Elliptic flow at high transverse momentum in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV with the ALICE experiment

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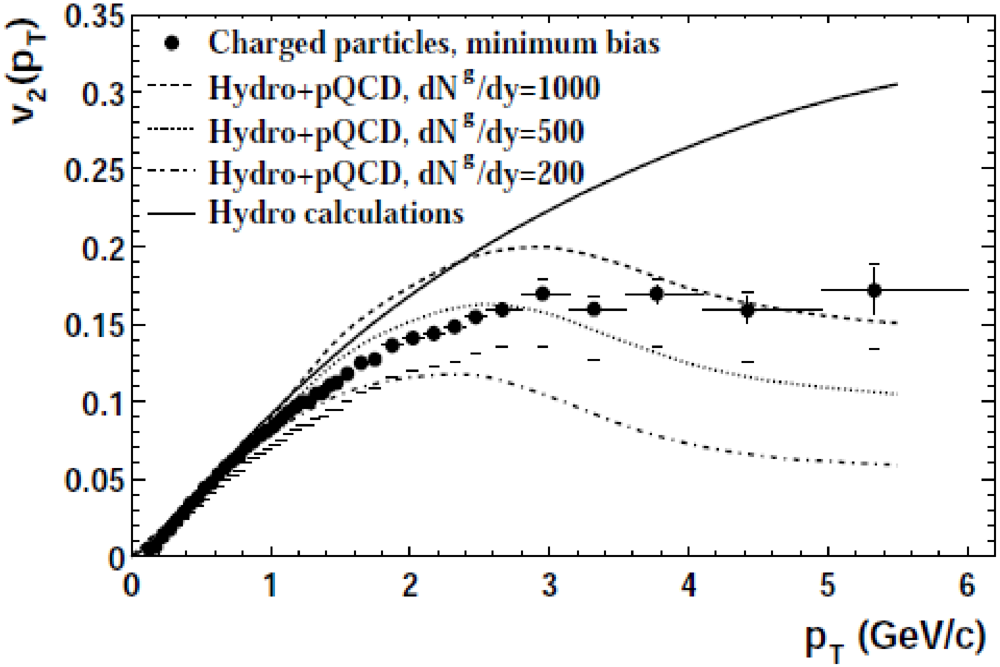
for the ALICE Collaboration

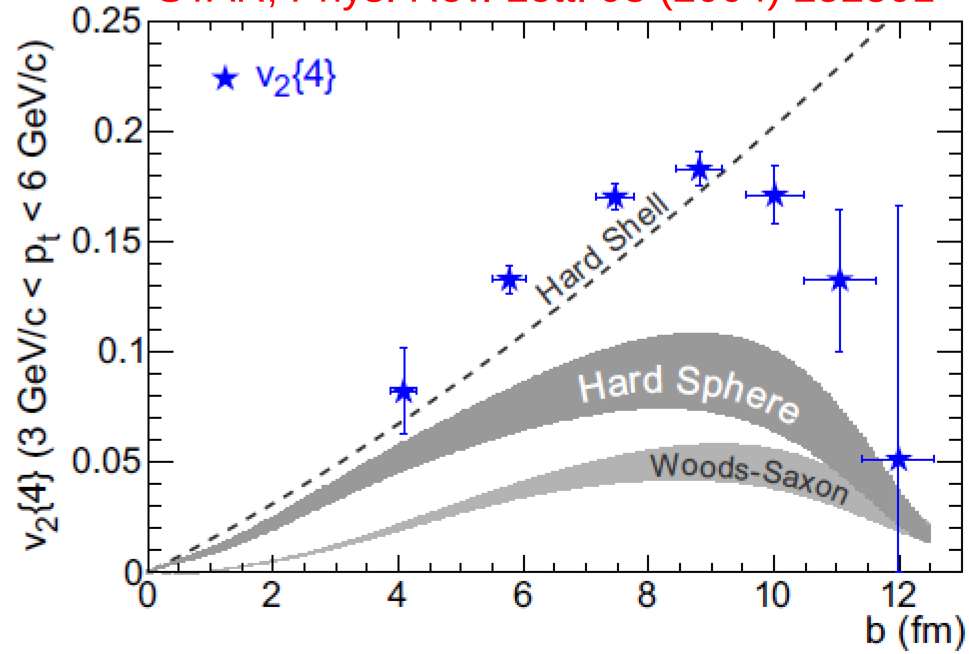
- Motivation
- Flow and non-flow
- Experimental methods
- The ALICE experiment
- Unidentified charged particle v_2 at high p_T
- PID v_2 at high p_T
- Summary

Motivation (I)

