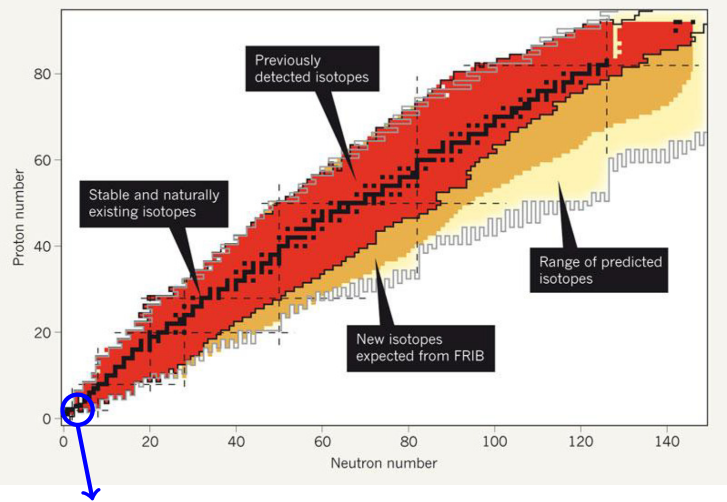
Ab initio prediction for ^{4}He$(d,\gamma)^6$Li and challenges for reactions involving heavier nuclei

Chloë Hebborn

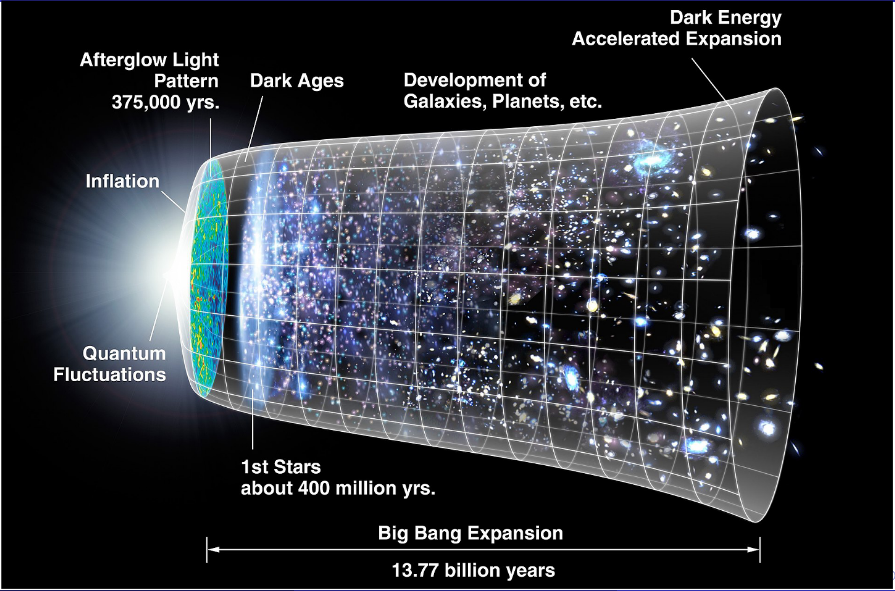
August, 9 2022

Exciting time to be a nuclear physicist with FRIB starting !

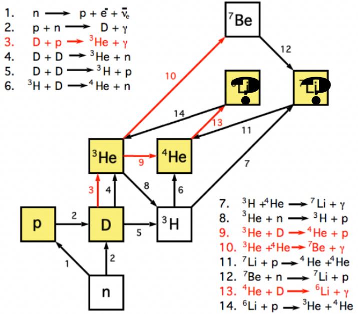


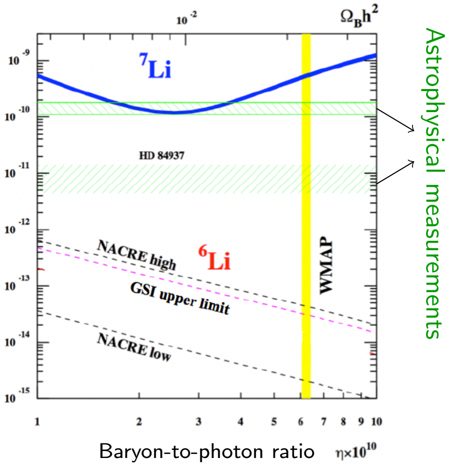
What is the origin of light elements ?

