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Accelerator Tests of Angle Detecting Inclined Sensor (ADIS) Prototypes with Beams of ^{48}Ca and Fragments

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The resource constraints on spacecraft generally mean that instruments that measure cosmic rays and Solar energetic particles must have low mass (a few kg) and power (a few W), be robust and reliable yet highly capable. Such instruments should identify ionic species (at least by element, preferably by isotope) from protons through the iron group. The charge and mass resolution of heavy ion instruments in space depends upon determining ions' angles of incidence. The Angle Detecting Inclined Sensor (ADIS) system is a highly innovative and uniquely simple detector configuration used to determine the angle of incidence of heavy ions in space instruments. ADIS replaces complex position sensing detectors (PSDs) with a system of simple, reliable and robust Si detectors inclined at an angle to the instrument axis. In August 2004 we tested ADIS prototypes with a ^{48}Ca beam at the National Superconducting Cyclotron Laboratory's (NSCL) Coupled Cyclotron Facility (CCF). We demonstrate that our prototype charged particle design with an ADIS system has a charge resolution of better than 0.25 e.

1. Introduction

The most common methods of identifying heavy ion species in space radiation use $\Delta E/\Delta x$ measurements. Since Δx depends upon the angle of incidence, corrections are required. The Angle Detecting Inclined Sensor (ADIS) system (Figure 1 left) takes advantage of the variations in the thickness of detector material particles traverse to determine the angle of incidence using a simple system of two detectors inclined to the telescope axis together with one detector normal to the axis [1]. Let θ be the angle of incidence projected into the x-z plane. The signal in D1 is then proportional to $\sec(\theta)$ while the signal from D2 is proportional to $\sec(\theta + \phi)$ where ϕ is the inclination angle of D2. Assuming D1 and D2 are of the same thickness, for very high energy particles where the rate of energy loss does not vary significantly

$$\frac{E_1}{E_2} = \frac{\cos(\theta + \phi)}{\cos(\theta)} \quad (1)$$

where E_1 and E_2 are the energy signals in D1 and D2 respectively. Thus, by inverting the equation, θ can be determined from the ratio of the signals. The third detector (D3) inclined in the y-direction makes it possible to fully determine the angle of incidence. A derivation of the ADIS response for stopping ions with a fixed angle of detector inclination is provided in [1]. The generalized result, derived in [2], is shown in equation (2) below; the I's, J's and K's are the components of the unit vectors normal to D2 and D3, the T's are the detector thicknesses, and the E's are the energy depositions in each detector. D_x and D_y define the particle direction of incidence and Z is the charge. α and κ are empirically derived constants [3]. We demonstrate the capability to derive instrument parameters from data in [2]. For good resolution at Fe, the angles of inclination must be known to ~1° and thickness to ~2% [2].

$$D_y = \frac{1}{I_2 J_3 - I_3 J_2}\left\{\frac{1}{T_1}\left[(E_4+E_3+E_2+E_1)^{\alpha} - (E_4+E_3+E_2)^{\alpha}\right]\left[\frac{J_3 T_2}{(E_4+E_3+E_2)^{\alpha} - (E_4+E_3)^{\alpha}} - \frac{J_2 T_3}{(E_4+E_3)^{\alpha} - E_4^{\alpha}}\right] - (J_3 K_2 - J_2 K_3)\right\}$$

$$D_y = \frac{1}{I_3 J_2 - I_2 J_3}\left\{\frac{1}{T_1}\left[\left(E_4+E_3+E_2+E_1\right)^{\alpha}-\left(E_4+E_3+E_2\right)^{\alpha}\right]\left[\frac{I_3 T_2}{\left(E_4+E_3+E_2\right)^{\alpha}-\left(E_4+E_3\right)^{\alpha}}-\frac{I_2 T_3}{\left(E_4+E_3\right)^{\alpha}-E_4^{\alpha}}\right]-\left(I_3 K_2 - I_2 K_3\right)\right\}$$

$$Z = \left[\frac{\kappa}{T_1}\frac{\left(E_4+E_3+E_2+E_1\right)^{\alpha}-\left(E_4+E_3+E_2\right)^{\alpha}}{\left(1+D_x^2+D_y^2\right)^{1/2}}\right]^{1/(1+\alpha)} \tag{2}$$

