# Beam energy dependence of elliptic flow in relativistic heavy-ion collisions in hybrid models and scaling relations.

<u>A. Demanov</u>, P. Parfenov, A. Taranenko (NRNU MEPhI)

International School on Nuclear Physics and Engineering (NPhE-2020) November 19-20, 2020, Moscow

This work is supported by: the RFBR according to the research project No. 18-02-40086 and by Ministry of Science and Higher Education of the Russian Federation, No 0723-2020-0041.

## OUTLINE

- 1. Why measure anisotropic flow?
- 2. Anisotropic flow (v<sub>n</sub>), scaling relation and sQGP at RHIC/LHC
- 3. Elliptic flow results from Beam Energy Scan (RHIC) and comparison with hybrid models
- 4. Summary and Outlook

# Phase Diagram of the Strongly-Interacting Matter



**Top RHIC/LHC: validation of the cross over transition leading** 

n=2

n=3

n=4

- Top RHIC energy /LHC access to high T and small  $\mu_{R}$
- RHIC-BES/SPS/NICA/FAIR access to different systems and a broad domain of the  $(\mu_{B'}T)$ -plane



# **Anisotropic Collective Flow at top RHIC / LHC**



 $V_n(p_T, centrality)$  - sensitive to the early stages of collision. Important constraint for transport properties: EOS,  $\eta/s$ ,  $\zeta/s$ , etc.

**Mass ordering at p**<sub>T</sub> **< 2 GeV/c** (hydrodynamic flow, hadron rescattering)

Baryon/meson grouping at p<sub>T</sub> > 2 GeV/c (recombination/coalescence)

No difference between particles and antiparticles

Number of constituent quark (NCQ) scaling

#### **Goal of this work:**

Perform simulations with hybrid models (vHLLE+UrQMD and AMPT), analyse them as in the real experiment and make comparison with RHIC BES published measurements of  $v_2$  and test the number of constituent quark scaling.

# Analysis method: Event plane method (η-sub)



resolution

<u>The resulting values for event plane resolution for simulated events from hybrid</u> <u>models: vHLLE+UrQMD and AMPT are close to STAR experimental data.</u>

## vHLLE+UrQMD: Elliptic flow at top RHIC energy : $\sqrt{s_{NN}}$ 200 = GeV



UrQMD + 3D viscous hydro model vHLLE + UrQMD

Iurii Karpenko, Comput. Phys. Commun. 185 (2014), 3016 (<u>https://github.com/yukarpenko/vhlle</u>) Parameters: from Iu. A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher, Phys. Rev. C91 (2015) no.6, 064901 – good description of STAR BES results for  $v_2$  of inclusive charged hadrons (7.7 – 62.4 GeV)

Initial conditions: model UrQMD <u>QGP phase:</u> 3D viscous hydro (vHLLE) EOS (XPT) <u>Hadronic phase:</u> model UrQMD

# Reasonable agreement between results of vHLLE+UrQMD model and published PHENIX data for 200 GeV including KET/nq scaling

## vHLLE+UrQMD: $v_2$ of identified hadrons at RHIC BES ( $\sqrt{s_{NN}}$ = 27 GeV)

STAR data: Phys. Rev. C 93 (2016) 14907





- Reasonable agreement between vHLLE+UrQMD and data for charged pions and kaons
- Difference between results from vHLLE+UrQMD model and data for protons and antiprotons.
  Model predicts that v<sub>2</sub> (protons) < v<sub>2</sub> (antiprotons), data show v<sub>2</sub> (protons) > v<sub>2</sub> (antiprotons)

## AMPT: $v_2$ of identified hadrons at RHIC BES ( $\sqrt{s_{NN}}$ = 27 GeV)

STAR data: Phys. Rev. C 93 (2016) 14907



<u>A Multi-Phase Transport model (AMPT) for high-energy nuclear collisions.</u> The main source codes: Zi-Wei Lin (http://myweb.ecu.edu/linz/ampt/v1.26t9b/v2.26t9b) Z.W. Lin, C. M. Ko, B.A. Li, B. Zhang and S. Pal: Physical Review C 72, 064901 (2005).

Initial conditions: model HIJING QGP phase: Zhang's parton cascade for modeling partonic scatterings Hadronic phase: model ART



Difference between results from AMPT model SM and data for all particles – tunning of parameters? Model also predicts that  $v_2$  (protons) <  $v_2$  (antiprotons), data show  $v_2$  (protons) >  $v_2$  (antiprotons)

# Quality of $KE_T / n_q$ scaling : BES data and model data



NCQ scaling tests were performed for experimental and model data. NCQ scaling holds better in model data.

## Summary

• We performed a high statistics simulations with hybrid models (vHLLE+UrQMD and AMPT) for several points in collision energy from RHIC BES program.

• The events were analysed in a similar way as the real experimental data and results were compared with STAR published results of v2 for charged pions, kaons and (anti)protons.

• The results from vHLLE+UrQMD model are in a better agreement with experimental data than for AMPT (tunning of the input parameters?) Both models in the present configuration fails to reproduce the difference between elliptic flow signal of particles and antiparticles: models predict that  $v_2$  (protons) <  $v_2$  (antiprotons), data show  $v_2$  (protons) >  $v_2$  (antiprotons)

• Both models show good NCQ scaling test. NCQ scaling holds better in model data rather than the experimental one.

Thank you for your attention!

# Quality of $KE_T / n_q$ scaling : BES data



(c)

# Quality of $KE_T / n_q$ scaling : BES data

Star Data, Phys.Rev.C 93 (2016) 1, 014907



12