Charged particle multiplicities in $pp$ interactions at $\sqrt{s} = 0.9$ and 7 TeV in a diffractive limited phase space measured with the ATLAS detector at the LHC and a new PYTHIA6 tune

The ATLAS Collaboration

Abstract

This note presents charged particle minimum bias analysis results similar to those presented in ATLAS-CONF-2010-024, but where the phase space is restricted to $\geq 6$ charged particles in order to suppress the contribution due to diffraction processes. The data sample and corrections procedure remain the same except for the need for an additional correction to account for the cut at six or more charged particles. These samples with reduced diffractive contamination at both $\sqrt{s} = 0.9$ TeV and $\sqrt{s} = 7$ TeV are used to generate the new Monte Carlo tune AMBT1 (ATLAS Minimum Bias Tune 1) which better models the $p_T$ and charged multiplicity spectra. This is the first tuning of PYTHIA6 to LHC data at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV.
1 Introduction

The first ATLAS measurements of charged particle distributions at \( \sqrt{s} = 7 \) and 0.9 TeV were recently presented [1, 2]. Results were presented for charged particles within the kinematic phase space \( p_T > 500 \) MeV and \( |\eta| < 2.5 \), where \( p_T \) is the momentum in the direction transverse to the beam and \( \eta \) is the pseudorapidity. The following distributions were measured:

\[
\frac{1}{N_{\text{ev}}} \frac{dN_{\text{ch}}}{d\eta}, \quad \frac{1}{N_{\text{ev}}} \frac{1}{2\pi p_T} \frac{d^2N_{\text{ch}}}{d\eta dp_T}, \quad \frac{1}{N_{\text{ev}}} \frac{dN_{\text{ev}}}{dn_{\text{ch}}} \quad \text{and} \quad \langle p_T \rangle \text{ v.s. } n_{\text{ch}},
\]

where \( N_{\text{ev}} \) is the number of events with at least one charged particle inside the selected kinematic range, \( N_{\text{ch}} \) is the total number of charged particles in the data sample, \( n_{\text{ch}} \) is the number of charged particles in an event and \( \langle p_T \rangle \) is the average \( p_T \) for a given number of charged particles \(^1\).

It was found that while the agreement between data and the MC09c tune of \textsc{pythia} Monte Carlo\(^2\) [3] was good in most distributions in our paper, deviations were found in the \( p_T \) spectrum in the region \( p_T > 3 \) GeVand the \( n_{\text{ch}} \) distribution at \( n_{\text{ch}} > 40 \) at both energies. The tune of the non-diffractive models in \textsc{pythia} presented here attempts to improve this description.

\[\text{Figure 1: } n_{\text{ch}} \text{ distributions in ATLAS phase space at 900 GeV and 7 TeV split into non-diffractive (light), single-diffractive (dark) and double-diffractive (medium dark) processes according to \textsc{pythia}.}\]

As a reminder, the measurements presented here have no suppression of diffractive contributions due to the trigger selection. Diffractive contributions affect the charged particle multiplicity \( 1/N_{\text{ev}} \cdot dN_{\text{ev}}/dn_{\text{ch}} \) distribution, and the \( \frac{1}{N_{\text{ev}}} \cdot \frac{dN_{\text{ch}}}{d\eta} \) and \( \frac{1}{2\pi p_T} \cdot \frac{1}{N_{\text{ev}}} \cdot \frac{d^2N_{\text{ch}}}{d\eta dp_T} \) distributions through the normalisation factor, \( \frac{1}{N_{\text{ev}}} \). This makes it more difficult to use these data for tuning of the non-diffractive Monte Carlo (MC) models, as an accurate modelling of the diffractive component would be needed as well. In order to be able to tune at least the non-diffractive models, a minimum bias analysis with a restricted phase space is used.

Even though the exact cross section and differential distributions of diffractive events at LHC energies are not known, the diffractive contributions are expected predominantly at low \( n_{\text{ch}} \). As an example

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\(^1\)The factor \( 2\pi p_T \) in the \( p_T \) spectrum comes from the Lorentz invariant definition of the cross section in terms of \( d^3 p \). This can be expressed as \( dB \cdot dp \cdot d\eta \). Furthermore, we use the massless approximation: \( dy \approx d\eta \).

