Preliminary Tunes of PYTHIA to the Minimum Bias data from Hadron Collider Experiments

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Abstract— Current high energy event generation software combines Quantum Chromodynamics and phenomenological models which requires many free parameters. These relatively free parameters need to be tuned to describe the experimental data well. We present tuning of Monte Carlo event generator PYTHIA6 to the published Minimum Bias data from high energy proton-(anti)proton collider experiments, Large Hadron Collider and Tevatron. Five parameters of Multiple Parton Interactions model are selected and tuned using two different parton density functions. The results are compared to the tunes from ATLAS called AMBT1 tune. Studies have shown that the parameter values depend sensitively on the chosen hadronisation tuning and the chosen PDF set.

Index Terms— ATLAS, Collider experiment, Large Hadron Collider, Minimum Bias, Multiple Parton Interactions, PYTHIA6, Parton Density Functions, Tuning, Tevatron

1. INTRODUCTION

MONTE Carlo Event Generators (MCEGs) are computer programs that simulate high energy collision event i.e., generate simulated particles as produced in real collider experiments. The observed real event at any high energy collision experiment is usually too complex to be easily evaluated in real calculations. Furthermore, it contains non perturbative Quantum Chromodynamics (pQCD) contribution which requires a phenomenological description. Different software packages called event generators, like PYTHIA [1], HERWIG [2] and SHERPA [3], are used to give full description of an event. MCEGs try to simulate high energy collision events using phenomenological models. These models implemented assumptions and approximations so have many free parameters which need to be optimized to describe the real data. In this study we consider PYTHIA6 software which is a general purpose event generator and still a choice in Large Hadron Collider (LHC). Like other generators it has many phenomenological models like, Multiple Parton Interaction (MPI) model and models for Parton Shower (PS), Color Reconnection (CR), Initial and Final State Radiation (ISR and FSR) etc. These models have several free parameters needs to be tuned to describe the experimental data. The Multiple Parton Interaction (MPI) model implemented in PYTHIA allows several parton-parton scatterings to occur within a single hadron-hadron collision. The same model is intended to also describe the activity which underlies a hard process. In this article we select the five sensitive parameters of MPI model and tuned to published Minimum Bias data from Large Hadron Collider (LHC) experiments at 0.9 [4], [5] and 7 TeV and CDFII at Ecm = 1.96 TeV [6], [7]. To describe hadron collisions, it is inevitable to select a set of Parton Density Functions (PDF) that describes the momentum distribution of the partons within a hadron. PDFs are usually derived from fits to various data collected in deep inelastic scattering experiments. Traditionally, LO PDFs are supposed to be the best choice for use with LO Matrix Element (MEs) as implemented in most Monte Carlo programs. PYTHIA6 is a leading order MCEG and has CTEQ5L as a default leading order PDF set. However, another interesting view point has been put forward, which combines the advantages of both the LO and NLO PDFs. These are called MC-adapted PDFs (LO* and LO**) [8], [14].These two different Parton Density Functions are used in this study, CTEQ5L and MC adapted PDF set called MRSTMLO* especially designed for LO generator from LHAPDF [9]. The results are compared to the tunes from ATLAS collaboration called AMBT1 tune [10].

2 MODEL SELECTION

Monte Carlo event generators employ leading order perturbative Quantum Chromodynamics (pQCD) 2 →2 partonic cross-sections which are extended towards zero pT (transverse momentum) and interpreted as multiple parton-parton interactions. A regularisation parameter, Pt0, has to be introduced which is the main free parameter of the MPI model called (PARJ(82)) in PYTHIA software. A possible power law dependence of this parameter on centre of mass energy (E_{CM}) is described by parameter PARP(90). PYTHIA6 implemented a new interleaved MPI and ISR (Initial State Radiations) scenario, which can be chosen with so called switch MSTP(82)=5 for the matter overlap in the varying impact parameter model which is controlled by a single parameter, d = PARP(83). The ISR, FSR (Final State Radiation) and beam remnant parameters have been set as in 2. We have selected the colour annealing scenario in which the amount of colour reconnection in the final state is controlled by parameter PARP(78). In addition we utilize parameter PARP(77) which provides suppression of CR for fast moving strings. This parameter has been introduced in order to improve the description of charged particle pT distributions. The parton shower and hadronisation parameters have been determined independently from fits to e^+e^- → hadrons data collected at the Z0 pole by the ALEPH experiment [11]. Recently, a retuning has been performed for the pT-ordered parton shower. We tried two Parton Density Functions (PDF) sets for the proton, CTEQ5L and MRST LO*. The five parameters considered for simultaneous variation in this paper are listed in Table 1 and 2. Studies has shown that the parameter values depend sensitively on the chosen hadronisation tuning, on the PDF-set and on the model for diffractive processes. .

