Analysis of Atomic Mass Spectrometry Data

for the Argon 39 Experiment

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ABSTRACT:

Accelerator Mass Spectrometry (AMS) is a particle detection technique that is particularly useful for nuclear physics experiments that require extraordinarily precise measurements of lifetime, masses, decay rates or concentrations of nuclei. At Notre Dame a magnetic spectrometer was readied for experiments on $^{40}Ca(\alpha,\gamma)^{44}Ti$ by installing an improved gas handling system as well as conducting vacuum tests. AMS data on beams of Argon-39 taken at Argonne National Laboratory was analyzed. The data collected in this experiment is not only useful for nuclear physics research but is also valuable to geophysical and environmental research. Noise in the data was reduced by implementing various cuts in the data and the effect of gas pressure in the spectrograph on detector response were quantified. Several strategies have been implemented for performing further cuts in the data, and our goal is to improve detection limits of ^{39}Ar over the current record.

INTRODUCTION:

Many experiments require the detection of very rare particles against backgrounds many orders of magnitude larger in counting rate [1]. These types of problems are perfectly suited for the detection techniques used in Accelerator Mass Spectrometry. AMS is such a powerful tool because the particle is detected using nuclear charge and utilizing the properties of range and stopping power in different substances [1]; using these characteristics one is able to separate the species and clearly identify nuclei whereas in conventional mass spectrometry , which uses only ionic charge, the isobaric backgrounds are not removed.

Other experiments that detect particles using their gamma-ray signatures are often not effective since the lifetimes are often so long that particle detection is not practical, e.g. Carbon-14. So few ^{14}C atoms decay in a reasonable amount of time that it would take hundreds of thousands of atoms to be captured in order to produce one decay an hour [1].

One experiment that is of particular interest for this technique and will be conducted in the near future is the study of the $^{40}Ca(\alpha,\gamma)^{44}Ti$ reaction. This experiment is important for the study of supernovae nucleosynthesis[2]. Since this experiment produces large backgrounds of Calcium and Titanium isobars, it is well suited for study using AMS.

Another experiment that this technique has been applied to is the detection of Argon-39. The difficulty in measuring the abundance of ^{39}Ar is the very high concentration of the isobar ^{39}K. In this paper we describe data analysis that was performed on an AMS data on ^{39}Ar at Argonne National Laboratory over the course of April 2008.

PURPOSE:

An accurate method for detecting Argon-39 is important for two different reasons. It is an important radioactive contaminant of liquid argon dark matter detectors searching for weakly interacting massive particles (WIMPS) as outlined in [3]. Detection and measurement of low concentrations of ^{39}Ar is therefore essential to improve the sensitivity of future WIMP detectors.

Argon-39 is also interesting for its usefulness as a tracer for monitoring environmental phenomena, specifically the great oceanic conveyer belt [4]. ^{39}Ar has several properties that make it ideally suited as an oceanic tracer. It is produced almost exclusively by the induced reaction ^{40}Ar(n,2n)^{39}Ar, which is the only reaction that would affect Argon in the oceans [5]. Furthermore, the abundance of Argon in the atmosphere has remained stable despite nuclear testing whereas many other tracers have undergone a change in atmospheric concentration. This stability makes it easier to accurately determine the time that the water has been submerged since it can be compared to the current atmospheric concentration. Also, Argon-39 has a half-life of 269 years which is consistent with the time scale of the oceanic conveyer belt whereas other possible tracers are too long-lived (e.g. Carbon-14) or too unstable (e.g. tritium) [5]. Since Argon-39 is well suited as an environmental tracer and as a potential detector for dark matter, it is important to develop a technique to measure its concentration.

