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CORRELATION BETWEEN $\langle p_\perp \rangle$ AND THE CENTRAL MULTIPLICITY IN HYDRODYNAMICAL MODEL

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CORRELATION BETWEEN $\langle p_\perp \rangle$ AND THE CENTRAL MULTIPLICITY IN HYDRODYNAMICAL MODEL+

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It is shown that the recently observed growth of $\langle p_\perp \rangle$ when the central multiplicity increases may be interpreted as a natural consequence of hydrodynamical expansion of highly dense hadronic matter which is formed during multiparticle production processes.

+The main points of the present work have been presented to I CONGRESSINO DI FENOMENOLOGIA DELLE PARTICELLE ELEMENTARI (Torino, Italy, Feb. 1983).

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1. One of the characteristics of multiparticle production processes, revealed by experiments at the CERN $p\bar{p}$ collider, is a close correlation between the number of particles produced in each event and the average $p_\perp$ of these particles [1]. Quantitatively, when the number of charged particles per unit of rapidity in the central region ($|y| \leq y_o = 2.5$)

$$n = \frac{1}{2y_o}\int_{-y_o}^{y_o} \left(\frac{dn}{dy}\right) dy \qquad (1)$$

increases from 1 to 10, $\langle p_\perp \rangle$ grows by a factor of about 50%. For larger values of n, it seems that $\langle p_\perp \rangle$ remains constant.

As far as we know, no such correlation has ever been reported at lower energies including the ISR experiments*1. However, as will be discussed later, one should not interpret this as an indication of an essential energy dependence of the phenomenon, but it should rather attributed to the lack of information.

2. A possible explanation of this phenomenon has been given by Van Hove in terms of thermodynamics [4]. Accordingly, higher multiplicity would mean larger entropy, so more violent collision and generally larger temperature, leading to a flatter $p_\perp$ distribution. At a certain temperature T_c, a phase transition would occur from hadron gas to quark-gluon plasma, implying the near constancy of $\langle p_\perp \rangle$ above

*1 *The only published data we could find are those of Ref. [2]. However, they are not consistent with the well known inclusive $\langle p_\perp \rangle$, which is much lower. For instance, see [3].*

a certain multiplicity. This would be so because the hot blob would undergo first a process of expansion and cooling, and thus the final temperature of the hadronic matter would never be larger than T_c .

Although this version is quite appealing, we think, however, that it contains some difficulties. Namely, since the volume in which the incomming particles interact is expected to be small, these blobs theirselves are initially very small in spatial extension. Then, it is hard to imagine so many hadrons (~50) in so small volume unless their properties are completely different in these states. One may argue that the blob is formed at the beginning of a few heavy hadrons which would subsequently decay until arriving at final light hadrons. But in this case, as far as $p_\perp$ distribution is concerned, the way how these decays occur may become much more important than the initial temperature and we cannot see a clear correlation between these quantities. Many other specific assumptions would be required in order to allow a quantitative confront with the data, along this line.

3. The purpose of the present work is to present an alternative view of the phenomenon, in some sense an improvement of the preceding interpretation. Following the general concepts of Landau's hydrodynamical model [5][*2], we consider the expansion of the initially hot blob until some dissociation temperature $T_d = T_c$ (?) is reached. The final $p_\perp$ distribution is thus a result of two independent factors: a) thermal motion which is constant (because it is computed when $T = T_d \cong m_\pi$) and

[*2] *For a recent review in the QCD framework, see Shuryak [6].*

b) transverse expansion which is dependent on the initial temperature and so responsible for the variation of $\langle p_\perp \rangle$. The phase transition invoked in Ref. [4], in order to explain the approximate constancy of $\langle p_\perp \rangle$ above a certain multiplicity, is in our view always present. However, it does not necessarily imply the independence of $\langle p_\perp \rangle$ of the initial temperature. According to our view, a larger multiplicity means on the average a larger mass of the produced cluster, implying a higher initial temperature and so a larger transverse expansion. This will finally cause a flatter $p_\perp$ distribution. The slowing down of the increase of $\langle p_\perp \rangle$ with multiplicity is due to the existence of a natural upper bound in the cluster mass, which will limit the transverse expansion of the blob, although the actual number of charged particles detected in the central region may still increase due to a fluctuation.

