Nuclear Instruments and Methods in Physics Research A 623 (2010) 968–981

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

The scintillator detector for the fast trigger and time-of-flight (TOF) measurement of the space experiment AMS-02

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ARTICLE INFO

Article history:
Received 25 February 2010
Received in revised form
10 August 2010
Accepted 10 August 2010

Keywords:
AMS experiment
Plastic scintillator
Time-of-flight
Cosmic rays

ABSTRACT

The "Time-Of-Flight" (TOF) system of the AMS-02 superconducting spectrometer, to be installed in the ISS International Space Station, consists of four layers of plastic scintillation counters. During the precursor mission AMS-01 (June 1998), a similar system successfully operated in space for 10 days. However, the AMS-02 TOF had to be redesigned taking into account the more stringent mass and power constraints of the AMS-02 detector. The main characteristics of the new TOF system are (a) capability to stand the high fringing field of AMS-02 superconducting magnet; (b) high redundancy of electronic components for unmanned operation of at least three years in the space station; (c) capability to operate in the space environment on the ISS. Counters and electronics have been extensively tested before the installation in the spectrometer.

1. Introduction

The AMS-02 cosmic ray detector is the final achievement of an international collaboration started in 1994 [1] by S.C.C. Ting[3] with the support of A. Zichichi,[4] which presently includes 500 physicists from 60 research institutes in 16 countries.

AMS-02 is an improved version of the AMS-01 space spectrometer, which flew on the shuttle Discovery (NASA mission STS-91) in June 1998. AMS-01 took data for about 90 h at different flight altitudes, from 320 to 390 km, with latitude ranging within $\pm 51.7^{\circ}$ and all longitudes [2].

Fig. 1 shows a schematic view of the AMS-02 detector. The 0.8 T dipole field of the superconducting magnet (Fig. 2) has an intensity of about 6 times larger than the permanent magnet of AMS-01, with a residual magnetic field (<15.2 mT at 2.3 m) and a dipole moment well below the ones allowed by the International Space Station (ISS) safety requests, thanks to the "racetrack" coils. The magnet operates at a temperature of 1.8 K, cooled by superfluid Helium stored in a 2500 l vessel, which should assure a three years lifetime to the experiment. The silicon tracker has a larger surface than in AMS-01 and two more planes (eight in total). Its space resolution has been improved to 10 μm, to be able to measure rigidities[5] in the TV range.

The tracker measures the particle charge and the trajectory curvature which, together with the knowledge of the magnetic field intensity, provides an estimate of the particle momentum. The direction of motion, measured by the TOF system, is then used to determine the sign of the charge, an essential step to separate matter from antimatter particles. Finally, the anti-coincidence counters are used to veto all events in which particles enter the detector from a side, to avoid fake antimatter tracks originating by secondary particles produced by the interaction with the detector envelope.

To improve redundancy and particle identification, the following detectors have been installed on AMS-02:

- a transition radiation detector (TRD) which provides an electron/hadron separation of 10^3 at 20 GeV momentum, down to 10^2 at 300 GeV;
- a ring-imaging Cherenkov system (RICH) which provides a velocity resolution of 0.1% for $Z>1$ nuclei, up to about 10 GeV/n, and measures the particle charge up to Fe;

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[5] The rigidity is defined as the ratio between the particle momentum and the charge.

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doi:10.1016/j.nima.2010.08.019

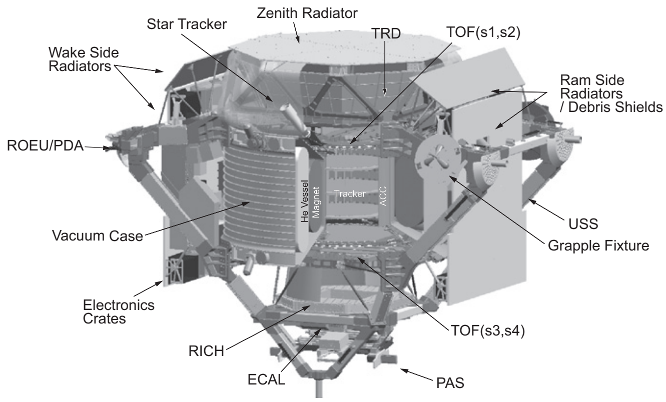

Fig. 1. The AMS-02 detector.

