St. George Recoil Mass Separator Time of Flight and Position Sensitive Detector

Luis Alfredo Morales

NSF/REU Program

Physics Department, University of Notre Dame

Advisor: Manoel Couder

Abstract

The St. George recoil mass separator at the University of Notre Dame will be used to study (α, γ) reactions of astrophysical interest. A detection system being developed for St. George at Indiana University South Bend and Notre Dame will utilize energy, time-of-flight, and position to separate reaction products from residual unreacted beam particles. Two designs for the timing detectors have been investigated – an electrostatic mirror design and a combination of electrostatic plates with magnetic deflection. Both designs deflect secondary electrons produced by the passage of an ion through a thin carbon foil onto a microchannel plate (MCP) detector, which registers timing and position measurements. A detailed analysis of position and timing resolution for the two designs was conducted using the ion optics simulation software SIMION, in order to identify the configuration best suited for the challenges presented by these low energy and low count rate experiments. SIMION was also used to study an electrostatic deflector that will be used to test the angular acceptance of St. George.

Introduction

Notre Dame's Nuclear Science Lab (NSL) is the bridge between nuclear physics and astrophysics. Nuclear Astrophysics at Notre Dame is focused in measurements of nuclear reaction rates and decay processes and extrapolates those to stellar temperatures[2]. The cross-sections drop exponentially at stellar energies and so become difficult to separate from background. The three main background components are natural radiation, cosmic rays, and beam induced radiation.

The Strong Gradient Electromagnetic Online Recoil separator for capture Gamma Ray Experiment (St. George) was specially designed for low energy (α, γ) reactions. The St. George consists of a helium gas jet target, six dipole magnets, 11 quadrupole magnets, a Wien filter, and a detection system [1]. St. George is divided up in three sections: Section 1 consists of the helium gas target where the reaction occurs; Section 2 consists of several bending magnets to reject particles of the wrong charge, along with the Wien filter, which is the mass selector; Section 3 provides additional background reduction while at the same time bending the desired particles to the detection system. The detection system separates the background from the reaction product. The background consists of mainly unreacted beam and possibly other particles that entered the beam line due to the beam colliding with the inside of the separator. This is where a detection system that measures time of flight and energy deposited becomes a great asset in discerning particles of interest from background.

In order to explore the various detection set-ups we did simulations using an ion optics program called SIMION. Our main goal was to determine the limits to the position and timing resolution imposed by the geometry. To keep our results consistent for multiple design options we standardized the particle attributes. To simplify things we excluded the ion and simply focused on the electrons being emitted at the surface. Using SIMION's built-in functions we generated 30 electrons for each passing ion with a half angle of 45 degrees with respect to the normal of the carbon foil with a Gaussian energy distribution around 30 eV (FWHM=10 eV). For each electron we recorded it's initial and final timing as well as the position. We used the ROOT data analysis framework [3] to analyze the data and extract the timing and position resolution.

Electrostatic Mirror

The electrostatic mirror design consists mainly of three different electrodes (Fig. 1). The first electrode consists of a self-supporting thin carbon foil at a negative potential. This is where the ion begins its journey through the detection system, depositing some energy in the foil and ejecting electrons from the carbon foil. The electrons are then accelerated toward the entrance grid where they enter electrode number 2. Electrode number 2 is also known as the faraday cage portion, which consists of the microchannel plate (MCP), three plates arranged in a right triangle with two of those plates containing grids with wires of thickness of 20 μm . Once the electrons enter the faraday cage they essentially experience no force until they pass through the exit grid. After they pass the plane created by the exit grid they come to the third electrode also known as the mirror grid. This is where the electrons are deflected back into the faraday cage in the direction of the MCP where they will be detected.

