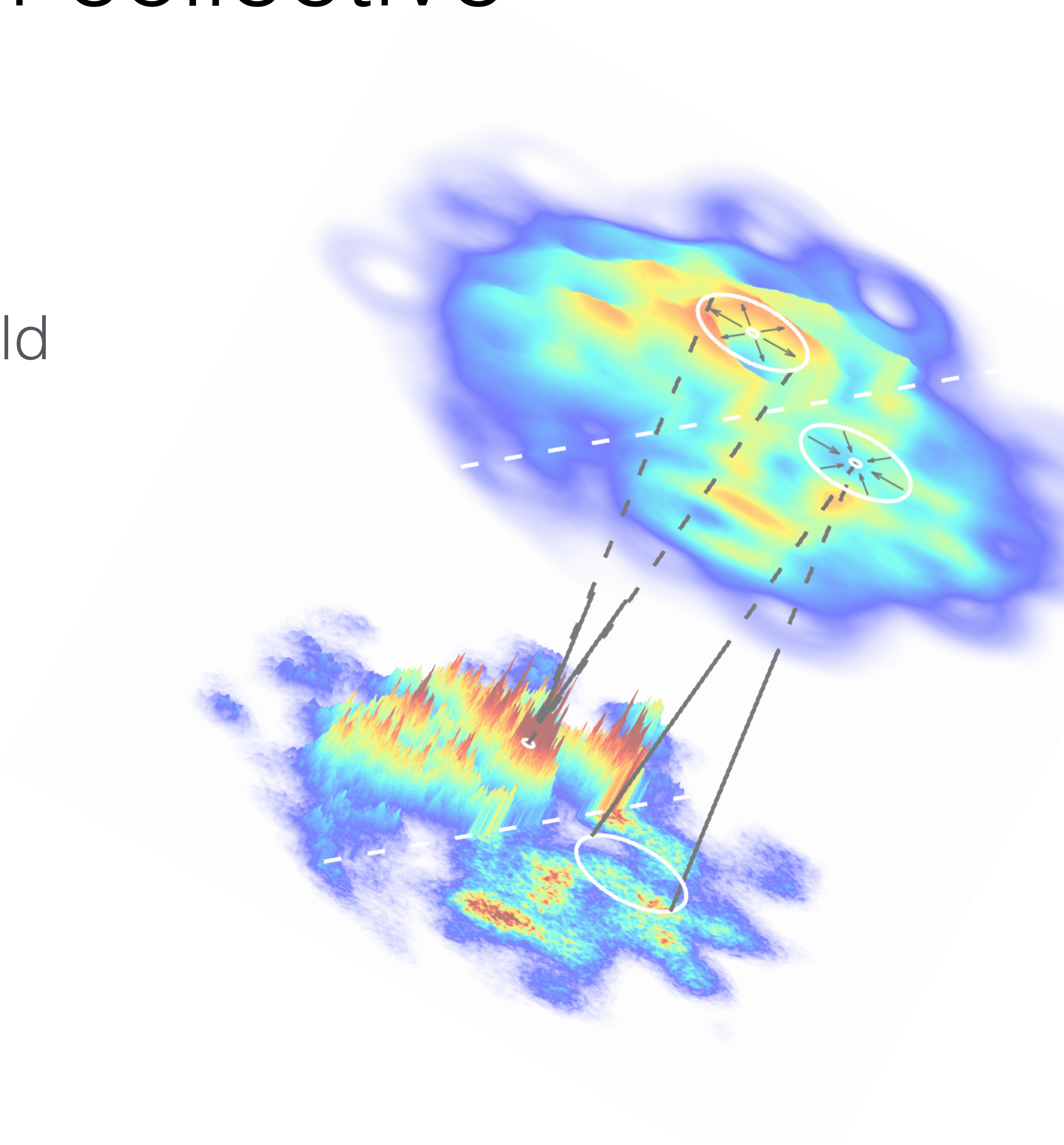
Exploring the origins of collective flow in p+A collisions



Sören Schlichting | Universität Bielefeld

Based on
Ambrus, SS, Werthmann
Phys.Rev.Lett. 130 (2023) 15, 152301
Phys.Rev.D 107 (2023) 9, 094013
+work in preparation