4. Although other versions of hydrodynamical model are not excluded, we assume in order to make a quantitative prediction that the hot blobs which have been mentioned above are formed around one or both of the incident particles during their interaction. As explained in an earlier work [7], this assumption together with the equation of state (we assume here $p = \frac{\varepsilon}{3}$) allow us to establish a definite relation between the mass of the blob in one hand and the thermodynamic quantities such as the initial temperature and the entropy on the other hand. The existence and the dominance of such a mechanism of production (illustrated by Fig. 1) are moreover supported by the results we have already reported [7,8] and also by some other collider data. We will come back to this

point in a future publication.

Consider then a cluster of mass M . Following Refs. [7,8], the average charged multiplicity is

$$\langle n_{ch}\rangle (M) \cong 2.2\sqrt{M} \quad . \tag{2}$$

The longitudinal rapidity distribution has well been studied in the past and, when applied to the present case, turns out to be approximately [5,9]

$$\frac{dn}{dy} = \frac{\langle n_{ch}\rangle}{\sqrt{\pi L_M}} \exp\left[-\frac{(y-y_M)^2}{L_M}\right] \quad , \tag{3}$$

where

$$\begin{cases} y_M \cong \ell n \dfrac{\sqrt{s}}{M} \quad , \quad \text{(center of mass of the cluster)} \\ L_M \cong 3\ \ell n\ M \quad . \end{cases} \tag{4}$$

As for the transverse expansion, no complete solution of the hydrodynamical equations has ever been obtained and what is usually done is to neglect it because it is very small and almost constant in confront with the longitudinal motion. The only quantitative result known is the one obtained by Milekhin [9], who studied everything in terms of average quantities. Applied to the present case, his result reads

$$\text{sh}\langle\xi\rangle \cong \frac{0.53}{(2m_p^2)^{1/14}}\ M^{1/7}\ \exp\left[-\frac{(y-y_M)^2}{L_M}\right] \quad , \tag{5}$$

where ξ is the transverse rapidity of the fluid. We will, in the following, accept this result, except for the constant factor in front of it, which turns out to be smaller.

5. Let us now put all the ingredients above together and establish a relation between the central multiplicity and $\langle p_\perp\rangle$. To fix our idea, let us here consider one cluster formation (Fig. 1, a and b). Then, from eqs. (1), (2) and (3) it immediately follows

$$n = \frac{1.1\sqrt{M}}{2y_o}\left[\text{Erf}\left(\frac{y_o-y_M}{\sqrt{L_M}}\right) + \text{Erf}\left(\frac{y_o+y_M}{\sqrt{L_M}}\right)\right] \quad . \tag{6}$$

To obtain $\langle p_\perp\rangle$, we first write $\frac{d\sigma}{dy_\perp}$, by assuming $\xi = \langle\xi\rangle$ given by (5), recalling that the overall momentum distribution is cigar-shaped with a very sharp $p_\perp$ cut off[*3]. Then, in the dominant order (we assume $T_d = m_\pi$ as in [7,8])

$$\frac{d\sigma}{dy_\perp} \cong \text{const.}\sqrt{\text{sh}y_\perp \text{ch}y_\perp}\ \text{ch}(y_\perp-\langle\xi\rangle)\ \exp\left[-\frac{m_\pi}{T_d}\ \text{ch}(y_\perp-\langle\xi\rangle)\right] \quad , \tag{7}$$

and $\langle p_\perp\rangle$ is now written

$$\langle p_\perp\rangle = \frac{\int_0^\infty m_\pi\ \text{sh}y_\perp \frac{d\sigma}{dy_\perp}\ dy_\perp}{\int_0^\infty \frac{d\sigma}{dy_\perp}\ dy_\perp} \quad . \tag{8}$$

Given M , eqs. (6) and (8) establish the relation we are seeking. As is readily seen in (6) and (8) (where $\langle\xi\rangle$ is given by (5)), when M increases both n and $\langle p_\perp\rangle$ grow as required by the experimental data. As mentioned before, M cannot be larger than $\sqrt{s}$ and so both $\langle n\rangle$ and $\langle p_\perp\rangle$ have upper bounds. However, we are dealing with average

*3 *See, for example, Ref. [10] for the details.*

quantities and indeed there exist fluctuations, which nevertheless become small when M increases. Naively, we expect that both $\langle p_{\parallel} \rangle$ and $\langle p_{\perp} \rangle$ become smaller when the multiplicity exceeds $\langle n \rangle$, as a reflection of the energy-conservation, but we will not consider this fluctuation for the sake of clearness. Another fluctuation, which is present even when the total (charged + neutral) multiplicity is fixed, refers to the actual charged multiplicity detected in the central region, and this does not affect $\langle p_{\perp} \rangle$. Our conclusion is that events with n larger than the value given by (6), with $M = \sqrt{s}$, may exist, but the corresponding $\langle p_{\perp} \rangle$ cannot be larger than some upper bound.

