Determining QCD matter viscosity from fluid dynamics with saturated minijet initial conditions in ultrarelativistic A+A collisions

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Introduction

This work [1,2]:

- Rigorous NLO pQCD calculation for E_T production from minijets & EKRT type saturation for E_T

$\Rightarrow$ Compute initial conditions for hydrodynamics in A+A

- Apply 2+1D EbyE viscous hydrodynamics

$\Rightarrow$ Centrality dependence of multiplicity, p_T spectra and v_n simultaneously at the LHC and RHIC

Initial conditions

Minijet E_T production in A+A and Δy

$$\frac{\mathrm{d}E_T}{\mathrm{d}^2\mathbf{s}}(\sqrt{s_{NN}}, p_0, \mathbf{s}, \mathbf{b}; \beta) = T_A(\mathbf{s}+\frac{\mathbf{b}}{2})T_A(\mathbf{s}-\frac{\mathbf{b}}{2})\sigma\langle E_T\rangle_{p_0,\Delta y,\beta}$$

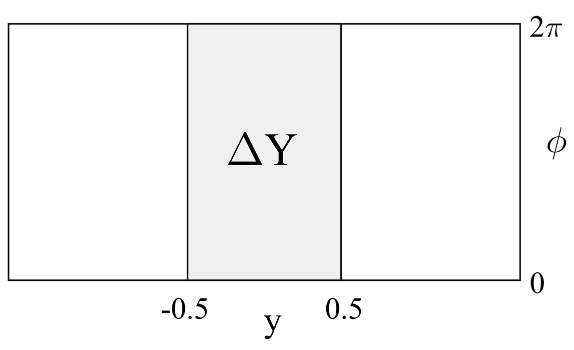
- EbyE: $T_A = \rho^{\mathrm{WS}}_{\mathrm{nucleon}}(\mathbf{s}) \otimes \rho^{\mathrm{Gauss}}_{\mathrm{gluon}}(\mathbf{s})$
- NLO pQCD computation of $\sigma\langle E_T\rangle_{p_0,\Delta y,\beta}$
- $\beta \in [0,1]$ controls the soft pQCD kinematics Δy

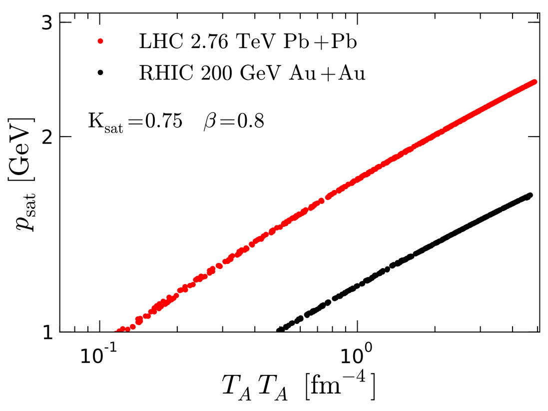
Infrared safe saturation criterion for E_T

$$\frac{\mathrm{d}E_T}{\mathrm{d}^2\mathbf{s}}(\cdots; \beta, K_{\mathrm{sat}}) = \Delta y \left(\frac{K_{\mathrm{sat}}}{\pi}\right) p_0^3$$

$$\Rightarrow p_0 = p_{\mathrm{sat}}(\sqrt{s_{NN}}, p_0, \mathbf{s}, \mathbf{b}; \beta, K_{\mathrm{sat}})$$

