The AMS-2 Tracker Alignment System: design and performance

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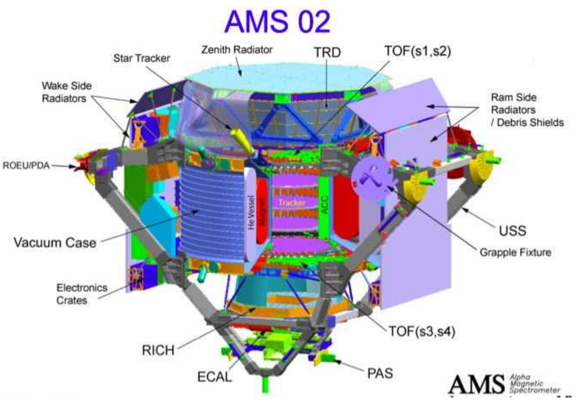

Fig. 1: The AMS-2 detector.

***Abstract*. The AMS-2 Experiment will be installed on the International Space Station in 2010 to measure cosmic ray spectra for 3 years. Its silicon tracker consits of 8 layers of double-sided silicon (Si) microstrip detectors and has a total area of 6 m^2.**

The single hit resolution transverse (parallel) to the magnetic field is σ_y=10 μm (σ_x=30 μm). The AMS-tracker is equipped with a Tracker Alignment System (TAS) based on 40 pulsed infrared (λ=1082 nm) laser beams, that are directly seen by the Si-sensors of the tracker. The TAS can detect lateral displacements of less than 5 μm. The AMS-2 detector was pre-assembled from August 2007 until March 08 and tested with cosmic rays from January 2008 until June 2008. Results concerning the TAS monitoring performance and possible contributions to the Si-tracker global alignment will be reported.

***Keywords*: Alignment, Laser, Tracking.**

I. Introduction

The Alpha Magnetic Spectrometer (AMS) is a general purpose magnetic spectrometer that will be installed in 2010 on the International Space Station (see Fig. 1).

AMS-2 will be able to search for 3 years with unprecedented sensitivity for cosmic dark matter and antimatter. As all space based particle detection systems, it has to cope with a far wider range of environmental conditions than those at accelerators. This concerns notably the vibrations during the transport before deployment and the rapid periodic changes in the thermal settings due to solar radiation and cooling while in the shadow of Earth.

The central detection system of AMS-2 is the silicon-tracker whose technology has been space qualified through the successful flight of AMS-1 [1] on the Space Shuttle Discovery in 1998. In spite of actively cooling the tracker front-end electronics it can be expected that the thermal environment of the tracker is changing constantly with the orbit position of the ISS and its attitude towards the sun. It has been shown that during the AMS-1 flight excursions in position were observable at a level exceeding the internal tracker single point resolution [2].

The AMS alignment system, developed by RWTH-Aachen, provides optically generated signals in all the eight layers of the silicon tracker that mimic straight (infinite rigidity) tracks. It has also served as a benchmark for the CMS silicon tracker alignment system [4].

II. A Particle Spectrometer in Space

The AMS-2 silicon-tracker has an acceptance of 0.4 m^2 sr. The rigidity and the charge of cosmic particles are determined from track curvature measurements in a field of B = 0.8 T. The magnetic field is generated by two superconducting coils in a Helmholtz like configuration. The field is returned by a set of superconducting coils in a racetrack configuration outside the AMS-2 acceptance. Particle identification is performed by the dE/dx measurement in the silicon tracker, by the Time of Flight system[6] above and below the tracker, by a transition radiation detector [5] on top of the tracker and by Ring Image Cherenkov counter [8] and an an electromagnetic calorimeter [7] below the tracker (see Fig. 1).

The long observation time and the large acceptance will allow high statistics measurements of cosmic ray particle spectra.

III. The Tracker Design

The tracking is realized with eight layers of double-sided silicon detectors. The microstrip sensors have a size of 41.4 × 73 × 0.3 mm^3, and are of n-type material, with p+ blocking strips on the ohmic side. The sensor strip implant pitch is of 27.5μm on the p-side (junction side: bending coordinate) and 104μm on the n-side (ohmic side: non-bending). The interstrip capacitive coupling allows for a readout pitch of 110 and 208μm respectively. In total 640 y-strips and 384 x-strips on one sensor are read out. Individual silicon-sensors are bonded together forming ladders of up to 70 cm length. These ladders constitute the basic mechanical and electrical units of the AMS tracker. For the coordinate parallel to the magnetic field the n-side detector strips of alternating sensors are connected through Kapton cables to reduce the total number of readout channels. This leads to ambiguities which have to be resolved by the pattern recognition software.

