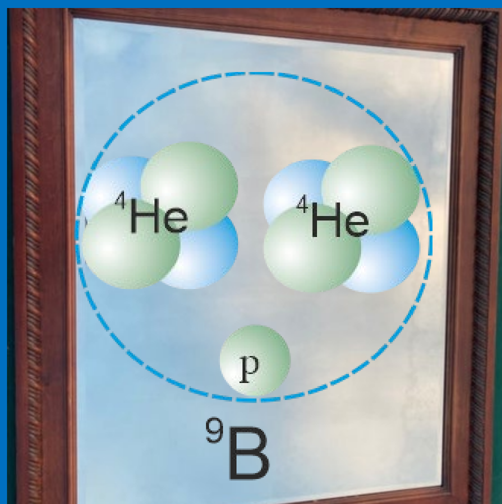
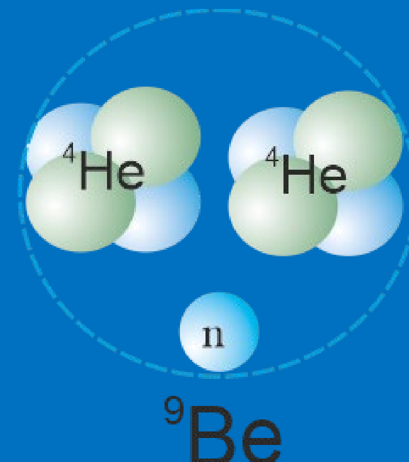
Many-channel cluster microscopic theory of resonance states and scattering in ^{9}Be and ^{9}B





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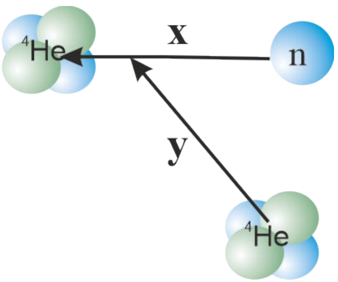
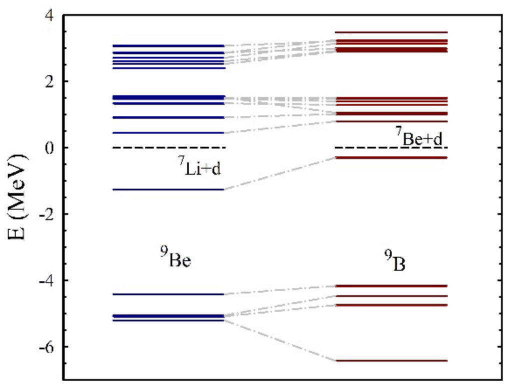
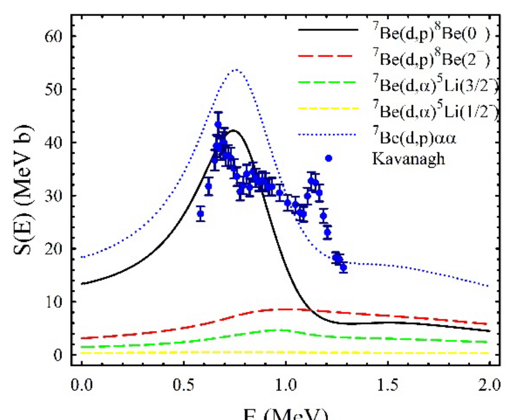
We studied the nature of high-energy resonance states in ^{9}Be & ^{9}B and S-factors of reactions ^{7}Li(d, n)αα & ^{7}Be(d, p)αα



1. Three-cluster model

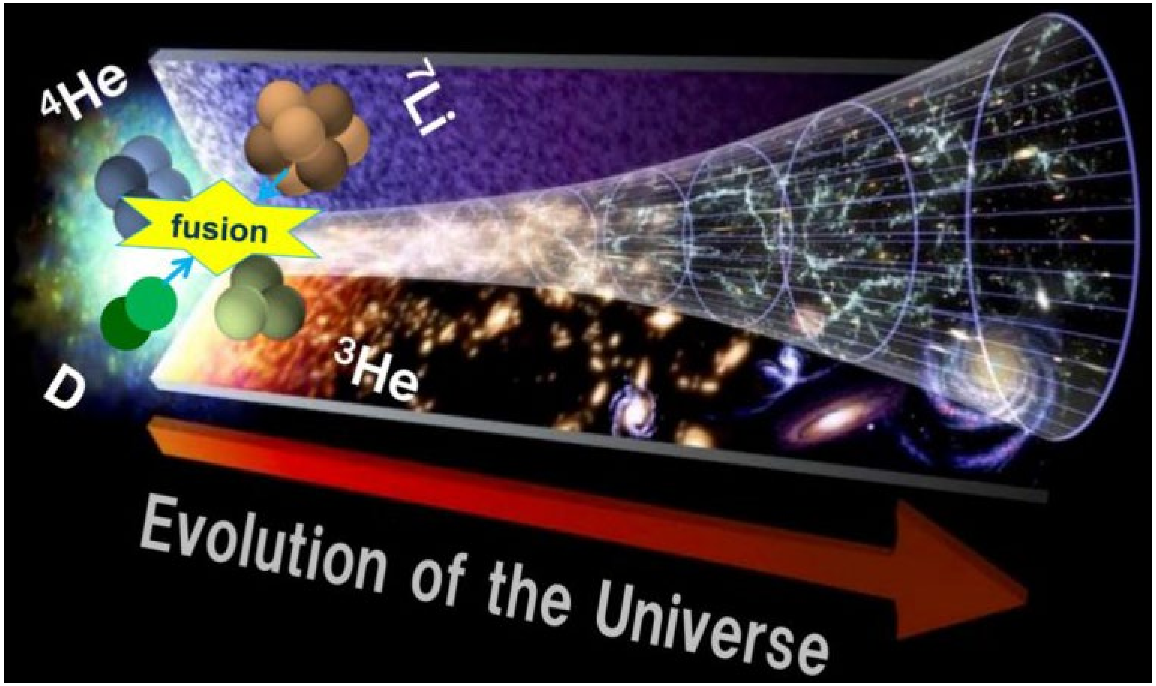


2. Spectra of ^{9}Be, ^{9}B



3. Astrophysical S-factors of ^{7}Li (^{7}Be)+d=α+α+n (p)

To find astrophysical S-factors for the reactions $^{7}Li+d=\alpha+\alpha+n$, $^{7}Be+d=\alpha+\alpha+p$ related to cosmological lithium problem

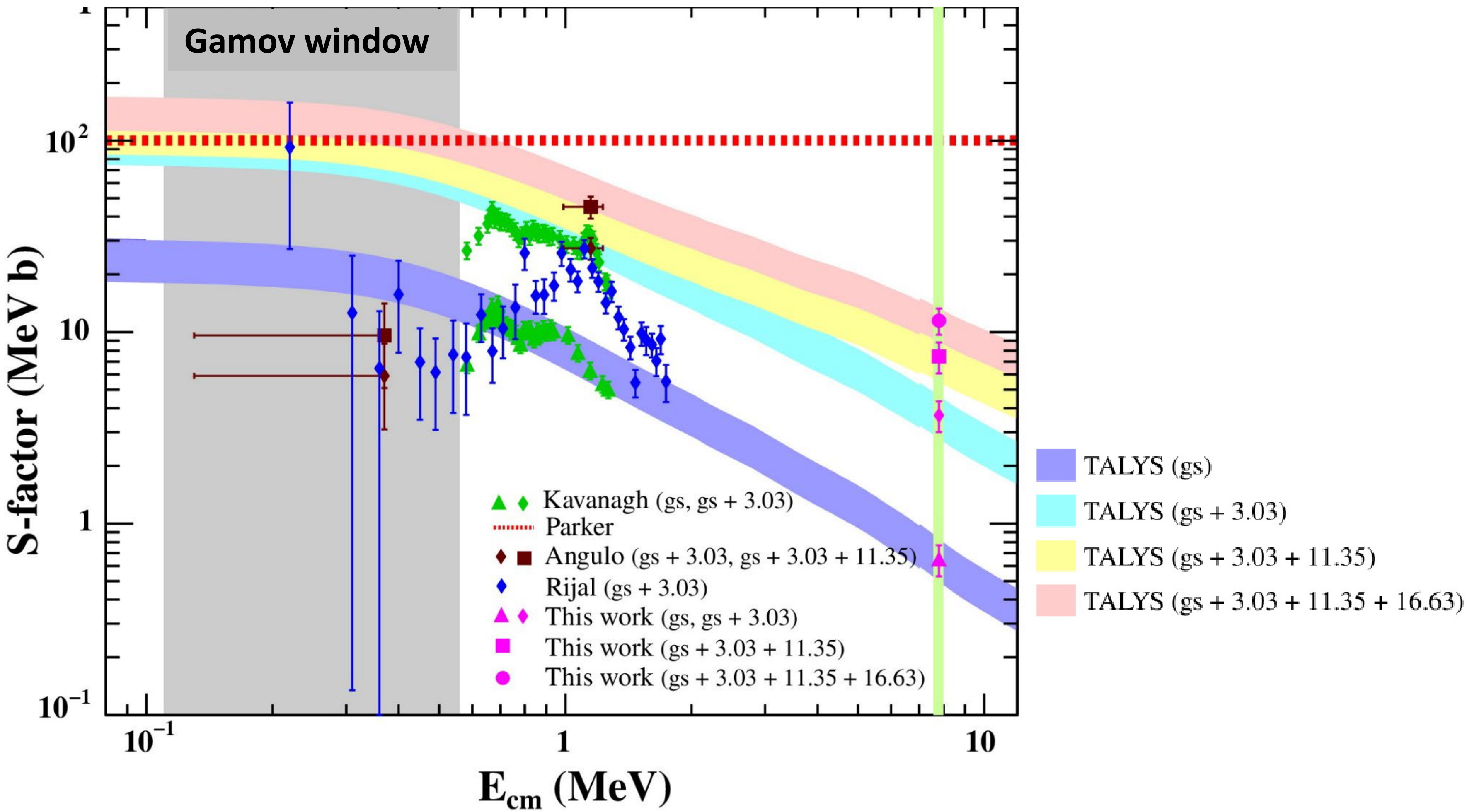


Resonances in ^{9}Be, ^{9}B

Where is 2/3 of ^{7}Li?

