Collective flow of light nuclei in Au+Au reactions at 1.23 A GeV

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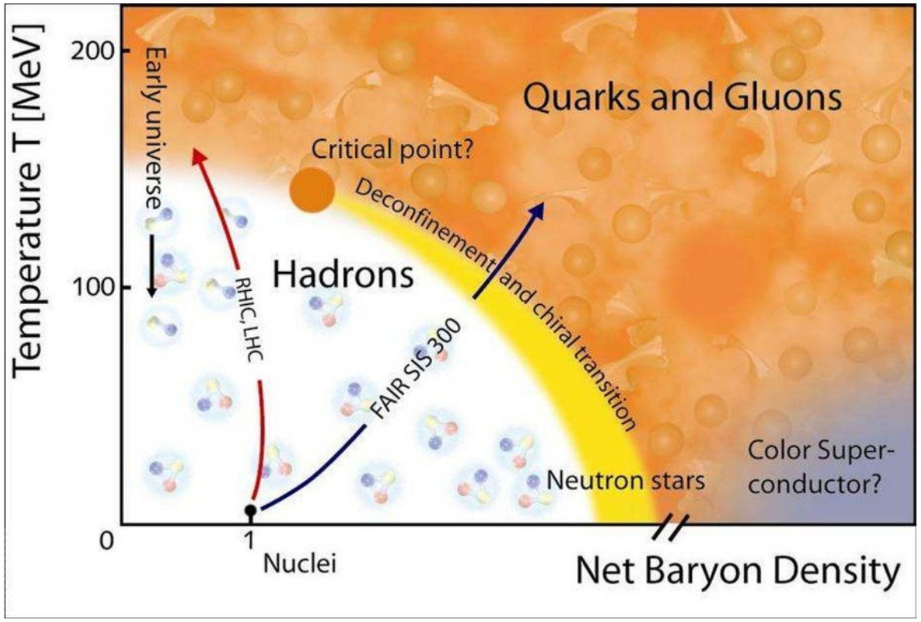
Motivation

- At low energy Au+Au collisions baryon density is 3-4 times higher than the ground state density can be reached. One expects to find exotic particles or maybe even super conducting matter and a phase transition to the Quark Gluon Plasma.



picture: https://www.researchgate.net/figure/A-possible-sketch-of-the-QCD-phase-diagram_ fig3_ 269116454

Motivation

- The HADES experiment performed Au+Au collisions at E lab = 1.23 A GeV with a huge amount of data and is able to measure even flow components of light nuclei with a high precision.
- The dynamics of this dense matter are sensitive to the initial density and potential interactions and therefore the nuclear equation of state (EoS).

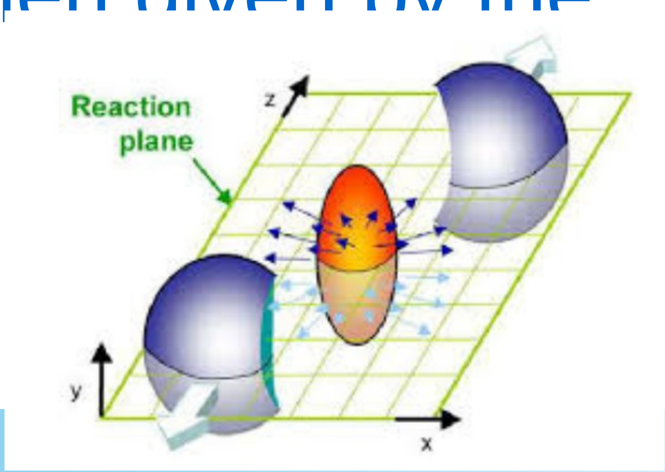
Collective flow

- Being sensitive to initial pressure gradients the collective flow is a promising variable to study the EoS. It is given as the Fourier series of the momentum distribution:

(1) $$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_{RP})]\right)$$

- The different coefficients are then given by the corresponding integral:

(2) $$v_n(p_T, y) = \langle \cos[n\varphi] \rangle$$



picture: Heinz, Ulrich W. J.Phys. A42 (2009) 214003

UrQMD

- UrQMD is based on a geometrical interpretation of the Nuclear cross section. A reaction occurs, when:

(3) $$d < \sqrt{\frac{\sigma}{\pi}}$$

- The model includes strangeness exchange, and resonance and string dynamics
- At low beam energies the equation of state has a huge effect to the dynamics

S. A. Bass et al. Prog. Part. Nucl. Phys. 41 (1998) 225-370,
M.Bleicher et al. J. Phys. G: Nucl. Part. Phys. 25 (1999) 1859-1896

Equation of state

- In the following the potentials of the EoS are shown.
- Yukava-potential for strong interaction:

(4) $$V_Y^{ij} = V_0^Y \cdot \frac{\exp\left(\left|\mathbf{r_i} - \mathbf{r_j}\right| / \gamma_Y\right)}{\left|\mathbf{r_i} - \mathbf{r_j}\right|}$$

$V_0^Y = -0.498$ MeV
$\gamma_Y = 1.4$ fm

- Coulomb-potential for electromagnetic int.:

(5) $$V_C^{ij} = \frac{Z_i Z_j e^2}{\left|\mathbf{r_i} - \mathbf{r_j}\right|}$$

Equation of state

- Skyrme-potential for density abundance:

(6) $$V_{Sk} = \alpha \cdot \left(\frac{\rho_{int}}{\rho_0}\right) + \beta \cdot \left(\frac{\rho_{int}}{\rho_0}\right)^{\gamma}$$

- The paramters α, β, and γ describe the siffness of the EoS.

- We use a hard EoS with the following parameters:

Parameters	hard EoS
α [MeV]	-124
β [MeV]	71
γ	2.00

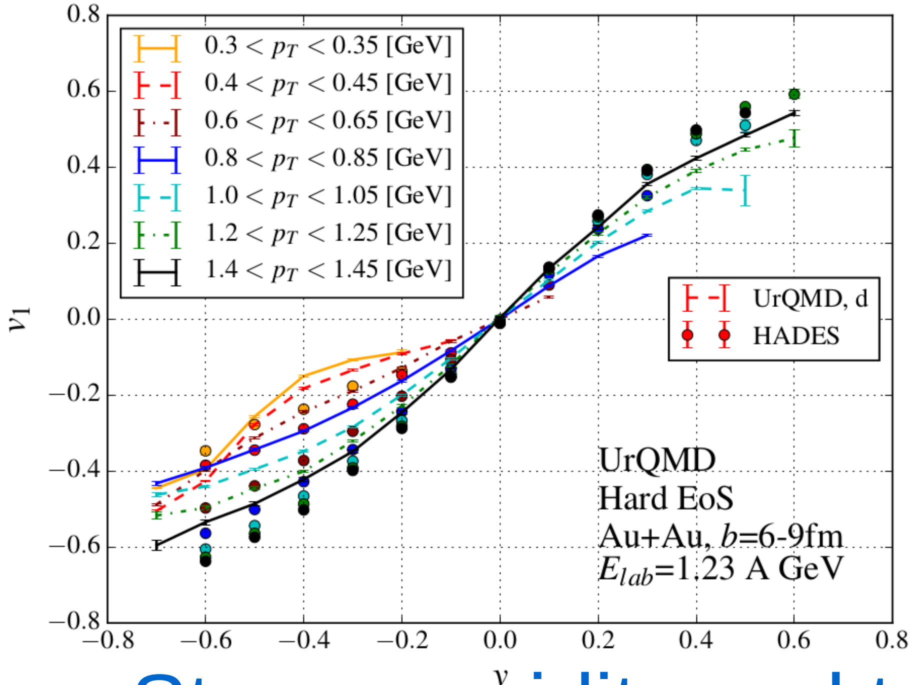
P.Hillmann et al., J.Phys. G45 (2018) no.8, 085101 (2018-06-25)

