FAUST upgrade (FAUSTUPS) for experimental proton-proton correlation functions

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The proton-proton correlation function has been predicted to be sensitive to the asymmetry energy of nuclear matter [1]. We have taken data for reactions of 40 MeV/nucleon ^{40}Ar+^{58}Fe, ^{70}Zn and ^{40}Ca+^{58}Ni at the Texas A&M Cyclotron Institute. After calibration, proton-proton correlation functions will be extracted. The data will then be compared to Constrained Molecular Dynamics (CoMD) [2] and isospin-dependent Boltzmann-Uehling-Uhlenbeck (iBUU) model[1] results, for the purpose of investigating the impact of the asymmetry energy term of the equation of state on the shape and magnitude of the correlation function. FAUST (Forward Array Using Silicon Technology) is comprised [3] of sixty-eight dE-E telescopes arranged to provide coverage of particles emitted from quasiprojectiles (QP, the excited source resulting from heavy ion reactions). Each telescope consists of a 2x2cm 300 μm thick silicon backed by a CsI(Tl)-photodiode detector. The array has been modified to include Upgraded Position Sensitivity, to complete the new acronym, FAUSTUPS. The successful upgrade and subsequent campaign and data collection are described here.

A precise knowledge of the point of detection of the particles is essential when measuring a correlation function, so satisfactory angular resolution is of paramount importance [4]. In order to increase the angular resolution of charged-particle detection, the FAUST array has been upgraded using Dual-Axis Dual-Lateral (DADL) Si detectors [5]. The DADLs have uniform resistance across the front and back of the detectors and employ charge-splitting to determine the position of the detected light charged particles to within 200 μm [5].

Fig. 1 illustrates the features of a DADL detector. A reverse bias is applied to the silicon semiconductor, which depletes the conduction band. Electrons and holes liberated by ionizing radiation migrate to opposite faces of the detector due to the bias voltage. Due to the resistive surface across each face of the detector, the electrons on the back of the detector split proportionally to the two back signals, while the holes are charge split proportionally to the two front signals. These four signals

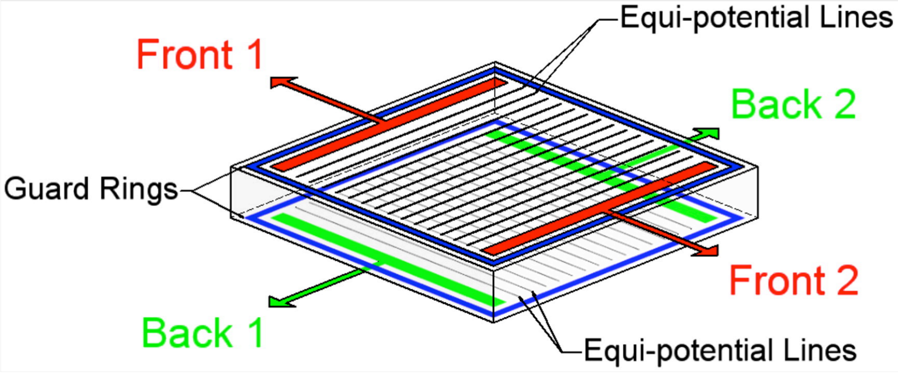

FIG. 1. Schematic of DADL, showing the equipotential lines on the uniformly resistive surface, which allows position to be determined by charge splitting [5].

allow the relative x and y position of the detected fragment to be determined. Guard rings and conductive equipotential strips ensure a uniform potential across the entire surface of the detector [5]. The additional signals on each Si-CsI(Tl) telescope resulted in an 150% increase in the number of channels processed, so Application-Specific Integrated Circuit (ASIC) Heavy Ion Nuclear Physics (HINP) chip electronics are used to deal with the increased number of signals [6].

As of fall 2014, all of the original silicon detectors of FAUST have been replaced with position-sensitive DADLs. Reactions of 40 MeV/nucleon ^{40}Ar+^{58}Fe, ^{70}Zn and ^{40}Ca+^{58}Ni were measured, along with 10 MeV/nucleon proton-α and 15 MeV/nucleon α beams for energy and position calibrations. Particle identification (PID) and position of protons and other light charged particles produced in the reactions were measured in FAUSTUPS using high-gain CSAs (charge sensitive amplifier) developed by RIS Corporation [7]. The charge-splitting across the surface of the detector can result in a very small signal, which demands high-gain preamps. The total energy deposited in the Si wafer is determined by adding the two sides (Front 1 + Front 2 or Back 1 + Back 2). The separation of the LCPs is shown in an E-dE plot, derived from Si and CsI(Tl) signals, Fig. 2. The E-dE plot for the CsI energy calibration from 10 MeV/nucleon proton-α beam is shown in Fig. 3.

