MULTIPLICITY DEPENDENCE OF MEAN TRANSVERSE MOMENTUM FOR STRANGE PARTICLES AND BARYONS PRODUCED IN e^+e^- ANNIHILATIONS AND IN HADRON-HADRON COLLISIONS*

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(Received August 7, 1992)

We argue, using the Lund Monte Carlo model, that the increase in mean transverse momentum $\langle p_T \rangle$ with the number of charged particles n_{ch}, recently observed in e^+e^- annihilations at LEP, has a significant contribution from the production of strange particles and (anti)baryons. The correlations of $\langle p_T \rangle$ with n_{ch} for kaons, protons and hyperons are much stronger than for pions. The pattern of relative strengths of the correlations for these particles is similar to that observed in high energy $p\bar{p}$ collisions. The comparison of the data for the two reactions could provide a new insight into the dynamical origin of these correlations in hadronic interactions.

PACS numbers: 13.65. +i, 13.85. Ni, 13.87. -a

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* This work was supported in part (G.W.) by the Polish Committee for Scientific Research, Grant No 2 0423 91 01.

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Recently we have argued [1] that the observed, but still not fully understood, increase in mean transverse momentum $\langle p_{\rm T}\rangle$ with the number of charged particles $n_{\rm ch}$ in high energy hadron-hadron collisions should be also seen in e^+e_- annihilations into hadrons. In this earlier paper, we also argued that the origin of this correlation in e^+e^- annihilations is due to radiation of hard gluons. This prediction was soon thereafter confirmed by the DELPHI Collaboration at LEP [2]. Meanwhile, it was also reported [3] that in hadronic collisions $\langle p_{\rm T}\rangle$ *vs* $n_{\rm ch}$ correlations have an important contribution (at least for $\sqrt{s} = 1800$ GeV) from the production of $K^\pm$, Λ, $\bar{\Lambda}$ and $\bar{p}$ [4].

The e^+e^- annihilation processes are believed to be adequately described in terms of perturbative QCD amended by some acceptable fragmentation scheme as, *e.g.*, in the JETSET Lund Monte Carlo model [5]. These e^+e^- annihilations are also regarded as the simplest and cleanest examples of multihadronic production processes which can (and whenever possible, should) be used as a testing ground, or even as building blocks, for models of all hadronic multiparticle reactions. Also in [1], we indicated that such an e^+e^- building block approach, although quite successful if applied to such observables as mean multiplicities, mean p_T or even multiplicity distributions, seems to fail in the simple, yet nontrivial correlation, $\langle p_{\rm T}\rangle$ *vs* $n_{\rm ch}$. The predicted growth of $\langle p_{\rm T}\rangle$ with energy in e^+e^- annihilations is hard to temper to provide the much milder one seen in hadronic collisions (and it is incompatible with possible saturation of $\langle p_{\rm T}\rangle$ with energy for hh reactions at Fermilab Tevatron energies). A possible solution (and only if such a saturation does not occur) is to allow for (at least) two component structure in the hadronic collisions: *(i)* — one component is constant with energy and nonperturbative in origin, dominating at lower energies and *(ii)* — a second component, calculable in perturbative QCD, growth with energy, the best candidate being the mini-jets [6]. This conjecture is strengthen by the claim that such a perturbative QCD approach is also able to explain the dependence of the correlations strength on masses of particles as measured in hadronic collisions [7]. On the other hand, there are also other approaches explaining this effect without any reference to perturbative QCD, hence without any connection with the e^+e^- annihilation processes [8]. As an example, we only mention the picture of a collective outward flow developing during the expansion and final breakup of the produced high-density state (believed to be quark–gluon plasma) [9]. Such a flow would manifest itself in a nonthermal shape of the p_T spectrum and together with random thermal motion would also provide the observed growth of the correlations with the mass of emitted particles.

The mass and flavour dependence of $\langle p_{\rm T}\rangle$ *vs* $n_{\rm ch}$ correlations is therefore at the center of the vivid contest between the orthodox (here: at least partially perturbative QCD, valid also for e^+e^- annihilation processes) and unorthodox (which means here the possible quark–gluon plasma formation specific only for hadronic and/or nuclear collisions) view of the high energy *hh* processes. It is then of vital importance to check what the mass dependence of the correlations is in such elementary processes as e^+e^- annihilations governed mainly by perturbative QCD. This is the aim of our work.

