Directed flow measurement in Pb-Pb collisions with ALICE at the LHC

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Abstract

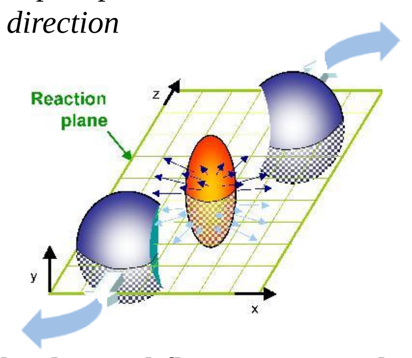
Directed flow, v_1, is measured over a wide range of pseudo-rapidity, $|\eta|<5.1$, in Pb-Pb collisions at 2.76 TeV with ALICE at the LHC. The results of v_1 are reported as a function of the pseudo-rapidity and the transverse momentum for different collision centralities. Using the neutral spectator deflection at beam rapidity we investigate both the rapidity asymmetric v_1 which is sensitive to the collision reaction plane, together with the rapidity symmetric v_1 which is sensitive to the energy fluctuations in the initial geometry. Results are compared to RHIC measurements.

Directed flow

Physics motivation

The study of collective phenomena of produced particles gives an insight into the evolution and properties of the created matter.

Reaction plane is defined by the impact parameter and the beam direction



Fourier decomposition of the particle's azimuthal distribution w.r.t. the reaction plane angle of the collision Ψ_{RP}:

$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos[n(\varphi-\Psi_{RP})]\right)$$

Anisotropic transverse flow coefficients

The directed flow v_1 arises due to created matter that deflects the remnants and expands. Directed flow probes the compressibility of the created matter.

Methods used for flow measurements

Flow vector: $Q=\{\sum w_i\cos(\varphi_i),\sum w_i\sin(\varphi)\}$ Sum over i particles, w_i are weights

Event plane method

$$\Psi_1=\tan^{-1}\frac{\sum w_i\sin(\varphi_i)}{\sum w_i\cos(\varphi_i)}=\tan^{-1}\left(\frac{Q_y}{Q_x}\right)$$ estimated with the first harmonic reaction plane Ψ_1

$$v_1^{obs}(\eta,p_T)\{EP\}=\langle\cos(\varphi_i-\Psi_1)\rangle$$ Fourier coefficient w.r.t. Ψ_1

$$v_1\{EP\}=\frac{v_1^{obs}\{EP\}}{R}=\frac{v_1^{obs}\{EP\}}{\sqrt{2}\sqrt{\langle\cos(\Psi_1^A-\Psi_1^C)\rangle}}$$ The correction for the event plane resolution R

A and C are two sub-events

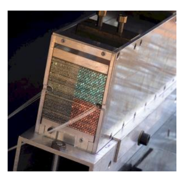
Scalar product method

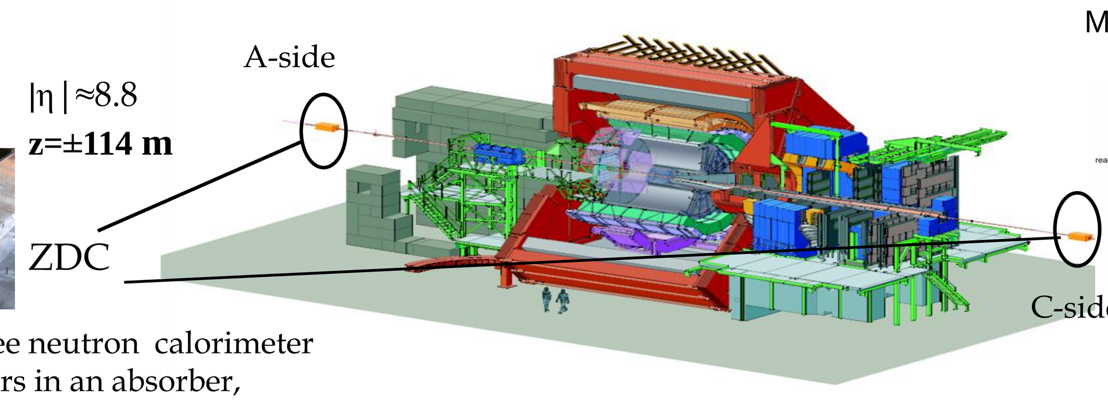
$$v_{1y}^{obs}\{SP\}=\langle\sin(\varphi_i)Q_y\rangle \quad v_{1x}^{obs}\{SP\}=\langle\cos(\varphi_i)Q_x\rangle$$

