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Space flight experience with the AMS infrared tracker alignment system

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Abstract. The large acceptance Antimatter Spectrometer (AMS) experiment (Becker, 1999) has been flown successfully on the STS91 (02-June-98 - 12-June-98) shuttle flight. AMS-01 particle tracking is based on 6 planes of double sided Si detectors in a permanent magnetic field. The position stability of the tracking elements has been con-trolled using infrared laser generated and cosmic straight tracks. Over the whole flight -including lift-off and landing- all tracking elements were found at their expected positions within ±15 µm.

1 Intoduction

AMS-01 high accuracy momentum measurement is based on 6 (2+1)D - high precision position determinations of charged particle tracks through a 1m^3 magnetic field (|B| ≈ 1.2kG) volume. A particle track of 10 GeV has a 0.5 mm

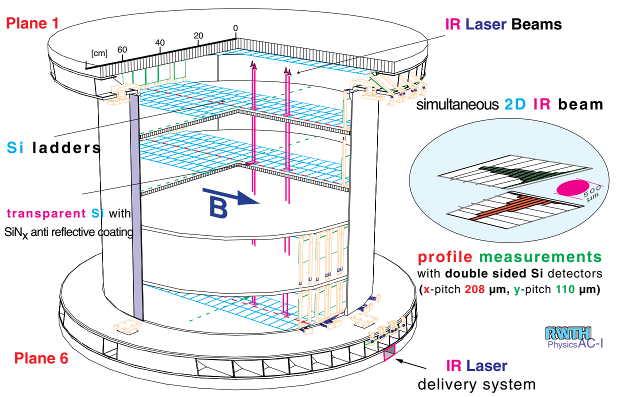

Fig. 1 AMS-01 Si tracker and the Tracker Alignment System. The insert shows laser profiles observed while AMS was in orbit.

sagitta. 2D particle position information is derived from double sided Silicon strip detectors arranged in "ladders" of up to 65cm of length (fig. 1) tiling the 6 detector planes.

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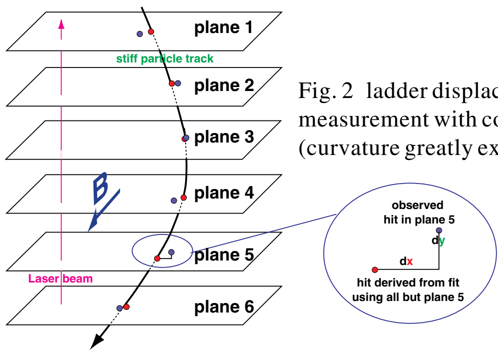

Fig. 2 ladder displacement measurement with cosmic tracks (curvature greatly exaggerated).

The main component of the magnetic field runs parallel to the "y-strips" on the junction side of the Si detectors. From the electrical signals on the implantations (pitch Δy/Δx 27.5/52 µm) the sagitta can be measured to about 25 µm precision (Alcaraz et al. 1999). The third dimension is derived from metrology during the assembly of the tracker plates (Δz ≈ 50 µm). Taking multiple scattering into account the AMS-01 tracker has about 10% momentum resolution at 10 GeV allowing for a maximum detectable momentum (MDM) of 500 GeV. It is evident that a precise momentum measurement is only possible if the detector positions perpendicular to the magnetic field vector (y-axis) are known at all times with an accuracy of better than a small fraction of the to be measured sagitta.

2 Tracker alignment

Straight tracks measured with the Si sensors themselves are most appropriate for an alignment check of these sensors on the 6 detector planes. In the following a subset of AMS-01 Si ladders are aligned using both artificial straight tracks produced by laser (λ = 1082 nm) beams (fig. 1) and quasi straight tracks of high rigidity (p > 4 GV) particles (fig. 2).

The sets of advantages (+) and disadvantages (-) for both sort of straight tracks are quite different.

