CERN Summer Student Report

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Optimization of the Antiproton Extraction Beam Trajectory in AE$\bar{g}$IS

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Abstract

Currently, CERN is the only place in the world where antiprotons can be produced, decelerated, and studied at low energy. One research initiative within the AE$\bar{g}$IS collaboration, one of five experiments at CERN focused on studying antimatter at low energy, is to establish a portable radio-frequency (Paul) ion trap that can store antiprotons for extended periods of time. This would allow antiprotons to be transported to other research institutions around the world, expanding the amount and types of research that can be conducted surrounding antimatter. To test the capabilities of this trap, antiprotons must be extracted from the main AE$\bar{g}$IS apparatus and recaptured by the Paul trap. For extraction and recapture, antiprotons will be guided into a secondary beamline, a process that is currently under development. This report describes the installation of scintillator detectors along the beamline and the analysis of the resulting data to create a streamlined process for optimization of the antiproton transfer into the trap.

1 Introduction

Matter-antimatter asymmetry remains one of the most enduring mysteries of our universe. CPT invariance, a direct result of Quantum Field Theory, dictates that the laws of physics are invariant under changes to charge (C), parity (P), and time reversal (T), and therefore do not apply differently to matter and antimatter. However, despite predictions that the Big Bang produced them in equal amounts, we observe matter in far greater quantities within our universe [4, 3].

The Antimatter Experiment: gravity, Interferometry, and Spectroscopy, otherwise known as AE$\bar{g}$IS, is one of five experiments located within CERN's Antimatter Factory that is focused on exploring this anomaly through a variety of different methods. The research conducted in this factory uses antiprotons that are first produced in the Proton Synchrotron. These antiprotons are then collected and transferred to the Antiproton Decelerator, which decelerates them to a kinetic energy of approximately 5 MeV. The next stage of cooling occurs when the antiprotons are transferred into the Extra Low ENergy Antiproton (ELENA) ring, reducing them to approximately 100 KeV, before they are distributed to the individual experiments within the Antimatter Factory. As of right now, CERN is the only place in the world where antiprotons are produced and decelerated, and this type of research can take place [5].

