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The AMS-02 Time of Flight System

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The Time-of-Flight (TOF) system of the AMS detector gives the fast trigger to the read out electronics and measures velocity, direction and charge of the crossing particles. The first version of the detector (called AMS-01) has flown in 1998 aboard of the shuttle Discovery for a 10 days test mission, and collected about 10^8 events. The new version (called AMS-02) will be installed on the International Space Station and will operate for at least three years, collecting roughly 10^{10} Cosmic Ray (CR) particles. The TOF system of AMS-01 successfully operated during the test mission, obtaining a time resolution of 120 ps for protons and better for other CR ions. The TOF system of AMS-02 will be different due to the strong fringing magnetic field and weight constraints.

1. Introduction

The *Alpha Magnetic Spectrometer* (AMS) [1] is a particle detector that will be installed on the International Space Station in 2005 to measure cosmic ray fluxes for at least three years. Amongst the AMS goals we may cite:

- Search for cosmic antimatter;
- Search for dark matter signatures;
- Measurement of primary Cosmic Ray (CR) spectra below 1 TeV:
  - Hydrogen and Helium isotopes: solar modulation on a weekly basis;
  - Very high statistics for CR ions below Iron;
  - Precise measurements of electron and positron spectra;
  - Cosmic gamma-rays spectrum.

During the precursor flight aboard of the shuttle Discovery (NASA STS-91 mission, 2–12 June 1998), AMS collected data for about 180 hours [2]. Figure 1 shows the test detector (called AMS-01 in the following), consisting of a permanent Nd-Fe-B magnet, six silicon tracker planes, a scintillator counters anticoincidence system, the time of flight (TOF) system consisting in four layers of scintillator counters and a threshold aerogel Čerenkov detector.

The TOF system of AMS-01 [3] was completely designed and built at the INFN Laboratories in Bologna, Italy. Its main goals are to provide the fast trigger to AMS readout electronics, and to measure the particle velocity (β), direction, crossing position and charge. In addition, it had to operate in space with severe limits for weight and power consuption (see section 3 for more details).

Figure 2 shows the new version of the detector (named AMS-02), that will be installed aboard of the ISS for a 3 years mission. AMS-02 will be based on a superconducting magnet that will produce a dipolar field of 0.85 T maximum intensity (hence the separating power will be $BL^2 \approx 0.85$ T m^2).

In addition to a veto system of 8 organic scintillator paddles, a Silicon tracker of 8 (x, y) planes will be placed inside the magnet. The new tracking system will reach a spatial resolu-

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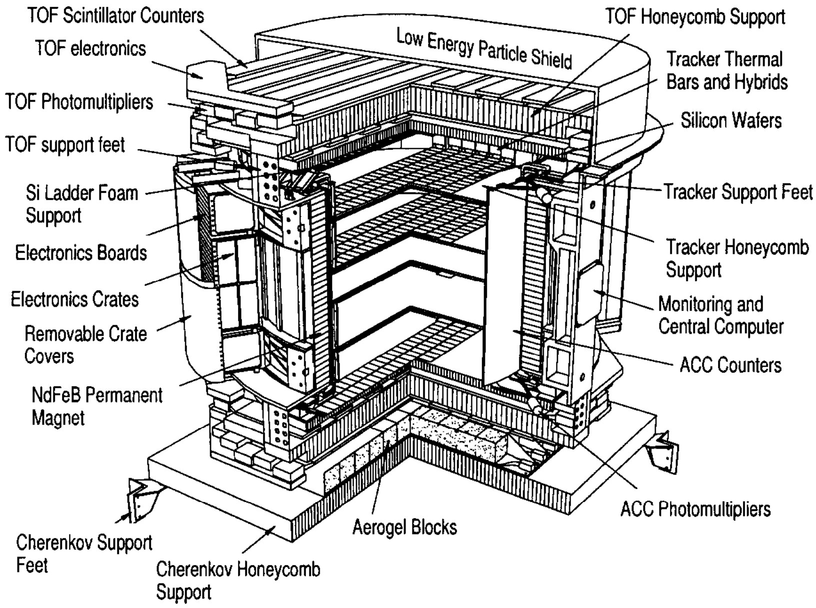

