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MULTIPLE INTERACTIONS IN HADRONIC EVENTS

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ABSTRACT

The event structure in hadronic collisions is very complex, and the task of understanding this structure is correspondingly difficult. It is often convenient to imagine the physics subdivided into a number of components, like hard central interactions, initial and final state radiation, structure functions, beam jet structure and fragmentation. In this note we discuss so-called beam jet or minimum bias physics, but in a way that links it with the hard interaction physics. Specifically, we argue that hadronic events contain a varying number of semihard interactions, with average interaction rate given by perturbative QCD. The variation between different events results from Poissonian statistics for each impact parameter separately. Multiple interactions are to be seen as a natural consequence of the composite nature of hadrons, an impact parameter dependence as a result of the extended nature of hadrons. Experimental support for and consequences of this picture are outlined, in particular for Collider data.

The studies reported here have been carried out in collaboration with Maria van Zijl, and are further described in Ref. 1.

The differential cross-section for a hard parton-parton interaction is given by perturbative QCD, as a convolution of the hard scattering matrix elements and the structure functions of the incoming hadrons. The integrated cross-section of all interactions with transverse momentum $p_T > p_{T\min}$, $\sigma_{\mathrm{hard}}(p_{T\min})$, is divergent for $p_{T\min} \to 0$. At present Collider energies, $\sigma_{\mathrm{hard}}(p_{T\min})$ becomes comparable with the total cross-section for $p_{T\min} \approx 1.5 - 2.0$ GeV. This need not lead to contradictions: $\sigma_{\mathrm{hard}}(p_{T\min})$ does not give the hadron-hadron cross-section but the parton-parton one. Each of the two incoming hadrons may be viewed as a beam of partons, with the possibility of several parton-parton interactions when the hadrons pass through each other, so that $\sigma_{\mathrm{hard}} > \sigma_{\mathrm{tot}}$ is perfectly allowed.

A comparison with Collider data indicates a significant probability for multiple interactions at 540 GeV [1]. Specifically, if there is at most one hard interaction per event, the predicted multiplicity distribution is much narrower than the UA5 one, and the experimentally observed forward-backward multiplicity correlations are almost absent. These conclusions are based on a detailed simulation of complete hadronic events, using the Lund Monte Carlo for Hadronic Processes, PYTHIA [2].

If, for any given hadron-hadron collision, several different parton interactions above $p_{T\min}$ are assumed to take place (essentially) independently of each other, one obtains a Poissonian multiplicity distribution in the number of interactions, with mean given by $\sigma_{\mathrm{hard}}(p_{T\min})/\sigma_{\mathrm{tot}}$, where σ_{tot} is the total inelastic, nondiffractive cross-section. With a varying number of interactions in an event, the multiplicity fluctuations are increased, and strong forward-backward multiplicity correlations are introduced. Results are sensitive to the choice of $p_{T\min}$ value, with a reasonable description of the multiplicity distribution obtained for $p_{T\min} \approx 1.6$ GeV. The presence of some regularization of the divergent parton-parton cross-section can be motivated by the fact that the incoming hadrons are colour singlets: a gluon of small p_T, and hence large transverse wavelength, will not resolve the individual colour charges inside the hadrons and therefore effectively decouple.

Up to this point, it has been assumed that the initial state of all hadron collisions is the same, whereas in fact each collision is also characterized by a varying impact parameter b (here b is to be thought of as a distance of closest approach, not as the Fourier transform of the momentum transfer). A small b value corresponds to a large overlap between the two colliding hadrons, and hence an enhanced probability for multiple interactions. A large b, on the other hand, corresponds to a grazing collision, with a large probability that no parton interactions at all take place. This effect will tend to broaden the minimum bias multiplicity distribution at higher energies. At present energies the change in the multiplicity distribution is less dramatic, since the mean number of interactions is small anyhow. Note, however, that events containing hard interactions are biased towards small impact parameters, and hence have a larger than average multiple interaction probability.

Different matter distributions inside the colliding hadrons have been studied, with the maybe unexpected result that data seem to indicate the need for large fluctuations in matter density. The latter may be parametrized e.g. by a double Gaussian, where half the matter is concentrated in a region a fifth the radius of the other half. The physical picture may be that of a hard core, or several cores corresponding to the three valence quarks.

