Directed flow at midrapidity at the LHC*

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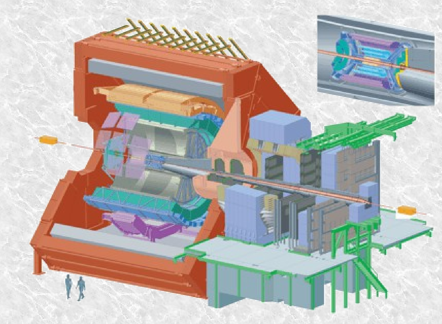
Abstract

We analyze published data from the ALICE Collaboration in order to obtain the first extraction of the recently-proposed rapidity-even directed flow observable v_1. An accounting of the correlation due to the conservation of transverse momentum restores the factorization seen by ALICE in all other Fourier harmonics and thus indicates that the remaining correlation gives a reliable measurement of directed flow. We then carry out the first viscous hydrodynamic calculation of directed flow, and show that it is less sensitive to viscosity than higher harmonics. This allows for a direct extraction of the dipole asymmetry of the initial state, providing a strict constraint on the non-equilibrium dynamics of the early-time system. A prediction is then made for v_1 in Au-Au collisions at RHIC.



Object of our study: rapidity-even directed flow

The variation of directed fow with rapidity can uniquely separated into even and odd parts:

$$v_1(y)=v_1^{even}e^{i\psi_1^{even}}+v_1^{odd}e^{i\psi_1^{odd}}$$

arxiv:1010.1876

V_1^{odd}-usual directed flow, odd in rapidity, correlated with reaction plane: already studied!

V_1^{even}-even in rapidity, created by fluctuations: our study!

V_1^{even} is measured: we average over rapidity due to the symmetry of the detector!

First measurement of rapidity-even directed flow v_1 at the LHC

Measurements

What is measured at ALICE?

Distributions of angles $\Delta\phi$ and/or $\Delta\eta$ between:

- a "trigger" particle at transverse momentum p^t_T
- an "associated" partner at p^a_T

Fourier decomposition of two-particle azimuthal correlations

$$V_{n\Delta}=\langle\cos n(\Delta\phi)\rangle$$

Two-particle correlation factorizes in long-range correlations with $|\Delta\eta|>0.8$:

$$V_{n\Delta}=v_n(p^t_T)*v_n(p^a_T)$$

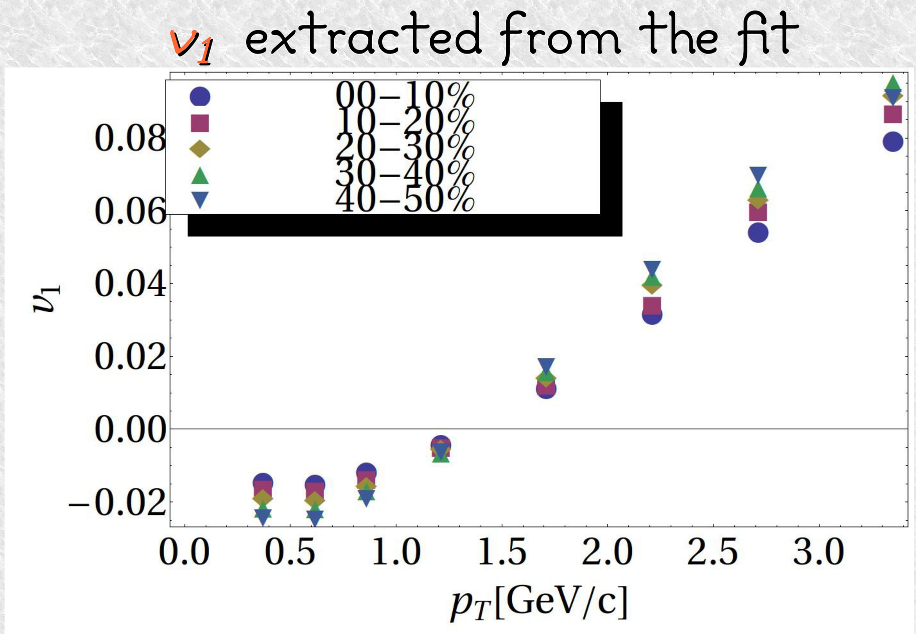
fit with N parameters (v_1)

ALICE shows that factorization doesn't work for n=1

arxiv:1109.2501v2

Result

v_1 extracted from the fit



Comparison of two fit functions:

centrality	χ^2/d.o.f. (N param)	χ^2/d.o.f. (N+1 param)
0-10%	6	2
10-20%	17	1.7
20-30%	45	2.1
30-40%	75	2.2
40-50%	126	2.4

