



Beam energy dependence of squeeze-out effect on the directed and elliptic flows in Au+Au collisions at high baryon density region

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Outline

1. Introduction

- EOS effects
- Squeeze out and hadronic re-scattering effects

2. Results

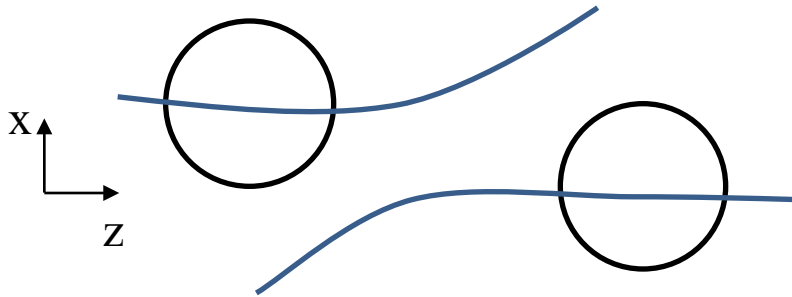
- Collective transverse flow and directed flow of identified particles with different EOS.
- Squeeze-out and hadronic re-scattering effects on v_1 and v_2 .
- **Beam energy dependence** of the v_1 and v_2 .
- Comparing with data.

3. Summary

Introduction

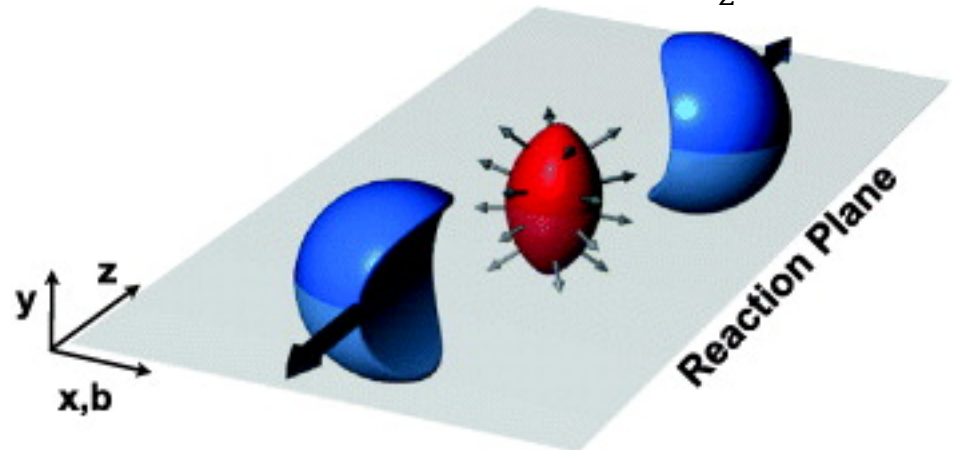
$$\frac{dN}{d(\phi - \Psi)} \propto 1 + 2 \sum_{n \geq 1} v_n^{\text{obs}} \cos[n(\phi - \Psi)],$$

First fourier coefficient v_1



Created in the overlapping stage of two nuclei →
Sensitive to the EoS in the early stage.

Second fourier coefficient v_2



Initial spatial anisotropy

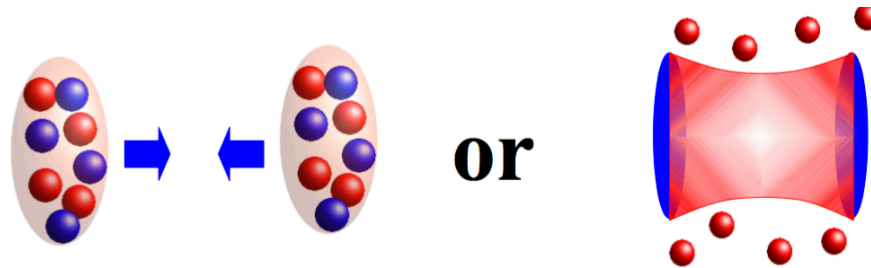


Final anisotropic momentum distribution
Sensitive to the early stage of the system evolution