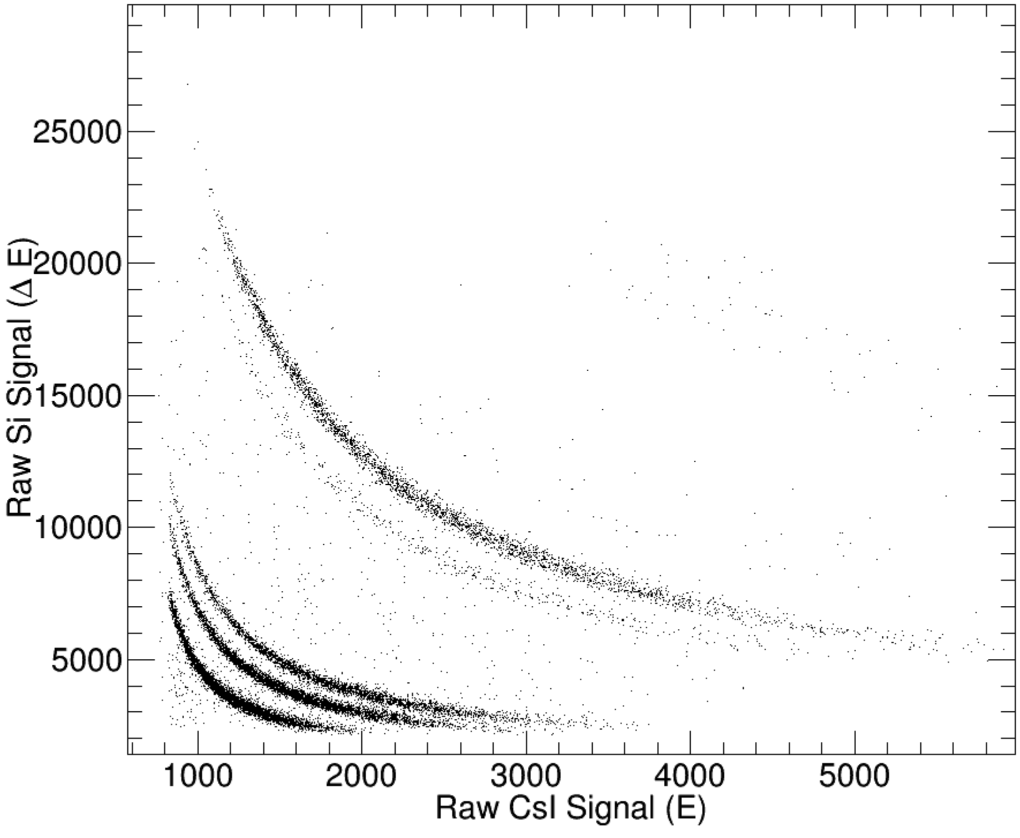

FIG. 2. Representative dE-E plot, from one of the detectors in Ring E for the reaction of 40A MeV ^{40}Ar + ^{58}Fe, demonstrating the excellent p-d-t differentiation using the new silicons and electronics from the FAUSTUPS upgrade.

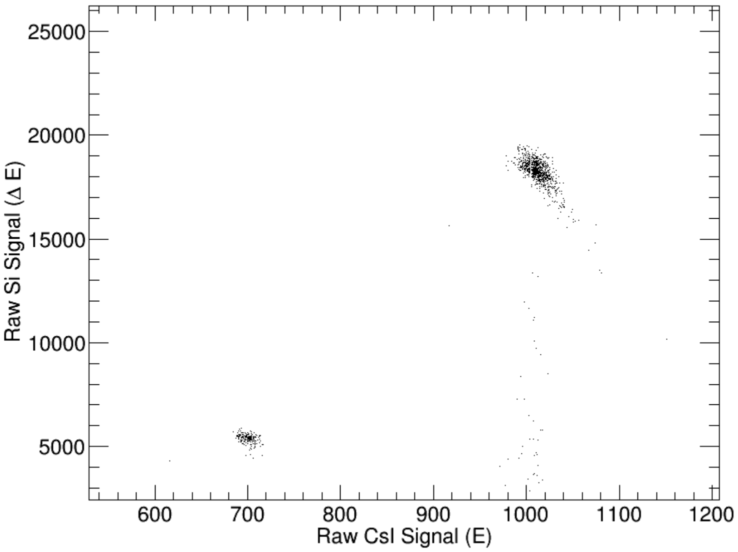

FIG. 3. Representative dE-E plot, from one of the detectors in Ring A for the calibration beam of 10 MeV/A proton and α + ^{197}Au, useful for a check of the energy calibration process.

In addition to high positional accuracy of a detected particle within a detector, the relative alignment from one detector to another must be known. In order to calibrate relative detector position, a mask of 0.040" tungsten was designed and produced. Slits of 0.010" were angled through the mask in order to allow α particles from a well-collimated source or elastically