Figure 1. The AMS detector for the STS-91 mission (AMS-01).

tion of $\sigma_y = 10\ \mu$m on the bending plane and $\sigma_x = 30\ \mu$m for the non-bending plane. The total active area will be $\approx 7\,\mathrm{m}^2$ ($\sim 2\times10^5$ channels), and its rigidity resolution will be $\Delta R/R \approx 2\%$ for $R = (1 \div 30)\,\mathrm{GV}$ for protons.

The new time of flight system will consist of 4 planes of 8, 8, 10, 8 scintillator counters respectively (see section 3 below). Its time resolution will be ~ 140 ps for protons and better for higher charged particles, making AMS-02 able to distinguish between negative and positive charged particles (hence between CR matter and antimatter) at the 10^{-9} level. The main differences with respect to the TOF system of AMS-01 are due to the very strong magnetic field in the photomultiplier tubes (PMT) zone and to more severe weight limits.

Below the magnet, a proximity focusing RICH will substitute the AMS-01 threshold Čerenkov counter. With a 2 cm thick aerogel radiator and a pixel plane 48 cm far from it, by reconstructing the Čerenkov angle it will reach a velocity resolution $\Delta\beta/\beta \sim 0.1\%$ and by counting the emitted photons it will measure the charge of the incident particle. This instrument will improve the AMS sensitivity to light elements isotopes up to $(12 \div 13)$ GeV/A and will enhance element discrimination up to Fe.

Finally, two new instruments will be added to the AMS-02 detector with respect to AMS-01: a Transition Radiation Detector (TRD) on the top, and an electromagnetic calorimeter (ECAL) at the bottom of the detector. By improving the discriminating power amongst electrons and protons up to high energies, TRD and ECAL will allow AMS-02 to measure with high statistics the positron and electron spectra up to ~ 300 GeV, covering the most promising energy range for the search of supersymmetric dark matter particle annihilations.

2. The AMS-01 TOF

The time of flight of the AMS-01 detector consisted of 4 planes of Bicron BC408 plastic scintillator paddles, two above and two below the magnet (figure 3). Each TOF plane had 14 scintillator

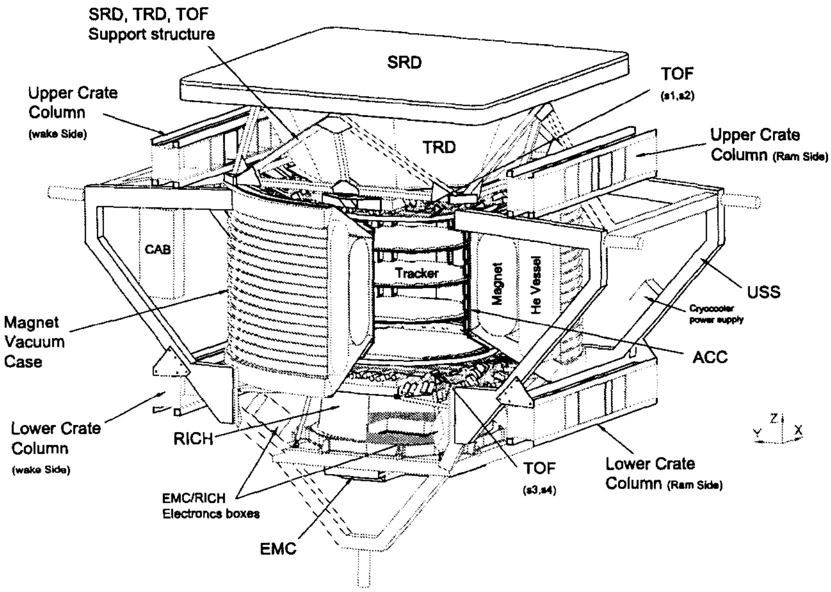

Figure 2. The AMS detector to be installed on ISS (AMS-02).

counters 1 cm thick covering a roughly circular area of 1.6 m^2. The scintillation light was guided to 3 Hamamatsu R5900 photomultipliers per side, whose signals were summed together to have a good redundancy and light collection efficiency. The total power consumption of the system (112 channels, 336 phototubes) was 150 W, while its weight (support structure included) was 250 kg.

