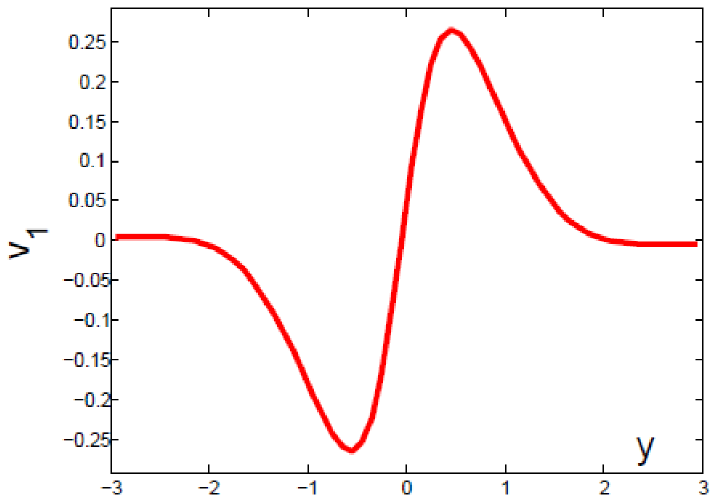
Change of v1 flow at LHC due to rotation



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Fluid dynamical prediction of changed v1 flow at energies available at the CERN Large Hadron Collider

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Overview

- Fluid Dynamical model
- Change of direction of strongest pressure gradient
- Calculation of flow component v1
- Rapidity and transverse momentum dependence
- New function v1s
- Initial state longitudinal fluctuations

Fluid Dynamical model

The collective flow in non central collisions is evidenced by the assymetric azimuthal distribution around the beam axis

$$\frac{d^3N}{dy\,dp_t\,d\phi} = \frac{1}{2\pi}\frac{d^2N}{dy\,dp_t}\left[1 + 2v_1(y,p_t)\cos(\phi) + 2v_2(y,p_t)\cos(2\phi) + \cdots\right]$$

Elliptic flow coefficient

may estimate the pressure and transport properties of the Quark-Gluon Plasma

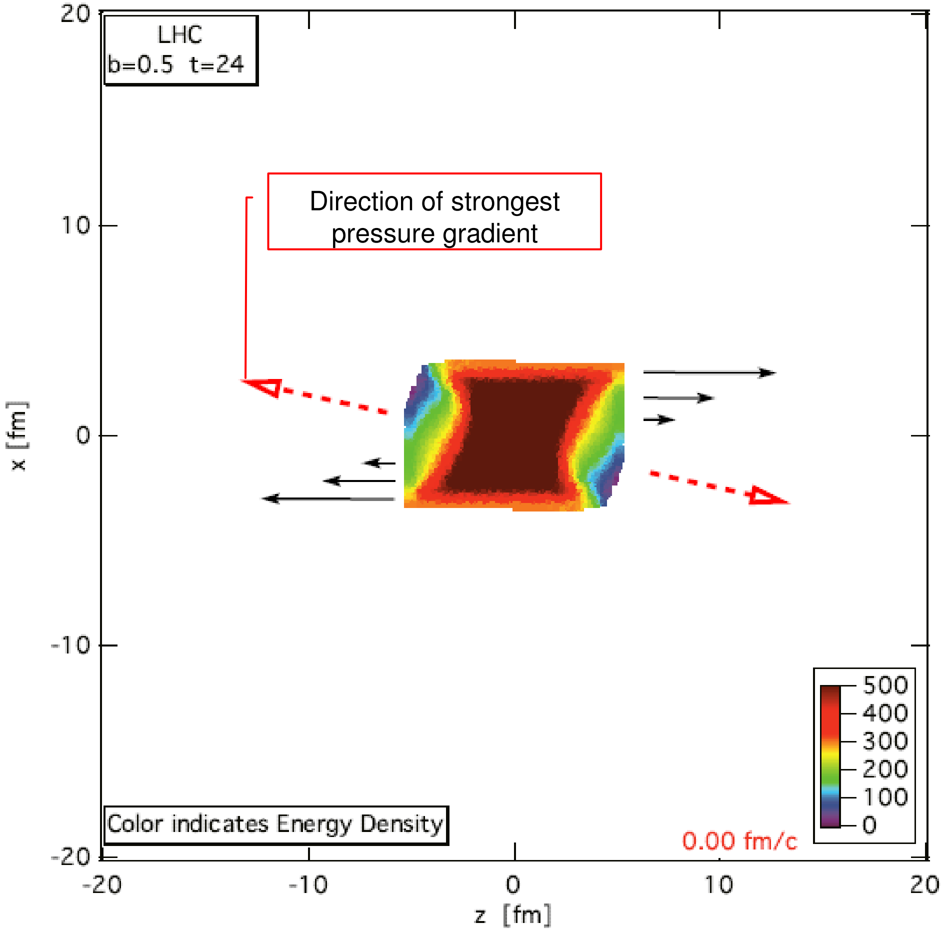
Azimuthal angle in the transverse plane with respect to impact parameter b

