Determination of Impact Parameter for Fermi Energy Heavy Ion Collisions Using the HIPSE Event Generator

Mike Mehlman, Rice University

Mentors: Sherry Yennello and Zach Kohley, Texas A&M Cyclotron Institute

Introduction

Impact parameter is a very important event attribute, though it cannot be directly observed. Therefore, it is necessary to deduce impact parameter from experimentally observable quantities. As discussed in Ogilvie et al.[1], there exists a strong correlation between impact parameter and several observables, such as charged particle multiplicity and event total transverse momentum (Fig. 1), that can be exploited to estimate this quantity. Using the HIPSE (Heavy-Ion Phase-Space Exploration[2]) event generator, theoretical events are rendered for Fermi energy, heavy ion collisions and various observables are considered to deduce the impact parameter. The observables that offer the best correlation are then analyzed using a neural network, as in Haddad et al.[3], in an attempt to achieve the best possible event by event impact parameter estimation.

Fig. 1 - Event transverse momentum versus reduced impact parameter (HIPSE).

Method

HIPSE Event Generator[2]

The HIPSE (Heavy-Ion Phase-Space Exploration) event generator seeks to produce experimentally accurate event observables by employing methods parameterized to replicate data taken on the INDRA detector. After the initial stage of the reaction is carried out by HIPSE, the resulting hot fragments are then de-excited using the statistical model, SIMON. The HIPSE event generator has been shown to accurately reproduce experimental event observables, while at the same time providing the theoretical impact parameter, allowing direct evaluation of each impact parameter estimation method by comparison with the HIPSE value.

NIMROD Filter

The purpose of this project is to deduce the best method of estimating impact parameters in order to apply the technique to experimental data currently (July 2008) being taken on the NIMROD (Neutron Ion for Reaction Oriented Dynamics) 4π detector. Therefore, HIPSE outputs have been passed through a NIMROD filter (Fig. 2) in order to approximate experimental data that will be used in analysis.
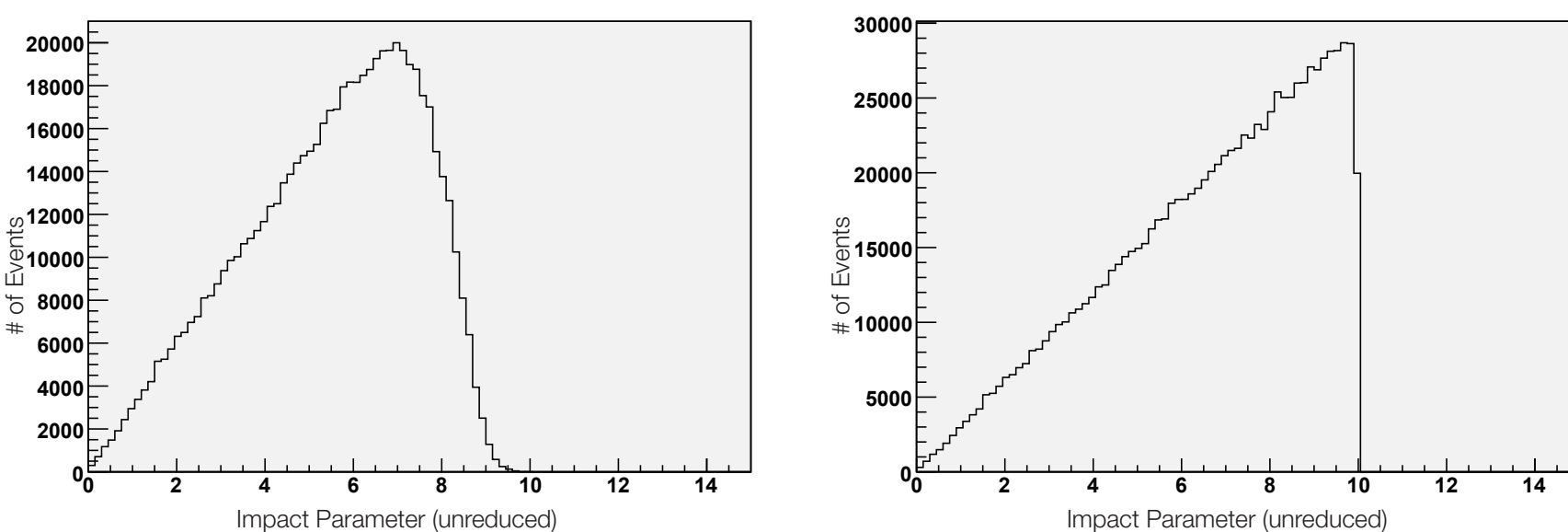

Fig. 2 - Distribution of HIPSE events sorted by impact parameter with (left) and without (right) NIMROD filter.

