Evolution of anisotropic flow of produced particles from Au+Au collisions at $\sqrt{s_{NN}}$ = 3-200 GeV in a transport models.

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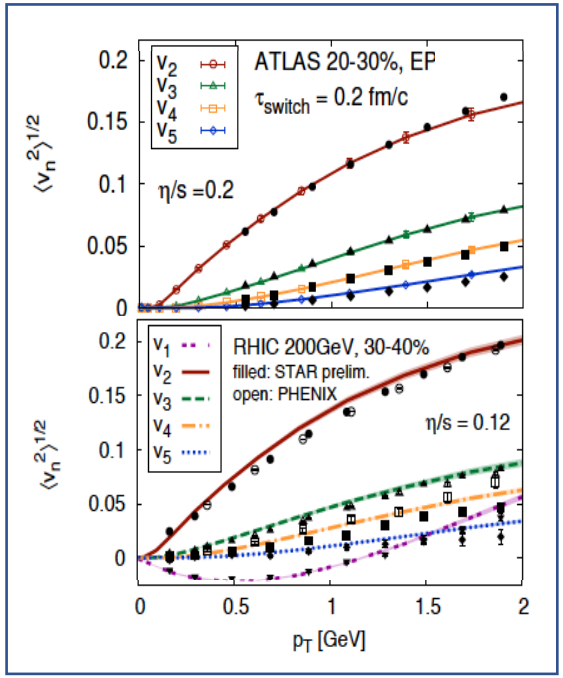
OUTLINE

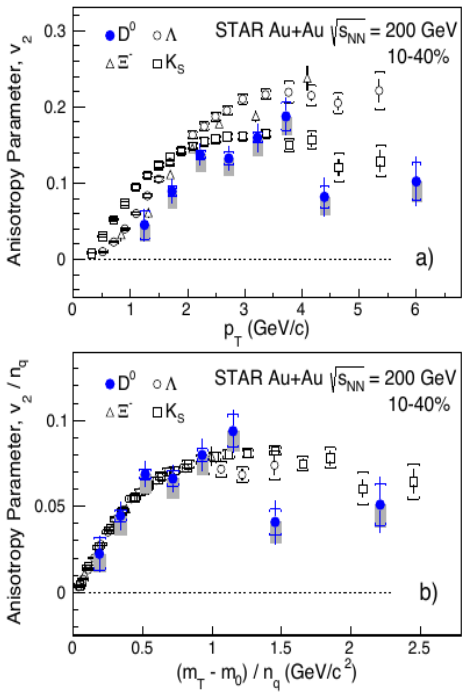
1. Why measure anisotropic flow?
2. Beam energy dependence of anisotropic flow. Models vs Data
3. What to expect for flow at NICA energies
4. Summary and outlook

Anisotropic Collective Flow at top RHIC / LHC

Initial eccentricity (and its attendant fluctuations) ε_n drive momentum anisotropy v_n with specific viscous modulation



Gale, Jeon, et al., Phys. Rev. Lett. 110, 012302



STAR PRL118 (2017) 212301

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

v_n of identified hadrons:

Mass ordering at p_T < 2 GeV/c
(hydrodynamic flow, hadron rescattering)

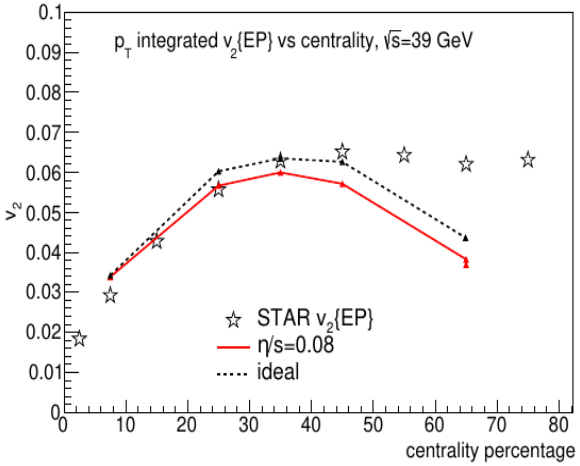
Baryon/meson grouping at p_T > 2 GeV/c
(recombination/coalescence),
Number of constituent quark (NCQ) scaling

No difference between particles and antiparticles

Hybrid models for anisotropic flow at RHIC/LHC

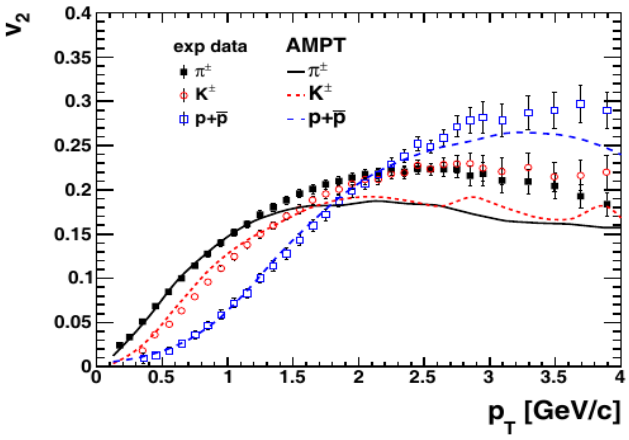
1) UrQMD + 3D viscous hydro model vHLLE + UrQMD

Iurii Karpenko, Comput. Phys. Commun. 185 (2014), 3016
https://github.com/yukarpenko/vhlle
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
QGP phase: 3D viscous hydro (vHLLE) with crossover EOS (XPT)
Hadronic phase: model UrQMD

2) A Multi-Phase Transport model (AMPT) for high-energy nuclear collisions. *The main source codes: Zi-Wei Lin (http://myweb.ecu.edu/linz/ampt/v1.26t9b/v2.26t9b)*



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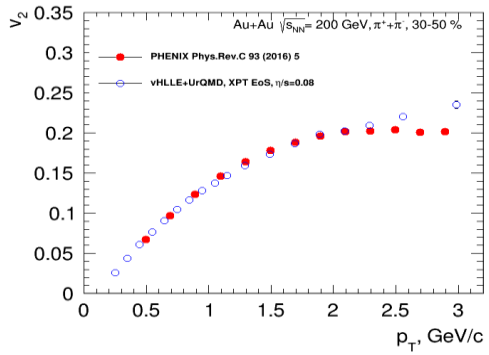
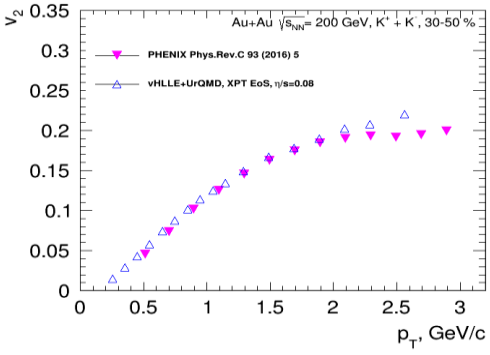
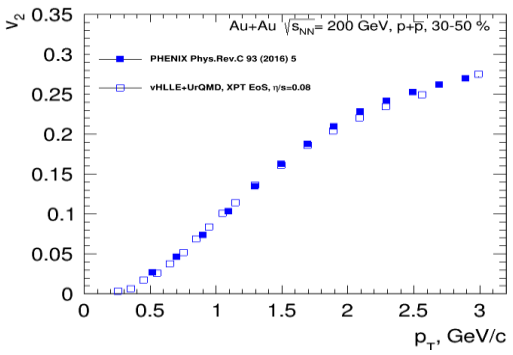
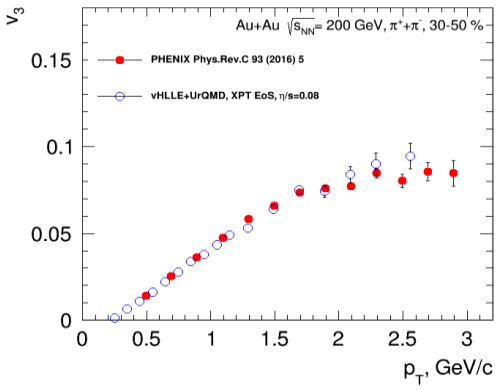
Z.W. Lin, C. M. Ko, B.A. Li, B. Zhang and S. Pal: Physical Review C 72, 064901 (2005).

