KU LEUVEN

erc European Research Council

UNIVERSITY OF NOTRE DAME

Study of the near-barrier fusion of the ^{8}B+^{40}Ar proton-halo system

Maxime Renaud

NUSPRASEN workshop, Warsaw - January 23, 2018

Outline

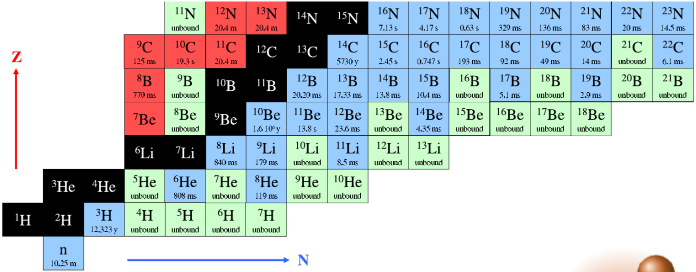
1. The physics case
   - Halo nuclei reactions
   - The Boron-8 case

2. The experiment
   - Active Target Time Projection Chambers
   - Proof-of-concept
   - Expectations

Outline

1. The physics case
   - Halo nuclei reactions
   - The Boron-8 case
2. The experiment
   - Active Target Time Projection Chambers
   - Proof-of-concept
   - Expectations

"Halo" nuclei?



- Low separation energy for valence nucleon(s),
- Large reaction cross-section,
- Large matter radii.

Figure 1: ^{6}He, 2n halo

Image from H. Simon, Phys. Scr. T152 (2013), 014024

Fusion reactions with halo nuclei

Nuclear reaction are sensitive to nuclear structure.

In the case of fusion:

- Effect of break-up and transfer on fusion cross-section?
- Multi-body quantum tunneling problem.

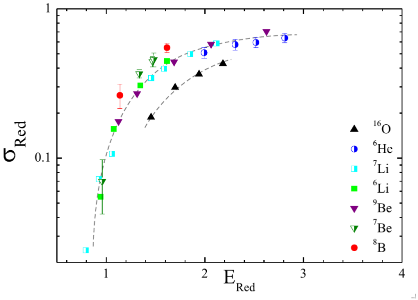


Figure 2: Reduced total reaction cross section on ^{27}Al for different weakly-bound projectiles $vs.$ ^{16}O. [1]

[1] V. Morcelle *et al.*, Phys. Rev. C 95 (2017), 014615

Comparing with what?

Universal Fusion Function :

- Proposed in $[1]$, to compensate for the static effects in the fusion excitation function
- $F(x) = \frac{2E}{\hbar\omega R_B^2}\sigma_F(x)$,
  where $x = \frac{E - V_B}{\hbar\omega}$,
  with $\hbar\omega = \sqrt{\frac{\hbar^2 |V"(R_B)|}{\mu}}$.

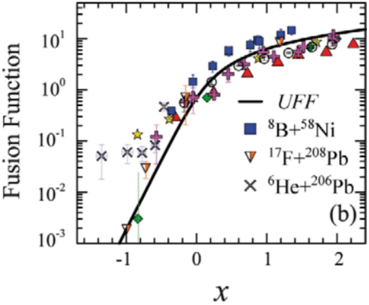


Figure 3: UFF for several experiments (J. Rangel *et al.*, Eur. Phys. J. A49 (2013), 57)

[1] L.F. Canto *et al.*, J. Phys. G36 (2009), 015109

Boron-8

Properties:

- one-proton halo,
- separation energy of 0.138 MeV,
- important in CNO cycle.

E.F. Aguilera *et al.* [1] & A. Pakou *et al.* [2] reported divergent behaviour for the fusion excitation function.

