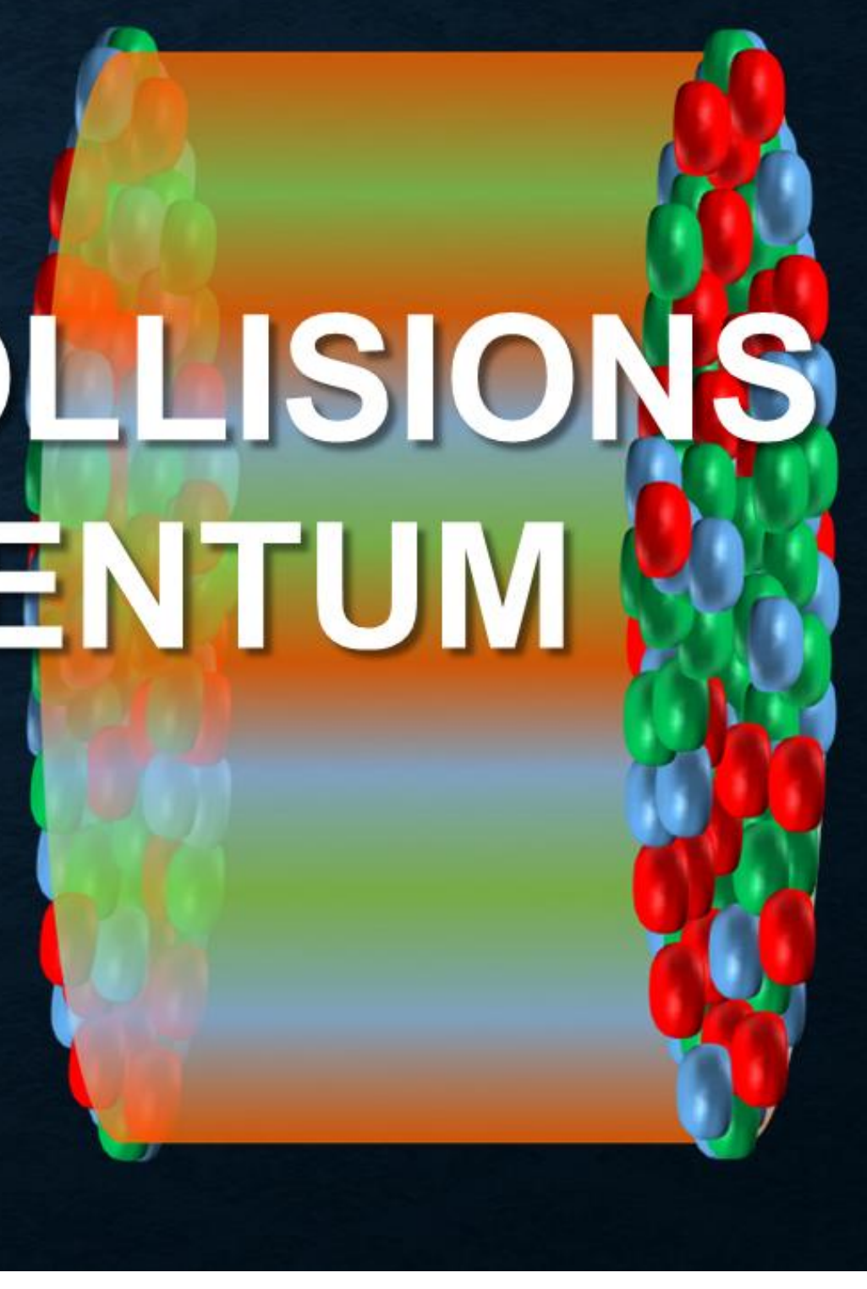
APPLICATION OF (3+1)D GLASMA SIMULATION TO AU-AU COLLISIONS AT $\sqrt{s_{NN}} = 200$ GEV: ECCENTRICITY, AND ANGULAR MOMENTUM



