SOME RESULTS IN ALIGNING LONG RANGE AREA OF SENSORS

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Detectorii cu microstrip din siliciu reprezintă principalele elemente de detectie ale traiectoriilor particulelor în multe experimente ale experimentelor de fizica particulelor. In ultima decadă ei sunt utilizati pe scara largă. Principala unitate de detecţie în trackerul AMS este detectorul de siliciu. O metoda rapidă şi precisă de aliniere a senzorilor de siliciu utilizând alinierea la pini va fi detaliată în acesta lucrare. De asemenea, este prezentat succint experimentul AMS. Rezultatele arată ca alinierea la pini este preferată pentru asamblarea unei suprafeţe mari de senzori din siliciu.

Silicon microstrip detectors represent principal detection elements of particle trajectories in many of particle physics experiments. In the last decade they are used in a very large scale. The main detection unit in the AMS tracker is the silicon sensor. A fast and precise mechanical alignment method of silicon sensors by using alignment pins will be detailed in this paper. The results show that the pin alignment method is fast and precise, and is preferred for assembly of a large area of silicon sensors.

Keywords: silicon microstrip detector, alignment, AMS, metrology.

1. Introduction

Alpha Magnetic Spectrometer (AMS) is scheduled for launch in 2010 for a long period of operation on International Space Station (ISS), at an altitude of about 400km. The project started in 1995, and is the most ambitious space physics experiment in progress. The principal scientific objectives of the experiment are: a) the searches of dark matter as signatures in $\overline{p}, e^{+}$ and γ spectra; b) the search of antimatter in extragalactic component of cosmic ray (in three years of operation on ISS, it will improve by a factor of 10^3 the observational limit for antiHe nuclei); c) precise measurement of the cosmic-ray composition in the energy range between 0.5GeV and several TeV for nuclei charge up to Z=26. The large acceptance and the long duration acquisition period will allow large statistics to fulfil these objectives.

In a reduced configuration, the first version of the device - AMS-01, has been successfully launched on the space shuttle STS-91 Discovery, in June 1998,

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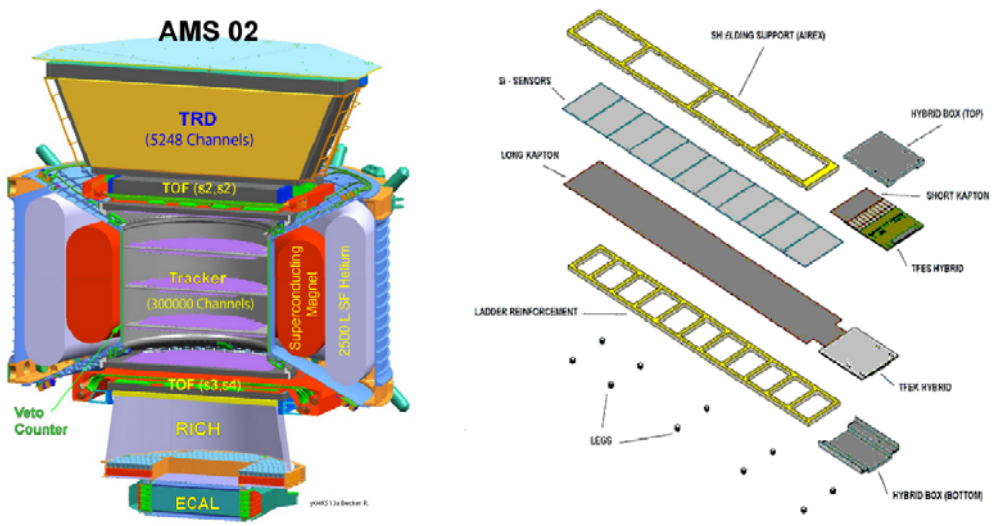
in a 10-day flight. The device supported high level vibrations (150dB) and acceleration up to 6.5g, and functioned properly in the strong conditions of the space. Though this was an engineering flight, were collected over 100 million events which were analysed. Were done studies about e^+, e^-, p, antiprotons and deuterium. No antihelium nuclei were found, and a new upper limit of the relative flux of antihelium to helium of $1.1 \cdot 10^{-6}$ was established. Physics results and AMS-01 description can be found in [1-7].

