Multi-parton interactions and underlying events from Tevatron to LHC

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2009-01/43

Abstract

We give a review of the Multiple Parton Interaction measurement plan at the LHC concentrating on the original Underlying Event and mini-jet feasibility studies. The Tevatron and SPS phenomenological legacies and the most popular Multiple Parton Interaction models are also briefly covered.

1 The QCD models and the Multiple Parton Interaction concept

In the years '80, the evidence for Multiple Parton Interaction (MPI) phenomena in the high-p_T phenomenology of hadron colliders [1] suggested the extension of the same perturbative picture to the soft regime, giving rise to the first implementation of the MPI processes in a QCD Monte Carlo model [2] which was very successfull in reproducing the UA5 charged multiplicity distributions [3].

On top of the general Minimum Bias (MB) observables these MPI models turn out to be particularly adequate to describe the Underlying Event (UE) physics at Tevatron [4], in particular they partly account for the pedestal effect (i.e. the enhancement of the Underlying Event activity with the energy scale of the interaction) as the effect of an increased probability of multiple partonic interactions in case a hard collision has taken place[1].

Examples of MPI models are implemented in the general purpose simulation programs PYTHIA [5], HERWIG/JIMMY [6] and SHERPA [7]. Other successful descriptions of UE and MB at hadron colliders are achieved by alternative approaches like PHOJET [8], which was designed to describe rapidity gaps and diffractive physics (relying on both perturbative QCD and Dual Parton Models). The purely phenomenological UE and MB description available in HERWIG [9] provides a very useful reference of a model not implementing multiple interactions. The most recent PYTHIA versions [10] adopt an optional alternative description of the colliding partons in terms of correlated multi-parton distribution functions of flavours, colors and longitudinal momenta.

† speaker

[1]A second important effect that can contribute to the pedestal effect is the increase in initial state radiation associated to the presence of a hard scattering

2 Progress in the study of the Underlying Events

CMS proposes [11] an original refinement to the standard CDF UE analysis in charged jets [4].

The strategy of the measurement is very much along the lines of the CDF one. Charged particle jets are defined using an iterative cone algorithm on charged particles only. The direction of the leading charged jet, which in most cases results from the hard scattering, is used to isolate different hadronic activity regions in the $\eta - \phi$ space and to study correlations in the azimuthal angle ϕ. The plane transverse to the jet direction is where the 2-to-2 hard scattering has the smallest influence and, therefore, where the UE contributions are easier to observe.

The ratios between (uncorrected) UE multiplicity (and momentum) density observables in the "transverse" region, for charged particles with $p_T > 0.9\,\mathrm{GeV/c}$ and with $p_T > 1.5$ GeV/c, are presented in Figure 1, for an integrated luminosity of 100 pb^{-1}. Ratios are shown here as obtained after track reconstruction, without applying additional reconstruction corrections; given the uniform performance of track reconstruction, the ratios presented here at detector level are similar to those at generator level. These ratios show a significant sensitivity to differences between the PYTHIA tunes DW [12], DWT [12] and S0 [13], thus providing a feasible and original investigation method.

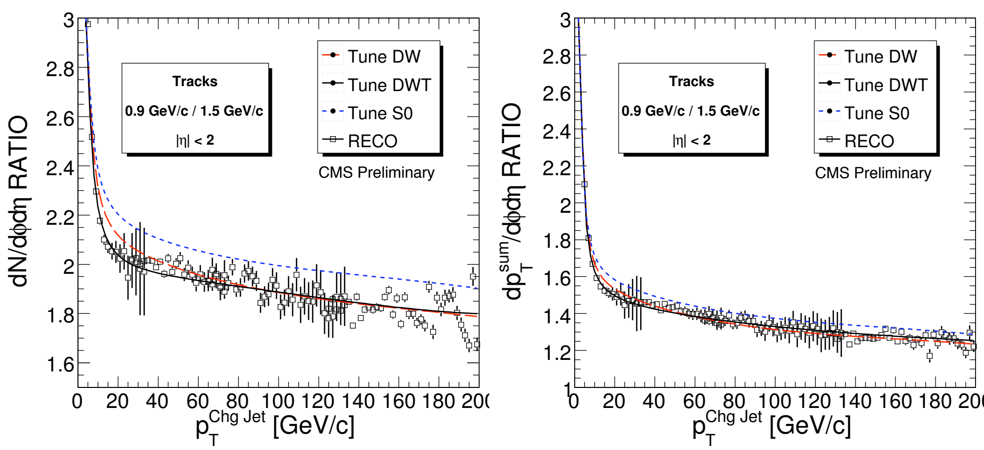

Fig. 1: Ratio of the UE event observables, computed with track transverse momenta $p_T > 1.5$ GeV/c and $p_T > 0.9\,\mathrm{GeV/c}$: densities $dN_{chg}/d\phi d\eta$ (*left*) and $dp_{T.sum}/d\phi d\eta$ (*right*), as a function of the leading charged jet P_T, in the transverse region, for an integrated luminosity of 100 pb^{-1} (uncorrected distributions). The input to the simulation is tune DWT.