METHODS:

In April 2008, an experiment was conducted at the Argonne National Laboratory ATLAS accelerator in order to determine the possibility of measuring Argon down to 0.1% atmospheric

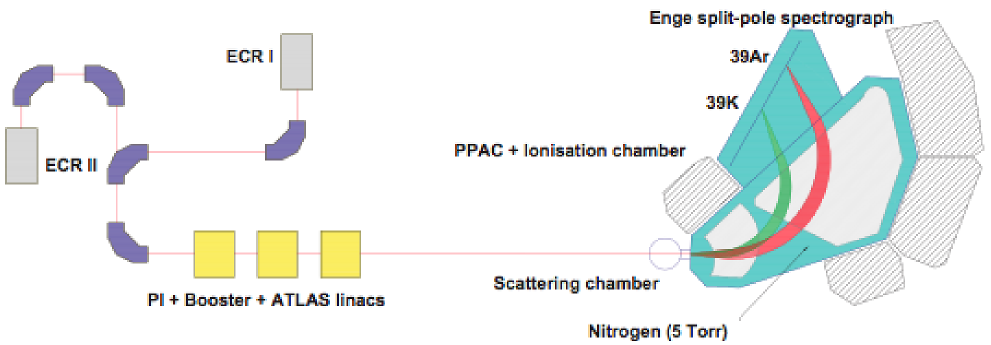

Fig. 1. Experimental set-up used for the detection of ^{39}Ar. ECR II was added after the 1994 experiment [1].

Argon-39. The set-up for the experiment is shown in Fig. 1. [4]

The argon beam from the ECR II source was accelerated by the ATLAS linacs to the spectrograph. Initially a beam of $^{76}Kr^{16+}$ was used to tune the spectrograph since it has the same charge to mass ratio as $^{39}Ar^{8+}$. The only difference between the two is that the kinetic energy of the krypton was twice that of argon. In an attempt to remove the massive amount of background from the beam, a quartz liner was used in the ECR. This liner did not work, but rather prevented plasma discharge. Later attempts used ultra-pure aluminum liners but their effectiveness is still unclear.

Separating the intense ^{39}K isobaric background from the extremely low concentration of ^{39}Ar was also accomplished using the gas-filled magnet technique. Isobars will coalesce around different charged states due to electron exchange with a gas. By filling the detection device (in this case a parallel plate avalanche collector) with isobutene, the ions will have an average magnetic rigidity that is different for different the isobars [6]. While passing through gas, the ions will be deflected differently by the magnetic field and can be more easily separated[1].In addition to applying the gas-filled magnet technique an ionization chamber was used in conjunction with the PPAC. An ionization chamber is a device that measures the energy loss of an energetic particle. This loss is measured with the use of gas in a chamber. As the particle passes through, interacting with the gas particles slows it. This interaction results in the creation of ion pairs in an amount proportional to the energy loss of the ion [5]. Measuring the amount of ion pairs that are created in coincidence with an event in the PPAC makes it possible to plot Delta E vs. X. In Fig 2. one can see such a plot and notice the definite separation between the two isobars.

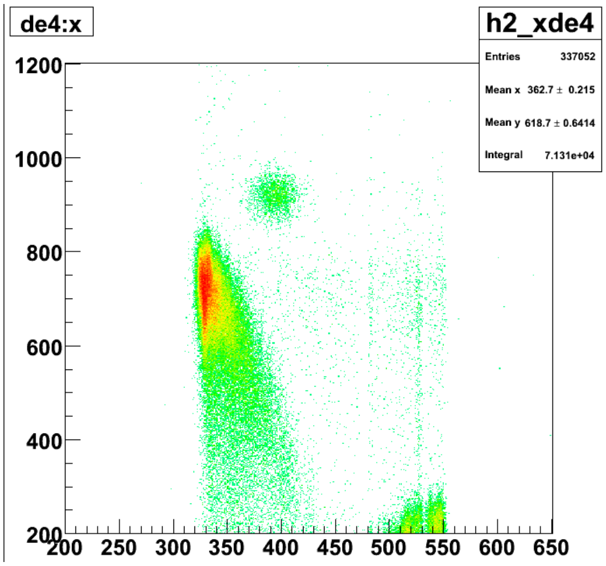

Fig. 2. Delta E. vs. X. Note the separation between different peaks in the figure, representing different isobars

ANALYSIS

ROOT was the primary tool used for analysis of the experimental data. ROOT is an object oriented data analysis framework for physics experiments developed at CERN [7]. All data collected was stores as binary run files, which were converted to ROOT files using the “daphsort” program written by collaborators at Argonne National Laboratory. The ROOT file stores the experimental data and allows for making cuts on the data and making cuts. Each detector event stored in the ROOT file contains information about the x-position of the event, timing data, energy deposited in the ionization chamber, and time of flight information.