3 TUNING METHOD

The program package described in [11] and employed to tune the parameters is based on a linear and iterative method and allows the simultaneous use of distributions from different center-of-mass energies and of different phase spaces. Correlations exist between different parameters which require simultaneous variation of many parameters and can be done easily with linear tuning approach. It has been developed and extensively used within ALEPH and recently adapted for pp or $p\bar{p}$ reactions.

4 Selected Data

Different distributions from published MB data have been used to tune the selected parameters. MB processes or events, is an experimental definition depending on the trigger and the offline cuts to select events. These events are important as they have a large cross section of about 50mb at 7TeV. The physics of the minimum bias events is not easy to understand, yet they are important for understanding of high energy reactions in contemporary collider experiments.
The following differential distributions measured in Minimum Bias interactions are included:

- **CDF run II at 1.96 TeV** [6], [7]
  1. Phase space defined by Nch ≥0; pT > 0.4 GeV; │η│< 1, diffractive processes are neglected.
  2. Charged stable particle event multiplicity, Nch
  3. Transverse momentum, pT, extending from 0.4 to 9 GeV,
  4. Average pT(< pT >)as a function of Nch
  5. Σ Et (charged+neutral)

- **ATLAS at 0.9 TeV** [4], [5]
  6. Phase space defined by Nch ≥1; pT > 0.5GeV; │η│< 2.5.
  7. Charged stable particle event multiplicity, Nch;
  8. Transverse momentum, pT;
  9. Average transverse momentum, < pT > , as a function of Nch
  10. Central rapidity densities from ATLAS in a diffraction-reduced phase space Nch _ 6 7,

- **ALICE at 0.9 TeV and 7TeV**
  For INEL> 0; │η│< **1** events, without pT cut [12],

- **CMS at 7 TeV [5]**

1. For non-single diffractive events.
2. the charged particle differential pT distribution

To compare to LHC data, single and double diffractive processes are included in the Monte Carlo. Statistical and systematical uncertainties on the data points are added in quadrature.

Table 1.

Parameter	Default	Tune CTEQ5L CDF	LHC	Both	Description
PARP(82)	2.00	1.78	1.70	1.75	P⊥0 at reference Ecm=1.8TeV
PARP(83)	1.80	2.13	2.55	2.28	d, power in matter overlap
PARP(77)	0.00	1.65	1.65	1.65	Sup. Of CR for fast moving strings
PARP(78)	0.03	0.50	0.53	0.51	Color reconnection in final state
PARP(90)	0.16	0.25	0.24	0.26	P⊥0 evolution with Ecm

5 Results and Discussion

The results of our global PYTHIA fits are shown in Figures 1 and 2.
Tuned parameter values for two PDF sets are given in Table 1 and 2 along with default parameter values. The description of all the differential distributions using a single set of parameter values is reasonably good, though far from being perfect. For example, it turns out to be difficult to reproduce in detail the shape of the multiplicity distributions. The parameter PARP(77), suppression of color reconnections for fast moving strings, was introduced in the PYTHIA6 software to improve the transverse momentum description. Despite its usage the PYTHIA predictions are still systematically high in the higher pT region (pT > 3 GeV), possibly indicating a true limitation of the model.

Fitting either CDF run2 data alone or LHC data alone leads to slightly inconsistent results, see Table 1 and 2. The main effect is on the average particle multiplicity. For example, the fit to CDF data predicts 4.5 percent less particle density at _ = 0 than measured by ATLAS at 0.9 TeV 6 whereas the fit to LHC data exactly matches the measured value.
Table 1 and 2 shows that Pt0, the principal parameter of the MPI model, comes out close to 2 GeV. The availability of several center of mass energies, Ecm, values allows determination of the PARP(90) parameter. This parameter should be considered in the tuning when using data at different energies.

Table 2.

Parameter	Default	TuneMRSTMLO* CDF	LHC	Both	Description
PARP(82)	2.00	2.01	1.92	2.00	P⊥0 at reference Ecm=1.8TeV
PARP(83)	1.80	2.20	2.38	2.26	d, power in matter overlap
PARP(77)	0.00	1.65	1.65	1.65	Sup. Of CR for fast moving strings
PARP(78)	0.03	0.39	0.48	0.41	Color reconnection in final state
PARP(90)	0.16	0.25	0.23	0.22	P⊥0 evolution with Ecm

The two CR parameters are strongly and positively correlated and are thus not very well constrained. In only one case (CTEQ5L,both) PARP(77) is a fitted value. In all other cases it has been fixed to that value to avoid the uncertainty in the fit results. The total chi2 per degree of freedom values are 5.2 and 6.9 for our CTEQ5L fit and the AMBT1 tune7, respectively. Thus the fit quality is comparable. Our fit using MRST LO* gives a considerably higher value, namely 12.0. The charged particle densities at _ = 0 predicted by the PYTHIA fits agree quite well with ATLAS data. The densities which extend to very low.