- MIT Bag Model EoS and the energy-momentum tensor for a perfect fluid

$$T^{\mu\nu} = (e + P)u^\mu u^\nu - Pg^{\mu\nu}$$

- Particle In Cell method

Change of direction of strongest pressure gradient

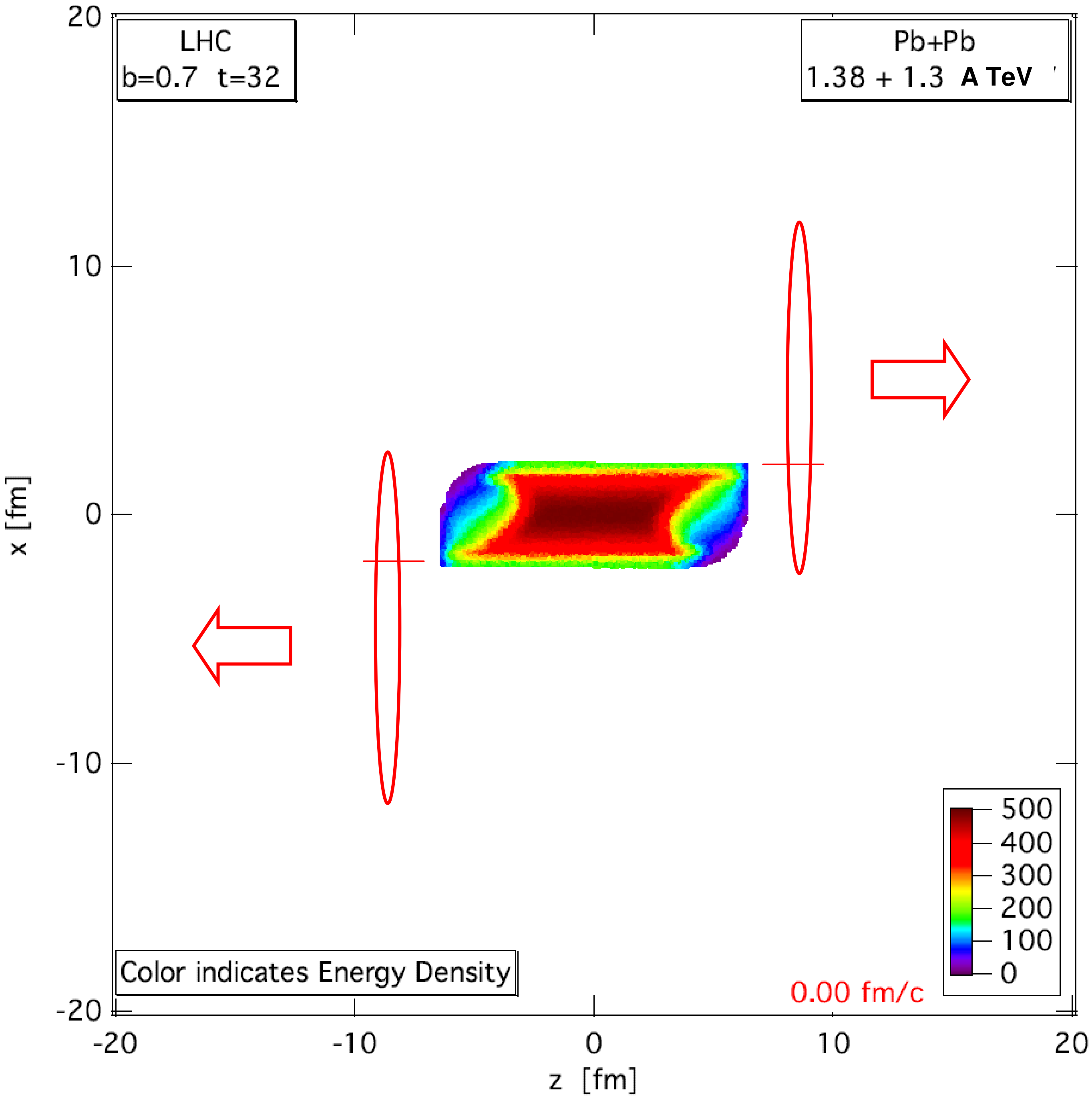


Initial energy density distribution (GeV/fm3)
in the reaction plane at t=4 fm/c

Analytical initial state model

Initial flow velocity distribution
→Angular momentum