Laser beams provide :
+ excellent straightness (< 1µrad)
+ high accuracy (< 2µm)
+ fast measurements (< 100ms, 100evts)

Quasi straight cosmic rays offer:
+ continuous coverage of the full detector area
+ quasi constant detector signal in all planes
+ single go alignment of a large number (≥ 6) of detector planes

Limitations of fundamental and technical nature for laser alignment include:
- sampling frequency and accuracy of laser beam profiles
- transparency of Si sensors
- optical homogeneity of the sensors
- beam access holes in the support and shielding
- optical system stability

Limitations for quasi straight cosmic rays are:
- rate
- accuracy of magnetic field model and sensitivity to field changes
- no absolute displacement
- correlation/degeneracy of displacement measurements in successive planes

In consequence both alignment methods are complementary: Laser alignment is good for quick stability tests and rapid variations of the support. Quasi straight tracks are needed for the global picture of tracker deformations.

3 Laser alignment test

Sensitivity and accuracy of the Laser Tracker Alignment System have been determined in the MPPF laboratory at KSC. The Laser base plate, plane 6 of the AMS tracker (fig.1), has been deformed in a controlled fashion by putting 3.7(2) kg weights at off center positions. By comparing the observed laser impacts in planes 6, 5, 4, 3 for weight positions on either side of the Si-ladders (fig.3a) the difference in slope of the bendingline of the support plate at the position of the laser beam ports has been measured (fig.3b) and compared to expectations from finite element models of the tracker support structure (fig.3a). From this measurement we deduce that the actual stiffeness of the Laser/Tracker support plate exceeds the model based expectations by 20%.

The laser position measurement error increases with the distance from the beamport, since the intensity drops sharply primarily due to the high obturation of the Si sur-

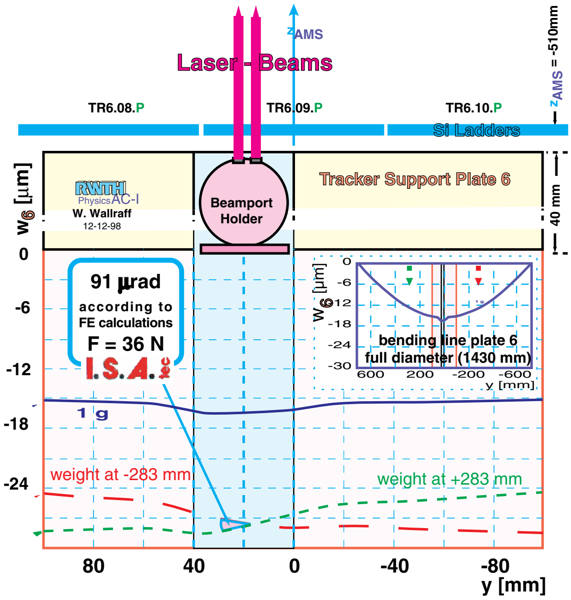

Fig. 3a Laser beam port and Laser/Tracker support plate; bending line unloaded (1g), loaded at +283mm (dotted), loaded at -283mm (dashed), FE model; insert shows full bending line, arrows mark the load positions.

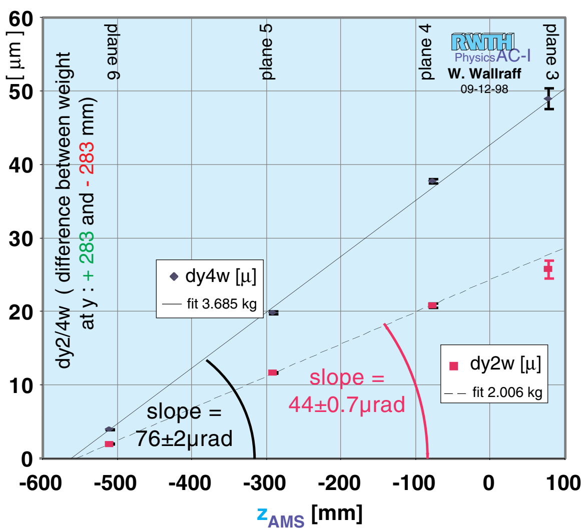

Fig. 3b Measured sloping angle at laser beamports under asymmetric load (details see text)

face by the metallized contacts (for details regarding the sensor optical properties see Vandenhirtz, 2001). The large variation of laser signals (1000 - 0.2 mip) on an alignment beam require a careful understanding of amplification and baseline instabilities of the tracker electronics

Furthermore it has been shown by this procedure that the optical inhomogeneities (non-parallelism of sensor surfaces, roughness of optical path) are sufficiently small for allowing precision measurements at the 1µm level. In addition it has been proven that the determination of the centroid of the laser intensity profiles spanning typically 10 Si sensor readout strips (≈ 1mm, see insert fig. 1) is not suffering from the rather coarse samplings.

