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Instanton-induced processes in unusual cosmic ray events in TeV Region energy

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Abstract. High order intermittency analysis of cosmic ray interactions in TeV region energy has been performed.It has been obtained that the behaviour of intermittency index $\varphi_q(q)$ is essential differed for unusual events (mean transverse momentum of secondary particles $< p_t > \approx 0.8\ GeV/c$) in the comparison with standard ones ($< p_t > \approx 0.2\ GeV/c$). Instanton-induced interpretation of unusual interactions has been considered.

1 Introduction

At last time the investigation of different characteristics of nucleon - nuclei and nucleus - nuclei interactions at TEV region of energy became a great importance in connection with the modern development of both an experiment and a theory of strong interactions (Shuryak, 2001; Manjavidze and Sisakian, 2001). In this situation we would like to pay attention to the interpretation of an unusual type of cosmic ray interactions at large energy in which practically all secondary particles were produced with a large transverse momenta $p_t \sim 1\ GeV$: the works of Stratosphere (Dobrotin et al.,1979; Apanasenko et al., 1990), (JACEE, 1986) and (CONCORDE, 1986,1988) Collaborations. The interesting feature of these events was in the large difference of p_t distribution of the secondary particles in compare with the distribution in ”usual” events with $p_t \approx 0.2\ GeV$. Unfortunately, in spite of the fact that the first data on existence of ”anomalous” events were obtained more than ten years ago, the underlying mechanism of hadron-hadron interaction, which is responsible for these events, have not been understood so far. The main goal of this report is the investigation of the possible distinction in underlying mechanism of the formation of the hadronic final states in the ”anomalous” and ”usual” events by the study of the structure of dynamical fluctuations, which is one of more stringent test on models of multiparticle production (De Wolf et al., 1996).

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2 Data

Cosmic ray interactions at $E_0 > 5 * 10^{13} eV$ were found in X-ray film - emulsion chambers exposed in the stratosphere.The number of events is 24 and multiplicities of events are in the interval from 50 up to 675. The each chamber included a target and gamma blocks. The target block was gathered of many layers of heavy or light material interplead with thin nuclear emulsions; gamma block consisted of 4 - 10 lead plates each $5mm$ thickness with nuclear emulsions and X-ray films between them (Dobrotin et al., 1979).

For each interaction in the target block the number of charged secondary particles (n_{ch}), the number of secondary γ - quanta (n_γ), the angles of emission of each secondary particle in the laboratory coordinate system Θ_{ch} and Θ_γ , an energy and a transverse momentum of each overthreshold γ - quantum E_γ and $p_{t\gamma}$ have been determined. The threshold for the electromagnetic cascade in X-ray films was $2TeV$ and in nuclear emulsion - $0,05TeV$. The deviation of the accuracy for $p_{t\gamma}$ has not been greater than 30%.

The analysis of measured values of transverse momentum of each photon in interactions with $\sum E_\gamma > 10TeV$ showed that 7 of them (index ”$P_T = 1$”) were quite different from others. The transverse momentum of most photons in these 7 interactions were several times greater than average transverse momentum of secondary photons in ”standard” type events with $< P_{T\gamma} > \sim 0,2GeV/c$ (index ”$P_T = 0$”). The integral distribution of transverse momentum of all the secondary photons has been given in Fig.1.

It can be describe by the superposition of two exponents:

$$N_\gamma(> p_{t\gamma}) = A_1 exp(-p_{t\gamma}/p_{01}) + A_2 exp(-p_{t\gamma}/p_{02}), \quad (1)$$

where $p_{01} \sim 0,2GeV/c$ for ”standard” events and $p_{02} \sim 0,8GeV/c$ for ”anomalous” ones. The main feature of these 7 ”anomalous” interactions is that most of photons have the transverse momentum $p_{t\gamma} \geq 0,5GeV/c$.

