Colour Reconnections and Top Physics

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Abstract
In simulations of hadron collisions the description of multiple parton interactions play an important role. These descriptions cannot be derived from first principles, but are described by models which have a priori unknown parameters. Tevatron data seem to indicate that the description of underlying events requires the presence of some non-trivial colour reconnection effects. Several parameter sets ('tunes') of such models, constrained by fits to Tevatron minimum-bias data, were used to determine the sensitivity of top physics results on the differences of underlying event models. A first attempt to isolate the genuine non-perturbative effects gave an estimate for the uncertainty on the top mass of the order of ± 0.5 GeV from these non-perturbative sources.

1 Introduction

In hadron-hadron collisions in principle more than a single a pair of partons may collide. Collisions beyond the hardest interaction are usually called the underlying event or multiple parton interactions. These additional interactions will add further soft or semi-hard particles to the final state. Because these multiple parton interaction cannot be computed perturbatively event generator use models to incorporate their effects.

Given the size of the proton and the large amount of colour charges present inside a proton it seems be possible that these additional soft or semi-hard interactions modify the colour structure of the hard interaction. LEP studies have shown that mass measurements can be especially sensitive to such colour reconnections. Thus to study the sensitivity of top physics to effects of colour-reconnection and of the underlying event in general as a first step their influence on measurements of the top mass measurements was studied.

The studies summarised in this article are described in detail in [1] and were updated in [2].

2 Colour Reconnection Models

The discussion of colour reconnection in hadron hadron collisions has to start with a dicussion of underlying event models.

Monte Carlo event generators like Pythia 6.4 [3] provide *models* to decribe the effects of the underlying event. Pythia provides two models: the 'old' model [4] treats the underlying event only after initial-state showering of the hard process is complete. It add additional back-to-back parton pairs and feeds these directly into the hadronisation together with the partons from the hard process. The 'new' model [5] interleaves the additional interactions with the initial-state parton shower off the hard process and allows the additional partons to radiate further. Various options for colour connections and colour reconnections between and inside the multiple parton interaction chains exist.

Like all others these models contain several parameters which are not know a priori and need to be optimised to describe data. Several tunes of Pythia parameters for the old model were obtained by CDF, e.g. Tune A, Tune DW, Tune BW, etc. [6]. A common feature of these tunes is that the parameters describing the probability of non-trivial colour connections between the additional-parton interactions and the hard scattering, `PARP(85)` and `PARP(86)`, are significantly enhanced. This is interpreted as a sign of actual colour reconnections happening in the underlying event.

The models described so far don't contain explicit colour reconnection. Moreover the colour reconnection models studies at LEP [7–10] focused exclusively on WW physics and thus were not directly applicable to hadron collitions. Thus simple models of colour reconnection for more general situation were introduced [11]. These base on an annealing-like algorithm, which minimises the string length and thereby the potential energy of the confinment field. Several variants of the algorithms were implemented in Pythia which vary in the way closed gluon loops are suppressed.

Because the colour reconnection may significanty modify the effects of the underlying event model, the parameters of the colour reconnection model *and* the underlying event model were retuned simultaneously. Tunes for the described colour reconnection models (named S0, S1 and S2) first appeared in Pythia v6.408 and were revised in v6.414 after a bug affecting the p_T ordered shower was fixed [12].

3 Toy Top Mass Measurements

The underlying event and colour reconnection effects may influence the results obtained in measurements of the hard process. At LEP, the W mass was especially sensitive to these effects, thus first the influence of the various models on measurements of the top quark mass at the Tevatron was studied.

Measurements of the top quark [13] consist of three main ingredients: First, a mass estimator based on the reconstructed physics objects, i.e., jets, lepton and missing transverse energy. Such an estimator uses a jet-parton assignment done by either choosing or weighting the various possibilities. Second, current measurements include an overall jet energy scale (JES) correction factor, which reduces the dominating systematic uncertainty by using the well known W mass as an additional constraint. And finally all methods are calibrated to simulation by correcting any offset between the reconstructed top mass and the nominal value of the simulation. It is especially in this last step that the different models may affect the outcome of the procedure.

A simplified toy mass measurement for semileptonic top pair events on generator level was implemented to study the colour reconnection and underlying event effects without dealing with detector simulation and reconstruction effects. This toy mass measurements uses events with exactly four jets from a cone algorithm [14, 15] with $\Delta R = 0.5$, $p_T > 15\,\mathrm{GeV}$. The jet-parton assignment is done by matching the reconstructed jets to the Monte Carlo truth by ΔR keeping only events with a unique assignment. The top mass is computed in each event from the three jets assigned to the hadronically decaying top quark.