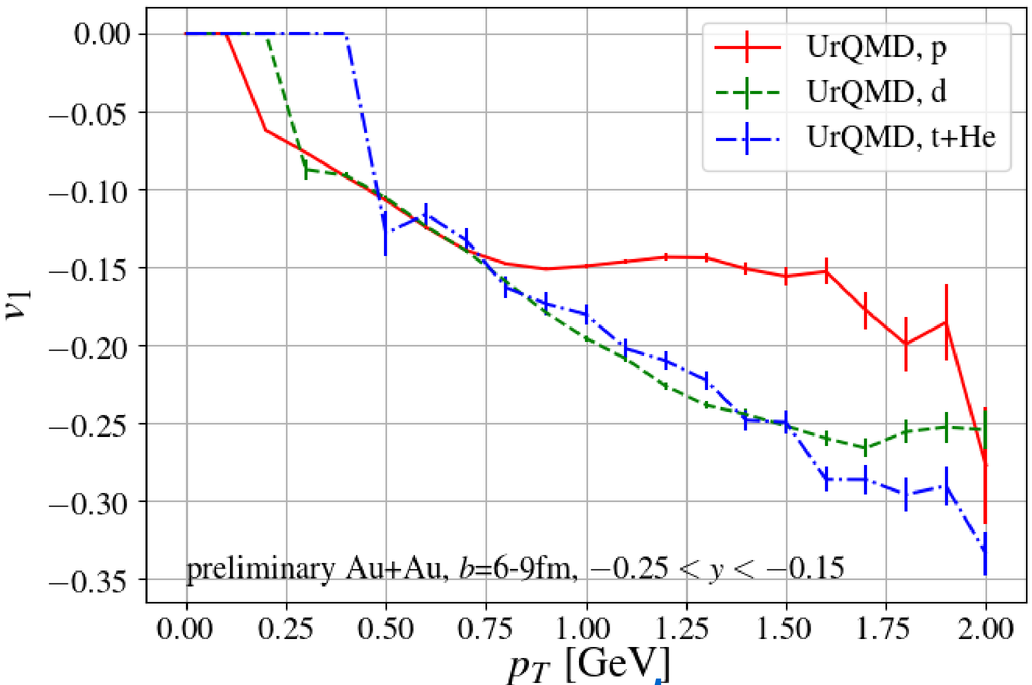
Phase-space coalescence

- A possible two-particle state is formed if the relative distance $\Delta r<3.575$fm and momentum difference $\Delta p<0.285$ GeV.
- If this possible pair is in the same distances to another nucleon, a 3N-cluster is formed with the factor of ¼ (average over initial spin-and iso-spin states) .
- For the deuteoron the corresponding factor is 3/8.

Deuterons: S.Sombun et al., Phys.Rev. C99 (2019) no.1, 014901 (2019-01-10)

