

ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-85/47

G. Pancheri, Y. Srivastava:
JETS IN MINIMUM BIAS PHYSICS

Estratto da:
Phys. Lett. 158B, p. 69(1985)

85/417

JETS IN MINIMUM BIAS PHYSICS**G. PANCHERI**¹*Physics Department, Harvard University, Cambridge, MA 02138, USA
and INFN, Laboratori Nazionali di Frascati, PO Box 13, 00044 Frascati, Italy*

and

Y. SRIVASTAVA*Physics Department, Northeastern University, Boston, MA 02115, USA*

Received 7 May 1985

We discuss and present phenomenological evidence to support the hypothesis that several new phenomena observed in low- p_t physics are due to the presence of low- x QCD jets in minimum bias physics. The phenomena we examine are KNO scaling violations, growth of $\langle p_t \rangle$ with multiplicity and rise of the non-diffractive part of the total cross section.

In this letter we discuss the hypothesis that many new phenomena observed in low- p_t physics at the collider have as a common origin the emergence of QCD jets, which can be a visible component of the cross section in minimum bias physics. In what follows, we shall first illustrate the motivation for this suggestion [1], then describe a simple model which shows how to relate KNO [2] scaling violations [3] to the multiplicity dependence of $\langle p_t \rangle$ for single-particle inclusive distributions [4,5]. We will comment upon the energy dependence of the jet cross section and compare it with the presently observed $\log^2 s$ growth of σ_{tot} [6,7]. To test the hypothesis that minimum bias physics is being affected in a "macroscopic" way by QCD jets, we suggest to study the transverse energy distribution of minimum bias events and try to separate the mini-jet contribution from the bulk of many-parton interactions. A calculation of transverse energy distribution which takes into account the structure of the underlying event is proposed.

Several anomalous effects have been observed in

low- p_t physics as the available energy increased from $\sqrt{s} = 30$ GeV to 540 GeV. Some of these effects were already observable at the ISR [8], but it was at the CERN collider that the data fully confirmed the previous trend. These effects include:

- (i) KNO scaling violations;
- (ii) rise of the non-single diffractive part of the total cross section;
- (iii) growth of $\langle p_t \rangle$ with multiplicity;
- (iv) rise of the central plateau [9] and the $\log^2 s$ type increase of the average multiplicity $\langle n \rangle$ [10].

Each of the phenomena described above has received a variety of interpretations^{†1}, ranging from the emergence of quark-gluon plasma [12] to increase of central region collisions [13–15]. The point must be made however that all of the above data show violations from the $\log s$ type behaviour which dominated low-energy physics through FNAL and ISR. The most appealing explanation of the above phenomena is that QCD parton-parton scattering is responsible for such "scaling violations" and we suggest that a full program be started to verify this

¹ Supported in part by NSF PHY-82-15249 and DOE DE-AC02-76ER03064.

^{†1} For a review of theoretical and phenomenological interpretations see ref. [11].

hypothesis both experimentally and phenomenologically. Experimentally, an attempt must be made to separate low- E_T jets from the minimum bias sample and study, for each separate sample, the multiplicity distribution as well as the p_t distribution as a function of the multiplicity. An effort in this direction has started and has been reported [16]. A sample of 40k minimum bias events was analyzed with the standard UA1 jet finding algorithm applied to the calorimeter information (jet axis: $|\eta| < 1.5$). The events were then divided into two data samples: the “jetty” events characterized by the presence of at least one jet of energy ≥ 5 GeV and the “non-jetty” events, to which the remaining events belonged.

Preliminary findings can be summarized as follows:

(i) a large fraction of minimum bias events exhibits *jet activity*, i.e. $\approx 12-15\%$ of the sample has at least one jet with $E_T \geq 5$ GeV;

(ii) the uncorrected unclusive cross section extrapolates nicely to the standard high- E_T data;

(iii) the two classes of events exhibit remarkable differences:

- different $\langle n_{\text{ch}} \rangle (|\eta| < 2.5)$: $\langle n \rangle_{\text{no-jets}} = 15$, $\langle n \rangle_{\text{jetty}} = 35$,
- different KNO distributions,
- for events with jet(s), $\langle p_t \rangle$ is independent of the multiplicity and larger than the one for the non-jetty events,
- the transverse energy distribution accompanying the two samples is different and is characterized by

$$\langle E_T \rangle_{\text{jetty}} \approx 2 \langle E_T \rangle_{\text{no-jets}} .$$

The KNO distribution of jetty events shows much less fluctuations than that of the rest of the sample, a situation close to that found in e^+e^- . Also, the average transverse momentum of inclusive pions is higher for the jetty events than for the rest of the sample and the separation into two samples has either eliminated altogether the multiplicity dependence (jetty events) or very much reduced it (non-jetty events).