\(^2\)version 6.4.21
The strategy of not using any MC to correct for physics processes is maintained; we chose instead to limit the kinematic phase space of the analysis to a region where the contribution from charged particles produced by diffractive processes is small. For both energies, a cut at \(n_{\text{ch}} \geq 6\) was chosen. According to the PYTHIA model, this cut would essentially completely remove the diffractive component: see Figure 1. Even using the diffractive model as implemented in the PHOJET MC generator [4], which predicts diffractive contributions at higher \(n_{\text{ch}}\), the remaining influence of the diffractive component is smaller than the uncertainties.

ATLAS measured recently also the charged particle flow in different event regions relative to the leading track in the same minimum bias events at 900 GeV and 7 TeV [5]. Observables sensitive to the underlying event, i.e. the charged particle density and the charged transverse momentum sum are measured as function of the leading track transverse momentum. These data show a slightly higher underlying event activity than predicted by the different Monte Carlo models to which they are compared. Even though it’s the same data sample as the minimum bias analysis in [1, 2], the contribution from diffractive events is naturally suppressed in these distributions at high transverse momentum of the charged track. Therefore the regions with leading track \(p_T > 10\) GeV at \(\sqrt{s} = 7\) TeV and with leading track \(p_T > 5.5\) GeV at \(\sqrt{s} = 0.9\) TeV are included in the tune.

The note is structured as follows. Section 2 describes the new correction due to the new kinematic cut. Section 3 describes the tuning procedure used to obtain a new MC tune to this data and presents the list of new parameters. The comparisons between the data and the new MC tune is shown in Sec. 4.

### 2 Measurement in the Diffractive Limited Phase Space

For this measurement, the data sample, analysis strategy, corrections and binning are almost identical to the one used in [1] and [2], except for the addition of a cut on \(n_{\text{sel}} \geq 6\). The only difference in the correction procedure from track to particle level is the need for an additional term that takes into account this cut on both the number of tracks and number of particles. The results of this analysis are then used to make a new tune to PYTHIA 6. The total number of events considered for both energies and for both the \(n_{\text{sel}} \geq 1\) and \(n_{\text{sel}} \geq 6\) cuts are shown in Tab. 1.

<table>
<thead>
<tr>
<th>(\sqrt{s})</th>
<th>(N_{\text{events}}) for (n_{\text{sel}} \geq 1)</th>
<th>(N_{\text{events}}) for (n_{\text{sel}} \geq 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 TeV</td>
<td>326201</td>
<td>157896</td>
</tr>
<tr>
<td>7 TeV</td>
<td>369673</td>
<td>231665</td>
</tr>
</tbody>
</table>

Table 1: The table shows the number of selected events at 0.9 and 7 TeV with the \(n_{\text{sel}}\) cut at 1 and at 6.

The procedure for unfolding the distributions is, for the most part, the same as is described in [2]. In this unfolding process the number of events \(N_{\text{ev}}\) which is used to normalise the first three distributions mentioned in the introduction, is obtained by unfolding the multiplicity distribution of the whole spectrum and then applying the \(n_{\text{ch}}\) cut. The distribution is unfolded using a matrix which expresses the migration from the detector level track multiplicities \(n_{\text{sel}}\) to true particle multiplicities \(n_{\text{ch}}\). This procedure does not account for events which were not measured because none of the charged particles in the event were reconstructed as tracks (i.e. \(n_{\text{sel}}=0\) and \(n_{\text{ch}} \geq 1\)). This is corrected for by applying an ad-
Table 2: The table shows the mean \( \frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta} \) obtained for \( |\eta| < 0.2 \) at different LHC energies.

<table>
<thead>
<tr>
<th>( \sqrt{s} )</th>
<th>( 0.9 ) TeV</th>
<th>( 7 ) TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( 2.38 \pm 0.01 ) (stat.) ( \pm 0.08 ) (syst.)</td>
<td>( 3.64 \pm 0.01 ) (stat.) ( \pm 0.12 ) (syst.)</td>
</tr>
</tbody>
</table>

3 Monte Carlo Tuning

The charged particle distributions for events with \( n_{ch} \geq 6 \) are sensitive to multi-parton interactions (MPI) and colour reconnection (CR) of the hadronic final state [6] which are the parameters we tune. In addition, a recent ATLAS measurement of the charged particle flow in different event regions relative to the leading charged particle in minimum bias events at 900 GeV and 7 TeV [5] is used. Parameters related to final state radiation, hadronisation and fragmentation were not tuned as these are constrained by many LEP data and a separate analysis would be needed.
Starting from the MC09c [7] tune we attempt to adapt the model parameters to describe the new ATLAS data over the full range while still keeping consistency with the Tevatron results. The MC09c tune uses the MRST 2007LO* parton density function [8] and has been tuned to describe charged-hadron production and the underlying event in \( pp \) and \( p\bar{p} \) data at centre-of-mass energies between 630 GeV and 1.96 TeV.

