Event shape engineering with ALICE

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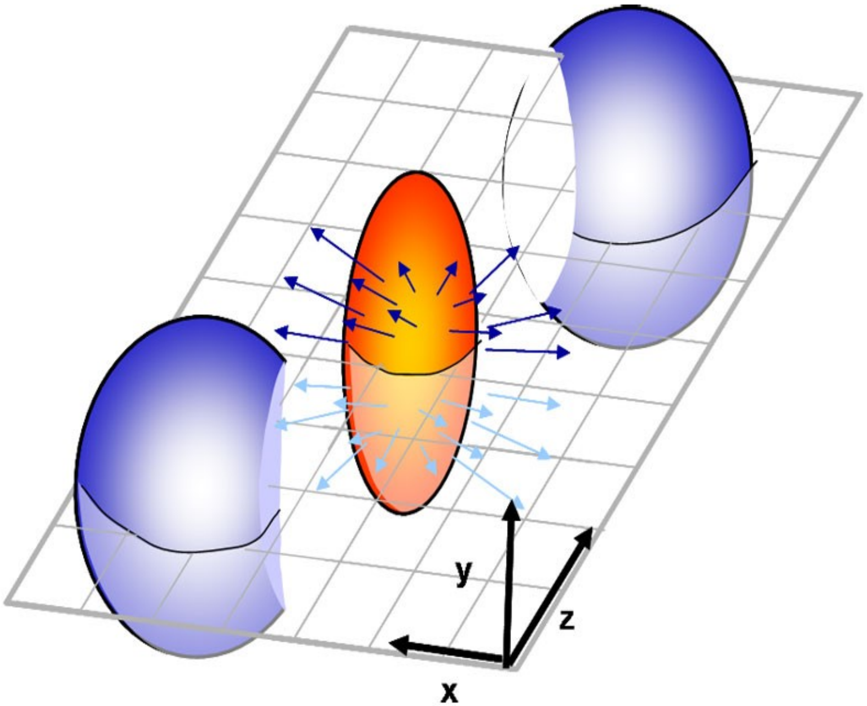
for the ALICE Collaboration

- Anisotropic flow
- The ALICE experiment
- Event shape selection
  - Unidentified charged particle v_2
  - Identified particle v_2
- Summary

Anisotropic flow



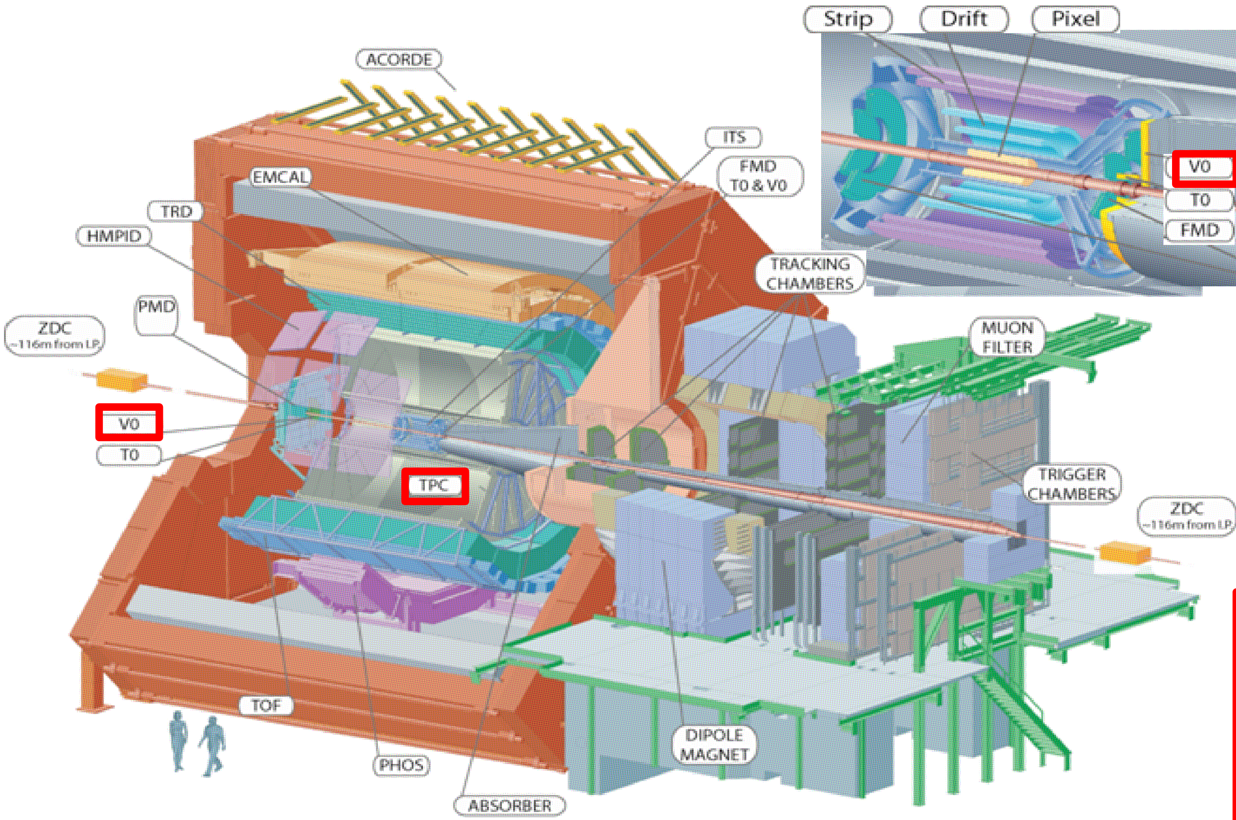
- Particle azimuthal distribution measured with respect to the symmetry planes is not isotropic

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

$$v_n=\langle\cos\left(n\left(\phi_i-\Psi_n\right)\right)\rangle$$

- Ψ_n – n-th harmonic symmetry plane
- v_n quantify the event anisotropy
  - v_2 elliptic flow
- Issues:
  - Non-flow
  - Flow fluctuations

A Large Ion Collider Experiment



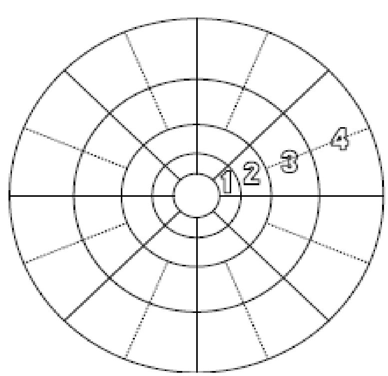
Time Projection Chamber (TPC): tracking and particle identification

Two scintillators arrays (VZERO): trigger, determination of centrality and symmetry planes

- Segmented into 32 individual counters each arranged in four rings and eight sectors of 45°

Pseudo-rapidity ranges:

- TPC: $|\eta|<0.8$
- VZERO-A: $2.8<\eta<5.1$
- VZERO-C: $-3.7<\eta<-1.7$

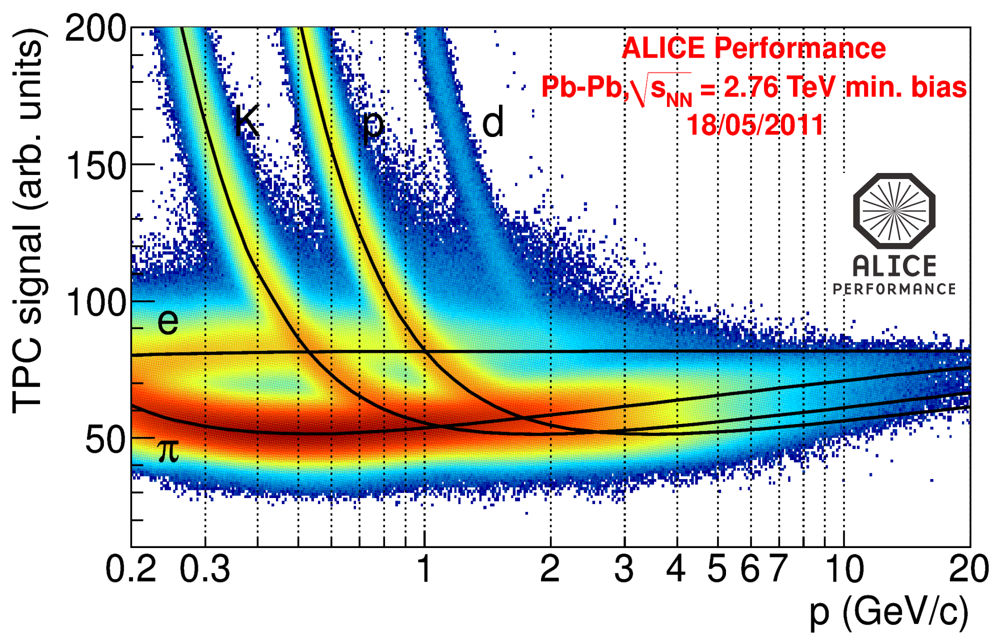


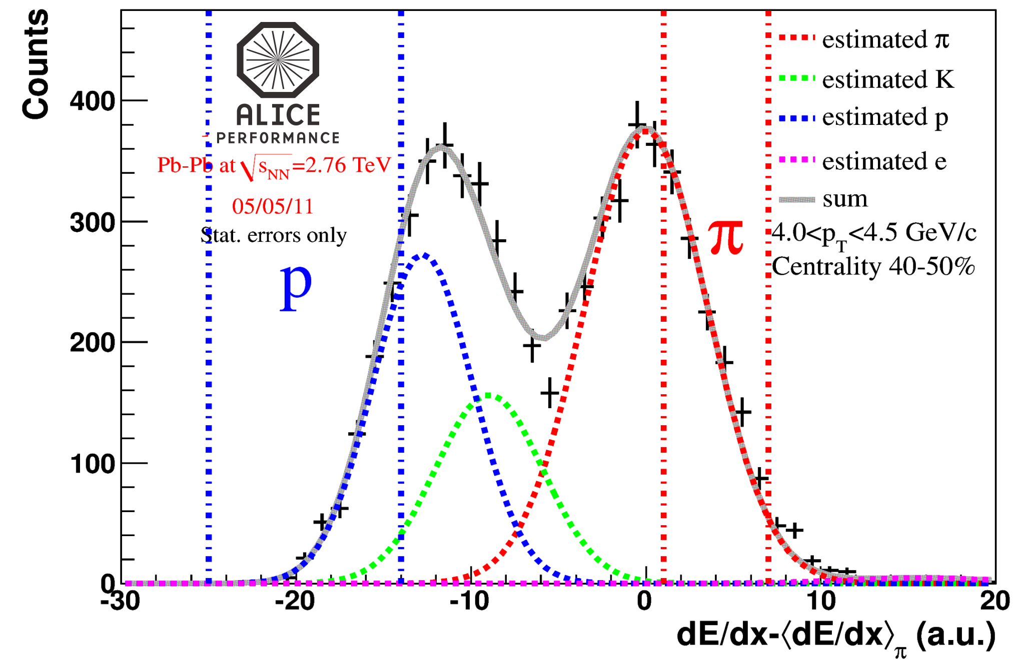
VZERO-A / VZERO-C

~12M minimum-bias Pb-Pb events at $\sqrt{s_{NN}} = 2.76$ TeV (2010 run) used in this analysis