→Rotation of system during expansion

Pb-Pb
1.38+1.38 A.TeV
Impact parameter b=0.5 bmax



PIC-hydro

Pb+Pb 1.38+1.38 A TeV, b= 70 % of b_max

Lagrangian fluid cells, moving, ~ 5 mill.

MIT Bag m. EoS

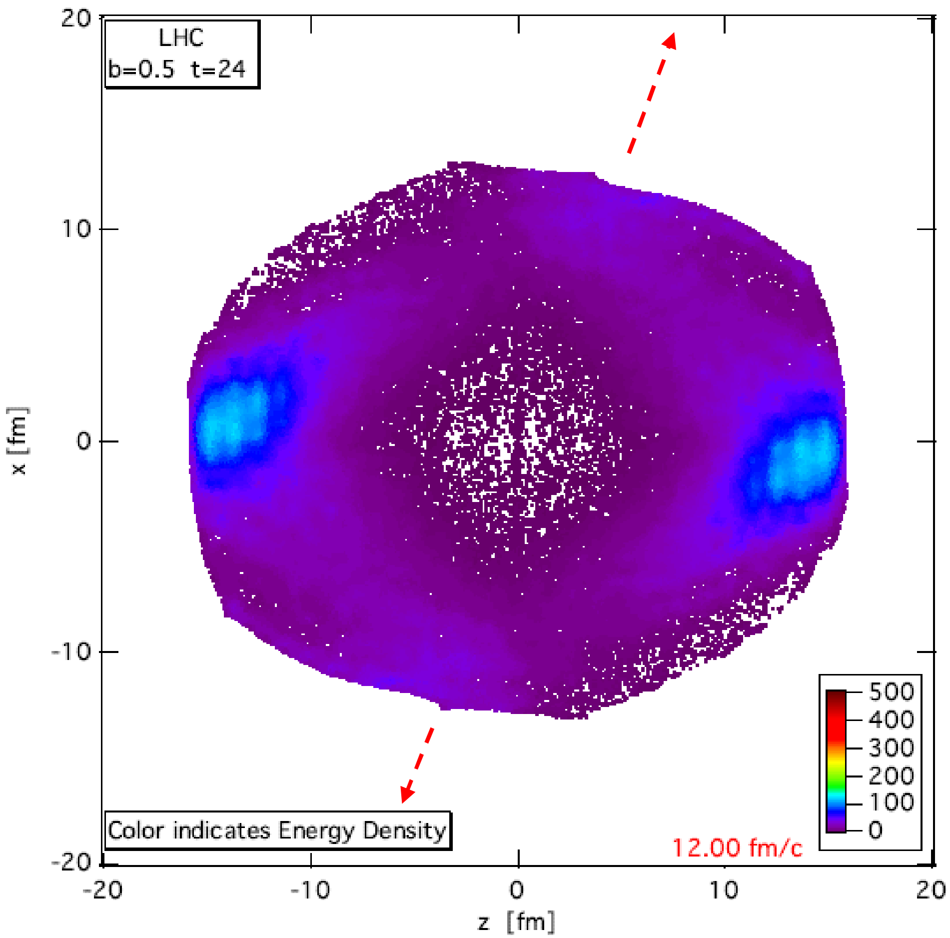
FO at T ~ 200 MeV, but calculated much longer, until pressure is zero for 90% of the cells.

Structure and asymmetries of init. state are maintained in nearly perfect expansion.

