Perspectives for indirect dark matter search with AMS-2 using cosmic-ray electrons and positrons

B Beischer, P von Doetinchem, H Gast, T Kirn and S Schael
I. Physikalisches Institut, RWTH Aachen University, 52074 Aachen, Germany
E-mail: Stefan.Schael@physik.rwth-aachen.de

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Abstract. The AMS-2 experiment will be launched with the Space Shuttle Discovery and installed on the International Space Station in 2010. It is designed to perform precision spectroscopy of many different cosmic-ray species including electrons and positrons. While the nature of dark matter is as yet unknown, dark matter annihilating in the Galactic halo is a well-motivated source of cosmic-ray electrons and positrons. The cosmic-ray positron fraction data available so far show significant deviations between different measurements and from the expectation for purely secondary production. The differences between the measurements up to particle energies of 6 GeV can be understood in a framework of charge-sign-dependent solar modulation and the spectra show excellent agreement if corrected for these time-dependent effects. Recent observations of an excess in the high-energy electron spectrum by ATIC might be connected to the excess in the positron fraction. A possible source of both signatures could be dark matter annihilation or a nearby pulsar. A measurement of the anisotropy of high-energy electrons could distinguish between both scenarios. Therefore the sky coverage of AMS-2 will be discussed in addition to possible dark matter scenarios and the sensitivity of the AMS-2 experiment to these effects.
1. Introduction

Cosmic rays mainly consist of nuclei. Roughly 90% of them are protons, 9% are $\alpha$-particles and heavier nuclei make up the rest. Electrons, positrons and antiprotons are found in small quantities. Starting in the GeV range, the number density of primary cosmic rays as a function of energy follows a power law (figure 1 left), $dN/dE \propto E^{-\gamma}$ with a spectral index for protons of $\gamma_p = 2.7$ up to roughly $10^{15}$ eV. At energies below a few GeV, the spectra of cosmic rays are affected by solar modulation.

As cosmic rays travel through the Galaxy, their spectra are altered and their composition is changed by a variety of physical processes. Hadronic interactions of protons and nuclei with interstellar matter create secondary charged particles, as well as $\gamma$-rays by $\pi^0$ production. Electrons lose energy by bremsstrahlung processes due to the interstellar matter, synchrotron radiation in the Galactic magnetic field, and inverse Compton scattering on photons of the cosmic microwave background and of starlight. Radioactive isotopes decay in flight. To simulate these effects we have chosen to use the numerical model described by the Galprop code [8, 9], version 50p, which incorporates as much current information as possible, for example, on galactic structure and source distributions. There are two sets of propagation parameters for Galprop that have been found to give a good description of a wide range of available cosmic-ray data, the so-called conventional and the plain diffusion model [8].

Recent measurements of cosmic-ray electrons and positrons show interesting new features (figure 2) not expected within the Galprop model. At low energies, the new PAMELA measurement [10] of the positron fraction deviates significantly from previous measurements [4], [11]–[14]. We will show in this paper that this can be well understood in the framework of a charge-sign-dependent solar modulation (section 2). At energies above 10 GeV, the positron fraction measured by PAMELA deviates significantly from the expectation for purely secondary production as calculated in the framework of the Galprop program, confirming earlier measurements but with much better statistics. The origin of this feature in the positron fraction has been discussed since the first HEAT measurements taken in 1994 [3, 21]. Various explanations have been suggested, varying from new effects in cosmic-ray propagation, to a nearby source for electrons and positrons like a pulsar or dark matter annihilation (sections 3 and 4). We will discuss the prospects to solve these questions with new measurements from AMS-2 [22]. At energies around 500 GeV, the ATIC experiment [18] and PPB-BETS [19] have reported an excess in the combined flux of electrons and positrons. This could well be connected to the feature in the positron fraction if a local source produced an equal amount of electrons.
Figure 1. Left: measured fluxes of protons [1], helium [2], electrons and positrons [3, 4], antiprotons [5, 6], and diffuse \( \gamma \)-rays from the Galactic center region [7]. The solar-modulated predictions obtained in the conventional Galprop [8, 9] model for each species are included. Right: energy dependence of the proton-to-positron ratio in cosmic rays as predicted by Galprop [8, 9].