where K_{sat} is proportionality constant $\mathcal{O}(1)$





Energy density profile

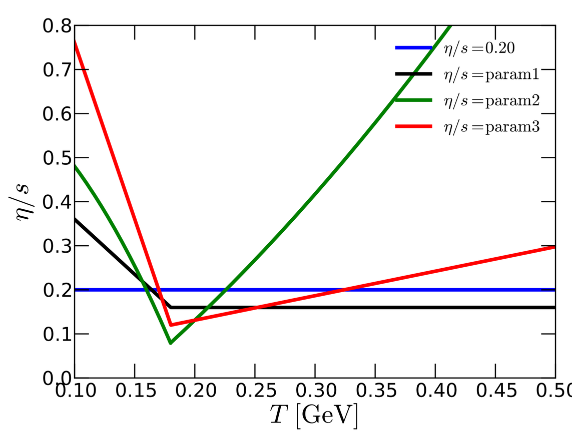
$$\epsilon(\mathbf{s}, \tau_{\mathrm{sat}} = \frac{1}{p_{\mathrm{sat}}}) = \frac{\mathrm{d}E_T}{\mathrm{d}^2\mathbf{s}}\frac{1}{\Delta y \tau_{\mathrm{sat}}} = \frac{K_{\mathrm{sat}}}{\pi}p^4_{\mathrm{sat}}(\mathbf{s})$$

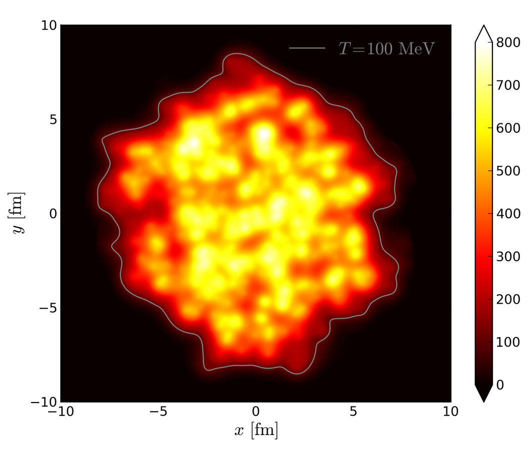
Pre-thermal evolution $\tau_{\mathrm{sat}}(\mathbf{s}) \to \tau_0 = 0.2$ fm via FS/BJ!

Hydro setup

2+1D EbyE viscous hydrodynamics

- s95p-PCE-v1 EoS [3], $T_{\mathrm{chem}} = 175$ MeV
- Freeze-out temperature $T_{\mathrm{f}} = 100$ MeV
- Initial $\pi^{\mu\nu} = 0$ and $\mathbf{v} = 0$ (flow velocity)
- Temperature dependent $\eta/s(T)$ parametrizations:





Initial $T_0(\mathbf{s})$

References

[1] R. Paatelainen, K. J. Eskola, H. Niemi, K. Tuominen, Phys. Lett. B731 (2014) 126

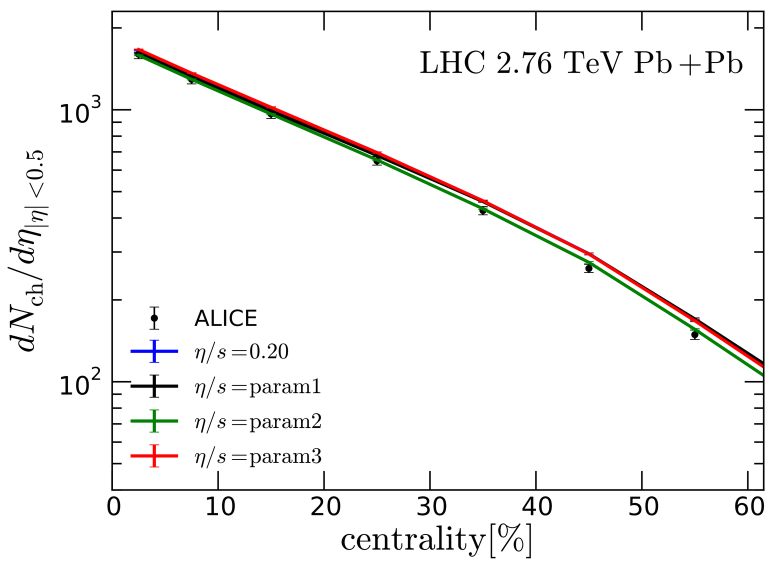
[2] H. Niemi, K. J. Eskola, R. Paatelainen, K. Tuominen, work in progress

