# QGP shear viscosity from combined analysis of elliptic and triangular flow

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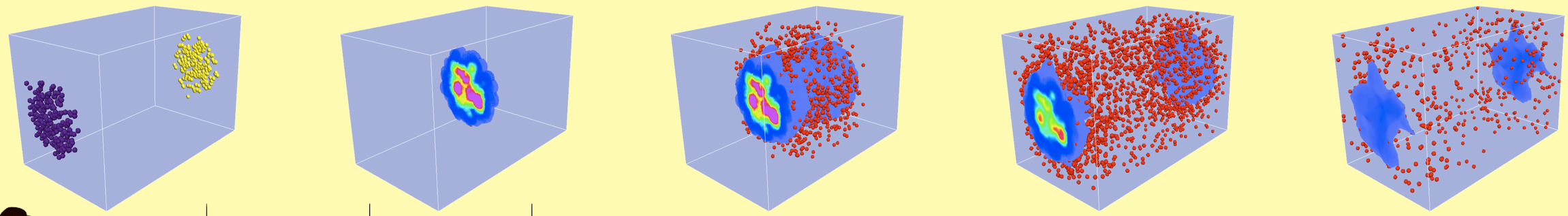
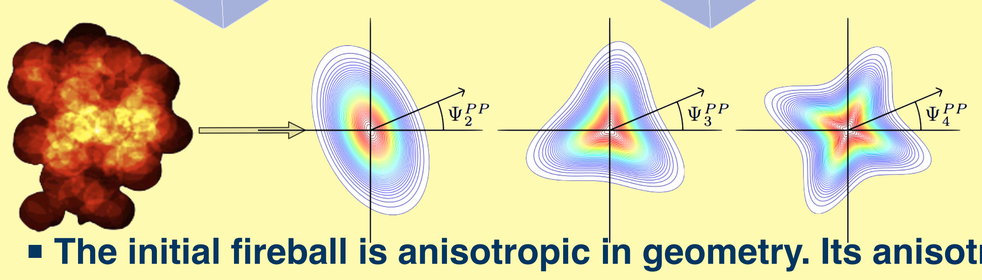
## Abstract

**By utilizing both measured elliptic and triangular flows, the uncertainty induced by initial condition ambiguities for the QGP shear viscosity (η/s) in relativistic heavy-ion collisions can be reduced to η/s~0.08±O(50%).**


## Introduction

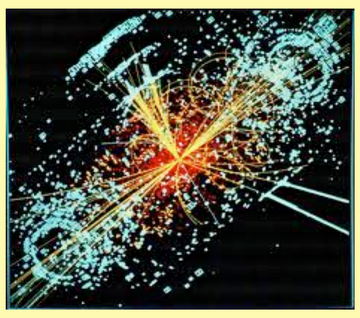
**Relativistic heavy-ion collisions create small QGP fireballs that evolve hydrodynamically and freeze out into particles.**






- The initial fireball is anisotropic in geometry. Its anisotropies are given by Fourier coefficients, the eccentricities $\varepsilon_n$.

$$\varepsilon_n e^{in\Phi_n} = \frac{\int e(\vec{r}) r^n e^{in\phi} r dr d\theta}{\int e(\vec{r}) r^n r dr d\theta}$$



$$\frac{dN}{d\phi} = \bar{N}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \Psi_n))\right)$$

- The momentum distribution of final particles is also anisotropic, which gives anisotropic flow $v_n$.
- $v_2$: elliptic flow; $v_3$: triangular flow

- It has been found (PRL 106, 192301) that the ratio $v_2/\varepsilon_2$ as function of $(1/S)(dN_{ch}/d\eta)$ is model independent and can be used to extract η/s; however there is a ~100% uncertainty for the extracted η/s value due to the ambiguity in $\varepsilon_2$ from different initial condition models.

## Using multiple anisotropic flow to extract η/s with reduced initial condition ambiguity

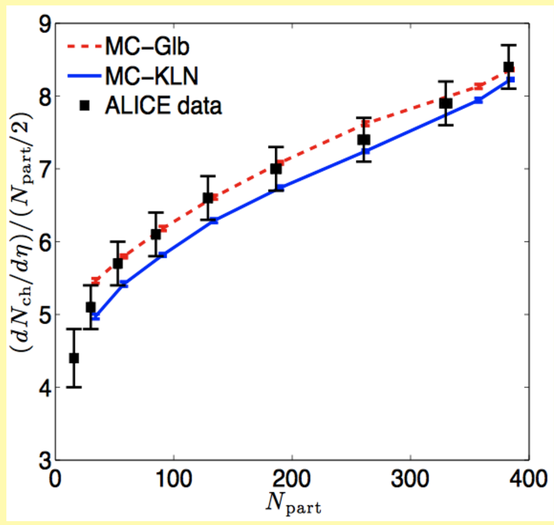
**The agreement of hydrodynamical simulations with observed spectra and elliptic flow $v_2$ fixes the η/s value and other parameters; additional observables will allow to distinguish between different initial conditions. We use ALICE triangular flow $v_3$ data.**