Using the JETSET 7.2 Lund Monte Carlo model [5] with gluonic shower and string fragmentation (to date the most successful model for all e^+e^- annihilation data), we have calculated $\langle p_{\mathrm{T}} \rangle$ *vs* n_{ch} correlations for two energies and, unlike Ref. [1], we have resolved it into contributions from different types of produced particles: K, $\Lambda(\bar{\Lambda})$, $p(\bar{p})$, Σ and Ξ [10]. The results for $\sqrt{s} = 30$ GeV and 91 GeV are shown in Fig. 1 for the mean transverse momenta in the event plane $\langle p_{\mathrm{T}} \rangle$, and in the direction perpendicular to the event plane, $\langle p_{\mathrm{T\,out}} \rangle$. Both directions are defined in the standard way by using the second-rank tensor constructed from the final charged hadron momenta [11]. For $\sqrt{s} = 30$ GeV, the gluon radiation effects are relatively small [1]. We observe, however, that the very weak positive correlations for the whole sample are magnified for heavier particles. This effect is enhanced for $\sqrt{s} = 91$ GeV, where we observe a strong increase of $\langle p_{\mathrm{T\,in}} \rangle$ and $\langle p_{\mathrm{T\,out}} \rangle$ with n_{ch}, for the whole sample and large differences of the magnitude in correlations for different types of particles. The correlations are much stronger in the event plane (*i.e.*, for $\langle p_{\mathrm{T\,in}} \rangle$), defined essentially by the quark and the most energetic gluon emitted. They come mainly from gluon radiation [1] and thus are controlled by perturbative QCD (modulo the fragmentation procedure). This can be seen in Fig. 2, where the correlations are either slightly negative for pions or absent for heavier particles in $q\bar{q}$ events without hard gluon radiation generated by the matrix element version of the Lund model [12]. Comparison of Fig. 1c and Fig. 1d with Fig. 2 shows that the very weak mass effects in $\langle p_T \rangle$ *vs* n_{ch} correlations for heavy particles in quark fragmentation are strongly amplified by the presence of hard gluon radiation. We conclude then, that $\langle p_{\mathrm{T}} \rangle$ *vs* n_{ch} correlations for heavier particles provide more sensitive probes of hard gluon radiation than the same correlations for pions.

The results presented in Fig. 1 show strikingly similar pattern of correlations strengths to that observed in $p\bar{p}$ collisions [3, 4] although, as noted in [1] for all particles, the effect is more pronounced in e^+e^- annihilations. The comparison of the two types of reactions (*cf.*, for example, Fig. 2 in Turkot's presentation [4]) shows a steeper increase of $\langle p_T \rangle$ with n_{ch} and higher values of $\langle p_{\mathrm{T}} \rangle$ expected in e^+e^- annihilations at LEP energies than in $p\bar{p}$ interactions at the Tevatron for all the corresponding species of particles.

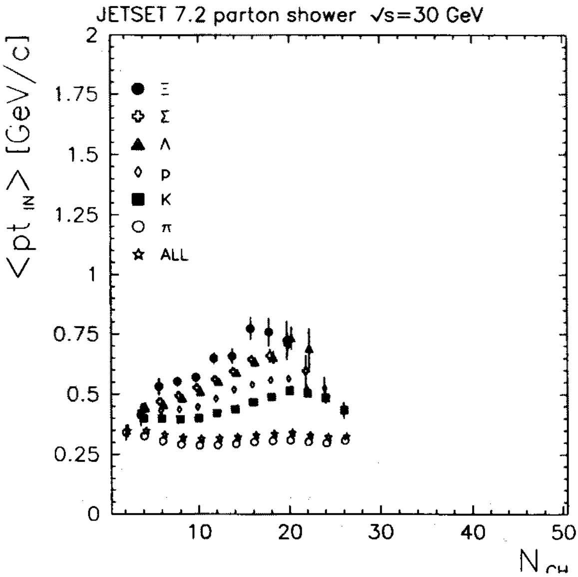
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Fig. 1a.