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<Abstract>

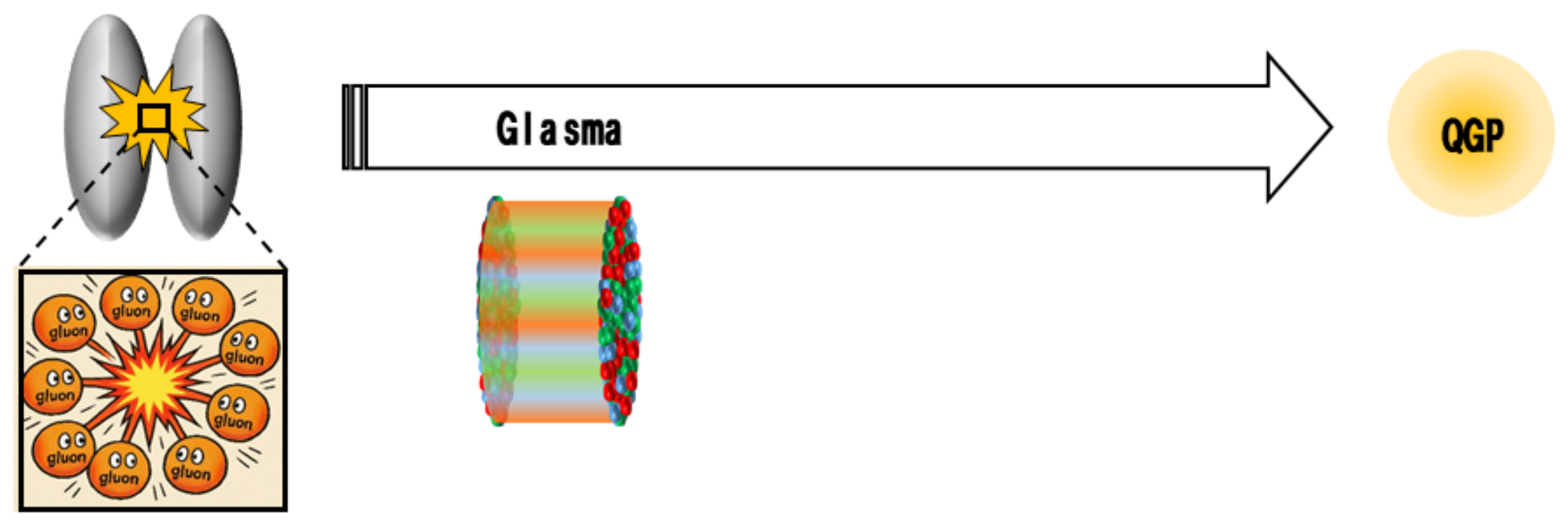
We perform a (3+1)D glasma simulation of the early stages of Au–Au collisions at $\sqrt{s_{NN}} = 200$ GeV over a wide range of impact parameters [1]. This approach goes beyond the usual boost-invariant approximation by incorporating the nuclei's longitudinal structure, including finite nucleon thickness and random positions along the beam axis. We study geometry-dependent observables such as eccentricity and angular momentum, finding that eccentricitys grow with impact parameter. While angular momentum also increases, its generation at mid-rapidity is suppressed across all impact parameters, consistent with experimental observations of global polarization at $\sqrt{s_{NN}} = 200$ GeV.

[1] Phys. Rev. D **110**, 114032, (2024)