Results on directed flow

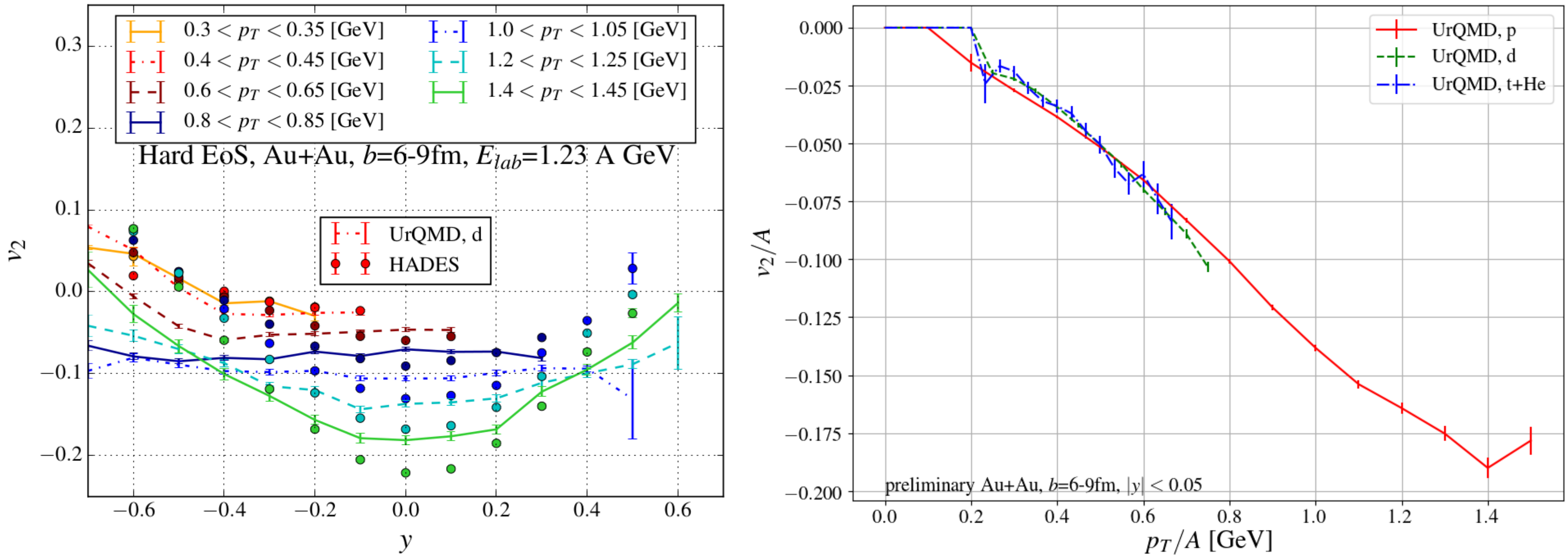




- Strong rapidity and transverse momentum dependence.
- The higher the mass the more negative the flow at high pT.

HADES Data:B. Kardan et al., PoS CPOD2017 (2018) 049 and Nucl.Phys. A982 (2019) 431-434

