

β -delayed proton emission from ^{11}Be in EFT



Nuclear physics at the edge of stability

ECT* – workshop

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Outline

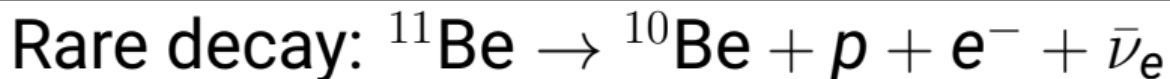


- ▶ Motivation for rare decay $^{11}\text{Be} \rightarrow ^{10}\text{Be} + p + e^- + \bar{\nu}_e$
- ▶ Halo EFT for β -delayed proton emission from ^{11}Be
- ▶ Effective Lagrangians
 - ▶ Strong sector
 - ▶ Weak sector
- ▶ Results
- ▶ Conclusion

Motivation for rare decay of ^{11}Be



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Model Calculation

- ▶ [Baye and Tursunov, 2011]:

$$b_p = 3.0 \times 10^{-8}$$



Experiment

- ▶ [Riisager et al., 2014]:

$$b_p = 8.3(6) \times 10^{-6}$$

Riisager et al.:

- ⇒ New single-particle resonance in ^{11}B ? [Riisager et al., 2014]
- ⇒ Possible pathway to detect physics beyond the SM? [Pfützner and Riisager, 2018]

Motivation for rare decay of ^{11}Be



More recent experiments

- ▶ [Ayyad et al., 2019]: $b_p = 1.3(3) \times 10^{-5}$
 - ▶ New evidence for resonance in ^{11}B with $E_R = 0.196(20)$ MeV and $\Gamma_R = 12(5)$ keV
- ▶ [Riisager et al., 2020]: $b_p \leq 2.2 \times 10^{-6}$
 - ▶ Inconsistencies between different measurements

⇒ Branching ratio for β -delayed proton emission in ^{11}Be remains an unsolved problem

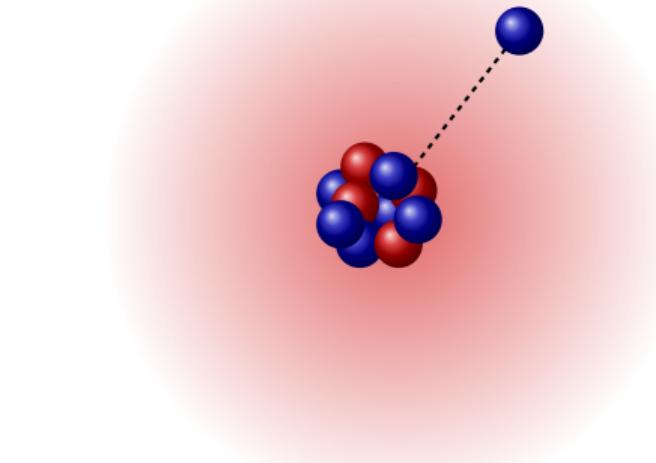
Halo EFT for β -delayed proton emission from ^{11}Be



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Halo EFT offers new perspective on β -delayed proton emission from ^{11}Be

- ▶ Ground state of ^{11}Be is a halo state
- ▶ $S_n = 501.65(25)$ keV [Kelley et al., 2012],
 $E_{\text{ex}} = 3368.03(3)$ keV [Tilley et al., 2004]
⇒ Separation of scales: $S_n \ll E_{\text{ex}}$



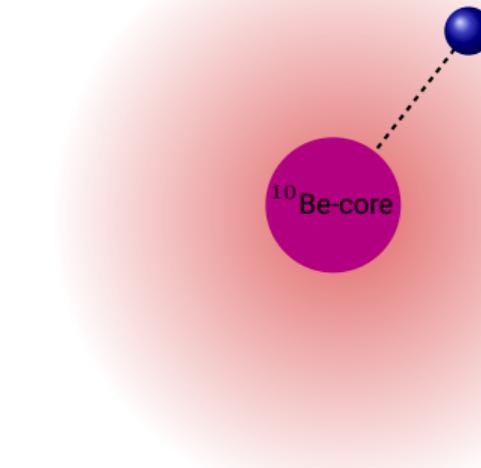
Halo EFT for β -delayed proton emission from ^{11}Be



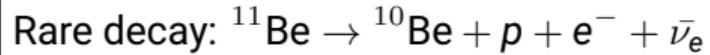
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⇒ Separation of scales: $S_n \ll E_{\text{ex}}$
- ▶ Halo EFT degrees of freedom:
tightly bound core and loosely bound
valence neutron

