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The thermal model on the verge of the ultimate test: particle production in Pb-Pb collisions at the LHC

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Abstract. We investigate the production of hadrons in nuclear collisions within the framework of the thermal (or statistical hadronization) model. We discuss both the ligh-quark hadrons as well as charmonium and provide predictions for the LHC energy. Even as its exact magnitude is dependent on the charm production cross section, not yet measured in Pb-Pb collisions, we can confidently predict that at the LHC the nuclear modification factor of charmonium as a function of centrality is larger than that observed at RHIC and compare the experimental results to these predictions.

One of the major goals of ultrarelativistic nuclear collision studies is to obtain information on the QCD phase diagram [1]. The experimental approach is the investigation of hadron production at chemical freeze-out [2]. Hadron yields measured in central heavy ion collisions from AGS up to RHIC energies can be described very well (see [3] and refs. therein) within a hadro-chemical equilibrium model. In our approach the only parameters are the chemical freeze-out temperature T, the baryochemical potential μ_b and the fireball volume V. The main result of these investigations was that the extracted temperature values rise rather sharply from low energies on towards $\sqrt{s_{NN}} \simeq$10 GeV and reach afterwards constant values near T=160 MeV, while the baryochemical potential decreases smoothly as a function of energy. The limiting temperature [4] behavior suggests a connection to the phase boundary and it was, indeed, argued [5] that the quark-hadron phase transition drives the equilibration dynamically, at least for SPS energies and above. The conjecture of the tricritical point [6] was put forward for the lower energies. Alternative conjectures are that the thermodynamical state is a generic fingerprint of hadronization [7, 8] or is a feature of the excited QCD vacuum [9].

The values of T and μ_b obtained from fits can be parametrized as a function of $\sqrt{s_{NN}}$ with the expressions: $T = T_{lim}/[1 + \exp(2.60 - \ln(\sqrt{s_{NN}(\mathrm{GeV})})/0.45)]$ and $\mu_b[\mathrm{MeV}] = 1303/[1 + 0.286\sqrt{s_{NN}(\mathrm{GeV})}]$, with the "limiting" temperature T_{lim}=164 MeV. The μ_b value expected at the LHC is around 1 MeV. We employ these parametrizations to compare the model to data over a broad energy range. As an illustration, the production

