IOP Institute of Physics

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Solving the apparent inconsistency between GSI and RIKEN estimates of the E1 strength in ^{11}Be

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Glasgow, 02.08.2019

ENSAR2

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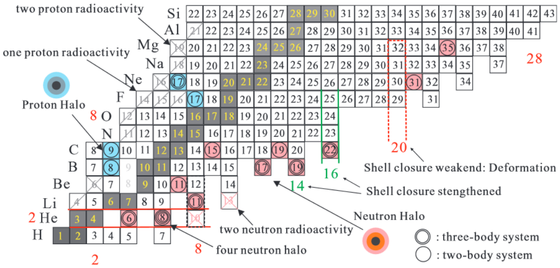
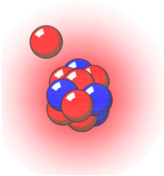
Halo nuclei

Exotic nuclear structures far from stability





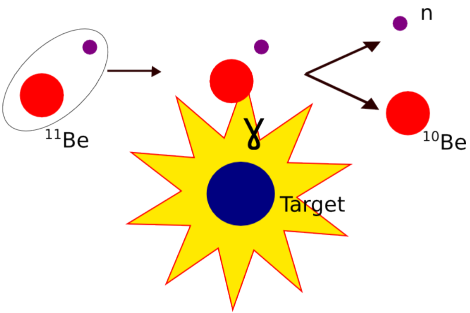
One-neutron halo nuclei

$^{11}\text{Be} = {}^{10}\text{Be} + \text{n}$

$^{15}\text{C} = {}^{14}\text{C} + \text{n}$

Breakup reaction as spectroscopic tool

$\tau_{1/2}(^{11}\text{Be}) \sim 13$ s $\Rightarrow$ indirect techniques: **reactions**

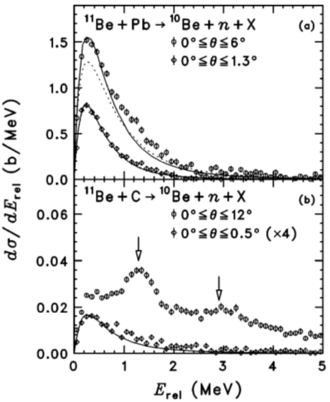


- $\frac{d\sigma_C}{dE} \propto \frac{dB(E1)}{dE} \propto \sum_i |\langle\varphi_i||Z_{eff}\, r\, Y_{1\mu}(r)||\varphi_0\rangle|^2$

$^{11}Be+^{208}Pb$ and $^{11}Be+^{12}C$ breakup

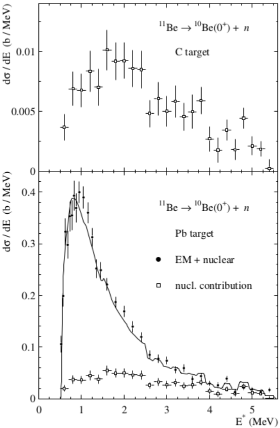
@ ∼70A MeV (RIKEN)

Fukuda *et al.*, PRC **70** (2004)



@ 520A MeV (GSI)

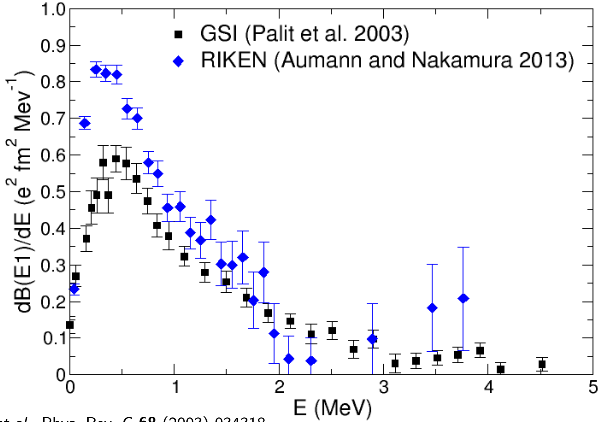
Palit *et al.*, PRC **68** (2003)