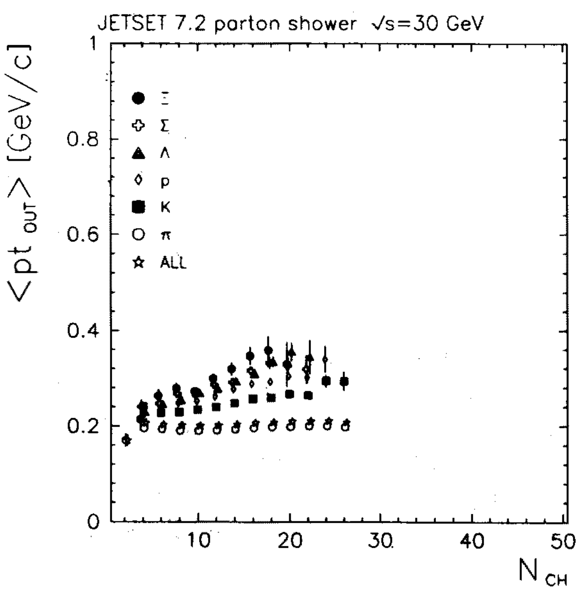
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Fig. 1b.

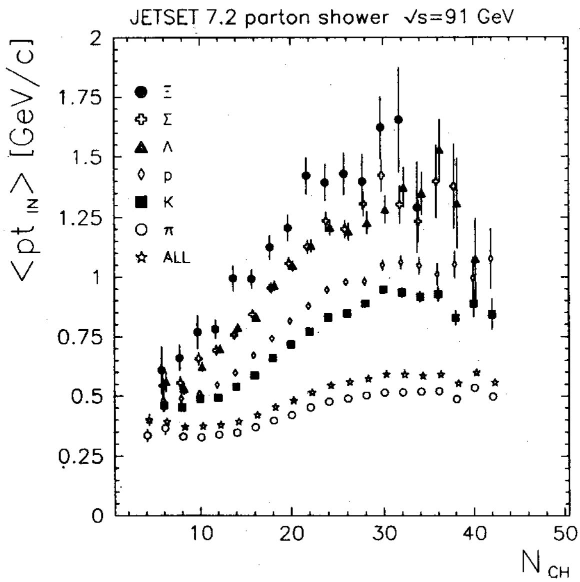

Fig. 1c.

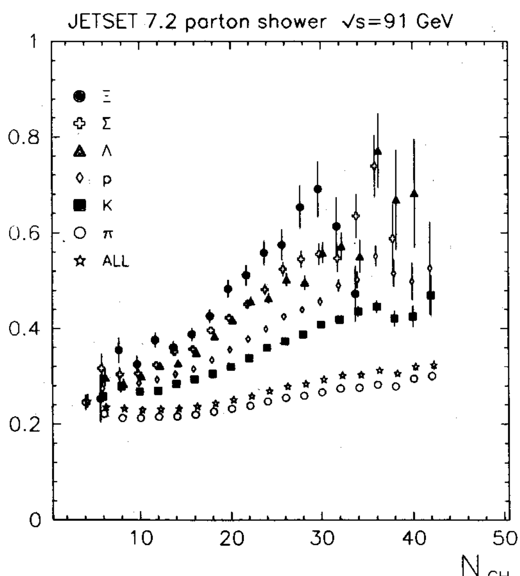

Fig. 1d.

Predictions of the Lund parton shower model for the dependence of average transverse momenta of various particles in the event plane, $\langle p_{T\,in} \rangle$, and in the direction perpendicular to the event plane, $\langle p_{T\,out} \rangle$, on charged-particle multiplicities in e^+e^- annihilations into hadrons at $\sqrt{s} = 30$ GeV [(a) and (b)] and $\sqrt{s} = 91$ GeV [(c) and (d)].