CERN Workshop
Jul 2024

CRC-TR 211
Strong-interaction matter under extreme conditions

FSP ALICE
Erforschung von
Universum und Materie

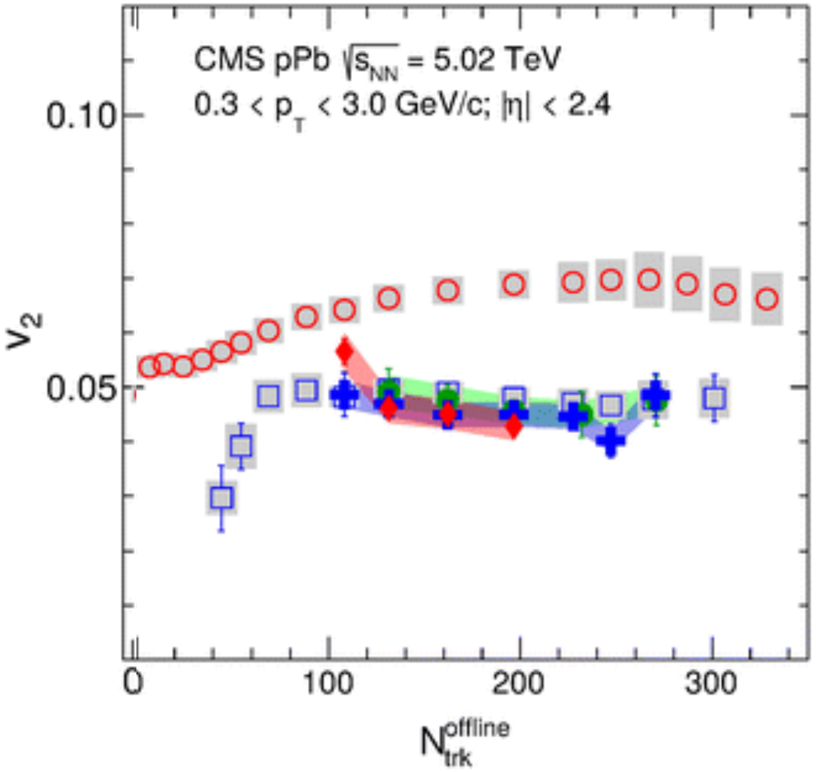
UNIVERSITÄT
BIELEFELD

Flow in pA

Collective flow emerges as
dynamical response to initial eccentricity

$$v_2 \simeq \kappa \epsilon_2$$

observed in all collision systems at LHC



Initial state geometry in p+A arises from proton shape fluctuations and is poorly constrained => severely limits predictive power of models

Different physics pictures can explain observed magnitude of flow in p+A collisions, due to poorly constrained initial state geometry in p+A

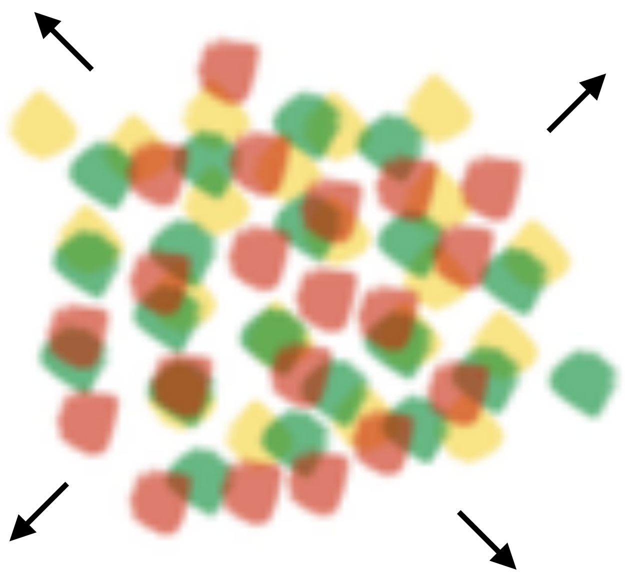
How to discriminate small opacity (weekly interacting final state) from large opacity (nearly perfect fluid) regime?

