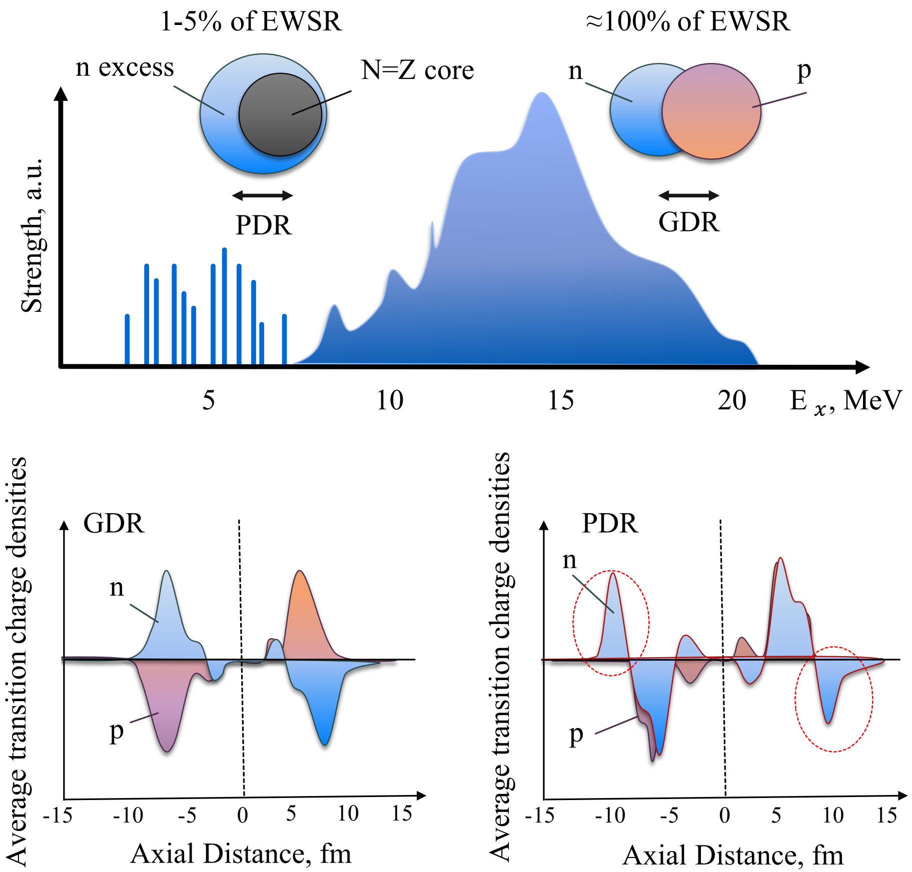
Approaching the pygmy dipole resonance in Sn isotopes with the Oslo method

[1]Markova Maria, [1]A.C. Larsen, [1] F.L.B.Garrote
[1]University of Oslo, Department of Physics, Nuclear Physics group

10 July 2024

Compound-Nuclear Reactions and Related Topics CNR*24

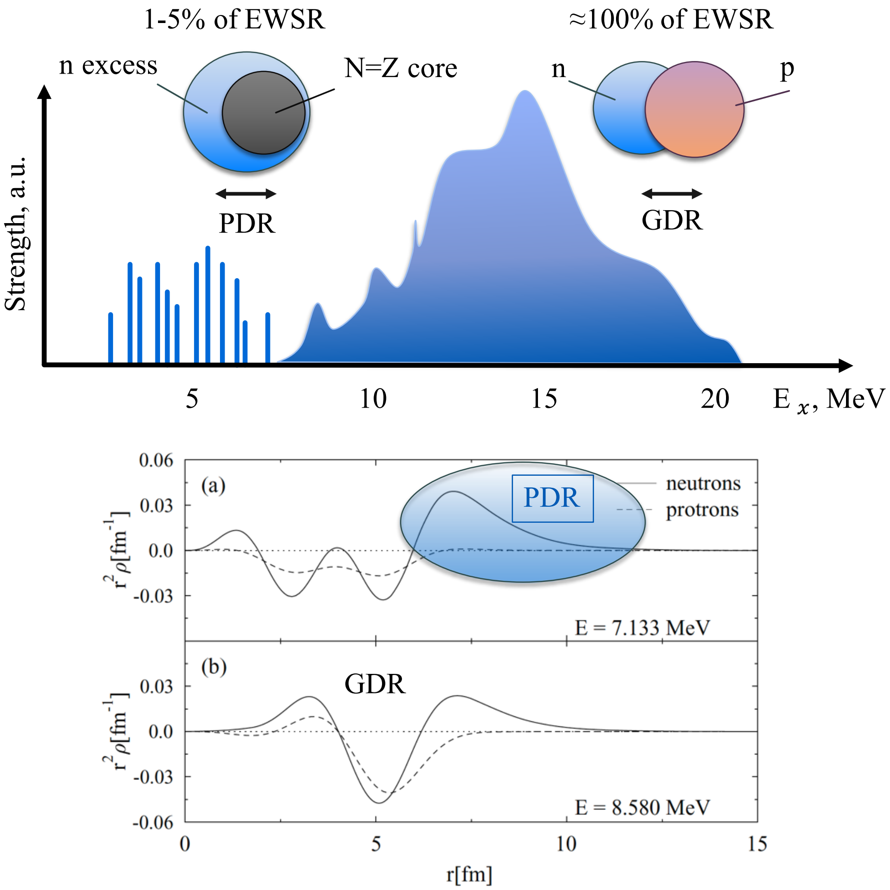
The pygmy dipole resonance in nuclei



The giant and pygmy dipole resonance modes.

- Hydrodynamic interpretation of the IVGDR as an out-of-phase oscillation of protons against neutrons (enhancement of ≈ 100 % of the EWSR).
- The PDR is often associated with a low-lying $E1$ strength in the vicinity of the neutron threshold (several % of the EWSR).
- The macroscopic picture of the PDR is oscillations of a neutron excess against a $N = Z$ saturated core.
- This macroscopic interpretation is still questioned and debated! (Toroidal dipole mode?)

The pygmy dipole resonance in nuclei

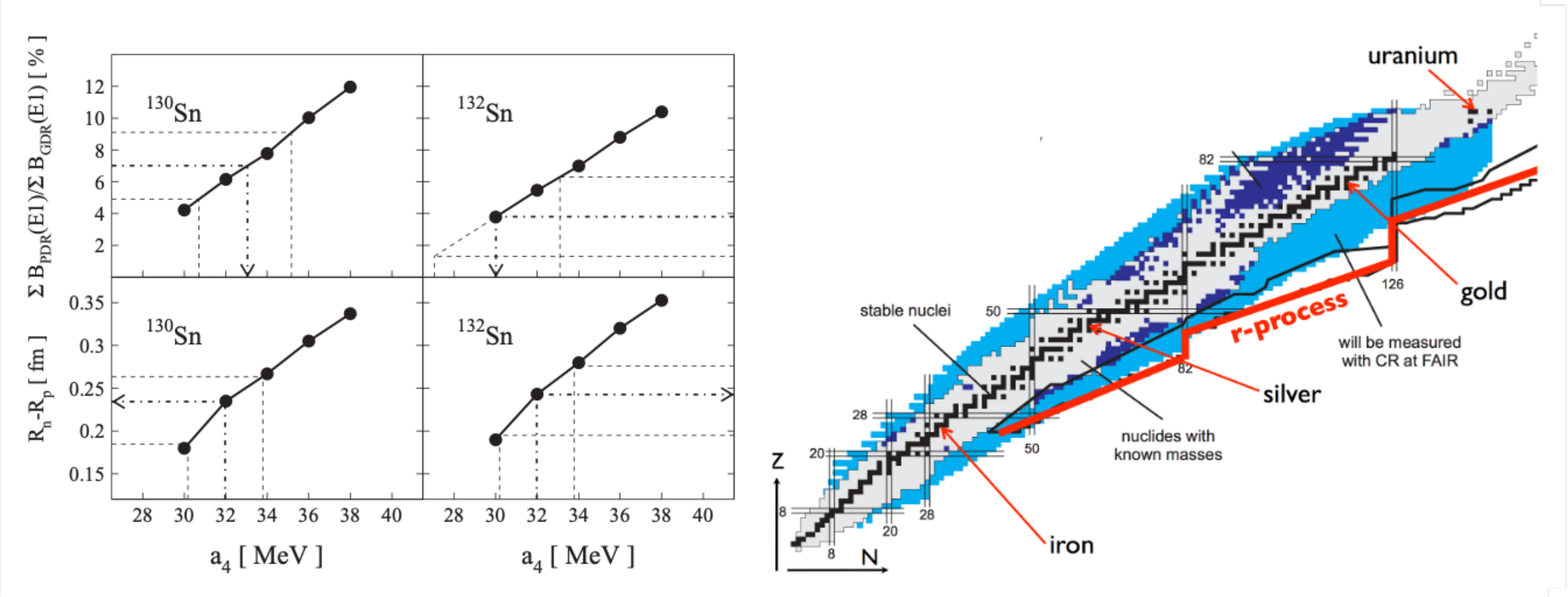


The giant and pygmy dipole resonance modes.

- Hydrodynamic interpretation of the IVGDR as an out-of-phase oscillation of protons against neutrons (enhancement of ≈ 100 % of the EWSR).
- The PDR is often associated with a low-lying E1 strength in the vicinity of the neutron threshold (several % of the EWSR).
- The macroscopic picture of the PDR is oscillations of a neutron excess against a $N = Z$ saturated core.
- This macroscopic interpretation is still questioned and debated! (Toroidal dipole mode?)

Motivation: why PDR?

- Relation of the PDR to the neutron skin thickness → equation of state → information on neutron stars?
- Potential impact of the PDR on neutron capture rates and abundances of elements produced in the r-process.
- Appearance of the PDR increases probability of the (n, γ) reaction.

