Suitability study of the quadrupole triplet spectrometer (QTS) for selecting complete fusion residues in heavy ion collisions

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We have previously reported on observations of an asymmetry dependence of nuclear temperatures [1, 2, 3]. The experimental data used is a rich data set, but was not designed with this particular analysis in mind. There are two aspects of this measurement that one would like to improve. First and most important is the measurement of the free neutron multiplicity, which is the largest uncertainty in the measurement. Second, the reconstruction of quasi-projectile (QP) sources and the very strict selection on these sources allow only a very small fraction of the events into the analysis, increasing statistical error. Thus we propose to conduct an experiment that does not suffer these drawbacks, and will be poised to confirm or repudiate the temperature dependence of the caloric curve.

We intend to measure complete fusion of ^{64,70}Zn+^{12}C@15,25,35MeV/u. Light charged particles (LCPs) will be measured with the FAUST array, upgraded with the position-sensitive DADL [4, 5] detectors. To tag the events as fusion events, the heavy fusion residue would be measured via time-of-filght (TOF) and total energy. GEMINI and CoMD simulations have been performed [6] to investigate the suitability of the FAUST/QTS detector suite; the suite appears well suited to the measurement.

Previously, a Quadrupole Triplet has been re-commissioned as a focusing element for heavy reaction products at TAMU [7] for the reactions Xe,Sn+Ni@15MeV/u. The timing detectors in the device (PPACs) are expected to have more difficulty triggering on the small signals from lighter beams, and so plastic scintillators with photomultiplier tubes were added to the detector suite. The performance of the triplet was investigated with beams of ^{84}Kr@15,24.8MeV/u and ^{40}Ar@15,24.8MeV/u impinging on carbon targets; data of these beams as well as helium beams on nickel and gold targets was also obtained for testing the DADL upgrade of FAUST [8].

The QTS was able to focus all of these beams onto the downstream timing and energy detectors. The left panel of Fig. 1 shows the position of the elastically scattered (and stripped) beam as measured in the downstream PPAC for ^{84}Kr+^{12}C@24.8MeV/u after being focused by the QTS. By scaling the QTS power supply currents down to 80% of those used to focus the beam, the majority of the beam is defocussed. Impressively, a second set of ions can be focused by settings in the vicinity of 80%. This is illustrated in the right panel of Fig. 1. Here the outer ring corresponds largely to elastically scattered beam, while the inner spot corresponds to products with a lower BRho, such as the fusion residues of interest.

The PPACs were able to produce timing signals above the noise for the krypton beams at 15 and 24.8MeV/u, but not for the argon beams. Without significant improvement in the level of noise, this would not work for 35MeV/u Zn beams either. Though this should be possible, the use of the plastic scintillators seems best to more easily realize accurate timing signals. However, the use of PPACs for position information is still easily possible.

