Results on angular correlations with ALICE

Panos Christakoglou
Nikhef

for the ALICE Collaboration

Outline

Flow results in Pb-Pb

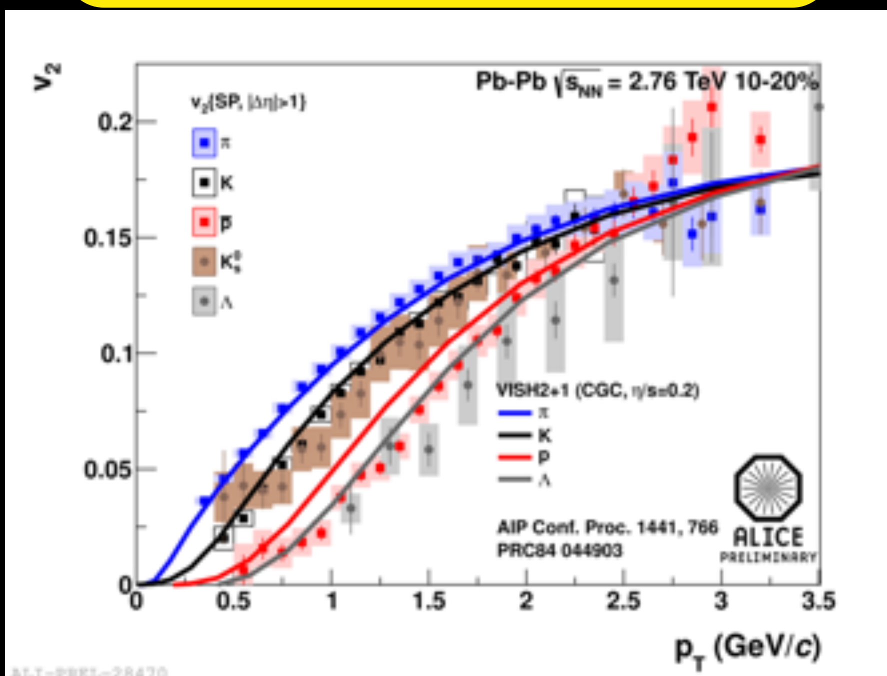
- Directed flow measurements
- Flow fluctuations at high p_T and at forward η
- Symmetry plane correlations
- Identified particle v_2 in Pb-Pb

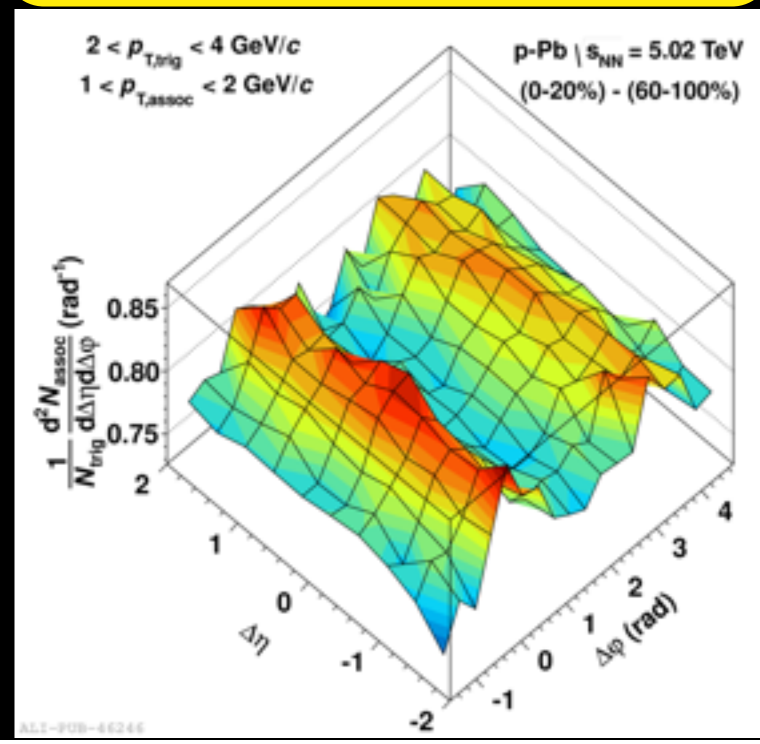
Particle correlations in p-Pb

- Double ridge
- Identified particle correlations

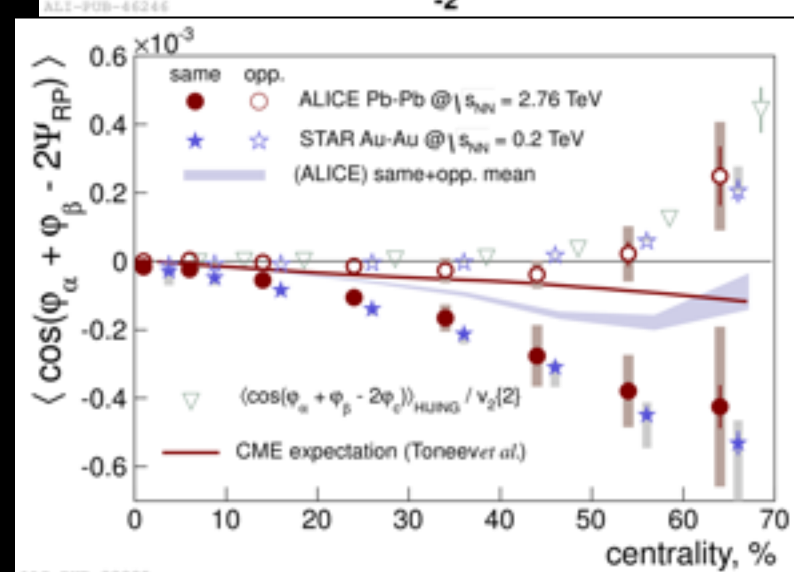
Two-particle correlations in Pb-Pb

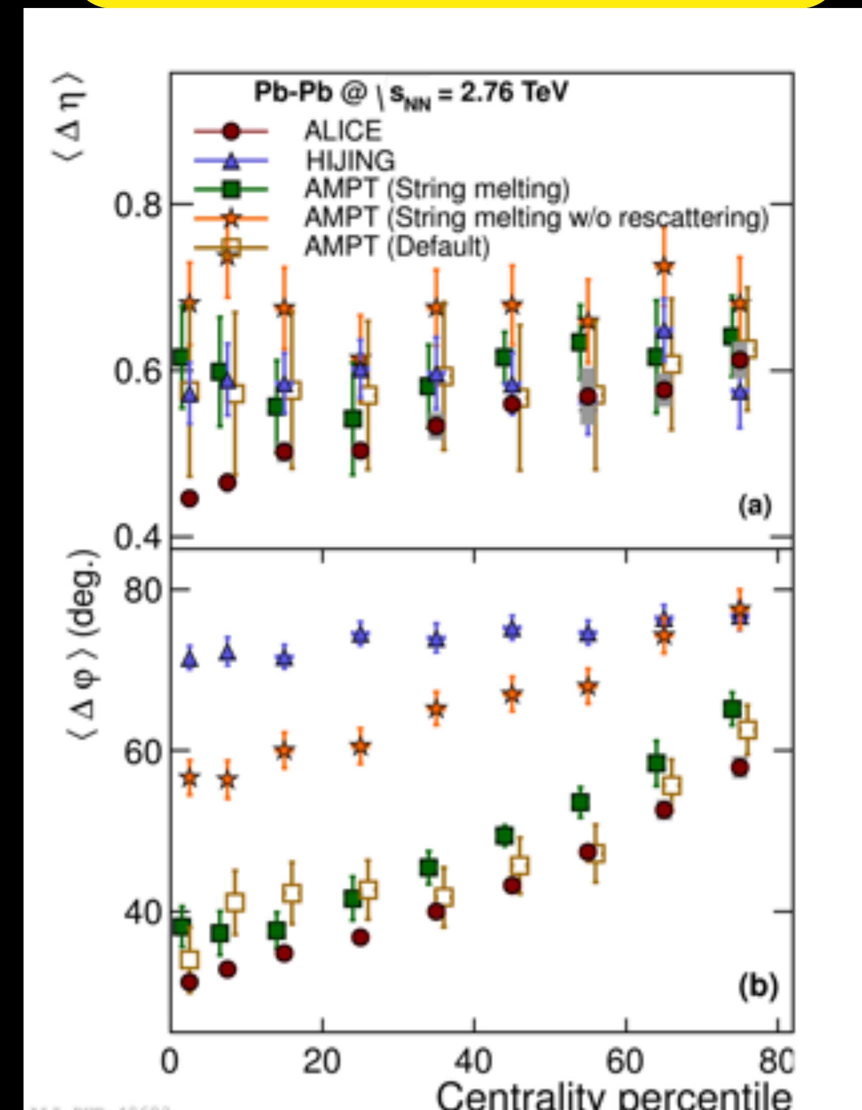
- Jet shape
- Balance functions





Testing the Chiral Magnetic Effect





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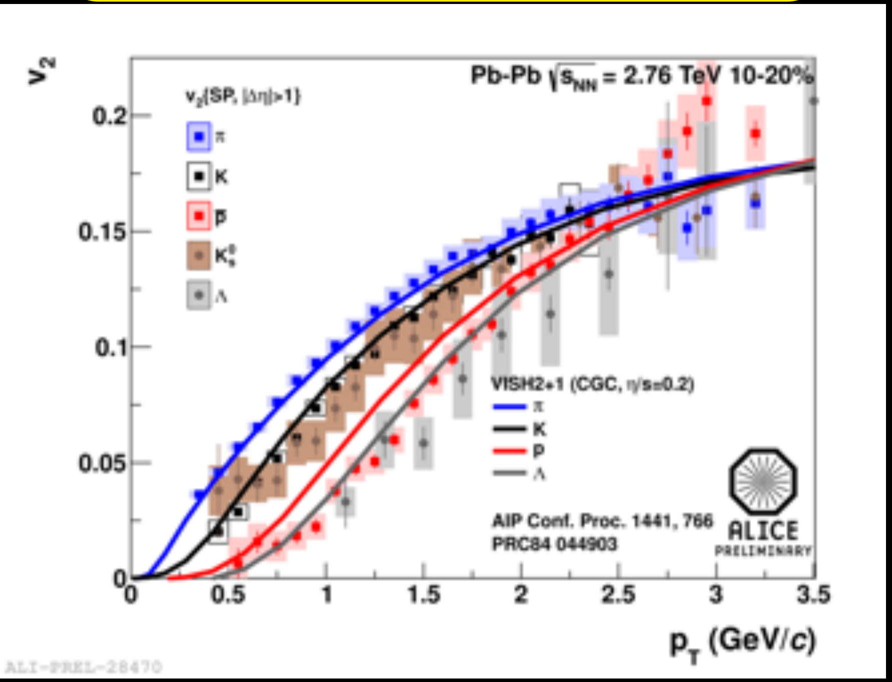

