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The spatial resolution of the silicon tracker of the Alpha Magnetic Spectrometer

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A B S T R A C T

The Alpha Magnetic Spectrometer (AMS) is a high energy physics experiment operating aboard the International Space Station (ISS) since May 2011. So far more than 100 billion of charged cosmic ray events have been collected by AMS. The AMS silicon tracker, together with the magnet, measures the rigidity (momentum/charge) of cosmic rays in the range from ∼0.5 GV to several TV. To accurately determine the trajectory of charged particles, a novel tracker position reconstruction method has been developed. In the paper, the details of the method and the obtained tracker spatial resolution for nuclei with charge $2 \leq Z \leq 26$ are presented.

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1. Introduction

The AMS is a multi-purpose experiment which aims to precisely measure the rigidity spectra of cosmic rays up to several TV and to search for dark matter and antimatter in the Universe. Installed in May 2011, AMS is expected to operate through the life time of the ISS to at least 2024.

The layout of the AMS detector is shown in Fig. 1. It consists of a silicon tracker (Tracker) [1], a 0.14 T permanent magnet [2], 4 layers of time of flight counters (TOF) [3], a transition radiation detector (TRD) [4], an array of anti-coincidence counters (ACC) [5], a ring imaging Cherenkov detector (RICH) [6], and a 17 radiation lengths thick electromagnetic calorimeter (ECAL) [7]. A detailed description of the AMS detector is presented in Ref. [8].

The tracker is designed to precisely measure positions and ionization losses of particles and nuclei with charge $1 \leq Z \leq 30$. To obtain good position resolution for $Z = 1$ particles while accommodating the measurement of highly charged nuclei, a nonlinear electronics response was implemented. Therefore, a special position finding algorithm together with a linearization procedure is required to fully exploit the potential of the detector.

2. The silicon tracker

The tracker is composed of 2284 double-sided silicon micro-strip sensors, with dimensions $41.360 \times 72.045 \times 0.300$ mm^3, assembled in mechanical and electrical units called ladders. Each ladder is composed of 9 to 15 sensors. With a total of 192 ladders, the active area is 6.42 m^2. Both sides of a sensor are implanted with metallic strips running in orthogonal directions, providing the three dimensional measurement of the particle's position. The p side is composed of p+ doped strips, for an implantation (readout) pitch of 27.5 (110) μm; the opposite n side has an implantation (readout) pitch of 104 (208) μm [9]. The p side strips provide the measurement of the particle bending coordinate y.

From 16 to 26 ladders are assembled into each of the 9 layers. The first layer (L1) at the top of the detector, the second (L2) just above the magnet, six (L3 to L8) within the bore of the magnet, and the last (L9) just above the ECAL. L2 to L8 constitute the inner tracker. The maximum lever arm from L1 to L9 is about 3 m. There are two important tracker geometrical acceptances being used for proton and nuclei measurements: (a) full span acceptance with events passing through L1 to L9, (b) the wider L1 inner acceptance with events passing through L1 to L8. With a spatial resolution in each layer of ∼5 μm ($Z = 6$, from this work) in bending direction, the maximum detectable rigidity (MDR) of the full span sample is ∼3.7 TV and of the L1 inner sample is ∼1.3 TV.

The readout strips of the silicon sensors are AC-coupled via 700 pF capacitor to the low noise, high dynamic range front-end chips (VA Hdr9A) [10]. The amplified signals from the 196 608 readout channels are transmitted to the Tracker Data Reduction (TDR) board and then

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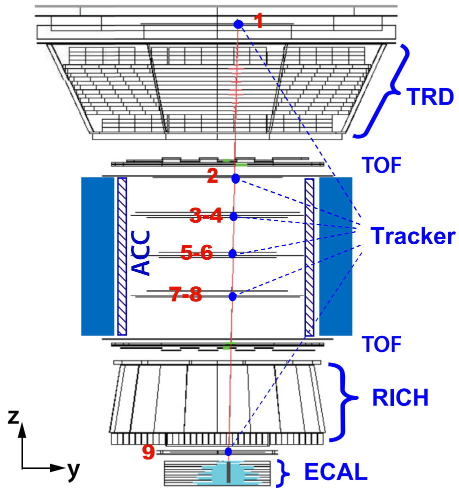

Fig. 1. The reconstruction of a 369 GeV positron event measured by AMS, with the signals in TRD, TOF, tracker, RICH and ECAL. Also shown are permanent magnet and ACC.