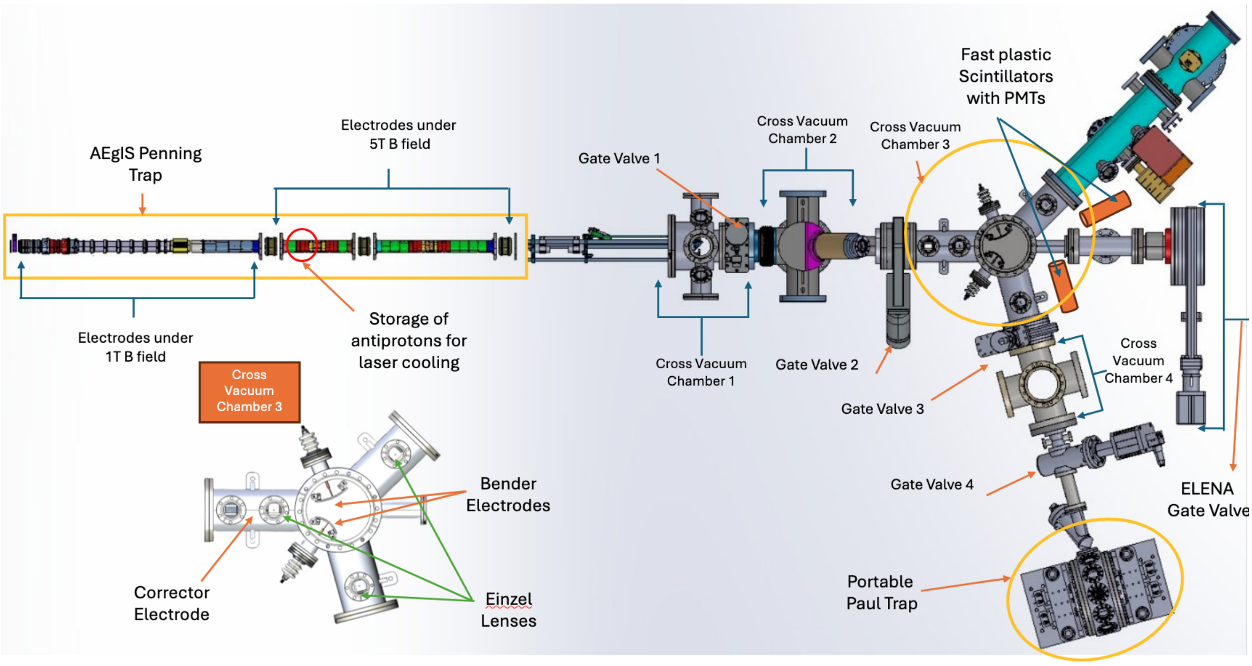


Figure 1: Beamline Diagram for AE$\bar{g}$IS. Antiprotons are injected into the experiment from the right (ELENA Gate Valve) and captured in the "Electrodes under the 5T B-field". After manipulation in this segment of the apparatus, they will be extracted backwards (from left to right) and deflected towards the "Portable Paul trap", using the "Bender Electrodes". The work of this summer student project focused on the commissioning and first detection of antiprotons with the "Fast Plastic Scintillators with PMTs" that will be used to optimize extraction [2].

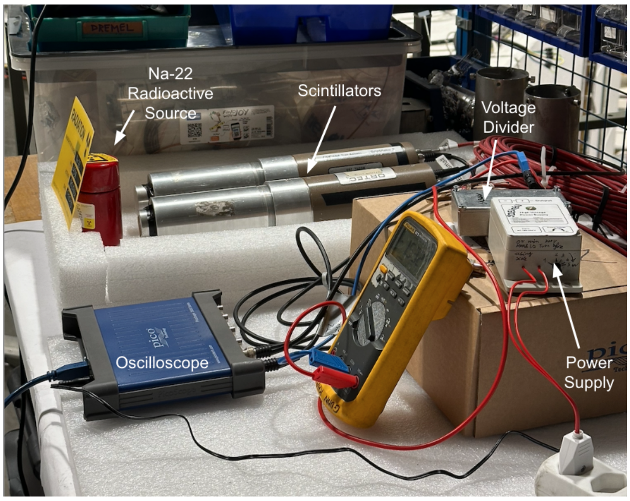


Figure 2: Scintillator Testing Setup. A high voltage power supply is connected to a voltage divider and a digital multimeter to monitor the voltage being supplied to the scintillators. A ^{22}Na radioactive source is placed in front of the scintillators and produces a clear pion signal for detection. An oscilloscope is connected to the scintillators to read the resulting outputted signal.