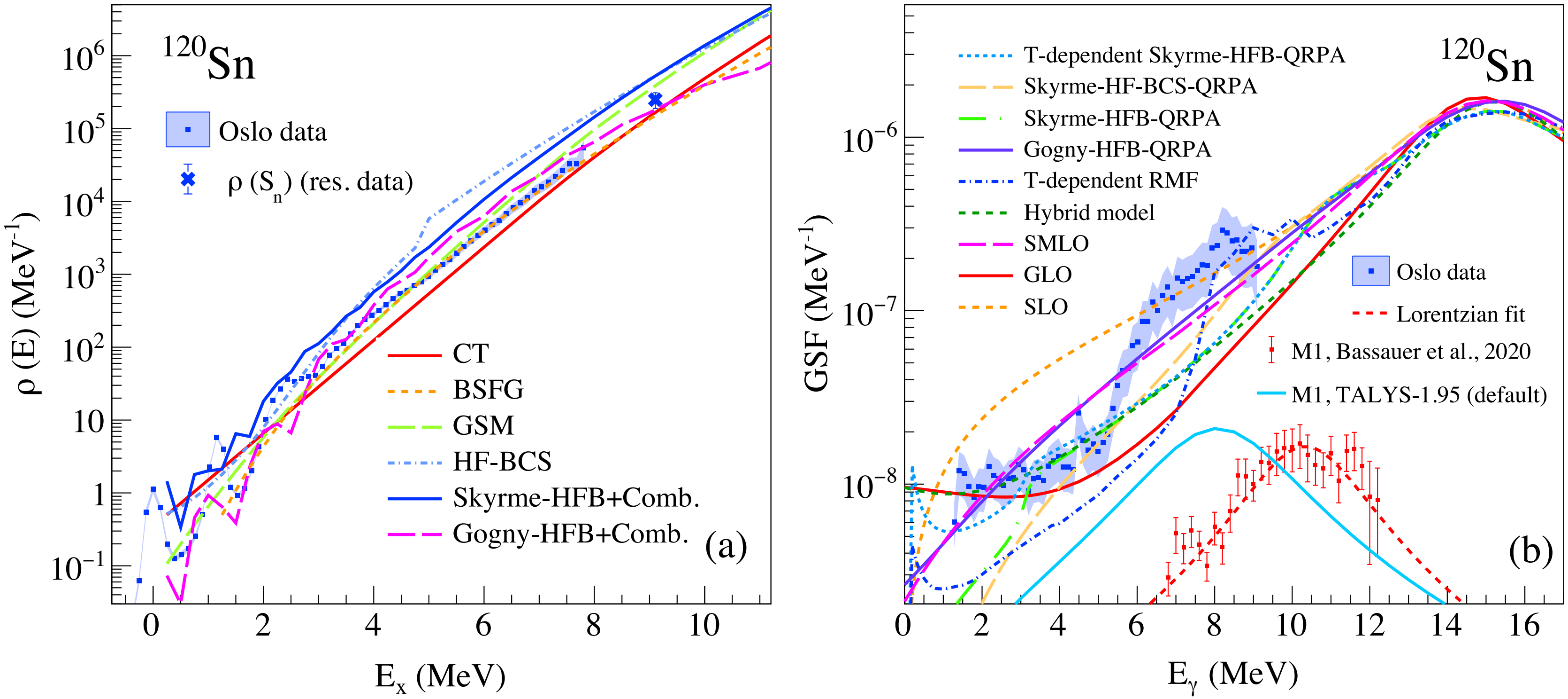


Left part: Relation between the a_4 and neutron skin thickness. A. Klimkiewicz, Phys. Rev. C 76, 051603(R) (2007)

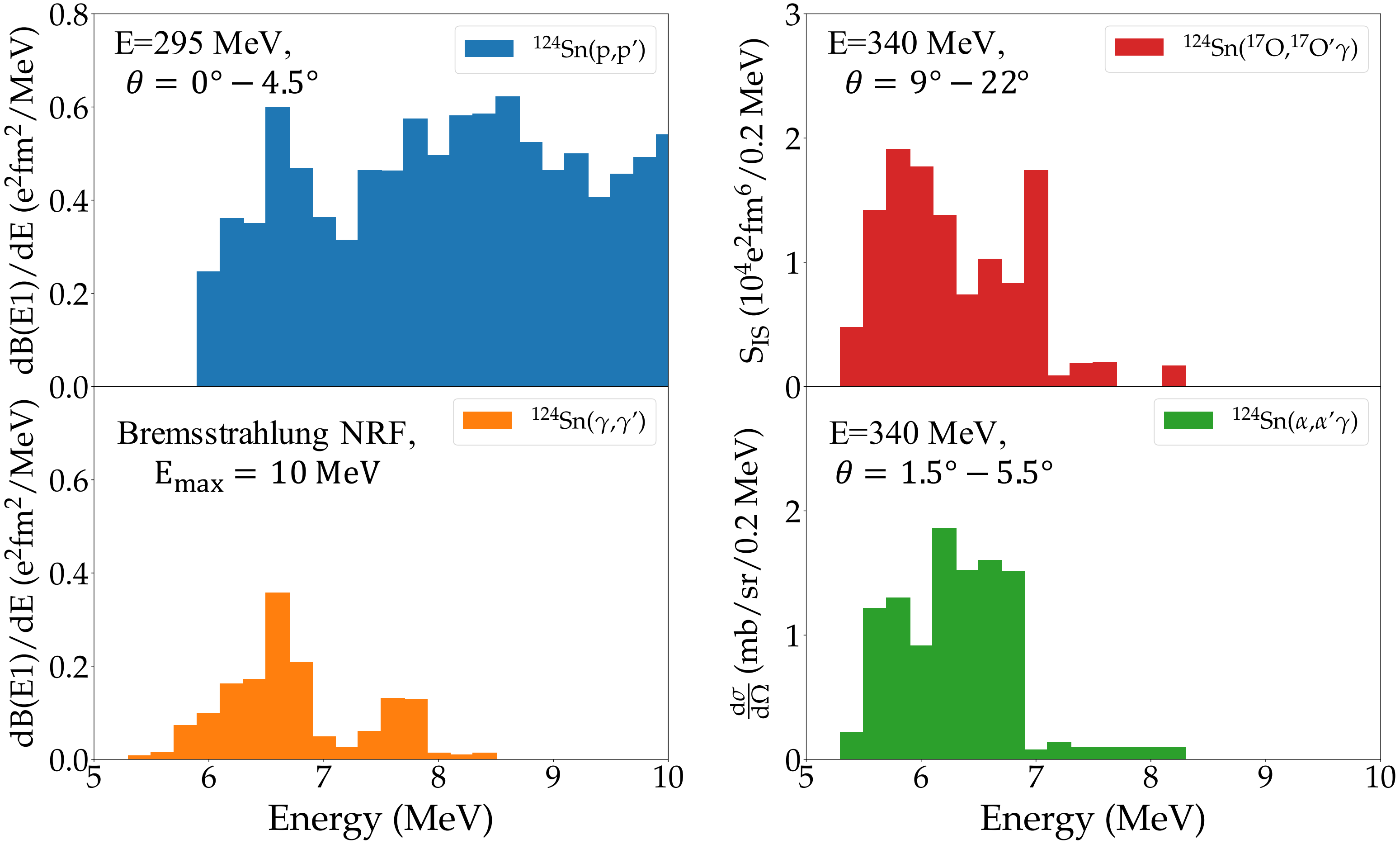
Right part: Probable pathway of the r-process.

GSF and NLD: The Oslo method as a method of choice

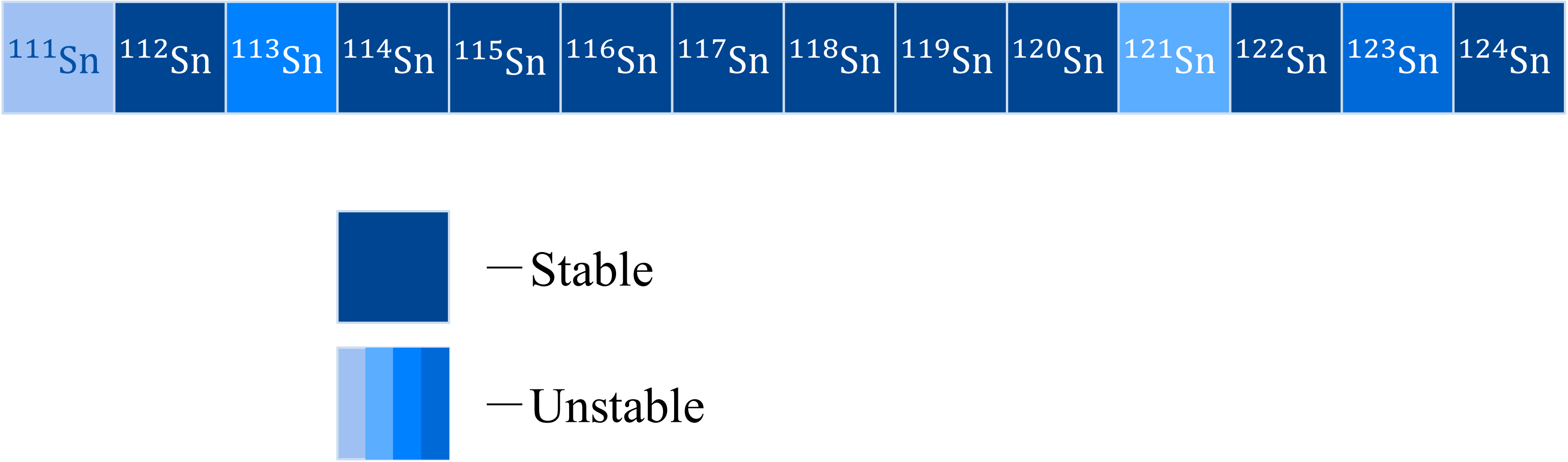
- Both the NLD and the GSF are important ingredients of statistical model calculations.
- The Oslo method is commonly used for a simultaneous extraction of these nuclear characteristics.
- There is a plethora of theoretical approaches, and systematic experimental constraints are highly demanded.



Why Sn isotopes?



Sn isotopes studied at the OCL

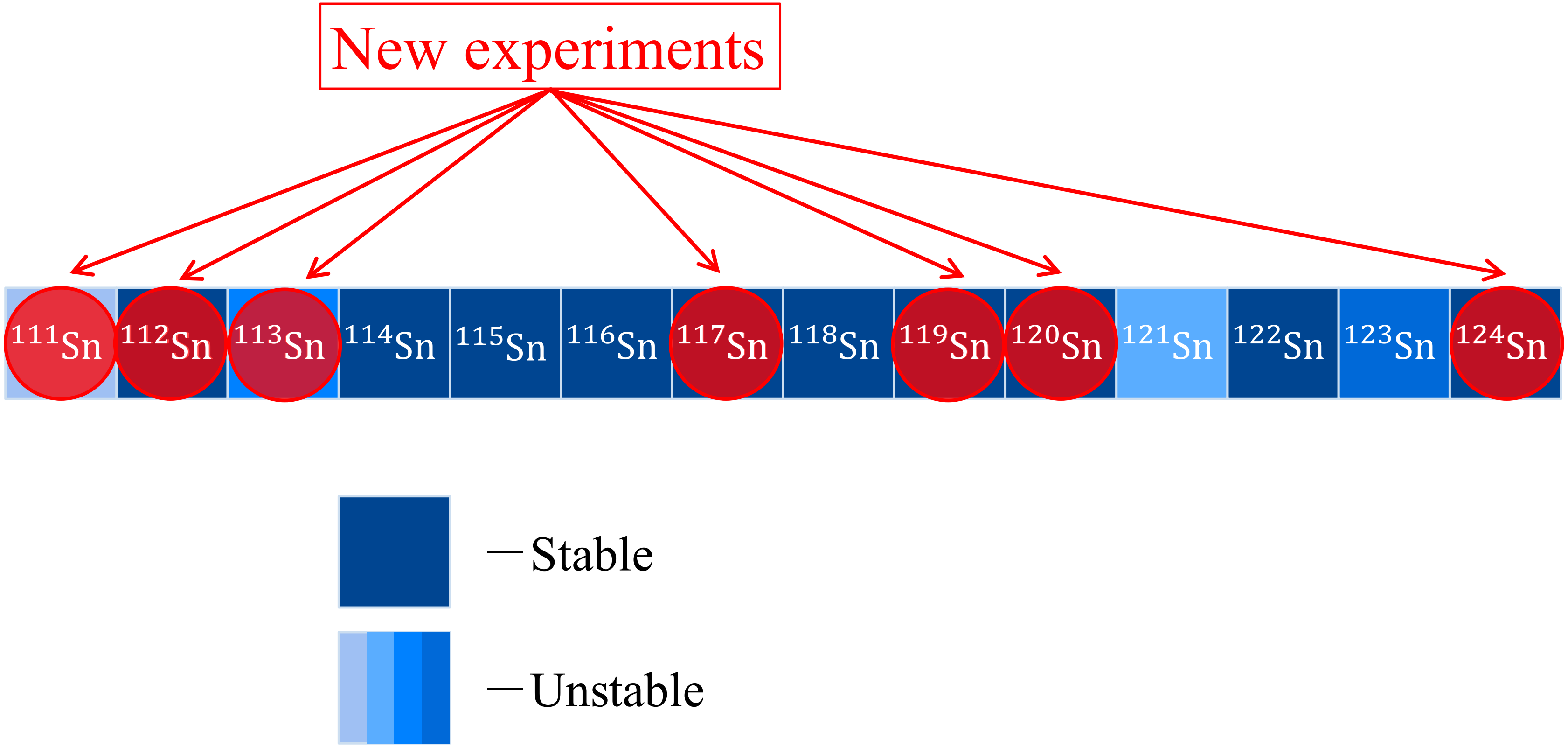


^{111}Sn	^{112}Sn	^{113}Sn	^{114}Sn	^{115}Sn	^{116}Sn	^{117}Sn	^{118}Sn	^{119}Sn	^{120}Sn	^{121}Sn	^{122}Sn	^{123}Sn	^{124}Sn