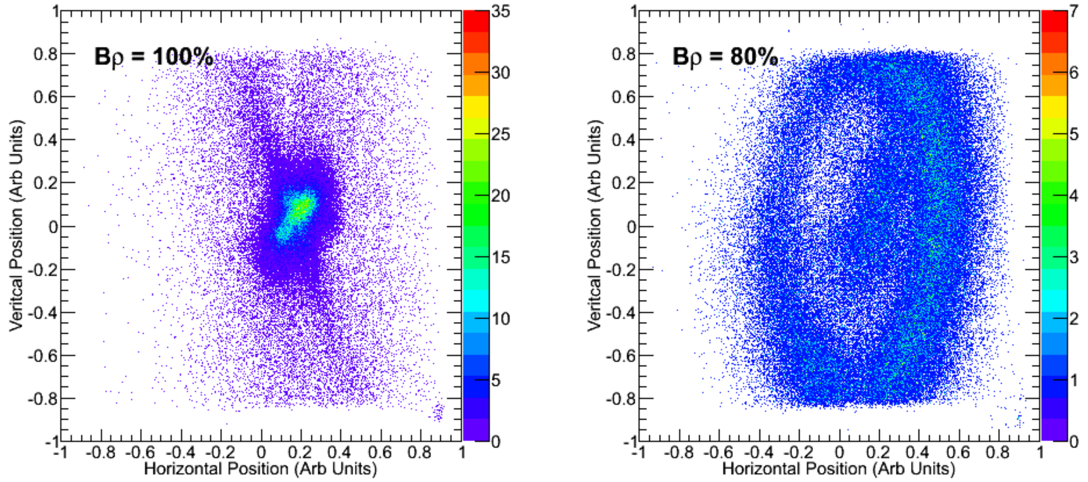

FIG. 1. Focus of heavy ions through the quadrupole triplet for reactions of ^{84}Kr@24.8MeV/u + C-nat. The left panel corresponds to the magnetic rigidity of the beam and the right panel to 80% of the rigidity of the beam. Similar focusing of beam and residues is observed in PPAC2 also for ^{84}Kr@15MeV/u and ^{40}Ar@15 and 24.8MeV/u.

The separation of products by the energy (y-axis) and TOF (x-axis, running backward) is shown in Fig. 2 for ^{84}Kr+^{12}C@5MeV/u. The upper peak corresponds to elastically scattered beam. Interestingly,

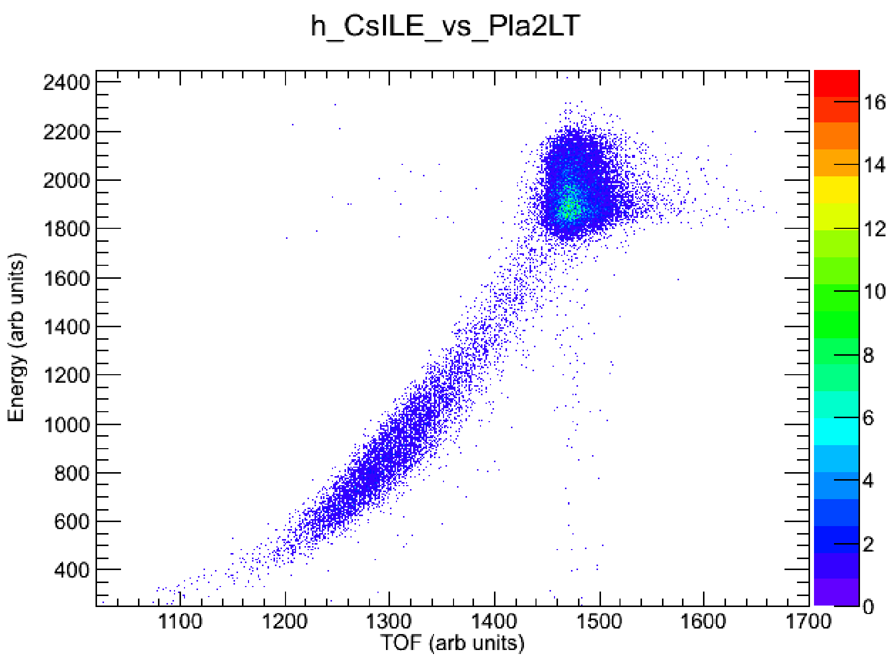

FIG. 2. Energy vs time-of-flight through the QTS for heavy products of ^{84}Kr@15MeV/u + C-nat. The magnetic field in the QTS is at 80% of what is necessary to focus the beam. The Energy is that measured in CsIL, and the TOF is started by Pla2L and stopped by PPAC1. The upper peak corresponds to beam particles and can be focused at BRho setting 100%. The lower band can be focused around 80% of the BRho of the beam as in Fig. 1.

the upper peak corresponds to particles that can be focused with a BRho of 100% (the beam), and to particles seen in the outer ring (as in Fig. 1, right panel), while the lower band corresponds to particles that can be focused with a BRho of 80% (is in Fig. 1 right panel). The band sweeping to lower energy and longer time may have two origins. This band is where the fusion residues would be located, but it is also possible that slit-scattered particles [9, 10] would lie in this band.