In the case of the two-cluster formation with masses M_1 and M_2 (as shown by Fig. 1,c), similar calculations may be performed for each cluster. The final multiplicity will then be the sum $n = n_1 + n_2$, whereas $\langle p_{\perp} \rangle$ is an average of $\langle p_{\perp} \rangle_1$ and $\langle p_{\perp} \rangle_2$.

6. We are now going to compare the preceding results with experiments. Evidently, to obtain the final $\langle p_{\perp} \rangle$ we still need informations about the relative weight of the single- to the double-cluster events, as well as how M_1 and M_2 are distributed in the latter. While an implementation of this is indeed possible, this may however obscure the clearcut relation between the fundamental physical ideas and the results which follow, without bringing any qualitative new consequence. Instead, we prefer to consider just the two opposite situations which give the upper and the lower bound in $\langle p_{\perp} \rangle$ as a function of the central multiplicity. Namely, they are i) one-cluster events and ii) two-cluster events with $M_1 = M_2$. We plot in Fig. 2 the curves obtained for these cases at the collider energy ($\sqrt{s} = 540$ GeV) and an ISR energy ($\sqrt{s} = 63$ GeV). The only change with respect to the preceding results, eqs. (4)-(8), which we had to introduce in this comparison was the reduction of the proportionality constant in Milekhin's formula, eq. (5), by a factor of $\frac{1}{2}$. As can be seen, the agreement with the collider's data is very good, supporting our point of view. Recall that the only parameter which has been chosen in the present analysis is the constant mentioned above, which actually contains some uncertainty in the original Milekhin's work. As for the prediction at the ISR energies, it does show the same kind of correlation, the plateau being reached at lower $\langle p_{\perp} \rangle$ and n values. When compared with the data of Ref. [2], one sees that the agreement is very nice in the whole plateau region and we presume the inconsistency we mentioned before*) is caused by the small-multiplicity events. Actually, preliminary results at the ISR do indicate a pronounced $\langle p_{\perp} \rangle$-$n$ correlation for smaller n [11].

The authors aknowledge that the main part of the present work has been done while one of them [Y.H.] was visiting CERN's TH Division within the framework of the CNPq-CERN agreement. He is especially indebted to L. Van Hove for stimulating discussions. We also thank G. Giacomelli for useful experimental informations.

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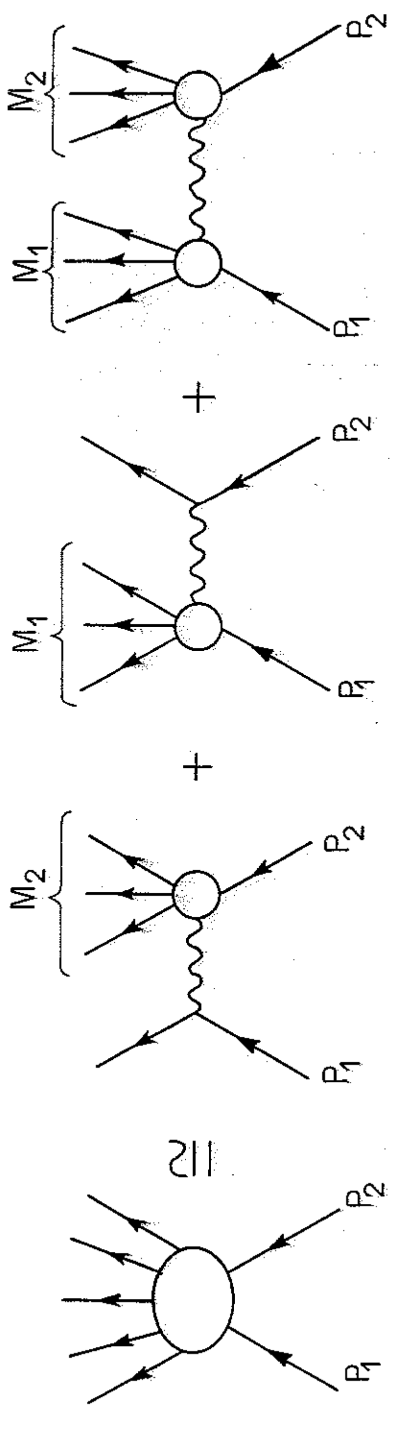
FIGURE CAPTIONS

