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QCD PARTON SHOWER MODEL AND GENERALIZED LOCAL PARTON-HADRON DUALITY

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ABSTRACT

We study the dependence on the parton virtuality cut-off (Q_0 = 1-2 GeV) and on the angular ordering option of the charged hadron and parton multiplicity distributions for symmetric c.m. rapidity windows $|y| < y_0$, in the QCD shower model with Lund hadronization, for quark-antiquark and gluon-gluon systems at c.m. energies $\sqrt{s}$ = 200 and 2000 Gev. In all cases, Negative Binomial fits are found to be generally good. The results are presented in terms of the standard NB parameters $\bar{n}$, k at $\sqrt{s}$ = 2000 GeV and of the clan structure parameters $\bar{N}$, $\bar{n}_c$ at both energies. The only substantial dependence on Q_0 and on angular ordering are found in the mean multiplicity $\bar{n}$, which turn out to be changed by factors depending little on y_0. For the Q_0 dependence of the hadronic $\bar{n}$, the factors are close to 1, a strong confirmation for the infra-red stability of the Lund hadronization prescription. The weak dependence of k on Q_0 agrees with the expectation of the generalized local parton-hadron duality.

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1. INTRODUCTION

In this paper we continue our earlier study [1] of multiplicity distributions (MDs) produced by high energy quark-antiquark ($q\bar{q}$) and gluon-gluon (gg) systems according to the Monte Carlo version JETSET 6.3 of the Lund Shower Model[2]. Working at the c.m. energies $\sqrt{s} = 200$ and 2000 GeV, we examine how the MDs are modified when the following options of the model are changed:

A. Change of the virtuality cut − off Q_0 at which the parton shower is interrupted and hadronization by the string fragmentation mechanism takes over. In [1] we had adopted $Q_0 = 1$ GeV, the value favoured by the overall fit to the e^+e^- annihilation data performed in Ref.[3]. Here we compare the values $Q_0 = 1$ and 2 GeV.

B. Suppression of the angular ordering (AO) in the development of the shower. The AO constraint, which simulates destructive interference effects present in perturbative QCD, had been applied in [1] because of its theoretical merits.

As in [1] we study two classes of MDs, those of the final partons of the shower (to be called partonic MDs, subscript p) and those of the (meta) stable charged hadrons in the final state (to be called hadronic MDs, subscript h). We concentrate on the MDs in symmetric rapidity windows $|y| < y_0$, the c.m. rapidity y being defined as in [1] with respect to the linear sphericity axis of the final partons. With a few exceptions similar to those mentioned in [1], we find that the MDs are well represented by negative binomial (NB) fits. This allows us to compare all MDs in terms of the NB parameters $\bar{n}_p, k_p$ and $\bar{n}_h, k_h$ for $Q_0 = 1$ GeV, and $\bar{n}'_p, k'_p, \bar{n}'_h, k'_h$ for $Q_0 = 2$ GeV.

For each system ($q\bar{q}$ or gg) with and without AO, these eight numbers are functions of y_0 and $\sqrt{s}$.Their dependence on Q_0 is discussed in Section 2 and their AO dependence is analyzed in Section 3, both at $\sqrt{s} = 2000$ GeV (Figs. 1-4). The comparison between $\sqrt{s} = 200$ GeV and 2000 GeV is presented in Section 4 (Figs. 5-8). All our results are based on the Monte Carlo generation of 4000 events for each system, AO option, Q_0-value and energy. Concluding remarks are summarized in Section 5.

2. THE DEPENDENCE OF THE MDs ON THE VIRTUALITY CUT-OFF Q_0

At the accuracy level of $10 - 20\%$ the Q_0 dependence of all NB parameters $\bar{n}, k$ is remarkably simple. The ratios $\bar{n}'/\bar{n}$ and k'/k of the $Q_0 = 2$ GeV to $Q_0 = 1$ GeV values do not vary by more than the above percentage as y_0 grows from 0.5 to the maximum corresponding to full phase space. The approximately constant values of the ratios are listed in table I for $\sqrt{s} = 2000$ GeV.

The most important feature is that all hadronic ratios $\bar{n}'_h/\bar{n}_h$ and k'_h/k_h are very close to unity. This means that the charged hadron MDs are essentially independent of Q_0 for all y_0, a manifestation of the infrared stability property embodied in the Lund hadronization model [4]. We have also verified this for intermediate values of Q_0.

