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

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Outline

❑Introduction:

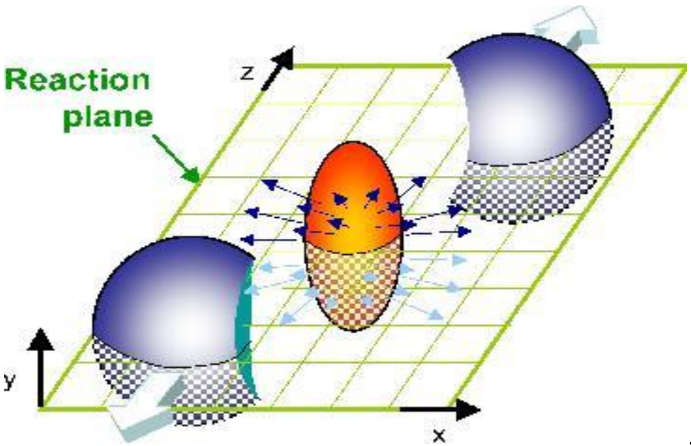
Collective flow in heavy-ion collisions
Directed flow (v1) measurements

❑Results:

Comparison to RHIC and Monte-Carlo event generators
v1 (η) , v1 (pt), v1(centrality)
v1 fluctuations

❑Conclusions

Collective anisotropic flow in heavy-ion collisions



The angular distribution of the produced particles reflects the special asymmetry of the nuclei overlap zone due to the interactions among the constituents of the produced matter.

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

Flow components v_n: $$v_n = \langle \cos[n(\phi_i - \Psi_{RP})] \rangle$$

Where Ψ_{RP} is a reaction plane, which is not known and estimated experimentally

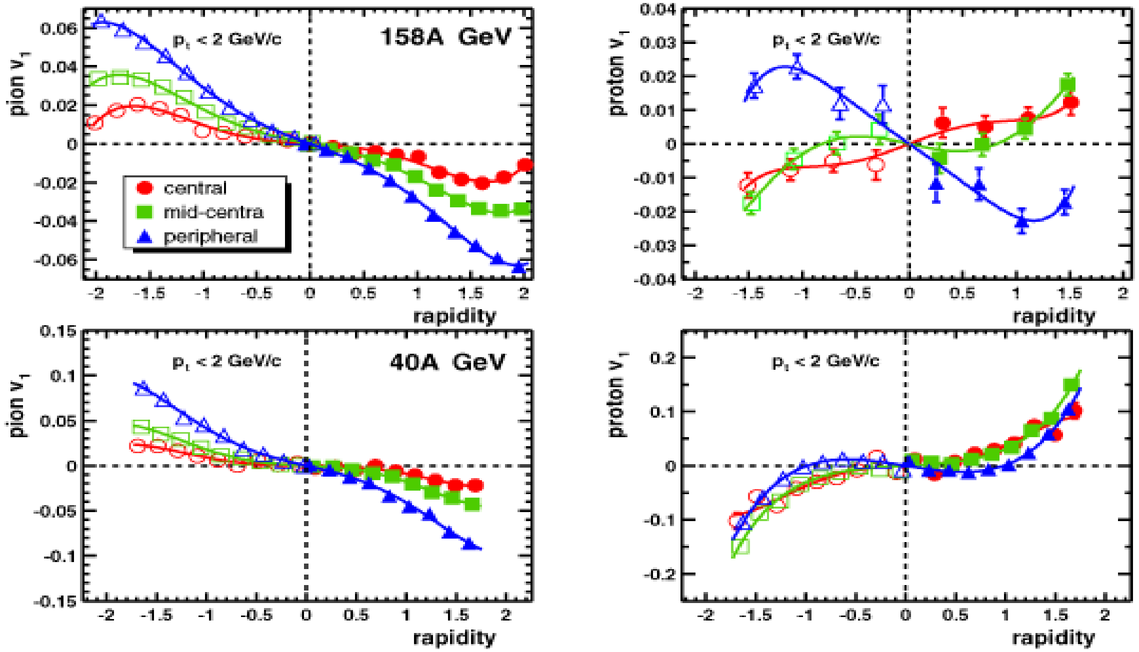
directed flow v_1:

- Probes the system at early time
- Sensitive to EoS and phase transition

(the change of $v_1(\eta)$ slope with energy can indicate for a phase transition in some of the models)

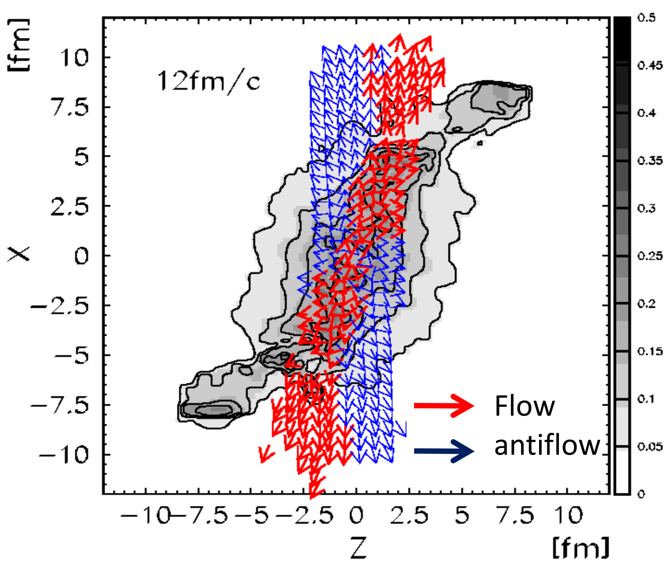
Directed flow, v_1

NA49: *Phys.Rev. C68 (2003) 034903*



- ✓An odd function of rapidity, linear at mid-rapidity
- ✓A sign of the slope for different particle species changes with energy