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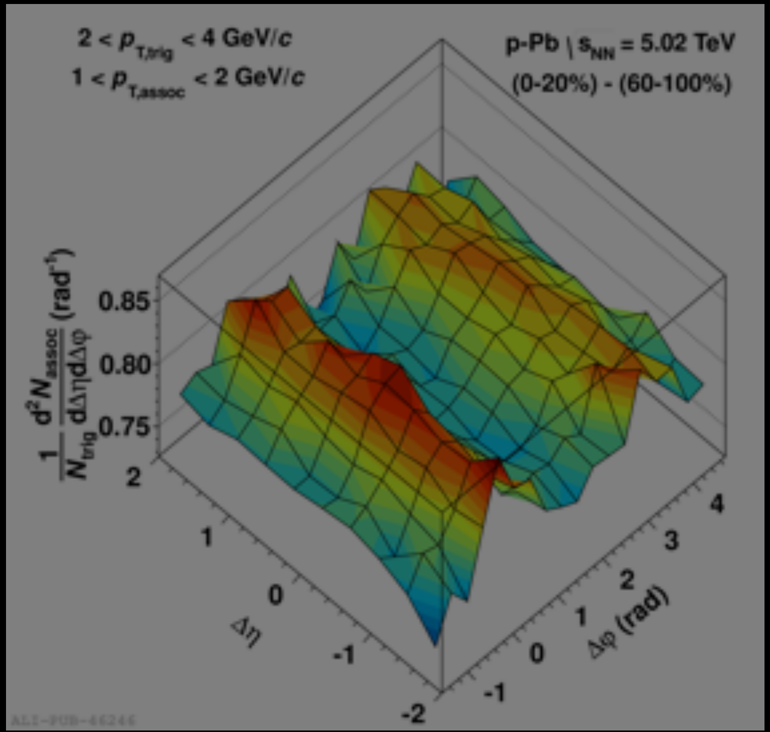

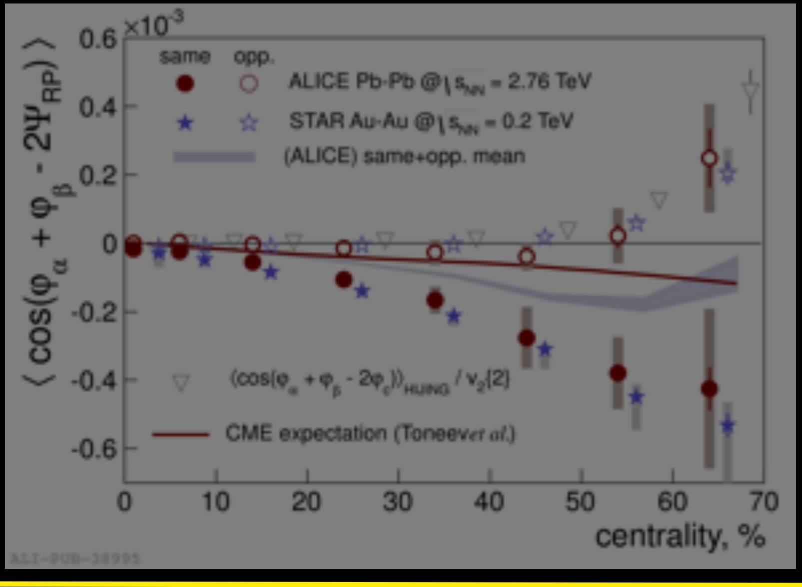

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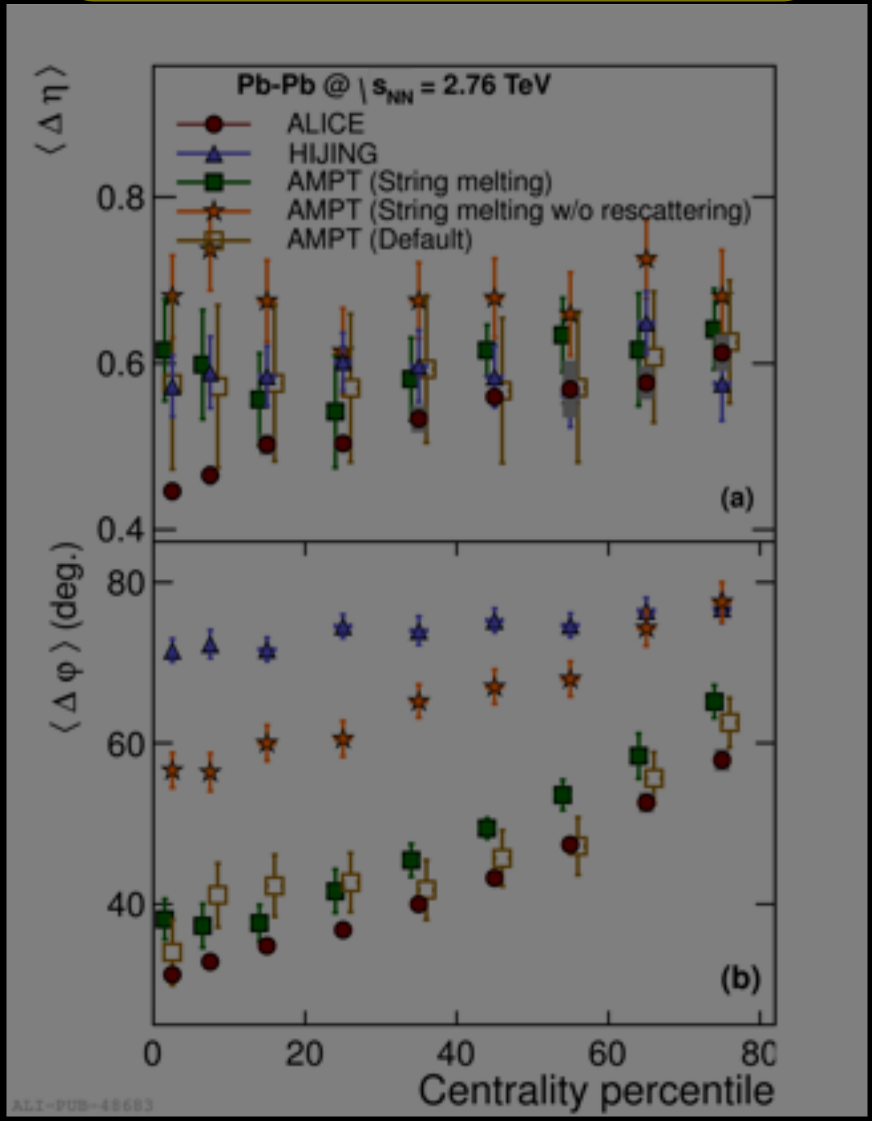
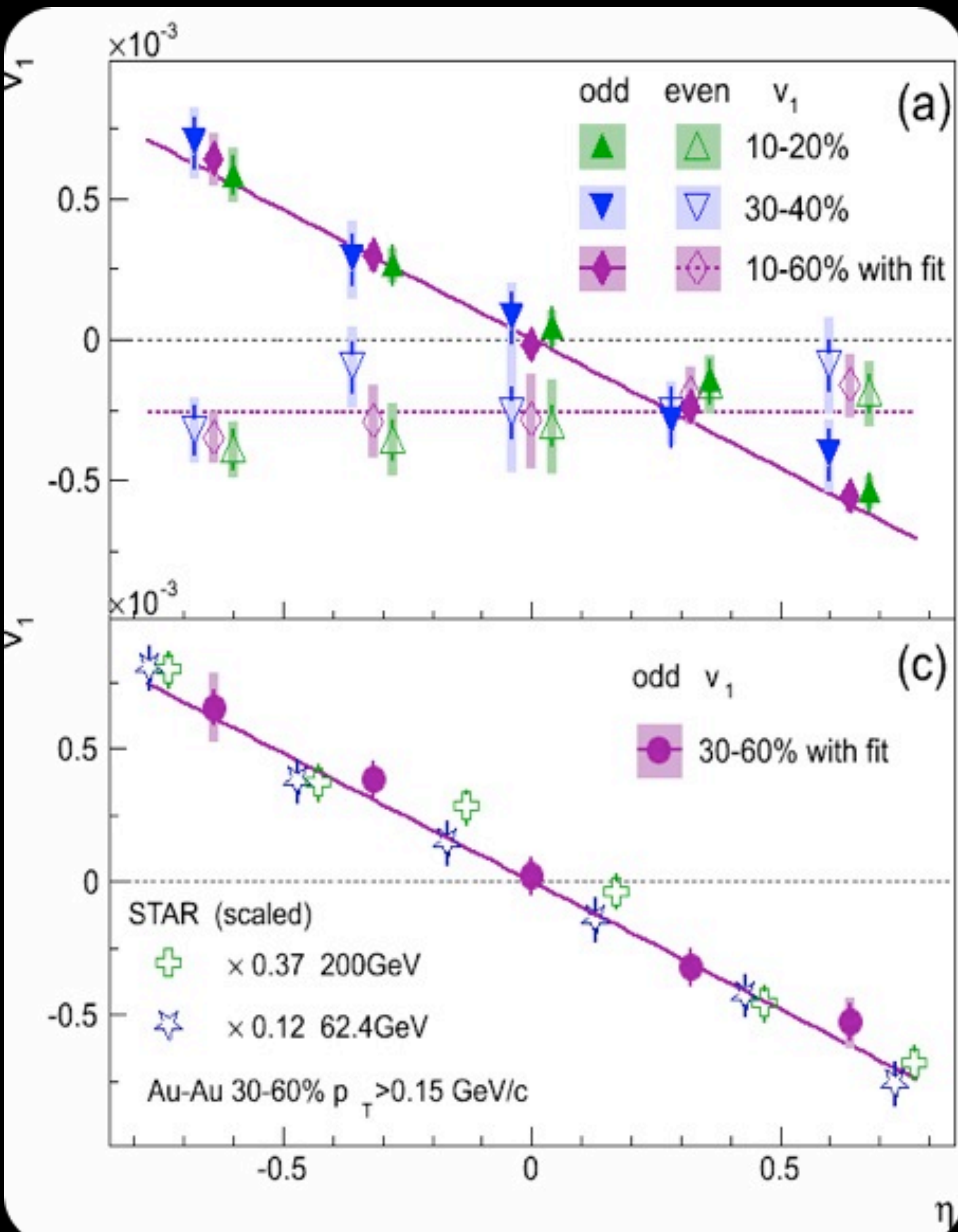


Directed flow measurement: η dependence

(ALICE Collaboration) arXiv:1306.4145



$$v_1 = \langle \cos(\varphi - \Psi) \rangle$$

$$v_1^{odd}\{\Psi_{SP}\} = \frac{1}{2}\left[v_1\{\Psi_{SP}^p\} + v_1\{\Psi_{SP}^t\}\right]$$

