Yennello Research Group

1967 - 2017 YEARS OF BEAM exploring the nuclear frontier

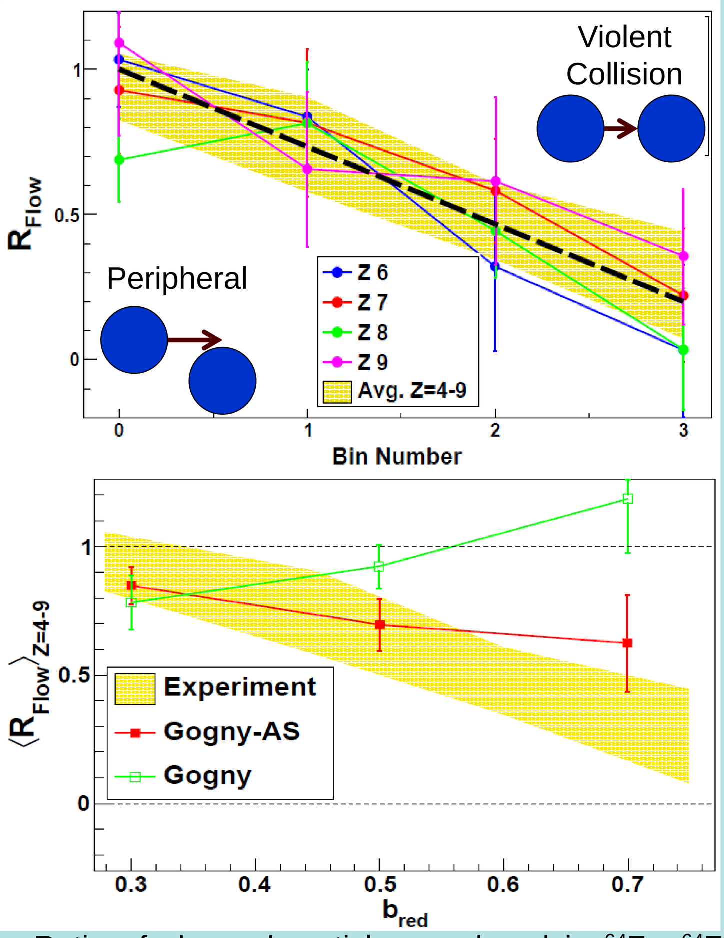
Research Overview

In the nuclear equation of state, the energy associated with an imbalance of neutrons and protons is termed the asymmetry energy, and the density dependence of this quantity is currently the largest uncertainty. The Yennello Research Group focuses on further constraining this density dependence using heavy-ion collisions. Utilizing the K500 and K150 cyclotrons, heavy-ion projectiles are accelerated to up to 40% the speed of light and collided with stationary targets. These reactions are important for studying structure, chemical composition, and the evolution of neutron stars and dynamics of supernovae explosions.

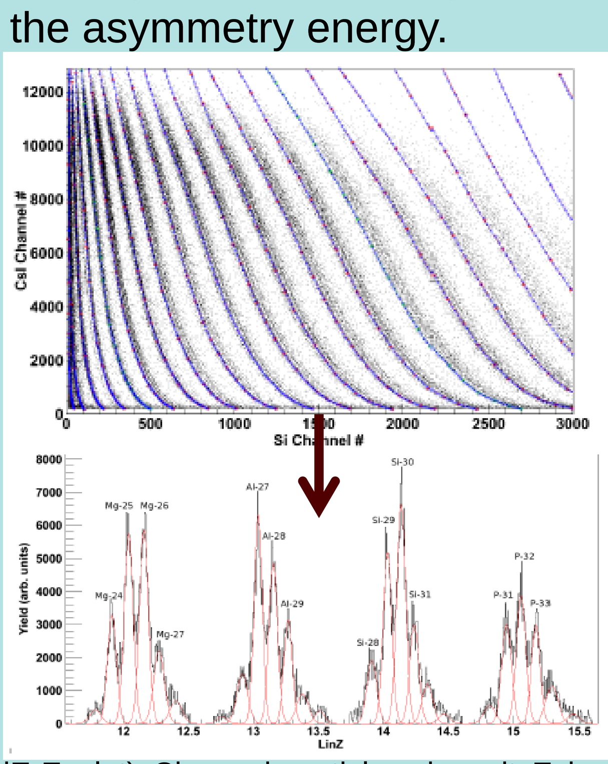
Isospin Transport Equilibrium in ^{70}Zn, ^{64}Zn and ^{64}Ni Systems at 35A MeV

