Bound-to-continuum Approach for Resonant Elastic Scattering

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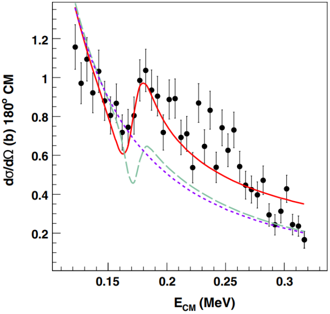
New near-threshold proton-emitting resonance in ^{11}B

- [**Ayyad et al., PRL 129 (2022)**] (LHS)
- [**Lopez-Saavedra et al., PRL 129 (2022)**] (RHS)



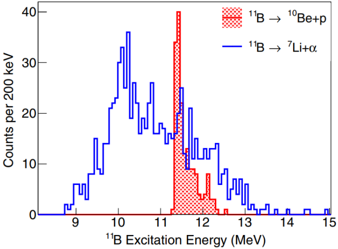


Figure 1: LHS (p, p) $E_{res} = 182$ keV. RHS (d, p) $E_{res} = 211$ keV.

Noted that $S_p(^{11}\mathrm{B}) = 11.228$ MeV.

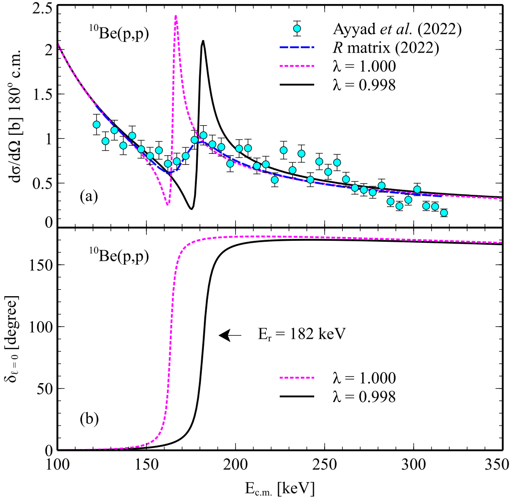


Figure 2: The new resonance in ^{11}B is the single-particle resonance in the mean-field theory, [**Phys. Rev. C 106**, **L051302 (2022)**].

Beta-delayed proton emission (βp) in ^{11}Be.

- The βp in ^{11}Be (one-neutron halo nucleus with the halo neutron bound by $\approx$ 500 keV). [1]

$$^{11}\text{Be} \rightarrow {}^{10}\text{Be} + p + e^{-} + \bar{\nu}$$

- Unexpectedly high intensity! 3.0×10^{-8}, theoretical prediction. [2]
- It is indirectly observed at ISOLDE, CERN with the branching ratio of $8.3 \cdot 10^{-6}$. Higher than the prediction. [3]
- There were two possible explanations [**Riisager (2014)**]:
    1. The existence of an unknown narrow resonance in ^{11}B.
    2. The so-called **dark decay**, the weakly bound (quasifree) neutron decays to a **dark matter** as proposed for the free neutron?

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[1] [**Horoi, and Zelevinsky, April Meeting, APS (2003)**]
[2] [**Baye, and Tursunov, PLB 696 (2011)**]
[3] [**Riisager et al., PLB 732 (2014)**]

- ISOLDE, CERN: ^{11}Be ($T_{1/2} = 13.8$ s) was implanted in a catcher. Using accelerated mass spectroscopy, the amount of ^{10}Be ($T_{1/2} = 1.5 \times 10^6$ yr) was measured in the samples. [**Riisager et al. PLB 732 (2014)**]
- ISAC-TRIUMF: Measuring the emitted protons and their energy distribution. [**Y. Ayyad et al.**, **PRL 123 (2019)**]

Nuclide[4] [n 1]	*Z*	*N*	Isotopic mass (Da)[5] [n 2][n 3]	Half-life [resonance width]	Decay mode [n 4]	Daughter isotope [n 5]	Spin and parity [n 6]
	Excitation energy						
^{11}Be[n 11]	4	7	11.021 661 08(26)	13.76(7) s	β^- (96.7(1)%)	^{11}B	1/2+
					$\beta^-\alpha$ (3.3(1)%)	^{7}Li	
					β^-p (0.0013(3)%)	^{10}Be	

Figure 3: https://en.wikipedia.org/wiki/Isotopes_of_beryllium

Impact on nuclear astrophysics

Role of low-lying resonances for the ^{10}Be$(p, \alpha)^7$Li reaction rate and implications for forming the Solar System.

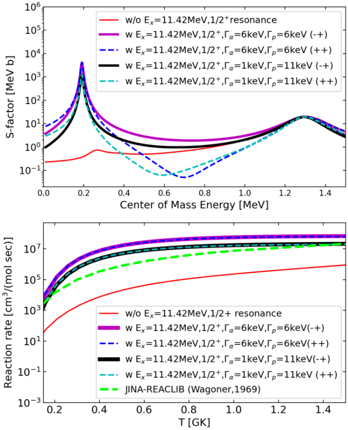

Figure 4: The *S*-factor and reaction rate w/ and w/o the new resonance in ^{11}B [**Sieverding et al., PRC 106 (2022)**].

Method of calculation. Standing on the shoulders of giants.

D. Vautherin and M. Vénéroni PLB 26 (1968)
C. B. Dover and N. Van-Giai NPA 177 (1971), NPA 190 (1972)
The scattering equation for *s*-state ($\ell = 0$)

$$\left\{ \frac{\hbar^2}{2m} \left[-\frac{d^2}{dr^2} + \frac{1}{r^2} \right] + V(E,r) - E \right\} \chi_s(E,r) = 0. \tag{1}$$

The optical potential from *the HF s.p. in the continuum*

$$\begin{aligned} V(E,r) &= \frac{m_\tau^*(r)}{m} \left\{ V_{\mathrm{HF}}^{\tau}(r) + \frac{1}{2} \left(\frac{\hbar^2}{2m_\tau^*(r)} \right)'' - \frac{m_\tau^*(r)}{2\hbar^2} \left[\left(\frac{\hbar^2}{2m_\tau^*(r)} \right)' \right]^2 \right\} + \\ &+ \left[1 - \frac{m_\tau^*(r)}{m} \right] E. \end{aligned} \tag{2}$$

When the phase shift is obtained, the width of the resonance is computed by

$$\Gamma(E_r) = 2 \left[\frac{d}{dE} \delta_{\ell=0}(E) \right]^{-1}. \tag{3}$$

Highlights and Challenges

Highlights:

1. All components of the optical potential can be computed *self-consistently*.
2. Complicated corrections in the *reaction theory* are already included in the Skyrme HF formalism:
   - center-of-mass correction
   - non-locality effect
   - rearrangement term
   - short-range correlations
3. The location of the resonance is very sensitive to the parameter λ_s introduced in our calculation.

Challenges: Skyrme parameters (EDFs) do not take into account from the very beginning the existence of the continuum.
Is it possible to predict exactly the location of the resonance?
At present, the solution is:

$$\mathcal{V}_s(E,r) = \lambda_s \mathcal{V}_s^{\mathrm{c}}(E,r). \tag{4}$$

Conclusions

1. The Skyrme HF calculation is the excellent starting point for the low energy reactions.
2. We introduced a controllable calculation that is microscopic and consistent with 01 additional parameter.
3. The possibility to describe the data by the little movement of the potentials is a good feature of our approach.

Thank you for staying with us!