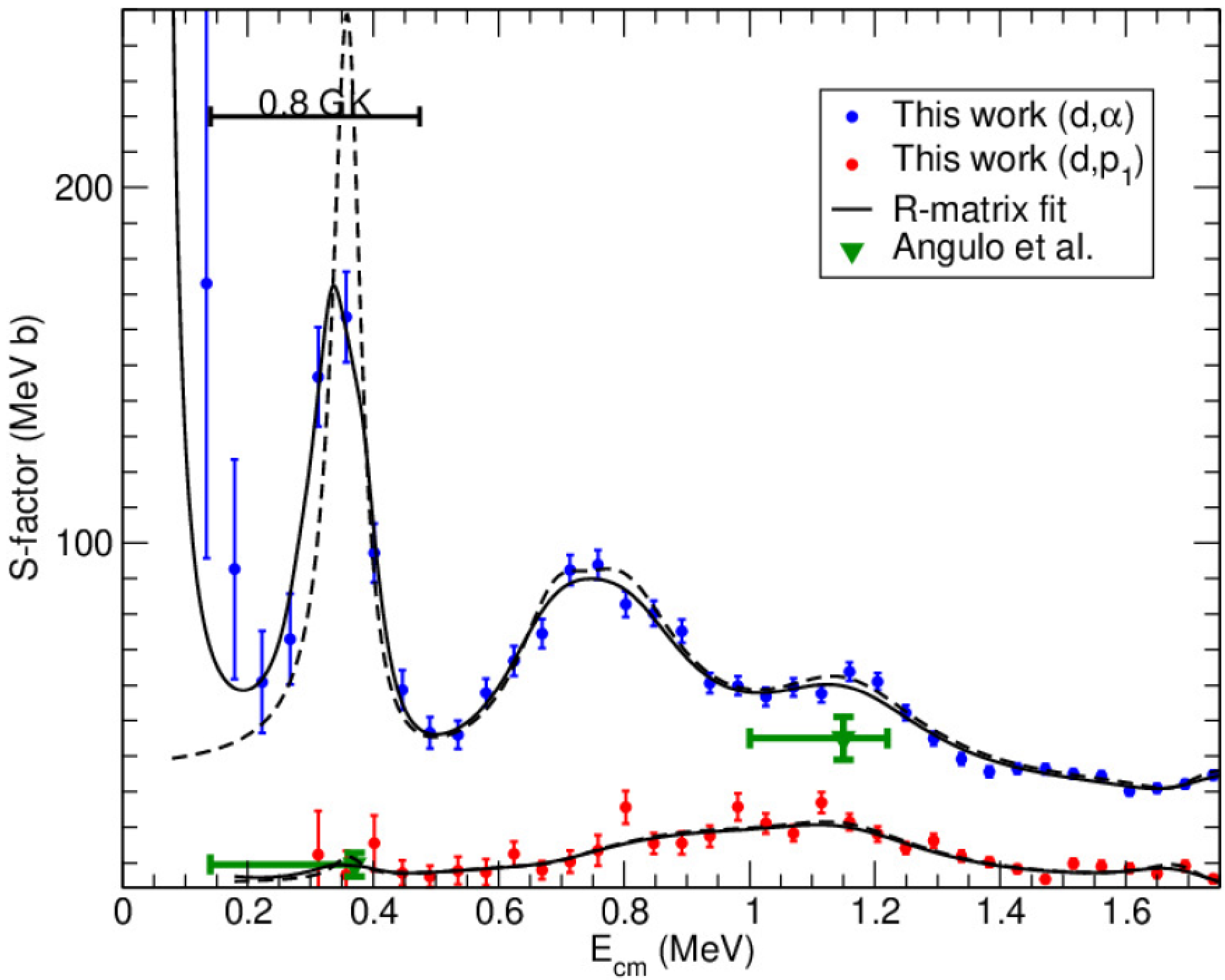
Primordial ^{7}Li abundance is 3 times overpredicted compared to the observed value

Experimental astrophysical S-factor of the reaction $^{7}Be(d, p)^{8}Be$



Sk. M. Ali et al, "Resonance Excitations in $^{7}Be(d; p)^{8}Be$ to Address the Cosmological Lithium Problem", Phys. Rev. Lett, Vol. 128, № 25, 252701, 2022

Experimental astrophysical S-factor of reactions $^7Be(d, p)\,^8Be$ and $^7Be(d, \alpha)\,^5Li$ shows a resonant behaviour



N. Rijal et al., "Measurement of d+^{7}Be reaction rates for Big-Bang nucleosynthesis", Phys. Rev. Lett., vol. 122, p. 182701, 2019.

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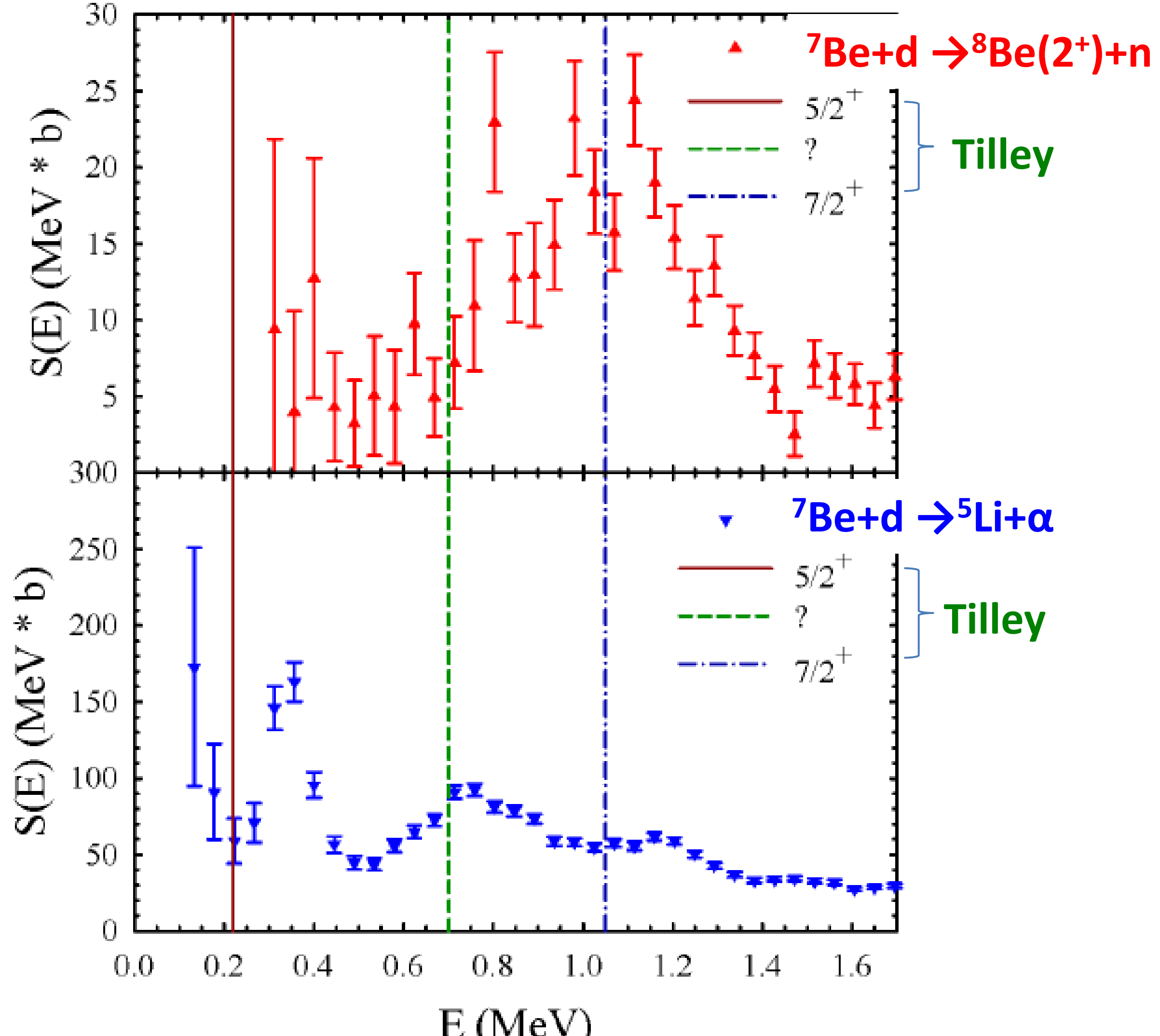
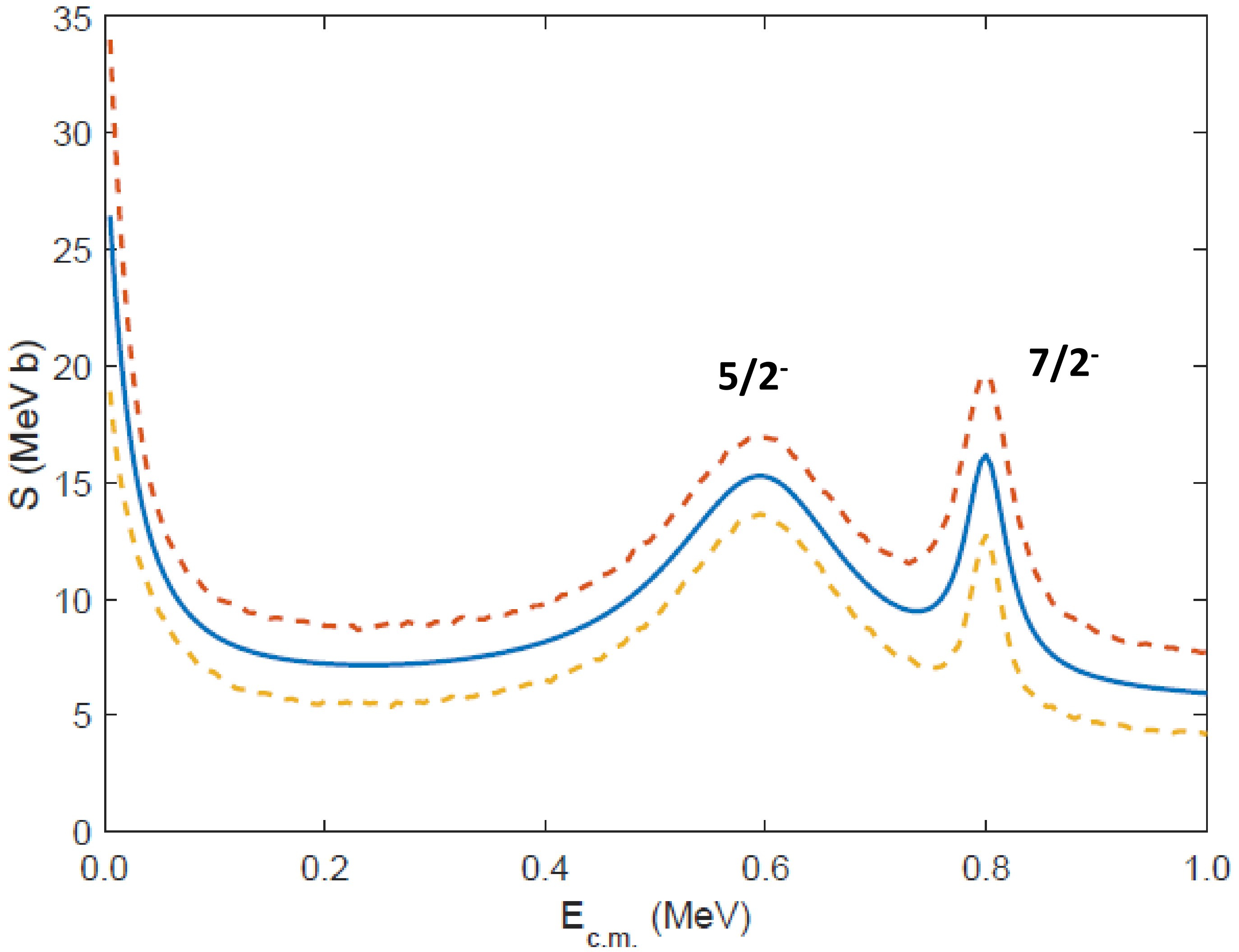