The size of the MPI component in the \texttt{pythia} model is regulated by a simple cut-off parameter for the \( p_T \) of \( 2 \to 2 \) scattering processes. This cut-off parameter is fixed at a reference energy, which is generally taken as 1.8 TeV. The cut-off at this reference scale is called PARP(82). It is then rescaled for other centre-of-mass energies using a parameter PARP(90). The rescaling is done according to the following formula:

\[
p_T^{\text{min}} = \text{PARP}(82) \left( \frac{E}{1.8 \text{ TeV}} \right)^{\text{PARP}(90)}
\]

Both PARP(82) and PARP(90) were considered as tuning parameters.

The amount of scattering is described by the matter overlap distribution between the two protons, which regulates how many central, hard scattering and how many less central, softer scattering happen. This distribution is chosen to be a double Gaussian probability density function, where the parameter PARP(83) describes the fraction of matter in the inner Gaussian, and and the size of the inner Gaussian is given as a fraction PARP(84) of the main radius.

The colour annealing scenario of \texttt{pythia}, which is used here, minimises the total string length. As described in [3], the probability that a given string piece does not participate in the colour annealing is given by \((1 - \text{PARP}(78))^{n_{MI}}\), where \( n_{MI} \) is the number of multi-parton interactions. In addition to this parameter, an additional parameter PARP(77), is present in \texttt{pythia}, which is used to describe a suppression factor for the colour annealing of fast moving string pieces. The suppression factor is given by \(1/(1 + \text{PARP}(77)^2 \cdot p_{a\text{vg}}^2)\), where \( p_{a\text{vg}}^2 \) is a measure of the average squared momentum that hadrons produced by the string piece would have. Both of these parameters were considered for the tuning.

In an initial study, the cut-off parameter for initial state radiation (PARP(62)) and the cut-off for momentum smearing in primordial \( k_\perp \) (PARP(93)) were considered, but not found to have a significant influence on the distributions used for tuning. Therefore they were set to fixed values. In total, five parameters were tuned in one single step, as listed in Table 5.

The tune described in this note focuses on the new ATLAS data listed in Table 3 and includes the Tevatron data for the energy range of 630 GeV to 1800 GeV with a weight which is ten times lower than that of the ATLAS data. This allows a check of the consistency of the resulting tune with the Tevatron data while forcing the ATLAS data to drive the tuning process. Similar datasets were used for the MC09c tune, see Table 4 for a list of the distributions. The charged particle multiplicity shown in [9] was not included in the tune as a conflict between this measurement and the new ATLAS results could not be resolved.

For the data MC comparisons we used the \texttt{Rivet}^3 [10] package and for the tuning the \texttt{Professor}^4 [11] tool. The \texttt{Professor} tool is based on an interpolation of the generator response in each bin of the distributions considered for tuning. For this tune, we used a cubic interpolation of the generator response in each bin of the distributions considered for tuning. The interpolation is calculated based on singular value decomposition techniques and a simple \( \chi^2 \) variable based on the difference between the interpolation and the measured data is minimised for tuning using MINUIT [12].

The parameter values resulting from the tuning are listed in Table 5. It is interesting to note that the \( p_T^{\text{min}} \) cut-off for multi-parton interaction and its energy extrapolation remain the same as in MC09c. The new ATLAS data seem to indicate that the hadronic matter distribution and the colour reconnection parameters of the final state need to be adjusted to describe the shape of the \( N_{ch} \) and the \( p_T \) distributions.

\(^3\text{version 1.2.2a0}\)