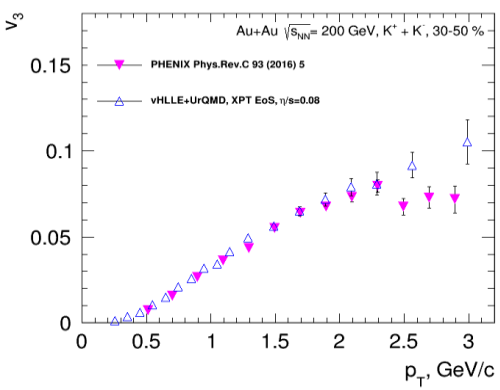
vHLLE+UrQMD: Elliptic and triangular flow in Au + Au collisions at 200 GeV

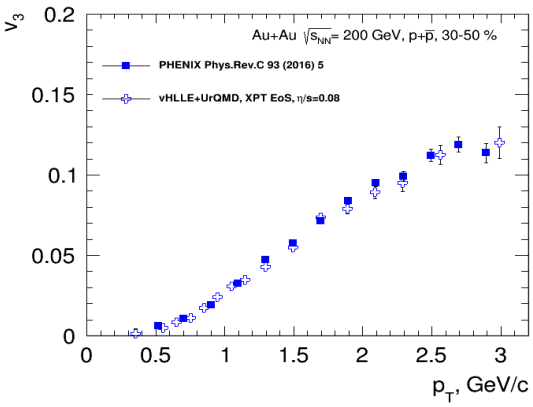








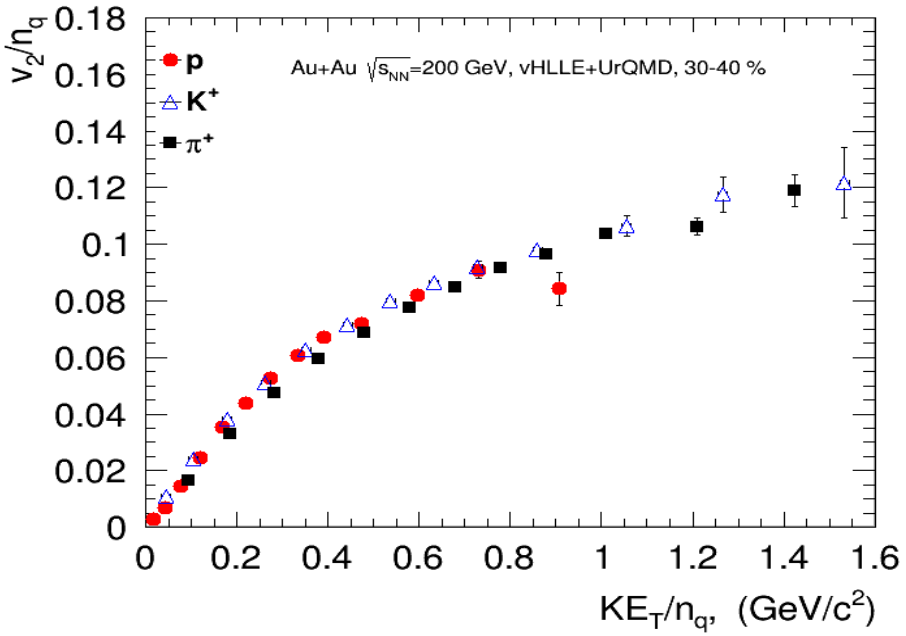


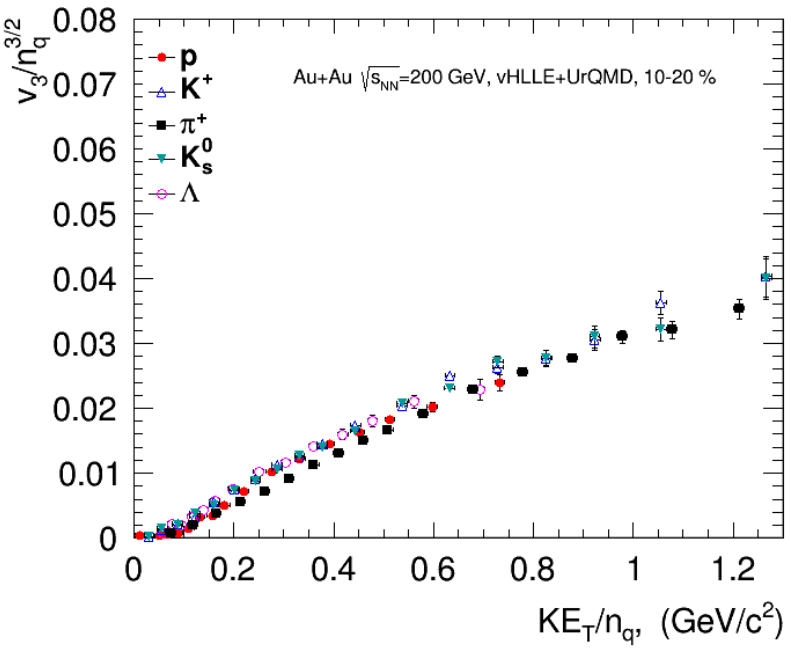


3D hydro model vHHLE + UrQMD (XPT EOS), $\eta/s = 0.08$ + param from Iu.A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher , Phys.Rev. C91 (2015) no.6, 064901

Reasonable agreement between results of vHLLE+UrQMD model and published PHENIX

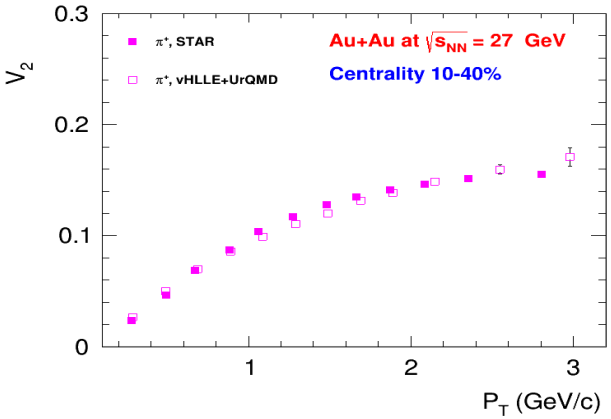
vHLLE+UrQMD: Scaling of elliptic and triangular flow at top RHIC energy