Basic Idea

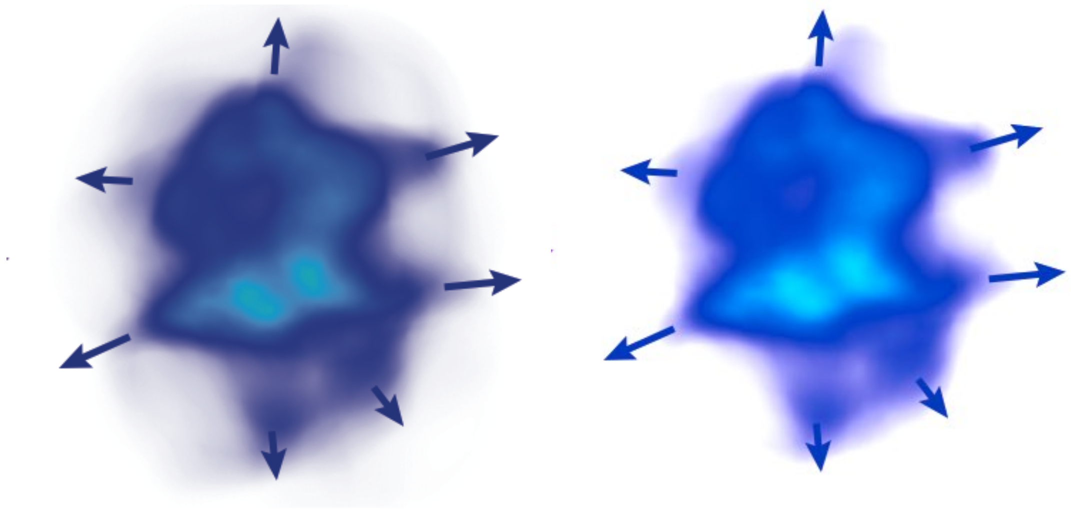
Discriminate low opacity and high opacity regime, by studying the change of flow as a function of center of mass energy