An apparent discrepancy

The $dB(E1)/dE$ of ^{11}Be

extracted from GSI data **differs** from RIKEN results

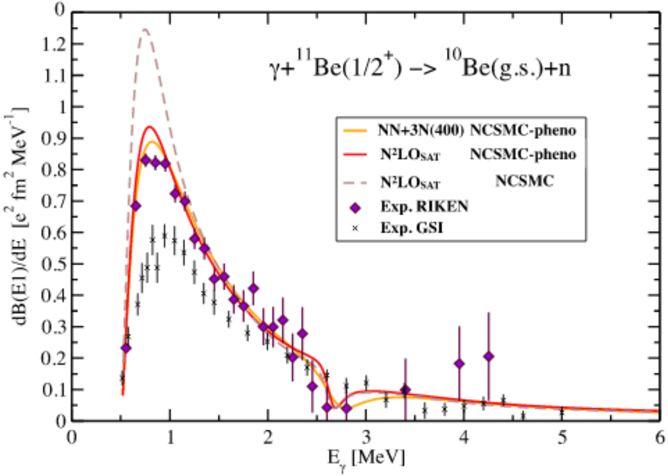


GSI: Palit *et al.*, Phys. Rev. C **68** (2003) 034318

RIKEN: Aumann and Nakamura, Phys. Scr. **T152** (2013) 014012

...an open problem!

Calci, Navrátil, Roth, Dohet-Eraly, Quaglioni and Hupin, PRL **117** (2016)



Our goal

To describe both RIKEN and GSI cross sections

using only one structure model of ^{11}Be

$\rightarrow$ which is related to a $dB(E1)/dE$

The ^{11}Be internal structure: Halo-EFT @NLO

$$H_0\ \varphi_{ljm}(E,\mathbf{r}) = E\ \varphi_{ljm}(E,\mathbf{r}) \quad \rightarrow \quad H_0 = -\frac{\hbar^2\Delta}{2\mu_{Cf}} + V_{Cf}(\mathbf{r})$$

$$V_{Cf}(r) = V_0 e^{-\frac{r^2}{2{r_0}^2}} + V_2 r^2 e^{-\frac{r^2}{2{r_0}^2}}$$

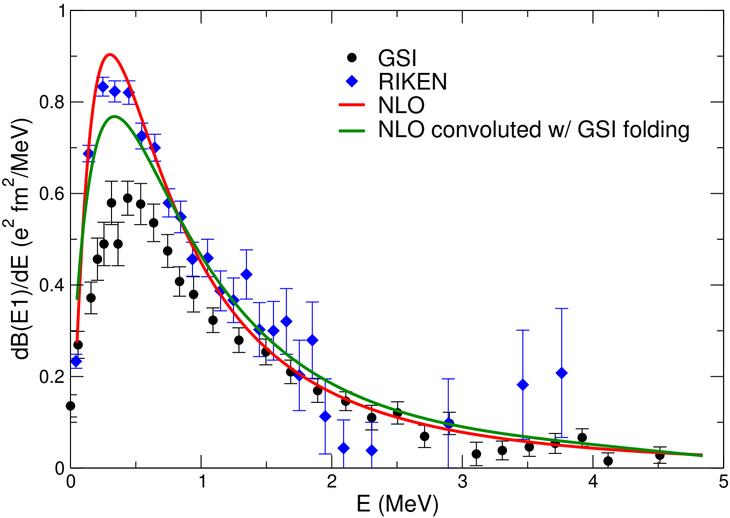
- V_2 and V_0 are adjusted in s and p waves to fit
  - Binding Energy and Asymptotic Normalization Constant for bound states
  - phaseshift δ, for continuum

  ANC and δ_p from *ab initio* calc. Calci *et al.*, PRL**117** (2016)
- $V_{Cf} = 0\ \forall l > 1$
  $\Rightarrow$ no d waves $\Rightarrow$ no description of resonances for ^{11}Be!
- r_0 to evaluate the sensitivity to short-range physics

Review: Hammer, Ji and Phillips JPG 44 (2017) 103002

$dB(E1)/dE \sim \sum_i |\langle \varphi_i || Z_{eff}\, r Y_{1\mu}(r) || \varphi_0 \rangle|^2$

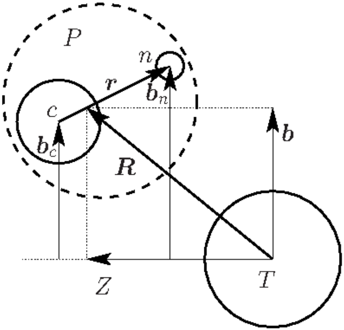
from ^{11}Be Halo EFT model



Are we able to describe RIKEN and GSI reactions

using this Halo EFT structure model?