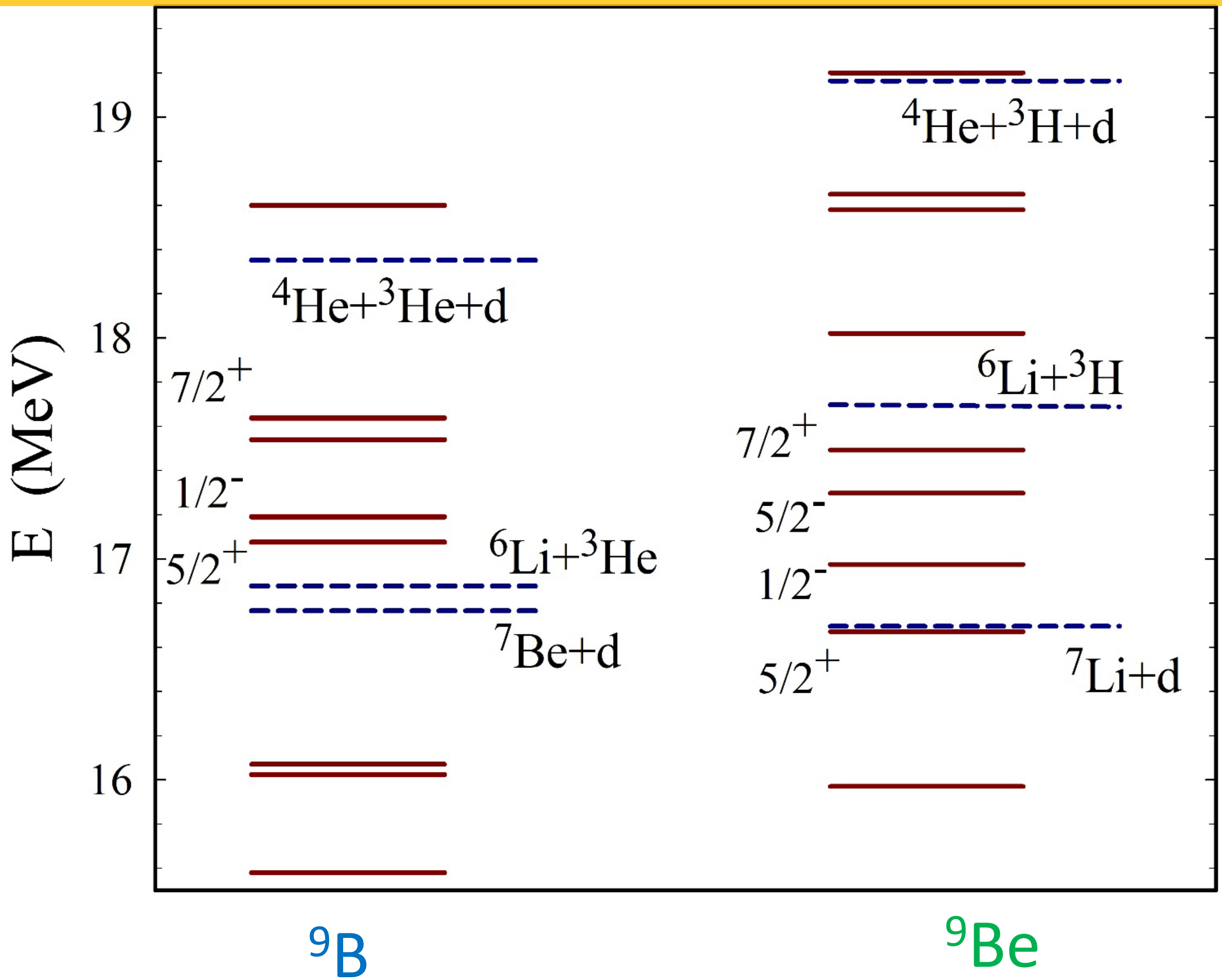
N. Rijal et al., "Measurement of d+^{7}Be reaction rates for Big-Bang nucleosynthesis", Phys. Rev. Lett., vol. 122, p. 182701, 2019.

Experimental astrophysical S-factor of reactions $^7Li(d, p)2\alpha$



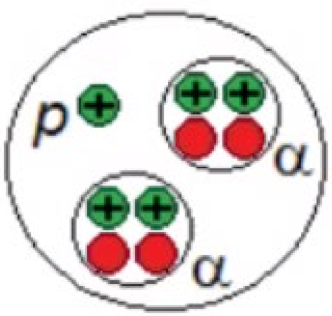
S. Q. Hou, T. Kajino, et al, Astrophys. J., vol. 920, 145, 2021.

Experimental data for energy levels of ^9Be and ^9B near ^7Li+d and ^7Be+d thresholds



We account for 2 three-cluster configurations of ^{9}B nucleus which generate different binary reaction channels

$$^{9}\mathrm{B} = \begin{cases} \alpha + \alpha + p \\ \alpha + {}^{3}\mathrm{He} + d \end{cases} \Rightarrow \begin{cases} {}^{8}\mathrm{Be} + p \\ {}^{7}\mathrm{Be} + d \\ {}^{6}\mathrm{Li} + {}^{3}\mathrm{He} \\ {}^{5}\mathrm{Li} + {}^{4}\mathrm{He} \end{cases}$$

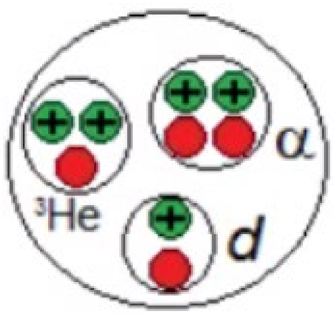


$$^{8}\mathrm{Be} = \alpha + \alpha$$

$$^{7}\mathrm{Be} = \alpha + {}^{3}\mathrm{He}$$

$$^{6}\mathrm{Li} = \alpha + d$$

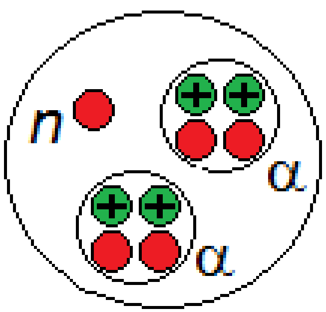
$$^{5}\mathrm{Li} = \alpha + p$$



Description of binary cluster structure of the subsystems

We account for 2 three-cluster configurations of ^{9}Be nucleus which generate different binary reaction channels

$$^{9}\text{Be} = \begin{cases} \alpha + \alpha + n \\ \alpha + {}^{3}\text{H} + d \end{cases} \Rightarrow \begin{cases} {}^{8}\text{Be} + n \\ {}^{7}\text{Li} + d \\ {}^{6}\text{Li} + {}^{3}\text{H} \\ {}^{5}\text{He} + {}^{4}\text{He} \end{cases}$$

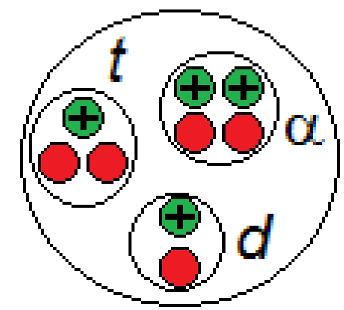


$$^{8}\text{Be} = \alpha + \alpha$$

$$^{7}\text{Li} = \alpha + {}^{3}\text{H}$$

$$^{6}\text{Li} = \alpha + d$$

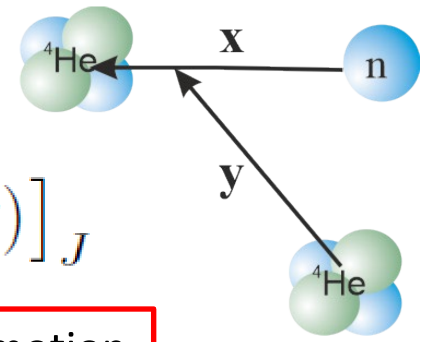
$$^{5}\text{He} = \alpha + n$$



Description of binary cluster structure of the subsystems

Asymptotically the three-cluster Schrödinger equation can be reduced to a two-body-like multichannel problem

Three-cluster wave function



$$\Psi^{J}\left({}^{9}Be\right) = \widehat{\mathcal{A}}\left[\Phi_{1}(n)\,\Phi_{2}\left({}^{4}He\right)\Phi_{3}\left({}^{4}He\right) f(\mathbf{x},\mathbf{y})\right]_{J}$$