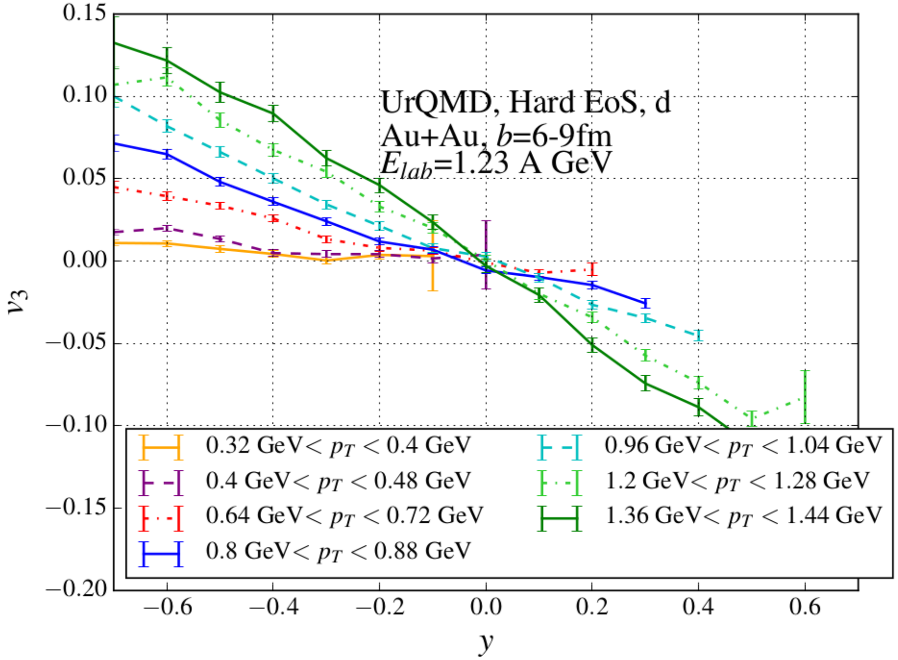
Results on elliptic flow

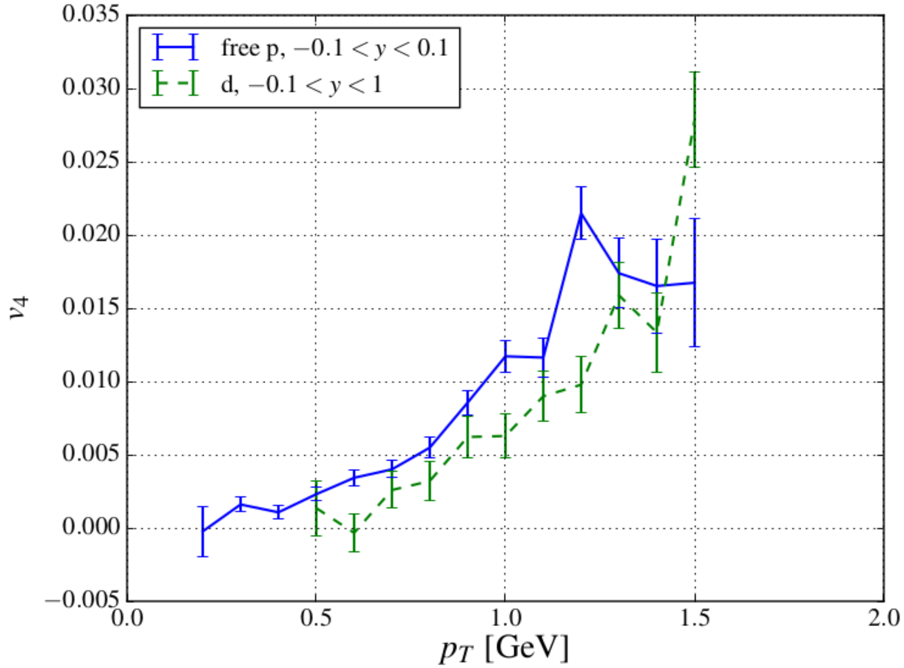


- Strong rapidity and transverse momentum dependence.
- Direct mass number scaling as indicator of coalescence

HADES Data:B. Kardan et al., PoS CPOD2017 (2018) 049 and Nucl.Phys. A982 (2019) 431-434