In order to suppress unphysical events, the PPAC detector electronics contain a 200 ns delay line. When a charged particle triggers the wire grid in the detector, as shown in Fig. 4, a signal is sent through both ends of the delay line and the time it takes for the signal to reach both ends is summed and stored for each event (for convenience, this value is referred to as “hesum” throughout the rest of this paper). For all the events in a run, this setup should produce a narrow Gaussian peak around 200 ns for real events [8].

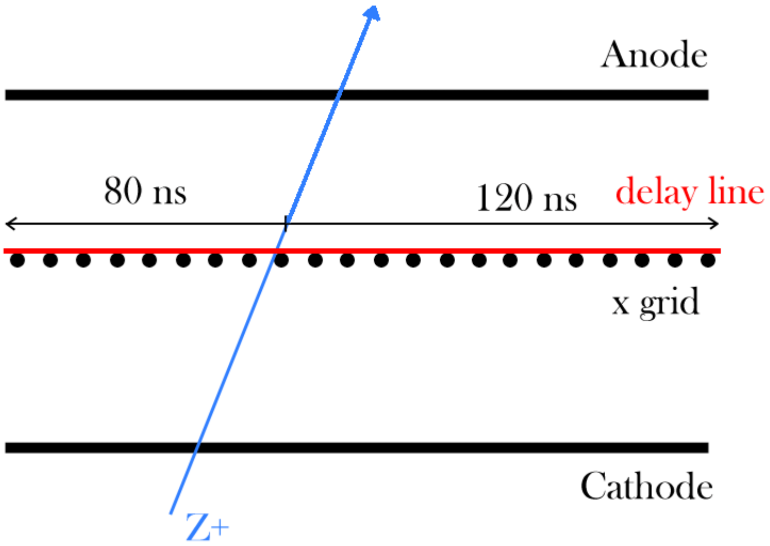

Figure 4: Schematic of the PPAC detector.

Fig. 5 shows a histogram of hesum for a typical run without any cuts on the data. Despite the presence of a well-defined peak around 200 ns, there remain a large number of events that are clearly unphysical. Figure 6 shows a 2-d scatter plot of events in the position and energy plane.

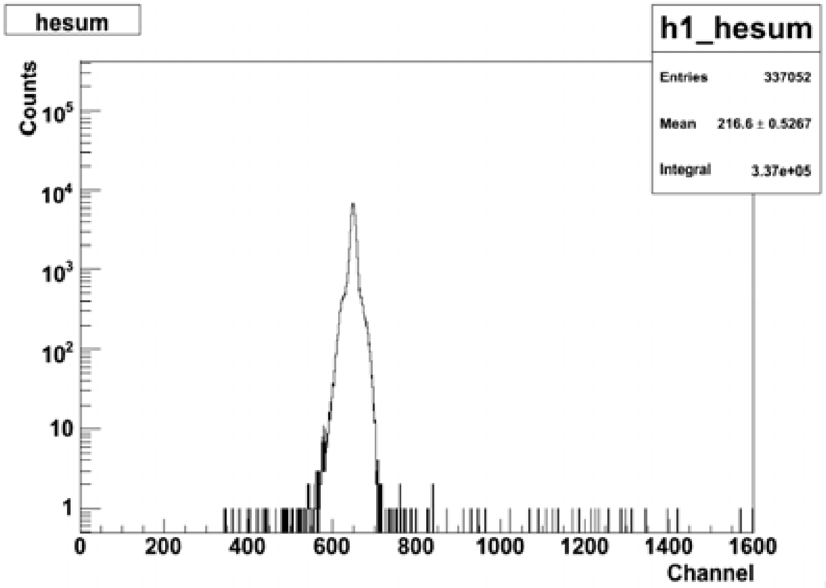

Figure 5: Histogram of hesum values for a ^{39}Ar run, clearly showing the central peak at 200 ns and the large spread of spurious events.