\(^4\text{version 1.0.0a0}\)
Table 3: ATLAS observables and ranges of distributions used in the tuning.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Observable</th>
<th>Tuning range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS 0.9 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta} )</td>
<td>-2.5 – 2.5</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2N_{ch}}{d\eta dp_T} )</td>
<td>( \geq 5.0 )</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \frac{1}{N_{ev}} \cdot \frac{d^2N_{ch}}{d\eta d_{ch}} )</td>
<td>( \geq 20 )</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \langle p_T \rangle ) vs. ( n_{ch} )</td>
<td>( \geq 10 )</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, UE in minimum bias</td>
<td>( \frac{d^2N_{ch}}{d\eta dp_T} ) (towards)</td>
<td>( \geq 5.5 ) GeV</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, UE in minimum bias</td>
<td>( \frac{d^2N_{ch}}{d\eta dp_T} ) (transverse)</td>
<td>( \geq 5.5 ) GeV</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, UE in minimum bias</td>
<td>( \frac{d^2N_{ch}}{d\eta dp_T} ) (away)</td>
<td>( \geq 5.5 ) GeV</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, UE in minimum bias</td>
<td>( \frac{d\sum p_T}{d\eta dp_T} ) (towards)</td>
<td>( \geq 5.5 ) GeV</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, UE in minimum bias</td>
<td>( \frac{d\sum p_T}{d\eta dp_T} ) (transverse)</td>
<td>( \geq 5.5 ) GeV</td>
</tr>
<tr>
<td>ATLAS 0.9 TeV, UE in minimum bias</td>
<td>( \frac{d\sum p_T}{d\eta dp_T} ) (away)</td>
<td>( \geq 5.5 ) GeV</td>
</tr>
<tr>
<td>ATLAS 7 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta} )</td>
<td>-2.5 – 2.5</td>
</tr>
<tr>
<td>ATLAS 7 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2N_{ch}}{d\eta dp_T} )</td>
<td>( \geq 5.0 )</td>
</tr>
<tr>
<td>ATLAS 7 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \frac{1}{N_{ev}} \cdot \frac{d^2N_{ch}}{d\eta d_{ch}} )</td>
<td>( \geq 40 )</td>
</tr>
<tr>
<td>ATLAS 7 TeV, minimum bias, ( n_{ch} \geq 6 )</td>
<td>( \langle p_T \rangle ) vs. ( n_{ch} )</td>
<td>( \geq 10 )</td>
</tr>
<tr>
<td>ATLAS 7 TeV, UE in minimum bias</td>
<td>( \frac{d^2N_{ch}}{d\eta dp_T} ) (towards)</td>
<td>( \geq 10 ) GeV</td>
</tr>
<tr>
<td>ATLAS 7 TeV, UE in minimum bias</td>
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<td>( \frac{d\sum p_T}{d\eta dp_T} ) (away)</td>
<td>( \geq 10 ) GeV</td>
</tr>
</tbody>
</table>

4 Results

Figure 2 and 3 show the new optimised tune (AMBT1) compared to the ATLAS minimum bias data. In addition, the tunes MC09c [7], Perugia0 [18] and DW [19] are shown which were done without LHC data. All tunes are done for the new, \( p_T \)-ordered \( \text{PYTHIA} \) shower except for DW which uses the older \( q^2 \) ordering.

As a general trend, the pre-LHC tunes undershoot the \( \frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta} \) spectrum at high \( n_{ch} \) and predict a too hard \( \frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2N_{ch}}{d\eta dp_T} \) spectrum above \( p_T \sim 3 \) GeV at both energies, with the observations more pronounced at 7 TeV. With the new AMBT1 tune, these deviations are significantly decreased and a good description of the data is reached also in the regions of low \( n_{ch} \) and low \( p_T \) that were not included in the tune. However, the \( p_T \) spectrum in MC still overshoots the data above 4 GeV by about 40%. The fact that all tunes based on the new parton shower predict a too hard \( p_T \) spectrum may indicate that this is a genuine limitation of this shower. The older \( q^2 \)-ordered shower model seems to do better at reproducing this distribution.

An agreement of better than 5% is reached for the \( \frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta} \) and \( \langle p_T \rangle \) vs. \( n_{ch} \) distributions. The
$\frac{1}{N_{ch}} \cdot \frac{dN_{ch}}{d\eta}$ spectrum agrees within the systematic errors of the measurement. At 7 TeV, the different shape of Perugia0 in $\frac{1}{N_{ch}} \cdot \frac{dN_{ch}}{d\eta}$ is visible and the data are precise enough to discriminate between the tunes.

Figures 4 to 6 show the new tune compared to the ATLAS underlying event data [5]. The new tune significantly improves the description and an agreement within 10% is reached for all distributions. The tune predicts systematically fewer charged particles in the transverse region for events with a leading track $p_T < 6$ (10) GeV for 900 GeV (7 TeV). It should be noted that the model interpretation of the very low $p_T$ region in this data set might suffer from the presence of diffractive contributions. In addition, there might be significant effects from fragmentation and hadronisation at low $p_T$ which were not considered in this tune. The plateau at the high leading track $p_T$ is described, however the statistical uncertainties on the data in this region are relatively large.

