STUDY OF PHOTONUCLEAR MUON INTERACTIONS AT BAKSAN UNDERGROUND SCINTILLATION TELESCOPE

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ABSTRACT

The method of π-μ-e decays recording has been used to distinguish between purely electron-photon and hadronic cascades, induced by high energy muons underground. At energy ~ 1 Tev a ratio of the number of hadronic to electromagnetic cascades was found equal $0.11 \pm .03$ in agreement with expectation. But, at an energy ~ 4 Tev a sharp increase of this ratio was indicated though not statistically sound ($0.52 \pm .13$).

1.Methods. The observation of high energy muon induced cascades at Baksan Underground Scintillation Telescope is described elswhere (1,2). Using π-μ-e decay's delayed signal recording an attempt has been made to distinguish the fraction of cascades induced by muons through inelastic μ-A interactions. The technique of μ-e decays recording is described in ref.(3). For every scintillators layer the summarized P.M.'s anode signal is put to 10-beam, 10 μs oscilloscope which is the main device to register μ-e decays. The recording efficiency ε depends on the position of the decay location relative to scintillator, also on the time window and on energy threshold, the mean value being $\langle\varepsilon\rangle = 0.05$. The energy threshold for delayed pulses recording was 7 Mev or about 300 photoelectrons from PM photocathode and it was high enough to exclude afterpulses. To check this we used high power pulsed X-ray sources.

2. Results and discussion. During a 11640 h run, 1302 cascades with an energy more than 700 Gev have been recorded and among them 556 cascades with π-μ-e decays. Unfortunately, a presence of decays is not a strong evidence for the cascade to be hadronic or not, because of nonzero probability to produce pions in purely electromagnetic cascade through photonuclear interactions of real photons. The mean number of stopping charged pions in electromagnetic cascade of energy E_c was calculated as:

$$\bar{n}_{\pi^\pm} = \frac{N_{Av}}{A^{0.1}} \cdot X_0 \cdot \int_{E_0}^{E_c} \sigma_{\gamma p}(E_\gamma) \cdot m_{\pi^\pm}(E_\gamma) \cdot \frac{dN(E_\gamma)}{dE_\gamma} \cdot dE_\gamma$$

where A is the atomic weight of the target material,$N_{Av}$is Avogadro's number,X_0 is the radiation length (23 g/sm² in our case), $\sigma_{\gamma p}(E_\gamma)$is the differential total photoproduction cross section taken from (4,5),$m_{\pi^\pm}(E_\gamma)$ is the yeild of stopping pions per one γ-A interaction,$E_0 \approx m_\pi$ is the threshold energy for photoproduction which is about pion rest mass,$dN(E_\gamma)/dE_\gamma$ is the differential photon spectrum in the cascade with energy E_c (6).

All stopping π^+ and only a fraction of π^- decaying in flight (35% in our case) should be taken into account.The total number of stopping pions in electromagnetic cascade of energy E_c was found to be $\bar{n}_{\pi^\pm}=5.7\cdot 10^{-3}\cdot E_c$.

Assuming stopping pions disribution along the cascade axis the same as for electrons,the mean number of π-μ-e decays recorded by the telescope has been calculated as a function of cascade energy.The results are shown in table 1 in the first two columns.

Assuming Poisson distribution for the number of π-μ-e decays in electromagnetic cascade criteria may be suggested to separate electromagnetic and hadronic cascades for each energy range.We chose as a criterion such number of μ-e decays n_t, that probability of $n<n_t$ is more than 99% for electromagnetic cascade.This "separation-number" is shown in 3th column of table 1 as a function of cascade energy.The total numbers of recorded (N_{rec}) cascades and that selected by the criterion as a purely electromagnetic ones (N_{em}) are plotted in 4th and 5th column.In the next columns there is a distribution of selected events in comparison with Poisson distribution (expected $\bar{n}_{\mu-e}$ are shown in the second column).An agreement is good enough and this is a reason to belive that the criterion is good.

