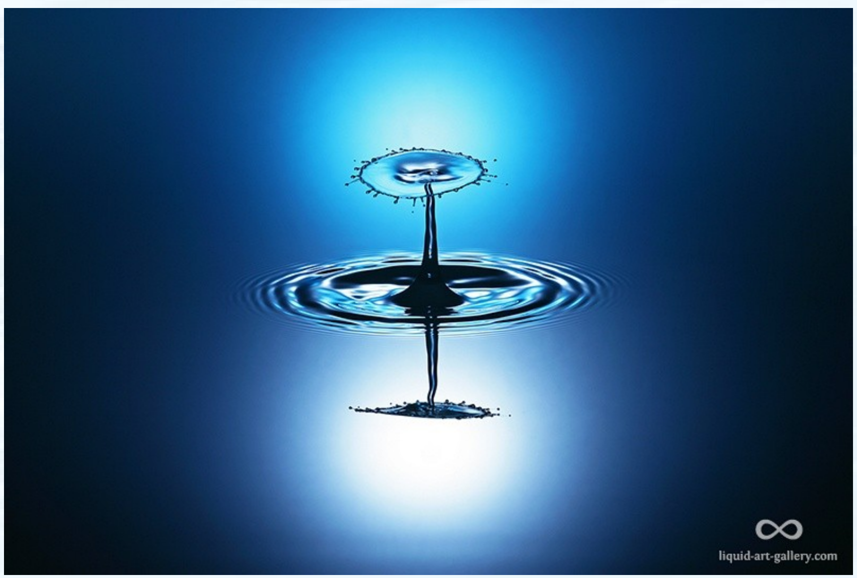
Directed flow at midrapidity in $\sqrt{s}=2.76$ TeV PbPb collisions*



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Heavy-ion meeting

IPN Orsay

8 June 2012

* arxiv:1203.0931v1, to appear in PRL soon!

Outline:

- Dihadron correlations and factorisation
- Momentum conservation coefficient: fit parameter
- Momentum conservation coefficient: estimation
- Viscous hydro calculations: LHC and RHIC calculations
- Conclusions

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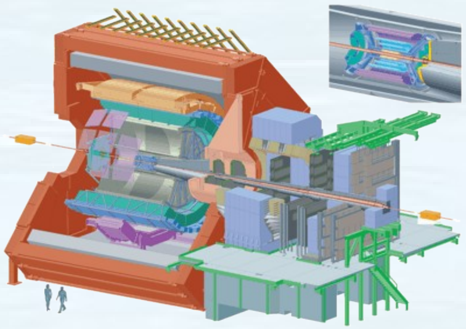
Measurements at ALICE



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}

Two-particle correlations:

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

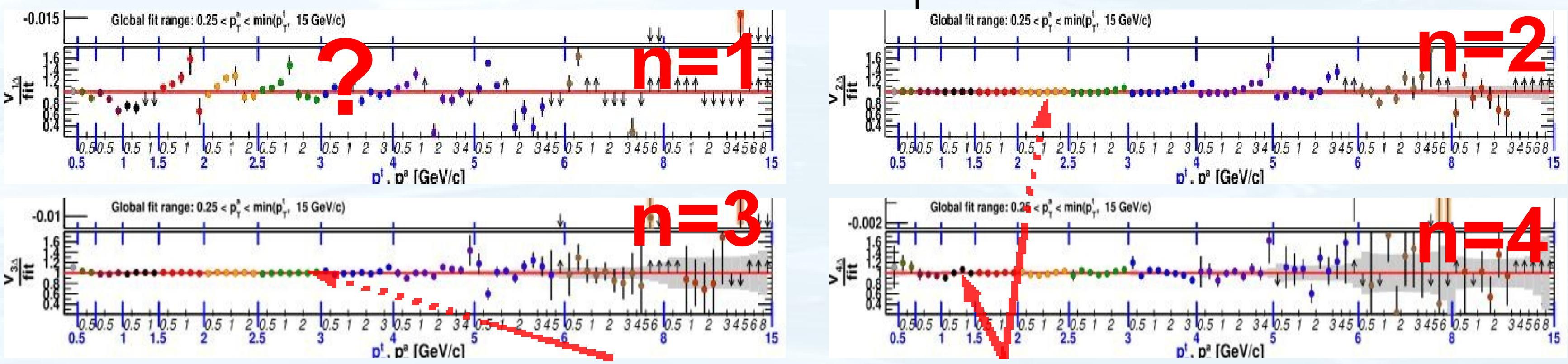
ALICE analysis

It was found recently, that two-particle correlation factorizes in long-range correlations with $|\Delta\eta|>0.8$:

$$V_{n\Delta}=v_n(p_T^t)*v_n(p_T^a)$$

ALICE: fit NxN matrix with **N** parameters of v_n:

N-number of p_T bins



Fit is good for $n>1$

arXiv:1109.2501v2

Factorization

$$V_{n\Delta} = v_n(p_T^t)\, v_n(p_T^a)$$

How do we understand this?