- TPC tracks ($0.2<p_T<20$ GeV/c)

Particle identification (PID)

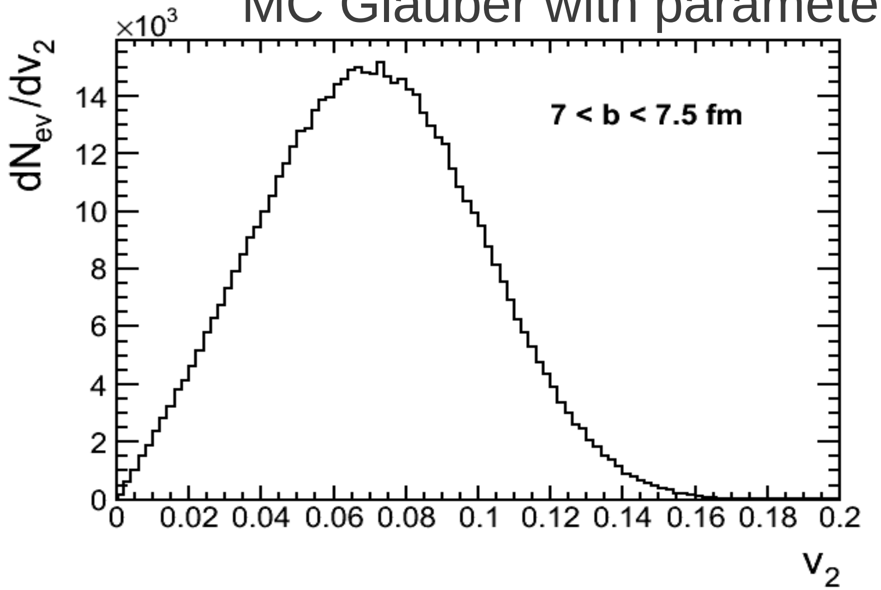


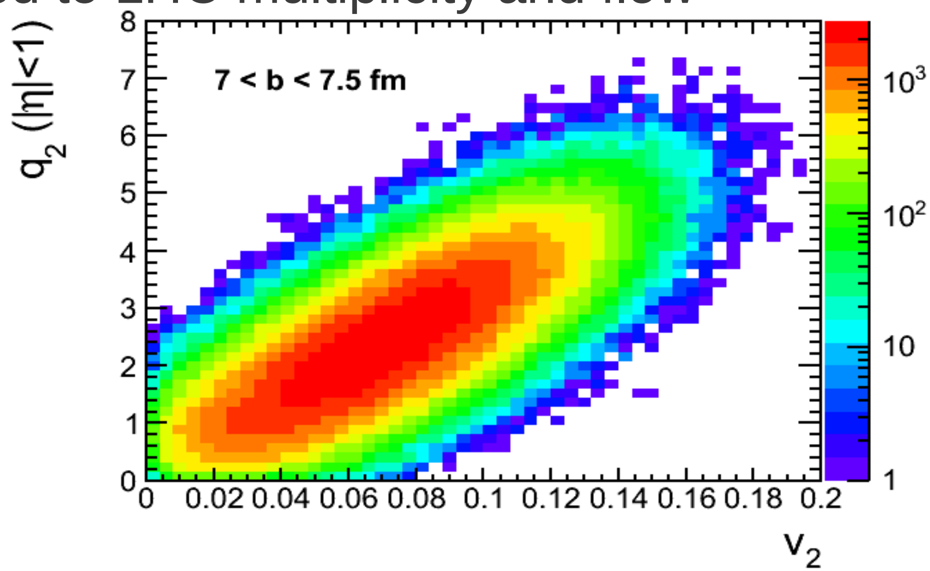


- PID based on the ionization energy loss in the TPC
  - Calculate $\Delta_\pi = dE/dx - \langle dE/dx \rangle_\pi$
- Select ranges where the contamination is small:
  - Pions: contamination < 1 %
  - Protons: contamination < 15 %

Event shape selection: Idea

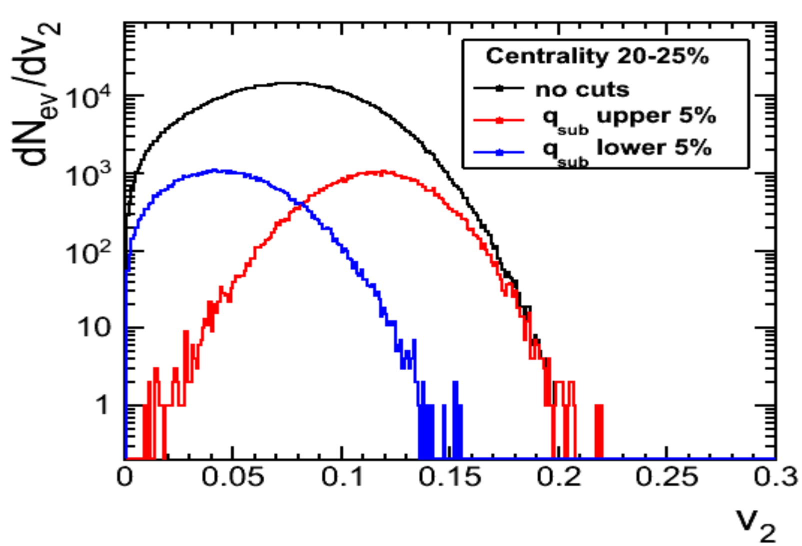
MC Glauber with parameters tuned to LHC multiplicity and flow





For fixed centrality, flow fluctuates. Can we select events with given flow value?

Yes, based on the length of flow vector



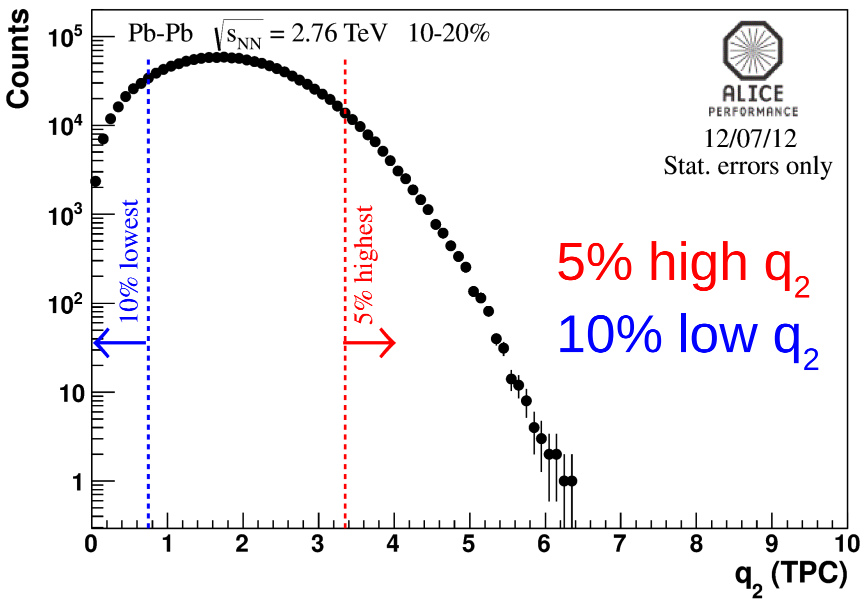
Flow vector → q-distributions

$$Q_{n,x} = \sum_i \cos(n\phi_i) \qquad Q_{n,y} = \sum_i \sin(n\phi_i) \longrightarrow Q_n = \{Q_{n,x}, iQ_{n,y}\} \qquad q_n = |Q_n|/\sqrt{M}$$

Cutting on q_2 in one pseudo-rapidity window and measure v_2 in another window:

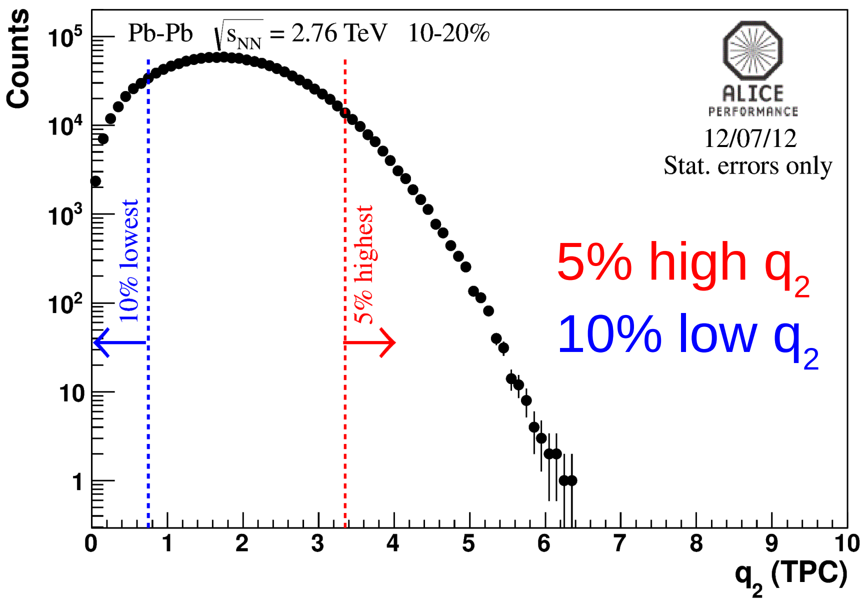
- Width of v_2 distribution for shape engineered (SE) events smaller than unbiased results
- Variation of v_2 up to factor of 2-3

