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NEW PHYSICS SIGNALS IN GLOBAL EVENT PROPERTIES IN *pp* COLLISIONS AT THE LHC*

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The properties of a new possible class of events, characterised by large hadronic densities and very few clans, in proton-proton collisions at LHC energy are explored within the mechanism of the weighted superposition of different substructures. The most surprising feature is the appearance of an "elbow structure" in the high multiplicity tail, leading to very large expected multiplicity fluctuations.

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1. Introduction

The weighted superposition mechanism has been successful [1–3] in explaining several features of multiparticle producing high energy collisions. It assumes that events can be classified in (for the moment) two classes, characterised by different global properties, but with a common structure to be found in the idea that each class' charged particle multiplicity distribution (MD) is described in terms of a negative binomial (NB), also known as Pascal, MD with characteristic parameters $\bar{n}$ (the average multiplicity) and k (related to the variance D^2 by $k^{-1} = D^2/\bar{n}^2 - 1/\bar{n}$). Thus the total MD is obtained by superimposing the two classes with an appropriate weight:

$$P_n = \alpha_{\rm soft} P_n^{\rm (NB)}(\bar{n}_{\rm soft}, k_{\rm soft}) + (1 - \alpha_{\rm soft}) P_n^{\rm (NB)}(\bar{n}_{\rm semihard}, k_{\rm semihard}). \quad (1)$$

For pp and $p\bar{p}$ collisions, the two classes correspond to soft events (events without mini-jets) and semi-hard events (events with mini-jets), and the weight is the fraction of soft events.

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The experimental facts explained by this mechanism up to presently available collider energies are:

(i) the shoulder structure in the MD in the intermediate multiplicity range;

(ii) the quasi oscillatory behaviour of the ratio of factorial cumulants, K_n, to factorial moments, F_n, when plotted as a function of the order n (after an initial sharp decrease towards a negative minimum at $n \approx 5$);

(iii) the energy dependence of the strength of forward-backward multiplicity correlations.

The NBMD for each class of events can then be interpreted using clan analysis in the two-step mechanism framework [6]. Clans are defined as sets of particles of common ancestry, as the first step consists in the production of statistically independent 'ancestors', whose number $\bar{N}$ is Poisson distributed; in the second step, each ancestor 'decays' into (correlated) final particles following a logarithmic distribution in which the average number of particles per clan is $\bar{n}_{\mathrm{c}}$. These just introduced parameters are related to $\bar{n}$ and k in the following non-trivial way:

$$\bar{N} = k \ln(1 + \bar{n}/k); \qquad \bar{n}_{\mathrm{c}} = \bar{n}/\bar{N}. \tag{2}$$

Notice that each clan contains at least one particle (the ancestor) and that correlations among particles are exhausted within each clan.

The behaviour of the two components thus described has been extrapolated at high energies [1, 2], assuming that the total average multiplicity grows as $\log^2 \sqrt{s}$, finding that the soft component satisfies KNO scaling, and presenting three scenarios for the behaviour of the semi-hard component: in the first one, it also obeys KNO scaling (this scenario is disfavoured by recent Tevatron results [4]); in the second one k^{-1} grows as $\log s$ (maximally violating KNO scaling); in the third scenario, inspired to leading log QCD calculation, k^{-1} grows as $\sqrt{\log s}$, which also violates KNO scaling at present energies but satisfies it asymptotically. Further Tevatron results [5] seem to favour scenario II, although there are still doubts due to some incompatibilities in the MD at SPS energies when compared with UA5 results [8].

The second scenario presents some surprising features: going from the GeV energy range to the TeV energy range, the average number of clans decreases by a factor 2, while the average number of particles per clan increases by a factor 3. If this aggregating behaviour of clans were to continue up to very high energies, one would eventually reach maximum aggregation when $\bar{N} = 1$. This condition, from the definition, Eq. (2), implies that

$$\bar{n} = k(\mathrm{e}^{1/k} - 1), \tag{3}$$

and being at such energies $\bar{n} \gg k$ one obtains

$$k < 1 \tag{4}$$

as the benchmark for a new class of multiplicity distributions. At this point, one is lead to ask whether this is an asymptotic property of the semihard component, or the characteristic property of an effective third class of events to be added to the soft and semihard ones. In the following, we explore some consequences of the second possibility (for a deeper discussion see [9]); we will refer to third component's quantities by the suffix 'th'.

