PRODUCTION ASSOCIATED TO RARE EVENTS IN HIGH ENERGY HADRON-HADRON COLLISIONS.

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Abstract

At very high energy the same universal relation between the multiparticle or the transverse energy distribution associated to a rare event $C$, $P_C$ and the corresponding minimum bias distribution $P$, $P_C(\nu) \equiv \nu/ <\nu> P(\nu), \nu \equiv n$ or $E_T$ works for nucleus-nucleus collisions as well as for hadron-hadron collisions. This suggests that asymptotically, all hadronic processes are similar.

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Successful models for multiparticle production in hadron-hadron, hadron-nucleus and nucleus-nucleus collisions are multiple interaction models where the final multiplicity distribution and correlations are obtained from the superposition of the elementary collisions. A typical model of this kind is the Dual Parton Model (DPM) [1, 2].

We have recently made an attempt to abstract the general properties of such models in the limit when the number of elementary collisions is very large [3, 4]. There are two possibilities for increasing the number of elementary collisions. One is by increasing the number of constituents, i.e., by increasing the atomic number of the incoming particles and going to heavy ion collisions. The other possibility is by increasing the center of mass energy and going to hadron colliders. It is this possibility that we would like to discuss here.

In models where particle distributions are obtained from the superposition of independent contributions of the elementary collisions one can in general, write

\[ P(n) = \sum_{\nu=1}^{\infty} \sum_{n_1, \ldots, n_\nu} \varphi(\nu)p(n_1)p(n_2)\ldots p(n_\nu) \]  

(1)

where \( P(n) \) is the normalized multiplicity distribution, \( \varphi(\nu) \) the distribution in the number of elementary collisions and \( p(n_i) \) the elementary collision particle distribution.

A strong approximation is made in (1): all elementary collisions are treated as equivalent.

From (1) it follows, in a straightforward manner, for the average multiplicity \( \langle n \rangle \) and the square of the width of the distribution \( D^2 \equiv \langle n^2 \rangle - \langle n \rangle^2 \) [3]

\[ \langle n \rangle = \langle \nu \rangle \bar{n} \]  

(2)

and

\[ \frac{D^2}{\langle n \rangle^2} = \frac{\langle \nu^2 \rangle - \langle \nu \rangle^2}{\langle \nu \rangle^2} + \frac{1}{\langle \nu \rangle} \frac{d^2}{\langle \nu \rangle^2} , \]  

(3)

where \( \bar{n} \) and \( d^2 \) are the quantities equivalent to \( \langle n \rangle \) and \( D^2 \), respectively, for the elementary collision. Relations similar to (3) can be written for higher order correlations [3].

It is experimentally known that the average multiplicity \( \langle n \rangle \) and the normalized dispersion \( D/ \langle n \rangle \) increase with the atomic number \( A \) of the colliding particles and with the energy. In particular, \( D/ \langle n \rangle \) is larger in AA collisions than in hh collisions and increases with energy as shown by KNO scaling [6] violations at the CERN \( p\bar{p} \) collider, [4].

These observations imply, from (2) and (3), that \( \langle \nu \rangle \) and \( (\langle \nu^2 \rangle - \langle \nu \rangle^2) / \langle \nu \rangle^2 \) increase with energy (and \( A \)). Asymptotically we obtain

\[ \frac{D^2}{\langle n \rangle^2} = \frac{\langle \nu^2 \rangle - \langle \nu \rangle^2}{\langle \nu \rangle^2} \]  

(4)

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In general, at high energy, fluctuations in the number of elementary collisions will dominate correlations.

A word of caution is needed here. At present $p\bar{p}$ collider energies, (0.2-2) TeV, the average number $<\nu>$ of elementary collisions is not large \[2\]. On the other hand, valence quark-valence quark interactions are still dominant making the approximation “all elementary collisions are treated as equivalent” somehow suspicious. This is particularly true if one triggers on fast particles ($x \approx 1$) or low $p_T$ heavy weak bosons ($W$ or $Z^0$): they must come from valence quarks.

We look now at the multiparticle distribution $P_C$ associated to a rare weakly absorbed event $C$, in comparison with the minimum bias distribution $P$. The discussion of \[4\] on nucleus-nucleus collisions, extended to high energy hadron-hadron collisions, means that the universal relation

$$P_C(n) = \frac{n}{<n>} P(n)$$

should hold. This relation can as well be written for transverse energy $E_T$ distributions.

Eq. (5) was shown to work reasonably well in nucleus-nucleus collisions. Before testing (5) for high energy hadron collisions we would like first to further discuss its content.

