Inclusive distributions in pp collisions at LHC energies compared with an adjusted DPMJET-III model with chain fusion

Fritz W. Bopp, Johannes Ranft

Siegen University, Siegen, Germany

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A DPMJET-III model (DPMJET-III-2011) with chain fusion adjusted to include energy-dependent parameters is used to calculate inclusive distributions in p–p collisions at LHC energies. Presented are charged hadron rapidity distributions, transverse momentum distributions, multiplicity distributions as well as multiplicities at mid-rapidity as function of the collision energy. For hadrons with strangeness we present rapidity distributions and transverse momentum distributions. With the considered merely energy-dependent adjustments the obtained agreement with the transversal Λ and Ξ distribution is not satisfactory.

1 Introduction

Monte Carlo codes based on the two–component Dual Parton Model involving soft and hard hadronic collisions producing chains of particles are available since almost 20 years [1]. The present codes are:

PHOJET	for h–h and γ–h collisions [2]
DPMJET-III	for h–h, h–A and A–A collisions [3]

In distinction to earlier versions DPMJET-III is based on PHOJET for its h–h collisions. In such collision it is therefore - except for a few additions like the fusion discussed below - identical to PHOJET. PHOJET describes the production of strings. For the string decay it calls PYTHIA version 6.412 [4]. For a few special cases we found it necessary to change the PYTHIA fragmentation. These were done in the DPMJET part, leaving the PYTHIA code itself untouched. As we use the full program we will refer below just to DPMJET-III. We now outline its main additions.

Comparing DPMJET-III to RHIC data it was learned that something had to be done to decrease the particle density. As the strings are quite dense in impact parameter space interactions between strings are plausible. The expected percolation was modeled as fusion of close hadronic chains implemented in DPMJET-III [5] in 2004. The obtained reduction was very essential for central collisions of heavy ions, but fusion also changes the particle production in very high energy p–p collisions when the number of contributing chains obtained by a Glauber or eikonal formalism gets sizable.

RHIC and Fermilab data also contain interesting information about particle-antiparticle ratios [6]. For the baryon/antibaryon distribution the string fusion mentioned above can be significant (i.e. two quark-antiquark strings can fuse to a diquark-antidiquark string yielding baryons and antibaryons).

In the diquark string decay used in PYTHIA one observes a dip in the ratio of the $\Omega/\bar{\Omega}$ spectra not seen in the data. A solution of the problem is to include a small contribution of diquark-diantiquark meson production in the first rank so that Ω can appear in the second rank. The idea is that such tetra-quark mesons are always produced but decay too fast to be identified in mass plots.

The LHC experiments did compare DPMJET-III to particle production at LHC–energies, see [7], [8] and [9]. There were some successful predictions of DPMJET. However, LHC experiments found that around 7 TeV the multiplicity rises faster with energy than predicted by DPMJET-III.

In order to make the program usable for ongoing data analyses at LHC energies we adjusted the program to improve the agreement with available experimental results. We allowed for an energy-dependence of string decay parameters. No differentiation between softer and harder strings was attempted. The new results of this modified version will be reported in section 3 and 4.

2 Modifications of DPMJET-III needed for LHC energies

There are essentially three additional modifications of DPMJET-III implemented in order to get better agreement with LHC data on particle production.

(1) The first modification is connected to a problem with collision scaling known since 2004 [10]. DPMJET-III uses an eikonal formalism to determine the size of various multiple scattering contributions $P_{n,\{\alpha_i^f\},\{\alpha_i^b\}}$ where n is the number of chains and $\alpha_i^{f/b}$ is the Regge intercept depending on the diquark, valence quark or sea quark nature of the forward/backward parton of i-th chain. Let us consider the forward direction. For each such configuration the attributed energy fractions $\{x_i\}$ to these partons are then chosen with a factorizing structure function of the form:

$$P_{n,\{\alpha_i\}} \int \prod_i^n x_i^{\alpha_i - 1} \delta(1 - \sum_j^n x_j)$$

in which the energy available for a scattering process depends on the remainder. There are two kinds of chains in DPMJET: Hard chains produced by hard collisions of partons from the colliding hadrons (typically large $p_\perp$) and soft chains representing soft hadron production in the collisions. In the factorizing formalism soft processes affect the energy sampled in hard processes. The discussion concerns the DPMJET part. PHOJET avoids the problem.