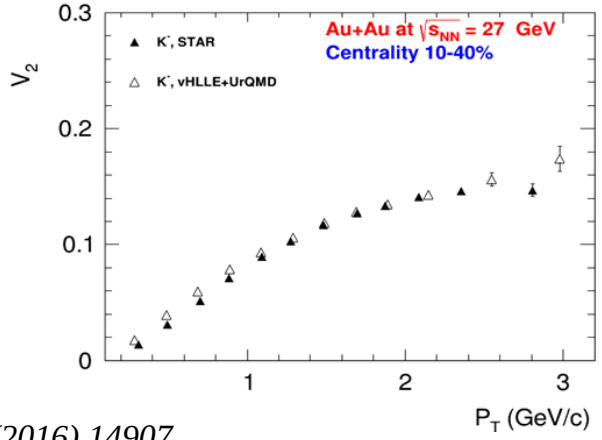




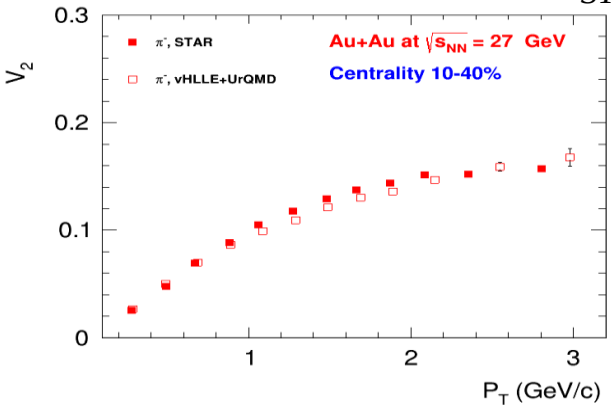
Reasonable agreement between results of vHLLE+UrQMD model and published PHENIX data for 200 GeV including KET/nq scaling

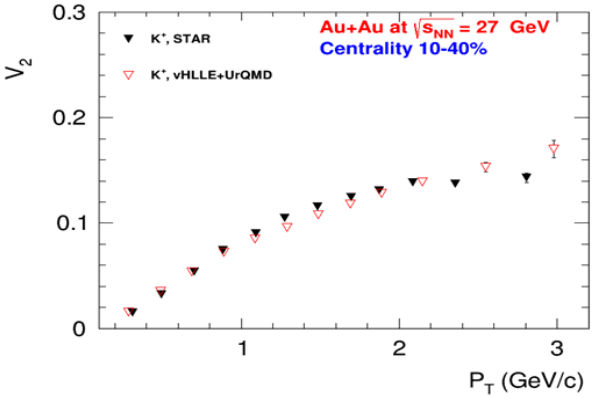
v_2 of charged mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV





