HADRON PRODUCTION IN NUCLEUS–NUCLEUS
COLLISIONS AT LHC ENERGIES IN THE DUAL
PARTON MONTE–CARLO MODEL DTUNUC

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1. Introduction, the new Monte–Carlo Dual
Parton Model event generator DTUNUC

The model used will be described in more detail elsewhere[1]. DTUNUC
uses the Glauber model cascade in the formulation of Zadorozhnyi et al. [2]. The
multiparticipant chains are fragmented using the BAMJET independent chain decay
code[3].

After the production of fast hadrons in the Glauber–cascade we continue with
the full (multi–generation) formation zone intranuclear cascade[4] in the target
and projectile nuclei. In [4] only the first generation formation zone cascade in the
target nucleus was considered.

DTUNUC can be used to sample hadron–hadron, hadron–nucleus and normal
and central nucleus–nucleus collisions according to the Dual Parton Model. Only
the naive two–chain per collision (single Pomeron exchange) Dual Parton Model is
used. Multiple Pomeron exchange and minijets resulting from hard perturbative
QCD collisions will be included in DTUNUC in the future. Central nucleus–
nucleus collisions in the model are understood as collisions, where for projectile
nuclei with mass numbers smaller than the ones of the target nuclei all projectile
nucleons and wherether in collisions of identical nuclei more than 95 percent of the
projectile nucleons take part in the collision.

Increasing the collision energy is a severe test for a Monte–Carlo model of the
type considered. One problem is the large number of produced chains and particles.
This requires a drastic increase of the storage requirement of the code. A second
problem is the requirement of numerical stability for all kinematical calculations,
which becomes more difficult to maintain with growing collision energy.

First results obtained with DTUNUC and comparison to data on hadron pro-
duction in hadron–nucleus collisions have been presented at the Meeting Quark
Matter 90 at Menton [5]. Here we present only results at energies beyond the
energies of presently existing heavy ion accelerators.
2. DTUNUC results for heavy ion collisions at the energies of future heavy ion colliders up to LHC

In the calculations reported, we use the naive two-chain-per-collision Dual Parton Model at energies, where in reality multi-pomeron exchange contributions become important and where furthermore a second component (the production of minijets due to parton-parton collisions as described by perturbative QCD) becomes important. These modifications to the model are presently understood in the case of hadron–hadron collisions at the energies of present and future hadron–hadron colliders [6]. It will take some time until all of this is also implemented for the nuclear collisions considered here.

In the calculations reported, we also neglect the formation time intranuclear cascade. This is reasonable for central collisions, where all nucleons of the colliding nuclei interact, but not completely realistic for normal noncentral collisions.

Besides multipomeron exchange and the formation of minijets, there are two more reasons for the multiplicity and the rapidity plateau of heavy ion collisions to rise with the collision energy in the Dual Parton Model.

(i) At low energies, many of the sea–sea collisions demanded by the Glauber cascade are suppressed kinematically. This suppression disappears with rising energy.

(ii) The cross–sections of nucleon–nucleon collisions, which have to be used as input for the Glauber cascade rise strongly with the collision energy. This leads to a slow rise of the nucleus–nucleus collision cross–sections with rising energy and to a rather rapid rise of the total number of elementary collisions in central nucleus–nucleus interactions. This number of collisions in central Au–Au collisions doubles approximately between the RHIC energy (200 GeV in the nucleon–nucleon c.m.s.) and the LHC energy of 6300 GeV per nucleon–nucleon c.m.s. Correspondingly, we get such a rise of the rapidity plateau.

Table 1. Results of the Glauber model cascade for Au–Au collisions at the energies of future heavy ion colliders.