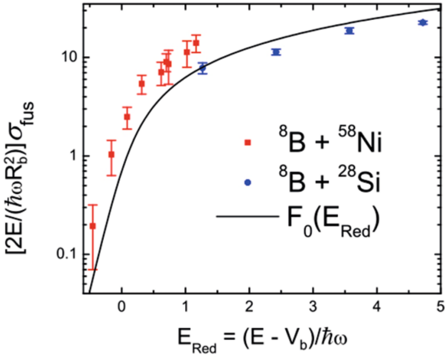


Figure 4: Data from the papers [1, 2] shown with the UFF. [3]

[1] E.F. Aguilera *et al.*, Phys. Rev. Lett. 07, 092701 (2011), [2] A. Pakou *et al.*, Phys. Rev. C 87, 014619 (2013),
[3] J.J. Kolata *et al.*, Eur. Phys. J. A 52, 16123 (2016)

Boron-8

The difficulties:

- weak beam intensities ($\sim 10^4$ ions/s),
- heavily contaminated ($\sim 100\%$ $[1]$),
- fusion dominated by break-up around/below V_B $[2]$.

$\Rightarrow$ **Collecting enough relevant data is a major challenge.**

[1] L.F. Canto *et al.*, Phys. Rep. 596 (2015), 1-86 [2] J.J. Kolata *et al.*, Nucl. Instr. Meth. Phys. Res. A830 (2016), 82-87.

Outline

1. The physics case
   - Halo nuclei reactions
   - The Boron-8 case

2. The experiment
   - Active Target Time Projection Chambers
   - Proof-of-concept
   - Expectations

"Active target time projection chambers"

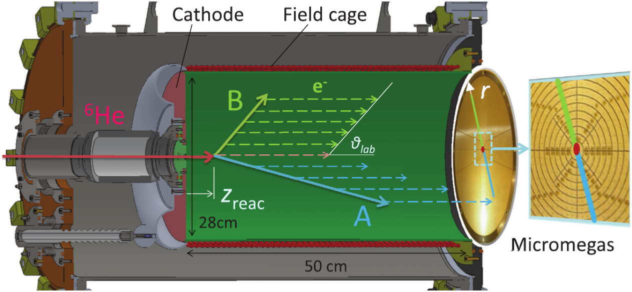


Figure 5: AT-TPC operating principle. [1])

- Detection medium = target,
- Almost 4π coverage,
- High efficiency at low intensities.

[1] D. Suzuki *et al.*, Phys. Rev. C87 (2013), 054301.

Proof-of-concept: ^{10}Be fusion measurement

J.J. Kolata *et al.* used the same detector to investigate the fusion excitation function for ^{10}Be+^{40}Ar. [1]

One 90h run @ 100 cps, P10 gas target:

- good off-line channel identification,
- disentangled CF and NCF.

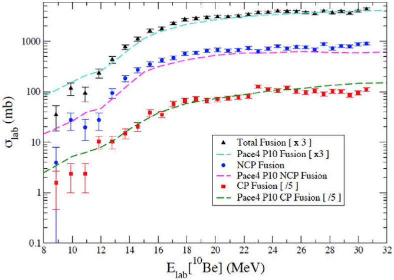


Figure 6: Experimetal total (black), complete (blue) and incomplete (red) fusion cross section. [1]

[1] J.J. Kolata *et al.*, Nucl. Instrum. Meth. Phys. Res. A830 (2016), 82-87.

Expectations

Experiment to be performed at the *TwinSol* facility, University of Notre Dame, USA.

Beam yield: $\sim 10^4$ ^{8}B ions/s, @ maximum 27 MeV

Coulomb barrier height: 14 MeV

$E_{lab.}$ [MeV]	Estim. $\sigma_{tot.fus.}$ [mb]	Rate (ev./s)
14	0.66	0.02 (~ 1.2/min)
15	3.47	0.1
17	63.2	2.1
18	152	5.1
19	252	8.4

Calculation made with the PACE4 engine.

Thank you for your attention!

Questions?

