Viscous Hydrodynamic Elliptic Flow from RHIC to LHC*

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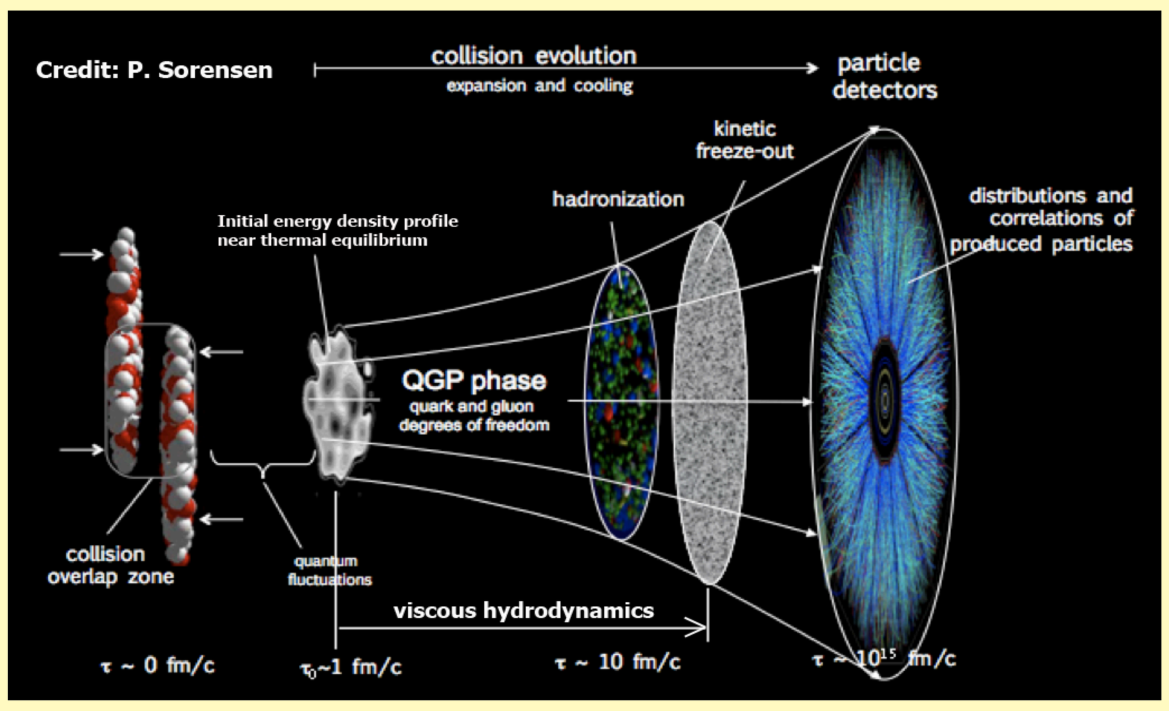
Abstract

Almost perfectly liquid quark-gluon plasma (QGP) is created in ultrarelativistic heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC). The elliptic flow coefficient v_2, characterizing the momentum anisotropy of the finally emitted particles, is a key observable constraining the shear viscosity of the QGP. Using pure viscous hydrodynamics, we perform a global fit to hadron spectra and elliptic flow measured in Au+Au collisions at RHIC and use this as a basis for extrapolation to higher LHC energies. Comparison with first elliptic flow data from ALICE shows that the model correctly predicted 30% increase of v_2 from RHIC to LHC, but overpredicts $v_2\{4\}$ by $\sim$10% at both energies. We explore a possible variation of the shear viscosity η/s at higher temperature. We predicted spectra and v_2 for identified hadrons as further tests of the model.