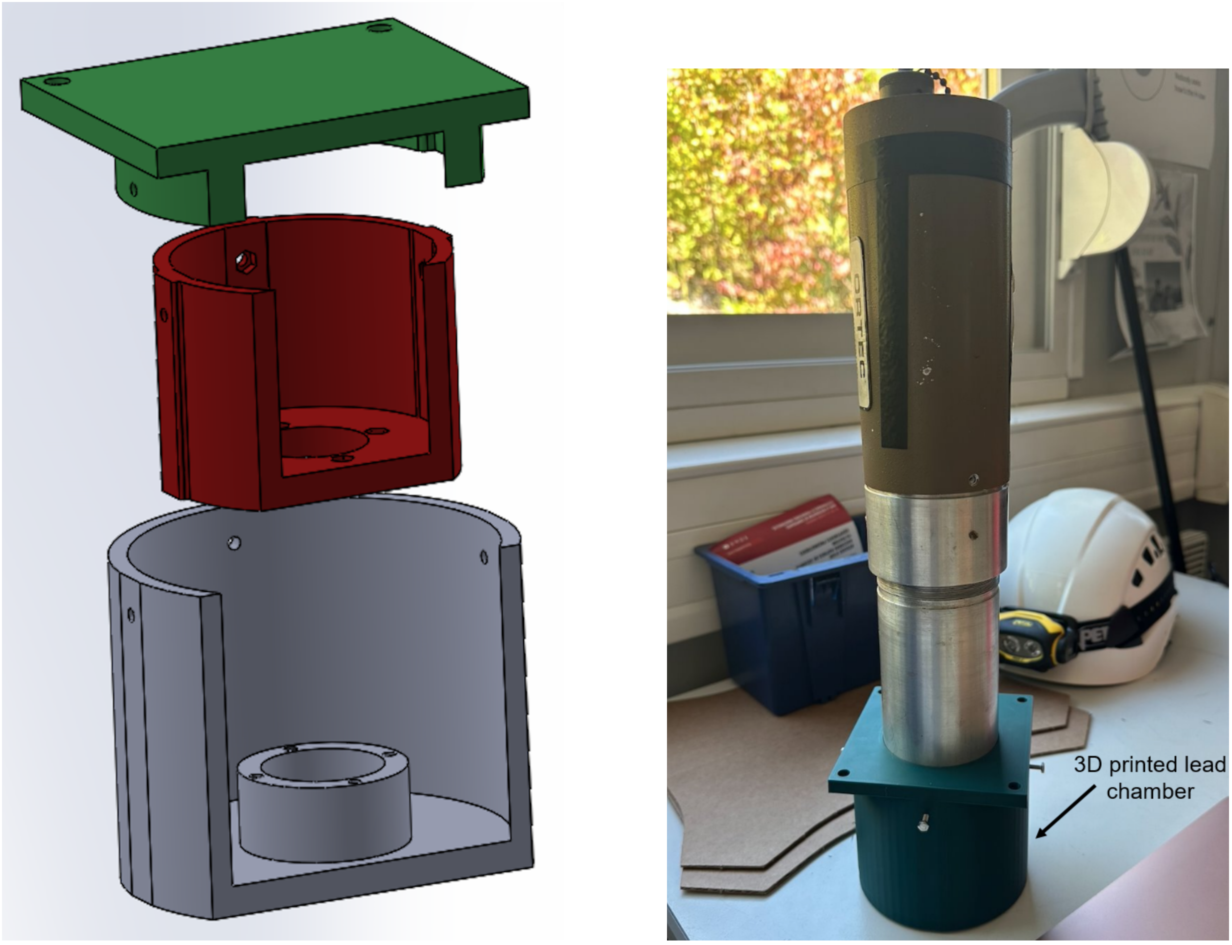
AE$\bar{g}$IS, specifically, has a variety of different research initiatives, spanning antihydrogen gravity measurements and antiprotonic bound systems [4]. An additional area of focus that has taken shape in the last few years is the development of a portable ion trap that could be used to hold and maintain antiprotons for extended periods of time. This would allow for antiprotons to be transported to other facilities around the world, expanding the amount and types of research that can be conducted surrounding antimatter. This report describes the installation of scintillator detectors and the analysis of the resulting data to create a streamlined process for the optimization of the antiproton beam trajectory into this portable ion trap.

2 Experimental Setup

The AE$\bar{g}$IS beamline is shown in Figure 1. The portable ion trap and the necessary vacuum components have been assembled and will be connected to the main beamline at an angle.

Antiprotons entering through the ELENA gate valve, at approximately 100 keV, are injected into the Penning Trap, where they are then cooled from a few keV to about 100 K. From here, the antiproton beam will be extracted back out of the Penning Trap towards the ELENA gate valve. The beam will then be bent using the bender electrons in Cross Vacuum Chamber 3, labeled in Figure 1, and directed into the portable trap.

To adjust the beam trajectory and maximize the number of antiprotons that reach the portable trap, two mobile fast plastic scintillator detectors will be attached to the apparatus. These scintillators will be placed at various points along the beamline to measure the antiproton annihilation that occurs there. When antiprotons come in contact with the sides of a vacuum chamber or a gate valve, they will annihilate. The resulting pions are absorbed



(a) CAD for the lead chamber.

