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Antimatter, Dark Matter and Cosmic rays with AMS

J.P. VIALLE

**LAPP, IN2P3-CNRS, Chemin de Bellevue, BP110,
F-74941, Annecy-le-Vieux**

abstract

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ANTIMATTER, DARK MATTER AND COSMIC RAYS WITH AMS

J.P.Vialle[1]
LAPP/IN2P3-CNRS and University of Savoie
AMS Collaboration

[1]Laboratoire d'Annecy-le-Vieux de Physique des Particules, Chemin de Bellevue, B.P. 110, F-74941 Annecy-le-Vieux Cedex, France

Abstract

The AMS experiment aims at searching for primordial antimatter, non-baryonic dark matter, and at measuring with high statistics and high accuracy the electrically charged cosmic ray particles and light nuclei in the extraterrestrial space beyond the atmosphere. AMS is the first magnetic spectrometer which will be flown in space. It will be installed for 3 to 5 years on the international space station (ISS) in 2004, covering a range in energy from 1 GeV to a few TeV, with an increase in sensitivity of 3 to 4 order of magnitudes compared to existing experiments. A test flight with the space shuttle DISCOVERY took place in June 1998 with a dedicated instrument and gave many results on the fluxes of particules above and below the geomagnetic threshold. These results are described here with their interpretation. The physics goal and perspectives for AMS on the space station are described as well

1 Introduction

The apparent absence of primordial antimatter (antihelium, anticarbon, ...) in the universe is one of the great puzzles in physics. The absence of annihilation of gamma rays peaks excludes the presence of large quantity of antimatter within a distance of the order of 10 Mpc from the earth, and balloon borne experiments have searched for antinuclei of helium or carbon for more than 20 years with negative results[1)]. On the other hand, was demonstrated by A. Zacharov[2)] that to generate an asymmetric universe made of matter only, starting from a symmetric universe, i.e. an universe in which there is the same amount of matter and of antimatter, as it is in the big-bang theory at the very beginning of the universe, 4 conditions must be fulfilled : i) Violation of the baryonic number ii) Violation of the charge conjugation C iii) large CP violation iv) Baryogenesis out of the thermal equilibrium. These conditions are not supported by particle physics experimental data so far. On the other hand it is advocated, from the absence of observation of gamma ray peaks from matter-antimatter annihilation, and from the spectrum of Cosmic Microwave Background, that large amounts of antimatter if it exists are beyond several hundreds Mpc of the earth[3)]. As a matter of fact, there is no firm experimental foundation to the theories predicting the absence of antimatter. Universe can still have islands of antimatter[4)].

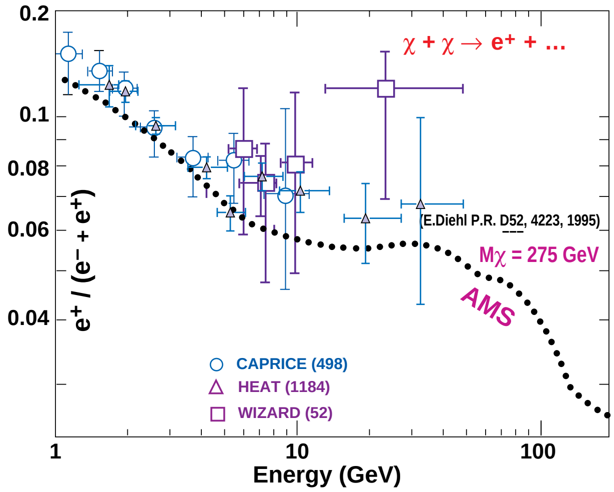

Figure 1: Fraction of positrons in the summed spectra of electrons and positrons with the effect of a neutralino of mass 275 GeV/c^2 according to Diehl et al.

From the motion of the spiral arms of galaxies and of the cluster of galaxies it can be deduced that about 90% of the mass of the universe is non-radiating. Experimental data[5)] show that most of the dark matter is of non baryonic origin, the so-called WIMP's. In supersymmetric theories, a good candidate for WIMP's is the neutralino χ, the lightest supersymmetric particle. It could be detected in cosmic rays through its annihilation into antiprotons, positrons, and gammas[6)] resulting in specific structures in the falling energy spectra of such particles at high energy.

The search for antimatter and for dark matter necessitates measurements at high accuracy and high statistics of electrically charged cosmic rays, with excellent identification of the nature of particles and of the sign of their electric charge. The AMS (Alpha Magnetic Spectrometer)experiment aims at such a measurement. It is a large acceptance high resolution spectrometer which will be installed in 2004 for 3 to 5 years on the International Space Station, taking profit of the background free environment of the extraterrestrial space beyond the atmosphere.