For subsequent experiments, both the QTS and rings A and C of FAUST were used. Though both arrays were working well independently, in any single given run, a very small number of coincidences were observed between FAUST and the QTS. There are several possible causes for the lack of coincidences. There may be a problem in the relative timing between the two electronic subsystems, which causes signals from the same physical event to be recorded in two separate data events. Another possible cause of the very low coincidence rate is a low live time of the data acquisition system. Still another possibility is that the probability for measuring these coincidences is low due to a combination of the acceptance angle of the triplet and the transport efficiency through the triplet. This needs to be investigated in detail.

These experiments have provided data that is useful as a guide to tuning the QTS to focus a desired BRho. The current settings required to focus each of the four beams (84Kr and 40Ar, each at 15 and 24.8MeV/u) were recorded. As shown in Fig. 3, the current required in each magnet increases linearly with the BRho of the (stripped) beam. A significant negative intercept exists for each magnet, suggesting a region of non-linear response at low current. Based on this data, we are able to say with confidence what power supplies will be necessary to focus beams of 70Zn@35MeV/u (BRho=2.04Tm). The supplies for Q26 and Q27 are adequate, while the supply for Q28 reaches a maximum current of 250A if wired in parallel, or 109A if wired in series. To focus particles with BRho=2.04Tm, 307A is required for Q28 if wired in parallel, or 54A if wired in series. Wiring in series is preferable, to minimize asymmetries in the magnetic field generated.

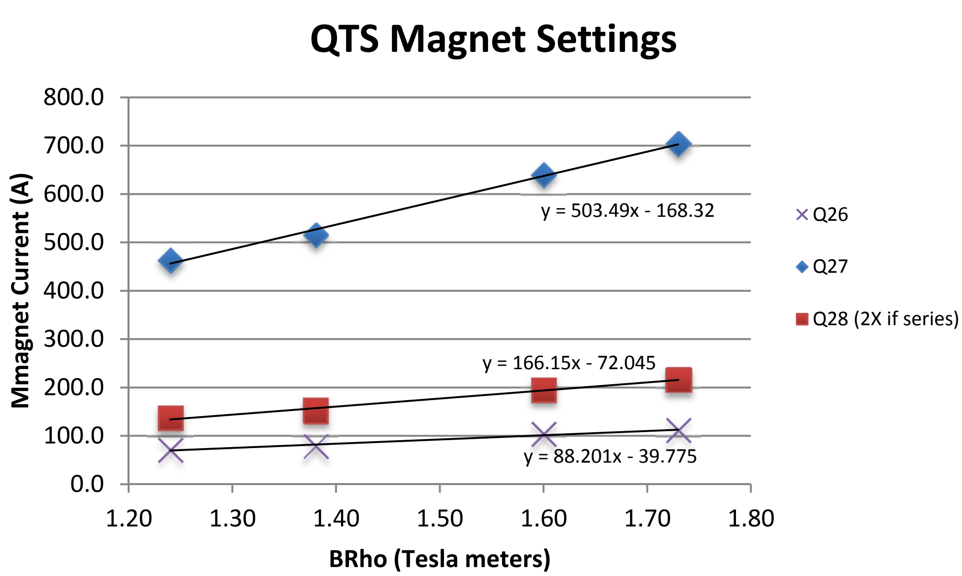

FIG. 3. Measured current setting for the QTS for four beams: 40Ar @ 15MeV/u (1.24Tm), 84Kr @ 15MeV/u (1.38Tm), 40Ar @ 24.8MeV/u (1.60Tm), and 84Kr @ 24.8MeV/u (1.73Tm). Q26, Q27 and Q28 refer to the three quadrupole magnets of the QTS. The magnetic field increases linearly with current; there is a large negative offset for all three magnets.

In summary, the QTS is capable of focusing quite well particles in the BRho region of interest for measuring complete fusion of Zn+C, though an upgraded power supply is required. The fusion residues likely can be well separated from the elastically scattered beam by the E-TOF technique. The main obstacles to be overcome are the low coincidence rate between FAUST and the QTS, and the large background of what may be slit-scattered particles in the region of the fusion residues.

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