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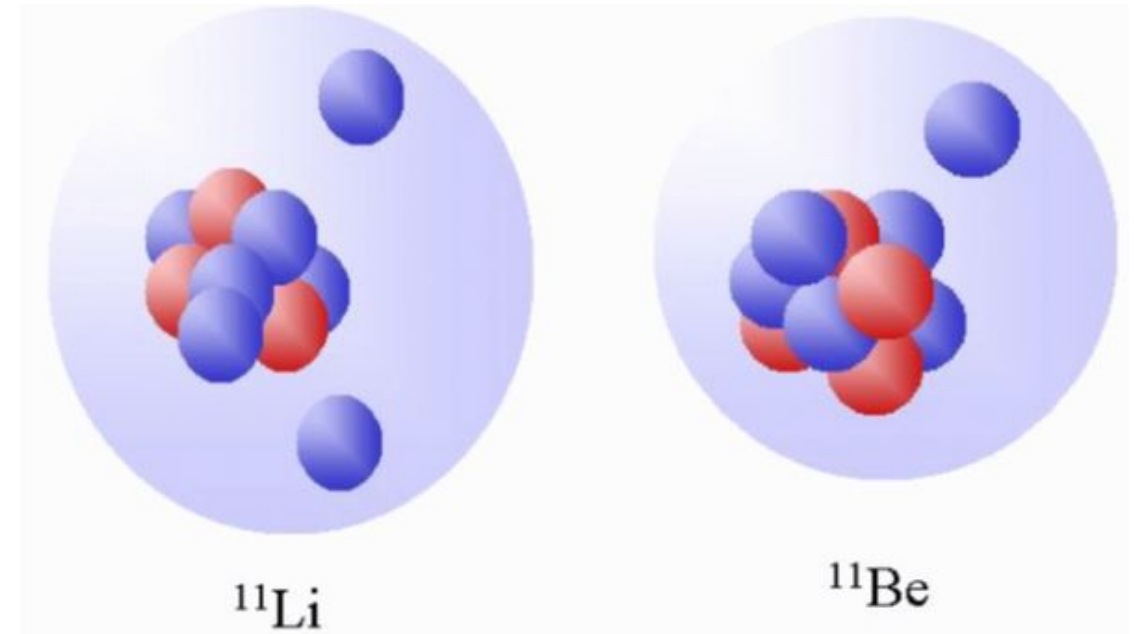


