MINIJETS AS A PROBE OF THE HADRONIC MANY-BODY PARTON STRUCTURE AT LHC

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The integrated inclusive cross section σ_S to produce minijets in high energy hadronic collisions is expressed in the perturbative QCD parton model by the convolution of the hadronic distributions with the partonic cross section:

$$\sigma_S = \int_{p_t^c} f_{eff}(x_A) f_{eff}(x_B) \hat{\sigma}(x_A, x_B) dx_A dx_B \tag{1}$$

In Eq.(1) f_{eff} is the effective parton distribution, namely the gluon plus 4/9 of the quark and anti-quark distributions, and it is a function of the momentum fraction x and of the scale p_t^c, which is the lower threshold to observe final state partons as minijets. A, B are labels to identify the two interacting hadrons. $\hat{\sigma}(x_A, x_B)$ is the parton-parton cross section integrated with the cut off p_t^c. $\hat{\sigma}$ is computed in perturbation theory and, although it may vary sizably depending on the theoretical approach and on the kinematical regime of the partonic interaction, its average value is typically rather small as compared to the hadronic inelastic cross section σ_{in}. At LHC energy, with $p_t^c = 8GeV$ and by representing the partonic interaction by means of the BFKL Pomeron exchange[1] one may obtain an average value $\langle\hat{\sigma}\rangle \simeq 2\times 10^{-2} mb$. On the other hand the corresponding value of σ_S is sizably larger than σ_{in} (in the actual case one may estimate $\sigma_{in} \simeq 100 mb$) and one may obtain values of σ_S almost one order of magnitude larger by using smaller but still sensible values of p_t^c. The reason of the large value of σ_S, which one obtains by using the expression in Eq.(1), is the large flux factor $f_{eff}(x_A) f_{eff}(x_B)$. The picture of the semihard interaction which corresponds to small values of $\langle\hat{\sigma}\rangle$ and to $\sigma_S > \sigma_{in}$ because of a large flux of partons is essentially a geometrical one: two colliding hadrons overlap in transverse space in a region of size of a few fm^2. Inside the overlap region several pairs of partons interact in much smaller regions of size $\simeq 10^{-2} \div 10^{-3} fm^2$. Being an inclusive quantity the cross section in Eq.(1) is proportional to the multiplicity of partonic interactions, giving rise in this way to values of σ_S larger with respect to σ_{in}.

One is obviously interested in identifying the different multiple scattering processes. The simplest case is double parton scattering. The corresponding inclusive cross section is written as[2]:

$$\sigma_D = \int_{p_t^c} D_2(x_A, x'_A; b) \hat{\sigma}(x_A, x_B) \hat{\sigma}(x'_A, x'_B) D_2(x_B, x'_B; b) d^2b\, dx_A dx_B dx'_A dx'_B \tag{2}$$

σ_D is a function of the product $\hat{\sigma}(x_A, x_B)\hat{\sigma}(x'_A, x'_B)$, since the two different partonic interactions are incoherent, being localized at different points in the transverse space. The non

perturbative input to the process is the two-body parton distribution $D_2(x, x'; b)$, which depends on the fractional momenta of the two partons which take part to the interaction and on their relative transverse distance b. The transverse distance b has to be the same for the two partons of hadron A and the two partons of hadron B in order to have the alinement which is needed for a double collision to occur. D_2 is a dimensional quantity and therefore the process introduces a non perturbative scale factor which is related to the hadron transverse size.
The simplest possibility to consider is the one where the dependence of D_2 on the different variables is factorized:

$$D_2(x, x'; b) = f_{eff}(x) f_{eff}(x') F(b) \tag{3}$$

and $F(b)$ is normalized to one. Multiparton distribution are then uncorrelated and D_2 does not contain further informations with respect to the one-body parton distribution (which is identified here with f_{eff}) apart form the dependence on b, whose origin is the dimensionality of D_2 and which gives rise to the scale factor σ_{eff}. One obtains in this case

