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

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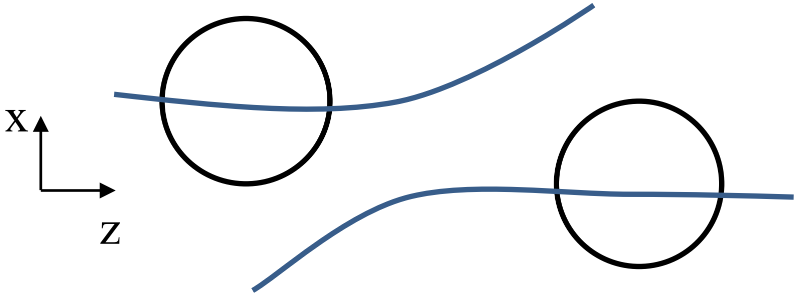
   - EOS effects
   - Squeeze out and hadronic re-scattering effects
2. Results
   - Collective transverse flow and directed flow of identified particles with different EOS.
   - Squeeze-out and hadronic re-scattering effects on $v_1$and v_2.
   - Beam energy dependence of the $v_1$and v_2.
   - Comparing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

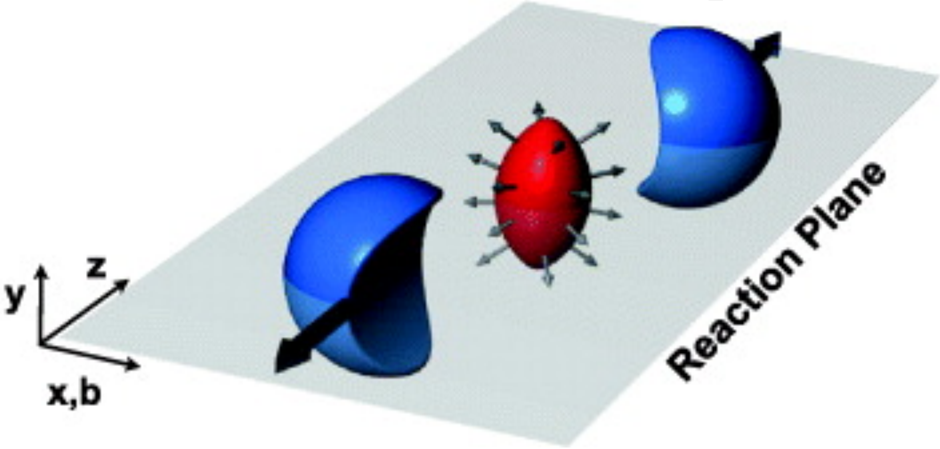
Introduction

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

First fourier coefficient v_1



Second fourier coefficient v_2



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

Initial spatial anisotropy

↓

Final anisotropic momentum distribution

Sensitive to the early stage of the system evolution

JAM model and EOS effects

JAM: Hadronic transport model

Particle production is modeled by resonance and string production and their decay.

Effects of EoS:

- **Nuclear mean field potential**
- **Softening effect**

Mean field Potential in the framework of RQMD/S

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

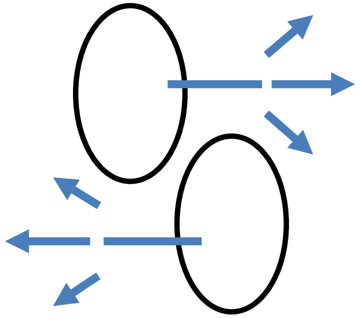
Skyrme-type density dependent + Lorentzian-type momentum dependent mean field potential

Softening the EOS

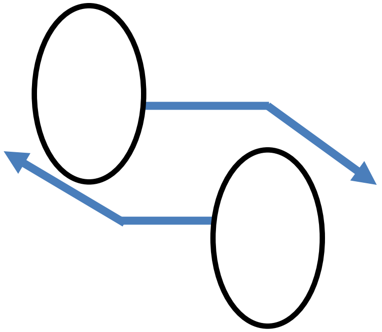
Control the pressure of the system by changing the scattering style in the two-body collisions