Antisymmetrization operator

Intrinsic cluster w.f. (fixed)

W.f. of inter-cluster motion (to be found)

Wave function of a two-cluster system

$$\Psi^{J}_{{}^{5}He} = \widehat{\mathcal{A}}\left\{\Phi_{2}\left({}^{4}He\right)\left[\Phi_{1}(n)\right]_{S}\left[g(\mathbf{x})\right]_{\lambda}\right\}_{J}$$

W.f. of two-cluster subsystem

Two-body-like asymptotic behaviour at x<<y

$$f(x,y) \Rightarrow g(x)\left[\delta_{c,c'}\cdot\psi^{(-)}(py) - S_{c,c'}\cdot\psi^{(+)}(py)\right]$$

Scattering matrix

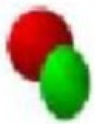
Input parameters

Assumption: internal cluster functions are approximated by the simplest translation-invariant shell model functions

NN potential: the Minnesota potential

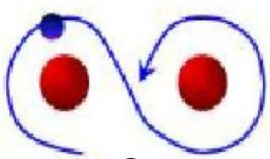
Free parameters: the oscillator length **b=1.285 fm**
the Majorana parameter **u=0.95**
parameters b_ν of Gaussian functions

Our input parameters are fitted to:



^{7}Li

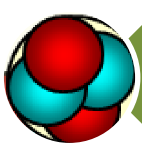
give experimental binding energy of ^{6,7}Li and ^{7}Be



^{9}Be

reproduce the energies of $3/2^{-}$ ground states in

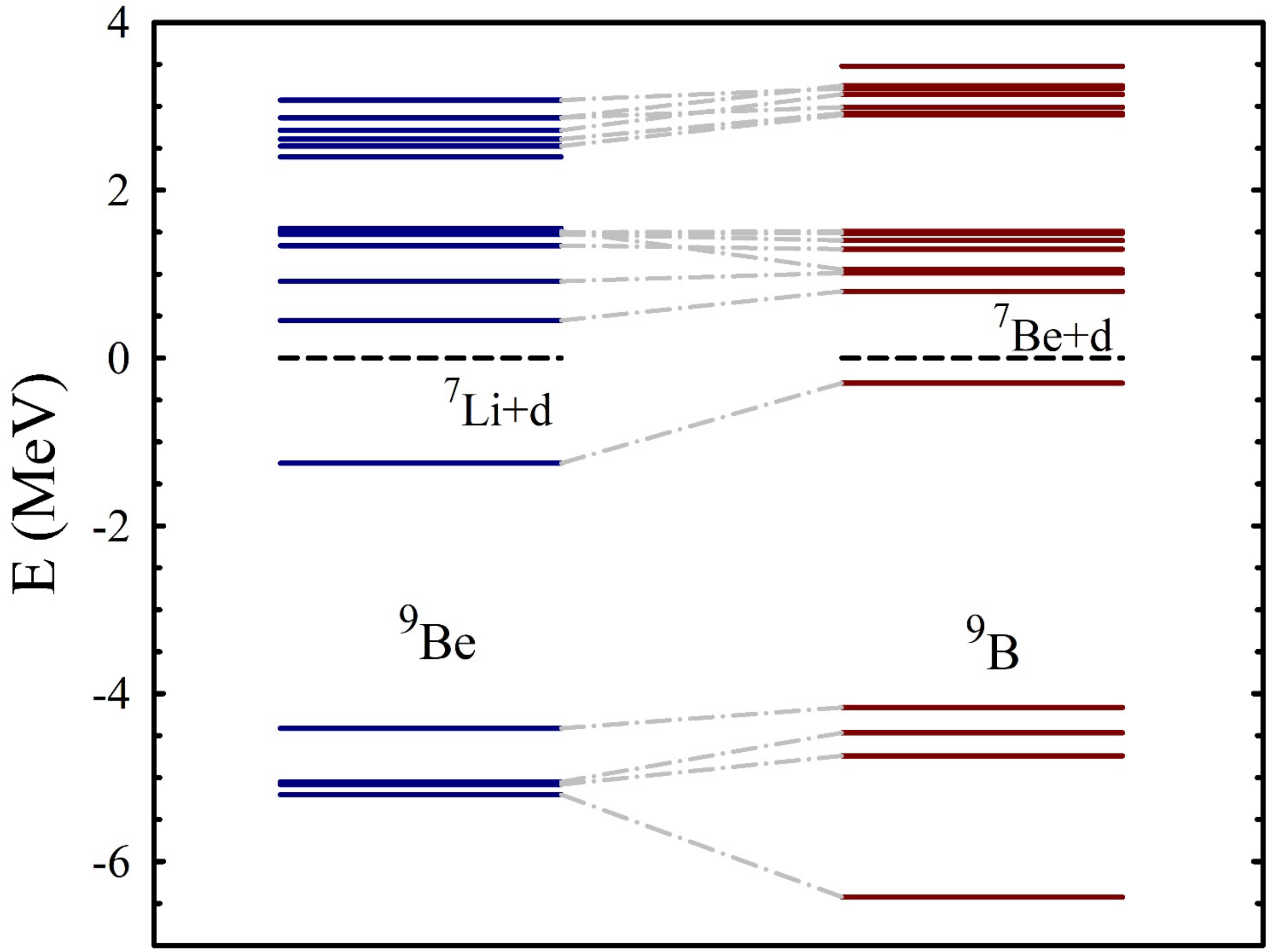
^{9}B = 2α+p and **^{9}Be=2α+n**



α

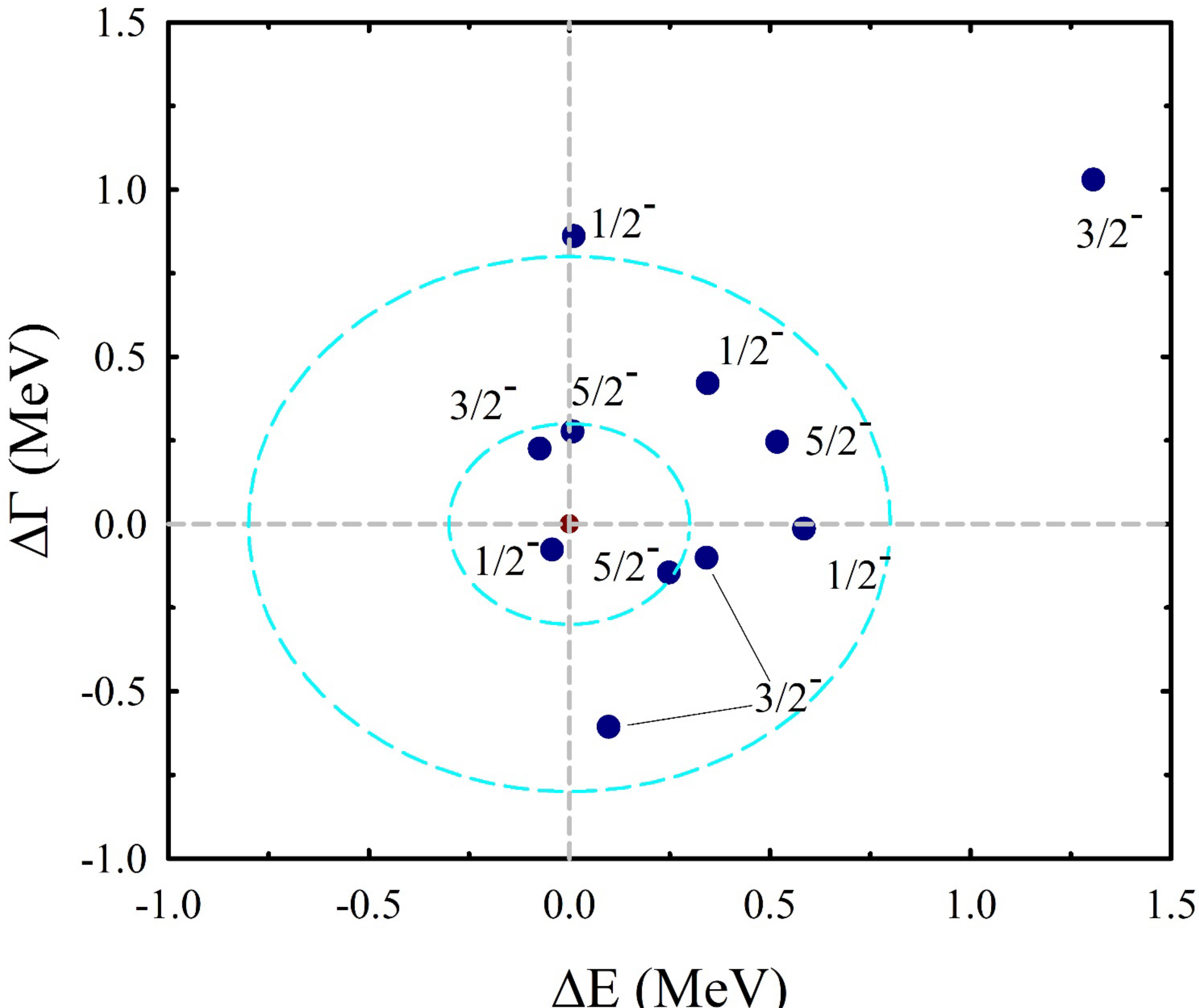
minimize the ground state energy of ^{4}He

A total of 18 resonance states were detected in each nucleus, majority of which has a negative parity