■ — Stable

▨ — Unstable

Sn isotopes studied at the OCL



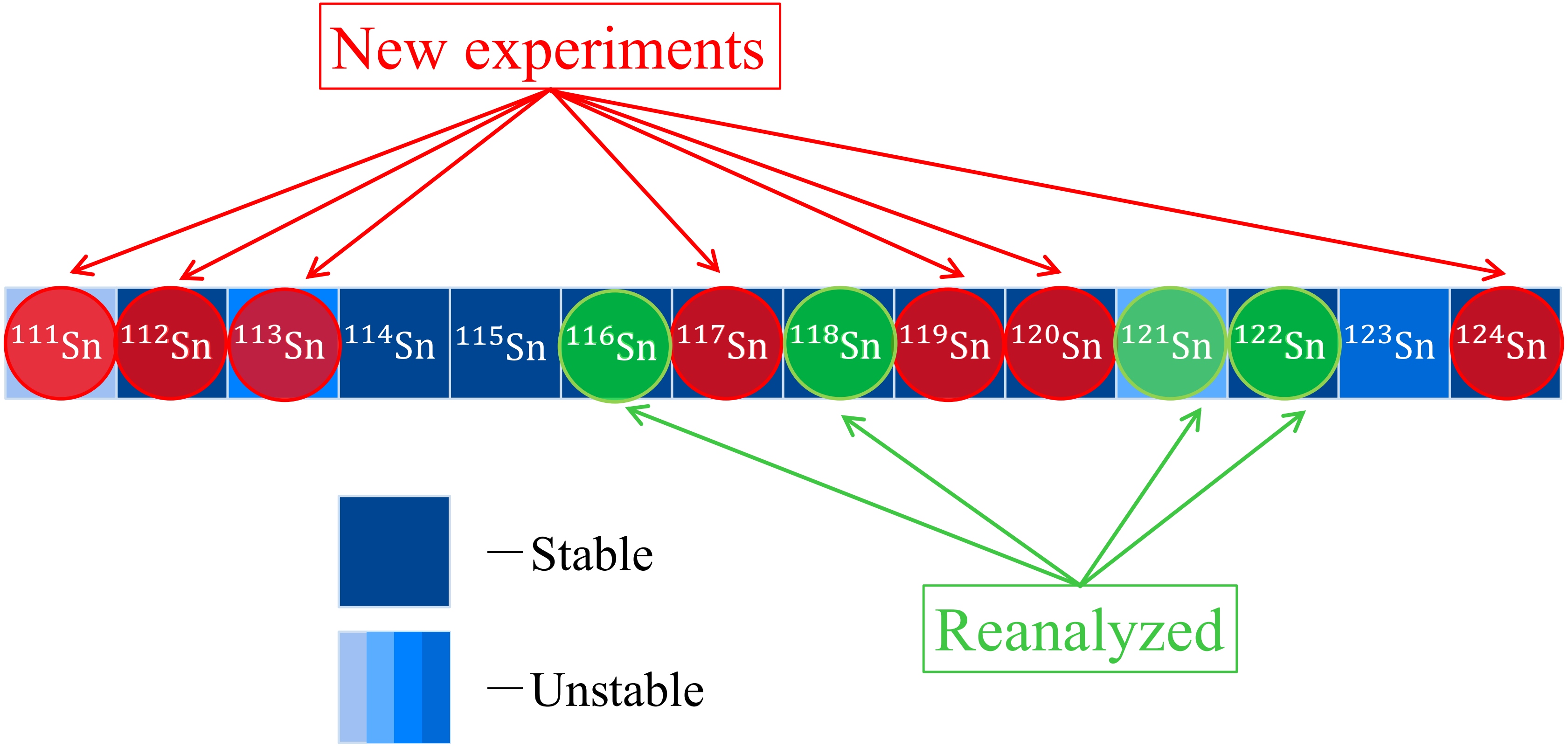
New experiments

^{111}Sn ^{112}Sn ^{113}Sn ^{114}Sn ^{115}Sn ^{116}Sn ^{117}Sn ^{118}Sn ^{119}Sn ^{120}Sn ^{121}Sn ^{122}Sn ^{123}Sn ^{124}Sn

— Stable

— Unstable

Sn isotopes studied at the OCL



New experiments

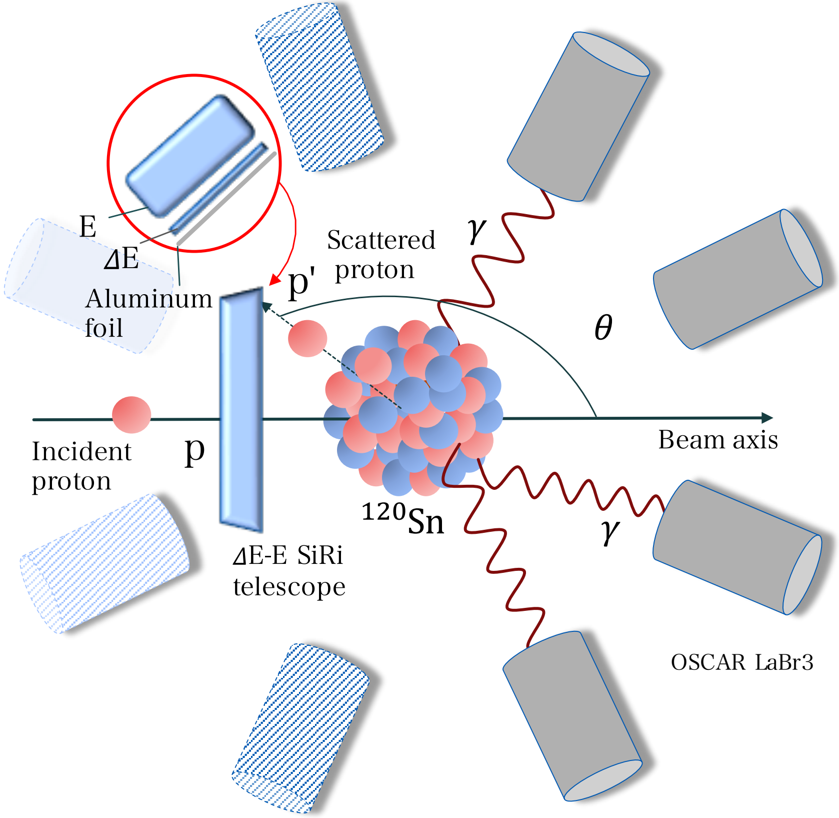
^{111}Sn ^{112}Sn ^{113}Sn ^{114}Sn ^{115}Sn ^{116}Sn ^{117}Sn ^{118}Sn ^{119}Sn ^{120}Sn ^{121}Sn ^{122}Sn ^{123}Sn ^{124}Sn

— Stable

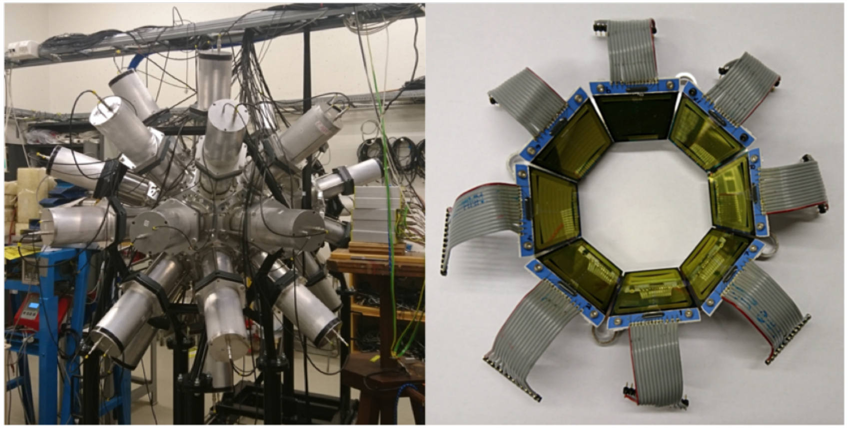
— Unstable

Reanalyzed

Oslo method: Experiments on Sn at the Oslo Cyclotron Laboratory



The principal scheme of the experiment.

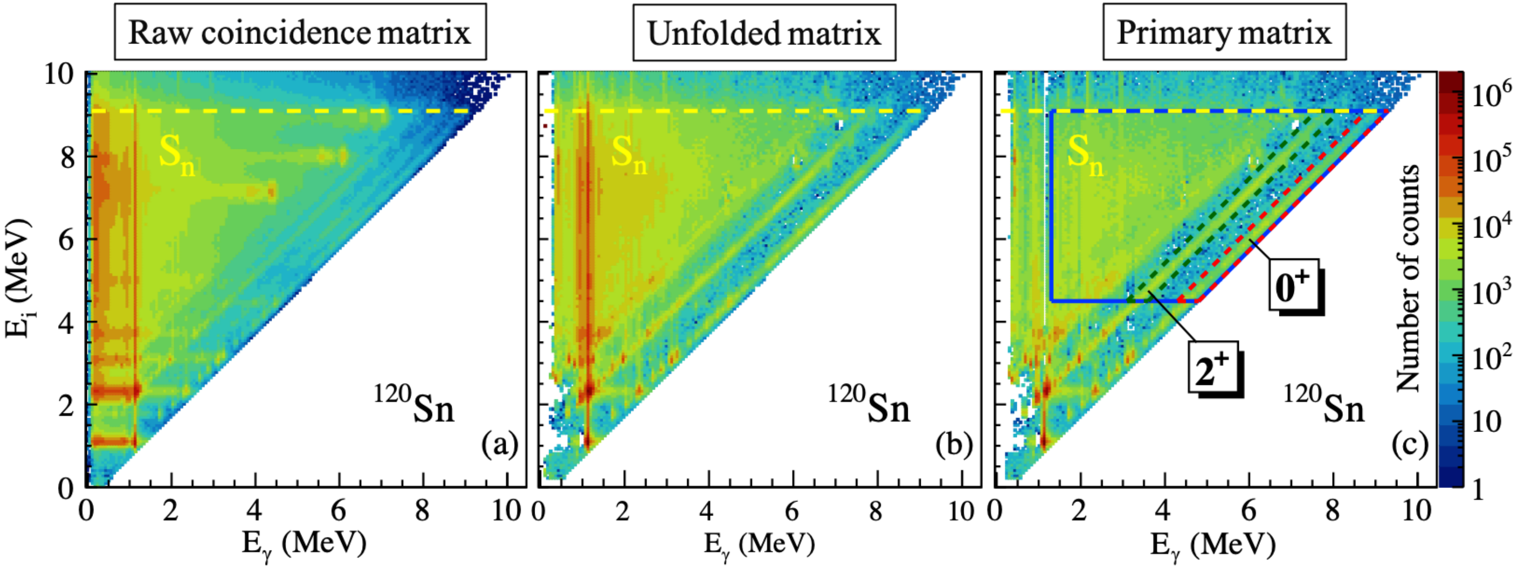


Left: OSCAR LaBr$_3$:Ce detector array. **Right**: SiRi particle telescope.