<Background>

IP-Glasma Model

B. Schenke, *et al.* (2012)

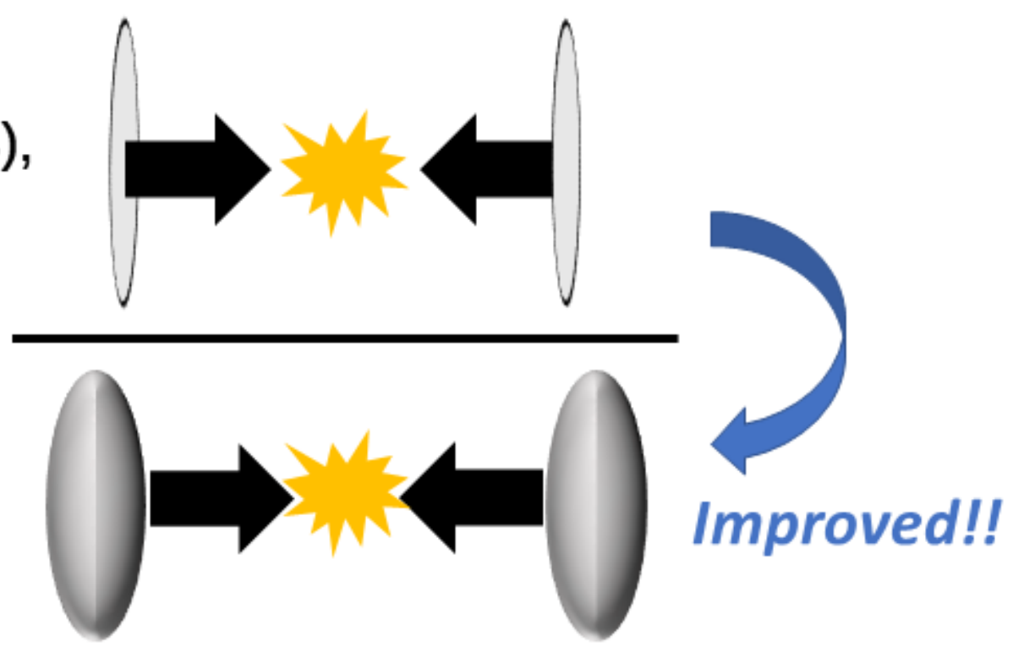


IP-Glasma Model: an "Initial State Model" focusing on early gluon dynamics

- **Simulate generation and evolution of the glasma, based on CGC effective theory**
- **Assume physical quantities of the glasma are directly inherited by QGP, and interpret them as inputs for relativistic hydrodynamics**
- **Be widely used and successfully reproduce experimental results**
- ***Neglect the longitudinal structure of the nucleus***

3D Glasma: Finite Longitudinal Structure and Color Rotation

<Recent attempt>
D. Gelfand, *et al.* (2016), A. Ipp, *et al.* (2017,2018,2020,2021,2024),
S. Schlichting, *et al.* (2021), D. Avramescu, *et al.* D (2023),
H. M. and X.-G. Huang (2023,2024)



In this talk, we applied the 3D glasma simulation to Au+Au collisions and clarified the collision geometry dependence of various physical quantities

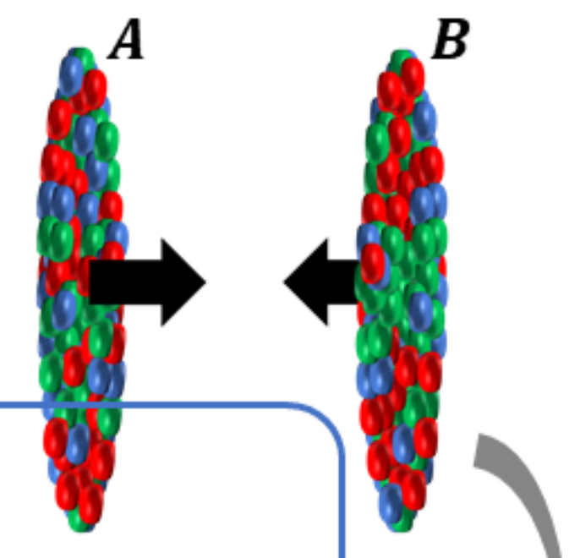
Phys. Rev. D 110, 114032, (2024)

<Method>

*Phys. Rev. D **108**, 114008, (2023)*

Step 1: Set initial conditions of two nuclei on the lattice

$$\left(\rho^{A}_{\text{ini}}, \rho^{B}_{\text{ini}}, A_{\text{ini}}, E_{\text{ini}}\right)$$

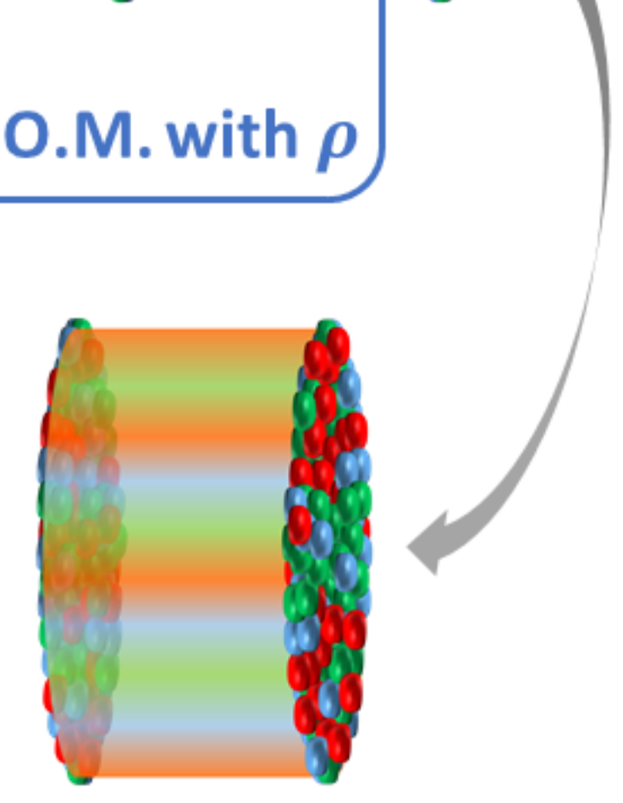


Classical color charge density (ρ)
- **Hard parton**
- **Input of model**

Classical Yang-Mills field (A_μ)
- **Soft gluon**
- **Determined by solving Classical E.O.M. with ρ**

