High energy positron detection via synchrotron emission in magnetosphere

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Abstract. The space project "Sonya" is designed to detect cosmic positrons and electrons through their synchrotron X-ray emission in the Earth magnetic field. The proposed instrument can identify the charge sign and determine the energy of TeV electrons and positrons. Modern magnetic spectrometers aren’t able to measure positrons above several hundreds GeV. Simulation of the instrument were performed. Advantages of the method are high proton background rejection and high value of effective area of the instrument with energy. As simulation shows the proposed instrument with effective area about 1m\textsuperscript{2} will detect several tens of TeV positrons per year

1. Introduction

High energy electrons are produced mainly in accelerating processes in supernova remnants. Small number of electrons are produced in the inelastic interaction of cosmic rays with the interstellar medium together with positrons. Recent measurements of the ratio of positron flux to total electron and positron flux in PAMELA and AMS-02 experiments \cite{1,2,3} have shown that it increases with energy beginning from 5-10 GeV, in opposition to the standard diffuse cosmic ray propagation model and secondary production mechanism of positrons. To solve this mystery is necessary to measure positron fraction at high energy in TeV region. For local astrophysical sources the fraction may remain constant till extremely high energies. Aslo there are hypothesis that positron anomaly deals with heavy dark matter particles annihilation. In this case there will be cut-off of positron at energy $E \sim M$ which may lie in TeV region.

Meanwhile it is worse to note that modern detectors aren’t effective in searching electrons and positrons with energies higher than 1 TeV and therefore, such particles remain practically uninvestigated. Maximum detected rigidity (MDR) of AMS-02, largest magnetic spectrometer now working in space, is about 2 TV \cite{3} and this limits today’s measurements of positrons. This innovate spectrometer has a permanent magnet 1 meter height with weigh about 1 ton. To reach $\sim$20 TV MDR the magnet length or strength of magnetic field have to be increased about one order of magnitude. At existed space technologies it is absolutely unreal to provide capacity such type spectrometers to use it on the Earth orbit. It is clear that the development of alternative methods are necessary to investigate the origin of the positron excess at high energy.
In 1972 in the work [4] was suggested studying cosmic rays with the detector that would detect electrons and positrons by using their synchrotron photons they emit, moving along the trajectories, curved by magnetic field of the Earth. Emission power of protons is negligible in comparison with positrons and electrons due to their mass. So, by detection of particle together with photons give possibility to separate electrons /positrons from protons and more heavy nuclei.

Using this method the balloon instrument CREST was designed to detect cosmic electrons at energy above 2 TeV [5]. The CREST detects electrons through their geo-synchrotron X-ray emission, resulting in a co-linear, isochronous arrangement of X-ray hits in the detector. An array of 1024 BaF2 crystal detectors was built, surrounded by veto plastic scintillators to guard against chance alignments of charged particles in air showers. This instrument was flown on a high-altitude balloon for 10 days in Antarctica during the 2011/2012 season (∼40 km, ∼8 g/cm²). The main advantages of balloons experiment are big detector size. The main problems of balloon experiment are attenuation of photons in atmosphere and very high background from interactions of cosmic ray in atmosphere.

The results of CREST experiment illustrates some of the challenges faced in a practical implementation of the new technique. The production of high-energy bremsstrahlung in the atmosphere and its subsequent interaction in the detector can mimic the synchrotron event signature and significantly decreases event selection efficiencies. A space-based version of this experiment would avoid some of these issues [5].

The synchrotron radiation detector together with calorimeter is able to identify the charge sign of the particle and so to separate electrons and positrons [6].

The new experiment Sonya with synchrotron radiation detector is proposed to be operated on low orbiting satellite like the International Space Station and presente in this paper.