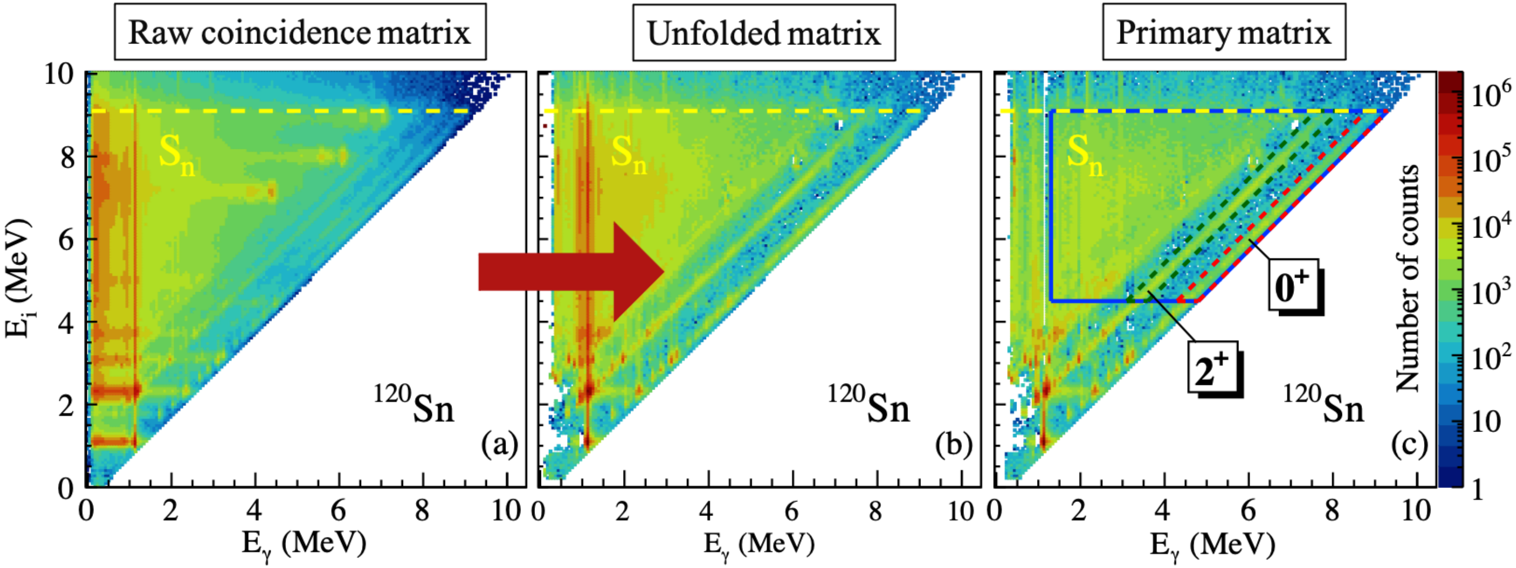
$^{111-113,116-122,124}$**Sn:**

- SiRi Si particle telescope + NaI(Tl) (older)/ LaBr$_3$(Ce) (recent) detector array.
- 126°-140° particle angles are covered.
- $(p,p'\gamma)$, $(p,d\gamma)$, $(d,p\gamma)$, (^{3}He,^{3}He γ), (^{3}He,$\alpha\gamma$) reactions with 16 and 25 MeV proton, 11.5 MeV deuteron, 38 MeV ^{3}He beams.
- particle-γ coincidences were extracted.

