Detector effects and systematic uncertainties in the directed flow measurement with spectator neutrons in ALICE at LHC

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Abstract

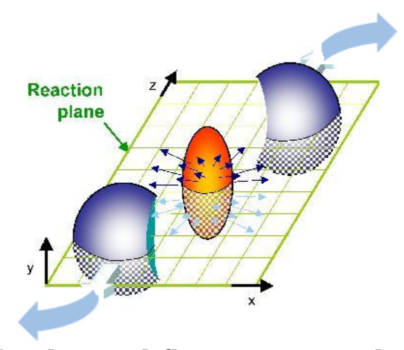
Directed flow serves as one of the key observables to understand the properties of the hot and dense matter produced in ion-ion collisions. We report on a study of systematics and detector effects in the directed flow measurement using the reaction plane estimate provided by the sideward deflection of neutral spectators measured with the help of ALICE ZDC (Zero Degree Calorimeter) detectors. Effects from variation in the beam crossing parameters on the reaction plane resolution are studied via cross correlations between spectator deflection in the plane transverse to the beam direction. Systematic uncertainties of the measured signal are assessed by comparing results from different flow measurement techniques, such as the scalar product and the event plane methods.

Directed flow

Physic motivation

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

Reaction plane is defined by impact parameter and beam direction



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

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

Anisotropic transverse flow coefficients

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

Methods used for flow measurements

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

Event plane method [1]

$$\Psi_1=\tan^{-1}\frac{\sum w_i\sin(\varphi_i)}{\sum w_i\cos(\varphi_i)}=\tan^{-1}\left(\frac{Q_y}{Q_x}\right)$$ 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

$$v_1\{EP\}=\frac{v_1^{obs}\{EP\}}{R}=\frac{v_1^{obs}\{EP\}}{\sqrt{2}\sqrt{\langle\cos(\Psi_1^A-\Psi^C{}_1)\rangle}}$$ The correction for the event plane resolution R

A and C are two sub-events

Scalar product method

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

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

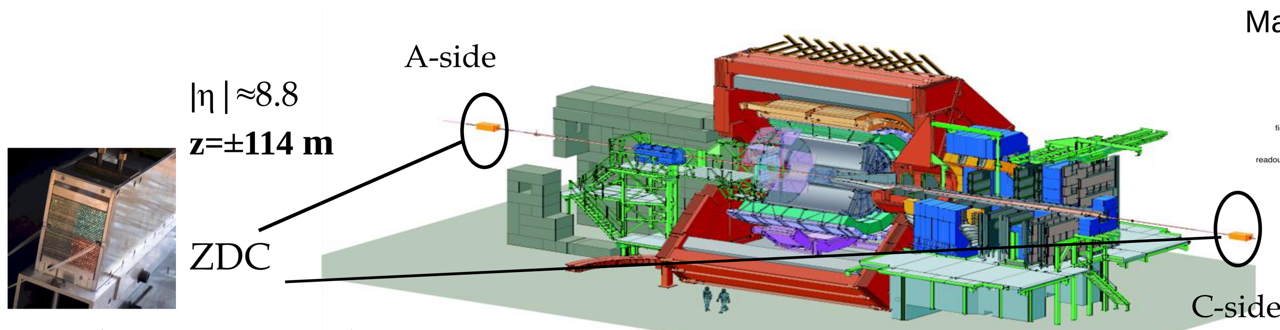
Separate estimation of the correlations in x- and y-direction for EP method:

$$v_1^{obs}\{EP\}=v_{1x}^{obs}+v_{1y}^{obs}=\langle\cos(\varphi)\cos(\Psi_1)+\sin(\varphi)\sin(\Psi_1)\rangle$$

$$R_x=1/\sqrt{2}\sqrt{\langle\cos(\Psi_1^A)\cos(\Psi^C{}_1)\rangle}\quad R_y=1/\sqrt{2}\sqrt{\langle\sin(\Psi_1^A)\sin(\Psi^C{}_1)\rangle}$$

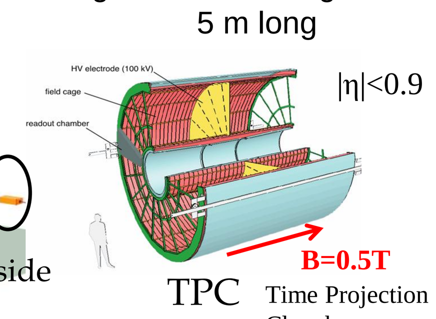
Experimental setup

- Detectors used: ZDC for reaction plane measurement; TPC and V0 for v_1 measurements
- 6M Pb+Pb minimum-bias events, 0-80% centrality, |z|<10 cm
- tracks in TPC, |η|<0.9, with transverse momentum $0.1<p_T<10$ Gev/c
  - number of TPC clusters ≥ 80 (up to the maximum = 159)
  - normalized track $\chi^2\le 4.0$
  - longitudinal DCA ≤ 3 cm
  - transverse DCA ≤ 3 cm



