The Response of Particle Detectors to Gold Nuclei at 11 GeV/nucleon

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ABSTRACT

A set of particle detectors has been exposed to beams of $_{79}$Au nuclei at $\sim$ 11 GeV/nucleon from the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL). We report preliminary results on the responses obtained from silicon solid state detectors and from Cerenkov counters utilizing total internal reflection with waveshifter bars for readout.

INTRODUCTION

An important future objective in cosmic ray astrophysics is the precise determination of the relative abundances of individual ultraheavy (UH, $Z > 28$) elements. The measurement of the heaviest of these rare, UH species at multi-GeV energies is very demanding in terms of sensor area, charge resolution, and energy determination capability. We investigated the response of several sensor types to high energy UH nuclei in a run at the BNL / AGS accelerator in January 1997 in order to better understand the capabilities and limitations of available radiation detectors.

SILICON SOLID STATE DETECTORS

We tested a stack of six ion-implanted silicon detectors having active areas of 65 cm^2 and thicknesses ranging from 250 to 1000 μm (Dougherty et al. 1996). The beam spot measured at the detectors had a diameter of approximately 1.5 cm and the beam rate was kept low ($\lesssim 10^3$/sec) to avoid pulse pile-up effects.

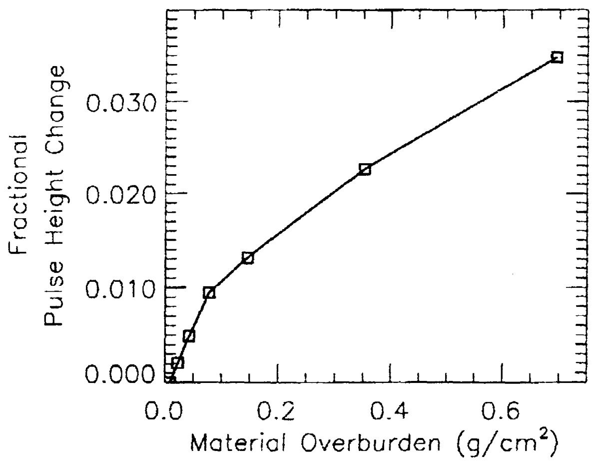

Fig. 1: Dependence of measured pulse height on amount of aluminum in front of detector. The uncertainties on the data points are smaller than the symbols that are plotted.

A fast heavy nucleus passing through matter produces a spectrum of knock-on electrons which extends to quite high energies. For example, at 11 GeV/nucleon, knock-ons can be produced up to a kinematic limit of 167 MeV. Since the higher energy electrons are very penetrating, knock-ons produced in material in front of a detector contribute to the detector's pulse height, and some of those produced in the detector escape without depositing all their energy. Knock-ons can have important effects on both a detector's mean pulse height and on pulse height fluctuations. Figure 1 shows how pulse heights measured in the front Si detector (250 μm thick) changed in a series of runs in which various thicknesses of aluminum were placed immediately in front of this detector. We have not attempted to make a correction for

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the effective thickness of air which contributes to the material overburden and alters the reference signal used for calculating pulse height changes. Note that the difference in pulse heights between adjacent elements near $_{79}$Au is 2.5%, comparable to the effect of having 1 mm of aluminum in front of the detectors. To obtain element separation, it is essential that the overlying material be kept rather uniform.

Epstein et al. (1971) derived an approximate formula for the fluctuation in the energy deposited by a heavy nucleus in a detector when one takes into account energy carried into and out of the detector by knock-on electrons. These energy *deposit* fluctuations can be appreciably less than the fluctuations in the energy *lost* by the nucleus because the latter quantity has a sizable contribution from energy transfers to high energy knock-ons, which play a lesser role in the energy deposition since they can escape from the detector volume. For an 11 GeV/nucleon $_{79}$Au nucleus passing through 250 μm of Si, the Epstein et al. formula predicts rms fluctuations which range from 4.05 MeV when there is negligible overlying material to 7.12 MeV when there is thick enough overburden to bring the knock-on production and absorption into equilibrium. Using the front Si detector with minimum material in front we find pulse height resolution $\sigma = 5.23$ MeV, which corresponds to the Epstein et al. prediction for an overburden of 0.28 g/cm^2. The agreement appears reasonable, given the uncertainty in the effective thickness of air contributing to the knock-on signals.