Corrected for resolution signal: $$v_{1x,y}\{SP\}=\sqrt{2}\frac{v_{1x,y}^{obs}\{SP\}}{\sqrt{Q_{x,y}^A Q_{x,y}^C}}$$

Experimental setup

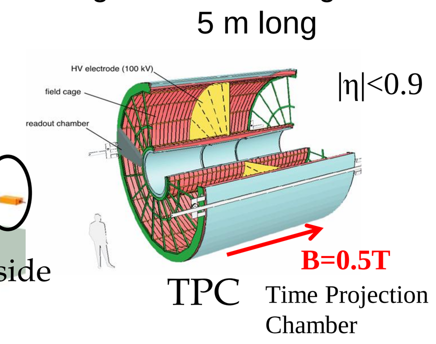
- Detectors used: ZDC for reaction plane measurement; TPC and V0 for v_1 measurements
- 8M Pb-Pb minimum-bias events, 0-80% centrality, $|z|<10$ cm
- Tracks in TPC, $|\eta|<0.8$, with transverse momentum $0.15<p_T<10$ GeV/c
  - number of TPC clusters ≥ 70 (up to the maximum = 159)
  - normalized track χ^2 with 2 degrees of freedom ≤ 4.0
  - longitudinal distance of closest approach (DCA) ≤ 3 cm
  - transverse DCA ≤ 3 cm





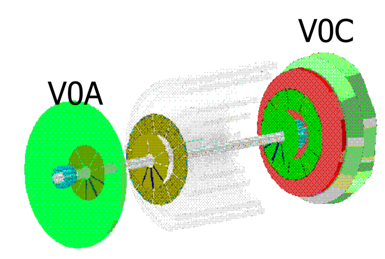
Zero-degree neutron calorimeter quartz fibers in an absorber, 4 towers

Main gas-filled tracking detector, 5 m long



V0A, **z = 3.3 m**, 2.8<η<5.1

V0C, **z=-0.9 m**, -3.7<η<-1.7

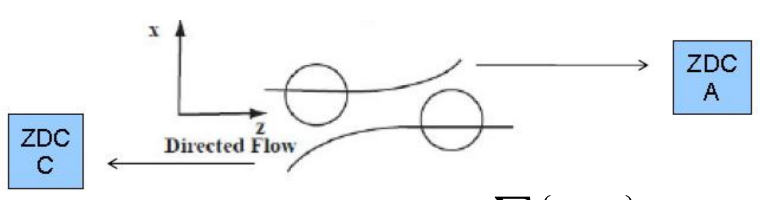


Two arrays of plastic scintillators

Results

Event plane estimate with the ALICE ZDC

The spectator deflection should be aligned in reaction plane.



Spectator deflection: $$\{X,Y\}=\beta\frac{\sum_{i=1,4}\{x_i,y_i\}E_i^{\alpha}}{\sum_{i=1,4}E_i^{\alpha}}$$ α, β are parameters

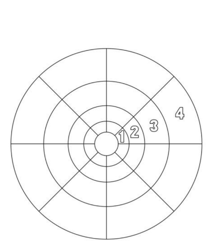
Reaction plane estimation: $\Psi_1=\tan^{-1}\frac{Y-\langle Y\rangle}{X-\langle X\rangle}$ EP method

$Q_x=X-\langle X\rangle;\ Q_y=Y-\langle Y\rangle$ SP method

$\langle X\rangle,\langle Y\rangle$ are the mean over events coordinate

Directed flow at forward rapidity (V0)

