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High energy cosmic ray investigations by Cerenkov radiation generated in the upper atmosphere

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Abstract. We discuss opportunities to study nuclei/antinuclei and electron/positron cosmic rays fluxes by Cerenkov radiation generated in the upper atmosphere. For balloon experiment (altitude of flights ~ 30-35 km) an ability to register nuclei/antinuclei cosmic rays fluxes at energies 0.4-4 TeV/n is revealed. Electron/positron spectra can be determined at energies 40 GeV - 1 TeV.

1 Introduction

As it is well known, to get the answers to many fundamental questions in astroparticle physics is impossible until we have a possibility of determination a sign of high energy cosmic rays charge. We offer a method enabling to perform such measurements. The essence of our proposal is to consider the Earth's atmosphere at altitudes ~30-80 km as a "radiator of the gas Cerenkov counter". The probability of charged particles inelastic interaction at these altitudes is sufficiently small. So we investigated the Cerenkov radiation emitted by single high energy charged particles by means of computer simulations. It is well known that at high altitudes the pressure has an exponential dependence on height above sea level. Due to this fact we have discovered the Cerenkov photons formed a light image with high photons density at its border. Moreover the Cerenkov radiation emitting trajectory is ~30 km long and thus it deflects by the Earth's magnetic field, that causes the significant asymmetry of Cerenkov light image. These effects can be applied to investigate cosmic nuclei/antinuclei and electrons/positrons ratio at the energies inaccessible to the other methods up to day.

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2 Simulation results

To calculate the method characteristics we used exponential approximation of pressure (p) at high altitudes (h > 11 km) $p=\exp(7.174-0.158h)$ (g/cm^2) (Bergamasko et al., 1983) and air refractive index n dependence on air density r, $n = 1 + k(r/r_0)$, $k = 2.927 \cdot 10^{-4}$, r_0 is the air density at sea level (Physical constants tables, 1976).

It was supposed that the equipment would be exposed onboard a balloon at altitudes 30-35 km. The simulation shows that the Cerenkov light forms in the transversal plane of observation an image similar to a circle. The important peculiarity of the light image is a large light density near the particle trajectory and at the borders. An averaged radius and a shape of the image do not depend on the type of a nucleus, while the Cerenkov radiation intensity increases proportionally to a squared charge of the primary particle.

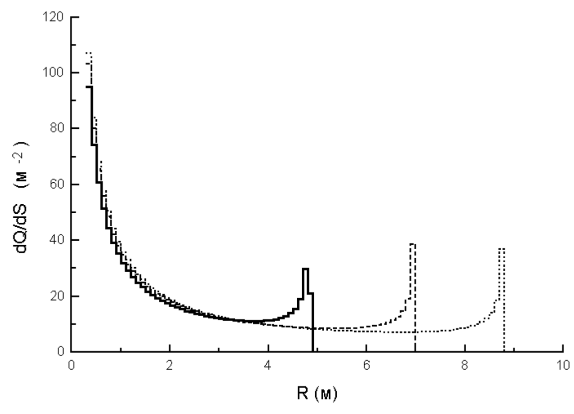

Fig.1. Cerenkov photons spatial density. Proton. E=1 TeV (solid line); 1.6 TeV (dashed); 4 TeV (dot)

For example, in **Fig.1** the spatial light distributions *dQ/dS* (*Q* is number of fotons with l =220–500 nm and *S* is an area) is shown as a function of the radius R at *h*=35 km for protons of various energies. The zero point is the intersection of the particle trajectory and the observation plane.

The photons emission level at various air density of the Earth's atmosphere determines this shape of photons distribution. On the one hand a number of the Cerenkov photons decreases and on the other hand the light cone of photons emission narrows with increasing altitude. It causes rise in the Cerenkov radiation intensity at borders of the image. The peak of intensity in the image center is formed by quanta emitted in the nearest area of atmosphere where its density is highest. For example, a primary proton (4 TeV) begins to emit Cerenkov light at *h* ~60 km at value of a radiation angle ~0. Both the photons emission and the radiation angle increase with increasing air density. So there is such an area of the trajectory where the emitted photons from different altitudes are placed in one (periphery) part of the image. In the adduced example it is a part of trajectory at h =43-52 km. In detail this process is demonstrated in **Fig.2,** where the values *R* and *dQ/dh* for various emission altitude *h* are shown.