Figure 2. Left: the positron fraction measured by PAMELA [10] and by AMS01 [4, 11], HEAT [12], CAPRICE [13], TS93 [14] and the weighted mean of these data [15] together with the secondary background as predicted by Galprop's conventional and plain diffusion models. Right: the cosmic-ray electron spectrum measured by AMS01 [4], CAPRICE [13], HEAT [16], SANRIKU [17], ATIC [18], PPB-BETS [19] and HESS [20], together with the prediction for a nearby pulsar.

and positrons at these energies as for example a pulsar or dark matter annihilation could do. We will discuss up to which energies a direct measurement with a magnetic spectrometer like AMS-2 could contribute and help to understand the origin of this bump.

The new PAMELA data show that we have entered a new era of astroparticle physics where precision data are available to be compared with advanced theoretical models like Galprop for cosmic-ray propagation. The previous data sets for the cosmic-ray electron spectra as shown
in figure 2 (right) show significant variations in the normalization and in the spectral index. In order to ensure that this is not due to time variations in the cosmic-ray flux an overlap in the measurement time between experiments is needed, as will be the case in the coming years between PAMELA, GLAST/FERMI [23] and AMS-2.

The other crucial issue is the understanding of the hadronic background, which is induced mainly by protons (figure 1 right). Even though it seems unlikely that the rise in the positron fraction is a detector artifact, this option cannot completely be excluded today. The ratio of protons to positrons as predicted by Galprop (figure 1 right) increases very fast with energy due to the different spectral indices of protons and positrons. With an electromagnetic calorimeter alone, as in PAMELA, GLAST/FERMI and ATIC, it is experimentally very challenging to achieve the required hadron rejection. The nonzero cross section for $\pi^0$ production in hadron—nucleon interactions generates an irreducible background for all such experiments. In an event where a high-energy $\pi^0$ is created at the top of the calorimeter, the shower in the calorimeter looks exactly like an electromagnetic shower. For better separation of electrons and positrons from hadrons, more than one subdetector is needed in the energy range of interest here. This will be achieved by AMS-2 by the combination of an electromagnetic calorimeter and a transition radiation detector, which will allow us to reduce the hadronic background basically to zero. AMS-2 will be launched by the Space Shuttle Discovery in 2010 and it will measure undisturbed by the Earth’s atmosphere on the International Space Station for three years. With an exposure for electrons and positrons of 90 sr day m$^{-2}$, its capabilities for particle identification, and its excellent energy resolution due to the combination of a superconducting magnet and a silicon tracker, AMS-2 will improve all existing measurements significantly as will be discussed in section 5.

2. Charge-sign-dependent solar modulation

The pre-PAMELA measurements of the cosmic-ray positron fraction are consistent [15] within the error bars (figure 2 left) but they differ significantly from the PAMELA data in the energy range below 5 GeV. In this regime, the fluxes of cosmic-ray particles are modulated due to interactions with the solar wind when they arrive at the outskirts of the solar system. The first hints at the effect of solar modulation came from observations of an anticorrelation between neutron monitor counts and the sunspot number, the latter being an indicator of the level of solar activity [24]. The solar wind originates from the corona of the Sun. A magnetic field, rooted in the Sun, is frozen into the solar wind plasma, and the Sun’s rotation leads to the creation of the large-scale structure known as the Archimedes spiral. Cosmic-ray particles are scattered on the magnetic fields. Gleeson and Axford [25] have modeled solar modulation by taking into account cosmic-ray diffusion through this magnetic field, convection by the outward motion of the solar wind, and adiabatic deceleration of the cosmic rays in this flow. In the force-field approximation, the effect of solar modulation can be described by a single parameter $\phi$ that depends on the solar wind speed $V$ and the diffusion coefficient $\kappa$. The interstellar cosmic-ray flux $J_{IS}$ is then modulated to yield the locally observed one $J$ as

$$J(E) = \frac{E^2 - m^2}{(E + |z|\phi)^2 - m^2} \cdot J_{IS}(E + |z|\phi), \quad (1)$$

where $E$ and $m$ are the total and rest energy of a cosmic-ray particle, respectively, and $z$ is the particle charge. The modulation parameter $\phi$ has the dimension of a rigidity and is typically of

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the order of 500 MV but it changes with time in accordance with the solar cycle (figure 3 right). The modulation parameter is not a model-independent quantity. The values of $\phi$ quoted in this paper have all been determined in the framework of the Galprop model. For example, using power spectra for protons and electrons instead, one would observe the same correlation with the sunspot numbers, but with a different scale factor.