The quality of the fit with N+1 parameters is strongly increased

Method

1) Add one nonflow term due to the global momentum conservation

$$V_{1\Delta}=v_1(p^t_T)v_1(p^a_T)-kp^t_Tp^a_T$$

arxiv:nucl-th/0004026v2

fit with N+1 parameters (v_1 + k)

2) Make fit of NxN matrix with N+1 parameters v_1 +k

3) Find k:

- As fit parameter
- Calculate it as $1/\langle\Sigma p_T^2\rangle$

cent, %	k fit, x10^-5, GeV^-2			k est, x10^-5, GeV^-2
0-10%	2.5	+1.1	-0.3	6.1
10-20%	4.7	+1.4	-0.4	8.8
20-30%	10.3	+2.1	-0.5	13
30-40%	21	+3.2	-1.6	21
40-50%	42	+4.7	-3	35

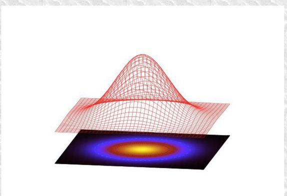
Range of the values is comparable, but k_{fit} is increasing quicker.

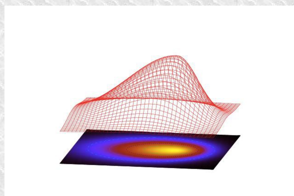
6) Take into account systematic errors, using all possible ranges of p_T bins (here not shown, see Section 3)

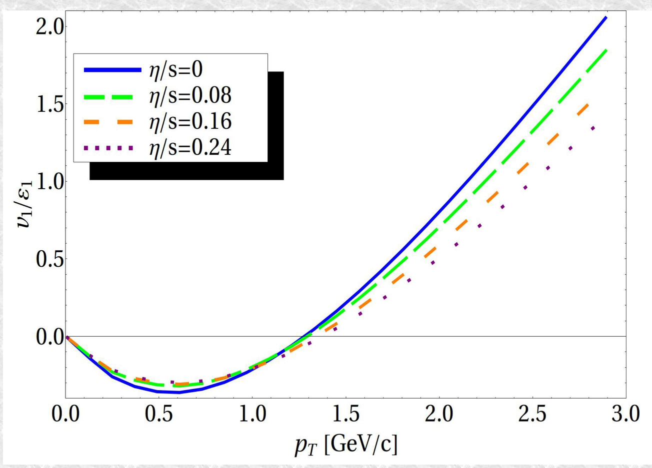
First viscous hydro calculations of directed flow

Model

We use a smooth, symmetric density profile which we deform to introduce a dipole asymmetry of the desired size and orientation.

