AMS-02 Track reconstruction and rigidity measurement

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Abstract: The Alpha Magnetic Spectrometer 02 is a particle detector taking data on the International Space Station since May 19th 2011. A key element of AMS-02 is the Silicon Tracker that allows to determine the trajectory of the charged cosmic rays passing through the AMS-02 magnetic field. In this contribution, we discuss the procedures that from the tracker raw signals allow to reconstruct a full particle trajectory. We discuss how different fitting procedures achieve the best rigidity measurement accuracy in different intervals and we present the overall performance in the rigidity measurement for protons and helium nuclei. Finally we present a technique to reduce the charge confusion.

Keywords: AMS, silicon tracker, resolution

1 Introduction

The Alpha Magnetic Spectrometer 02 is a particle detector devoted to the measurement of the charge and neutral Cosmic Ray fluxes. AMS-02 is taking data on the International Space Station since May 19th 2011 and it is foreseen to continue for the whole life of the ISS.

The main Physics goals of AMS-02 are the search for Dark Matter signatures, the search for primordial Anti-Matter, the accurate measurement of nuclei fluxes from H to Fe and the search for signals of new physics. Given the AMS-02 large acceptance and the long duration of the mission, AMS-02 measurement will provide an accurate description of the influence of the solar activity on the cosmic rays fluxes.

As depicted in fig.1 at the core of AMS-02 there is a permanent magnet of hollow cylinder shape that provides a transverse field of $\sim$ 1.4 kG. Nine layers of silicon detectors are placed along the particle trajectory. Two layers of plastic scintillators oriented in orthogonal directions are placed above the magnet and two similar ones below. This scintillators system called Time of Flight detector (ToF), provides the trigger to the experiment, determines if a particle is crossing the magnet with upward or downward direction and measures accurately the relativistic beta with $\sim 1\%$ resolution. An additional set of scintillators covering inner circular part of the magnet acts as a veto system against particles crossing the detector sideways.

In the top part of AMS a Transition Radiation Detector (TRD) provides particle identification with best performance in separating $e^{\pm}$ from protons, it also provides tracking with a resolution for the order 0.4 *mm*.

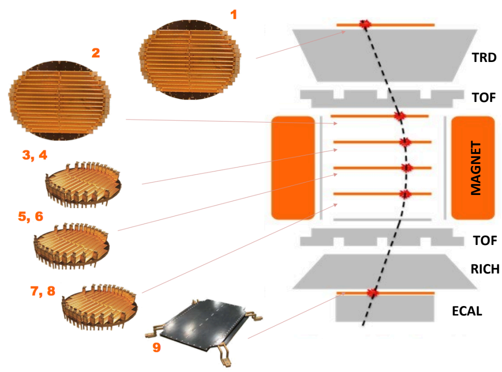

Fig. 1: Schematic view of the AMS-02 detector. With pictures of the Silicon tracker layers from 1 to 9.

In the lower part, a Ring Image Cherenkov detector (RICH) provides high precision relativistic beta measurement (0.1% $Z=1$, 0.06% $Z>5$) and particle charge identification up to *Fe*. At the bottom a lead-scintillating fibers Electromagnetic Calorimeter (ECAL) of 17 radiation lengths provides accurate energy measurement for $e^{\pm}$ and powerful particle identification [2].

More details on the subdetectors can be found in[1].

2 The Silicon Tracker

The AMS silicon tracker is made of 2284 double sided microstrip silicon wafers of size $\sim$ 72 x 41 x 0.3 mm^3.

The microstrip implantation(readout) pitch is 27.5(110) and 104(208) μm respectively for the bending(Y) and and non-bending(X) projections.

Silicon wafers are arranged in mechanical and electrical units called ladders. Each ladder consists of a support structure and a linear arrangement of 9 to 15 sensors. Ladders are placed on support planes to cover the AMS acceptance at various heights in the detector. As also depicted in fig.1 the Silicon Tracker is made of 9 layers covering the full span of the AMS detector. Three support planes each equipped with ladders on both sides are placed inside the magnet bore, another support plane holding a single layer of silicon detectors is placed at the top end of the magnet. Two additional single layer planes are placed on top of the TRD and the ECAL to get the largest lever arm in measuring the particle rigidity. Collectively layers from 2 to 8 are referred as the inner tracker.

The Tracker spatial resolution for charge Z=1 particles is ~10(30) μm in the bending (non-bending) projection[3]. Once determined with the ToF if the particle is going upward or downward, the deflection measurement in the tracker provides the rigidity and the charge sign of the particle while the multiple measurements of the energy deposition in the silicon provide the absolute value of the charge.