Six of the eight layers are mounted pairwise on three thin honeycomb CFC plates inside the magnet proper. Thus, a charged particle track is measured at eight space points with a precision of $\sigma_x = 30\ \mu m$, $\sigma_y = 10\ \mu m$ and $\sigma_z = 35\ \mu m$. The precision of the z-coordinate is based on the metrology measurements during the tracker assembly. Silicon detectors and support structures in between the outer layers amount to ∼3.9% of a radiation length.

The key component of the front-end electronics is a low-noise, low-power 64-channel pre and shaping-amplifier ASIC designed specifically for AMS. This chip (VA64_hdr9) has an input pitch of 96 μm which fits well to the strip pitch of the sensor and lends itself to be mounted in vacuum due to its low power consumption of less than 1 mW/channel. The dynamic range allows to measure in each channel up to about 8 MeV energy deposition equivalent to 100 mips. During the flight, the tracker calibrations will be done every 30 minutes or less. Each calibration session collects a total of 4000 random triggers. The averaged pedestal (∼ 300 ADC counts) and the RMS noise are calculated for each strip. These calibration results are used for the online data reduction processor. Typical p(n)-side noise level was 2.5 (3.5) ADC counts. The signal-to-noise ratio, defined as the ratio between the peak mip (minimal ionization particle, ∼ 30 ADC counts) signal for charge one particles and the RMS noise, is ∼ 10.

IV. The Tracker alignment system

The alignment concept for the AMS-2 silicon tracker is based on a two step procedure. In a first step measurements with the laser system are used to monitor the silicon tracker stability. In a second step charged cosmic tracks accumulated over several hours are used to align each individual silicon sensor to micron accuracy. This concept was succefully tested during the AMS-1 flight in 1998 [2]. Movements of up to $20\mu m$ were observed with the laser system during the 10 days flight on board of the Space Shuttle Discovery. These excursions were correlated with changes in the thermal conditions following changes in the spacecraft attitude. Correcting for these displacements improved the rigidity resolution by 20% [3].

An improved version of the laser alignment system used in AMS-1 will be installed in AMS-2. Altogether 40 infrared laser rays will be used to monitor the stabilty of the central tracker area (Fig. 2). Due to the attenuation of the laser signals 20 rays will be provided from the top tracker plate and 20 from the bottom tracker plate.

The beams are narrow (diameter <0.5 mm) and of small divergence (< 1 mrad). They enter the tracker volume through 2 × 5 beamport boxes (LBBX) mounted on the outer faces of the the two outer

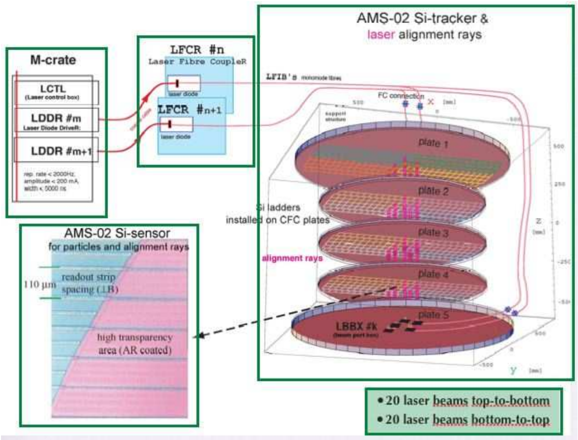

Fig. 2: The layout of the AMS-2 tracker alignment system.

tracker support plates. The photons of these beams are generated with laser diodes (LFCR) installed outside of the tracker volume and are brought, pratically loss free, to the LBBX via mono-mode optical fibers. The pulse length is less than the electronics integration time so that the repetition rate is limited only by the readout.
The wavelength of these beams, 1082 nm, has been chosen such as to penetrate all 8 silicon detector layers of the tracker at once.