The most direct evidence for this picture comes from the observation of four-jet events with the expected multiple interaction kinematics in the AFS detector [3], and at a rate consistent with the model above. The UA1 multiple minijet rate [4], Table 1, is by us also interpreted as a good signal, in that we can only understand the high rate of 3- and 4-jet events by invoking multiple interactions. On the other hand, the UA2 Collaboration has recently set a limit on the multiple interaction rate [5], at a level which is almost in contradiction with our model.

In addition to giving a fair description of minijet data, the model also reproduces the UA1 jet profile and, in particular, the energy flow away from the jet core (the "pedestal" effect) [6], Fig. 1. Up to roughly 10 GeV jet energy the underlying event activity increases, because events become more and more biased towards small impact parameter. Above that energy, with events already maximally biased, the small drop in underlying event activity is mainly related to the transition from $gg \rightarrow gg$ to $q\bar{q} \rightarrow q\bar{q}$ interactions.

Further comparisons with data may be found in Ref. 1.

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TABLE 1

Jet rate and other properties of jet and nojet events at 630 GeV, UA1 data [4,6] and different models. $<n_{ch}>$, $<p_T>$ and $<\Sigma E_T>$ are evaluated for the region $|\eta| < 2.5$. Various uncertainties are involved in the attempted simulation of UA1 detector effects, so the detailed results (as opposed to the general trends) should be taken with a grain of salt.

	UA1	no multiple interactions	impact parameter independent	matter distributed according to simple Gaussian	matter distributed according to double Gaussian
≥1 jet fraction (%)	14.8	17.0	14.3	13.7	12.6
1 jet fraction (%)	9.96	14.30	11.51	10.79	8.88
2 jet fraction (%)	3.45	2.45	2.45	2.70	2.67
3 jet fraction (%)	1.12	0.22	0.32	0.19	0.74
4 jet fraction (%)	0.22	0.01	0.04	0.05	0.25
5 jet fraction (%)	0.05	0.00	0.00	0.01	0.07
$<n_{ch}>_{nojet}$	15.06	14.3	11.9	13.5	12.9
$<n_{ch}>_{jet}$	32.21	23.7	26.6	30.9	34.2
$<p_T>_{nojet}$ (GeV)	0.407	0.415	0.398	0.395	0.392
$<p_T>_{jet}$ (GeV)	0.502	0.508	0.515	0.473	0.471
$<\Sigma E_T>_{nojet}$ (GeV)		13.5	11.0	12.4	12.5
$<\Sigma E_T>_{jet}$ (GeV)		26.2	29.3	32.1	38.2

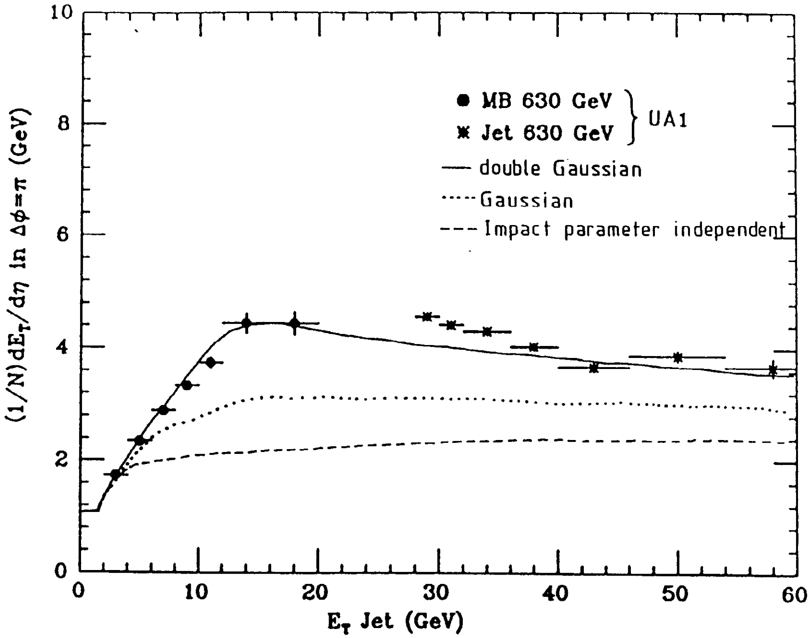

FIGURE 1

Average transverse energy $<dE_T/d\eta>$ in $1 < |\eta-\eta_{jet}| < 2$, $|\phi-\phi_{jet}| < 90^\circ$ as a function of the E_{Tjet} trigger. Data points UA1 at 630 GeV [6], dashed curve with impact parameter independent model, dotted with Gaussian and full with double Gaussian matter distribution.