# Charged-hadron pseudorapidity distributions in the RDM at LHC energies

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## 1. INTRODUCTION

To calculate and predict pseudorapidity distributions of produced charged hadrons in heavy-ion collisions at RHIC [1] and LHC [2] energies, an analytically soluble nonequilibrium-statistical RDM-model [3,4] is outlined. It successfully describes pseudorapidity distributions for produced hadrons with their detailed centrality dependence at RHIC energies, and it is used to predict the distribution functions at LHC energies. The model relies on three sources for charged-hadron collisions, a midrapidity source due to gluon-gluon collisions, and two forward-centered fragmentation sources arising essentially from valence quark - gluon interactions.

It has been shown in [5,6] within the relativistic diffusion model (RDM) that at RHIC energies of 0.13 TeV (0.2 TeV) the midrapidity source generates about 13 % (26 %) of the produced particles in a 0-6% central AuAu collision, whereas the bulk of the particles is still produced in the two fragmentation sources. At SPS, and low RHIC energies of 19.6 GeV the effect of the midrapidity source is negligible [6].

In this work [4] the energy dependence of the three sources for particle production in collisions of heavy symmetric systems is investigated with emphasis on predictions for the distribution functions in PbPb at LHC energies of 2.76 and 5.52 TeV.

## 2. RELATIVISTIC DIFFUSION MODEL

In the Relativistic Diffusion Model, the (pseudo-)rapidity distribution of produced particles emerges from an incoherent superposition of the beam-like fragmentation components at larger rapidities arising mostly from valence quark-gluon interactions, and a component centered at midrapidity that is essentially due to gluon-gluon collisions. All three distributions are broadened in rapidity space as a consequence of diffusion-like processes.

The time evolution of the distribution functions is governed by a Fokker-Planck equation (FPE) in rapidity space [3,4 and refs. therein]

$$\frac{\partial}{\partial t}[R(y,t)]^{\mu} = -\frac{\partial}{\partial y}\Big[J(y)[R(y,t)]^{\mu}\Big] + \frac{\partial^2}{\partial y^2}\left[D_y \cdot R(y,t)\right]^{\nu}$$

The standard linear FPE corresponds to μ=ν=1 and a linear drift function $J(y)=(y_{eq}-y)/\tau_y$ with the rapidity relaxation time $\tau_y$, and the equilibrium value $y_{eq}$ of the rapidity. This is the so-called Uhlenbeck-Ornstein process, applied to the relativistic invariant rapidity for the three components $R_k(y,t)$ (k=1,2,3) of the distribution function in rapidity space:

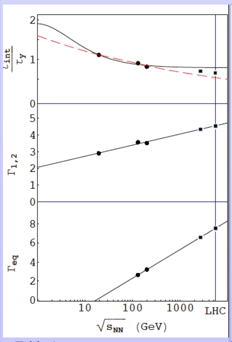


Fig 1: Dependence of the diffusion-model parameters for heavy systems at RHIC (dots) and LHC (squares) energies on sqrt(s_NN), according to [6]: Quotient of interaction time and relaxation time for sinh- and exponential (dashed) extrapolation (upper frame); width of the peripheral sources including collective expansion (middle frame); effective width of the midrapidity source (lower frame).
The results are for charged-hadron pseudorapidity distributions. From [4,6].

Table 1:

| $\sqrt{s_{NN}}$ (TeV) | $y_{beam}$ | $\tau_{int}/\tau_y$ | $\langle y_{1,2}\rangle$ | $\Gamma_{1,2}$ | $\Gamma_{eq}$ | $N_{ch}^{1,2}$ | $N_{ch}^{eq}$ |
|---|---|---|---|---|---|---|---|
| 0.13 | ∓4.93 | 0.89 | ∓2.02 | 3.56 | 2.64 | 1837 | 560 |
| 0.20 | ∓5.36 | 0.80 | ∓2.40 | 3.51 | 3.20 | 1887 | 1349 |
| 2.76 | ∓7.99 | 0.67 | ∓4.09 | 4.2* | 6.8* | 3660* | 11075 |
| 5.52 | ∓8.68 | 0.66 | ∓4.49 | 4.6* | 7.5* | 4120* | 14210* |

$$\frac{\partial}{\partial t}R_k(y,t) = -\frac{1}{\tau_y}\frac{\partial}{\partial y}\Big[(y_{eq}-y)\cdot R_k(y,t)\Big] + \frac{\partial^2}{\partial y^2}\Big[D_y^k \cdot R_k(y,t)\Big]$$

Since the equation is linear, a superposition of the distribution functions using the initial conditions $R_{1,2}(y,t=0)=\delta(y\pm y_{max})$ with the absolute value of the beam rapidities $y_{max}=\ln(\sqrt{s_{NN}}/m_p)$ and $R_{eq}(y,t=0)=\delta(y-y_{eq})$ yields the exact solution

$$\frac{dN_{ch}(y,t=\tau_{int})}{dy} = N_{ch}^1 R_1(y,\tau_{int}) + N_{ch}^2 R_2(y,\tau_{int}) + N_{ch}^{eq} R_{eq}(y,\tau_{int}).$$

In the solution, the mean values and variances are obtained analytically from the moments equations. In general, relaxation time and diffusion coefficient are related through a dissipation-fluctuation theorem (Einstein relation). Due to the collective expansion of the system, however, the effective diffusion coefficient is substantially larger. Hence the partial widths $\Gamma_k$ (FWHM) are treated here as independent variables, which are related to the standard deviations through $\Gamma_k=\sqrt{(8\ln 2)}\cdot\sigma_k$.
For symmetric systems, the RDM then has 4 parameters.

