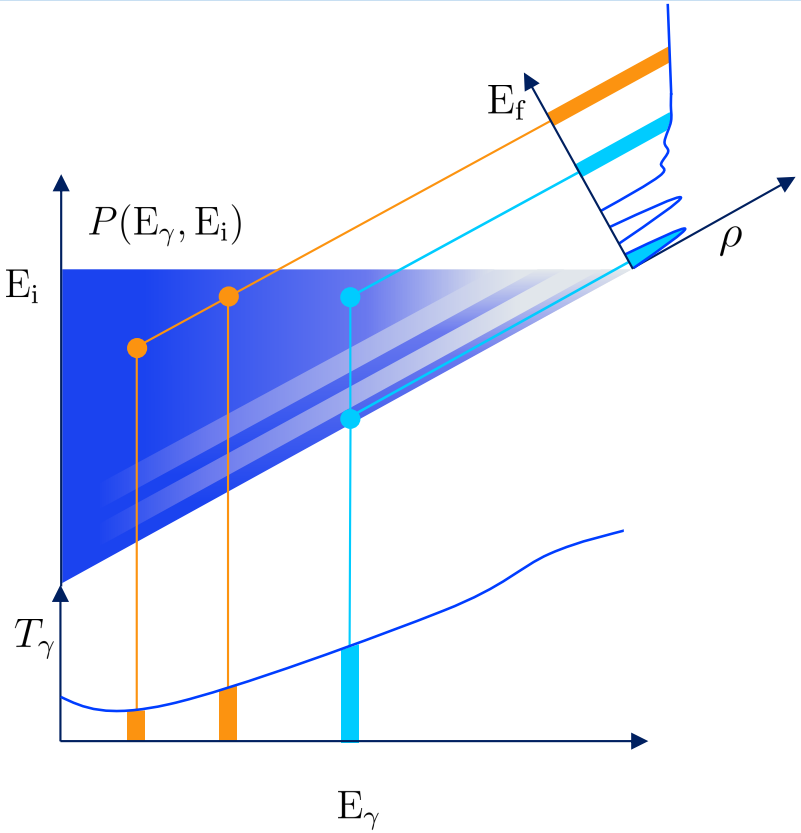
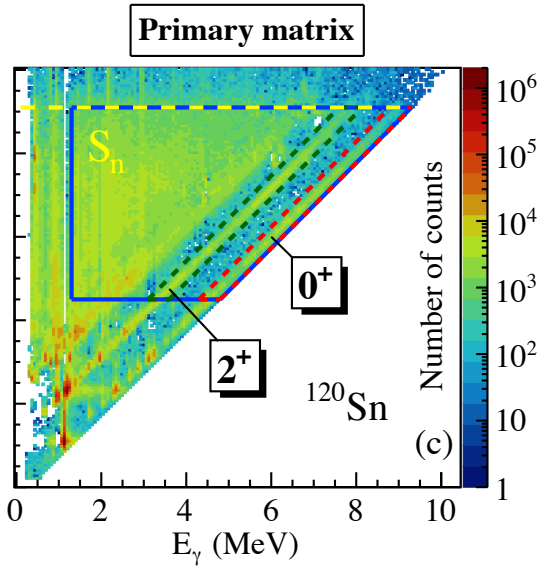


Brink-Axel hypothesis! ($\overrightarrow{f} \approx \overleftarrow{f}$)

$$P(E_\gamma, E_i) \propto \mathcal{T}_{i \to f} \cdot \rho_f$$

$$\mathcal{T}(E_\gamma) = 2\pi E_\gamma^3 f_\gamma(E_\gamma)$$

(dipole transitions)



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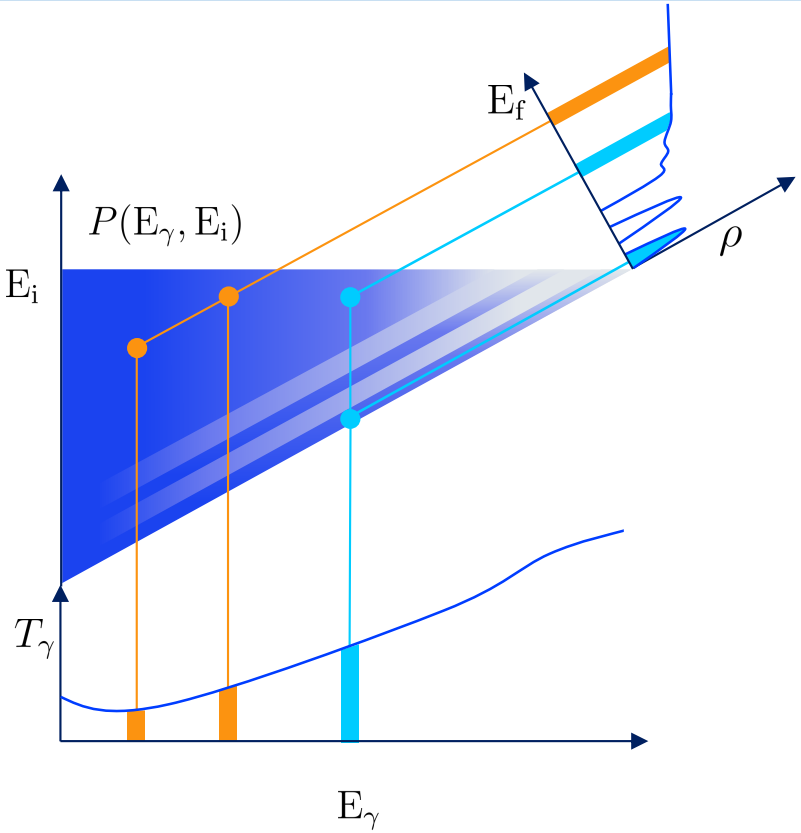

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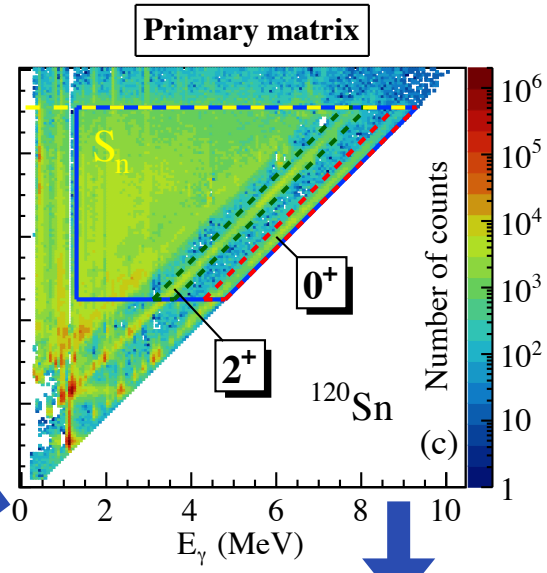

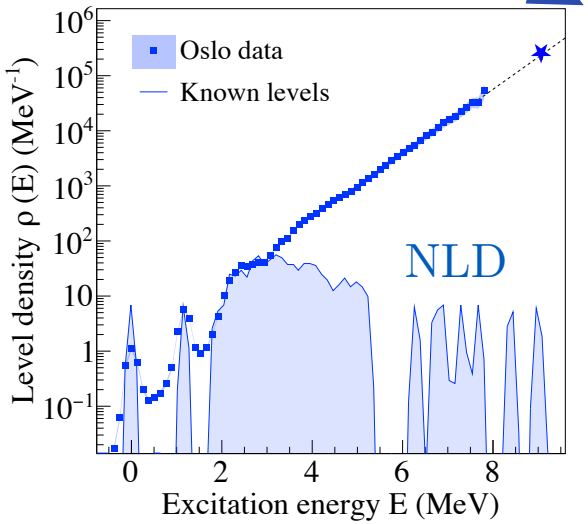

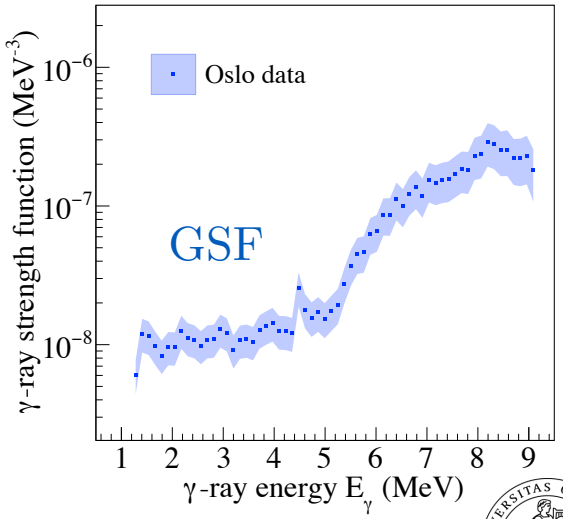

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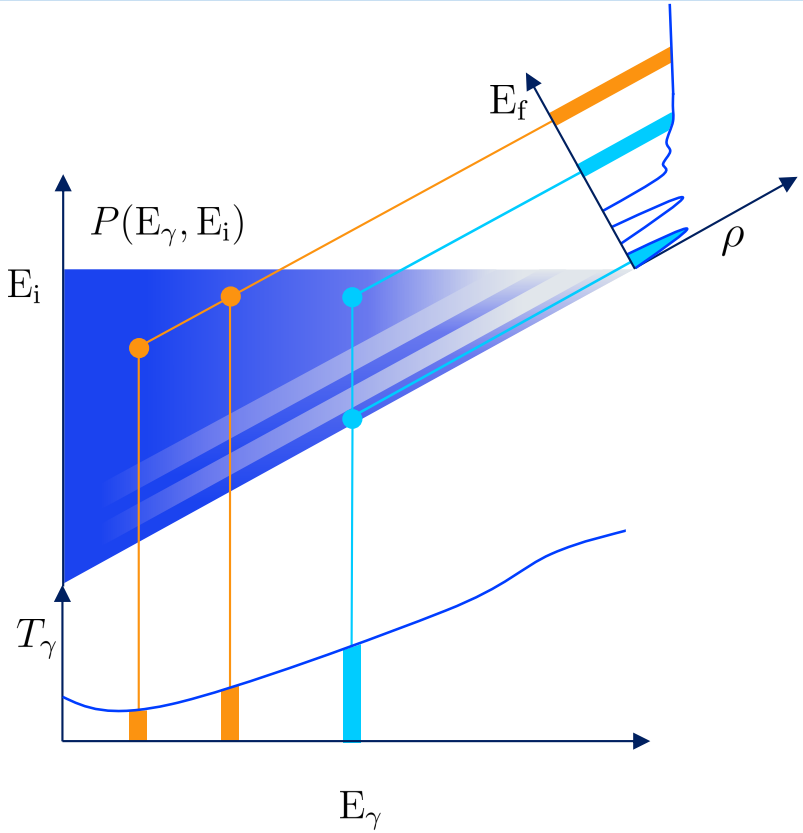

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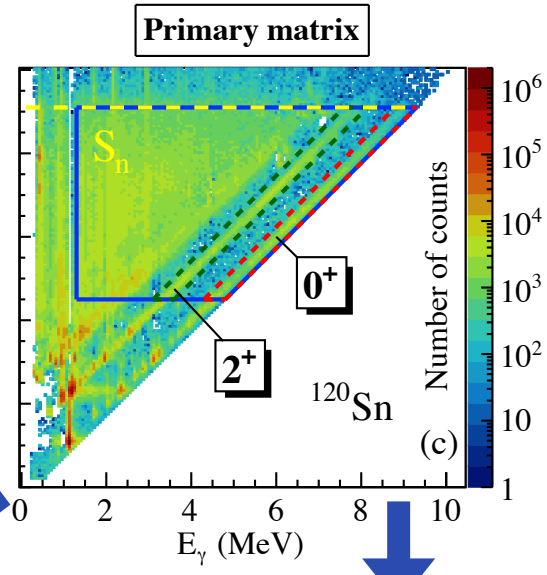
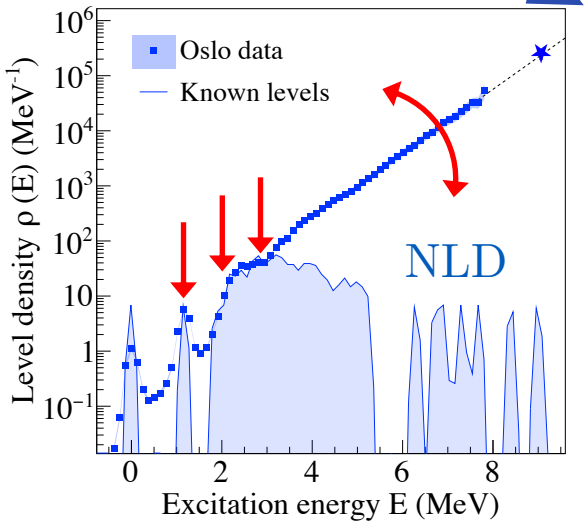
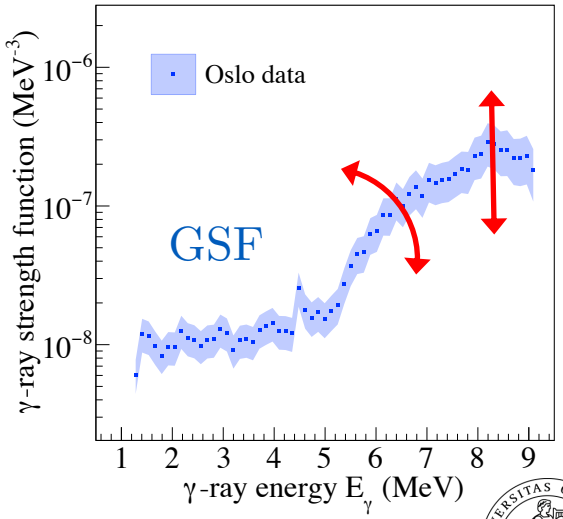




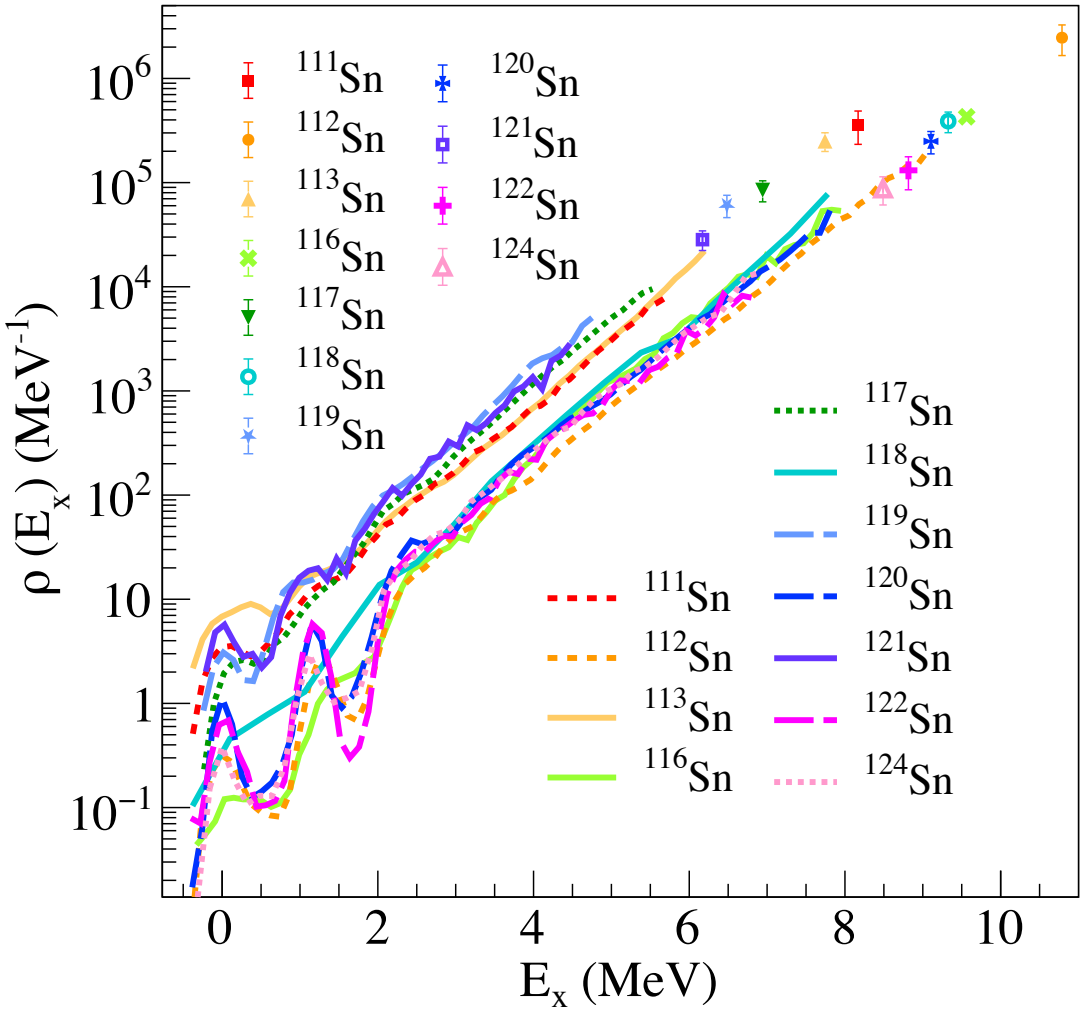


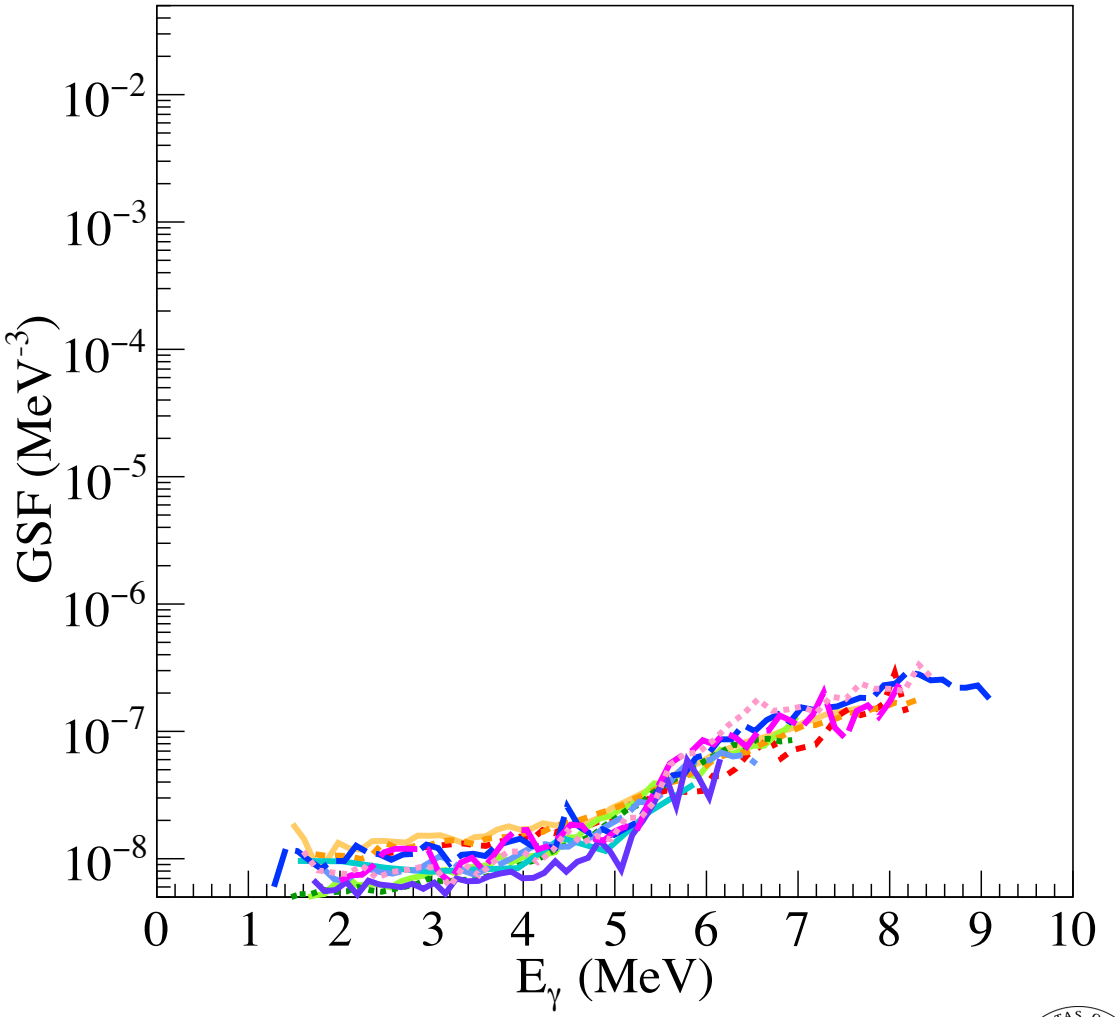
Scaling the NLD to discrete low-lying states.