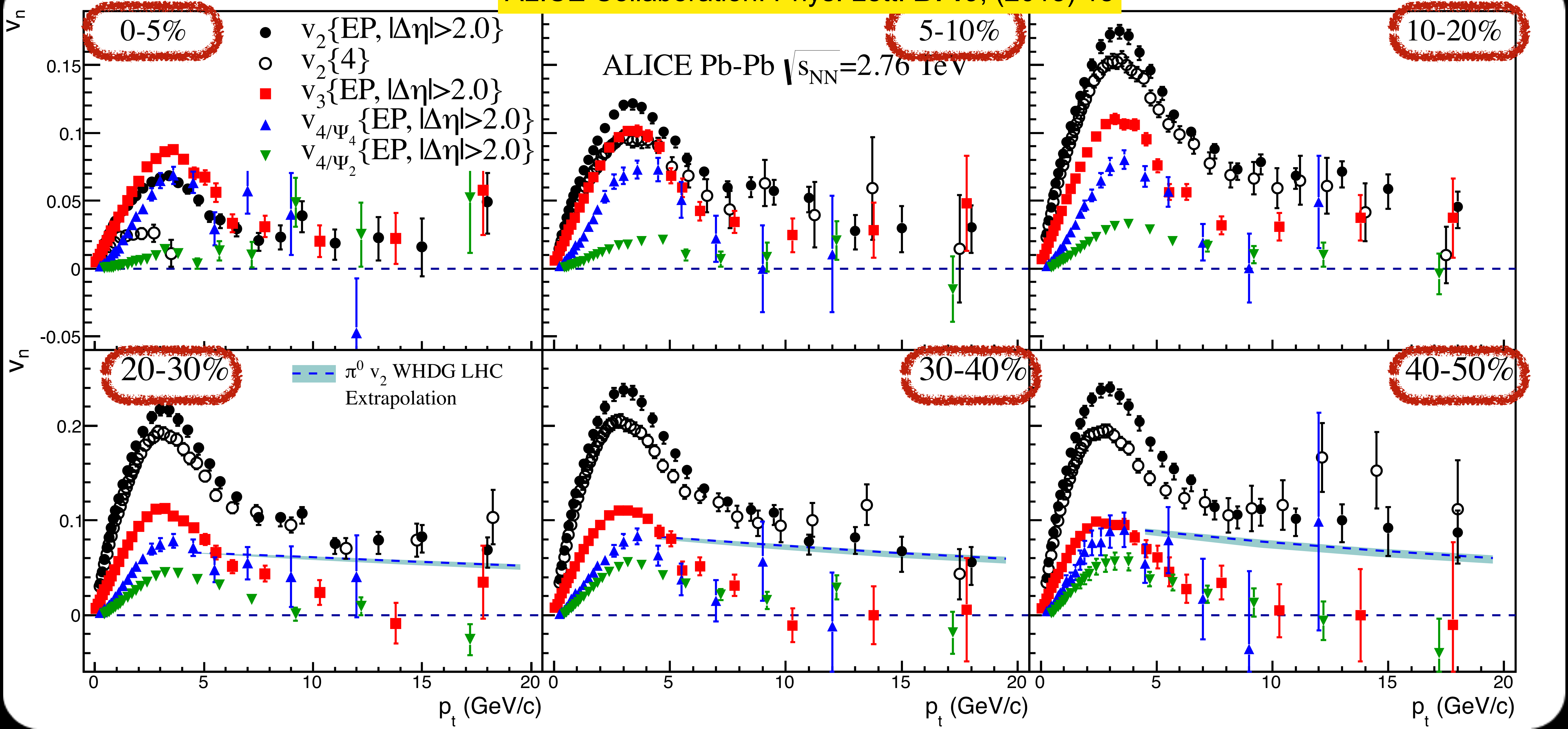
$$v_1^{even}\{\Psi_{SP}\} = \frac{1}{2}\left[v_1\{\Psi_{SP}^p\} - v_1\{\Psi_{SP}^t\}\right]$$

- Measured wrt the spectator deflection
- v_1^{odd} negative slope
  - similar observation @ RHIC but a factor of ~3 smaller magnitude
  - consistent with models considering a smaller tilt in x-z @ LHC wrt RHIC
- v_1^{even} negative with no evident η dependence

Panos.Christakoglou@nikhef.nl

Flow @ high p_T

ALICE Collaboration: Phys. Lett. **B719**, (2013) 18



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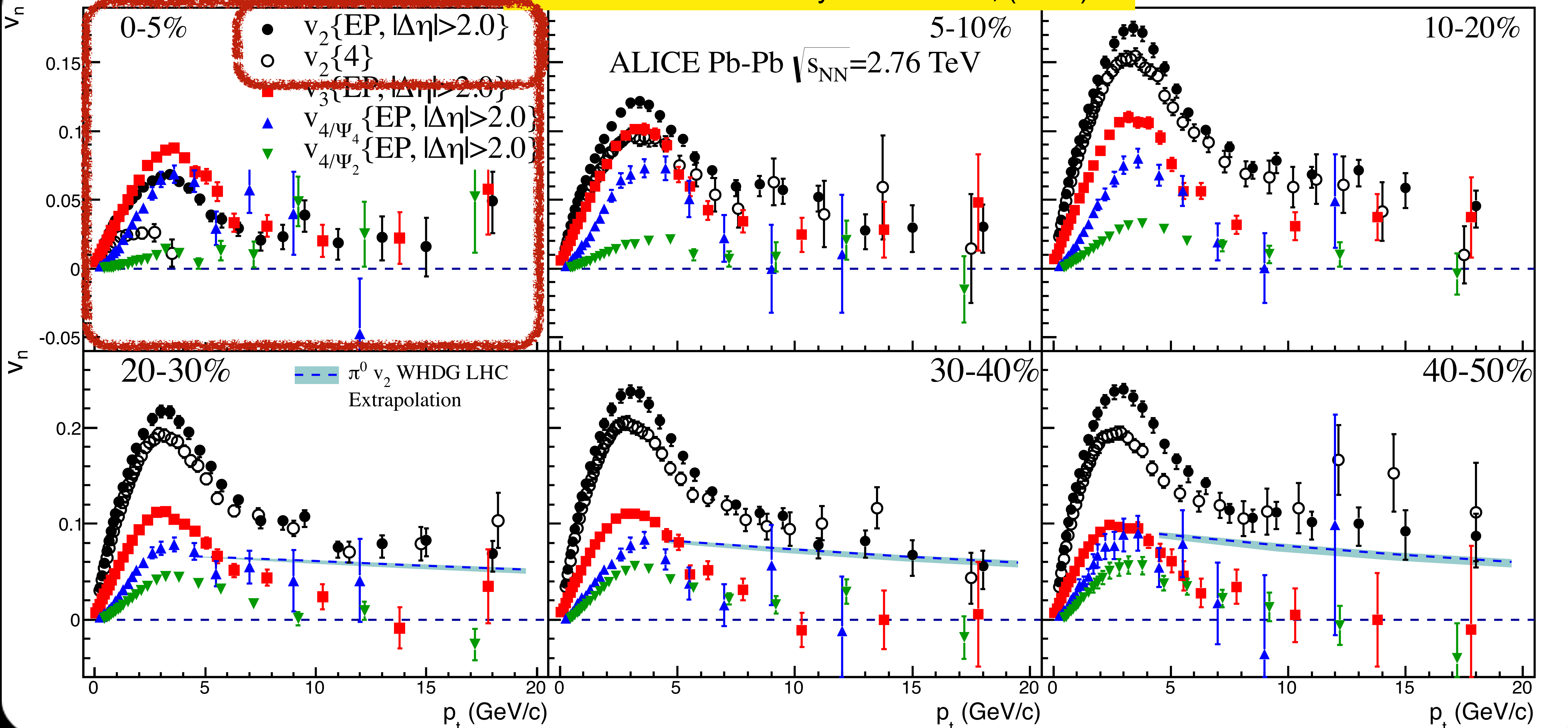

- Elliptic flow the dominant harmonic for all centralities except the more central events

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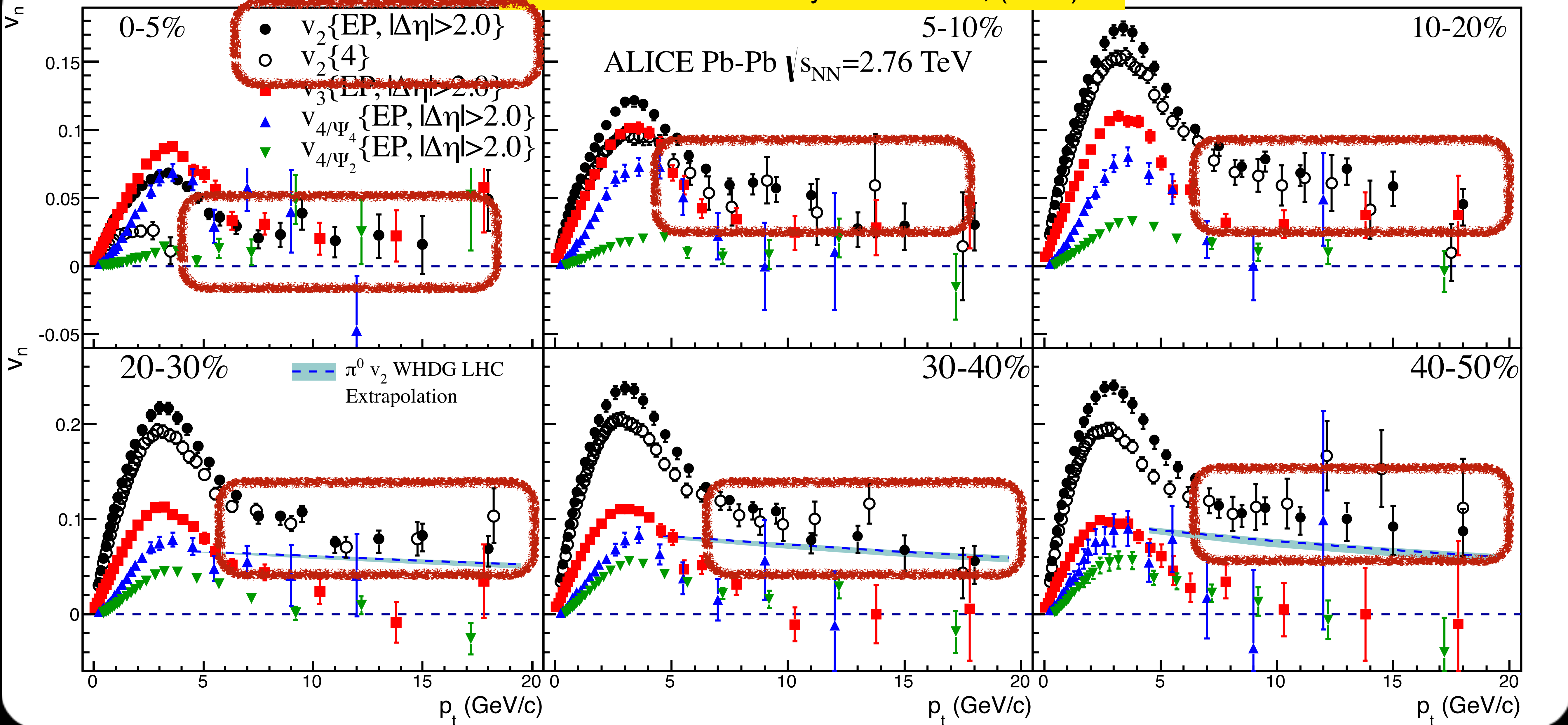

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- Finite v_2 values at high p_T (path length dependence)

