# Level Densities and γ Strength Functions in $^{116,118,119}$Sn

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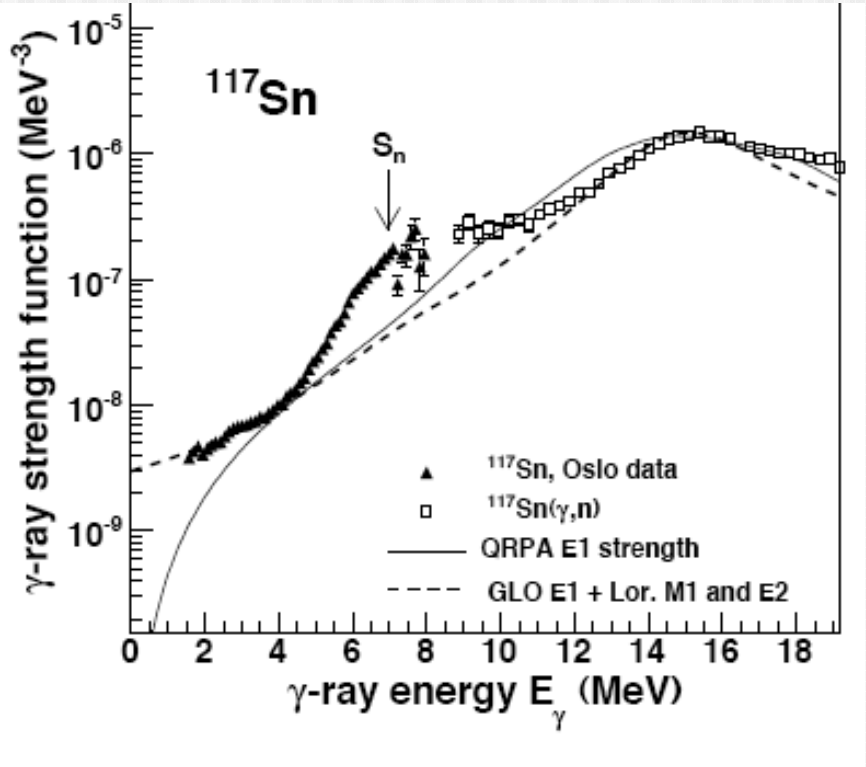
# Outline

1. Experiment motivation
2. The Oslo method
3. Preliminary level densities and $\gamma$ strength functions
    1. $^{119}$Sn
    2. $^{116,118}$Sn

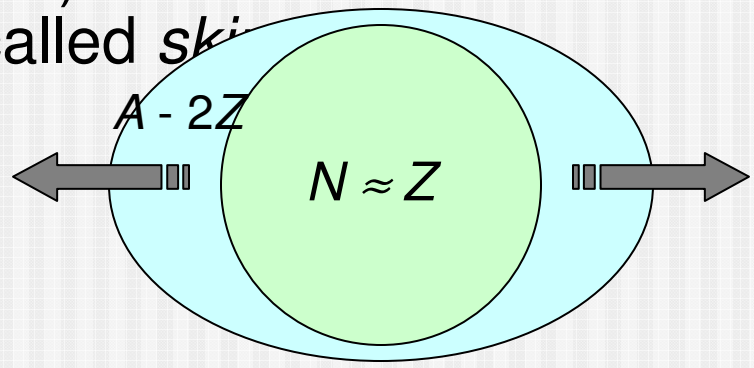
# Discovery of a new resonance in another Sn isotope

- $^{117}$Sn: New small resonance in γ strength function.
- Recent PRL publication from Oslo.
  *(PRL **102**, 162504 (2009).)*
- "Pygmy" resonance.
- Located on the GEDR tail, for low *Eγ*, but higher than for the scissor mode.
- Peak *Eγ*≈ 9 MeV.