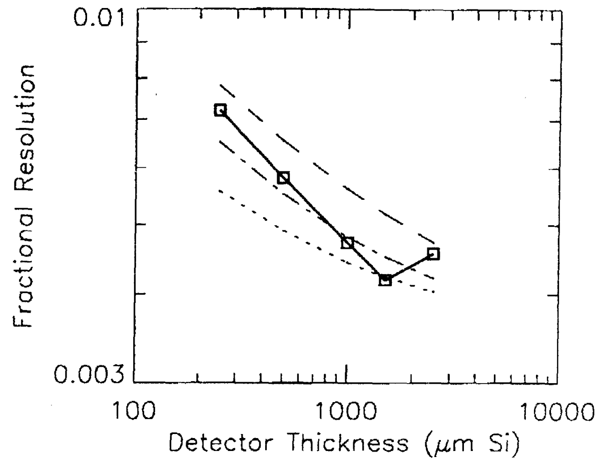

Fig. 2: Dependence of relative rms pulse height resolution on detector thickness. Calculated curves assume different amounts of overlying material: dotted - none; dash-dot - 0.07 g/cm^2 Al; dashed - 0.7 g/cm^2 Al. The uncertainties on the data points are smaller than the symbols that are plotted.

By summing pulse heights measured in successive Si detectors starting at the front of the stack we investigated the dependence of the pulse height resolution on the detector thickness, in the range 250 to 2500 μm. The results are shown in Figure 2 (points connected by solid a line). At low energies where knock-on effects are unimportant one expects $\sigma_P/P \propto L^{-0.5}$, where P is the pulse height and L is the detector thickness. The measurements shown in Figure 2 have $\sigma_P/P \propto L^{-0.3}$ for $L < 1500\,\mu$m. The other curves are calculated following Epstein et al. (1971) assuming different thicknesses of overlying material (see figure caption). The calculations suggest a weaker dependence of the pulse height resolution on detector thickness than found from our data.

To investigate the charge resolution obtainable for a monoenergetic beam at a fixed angle of incidence, we used a 2.5 cm thick aluminum target to fragment a portion of the $_{79}$Au nuclei. The target was placed well upstream ($\sim$ 10 m) from the detectors in an attempt to minimize contributions of knock-ons produced in the target to the signals measured in the detectors. For each detector we obtain a charge estimate from the square root of the measured pulse height, scaled to give a charge of 79 for the $_{79}$Au peak. Figure 3 shows the charge histogram obtained by averaging the measurements from the front two Si detectors (each 250 μm thick). The charge resolution obtained for the $_{79}$Au peak is 0.226 charge units, sufficient for measuring adjacent elements differing by an order of magnitude in abundance, as shown by the $_{78}$Pt peak.

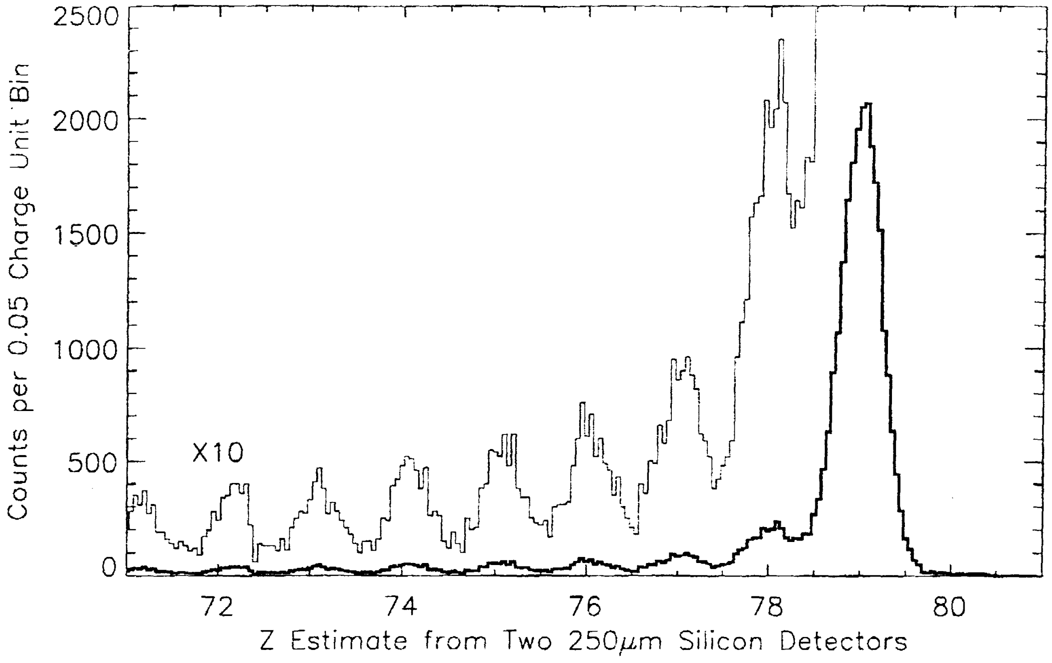

Fig. 3: Charge histogram obtained using two 250 μm thick silicon detectors. The light line shows the region below $_{79}$*Au with the vertical scale expanded by a factor of 10.*

CERENKOV COUNTERS

Cerenkov detectors are commonly used in conjunction with dE/dx sensors to measure particle charge and velocity. The Cerenkov detectors employed for such applications often use light-integrating boxes because they can provide uniform light collection. However, in space applications where mass and volume are often severely constrained, it would be advantageous to have Cerenkov counters which do not require large light-integrating boxes.

