Calculation of Transition Strength of Nuclei

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2. Density functional theory and QRPA
3. Spherical nuclei
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5. Summary

Dec. 5, 2011
Shima

1. Motivation and purpose

One of the goals of nuclear physics :
to establish theoretical methods to describe all properties of all nuclei

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To establish capability to supply other fields including nuclear astrophysics with the nuclear data they need.

My basic idea : application is very important.

The purpose of my research :
to calculate as many transition strengths and energies of nuclei as possible using density functional theory and Search reliable nuclear density functional

2. Density functional theory (DFT)

Energy density functional

$$\langle \hat{H} \rangle = \int d^3\vec{r}\, \mathcal{H}(\rho(\vec{r})) = E[\rho]$$

Dynamical equation

$$\frac{\delta}{\delta\rho} E[\rho] = 0 \longrightarrow \text{technically mean-field eq.}$$

The density functional which I use : Skyrme-type

Most parts are contact interaction $\delta(\overrightarrow{r_1} - \overrightarrow{r_2})$.

- volume term $\propto \delta(\overrightarrow{r_1} - \overrightarrow{r_2})$
- momentum^2 $\delta(\overrightarrow{r_1} - \overrightarrow{r_2})$ （gradient approximation）
- spin-orbit term $\propto \delta(\overrightarrow{r_1} - \overrightarrow{r_2})$
- density-dependent term $\rho(\vec{r}_1)^\alpha \delta(\overrightarrow{r_1} - \overrightarrow{r_2})$
- Coulomb term (exchange term in Slater approximation)

The previous dynamical equation → ground state

Derivation of dynamical eq. for excited states :

- Extend to time-dependent formulation. Introduce fluctuation around the ground state.
- Assume the time dependence of the fluctuation as $e^{i\omega t}$.
- Neglect many-body many-hole correlations

↓

Dynamical eq. of random-phase approximation（RPA）.
Solutions are stationary states.
Add pairing energy density (contact interaction, volume type)

↓

Quasiparticle RPA（QRPA）

3 . Spherical Nuclei

Strength function

$$S_J(E) = \sum_k \sum_{M=-J}^{J} \left| \left\langle \Psi_k \middle| \hat{F}_{JM} \middle| \Psi_0 \right\rangle \right|^2 L_k(E)$$

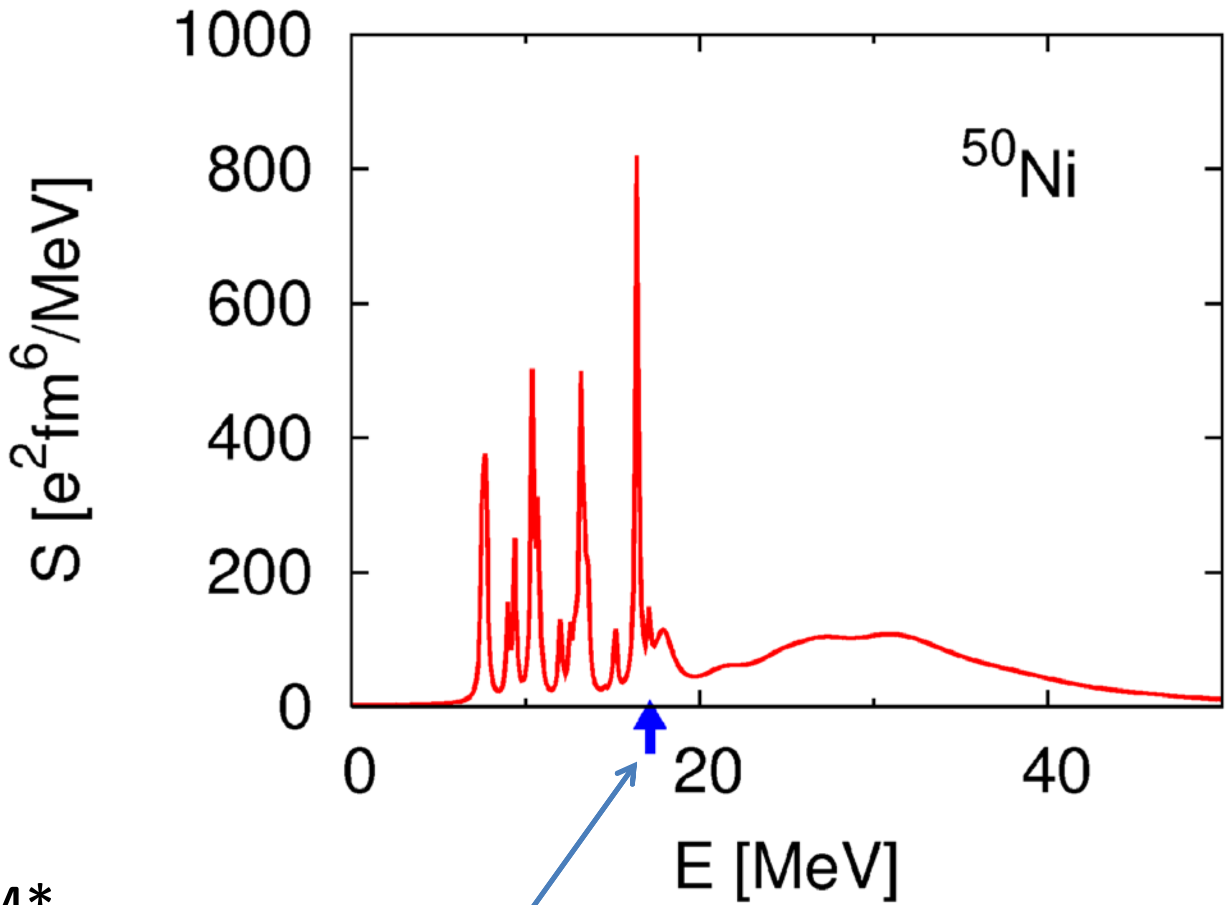
Transition operator

Isoscalar $$e\frac{Z}{A}\sum_{i:\text{nucleons}} f_J(r_i) Y_{JM}(\Omega_i)$$

Isovector $$e\frac{N}{A}\sum_{i:\text{proton}} f_J(r_i) Y_{JM}(\Omega_i) - e\frac{Z}{A}\sum_{i:\text{neutron}} f_J(r_i) Y_{JM}(\Omega_i)$$

$$f_J(r_i) \propto r_i^n$$

Isoscalar 1$^-$ strength functions



SkM*

Threshold energy

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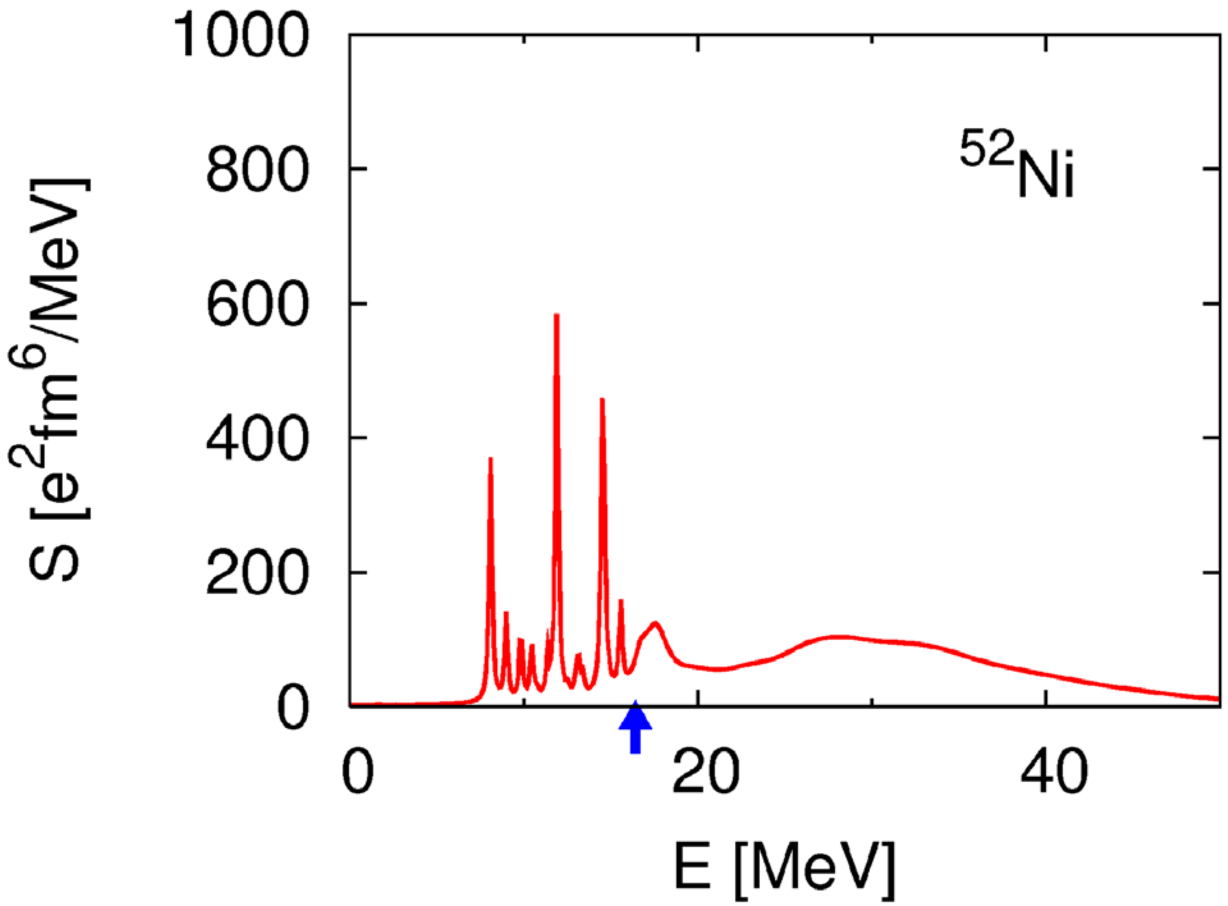
Isoscalar 1^- strength functions



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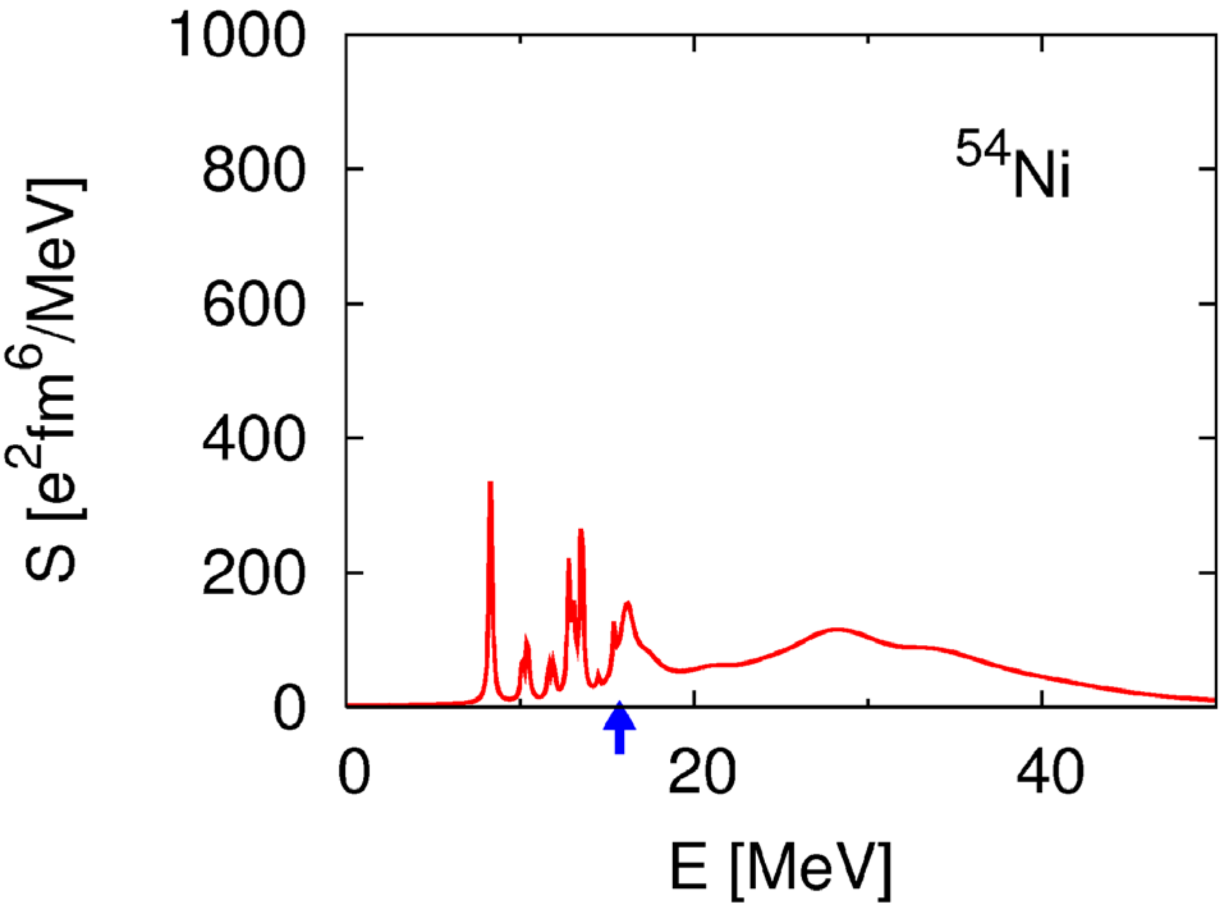

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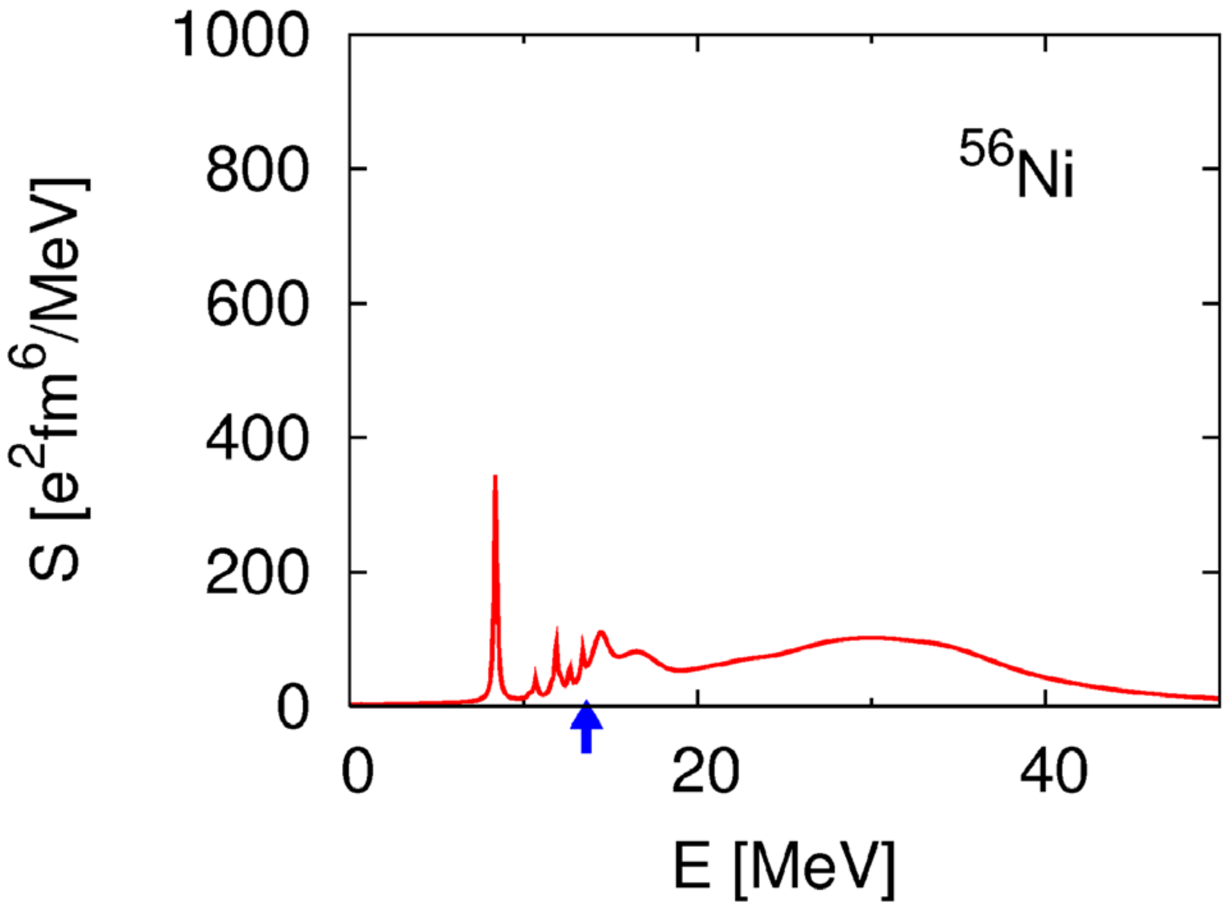

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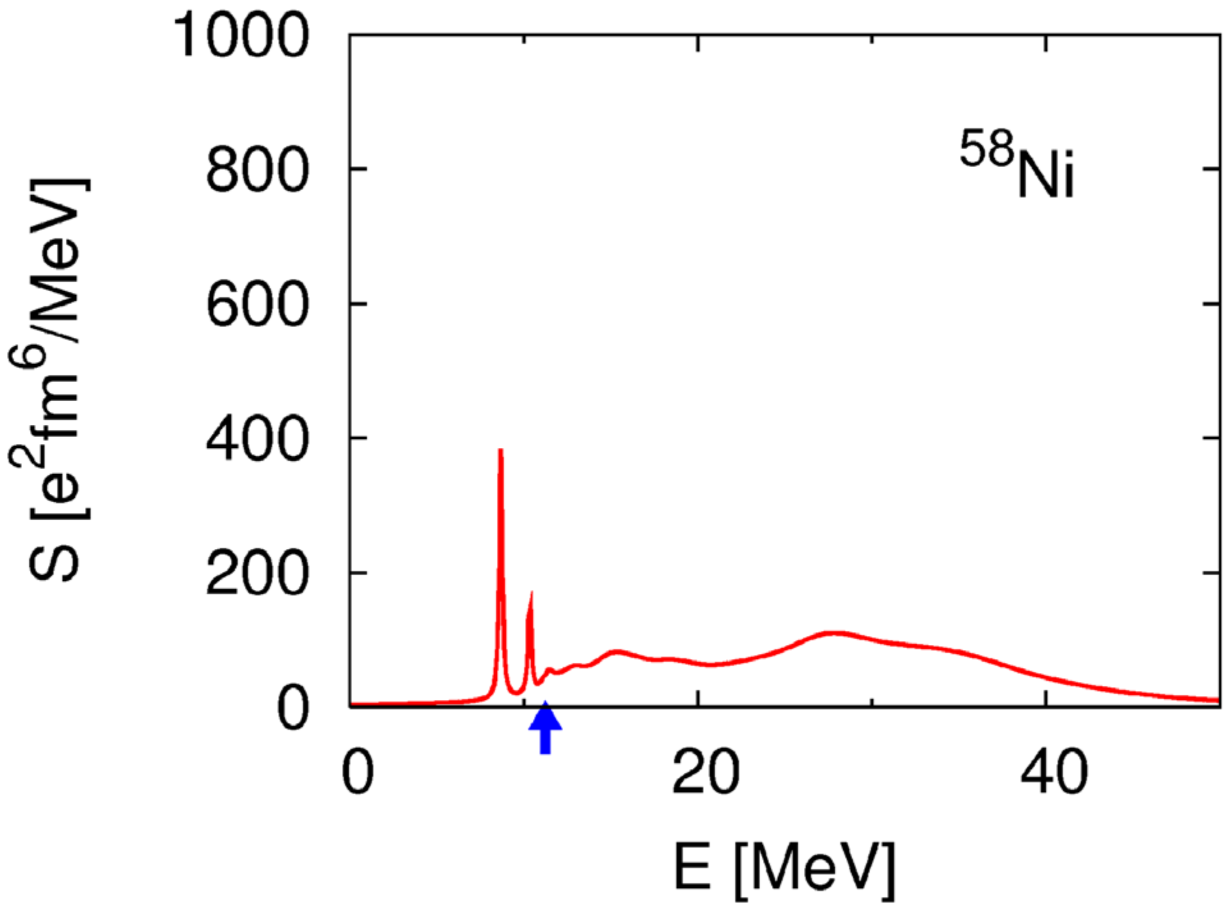

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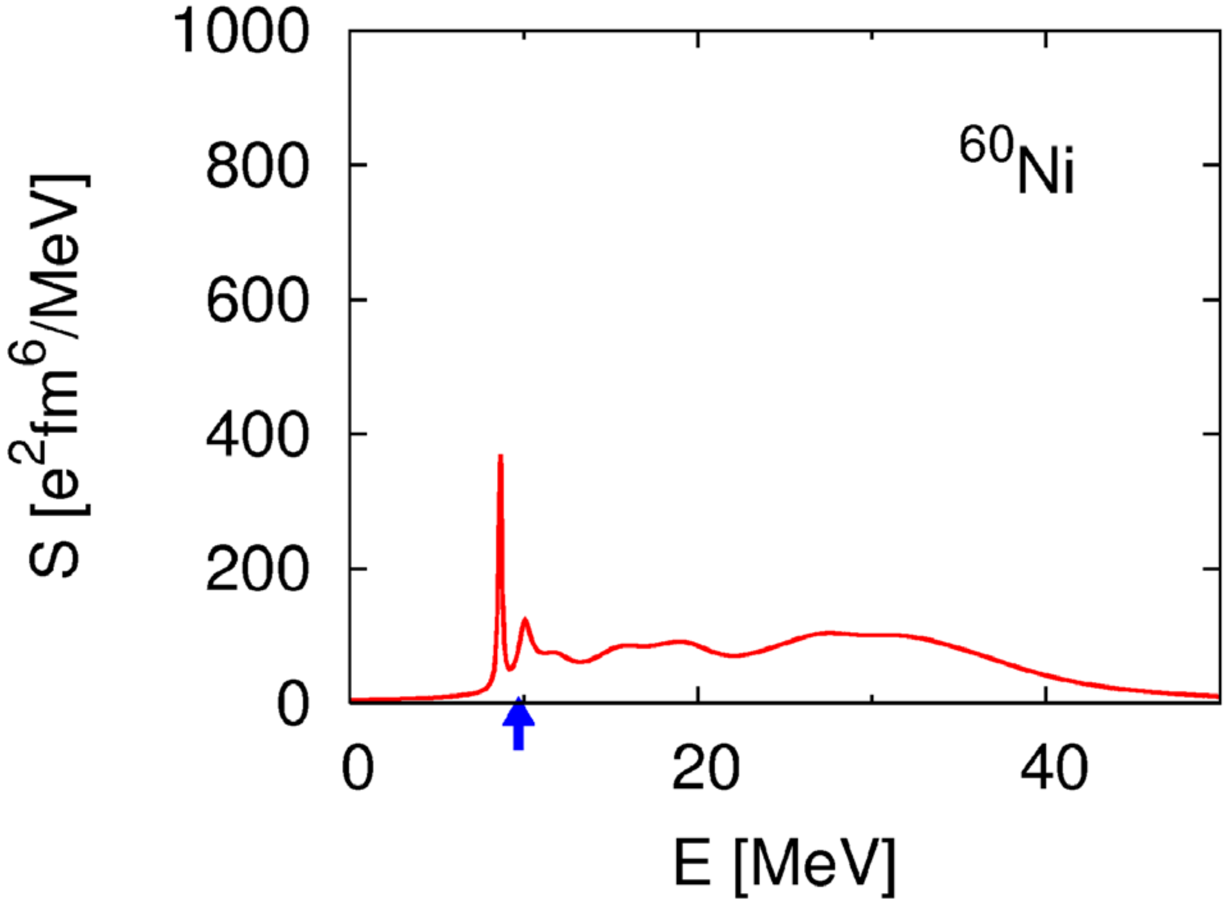

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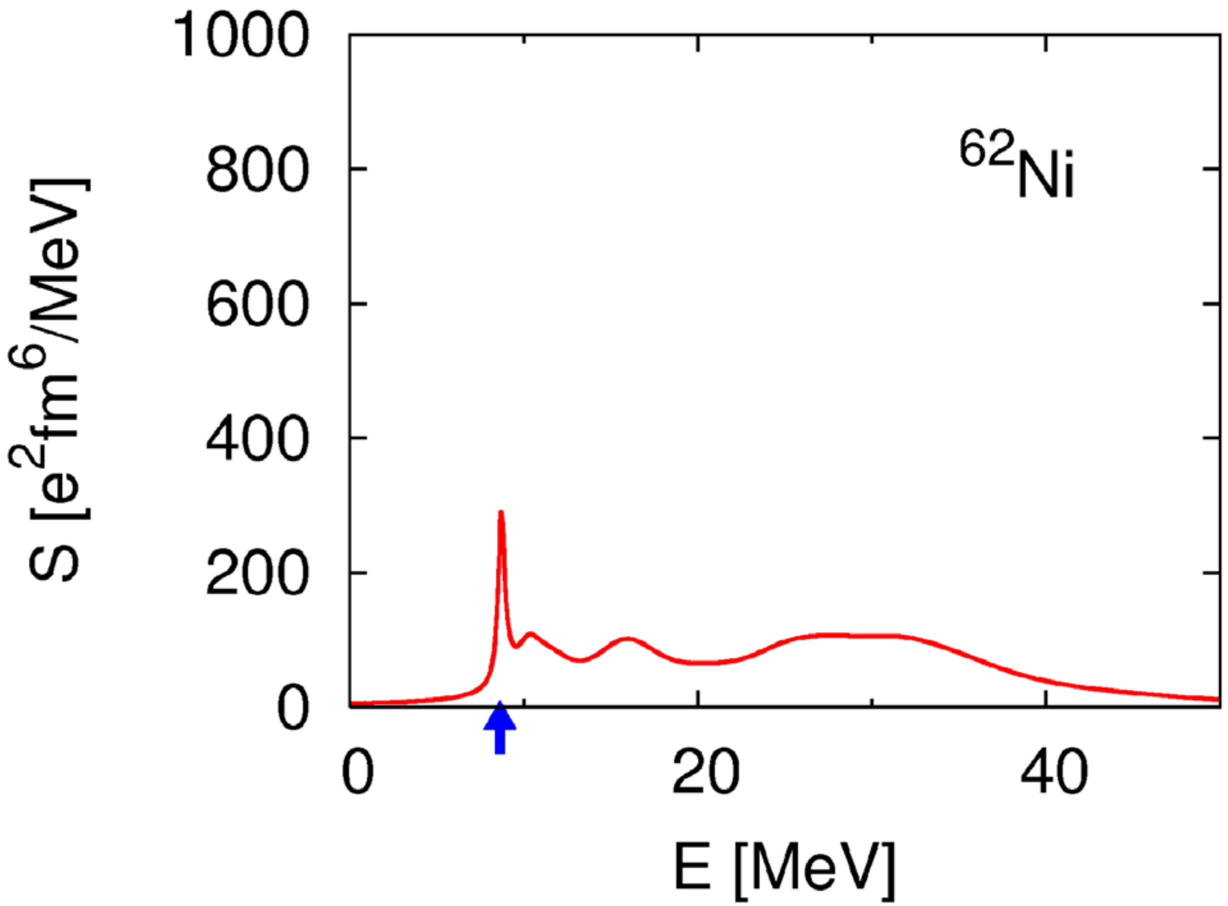