Event shape selection: Implementation

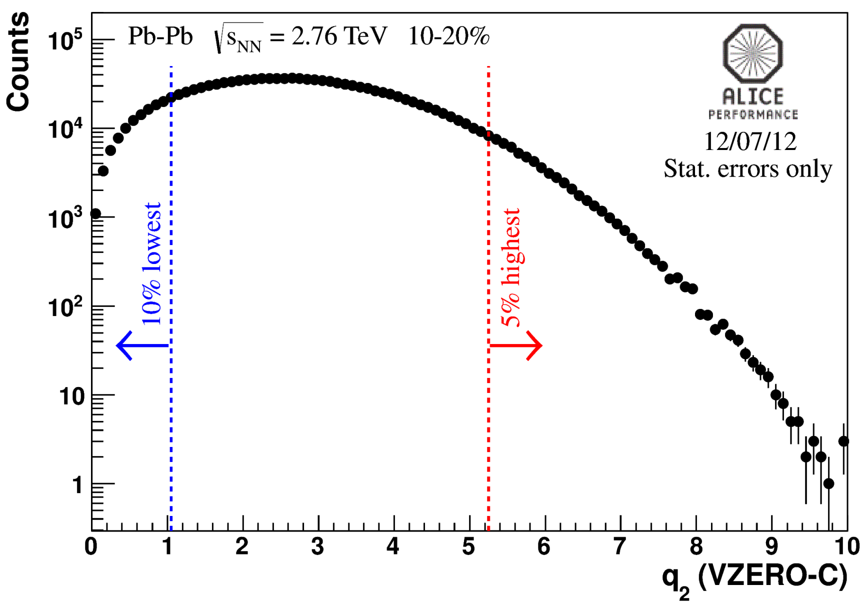


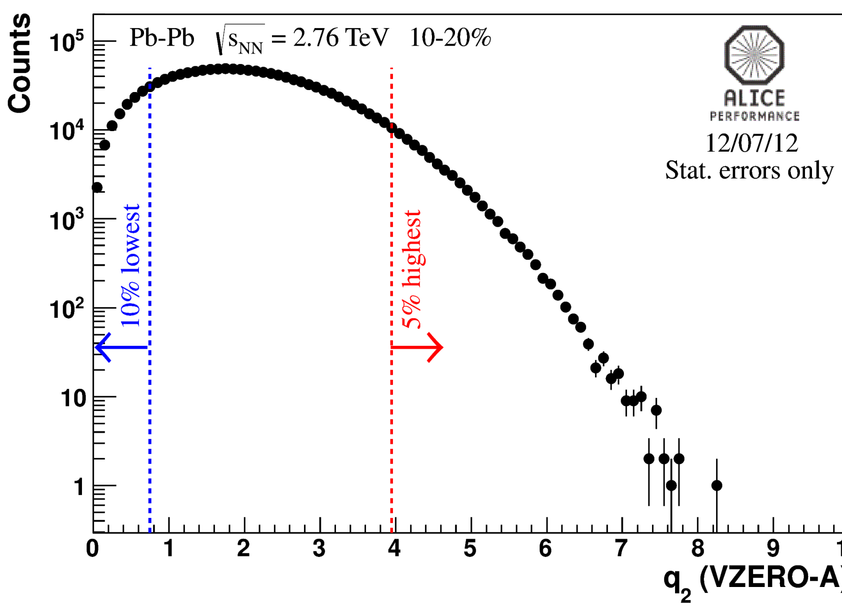
- Tools:
  - Cut on q_2 from one η window of the TPC (-0.8<η<0 or 0<η<0.8) and measure v_2 in the second window

Event shape selection: Implementation



- Tools:
  - Cut on q_2 from one η window of the TPC (-0.8<η<0 or 0<η<0.8) and measure v_2 in the second window
  - Cut on q_2 from VZERO-C (-3.7<η<-1.7) and measure v_2 in TPC (-0.8<η<0.8)
  - Cut on q_2 from VZERO-A (2.8<η<5.1) and measure v_2 in TPC (-0.8<η<0.8)
- Systematics:
  - Different η gaps → different non-flow contributions
  - Different detector coverages → different flow and multiplicities → different method sensitivity



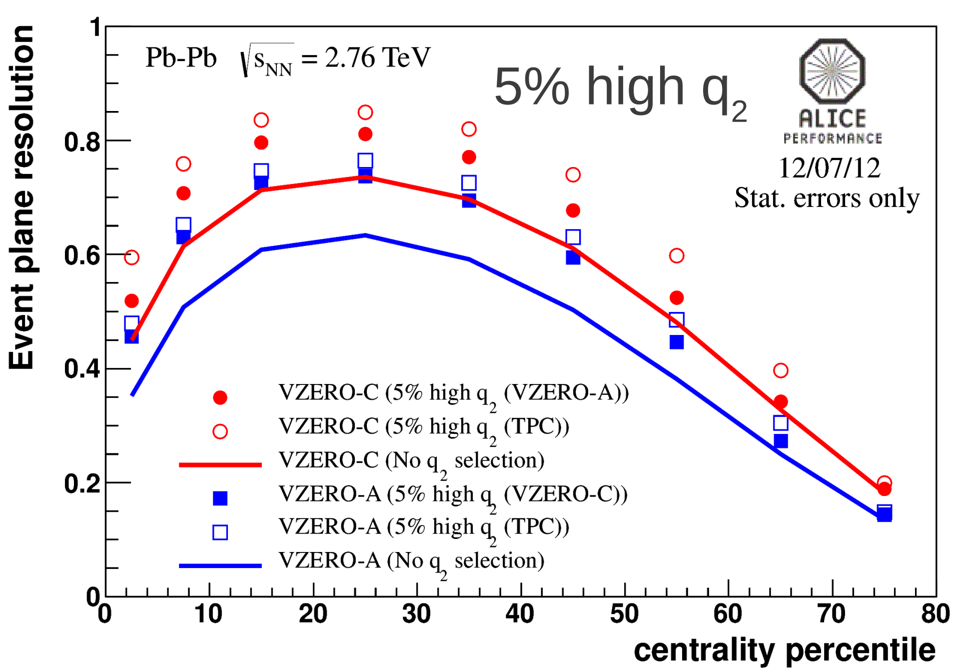


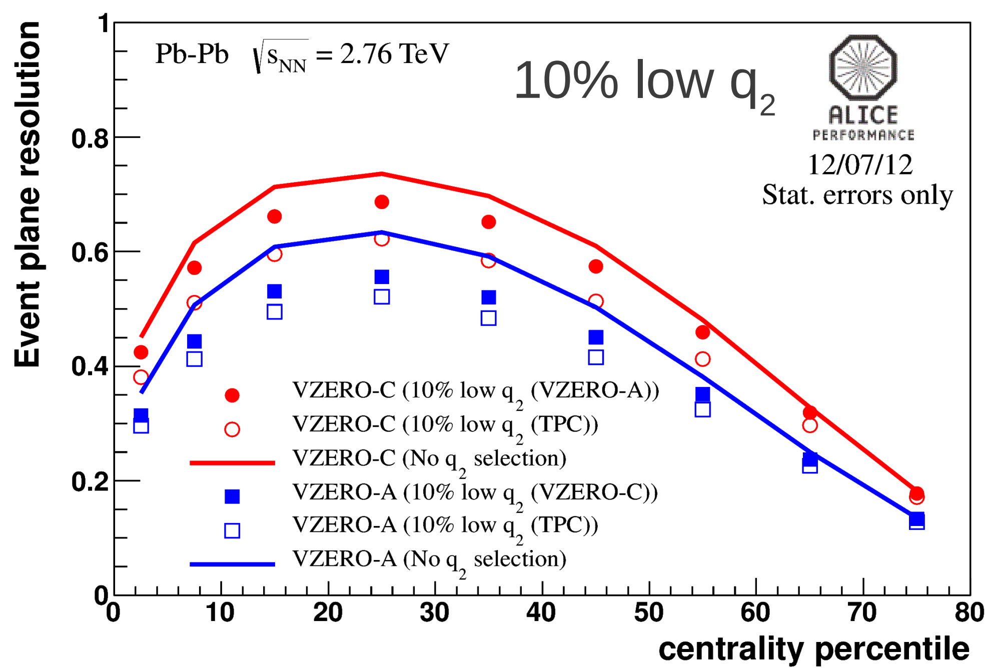
Event plane (EP) method

- Calculate the flow vectors: $Q_{n,x}=\sum_i w_i \cos(n\phi_i)$ $\quad Q_{n,y}=\sum_i w_i \sin(n\phi_i)$
- Determine the event plane angle: $\psi_n=\mathrm{atan2}(Q_{n,y},Q_{n,x})/n$
- The flow coefficients are given by: $v_n=\langle\cos(n(\phi_i-\psi_n))\rangle/R_n$

  R_n is the event plane resolution: $R_n=\langle\cos(n(\psi_n-\Psi_n))\rangle$

- Resolution: assuming $X_{VZERO\text{-}A(C)}/X_{TPC}$ and $X_{VZERO\text{-}A}/X_{VZERO\text{-}C}$ in the unbiased sample to be the same as in the biased one (X=v*√M – the parameter used to determine the event plane resolution)

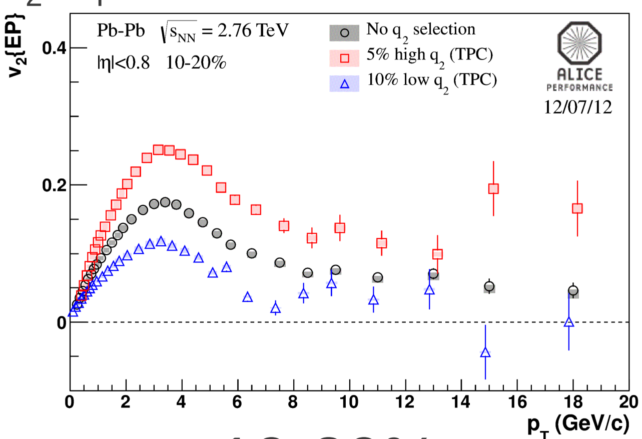




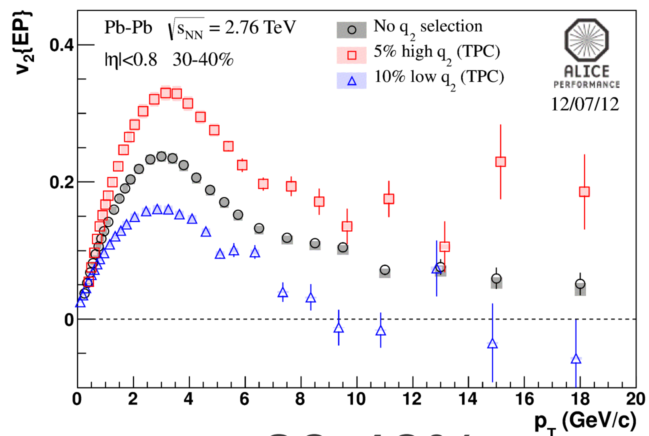
$v_2(p_T)$: SE (q_2 TPC) vs unbiased

Cutting on q_2 from half of the TPC ($-0.8<\eta<0$ or $0<\eta<0.8$) and correlate tracks from the other half ($0<\eta<0.8$ or $-0.8<\eta<0$) with EP from VZERO