Higher C.O.M energy => Higher initial energy density

low opacity



high opacity



Increased number of final state interaction

=> Strong increase in flow

Smaller dissipative effects

=> mild increase in flow

Effective kinetic theory description

Effective kinetic theory can capture both low and high opacity regime

Event-by-event simulations feasible within
simple conformal kinetic theory

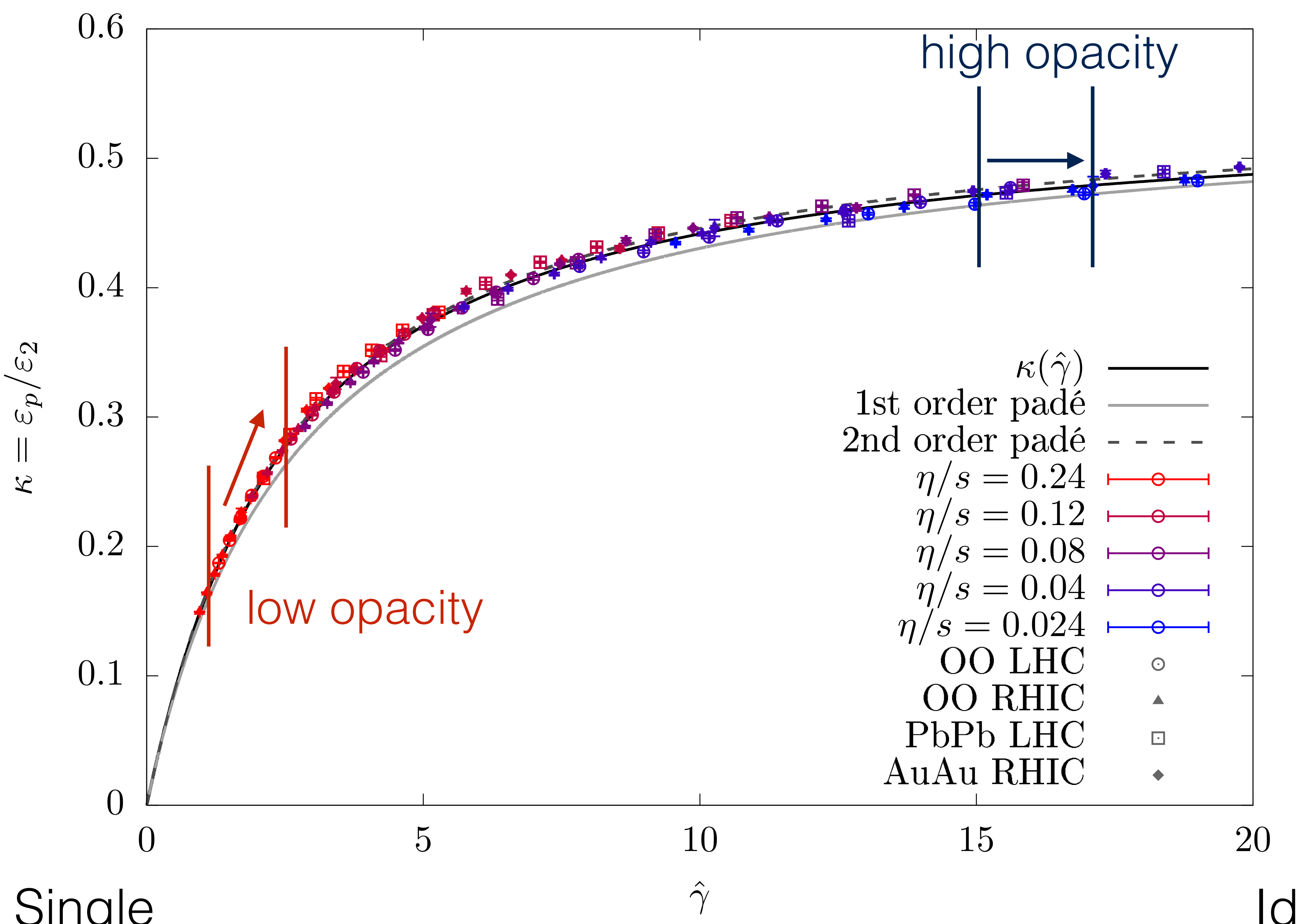
$$p^\mu \partial_\mu f = -\frac{p \cdot u}{\tau_R}(f - f_{\mathrm{eq}}),$$

Elliptic flow of energy-momentum tensor only depends on initial state geometry e(xT) and single dimensionless opacity parameter

$$\hat{\gamma} = \frac{1}{5\eta/s}\left(\frac{R}{\pi a}\frac{\mathrm{d}E_\perp^0}{\mathrm{d}\eta}\right)^{1/4},$$

system size, viscosity and energy dependence

Effective kinetic theory description



Single scattering

Ideal Hydro

Disentangling geometry & evolution

Separate initial state geometry and dynamical response by studying same system **at two different energies**

