Non-local potentials in nuclear reactions

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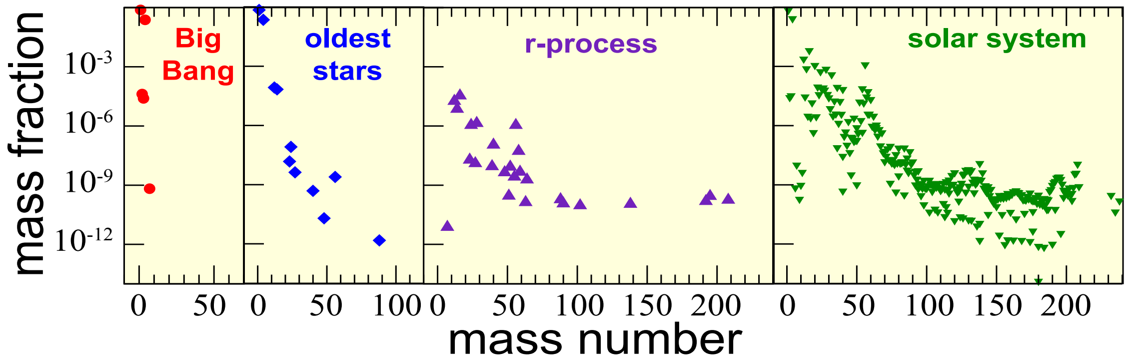
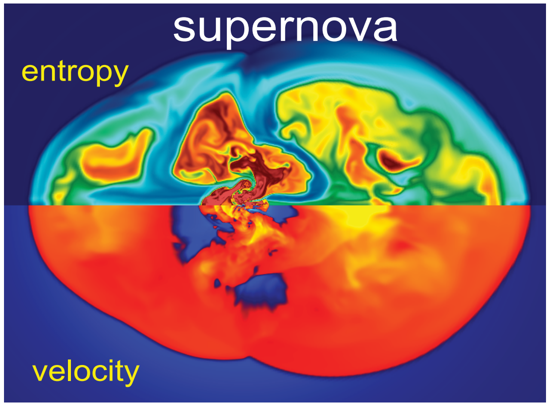
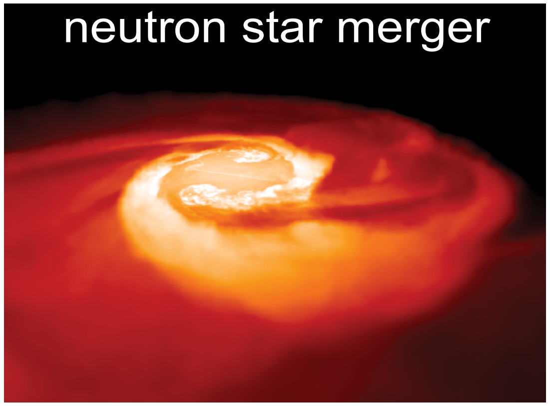
Big science questions

How did matter come into being and how does it evolve?





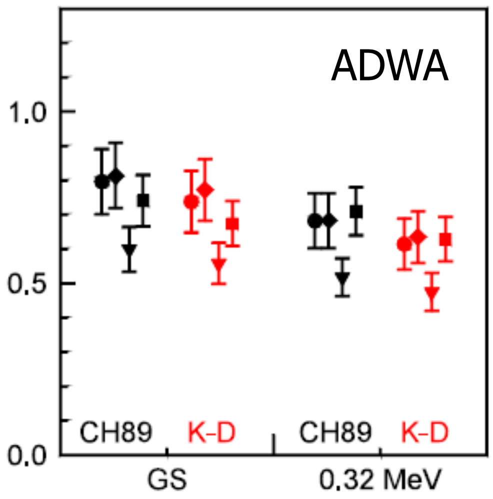


FRIB theory manifesto, Balantekin et al, MPLA 2014 (arXiv:1401.6435)

Neutron capture on unstable nuclei needed for understanding possible site of r-process: (d,p)/(p,d) reactions offer an indirect tool to extract this information