Introduction



Viscous hydrodynamics solves Israel-Stewart equations. The energy-momentum tensor is written as $\boxed{T^{\mu\nu} = e u^\mu u^\nu - p\Delta^{\mu\nu} + \pi^{\mu\nu}}$, where e is energy density, u^μ is the flow velocity, p is the pressure, $\Delta^{\mu\nu} = g^{\mu\nu} - u^\mu u^\nu$ projects transverse to the flow, and $\pi^{\mu\nu}$ is the shear stress tensor. The equations of motion are

$$d_\mu T^{\mu\nu} = 0 \quad , \qquad (1)$$

$$\Delta^{\mu\alpha}\Delta^{\nu\beta} D\pi_{\alpha\beta} = -\frac{1}{\tau_\pi}(\pi^{\mu\nu} - 2\eta\sigma^{\mu\nu}) - \frac{1}{2}\pi^{\mu\nu}\frac{\eta T}{\tau_\pi} d_\lambda\left(\frac{\tau_\pi}{\eta T}u^\lambda\right). \qquad (2)$$

The final particle momentum distributions are calculated from the Cooper-Frye formula

$$E\frac{d^3N_i}{d^3p} = \frac{g_i}{(2\pi)^3}\int_\Sigma p\cdot d^3\sigma(x)[f_{\mathrm{eq},i}(x,p) + \delta f_i(x,p)], \qquad (3)$$

with dissipative correction

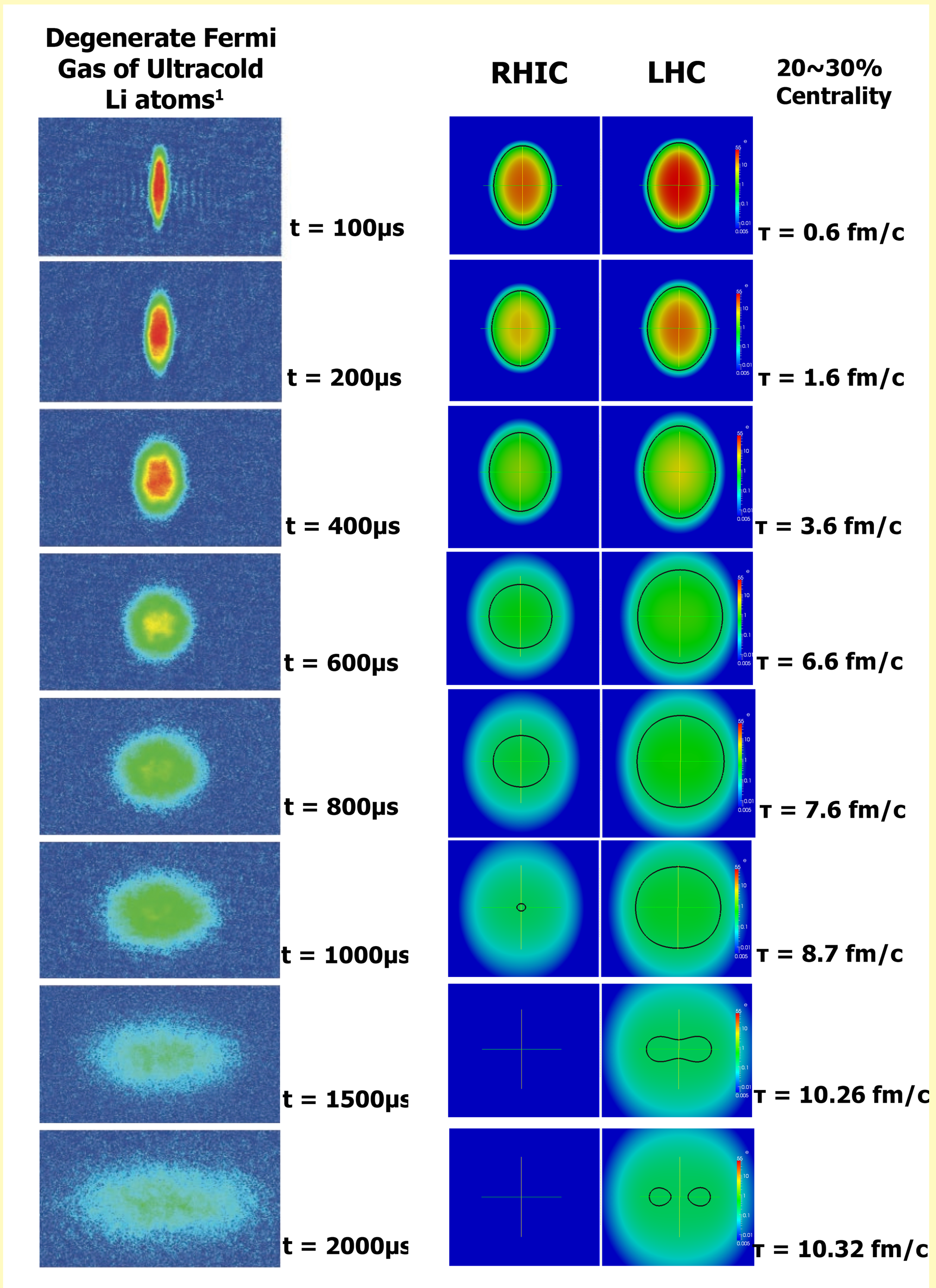
$$\delta f_i = f_{\mathrm{eq},i}\frac{1}{2}\frac{p^\mu p^\nu}{T^2}\frac{\pi_{\mu\nu}}{e+p}. \qquad (4)$$