Step 2: Evolve CYM fields and classical color charges numerically

$$\left[D_\mu, F^{\mu\nu}\right] = \delta^{\nu+}\rho^{A} + \delta^{\nu-}\rho^{B}$$
$$\left[D_\mu, \delta^{\pm}\rho^{A/B}\right] = 0$$



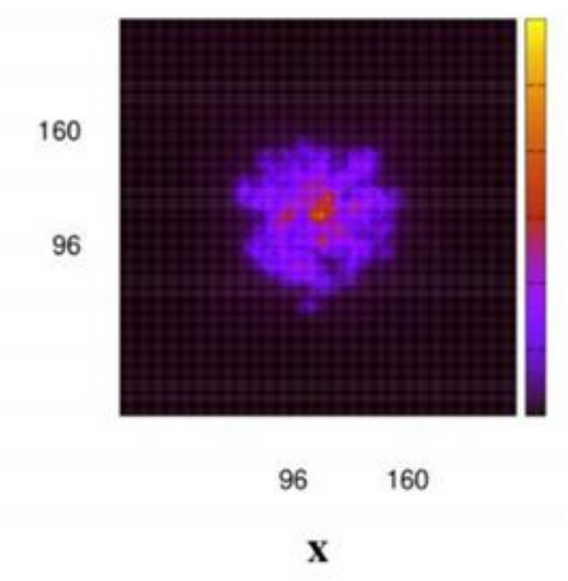
Step 3: Repeat steps 1 and 2, and take the event average of the observables of interest

<Setup>

Gold Nucleus:

- $\rho(x)$: Incoherent sum of nucleon's color charge densities (ρ_i)
- $\rho_i(x)$: Gaussican Nucleon shape × event-by-event random number (Γ_i)
- $\Gamma_i(x)$: Average of squared Γ_i is given by saturation scale (Q_s)
- $Q_s(x_\perp)$: Estimated by IP-sat model

Bartels, *et al.* (2002), H. Kowalski and D. Teaney (2003



Simplicity: SU(2)