The pre-PAMELA experiments all took place at a similar solar activity and at the same orientation of the solar magnetic field. In 2000, the polarity of the Sun’s magnetic field flipped and PAMELA data were taken under quiet solar conditions (figure 3 right). Drift models have been proposed [26, 27] to account for charge sign-dependent effects in the solar modulation. In the framework of the force-field approximation the charge-sign-dependent solar modulation can be introduced by assuming that the spectra of positively and negatively charged particles can be described by two different parameters $\phi^+$ and $\phi^-$. BESS [28]–[30] has measured continuously the proton and antiproton fluxes, while only few electron and positron spectra are available. No special spectral feature is observed in the antiproton flux and therefore one can assume that the antiproton spectrum is purely secondaries as described in the Galprop model (figure 4 left). $\phi^+$ is then determined for each measurement from a fit to the proton spectrum (figure 3 left), while antiproton [28]–[30] and electron [3, 4] measurements are used for the calculation of $\phi^-$. The obtained values for $\phi^+$ and $\phi^-$ are summarized in table 1. For several years we obtain a value for $\phi^- = 0$ which, if taken literally, implies that the negative cosmic-ray flux is not modulated by the solar magnetic field at all. To our understanding this points to problems with the simplified ansatz used in the force-field approximation presented here and one would expect that much better motivated descriptions like in drift models [26, 27] would solve this problem.
Figure 4. Left: antiproton-to-proton ratio measured by PAMELA [32] compared to the prediction obtained by assuming charge-sign-dependent solar modulation with $\phi^+ = 390$ MV and $\phi^- = 0$ MV. Right: positron fraction data corrected for solar modulation effects according to the Galprop conventional model.

Table 1. Values obtained for $\phi^+$ from the proton spectra and for $\phi^-$ from antiproton and electron spectra.

| Experiment | Year | $\phi^+_p$ (MV) | $\phi^-_p$ (MV) | $\phi^-_e$ (MV) |
|------------|------|-----------------|-----------------|-----------------|
| BESS       | 1993 | 537             |                 |                 |
| BESS       | 1997 | 385             | 0               |                 |
| AMS1       | 1998 | 454             |                 | 442             |
| BESS       | 1998 | 487             | 0               |                 |
| BESS       | 1999 | 571             | 345             |                 |
| BESS       | 2000 | 1238            | 632             |                 |
| BESS       | 2002 | 1037            | 568             |                 |
| BESS       | 2004 | 689             | 461             |                 |
| PAMELA     | 2007 | 390             | 0               |                 |

Fitting the low-energy part of the positron fraction as measured by PAMELA with the prediction from the Galprop model, leaving $\phi^+$ and $\phi^-$ as free parameters, leads to the same values as obtained from the fit of the proton and antiproton PAMELA data (figure 4 left). However, the same exercise for the antiproton data from 1998 from BESS and the electron data from AMS-1 leads to significantly different values of $\phi^-$, which is difficult to understand. The AMS-1 electron spectrum has been measured in space and does not have any corrections due to atmospheric effects. We hence assume that it has significantly smaller systematic uncertainties and use the electron $\phi^-$ from 1998 in the following.

With these data for $\phi^+$ and $\phi^-$, the positron fraction measurements from AMS-1, HEAT, TS-93, CAPRICE and PAMELA can be corrected for solar modulation effects in the framework of the force-field approximation to obtain the local interstellar spectrum ($J_{IS}$) as shown in figure 4 (right). Now the agreement between the data sets from the various experiments and with the expectation from Galprop is intriguing. At the very least, it increases our confidence in the measurements above 5 GeV significantly.
Figure 5. Left: AMS-2 on board the ISS together with the definition of the angles, which define the orientation of the ISS and hence of AMS-2. Right: sky coverage of AMS-2 on board the ISS in the Galactic coordinate system. Corresponding to estimated changes is the ISS orientation yaw, pitch and roll have been varied in the ranges $[-180, +180]$ degrees, $[-4, +22]$ degrees and $[-5, 0]$ degrees, respectively.