Light nuclei, such as Lithium, were already present ~3 minutes after the Big Bang



The Big-Bang nucleosynthesis accurately predicts abundances at early time... but for Lithium isotopes



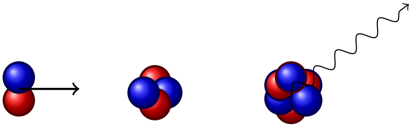


[Gustavino *et al.* JPCS 665 012004 (2016)]

→ **Need to know accurately ^{4}He(d,γ)^{6}Li rate**

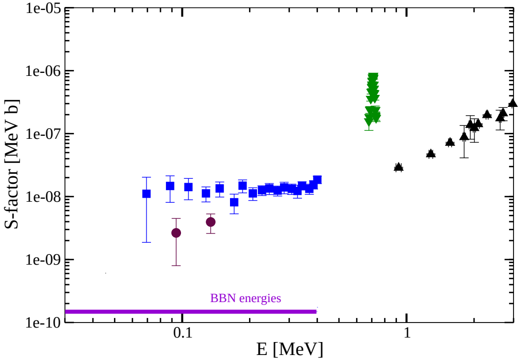
Reactions at low energy are difficult to measure as the two charged nuclei repulse each other

$^{4}\mathrm{He}(d,\gamma)^{6}\mathrm{Li}$



very low cross section

$$\sigma(E) = \frac{\exp[-2\pi\eta]}{E}\,\boxed{S(E)}$$



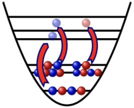
→ **Need for accurate prediction to fill the exp. gap at low E**

For a complete *ab initio* description, we need both structure... and dynamical clustered description

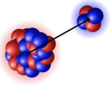
No core shell-model with continuum

[Navrátil, Quaglioni, Hupin, Romero-Redondo and Calci, Phys. Scr. **91**, 053002 (2016)]

$$\Psi = \sum_{\lambda} c_{\lambda} \big|$$



$$\big\rangle + \sum_{\nu} \int dr\, u_{\nu}(r) \big|$$



$$\big\rangle$$

Discrete structure information input

Continuous dynamical input (clustering/reactions)

⊕ **Bound states, narrow resonances**

→ short-range

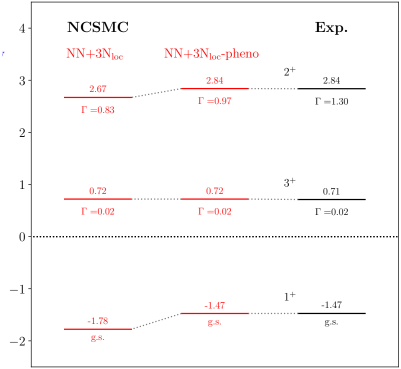
⊕ **Bound & scattering states, reactions**

