Near threshold resonances and exotic decay of ^{11}Be

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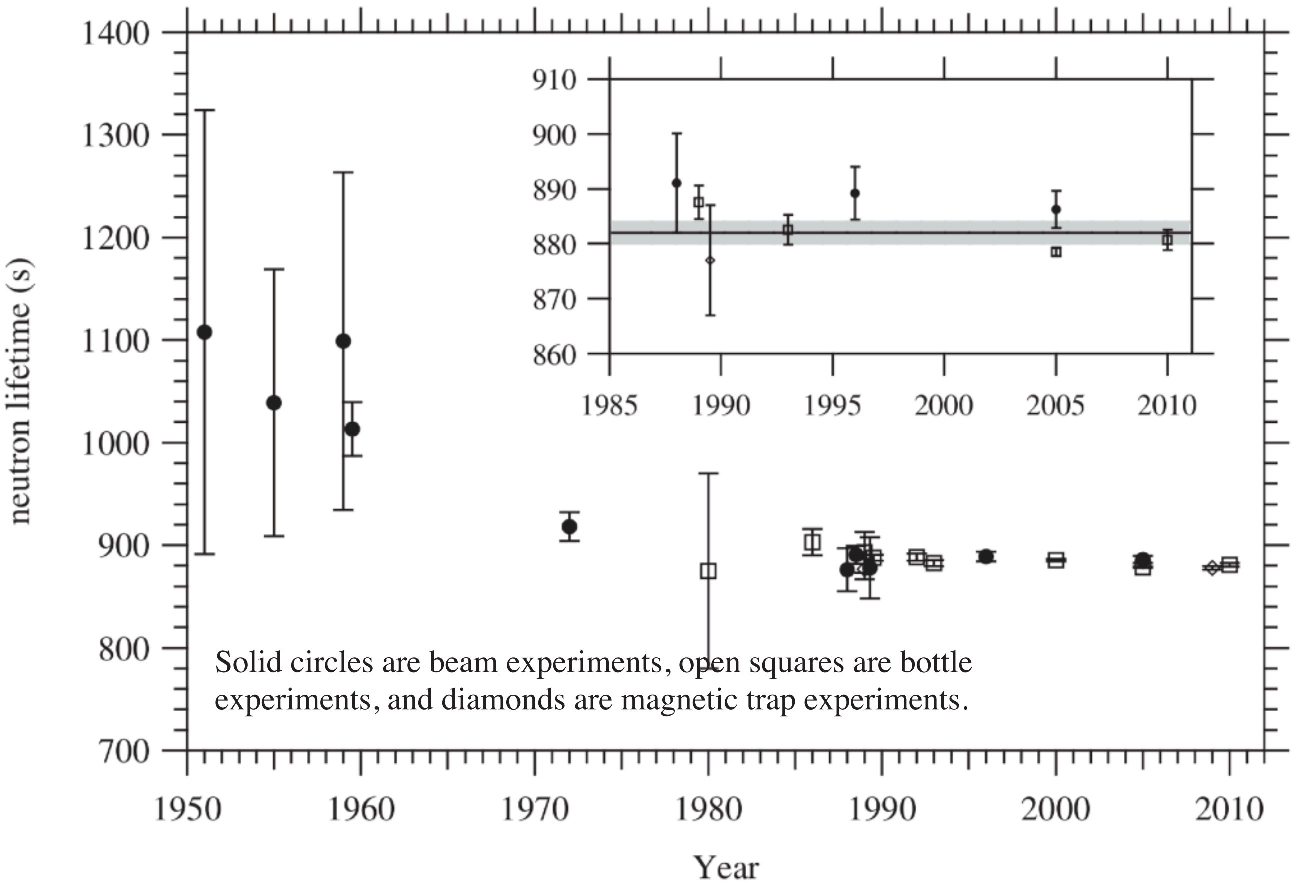
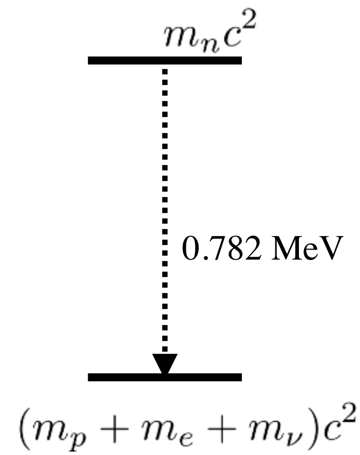
Four seconds of uncertainty

$$n \rightarrow p + e^- + \bar{\nu}_e$$





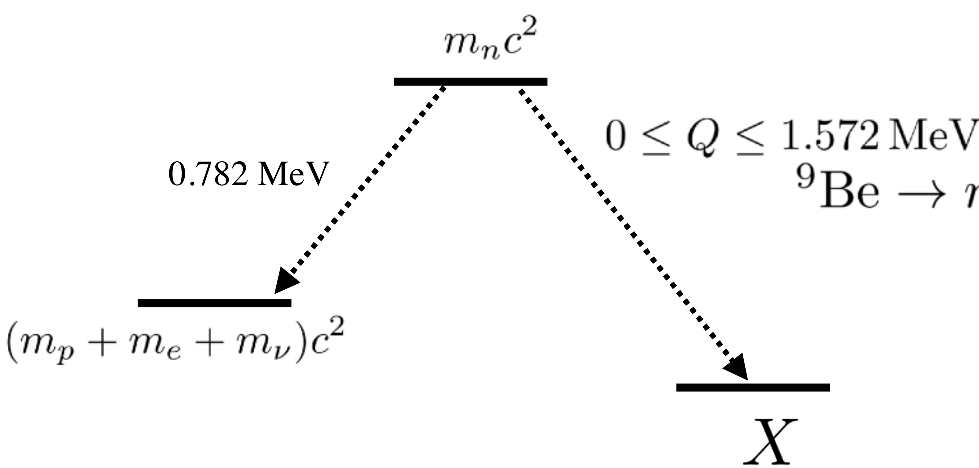
$880\text{s} \leq \tau_n \leq 884\text{s}$ Half-life $610\text{s} \leq t_n \leq 613\text{s}$

F. E. Wietfeldt, G. L. Greene, *Colloquium: The neutron lifetime,* Rev. Mod. Phys. **83** (2011) 1173--1192.

What if?

$$n \nearrow p + e^- + \bar{\nu}_e \qquad t_n = 613\text{s}$$

$$n \searrow X$$ Unknown dark matter fragments $$t_{n \to X} = 6.8 \times 10^4\text{s}$$



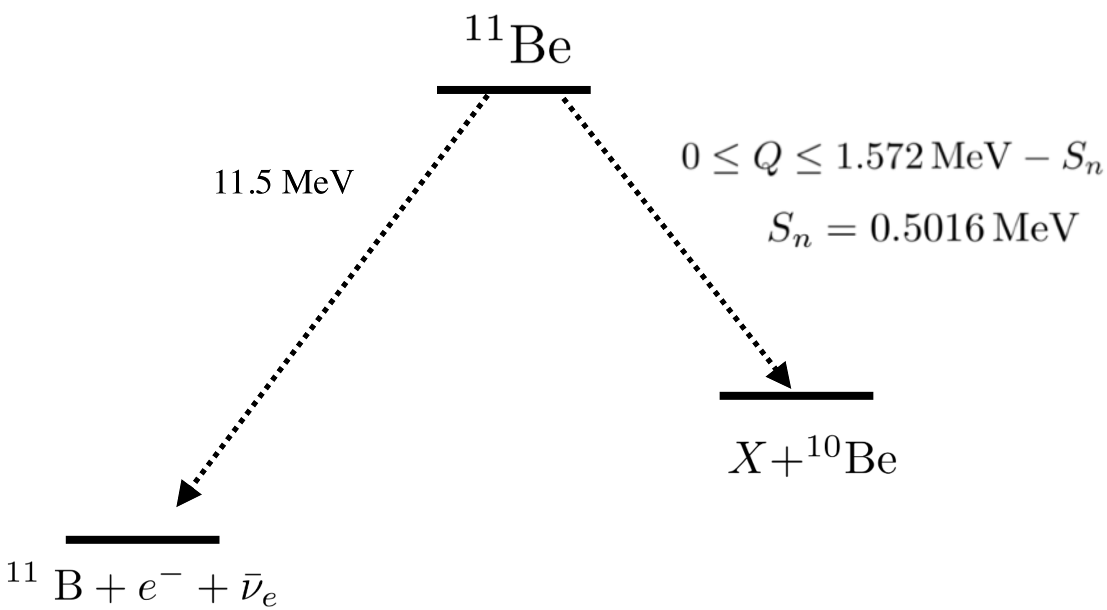
$^9\text{Be} \to n + \alpha + \alpha$ (does not happen)

M. Pfützner, K. Riisager, *Examining the possibility to observe neutron dark decay in nuclei,* Phys. Rev. C **97** (2018) 042501.
F. E. Wietfeldt, G. L. Greene, *Colloquium: The neutron lifetime,* Rev. Mod. Phys. **83** (2011) 1173.