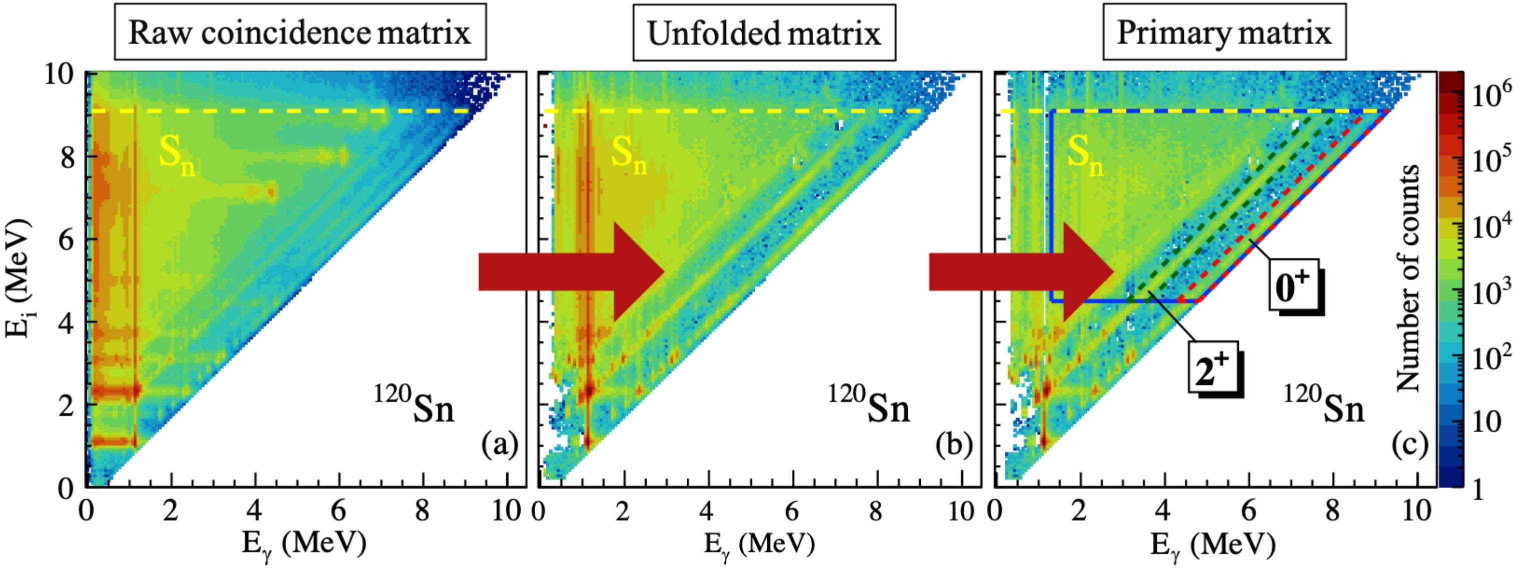
The Oslo method: Step-by-step

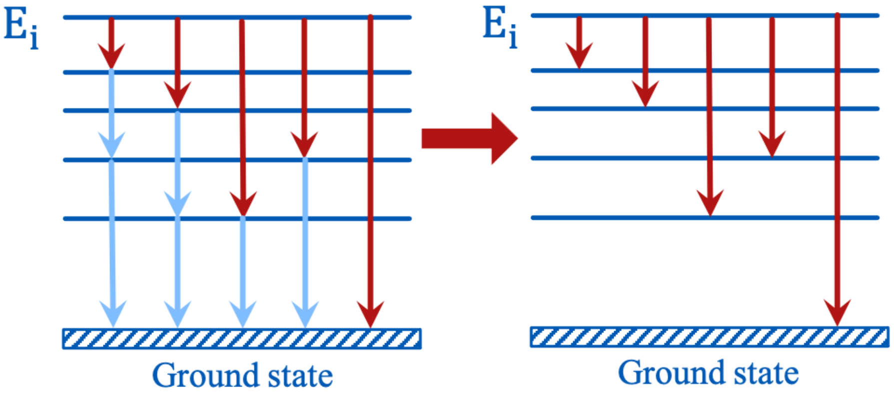


The Oslo method: Step-by-step

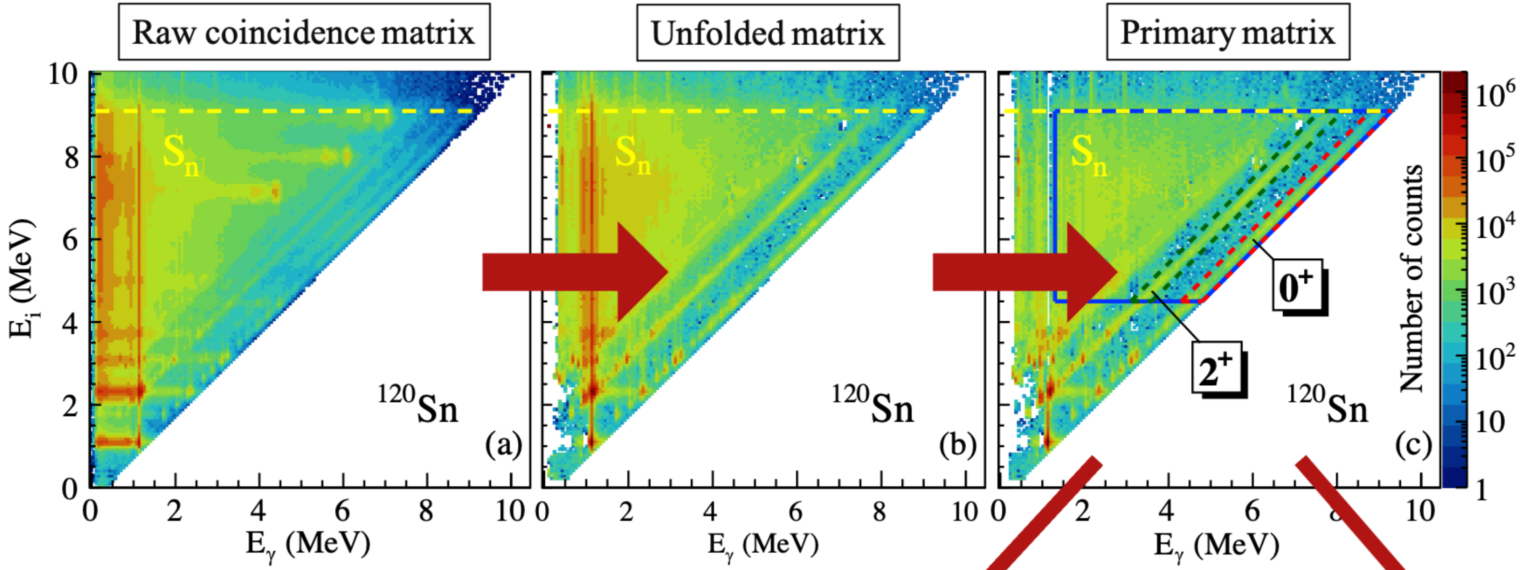


The Oslo method: Step-by-step



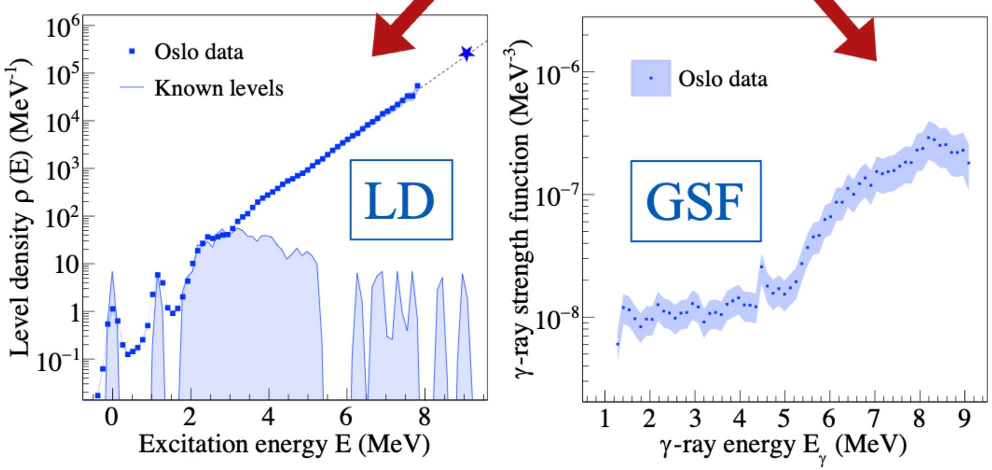


The Oslo method: Step-by-step

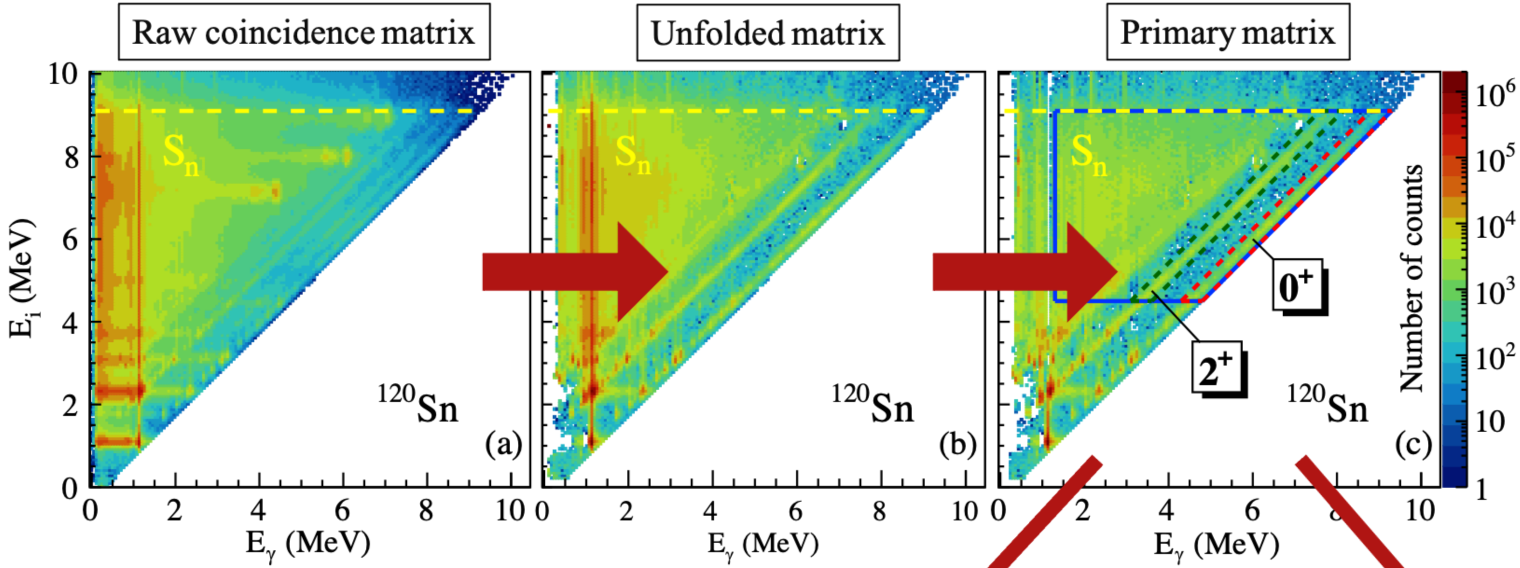


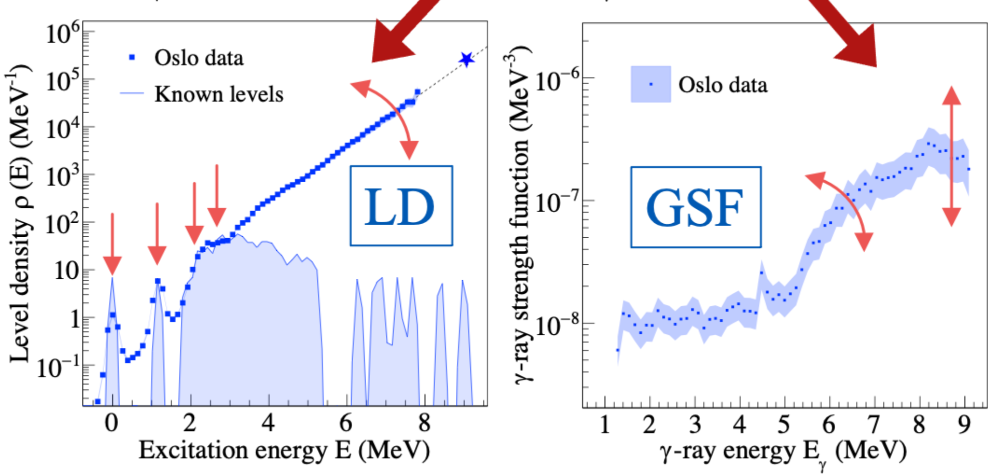
$$P(E_\gamma, E_i) \propto \mathcal{T}_{i\to f} \cdot \rho_f$$

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



The Oslo method: Step-by-step

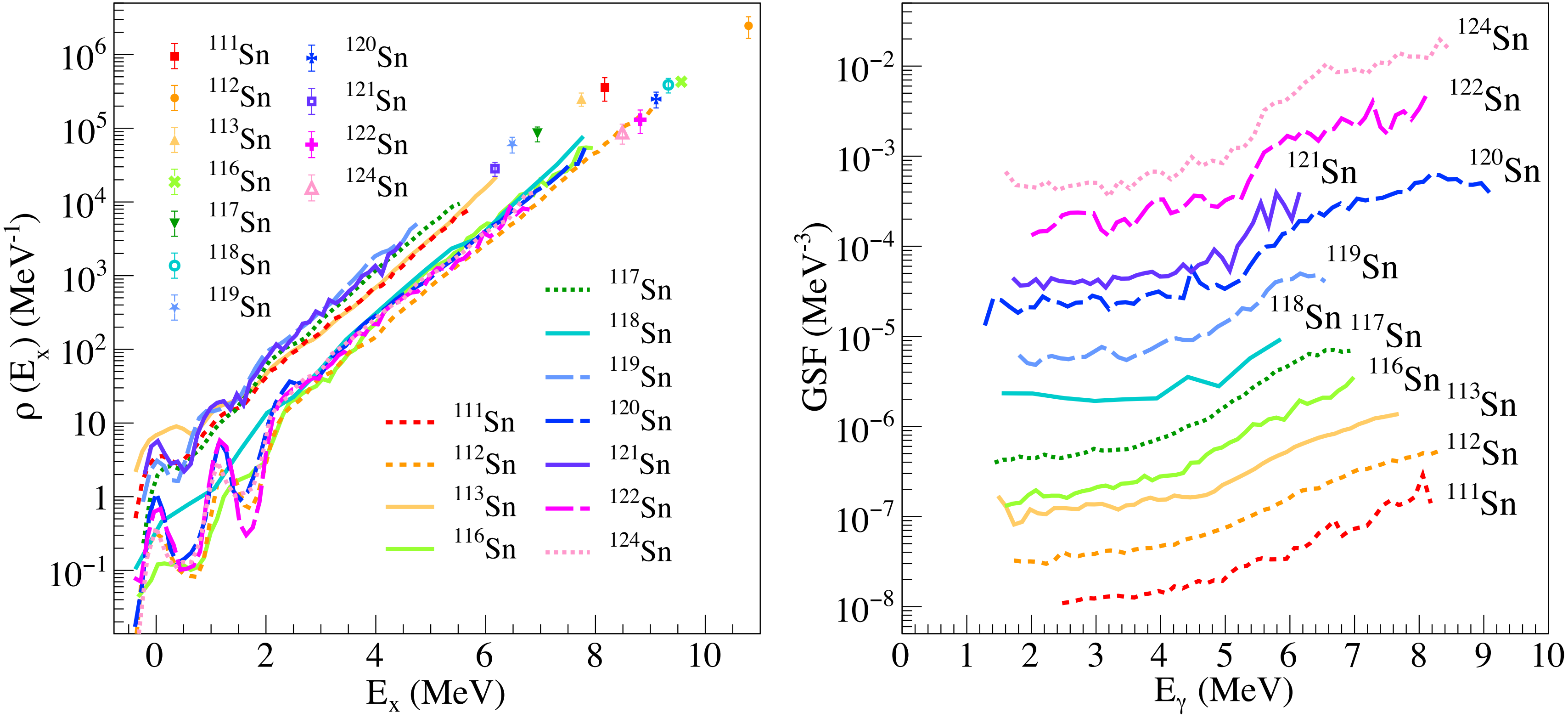




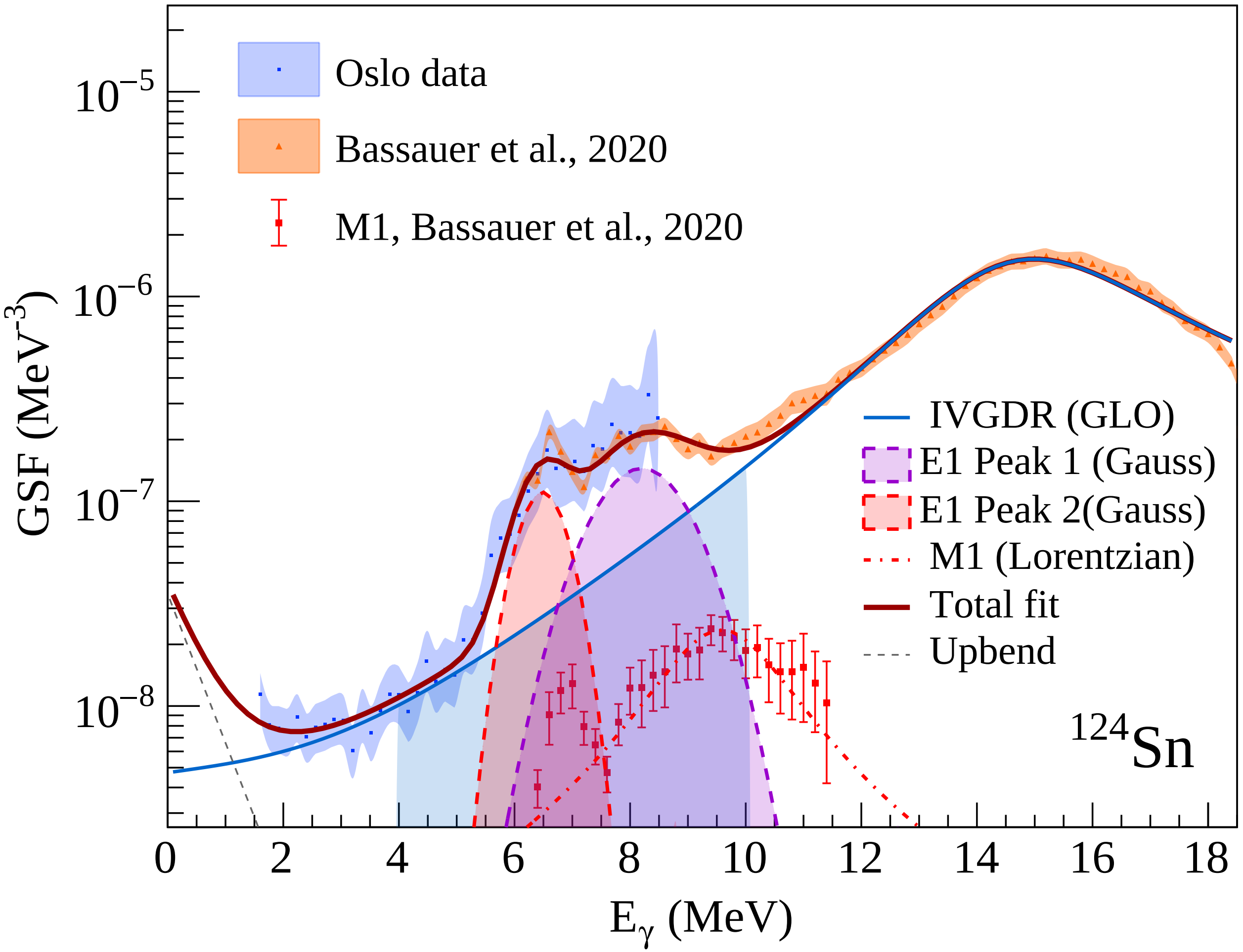
Normalization:

- 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.

