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Upper limit on high - ionizing particle flux underground

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Abstract. An experimental search for high-ionizing particle flux at depth 850 hg/cm^2 has been performed using Baksan Underground Scintillation Telescope data. Our trigger conditions were following: only one track in the Telescope; energy deposit >1.5 relativistic particle in each of 4 scintillator layer; <16 hitted detectors in each layer. Thus, our experimental upper limit can be applied to at least 3 underground phenomena: 1) very high-energy muon flux; 2) narrow muon bundle flux; 3) any exotic high-ionizing particle flux. The upper limit for sum of all these fluxes for particle (or particles) with more than 8-fold energy losses is equal to:

$$I(>8 \text{ r.p.})<1.8\cdot 10^{-14} \text{ cm}^{-2} \text{ s}^{-1} \text{ ster}^{-1} \quad (67\% \text{ c. l.})$$

1 Introduction

An attention from time to time was paid to different underground phenomena, which we can call as “abnormal ionization”. Many objects pretend to be regarded as *high-ionizing particle.* Among them are: magnetic monopole; multi-charged particles; strangelets; narrow muon bundles and so on. Many experimental works were performed to search for these objects: some of them were even observed and upper limits for others have been put. But, there exists a well-known object underground capable to produce high ionization in a detector: very high-energy muons. Multi-TeV muon can look like a *high-ionizing particle.* due to pair production and knock-on electrons accompanying it.

An experimental search for high-ionizing particle flux at a depth of 850 hg/cm^2 underground has been performed using Baksan Underground Scintillation Telescope (Alexeyev et al., 1979). Our trigger conditions allow us to put an upper limit on the sum of all possible fluxes mentioned above.

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2 Experimental details

The Baksan Underground Scintillation Telescope (BUST) is rather convenient instrument for experiments of such a kind. It has 4 horizontal layers of thick (30 cm x 200 m^2) liquid scitillator separated by concrete absorber (8 radiation lengths each). It has also 4 vertical scintillator planes surrounding the horizontal ones. Its dimensions are: 16.7 x 16.7 x 11.2 m^3. Each horizontal scintillator layer consists of 400 tanks of 70cm x 70cm x 30cm size, viewed by 6” PMT (FEU-49). The upper layer consists of 576 detectors. BUST is located at a depth of 850 hg/cm^{2}underground under a mountain slope. In this experiment only horizontal plane were used. Energy deposit (ε) in each plane is measured by a logarithmic ADC (step=10%) with a threshold equal to 1/4 of relativistic particle (1 r.p. ≈ 50 MeV in our case). Our track separation resolution is limited by the detector size and is equal to 0.7 m. The Telescope angular resolution is equal to 2°.

Schematic view of the experiment is shown in Fig.1. Our main hardware trigger (#1) was following:

Only one spot of detectors in a plane and less than 16 hitted detectors in it;

these 16 detectors must be inside a square of 5 x 5 detectors or 3.5m x 3.5m;

energy deposit ε must be > 1.5 r.p. in each plane.

But, we changed these conditions during the experiment as we can see below. The trigger counting rate was 0.02 sec^{-1}.

3 Data processing and results

First of all we have made energy deposit calibration by recording real muon groups of fixed multiplicity in BUST: 1, 2, 3, 4, etc without application of trigger #1. Due to this calibration we know a probability for each multiplicity to give energy deposit in following ranges: 1.0 – 2.0 r.p.; 2.0 – 3.0 r.p. etc. Using these data along with experimental multiplicity spectrum of muon bundles in BUST (Chudakov et al., 1991) we calculated expected energy deposit spectrum one could expect from usual muon bundles taking into account fluctuations of muon lateral distribution and their ionization Landau fluctuations. This spectrum is shown in Fig.2 (solid line) along with experimental data (solid squares).