^{11}Be best candidate

$$^{11}\mathrm{Be} \nearrow \; ^{11}\mathrm{B} + e^- + \bar{\nu}_e \qquad t_{\mathrm{Be}} = 13.76\ \mathrm{s}$$

$$^{11}\mathrm{Be} \searrow \; X + ^{10}\mathrm{Be} \qquad t_{\mathrm{Be}\to X} > 10^5\ \mathrm{s}$$



M. Pfützner, K. Riisager, *Examining the possibility to observe neutron dark decay in nuclei,* Phys. Rev. C **97** (2018) 042501.
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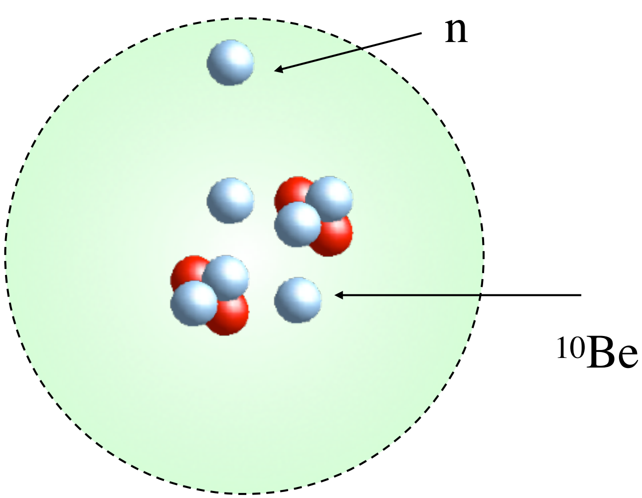
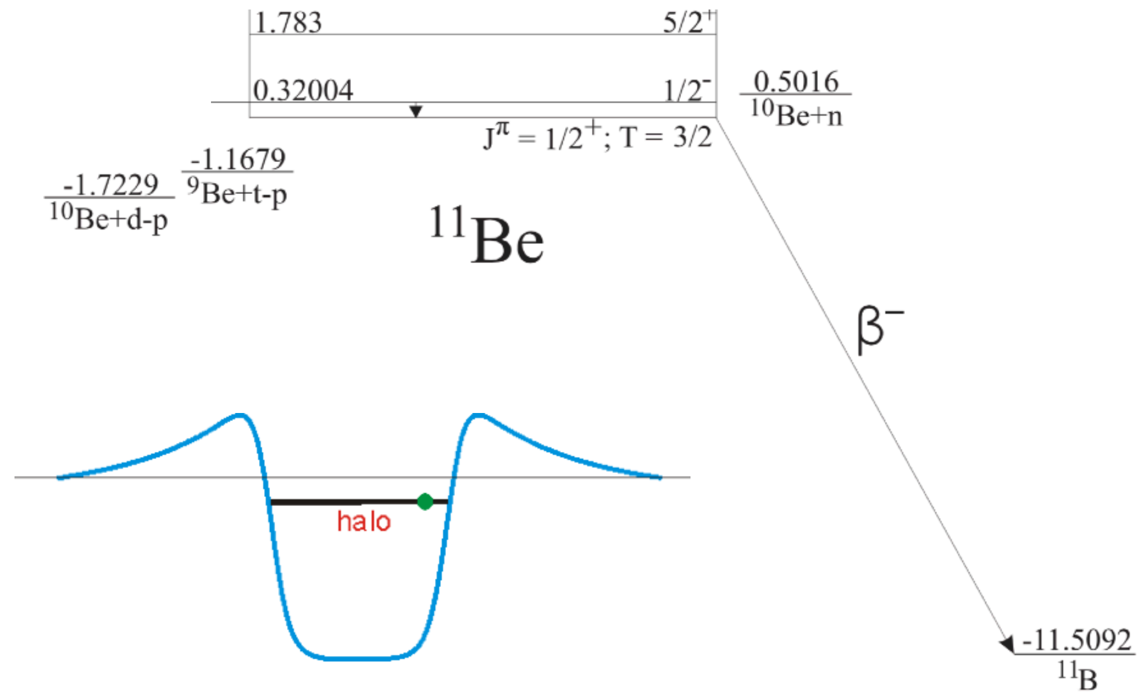
^{11}Be, an interesting nucleus

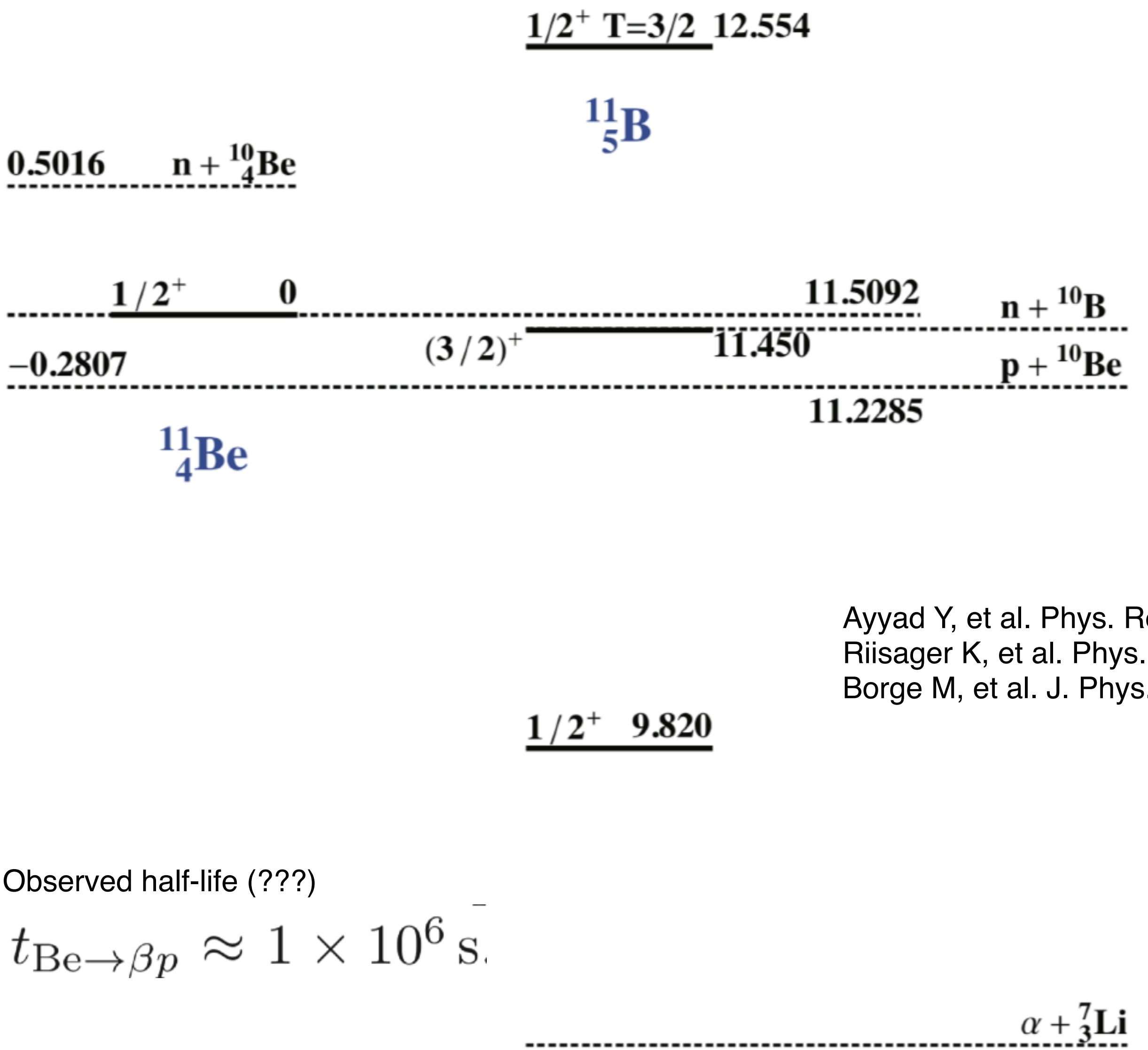
Halo phenomenon, weakly bound neutron
Clustering+molecular structure
Rotations

$$S_n = 0.5016\,\mathrm{MeV}$$





^{11}Be beta-delayed proton decay



Ayyad Y, et al. Phys. Rev. Lett., 123 (2019) 082501.
Riisager K, et al. Phys. Lett. B, 732 (2014) 305.
Borge M, et al. J. Phys. G, 40 (2013) 035109.