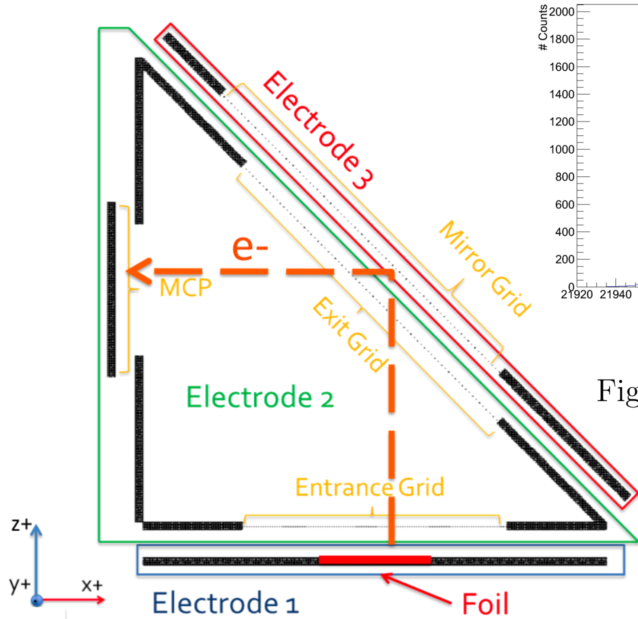

Figure 1: Electrostatic Mirror

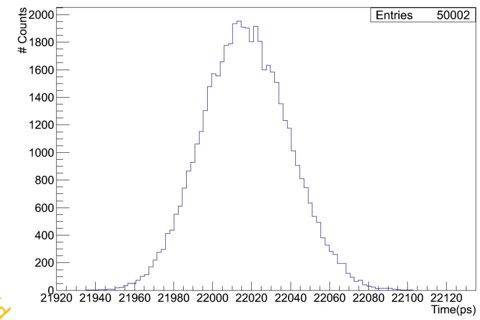

Figure 2: t-fwhm = 49.5 ps

Analysis

Last summer, in research at Indiana University South Bend on the electrostatic error using the same techniques it was found that the timing resolution was 49.5 ps (Fig. 2) and the position resolution was 2.25 mm $\hat{y}$ (Fig. 3) and 2.16 mm in $\hat{z}$ (Fig. 4). It was also recognized that the grids presented a problems because we had 3 grids and there were chances of one of the ions of interest being stopped.

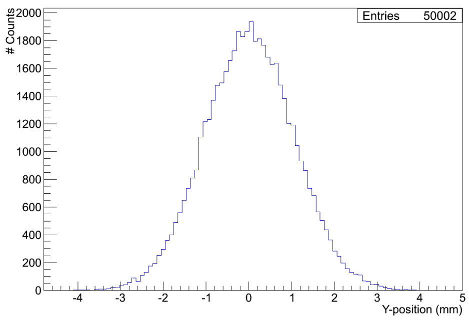

Figure 3: y-fwhm = 2.25 mm

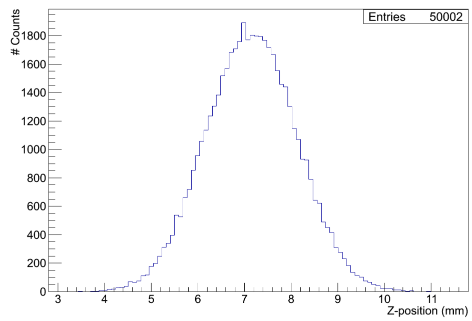

Figure 4: z-fwhm = 2.16 mm

Magnetic Deflection

The magnetic deflection design consists of a foil, four electrodes, an MCP, and a magnetic field perpendicular to the direction of electron emission. As the ions pass through the carbon foil electrons are emitted from the surface of the Carbon foil and are then accelerated away from the carbon foil which is at a negative potential toward electrode 1 which is at ground potential (Fig. 5). At any given point the particle experiences a force, which can be described with the formula.

$$F = Q(E + (v \times B)) \tag{1}$$

The Lorentz force is responsible for turning the electrons is such that the electrons accelerate until they reach in-between last two electrodes and then magnetic field starts to dominate. Hence, they experience a net force towards the MCP. While moving towards MCP, electrons are decelerated due to electric field. The MCP is set at a lower potential than the foil to ensure that the electrons don't lose all their energy before being detected. The MCP then records the timing and position of the electron cloud that is produced.