The elliptic flow $v_2(p_T)$ is calculated as

$$v_2(p_T) = \frac{\int d\phi \frac{dN}{dy p_T dp_T d\phi}\cos(2\phi)}{\int d\phi \frac{dN}{dy p_T dp_T d\phi}}. \qquad (5)$$

Snapshots of Hydro Evolution

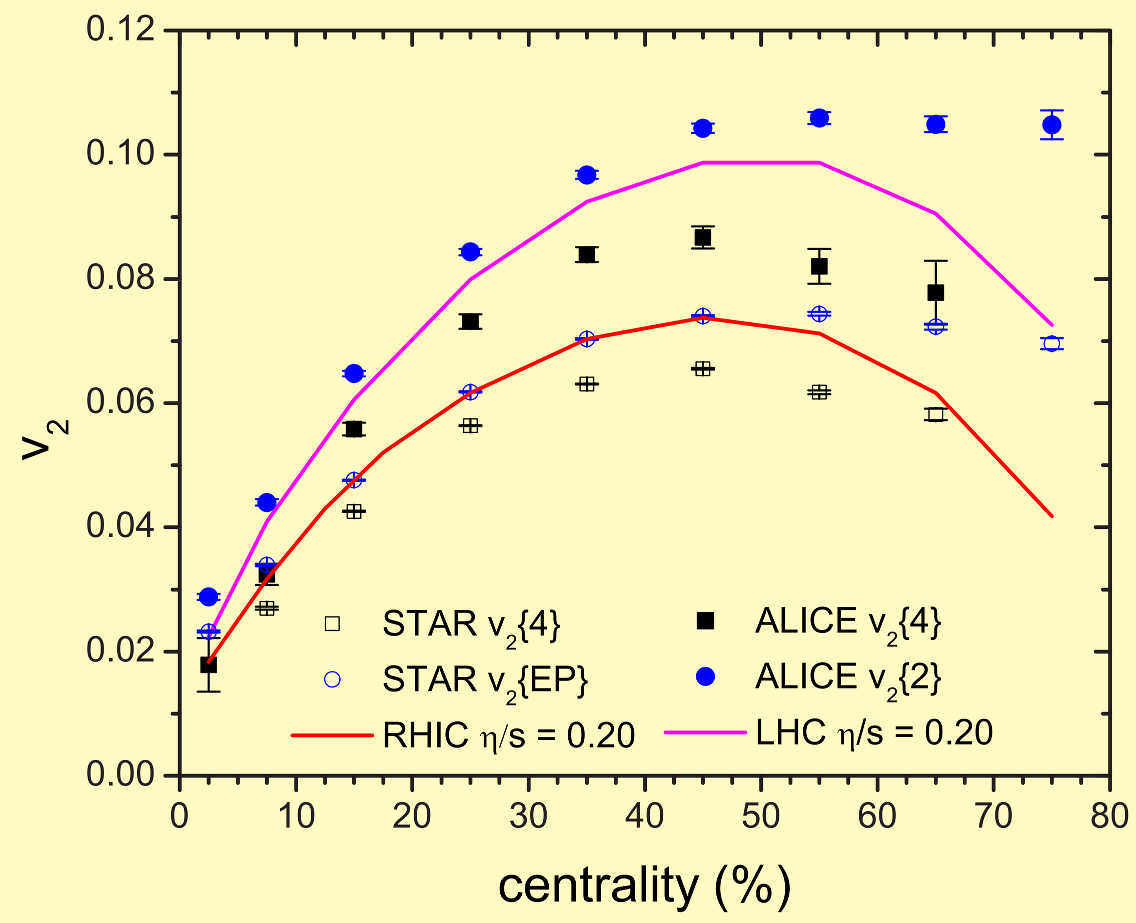
Any strongly coupled system exhibits **collective flow** which can be described macroscopically by hydrodynamics. The systems are driven by large anisotropic **pressure gradients** due to highly deformed initial spatial configurations, generating strong elliptic flow.