3 Analysis of the structure of fluctuations

New intermittency analysis of Stratosphere Collaboration data (Dobrotin et al.,1979; Apanasenko et al., 1990) has been performed. To study dynamical density fluctuations over the background of the statistical fluctuations, the analysis of the scaled factorial moments of the multiplicity distribution (Bialas and Peschanski,1986,1988) has been used:

$$< F_q(\delta) > \quad = \quad \frac{< n^{[q]} >}{< n >^q} \tag{2}$$

where $< n^{[q]} >=< n_m(n_m-1)\dots(n_m-q+1) >$ for ever decreasing domains of phase-space δ, down to the experimental resolution.

If self-similar fluctuations of many different sizes exist, then the dependence of the moment $< Fq >$ from the size of the phase-space bin follows the power law and process is called ”intermittency”:

$$< F_q > \quad = (1/\delta)^{\varphi_q} \tag{3}$$

for $\delta \to 0$. Positive constant $\varphi_q \neq 0$ is the so called intermittent exponent.

The distribution (2) is discontinues, i.e. contains sharp spikes and holes between particles in phase-space. The observation of such a power law in a sufficiently large range of scales δ would be indicate at the selfsimilar fractal structure of the short range particle density fluctuations.

In the opposite case of the smooth distribution (probability density is continuous), the factorial moments are

$$< F_q > \quad \sim \quad Const. \tag{4}$$

It should be mentioned that the high order moments resolve the large tail of the multiplicity distribution. Thus, they are very sensitive to density fluctuations at the various scales δ used in the analysis. Therefore, the study of fluctuations in the large of scales δ, especially at small δ and large q, can improve our phenomenological understanding of multiparticle production processes.

On the experiment the particle multiplicity distribution are studied for a sequence of phase space domains δ by consecutive subdivision of an initial region Δ in M equal subdomains: $\delta = \Delta/M$.

In order to improve the statistical accuracy in the experimental estimation of factorial moments F_q's of individual cells (1) are averaged over events and over M cells (”vertical analysis”). In this work we used the modified method of vertically averaging (Argynova et al., 1997) in which moments are averaged over the start point of the original region Δ location

$$< F_q >= \frac{1}{M}\sum_m \frac{1}{N_{step}}\sum_{step}\frac{1}{N_{evt}}\sum_{evt}\frac{< n_m^{[q]} >}{< n_m >^q}, \tag{5}$$

where N_{step} is the number of small $(step/\Delta \ll 1)$ steps of the start position of the original region Δ in the area of pionization. In every subdomain $m \quad (m = 1, ..., M) \quad n_m$ is the multiplicity of that bin.

As the basic variable the pseudo-rapidity $\eta = -ln\ tg\Theta/2$ of the charge secondary particles has been used. The initial region of Δ was 4.0 and $M = 40$. In more detailed analysis we additionally took Δ equal 3.5 and 3.8 and $M = 35$ and $M = 38$.

4 Results and discussion

From our point of view the lowest order of correlations are not very sensitive to the instanton-induced processes and only the consideration of high orders can give the correct results. Therefore, the high order intermittency analysis with rank of moments up to 8 has been performed. For events with standard p_t distribution the results of the analysis demonstrates that the $ln\ F_q$'s rise with increasing $-ln\delta\eta$ for all orders. The data are consistent with intermittent behaviour, i.e. with power law (2). On the contrary, for large p_t events, i.e. for the ”anomalous” events the values of the slopes and their changing as function of q are essentially smaller. The details of the analysis are described in (Argynova et al.,1998), (Argynova et al.,1999). The results of the fit of the $ln\ F_q$'s as a function of $-ln\delta\eta$ (over $0.1 \le \delta\eta \le 1.0$ and for $\Delta = 4.0$) have shown that the all slopes φ_q are essentially larger for the events with small p_t in comparison with the case of the large p_t events: see Table 1.