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

Virial theorem



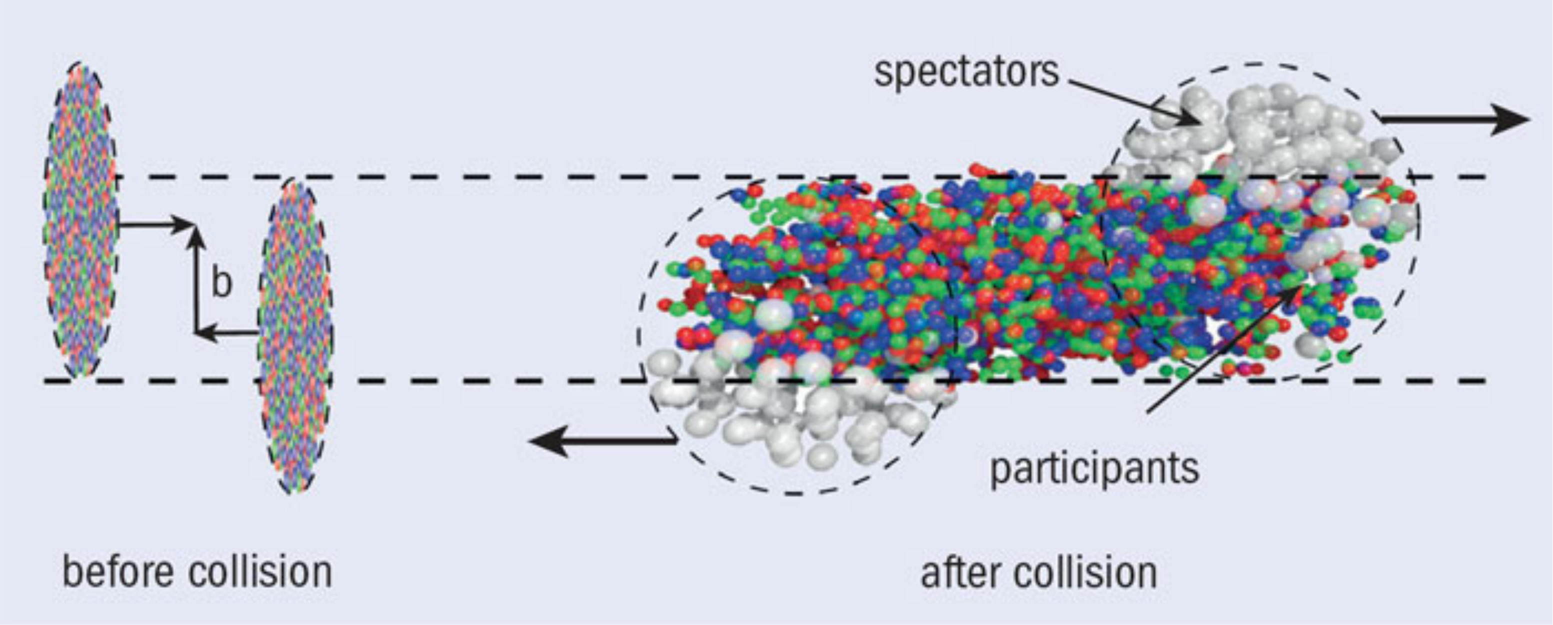
Standard approach:
Azimuthal angle is randomly chosen
The pressure is zero in average



Attractive orbit approach:
Particle trajectory are bended in denser region.
The pressure of the system is reduced.