3. Sources of high-energy electrons and the sky coverage of AMS-2

The direct detection of nearby electron sources by observing the energy spectrum in the TeV region is a well known, challenging goal of cosmic-ray physics. The energy loss of high-energy electrons (see e.g. [36] and references therein) per unit time is proportional to $E^2$ and is caused by synchrotron radiation in the galactic magnetic field and inverse-Compton scattering on background photons. Therefore, in the TeV region, only electrons from sources at a distance within 1 kpc and with an age less than $10^5$ years can reach the Earth. Since the number of such possible sources should be very limited, the energy spectrum of electrons might have a characteristic structure [37], and the arrival directions are expected to show a detectable anisotropy [38, 39] modulated by the diffusion process in the Galaxy. The electron energy spectrum could, therefore, give direct knowledge of the nearby sources and the diffusion characteristics.

As several authors have pointed out already (e.g. [36], [40]–[42]), both a pulsar and dark matter annihilations could explain the features observed in the electron spectrum and in the positron fraction and both observations might be connected, i.e. for high energies there might be an equal amount of electrons and positrons in cosmic rays. If the dominant source was a nearby pulsar, for which Vela and Geminga are promising candidates, it could lead to an observable anisotropy of TeV electrons, while dark matter annihilation would lead to a homogeneous distribution of electrons on the sky [43]. In order to experimentally test these hypotheses, a full sky map in the TeV electron and positron light is needed. The GLAST/FERMI experiment will be able to do this only for the sum of electrons and positrons and it will be challenging for GLAST/FERMI to control the hadronic background to the required precision. The AMS-2 instrument has an opening angle of 50 degrees and covers the sky as shown in figure 5 taking changes in the orientation of the ISS into account [44]. Anisotropies in this map could only be produced by local, nearby sources because of the diffusion process in the galactic magnetic field. But to our knowledge, the idea that the TeV cosmic-ray electron flux is isotropic has never been tested experimentally and as illustrated in figure 5 this can be done by AMS-2 with good statistics.
4. Dark matter annihilation as a local fresh source for cosmic-ray electrons and positrons?

Among the most intriguing open questions in modern physics is the nature of the dark matter, that has been shown to contribute around 23% to the total energy density of the universe [60, 61]. While the nature of dark matter is as yet unknown, dark matter annihilating (see e.g. [61]) in the Galactic halo is a well-motivated source of cosmic-ray electrons and positrons. The cosmic-ray positron fraction data available so far indicate an excess over the expectation for purely secondary production (see figure 6 right), a trend recently confirmed and intensified by measurements of the PAMELA experiment [10]. Certain extensions to the standard model of particle physics like supersymmetry [62, 63] or universal extra dimensions [64, 65] predict a new particle, which would have all the properties required of a dark matter candidate. It will form halos around galaxies and annihilate pair-wise producing a variety of indirect signals in cosmic rays such as $\gamma$-rays, neutrinos and antiparticles. Its annihilation could be enhanced by the Sommerfeld effect [66]–[68] and by a possible clumpiness of dark matter [43, 69], which...
Table 2. Range of parameter variation for random scans of the parameter space of the conventional Galprop model. Slashes separate values below and above the respective break rigidities quoted in the text.

| Parameter | Nominal value | Lower bound | Upper bound |
|-----------|---------------|-------------|-------------|
| \( \gamma_s \) | 1.82/2.36     | 1.77/2.31   | 1.87/2.41   |
| \( \gamma_e \) | 1.6/2.5       | 1.4/2.3     | 1.8/2.7     |
| \( D_0 \) (cm\(^2\) s\(^{-1}\)) | \(5.75 \times 10^{28}\) | \(4.4 \times 10^{28}\) | \(7.2 \times 10^{28}\) |
| \( v_A \) (km s\(^{-1}\)) | 36            | 26          | 46          |
| \( z_h \) (kpc) | 4             | 3.2         | 5.5         |

we account for by an additional boost factor in the modeling of the cosmic ray spectra. Rare cosmic antiparticles like positrons, antiprotons and anti deuterons are sensitive probes for new phenomena as there are no known primary sources of antiparticles in the Galaxy [70]–[73].

