TEST RESULTS FROM THE ATLAS HYBRID PARTICLE DETECTOR PROTOTYPE*

C.A. Dickerson#, B. DiGiovine, L.Y. Lin, Argonne National Laboratory, Lemont, IL 60439, USA
D. Santiago-Gonzalez, Louisiana State University, Baton Rouge, LA 70806, USA

Abstract

At the Argonne Tandem Linear Accelerator System (ATLAS) we designed and built a hybrid particle detector consisting of a gas ionization chamber followed by an inorganic scintillator. This detector will aid the tuning of low intensity beam constituents, typically radioactive, with relatively high intensity (>100x) contaminants. These conditions are regularly encountered during radioactive ion beam production via the in-flight method, or when charge breeding fission fragments from the CAlifornium Rare Isotope Breeder Upgrade (CARIBU). The detector was designed to have an energy resolution of ~5% at a rate of 10^5 particles per second (pps), to generate energy loss and residual energy signals for the identification of both Z and A, to be compact (retractable from the beamline), and to be radiation hard. The combination of a gas ionization chamber and scintillator will enable the detector to be very versatile and be useful for a wide range of masses and energies. Design details and testing results from the prototype detector are presented in this paper.

INTRODUCTION

At the Argonne Tandem Linear Accelerator System (ATLAS) we built and tested a fast, compact particle detector to aid the tuning of low intensity beam constituents with relatively high intensity (>100x) contaminants. These conditions are regularly encountered during radioactive ion beam production via the in-flight method, or when charge breeding fission fragments from the CAlifornium Rare Isotope Breeder Upgrade (CARIBU). The in-flight method of RIB production at ATLAS generally produces beams of interest with energies 5-15 MeV/u and masses less than 30 AMU, while reaccelerated fission fragments from CARIBU, 80 < A < 160, are typically accelerated to energies of 4-10 MeV/u. Our goal is to achieve ~5% energy resolution at a total rate of 10^5 pps over these energy and mass ranges without significant performance degradation after extended use.

The detector combines a gas ionization chamber (IC) with an inorganic scintillator, Fig. 1, to generate energy loss, ΔE, and residual E signals, which enable the identification of both the Z and the A of the beam constituents. The IC configuration followed designs for similar Tilted Electrode Gas Ionization Chambers (TEGIC) [1-2] – closely spaced parallel grids normal to the beam direction. Resolutions of ~4% and ~2% were reported for A and Z identification, respectively. GSO:Ce, the chosen scintillator, is the most radiation hard of any well characterized scintillator [3], has a 60 ns decay time, and 3-5% energy resolution for heavy ions [4-5]. The scintillator will provide residual E for particles not stopped in the gas, and enables the flexibility to tune the gas properties for the best signal while largely ignoring the gas' stopping power. An avalanche photo diode (APD) was selected as the photoelectric device mainly due to the device's compactness. A more detailed discussion of the design considerations was previously reported [6].

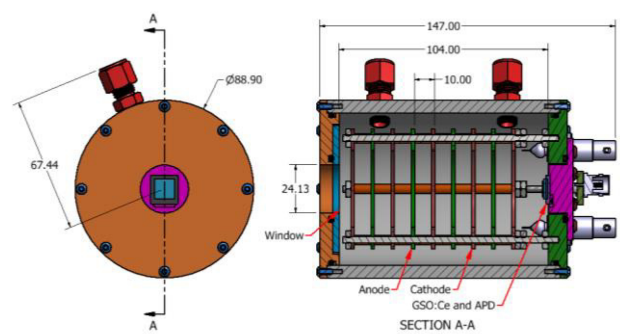

Figure 1: A model of the ATLAS hybrid detector. Dimensions are in mm.

EXPERIMENT

For the results reported here the scintillator and the gas IC were tested separately; the GSO:Ce was not incorporated into the assembly of the IC. Additionally, an insertion mechanism and vacuum chamber for the hybrid detector have not been designed yet, so the front plate of the IC was adapted to fit directly on a 6 in. CF flange at the end of the beamline.

The ion beam used in these tests was a cocktail of 7.28 MeV/u $^{18}O^{4+}$, $^{27}Al^{6+}$, and $^{36}Ar^{8+}$, corresponding to 131 MeV ^{18}O, 197 MeV ^{27}Al, and 262 MeV ^{36}Ar. The ^{36}Ar and ^{18}O were injected into the ECR source via gas metering valves, and were delivered at similar intensities. The ^{27}Al was a contaminant from the ECR plasma chamber walls, thus it was much less intense and only identified upon analysis.

