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Electron and Positron solar modulation and prediction for AMS02.

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The solar modulation, a combination of diffusion, convection, magnetic drift and energy loss inside the heliosphere is usually seen as a depletion in the Galactic cosmic ray (CR) flux at low energy (less than 10 GeV/nuc). Antiparticles such as antiprotons or positrons undergo the same processes of respective particles but with a different magnitude depending on the Solar magnetic field polarity. For electrons and positrons, due to the small mass, energy loss mechanisms as inverse compton, synchrotron, bremsstrahlung and ionization have to be taken into account, together with the typical adiabatic losses considered in the heliosphere. We developed a Monte Carlo stochastic simulation with the aim to compare the solar modulation of particles and antiparticles in the same observation period. We are able to estimate the different behaviours associated to the charge sign dependent processes of the heliospheric modulation. We compared the simulated positron fraction with measurements performed by AMS-01 and PAMELA. We also present the prediction for the AMS-02 experiment.

Keywords: cosmic rays; heliosphere; positron ratio; solar modulation;

1. Introduction

Solar modulation of Cosmic Rays (CRs) is actually described by model integrating the Parker's equation¹. The CRs propagation is depending on the charge sign of CRs and to the solar magnetic polarity^{2,3}. In this work we introduce a description of our present modulation model, then we summarize the different behaviours with particles of opposite charge sign in same observation periods. Finally we compare results with experimental data providing also a prediction for AMS-02.

2. Model Description

Present model⁴ is based on the 2D (radius and colatitude) approximation of Parker equation¹: a Fokker-Planck equation including diffusion, convection, adiabatic energy loss and magnetic drift. A rigorous proof by Ito⁵ demonstrate the equivalence with a set of ordinary stochastic differential equations (SDEs). The main advantage is that SDEs could be easily integrated with Montecarlo techniques. The model depends on some parameters related to the solar activity and is fine-tuned by comparing results with experimental data⁶. We used the Heliospheric Magnetic Field (HMF) introduced by Parker and modified according to Jokipii and Kóta⁷: the magnitude of the HMF in the polar regions is increased without modifying the topology of the field. The major effect is a reduced CR penetration along the polar field lines in the inner part of the heliosphere, due to a lower magnetic drift velocity. According to Ulysses data⁸, for periods of low solar activity, we used a latitudinal dependence of the solar wind speed: the value increases by a factor of two moving from the ecliptic plane to the polar region. For the drift description we use the model by Potgieter & Moraal^{9,10} that describes periods of solar maximum as well solar minimum. The model requires as input a Local Interstellar Spectrum (LIS). We use the model proposed by Zhang & Cheng¹¹, which has been corrected comparing it with the experimental data¹².

3. Results

3.1. Drift effect on modulation

The charge dependence of propagation is due to the drift term of the Parker equation. The fundamental parameter that fix the direction of particle magnetic drift is qA , where q is the particle charge and A is the normalization factor of the magnetic field (B) that gives its polarity. We made a simulation of a typical solar minimum in both polarities for both electrons and positrons. We found, in agreement with theory¹³, that the flux is lower when $qA < 0$ than for $qA > 0$ conditions. Results are shown in fig. 1 (left panel). In the right panel of fig. 1 we show the modulated positron fraction above 1 GeV: for a period with $A > 0$ the modulation does not affect $e^-/(e^+ + e^-)$ ratio significantly; for a period with $A < 0$ the effect of solar modulation is relevant up to ~ 10 GeV, reducing the modulated fraction by a factor of two or more.

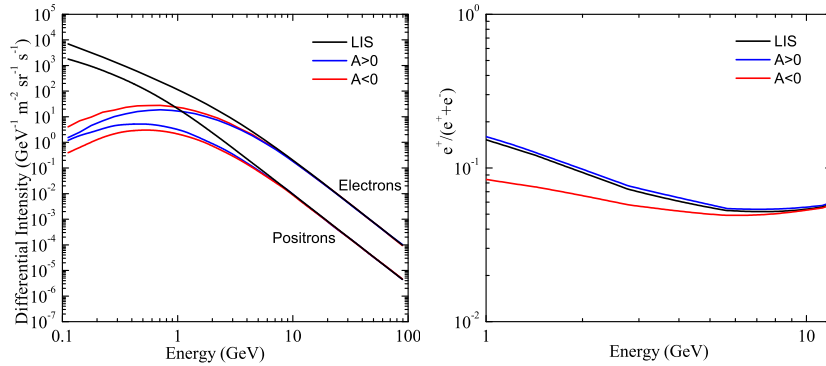


Fig. 1. Electron and positron modulation (left) and positron ratio for a typical solar minimum period (we use conditions related to June 1998) with both magnetic field polarities.

3.2. Measurements by AMS-01 and PAMELA

We selected two data set in similar solar conditions but opposite magnetic field polarity. AMS-01¹⁴ operated on board the Space Shuttle in June 1998, at the end of a solar minimum occurred during a period with $A > 0$. PAMELA¹⁵ is a space born experiment working since July 2006. Published data have been taken between 2006 and December 2008, therefore during the last long solar minimum with $A < 0$.

