Source Specific Neutron Efficiencies of the Neutron Ball Detection Apparatus Using HIPSE-SIMON

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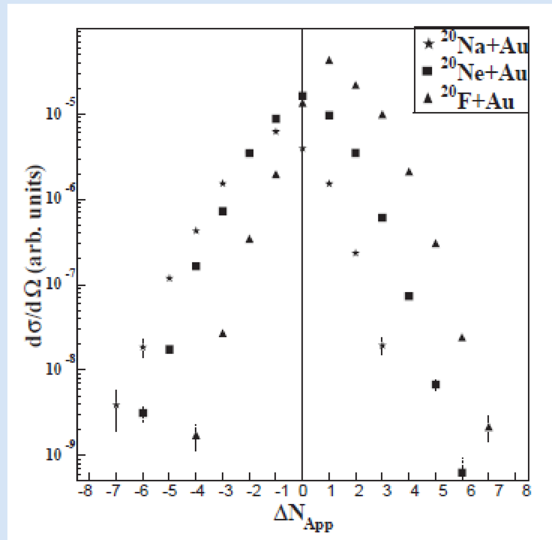
Motivation

The NIMROD-ISiS (Neutron Ion Multidetector for Reaction Oriented Dynamics – Indiana Silicon Sphere) detector array, located at the Texas A&M University Cyclotron Institute, can be used to study the symmetry energy contribution to the nuclear equation of state. Many experimental analyses have relied on precise reconstruction of the Quasi-Projectile (QP). As shown below, for a QP with a given Z there is a distribution in A.

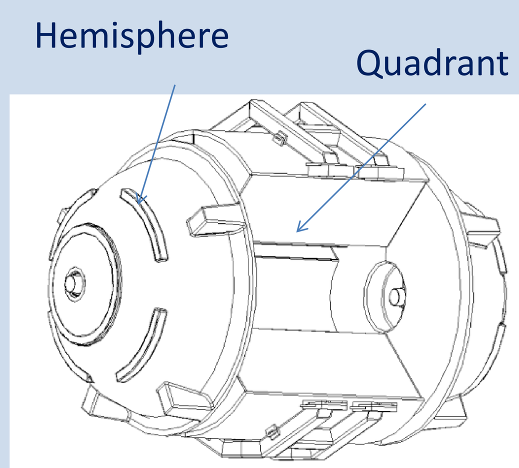


While the capabilities of the NIMROD setup allow for the measurement of neutrons (using the Neutron Ball), an estimate of the event-by-event number of neutrons emitted from the QP requires source-specific neutron efficiencies. In order to accomplish this, the HIPSE-SIMON event generator was used in conjunction with a virtual filter which simulates the geometric and energetic restrictions of the Neutron Ball. Neutron detection efficiencies were produced as a function of the source it was emitted from and a technique for the event-by-event addition of neutrons to the QP reconstruction is presented.

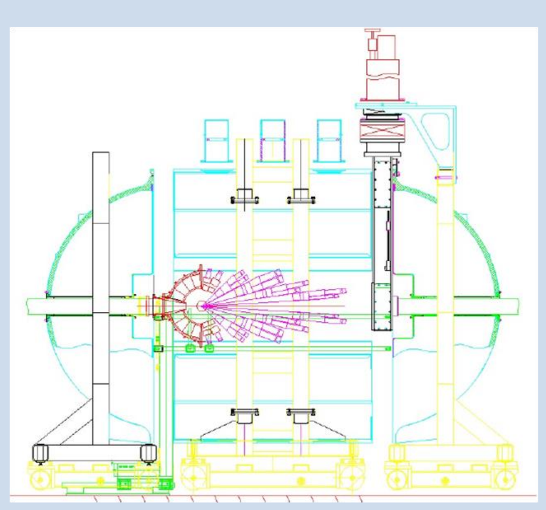
Rowland *et al.* **PRC** 67, 064602 (2003)

The NIMROD Detector

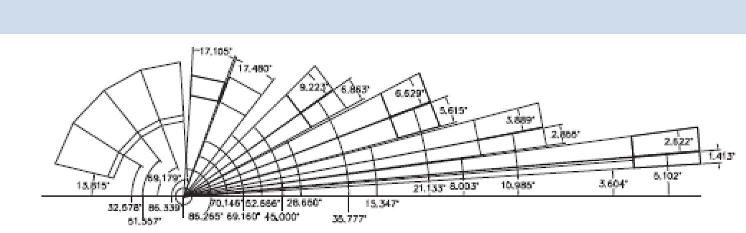
- NIMROD is a 4π neutron and charged particle detector
- Excellent isotopic resolution
- 14 radially symmetric rings from 3.6° to 167°
- The charged particle detector array includes 228 Si-CsI telescopes, 20 of which are Si-Si-CsI super-telescopes
- CsI light output read using photomultiplier tubes (NIMROD) and photodiodes (ISiS)
- Neutron Ball contains a scintillator made up of ~0.3 wt% Gd doped 1,2,4-trimethylbenzene and photons are detected using photomultiplier tubes mounted on viewing ports.