Table 1

$\langle E_c\rangle$, GeV	$\bar{n}_{\mu-e}$	n_t	N_{rec}	N_{em}	0μ-e	1μ-e	2μ-e	3μ-e	4μ-e	5μ-e	6μ-e	
738	0.30	3	490	440	318	101	21					experim.
					326	97	15					Poisson
894	0.36	3	305	261	184	66	11					e
					183	65	12					P
1070	0.44	3	204	177	120	48	9					e
					114	50	11					P
1552	0.63	4	265	228	119	76	22	11				e
					121	78	24	5				P
3880	1.52	6	38	25	5	6	5	7	1	1	0	e
					5.5	8.3	6.3	3.2	1.2	0.4	0.1	P

The mean number of recorded μ-e decays in cascades distinguished as hadronic is shown in Table 2 as a function of the mean cascade energy $\langle E_c\rangle$. The expected values of $\langle n_{\mu-e}\rangle$ are shown in the last line of the table. The results from ref.(7) multiplied by our recording efficiency ε=0.05 have been used:

$$\langle n_{\mu-e}\rangle\ (\text{calculat.}) = \varepsilon\cdot 0.8 E_c^{3/4} .$$

Table 2

$\langle E_c \rangle$ in Gev	890	1060	1260	1790	4260
$\langle n_{\mu-e} \rangle$ (exper.)	10.2±.8	9.9±.7	12.3±1.3	15.4±1.4	28.7±4.8
$\langle n_{\mu-e} \rangle$ (cal.)	6.8	7.7	8.8	11.4	21.9

There is some excess in experimental data as compared with calculations. It should be emphasized that unlike to the case of electromagnetic cascades the fluctuations of $n_{\mu-e}$ in hadronic cascades in a given energy interval are certainly bigger, than Poissonian ones. But, there is nothing to make one suspicious of separation procedure as being not reliable.

The ratio of separated hadronic cascades to the electromagnetic ones is shown in fig.1 as a function of cascade energy. The expected ratio shown by the solid line is calculated suggesting muon energy spectrum at our depth as $\frac{dN}{dE} \sim (200+E)^{-3.8}$, E in Gev and using μ-A cross-section for hadronic and electromagnetic interactions from (8).

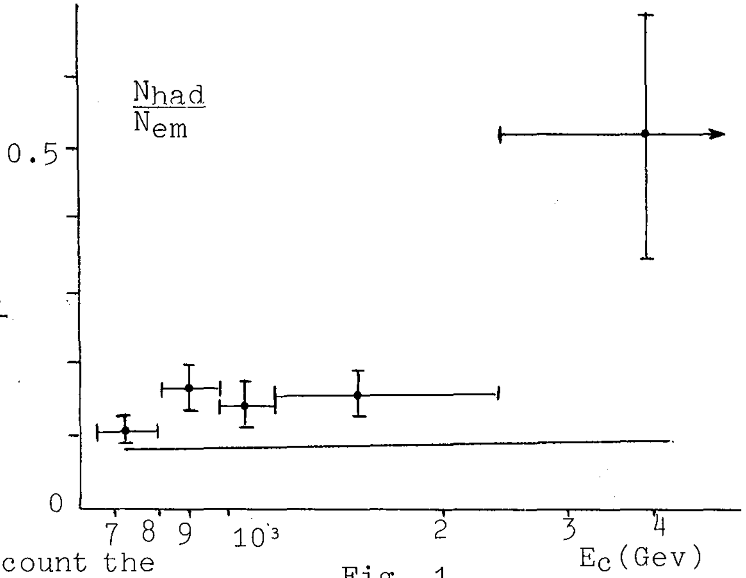

Fig. 1

In the energy range $E_c < 2500$ Gev the experimental data are in agreement with expectation if taken into account the statistical and possible systematic errors. For higher energies $E_c > 2500$ Gev there is an indication of a sharp increase of the fraction of hadronic cascades. This probably can not be taken too seriously as statistically it is only ~2σ effect.

References

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