As already mentioned, the request of an average number of clans, $\bar{N}_{\text{th}}$, of few units in the third component leads to values of k_{th} less than one whereas that of $\bar{N}_{\text{th}} \approx 1$ implies $k_{\text{th}} \to 0$ for large $\bar{n}_{\text{th}}$. Notice that in this last extreme situation the average number of particle per clan, $\bar{n}_{\text{c,th}}$ coincides of course with the average number of particles of the new component, $\bar{n}_{\text{th}}$. Under the condition $k_{\text{th}} \ll \bar{n}_{\text{th}}$, the NBMD is well approximated by a log-convex gamma distribution, which for k_{th} close to zero leads to the average number of clans ≈ 1 and to the total MD well described by a logarithmic one. This result is therefore consistent with the clan interpretation of the two-step mechanism mentioned above.

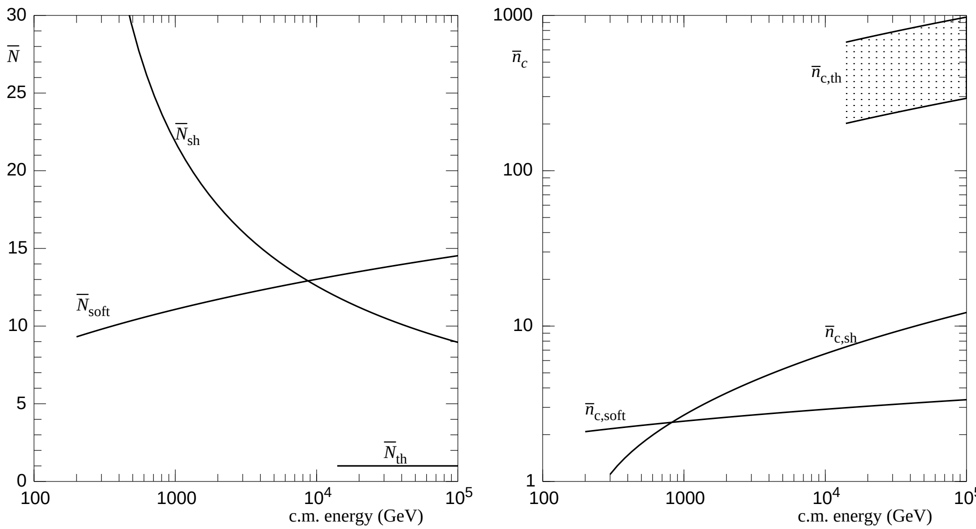

Fig. 1. Energy dependence of the average number of clans (left panel) and of the average number of particles per clan (right panel) for the three components (the band illustrates different choices for $\bar{n}_{\text{th}}$, see discussion in the text.)

In Fig. 1 are plotted $\bar{N}$ and $\bar{n}_{\text{c}}$ for the three components as a function of c.m. energy in full phase space: the first two components are those discussed in [1], the semi-hard behaviour considered being that of scenario 2. The lack of experimental data on the third component at lower c.m. energies and the consequent impossibility to guess its behaviour in terms of extrapolations as it was done for the soft and semihard components in Ref. [1], led us to show a band of possible values. A conservative guess that the total multiplicity variation due to the third component over the extrapolation of Ref. [1] is limited to 10% leads to $\bar{n}_{\rm th}$ values from 3 to 10 times larger than the total multiplicity, *i.e.*, to a third component weight ranging from 1 to 3%. Notice that to a small variation of $k_{\rm th}$ according to Eq. (3) corresponds a quite large variation of $\bar{n}_{\rm th}$. This is clearly shown in the figure, where $\bar{N}_{\rm th} = 1$ whereas $\bar{n}_{\rm c,th}$ is 3 times larger in one case with respect to the other. Last but not least, $\bar{n}_{\rm c,th}$ is, as assumed, much larger than in the two other components.

Finally, in consequence of the assumed quite extreme clan and particle aggregation into few clans, quite large forward-backward multiplicity correlations are also expected, and the leakage parameter (clans spilling from one hemisphere to the other) is expected close to its extreme value 1/2, see [3]. At partonic level the mentioned remarks would suggest for the third component high parton density clan production with huge colour exchange processes originated from a relatively small number of high virtuality ancestors, which would indicate probably an emission mechanism harder than that seen in the semihard component.

