Proceedings of ICRC 2001: 4120 © Copernicus Gesellschaft 2001

ICRC 2001

Reproduction and interpretation of the large e+/e- ratio observed with AMS

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Abstract. The AMS (Alpha Magnetic Spectrometer) group reported unexpected results on the albedo electrons below the geomagnetic cutoff at a height of 380 km; the average ratio of e+/e- is about 2 and it is dependent on the (magnetic) latitude. The ratio at low latitudes even reaches to 4. A semi-quantitative interpretation of this observation was given by one of the authors (Huang) using the east-west effect due to the geomagnetic field. Extending that work, we try to reproduce all the observed features by a Monte-Carlo simulation. In this paper we introduce the method of simulation and show some of the preliminary results.

1 Introduction

With their first test flight observation on board a space shuttle, the AMS group obtained lepton (e^+ and e^-) spectra which have following peculiar features (Alcaraz et al, 2000):

1. There are lots of leptons below the geomagnetic cutoff.
2. They are albedo particles produced in the atmosphere and bounced back to the outer space.
3. Their trajectories, if traced back and forth, give their birth and sink points in the atmosphere. The flight time from the birth to sink is classified into two distinct groups: one is short flight time (SFT) typically <0.1 s, and the long flight time (LFT) typically $0.2 \sim 20$ s.
4. The birth place of SFT particles has no geographical longitudinal dependence.
5. The birth place of LFT particles has concentration near the equator and are distributed in limited longitudinal regions.
6. The birth place region of electrons (positrons) is the sink region of positrons (electrons).
7. The e^+/e^- ratio depends on the (magnetic) latitude; the value reaches even 4 near the equator and decreases to 1 at higher latitudes. Consequently, LFT leptons are dominated by positrons.
8. If a scatter plot of 'the kinetic energy vs flight time' is constructed for leptons, the SFT leptons show two distinct band structures which are independent of energy: one is $0.02 \sim 0.04$ s and the other $0.06 \sim 0.1$ s.
9. The LFT leptons are also grouped into two bands which, however, have dependence of $Time \sim E^{-1}$.

One of the authors (Huagn, M.A., 2001) has given semi-quantitative explanation of these properties. The basic ingredient is the east-west effect due to the geomagnetic effect and positive charge (proton) dominated primary cosmic rays.

The positive charge dominance leads to the fact that the more primaries come from the west than east, and if e^+-e^- pair is created in the atmosphere, e^+ directed from west to east has much chance to be bounced to outer space than e^-, while for leptons running from east to west, the relation is reversed. Hence e^+ is expected to dominate over e^-, especially in the high magnetic cutoff region where the east-west effect is stronger and more secondary particles are produced by primaries with high rigidity cutoff.

We try to confirm the semi-quantitative analysis based on this basic assumption. For this purpose we use a Monte-Carlo simulation and reproduce the peculiar properties.

2 Procedure of Monte-Carlo simulation

We use the Cosmos code (Kasahara , 2001) for the simulation. It has been used to calculate atmospheric neutrino flux (Honda et.at, 1995). Recently the interaction models in that code has been calibrated by observations of atmospheric gamma rays, muons and protons(Kasahara , 2001b).

We divide the simulation into two phases: the first phase is to establish primaries that can enter into the earth atmosphere region (i.e, to establish rigidity cutoff). The second

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phase is to inject such primaries into the earth atmosphere, and follow all the particles generated by interactions of them or their descendents. They are 'observed' if they cross the AMS detector height.

2.1 First phase

The basic environment we assume is

1. The earth is a sphere of radius, $R_e = 6378.1$ km
2. The atmosphere is expressed by (Chamberlain, 1987); it is defined up to 1000 km and it's lower part coincides with the US standard atmosphere defined below 86 km. Above 1000 km, we assumed an exponentially slowly decreasing density.
3. The geomagnetic field is expressed by the IGRF data (Mandea et al, 2001) and we used the values for year, 1998.5. Although it is not guaranteed at very high altitudes, we use it up to $\sim 10R_e$. At large distances, the field strength generally decreases as $\sim 1/r^3$, i.e, like a dipole field.
4. The primary cosmic rays at large distances are assumed to be isotropic and composed of protons, He, CNO, e^+ and e^-. The minimum kinetic energy/n is set to 0.2 GeV. For the protons and He we used the BESS data (Sanuki , 2000) which is almost completely coincide with the AMS data(Alcaraz et al, 2000b). For the leptons, we used data from AMS. In the region where no definitely reliable data exists, we make a smooth extrapolation; however, such high energy region would not affect the current calculation.