Table 1. Slopes φ_q as a function of $-ln\delta\eta$ fitted over $0.1 \le \delta\eta \le 1.0$ for large and small p_t events

	small p_t events	large p_t events
q	φ_q	φ_q
2	0.100 ± 0.004	0.068 ± 0.005
3	0.260 ± 0.014	0.095 ± 0.010
4	0.310 ± 0.027	0.094 ± 0.016
5	0.51 ± 0.05	0.08 ± 0.02
6	0.66 ± 0.06	0.10 ± 0.03
7	0.77 ± 0.09	0.11 ± 0.04
8	1.29 ± 0.11	0.13 ± 0.06

The clear comparison of the slopes φ_q for two types of interactions has been presented on Fig.2.

The fit of the slopes φ_q as a function of q: $\varphi_q(q) \sim b_1 q + b_2 q^2$ for two types of interactions has led to the result in the next table.

Table 2 . Slopes φ_q as function of q fitted over for large and small p_t events

	small p_t events	
Δ	b_1	b_2
4.0	0.09 ±0.03	0.007 ± 0.004
3.8	0.03 ±0.03	0.014 ± 0.004
3.5	0.05 ±0.03	0.011 ± 0.005
	large p_t events	
4.0	0.03 ± 0.02	-0.002 ± 0.002
3.8	0.02 ± 0.02	-0.003 ± 0.003
3.5	0.03 ± 0.02	-0.002 ± 0.003

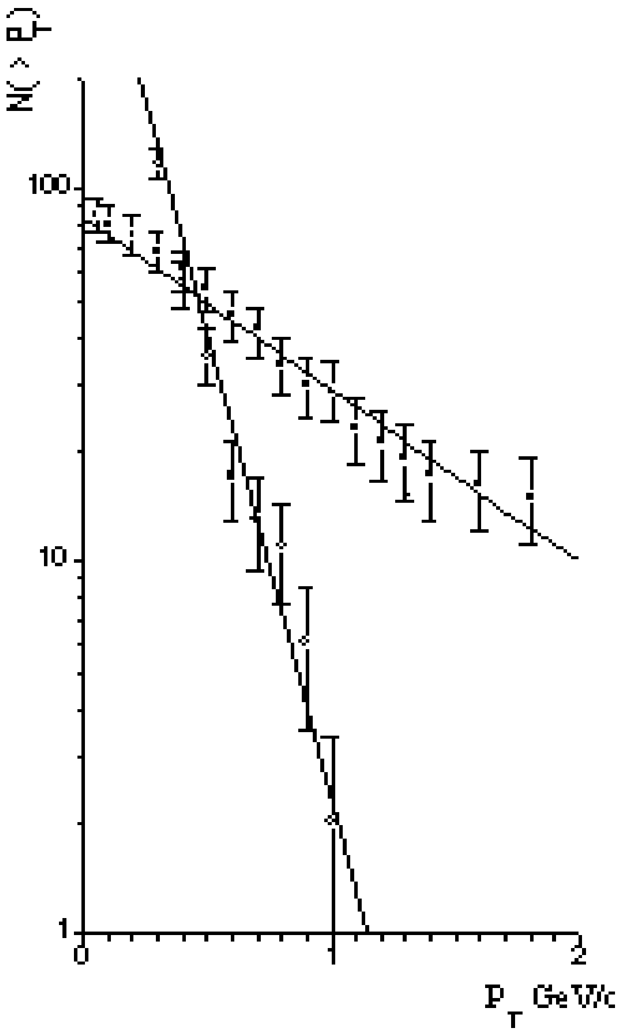

Fig. 1. p_t distribution of secondary particles in two kinds of interactions.