AMS will be able to improve our knowledge of the fluxes of charged cosmic rays and nuclei in a rigidity range typically from 1 GeV to a few TeV, where little or no precise experimental data exist. For light nuclei fluxes, the isotopic content, gives information on the confinement in the galaxy. The unstable isotopes act like a clock which gives the time spent in the galaxy by the nuclei between their production and the measurement. This is for instance the case for the Be^9 and Be^{10}, for which the ratio of abundance gives a direct measurement of the confinement time. AMS will be able to measure accurately the fluxes of light nuclei with their isotopic content up to the oxygen on a kinetic energy range from few tens of MeV/Nucleon up to around 15 GeV/N. AMS will also be able to measure the nuclei spectra for masses up to the aluminium in an energy range up to about 1 TeV, providing invaluable informations on the mechanisms of galaxies.

2 AMS on the international space station ISS: AMS02

AMS is scheduled to fly to the international space station ISS in march 2004, and to take data for 3 to 5 years.

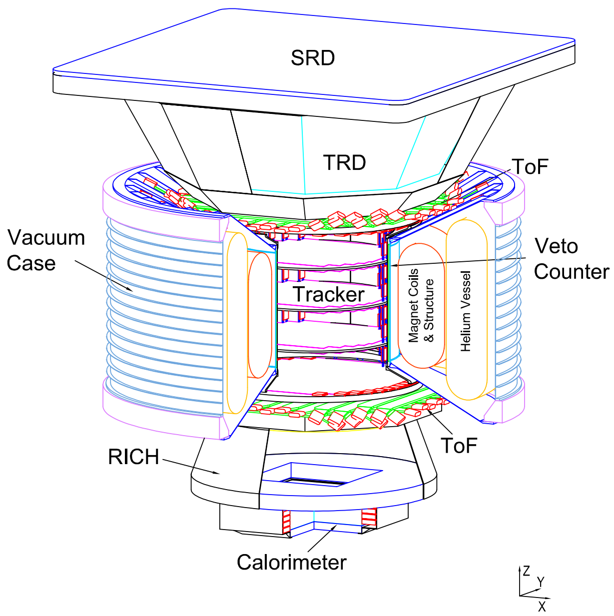

Figure 2: The AMS02 detector to be installed on the International Space Station

The AMS detector is designed around a superconducting magnet with a cylindrical inner volume of 1.115 meters diameter and 80 cm height giving a bending power of $BL^2 = 0.86Tm^2$. Eight layers (6.45 m^2) of double-sided silicon tracker placed inside the magnet provide a coordinate resolution of 10μ in the bending plane and 30μ in the non-bending plane. This will allow to measure particle momenta with a resolution better than 2% up to 100 GeV, 20% at 1 TeV, and to have a excellent determination of the sign of electric charge up to several TeV.

Four layers of Time of Flight (TOF) hodoscopes in plastic scintillator, 2 above and 2 below the tracker,provide precise time of flight measurement (about 120 picoseconds) and dE/dx measurements. A layer of Veto counters made of plastic scintillator lines the inner face of the magnet to ensure that only particles passing through the magnet aperture will be accepted.

A Transition Radiation Detector placed above the TOF detector, made of 20 planes of straw tubes and foam, will identify electrons and positrons with a rejection factor against hadrons of 10^2-10^3 from 1.5 GeV to 300 GeV, and will give additional measurements of the trajectory of particles.

Below the TOF, a RICH cerenkov counter with an aerogel radiator measures the velocity (to 0.1%) and the charge $|Q|$ of particles and nuclei. Combined with the momentum measurement in the tracker, it will enable AMS to measure directly the mass of objects. Nuclei up to Aluminium will be identified on the whole energy range of AMS (up to 1 TeV/n), and isotopic content will be measured up to Oxygen for nuclei with an energy per nucleon below 12 GeV.

Underneath the RICH, an imaging electromagnetic calorimeter made of a sandwich of lead and scintillating fibers of depth 16.5 X_0 will measure the electromagnetic shower energy with an accuracy of a few percent and the direction of electromagnetic particles to about 2^0. Thanks to its very fine granularity (18 sampling in depth, and a transverse granularity of 0.5 Moliere radius in both direction) the calorimeter will allow to achieve a rejection power of electron, positron and gammas against hadrons close to 10^4, which combined with the TRD will achieve the identification power required for the precise measurement of charged cosmic rays fluxes up to the TeV range.

The detector was designed with two main principles :

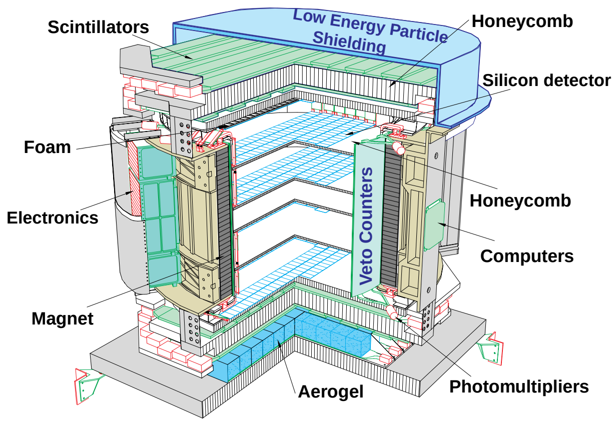

Figure 3: The AMS01 detector

i) a minimal amount of material on the particle trajectory to avoid possible sources of background andto minimize large angle nuclear scattering along the trajectory.

ii) many repeated measurements of momentum, velocity, charge, energy loss, in order to get excellent identification power and background rejection capability.

