Cosmic Ray Measurements with the AMS experiment

B.Bertucci[a]

[a]Dipartimento di Fisica dell'Università di Perugia e INFN sezione di Perugia,
Via Pascoli , 06100 Perugia, Italy

The Alpha Magnetic Spectrometer (AMS) was flown in June 1998 on board of the shuttle DISCOVERY during its STS91 mission. During 10 days, AMS recorded about 100 Million triggers along a 51.7 inclined orbit at altitudes ranging from 320 to 390 Km. We report on the AMS measurement of the cosmic proton spectrum in the kinetic energy range 0.2 to 200 GeV and of the cosmic helium spectrum in the kinetic energy range 0.1 to 100 GeV/nucleon. The good accuracy of these measurements provides better contraints in the modelling of the primary cosmic ray fluxes, first ingredient for a correct calculation of the atmospheric ν fluxes.

1. Introduction

The AMS experiment has been conceived as a particle physics detector for the search of anti-matter and dark-matter signals in Cosmic Rays (CR). This ambitious program is based on three years of continuous operation of the AMS detector on board of the International Space Station, starting in year 2003.

A prototype of the apparatus (AMS-01) has been built and flown in June 1998 on board of a shuttle, in order to test the design and to gain experience in operating in space. Already from this test flight, a sensible limit has been achieved on the presence of $\bar{\mathrm{H}}\mathrm{e}$ in CR and accurate measurements of proton, lepton and helium fluxes near earth have been performed.

In the following, we will report on the measurements of cosmic proton and helium energy spectra [1], the accuracy of these results being relevant for a better estimate of atmospheric ν fluxes. The AMS-01 apparatus will be first introduced, together with the characteristics of the STS91 mission.

2. The AMS-01 detector

In Fig.1 a side view of AMS-01 is shown together with the definition of the local coordinate system. A cylindrically shaped permanent magnet generates a dipolar B field along the x direction, 0.14 T in the center.

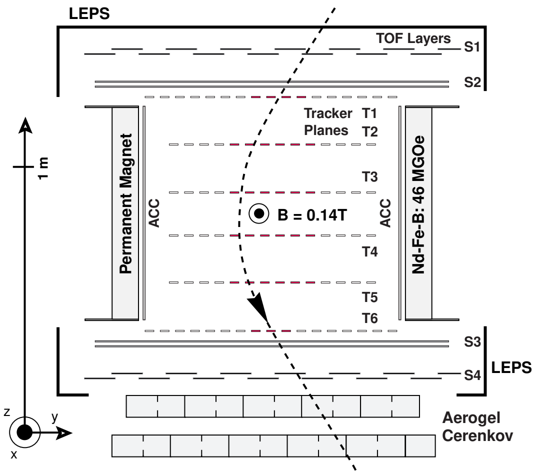

Figure 1. Side view of the AMS01 detector

Six circular planes of double sided silicon microstrip detectors measure the trajectory of the charged particles with a single point resolution of $10(30)\mu$ in the bending(orthogonal) plane. Only the central part of the tracker planes has been equipped with silicon sensors in AMS-01, for a total instrumented area of $\approx 2\mathrm{m}^2$, resulting in an average geometrical acceptance of $0.15\,\mathrm{m}^2\,\mathrm{sr}$ for protons. Two pairs of scintillator planes, alternatively segmented along the x and y directions, cover the top and the bottom of the spectrometer, providing the trigger and measuring the time of flight of particles in the detector. A measure of the magnitude of the charge, Z, is given independently by the energy loss in each of the scintillator planes (up to Z=2) and in the tracker planes (up to Z=8), allowing for a proton background in helium selection $< 10^{-4}$ over all energies. The detector is completed by two layers of Aereogel Cherenkov Threshold Counters, a thin shield of carbon fiber surrounding the TOF system, the Low Energy Particle Shield and a system of scintillators covering the inner surface of the magnet to veto multiparticle events.

