DRAFT 00-002

Contributions from the PWG1 groups:
MexNICA team: ....
SPbSU team: ....
INR team: ....
MePHI team: ......

(Dated: January 20, 2020)

B. KEY FIRST-DAY OBSERVABLES

Introduction

The diversity of the experimental landscape of relativistic heavy-ion collisions data, obtained at the AGS, SPS, RHIC and LHC, is already quite rich and impressive. One may start here with referring to the studies of NA49 collaboration at SPS [1] in investigations of the phase diagram of strongly interacting matter which were continued later by a pioneering two-dimensional scan in collision and size of colliding nuclei by NA61/SHINE [2], [3], [4]. Considerable amount of data were collected in the very first three years of RHIC operation by BRAHMS, PHOBOS, PHENIX and STAR experiments [5], [6], [7], [8]. The main scientific goals of the Beam Energy Scan (BES) at RHIC included the search for the onset of the deconfinement and scan of the phase diagram with variable collision energy from 200 GeV down to a few GeV [9, 10]. The BES program produced a wealth of results to describe the bulk properties of the medium created in Au+Au reactions for $\sqrt{s_{\rm NN}}$=7.7, 11.5, 19.6, 27, 39, 62.4 and 200 GeV [9] by measuring identified hadrons p_T spectra at mid rapidity. The new experimental program planned at high intensity NICA beams will bring deeper insight into the dynamics of hadronic interactions and multiparticle production mechanisms in the expected high baryonic density regime.

The properties of the matter created in Au+Au collisions at NICA energies will be characterized on the event-by-event base by using a variety of different observables. The global quantities, such as multiplicity and transverse energy ($E_{\rm T}$) are considered as the main tools to reveal the energy density achieved in the collision. Naturally, these "the first-day" MPD/NICA key global observables, which can be measured with the initial data sample, are selected, first-of all, to check the reliability of the new experimental MPD set-up by comparison the results to the available world data. Secondly, these first-day global observables are expected to provide the basic information for more precise further physics studies relevant to the problems of quark confinement, transformation from hadronic degrees of freedom to the partonic ones and search of critical energy point of strongly interacting matter.

The Multi Purpose Detector (MPD) installation is designed as a 4π spectrometer capable to detect charged hadrons, electrons and photons in heavy-ion collisions at high luminosity in the energy range of the NICA collider. The first day measuremens are supposed to be done for Au+Au collisions at $\sqrt{s_{\rm NN}}$=10 GeV collision energy per pair of nucleons. The MPD installation will provide precise 3-D tracking and a high-performance particle identification (PID) system based on the time-of-flight measurements and calorimetry. Thus it is expected for the MPD to be operational to produce the event-by-event information on charged particle well measured tracks coming from the primary interaction vertex, the PID information and the number of participants. This will provide, on the event-by-event base, the wealth of data on yields of charged particles of different types, on multiplicity, transverse momenta and rapidity distributions as a function of collisions centrality.

Strategy for the first-day physics preparation: global observables.

It is proposed, for the purposes of measurement of "the first-day" MPD/NICA key global observables, to start with extensive simulations of charged hadron multiplicity production using the available MC event-generators. This will include also the particle identification studies. In preparation for "the first-day physics", an off-line strategy with both standalone generators (e.g. UrQMD, PHSD, SMASH, etc) and the tools of the MPDroot framework are supposed to be developed. This involves using the currently approved capabilities of the MPD, such as the Time of Flight (TOF) and the Time Projection Chamber (TPC). All this will enable reliably determine corrections and systematic errors of "the first-day physics" results.

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Event-by-event centrality determinarion for the first-day physics data is to be done following the general Glauber routine currently used by the HEP community. This is in order to be capable to make a proper compar-

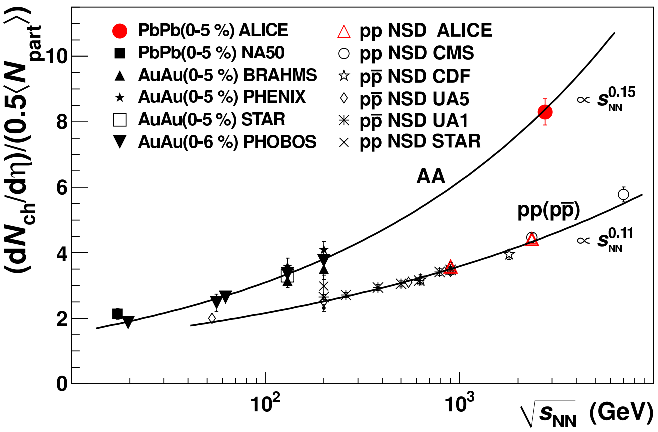

FIG. 1. Comparison of the 1st ALICE measurement of charged particle density at midrapidity with model predictions. Dashed lines group similar theoretical approaches. (See references in [11]).