Systems

Events were generated and analysis was carried out for the following four systems:

- ^{70}Zn on ^{70}Zn at 35MeV
- ^{64}Zn on ^{64}Zn at 35MeV
- ^{64}Ni on ^{64}Ni at 35MeV
- ^{64}Zn on ^{64}Ni at 35MeV

Note: the systems under consideration behave very similarly, so figures displayed here will represent ^{70}Zn on ^{70}Zn at 35MeV/u, unless otherwise stated.

Procedure

To estimate the impact parameter from experimental observables, the geometrical impact parameter distribution is separated into portions (as in Fig. 3). The percentage of each portion with respect to the total distribution is calculated. Next, the distribution of the global observable is binned such that the integral percentage of each bin is equal to the corresponding percentage of the impact parameter portion. The bins from the observable distribution should now be mapped to distinct impact parameter ranges. The precise method of binning is accomplished through three slightly different approaches, dictated by the quality of the global observable distribution:
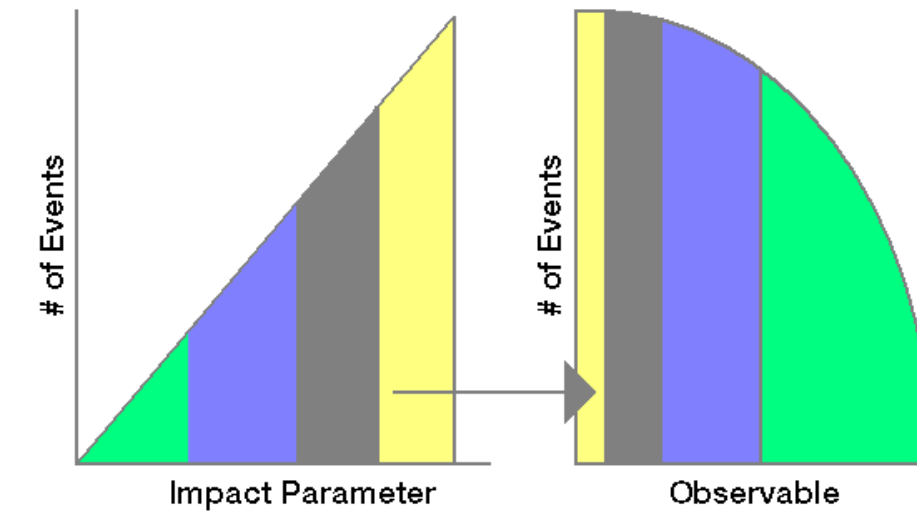

Fig. 3 - Example of mapping percentages of impact parameter distribution (left) with percentages of observable distribution (right).

- Impact parameter distribution is separated into four or five evenly spaced portions to which observable distributions are mapped.
- Observable distribution is separated into four or five evenly spaced portions to which impact parameter distribution is mapped.
- Observable distribution is binned by hand to avoid discontinuities. Impact parameter distribution is then mapped to these bins.

Quantities Examined

A variety of quantities generated by HIPSE were analyzed to estimate impact parameter:

- Event transverse momentum* and velocity (avg. and total)
- Event parallel momentum and velocity (avg. and total)
- Transverse energy
- Average detector angle (theta)
- Neutron multiplicity*
- Charged particle multiplicity*
- Total particle multiplicity
- Mid-rapidity charge (amount of charge per event with -$V_{proj} < V_{particle} < V_{proj}$ in center of mass frame)
- Forward charge (theta < 35°)
- Backward charge (theta > 70°)*
- Heavy (Z > 2) / light (Z ≤ 2) fragment ratio
- Intermediate (6 > Z > 2) / light (Z ≤ 2) fragment ratio

*Note: marked quantities are examined with and without Z-V cut ($\sum Z_{frag} x V_{\|frag} > \frac{1}{2} Z_{proj} x V_{proj}$); others are examined only with the Z-V cut.

Neural Net

Four of the most promising observables for estimating event impact parameter, charged particle multiplicity, event total transverse momentum, neutron multiplicity, and intermediate to light fragment ratio were used to train a Neural Net. The Net was programmed to place events in one of five equally spaced impact parameter bins, and outputs were compared with similarly binned HIPSE generated values.