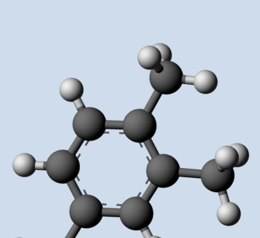


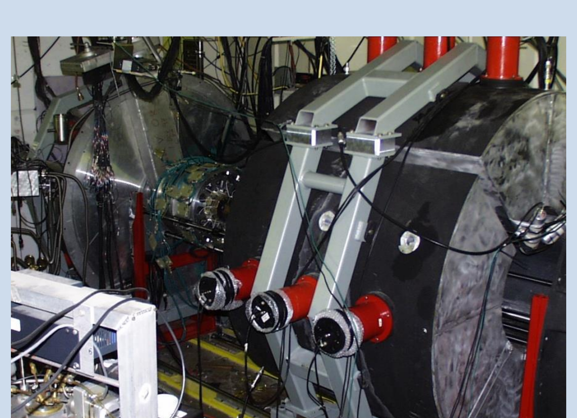
Schematic of the Neutron Ball with one of the four quadrants removed.



Schematic of the entire NIMROD-ISiS system with the Neutron Ball closed







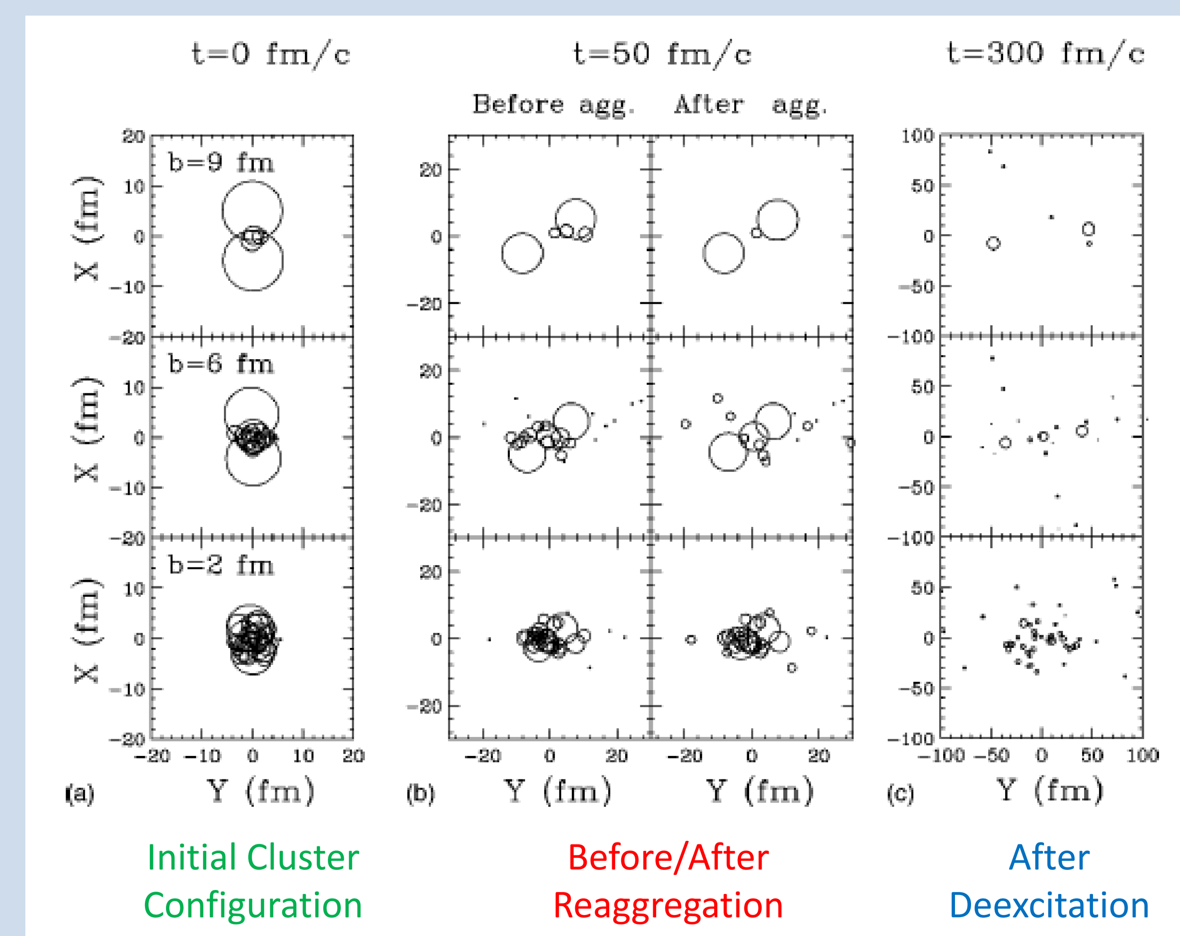
Photograph of the NIMROD-ISiS detector being built

