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M.I.Gorenstein, V.P.Shelest, G.M.Zinovjev

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One of the most important experimental results obtained at the largest modern accelerators is the discovery of secondaries with large transverse momenta in pp -collisions /1/. The essential difference in the particle behaviour at large and small transverse momenta regions is seen from the following table presenting experimental data available.

In the most multiparticle models transverse momenta distribution of particles is postulated without serious foundations. The Hagedorn statistical bootstrap model /2/ is considered as one of the most consistent explanations of the transverse motion of secondaries. In this model the transverse motion has purely thermodynamical nature while the hadron system temperature does not exceed the ultimate value $T_H (T_H \simeq m_\pi)$. Longitudinal motion of hadron matter is fitted phenomenologically. Then it is possible to get a good agreement with experimental data at $p_\perp < 1.5$ *GeV*. However, explanation of large $p_\perp$ particle behaviour encounters, in this approach, serious troubles. Note, that despite the number of secondaries with large $p_\perp$ is small their study is, nevertheless, of much importance.

In this note a possible interpretation of the secondary transverse momentum distribution is considered in the Landau hydrodynamical model /3/. The hadron fluid temperature at initial states of motion, in this model, may considerably exceed the ultimate temperature T_H. It is just the presence of large initial temperatures that we relate to a possibility of appearance of large $p_\perp$ -secondaries. Note, first of all, that though the hadron fluid ultimate temperature does not exist in the hydro-

Table

C.m.s. colliding particle energy 20 GeV $< E_0 <$ 50 GeV

	small transverse momenta ($p_\perp < 1-1.5$ GeV)	large transverse momenta ($p_\perp > 3-4$GeV)
1. $p_\perp$ dependence of $f(E_0, p_\perp) \equiv p_0 \frac{d\sigma}{d^3p} \Big|_{90^\circ}$	$\sim \exp(-6p_\perp)$	decreases much slower than $\exp(-6p_\perp)$
2. Secondary composition	dominantly π -mesons	large heavy particles share
3. E_0 dependence	at large E_0 $f(E_0, p_\perp) \to \phi(p_\perp)$ (scaling)	at $p_\perp$ fixed $f(E_0, p_\perp)$ increases with E_0
4. $x = \frac{2p_\parallel}{\sqrt{s}}$ dependence of $p_\perp$ distribution	$p_\perp$ distribution nearly independent of x	$p_\perp$ distribution decreased rapidly for $x \neq 0$
5. Charge effect	equal π^+ and π^- numbers	considerable more π^+ mesons than π^- mesons

dynamical approach, the character of transverse motion in this model turns out to be very similar to that in the Hagedorn model. Due to the Lorentz contraction of the initial volume of the system along the collision axis the fluid expansion is essentially anisotropic. For not very large initial energies (including the considered energy region) the quasi-one-dimensional approximation is valid with a good precision /4/. This approximation means the one-dimensionality of hydrodynamical motion along the collision axis. In the transverse (to the collision axis) direction, the heat motion is determinative at the moment of fluid element decay to the secondaries. At that time the fluid element temperature reaches some critical value $T_{cr} \simeq m_\pi$. This critical value in the hydrodynamical model is close to the value of ultimate temperature in the Hagedorn model. The longitudinal motion is directed by the solutions of one-dimensional relativistic hydrodynamic equations /5/ at the state equation fixed /6/

$$p = c_0^2 \epsilon , \quad 0 < c_0^2 < 1 \tag{1}$$

(p is the pressure, ϵ - the energy density, c_0^2 - the constant with the physical meaning of the sound velocity). The results obtained in such a way are in rather good agreement with experiments and lead /7/ to the quasi-scaling behaviour.

The existence of large initial temperatures in the hydrodynamical model, however, manifests itself in the effect of particle emission at the hydrodynamical expansion stage at $T \gg m_\pi$. This possibility crucially distinguishes the hydrodynamical model from the model with the ultimate temperature /8/.

Let us suppose that there is a particle emission from the surface of the expanding fluid at the one-dimensional hydrodynamical motion stage (for brevity we will call this effect as "evaporation"). If a fluid element with the coordinate x at time t, possessing by velocity $v(x,t)$ along the collision axis and temperature $T(x,t)$ emits, in its rest system, secondaries (π -mesons) with the isotropic Boltzman distribution, then we find easily the resulting distribution in the direction perpendicular to the collision axis as follows:

$$f(E_0, p_\perp) = C \int dt\, dx\, \exp\left[- \frac{\sqrt{p_\perp^2 + m_\pi^2}}{T(x,t)(1-v^2(x,t))^{1/2}}\right]. \qquad (2)$$