Results

Event Distribution Correlation

Several of the quantities considered for application did not provide accurate impact parameter separation, such as mid-rapidity charge and total parallel momentum (Fig. 4).
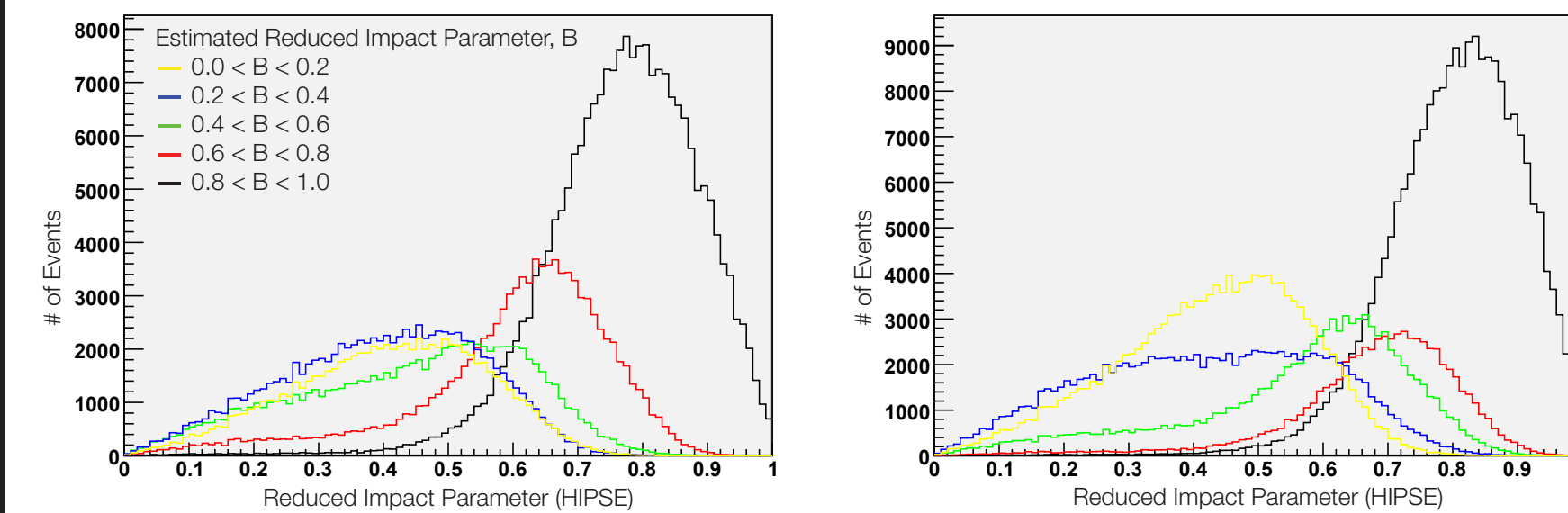

Fig. 4 - Separation of impact parameter by mid-rapidity charge (left) and total parallel momentum (right). Curves should be completely separated.

However, other quantities yielded very promising results. Event total transverse momentum (without Z-V cut) (Fig. 5), total particle multiplicity (Fig. 6), neutron multiplicity (Fig. 6), and charged particle multiplicity (Fig. 7) all demonstrated convincing separation by impact parameter.
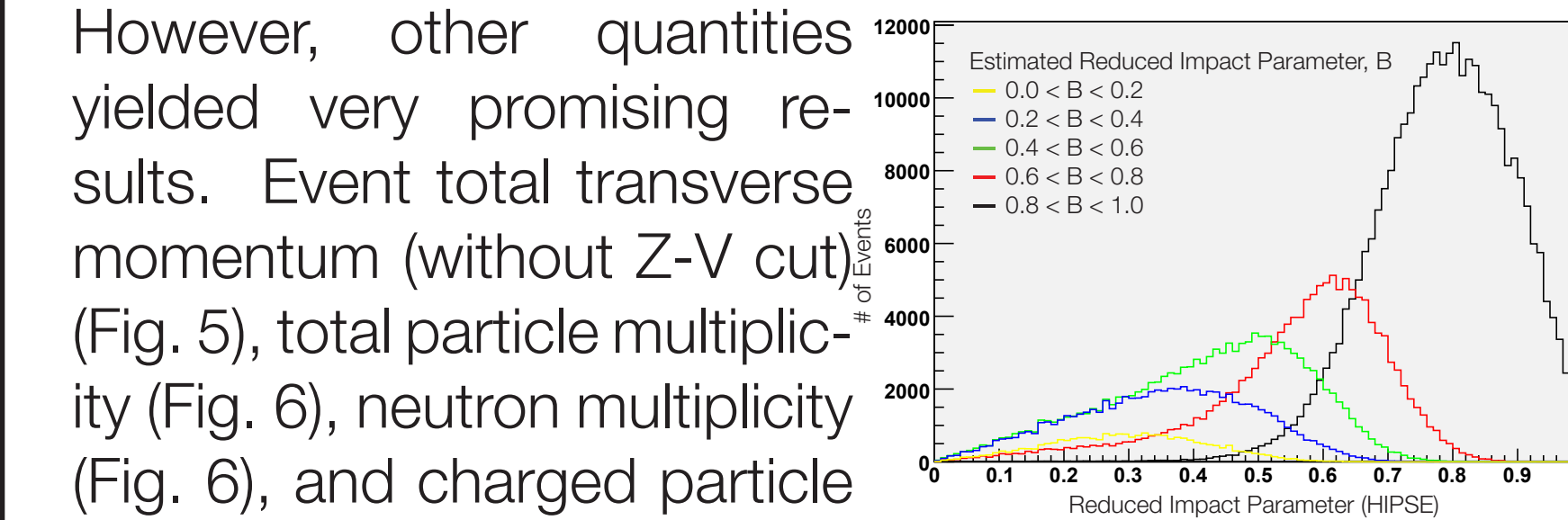