$$v_2 \simeq \kappa \epsilon_2$$

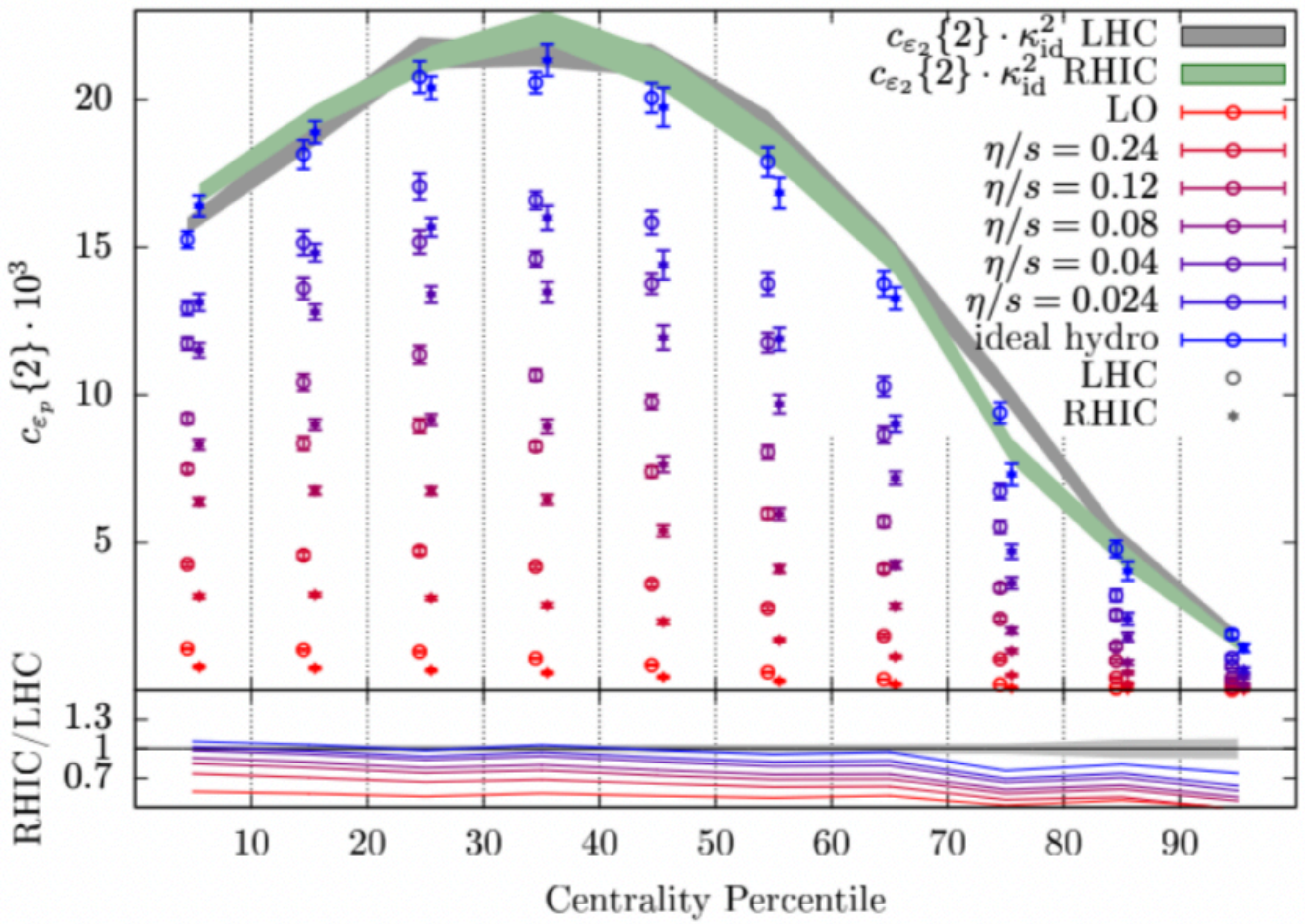
as geometry (e_2) stays identical but dynamical response (κ) changes

Change in response is highly sensitive to opacity as

low opacity: $\kappa(\hat{\gamma} \ll 1) = \kappa_0' \hat{\gamma}$

high opacity: $\kappa(\hat{\gamma} \gg 1) = \kappa_{\mathrm{Id}}$

O+O collisions @ RHIC vs. LHC



Disentangling geometry & evolution

Eliminate geometry by studying difference/mean

$$\frac{v_2^2(\sqrt{s}_>) - v_2^2(\sqrt{s}_<)}{(v_2^2(\sqrt{s}_>) + v_2^2(\sqrt{s}_<))/2} \approx \Delta \log(v_2^2)$$

Since change in opacity is $\sim \left(\frac{dE_\perp}{d\eta}\right)^{1/4}$ it is natural to also measure

$$\frac{dE_\perp/d\eta(\sqrt{s}_>) - dE_\perp/d\eta(\sqrt{s}_<)}{(dE_\perp/d\eta(\sqrt{s}_>) + dE_\perp/d\eta(\sqrt{s}_<))/2} \approx \Delta \log(dE_\perp/d\eta)) \approx 4\Delta \log(\hat{\gamma})$$