This turned out to be too simple. Experiments [11] gave evidence for collision scaling in not too central scattering processes[1]. Collision scaling means, that exactly as many hard chains are produced as predicted by considering just hard collisions.

To correct for the missing collision scaling an additional parameter was introduced [10] which increases the number of hard collisions in such a way that collision scaling is obtained. We here adjusted these constants to the LHC data.

[1] For central heavy ion collision collision scaling is lost as transport effects become important. So far these effects are not implemented.

(2) LHC experiments [7, 8, 9] found that the produced hadron multiplicity rises with energy somewhat faster than the model. To obtain this faster rise with collision energy one needs to introduce energy-dependent parameters. This is not unreasonable. The time scale of the initial scattering is inversely proportional to the energy. This causes a more localized string and a widening of the $p_\perp$distribution of the string ends, which was observed as one contribution to the multiplicity dependence of the average transverse momentum $< p_\perp >_n$. There are of course many different parameters in PYTHIA which can be tuned in an energy-dependent way.
The solution which was adopted for the moment is not to search for a suitable, possible theoretically plausible energy-dependence but just to adjust parameters. The two parameters which determine the multiplicity of fragmenting chains are the Lund parameters PARJ(41) and PARJ(42) for which we use the following values:

for E_{cm} (TeV)	≤ 3.0	$\in [3.0\,, 7.0]$	$\in [7.0\,, 14.0]$	≥ 14.0
PARJ(41) =	0.2	$0.2 + (E_{cm} - 3)/40$	$0.3 + (E_{cm} - 7)/140$	0.35
PARJ(42) =	0.8	$0.8 - (E_{cm} - 3)/20$	$0.6 - (E_{cm} - 7)/70$	0.5

We do not continue to change PARJ(41) and PARJ(42) for E_{cm} larger than the maximum LHC energy of 14000 GeV. For the moment (in "DPMJET-III-2011") we replace in the FORTRAN code PARJ(41) and PARJ(42) by the values given in the table above as soon as in the input cards a change of PARJ(41) and PARJ(42) is demanded.

(3) The third modification is connected to the production of strange hadrons. The production of K_s^0 mesons and of Λ and Ξ^- hyperons in p-p collisions was measured by the CMS Collaboration [19]. The program gave more K_s^0 than measured by CMS, while it obtained less Λ and Ξ^- production than measured by CMS. To increase the agreement with the measurements in this regard more energy-dependent parameters have to be introduced.

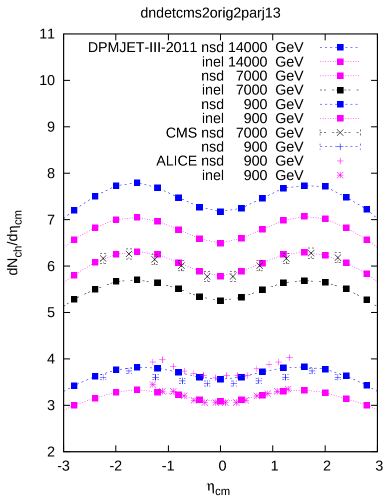
Hyperon and strange meson production in DPMJET-III is controlled by the Lund parameters PARJ(1), PARJ(2), PARJ(3), PARJ(5) and PARJ(6). The default of the parameter PARJ(2) was not touched. For the other parameters the following energy-dependent values (in the energy range up to $E_{cm} = 14$ TeV) were implemented:

for E_{cm} (TeV)	≤ 0.5	$\in [0.5\,, 0.9]$	$\in [0.9\,, 1.0]$	$\in [1.0\,, 3.0]$	$\in [3.0\,, 7.0]$	≥ 7.0
PARJ(1) =	0.1	$0.1 + \frac{(E_{cm}-0.5)}{4}$	0.2			
PARJ(3) =	0.4	$0.4 + \frac{(E_{cm}-0.5)}{0.25}$	2.0			
PARJ(5) =	0.5				$0.5 - \frac{(E_{cm}-3.0)}{80}$	0.45
PARJ(6) =	0.5			$0.5 + \frac{(E_{cm}-1.0)}{10.91}$		1.05