# Possibilities for pygmy◈s origin

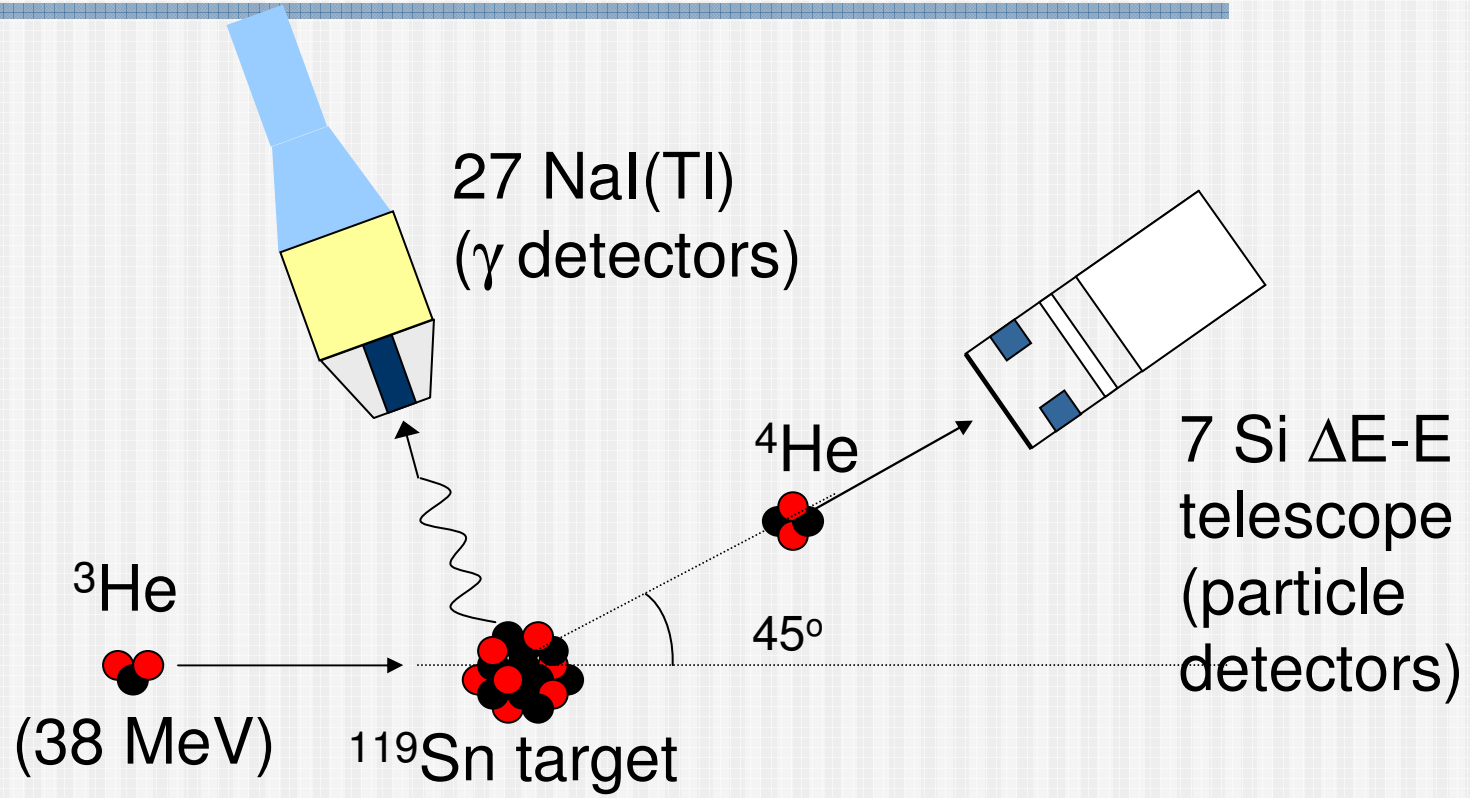
- Already theory predictions of small resonances in this area:
  - GMDR (M1 mode) - but strength too small;
  - Neutron-skin oscillation resonance (E1 mode).
    *(van Isacker et al., PRC **45**, R13 (1992).)*
- Visualization of skin oscillation:
  - A non-moving core of $Z$ protons and $N \approx Z$ neutrons.
  - Excess neutrons ($\approx A - 2Z$) oscillate in the nucleus◈ outer part, so-called *ski*



# Motivation for performing $^{118,119}$Sn experiment

- Confirm pygmy recently published in PRL.
- Study pygmies of different tin isotopes.

# Experimental setup

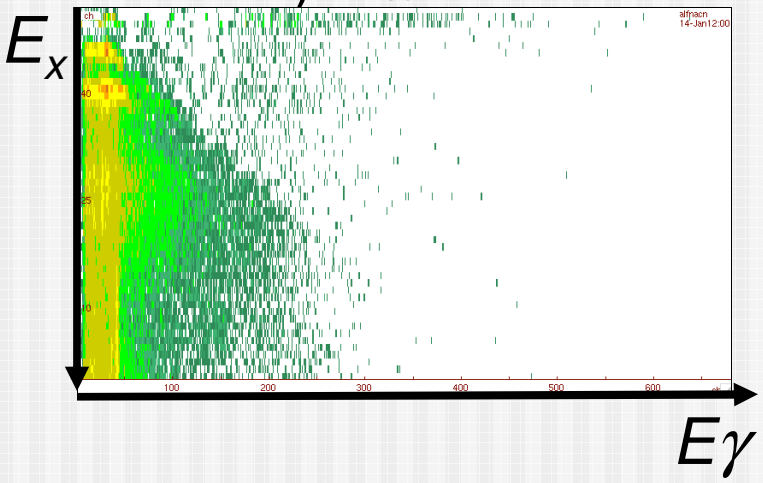


# The Oslo method

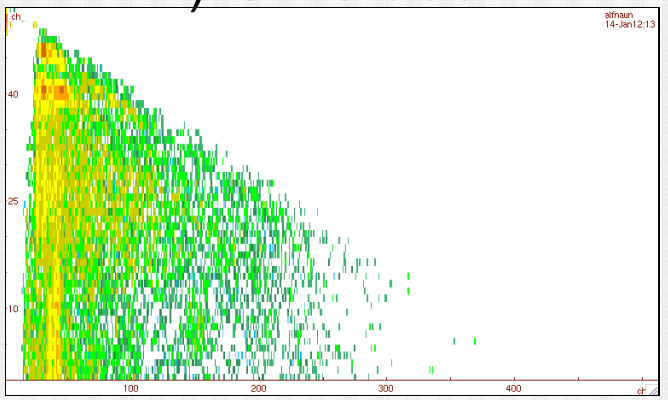
- Experimental detection of particle and γ coincidences, $E\gamma < B_n$:
  - Pick-up reaction: $^{119}$Sn ($^{3}$He,$^{4}$He γ) $^{118}$Sn.
  - Inelastic scattering: $^{119}$Sn ($^{3}$He,$^{3}$He´ γ) $^{119}$Sn.
- Unfolding of γ spectra using detector response function.
- Extraction of first generation γ◈s.
- First generation coincidence matrix ($E\gamma$, $E_x$).
- Simultaneously extract estimates for level density $\rho$, and for γ transmission coefficient $T$:
  $P(E_x,E\gamma) \propto \rho(E_x - E\gamma) \cdot T(E\gamma)$.
- Determine γ strength function $f(E\gamma)$:
  $f(E\gamma) = T(E\gamma) \cdot E(\gamma)^{2L+1}$.