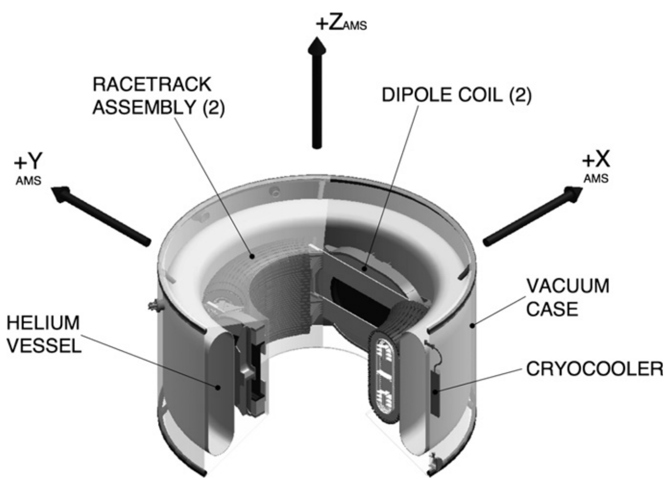

Fig. 2. The AMS-02 superconducting magnet.

Table 1
Monte Carlo expected number of cosmic ray particles in the AMS-02 acceptance above a given energy threshold in three years of data taking on board of the International Space Station.

	>1 GeV/c	>10 GeV/c	$>10^2$ GeV/c	>1 TeV/c
p		6.1×10^9	1.5×10^8	2.5×10^6
e^-	1.4×10^8	6.8×10^6	7.2×10^4	4.4×10^2
e^+	9×10^6	3×10^5	1.6×10^3	6
$\bar{p}$	1.4×10^8	6.8×10^6	7.2×10^4	4.4×10^2
He	6.4×10^8	2.1×10^8	7.3×10^6	1.7×10^5

- an electromagnetic calorimeter (ECAL), 16 radiation lengths thick, which measures electromagnetic particles with a 2% energy resolution at high energy and provides the electron/hadron rejection factor exceeding 10^3.

The expected performances and the powerful particle identification capabilities of AMS-02 are best illustrated in Table 1, which shows the expected flux of cosmic rays detected in three years of data taking on board of the International Space Station.

2. Design considerations

The AMS-02 TOF system is based on previous experience and well-established techniques [3–6]. It has been completely designed and built at the INFN Laboratories in Bologna, to provide:

- the fast trigger to the experiment;
- the measurement of the time-of-flight of the particles traversing the detector with a resolution sufficient to distinguish upward from downward going particles at a level of at least 10^{-10}, and anti-protons from electrons up to about 1.2 GeV;
- the measurement of primary cosmic nuclei velocity with a resolution of a few %, and of their absolute charge up to $Z\approx15$.

The main parameters taken into account while designing the detector have been the following:

(a) *Total sensitive area*
AMS-02 has been designed to have a large acceptance for cosmic ray tracks. The superconducting magnet aperture is about 0.4 m^2sr, in order to reach a 10^{-9} sensitivity for the flux of anti-Helium/Helium nuclei, in one year of running. To match the full acceptance of the magnet, each layer of the TOF system has to cover a circular area of about 1.6 m^2.

(b) *Trigger selection*
The TOF system has to provide the fast trigger to the AMS experiment. It consists of two planes of scintillator paddles mounted inside AMS-02. Each plane contains two layers of counters, in x and y directions, respectively. The first plane is situated at the entrance of the magnetic volume, the second one at the exit, at a distance of ±626 mm in the z direction, as defined in the reference frame of the experiment. Each layer is made by 8–10 scintillator paddles of different lengths, staggered by 1.5 cm in z and overlapped by 0.5 cm to avoid geometrical inefficiencies (see Figs. 11 and 12). The scintillator TOF-ACC system provides an efficient background rejection allowing, for trigger purposes, a TOF granularity of about $12\times12\,cm^2$ and a lateral cylindrical segmentation of 22.5° of the 16 anti-coincidence scintillator counters (ACC).

(c) *Weight*
Given the strong limitations in the total weight of the AMS detector, the TOF system was allotted 268 kg to accommodate for the detector itself and for the support structure.

(d) *Power consumption*
The TOF system was allowed to use about 150 W for photomultiplier tube operation and signal read-out, out of the 2 kW electric power given by NASA to the AMS experiment on the ISS.

(e) *Time-of-flight resolution*
A resolution in the TOF better than 180 ps is needed to satisfy the physics requirements outlined in Section 1. The choice was one centimeter thick scintillator, as a compromise between the minimum thickness and the light output needed to reach this resolution.

A number of technical constraints had to be taken into account in designing the detector to ensure the performances previously described.

It must be reminded that the TOF system must tolerate the high mechanical stresses during the launch phase without breaking or damaging of any part of the detector. Moreover, it must survive for at least five years in the harsh space environment, the main threats being the large temperature changes depending of the ISS orbits and attitudes, and the possible impact with micrometeorites and mini debris. The weight of the detector must also be kept as low as possible.

To accomplish all that, the counters are housed in mechanically robust and light-tight covers with a system for fast