Quark coalescence from RHIC to LHC

Vincenzo Minissale\textsuperscript{1,2}, Francesco Scardina\textsuperscript{1,2} and Vincenzo Greco\textsuperscript{1,2}

\textsuperscript{1} Department of Physics and Astronomy, University of Catania, Via S. Sofia 62, I-95123, Catania, Italy.
\textsuperscript{2} INFN-LNS, Laboratori Nazionali del Sud, Via S. Sofia 64I-95123, Catania, Italy

E-mail: vincenzo.minissale@lns.infn.it, scardinaf@lns.infn.it, greco@lns.infn.it

Abstract. We discuss the application of a phase-space coalescence plus fragmentation model for the hadronization of the quark-gluon plasma (QGP) created in ultra-relativistic heavy-ion collisions. Recombination of minijet partons with the partons from the QGP is also included and plays a role at $p_T \sim 2-4$ GeV where the baryon to meson anomaly is observed experimentally. We show our prediction for light and strange hadrons transverse momentum spectra ($\pi$, $p$, $k$, $\Lambda$) and baryon to meson ratios ($p/\pi$, $\Lambda/k$) in a wide range of $p_T$, both for RHIC and LHC energies. The baryon to meson ratio at LHC presents similar features of that at RHIC, but with a shift in the peak of about 0.5 GeV, and this is well predicted by our model.

1. Introduction

Heavy Ion Collisions (HIC) at ultrarelativistic energy can be used to probe the properties of nuclear matter under such extreme conditions. The predictions of Lattice Quantum Chromodynamics indicate that the critical temperature in which the nuclear matter experiences a phase transition is $T_c \approx 160$ MeV, and new state of matter can exist in which the colour charges are deconfined in a Quark Gluon Plasma (QGP) [1]. Signatures of a Quark Gluon Plasma formation became manifest in the experiment with energies up to 200 AGeV performed at RHIC and further confirmations as well as new discoveries have been coming from the experiments at LHC. In the studies of the QGP created in HIC is necessary taking into account that partonic behaviour is not directly projected on the observables measured in heavy ion collision experiments. Thus the choice of the model for hadronization process is a crucial point in order to have a comparison with experimental data. Some unexpected observations in Au+Au collisions at RHIC have been the enhancement of baryon to meson ratio at intermediate transverse momenta and the scaling of elliptic flow according to the constituent quark number. The coalescence hadronization process can explain both these features that appears in the same intermediate $p_T$ region [2, 3, 4]. The coalescence approach born from the idea that comoving partons in the quark-gluon plasma combine their transverse momentum to produce a final-state meson or baryon with higher $p_T$ than the partons themselves if they are in a bulk QGP matter at a time scale in which the partons can rescatter and generate a thermal medium expanding with a collective radial flow [10, 11, 5, 6, 7, 8, 9]. The hadron spectra at high transverse momentum are dominantly produced from minijet partons originated from initial hard processes between colliding nucleons. In the coalescence model used here, these minijet partons are allowed to recombine with thermal quarks and antiquarks from the quark-gluon plasma created in the collisions to form hadrons. We report in this paper results obtained using coalescence model.
for central collision (0-10%), \( Au + Au \) at RHIC with \( \sqrt{s} = 200 \) GeV and \( Pb + Pb \) at LHC with \( \sqrt{s} = 2.76 \) TeV.

2. Hadronization via Coalescence and Fragmentation

2.1. Fragmentation

The fragmentation is the dominant way to hadronize in ultra-relativistic proton-proton collisions. Fragmentation functions are not reliably calculable from first principles in QCD. However, they are observables and can be measured experimentally. In this case are used the Albino-Kniehl-Kramer (AKK) fragmentation function [12, 13].

As said before the hadron spectra at high transverse momentum are dominantly produced from minijet partons. The amount of energy loss of minijet partons is consistent with the scenario that they have traversed through a dense matter that consists of coloured quarks and gluons.

The recombination between minijet partons and thermal partons from the quark-gluon plasma is important for production of hadrons with intermediate transverse momentum, leading to comparable antiproton and pion yields in this momentum region as observed experimentally. It further predicts that the antiproton to pion ratio would decrease as their transverse momenta become large. In this high transverse momentum region, independent fragmentations of minijet partons dominate particle production and lead to a very small antiproton to pion ratio.