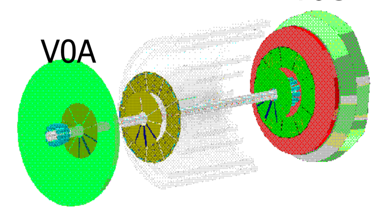
Zero-degree neutron calorimeter quartz fibers in an absorber

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

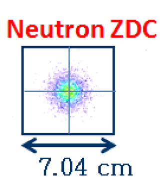


Two arrays of plastic scintillators

Event plane estimate with the ALICE ZDC

The spectators deflection should be aligned in reaction plane.

Neutron ZDC segmentation: 4 towers



measures coordinates of the hitting neutron spot, providing an estimate of reaction plane [2].

Coordinates reconstruction:

$$\{X,Y\}=\beta\frac{\sum_{i=1}^{4}\{x_i,y_i\}E^{\alpha}{}_i}{\sum_{1}^{4}E^{\alpha}{}_i}$$

Parameters: α=0.395; β accounts for the number of neutrons.

The deflection happens randomly event by event → the averaged neutron spot should be centered. Due to beam conditions and alignment it is not. The recentering should be done before the estimation of the reaction plane.

The recentering was done
- run by run
- per centrality bin

Reaction plane estimation:

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

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

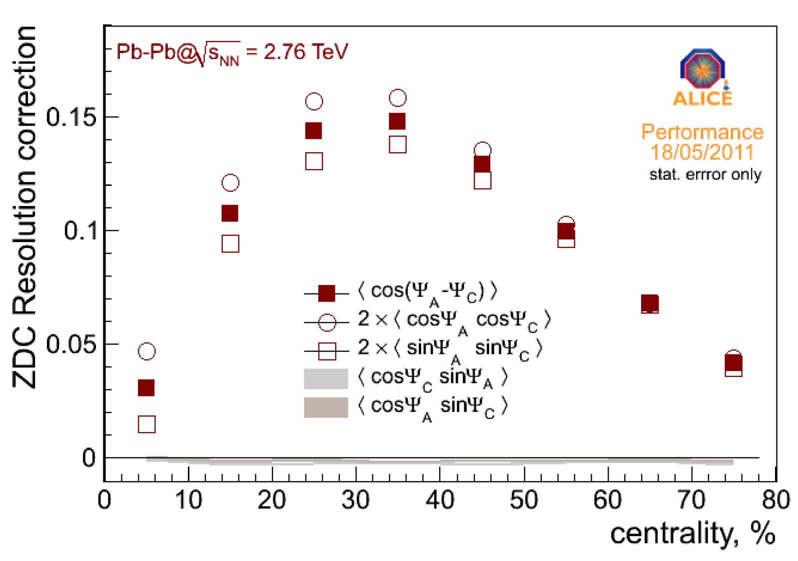


Fig.1. *The terms for ZDC reaction plane resolution depending on centrality*

- Difference is present in resolution for x and y-direction
- Resolution cross-terms are consistent with zero

References
1) *AM. Poskanzer and S. A. Voloshin, Phys. Rev. C* ***58****, 1671 (1998)*
2) *N. De Marco, Indian Journal of Physics,* ***84****, 1831 (2010)*

Directed flow at mid-rapidity (TPC)

Systematics study

For an ideal detector
- cross-terms (correlations perpendicular to the reaction plane) should be zero
- the terms within a sub-event and from two sub-events should be equal

The following test were done:
- Cross terms for event plane resolution → **Fig.1**
- Test with ZDC gain equalization
- Recentering of the neutron spot vs.transverse collision vertex position; Recentering vs z-vertex position
- Flattening of reaction plane angle distribution
- Test with artificial tilt of one of the ZDC detector
- Comparison of different terms for directed flow → **Fig.2, Fig.6** (for V0 also)
- Cross terms for directed flow in comparison with uncorrelated flow terms → **Fig.3**
- Comparison of different measurement techniques → **Fig. 4**
- Different charge combination of particles
- Using TPC-only or TPC+ITS (Inne Tracking System) tracks
- Test with no sign flip at η → **Fig.5**