The acceptance of the detector for antihelium search is 0.5 m^2Sr.

3 The precursor flight STS-91 : AMS01

In order to test the technology and to have a first measurement of the environmental conditions on the space station, it was decided to fly a first version of the detector on board of the space shuttle DISCOVERY. This so-called AMS01 precursor flight took place in june 1998 and lasted 10 days. AMS consisted mainly of a permanent magnet, a silicon tracker, time of flight hodoscopes, anticoincidence counters, and an aerogel threshold Cerenkov counter. The acceptance was about 0.3 m^2sr.

The permanent magnet had the same inner volume and the same field structure as the superconducting magnet of AMS02, with a bending power of 0.14 Tm^2. There was only six planes of double sided silicon microstrip detectors. The four layers TOF hodoscope was the same as in AMS02. The typical accuracy on the time measurement was 120 psec for particles of unit charge, and 105 psec for charge $|Z| = 2$, allowing to identify electrons and positrons against protons up to 1.5 GeV/c. An other velocity measurement for identifying positrons and electrons was made by a threshold Cerenkov counter[7)] with an aerogel radiator of refractive index n=1.035, giving a rejection factor of about 300 up to 3.7 GeV/c. Finally, the detector was also shielded from low energy (a few MeV) particles by thin carbon fiber walls. The basic trigger was made of the coincidence of signals in 3 out of 4 of the TOF planes, with a veto on a signal in the anticoincidence counters.

After the flight, the detector was extensevely checked at two accelerators: At GSI Darmstadt with Helium and Carbon beams from 1.0 to 5.6 GV in rigidity at 600 incident angles and locations for a total of 10^7 events, and at CERN-PS with protons of 2 to 14 GeV at 1200 incident angles and locations for a total of 10^8 events. This ensured that the behaviour of the detector and its performances on momentum measurement, mass separation and charge separation were thoroughly understood.

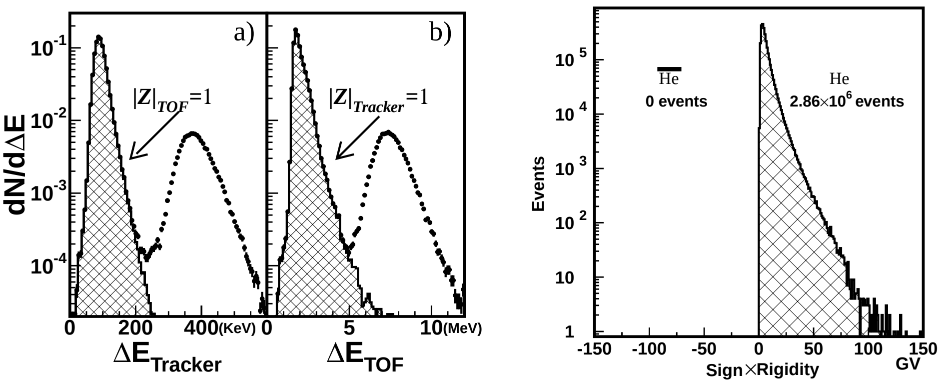

Figure 4: Charge separation from dE/dx (left) and Measured rigidity times the charge sign for selected $|Z| = 2$ events (right)

During the flight STS-91 the orbit was the same as the orbit of the space station. It was inclined by 51.6^o on the geographic equator, at an altitude varying between 320 kms and 390 kms. More than 100 millions triggers in total were gathered.

The fluxes of cosmic rays from outer space is affected by the earth magnetic field which bends their trajectories back to space when the energy is below a threshold that depends on the impinging angle and the geomagnetic latitude of the particle. Near the magnetic pole the kinetic energy threshold is as low as 10 MeV while at the magnetic equator it raises beyond 10 GeV. In the South Atlantic the magnetic field is much weaker (i.e. the so-called SAA or South Atlantic Anomaly) which allows a high flux of low energy particles to reach the Earth. Data taken while passing through or near the SAA were excluded from all the analysis.