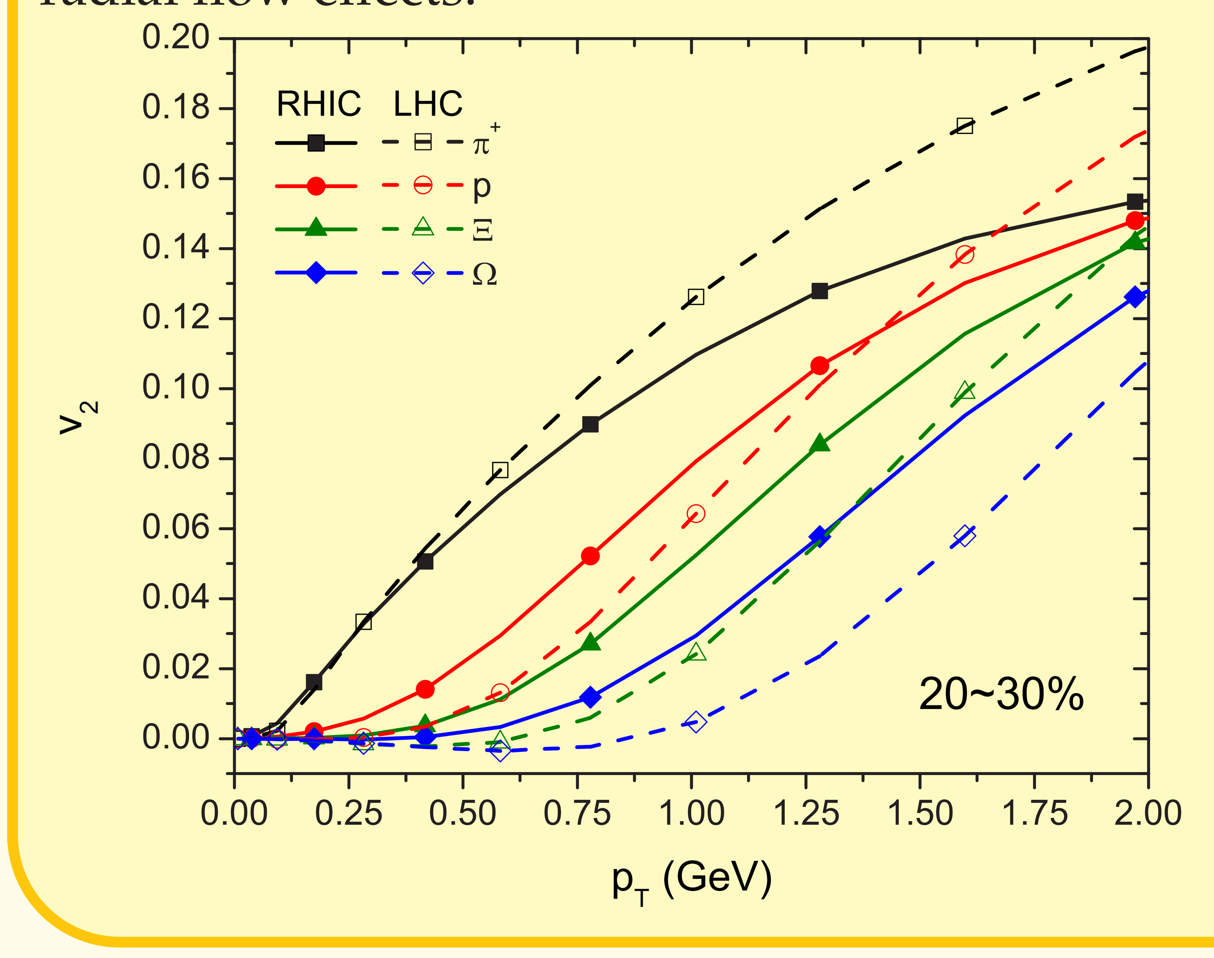
The right column compares hydrodynamic evolutions at RHIC and LHC in 20$\sim$30% peripheral AuAu or PbPb collisions. (Black line = freeze out surface at T_{dec}=120 MeV.) At LHC energy the **expansion rate is much larger** than at RHIC. The stronger hydrodynamic force generates **more elliptic flow**, which is large enough to tear the fireball into two pieces along the reaction plane at the very end of the evolution.