Motivation

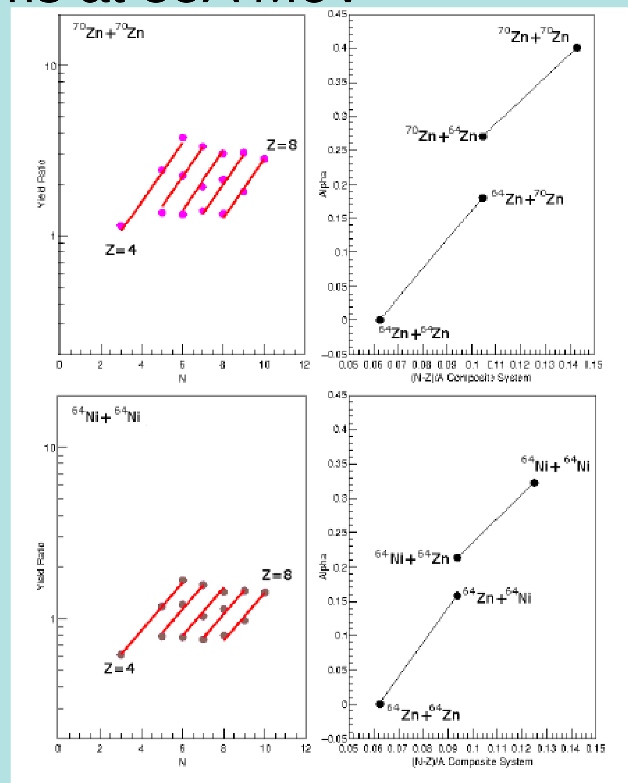
Isospin transport is the exchange of nucleons between a projectile and target. The extent of this multi-neutron and multi-proton exchange between neutron-poor and neutron-rich nuclei, leading to rapid neutron-proton equilibration, can give insight into the characteristics of the density dependence of the asymmetry energy.



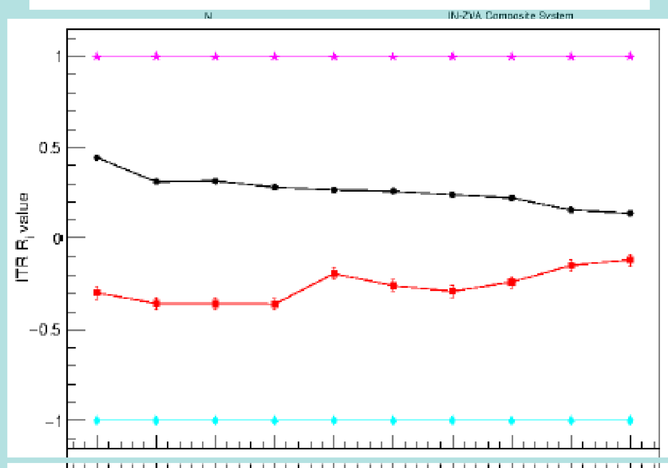
- Ratio of charged particles produced in ^{64}Zn+^{64}Zn system was compared to ^{64}Ni+^{64}Ni system relative to ^{70}Zn+^{70}Zn system.
- Plotted as a function of the violence of the collision.
- As the collision becomes more violent, dependence goes from mass dominated to charge dominated.



