Uncertainty Quantification for Three Nucleon force with light ion reactions

ISNET-6: Uncertainty Quantification in the Extremes
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Outline

- Introduction
- Astrophysical S-Factor
- No Core Shell Model with Continuum
- 2N + 3N Chiral EFT interactions
- A simpler problem(n-α scattering)

The p-p chain

$$p + p \rightarrow d + e^+ + \nu_e \qquad p + e^- + p \rightarrow d + \nu_e$$

99.6%

$$d + p \rightarrow {}^3\text{He} + \gamma$$

85%

$${}^3\text{He} + {}^3\text{He} \rightarrow {}^4\text{He} + p + p \qquad {}^3\text{He} + p \rightarrow {}^4\text{He} + e^+ + \nu_e$$

15%

$${}^3\text{He} + {}^4\text{He} \rightarrow {}^7\text{Be} + \gamma$$

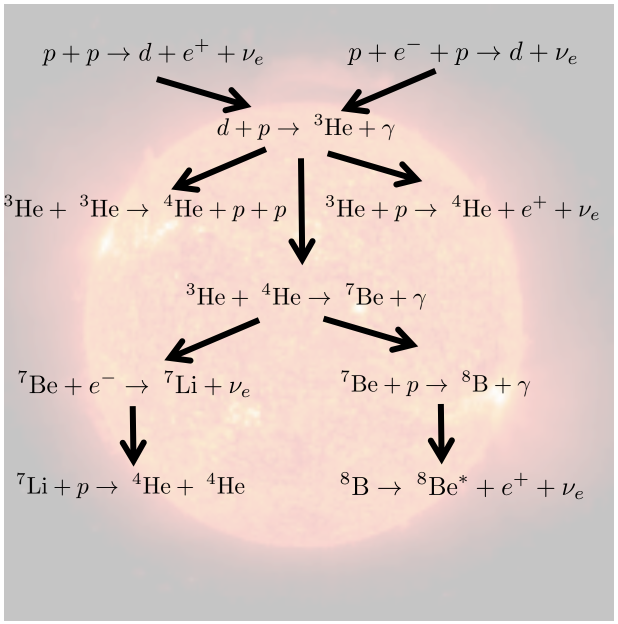
99.9%

$${}^7\text{Be} + e^- \rightarrow {}^7\text{Li} + \nu_e \qquad {}^7\text{Be} + p \rightarrow {}^8\text{B} + \gamma$$

$${}^7\text{Li} + p \rightarrow {}^4\text{He} + {}^4\text{He} \qquad {}^8\text{B} \rightarrow {}^8\text{Be}^* + e^+ + \nu_e$$

- Neutrinos are produced at several stages of the p-p chain.
- The second most energetic neutrinos are produced by Boron β decay.
- Mismatch between theory and observation could indicate new physics.

The Quantity of Interest



How fast do these reactions happen?

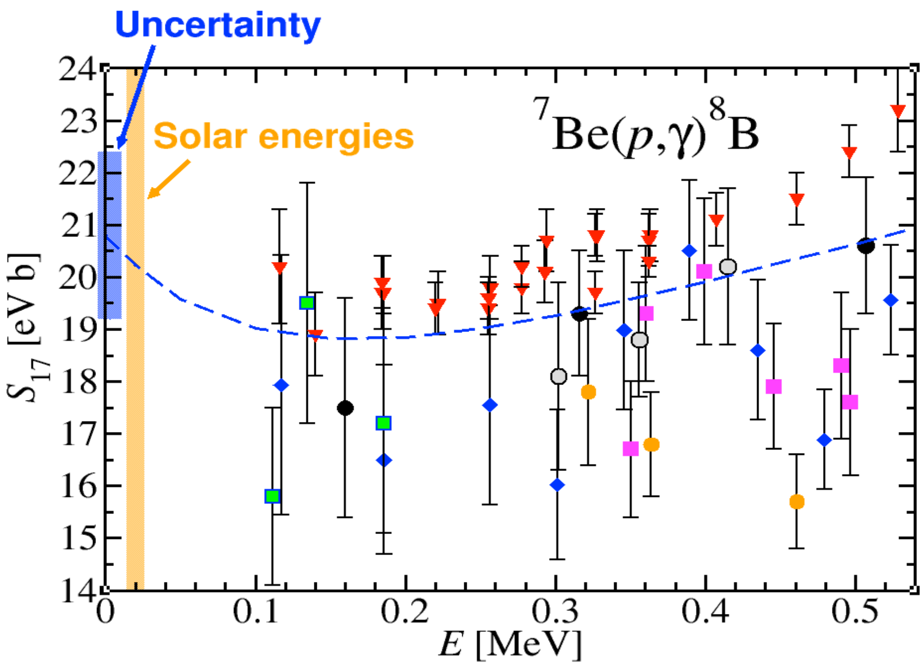
If put everything we know together, can we reconstruct what we observe?