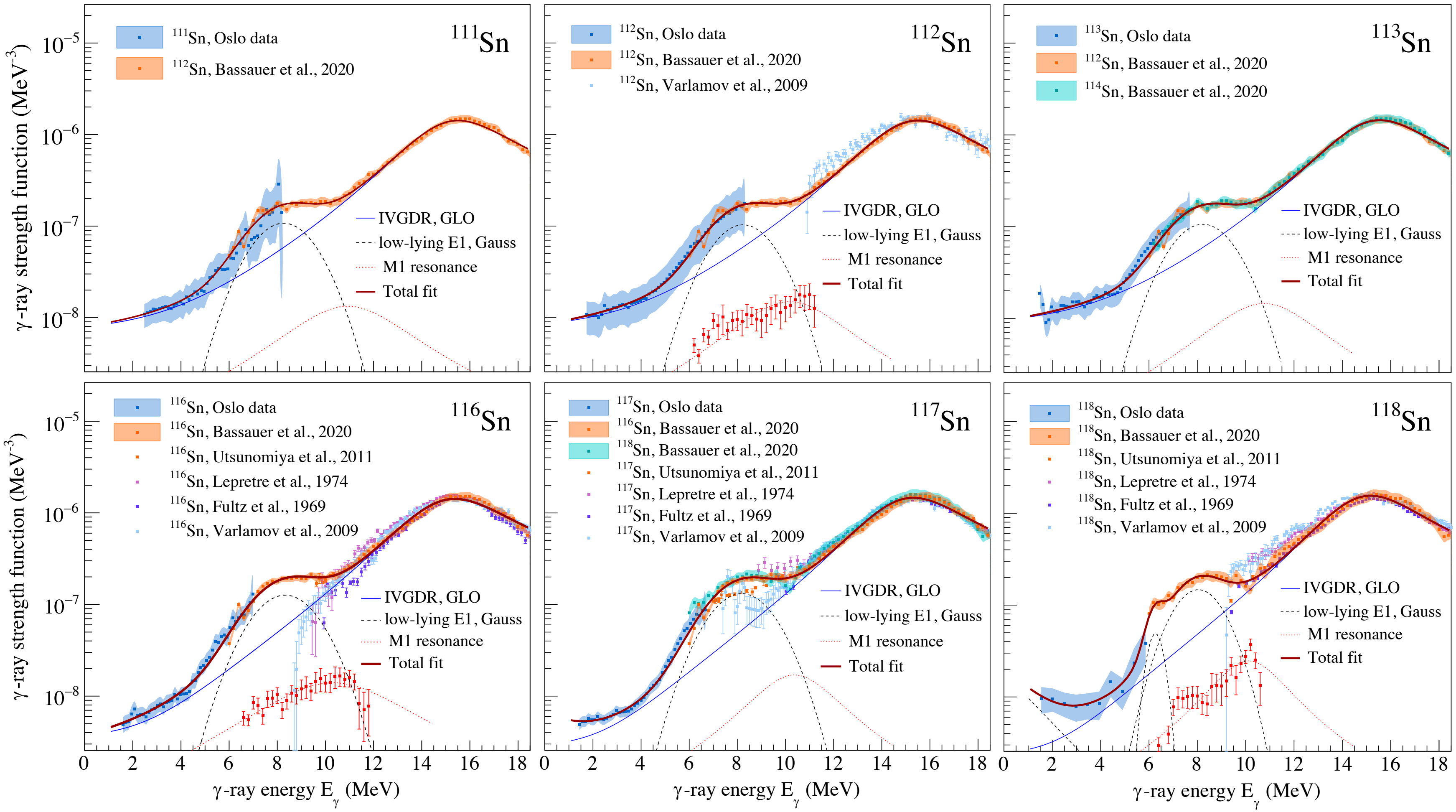
Main results: NLDs and GSFs of Sn isotopes



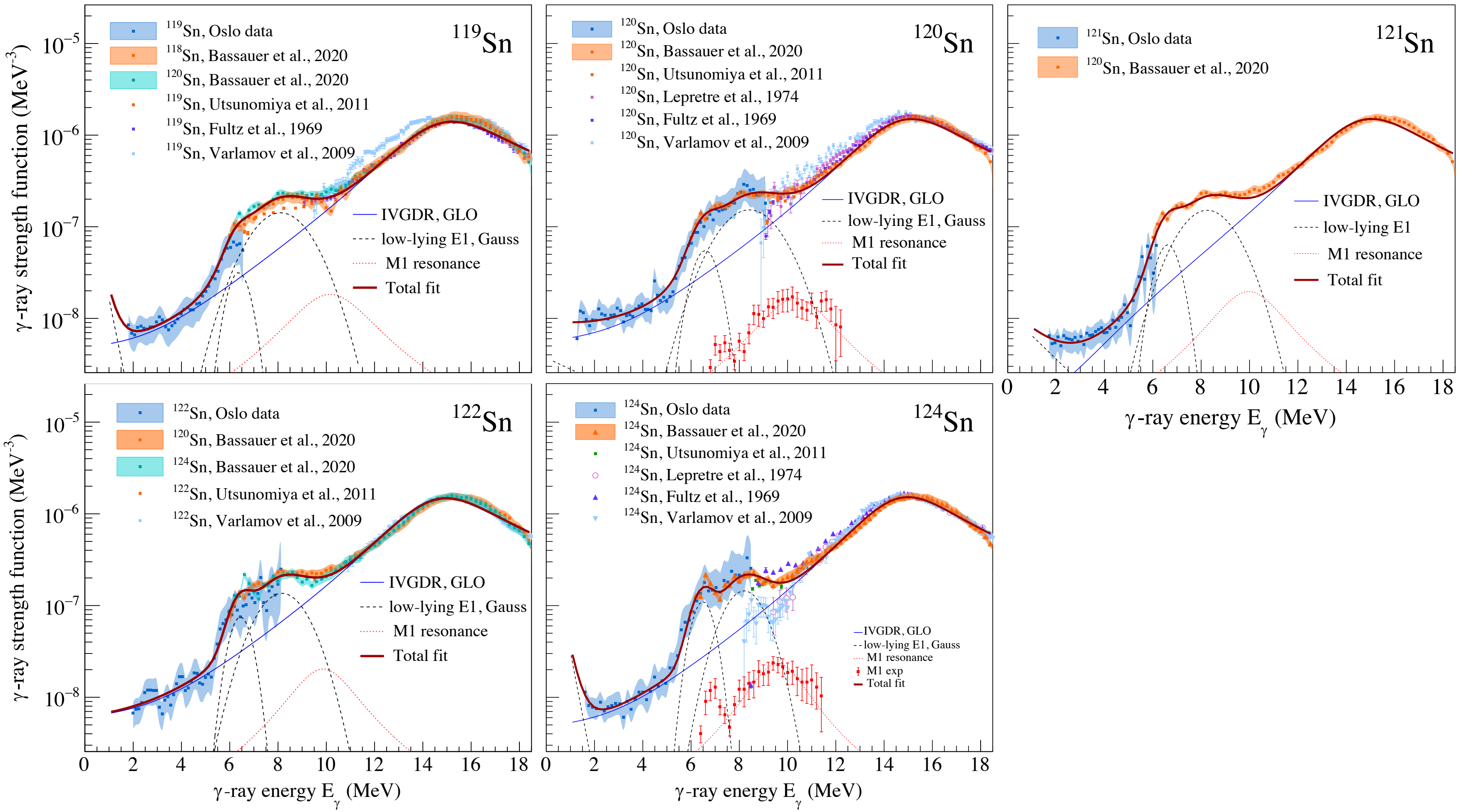
Main results: Evolution of the low-lying strength



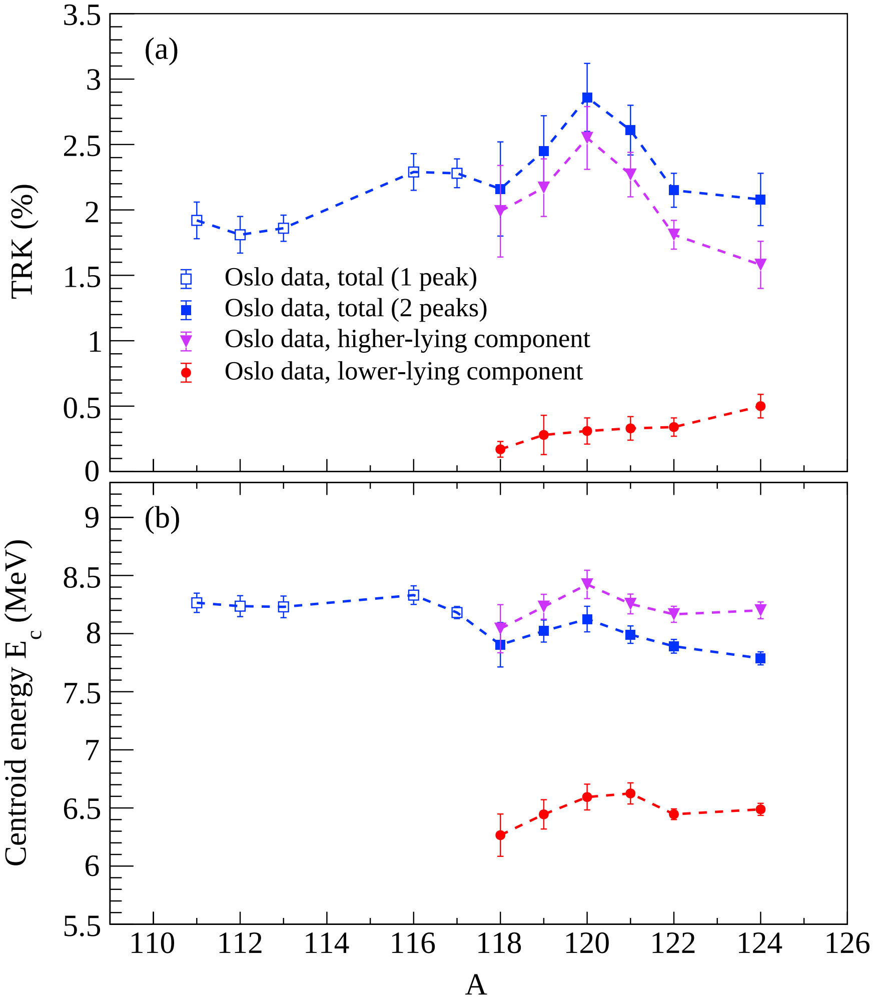
Main results: the GSF and PDR in $^{111-113,116-118}$Sn