<table>
<thead>
<tr>
<th>Collision</th>
<th>( \sqrt{s} ) (GeV)</th>
<th>( \sigma_{pp,\text{tot}} ) (mb)</th>
<th>( n )</th>
<th>( n_a )</th>
<th>( n_b )</th>
<th>( \sigma_{Au-Au} ) (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>central</td>
<td>200</td>
<td>52</td>
<td>1278</td>
<td>197</td>
<td>197</td>
<td>6.821</td>
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<td>200</td>
<td>52</td>
<td>314</td>
<td>64</td>
<td>64</td>
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<td>63</td>
<td>1446</td>
<td>193</td>
<td>193</td>
<td>6.977</td>
</tr>
<tr>
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<td>63</td>
<td>299</td>
<td>56</td>
<td>57</td>
<td>6.977</td>
</tr>
<tr>
<td>central</td>
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<td>77</td>
<td>1697</td>
<td>195</td>
<td>195</td>
<td>7.134</td>
</tr>
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<td>77</td>
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<td>56</td>
<td>59</td>
<td>7.134</td>
</tr>
<tr>
<td>central</td>
<td>7000</td>
<td>93</td>
<td>2027</td>
<td>197</td>
<td>196</td>
<td>7.313</td>
</tr>
<tr>
<td>normal</td>
<td>7000</td>
<td>93</td>
<td>362</td>
<td>50</td>
<td>57</td>
<td>7.313</td>
</tr>
</tbody>
</table>

We consider only gold (Au) nuclei as typical heavy projectiles and targets. In Table 1 we give the average number of collisions \( (n) \), the average number of interacting projectile nucleons \( (n_a) \) and the average number of interacting target nucleons \( (n_b) \) in normal and central Au–Au collisions as obtained from the Glauber model cascade. The input total p–p cross–section and the output gold–gold inelastic cross section are also given. Some of the numbers in the Table have large statistical errors because of the small number of events sampled. From the numbers given and similar calculations for other hadron–nucleus and nucleus–nucleus
collisions (we use in addition p–O, p–Ar, p–Xe and O–O, Ar–Ar and Xe–Xe) we can study the general behaviour of the inelastic output cross-sections and of the number of elementary collisions, which at high energies should be proportional to the central rapidity plateau obtained after the hadronization. We obtain from a fit to the cross-sections between $\sqrt{s} = 20$ GeV and 6300 GeV calculated in our Monte–Carlo calculation for proton–nucleus collisions

$$\sigma_{p-A} = 18.5^{0.34} \sigma_{pp, tot}^{0.29} A^{0.61}$$

and for collisions of two identical nuclei

$$\sigma_{A-A} = 71.5^{0.29} \sigma_{pp, tot}^{0.29} A^{0.63}.$$  

The A-dependence corresponds closely to the one expected in the Glauber model as recently summarized by Kaidalov [7]. The dependence on $\sigma_{pp, tot}$ contradicts the naively expected proportionality of the nucleus–nucleus cross-section to the input nucleon–nucleon cross-section. The reason is, that we are in an energy region with $\sigma_{pp, tot}$ between 39 and 93 mb, where the nucleus–nucleus cross sections approach the geometrical value, which rises slowly only due to contributions from the periphery of the colliding nuclei.

A similar fit is performed to the calculated product of $\sigma_{p-A}$ or $\sigma_{A-A}$ with $n$, where $n$ is the number of elementary collisions in the p–A or A–A collision. The number of collisions $n$ is at high energies above all threshold effects proportional to the central rapidity plateau. We obtain in the fit a $A^\alpha$ dependence with $\alpha = 0.99$ for p–A collisions and $\alpha = 1.98$ for minimum bias A–A collisions. These $\alpha$–values correspond closely to the expectation ($\alpha_{p-A} = 1$ and $\alpha_{A-A} = 2$) in the Glauber–model [7]. For $n$ the fit gives the behaviour

$$n_{p-A} = 0.095^{0.49} \sigma_{pp, tot}^{0.38} A^{0.38}$$

and for minimum bias nucleus–nucleus collisions

$$n_{A-A, minimum bias} = 0.043^{0.43} \sigma_{pp, tot}^{0.43} A^{1.35}.$$  

The A-dependence corresponds completely to the expectations [7], while the dependence on the input nucleon–nucleon cross-section is again modified by the effects as discussed already above.