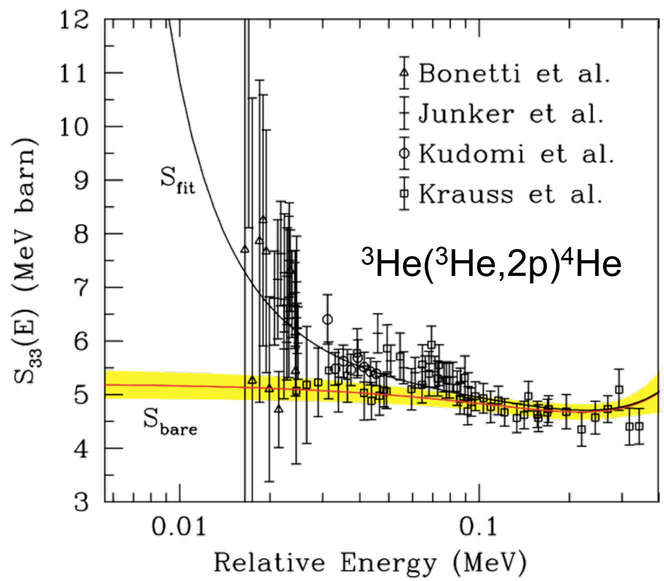
$$r_{12} = \frac{n_1 n_2}{1 + \delta_{12}} \langle \sigma v \rangle_{12}$$