LHC-Ec-1h-b7-A.mov

LHC-Ec-1h-b7-A.mp4

Change of direction of strongest pressure gradient



Energy density distribution (GeV/fm3) in the reaction plane at t=12 fm/c

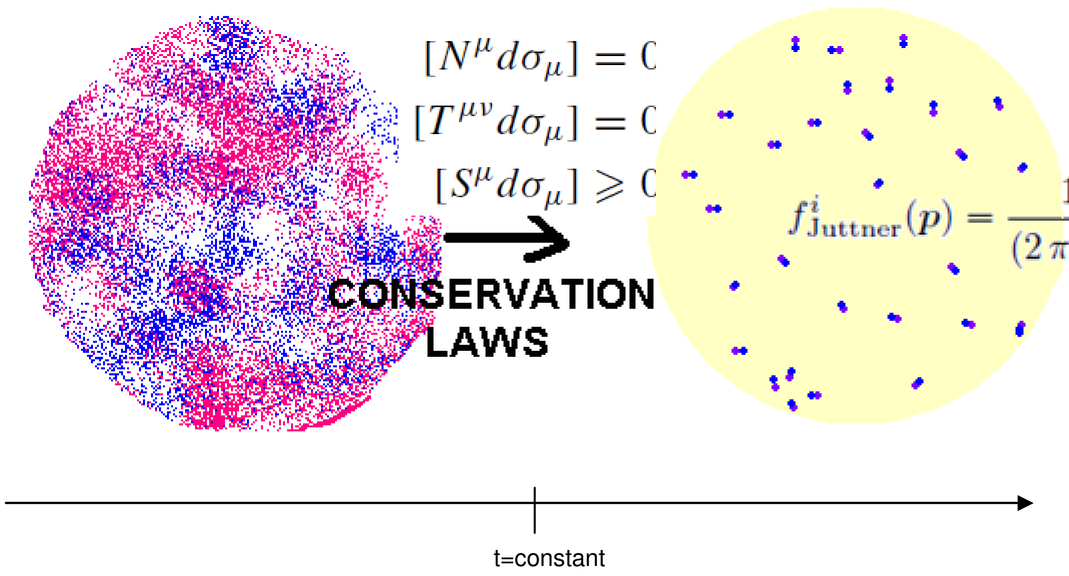
No more antiflow!

Pb-Pb
1.38+1.38 A.TeV
Impact parameter b=0.5 bmax

Calculation of flow component v1

- Constant time FO hypersurface imposed after calculation
- Conservation laws across FO hypersurface → parameters for Juttner distribution of ideal massless pion gas

Cooper-Frye formula: $$E\frac{dN_i}{d^3p} = \int_\sigma f_i(x,p)\, p^\mu d\sigma_\mu$$



$$f^i_{\text{Juttner}}(p) = \frac{1}{(2\pi\hbar)^3} \exp\left\{\frac{\mu^i - \gamma_i\,(p^i_0 - p v_i)}{T_i}\right\}$$

Calculation of flow component v1

$$\langle C \rangle = \frac{\int d^3x \int d^3p \, f(x,p) \, C(x,p)}{\int d^3x \int d^3p \, f(x,p)}$$

$$v_1 = \left\langle \frac{p_x}{p_\perp} \right\rangle = \langle cos(\phi) \rangle$$

$$v_n = \frac{\int d^3x \int_0^{2\pi} d\phi \int_{-\infty}^{\infty} dp_z \int_0^{\infty} dp_\perp p_\perp \; f(p) \; \cos n\phi}{\int d^3x \int_0^{2\pi} d\phi \int_{-\infty}^{\infty} dp_z \int_0^{\infty} dp_\perp p_\perp \; f(p)}$$

$$v_n = \frac{\sum_{i=1}^{N} V_i \int_0^{2\pi} d\phi \int_{-\infty}^{\infty} dp_z \int_0^{\infty} dp_\perp p_\perp \; f^i(p) \; \cos n\phi}{\sum_{i=1}^{N} V_i \int_0^{2\pi} d\phi \int_{-\infty}^{\infty} dp_z \int_0^{\infty} dp_\perp p_\perp \; f^i(p)}$$

$$f^i_{\text{Juttner}}(p) = \frac{1}{(2\pi\hbar)^3} \exp\left\{ \frac{\mu^i - \gamma_i \left(p_0^i - p v_i\right)}{T_i} \right\}$$

+ Simplifications:

- Flow parameter constant i each cell
→ can take d^3x integral

- Chemical potential for pion gas=0
→ normalisation factors cancle

- All cells have the same volume

$$v_n(p_t) = \frac{\sum_i^{cells} B(\vec{v}^{\,i}, T^i, p_t) I_n(\gamma^i v_t^i p_t / T^i) cos(n\phi_0^i)}{\sum_i^{cells} B(\vec{v}^{\,i}, T^i, p_t) I_0(\gamma^i v_t^i p_t / T^i)}$$

$$v_n(y) = \frac{\sum_i^{cells} J_n(y, \vec{v}^{\,i}, T^i) cos(n\phi_0^i)}{\sum_i^{cells} J_0(y, \vec{v}^{\,i}, T^i)}$$

Calculation of flow component v1

$$B(\vec{v},T,p_t) = e^{-\gamma p_t/T}\frac{1}{1-v_z^2}\left(v_z\frac{T}{\gamma} - p_t|v_z|\right) + \frac{p_t}{\sqrt{1-v_z^2}}K_1\left(\frac{\gamma p_t\sqrt{1-v_z^2}}{T}, \frac{\gamma p_t}{T}\right)$$

$$K_1(a,b) = \frac{1}{a}\int_b^\infty dx\sqrt{x^2-a^2}e^{-x}$$

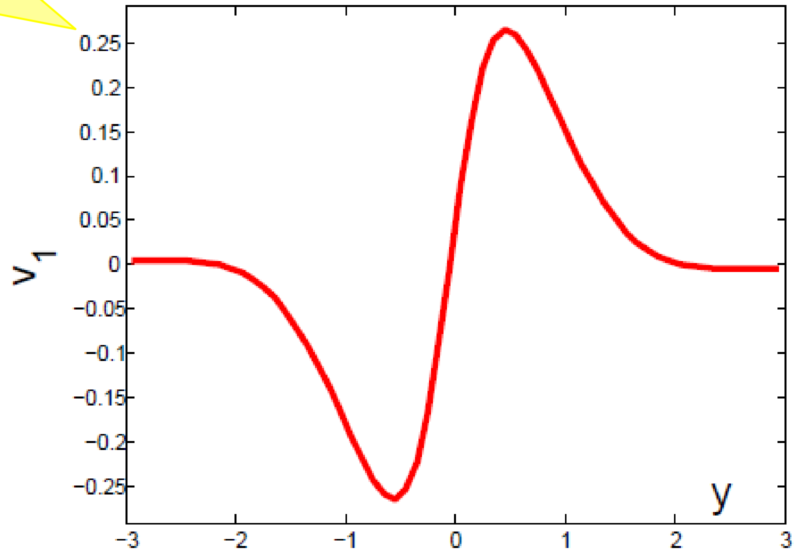
Bessel-function

$$v_n(p_t) = \frac{\sum_i^{cells} B(\vec{v}^{\,i},T^i,p_t)I_n(\gamma^i v_t^i p_t/T^i)cos(n\phi_0^i)}{\sum_i^{cells} B(\vec{v}^{\,i},T^i,p_t)I_0(\gamma^i v_t^i p_t/T^i)}$$

$$v_n(y) = \frac{\sum_i^{cells} J_n(y,\vec{v}^{\,i},T^i)cos(n\phi_0^i)}{\sum_i^{cells} J_0(y,\vec{v}^{\,i},T^i)}$$