→ long-range

Ab initio predictions are accurate for ^{6}Li spectrum but... not perfect

In this work : N^{3}LO NN force + 3N force NNLO

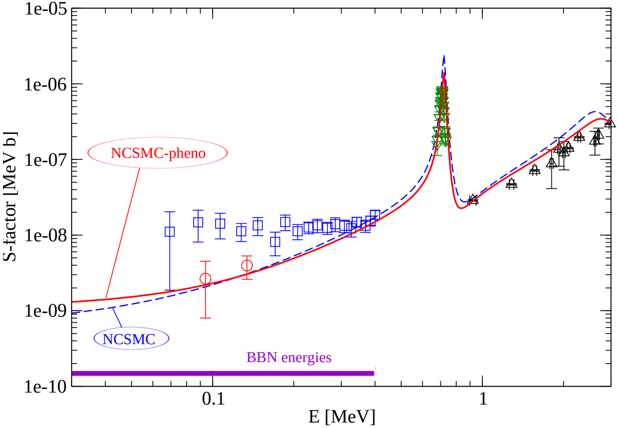
HPC at LLNL



Accurate prediction of $^4\mathrm{He}(d,\gamma)^6\mathrm{Li}$

→ need to have the right ^{6}Li binding

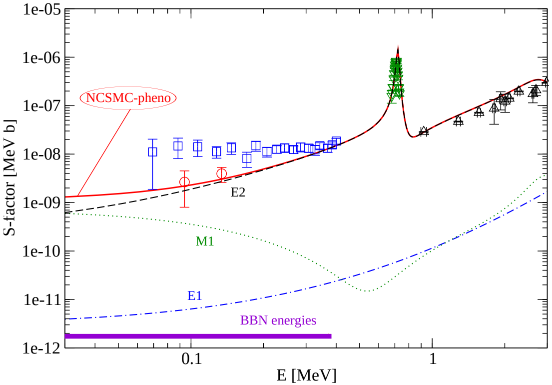
Ab initio prediction fills the experimental gap for $^4\mathrm{He}(d,\gamma)\,^6\mathrm{Li}$



→ At low E, importance of the tail of ^{6}Li g.s. : E_{1^+} and s-wave ANC

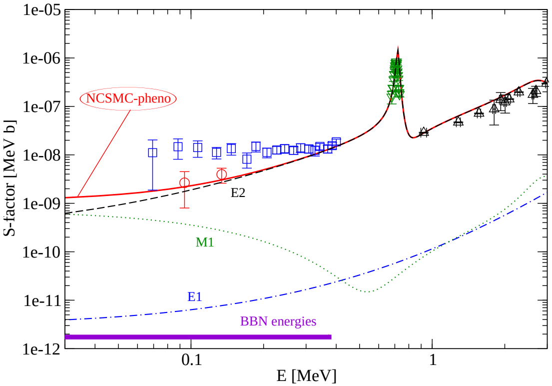
Which electromagnetic transitions drive this capture reaction ?

The S-factor is dominated by E2 and M1 at low energies



E2 larger than previous eval. → larger **ANC**, impact on (^{6}Li,d) ?

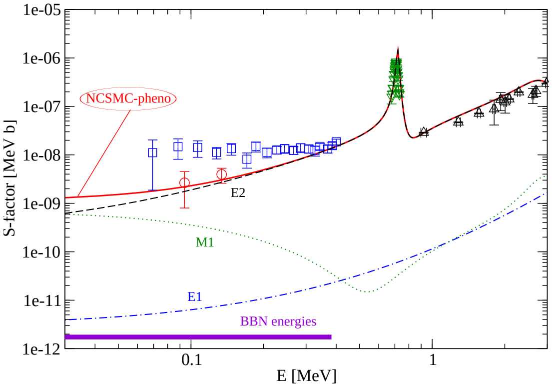
The S-factor is dominated by E2 and M1 at low energies



M1 are typically not evaluated in few-body models

M1 important at low E → which role in other capture reactions ?

The S-factor is dominated by E2 and M1 at low energies

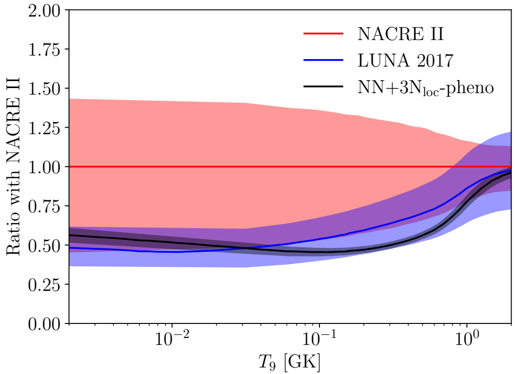


E1 evaluated with pheno. prescriptions predicted to be dominant
Isovector **E1 transitions negligible** due to small $T = 1$ mixing in ^{6}Li

What is the uncertainty due to the choice of χ-EFT force & to the finite size of the basis ?