After flight the original design was changed, the denomination for the second-generation detector was AMS-02. The permanent magnet was changed with a 0.8 T superconducting magnet, six times stronger than for AMS-01. Other systems were added to register photons with energy between 1GeV and 1TeV.

The trajectory of charged particles is reconstructed using positions of the hits from eight layers of the Silicon Tracker, short presented in Section 2. Structural unit of a layer is the ladder (figure 1b). To assemble with high precision double-sided silicon microstrip sensors in a ladder, AMS Collaboration decided to use alignment against pins method. Working in the Clean Room of INFN-Perugia (Italy), the author has developed various implementations of this method. Here is presented an analysis of precision obtained with this method, and alignment errors of a number of ladders assembled for AMS-02 experiment.

2. Silicon Tracker

To measure the trajectory of charged particles in the AMS magnetic field, momentum and charged sign, the AMS-02 silicon tracker is composed of eight layers of double-sided microstrip detectors ($41.360 \times 72.045 \times 0.300 mm^3$). These sensors are used to build basic structural unit in Tracker, the ladder (fig. 1b). The AMS-02 contains a total of 2264 silicon sensor grouped in 192 ladders. The ladder has a common bias voltage and read-out. The number of sensors in a ladder varies between 7 and 15. The different lengths are required to match the cylindrical shape. Each ladder is up to 60cm long and it is built from 7 to 15 double side silicon microstrip sensors (figure 1). The silicon resistivity is order of 10kΩcm. On the p-side of the wafer there are p+ implantation strips with a 27.5μm pitch and the read out pitch is of 110μm. The p+ strips run along the ladder length, parallel with the magnetic field and will be used to measure the tracks coordinate in the bending plane (this face of the sensor is called the “S-side” or “bending face”). On the opposite side of the wafer (K-side or the non-bending face) there are n+ implantation strips every 52 μm interdigitated with p+ blocking strips, needed in order to interrupt the accumulation charge layer between two adjacent n+ strips. These strips are transversal on the magnetic field and are used to measure the tracks coordinate in the non-bending plane. The readout pitch on this side is 208 μm (only one out of 4 strips). The p+ strips are joined ends to end from one sensor to the next by aluminum ultrasonic bonding wires. On n side (K-side) a foil of kapton with diagonal traces is used to connect the strips and to bring the signal to the end of the ladder to the readout electronics. With the chosen readout pitch on the n side, there are up to 6 times more silicon readout strips then electronics readout channels. In this way an m-fold ambiguity is introduced by connecting more strips to the same readout channel. The ambiguity is solved by choosing a proper kapton foil design and during track reconstruction.



a) b)

Fig. 1. a) AMS-02 device. The systems are: superconducting magnet, silicon tracker, transition radiation detector (TRD), time-of-flight (TOF) system, ring-imaging detector (RICH), and electromagnetic calorimeter, anti-coincidence system (ACC). b) The principal components of the silicon ladder.

To choose a silicon tracker for a space born experiment, several conditions must be fulfilled: to be reliable and stable during long operation periods, to not require gas, to be able to operate either in vacuum or at low pressure, to require low voltages and low power consumption. The silicon tracker respects all these conditions and, in addition, because of its high modularity, a silicon system can be easily adapted to different shapes. A good presentation of the problems of construction and testing of AMS-02 tracker is in [8].

3. Assembly method

The spatial resolution of the tracker is of 10μm for the coordinate determined by the long strips of a ladder (y coordinate in fig. 2), and of 30μm for x coordinate. For this the assembly tolerances of positioning sensors in ladder are 5μm for displacements perpendicular to the ladder length, and 10μm for distances between two adjacent sensors.