The hadron spectra are given by:

\[
\frac{dN_{\text{had}}}{d^2p_T dy} = \sum_{\text{jet}} \int dz \frac{dN_{\text{jet}}}{d^2p_T dy} \frac{D_{\text{had/jet}}(z, Q^2)}{z^2}
\]

where \( D \) are the partons fragmentation functions, \( z \) is the fraction of minijet momentum carried by the hadron and \( Q^2 = (p_{\text{had}}/2z)^2 \) is the momentum scale for the fragmentation process.

2.2. Coalescence

The coalescence approach is based on a Wigner function formalism. The hadron spectrum can be written as:

\[
\frac{dN_H}{d^2p_T} = g_H \int \prod_{i=1}^{n} \frac{d^3p_i}{(2\pi)^3E_i} p_i \cdot d\sigma_i f_q(x_i, p_i) f_H(x_i..x_n, p_i..p_n) \delta^{(2)} \left( P_T - \sum_{i=1}^{n} p_{T,i} \right)
\]

where \( f_H(x_i..x_n, p_i..p_n) \) is the Wigner distribution function and is the probability for \( n \) quark to form an hadron, \( d\sigma \) denotes an element of a space-like hypersurface, \( g_H \) is the probability of forming a color neutral object with the spin of the hadron considered from \( n \) coloured quarks.\n
The function \( f_q(x, p) \) is the covariant distribution functions of quarks (and antiquarks) in the space-time. The light hadrons Wigner function that is used is a sphere in both space and momentum, with radii \( \Delta_r \) and \( \Delta_p \), respectively, which in the Wigner formalism are related by \( \Delta_r \cdot \Delta_p = 1 \). For example, the meson wigner function is:

\[
f_{M}(x_1, x_2; p_1, p_2) = \frac{9\pi}{2(\Delta_r \Delta_p)^3} \Theta(\Delta_r^2 - (x_1 - x_2)^2)\Theta(\Delta_p^2 - (p_1 - p_2)^2 + (m_1 - m_2)^2)
\]

A good description of pion, kaon, proton, antiproton and \( \Lambda \) spectra can be obtained with a radius parameter \( \Delta_p = 0.19 \) GeV for mesons, 0.33 GeV for proton, 0.38 GeV for Lambdas, which in terms of mean square radius corresponds to take a slightly smaller radius for \( \Lambda \) as one can expect from the harmonic oscillator wave function, which has a width that scales with the inverse square root of the system reduced mass.
These multidimensional integrals are evaluated in the full 6D phase space by the Monte-Carlo method via test particle. In order to well describe the particle spectra, have been included some resonances decays. Is also taken in account the Boltzmann probability to produce an excited state with the statistical factor \( \exp(- (E_{H^*} - E_{H})/T) \), where \( E_{H^*} = (p_T + m_{H^*})^{1/2} \). Are also taken in account the degeneracy factors that come from different values of isospin and total angular momentum.

\[ \begin{align*}
\bullet \ \pi & \ (I=1, \ J=0) \\
& \quad - \ k^\ast \ (I=1, \ J=1/2); \ k^\ast \rightarrow k\pi \\
& \quad - \ \rho \ (I=1, \ J=1); \ \rho \rightarrow \pi\pi \\
& \quad - \ \Delta \ (I=3/2, \ J=3/2); \ \Delta \rightarrow N\pi \\
\bullet \ \Lambda(1116) & \ (I=0, \ J=1/2)
\end{align*} \]

3. Fireball parameters

In this study is considered a fireball of thermalized particles which includes light quarks, antiquarks and gluons at a temperature corresponding to \( T_c = 165 \) MeV, that is about the cross-over transition temperature [1, 14]. Partons position in transverse direction has a radial uniform expansion, the values obtained for this quantities are:

\[ \beta_{max} = 0.37, \ R_\perp = 8.7 \text{ fm}, \ \tau = 4.5 \text{ fm}/c \] at RHIC, and \( \beta_{max} = 0.60, \ R_\perp = 10.2 \text{ fm}, \ \tau = 7.8 \text{ fm}/c \) at LHC. We notice that such a values correspond in one unity of rapidity to a volume of \( V \sim 1100 \text{ fm}^3 \) at RHIC, while at LHC \( V \sim 2500 \text{ fm}^3 \), which means an increase of a bit more than a factor of two in agreement with the estimate from pion HBT interferometry [15]. For their longitudinal momentum distribution we assume boost-invariance, i.e. a uniform rapidity distribution in the rapidity range \( y \in (-0.5, +0.5) \).