mechanism for generating directed flow at lower energies

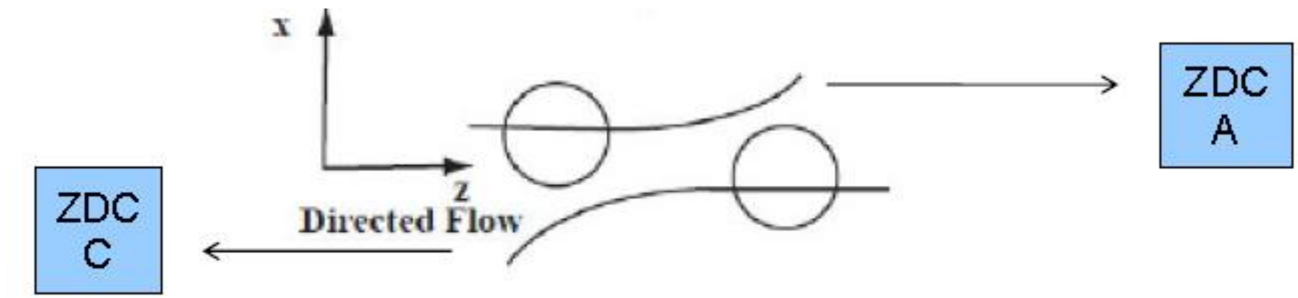


- ✓Baryon and mesons have different slope v_1 (η)

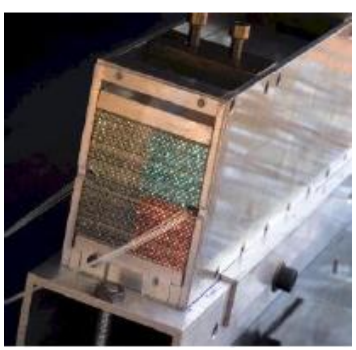
Brachmann, et. al. , Phys.Rev. C 61 (2000) 024909.
Bravina et. Al., Phys Rev C 61 (2000) 064902

Directed flow measurements
Reaction plane : directed flow of spectators

Deflection of the spectators in non-central collisions measured by ZDC is used to determine first order reaction plane angle Ψ1 and flow vector {X,Y}



Neutron Zero Degree calorimeter
(quartz fibers in an absorber)



4 tower

η >8.8, 114 m from interaction point

Spectator deflection:

$$\{X, Y\} = \beta \frac{\sum \{x_i, y_i\} E_i^{\alpha}}{\sum E_i^{\alpha}}$$

E_i tower energy; (x_i, y_i) tower center
α, β parameters

First order reaction plane angle:

$$\Psi_1 = \tan^{-1}\left(\frac{Y}{X}\right)$$

Event plane and scalar product methods

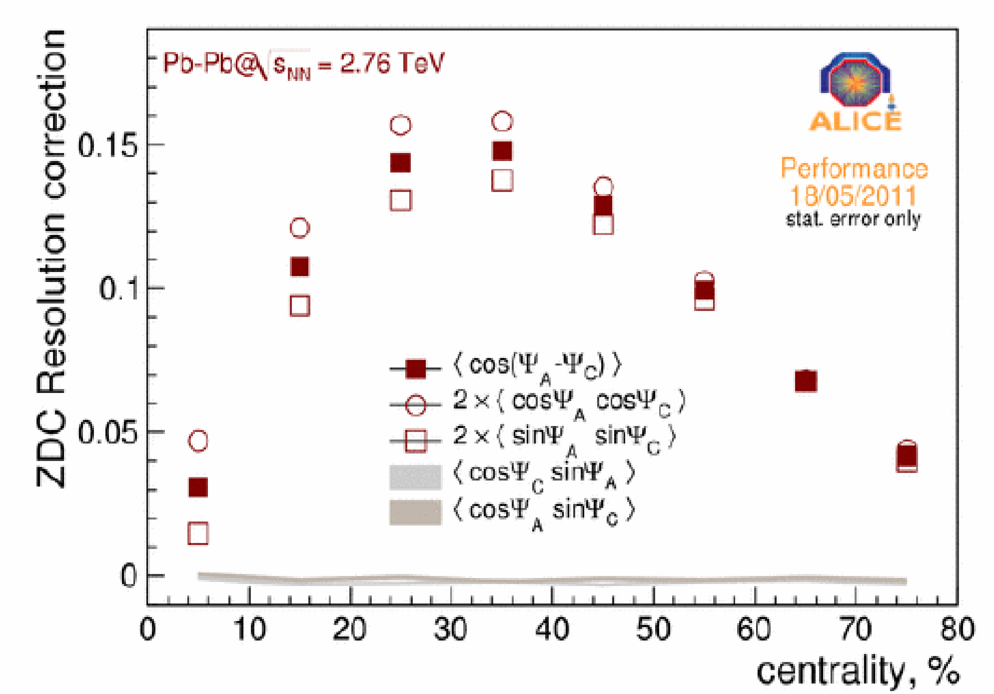
EP method

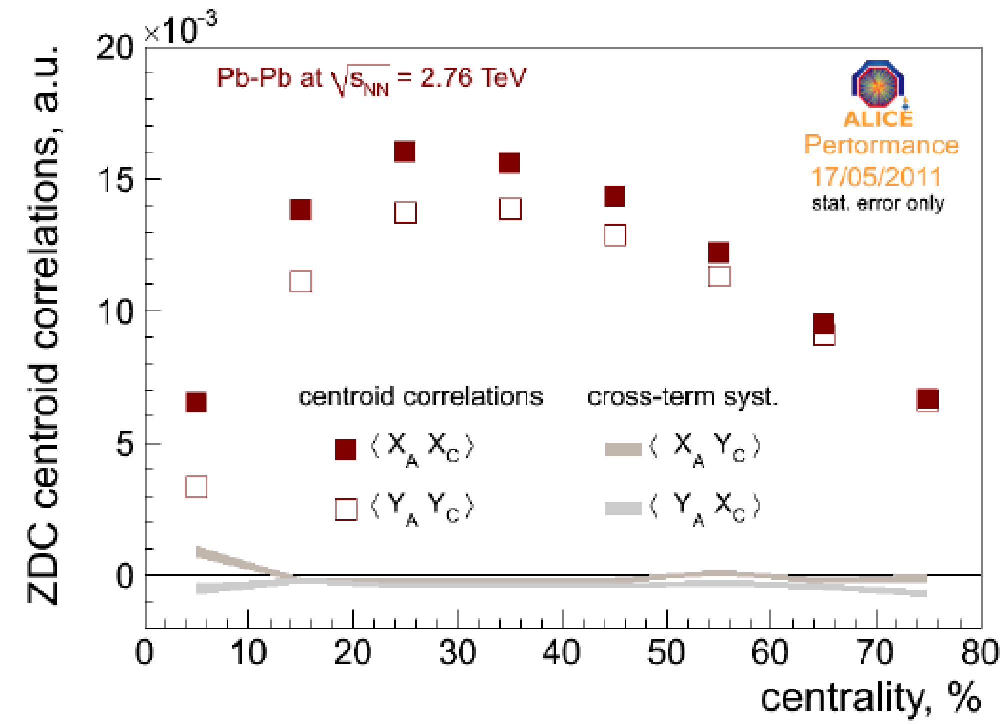
$$v_1 = \frac{\langle \cos(\varphi - \Psi_{(A+C)}) \rangle}{\sqrt{2 \langle \cos(\Psi_A - \Psi_C) \rangle}}$$

SP method

$$v^{A,C}_{1;x,y} = \sqrt{2} \frac{\langle \cos\varphi \cdot X_{A,C} \rangle}{\sqrt{\langle X_A X_C \rangle}} = \sqrt{2} \frac{\langle \sin\varphi \cdot Y_{A,C} \rangle}{\sqrt{\langle Y_A Y_C \rangle}}$$

Resolution correction

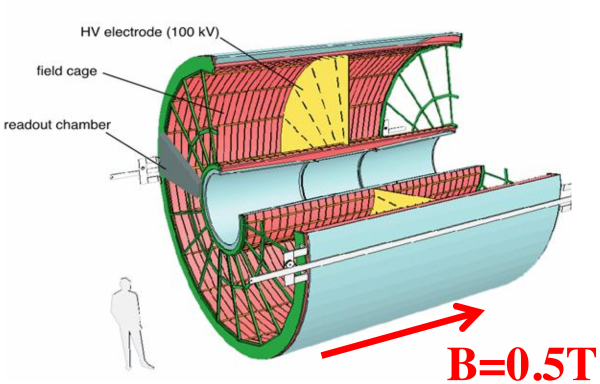




- Correlation of deflection coordinates from both sides: sensitivity to directed flow of spectators
- No/weak correlation along orthogonal directions: systematics from detector effects are small

Directed flow measurements
directed flow of produced particles

$|\eta|<0.9$



TPC

TPC (Time Projection Chamber) measurements:

✓tracks in TPC, $|\eta|<0.9$, with transverse momentum $0.15<p_T<10$ Gev/c

✓number of TPC clusters ≥ 80 (up to the maximum = 159)

✓normalized track $\chi 2 \leq 4.0$

✓longitudinal DCA ≤ 3 cm ; transverse DCA ≤ 3 cm

Vzero measurements:

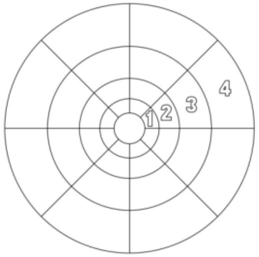
V0A , z = 3.3 m, $2.8<\eta<5.1$

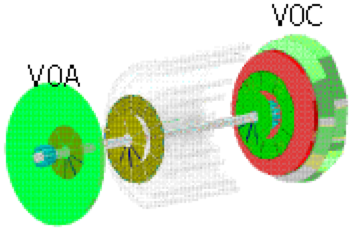
V0C , z=-0.9 m, $-3.7<\eta<-1.7$

✓4 rings of plastic scintillators at fixed Z-positions (fixed η) from both sides from IP

✓ ϕ-granularity on 8 sectors.