A fast and precise method for assembly silicon sensors in ladders is required given the big number of silicon sensors in one ladder and the big number of ladders. This method is based on the alignment of the silicon sensors against the three pins located on a precise mechanical support (assembly jig). Figure 2 presents an oversimplified sketch of this jig, where S*1, S2… Sn* are the silicon sensor locations (n=7÷15), and (*1)*, (*2)*, and (*3)* are the three alignment pin positions. "*Left*", "*bottom*", "*right*" and "*top*" is the denomination of the four sides of the silicon sensors, as they are used in the AMS naming schemes. A reference cross is located at each corner of the sensor and the coordinates of these crosses are measured and used in all steps of the assembly. To align one ladder, first we fix the three pins in the first location (S1) on the jig and align the first silicon sensors against them. After that the aligned sensor is maintained in this position by vacuum and the pins are rotated and gently pulled off. Then, the second sensor is aligned in second location (S2), and the procedure will be repeated until all the sensors of the ladders are positioned and vacuum fixed on the mechanical support.

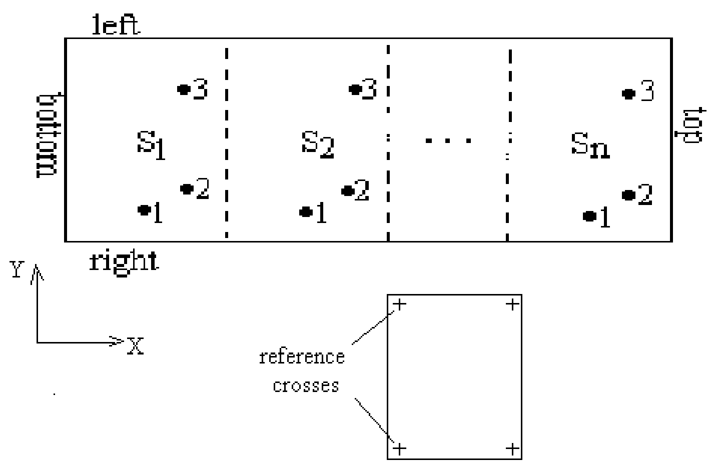


Fig. 2. An oversimplified draws of an assembly jig with n locations. In detail it is figured presence of reference crosses on each sensor.

The precise location of each silicon sensor (S1, S2...) depends on the position of the three alignment pins. After the positioning of the first silicon sensor against the three pins, it is maintained in this position by vacuum. The pins are slightly pulled off and then the second sensor is aligned. The procedure is repeated until all the sensors are aligned on the assembly jig.

Then the cutting line of the sensors, the positioning precision of the three pins and errors of manipulation during assembly operation determine the alignment precision of the ladder. The extensive measurements of the cutting line of sensors, made in AMS01, have shown that the reference crosses are located at 300μm of both adjacent borders with a mechanical tolerance of less than 5μm [9].

A very detailed study of the manufacturing imprecision of the jigs was done to evaluate its influence in the precision of the silicon sensors positioning. For this we have measured the coordinates of the pins on the jig and we have evaluated the residuals to fit lines for pins in position 1, 2 or 3 (first 12 locations).

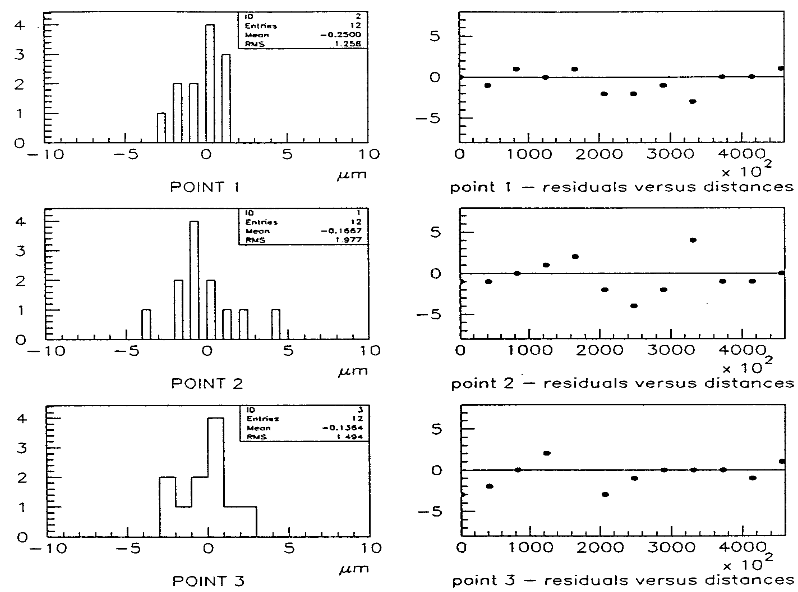


Fig. 3. The three distributions of residuals to fitting line (left), and the residuals versus pin positions on the jig (right).

