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

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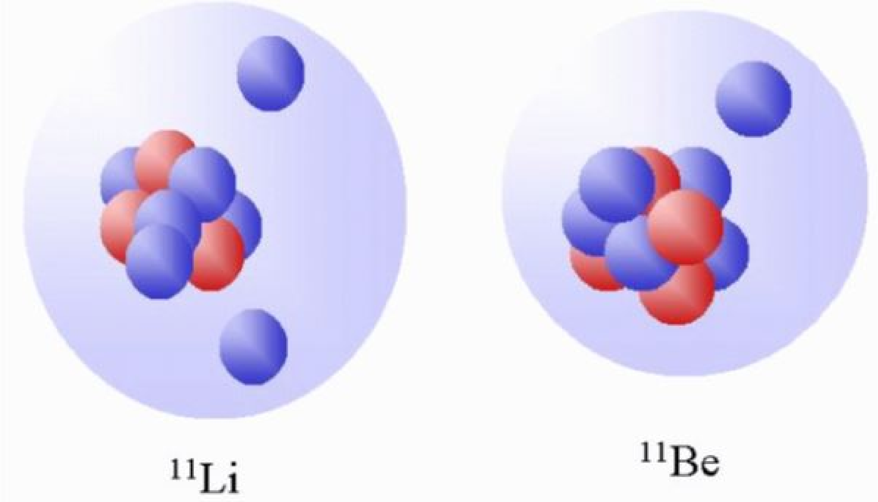
Introduction

- Halo nuclei : unstable, extended, nuclei with 1-2 nucleons at large distance from the core
- Examples : $^{11}\mathrm{Be}$, $^{19}\mathrm{C}$, $^{19}\mathrm{B}$ and $^{22}\mathrm{C}$
- Unstable, cannot be used as target, studied through reactions
- Use of breakup reactions, halo nucleon splits from the core



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

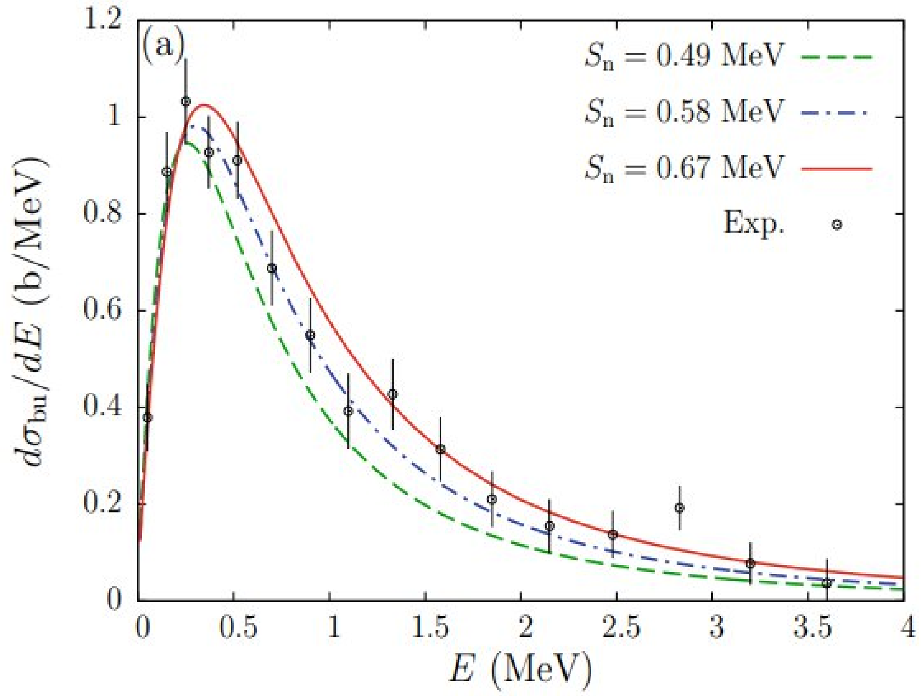
Introduction

- ^{19}C : large breakup cross section, especially on heavy target (e.g.Pb)

- Coulomb breakup experiment : performed at RIKEN [Nakamura *et al.* PRL, **83**, 1112, (1999)]

- $^{19}\mathrm{C} + {}^{208}\mathrm{Pb} \rightarrow {}^{18}\mathrm{C} + \mathrm{n} + {}^{208}\mathrm{Pb}$ (67 A MeV)

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



[Capel , Phillips, *et al*. EPJA, **59**, 273, (2023)]

Coulomb breakup of ^{19}C

- Use of cluster decomposition :

