3-D MEASUREMENT OF THE NSCL POSITION-SENSITIVE GAMMA RAY DETECTOR ARRAY*

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1. INTRODUCTION

The National Superconducting Cyclotron Laboratory (NSCL) is a national nuclear physics research laboratory on the campus of Michigan State University. In a typical experiment, heavy ions with masses ranging from hydrogen to uranium are created in an Electron Cyclotron Resonance (ECR) ion source and injected into the K500 cyclotron. The accelerated beam is transported to the K1200 cyclotron, where its electrons are stripped to a higher charge state before additional acceleration. After extraction, the beam has an energy of up to 200 MeV per nucleon. The extracted beam is focused onto a production target and the secondary beam from the fragmentation reaction is analyzed in a series of dipoles and quadrupoles/multipoles. A beam switchyard focuses the beam into one of nine experimental stations. Superconducting magnets are found in the main coils of the two cyclotrons, one of the ECR ion sources, and in all of the high energy beam transport dipoles and quadrupoles/multipoles. The research programs at NSCL include nuclear astrophysics, nuclear structure, and the production of isotopes far from the valley of stability.

One of the newest pieces of experimental equipment is the Segmented Germanium Array (SeGA).[1,2] SeGA is an array of eighteen 32-fold segmented germanium detectors (see Figs. 1 & 2). These detectors are designed to measure gamma rays emitted from heavy-ion beams with energies up to 140 MeV per nucleon. At high beam velocities the detected energy of a gamma ray emitted from the beam nucleus will depend on the angle at which the gamma ray was detected. For example, a 1-MeV gamma ray emitted by a ^{32}Mg beam with a velocity of 0.4*c* will have an apparent energy of 1.4 MeV when detected at 30 degrees with respect to the beam; while, at 150 degrees this same gamma ray will have an apparent energy of 0.68 MeV. The energy of the gamma ray must be measured in the reference frame of the beam, so the detected energies must be transformed based on the angle at which the gamma ray was recorded. The intrinsic gamma-ray energy resolution of our SeGA detectors is better than 0.3%. For the example presented above a 0.3% change in the gamma ray energy would correspond to a three millimeter change in the position of the detector. Thus in order to achieve the maximum resolution of our detector array, the detector positions must be known with respect to the emission point of the gamma rays (which is assumed to be a target placed in the center of the array) to an accuracy of better than one millimeter.

* Work supported by: The National Science Foundation, Grant No. PHY-0110253.

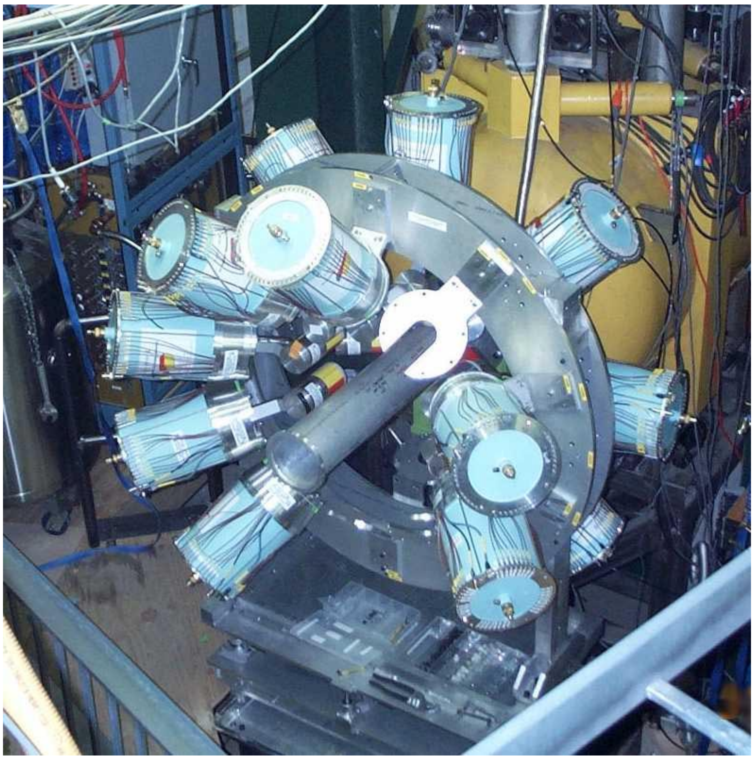

Fig. 1. Photograph of the SeGA during assembly of the array in front of the S800 magnetic spectrograph. The dewars holding the liquid nitrogen necessary for the operation of these detectors are prominently visible in light blue.