$$\langle \sigma v \rangle_{12} \sim \int_0^\infty E \sigma(E) e^{-E/kT} dE$$

$$\sigma(E) = \frac{S(E)}{E} \exp\left(-2\pi\eta(E)\right)$$

Uncertainty contributions to the S-factor



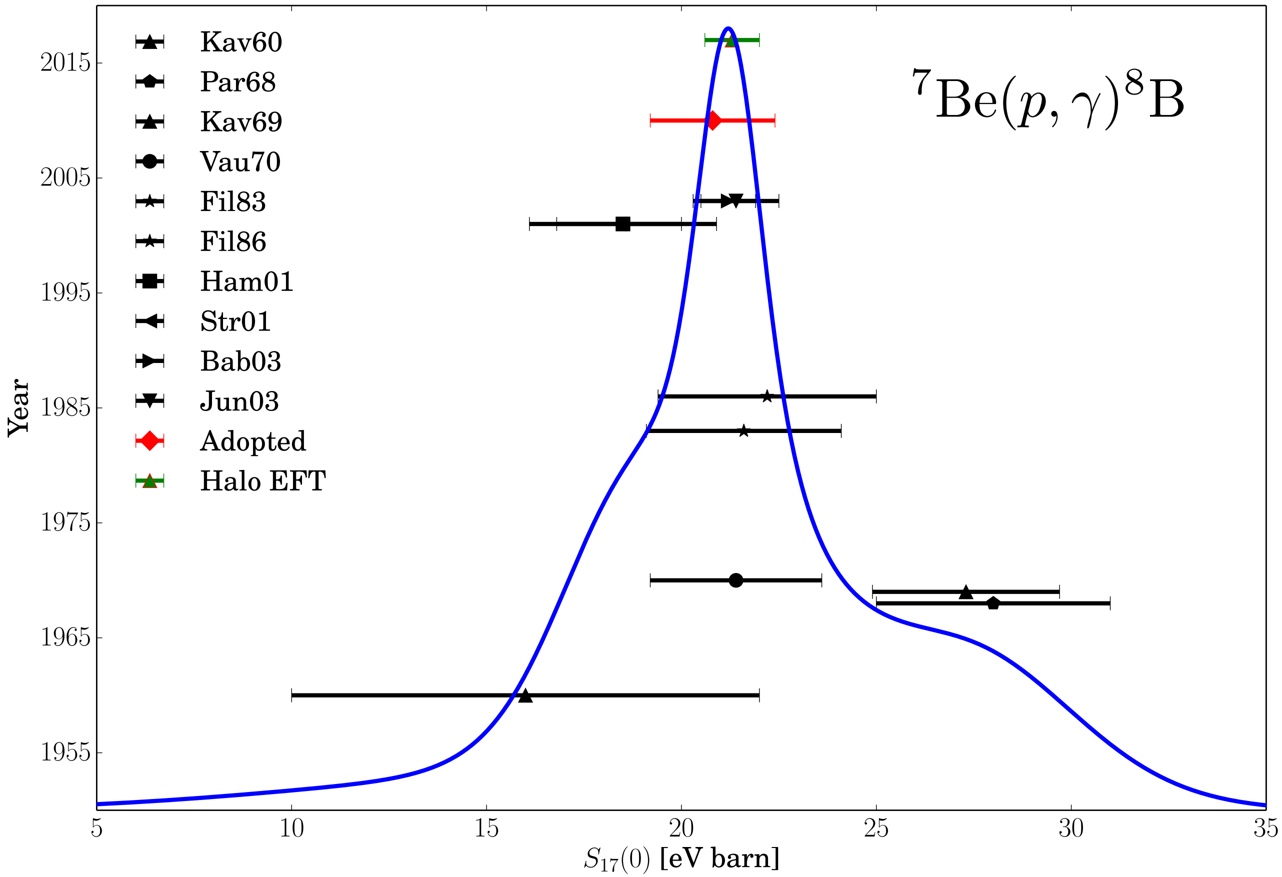


Uncertainty in the S-Factor is both experimental and theoretical in origin.