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

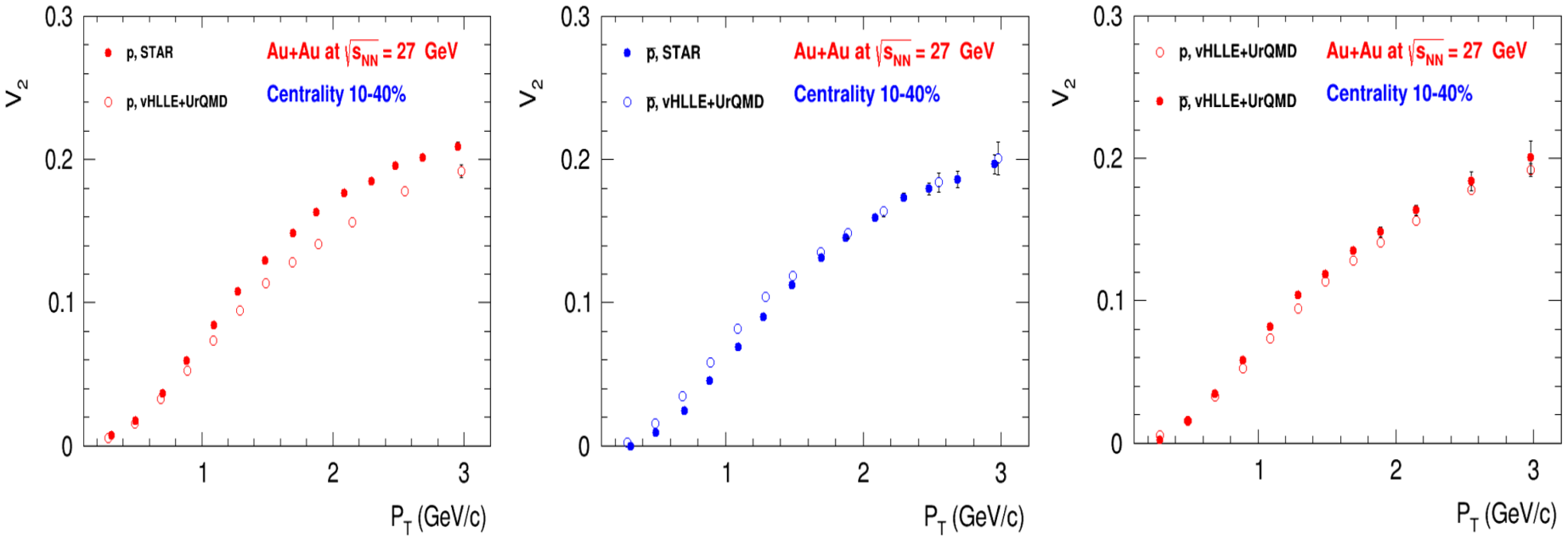




reasonable agreement between vHLLE+UrQMD and data for charged pions and kaons

v_2 of (anti)protons in Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV

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

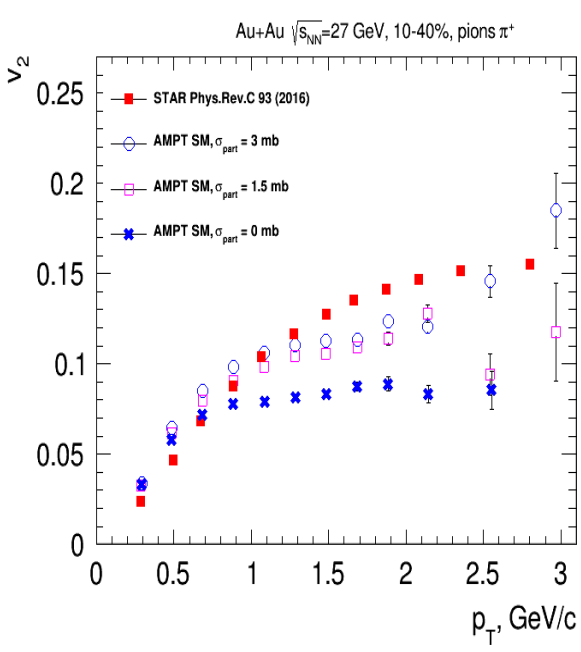


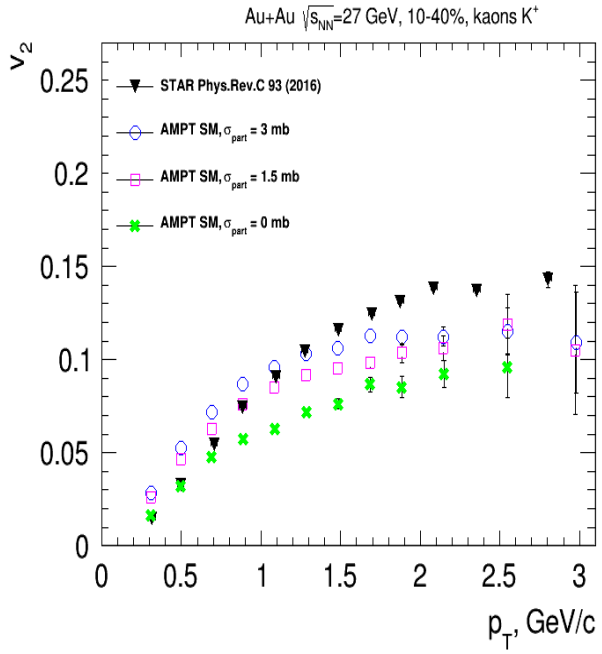
Difference between results from vHLLE+UrQMD model and data for protons and antiprotons

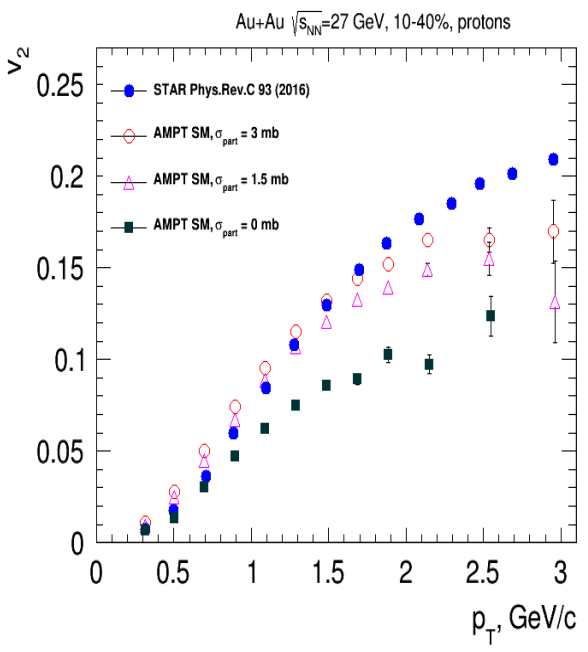
Model predicts that v_2 (protons) < v_2 (antiprotons) , data show v_2 (protons) > v_2 (antiprotons) and the difference is growing with decreasing of collision energy.

v_2 of identified charged hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV: AMPT vs Data

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





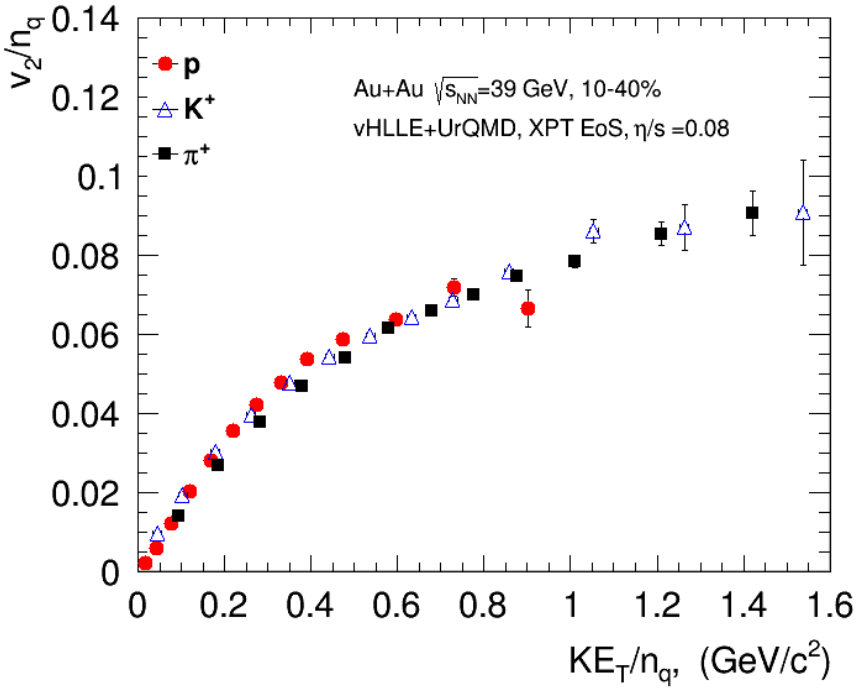


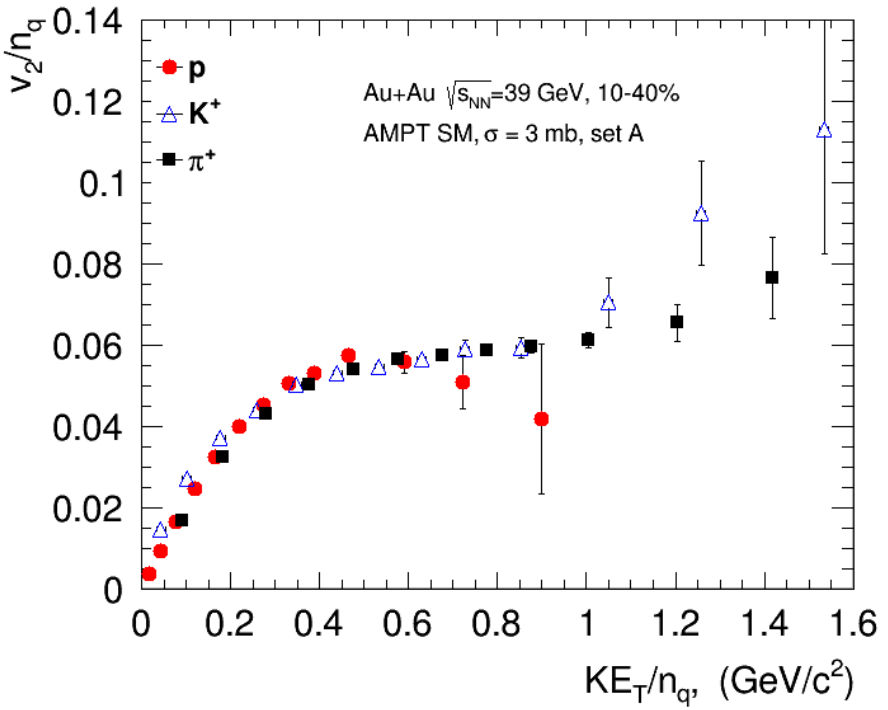
Difference between results from AMPT model SM and data for all particles – tunning of parameters?