$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events



10-20%



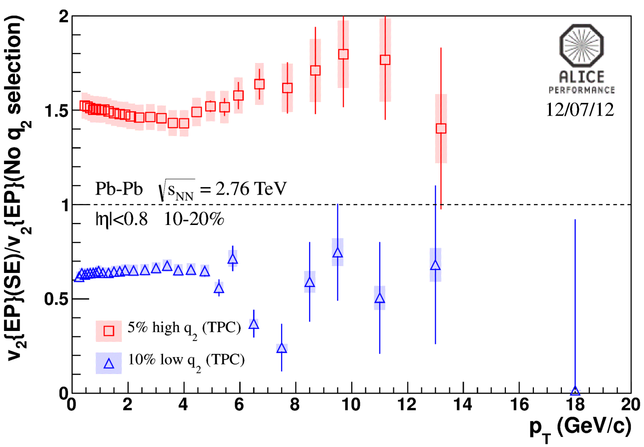
30-40%

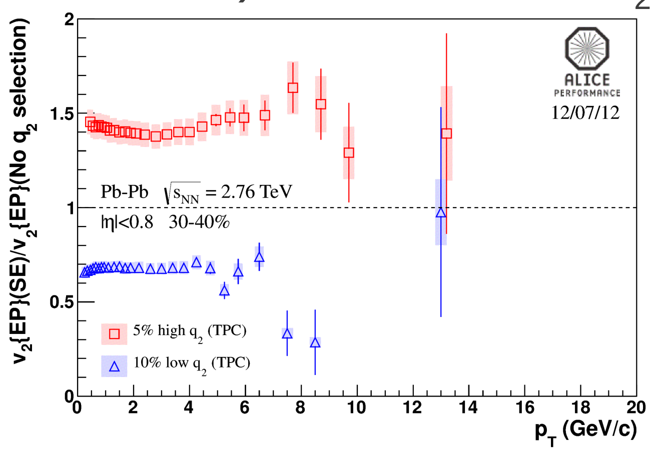
5% high q_2

10% low q_2

No q_2 selection

Ratio between SE (5% high, 10% low) and unbiased v_2





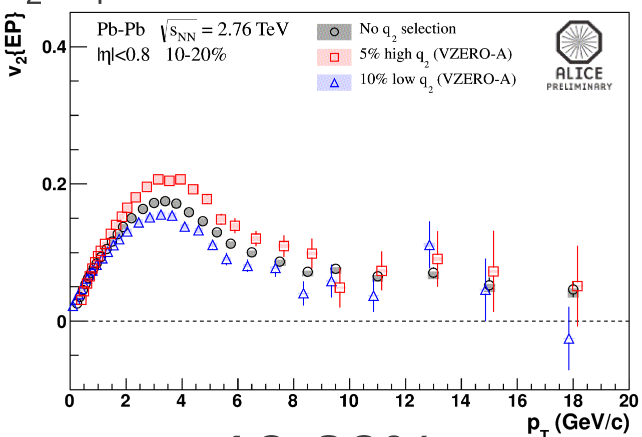
- Non flat ratios may indicate non-flow contributions

$v_2(p_T)$: SE (q_2 VZERO-A) vs unbiased

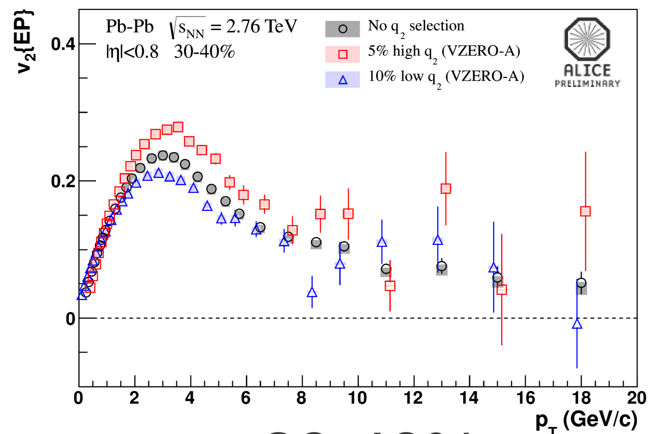
Cutting on q_2 from VZERO-A (2.8<η<5.1) and correlate tracks from TPC (-0.8<η<0.8) with EP from VZERO-C (-3.7<η<-1.7)

Cutting on q_2 from VZERO-C also investigated (see backup)

$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events



10-20%



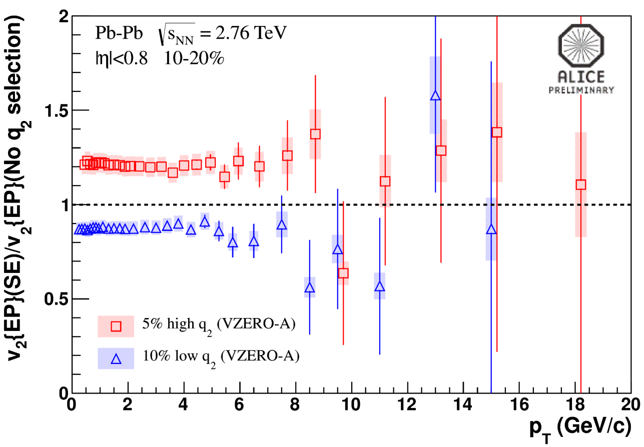
30-40%

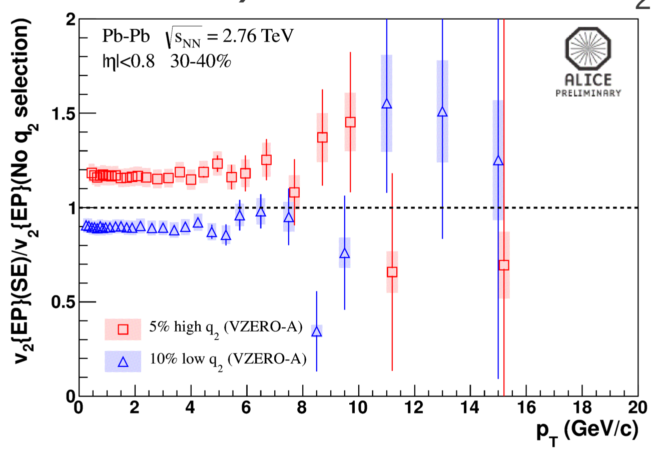
5% high q_2

10% low q_2

No q_2 selection

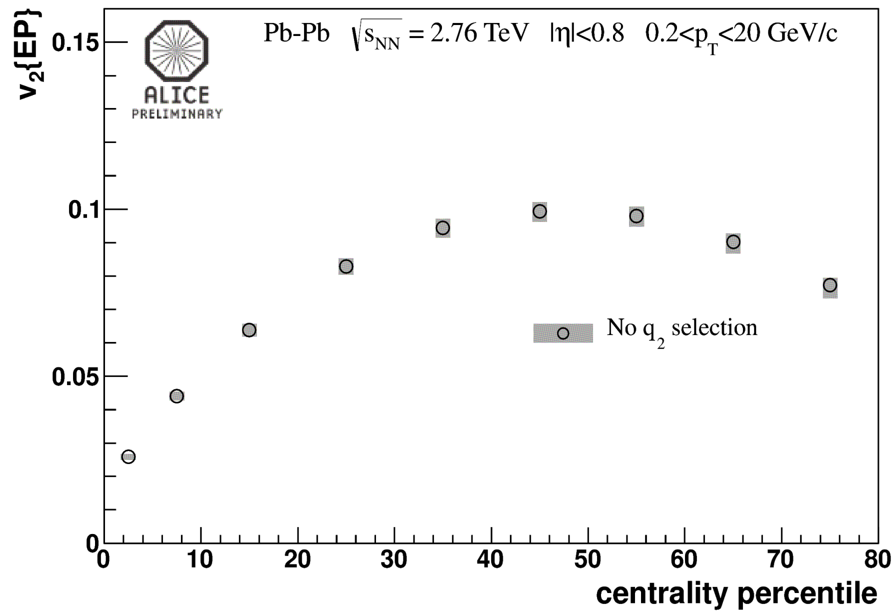
Ratio between SE (5% high, 10% low) and unbiased v_2