The analysis, whose preliminary results have been summarized above, points to the validity of the hypothesis of a sizable jet contamination in minimum bias events. Next we shall try to describe a simple phenomenological model which incorporates our main idea, i.e. that first-order QCD corrections to the bulk of multiparton scattering are responsible for the phenomena described above.

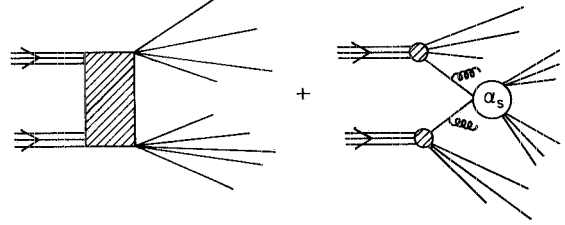


Fig. 1. Decomposition of the cross section into non-perturbative and perturbative (order α_s) component.

The simplest way to study the relationship between KNO scaling violations and the growth of $\langle p_t \rangle$ with multiplicity is to separate the cross section into two parts, as shown graphically in fig. 1. Correspondingly, one can write:

$$\sigma_{\text{tot}}(s) = \sigma_0(s) + \sigma_1(s) , \quad (1)$$

$$d\sigma(s)/dn = d\sigma_0(s)/dn + d\sigma_1(s)/dn , \quad (2)$$

$$d\sigma(s)/dn dp_T = (d\sigma_0/dn)P_0(p_T) + (d\sigma_1/dn)P_1(p_T) . \quad (3)$$

In eqs. (2) and (3), $d\sigma_i/dn$ represent the inclusive n -particle cross sections and $P_i(p_T)$ the normalized single-particle transverse momentum distribution in a given n -inclusive process.

In the above approximation we can say that low- p_t physics, for which KNO scaling is supposed to hold and for which the transverse momentum distribution does not show any multiplicity dependence, is the one described by the first term at the right-hand side of the above equations. The “new” effects can then be considered to arise from the second term. Previously we have discussed a model for the KNO function derived from soft QCD bremsstrahlung. In the following we shall show how this function can be approximated by the well-known gamma distribution. The latter is one of the limits of the negative binomial distribution, introduced by Carruthers and Shih [17] to describe, among other physical phenomena, the multiplicity distribution and used by the UA5 Collaboration to fit the KNO function in various rapidity intervals [18]. We shall then use the soft QCD bremsstrahlung model in conjunction with eqs. (2) and (3) to relate KNO scaling violations to the growth of $\langle p_t \rangle$ with multiplicity.

In the soft QCD bremsstrahlung model [19], the

shape of the KNO function is obtained from that of the soft QCD radiation emitted in the scattering of quarks and gluons. By summing all soft massless quanta emitted in the collision one obtains the following expression for the KNO function:

$$\Psi(n/\langle n \rangle) = \beta(s) \int \frac{dt}{2\pi} \exp[i\beta(s)zt - \langle h(t) \rangle], \quad (4)$$

with

$$\langle h(t) \rangle = \beta(s) \int_0^1 \frac{dk}{k} (1 - e^{-ikt}). \quad (5)$$

The parameter $\beta(s)$ which appears in the above expression is an effective soft gluon spectrum which incorporates the averaging process which takes place when the bremsstrahlung distribution is integrated between initial parton densities and final hadron fragmentation and the symbol $\langle \rangle$ indicates such average. We expect the effective parameter $\beta(s)$ to have a residual $\log \log s$ dependence as well as to be proportional to the color factors $c_F (= \frac{4}{3})$ or $c_A (= 3)$ according as to whether the emitting partons were quarks or gluons. A model which incorporates scaling violations of the type observed by the UA5 Collaboration has been constructed [20] by assuming that at low energy the dominant mechanism of particle production is through gluon radiation from quarks, and that only at high energy, i.e. past ISR and beyond, the contribution of gluon radiation from gluons starts becoming important. Although at present, this is strictly only a convenient model and nothing more, this subdivision may reflect the fact that for bremsstrahlung to take place in a significant way, the emitting gluons must be energetic and in a large amount. This means that one needs the fraction of energy x carried by the gluon to be small enough to correspond to a large density, but the energy of the emitting gluons to be large enough to allow the radiation of other gluons. This is so that α_s can be small enough for QCD effects to take place in lieu of particle production. In other words, we start by assuming that all gluons, soft and hard, are emitted by quarks. If the energy of the gluons is small enough that α_s is still in the confining phase, then these gluons will directly hadronize. Thus the relevant mechanism of particle production is, as we said, through gluons emitted by quarks. If on the other hand the gluons are energetic enough that α_s is in the

