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Detection and measurement of gamma rays with the AMS-02 detector

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The Alpha Magnetic Spectrometer (AMS-02) [1] detector will collect data on the International Space Station (ISS) for at least three years. The gamma rays can be measured through gamma conversion into e^+e^- pair, before reaching the Silicon Tracker or by measurement of a photon hitting directly the Electromagnetic Calorimeter (ECAL). AMS-02 will provide precise gamma measurements in the GeV range, which are particularly relevant for Dark Matter searches. In addition, the good angular resolution and identification capabilities of the detector will allow clean studies of the main galactic and extra-galactic sources, diffuse gamma background and Gamma Ray Bursts.

1. Introduction

EGRET measurements of gamma ray fluxes performed in 1990s' are the most precise data available nowadays in the GeV energy range [2, 3, 4]. These data are studied and reinterpreted in many recent works and clearly more precise measurements are demanded. The main fields where more accurate measurements are requested are: emissions from gamma sources (pulsars, blazars, AGNs), diffuse gamma background emission, Dark Matter searches and Gamma Ray Bursts (GRB).

AMS-02 is a detector optimized for detection of charged cosmic rays and performs well in the gamma ray domain. It is sensitive to photons in the poorly explored energy range from 1 GeV up to a few hundred GeV. Due to its large acceptance it will play an important role in the squad of gamma ray observatories already placed or planned to be placed in orbit in the near future.

2. Detector performance

AMS-02 is able to detect gamma rays in two complementary modes. In so called "conversion mode" photons are converted into electron-positron pairs in the Transition Radiation Detector (TRD) material (about $0.25X_0$) before reaching the first Time-of-Flight (TOF) layer. The electron-positron pair is triggered by the TOF system. In this mode the viewing angle is about 42 degrees.

The photon which passes through AMS without interaction can be measured only in ECAL. To trigger for such photons a special ECAL-based trigger has been developed. The viewing angle in this, so called, "ECAL mode" is about 23 degrees.

Both modes are characterized by different energy and angular resolutions, as shown in Figure 1. Their acceptances are comparable: $0.05 - 0.06\ \mathrm{m}^2\mathrm{sr}$.

The AMS-02 orbit and inclination angle are determined by the fact that the detector is rigidly attached to the ISS. From orbit simulation [5] the total exposure time of the detector for the different sky regions is calculated. Convolution of observation time ($\mathrm{T_{obs}}$) and acceptance ($\mathrm{A(E, d\phi) \times T_{obs}}$) gives the sensitivity of AMS-02 for the considered regions of the sky. Maps of the sensitivity are presented in Figure 2.

The main background for gamma detection in both detection modes are protons, due to their high abundance in cosmic rays. Simulations show that the background rejection factor at the level of $\mathrm{O}(10^6)$ can be achieved. This will allow to keep background-to-signal ratio at the level of a few percent.

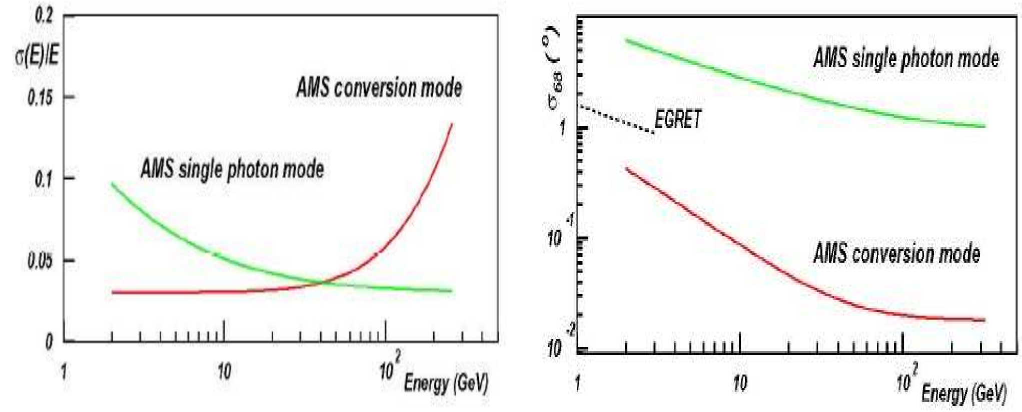

Figure 1. Energy resolution (left plot) and angular resolution (right plot) for the two modes of gamma detection in AMS-02.

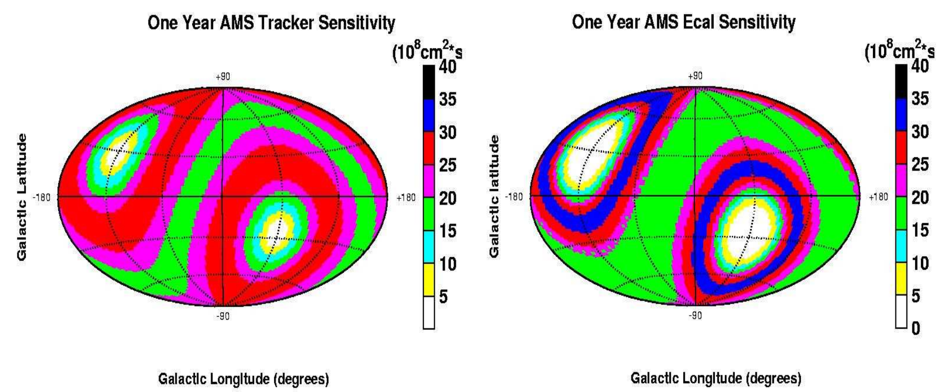

Figure 2. Maps of sensitivity of the AMS-02 detector for the two modes of gamma detection. The time intervals when ISS orbits over South Atlantic Anomaly region are subtracted.