STAR, Phys. Rev. Lett. 90 (2003) 032301

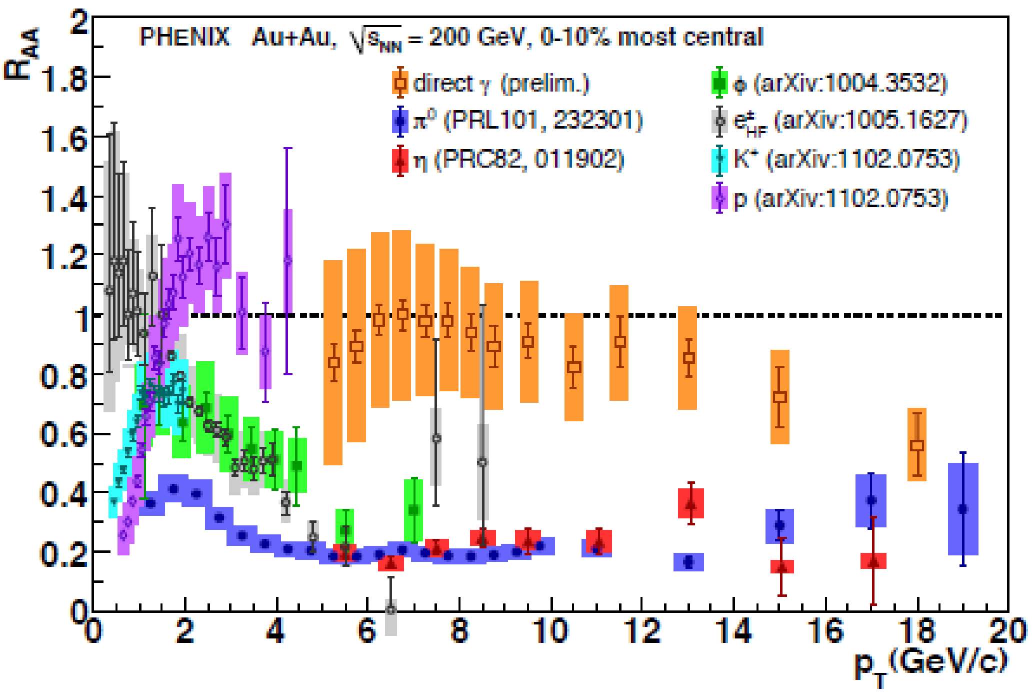


STAR, Phys. Rev. Lett. 93 (2004) 252301

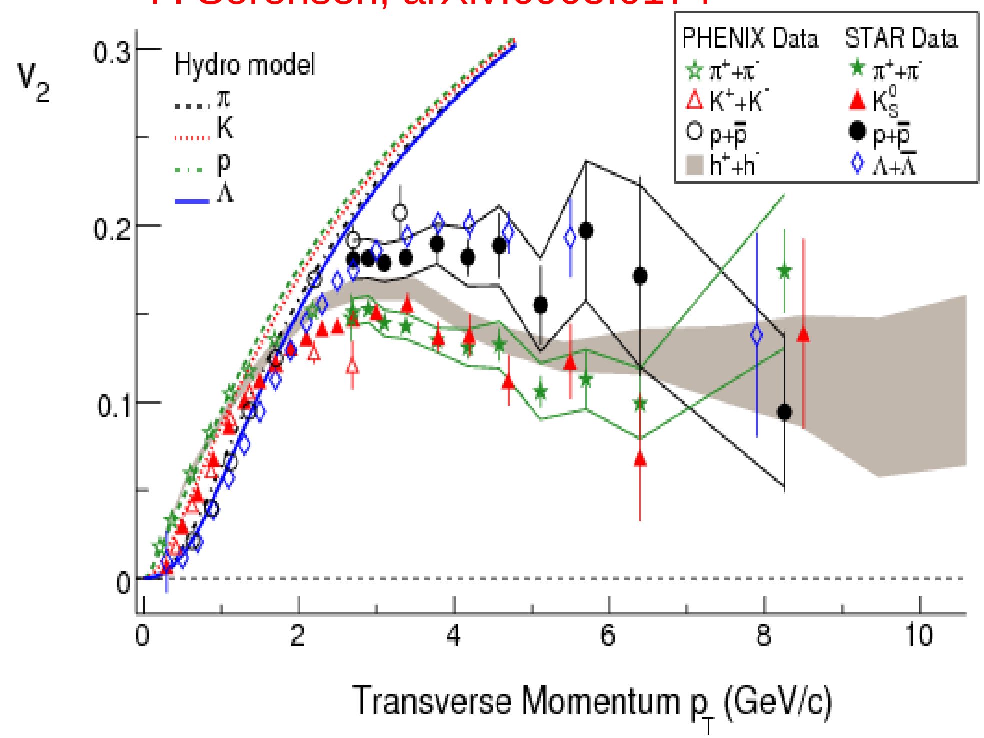


- v_2 at high p_T is sensitive to the path length dependence of jet quenching
  - Constrain the mechanism responsible for energy loss
  - Functional form of energy loss: $\Delta E = f(E; T, \alpha, L)$
    - $v_2 + R_{AA} \rightarrow R_{AA}(\varphi)$
- Coalescence ($2<p_T<6$ GeV/c) $\rightarrow$ v_2 measured above $p_T = 6$ GeV/c

Motivation (II)

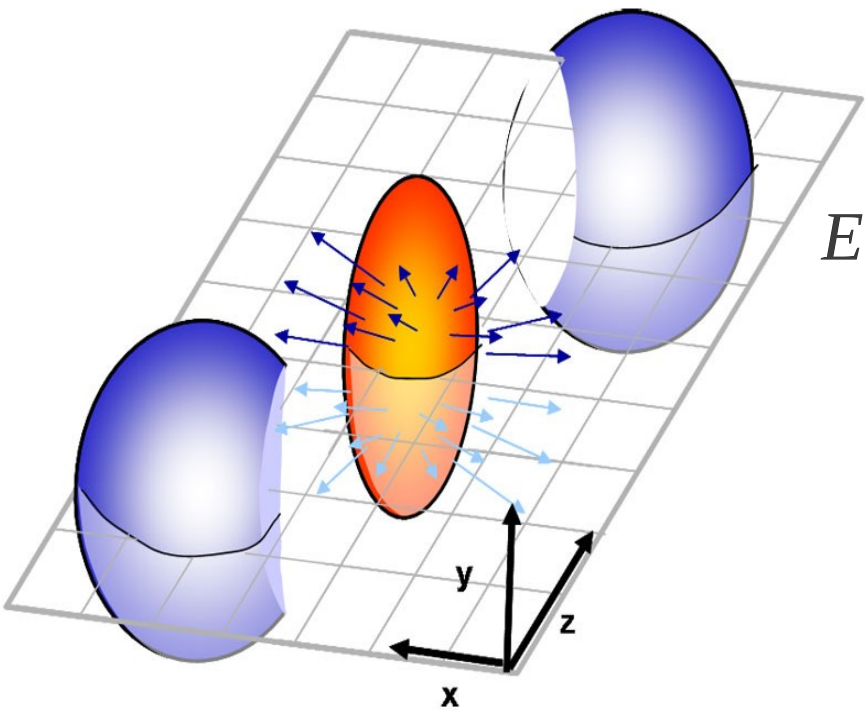


P. Sorensen, arXiv:0905.0174



- PID v_2 at high p_T determines the regime where the coalescence mechanism stops being important

Flow and non-flow



- Particle azimuthal distribution measured with respect to the reaction plane is not isotropic (S. Voloshin and Y. Zhang):

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

$$v_n=\langle\cos(n(\varphi_i-\Psi_{RP}))\rangle$$

- v_n quantify the event anisotropy
  - v_2 elliptic flow
- Ψ_{RP} can be estimated from particle azimuthal distribution

- Two problems:
  - Non-flow (other sources of azimuthal correlations) quantified by δ_n:

$$\langle\cos(n(\varphi_i-\varphi_j))\rangle=\langle v_n^2\rangle+\delta_n$$

  - Flow fluctuations:

$$\langle v_n^2\rangle=\langle v_n\rangle^2+\sigma_{vn}^2$$

Experimental methods

- Event plane (EP) method:
  - Calculate the flow vectors: $Q_{n,x} = \sum_i w_i \cos(n\varphi_i)$ $Q_{n,y} = \sum_i w_i \sin(n\varphi_i)$
  - Determine the event plane angle: $\Psi_{\mathrm{n}} = \mathrm{atan2}(\mathrm{Q}_{\mathrm{n,y}}, \mathrm{Q}_{\mathrm{n,x}})/n$
  - Obtain the observed flow: $v_n^{obs} = \langle \cos(n(\varphi_i - \Psi_n)) \rangle$
  - The flow coefficients are given by: $v_n = v_n^{obs}/R_n$