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

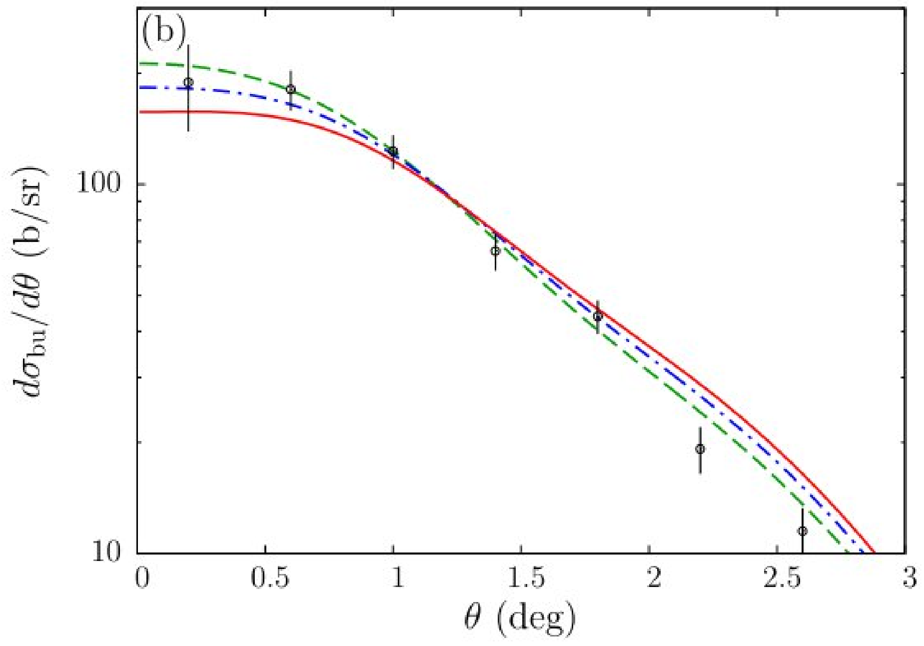
with $V_{\mathrm{cn}}(r) = \left[C_1(r_0)\exp\left(\frac{-r^2}{2{r_0}^2}\right) + C_2(r_0)\, r^2 \exp\left(\frac{-r^2}{2{r_0}^2}\right)\right]$

(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)]

- Two types of distributions : energy and angular



[Capel , Phillips, *et al*. EPJA, **59**, 273, (2023)]