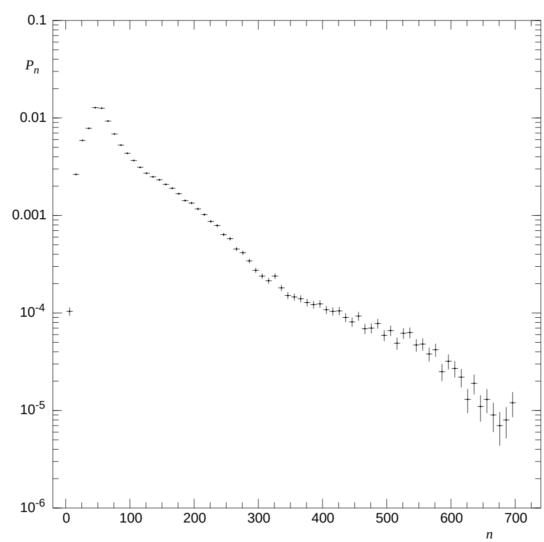

Fig. 2. n charged particle multiplicity distribution P_n predicted for minimum bias events in full phase space by PYTHIA Monte Carlo (version 6.210, default parameters using model 4 with a double Gaussian matter distribution) at 14 TeV c.m. energy, showing two shoulder structures.

It is interesting to point out that the total charged particle MD, P_n, of the events generated with the last version of the PYTHIA Monte Carlo model [7] both in full phase space and in a restricted rapidity interval ($|\eta| < 0.9$) cannot be fitted in terms of the weighted superposition of two NBMD's and that the plot of P_n *versus* n shows two shoulders (see Fig. 2). These two shoulders appearing in the total multiplicity distribution come, in our framework, from the weighted superpositions of the first with the second and of the second with the third component. It would be tempting to identify the third component found in PYTHIA with the hard one discussed above, but striking differences between them make this identification impossible.

Indeed, the result of adding a new, third class looks quite different, as shown in Fig. 3: in addition to the weighted superposition of the soft component with the semihard one which gives the shoulder at intermediate multiplicity, already seen in Ref. [1], an "elbow structure" is expected, as the result of the weighted superposition of the NB MD of the semihard component with the gamma log-convex MD of the (third) hard one. The figure also shows an enhancement at very low multiplicity, which however is experimentally troublesome; in any case, this clearly shows the unusual amount of fluctuations this new component provides. In the end, it should be pointed out that the QCD-inspired scenario does not provide for such a dramatic

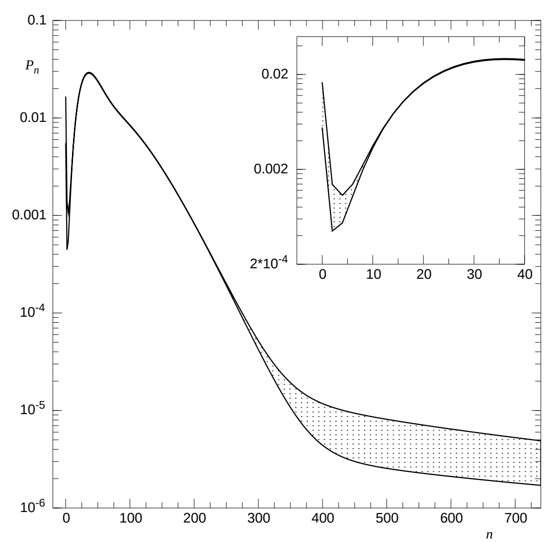

Fig. 3. n charged particle multiplicity distribution P_n expected at 14 TeV in presence of a third (maybe hard) component with $\bar{N}_{\rm th} = 1$, showing one shoulder structure and one 'elbow' structure. The band illustrates the range of values of parameters $\bar{n}_{\rm th}$, $k_{\rm th}$ and $\alpha_{\rm th} = 1 - \alpha_{\rm soft} - \alpha_{\rm sh}$ discussed in the text.

decrease of the parameter k: on the contrary, it is in such case expected to stop decreasing and start increasing again; this same behaviour is expected also in string fusion models of multiparticle production due to saturation effects which dampen fluctuations [10].

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