Before one can search for any signal of dark matter annihilation in charged cosmic rays one has to understand the uncertainties in the propagation within our galaxy. Charged cosmic rays in the energy range considered here do not contain any directional information due to the galactic magnetic field as opposed to gamma or neutrino rays. This makes the experimental signal discrimination much more difficult. In this context, it would therefore be rather difficult to establish a dark matter signal only by observing a slight deviation in the spectrum normalization as it has been discussed for the antiproton spectrum. A change in the spectral index as observed in the positron fraction is much more difficult to account for and since the first HEAT measurements in 1994 [3, 21] this is a pending problem in particle astrophysics.

In the following, the key parameters of the conventional Galprop model have been varied to study their statistical uncertainties using the measured B/C ratio and the positron fraction outside the expected signal region from dark matter annihilation as constraints. The parameters considered are the spectral indices \( \gamma_s \) for nuclei and \( \gamma_e \) for electrons at injection, the diffusion coefficient \( D_0 \), the Alfven velocity \( v_A \), and the halo size \( z_h \) [8, 9]. The solar modulation parameters are kept fixed in the process. A random scan of the parameter space within the limits as given in table 2 has been performed. Models giving a description of the B/C data with equal or better \( \chi^2 \) than the conventional Galprop model fall within the gray band in figure 6 (left and right). Models additionally falling within the 99% confidence level interval with respect to the positron fraction data points below 3 GeV i.e. outside the expected signal region for dark matter annihilation, yield the green uncertainty band in figure 6 (right). It should be noted that none of the individual curves in the gray band in figure 6 (right) gives a \( \chi^2 \) for the measured positron fraction. The minimum found corresponds to the nominal Galprop parameter values in table 2 which are therefore used in the following.

As an example for a quantitative analysis of the sensitivity of the positron fraction to dark matter models we studied neutralino dark matter in the minimal supergravity grand unification (mSUGRA) model. A \( \chi^2 \) minimization was performed with respect to the positron fraction data in the \( m_{1/2}-m_0 \)-plane. The correction for solar modulation according to section 2 was applied to the data and the local interstellar spectra of the Galprop conventional model were used. The remaining statistical uncertainty of the background model corresponding to the green band as shown in figure 6 (right) was taken into account in the calculation of the \( \chi^2 \). Only models fulfilling constraints on relic density, the \( BR(b \rightarrow s \gamma) \) at the 3\( \sigma \)-level and giving a value of
the anomalous magnetic moment of the muon, $a_{\mu}$, falling within the preferred region at the $3\sigma$-level, as well as existing mass limits and direct detection limits and having a best-fit boost factor of less than $10^4$ are included. As shown in figure 7 (left) a moderately good fit to the high-energy PAMELA data can be obtained in the mSUGRA model. The $\chi^2_{\text{ndof}}$ improves from 227/29 for the background only fit to 49/28 for the model including a possible dark matter signal from neutralino annihilation. In this example, PAMELA would not be able to observe the return to the background curve due to its limitations in acceptance. This has a significant impact on the capabilities to substantially constrain the mSUGRA parameter space as shown in figure 7 (right). Details concerning the analysis are found in [74].

As has been pointed out in [75] radiative corrections could enhance the annihilation signal in the positron fraction without leaving any observable effect in the antiproton spectrum. Taking this effect into account improves the agreement between the measured positron fraction and the predictions within the mSUGRA model significantly [75].

