Method of positron detection using the Earth magnetic field in orbital experiment

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Abstract. The phenomenon of a positron anomaly in cosmic rays at energies above 10 GeV can not be explained within the framework of secondary positron production mechanisms into interstellar media. One possible explanation can be that positron excess is generated by ~ TeV dark matter particles annihilation or decay. Very high energies are not available for modern magnetic spectrometers because of their small size, but magnetic analysis with geomagnetic field extending for thousands of kilometres can be used. One approach to the high energy positron detection deals with allowed and forbidden trajectories Earth's magnetic field. It was shown that at the equatorial position of the detector it is possible to separate positrons and electrons using only a position-sensitive electromagnetic calorimeter up to energies ~ 250 GeV using detector with angular resolution of about 5 degrees. Second approach consists in the joint registration of an electron, or positron, and the synchrotron photons emitted by them into magnetosphere. It is shown that for space born detector at about ~ 400 km orbit identification of positrons up to tens TeV is possible using synchrotron radiation detector and imaging calorimeter.

1. Introduction

It is believed that the main source of high-energy electrons detected in near-Earth space is acceleration of particles the supernova remnants. Due to the absence of the primary source of positrons, the fraction of positrons in the total flux of electrons and positrons should be decreasing with increasing particle energy. Figure 1 shows the dependencies of this ratio obtained in the recent experiments [1]. Starting with the particle energy of 10 GeV and higher, an increase in the fraction of positrons in the total electron and positron flux is obvious from these observations. The appearance of an excess of positrons can be associated with other astrophysical objects, e.g. pulsars. By the mechanism of formation of positrons excess due to pulsars it is difficult to explain very high energy above 100 GeV; because nearby solar system it should be several pulsars, otherwise positrons losses energy by interacting with the interstellar environment. There are no known candidates for pulsars at such short distance from the Earth [2]. According to many models, positron fluxes are formed during the annihilation or decay of particles of dark matter.

The dependence of the ratio of positron fluxes to the total flux of electrons and positrons at high energies above 1 TeV would be crucial to determine origin of the excess and, in any case, will impose restrictions for dark matter models.

Unfortunately, this range is not available for modern magnetic spectrometers because of their small size, but for magnetic analysis with geomagnetic field extending for thousands of kilometers can be used.
A method that was used in [3] was based on the fact that at each orbit latitude there is a definite range of angles from which a charged particle could arrive to the Earth from the space. In other words, the effect of the geomagnetic field shields the certain arrival directions of positrons or electrons of certain energy.

A method based on the using of synchrotron radiation in a geomagnetic field to measure primary cosmic electrons with energy of more than 100 GeV was proposed in [4]. In [4] it is shown that, when entering the detector, photons together with the primary electron form one line. The registration of this line allows identifying the electron. The method was studied in details for balloon altitudes in [5]. It was shown that for the electron identification, it is necessary to detect minimum three photons lying along the line but for precise energy measurements it is necessary to have at least seven photons.

Obviously, electrons and positrons will be located on opposite sides of the photon line; therefore, using additional detector, e.g., the imaging electromagnetic calorimeter for registration of primary electrons and positrons, it will be possible to determine also the charge sign of the particles. Other advantage is that for rather thick calorimeter the electron energy could be measured independently with high precision. Thus, to identify the charge of the detected particle, it is better to combine the detector registering the synchrotron radiation and the imaging calorimeter (figure 2).

![Figure 1](image1.png)  
**Figure 1.** Dependences of the ratio of the fraction of positrons in the total flux of electrons and positrons on energy, obtained in different experiments. The gray band represents DAMPE systematic errors.

![Figure 2](image2.png)  
**Figure 2.** Scheme of the method for registering an electron using a synchrotron radiation detector and a imaging calorimeter.

This experiment should be carried out on a low-Earth orbit satellite outside the atmosphere (at an altitude of ~ 400 km) to reduce the background, which did not allow a positive result in the CREST experiment [6].

The purpose of this work is to simulate the processes of the motion of electrons and positrons in the Earth magnetic field together with synchrotron radiation of these particles and to study the efficiency of registration of high-energy positrons of cosmic rays using a synchrotron radiation detector and a position-sensitive calorimeter in low-Earth orbit.