To determine appropriate cuts for all of the data, the hesum data for 25 runs were fitted with Gaussian functions and the mean and standard deviations were averaged. Cuts were then performed on all runs by gating the hesum data two standard deviations away from the mean. Fig. 7 shows the scatter plot of the same run as in Fig. 6 after the cuts have been applied. We found that for all runs, the peaks in the x/energy plane were better defined, and events outside of the ^{39}Ar and ^{39}K peaks were highly suppressed. On average, we found that the cuts at two standard deviations suppressed 49% of events in the runs. A similar proportion was suppressed in the ^{39}Ar counts, as well as the ^{39}K calibration runs, indicating that our cuts were not biased towards one type of run over another.

However, there were two problems with these cuts. 49% is much too high a proportion of events to be ascribed to unphysical events, indicating that two standard deviations from the mean was two tight of a window, excluding many real events. Secondly and more troubling, runs with over 1000 counts showed a double Gaussian shape in their hesum histograms, as shown in Figure 9. To further analyze the data, a program was developed that automatically tried to fit either a single or a double Gaussian function to the peaks in hesum.

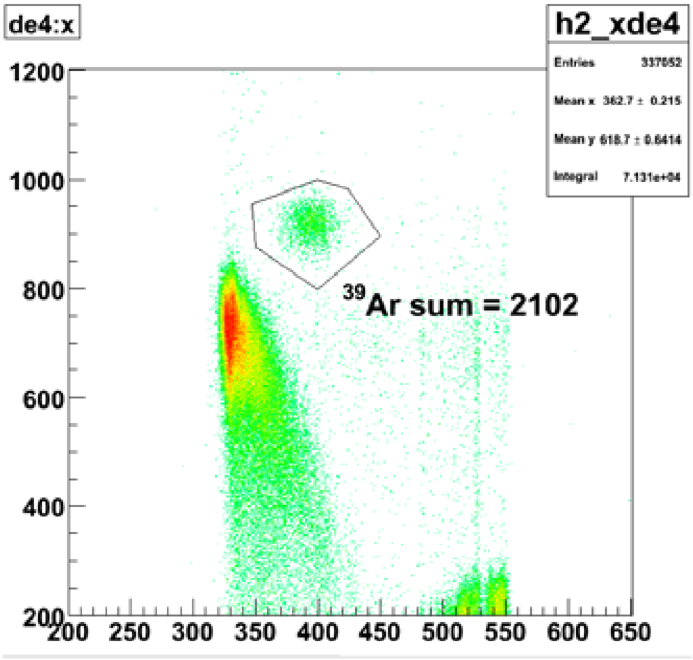

Figure 6: Uncut ^{39}Ar data run. The circled blob are the ^{39}Ar counts while the region with many counts is the ^{39}K background. Note significant pileup above and to the right of the ^{39}K peak.

Goodness of fit was evaluated using the χ^2/ndf characteristic [9]. This test suggested that the majority of runs were better approximated by the double Gaussian function. This in turn suggests that the appearance of a double peak is caused not by a physical process but by an error in the timing electronics. This hypothesis was further supported by the fact that the events contained in each side of the double Gaussian were located in the same range in the x-coordinate (Fig. 9), same energy deposited in the ionization chamber, and same time of flight.

An important method of resolving the ^{39}Ar peak from the ^{39}K background is changing the isobutene gas pressure in the spectrograph, detector, and ionization chamber. Gas pressure affects both energy loss in the ionization chamber, changing which channel the event will appear in energy, and the mean charge state which will alter how much the magnet bends an ion's path, in turn changing the x-position the event is registered in the PPAC detector. To gain a better