For partons in the quark-gluon plasma we take a thermal distribution for transverse momenta up to \( p_0 = 2 \) GeV, in particular the momentum spectra for quark and antiquarks is given by:

\[ \frac{dN_{q,q}}{dT_{\perp} \ d^2 p_T} = \frac{g_{q,q} \tau m_{T}}{(2\pi)^3} \exp\left(-\frac{\gamma_T (m_T - p_T \cdot v_T \mp \mu_q)}{T}\right) \tag{4} \]

where \( g_q = g_{\bar{q}} = 6 \) are the spin-color degeneracy of light quarks and antiquarks, and the plus and plus signs are for quarks and antiquarks, respectively. The slope parameter \( T \) is taken to be \( T = 165 \) MeV. Masses of light quarks and antiquarks are taken to be \( m_{u,d,u,d} = 300 \) MeV and \( m_{s,s} = 475 \) GeV, similar to the masses of constituent quarks. For the quark chemical potential \( \mu_q \), we use a value of light antiquark to quark ratio which lead to the antiproton to proton ratio observed at midrapidity in heavy ion collisions experiments.

Partons at high transverse momenta (greater than 2 GeV), as said, are mainly from the minijets produced in initial hard collisions among nucleons. These spectra can be parametrized (Table 1...
Table 1. Parameters for minijet parton distributions at midrapidity from Au+Au at $\sqrt{s} = 200$ GeV

| $A[1/GeV^2]$ | $B[GeV]$ | $n$    |
|-------------|---------|-------|
| $g$        | $3.18 \cdot 10^4$ | 0.5   | 7.11 |
| $u,d$      | $9.79 \cdot 10^3$ | 0.5   | 6.84 |
| $\bar{u},\bar{d}$ | $1.89 \cdot 10^4$ | 0.5   | 7.59 |
| $s$        | $6.51 \cdot 10^3$ | 0.5   | 7.36 |
| $\bar{s}$  | $8.02 \cdot 10^3$ | 0.5   | 7.57 |

Table 2. Parameters for minijet parton distributions at midrapidity from Pb-Pb at $\sqrt{s} = 2.76$ TeV

| $A_1$  | $A_2$  | $A_3$  | $A_4$  | $A_5$  | $A_6$  |
|--------|--------|--------|--------|--------|--------|
| $g$    | 23.46  | 4.84   | 8.08   | 2.78   | 2.79   | 2.31   |
| quark  | 24.68  | 5.11   | 8.01   | 0.55   | 5.65   | 2.56   |

and Table 2) at RHIC (left equation) and at LHC (right equation) as

$$\frac{dN_{jet}}{d^2p_T} = A \left( \frac{B}{B + p_T} \right)^n$$

$$\frac{dN_{jet}}{d^2p_T} = A_1 \left[ 1 + \left( \frac{p_T}{A_2} \right)^2 \right] A_3 + A_4 \left[ 1 + \left( \frac{p_T}{A_5} \right)^2 \right] A_6$$

4. Spectra at RHIC and LHC

4.1. RHIC

We start with comparing the results obtained using the coalescence model with the spectra at RHIC in Au+Au collisions at $\sqrt{s} = 200$ GeV.

In Fig.1 we show the transverse momentum spectrum of pions, we can see that an important contribution comes from the decays, in particular especially at low momenta the dominant one comes from $\rho$, in a region up to about $p_T \sim 3$ GeV, which is, also, the region anyway the fragmentation is starting to take over. The contribution from $K^*$ and $\Delta$ are less relevant and only contribute to some little better description at very low momenta. It is known that for pions almost all the hadrons contribute to the feed-down, but in the region we are interested in, the resonances included are sufficient to have a good description for the spectra at $p_T < 1$ GeV.

Figure 1. Pion transverse momentum spectrum at RHIC in Au+Au collisions at $\sqrt{s} = 200$ GeV. Experimental data from PHENIX [16] [17]

Figure 2. Antiproton transverse momentum spectrum at RHIC in Au+Au collisions at $\sqrt{s} = 200$ GeV. Experimental data from PHENIX [16].
Can be seen that the production from coalescence and fragmentation becomes about similar for $p_T \sim 3.5$ GeV. In Fig.2 is shown the antiproton spectrum at RHIC. We show the relative contribution from coalescence and fragmentation by orange dashed line and brown dashed line respectively. We notice that for anti-protons the two mechanism become comparable at $p_T \sim 5$ GeV, that is a significant shift for protons with respect to pions. The description appears to be quite good. In Fig.3 we see that, also here, at low $p_T$ the contribution from decay becomes important. $K^*$ contribution is necessary in order to have a correct slope of the spectrum. For the $\Lambda$, in Fig.4, there are indeed several hadronic state that have a significant contribution in the yield that comes from decays. We have included the closest resonances with their decay channel and the pertinent branching ratios (B.R.), as said above. Also for Lambdas the spectrum is correctly described in a wide range of $p_T$. We also find, similarly to the anti-proton, that the contribution from independent fragmentation becomes dominate at $p_T > 6$ GeV.