Extracting the NLD and GSF slope from neutron resonance data.

Scaling the GSF to the neutron resonance data.

NLD and GSF in Sn isotopes





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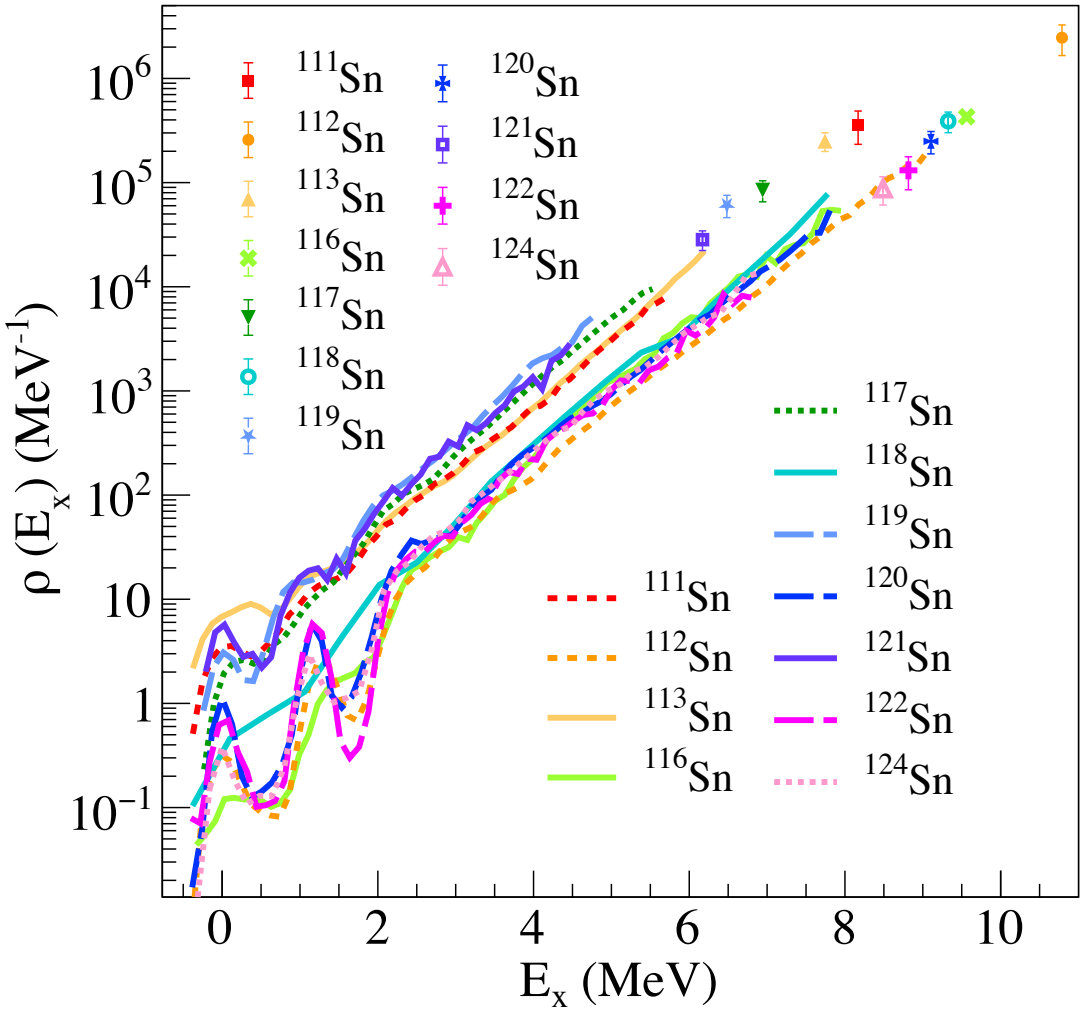

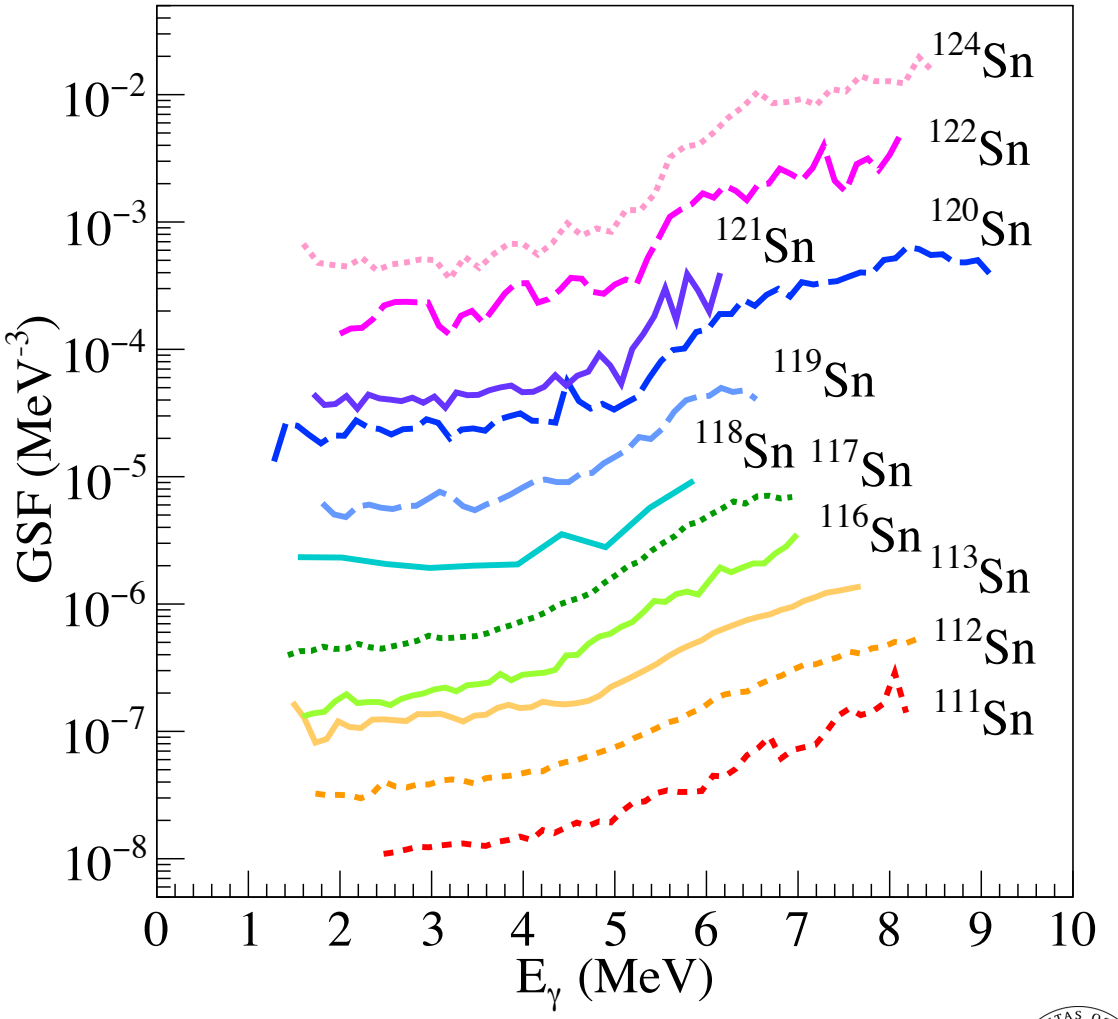

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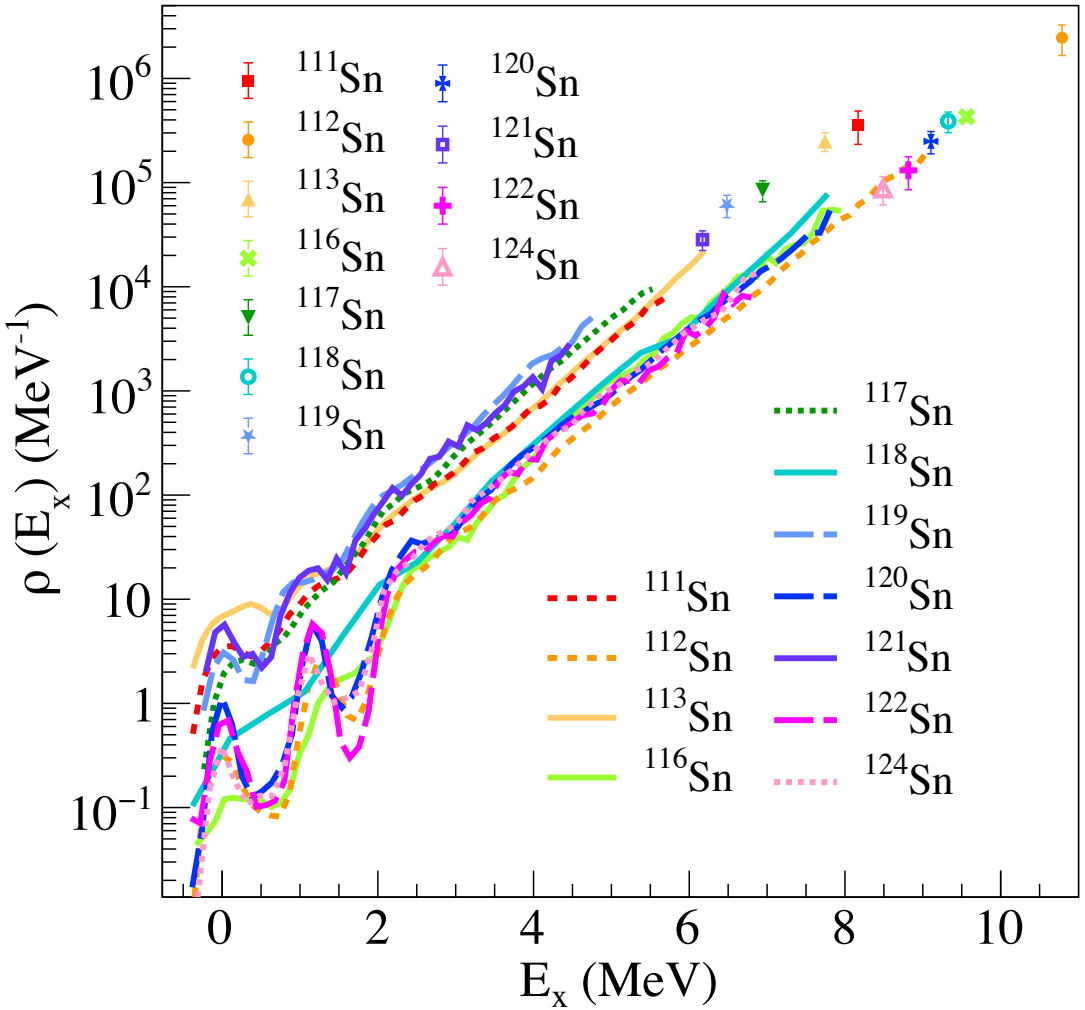
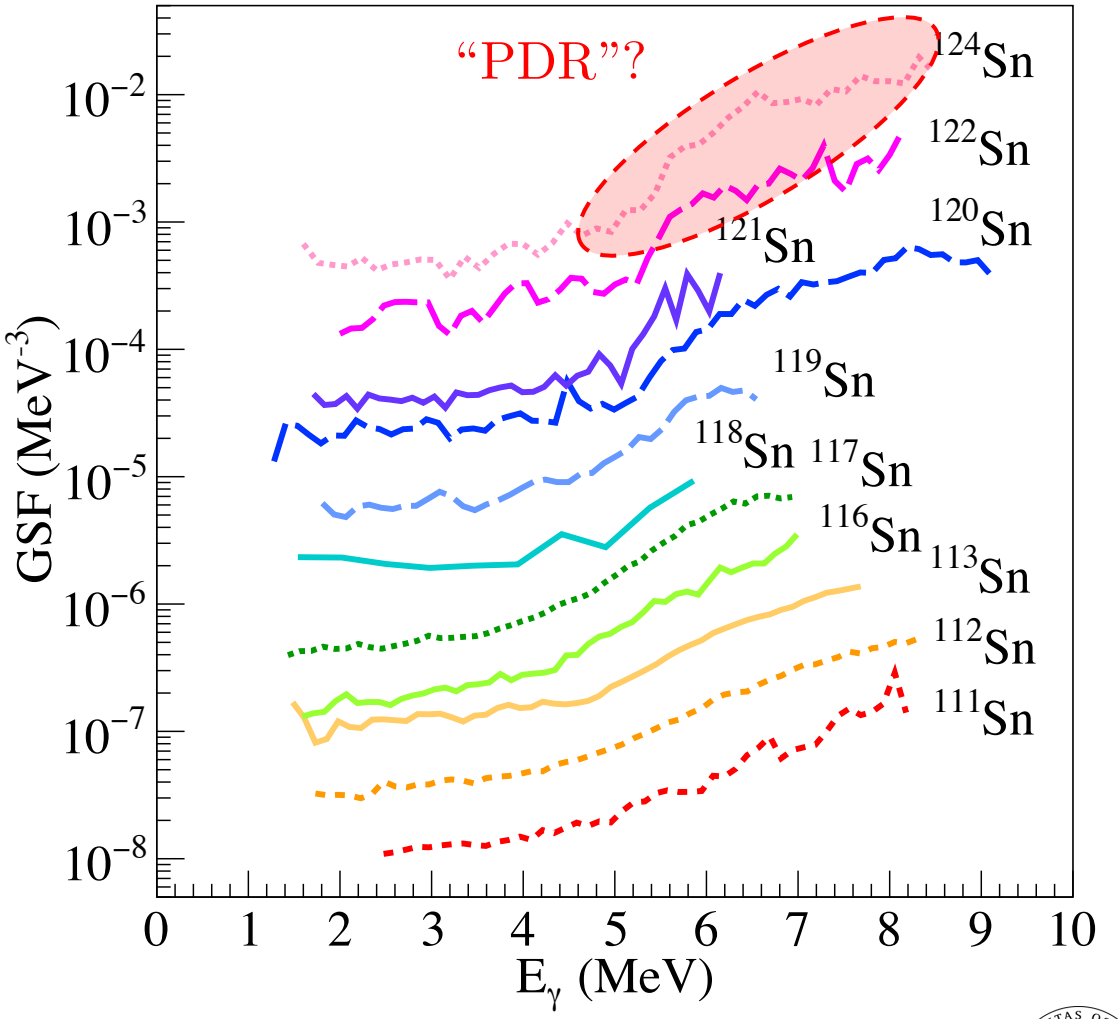
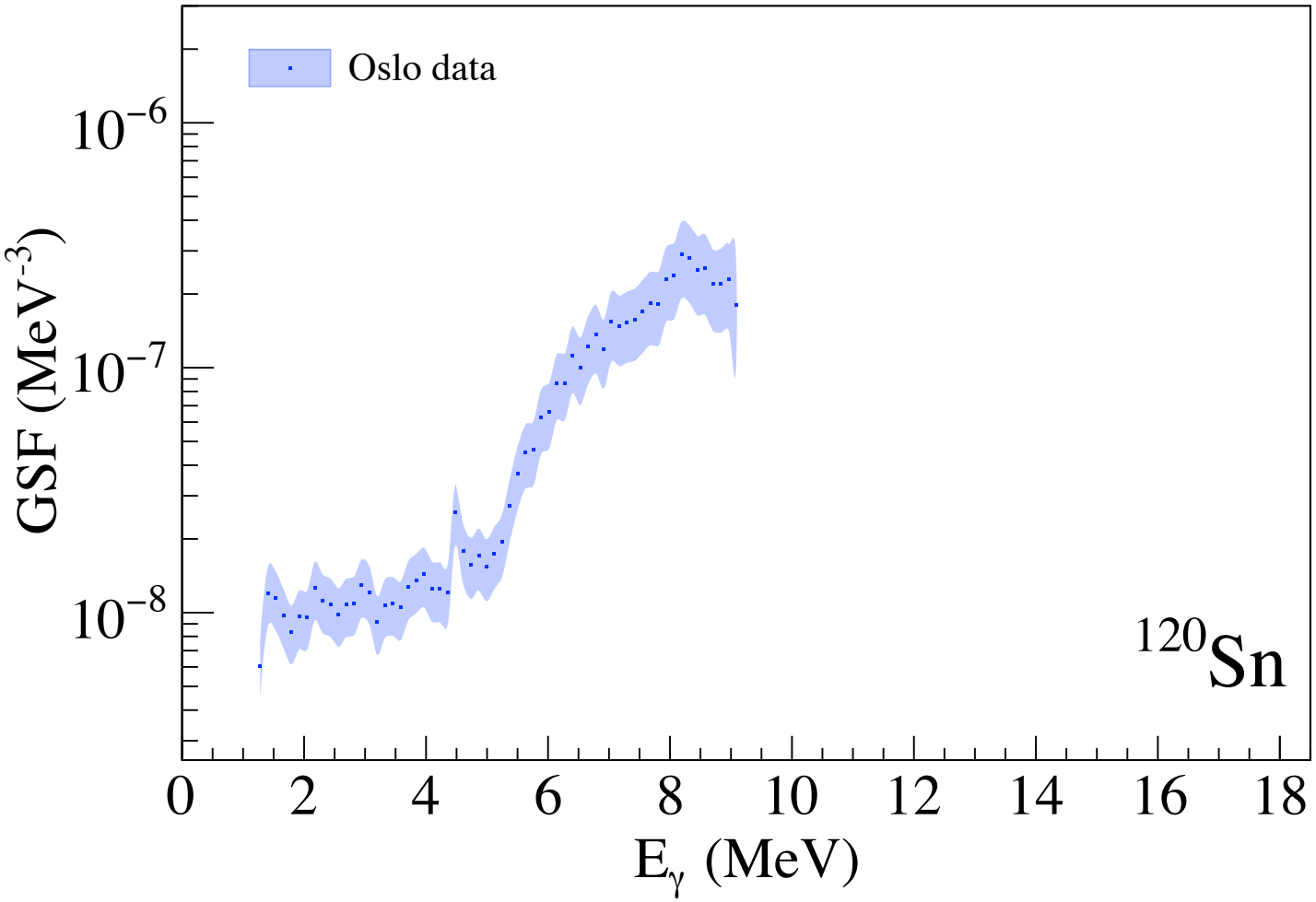