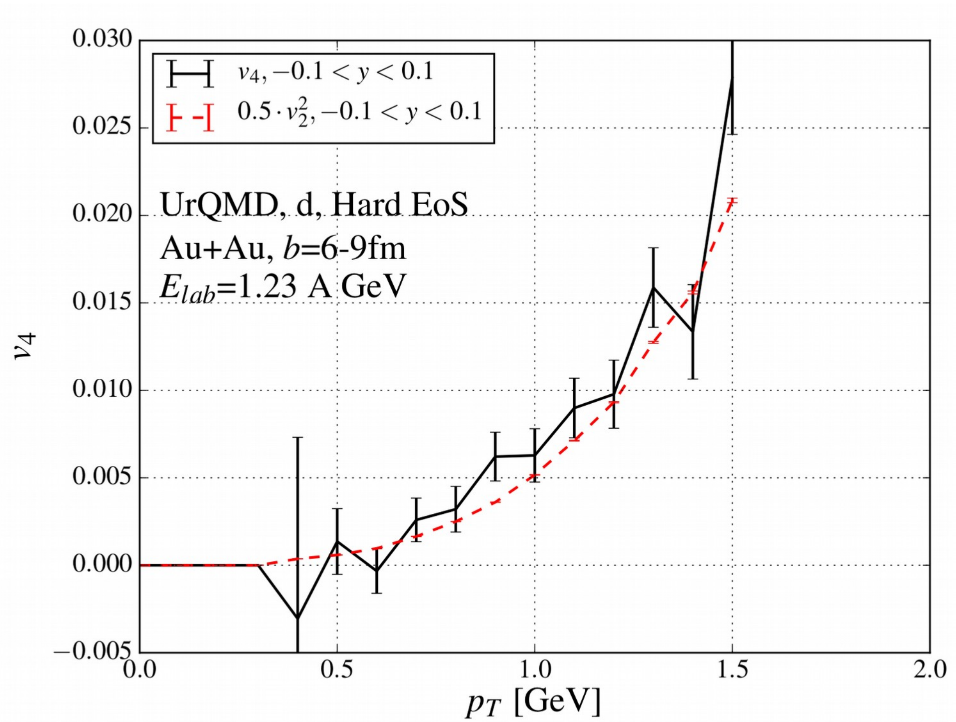
Higher order flow components

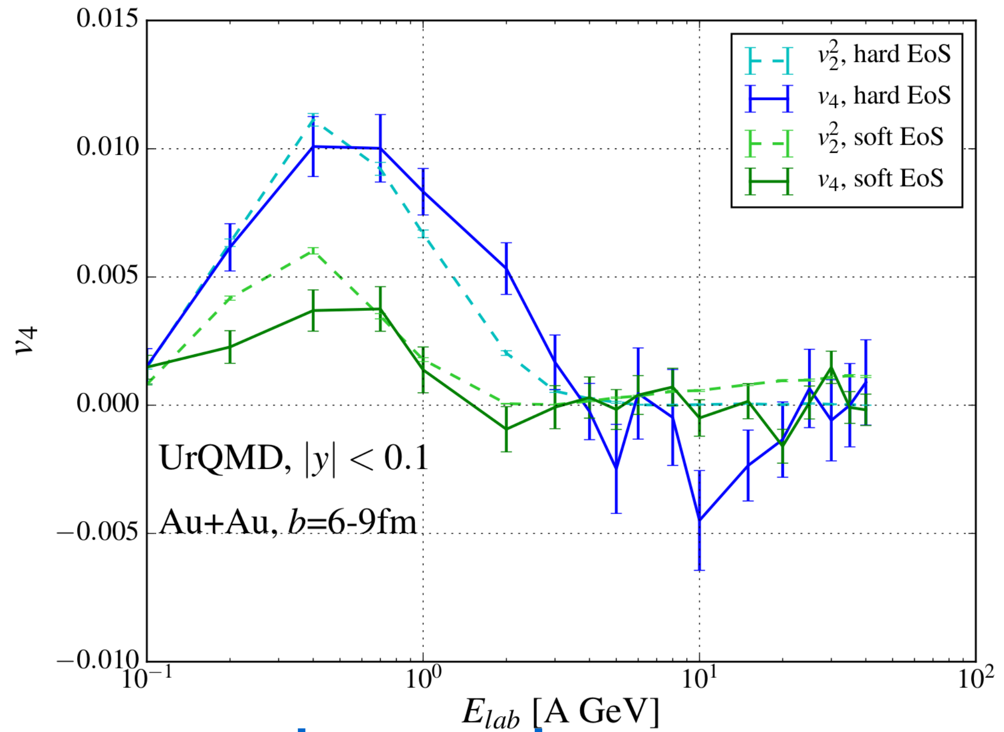




- Strong rapidity and transverse momentum dependence.
- Non-0 higher order flow indicates interplay of initial and expansion stage of the system.

Scaling of v4 and v2





- Strong transverse momentum dependence.
- Scaling of the harmonics both for transverse momentum and energy at mid-rapidity.

Summary

- UrQMD with a non-momentum dependent hard EoS and a coalescence approach was used to study collective flow of light nuclei in Au+Au reactions at 1.23 AGeV
- Cluster formation shows an impact to the collective flow. The mass number scaling indicates coalescence.
- Non-vanishing higher order flow indicates interplay between initial stage and expansion.