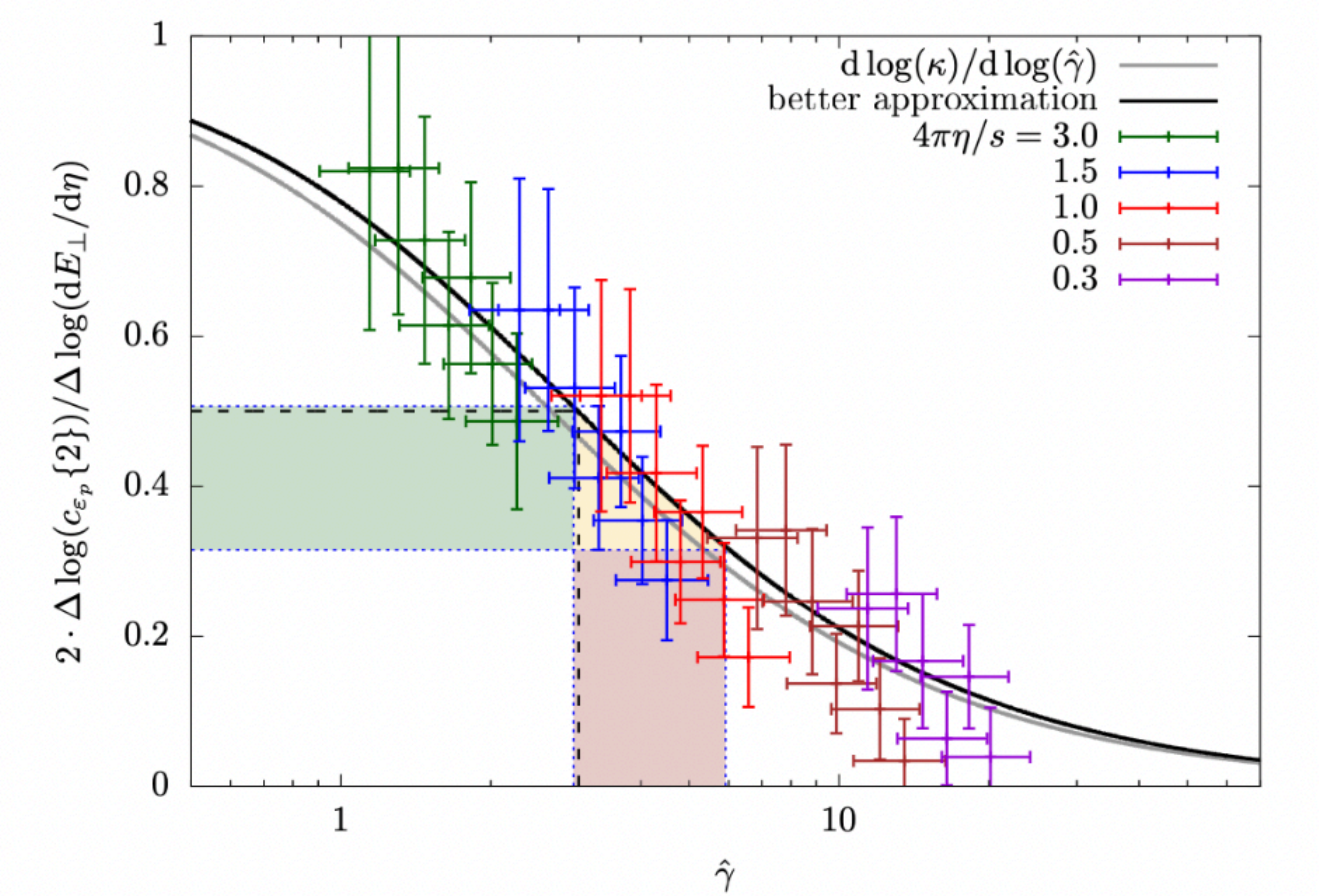
such that $W = 2\frac{\Delta \log(v_2^2)}{\Delta dE_\perp/d\eta} \approx \frac{d \log(\kappa(\hat{\gamma}))}{d \log(\hat{\gamma})} \rightarrow$

1 (low opacity)

0 (high opacity)