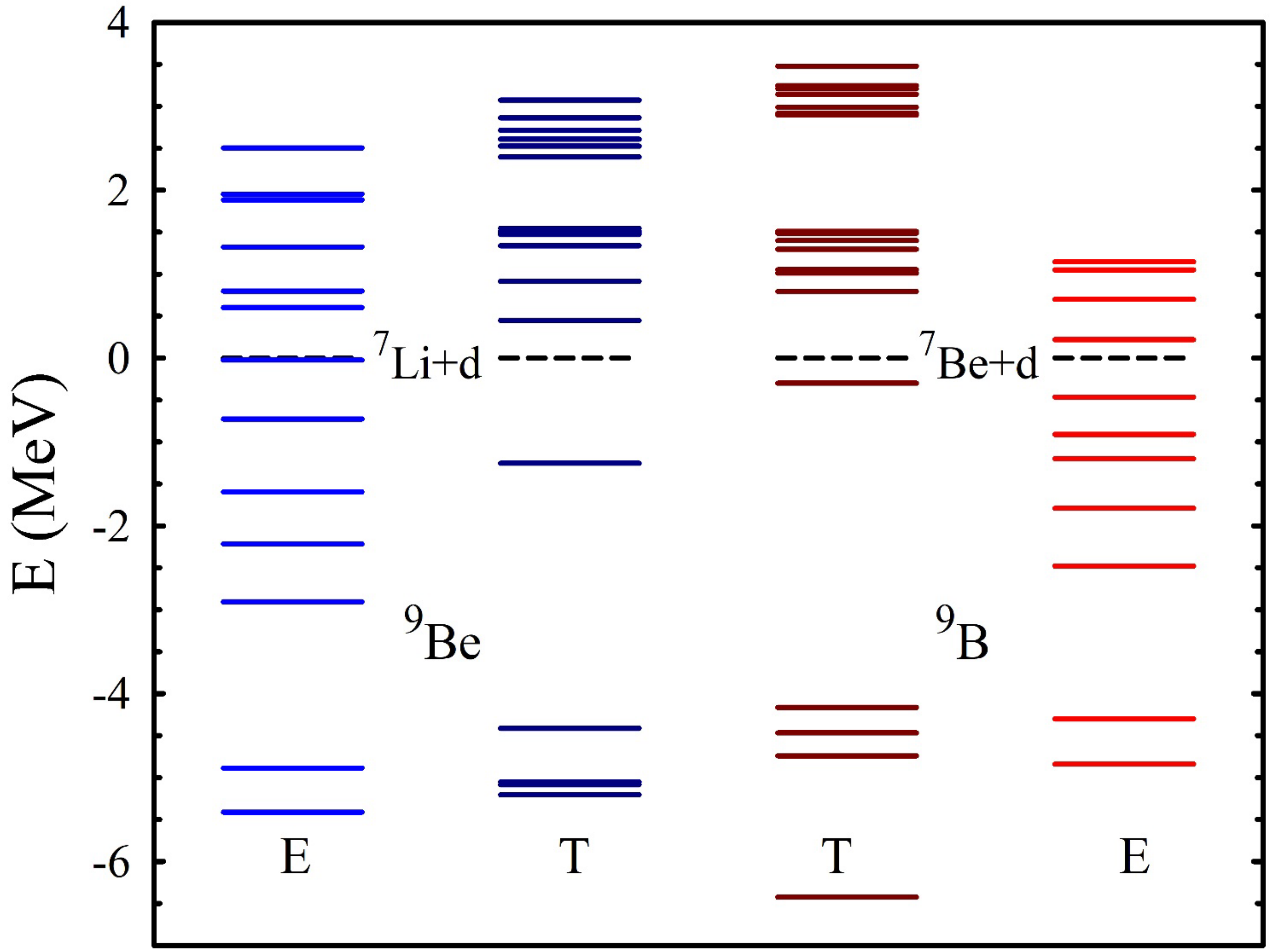
Spectra of resonance states in ^{9}Be and ^{9}B obtained within the present model

Two dashed circles mark borders between regions of small, intermediate and large effects of the Coulomb interaction



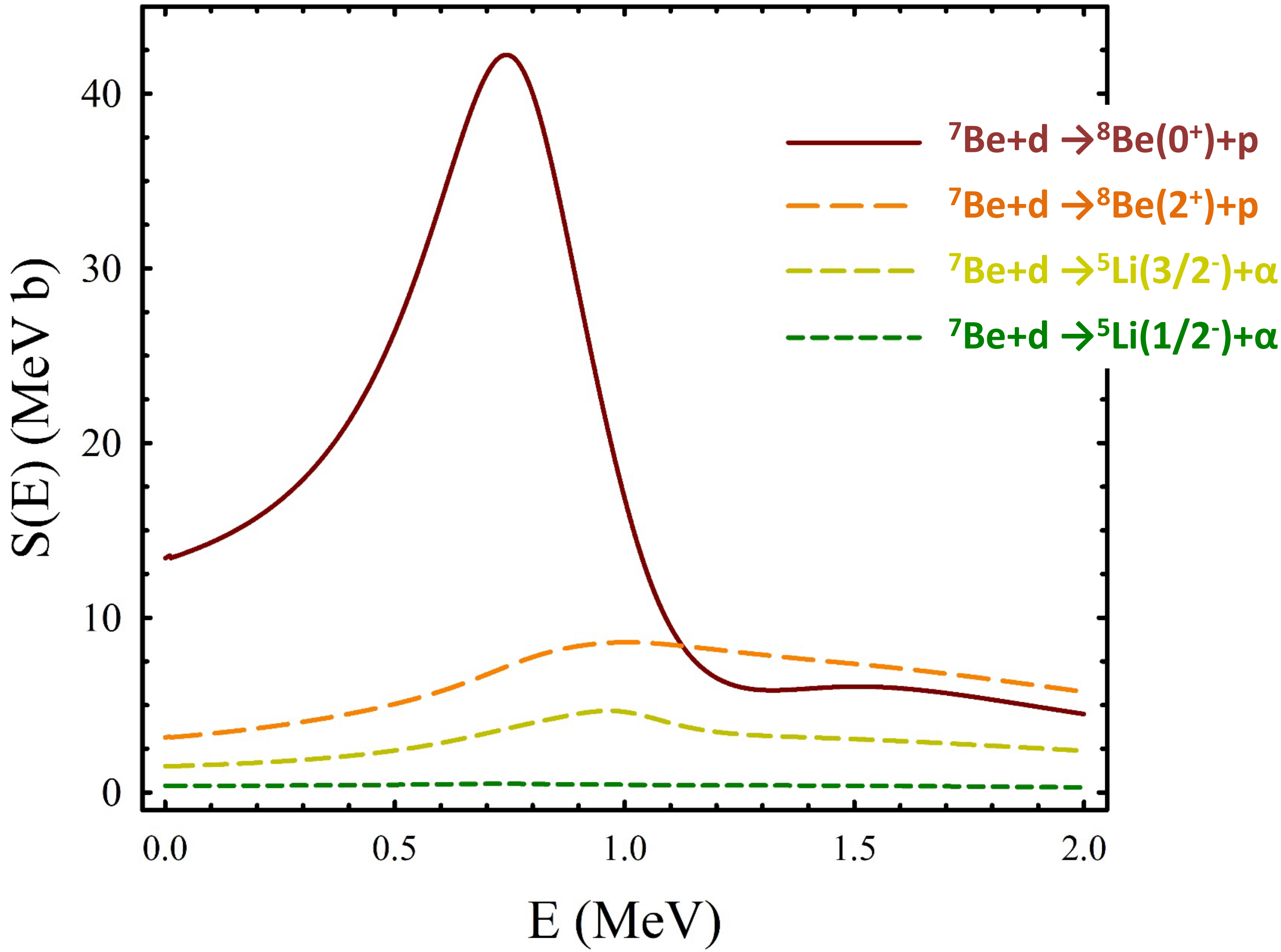
Effects of the Coulomb interaction on energies and widths of negative parity resonance states in ^{9}B (●) and ^{9}Be (●)

There is some agreement between our results and the available experimental data



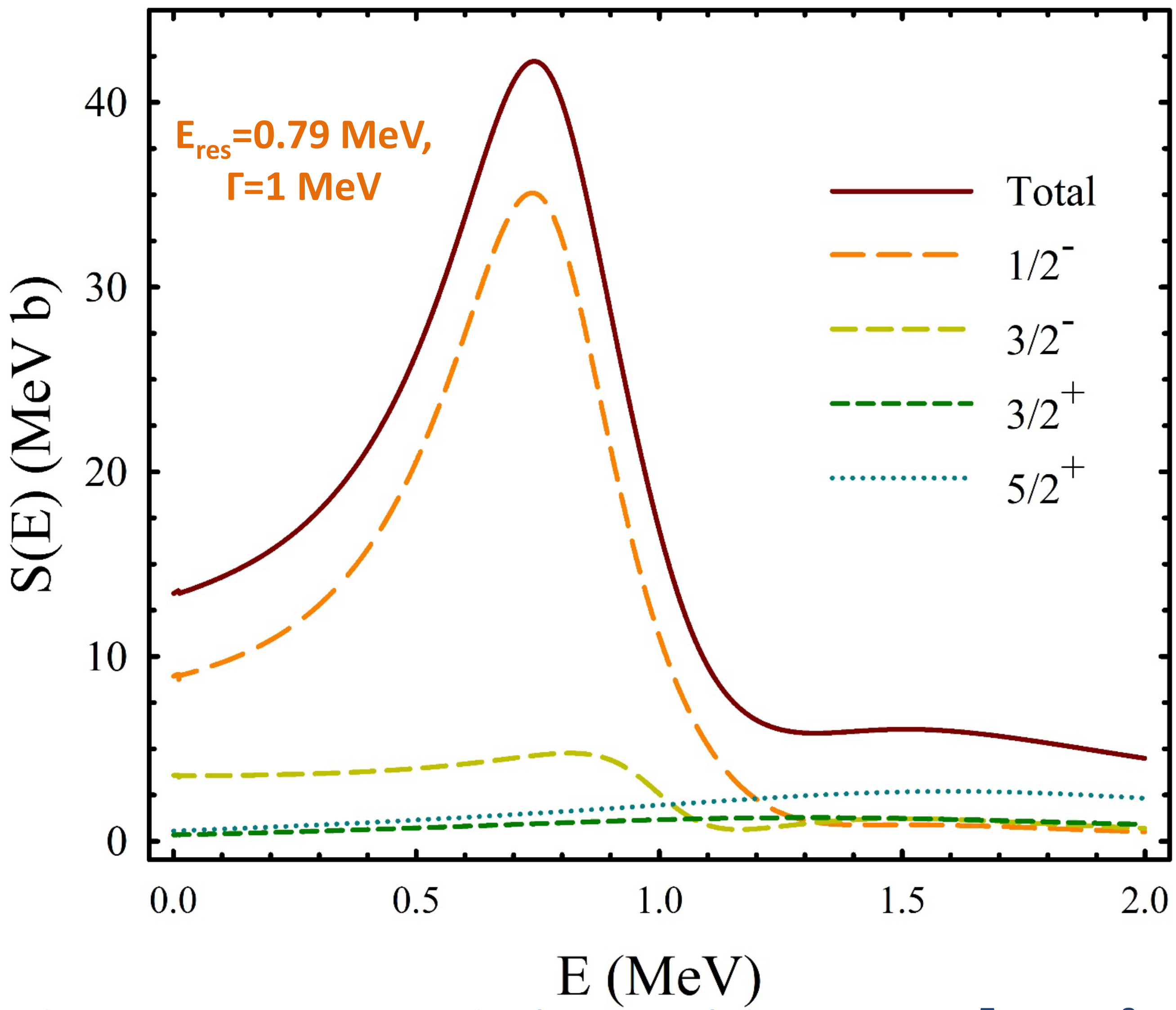
Spectra of ^{9}Be and ^{9}B identified in different experiments compared with our results