The gas IC window was 1.14 mg/cm^2 (8 μm) Kapton epoxied to an aluminum window mount to facilitate replacement in the event a window broke, Fig. 2.a. The electrical grids were made using ø20 μm gold plated W wire spaced 1 mm apart, Fig. 2.a, which allowed ~98% transmission. The grid frames are printed circuit boards with the appropriate solder traces to mount the grid wire and solder pads to make inter-grid connections. Kapton

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#cdickerson@anl.gov

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coated wire was used to electrically connect grids, and the electrodes were configured into two 40 mm long sections, each consisting of two anodes and four cathode-anode gaps, Fig. 2.b. The cathode grids were commonly connected, and grounded to the chamber.

A bias of 350 V was applied to the anodes, and with 450 Torr of CF_4 supplied to the IC a normalized electric field of 0.78 V/(Torr-cm) was present. At this field the electron drift velocity in pure CF_4 was 9×10^6 cm/µs [7]. Ortec 142B preamplifiers and 572 spectroscopy amplifiers set to 0.5 µs shaping times conditioned and amplified the anode signals, then a 12 bit ADC digitized the pulses before recording. A Hamamatsu S8664-1010 APD with a gain of 50 converted and amplified photons from the scintillator. Electrical signals from the APD were conditioned and recorded in the same manner as the IC signals.

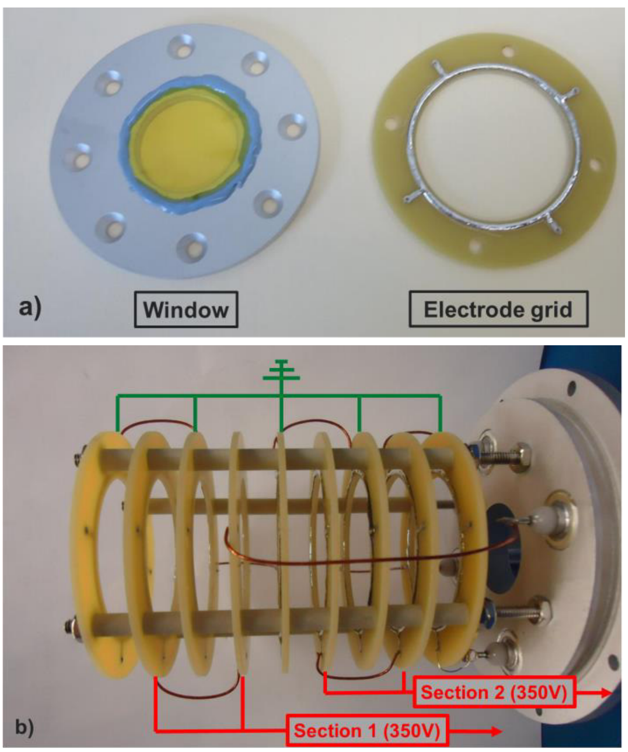

Figure 2: a) IC assembly components: 1.14 mg/cm^2 (8 µm) Kapton window epoxied to an aluminum mount, and an electrode grid of ø20 µm gold plated W wire soldered to a printed circuit board frame. b) The assembled electrode grids configured in two 40 mm long sections.

RESULTS

Signal amplitudes corresponded to the amount of energy deposited in the given section. All the ions in the beam made it through section 1, so these signals corresponded to energy loss, ΔE, signals. The ^{18}O and ^{27}Al also punched through section 2 and produced additional ΔE signals, while the ^{36}Ar stopped in section 2, resulting in residual E signals. The raw data was calibrated with energy loss calculations from LISE++ [8] using the appropriate thicknesses of the various energy loss regions: the window, the dead zone between the window and the first cathode, section 1, and section 2.

Section 1 signals were converted to represent the Z of the ions, since $\Delta E \propto Z^2/v^2$, and the velocities of the ions from the linac were identical, $\Delta E \propto Z^2$ in this case. Energy signals from both sections could be added to indicate the total deposited ion energy. Summing the calibrated energy loss from section 1 and the residual energy from section 2 for ^{36}Ar, the only ion completely stopped in the gas, indicated the mass (A) resolution of the detector since the total energy is directly proportional. Figure 3 shows the results of a typical IC spectrum acquired at a rate of 0.7 kpps. Artifacts from the wire grids are seen as intense, discreet spots along the same ordinate values as identified ions, and striations near ^{18}O are attributed to reaction products from interactions with the window.