Experiment:
Low rates, noise, electron screening.

Theory:
Possible unknown resonances in the region require a theory with predictive power

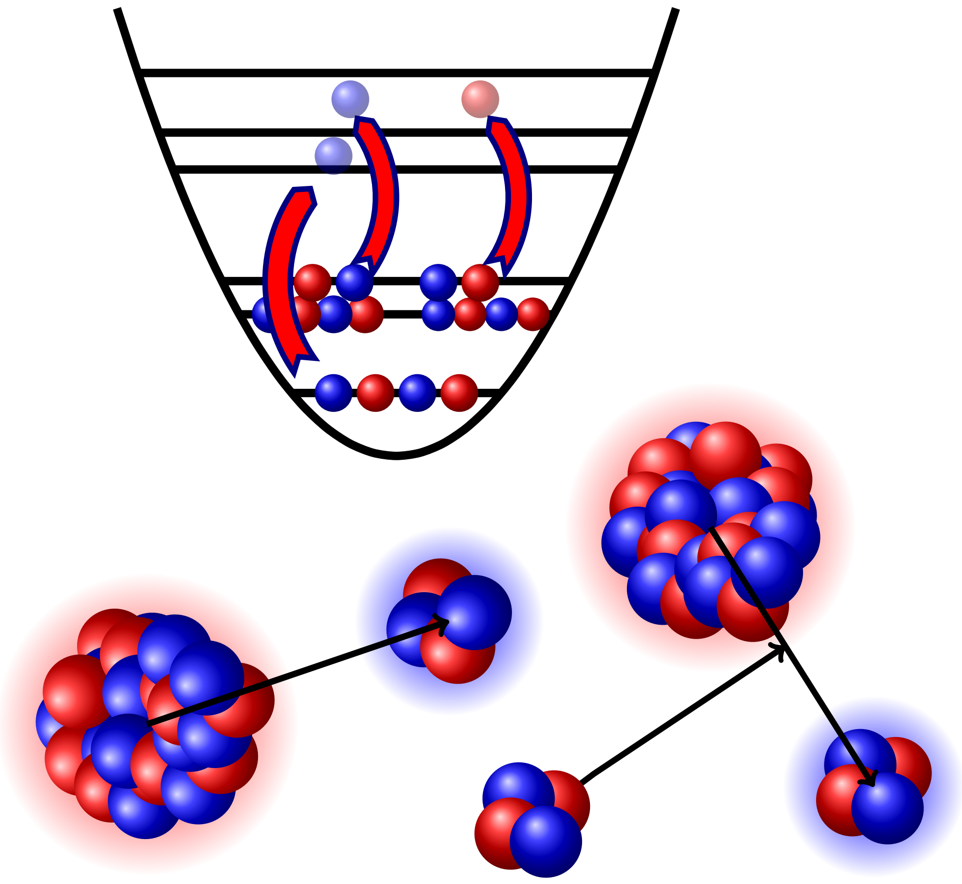
Zero Energy S-Factor for $^7Be(p,\gamma)^8B$