(b) Full chamber assembly attached to the scintillator.

Figure 3: 3D printed lead chamber for signal collimation that was fully developed during this summer project. The hollow interior is filled with small lead pellets, and the chamber is securely fastened to the photomultiplier tube by the tightened screws visible in (b).

by the scintillator detectors, which then release a fluorescence corresponding to the amount of products it detects. This fluorescence is then collected and amplified by the attached photomultiplier tube, where it is turned into an electrical signal that can be measured by an oscilloscope [1].

Prior to installation, we tested the scintillators to verify their functionality, using the setup shown in Figure 2. A voltage divider was connected to the high voltage power supply to allow for voltage monitoring using a digital multimeter. The scintillators were supplied with a voltage of approximately 1.9 kV and placed near a ^{22}Na radioactive source. Using an oscilloscope, we determined that both scintillators were producing the expected signal.

We then designed two mechanisms that attach to the scintillators. The first is a 3D printed chamber filled with lead pellets. This chamber reduces the noise and stray events that the scintillator detects, ensuring that the signal received originates from antiproton annihilation events along the beamline. The computer-aided design (CAD), as well as the

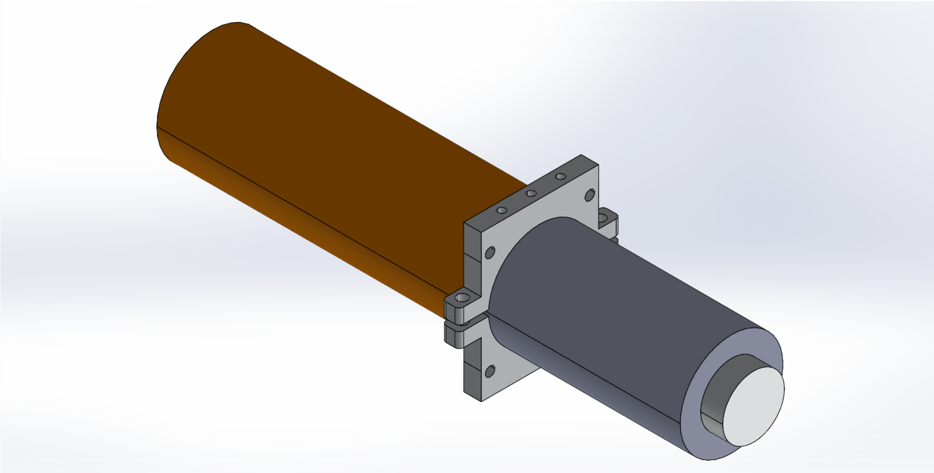


Figure 4: CAD of the metal clamp on a scintillator. Two pieces are placed around the scintillator and screwed together. Holes on the four corners and on the flat sides of the clamp allow for multiple attachment options depending on the location along the beamline.

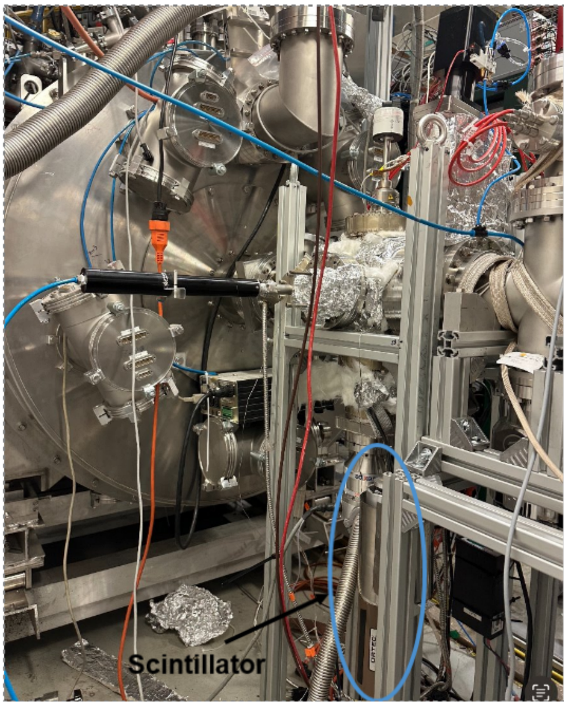
3D printed assembly are shown in Figure 3. The second consists of a metal clamp to hold the scintillators and allows for attachment to the structures above the beamline. This has been designed such that the scintillators can be moved around as needed and attached at various points. The CAD is shown in Figure 4 and is currently in production at the University of Siegen.