Model also predicts that v_2 (protons) < v_2 (antiprotons) ,

data show v_2 (protons) > v_2 (antiprotons)

KE_T / n_q scaling : hybrid models





UrQMD + 3D viscous hydro model vHLLE + UrQMD

Iurii Karpenko, Comput. Phys. Commun. 185 (2014), 3016
https://github.com/yukarpenko/vhlle

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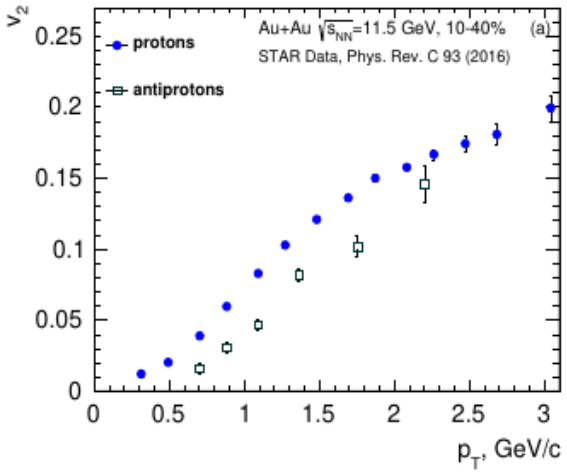
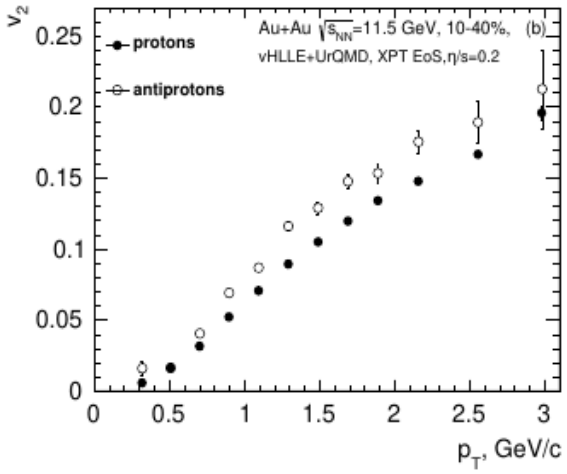
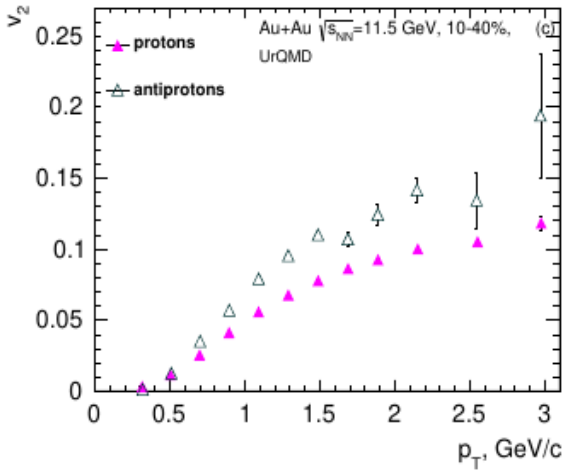
Elliptic flow: protons vs. antiprotons

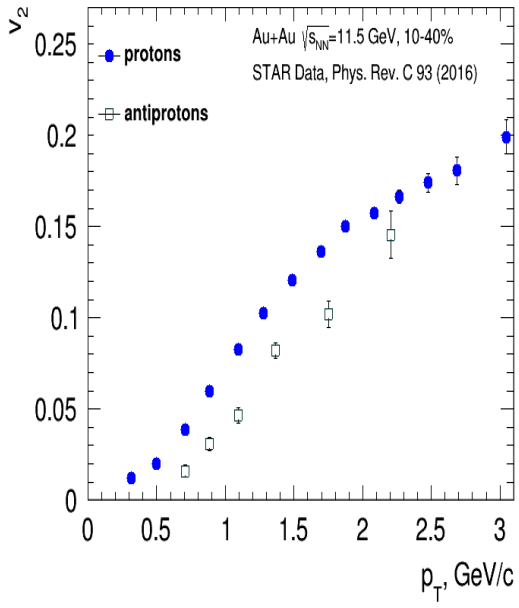


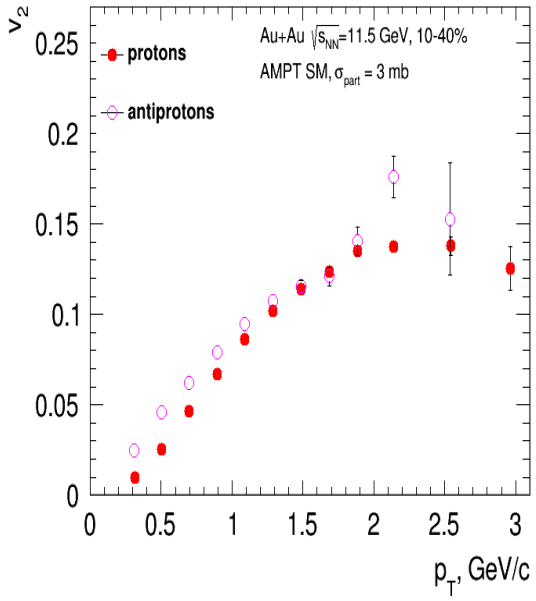


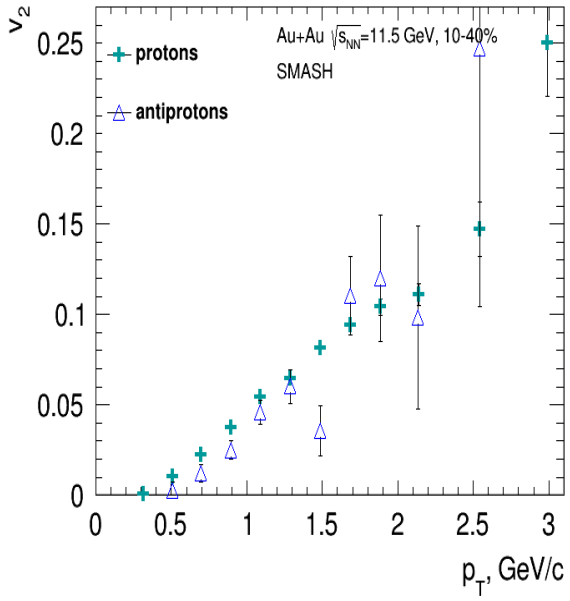


- Both vHLLE+UrQMD and UrQMD predict $v_2(p) < v_2(\bar{p})$ but experimental data shows $v_2(p) > v_2(\bar{p})$