Decomposition of the dipole GSF



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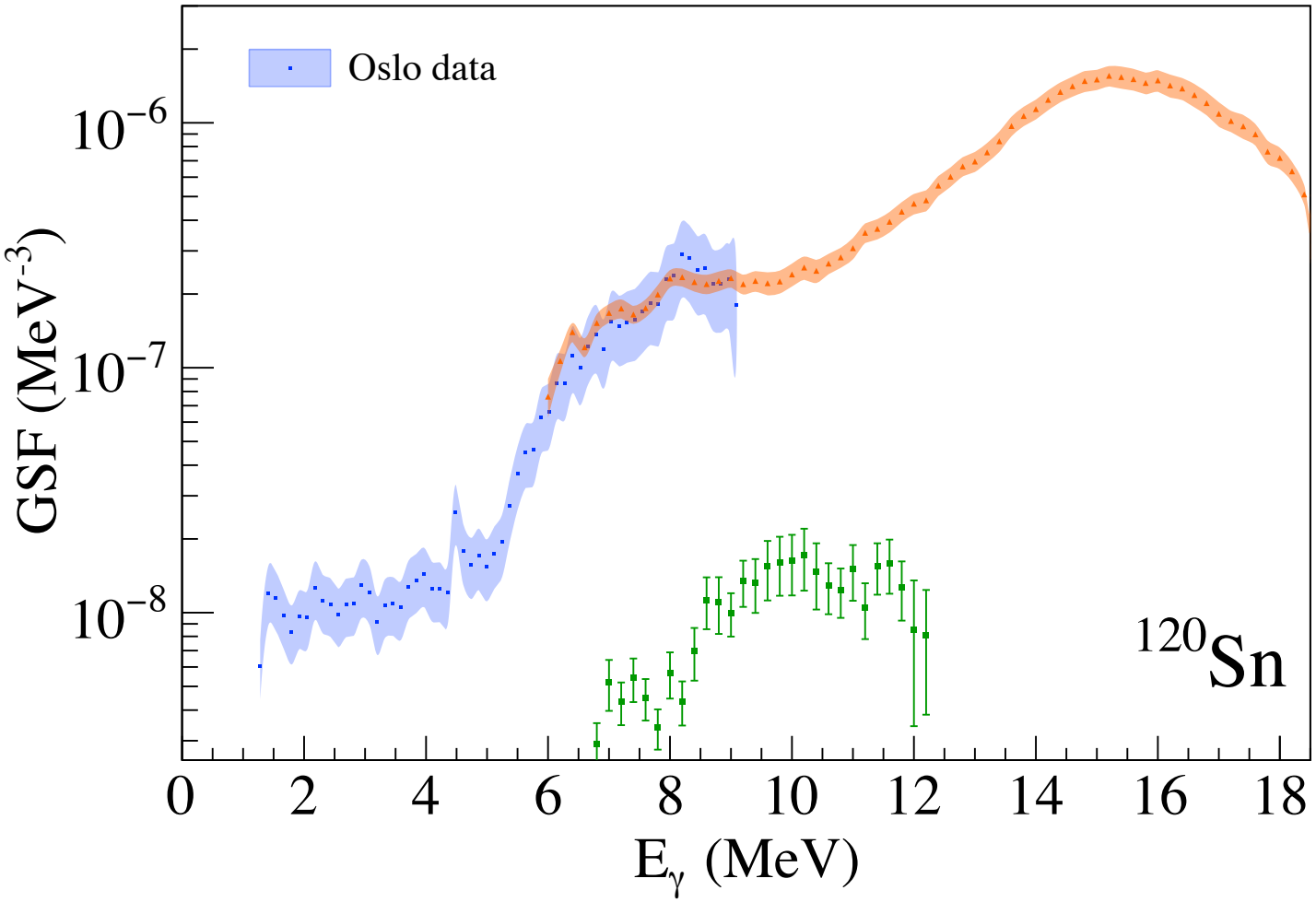

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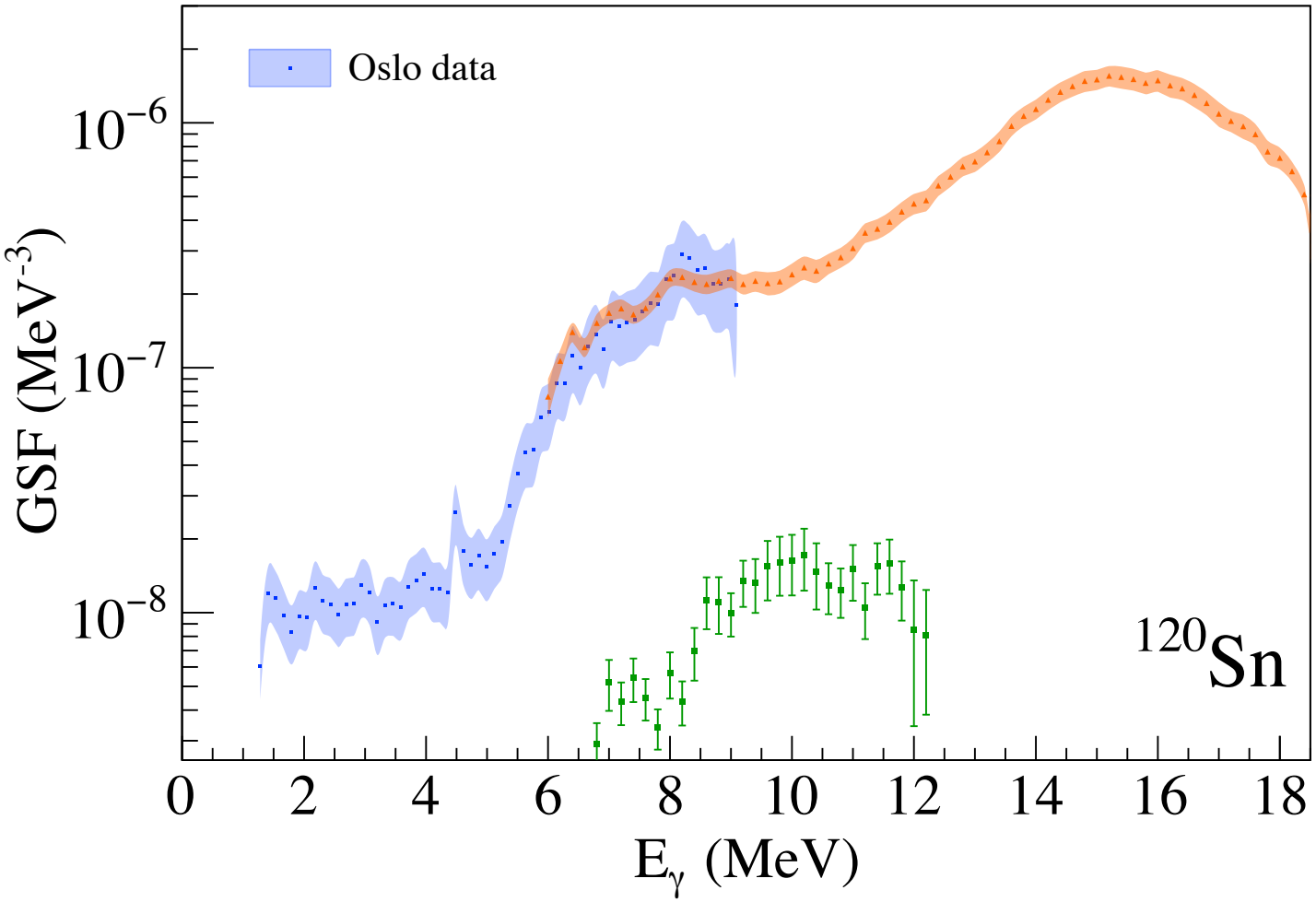

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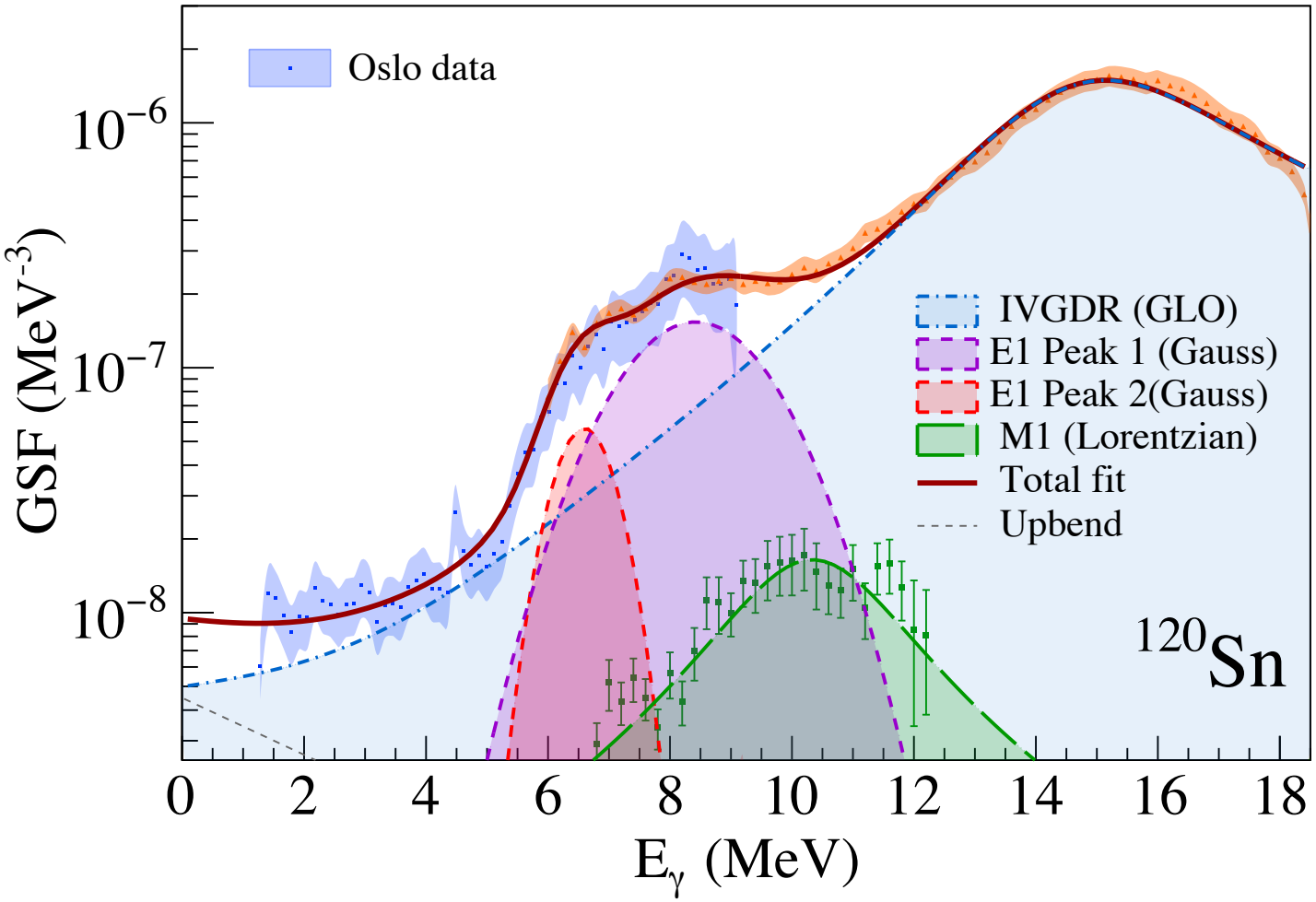

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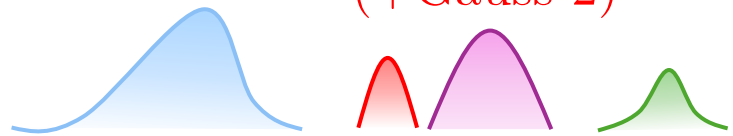
GLO Gauss 1 SLO

(+Gauss 2)



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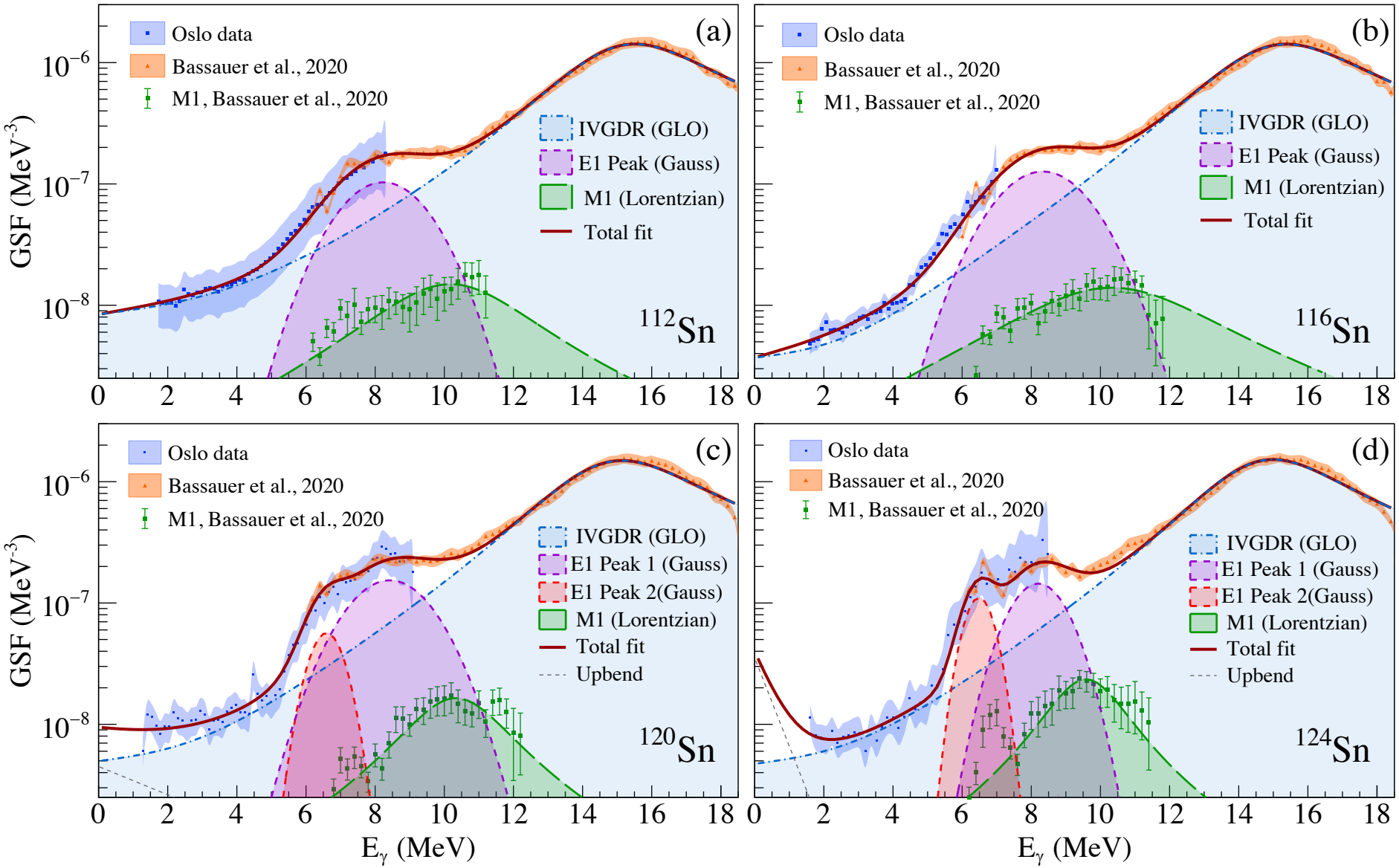
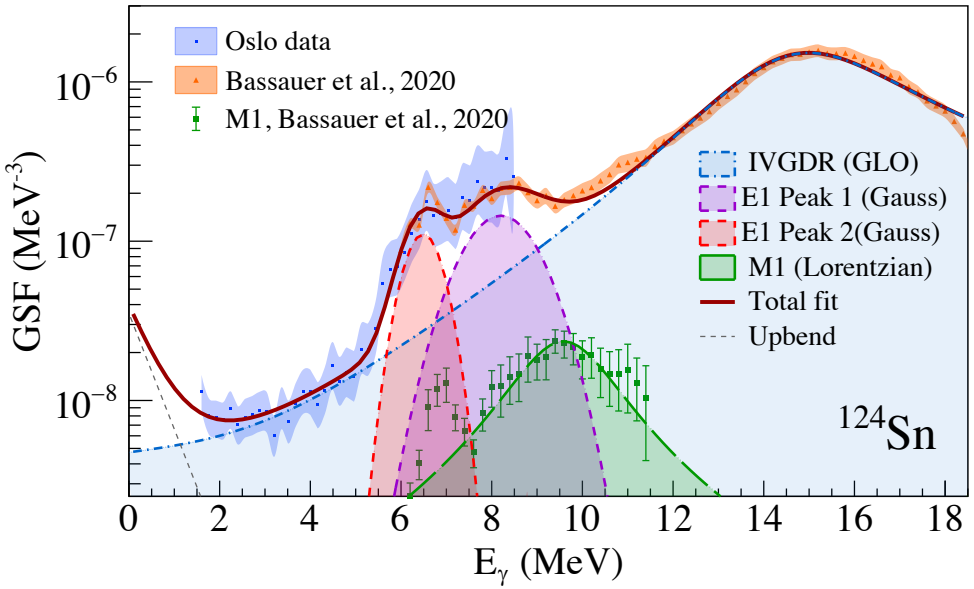
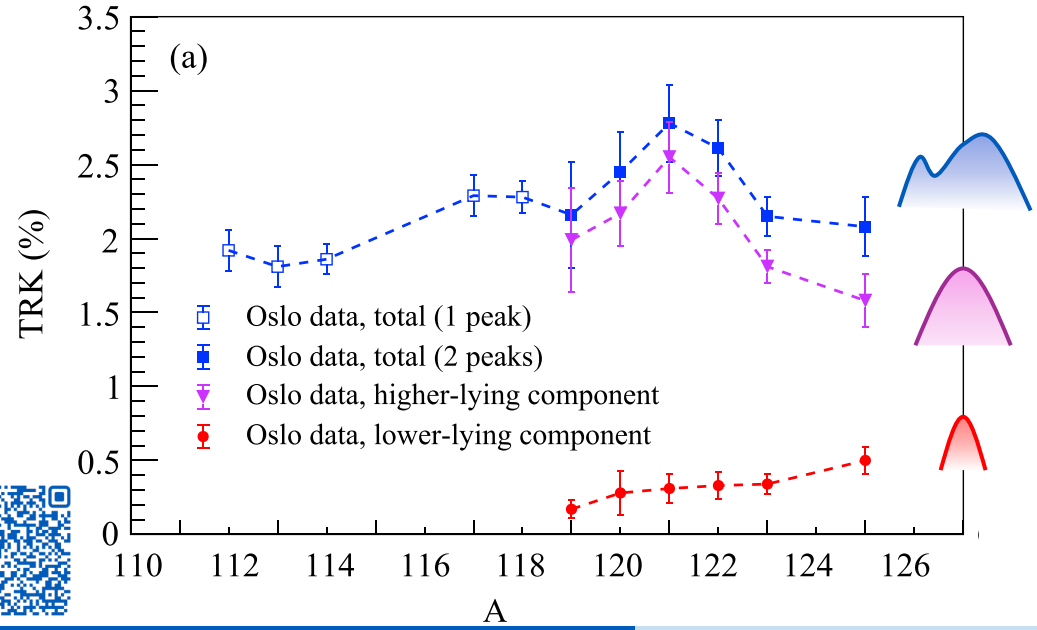