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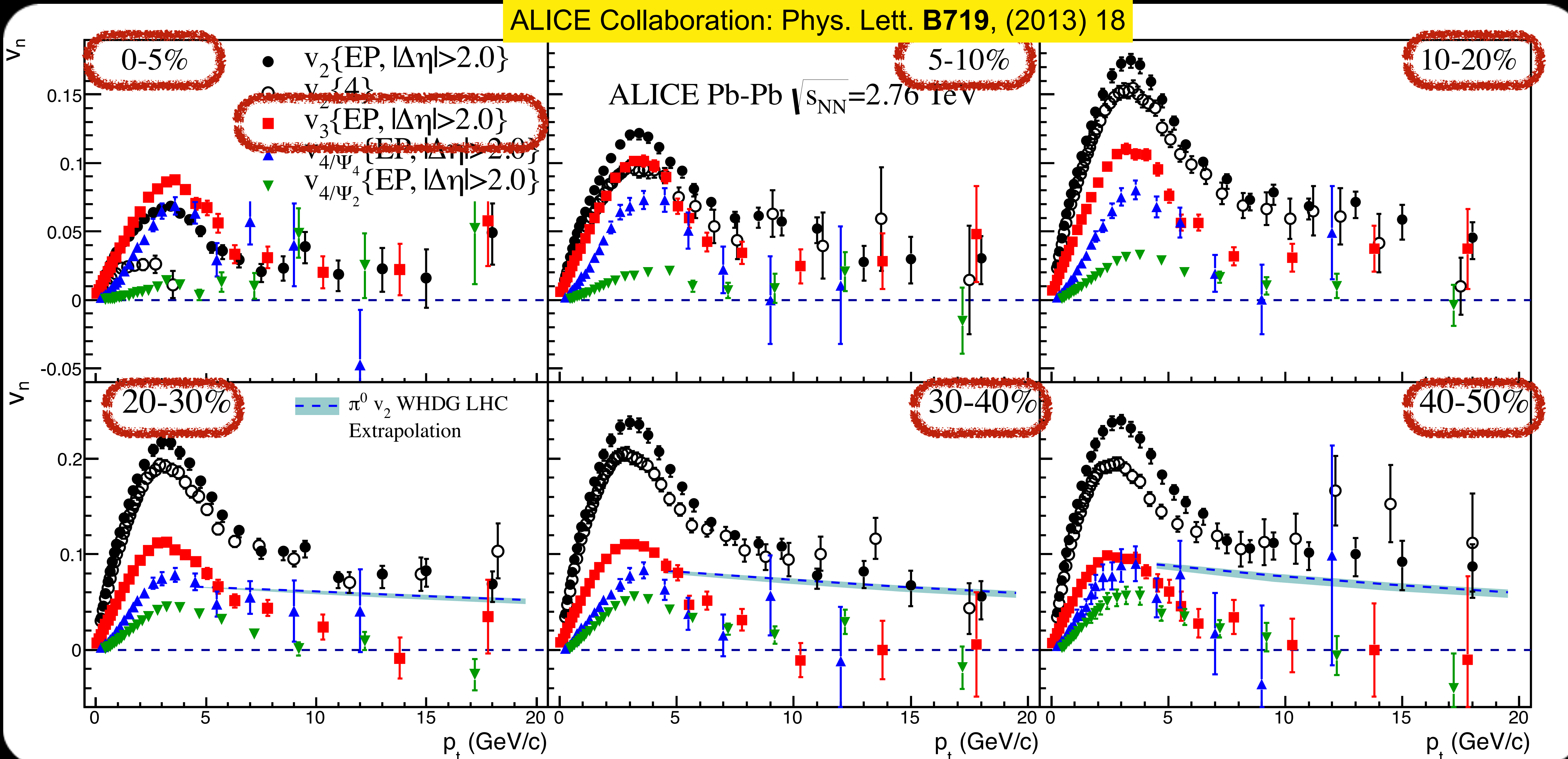
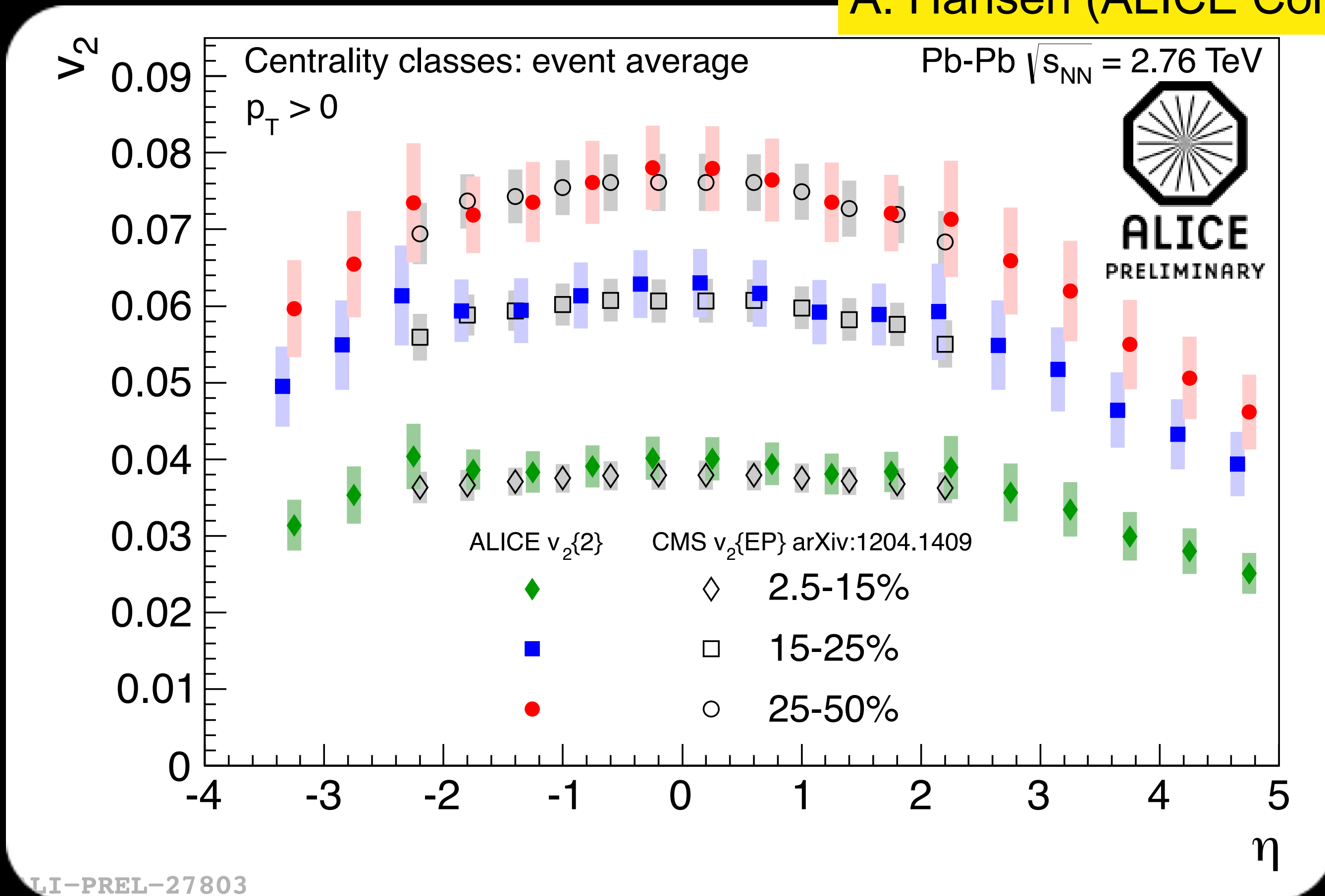


- Elliptic flow the dominant harmonic for all centralities except the more central events
- Finite v_2 values at high p_T (path length dependence)
- Triangular flow (red points) shows little centrality dependence

Elliptic flow @ large η

A. Hansen (ALICE Collaboration) @ QM2012



- Extension of the mid-rapidity measurement with the help of the SPD (|η| < 2) and the FMD (-3.4 < η < -1.7 and 1.7 < η < 5.0)
  - Hit based analysis
- Strong centrality dependence of v_2 (in good agreement with CMS)

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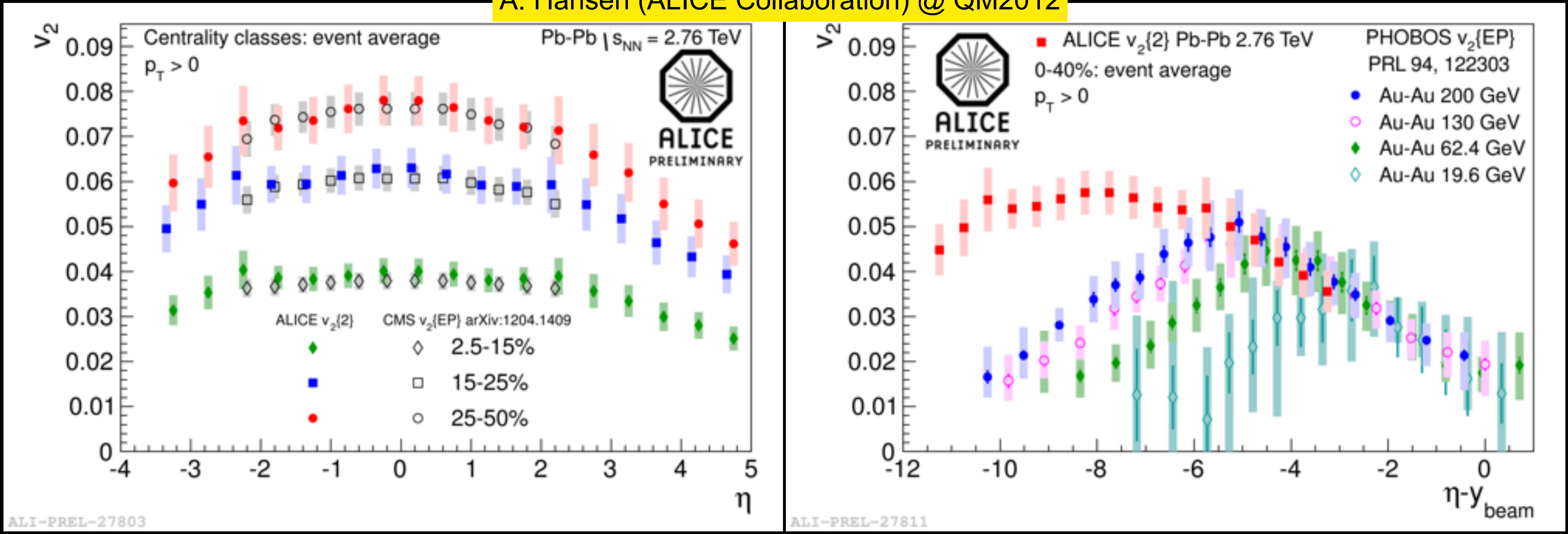