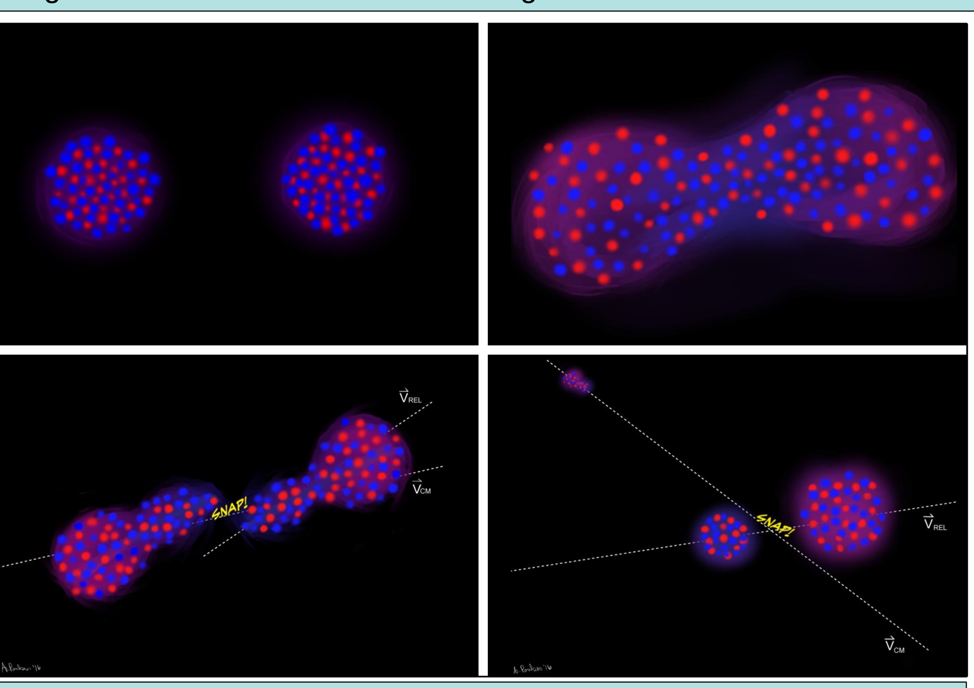
- (Above dE-E plot) Charged particles deposit E in Si and CsI detectors based on m/q
- X-axis is energy deposited in CsI. X-axis is energy in Si detector
- Allows for particle identification in bands
- (PID plot) Calculate single particle identification (PID) from dE-E
- PID used to isotopically separate fragments.



- (Above, Right) The yield of the 3 most abundant isotopes for Z=4-8 in ^{70}Zn+^{70}Zn (top, left) and ^{64}Ni+^{64}Ni system (bottom, left).
- (Above, Right) The isoscaling parameter for A=3 is compared for the symmetric and anti-symmetric systems of ^{64}Zn and ^{64}Ni, and ^{64}Zn and ^{70}Zn.



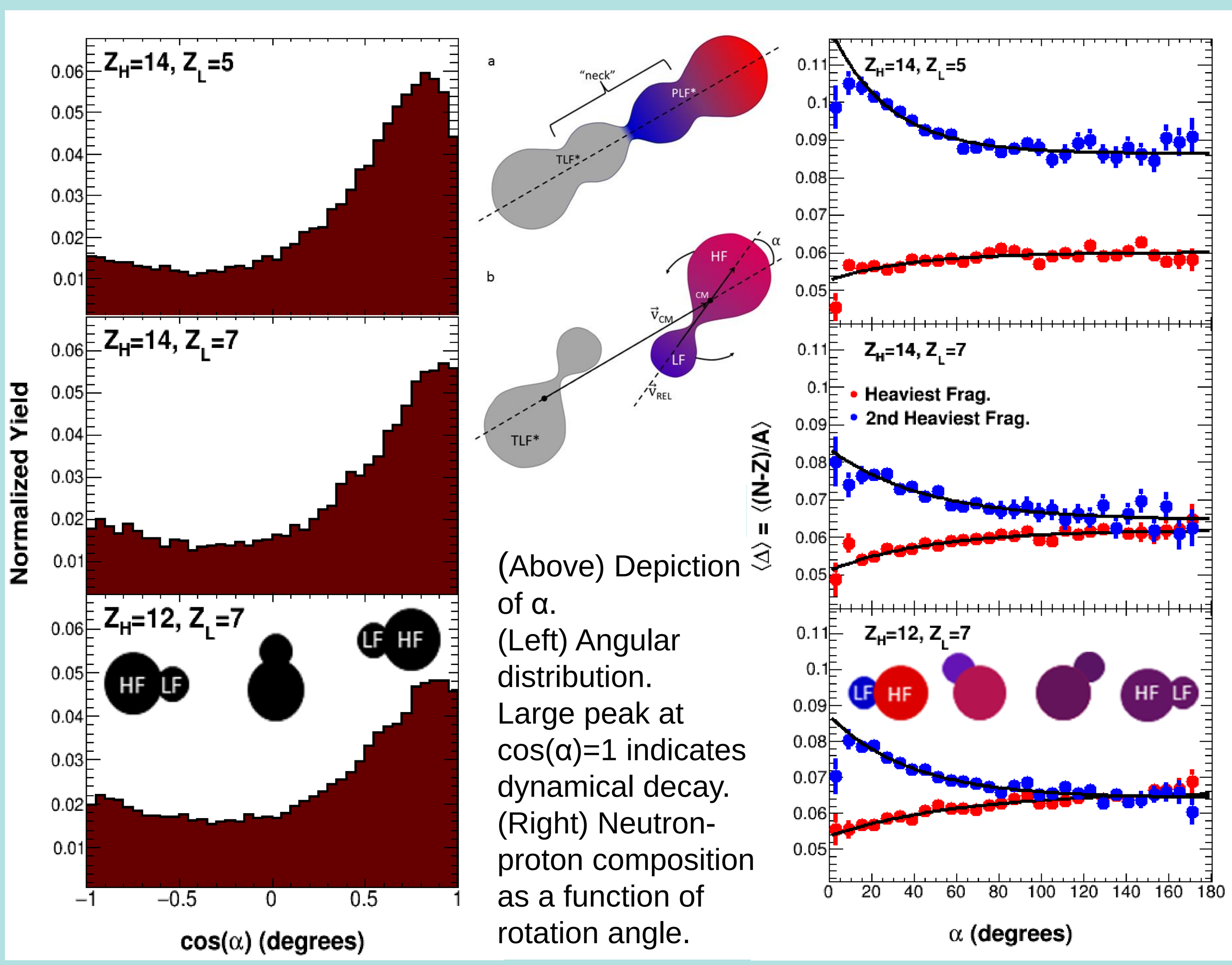
- (Below, Right) The isoscaling parameter for A=3 as a function of the velocity of the quasi-projectile in center-of-mass frame.
- Lower velocity indicates central collision.



