Anisotropic flow of charged and identified hadrons at FAIR energies and its dependence on the nuclear equation of state

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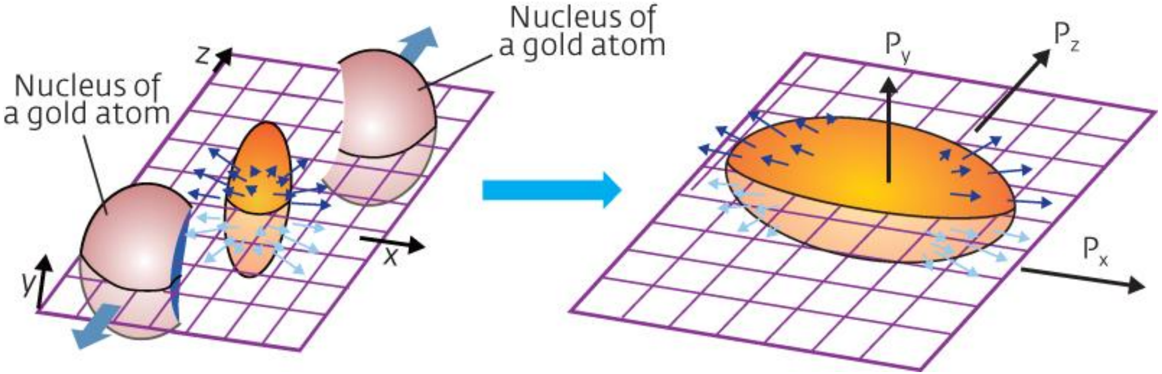
Outline

- Motivation
- UrQMD Model
- Results and discussions
- Conclusions

Motivation

- The azimuthal anisotropy of the final-state hadrons produced in the heavy ion collisions has long been considered as a deterministic probe to investigate collective effects in multi-particle production.
- At relatively higher energies, the collective flow is driven by pressure gradient which encodes the information about the underlying equation of state.



- In non-central AA collisions, the asymmetry of the momentum distributions of hadrons are quantified in terms of coefficients of Fourier expansion of the azimuthal distribution of the emitted particles as

$$v_n = < \cos[n(\phi - \Psi)] >$$

- Where ϕ and Ψ denote the azimuthal angle of the particle and reaction plane angle respectively and v_1, v_2,..... are the anisotropic flow coefficients.
- These observables are less explored at high baryon density regime on the QCD phase diagram

UrQMD model

- The Ultra-relativistic Quantum Molecular Dynamics (UrQMD) model is an event generator designed to simulate the high energy nucleus-nucleus collisions.

- In the transport (cascade) mode, the description of the heavy-ion reactions on the basis of an effective solution of the relativistic Boltzmann equation.

