Bayesian analysis of the Coulomb breakup of ^{19}C

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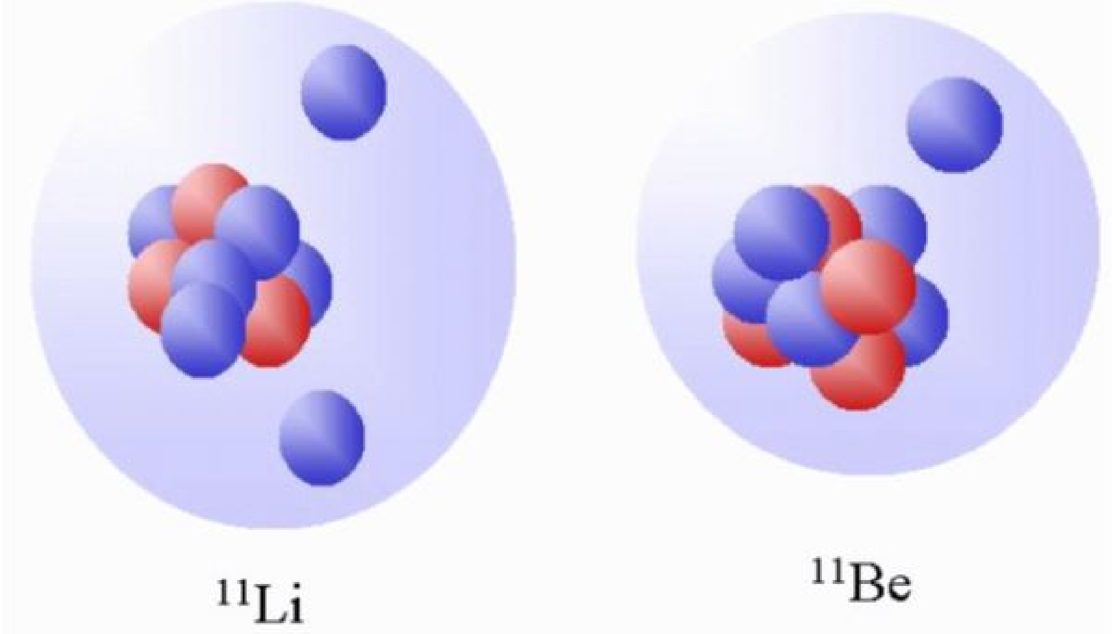
Introduction

- Halo nuclei : unstable, large matter radii, nuclei with 1-2 nucleons at large distance from the core
- Examples 1 neutron halo : $^{11}\mathrm{Be}$ and $^{19}\mathrm{C}$
- Example 2 neutron halo : $^{11}\mathrm{Li}$
- Unstable (half-life $^{19}\mathrm{C}$ = 46 ms), cannot be used as target



[https://epscollege.uoanbar.edu.iq/English/News_Details.php?ID=466]