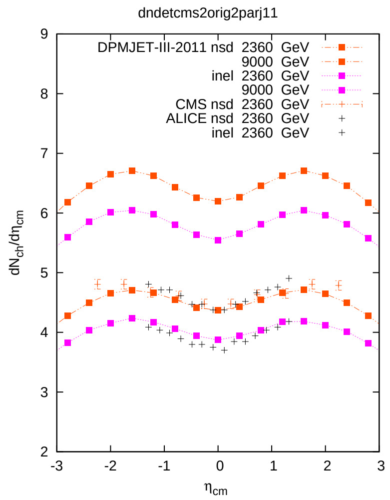
3 Comparison of DPMJET–III–2011 results with LHC data on charged hadron production

We start to discuss the non single diffractive (*nsd*) and inelastic (*inel*) pseudo-rapidity distribution $dN_{ch}/d\eta_{cm}$ measured by the CMS and ALICE Collaborations.

In figure 1 we present for p–p collisions the non single diffractive data from CMS [12] at 900, 2360 and 7000 GeV and the non single diffractive and inelastic data from ALICE [13]



(a)



(b)

Figure 1: Central η_{cm} distributions of charged particles in (a) $\sqrt{s}$ = 900, 7000 and 14000 GeV and (b) $\sqrt{s}$ = 2360 and 9000 GeV p–p collisions compared to non single diffractive (*nsd*) and inelastic (*inel*) pseudo-rapidity distributions obtained with DPMJET-III-2011. The experimental data are from the CMS Collaboration [12] for *nsd* collisions and from the ALICE Collaboration [13] for *nsd* and *inel* collisions.

at 900 and 2360 GeV and compare them with the results from DPMJET–III-2011. Excellent agreement is obtained.

Also included are the results at 9000 and 14000 GeV in p–p collisions. At these energies the distributions are expected to be be measured at the LHC in the future.

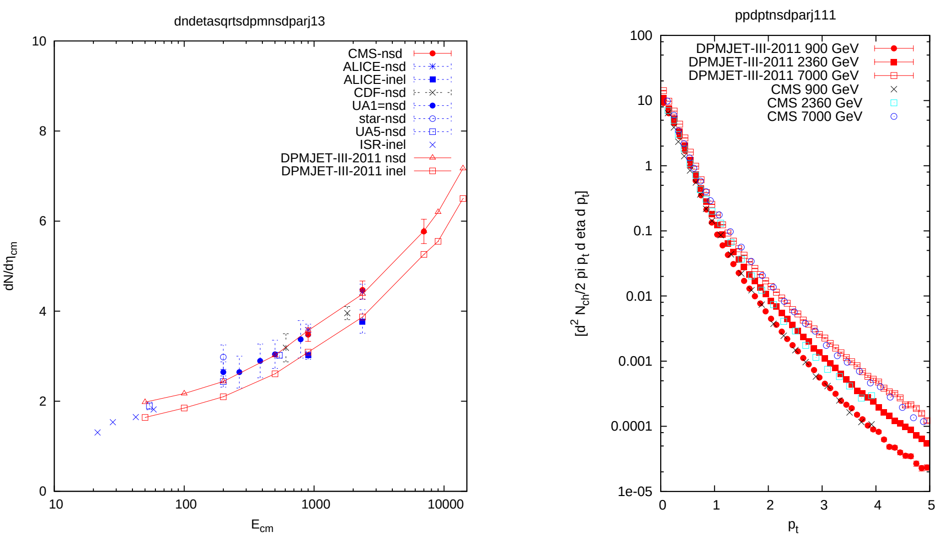
The energy-dependence of the central density $dN/d\eta_{cm}$ at $\eta_{cm} = 0$ is presented in figure 2(a) for p–p collisions of *nsd* and *inel* events. The DPMJET–III-2011 results are compared with data from various energies. In all cases a good agreement is obtained.

In figure 2(b) we compare p_t distributions from the DPMJET–III-2011 in p–p collisions at $\sqrt{s}$ = 900, 2360 and 7000 GeV with representative experimental data points from the CMS Collaboration [7]. The agreement between the modified program and the CMS data points is good.

In figures 3 we compare the multiplicity distributions for $|\eta| < 1$ with experimental data from the ALICE Collaboration [13]. Again a reasonable agreement is obtained.

