ON THE SEPARATION OF QUARK AND GLUON JETS IN HIGH-p_T EVENTS

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SUMMARY

We suggest a procedure, based on the kinematics of qg-scattering in high-p_T events, whereby it is possible to obtain enriched samples of quark and gluon jets. At Sp$\bar{p}$S energies this could be used to indicate whether quark and gluon jet fragmentation agree or not. At higher energies the application would rather be to study the differences in the parton cascades, i.e. jet substructure.

It is well know that hard interactions in p$\bar{p}$ or pp collisions are dominated by qq (or q$\bar{q}$, in the following we make no explicit distinction between q and $\bar{q}$) scattering at high x_T and by gg scattering at low x_T. This is a consequence of the quark structure function being harder than the gluon one. Although this allows a straightforward method to obtain enriched samples of quark and gluon jets separately, there is not very much to be learned from comparing these samples: the jets are of different energy, at different hard scattering Q^2 scales (with related problems of different initial and final state parton cascades) and with different efficiencies in isolating the high-p_T jets from the low-p_T "beam jet background".

Instead we propose to study intermediate x_T, where qg-scattering dominates. For this process we then have a q jet on one side and a g jet on the other, both characterized by the same Q^2 and x_T scale In order to distinguish the q from the g we note that, for events were the two interacting partons have unequal energy fractions x, the one with larger x is likely to be the quark, because of the difference in structure functions noted above. Further, the hard scattering cross section is peaked for small t, i. e. forward scattering, such that also in the final state the q jet is most likely the one with largest x value.

We now proceed to give some numerical estimates for these effects, using the Lund Monte Carlo[1] with Glück-Hoffmann-Reya[2] structure functions. The processes studied are p$\bar{p}$ at 540 GeV (Sp$\bar{p}$S) and pp at 40 Tev (SSC).

For the subsequent kinematics we assume incoming partons 1 and 2 with momenta (in units of $\sqrt{s}/2$) x_1 and x_2 directed along the ± z axis, with + z defined such that $x_1 > x_2$. The outgoing partons 3 and 4 then have longitudinal momentum components x_{3L} and x_{4L}, with labelling such that $x_{3L} > x_{4L}$. Both partons have compensating transverse momenta x_T, such that the parton energies are given by $x_{3,4}^2 = x_{3L,4L}^2 + x_T^2$. Conservation of energy and longitudinal momentum then gives

$$x_1 + x_2 = x_3 + x_4 \qquad (1)$$

$$x_1 - x_2 = x_{3L} + x_{4L}$$

or

$$x_{1,2} = \frac{1}{2}(x_3 + x_4) \pm \frac{1}{2}(x_{3L} + x_{4L}) \qquad (2)$$

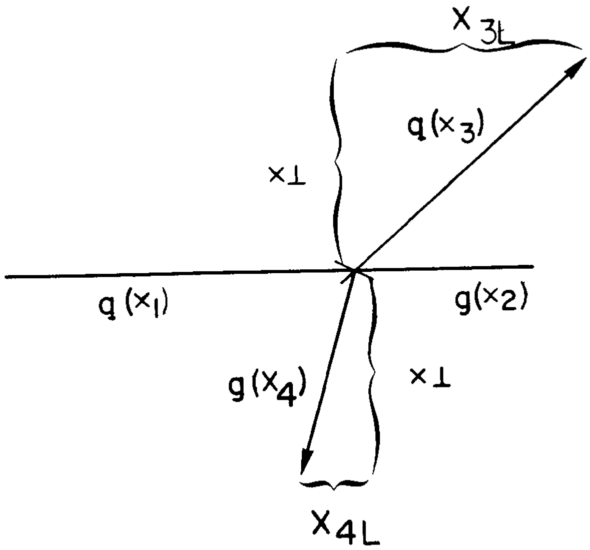

FIG 1. The kinematics of a typical qg scattering event.

The kinematics is illustrated in Fig. 1, labelled for the desired case when partons 1 and 3 is a q and 2 and 4 a g.

To enrich the desired kinematical configurations, a number of cuts is required. A cut in x_T is used both to ensure that the scattering is a hard one and that the high-p_T jets come out at angles not too close to the beam jets. At 540 GeV this makes $x_T > 0.1$ a realistic limit, at higher energies it would be advantageous to use even smaller x_T.

Further, we must make a cut in $x_1 - x_2$ such that the difference in x_1 and x_2 improves the probability of 1 being q and 2 being g. Finally, a cut in $x_{3L} - x_{4L}$ is necessary, since a situation with $x_{3L} \approx x_{4L}$ corresponds to the t for $q(x_1) \to q(x_3)$ and $q(x_1) \to q(x_4)$ being comparable, such that we don't know which of the final state partons is the q one. There is a tradeoff between these latter two cuts, so to keep the number of cut parameters at a minimum, we below give results obtained by cutting on the product

$$(x_1 - x_2)(x_{3L} - x_{4L}) = (x_{3L} + x_{4L})(x_{3L} - x_{4L}) = x_{3L}^2 - x_{4L}^2 = x_3^2 - x_4^2 \qquad (3)$$

Some results are quoted in Table 1. In addition to the total cross section σ expected for the given x_T and $x_3^2 - x_4^2$ cuts, we give the relative composition of qq, qg and gg final state partons, the probability of correctly identifying the q jet in qg scattering (p(hard q)), and the probability of what we label as the "q" and the "g" jet really being a q one (it being a g one in the rest of the cases), i. e. where also contamination from qq and gg final states are included. It is the difference between the latter two numbers which tells us how good a given set of cuts really is.