# Matrix ($E\gamma$, $E_x$)

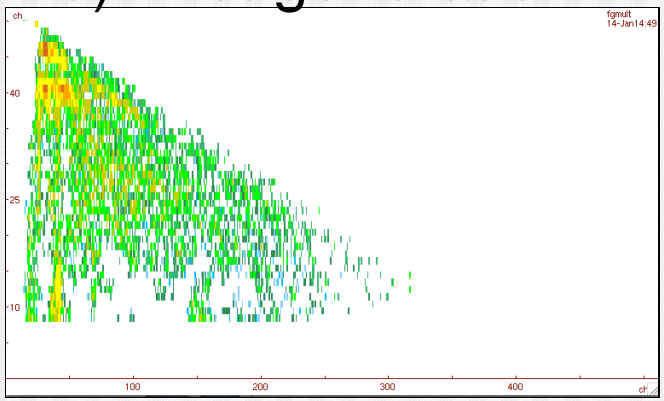
1) Raw



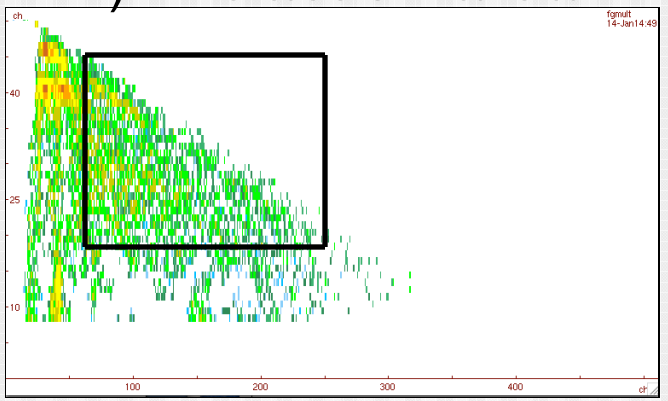

2) Unfolded



3) First generation



4) Extraction area



# Normalization

- Transformation invariance:

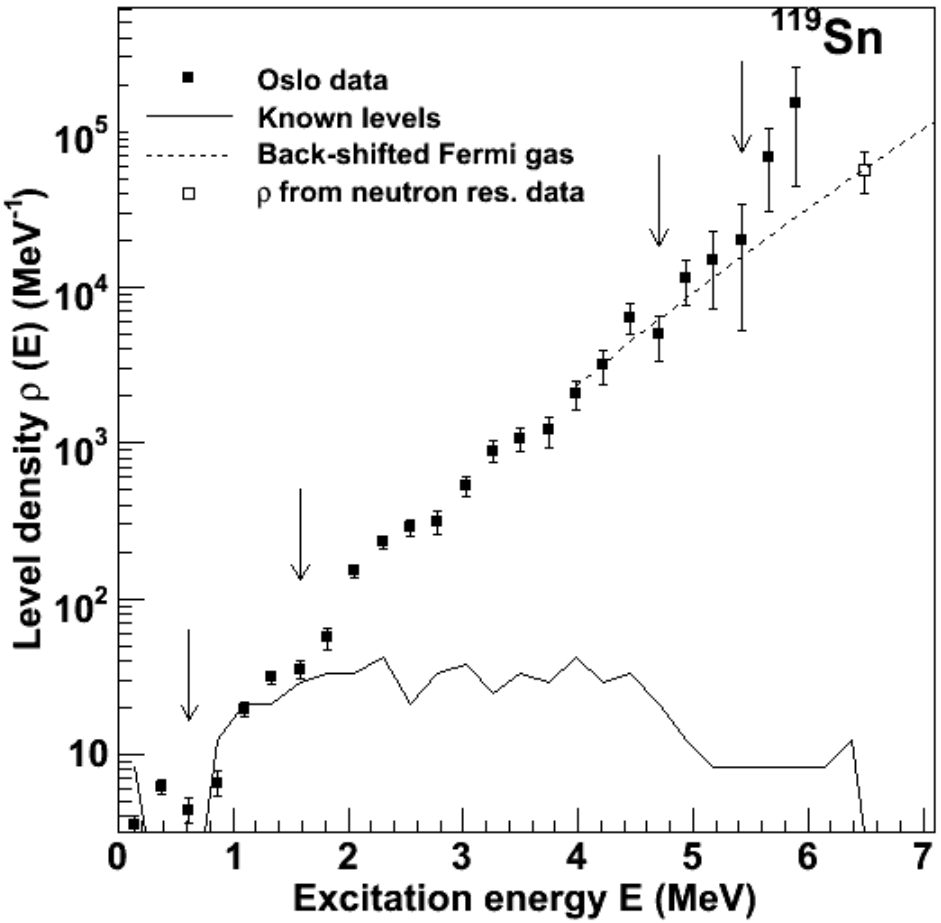
$$\tilde{\rho}(E_i - E_\gamma) = \rho(E_i - E_\gamma) \cdot A \cdot \mathrm{e}^{\alpha(E_i - E_\gamma)}$$

$$\tilde{T}(E_\gamma) = T(E_\gamma) \cdot B \cdot \mathrm{e}^{\alpha(E_\gamma)}$$

- Normalization of absolute value $A$ of $\rho$ :
  From literature value of discrete level density for low $E_x$.
- Normalization of common slope $\alpha$:
  From calculating $\rho(B_n)$ from literature values.
  $\rho = 1 / D$, from $D_0$ (s-wave resonance spacing).
- Normalization of absolute value $B$ of $T$:
  From calculating $T(B_n)$ from literature values.
  $T = \langle \Gamma\gamma_0 \rangle / D_0$, where $\langle \Gamma\gamma_0 \rangle$ is average s-wave radiation width.