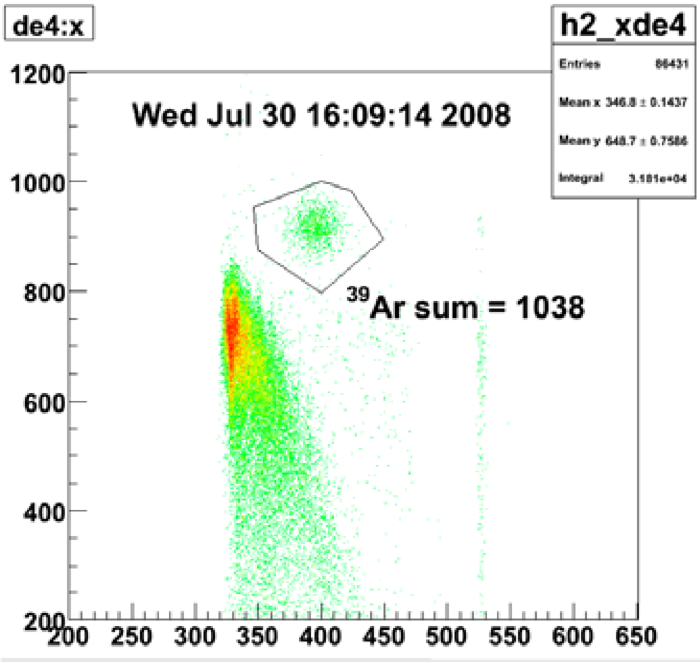

Figure 7: Data with hesum cut at two standard deviations. Note reduction in ^{39}Ar counts as well as reduction of pileup.