Ab initio predictions reduce the uncertainties on the ^{4}He(d,γ)^{6}Li rate by an average factor 7

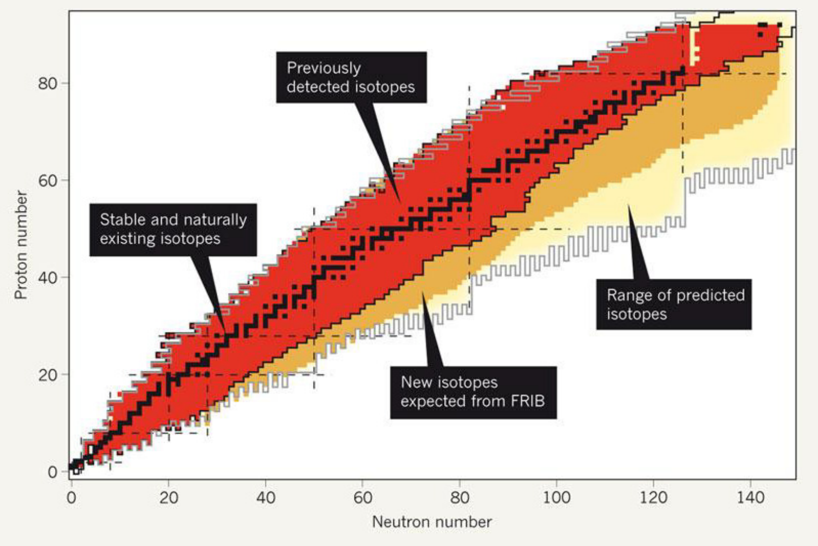
Small uncertainties thanks to the adjustment of the ^{6}Li g.s. energy



[Hebborn, Hupin, Kravvaris, Quaglioni, Navrátil, Gysbers, Phys. Rev. Lett. **129**, 042503 (2022)]

→ **Discrepancy in ^{6}Li abundances due to exp. syst. uncertainties**

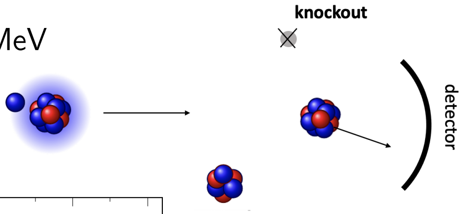
This was only one example, there are many nuclei...

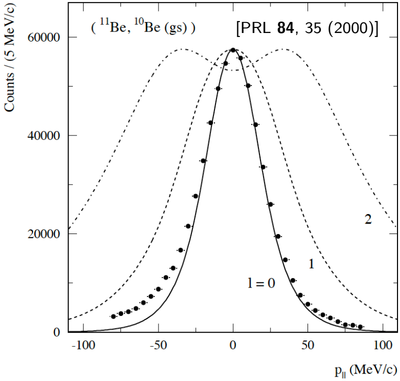


Knockout reactions are powerful probes of the single-particle structure of unstable nuclei

