Anisotropic Flow of Charged particles at High Transverse Momentum in 2.76TeV Pb-Pb Collisions in ALICE Experiment

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outline….

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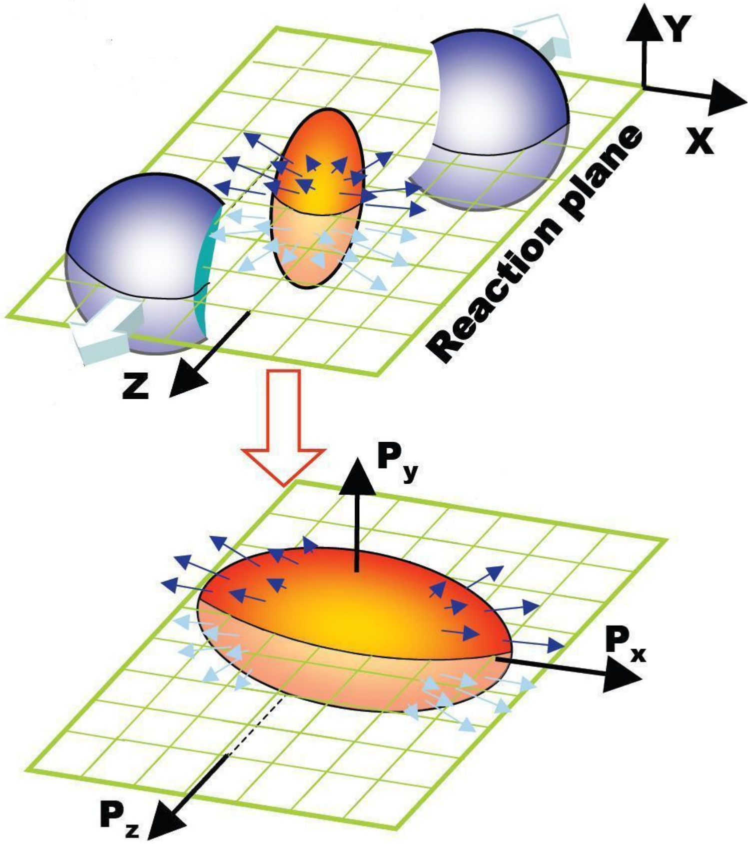
Anisotropic Flow

$$E\frac{d^3N}{d^3P} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi - \Phi_n)]\right)$$