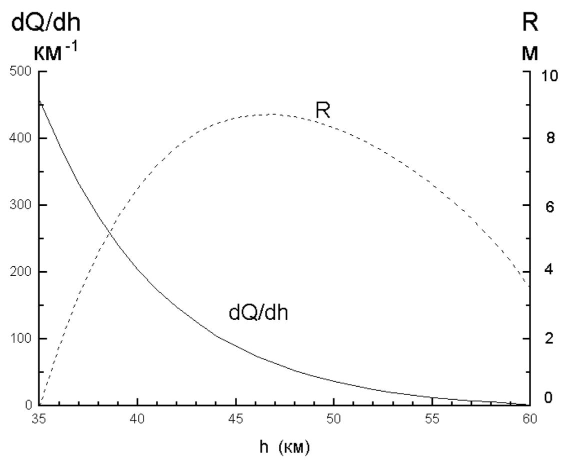

Fig.2. *R* and *dQ/dh* dependences on photons emission altitude

However actually the primary particle trajectory deflects by the Earth's magnetic field. To evaluate the asymmetry of Cerenkov light image let us consider the last example of 4 TeV proton image at *h* ~35 km, **Fig.3**.

The magnetic field value was accepted to be equal to 0.41 Gs (middle latitudes ~60°). In **Fig.3** R_1 is a light image radius taken in the line of a magnetic field of the Earth, R_2, is the East radius, R_3 is the West radius. The ratio $K=(R_3 - R_2)/R_1$ is ~ 16%. For 4 TeV antiproton situation is the same but the *K* ratio changes a sign. The similar situation is for 0.4-4 TeV protons (antiprotons) at *h* ~27-35 km. The size of the image and the total Cerenkov radiation intensity varies but the *K* ratio is within the limits of 8-18%. For particles with *Z*>2 the *K* ratio is proportional to a value *Z/A* (*Z* is a charge, *A* is a mass number of a nucleus) and the total number of photons is proportional to Z^2.

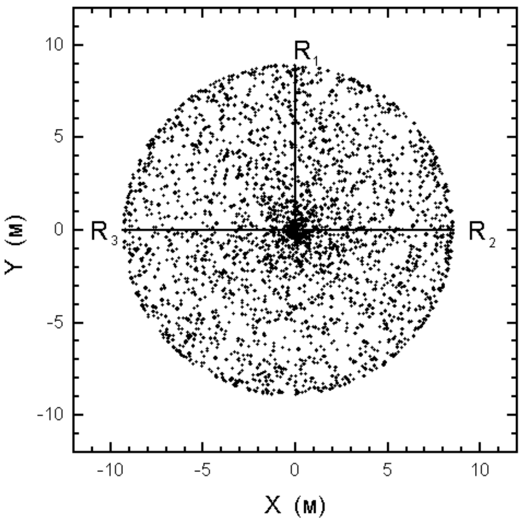

Fig.3. The spatial density of Cerenkov light. Proton. E=2 TeV. h_0=35 km. $a = 30^\circ$ .The Y axis is directed along the magnetic meridian. Every point is a Cerenkov photon.

The situation with the electrons (positrons) is a little different. The threshold of Cerenkov radiation is determined by Lorentz factor of a particle. Under identical conditions the total number of quanta (photons yield) emitted from 1 TeV proton (antiproton) is approximately the same as that for 0.5 GeV positron (electron) and the photons yield has its total saturation at energies more than 2 GeV. The asymmetry of the image is determined mainly by magnetic rigidity of a particle. Very low mass of an electron (positron) causes a significant asymmetry of the image. For example, in **Fig.4** the spatial light distribution is shown as a function of the radius R at *h*=35 km for 200 GeV positron. It is obvious that the sign can be easy determined even in the total saturation case.

With increasing primary positron (electron) energy the shape of an image changes so that it looks like an image of a proton (antiproton). In **Fig.5** the radius R_1 is shown as a function of the radius R_2 at *h*=35 km for 0.5-4.5 TeV protons and for 0.007-1.7 TeV positrons. (Proton and positron energies for various R_2 are given in the **Table 1**.) We can see that the values of ratio R_1/R_2 for proton and positron are different in the considered energy ranges.

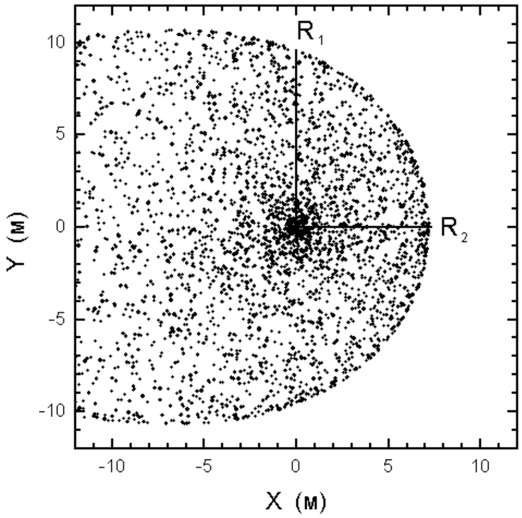

Fig.4. The shape of light spot. Positron. E=0.2 TeV. h_0 =35 km. $a = 30°$ .The Y axis is directed along the magnetic meridian. Every point is a Cerenkov photon.