One of the main findings of [1] was the approximate equality $k_h \sim k_p$. It is shown with $Q_0 = 1$ GeV in Figs.3 and 4 for both AO options. Table I shows that it still holds at $Q_0 = 2$ GeV, be it with a poorer approximation. In [5] we interpreted k^{-1} as an aggregation parameter in terms of the clan analysis of NB distributions. Table I and Figs 3,4 show that approximately the same degree of aggregation occurs at the parton level for $Q_0 = 1 - 2$ GeV and at the hadron level. This property agrees with the expectations of the generalized local parton-hadron duality discussed in [1].

3. THE EFFECTS OF ANGULAR ORDERING

The AO effects are shown in Figs. 1-4 at $Q_0 = 1$ GeV. The most striking feature is that for each system the four curves for the mean numbers $\bar{n}_h, \bar{n}_p$ with and without AO are very close to proportional, with only a slight difference in shape between the $q\bar{q}$ and gg systems (Figs. 1,2). The proportionality coefficients are listed in Table II.

Regarding the k parameters (Figs. 3,4), the four curves for $q\bar{q}$ are rather similar, and so are those for gg, with a marked difference between the two systems. For the case without AO, we found in the clan analysis of [1] that the main difference between $q\bar{q}$ and gg is in $\bar{N} = k \quad ln[1 + (\bar{n}/k)]$, the mean number of clans, which is about a factor 2 larger for gg whereas the multiplicity per clan $\bar{n}_c = \bar{n}/\bar{N}$ differs much less. This is found to hold for both AO options, as shown in Figs. 5-8.

4. DEPENDENCE ON THE CENTRE-OF-MASS ENERGIES

We have discussed so far the $\sqrt{s} = 2000$ GeV results. We performed the same analysis at $\sqrt{s}$ = 200 GeV and found the same behaviour as described in the previous sections and in Table I and II, with the exception of the ratio k'_p/k_p which is larger and less constant than at $\sqrt{s}$ = 2000 GeV (it is $\sim 1.2 - 1.5$ for $0.5 \leq y_0 \leq 4.0$ and ~ 2 at $y_0 = 3.0$).

As to the variation of the NB parameters between $\sqrt{s}$ = 200 GeV and 2000 GeV, we confirmed for both AO options the main result found in [1] in the broader energy range $\sqrt{s} = 29 - 2000$ GeV. At fixed y_0 the mean numbers of clans $\bar{N}$ depend very little on $\sqrt{s}$, and most of the increase of multiplicity is due to the increase of the mean clan multiplicity $\bar{n}_c$. This is shown in Figs. 5-8 for $Q_0 = 1$ GeV, at partonic and hadronic levels and for both AO options.

5. CONCLUDING REMARKS

Continuing the study of parton and charged hadron multiplicity distributions in symmetric rapidity windows for quark-antiquark and gluon-gluon systems at $\sqrt{s}$ = 200 GeV and 2000 GeV, the present work shows that the negative binomial (NB) regularities found in Ref. [1] using the Lund Shower Model with angular ordering (AO) also hold when the AO constraint is removed. In addition, with and without AO, the NB regularities are maintained when the parton virtuality cutoff Q_0 is varied from 1 to 2 GeV, a confirmation of the infrared stability of the model [4]. For each rapidity window $|y| < y_0$, the NB parameter k is about the same at partonic and hadronic level, and it depends only weakly on Q_0 and on the AO option, whereas the mean multiplicity $\bar{n}$ changes by factors which are independent of y_0. These results agree with the expectations based on the generalized local parton-hadron duality formulated in [1].

Table I: Standard NB parameters for charged hadrons (h) and for partons (p), at QCD cut-off $Q_0 = 2$ GeV $[\bar{n}'_h, \bar{n}'_p, k'_h, k'_p]$ are compared to the corresponding parameters for $Q_0 = 1$ GeV $[\bar{n}_h, \bar{n}_p, k_h, k_p]$; their ratios are shown for $q\bar{q}$ and gg systems at $\sqrt{s}$ = 2000 GeV, maintaining $[WAO]$ and removing $[NAO]$ the angular ordering option. Since the ratios vary little with the window $|y| < y_0$ considered, averages over y_0 are given.