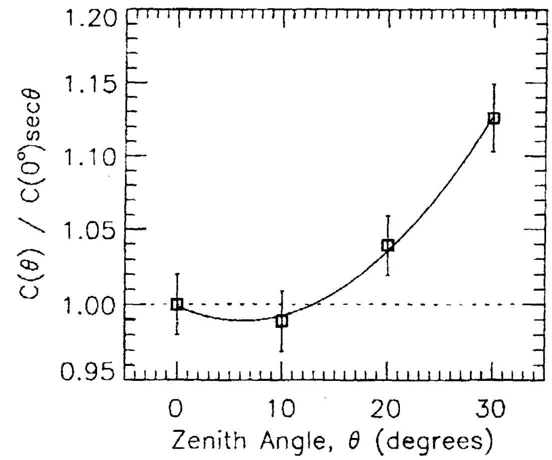

Fig. 4: Relative Cerenkov signal, corrected for pathlength, as a function of angle of incidence for 11 GeV/nucleon $_{79}$*Au. The error bars shown are dominated by systematics.*

We have undertaken investigations of one concept for such a detector. In this device, waveshifting dyes are incorporated in a standard Cerenkov radiator, such as Pilot-425, to isotropize a portion of the highly directional Cerenkov radiation. A fraction of this isotropized light then undergoes total internal reflection (TIR) and is transported to the edges of the radiator where some of it escapes. A waveshifting bar absorbs this light and re-emits a portion of it to photo-detectors at the ends of the bar. In practice, a fraction of the primary, directional Cerenkov radiation is not absorbed by the waveshifting dyes, but instead propagates to the edge of the radiator along with the isotropized light. The fraction of this primary Cerenkov radiation reaching the waveshifter bars is dependent on a complicated function of the trajectory and velocity of the incident particle. By optimizing the dyes used in the radiator and waveshifter bar one can decrease the amount of directional light included in the measured signals.

To test this concept we constructed a Cerenkov detector using a BC-480 radiator of dimensions 60 cm × 60 cm × 1.27 cm viewed by a 1.27 cm × 1.27 cm cross-section BC-482a waveshifting bar at each edge of the radiator. The waveshifting bars were readout with one Phillips XP2971 green-extended photomultiplier tube per bar. The full detector was enclosed in a white housing. We exposed this detector to the same 11 GeV/nucleon $_{79}$Au beams used for the silicon detector tests discussed above. During the test the detector was oriented at four angles with respect to the beam direction: 0°, 10°, 20°, and 30°. In Figure 4 we plot the results of this test, normalized to the 0° measurement and corrected for pathlength. If there were no directionality in the detected light one would expect all the plotted values to be 1.0, corresponding to signals which only vary due to pathlength changes. We see that this is not true for the larger angles of incidence. The excess light at large angles is attributed to the non-isotropized primary Cerenkov radiation. For a non-waveshifting TIR Cerenkov counter the variation in light collection over similar angles at this energy is $\sim 35\%$ (Mewaldt 1971), as compared to 12% for this detector. In addition, non-waveshifting TIR counters have stronger energy dependence than the waveshifting counter described here.

CONCLUSIONS

Our results indicate that high resolution measurements of UH cosmic ray abundances are possible using the ionization signals measured in silicon solid state detectors, together with Cerenkov counter and hodoscope measurements to provide particle energy and trajectory. A realistic configuration might use a mosaic containing two layers of 300 μm silicon detectors, with individual detectors having active areas $\sim 100\,\mathrm{cm}^2$. Among the questions still requiring study are: 1) Do measured pulse heights have a significant dependence on particle's distance from the detector edge where knock-ons will be more likely to escape detection? 2) How does the dependence of pulse heights on the angle of incidence differ from the simple $\sec\theta$ variation of the penetrated detector thickness? 3) Can one realize a significant improvement in pulse height resolution if layers of Si detectors are separated by enough (uniform) material to remove correlations between the knock-on signals they detect? 4) How much can one further reduce the directional component of the signal in waveshifted TIR Cerenkov counters through the use of alternative dyes? 5) How do the photoelectron yields from TIR Cerenkov counters compare with those obtained using light integrating boxes, and are they sufficient for resolving individual charges?

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