Elliptic flow: protons vs. antiprotons

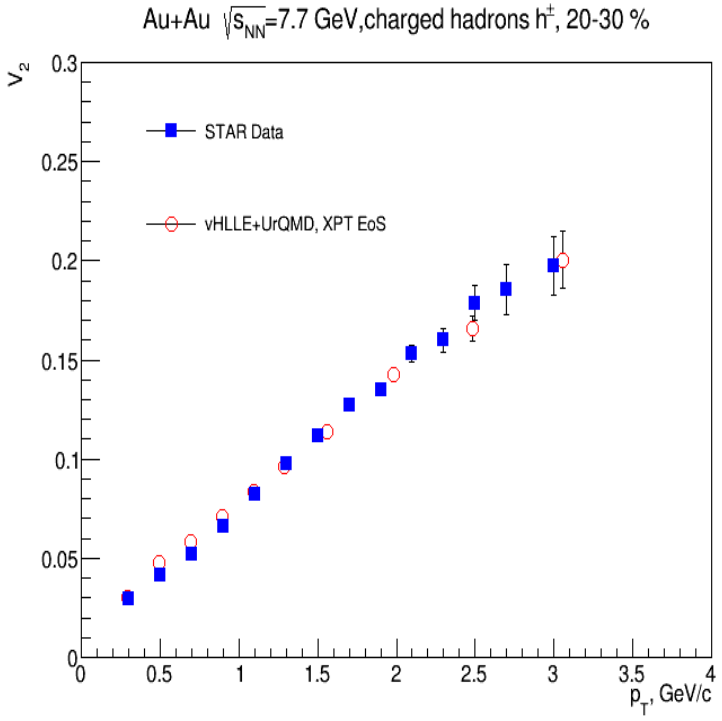


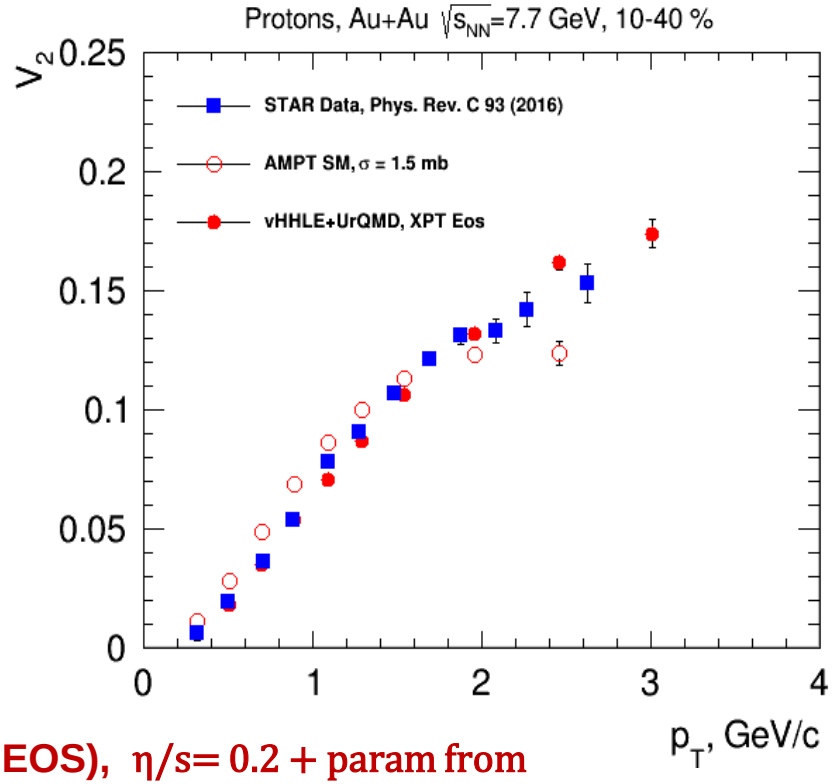




- The same trend is apparent in both UrQMD and AMPT
- SMASH gives a different trend – close to the data

Elliptic flow at NICA energies: Models vs Data comparison





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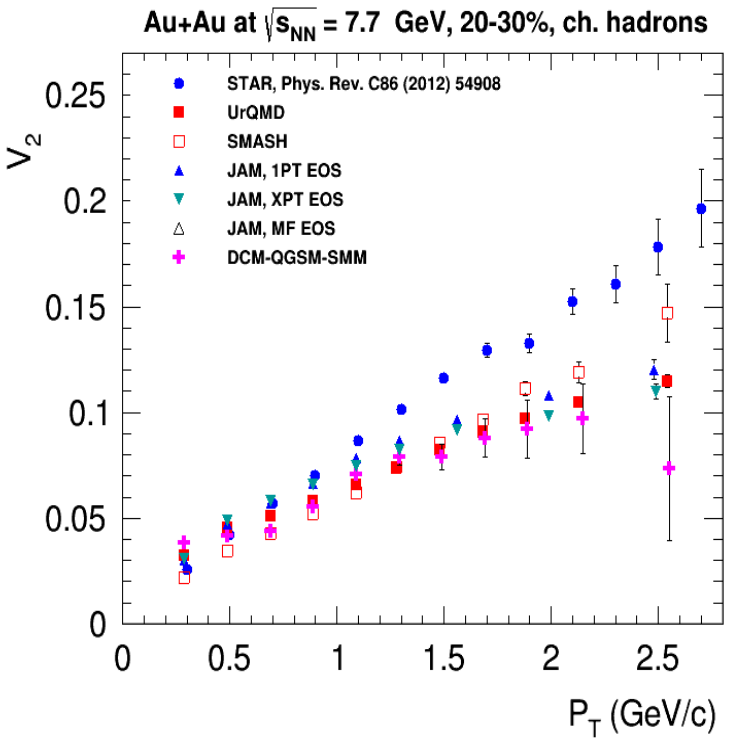
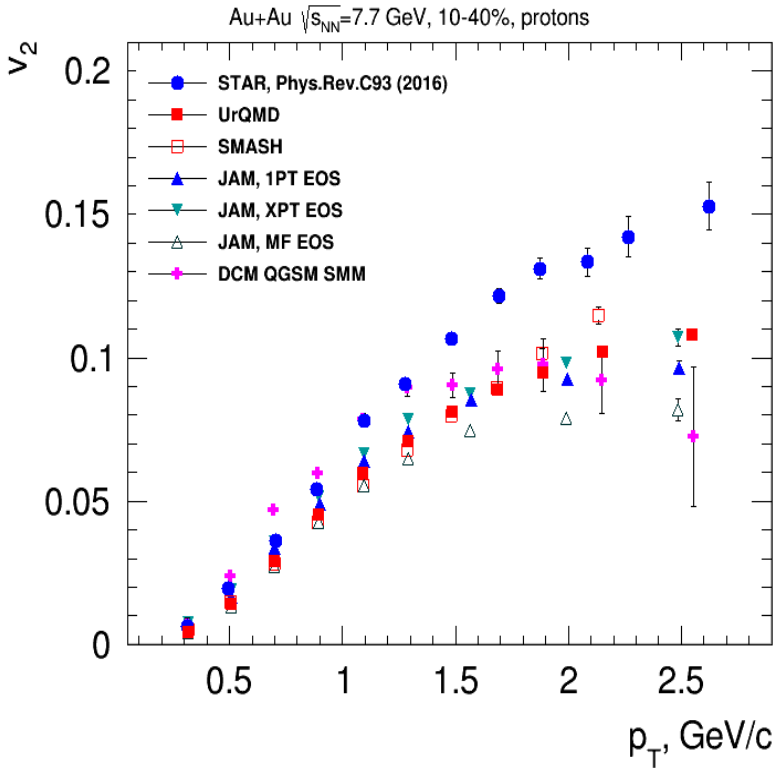
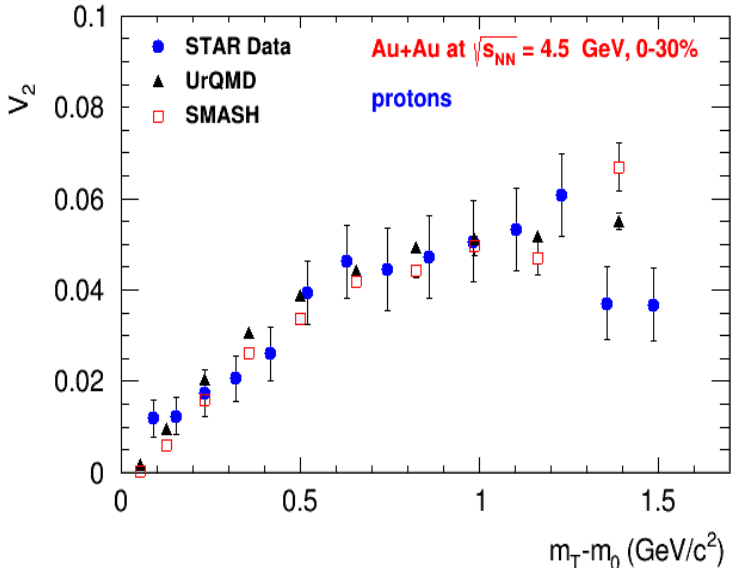
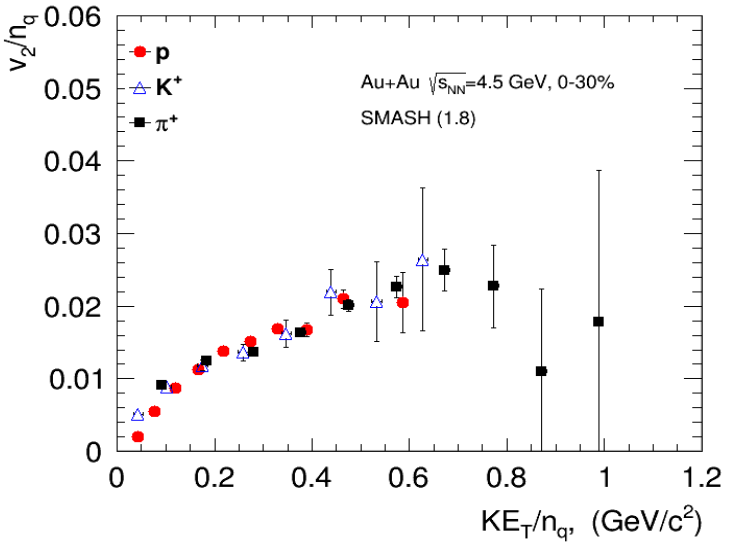