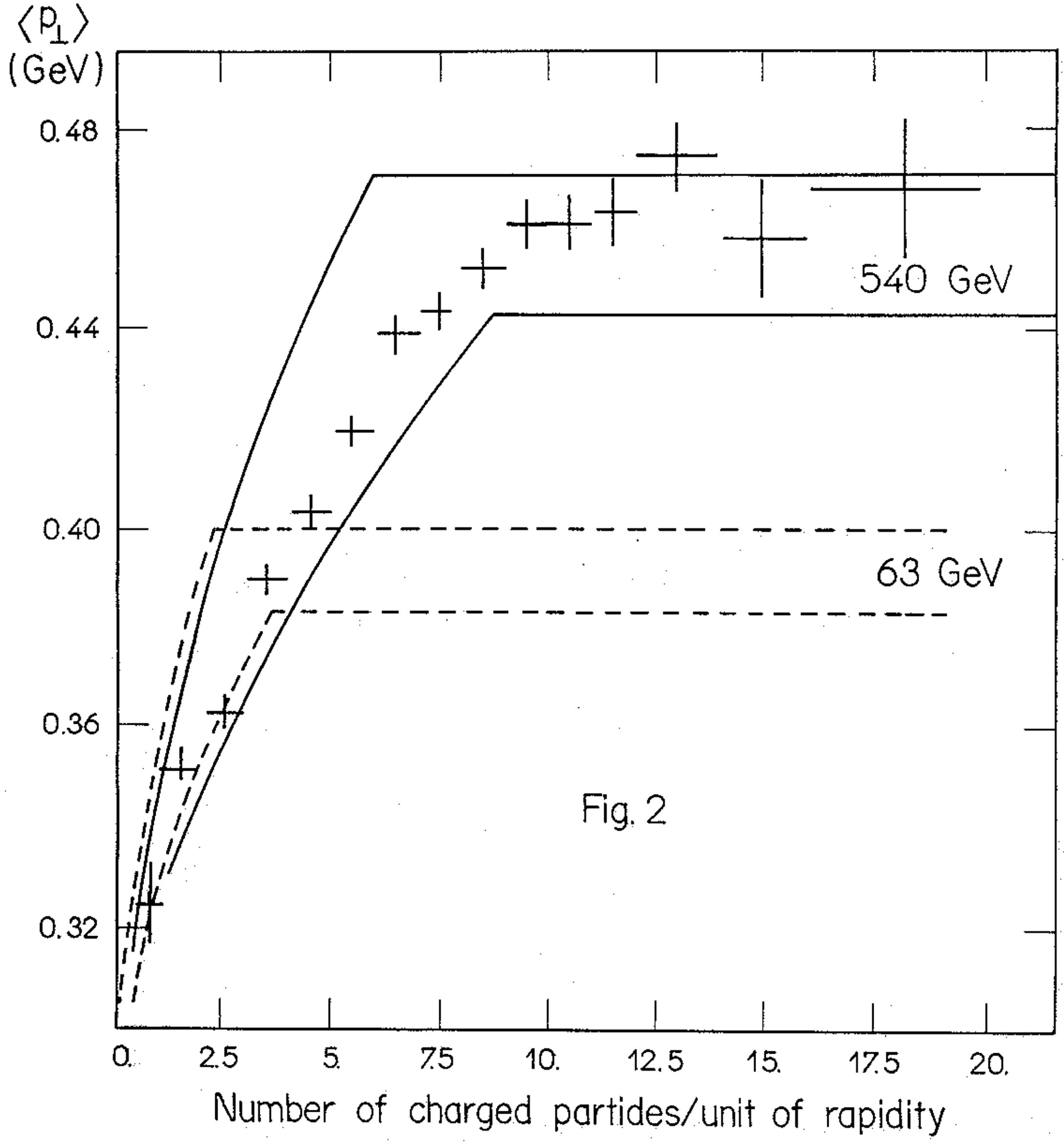
FIG. 1 - Diagramatic representation of the model explained in 4.

FIG. 2 - Predicted n-dependence of $\langle p_\perp \rangle$ at $\sqrt{s}$ = 540 GeV (solid lines) and at $\sqrt{s}$ = 63 GeV (broken lines). The upper lines correspond to one-cluster events and the lower ones to two-cluster events with $M_1 = M_2$. The data points are from [1].



M2
M1
P1
P2
(a)
(b)
(c)

Fig. 1



⟨p⊥⟩
(GeV)
0.48
0.44
0.40
0.36
0.32
540 GeV
63 GeV
0.
2.5
5.
7.5
10.
12.5
15.
17.5
20.
Number of charged partides/unit of rapidity

Fig. 2