Wuenschel *et al.* **NIM A** 604, 578-583 (2009)

HIPSE-SIMON

- HIPSE (Heavy-Ion Phase Space Exploration) event generator developed to describe reactions in intermediate energy range
- Simulates heavy-ion interactions at all impact parameters
- Created as a phenomenological event generator that would help bridge the gap between macroscopic (statistical/thermodynamic) and microscopic (dynamical) models
- Simulates a reaction from initial projectile and target, through the interaction and outputs excited nucleon clusters
- When all clusters are formed, the configuration is propagated to 50 fm/c. Then, if the relative energy of the two clusters is lower than the fusion barrier the two clusters fuse.
- This reaggregation phase allows us to simulate reactions ranging from fusion to completely participant-spectator.
- A statistical deexcitation program (SIMON) is used for the secondary decays of the clusters.

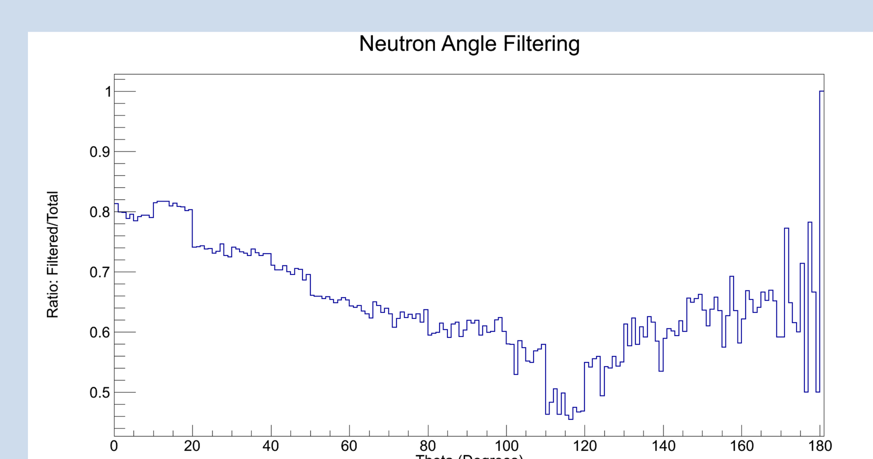
129Xe + 120Sn @ 50 MeV/nucleon

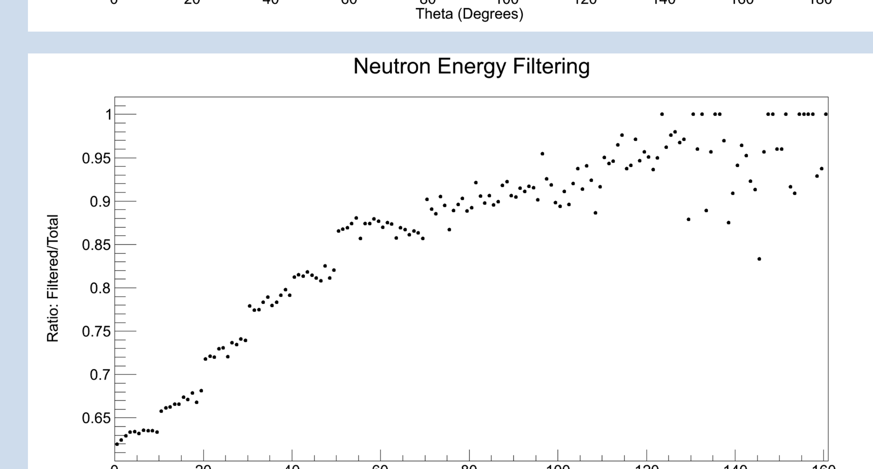


Lacroix *et al.* **PRC** 69, 054604 (2004)