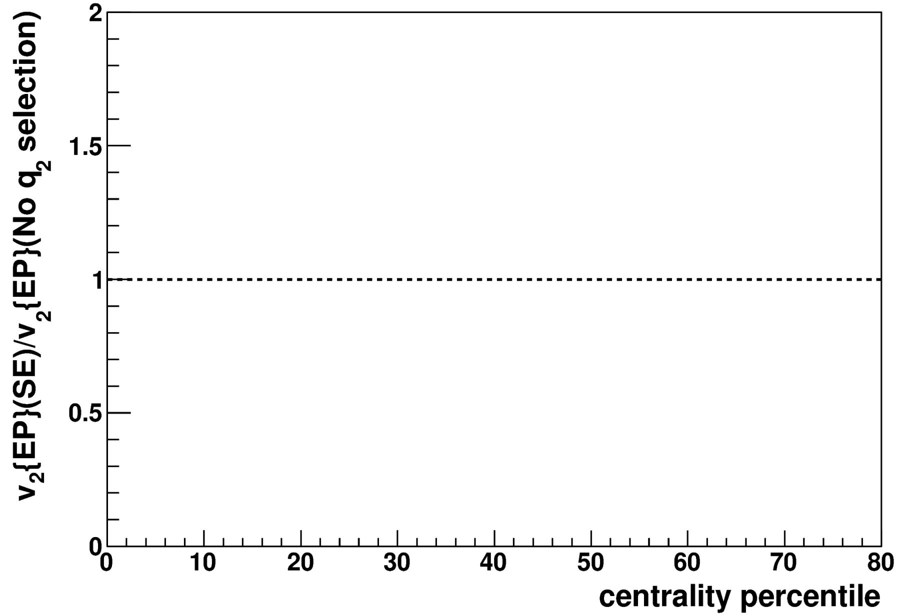


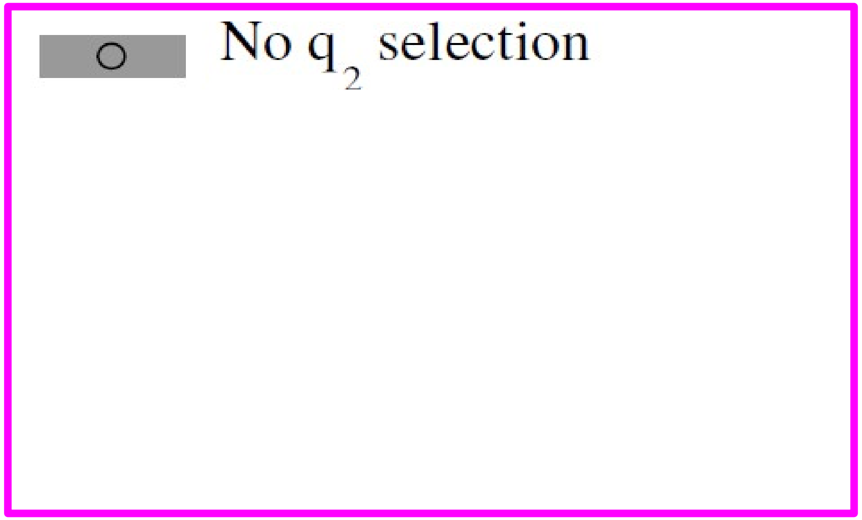


- Non-flow contributions significantly reduced using η gap
- Smaller ratios due to smaller flow and multiplicity → method sensitivity to the event shape
- v_2 ~ shape (ratio almost constant) at least up to p_T=6 GeV/c
- Effect of event shape fluctuations becomes small for p_T>6 GeV/c