Observed half-life (???)

$$t_{\mathrm{Be}\to\beta p} \approx 1 \times 10^6 \text{ s.}$$

Notes on beta-decay rates

$$ft = \frac{\mathcal{T}}{B(F) + \lambda_A^2 B(GT)} \qquad \mathcal{T} = 6145\,\mathrm{s}$$

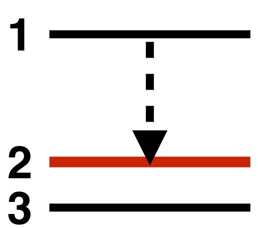
$$\lambda_A = 1.27$$

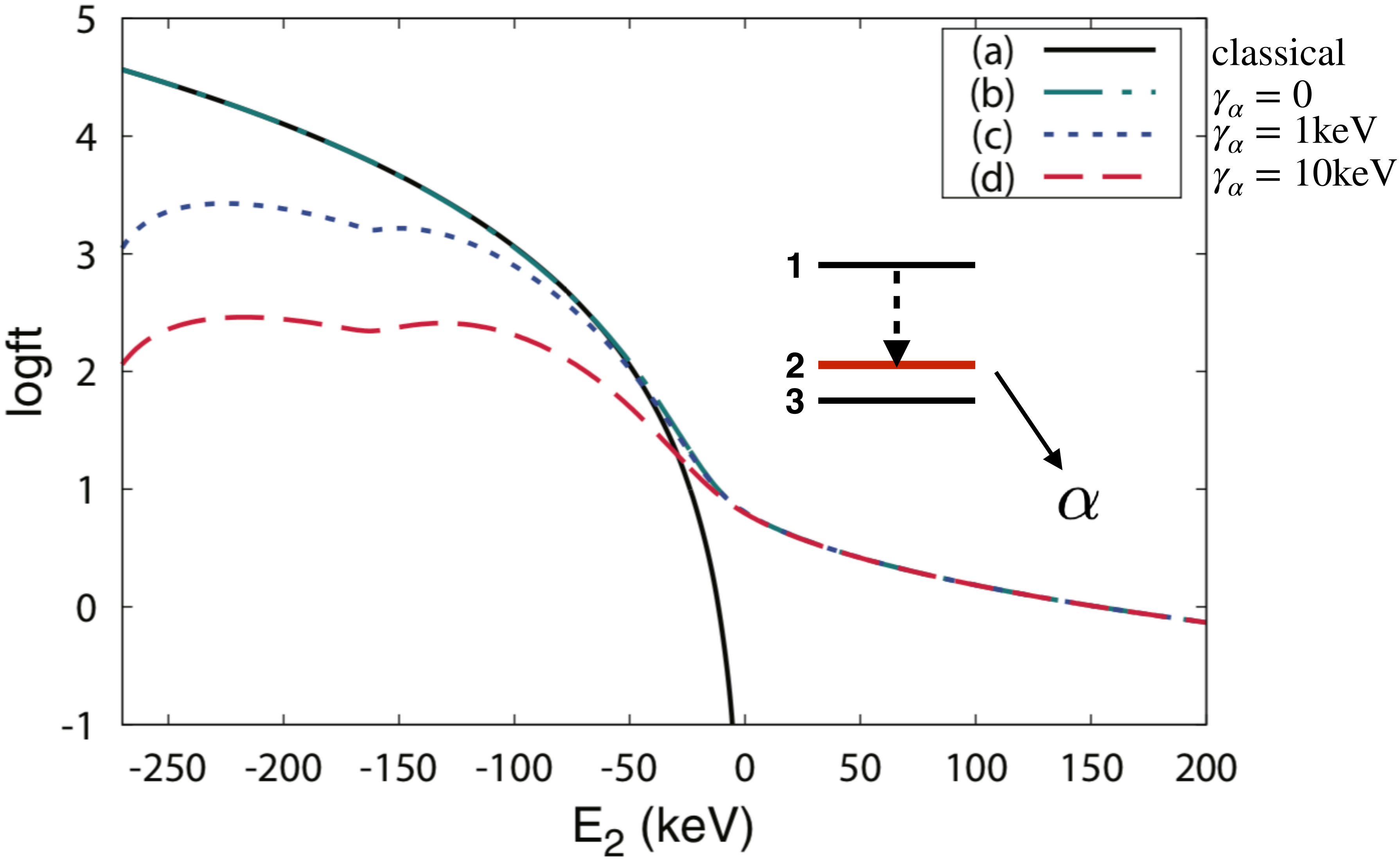
Neutron decay $n \to p + e^- + \bar{\nu}_e \quad B(F) = 1 \quad B(GT) = 3$

$$f(Q) = 1.715$$

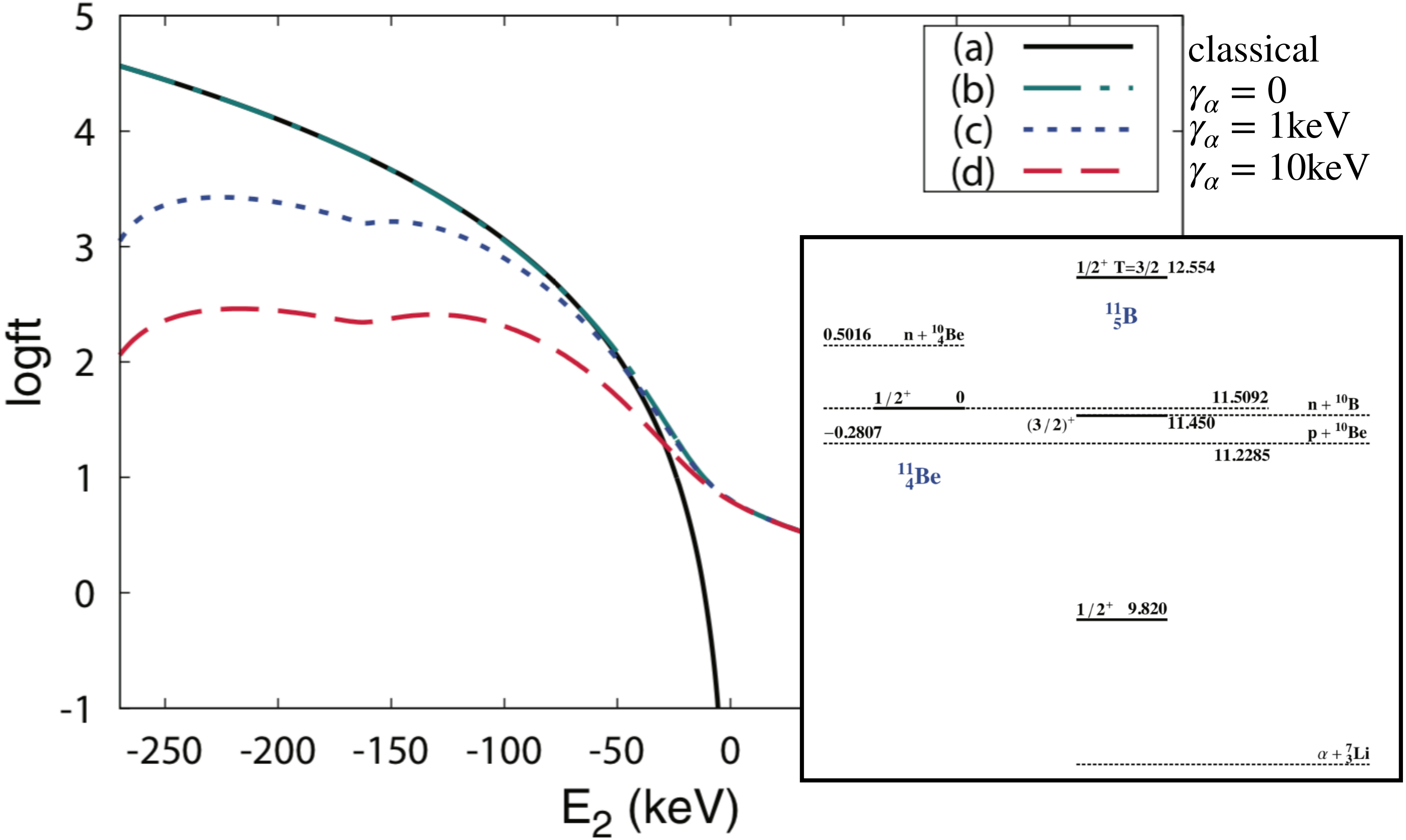
Sequential beta decay

For sequential decay $\mathcal{F}(Q) = \int_0^Q \frac{\mathrm{d}\epsilon}{2\pi} \frac{f(\epsilon)\gamma_2(Q-\epsilon)}{(\epsilon + E_2)^2 + \Gamma_2^2(Q-\epsilon)/2}$