AMS-02 will have a star tracker onboard. This device will allow to determine the reference system for the incoming photons with accuracy better than a few arcminutes. This, together with a very good angular resolution, will allow to localize sources with accuracy better than 2 arcminutes.

The above detector performance were obtained from detector simulation with use of GEANT [6] simulation software and tested in numerous beam tests. There exists a software package (AMS Fast Simulator [7]) for fast estimation of the AMS potential in detection of various gamma ray phenomena. It includes a parametrization of the detector response. Many studies presented here are performed using the AMS Fast Simulator.

3. Astrophysical gamma sources

The 3rd EGRET catalog [4] contains 271 sources among which 170 are unidentified. With larger statistics and a different energy range AMS-02 will provide interesting data about unidentified sources as well as known pulsars, blazars and AGNs. The very good angular resolution of AMS-02 will allow to localize sources more precisely and determine their flux with better accuracy due to better separation from diffuse background. Discovery of new sources is also expected.

For example a possible AMS-02 measurement is presented on the left plot of Figure 3. AMS-02 data on the spectrum of Vela pulsar the in energy range from 5 to 50 GeV, where there is not enough statistics from EGRET, will allow to distinguish between two models of gamma emission [8].

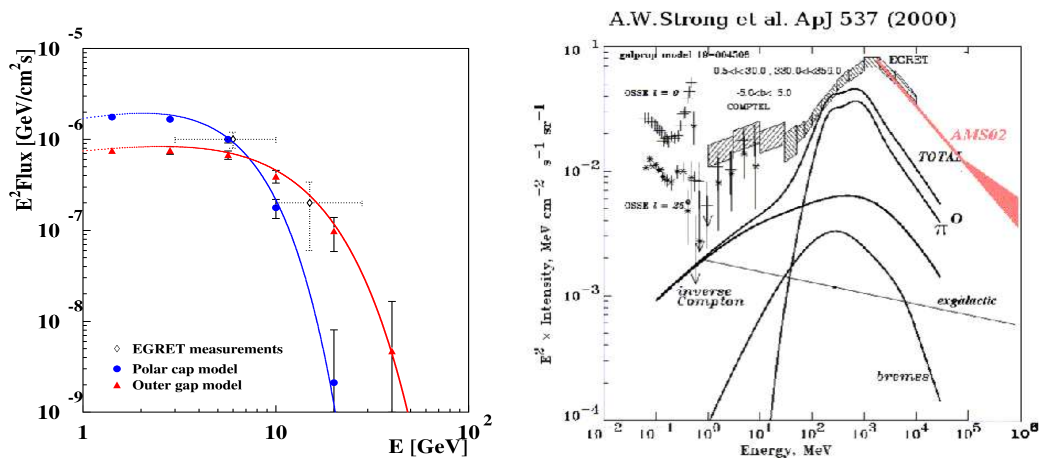

Figure 3. Left plot: expectations from *Outer Gap* and *Polar Cap* models of gamma ray emission from the Vela pulsar. AMS-02 will be able to distinguish between these two models [8]. Right plot: measurements and model predictions for diffuse gamma emission from the central part of the Galaxy [9]. Estimated AMS-02 measurements are shown in red.

4. Diffuse gamma background

The galactic gamma ray diffuse background is believed to be produced in the interstellar medium by π^0 decay, bremsstrahlung and inverse Compton scattering. It has been measured by EGRET [3] and is usually presented as integrated flux in energy bins. It allows not only to create sky maps of the diffuse background but also to perform spectral studies. On the right plot of Figure 3 the gamma ray spectrum observed by EGRET and other experiments is shown together with a gamma ray emission model. The EGRET measurements present a flux excess in the GeV energy region. This is explained in various ways, from model tuning [10] to assumption of Dark Matter annihilation [11]. AMS-02 will contribute to a better understanding of the diffuse gamma spectrum in the GeV region.

5. Dark matter

AMS-02 has potential in observation of Dark Matter signal from the Galactic Center in the gamma channel. The expected signature is a deformation of the spectrum or a monochromatic line from $\chi\chi \to \gamma\gamma, Z\gamma$ processes. More on this subject can be found in [12].

6. Gamma Ray Bursts

Gamma Ray Bursts are the most energetic phenomena in the Universe. Their nature, after many years of observations and collection of rich GRB catalogs, remains unexplained. More observations are needed especially at high energy as the dynamic range of previous experiments extended up to around 1 GeV.

Due to the large AMS-02 acceptance and to the relatively large field of view, observation of a few GRBs during the 3 year mission is expected. AMS-02 observations lie in the unexplored energy range. An extrapolation from previous GRBs allows to estimate that about 30 gammas above 1 GeV will be measured if a burst similar to GRB950503 happens again. In addition, at the time of AMS-02 mission, other dedicated GRB observatories will be on orbit. A synchronization of observations (one of the main reasons for the presence of a dedicated Global Positioning System onboard AMS-02) might lead to interesting results. The good time resolution of the detector will also allow to perform some studies on quantum structure of the space-time [13].

7. Conclusion

The AMS-02 gamma ray physics program is rich. It includes the mapping of the gamma ray diffuse background, observation of gamma ray sources and measurements of their spectra, search for Dark Matter signal and for rare, high energy Gamma Ray Bursts.

8. Acknowledgments

We want to thank the many organizations and individuals listed in the acknowledgments of ref [1].

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