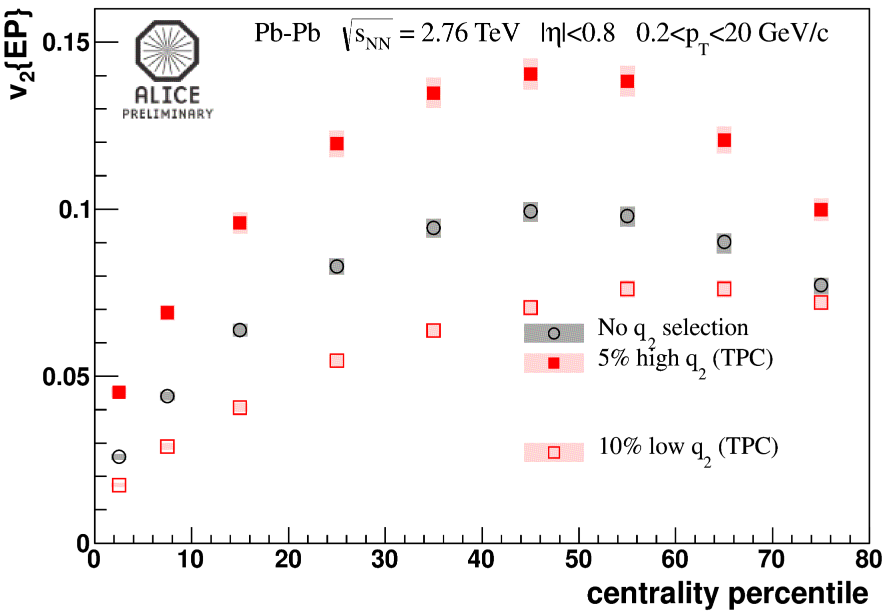
Integrated v_2: SE vs unbiased

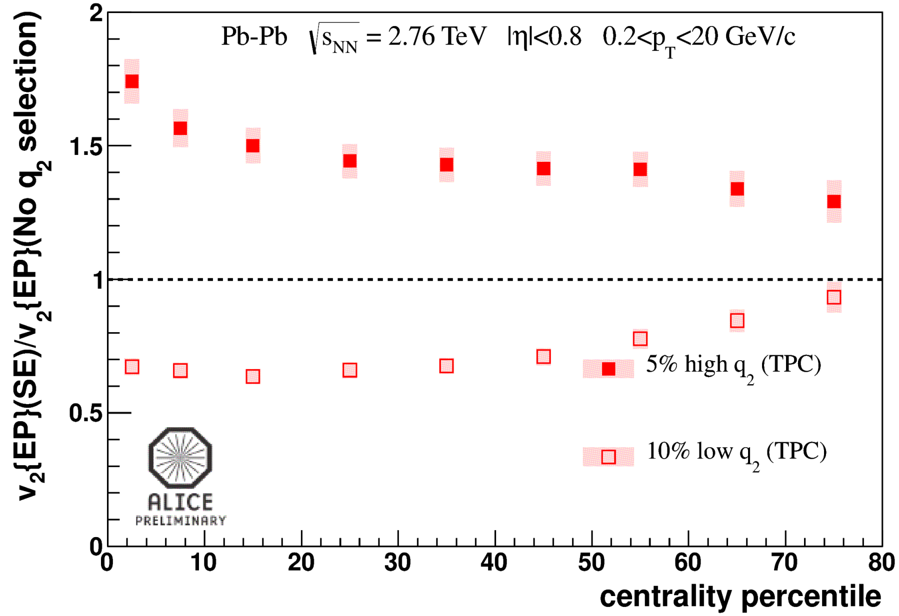


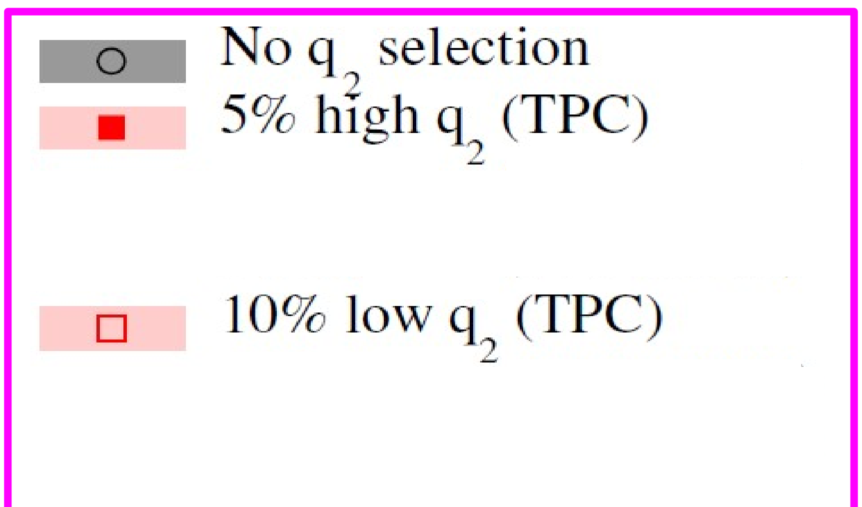




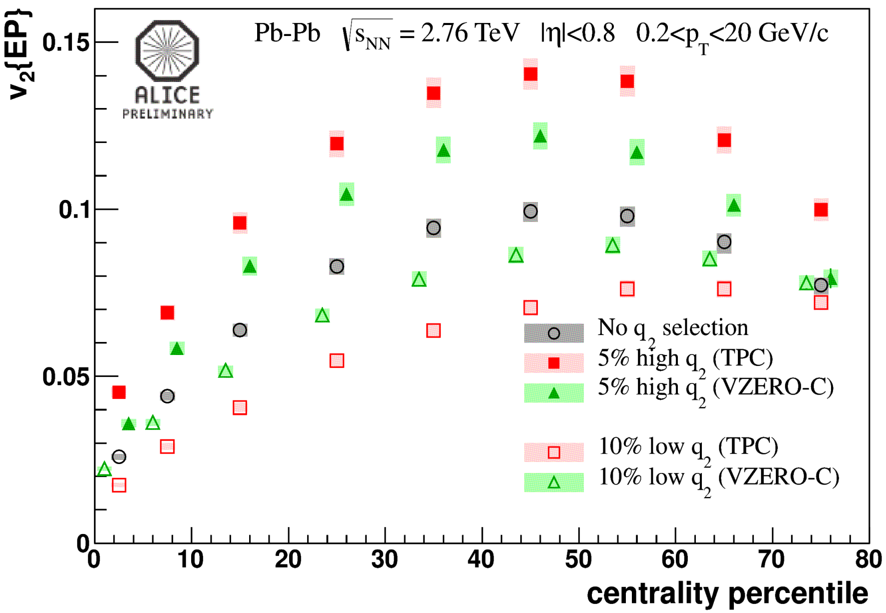
Integrated v_2: SE vs unbiased

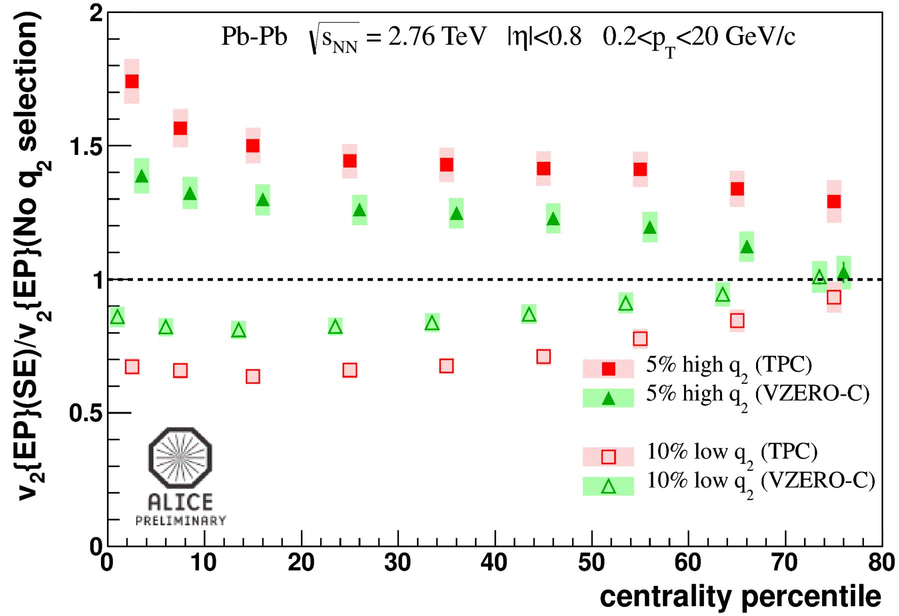


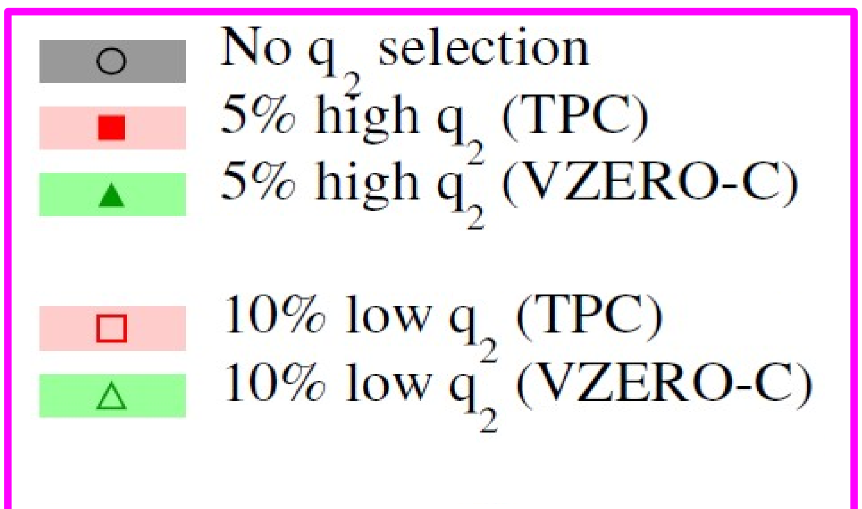




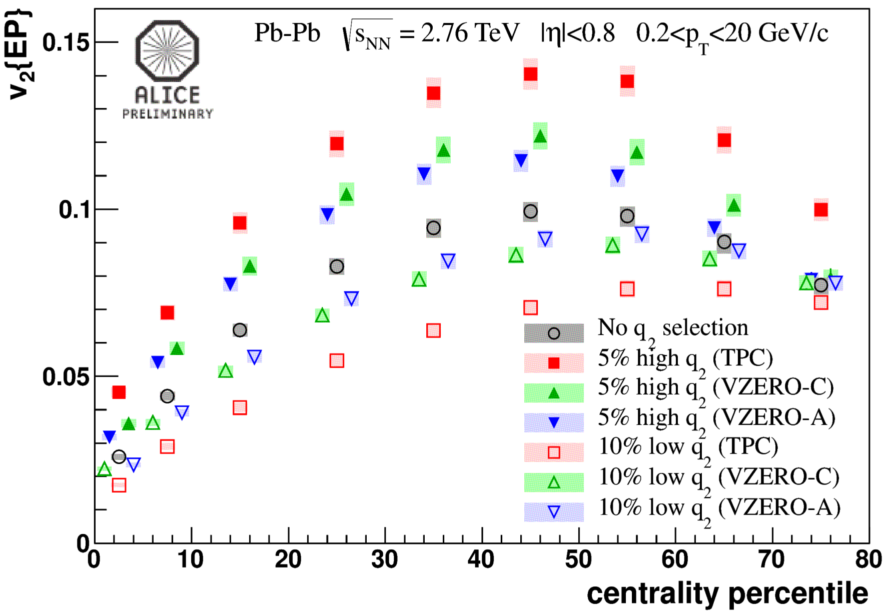
Integrated v_2: SE vs unbiased

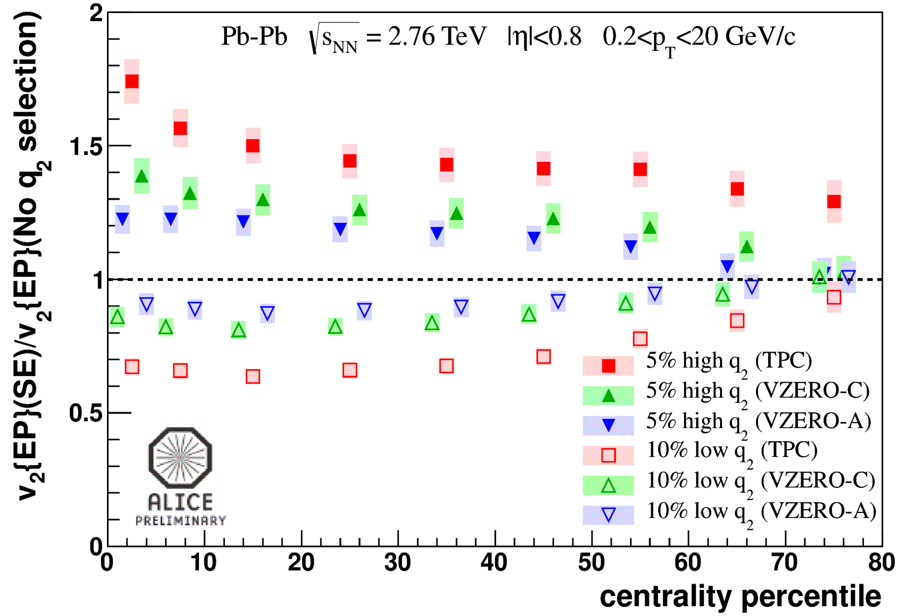


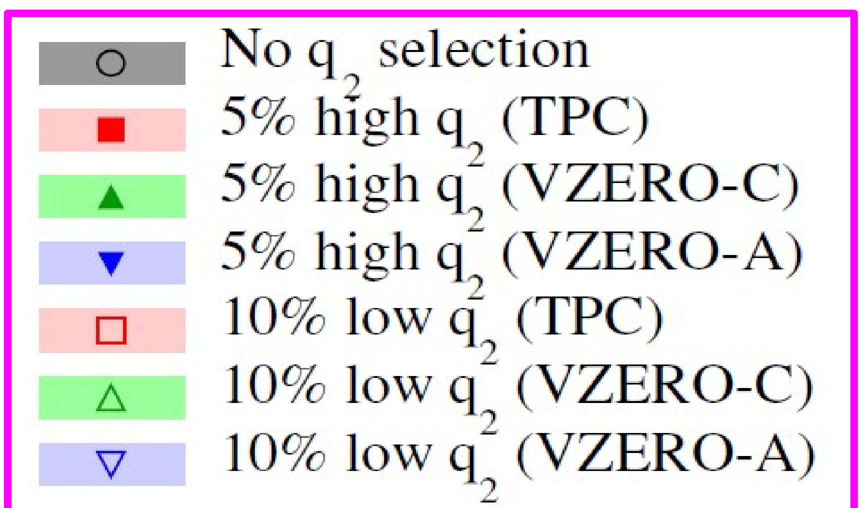




Integrated v_2: SE vs unbiased





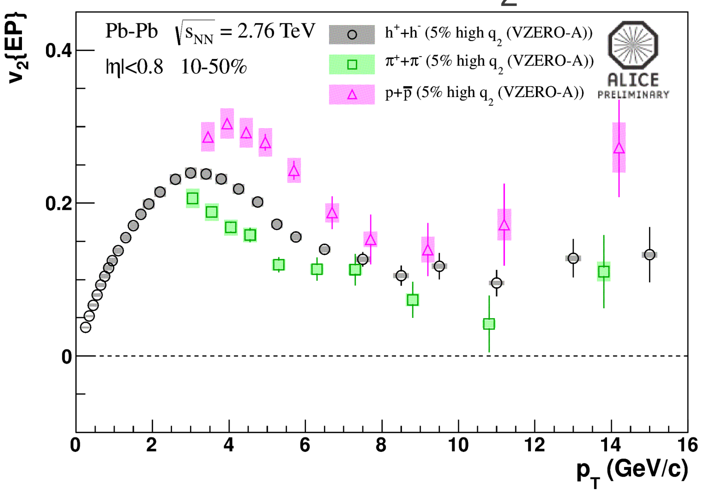


- Method gives consistent results in the case of q_2 VZERO-A and VZERO-C
  - Non-flow contributions present in the case of q_2 TPC
- Method sensitivity to the event shape deteriorates for peripheral collisions

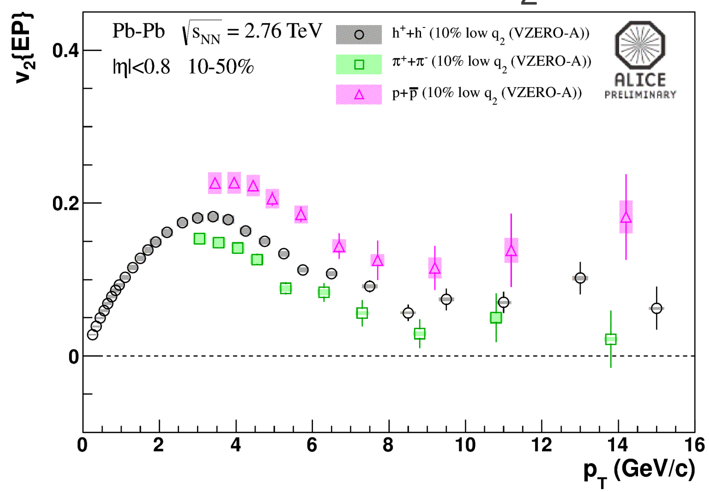
PID $v_2(p_T)$: SE (q_2 VZERO-A) vs unbiased

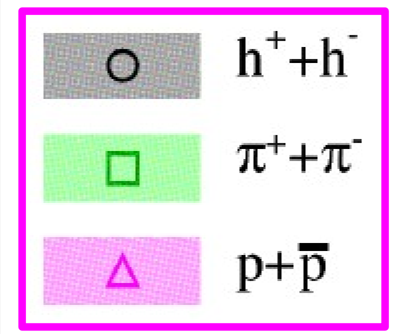
Cutting on q_2 from VZERO-A ($2.8<\eta<5.1$) and correlate tracks from TPC ($-0.8<\eta<0.8$) with EP from VZERO-C ($-3.7<\eta<-1.7$)