Here integration is performed over the one-dimensional motion region, and C is some constant. From (1) for system with the zeroth chemical potential one gets:

$$T = \text{const}\; \epsilon^{\frac{c_0^2}{1+c_0^2}} . \qquad (3)$$

The value of constant is found from the condition of the use of the ideal gas statistics at the decay moment ($T = m_\pi$) /6/. Finally, the initial temperature value is

$$T_0 = m_\pi \left(\frac{E_0^2}{8/3\, \pi\, m_\pi M}\right)^{c_0^2/(1+c_0^2)} . \qquad (4)$$

In (2) T and v are the solutions of relativistic hydrodynamic equations, and one can easily see that the dominating contribution at large $p_\perp$ comes from the initial stage of motion ($T \simeq T_0$; $v \simeq 0$). The use of the exact solution of one-dimensional hydrodynamical problem allows one to obtain rather easily the estimate

$$f(E_0, p_\perp) \simeq C\left(\frac{2m_\pi^2}{E_0}\right) \frac{1}{2c_0^2} \exp\left(- \frac{\sqrt{p_\perp^2 + m_\pi^2}}{T_0}\right), \qquad (5)$$

where M is the proton mass. Therefore, the evaporation effect leads to the Boltzmann distribution over $p_\perp$ in the normal to the collision axis direction and with the temperature equal to its initial value (4). In the large $p_\perp$ region heat motion at the decay moment gives considerably smaller contribution (see Fig. 1) of the small value of temperature.

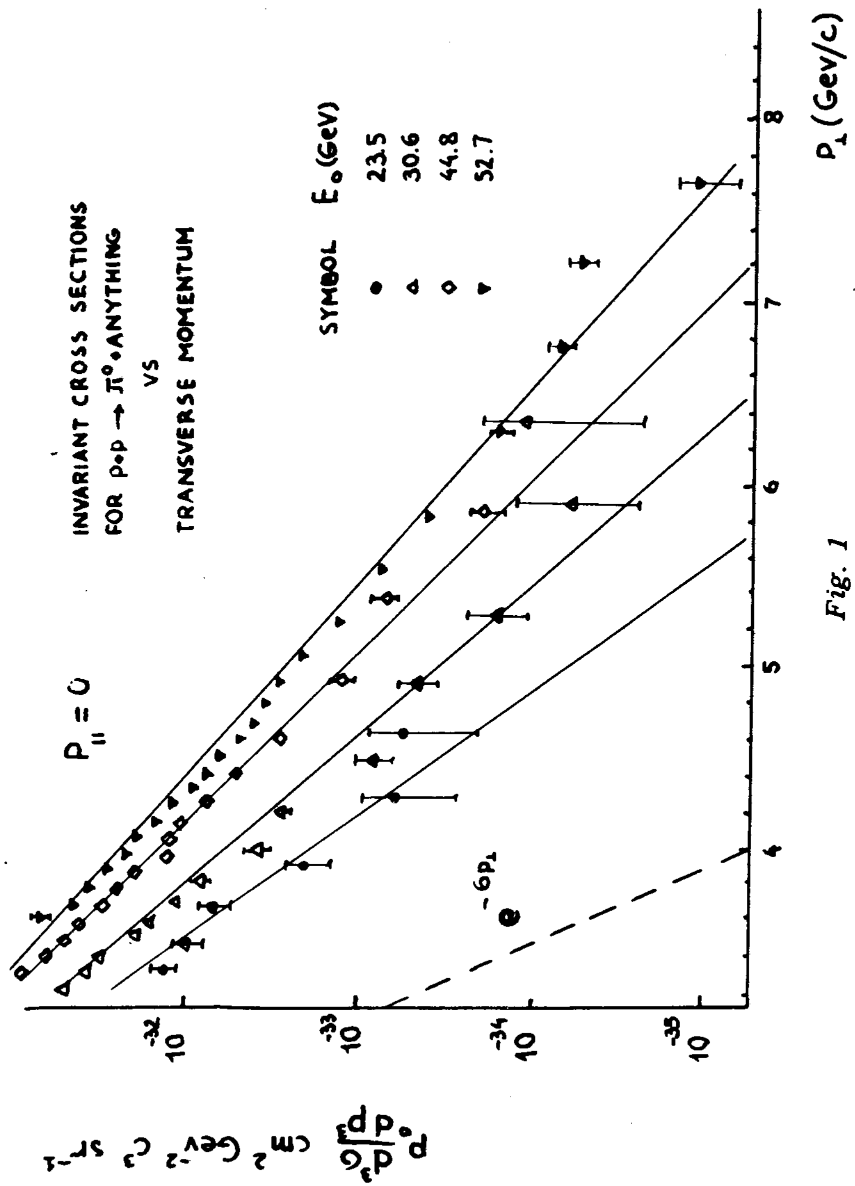

Fig. 1

Comparison with Experiment

1. Comparison of (5) with experimental data (considering c_0^2 as a free parameter) reveals good agreement with experiment (for 20 *GeV* $< E_0 <$ 50 *GeV*) in the region $p_\perp \geq$ 3-4 *GeV* (see Fig. 1). For c_0^2 then we get the fitting value:

$$c_0^2 = \frac{1}{5} \pm 0{,}01 . \qquad (6)$$

In the region $p_\perp <$ 1-1.5 *GeV* the correct description of experimental data is given by assumption of heat motion at the decay moment with $T = T_{cr} \simeq m_\pi$.

