Weak decay of ^{11}Be in Halo EFT

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Outline

- Motivation for rare decay ${}^{11}\text{Be} \rightarrow {}^{10}\text{Be} + p + e^{-} + \bar{\nu}_e$
- Halo EFT for weak decay of ${}^{11}\text{Be}$
- Effective Lagrangians
  - Strong sector
  - Weak sector
- Results
- Conclusion

Motivation for rare decay of ^{11}Be

$$\boxed{\text{Rare decay: } {}^{11}\text{Be} \rightarrow {}^{10}\text{Be} + p + e^{-} + \bar{\nu}_e}$$

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]: $b_p = 1.3(3) \times 10^{-5}$
  - 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
- [Ayyad et al., 2022]: Proton resonance scattering
  - New evidence for resonance in ^{11}B with $E_R = 0.171(20)$ MeV and $\Gamma_R = 4.5(1.1)$ keV

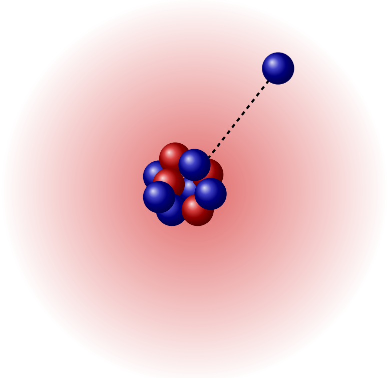
$\Rightarrow$ Branching ratio for β-delayed proton emission in ^{11}Be remains an unsolved problem

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

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]
  $\Rightarrow$ Separation of scales: $S_n \ll E_{\text{ex}}$



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

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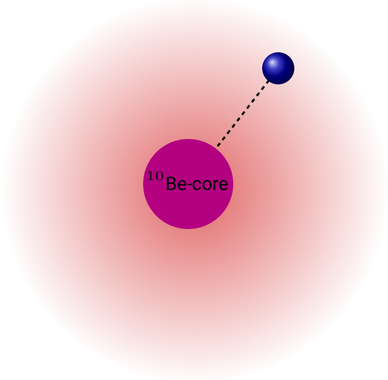
- Ground state of ^{11}Be is a halo state
- $S_n = 501.65(25)$ keV [Kelley et al., 2012],

  $E_{\text{ex}} = 3368.03(3)$ keV [Tilley et al., 2004]

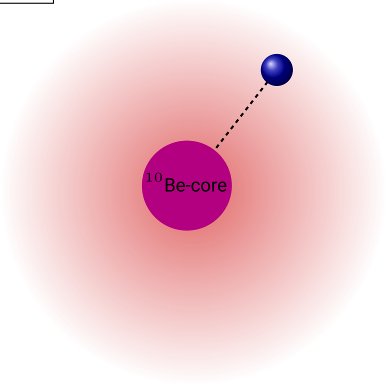
  $\Rightarrow$ Separation of scales: $S_n \ll E_{\text{ex}}$
- Halo EFT degrees of freedom:
  tightly bound core and loosely bound
  valence neutron



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

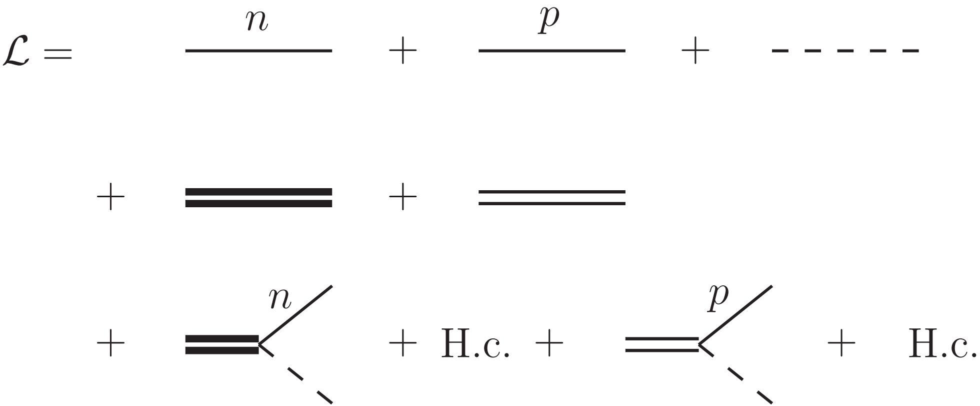
Rare decay: $^{11}\text{Be} \rightarrow {}^{10}\text{Be} + p + e^{-} + \bar{\nu}_e$

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



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

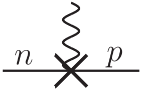
Strong effective Lagrangian



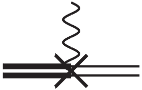
Weak Effective Lagrangian

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

1b current:



2b current:

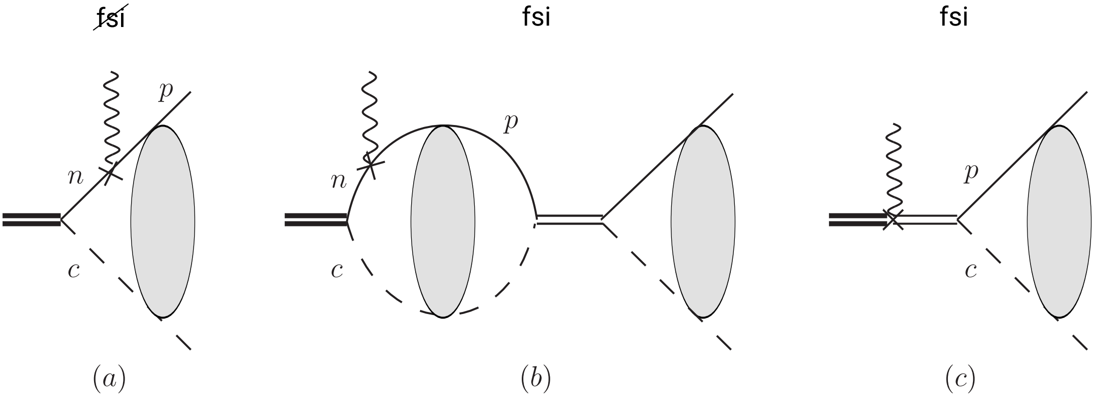


$$\ell_-^{\mu} = \bar{u}_e \gamma^{\mu}(1-\gamma^5) v_{\bar{\nu}}$$

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

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

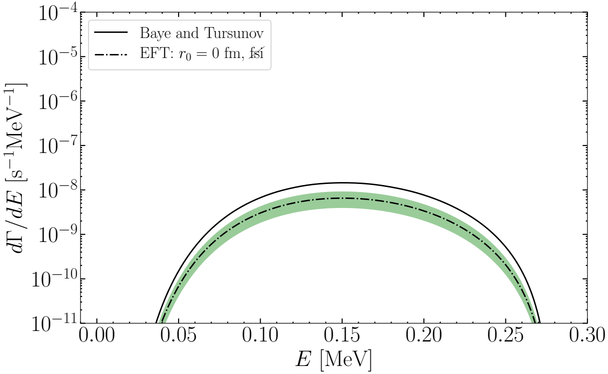
Feynman diagrams



Differential decay rate

No strong fsi

- $b_p^{\text{B\&T}} = 3 \times 10^{-8}$ [Baye and Tursunov, 2011]
- $b_p^{\cancel{\text{fsi}}} = (1.31 \pm 0.51) \times 10^{-8}$



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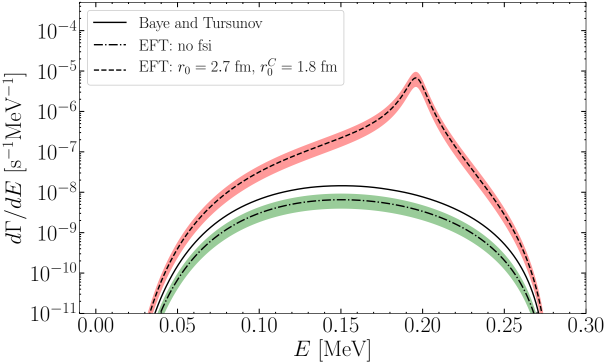
EFT including resonance up to NLO

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

$$b_p = \left(2.3^{+2.5}_{-1.3}(\text{exp.})^{+1.8}_{-0.4}(\text{theo.})\right) \times 10^{-6}$$



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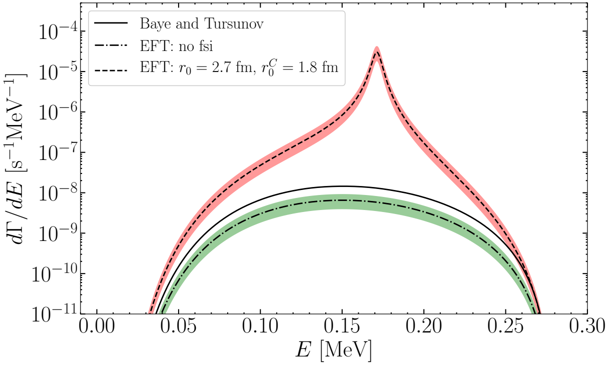
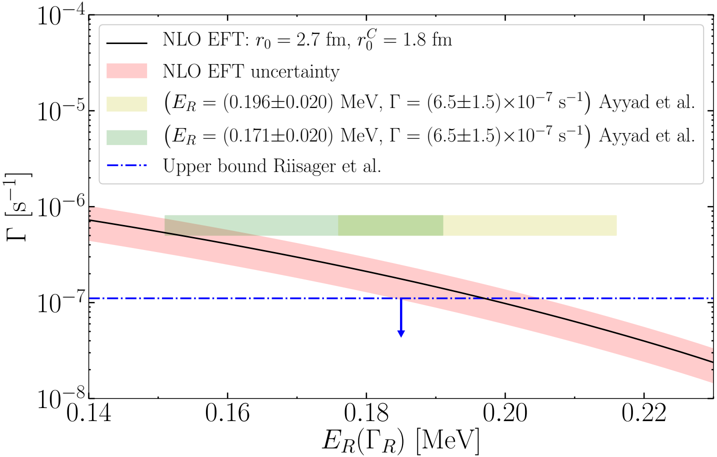
EFT including resonance up to NLO