Our main data sample consists of $9.4 \cdot 10^7$ muons passed through the BUST horizontal planes accumulated during about one year ($T=2.7 \cdot 10^7$ sec). In addition to the trigger conditions we also required an equal energy deposit ε in each scintillator plane within accuracy of 1 r.p.. This means that different plane energy deposits ε_i should lie inside an interval (ε_m , ε_m+ 1.0 r.p.), where ε_m is ionization mean energy deposit value corresponding to the number of relativistic particles **m** =2, 3, 4, ...

To measure real high-ionizing particle and/or narrow muon bundle fluxes we first applied such a requirement for

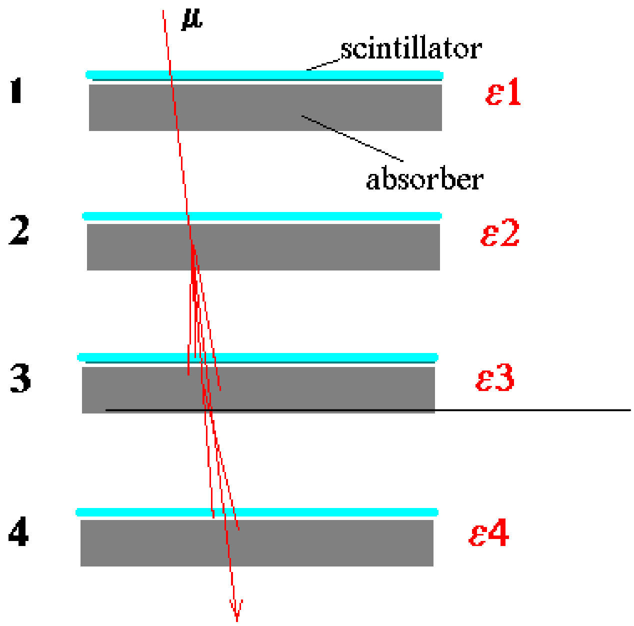

Fig. 1. Schematic view of the experiment

all 4 scintillator planes. Results are shown as $N_{4\text{-fold}}$ in Table 1. As we mentioned above, the most probable candidate for check high-ionizing particle underground is multi-TeV muons. To this experimentally we have done following. Taking into account results of our previous Baksan data analysis (Marchuk et al., 1987) dealt with study of low energy transfer (of several GeV) muon interactions, we applied the requirement of equal high ionization only to two lower scintillator planes (#3 and #4) and applied upper threshold ($\varepsilon < 2$ r.p) for two upper planes (#1 and #2). This assumed to correspond to a passage of a single muon interacting inside the BUST as shown in Fig.1. These results are also shown in Table 1 as $N_{2\text{-fold}}$. Note, if one knows a probability $P_{2\text{-fold}}$ for muons to imitate equal high ionization in 2 neighboring planes due to electro-magnetic interactions, one can easily estimate the probability ($P_{4\text{-fold}}$) to imitate such a process in 4 planes of similar detectors.

Table 1

ε_m, r.p.	2	3	4	5	6	7	8	9
$\mathbf{N_{4\text{-fold}}}$	13851	350	20	8	2	0	1	0
$\mathbf{N_{2\text{-fold}}}$	495	78	31	14	7	3	2	3

These two distributions should be connected by a simple ratio: $P_{4\text{-fold}} = C \cdot (P_{2\text{-fold}})^2$, where C=1 in a case of absolutely independent events (2-fold muon interactions in 2 pairs of target planes are independent). In our case one can expect $C \geq 1$ because distance between interactions is not high enough (only 16 rad. lengths) and interference between 2 close cascades is possible. These calculated probabilities are plotted in Fig.2 as a function of energy deposit (open circles).