While the scintillators are attached to the beamline, they must be triggered remotely, so data is collected at intervals that coincide with the injection and extraction of antiprotons. The oscilloscope signal must then be recorded and saved. To accomplish this, a LabView interface configures the oscilloscope and saves the data. The oscilloscope is further connected with the main control system of the AE$\bar{g}$IS experiment for triggering. The control system triggers both the pulsed release of antiprotons and the oscilloscope in order to detect antiproton events with respect to the start of the extraction procedure. As a result of this triggering, the antiprotons' time of flight can be calculated, which provides information on where the annihilation events occur along the beamline. Using this information, the necessary electrodes are determined and the voltages can be gradually adjusted to guide the antiprotons towards the secondary trap. A computer in the AE$\bar{g}$IS zone is remotely accessed using TeamViewer, and the necessary data from the scintillators is obtained.

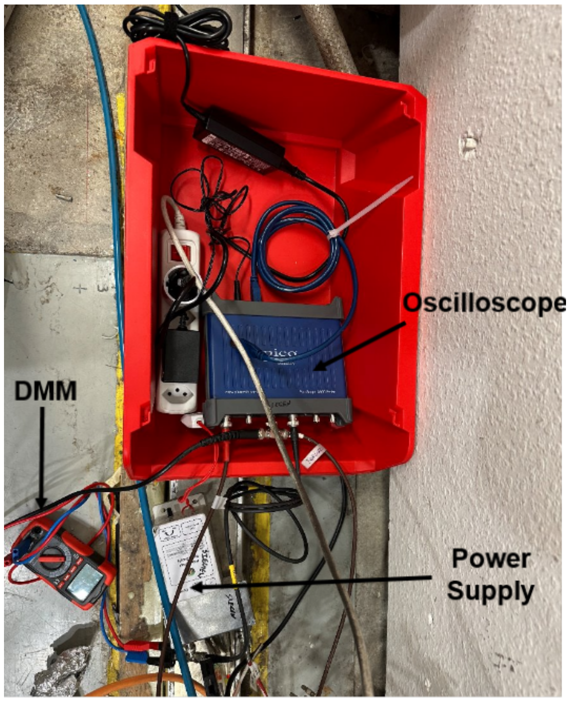
For the first tests, the scintillator was attached to the Bosch profile table in front of the AE$\bar{g}$IS Penning trap, shown in Figure 1, and surrounded by μ-metal for shielding against the magnetic field. This placement is shown in Figure 5a. The rest of the setup is placed a small distance away and is shown in Figure 5b.

3 Results

The scintillator data is read using the oscilloscope and saved as .txt file through the LabView interface. It is then analyzed using Python. The oscilloscope is triggered on the falling edge of a signal, and then saves data for the following 800 microseconds. Two different tests were



(a) Scintillator placement along the beamline near the AE$\bar{g}$IS Penning trap.



(b) Scintillator electronics connected to the scintillator and the control computer.

Figure 5: Scintillator Experimental Setup within the AE$\bar{g}$IS zone.

conducted.

The first, shown in Figure 6, occurred when antiprotons were not being ejected out of the Penning trap. The large negative drops correspond to the detection of pions either from cosmic rays or from antiproton events occurring elsewhere within the AD. Figure 7 shows the resulting plot from data collected when antiprotons were being ejected out of the AE$\bar{g}$IS Penning trap. This plot contains only 400 nanoseconds from the 800 microseconds acquisition time to show the antiproton signals in more detail.

