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INCLUSIVE CHARGED PARTICLE DISTRIBUTION IN NEARLY 3-FOLD SYMMETRIC 3-JET EVENTS AT $E_{cm} = 29$ GEV*

A. PETERSEN
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

Results of inclusive charged particle distribution for gluon jets using nearly 3-fold symmetric 3-jet events taken at center of mass energies of 29 GeV in e^+e^- annihilation are presented. The charged particle spectrum for these jets is observed to be softer than that of quark jets with the same jet energy.

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Jets initiated by a quark or antiquark have been measured in great detail by various experiments. However, experimental studies about jets which originate from a high energy gluon are just at the beginning.[1],[2]

We studied inclusive charged particle production in 3-jet events which have nearly 3-fold symmetry under the assumption that these events originate from two quark jets and one gluon jet. This requirement has the following advantage: all three jets have nearly the same energy $\simeq 1/3\ E_{cm}$, the jets have the best possible separation, and the gluon jet has a relatively high energy. On the other hand the production of such events is very suppressed, and it has been shown that quark and gluon jets do not fragment totally independently in an event,[3] but these results show that mainly the soft particles are affected, whereas the high momentum particles follow more the direction of the partons. We compared the particle distribution of these 3-jet events with distributions of events originating from initial quark jets with the same jet energies.[4]

The data sample used in this measurement was collected by the Mark II detector at $E_{cm} = 29$ GeV. The total integrated luminosity of 215 pb^{-1} corresponds to 90000 hadronic events. A subset of these data was used for a measurement of the inclusive charged particle cross section.[5]

The Mark II detector has been described in detail elsewhere.[6] The track selection criteria are the following: a well reconstructed charged track has to pass within 40 mm in radius and 60 mm in z from the event vertex and have at least 100 MeV/c of transverse momentum. Neutral particles assumed to be photons are detected by the central region lead-liquid argon calorimeter modules.[7] A neutral cluster with $E > 150$ MeV and a distance (at the radius of the shower counter) of $d > 300$ mm from the closest charged track is defined as a photon.

Hadronic events are selected by requiring at least 5 well reconstructed charged tracks and a total charged and neutral energy > 55% of E_{cm}. A cluster algorithm[8] which uses the vector momenta of charged and neutral particles partitions the data into n-jet events. Only 3-jet events are retained of which each jet has to have greater than 2 GeV of observed energy and to contain at least 3 (charged or neutral) particles. The jet axes are defined by the vector sum of the particle momenta within each jet, and the jet energies (E_j) are calculated from the angles between the jet axes assuming three massless partons. To require almost 3-fold symmetry for the 3-jet events, all three angles between the jet axes have to lie between 100° and 140°. All of the above criteria are met by 560 events which corresponds to about 0.5% of all hadronic events. Monte Carlo calculations using models having QCD plus fragmentation estimate a background of (0.4 ± 0.2)%. The model calculations show further that the fraction of heavy quarks in this sample is the same fraction as for all hadronic events.

The inclusive charged particle distribution is analyzed in terms of the fractional momentum $x_i = p_i/E_j$, where p_i is the momentum of particle i, and E_j the energy of the jet to which it is assigned. The fact that all three jets have nearly the same energy implies that a wrong assignment of a particle to a jet is not a severe problem. The data are corrected by a bin by bin correction factor, calculated by different Monte Carlo generators[9],[10],[11] to correct for the detector inefficiencies and initial state QED radiation. The correction factor increases slightly from 0.85 at low x to 0.92 at high x values.

Figure 1 shows the corrected x distribution of the 3-fold 3-jet events (full symbols), where the errors include both statistics and the uncertainty in the efficiency. To compare this x distribution originating from events containing two quark jets and one gluon jet, each with approximately 10 GeV energy, with x distributions initiated by events containing two quark jets each with the same energy, we use the published data at E_{cm} = 5.2, 6.5, 14, 22, 29 and 34 GeV,[5],[12],[13],[14] In Fig. 2 all these results are shown in terms of their c.m. energy dependence. $1/N_j\ dn/dx$ is plotted for the twelve fixed x intervals shown in Fig. 1 as a function of the beam energy. Within a fixed x interval, all the data points with N_{jet} = 2 are fitted to the form suggested by QCD:[15]

$$\frac{1}{\sigma_{tot}}\ \frac{d\sigma}{dx} = c_1(x)(1 + c_2(x)\, ln(s)) \tag{1}$$

where $c_1(x)$ and $c_2(x)$ are free parameters. The resulting fits are represented by the curves in Fig 2. For $x > 0.15$ all the different data points agree quite well with the fitted curves, whereas for low x values some larger deviations are visible, probably due to higher background problems for low momentum tracks.