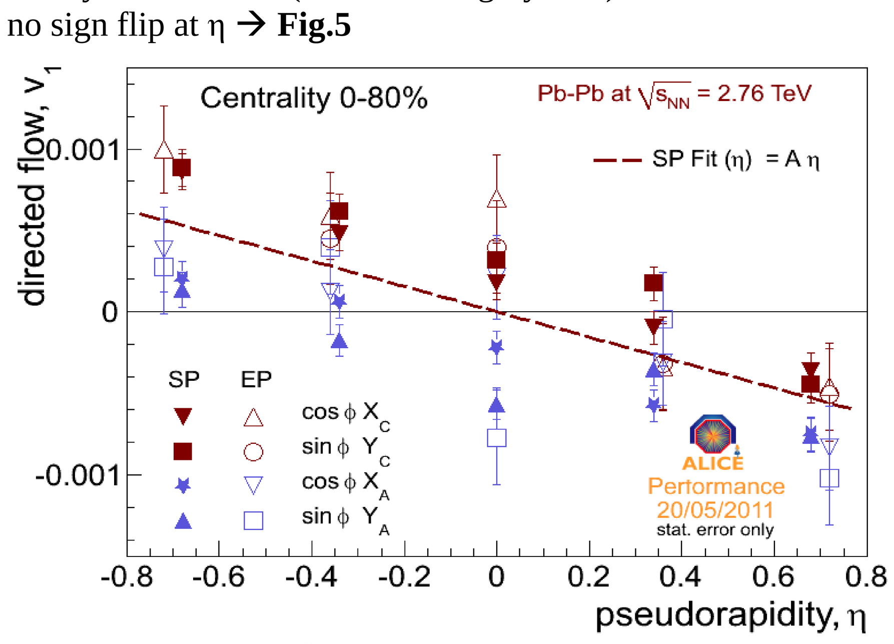


Fig.2 *Four terms, $v_{1x,y}^{A;C}$ (η) for EP and SP methods, the fit is for averaged $v_1\{SP\}(\eta)$*

- the consistency between $v_{1x,y}$ within each sub-event
- systematical difference between A and C sub-events.

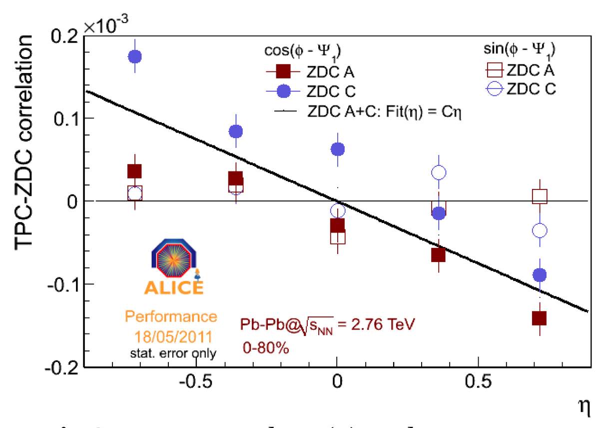


Fig.3 *Uncorrected v_1 (η) and cross terms for 2 sub-events, EP method*

- cross-terms are consistent with zero

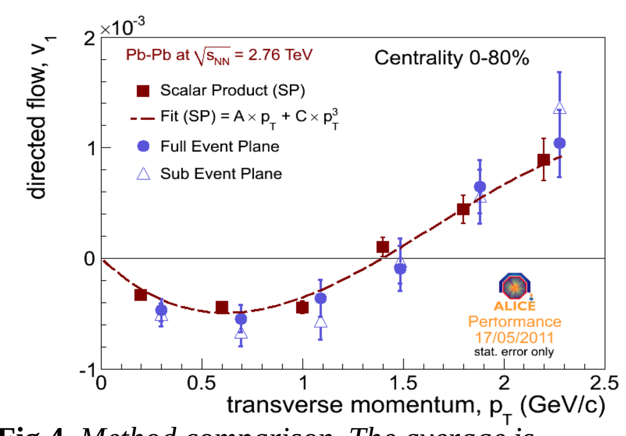


Fig.4 *Method comparison. The average is shown for sub-events SP and EP methods.*

Systemetic study of v_1 (p_T) with no sign flip at η

$v_1(\eta)$ is odd → $\int_{-\eta}^{\eta} v_1(\eta)d\eta=0$

the splitting of the sub-events $v_1^{A;C}(p_T)$ for the zero signal (no sign flip) was observed

- the average of $v_1^A(p_T)$, $v_1^C(p_T)$ gives zero
- ($v_1^A(p_T)$ - $v_1^C(p_T)$) looks similar to $v_1(p_T)$ itself