2. Results
To solve the problems, a set of programs was used, including a program for modeling the motion of a charged particle in a magnetic field with simulation of synchrotron photon emission, as well as Monte-Carlo simulation the passage of particles through a detector material based on the GEANT 4 package.
The model sampling imaging calorimeter used for simulations was comprised 15 scintillator strip detector planes interleaved with 15 equidistant plates of tungsten absorber. The scintillator plane has 70 strips with pitch 3cm and consists of three layers. The orientation of the strips in layer rotates 60 degrees each other and therefore provides multi-dimensional spatial information. Each tungsten layer has a thickness 0.5 cm corresponding to ~1.5 radiation lengths, giving a total depth around 32X0.

Various locations of the detector in orbit with altitude of 400 km were chosen. The particle trajectories were calculated from 30 km (the boundary of the atmosphere) to 40,000 km.

2.1. Separation of electrons and positrons only at the angles of arrival
At the equatorial position of the detector, there were obtained distributions by the zenith and azimuth angles of the arrival positrons and electrons of different energies for isotropic flux in $4\pi$ geometry. Figure 3 shows that positrons and electrons can be separated each other using only angular distributions of particles. The modeled electromagnetic calorimeter provides angular resolution of about 5 degrees and could be used for positron identification up to ~250 GeV because calorimeter itself also can provide proton rejection. Above this energy only negligible part of the instrument acceptance will be used and this method becomes useless.

![Figure 3](image)

**Figure 3.** The distribution by the zenith and azimuth angles of the arrival of the positron (a) and the electron (b) with energies of 70 GeV.
2.2. Separation of electrons and positrons on the basis of synchrotron radiation

During detecting synchrotron radiation from electrons and positrons in the Earth's magnetosphere, there were modeled various locations of the detector in orbit near the equator and in the polar region. Figures 4 - 6 show the photons coordinates in the detector plane. A Cartesian coordinate system is used that is connected with the plane of the detector; the report point is at the point of particle registration.

For each incoming direction in detector there were simulated two trajectories, one for electron and other for positron with the same energy. The photons emitted by the positron and the electron are separated by a solid line. The figures show that the determination of the sign of the particles charge is possible if one knows incidence angles of the particle into the detector, since, depending on this direction; the photons line up (figures 4, 6) or are located along the arc of the circle (figure 5).

Figure 4. Distribution of synchrotron photon registration points in the plane of the detector. Horizontal position of the detector at the equator. For the energy of 3 TeV.
2.3. Estimation of the synchrotron radiation detector size

From the distribution of distances from the point of registration of a charged particle to photons (figure 7), one can estimate the size and efficiency of such a detector because for particle identification minimum three aligned photons are needed. Distributions were calculated for different positions of the detector and for different electron energies.

Figure 5. Distribution of the points of registration of the synchrotron photon in the plane of the detector. The horizontal position of the detector at the pole. For the energy of 4 TeV.

Figure 6. Distribution of the points of registration of the synchrotron photon in the plane of the detector. The vertical position of the detector at the pole. For the energy of 4 TeV.
It was found that with a horizontal position at the equator of a detector with dimensions of ~ 2 m, the efficiencies of detecting an electron with energies of 10 TeV and 30 TeV, respectively, are at least 60% and 80%. The efficiency of registration increases, since the number of registered synchrotron photons increases with increasing energy. With a vertical position at the pole of the detector with dimensions of ~ 2 m, the efficiencies of measuring an electron with energies of 4 TeV and 10 TeV, respectively, are not less than 80% and 95%. With a horizontal position of the detector at the pole the efficiency corresponding to these energies is slightly less.

**Figure 7.** The distribution of the distances from the particle registration point to the registration point of the third photon. The vertical position of the detector at the Earth’s pole. The electron energy is 4 TeV (a) and 10 TeV (b).
3. Conclusions
Model for simulation of positron detector consisting of a synchrotron radiation detector and a sampling imaging calorimeter was developed. Monte-Carlo simulations of electrons and positrons with energy from 20 GeV till ~ 30 TeV in the Earth magnetosphere and their response in synchrotron radiation detector and calorimeter were performed. The efficiency of the detector in various parts of the low-Earth orbit with altitude 400 km varies from ~60 up to ~90% in TeV energy range. The results of the calculations confirm that the Earth's magnetic field allows registering positrons up to very high energies with large enough instrument.

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