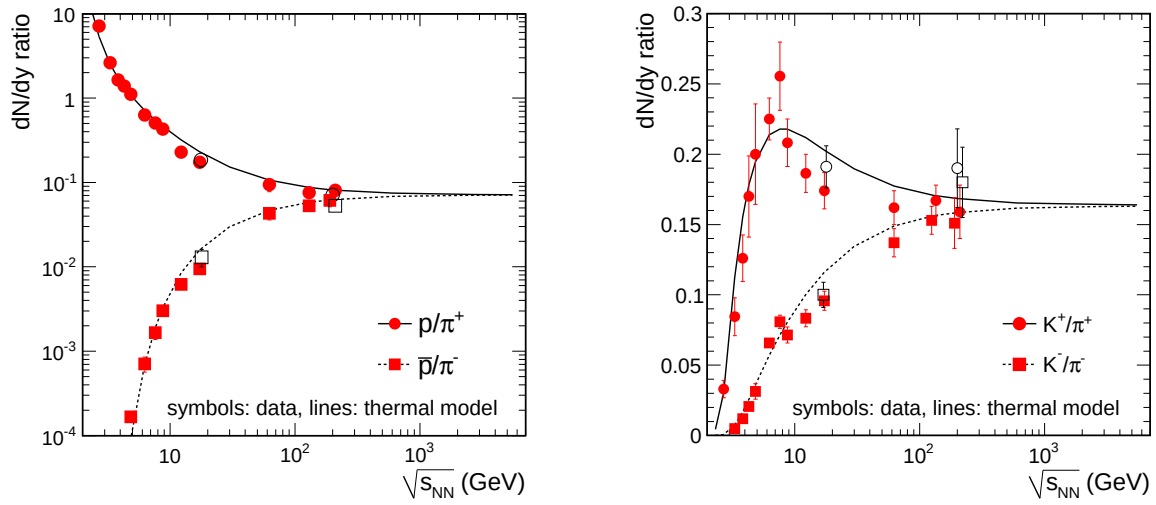

Figure 1. Energy dependence of the relative production ratios of protons ($\bar{p}$) and kaons (K^-) to pions (π^-). The open symbols represent the data points for the NA44 and PHENIX experiments at SPS and RHIC, respectively (the full symbols are for NA49 and STAR data). Note that ad-hoc feed-down subtraction was applied for STAR data for protons (25%) and for PHENIX data for pions (10%). The errors of the p/π and $\bar{p}/\pi$ data are smaller than the symbols.

yields of protons and kaons relative to pions are shown in Fig. 1, demonstrating that the model describes the data well (although smaller p/π^+ and $\bar{p}/\pi^-$ ratios are measured by PHENIX and at SPS [3]). The trends seen in the p/π^+ and $\bar{p}/\pi^-$ ratios reflect both the strong increase followed by saturation for T and the strong decrease of μ_b as a function of $\sqrt{s_{NN}}$. While the K^-/π^- ratio shows a monotonic increase and saturation as a function of energy, the K^+/π^+ ratio shows a maximum at a beam energy of 30 AGeV. In the thermal model this maximum occurs naturally at as an effect of the steep rise and saturation of T and the strong monotonous decrease in μ_b [3].

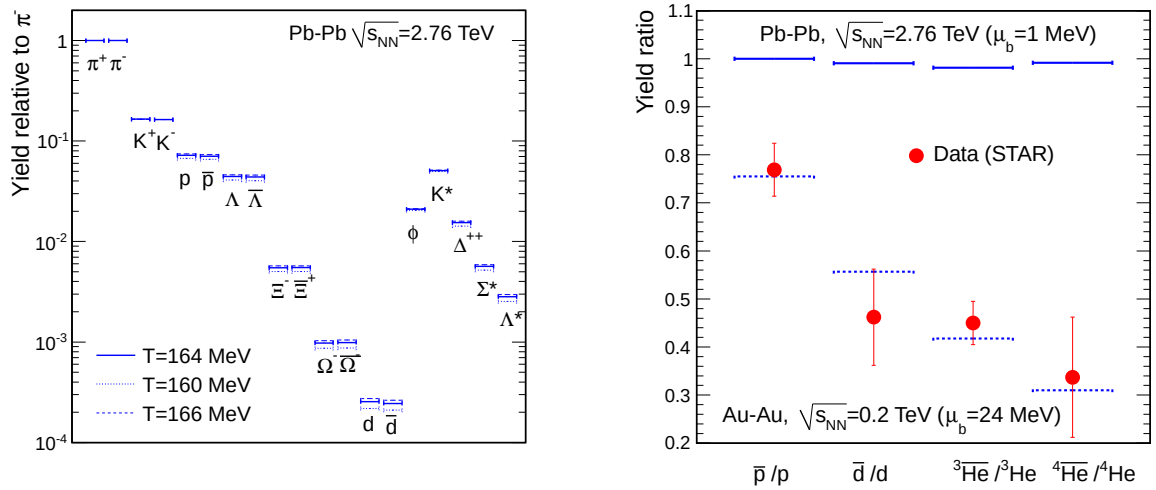

Figure 2. Model prediction for hadron yields relative to pions at LHC (left panel) and of anti-matter to matter production at RHIC and LHC.

In Fig. 2 we provide predictions for the production of various hadrons relative to pions, to be tested soon by experiment. Preliminary ALICE data [10] indicate a lower $\bar{p}/\pi^-$ ratio. We show also how dramatic the balance between matter and anti-matter production is changing from RHIC to LHC energies, as illustrated by the ratios of anti-baryons to baryons. Prediction for (anti-)hyper-nuclei are also available [11].