Bayesian analysis of the Coulomb breakup of ^{19}C

Quentin Bozet, Pierre Capel

Introduction

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



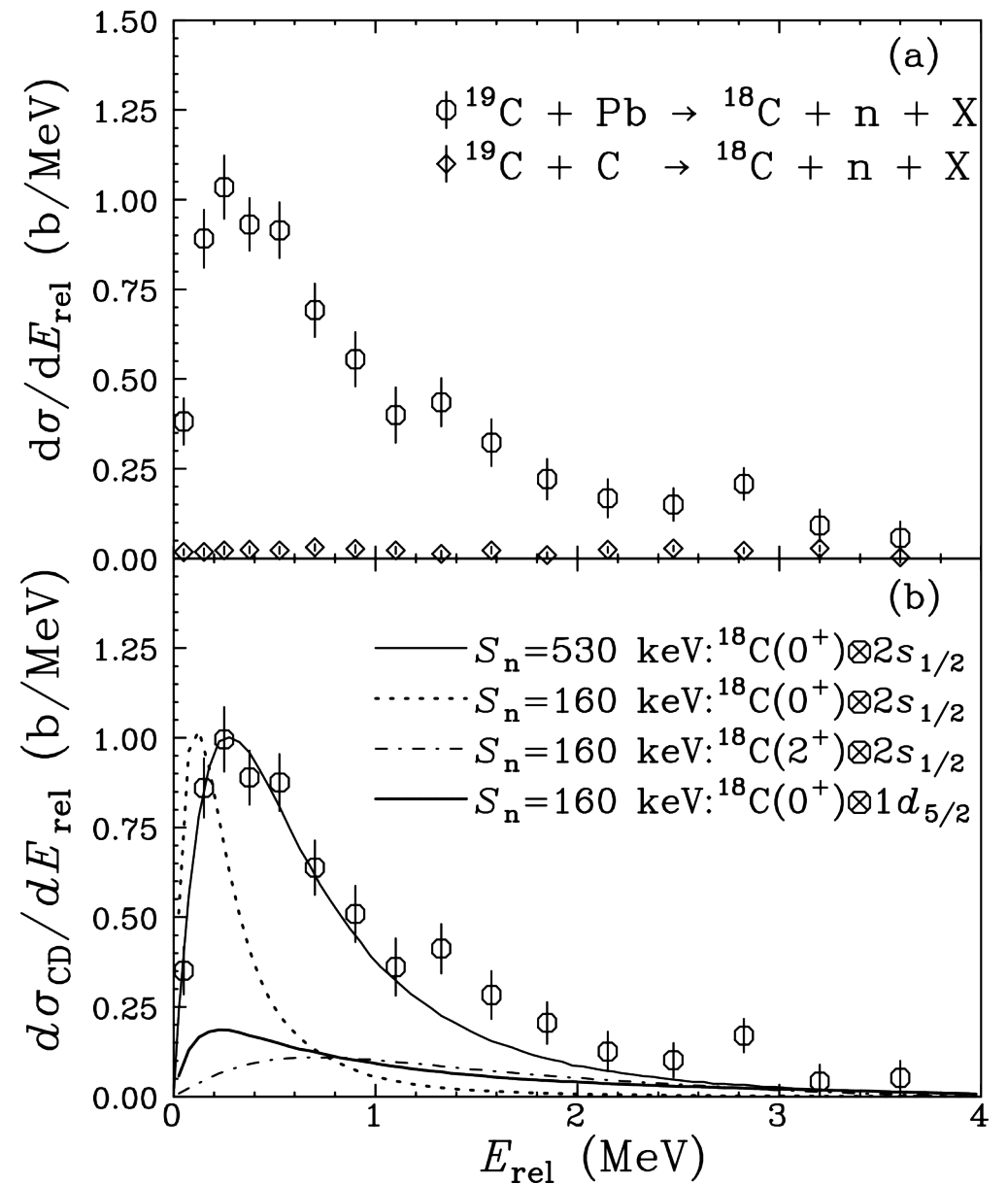
[https://epscollege.uoanbar.edu.iq/English/News_Details.php?ID=466]

Coulomb breakup of ^{19}C

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

Coulomb breakup of ^{19}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}C (binding energy S_n and ANC, $u(r) \xrightarrow{r \rightarrow +\infty} C f(r)$)
- Expect large ANC, halo structure



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

Reaction model

- Use of cluster decomposition :

$$H = K_p + K_n + V_{cn}(r) + V_{cT}(R_{cT}) + V_{nT}(R_{nT})$$

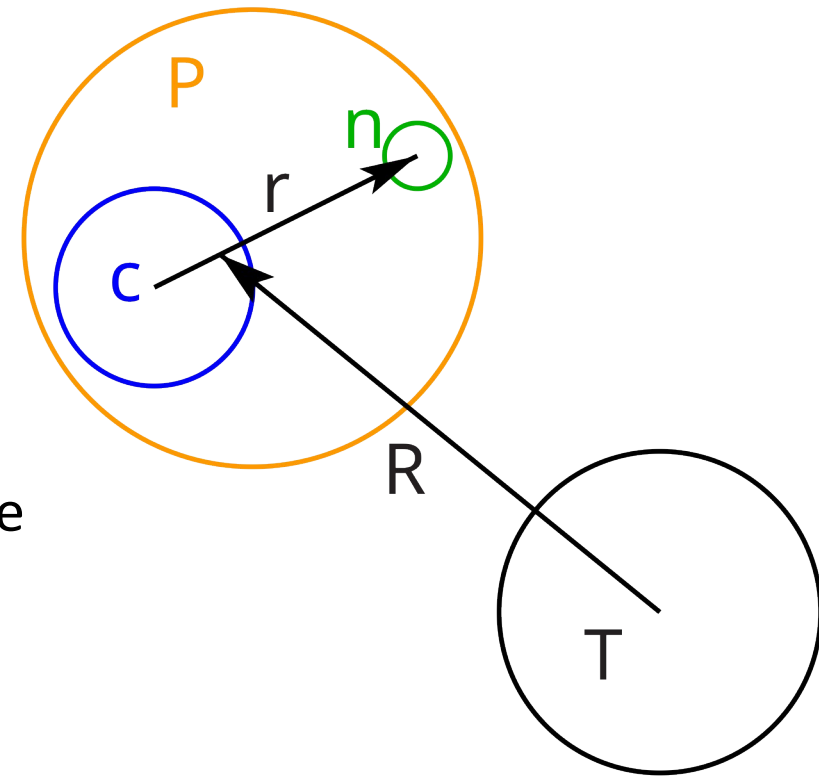
$$\text{with } V_{cn}(r) = \left[C_1(r_0) \exp\left(\frac{-r^2}{2r_0^2}\right) + C_2(r_0) r^2 \exp\left(\frac{-r^2}{2r_0^2}\right) \right]$$