N-Z Equilibration within a deformed nuclear system

Motivation

The extent of neutron-proton (N-Z) equilibration is governed by the contact time and the gradient of the potential driving this interaction. By using the rotation angle between the two heaviest fragments of the deformed, excited projectile-like fragment as a clock, the N-Z equilibration was determined to follow first-order kinetics. A mean equilibration time of $0.3 \pm^{0.6}_{0.1}$ zeptoseconds (10^{-21} s)!

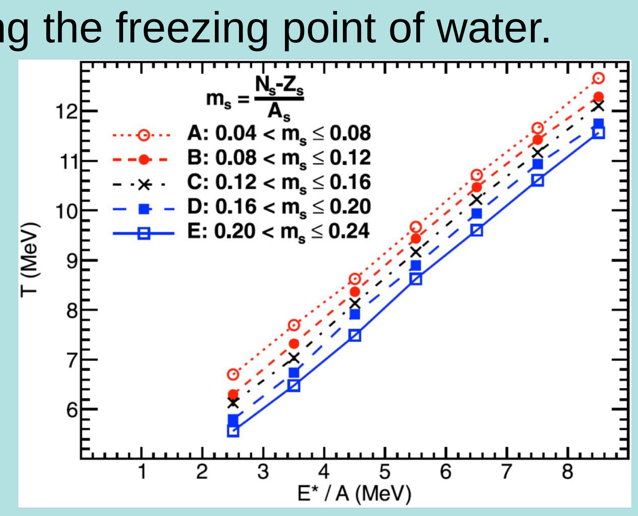


(Above) Depiction of α.
(Left) Angular distribution. Large peak at cos(α)=1 indicates dynamical decay.
(Right) Neutron-proton composition as a function of rotation angle.