	$q\bar{q}[WAO]$	$q\bar{q}[NAO]$	$gg[WAO]$	$gg[NAO]$
$\bar{n}'_h/\bar{n}_h$	0.97	0.93	0.98	0.93
k'_h/k_h	0.99	0.90	0.99	0.92
$\bar{n}'_p/\bar{n}_p$	0.56	0.45	0.55	0.45
k'_p/k_p	1.15	0.93	1.2÷1.4	1.2

Table II: The mean number of charged hadrons in the options $[WAO]$, $\bar{n}_h^{[WAO]}$, and $[NAO]$, $\bar{n}_h^{[NAO]}$, and the mean number of partons in the option $[NAO]$, $\bar{n}_p^{[NAO]}$, are compared to the mean number of partons in the options $[WAO]$, $\bar{n}_p^{[WAO]}$, and $[NAO]$, $\bar{n}_p^{[NAO]}$, for the $q\bar{q}$ and gg systems, all at $Q_0 = 1$ GeV and $\sqrt{s}$ = 2000 GeV. Since the ratios vary little with y_0, averages over y_0 are given.

	$\bar{n}_h^{[WAO]}/\bar{n}_p^{[WAO]}$	$\bar{n}_h^{[NAO]}/\bar{n}_p^{[NAO]}$	$\bar{n}_p^{[NAO]}/\bar{n}_p^{[WAO]}$
$q\bar{q}$	2.1	1.2	2.9
gg	2.1	1.2	3.0

REFERENCES

[1] Van Hove, L. and Giovannini, A. "Multiplicity Distributions in the Lund Shower Model of e^+e^- Annihilation - CERN preprint TH 4885 (October 1987), to be published in Acta Physica Polonica.

[2] Bengtsson, M. and Sjöstrand, T., Nucl. Phys. B289 (1987) 810.
Sjöstrand, T. and Bengtsson, M., Computer Physics Communications 43 (1987) 367.
Sjöstrand, T., Computer Physics Communications 39 (1986) 347.

[3] Petersen, A. et al. Phys Rev. D37 (1987) 1.

[4] Sjöstrand, T. , Phys.Lett. B142 (1984) 420.
Ingelman, G., Physica Scripta 33 (1986) 39.

[5] Van Hove, L. and Giovannini, A., " Negative Binomial Multiplicity Distributions, a New Empirical Law for High Energy Collisions" in the Proceedings of the Int. Symposium on Multiparticle Dynamics Ed. by Markytan et al. (World Scientific, Singapore 1987) p.561.

FIGURE CAPTIONS

Fig. 1: The mean numbers of charged hadrons (black dots) and partons (empty dots) in rapidity windows $|y| < y_0$ resulting from NB fitting to data generated by the QCD parton shower model with Lund hadronization at $\sqrt{s} = 2000$ GeV and $Q_0 = 1$ GeV, for $q\bar{q}$ system, by removing (full line) or maintaining (dashed line) the angular ordering option.

Fig. 2: Same as in Fig. 1 for the gg system.

Fig. 3: The NB parameters k for the same data sample as in Fig. 1 ($q\bar{q}$ system).

Fig. 4: Same as in Fig. 3 for the gg system.

Fig. 5: Average numbers of clans $\bar{N}$ of parton distributions in rapidity windows $|y| < y_0$ at $\sqrt{s} = 2000$ GeV (empty dots) and $\sqrt{s} = 200$ GeV (empty triangles) with $Q_0 = 1$ GeV for the $q\bar{q}$ and gg systems, by removing (full line) for maintaining (dashed line) the angular ordering option.

Fig. 6: Same as in Fig.5 for the charged hadron distributions at $\sqrt{s} = 2000$ GeV (black dots) and at $\sqrt{s} = 200$ GeV (black triangles).

Fig. 7: Same as in Fig. 5 for the average clan multiplicities $\bar{n}_c$ of the parton distributions.

Fig. 8: Same as in Fig. 6 for the charged hadron distributions.