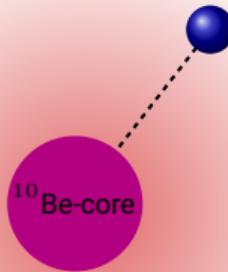


Halo EFT for β -delayed proton emission from ^{11}Be



- ▶ $T_{1/2}^{1n} \approx 10 \text{ min} \ll T_{1/2}^{^{10}\text{Be}} \approx 10^6 \text{ a}$
⇒ Always halo neutron that β -decays in the halo picture
- ▶ Decay observables parametrized in terms of few measurable parameters
- ▶ EFT power counting ⇒ robust uncertainty estimate

Halo EFT well suited for the theoretical description of this decay providing decay rate with robust uncertainty estimate



Strong Effective Lagrangian



$$\mathcal{L} = \frac{n}{\text{---}} + \frac{p}{\text{---}} + \dots$$

$$+ \quad \text{---} \quad + \quad \text{---}$$

$$+ \quad \text{---} \begin{cases} n \\ p \end{cases} + \text{H.c.} + \text{---} \begin{cases} n \\ p \end{cases} + \text{H.c.}$$

Weak Effective Lagrangian



$$\mathcal{L}_{\text{weak}} = -\frac{G_F}{\sqrt{2}} \ell_-^\mu \left(\left(J_\mu^+ \right)^{\text{1b}} + \left(J_\mu^+ \right)^{\text{2b}} \right)$$

1b current:



$$\ell_-^\mu = \bar{u}_e \gamma^\mu (1 - \gamma^5) v_{\bar{\nu}}$$

2b current:



$$\left(J_\mu^+ \right)^{\text{1b}} = \begin{cases} p^\dagger n & \mu = 0 \text{ (Fermi)} \\ -g_A p^\dagger \sigma_k n & \mu = k = 1, 2, 3 \text{ (Gamow-Teller)} \end{cases}$$

$$\left(J_\mu^+ \right)^{\text{2b}} = \begin{cases} -d_B^\dagger d_{Be} & \mu = 0 \text{ (Fermi)} \\ g_A d_B^\dagger \sigma_k d_{Be} & \mu = k = 1, 2, 3 \text{ (Gamow-Teller)} \end{cases}$$

Feynman diagrams

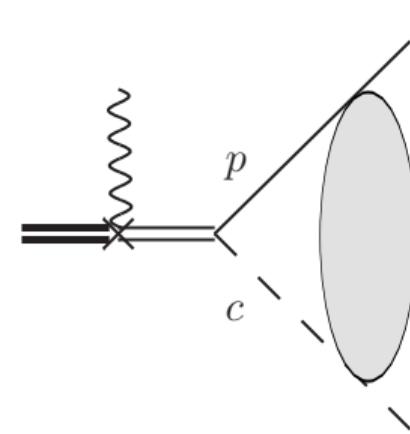
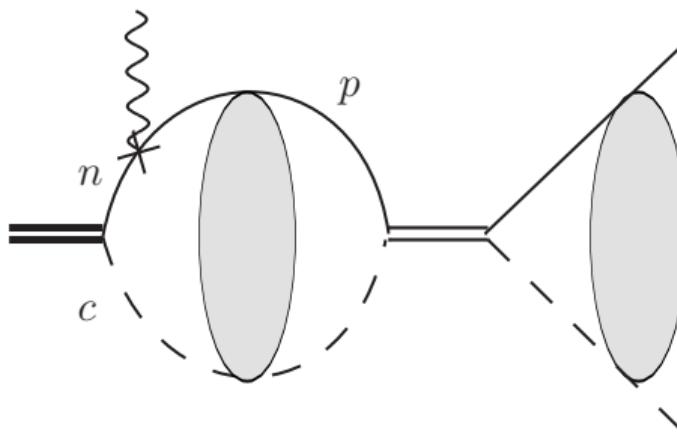
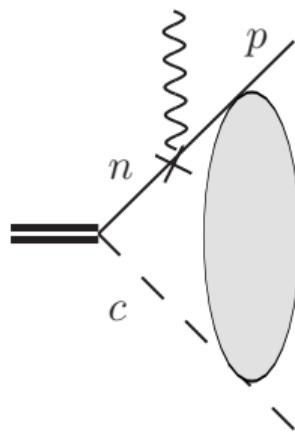