$$\sigma_D = \sigma_S^2 / \sigma_{eff} \tag{4}$$

with

$$\sigma_{eff} = \int F^2(b) d^2 b \tag{5}$$

The search for double parton collisions has been part of the program of most high energy hadronic collider experiments in the last years[3]. Eq.(3) is the basic hypothesis underlying the signature of a double parton collision which one has been looking for in the experimental search. The expected characteristic feature of a double collision is in fact that it should produce a final state analogous to the one obtained by super-posing two single scattering processes. The most recent and most successful result of this search is due to CDF[4] which, looking at a final state with 3 minijets and one photon, shows evidence of a quite abundant rate of double parton collisions and gives the most accurate estimate of σ_{eff}:

$$\sigma_{eff} = 14.5 \pm 1.7^{+1.7}_{-2.3} mb$$

The main reason of interest in multiple parton collisions, besides the identification of the process itself, goes however beyond the approximation in Eq.(3). One is in fact interested in the actual measure of the multiparton distributions. The many-body parton distributions are indeed independent on the one-body parton distributions which are usually considered in hard processes, since they depend on the many-body parton correlations. In the present note one points out that one has a direct access to at least the lowest order correlations in the multiparton distribution by looking at the inclusive cross section to produce minijets in the forward direction.

A parton in the initial state with fractional momentum x may interact with the target giving rise to a minijet in the final state with rapidity y and transverse momentum k_t, with $x \simeq k_t e^y / \sqrt{s}$. At LHC and with $k_t = 10 GeV$ one obtains $x \simeq .1$ for $y = 5$ and

$x \simeq .29$ for $y = 6$. One may moreover estimate that a minijet with a rapidity larger than 5 units (and $k_t = 10GeV$) may be identified reasonably unambiguously as a initial state parton which has undergone a semihard interaction. To have access to the two-body parton distributions, which is the simplest case to be considered, one needs to identify two initial state partons belonging to the same hadron. A quantity which is useful to that purpose is the cross section to produce at least two minijets. Both single and double parton collision terms contribute to the cross section. One is interested in the double scattering term alone. To diminish the contribution of the single scattering term one may observe that, also if the partonic interactions has a non trivial structure, say it is described by the BFKL Pomeron exchange, two minijets produced in a single partonic interaction are back to back in the transverse plane when the rapidity distance between the two minijets goes to zero. For small values of the difference $y - y'$ of the rapidities of the two observed minijets the inclusive cross section is therefore dominated by the double scattering term contribution when the two minijets are aligned in the transverse space:

$$\frac{d\sigma}{dydy'd\phi}\Big|_{\phi=0} = \frac{d\sigma_S}{dydy'd\phi}\Big|_{\phi=0} + \frac{d\sigma_D}{dydy'd\phi}\Big|_{\phi=0} \underset{y\to y'}{\Longrightarrow} \frac{d\sigma_D}{dydy'd\phi}\Big|_{\phi=0} \tag{6}$$

Here ϕ is the azimuthal angle between the two observed minijets. To probe directly the hadron structure one has therefore to go at large rapidities and one has to look for minijets parallel in transverse space in order to reduce the contribution of the single scattering term.

As an illustrative example one may consider an explicit expression for the two-body parton distribution:

$$\begin{aligned} D_2(x,x';b) &= f(x,x')F(b) \\ f(x,x') &= f_{eff}(x)f_{eff}(x')\Big[1+\eta\times\exp\Big(\frac{x-x'}{\delta}\Big)^2\Big]\times N \end{aligned} \tag{7}$$