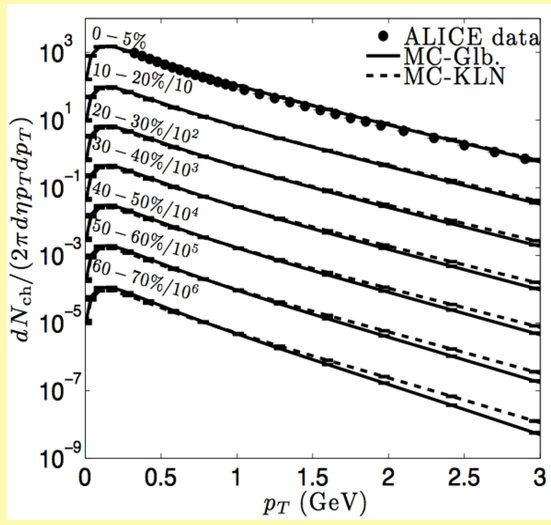
**Realistic hydrodynamic approach:**

- Event-by-event simulations with fluctuating initial conditions generated from the MC-Glauber and MC-KLN models. (This improves on earlier work in PLB707 151-155 based on averaged initial conditions.)
- Decay particles from resonances up to 2.2 GeV included.
- Use parameters that are known from single-shot calculations to fit multiplicity and spectra.

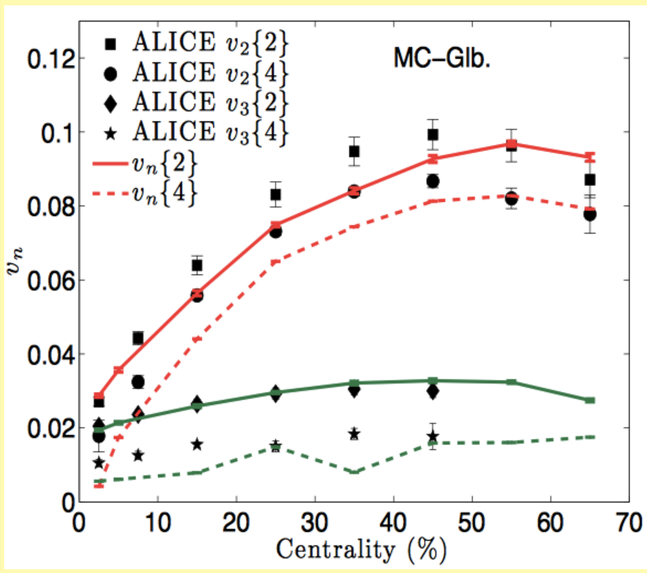
**Limitations of the approach:**

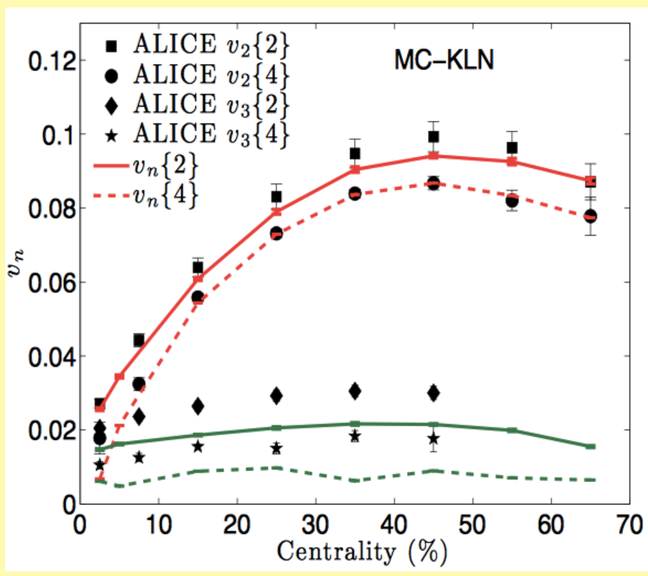
- No pre-equilibrium dynamics.
- No gluonic or hydrodynamical fluctuations.
- No hadronic afterburner. The hadronic matter is simulated hydrodynamically. No fluctuations from hadronization.