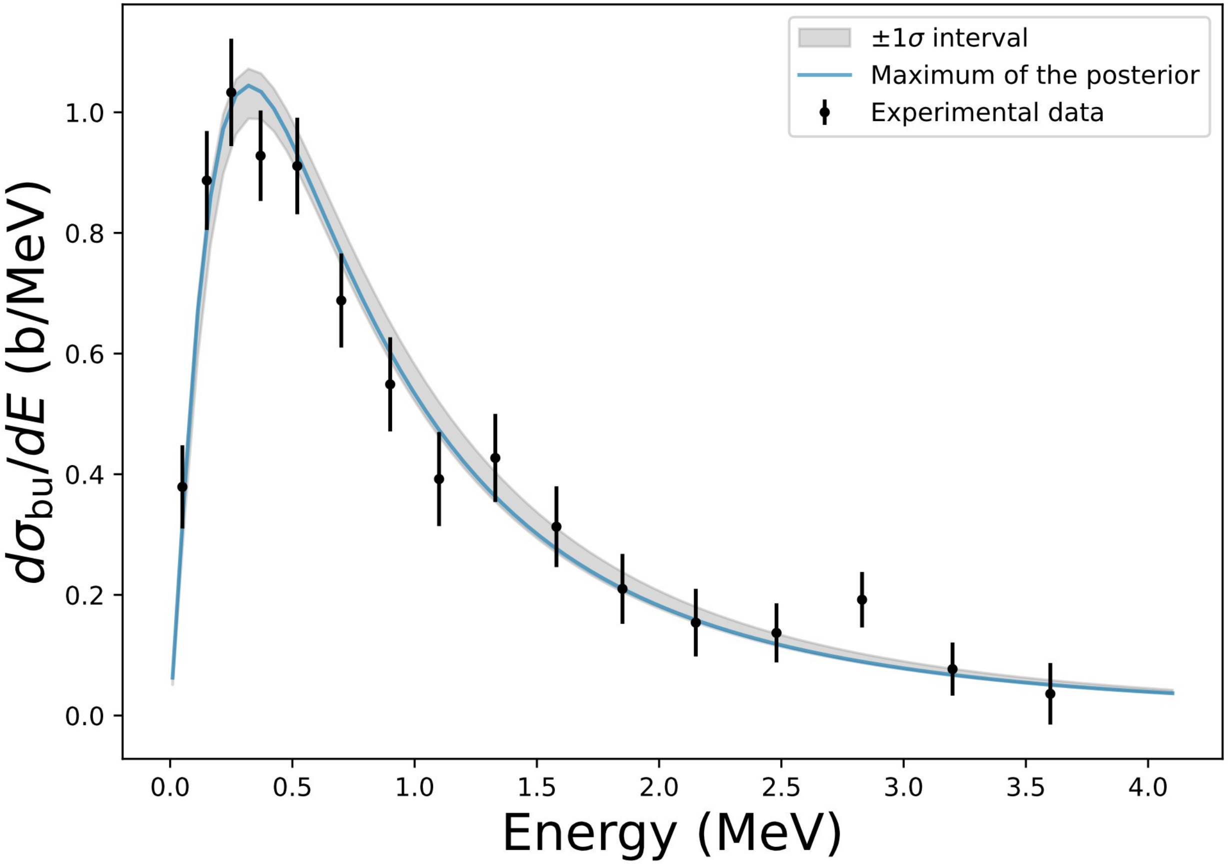
Assumptions

- Only taking into account experimental errors. 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 are experimental cross sections, α_j are theoretical cross sections and σ_j are the experimental confidence intervals
- Likelihood is computed using energy distribution
- 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 section, cutoff of 1.5 fm

- Good agreement with experimental data for the MAP completed by the 1σ interval

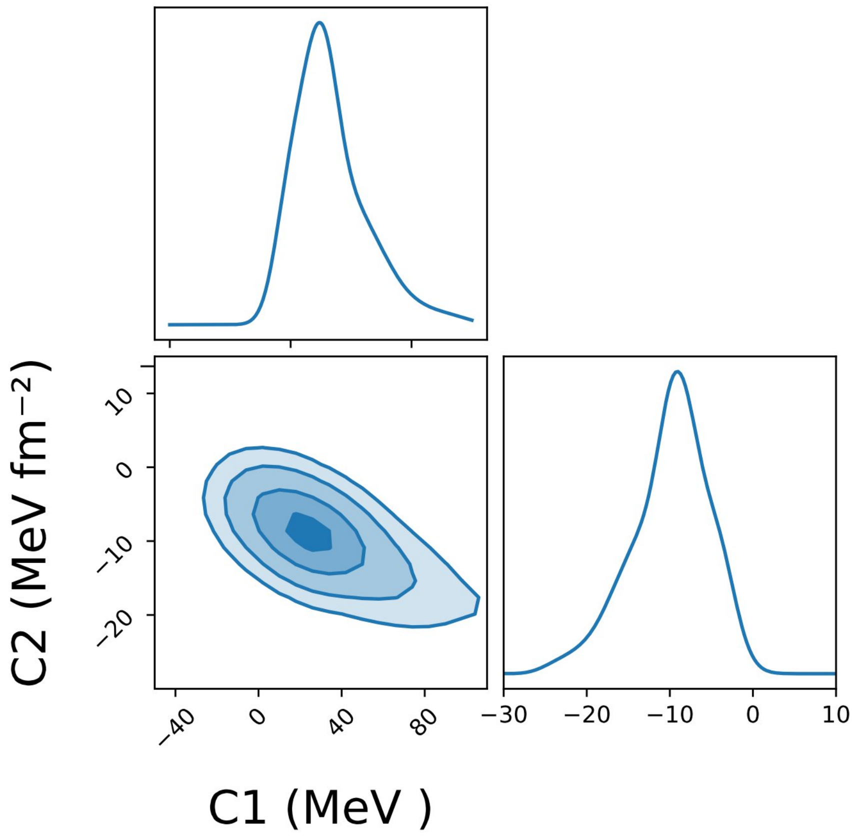
- Not convolved with experimental resolution, negligible impact