3 The Direct Observation of Multiple Partonic Interactions

The final goal of the MPI study is to achieve a uniform and coherent description of MPI processes for both high- and the low-p_T regimes. Recent theoretical progress in this field has been reported [14]. The cross section for a double high-p_T scattering is parameterized as:

$$\sigma_D = \frac{m\sigma_A\sigma_B}{2\sigma_{eff}}$$

where A and B are 2 different hard scatters, m=1,2 for indistinguishable or distinguishable scatterings respectively and σ_{eff} contains the information about the spatial distribution of the partons [15] [16]. In this formalism $m\sigma_B/2\sigma_{eff}$ is the probability that a hard scatter B occurs given a process A and this does strongly depend on the geometrical distribution of the partons inside the interacting hadrons. The LHC experiments will perform this study along the lines of the CDF experiment [17], i.e. studying 3jet+γ topologies [18]. On top of that the extension to the study of same sign W production is also foreseen. Here we would like to propose an original study concentrating on the search for perturbative patterns in MB events looking for mini-jet pair production.

Let's introduce the formalism for the study of MPI in charged particle jet production. We re-write the inelastic cross section as the sum of one soft and one hard component.

$$\sigma_{inel} = \sigma_{soft} + \sigma_{hard} \tag{1}$$

with σ_{soft} the soft contribution to the inelastic cross section σ_{inel}, the two contributions σ_{soft} and σ_{hard} being defined through the cutoff in the momentum exchanged between partons, p_T^c. Notice that, differently from the case of the inclusive cross section (σ_S), which is divergent for $p_T^c \to 0$, both σ_{hard} and all exclusive contributions to σ_{hard}, with a given number of parton collisions, are finite in the infrared limit.

A simple relationship links the hard cross section to $\langle N \rangle$, i.e. the average number of partonic interactions:

$$\langle N \rangle \sigma_{hard} = \sigma_S \tag{2}$$

While the effective cross section σ_{eff} turns out to be linked to the dispersion $\langle N(N-1) \rangle$:

$$\frac{1}{2}\langle N(N-1) \rangle \sigma_{hard} = \sigma_D \tag{3}$$

These relationships can be used to express σ_{eff} in terms of the statistical quantities related to the multiplicity of partonic interactions:

$$\langle N(N-1) \rangle = \langle N \rangle^2 \frac{\sigma_{hard}}{\sigma_{eff}} \tag{4}$$

This last equation is particularly relevant from an experimental point of view. Indeed, even with a reduced detector acceptance and detection efficiency, one can always measure the physical observable $\sigma_{hard}/\sigma_{eff}$ that accounts for the probability enhancement of having additional partonic interactions above the scale p_T^c.

We propose to perform this measurement counting the charged particle jet pairs above a minimal scale p_T^c in MB events. Charged particle jets are reconstructed along the lines described in the previous section. First of all the charged jets are p_T-ordered. A pairing criteria is introduced which is based on the maximum difference in azimuth between the charged jets. The pairing algorithm starts from the leading charged jet and associates the first secondary jet in the hierarchy that respects the criteria. The highest p_T of the pair is assumed to be the scale of the corresponding partonic interaction. The paired charged jets are removed from the list and the remnant charged jets are re-processed following the same steps. One end-up with a list of paired charged jets. N is the number of charged pairs above the scale p_T^c.

Fig. 2 shows the difference in azimuth versus the p_T ratio between the first and the second charged jet in the event. Right plot shows the case when both MPI and radiation are switched off to study the sensitivity of the pairing algorithm in a clean hard process. Two cuts have been set to define the pairs: $\Delta\phi > 2.7$ and $p_T\ ratio > 0.25$.

Fig 3 reports σ_{eff} for two different pseudorapidity ranges $|\eta| < 5$ $(left)$ and $|\eta| < 2.4$ $(right)$. As expected σ_{eff} does not depend on the detector acceptance. In the same figures is shown the sensitivity of the pairing algorithm to radiation coming from initial and final state (red points refer to the no-radiation case).