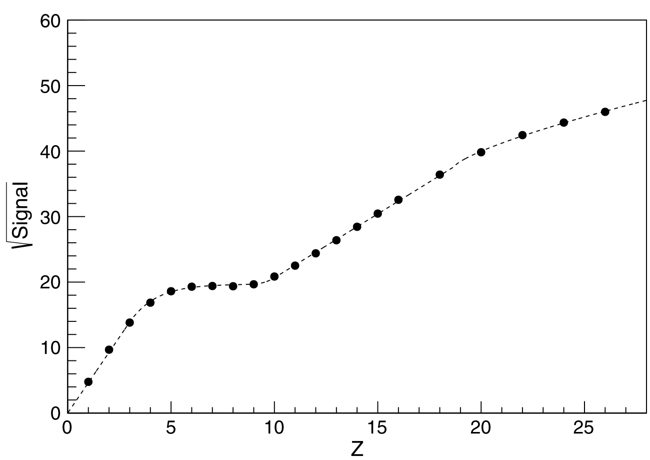

Fig. 2. The square root of the amplitude measured by the seed strip, versus the nuclei charge Z.

are digitized by 576 12-bit ADCs. The ADC signal contains the pedestal, the VA common noise (subtracted on event-by-event basis), the strip noise and an eventual signal. On the TDR board, calibration parameters and zero-suppression algorithms are executed on the digitized signals. Typical in-flight values of the pedestal and strip noise are 390 ADC and 2.5 ADC channels for the p side [11]. With a signal ∼20 ADC channels for $Z = 1$ seed strip (the highest amplitude strip in a cluster), the position resolution of ∼13 μm in bending direction is achieved. To accommodate signal response up to $Z = 26$ within the ADC dynamic range, the VA response was adjusted to have the linear region $1 \leq Z \leq 3$; followed by the nonlinear region $4 \leq Z \leq 9$; again the linear region $10 \leq Z \leq 18$; and then the nonlinear region $Z \geq 19$ (see Fig. 2).

3. Position finding algorithms

For silicon microstrip detectors, the particle position is usually reconstructed from several high amplitude adjacent strips. To obtain the particle impact position, different position finding algorithm (PFA) may be used. A detailed description of commonly used PFAs can be found in Ref. [12]. The few relevant algorithms for the AMS tracker are:

1. Center-Of-Gravity (COG) algorithm: The cluster position is reconstructed by the average of n strips positions weighted with signal amplitudes:

$$X_{\mathrm{COG}} = \frac{\sum_{i=1}^{n} A_i x_i}{\sum_{i=1}^{n} A_i} \quad (1)$$

where x_i is the position of ith strip and A_i is the signal amplitude on that strip.

2. Linear algorithm: It is a special case of the COG algorithm that only uses 2 neighboring highest signal amplitudes strips to reconstruct the position:

$$X_{\mathrm{LIN}} = \frac{A_L x_L + A_R x_R}{A_L + A_R} \quad (2)$$

where $x_{R(L)}$ is the position of right(left) strip and $A_{R(L)}$ is the signal on that strip. This algorithm is fairly important for the AMS tracker, because the charge carriers produced by the particle ionization mostly spread over the two adjacent strips. In this algorithm, the measured position can be expressed in another form as

$$X_{\mathrm{LIN}} = x_L + P\eta \quad (3)$$

where P is the read-out pitch size, and variable η is defined by

$$\eta = \frac{A_L}{A_L + A_R} \quad (4)$$

3. Nonlinear η algorithm: In the Nonlinear η algorithm [13], η is no longer expected to be linear function of the particle impact point position x. The Eq. (3) therefore has to be modified as

$$X_\eta = x_L + P f(\eta) \quad (5)$$

where $f(\eta)$ is a monotonic ($df/d\eta > 0$) function of η, with $f(0) = 0$ and $f(1) = 1$. In the next section, we will discuss this algorithm in more detail.

4. The causes of the nonlinearity

Assuming cosmic rays uniformly hit the tracker, the position distribution reconstructed by Eq. (3) is expected to reproduce this feature. However, many physical sources of nonlinearity will break it down.

Firstly, the charge division between the two strips is far from being linear, as a result of the diffusion mechanism of charge carriers [13]. For example, for normal incident particles, η distribution will reveal two peaks around $\eta = 0$ and $\eta = 1$. The flatness of η distribution can be improved if intermediate strips are present [12]. For AMS tracker p side, there are 3 intermediate strips located between the 2 readout strips. The AMS tracker p side η distribution for helium nuclei with small inclination angles is shown in Fig. 3(a). It has three small peaks around intermediate strips $\eta = 1/4$, $\eta = 1/2$ and $\eta = 3/4$. Moreover, η distribution is also affected by the capacitive and diffusion couplings [12], which shrink the η distribution to the center and leave two margins at $\eta = 0$ and $\eta = 1$.

Secondly, particularly for nuclei with higher charge, the η linearity can be distorted by the nonlinear behavior of the readout electronics (preamplifiers). This is essentially the case of the AMS tracker p side, as shown for carbon, in Fig. 3(b).

5. AMS position finding algorithm

To deal with all possible sources of nonlinearity, we will utilize the uniformity of the particle impact position distribution, which is expected as cosmic rays uniformly hit the tracker.

The reconstructed position can be linearized and obtained by Eq. (5) with $f(\eta)$ calculated as [13]

$$f(\eta) = \int_0^\eta \frac{dN}{d\eta} d\eta \Big/ \int_0^1 \frac{dN}{d\eta} d\eta \quad (6)$$

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