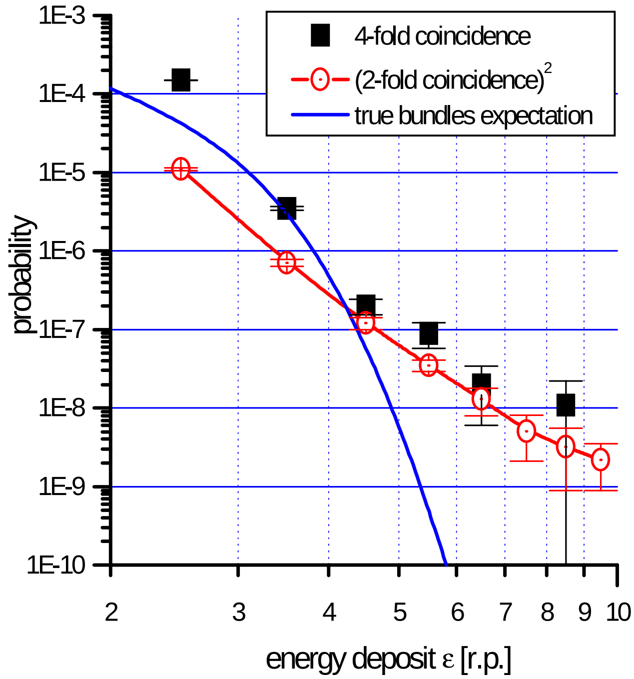

Fig. 2. Experimental and expected energy deposit spectra.

4 Discussion

As one can see from Fig. 2 our experimental ionization distribution is in contradiction with that expected from fluctuations of real muon bundles lateral distribution. Nevertheless, the experimental distribution should not be interpreted as an existence of "narrow muon bundles" of high multiplicity because it agrees very well with that expected for multiple (2-fold) interactions of single high-energy muon inside the BUST. The only exception is the first shown bin of ionization between 2 and 3 r.p.. To explain this we should remind another process, namely muon pair production by high-energy muons in the rock (Bugaev et al., 1970; Logunov, 1972) above the detector. This effect leads to an excess of real narrow groups of parallel muons of multiplicity "2" and "3" underground. Thus, excess in the first bin of our experimental distribution can be regarded as an evidence for the existence of such events. Also we should emphasize that no one event has been recorded with ionization corresponding to $\varepsilon > 8$ r.p..

5 Conclusions

Taking into account time of data accumulation, the BUST aperture and recording efficiency and the trigger conditions we can claim following:

1) upper limit on flux of any objects having more than 8-fold ionization ability (or losses dE/dx > 16 MeV/(g/cm^2) is equal to:

$$\mathbf{I(>8\ r.p.) < 1.8 \cdot 10^{-14}\ cm^{-2}\ s^{-1}\ ster^{-1}\ \ (67\%\ c.l.)}$$

31 founded candidates for "narrow muon bundle" with multiplicity of muons m> 4 or any other objects with more than 4-fold ionization ability are explained very well by the double interactions of a single very high energy about several GeV in two neighboring pairs of detector planes can imitate equal energy deposit and so can mimic a high-ionizing object;

2) the effect mentioned above is the main background for experiments searching for high-ionizing relativistic particles: only big number of detection planes could reduce this background;

3) the measured flux of high-ionizing particles with ionization losses corresponding to that of 2 – 3 relativistic particles is by a factor of ~ 5 higher than expected one and this is in our opinion an evidence of real existence of narrow muon bundles with number of muons "2" or "3" due to μ^+ - μ^- pair production by very high-energy muons underground.

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References

Alexeyev, E.N. et al., *Proc. of 16th ICRC, Kyoto, v.10, p.276*, 1979
Marchuk, D.L. et al., *Medlennye piony v electro-magnitnyh livnyah. . Preprint of INR, П-0538*, 1987
Chudakov, A.E. et al., *Proc. of 22d ICRC, Adelaide*, v.9, 348-351, 1990
Bugaev, E.V. et al., *Kosmicheskie muony i nejtrino*. *Atomizdat. Moscow*, 1970
Logunov, B.M. *Nekotorye issledovaniya kosmicheskih muonov i gamma-kvantov*. Ph.D. Thesis, MEPhI, 1972