From (5) one arrives at the following relations for moments $<n^q>$:

$$<n^q> = <n^{q+1}> / <n>, \quad q = 1, 2, \ldots$$

with, in particular,

$$<n>_c = \frac{<n^2>}{<n>_2<n>}, \quad (7)$$

or,

$$<n>_c \geq <n>. \quad (8)$$

Making use of the KNO variable,

$$z \equiv n/ <n> \quad (9)$$

(7) becomes

$$<z^q>_c = <z^{q+1}> / <z^q>. \quad (10)$$

If one now writes the probability distribution in the KNO form,

$$<n> P(n) \longrightarrow \Psi(z), \quad (11)$$
with \( \int \Psi(z)dz = \int z\Psi(z)dz = 1 \), one sees that the event C KNO function goes to zero as \( z \to 0 \), faster than the standard KNO function, because of the factor \( n \) in (3), and that, at large \( z \), as \( <n> <<n> \), it is displaced to smaller values of \( z \).

Parametrizing the function \( \Psi(z) \) by using the generalized gamma function, with parameters \( \kappa \) and \( \mu \), \( \kappa > 0 \) and \( \mu > 0 \),

\[
\Psi(z) = \frac{\mu}{\Gamma(\kappa)} \left[ \frac{\Gamma(\kappa + 1/\mu)}{\Gamma(\kappa)} \right]^{\kappa \mu} z^{\kappa \mu - 1} \exp \left( - \left( \frac{\Gamma(\kappa + 1/\mu)}{\Gamma(\kappa)} \right) z^\mu \right),
\]

(12)

with

\[
<z^q> = \frac{\Gamma(\kappa + q/\mu)}{\Gamma(\kappa + 1/\mu)^q} \Gamma(\kappa)^{q-1},
\]

(13)

from (10) one easily sees that if the parameters of the minimum bias multiplicity distribution are \( \kappa \) and \( \mu \), the parameters \( \kappa_C \) and \( \mu_C \) of the distribution associated to event C are related to \( \kappa \) and \( \mu \) by:

\[
\kappa_C = \kappa + \frac{1}{\mu},
\]

(14)

\[
\mu_C = \mu.
\]

Let us now consider the application of (5) and (10) to \( p\bar{p} \) collisions at CERN and Fermilab collider energies.

1 Multiplicity distributions associated to \( W^\pm, Z^0 \) production ( \( \sqrt{s} = 1.8 \) TeV)

The CDF Collaboration at Fermilab has measured the multiplicity (and \( E_T \)) distribution associated to \( W^\pm \) and \( Z^0 \) production in high energy \( p\bar{p} \) collisions [3]. For large enough \( p_T^W (\gtrsim 5 \text{ GeV}/c) < n >_c \) becomes independent of \( p_T^W \) as expected. For smaller values of \( p_T^W \), \( < n >_c \) approaches \( <n> \) and the distributions become identical. This can be understood in the following way: as triggering in low \( p_T \) \( W \) or \( Z^0 \) means triggering on valence quark collisions, and these collisions are always present, such triggering is not selective (gives the same result as without trigger). The relevance of valence quarks is reflected also in the observed forward-backward \( W^+ - W^- \) asymmetry. At high \( p_T \) hard collisions, Drell-Yan \( W \) and \( Z^0 \) production, low \( x \) parton collisions become important and the rare event probability becomes proportional to \( \nu \).

In Fig.1 we directly test (5) by using CDF data. The result is fairly reasonable. Note that the existing \( E_T \) distributions [4] are also consistent with (5).
Associated particle production to large $E_T$ jets and $W^\pm, Z^0$ detection has been previously discussed, in the framework of DPM, in [9].

2 Multiparticle distributions associated to jet events ($\sqrt{s} = 0.2 - 0.9$ TeV)

The UA1 Collaboration at CERN has studied multiplicity and $E_T$ distributions associated to jet events, characterized by $E_T^{\text{jet}} > 1.5$ GeV in the acceptance region $|\eta| < 1.5$ and $\Delta\phi < 30^\circ$ from the vertical, and compared the obtained KNO distribution to the no-jet event distribution [10, 11]. It was found that the average multiplicity and the transverse energy density of events with jets was larger (by a factor of the order of 2) than in the no-jet events and both quantities were independent of $E_T^{\text{jet}}$, $E_T^{\text{jet}} > 5$ GeV.

This kind of behavior is expected in our approach. For rare events the associated $< n >$ and $< E_T >$ are larger, see (10), than in the remaining events. As far as the jet criterion does not allow for too many events ($E_T^{\text{jet}} > 5$ GeV seems to be the right criterion) the associated average multiplicity and transverse energy should be independent of $E_T$.

