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

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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) 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.

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 INDEA 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, SISMON. 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) 4n 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.

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

- 208Zn + 208Zn at 35MeV
- 208Zn on 64Ni at 35MeV
- 12C on 12C at 35MeV
- 64Ni on 64Ni at 35MeV

Note: the systems under consideration behave very similarly, so figures displayed here will represent 208Zn on 208Zn at 35MeV, 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 observables 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:

- 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 \( V_{ch} < V_{rap} \) in center of mass frame)
- Forward charge (theta < 35°)
- Backward charge (theta > 70°)
- Heavy (Z > 2)/(light (Z ≤ 2) fragment ratio
- Intermediate (Z > 2)/(light (Z ≤ 2) fragment ratio

*Note: marked quantities are examined with and without Z-V cut.

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). 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.

Conclusion
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.

Acknowledgements
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.

References:

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