3. The STS91 mission

The AMS-01 spectrometer has been flown in 1998, June 2-12, on board of the shuttle DISCOVERY along a 51.7^o inclined orbit at altitudes of 320-390 Km. The first half of the mission has been devoted to the refurnishment of the MIR station and only in the last 100 hours of flight the optimal conditions for AMS data taking have been reached. Time intervals of 19, 25, 20 hours have been spent with the AMS z axis pointing within 0^o, 20^o, 45^o of the zenit: the events collected during these periods are those used for the measurements of cosmic p and He fluxes. The large geographical coverage above the atmosphere and the different data taking attitudes are the real peculiarity of the AMS data: the primary fluxes are measured with the same apparatus and in the same mission at different geomagnetic locations and looking towards different directions.

4. The proton flux

Protons represent $\approx 85\%$ of the incident radiation: their selection is therefore quite straightforward and efficient. A more delicate issue is to translate the measured counting rates into differential proton fluxes. This implies an accurate knowledge of the detector acceptance and resolution both as a function of the rigidity and of the particle's arrival direction and location. A large MC sample (10^7 events) has been used to determine the detector response, the results being crosschecked both with unbiased trigger events taken during the flight and with beam tests (π and p in the energy range 1-14 GeV) at the CERN Sp$\bar{\text{p}}$S ring. The resolution functions obtained with the simulation have been used as inputs in an unfolding procedure to extract the differential energy spectra from the measured ones.

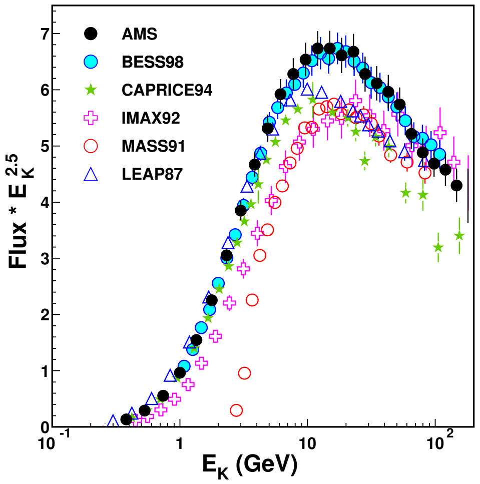

Figure 2. The cosmic p flux multiplied by $E_K^{2.5}$ in units of $GeV^{2.5}/(m^2\,s\,sr\,MeV)$ as measured by AMS and recent balloon experiments [3]

A substantial flux of protons has been measured at all latitudes for rigidities below the expected geomagnetic cutoff. This *second* spectrum is due to secondaries produced in the atmosphere and trapped in the earth's magnetic field. Interesting studies have been done and are still undergoing on its caracteristics, however, only marginal effects are expected from the under-cutoff component on the atmospheric ν fluxes.

We will then concentrate on the results on the cosmic component. It has been selected by requiring the proton rigidity to exceed the cutoff value: $R > R_S(1.2 \times 2\sigma)$, being R_S the maximum cutoff rigidity in a given location according to Stormer's definition and σ the measurement error on R. Multiple checks have been performed to verify the independence of the primary spectra on the AMS position, on its pointing attitude and on possible detector effects: no significant deviations were found from an isotropic cosmic flux having the same intensity all over the spanned locations.