Coulomb breakup of $^{19}\mathrm{C}$

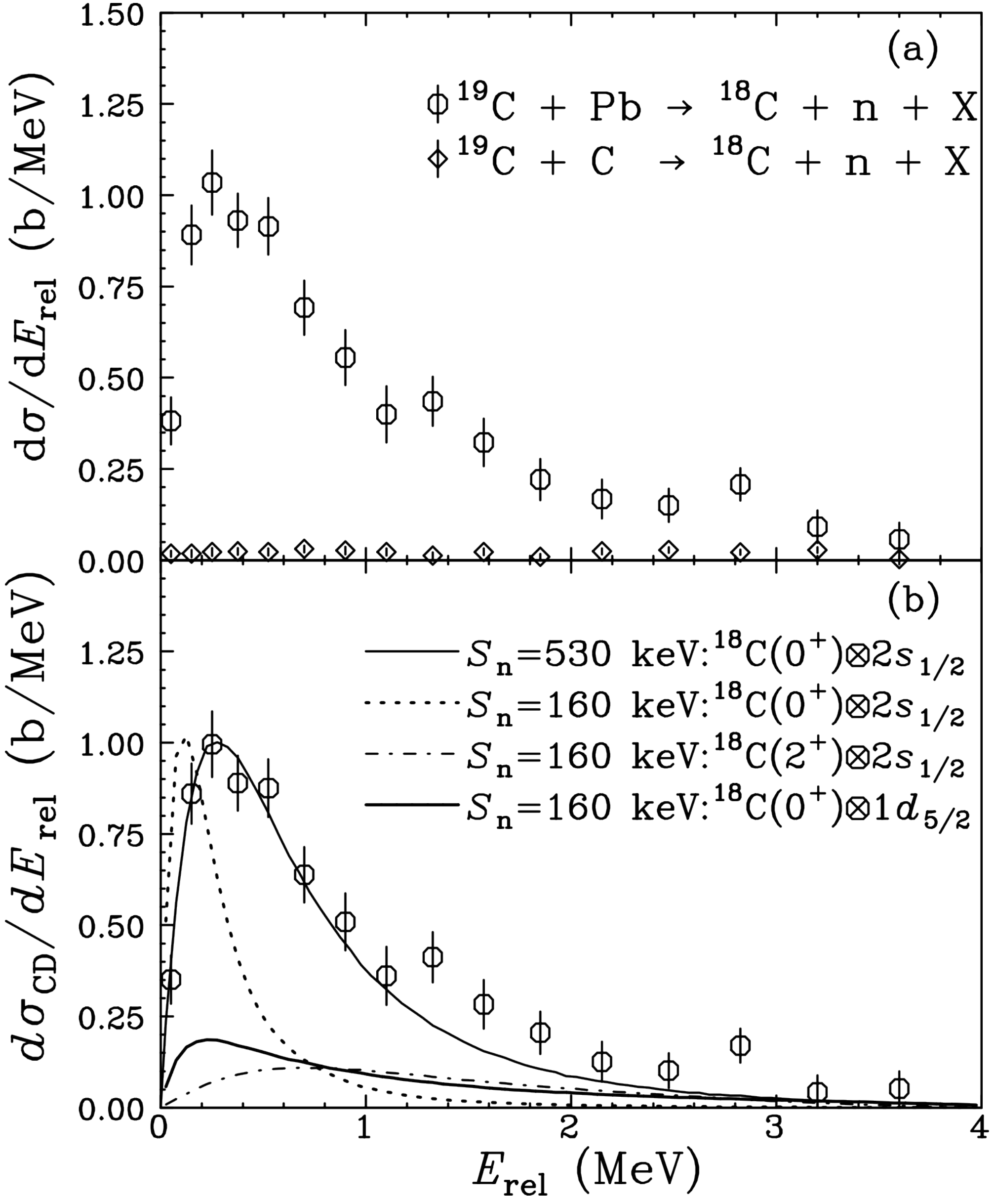
- Use of breakup reactions, halo nucleon dissociates from the core
- $^{19}\mathrm{C}$: large breakup cross section, especially on heavy target (e.g. Pb)
- $^{19}\mathrm{C} + {}^{208}\mathrm{Pb} \rightarrow {}^{18}\mathrm{C} + \mathrm{n} + {}^{208}\mathrm{Pb}$
- Shows the cluster structure

Coulomb breakup of $^{19}\mathrm{C}$

- Coulomb breakup experiment : performed in Japan at 67 A MeV
  [Nakamura *et al.* PRL, **83**, 1112, (1999)]

- Bayesian analysis : used to extract values and uncertainties on physical parameters of $^{19}\mathrm{C}$ (binding energy S_n and ANC, $u\,(r) \xrightarrow[r\to+\infty]{} C\,f(r)$)

- Expect large ANC, halo structure



[Nakamura *et al.* PRL, **83**, 1112, (1999)]

Reaction model

- Use of cluster decomposition ：

$$H = K_{\mathrm{P}} + K_{\mathrm{n}} + V_{\mathrm{cn}}(r) + V_{\mathrm{cT}}(R_{\mathrm{cT}}) + V_{\mathrm{nT}}(R_{\mathrm{nT}})$$