In the first phase, we do the following.

- The primary injection point is randomly chosen on the surface of earth at a vertical height of 100 km a.s.l. The angular distribution is assumed to be isotropic, i.e., the zenith angle (θ) distribution at a given point is $\cos\theta d\cos\theta(\cos\theta > 0)$. However, the real primary at 100 km is never isotropic so that we use the following step.
- When a primary is sampled, we take its charge conjugate and reverse the direction. We follow the particle until either of the following conditions are reached:
  1. It reaches a preset radial distance, normally, $10R_e$ (upper boundary).
  2. Its flight time exceeds prefixed maximum, normally, 25 s ('max flight time').
  3. Its height becomes lower than the injection height.

  The primaries that satisfy the first condition are regarded as true primaries that can come from the outer space. We record the random number seed of each of such events.

This procedure is legitimated if the primary is isotropic at large distances, the geomagnetic field is static and no electric field exists.

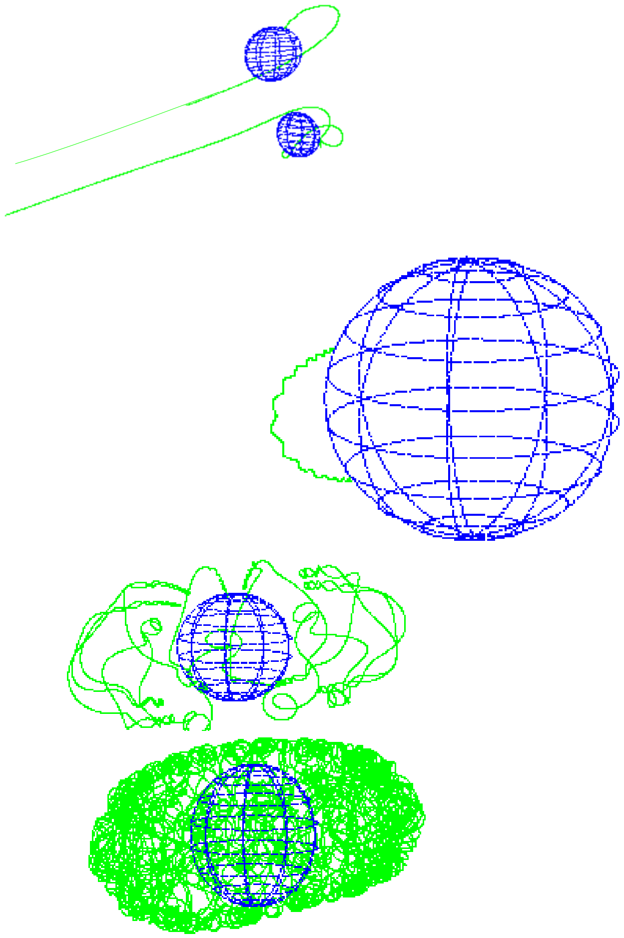

Fig. 1. Examples of the particle trajectories in the first phase. Upper 2: particle can escape from the geomagnetic field; true primaries. Middle: typical trapped case. Lower 2: chaotic examples. The last one is in the so called penumbra

2.2 Second phase

Using the random seeds recorded in the first phase, we start simulation of particle interactions and tracking. Particle tracking is ceased when the flight time exceeds the 'max flight time', particle position becomes 'lower boundary' (normally, at 4 km a.s.l) or upper boundary, or the kinetic energy becomes lower than 0.2 GeV. During the tracking, if a particle crosses the AMS observation height (380 km), its information is recorded. One and the same particle may cross the observation height many times; we can identify such a particle. For electrons, we apply synchrotron energy loss in addition to the usual interactions. Once a lepton comes back to the earth atmosphere region (below 100 km) from outer space, it normally never goes up again but lose energy by ionization, bremsstrahlung or knock-on process, and eventually dies somewhere, typically, between 70 km to 10 km a.s.l. This defines the sink point. Although very rare, a new particle may be born from the sink point. Such particles are regarded as new and the flight time is reset in this case.

3 Preliminary results

Our calculation is on going and in this paper we show preliminary results obtained by snatching the computer output 'on the fly'. A complete result will be presented at the conference.