The normalization factor N is fixed by the requirement of giving a constant integrated value for the double scattering term when varying the correlation parameters η and δ.
In the case of large rapidity values y, y' and of a small difference $y - y'$, the factorization hypothesis in Eq.(7) leads to an expression for the inclusive cross section which exhibits a direct proportionality relation with the double parton distribution:

$$\begin{aligned} \frac{d\sigma}{dydy'd\phi}\Big|_{\phi=0} &\underset{y\to y'}{\Longrightarrow} \frac{d\sigma_D}{dydy'd\phi}\Big|_{\phi=0} \\ &\underset{y,y'\gg 1}{\Longrightarrow} \frac{x_A x'_A}{\sigma_{eff}2\pi} f(x_A,x'_A)\int_{p_t^c}\hat\sigma(x_A,x_B)\hat\sigma(x'_A,x'_B)f(x_B,x'_B)dx_B dx'_B \end{aligned} \tag{8}$$

here $x_A \simeq p_t^c e^y/\sqrt{s}$ and $x_B \simeq p_t^c e^{y'}/\sqrt{s}$.
The actual inclusive cross section which one obtains by using the two-body parton distribution in Eq.(7) is shown in fig.1 and in fig.2.
In fig.1 $\frac{d\sigma}{dydy'd\phi}|_{\phi=0}$ is plotted as a function of y at $y' = 6$, $p_t^c = 10GeV$ and LHC $p\bar p$ c.m. energy. The BFKL expression of the partonic cross section has been used to represent $\hat\sigma(x_A, x_B)$. The dotted line is the contribution of the single scattering term, which goes to

zero for $y \to y'$. The lower dashed line is the double scattering without correlation ($\eta = 0$). The higher dashed line is the total, single plus double at $\eta = 0$. The continuous lines show the same with correlation included. The actual case considered corresponds to a positive correlation, $\eta = 1/2$ and $\delta = .2$ in Eq.(7). The peak near $y = 6$ reflects directly the enhancement in the two-body parton distribution induced by the presence of the positive correlation term. The effect of the presence of the correlation term in the two-body parton distribution is obviously better seen in the ratio of the cross sections with and without correlation. The ratio is shown in fig.2 for positive and negative correlations, $\eta = +1/2$ continuous lines and $\eta = -1/2$ dashed lines. The two different curves for each value of η correspond to different choices of the width of the correlation term, $\delta = .1$ and $\delta = .2$.

One finally has to point out that the structure, which is expected in the inclusive cross sections $\left.\frac{d\sigma}{dy\,dy'\,d\phi}\right|_{\phi=0}$ at large values of y and y' as shown in fig.1 and in fig.2, is not going to appear in one goes at small rapidity values. At small values of y, y' also a strong correlation factor is going to produce a flat distribution in the difference $y - y'$. The reason is twofold. On one side in the central rapidity region the observed minijets can have different origins. They may be originated by the partonic interaction or they may be initial state partons. In this case the distributions of both interacting hadrons contribute and therefore there is no way to write a proportionality relation like Eq.(8). The second reason is kinematical. One expects that the correlation is a function of the difference $x - x'$ and finite values of fractional momenta correspond to large rapidities. All the central rapidity region on the contrary is mapped into to a small region of momentum fraction close to zero. There is no appreciable variation as a function of y in the central region if the correlation is a function of $x - x'$.

References

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Figure captions

Fig.1: $\frac{d\sigma}{dydy'd\phi}|_{\phi=0}$ plotted as a function of y at $y' = 6$ in a $p\bar{p}$ collision at LHC c.m. energy and with the lower cut off in transverse momentum for observing minijets $p_t^c = 10GeV$. The dotted line is the contribution of the single scattering term, the lower dashed line is the double scattering without correlation ($\eta = 0$), the higher dashed line is the total, single plus double at $\eta = 0$. The continuous lines show the same with correlation included. The actual case considered corresponds to a positive correlation, $\eta = 1/2$ and $\delta = .2$ in Eq.(7).

Fig.2: Ratio of the cross section $\frac{d\sigma}{dydy'd\phi}|_{\phi=0}$ with correlation and without correlation. The continuous lines correspond to a positive correlation (the actual value is $\eta = +1/2$), the dashed lines to a negative correlation ($\eta = -1/2$). The two curves for each value of η correspond to different choices of the width of the correlation term ($\delta = .1$ and $\delta = .2$).