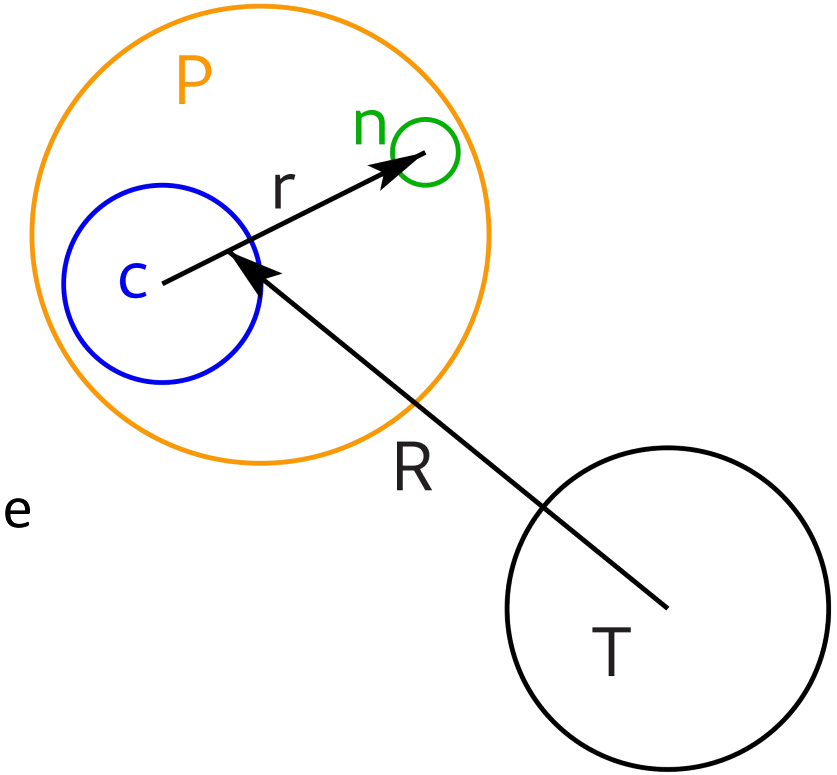
with $V_{\mathrm{cn}}(r) = \left[C_1(r_0)\exp\left(\frac{-r^2}{2{r_0}^2}\right) + C_2(r_0)\,r^2\exp\left(\frac{-r^2}{2{r_0}^2}\right)\right]$

(Halo EFT)

[Hammer, Ji & Phillips *JPG,* **44**, 103002, (2017)]

$V_{\mathrm{cT}}(R_{\mathrm{cT}}), V_{\mathrm{nT}}(R_{\mathrm{nT}})$ are optical potentials

- Use of Coulomb corrected eikonal approximation (CCE) to solve the Schrödinger equation
  [Capel , Baye, & Suzuki, PRC, **78**, 054602, (2008)]



Bayesian analysis

- Only taking into account experimental uncertainties. Optical potentials are fixed

- Assumptions : independent and normally distributed measurements

- Consequence : likelihood is defined using the standard χ^2
  [Furnstahl, Phillips & Wesolowski, JPG, **42**, 034028, (2015)]

- $\mathcal{L} = e^{-\frac{\chi^2}{2}} \prod_{k=1}^{N} \frac{1}{\sigma_k \sqrt{2\pi}}$ with $\chi^2 = \sum_{j=1}^{N} (\frac{d_j - \alpha_j}{\sigma_j})^2$, where d_j experimental cross sections, α_j theoretical cross sections and σ_j experimental confidence intervals

