TUNING Herwig 7 WITH LUND STRING MODEL*

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We present selected results of a systematic study of non-perturbative effects of the Lund string hadronization model from Pythia 8 on top of the angular ordered parton shower in the Herwig 7 Monte Carlo Event Generator. We adopt the Professor approach to tune a set of model parameters to lepton- and hadron-collision data and compare obtained results to the default Herwig 7 tune, the Autotunes tune as well as the Pythia 8 tune.

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1. Introduction

General-purpose Monte Carlo Event Generators such as Herwig [1–3], Pythia [4–6], and Sherpa [7–9] are computational tools that can exclusively simulate full particle collisions (*i.e.* describe all particles in the final state) in collider experiments such as the Large Hadron Collider (LHC). They are used to predict a wide range of observables for direct comparison with experimental data, which are important for precise tests of the Standard Model as well as the search for physics Beyond the Standard Model. With increased precision of higher-order perturbative calculations, accurate modelling by the event generators is most often limited by their non-perturbative components such as hadronization models [10–14]. These phenomenological models contain several free parameters that cannot be inferred from first principles and need to be tuned to better model the data. It also becomes crucial to study the systematics of non-perturbative phenomenological models to gain better control over uncertainties in predictions by Monte Carlo event generators. A recent attempt was made to tune the combination of

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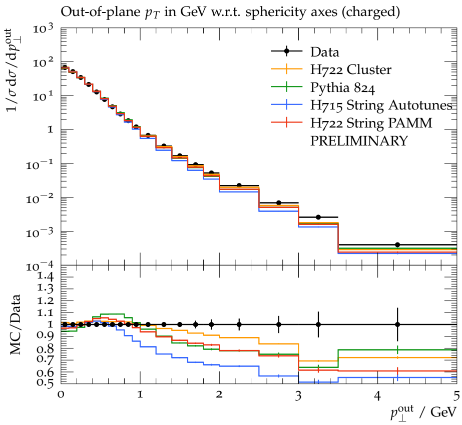
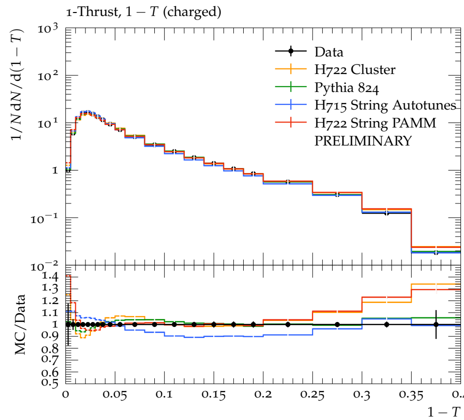
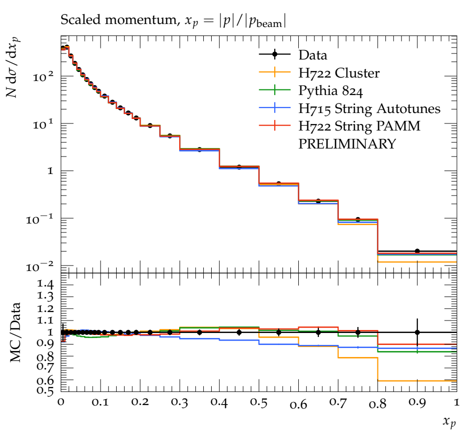
the angular-ordered parton shower in Herwig 7 and a version of Lund string hadronization model [15, 16] implemented in Pythia 8 to LEP data with a new approach called Autotunes [17]. However, the resultant tune shows worse performance to important observables, *e.g.* LEP event shapes [18–22], when compared to the previous tunes as shown in Fig. 1. Since the angular ordered parton shower and the Lund string hadronization model