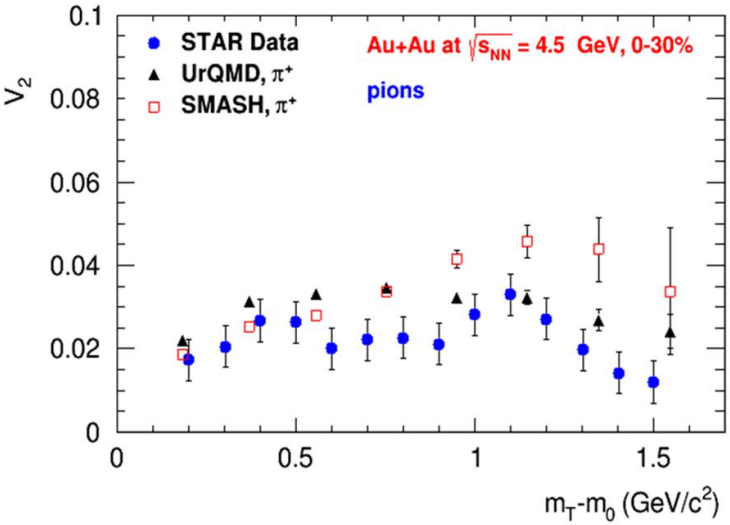


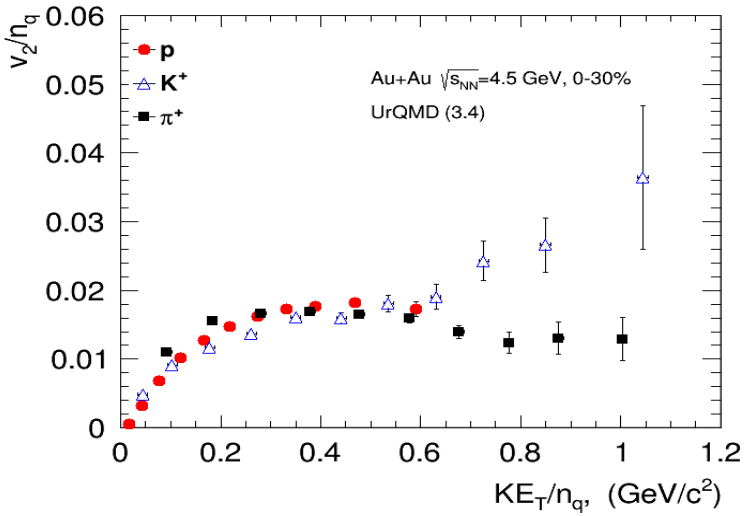
Pure String/Hadronic Cascade models give smaller v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=7.7 GeV and above