We can see in Fig.5 and Fig.6 that the ratios $\bar{p}/\pi^-$, $\Lambda/K$ are well predicted, from the rise at

**Figure 3.** Kaon production at RHIC from Au+Au collisions at $\sqrt{s} = 200$ GeV. Experimental data from PHENIX [16], STAR [18].

**Figure 4.** $\Lambda$ production at RHIC from Au+Au collisions at $\sqrt{s} = 200$ GeV. Experimental data from STAR [19].

**Figure 5.** Lambda to kaon ratio at RHIC from Au+Au collisions at $\sqrt{s} = 200$ GeV. The model prediction is the solid line. STAR data by circles [20].

**Figure 6.** Particles ratio at RHIC from Au+Au collisions at $\sqrt{s} = 200$ GeV. Data from PHENIX [16] and STAR [18].
low $p_T$ up to the peak region and then the falling-down behaviour. However in both cases it is clear that in the region of $p_T \sim 5 - 7$ GeV there is a lack of baryon yield. In Fig.6 is shown with the dashed line the result switching off the radial flow of the QGP matter. We can see how a coalescence model without radial flow could not reproduce the baryon over meson enhancement.

4.2. LHC

In Fig.7 is shown the transverse momentum spectrum for pions at LHC. The result obtained is quite in good agreement with the experimental data in all the transverse momentum region, except some lack of yield at very low $p_T$ due to absence of all the resonance that are not taken in account. The yields from coalescence and fragmentation cross each other at $p_T \sim 4$ GeV, which is about a shift of 1 GeV with respect to RHIC. This is due to the larger collective flow present at LHC. Because the effect of radial flow is to shift the hadrons that are formed with coalescence mechanism, to larger $p_T$. Already here, we can see a very good agreement of the $p_T$ distribution. The model is able to correctly predict the evolution, from RHIC to LHC, of the absolute yield and especially its $p_T$ shape. The proton momentum spectrum is shown in Fig.8, also here there is a very good agreement is for $p_T > 1$ GeV up to 5 GeV. At very low $p_T$ we have an overprediction for the yield. This discrepancy at LHC is more visible respect to RHIC case, and can be imputed to a larger expected annihilation of $p$ and $\bar{p}$, this process could explain the disagreement between the statistical model prediction and the experimental data. The crossing between fragmentation and coalescence yields occurs at $p_T \sim 6$ GeV, which is about a momentum 50% larger with respect to the pions and is a shift of about 1.5 GeV with respect to RHIC. In Fig.9 the $p_T$ distribution for $K$ is shown by the red solid line. Also here there is good agreement with the experimental data in the entire range of $p_T$. We can notice that in the region where coalescence and fragmentation are comparable, at RHIC for both pions and kaons there was some lack of yield, instead at LHC energy for both cases the agreement appears quite better. The $\Lambda$ spectrum at LHC, shown in Fig.10, is in good agreement for $p_T > 1$ GeV, in this case we have available data up to 9 GeV and this allows us to see that in the $p_T$ region where the fragmentation dominates, i.e. $p_T \sim 6 - 7$ GeV, there is some lack of yield.

The baryon over meson ratios at LHC are shown in Fig.11 and Fig.12, there is a good agreement with experimental data, especially in the peak region. The model overestimate the ratio in the low $p_T$ region, due to the production excess of $p$ and $\Lambda$. These ratios show also that in the region where fragmentation becomes dominant, as anticipated before, the description is...
not so good. It is interesting to notice that recombination of thermal partons with a high-$p_T$ minijet parton give an important contribution to reproduce well the ratio in the peak region, as shown by the black dashed curve in Fig.11. Fragmentation function for baryons in general, and in particular for $\Lambda$ are known not be very well constrained. In particular both at RHIC and at LHC seems that where in our approach coalescence becomes less important the spectrum from AKK fragmentation function appears too flat. Studies of in-medium fragmentation function can solve it or it could be that coalescence contribution should extend to large $p_T$ with respect to the present modeling. There are studies that, recently, investigate a process that within the coalescence plus fragmentation approach could be quite important in solving this issue [26, 27]. They essentially describe the in-medium fragmentation as a quark recombination of shower partons taking into account also the gluon splitting in quark pairs that recombine. This mechanism can produce a large contribution for baryons in the region of $p_T \sim 6$ GeV.