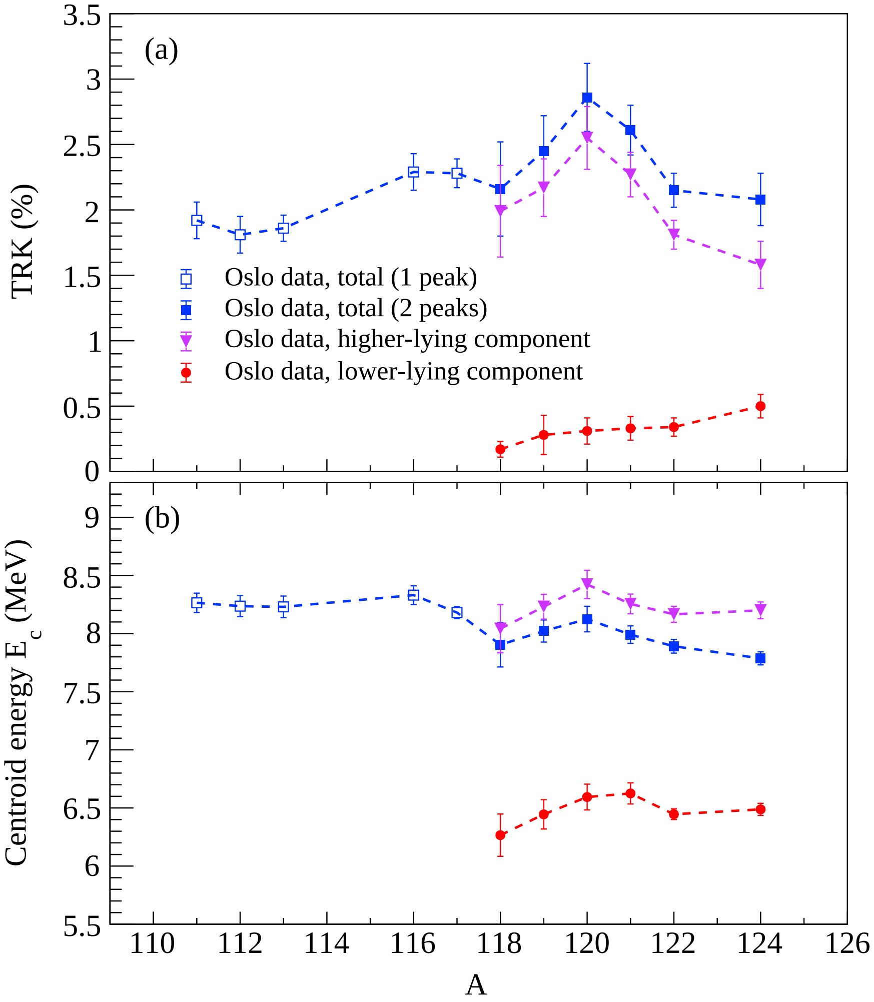
Main results: the GSF and PDR in $^{119-122,124}$Sn



Main results: Evolution of the low-lying strength



Main results: Evolution of the low-lying strength



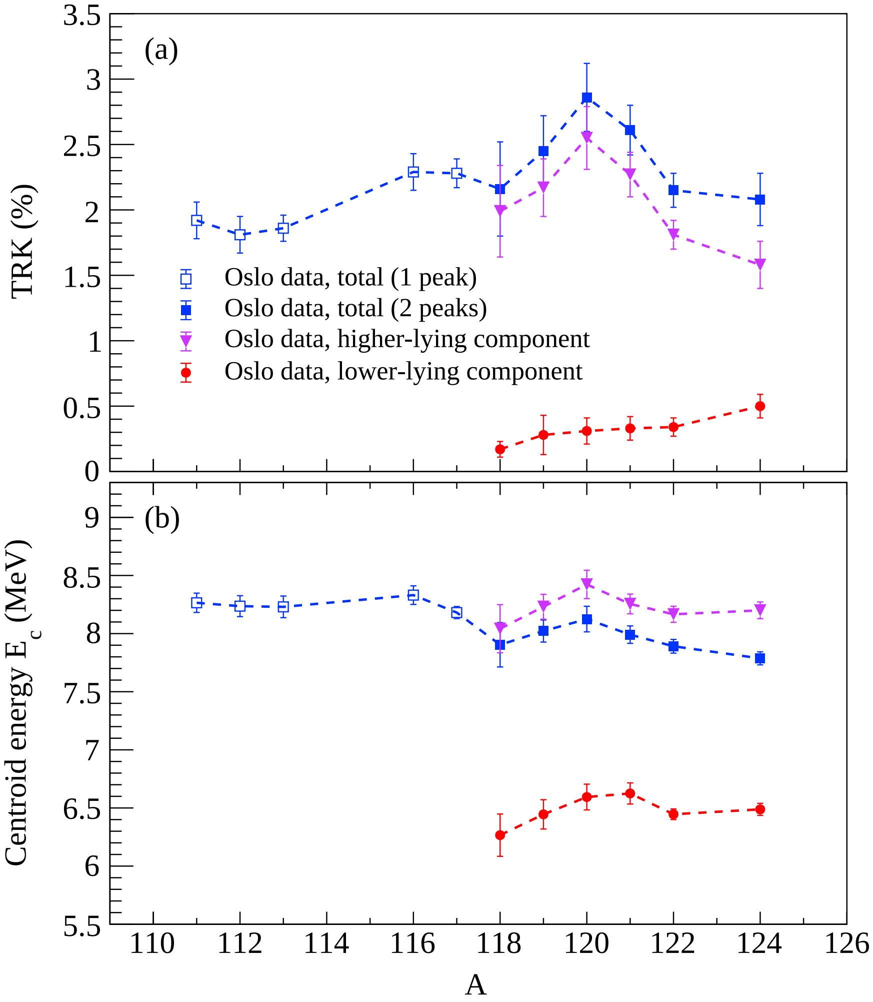
Conclusion 1:

The low-lying strength is centered at ≈ 8.4 MeV in all studied Sn isotopes.

Conclusion 2:

The low-lying component remains at ≈ 6.5 MeV in heaviest tins.

Main results: Evolution of the low-lying strength



Conclusion 1:

The low-lying strength is centered at ≈ 8.4 MeV in all studied Sn isotopes.

Conclusion 2:

The low-lying component remains at ≈ 6.5 MeV in heaviest tins.

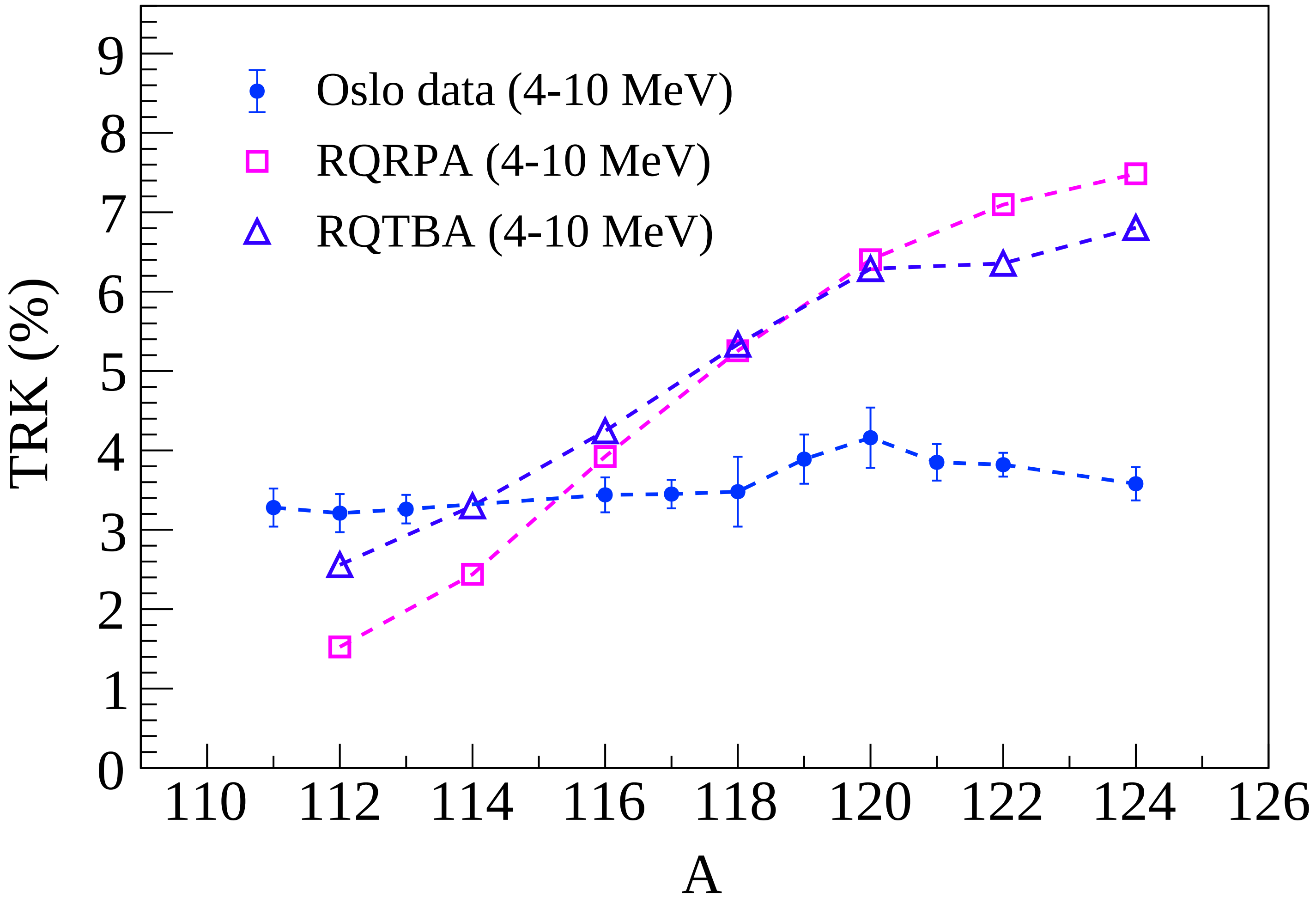
Conclusion 3:

Ranges from 2% to 3%, the largest strength in ^{120}Sn.