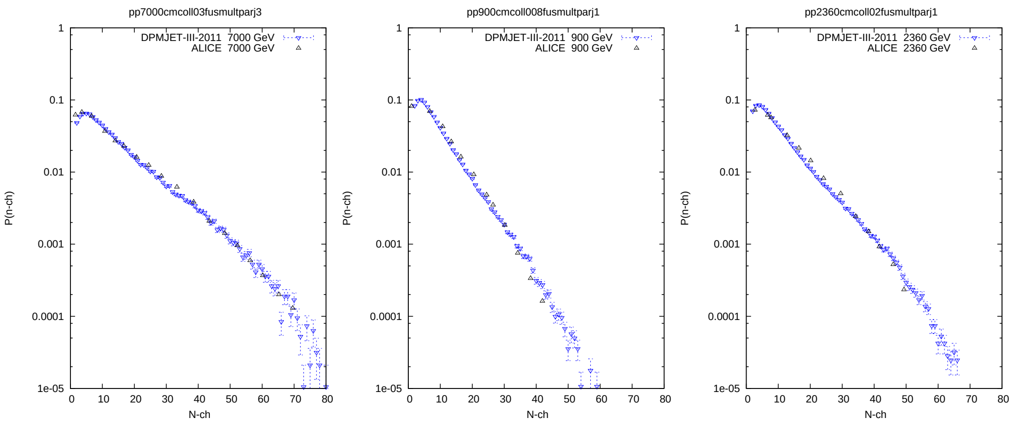
Unfortunately here the situation becomes even more problematic. In figure 4(a) we compare the dn/dy_{cm} distributions of Ξ hyperons in the DPMJET-III-2011 with the measurements of CMS. The modified model predicts Ξ distributions about three times as large as measured by CMS.

We have modified the parameters in such a way, that the Λ hyperons agree with the CMS data. The same parameters should also lead to agreement for the Ξ hyperons. They do not (figure 5). We can only conclude, that so far we do not fully understand the production of Ξ hyperons.



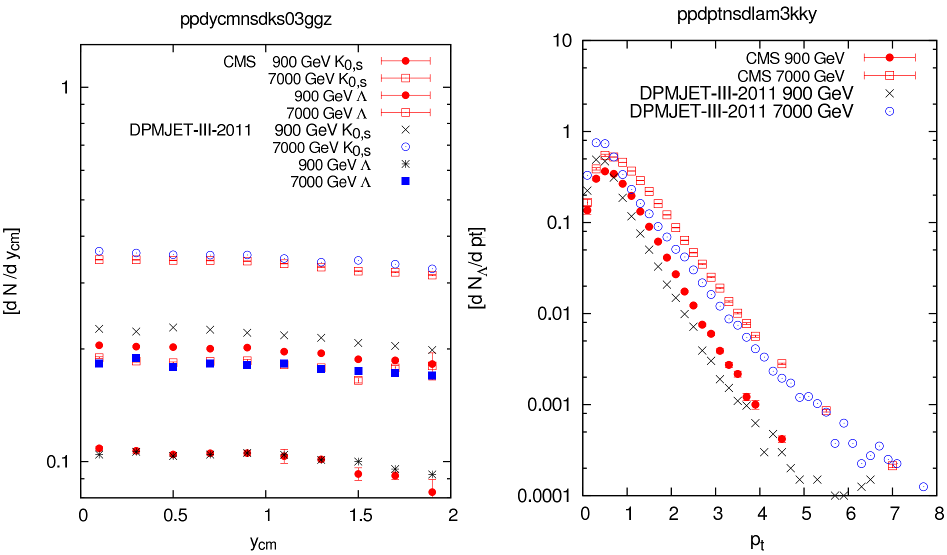
(a) (b)

Figure 2: (a) Central η_{cm} values of all charged particles in p–p collisions compared to DPMJET-III-2011 results. The experimental data are from the CMS Collaboration [12] for *nsd* collisions and from the ALICE Collaboration [13] for *nsd* and *inel* collisions. Further data are from UA5 [14], the ISR [15], STAR [16], UA1 [17] and CDF [18]. (b) Transverse momentum distributions in p–p collisions at $\sqrt{s} = 900$, 2360 and 7000 GeV. We compare data from the CMS Collaboration [7] to DPMJET-III-2011 results.