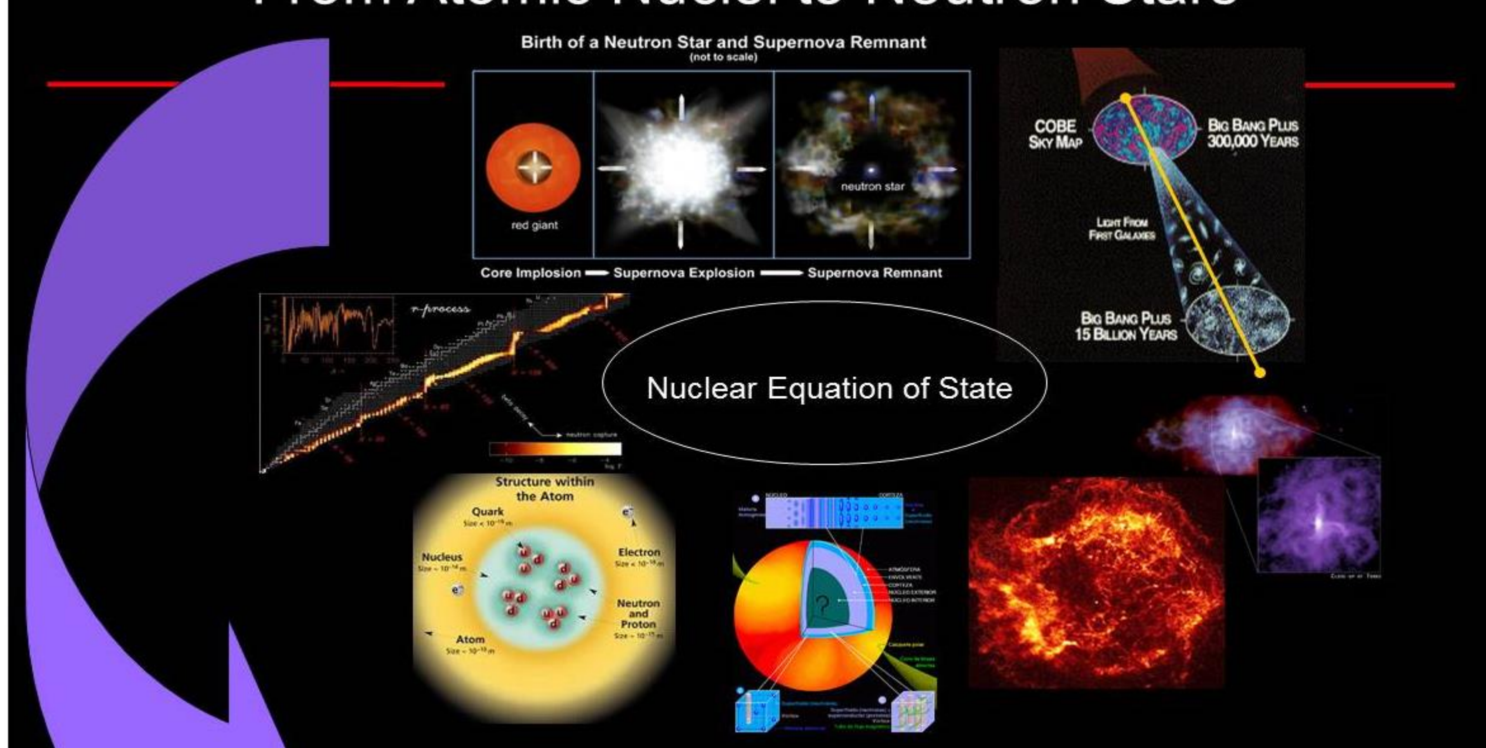
Nuclear Temperatures

Motivation

The nuclear equation of state relates temperature, density, internal energy, pressure, and neutron-proton asymmetry. One facet of this is the caloric curve (temperature vs excitation energy). Our measurement shows that adding more neutrons at a constant excitation decreases the temperature – similar to salt lowering the freezing point of water.