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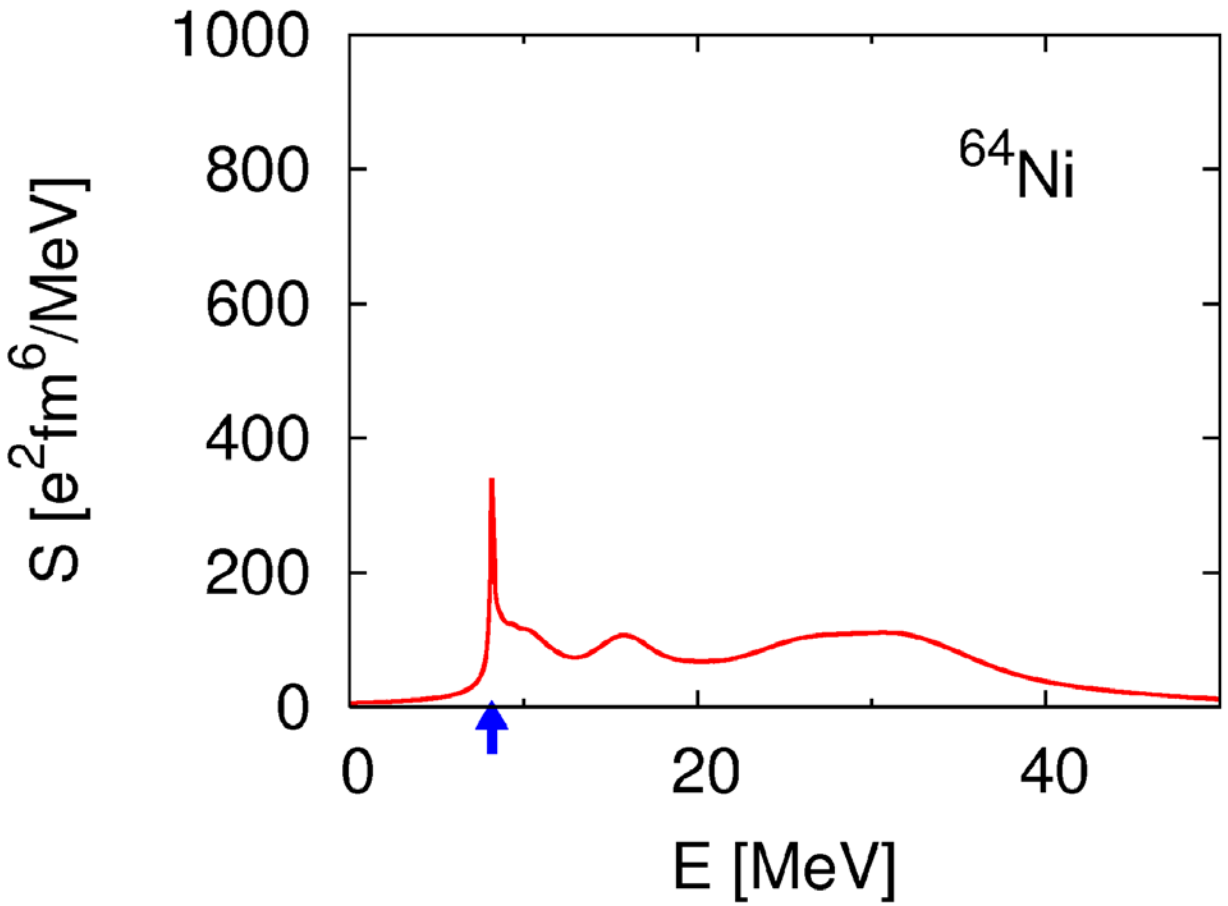

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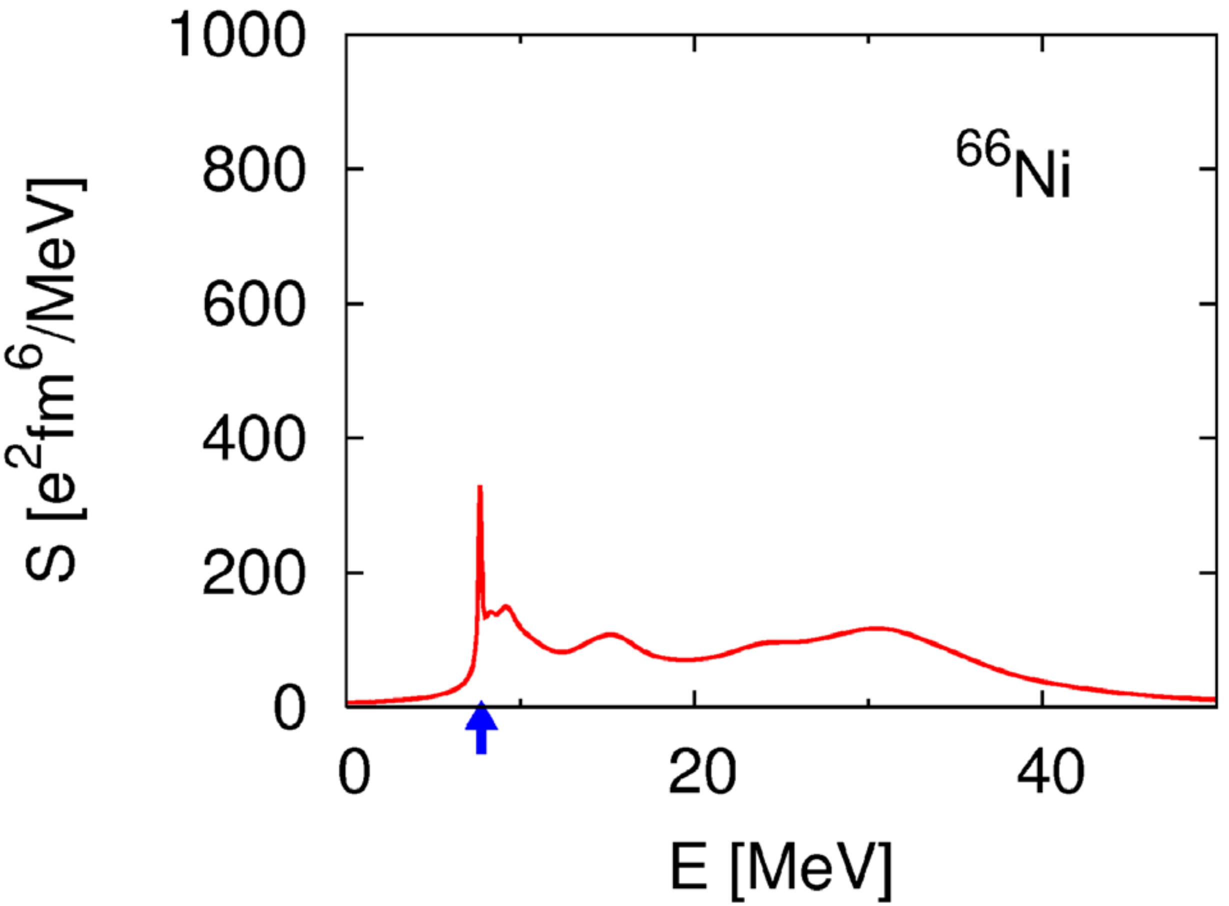

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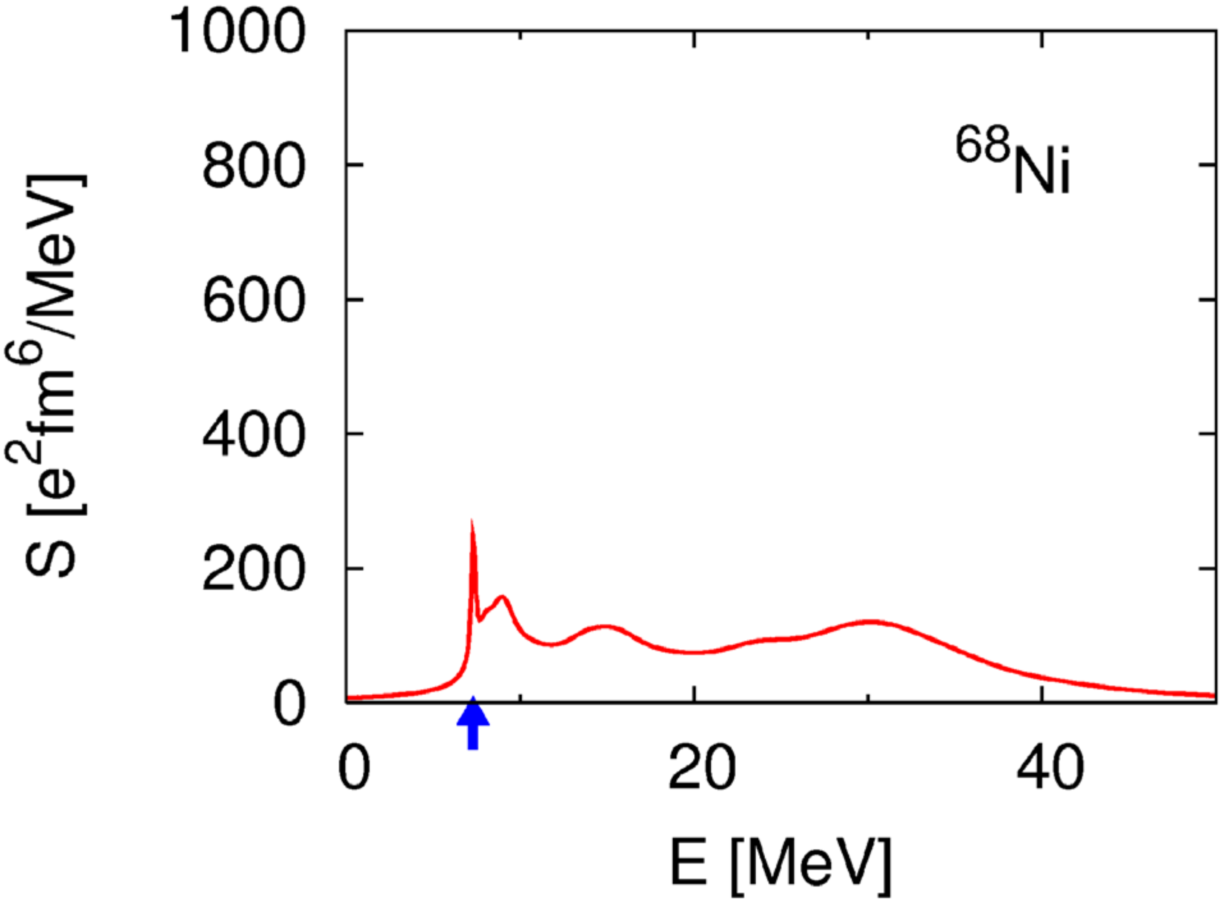

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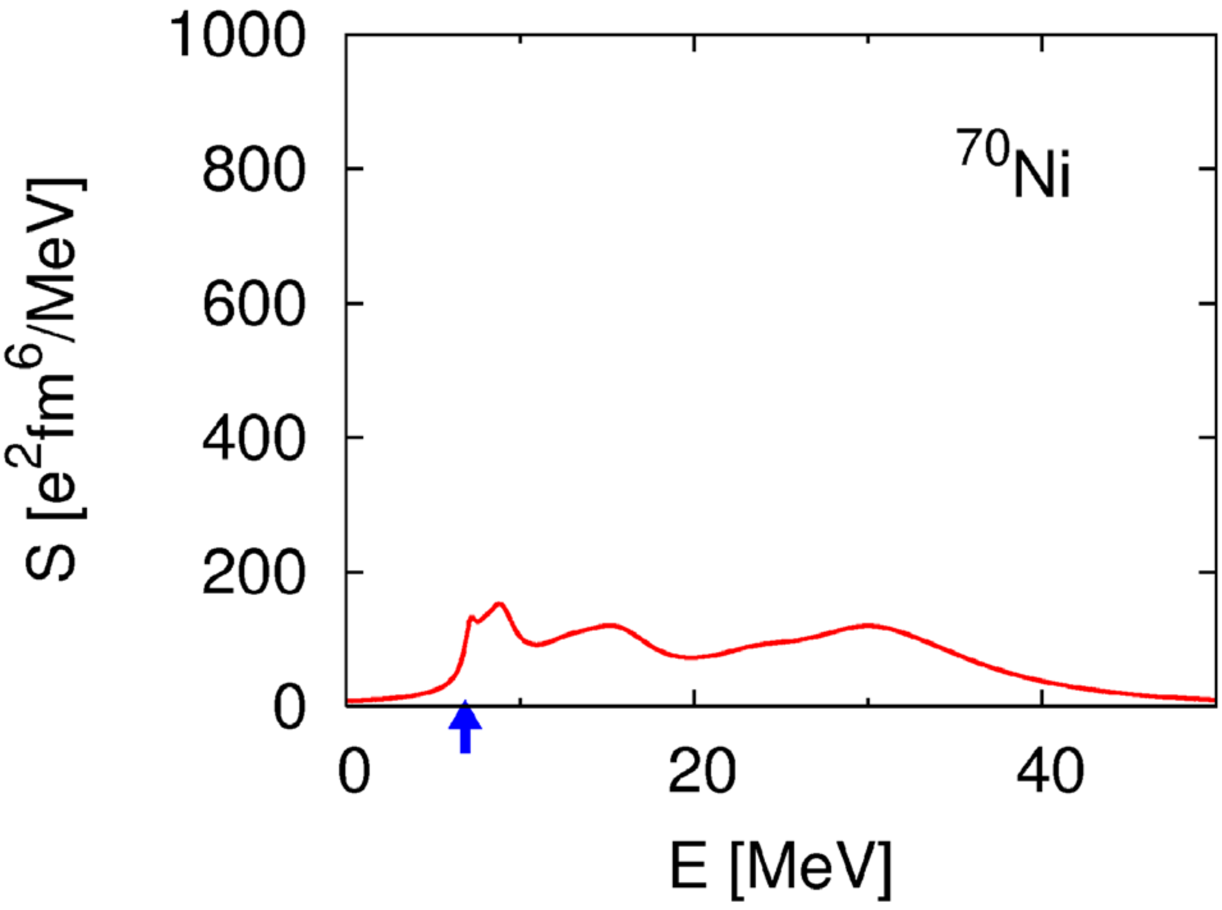

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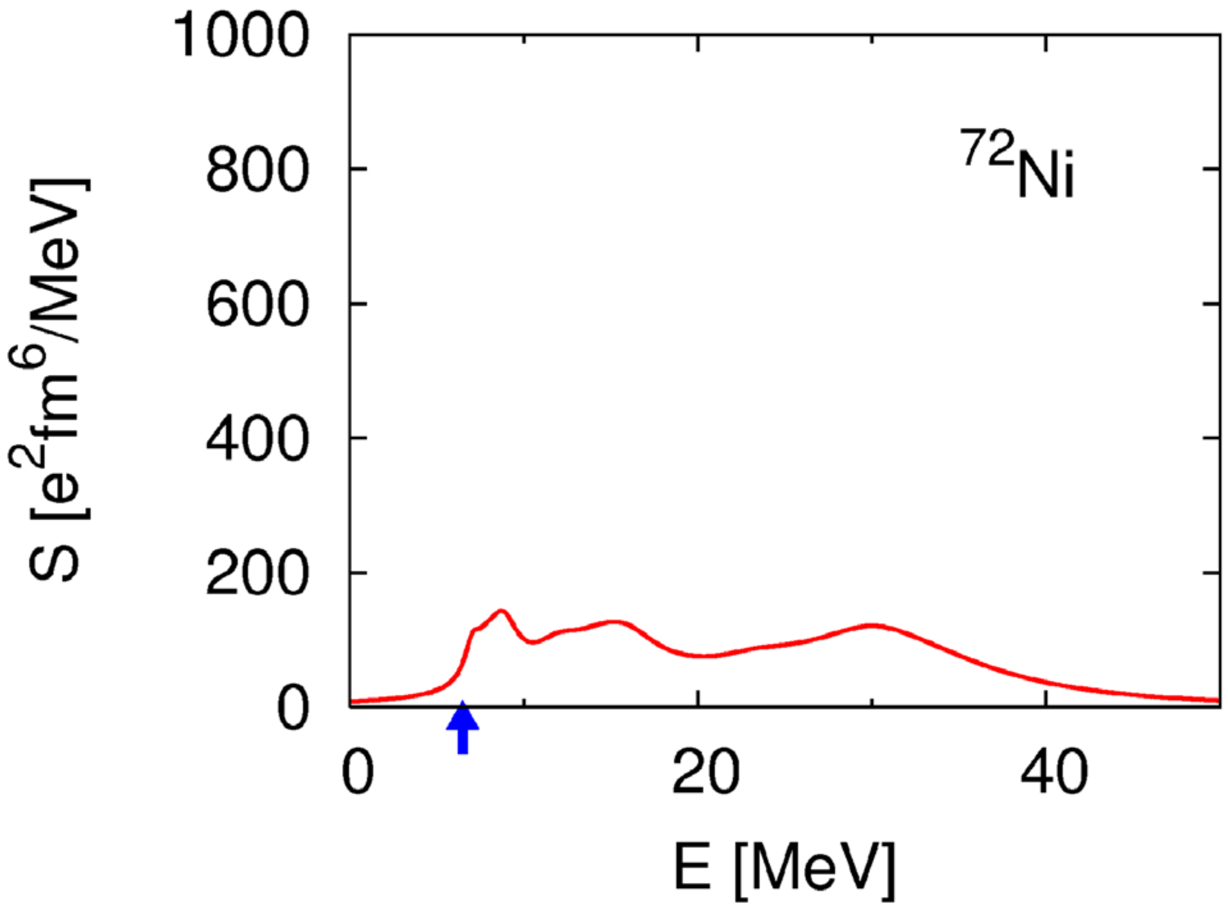

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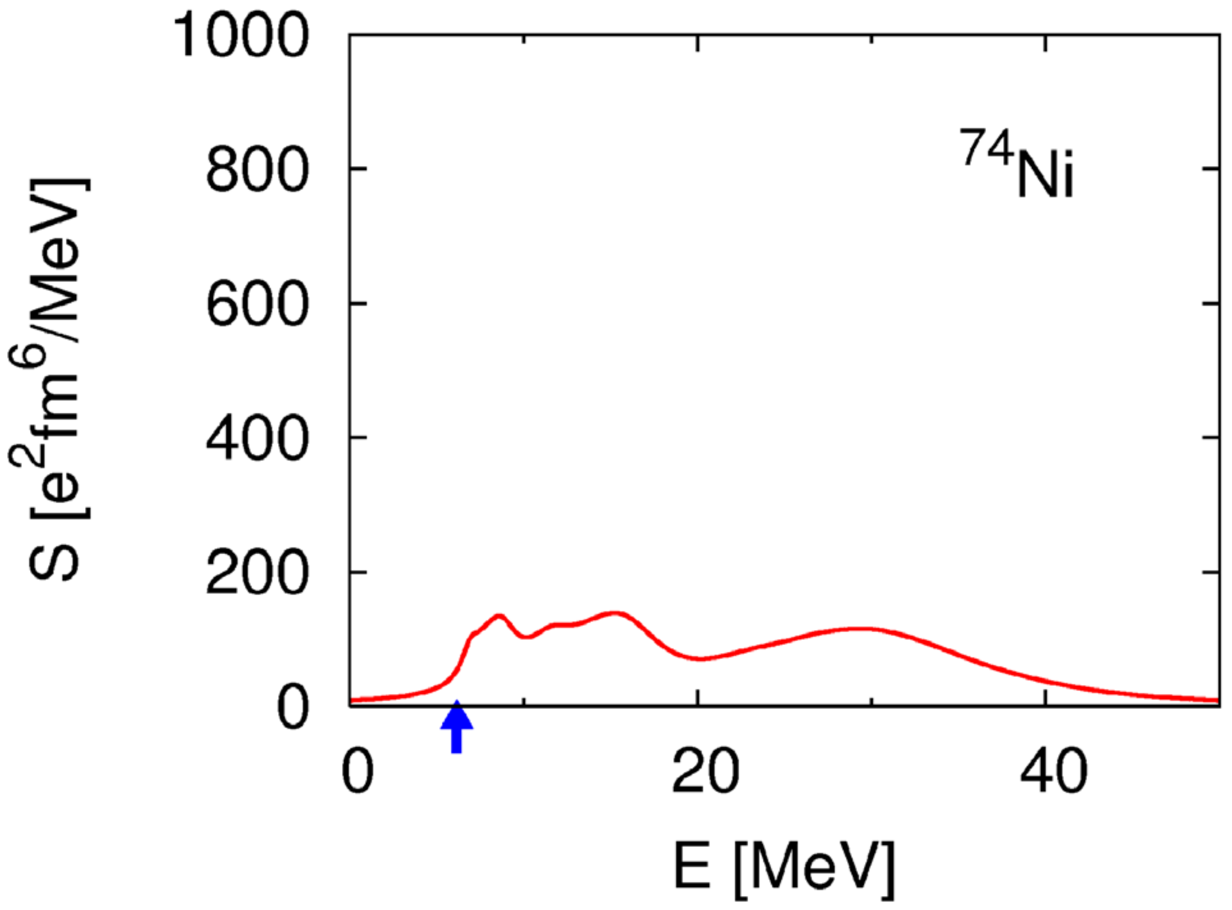

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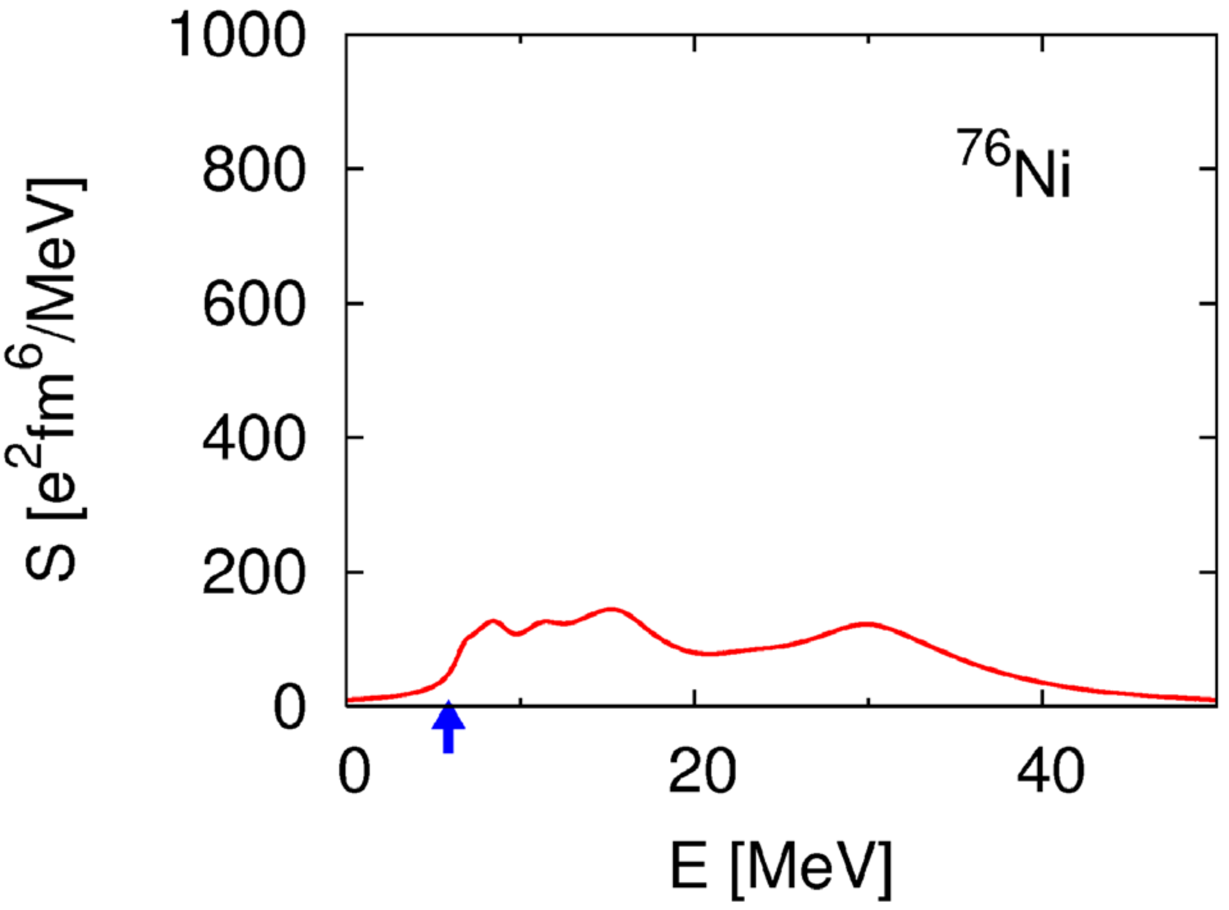

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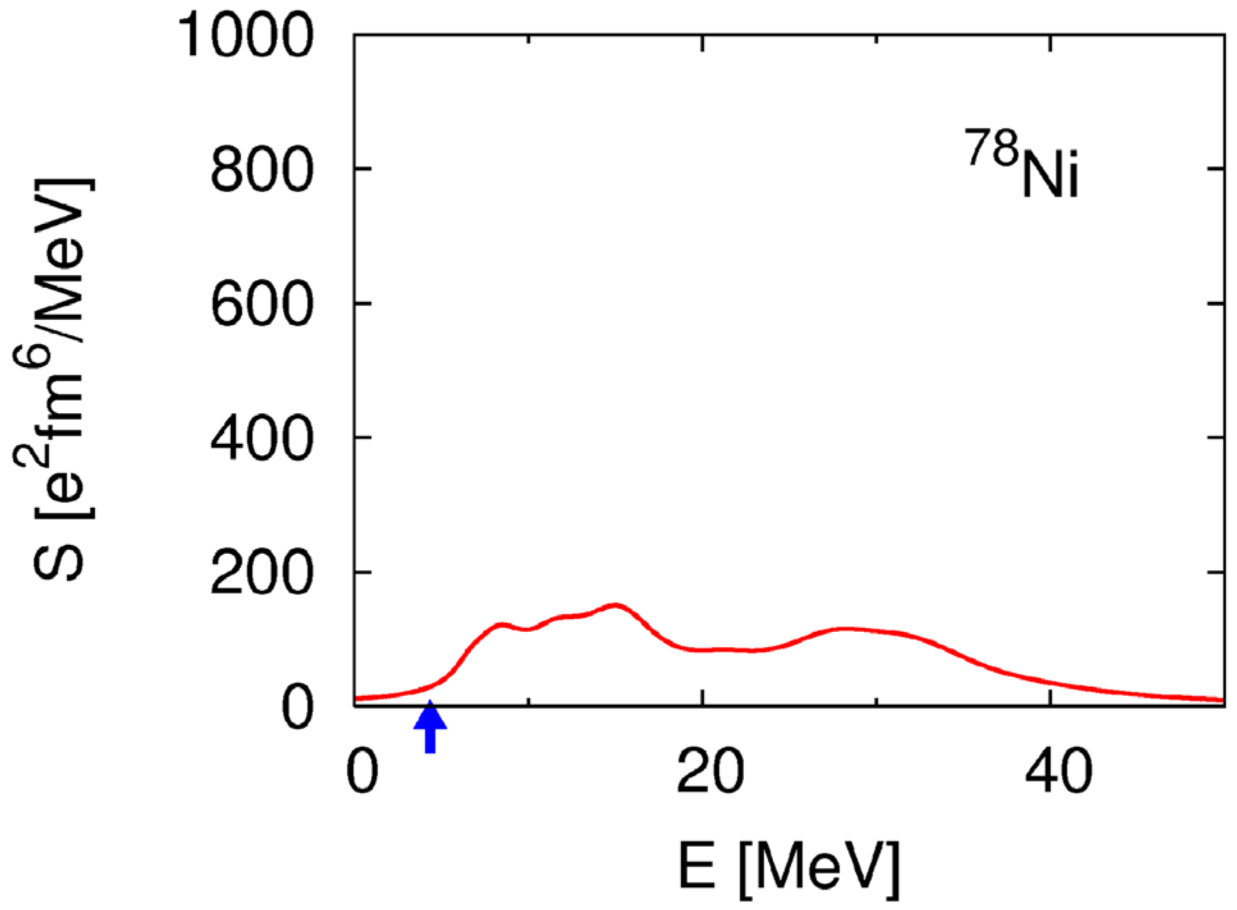