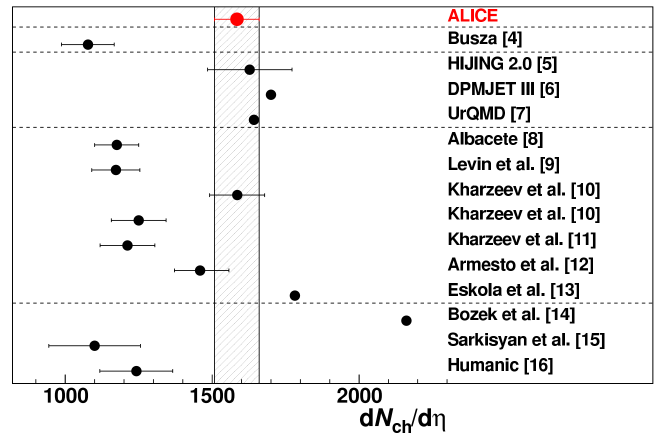

FIG. 2. Charged-particle pseudorapidity density per participant pair for central nucleus-nucleus and nonsingle diffractive pp (ppbar) collisions (see [11]). The solid lines are superimposed on the heavy-ion and pp (p-pbar) data, respectively [11]).

ison with the available data in similar terms.

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The MPD centrality determination is described in details in a separate document: `https://drive.google.com/file/d/1q32HGFImWHXCz_hYLxKh4PUGVWeR8YLQ/view?usp=sharing`

So, from the point of view of the PWG1 group, the first-day physics analysis should be concentrated on the multiplicity yields and on the ratios of identified charged hadrons as a function of collision centrality. The particle identification (PID) is considered as an important and challenging task that will definitely require special efforts.

Key observables: multiplicity yields and ratios of identified charged hadrons

In the past, theoretical models relevant to the multiplicity pseudorapidity density of charged particles created in hadronic collisions predicted a wide range of values for the highest available energies [11], as shown in Figure 1.

These results in the Figure 1 show that the charged particle density variable, measured at midrapidity in hadron collisions, is an important test of theoretical models, as the first global observable relevant to the energy density reached in the event.

The energy dependence of the charged particle density at midrapidity per participant pair for central nucleus-nucleus and nonsingle diffractive pp ($p\bar{p}$) collisions is shown in the Figure 2. The power-law behaviour is proved to be well established [11] in this wide energy range.

As to the region of decrease of collision energy, the overall trend for the charged-particle pseudorapidity density per participant pair for 5% central nucleus-nucleus colliisons – one may see that the normalised yieds in AA case are approaching the minimum bias pp data. This could be considered as an expected trend (for the behavior of global multiplicity observables) from the point of view of general decrease of possible collectivity effects with the decrease of collision energy. It is important to verify whether at NICA energies the charged-particle pseudorapidity density per participant pair for central nucleus-nucleus collisions follows the decreasing trend that has been determined to behave as ${s_{NN}}^{0.15}$, as defined in [11].

This information becomes particularly relevant as input for the thermal/statistical models [9] to find the freeze-out parameters describing the reaction in case of application of this model in the given energy domain. The Figure 3 below shows different phenomenological fitting functions that were used to fit the energy dependence of the normalized charged particle multiplicity density in pp and A+A collisions [12]. One may conclude that the additional high accuracy information from the MPD on the charged particle multiplicity density in Au+Au collisions at 10 GeV will be useful.

Studies of rapidity distributions of charged particle density vs. centrality will provide also the possibility to estimate the mean total multiplicity ($N_{\mathrm{ch}_{\mathrm{total}}}$) of charged particles produced in of Au+Au collisions at 10 GeV. Thus a new experimental information might be added to the existing data on $N_{\mathrm{ch}_{\mathrm{total}}}$ normalized to participant pair as a function of N_{part} for Au+Au collisions at different collision energies shown in the Figure 4 (see in [12]).