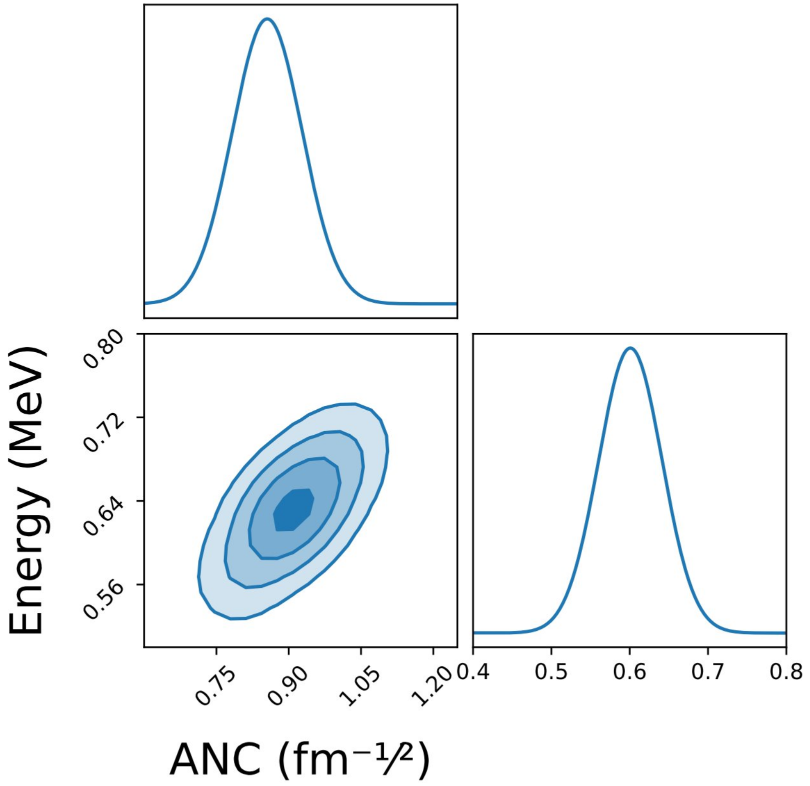


[Nakamura *et al.* PRL, **83**, 1112, (1999)]