$$v_n \equiv \langle \cos n(\phi - \Phi_n) \rangle$$

spatial anisotropy ε_n

↓ ↓

momentum anisotropy v_n

Motivation

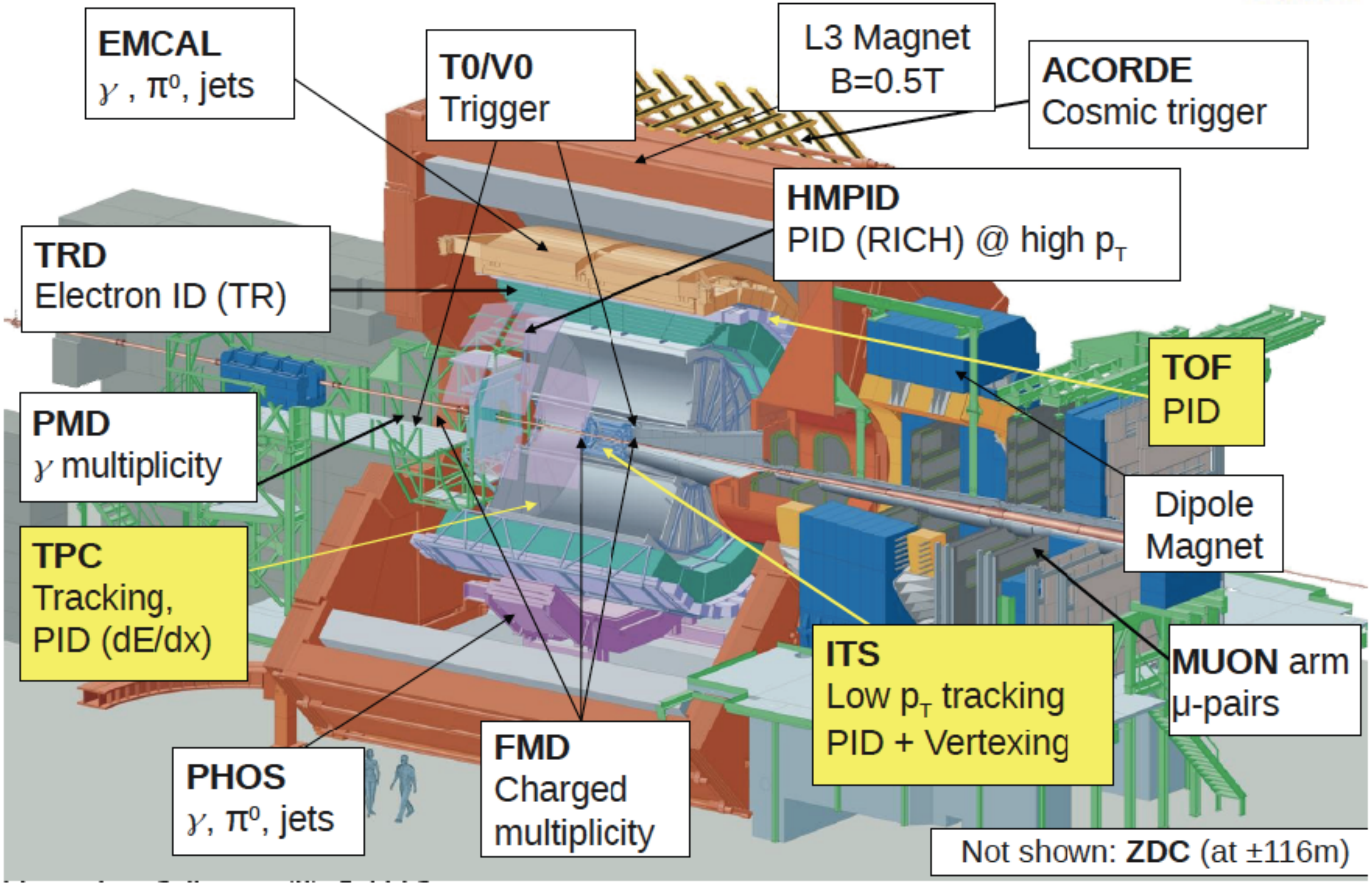
- The Anisotropic flow develops at early times of heavy-ion collision and is a powerful tool to understand collision dynamics.

- The large elliptic flow at RHIC and LHC provides evidence for strongly interacting matter, which appears to be almost perfect liquid.

- The magnitude and transverse momentum dependence of v_n is sensitive to a value of η/s (shear viscosity over entropy density ratio). Data suggest small η/s, a few times $1/4\pi$.

- The measurement of v_2 , v_3, v_4 provides strong constraints on the profile of the initial energy density, fluctuations and η/s ratio.

A Large Ion Collider Experiment



- Time Projection Chamber (TPC): Tracking and particle identification
- Time OF Flight : Particle identification
- VZERO detector: Centrality Selection

Event Selection

- **Data:** 2.76TeV Pb-Pb collisions
- **Event Selection:** 11M Minimum Bias events (0-80%)