PARTICLES ARE EMITTED INDEPENDENTLY WITH DISTRIBUTION:

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + 2\sum v_n \cos(n\phi - n\psi_n)\right)$$

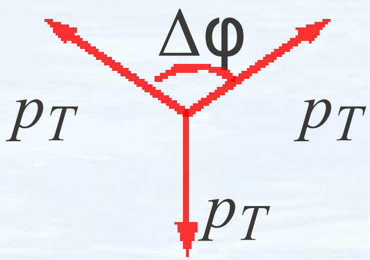
WHERE $\langle e^{in\phi} \rangle = v_n e^{in\psi_n}$

$$V_{n\Delta} = \langle \cos n\Delta\phi \rangle = \langle e^{in(\phi_t - \phi_a)} \rangle = \langle e^{in\phi_t} \rangle \langle e^{-in\phi_a} \rangle = v_n^a v_n^t$$

Momentum conservation

Factorization doesn't work for n=1:

We add one nonflow term due to global momentum conservation



$$\langle \cos(\Delta\phi)\rangle_{mom.cons.} = -k p_T^t p_T^a < 0$$

$$\sum \vec{p}_T = 0$$

momentum conservation

$$V_{1\Delta} = v_1(p_T^t)\, v_1(p_T^a) - \boxed{k p_T^t p_T^a}$$

Two possibilities to find k:

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

N. Borghini, M. Dinh, J.-Y. Ollitrault
arXiv:nucl-th/0004026v2

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Comparison of two fit functions:

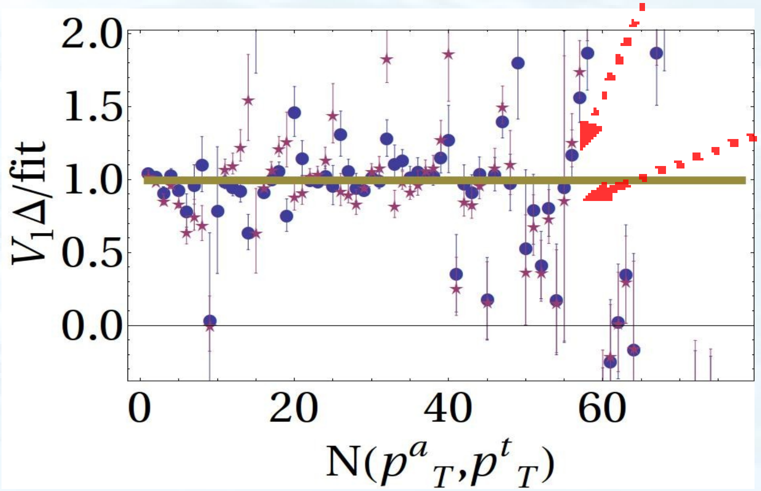
Our fit with **N+1** parameters **(v_1 + κ)**:

$$V_{1\Delta} = v_1(p_T^t)\, v_1(p_T^a) - k p_T^t p_T^a$$

VS

ALICE fit with **N** parameters **(v_1)**:

$$V_{1\Delta} = v_1(p_T^t)\, v_1(p_T^a)$$

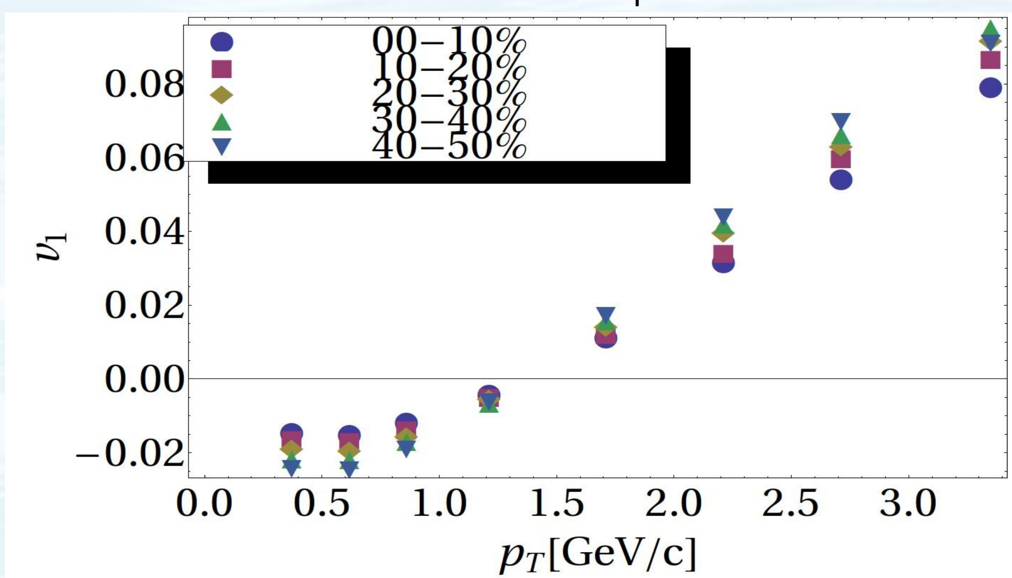


centrality	χ^2 /d.o.f.,k=0	χ^2/ d.o.f.
0−10%	6	2
10−20%	17	1.7
20−30%	45	2.2
30−40%	75	2.3
40−50%	126	2.5

The quality of the fit is much better!

First measurement of v_1 at the LHC

Extracted values from the fit give us the first measurement of v_1 at the LHC!



No net transverse momentum -> low p_T particles flow in the opposite direction to high p_T !

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How to estimate $k = 1/\langle \Sigma p_T^2 \rangle$?

Sum runs over **ALL** the particles!

What we know:

- p_T spectra of π,K,p at midrapidity in a limited p_T range
- Total charged multiplicity Nch: extrapolation made by ALICE

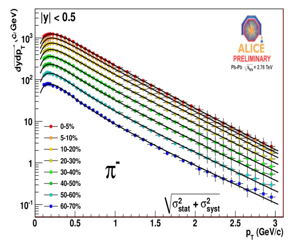
?

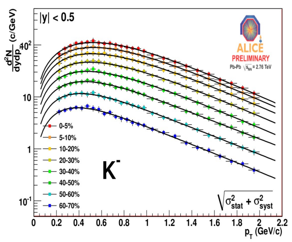
What we don't know:

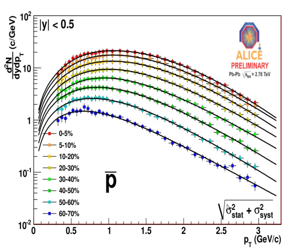
- ALICE doesn't measure number of neutral particles
- p_T spectra outside midrapidity

Calculating k

arXiv:1109.2501v2







- fit p_T spectra by Levy function to extrapolate from 0 to ∞

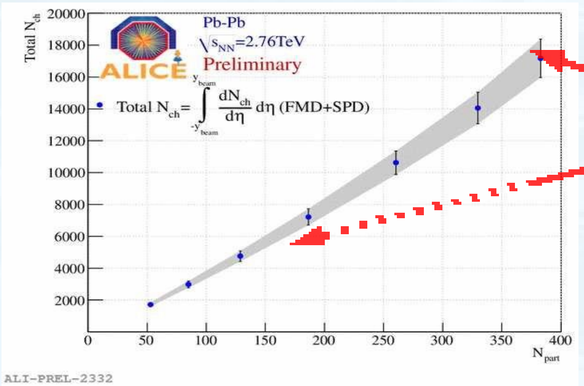
$$\frac{dN}{dy\,dp_t} = \frac{dN}{dy}\,\frac{p_t\cdot(n-1)\cdot(n-2)}{(n\cdot C\cdot(n\cdot C+m\cdot(n-2)))}\cdot\left(1+\frac{(\sqrt{p_t^2+m^2}-m)}{(n\cdot C)}\right)^{-n}$$

- integrate function to get dN/dy, $\langle p_T^2\rangle$

$C, \frac{dN}{dy}, n$ – Levy parameters

$$\langle p_t^2\rangle = \frac{\int p_t^2 \frac{dN}{dp_t\,dy}\,dp_t}{\int \frac{dN}{dp_t\,dy}\,dp_t}$$

- neutral particles are taken into account assuming to **isospin symmetry**



total N_{ch}

arXiv:1107.1973v1

Comparison of k-coefficients

centrality	k fit, $\times 10^{-5}$	k est, $\times 10^{-5}$
0-10%	2.5	6.1
10-20%	4.7	8.8
20-30%	10.3	13
30-40%	21	21
40-50%	42	35

