Experience of Application of Silicon Matrix as a Charge Detector in the ATIC Experiment

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Abstract

The ATIC (Advanced Thin Ionization Calorimeter) Experiment has had two successful balloon flights in Antarctica from 28 Dec 2000 to 13 Jan 2001 (ATIC-1) and from 29 Dec 2002 to 18 Jan 2003 (ATIC-2). The instrument is intended to measure composition for elements from hydrogen to iron and energy spectra from 30 GeV to near 100 TeV. When calorimeter is used for energy measurements, a problem of charge determination arises due to backscatter particles from the calorimeter. In the ATIC experiment, a finely segmented silicon matrix is used as a charge detector to solve this problem. To provide elemental charge resolution, careful calibration of each pixel is required. Different methods of calibration of the silicon matrix of the ATIC-1 experiment are described, and the resulting charge resolution is presented.

1. Calibration of silicon pixels

ATIC contains a fully active BGO calorimeter, a carbon interaction target, a scintillator hodoscope and a silicon matrix that is used as a charge detector in the experiment. The silicon matrix was built from 4480 individual silicon pixels each 2 cm × 1.5 cm. The design of the ATIC instrument and of the silicom matrix are described in [1,2,3]. To obtain a good charge resolution in the silicon matrix, it is necessary to bring the signals measured in each pixel to a common scale, i.e. to correct different gains in different electronic channels. At a first step, the correction was made using the pre-flight muon calibration. However, the muon calibration had poor statistics in each pixel. The number of events were sufficient

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to resolve protons and He nuclei, but were insufficient for the heavy nuclei. The charge resolution for protons and He nuclei is presented in accompanied paper [5].

To improve the resolution for the heavy nuclei, a correction was done using the in-flight Helium peak in each pixel [4]. This 'helium calibration' assumed that two conditions were fulfilled: 1) the Si-matrix electronics were stable during the entire flight and 2) the pulse characteristics of all electronic channels were linear. The analysis of the flight data showed very high stability of the operation of electronics during the entire flight. The second condition appeared not to be met: both laboratory and in-flight measurements showed small non-linearities, which were different for different channels. During the entire flight two types of calibration runs were performed periodically. One of them - measurement of individual channel pedestals - was done every six minutes in the aim of automatic correction of sparsification thresholds and were stored for further data correction. Second type of calibration was performed every hour and was also stored for post-flight data analysis. This latter calibration contained the full amplitude calibration of each channel using a set of 27 test pulse amplitude settings from 0.3 mip up to 1700 mip. Significant non-linearity of pulse characteristics of CR-1 chips (16-channel amplifiers used for reading out signals from silicon detectors) exists only for pulses higher than 300 mip (>10000 ADC channels), that is why the flight data were processed both in the linear approximation and using the full procedure taking into account the non-linearity. The detailed procedures for the calibration will be published elsewhere.

2. Results and Analysis

The results on charge distribution obtained with the full correction method are shown in Fig.1. The resolution obtained for different methods of charge measurement correction in the silicon matrix is compared in Table 1, which gives the width σ of Gaussian distribution in charge units. For calculations of σ values, the fact was used that the silicon matrix was designed with overlapping of silicon pixels. For vertical direction this overlapping is of 20% of the area. The events were selected in which maximal signal in the search area was followed by a signal in an overlapping pixel. The value of σ was estimated from distribution of difference of these two signals. We can make the following conclusions from Table 1: a) in the region of middle nuclei all three methods lead to the same results and b) for nuclei heavier than oxygen taking into account non-linearity of the pulse characteristics of the electronic channels leads to the significant improvement of charge resolution (especially for iron nuclei). The initial calculations for bare silicon pixels gave an expected performance of $\sigma = 0.23$, essentially independent of charge. Such a value would allow practically full separation of neighboring elements. However, in the ATIC silicon matrix, a printed circuit board is located immidiately above and below each pixel. The presence of this material can intro-