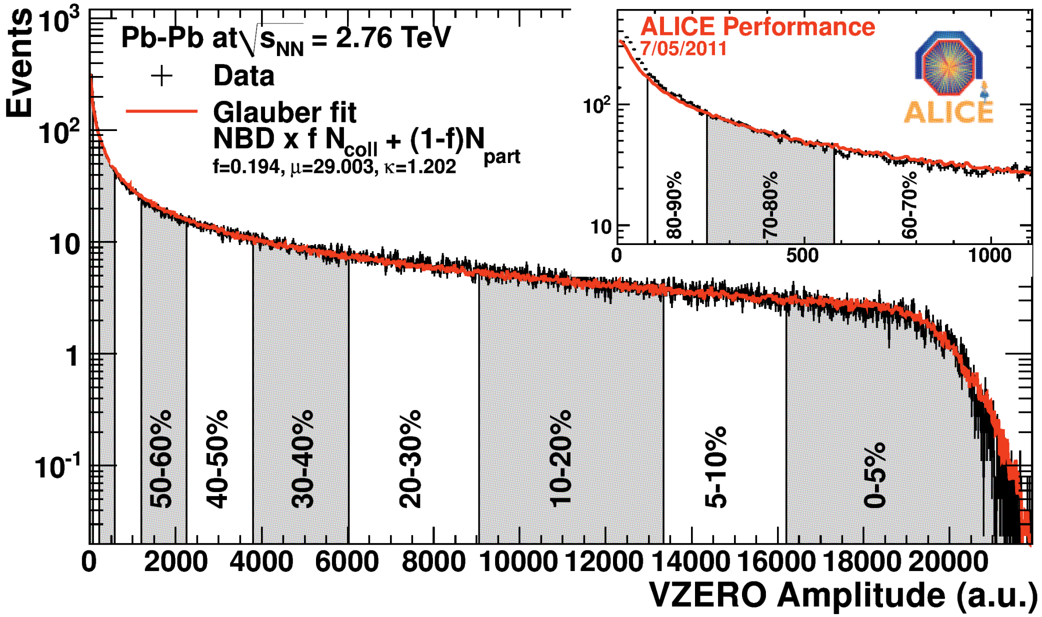
  Abs(Zvertex) <10cm

- **Track Selection:**

  Pseudorapidity Range: $|\eta| < 0.8$

  P_T Range: $0.2 < P_T < 20$Gev/c

- Centrality selection : VZERO detector multiplicity fitted with Glauber model



Experimental Methods

- **Event Plane Method:**

  - Calculate Flow Vector, Q = (Q_x, Q_y): $Q_{n,x} = \sum_i w_i \cos(n\phi_i)$ $Q_{n,y} = \sum_i w_i \sin(n\phi_i)$
  - Event plane angle: $$\psi_n = \frac{1}{n}\tan^{-1}\left(\frac{Q_{n,y}}{Q_{n,x}}\right)$$
  - Observed nth harmonic flow: $$v_n^{obs} = \left\langle \cos[n(\phi - \psi_n)] \right\rangle$$
  - Event Plane Resolution: $$R_n = \left\langle \cos n(\psi_n - \Phi_n) \right\rangle$$
  - Flow Coefficients: $$v_n = \frac{v_n^{obs}}{R_n}$$

- **Cumulants:**

  - 2-particle and 4-particle azimuthal correlations for an event:

$$\langle 2 \rangle \equiv \left\langle \cos n(\phi_i - \phi_j) \right\rangle \quad \langle 4 \rangle \equiv \left\langle \cos n(\phi_i + \phi_j - \phi_k - \phi_l) \right\rangle \quad \phi_i \neq \phi_j \neq \phi_k \neq \phi_l$$

  - Averaging over all events:

$$C_n\{2\} \equiv \left\langle \langle 2 \rangle \right\rangle = v_n^2 + \delta_n \qquad C_n\{4\} = \left\langle \langle 4 \rangle \right\rangle - 2\left\langle \langle 2 \rangle \right\rangle^2 = -v_n^4$$

Analysis Procedure

Flow components(v_2, v_3, v_4) are calculated with event plane from VZERO detector and 4-particle cumulants.

Event Plane Method: Charged particles from TPC |η|<0.8 are correlated with the event plane from VZERO-A (2.8<η<5.1)and VZERO-C (-3.7<η<-1.7), the observed flow is corrected with event plane resolution.

Event Plane Resolution: Resolution is calculated by three sub-event plane method VZERO-A, VZERO-C and TPC event planes.