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Types of v_1

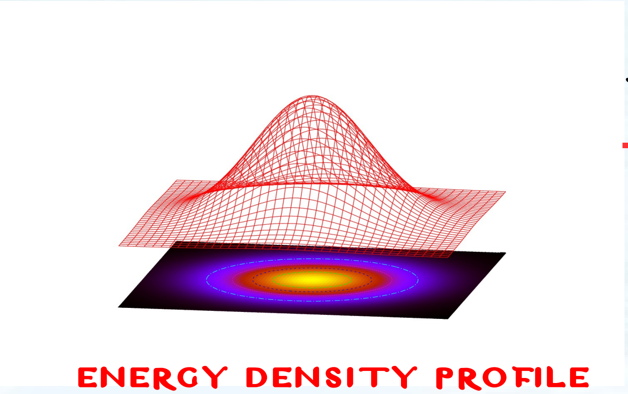
Corresponding to:

- event-plane method, odd in rapidity – already studied
- fluctuations in energy-density profile, even in rapidity – our study

Next step: viscous hydro

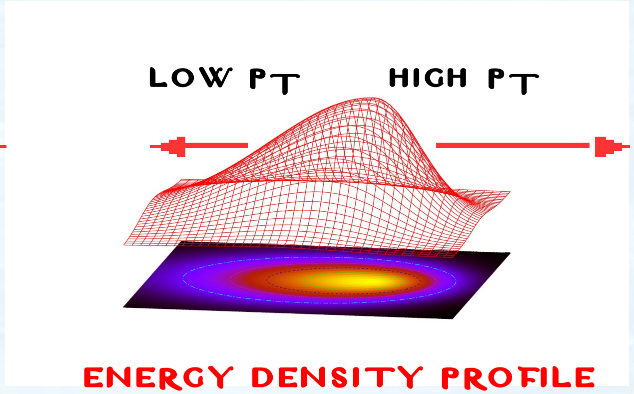
We use a smooth, symmetric density profile which we deform to introduce a dipole asymmetry ε_1 of the desired size and orientation.

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



Energy density profile without fluctuations

Fluctuations →

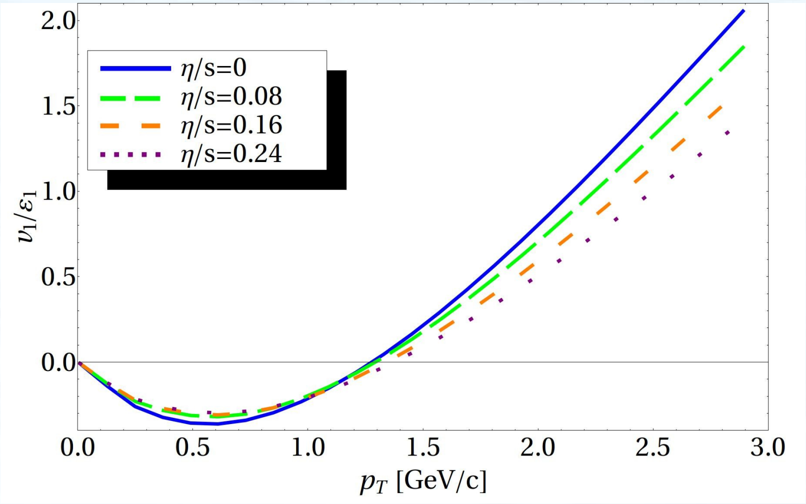


Energy density profile with fluctuations

Our calculation is a 2+1D viscous hydrodynamic uses as initial condition the transverse energy density ($\epsilon(r, \phi)$) profile from an optical Glauber model:

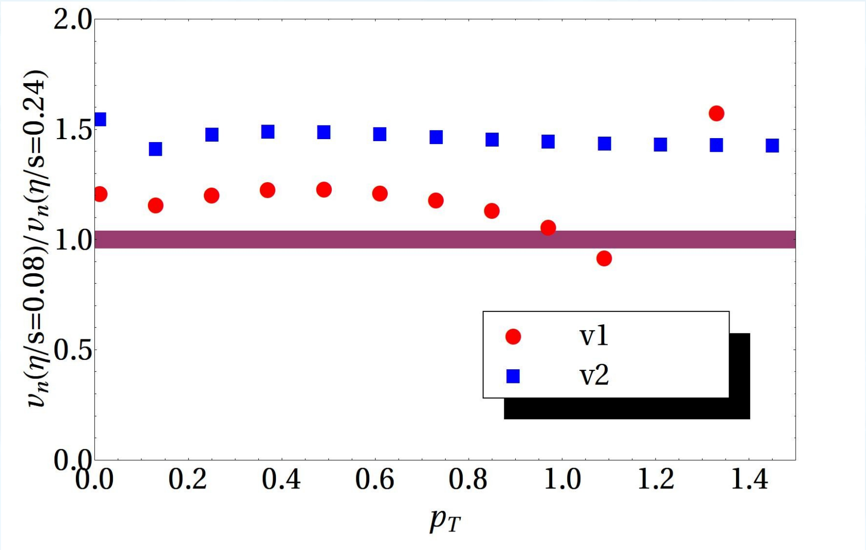
$$\epsilon(r,\phi) \rightarrow \epsilon\left(r\sqrt{1+\delta\cos(\phi-\Psi_1)},\phi\right) \qquad \delta <<1 \qquad V_1 \sim \varepsilon_1 \sim \delta$$

Dependence on viscosity of v_n/ε_n



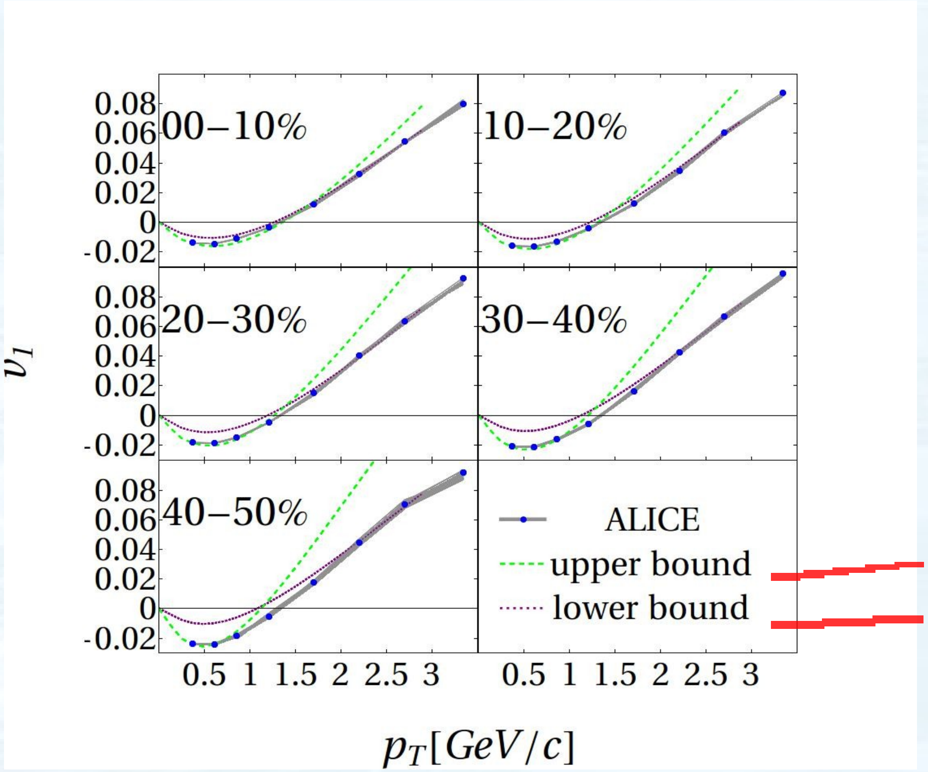
v_1/ε_1 (p_T)