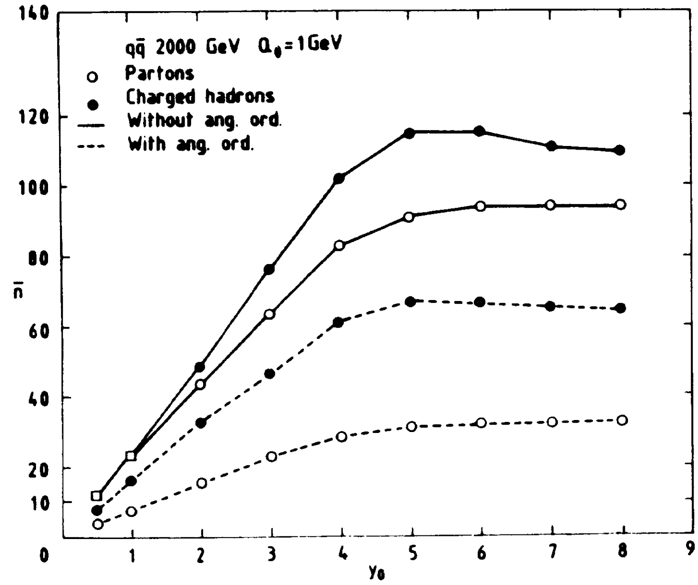

Fig. 1

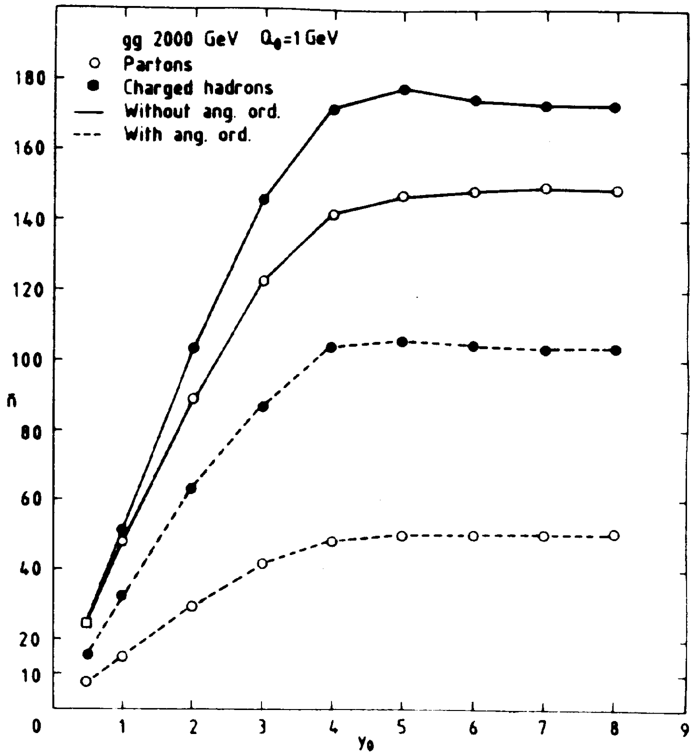

Fig. 2

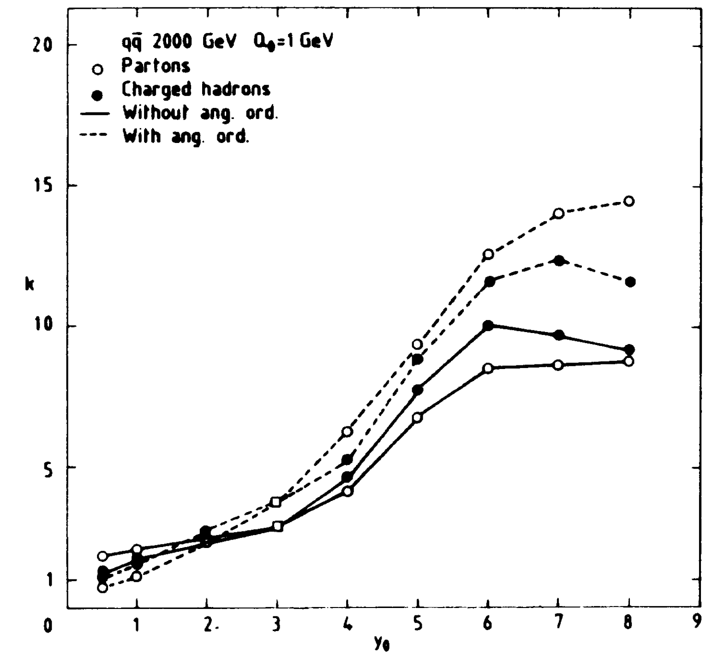