5. Alpha magnetic spectrometer (AMS)

AMS-2 [22] will be launched on board the Space Shuttle Discovery in 2010. The detector design is optimized for precision particle spectroscopy in space and is based on the experience gained in the successful 10-day precursor flight of AMS-1 in 1998 [76]. The AMS-2 spectrometer design includes a superconducting magnet, a time-of-flight (TOF) system, a silicon tracker, an anticoincidence counter (ACC) system, a transition radiation detector (TRD), an

Figure 7. Left: best-fit positron fraction with respect to the data of AMS-1, HEAT, CAPRICE, TS93 and PAMELA, for a representative mSUGRA model. Right: 99% confidence level areas derived from the $\chi^2$ contours for fits to the projected data from PAMELA and AMS-2, for a fixed mSUGRA parameter point in a small part of the $m_{1/2}$-$m_{0}$-plane, for $\tan \beta = 40$, $m_t = 172.76$ GeV and $m_{\chi_0^0} = 93$ GeV. The PAMELA contour refers to the projected data based on acceptance and mission duration, for comparison to AMS-2, not to the actual data.
electromagnetic calorimeter (ECAL) and a ring imaging Cherenkov detector (RICH). The total weight is limited to 6850 kg and the total power consumption is 2.7 kW. A full view of the AMS-2 detector with its main components is shown in figure 8 (left). A preintegration of all subdetectors but the superconducting magnet has been performed at CERN in 2007/2008 (figure 8 right) including extensive and successful tests of the trigger and readout system with cosmics.

The superconducting coils of the magnet system are situated inside a vacuum case and operated at 1.8 K with superfluid helium. The superconducting magnet [77] generates a magnetic field of 0.86 T in the center. Inside the cylindrical volume of the vacuum tank a double-sided silicon strip detector measures the trajectories of charged particles at eight planes. The single point resolution of the silicon tracker is 0.0085 mm in the bending plane and 0.030 mm in the nonbending plane. The combination of the large lever arm, $BL^2 = 0.86 \text{Tm}^2$, together with the high accuracy of the silicon microstrip detector gives a measurement of particle rigidity with an accuracy of $\sigma_p^2/p = 4.0 \times 10^{-4} \text{p/GeV} \oplus 0.018$. This corresponds to a maximal detectable rigidity of 2500 GV and allows charge separation with three standard deviations up to 800 GV. The mechanical stability of the silicon tracker is monitored via an infrared laser system with a position accuracy of better than 0.005 mm [78].

The TOF system is made out of four scintillator planes (two on top and two below the silicon tracker) read out by fine-mesh phototubes due to the operation in regions with high magnetic field [79]. The TOF provides a fast trigger within 200 ns for the read out of the AMS-2 detector and it measures the particles charge and the time a particle needs to traverse the tracker with a resolution of $\sigma_t = 125 \text{ps}$.

The silicon tracker is surrounded by the ACC system, which consists of 16 scintillation panels of 8 mm thickness read out by fine-mesh phototubes (same type as for the TOF system) [80]. The ACC system detects and vetos particles, which enter the tracking volume from the side, outside of the main acceptance, in coincidence with a particle going through the TOF system and the silicon tracker.

A conical-shaped octagon structure is placed on top of the magnet vacuum case which houses a 20 layer TRD for particle identification. The combination of TRD and lead/fiber ECAL, which is located at the bottom of AMS-2 provides a proton rejection at the $10^6$ level up

Figure 8. Left: full view of the AMS-2 experiment mounted in the structural interface (USS) which connects the detector to the shuttle and to the ISS. Right: the AMS-2 experiment at CERN in Spring 2009 after the completion of the pre-integration.
Figure 9. Left: the AMS-2 TRD after the completion of the construction in the clean room at the RWTH Aachen. Right: the construction principle of a TRD straw module.

to particle energies of 300 GeV. The particle identification capabilities of AMS-2 are completed by the RICH system [81], which is located below the silicon tracker. The geometric acceptance of the AMS-2 silicon tracker is 0.4 m$^2$sr. The combination of TRD and ECAL reduces the geometric acceptance to 0.09 m$^2$sr.

The AMS-2 ECAL [82]–[84] is a 3D-sampling device made out of a 16.7 $X_0$ (radiation lengths) lead/scintillating fiber structure, which measures gamma-rays, electrons and positrons and discriminates leptons from hadrons with a rejection of $10^3$–$10^4$ in the energy range from 1 GeV up to 1 TeV. The energy resolution is well parameterized by $\sigma(E)/E = (10.2 \pm 0.3)\%/\sqrt{E/\text{GeV}} \oplus (2.3 \pm 0.1)\%$.