  R_n is the event plane resolution: $R_n = \langle \cos(n(\Psi_n - \Psi_{RP})) \rangle$

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

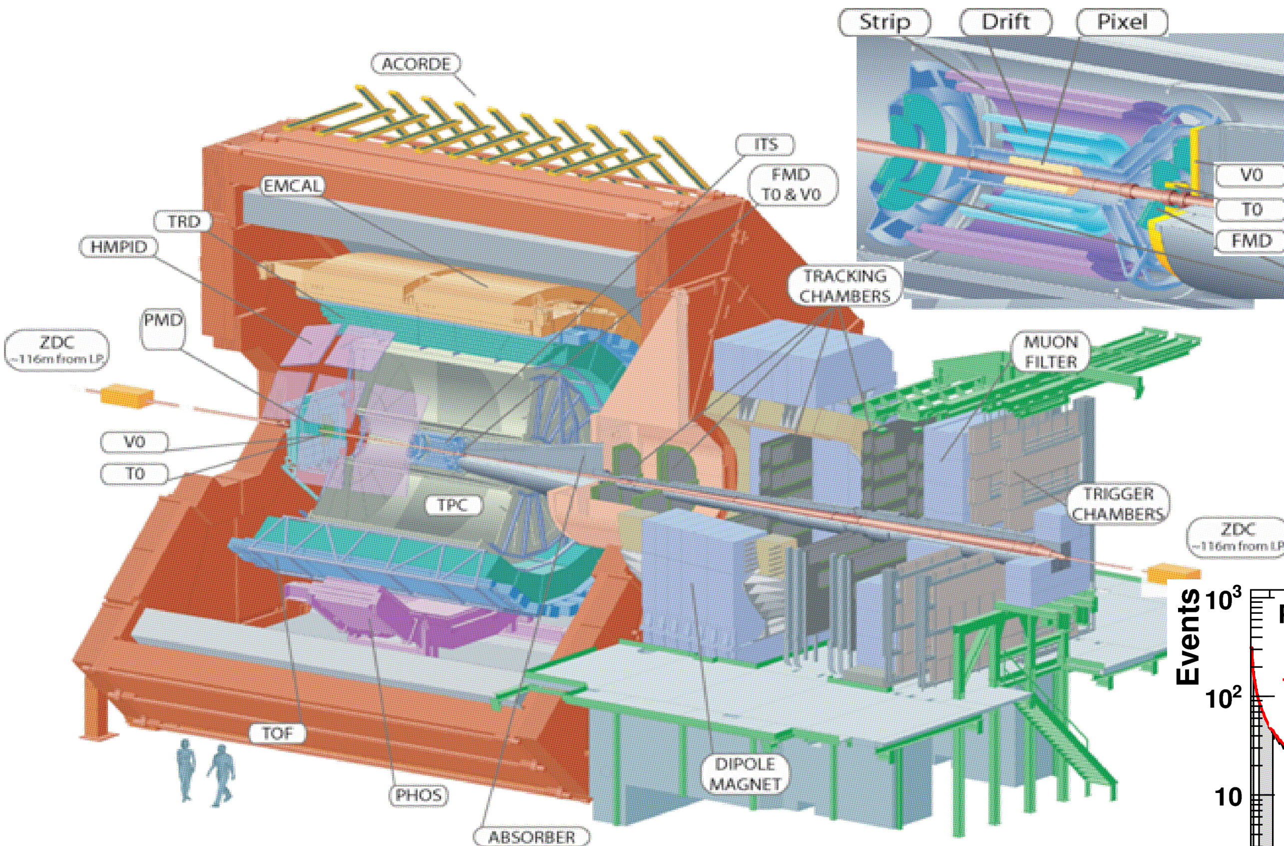
$$\langle 2 \rangle \equiv \langle \cos(n(\varphi_i - \varphi_j)) \rangle, \varphi_i \neq \varphi_j$$
$$\langle 4 \rangle \equiv \langle \cos(n(\varphi_i + \varphi_j - \varphi_k - \varphi_l)) \rangle, \varphi_i \neq \varphi_j \neq \varphi_k \neq \varphi_l$$

  - Averaging over all events, the 2nd and 4th order cumulants are given:

$$c_2\{n\} = \langle\langle 2 \rangle\rangle = v_n^2 + \delta_n$$
$$c_4\{n\} = \langle\langle 4 \rangle\rangle - 2\langle\langle 2 \rangle\rangle^2 = -v_n^4$$