$E_R = 0.171 \pm 0.020$ MeV [Ayyad et al., 2022]

$b_p = \left(5.7^{+5.0}_{-2.9}(\text{exp.})^{+4.1}_{-1.1}(\text{theo.})\right) \times 10^{-6}$



Partial decay rate as a function of E_R



Comparison to both experiments by Ayyad et al.

$E_R = (0.196 \pm 0.020)$ MeV [Ayyad et al., 2019]

$$b_p = \left(2.3^{+2.5}_{-1.3}(\text{exp.})^{+1.8}_{-0.4}(\text{theo.})\right) \times 10^{-6}$$

$$b_p = (1.3 \pm 0.3) \times 10^{-5}$$ [Ayyad et al., 2019]

$$\Gamma_R = \left(11.3^{+6.9}_{-4.2}(\text{exp.})^{+7.0}_{-2.7}(\text{theo.})\right) \text{ keV}$$

$$\Gamma_R = (12 \pm 5) \text{ keV}$$ [Ayyad et al., 2019]

$\log(ft) = 3.38$, $B_{\text{GT}} = 1.59$

$E_R = (0.171 \pm 0.020)$ MeV [Ayyad et al., 2022]

$$b_p = \left(5.7^{+5.0}_{-2.9}(\text{exp.})^{+4.1}_{-1.1}(\text{theo.})\right) \times 10^{-6}$$

$$b_p = (1.3 \pm 0.3) \times 10^{-5}$$ [Ayyad et al., 2019]

$$\Gamma_R = \left(6.2^{+3.8}_{-2.6}(\text{exp.})^{+3.9}_{-1.4}(\text{theo.})\right) \text{ keV}$$

$$\Gamma_R = (4.5 \pm 1.1) \text{ keV}$$ [Ayyad et al., 2022]

$\log(ft) = 3.37$, $B_{\text{GT}} = 1.63$

Conclusion

- No fsi $\Rightarrow$ qualitative agreement with [Baye and Tursunov, 2011]

- Inclusion of low-lying resonance in ^{11}B with either $E_R = 0.196$ MeV [Ayyad et al., 2019] or $E_R = 0.171$ MeV [Ayyad et al., 2022]

  $\Rightarrow$ Partial decay rates and resonance widths consistent with these experiments

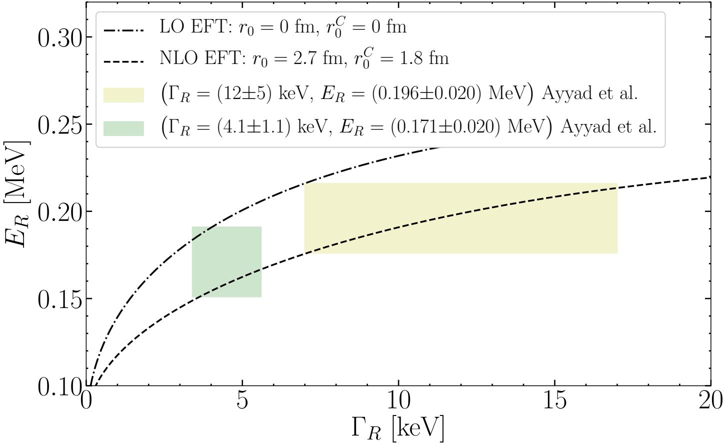
- Our model-independent calculations support experimental finding of a low-lying resonance

- 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



Differential decay rate (no definite isospin)