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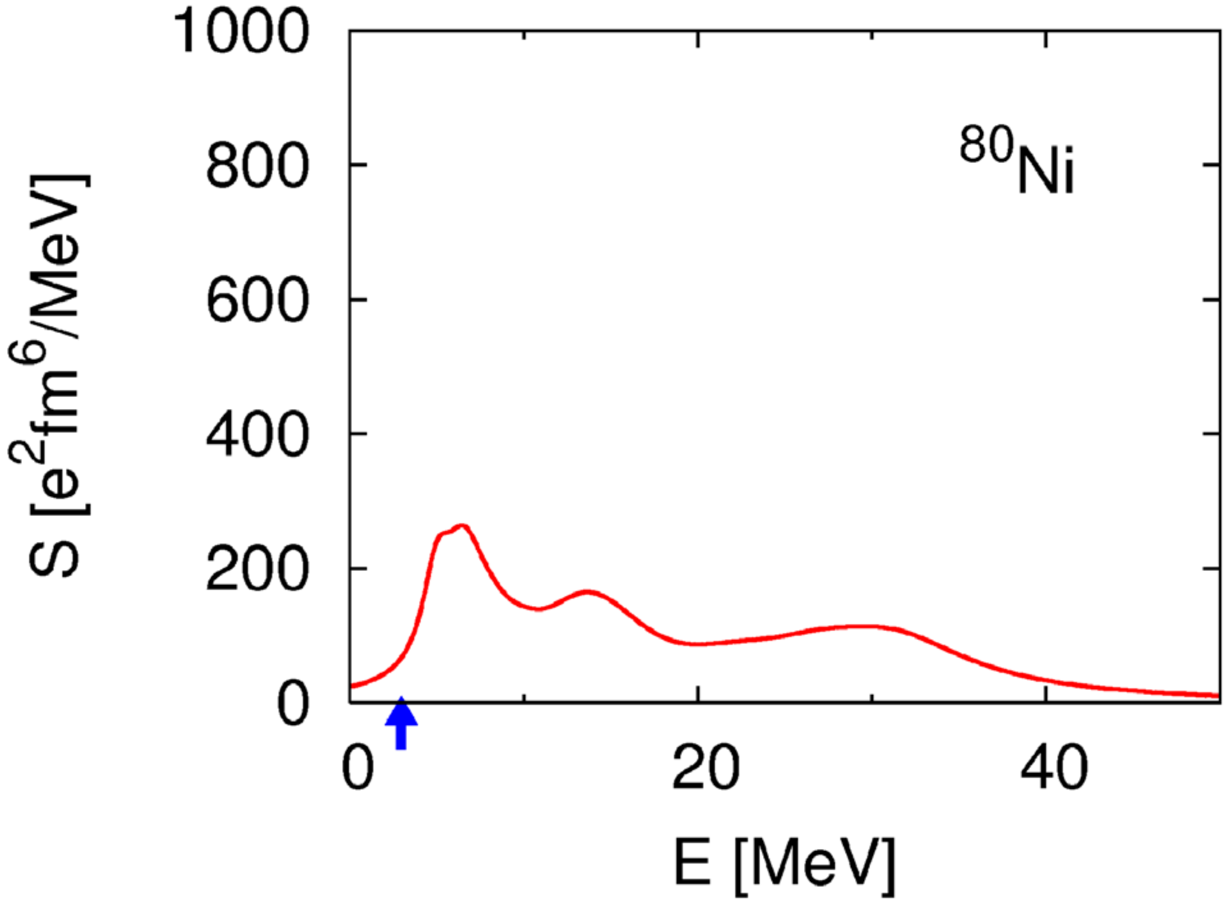

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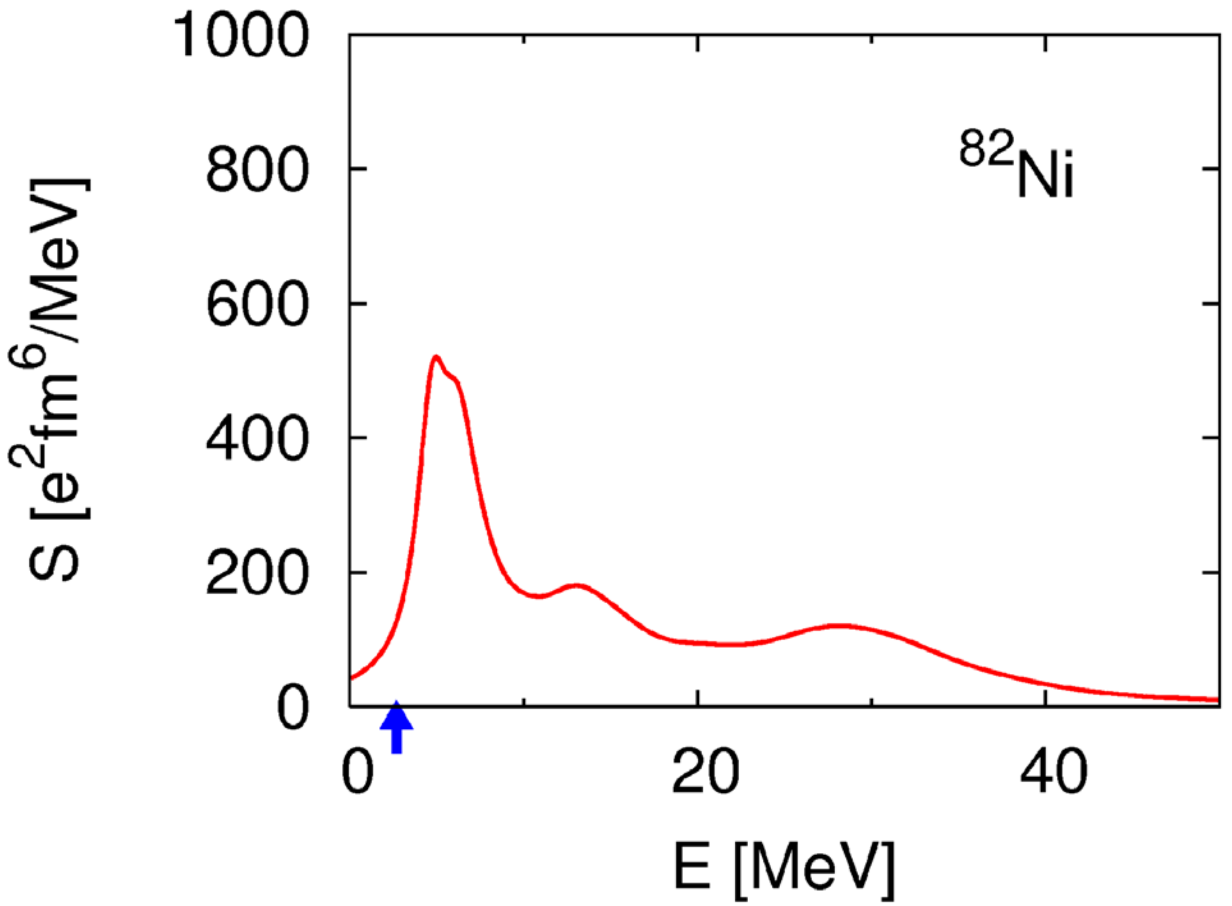

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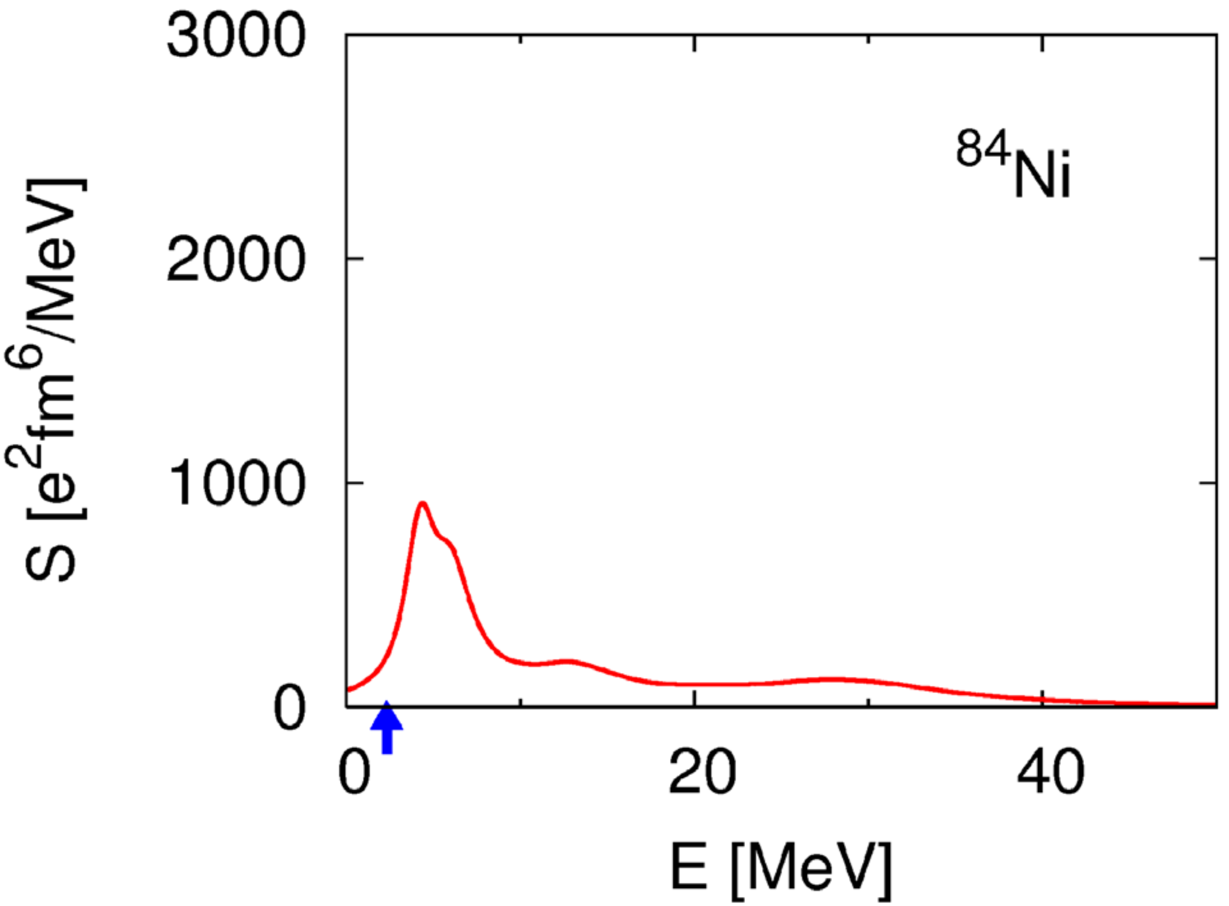

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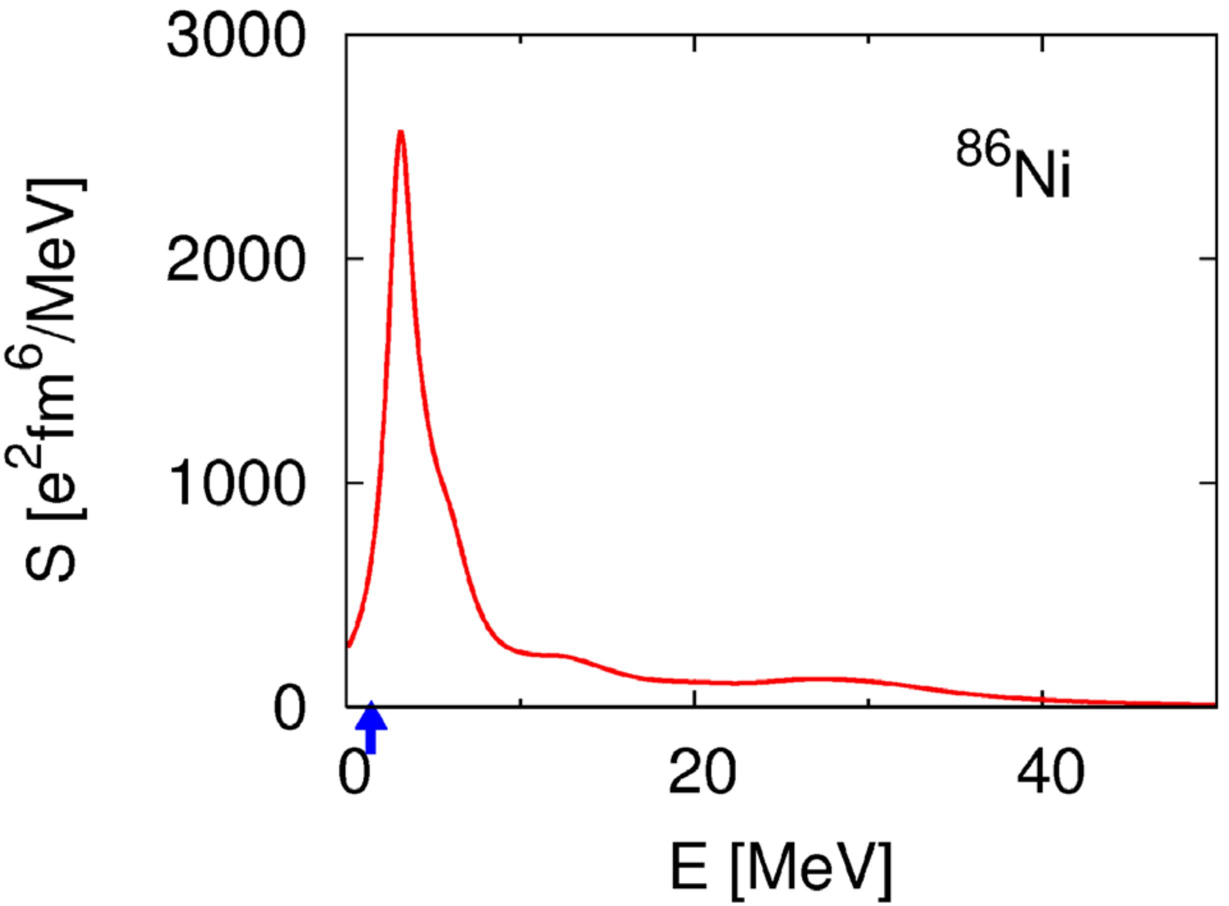
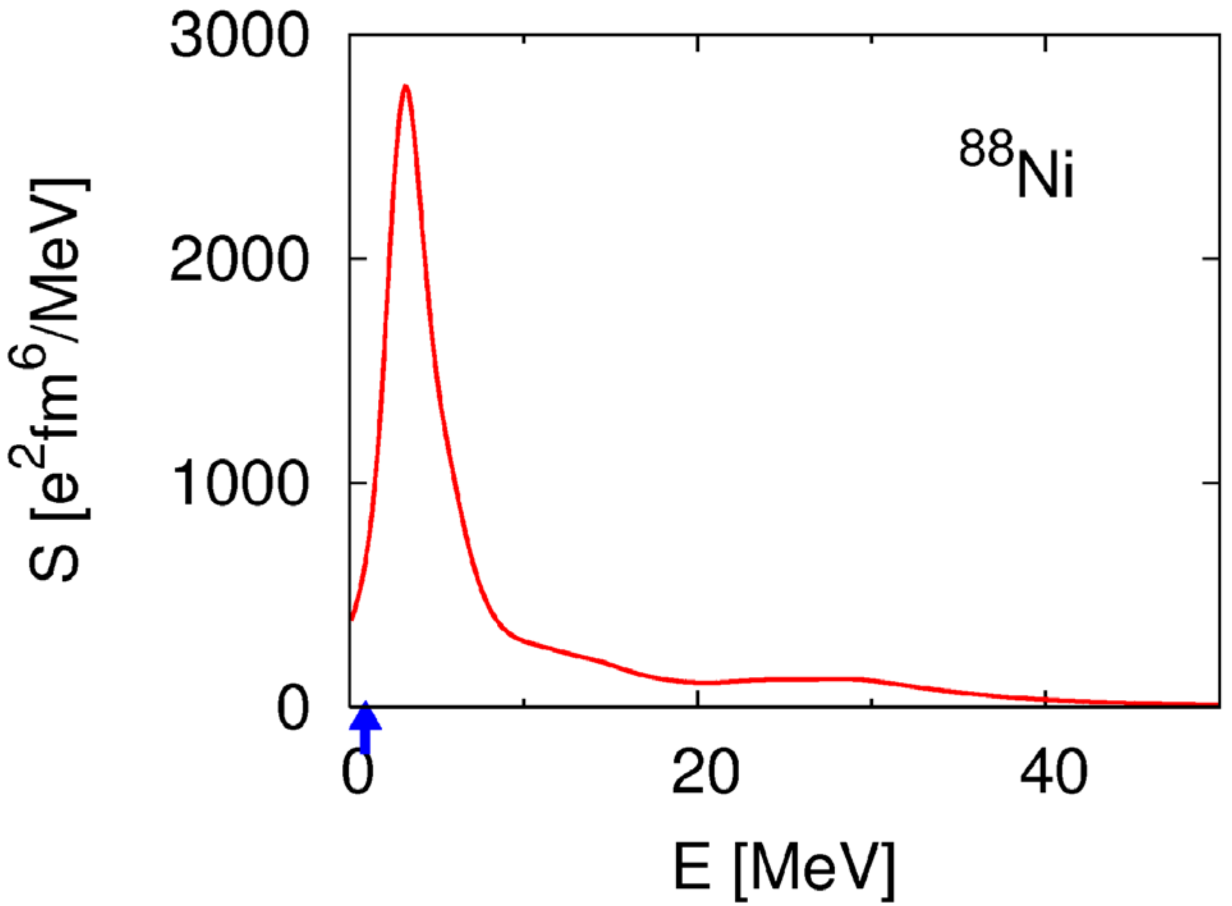


Isoscalar 1^- strength functions



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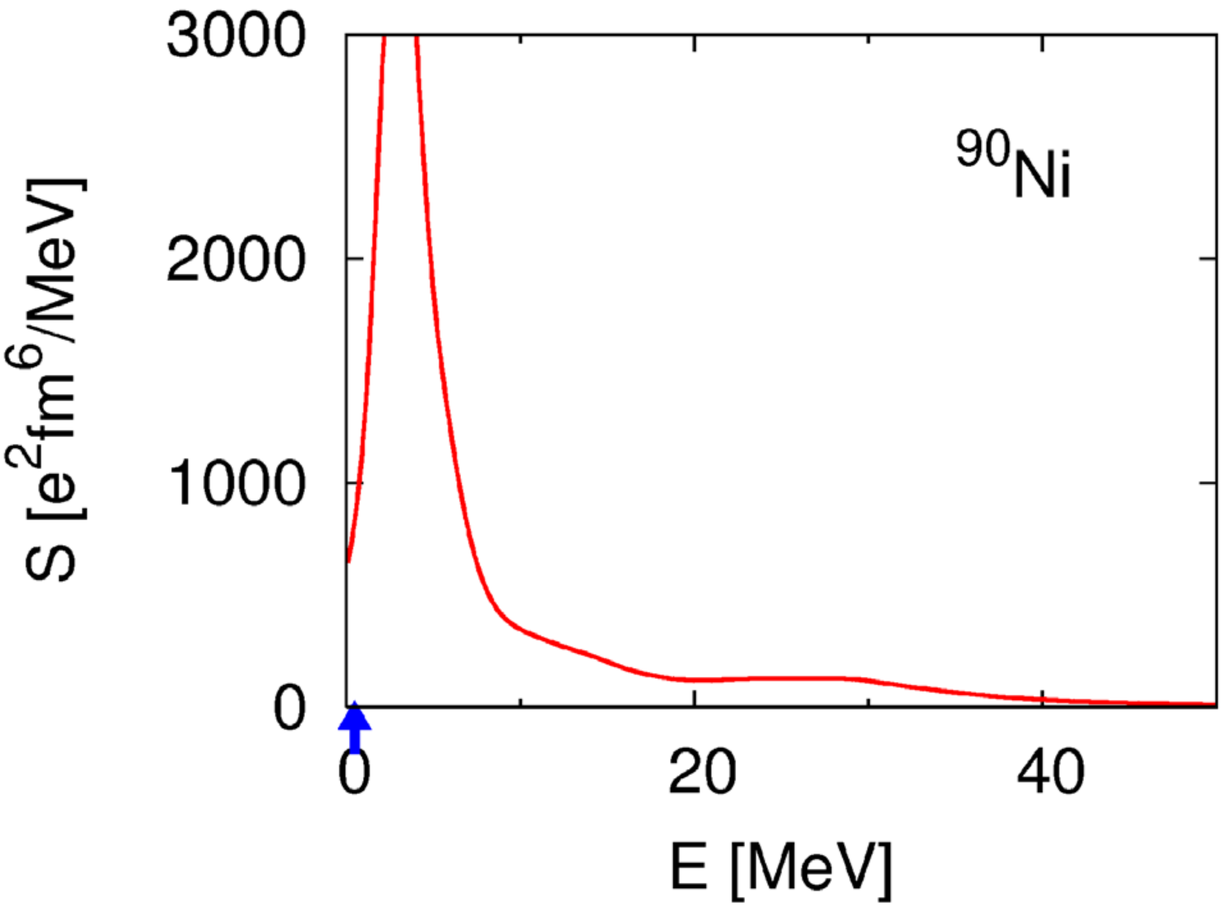

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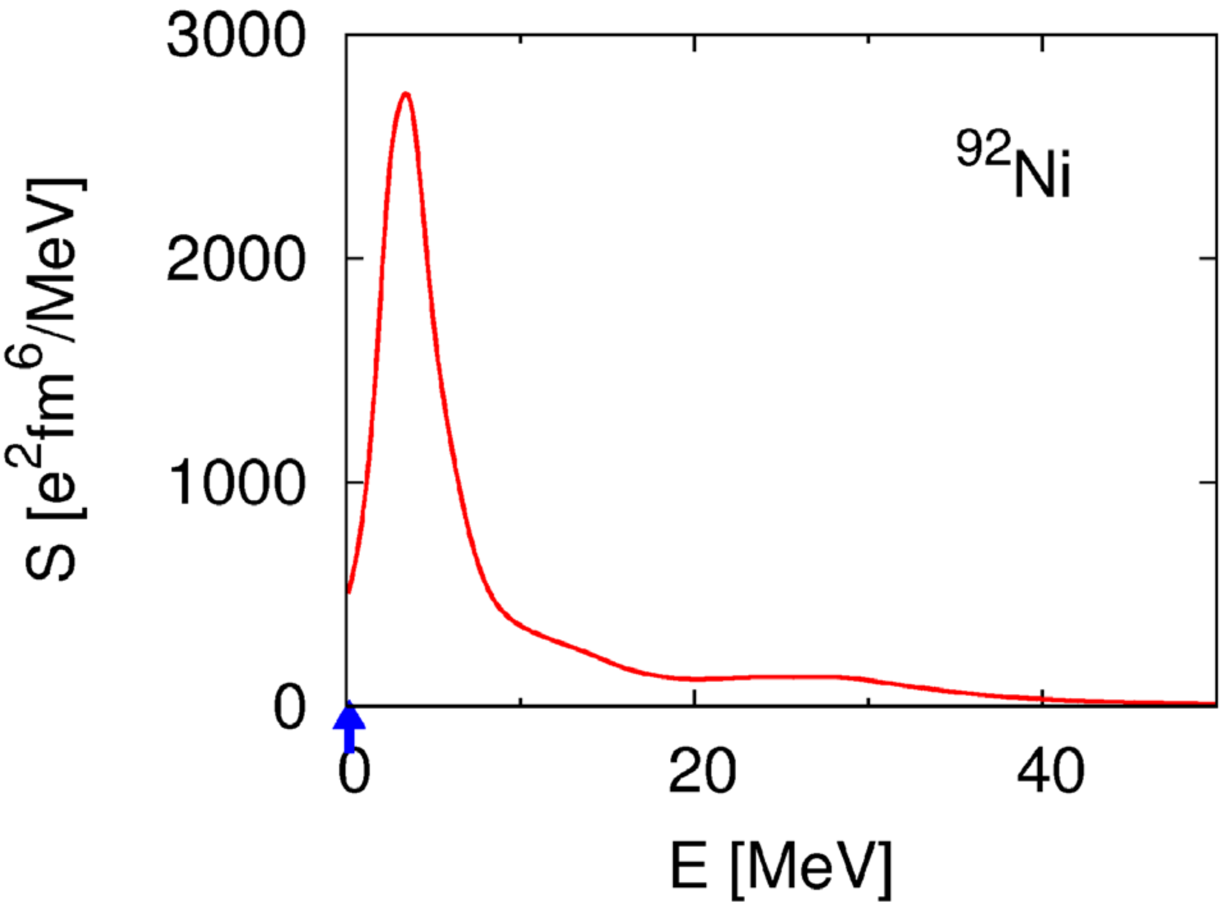

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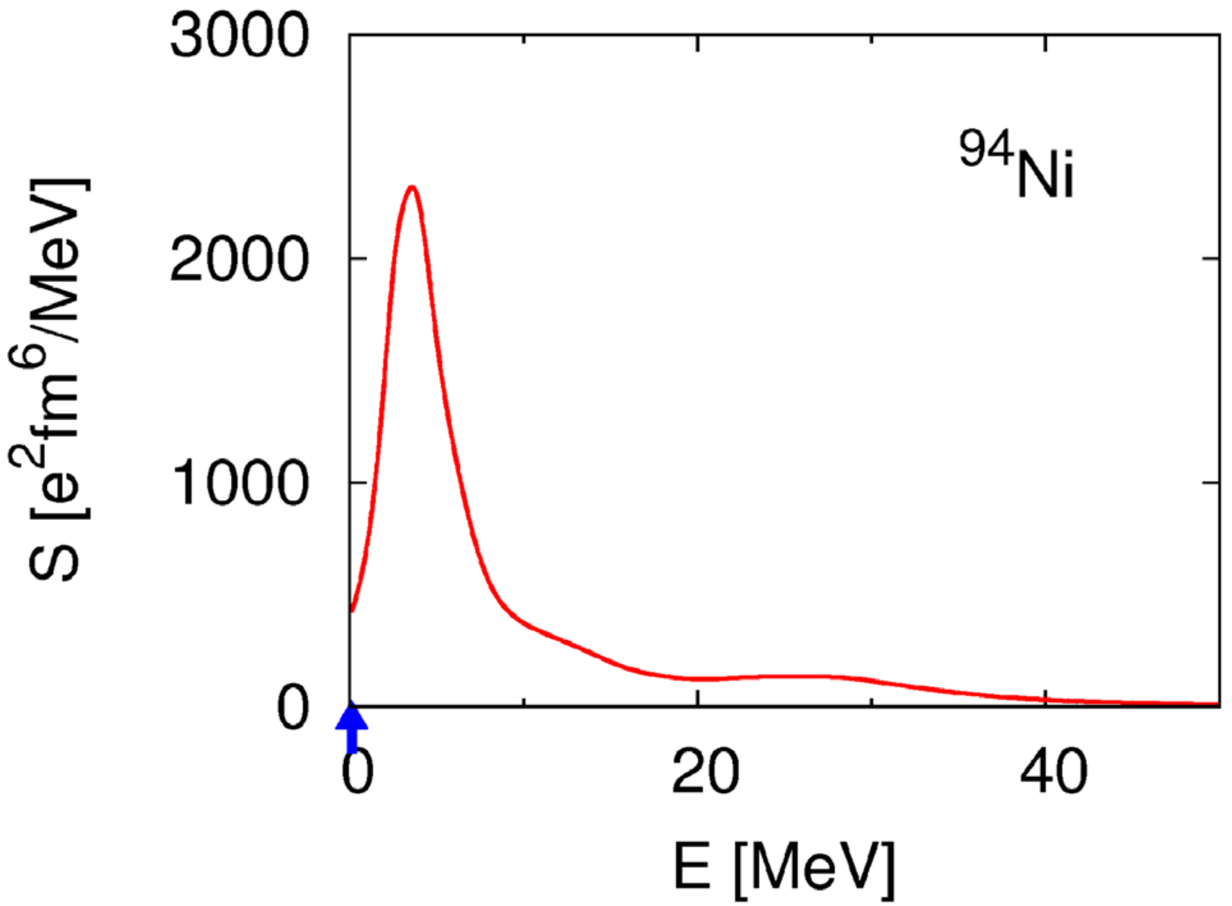
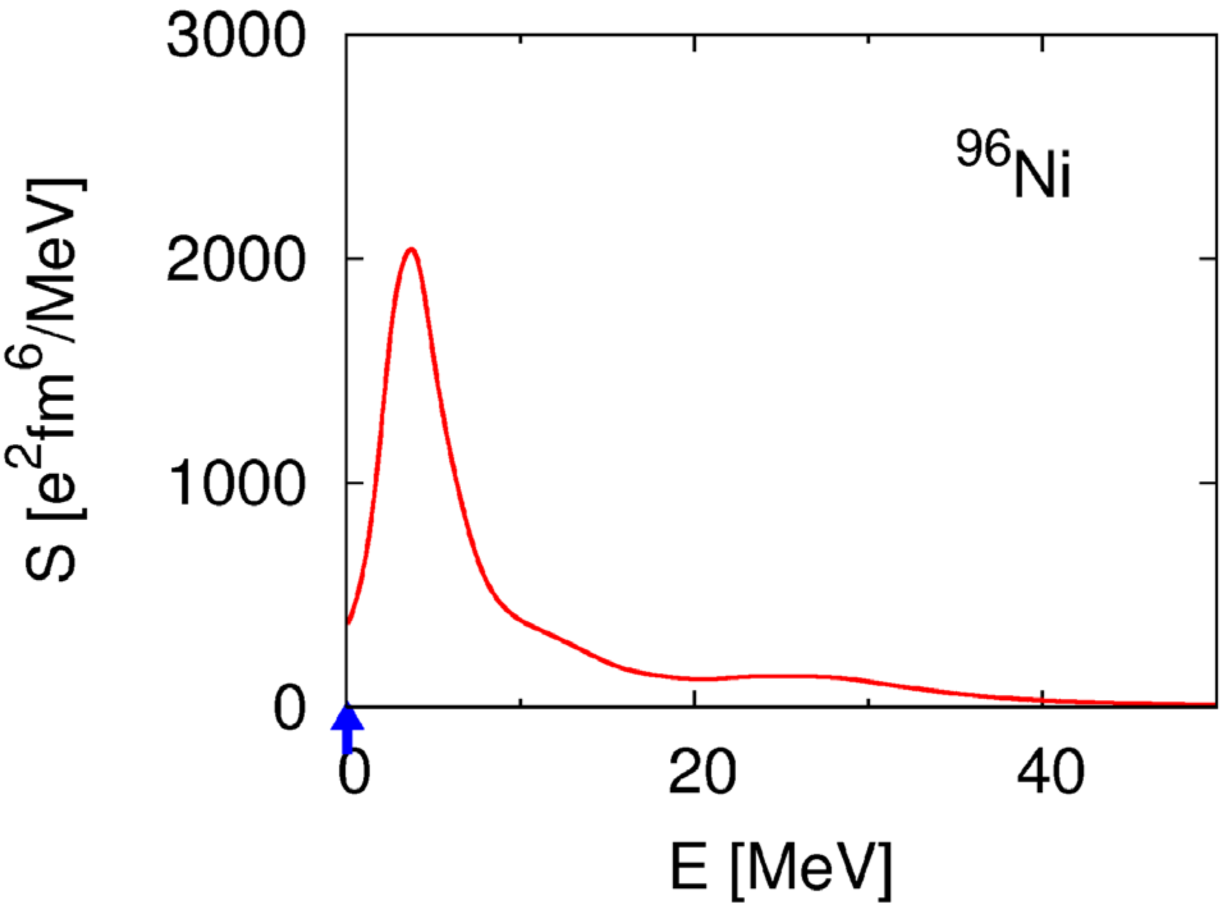
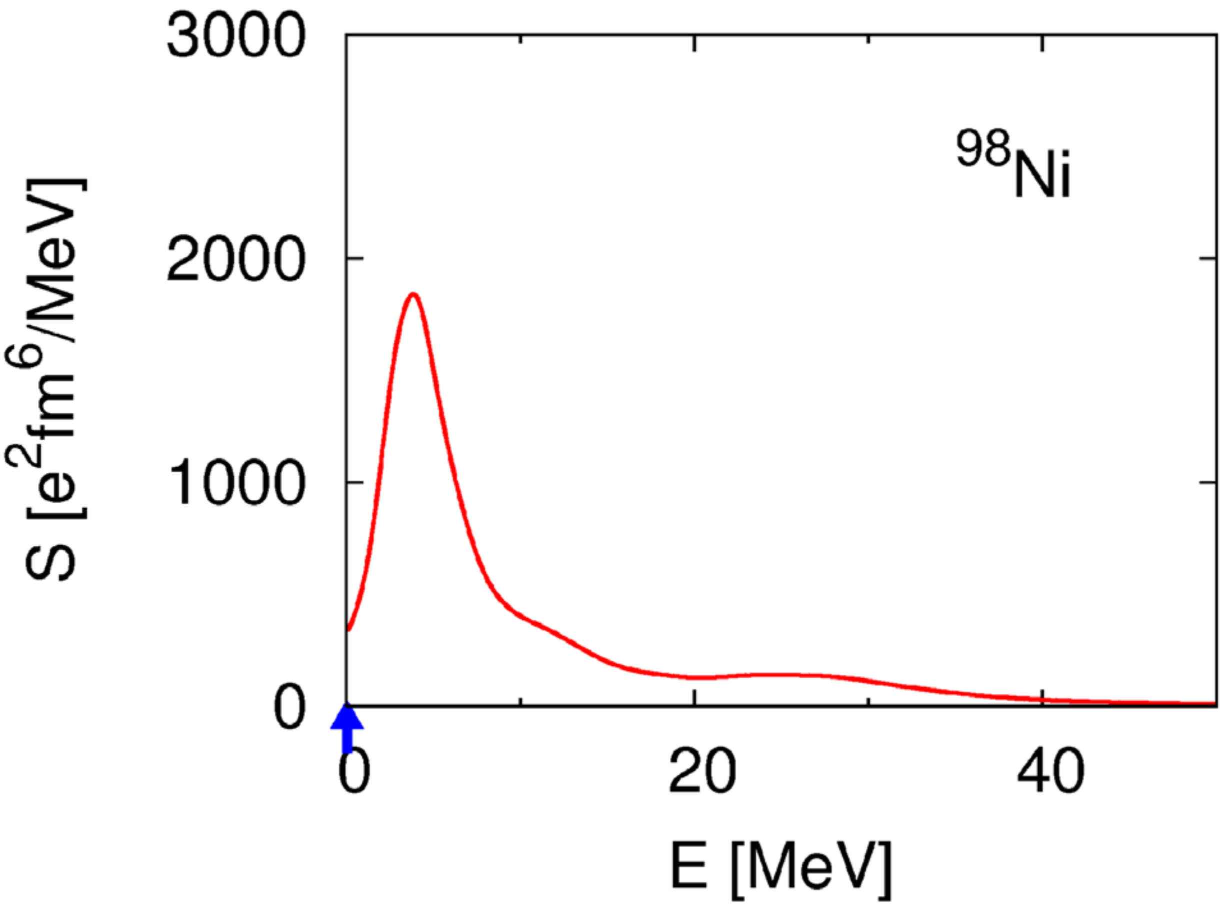