KE_T / n_q scaling : String/Hadronic Cascade models







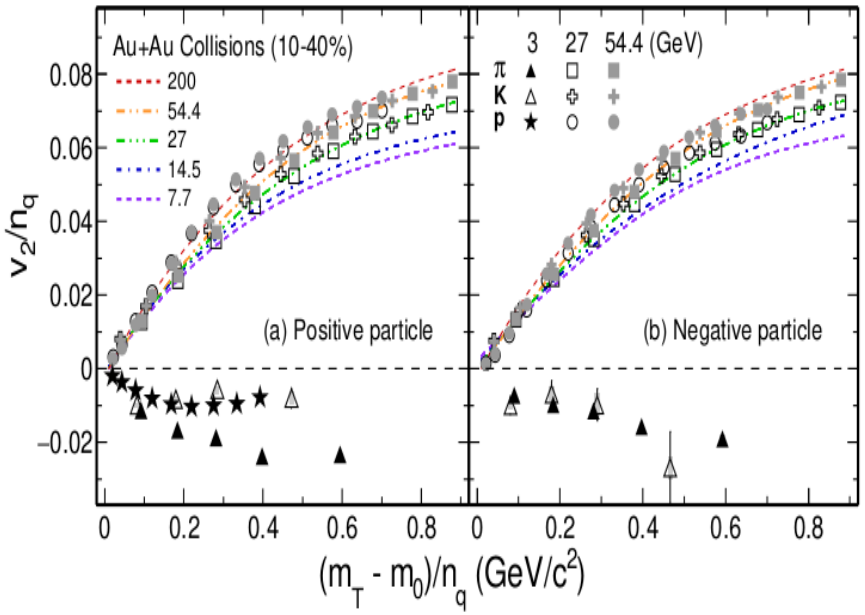


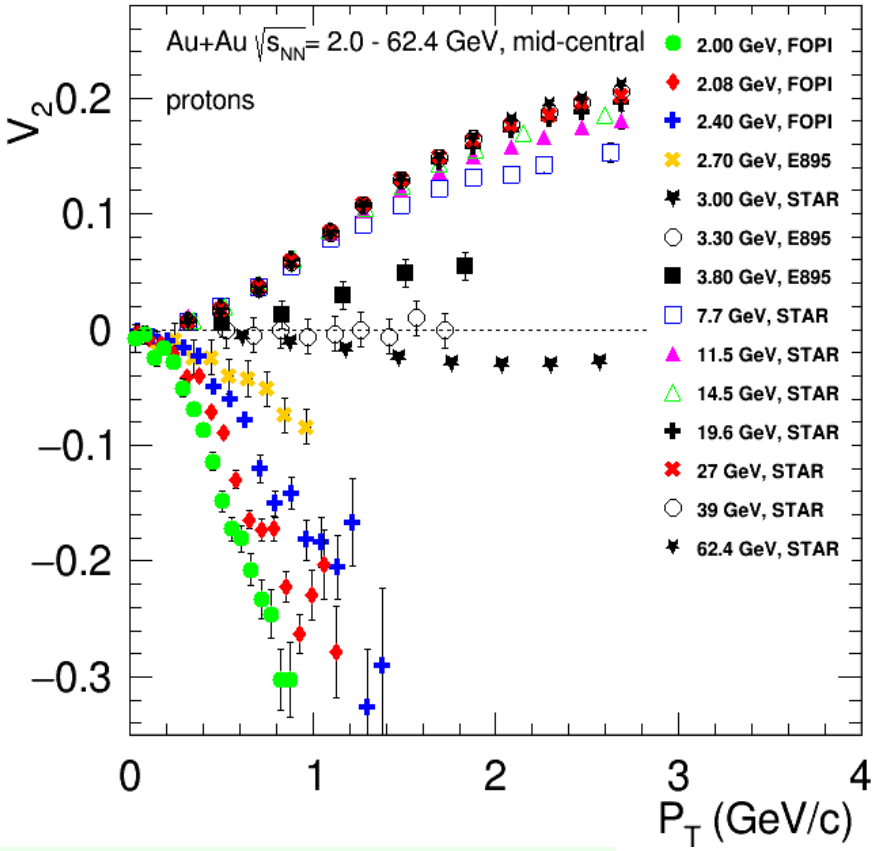
Pure String/Hadronic Cascade models give similar v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=4.5 GeV

Elliptic Flow at $\sqrt{s_{NN}}$ = 3 GeV : interactions with spectators

Disappearance of partonic collectivity in $\sqrt{s_{NN}}$ = 3 GeV Au+Au collisions at RHIC

STAR: https://arxiv.org/abs/2108.00908





Passage time: $2R/(\beta_{cm}\gamma_{cm})$

Expansion time: R/c_s , $c_s = c\sqrt{dp/d\varepsilon}$ - **speed of sound**

a delicate balance between (i) the ability of pressure developed early in the reaction zone and (ii) the passage time for removal of the shadowing by spectators

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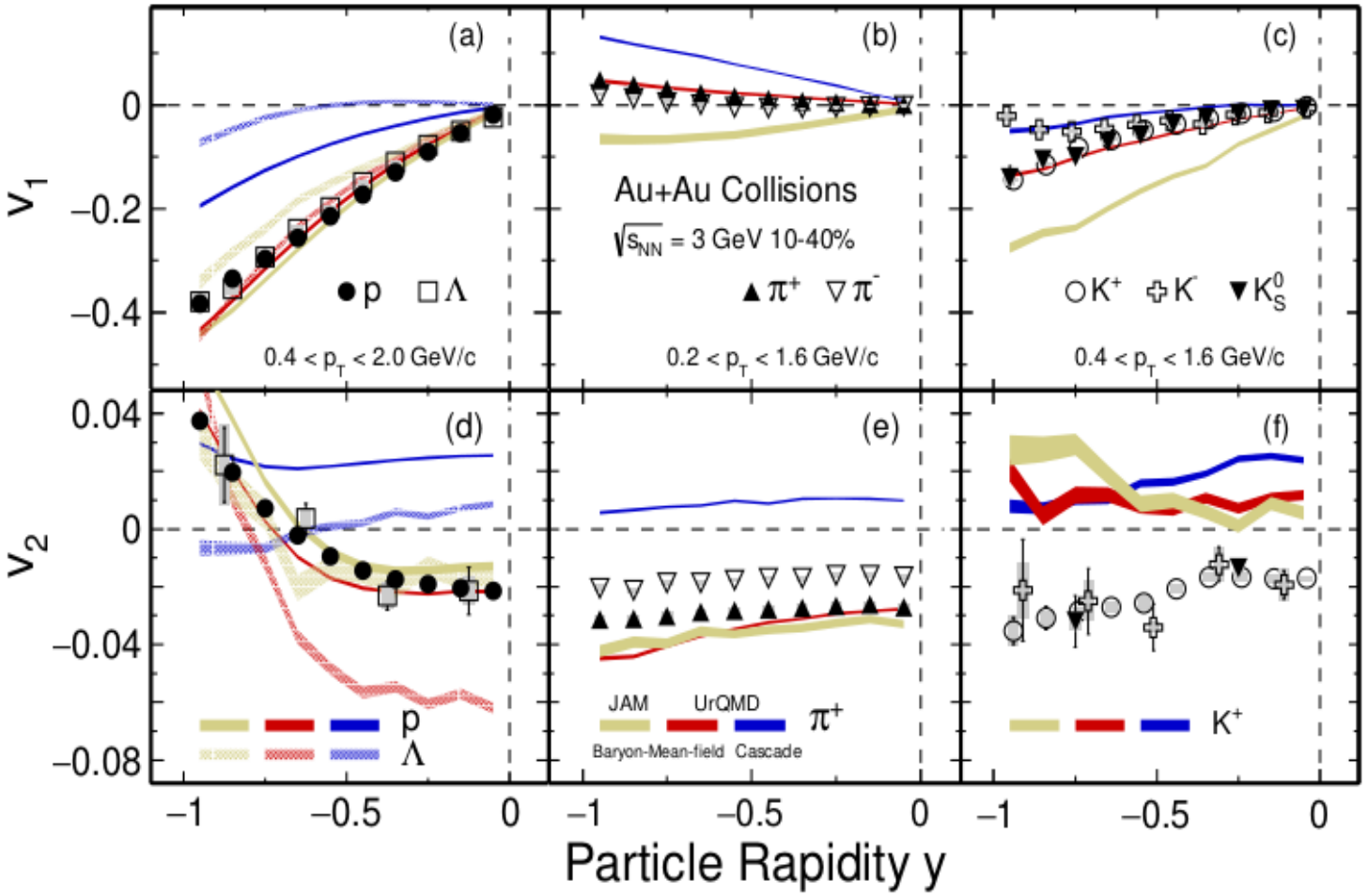

Summary

- 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 resuls 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)

Model/Data comparison for NICA energy range (4-11 GeV):

Pure String/Hadronic Cascade models (no QGP phase) give smaller v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=7.7-11.5 GeV and
models give similar v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=4.5 GeV.

v_2 signal of produced particles from Au+Au at $\sqrt{s_{NN}}$=3.0 GeV is negative – strong interactions of produced particles with spectators

Thank you for your attention!