This practically flat behavior of $N_{\mathrm{ch}_{\mathrm{total}}}$ normalized to participant pair vs. N_{part} is a remarkable feature of A+A collisions at RHIS and SPS energies. The deviations are observed at the LHC, pointing at some peculiarities of

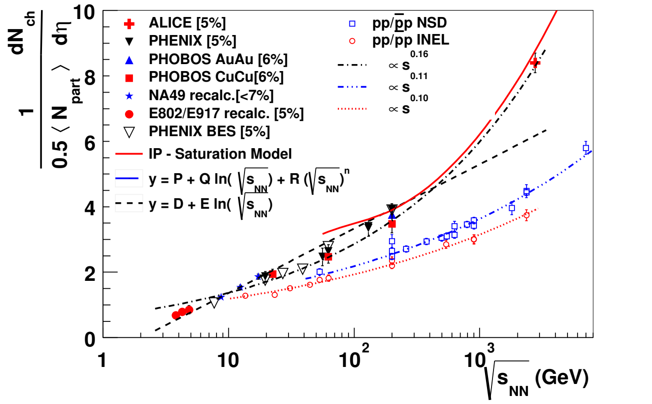

FIG. 3. Caption see [12]. Energy dependence of charged particle multiplicity density per participant pair for most central collisions at midrapidity. Compared are the corresponding measurements in p+p/$p+\bar{\mathrm{p}}$ NSD and INEL collisions, see in [12]

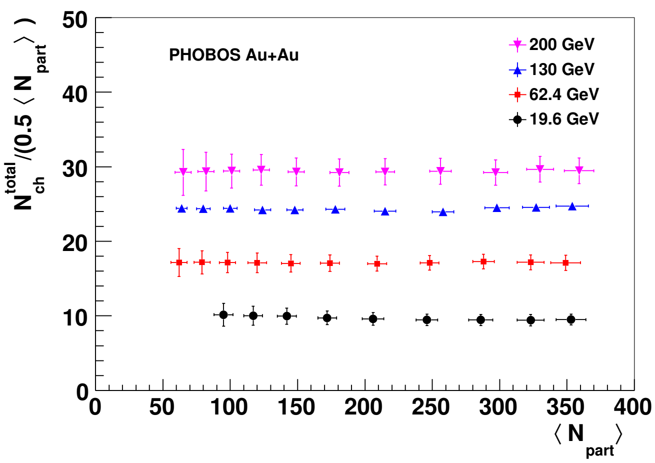

FIG. 4. By PHOBOS Collaboration. $N_{\mathrm{ch}_{\mathrm{total}}}$ normalized to participant pair as a function of N_{part} for Au+Au collisions at different collision energies. (See in [12]).

multiparticle production with the growing energy density in the interaction region (see [13]). So, the low-energy behavior of this observable $N_{\mathrm{ch}_{\mathrm{total}}}/(0.5N_{\mathrm{part}})$ is to be investigated.

Key observables: mean transverse energy per identified charged hadron

The particle identification (PID) is considered as an important and challenging task for MPD data analysis. It will definitely require special efforts, but it will allow to provide data for the transverse energy (E_{T}) determination. In particular, ratio of transverse energy and number of charged particles at midrapidity, i.e.

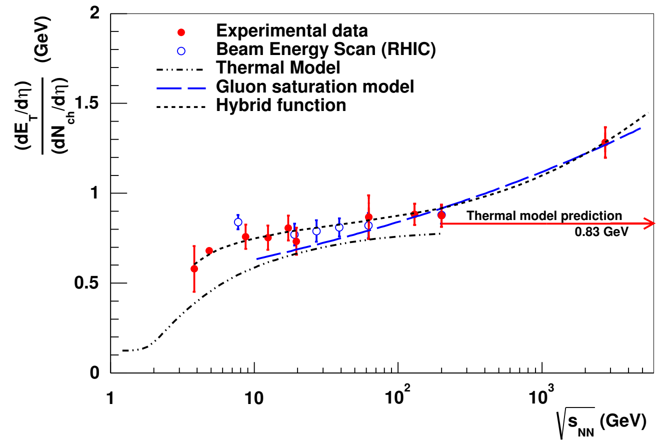

FIG. 5. The ratio of $dE_{\mathrm{T}}/d\eta$ and $dN_{\mathrm{ch}}/d\eta$ at midrapidity, as a function of center of mass energy. Experimental data are compared to the predictions from thermal model, gluon saturation model, and the estimations obtained in the framework of the hybrid model fitting to transverse energy and charged particle data, see in the overview paper [12]