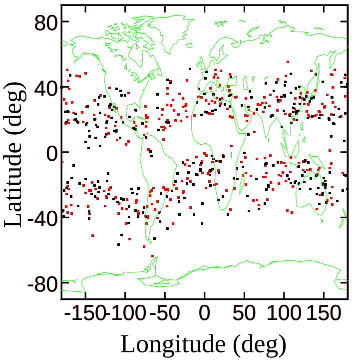

Fig. 2. SFT lepton (flight time < 0.1 s) birth place. Electrons (black dots) and positrons (red dots).

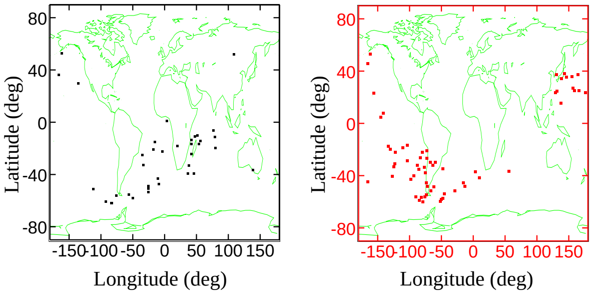

Fig. 3. LFT lepton (flight time > 0.2 s) with CGM latitude $|\lambda_m| < 0.3$(rad). Birth points of e^-(left) and e^+(right)

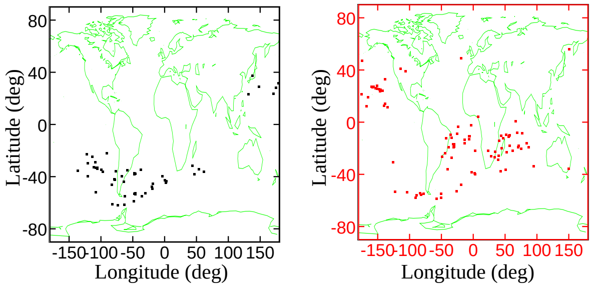

Fig. 4. LFT lepton (flight time > 0.2 s) with CGM latitude $|\lambda_m| < 0.3$(rad). Sink points of e^-(left) and e^+(right).

The SFT lepton birth place is shown in Fig.2. The feature is very similar to the real observation. There is no systematic difference between electrons and positrons.

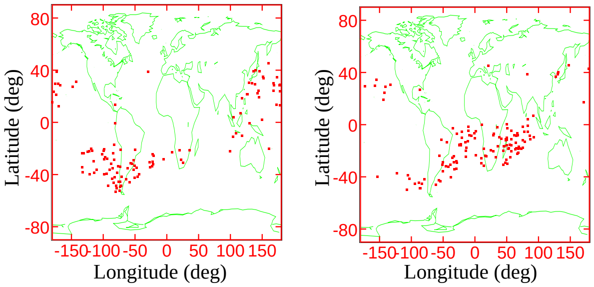

Fig. 5. LFT proton (flight time > 0.2 s) birth and sink points. These have the same feature as the LFT positrons.

The energy spectrum (Fig.**??**) of leptons can be fitted by a power function of energy. The power is consistent with (Huagn, M.A., 2001) who predicts a power to be primary power index - 0.45'. The overall e^+/e^- ratio is ~ 2.

Acknowledgements. Two of the authors (M.H and K.K) sincerely thank Dr.S.C Lee for the hospitality when they were invited to Taiwan for discussion.

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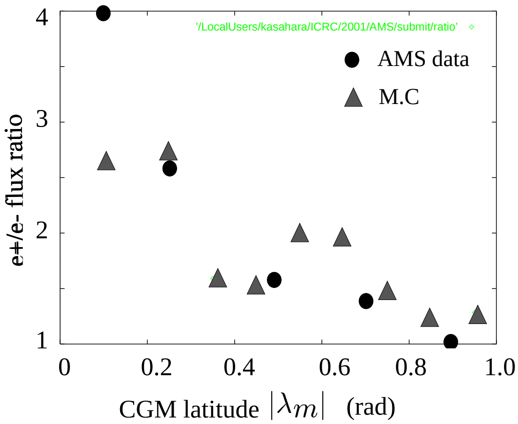

Fig. 8. The e^+/e^- flux ratio as a function of the CGM-latitude. Although the statistics of M.C is not enough, the tendency is the same as the observation. Note, however, the observation is for all shuttle altitudes while M.C is for at 380 km