Systematics of the PDR





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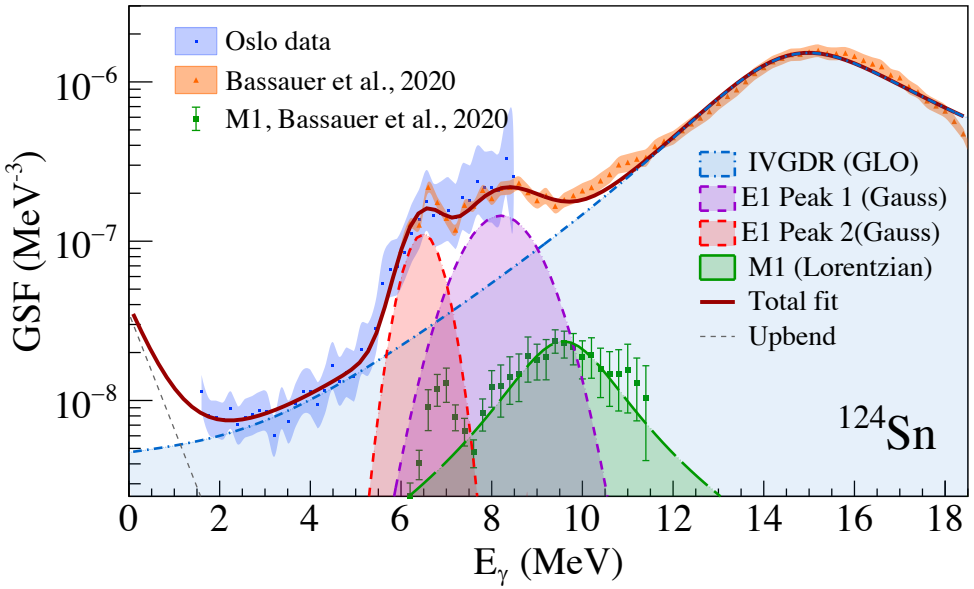

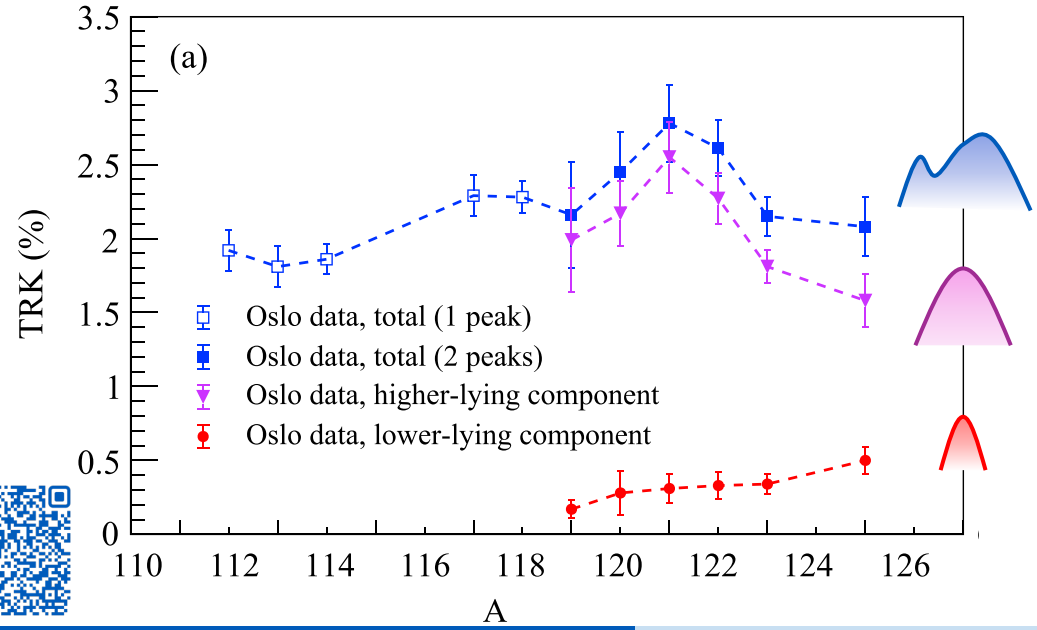

Ranges from 2% to 3% TRK,
the largest strength is in 120Sn.

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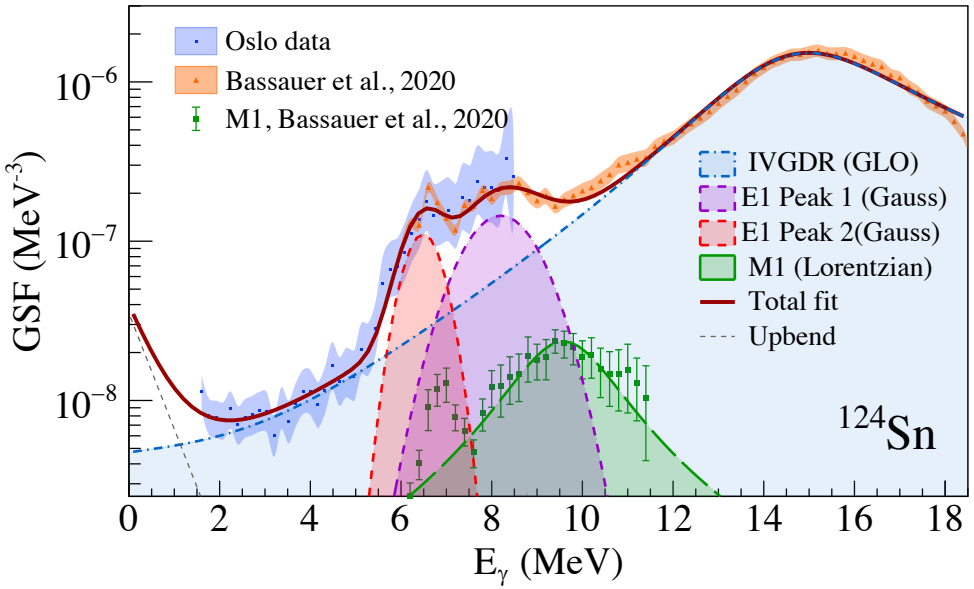

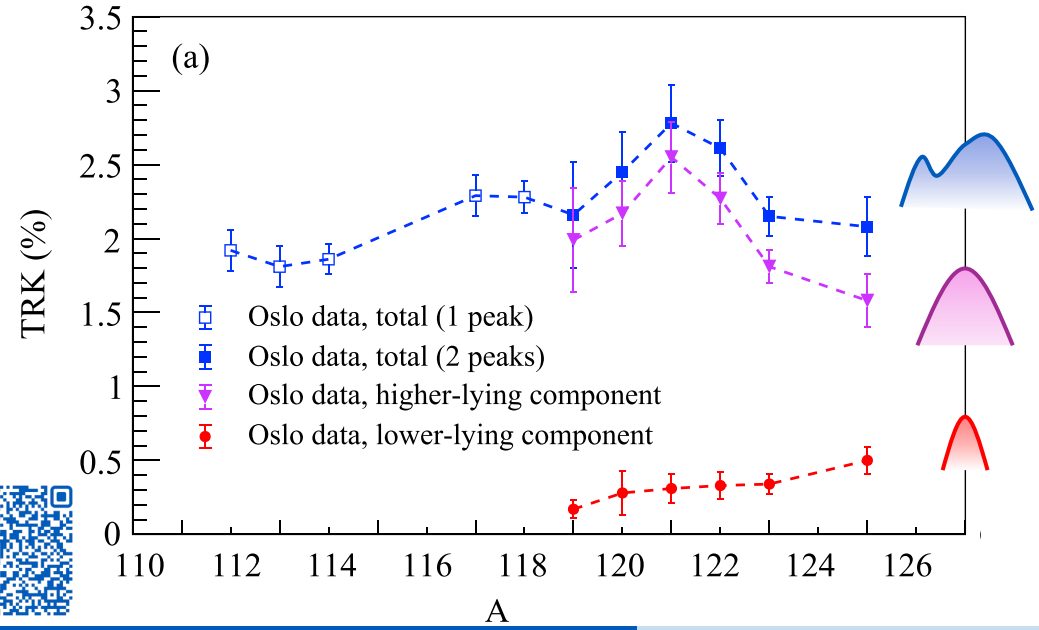

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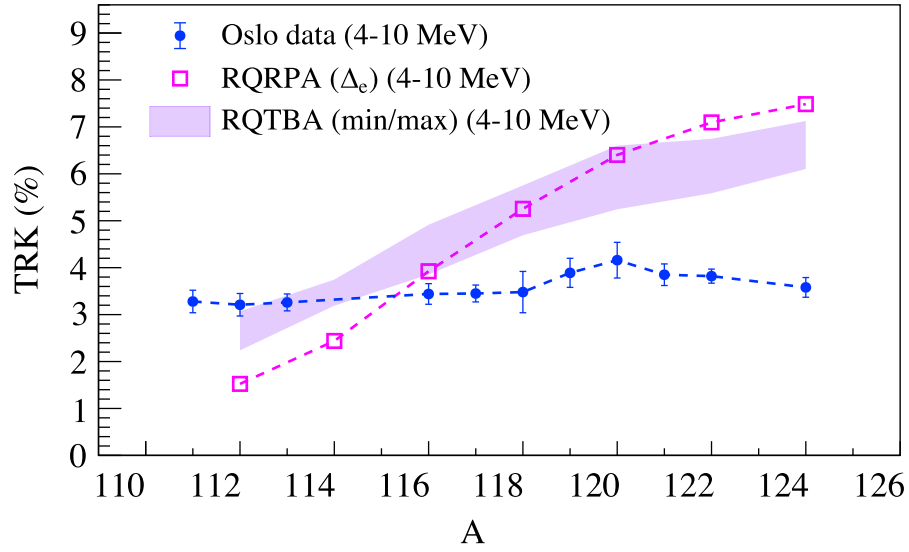

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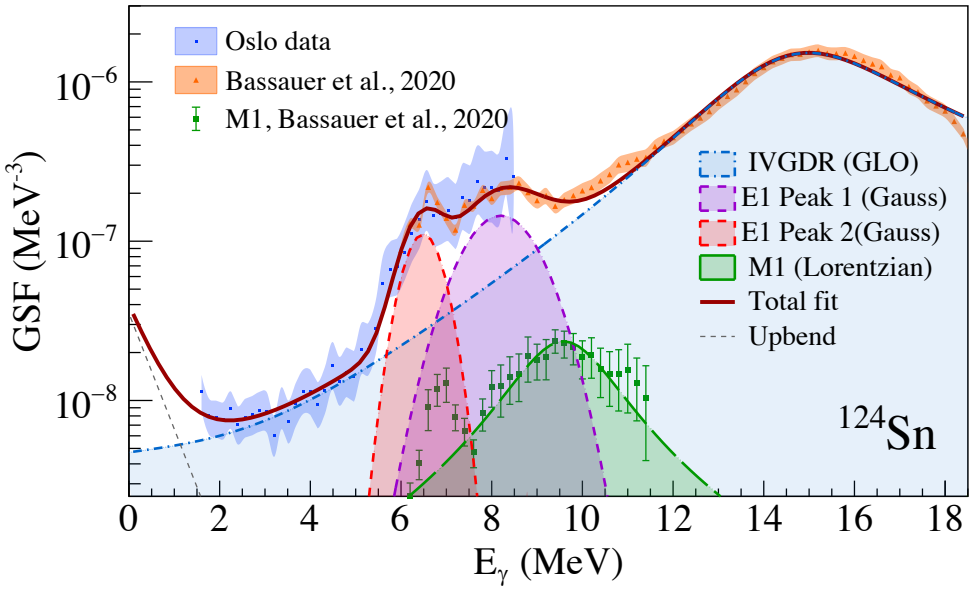

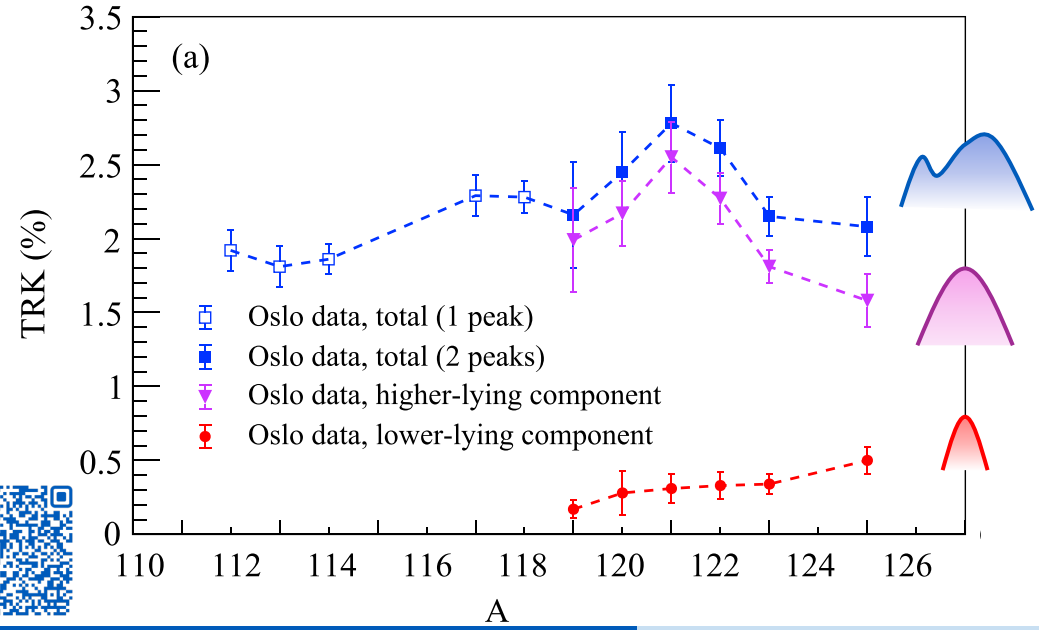

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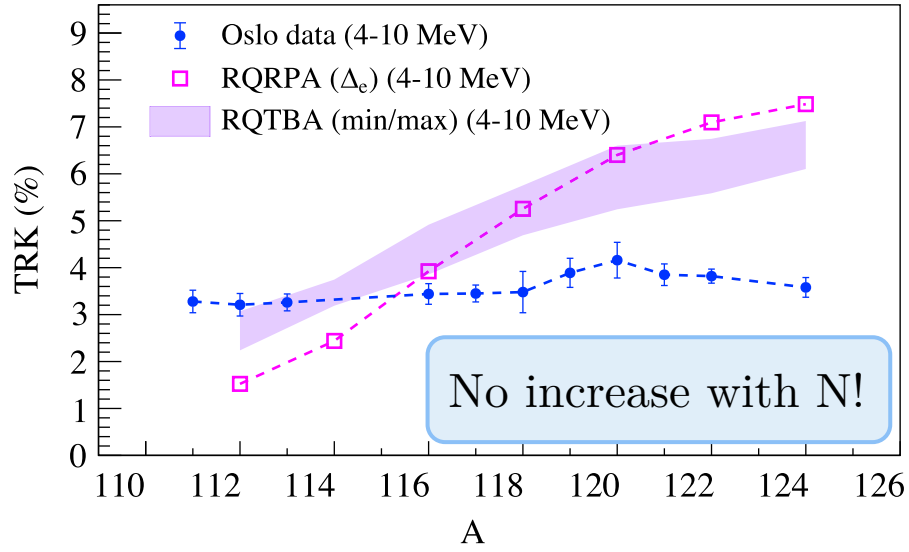

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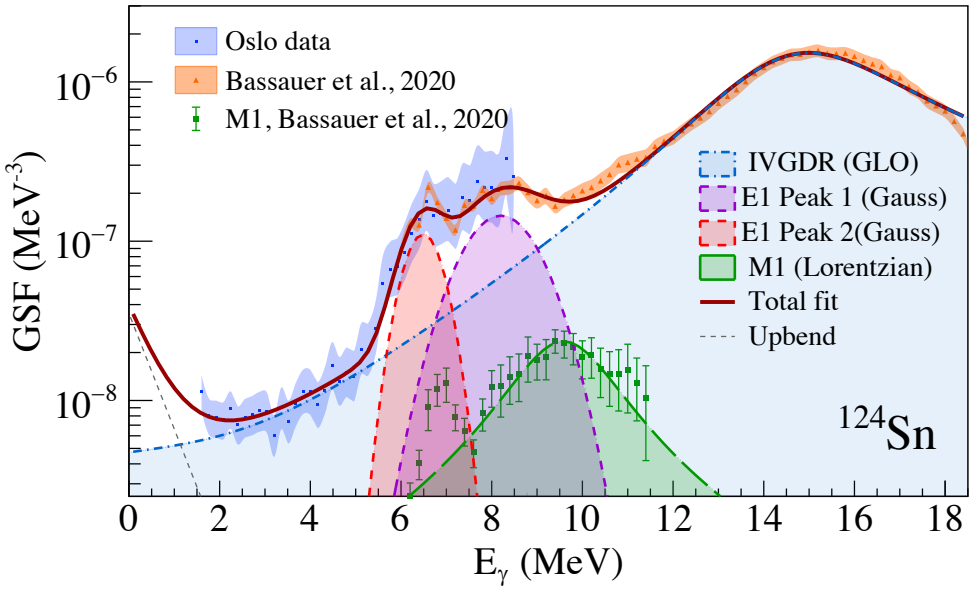