4 Tracker stability during the STS-91 space flight

Silicon ladder displacements have been monitored in all phases of AMS-tracker operations using IR lasers and quasi straight cosmic rays (STS91).

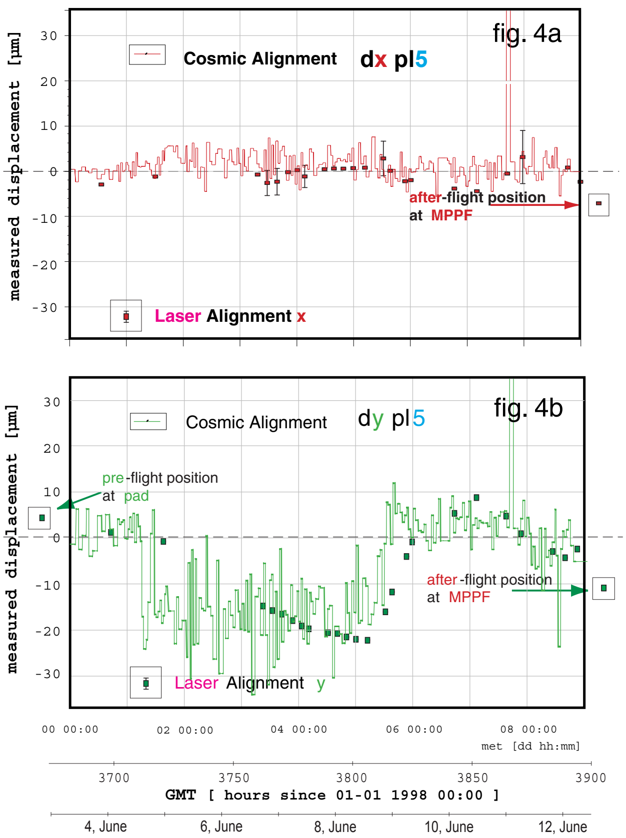

Fig. 4 Measured (see text) time evolution of plane 5 displacements. x (y) parallel (orthogonal) to main B component. The glitch in the early morning of June 11th is excluded from AMS physics data.

Fig. 4a (4b) shows x (y) - displacements of the laser alignment ladder in tracker plane 5 for the full flight. Laser data (full squares) has been taken (for typically 5 sec) at about 4-5 hours (3 orbits) intervals and before (on the launching pad !) as well as after the flight. High rigidity cosmic ray flight data (lines) are averaged for typically 2700 s (0.5 orbits).

The AMS tracker is a rather stable mechanical environment. Only small deviations in the y-coordinate have been observed (fig. 4b) over the STS 91 flight.

Laser and cosmic ray determinations of tracker stability coincide well. Including the laser measurements before the start (tracker z axis horizontal) and after the landing (z-axis vertical) the total absolute displacement in x (y) is less than 5 (25) µm.

From the continuous tracking of high rigidity cosmic rays with the full AMS tracker the relative displacements of all tracker planes have been determined at time intervals of typically 200 sec.

The results from a sample of about 90000 singly charged particles specifically selected are shown in fig. 5a(5b) for x(y).

Accepted are:
1) 5 planes {x,y} data.
2) tracks hitting Laser alignment ladders in plane 4 and plane 5.
3) p(rigidity) > 4 GV.
4) no anticounter.
5) |Q| = 1
6) ntrack =1.