A Large Ion Collider Experiment

Description of the experimental setup → Jurgen Schukraft's talk



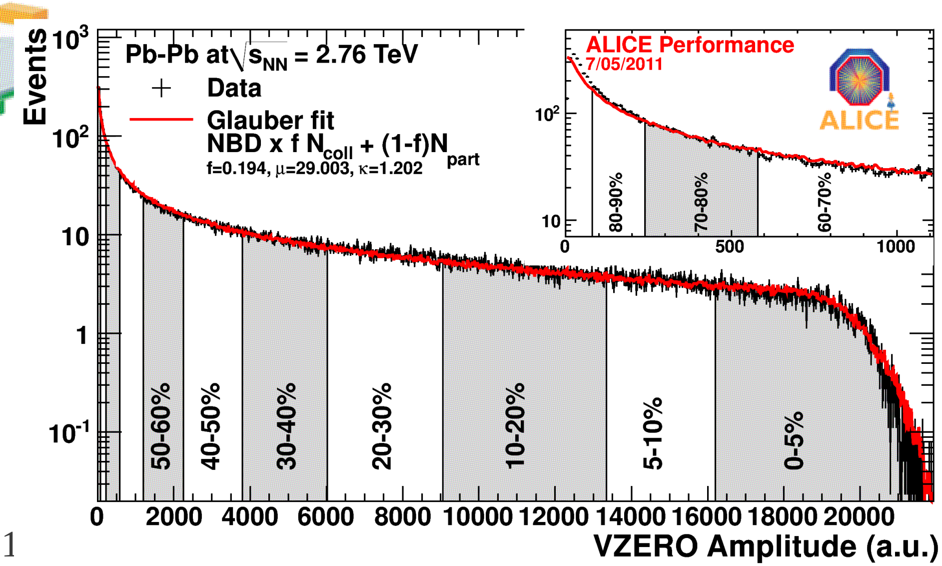
Analysis → TPC tracks

$p_T > 0.2$ GeV/c

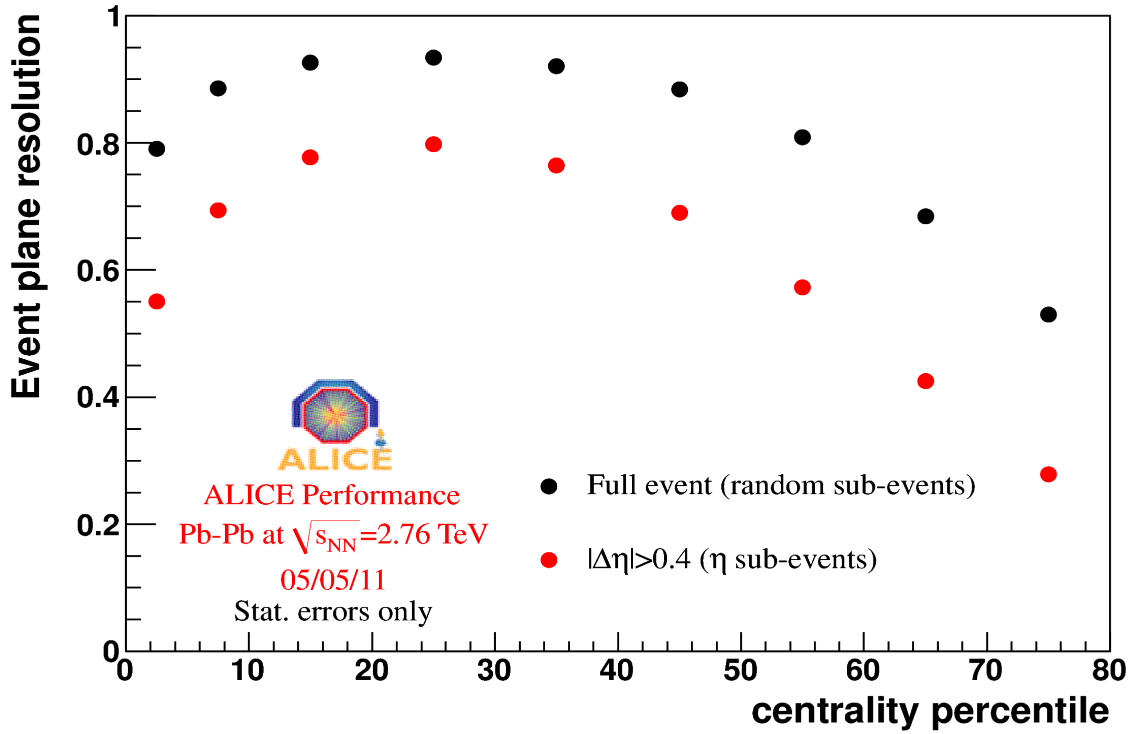
$|\eta| < 0.8$

Centrality selection: V0 amplitude as an estimator

→ A. Toia's talk

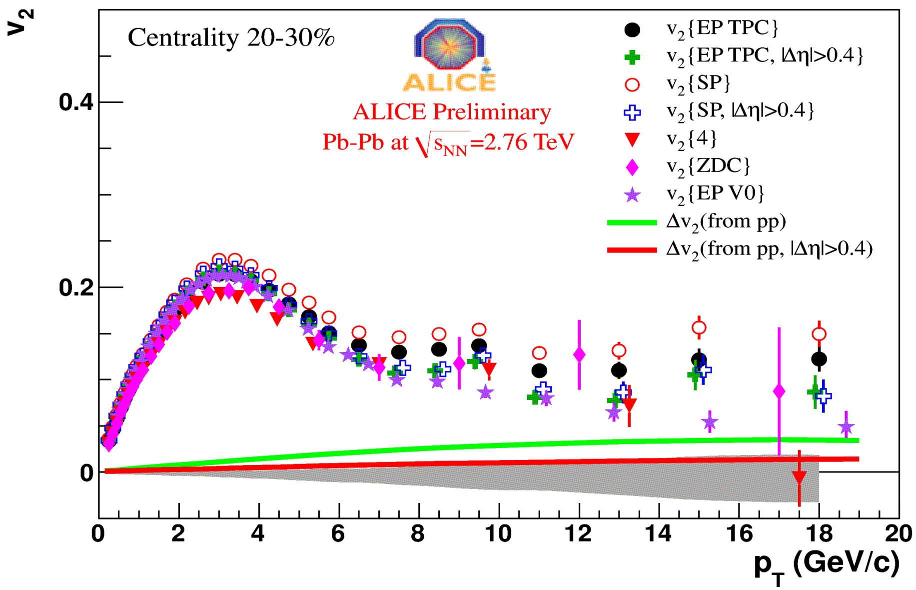


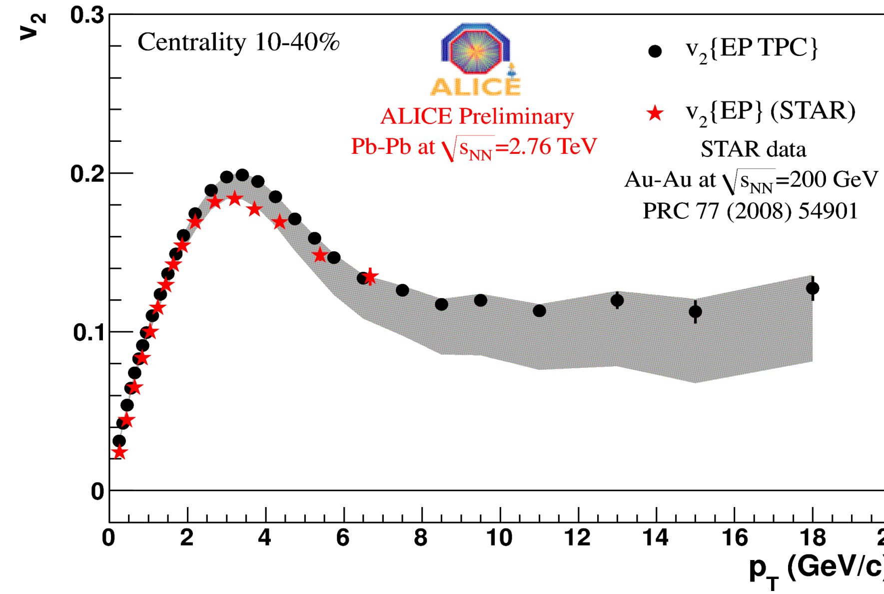
Suppressing non-flow



- By introducing an η gap (|Δη| > 0.4)
  - Correlate particles from (-0.8, -0.2) with particles from (0.2, 0.8) (and vice versa)
  - Event plane resolution is calculated from the two η sub-events (red points), while for the full event (black points) random sub-events are used
  - Larger η gap using V0 → B. Chang's poster
- Determining Ψ_{RP} using ZDC
- Using multiparticle correlations (4^{th} order cumulant)