We would like to comment on how such mass effects originate generally in the Lund Model. The distinctive feature of the (nonperturbative in character) procedure of string fragmentation [13] is its strong dependence on the mass of produced particles for small z. This region is almost totally dominated by the pions whereas for larger z this dominance is greatly diminished [11]. This z-dependence on mass is transformed by gluon radiation to transverse dimensions because $p_T \sim z \cdot E_{\mathrm{jet}} \sin\theta$, where E_{jet} is the energy carried by the gluon jet and θ is the angle between thrust axis and the direction of the gluon jet. Very important are also decays of resonances, which finally produce slow pions whereas relatively "stable" final baryons, like $\mathrm{p}(\bar{\mathrm{p}})$ or $\Lambda(\bar{\Lambda})$ retain their original larger p_T (being, therefore, much more sensitive probes of gluon emission). The consequences of such behaviour for the correlations can be seen most clearly in Fig. 3, where we have plotted the expected $\langle p_{\mathrm{T}} \rangle$ *vs* n_{ch} correlations but here $\langle p_{\mathrm{T}} \rangle$ was calculated only for particles with the longitudinal momentum $|p_{\mathrm{L}}| > 2$ GeV/c. One can see immediately that in this case the correlations for pions are also very much enhanced, in fact in a way similar to other particles. The main reason is that the averaging procedure inherent in calculating $\langle p_{\mathrm{T}} \rangle$ does not "dilute" the effect for large z pions as it does in the case for the total pion sample [14]. The remaining differences in Fig. 3 can be attributed to the phase space effects for particles with different masses [15].

To summarize, the main difference between $\langle p_{\mathrm{T}} \rangle$ *vs* n_{ch} correlations for pions and heavier particles can be explained by the abundant production of pions at low momenta in e^+e^- annihilations [14]. If the origin of the correlations in hadronic collisions is similar (*i.e.*, caused mainly by gluonic mini-jets [6, 7]), we expect that the same mechanism should explain also the differences in the magnitude of the correlations observed for pions, strange particles and baryons in $\mathrm{p}\bar{\mathrm{p}}$ collisions at the Tevatron. In this case we predict that the magnitude of the correlations for pions should increase if very low momenta particles are removed from the sample. It is also possible to explain the difference between the magnitude of the $\langle p_{\mathrm{T}} \rangle$ and n_{ch} correlations in e^+e^- annihilations and in hadronic collisions if the amount of low momentum particles is much larger in these last processes because, for example, of the presence of a second, nonperturbative component.

Our findings, if confirmed experimentally, would, therefore, support the orthodox (*i.e.*, partially based on the perturbative QCD) models of multiparticle production processes in hh collisions such as the one presented in [6, 7]. On the other hand, however, as can be seen from Fig. 1 for e^+e^- annihilations, we should expect strong energy dependence of the $\langle p_T \rangle$ *vs* n_{ch} correlations for different particles in hadronic collisions, essentially the same as the one observed in [1] for the whole effect. The crucial test which would then possibly differentiate between the proposed mechanisms lies in

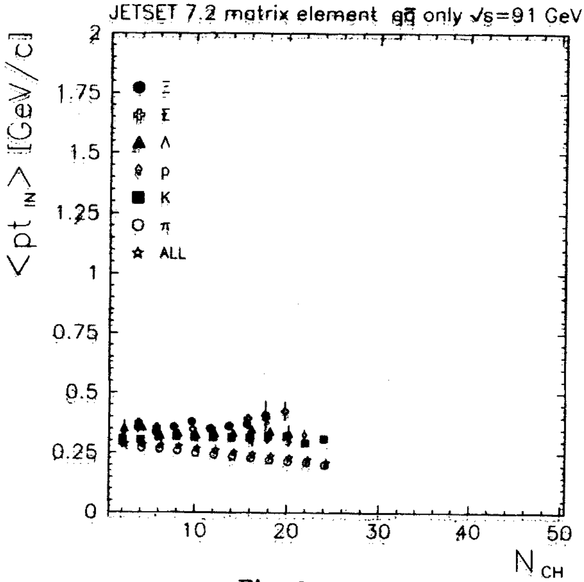

Fig. 2a.

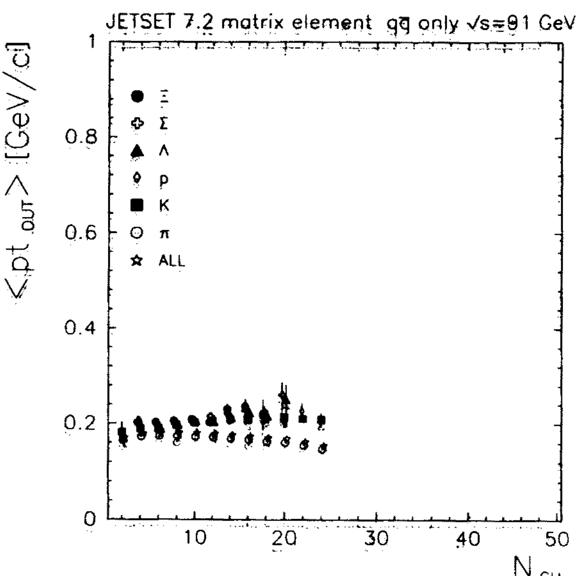

Fig. 2b.