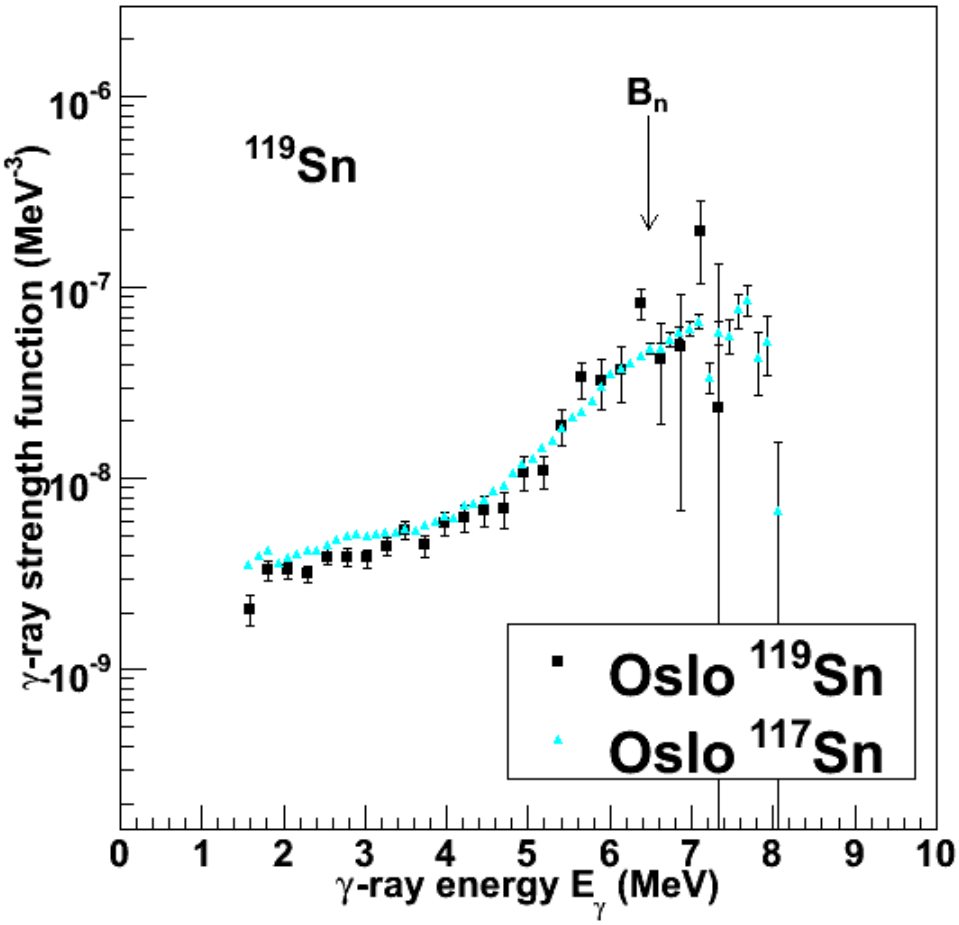
# $^{119}$Sn level density (preliminary)

- Level density generally has a stepwise increase as a function of $E_x$.
- Breaking of neutrons and protons pairs.
- In tin, the steps are easily seen, since only neutron pairs are broken ($Z = 50$).
- $^{119}$Sn steps: Verification of pair-breaking published for $^{116,117}$Sn. *(PRC **79**, 014320 (2009).)*
- Future: Extraction of thermodynamic properties.



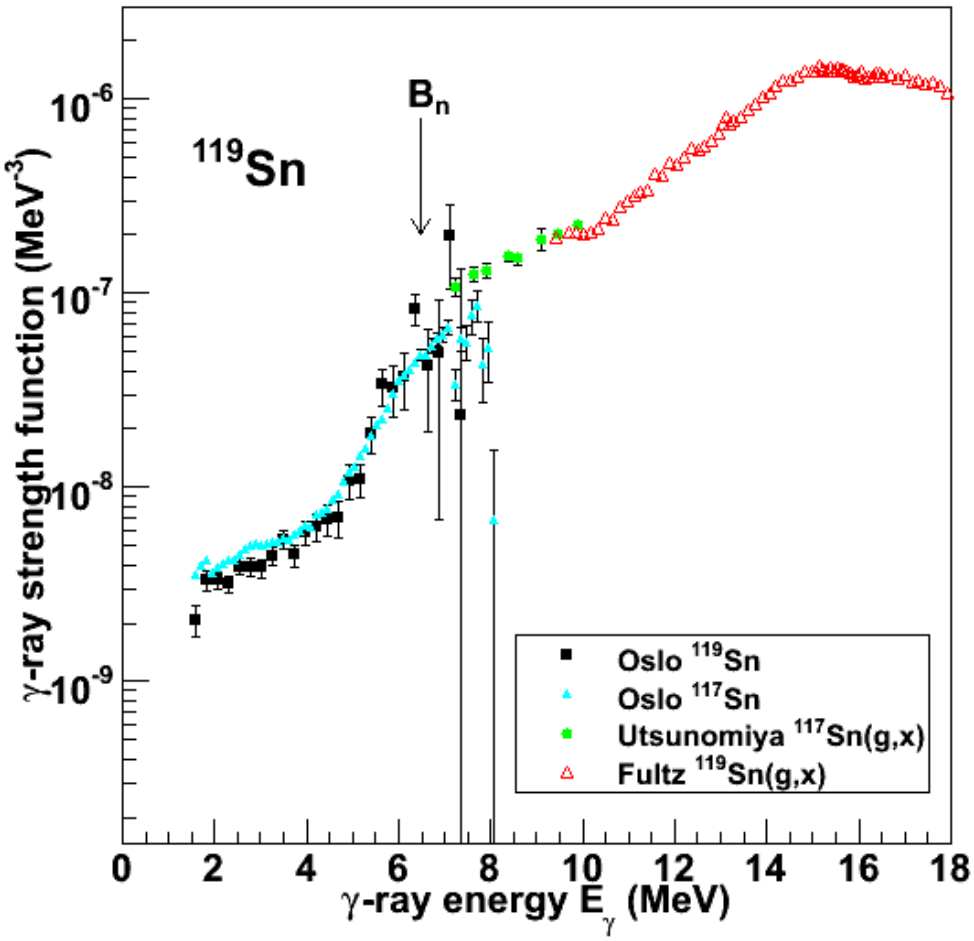
# $^{119}$Sn γ strength function (prelim.)