NIMROD Filter

- The NIMROD filter acts as a proxy detector, eliminating particles from an event which would not have been detected by NIMROD-ISiS (charged particles) or the Neutron Ball (neutrons)
- Restrictions include detector geometry and energy thresholds.
- Plots were produced using HIPSE-SIMON data for the reaction of ^{86}Kr on ^{64}Ni at 35 MeV/nucleon and include only data for neutrons





Acknowledgments

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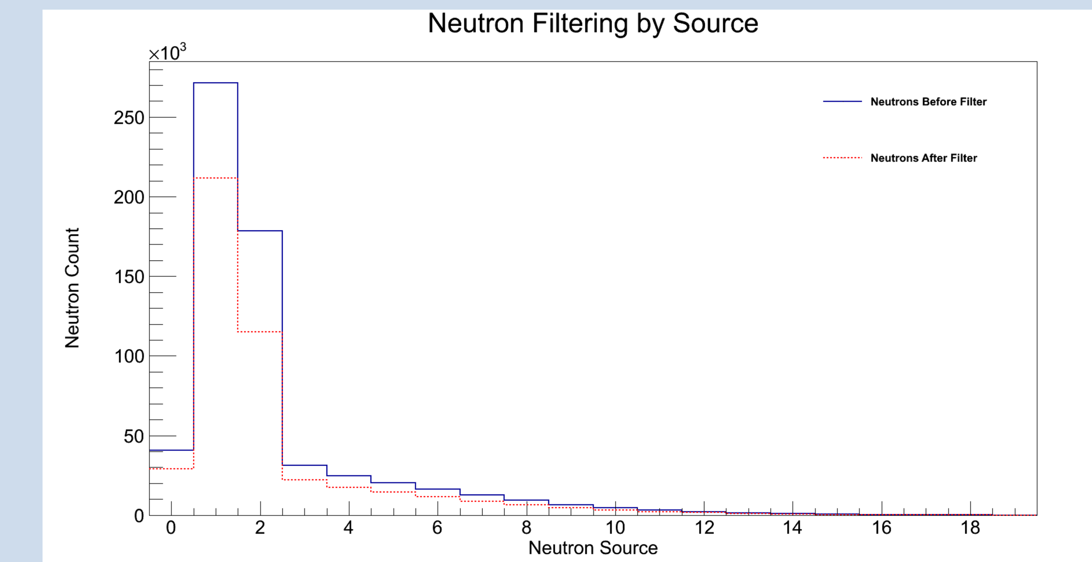
Neutron Efficiencies



- Plot above shows neutron data from HIPSE-SIMON analyzed with the NIMROD filter for the reaction of ^{86}Kr on ^{64}Ni at 35 MeV/nucleon
- Source numbers are used in the code to keep track of the origin of the particles.
- Previous Neutron Ball efficiency calculations using GEANT and GCALOR show an efficiency around 60% averaged over all angles

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%

- Further work needs to be done to better understand the consequences of reaction kinematics on the neutron detection efficiency – a major point of difference between the HIPSE-SIMON and GEANT calculations

Wada *et al.* **PRC** 69,044610

QP Neutron Correction

With the neutron efficiencies that were calculated using this technique, it is possible 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:

$$n_{det} = n_{QT} eff_{QT} + n_{QP} eff_{QP} + n_{IMFs} eff_{IMFs}$$

Where n_{det} is the detected number of 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 neutron detection efficiencies. By neglecting these IMF neutrons and simplifying the equation based on the approximation to the right where N_{Tgt} and N_{proj} are the number of neutrons in the target and projectile before the reaction it is possible to extract the approximate number of neutrons that should be re-added to the QP during reconstruction, given below.

$$\frac{N_{Tgt}}{N_{Proj}} \approx \frac{n_{QT}}{n_{QP}}$$

$$n_{QP} = \frac{n_{det}}{\left(\frac{N_{Tgt}}{N_{Proj}} eff_{QT} + eff_{QP}\right)}$$

S. Wuenschel. Thesis. Texas A&M University 2009