(Halo EFT)

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

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

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



Bayesian analysis

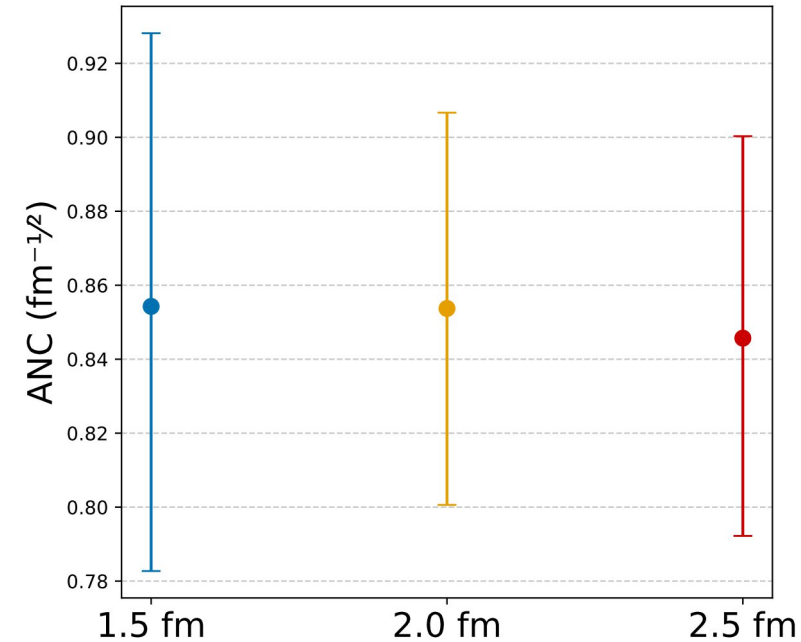
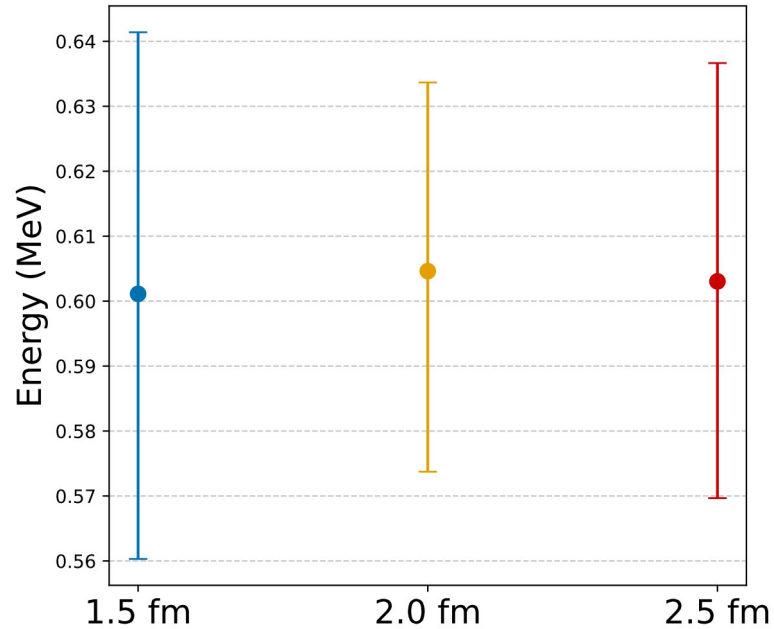
- Using Bayes theorem $p(\theta | D) = p(D|\theta) p(\theta)$, where D , experimental data, θ , low energy constants (LECs), $p(D|\theta)$ likelihood, $p(\theta)$ prior, $p(\theta | D)$ posterior
- Only taking into account experimental uncertainties. Optical potentials are fixed
- Assumptions : independent 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 $\chi^2 = \sum_{j=1}^N \left(\frac{d_j - \alpha_j}{\sigma_j} \right)^2$, where d_j experimental cross sections, α_j theoretical cross sections and σ_j experimental confidence intervals
- Uniform priors $C_1 \sim \mathcal{U}(-100 \text{ MeV}, 100 \text{ MeV})$ and $C_2 \sim \mathcal{U}(-100 \text{ MeV fm}^{-2}, 150 \text{ MeV fm}^{-2})$