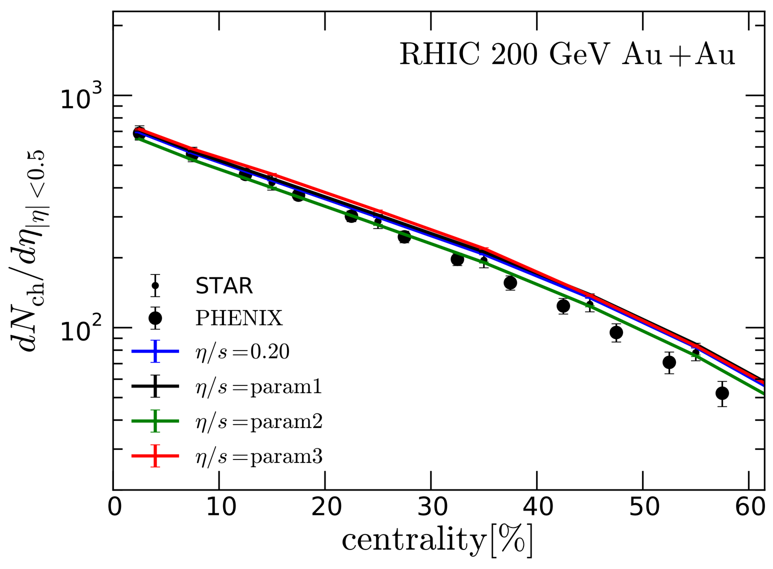
[3] P. Huovinen, P. Petreczky, Nucl. Phys. A837 (2010) 26

New EbyE results (preliminary)

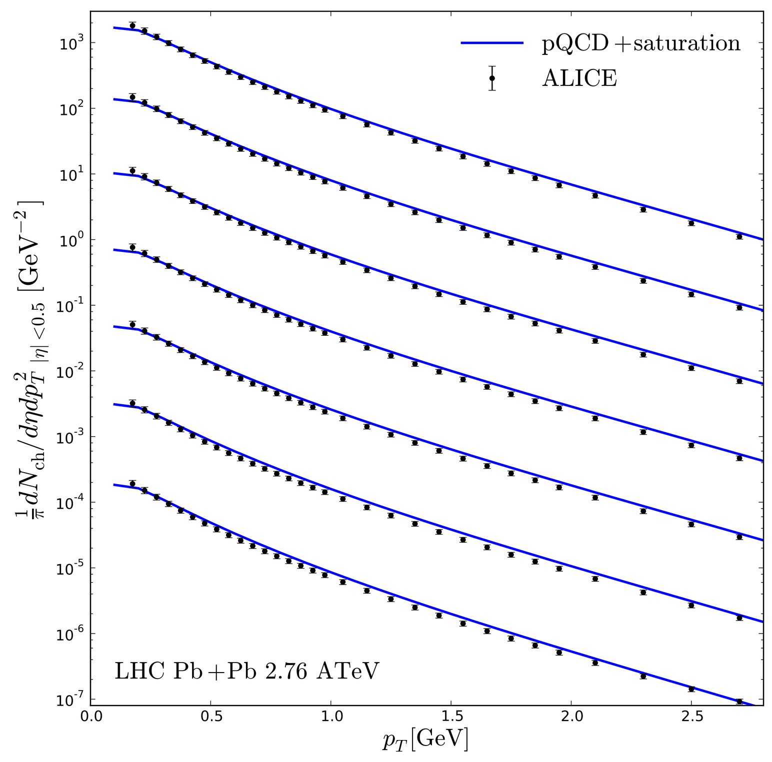
$(K_{\mathrm{sat}}, \beta)$ fixed to give 0-5% LHC multiplicity!