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



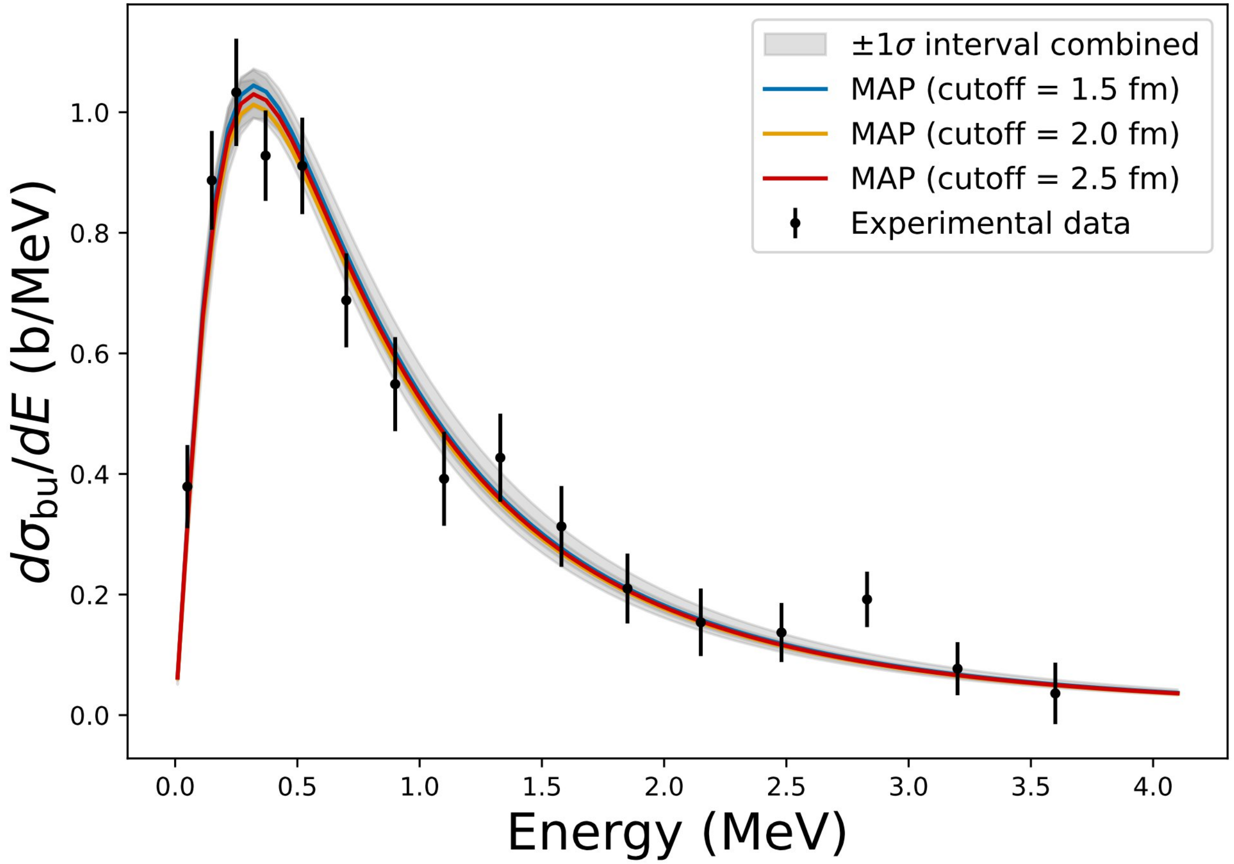


Energy cross sections for different cutoffs

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

- 1σ intervals are combined for clarity

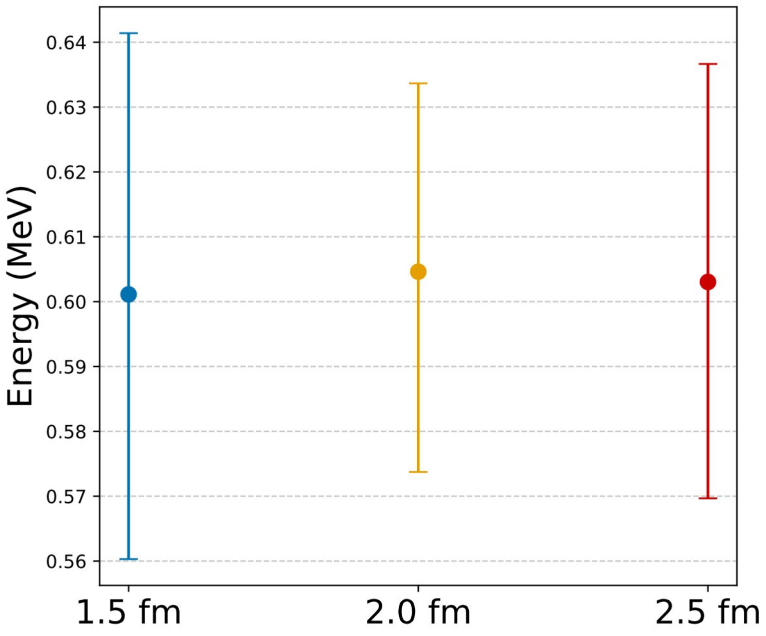
- Also for Gaussian priors, results are similar

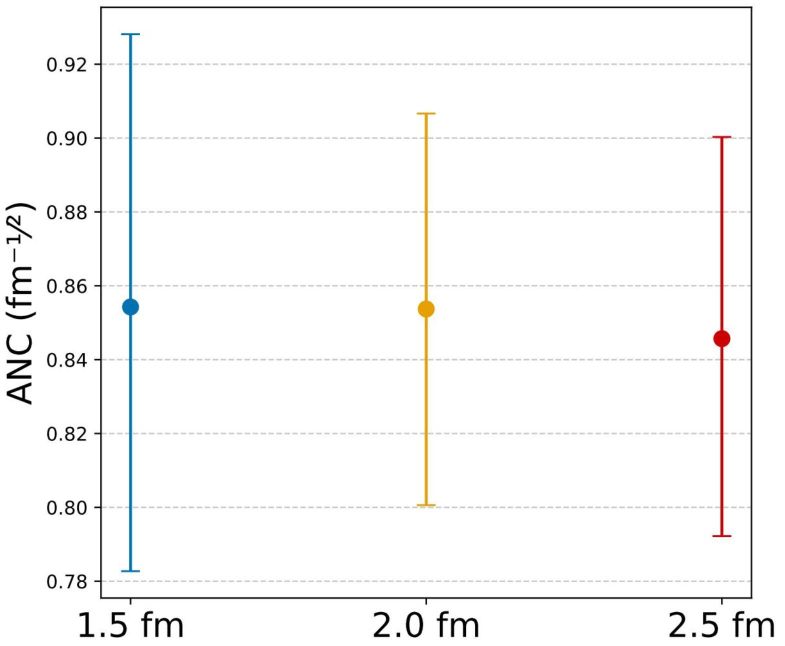


[Nakamura *et al.* PRL, **83**, 1112, (1999)]