(a) (b) (c)

Figure 3: (a) Multiplicity distributions in p–p collisions at $\sqrt{s}$ = 7000 GeV. We compare data for $|\eta| < 1$ from the ALICE Collaboration [13] to the DPMJET-III-2011 result. (b) Multiplicity distributions in p–p collisions at $\sqrt{s}$ = 2360 GeV. We compare data for $|\eta| < 1$ from the ALICE Collaboration [13] to the DPMJET-III-2011 result. (c) Multiplicity distributions in p–p collisions at $\sqrt{s}$ = 900 GeV. We compare data for $|\eta| < 1$ from the ALICE Collaboration [13] to the DPMJET-III-2011 result.



(a) (b)

Figure 4: (a) dn/dy_{cm} distributions in p-p collisions of K_s^0 and $\bar{K}_s^0$ as well as Λ and $\bar{\Lambda}$. We compare LHC data from the CMS Collaboration [19] to the DPMJET-III-2011 result. (b) Transverse momentum distributions of Λ and $\bar{\Lambda}$. We compare experimental data from the CMS Collaboration [19] to the DPMJET-III-2011 result.

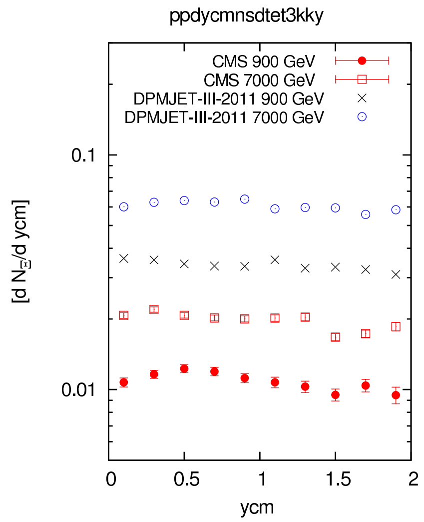


Figure 5: dn/dy_{cm} distributions of Ξ and $\bar{\Xi}$. We compare experimental data from the CMS Collaboration [19] to DPMJET-III-2011 calculations.

4 Comparison of DPMJET–III-2011 results with LHC data on the production of strange hadrons

Strange hadron production in p-p collisions was measured by the CMS Collaboration [19]. It determined the production of K_s^0 mesons and the production of Λ and Ξ^- hyperons.

Similar data on the production of strange hadrons were also given by the ALICE Collaboration [20]. We did not include them so far as they do not affect the consideration discussed below.

In figure 4(a) we compare the production of K_s^0 and Λ hyperons in dependence of the dn/dy_{cm}. With energy-dependent parameters good agreement of the DPMJET-III-2011 and the CMS measurements is obtained.

But the situation is not perfect. CMS also measures transverse momentum distributions. Comparing transverse momentum distributions we find the shape of the distributions to differ. This can be seen in figure 4(b) showing the transverse momentum distributions of Λ hyperons. Above 1 GeV the model is below the data. A similar problem seems to appear in many model calculations [21].

If we would also adjust the parameters in such a way, that the agreement between the transverse momentum distributions is optimal in this region, we would obtain a disagreement in the dn/dy_{cm} distributions.

5 Conclusions

DPMJET-III is a code for hadron production in hadron-hadron, photon-hadron, hadron-nucleus and nucleus-nucleus collisions [2, 3], which is about 10 to 15 years old. The measurements of hadron production in p-p collisions at LHC energies gave the occasion to check how well DPMJET-III agrees to the data in this higher energy region. We knew already from comparisons at the lower FERMILAB energies, that not all features of DPMJET-III are valid at higher energies, a well known example is the collision scaling [22] in hadron-nucleus and nucleus-nucleus collisions and which is not a property of DPMJET-III.

Comparing DPMJET-III with the LHC data we found further problems of DPMJET-III. The energy-dependence of hadron production measured by the LHC collaborations at 7 TeV differs from the one predicted by the original DPMJET-III. In the present paper we find, that this energy-dependence can be corrected in DPMJET-III by making in DPMJET-III the PYTHIA-parameters energy dependent. We consider the introduction of energy-dependent parameters only as a temporary solution to get agreement of DPMJET-III with the new LHC data.

A more permanent solution will require deeper changes in the program. Of course the parameters entering DPMJET-III, PHOJET and PYTHIA should not be adjusted per hand to determine the energy-dependence of the hadron production models. This energy-dependence should be an intrinsic property of the hadron production models. We conclude that we need a new version of the model which agrees better with the data in the new energy region opened by the LHC.

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