Near and sub-barrier fusion as a probe of nuclear structure

Neutron-rich and proton-rich nuclei probe intrinsically different environments due to the Coulomb barrier.

Very neutron-rich nuclei: $N/Z \approx 2 - 2.5, S_n < 1 \text{ MeV}$
- Diffuseness of neutron distribution (neutron skins & halos)
- More states near the Fermi surface (level density)
- Breakdown of the single-particle description (Clustering at low $\rho$)
- Redefinition or disappearance of magic numbers

Sub-barrier fusion is particularly sensitive to the tail of the nuclear matter distribution, hence provides a good probe of the neutron and proton distributions.

Measuring fusion for an isotopic chain of projectile nuclei one can sensitively examine the dependence of fusion on the isospin degree-of-freedom.

Comparison of high quality, experimental data with microscopic models provides information about the density distributions of neutrons and protons.

A.S. Umar et al., PRC 85 055801 (2012)

R.T. deSouza, Indiana University
Direct measurement of evaporation residues by Energy-TOF allows determination of the fusion cross-section to the 2-3 mb level (one order of magnitude lower than prior measurements!)

It is now possible to perform microscopic calculations that include pairing (density constrained TDHF), providing a relevant comparison for the experimental data.

The experimental data manifest a significant enhancement in the sub-barrier region. Can be interpreted as:

- Larger tunneling probability, weaker barrier/deviation from inverted parabolic shape (sensitivity to n/p density distributions)
- Pairing configuration changes as reaction dynamics proceeds

Present status of sub-barrier fusion with n-rich light nuclei

Measuring the fusion cross-section near and below the barrier with low intensity beams

Beam intensity: $10^4 - 10^5$ pps

Theoretical support: S. Umar/V. Oberacker, Vanderbilt University
Future Plans and Challenges

1) Establish a high quality, systematic set of sub-barrier fusion excitation functions for neutron-rich nuclei in this mass range. [e.g. $^{19,20,22}$O beams; $^{12}$C, $^{18}$O targets]

- Stringent test of microscopic models (both statics and dynamics)
- Astrophysical implications: Constrain neutron star crust models

Challenge: Availability of low energy, neutron-rich beams with sufficient intensity
Challenge: Improved detector systems to reduce sensitivity to background

2) Utilize (measure) the multiplicities, kinetic energies, and angular distributions of the emitted particles (proton, alpha, and neutron) to examine the decay characteristics of the compound nuclei.

- Access information on the level density of dilute nuclear matter
- Clustering effects in low density nuclear matter at low excitation

Challenge: Efficient measurement of low energy emitted particles, including neutrons in coincidence with the evaporation residue

3) Improve microscopic models (e.g. to allow pairing to evolve as the reaction dynamics proceeds)

Grand Challenge Theoretically: develop TDHFB code on 3D lattice for nuclear reactions