Predictions of the Lund matrix element model for the dependence of average transverse momenta of various particles in the event plane, $\langle p_{T\,in}\rangle$ (a), and in the direction perpendicular to the event plane, $\langle p_{T\,out}\rangle$ (b), on charged-particle multiplicities in e^+e^- annihilations into hadrons at $\sqrt{s} = 91$ GeV. Events were generated only for $q\bar{q}$ configurations without hard gluon emission.

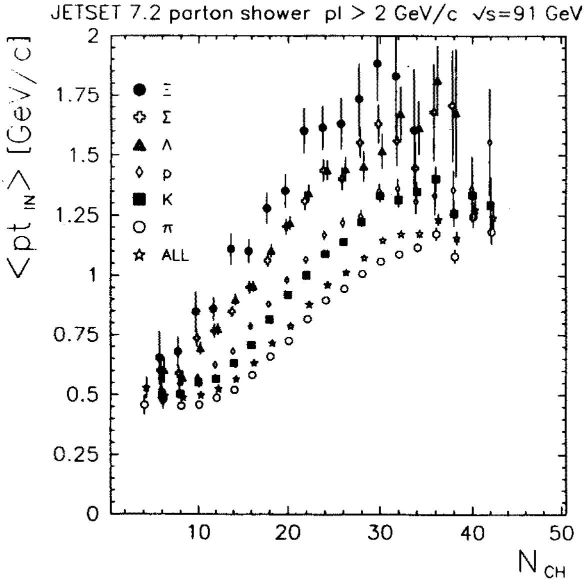

Fig. 3a.

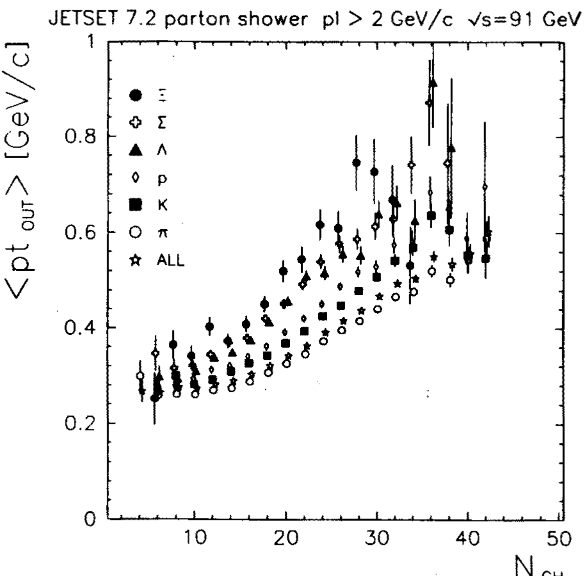

Fig. 3b.

Predictions of the Lund parton shower model for the dependence of average transverse momenta $\langle p_{T\,in}\rangle$ (a) and $\langle p_{T\,out}\rangle$ (b), for various particles with longitudinal momentum $|p_L| > 2$ GeV/c, on charged-particle multiplicities in e^+e^- annihilations into hadrons at $\sqrt{s} = 91$ GeV.

the energy dependence of this effect in hadronic reactions and so far we have data only for $\sqrt{s} = 1800$ GeV. The purely perturbative QCD approach clearly demands the untempered with energy growth of such correlations.

Therefore, any hint of its weakening with energy would suggest either a growing with energy importance of the nonperturbative component (as the one present already in [6, 7]) or even the nonperturbative origin of the whole effect, the formation of (some sort of) quark–gluon plasma being the most obvious candidate [16].

Before concluding we would like to draw attention to still another important feature of the Lund Model, namely to its apparent ability to mimic genuine flow effects. In $e^+e^- \to q\bar{q}g$ type of events it is known that strings spanned between $q - g - \bar{q}$ are boosted in the overall c.m.s. This boost affects mostly the heavier produced particles, in *qualitatively* the same way as a collective flow of the type described in [9]. This *collective* feature of the string in an otherwise elementary perturbative description of the e^+e^- annihilation processes should be then kept in mind in any analysis of the type presented above.