3 Reconstruction procedures

Tracker raw data are grouped by the tracker mechanical/electrical units (ladders) and they contains sets of contiguous readout channels with signals above threshold, called Raw Clusters. The final goal of the tracker reconstruction is to provide the particle trajectory in AMS allowing to: determine the particle rigidity from the curvature, associate the signals from the other detectors, determine the particle charge by the energy deposition in the silicon and find the particle charge sign by the sign of the curvature.

The on board algorithms are optimized to provide the best data reduction but not a detailed signal clusterization, Raw Clusters must be processed to search for double peak structure or combined when made of peakless contiguous readout channels. The new clusters resulting from this operation, called TrClusters, represent the most basic information from the silicon tracker. Depending on the readout channels range a TrCluster represents an energy deposition in the bending(Y) or not bending(X) coordinate.

While the 640 Y readout channels correspond to unique position along the ladder Y coordinate, the 384 X readout channels cover just two silicon sensors[1]. By means of a printed kapton cable X readout channels of the first two sensors are connected with those of the next two sensors and this scheme continues so to cover all the sensors in a ladder. Being the ladders made of 9 to 15 sensors the X measurement present a 4 to 8 fold ambiguity in the measured coordinate.

The coordinate of passage of the particle is estimated by the center of gravity of the cluster signals. Test beam studies[3] have shown that for vertical tracks the best spatial resolution is obtained with center of gravity calculated with the highest strip of the cluster and its highest first neighbor. When the inclination of the incoming particle is larger than 20° (Y) or 35° (X), the algorithm is adjusted to make use of three strips. The incoming particle angle however is known only for clusters associated to a track.

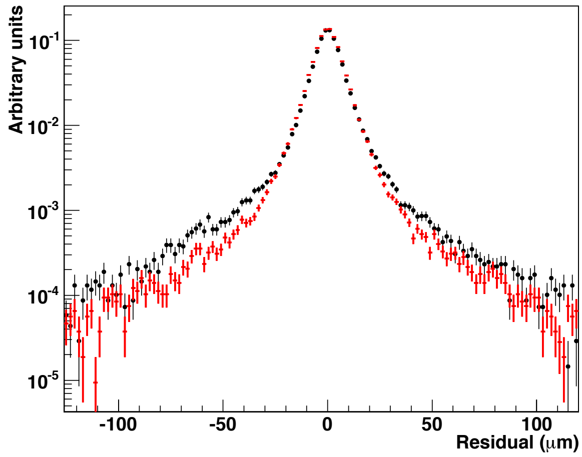

Fig. 2: Helium tracks fit residual on bending coordinate (Y) for inner layers. Black points ISS data, red points Monte Carlo simulation.

The total signal of the cluster is related to energy deposited by ionization in the silicon. Once properly corrected for the readout chip gain, the estimated point of passage of the particle in the inter strip gap and the track inclination, this signal can be used to determine the absolute charge of incoming particle [5] and to correlate X and Y side clusters. Correlated X and Y clusters are combined into a tracker reconstructed hit (TrRecHit).

By means of a data base containing the position and the orientation of each ladder in the AMS-02 master reference frame as well as the alignment corrections, a TrRecHit represent a tridimensional determination of the point of passage of a particle in AMS.

The correlation between X and Y side clusters is very effective for particle charges $Z \geq 2$, since the typical signal is well above the noise. For single charge particle a more conservative approach must be followed. The same Y clusters is matched to different X clusters discarding only the least probable (signal-wise) pairs. Furthermore since the X side appears to be less efficient, TrRecHits made of just a Y cluster are also produced. When a TrRecHit is associated to a track, other hits using the same TrClusters are purged from the TrRecHit list.

In AMS-02 typically just one particle per trigger is crossing the detector and even in the most complex cases just an handful of particles must be considered. Despite this apparent simplicity track finding in AMS-02 can be challenging since clusters from a single charge particle have a similar signals as the noise ones. Given the size of the AMS-02 silicon tracker and the large number of readout channels ($\sim 196k$) the typical number of clusters per event is 100 while a track is supposed to have at most 18 (9 layers times 2 sides). A brute force approach to track finding, although effective, is computationally heavy and almost unbearable for events with a large number of hits.

Our optimized procedure relies on the tracker geometry to reduce the complexity of the problem. It starts searching for a track in the innermost part of the tracker, namely layers

1. Ladders on layers 1 2 and 9 present a different routing of the X readout channels and in this case 384 readout channels cover less than two sensors.