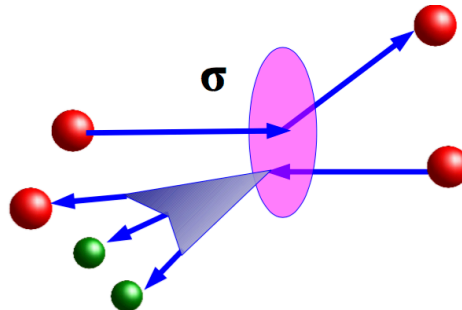
JAM(Jet AA microscopic transport model)

JAM: Hadronic transport model

Initial condition = phase space distribution of hadrons,



Nuclear collision is described by the sum of independent binary hh collisions,
Two-body collision at the closest distance according to σ .



Particle production is modeled by resonance and string production and their decay(PYTHIA).

EOS effect

Simulate the equation of state effect with two approach:

- Nuclear mean field potential
- Softening effect

Mean field Potential in the framework of RQMD/S

$$V = \sum_i V_i = \int d^3r \left[\frac{\alpha}{2} \left(\frac{\rho}{\rho_0} \right)^2 + \frac{\beta}{\gamma + 1} \left(\frac{\rho}{\rho_0} \right)^{\gamma+1} \right] + \sum_k \int d^3r d^3p d^3p' \frac{C_{ex}^{(k)}}{2\rho_0} \frac{f(\mathbf{r}, \mathbf{p}) f(\mathbf{r}, \mathbf{p}')}{1 + (\mathbf{p} - \mathbf{p}')^2 / \mu_k^2}$$

$f(\mathbf{r}, \mathbf{p}) = \left(\frac{4}{3} \pi p_F^3 \right)^{-1} \rho(\mathbf{r}) \Theta(p_F - |\mathbf{p}|)$. is the phase space distribution function

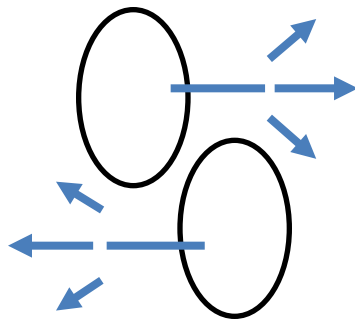
Skyrme-type density dependent + Lorentzian-type momentum dependent mean field potential

Softening the EOS

Control the pressure of the system by changing the **scattering style** in the two-body collisions

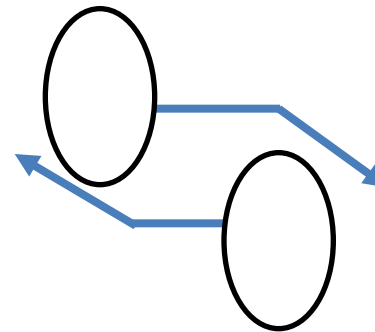
$$P = P_f + \frac{1}{3TV} \sum_{(i,j)} (\mathbf{p}'_i - \mathbf{p}_i) \cdot (\mathbf{r}_i - \mathbf{r}_j)$$

Virial theorem



Standard approach:

Azimuthal angle is randomly chosen
The pressure is zero in average

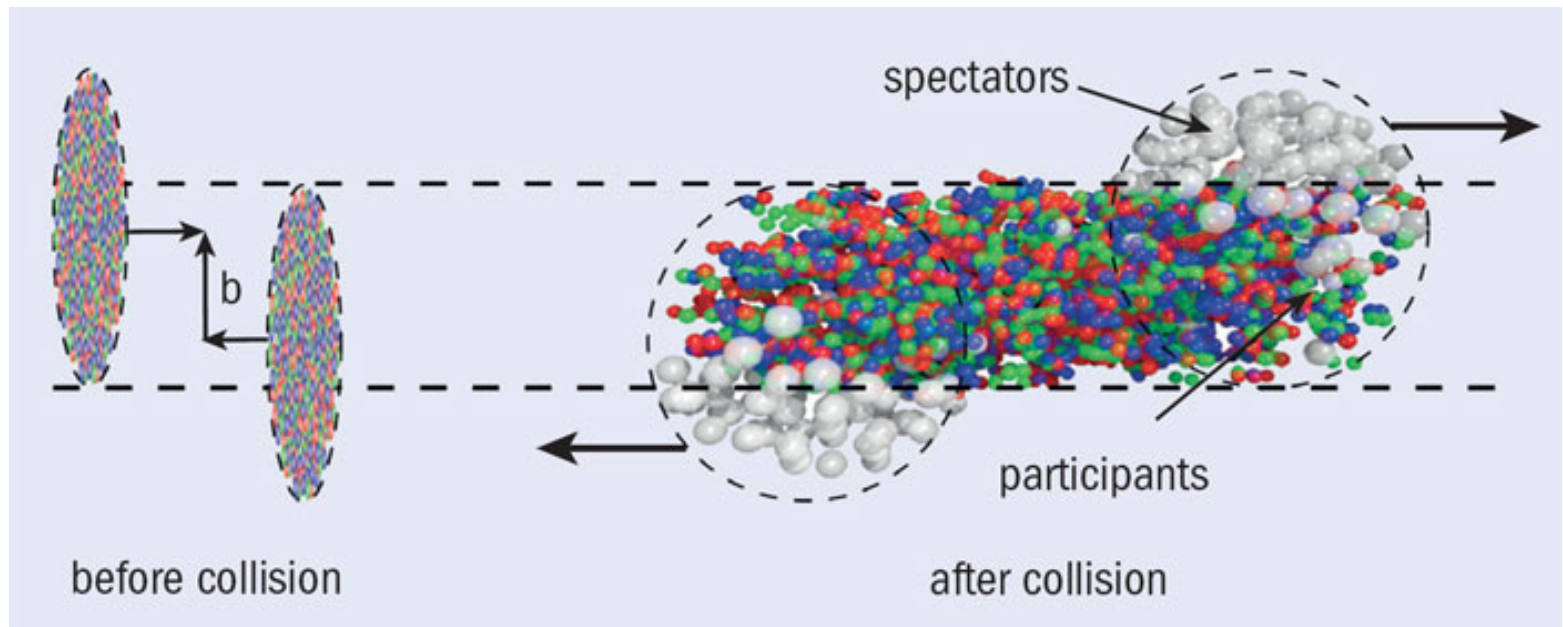


Attractive orbit approach:

Particle trajectory are bended in denser region.
The pressure of the system is reduced.

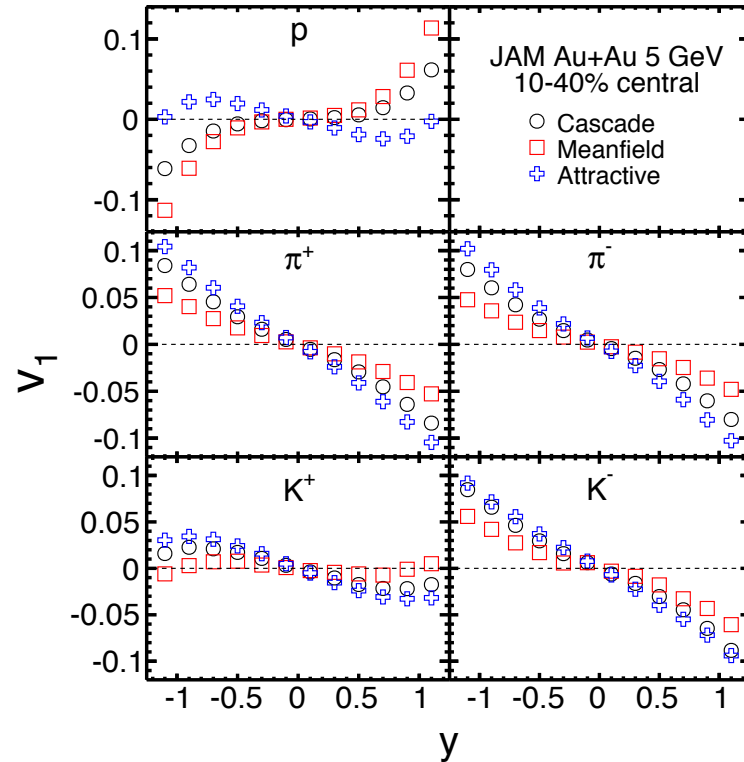
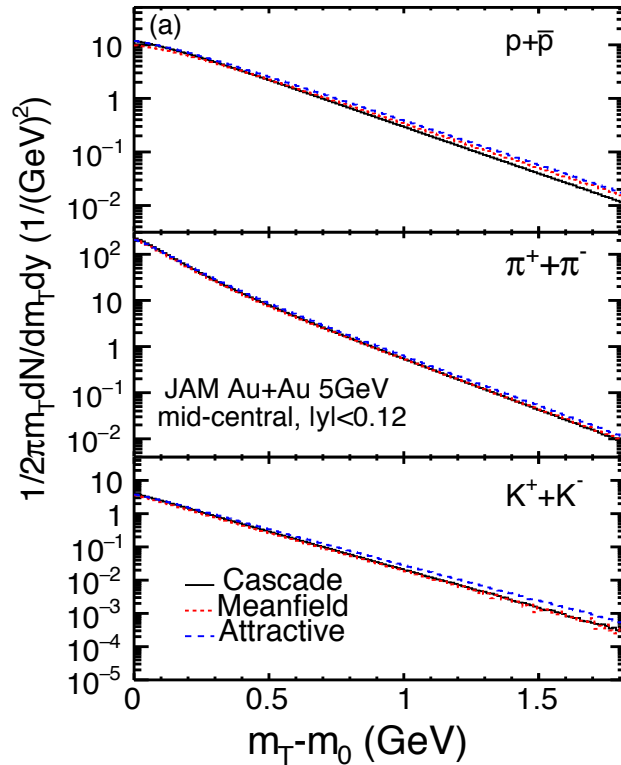
Spectator and hadronic re-scattering effect