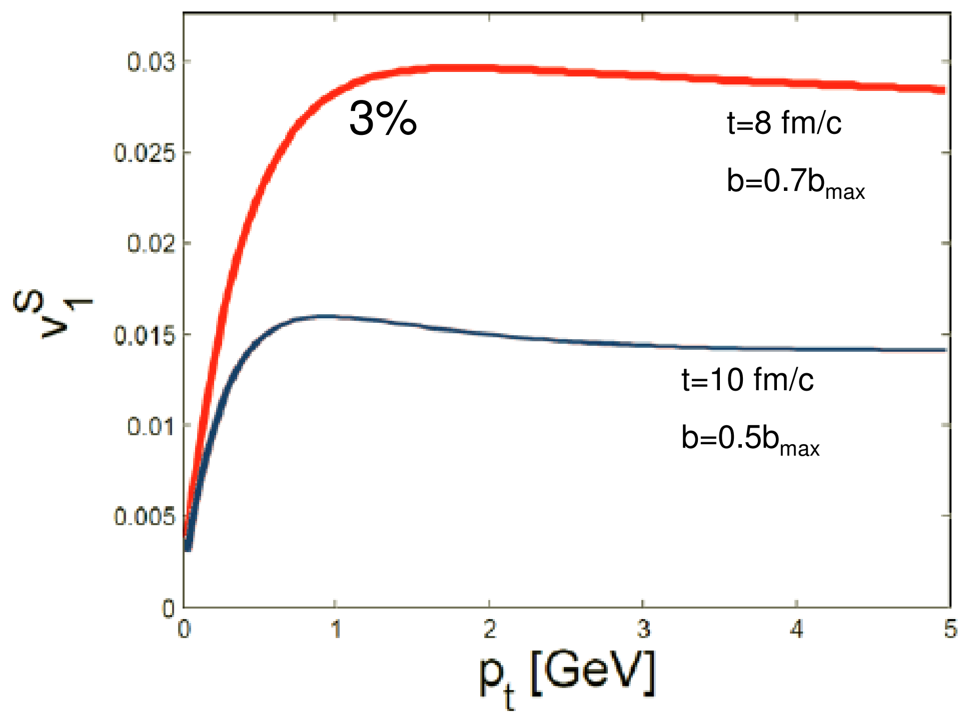
$$J_n(y,\vec{v}^{\,i},T^i) = \int_0^\infty dp_t p_t^2 I_n(\gamma_t^i v_t^i p_t/T^i)e^{-\gamma_t^i p_t cosh(y-y_0^i)/T^i}$$

Analytic expressions!!!



v1 antisymmetric function of pz and y, so the pz or y integral of v1 should vanish.

New function v_1^s



$$v_1^S(p_\perp) = \frac{\sum_{i=1}^{N} 2\pi V_i A_i D(i, m_\perp^i) I_n(\gamma^i v_\perp^i p_\perp / T_i) \cos n\phi_0^i}{\sum_{i=1}^{N} 2\pi V_i A_i B(i, m_\perp^i) I_0(\gamma^i v_\perp^i p_\perp / T_i)}$$

$$D(i, m_\perp^i) = e^{-\gamma^i m_\perp^i / T^i} \frac{2v_z}{1 - v_z^2} \frac{T^i}{\gamma^i}$$

- v_1 antisymmetric function of p_z and y, so the p_z or y integral of v_1 should vanish.
- Reverse the $p_\perp$ direction of backward going particles before doing the y-integral
→ non-vanishing $v_1^S(p_\perp)$ function, much less sensitive to random thermal fluctuations
- $v^S_1(p_\perp)$ has a small magnitude as it is an integral value for the whole rapidity range

Initial longitudinal state fluctuations - v_1

!!RHIC: v1 measured to be 5 times smaller than predicted by our FD calculations!!

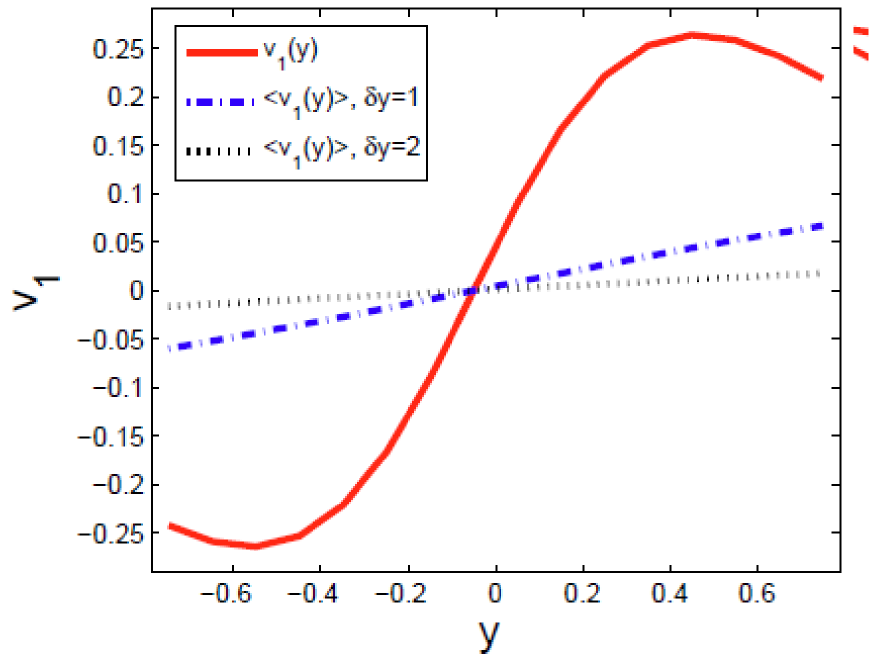
Initial fluctuations in the positions of nucleons in the transverse plane

→different number of participants from projectile and target

$$N_{part} m_N \sinh(\triangle y_{CM}) = m_N \sinh(y_0) \Rightarrow$$
$$\triangle y_{CM} = \sinh^{-1}\left[\sinh(y_0)/N_{part}\right] = 3.8\,.$$

→Reduce v_1 at central rapidities, as v1 has a sharp change at y=0, and the initial fluctuations have not.