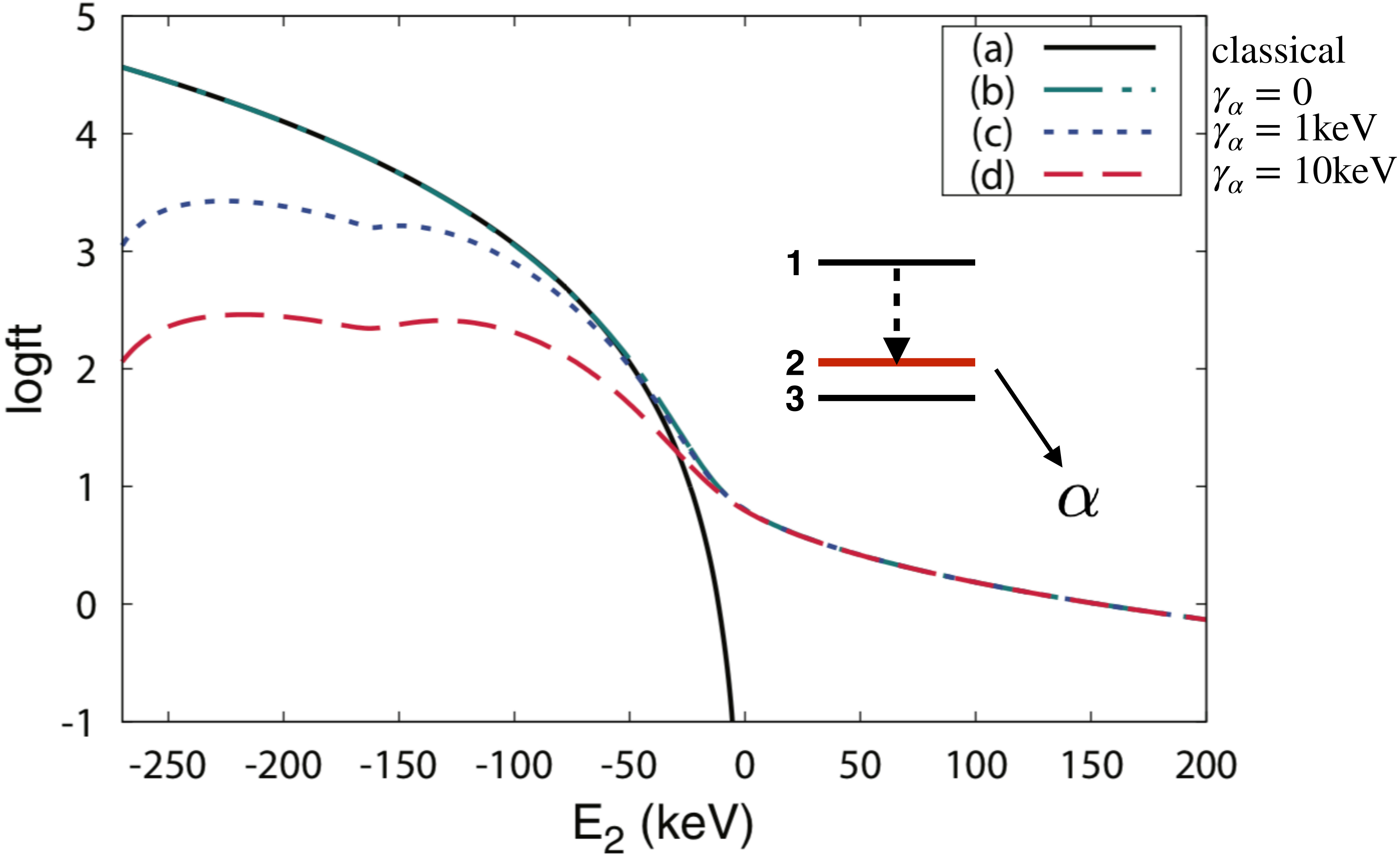




5
4
3
2
1
0
-1
logft
-250
-200
-150
-100
-50
0
50
100
150
200
E$_2$ (keV)
(a) classical
(b) $\gamma_\alpha = 0$
(c) $\gamma_\alpha = 1$keV
(d) $\gamma_\alpha = 10$keV
1
2
3
α



logft
E2 (keV)
5
4
3
2
1
0
-1
-250
-200
-150
-100
-50
0
(a) classical
(b) γα = 0
(c) γα = 1keV
(d) γα = 10keV
1/2+ T=3/2 12.554
11 5 B
0.5016 n + 10 4 Be
1/2+ 0
11.5092
n + 10B
(3/2)+
11.450
−0.2807
p + 10Be
11.2285
11 4 Be
1/2+ 9.820
α + 7 3 Li



(a) classical
(b) $\gamma_\alpha = 0$
(c) $\gamma_\alpha = 1$keV
(d) $\gamma_\alpha = 10$keV
1
2
3
α
logft
E_2 (keV)
5
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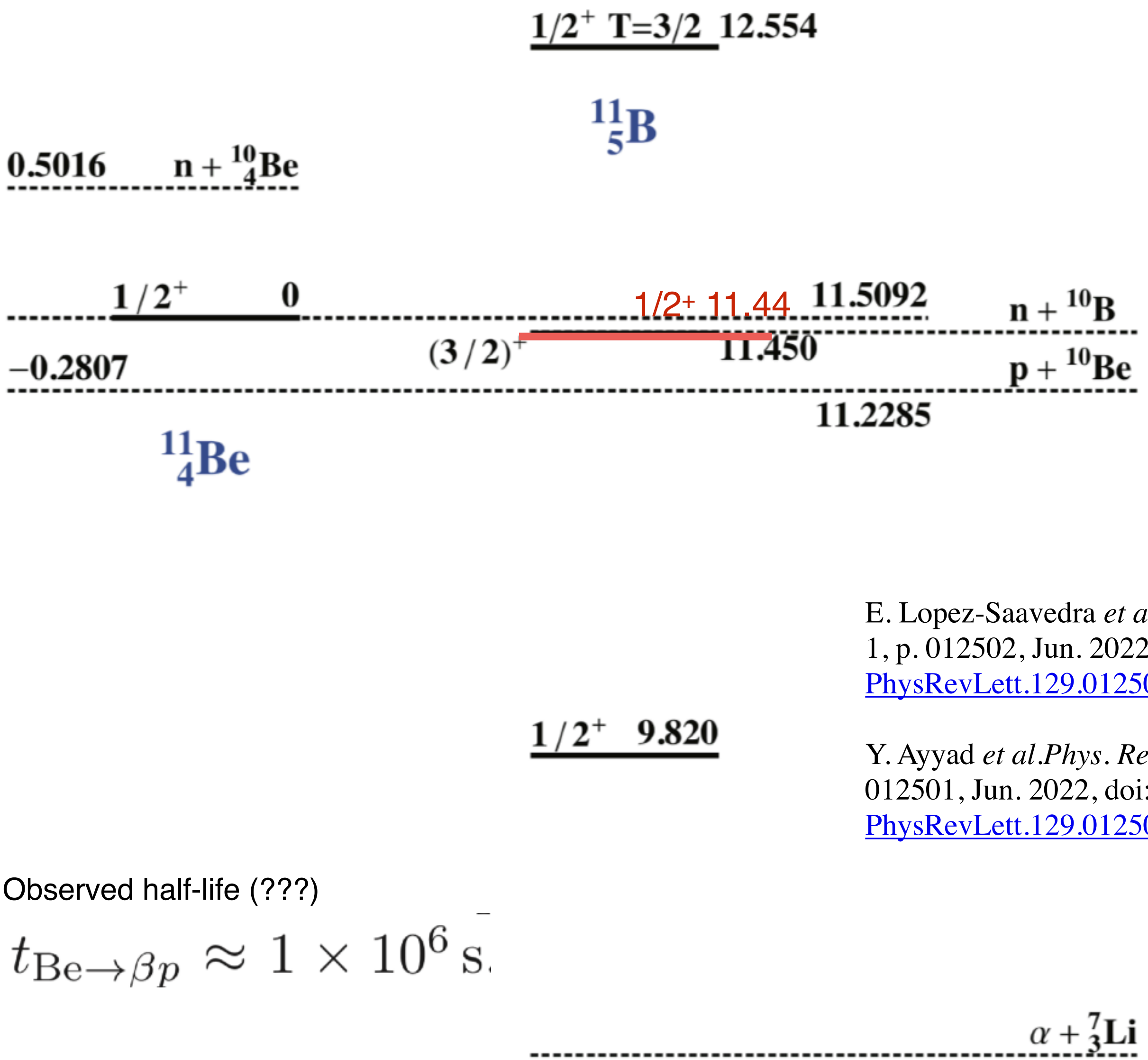
-1
-250
-200
-150
-100
-50
0
50
100
150
200

^{11}Be beta-delayed proton decay



E. Lopez-Saavedra *et al.*, *Phys. Rev. Lett.*, vol. 129, no. 1, p. 012502, Jun. 2022, doi: 10.1103/PhysRevLett.129.012502.