Comparison of methods





- Non-flow contributions significant at high p_T
  - Addressed in multiple ways: v_2\{4\}, v_2\{ZDC\}, v_2\{EP V0\}, v_2\{EP TPC, |Δη|>0.4\}, v_2\{SP, |Δη|>0.4\}, v_2\{SP\} and v_2\{EP TPC\}
- Left: gray band → systematic uncertainty for |Δη|>0.4 methods
- Magnitude of the v_2 similar with what is reported by STAR
- Correction factor estimated using <u*Q> method in pp

$$v_2 = \frac{\langle u^* Q \rangle^{AA}}{M \langle v_2 \rangle}$$

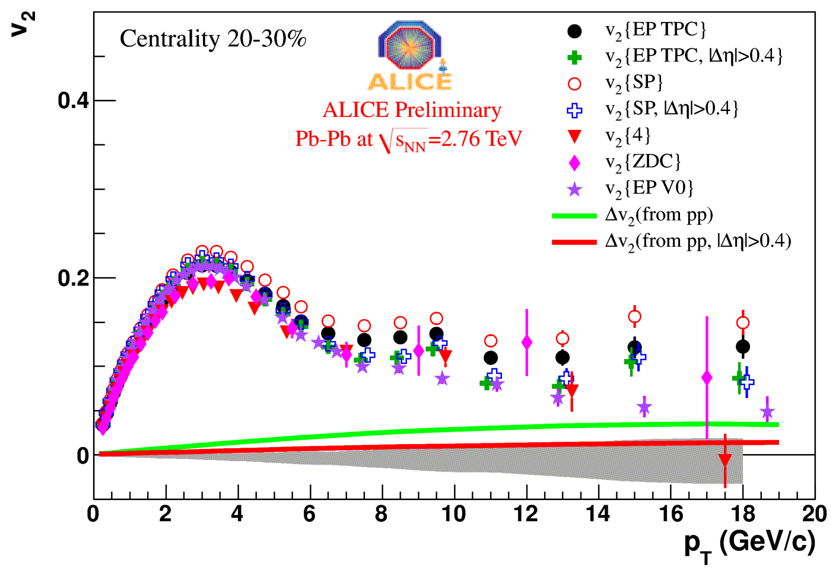
$$\langle u^* Q \rangle^{corr} = \langle u^* Q \rangle^{AA} - \langle u^* Q \rangle^{pp}$$

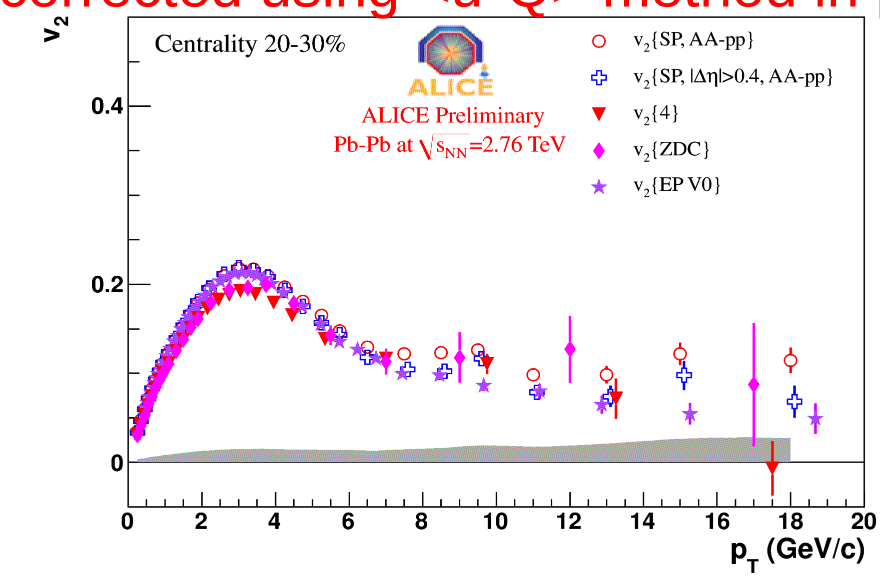
$$v_2^{corr} = \frac{\langle u^* Q \rangle^{AA} - \langle u^* Q \rangle^{pp}}{M \langle v_2 \rangle} = v_2 - \boxed{\frac{\langle u^* Q \rangle^{pp}}{M \langle v_2 \rangle}}$$

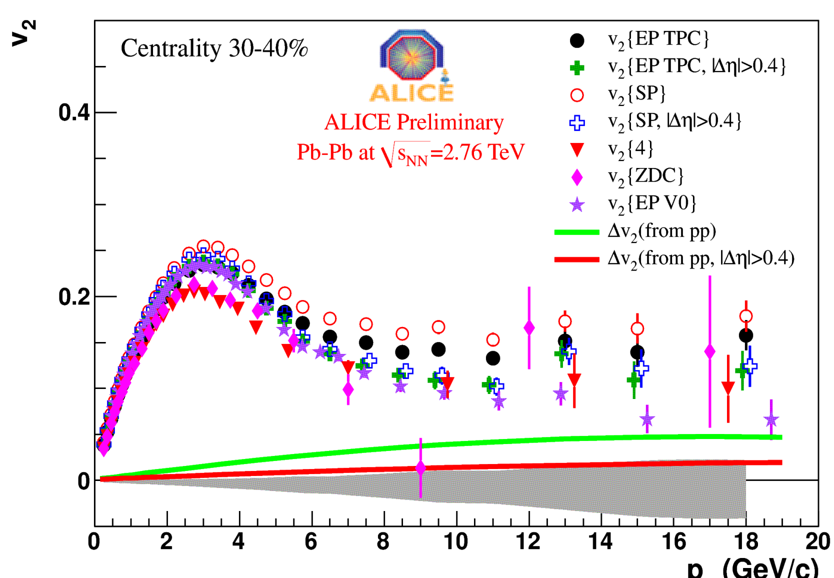
- Red and green lines in the left figure
- v_2\{SP\} corrected with green line, while v_2\{SP, |Δη| > 0.4\} corrected with red line (see next slide)