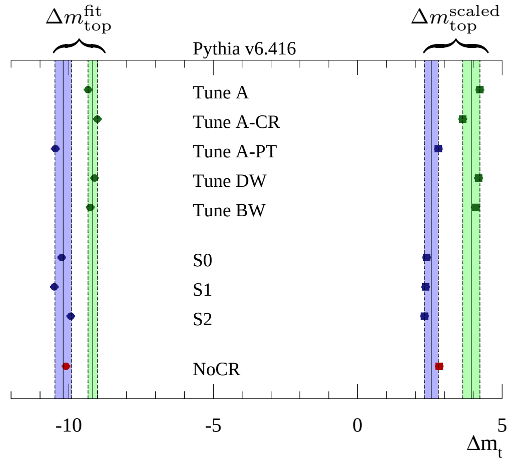

Fig. 1: Comparison of calibration offsets obtained for each model. The column on the left (dots) show the results obtained before JES rescaling, the right column (squares) after rescaling. The statistical precision due to the finite number of generated events is at the level of $\pm 0.15\,$GeV.

As mass estimator for the full dataset the peak of the the distribution of reconstructed top mass values is fitted with a Gaussian $m_{\rm top}^{\rm fit}$. At this stage jets aren't corrected for out-of-cone effects so this mass estimator is expected to give results that are lower than the nominal value in the simulation. In analogy to the JES correction factor this can be corrected for by using the W mass information. An event-by-event W mass is reconstructed again by fitting a Gaussian to the distribution of mass values reconstructed from the two jets assigned to the hadronic W decay. A scaled top mass estimator is then constructed as $m_{\rm top}^{\rm scaled} = s_{\rm JES}\, m_{\rm top}^{\rm fit}$ where the scale factor is $s_{\rm JES} = 80.4\,{\rm GeV}/m_W$, with m_W being the W mass obtains from the fit. Thus the simplified top mass measurements provide two results $m_{\rm top}^{\rm fit}$ and $m_{\rm top}^{\rm scaled}$, one before JES correction and one after. For both top mass estimates calibration curves were computed by scanning the nominal top mass and determining the described mass estimator for each of the nominal values. The calibration curves show an excellent linearity. As expected the offset for the un-scaled estimator ($m_{\rm top}^{\rm fit}$) is negative and after scaling the results ($m_{\rm top}^{\rm scaled}$) is closer to the nominal result.

In real top mass measurements such calibration curves are used to correct a possible bias in the mass estimation. Thus comparing the offsets obtained using the various underlying event model tunes yields and estimation of the possible size of the uncertainty due to modelling multiple parton interaction. The offsets evaluated at a nominal mass of $175\,$GeV for the various models are shown in Fig. 1 for both mass estimators. The models exhibit a spread of $\pm 0.8\,$GeV and $\pm 1.0\,$GeV for the $m_{\rm top}^{\rm fit}$ and $m_{\rm top}^{\rm scaled}$ estimators, respectively.

It is observed that the models fall into two classes: Those that utilise the 'old' virtuality-ordered parton shower of Pythia and those that utilise the 'new' p_T-ordered one (highlighted by bands in Fig. 1). The biggest component of the difference is *between* these two classes, indicating a perturbative nature of it. Within each class a spread of less than $\pm 0.5\,$GeV on the top mass remains, which is assigned to the non-perturbative differences between the various models, i.e. to modelling the underlying event and colour reconnection.

The observed model dependence repesents a significant source of uncertainty on the top mass measurement, which has only partially been taken into account by recent top mass results of the Tevatron [13]. It has to be noted, though, that real life measurements may have a different significance to the underlying event than the described toy analysis. Recently, improved tunes of final stated parameter were obtained for Pythia, which might help to reduce the perturbative portion of the observed uncertainty [16, 17].

4 Summary

The description of the underlying event in hadron hadron collisions seems to require colour reconnection, explicit or implicit, to describe Tevatron minimum bias data. A set of new universally applicable models with colour reconnection effects in hadronic final states were tuned to Tevatron data. With these new models and existing older models the influence of changing the underlying event and the colour reconnection model, which includes modifying the parton shower, was studied for a toy mass measurement. Of the spread of results of about ± 1.0 GeV on the reconstructed top mass, about 0.7 GeV can be attributed to perturbative effects and only less than 0.5 GeV to non-perturbative sources [1]. These results were obtained with Pythia v6.416 with tunes updated after fixing a bug in the p_T ordered shower.

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