The absorption coefficient of silicon at a wavelength of 1080 nm and at room temperature is 10/cm [9] leading only to small transmission losses (< 10%) at this wavelength in the 0.3 mm-thick silicon sensors. The reflection at the silicon surface however has to be suppressed in order to overcome the intensity limitations in recording the alignment beams due to the strong effective attenuation (factor of 4-5 per silicon layer) caused by the high refractive index $n = 3.95$ of silicon. Furthermore the transparency of the silicon detector surfaces is obstructed by the aluminized readout strips.
In consequence, the tracker sensors on the alignment beams have been equipped with antireflective coating (SiO_2 ans Si_3N_4) optimized for the chosen wavelength (residual reflectivity 1%). In addition, the readout strip metallization width was reduced to 10μm width in the coated areas and other implants not metallized.
With hight quality distributed bragg reflector diodes the very high electro-optical efficiency allows for comfortably large photon fluxes even during small optical power (100 nJ/pulse) operation. This results in signals induced by the laser that can exceed those of Z=26 nuclei in the tracker planes closest to the LBBX.

V. The Tracker Alignment System Performances

The AMS-2 detector was pre-assembled from August 2007 till March 2008 and tested with cosmic rays from January 2008 till June 2008. At the same time, the

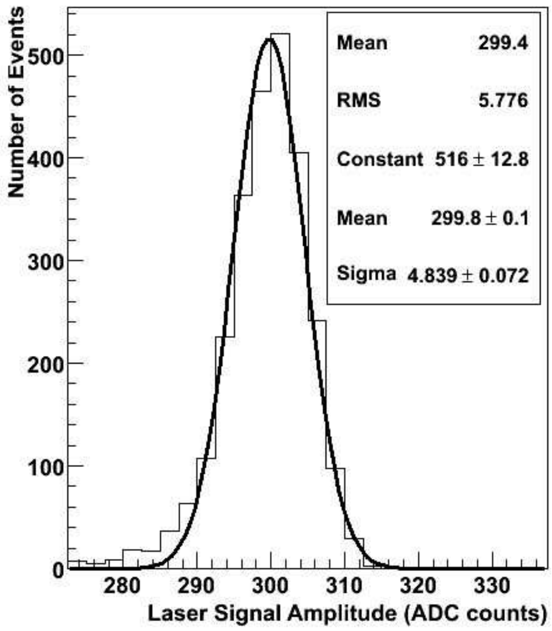

Fig. 3: Typical laser signal amplitude distribution sampled over 4000 events of one of the 40 laser rays of the AMS-2 silicon tracker laser alignment system.

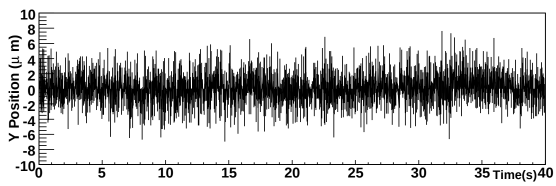

Fig. 4: Position of a laser cluster as a function of time.

performances of the tracker alignment system and the related electronics were extensively studied.

The stability of the laser signals has been studied monitoring the change in amplitude and position as a function of time. Runs with 4000 laser events, lasting 40 seconds each, have been analyzed on an event-by-event basis. The laser beams have a nice gaussian profile. The distribution of the laser signal amplitudes of a typical beam, as obtained from a fit to the signal cluster with a single gaussian, is shown in Fig. 3. The event-by-event spread is at the level of $\sim 2\%$.

The position stability of the laser signal has also been monitored. The position of a typical laser cluster as a function of the event number is shown in Fig. 4. The projection of the position for all events is shown in Fig. 5. No time dependence is visible in the cluster position and its reproducibility is at the level of $\sim 2.1 \mu m$.

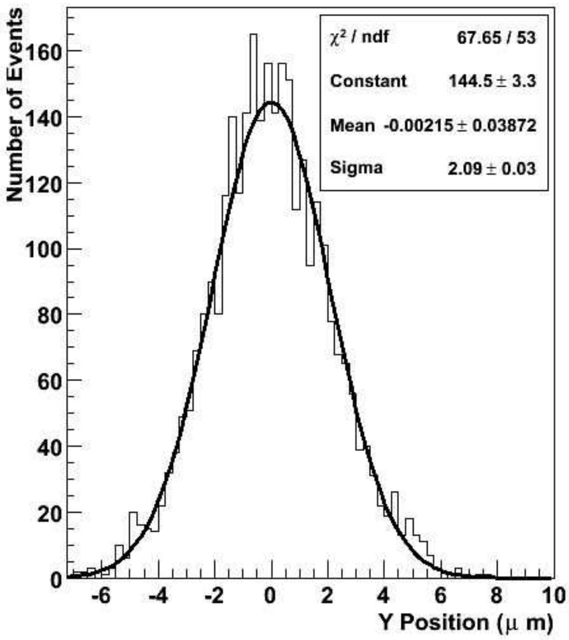

Fig. 5: Distribution of the laser signal positions as determined from 4000 events taken within 40 seconds.