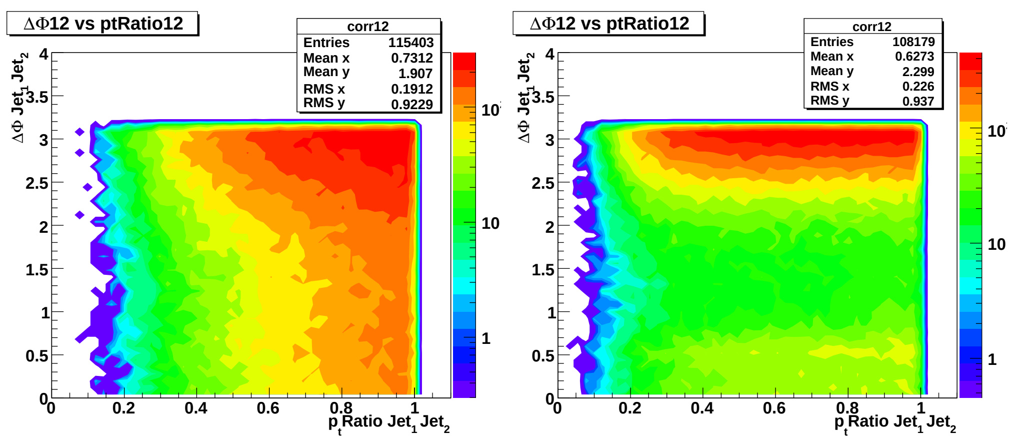

Fig. 2: Delta azimuth versus the p_T ratio between the first and the second charged jets in MB events at the LHC. Right plot is considered as a cross check for the pairing algorithm when Multiple Parton Interactions and radiation processes are switched off. PYTHIA Tune S0 is considered.

Notice that in the result of the simulation the effective cross section does not depend on the acceptance of the detector. One observes the same dependence of σ_{eff} on p_T^{min} also after switching off the radiation. It should be emphasized that this feature would not show up in the simplest model of multiparton interactions, where the distribution in the number of collisions, at fixed hadronic impact parameter, is a Poissonian. In this case one would in fact obtain that the effective cross section is constant not only as a function of the acceptance of the detector, but

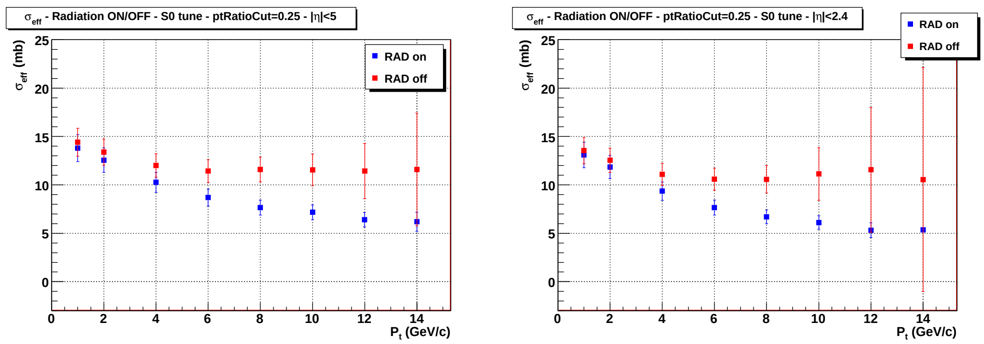

Fig. 3: Effective cross section in MB events at the LHC quoted for mini-jet processes in two different pseudorapidity ranges: $|\eta| < 5$ (left) and $|\eta| < 2.4$ (right) with and without radiation processes (blue and red). PYTHIA Tune S0 is considered.

also as a function of the cutoff. While the matter distribution in the transverse parton coordinates determines the dependence of the average number of multiparton collision on the impact parameter, a cutoff dependent effective cross section might be produced by a distribution in the number of collisions at fixed impact parameter different from a Poissonian. Observing a dependence of σ_{eff} on p_T^{min} one would hence provide evidence of further non trivial correlations effects between partons in the hadron structure. To trace back the origin of the dependence of σ_{eff} on p_T^{min}, observed in the simulation, one might notice that, in the simplest uncorrelated Poissonian model, the impact parameter is chosen accordingly with the value of the overlap of the matter distribution of the two hadrons and independently on value of the cutoff p_T^{min}. In Pythia, on the contrary, events are generated through a choice of the impact parameter which is increasingly biased towards smaller values at large p_T. The correlation induced in this way between the impact parameter of the hadronic collisions and the scale of the interaction has the result of decreasing the behavior of σ_{eff} at large p_T^{min}.

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