The V0A/V0C segmentation:
- four rings on each side
- a ring is divided into eight sectors of 45 degrees.



$$v_{1x}^{obs}=\left\langle\frac{\sum M_i\cos(\varphi_i)}{\sum M_i}\cos(\Psi_1)\right\rangle$$

$$v_{1y}^{obs}=\left\langle\frac{\sum M_i\sin(\varphi_i)}{\sum M_i}\sin(\Psi_1)\right\rangle$$

i=1,8 is the sector's number
M is the charged particle multiplicity counted in a sector

The systematics due to secondary particles produced from interaction with the detector material is not accounted for in this measurements.

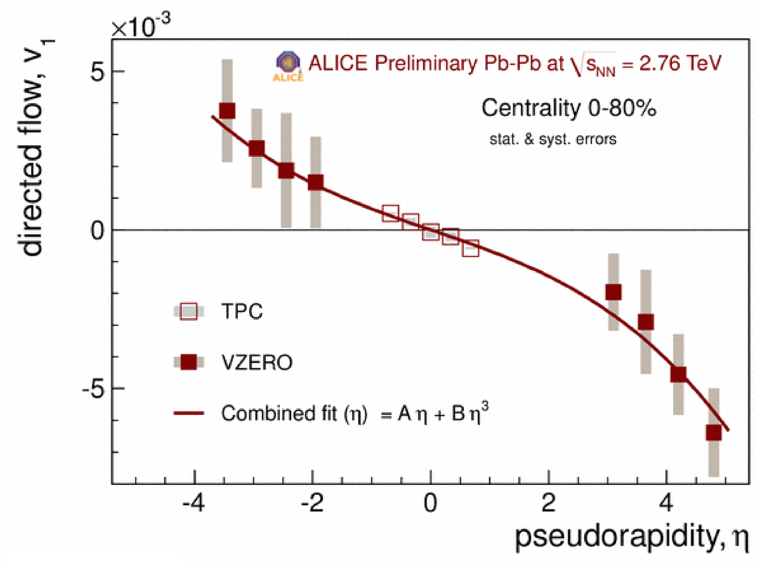
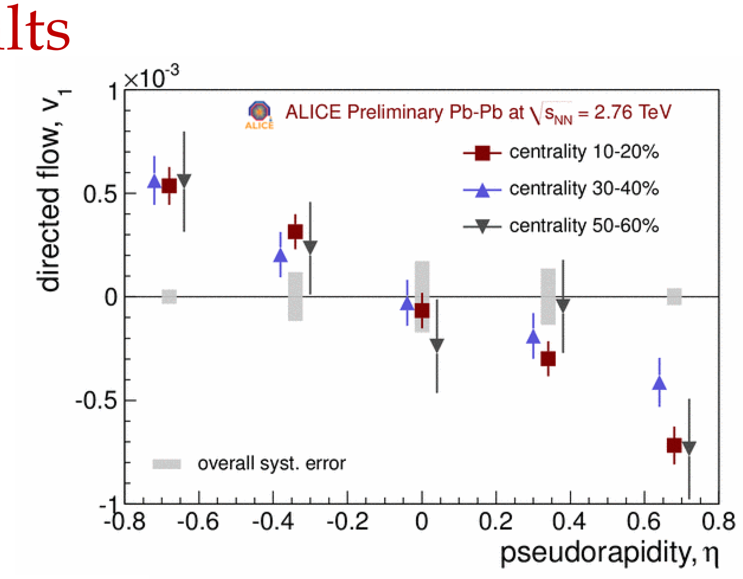


