Laboratori Nazionali di Frascati

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JET-JET $p_\perp$ DISTRIBUTIONS IN THE PROCESS $qq \to qqg$

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ABSTRACT

Leading terms in the jet-jet acollinearity distributions corresponding to $q_i\, q_j \rightarrow q_i\, q_j\, g$ have been considered and compared to corresponding Drell-Yan distributions. Almost identical behaviour emerges for large CM jet scattering angles, or if the average over all angles is performed. On the other hand differences are expected when the jets are produced at small angles.

The producting of high $p_\perp$ jets at ISR energies proceeds predominantly via the parton process of quark-quark scattering. Then the relative transverse momentum $q_\perp$ of almost back to back jets produced at large angles is expected to be quite similar to the $q_\perp$ distribution[1] of Drell-Yan pairs produced at the same energy. Indeed in both cases gluons are radiated by quarks, causing a departure from the naive parton model prediction $\delta(q^2{}_\perp)$. The resulting distributions are expected to be identical in the leading logarithmic approximation. This is not the case at the p p collider energies, where in fact gluon scattering is the dominant parton process and one expects[2] broader distributions in the q unbalance of the jets.

In the present note we discuss the leading behaviour of the $q_\perp$ distribution of q-q jets and compare it with the corresponding spectrum for Drell-Yan pairs. This accomplished by a simple study of the leading singularities in the process $q_i\, q_j \rightarrow q_i\, q_j\, g$ ($i \neq j$). The complete one loop corrections to the process, which have been calculated in ref. (3), can be used to extract also the next - to - leading terms.

For the process

$$q_i(p_1) + q_j(p_2) \rightarrow q_i(p_3) + q_j(p_4) + g(k) \qquad (1)$$

let us introduce the kinematic variables $t = (p_1-p_3)^2$, $s = (p_1+p_2)^2$, $u = (p_1-p_4)^2$, $k^2_\perp = (p_4+k)^2$, which is related to the acollinearity angle of the two jets.

Furthermore $v = 1-t/s = 1/2(1+\cos\theta_{cm})$, where qcm is the scattering angle in the CMS in the case of elastic scattering, and $w = -u/s+t$ is the acollinearity parameter, being related to $k^2_\perp$ by $k^2_\perp = s\, v\, (1-w)$.

The corresponding hadronic variables[3] are labelled by capital letters, and related to parton variables by $p_i = x_i P_i$, with

$$s = x_1 x_2\, S,\; v = \frac{x_2 - 1 + V}{x_2},\quad w = \frac{x_2\, VW}{x_1\,(x_2 - 1 + V)}$$

The matrix element squared for the process (1) is [4]:

$$|M|^2 = 4g^6\, |M_0|^2\, \{C_1\, [\frac{p_1\, p_4}{kp_1\, kp_4} + \frac{p_2\, p_3}{kp_2\, kp_3}] + C_2\, [\frac{2\, p_1\, p_2}{kp_1\, kp_2} + \frac{2\, p_3\, p_4}{kp_3\, kp_4} - \frac{p_1\, p_3}{kp_1\, kp_3} - \frac{p_2\, p_4}{kp_2\, kp_4} - \frac{p_1\, p_4}{kp_1\, kp_4} - \frac{p_2\, p_3}{kp_2\, kp_3}]\} \qquad (2)$$

with $C_1 = \frac{C^2_F}{4N}$, $C_2 = \frac{CF}{8N^2}$, $CF = \frac{N^2 - 1}{2N}$ and $|M|^2 = \frac{s^2 + s'^2 + u^2 + u'^2}{t\, t'}$

Average over initial state spin and colors introduces an additive factor $1/4N^2$.