perturbative region, then these gluons can interact perturbatively with other gluons or quarks and thus can start bremsstrahlung on their own. From this latter bremsstrahlung process, characterized by the triple-gluon coupling, there arises a mechanism of particle production which becomes important only at high energy, when the density of hard, low- x , gluons becomes large. With this model in mind, one can then approximately interpret the two terms at the right-hand side of eq. (2) as one dominated by quark bremsstrahlung and the second dominated by gluon bremsstrahlung.

The required function is obtained as the sum of two components, each one of them characterized by a different average multiplicity $\langle n_i \rangle$ and a different effective spectrum β_i . Using eqs. (2) and (4) one has

$$\Psi(z, s) = \frac{\Phi_0(n/\langle n_0 \rangle) + r\Phi_1(n/\langle n_1 \rangle)}{1 + r} \quad (6)$$

with

$$r(s) = \sigma_1(s)/\sigma_0(s),$$

$$\Phi_i = \langle n \rangle [1/\sigma_i(s)] d\sigma_i(s)/dn = [\langle n \rangle / \langle n_i \rangle] \beta_i(s)$$

$$\times \int \frac{dt}{2\pi} \exp\left(i\beta_i(s) \frac{n}{\langle n_i \rangle} t - \beta_i \int_0^1 \frac{dk}{k} (1 - e^{-ikt})\right). \quad (7)$$

One also has

$$\langle n(s) \rangle = \frac{\langle n_0(s) \rangle + r(s)\langle n_1(s) \rangle}{1 + r(s)}.$$

The number of parameters can be reduced by using the known ratio of the color factors $c_A/c_F = \frac{9}{4}$. According to the interpretation we have put forward for the two terms in eq. (2), we would write

$$\beta_0(s)/\beta_1(s) \approx c_F/c_A \approx \langle n_0 \rangle / \langle n_1 \rangle. \quad (8)$$

By fixing $\beta_0(s) = 2.5$ at ISR (from the dispersion) and evolving to the collider energy, we find [20] that a good description of the UA5 data [3] can be obtained if the fraction of events produced through the triple-gluon coupling is as large as 12%.

From the point of view of doing numerical calculations, the bremsstrahlung distribution of eq. (4) is not very convenient. We then resort to approximate eq. (5) as follows

$$\langle h(t) \rangle \approx b \log(1 + it),$$

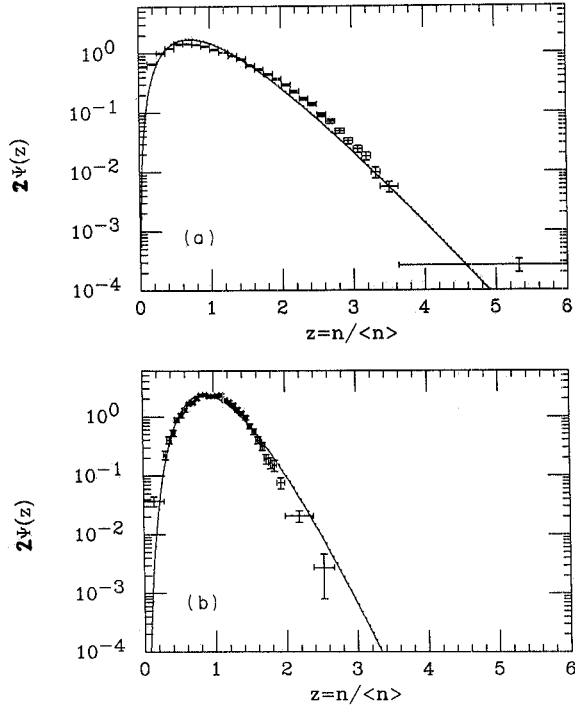


Fig. 2. (a) KNO distribution of minimum bias no-jets events (see text). UA1 1983 Data [16]; (b) KNO distribution of jet ($E_T > 5$ GeV) sample (see text). UA1 1983 Data [16]. Fits are from the two-component bremsstrahlung model described in the text.