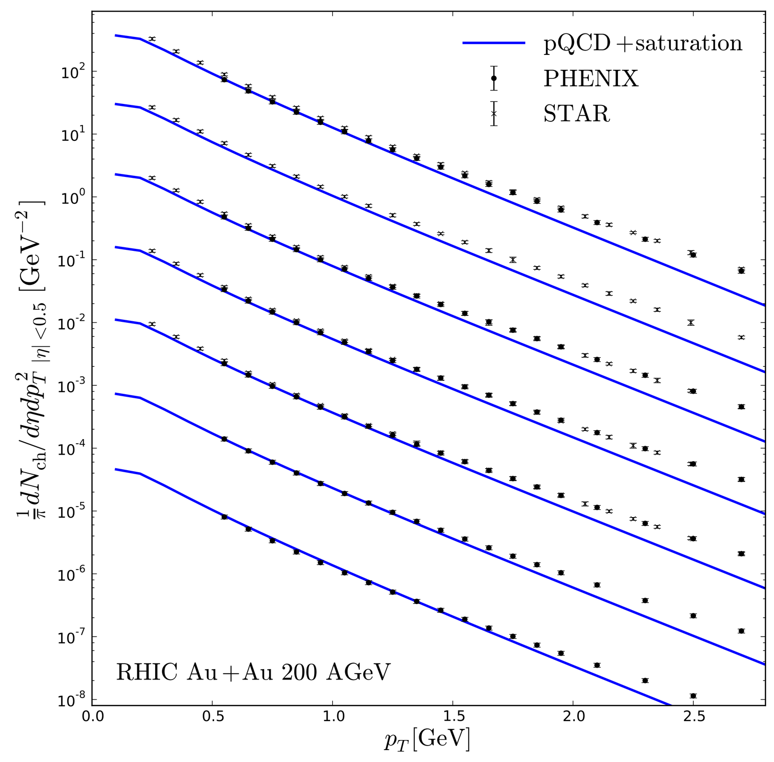
- Centrality dependence of multiplicity



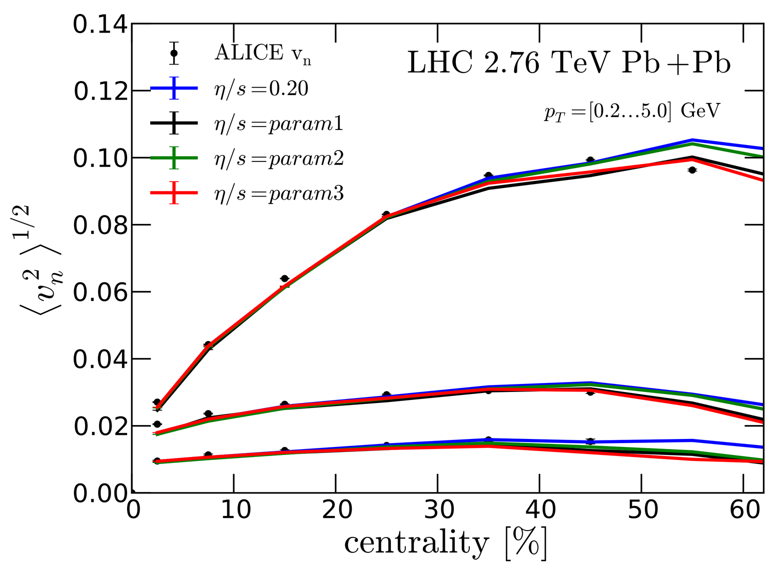


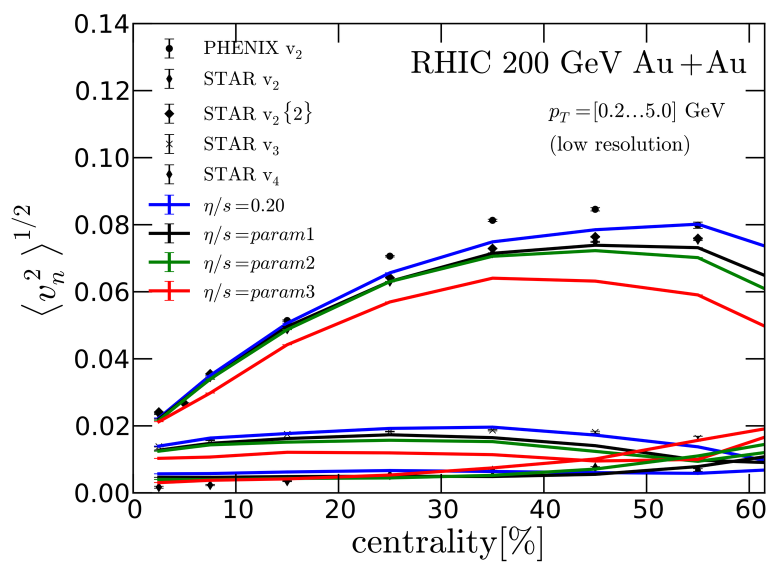
- Charged particle p_T spectra