Fig. 5 - Separation of impact parameter by event total transverse momentum without Z-V cut.
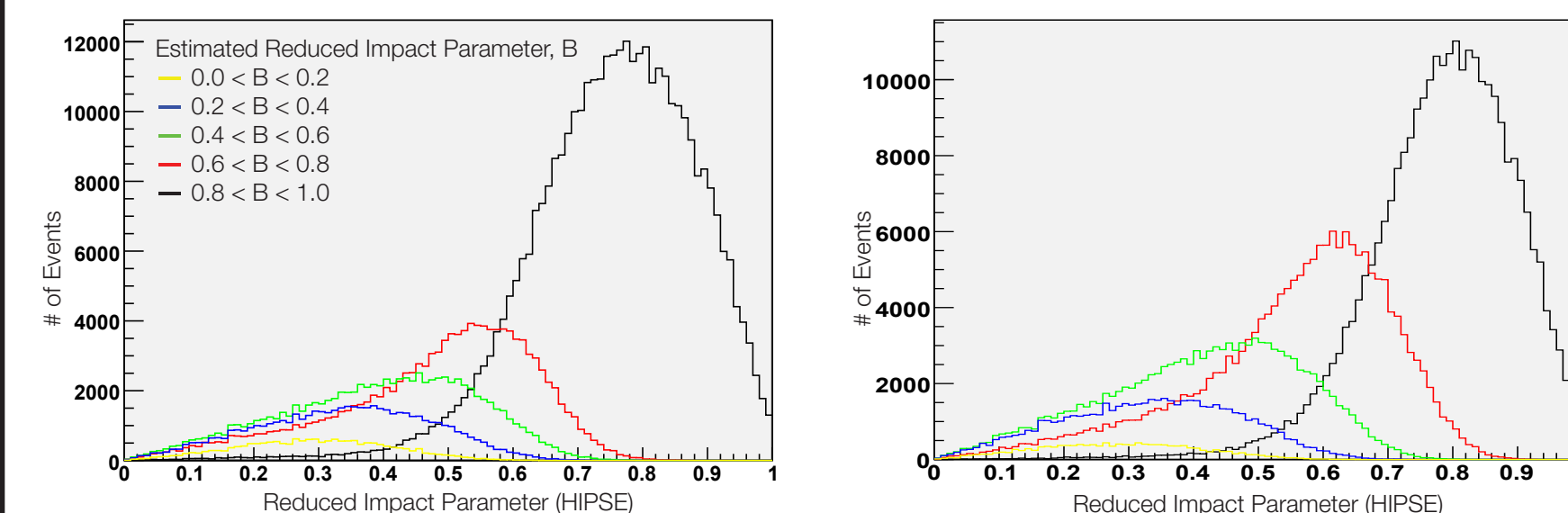