Figure 4 shows the exploded view of a counter: the scintillator paddle is connected to its Hamamatsu R5900 PMTs through small plexyglass light guides glued to the counter and soft transparent optical pads that provide also the mechanical coupling. The paddle and light guides are surrounded by a thin reflecting mylar foil and enclosed within a 0.5 mm thick carbon fiber rigid shell (that has a depressurization pipe for the outgassing phase while reaching the orbiting altitude), and then it is fixed to a honeycomb plane connected to the magnet structure by 4 support feet. The 3 PMTs of each side are shielded by the residual magnetic field of $\sim$ 200 G by Permalloy boxes.

Figure 5 shows the read-out scheme of a scintillator: the anode analog signal is split and then is sent to different discriminators, used to start the "time expansion" logic (LT, low threshold), to send a signal to the trigger box (HT, high threshold) for the "fast trigger" (FT) generation (that is the reference time of AMS), and to flag He and other nuclei (UHT, ultra-high threshold). In addition, the anode and dynode signals are used to charge two capacitors whose discarging times are measured with a pipeline multichannel TDC (these times are logarithmic functions of the charge).

For every counter edge, four digitized data buffers are recorded: the anode and dynode charges, the time expansion channel (equal to 40$\times$ time between the PMT signal and the FT arrival), and the "history" channel (corresponding to the HT), that is used to check for multiple particle crossing in a 16 μs time windows around the FT. The TDC sampling rate was 1 GHz, being able to measure the time between the PMT signal and the FT arrival with 25 ps effective bins.

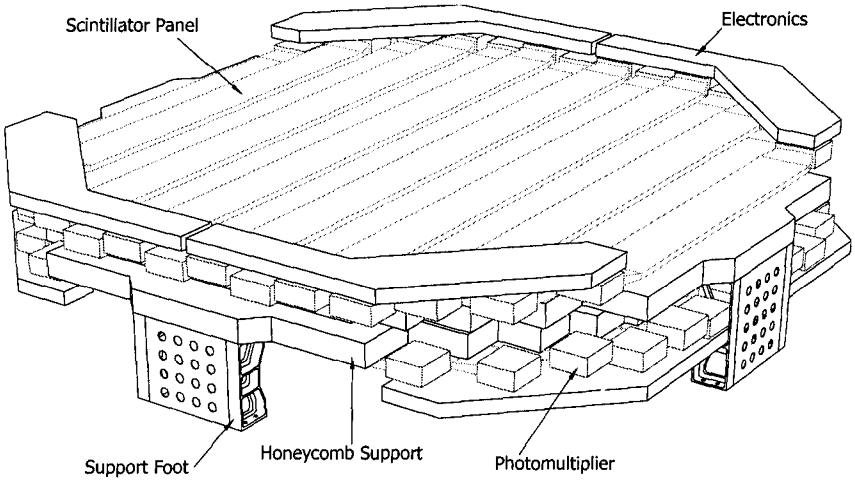

Figure 3. Upper two planes of the TOF system of AMS-01.

The electronic noise, that is the lower limit to the time resolution of the TOF system, was measured with the STS-91 data to be $(80 \div 90)$ ps [4].

3. The AMS-02 TOF

The counters of the new TOF system are similar to those of AMS-01: they are wrapped by a reflecting mylar foil and enclosed by thin carbon fiber shells. The scintillation light is collected by 2 light guides per side (3 per side on the external counters of the two outermost planes), and the PMT anode and dynode signals are summed together. However, the shape of the light guides and the phototube model are different from AMS-01, and the two external counters of each plane have a different shape.