In conclusion, we suggest measurements of $\langle p_T \rangle$ *vs* n_{ch} correlations for various identified particles in e^+e^- annihilations and hh collisions at different energies as a sensitive probe of the mechanisms of multiparticle production.

We would like to thank M. Gaździcki, M. Gyulassy, S. Pokorski, T. Sjöstrand and R. Sosnowski for very useful and illuminating discussions and K. Lassila for critical reading of the manuscript.

REFERENCES

[1] M. Szczekowski, G. Wilk, *Phys. Rev.* **D44**, R577 (1991), (more detailed analysis of these correlations is in preparation). This paper contains also references to the earlier theoretical and experimental works on this subject.
[2] DELPHI Collaboration, *Phys. Lett.* **B276**, 254 (1992).
[3] C.S. Lindsey (E735), in Proc. of Quark Matter'91 Conference, *Nucl. Phys.* **A544**, 343c (1992).
[4] S. Banerjee *et al., Phys. Rev. Lett.* **62**, 12 (1988); T. Alexopoulos *et al., Phys. Rev. Lett.* **64**, 991 (1990); *cf.* also: F. Turkot, *Nucl. Phys.* **A525**, 165c (1991).
[5] M. Bengtsson, T. Sjöstrand, *Phys. Lett.* **B185**, 435 (1987).
[6] T. Sjöstrand, M. van Zijl, *Phys. Rev.* **D36**, 2019 (1987); *cf.* also: X. Wang, *Phys. Rev.* **D43**, 104 (1991) and references therein.
[7] X. Wang, M. Gyulassy, *Phys. Lett.* **B282**, 466 (1992); *cf.* also: X. Wang, M. Guylassy, *Phys. Rev.* **D44**, 3501 (1991) and **D45**, 844 (1992).
[8] B. Müller, Proc. of Quark Matter'91 Conference, *Nucl. Phys.* **A544**, 95c (1992); *cf.* also: C. Merino, C. Pajares, J. Ranft, *Phys. Lett.* **B276**, 168 (1992).

[9] P. Levai, B. Müller, *Phys. Rev. Lett.* **67**, 1519 (1991).
[10] This is in anticipation of new data on the hyperon production coming soon from Fermilab Tevatron, *cf.* W.D. Walker (E-735), Volume of Contributed Papers Submitted to the Quark Matter'91 Conference, paper E50, unpublished.
[11] *Cf.*, for example, S.L. Wu, *Phys. Rep.* **107**, 59 (1984).
[12] T. Sjöstrand, *Comput. Phys. Commun.* **27**, 243 (1982); T. Sjöstrand, M. Bengtsson, *Comput. Phys. Commun.* **43**, 367 (1987).
[13] T. Sjöstrand, *Int. J. Mod. Phys.* **A3**, 754 (1988) and CERN preprint CERN-TH 5902/90, October 1990 (lectures at the Cargèse Summer Institute on "Z^0 Physics", Cargèse, France, August 14–24, 1990); *cf.* also: B. Andersson, *J. Phys. G* **17**, 1507 (1991).
[14] Notice that this is essentially the reverse of the experimental procedure applied in [4] and used also in [7] in order to obtain an agreement between the predictions of the HIJING model and data. One essentially *deduces* $\langle p_T \rangle$ for the whole range of p_T from the measurements confined to $p_T > p_{T0}$ only. In the view of our discussion here it would be of great value in our opinion to have also uncorrected (*i.e.* free from any possible biases at small p_T) data from [3, 4] to compare with.
[15] It is interesting to remind the reader at this moment that similar dependence of the $\langle p_T \rangle$ on the mass of the produced secondaries has been known to exist for quite a long time in hadronic collisions, *cf.* A. Bigi *et al.*, *Nuovo Cim.* **33**, 1265 (1964).
[16] *Cf.* [1, 9] above and also: J. Kapusta, S. Pratt, L. McLerran, H. von Gersdorff, *Phys. Lett.* **B163**, 253 (1985); S. Kagiyama, A. Nakamura, A. Minaka, *Prog. Theor. Phys.* **75**, 319 (1986), **76**, 171 (1986) and **81**, 266 (1989); Yu. A. Tarasov, *Sov. J. Nucl. Phys.* **42**, 260 (1985) and **45**, 858 (1987); Y. Hama, F.S. Navarra, *Z. Phys.* **C53**, 501 (1992).