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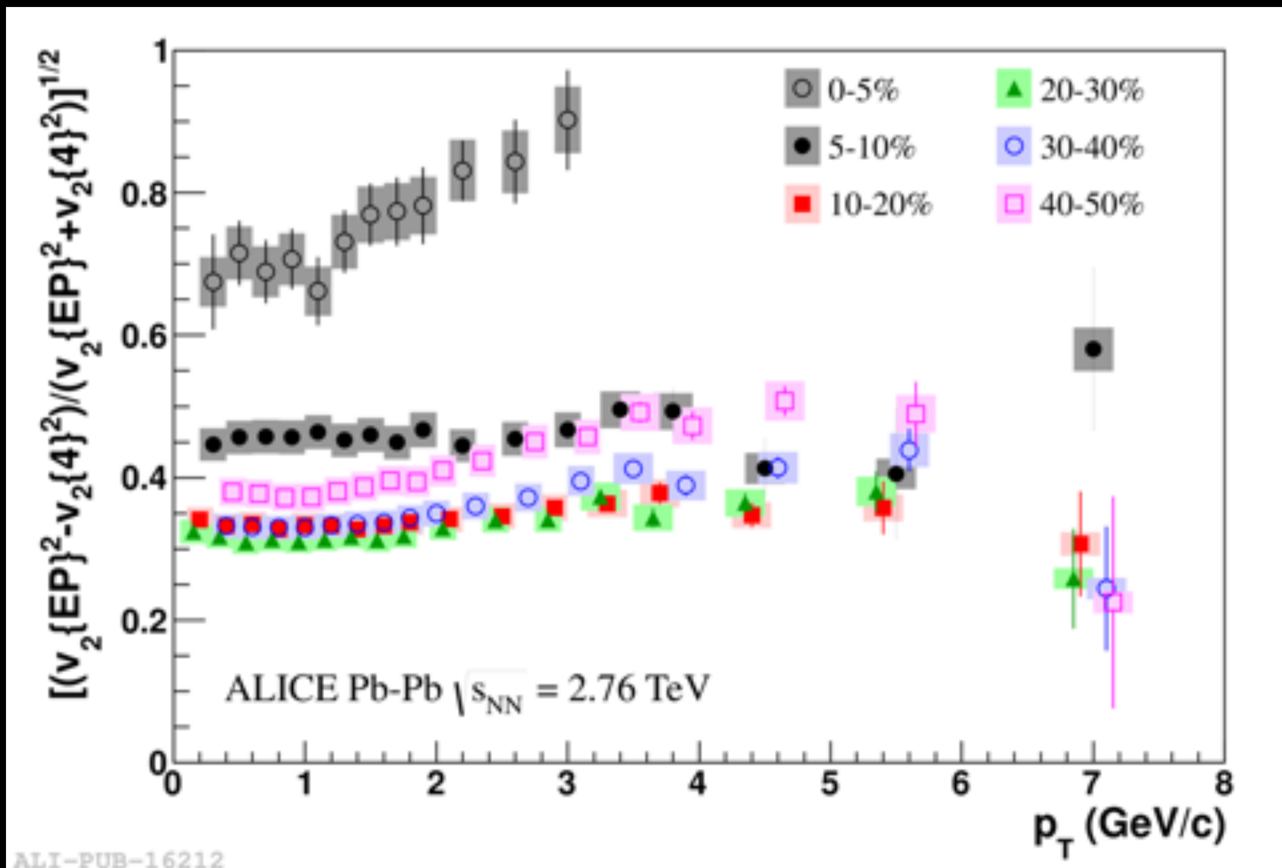
  - Hit based analysis
- Strong centrality dependence of v_2 (in good agreement with CMS)
- Longitudinal scaling holds between RHIC and LHC

Flow fluctuations @ high p_T and large η

ALICE Collaboration: Phys. Lett. **B719**, (2013) 18



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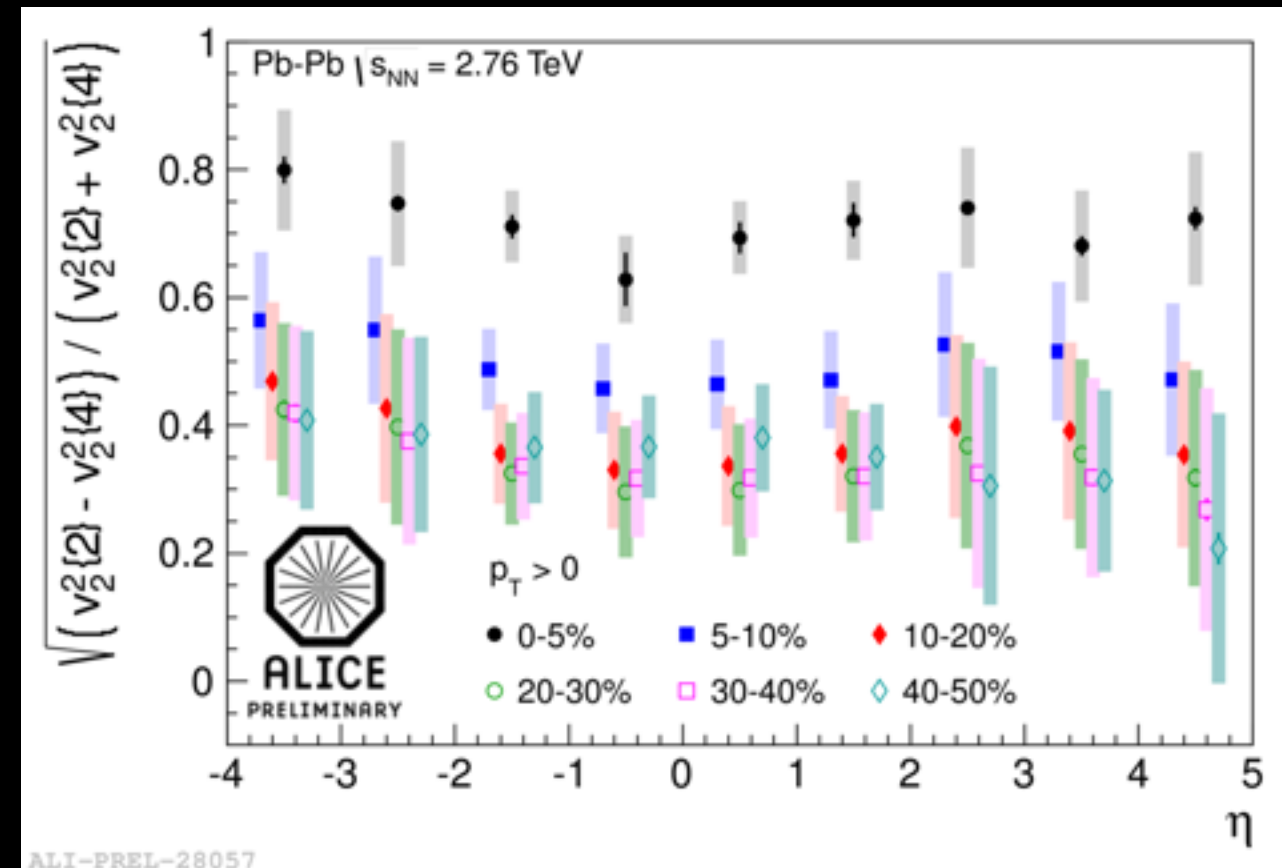

- No strong transverse momentum dependence except
  - the most central events (i.e. 0-5%)
  - the 40-50% class
- Little pseudorapidity dependence

Symmetry plane correlations

R.S. Bhalerao, M. Luzum, J.-Y. Ollitrault, Phys. Rev. **C84** , (2011) 034910

$$\langle \cos(n_1\varphi_1+n_2\varphi_2+...+n_k\varphi_k) \rangle = v_{n_1} v_{n_2} ... v_{n_k} \langle \cos(n_1\Psi_1+n_2\Psi_2+...+n_k\Psi_k) \rangle$$

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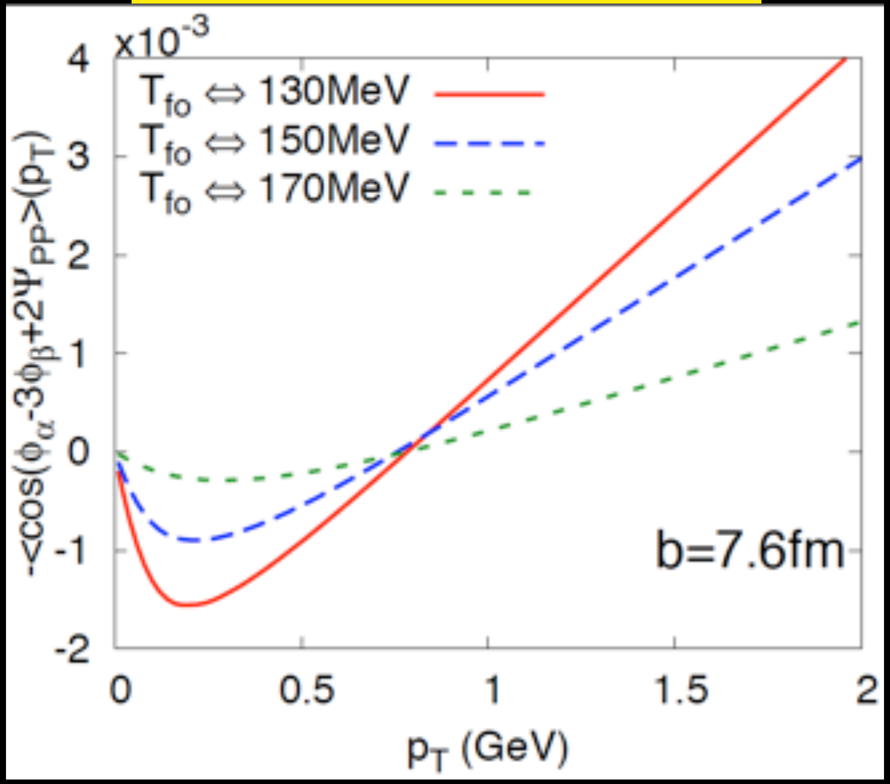
$$\langle \cos(\varphi_1-3\varphi_2+2\varphi_3) \rangle = v_1 v_2 v_3 \langle \cos(\Psi_1-3\Psi_3+2\Psi_2) \rangle$$

D. Teaney and L. Yan, Phys. Rev. **C83**, (2011) 064904



Glauber MC + ideal hydro

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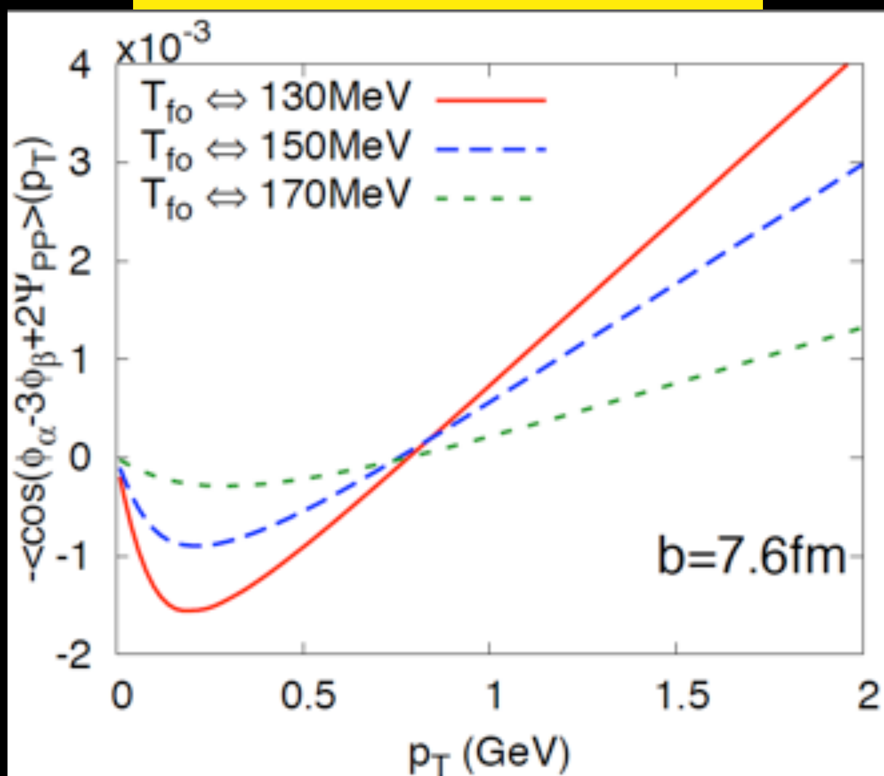