Given the stability of the cluster position, one would expect that the position resolution should improve proportional to $1/\sqrt{N}$, where N is the number of laser signal events used to determine the position until the systematic limit for the internal resolution of the laser alignment system is reached. Therefore subsamples of events have been formed and the RMS of the position stability determined from the subsamples has been plotted as a function of the subsample size. The resulting graph, shown in Fig. 6, is fitted with the relation:

$$\sigma = \sqrt{P_1^2/N + P_0^2} \qquad (1)$$

where P_1 is the purely statistical term and P_0 determines the systematic limit for the internal tracker alignment resolution.

The obtained value for P_0 is independent of the number of silicon layers the laser went through. From this analysis we conclude that there is little gain in combining more than 100 laser events.

The transmission of the laser signal through the 0.3 mm thick silicon tracker layers has been studied for the 32 laser beams available during the detector pre-integration period as shown in Fig. 7. The signal amplitudes are normalized to the amplitude on layer two for top-bottom laser beams and on layer seven for bottom-top beams. This was necessary as the first silicon layers infront of the beamport boxes show saturated laser signals.

From a fit to these curves with an exponential fuction the average transmission per silicon layer has been determined to be 44%.

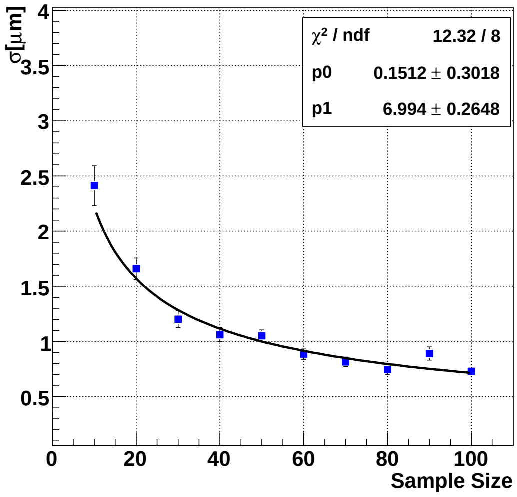

Fig. 6: Position resolution of the AMS-2 tracker laser alignment system as a function of the number of laser signal events used for the analysis.

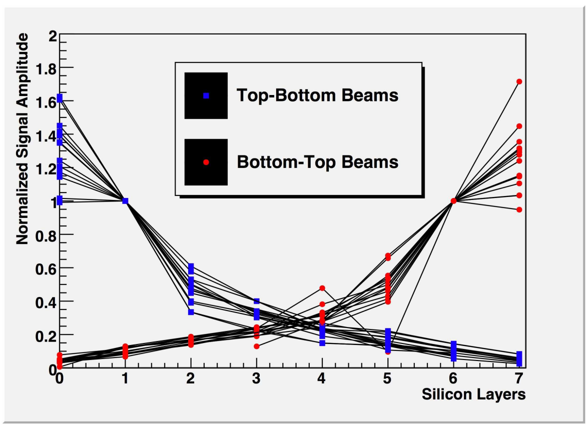

Fig. 7: Normalized laser signal amplitude as a function of silicon tracker layer number where top-bottom (bottom-top) beams are indicated by blue (red) dots.

VI. Conclusions

The AMS-2 detector was pre-assembled from August 2007 until March 2008 and tested from January 2008 until June 2008 with cosmic rays at CERN in Geneva. The silicon tracker laser alignment system performance and monitoring capability has been studied and verified. The results confirm the design specification. The laser alignment system will be able to monitor online the AMS-2 silicon tracker stability on board of the international space station. Using this information a track based aligment will be performed to achieve the required position accuracy of better that $5 \mu m$ for all silicon sensors to reach the design momentum resolution of the AMS-2 silicon tracker of $\sigma_p/p = 100\%$ at $p = 2.3\ TeV$. This will allow AMS-2 to perform precision measurements of cosmic ray particles up to the TeV scale. Recent measurements from PAMELA [10], Fermi-LAT[11] and H.E.S.S.[12] on cosmic ray electrons and positrons will be significantly improved up to the TeV energy scale. This might allow us to take some conclusions about the origin of the observed unexpected features is the cosmic ray electron and positron spectrum at this energy scale.

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