✓M_i is charged particle multiplicity in a sector i

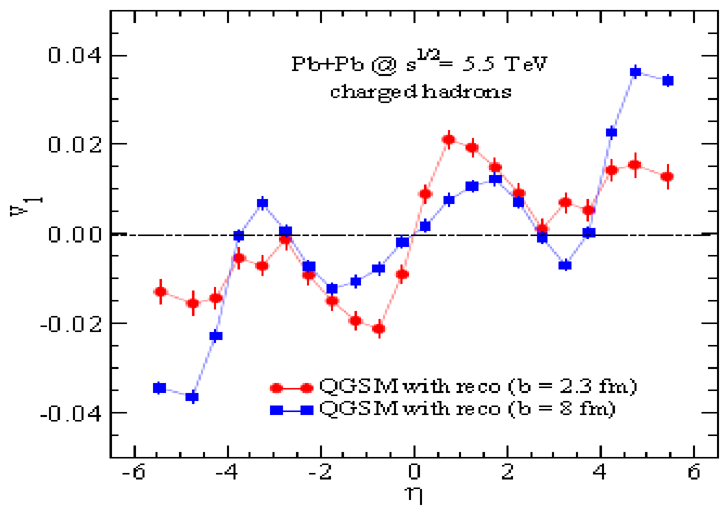




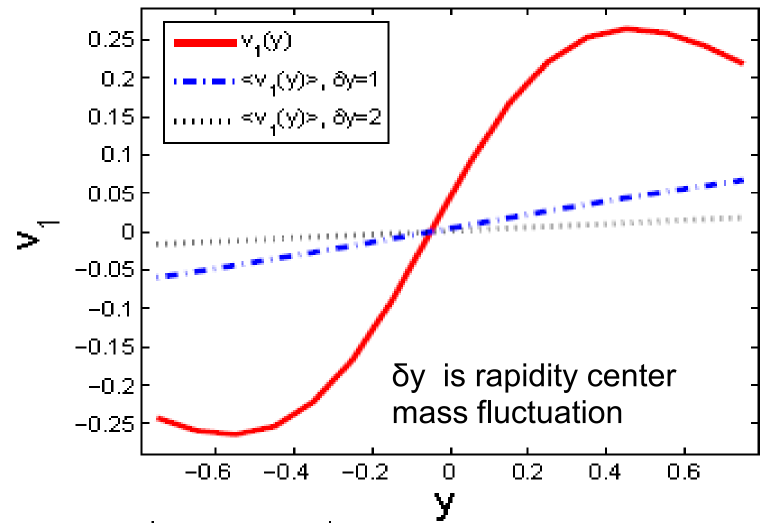
Two arrays of plastic scintillators

$$v_1^{obs} = \left\langle \frac{\sum M_i \cos(\varphi_i - \Psi)}{\sum M_i} \right\rangle$$

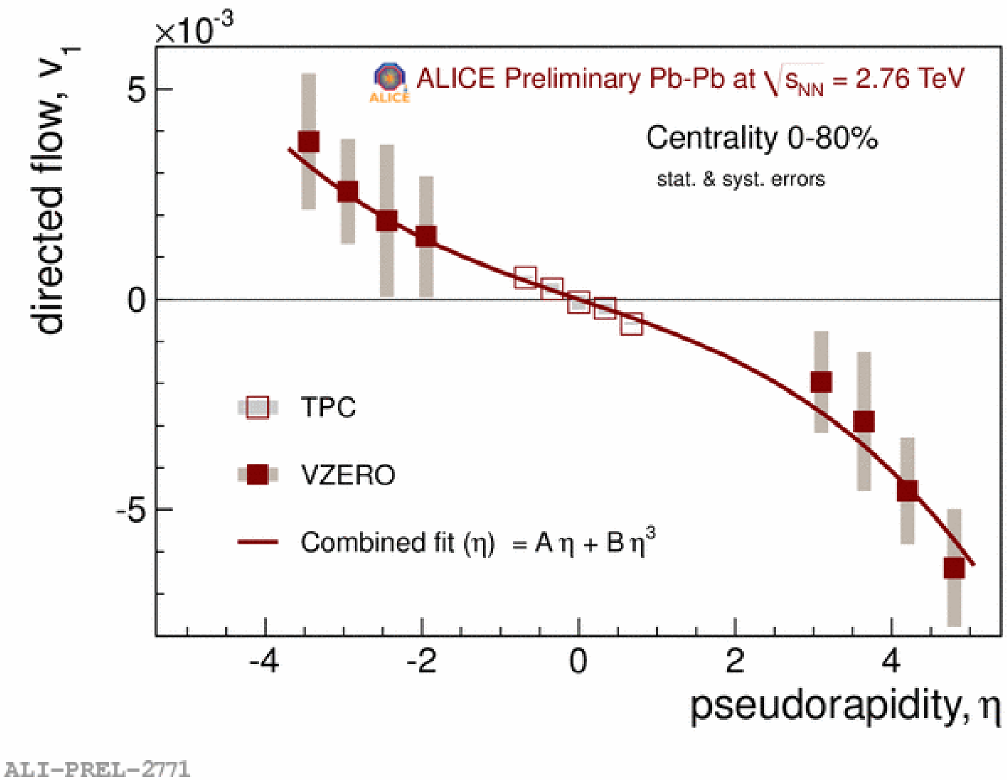
LHC predictions vs data



Bleibel et.al., Pys Let B 659, 520 (2008)