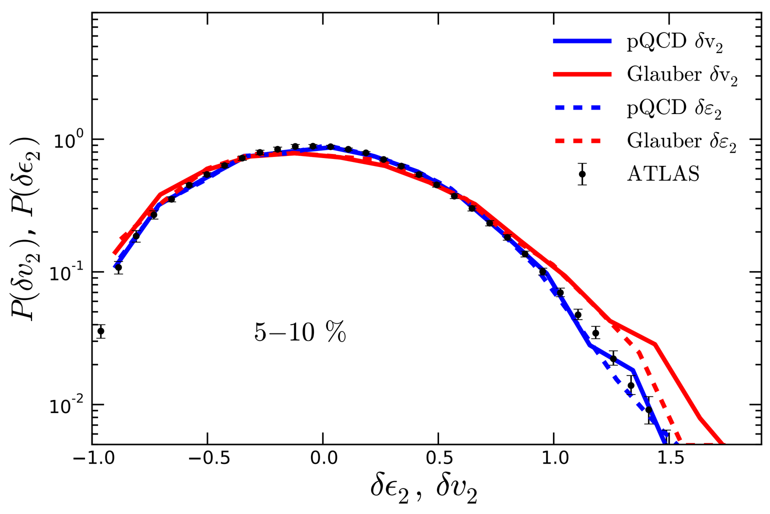


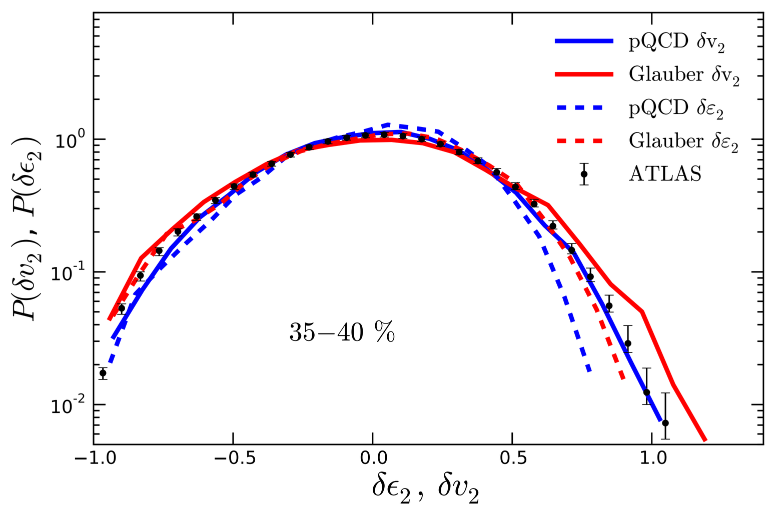
- Flow coefficients v_n: <u>simultaneous</u> LHC & RHIC analysis constrains $\eta/s(T)$ & IS