In the intermediate region 1-1.5 *GeV* $< p_\perp <$ 3-4 *GeV* several factors are important (evaporation and decay contributions are of the same order; correction to the formula (5); consideration of transversal hydrodynamical motion), all these corrections improve agreement with experiment.

In the region of extremely large $p_\perp$ the use of the canonical ensemble (the Boltzmann distribution), which does not take into consideration the energy-momentum consideration law, is no longer valid. The use of the microcanonical ensemble makes temperature fluctuations possible which leads in the region $p_\perp \gg T_0$ to the effective increase of temperature.

2. Due to the very sense of the evaporation effect the particle emission probability depends on its mass through the statistical factor $\exp(-\frac{\sqrt{p_\perp^2 + m^2}}{T_0})$. It is clear that in the region of large T_0 and $p_\perp$ $(p_\perp T_0 \gg m^2)$ the m -dependence is not essential.

Therefore we must expect considerable increase of heavy particle fraction as compared with the region of small $p_\perp$ $(p_\perp \sim 1\,\mathrm{GeV})$, and, respectively, low temperature $T = T_{cr} = m_\pi$ where the fraction of heavy particles is exponentially small. The correct explanation of the secondary composition in the region of large $p_\perp$ is considered, as we think, to be an important argument to the proposed evaporation mechanism /8/. Thus, for instance, explaining the transversal motion as hydrodynamical expansion secondary composition at large $p_\perp$ is the same as that for small $p_\perp$ because the former as well as the latter appear at the same temperature $T_{cr} \sim m_\pi$.

3. Immediate comparison of (5) with experiment at $c_0^2 = 1/5$ gives the correct dependence $f(E_0, p_\perp)$ on E_0 at $p_\perp$ fixed ($p_\perp >$ 3-4 *GeV*).

4. If the $p_\perp$ secondaries distribution at $p_\perp >$ 3 *GeV* and $p_{||} \neq 0$ (for example at $x = 2p_{||}/E_0$ fixed) is considered, it is clear that secondaries evaporation from fluid elements with $T < T_0$ and $v > 0$ will contribute to this distribution too. However, this contribution will be essentially smaller than that from the $v = 0$ and $T = T_0$ region.

5. The hadron system which is produced in pp-collision has large electric charge density. This fact could, to some extent, favour the exceeding of π^+ number over π^- number at large transverse momenta.

On the basis of the above consideration one may conclude that the proposed mechanism of particle evaporation in the hydrodynamical model of multiparticle production explains rather well both qualitatively and quantitatively (at $c_0^2 = 1/5$) the basic regularities of particle behaviour in the region of large transverse momenta.

In conclusion let us discuss some specific features of initial state. The central collisions only are considered in the Landau hydrodynamical model. It is possible, however, to take into account peripheral collisions phenomenologically, assuming that the inelasticity coefficient k changes from collision to collision (i.e., that the fraction of initial energy for producing a statistical system is changing). In this case also the initial temperature of the system T_0 can change from collision to collision at E_0 fixed (T_0 is large at large k and small at small k). By the very meaning of the evaporation effect the large $p_\perp$ secondary production is an evidence of large initial temperatures. We thus conclude that in the collisions with large multiplicity (k large) the probability of large $p_\perp$ secondary production is larger than that in the collisions with small multiplicity (k small). This fact is supported by experiment, too.

References

1. *D.Morrison. Preprint CERN 73-46 (1973).*
2. *R.Hagedorn. Nuovo Cim. Suppl., 3, 147 (1965).*
3. *L.D.Landau. Izv. Akad. Nauk SSSR, 17, 51 (1953).*
4. *I.L.Rosental. J.Exp.Theor.Phys. (USSR), 31, 278 (1956).*
   G.A.Milekhin, I.L.Rosental. J.Exp. Theor. Phys. (USSR), 33, 197 (1957).
5. *I.M.Khalatnikov. J.Exp. Theor. Phys. (USSR), 27, 529 (1954).*
6. *G.A.Milekhin. J.Exp.Theor. Phys. (USSR), 35, 1185 (1958);*
   Proceedings of Moscow Cosmic Ray Conference, vol. 1, p. 212 (1960).
7. *E.V.Shuryak. Yadern.Phys. (USSR), 16, 395 (1972); 20, 546 (1974).*
8. *I.N.Sissakian, E.L.Feinberg, D.S.Chernavsky. J.Exp. Theor. Phys. (USSR), 52, 545 (1967).*
   M.I.Gorenstein, O.P.Pavlenko, G.M.Zinovjev. Preprint ITP-74-95E, Kiev, 1974.

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