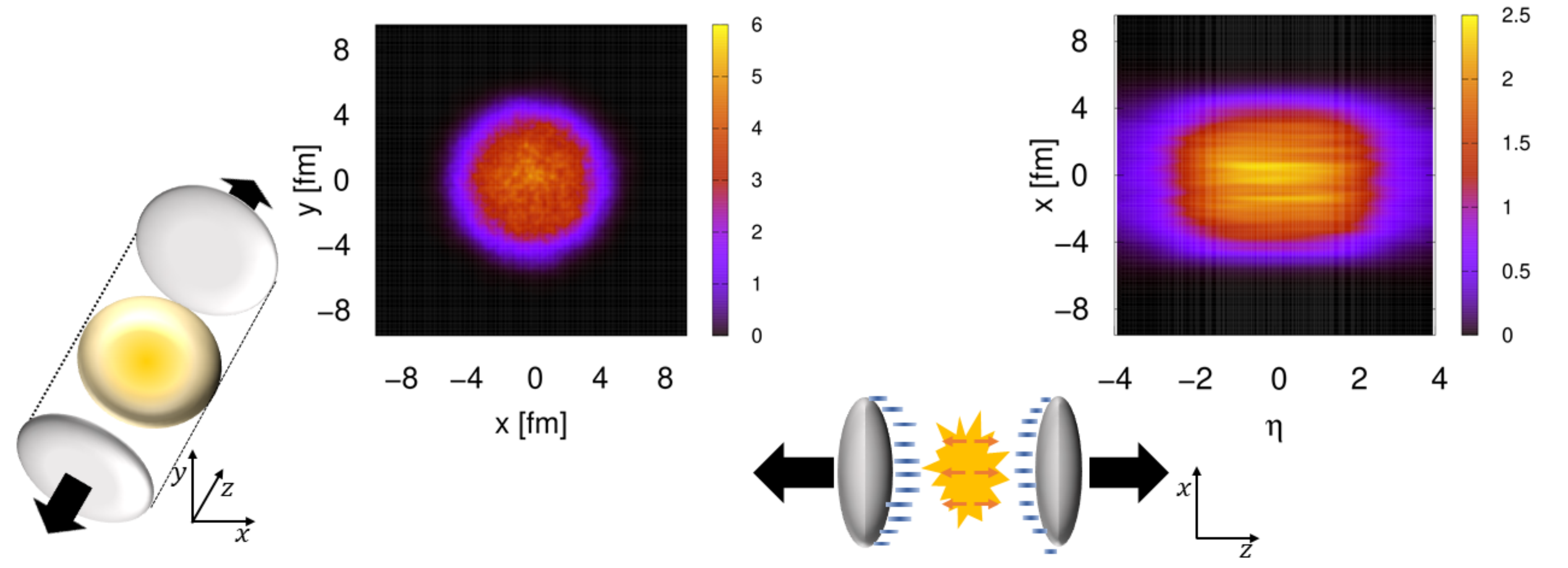
<Results>

Energy Density Profile

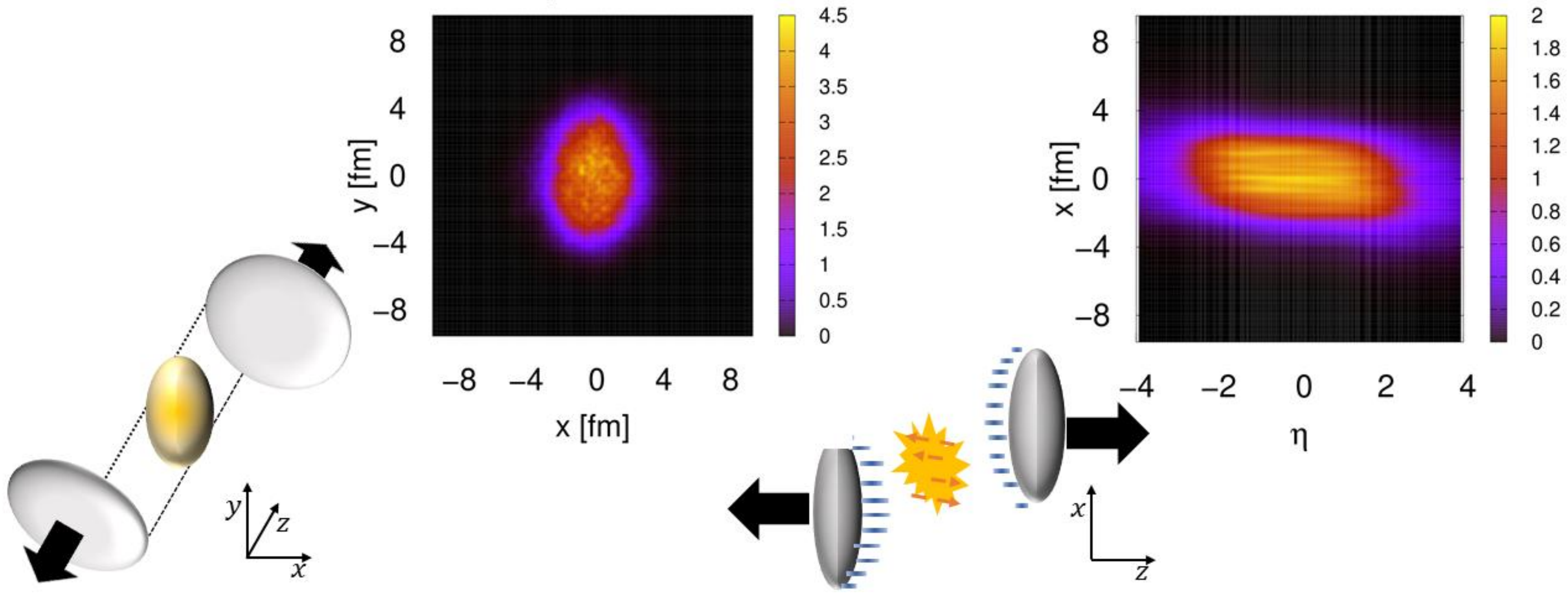
ε_{LRF}: Local rest frame energy density

✓ **The ε_{LRF} deformation reflects the shape of the overlap region of the colliding nuclei and the difference in their thickness.**

