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AMS-γ: High energy photons detection with the Alpha Magnetic Spectrometer on the ISS

B. Bertucci, G. Lamanna, B. Alpat, R. Battiston, W. J. Burger, G. Esposito, E. Fiandrini, and P. Zuccon

University of Perugia and INFN

Abstract. AMS is a large acceptance, superconducting magnetic spectrometer designed to study, with high accuracy, the composition of cosmic rays. We discuss how AMS will also identify γ rays in the energy interval 1-300 GeV, operating as a e^+e^- pair spectrometer. During the scheduled three-year mission on the International Space Station (ISS) starting in 2004, AMS will provide access to the largely unexplored γ energy range above 20 GeV complementary to other space missions and ground based Čherenkov detectors.

1 Introduction

The successful operation of the Compton Gamma Ray Observatory (CGRO) (Kurfess et al. (1997)) has provided a vast amount of information on the gamma emission in the Universe and has led to the discovery of new phenomena. In particular, the Energetic Gamma Ray Experiment Telescope (EGRET) (Hartman et al. (1999)) sensitive to high energy photons (0.1 up to 30 GeV) has been crucial for the identification of several classes of new gamma sources, such as extragalactic blazars, galactic pulsars, γ-ray bursters, as well as providing a measure of the diffuse emission both of galactic and extragalactic origins. A decade of operation has allowed to verify the extreme time variability of such objects and to correlate their high energy photon emission with their counterparts at longer wavelengths. The surprisingly dynamic universe emerging from these measurements has generated much interest in high energy γ-ray detection: new γ-ray telescopes AGILE (Morselli et al. (2000)) and GLAST (Engovatov et al. (1997)) are currently under construction to extend the survey up to 50 GeV and ~ 300 GeV respectively.

In this context, it is interesting to analyze the sensitivity for energetic photon detection of the Alpha Magnetic Spectrometer, a large acceptance particle detector which will be operating on the International Space Station for three years, starting in 2004. The AMS experiment has been proposed to study with high accuracy the composition of cosmic rays. A reduced version of the detector was flown and operated successfully during a 10-day shuttle flight in June 1998[1]. The data accumulated during the flight has provided new accurate measurements of the proton (Alcaraz 1 (2000)), helium (Alcaraz 3 (2000)) and lepton (Alcaraz 2 (2000)) fluxes.

Correspondence to: B.Bertucci (Bruna.Bertucci@pg.infn.it)
G.Lamanna (Giovanni.Lamanna@cern.ch)

2 The AMS-02 detector

Following the Shuttle flight data analysis, a significant upgrade of the AMS instrument has been started: a substantial increase of the magnetic field strength, the addition of a Transition Radiation Detector (TRD), a Ring Imaging Čherenkov

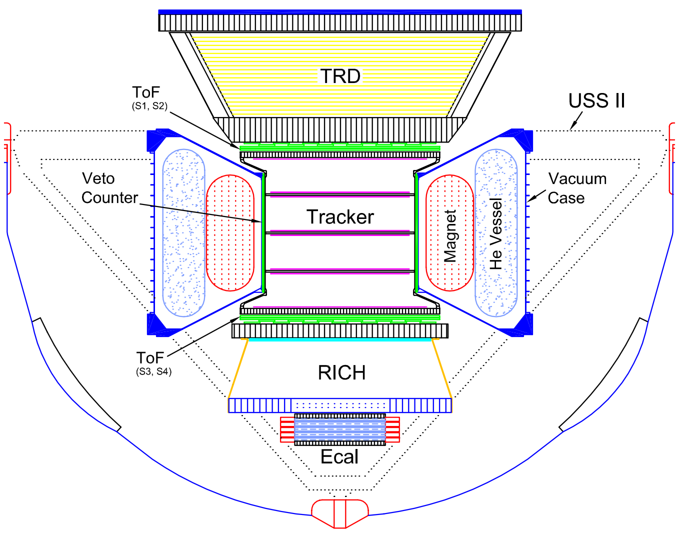

Fig. 1. Schematic view of the AMS-02 experiment which will operate on the International Space Station from the year 2004.

[1]NASA mission STS-91

detector (RICH) and an Electromagnetic CALorimeter (ECAL). The present paper represents an update of a precedent study (Battiston et al. (2000)) of the photon detection potential based on the shuttle-flight version of the detector (AMS-01).

A schematic view of the AMS instrument (AMS-02), in its configuration on the ISS, is shown in Fig.1.

It consists of a cylindrical superconducting magnet spectrometer with 1.2 m inner diameter providing a bending power $BL^2 \simeq 1\,Tm^2$, which will allow the detection of nuclei up to rigidities of the order of 10 TV. The track reconstruction will be performed by 8 planes of silicon detectors with a spatial resolution of 10 μm (30 μm) in the bending (non-bending) projection (Rapin et al. (2001)).