Csernai et.al., Phys. Rev. C 84, 024914 (2011)

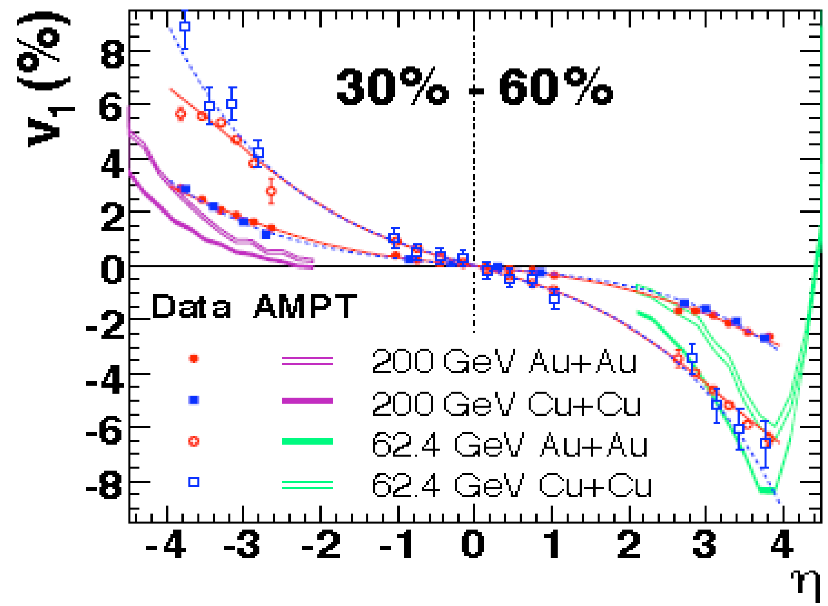


- ➢Some transport models (like AMPT) and fluid-dynamic model predicts positive slope of $v_1(\eta)$

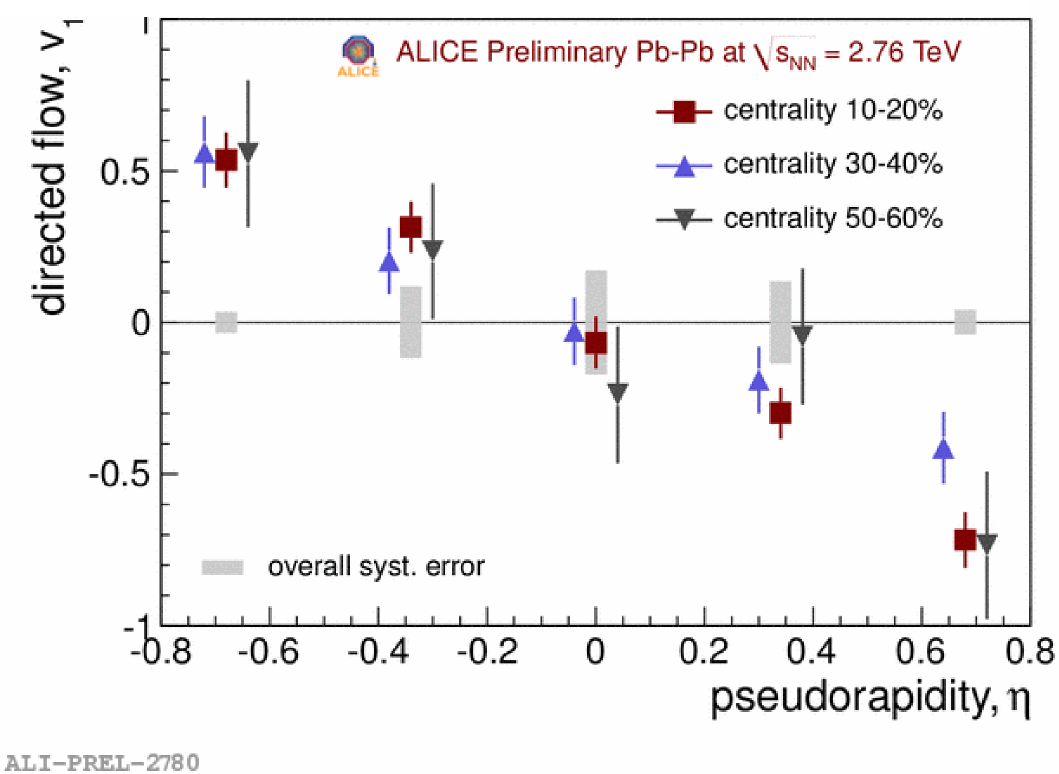
- ➢Negative slope is observed experimentally