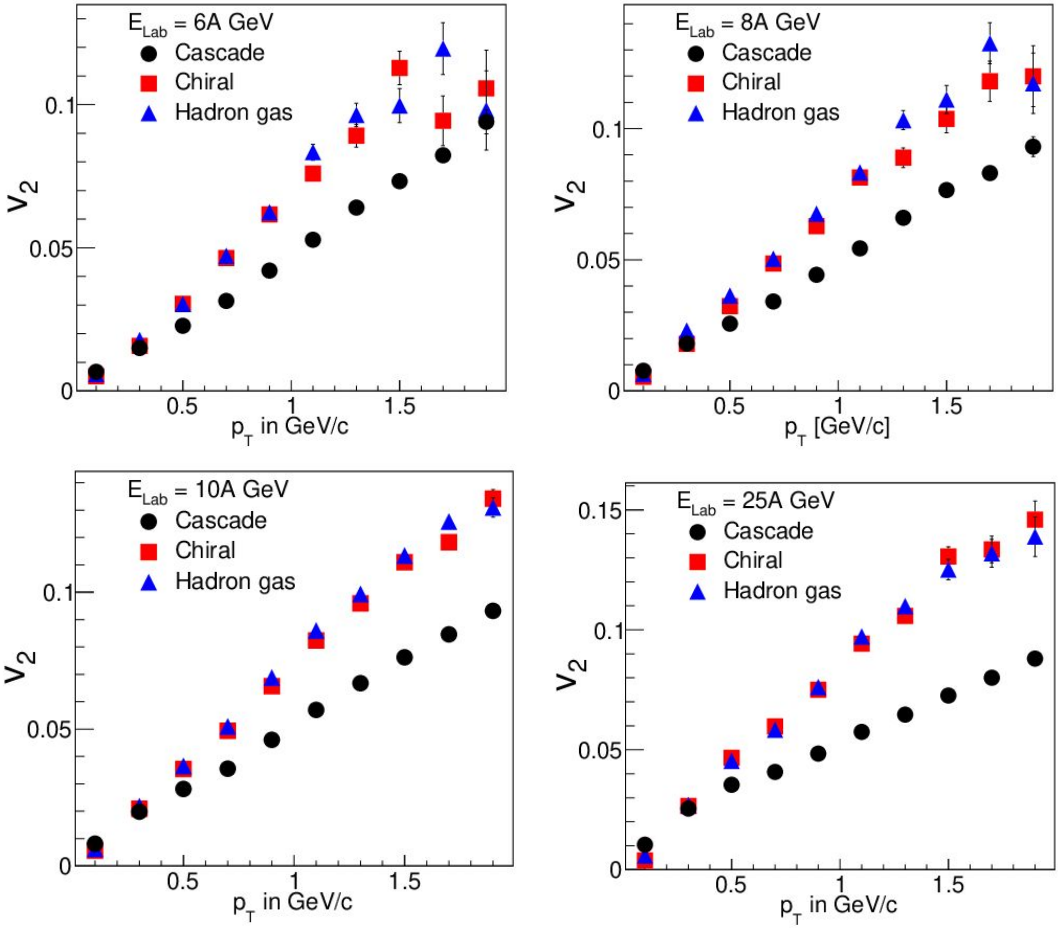
- Along with transport mode, with an aim to capture the entire evolution dynamics of the fireball, the so-called hybrid UrQMD model has been developed where the pure transport approach is embedded with a 3−D ideal relativistic one fluid evolution for the intermediate hot and dense stage of the reaction.

- After hydrodynamical evolution, the Cooper-Frye prescription is employed to map the hydrodynamical fields to the hadrons.

- In the hybrid mode, two different choices of the underlying EoS namely the hadron gas (HG) EoS and the Chiral EoS to mimic the hadronic and partonic scenarios,respectively.

- In this work, different flow coefficients viz. v_1, v_2, v_4 are measured in semi-central (5--9 fm) Au--Au collisions at 6*A*, 8*A*, 10*A* and 25*A* GeV beam energies.