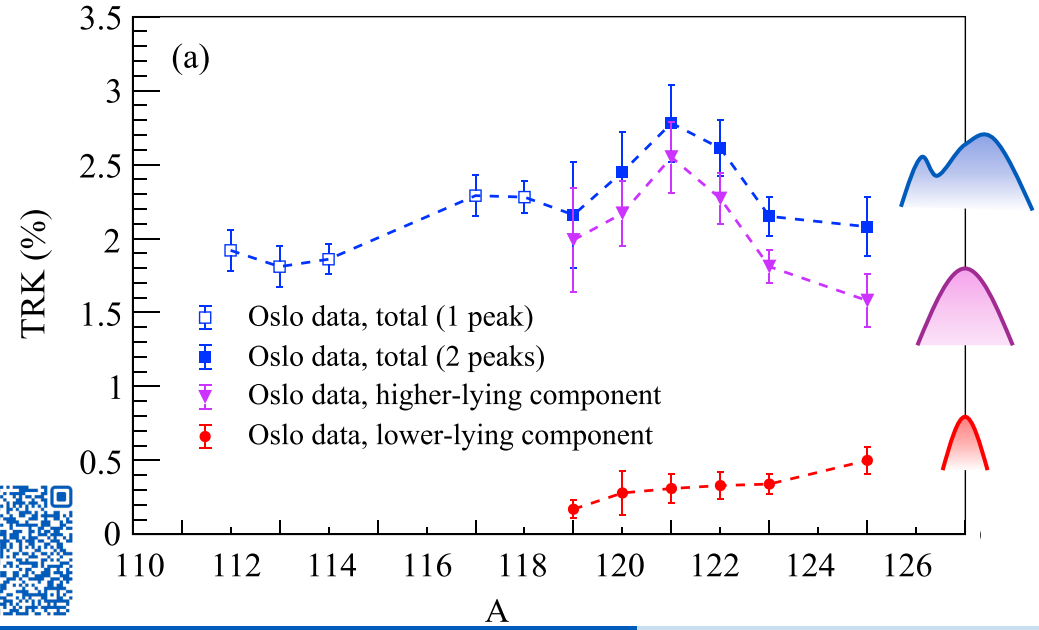

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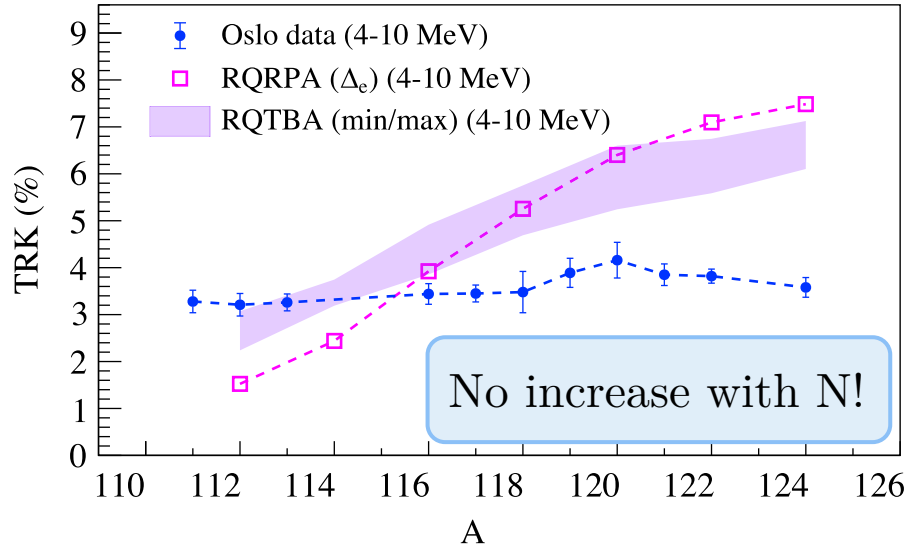
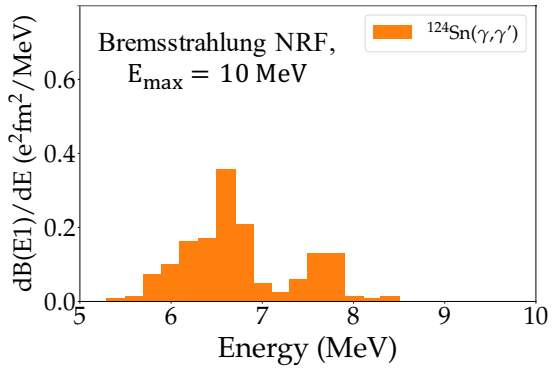
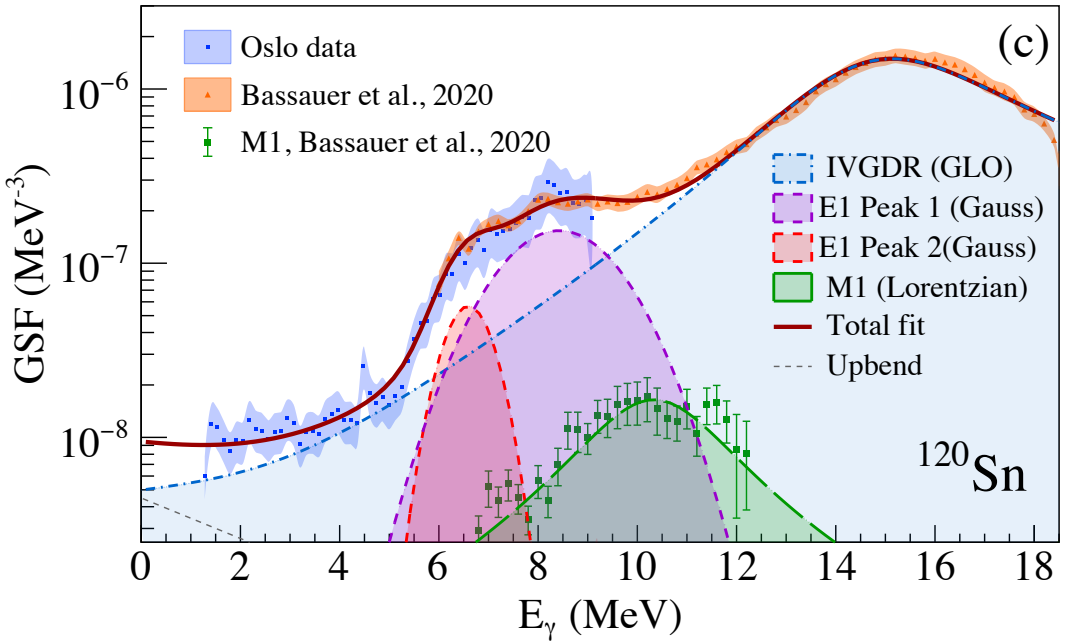


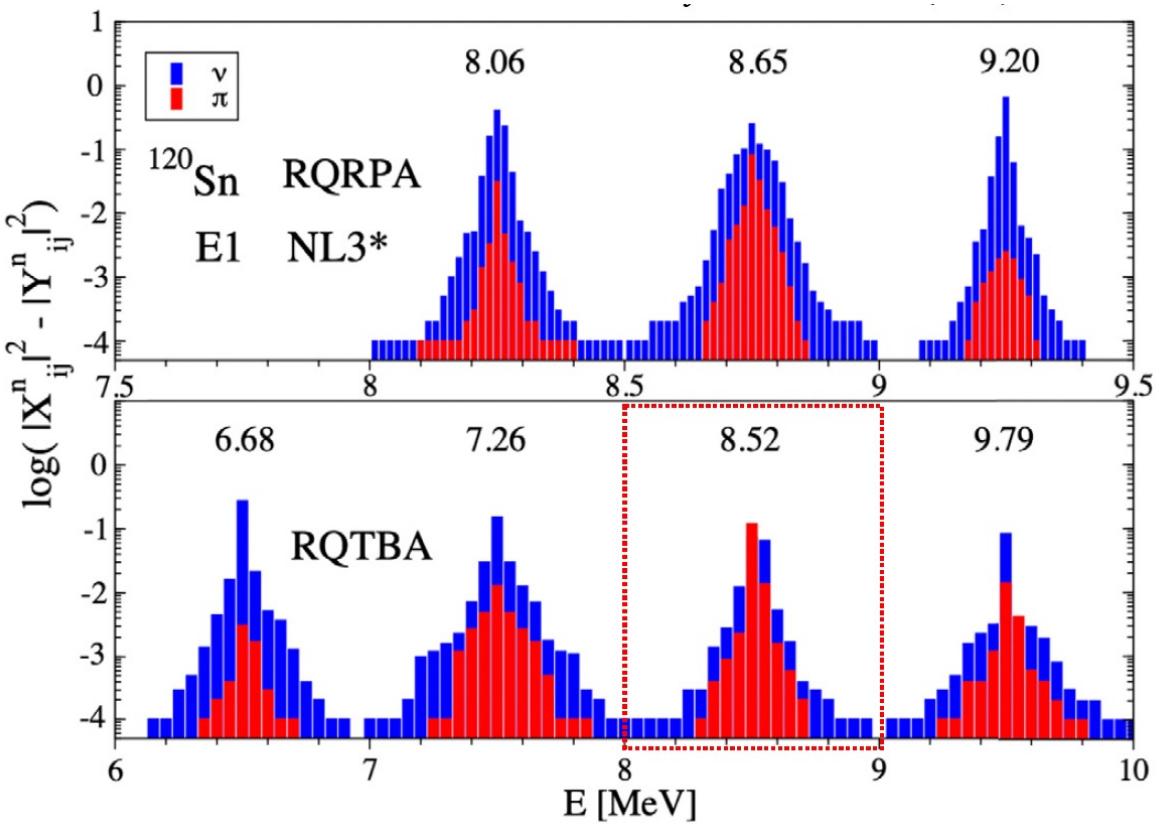
No increase with N!



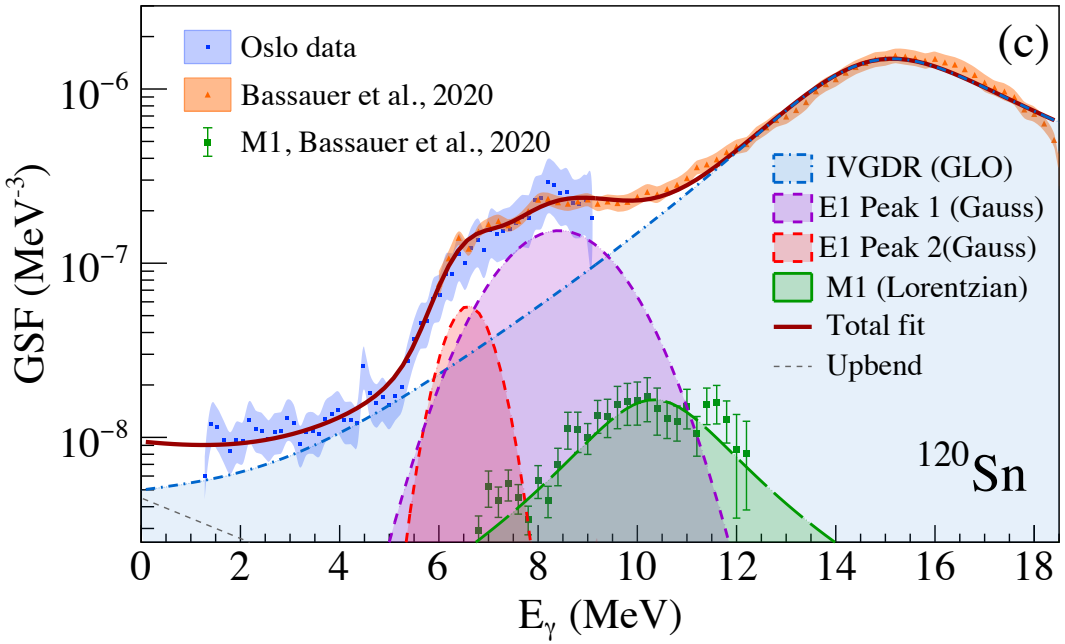
The low-lying component increases in strength with N, the "real" PDR (IV component)?