Fig. 6 - Separation of impact parameter by total particle multiplicity (left) and neutron multiplicity (right).
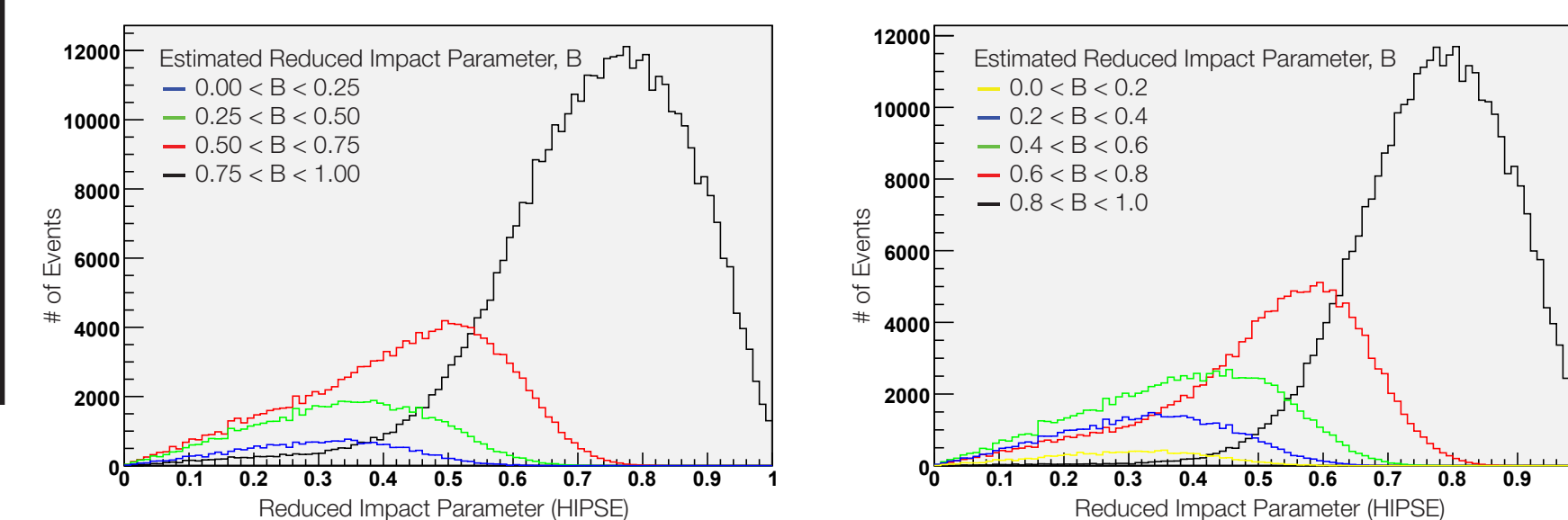

Fig. 7 - Separation of impact parameter by charged particle multiplicity using four bins (left) and five bins (right).

Neural Net

The output of the Neural Net proved to yield a more effective separation of events by impact parameter than any other method tested, as can be seen in Fig. 8.
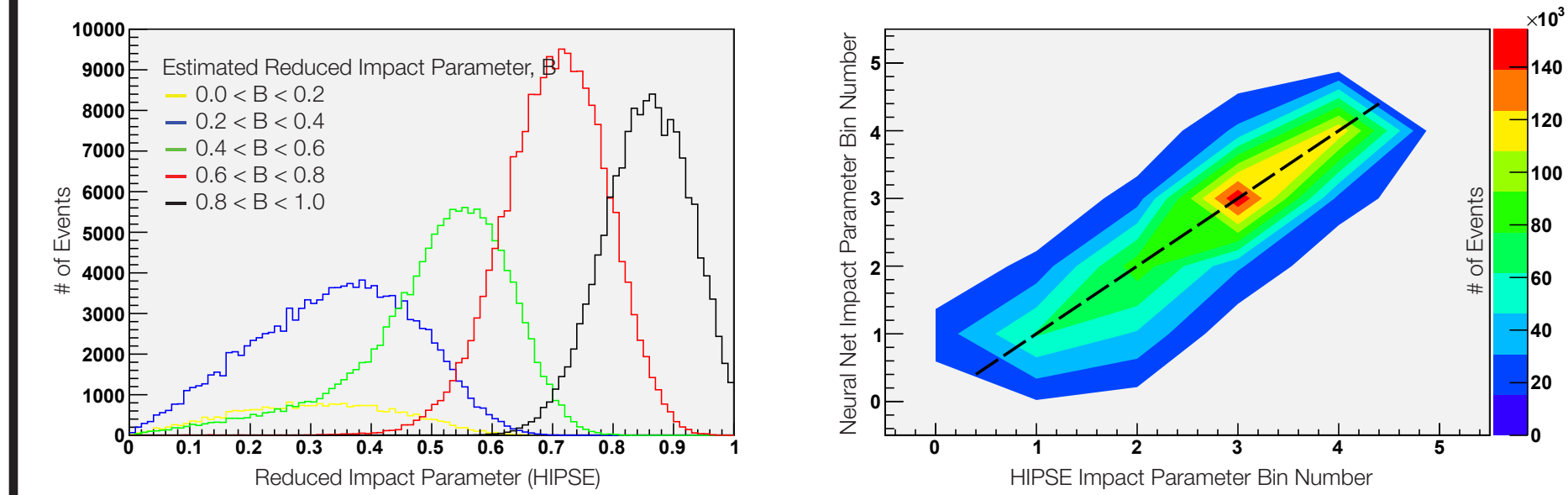