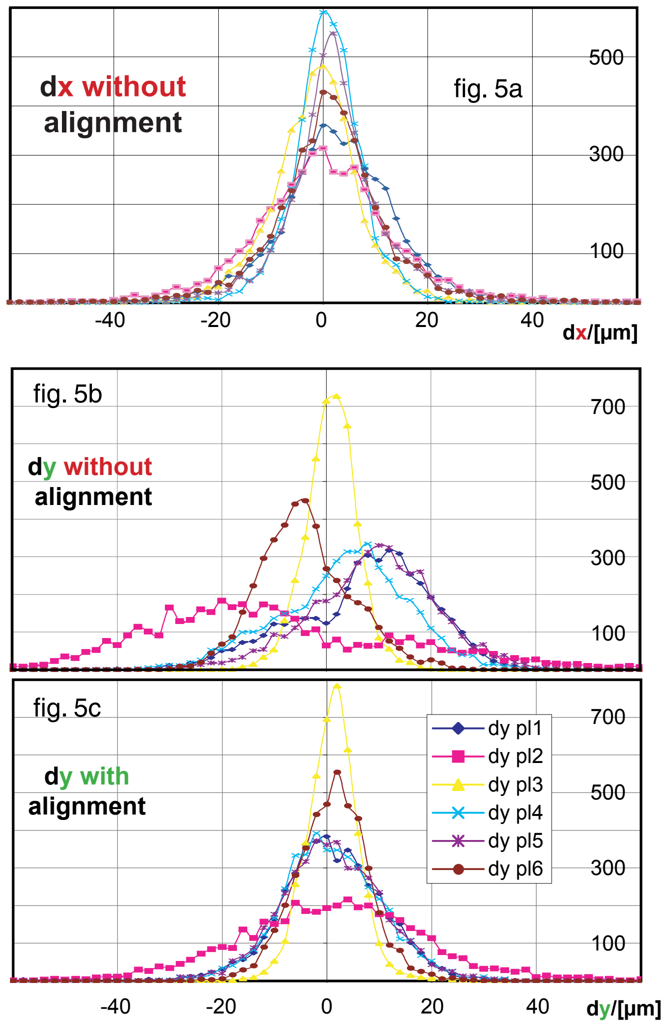

Fig. 5 Frequency distributions of single plane displacement measurements with stiff cosmic tracks (see text). a) [b), c)] parallel [orthogonal] to **B.**

These tracks allow to compare the extrapolation of the track fitted from the information of 4 or 5 planes with the observed unused one in the plane under study for displacement (see fig. 2).

In the y-coordinate small but finite (i.e. exceeding the alignment measurement accuracy) displacements are observed. (fig. 5b). Correcting for the time evolution of these displacements (see fig. 4b for plane 5) results in an approximately 20% better overall position resolution (fig. 5c). These corrections are important only for the high igidity tail of the cosmic ray spectra observable by AMS (p > 80 GV). They have been incorporated in the standard AMS-01 tracking algorithms.

The excursion found by the laser alignment system at 2 pairs of measurement points (in 5h intervals) are indeed confirmed by the continuous observations with high momentum tracks.

5 Summary

This alignment study has demonstrated that the AMS-01 tracker has behaved as required by its basic measurement accuracy (i.e. all deformations remained within the ± 15μm limit).

It has been shown that narrow infrared beams provide an unique power and weight saving approach to position stability control of multilayer Si particle detection systems in space. The AMS-01 laser system has been performing as expected i.e. at sufficiently high signal levels (> 30 mip signal integral) 1 - 2μm accuracy has been achieved with less than 100 shots.

High transparency is essential for adequate signal levels behind 4 layers of Si (anti-reflective coating and small shadowing by detector metallizations). For absolute displacement determinations a high stability of the laser beamports is obviously required.

Quasi straight cosmic rays are sufficiently abundant in the large AMS-01 acceptance with its not so high magnetic field integral. At the high in-trinsic resolution of the double sided Si detectors and the small multiple scattering in the tracking volume a displacement measurement of 5 - 8 μm accuracy can be performed with 400 reconstructed high rigidity tracks.

6 Prospects

AMS-02 the successor of AMS-01 will be installed on the ISS in spring 2004. The AMS-02 tracker (8 planes Si, SC magnet) will be equipped with 2 sets of 10 laser rays each, that traverse the Si in 2 opposite directions. Based on AMS-01 experience an all plane tracker stability verification with better than 4 μm accuracy can be expected 4 times per orbit.

In automatic run control the mode switching of the AMS DAQ to and from laser data can be done in 400 ms (unavailable for AMS-01). This allows for repeated measurements over one orbit. This is highly desirable since rather large temperature changes are to be expected in certain ISS flight attitudes.

Acknowledgements

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