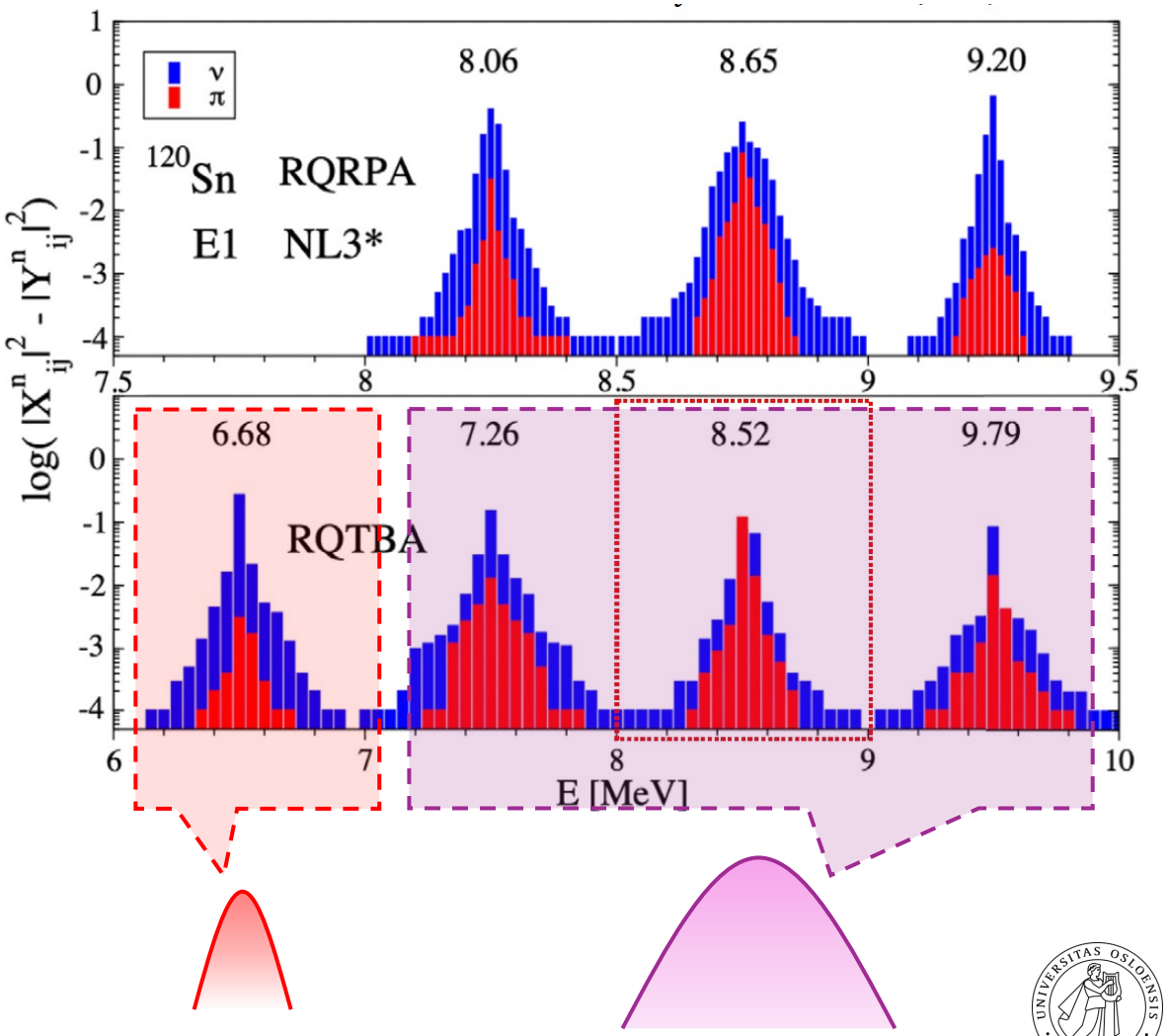
Systematics of the PDR



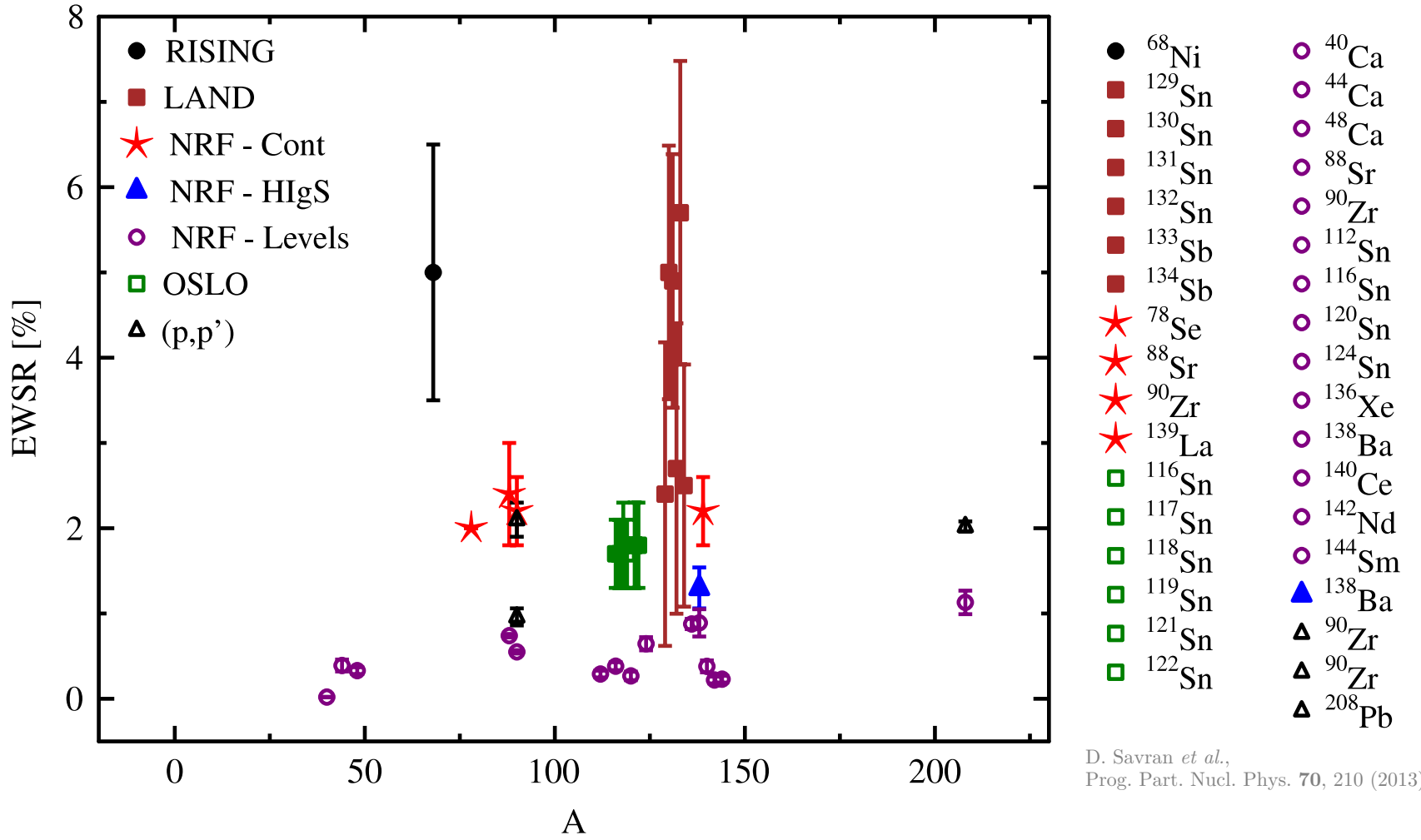


Systematics of the PDR



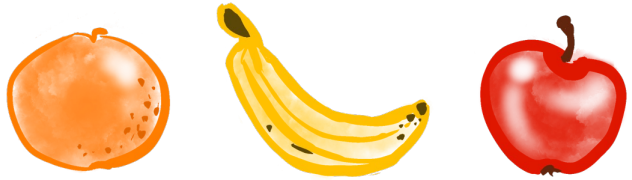


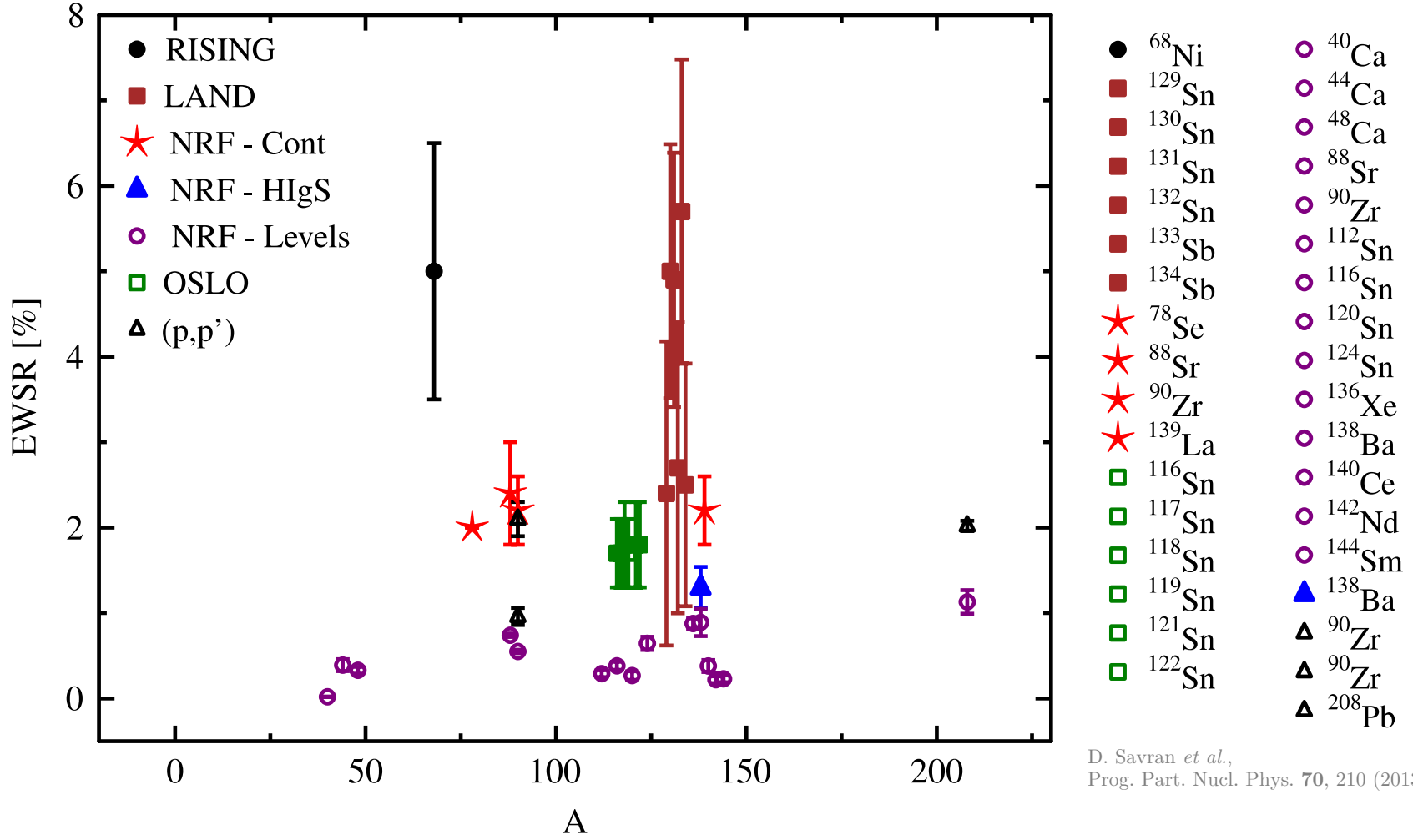
“PDR” in other nuclei



D. Savran *et al.*,
Prog. Part. Nucl. Phys. **70**, 210 (2013).

“PDR” in other nuclei





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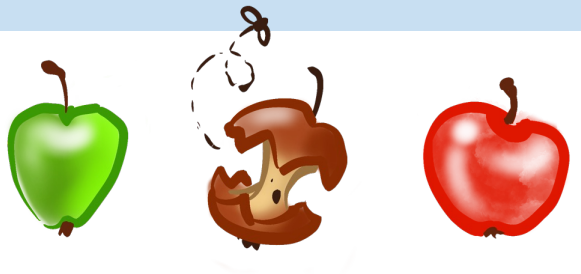
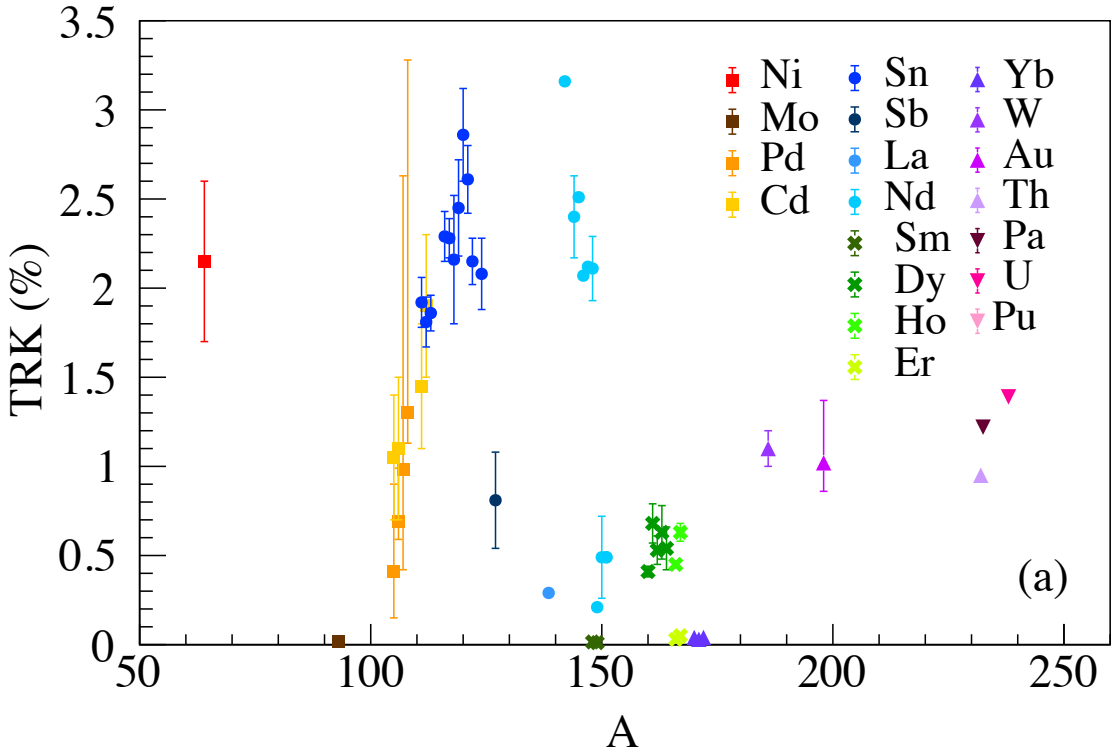
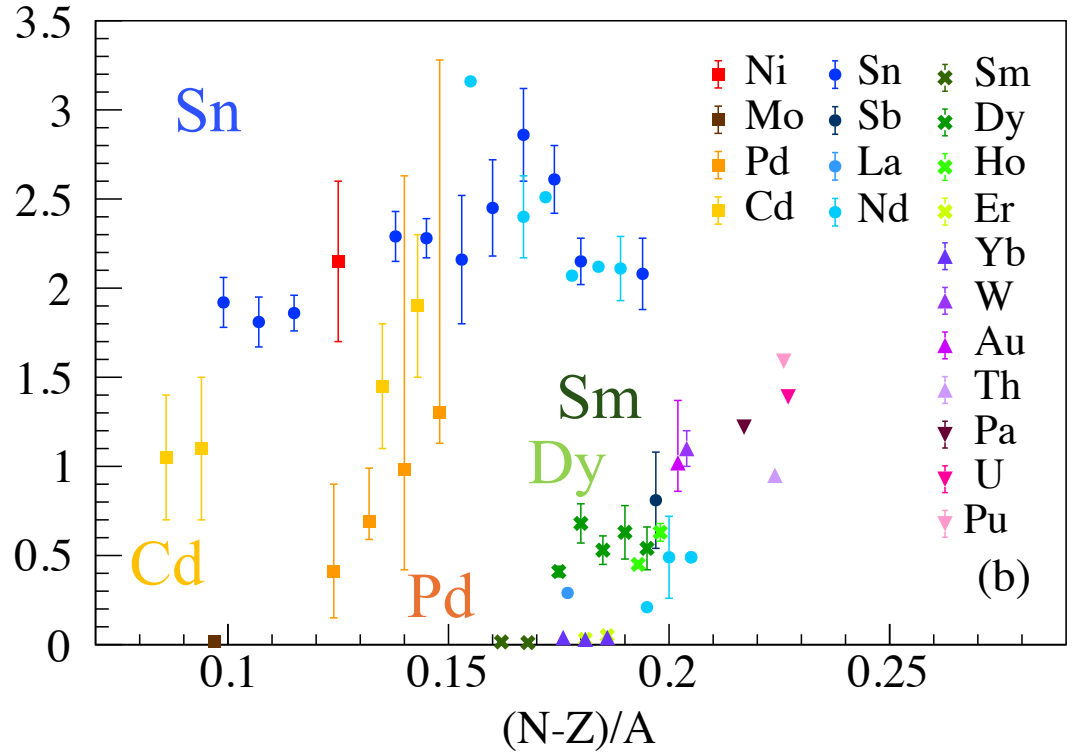
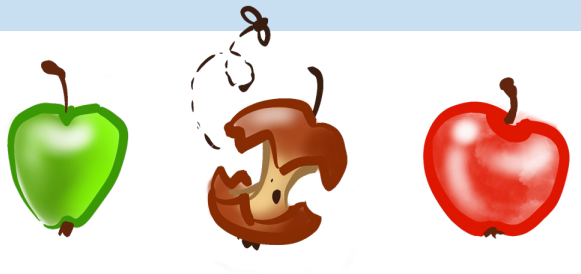
“PDR” in other nuclei