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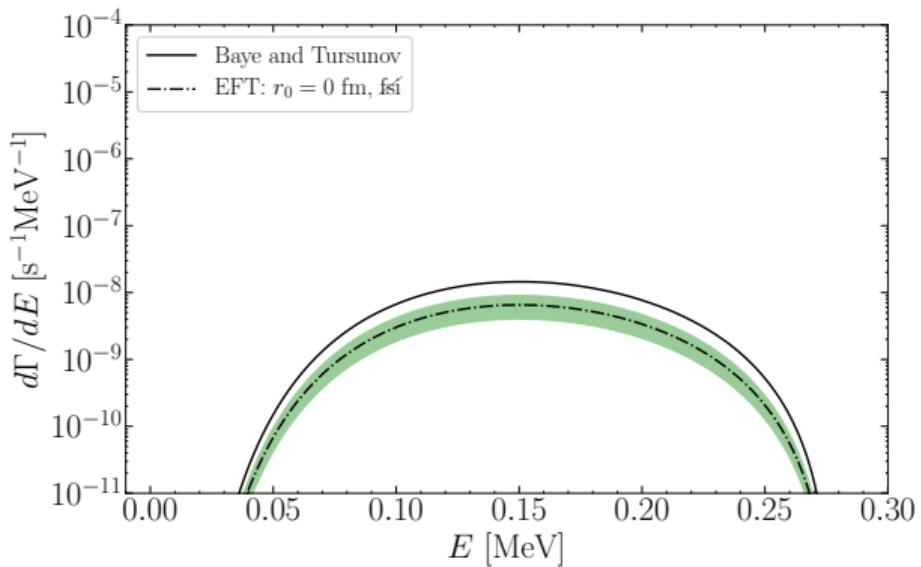
fsi



Differential decay rate

No strong fsi

- $b_p^{\text{B\&T}} = 3 \times 10^{-8}$
- $b_p^{\text{fsi}} = (1.31 \pm 0.51) \times 10^{-8}$



Differential decay rate

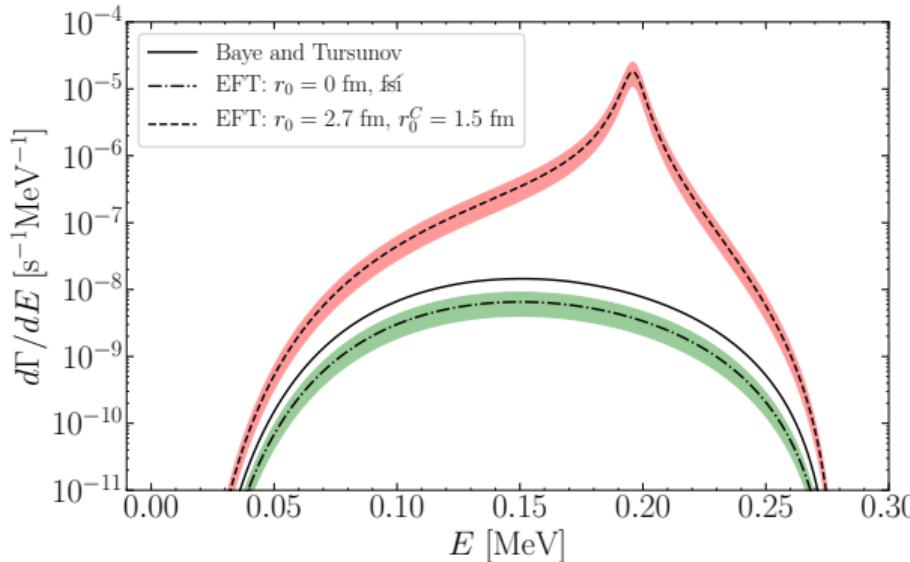
No strong fsi

- ▶ $b_p^{\text{B\&T}} = 3 \times 10^{-8}$
- ▶ $b_p^{\text{fsi}} = (1.31 \pm 0.51) \times 10^{-8}$

EFT including resonance up to NLO

$E_R = 0.196 \pm 0.020 \text{ MeV}$ [Ayyad et al., 2019]

$$b_p^{\text{NLO}} = 4.9_{-2.9}^{+5.6} (\text{exp.})_{-0.8}^{+4.0} (\text{theo.}) \times 10^{-6}$$