Fig. 3

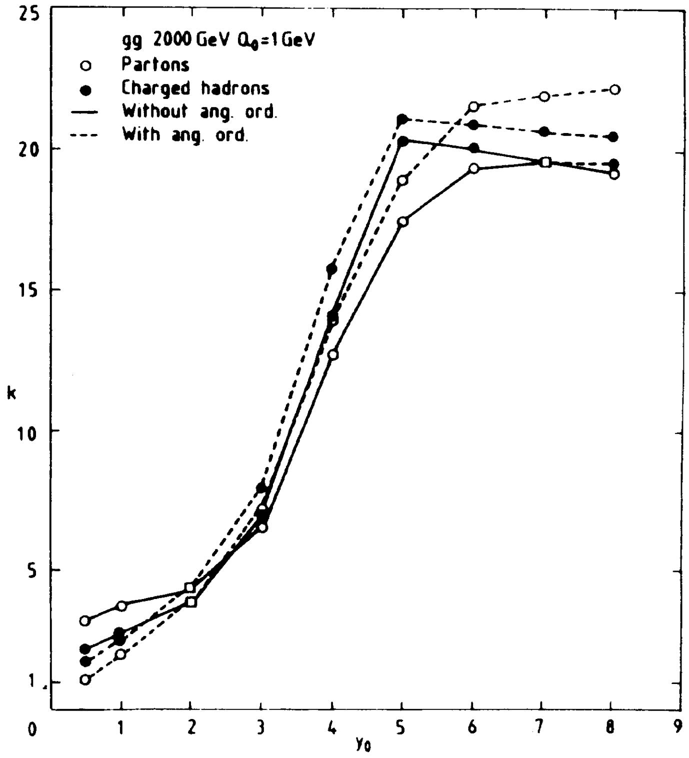

Fig. 4

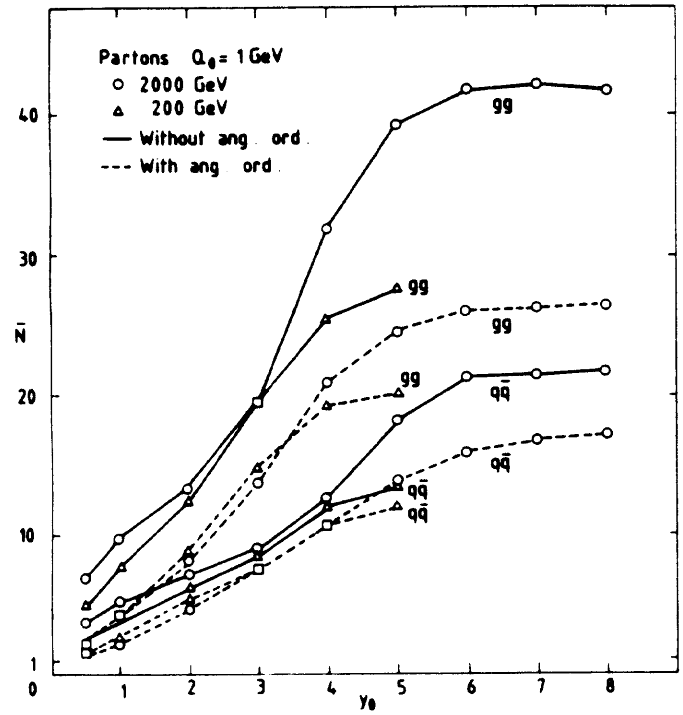

Fig. 5