Examples of using (d,p) to study unstable nuclei

Halo nuclei

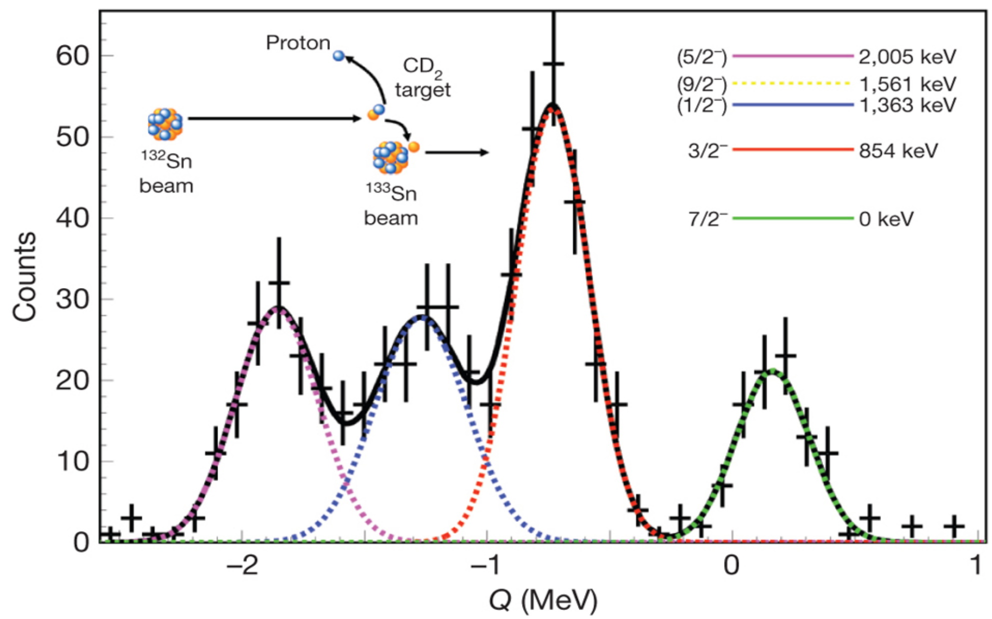


^{10}Be(d,p)^{11}Be @ 12-21 MeV

Schmitt et al, PRL 108, 192701 (2012), PRC 88, 064612 (2013)

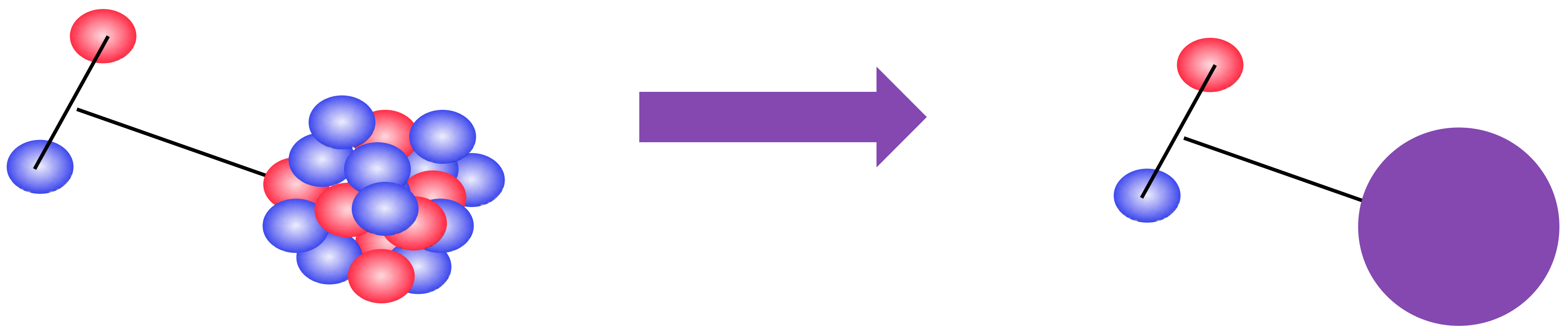
Neutron rich doubly magic nuclei

d(^{132}Sn,^{133}Sn)p@5 MeV/u



K. Jones et al, Nature 465 (2010) 454, PRC 84, 034601 (2011)

Reaction theory: from many body to few body



- ❑ isolating the important degrees of freedom in a reaction
- ❑ connecting back to the many-body problem

➢ effective nucleon-nucleus interactions
(non-local and energy dependent)

Non-local potential?

- Phenomenological optical potentials are usually made local **U(R)**
- Microscopically derived optical potentials are non-local **U(R,R')**
    - Does non-locality make a difference in the reaction?
    - Can we constrain non-locality with reactions?