Adopted value error bar contributions:
0.7 eVb (experiment)
1.4 eVb (theory)

Adopted value from:
Rev. Mod. Phys. 83, 195
Halo EFT in:
Phys. Lett. B 751 (2015) 535

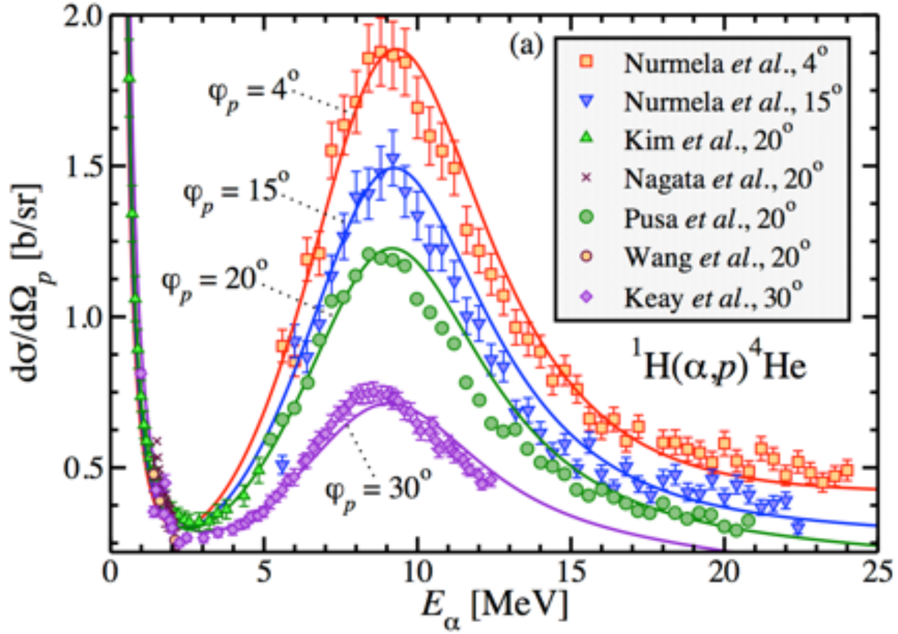
The many-body problem with the NCSMC



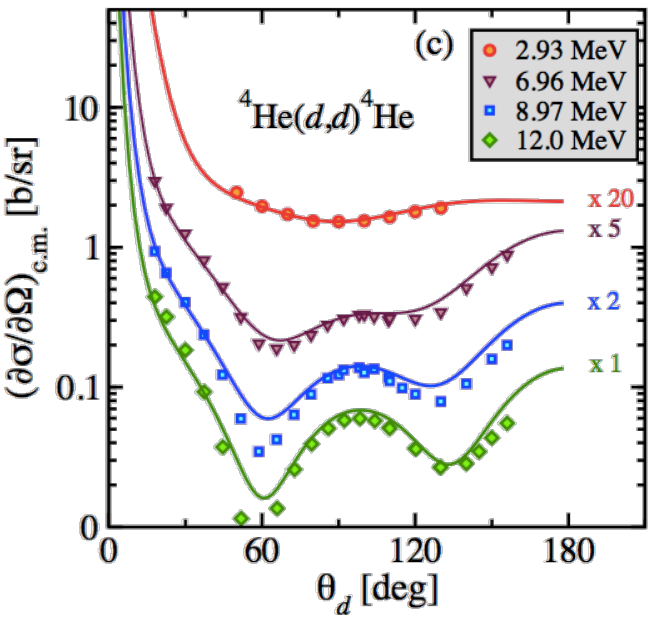
- All nucleons are "active"
- Only input is the interaction among nucleons
- Provides a unified description of structure and cluster dynamics thus enabling calculations of dynamical processes, reactions

Can we make accurate predictions?
Nucleon and deuterium elastic scattering on ^{4}He

PRC 90, 061601(R)