Eikonal reaction model

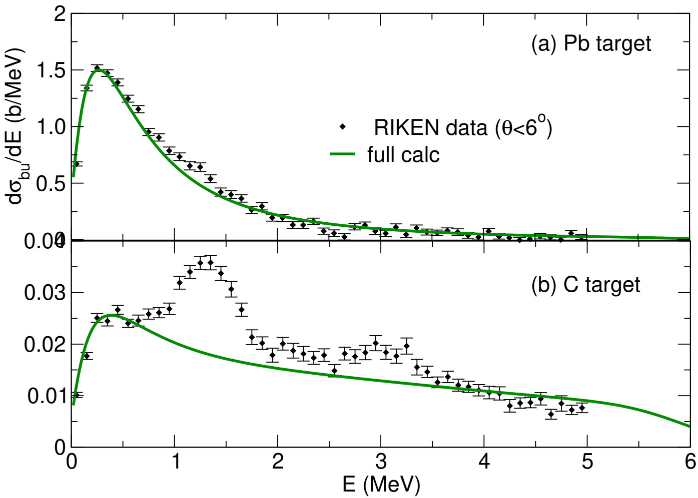


- $E_{LAB} = 69$ and 520 MeV/nucleon
- Halo-EFT ^{10}Be+n structure
- Pb and C targets
- no core excitation
- proper relativistic corrections
- $V_{PT} \rightarrow$ nuclear and Coulomb P-T interaction (at all orders)

Capel, Phillips, Hammer, PRC**98** (2018) 034610
Moschini and Capel, PLB**790** (2019) 367

^{11}Be model tested at RIKEN

^{11}Be+^{208}Pb @ 69 AMeV and ^{11}Be+^{12}C @ 67 AMeV

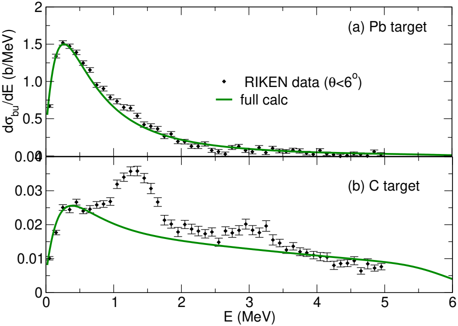


Capel, Phillips, Hammer, PRC**98** (2018) 034610

^{11}Be model tested at RIKEN

^{11}Be+^{208}Pb @ 69 AMeV and ^{11}Be+^{12}C @ 67 AMeV

Good agreement with data at low enegy on both targets

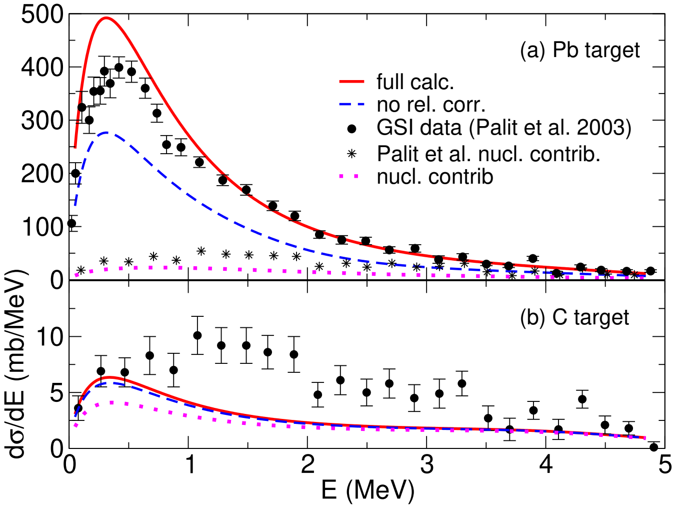


- Resonances are not reproduced on C target, because they are not included in the ^{11}Be structure model,
  but this is less important on Pb target

