Multiple Interactions in Herwig++

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In this contribution we describe a new model of multiple partonic interactions that has been implemented in Herwig++. Tuning its two free parameters we find a good description of CDF underlying event data. We show extrapolations to the LHC and discuss intrinsic PDF uncertainties.

1 Introduction

With the advent of the Large Hadron Collider (LHC) in the near future it will become increasingly important to gain a detailed understanding of all sources of hadronic activity in a high energy scattering event. An important source of additional soft jets will be the presence of the underlying event. From the experimental point of view, the underlying event contains all activity in a hadronic collision that is not related to the signal particles from the hard process, e.g. leptons or missing transverse energy. The additional particles may result from the initial state radiation of additional gluons or from additional hard (or soft) scatters that occur during the same hadron–hadron collision. Jet measurements are particularly sensitive to the underlying event because, although a jet's energy is dominated by the primary hard parton that initiated it, jet algorithms inevitably gather together all other energy deposits in its vicinity, giving an important correction to its energy and internal structure.

In this note, based on Refs. [1, 2], we want to focus on the description of the hard component of the underlying event, which stems from additional hard scatters within the same proton. Not only does this model give us a simple unitarization of the hard cross section, it also allows to give a good description of the additional substructure of the underlying events. It turns out that most activity in the underlying event can be understood in terms of hard minijets. We therefore adopt this model, based on the model JIMMY [3, 4], for our new event generator Herwig++ [5]. Thus far, we do not consider a description beyond multiple hard interactions. An extension of our model towards softer interactions along the lines suggested in [6] is planned and will also allow us to describe minimum bias interactions. As a first step, the allowed parameter space for such models at LHC has been identified in Ref. [7].

2 Tevatron results

We have performed a tune of the model by calculating the total ^{2} against the data from Ref. [8]. For this analysis each event is partitioned into three parts, the towards, away and transverse regions. These regions are equal in size in space and classify where

This work was supported in part by the EU Marie Curie Research Training Network MCnet under contract MRTN-CT-2006-035606. Preprint: MCnet/08/04

particles are located in this space with respect to the hardest jet in the event. We compare our predictions to data for the average number of charged particles and for the scalar p_T sum in each of these regions.

The parameter space for this tune is two dimensional and consists of the p_T cutoff p_T^{min} and the inverse hadron radius squared, μ^2. In Fig. 1 we show the χ^2 contour for describing all six observables. We have used the MRST 2001 LO [9] PDFs built in to Herwig++ for this plot, and discuss the PDF-dependence in the next section. For these, and all subsequent plots, we use Herwig++ version 2.2.1, with all parameters at their default values except the two we are tuning and, in the next section, the PDF choice.

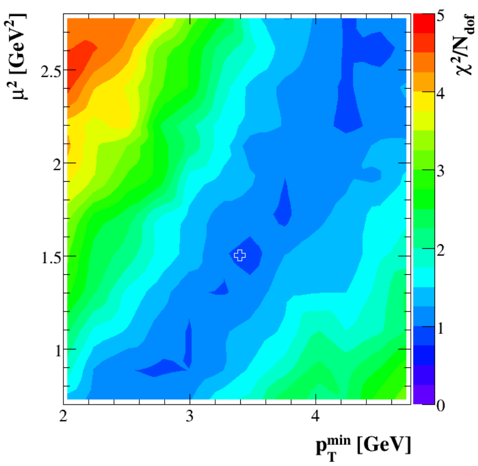

Figure 1: Contour plots for the χ^2 per degree of freedom of all considered observables.

The description of the Tevatron data is truly satisfactory for the entire range of considered values of p_T^{min}. For each point on the x-axis we can find a point on the y-axis to give a reasonable fit. Nevertheless an optimum can be found between 3 and 4 GeV. The strong and constant correlation between p_T^{min} and μ^2 is due to the fact that a smaller hadron radius will always balance against a larger p_T cutoff as far as the underlying event activity is concerned. As a default tune we use $p_T^{min} = 3.4$ GeV and $\mu^2 = 1.5$ GeV^2, which results in an overall χ^2/N_{dof} of 1.3.

2.1 PDF uncertainties

For precision studies it is important to quantify the extent to which hard scattering cross sections are uncertain due to uncertainties in the PDFs. As we have already mentioned, jet cross sections are particularly sensitive to the amount of underlying event activity, which introduces an additional dependence on the PDF in our model. In particular, it relies on the partonic scattering cross sections down to small transverse momenta, which probe momentum fractions as small as $x \approx 10^{-7}$ at the LHC and $x \approx 10^{-6}$ at the Tevatron, where the PDFs are only indirectly constrained by data. One will have measured the amount of underlying event activity at the LHC by the time precision measurements are being made, so one might think that the size of the underlying event correction will be known. However, in practice, jet cross section corrections depend significantly on rare fluctuations and correlations in the underlying event, so the correction must be represented by a model tuned to data, rather than by a single number measured from data. This will therefore entail in principle a retuning of the parameters of the underlying event model for each new PDF. This would make the quantification of PDF errors on a given jet cross section, or of extracting a new PDF set from jet data, much more complicated than a simple reweighting of the hard scattering cross section.