<Central Collision ($b_{\text{imp}} = 0$) at $\tau = 0$ >

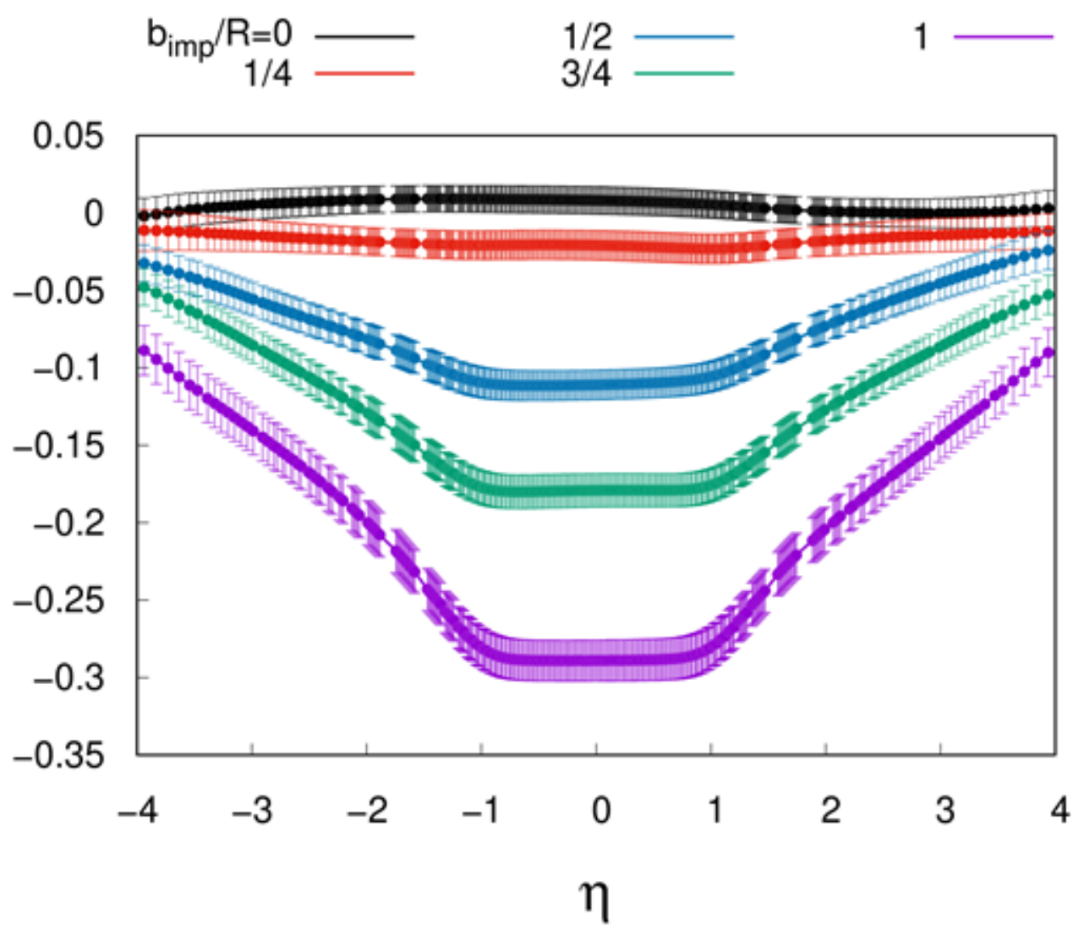


<Non-Central Collision ($b_{\text{imp}} = R$) at $\tau = 0$ >



Rapidity Profile of $\mathrm{Re}[\varepsilon_2]$

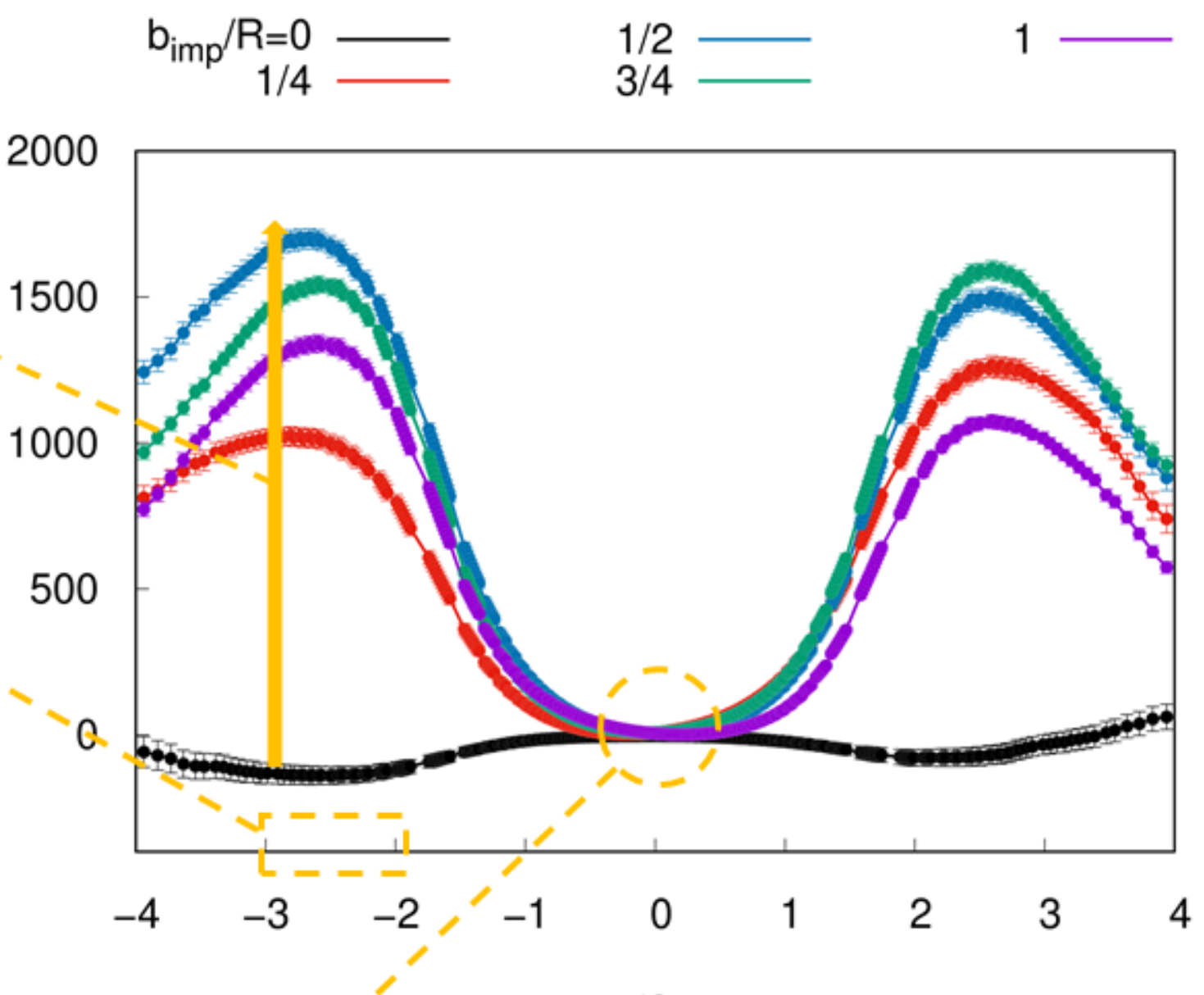
$$\varepsilon_n = \frac{\int d^2\boldsymbol{x}_\perp \varepsilon_{\mathrm{LRF}} r_\perp^n e^{in\phi}}{\int d^2\boldsymbol{x}_\perp \varepsilon_{\mathrm{LRF}} r_\perp^n} \quad \left[\begin{array}{l} \phi \equiv \arctan\left(x^2/x^1\right) \\ r_\perp \equiv \sqrt{(x^1)^2 + (x^2)^2} \end{array}\right.$$



✓ **consistent with shapes of energy densities**

✓ **consistent with experimental results of elliptic flow**

Rapidity Profile of L^y



✓ **Generation of L^y with increasing b_{imp}**

✓ **Emergence of a peak at $\eta = 2 - 3$**

✓ **Absence of L^y generation at $\eta = 0$**

Comment on little angular momentum around midrapidity

Given that CGC descriptions are more reliable at high energies, these results imply that effects beyond the high-energy limit may be important for explaining spin polarization at mid-rapidity, which is consistent with the experimental trend that spin polarization is very small at $\sqrt{s_{NN}} =$ 200 GeV, 2.76 TeV, and 5.02 TeV and increases as the beam energy decreases.

<Outlook>

Apply the 3D glasma model as the initial state for hydrodynamic simulations, and compare with experimental data.