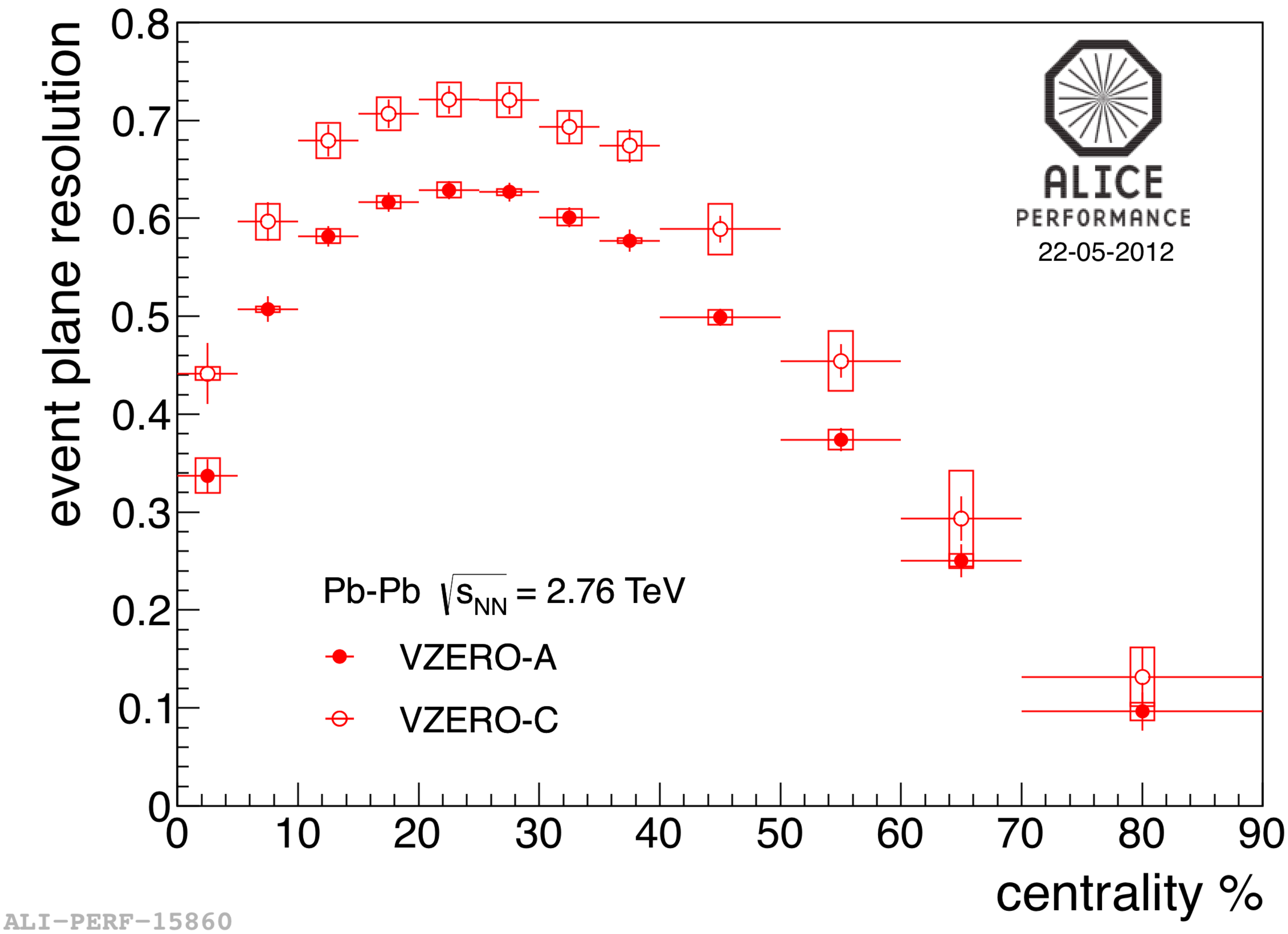
$$\left\langle \cos n(\psi_n^a - \Phi_n) \right\rangle = \sqrt{\frac{\left\langle \cos n(\psi_n^a - \psi_n^b) \right\rangle \left\langle \cos n(\psi_n^a - \psi_n^c) \right\rangle}{\left\langle \cos n(\psi_n^b - \psi_n^c) \right\rangle}}$$