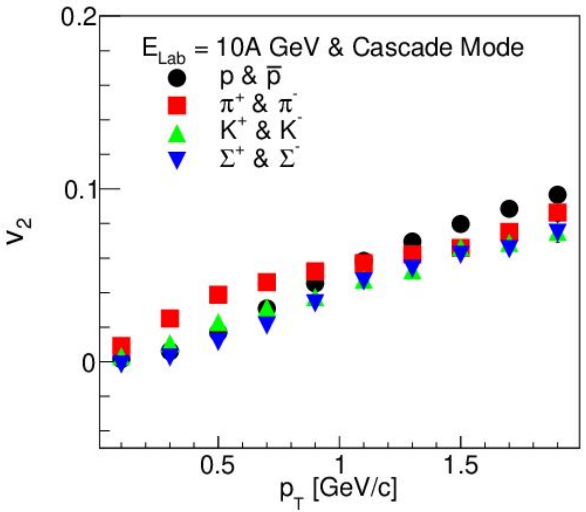
Elliptic flow: Charged hadrons

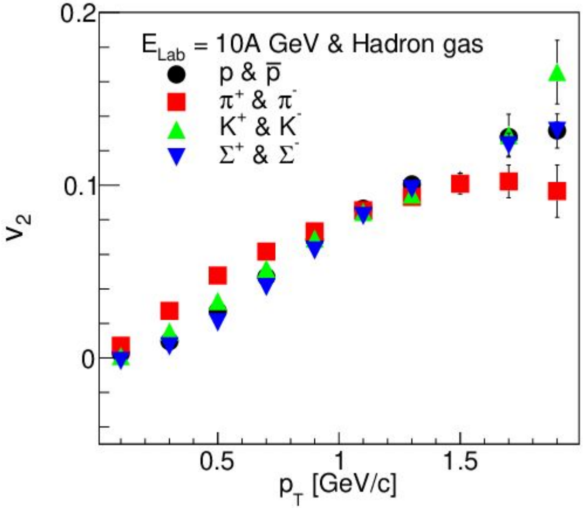


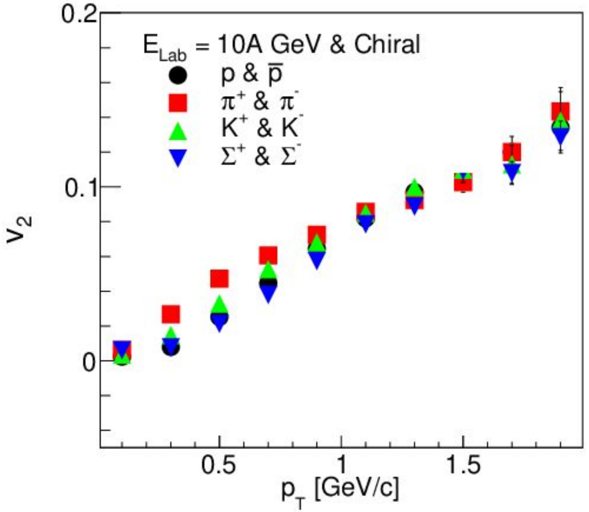
- Differential elliptic flow of the charged hadrons ($v_2(p_T)$) for different energies and different equations of state.
- Approximate linear rise is observed as function of transverse momentum.
- At higher p_T, the magnitude of v_2 depends on the evolution dynamics.
- The enhancement in case of hydrodynamic scenario is observed comparison to pure transport mode.

Elliptic flow: Identified hadrons

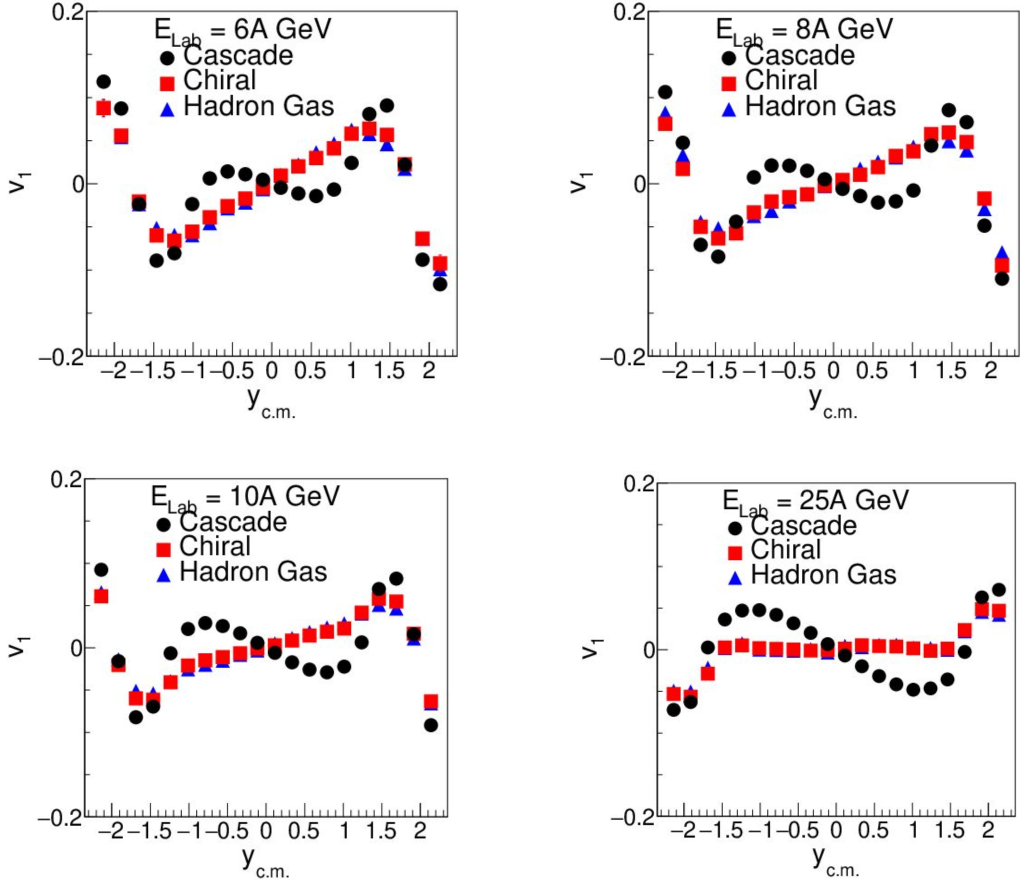
- Differential elliptic flow of the identified hadrons ($v_2(p_T)$) for different equations of state.
- Mass ordering among the particles is observed in all three cases at low transverse momentum.