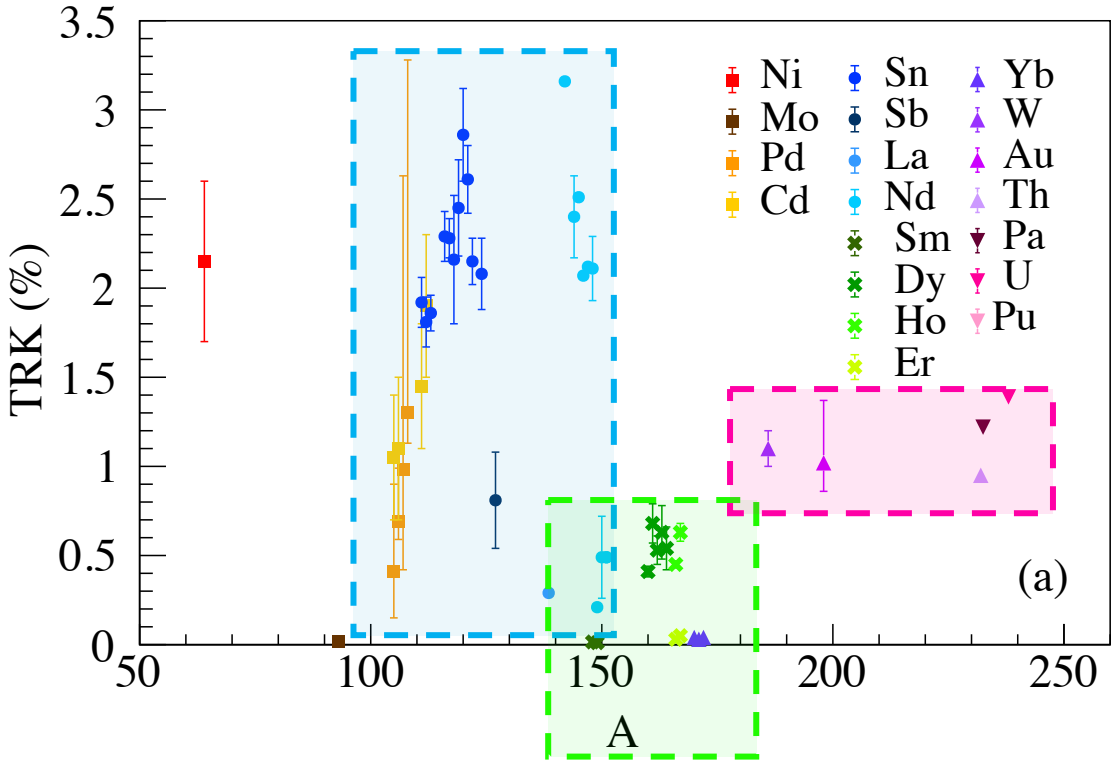


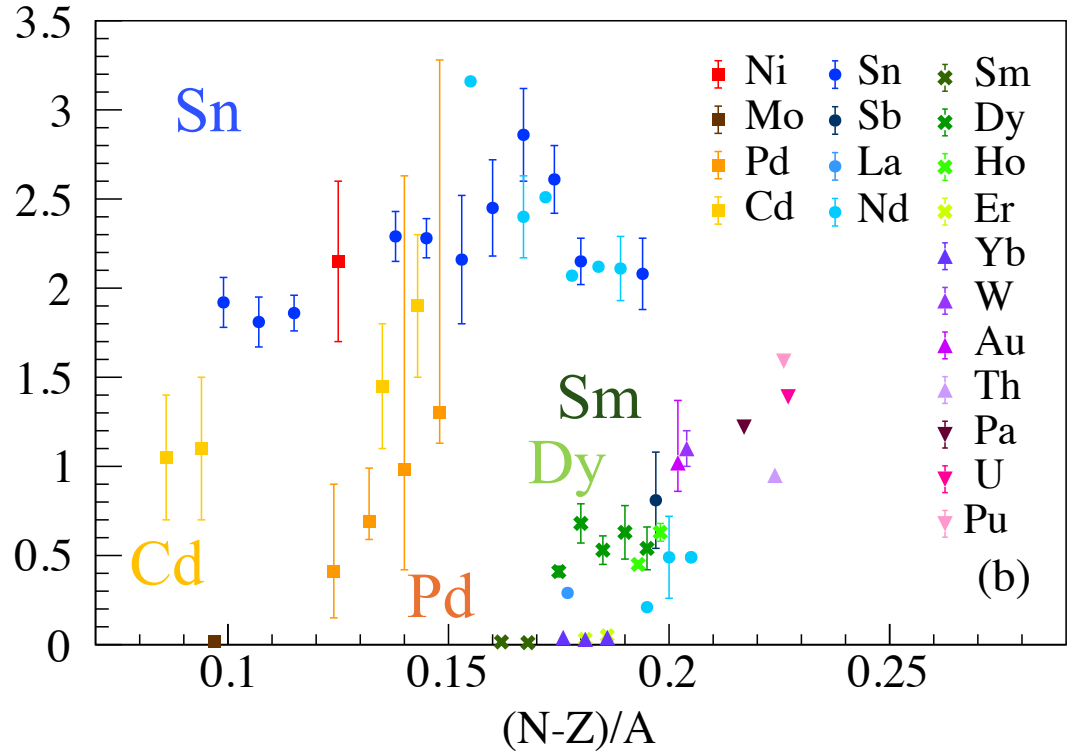




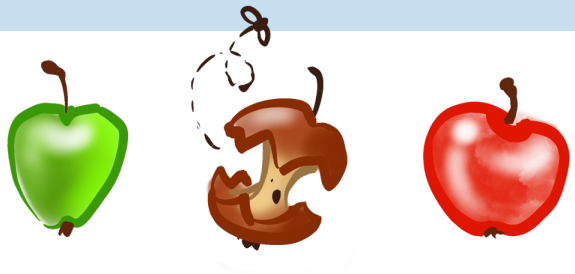
“PDR” in other nuclei

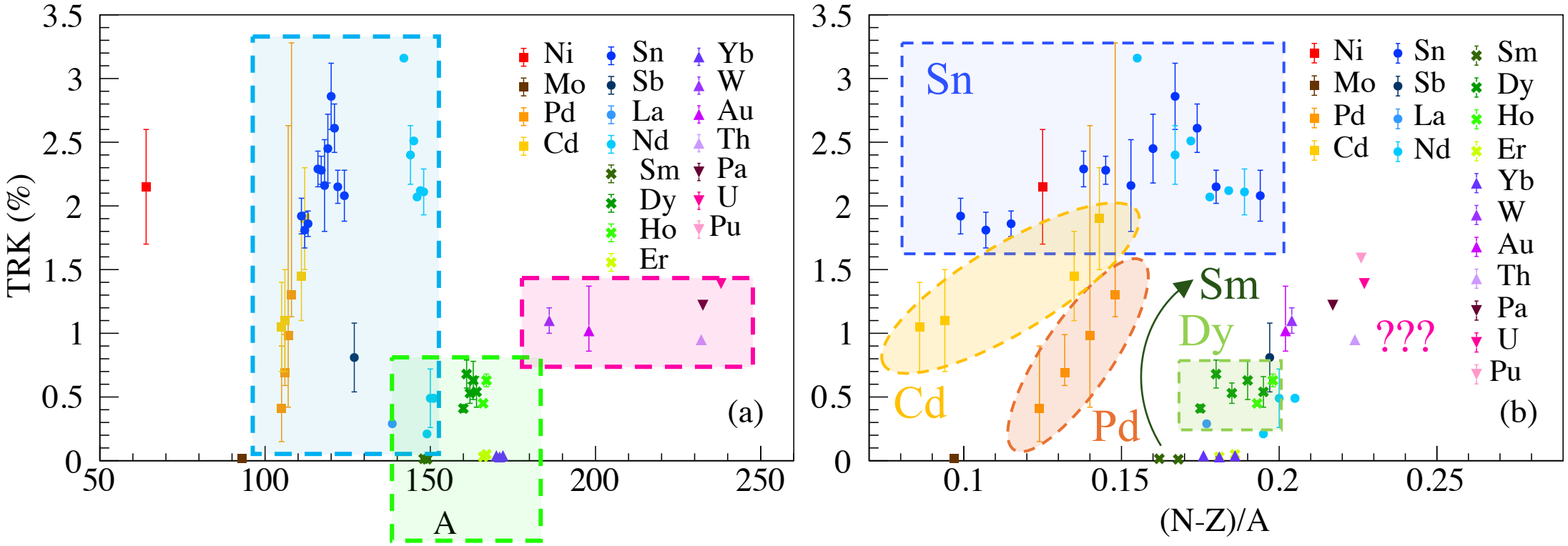




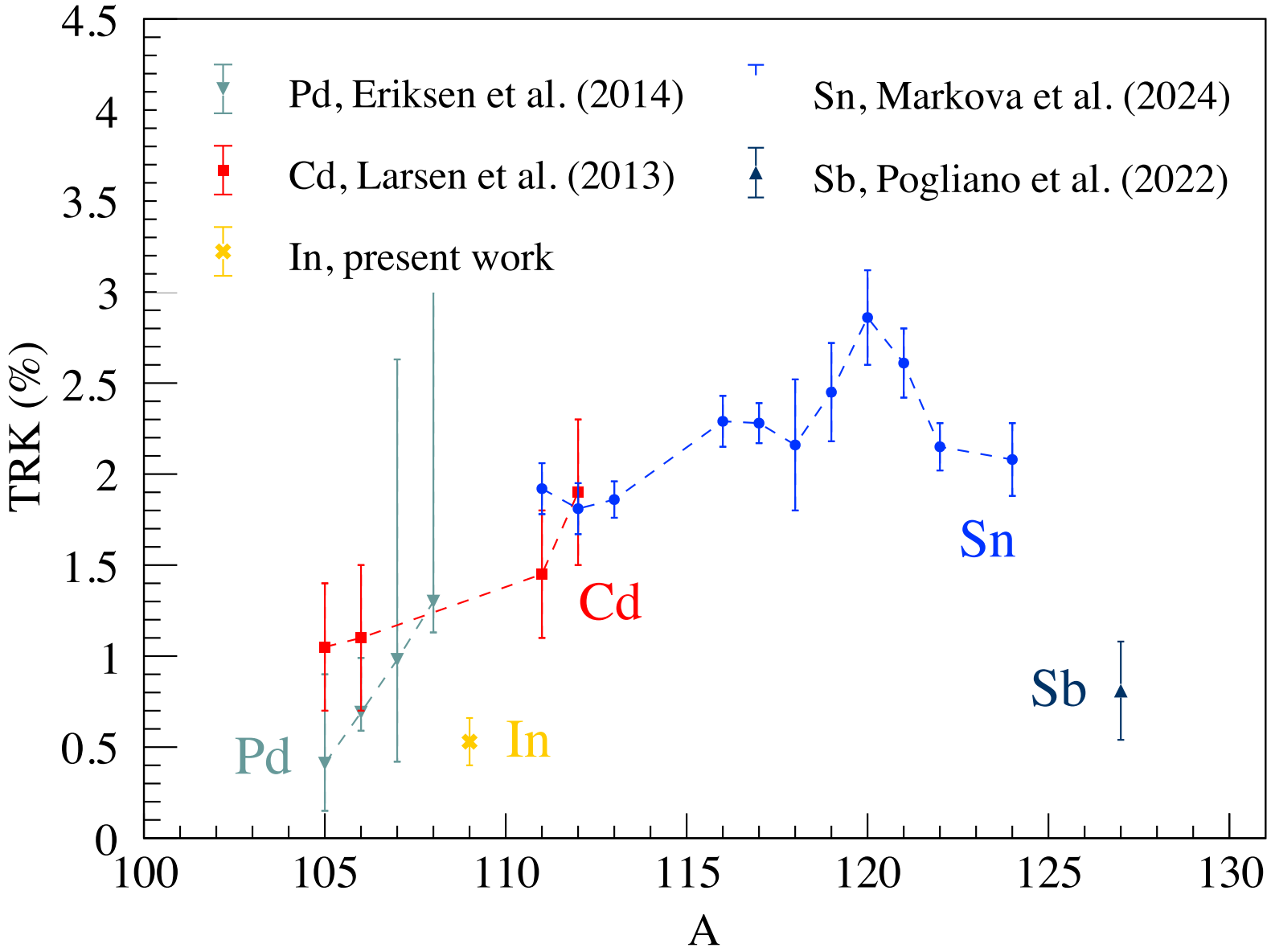


“PDR” in other nuclei

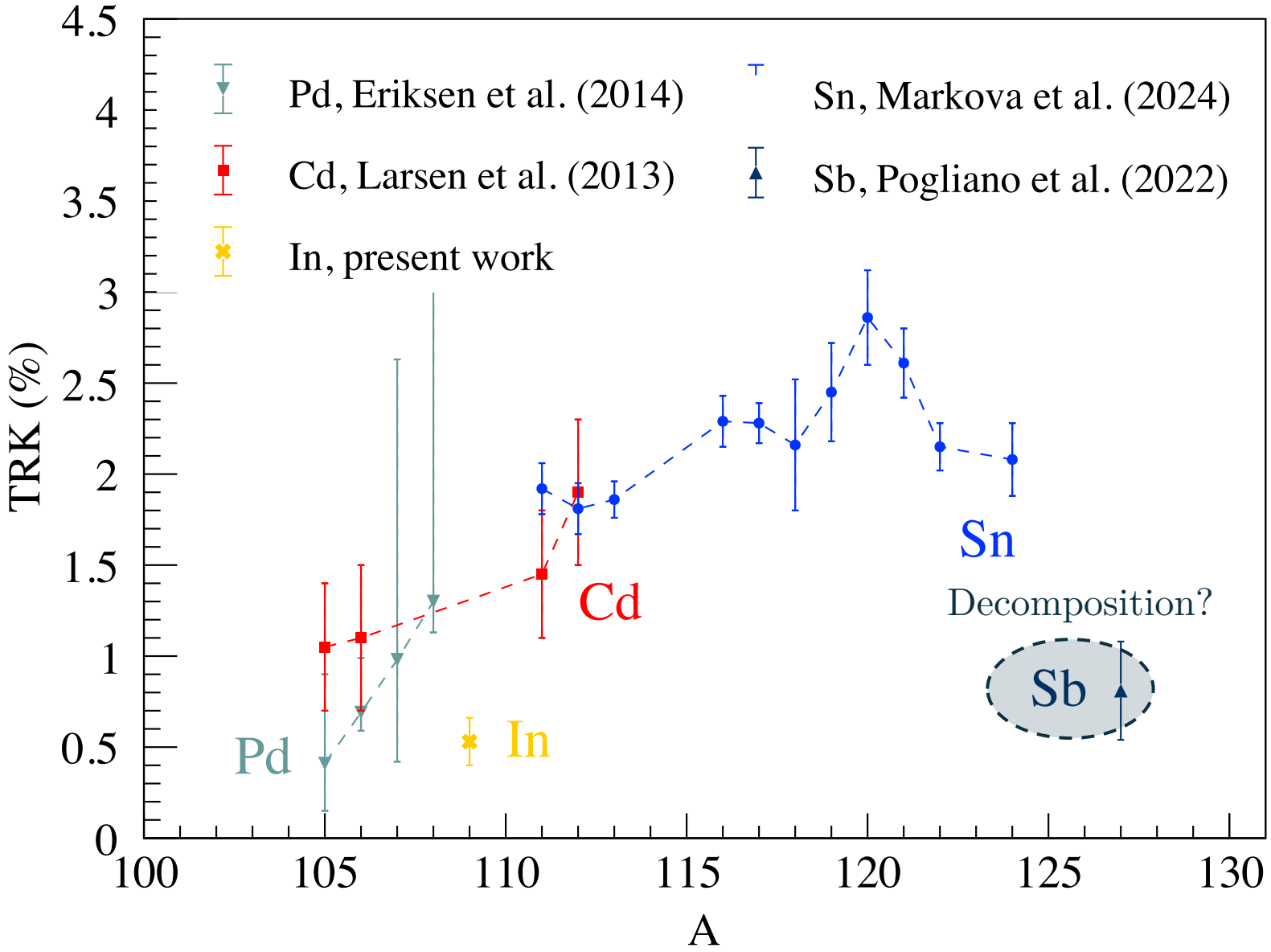




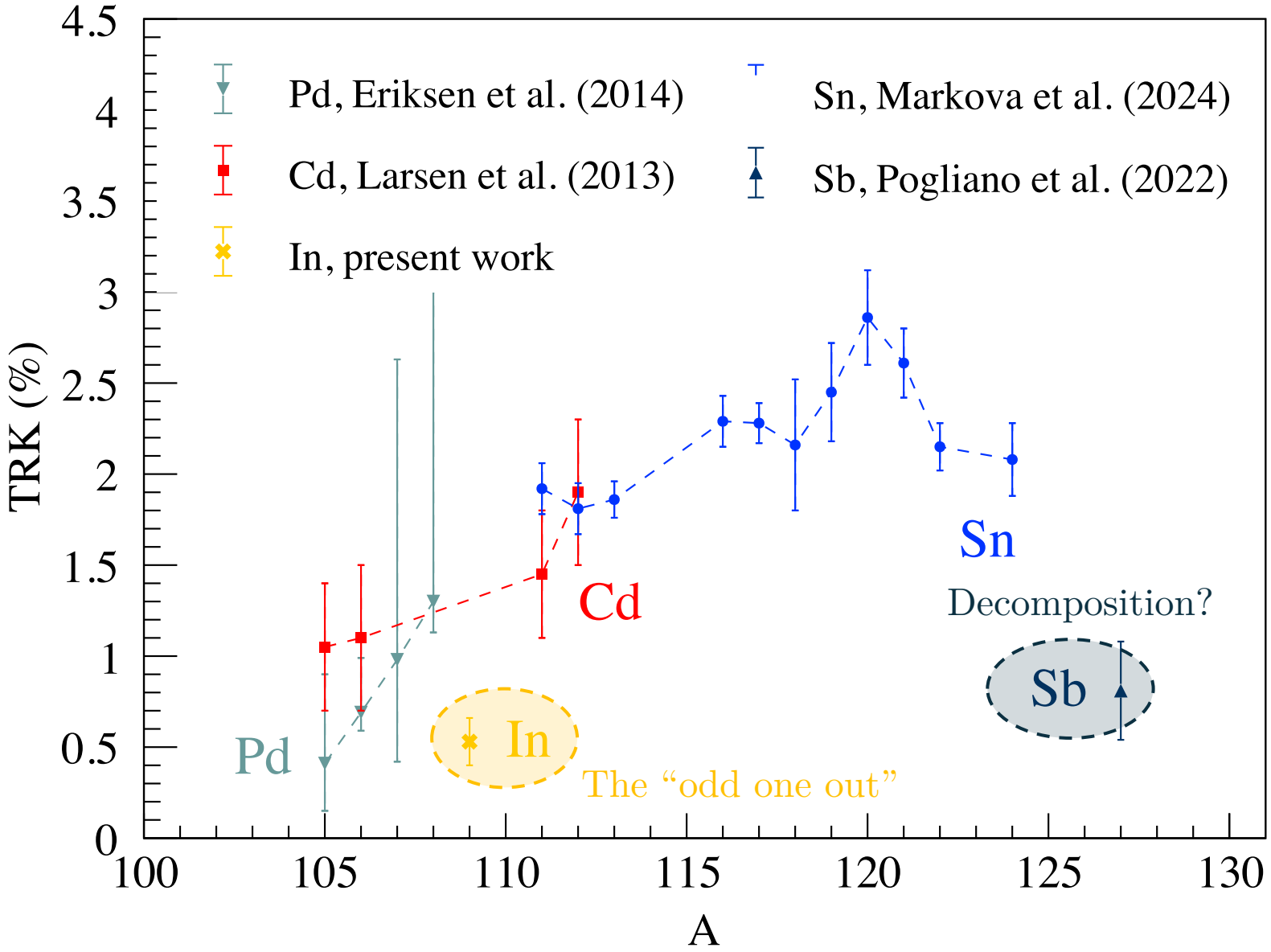
“PDR” around Sn



“PDR” around Sn



“PDR” around Sn



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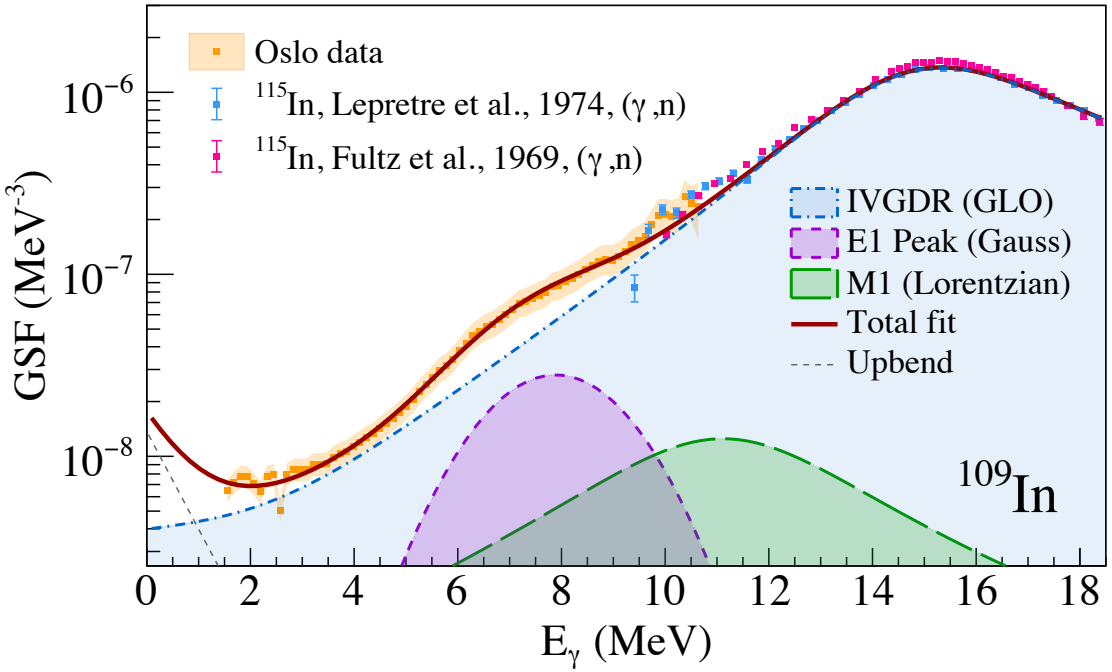

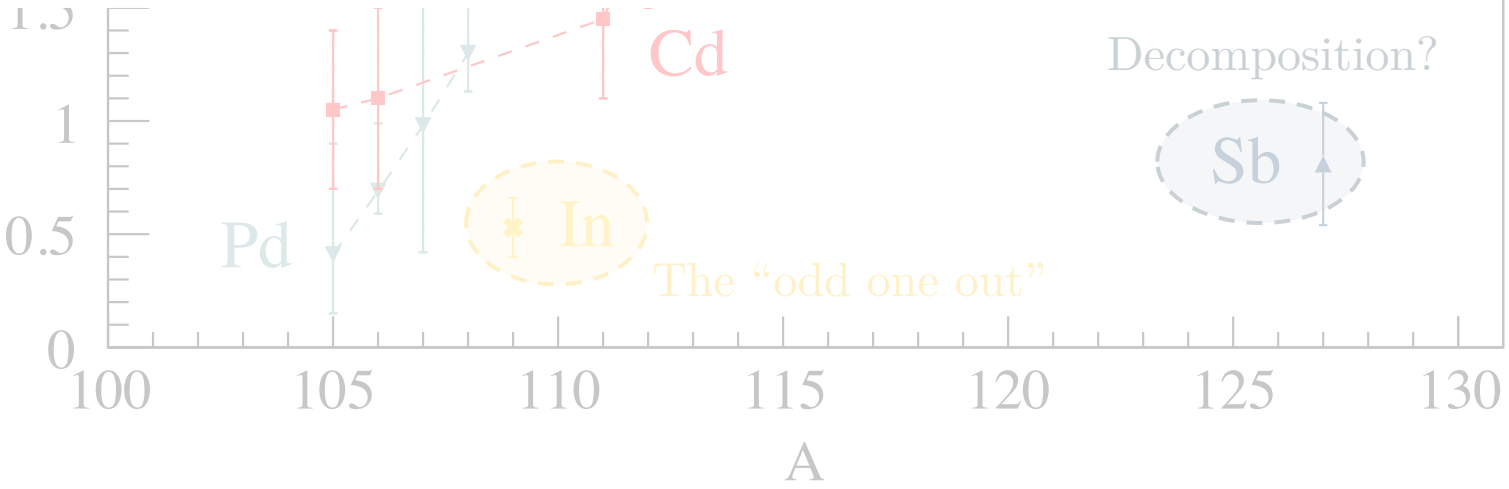

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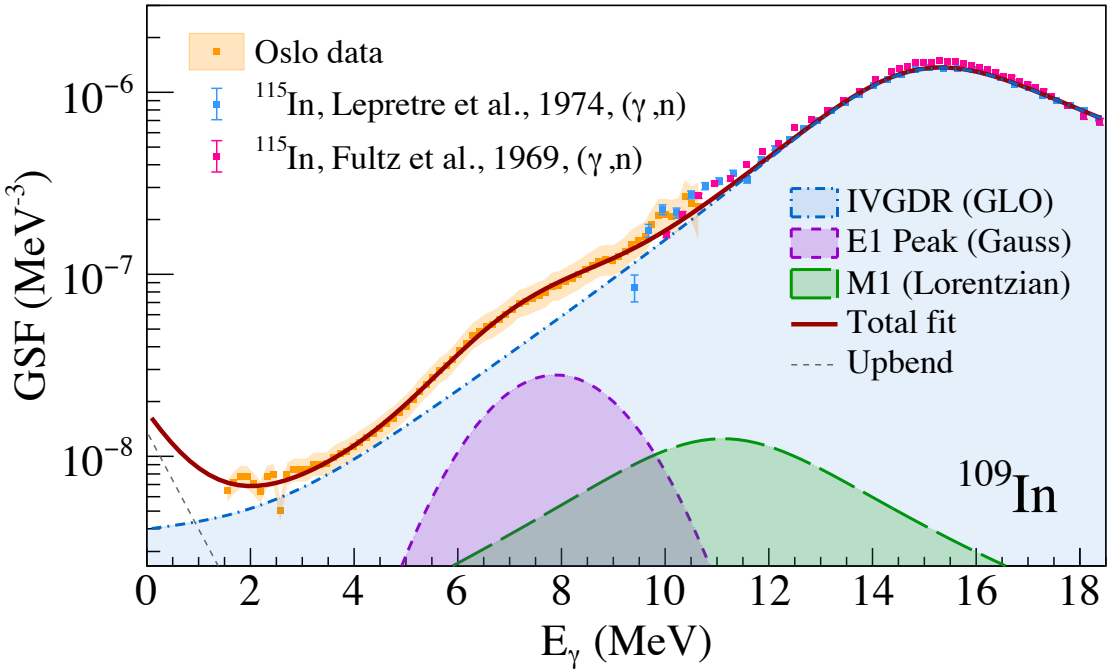