which, after some simple manipulations, leads to

$$\Psi(z) \approx [b/\Gamma(b)] (bz)^{b-1} e^{-bz}. \quad (9)$$

A numerical comparison between eqs. (9) and (4) shows that the two distributions have the same shape for $b \approx 2\beta(s)$. From here on we shall use the gamma distribution obtained above, instead of the actual bremsstrahlung formula.

The UA1 data [16] for the multiplicity distribution cover a restricted rapidity interval, $|\eta| < 2.5$. For this set of data and in particular for the no-jet sample, we find that a good fit is provided by the gamma distribution with $b = 3.45$. Then, according to the bremsstrahlung model, the KNO distribution relative to the jet sample should be obtained by making the substitution

$$b_{\text{jetty}}/b_{\text{no-jets}} = \frac{9}{4} = \langle n_{\text{jetty}} \rangle / \langle n_{\text{no-jets}} \rangle.$$

In figs. 2a, b we show the fit to both the no-jet and

jet sample with the parameters thus determined. It appears that the simple ansatz of eq. (8) represents the data quite well. The same ansatz can then be used to describe the growth of $\langle p_T \rangle$ with multiplicity. From eqs. (2), (3) one has

$$\langle p_T \rangle = \frac{\langle p_T \rangle_0 \Phi_0(n/\langle n_0 \rangle) + r(s) \langle p_T \rangle_1 \Phi_1(n/\langle n_1 \rangle)}{\Phi_0(n/\langle n_0 \rangle) + r(s) \Phi_1(n/\langle n_1 \rangle)}.$$

Fixing the fraction of jetty events to be $r = 0.12$ and the average $\langle p_T \rangle$ from the data, $\langle p_T \rangle_{\text{n-jets}} = 385$ MeV/ c^2 and $\langle p_T \rangle_{\text{jets}} = 500$ MeV/ c^2 , one obtains the curve shown in fig. 3. Notice that to describe these data, one needs a value $\langle n_0 \rangle = 13$, which is somewhat lower than the one characterizing the multiplicity data. This can be justified, by noticing that the data [16] definitely indicate a residual jet contamination in the no-jet sample.

The fits can be improved if a three component model is used: such a model could include, in addition to the quark-quark and gluon-gluon scattering terms, a mixed term corresponding to quark-gluon scattering. The correspondence between the data and the phenomenological curve would improve, but the number of parameters would increase as well. It is then necessary at this point to start a direct comparison between the data and QCD prediction for hard parton-parton scattering. We shall report on such a calculation next.

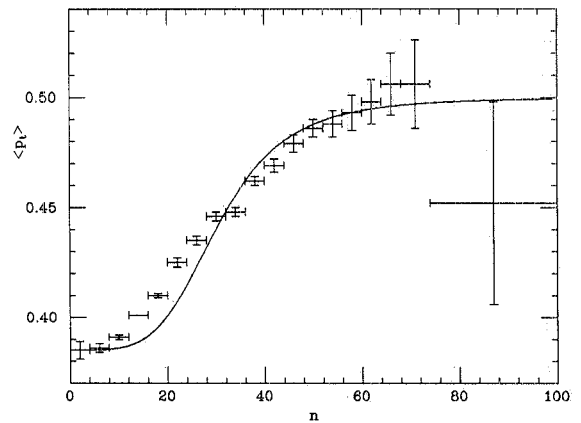


Fig. 3. UA1 1983 Data [16]. Growth of inclusive single pion $\langle p_T \rangle$ as a function of multiplicity. The continuous curve is based on the two-component model described in the text, using the same set of parameters as for the fits to the KNO function shown in figs. 2a, 2b.