In this section we explore the extent to which this effect is important, by studying how the predictions with fixed parameters vary as one varies the PDF. To quantify the effect of the uncertainties within a given PDF set, we have used the error sets provided with the CTEQ6 family, and the formula

$$\Delta X = \frac{1}{2}\left(\sum_{i=1}^{N_p}\left(X(S_i^+) - X(S_i^-)\right)^2\right)^{1/2}$$

from Ref. [10]. Here, X is the observable of interest and $X(S_i^{\pm})$ are the predictions for X based on the PDF sets $S_i^{\pm}$ from the eigenvector basis.

We have studied the relative PDF uncertainty, i.e. $\Delta X/X(S_0)$, as a function of the number of points used for each $X(S_i^{\pm})$. We show the result in Fig. 2 for one bin corresponding to 35–36 GeV of the leading jet for the multiplicity observables. The final statistics are obtained from 20M fully generated events for each PDF set and the value on the x axis is the number of events falling within this bin. We see that with these 20M events, we have still not completely eliminated the statistical uncertainties. However, a departure from the straight line on a log–log plot that would be expected for pure statistical errors, $\propto 1/\sqrt{N}$, is clearly observed. We use this to extract the true PDF uncertainty, P, by fitting a curve of the form

$$f(N) = \sqrt{\frac{k^2}{N} + P^2}$$

to these data. In performing the fit we get a reliable result already for a moderate number of events. Using our fit, we have a clear indication that the PDF uncertainty is around 4% for the multiplicity and 4.5% for the p_T^{sum} in the transverse region.

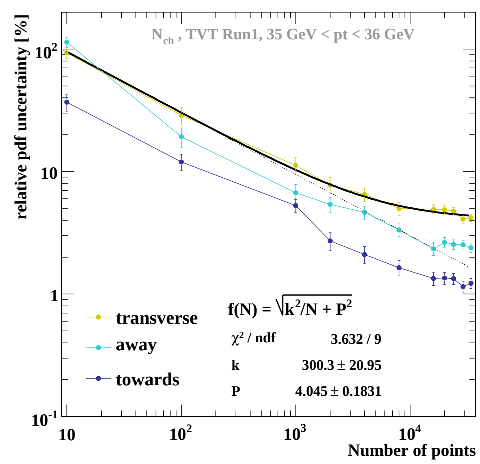

Figure 2: Relative PDF uncertainty in percent for the multiplicity observables. The different curves show the results for the three different regions defined in the experimental analysis. The PDFs used are CTEQ6M [10] and its corresponding error sets. The fit result shown as a solid line is for the transverse region. Also shown as a light dashed line is the fit assuming a purely statistical error.

It is noteworthy that the difference between the central values of the MRST and CTEQ PDF sets (shown in Ref. [2]) is larger than the uncertainty on each, at about 10%. Although, as we have already mentioned, the underlying event will have already been measured before making precision measurements or using jet cross sections to extract PDFs, a model tuned to that underlying event measurement will have to be used and its tuning will depend on the PDF set. We consider an uncertainty of 5–10% large enough to warrant further study in this direction.

3 LHC extrapolation

For calculating the LHC extrapolations we left the MPI parameters at their default values, i.e. the fit to Tevatron CDF data. In Ref. [11] a comparison of different predictions for an analysis modelled on the CDF one discussed earlier was presented. As a benchmark observable the charged particle multiplicity in the transverse region was used. All expectations reached a plateau in this observable for $p_T^{\mathrm{ljet}} > 10$ GeV. Our prediction for this observable also reached a roughly constant plateau within this region. The height of this plateau can be used for comparison. In Ref. [11] PYTHIA 6.214 [12] ATLAS tune reached a height of ≈ 6.5, PYTHIA 6.214 CDF Tune A of ≈ 5 and PHOJET 1.12 [13] of ≈ 3. Our model reaches a height of ≈ 5 and seems to be close to the PYTHIA 6.214 CDF tune, although our model parameters were kept constant at their values extracted from the fit to Tevatron data.

We have seen already in the previous section that our fit results in a flat valley of parameter points, which all give a very good description of the data. We will briefly estimate the spread of our LHC expectations, using only parameter sets from this valley. The range of predictions that we deduce will be the range that can be expected assuming no energy dependence on our main parameters. Therefore, early measurements could shed light on the potential energy dependence of the input parameters by simply comparing first data to these predictions. We extracted the average value of the two transverse observables for a given parameter set in the region 20 GeV $< p_T^{\mathrm{ljet}} <$ 30 GeV. We did that for the best fit points at three different values for p_T^{min}, namely 2 GeV, 3.4 GeV and 4.5 GeV.

LHC predictions	$\langle N_{\mathrm{chg}}\rangle^{\mathrm{transv}}$	$\langle p_T^{\mathrm{sum}}\rangle^{\mathrm{transv}}$ [GeV]
TVT best fit	5.1 ± 0.3	5.0 ± 0.5

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