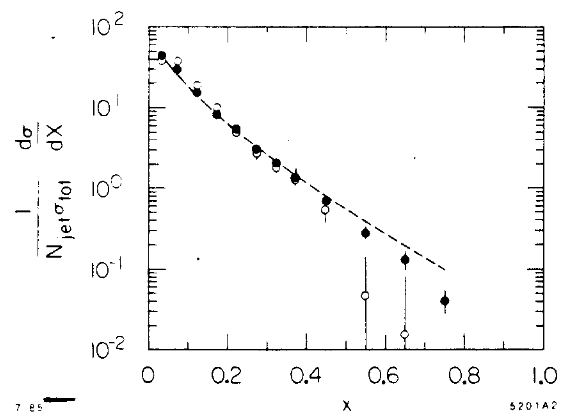

Fig. 1. The detector corrected inclusive charged particle distribution for 3-jet events at E_{cm} = 29 GeV (full symbols) in comparison with the inclusive charged particle cross section of hadronic events at E_{cm} = 19.3 GeV, extrapolated from the fitted curves in Fig. 2 (dotted curve) and the inclusive charged particle distribution of a gluon jet of E_j = 9 GeV (open symbols).

The x distribution of the 3-fold 3-jet events at E_{cm} = 29 GeV is also shown in Fig. 2 for the twelve x intervals. The points are drawn at E_j = 9.66 GeV. The deviation between the points and the fitted curves suggests a difference in the x distribution.

The results of the fits within the twelve intervals from Fig. 1 are used to interpolate the cross section at $E_{cm} = 19.3$ GeV. This is shown in Fig. 1 as a dotted curve. The slope of the distribution containing the 1/3 admixture of gluon jets is observed to fall off faster than that of initial quark jets. To extract to first approximation an inclusive charged particle distribution for a gluon jet of $\simeq 10$ GeV energy, we adopted the following ansatz:

$$\begin{aligned}\frac{1}{\sigma_{tot}}\frac{d\sigma}{dx}(\text{gluon jets}) = &\frac{1}{\sigma_{tot}}\frac{d\sigma}{dx}(\text{3–jet events}, E_{cm} = 29 \text{ GeV}) \\ &- \frac{1}{\sigma_{tot}}\frac{d\sigma}{dx}(\text{all events}, E_{cm} = 19.3 \text{ GeV})\end{aligned} \tag{2}$$

where for the events at $E_{cm} = 19.3$ GeV the fit results are again used. This cross section is also shown in Fig. 1 (open symbols).

Another way of displaying the data is to calculate the ratio

$$r(x) = \frac{\frac{1}{3\sigma_{tot}}\frac{d\sigma}{dx}(\text{3–jet events}, E_{cm} = 29 \text{ GeV})}{\frac{1}{2\sigma_{tot}}\frac{d\sigma}{dx}(\text{all events}, E_{cm} = 19.3 \text{ GeV})} \tag{3}$$

as a function of x which is shown in Fig. 3. For comparison, the calculation for the models are also indicated in Fig. 3.

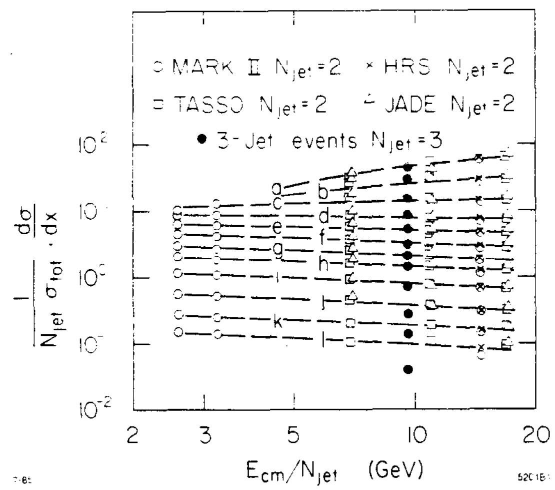

Fig. 2. The inclusive charged particle distribution for a jet versus the jet energy measured by various experiments. The curves represent fits to the different data points for each of the twelve x intervals a till l. The inclusive charged particle distribution for the 3-jet events is also shown.