Figure 7 shows the comparison of the same tunes to the Tevatron data used for tuning. The MC09c and AMBT1 tunes describe the data equally well. Only Perugia0 deviates about 5% more from the data, which is a remarkably small difference as Perugia0 did not include these data sets in the tune. The other Tevatron measurements included in the tune (see Table 4) have a similar or better agreement with the new tune than MC09c.

The energy scaling behaviour of the different tunes is shown in Figure 8, where the mean charged particle density at central pseudorapidity for events with at least six charged particles is shown for the new AMBT1 tune, the ATLAS MC09c tune and the Perugia0 tune along with the measured values shown in Table 2. The AMBT1 tune describes the ATLAS data well. The MC09c tune is a bit lower at both energies, but still in agreement with in the uncertainty. The Perugia0 tune is 10% lower than the central value at 7 TeV. The predictions of those tunes at 14 TeV also differ by about 10%.

5 Conclusions

We present a new tune, AMBT1, to the ATLAS minimum bias data at 900 GeV and 7 TeV in a diffraction limited phase space and to the ATLAS underlying event data with a leading track $p_T$ above 6 GeV. This tune describes most of the minimum bias data and the high $p_T$ plateau of the underlying event data within 10%. This is roughly the expected accuracy of leading order MCs and hence is a significant improvement over the other pre-LHC tunes. The remaining large deviation is in the $\frac{1}{N_{ch}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2N_{ch}}{d\eta dp_T}$ spectrum of the minimum bias events, where the predictions overshoot the data by up to 45% at $p_T > 6$ GeV. These deviations could not be removed for the models involved and will be investigated in the future.

References

[1] The ATLAS Collaboration, Charged-particle multiplicities in pp interactions at $\sqrt{s} = 7$ TeV measured with the ATLAS detector at the LHC, ATLAS-CONF-2010-024.


Observables

**CDF Run I underlying event in dijet events**[13] (leading jet analysis)
- $N_{ch}$ density vs leading jet $p_T$ (transverse), JET20
- $N_{ch}$ density vs leading jet $p_T$ (toward), JET20
- $N_{ch}$ density vs leading jet $p_T$ (away), JET20
- $\sum p_T$ density vs leading jet $p_T$ (transverse), JET20
- $\sum p_T$ density vs leading jet $p_T$ (toward), JET20
- $\sum p_T$ density vs leading jet $p_T$ (away), JET20
- $N_{ch}$ density vs leading jet $p_T$ (transverse), min bias
- $N_{ch}$ density vs leading jet $p_T$ (toward), min bias
- $N_{ch}$ density vs leading jet $p_T$ (away), min bias
- $\sum p_T$ density vs leading jet $p_T$ (transverse), min bias
- $\sum p_T$ density vs leading jet $p_T$ (toward), min bias
- $\sum p_T$ density vs leading jet $p_T$ (away), min bias

**CDF Run I underlying event in MIN/MAX-cones**[14] (“MIN-MAX” analysis)
- $\langle p_{max} \rangle$ vs. $E_{lead}^T$, $\sqrt{s} = 1800$ GeV
- $\langle p_{min} \rangle$ vs. $E_{lead}^T$, $\sqrt{s} = 1800$ GeV
- $\langle p_{diff} \rangle$ vs. $E_{lead}^T$, $\sqrt{s} = 1800$ GeV
- $\langle N_{max} \rangle$ vs. $E_{lead}^T$, $\sqrt{s} = 1800$ GeV
- $\langle N_{min} \rangle$ vs. $E_{lead}^T$, $\sqrt{s} = 1800$ GeV

**Swiss Cheese**
- $p_{sum}^T$ vs. $E_{lead}^T$ (2 jets), $\sqrt{s} = 1800$ GeV
- $p_{sum}^T$ vs. $E_{lead}^T$ (2 jets), $\sqrt{s} = 630$ GeV

**D0 Run II dijet angular correlations**[15]
- Dijet azimuthal angle, $p_{T}^{max} \in [75, 100]$ GeV
- Dijet azimuthal angle, $p_{T}^{max} \in [100, 130]$ GeV
- Dijet azimuthal angle, $p_{T}^{max} \in [130, 180]$ GeV
- Dijet azimuthal angle, $p_{T}^{max} > 180$ GeV