$v_1(\eta)$: comparison with RHIC

*(**STAR collaboration**), Phys.Rev.Lett. 101 (2008) 252301*



- Decrease of v_1 with collision energy
- Negative slope of $v_1(\eta)$



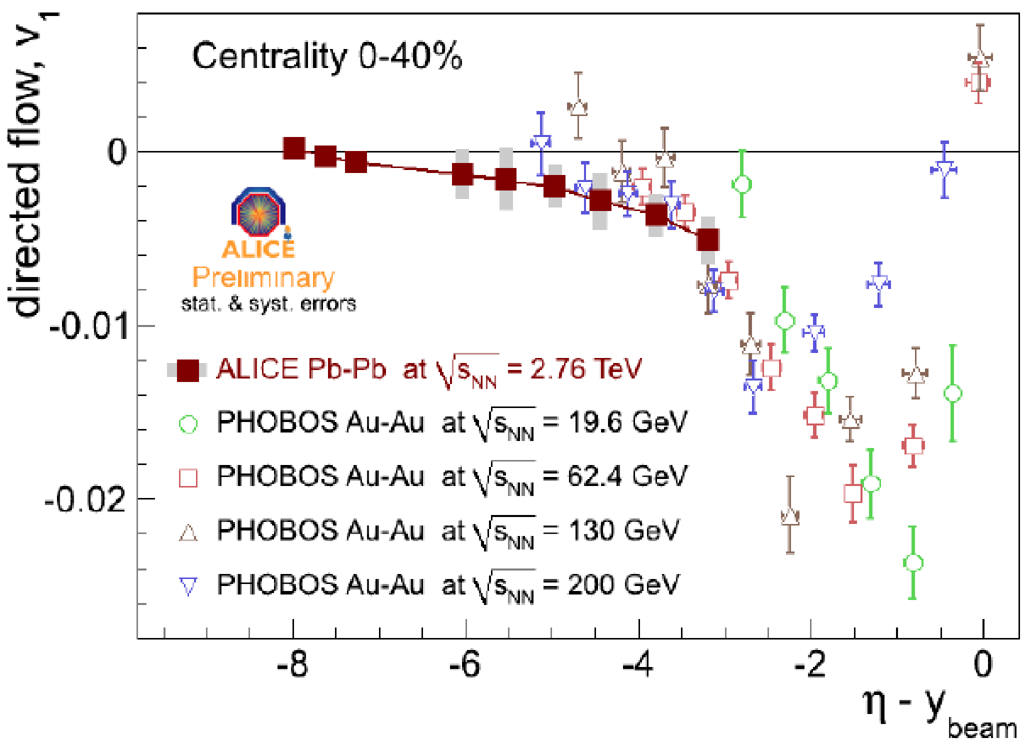
✓ The magnitude of $v_1(\eta)$ much smaller than at top RHIC energy

✓The slope decreases , become more flatten

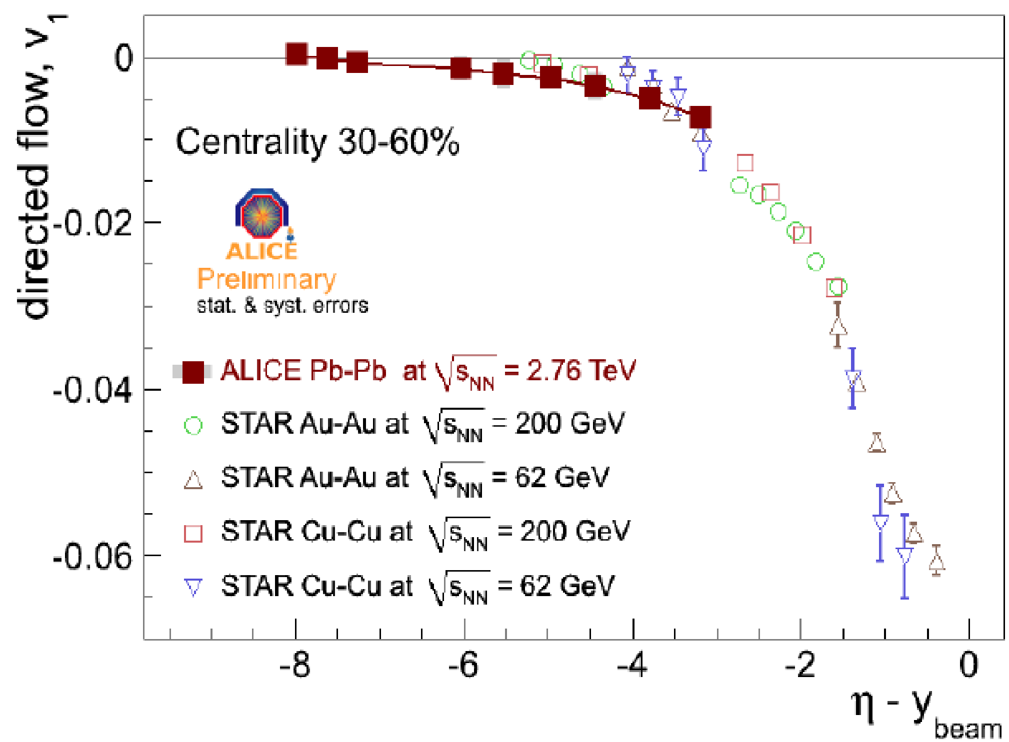
➢Weak centrality dependence at mid-rapidity