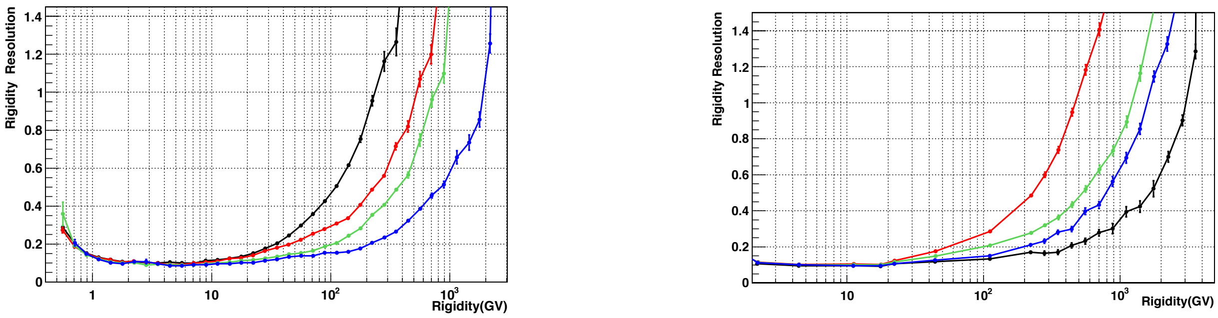

Fig. 3: Tracker rigidity resolution for protons(left) and Helium(right) as estimated from the Monte Carlo simulation. The four curves represent the tracker different spans. Black open circles: inner tracker, red full squares: layer1, green open squares: layer9 and blue full circles: layers 1 and 9.

from 3 to 8 and on the first step the search is performed on Y clusters only. A straight track is built using two clusters, the first chosen either on layer 3 or 4, the second on either layer 7 or 8. If a cluster on layers 5 or 6 is found within a road centered on this track, a circular fit[7] is performed to verify if the three hits are compatible with a curved track. The spatial arrangement of the tracker ladders, placed either on the positive or negative X semi-planes, allows discarding impossible combinations.

Once a Y projection track candidate is found, the same candidate is examined in terms of tridimensional hits. All the allowed combinations compatible with a linear fit of the X clusters are built, allowing also Y only tridimensional hit with the X coordinate coming from the track model. All these new track candidates are fitted on both projections (linear and path integral fits) and the one with the best χ^2 is selected.

If the track contains at least four 3D hits and there is at least one hit for each pair of inner layers (3-4, 5-6, 7-8) the track candidate is accepted.

As a consequence of the X side ambiguity the reconstructed track may be offset on X by a multiple of the size of two sensors (82 *mm*). A match in the Y projection with a TRD track, or if not available with a TOF cluster, is then searched. If a well matching track on the Y projection is not matching on the X one, all the other possible X positions of the track are tested and the one with the best matching is chosen.

As discussed elsewhere in these proceedings[4] the efficiency of the track finding is larger than 90%.

The last step consist in the extension of the track to the external layers on top of the TRD and in front of the ECAL. If the track extrapolation to the external layers falls close enough to a TrRecHit, the track is extended to include this hit. In order to account for the effects of the multiple scattering, the maximal distance allowed for the matching is a function of the measured inner rigidity.

In general four types of tracks can be individuated:

- inner: no hits on the external layers
- L1: hit on layer 1 and no hit on layer 9
- L9: hit on layer 9 and no hit on layer 1
- L19: hits on layer 1 and on layer 9

Tracker geometrical acceptance, obtained including only the passage of the particle through the active silicon so to generate the required hits to reconstruct a track, has been calculated with a simplified simulation. It results $\sim 0.50\,m^2 sr.$ for the inner tracker. When considering L1 or L9 tracks the acceptance reduces.

4 Rigidity Measurement

Rigidity measurements in AMS is obtained by the track trajectory fit in the magnetic field. Three algorithms are currently used for this purpose: two different implementation of a path integral fit with treatment of the multiple scattering[8] and an implementation of a Monte Carlo based fit adapted from[9].

The two implementations of the path integral fit differs because the first one (named A) performs path integral approximation along lines connected between measured points, while the second (named C) performs path integral calculation along the expected trajectory with Runge-Kutta tracking.

The actual advantage of having these two methods is the possibility to compare the results. The case of significant differences between the results of the two fit is typically a signature of some bad reconstruction. For example he track may contain foreign or bad hits.

The third method, (named K) aims to improve the rigidity estimation when the multiple scattering and the energy loss are playing a relevant role. The algorithm includes a simplified description of the AMS materials and reconstruct track's kinematical parameters with full non diagonal covariance matrix due to multiple scattering in the silicon tracker planes as well in TRD, TOF and RICH. The K method results to provide a slightly better momentum resolution with respect the A and C methods in the rigidity range below 40 GV.