In both plots, the signals corresponding to the detection of pions, and thus some antiproton annihilation events, are clearly visible against any background noise. This provides strong evidence that our scintillator setup is functioning as intended and can be used for beam steering in the near future.

4 Conclusion

While only preliminary data for the antiproton beam trajectory was obtained, the experimental setup and data collection process were created, tested, and streamlined. The results of these initial tests show that the scintillator detectors provide the necessary information for beamline optimization, and the creation and testing of the step-up allows for easy implementation in the future.

Further work must be done to fully integrate the oscilloscope into the AE$\bar{g}$IS control system, so that it can be fully operated from the control room without needing an additional

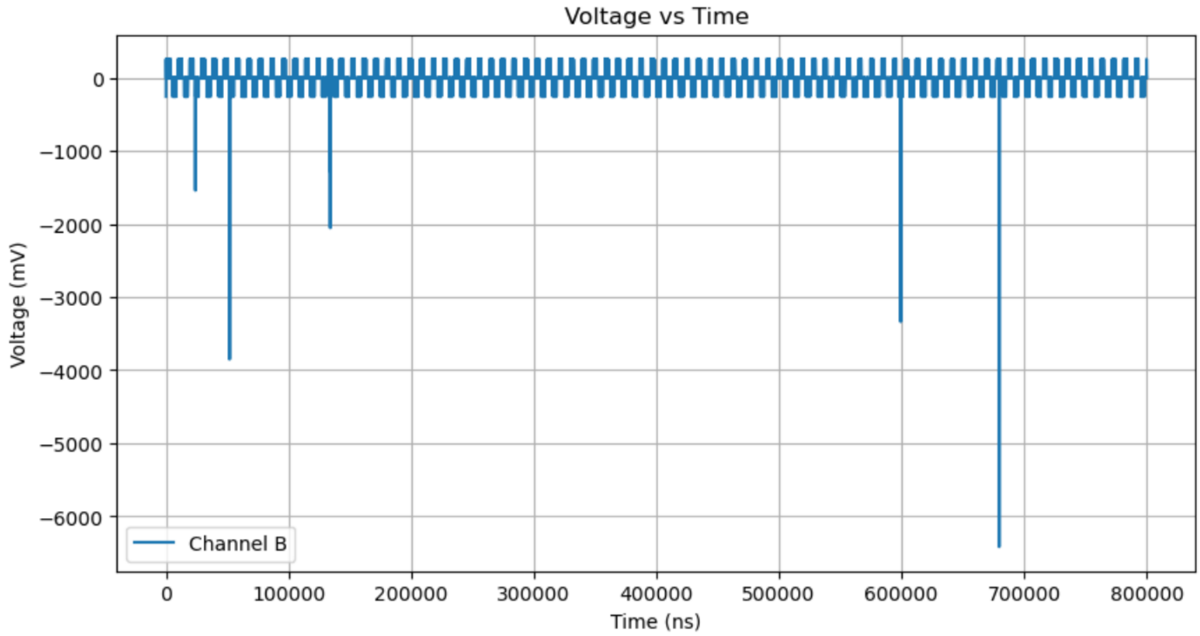


Figure 6: Plot of the scintillator signal without AE$\bar{g}$IS antiproton ejection. All 800 microseconds are shown. Negative voltage peaks correspond to pion detection.