Physical quantities for different cutoffs

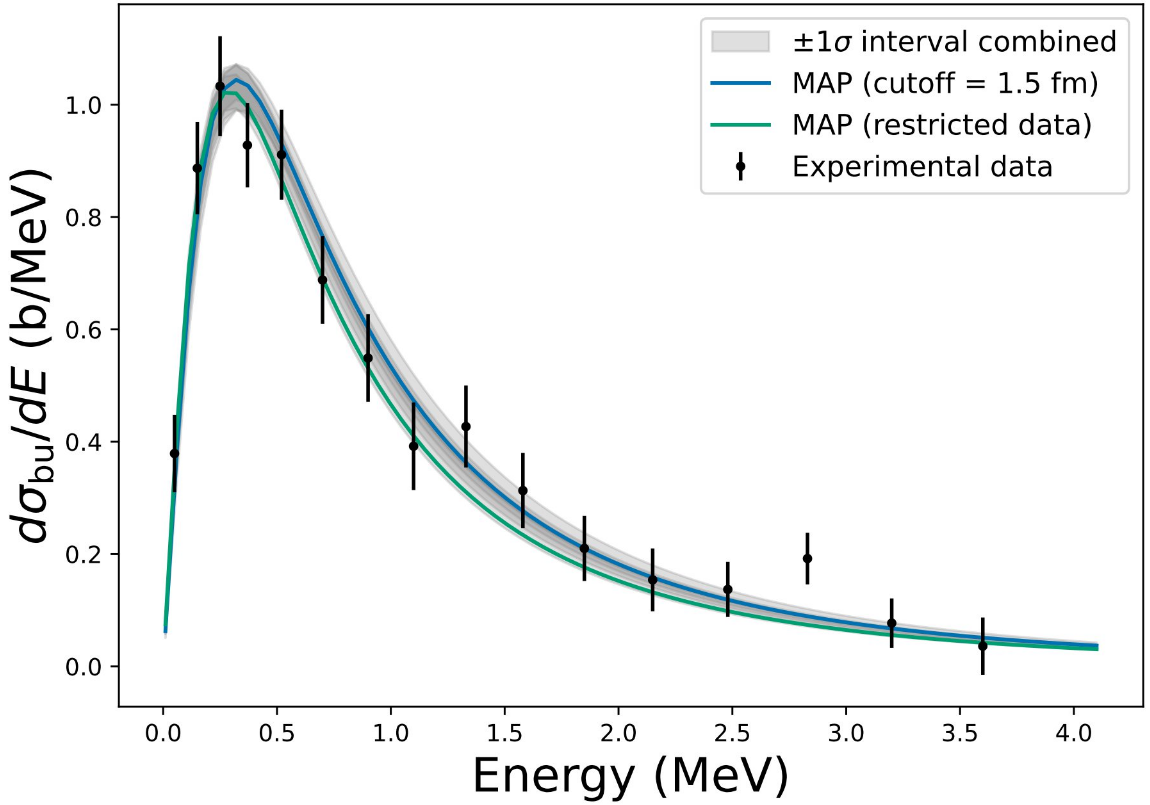
- Maxima of the posteriors obtained for different cutoffs, along with the 1σ interval
- Results similar for the different cutoffs
- MAP values
  - $S_{\mathrm{n}} = 0.60 \pm 0.04\ \mathrm{MeV}$
  - $\mathrm{ANC} = 0.85 \pm 0.07\ \mathrm{fm}^{\frac{-1}{2}}$





Energy distribution for restricted dataset

- Likelihood also computed with a restricted number of energy points ($\mathrm{E} \leq 1.2\ \mathrm{MeV}$)
- Different distribution shape than with the full dataset
- Effect of lower S_{n} and ANC