The inner surface of the magnet will be covered by scintillator counters to veto stray trajectories and background particles. On the two end caps of the magnet two scintillators layers, segmented orthogonally in paddles, will measure the Time-of-Flight (ToF) and provide the fast trigger for the experiment.

The TRD, on top of the spectrometer, is $\sim$ 0.6 m long. Its layout consists of multi-arrays of a 12 mm thin foam radiator seen by two layers of fourteen 5$\times$5 mm^2 gas proportional tubes. These arrays will provide a measurement of the x and y coordinates of the transition point of the radiated quanta. The TRD will be sensitive to isotropic incident e^+, p and γ within the full magnet acceptance and will allow a p/e discrimination up to 300 GeV.

The RICH detector will allow light nuclei isotopes separation. Placed immediately downstream the last two ToF planes, it consists of two radiator materials: sodium fluoride (NaF) and aerogel (AGL). A pixel photo-tubes matrix is used for the light detection.

At the bottom of AMS, the ECAL is a three-dimensional electromagnetic sampling calorimeter consisting of 1 mm diameter blue scintillating fibers sandwiched between grooved lead plates. With an overall dimensions of 63$\times$63$\times$16 cm^3 and a total radiation length of 16X_0, the ECAL will provide an energy resolution $\sigma_E/E \sim$ (5.5/$\sqrt{E}$ (GeV) + 1) % providing a proton suppression factor of about 10^{-4} up to 100 GeV.

3 The simulation

The response of the AMS for γ-ray detection by means of the identification and reconstruction of e^+e^- pairs from γ conversions, in the material upstream of the second silicon tracker layer, was studied with the AMS detector simulation and reconstruction program based on GEANT (Brun et al. (1987)).

Gamma rays have been generated isotropically over the full solid angle of the detector, at several fixed energies, ranging from 1 to 300 GeV. All physical processes for electrons and γ-rays were included. However the bremsstrahlung photons were not followed for energies below 20 MeV.

The material in front of the first silicon tracker plane, consisting of the TRD, the first two layers of ToF scintillators, and mechanical supports, represents $\simeq 0.22{X_0}^2$.

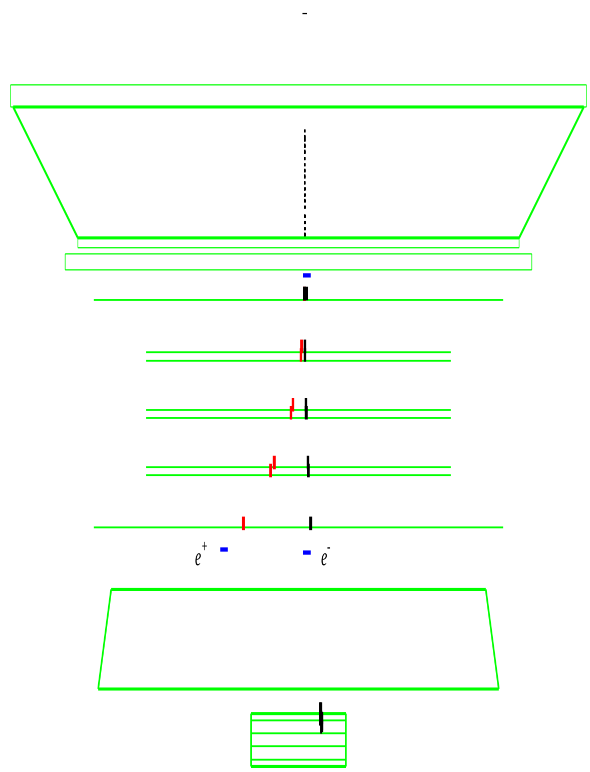

Fig. 2. AMS-02-γ Monte Carlo event: a 10 GeV γ converts in the TRD. e^- is detected also by ECAL. Such an event is triggered by a scintillator paddle in the first ToF layer and two separated hits on the fourth ToF layer.

Events with photons converting in the detector material and releasing a signal in at least two scintillator planes were considered for the reconstruction of the e^+e^- pair in the spectrometer. A minimum of 4 reconstructed hits over a minimum lever arm larger than 3/4 height of the tracker (from the first to the last plane) for each lepton track was required in order to accept the event. Primary γ-ray energy and incidence direction were determined by adding the fitted momenta vectors of all secondaries, evaluated at the entrance of the magnetic field. An example of a reconstructed MC event is shown in Fig.2.

[2] Compared to the 0.3X_0 of the converter plate used in the previous study (Battiston et al. (2000)).