Physical quantities for different cutoffs

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

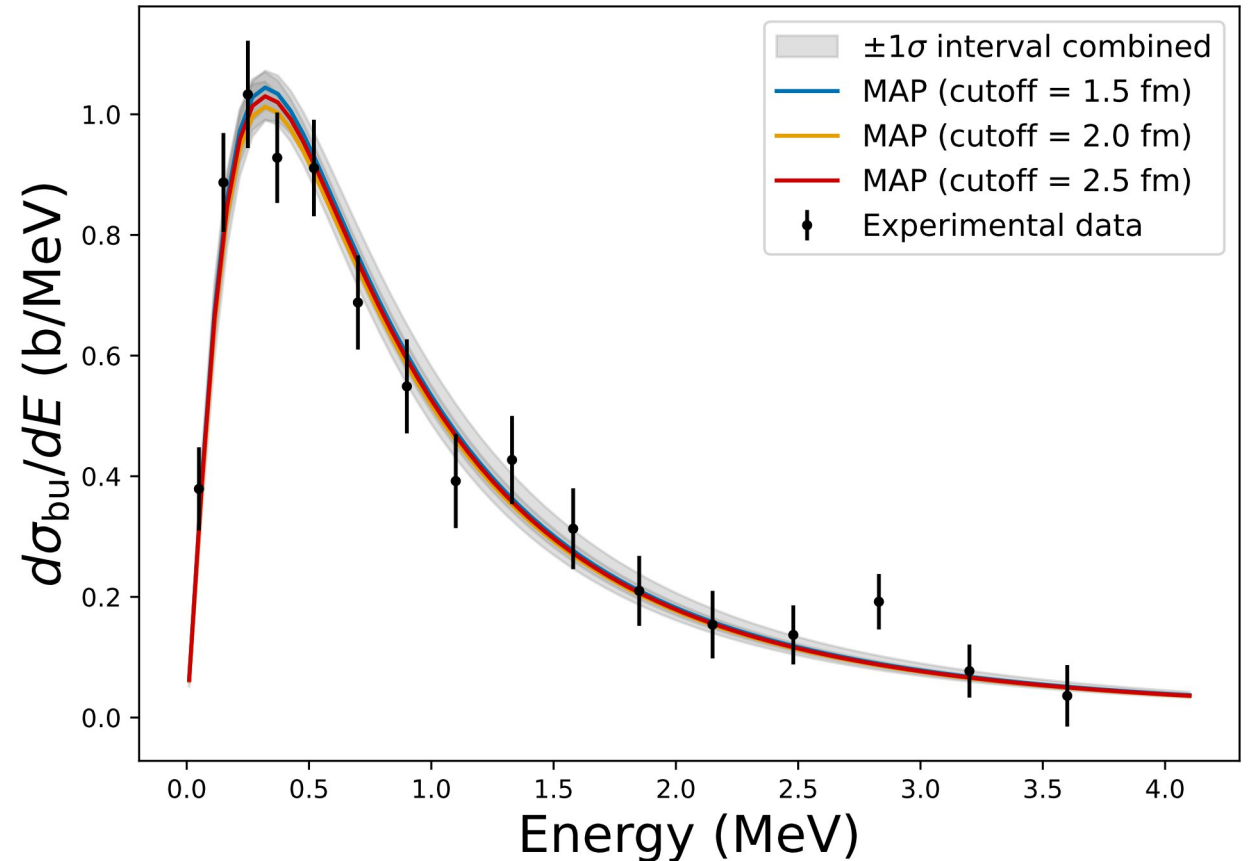
- Results similar for the different cutoffs