## 3. PRODUCED CHARGED HADRONS

If particle identification is not available, one has to convert the results to pseudorapidity, $\eta = -\ln[\tan(\theta/2)]$ with the scattering angle $\theta$. For the conversion I use the approximate Jacobian

$$\frac{dy}{d\eta} \simeq J(\eta,\langle m\rangle/\langle p_T\rangle) = \cosh(\eta)\cdot[1+(\langle m\rangle/\langle p_T\rangle)^2+\sinh^2(\eta)]^{-1/2}$$

with the mean mass $\langle m\rangle \approx \langle m_\pi\rangle$, and the mean transverse momentum $\langle p_T\rangle$ taken from experiment [1] at RHIC energies, and estimated at LHC, where the effect from the Jacobian is very small due to the high mean transverse momentum.

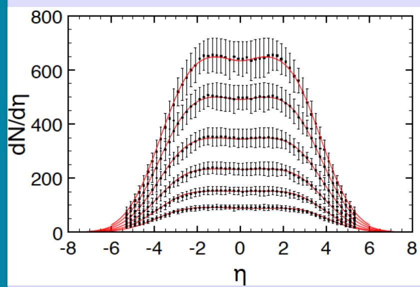


Fig 2: Calculated RDM charged-hadron pseudorapidity distributions for AuAu collisions at six centralities compared with 0.2 TeV PHOBOS data [1] in a $\chi^2$-minimization. (Unpublished, GW).

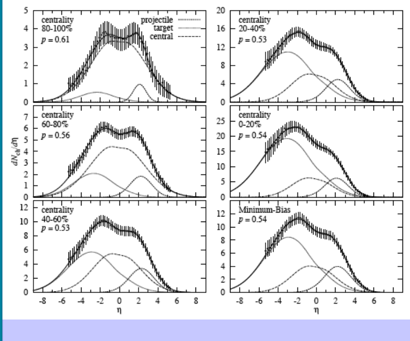


Fig 3: Calculated charged-hadron pseudorapidity distributions for dAu collisions at various centralities compared with 0.2 TeV PHOBOS data [1] in a $\chi^2$-minimization ($p = 1 - \exp(-\tau_{int}/\tau_y)$). From [5].

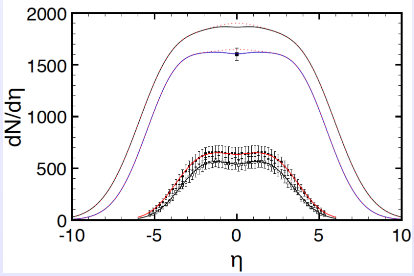


Fig 4: Calculated pseudorapidity distributions of produced charged particles from AuAu collisions (bottom) at 0.13 and 0.2 TeV (0-6% centrality) in comparison with PHOBOS data [1]. Distribution functions for 0-5% central PbPb collisions at LHC energies of 2.76 and 5.52 TeV are shown in the upper part of the figure, with the lower-energy result adjusted to the ALICE midrapidity data point [2]. Dotted curves are without the Jacobian transformation. The corresponding parameter values are given in table 1. From [4].

## 4. RESULTS

With parameter values for central collisions given in Fig. 1 and Table 1, the 3-sources RDM results for AuAu at 0.2 TeV RHIC energy are shown in Fig. 2. Six centralities (0-6%...45-55%) are compared with the PHOBOS data [1] in a $\chi^2$-minimization.

Corresponding results for the dAu system at 0.2 TeV are shown in Fig. 3 from [5]. Here the asymmetric shapes of the distributions are much more sensitive to the details of the model, enhancing the credibility of the 3-sources approach.

Results of the RDM-predictions [4] for central PbPb at LHC energies of 2.76 and 5.52 TeV are based on extrapolated diffusion-model parameters (Fig. 1 and Table ). They are shown in Fig. 4 together with the RHIC results, and the ALICE midrapidity data point [2] which is used for the normalization. The underlying partial distribution functions (with and without Jacobian) are shown in Fig. 5.

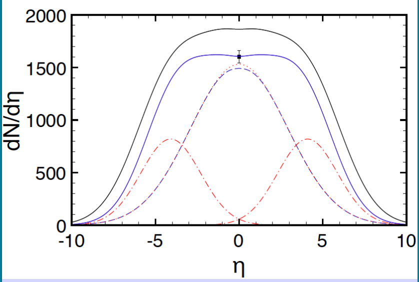


Fig 5: Pseudorapidity distributions of charged hadrons in 0-5% central PbPb collisions at LHC energies of 2.76 and 5.52 TeV. The underlying theoretical distributions are shown for 2.76 TeV. Their shapes are not significantly modified by the Jacobian. From [4].

## 5. CONCLUSION

Based on the description of charged-hadron pseudorapidity distributions in collisions of heavy systems at RHIC energies in a non-equilibrium-statistical model, I have presented predictions of pseudorapidity distributions of produced charged hadrons for central PbPb collisions at LHC energies of 2.76 and 5.52 TeV. These rely on the extrapolation of the transport parameters in the relativistic diffusion model (RDM) with increasing center-of-mass energy.

In a three-sources model, the midrapidity source that is associated with gluon-gluon collisions accounts for more than 90% of the midrapidity yield. The fragmentation sources that are mainly due to valence quark-gluon collisions are centered at relatively large values of pseudorapidity ($\langle\eta_{2,1}\rangle \approx \pm 4.1$) and hence, these contribute only marginally to the midrapidity yield.

This finding agrees with results of a QCD-based model [7] for net-baryon transport at LHC energies. There, the net-baryon yield at large rapidities is calculated from the interaction of valence quarks with the gluon condensate in the respective other nucleus.

Updates of the number of produced particles in the fragmentation sources may be required once the measured distributions become available from CMS, ATLAS and ALICE at both LHC energies.

## References


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