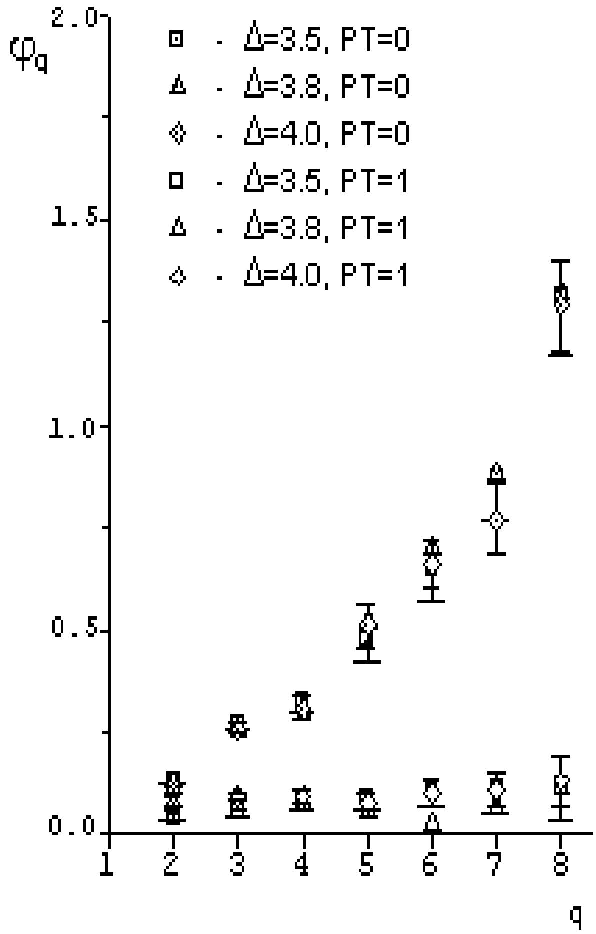

Fig. 2. Fig. 2 The comparison of the slopes φ_q as a function of the moment order q for two kinds of interactions

It is evidently that the differences of the p_t and φ_q characteristics in these classes of events are so large to be explained by the errors in the estimation of E_γ or by statistical fluctuations. So, the studied intermittency index behaviour in addition to the previous results on distributions of transverse momentum hint to the conclusion that there is a strong indication of the existence of the second class of interactions with large p_t of secondary particles.

In the conventional theoretical interpretation the $< F_q(\delta) >$ behaviour for small p_t events can be understand as a result of perturbative QCD evolution of partonic cascade at high energy. In this case the independent hadronization of the quarks and gluons in partonic chain leads to the significant intermittency patterns.

For the ”anomalous” large p_t events, the behaviour of the factorial moments is very different in compare with the ”usual” events. This is extremely interesting result. It seems that the perturbative QCD can not describe the new data and new mechanism shuld be involved in that case. One of the possible candidate for that mechanism could be some contribution from nonperturbative QCD dynamics to hadron-hadron interactions at large energies: the existence in QCD vacuum the strong nonperturbative fluctuations of gluon fields so-called instantons, (Schafer and Shuryak,1998). The instantons describe the subbarrier transition between different classical vacuum states in QCD and reflect the selfinteraction of the gluon fields.

Recently it was shown that instantons can play the important role not only in the description of the complex structure QCD vacuum and static hadron properties but also can give the significant contribution to quark-quark, quark-gluon and gluon-gluon interactions at high energies (Balitsky and Braun,1993), (Dorokhov et al.,1993), (Carli et al.,1999). Investigation of search strategies for QCD instanton-induced processes at HERA in deep-inelastic scattering regime and the first results are reported in (Carli et al.,1999) and (Buschhorn, 2001). In (Kuvshinov and Shulyakovsky,1999) the analysis of the correlation moments of second order has been suggested to search such events at HERA. However, the lowest orders of moments are not very sensitive to the recognition of the instanton-induced events.

It is mentioned that due to spherical space-time symmetry of the instanton solutions the specific final hadronic states produced by these interactions is expected. One of the clear feature of instanton-induced processes is a rather large value of the transverse momentum of all produced particles and smooth distribution of them in phase-space. Just the same kinematical features have our "anomalous" events. Therefore, these events seem a promised candidates for the instanton-induced events.

5 Summary

A strong indication of the existence of the new class of hadron-hadron interactions at large energies is obtained. The possible explanation of these interactions as the result of contribution of the nonperturbative QCD dynamic is given.

The application of approach of our paper to the collider's data could be very useful for the search of the instanton-induced events in lepton-hadron and hadron-hadron interactions.

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