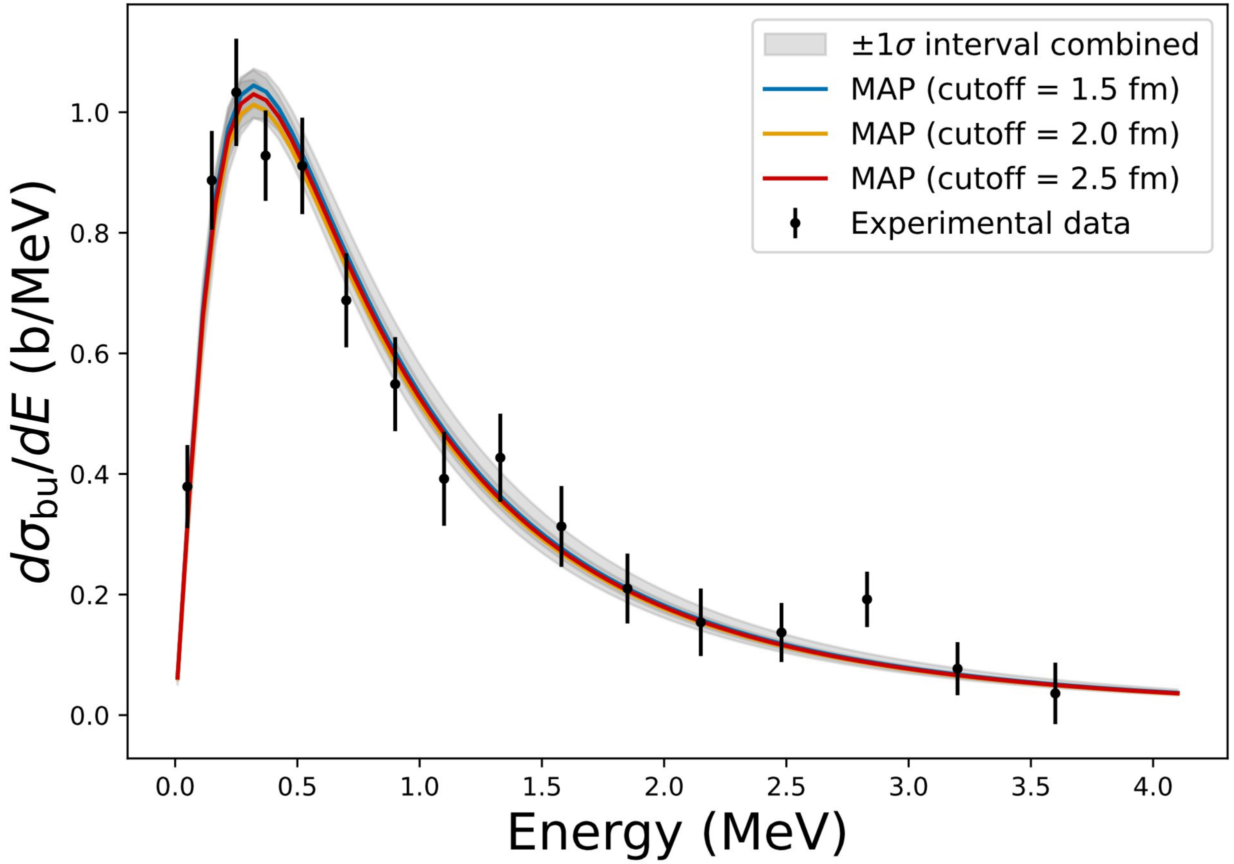
- Uniform priors $C_1 \sim \mathcal{U}(-100\ \mathrm{MeV}, 100\ \mathrm{MeV})$ and $C_2 \sim \mathcal{U}(-100\ \mathrm{MeV\ fm}^{-2}, 150\ \mathrm{MeV\ fm}^{-2})$

Energy cross sections for different cutoffs

- MAP energy distribution for different cutoffs (1.5 fm, 2 fm, 2.5 fm). Results very close to each other