One-neutron knockout @ $>60A$ MeV

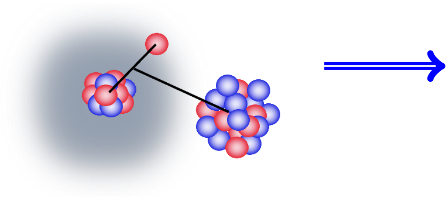
⇒ high statistics



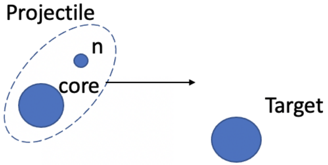


Knockout reactions with heavier nuclei and at higher energies, simplications are needed

light nuclei & low E



heavier nuclei & higher E

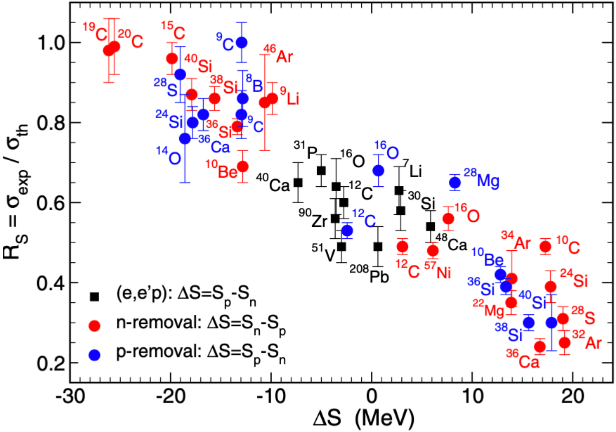


- effective core-neutron Hamiltonian
- core-target and neutron-target optical potentials

Spectator-core and eikonal approximations

[Hussein and McVoy, NPA **445**, 124 (1985)]

Asymmetry dependence of the experimental to theoretical knockout cross section is not understood

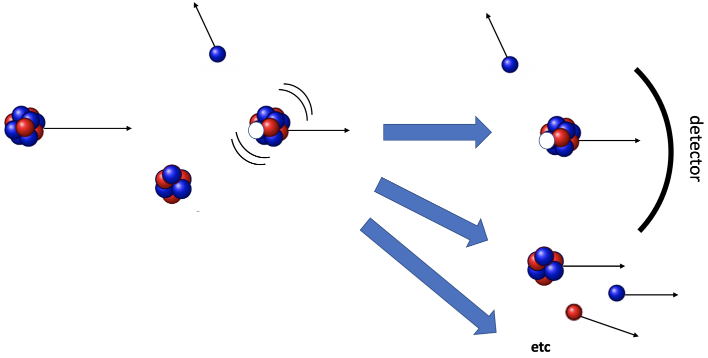


Importance of core particle decay for $\Delta S \gg 0$ [PRC **83**, 011601(R) (2011)]

→ not included in the eikonal theory !

We develop a new formalism to include many-body core-hole dynamics via dispersive optical potentials

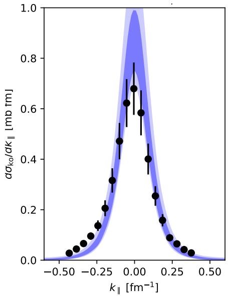
Green's function knockout [Hebborn and Potel, arXiv : 2206.09948]



Structure properties included in the core-neutron dispersive potential !

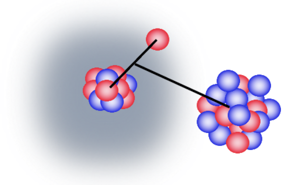
→ Applicable to N-removal & -addition, e.g. knockout, (p,d), (d,p)

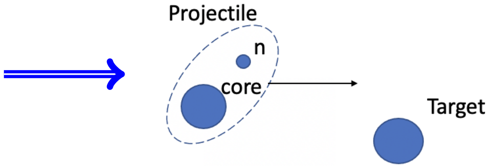
UQ due to the optical potentials in knockout reactions



Integrating microscopic predictions in few-body description :

ab initio n-T optical potentials





Thanks to my collaborators

Sofia Quaglioni
Kostas Kravvaris
Gregory Potel

Filomena Nunes
Taylor Whitehead

Amy Lovell

Petr Navrátil
Peter Gysbers

Pierre Capel

Guillaume Hupin

Thank you for your attention