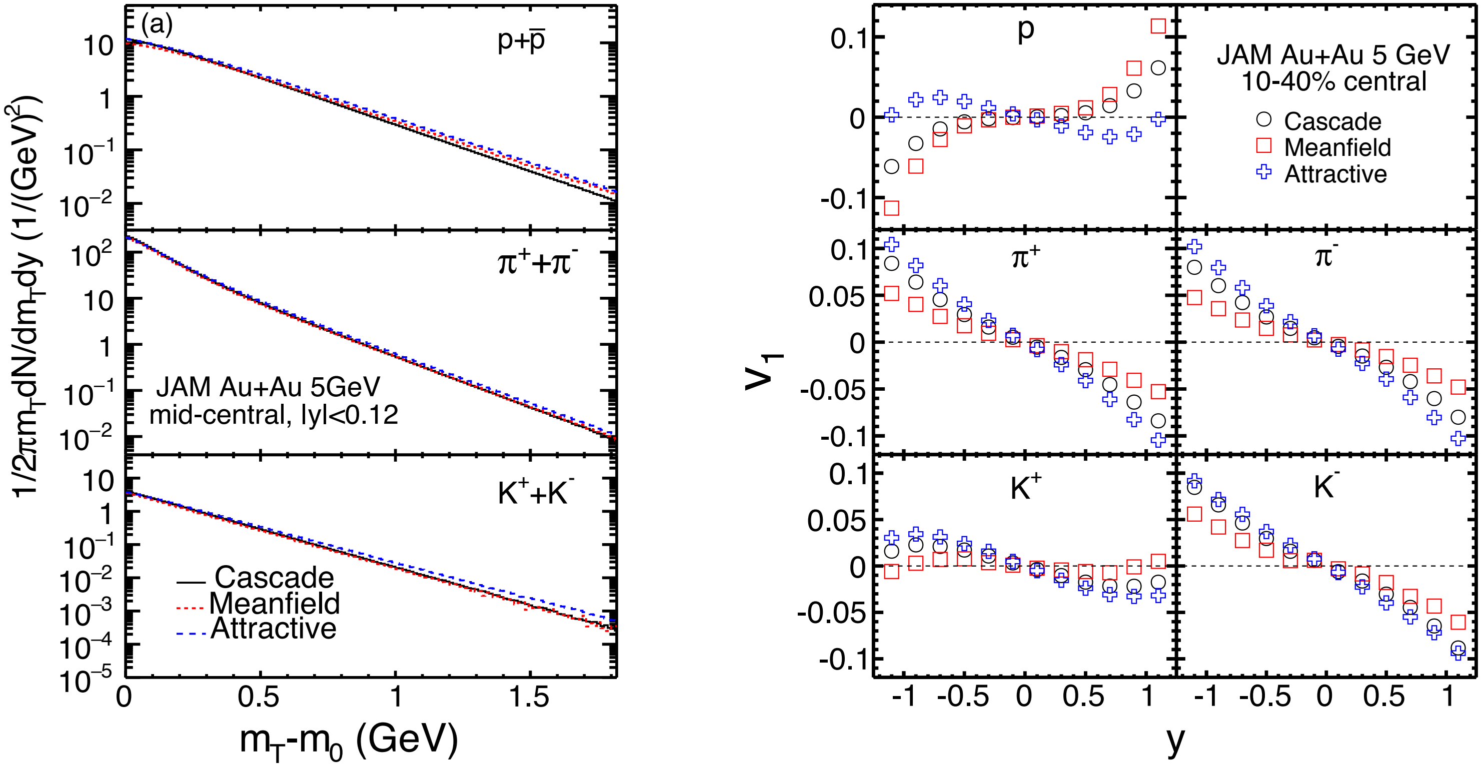
Effects of spectator and hadronic re-scattering

