The density dependence of the symmetry energy

Abstract
The behavior of the symmetry energy at sub-saturation densities will be explored through the study of selected isospin observables in mid-peripheral collisions of exotic nuclei. Differential observables between systems of similar mass and isospin ratios ranging from N/Z~1 to N/Z~1.7 will be constructed to experimentally disentangle isospin effects from isoscalar transport properties.

Keywords
Density functional theory, symmetry energy, effective interactions, neck decay, isoscaling, pre-equilibrium particles

Physics case

We want to address the question of the energy functional of asymmetric nuclear matter, and specifically constrain its isovector part, the symmetry energy. Indeed the density functional theory (DFT) through self-consistent mean field calculations (and their extensions) is probably the only possible framework in order to understand the structure of medium-heavy nuclei; the largest uncertainties on the energy functional concern the density dependence of its isovector, or symmetry part.
We expect important synergies on this issue with the Single Particle and Collective Properties subtask, and with the Ground State Properties subtask. Since extended mean field theories with a density functional constraint in a large density domain are a unique tool to understand the structure properties of neutron stars crusts, we also expect an important synergy with the Astrophysics subtask. To address this physics case we need to produce sub-saturation and super-saturation density matter through heavy ion collisions.

Observables

Observables include: Isospin imbalance ratios, neck composition, isoscaling, emission times of pre-equilibrium particles.

Proposed experiment

The symmetry energy cannot be directly accessed from data, however the different $E_{sym}(\rho)$ functionals can be implemented in transport equations and confronted to transport observables. The asy-stiffness of the EOS rules the drift and diffusion of isospin, which lead to isospin equilibration (transfer to bound states) and emission (transfer to continuum states). Isospin equilibration is measured by the global isospin content of the QP in peripheral reactions, while isospin emission is measured by the isospin content of mid-rapidity fragments and pre-equilibrium particles. In order to focus on the isovector properties and minimize the theoretical as well as experimental uncertainties, we will compare systems of similar size and largely different N/Z from ~1 to ~1.7. To produce and detect low density matter we need to use reaction mechanisms leading to the formation of a neck, and a 4π detection for impact parameter selection.

Requirements:

Beam properties

Different isotopes of medium and medium-heavy beams from neutron poor to neutron rich (e.g. ^{56}Ni -> ^{74}Ni, ^{106}Sn -> ^{132}Sn) in an energy range 15-50 A.MeV.

Detection

- 4π and low threshold complete A and Z identification for IMF (FAZIA)
- Large acceptance spectrometer for mass identification of QP remnant
- High angular resolution $\Delta\theta<0.5$ LCP and neutron arrays for correlation measurements

Theoretical support

Transport calculations (BUU,SMF,QMD,AMD,FMD). We will need extensive simulations with different effective interactions. A strong effort is also needed at the theoretical level, in a first time to assess and improve the compatibility between the different codes, and on a longer timescale to improve the description of clusterization in dilute quantum media.