Besides the enormous increase in acceptance the main difference in electron and positron identification between PAMELA and AMS-2 is the AMS-2 TRD. This is the key feature of AMS-2, which allows the reduction of the proton background in the positron measurement basically to zero. The AMS-2 TRD [85]–[88] is shown after its completion at the RWTH Aachen in figure 9. The transition radiation photons are produced by charged particles passing through the 20 mm thick fleece, which is used as radiator. The TR photons are detected in straw tubes, filled with a Xe/CO$_2$ (80%/20%) gas mixture and operated at a voltage of 1400 V. The TRD consists of 20 layers of straw modules interleaved with a fiber fleece radiator and arranged in a conical octagon structure (figure 9). The top and the bottom 4 layers are oriented parallel to the AMS-2 magnetic field while the middle 12 layers run perpendicular to provide three-dimensional (3D) tracking. Each straw module consists of 16 straws as shown in figure 9. The straws have an inner diameter of 6 mm, the wall material is a multilayer aluminum–kapton foil with a total thickness of 0.072 mm. A gold-plated 0.030 mm thick tungsten wire, fixed in a polycarbonate end-piece, is used as sense wire. The straw modules are mechanically stabilized by longitudinal and vertical carbon fiber stiffeners. The AMS-2 TRD has a proton rejection between 1000 and 100 in the energy range from 10 to 250 GeV at an electron efficiency of 90% [87].

AMS-2 will not only measure electrons and positrons in cosmic rays. The combination of TRD, TOF, silicon tracker, RICH and ECAL will allow precision measurements of the $B/C$ and the $^3\text{He}/^4\text{He}$ ratio [89]. These measurements will allow us to constrain and test cosmic-ray
propagation models like Galprop to much greater precision than today. This will reduce the systematic errors in the background expectation for the positron fraction and the electron spectrum significantly. In the example of the statistical uncertainties of the conventional Galprop model discussed in section 4 the gray-shaded bands in figure 6 (left and right) would be reduced to narrow lines, indistinguishable from the lines shown for the Galprop background expectation itself.

The AMS-2 instrument as described above is expected to measure the electron and positron spectra in cosmic rays as shown in figure 10. Within the energy range considered here of up to 800 GeV where AMS-2 can separate positive and negative particle charges with three standard deviations the statistical error bars are smaller than the symbols displayed.

6. Summary

Earth’s atmosphere prohibits measurements of GeV-range cosmic rays from the ground. AMS-2 [22] will be launched by the Space Shuttle Discovery to the International Space Station in 2010. It will measure charged cosmic rays with unprecedented precision and statistics for three years until the superconducting magnet runs out of helium. AMS-2 covers a broad physics program and is an excellent detector for cosmic-ray electron and positron measurements.

In combination with the results on dark matter particles expected from the LHC collider in Geneva, indirect dark matter search in cosmic rays could become a major cornerstone of particle physics in the coming years.

References

[1] Alcaraz J et al (AMS Collaboration) 2000 Phys. Lett. B 490 27–35
[2] Alcaraz J et al (AMS Collaboration) 2000 Phys. Lett. B 494 193–202
[3] DuVernois M A et al (HEAT Collaboration) 2001 Astrophys. J. 559 296–303
[4] Alcaraz J et al (AMS Collaboration) 2000 Phys. Lett. B 484 10–22
[5] Maeno T et al (BESS Collaboration) 2001 Astropart. Phys. 16 121–8