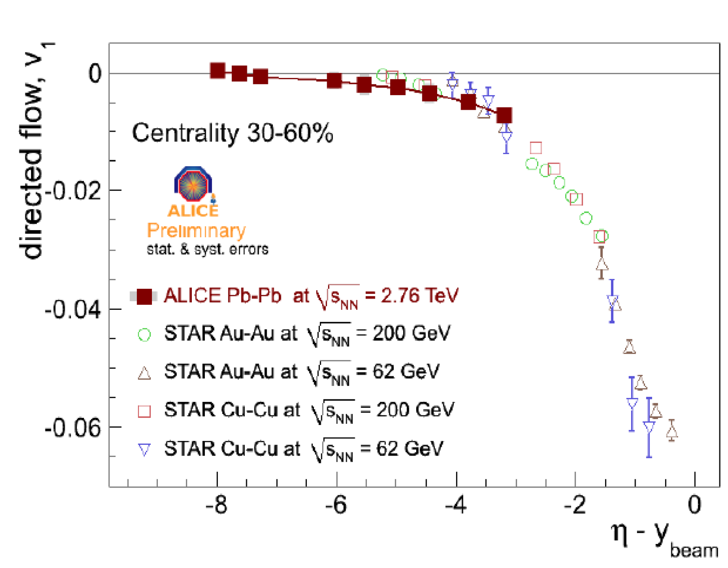
Fig.1. *Charged particle directed flow in Pb-Pb* for 0-80% centrality bin *at LHC*



Weak centrality dependence at mid-rapidity

Fig.2. *Charged particle directed flow* $v_1(\eta)$ for different centrality bins

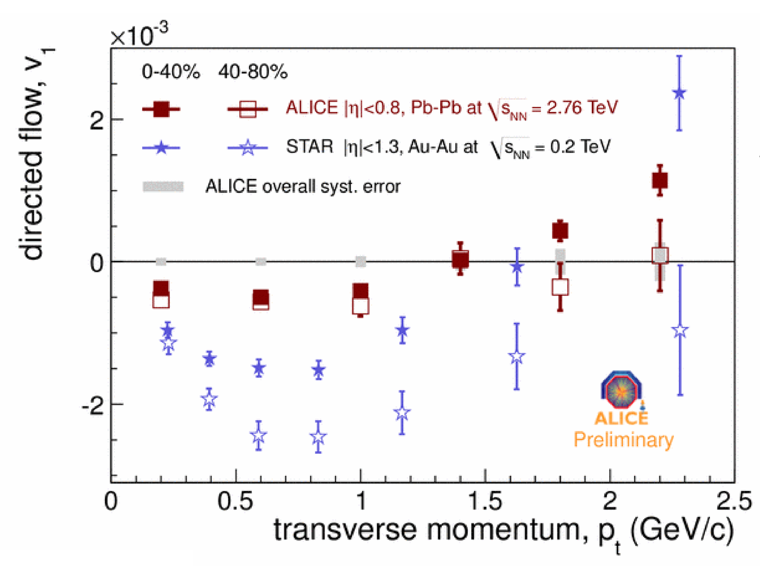
- Some transport models (like AMPT) and fluid-dynamic model predict positive slope of v1(η)
- Negative slope is observed experimentally



Universal trend when shifted to beam rapidity

Data follows the longitudinal scaling observed at RHIC

Fig.3. *Charged particle directed flow shifted to the beam rapidity* $v_1(\eta-y_{beam})$ *in comparison to STAR data at different energies*



- p_t-dependence is similar to what found at RHIC
- Zero crossing around p_t =1.5 GeV/c
- For peripheral collisions zero crossing point moves toward higher p_t

Fig.4. *Charged particle directed flow* $v_1(p_T)$ for 2 centrality bins in comparison to STAR data

Flow fluctuations: $\sigma^2=\langle v^2\rangle-\langle v\rangle^2$

- Flow methods are biased by 1) non-flow correlations and 2) flow fluctuations
- ZDC RP method has a negligible contribution from non-flow correlations, but could be sensitive to flow fluctuations (**v_1-even)**
- A contribution from flow fluctuations is different for a particular method. A measured value for different methods can be approximated as $\langle v^{\alpha}\rangle^{1/\alpha}$. For RP method α depends on resolution