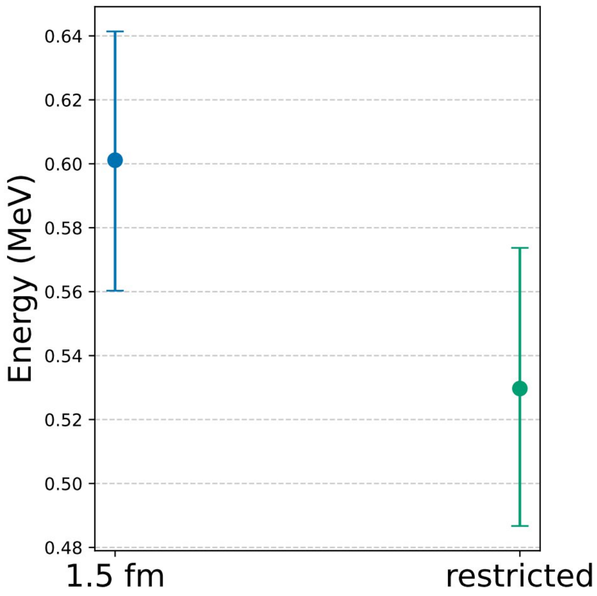


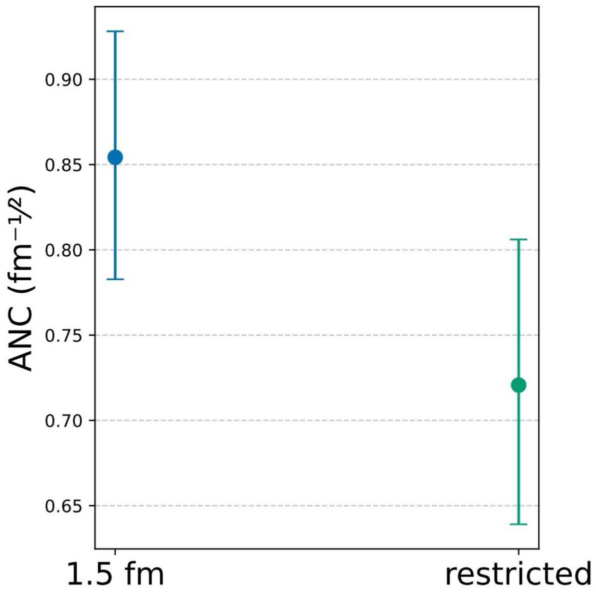
[Nakamura *et al.* PRL, **83**, 1112, (1999)]

Physical quantities for different datasets

- Results sensitive to the number of data points taken

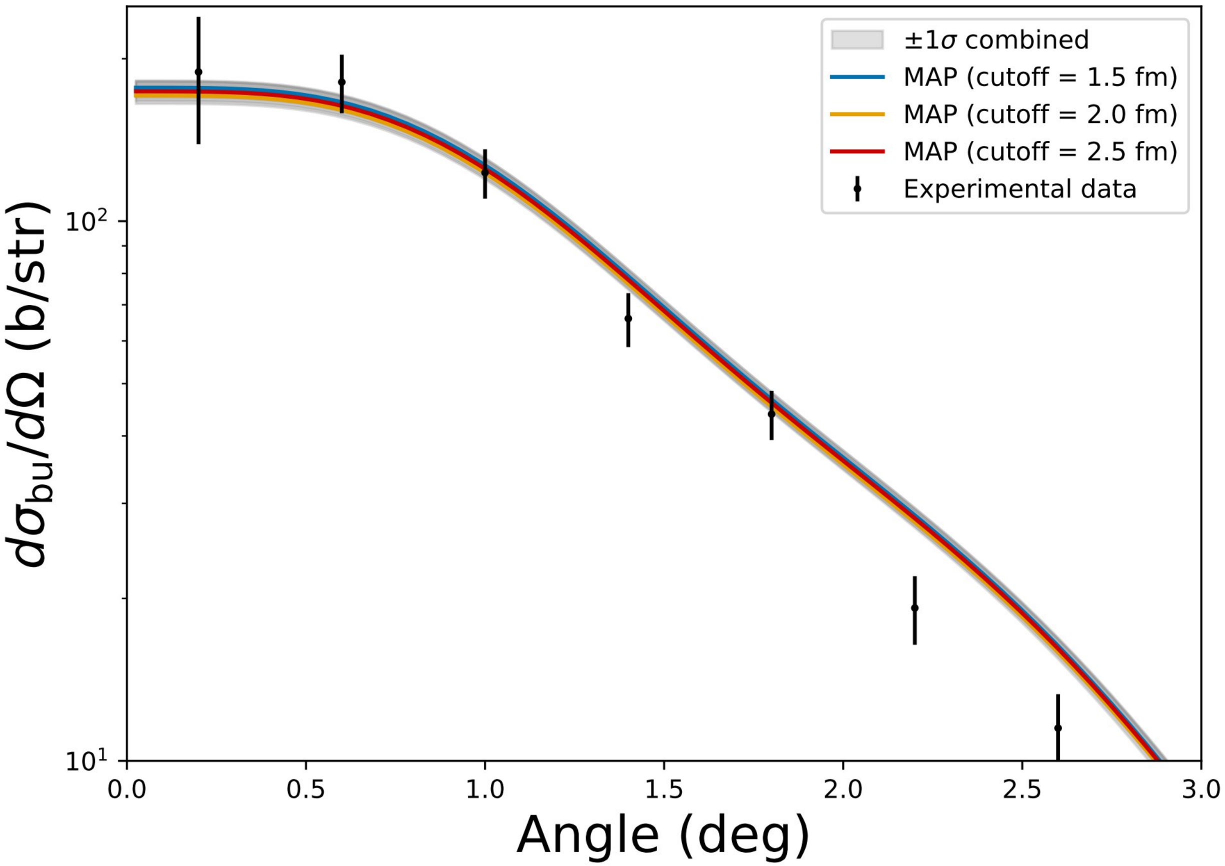
- Lower ANC and S_{n}
  - $S_{\mathrm{n}} = 0.53 \pm 0.05\ \mathrm{MeV}$
  - $\mathrm{ANC} = 0.72 \pm 0.06\ \mathrm{fm}^{\frac{-1}{2}}$