We can see in figure 3 the three distributions of residuals. The group of positions number 1, which determines Y-displacement of the sensor, is very well grouped with r.m.s. $\sigma = 1.3\mu m$. The distribution of the tilt angles for the lines determined by the position 2 and 3 of the pins with respect to the OY axis (OY is directed along short side of the ladder) is presented in the top-left corner of figure 4.

To establish the effect of the jig manufacturing precision, a simulation has been done, assuming a perfect positioning of ideal silicon sensors on the real jig. The ideal sensor was assumed to have a perfect rectangular cut with an angle between sides of 90 degrees and the overall dimensions of 41360μm x 72045μm. Figure 4 presents the simulation results for all right reference crosses, top and bottom altogether. It can be seen that the r.m.s. for the distribution of distances between right crosses on two neighboring silicon sensors is 2.5μm and r.m.s. for distribution of residuals to the fit line for the right crosses is 1.5μm.

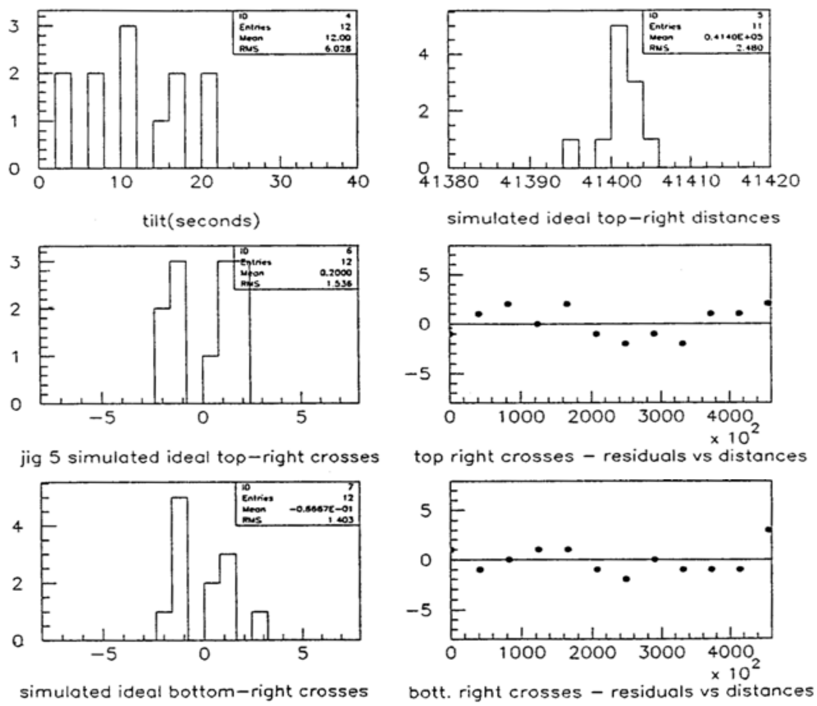


Fig. 4. The simulation results for right crosses distributions. In top left corner is placed the distribution of the tilt angles for the lines determined by the positions 2 and 3 (see text).

Given the high precision of the cut most measurements were due to operator mistakes. To minimize the errors given by the wrong positioning of the sensors to the pins, during AMS01 construction was developed a checking program on the 3D coordinate measuring machine. Three points are automatically measured on the edge of the silicon sensor, which was previously aligned, to the three pins. The difference value between the coordinates of the measured points and the referencing values (found by measuring a big sample of sensors before), must be under 5μm. If this value is bigger, the sensor is realigned or replaced with another one until this condition is fulfilled. In AMS02 this check was done with a Mitutoyo 3D-metrology table, with QVP vision system. After positioning each sensor, the position of crosses is verified.