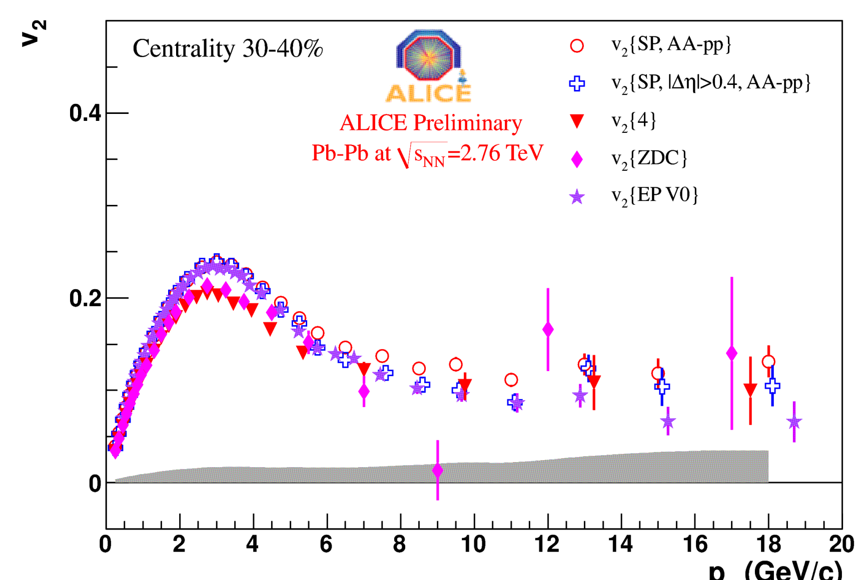
$v_2\{AA\text{-}pp\}$

corrected using <u*Q> method in pp

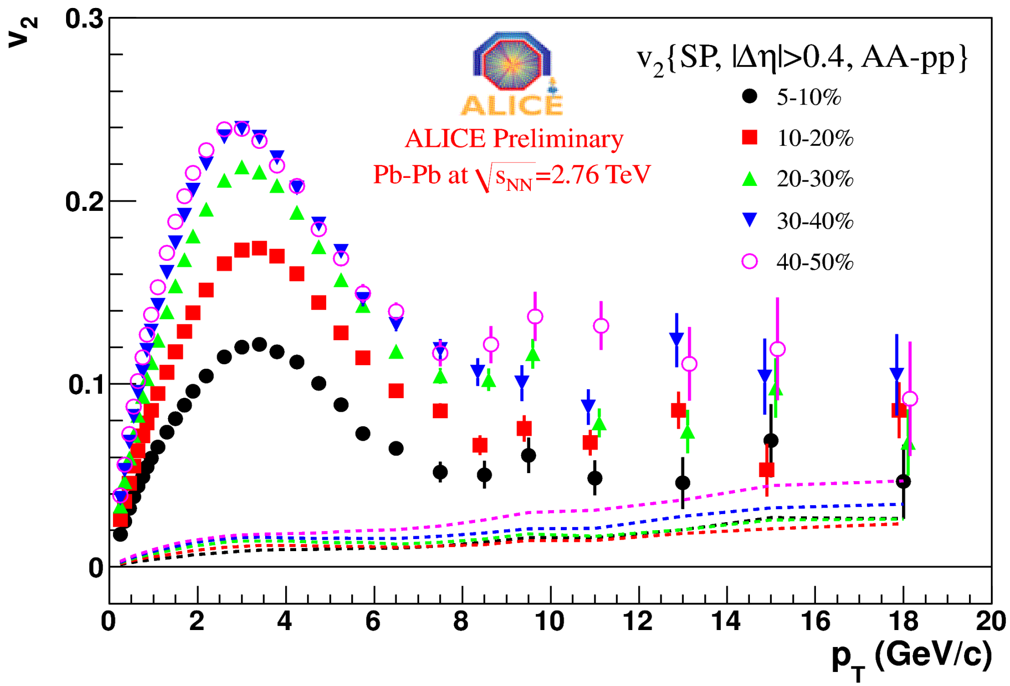




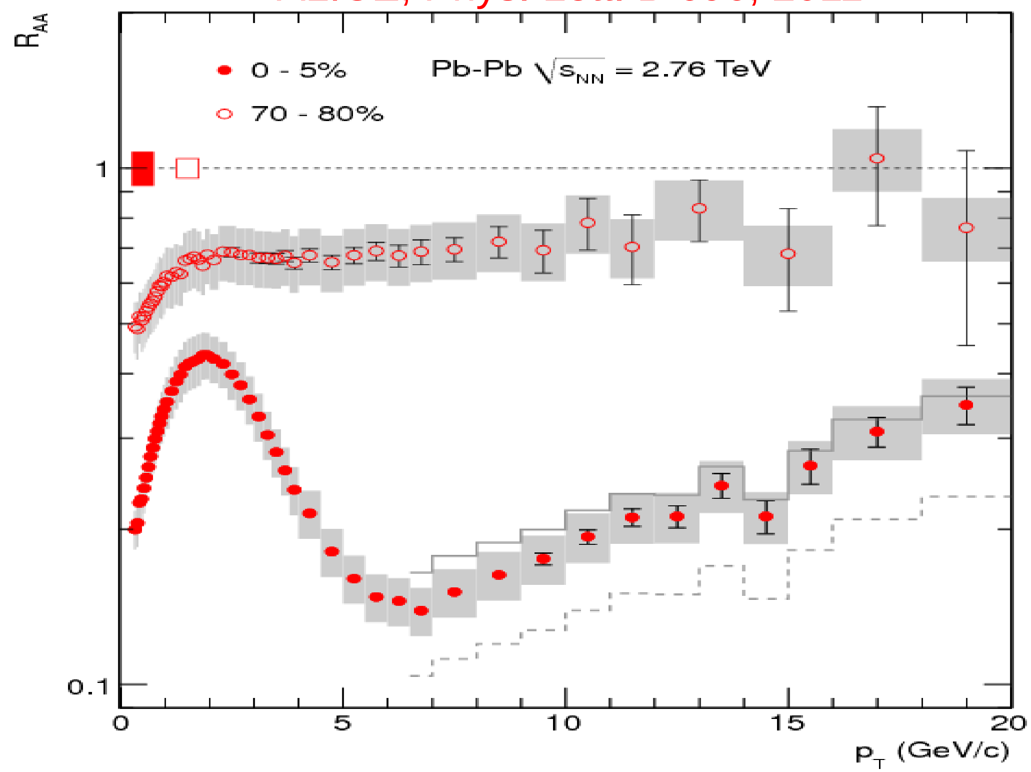




v_2 charged particles

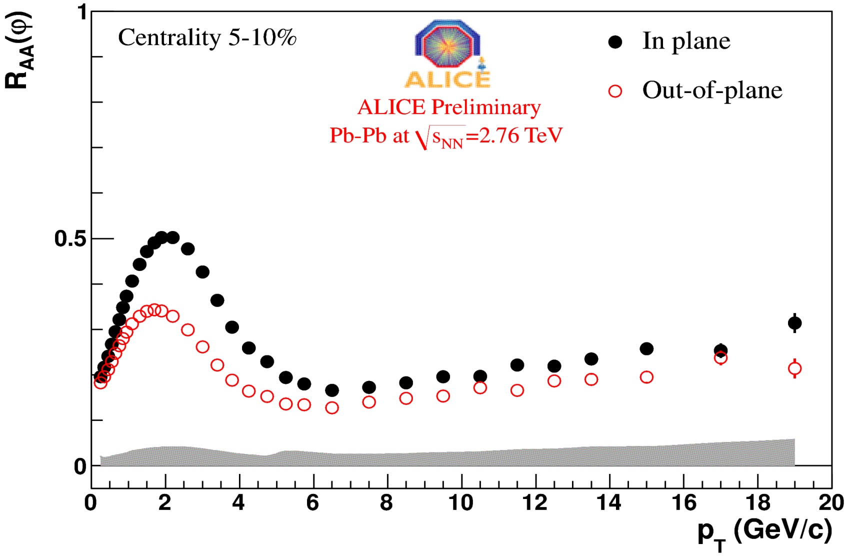


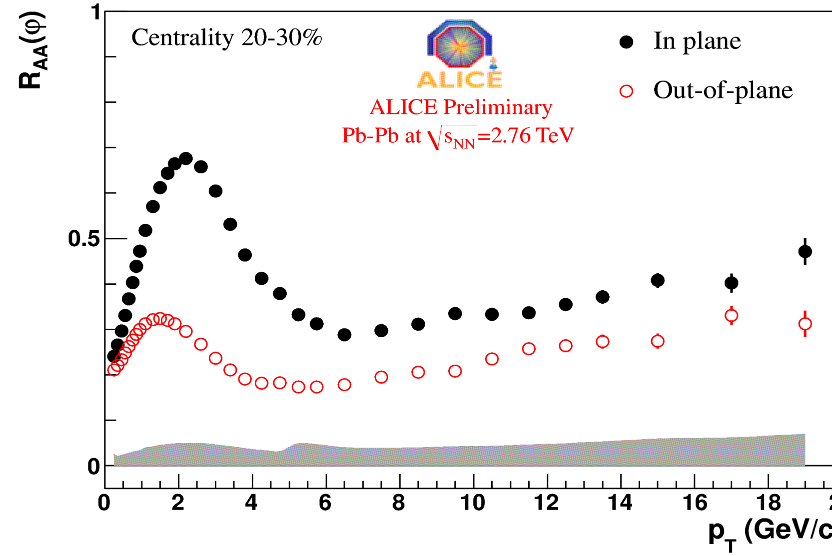
ALICE, Phys. Lett. B 696, 2011