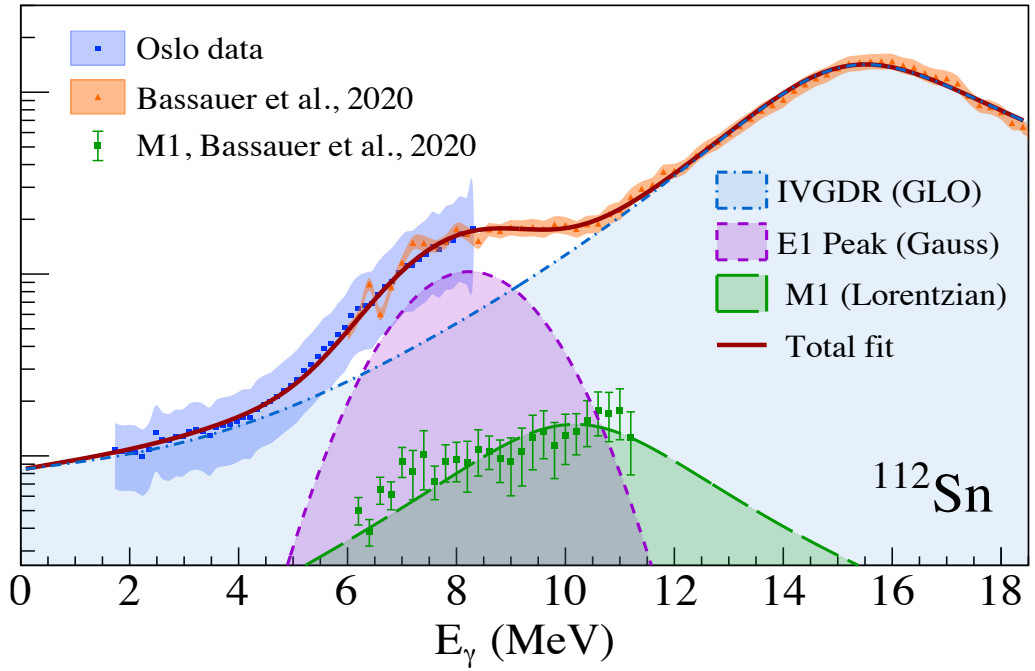

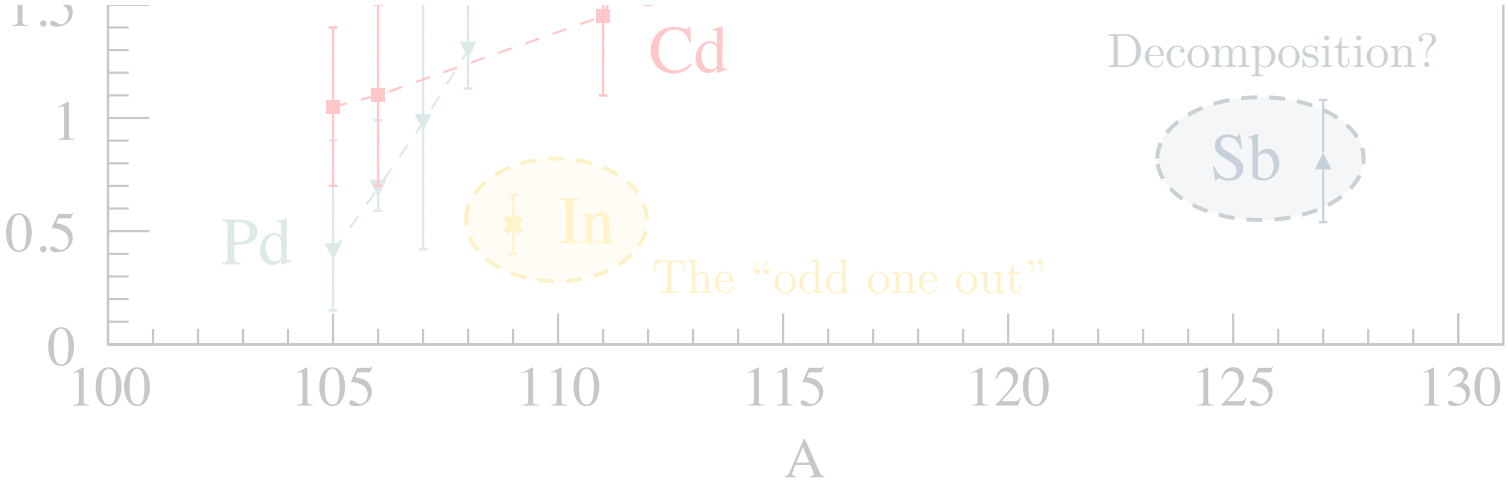

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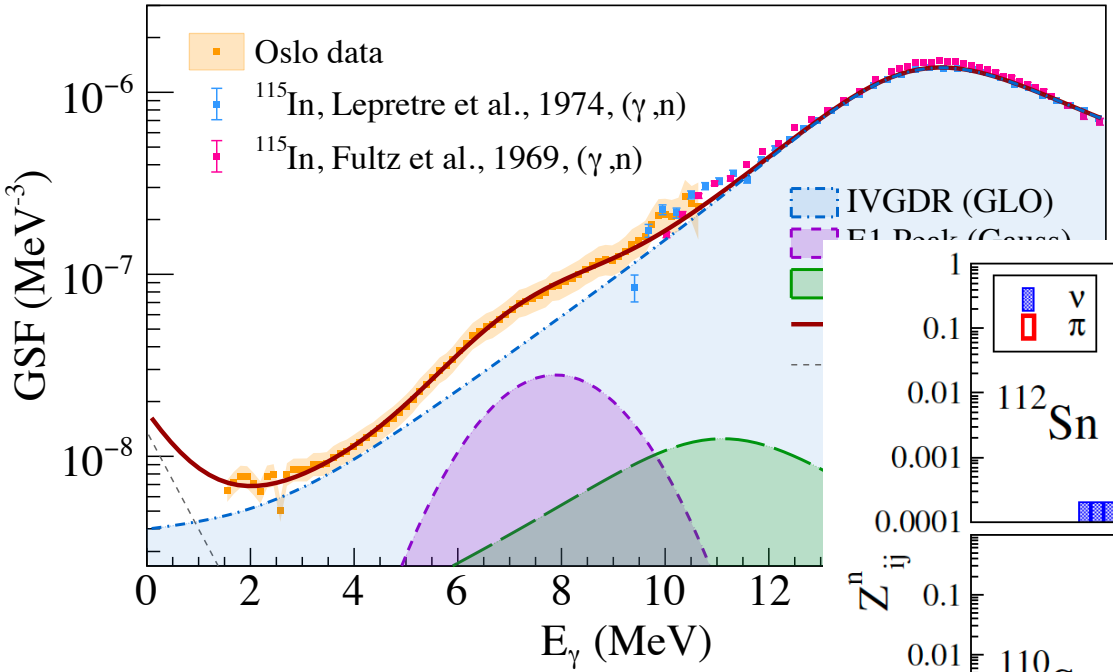
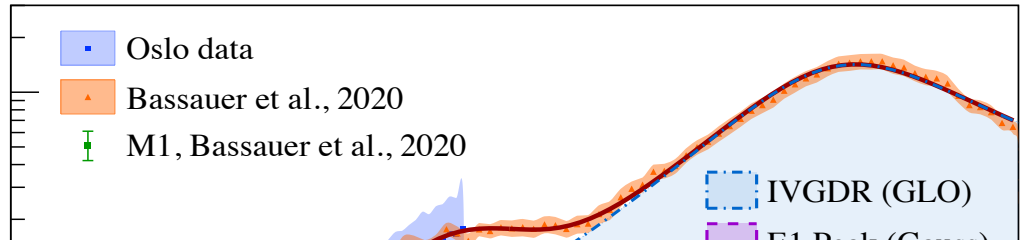
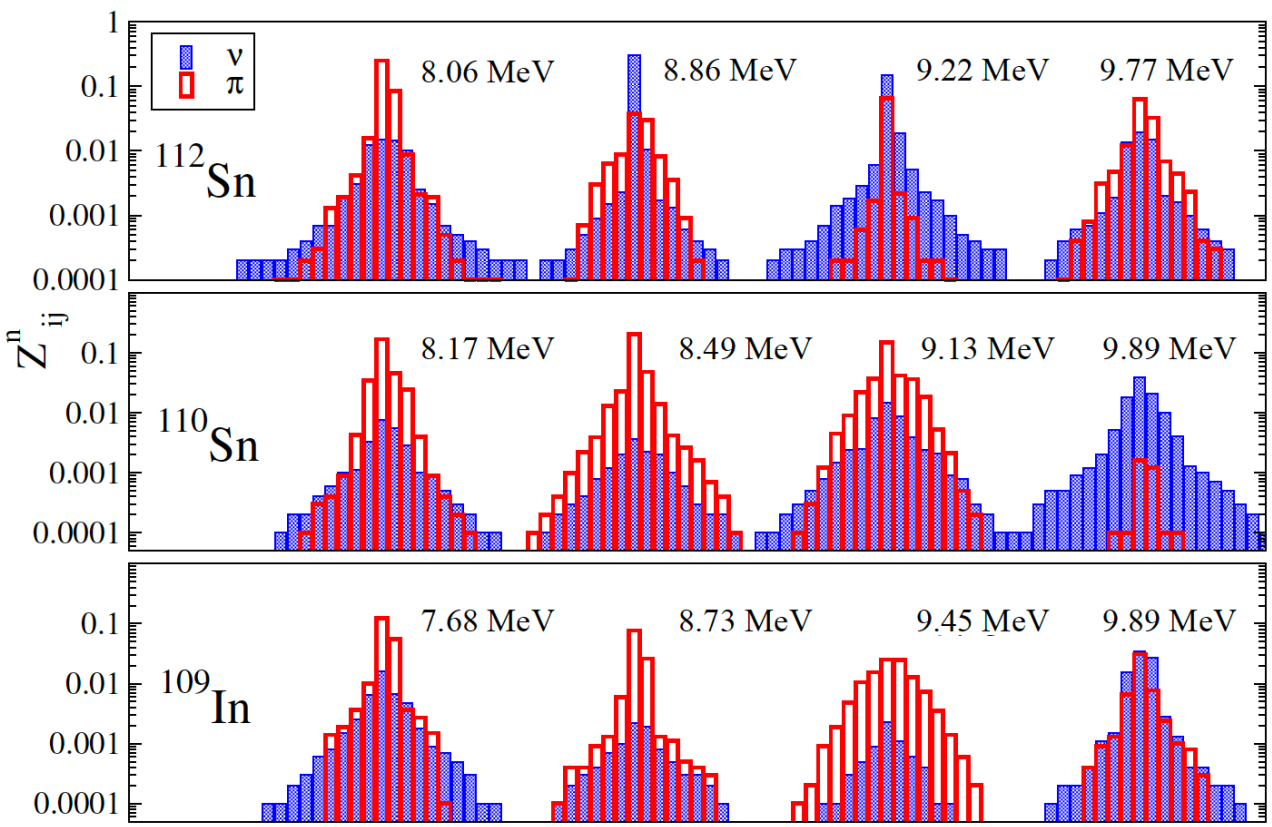
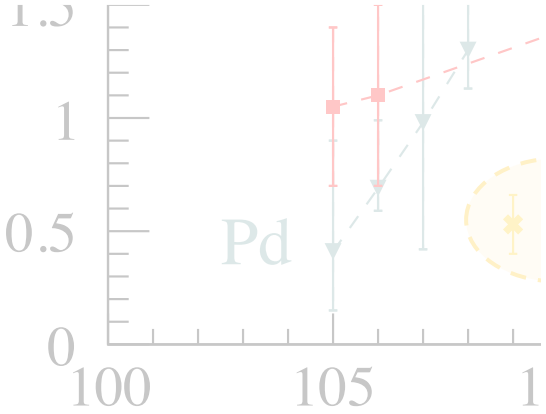
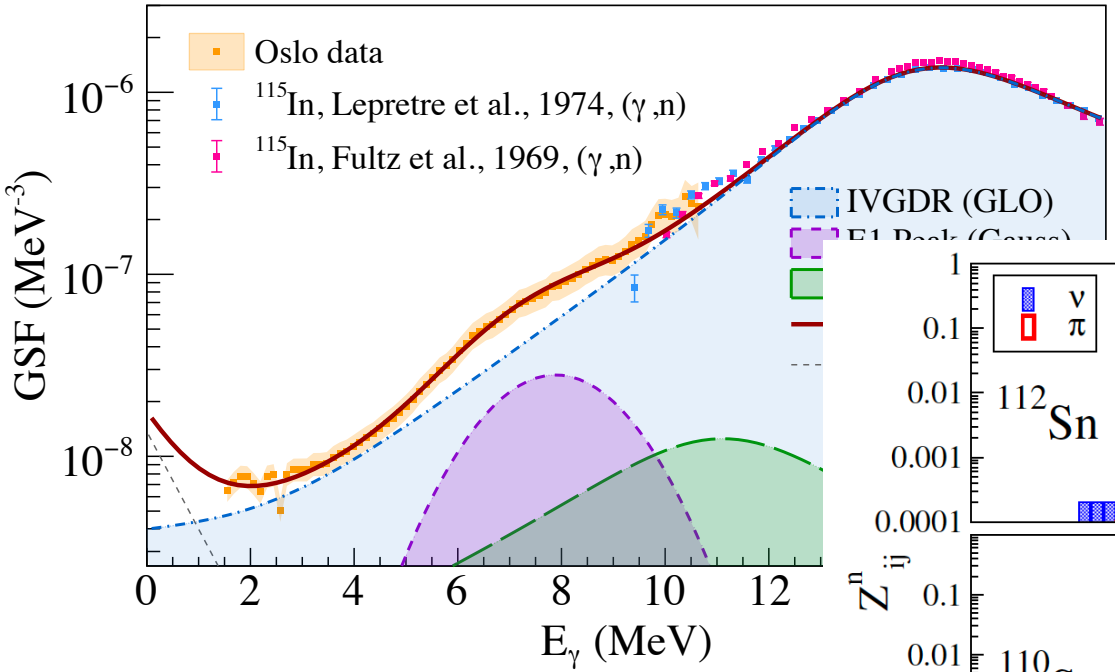


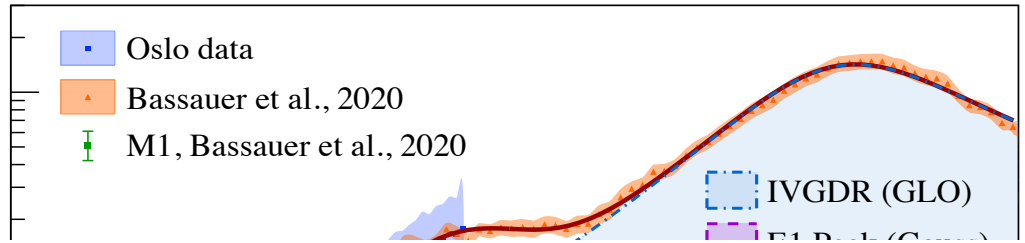


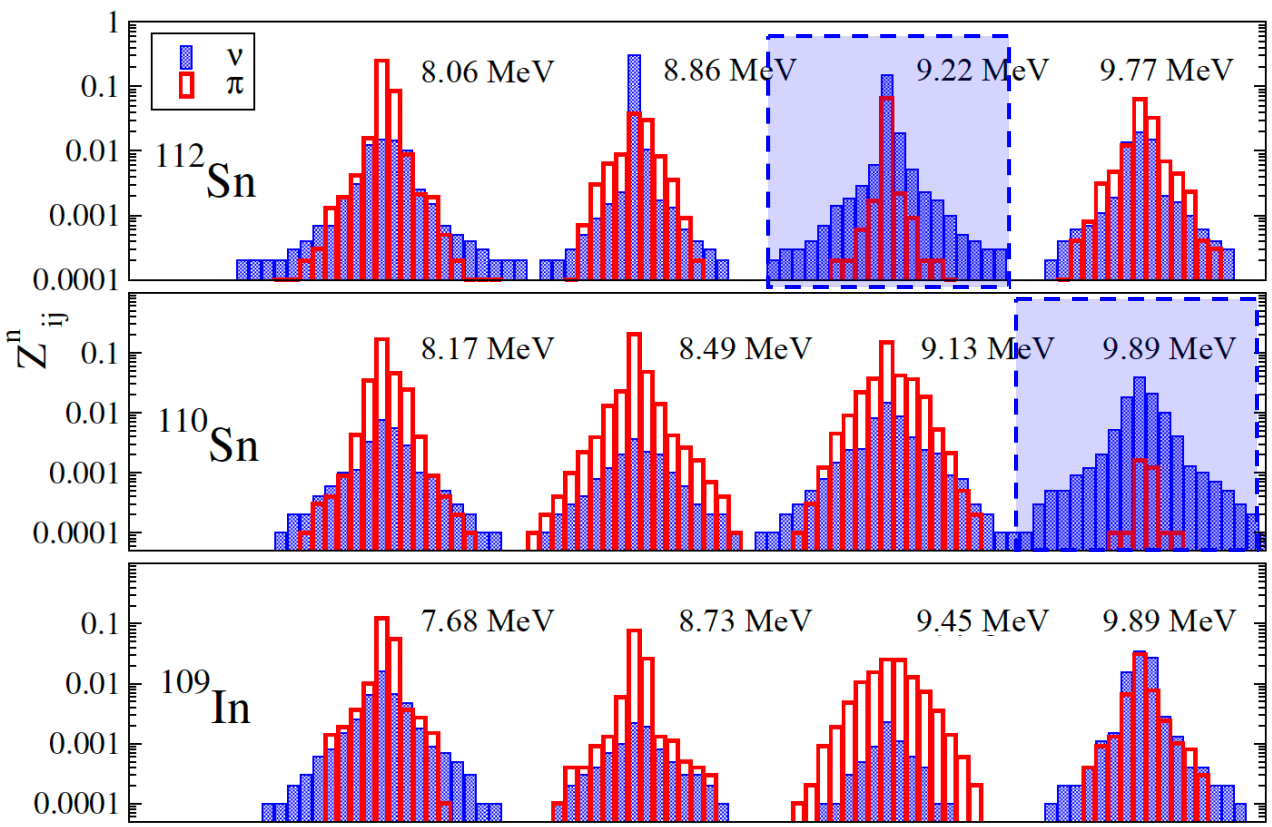


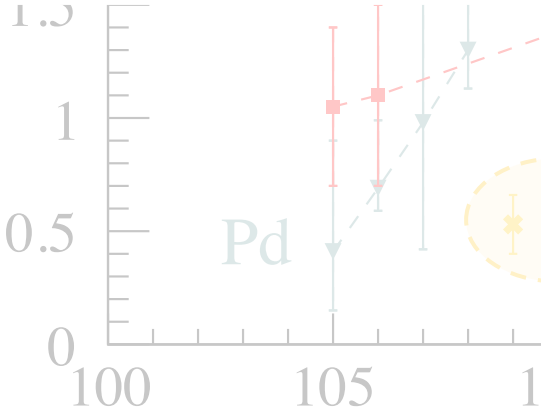


“PDR” around Sn









Summary and Outlook

- An extensive study of statistical properties of nuclei in the Sn mass region has been done in Oslo from 2013 – 2026.
- The GSFs and NLDs from the Oslo experiments provide new insights into the evolution of the "PDR".
- No systematic increase of the low-lying E1 strength with N was observed in Sn isotopes and other nuclei in the Sn mass region.
- The presumed IV component of the PDR at 6 MeV was extracted.
- Suppression of the low-lying E1 strength in the neutron-deficient 109In was observed.

Special thanks to our collaborators!

Western Michigan University — E. Litvinova

eli nuclear physics — P.-A. Söderström

Our most recent results

Oslo Cyclotron Laboratory — J. C. Müller, P. A. Sobas, J. C. Wikne, and V. Modamio.

Universitetet i Oslo — A. C. Larsen, A. A. Görgen, M. Guttormsen, F. L. Bello Garrote,

Norwegian Nuclear Research Centre — M. M. Bjørøen, T. K. Eriksen, D. Gjestvang, V. Ingeberg, E. Lima, F. Pogliano, W. Paulsen, L. G. Pedersen, N. I. J. Pettersen, E. Sahin, S. Siem, G. M. Tveten, V. M.Valsdottir, F. Zeiser.

Technische Universität Darmstadt — P. von Neumann-Cosel, J. Isaak

ULB — S. Goriely, A. Choplin, S. Martinet, L. Siess

Thank you for your attention!