To check the sensitivity to the choice of structure functions, the exercise was repeated with the Eichten-Hinchliffe-Lane-Quigg[3] (set 1) structure functions. Agreement was generally very good, but at 40 TeV the EHLQ structure functions predicts about 10% lower cross sections and a slightly higher fraction of qg final states at the expense of gg ones, such that the separation between q and g jets is somewhat better than in Table 1.

As we see, a smaller x_T cut favors gg scattering, but the additional cut in $x_3^2-x_4^2$ brings up the qg rate again. Also, for fixed $x_3^2-x_4^2$ cut, events with lower x_T corresponds to a larger difference in t values between forward and backward qg scattering, such that the possibility of correctly identifying the q jet is larger. It is is therefore advantageous to choose x_T small and $x_3^2-x_4^2$ correspondingly large, provided the detector is able to do a good job for jets down to polar angels $\theta \sim 2x_T$.

At present energies we have applied this method to the study of quark and gluon jet fragmentation differences. Here the UA1 collaboration has published a comparison[4] between its (gluon-dominated) high-p_T jet sample and the TASSO e^+e^- events, concluding that quark and gluon jets seem to have very similar longitudinal fragmentation functions. There are, however, many uncertainties in such a comparison. The amount of quark jets in the UA1 data is not negligible (almost 30% quark jets for $x_T>0.1$, see Table 1), there are significant statistical errors at large z and, most importantly, wereas the total CM energy is known in the TASSO case, UA1 is forced to determine the jet energy event by event. Since the fragmentation function is steeply falling, one is very sensitive to errors in the jet energy and hence the z scale. Even if the parton energies are correctly reconstructed in the mean, fluctuations tend to raise the fragmentation function at large z. Further, corrections are model-dependent, both to whether independent or string fragmentation is used and to whether it was assumed that gluon equals quark in the first place.

With the method proposed above, and explicitly using the constraint that the total transverse momentum has to vanish, any errors in jet energy determinations cancel event by event. The ratio of fragmentation functions for the "q" to the "g" jet sample thus provides a sensitive test whether gluon really equals quark. In Fig. 2 we illustrate the results obtained for this ratio for the two cases of independent fragmentation with gluon=quark and of Lund string fragmentation[5], in which case the gluon jet is much softer (the gluon energy being shared by two string pieces compared to only one for a quark). Indeed the ratio comes out close to 1 in the former case, and falls with z in the latter one.

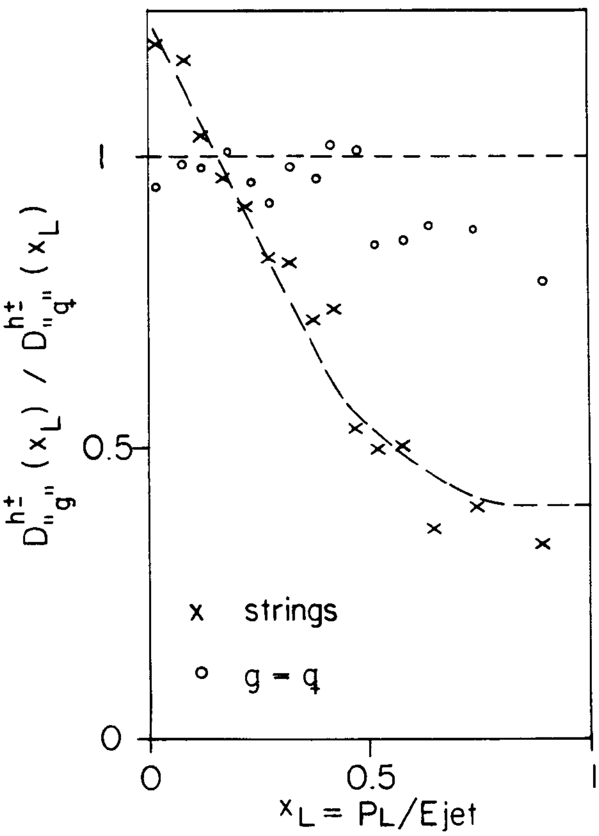

FIG 2. Ratio of "g" to "q" fragmentation functions for strings (crosses) and g=q (circles), with dashed lines drawn both to guide the eye and to reflect theoretical prejudice.

At SSC energies, the same method could be used to explicitly compare jet substructure, i. e. the expected differences in quark and gluon initiated parton cascades. The main virtue above many other methods proposed to "flavour tag" jets is that it makes no assumption as to what way a given jet fragmented, such that no bias is introduced in the study of jet properties.

REFERENCES

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TABLE 1

RESULTS FOR GLÜCK-HOFFMANN-REYA STRUCTURE FUNCTION

PROCESS	540 GeV $p\bar{p}$				40 TeV pp							
$x_T>$	0.1	0.1	0.1	0.1	0.05	0.05	0.05	0.05	0.1	0.1	0.1	0.1
$x_3{}^2-x_4{}^2>$	0	0.05	0.1	0.15	0	0.05	0.1	0.15	0	0.05	0.1	0.15
σ(nb)	827	187	79	38	0.86	0.10	0.040	0.019	0.019	0.0035	0.0014	0.0007
p(→qq)(%)	11	17	20	22	8	15	18	20	15	24	28	30
p(→qg)(%)	35	45	51	57	32	51	57	60	37	50	53	57
p(→gg)(%)	54	38	29	21	60	34	25	20	48	26	19	13
p(hard q)(%)	63	78	84	89	65	84	90	93	65	81	86	87
p("q"=q)(%)	34	52	62	72	29	57	69	76	39	64	74	80
p("g"=q)(%)	24	27	28	28	19	23	24	24	28	34	35	37