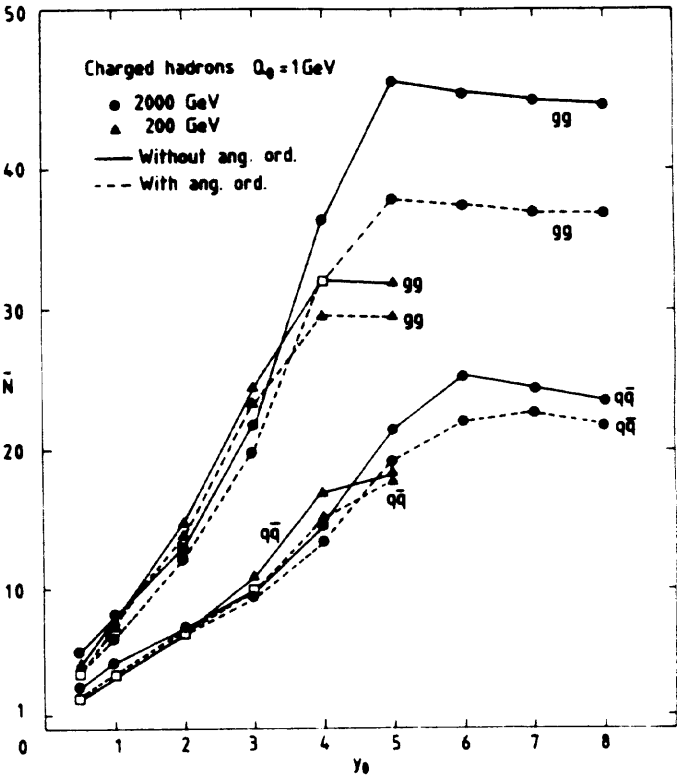

Fig. 6

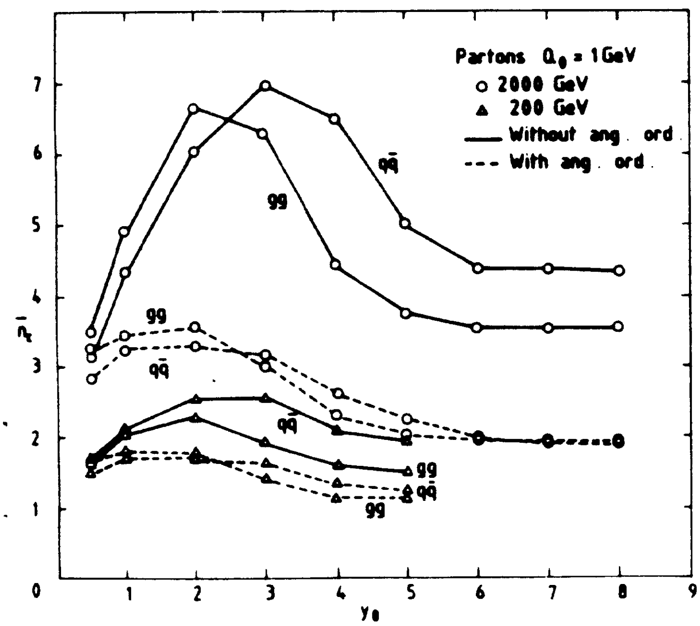

Fig. 7

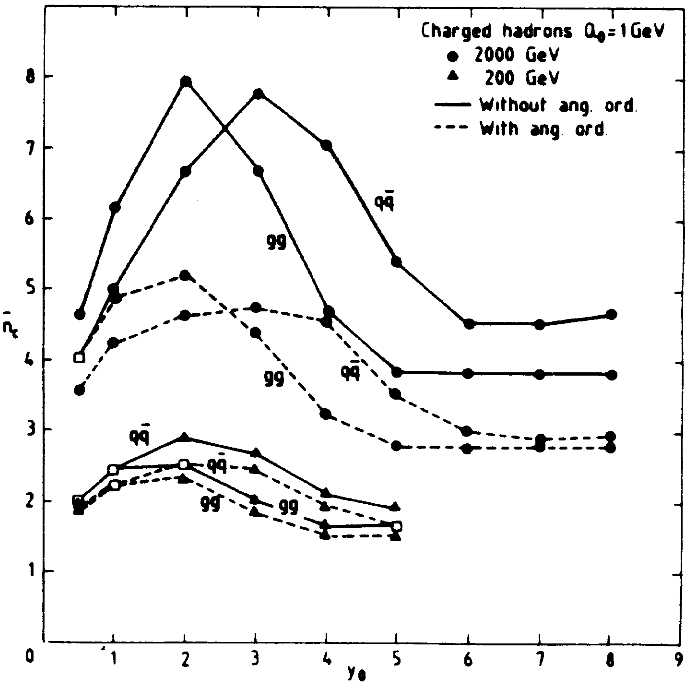

Fig. 8