Longitudinal scaling

PHOBOS data: *Phys Rev Let97, 012301 (2006)*

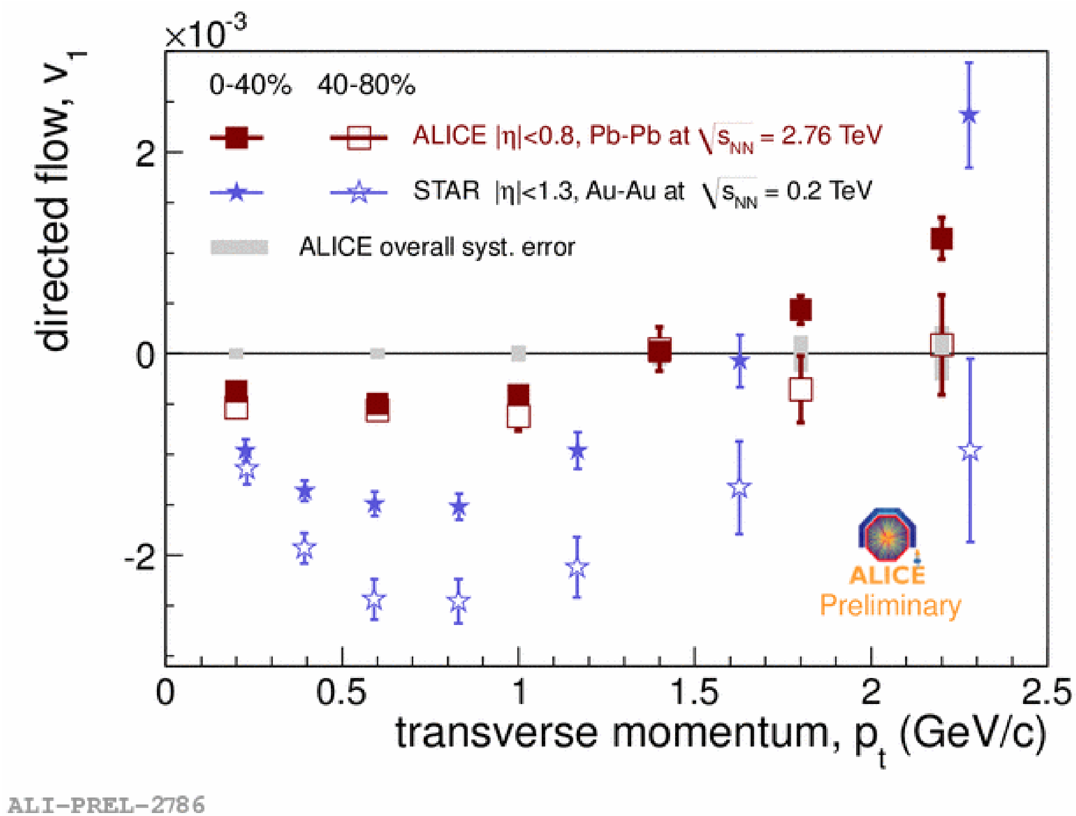


STAR data: *Phys Rev Let 101, 252301 (2008)*



- Universal trend when shifted to beam rapidity
- Data follows the longitudinal scaling observed at RHIC

P_t dependence of v_1



- Pt 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 pt

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 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 :

$$v\{\mathrm{subEP}\} = \frac{\langle v\, \mathcal{R}(v\,\sqrt{N/2})\rangle}{\sqrt{\langle[\mathcal{R}(v\,\sqrt{N/2})]^2\rangle}}$$