Non-local Perey and Buck potential in (d,p)

Solve the single channel scattering problem with non-local optical potential
Solve the single channel bound state problem with non-local mean field

$$\frac{\hbar^2}{2\mu}\nabla^2\Psi(\mathbf{r}) + E\Psi(\mathbf{r}) = U_o(\mathbf{r})\Psi(\mathbf{r}) + \int U^{NL}(\mathbf{r},\mathbf{r}')\Psi(\mathbf{r}')d\mathbf{r}'$$

Construct the (p,d) amplitude within DWBA

Perey and Buck type non-locality

$$U^{NL}(\mathbf{r},\mathbf{r}') = U^{NL}_{WS}\left(\left|\frac{\mathbf{r}+\mathbf{r}'}{2}\right|\right)\frac{\exp\left(-\left|\frac{\mathbf{r}-\mathbf{r}'}{\beta}\right|^2\right)}{\pi^{3/2}\beta^3}$$

F. Perey and B. Buck, Nucl. Phys. 32, 353 (1962).

Perey correction factor: if the local momentum approximation is valid

$$\psi_\ell^{PCF}(r) = F(r)\psi_\ell^{Loc}$$

$$F(r) = \left[1 - \frac{\mu\beta^2}{2\hbar^2}\left(U^{LE}(r) - U_o(r)\right)\right]^{-1/2}$$

N. Austern, Phys. Rev. 137, 752 (1965)

Non-local Perey and Buck potential: effect on (p,d)

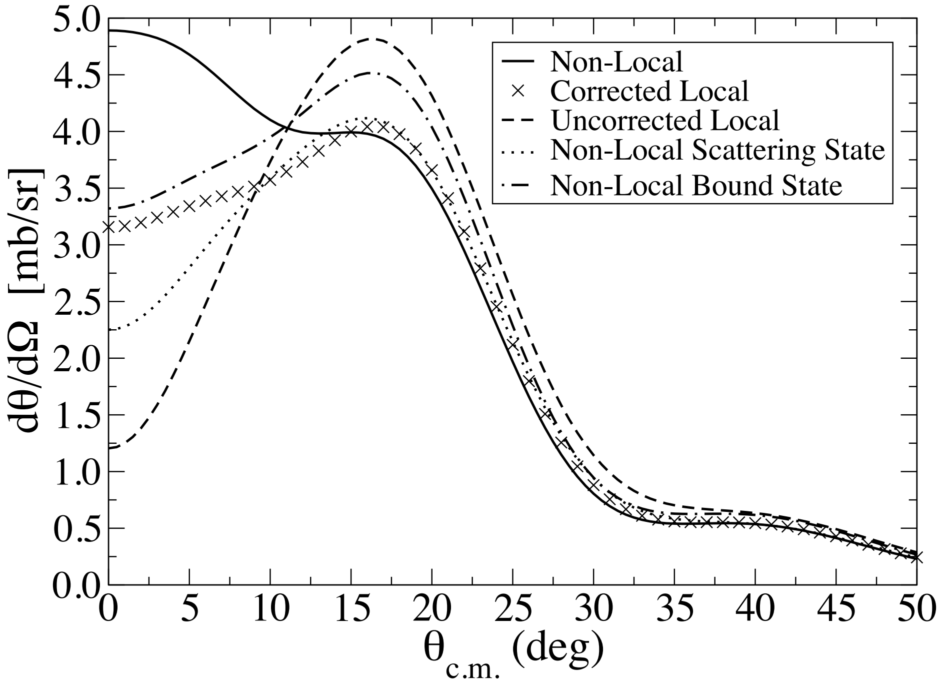


FIG. 5: Angular distributions for ^{49}Ca$(p,d)^{48}$Ca at 50.0 MeV: inclusion of non-locality in both the proton distorted wave and the neutron bound state (solid line), using LEP, then applying the correction factor to both the scattering and bound states (crosses), using the LEP without applying any corrections (dashed line); including non-locality only to the proton distorted wave (dotted line), and including non-locality in the neutron bound state only (dot-dashed line).