![Figure 1. Scheme of positron and electron detection in magnetosphere of the Earth with synchrotron emission.](image)

2. Method
The synchrotron radiation detector principle is based on papers [4] and [7]. To simulate performances of the detector a special code was developed to trace particles in magnetosphere. For the calculation of the Earth magnetic field the IGRF (http://nssdeftp.gsfc.nasa.gov/models/geomagnetic/igrf) Tsyganenko models were used. To determine the incoming direction on the boundary of the magnetosphere for a particle recorded
by the detector, its antiparticle (positron for electron and vice versa) was started up from the
detector surface calculating the trajectory to a height of several tens of thousands kilometers.
The second part of the program reproduced movement of the particle in opposite direction from
boundary of the magnetosphere to the detector. At that stage the emission of photons switched
on and is simulated by Monte-Carlo method and trajectories of photons are also calculated. Fi-
nally the checking is carried out that the trajectories of synchrotron photons cross the sensitive
surface of the detector. Calculation were performed for International Space Station orbit with
altitude 400 km.

From figure 1 it is easy to see that in case of detection of synchrotron photons and with
parent particle it is possible to identify sign of charge of particle.

Our calculation shows that the effective photon generation begin at the height of about
40,000 km and a "fan" from photons has a length of up to several tens km. But more intense
emission take place on altitudes below 1000 km. Electron with energy $\sim 1$ TeV emit about several
hundreds of photons there. To identify electron and positron the registration of minimum three
co-linear signals is required to detect at least two emitted photons and the charge particle itself.
Detector size about 1 m$^2$ satisfy this condition with $\sim 0.9$ registration efficiency from energy $\sim 3$
TeV. Calculated average photon energy for different electron energies and altitudes are shown in
figure 2. Photon energy lies in x-ray spectrum interval (about several tens keV). From figure 2 it
is clear that the satellite has to have altitude not more then 100 km, for example, International
Space Station is an appropriate place for such measurements.

![Figure 2](image-url)

**Figure 2.** Average energy of synchrotron photons emitted by electrons with different energies

Total expected number of electrons will be more several tens of positrons per year. It is
interesting to note that gathering power of the detector is increasing with energy because photon
emission will be higher. So the identification of electrons and positrons will be higher because
number of registered photons will be larger.

3. Instrument
The scheme of the *Sonya* instrument is shown in figure 3.

The instrument consists of two layers of X-ray strip detectors (SRD) and telescope of
scintillator detectors (C1, C2) to provide trigger and to determine particle direction. Each of
detectors C1 and C2 has two layers of plastic strip scintillator detectors to measure coordinates of particle in two orthogonal projections. To discriminate cosmic ray protons tungsten layer W with thickness about 3 radiation length will be used between C1 and C2. Only events with trigger signal C2 >> C1 will be triggered and stored in memory. Practically all electrons will interact in tungsten layer W producing electromagnetic shower providing trigger condition. Weight of such detector will not exceed 400 kg.

As the X-ray detector it proposed to use CdZnTl crystals. This detector is widely used in various fields e.g. It was already successively used in Swift space mission for X-ray astronomy [8]. Simple laboratory tests with standard CAMAC pre-amplifier showed that it is possible to reach rather good energy resolution around 10%.

To solve the problem with background produced in the instrument it is necessary to increase spatial resolution of synchrotron the detector. The probability that noise events will be in line with particle depends on total number of cells. at resolution of 10 mm this background doesn’t exceed few percent With CdZnTe strip detectors it is possible to achieve a necessary spatial resolution.

Obviously that than more photons will be registered on the detector than identification of electrons and positrons will be better and the accuracy of the energy measurement will be higher.

4. Summary
The space-born project Sonya is proposed to study cosmic electrons and positrons through their synchrotron x-ray emission in the Earth magnetic field. Advantages of the instrument are high proton background rejection and relatively small weight and size that allows to perform it on ISS or low orbiting satellite The instrument can identify the sign and determine the energy of TeV electrons and positrons. The detector with size about 1 m$^2$ can detect about several tens of positrons with energy more then 1 TeV per year on International Space Station.

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Figure 3. Simplified scheme of the Sonya instrument
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