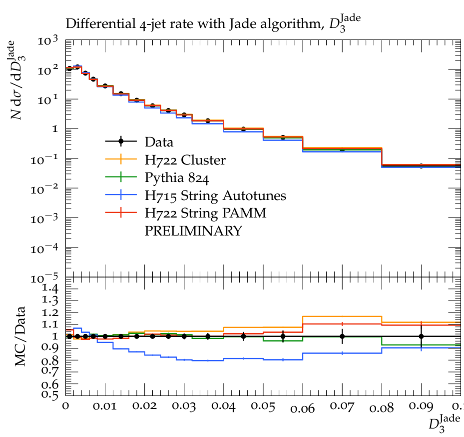
(a) Out-of-plane p_{T} distribution



(b) Thrust $(1-T)$ distribution



(c) Scaled momentum distribution x_p



(d) Differential 4-jet rate

Fig. 1. Observables measured by the ALEPH and DELPHI experiments at LEP alongside four Monte Carlo predictions: Herwig 7.2.2 with its default cluster hadronization model (yellow), Pythia 8.240 with its default string hadronization model (green), Herwig 7.1.5 with a string hadronization model tuned using Autotunes (blue), and Herwig 7.2.2 with a string hadronization model newly tuned by the PAMM team (red). Final plots will be published in [31].

separately perform well in other tunes of Herwig 7 [23–26], Pythia 6 [27], and Pythia 8 [28, 29], we would naively expect them to perform better together and thus investigate further by tuning with the Professor approach [27]. Such a combined setup was possible through the TheP8I interface [30] along with some modifications to include colour reconnections. The results of our tune are presented here with comparisons to the Herwig 7 default, Autotunes (run with Herwig 7.1.5), and Pythia 8 tunes.

2. Tuning strategy

We tune our setup of the Herwig angular ordered shower and the Lund string hadronization model systematically in a multi-stage approach similar to the Pythia 6 tune [27]. This starts with first fixing the fragmentation and flavour parameters using LEP data. The hadron collision-sensitive parameters are then tuned, with colour reconnection enabled, using LHC and Tevatron data at different energies. The Professor approach minimizes a Goodness-of-Fit (GoF) function, typically a χ^2 function, between the generator response and reference data [32, 33]. The generator response is parameterised as a polynomial in the parameters vector. The GoF measure is defined as

$$\chi^2(\boldsymbol{p}) = \sum_{\mathcal{O}} w_{\mathcal{O}} \sum_{b\in\mathcal{O}} \frac{\left(f^{(b)}(\boldsymbol{p}) - \mathcal{R}_b\right)^2}{\Delta_b^2}\,, \tag{1}$$

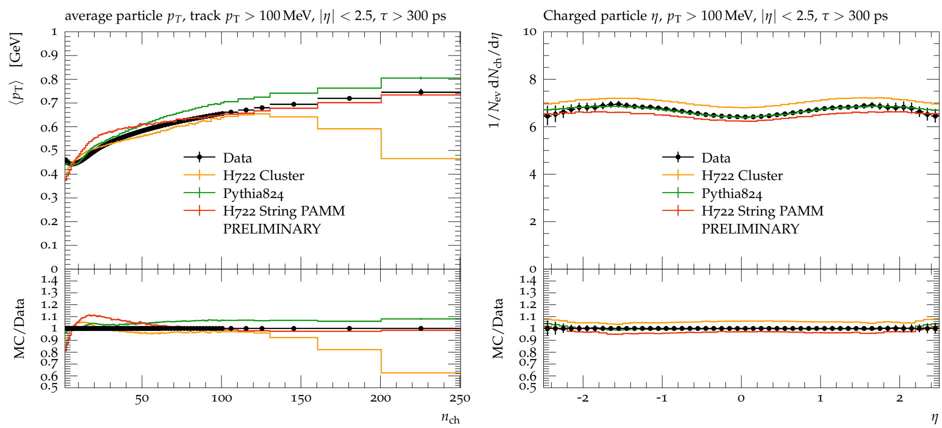
where $w_{\mathcal{O}}$ is the weight for each observable $\mathcal{O}$ which we adjust in our tune, $f^{(b)}(\boldsymbol{p})$ is the generator response function, $\mathcal{R}_b$ is the reference value for bin b and Δ_b is the total uncertainty for reference in bin b. Other GoF functions can also be used in newer versions of Professor.