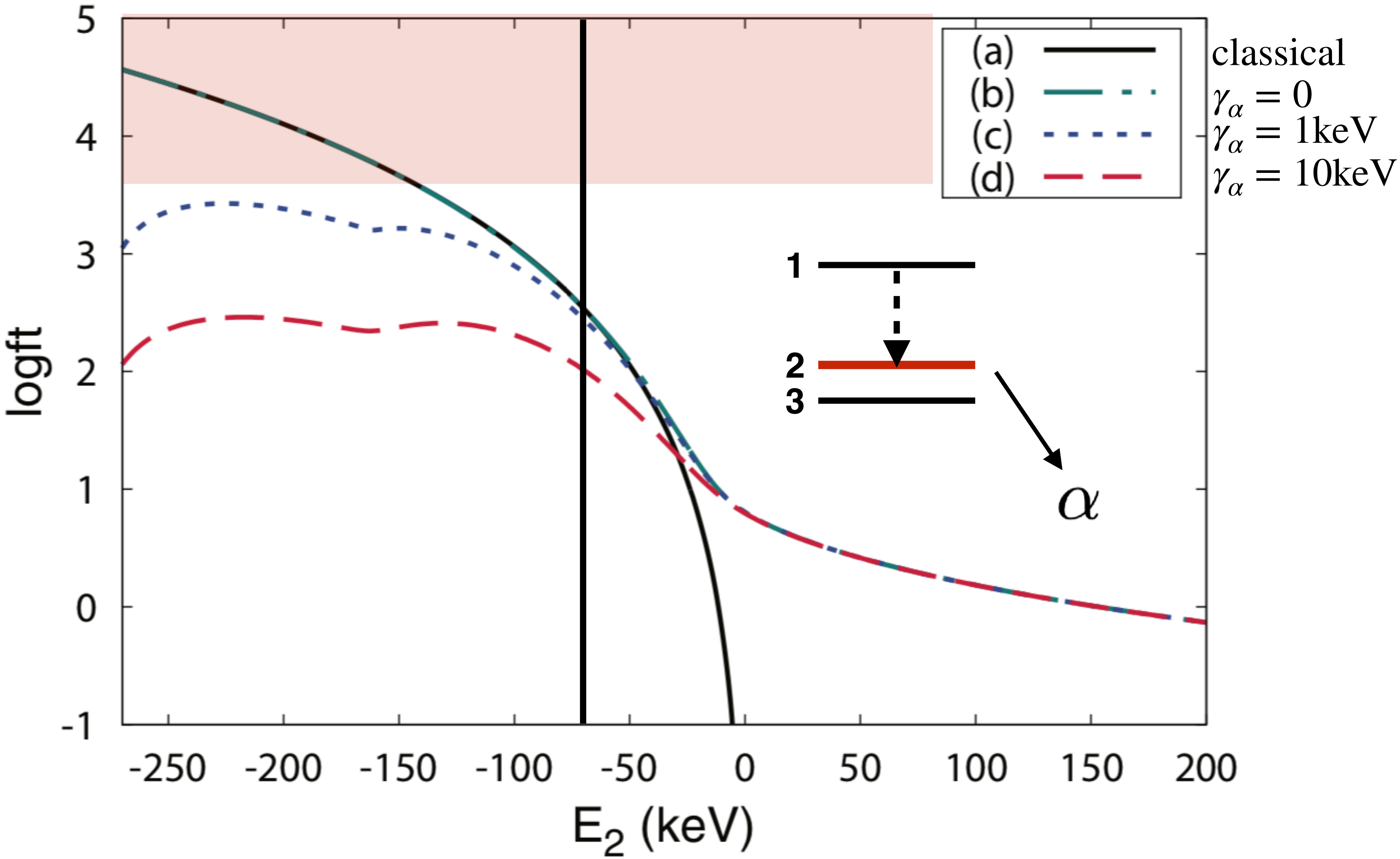
Y. Ayyad *et al.Phys. Rev. Lett.*, vol. 129, no. 1, p. 012501, Jun. 2022, doi: 10.1103/PhysRevLett.129.012501.

Observed half-life (???)

$$t_{\mathrm{Be}\to\beta p} \approx 1 \times 10^{6}\ \mathrm{s}.$$

1/2+ states in 11B

	Theory (FSU)			Experiment	
J	**E(MeV)**	**log(ft)**	**SF(p)**	**E(MeV)**	**SF(p)**
1/2+(1)	5.709	5.5	0.262	6.792	
1/2+(2)	10.545	3.4	0.117	9.820	
1/2+(3)	11.952	3.5	0.134	**11.44**	**0.27(6)**
1/2+(4) T=3/2	12.181		0.274	12.554	
1/2+(5)	12.827	4.0	0.028		
1/2+(6)	14.105	5.4	0.001		

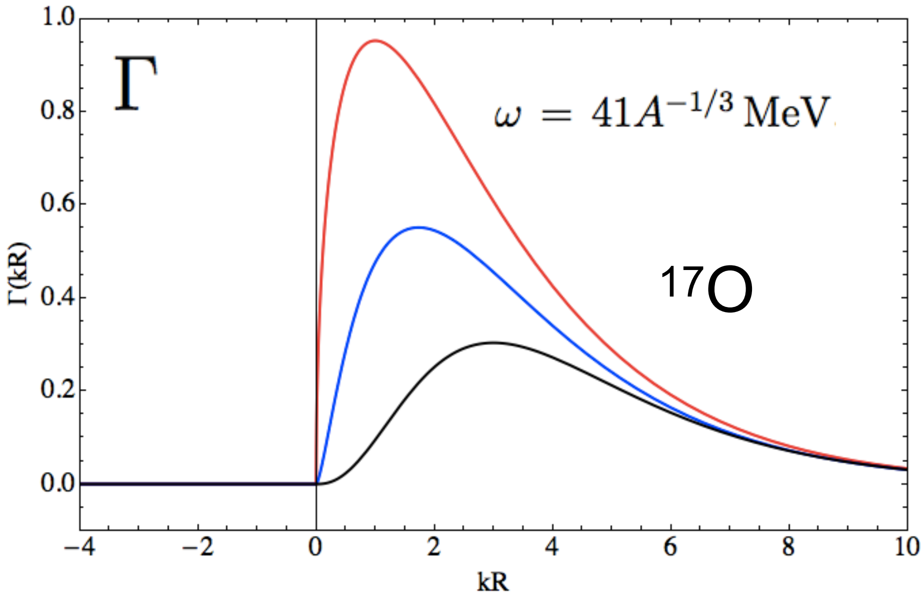


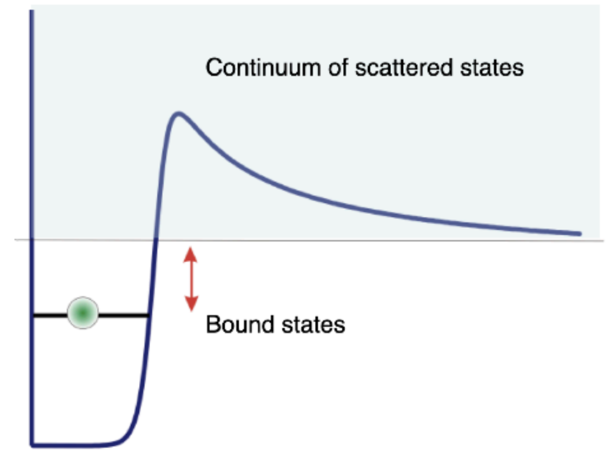
A. Volya, "Assessment of the beta-delayed proton decay rate of 11Be," *EPL*, vol. 130, no. 1, p. 12001, 2020, doi: 10.1209/0295-5075/130/12001.