4 The Results

4.1 Sensitivity

Astrophysical γ-sources fall into two categories: point sources, such as blazars and GRBs, and diffuse sources, such as the cosmic isotropic γ-ray background, as well as possible γ-ray emission from neutralino annihilation near the center of our Galaxy. Some galactic sources fall into an intermediate category of "extended" sources, such as pulsar nebula and supernova remnants.

The capability to disentangle a source signal from background depends on several factors: the angular and energy resolutions, the detector aperture and the exposure time at a given position on the celestial sphere. Following EGRET's definition (Thompson et al. (1993)), the solid angle $\Omega(E)$, over which the background must be integrated when viewing a source, is $\Omega(E) = \pi\sigma_{68}^2(E)$, where σ_{68} is defined as the angular radius within which 68% of the source photons fall (Battiston et al. (2000)). The results of AMS-02-γ simulation with the EGRET criteria yield the angular resolutions as a function of photon energy shown in Fig.3. They range from 10^{-4} to 10^{-2} radians, due mainly to the multiple coulomb scattering.

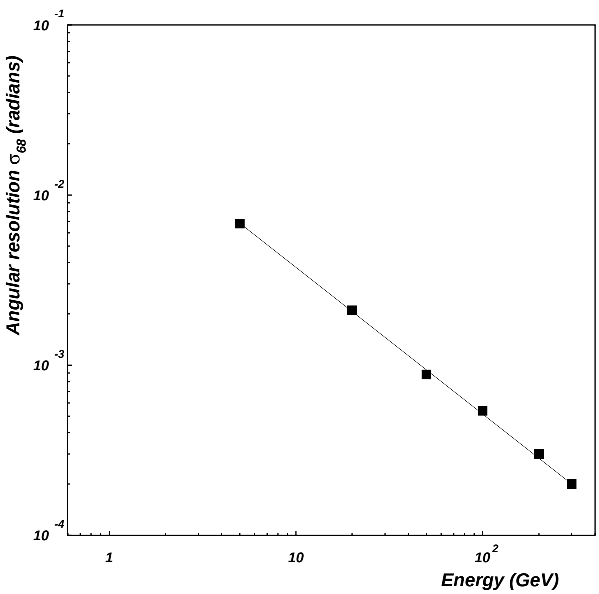

Fig. 3. Angular resolution of AMS-02-γ as a function of primary γ energy in the interval 5 to 300 GeV.

The second figure of merit for photon detection is the detector aperture. The AMS-02-γ aperture has been determined as a function of the γ-ray energy between 1 and 300 GeV (Fig.4). The aperture is a result of three main contributions: the AMS geometrical acceptance (0.5 $m^2 sr$), the pair conversion probability, and the double-track reconstruction efficiency.

As seen in Fig.4, below a γ-ray energy of 5 GeV, the converted electrons have a too small radius of curvature for detection. Above 200 GeV the electron and positron detection is limited by the double-hit resolution of the silicon tracker.

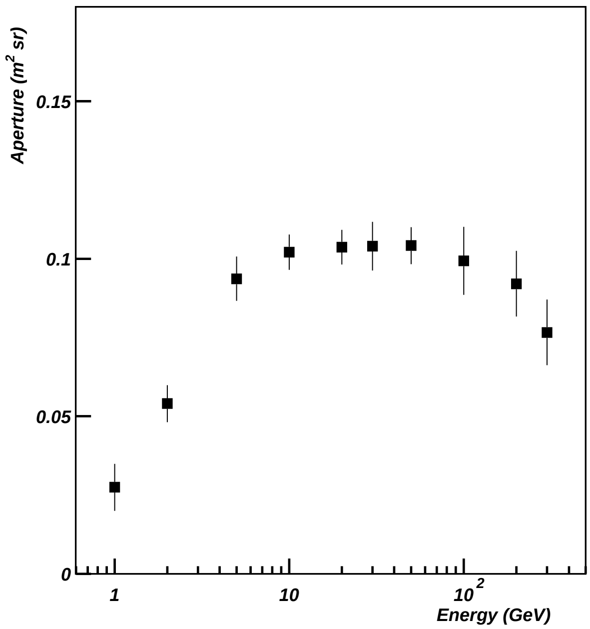

Fig. 4. AMS aperture as a function of γ-ray energy. The errors are statistical.

The AMS-02-γ aperture is also a function of the inclination of the incident photon, dropping to zero at about 50^o as it is shown in Fig. 5.