4 Search for antihelium

For this search[8)], the sample was restricted to data taken with the shuttle attitude such that the z-axis of AMS was pointing toward the zenith within an angle of 45 degrees. Events were selected after full reconstruction (momentum, sign, velocity, direction upward or downward, energy loss in the tracker and in the TOF estimated by truncated mean) and were required to give hits in at least 4 tracker planes out of 6, and to have an energy loss in tracker and in TOF compatible with Z=2 charge. The latter criteria rejected the background of electrons with wrongly measured charge, since the combined charge confusion probability was found to be less than 10^{-7} (fig 2). The possibility of misidentifying the direction upward or downward of the cosmic ray was found to be negligible from a control sample. To get rid of large angle nuclear scattering on one of the tracker plane, it was also requested that the parameters of the track reconstructed with the first 3 hits, the last 3 hits, and using all the hits in the tracker be compatible. To remove events with colinear delta rays which could disturb the reconstruction a last cut was applied on events with an excess of energy deposited within $\pm$ 5 mm of the track. Finally a probability function was constructed from the measurement of velocity, rigidity, and energy loss to to check the compatibility of the track with the passage of an helium or antihelium nuclei with A=3 or 4. While this last cut removed the 4 last remaining antihelium candidates, the Helium sample was very little affected. A total of $2.8 \cdot 10^6$ He was obtained in a rigidity range of up to 140 GV while there was no antihelium at any rigidity(fig 4). The limit on antihelium is: N(antihelium)/N(helium)$< 1.1 \cdot 10^{-6}$ over the range 1 to 140 GV in rigidity. The same study applied to nuclei with $|Z| > 2$ gave $1.56 \cdot 10^5$ events in the same rigidity range and no antinucleus candidate.

5 Measurement of spectra at high energy

Spectra of cosmic rays are generally expected to fall off like a power law at high energy. A measurement of the slope for protons and helium nuclei has been done with the AMS-01 data[9, 10)].

Protons and Helium are easy to study since they are the most abundant charged cosmic rays. All the other ones are orders of magnitude lower in flux.The data used for this study were restricted to the periods when the axis of AMS was pointing toward the Zenith within 45^o. It was required to have at least 4 hits in the tracker in the bending plane and 3 in the non-bending plane in order to fit the particle rigidity R=$pc/|Z| \cdot e$. The charge was measured from energy loss in tracker and TOF, leaving less than 10^{-4} proton contamination in the Helium events whose flux is typically 10 times lower. The remaining background events in the proton sample from pions produced in the top part of AMS was found to be less than 0.5% below 1 GeV and vanishing rapidly with energy, while the contamination of deuterons was reduced to a negligible level by requiring the measured mass to be within 3 standard deviations of the proton mass. The distributions obtained were corrected for the differential acceptance of the detector as a function of the latitude and of the pointing angle, giving a contribution to the total systematic error of 5%. They were then unfolded for the effect of the rigidity resolution.

After applying all these corrections the spectrum was parametrized by a power law in rigidity as: $\Phi_0 \cdot R^{-\gamma}$

Fitting the parameters on the rigidity range 10 to 200 GV for the protons yields :

$$\gamma = 2.78 \pm 0.009(fit) \pm 0.019(sys)$$
$$\Phi_0 = [17.1 \pm 0.15(fit) \pm 1.3(sys) \pm 1.5(\gamma)]GV^{2.78}/(m^2.sec.sr.MV)$$

Fitting the parameters on the rigidity range 20 to 200 GV for the Helium yields:

$$\gamma = 2.740 \pm 0.010(fit) \pm 0.016(sys)$$
$$\Phi_0 = [2.52 \pm 0.09(fit) \pm .13(sys) \pm .14(\gamma)]GV^{2.74}/(m^2.sec.sr.MV)$$

6 Particles spectra below the geomagnetic threshold

6.1 Protons fluxes

Due to the difficulty to launch and operate a magnetic spectrometer in space, the previous measurements of charged particles at high energy were done with balloon-borne experiment, flying at a maximum altitude of 40 kms,where there is still 5 g/cm^2 of atmosphere above. It had been demonstrated by Stoermer[[11)]] that if there was under cutoff particles they could not come from the outer space. Under cutoff particles were detected and classified in 3 categories : i) Atmospheric Secondaries, for the particles produced in the air above the detector and going downward ii) Splash Albedo for upward going particles produced by interaction in the air iii) Return Albedo for the fraction of splash albedo going back to the earth on the opposite atmosphere. Particle produced and then detected in these experiments were immediately absorbed in the atmosphere. At higher altitude like the 400 km orbit of AMS, no measurement existed above 200 MeV.