In 1973, a suggestion [21] was made that the observed rise of the total cross section at the ISR could be attributed to hard parton-parton collisions. Subsequent calculations of the QCD cross section could neither confirm nor exclude this ansatz, the reason being that the jet cross section is singular at $t = 0$ and its integrated value depends upon the minimum p_t of the jets [22]. There is thus a theoretical uncertainty which reflects the transition from a many-body interaction type regime to the perturbative area. Recent results at the collider concerning the total cross section have confirmed the rise in a very dramatic way. We shall now evaluate the QCD contribution to the rise of the non-single-diffractive part of the total cross section and compare this value with that obtained by the preliminary UA1 analysis mentioned earlier. For such a comparison with theoretical expectations, we are interested in the overall QCD contribution when the minimum transverse momentum of the partons is 5 GeV. At the collider, such a transverse momentum corresponds to $x_T \approx 0.02$, for which value the dominant contribution is from gluon-gluon scattering. An order of magnitude estimate can easily be obtained by using the small angle limit for the various scattering amplitudes [22], i.e. we can write

$$\sigma^{\text{jet}} = \frac{\pi\alpha_s^2}{2s} \int_{\tau_0}^1 \frac{d\tau}{\tau^2} \mathcal{F}(\tau) \int_{-z_0}^{+z_0} dz^* |\mathcal{A}(z^*, \tau)|^2,$$

with

$$\mathcal{F}(\tau) = \int_{\tau}^1 \frac{dx}{x} F(x, Q^2) F(\tau/x, Q^2),$$

$$|\mathcal{A}(z^*, \tau)|^2 = \frac{9}{8} (3 + z^{*2})^3 / (1 - z^{*2})^2.$$

The limits of integration z_0 and τ_0 depend upon the minimum allowed value for the p_t of the partons. To wit, we have

$$2p_{t \text{ min}} = (s\tau_0)^{1/2} = [s\tau(1 - z_0^2)]^{1/2}.$$

Using UA1 parton densities [23], i.e.

$$F(x, Q^2) = G(x, Q^2) + \frac{4}{9} [Q(x, Q^2) + \bar{Q}(x, Q^2)]$$

$$= 6.2 e^{-9.5x}, \quad \text{at } Q^2 = 2000 \text{ GeV}^2,$$

$\alpha_s = 0.3$ and $p_{t \text{ min}} = 5 \text{ GeV}$, one obtains an integrated inelastic cross section of 3 mb, not very far from the preliminary UA1 results on the mini-jets

(10–15% of σ_{NSD}). Thus the experimental results are in reasonable agreement with QCD predictions on low- x jet production. Concerning the s -dependence of the cross section, it is worth noting that gluon-gluon scattering as given above, is characterized by a $\ln^2 s$ growth. This is similar to the well-known case of $\gamma\gamma$ scattering in e^+e^- processes.

To proceed with the QCD analysis of the mini-jet sample, one must study the p_t - and E_T -distribution of the sample. The calculation of the total scalar E_T comes from two sources: final-state fragmentation and initial-state bremsstrahlung accompanying the hard parton-parton scattering process, on the one hand, and bremsstrahlung from the rest of the event, on the other. In fact, unlike the p_t distribution of the jets, the variable scalar E_T directly reflects the hermeticity of the UA1 detector, and thus it measures not only the hard parton scattering process but also the debris which result from the breaking up of the proton when a hard parton is emitted. We refer to this as the underlying event (UE). The contribution of the underlying event to this type of measurement when jet production occurs, can be observed if one plots the transverse energy flow around the jet axis [16]. These figures indicate that away from the jet there is a constant "floor", which points to an isotropic distribution. One can see that the jet profile stand out less and less as the jet trigger is lowered, reflecting the experimental difficulty of detecting low- E_T jets. The effect of the underlying event can be incorporated by writing the following expression for the total scalar transverse energy measured in a jet event:

$$\frac{d\sigma}{dE_T} = \sum_{ij} dE P_{ij}^{\text{UE}}(E_T - E) \frac{d\sigma_{ij}^{\text{jet}}}{dE} \quad (10)$$

where P_{ij}^{UE} represents the normalized E_T distribution of the underlying event while $d\sigma_{ij}^{\text{jet}}/dE$ is the E_T distribution from bremsstrahlung and fragmentation accompanying the hard scattering. The subscript ij indicates the contribution from various types of partons and reflects the possibility that the underlying event be correspondingly different. A model for scalar E_T distribution at the collider has been advanced by Greco [24]. Here we examine only the case when a hard process has taken place. Referring to the hard process shown in fig. 1, the differential transverse energy cross section is written as