6 Conclusion

The PYTHIA6 event generator has been tuned and is found to describe published Minimum Bias data reasonably well, though some systematic deviations and some discrepancy among fits to different data sets are observed. The new AMBT1 tune provides a comparable description. Results are preliminary. More LHC data distributions at 7 TeV and 13TeV and other event generators like HERWIG will be included in coming work.

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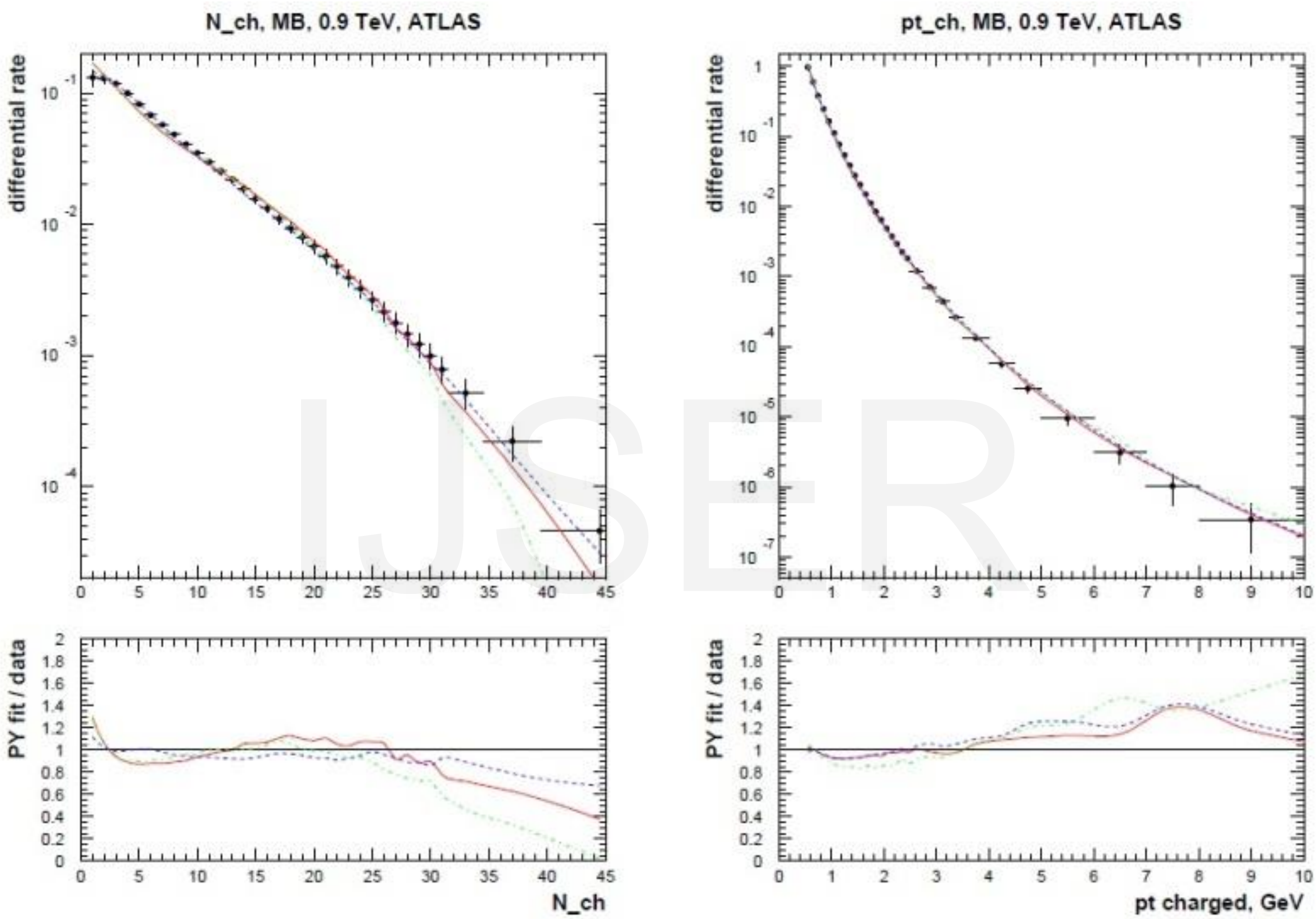