The calculation of hard collinear emission singularities easily gives the leading terms of jet cross section, as

$$\frac{E_3\, d\sigma}{d^3P_3 dK_\perp} \quad \frac{8\alpha^3_s\, C^2_F\, |M_0|^2}{N\, s\, \pi} \quad \frac{1}{K_\perp}\, [\ln K_\perp + \ldots]$$

In order to extract the next to leading terms, we will now consider the result of ref. [3], where one loop real and virtual corrections ahve been calculated. In particular their final result, expressing the one hadron inclusive cross section, is written as

$$E_3 \frac{d\sigma}{d^3P_3} = \frac{1}{\pi S} \int_{vw/x_3}^{1} \frac{dx_3}{x_3^2} \int_{vw/x_3}^{1-(1-v)/x_3} \frac{dv}{I-v} \int_{vw/x_3 v}^{1} \frac{dw}{w} F_1(x_1, M^2)\, F_2(x_2, M^2) \cdot$$

$$\cdot\, D(x_3, M^2) \cdot \left[\frac{\pi \alpha_s^2(Q^2) C_F}{N s v} \frac{1+v^2}{(1-v)^2} \delta(I-w) + \frac{\alpha_s^3(Q^2)}{2\pi} K(s, v, w, M^2)\right]$$

where the term in α^2 is the Born cross section, and the factor $k(s, v, w, M^2)$ gives the full one loop correction. In eq. (4) $F_i(x_1, x_2, M^2)$ are the parton distribution and fragmentation functions at the scale M^2. The inclusive jet cross section is obtained with $D(x_3, M^2) = \delta(x_3-1)$. Furthermore, from the long expression of the K-factor we only retain the leading terms, in the small acollinearity angle limit ($w \leq 1$). Assuming $M^2 = s$ for the scale of the quark structure functions and expressing w in terms of the experimentally convenient variable $s_\perp/k^2_\perp 4$, we get for the acollinearity distribution of the two almost back to back jets

$$E_3 \frac{d\sigma}{d^3P_3 dS_\perp} = \frac{4\,\alpha_s^3\, C_F^2\, |M_0|^2\, \delta(s_\perp - s_v(I-w)/4)}{N s \pi s_\perp} \cdot$$

$$\cdot \left[\ln \frac{s}{s_\perp} - \ln 4 + \ln v + \frac{3}{4}(1 + 6 \ln v + 2 \ln (I-v)) + \frac{N}{C_F}(\ln v + \ln (I-v))\right.$$

The leading term of (s) is, of course, identical to eq. (3).

The non leading term exhibits a dependence on the CM scattering angle. In Fig. 1 this term, called c(v), is plotted. The average value of c(v), < c(v), is also shown, which is of interest for experiments which do not measure the complete CM parton angular distributions.

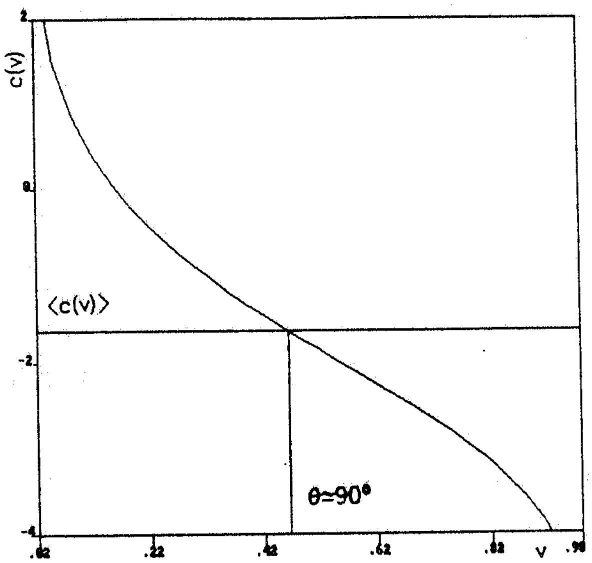

FIG. 1 - $c(v) = -\frac{5}{4} \ln v + \frac{3}{4} \ln (1-v) - \frac{3}{4} - \ln 4$