Where a= VZERO-A (VZERO-B), b=VZERO-B (VZERO-A) and c=TPC

The combined results from VZERO-A and VZERO-C are v_n\{EP, V0\}

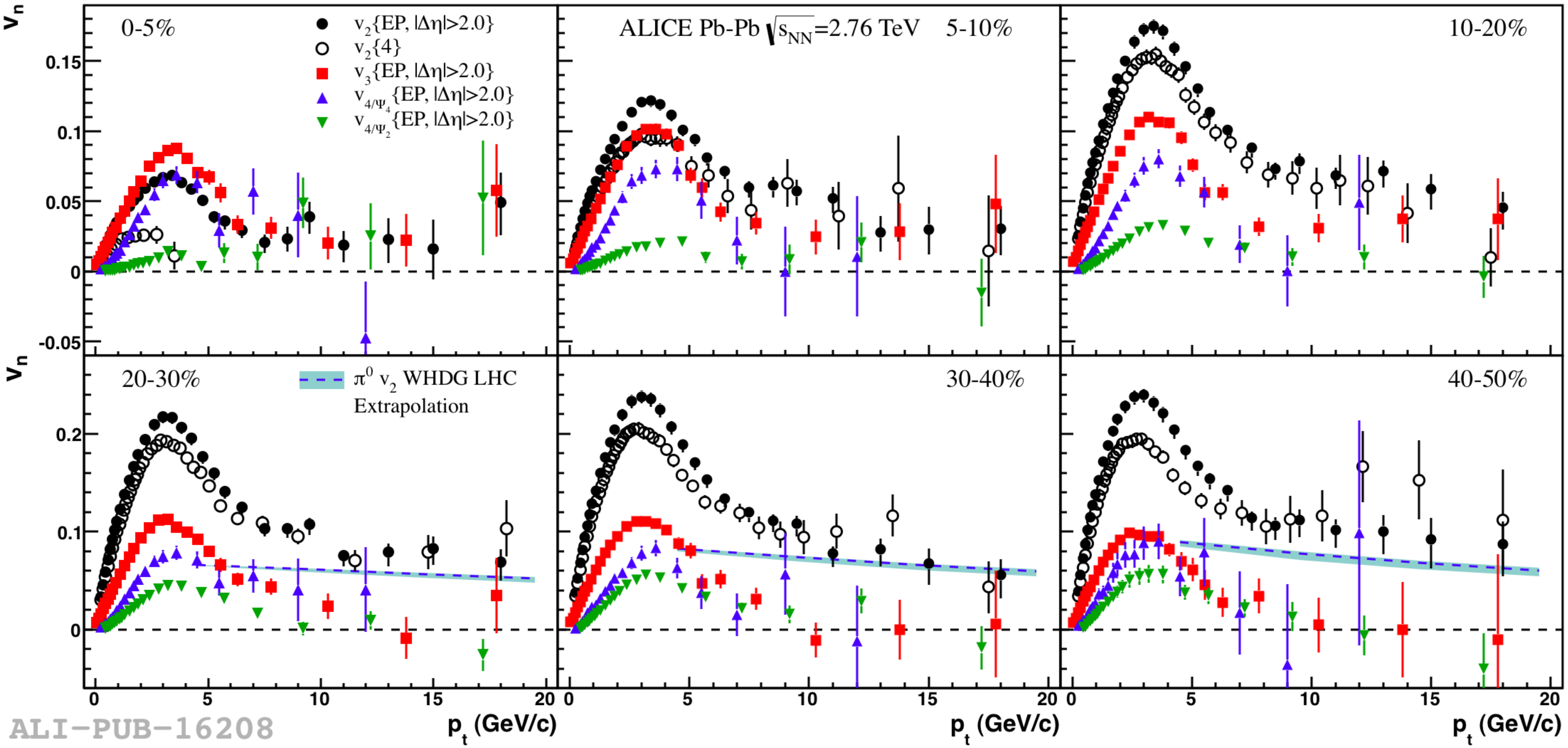
$$\bar{v}_n = \frac{\sum_i v_{n,i} / \sigma^2_{v_{n,i}}}{\sum_i \left(1/\sigma^2_{v_{n,i}}\right)} \qquad \sigma^2_{\bar{v}_n} = \frac{1}{\sum_i \left(1/\sigma^2_{v_{n,i}}\right)}$$