The reaction $d+{}^{7}Be={}^{8}Be(0^{+}) + p$ substantially dominates at the energy $0 \leq E \leq 1$ MeV



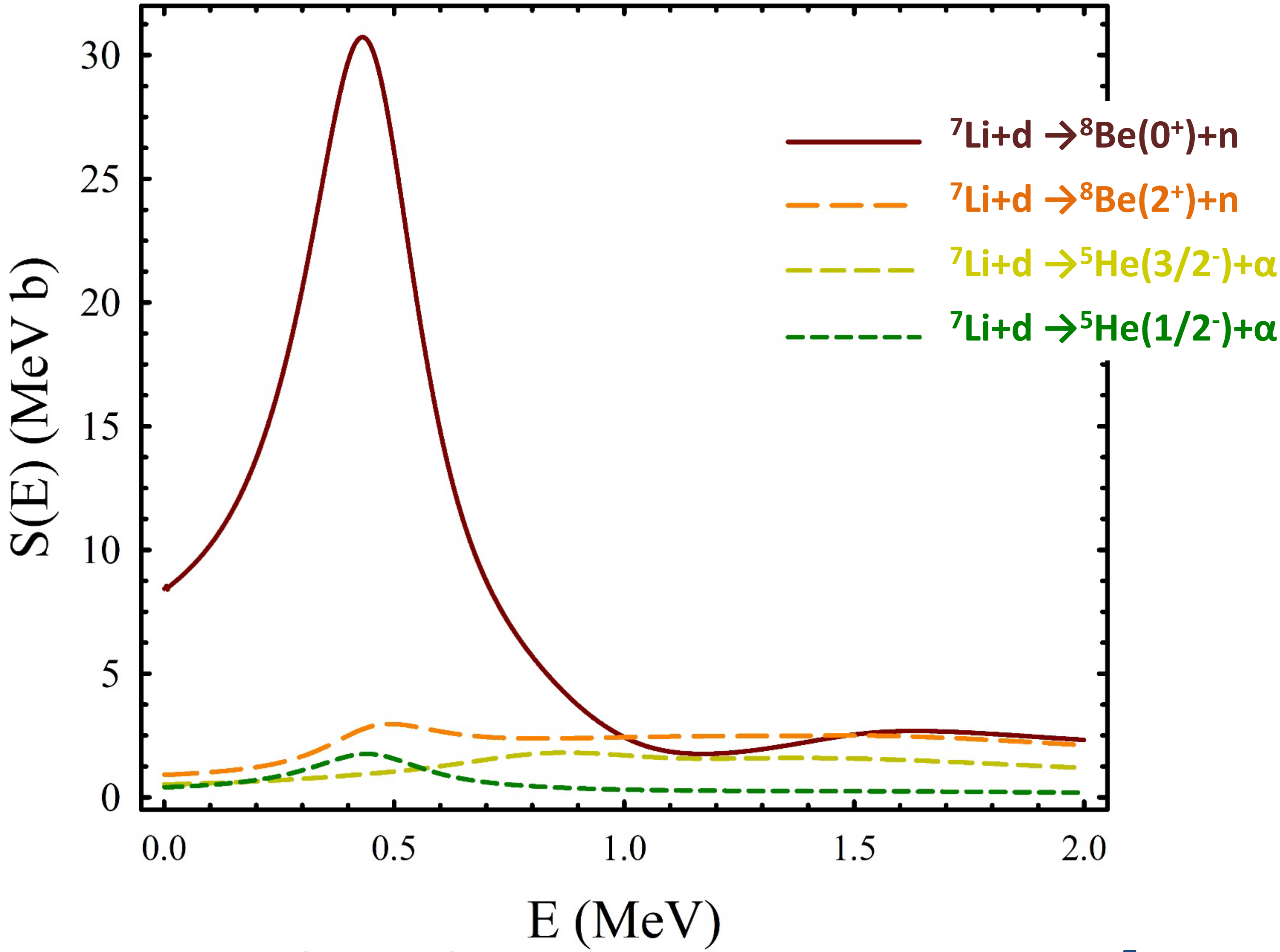
Total astrophysical S factor of 4 reactions initiated by interaction $^{7}Be+d$

The peak in the S-factor is caused by the wide 1/2⁻ resonance



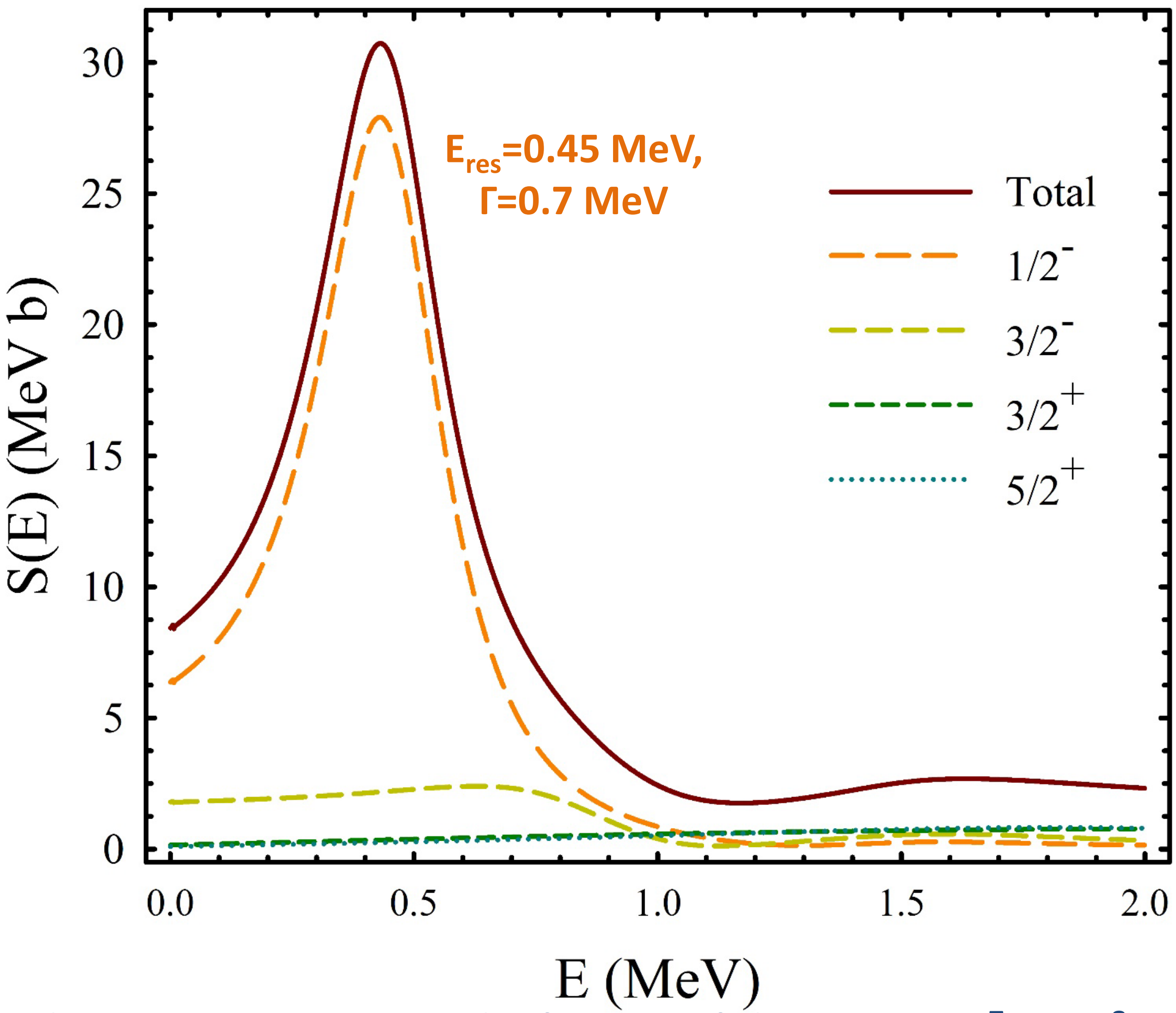
The total and dominant partial S factors of the reaction $^7Be+d=^8Be(0^+)+p$

The reaction $d+{}^{7}Li={}^{8}Be(0^{+}) + n$ substantially dominates at the energy $0 \leq E \leq 1$ MeV