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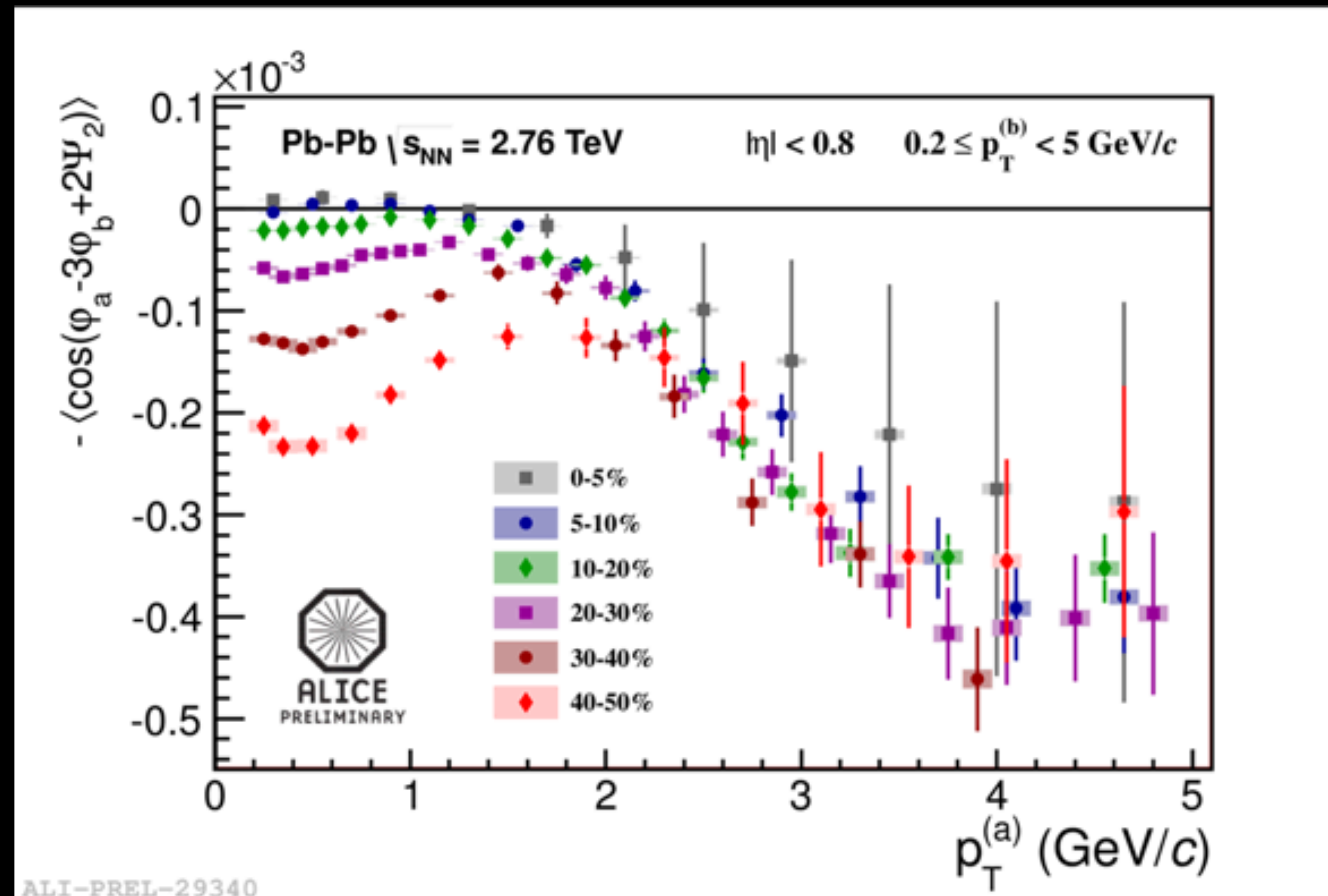
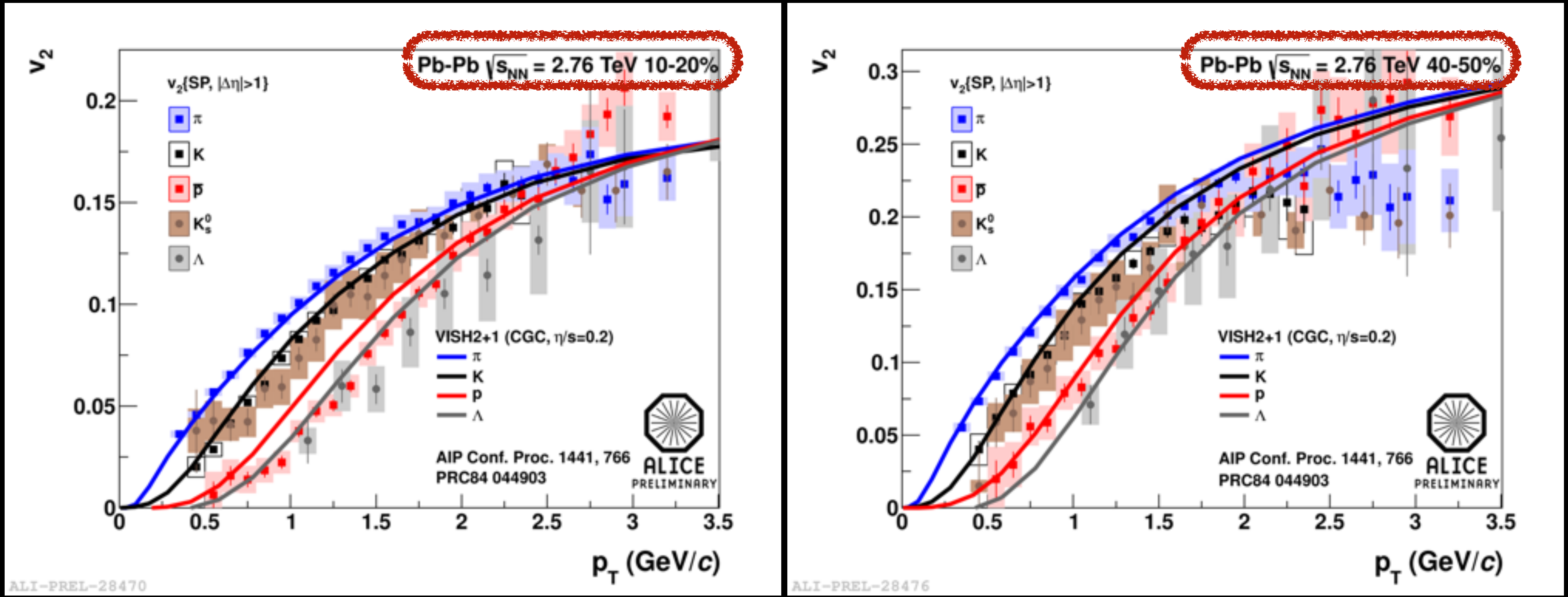


- Observation of a 3-plane correlation
- In qualitative agreement with MC Glauber+ideal hydro calculations at low p_T but hydro curves do not follow data at high p_T

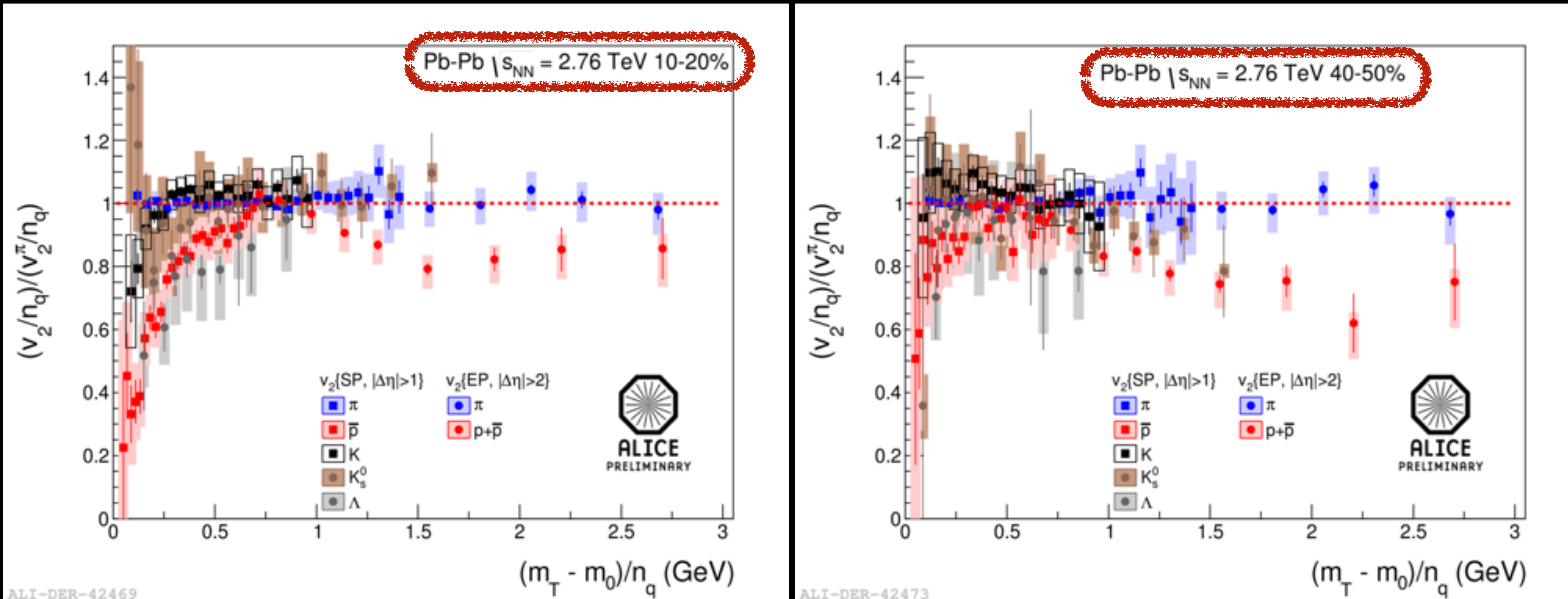
Identified particle v_2 in Pb-Pb collisions



- Observed mass splitting driven by radial flow
- Hydro curves describe data points fairly well
  - ★ Better agreement for more central events and for heavier particles when hydro is coupled to a hadronic afterburner

You Zhou (23/7 Parallel session @ 14:00)