Event Plane resolution



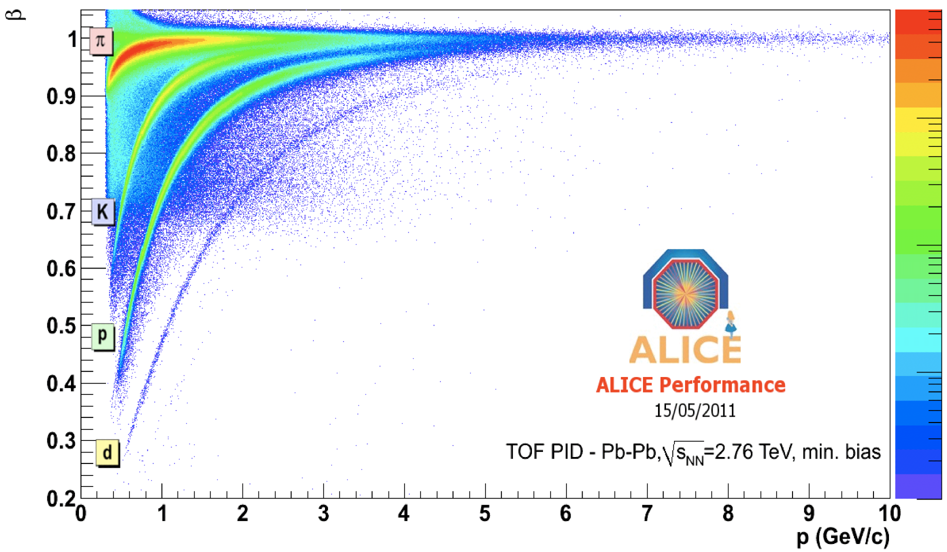
Charged particle V_n at High P_T

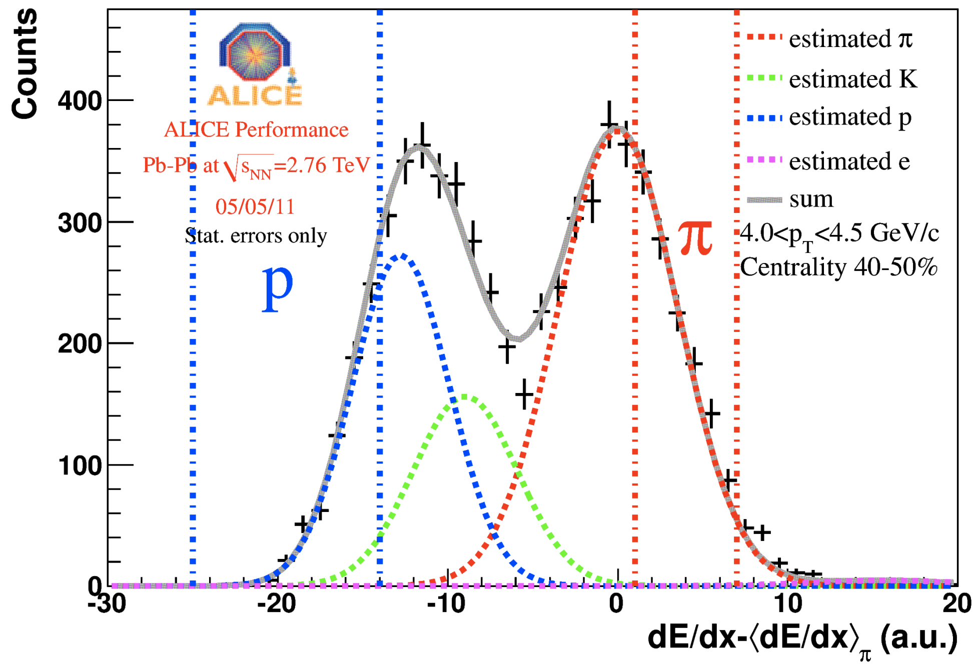
Ref:arXiv:1205.5761v1



- v_2 at high p_T (p_T>8 GeV/c) is finite and positive with values increasing from central to mid-peripheral events
- v_2\{EP\} for p_T>10 GeV/c reproduced by WHDG model calculations (W. A. Horowitz, M. Gyulassy, J. Phys. G 38, 124114 (2011))
- v_3 is smaller than v_2 in magnitude (except 0-5%) and exhibits much weaker centrality dependence.
- $v_4(\psi_4)$ does not depend strongly on centrality compared to $v_4(\psi_2)$
- v_4 at high p_T (p_T>8GeV/c) is consistent with zero within relatively large uncertainties