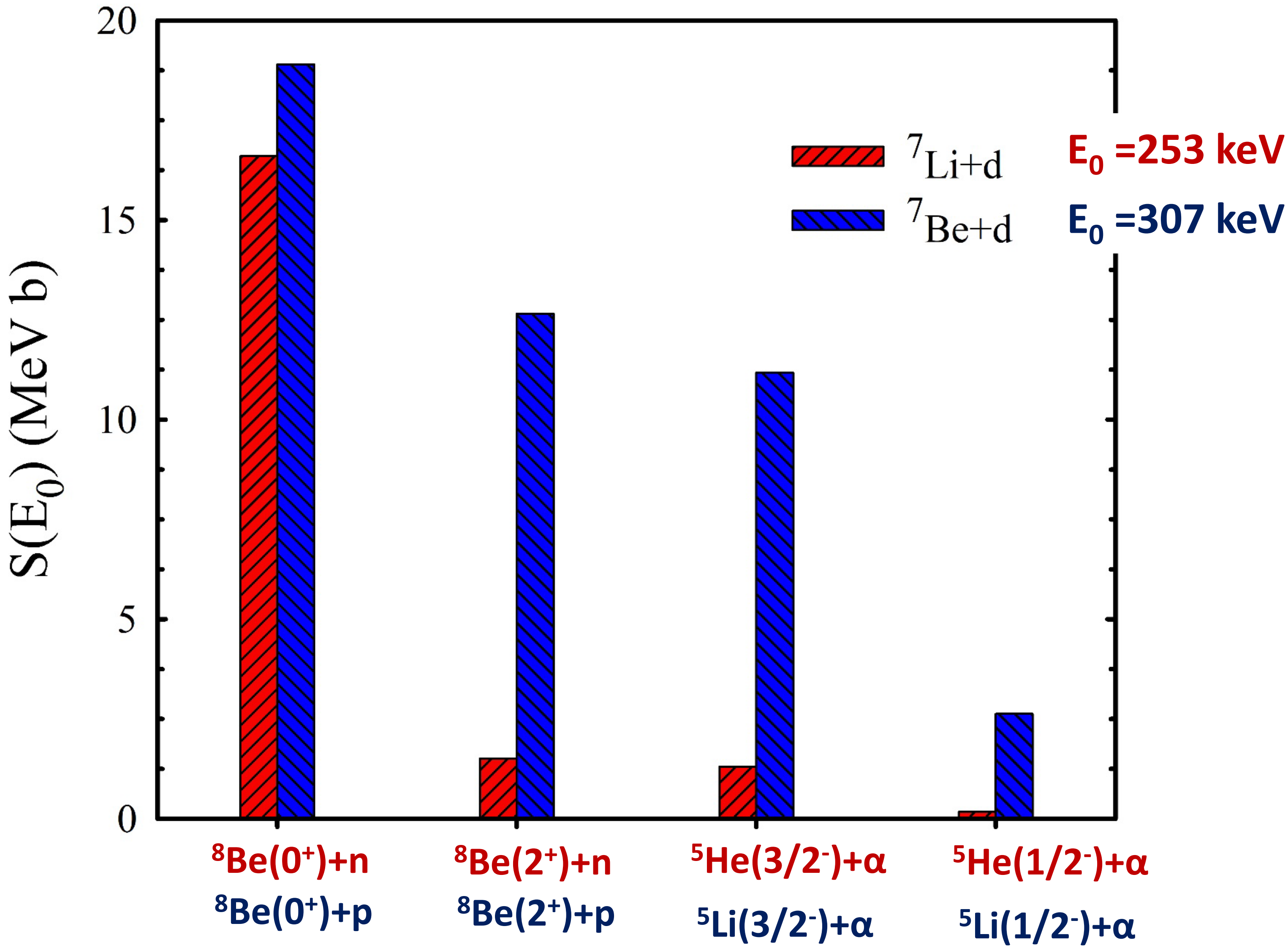
Total astrophysical S factor of 4 reactions initiated by interaction ${}^{7}Li+d$

The peak in the S-factor is caused by the wide 1/2⁻ resonance

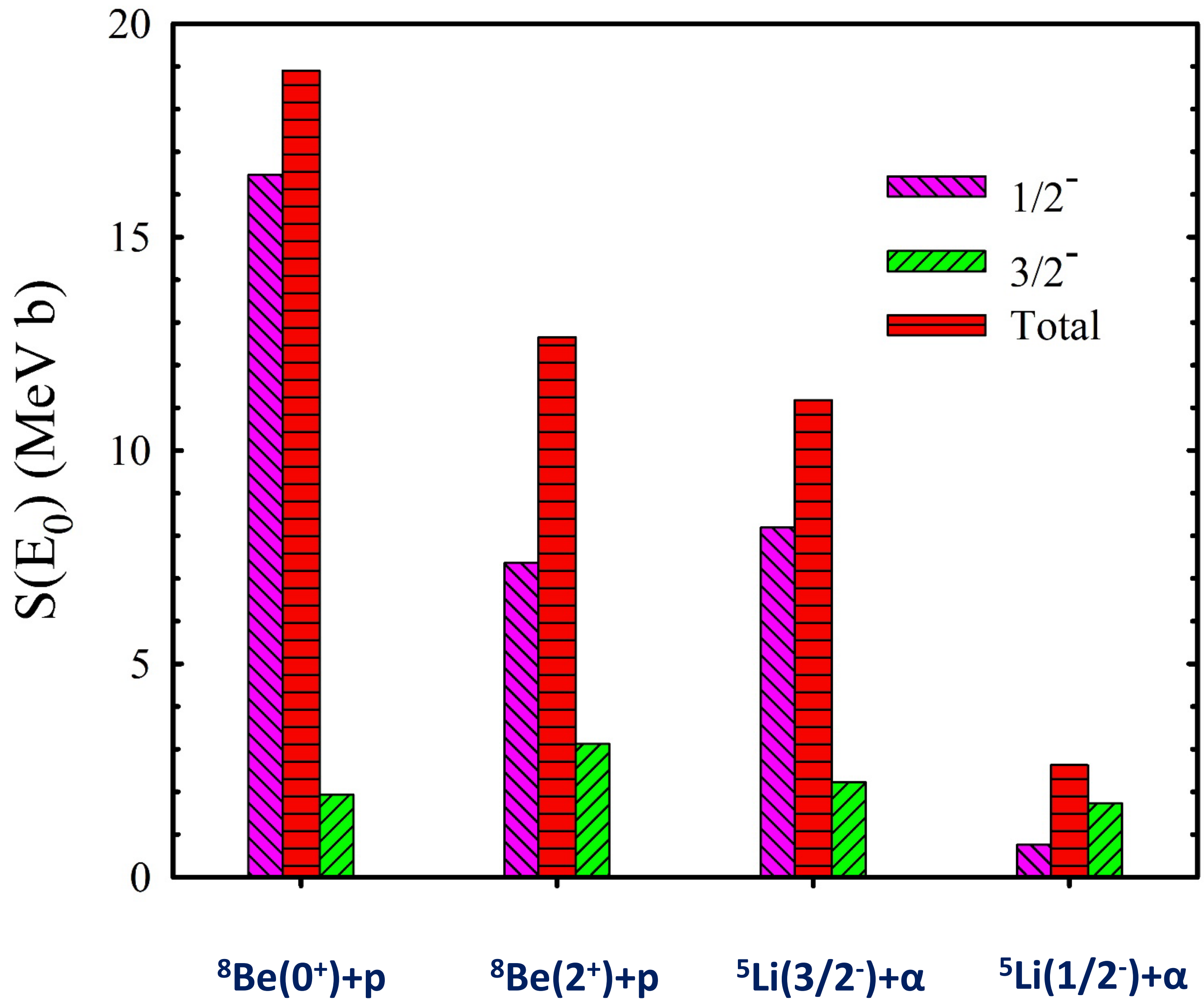


The total and dominant partial S factors of the reaction $^7Li+d=^8Be(0^+)+n$

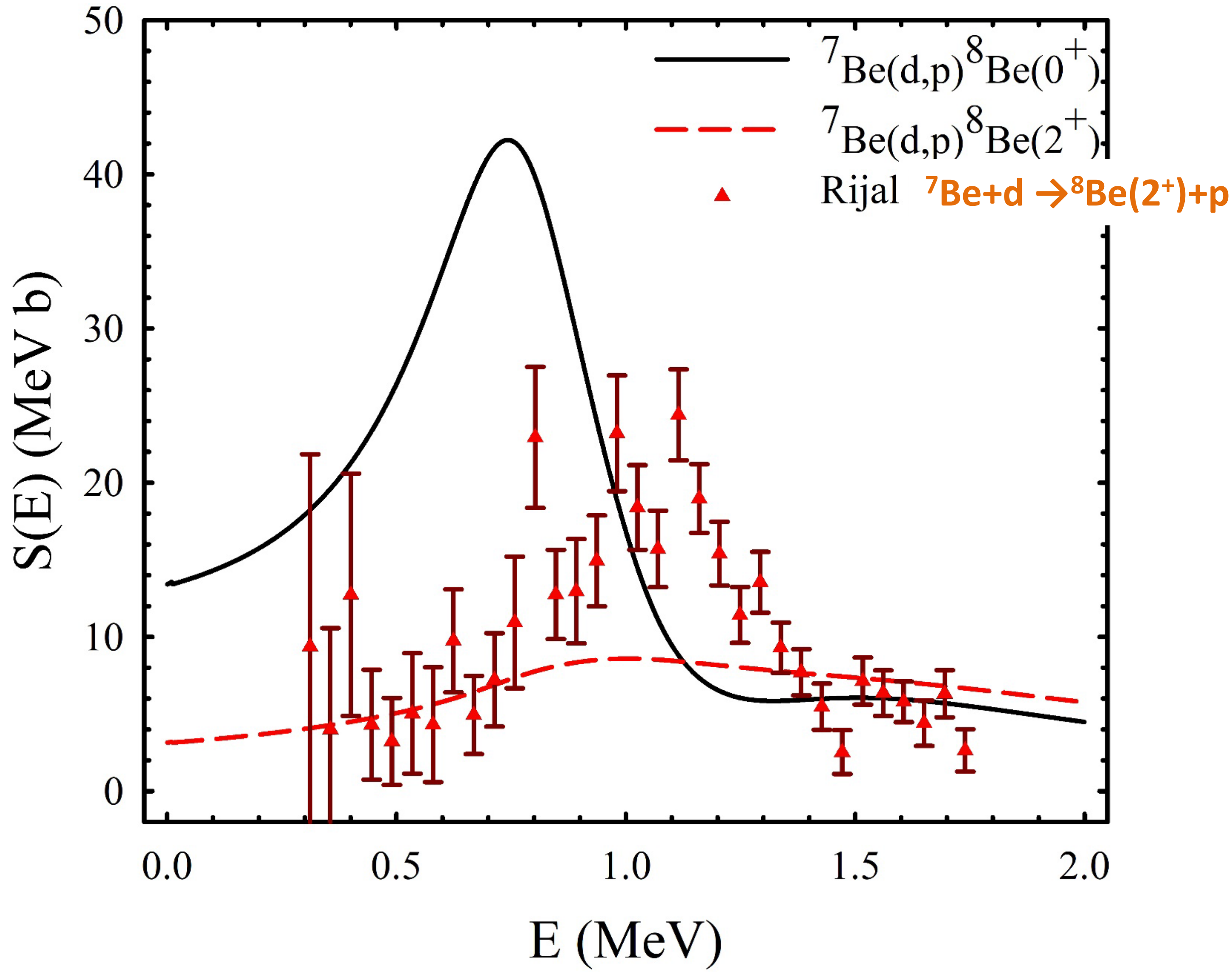
Total astrophysical S factor of the reactions generated by ^{7}Li+d and ^{7}Be+d collisions at the Gamow peak energies E_0