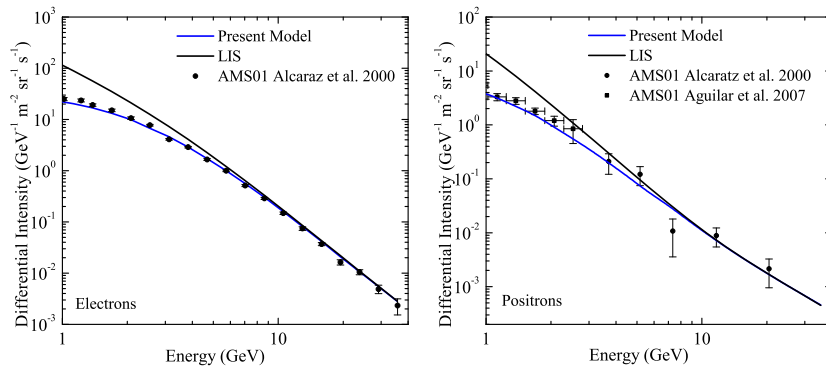


Fig. 2. Simulated spectra for AMS-01 mission.

We reproduce, within the errors bars, the AMS-01 data for electrons

and positrons (see figure 2). We find a good agreement between simulation and experimental data also for e^+ fraction. Despite of the large solar modulation of electron and positron flux the modulated ratio is very close to the interstellar ratio (figure 3) as obtained in previous results. We used the same model of propagation to reproduce data published by PAMELA collaboration. We simulated several heliospheric conditions covering the periods of the data taking. The results have been averaged and shown in figure 3. We reproduced PAMELA data and find that modulated ratio is lower than the interstellar one, as expected.

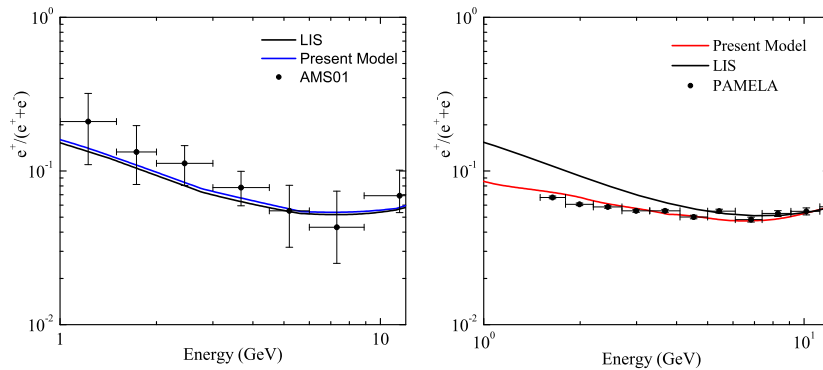


Fig. 3. Simulations of positron ratio for AMS-10 and PAMELA mission.

3.3. Prediction for AMS-02

The simulation code was used to predict CR fluxes for future measurements. The periodic behavior of the heliosphere allows us to predict, with a certain level of precision, the solar modulation parameters needed for the simulation. The assumption is that diffusion coefficient, tilt angle and solar wind speed show a near-regular and almost periodic trend. The periodicity is two consecutive 11-years solar cycles. In order to get these data we considered the prediction of Smoothed Sunspot Numbers from IPS (Ionospheric Prediction Service) of the Australian Bureau of Meteorology. Using SIDAC data (Solar Influences Data Analysis Center) we selected periods with a similar solar activity conditions and same solar field polarity of the simulation time: therefore approximately 22 years before. Under the previous assumption, we used the values measured in that periods as an estimation

of the conditions of the heliosphere in the near future. We concentrate the simulations on the AMS-02 mission that will be installed on the ISS in February 2011, and, in particular, on one period, during its data taking, approaching the solar maximum: January 2012. results are shown in figure 4. This period is still with $A < 0$ and the modulated positron fraction is still below the interstellar one.

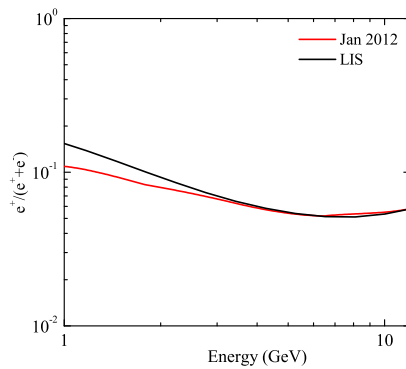


Fig. 4. Prediction of positron ratio for January 2012.

4. Conclusions

We built a 2D stochastic Monte Carlo code for particles propagation across the heliosphere. Present model takes into account drift effects and shows quantitatively a good agreement with measured values, both for positive and negative periods and for different particle's charge. We found that for periods with $A > 0$ the modulated positron ratio is similar to the interstellar one. During periods with opposite field polarity we found instead a significative reduction of the modulated positron ratio respect to the interstellar ratio. We compared simulations with positron ratio measured by AMS-01 and PAMELA. We found that the discrepancy of PAMELA positron ratio respect to the previous experiments can be well explained with a polarity-dependent effect of modulation, due to magnetic drift of particle. The prediction for AMS-02 shows that, in the first period of data taking, it will probably observe a modulation effect similar to the one measured by PAMELA. It will be interesting to compare the measurements of AMS-02 in the following years to confirm the behavior shown in fig. 1.

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