In fact, the superconducting magnet of AMS-02 is about 5 times stronger than the permanent magnet of AMS-01, and produces a very strong field in the zones where the TOF phototubes are positioned. For this reason, a different kind of PMT has been adopted: the Hamamatsu R5948 fine mesh model. In addition, the fringing field has many different directions (figure 6), making impossible to adopt straight light guides. In fact, the measured behavior of the PMTs depends on the angle between their logintudinal axis and the magnetic field, making angles wider than $(20 \div 30)$ degrees unacceptable [5].

In order to minimize the angle between the field direction and the PMT axis, a variety of bended light guides was produced. Due to the combined effect of the choice of the new PMT model and the use of bended light guides, the expected time resolution is worse than the AMS-01 one: the new TOF system will achieve a ≈ 140 ps resolution for protons, and better for other CR nuclei.

The other strong constraint on the new TOF system design is the allotted weight budget (240 kg instead of the 250 kg of AMS-01). In order to reduce its weight while still keeping at least a 0.4 m^2 sr geometrical acceptance full covered by the TOF and the tracker, the number of counters per plane was decreased to 8, 8, 10, 8 (from the first to last plane, respectively), and the shape of the external counters was changed.

Figure 7 shows the new TOF planes layout. The planes 1 and 4, whose counters are parallel to the x axis, have straight and short light guides and short (130 cm) counters. These are the planes with the best time resolution. The external counters of every plane have a trapezoidal shape and will be used mainly to check the consistency of TOF data.

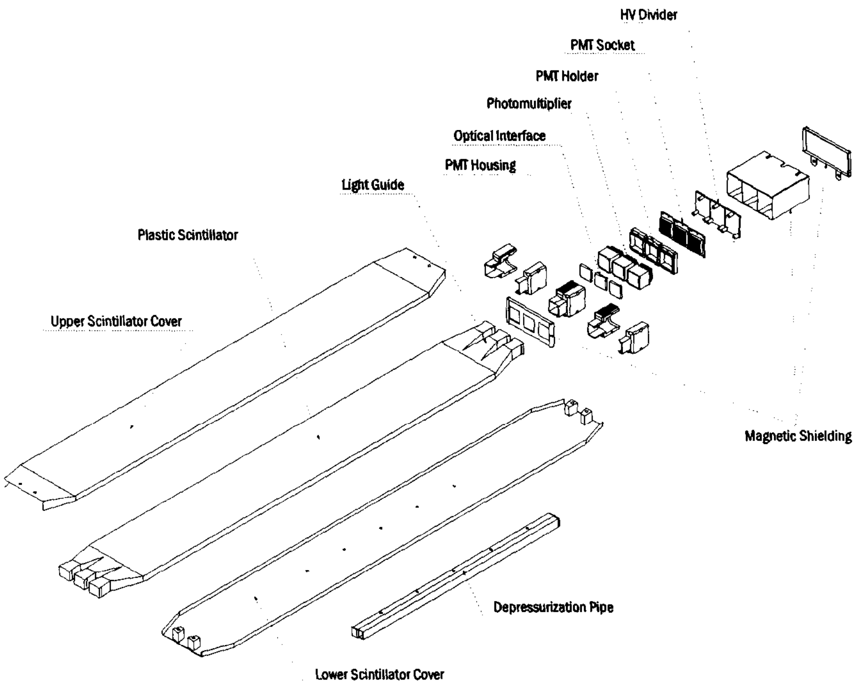

Figure 4. Exploded view of a single scintillator counter of the TOF system of AMS-01.

4. Conclusion

The time of flight system of AMS-02 will have the same goals of the TOF system of AMS-01, but it will operate with more severe conditions. The low weight and power consumption budgets and the very strong fringing magnetic field in the phototubes zone will cause a worsening of the time resolution, with respect to AMS-01.