Quark scaling in Pb-Pb collisions



- Low $(m_T\text{-}m_0)/n_q$: scaling is broken at the LHC
- Intermediate $(m_T\text{-}m_0)/n_q$: scaling holds at the level of ~20%

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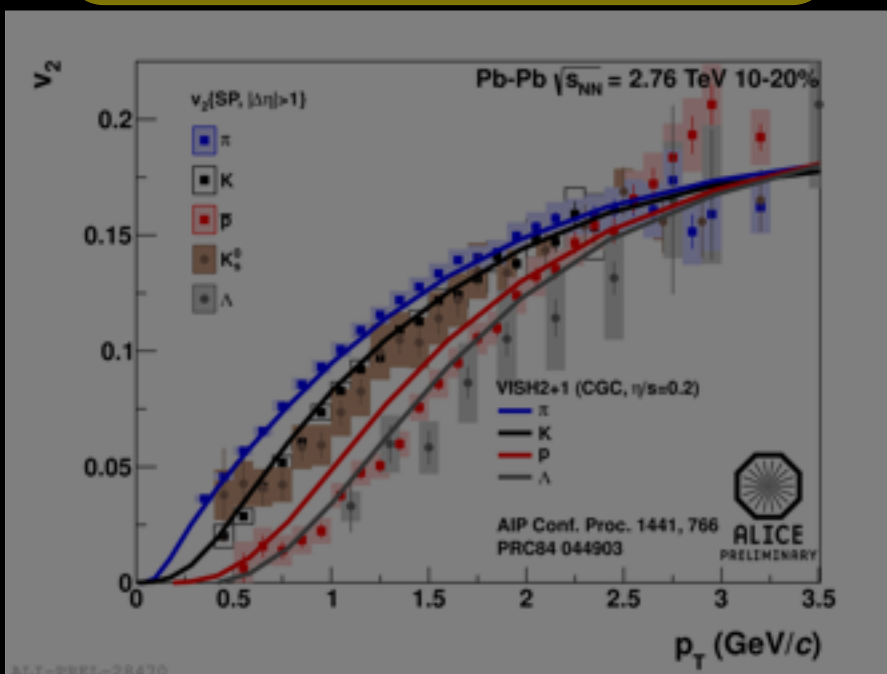
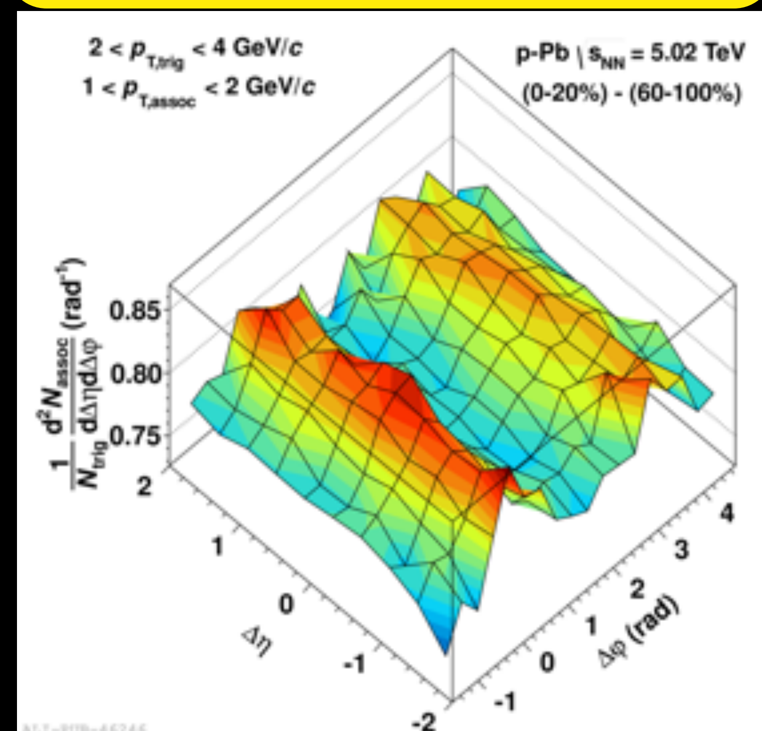


Particle correlations in p-Pb
- Double ridge
- Identified particle correlations



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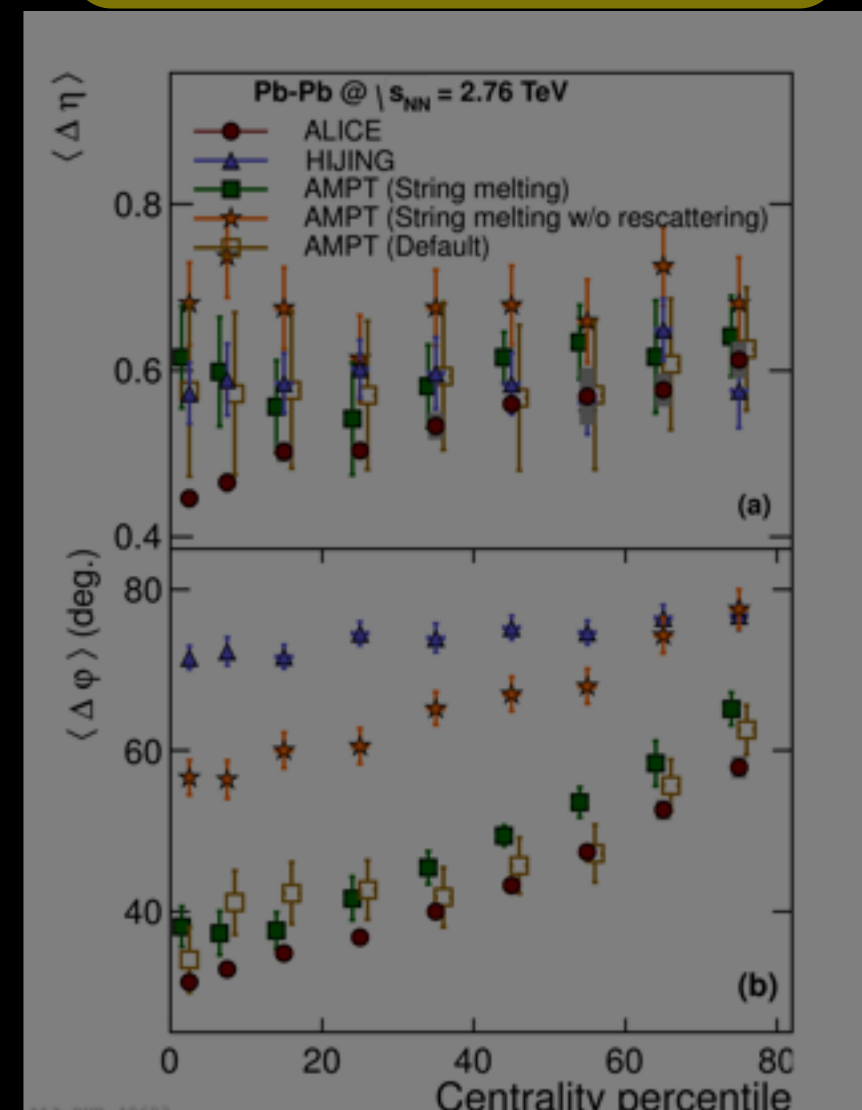
- Jet shape
- Balance functions



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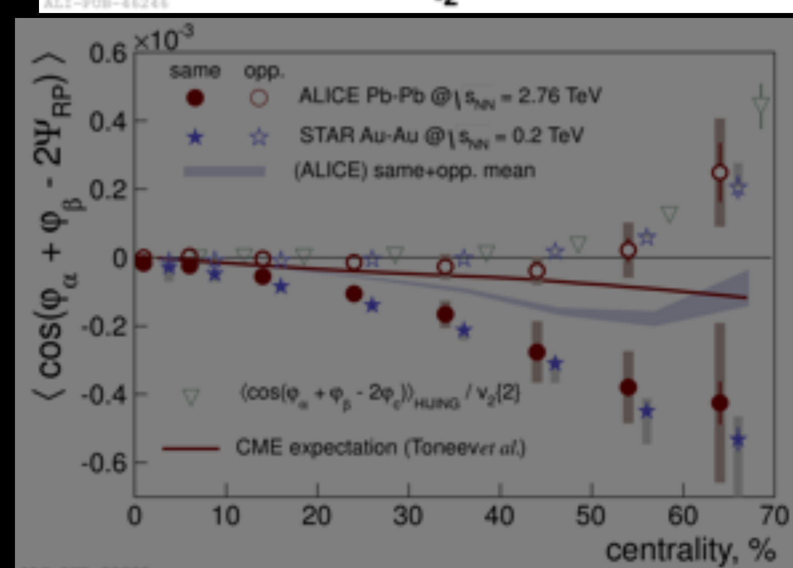
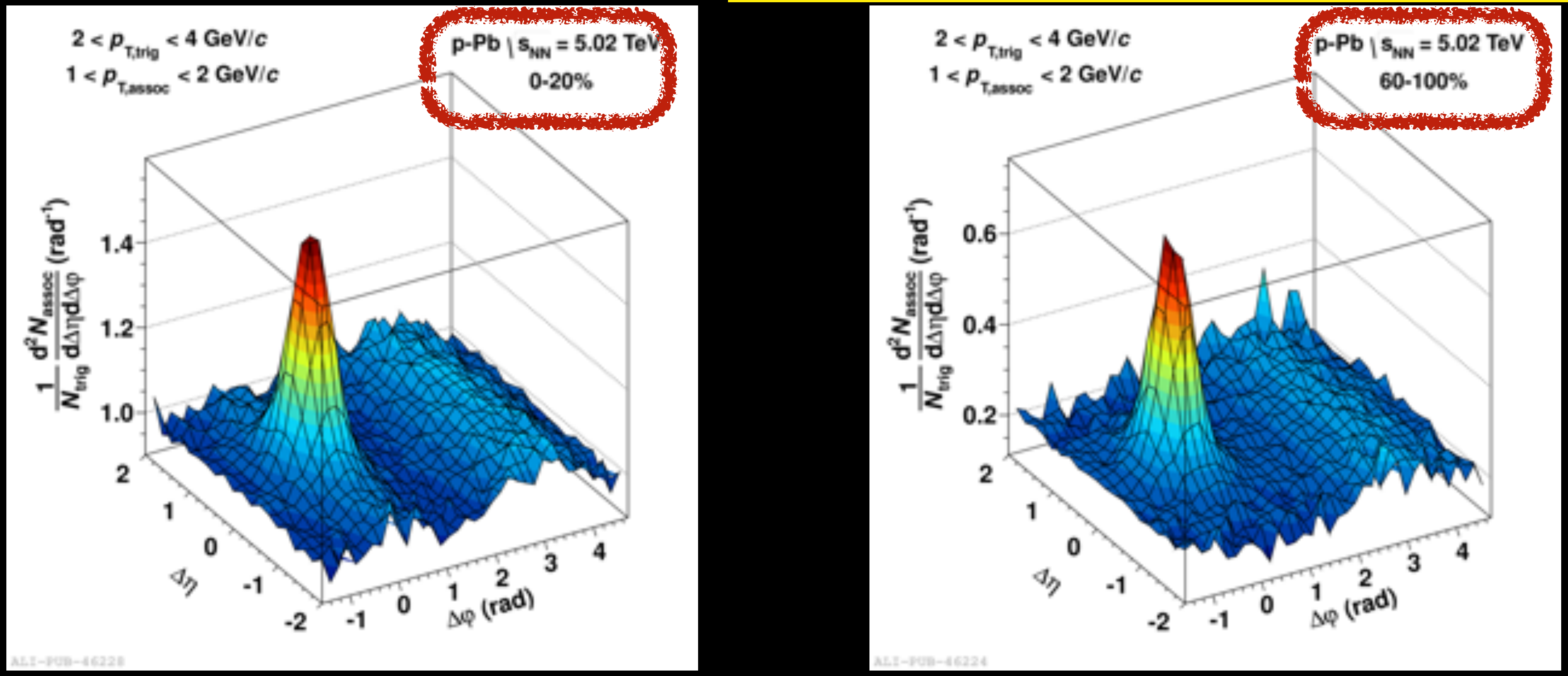