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



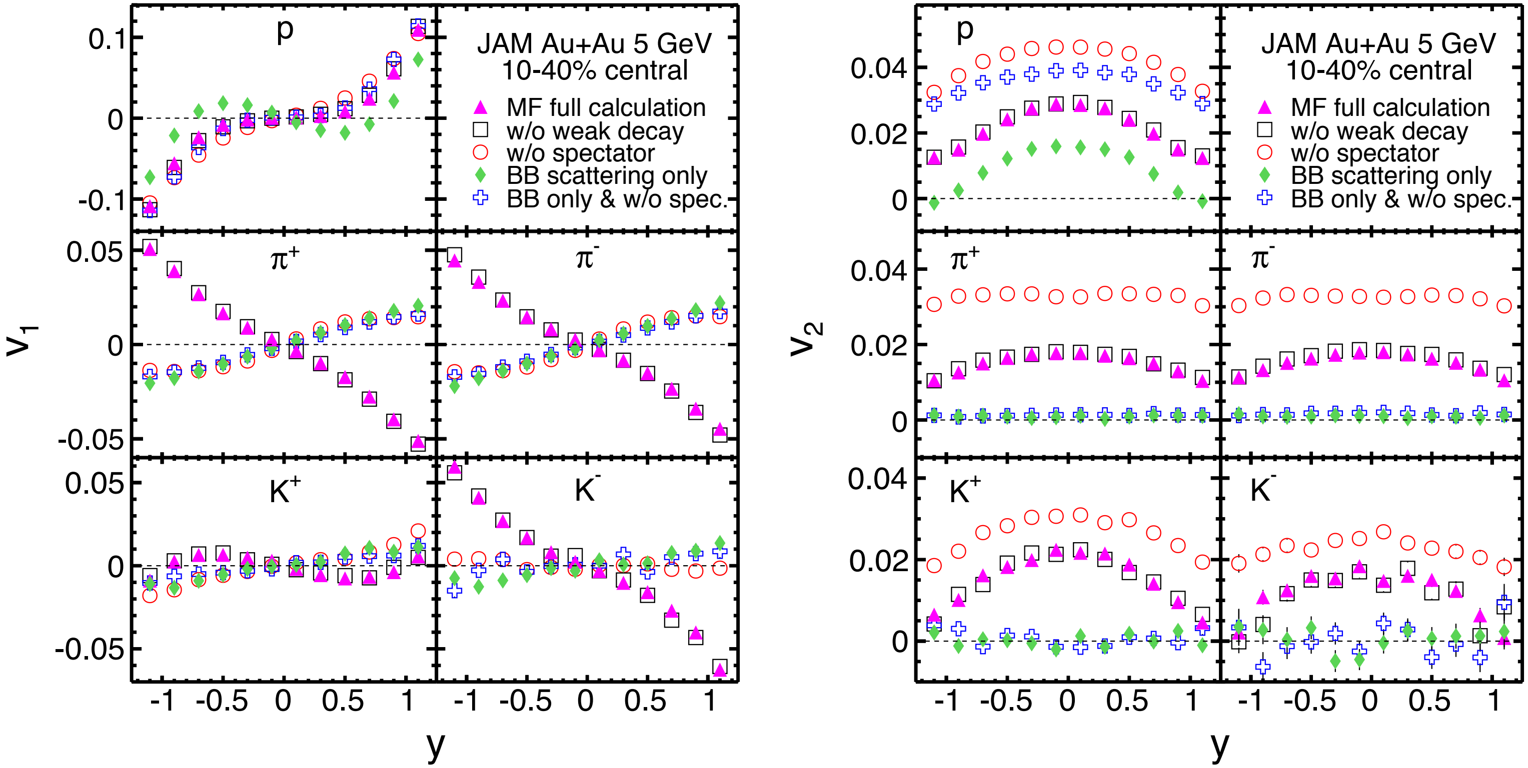
Spectator : disabling the interaction between spectator nucleons and participants.