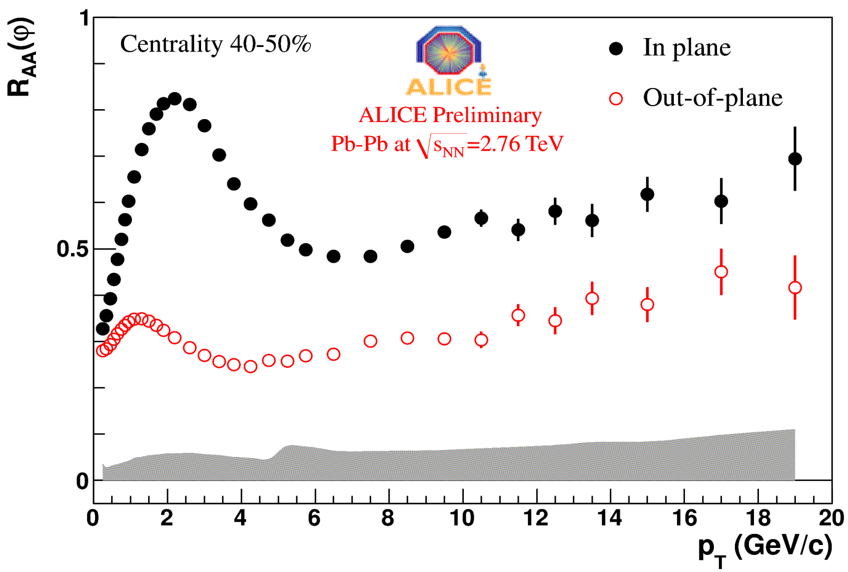


- Left plot: dashed lines → systematic uncertainties
  - The estimated non-flow correction from pp is included in the systematic error
- v_2 at high p_T (p_T>8 GeV/c) is finite and positive
  - Reaches a constant value dependent of centrality
  - Increasing with centrality