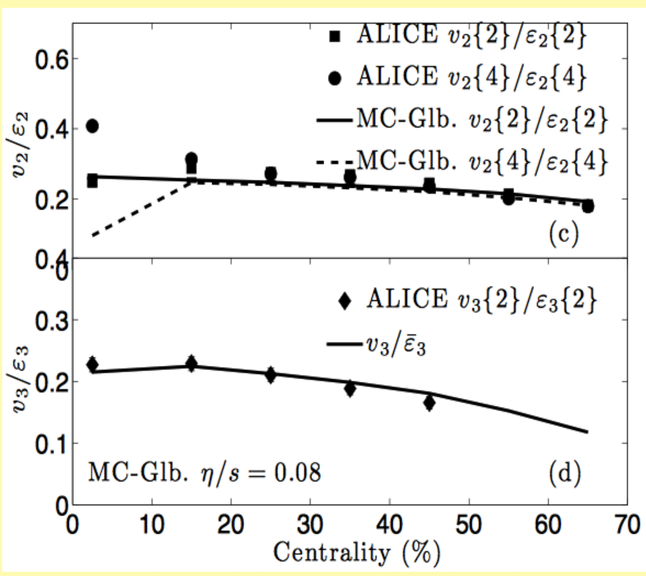


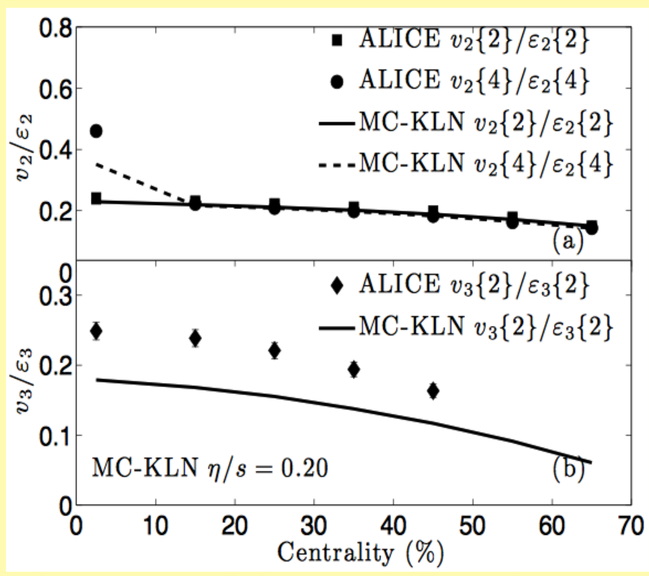




**The multiplicity (left) and $p_T$ spectra (right) agree with ALICE data.**



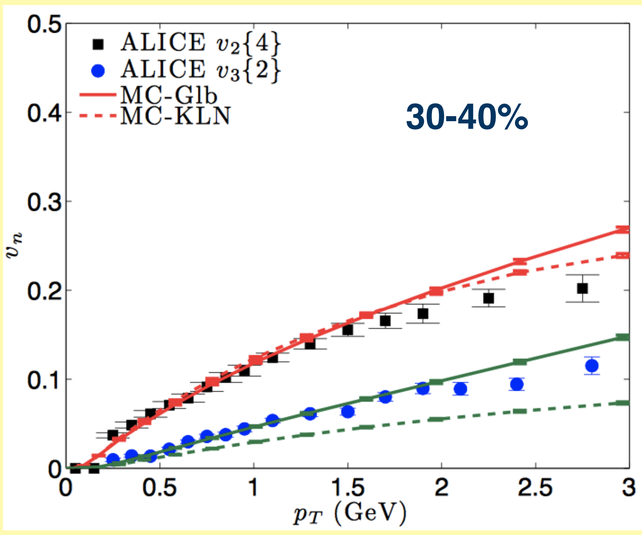




**Relative difference is clearly seen using eccentricity normalized flow.**

- The MC-KLN model produces larger $\varepsilon_2$, which requires η/s to be as large as 0.2 to get the correct $v_2$; the MC-Glauber model has smaller $\varepsilon_2$ allowing η/s to be as small as 0.08.
- Both models produce similar $\varepsilon_3$ which is only compatible with small η/s~0.08.

- The MC-Glauber model (left) with η/s=0.08 describes $v_2\{2\}$ within ~10% and gives excellent description to $v_3\{2\}$.
- The MC-KLN model (right) with η/s=0.2 describes well $v_2\{2\}$ but misses $v_3\{2\}$ by ~30%.

- Either the specific shear viscosity of the QGP created in relativistic heavy-ion collisions is indeed close to 0.08, or $\varepsilon_3$ produced by both models is too small by ~50%.




**Conclusions drawn from differential flows are consistent: the MC-Glauber model with η/s~0.08 gives a good description to both $v_2\{2\}(p_T)$ and $v_3\{2\}(p_T)$; the MC-KLN model with η/s~0.2 gives a good description to $v_2\{2\}(p_T)$ but misses $v_3\{2\}(p_T)$.**

## Conclusions and outlook

**The ALICE elliptic and triangular flow data prefer a small shear viscosity (η/s=0.08) together with the smaller MC-Glauber ellipticity (instead of the MC-KLN model with larger viscosity η/s=0.2). The reason is that the measured $v_3$ is too large to allow a large η/s. However, the extraction of η/s and the problem of initial condition ambiguity are not fully resolved until additional sources of initial state fluctuations have been explored. At this point a robust conclusion is that an η/s value as large as 0.2 is inconsistent with the triangularities produced by both the MC-Glauber and MC-KLN models.**

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