EOS effects



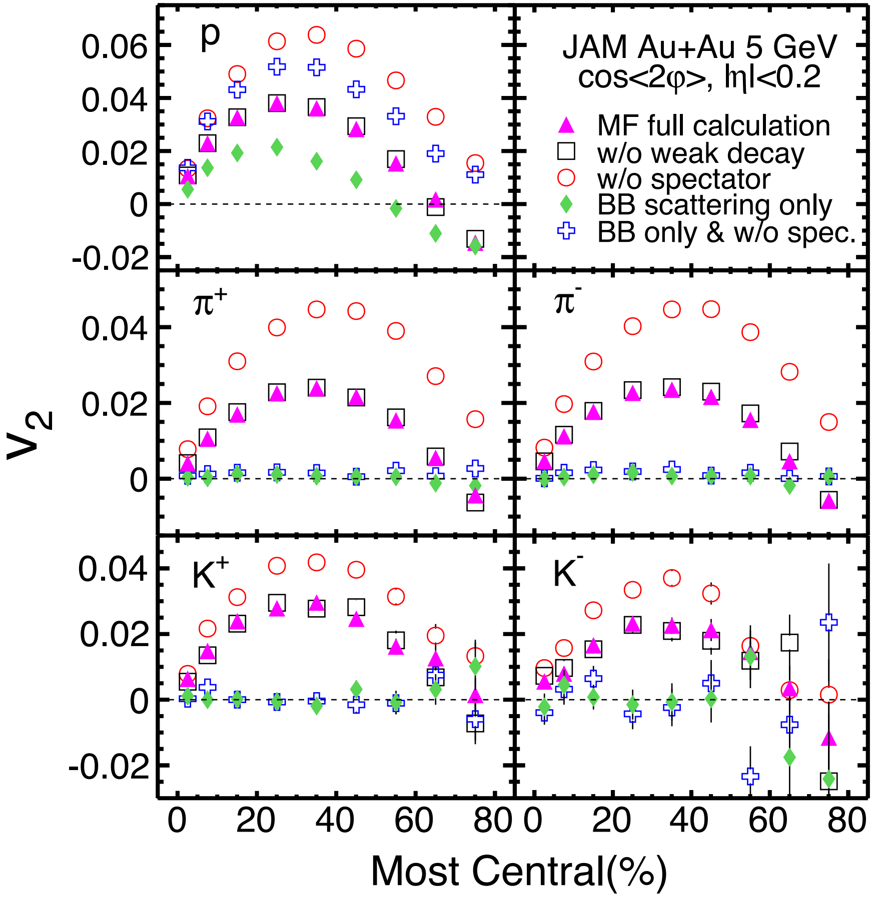
- Softening effect predicts enhancement of collective transverse flow for all particles, while mean field mode predicts harder slope of proton.
- Attractive orbit simulation predicts a negative slope of protons.

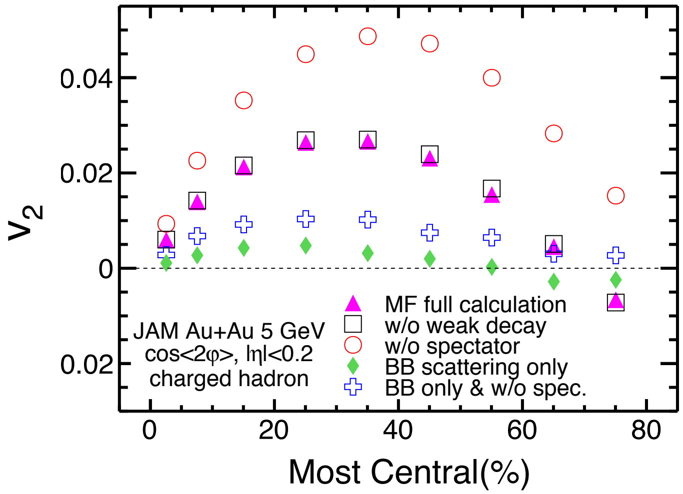
Squeeze-out and hadronic re-scattering effects



- Baryon-Baryon (BB) collisions: negative v_1 for proton, positive for pions and kaons.
- (BB): nucleon v2 : smaller by about 20% , pion and kaon elliptic flows zero.

v_2(Centrality dependence)