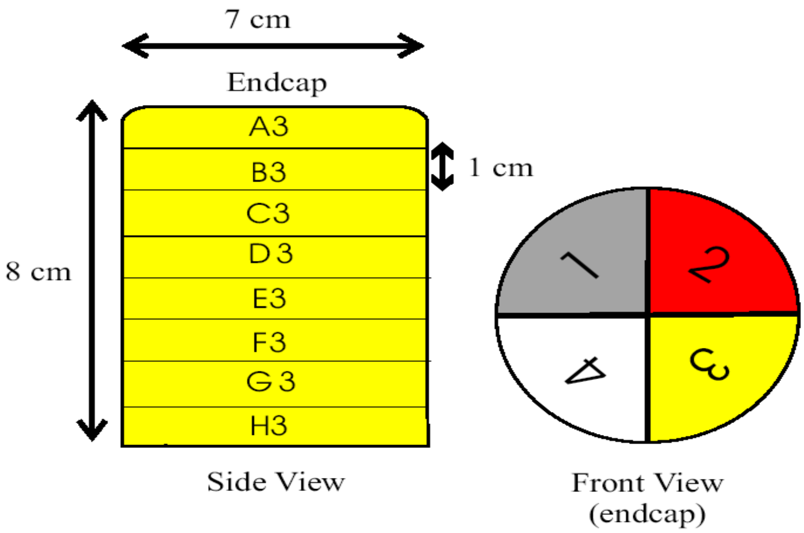

Fig. 2. The segmentation of the individual gamma ray detectors.

The beamlines, accelerators, and experimental apparatus at NSCL were installed using simple optical equipment(jig transits, alignment telescopes, etc.). This application required the measurement of the position and orientation of the individual crystal segments inside each detector assembly. Commercial 3-D measuring systems (laser radar, laser trackers, high precision total stations) were deemed too expensive. Two digital theodolites can measure the coordinates of an object in space if sufficient reference measurements are made. The general solution to this problem is the basis of the systems such as ManCAT[3], Axyz[3], or Spatial Analyzer[4]. Our application's geometry was simple enough that we could force-center two inexpensive theodolites into known locations and calculate the coordinates using the three dimensional geometric tools built into the laboratory's Computer Aided Design (CAD) program.

2. GEOMETRY

The natural Cartesian coordinate system for an experiment at the NSCL is: Y-axis along the beam path, Z-axis vertically up, and the X-axis forming a right handed coordinate system. The beam axis is defined as a line passing through targets mounted on kinematic mounts at each end of the last superconducting quadrupole magnet on the beamline. This same axis was used to map and adjust the links of the internal magnet assemblies such that the beam will not steer when passing through centered on this axis. The theodolites will measure two angles: θ, the angle relative to the X-axis in the XY plane, and φ, the angle relative to the Z-axis. Most digital theodolites can be set to provide these angles directly. The origin is set where the plane of the scattering target intersects the beam axis.

3. EQUIPMENT SET-UP

The basic set-up is two 5-second digital theodolites (Sokkia DT-5S)[5], mounted with their optical origins approximately 1 meter apart, perpendicular to the left and right of the beam axis at beam height. One of the laboratory's jig transits, with reticle illumination, is set up viewing down the beam axis. A pentaprism mounted at the approximate crossing point of the beam axis with the line between the two theodolites defines a perpendicular plane to the beam axis. This plane sets the zero of the θ angle of one of the theodolites. By setting both of the theodolites to infinity focus, the zero of the θ angle of the other theodolite can be set. The φ elevation angle is zeroed to gravity. The Y-value of the theodolite line is arbitrary, so it is set to the position of the first theodolite. The second theodolite's Y-value is set by removing the pentaprism, setting the focus of each instrument to 1 meter and adjusting the Y-position of the second theodolite to match the illuminated reticle of the first instrument.

With the pentaprism removed, the beam axis telescope is focused on a scale mounted horizontally approximately 1 meter downstream of the theodolites. By rotating the theodolites through 90 degrees, a reading on this scale of each theodolite and the beam axis sets the X-positions of the two instruments. A vertical scale viewable by all three instruments allows the two optical axes of the theodolites to be set to the beam height.