v_1 has a weaker dependence on viscosity than v_2

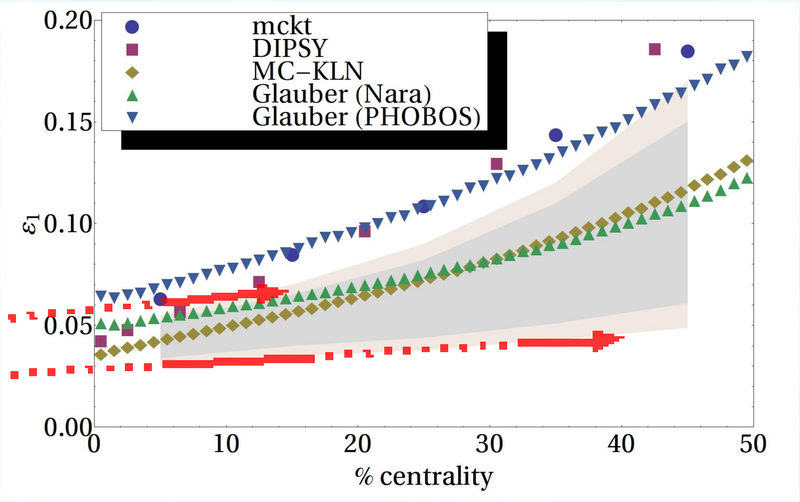


Hydro+experimental data

- Choose ε_1 to match the data from below or above



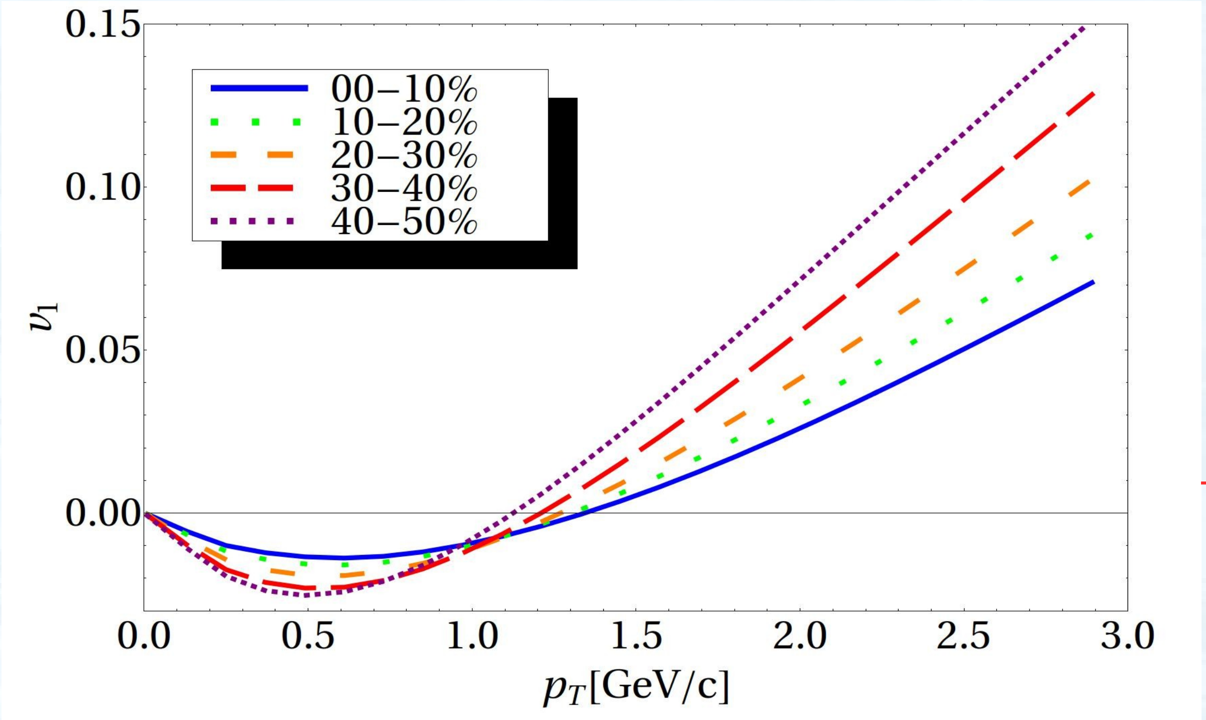
- Comparison of Monte-Carlo models



With hydro+experimental data, we can constrain ε_1

Through ε_1, we constrain models of initial state fluctuations

RHIC prediction for v_1



$$\varepsilon_{1LHC} * \left(\frac{V_1}{\varepsilon_1}\right)_{RHIC}$$

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
- first prediction made for directed flow at midrapidity in lower-energy collisions at RHIC

Backup slides

Estimated value of k

estimated value k: $k = \frac{1}{\langle \Sigma p_T^2 \rangle}$

$$\langle \sum p_t^2 \rangle = Nch \cdot \left(\frac{3 \cdot [\langle p_t^2 \rangle dN/dy]_{pion} + 4 \cdot [\langle p_t^2 \rangle dN/dy]_{kaon} + 4 \cdot [\langle p_t^2 \rangle dN/dy]_{proton}}{2 \cdot [dN/dy]_{pion} + 2 \cdot [dN/dy]_{kaon} + 2 \cdot [dN/dy]_{proton}} \right)$$

Total N_{ch}