- 1σ intervals are combined for clarity

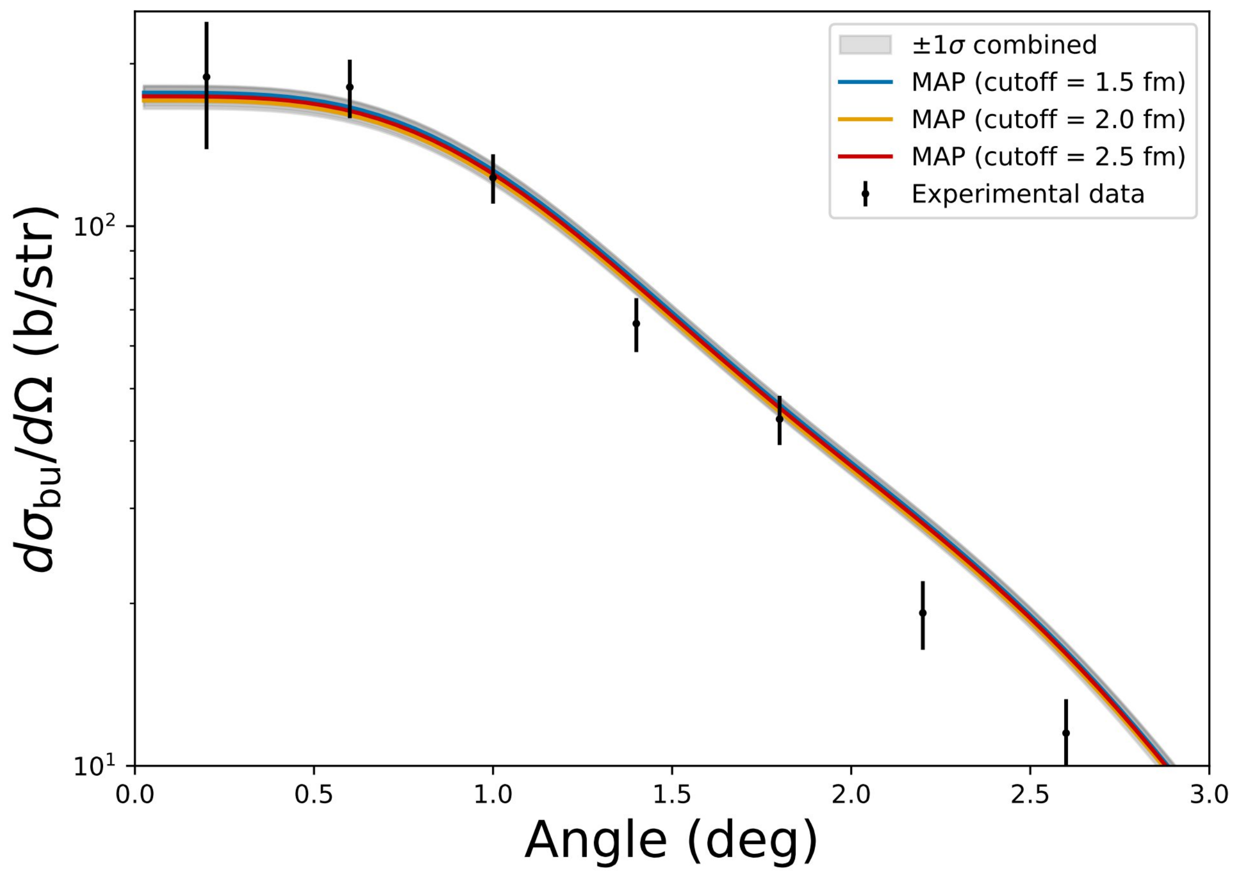
- Also for Gaussian priors, results are similar



Exp : [Nakamura *et al.* PRL, **83**, 1112, (1999)]

Angular distribution for different cutoffs

- Likelihood was computed using energy distribution
- Angular distribution also provided
- Here, angular distribution MAP and combined 1σ are displayed
- Again, we see a good agreement with experimental data