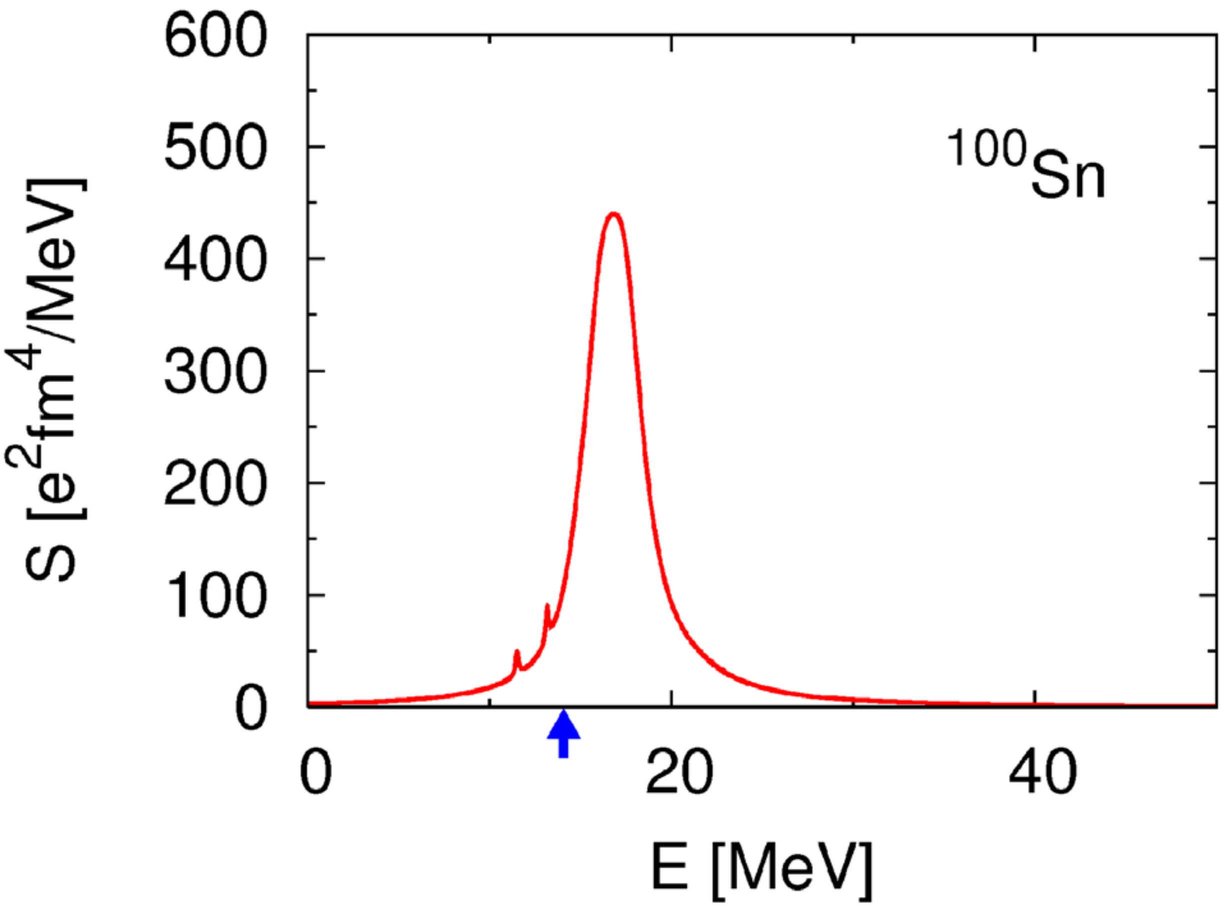
Isoscalar 1^- strength functions



Isoscalar 1⁻ strength functions

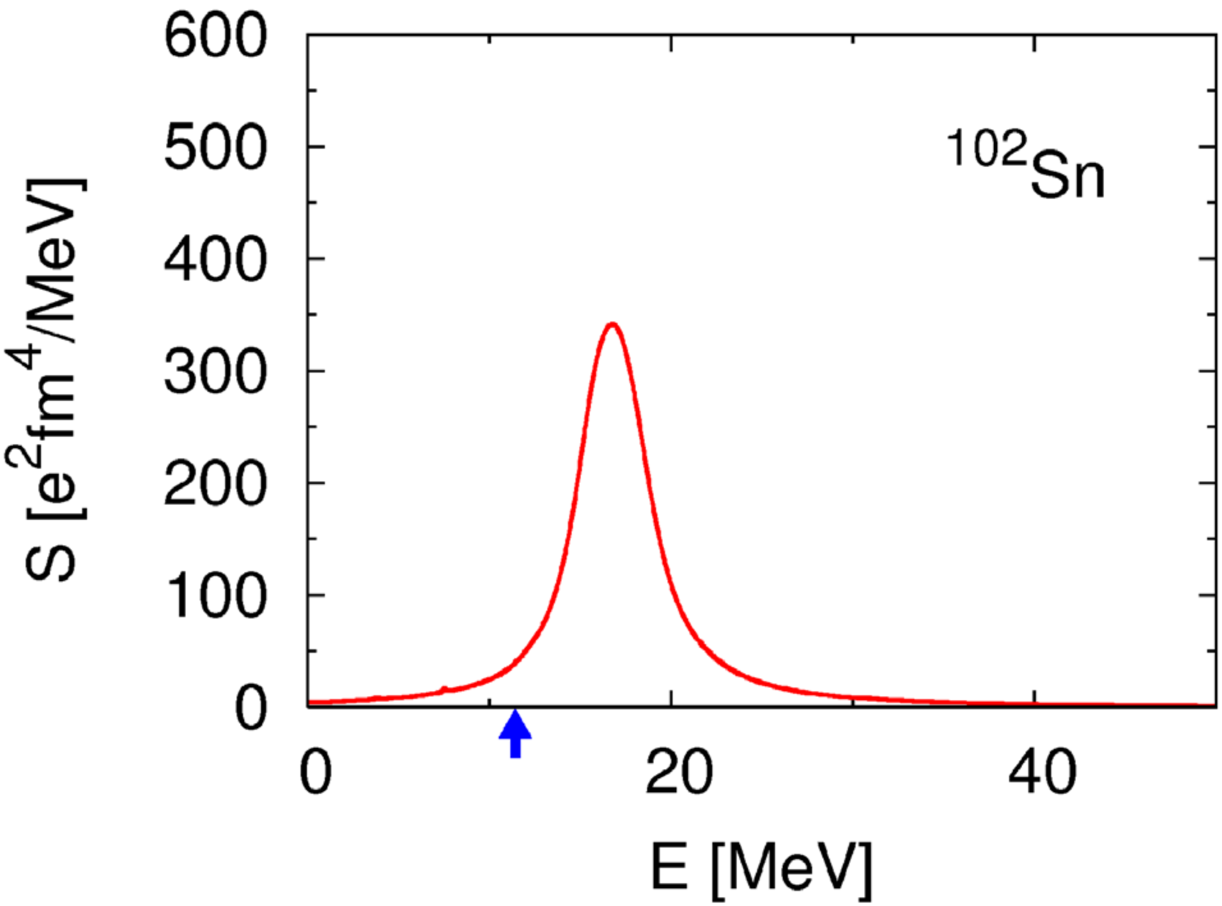


Isoscalar 0^+ strength functions

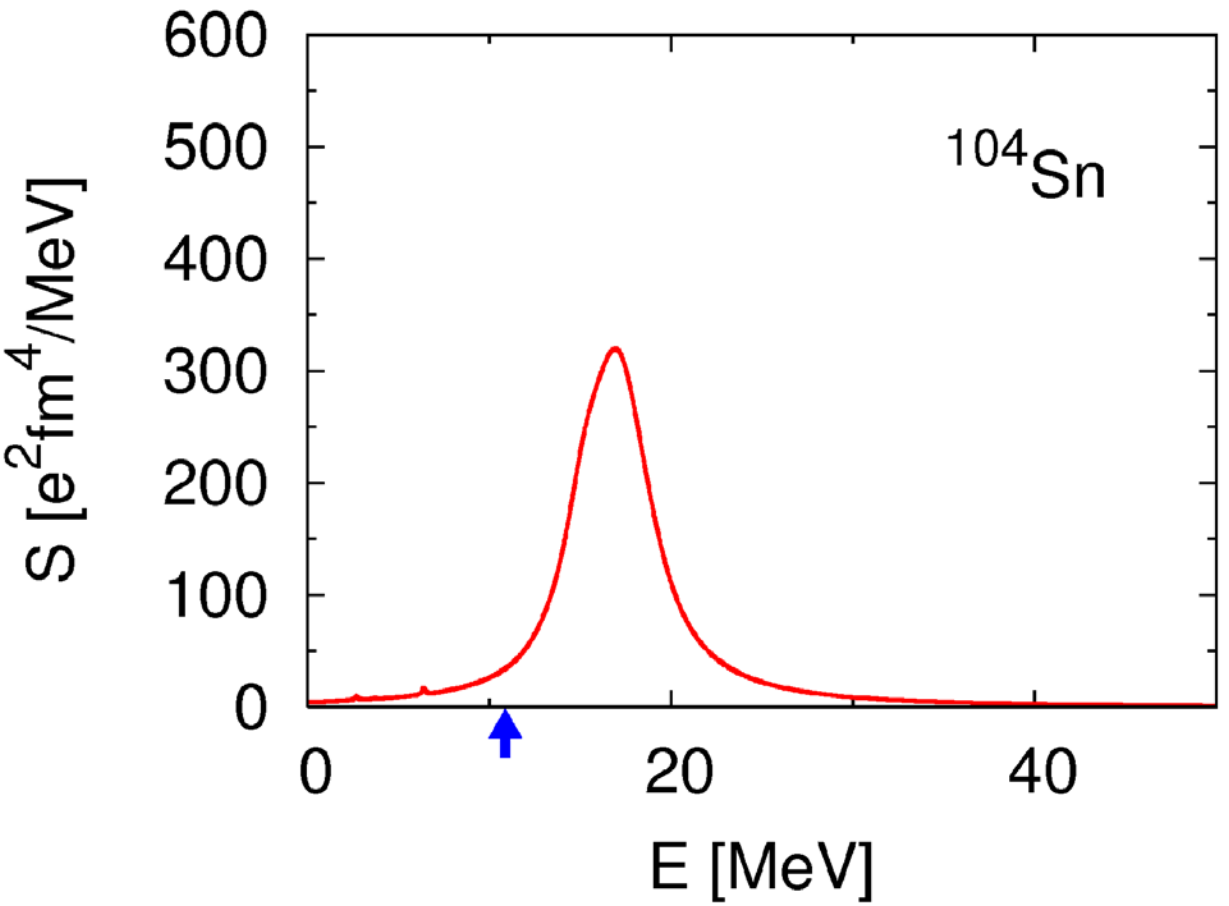


SkM*

Isoscalar 0^+ strength functions



Isoscalar 0^+ strength functions



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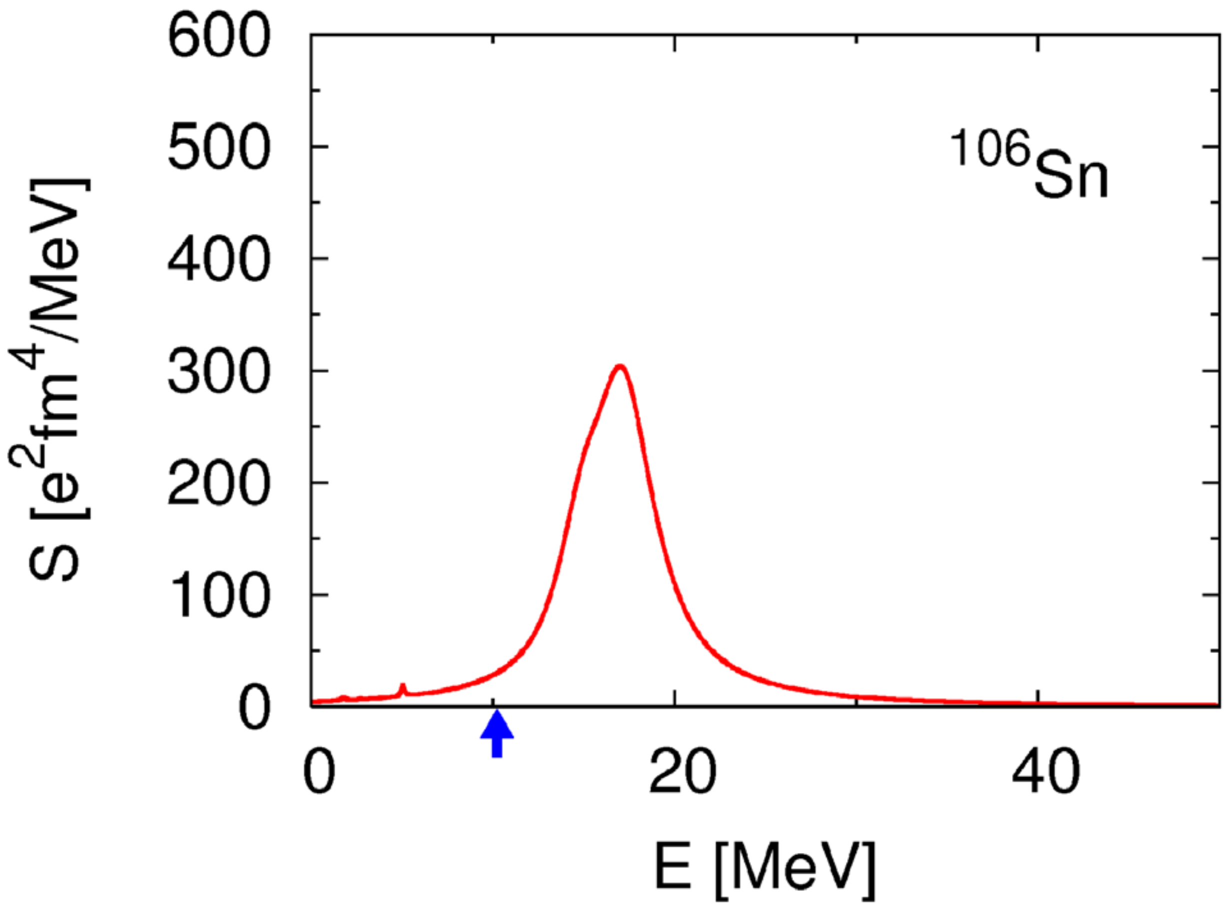

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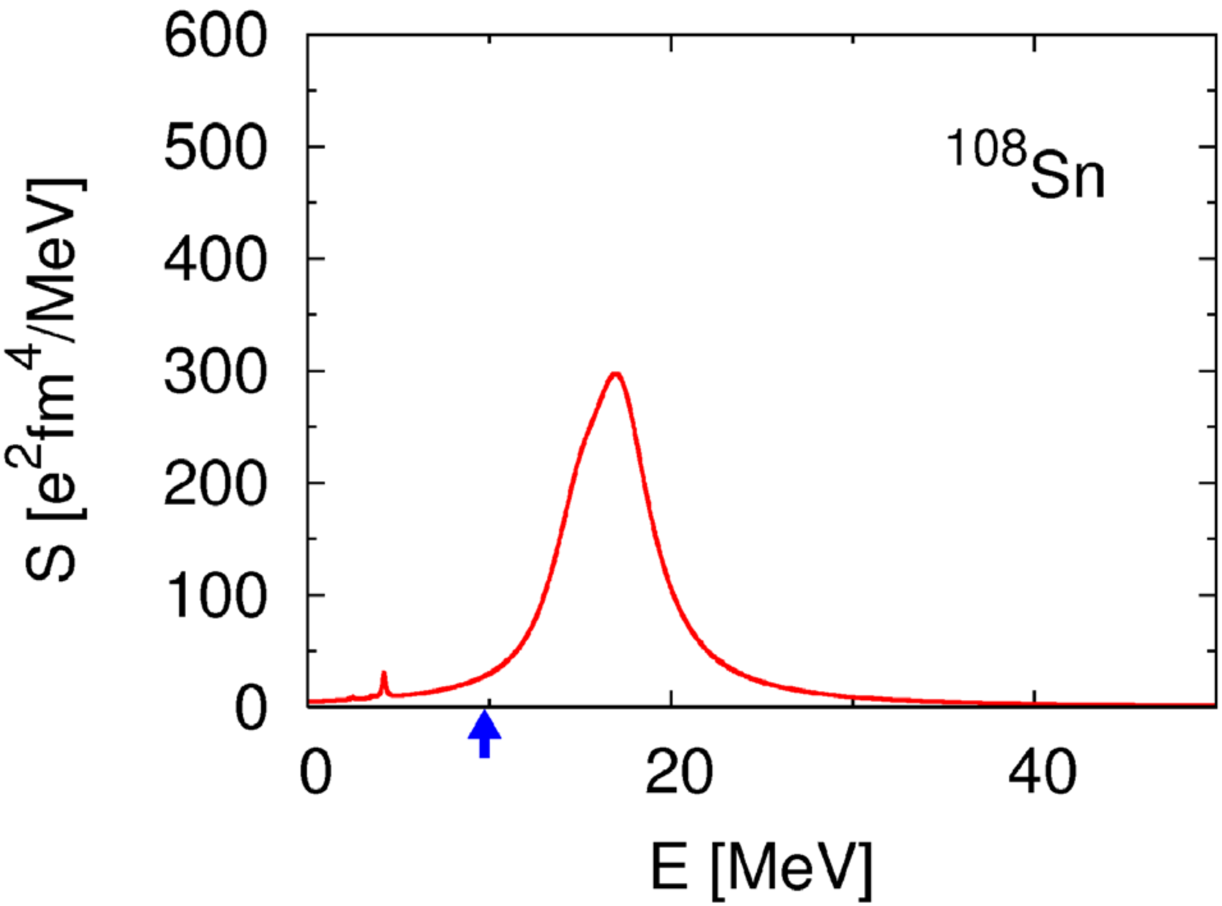

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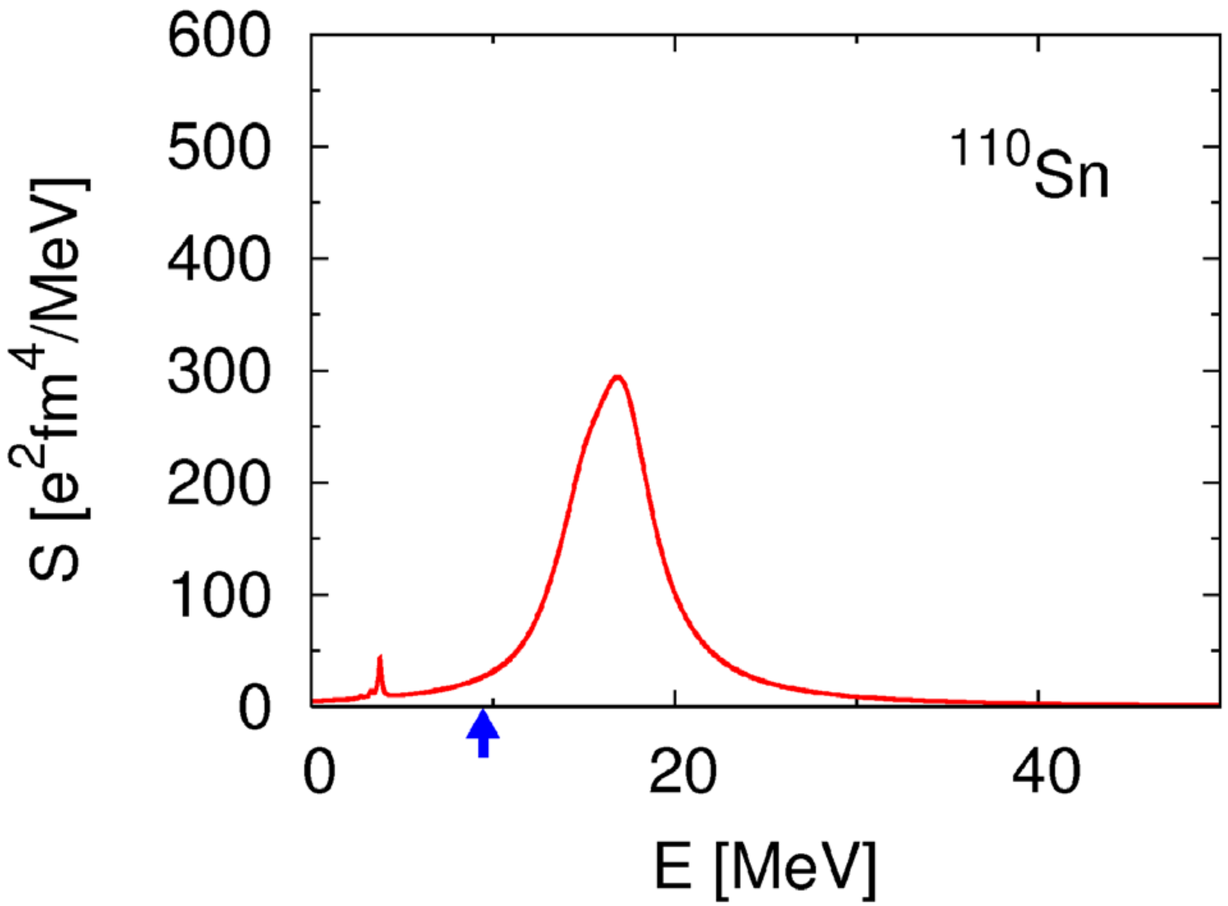

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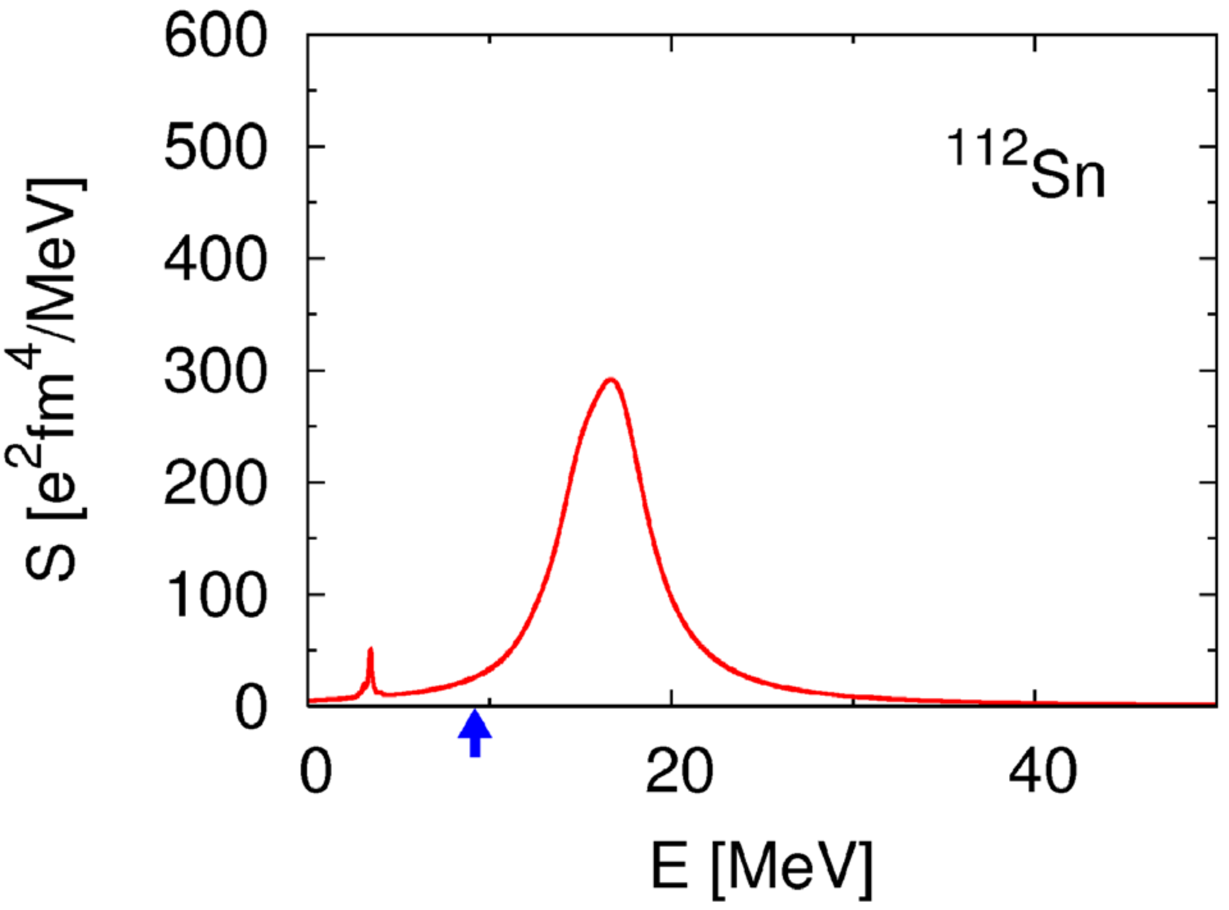