The resolution R=R(v, N) is a function of flow v and multiplicity N

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

$$<v_1\{ZDC\ EP\}> \sim <v_1(participants) * v_1(spectators)>$$

➢Mean value : $<v_1^{spect}(\eta>0)> = - < v_1^{spect}(\eta<0)>$

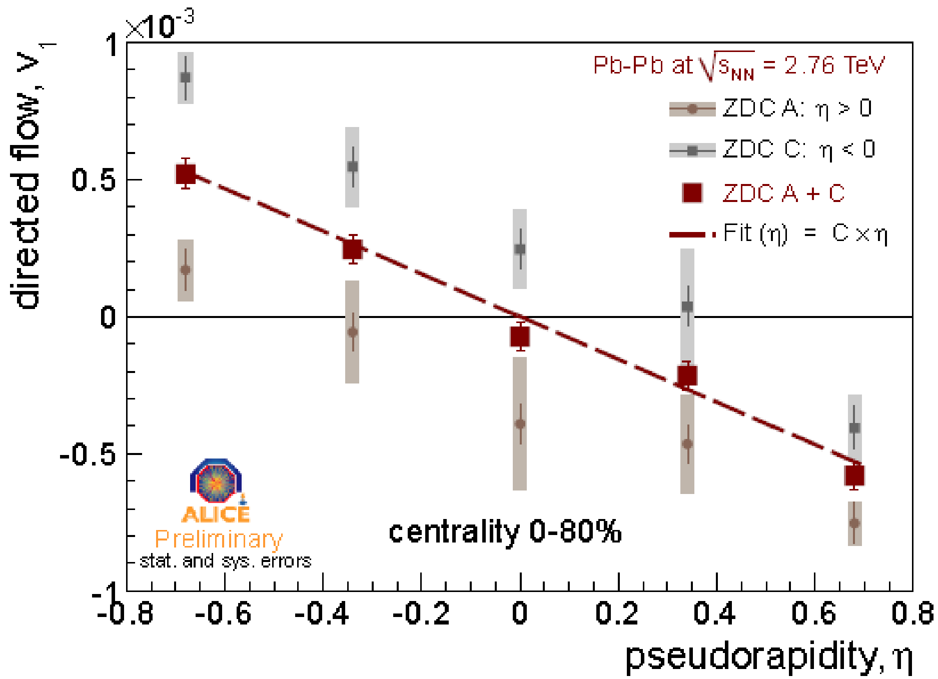
Since v1 is an odd function

➢E-by-E value : $<v_1^{spect}(\eta>0)> + \sigma \neq - <v_1^{spect}(\eta>0)> + \sigma$

➢In a EP method: $|<v_1 (\eta>0)> + \sigma| \neq |<v_1 (\eta<0)> - \sigma|$

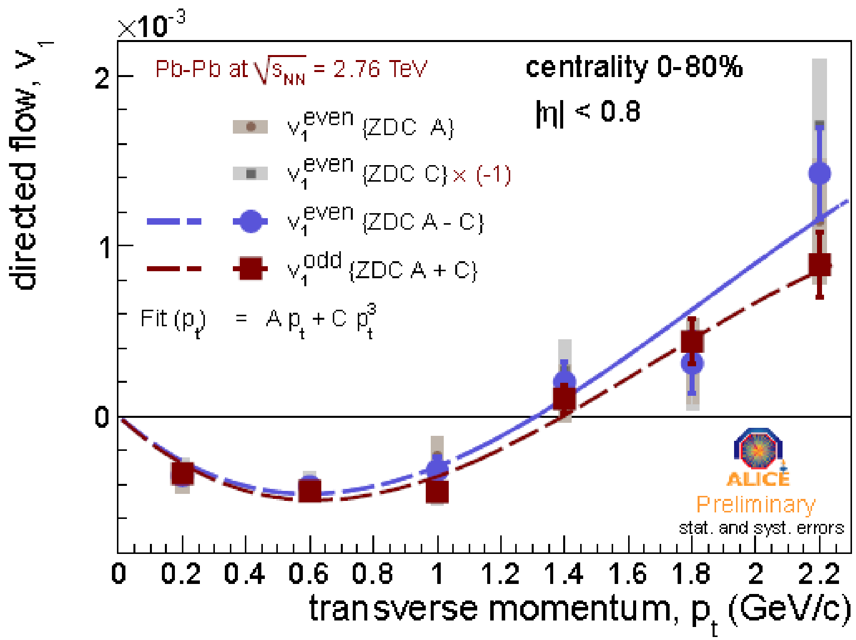
Flow fluctuations contribute with opposite sign to the correlation with spectators on the positive and negative rapidity side

Directed flow with two sub-events



- ➢A difference between two sub-events is consistent with flow fluctuation picture
- ➢Azimuthal correlations with spectators can be sensitive to flow fluctuations at mid-rapidity

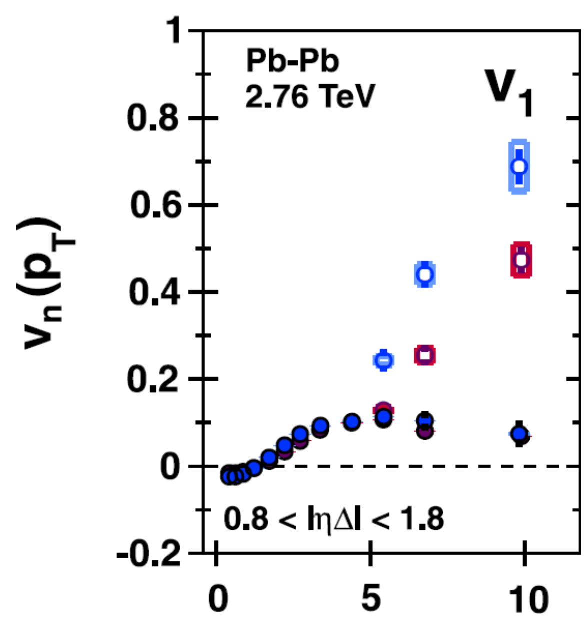
p_t dependence of the even part



- $\int v_1(\eta)d\eta$ cancel the odd part
- In a pt-dependence, v_1-even part can be revealed by integrating over η without a sign flip for η<0

The pt-dependence for odd- and even- v1 is the same

ALICE collaboration,
Phys.Lett. ***B 708*** *(2012) 249-264*



The analysis for harmonic decomposition of 2-particle correlations yields the similar shape for even part, but much larger magnitude
First harmonic flow extracted from the two particle correlations at mid-rapidity is susceptible to effects of momentum conservation and other non-flow correlations

Summary

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 LHC

- $v_1(\eta)$ has negative slope in contrast to some of the theoretical expectations
- Magnitude of v_1 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