Results and Conclusions

Our hydrodynamic simulations estimate the **same amount of increase** from RHIC to LHC for the integrated v_2, $\sim$30%, as seen in the STAR and ALICE $v_2\{4\}$ data.

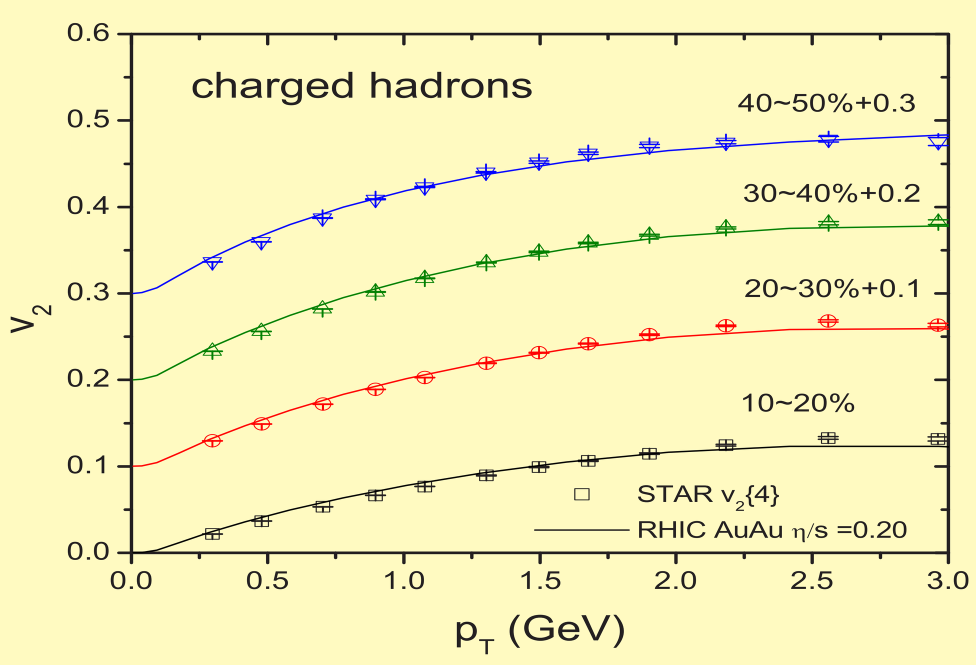


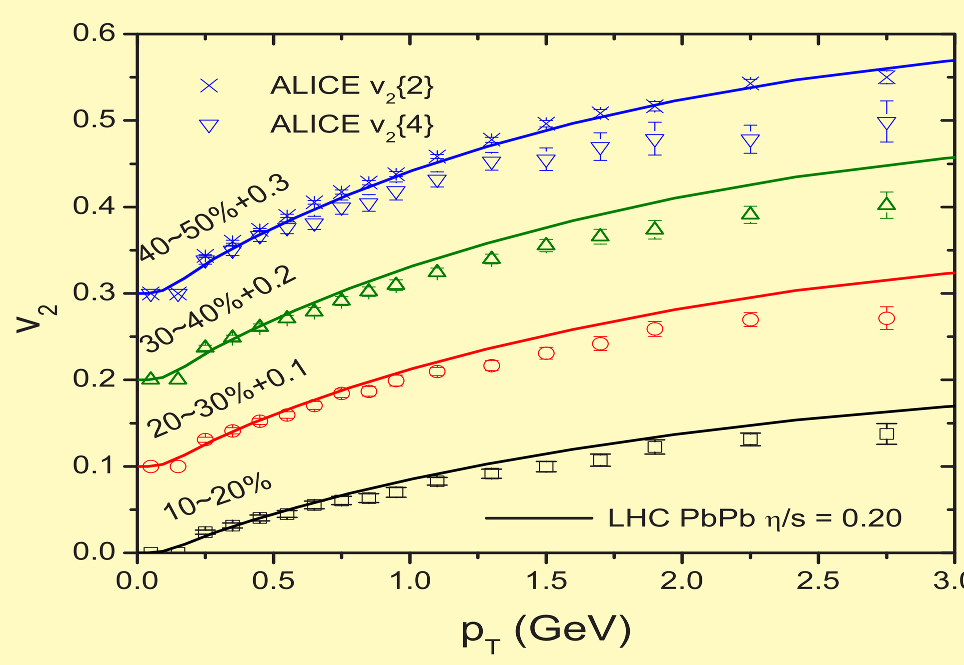