This last point is true at not very high energies, $\sqrt{s} = 0.2$ GeV, where the measured jet cross section is 2.4 mb [10]. This cross section rises very fast as the energy increases. Therefore at higher energies the jet events are not rare and they are strongly absorbed. For this reason we compare our prediction only with the experimental data at $\sqrt{s} = 0.2$ TeV.

However, we notice that from the only data available on the KNO no-jet and jet associated multiplicity function measured in the pseudorapidity range $|\eta| < 2.5$ and from the quoted no-jet and jet associated multiplicity $< n >_{\text{jet}} = 26.5 \pm 0.2$, $< n >_{\text{no-jet}} = 13.8 \pm 0.1$, the obtained minimum bias multiplicity distribution through the formula:

$$P(n) = P_{\text{jet}}(n)\frac{\sigma^{\text{jet}}}{\sigma^{\text{in}}} + P_{\text{no-jet}}(n)\frac{\sigma^{\text{no-jet}}}{\sigma^{\text{in}}}$$  (15)

and $\sigma^{\text{jet}} = 2.4mb$, $\sigma^{\text{in}} = 40mb$, $\sigma^{\text{no-jet}} = 37.6mb$ does not coincide with the experimental minimum bias data measured in the same pseudorapidity range as it is seen in Fig.2. It is seen that for $n > 35$ there is a clear disagreement which could be arranged by means of a broader jet distribution. Notice that a larger fraction $\sigma^{\text{jet}}/\sigma^{\text{in}}$ would improve the agreement at large $n$ but now the disagreement will appear for $n$ around 30.

Due to that, it is not expected a good agreement between our prediction and the actual experimental data and this is seen in Fig.3, where we show our prediction together with the jet associated multiplicity distribution obtained from the experimental data on the corresponding KNO function using the jet associated multiplicity obtained from (10). From Fig.3 it is seen that in order to obtain a good agreement, the experimental jet associated multiplicity distribution should be a little broader. We remark that this conclusion is the same that we deduced above by direct comparison with experimental data.
3 Multiplicity associated to annihilation events

The annihilation events in $p\bar{p}$ collisions are also rare events which should satisfy [5]. In fact, they are shadowed by themselves and as far as their cross section is small, the consequent absorption is also small [13, 14]. Unfortunately, there is not data on topological annihilation cross section at high energy [15] and for this reason the comparison is at $p_{\text{lab}} = 7$ GeV/c. In Fig. 4 it is show the minimum bias $\bar{p}p$ multiplicity distribution together the annihilation data [15] and our result which is again fairly reasonable.

As a conclusion we may say that even in $\bar{p}p$ collision, the simple approach developed and tested for nucleus-nucleus collisions in [3] and [4] can also be applied, which shows the same physics.

It can be shown that in the limit of infinite energy and therefore infinite multiplicity the multiplicity distribution of $\bar{p}p$ and nucleus-nucleus collisions is controlled by the multiplicity distribution of a single collision [16]. However, at the present energies the multiplicity distribution is controlled by the distributions on the number of collisions.

This fact can only be compatible with the infinite energy result if there is some transition mechanism which transforms the multiple scattering structure into a single one. A mechanism of this type is the percolation of strings [17]. As the density of strings increases due to the increasing of energy or to the size of the collision objects, they begin to overlap each other. When a critical density is reached, the percolation threshold, it is possible to go through the whole collision surface by a path of overlapping strings. In this way, the effective number of collisions is reduced drastically. The percolation of strings has been proposed to explain the recent $J/\Psi$ suppression [18] found by the NA50 Collaboration in Pb-Pb collisions [19, 20] and can be seen as the way of taking place the phase transition from hadronic matter to quark gluon plasma.

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Figure captions

Fig.1. Prediction for the associated multiplicity distribution for $W^\pm$ and $Z^0$ events (round black points) together with the experimental data ($W^\pm$ cross points and $Z^0$ white stars) and the minimum bias distribution (squares).

Fig.2. Minimum bias distribution obtained from equation (15) of the text (write crosses) and the experimental minimum bias (white squared points) together with the jet (black stars points) and no-jet (white rounds) associated multiplicity distribution.

Fig.3. Prediction for the jet associated multiplicity distribution (black round points) together with the experimental data and minimum bias multiplicity distribution (white squared points).

Fig.4. Prediction for the KNO function for annihilation events (dashed curve) and the experimental data (stars) together with the minimum bias data (white squared points) parametrized as (12) (solid line).