the $(dE_{\mathrm{T}}/d\eta)/(dN_{\mathrm{ch}}/d\eta)$ observable could be measured in order to understand the underlying particle production mechanism. This $(dE_{\mathrm{T}}/d\eta)/(dN_{\mathrm{ch}}/d\eta)$ observable is known as global barometric measure of the internal pressure in the ultra-dense matter produced in heavy-ion collisions (see discussion in [12]. The example of energy dependence of this observable is shown below in Figure 5. Measurements of this observable at $\sqrt{s_{\mathrm{NN}}}$=10 GeV could bring more accurate estimate to discriminate theoretical predictions of thermal and gluon saturation models (see discussion in [12]).

Another peculiar phenomenon obtained at RHIC in the first 3 years study is a practically flat behaviour with centrality of this observable. The mean transverse energy (E_{T}) normalized to the charged particle multiplicity (N_{ch}), measured at RHIC vs. N_{part} , is shown in Figure 5. The Beam Energy Scan program at RHIC has produced a wealth of results to describe the bulk properties of the medium created in Au+Au reactions for $\sqrt{s_{\mathrm{NN}}}$=7.7, 11.5, 19.6, 27, 39, 62,4 and 200 GeV [9] by means of measuring detailed hadron p_T spectra at mid rapidity. The results of BES-1 program at $\sqrt{s_{\mathrm{NN}}}$=11.5 GeV (E_{T} vs. N_{part}) could be considered, on the one hand, as a starting reference point to compare the MPD data with BES. On the other hand, the additional new information could be obtained with the MPD data.

More accurate additional data could be obtained by the MPD for the ratio of transverse energy and number of charged particles at midrapidity, i.e. for the $(dE_{\mathrm{T}}/d\eta)/(dN_{\mathrm{ch}}/d\eta)$ observable in order to understand the underlying particle production mechanism.

Summarising:

The following new measurements could be done by the

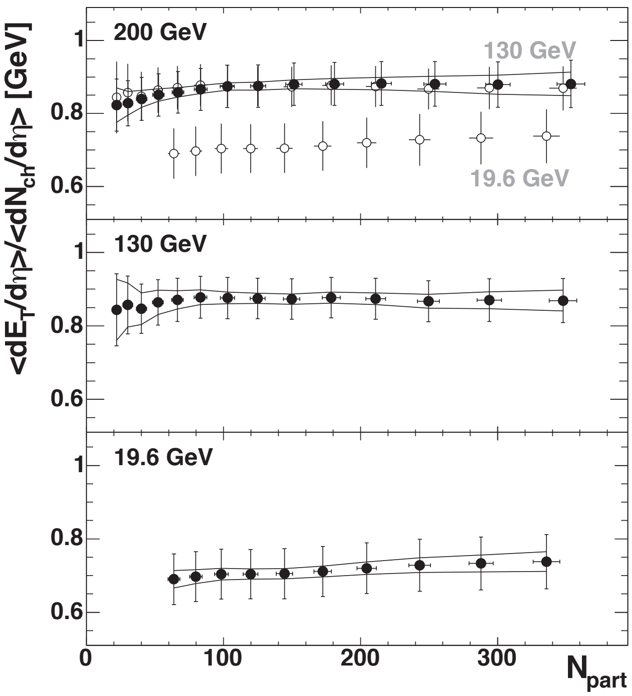

FIG. 6. The ratio of transverse energy density in pseudorapidity to charged particle density in pseudorapidity, at midrapidity; shown as a function of centrality, represented by the number of nucleons participating in the collision, $N_{\rm part}$, for three different RHIC beam energies [14].

MPD and the results for Au+Au collisions at 10 GeV could be added to the existing data:

1. measurements of the total normalized to participant pair as a function of $N_{\rm part}$ (to be added to the data of the Figures 3, 4)

2. measurements of mean transverse energy per identified charged hadrons (to be added to the data of the Figures 5, 6)

Key observables: particle yields (dN/dy) and ratios of identified charged hadrons

The still ongoing search for the onset of deconfinement and of the critical point of strongly interacting matter in AA collisions requires detailed measuremnets of yields and ratios of identified hadrons in AA collisions at NICA energy range.

dN/dy of $\pi\pm$, K$\pm$, and $p\bar{p}$, at midrapidity normalized by $\langle N_{\rm part}\rangle 2$ –are the observables that could be also considered as an object for the first day study in case of successful implementation and readiness with the PID analysis of the first MPD data.