Even though for unidentified charged hadrons the differential $v_2(p_T)$ does not change between RHIC and LHC, hydrodynamics predicts a slight increase of $v_2(p_T)$ for identified pions and **a significant shift of v_2 to larger p_T** for heavier hadrons, caused by large radial flow effects.



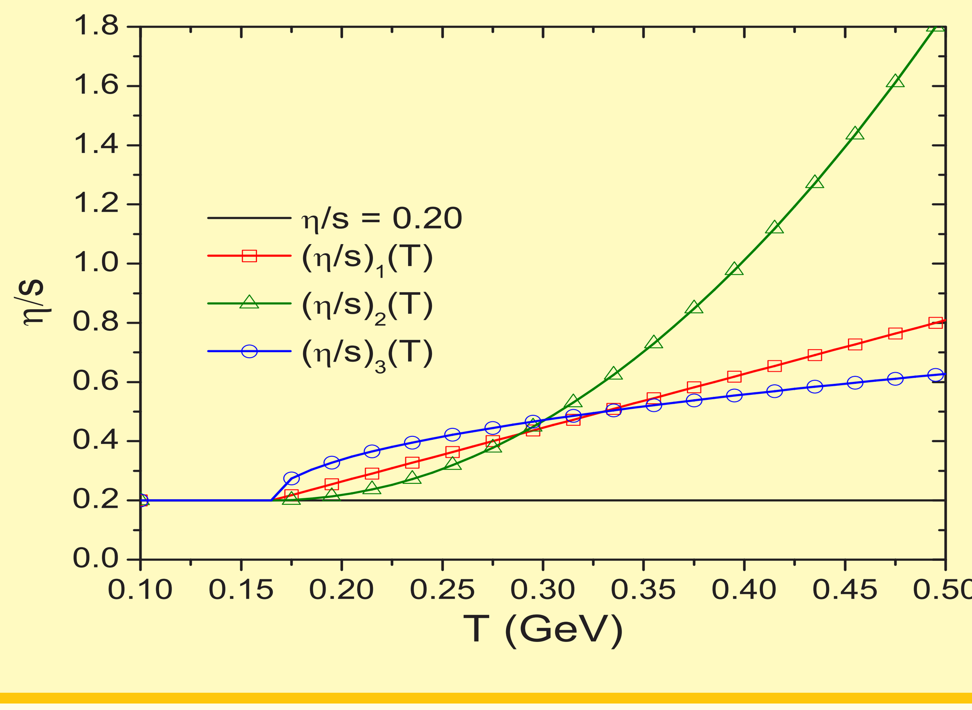
Results and Conclusions (cont.)