Angular distribution for different cutoffs

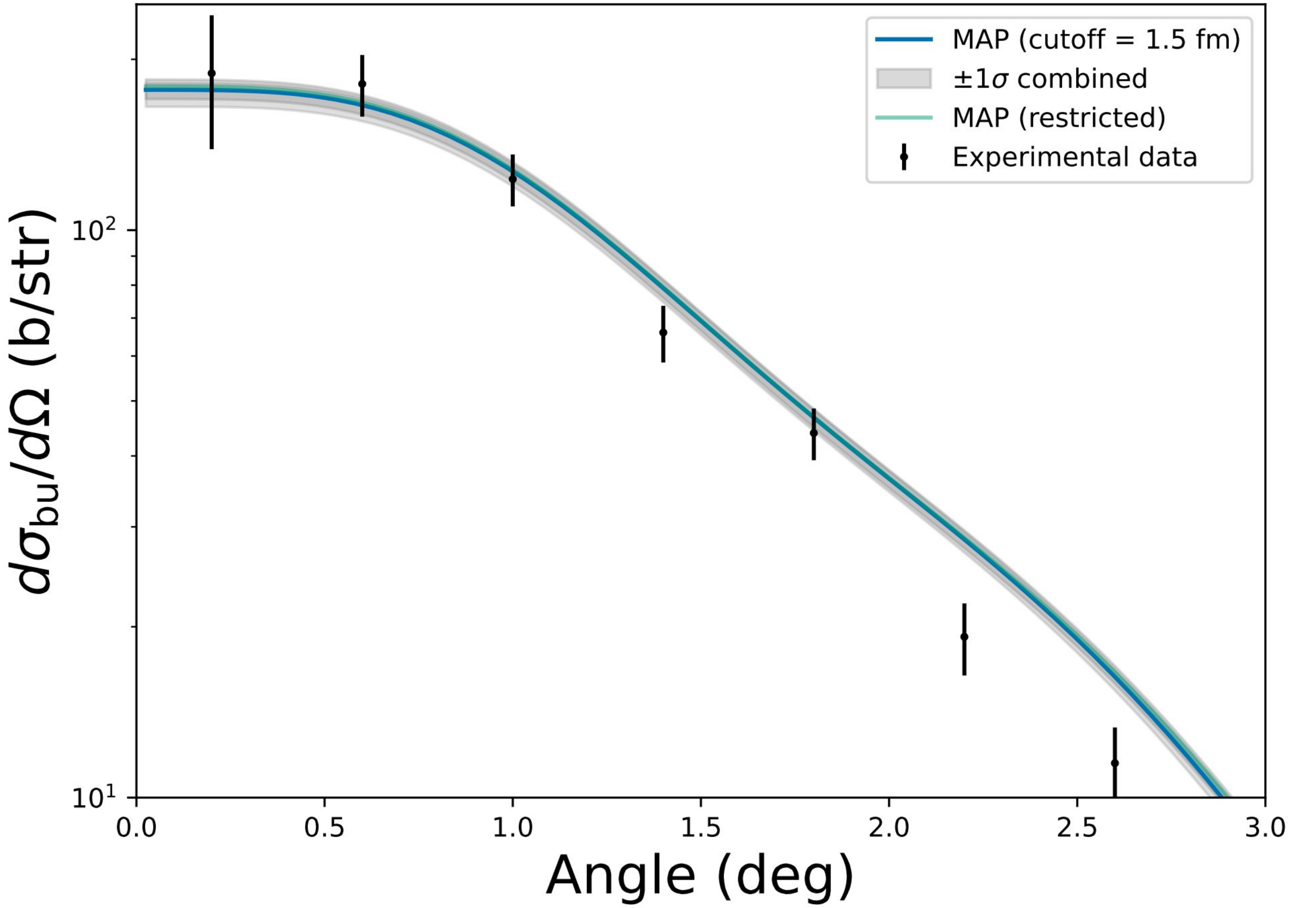
- Likelihood was computed using energy cross sections
- Here, angular cross sections MAP and combined 1σ are displayed
- Again, we see a good agreement with experimental data
- Convolved with experimental resolution, important impact



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

Angular cross sections for restricted dataset

- Results for restricted and full datasets are similar



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Conclusion and outlook

- Maxima a posteriori show strong agreement with experimental data

- Inferred structure observables independent of cutoff, but dependent on the size of dataset

- Energy distribution used in likelihood computation

- Angular distribution used for validation

- Extend comparison to knockout reactions

- Include theoretical uncertainties : truncation errors, higher-order partial waves, optical potential dependence

Acknowledgements

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