In central nucleus–nucleus collisions we found another unexpected result, which is maybe not so surprising. We obtain an $A^\alpha$–dependence with an $\alpha$ above the value 1.33 expected and obtained in minimum bias collisions. The behaviour depends certainly on the definition of central collisions. Our definition already given above is, that more than 93 percent of both the target and projectile nucleons are involved in the collision. We obtain in the fit

$$n_{A-A, central} = 0.074^{0.51} \sigma_{pp, tot}^{0.51} A^{1.47}.$$  

The $\alpha_{A-A, central} = 1.47$ together with the large A of gold explains the fact, that our model gives in central collisions of heavy nuclei rapidity plateaus larger than the ones reported from other models at this meeting.
Table 2. Average multiplicities calculated with DTUNUC for normal and central Au–Au collisions at energies up to LHC (7 TeV cms energy per nucleon–nucleon collision).

<table>
<thead>
<tr>
<th>Collision</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$n_{\text{tot}}$</th>
<th>$n_{ch}$</th>
<th>$n_{\pi^-}$</th>
<th>$n_{p}$</th>
</tr>
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<tbody>
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<td>18476</td>
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<td>3020</td>
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<td>32</td>
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<tr>
<td>central</td>
<td>630</td>
<td>31109</td>
<td>18041</td>
<td>7740</td>
<td>216</td>
</tr>
<tr>
<td>normal</td>
<td>630</td>
<td>7100</td>
<td>4110</td>
<td>1758</td>
<td>51</td>
</tr>
<tr>
<td>central</td>
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<td>48434</td>
<td>28148</td>
<td>12053</td>
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<tr>
<td>normal</td>
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<td>6225</td>
<td>2655</td>
<td>81</td>
</tr>
<tr>
<td>central</td>
<td>6300</td>
<td>71592</td>
<td>41525</td>
<td>17833</td>
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<td>3420</td>
<td>108</td>
</tr>
</tbody>
</table>

In Table 2 we give average multiplicities obtained from the DTUNUC runs and in Table 3 we give central rapidity densities obtained from the same Monte–Carlo runs. Again, we stress, that the statistical errors at the highest energies might be large due to the limited statistics in the Monte–Carlo runs.

Table 3. Central rapidity densities calculated with DTUNUC for normal and central Au–Au collisions at energies up to LHC (7 TeV cms energy per nucleon–nucleon collision).

<table>
<thead>
<tr>
<th>Collision</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$\frac{dn^{\text{sat}}}{dy_{\text{max}}}$</th>
<th>$\frac{dn^{ch}}{dy_{\text{max}}}$</th>
<th>$\frac{dn^{\pi^-}}{dy_{\text{max}}}$</th>
<th>$\frac{dn}{dy_{\text{max}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>central</td>
<td>200</td>
<td>3460</td>
<td>1960</td>
<td>829</td>
<td>224</td>
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<tr>
<td>normal</td>
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<td>928</td>
<td>526</td>
<td>224</td>
<td>1150</td>
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<tr>
<td>central</td>
<td>630</td>
<td>4830</td>
<td>2740</td>
<td>247</td>
<td>1150</td>
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<tr>
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<td>6300</td>
<td>8130</td>
<td>4660</td>
<td>1960</td>
<td>346</td>
</tr>
</tbody>
</table>

We are shure, that the multiplicities and rapidity distributions will be modified by the effects discussed above, which have not yet been implemented into DTUNUC.

The effect of taking multi–pomeron exchange into account will be a rise of the rapidity distribution. From proton–antiproton collisions, we know, that this rise at the energy of 6.3 TeV will be approximately a factor of two. The minimal rise to be expected in nucleus–nucleus collisions is this factor two for the valence–valence chains, there is one pair of valence–valence chains for each interacting projectile nucleon. The maximum possible rise is the same factor as for proton–antiproton collisions.
The effect of taking minijets into account is more difficult to understand. We expect in nucleus–nucleus collisions as compared to hadron–hadron collisions much larger numbers of minijets, but shadowing effects will modify this contribution significantly.

At high energies we get in minimum bias and central Au–Au collisions a central rapidity region with vanishing baryon number density. The total width in rapidity of this region is still $\Delta y = 0$ at $\sqrt{s} = 200$ GeV and it rises to $\Delta y = 3$ at $\sqrt{s} = 630$ GeV and $\Delta y = 6$ at $\sqrt{s} = 6300$ GeV.

REFERENCES