Effects of Gluon Bremsstrahlung in e^+e^- Annihilation and Leptoproduction Events

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Abstract:

The structure in e^+e^- annihilation and in leptoproduction events is studied, combining the relevant cross sections up to first order in QCD with a model for the subsequent soft fragmentation of quark and gluon jets. A generally good agreement with present experimental data is found, and predictions for further tests are made.

In this paper some studies made by the Lund group will be presented, and due credit should hence go to my collaborators Bo Andersson, Gösta Gustafson and Gunnar Ingelman.

The Lund model for the soft fragmentation of jets is based on the dynamics of the massless relativistic string with no excited transverse degrees of freedom, and provides a causal and relativistically invariant description of the fragmentation process [1]. As an original quark-antiquark pair moves apart, a string (a colour flux tube) is stretched out between them. New $q\bar{q}$ pairs may be created in this string, after which they are pulled apart by the field and join to form mesons. The resulting cascade is of an inside-out character, i.e. in any particular coordinate frame it is always the slowest particles which first become independent entities. Still, an iterative structure similar to cascade models [2] is obtained, as can be seen by making a Lorentz boost along the original quark direction, to a frame in which the first rank meson of the quark jet is also produced first in time.

We note that it is possible for a small pointlike part of the string to carry a finite amount of energy and momentum. Such a "kink" is acted upon by the string by twice the force upon an endpoint quark. This gives features very similar to those of a gluon in QCD, where the corresponding force ratio is expected to be $2/(1 - 1/n_c^2)$ where n_c is the number of colours, i.e. 9/4 for $n_c = 3$. We then obtain a picture for $q\bar{q}g$ events, where the string is stretched between the quark and the antiquark via the gluon. As the original partons move apart, the two string pieces then fragment like ordinary quark-antiquark strings. In addition, one meson is formed at the gluon "corner", receiving energy and momentum contributions from both string pieces.

One consequence of this model is that gluon jets become softer than quark jets, in that the gluon energy is shared between two string systems, whereas a quark only gives its energy to one string. Another consequence, coming from the Lorentz boost from a rest frame of the respective string to the lab frame, is that the final state mesons lie distributed along two hyperbolae in momentum space (Fig. 1). In particular, note that this Lorentz invariant scheme for $q\bar{q}g$ jet system fragmentation does not depend on any choice of a fixed point in space where the jets are to be joined.

Combining the models above for $q\bar{q}$ and $q\bar{q}g$ events with the relevant first order cross section, we obtain a Monte Carlo program for e^+e^- annihilation events [3]. By suitably fitting a few parameters, it is possible to reproduce the experimental data from PETRA on multiplicity, sphericity, thrust, oblateness, $p_\perp^2$ distributions, etc. There are, however, also definite predictions for three jet events coming from our gluon jet model. As noted above, we expect the gluon jet to be softer than a quark jet with the same energy. There should also be more particles in the angular ranges between the gluon and the quark or antiquark than between the quark and antiquark. This feature has in fact by now been observed by the JADE group [4]. The pattern should be even more marked when studying the energy flow in the event plane. An asymmetry, testing the nature of gluon jet fragmentation, may be defined by combining the first two features above, and this asymmetry does not depend on us knowing which is the gluon jet. Finally, we do not expect the flavour content of a gluon jet to be different from that of an ordinary quark jet.

For the leptoproduction process $\gamma q \to q$ there are to first order in α_s in addition the subprocesses $\gamma q \to qg$ and $\gamma g \to q\bar{q}$. For the final states we note that in the $\gamma q \to q$ and $\gamma q \to qg$ processes the target remnant diquark is an antitriplet in colour and hence behaves like an antiquark, whereas in $\gamma g \to q\bar{q}$ the target remnant is an octet in colour and behaves like a gluon. Neglecting that a baryon is formed in the target fragmentation region, we can hence use our $q\bar{q}$ and $q\bar{q}g$ models as the basis for a leptoproduction Monte Carlo [5], using the relevant matrix elements.

The QCD contributions give a rising $\langle p_\perp^2 \rangle$ with W^2, and the experiments [6] give results in fair agreement with our Monte Carlo, provided that a primordial $k_\perp$ with $\sqrt{\langle k_\perp^2 \rangle} = 0.8$ GeV/c is chosen, i.e. rather higher a value than what might be expected (Fig. 2).

The particular features described for $q\bar{q}g$ events are also applicable in leptoproduction. A simple way to see the predicted difference between quark and gluon jets is to trigger on a high-$p_\perp$ particle which, counted with respect to the incident γ direction, is assumed to define the quark side of a qg event. We then expect there to be more particles with a higher $\langle p_\perp \rangle$ on the opposite, gluon, side.

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Figure captions

Fig. 1 The momentum space distribution of the final state particles in a $q\bar{q}g$ event. The particles appear along two hyperbolae; the size of the hatches indicates the broadening coming from differences in $p_\perp$ during the soft fragmentation.

Fig. 2 The mean squared transverse momentum for different z bins is shown as a function of the CM hadronic energy squared W^2, experimental data compared to Monte Carlo calculations with $\sqrt{\langle k_\perp^2 \rangle} =$ $= 0.6$ GeV/c (dashed) and $= 0.8$ GeV/c (full line).