Figure 1: Selection of LHC data distributions together with PYTHIA fits. CTEQ5L (Solide Line) MRSTMLO* (Dashed dotted line) and AMBT1 (Dashed line)

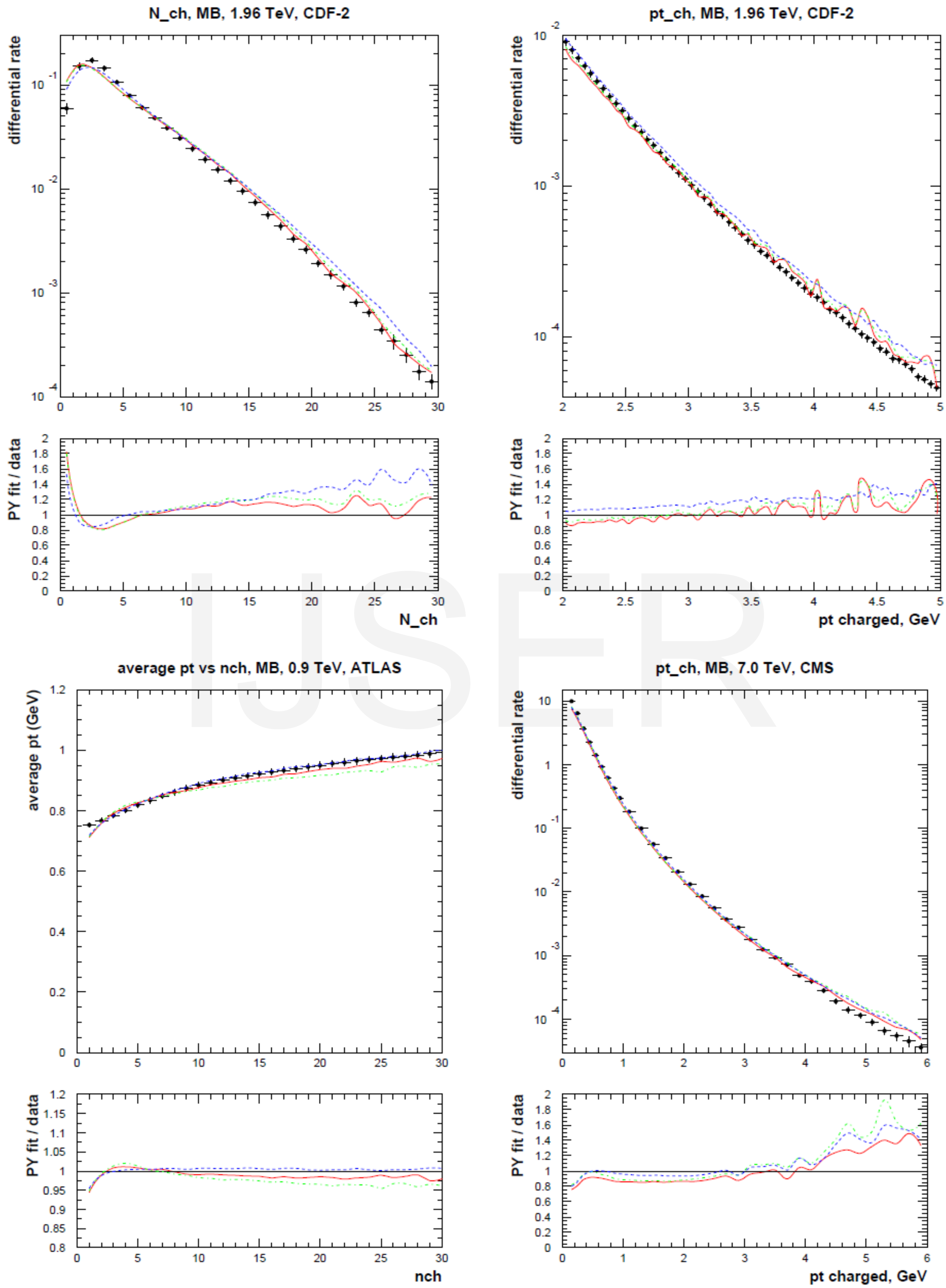

Figure 2: Selection of LHC data distributions together with PYTHIA fits. CTEQ5L (Solide Line) MRSTMLO* (Dashed dotted line) and AMBT1 (Dashed line)