Directed flow: Charged hadrons



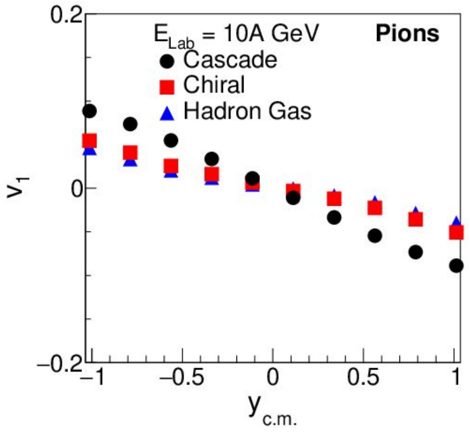
- Differential directed flow of the charged hadrons ($v_1(y_{c.m.})$) for different energies and different equations of state.

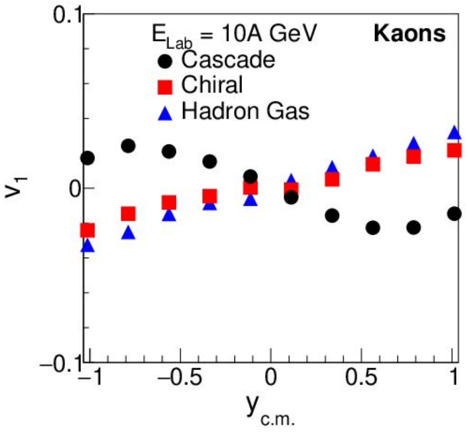
- Directed flow (v_1) is expected to be sensitive to the longitudinal dynamics of the medium so its rapidity dependence study is more relevant and interesting.

- Here also, Directed flow does not seem to be sensitive to the underlying degrees of freedom.

- But the slope at mid-rapidity shows some interesting behaviour for different energies.

Directed flow: Identified hadrons

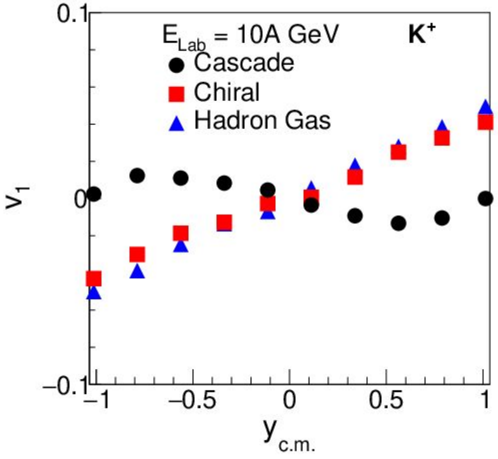


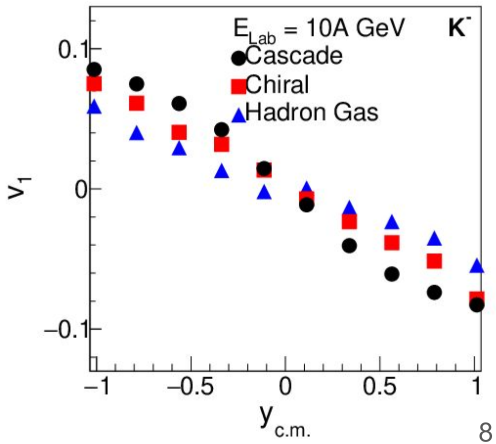


- The slope of the directed flow of pions ($\pi^+ + \pi^-$) is always negative for three cases of the EoS around mid-rapidity.
- For kaons ($K^+ + K^-$), normal flow is observed in the case of hydro mode and anti-flow in case of pure transport mode.

- Seems that K^+ and K^- are treated differently in the presence of hydrodynamic expansion which is visible by looking at the slope.
- Experimentally [1-2], it is found that K^+shows anti-flow and K^-shows normal flow as nucleons due to different potentials they experience while propagating through medium.