**CDF Run II minimum bias**[16]
- $\langle p_T \rangle$ of charged particles vs. $N_{ch}$, $\sqrt{s} = 1960$ GeV

**CDF Run I Z p_T**[17]
- $\frac{d\sigma}{dp_T^Z}$, $\sqrt{s} = 1800$ GeV

Table 4: Tevatron datasets used in the tuning. No specific cuts on the tuning ranges were made.
Table 5: Comparison of MC09c and resulting optimised parameters (AMBT1). The range for parameter variations in AMBT1 are also given.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Related model</th>
<th>MC09c value</th>
<th>scanning range</th>
<th>AMBT1 value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARP(62)</td>
<td>ISR cut-off</td>
<td>1.0</td>
<td>fixed</td>
<td>1.025</td>
</tr>
<tr>
<td>PARP(93)</td>
<td>Primordial kt</td>
<td>5.0</td>
<td>fixed</td>
<td>10.0</td>
</tr>
<tr>
<td>PARP(77)</td>
<td>CR suppression</td>
<td>0.0</td>
<td>0.25 – 1.15</td>
<td>1.016</td>
</tr>
<tr>
<td>PARP(78)</td>
<td>CR strength</td>
<td>0.224</td>
<td>0.2 – 0.6</td>
<td>0.538</td>
</tr>
<tr>
<td>PARP(83)</td>
<td>MPI (matter fraction in core)</td>
<td>0.8</td>
<td>fixed</td>
<td>0.356</td>
</tr>
<tr>
<td>PARP(84)</td>
<td>MPI (core of matter overlap)</td>
<td>0.7</td>
<td>0.0 – 1.0</td>
<td>0.651</td>
</tr>
<tr>
<td>PARP(82)</td>
<td>MPI ($p_T^{min}$)</td>
<td>2.31</td>
<td>2.1 – 2.5</td>
<td>2.292</td>
</tr>
<tr>
<td>PARP(90)</td>
<td>MPI (energy extrapolation)</td>
<td>0.2487</td>
<td>0.18 – 0.28</td>
<td>0.250</td>
</tr>
</tbody>
</table>
Figure 2: ATLAS minimum bias distributions at 0.9 TeV with \( n_{ch} \geq 6 \) compared to the new tune AMBT1 (red solid line), the MC09c tune (blue dashed line), Perugia0 tune (magenta dash-dotted line) and DW tune (brown long dashed line).
Figure 3: ATLAS minimum bias distributions at 7 TeV with $n_{ch} \geq 6$ compared to the new tune AMBT1 (red solid line), the MC09c tune (blue dashed line), Perugia0 tune (magenta dash-dotted line) and DW tune (brown long dashed line).
Figure 4: ATLAS underlying event analysis: charged particle density (top row) and charged particle transverse momentum sum density (bottom row) in the region transverse to the leading charged particle. The black data points show the data, the lines show predictions of the \textsc{pythia} Monte Carlo generator using the AMBT1 tune (red solid line), the MC09c tune (blue dashed line), Perugia0 tune (magenta dash-dotted line) and DW tune (brown long dashed line).
Figure 5: ATLAS underlying event analysis: charged particle density (top row) and charged particle transverse momentum sum density (bottom row) in the region towards to the leading track. The black data points show the data, the lines show predictions of the Pythia Monte Carlo generator using the AMBT1 tune (red solid line), the MC09c tune (blue dashed line), Perugia0 tune (magenta dash-dotted line) and DW tune (brown long dashed line).
Figure 6: ATLAS underlying event analysis: charged particle density (top row) and charged particle transverse momentum sum density (bottom row) in the region away from the leading charged particle. The black data points show the data, the lines show predictions of the \textsc{pythia} Monte Carlo generator using the AMBT1 tune (red solid line), the MC09c tune (blue dashed line), Perugia0 tune (magenta dash-dotted line) and DW tune (brown long dashed line).
Figure 7: Comparison of tunes to data for the transverse region of the leading jet analysis by CDF. The black data points show the CDF data [20]. The lines show the predictions for the AMBT1 tune (red solid line), the MC09c tune (blue dashed line) and the Perugia0 tune (magenta dash-dotted line) and DW tune (brown long dashed line).
Figure 8: Mean density of charged particles at central pseudorapidity as a function of the centre-of-mass energy. The black triangles show the data presented in this note, the lines the PYTHIA prediction using the AMBT1 tune (red solid line), the ATLAS MC09c tune (blue dashed line) and the Perugia0 tune (green finely dashed line).