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May gammas of energies 10^{15}-10^{16}eV from point sources be observed?

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Abstract

The flux of cosmic rays above 10^{15}eV is so low that it has been necessary to use ground-based air shower detectors to study a large sample of events. There is a great interest in understanding what is the primary composition in this energy region because of its potential significance for the origin and acceleration mechanism of high energy cosmic rays.

1 Introduction

Cosmic radiation in outer space is composed of photons, electrons and nuclei. In search for point sources of cosmic rays the main problem appears how to distinguish between the EAS originated by high energy quanta (especially those which come from the point sources) from the EAS initiated by charged particles such as Fe, N, α or p. Our incomplete knowledge about the processes at energies above accelerator energies, the rate of increase of a photoproduction cross section and the chemical composition of cosmic rays around and beyond the so called "knee" in the primary energy spectrum at $3*10^{15}$ eV leads to the fact that it is difficult to estimate the kind and the energy of the primary particle (both gamma or charged) which has initiated the shower. Muon - poor air showers with energies larger than 10^{15}eV were analyzed in search for gamma-rays from Cyg. X-3 /Samorski and Stamm 1983, Haverah Park group 1983, Akeno 1986/; the muon - poor shower method can be applied in order to select primary photons against the background of hadronic cosmic rays when it comes to looking for point sources. It is important to know whether muon content can be used to discriminate gamma-ray showers since the contribution of photoproduced muons increases with the increase of the primary energy. The recent result on the photoproduction cross section in electron-proton collisions at HERA do not rule out models in which it is necessary to consider a hadronic component in photon interactions at the highest energies. It should be noted that the absence of any unitary constrains allows for a very rapid (in comparison with the VMD prediction) increase of $\sigma_{\gamma-N}$ with energy as a result of gluonic structure of a high energy photon (“mini jet production mechanism”). Although the available cosmic ray data which were obtained with underground detectors (up to 10TeV) and with EAS arrays (up to 10^{15}eV) do not support this possibility a significant increase of a photoproduction cross section is not excluded at ultra high energies. The increase of a photonuclear interaction cross-section is one of the sources of uncertainties and puzzles to be solved in new experiments with great detection surface arrays. This problem is an important one in both high energy particle physics and astrophysics.

2 Assumption for electromagnetic cascades

In this paper the calculations of electromagnetic cascade were carried out in order to check what was the result of the growth of $\sigma_{\gamma-N}$ (according to the parameterization of Regge type) on individual characteristics of electromagnetic showers. The predicted value of $\sigma_{\gamma-N}$ at $\sqrt{s} = 200GeV$ is consistent with the reported numbers $\sigma_{\gamma-N}$ =0.154±0.016±0.032/mb/ for ZEUS and $\sigma_{\gamma-N}$ =0.159/mb/ for H1. The following model gave the best fit to the accelerator data:

$$\sigma_{\gamma-N} = [67.7 * s^{0.0808} + 129 * s^{-0.4525}]\mu b (s \ in \ GeV^2)$$

In our calculation the following transition formula was used to express $\sigma_{\gamma-N}$ in terms of $\sigma_{\gamma-air}$.

$$\sigma_{\gamma-air} = \sigma_{\gamma-|N} * A^{0.91}$$

Tab. 1 An energy dependence of photoproduction cross-section assumed in presented calculations:

$\sqrt{s}$ /GeV/	$\sigma_{\gamma-N}$ /mb/	$\sigma_{\gamma-air} = \sigma_{\gamma-\|N} * A^{0.91}$ /mb/
50	0.130	1.516
100	0.144	1.672
200	0.160	1.856
500	0.185	2.144
1000	0.207	2.395
1500	0.221	2.556
2000	0.231	2.677
3000	0.247	2.856
5000	0.268	3.100

The cross section for pair creation (e^+, e^-) by photons in the air $\sigma_{\gamma-air} = 520$ /mb/ according to Bethe-Heitler. The algorithm of electromagnetic cascade simulation included the hadron photoproduction and all those electromagnetic processes in which a particle may participate (radiation and pair creation, inelastic scattering of electrons and positrons with delta electron production, Coulomb scattering, the Compton effect and ionization losses). To describe a hadron photoproduction it was assumed that a γ-p interaction is similar to that of π-p but that inelasticity k=1; the spectrum of secondary particles was the same as in π-p interactions (our assumptions for hadron interactions were described J.Physc.G.17 (1991) 1261-1269).

3 Result of development of proton showers and the electromagnetic cascades with photoproduction

A considerable amount of muons produced during photoproduction processes in course of development of electromagnetic cascades come from the interactions of low energy photons (in EAS muons are produced in nuclear interactions) so those muons get more noticable with the increase of the shower size. The number of secondary photons (maximum at $3*10^7$eV for primary 10PeV) in gamma showers is so great that the photoproduction effect cannot be neglected despite the fact that its cross-section is so small. The increase of the photoproduction cross-section of gamma showers in the atmosphere may affect the development of a shower in two ways:

1) in the first interaction the shower has all characteristics of hadron showers (Tab 2 example 1)
2) in the following photon interactions – the shower is partly hadronic (other examples)

The simulations were performed for three energies of photon initiated showers (1PeV, 4PeV, 10PeV) – at the observation level – 0.765km above sea level – electron and muons numbers were calculated with different energy thresholds.