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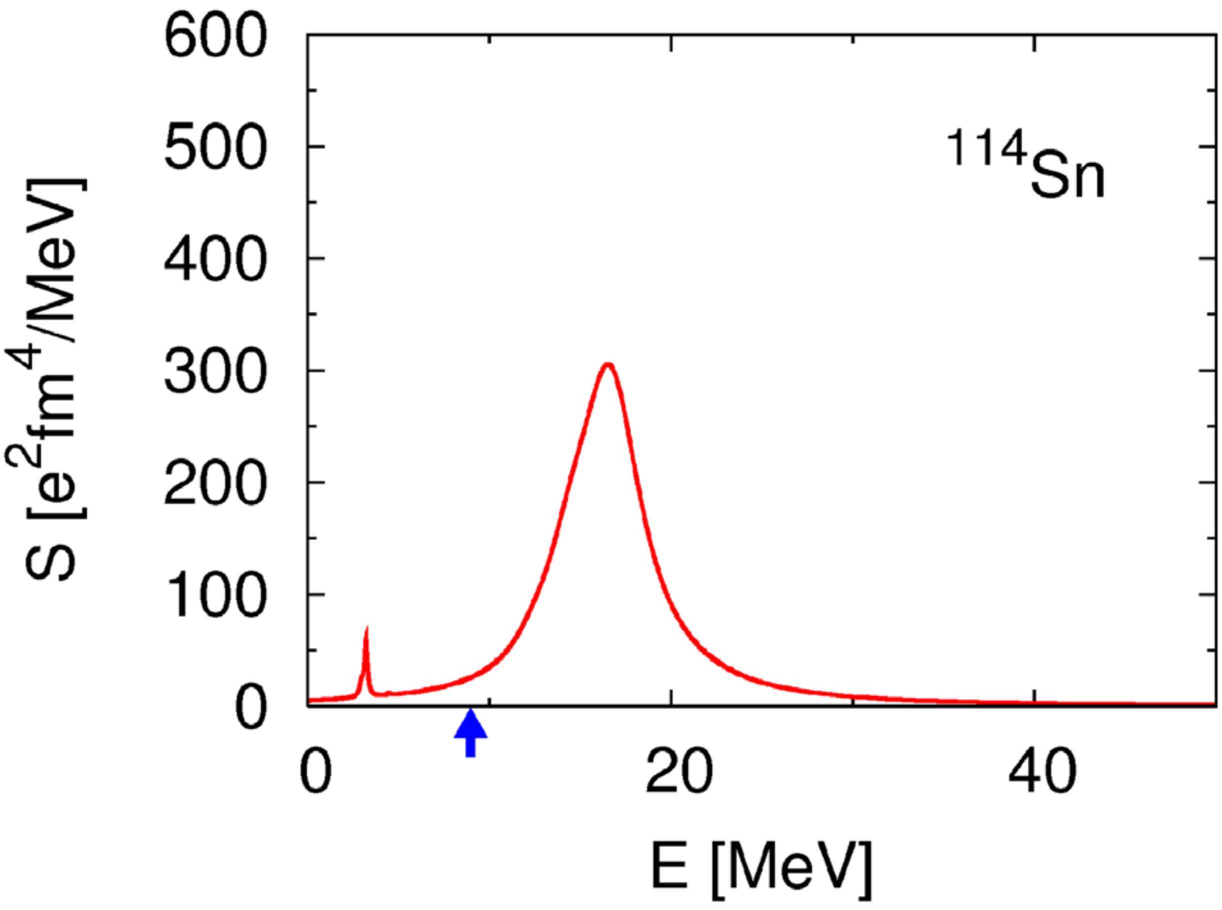

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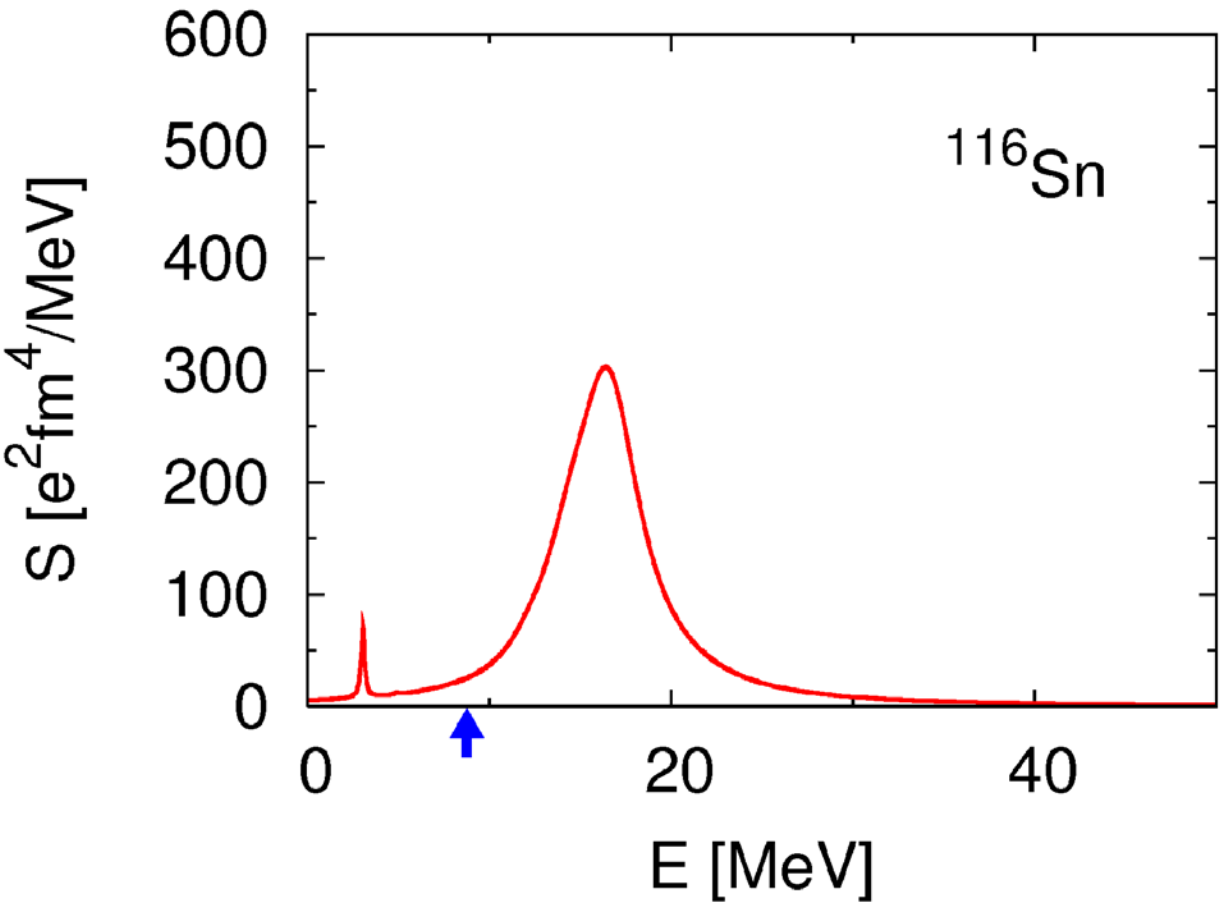

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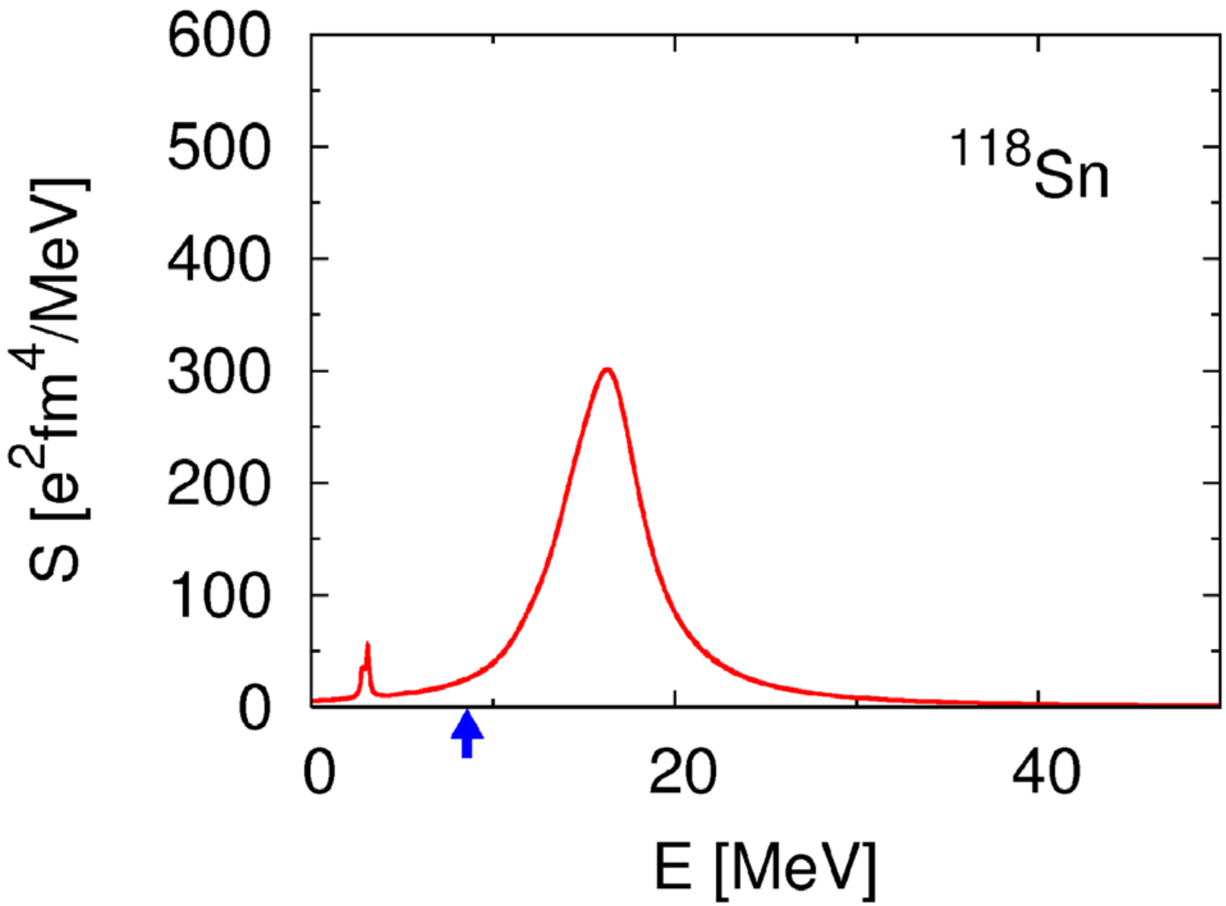

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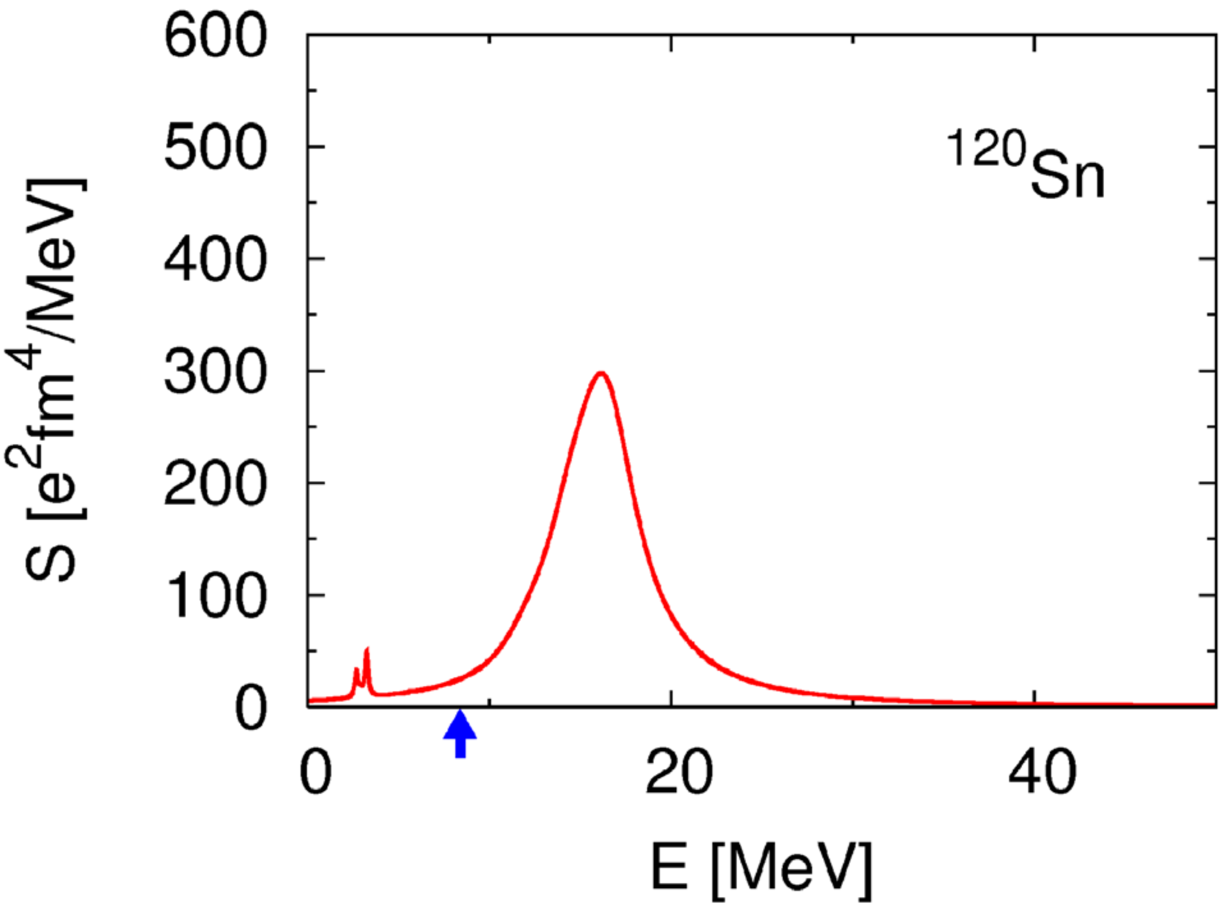
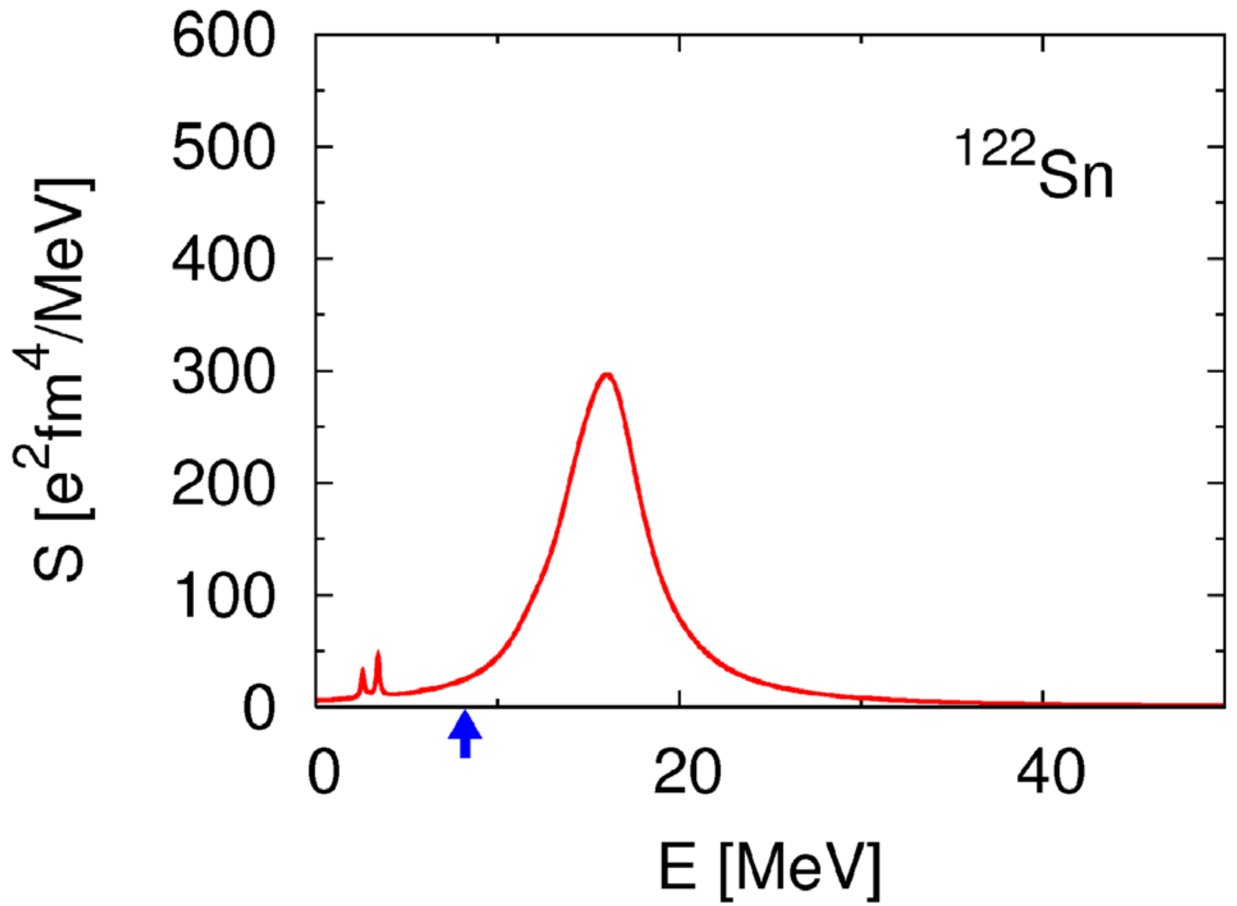
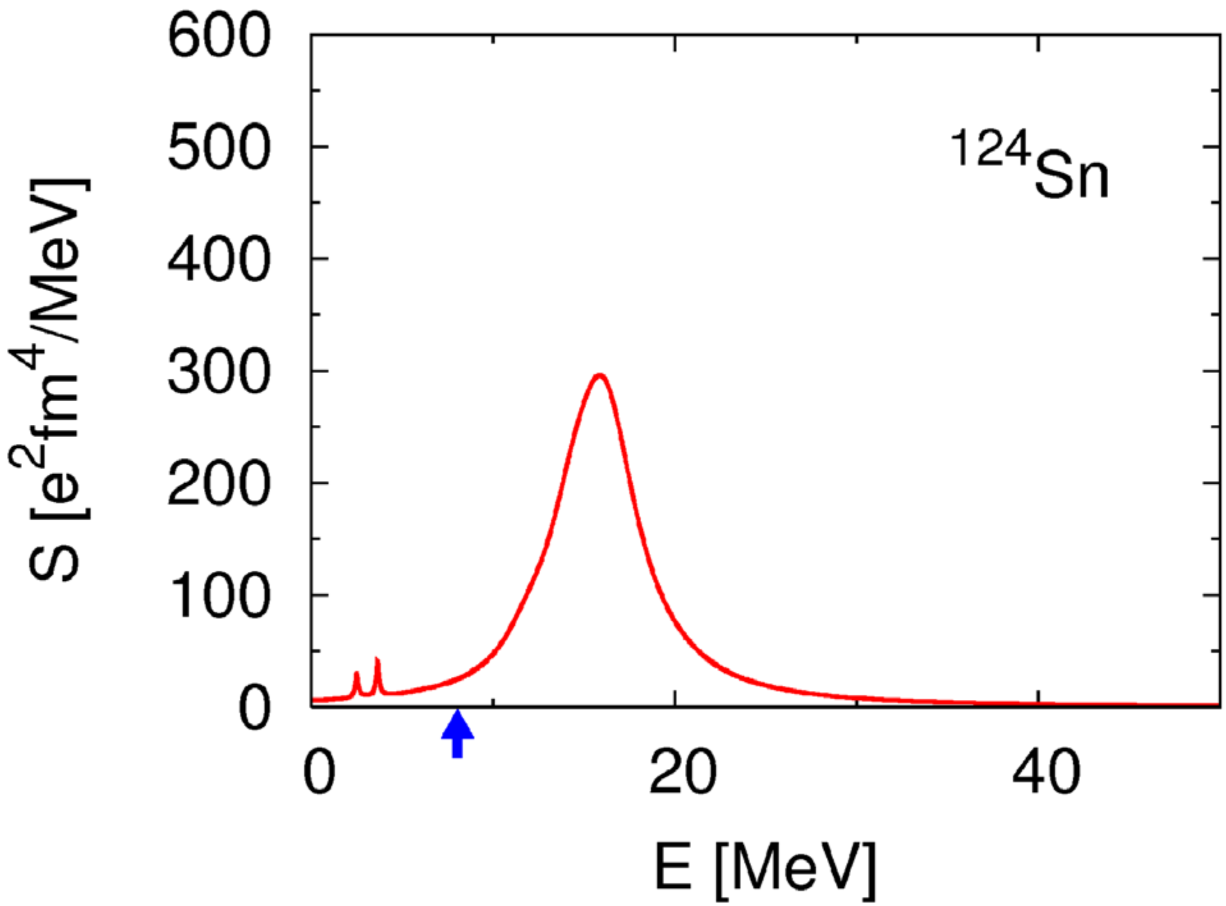