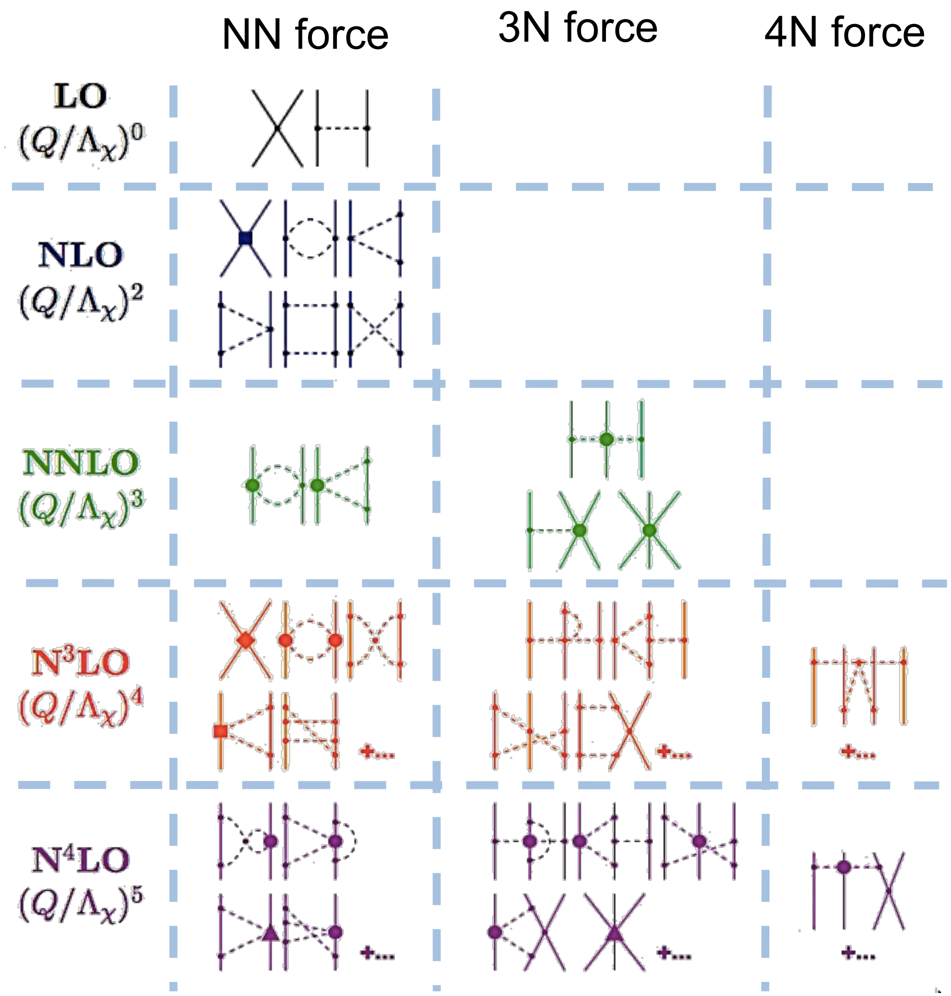


PRL114, 212502



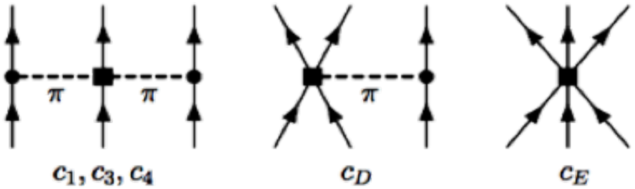
Chiral EFT interactions

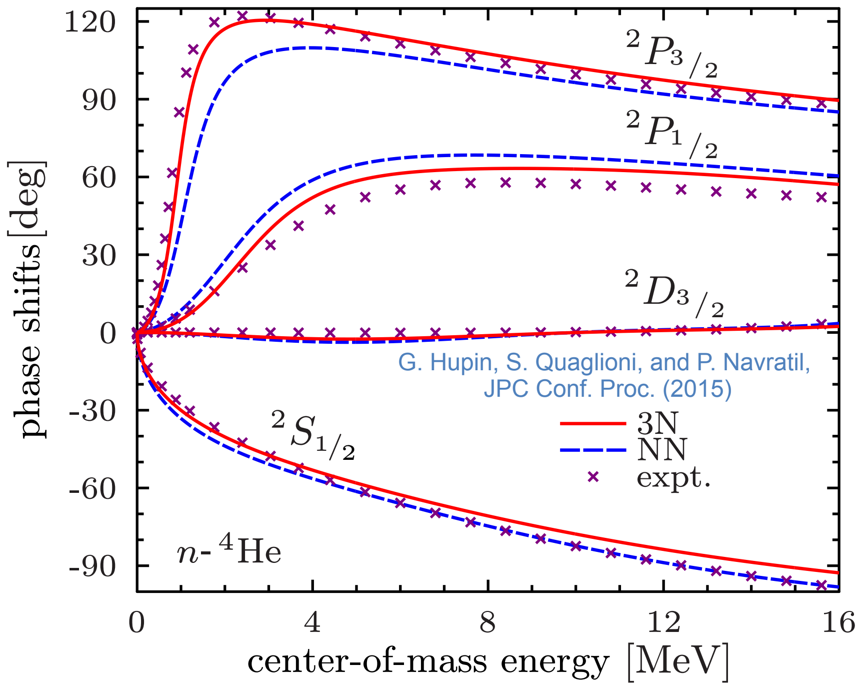
- The interaction depends on few parameters.
- These are fit to observables of *very* light nuclei.
- NN force is well constrained, we want to focus on the 3N force parameters.
- We need to constrain both NN and 3N parameters for an accurate prediction of the $^{7}Be(p,\gamma)^{8}B$ rate.
- Interactions are further altered to make them more well behaved (SRG evolution).



Determining the 3N LECs from scattering observables.

- The n-α phase shifts are particularly sensitive to the 3N force.
- A good place to start in order to provide an estimate for the uncertainty in the 3N force parameters.
- Other sources of uncertainty in the calculation are understood and under control.





Building GP emulators for reactions.

- Using the n-α calculations, construct a posterior distribution for 3N force parameters. This posterior will encode all correlations between parameters.
- Use the posterior as a prior to sample from and perform calculations for the $^{7}Be(p,\gamma)^{8}B$ reaction cross section.
- Combine the calculations with experimental data to arrive at a final value for the S-factor.
- Work is just starting so we are very interested in suggestions/ comments.

Summary

- We want to look for discrepancies between theory and observation, but this requires the uncertainty in our theory to be at least quantified.
- The 3N component of the interaction we use is not very well determined.
- Reaction observables will provide the constrains we need in order to produce an accurate estimate for the S-factor.

Thank you!

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