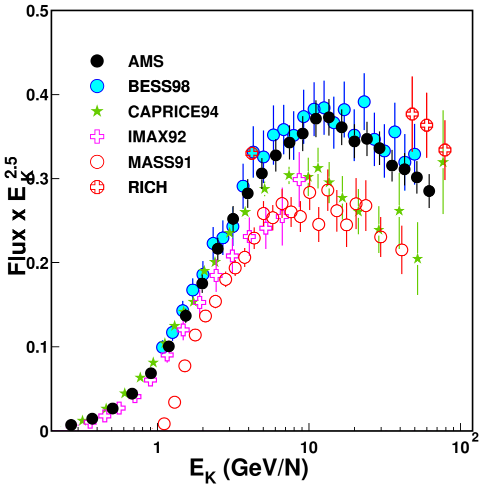

Figure 3. The cosmic He flux multiplied by $E_k^{2.5}$ in units of $GeV^{2.5}/(m^2\,s\,sr\,MeV)$ as measured by AMS and recent balloon experiments [3]

The differential proton flux as a function of the kinetic energy is shown in Fig.2: it is multiplied by $E_k^{2.5}$ and compared with some recent balloon based measurements. The total error is displayed for AMS data points: it varies from 5% to 12% with increasing energy, being dominated by systematic uncertainties.

A nice agreement of AMS and BESS98 measurements can be noticed at all energies: the data taking periods for the two experiments were quite close in time and a direct comparison can be done below few GeVs, where solar modulation effects are expected. A poorer agreement is found with the other measurements. However, it should be pointed out that a common systematic bias could affect these measurements, all performed with the same NMSU/NASA magnet facility equipped with different detectors in various flights.

Fitting the spectrum to a power law in rigidity, $\Phi_o R^{-\gamma}$, in the interval $10 < \mathrm{R} < 200\mathrm{GV}$ yields $\gamma = 2.780 \pm 0.009(\mathrm{fit}) \pm 0.019(\mathrm{sys})$.

5. The helium flux

The He selection has been quite straightforward thanks to the redundancy of Z measurements in AMS. Detector acceptance and resolution have been calculated by means of extensive MC simulation crosschecked with unbias trigger events and beam tests with C and He beams at GSI at energies $E_k = 1 - 6.5\,\mathrm{GeV/n}$. As for protons, a rigidity cut following the Stormer's formula has been used to isolate the cosmic from the second spectrum component: the resulting flux is reported in Fig.3, together with the more recent He measurements [1]. Both the systematic and statistical contributions are combined in the quoted error ($\approx$ 6%) of the AMS data points. Also in this case the BESS98 measurement is in quite good agreement with AMS, while a different normalization is suggested by earlier experiments. Fitting the spectrum to a power law in rigidity, $\Phi_o R^{-\gamma}$, in the interval $20 < \mathrm{R} < 200\mathrm{GV}$, yields $\gamma = 2.740 \pm 0.010(\mathrm{fit}) \pm 0.016(\mathrm{sys})$.

6. Conclusions

Due to the inconsistency among earlier [4] and more recent results [3], quite different parametrizations of the primary CR fluxes have been used until now by the most popular calculations [2] of atmospheric ν fluxes.

Thanks to the AMS results, this problem is basically solved for the lowest part of the energy spectra (R<200 GV), which directly reflects in the predictions for the "sub-GeV" event sample in Super-K. The AMS mission in 2003, with the real detector, will allow to reach a similar accuracy in an extended energy range, up to the TeV region.

REFERENCES

1. J.Alcaraz et al., PLB 472 (2000) 215, J.Alcaraz et. al., [AMS] PLB 490 (2000) 27, J.Alcaraz et al., submitted to PLB
2. M.Honda et al., PRD52 (1995) 4985, G.Barr et al. PRD39 (1989) 3532, V.Agrawal et al. PRD53 (1996) 1314 , V.Bugaev and V.A.Naumov et al.PLB 232 (1989) 391.
3. T.Sanuki et al., astro-ph/0002481, M.Boezio et al., ApJ 518 (1999) 457, W.Menn et al., ApJ 533 (2000) 281, E.S.Seo et al., ApJ 378 (1991) 763, R.Bellotti et al., PRD 60 (1999) 52002, J.Buckley et al., ApJ 429 (1994) 736
4. W.R.Webber et al., Proc. 20th ICRC (1987)

[1] a 15% component of ^{4}He is assumed for AMS data points