- $^{117}$Sn strength function was recently published in PRL.
- $^{119}$Sn is consistent with $^{117}$Sn.
- A sudden increase of strength at ≈ 5 MeV.
  - Indicates a resonance.



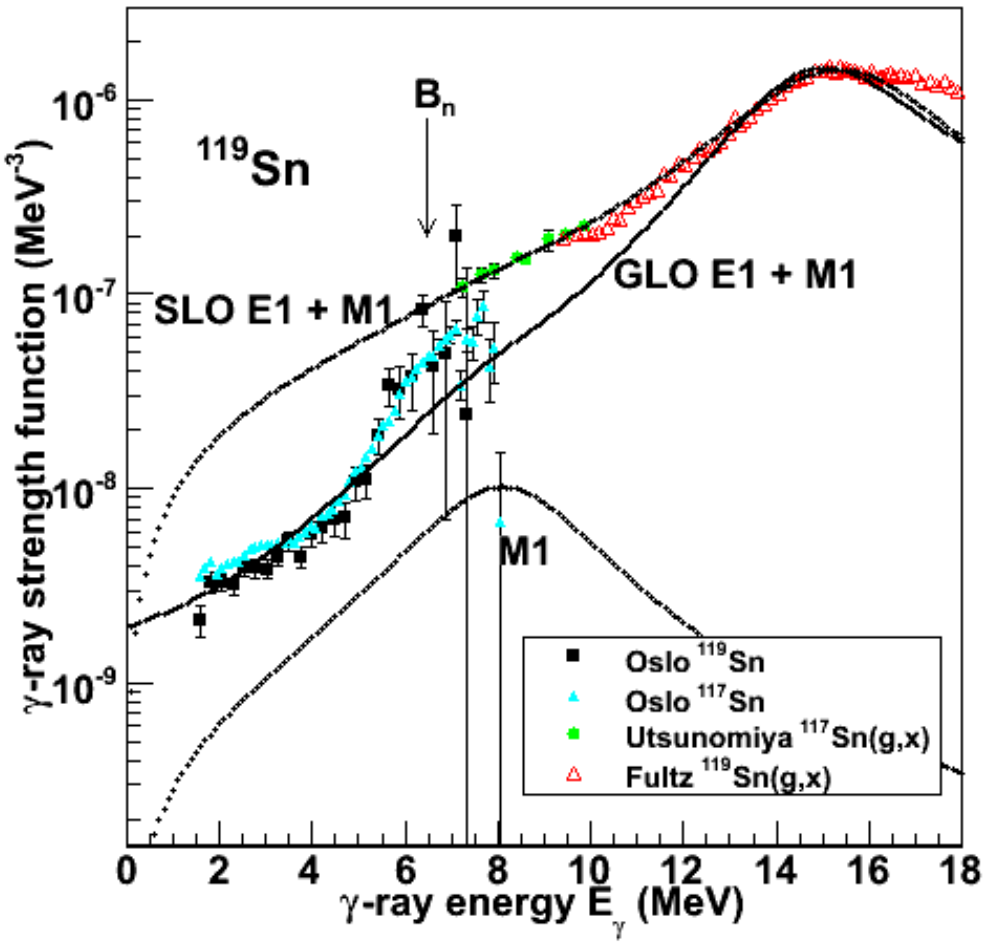
# Inclusion of $^{119}$Sn high $E\gamma$data

- Add high $E\gamma$data from other experiments.
- Interpretation.
- Gives the right hand side of the pygmy.