Hadronic re-scattering: disabling meson-baryon(MB) and meson-meson(MM) scattering.



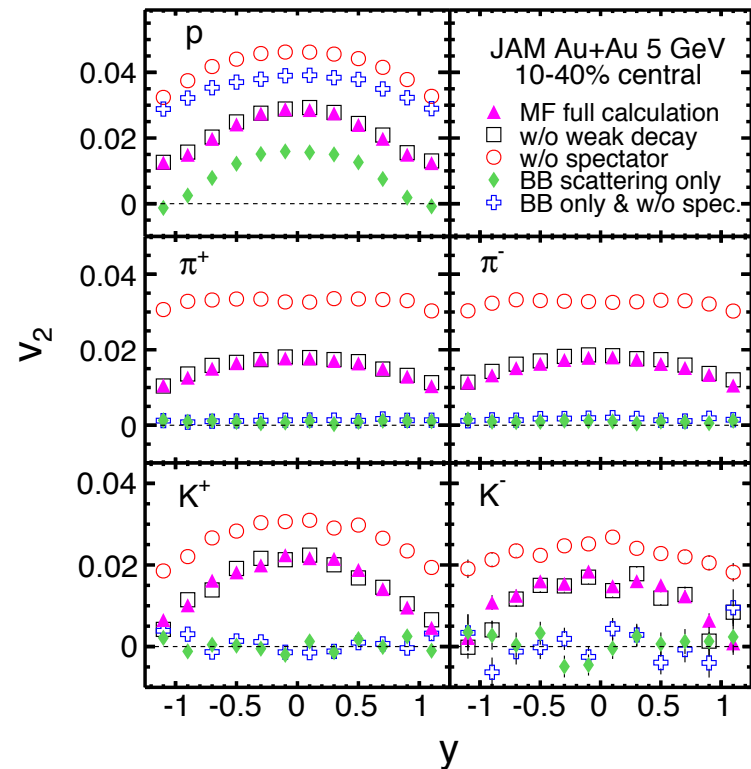
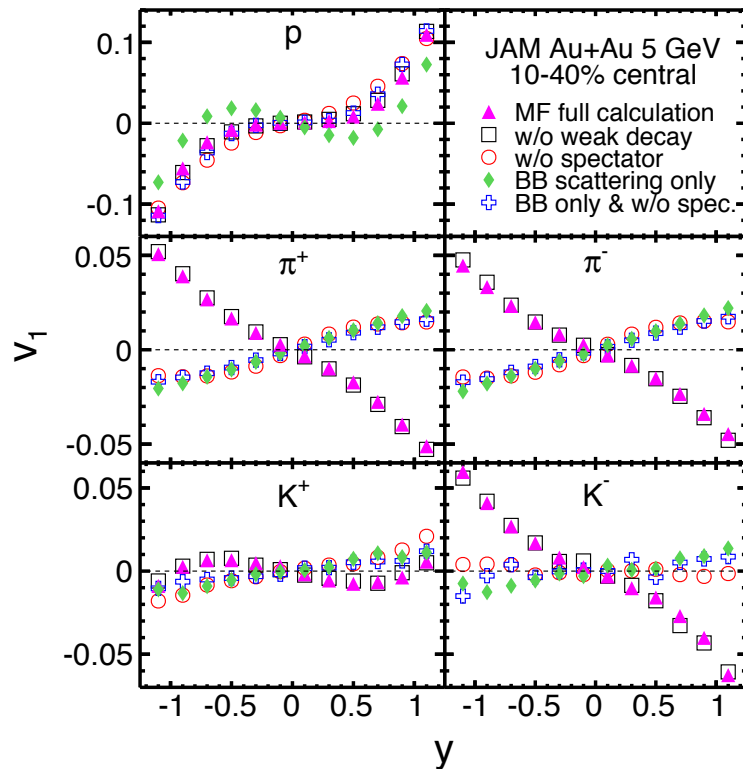
Spectator : disabling the interaction between spectator nucleons and participants.