$R_{AA}(\varphi)$





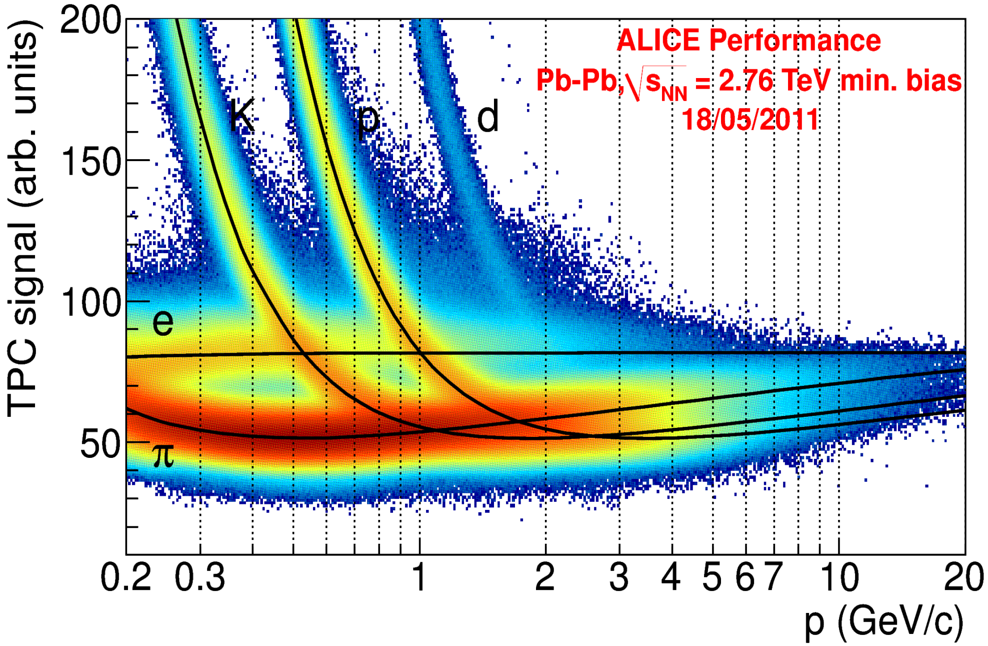


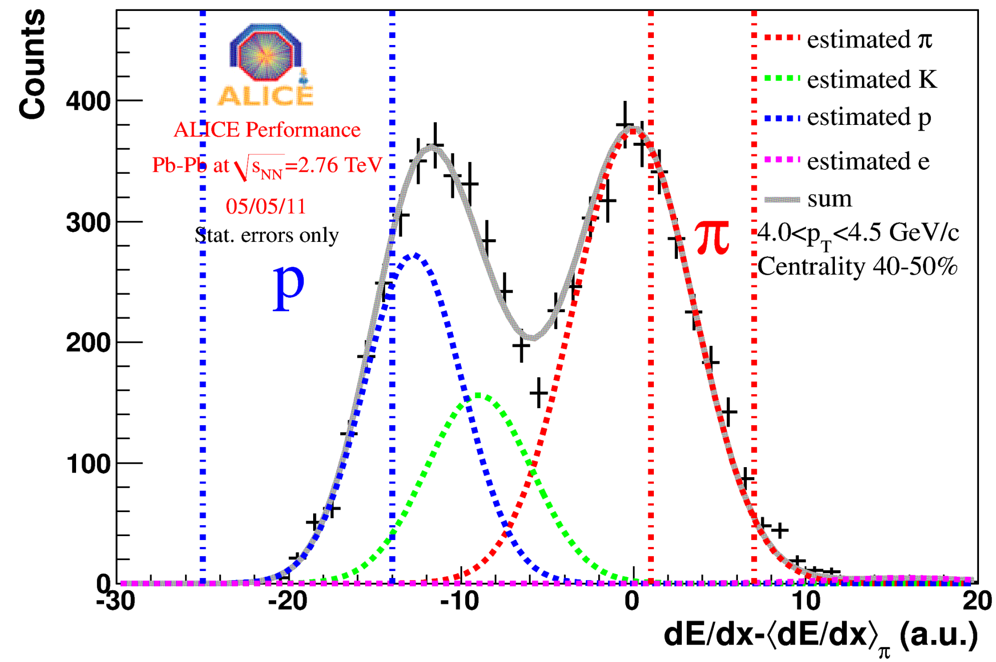
- v_2\{SP, $|\Delta\eta|>0.4$, AA-pp\} + $R_{AA} \rightarrow R_{AA}(\varphi)$:

$$R_{AA}(\varphi) = R_{AA}(1+2v_2\cos(2\varphi))$$
$$\varphi = 0 \rightarrow \textit{In plane}$$
$$\varphi = \pi/2 \rightarrow \textit{Out of plane}$$

- Systematic uncertainty (gray band): v_2 and R_{AA} systematics added in quadrature

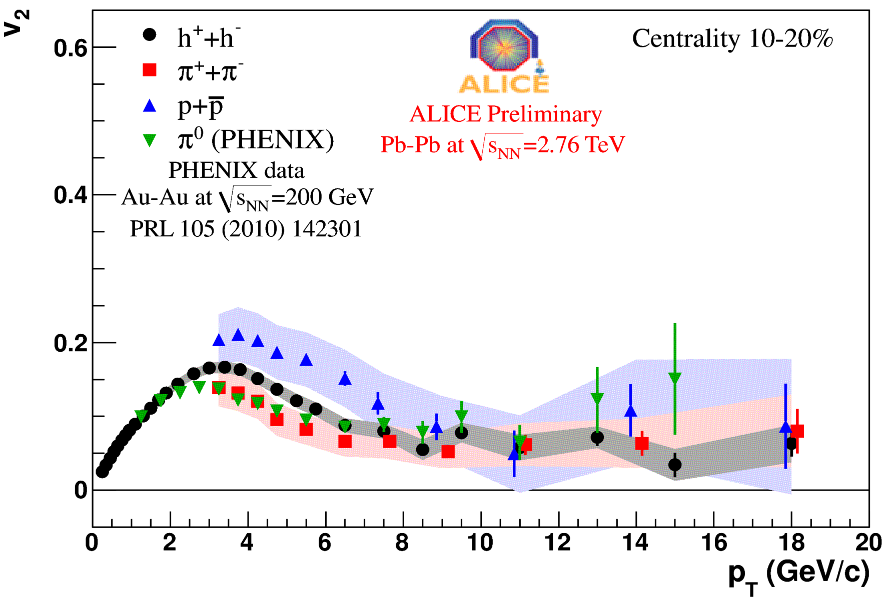
PID@high p_T

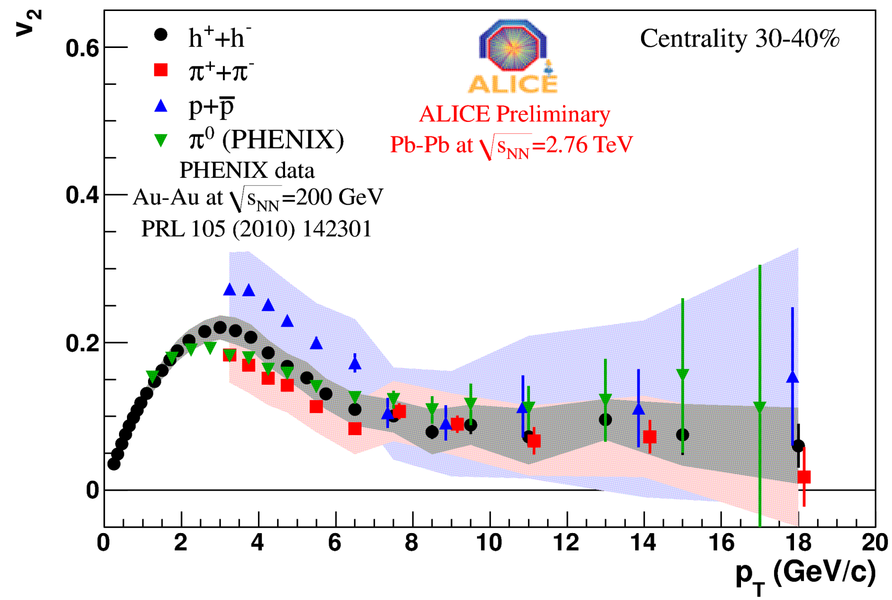




- PID based on the ionization energy loss in the TPC
  - Calculate Δ_π = dE/dx-<dE/dx>$_\pi$
- Select small ranges where the contamination is small:
  - Pions: contamination < 1 %
  - Protons: contamination < 15 %

PID v_2{EP TPC, |Δη|>0.4}





- Correcting for non-flow using data from centrality bin 70-80%

$$v_{2,cent}^{corr} = v_{2,cent} - v_{2,70-80\%} \frac{M_{70-80\%}}{M_{cent}}$$

  - Correction included in the systematic uncertainty
- Proton v_2 higher than pion at intermediate p_T
- Pion and proton v_2 start to overlap within systematic uncertainties for p_T>8 GeV/c
- Good agreement with PHENIX data

Summary

- Charged particle elliptic flow has been measured up to p_T= 20 GeV/c
  - v_2 is finite, positive and approximately constant at p_T>8 GeV/c
  - $R_{AA}(\varphi)$ might be sensitive to path length dependence
- Identified particle elliptic flow has also been measured up to p_T=20 GeV/c
  - Indication that jet quenching becomes dominant for p_T>8 GeV/c
- Need feedback from the theory community