5% high q_2

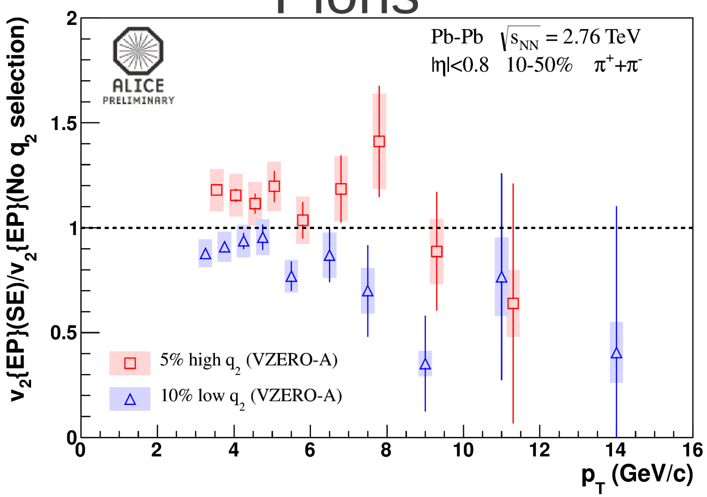


10% low q_2

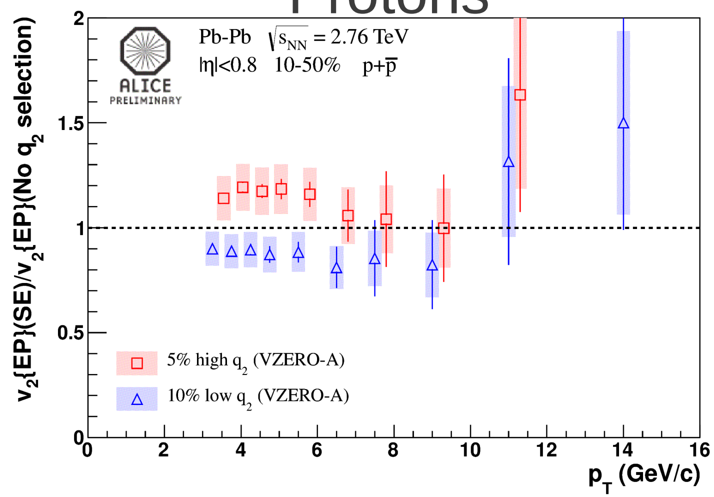




Pions



Protons



Summary

- Using q-distributions allows to select events with larger or smaller elliptic flow than the average
  - Effect of shape fluctuations extends at least up to p_T=6 GeV/c
- Method is sensitive to the pseudo-rapidity range used to determine the flow vector due to different multiplicities and flow
- Non-flow contributions are significant when no/small η gap is employed between the region used to determine the flow vector and the one in which the elliptic flow is measured

New, promising tool

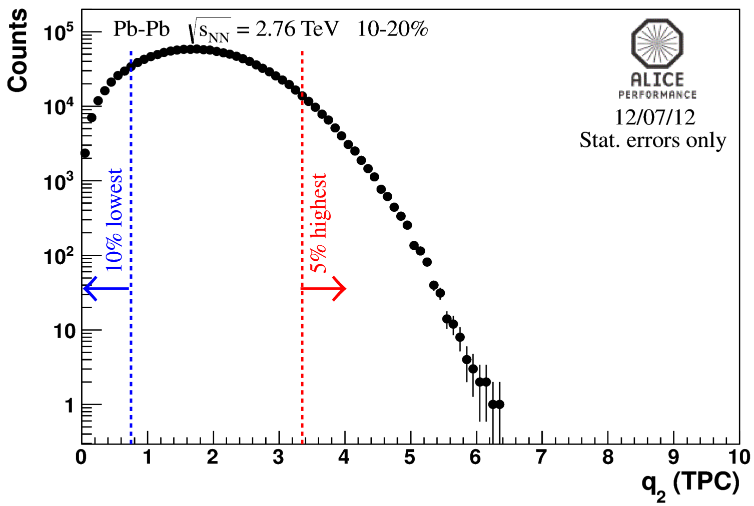
Plenty of reasons to use event shape selection:

- Anisotropic flow – shape evolution
- Identified particle flow – mass splitting
- Highly anisotropic events with large particle density – compare to hydrodynamic calculations
- Inclusive spectra and particle ratios – dependence on event shape
  - See talk by L. Milano, 5A, 14:00
- Two-particle correlations – check the presence of the away-side double bump in “no-triangularity” events
  - See poster 184 by A. Timmins
- Chiral magnetic effect study – background evaluation
- Evolution of eccentricities, dependence of the HBT radii on flow field
- ...

Backup

q-distributions

Select events based on the magnitude of flow vector → q-distributions (similar widths for different multiplicities)

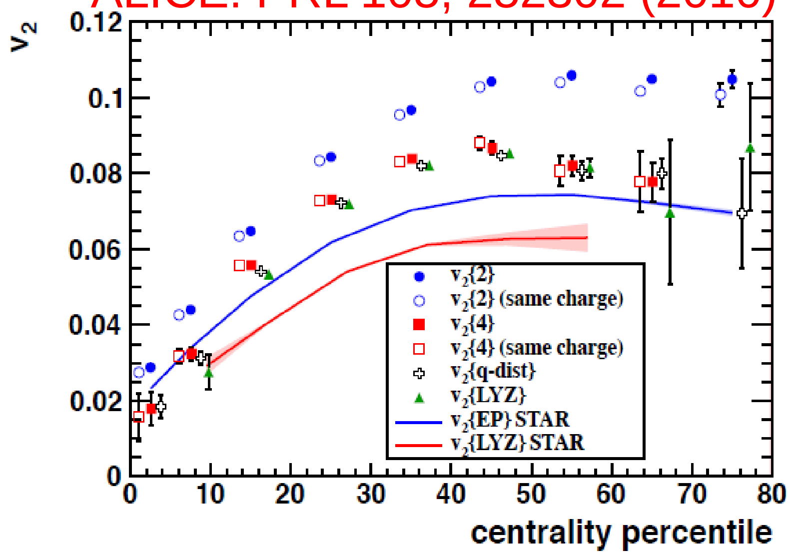


$$Q_{n,x} = \sum_i \cos(n\phi_i) \qquad Q_{n,y} = \sum_i \sin(n\phi_i) \quad \longrightarrow \quad Q_n = \{Q_{n,x}, iQ_{n,y}\} \qquad q_n = |Q_n| / \sqrt{M}$$

$$\frac{dN}{dq} \propto \frac{1}{\sigma^2 q} \exp\left(\frac{-M\bar{v}^2 + q^2}{2\sigma^2}\right) I_0\left(\frac{q\bar{v}\sqrt{M}}{\sigma}\right) \propto BG(q; \bar{v}\sqrt{M}, \sigma)$$

$$\sigma \approx [1 + M(\delta + 2\sigma_v^2)]/2 \qquad \langle q^2 \rangle = \bar{v}^2 M + 2\sigma^2$$

ALICE: PRL 105, 252302 (2010)



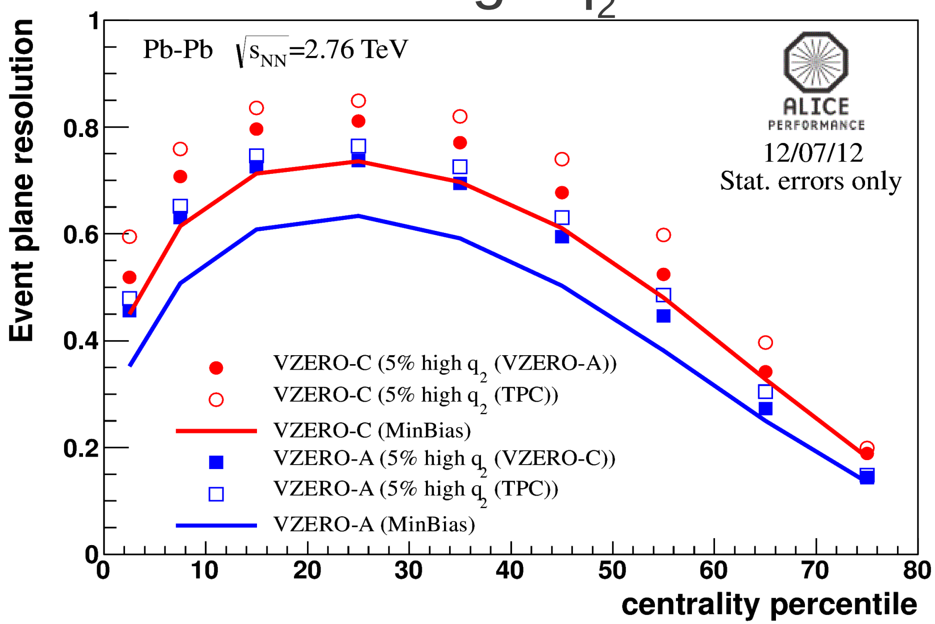
Parameters:

- M – multiplicity
- δ – non-flow
- σ_v – flow fluctuations width

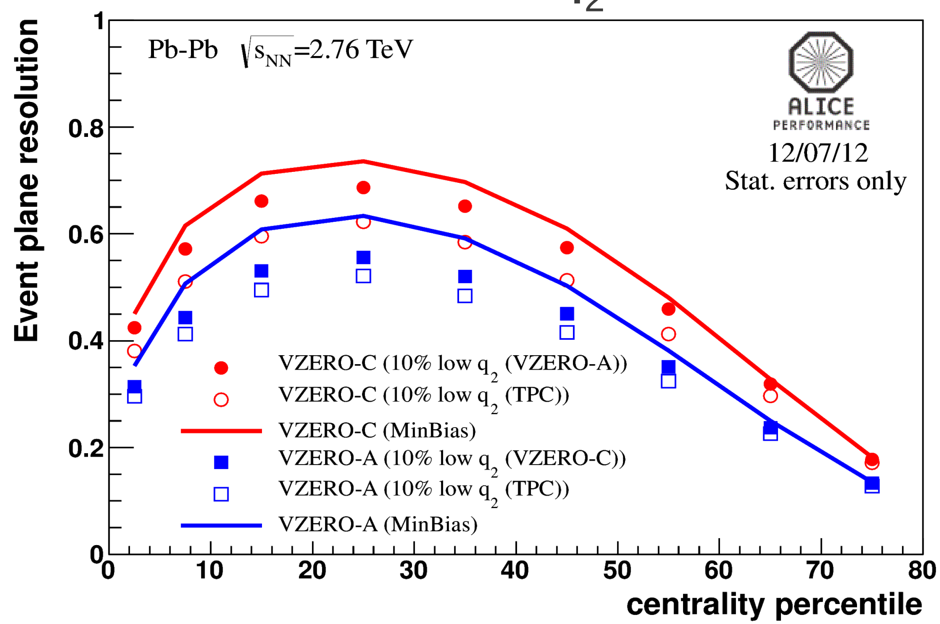
q-distributions well understood; used to extract elliptic flow