Tab. 2 a,b,c: An examples of the results for an individual γ-shower are shown below:

Eγ=10PeV

E^{μ}_{THR} /GeV/			10	20	100	200	500	1000
1	Ne=$5.22*10^6$	No. of μ	7008	3048	284	86	20	4
		R_μ /m/	53.2	31.7	8.9	5.33	1.9	1.2
2	Ne=$5.20*10^6$	No. of μ	668	281	21	6	0	0
		R_μ /m/	66.0	42.4	10.2	4.9		

3	Ne=3.50*10^6	No. of μ	619	260	17	5	2	0
		R_μ /m/	65.2	44.0	16.3	4.4	2.1	
4	Ne=3.86*10^6	No. of μ	531	238	15	6	2	0
		R_μ /m/	71.7	40.8	10.5	6.4	3.4	
5	Ne=3.60*10^6	No. of μ	630	283	19	6	3	0
		R_μ /m/	63.3	40.9	11.4	6.3	6.9	
6	Ne=6.20*10^6	No. of μ	763	168	7	2	0	0
		R_μ /m/	72.4	40.3	11.5	5.1	3.3	
7	Ne=4.50*10^6	No. of μ	383	168	7	2	0	0
		R_μ /m/	72.7	41.1	11.7	5.7		
8	Ne=2.70*10^6	No. of μ	365	163	12	7	2	0
		R_μ /m/	83.4	43.9	8.2	7.7	5.7	

$E\gamma$=4PeV

E^{μ}_{THR} /GeV/			10	20	100	200	500	1000
1	Ne=9.50*10^5	No. of μ	277	125	7	1	0	0
		R_μ /m/	75.9	43.4	15.5	14.9		
2	Ne=1.16*10^6	No. of μ	157	70	6	1	1	0
		R_μ /m/	80.2	42.9	9.2	3.8	3.8	
3	Ne=8.90*10^5	No. of μ	159	55	3	0	0	0
		R_μ /m/	76.6	44.5	14.5			
4	Ne=9.40*10^5	No. of μ	142	62	5	1	0	0
		R_μ /m/	82.5	44.7	10.9	7.8		
5	Ne=4.90*10^5	No. of μ	187	91	4	3	1	1
		R_μ /m/	96.5	61.6	12.7	8.3	5.7	5.7
6	Ne=1.27*10^6	No. of μ	145	65	3	1	0	0
		R_μ /m/	83.4	53.9	9.6	1.99		
7	Ne=9.0*10^5	No. of μ	170	76	8	4	1	1
		R_μ /m/	89.6	47.4	8.1	4.9	0.8	0.8
8	Ne=1.40*10^6	No. of μ	185	78	3	1	0	0
		R_μ /m/	79.4	49.7	12.8	8.7		

$E\gamma$=1PeV

E^{μ}_{THR} /GeV/			10	20	100	200	500	1000
1	Ne=1.65*10^5	No. of μ	249	111	16	41	20	0
		R_μ /m/	79.6	43.4	16.0	6.1	3.6	
2	Ne=3.10*10^5	No. of μ	62	26	26	0	0	0
		R_μ /m/	79.5	43.6	20.3			
3	Ne=3.82*10^5	No. of μ	63	24	4	1	0	0
		R_μ /m/	60.6	32.7	12.7	6.7		
4	Ne=1.13*10^5	No. of μ	54	21	0	0	0	0
		R_μ /m/	132	49.7				
5	Ne=1.30*10^5	No. of μ	25	12	2	1	0	0
		R_μ /m/	85.3	40.7	11.9	5.6		

6	Ne=1.87*10^5	No. of μ	33	13	1	1	0	0
		R_μ /m/	72.5	34.5	3.2	3.2		
7	Ne= 2.0*10^5	No. of μ	50	25	1	0	0	0
		R_μ /m/	90.4	61.2	6.8			
8	Ne=8.90*10^5	No. of μ	35	15	1	0	0	0
		R_μ /m/	95	50.1	34.2			

In EAS experiments the kind and the energy of a primary particle can be estimated from the registered numbers of electrons and muons. The presented examples show that not only electromagnetic component but also muons are registered in showers initiated by primary photons. Muons registered in such showers make the experimenters claim that a primary particle in such a case was charged particle i.e. proton. The results of simulations of the showers initiated by primary protons with such energies which give muons and electrons numbers close to those observed for gamma shower with fixed energies are shown Tab. 3.

Tab. 3: The results of the simulations for fifty proton showers (average)

E^μ_{THR} /GeV/			10	20	100	200	500	1000
E_0^p:								
1 PeV	Ne=1.46*10^5	No. of μ	3075	1478	174	58.8	14	4.1
		R_μ /m/	97.2	58.6	18.1	10.8	5.5	3.3
3 PeV	Ne=6.80*10^5	No. of μ	7964	3800	436	150	31	9
		R_μ /m/	91.0	55.7	16.8	10.3	4.9	2.9
8 PeV	Ne=2.00*10^6	No. of μ	17710	8333	907	303	69	20.6
		R_μ /m/	86.3	51.7	15.1	8.8	4.4	2.3

As one can see a considerable amount of showers initiated by primary gammas of energy 1PeV, 4PeV, 10PeV (a photoproduction process being included in calculations in accordance with the Regge parametrisation) were registred as proton showers with lower number of muons. The estimation of energy of such EAS (10PeV primary γ) evaluate from the number of electrons, is 5-20PeV where as from the amount of muons is 200TeV-2PeV.

4 Summary

The mechanism of photoproduction cannot be ignored when extrapolating accelerator data on photoproduction to higher energies. The discrepancy in evaluation of energy – on basis of electron and muon numbers gives the proof that the showers were initiated by primary photon. The obesrved excess of showers in the “knee” region of the primary spectrum may be partly connected with poor estimation of energy of the primary particle which has initiated the shower (especially a gamma shower; energy spectra for particles from point sources are very flat).

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