EOS effects



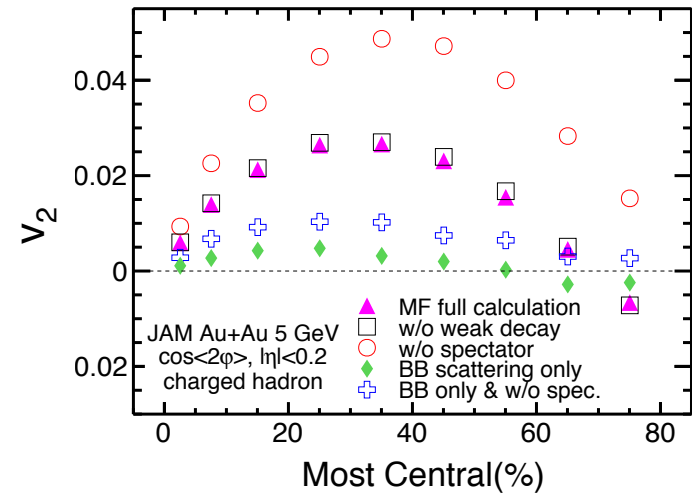
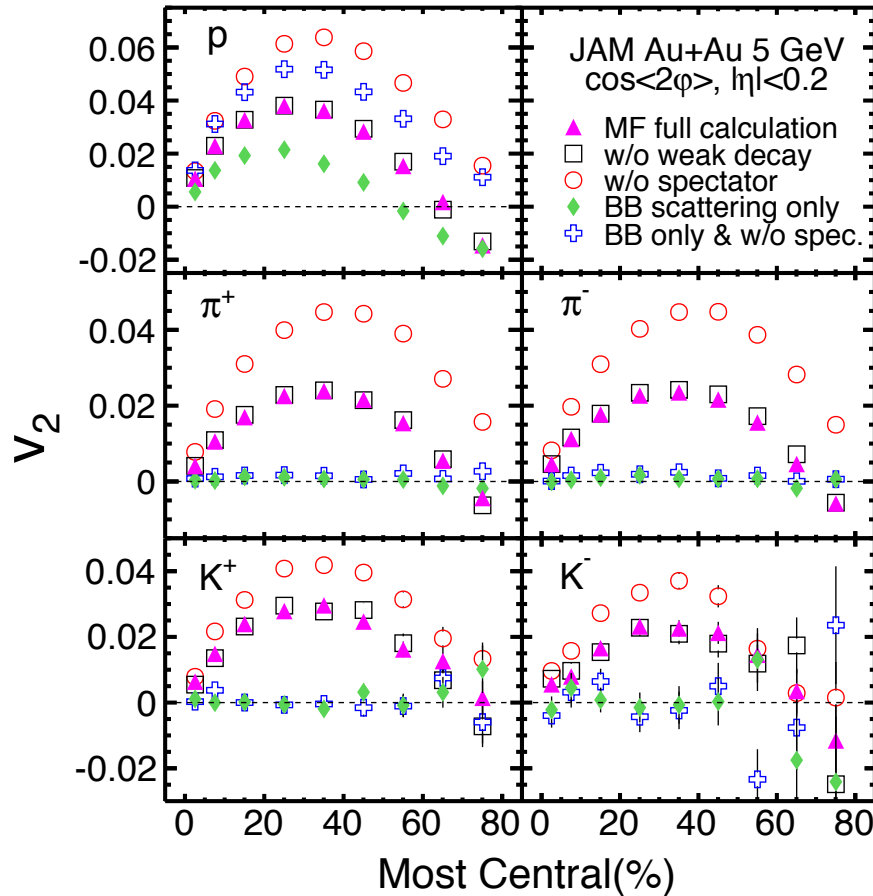
- Softening effect predicts enhancement of collective transverse flow for all particles, while mean field mode predicts harder slope of proton.
- Attractive orbit simulation predicts a **negative** slope of protons.