Particle Identification (Proton and pion) at High P_T





- **PID at low p_T:**

•Asymmetric β-cut in TOF detector to select high purity π, K and P

•Additional 2σ cut in th eTPC dE/dx to clean the data

-Contamination <5% for π, K and P

•**PID at hight p_T:**

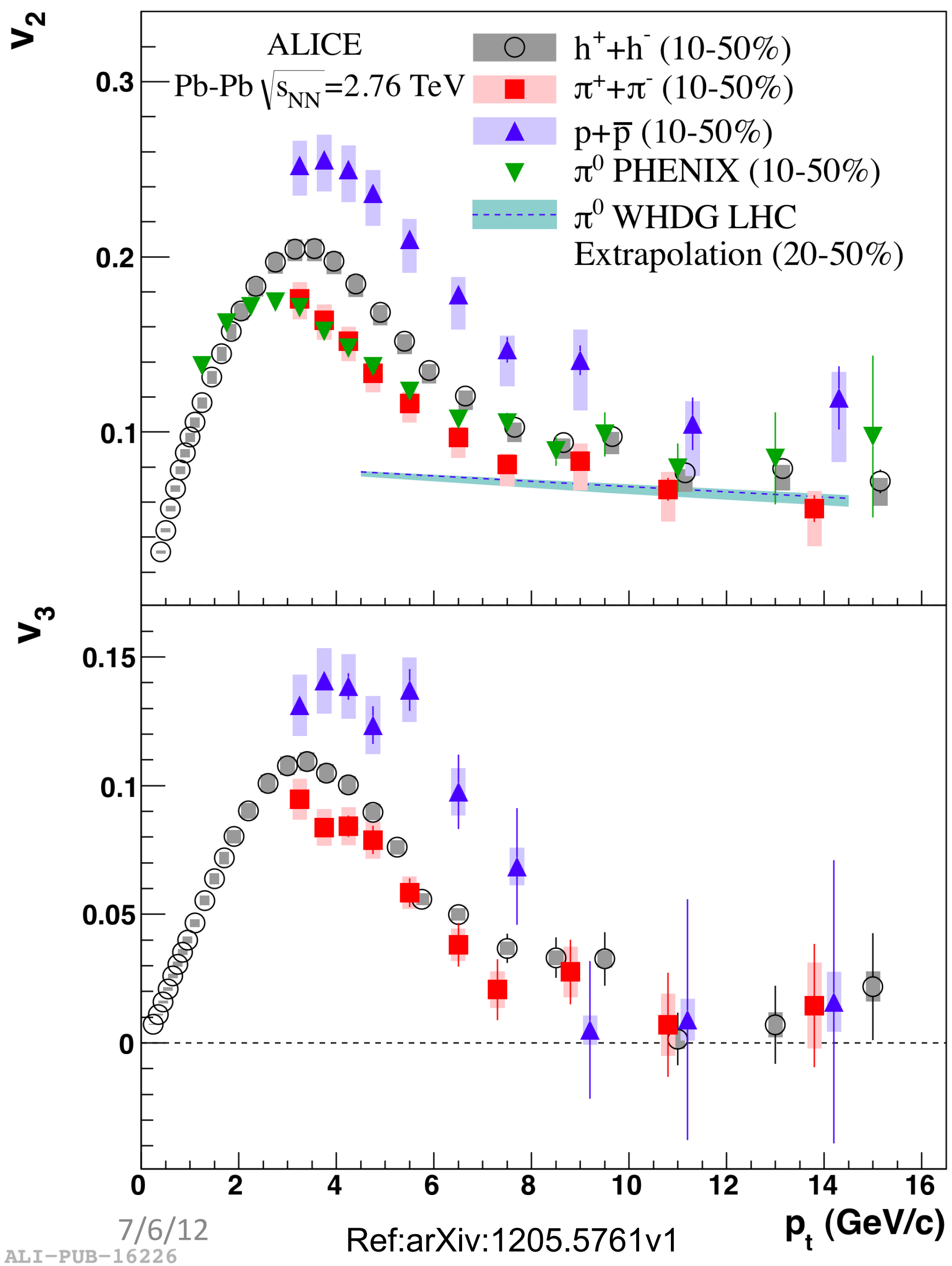
•PID based on the ionization energy loss in the TPC: Δ_π=dE/dx-$\langle$dE/dx$\rangle_\pi$

•Select ranges where the contamination is small:

-Pions: contamination <1%

-Protons: contamination <15%

Proton and pion v_2 at High P_T



Ref:arXiv:1205.5761v1

- (Anti-)Proton v_2 and v_3 higher than that of pion out to at least p_T=8GeV/c
- Charged pion v_2 reproduced by WHDG π^0 predictions for p_T>7GeV/c
- Charged pion v_2 consistent with PHENIX π^0 v_2 (PRL 105, 142301 (2010))

Summary

ALICE has measured charged particle flow up to 20GeV/c

- v_2 and v_3 are finite positive and approximately constant for p_T>8GeV/c
- v_4 for p_T>8GeV/c is consistent with zero within the large uncertainties
- v_2 , v_3, v_4 behave as expected from fluctuations in the initial geometry, which provides new strong experimental constraints on η/s (at low p_T) and initial conditions

ALICE has measured identified particle flow up to p_T=16GeV/c

- (Anti-)proton v_2 and v_3 higher than that of the pion at least out p_T=8GeV/c