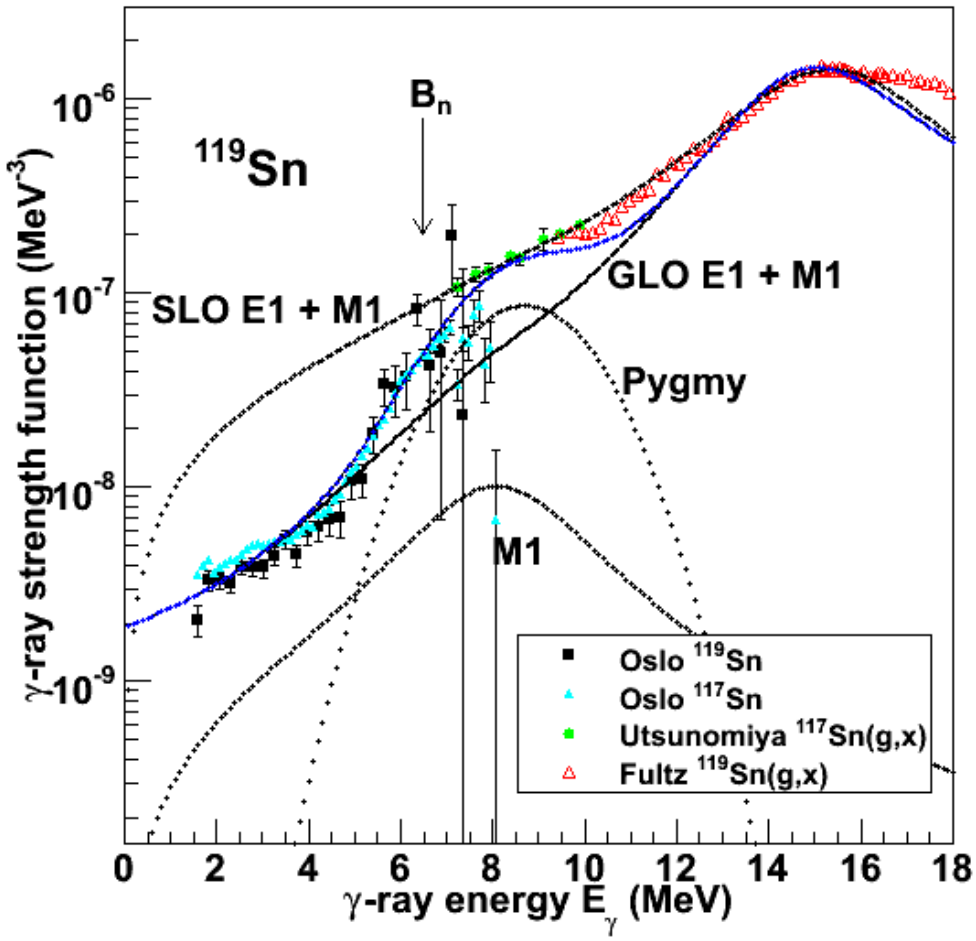
# Theoretical models for $^{119}$Sn

- SLO does not work:
  Fits to experimental values for high *Eγ*, but not low.
- GLO works:
  Fits to experimental values for both low and high *Eγ*.
- Also the case for all other investigated elements.
- Hence, a pygmy is added to a GLO baseline.



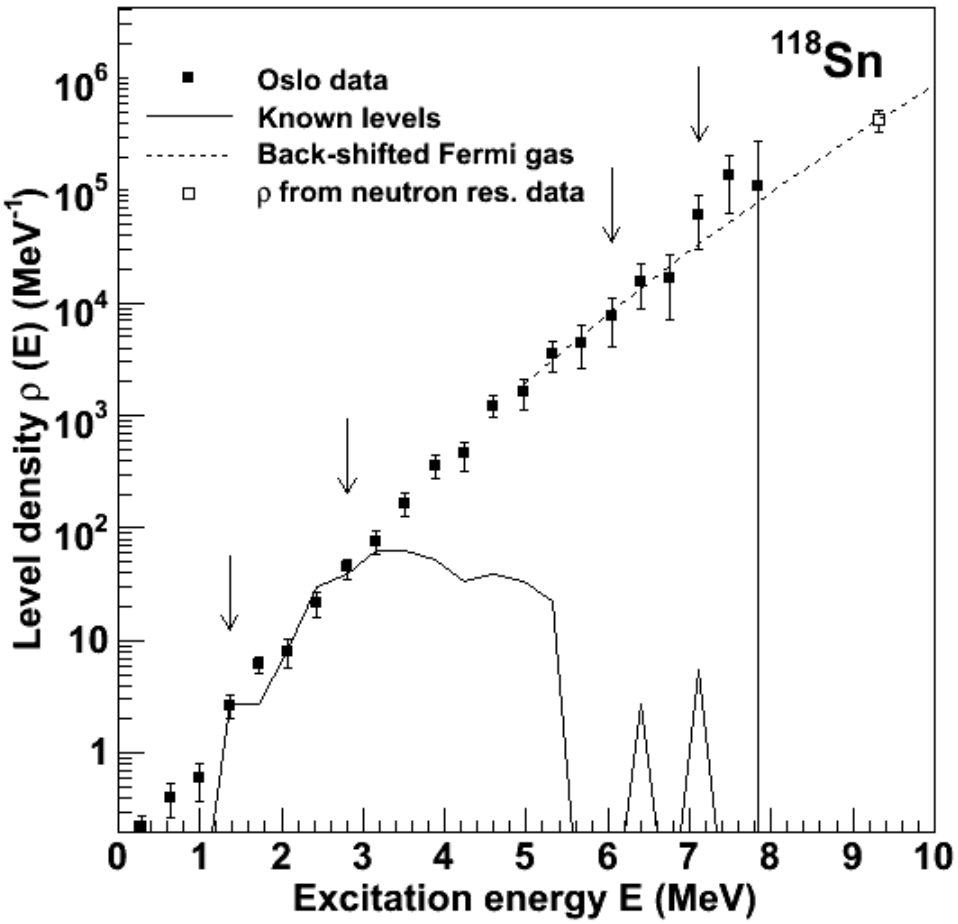
# $^{119}$Sn pygmy fit (preliminary)

- Gaussian pygmy.
- Empirical parameters will depend on choice of baseline.
- $T$ = 0.35 MeV.
- Peak $E_{pyg}$ = 9.2 MeV.
- Width $\sigma$ = 1.5 MeV.
- Normalization constant $C_{pyg} = 4.3 \cdot 10^{-7}$ MeV$^{-2}$.
- Pygmy strength: 1.8 % of Thomas-Reiche-Kuhn (TRK) sum rule.
  - Within uncertainty of $^{117}$Sn: 2.3(8) %.