To facilitate the above movements, we have mounted the two theodolites on a large aluminum extrusion (Newport X-95 rail)[6]. X-Y-Z fine adjustment manual motion stages(#401 and MVN80) under each theodolite provide the movement mentioned above. (see Fig. 2.)

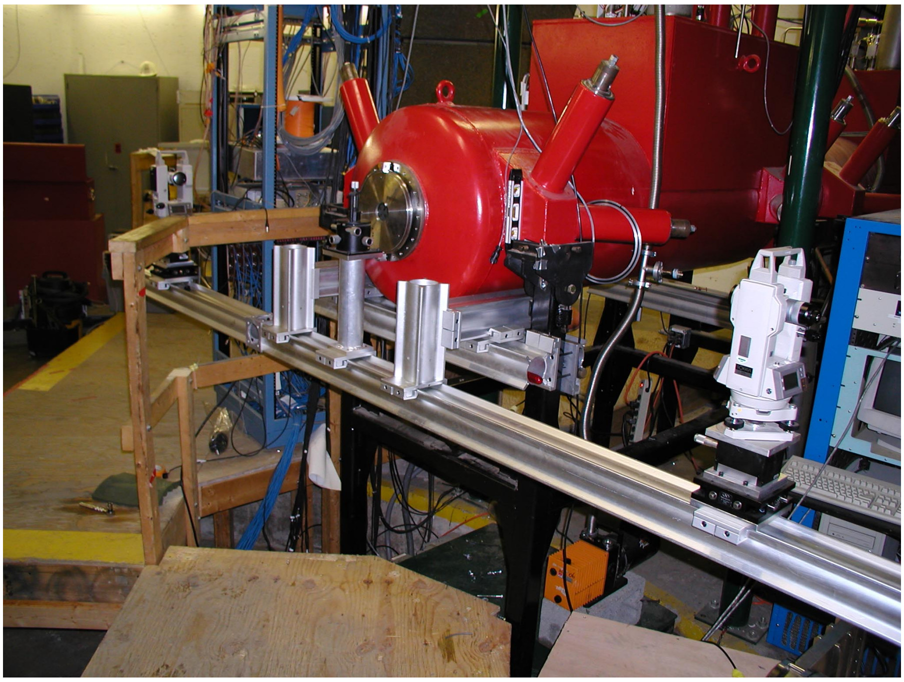

Fig. 2. The two theodolites mounted on their manual stages immediately after the last focusing quadrupole in the S800 beamline.

The last item before measuring the detector is to determine the Y-position of the theodolite line. This is done by either mounting a horizontal scale against the endflange of the last quadrupole and reading the value when $\theta = 0$, or by taking a reading of the four theodolite angles for the known experimental target position.

4. MEASUREMENTS

The ends of the Germanium detectors have a label to indicate the segmentation of the crystals inside. (see Fig. 3) By measuring the 3-D coordinates of the ⊗ pattern on this label, the orientation in space of the detector is known. Values of θ and φ were recorded for each point as viewed by the two theodolites. In the laboratory's CAD system(Microstation J)[7], it was a simple matter to generate long lines at these angles originating at the known positions of the two theodolites. The points where the two lines crossed gave the location of the spot being measured. By monitoring the distance between the two lines at this point(<0.1mm typ.), errors in data recording were caught. The result was a 3-D model in CAD space for the endcap labels of the detectors. Fig. 4 illustrates the results for the case of a set of six detectors in a barrel configuration. This model can be manipulated and measured in the CAD system to provide the angles for the Doppler corrections to the spectra for each detector.

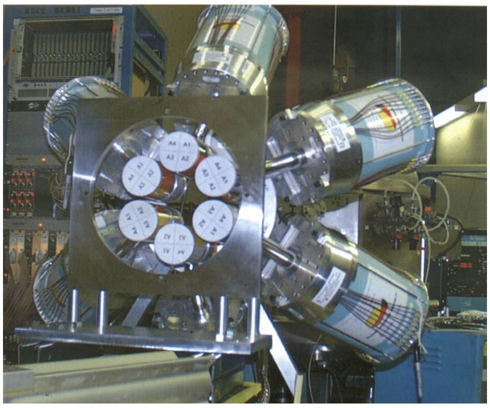

Fig. 3 A set of detectors with their endcap labels shown.