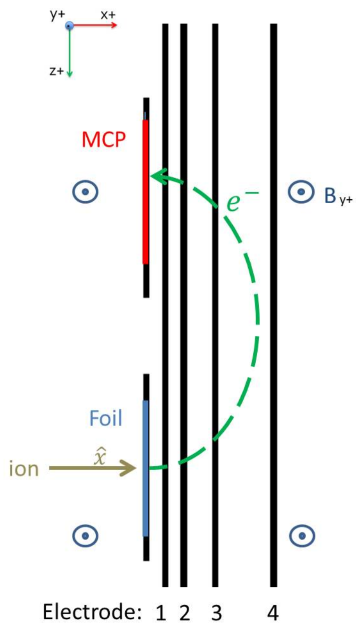

Figure 5: Magnetic Deflection

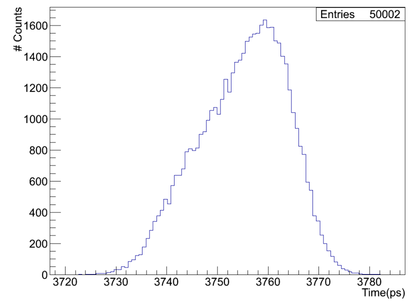

Figure 6: t-fwhm = 19.6 ps

Analysis

Using the standard particles to test the magnetic deflection set-up results found that timing resolution was on the order of 19.6 ps and our position resolution was 0.33 mm in $\hat{z}$ but much poorer in the $\hat{y}$ direction (1.68 mm) due to the fact that there is no focusing effect. We decided to make the magnetic deflection officially the detector of choice. The selection of the magnetic deflection design was mainly because allows us to reduce the number of wire grids introduced in the path of the beam line.

We have given up the large number of grids by deciding on this design, but with this design come new challenges, the most significant is creating a large enough good magnetic field region in the limited space available inside the detector chamber.

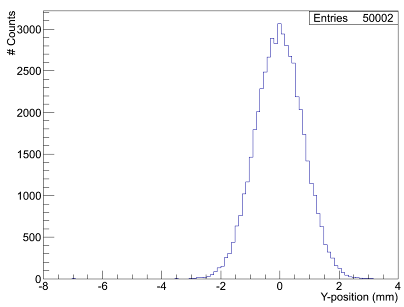

Figure 7: y-fwhm = 1.68 mm

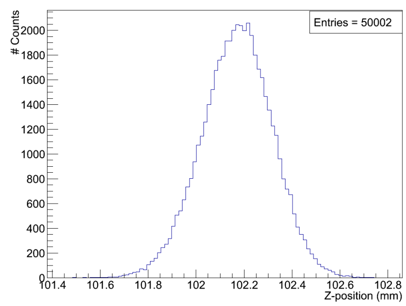

Figure 8: z-fwhm = 0.33 mm

Electrostatic Deflection

On a final note, a few steps were also taken into designing and simulating an electrostatic deflection device that will be used in commissioning the St. George by checking to see if it meets its design capability of 40 mrad acceptance angle. To test the electrostatic deflection a 3 mm diameter +1-charge Neon beam with a kinetic energy 5 MeV was simulated in SIMION. Checking only in two dimensions, the goal was to see what it would take to deflect the particle by 40 mrad. So, two plates were made and put at opposite potentials. This electrostatic deflector would temporarily have to take the place of the gas jet target, so there were size limitations. The only removable section was about 11.5 inches but that only really left a realistic length of 9 inches for the electrodes. Another design limitation was that we wanted to make sure that the particles that were being deflected had a trajectory that could be traced back to a single plane, that plane ideally being the location of the gas jet target. The plates at 14 mm apart created very distorted fringe fields for a 3 mm beam, which distorted the shape of the beam into a triangle. I increasing the plates to a distance of 40 cm apart with an extremely unrealistic voltage of 225 keV, indeed fixed our issue. Scaling down to 6 cm and a voltage of 50 keV, the distortion was present but acceptable. It is unworkable to place the large voltages that are required to bend a Ne 20 charge 1 with 5 MeV, but one can lower the energy of the beam and increase the charge state to decrease the potentials to levels that would not spark. We get a spark at about 3 kV/mm but we would like to stay at 1 kV/mm. In order to improve the design it will be necessary to see how close the plates can be brought together at the edges without exceeding the 1 kV/mm that has been set as a safety measure.

Conclusion

A prototype of the magnetic deflection set-up is currently being built at the University of Notre Dame machine shop. Designs to mount the new detector chamber to St. George are also being developed. Furthermore, the project to develop a stand inside the detector chamber for the magnetic deflection system is still ongoing. Designs for the electrostatic deflector to check acceptance angle of St. George are also ongoing. Moreover, the St. George is a continuing project with work being done to create a beam line that will link it to the new 5 MeV accelerator.

References

[1] M. Couder et al. Design of the recoil mass separator St. George. Science Direct. (2007): 35-45. Print

[2] http://physics.nd.edu/research/research-groups/nuclear-physics-group/

[3] http://root.cern.ch/drupal/