On the other hand, the new read-out electronics will make the new system able to reach a better charge resolution than the previous one, and the trigger efficiency will be unaffected by those problems. In addition, fast additional information based on the energy release of the crossing particles will be sent to the trigger logics, in order to be able to flag CR nuclei with charge greater than two.

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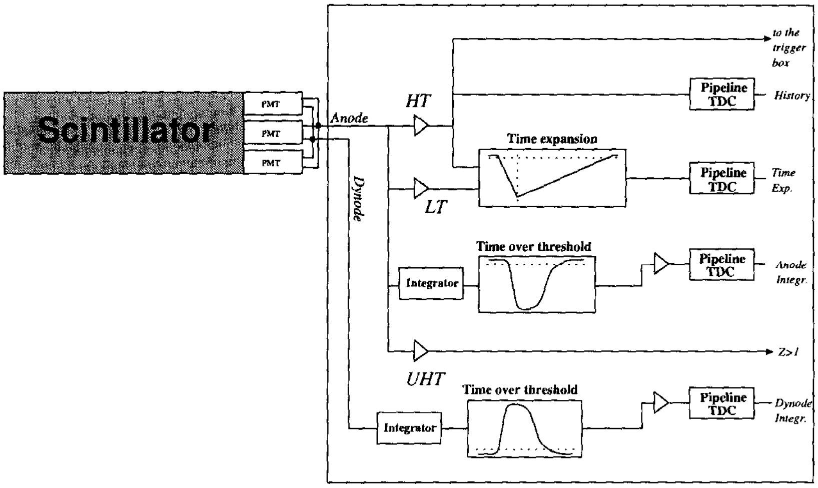

Figure 5. Schematic view of the scintillator read-out of the TOF system of AMS-01.

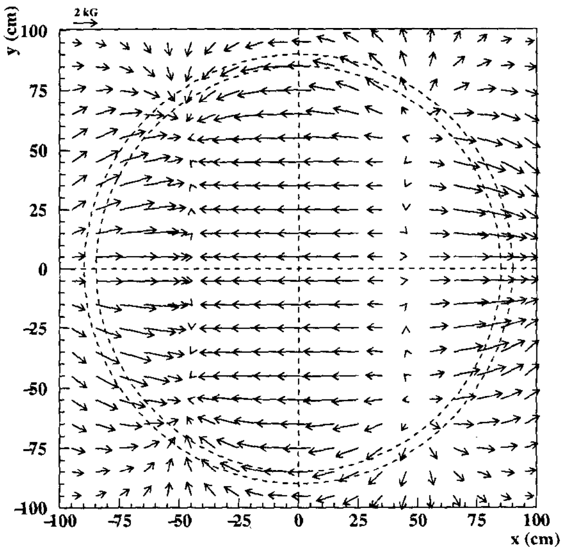

Figure 6. Fringing field in the PMT plane of the TOF system of AMS-02.

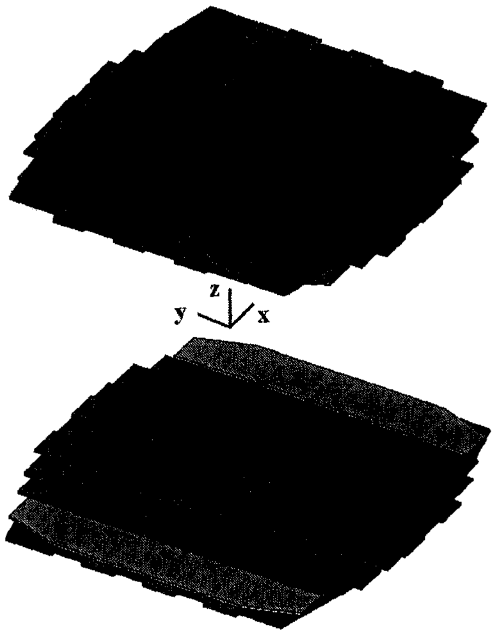

Figure 7. The new layout for the TOF planes of AMS-02.