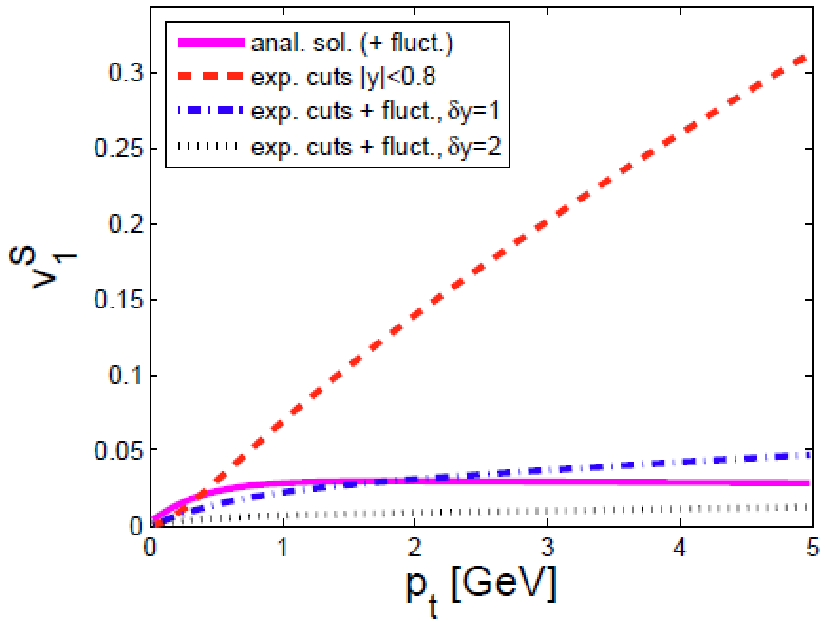
→v_1 is reduced but still measurable



Yun Cheng et al 2011 (in press) Phys. Rev. C

Initial longitudinal state fluctuations – v_1^s

$$v_1^S(p_t) = \frac{\sum_i^{cells} 2D(\vec{v}^{\,i}, T^i, p_t) I_1(\gamma^i v_t^i p_t / T^i) cos(\phi_0^i)}{\sum_i^{cells} B(\vec{v}^{\,i}, T^i, p_t) I_0(\gamma^i v_t^i p_t / T^i)}, \quad (4)$$



$v_1^s(p_t)$ affected by initial state y_{cm} fluctuations as the rapidity range is limited (-0.8<y<0.8)

Separation of Global flow v1 from the one produced by the random fluctuations of the initial state

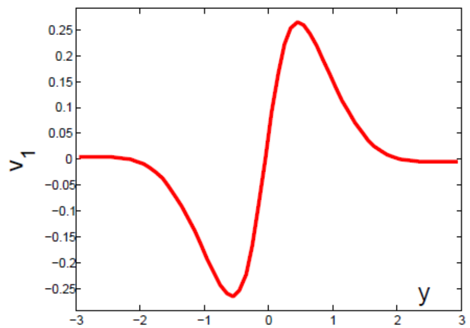
Preliminairy measures of v1 at LHC: antiflow!

→ Longitudial initial fluctuations may overshadow our predicted global collective flow

ALICE team:

$$v_1(\eta, p_t) = v_1^{\text{even}}(\eta, p_t) + v_1^{\text{odd}}(\eta, p_t)$$
$$v_1^{\text{even/odd}}(\eta, p_t) = [v_1(\eta, p_t) \pm v_1(-\eta, p_t)]/2$$