Figure 5 presents some results obtained with this type of alignment. In the top left corner of the figure there are distribution of the r.m.s. for the displacements of bottom crosses with respect to fitting line, direction of the ladder length (transversal errors) for a number of 34 ladders with 12 sensors. The mean of these errors is of 3.3µm, with one ladder far of the 5µm limit, and three ladders close to this limit. In the top right part of the figure there is distribution of difference between the nominal and measured distances between two neighbor sensors along the ladder length (longitudinal errors). The mean of the distribution is about 5µm, with two ladders outside of 10µm limit for these types of errors.

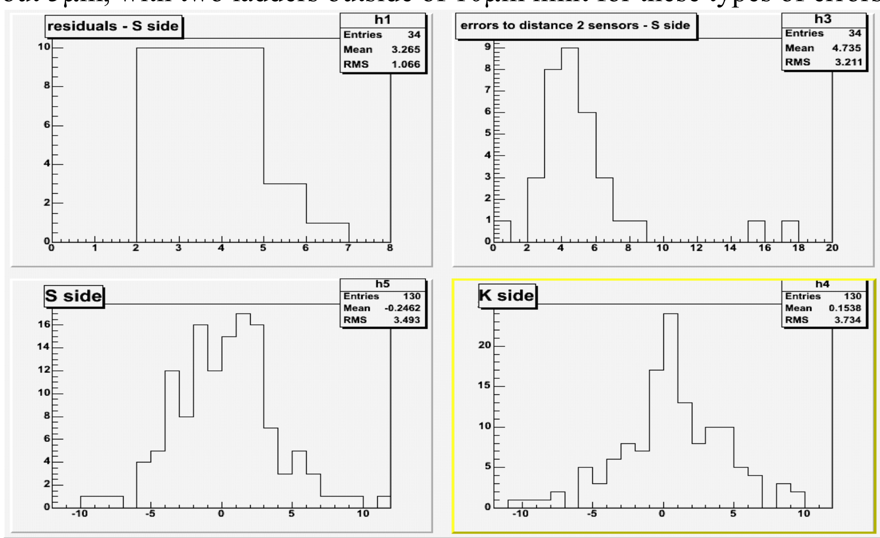


Fig. 5. Distribution of transversal and longitudinal errors (top) and a comparison between transversal errors on S and K side (bottom).

In the bottom part of the figure we present a comparison between S-side and K-side transversal errors, using the same ladders for both distributions. R.m.s. for both distributions is identical.

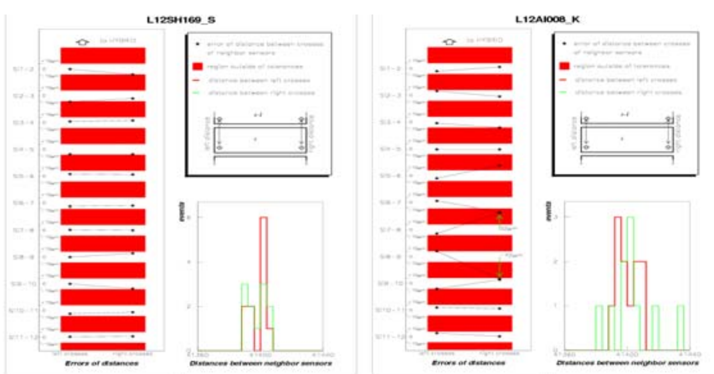


Fig. 6. a) A ladder with longitudinal errors in admitted range. b) A ladder with big longitudinal displacements.

The sensor alignment precision of all AMS02 ladders, reported in [2], is of 3.9μm for transversal errors, and 4.6μm for longitudinal ones, comparable with the precision obtained for the 57 ladders of the AMS-01, 3.5μm and 4.7 respectively.

Fig. 6 presents two ladders: a good ladder (a), and a ladder with big errors, which was an exception.

4. Conclusions

The silicon tracker, which will equip a 6 m^2 surface inside the magnet, is the first silicon tracker with these dimension constructed until now.

Giving the big number of silicon ladders to be built for the AMS tracker, a sturdy and fast method for assembly silicon sensors in the ladder was reclaimed. The assembly method based on the cutting line of the silicon sensors and on the pin alignment is fast and precise. Using very precise jigs and pins was obtained an alignment precision better than 5μm.

Acknowledgements

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R E F E R E N C E S

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