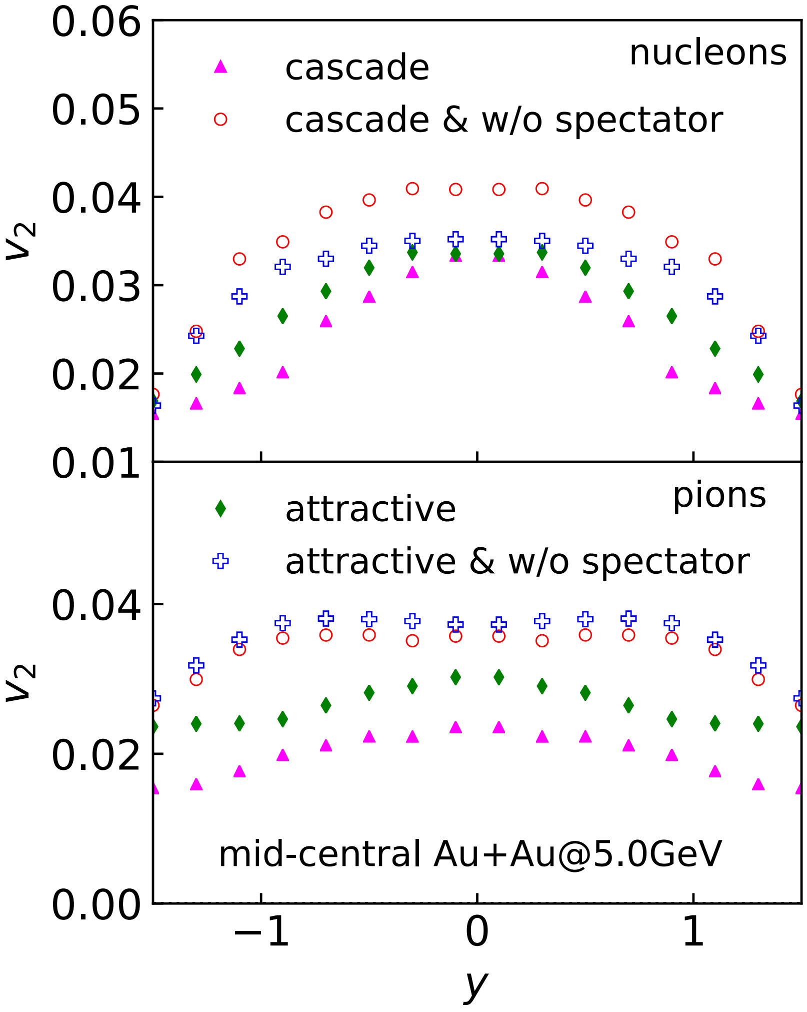




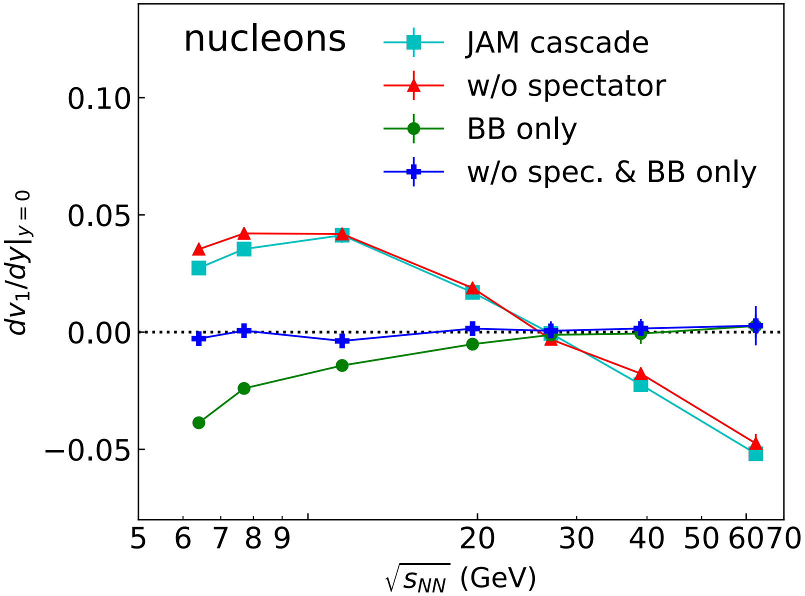
- Suppression of elliptic flow by the spectator can be seen for all centrality for all particles except for most central collisions.