Partial decay rate as a function of E_R

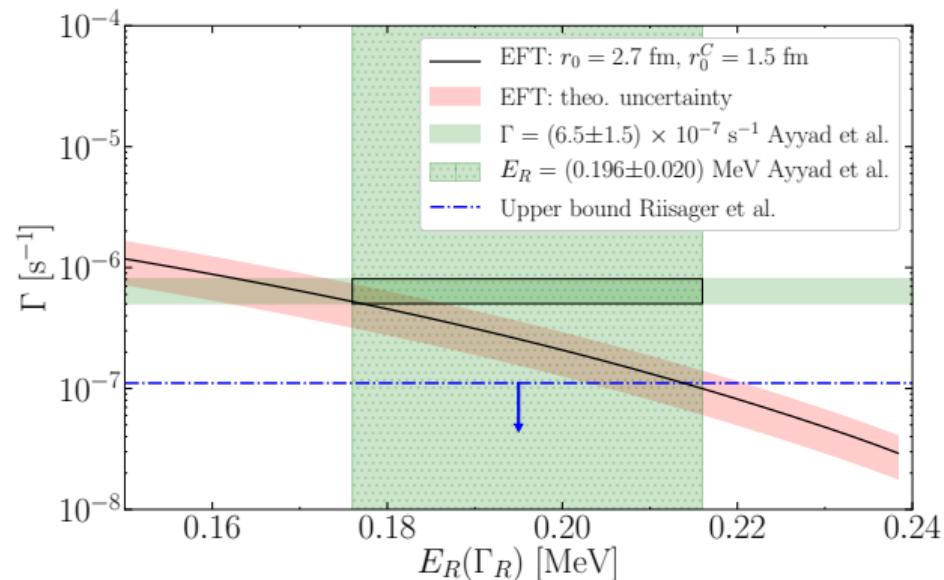
Final results

$$E_R = 0.196 \pm 0.020 \text{ MeV} \text{ [Ayyad et al., 2019]}$$

$$b_p^{\text{NLO}} = 4.9_{-2.9}^{+5.6} (\text{exp.})_{-0.8}^{+4.0} (\text{theo.}) \times 10^{-6}$$

$$\Gamma_R = (9.0_{-3.3}^{+4.8} (\text{exp.})_{-2.2}^{+5.3} (\text{theo.})) \text{ keV}$$

$$\log(ft) = 3.0, B_{\text{GT}} = 2.88, B_{\text{F}} = 0.96$$



Conclusion

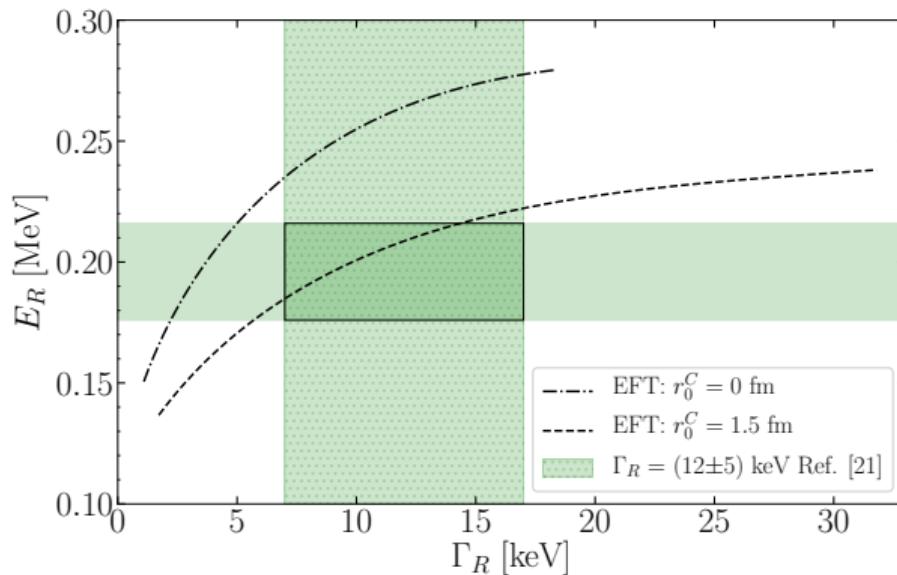


- ▶ No fsi \Rightarrow qualitative agreement with [Baye and Tursunov, 2011]
- ▶ Inclusion of low-lying resonance in ^{11}B with $E_R = 0.196 \text{ MeV}$ [Ayyad et al., 2019]
 \Rightarrow Partial decay rate and resonance width consistent with this experiment
- ▶ Our model-independent calculation supports experimental finding of a low-lying resonance
- ▶ No exotic mechanism needed for β -delayed proton emission from ^{11}Be

Thank you for your attention!

Backup slides

Possible resonance parameter combinations fulfilling sum rule



References



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