We now turn to the heavy-quark sector and compare the model predictions to data on charmonium prodution. Charmonium is considered, since the original proposal about its suppression in a Quark-Gluon Plasma (QGP) [12], an important probe of the energy density reached in the deconfined fireball produced in ultra-relativistic nucleus-nucleus collisions (see [13]). Because the large mass of charm quarks, heavy flavor hadron production cannot be described in a purely thermal approach as that discussed above. It was realized in [14] that charmonium production can be well described in the statistical model by assuming that all charm quarks are produced in initial, hard collisions while charmed hadron and charmonium production takes place exclusively at the phase boundary with statistical weights calculated in a thermal approach (for a recent review see [15]). An important element is thermal equilibration, at least near the critical temperature, T_c, which we believe can be achieved efficiently for charm only in the QGP. In recent publications [16] we have demonstrated that the data on J/ψ and ψ' production in nucleus-nucleus collisions at the SPS ($\sqrt{s_{NN}} \approx 17$ GeV) and RHIC ($\sqrt{s_{NN}}$=200 GeV) energies can be well described within the statistical hadronization model. We have recently shown [17] that there are crucial differences in elementary collisions compared to nucleus-nucleus for J/ψ production.

Besides the thermal parameters discussed above, which we keep unchanged, the model has as input parameter the charm production cross section in pp collisions, used to calculate the number of directly produced $c\bar{c}$ pairs $N_{c\bar{c}}^{dir}$ which enter into the balance equation [14, 15]: $N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{th} \frac{I_1(g_c N_{oc}^{th})}{I_0(g_c N_{oc}^{th})} + g_c^2 N_{c\bar{c}}^{th}$.

The centrality dependence of the nuclear modification factor $R_{AA}^{J/\psi}$ is shown in Fig. 3. The model reproduces very well the decreasing trend versus centrality seen in the RHIC data [18]. The larger $R_{AA}^{J/\psi}$ value at midrapidity is in our model due to the enhanced generation of charmonium around mid-rapidity, determined by the rapidity dependence of the charm production cross section. At the much higher LHC energy the larger charm production cross section could lead to a different trend as a function of centrality, depending on the magnitude of shadowing in Pb-Pb collisions. A generic prediction of the model is that the $R_{AA}^{J/\psi}$ value at LHC is larger than at RHIC and this is confirmed by the preliminary ALICE data [19] measured at forward rapidity, which demonstrate, in our view, that charmonium is produced at LHC at the phase boundary (chemical freeze-out). If further confirmed by data (importantly, also on ψ' production), this picture will consolidate the role of charmonium as a special observable to probe deconfinement of heavy quarks and to delineate the phase boundary of QCD matter with hadrons carrying heavy quarks. At the LHC, first results of Υ production have appeared [21]. The model predicts for Υ a suppression-like pattern of a similar magnitude as that of J/ψ at RHIC. We predict [17] for Pb-Pb much smaller ratios