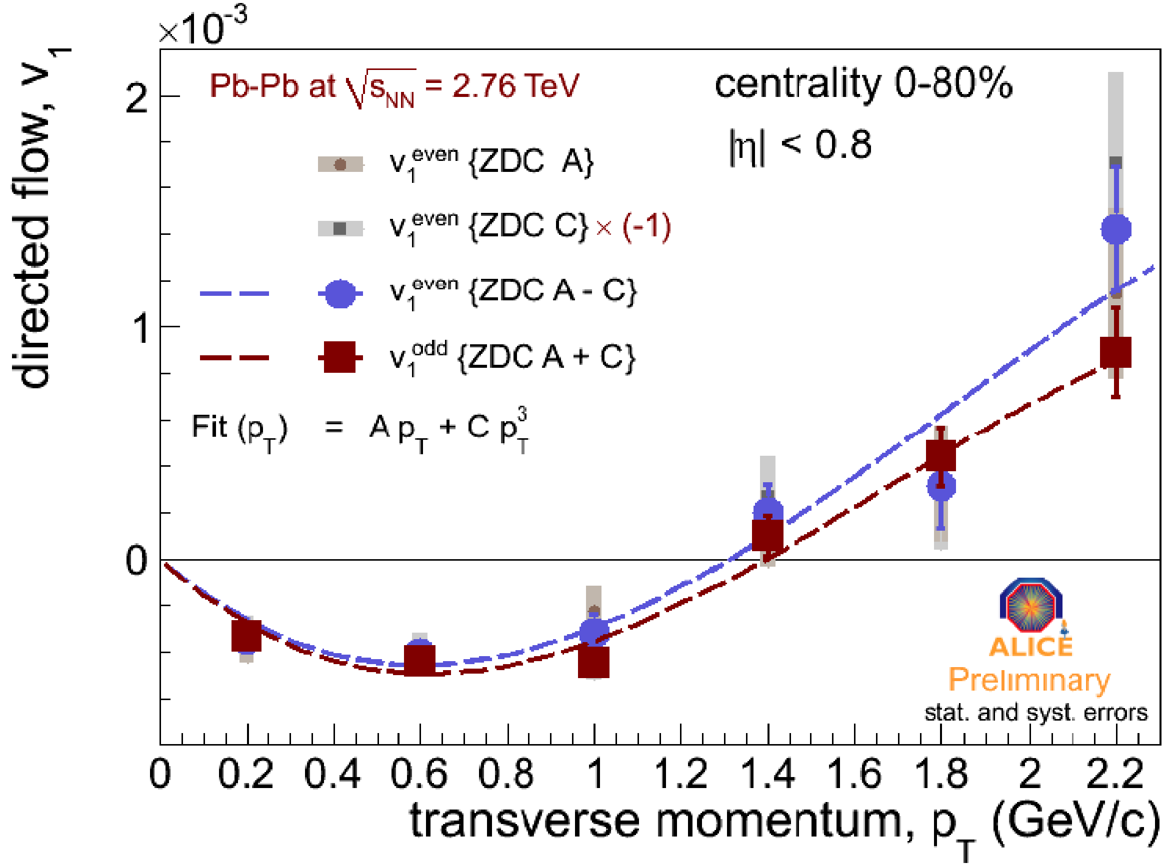
$$v^S_{1,\text{fluct.}}(p_t) = v_1^{S,\text{odd}}(p_t),$$
$$v_1^S(p_t) = v_1^{S,\text{even}}(p_t) - v_1^{S,\text{odd}}(p_t)$$



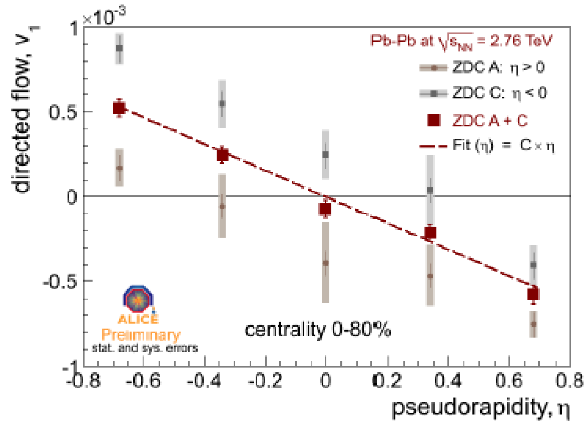
Global mirror ***a***symmetric

R.Snellings (QM2011), Gyulnare Eyyubova

Extracting even and odd parts of v_1



what we expect for even and odd projections:



Even and odd parts of v_1 have similar shape and magnitude

Contribution from the Global directed flow is zero, explains why the predicted rotation is vashed out by these fluctuations

Thank you for your attention!