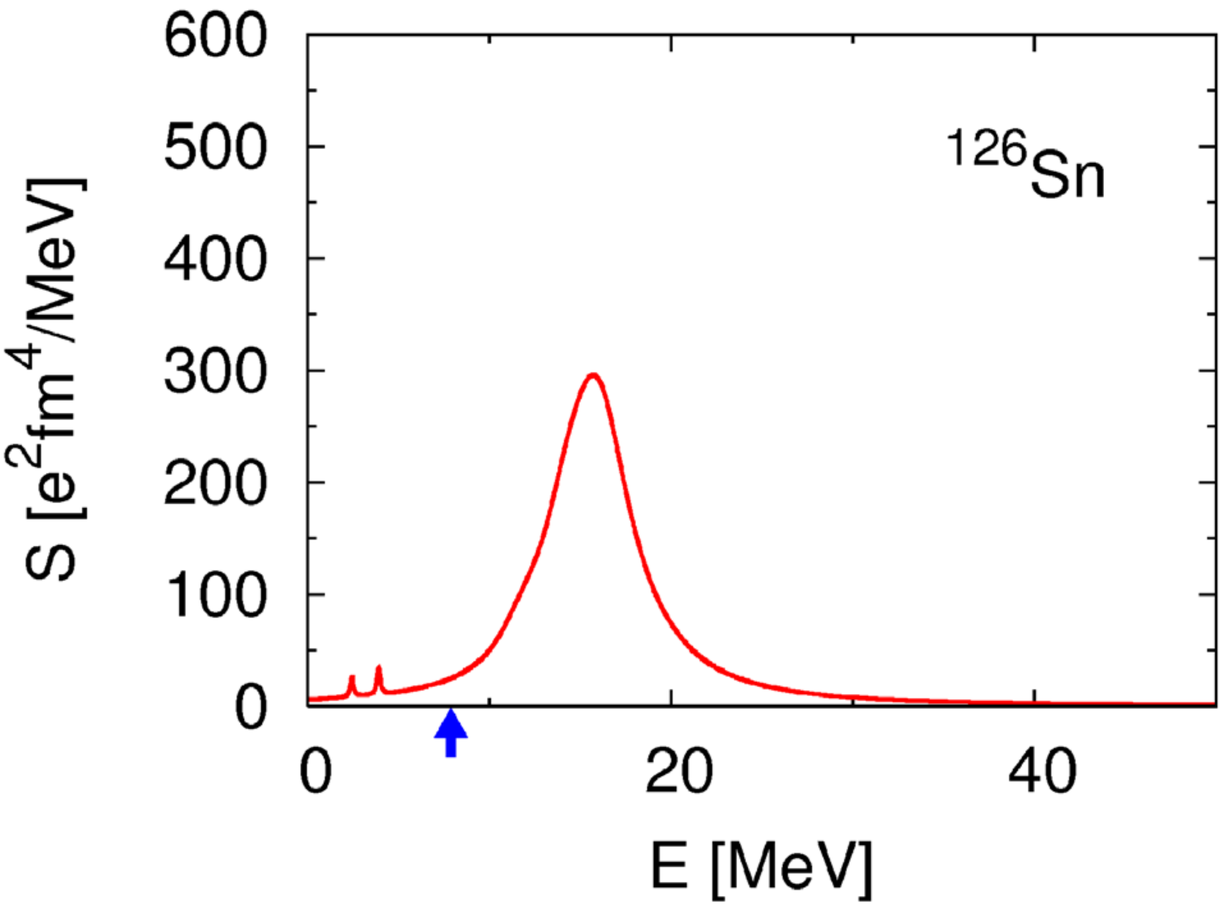
Isoscalar 0^+ strength functions



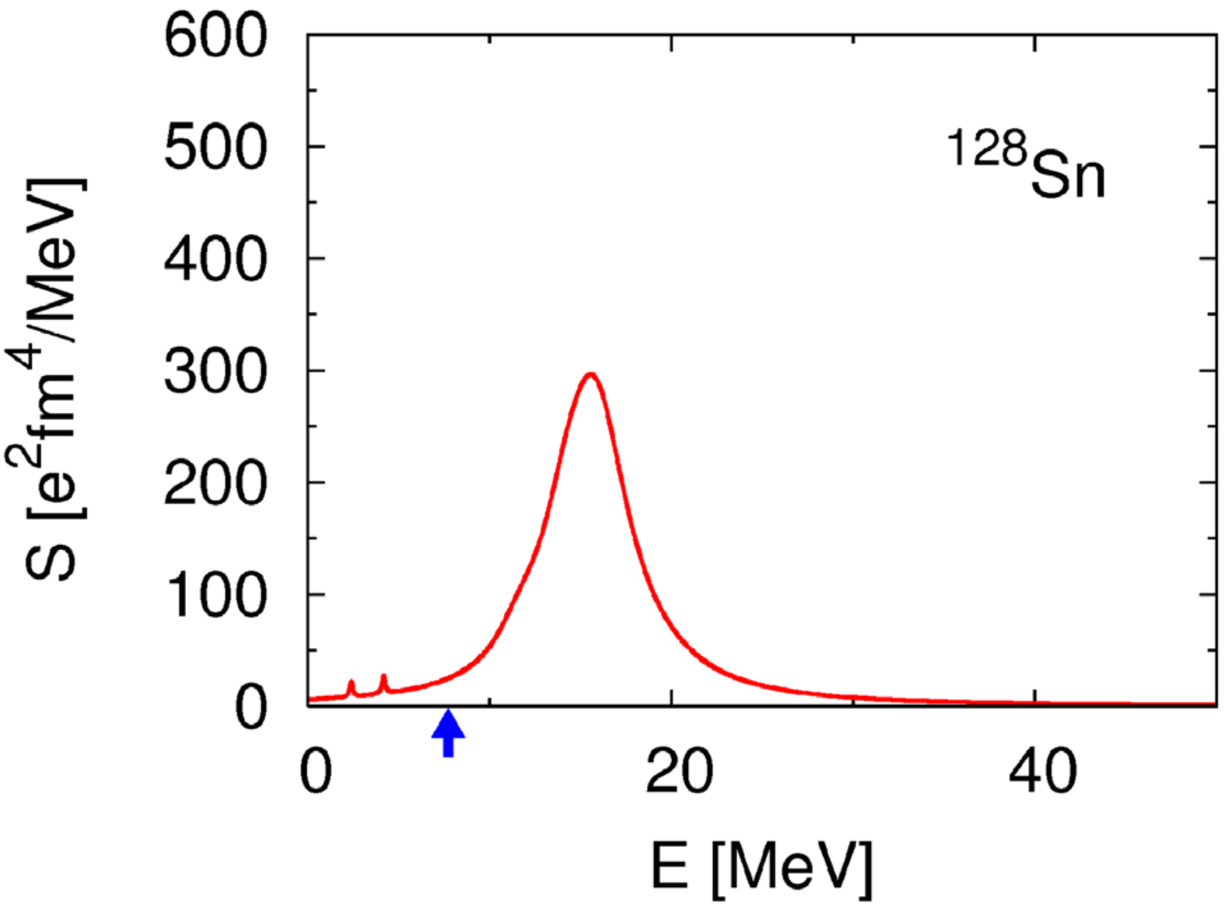
Isoscalar 0^+ strength functions



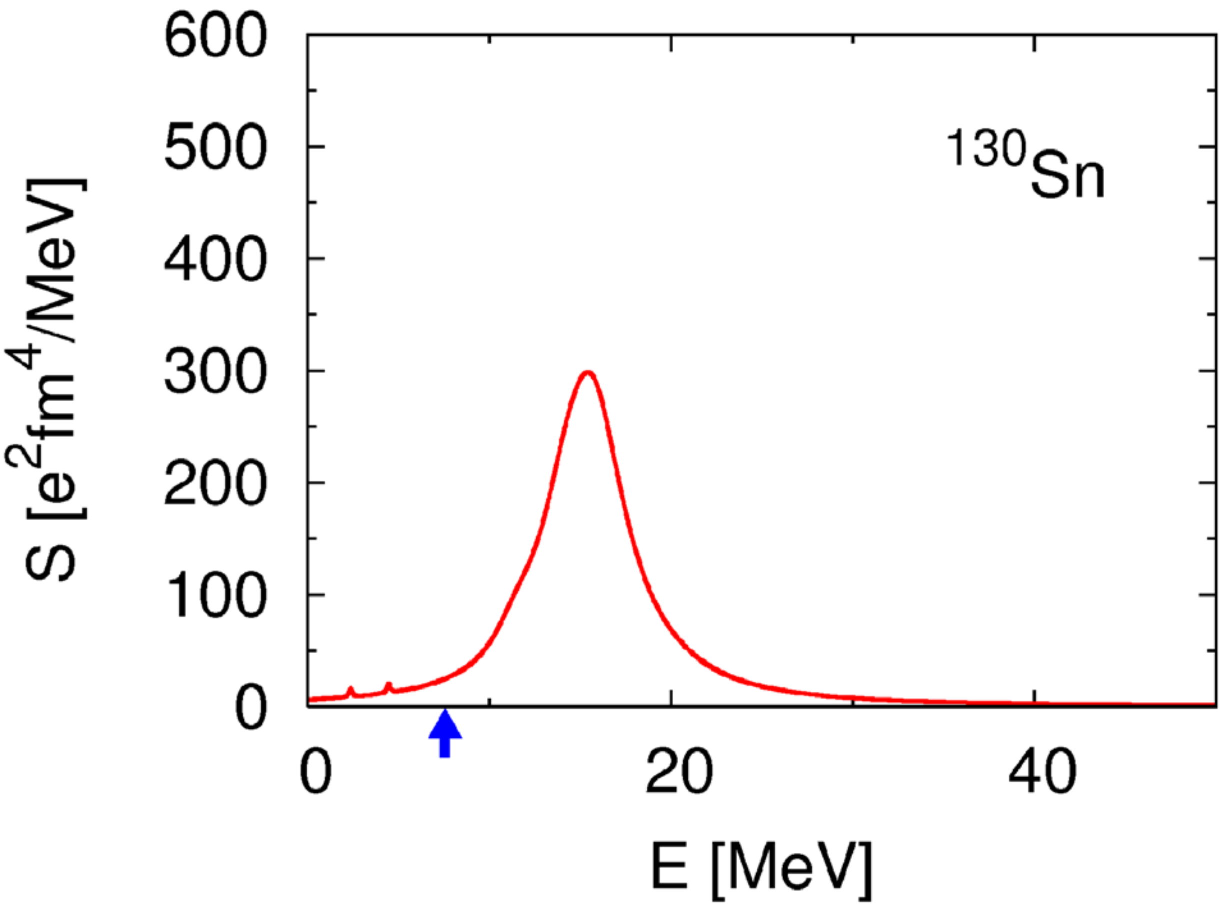
Isoscalar 0^+ strength functions



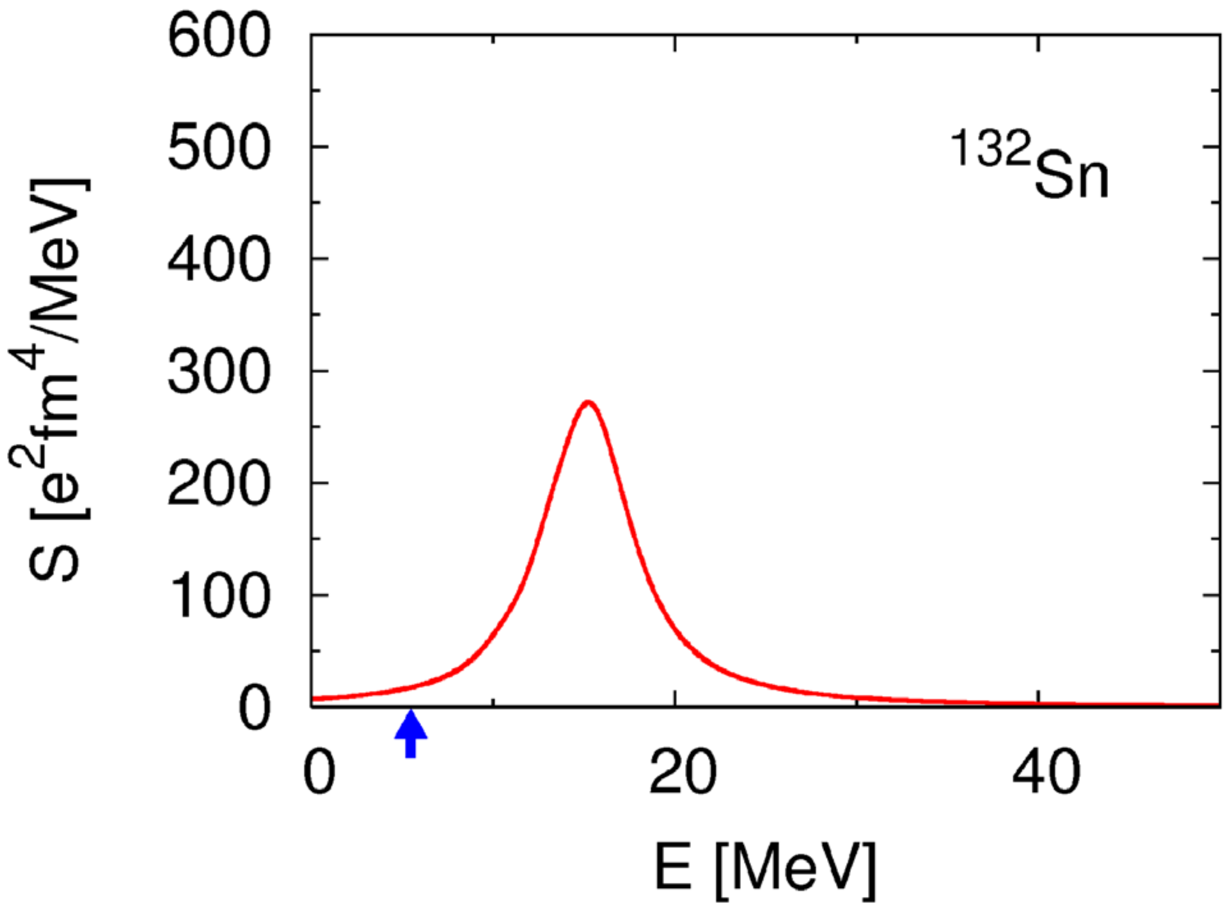
Isoscalar 0^+ strength functions



Isoscalar 0^+ strength functions



Isoscalar 0^+ strength functions



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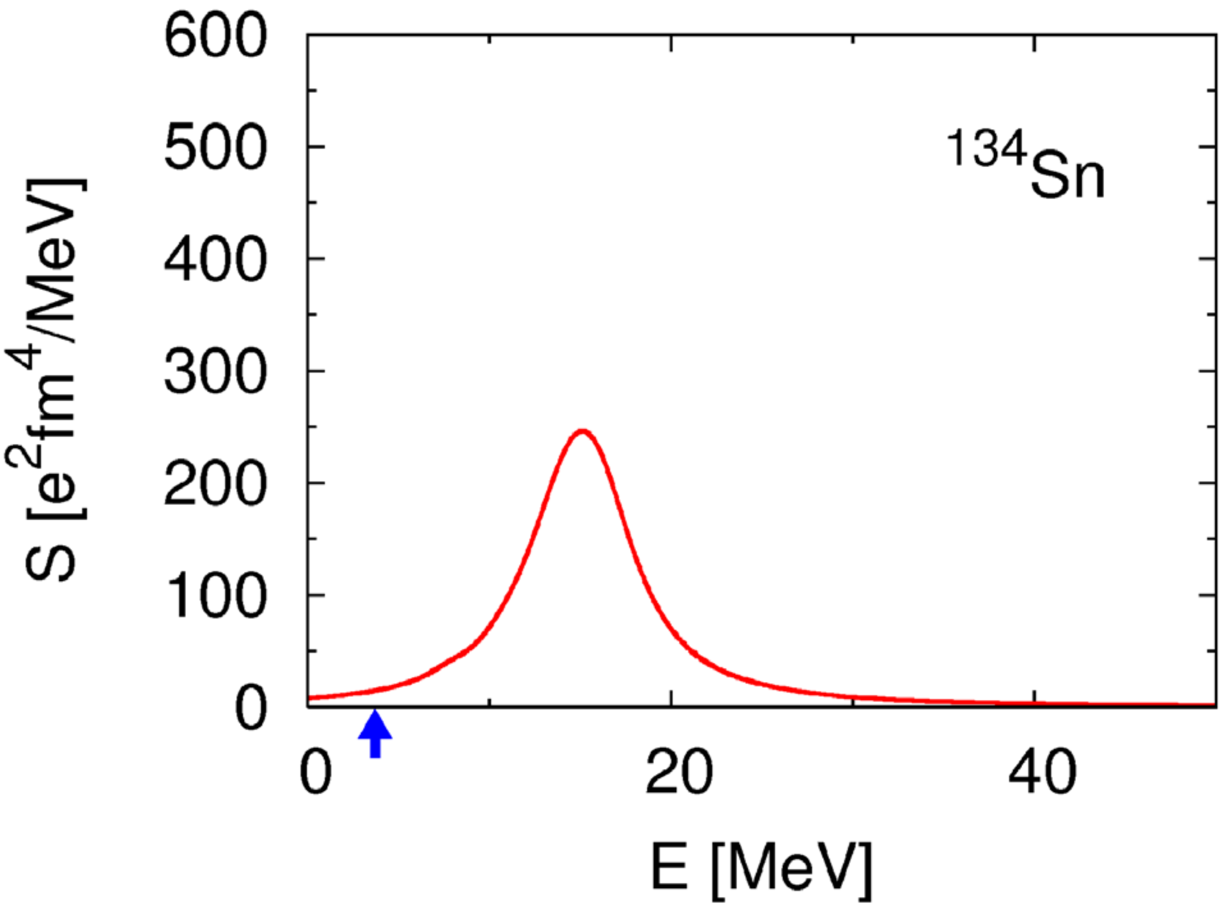

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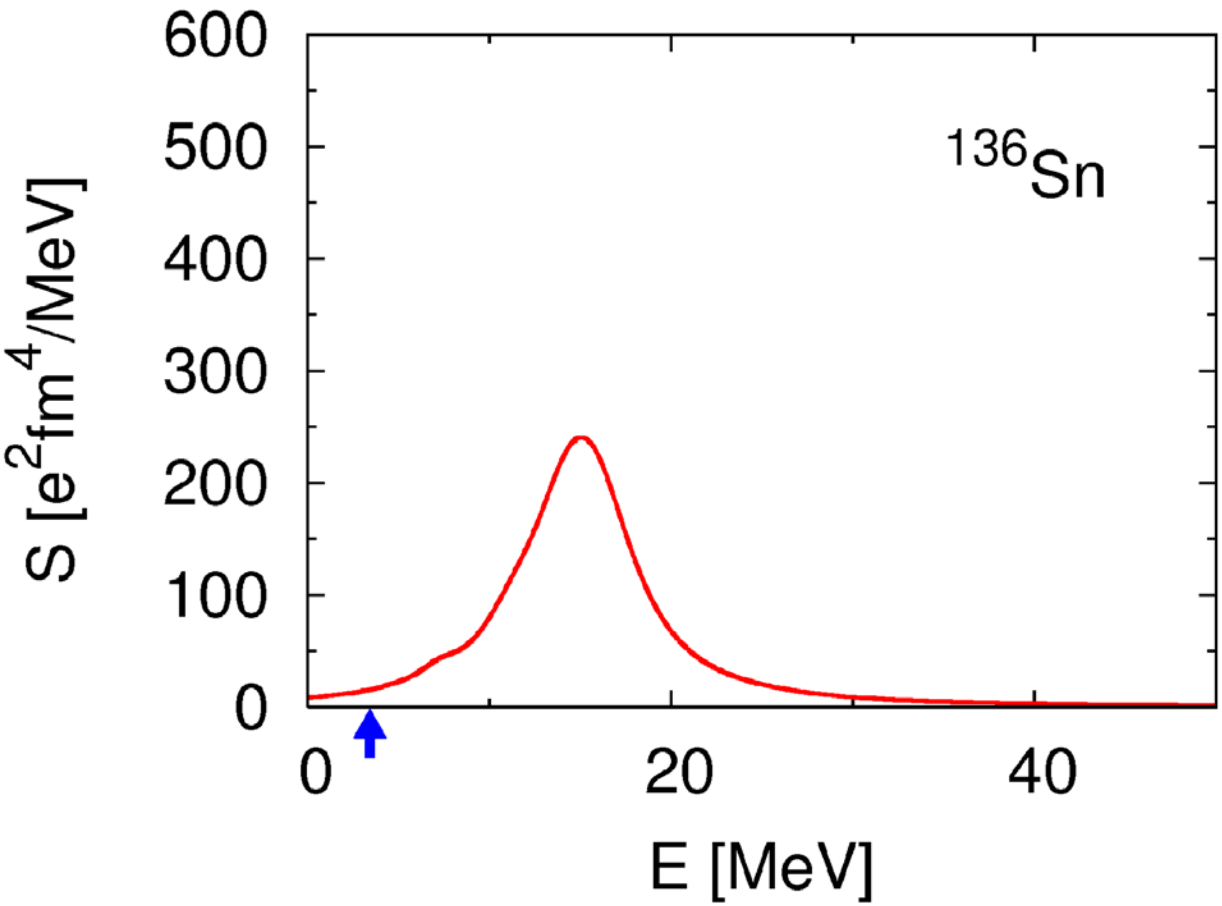

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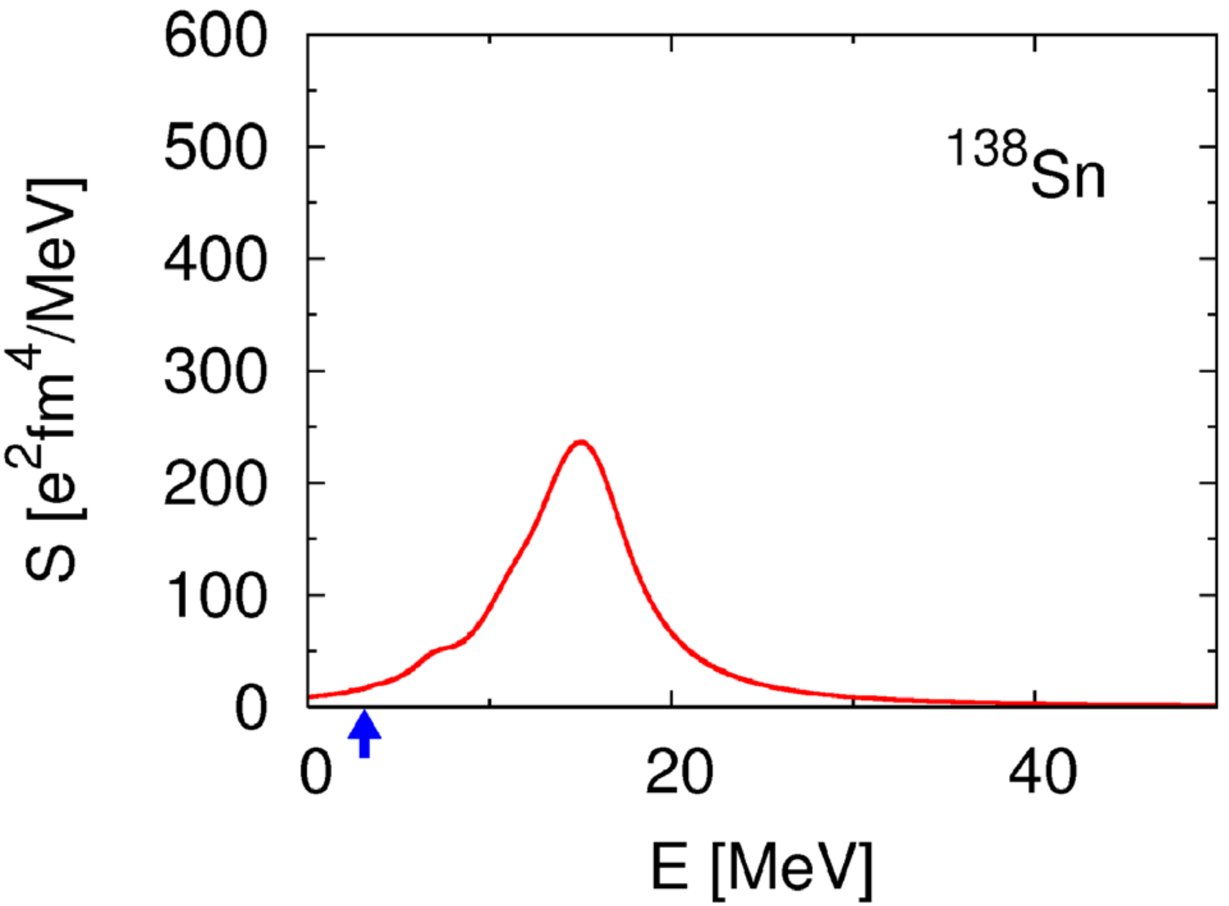

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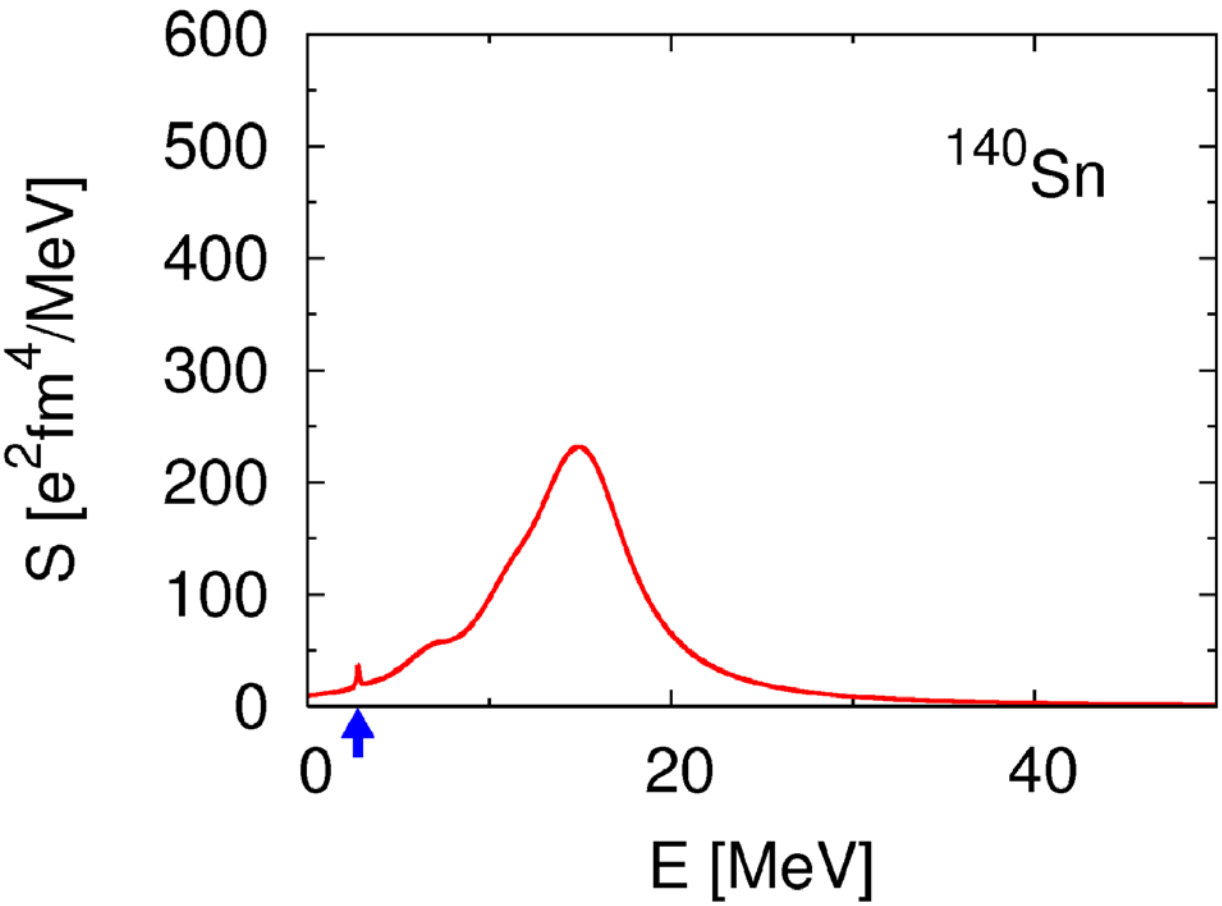

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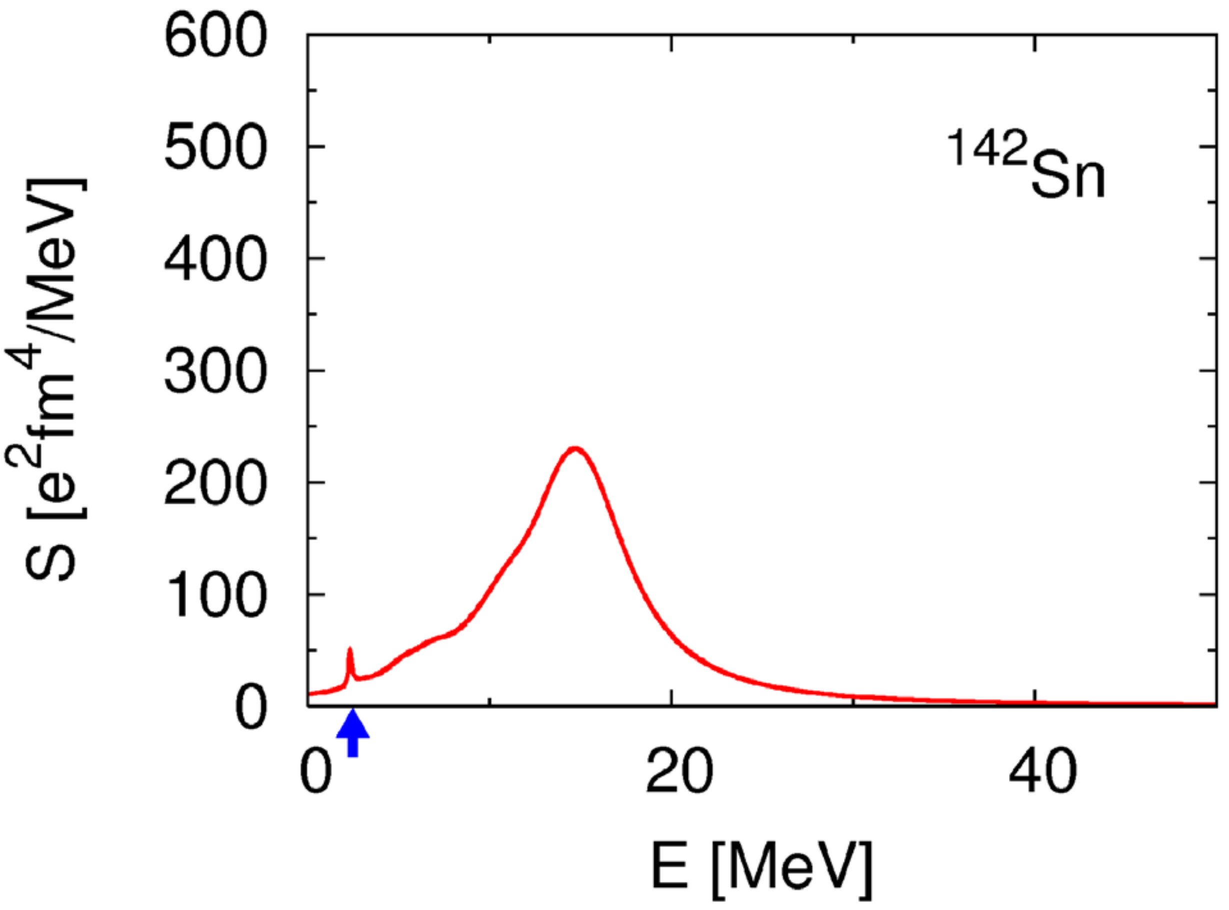