Rigidity resolution can be estimated from the Monte Carlo simulation once the point resolution and the effects of the residual misalignment are correctly simulated.

The tracker digitization model included in the AMS-02 Monte Carlo simulation has been tuned against the ISS data in order to reproduce the tracker point resolution for protons and Helia and also the effects of residual static misalignment have been included Fig.2 shows the Y residuals on the inner tracker layers for vertical Helium tracks. In black as measured on ISS and in red as simulated. Apart a slightly smaller tail population in the simulation there is a very good agreement between the two distributions. Similar agreement for both protons and Helia is observed on X and Y projections and for different track inclinations.

External layers need a time dependent (or dynamic) alignment[6], an additional smearing is then required to account for the residual (dynamic) misalignment. For this study a minimal approach has been chosen and we simply added a smearing following the data (see [6]).

The rigidity resolution for proton and helia is presented in fig. 3. The four curves correspond to the four track spans: inner, L1, L9 and L19. It is evident that larger spans correspond to smaller relative error at high rigidity.

In particular the 100% relative error is reached for a rigidity[2]:

	Inner	L1	L9	L19
p	240 GV	540 GV	750 GV	2000 GV
He	400 GV	1100 GV	1600 GV	3200 GV

These estimations are affected by a 10% error.

5 Charge confusion

Charge confusion, i.e. reconstructing a track with the wrong sign of charge, is one of the limiting factor in the measurement of antiparticle abundances in cosmic rays

Since tracker measures the curvature (1/R) with a given gaussian resolution, the tails of this gaussian may extend beyond zero introducing then the probability to get a measured rigidity of the wrong sign. The resolution on the curvature worsen for larger rigidities as a consequence the probability of charge confusion equally increases. This source of charge confusion, called intrinsic, can not practically reduced but can be well estimated once the rigidity resolution is well known.

Another source of charge confusion arises from the particle interactions with the AMS material. The scattering of a particle may create a kink in the trajectory. As a consequence of the finite tracker point resolution this kink may fake the fit procedure into producing a wrong sign rigidity.

This second class of charge confused events may be identified from the event features. These include:

- consistency of the measured rigidity with different fit algorithms and with different set of hits on the same track.
- presence of additional hits in the tracker in the proximity of the reconstructed track
- activity in the other sub detectors (ToF scintillators, Veto counters, ECAL, . . .) that seems not related to the passage of the principal particle.

We found a set of 22 variables to be considered in order to spot charge confusion events. None of these variables, however, shows individually a large separation power between ”well” and ”bad” reconstructed tracks. We then choose to exploit the correlation among these quantities. We implemented a Boosted Decision Tree[10] including the mentioned 22 quantities and we trained it on Monte Carlo simulated data.

The training up to now has been mostly focused in estimating the charge confusion for electrons and positron measurements. In fig.4 we present the charge confusion in the ISS data (black points) as estimated by our Tracker BDT. Charge confusion is presented as a function of the total electron energy as measured in the ECAL, thus corresponding to a very good estimation of the true rigidity. For comparison we show also (red line) the charge confusion from the Monte Carlo simulation.

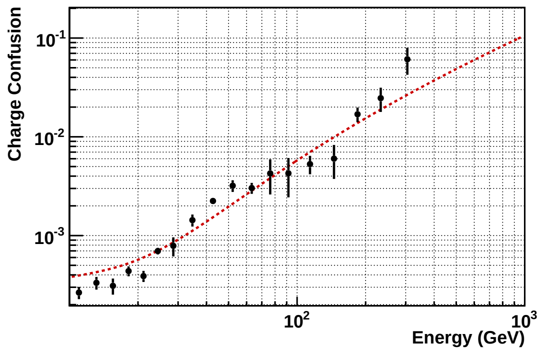

Fig. 4: Charge confusion for electron events as function of electron total energy measured in the ECAL. Red line: charge confusion as observed in the simulation. Black points: charge confusion on ISS data as estimated with the Tracker BDT.

An overall agreement between the Monte Carlo estimation and the Tracker BDT applied to the data confirms the validity of the approach. Further tuning of the algorithm in order to improve its performance is ongoing.

6 Conclusions

An accurate understanding of the silicon tracker in term of rigidity measurement and charge confusion is mandatory to provide the most precise measurements of the cosmic rays fluxes. In this contribution we discussed the procedures applied to reconstruct the tracks, we showed the principal features of track rigidity resolution and we discussed a method to evaluate the charge confusion from interactions.

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2. This rigidity value is often called: maximum detectable rigidity (MDR)