Dominant states via which reactions induced by the $^{7}Be+d$ collisions proceeds at the Gamow peak energy E_0=307 keV

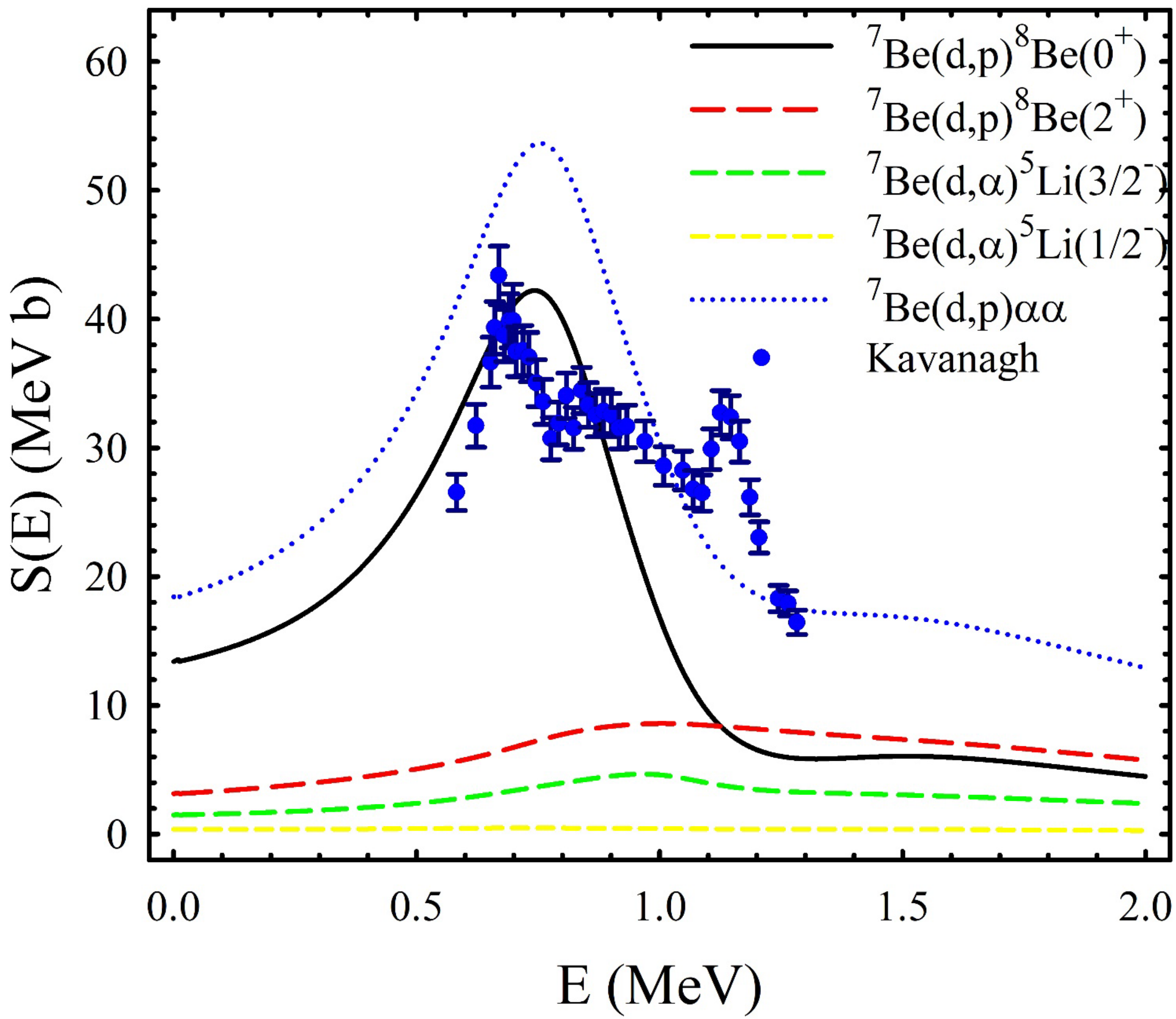


S-factor for $^7Be+d=^8Be(2^+)+p$ reaction corresponds well to the experimental data at 0.3< E <0.75 MeV and E >1.3 MeV



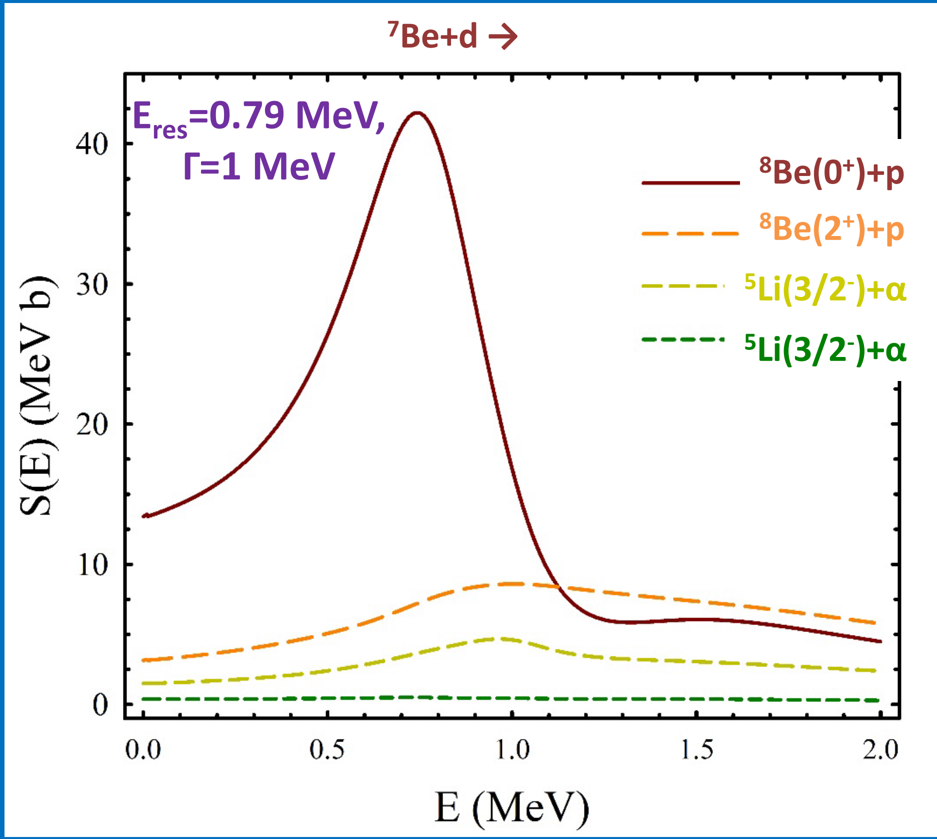
Experimental data: N. Rijal et al., Phys. Rev. Lett., vol. 122, p. 182701, 2019.

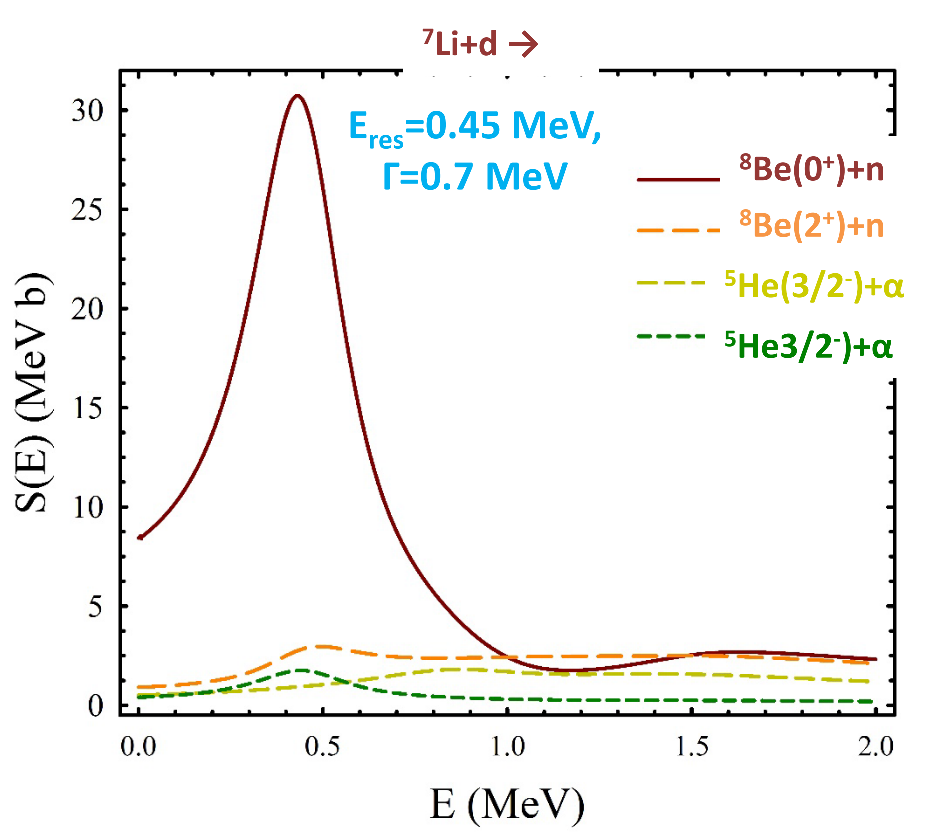
Within our model S-factor for $^7Be+d={}^8Be(0^+)+p$ reaction reproduces fairly well the experimental data below 1 MeV



Experimental data: **R. W. Kavanagh, Nucl. Phys. A, vol. 18, pp. 492–501 (1960)**

In summary, wide $1/2^-$ resonance states generate a large peak in S-factors of ^{7}Li(d, n)αα & ^{7}Be(d, p) αα reactions





No narrow resonance state near d+^{7}Be or d+^{7}Li threshold is found