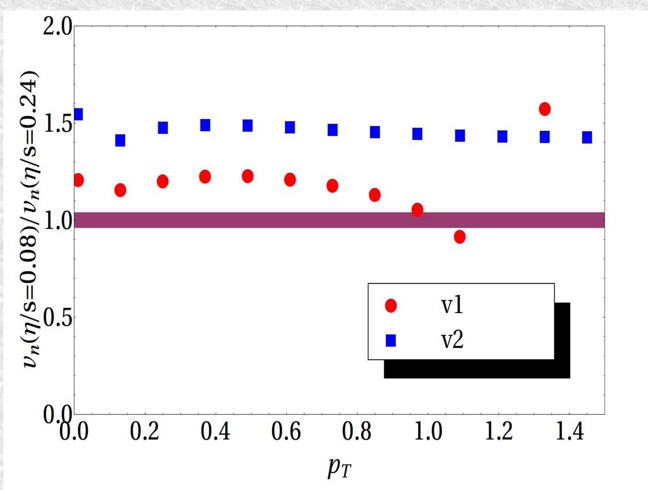






v_1/ε_1 (p_T) and viscosity

Result



A measure of the magnitude of the dipole asymmetry is

$$\varepsilon_1=\frac{|\{r^3e^{i\varphi}\}|}{\{r^3\}}$$

arxiv:1010.1876

$$V_1\propto\varepsilon_1$$

v_1 has a weaker dependence on viscosity than v_2

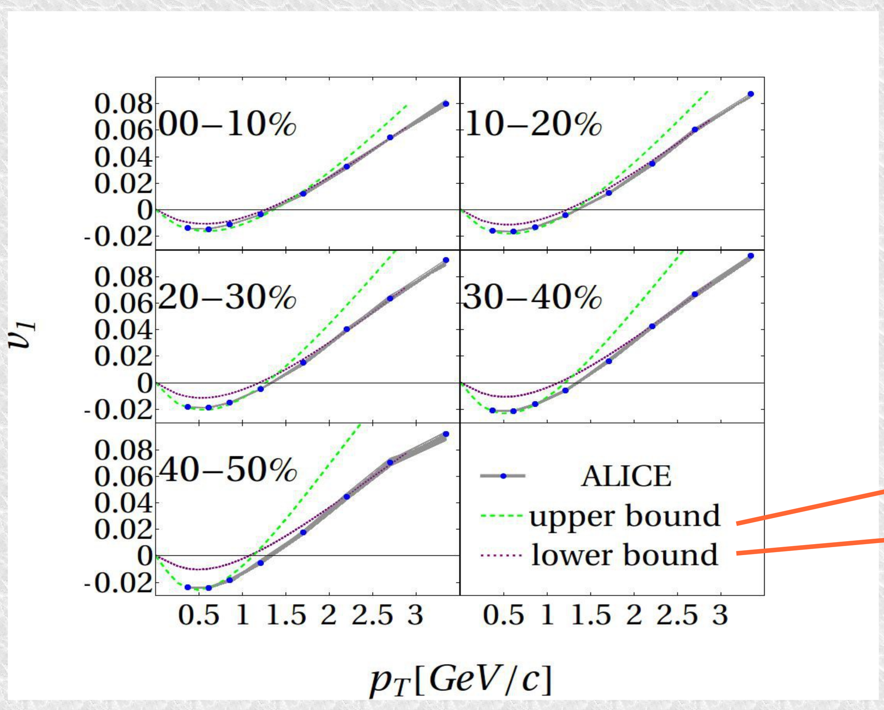
Constraining initial state fluctuations from v_1 data

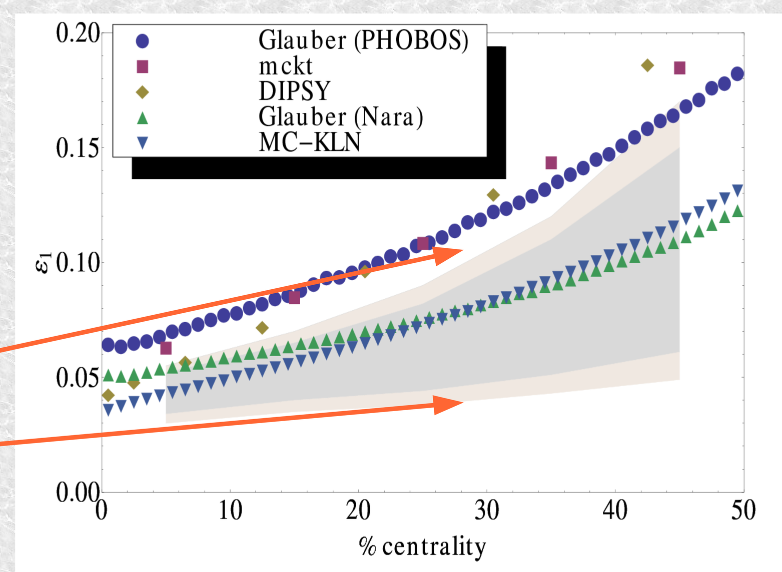
With hydro+experimental data, we can constrain ε_1

Fluctuations create dipole asymmetry ε_1

Choose ε_1 to match the data from below or above

$$\varepsilon_1*\left(\frac{V_1}{\varepsilon_1}\right)_{hydro}$$





This figure displays the allowed values of ε_1 as a function of centrality, together with the rms ε_1 from various Monte-Carlo models of initial conditions.

In a given centrality window and for a given value of the viscosity, one can tune the value of the dipole asymmetry ε_1 in the hydrodynamic calculation so as to obtain reasonable agreement with data. If one chooses to match data at the lowest p_T, calculation overpredicts data at high p_T. Conversely, if one matches data at high p_T, calculation underpredicts data at low p_T . The corresponding values of ε_1 can be considered upper and lower bounds on the actual value.

Conclusions:

- first measurement of directed flow, v1, at midrapidity at the LHC,
- similar analysis later by ATLAS: arXiv:1203.3087v2
- first viscous hydrodynamic calculation of directed flow
- v1 depends less on viscosity than v2 and v3
- data on v1 constrain the fluctuations of the early-time system -> rule out certain current theoretical models

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