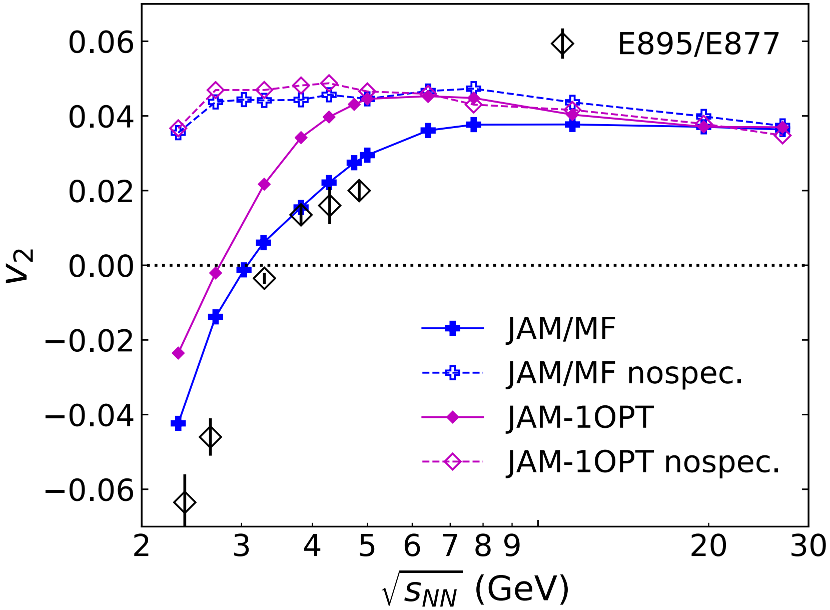
Suppression of the squeeze-out effect

With spectator:
reduction of nucleon v2 :
30% in cascade.
almost no reduction in
attractive orbit mode.