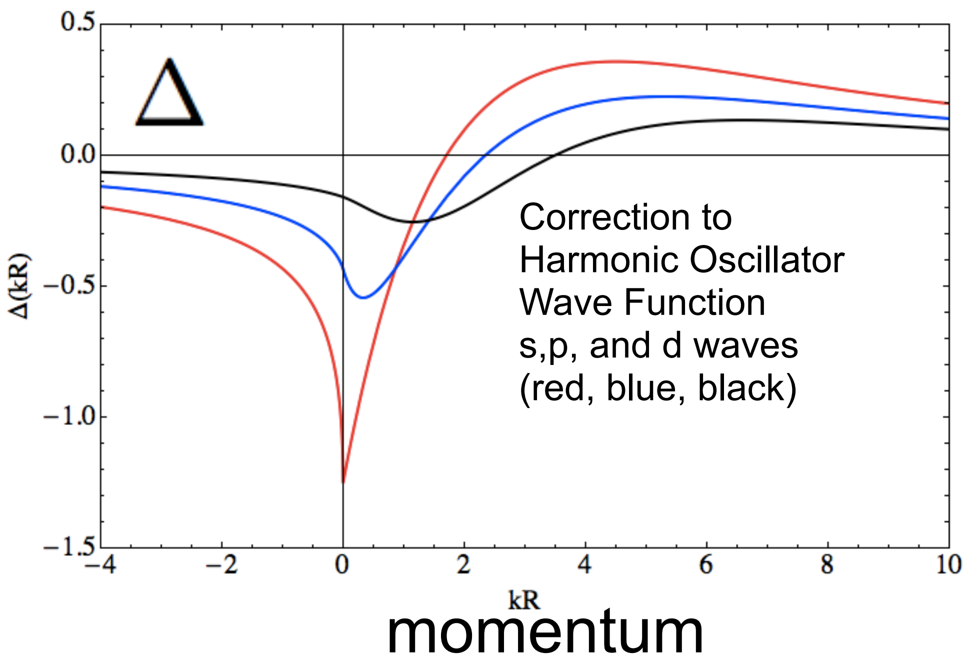
Questions

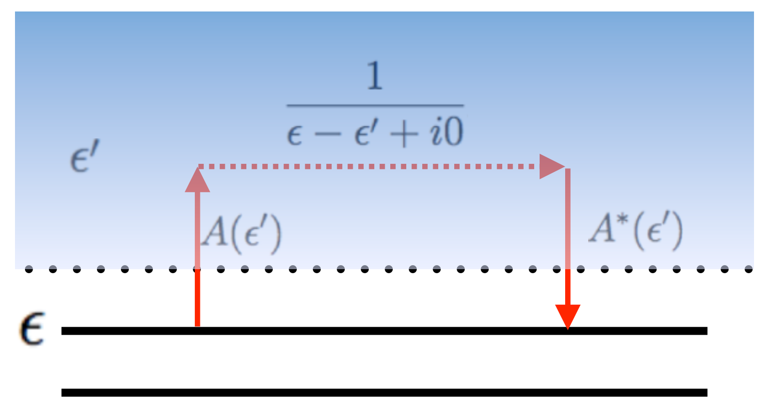
- Even with proton resonance, beta-delayed rate is impossible to explain
- The proton resonance is likely 1/2+(3), why it is lowered (predicted 12.2 MeV, observed at 11.44 MeV
- Why proton SF is so large, while there is no alpha decay?