![Figure 9](image9.png)

**Figure 9.** Kaon transverse momentum spectrum at LHC in Pb+Pb collisions at $\sqrt{s} = 2.7$ TeV.[21, 23, 24].

![Figure 10](image10.png)

**Figure 10.** $\Lambda$ transverse momentum spectrum at LHC in Pb+Pb collisions at $\sqrt{s} = 2.7$ TeV. [23] [24].

![Figure 11](image11.png)

**Figure 11.** Lambda to kaon ratio in Pb+Pb collisions at $\sqrt{s} = 2.7$ TeV. [23]

![Figure 12](image12.png)

**Figure 12.** Proton to pion ratio in Pb+Pb collisions at $\sqrt{s} = 2.7$ TeV [25].
4.3. Elliptic flow

The azimuthal distribution of the particle transverse momentum spectra, i.e. the probability of having a particle with a given transverse momentum $p_T$ and an azimuthal angle $\phi$, can be expressed in general in terms of the Fourier series $f(\phi, p_T) \propto 1 + 2 \sum_{n=1}^{\infty} v_n(p_T) \cos n\phi$ where $v_n$ denotes the $n$-th order momentum anisotropy, and $v_2$ coefficient is called elliptic flow. In the coalescence model, the meson (baryon) azimuthal distribution is given by the square (cubed) of the azimuthal distribution of parton $f(\phi)$, and can be expressed in Fourier series.

In Fig.13, we show the parton elliptic flow by dashed line together with the pion elliptic flow shown by green solid line and the proton elliptic flow given by blue solid curve. These are compared to data measured in ALICE experiment, shown by circles. For proton elliptic flow the contribution from fragmentation has not been taken into account. We notice that the maximum pion $v_2$ is about a factor of two times larger than the quark one, while the proton $v_2$ is almost a factor of 3 larger, in fact the coalescence process propagates the anisotropy of constituent quark at partonic level to hadronic level according with $v_2,M(p_T) \approx 2 v_2,q(p_T/2)$, $v_2,B(p_T) \approx 3 v_2,q(p_T/3)$ so the proton elliptic flow is greater than pion elliptic flow by a factor $\sim 3/2$, and a similar shift of the $p_T$ at which the $v_2$ reaches the maximum value. We can see, also, that the splitting between the pion and proton $v_2$ is well reproduced by the coalescence model.

It has been observed that due to local space fluctuation the angular distribution function of the hadron presents also a third-odd harmonics, $v_3 = \langle \cos 3\phi \rangle$. In Fig.14 parton $v_3$ relative to protons is shown by the dashed line while the $v_3$ relative to pion calculated in our model is given by the red solid line and $v_3$ for proton is indicated by the blue solid line. Experimental data by ALICE experiment are shown by circle, red for pions, blue for protons. We can see that both the large splitting in the $v_3$ of protons and pions as the location of the maximum are fairly well reproduced by the coalescence model.

5. Conclusions

The aim of this study has been to predict the evolution of the transverse momentum spectra from RHIC to LHC energy using the approach developed a decade ago used to investigate the RHIC data. In order to predict the feature at LHC no one adjustment of the coalescence parameter, like the width of Wigner function, has been made. The results obtained are in good agreement...
with the experimental data from LHC in a wide range of $p_T$. We also note that underlying such agreement a key role in the model is to ascribe to the radial flow of the QGP matter, a correct prediction of spectra and ratio is impossible without the effect due to radial flow. It appear that the independent fragmentation approach (at least using the AKK) gives too hard spectra at least up to $p_T \simeq 8$ GeV. The result seem to point to the need of an in-medium fragmentation process a result that is in agreement with the first results of a shower recombination of quarks from gluon decays. We remind that the coalescence has played an important role in the discussion about the QGP properties, in particular in the study of the anisotropy in the angular emission primarily measured by the so-called elliptic flow. Considering the elliptic flows as function of transverse momentum the coalescence model reproduces the observed splitting of pion and proton elliptic flow. We have extended the coalescence model to include also the next order harmonics of anisotropic flow, the $v_3$ coefficient. The predictions of our model for the $v_3$ harmonic present a splitting of pion and proton $v_3$ quite close to the one measured experimentally. A more realistic approach to coalescence in three dimension with radial flow correlations, finite hadronic wave function widths and resonance decays shows a relevant quark scaling breaking. At LHC appeared clearly that such a symmetry is broken by local space fluctuations but a quantitative approach requires an extension of the present approach to an event-by-event Monte Carlo approach.