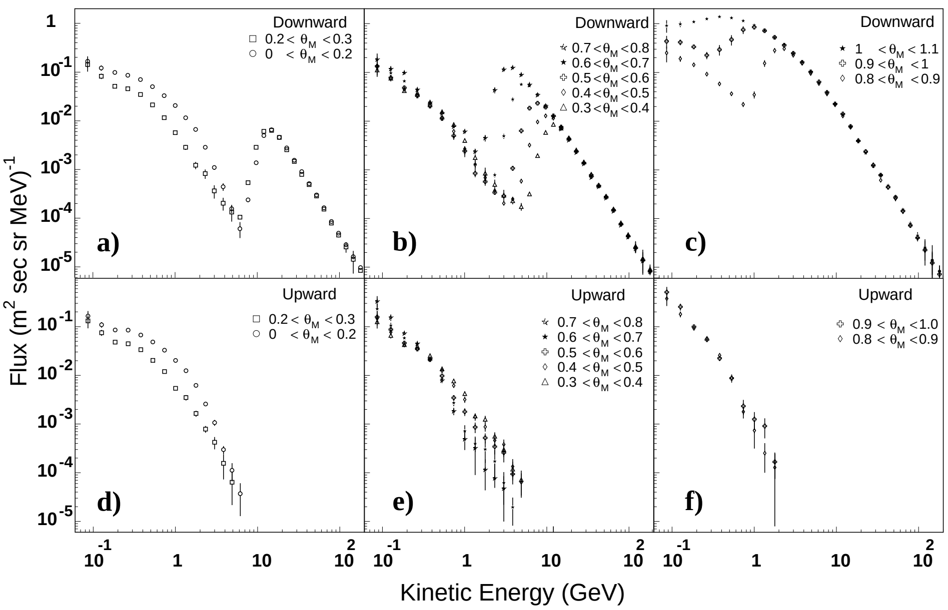

Figure 5: Fluxes of proton upward and downward in bins of geomagnetic latitude

It was a surprise in AMS to observe a large flux of under cutoff particles up to few GeV in energy, and that around the magnetic equator particles were trapped for a long duration[12)].

For the study of the proton flux, the sample was restricted to the period in which the z-axis was pointing within 1^o of the zenith (downward going particles) or of the Nadir (upward going particles). The background was found negligible like at higher energy and the corrections for the differential acceptance and the detector resolution were the same.

The effect of geomagnetic cutoff shows up very neatly as a function of the geomagnetic latitude. At high energy, say above 10 GeV, all the spectra have the same behavior. Surprisingly, a second (secondary) spectrum starts below the geomagnetic cutoff with a rate about an order of magnitude below. Near the equator the secondary spectrum has a distinct structure. In the region $\Theta_M < 0.3$, the spectrum extend from the lowest measured energy, 0.1 GeV to about 6 GeV, with a rate of $70m^{-2}.sec^{-1}.sr^{-1}$. In all the bins in latitude up to $\Theta_M = 0.7$ the secondary spectrum of downward particle has a flux equal to the one of upward particles measured with the detector pointing toward the earth (fig 5). By tracing back 10^5 protons of the secondary flux in the earth magnetic field and stopping the extrapolation either when the particle reach the top of the atmosphere defined at 40 kms, or when the flight time reached 10 seconds, it was found that all the protons from the secondany spectrum originate in the atmosphere. 30% of the protons flew for less than 0.3 seconds (so-called “short lived” particles) and their origin in the atmosphere is uniformly distributed around the globe reflecting the shuttle orbits. The remaining 70% , so-called long-lived particles, flew for more than 0.3 sec and originate from a restricted geographic region (Fig.6). This global behaviour with a complicated path of particles in the geomagnetic field is different from what is observed either with balloon-borne experiments in which particles are all “short lived”, or with satellites in the radiation belts where the protons bounce across the equator for a much longer time.

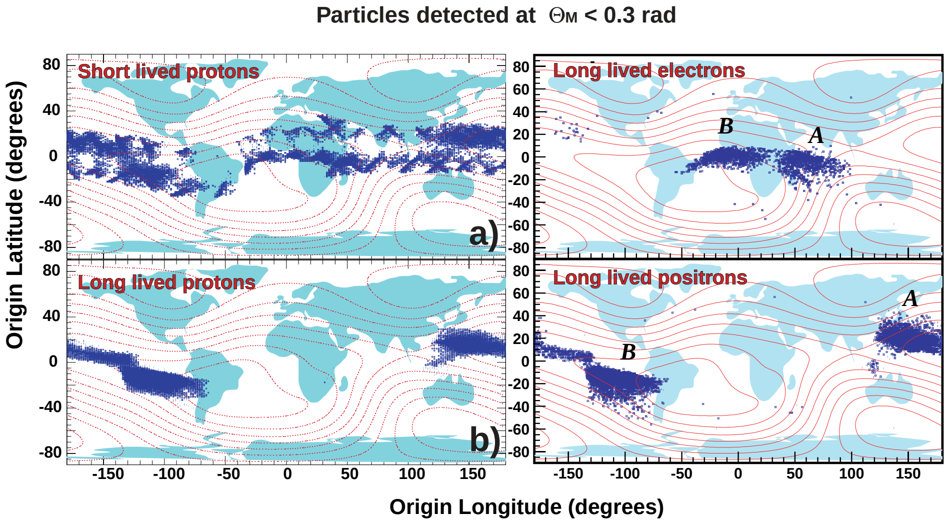

Figure 6: Geographical origin of a) short-lived and b) long-lived protons with $p < 3GeV/c$ (left) compared with geographical origin of long-lived electrons and positrons (right). The dashed lines indicate geomagnetic field contour at 380 km.