Threshold discontinuity



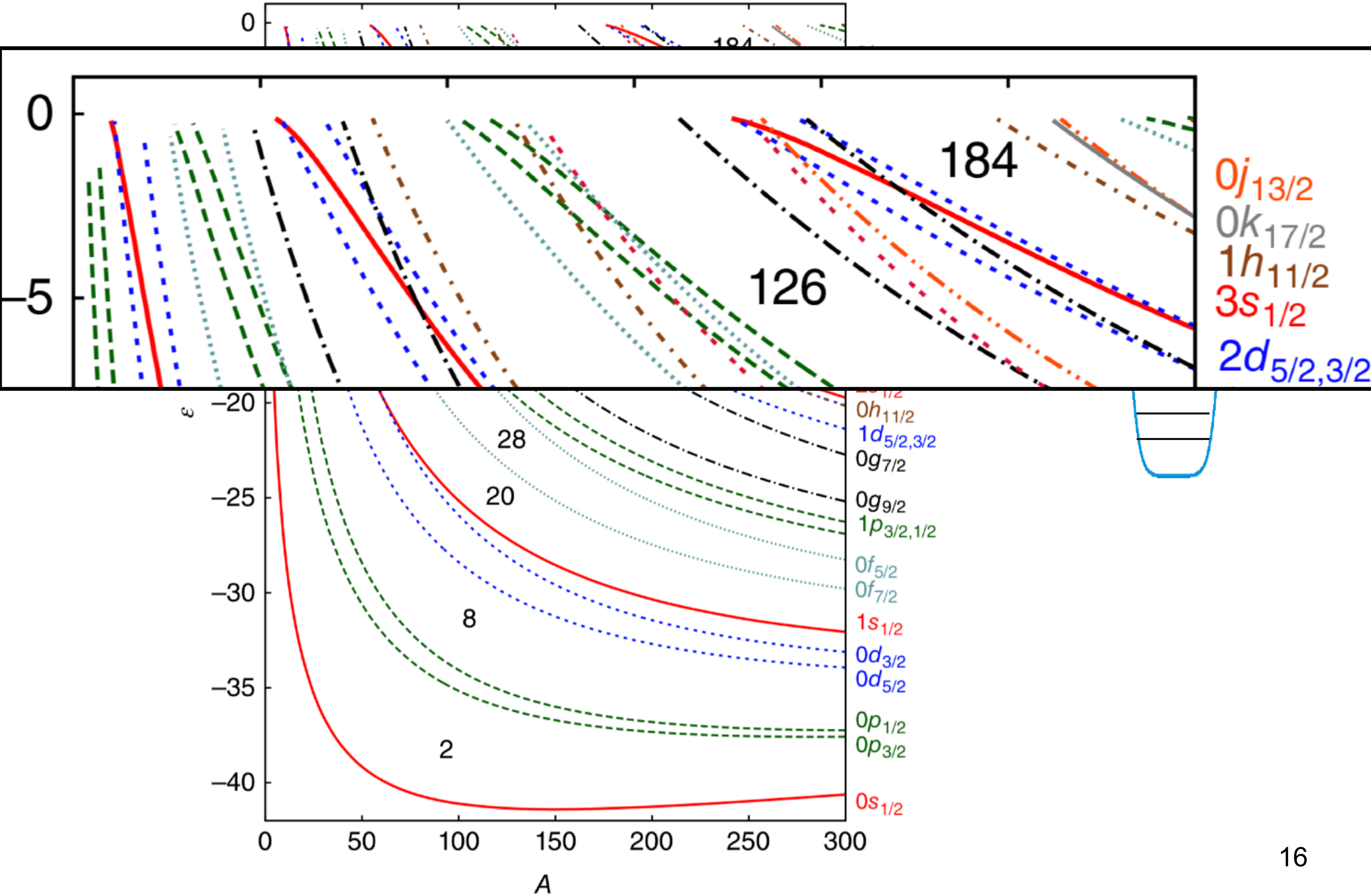




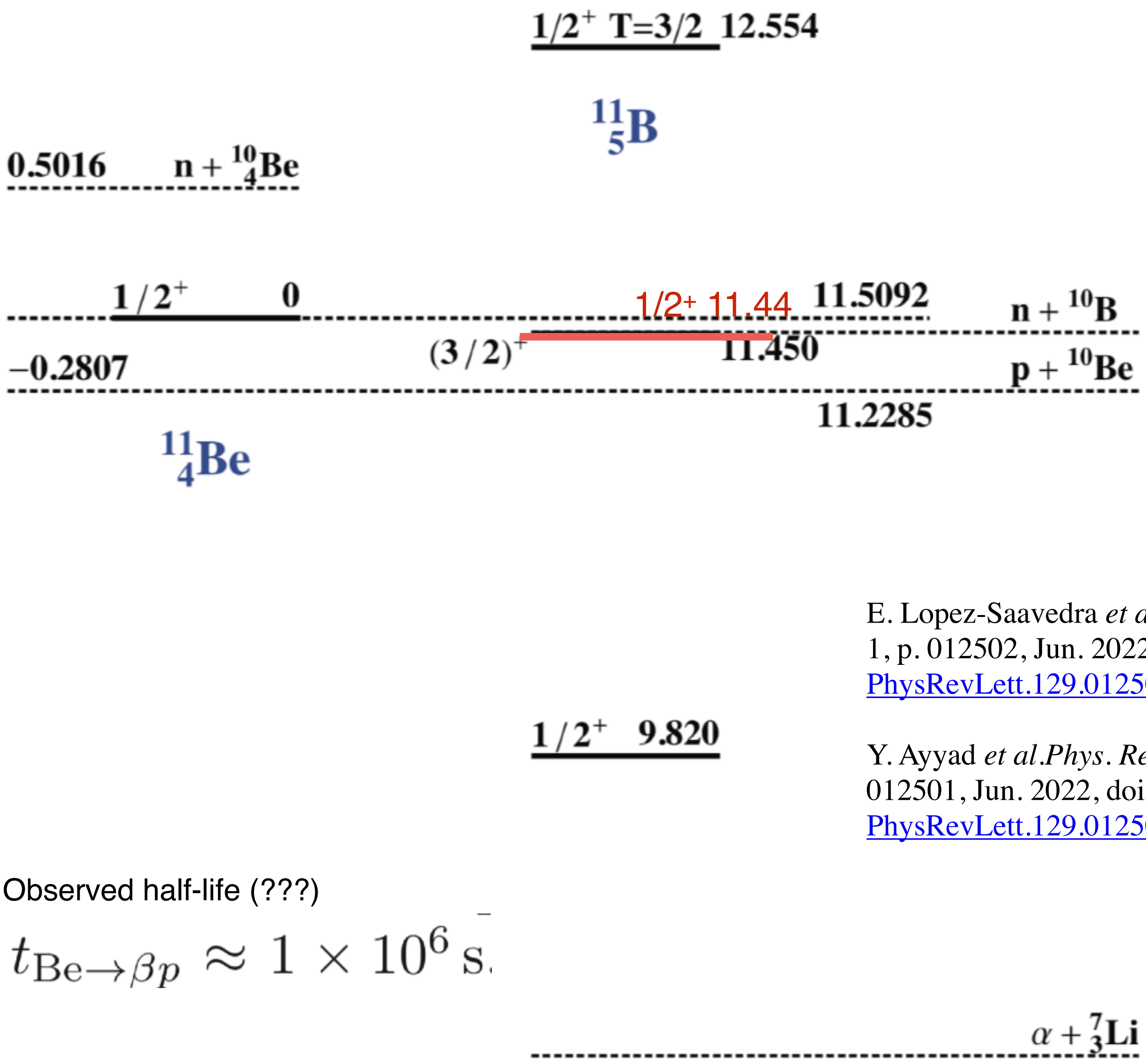


$$H'(\epsilon) = \int_0^\infty d\epsilon' \, A^*(\epsilon') \frac{1}{\epsilon - \epsilon' + i0} A(\epsilon')$$

Evolution of single particle energies



11Be beta-delayed proton decay



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Y. Ayyad *et al.* *Phys. Rev. Lett.*, vol. 129, no. 1, p. 012501, Jun. 2022, doi: [10.1103/PhysRevLett.129.012501](https://doi.org/10.1103/PhysRevLett.129.012501).

Observed half-life (???)

$$t_{\mathrm{Be}\to\beta p} \approx 1 \times 10^6 \text{ s.}$$

Wave function realignment
Superradiance

$$H = \begin{pmatrix} \epsilon - \frac{i}{2}\Gamma & v \\ v & 0 \end{pmatrix} = H_0 - \frac{i\Gamma}{2} A^\dagger A \qquad A = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

Stationary system $\Gamma = 0$

Energies $$E_{1,2} = \frac{1}{2}\left(\epsilon \pm \sqrt{\epsilon^2 + 4v^2}\right)$$

Spectroscopic Factors $$\mathrm{SF}_{1,2} = \frac{1}{2}\left(1 \pm \frac{\epsilon}{\sqrt{\epsilon^2 + 4v^2}}\right)$$

Observing superradiance

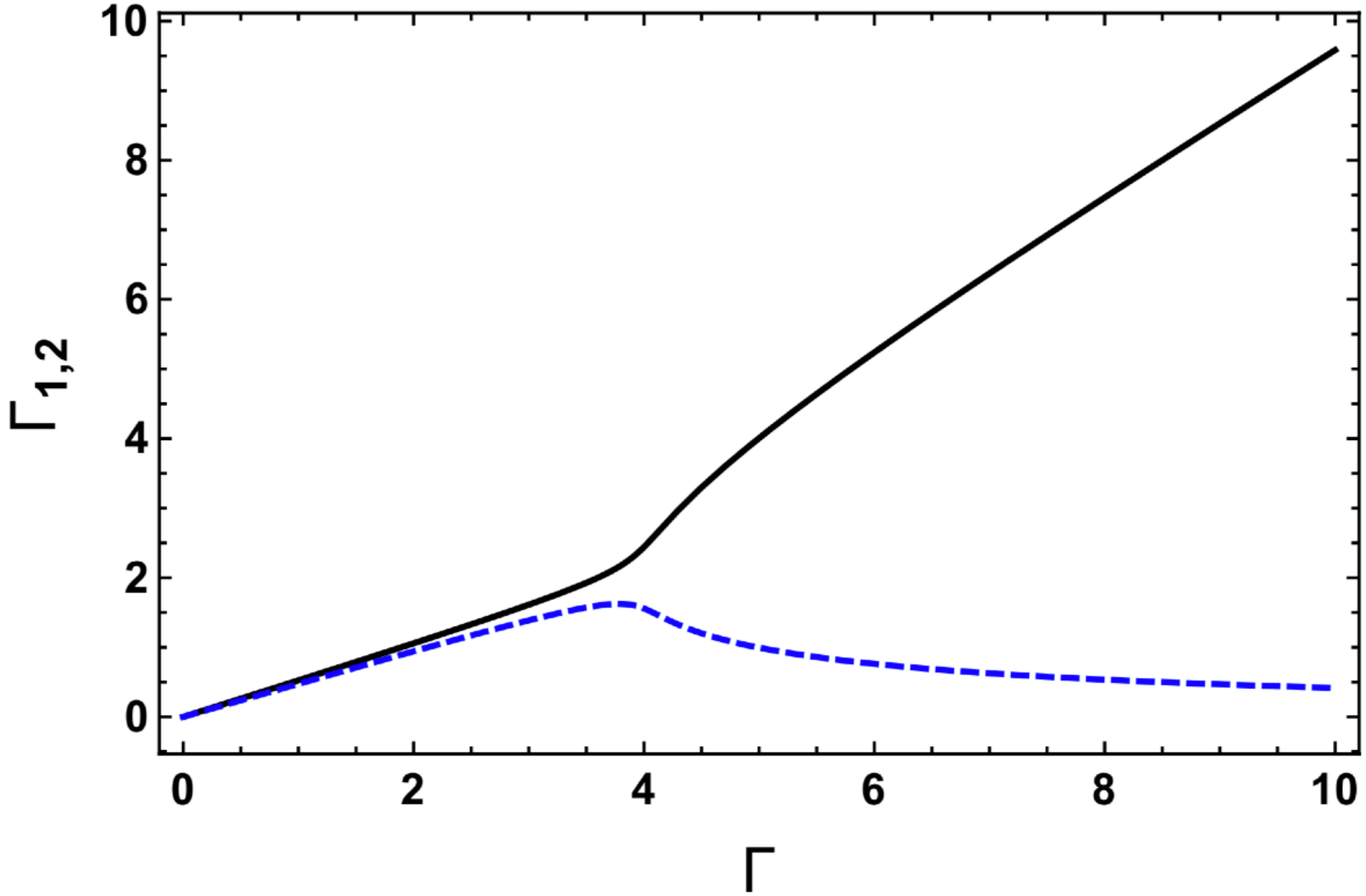
$$H = \begin{pmatrix} \epsilon - \frac{i}{2}\Gamma & v \\ v & 0 \end{pmatrix} = H_0 - \frac{i\Gamma}{2} A^\dagger A \qquad A = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