=> Data driven approach to quantify the degree of hydrodynamic behaviour

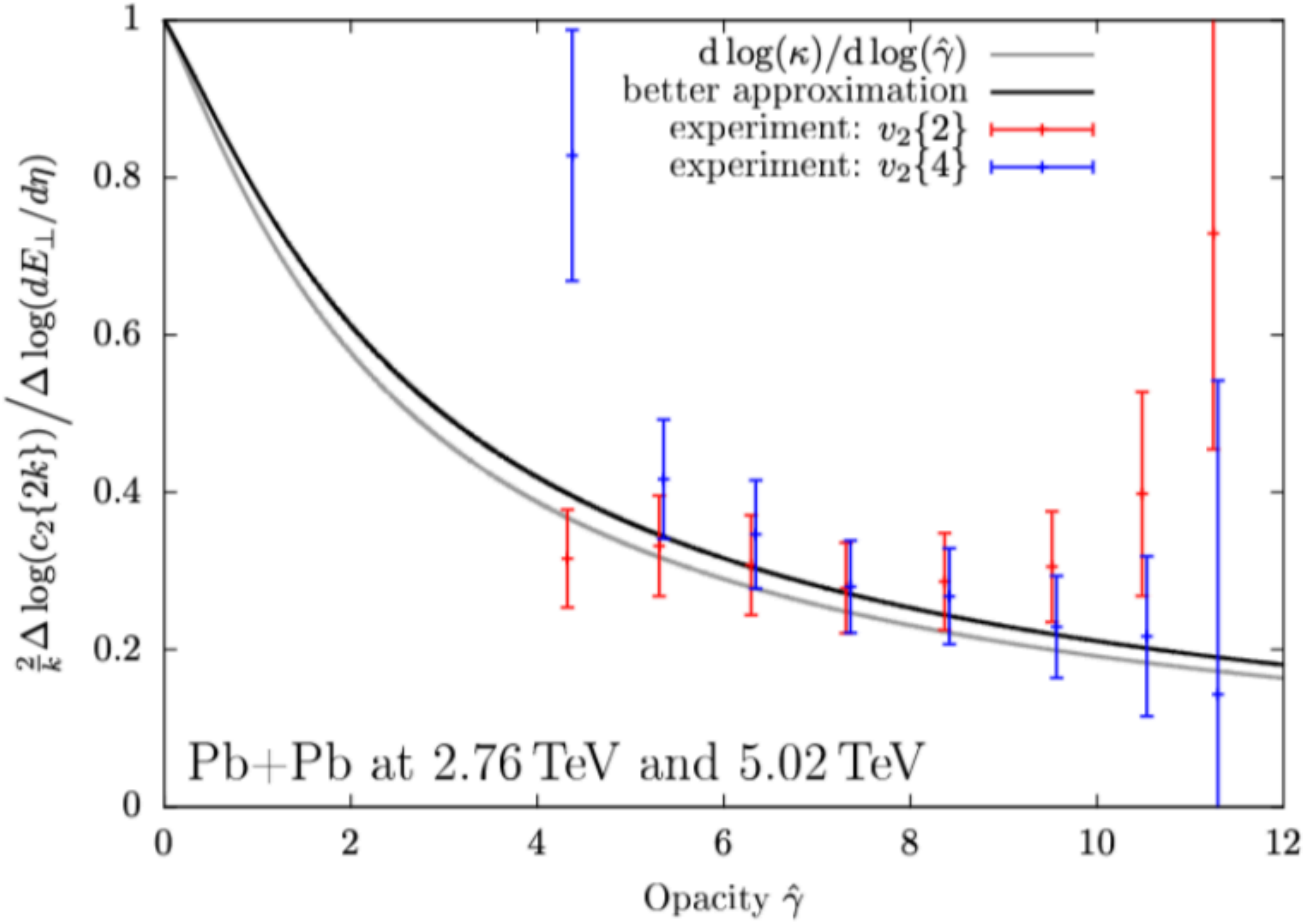
Proof of principle



Vary opacity by varying viscosity in simulation & re-construct from flow measurement

Proof of principle

Data comparison for Pb+Pb collisions at LHC



y-position deduced from experimental measurements

x-position is determined from theory (TrEnTo initial state & same η/s=0.12 as required to reproduce correct magnitude of flow)

Good agreement with calibration curve (within large errors)

Discussion

Change in collective flow as fct of COM energy can be used to pin point mechanism behind collective behaviour

Wish list:

- p+Pb collisions at two different COM energies

- precision measurements of collective flow and transverse energy (preferably energy (m_T) weigthed v_2 which is most directly related to anisotropy of energy-momentum tensor)

- event classification in terms transverse energy at mid-rapidity

ToDo's:

- Non-conformal effects (EoS)

- predictions for p+Pb