Capel, Phillips, Hammer, PRC**98** (2018) 034610

^{11}Be model tested at GSI energy

^{11}Be+^{208}Pb and ^{11}Be+^{12}C @ 520 AMeV



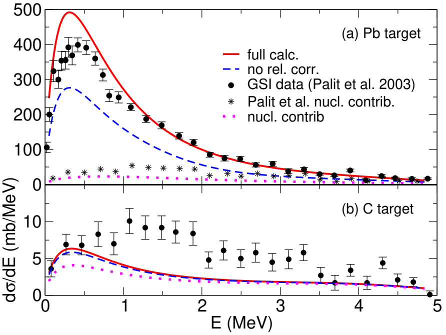
Moschini and Capel, PLB**790** (2019) 367–371

^{11}Be model tested at GSI energy

^{11}Be+^{208}Pb and ^{11}Be+^{12}C @ 520 AMeV

- **General good agreement with data**

except at small energies where data uncertainty is higher



- Our nuclear contribution on Pb target is lower than GSI estimate
  - We trust the reaction model: see results for ^{15}C in [arXiv:1907.11753]
- Relativistic corrections are important

Moschini and Capel, PLB**790** (2019) 367–371

^{11}Be model tested at GSI energy

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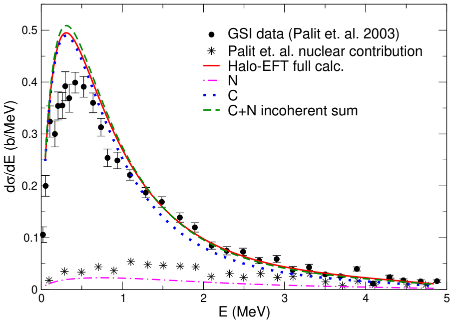

Moschini and Capel, PLB**790** (2019) 367–371

- Our nuclear contribution on Pb target is lower than GSI estimate
  - We trust the reaction model: see results for ^{15}C in [arXiv:1907.11753]
- Relativistic corrections are important
- Interference effect is not enough to explain the $dB(E1)/dE$ discrepancy!

$dB(E1)/dE$ is inferred from data

via the relativistic Coulomb excitation theory

$$\frac{d\sigma_C}{dE} = \frac{16\pi^3}{9\hbar c} N_{E1}(E, b_{min}) \frac{dB(E1)}{dE}$$

number of virtual photons with energy E
and with a minimum impact parameter b_{min}

Winther and Alder, *Nucl. Phys. A* **319** (1979) 518

Bertulani and Baur, Phys. Rep. **163** (1988) 299–408

$dB(E1)/dE$ is inferred from data

via the relativistic Coulomb excitation theory

$$\frac{d\sigma_C}{dE} = \frac{16\pi^3}{9\hbar c} N_{E1}(E) \frac{dB(E1)}{dE}$$

Coulomb breakup cross section is obtained by:

GSI subtraction of nuclear component to cross section on Pb

$\frac{d\sigma_C}{dE} = \frac{d\sigma_{bu}^{Pb}}{dE} - \Gamma \frac{d\sigma_N^C}{dE}$ (Yoshida et al., PTEP**2014** (2014) 053D03)

At 520AMeV this seems to work because interference and higher order effects are small!

RIKEN focusing on forward angles where the nuclear component is negligible

At 520AMeV we find destructive interference
$\Rightarrow$ the subtraction method could be dangerous
(but maybe, not enough to explain alone the discrepancy)
$\rightarrow$ we believe that to measure at small angles is safer

Summary and conclusions

Using only one Halo-EFT description of the projectile
related to one E1 strength in agreement with RIKEN estimate

we obtain quite good agreement with both RIKEN and GSI
measurements of the breakup of ^{11}Be

We can explain the apparent discrepancy
between RIKEN and GSI estimates of $dB(E1)/dE$
as a combination of different effects:

- C+N small destructive interference
- the method to determine the Coulomb cross section
- the disagreement at very small excitation energies
  between the reaction model and GSI data
  (where data uncertainty is higher)