6.2 Electron and Positron measurements

AMS was also able to measure electrons and positrons[13)]. The electrons thanks to their negative sign have clear identification and very small background, hence AMS was able to measure their spectra with limited statistics up to energies of 100 GeV. For a geomagnetic latitude of $\Theta_M < 0.3$, it was found that the electron spectrum has the same behaviour as the proton one, with a secondary flux below the geomagnetic cutoff extending up to 3 GeV (fig 7) and the same amount of electrons moving downward and upward, uniformly spread around the globe. For positrons, the high flux of protons with a rate about thousand time higher gives a lot of background at high energy, hence the study was done only below 2 GeV, an energy range where the time of flight of the particle and the signal in the aerogel counter allows to reduce the proton misidentification to a negligible level. As a consistency check, the positron fraction over the sum of positron and electron rate was compared in the polar region ($\Theta_M > 1.0$) to the previous measurement by balloon borne experiments and was found in excellent agreement.

The electron and positron spectra exhibits the same behaviour as protons spectra, with a secondary flux below the geomagnetic threshold which contains an equal number of downward and upward going particles. In the geomagnetic equator region $\Theta_M < 0.3$ radian the energy range 0.1 to 2.5 GeV, the sample contains also the so-called short-lived and long-lived particles. Short-lived electrons and positrons origin reflects the orbits of the shuttle while long-lived positrons come from the same limited geographical region than protons. Long-lived electrons originate from a restricted geographical region which is complementary of the one of protons and electrons. Eventually, the flux of positrons becomes 5 times higher than the electron one in the equator region.

6.3 Measurement of Helium fluxes and mass spectrum

Below the energy threshold after the fall of the primary spectrum a secondary spectrum shows up, 2 to 3 order of magnitude smaller in flux, in the equatorial region $|\Theta_M| < 0.4$ rad. Fitting the mass of helium nuclei above the threshold one gets M = 3.64 ± 0.01 GeV/c^2

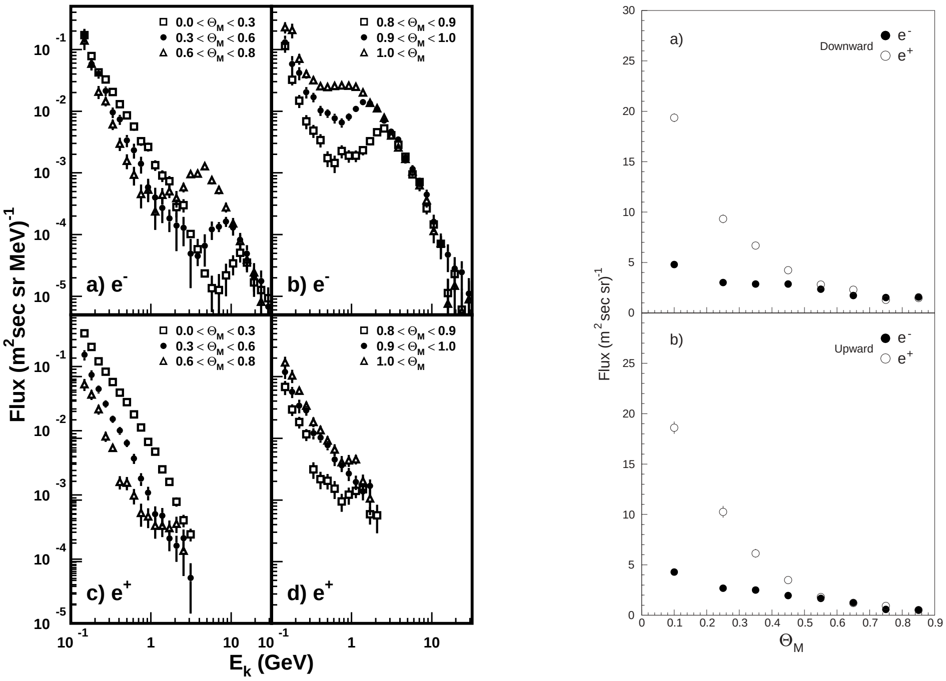

Figure 7: Electrons and positrons as a function of geomagnetic latitude. On the left the flux spectra for downward going electrons(a,b) and positrons(c,d) are shown. On the right the propoerties of second lepton spectra flux : (a) downward and (b) upward going electrons and positrons integrated over the range 0.2-2.5 GeV