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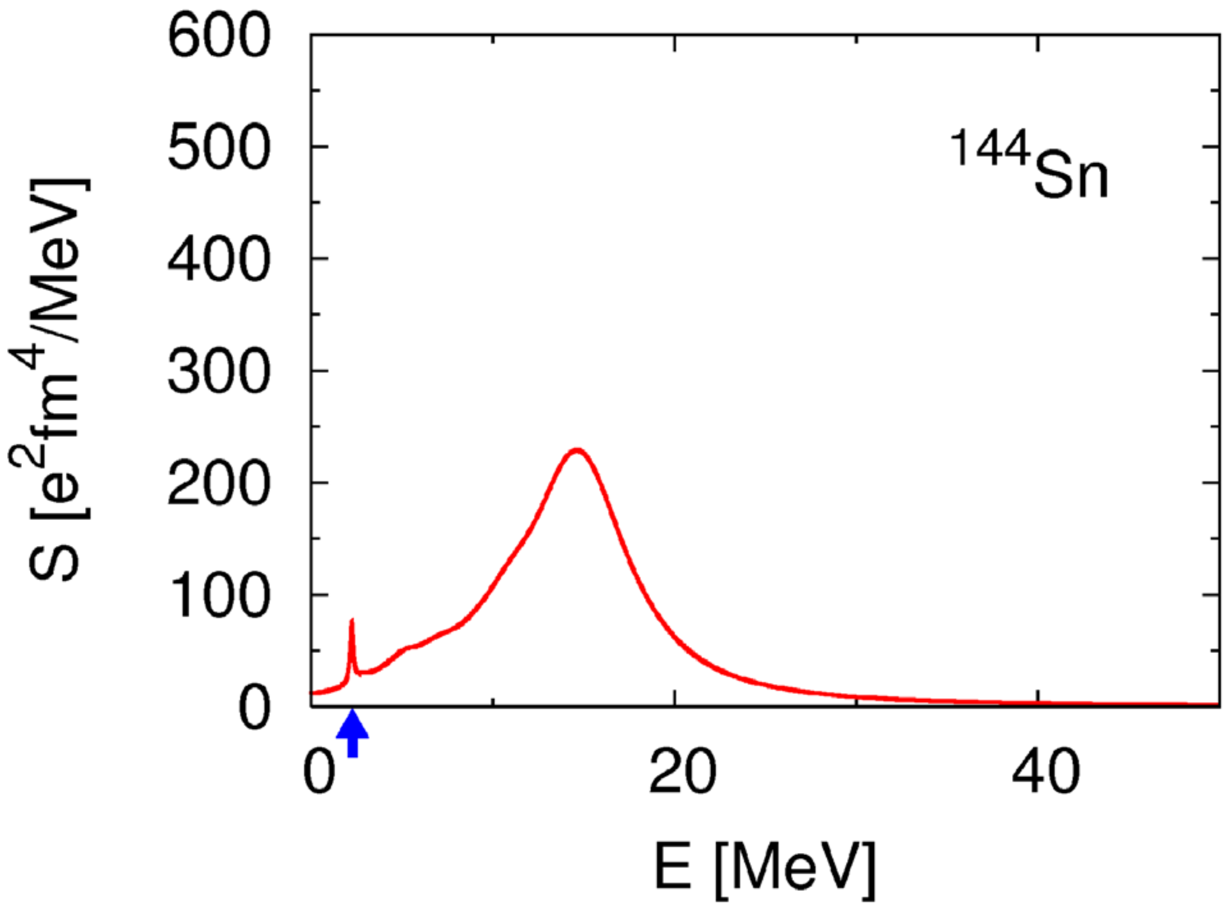
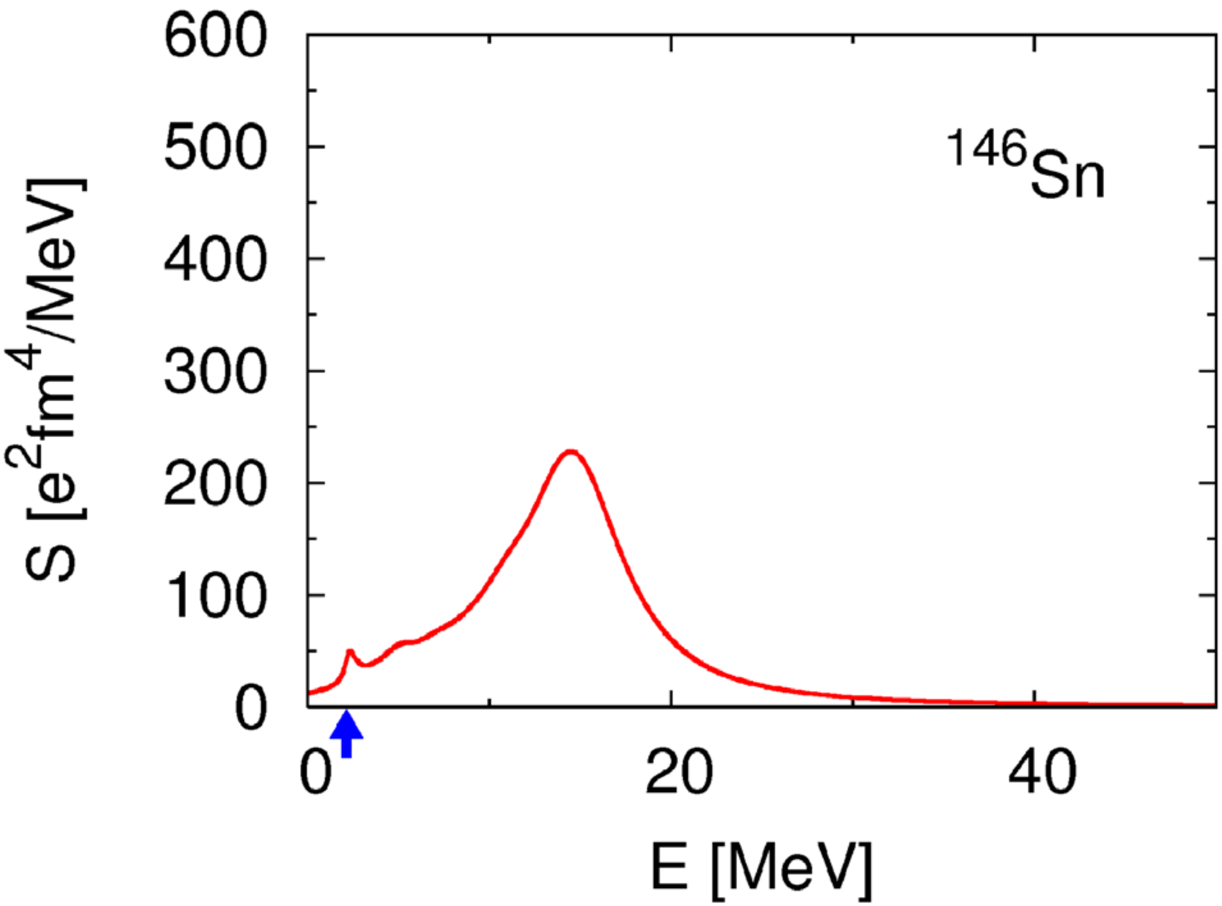


Isoscalar 0^+ strength functions



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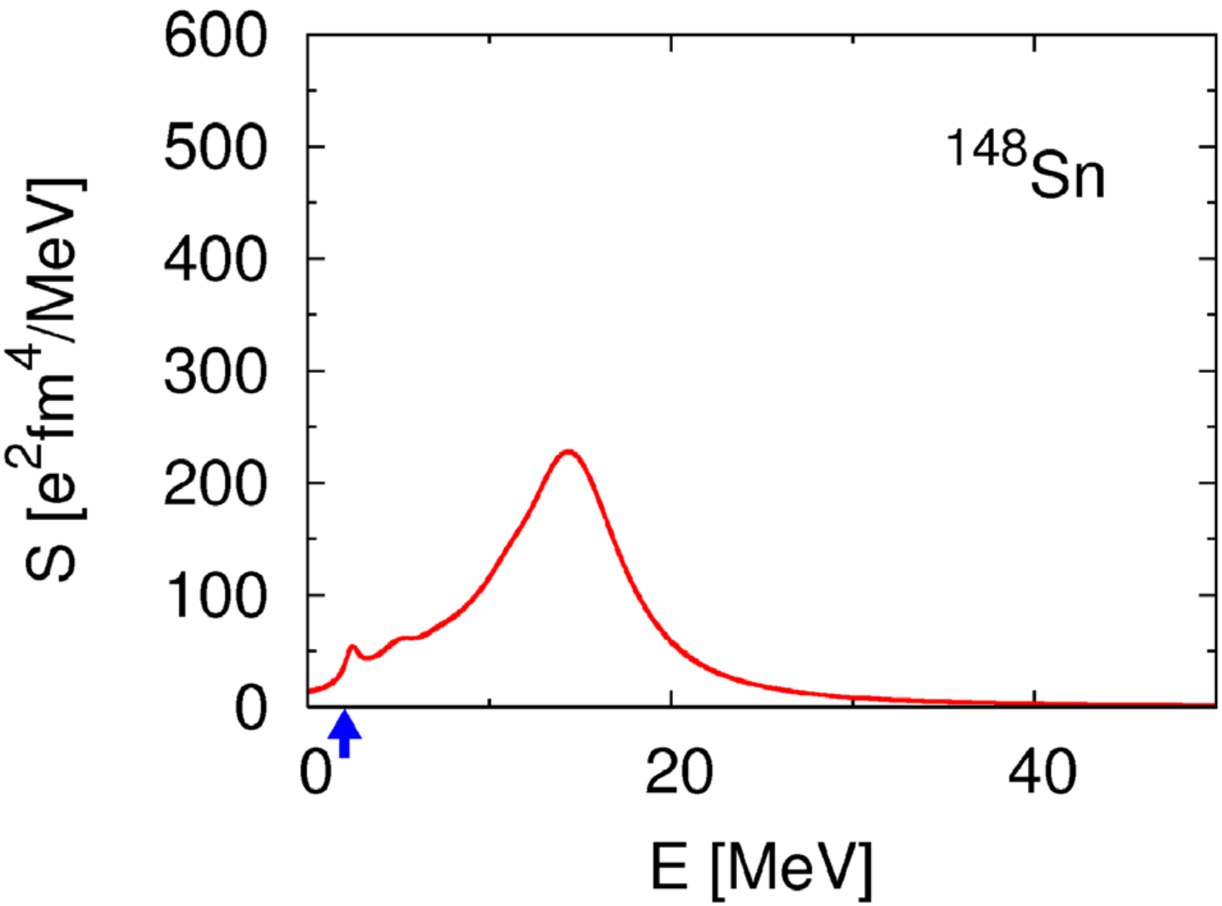
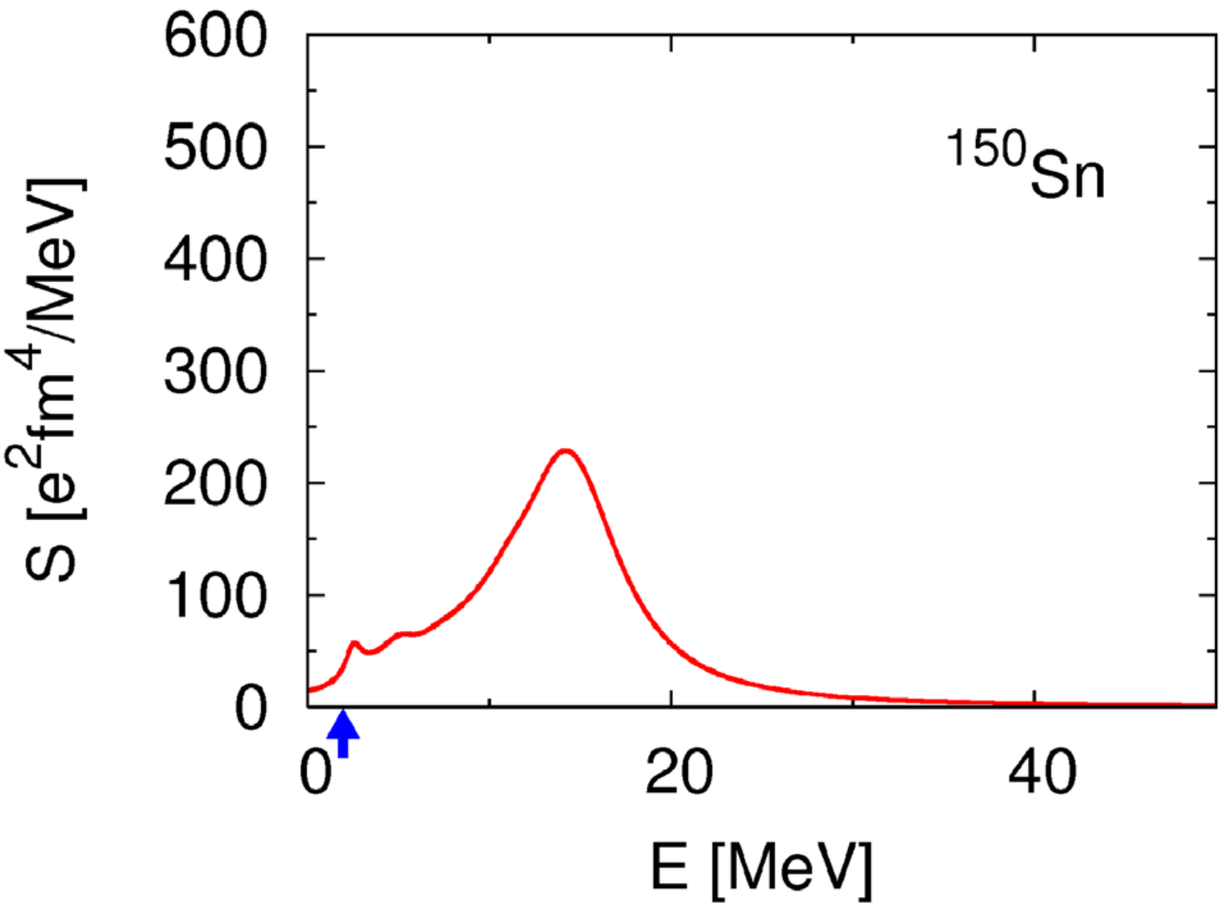
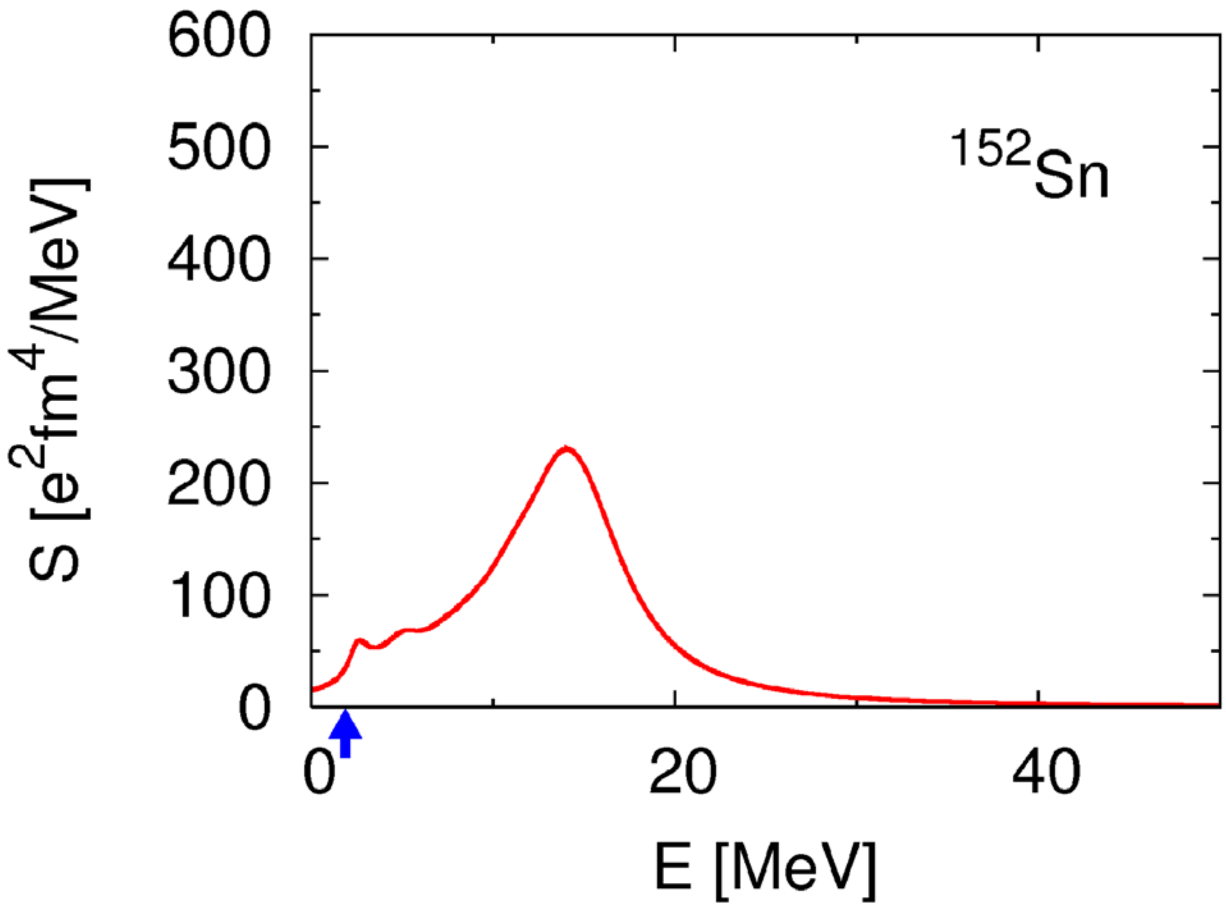