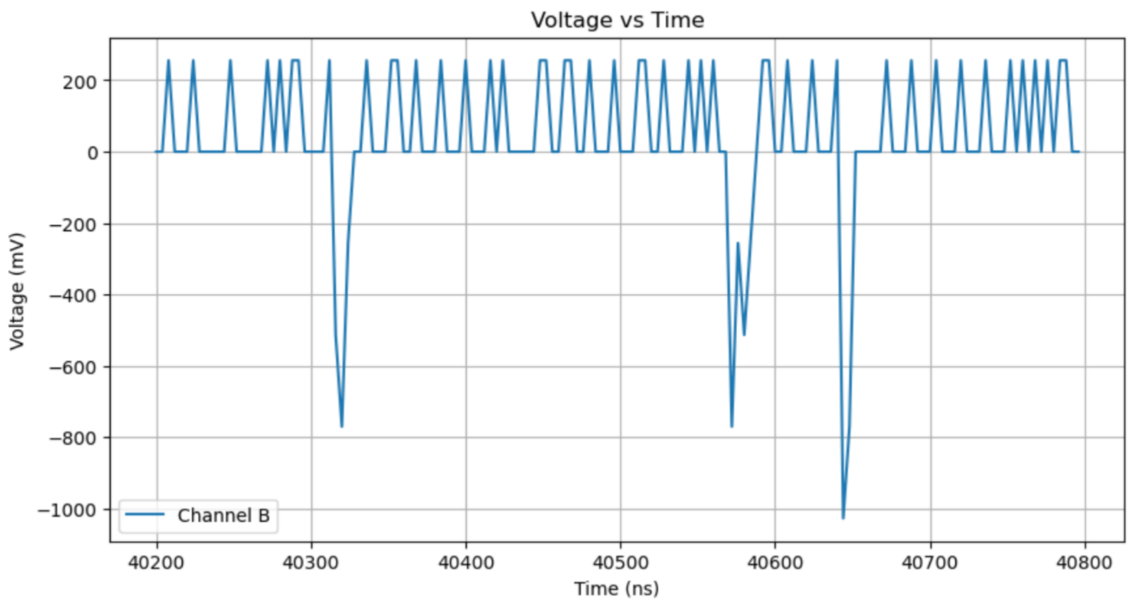


Figure 7: Plot of the scintillator signal with AE$\bar{g}$IS antiproton ejection. This has a time scale of only 400 nanoseconds to show the antiproton signals in more detail. Negative voltage peaks correspond to pion detection.

computer in the zone. Different tests with and without the lead chamber should be conducted and analyzed to determine if it improves the scintillator signal. Additionally, the scintillators must be moved to various points along the beamline and data must be obtained to get an initial estimate of the trajectory. Small adjustments to electrode voltages and additional data collection will allow for the maximization of antiprotons that reach the portable trap. Once this is accomplished, testing of and experimentation with the portable trap can begin.

5 Additional Contributions

In addition to the beamline optimization, work was done to assist in the development of high voltage switches for increased Penning-Malmberg trapping efficiency. These new switches will increase the trapping potential possible and provide both negative and positive voltages, allowing for more energetic species, as well as positive species, to be contained. This will expand the types of experiments that the AE$\bar{g}$IS collaboration can conduct and allow for further investigation into highly charged ions and nuclear fragments. Locations on the experimental apparatus, electrical components, and possible circuitry designs were discussed and considered. The high voltage switch is now being assembled at the University of Trento and will be installed into the AE$\bar{g}$IS system in the coming months.

Furthermore, the high voltage cabling for the equipment shown in Figure 1 was organized and ordered. These cables will allow for all components along the beamline including electrodes and micro-channel plate detectors to be powered and operated. Products that supported the desired functionality of the apparatus and satisfied the CERN safety requirements were determined. The necessary production teams and timelines were chosen, and the orders were placed.

Another future initiative that involves the portable Paul ion trap is the interaction of positive Barium ions with antiprotons. The ions will be injected into the trap, laser cooled, and then co-trapped with antiprotons. The ensuing interaction will result in the creation of highly charged ions, which will be studied and analyzed. To satisfy the laser safety requirements, a laser shutter is needed to block the beam path when conditions are not safe. Using a design implemented at Rice University, a 3D printed, DC driven optical shutter was modified and assembled, and will be integrated into the optical setup.

6 Acknowledgments

I would like to extend a thank you to all members of the AE$\bar{g}$IS collaboration. Your guidance and support throughout these past weeks have been invaluable, and have helped me grow as both a researcher and a collaborator. To the students in AE$\bar{g}$IS, thank you for making this such an enjoyable and interesting environment to work in. And finally, to the University of Michigan CERN REU coordinators, thank you for this incredible experience.

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