$$\begin{aligned} \frac{d\sigma^{\text{naive}}}{dE_T} &= \frac{\pi E_T}{2s^2} \sum_{ijkl} \frac{d\tau}{\tau^3} \int_{\tau}^1 \frac{dx}{x} F_i(x, Q^2) F_j(\tau/x, Q^2) \\ &\times [\alpha_s^2(E_T)/(1 - E_T^2/s\tau)^{1/2}] |\mathcal{A}(\tau, E_T^2)|_{ijkl}^2 \\ &= \sum_{ijkl} \int \frac{d\tau}{\tau} \mathcal{F}_{ij}(\tau, Q^2) \frac{d\sigma_{ijkl}^{\text{QCD}}}{dE_T}. \end{aligned} \quad (11)$$

To include initial state bremsstrahlung, eq. (11) is modified so as to obtain the following expression:

$$\begin{aligned} \frac{d\sigma_{ij}^{\text{jet}}}{dE_T} &= \sum_{kl} \int \frac{d\tau}{\tau} \mathcal{F}_{ij}(\tau, Q^2) \\ &\times \int_{E_0}^{E_T} dE' \mathcal{P}_{ij}(E_T - E') \frac{d\sigma_{ijkl}^{\text{QCD}}}{dE'}, \end{aligned} \quad (12)$$

with the soft bremsstrahlung distribution given by [25]

$$\mathcal{P}(\omega) = \frac{1}{\pi} \int_0^{\infty} dt \exp[-A(t, \omega_{\text{mx}})] B(t, \omega_{\text{mx}}, \omega), \quad (13)$$

with

$$\begin{aligned} A(t, \omega_{\text{mx}}) &= c_{ij} \frac{4}{\pi} \int_0^{\omega_{\text{mx}}} \frac{dk_{\perp}}{k_{\perp}} \alpha_s(k_{\perp}) \log(2\omega_{\text{mx}}/k_{\perp}) \\ &\times (1 - \cos k_{\perp} t), \end{aligned}$$

$$\begin{aligned} B(t, \omega_{\text{mx}}, \omega) &= \cos\left(\omega t - c_{ij} \frac{4}{\pi} \int_0^{\omega_{\text{mx}}} \frac{dk_{\perp}}{k_{\perp}} \alpha_s(k_{\perp})\right) \\ &\times \log(2\omega_{\text{mx}}/k_{\perp}) \sin(k_{\perp} t). \end{aligned}$$

A close inspection of eq. (13) shows that the bremsstrahlung distribution for the E_T variable is very close in form to that which we used for the soft gluon radiation and which led to the KNO function. This is an obvious consequence of the fact that in either cases, one is summing over all soft gluon emission diagrams, but with respect to different variables (energy versus *transverse* energy). As we discussed previously for the bremsstrahlung model, these bremsstrahlung distributions vary according as to the type of emitting partons involved. This is reflected in the coefficients c_{ij} which are defined as

$$\begin{aligned} c_{qq} &= c_F = \frac{4}{3}, \quad c_{gg} = c_A = 3, \\ c_{qg} &= \frac{1}{2}(c_F + c_A) = \frac{13}{6}. \end{aligned}$$

In the above expressions, the quantity ω_{mx} represents the maximum transverse momentum allowed to a single gluon emitted in the process. Energy-momentum conservation in eq. (12) suggests

$$m_{\text{mx}} = \sqrt{s\tau} - E'.$$

Finally, the bremsstrahlung corrected hard cross section of eq. (12) has to be folded with the E_T distribution of the underlying event. While the QCD calculation, although plagued by a number of uncertainties like gluon density and the value for Λ , is along a well trodden path, the question of what to choose for the underlying event is quite open. In principle, the underlying event is different for different parton types and it has a functional dependence upon the parton densities. In practice, these differences are smoothed down by the many integration processes taking place so that we can simply use an E_T distribution independent of the parton densities. This is the simplification adopted in writing eq. (10), which corresponds to using a distribution averaged over the densities. As for the specific form, one can take this function to be described by a bremsstrahlung type distribution, i.e. we write

$$\begin{aligned} P(E_T) &= (1/\langle E_T \rangle_{\text{UE}}) [b/\Gamma(b)] (bE_T/\langle E_T \rangle_{\text{UE}})^{b-1} \\ &\times \exp(-bE_T/\langle E_T \rangle_{\text{UE}}), \end{aligned}$$

with the choice of the two parameters b and $\langle E_T \rangle_{\text{UE}}$ which depend upon the type of partons involved in the hard scattering. Numerical calculations are in progress and will be presented elsewhere.