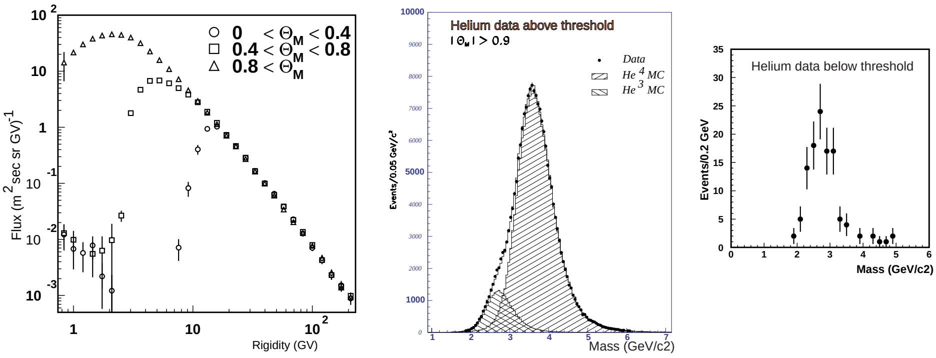

Figure 8: The left part of figure shows the spectra of Helium nuclei in bins of geomagnetic latitude, which exhibits also a secondary spectrum. The central figure shows the mass distribution of Helium candidates above threshold, compatible with a strong content of Helium 4, while the right figure shows the mass distribution of particles below threshold which is compatible with Helium 3.

in the polar region $|\Theta_M| > 0.4$ rad, and M $= 3.65 \pm 0.09$ GeV/c^2 in the equatorial region $|\Theta_M| < 0.4$ rad. Comparing with the He^4 mass of 3.727 GeV/c^2, it shows that the content is mostly He^4. However, the same mass fitting applied to Helium nuclei below the threshold in the equatorial region gives a mass of 2.86 ± 0.04 GeV (fig 8), close to the He^3 mass of 2.809 GeV/c^2 which implies that these nuclei are mostly He^3 which could be due to spallation of He^4 on the atmosphere.

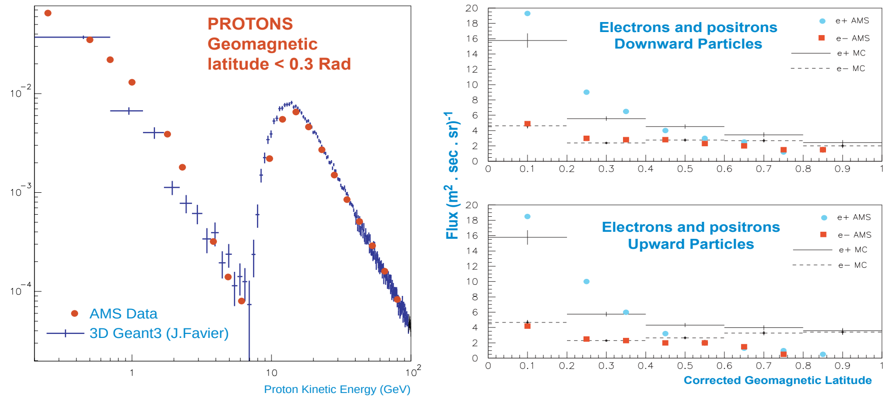

Figure 9: Comparison of Simulation and AMS data. The left part shows the energy spectrum of protons near the equator, while the right figure shows the flux of electrons and positrons for upward and downward particle.

7 Interpretation of the physics results of AMS01.

To understand the data under geomagnetic cutoff,a simulation has been made in LAPP[14)] with a detailed description of the earth atmosphere and of the earth magnetic field. Protons, electrons, and heliums were generated isotropically at 20 earth radii with energy spectra taken from the measurement of AMS. Particles were traced along the magnetic field and for those interacting with the atmosphere the secondary particles from the interaction were also traced to check if they cross the orbit of the detector. This simulation reproduced quite well the observed behaviour below the geomagnetic cutoff. As an example, the figure 9 shows the comparison of experimental data and Monte-Carlo simulation for the energy spectrum of protons, and the relative behaviour of electrons and positrons. This result was confirmed by simulations of other groups[15)].

The effect of trapping arould the geomagnetic equator, and the concentration of the origin of long-lived particle in a restricted geographic area is also well explained by the structure of the earth magnetic field. The earth magnetic field is in first approximation a dipole inclined of about 11^o with respect to the earth rotation axis, and the south magnetic pole near the north geographic pole. The dipole axis is shifted by about 400 kms from the center of the earth. Due to this configuration, particles are trapped in the earth magnetic field and they bounce north and south around the equator and oscillate east-west, but the altitude of the trajedctory varies as a function of the longitude, which impose that only particle generated in a restricted range of longitude can be trapped with their trajectory staying most of the time out of the atmosphere.