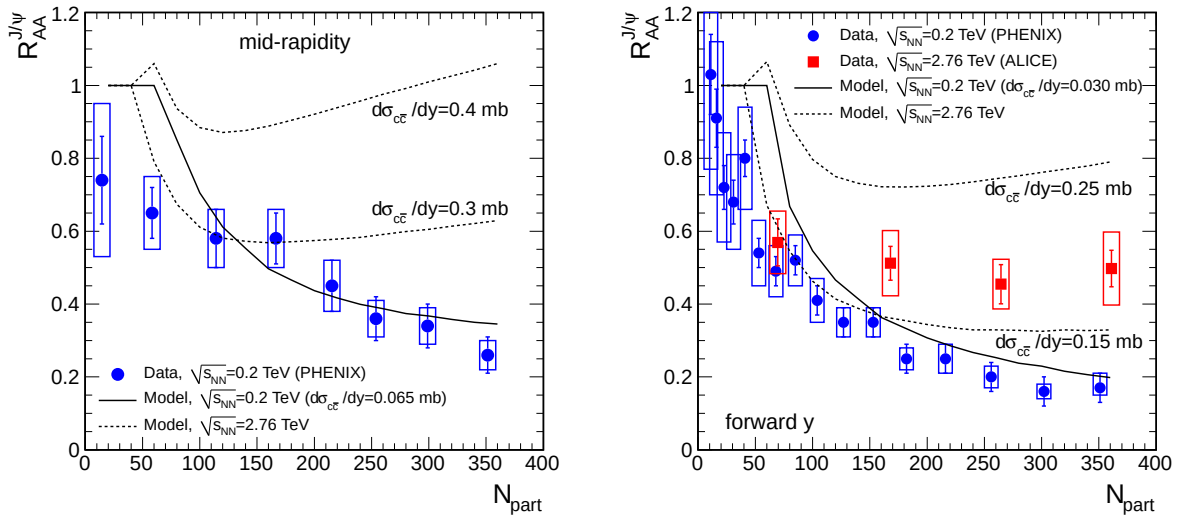

Figure 3. Centrality dependence of $R_{AA}^{J/\psi}$ for RHIC and LHC energies at mid-rapidity (left panel) and forward rapidity (right panel). The two curves shown for the LHC energy coorespond to a range of expected shadowing. The ALICE data shown in the right panel are preliminary results shown at this conference [19].

$\Upsilon(2S)/\Upsilon(1S)$=0.033 and $\Upsilon(2S)/\Upsilon(1S)$=0.005, compared to the values in $p\bar{p}$ collisions at Tevatron [20], 0.32 and 0.15, respectively. This feature is indicated in the CMS data [21].

References

[1] P. Braun-Munzinger, J. Wambach, Rev. Mod. Phys. **81** (2009) 1031.
[2] P. Braun-Munzinger, J. Stachel, arXiv:1101.3167 [nucl-th].
[3] A. Andronic, P. Braun-Munzinger, J. Stachel, Phys. Lett. B **673** (2009) 142; Erratum: ibid. B **678** (2009) 516; Acta Phys. Pol. **40** (2009) 1005.
[4] R. Hagedorn, CERN-TH-4100/85 (1985).
[5] P. Braun-Munzinger, J. Stachel, C. Wetterich, Phys. Lett. B **596** (2004) 61.
[6] A. Andronic et al., Nucl. Phys. A **837** (2010) 65.
[7] R. Stock, Phys. Lett. B **465** (1999) 277 [hep-ph/9905247].
[8] U. Heinz, Nucl. Phys. A **685** (2001) 414 [hep-ph/0009170].
[9] P. Castorina, D. Kharzeev, H. Satz, Eur. Phys. J. C **52** (2007) 187.
[10] M. Floris (ALICE coll.), these proceedings.
[11] A. Andronic et al., Phys. Lett. B **697** (2011) 203.
[12] T. Matsui, H. Satz, Phys. Lett. B **178** (1986) 416.
[13] L. Kluberg, H. Satz, arXiv:0901.3831 [hep-ph].
[14] P. Braun-Munzinger, J. Stachel, Phys. Lett. B **490** (2000) 196; Nucl. Phys. A **690** (2001) 119c.
[15] P. Braun-Munzinger, J. Stachel, arXiv:0901.2500 [nucl-th].
[16] A. Andronic et al., Nucl. Phys. A **789** (2007) 334; Phys. Lett. B **652** (2007) 259.
[17] A. Andronic et al., Phys. Lett. B **678** (2009) 350.
[18] A. Adare et al. (PHENIX coll.), Phys. Rev. Lett. **98** (2007) 232301; arXiv:1103.6269.
[19] P. Pillot (ALICE coll.), these proceedings.
[20] D. Acosta et al. (CDF coll.), Phys. Rev. Lett. **88** (2002) 161802.
[21] The CMS Collaboration, arXiv:1105.4894