- MAP values
 - $S_n = 0.60 \pm 0.04 \text{ MeV}$
 - $\text{ANC} = 0.85 \pm 0.07 \text{ fm}^{-1/2}$



Energy cross sections for different cutoffs

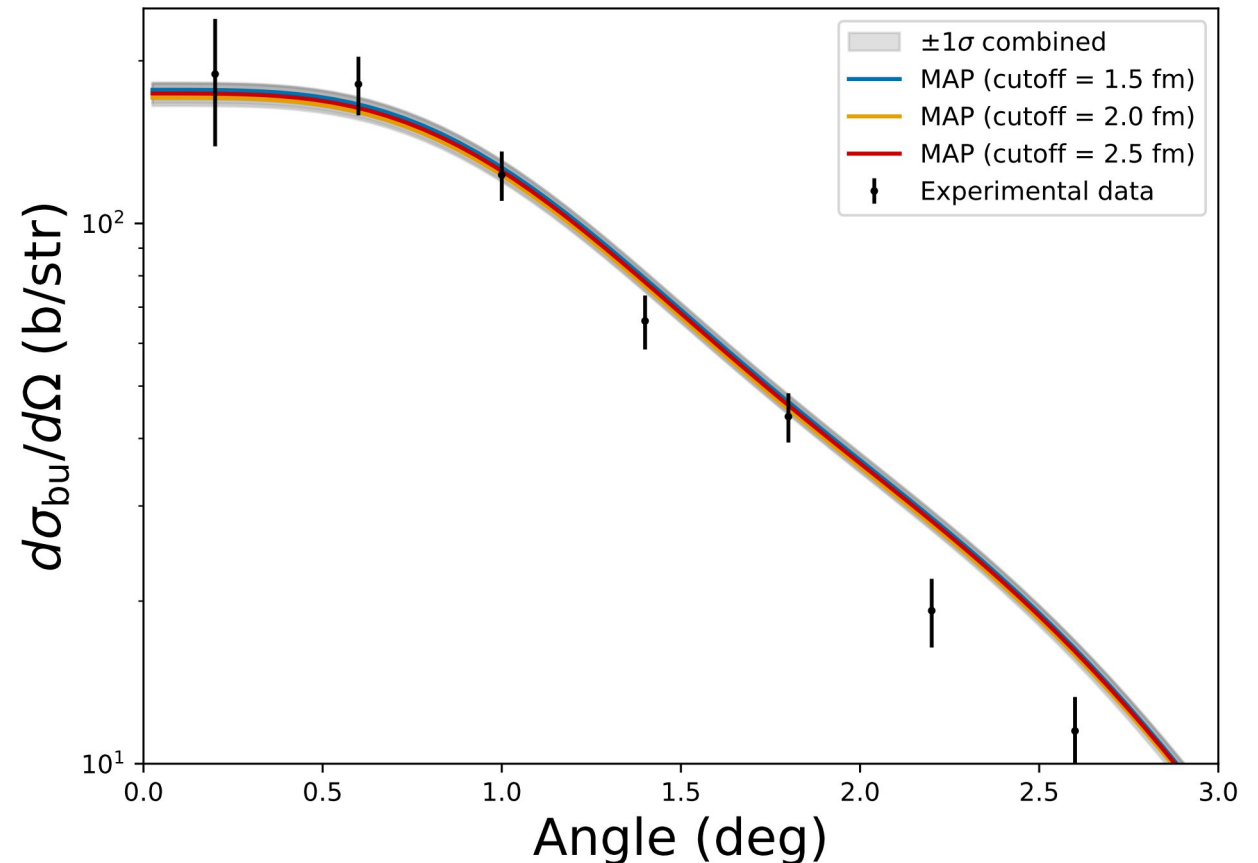
- MAP energy distribution for different cutoffs (1.5 fm, 2 fm, 2.5 fm). Results very close to each other
- 1σ intervals are combined for clarity
- Also for Gaussian priors, results are similar



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)]

Conclusion and outlook

- Maxima a posteriori show strong agreement with experimental data
- Large ANC, shows the halo nature of ^{19}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

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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 $\rightarrow C_1$ and C_2 anti-correlated
- ANC and binding energy are uncorrelated