In summary, we have discussed the importance of low- x hard parton scattering in minimum bias events and pointed out its connection to both KNO scaling violations as well as to the observed growth of $\langle p_{\perp} \rangle$ with multiplicity in inclusive pion distributions. The contribution of these mini-jets to the total cross section has been calculated and a model for the transverse energy distribution characterizing any event accompanied by jets has been presented.

It is a pleasure to thank C. Rubbia, G. Ciapetti and G. Piano Mortari of the UA1 collaboration for many useful discussions.

References

- [1] M. Jacob, Proc. SLAC Topical Conf. (July 1983);
G. Pancheri and C. Rubbia, Nucl. Phys. A418 (1984) 117c;
G. Pancheri and Y.N. Srivastava, Proc. APS-DPF Meeting (Santa Fe, NM, October-November, 1984).
- [2] Z. Koba, H. Nielsen and P. Olesen, Nucl. Phys. B40 (1972) 317.
- [3] UA5 Collab., K. Alpgard et al., Phys. Lett. 131B (1983) 309;
UA5 Collab., G.J. Alner et al., Phys. Lett. 138B (1984) 304.
- [4] C.M.G. Lattes et al., Phys. Rep. 65 (1980) 151.
- [5] UA1 Collab., G. Arnison et al., Phys. Lett. 118B (1982) 167.
- [6] UA4 Collab., R. Battiston et al., Phys. Lett. 117B (1982) 126;
UA1 Collab., G. Arnison et al., Phys. Lett. 128B (1983) 336.
- [7] T. Ekelof, in: Proc. Intern. Europhysics Conf. on High energy physics (Brighton, July 1983).
- [8] W. Thome et al., Nucl. Phys. B129 (1977) 365;
ABCHW Collab., A. Breakstone et al., Phys. Rev. D30 (1984) 528.
- [9] UA5 Collab., K. Alpgard et al. Phys. Lett. 107B (1981) 310;
UA1 Collab., G. Arnison et al., Phys. Lett. 107B (1981) 320.
- [10] R.V. Gavai and H. Satz, Phys. Lett. 112B (1982) 413.
- [11] G. Pancheri, Hadronic multiplicity distributions and KNO scaling violations, Proc. XVth Intern. Symp. on multiparticle dynamics (Lund, Sweden, June 1984) eds. G. Gustafson and C. Peterson.
- [12] L. Van Hove, Phys. Lett. 118B (1982) 138.
- [13] S. Barshay, Phys. Lett. 127B (1983) 129.
- [14] A. Capella, A. Staar and J. Tran Thanh Van, Proc. Rencontre de Moriond (March 1984).
- [15] M. Biyajima, Phys. Lett. 137B (1984) 225; 139B (1984) 93.
- [16] G. Ciapetti, Proc. Vth Topical Workshop on Proton-Antiproton collider physics (St. Vincent, Aosta Valley, Italy, February-March 1985).
- [17] P. Carruthers and C.C. Shih, Phys. Lett. 127B (1984) 242.
- [18] G. Ekspong, Proc. Vth Topical Workshop on Proton-antiproton collider physics (St. Vincent, Aosta Valley, Italy, February-March 1985).
- [19] G. Pancheri and Y. Srivastava, Phys. Lett. 128B (1983) 433.
- [20] G. Pancheri, Y. Srivastava and M. Pallotta, Phys. Lett. 151B (1985) 453.
- [21] D. Cline, F. Halzen and J. Luthe, Phys. Rev. Lett. 31 (1973) 491.
- [22] F. Halzen, QCD collider physics, Proc. XVth Intern. Symp. on Multiparticle dynamics (Lund, Sweden, June 1984), eds. G. Gustafson and C. Peterson;
T. Gaissner and F. Halzen, Phys. Rev. Lett. 54 (1985) 1754.
- [23] G. Arnison, Phys. Lett. 136B (1984) 294.
- [24] M. Greco, Nucl. Phys. B250 (1985) 450.
- [25] F. Halzen, A.D. Martin, D.M. Scott and M.P. Tuite, Z. Phys. C14 (1982) 351.