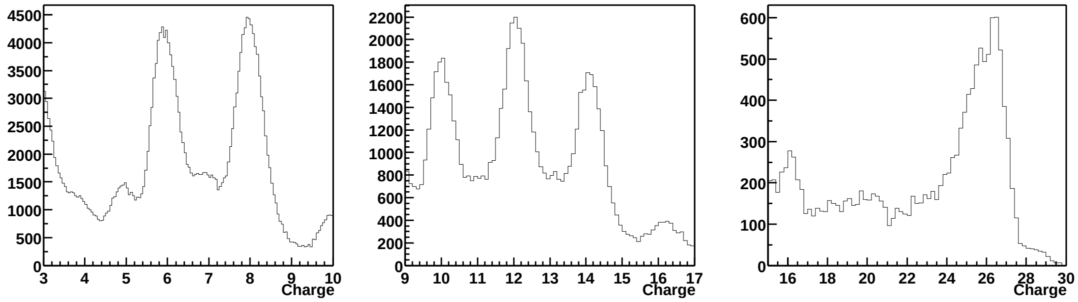

Fig. 1. Charge resolution of Si matrix; left panel: $3 < Z < 10$, middle panel: $9 < Z < 17$, right panel: $15 < Z < 30$

Table 1. The value of σ in charge units for three methods of calibration

	C	O	Ne	Mg	Si	Fe
Helium calibration	0.32	0.33	0.44	0.41	0.49	
Linear calibration	0.30	0.31	0.37	0.39	0.39	0.59
Non-linear calibration	0.32	0.31	0.32	0.36	0.37	0.47

duce additional fluctuations into the energy deposited in the silicon pixels. We have simulated this situation with 2 mm layers of fiberglass placed around the pixel and obtained an expected σ of 0.32, consistent with the results in Table 1 through Neon. For still heavier nuclei, the additional width may be connected to insufficient accuracy in taking account of the non-linear effects. For iron group it may be necessary to take into account the dispersion of silicon pixel thickness also. It might be performed using the position of Fe peak for the relativistic nuclei, but the available statistics is not enough yet.

3. Charge resolution of double layer Si matrix

For events which were detected in the overlapping areas of the pixels we were able to obtain charge resolution in 'double-layer matrix'. By requiring charge consistency in both pixels a more accurate measurement of the incident particle charge can be obtained. The charge resolution obtained for the double layer matrix is shown in Fig.2. Statistics in the double layer matrix is about 12% of the total statistics. One can see that good resolution of all neighboring elements has been achieved in this case.

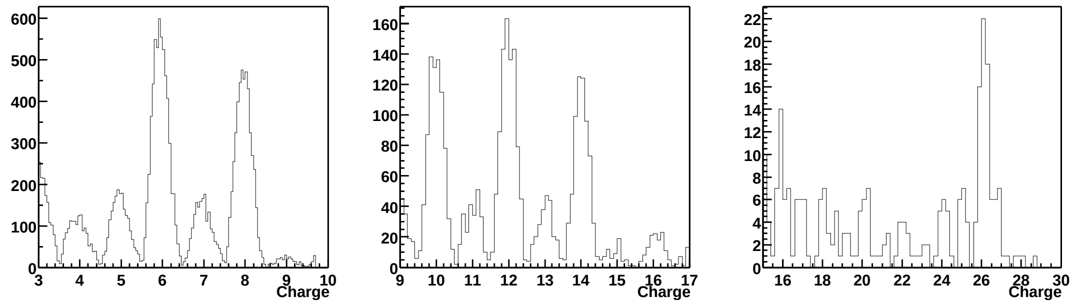

Fig. 2. Charge resolution of double layer Si matrix; left panel: $3 < Z < 10$, middle panel: $9 < Z < 17$, right panel: $15 < Z < 30$

4. Conclusion

The analysis of charge resolution obtained in the silicon matrix in the first flight of the ATIC spectrometer showed the following:

1. Even nuclei (C, O, Ne, Mg, Si, S and Fe) produce clearly visible peaks on the charge spectrum.

2. The existence of constructive material immediately above silicon pixels did not allow full elemental separation for medium nuclei.

3. The application of a silicon matrix with two layers of silicon detectors apparently will provide practically complete elemental resolution in the total charge range.

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6. References

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