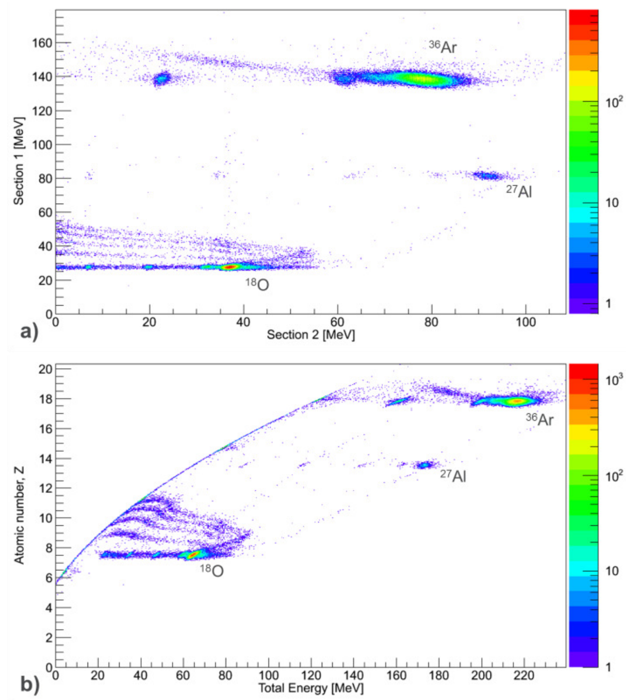

Figure 3: a) Energy loss in section 1 vs section 2, calibrated with energy loss calculations. b) Energy loss signals were converted to Z and total energy loss to measure Z and A resolutions.

Figure 4 shows the achievable Z and A resolutions for a variety of incident particle rates. The expected resolutions of ≤ 5% and ≤ 2% in A and Z, respectively, at 10^5 pps were not realized. Only at rates ≤ 2.4 x 10^4 pps were these resolutions achievable, so additional efforts, discussed below, will be made to increase the range at which this detector's resolution is sufficient.

The resolutions of the ^{18}O and ^{36}Ar peaks (3.5% and 4.8%, respectively) in the GSO:Ce are shown in Fig. 5, a typical spectrum acquired at 1.8 kpps. Possible evidence of quenching is seen in Fig. 5; the ratio of centroid channel numbers between the ^{36}Ar peak and the ^{18}O peak is 1.5 (1050/700), but should be 2, considering ^{36}Ar had

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twice the energy as ^{18}O. Evidence of rate dependent peak positions, not presented here, was also observed. These features, quenching and rate dependence, may be problematic for particle identification and require additional investigation.

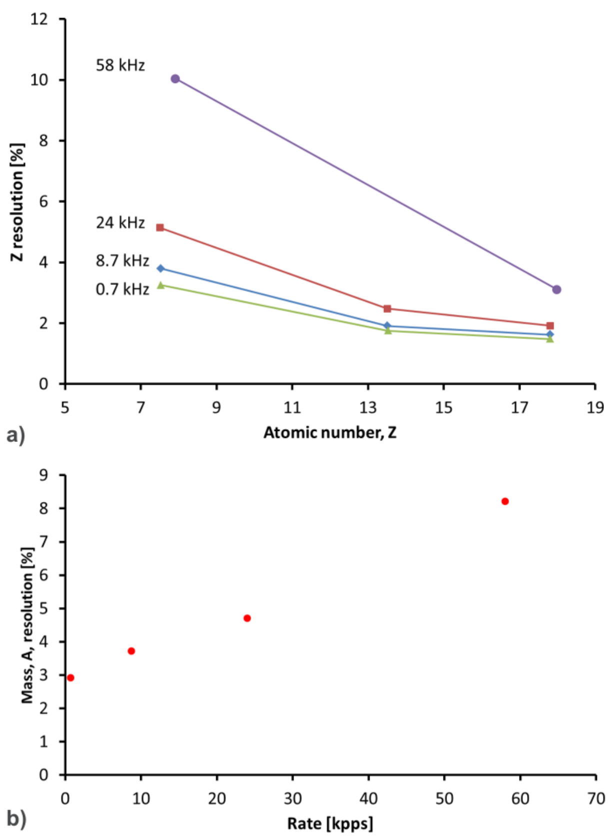

Figure 4: a) Z resolution vs. Z and rate in the IC. b) Mass, A, resolution vs. rate for ^{36}Ar deposited into the IC.