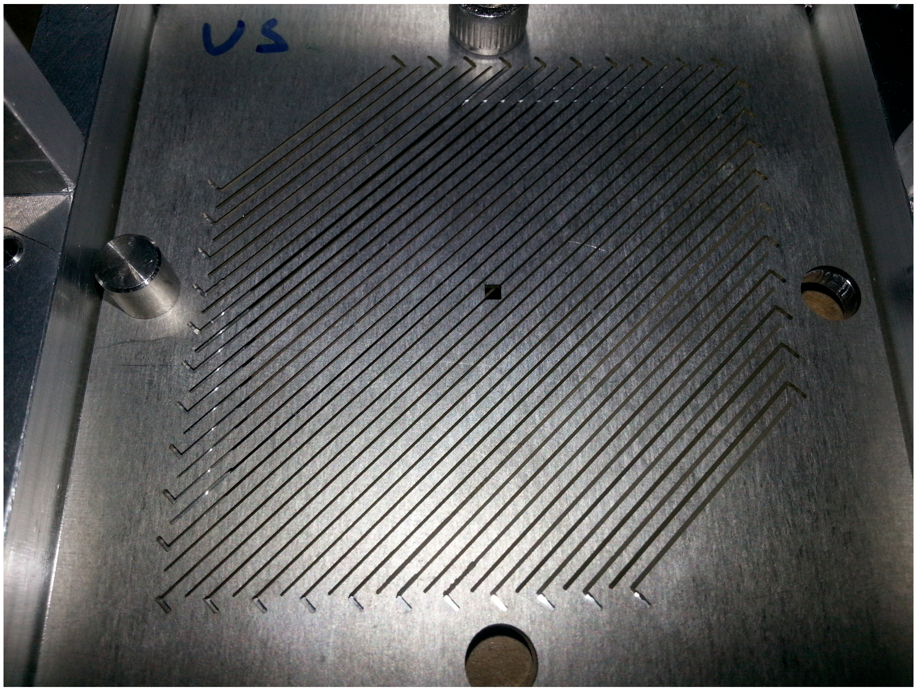

FIG. 4. Mask as machined by sinker and wire EDM at Reliable EDM. Square hole in the center allows the beam to pass through the mask, and deposit into a Faraday Cup after the FAUSTUPS array.

scattered off of a gold target to reach each ring of FAUSTUPS. To prevent the large beam spot from effectively scattering elastic alpha particles around the slits in the mask, an aluminum collimator was used to reduce the beam spot to 1 mm. The 0.0675" square cut through the center (see Fig. 4) allows the beam to pass through, reducing beam particle interactions with the tungsten mask. The stripes from the mask can be seen on the face of the detectors by gating on a single alpha energy from a thorium source or beam elastically scattered, the spectrum from a ^{228}Th high-energy alpha is shown in Fig. 5.

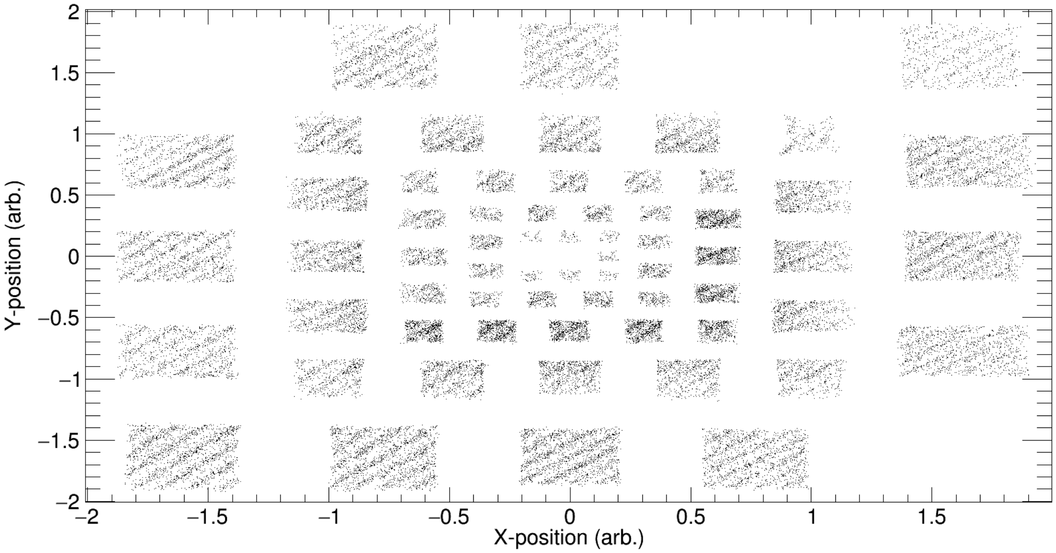

FIG. 5. Position spectra of detectors, cut on the E of the highest energy ^{228}Th α in the silicons, through the position-calibration mask.}

Based on previous successful test runs and preliminary analysis, excellent PID and position resolution are expected to be achieved. The systems were chosen to allow for comparisons of systems with varying N/Z asymmetry, but keeping constant either the total mass or Z of the system. Energy and position-calibrated multiple proton events will allow the correlation function to be extracted from the 40A MeV ^{40}Ar+^{58}Fe,^{70}Zn and ^{40}Ca+^{58}Ni reactions with different density-dependencies of the asymmetry energy in CoMD and iBUU simulations of the same reactions. For comparison between experimental data and results from simulations (CoMD and iBUU), a software filter of the geometric and energy acceptance of the FAUSTUPS array will be used event-by-event. The same data analysis performed upon the experimental results can then be compared to the simulations.

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