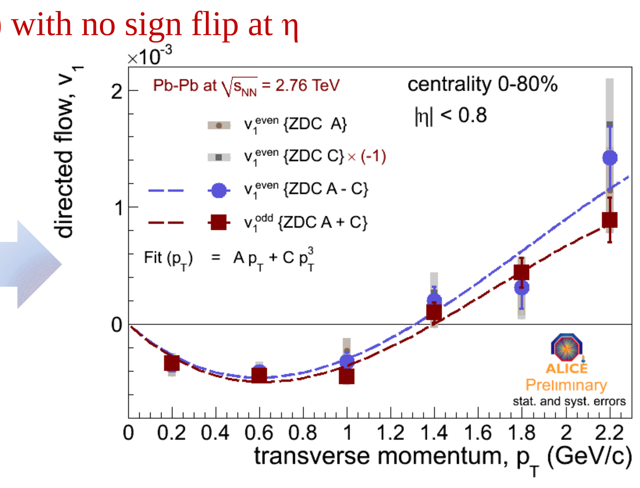
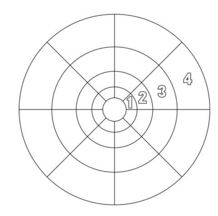


Fig.5 *Terms, $v_1^{A;C}$ p_T-dependence for no η-flip with comparison to η-flip*

Directed flow at forward rapidity (V0)

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



The rapidity coverage:
V0C (Δη = 0:5) η=[-3.7, -3.2, -2.7, -2.2, -1.7]
V0A (Δη = 0:6) η=[5.1, 4.5, 3.9, 3.4, 2.8]

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

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

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

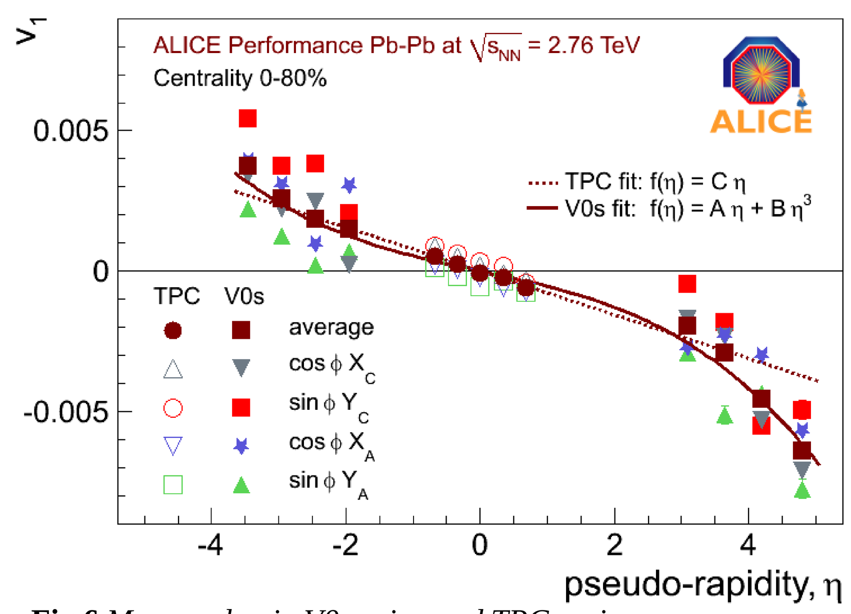


Fig.6 *Measured v_1 in V0 region and TPC region. Four components for v_1 as well as the average are shown separately.*

- The systematics for V0 and TPC is similar
- The offset between v_1^A and v_1^C sub-events is present

Conclusions

The directed flow of charged particles with the reaction plane reconstructed from the deflection of neutral spectators in heavy-ion collisions was measured.
- a negative slope of charge particles $v_1(\eta)$ is observed
- $v_1(p_T)$ is negative at low p_T and changes sign at p_T =1.5 GeV./c

Systematic study:
- No/weak correlation along orthogonal directions: systematics from detector effects is small
- The event plane resolution correction was applied in x and y-direction separately to account for detector imperfection.
- The possible effect of tilt between two ZDC and the effect of misrecentering due to transverse vertex deviation were found negligible.
- The full-event plane method agree well with sub-event plane and scalar product method.
- Sub-event method shows a systematical offset between two sub-event. The offset is present at all rapidities and centralities. This may indicate the presence of rapidity symmetric part in the correlations with spectators. The p_T shape of this symmetric part is the same as signal shape. → *flow fluctuation?* (talk by I. Selyuzhenkov)