Squeeze-out and hadronic re-scattering effects



- Baryon-Baryon (BB) collisions: negative v_1 for proton, positive for pions and kaons.
- (BB): nucleon v_2 : smaller by about 20% , pion and kaon elliptic flows zero.

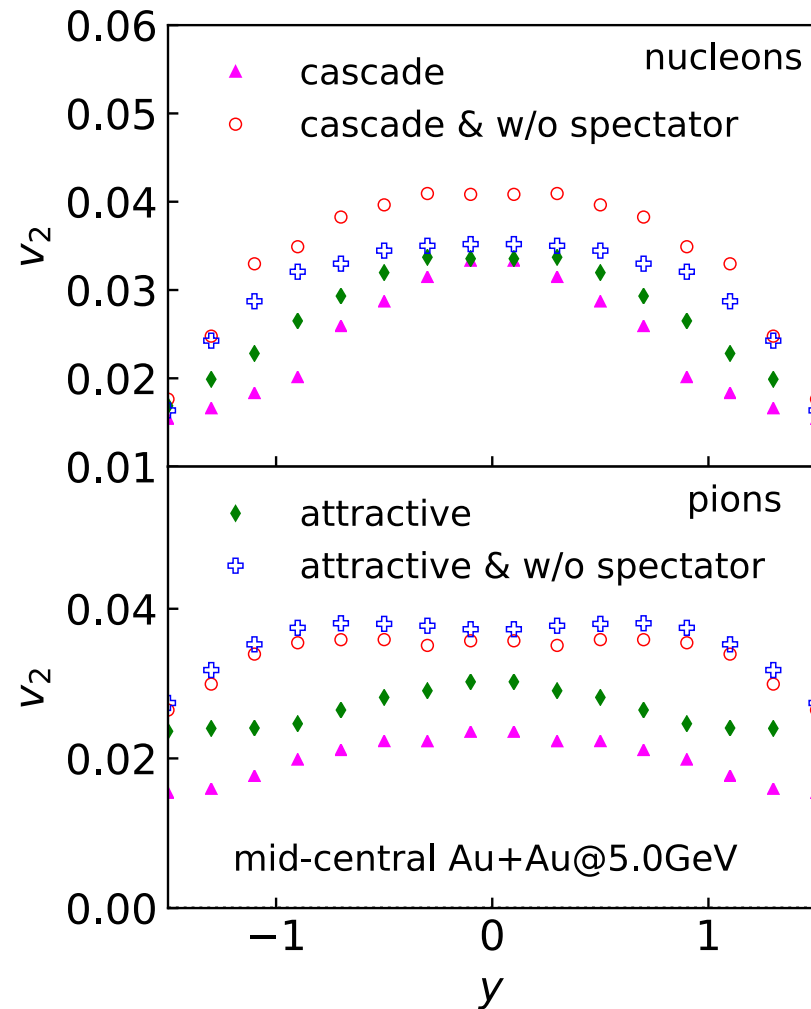
v_2 (Centrality dependence)