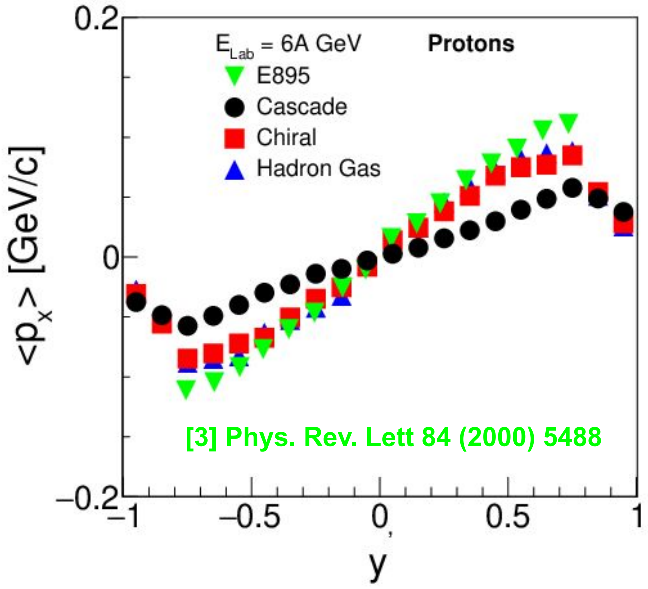
[1] Nucl.Phys. A646 (1999) 481-499
[2] Phys.Rev. C62 (2000) 061903

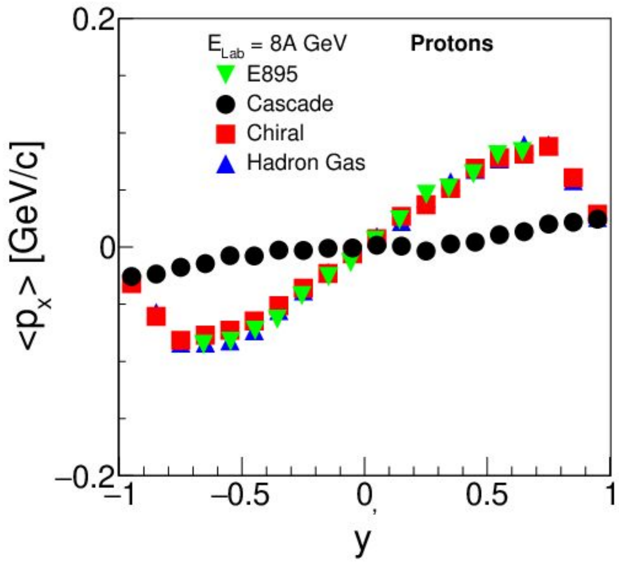




Comparison with Data

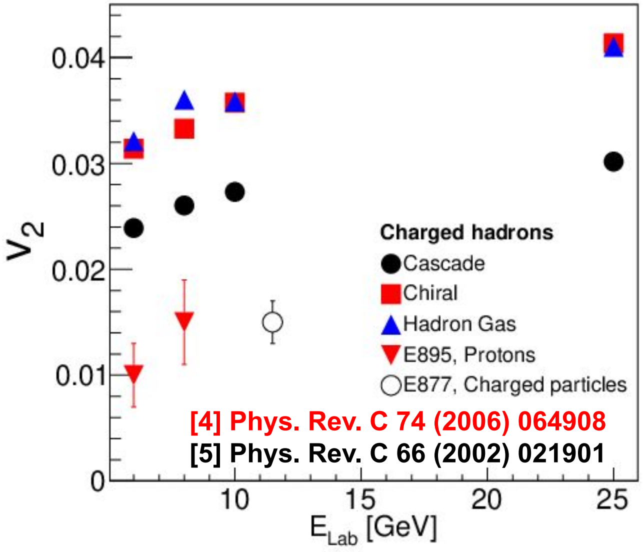
- Sideward flow $<P_x>$ of protons from E895 experiment is compared with the obtained results, y' is normalized rapidity. Normalized in a such way that the rapidity of target and projectile become -1 and 1 respectively.
- Slope of protons in data at the mid-rapidity seems to agree well with the hydrodynamic scenario.



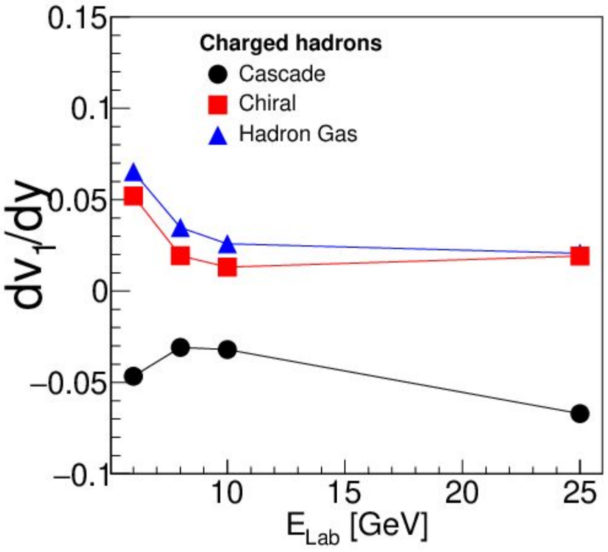


Energy dependence

- V_2 , irrespective of the equation of state clearly overestimate the data but shows monotonic trend as in data.
- It shows no sensitivity to the underlying degrees of freedom hinting towards the small life time of the hydrodynamic phase at such low energies.
- Positive slope of the directed flow of charged hadrons in hydrodynamic scenario whereas negative slope is observed for transport case.