8 Conclusion

Though the flight STS-91 was only a technological test, AMS obtained numerous, precise, and sometimes unexpected results on charged cosmic rays[16)], which demonstrates the quality of the instrument and its capability to fulfill its physics program in the future. A very detailed study of particle fluxes under the geomagnetic cutoff was achieved. The AMS02 experiment on the International Space Station will now concentrate on primary fluxes, and higher energy. Its design is specially suited to the range of energy from 1 GeV to a few TeV, a domain which is

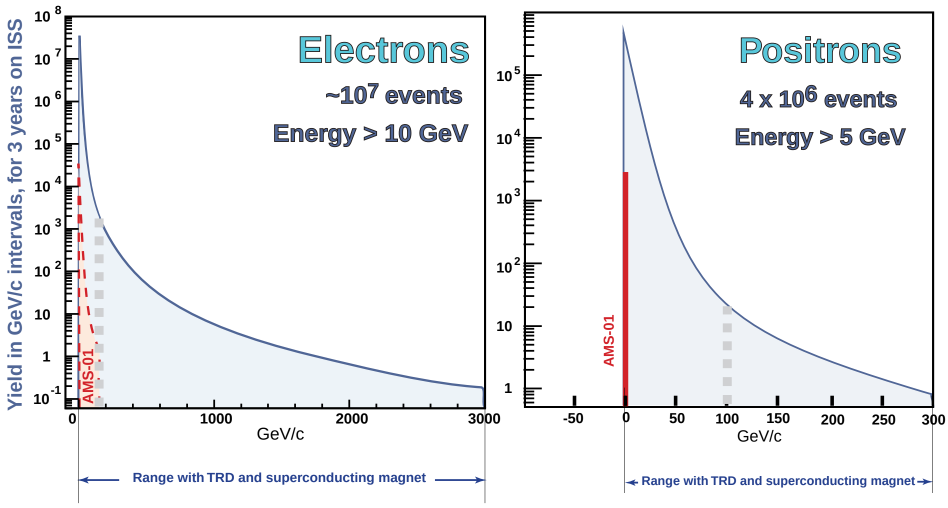

Figure 10: Measurement of electrons/positrons with AMS02

still largely unexplored. The long duration of data taking on the space station, 3 to 5 years, will enable AMS to collect a huge amount of data : 3 order of magnitude more than in AMS01, a much larger domain in energy, and a particle identification capability very powerful. The figure 10 shows an example of the capability of the new detector compared to AMS01.

All the fluxes of charged particles and nuclei will be measured at the same time on a wide energy range. This is especially important for the models of the dynamics of galaxies, since it allows to get rid of systematic errors on the relative fluxes. Furthermore, AMS is also capable of measuring high energy gamma rays, either by electron-positron pair conversion in the upper part of the detector, or by conversion in the electromagnetic calorimeter. AMS will be able to observe cataclysmic phenomena like AGN or GRB's in the domain of a few GeV to typically 300 GeV where no data exist yet. This should improve dramatically our knowledge of these phenomena.

With AMS on the space station, a new domain of energy for cosmic rays becomes accessible, in which many surprises could happen.

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References

1 G.F.Smoot et al. *Phys. Rev. Lett.*35 (1975) 258; G. Steiman et al. *Ann. Rev. Astr. Ap.*14 (1976) 339; G. Badhwar et al. *Nature* 274 (1978) 137; A. Buffington et al. *ApJ* 248 (1981) 1179; R.L. Golden et al, *ApJ* 479 (1997) 992; J.F.Ormes et al., *ApJ Letters* 482 (1997)187 ; T. Saeki et al., *Phys. Lett.* B422 (1998) 319;

2 A. D. Sacharov, *JETP Lett.* 5, 24, (1967).

3 Cohen, De Rujula, and Glashow *ApJ* 495 no.2.1, pp.539-549, (1998).

4 M. Yu. Khlopov et al., *Phys. Rev.* D62 (2000)

5 V.S. Berezinsky et al., in *TAUP 95 Conference*, Nucl. Phys. B, Proc. Suppl. : 48 (1996)

6 E. Diehl et al., *Phys.Rev.* **D** 52, 7 (1995).

7 F. Barancourt et al, *The AMS-01 Aerogel Threshold Cerenkov counter Nucl. Instrum. Methods* A, V465/2-3 (2001).

8 J. Alcaraz et al., *Search for antihelium in cosmic rays*, AMS Collaboration, *Phys. Lett.* B461,(1999)387.

9 J. Alcaraz et al.,*Cosmic Protons*, AMS Collaboration,*Phys. Lett.* B490,(2000)27.

10 J. Alcaraz et al.,*Helium in near earth orbit*, AMS Collaboration,*Phys. Lett.* B494 (2000) 193.

11 C. Störmer, *The Polar Aurora*, (Clarendon Press) Cambridge 1955.

12 J. Alcaraz et al., *Protons in near earth orbit*, AMS Collaboration,*Phys. Lett.* B472, 215 (2000).

13 J. Alcaraz et al.,*Leptons in near earth orbit*, AMS Collaboration,*Phys. Lett.* B484, 10 (2000).

14 J. Favier, R. Kossakowski and J.P.Vialle, LAPP-Note

15 L. Derome et al.,*Phys. Lett.* B489,(2000)1; V. Plyaskin, HEP-PH/0103286

16 J. Alcaraz et al., AMS Collaboration, Physics Report in preparation.