$\langle c(v) \rangle = -\frac{1}{4} - \ln 4 \simeq -1.63629$

Equation (5) is directly comparable with Drell-Yan and W, Z $p_\perp$ distributions [1] ($s_\perp \sim p^2_\perp$), which have the same leading funcitonal form. Indeed

$$\frac{1}{\sigma_0}\frac{E_3\, d\sigma^{DY}}{d^3P_3} \sim \frac{1}{K_\perp}\left[\ln\frac{s}{s_\perp} - \frac{3}{2}\right]$$

$$\frac{1}{\sigma_0}\frac{E_3\, d\sigma^{qq}}{d^3P_3} \sim \frac{1}{K_\perp}\left[\ln\frac{s}{s_\perp} + c(v)\right]$$

with

$$c(v) = -\frac{5}{4}\ln v + \frac{3}{4}\ln(I-v) - \frac{3}{4}\ln 4 \qquad \text{and}$$

$$< c(v) > = \ln 4 - \frac{1}{4} \cong -1.6362$$

The difference between the two subleading terms is very small, as indicated in Figs. 2, 3, where both qq and DY distributions are shown for CMS energies of 50 GeV (Fig. 2) and 100 GeV (Fig. 3). Relevant differences only come out when the jets ar(e produced at small CM angles. This behaviour is clearly shown in Fig. 4, where the cross section is plotted as a function of $k_\perp$ and v.

The above considerations neglect the role played by the subleading terms and the effect of a change of the scale in $\ln(s/k^2_\perp)$. It is clear that a complete evaluation of the distributions has to take into account all finite terms in the jet-jet cross section. Furthermore, for small transverse momentum values ($\Lambda < k^2_\perp < s$), perturbative αs expansion is not reliable and all order terms in ans $\ln s/s_\perp$, have to be summed for $m \leq 2n-1$ [5]. Indeed, for Drell-Yan processes, one has the impact parameter exponentiation

$$\frac{d\sigma}{dk_\perp} \sim \int db\, e^{-ibk_\perp}\, \overline{q}\,(x_1, \frac{1}{b^2})\, q\,(x_2, \frac{1}{b^2})\, e^{S(b,s)} J_0(bk_\perp)$$

where the Sudakov form factor is:

$$S(b, Q^2) = \int_0^{Q^2} \frac{d\,k^2_\perp}{k^2_\perp}\left(\ln\frac{Q^2}{k^2_\perp} - \frac{3}{2}\right)(J_0(bk_\perp) - 1)$$

This result has been also confirmed by W, Z transverse momentum measurements [6] at the CERN SppS collider. If this exponentiation holds also for jet production at small acollinearity angles, a very similar result is expected for the process qq → qqg.

From the above considerations it follows that a possible different behaviour could be observed only for small CMS angles.

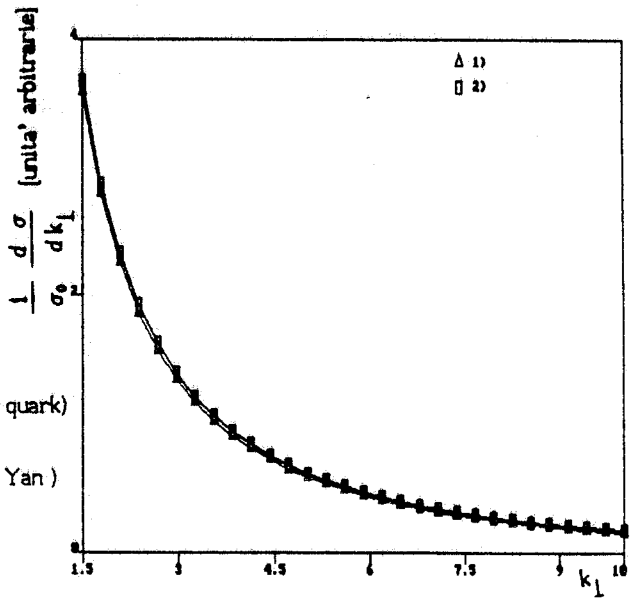

FIG. 2 -

$$\frac{1}{\sigma_0}\frac{d\sigma}{dk_\perp} \sim \frac{1}{k_\perp}\left\{ \ln\left[\frac{s}{k_\perp^2}\right] + c \right\}$$