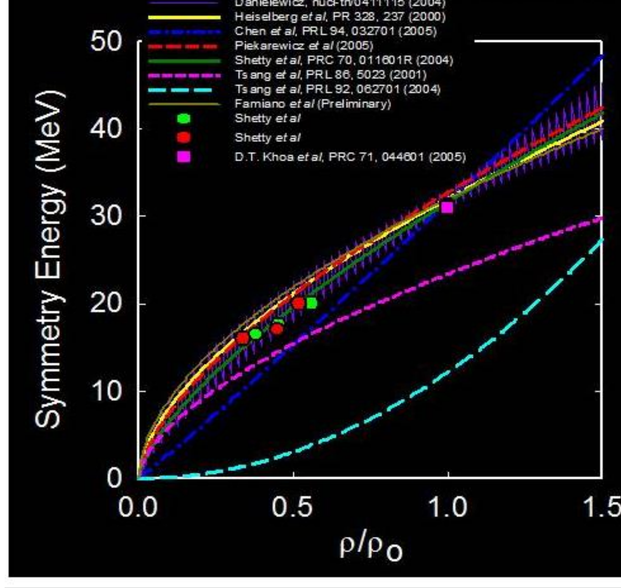
From Atomic Nuclei to Neutron Stars

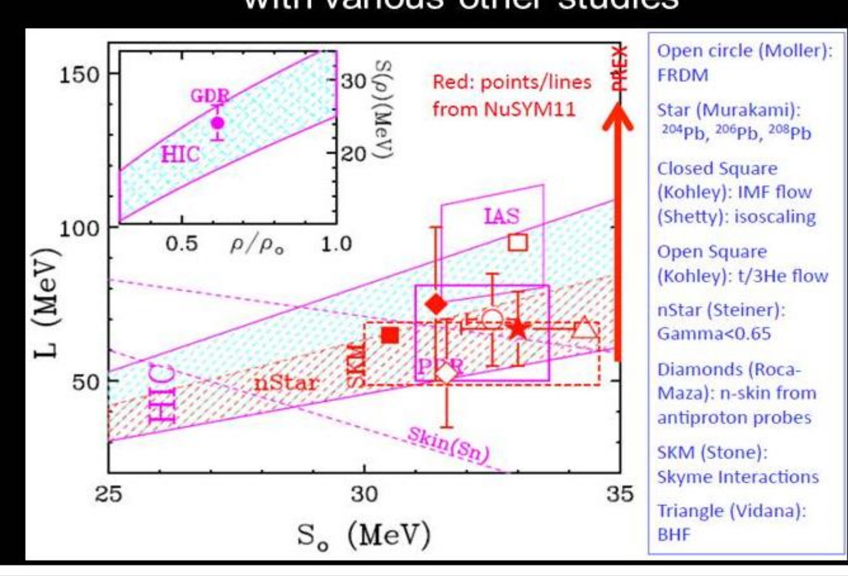


Density dependence of the symmetry energy in nuclear equation of state is largely unconstrained.

Data favors a " stiff " form of the density dependence of the symmetry energy

A constraint of $E_{sym}(r) = C(\rho/\rho_0)^{\gamma}$ with C = 31 – 33 MeV and γ = 0.6 – 1.05 is obtained by comparing with various other studies

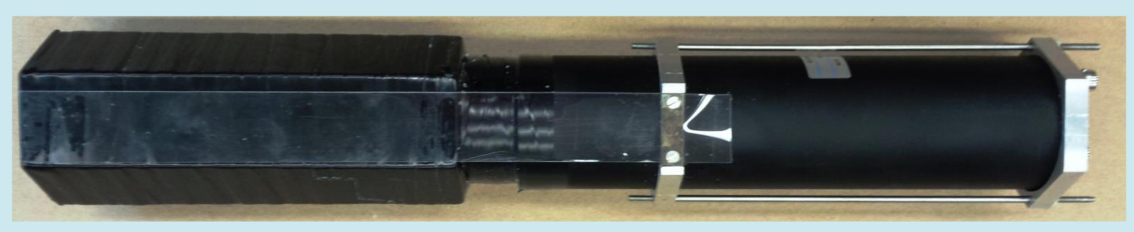




TAMU-ORNL BaF$_2$ array

Motivation

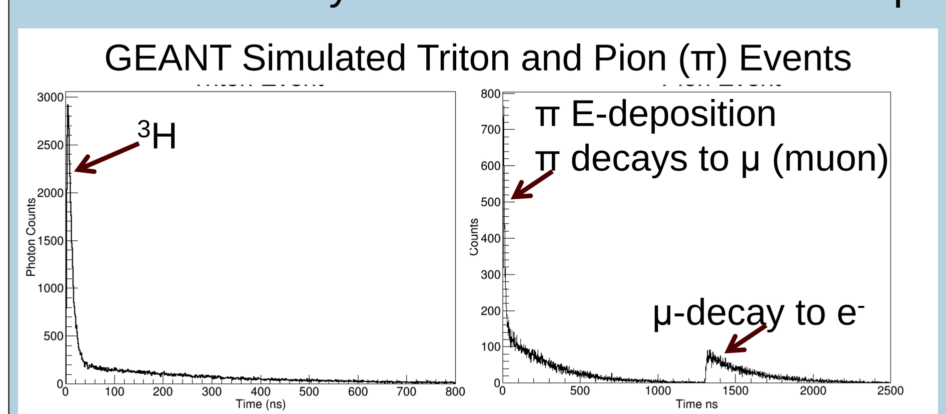
The TAMU-ORNL BaF$_2$ array is a large-area high-efficiency gamma ray detector. An upcoming experiment with the BaF$_2$ array will measure gamma rays produced from ^{60}Fe decay. By measuring the gamma strength function of ^{60}Fe, we can sharpen our understanding of how heavy elements are synthesized in stellar explosions. Another upcoming experiment with the BaF$_2$ array will measure high-energy photons produced from Bremsstrahlung between individual pairs of nucleons. The production of these photons is sensitive to the asymmetry energy in the nuclear equation of state.