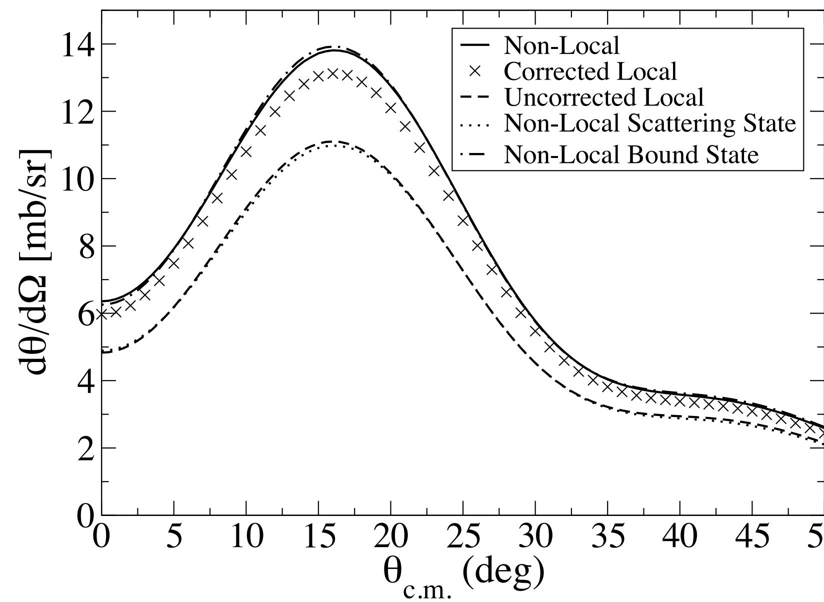


FIG. 7: Angular distributions for ^{133}Sn$(p,d)^{132}$Sn at 20.0 MeV (descriptions of each line is given in the caption of Fig.5).

Titus and Nunes, PRC 89, 034609 (2014)

Non-local Perey and Buck potential: effect in (p,d)

$E_{lab} = 20$ MeV	Corrected Relative to Local	Non-Local Relative to Local
$^{17}O(1d_{5/2})(p,d)$	7.1%	18.8%
$^{17}O(2s_{1/2})(p,d)$	20.1%	26.5%
$^{41}Ca(p,d)$	11.4%	21.9%
$^{49}Ca(p,d)$	10.4%	17.3%
$^{127}Sn(p,d)$	17.5%	17.3%
$^{133}Sn(p,d)$	18.2%	24.4%
$^{209}Pb(p,d)$	19.4%	20.8%

$E_{lab} = 50$ MeV	Corrected Relative to Local	Non-Local Relative to Local
$^{17}O(1d_{5/2})(p,d)$	17.0%	35.4%
$^{17}O(2s_{1/2})(p,d)$	0.2%	12.7%
$^{41}Ca(p,d)$	2.9%	5.8%
$^{49}Ca(p,d)$	−16.0%	−17.1%
$^{127}Sn(p,d)$	10.1%	4.5%
$^{133}Sn(p,d)$	−6.7%	−16.9%
$^{209}Pb(p,d)$	8.6%	8.6%

Titus and Nunes, PRC 89, 034609 (2014)

Dispersive Optical Potential (DOM)

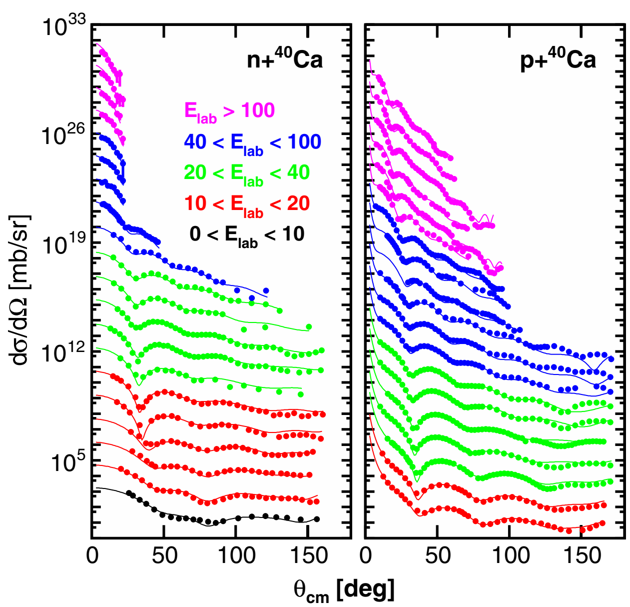


FIG. 1 (color online). Calculated and experimental elastic-scattering angular distributions of the differential cross section $d\sigma/d\Omega$. Panels shows results for $n + {}^{40}$Ca and $p + {}^{40}$Ca. Data for each energy are offset for clarity with the lowest energy at the bottom and highest at the top of each frame. References to the data are given in Ref. [15].