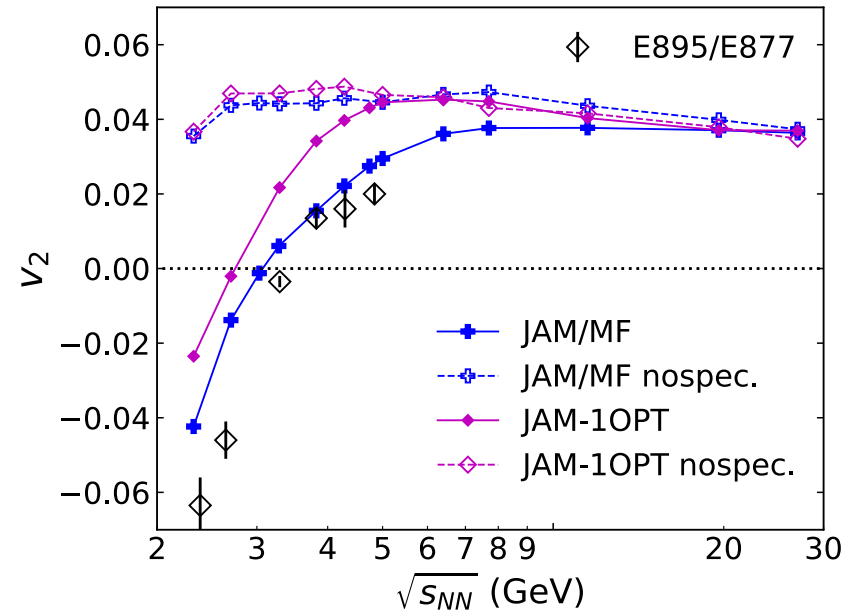
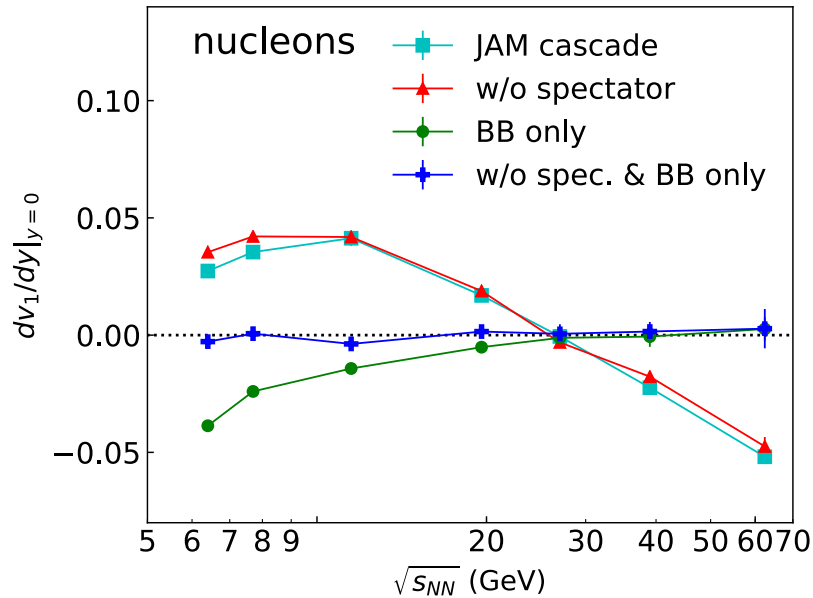
- **Suppression** of elliptic flow by the spectator can be seen for all centrality for all particles except for most central collisions.

Suppression of the squeeze-out effect

With spectator:
reduction of nucleon v_2 :
30% in cascade.
almost no reduction in
attractive orbit mode.