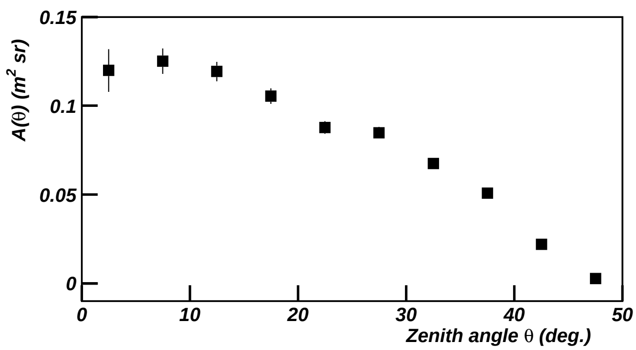

Fig. 5. Differential aperture $A(E,\theta)$ versus zenith angle at 50 GeV.

A second selection was also applied to estimate the acceptance for photons detected only in the electromagnetic calorimeter. We found that this approach would increase the AMS-02-γ acceptance by a factor of 4, attaining 0.3 to 0.4 $m^2 sr$ as a function of the energy, with a maximum energy between 100 and 200 GeV. There is a possibility that the ECAL signal can be implemented in the trigger of the experiment.

4.2 Energy Resolution

The γ-ray energy resolution is dominated by bremsstrahlung losses throughout the material traversed by e^+e^- pairs after the conversion. The fractional energy loss of the leptons is proportional to x/X_0. As a consequence the energy resolution depends on the distance between the conversion point and the position of the second silicon tracker plane.

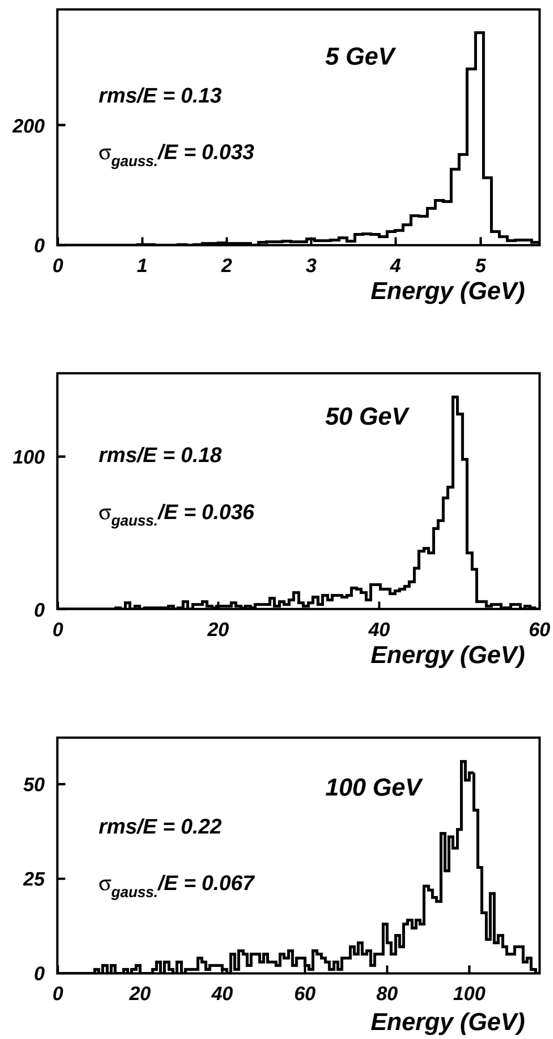

Fig. 6. The reconstructed energy distibutions for three different primary γ-ray energies, 5, 50, 100 GeV. The r.m.s. energy resolution and the width of the "gaussian" peak of the distributions are also indicated.

Figure 6 shows the reconstructed γ-ray energy distributions for primary energies of 5, 50, and 100 GeV. One sees the effect of bremsstrahlung losses in the large low-energy tails of the distributions. The nearly identical appearances of these distributions is a consequence of the fact that the probability for the electron to radiate a fraction ν of its energy as a bremsstrahlung photon depends only on ν.

There are two additional effects in the distributions in Fig. 6: the energy cutoff at 1 GeV due to the minimum detection threshold of the momenta of the leptons, and the broadening of the distribution at 100 GeV due to the fact that trajectory reconstruction errors begin to dominate bremsstrahlung losses in the energy determination. In Fig. 6 the r.m.s. energy resolution and the estimated "gaussian" width of the "peak" are also indicated for the three different primary γ-ray energy.

5 Conclusions

The performance of AMS-02 for γ-ray detection, via pair production, has been studied. Our preliminary results confirm the previous study based on AMS-01 design, $i.e.$ the performance in terms of acceptance, angular and energy resolutions makes AMS-02 a good candidate for gamma-ray detection.

Furthermore the decision to incorporate an electromagnetic calorimeter in AMS-02 enhances the gamma potential detection of the device.

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