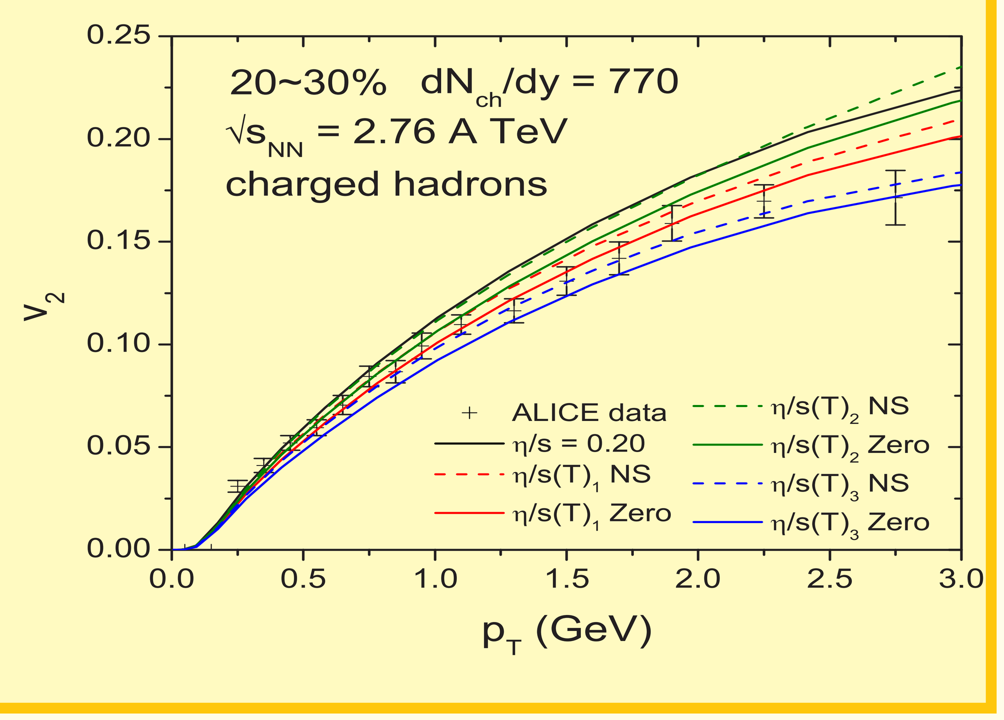
At RHIC energy, we get **an excellent fit** to the STAR $v_2\{4\}$ data in semiperipheral collisions, up to $p_T = 3$ GeV. With the ALICE $v_2\{4\}$ data at LHC we agree only up to 1 GeV and systematically **overpredict it by $\sim$ 10%** at higher p_T for all measured centralities.





Exploring a possible increase of η/s at higher temperatures we found a **sensitivity** of the differential $v_2(p_T)$ **to the initialization of the shear stress tensor $\pi^{\mu\nu}$**. With Navier-Stokes (NS) initial conditions we find less viscous v_2 suppression than for zero initial $\pi^{\mu\nu}$. v_2 at LHC is mostly **sensitive to η/s between T_c and $2T_c$.**





References

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