1) $\sqrt{s}$ = 50 Gev , $c = -1/4 - \ln 4$ (quark - quark)

2) $\sqrt{s}$ = 50 Gev , $c = -3/2$ (Drell - Yan)

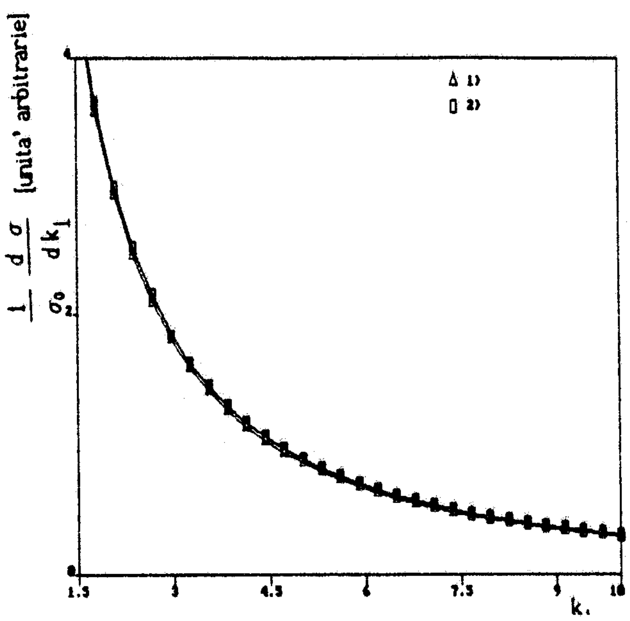

FIG. 3 -

$$\frac{1}{\sigma_0}\frac{d\sigma}{dk_\perp} \sim \frac{1}{k_\perp}\left\{ \ln\left[\frac{s}{k_\perp^2}\right] + c \right\}$$

1) $\sqrt{s}$ = 100 Gev , $c = -1/4 - \ln 4$ (quark - quark)

2) $\sqrt{s}$ = 100 Gev , $c = -3/2$ (Drell - Yan)

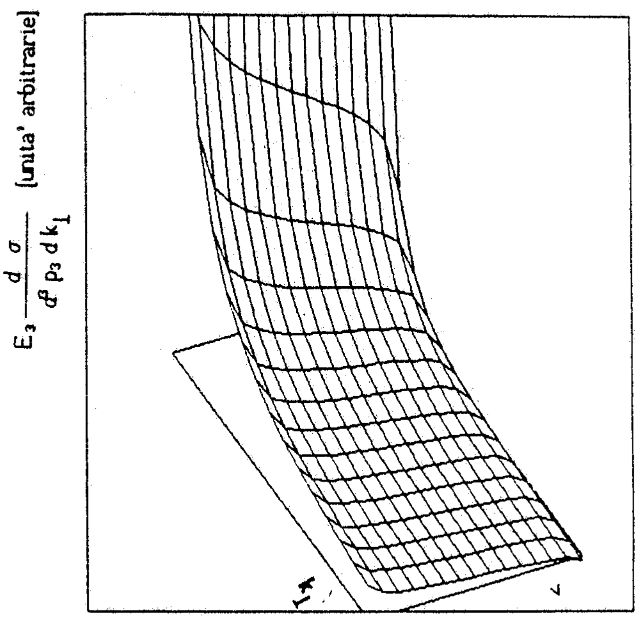

FIG. 4 -

$$\frac{E_3 \, d\sigma}{d^3p_3 \, dk_\perp} \sim \frac{1}{k_\perp}\left\{ \ln\left[\frac{s}{k_\perp^2}\right] + c(v) \right\}$$

$\sqrt{s}$ = 100 Gev

$$c(v) = -\frac{5}{4}\ln v + \frac{3}{4}\ln(1-v) - \frac{3}{4} - \ln 4$$

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