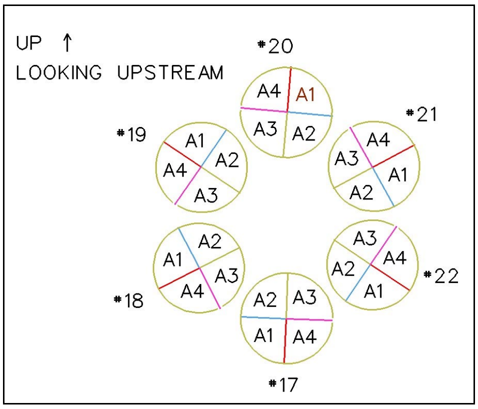

Fig. 4 CAD model of the endcap labels generated from the theodolite measurements.

5. RESULTS

The Doppler correction to a typical gamma ray spectrum is shown in Fig. 5. A secondary radioactive beam of ^{46}Ar was incident on a natural beryllium target. The gamma rays were measured in coincidence with the ^{45}Ar ejectile using the configuration in Fig. 1 and the S800 spectrograph to detect the charged particles. Since the stripped neutron does not necessarily stay with the target, the remainder is labeled X. Each gamma ray is event by event corrected in energy based on which segment of a given detector generates the signal. All of the corrected events are added together, resulting in the improved resolution spectrum in the projectile frame as compared to the raw uncorrected coincidence spectrum in the laboratory frame.

6. SUMMARY

We have assembled an inexpensive tool for measuring the 3-D coordinates and orientation of a multi-element gamma ray detector array. At the short distances encountered in a typical experiment, two 5-second theodolites provide sufficient accuracy for the Doppler corrections. By force-centering the instruments, the spherical geometry conversions can be carried out using a simple CAD program.

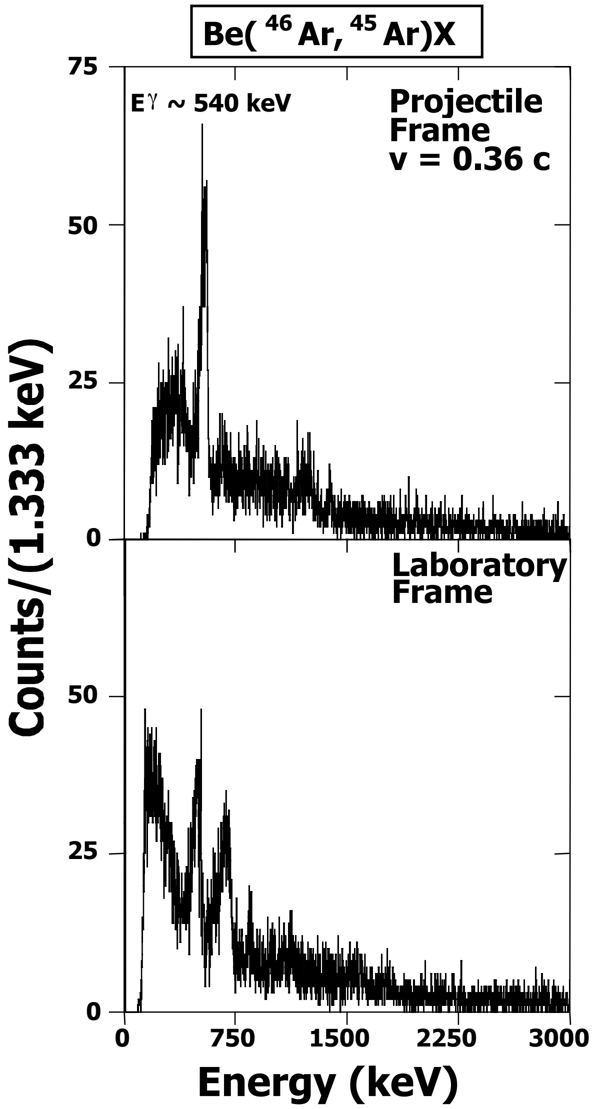

Fig. 5. Summed γ ray spectra for all of the detectors in Fig. 1 showing the doppler correction from the laboratory frame to the projectile frame.

7. REFERENCES

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[3] Leica Geosystems, Inc.

[4] New River Kinematics, Inc.

[5] Sokkia, Inc.

[6] Newport Corp.

[7] Bentley Corp.