Some characteristic cosmic ray events and an attempt at their explanation

S. Bhattacharyya
Physical and Earth Science Division
Indian Statistical Institute
Calcutta-700035,
India

«ABSTRACT»

Some cosmic ray events with very large multiplicities and very high transverse momenta have recently been reported in balloon-borne emulsion chamber experiments. The explanation for these events by the standard approaches has become a bit problematical. We have attempted here to understand and interpret them in the light of a dynamical model of multihadron production phenomena with power-law nature of average multiplicity and automatic scale-breaking derived in the model.

1. Introduction

In the recent past some cosmic ray events with very high multiplicities and large average transverse momenta have been observed in a balloon-borne emulsion chamber experiment(1) in the collisions between Si-AgBr nuclei. The charged multiplicity range is 750 ~ 1000 and the range of the average transverse momentum lies between 550-700 Mev/c and the observed event number is two. The rising behaviour of the average transverse momentum with energy is also confirmed by the CERN $P\bar{P}$ collider experiments.(2) But the CERN $P\bar{P}$ collider results, it is believed, set an upper limit $(\langle n\rangle \sim \ln^2 S)$ to the nature of growth of multiplicity which cannot accommodate such high multiplicity events. Herein lies the problem.

There has in recent times been a lot of theoretical studies(3) in understanding these events which are just not flukes. We would like to apply here a model for production of secondaries by BANDYOPADHYAY and BHATTACHARYYA(4) in order to see whether such events can be explained with the help of the expressions we arrive at from the viewpoint of this model.

2. The model and the method.

We will put our model for nucleon-nucleon reactions into use here for nucleus-nucleus collisions on the assumption that all nucleus-nucleus collisions can be treated with the basic dynamics of nucleon-nucleon interactions and taking into account an A-dependence term into final calculation in a somewhat hand-inserted manner, at least for the present.

According to the present model, nucleons are thought to be composed of pions and spectators so far as strong interactions are concerned and all hadronic collisions thus boil down to pion-pion interactions. The interactions proceed in a sequential chain through some ρ-ω-π exchanges with emission of free secondary pions at each vertex on both sides of the horizontal ρ-ω chain giving rise to the spray-like nature of emission of the secondaries (and thus contributing to some form of 'jettiness'). The chain ends as soon as both the mediating and final ρ meson is absorbed by the pions in the target. Kaons are produced from the decay of the virtual ϕ^0 mesons which are generated through $\rho\pi\phi^0$ coupling and the secondary baryons-antibaryons (non-leading) are the products the decays of pions arising out of the sequential $\rho\omega\pi$ chains as prescribed in the pion production. This model gives a unified description for production of both low and large p_T secondaries, an explanation for the leading particle effect and accounts for the by-now established <<universality>> of all hadron-involved interactions as well as of e^+e^- annhilations.

3. Theoretical Results

By applying the Feynman diagram techniques and some standard high energy assumptions the following expressions, very crucial for our cosmic ray physics purpose, were derived

$$E\frac{d^3\sigma}{dp^3}\bigg|_{pp\to\pi^- x} \simeq G_{\pi^-} \exp\left[-\frac{26.88}{\langle n_{\pi^-}\rangle}\frac{k_T^2+m_\pi^2}{1-x}\right] \exp\left[-2.38\langle n_{\pi^-}\rangle x\right] \quad — (1)$$

with

$$\langle n_{\pi^-}\rangle_{pp} \simeq \langle n_{\pi^+}\rangle_{pp} \simeq \langle n_{\pi^0}\rangle \simeq .33\, s^{\frac{1}{3}} \quad — (2)$$

and

$$E\frac{d^3\sigma}{dp^3}\bigg|_{pp\to\pi^+ x} \simeq \left[1+2.7\, s^{-\frac{1}{3}}\right] E\frac{d^3\sigma}{dp^3}\bigg|_{pp\to\pi^- x} \quad — (3)$$

and the inclusive crosssection for the π^0 production is just the mean of inclusive (secondary) π^+ and π^- crosssections.

The expression for the average transverse momentum of any type of particle C is defined by

$$\langle p_T\rangle_C = \frac{\int F(x,p_T)_C\, p_T\, dp_T^2}{\int F(x,p_T)_C\, dp_T^2} \quad — (4)$$

Using the above definition and making use of the expressions (1-2) deduced by our dynamical model we finally arrive at

$$\langle p_T \rangle_{\pi^-} \simeq 1{\cdot}1 \times 10^{-1}\, s^{\frac{1}{6}}\ \mathrm{GeV/c} \quad \text{—(5)}$$

The expression (2) with incorporation of a maximum $A^{\frac{1}{3}}$ (actually $\leq A^{\frac{1}{5}}$) dependence can account for the observed range of multiplicity events and the expression (5) gives their average transverse momenta in the expected limit. Why the number of such events is limited to two only could probably be explained in terms of phase transitional probability(3a) occurring in the structure of hadrons ; the pion clusters in the strong interaction domain might exhibit further structures leading to a change in the nature of interactions at such high energies. This aspect is now under study. Side by side, the explicit nature of A dependence is also being looked into.

4. Discussion and Conclusions

Our brief study shows that the problem might not be linked up with the validity or violation of the KNO scaling(3) or be connected with the unknown heavies as proposed by Sukuyama and Watanbe(3). Some further comments are in order here : (i) it is seen and supported here that "$\langle p_T \rangle$ increases gradually with energy and this increase is associated events corresponding to average multiplicities - not with events higher than average multiplicity" as was argued by Halzen,(5) (ii) our multiplicity pattern follows power law (although the rate is a bit larger here) as advocated by Muraki.(6) This inevitably leads to the violation of both Feynman and KNO scaling as argued and/or observed by many authors.(7,8) But the fair agreement that we claim here might be proven wrong by the uncertainties in the correctness of the measurement of the average transverse momentum as pointed out by Hagedorn.(9)

We would like to emphasise here a few more points. Unless the experimental results from the Fermilab $\bar{P}P$ collider at higher energies than the CERN $\bar{P}P$ collider are to hand no one can and should put a queitus to the power law nature - whatever its magnitude far less than unity - of average multiplicity practically on the basis of quasi empirical type of QCD predictions. QCD has many intrinsic loopholes(10) even in its philosophy of confinement, the very kernel of the theory. Thus we hope our model might have had a modest prospect in future studies vis-a-vis this QCD state and the so far illusive(11) (experimental) behaviour of the quarks.

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NOTE ADDED : In getting the order of magnitude of the multiplicity and the average transverse momentum we make use here of the relation $S = 2\, i\, M_A\, E$ where i = number of nucleons involved in each collision and the other letters have their usual significances. It is seen that in order to have a good fit one has to take here $i \sim 30$.