Fig. 1

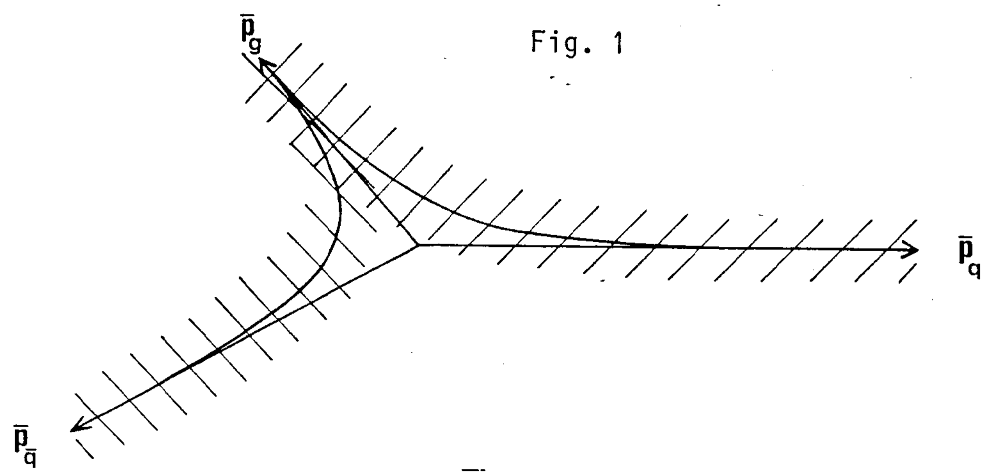
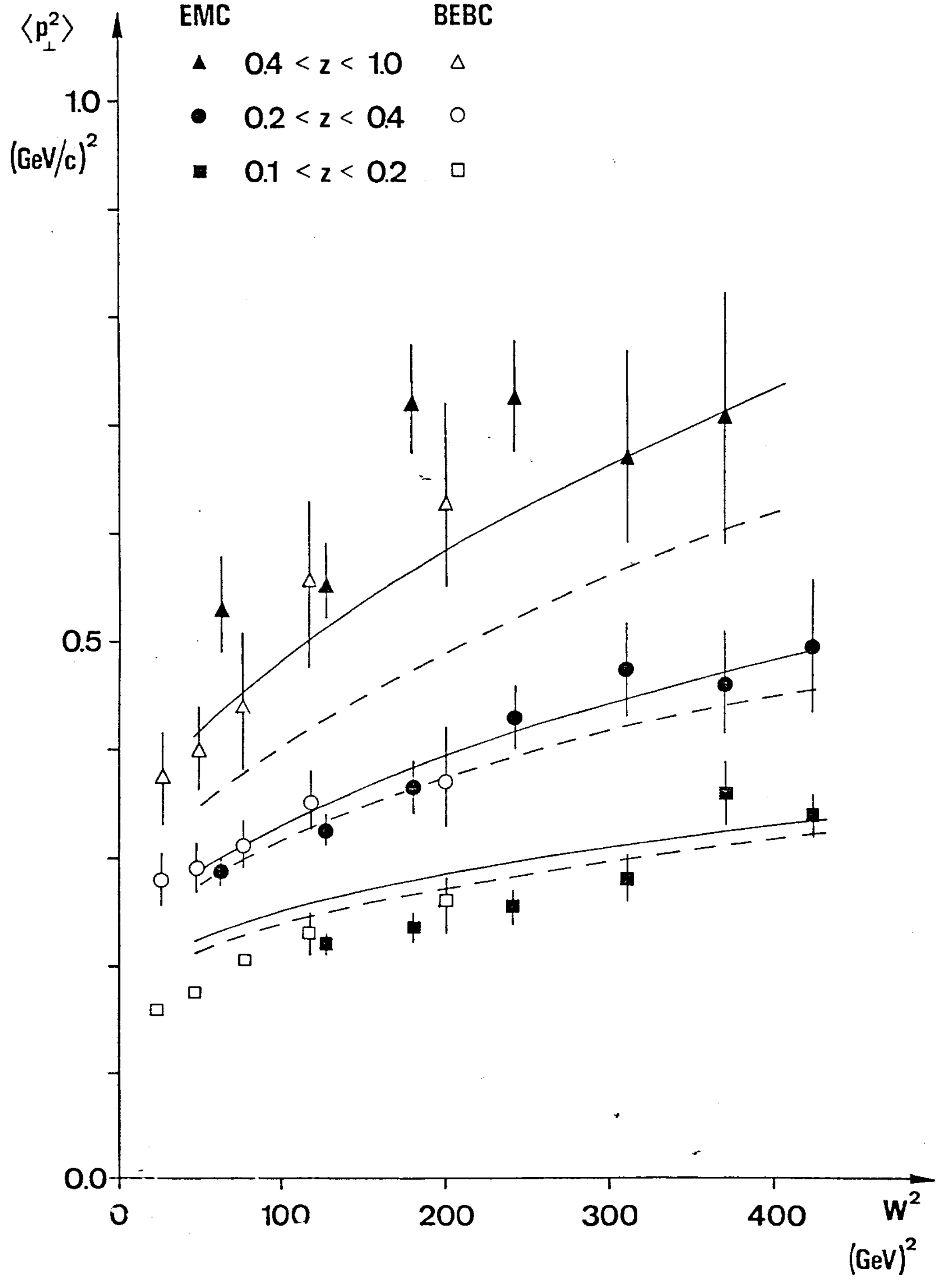

p̄g
p̄q
p̄q̄

Fig. 2


⟨p⊥²⟩
EMC
BEBC
0.4 < z < 1.0
0.2 < z < 0.4
0.1 < z < 0.2
1.0
(GeV/c)²
0.5
0.0
0
100
200
300
400
W²
(GeV)²