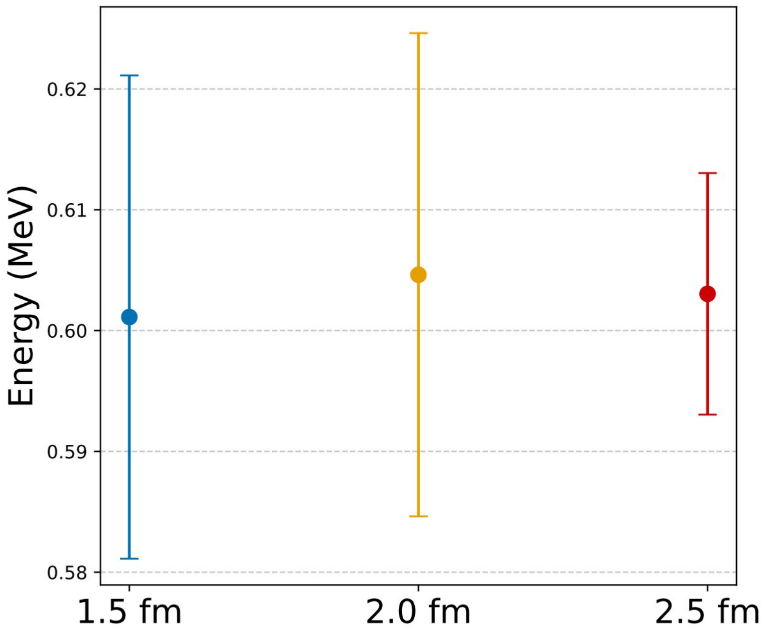
Exp : [Nakamura *et al.* PRL, **83**, 1112, (1999)]

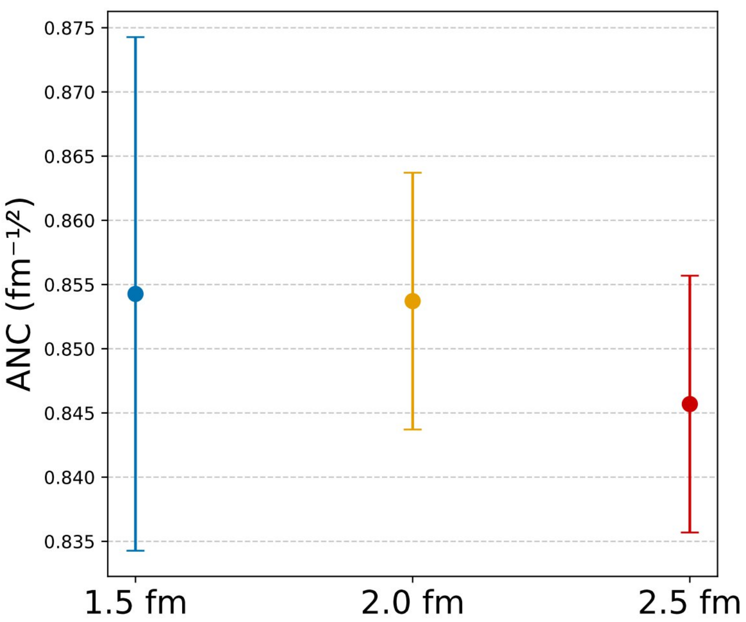
Physical quantities for different cutoffs

- Maxima a posteriori (MAP) obtained for different cutoffs, along with the 1σ interval

- Results similar for the different cutoffs

- MAP values
  - $S_{\mathrm{n}} = 0.60 \pm 0.02\ \mathrm{MeV}$
  - $\mathrm{ANC} = 0.85 \pm 0.02\ \mathrm{fm}^{\frac{-1}{2}}$





Conclusion and outlook

- Maxima a posteriori show strong agreement with experimental data
- Large ANC, shows the halo nature of $^{19}\mathrm{C}$
- Inferred structure observables independent of cutoff
- Energy distribution used in likelihood computation
- Angular distribution used for validation
- Include other sources of uncertainties (optical potentials, truncation error)

Acknowledgements

Finally, I wish to thank my supervisor Prof. Pierre Capel as well as Isak Svensson for their inputs and discussions

Posterior distributions, cutoff of 1.5 fm

- Slight correlations between the LECs

- Expected as C_1 is repulsive and C_2 is attractive, need to keep a bound state → C_1 and C_2 anti-correlated

- ANC and binding energy are uncorrelated