Back-Up

Boron-8

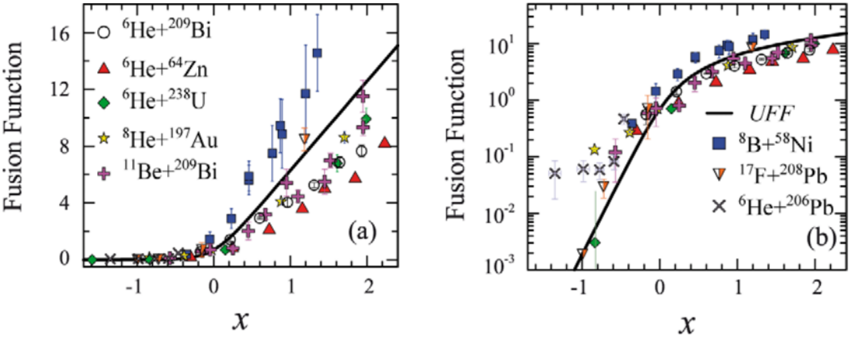


Figure 7: UFF and reduced $\sigma_{fus.}$ for several experiments (J. Rangel *et al.*, Eur. Phys. J. A49 (2013), 57)

Proof-of-concept: ^{10}Be fusion measurement

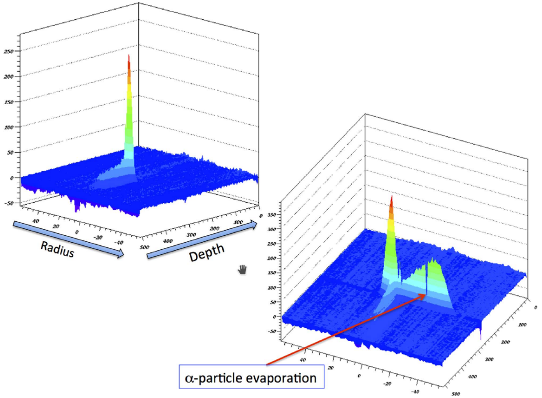


Figure 8: Reconstructed tracks of identified fusion events. (J.J. Kolata *et al.*, Nucl. Instrum. Meth. Phys. Res. A830 (2016), 82-87)

^{10}Be fusion measurement results

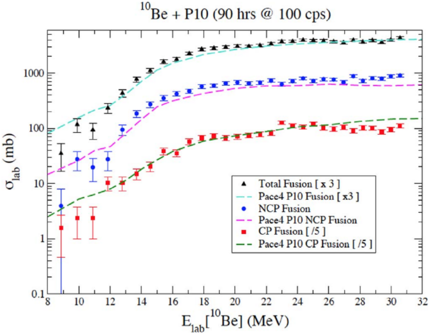


Fig. 9. Experimental total fusion cross section (triangles), fusion with neutron emission (dots), and fusion with emission of charged particles (squares). The curves are calculations using the PACE4 code. The total fusion cross section and prediction have been multiplied by a factor of three, and the charged-particle associated cross section and prediction have been divided by a factor of five, in order to sufficiently separate the data sets on this plot. See the text for a discussion of the absolute normalization.

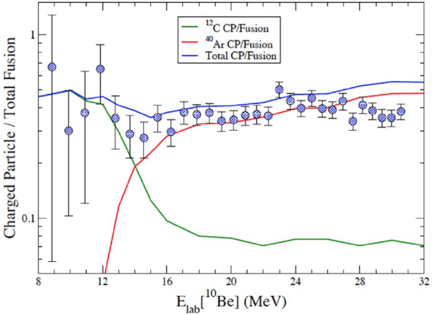


Fig. 10. Observed ratio of charged-particle-associated fusion to total fusion. PACE4 calculations of this ratio for a P10 target, for ^{40}Ar, and for ^{12}C are also shown.

^{10}Be energy of about 14 MeV. In this region the comparison between theory and experiment is very good, though there is an indication of a small excess of NCP fusion throughout the range and a deficit of CP fusion above about 27 MeV. It is not clear