Event plane resolution

5% high q_2



10% low q_2

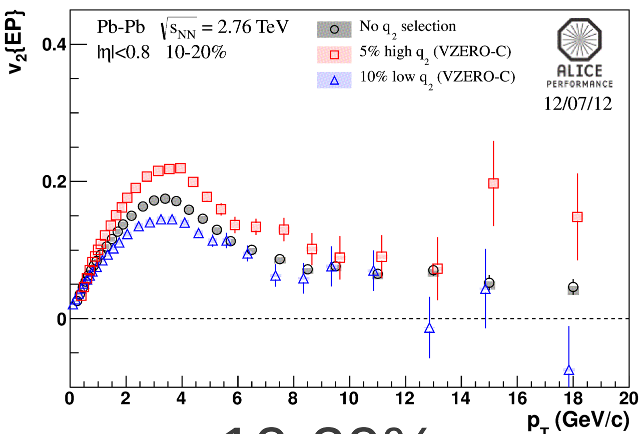


- From the unbiased sample get X_{TPC}, $X_{VZERO\text{-}C}$, $X_{VZERO\text{-}A}$ ($X=v^*\sqrt{M}$ – the parameter used to determine the event plane resolution)
- Assume $X_{VZERO\text{-}A(C)}/X_{TPC}$ and $X_{VZERO\text{-}A}/X_{VZERO\text{-}C}$ in the unbiased sample to be the same as in the biased one
- From the TPC – VZERO-A(C) and VZERO-A – VZERO-C correlation in the biased sample determine X_{biased}
- From X_{biased}, $(X_{VZERO\text{-}A(C)}/X_{TPC})_{unbiased}$, $(X_{VZERO\text{-}A}/X_{VZERO\text{-}C})_{unbiased}$ calculate resolution for VZERO-A and VZERO-C

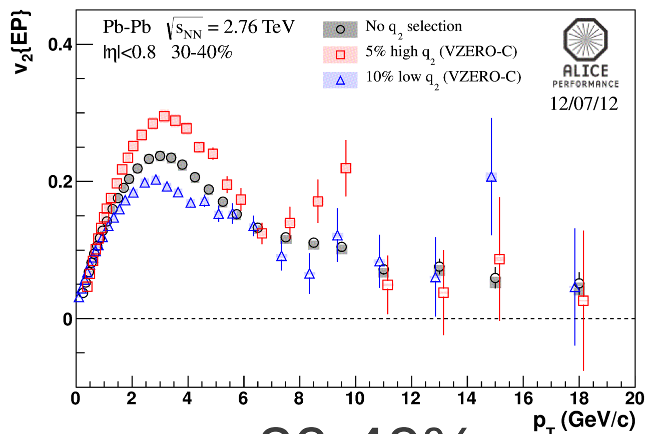
$v_2(p_T)$: SE (q_2 VZERO-C) vs unbiased

Cutting on q_2 from VZERO-C ($-3.7<\eta<-1.7$) and correlate tracks from TPC ($-0.8<\eta<0.8$) with EP from VZERO-A ($2.8<\eta<5.1$)

$v_2(p_T)$ for unbiased (black) and SE (5% high, 10% low) events



10-20%



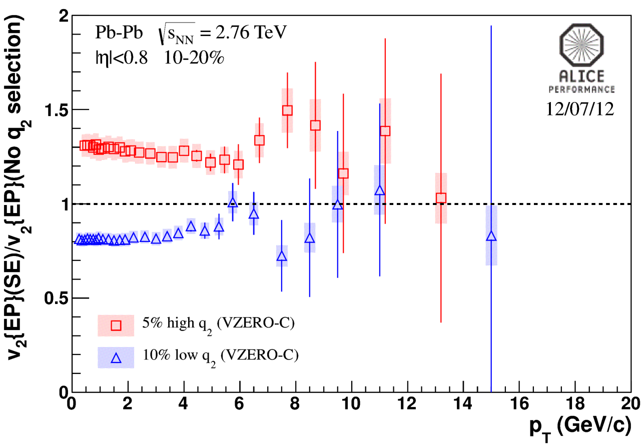
30-40%

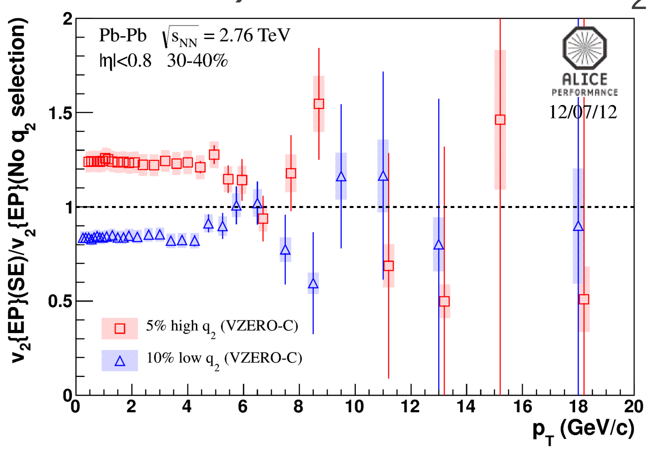
5% high q_2

10% low q_2

No q_2 selection

Ratio between SE (5% high, 10% low) and unbiased v_2

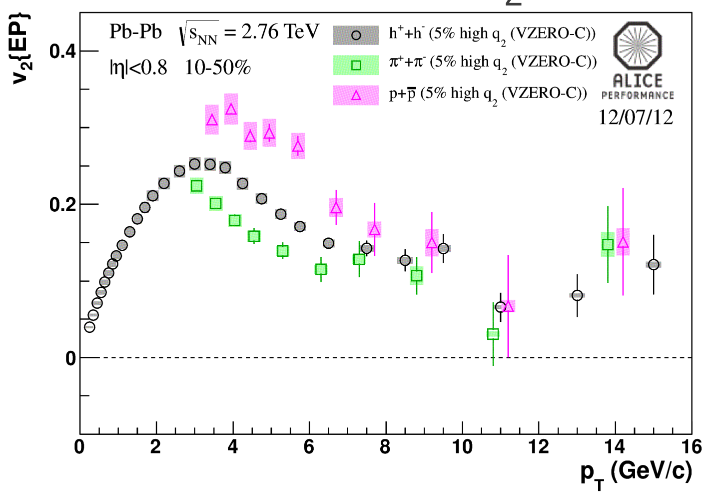




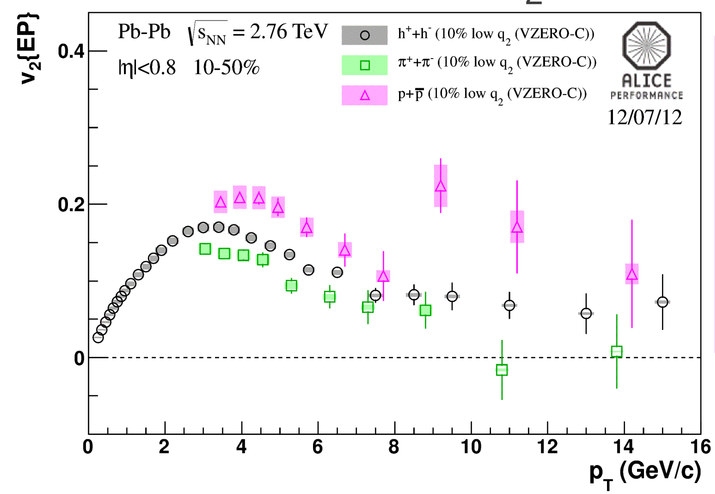
PID $v_2(p_T)$: SE (q_2 VZERO-C) vs unbiased

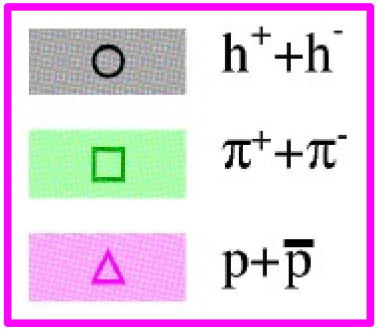
Cutting on q_2 from VZERO-C ($-3.7<\eta<-1.7$) and correlate tracks from TPC ($-0.8<\eta<0.8$) with EP from VZERO-A ($2.8<\eta<5.1$)

5% high q_2

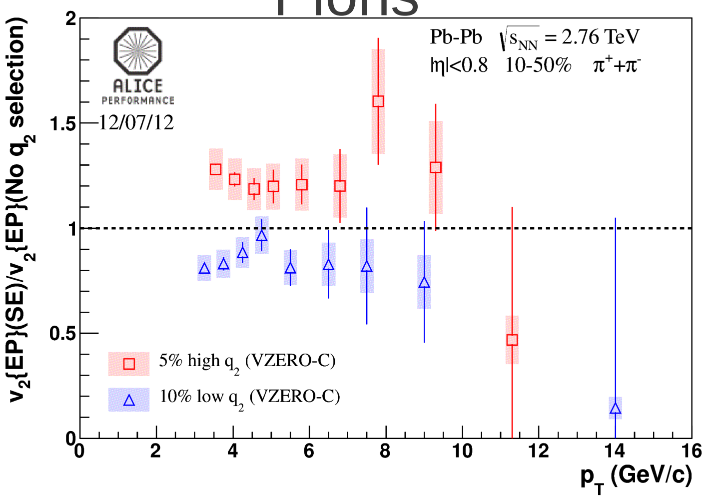


10% low q_2





Pions



Protons