Energies $$\mathcal{E}_{1,2} = \frac{1}{2}\left(\epsilon - \frac{i}{2}\Gamma \pm \sqrt{\left(\epsilon - \frac{i}{2}\Gamma\right)^2 + 4v^2}\right)$$

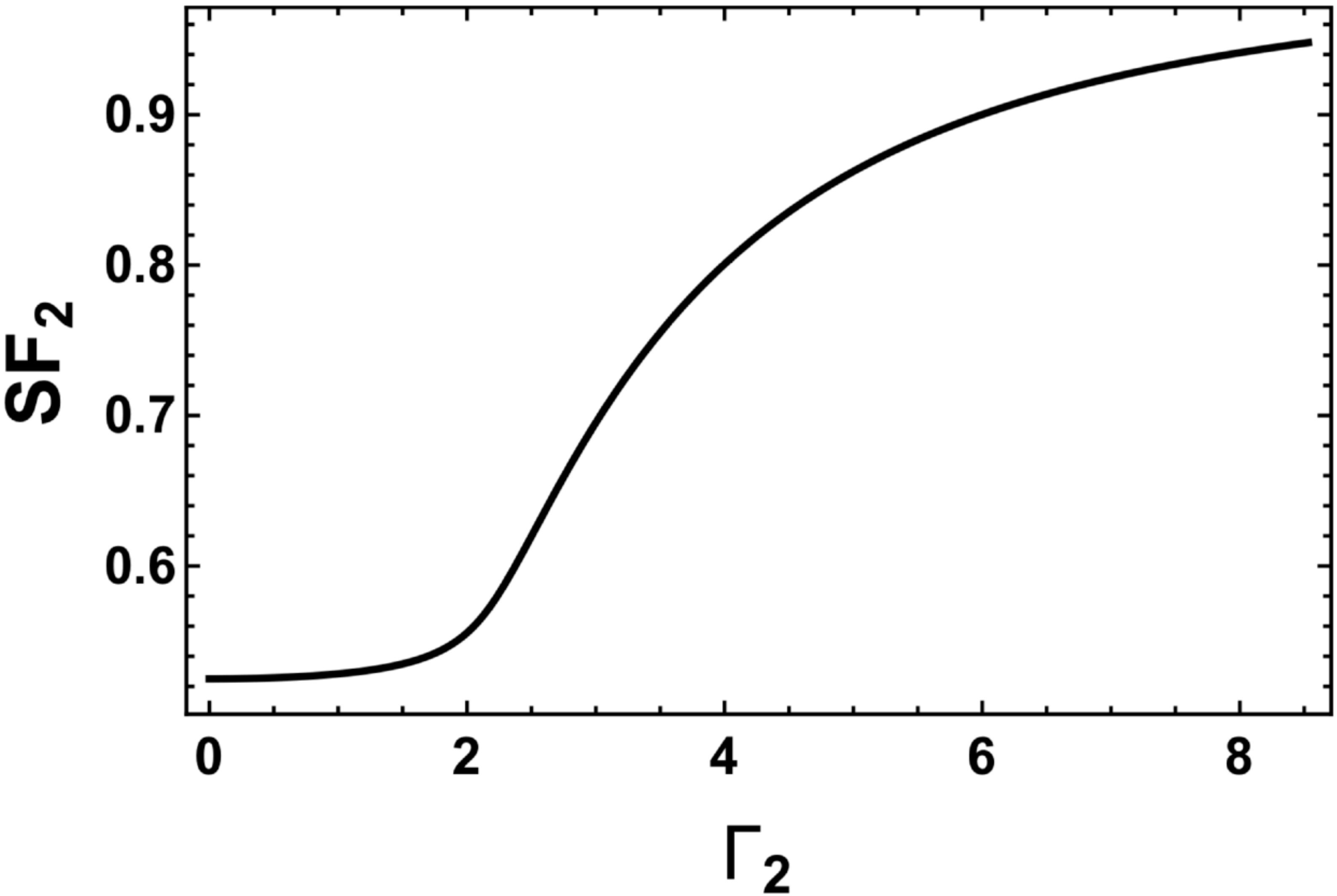
Width $$\Gamma_{1,2} = -2\,\mathrm{Im}\left(\mathcal{E}_{1,2}\right)$$

Spectroscopic Factors $$\mathrm{SF}_{1,2} = \Gamma_{1,2}/\Gamma$$

Observing superradiance

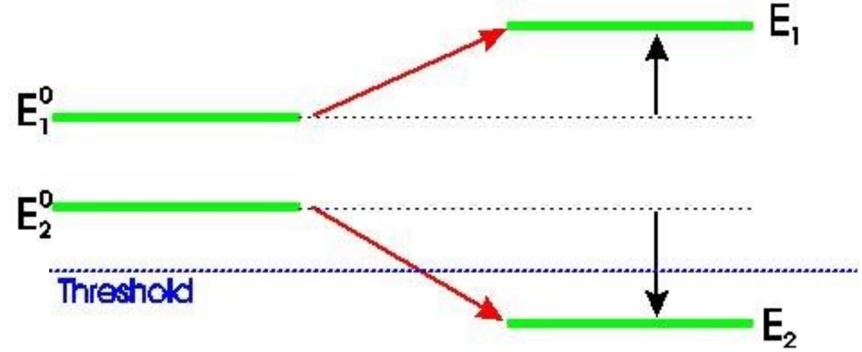


Spectroscopic factor for superradiant state

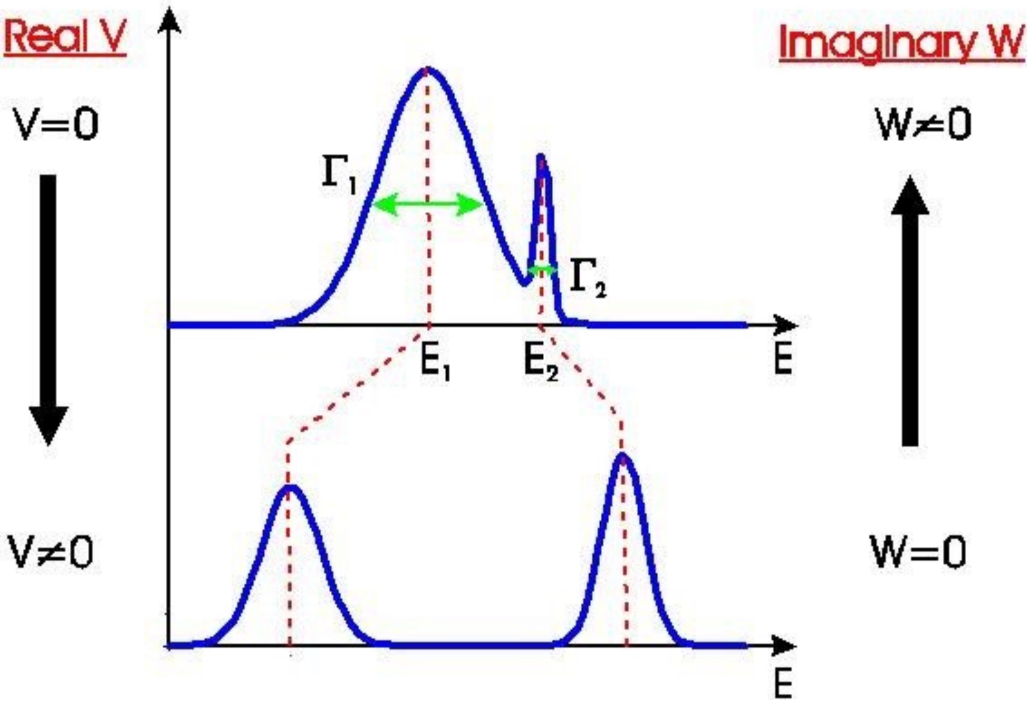


Example of interacting resonances

^{13}C, ^{13}N, ^{11}Li



$$\mathcal{H} = H^0 + V - iW/2$$



Summary:

11B resonant state may represent a remarkable near-threshold effect

- Position of the state
- Strong orientation towards proton decay channel
- Weak alpha channel

11Be decay and resonance in 11B is not a fully resolved story.

Acknowledgements:

Funding: U.S. DOE contract DE-SC0009883.

Publications:

A. Volya, EPL 130 (2020) 12001.

E. Lopez-Saavedra et al., Phys. Rev. Lett., 129, (2022) 012502.

A. Volya, M. Barbui, V. Z. Goldberg, and G. V. Rogachev, Commun Phys 5 (2022), 1