Isoscalar 0^+ strength functions

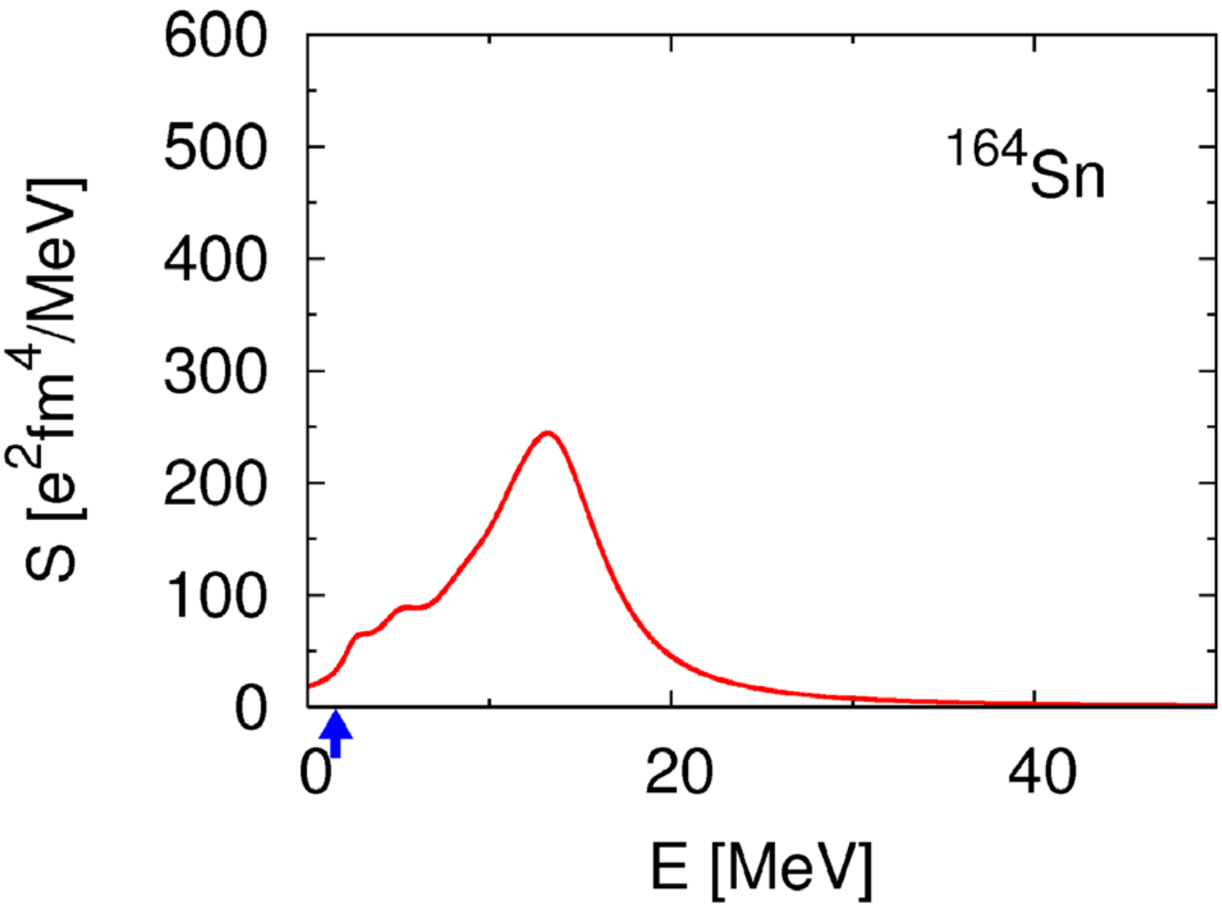


Isoscalar 0^+ strength functions

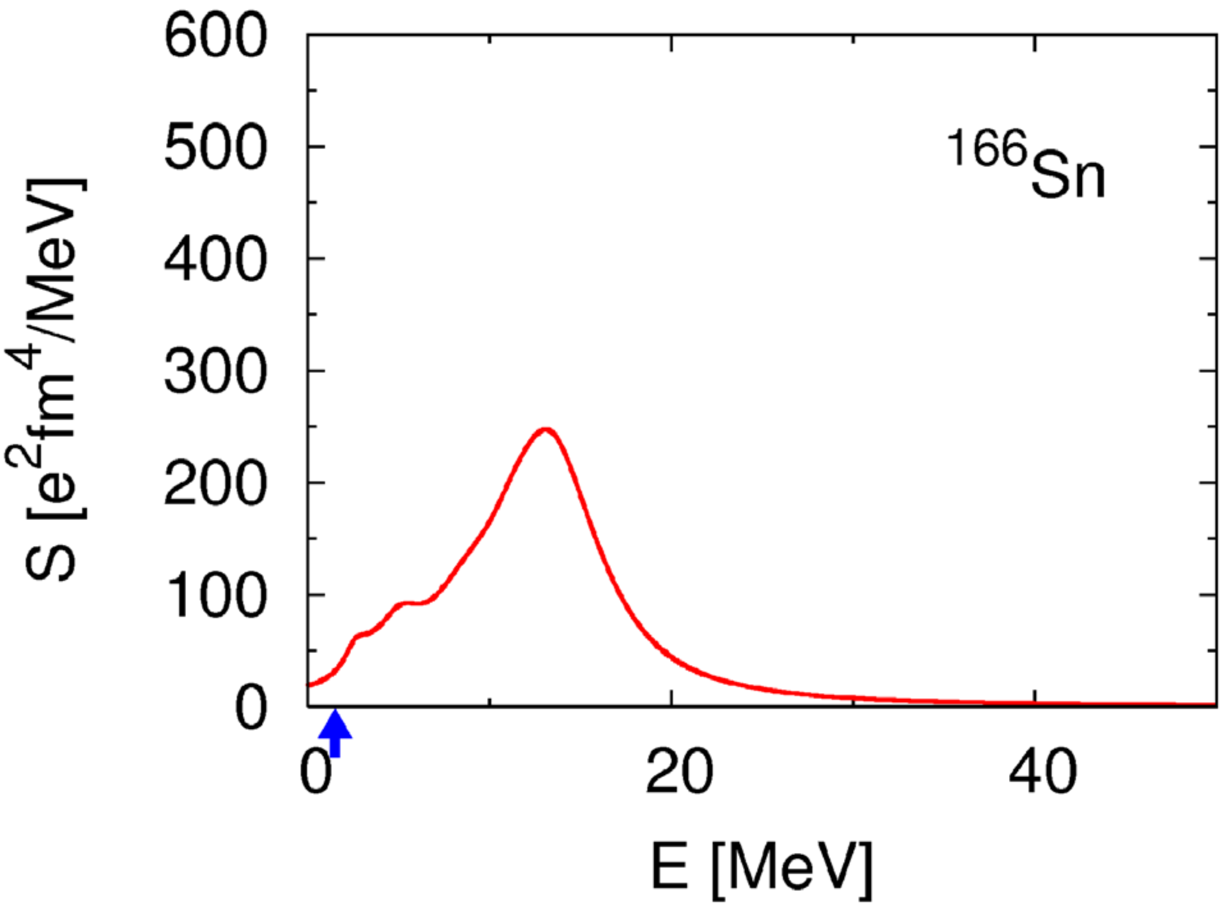


At A = 154 - 162 (N = 104 - 112)
ground states : deformed

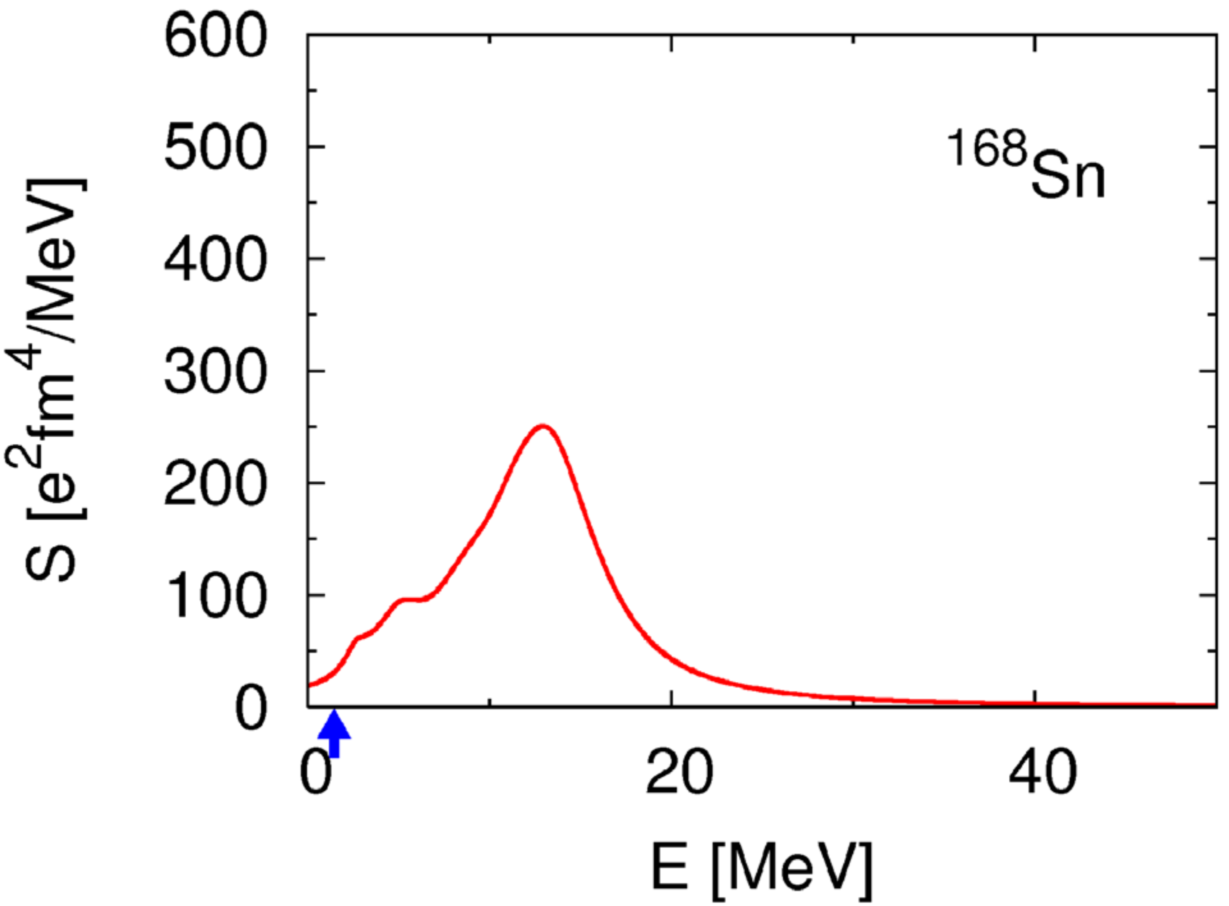
Isoscalar 0^+ strength functions



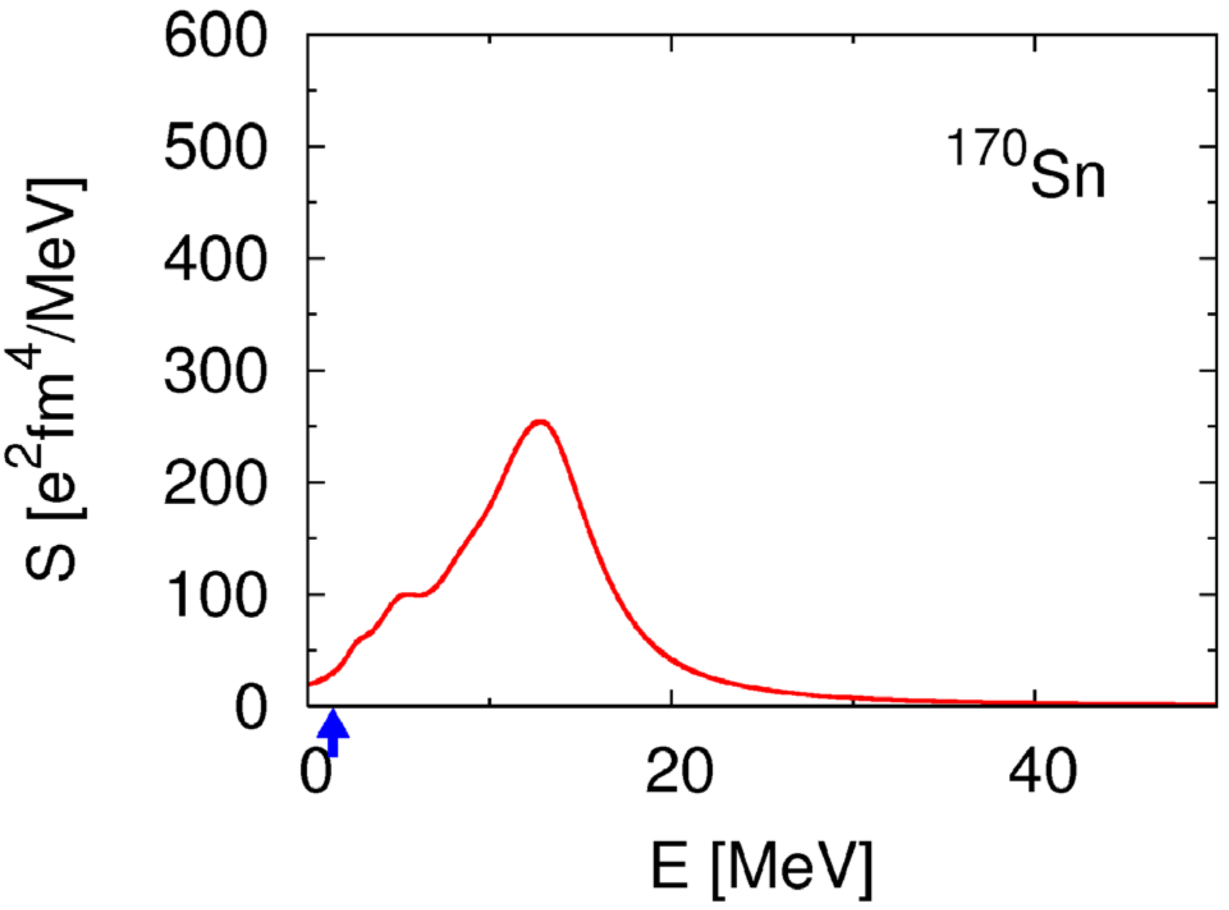
Isoscalar 0^+ strength functions



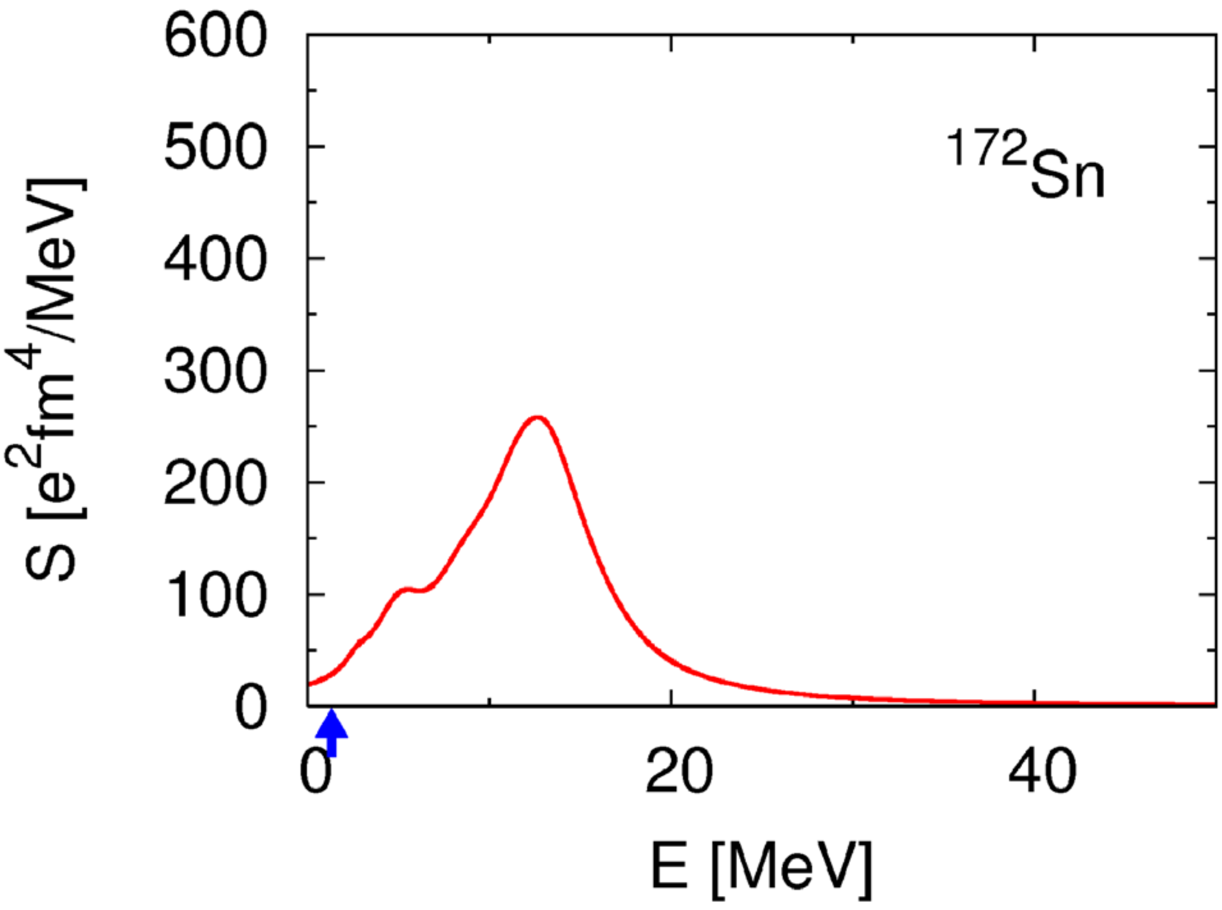
Isoscalar 0$^+$ strength functions



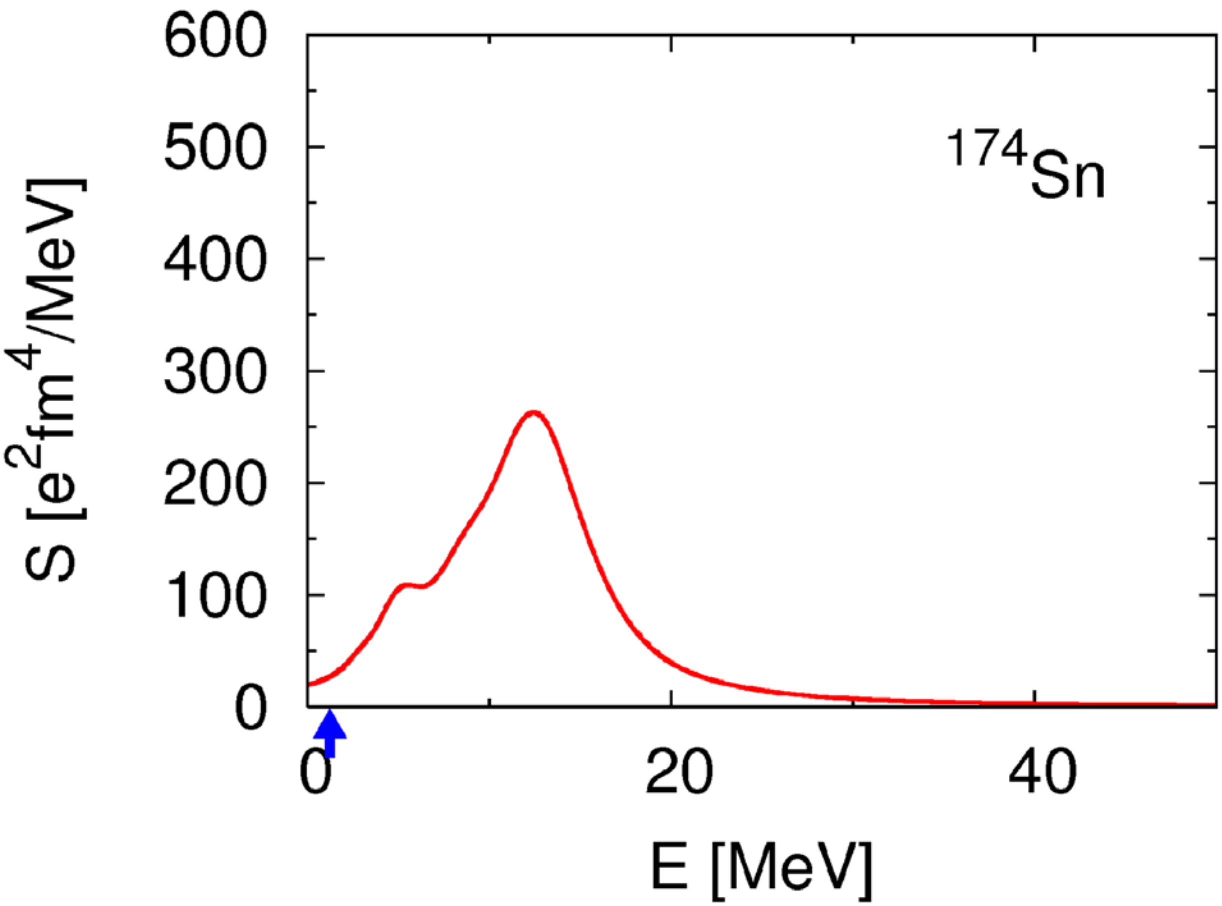
Isoscalar 0^+ strength functions



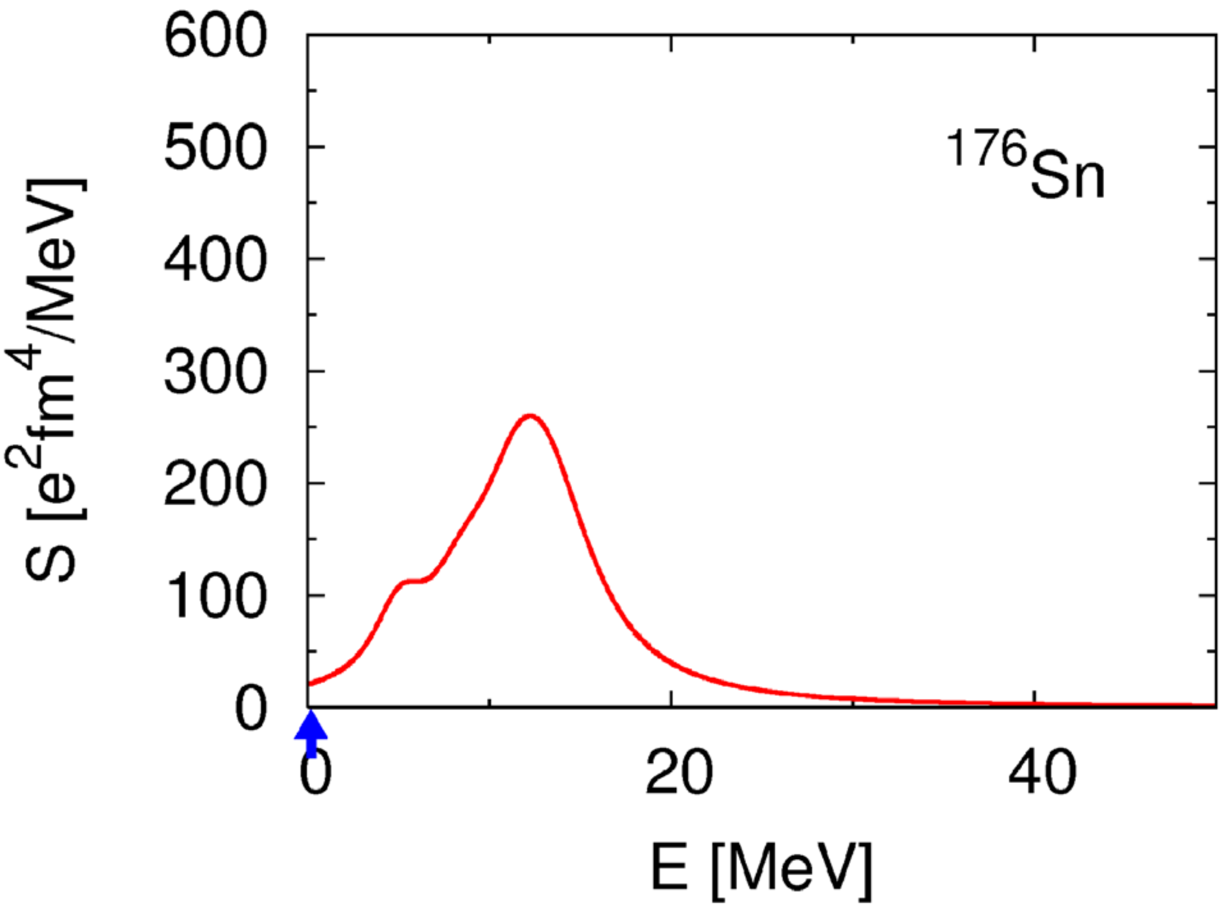
Isoscalar 0^+ strength functions



Isoscalar 0^+ strength functions



Isoscalar 0^+ strength functions

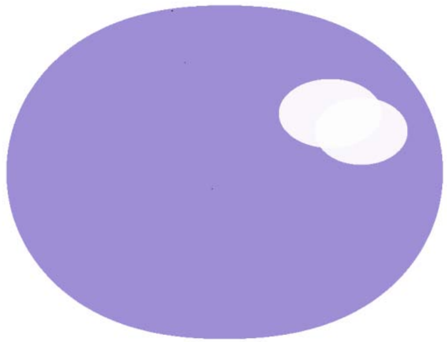


J.T. et al. Phys. Rev. C **74**, 044301 (2006)

4. Deformed nuclei

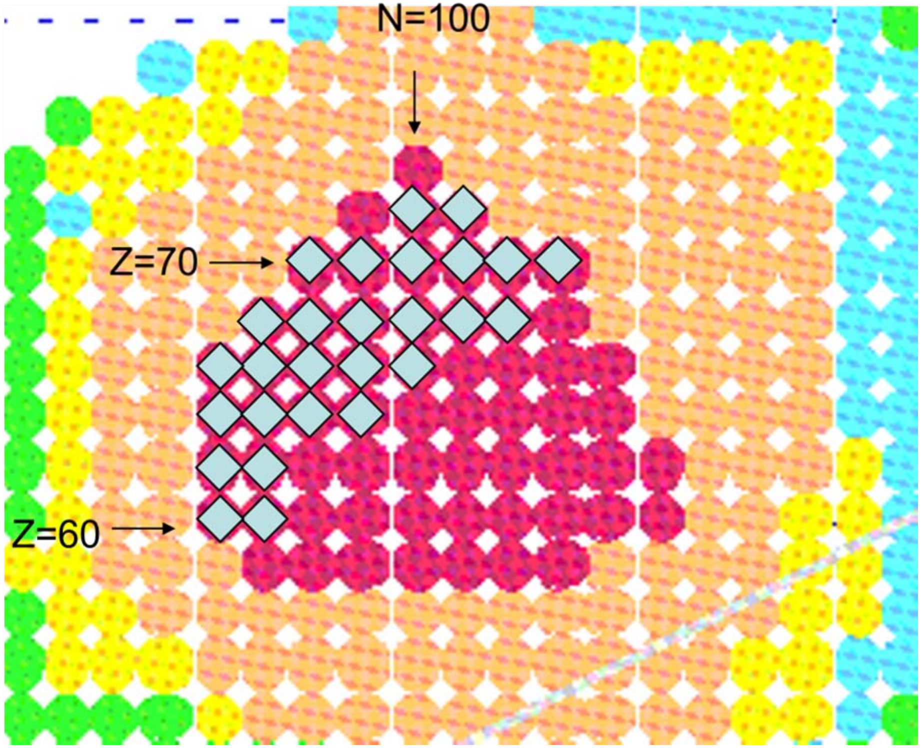
DFT breaks rotational symmetry in deformed nuclei.

Another code for deformed nuclei developed assuming axial symmetry and parity.



Quadrupole deformation $\beta = 0.3$
Well deformed

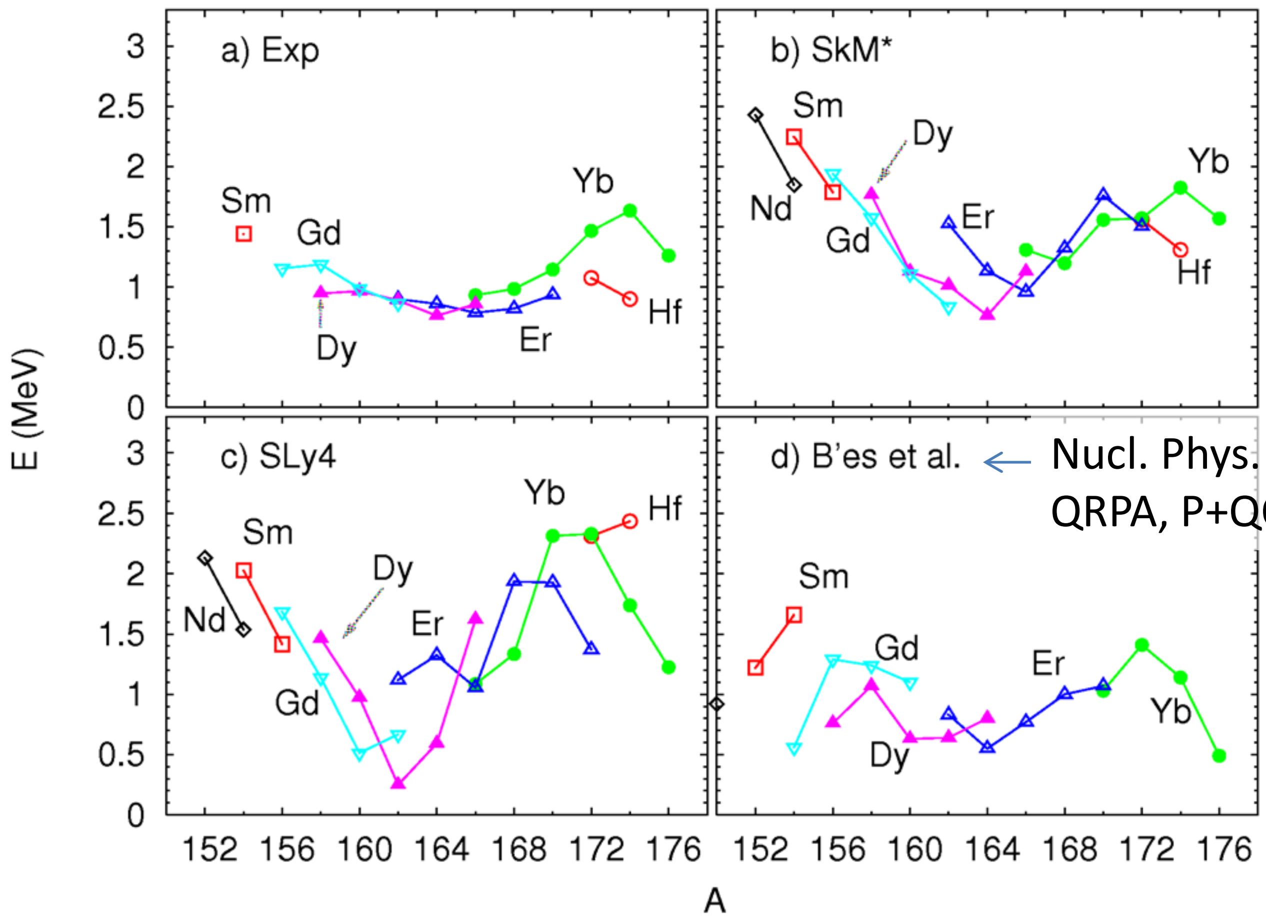
Deformed nuclei calculated



β > 0.3,
(SkM*)

Gamma-vibrational states measured

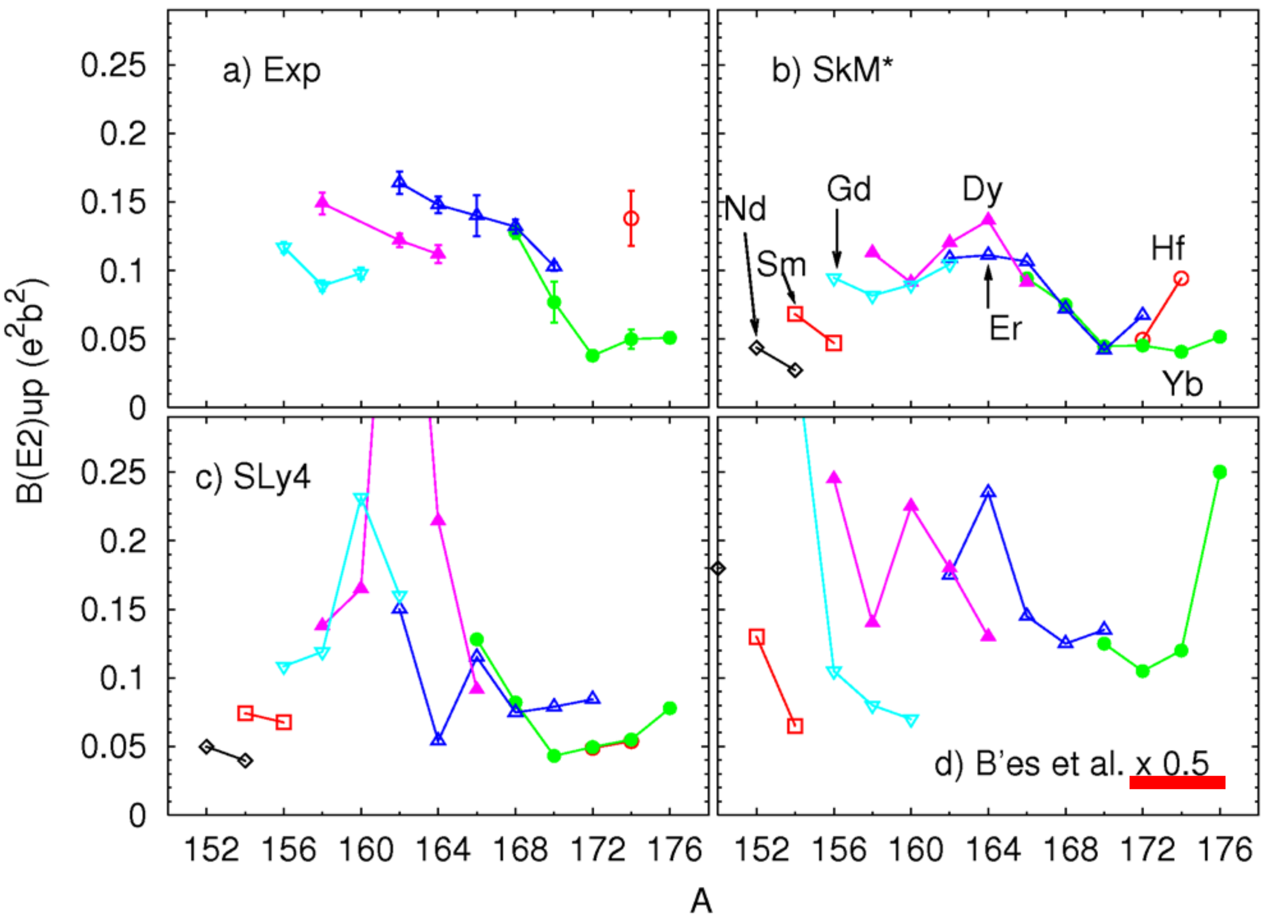
Energy of Gamma-vibrational states



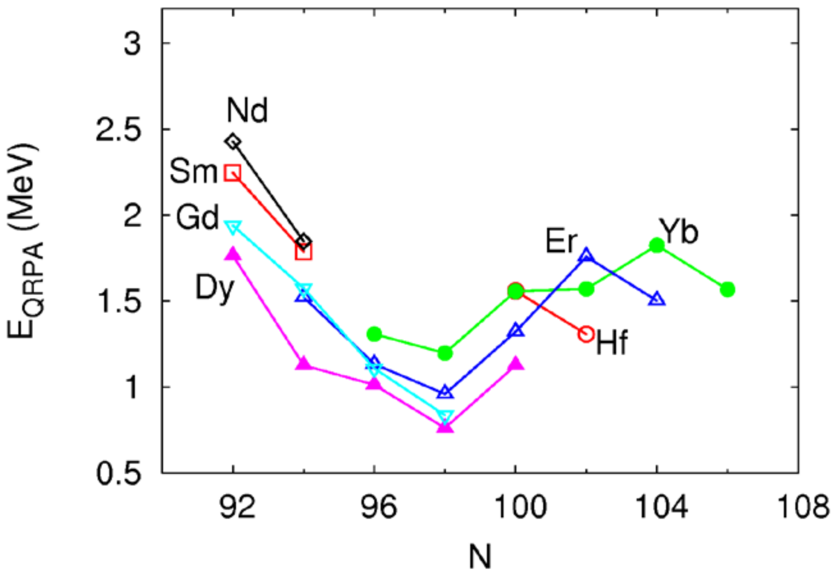
Nucl. Phys. **65**, 1(1965)
QRPA, P+QQ

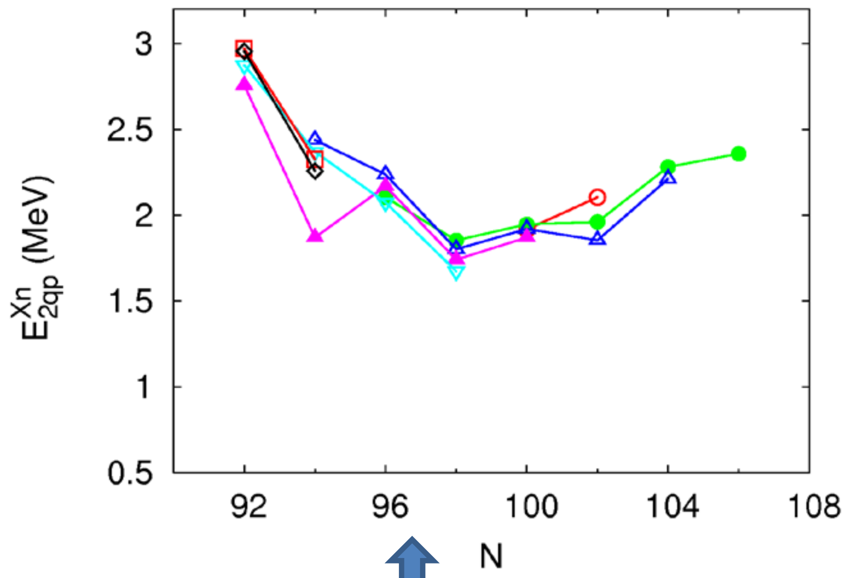
J. T. and J. Engel, Phys. Rev. C **84**, 014332 (2011)

B(E2)↑ of Gamma-vibrational states



N-dependence of the gamma-vib. states (SkM)*

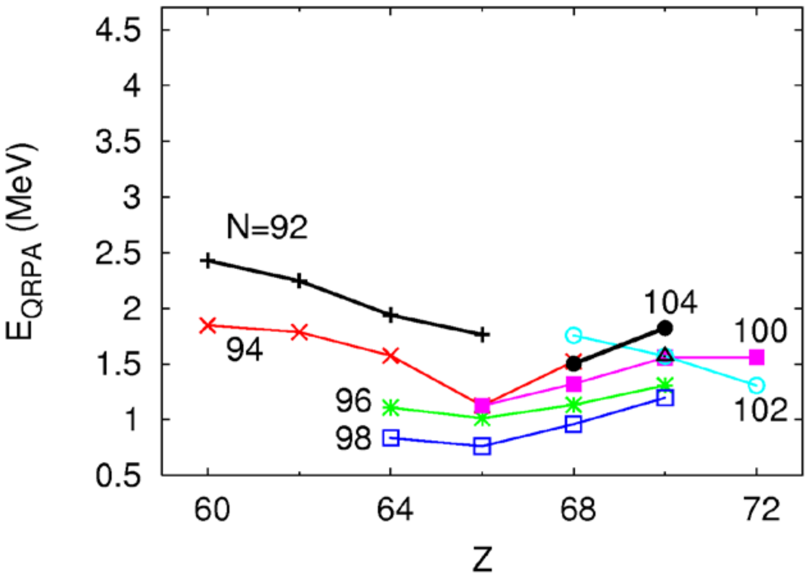


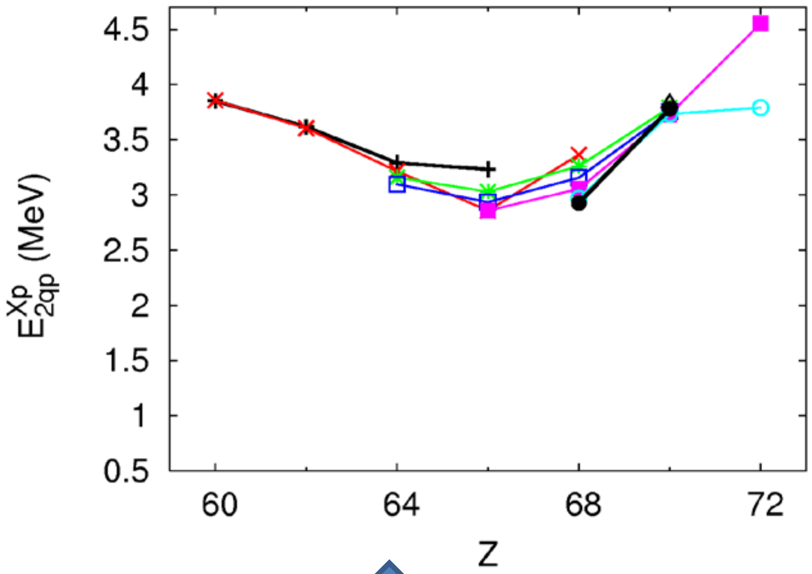


Two-quasiparticle energy of the comp. having the largest forward amp. of neutrons

Neutron unperturbed energy

Z-dependence of the gamma-vib. states (SkM)*





Two-quasiparticle energy of the comp. having the largest forward amp. of **protons**

Proton unperturbed energy

Correlation is seen in
N- and Z- dependences of E_{QRPA} and E_{2qp}

The N and Z-dependences of the calculated γ-vibrational states are dominated by the two-quasiparticle states

The experimental data show the weaker N- and Z- dependences than the calculation

⇩

The reality has more configuration mixing than QRPA.

5. Summary

1. It is coming possible to calculate not only ground but also excited states of a much larger number of nuclear species than before thanks to powerful parallel computers.

   The remarkable enhancement of the transition strength is found in the low-energy region of nuclei near the neutron drip line in a variety of isotopic chains and J^{π}.

2. Calculated results of γ -vibrational states have been compared with the exp. data systematically. They are not bad, but more many-body correlations are seen in the data.