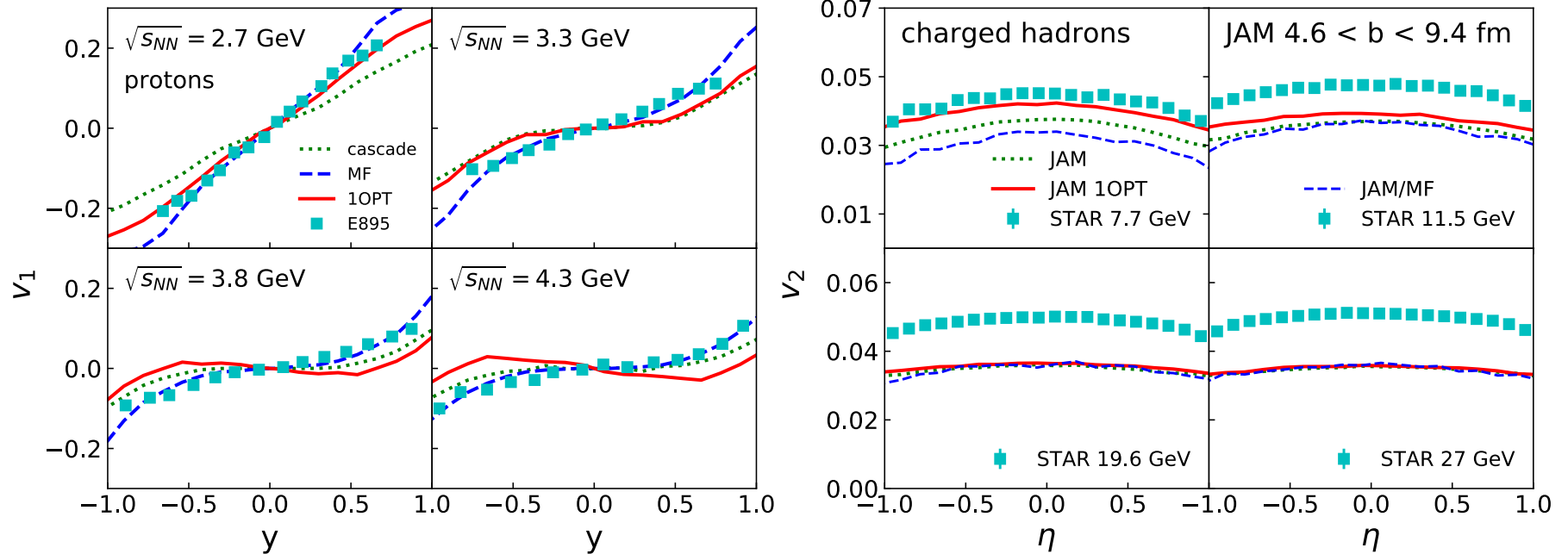


Beam energy dependence



- BB collisions generate negative directed flow below 30 GeV (green),
- MB and MM scattering effects to the slope of nucleon directed flow is opposite at low and high energies.
- Spectator shadowing effects up to 10 GeV in MF, on the other hand, it disappear around 5 GeV in 1OPT mode due to strong softening effect.

Data comparison



- Cascade mode underestimates the slope of directed flow while mean-field describe the data better due to the pressure of the system.
- The 1OPT scenario in JAM seems to be consistent with STAR data from RHIC-BES experiments at 7.7 GeV, at higher energies, due to the lack of partonic phase the JAM simulations predict less than data.

Summary

- We studied the effects from different EOS on the directed and elliptic flow.
- We studied the role of meson-baryon and meson-meson re-scattering as well as the interaction with spectator matter on the generation of directed and elliptic flows in Au+Au collisions at 3 - 62.4 GeV.
- We find that the dynamical origin of directed flow changes at 30 GeV.

Backup

The EoS of the system can be controlled by the formula in Ref. [42] by the following constraints in the two-body scattering:

$$\Delta P = \frac{\rho}{3(\delta\tau_i + \delta\tau_j)}(\mathbf{p}'_i - \mathbf{p}_i) \cdot (\mathbf{r}_i - \mathbf{r}_j), \quad (7)$$

where ΔP is the pressure difference from the free streaming pressure, ρ is the local particle density, and $\delta\tau_i$ is the proper time interval of the i -th particle between successive collisions. We show that a given EoS can be simulated by choosing the azimuthal angle according to the constraint in Eq. (7) in the two-body scattering process [32]. The main advantage of this approach is to be able to simulate any given EoS with a numerically efficient way as far as there are many two-body collisions, which happens in heavy-ion collision such as Au + Au collisions. We use the same EoS used in Ref. [32] to simulate IOPT (JAM/IOPT) based on Eq. (7) in this paper.