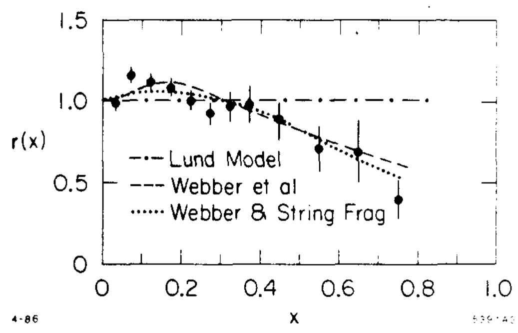

Fig. 3. The ratio of the inclusive charged particle distribution for 3-jet events at $E_{cm} = 29$ GeV to the inclusive charged particle cross section of hadronic events at $E_{cm} = 19.3$ GeV, together with several model predictions.

For the simulation of $q\bar{q}$ and $q\bar{q}g$ events the following steps have to be taken into account in the models, although there is no distinct separation between the different process: Hard parton emission from quark jets, hard parton emission from gluon jets, fragmentation of light quark jets, fragmentation of heavy quark jets (It has been shown that x distributions of particles from heavy quark jets are softer than that of light quark jets.[16]), and fragmentation of gluon jets. Assuming that parts of the hadronisation are similar for quark and gluon jets (e.g. probability of higher spin resonances, limited phase space at low energies, decays of heavy resonances), these things should cancel out in the ratio, and r should be less sensitive to fine tuning of the different models.

The Lund model, in which not the partons themselves but a string, stretched from the quark via gluon(s) to the antiquark, fragments and which contains a y_{min} cut to distinguish between the parton classes (y_{min} is the smallest invariant mass of any two partons over the c.m. energy), has r values close to unity over the whole x region. Although the fragmentation of a gluon jet differs quite drastically from a quark jet in this model, it does not show up in the ratio r. One reason is that the fixed y_{min} cut, implement more gluon emission at $E_{cm} = 19$ GeV. A further point in the model is the insufficient simulation of further parton radiation in the 3-jet events according to next higher orders, which are not accounted for, using only calculations up to second order in α_s.

On the other hand, the Webber model, which uses leading log evolution for the parton radiation, accounting for multiple parton emission in a better way, exhibits good agreement with the data. In the Webber model a $q\bar{q}$ event at $E_{cm} = 19$ GeV has on the average 4.1 partons, whereas a 3-fold $q\bar{q}g$ event at $E_{cm} = 29$ GeV produces 6.7 partons, resulting in a ratio of parton multiplicity of 1.3. This is still far away from 9/4 which is expected at infinite energies, indicating that the limited phase space plays still an important role at these energies. The limited phase space effect and the higher multiplicity of heavy quark jets cause in addition that the ratio in the charged multiplicity only amounts to 1.15.

A delicate issue in the Webber model is the decay mechanism of heavy clusters, which is normally used for cluster masses > 3.5 GeV. These decay according to a string like picture into two lighter clusters, which may pass the same procedure again, if their clusters are still to heavy. But using only this mechanism for the whole quark cascade leads to a particle x spectrum which is even softer than that for a gluon jet. So the following condition arises: If in the model the gluon branching $g \rightarrow gg$ is arbitrarily reduced by a factor 4/9, the parton multiplicity of the quark and gluon jets are nearly equal, but the gluon jet has more heavy clusters such that the final charged multiplicity of the gluon jet and the r distribution are the same as without the factor 4/9. This means that in the Webber model the changes on the parton level do not result in changes on the hadron level.

Another possibility is to use the parton shower of the Webber model and to stretch at the end of the parton evolution a string from the quark via the gluons to the antiquark and let this string fragment according to the Lund model.[17] The r distribution observed is similar to that of the original Webber model (dotted line in Fig. 3), and now this distribution is sensitive to changes in the gluon branching as one should expect.

In conclusion, we have used nearly 3-fold symmetric 3-jet events produced in e^+e^- annihilation at 29 GeV to investigate the inclusive charged particle distribution of gluon jets. Although the color configuration in these events differs from that in $q\bar{q}$ events, we have as a first approximation compared these distributions with charged particle distribution of all hadronic events at $E_{cm} = 19$ GeV. The comparison suggests a steeper slope for $x > 0.4$ for gluon jets.

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