2.1. Tuning to lepton data

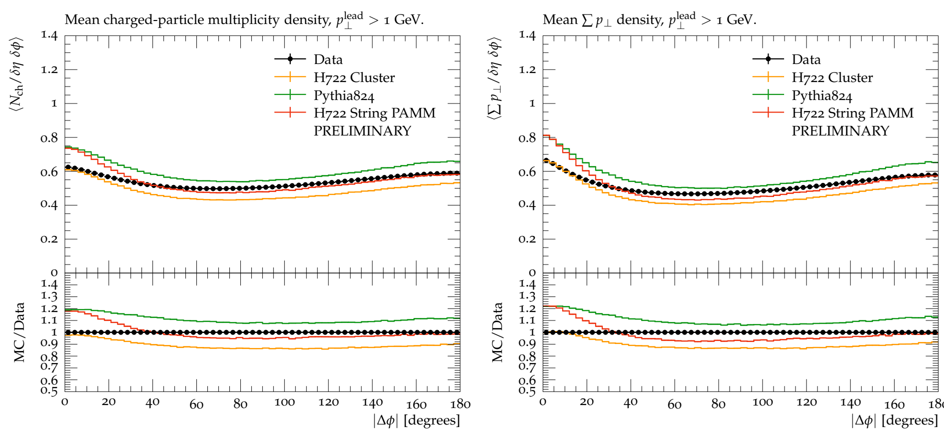
First, the setup is tuned to LEP data which provides a clean final-state environment sensitive only to the final-state parton shower and hadronization. To this end, two sets of parameters are tuned separately *i.e.* fragmentation and flavour parameters of the Lund string model as these sufficiently decouple. Event shapes and jet observable measurements are primarily used to tune the fragmentation parameters along with the shower cutoff, $p_{\mathrm{T}}^{\mathrm{min}}$, and strong coupling, α_{S}. The fragmentation parameters are then fixed and the flavour parameters are tuned to fix the flavour compositions. The observables used in the flavour tune are hadron multiplicities and their ratios with respect to the π^+ multiplicity, b-quark fragmentation function measured at DELPHI, and flavour-specific mean charged multiplicities measured at OPAL. The results for some of the observables [18, 19] are shown in Fig. 1.

2.2. Tuning to hadron data

Next, the setup is tuned to hadron-collision data at different energies. While the tuning procedure is done in a similar way to that of lepton data, modifications are made to the TheP8I interface to implement colour reconnections from Pythia 8 (the gluon-move model) [34, 35] prior to the hadronization process. This is a reshuffling of colours between favourable partons and is needed to partially fix the leading colour approximation of



(a) $\langle p_T \rangle$ *vs.* n_{ch} distribution (b) Pseudorapidity η distribution



(c) Mean charged particle multiplicity (d) Mean Σp_T distribution

Fig. 2. Track-based measurements from the ATLAS experiment at the LHC with $\sqrt{s} = 13$ TeV alongside three Monte Carlo predictions: Herwig 7.2.2 with its default cluster hadronization model (yellow), Pythia 8.240 with its default string hadronization model (green), and Herwig 7.2.2 with a string hadronization model newly tuned by the PAMM team (red). Final plots will be published in [31].

the parton shower which is evolved in the large-N_c limit of QCD. This also fixes the large difference observed in the average transverse momentum with increasing charged multiplicity as shown in Fig. 2 (a). The results of our tune are shown in Fig. 2 for some of the observables measured at ATLAS at 13 TeV [36, 37]. Our tune does better in most of these observable distributions compared to the default tune of Herwig 7 as well as the Pythia 8 tune.

3. Conclusions

In these proceedings, we have presented a combined setup of angular ordered parton shower in Herwig 7 and the Lund string hadronization model, tuned to both lepton- and hadron-collision data. We observe significant improvements in several important regions of observable phase space (shown in Fig. 1 and Fig. 2). The tune was done on Herwig 7.2 [2] and has been extended to Herwig 7.3 [1] which will be described in detail in forthcoming publication [31]. Thus, we obtain a new setup to study the systematics of non-perturbative effects for both e^+e^- and hadron collisions for different hadronization models in Herwig 7.

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