New Journal of Physics 11 (2009) 105021 (http://www.njp.org/)
[6] Boezio M et al (CAPRICE Collaboration) 2001 Astrophys. J. 561 787
[7] Hunter S D et al (EGRET Collaboration) 1997 Astrophys. J. 481 205–40
[8] Ptuskin V S et al 2006 Astrophys. J. 642 902–16
[9] Strong A W et al 2007 Annu. Rev. Nucl. Part. Sci. 57 285–327
[10] Adriani O et al (PAMELA Collaboration) 2009 Nature 458 697
[11] Aguilar M et al (AMS Collaboration) 2007 Phys. Lett. B 646 145–54
[12] Beatty J J et al (HEAT Collaboration) 2004 Phys. Rev. Lett. 93 241102
[13] Boezio M et al (CAPRICE Collaboration) 2000 Astrophys. J. 532 653–69
[14] Golden R L et al (TS93 Collaboration) 1996 Astrophys. J. 457 L103–6
[15] Chung C H, Gast H, Olzem J and Schael S 2007 arXiv:0710.2428
[16] Torii S et al (HEAT Collaboration) 2001 Astrophys. J. 559 973–84
[17] Nishimura J et al 2000 Adv. Space Res. 26 1827–30
[18] Chang J et al (ATIC Collaboration) 2008 Nature 456 362–5
[19] Torii S et al (PPB-BETS Collaboration) 2008 arXiv:0809.0760
[20] Aharonian F et al (HESS Collaboration) 2008 arXiv:0811.3894v2
[21] Barwick S W et al (HEAT Collaboration) 1997 Astrophys. J. 482 L191
[22] Borgia B (AMS Collaboration) 2005 IEEE Trans. Nucl. Sci. 52 2786–92
[23] Atwood W B (FERMI Collaboration) 2009 arXiv:0902.1089
[24] Evans T 2004 High Energy Cosmic Rays (Berlin: Springer)
[25] Gleeson L J and Axford W I 1968 Astrophys. J. 154 1011–26
[26] Moskalenko I V et al 2002 Astrophys. J. 565 280–96
[27] Bieber J W et al 1999 Phys. Rev. Lett. 83 674–7
[28] Wang J et al (BESS Collaboration) 2002 Astrophys. J. 564 244–59
[29] Shikaze Y et al (BESS Collaboration) 2007 Astropart. Phys. 28 145–67
[30] Hams T et al (BESS Collaboration) 2007 Proc. 30th ICRC vol 1
[31] Casolin M et al (PAMELA Collaboration) 2008 arXiv:0810.4980v1
[32] Adriani O et al (ATIC Collaboration) 2008 Phys. Rev. Lett. 102 051101
[33] Solar Influences Data Analysis Center, http://sidc.oma.be/sunspot-data/
[34] Snodgrass H B et al 2000 Solar Phys. 191 1–19
[35] Durrant C J and Wilson P R 2003 Solar Phys. 214 23–9
[36] Pohl M 2008 arXiv:0812.1174
[37] Nishimura J et al 1980 Astrophys. J. 238 394–409
[38] Shen C S and Mao C Y 1971 Astrophys. Lett. 9 169
[39] Ptuskin V S and Ormes J F 1995 Proc. 24th ICRC
[40] Hooper D, Blasi P and Serpico P D 2008 arXiv:0810.1527
[41] Yukset I, Kistler M D and Stanev T 2008 arXiv:0810.2784
[42] Hall J and Hooper D 2008 arXiv:0811.3362
[43] Hooper D, Stebbins A and Zurek K M 2008 arXiv:0812.3202
[44] von Doetinchem P 2009 PhD Thesis RWTH Aachen University (arXiv: 0903.1987)
[45] Davis A J et al 2000 Proc. ACE 2000 Symposium (New York: AIP) p 421
[46] Caldwell J H and Meyer P 1977 Proc. 15th ICRC
[47] Chapell J H and Webber W R 1981 Proc. 17th ICRC
[48] Dwyer R and Meyer P 1987 Astrophys. J. 322 981–91
[49] Garcia-Munoz M et al 1984 Astrophys. J. 280 L13–7
[50] Gupta M and Webber W R 1989 Astrophys. J. 340 1124–34
[51] Engellmann J J et al 1990 Astron. Astrophys. 233 96–111
[52] Krombel K E and Wiedenbeck M E 1988 Astrophys. J. 328 940–53
[53] Júliusson E 1974 Astrophys. J. 191 331–48
[54] Lezniak J A and Webber W R 1978 Astrophys. J. 223 676–96

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