Pionic Fusion of ^{4}He + ^{12}C at 220 MeV

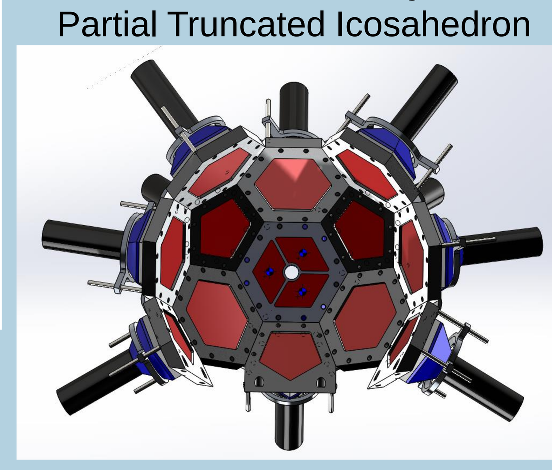
What is it?

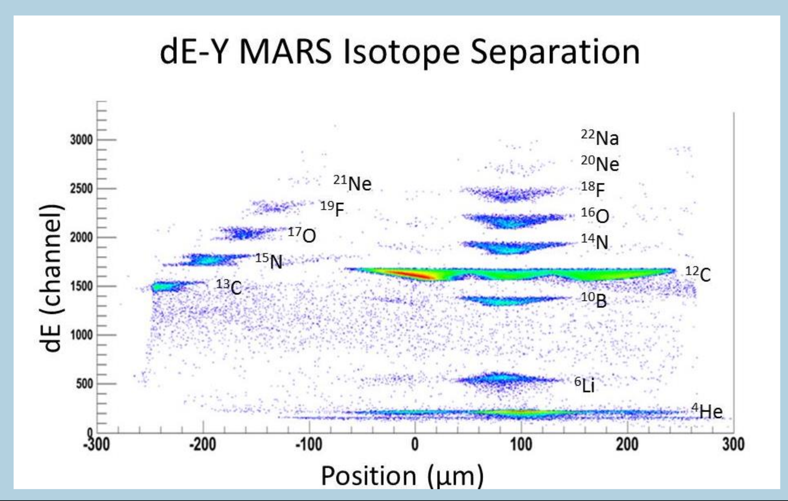
Pionic fusion is the process by which two nuclei fuse during a collision and then de-excite by the exclusive emission of a pion.



ParTI Array

Partial Truncated Icosahedron





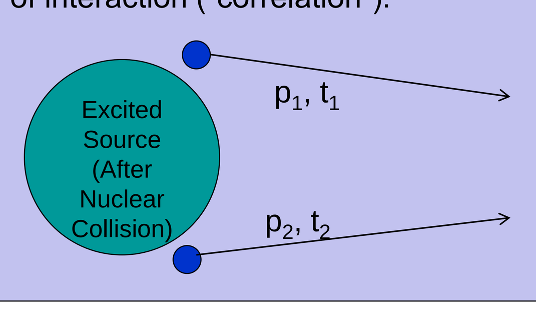
- 15 phoswich detectors
  - Scintillating plastic and CsI
  - Hexagonal + Pentagonal
- 3 partial hexes in center frame
- Modular for future experiment
- Position backward of target

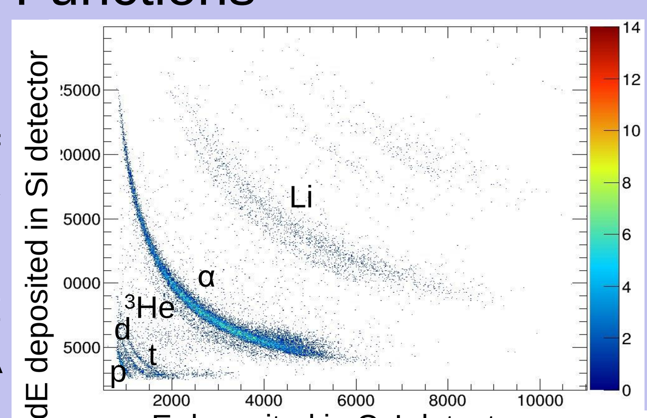
Proton-Proton (PP) Correlation Functions