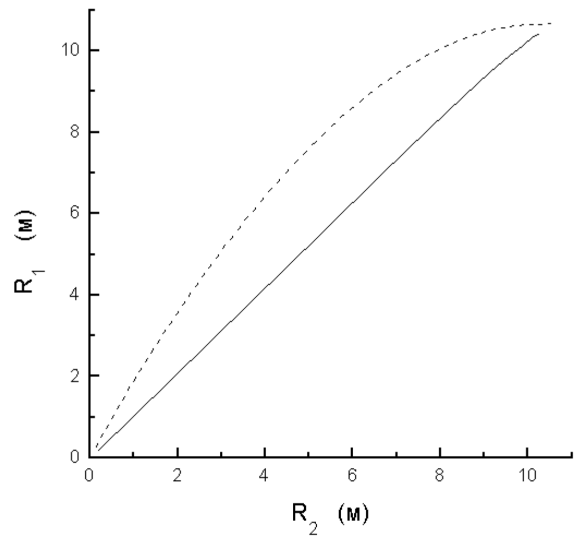

Fig.5. The R_1 dependence on R_2 for protons (solid line) and positrons (dashed line).

Table 1. Energy of protons and positrons as function of R_2.

R_2 , m	1	2	3	4	5	6	7	8	9	10
Proton energy, GeV	560	640	730	830	960	1120	1360	1720	2390	4510
Positron energy, GeV	7.2	17	38	48	75	115	181	303	584	1780

Therefore we can conclude that in principle the opportunities of studying both 0.5-4 TeV/n nuclei/antinuclei and 40 GeV - 1 TeV electron/positron cosmic rays spectra have been revealed. But is there an experimental ability to register this effect? For example, at h=35 km the total number of quanta of 1-4 TeV/n proton (antiproton) or 40 GeV - 1 TeV electron/positron is about 10^3 -10^4. These quanta are distributed over a light spot with a radius 5-8 meters, which has a large photons density near the particle trajectory and at the borders, (**Fig.1**). The Cerenkov flash duration is equal to ~0.1 ns.

Before offering the engineering solutions for design of the instrumentation it is necessary to estimate influence of a background. Its main physical source is the star sky light. (Of course, the light from the Sun and the Moon is not taken into consideration. It is supposed that the instrumentation would be exposured in moonless night or it would have such an aperture where the light from the heavenly bodies does not penetrate.)

We could not find the direct information about the star sky light background at 30-35 km height above sea level. Therefore we used on the one hand the well-known value of the total illumination intensity accepted in an observation astronomy ~ 0.0003 lux (Space physics, 1986) and on the other hand the experimental data obtained by ground-based equipment, for example ~$5\cdot 10^{11}$ photons/(m^2 s sr) including air fluorescence (Baltrusaitis et al., 1985).

The comparison of these data reveals sufficient agreement allowing us to use them for a tentative estimation. So we suppose that a flux density of the sky background S=$1.5\cdot 10^{11}$ photons/(m^2 s sr) for our spectral range 220-500 nm without orange and red light. Low energy photons make considerable contribution into background but their fraction in Cherenkov light is small enough. The background distorting a useful signal $S_{reg} = S\ \Gamma\ T$ (Γ - aperture of the instrumentation, T - duration of one event registration). To determine a sign of a primary particle we have to recognize the shape of a light spot. For that purpose it is necessary to register not less than half of the image size (**Fig.3**).

Astrophysical purposes require the probability of the antiproton imitation by a proton to be less than 10^{-5}.

We assumed that the instrumentation consists of separate elements and the single element of the instrumentation has an area ~ 1 square meter. (At present stage a detailed consideration is of no use.)

According to the simulation to provide the required proton/antiproton separation a value of ΓT has to be less than $3\cdot 10^{-10}$ m^2 s sr for a single element.

If we assume that the T value is ~ 10 ns then the value of Γ has to be ~0.03 m^2 sr.

It is necessary to have a large area of the instrumentation (for example circle with radius above 10 meters), that will allow to achieve the total geometric factor ~10 m^2 sr.

In this case it is possible to expect the nuclei/antinuclei statistics inaccessible to the other methods up to day.

All the above-mentioned can be repeated for the electron/positron separation, but in that case the requirement of the background influence is much more weak.

3 Summary

The theoretical considerations and the results of some estimations given in this paper allow us to hope for a possibility of the registration of 0.4-4 TeV/n nuclei/antinuclei and the measurement of 40 GeV - 1 TeV electron/positron cosmic rays spectra in a balloon experiment based on the new method. To make conclusions about its technical feasibility we should know a value of the star sky light background at height 30 - 35 km above sea level precisely. In the near future we are going to carry out a test experiment to investigate the background problem.

References

Bergamasko, L., Castellini, A., D'Ettore Piazzoli, B. et al., *Nuovo Cimento C*, 1983, *6C*, Ser.1, N6, P.569.

Physical constants tables. Moscow 1976 (in Russian)

Space physics. Moscow 1986 (in Russian)

Baltrusaitis, R.M., Cady, R., Cassiday, G.L. et. al., *NIM A.*, 1985, A420, P.410.