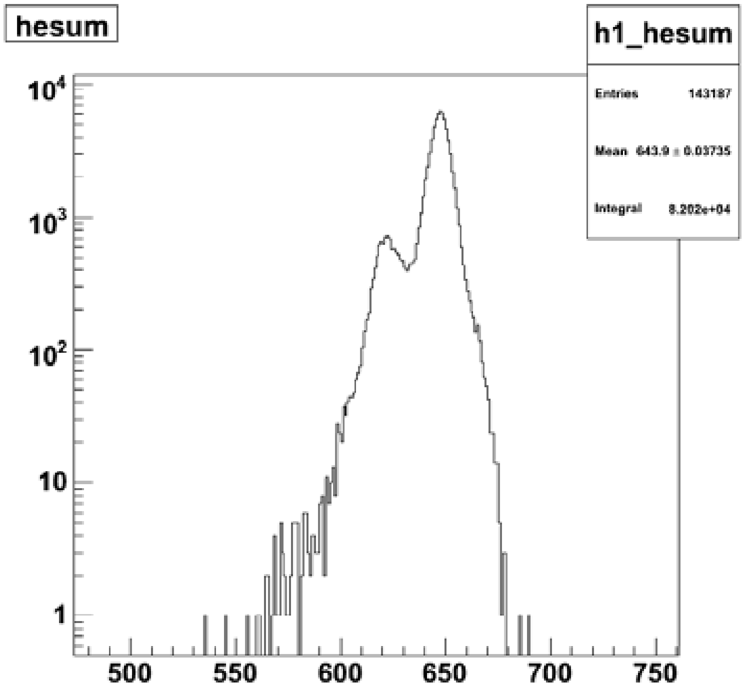

Figure 8: hesum histogram showing significant double peaking

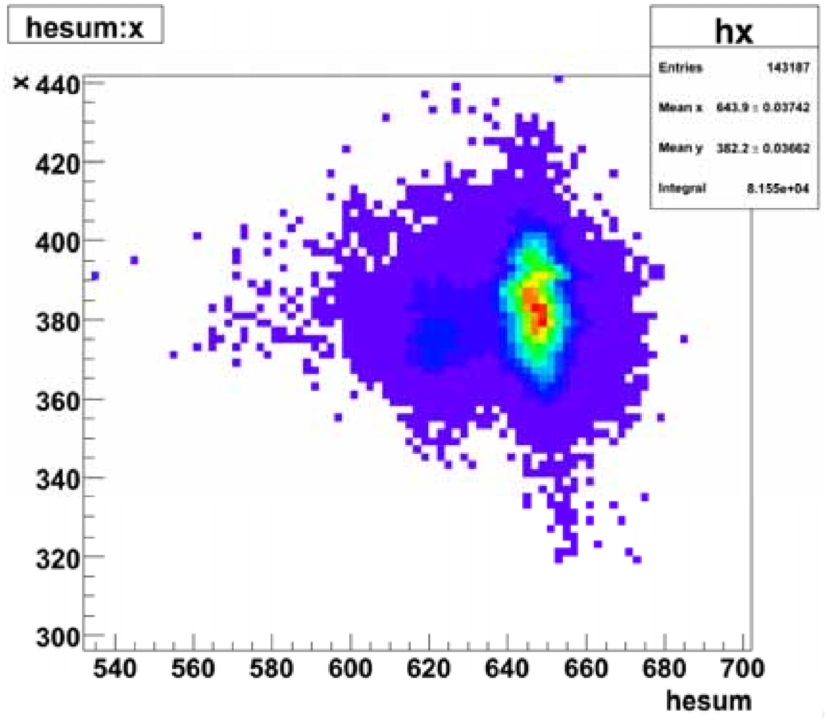

Figure 9: Scatter plot of hesum vs. x showing that the events in the hesum double peak occur at the same physical location. Scatter plots of other variables against hesum all look extremely similar.

understanding of these effects, we tracked the centroid of the argon-39 peak as gas pressures were changed (fig. 10). The data did not have sufficient runs at different pressures to obtain meaningful information from changes in IC or PPAC pressure, but as Fig. 11 shows, higher spectrograph pressure moved the argon peak away from the ^{39}K background counts. It is unclear what this means in the context of the limited amount of data (only 11 runs total).

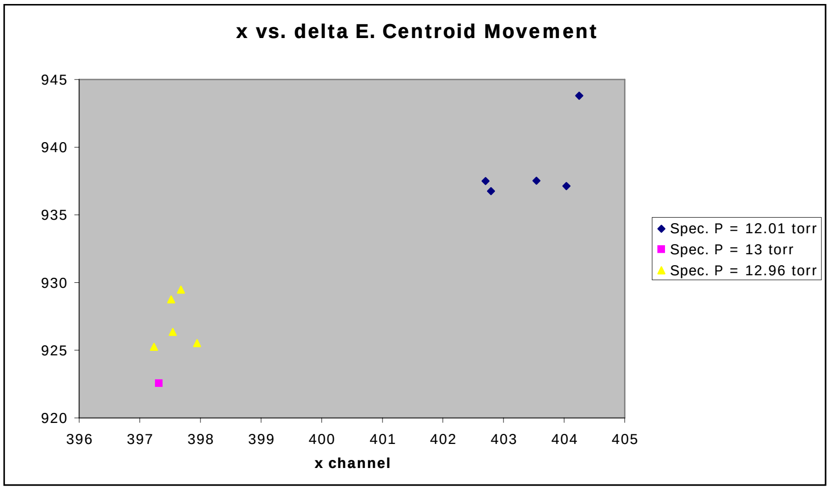

Figure 10: Plot of movement of ^{39}Ar centroid as spectrograph pressure was changed.

CONCLUSIONS AND FUTURE WORK

Many important tasks in the analysis of this run of argon-39 data remain to be done. The most important future goal will be to understand and either correct or mitigate the double peaking in the hesum data. While this analysis suggests that it is merely an electronic artifact and no error is introduced by considering all the events in the double peak, the delay line signal is one of the most important ways of rejecting false counts, and until the specific problem can be isolated we cannot be sure that we are either including or excluding physical events. Better cuts also need to be made on the ^{39}Ar data using hesum values, taking care not to exclude too many real events. And finally, different methods of cutting the data need to be identified. We have already begun steps to find a way to sum all the data from all the runs, then isolate the ^{39}Ar peak and look at the effect on the other detector information, effectively working backwards to identify potentially useful cuts.

The April 2008 data run was designed to understand the characteristics of the ATLAS accelerator when used for argon-39 measurements, and it at least succeeded in identifying multiple problems in the equipment and data. We have clearly only begun to scratch the surface of the data analysis work that needs to be done in order to understand what the systems are telling us. What we have succeeded in doing is identifying several areas that need further work, and establishing a robust framework for data analysis using the tools that ROOT provides.

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