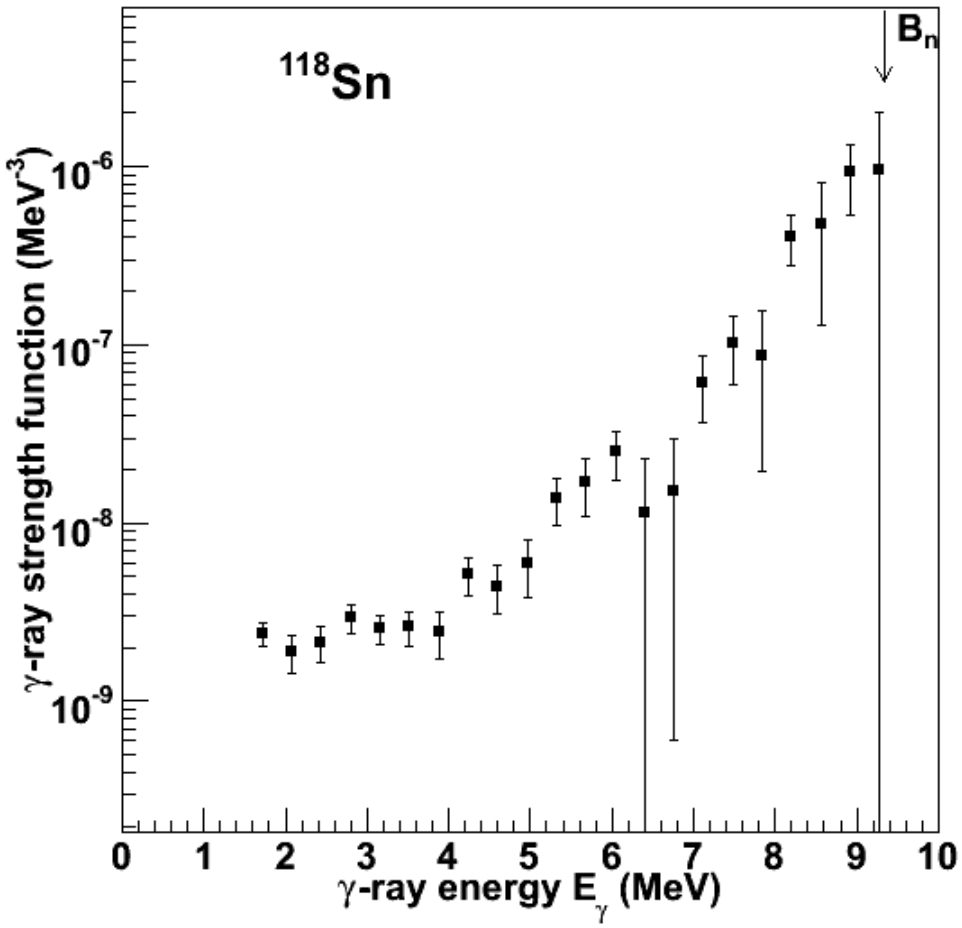
# $^{118}$Sn level density (preliminary)

- Stepwise increase of level density was seen in $^{116}$Sn.
- Expected in $^{118}$Sn.
- Hard to verify due to less statistics.
- Small reaction cross section.



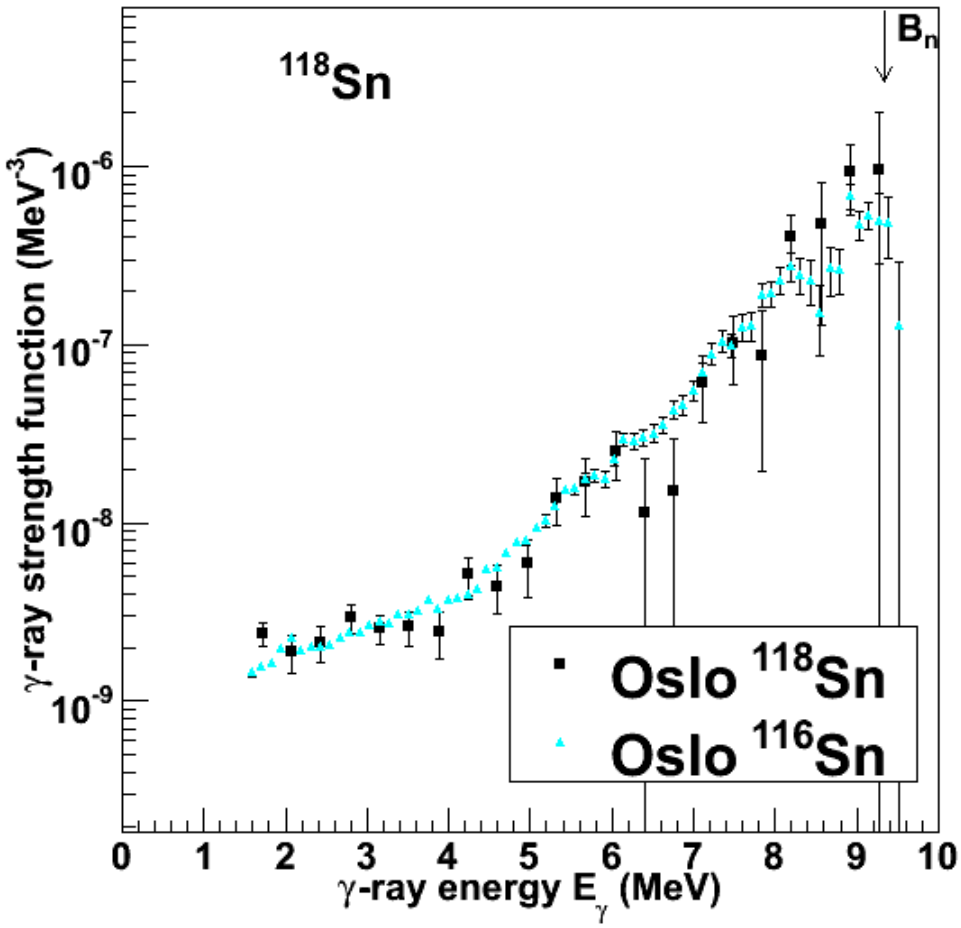
# $^{118}$Sn strength function (preliminary)