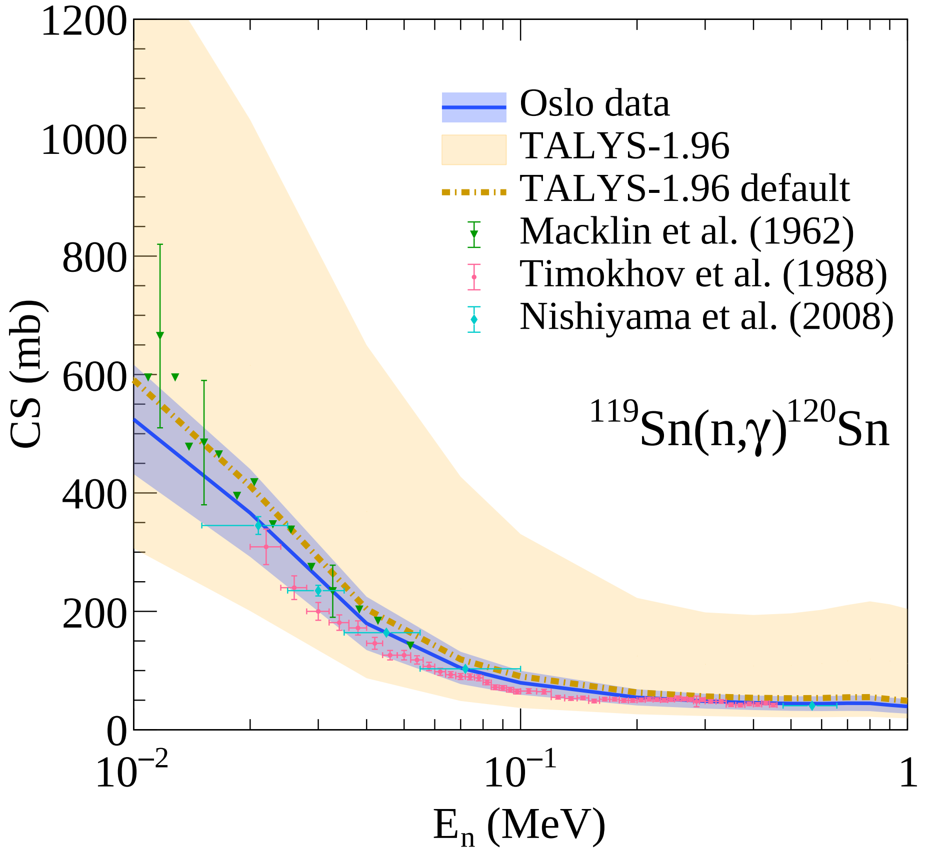
Conclusion 4:

The low-lying component increases in strength with N, the ”real” PDR?

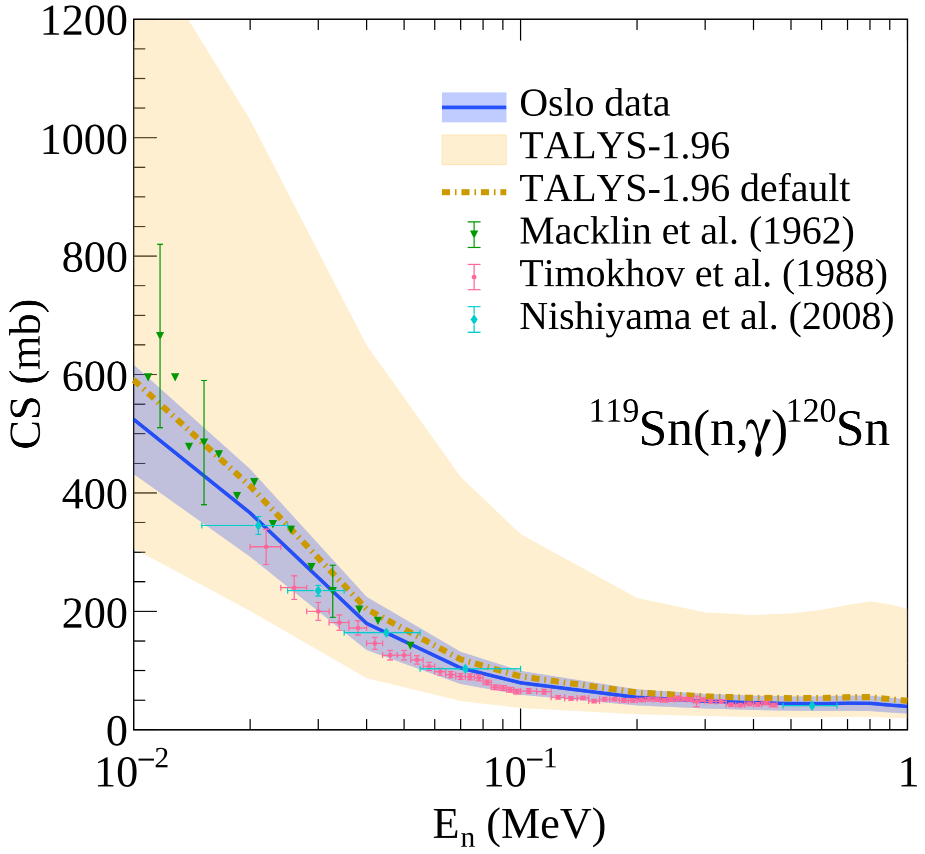
Main results: the GSF and PDR vs. theory



Main results: Neutron capture rates and cross sections



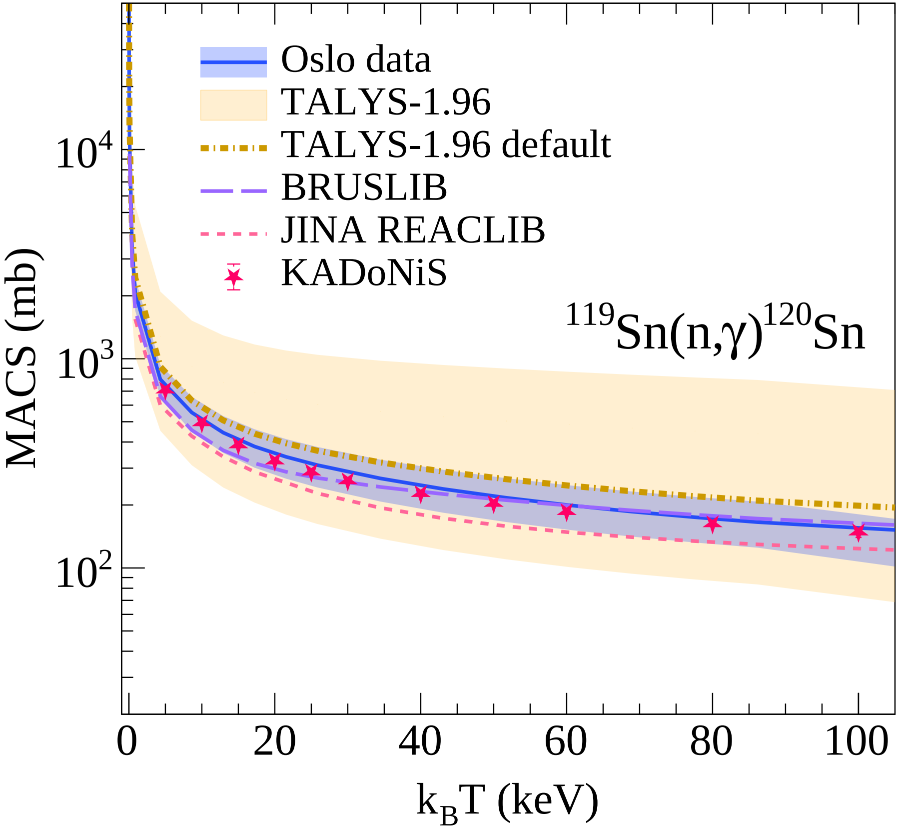
Main results: Neutron capture rates and cross sections



Conclusion 1:

Good agreement with other experimental data.

Main results: Neutron capture rates and cross sections



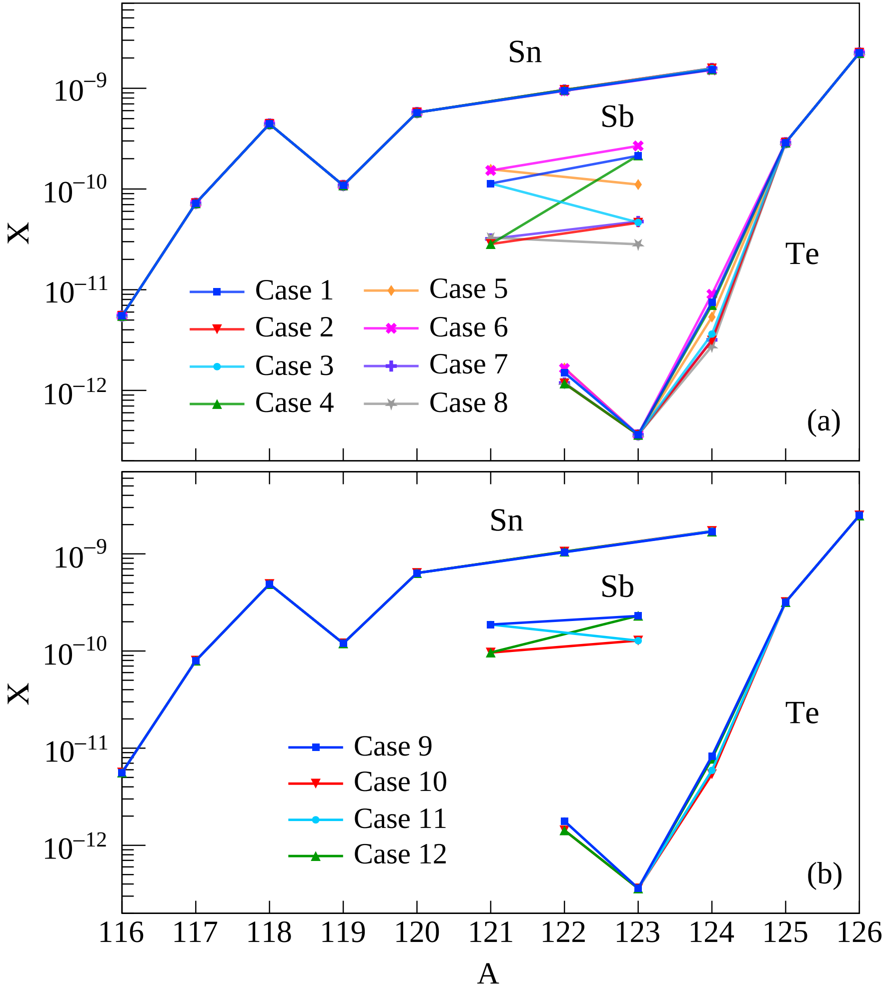
Conclusion 1:

Good agreement with other experimental data.

Conclusion 2:

Good agreement with the KADoNiS and BRUSLIB libraries.

Main results: Neutron capture rates and cross sections



Conclusion 1:

Good agreement with other experimental data.

Conclusion 2:

Good agreement with the KADoNiS and BRUSLIB libraries.

Conclusion 3:

Experimental NLDs and GSFs of ^{122,124}Sn allow to significantly reduce the model and parameter uncertainties of neutron capture rates and abundances of ^{121,123}Sb produced in the i process.

Summary and conclusions

- The nuclear level densities and $\gamma-$ray strength functions of eleven Sn isotopes ($^{111-113,116-122,124}$Sn) have been extracted in a model-consistent way from particle-γ coincidence data with the Oslo method.
- The experimental low-lying $E1$ strength and its evolution in a large number of Sn isotopes have been addressed for the first time.
- Interpretation of the total low-lying $E1$ strength as the PDR appears to be unjustified. The low-lying peak at ≈ 6.4 MeV might potentially be associated with the isovector component of the PDR.
- The newly extracted statistical properties of ^{122,124}Sn nuclei significantly reduce currently available theoretical model uncertainties in astrophysical calculations.

Thank you for your attention!