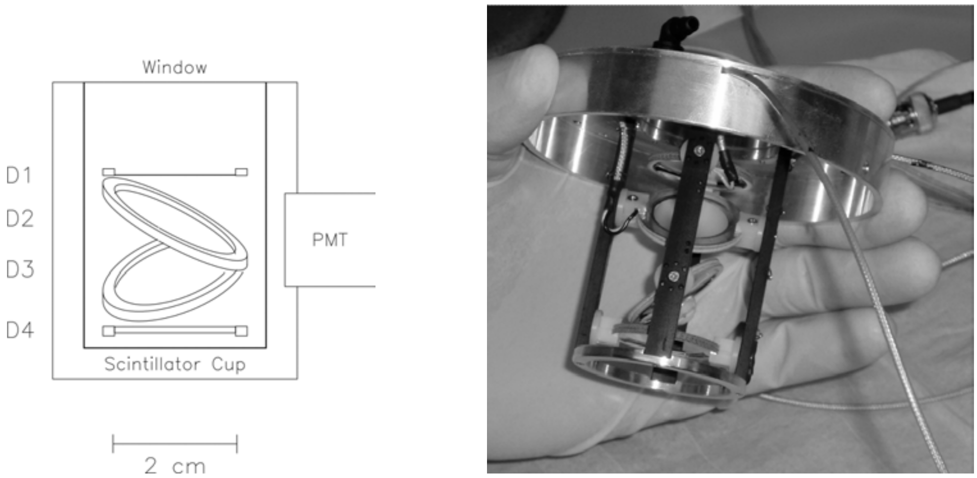

Figure 1. Left: Basic Angle Detecting Inclined Sensor configuration. D1, D2 and D3 are thin solid state detectors. D2 and D3 are inclined at 30° to the instrument axis, D2 with its major axis along the *x*-direction, and D3 along the *y*-direction. D4 serves as a stopping and residual energy detector. A scintillator cup viewed by a photomultiplier tube detect particles that penetrate D4, or exit the solid state detector stack. Right: Prototype ADIS charged particle telescope taken to NSCL for beam testing. Note the pivoting mounts for the ADIS detectors D2 and D3.

2. Test Instrument Design and Accelerator Exposure

Figure 1 right is a picture of the instrument we took to the NSCL. The D1, D2 and D3 detectors are the ADIS detectors. The D4 detector is the stopping detector and is 1000 µm thick. D2 and D3 are held with pivoting mounts and can be set at inclinations of 15°, 30° and 45° to the telescope normal axis. In this first test of the ADIS system, all four detectors were circular detectors—in future instruments D2 and D3 will be oval with a planar projection identical to the aperture defined by the circular D1 and D4 detectors. The main disadvantage of circular detectors was that it placed dead material (detector rings) in the instrument aperture. Surrounding the stack is a plastic scintillator, painted on the interior surface with $BaSO_4$ reflective white paint and enclosed by a reflective light box viewed by a photomultiplier tube. All the signals were read out through NIM bin linear electronics to a VME pulse height analysis data acquisition system.

The CCF supplied us with a primary beam of ^{48}Ca, which is sufficiently close to iron that the results of these analyses are a good indicator of how an ADIS instrument will function in space. In addition to the primary beam, we also were supplied with a fragment beam from the ^{48}Ca source. This fragment beam contained measurable amounts of P, S, Cl, Ar and K, giving us a mix of ions for more realistic testing. We had 18 hours of beam time; each run lasted approximately 5 minutes, and we collected on the order of several hundred thousand to a million events during each run. In order to effectively simulate omni-directional space radiation, our instruments were mounted on a moveable turntable. We rotated the turntable from –20° to +20°, in 5° increments, across the nominal beam axis, thus simulating an isotropic flux in one angular dimension. In order to simulate an isotropic flux in the other angular direction we manually rotated the instrument on its platform. An energy degrader, in the form of a wedge of aluminum, was continuously raised and lowered into the beam in front of our instrument aperture using a motor. Thus the CCF beams were spread in energy to simulate space radiation.

