Source specific neutron detection efficiencies of the TAMU Neutron Ball

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The NIMROD-ISiS detector array has been used to study the symmetry energy contribution to the nuclear equation of state [1,2]. The energy of nuclear matter can be represented as the sum of two terms, shown below, the first corresponding to the energy of symmetric nuclear matter and the second corresponding to the energy due to the asymmetry of the matter [3].

$$\frac{E}{A}(\rho, I) = \frac{E}{A}(\rho) + \frac{E_{sym}}{A}(\rho)I^2 \qquad (1)$$

In equation 1, E_{sym} is the symmetry energy, I is the isospin ($I = \frac{N-Z}{A}$) and ρ is the density. In order to constrain the effects of the symmetry energy, we need to be able to study nuclear matter away from normal nuclear densities. Many experimental analyses of nucleus-nucleus collisions have relied on precise reconstruction of the Quasi-Projectile (QP) – the highly excited, forward-moving remnant of the projectile immediately after the reaction. By studying these QP's we can access the properties of exotic forms of nuclear matter at lower-than-normal nuclear densities. As shown in Fig. 1, for a QP with a given Z there is a distribution of masses.

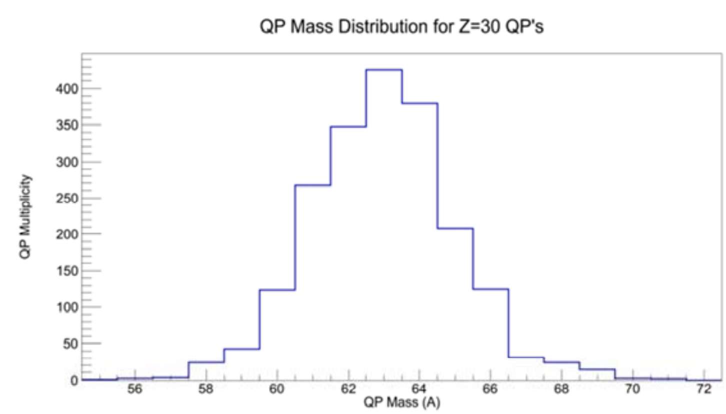

FIG. 1. HIPSE-SIMON simulation results for a ^{70}Zn + ^{70}Zn reaction at 35 MeV/nucleon beam energy. For QPs with a fixed Z (Z= 30 is shown in the figure), there is a distribution of masses. On the y-axis is the QP multiplicity and on the x-axis is the QP mass. The QP's are determined by a sum over charged particle fragments and free neutrons that we associate with the QP using velocity cuts.

Because of this QP mass distribution, it is important to know how many neutrons to associate with the QP during reconstruction. Using the Neutron Ball which surrounds the NIMROD-ISiS array, we can measure the event-by-event number of neutrons. An estimate of the number of neutrons emitted from the QP, though, requires source-specific neutron efficiencies. In order to accomplish this, we utilized the HIPSE (Heavy-Ion Phase Space Exploration) [4] event generator with the SIMON [5] statistical deexcitation code in conjunction with a software filter which simulates the geometric and energetic restrictions of the Neutron Ball. HIPSE is especially suited for this project due to its ability to keep track of the sources of all emitted particles.

Table I and Fig. 2 below give source-specific neutron detection efficiencies obtained using HIPSE-SIMON for the reaction ^{86}Kr + ^{64}Ni at 35 MeV/nucleon. This is a system for which there is NIMROD experimental data already and on which QP reconstruction has been performed. The source numbers are defined in the first column of the table.

Table I. Source-specific neutron detection efficiencies. These efficiencies were produced using the data form Fig. 2.

Source	Source Number	Efficiency
Fusion	0	70.96%
QP	1	78.11%
QT	2	64.51%
IMFs	3	70.36%
	4	70.57%
	5	70.84%
	6	70.66%
	etc	71.00%
	total	72.17%

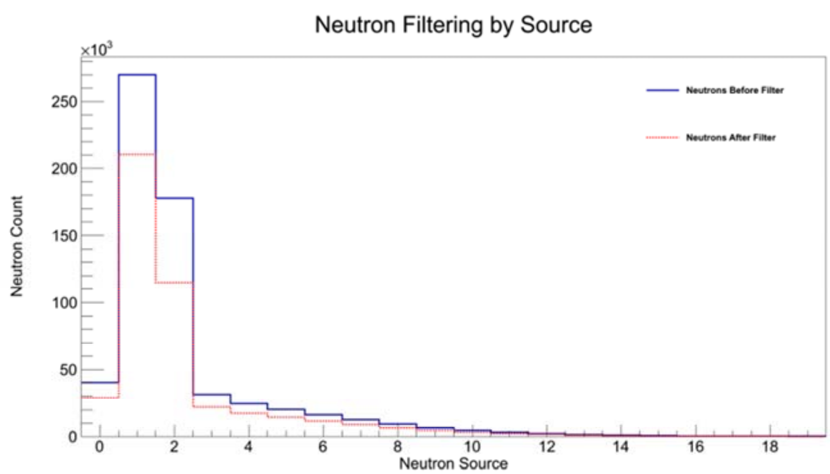

FIG. 2. Source specific neutron yield before and after the neutron filter.

Once we have the neutron efficiencies they can be used to find an estimate for the total number of neutrons emitted from the QP given the total number of neutrons measured and the following equation [1]:

$$n_{\det} = n_{QT} eff_{QT} + n_{QP} eff_{QP} + n_{IMFs} eff_{IMFs} \quad (2)$$

where n_{det} is the detected number of free neutrons in the event, $n_{QT/QP/IMFs}$ is the number of neutrons emitted by the QT/QP/IMFs, and the $eff_{QP/QT/IMFs}$ terms are the respective, source specific neutron detection efficiencies. By neglecting the IMF neutrons and simplifying the equation based on the approximation that the ratio of free neutrons from the QP to the free neutrons from the QT is equal to the ratio of neutrons in the projectile to neutrons in the target, it is possible to extract the approximate number of neutrons that should be associated with the QP during reconstruction [1]:

$$n_{QP} = \frac{n_{det}}{\frac{N_{tgt}}{N_{proj}} eff_{QT} + eff_{QP}}. \quad (3)$$

Currently, we are working towards a complete description of the neutron detection and reconstruction process using symmetric reactions of ^{70}Zn, ^{64}Ni, and ^{64}Zn [2]. In this work, we are also comparing the HIPSE-SIMON results with CoMD, a dynamical model.

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