Motivation

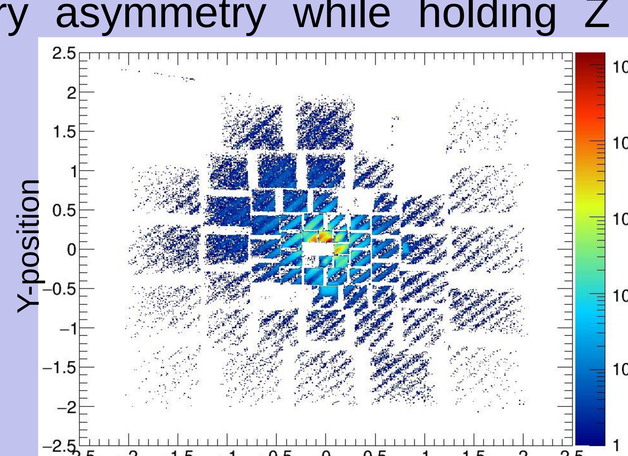
PP correlation functions [patterns in the proton relative momenta sensitive to pp interactions] are predicted to be sensitive to nuclear equation of state, especially asymmetry. We can measure these by using the new DADLs (see right) & calibrate position. Light charged particles are measured from 3 different systems (^{40}Ar+^{58}Fe, ^{40}Ar+^{70}Zn and ^{40}Ca+^{58}Ni at 40MeV/A). Systems chosen to vary asymmetry while holding Z or A constant.

Correlation Function: When any 2 protons are emitted in the same event, how closely they are emitted in time and space determines the amount of interaction ("correlation").

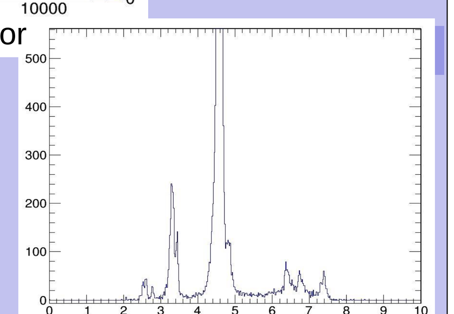




- Charged particles deposit E in Si and CsI detectors based on m/q
- Allows for particle identification in bands



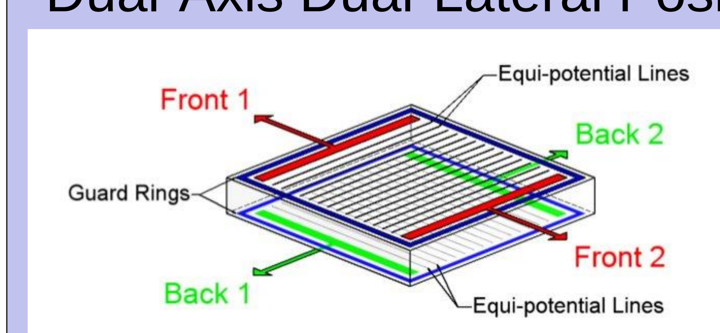
Resolution in relative momenta important to know relative position where detected.

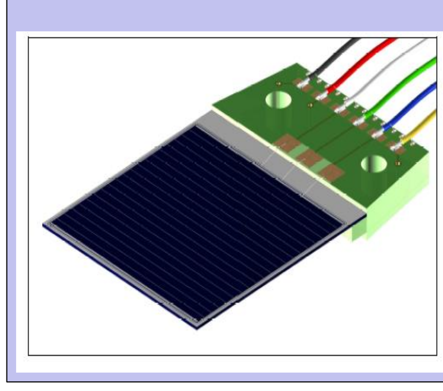


- Calculate a single "particle identification" (PID) value from dE-E
- PID cut on peaks to separate fragments isotopically

Machined to position specific stripes of charged particles on each of the detectors, to determine orientation

Dual-Axis Dual-Lateral Position Sensitive Silicon Detector





Energy given by:

$E_{Front} = Q_{F1} + Q_{F2}$
$E_{Back} = Q_{B1} + Q_{B2}$
$E_{Tot} = E_{Front} + E_{Back}$

Position given by:

$X = (Q_{B1} + Q_{B2})/(Q_{B1} + Q_{B2})$
$Y = (Q_{F1} + Q_{F2})/(Q_{F1} + Q_{F2})$

- Developed by a former grad student specifically for FAUST
- Diode detectors
- Charge-splitting across a resistive surface (Ohm's Law)
- Position sensitive to < 200μm
- 4 signals give position and energy information simultaneously
- Implemented in FAUST in 2013

For more information about the facility visit: http://cyclotron.tamu.edu

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