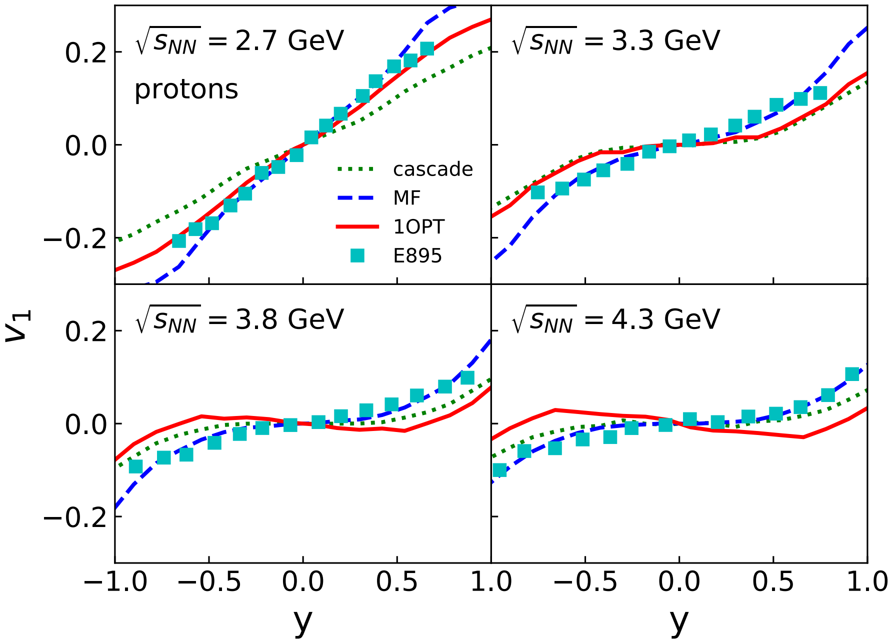
Beam energy dependence

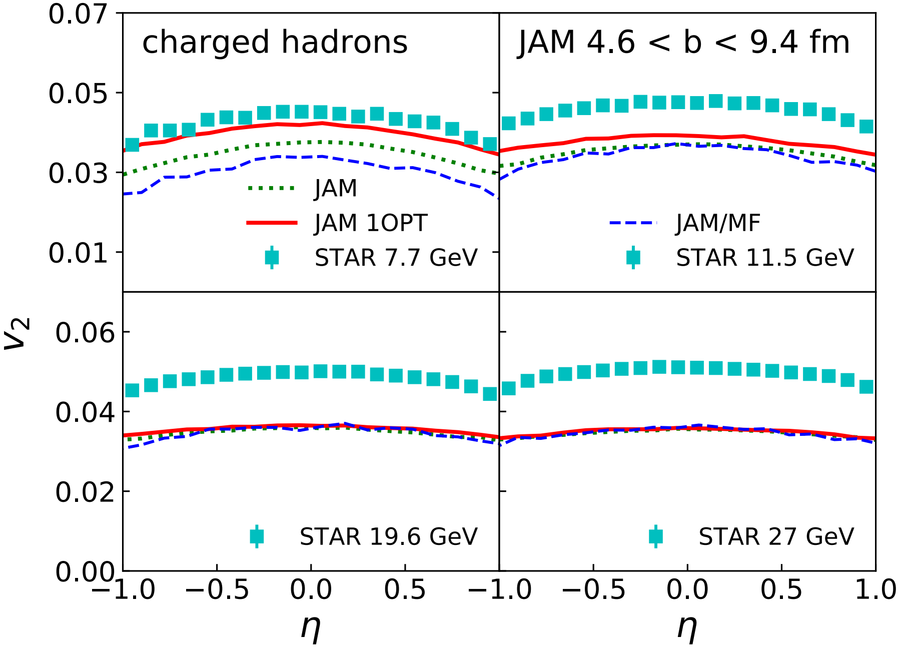




- BB collisions generate negative directed flow below 30 GeV (green),
- MB and MM scattering effects to the slope of nucleon directed flow is opposite at low and high energies.
- Spectator shadowing effects up to 10 GeV in MF, on the other hand, it disappear around 5GeV in 1OPT mode due to strong softening 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 7.7GeV, 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.

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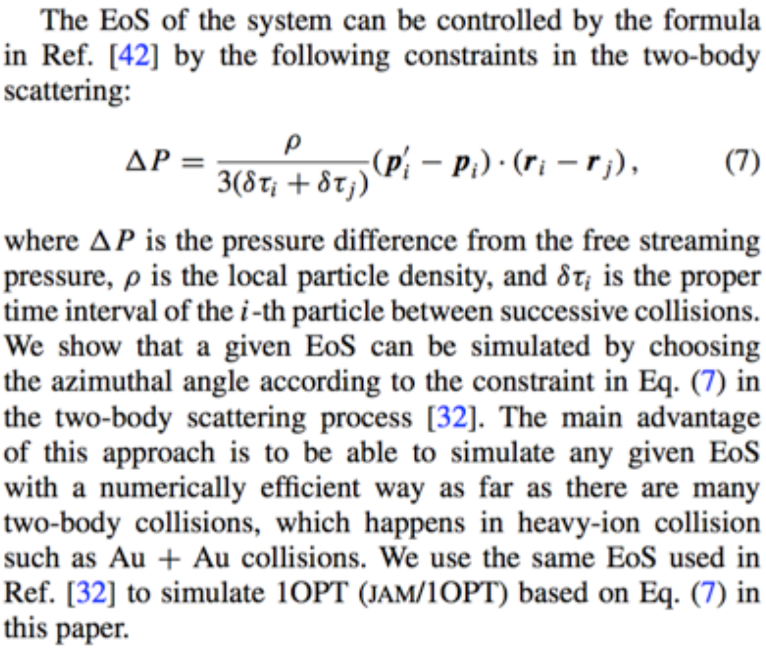

The EoS of the system can be controlled by the formula in Ref. [42] by the following constraints in the two-body scattering:

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

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 1OPT (JAM/1OPT) based on Eq. (7) in this paper.