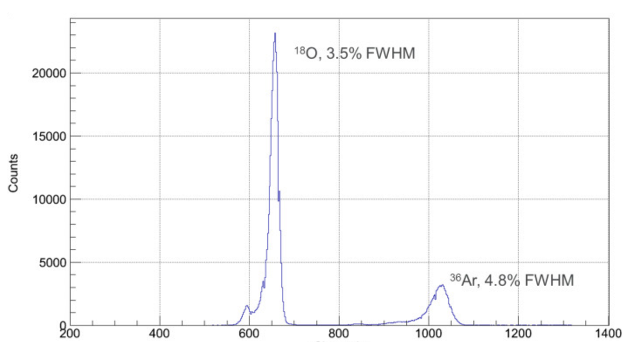

Figure 5: Typical GSO:Ce spectrum acquired at 1.8 kpps.

FUTURE WORK

Significant resolution degradation occurred by 5.8 x 10^4 pps in the IC, which is at a lower rate than we expected. Two potential factors influencing this performance were the ion beam density and the electron drift velocity. The ion beam was delivered directly from the linac, so the quality was relatively good and could be focused well. This most likely resulted in a high ion-gas interaction density along the beam axis while not utilizing much of the IC volume. Recombination was likely significant for these conditions. To lower the beam density in the future we will either defocus the beam or use a scattering foil up stream of the detector.

The electron drift velocity can be increased by ~30% by increasing the normalized field to ~3 V/(cm-Torr) for pure CF_4, or by mixing 20% CF_4 with 80% Ar. [7]. The preamplifiers are limited to a bias of 1000 V, so we will investigate the rate dependence of the detector performance with a gas mixture. The potential drawback is that the gas stopping power decreases significantly, so the scintillator is required to produce residual energy signals even for ion masses of ~50 at ~10 MeV/u.

SUMMARY

Optimizing ATLAS for the delivery of radioactive ion beams requires a detector capable of distinguishing a low intensity species of interest from a high intensity background. The combination of a gas ionization chamber and scintillator was designed, constructed, and tested to assess the detector's ability to perform the needed separation and particle identification. The gas IC chamber performance was promising up to a rate of 2.4 x 10^4 pps; mass resolution was 4.7% and Z resolution was 1.9% for $Z \geq 18$. Measures will be taken to minimize the beam density in the IC and increase the electron drift velocity to achieve similar performance up to a rate of 10^5 pps. The performance of the GSO:Ce was also promising – mass resolutions of 3.5% and 4.8% for 18O and 36Ar, respectively – but not without issues; potential influences of quenching and rate dependent peak positioning were observed and will be investigated further.

REFERENCES

[1] K. Kimura et al., "High-rate particle identification of high-energy heavy ions using a tilted electrode gas ionization chamber," *Nucl. Instr. Meth. A*, vol. 538, p. 608-614, 2005.

[2] K.Y. Chae et al., "Construction of a fast ionization chamber for high-rate particle identification," *Nucl. Instr. Meth. A*, vol. 751, p. 6-10, 2014.

[3] V.V. Avdeichikov et al., "Light output and energy resolution of CSI, YAG, GSO, BGO, and LSO scintillators for light ions," *Nucl. Instr. Meth. A*, vol. 349, p. 216-224, 1994.

[4] M. Kobayashi et al., "radiation hardness of cerium-doped gadolinium silicate GD2SiO3:Ce against high energy protons, fast and thermal neutrons," *Nucl. Instr. Meth. A*, vol. 330, p. 115-120, 1993.

[5] G. Miersch et al., "Fast scintillators as radiation resistant heavy ion detectors," *Nucl. Instr. Meth. A*, vol. 369, p. 277-283, 1996.

[6] C. Dickerson et al., "A fast, compact particle detector for tuning radioactive beams at ATLAS," in *Proc. HIAT'15*, Yokohama, Japan, Sep. 2015, paper MOPA29, pp. 107-109.

[7] L.G. Christophorou et al., "Fast gas mixtures for gas-filled particle detectors," *Nucl. Instr. Meth*, vol. 163, p. 141-149, 1979.

[8] LISE++, http://lise.nscl.msu.edu/lise.html

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