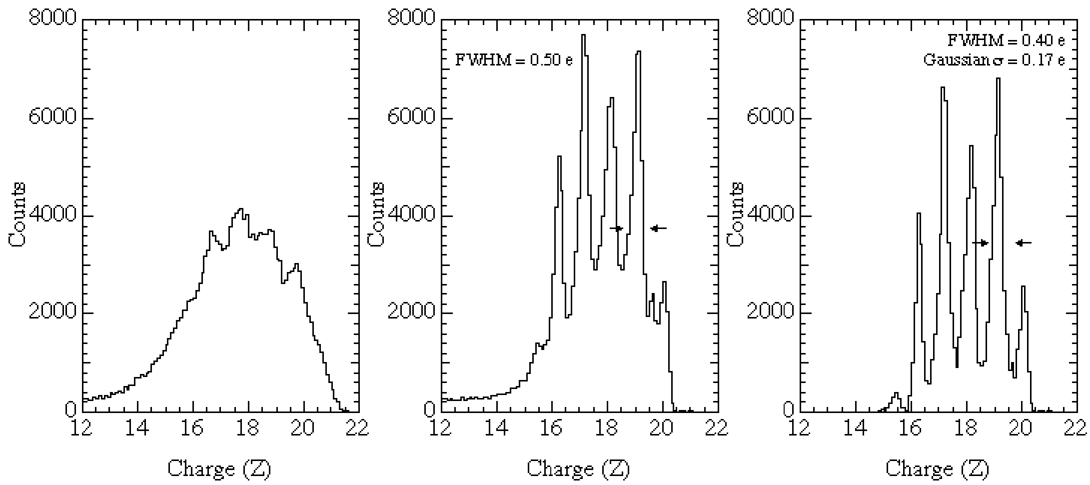

Figure 2. ADIS data with fragmented ^{48}Ca primary beam. In these runs D1-3 were 200 μm detectors. D2-3 were inclined 30^{o} to the instrument axis. Data are with a mixture of beam angles. Left shows the data with no correction for angles of incidence. Center shows the same data using our ADIS system to correct for the angle of incidence; the charge peaks are a direct result of the ADIS angle correction. Right shows the data with a cut to eliminate events that miss detectors; a charge resolution of 0.17 e is achieved.

3. Data Analysis

Figure 2 shows charge (Z) histograms for a series of fragment runs. The detector thicknesses were 200 μm and the ADIS detectors are inclined at an angle of 30°. This is a compilation of nine runs, with the instrument normal axis oriented at –20°, -15°, -10°, -5°, 0°, +5°, +10°, +15° and +20° to the beam. The left panel shows the charge histogram obtained when no correction for angle of incidence is made. The peaks in the distribution are not aligned on unit charges, and are merely an artifact of the data where, for example, a +20° beam angle has the P track falling on top of the track for Cl at +5°. In the center panel we show the charge histogram obtained after the ADIS angle correction is applied. Now six peaks are distinguished, and each lies on a unit charge corresponding to the elements from P to Ca. The right panel shows the charge histogram obtained when a selection for stopping particles is made. Again we see how the ADIS correction gives reasonable particle identification: here the best-fit Gaussian sigma, for the widest peak, is 0.17 e. Table 1 summarizes the results for both primary and secondary beams with different detector thicknesses and angles of inclination. (No data was taken with 50 μm detectors at 45° due to time constraints.)

Table 1. Sigma of best-fit Gaussians to charge histograms

	Primary Beam			Secondary Beam		
	15°	30°	45°	15°	30°	45°
50 μm	0.21 ± 0.062	0.15 ± 0.026	No data	0.19 ± 0.023	0.17 ± 0.015	No data
100 μm	0.17 ± 0.024	0.12 ± 0.020	0.16 ± 0.030	0.14 ± 0.012	0.16 ± 0.016	0.20 ± 0.024
200 μm	0.13 ± 0.020	0.10 ± 0.022	0.10 ± 0.035	0.18 ± 0.012	0.17 ± 0.017	0.17 ± 0.020

3. Conclusions

We have tested an ADIS model using ^{48}Ca primary and fragment beams. Despite the design compromises in this model, the results were very encouraging. Elements were clearly separated with a resolution of < 0.25 e, thus validating our earlier Monte-Carlo simulations. Nonetheless, the background remains significant. The primary source of the background events is ions passing through or stopping in dead material, one particular source being the rings on the circular—as opposed to oval—inclined detectors. The test model used for this first test was developed for maximum flexibility: for example, the structure supporting the detectors was complex so the detectors could be rotated and this added undesirable dead material to the instrument (see Figure 1 right). Our next objective is to further develop and test a more advanced prototype in a near-flight configuration to demonstrate the full capabilities of an ADIS instrument. The most critical improvement in the new prototype will be the oval D2-3 detectors mounted at a fixed angle of 30° of inclination. The new prototype will also have a minimum of dead material, resulting in a much reduced level of background. As in our previous beam runs, the instrument will be tested at varying angles to simulate the isotropic radiation, and a degrader will vary the energy.

Despite the substantial amount of dead material in the test instrument, the accelerator data to date shows exceptional charge resolution for so simple an instrument. An instrument providing data of this quality is attractive for many space applications even without the improvements in background to be expected in future instruments. Our prototype testing is of particular importance in both raising the Technology Readiness Level (TRL) and mitigating risk for ADIS-based instruments for future flight opportunities.

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References

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