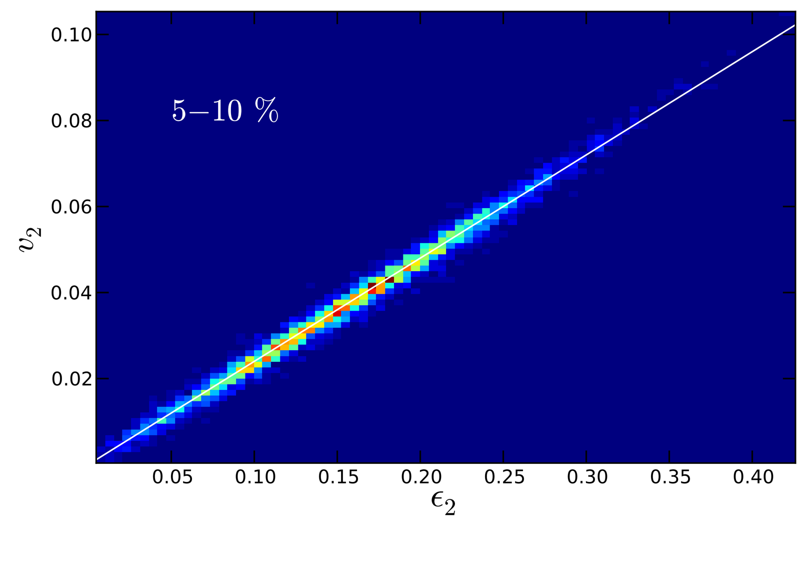


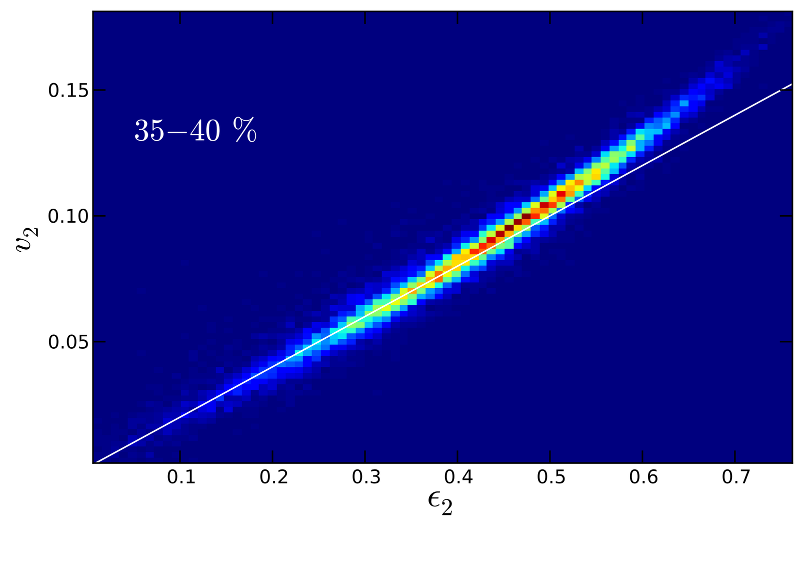


- EbyE distributions of $\delta v_2, \delta\epsilon_2$ at LHC constrain IS: pQCD + Saturation <u>works</u>!









Here

$$v_n = \left\langle \cos(n(\phi - \Psi_n)) \right\rangle / \left\langle 1 \right\rangle, \quad \text{where} \quad \left\langle \cdots \right\rangle = \int \mathrm{d}p_T^2 \mathrm{d}\phi \frac{\mathrm{d}N}{\mathrm{d}y\mathrm{d}\phi\mathrm{d}p_T^2}(\cdots)$$

and

$$\epsilon_{n,2} = \left\langle \epsilon(\mathbf{s}) r^2 \cos(n(\phi - \Psi_n)) \right\rangle / \left\langle \epsilon(\mathbf{s}) r^2 \right\rangle \quad \text{where} \quad \left\langle \cdots \right\rangle = \int \mathrm{d}x\mathrm{d}y(\cdots)$$

For us $\epsilon_{2,2} = \epsilon_2$ and energy density $\epsilon(\mathbf{s})$ from minijet initial conditions.