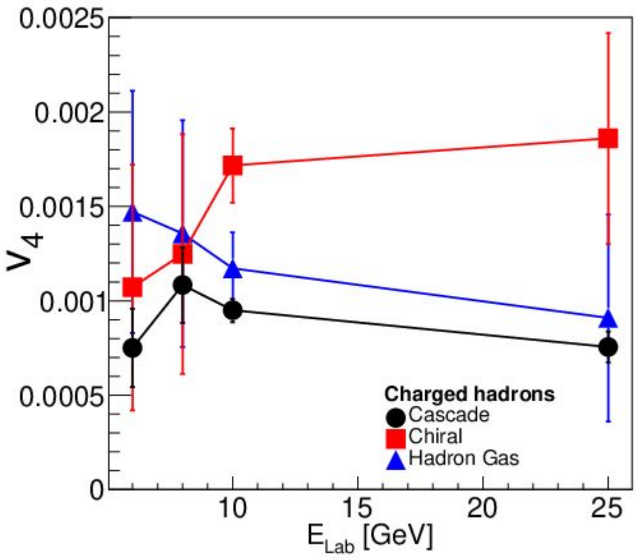
[4] Phys. Rev. C 74 (2006) 064908
[5] Phys. Rev. C 66 (2002) 021901

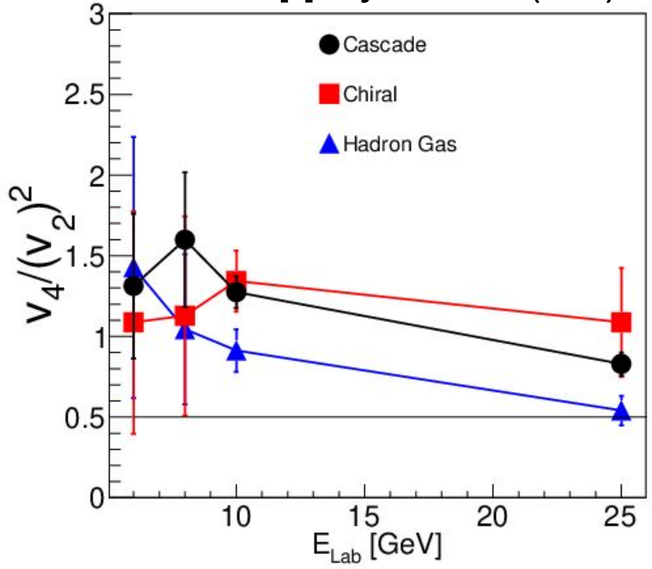


Energy dependence

- According to [6-8], the generation of v_4 is governed by both the intrinsic v_2 and the 4th order moment of collective flow.
- $v_4/(v_2)^2$ ratio always lie between 0.5 to 2 irrespective of the EoS.
- Upon the reduction in statistical uncertainties, more conclusive remarks can be made.

[6] Phys.Lett. B642 (2006) 227-231
[7] Phys.Rev. C81 (2010) 054910
[8] Phys.Rev. C81 (2010) 014901





Conclusions

- Equation-of-state dependence of the anisotropic flow observables viz. v_1, v_2 and v_4 is attempted at different FAIR energies.
- v_1 and v_2 fail to differentiate between partonic and hadronic equations of state which may be attributed to the small life time of the hydrodynamic phase.
- Sideward flow $\langle P_x \rangle$ of protons matches with the available experimental data.
- $v_4/(v_2)^2$ ratio as a function of beam energy lie between 0.5 to 2: medium is not expected to be fully equilibrated.
- Use of ideal hydrodynamics does not seem to be suitable for the medium evolution. Perhaps, viscous hydrodynamics expansion might be a reliable tool.

Thank you for your attention

BACK-UP

Motivation

- The azimuthal anisotropy of the final-state hadrons produced in the heavy ion collisions has long been considered as a deterministic probe to investigate collective effects in multi-particle production.
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- This observable is less explored at high baryon density regime on the QCD phase diagram