Fig. 8 - Separation of impact parameter using the Neural Net (left), and distribution of Neural Net generated impact parameters versus HIPSE generated impact parameters (both divided into five equally spaced bins) (right).

Conclusions

The results demonstrate that several quantities such as total particle, neutron, and charged particle multiplicities as well as event total transverse momentum are suitable for impact parameter determination at Fermi energy levels. In addition, it has been shown that the application of a Neural Net trained with such quantities yields an even more valuable method of impact parameter estimation (as in Fig. 9). These results provide useful information for analysis of experimental data being gathered by the NIMROD detector.
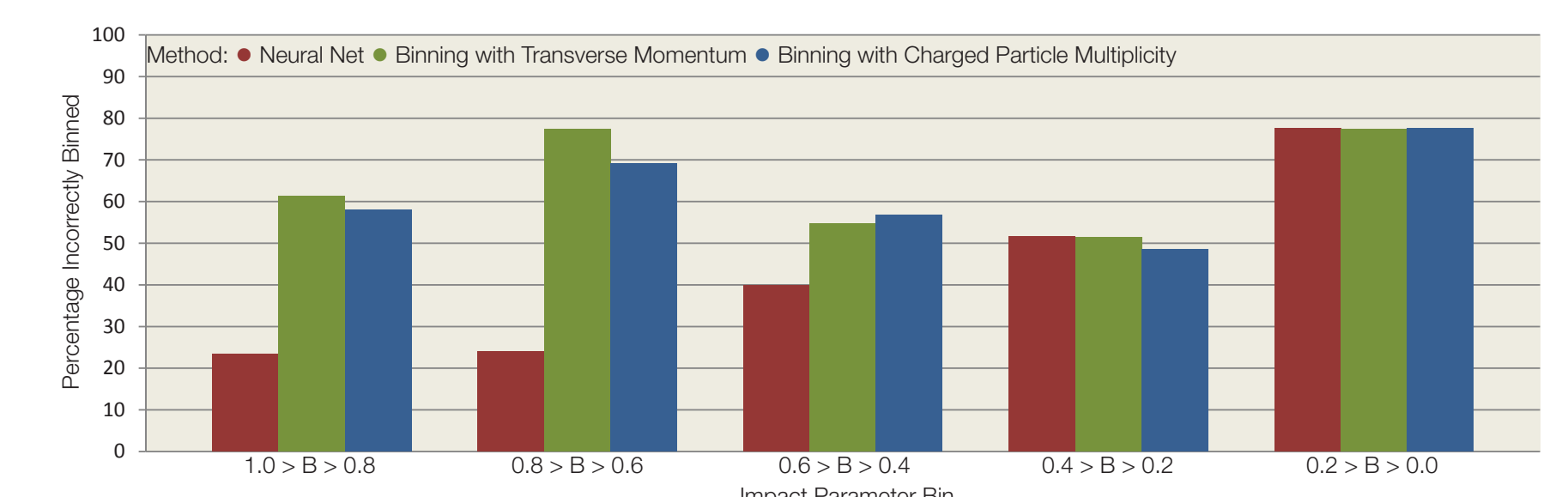

Fig. 9 - Percentage of events incorrectly binned (by bin) for the Neural Net, mapping with transverse momentum and mapping with charged particle multiplicity.

Continuing research on this subject would allow for additional quantities to be examined for their efficiency at determination of impact parameter, and for promising quantities to be integrated into the training of the Neural Net.

Acknowledgements

References:

[1] C. Ogilvie et al., Phys. Rev. C 40, 654 (1989).

[2] D. Lacroix et al., Phys. Rev. C 69, 1 (2004).

[3] F. Haddad et al., Phys. Rev. C 55, 1371 (1997).