B. Alver, Phys Rev C 77, 014906 (2008); J. Ollitrault, A. Poskanzer S. Voloshin PhysRev C.80, 014904 (2009)

In terms of true flow value ,v , the EP method : $v\{\mathrm{subEP}\}=\frac{\langle v\,\mathcal{R}(v\sqrt{N/2})\rangle}{\sqrt{\langle[\mathcal{R}(v\sqrt{N/2})]^2\rangle}}$

In v_1 {ZDC EP} method resolution R ~ v_1(spectators)

Flow fluctuations in v_1 measurements

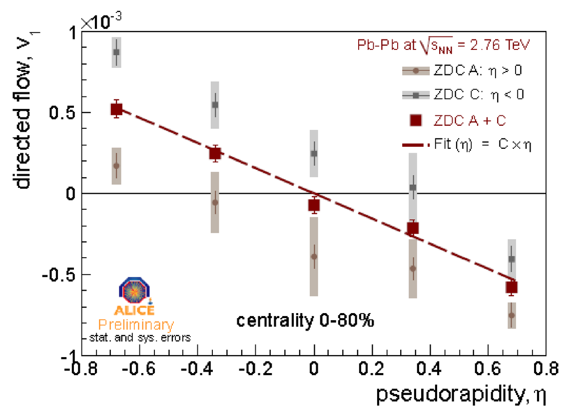
✓ Event-by-event fluctuations in the position of the participating nucleons and the transverse shape of the spectator distribution are connected

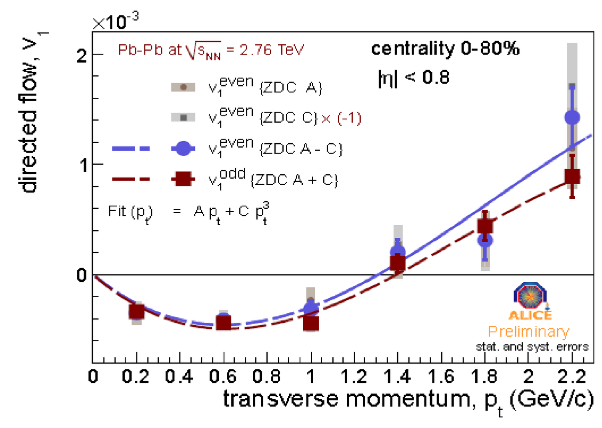
$\langle v_1\{\mathrm{ZDC\ EP}\}\rangle \sim \langle v_1(\mathrm{participants}) * v_1(\mathrm{spectators})\rangle$

- Mean value (for odd function): $\langle v_1^{spect}(\eta>0)\rangle = -\langle v_1^{spect}(\eta<0)\rangle$
- E-by-E value : $\langle v_1^{spect}(\eta>0)\rangle+\sigma \neq -\langle v_1^{spect}(\eta>0)\rangle+\sigma$
- In a EP method: $|\langle v_1(\eta>0)\rangle+\sigma| \neq |\langle v_1(\eta<0)\rangle-\sigma|$

Flow fluctuations contribute with opposite sign to the correlation with spectators on the positive and negative rapidity side

Directed flow with two sub-events





- A difference between two sub-events is consistent with flow fluctuation picture
- $\int v_1(\eta)d\eta$ cancel the odd part. In a p_T-dependence, v_1-even part is done without a sign flip for η<0
- A similar p_T dependence for odd and even v_1

Conclusions

Directed flow of charged particles has been measured at midrapidity, $|\eta|<0.8$, and forward rapidity, $1.7<|\eta|<5.1$, for Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ALICE detector at the LHC

- $v_1(\eta)$ has negative slope in contrast to some of the theoretical expectations.
- The magnitude of $v_1(\eta)$ is smaller than at top RHIC energy .
- $v_1(\eta-y_{beam})$ is consistent with a picture of longitudinal scaling observed at RHIC.
- $v_1(p_t)$ crosses zero at approximately p_T =1.5 GeV/c, depending on centrality .
- Azimuthal correlations with spectators can be sensitive to flow fluctuations at mid-rapidity providing a tool for study v_1-even.