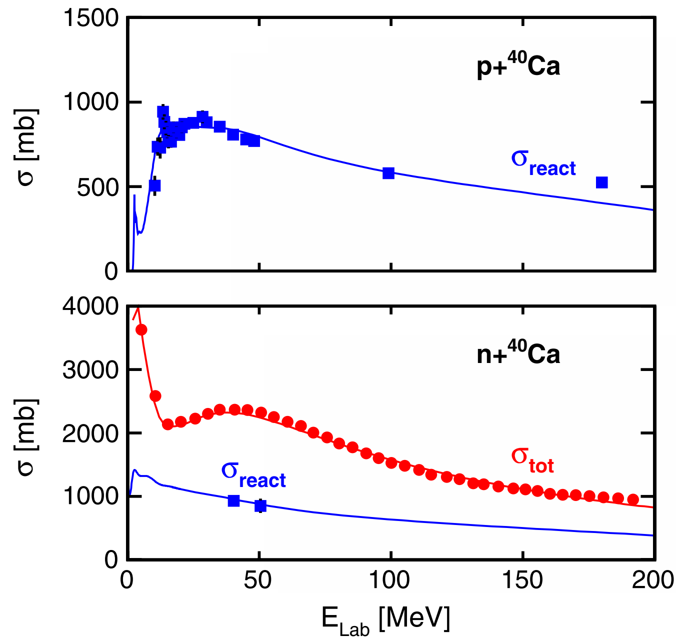


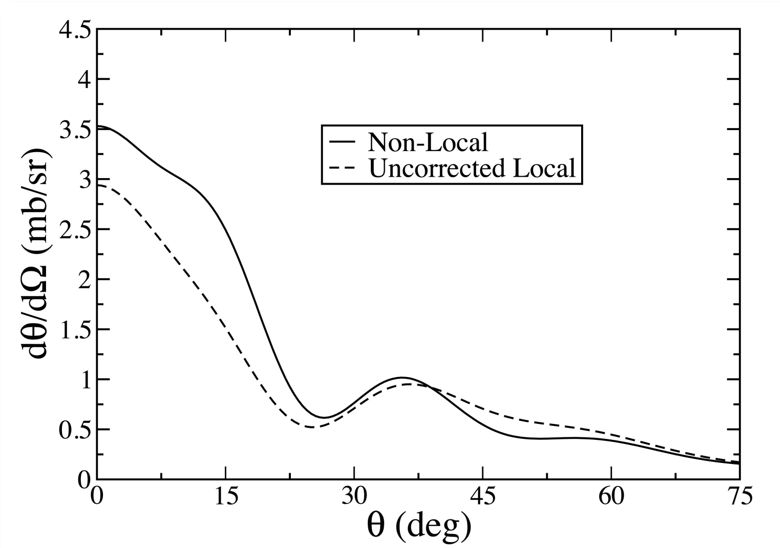
FIG. 2 (color online). Total reaction cross sections are displayed as a function of proton energy while both total and reaction cross sections are shown for neutrons.

TABLE I. Quasihole energies in MeV for neutron orbits in ^{40}Ca near the Fermi energy compared with experiment.

Orbit	DOM	Experiment
$1p_{1/2}$	−3.47	−4.20
$1p_{3/2}$	−4.51	−5.86
$0f_{7/2}$	−7.36	−8.36
$0d_{3/2}$	−16.2	−15.6
$1s_{1/2}$	−15.3	−18.3

Mahzoon et al, Phys Rev Lett 112, 162503 (2014)

Non-local DOM potential: effect on (p,d)



$^{40}Ca(p,d)^{39}Ca$ @ 50 MeV

Potential	**Perey-Buck**		**DOM**
Energy (MeV)	Non-Local relative to local	Corrected relative to local	Non-Local relative to local
20	42 %	1 %	21 %
35	50 %	6 %	32 %
50	28 %	2 %	20 %

Ross et al., in preparation, SEE REU POSTER

Summary and Outlook

- Impact of non-locality in nuclear reactions
  - DWBA tests show strong sensitivity to non-locality (20-30% change in cross section)

  - need to upgrade best reaction theories to handle non-local interactions
  - use state-of-the-art ab-initio methods with correlations to derive non-local optical potentials

thankyou!

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