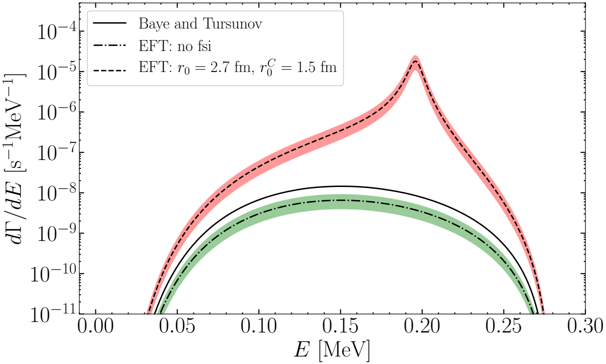
No strong fsi

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

EFT including resonance up to NLO

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

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



Differential decay rate (no definite isospin)

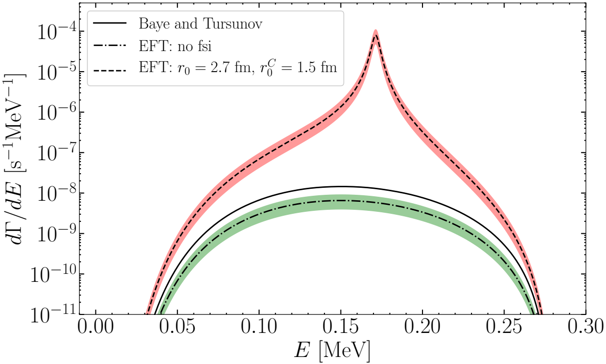
No strong fsi

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

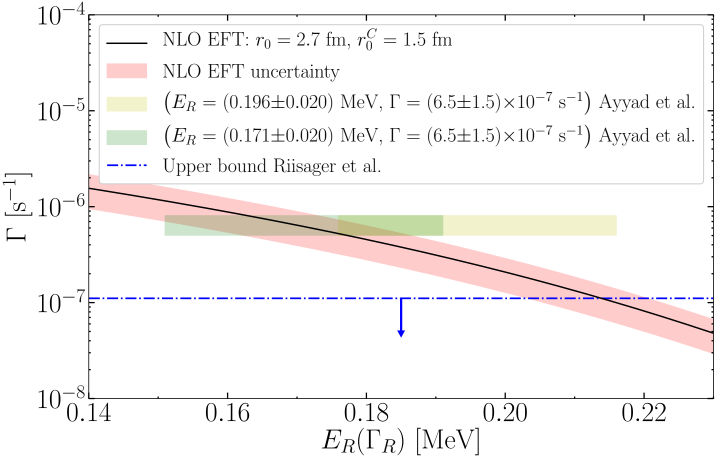
EFT including resonance up to NLO

$E_R = 0.171 \pm 0.020$ MeV [Ayyad et al., 2019]

$b_p^{\text{NLO}} = 1.2^{+1.0}_{-0.6}(\text{exp.})^{+0.9}_{-0.2}(\text{theo.}) \times 10^{-5}$



Partial decay rate as a function of E_R (no definite isospin)



Results (no definite isospin)

Final results using E_R from Ayyad et al., 2019

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

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

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

$$\log(ft) = 3.04,\ B_F = 0.96\ \text{and}\ B_{GT} = 2.88$$

Final results using E_R from Ayyad et al., 2022

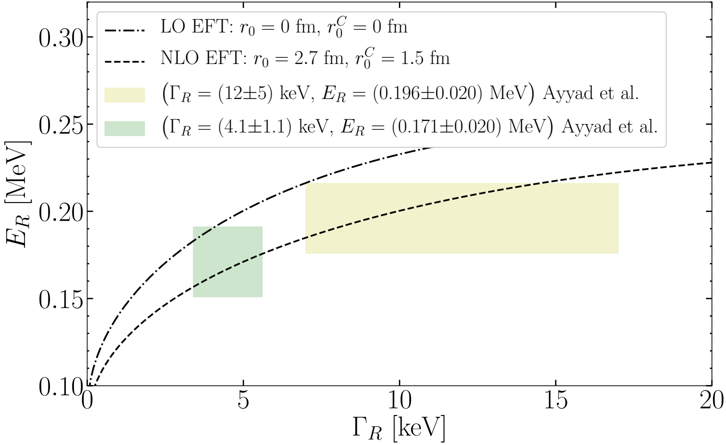
$E_R = 0.171 \pm 0.020$ MeV [Ayyad et al., 2022]

$$b_p = \left(1.2^{+1.1}_{-0.6}\text{(exp.)}^{+0.9}_{-0.2}\text{(theo.)}\right) \times 10^{-5}$$

$$\Gamma_R = \left(5.0^{+3.0}_{-2.1}\text{(exp.)}^{+3.1}_{-1.1}\text{(theo.)}\right)\ \text{keV}$$

$$\log(ft) = 3.03,\ B_F = 0.97\ \text{and}\ B_{GT} = 2.92$$

Possible resonance parameter combinations fulfilling sum rule (no definite isospin)



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