[1] Y. Aoki, G. Endrodi, Z. Fodor, S. Katz, and K. Szabo, Nature 443, 675 (2006), hep-lat/0611014.
[2] STAR Collaboration, J. Adams et al., Phys.Rev. C72, 014904 (2005), nucl-ex/0409033.
[3] STAR Collaboration, J. Adams et al., Phys.Rev.Lett. 95, 122301 (2005), nucl-ex/0504022.
[4] PHENIX Collaboration, S. Adler et al., Phys.Rev.Lett. 91, 182301 (2003), nucl-ex/0305013.
[5] R. Fries, B. Muller, C. Nonaka, and S. Bass, Phys.Rev.Lett. 90, 202303 (2003), nucl-th/0301087.
[6] V. Greco, C. Ko, and P. Levai, Phys.Rev.Lett. 90, 202302 (2003), nucl-th/0301093.
[7] V. Greco, C. Ko, and P. Levai, Phys.Rev. C68, 034904 (2003), nucl-th/0305024.
[8] R. Fries, B. Muller, C. Nonaka, and S. Bass, Phys.Rev. C68, 044902 (2003), nucl-th/0306027.
[9] D. Mohar and S. A. Voloshin, Phys. Rev. Lett. 91, 092301 (2003), nucl-th/0302014.
[10] T. Biro, P. Levai, and J. Zimanyi, Phys.Lett. B347, 6 (1995).
[11] T. Biro, P. Levai, and J. Zimanyi, Phys.Rev. C59, 1574 (1999), hep-ph/9807303.
[12] S. Albino, B. Kniehl, and G. Kramer, Nucl.Phys. B725, 181 (2005), hep-ph/0502188.
[13] S. Albino, B. Kniehl, and G. Kramer, Nucl.Phys. B803, 42 (2008), 0803.2768.
[14] S. Borsanyi et al., JHEP 1011, 077 (2010), 1007.2580.
[15] ALICE Collaboration, K. Aamodt et al., Phys.Lett. B696, 328 (2011), 1012.4035.
[16] PHENIX Collaboration, S. Adler et al., Phys.Rev. C69, 034909 (2004), nucl-ex/0307022.
[17] PHENIX Collaboration, S. Adler et al., Phys.Rev.Lett. 91, 072301 (2003), nucl-ex/0304022.
[18] STAR Collaboration, G. Agakishiev et al., Phys.Rev.Lett. 108, 072302 (2012), 1110.0579.
[19] STAR Collaboration, J. Adams et al., Phys.Rev.Lett. 98, 062301 (2007), nucl-ex/0606014.
[20] STAR Collaboration, G. Agakishiev et al., Phys.Rev.Lett. 108, 072301 (2012), 1107.2955.
[21] ALICE Collaboration, B. Abelev et al., Phys.Rev.Lett. 109, 252301 (2012), 1208.1974.
[22] ALICE Collaboration, Abelev, Betty Bezverkhny and others, Eur.Phys.J. C74 (2014) 3108,1405.3794.
[23] ALICE Collaboration, Abelev, Betty Bezverkhny and others, Phys.Rev.Lett. 111, 222301 (2013),1307.5530.
[24] ALICE, D. Chinellato, J.Phys.Conf.Ser. 446, 012055 (2013), 1211.7298.
[25] ALICE Collaboration, Abelev, Betty Bezverkhny and others, Phys.Lett B736, 196-207 (2014), 1401.1250
[26] K. C. Han, R. J. Fries, and C. M. Ko, J.Phys.Conf.Ser. 420, 012041 (2013), 1209.1141.
[27] C. M. Ko, Talk at 3rd Non Equilibrium Dynamics and TURIC Workshop (http://fias.uni-frankfurt.de/crete2014/talks/13/Ko.pdf), 13 June 2014, Crete.
[28] ALICE Collaboration, Abelev, Betty and others, Phys.Lett B719, 18-28 (2013), 1205.5761