The importance of h^-/h^+ ratios for the 1st day MPD measurements in Au+Au collisions at $\sqrt{s_{\rm NN}}$=10 GeV collision energy could be illustrated by the following example from RHIC at $\sqrt{s_{\rm NN}}$=11.5 GeV collision energy [15], see Figure 7:

The importance of these ratios, in particular, of π^-/π^+, K^-/K^+ are relevant here to the studies of charge transfer mechanism in reactions Au+Au at NICA energy. One may see the excess over 1.0 for π^-/π^+ ratio observed on Figure 7, left. This excess comes unexpectedly in view of positive charge presence at midrapiidity that occur due to baryon stopping mechanism in this energy domain. But it might be compensated in view of low values of K^-/K^+ measured for the same events. Thus we can conclude that the charge transfer mechanism could be relevant to the resonance decay dominating contribution and could be investigated by the MPD by using such observables like ratios of identified particles as a tool.

Key observables: number of participating nucleons ($N_{\rm part}$) and selection of centrality classses in Au-Au collisions

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Event-by-event centrality determinarion for the first-day physics data is to be done following the general Glauber routine currently used by the HEP community. This is in order to be capable to make a proper comparison with the available data in similar terms.

The MPD centrality determination is currently described in details in a separate document: `https://drive.google.com/file/d/1q32HGFImWHXCz_hYLxKh4PUGVWeR8YLQ/view?usp=sharing` . It could be added to the present chapter later at the nex stage of document preparation.

C. SUMMARY TIMELINE FOR FIRST-DAY PHYSICS RESULTS PUBLICATIONS

The following papers could be proposed from the PWG1:

1. Measurement of the charged particle pseudorapidity density in Au+Au collisions at 10 GeV at NICA/MPD.

2. Measurements of mean transverse energy per identified charged hadron as a function of $N_{\rm part}$ in Au+Au collisions at 10 GeV at NICA/MPD

3. Measurements of particle ratios at midrapidity in Au+Au collisions at 10 GeV as a function of centrality.

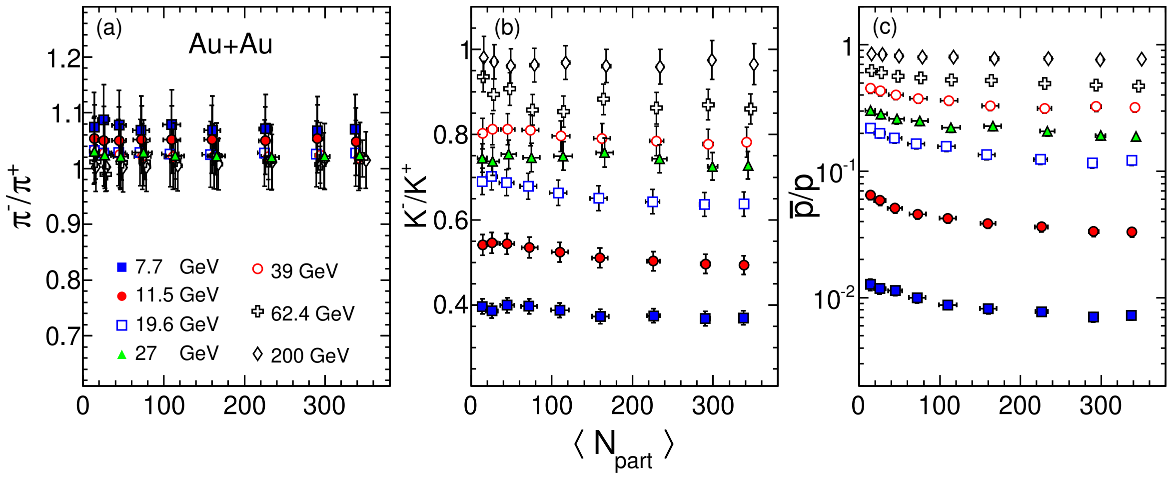

FIG. 7. Variation of (a) π^-/π^+, (b) $\mathrm{K}^-/\mathrm{K}^+$, and (c) $p\bar{p}$ ratios as a function of $\langle N_{\rm part}\rangle$ at midrapidity ($|y| < 0.1$) in Au+Au collisions at all BES energies. Also shown for comparison are the corresponding results in Au+Au collisions at $\sqrt{s_{\rm NN}} = 62.4$ and 200 GeV. See [9].

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