- Same structural form as $^{117,119}$Sn.
- Sudden increase at ≈ 5 MeV.



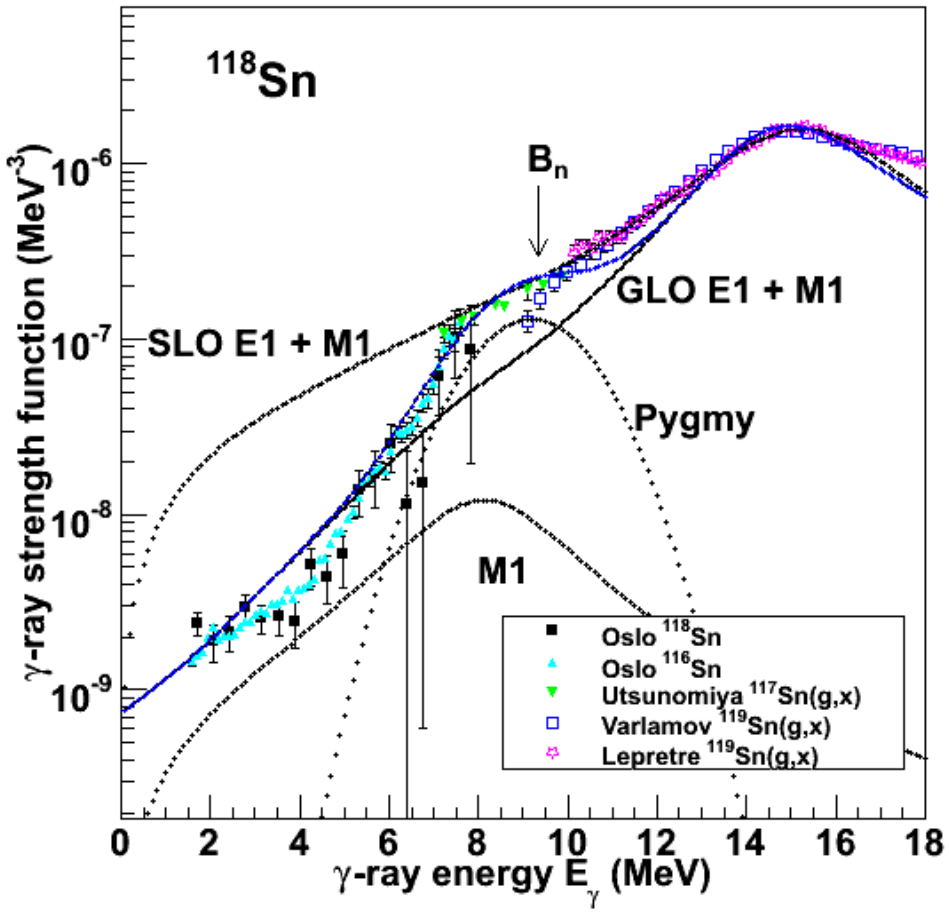
# $^{116}$Sn strength function (preliminary)

- Lack of literature data for $^{116}$Sn.
- Impossible to normalize the absolute value.
- However, the $^{118}$Sn strength function may be used as a means to adjust $^{116}$Sn.
- Publishable.



# $^{116,118}$Sn pygmy fit (preliminary)

- $T$ = 0.20 MeV.
- Peak $E\gamma$ = 9.2 MeV.
- Width $\sigma$ = 1.3 MeV.
- Normalization constant $C_{pyg} = 4.0 \cdot 10^{-7}$ MeV$^{-2}$.
- 2.6 % of TRK sum rule.
  - Within uncertainty of $^{117}$Sn: 2.3(8) %.



# Conclusions

- As in $^{116,117}$Sn, a stepwise increase of level density is seen in $^{119}$Sn.
- As in $^{117}$Sn, a pygmy resonance with peak $E\gamma \approx 9$ MeV is seen in the strength functions of $^{116,118,119}$Sn.
- The position, strength and width of the pygmies indicate that they are due to the neutron-skin oscillation mode.
- TRK values for $^{118,119}$Sn are consistent with $^{117}$Sn within uncertainty.

- $^{116,117,118,119}$Sn pygmies seem to be consistent.