Double ridge in p-Pb: Charged particles

ALICE Collaboration: Phys. Lett. **B719**, (2013) 29



$$\frac{1}{N_{trig}} \frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi} \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$

$$S(\Delta\eta,\Delta\varphi) = \left(\frac{1}{N_{trig}} \frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi} \right)_{same}$$

$$B(\Delta\eta,\Delta\varphi) = a \left(\frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi} \right)_{mixed}$$

- Near side ridge is observed in central p-Pb collisions

Andreas Morsch (25/7 Plenary session@ 11:30)

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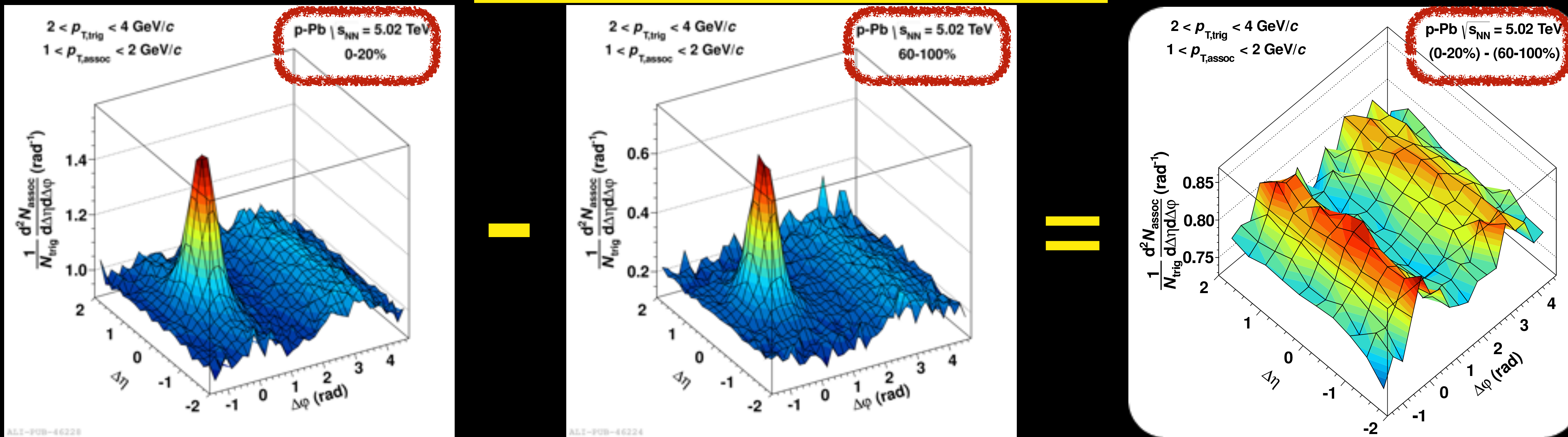

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$$B(\Delta\eta,\Delta\varphi)=a\left(\frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi}\right)_{mixed}$$

- Near side ridge is observed in central p-Pb collisions
- Subtraction of the jet component i.e. as measured in the 60-100% centrality class reveals
  - ★ a double symmetric ridge on the near and the away side!

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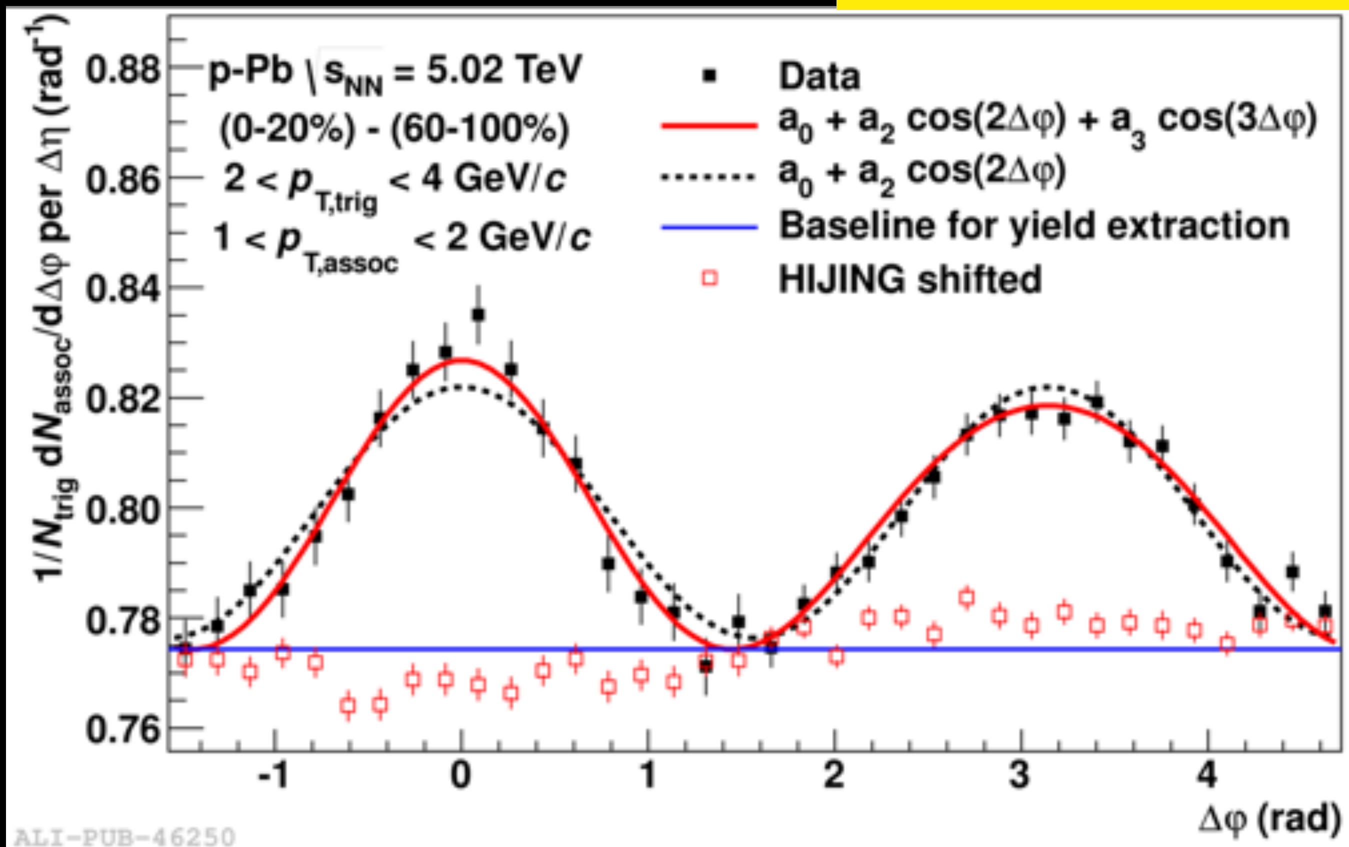
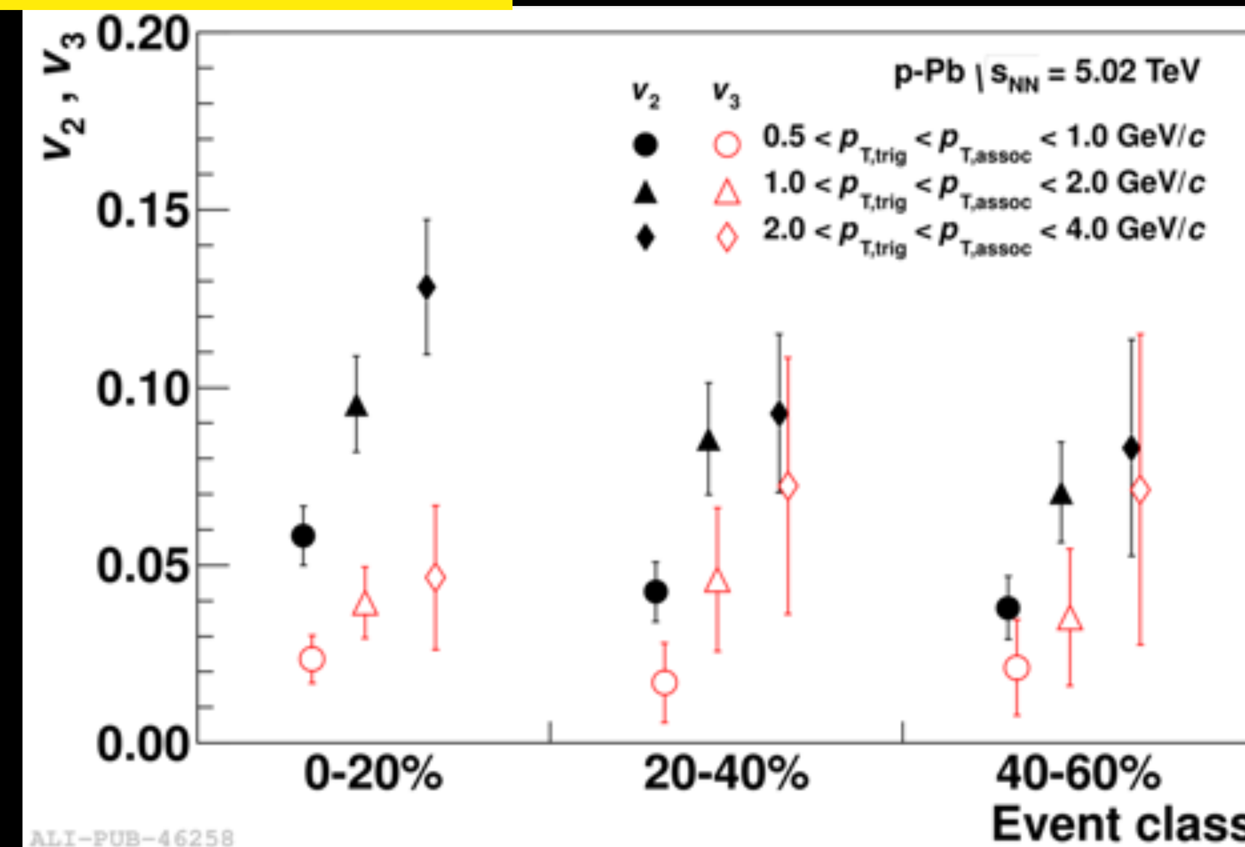


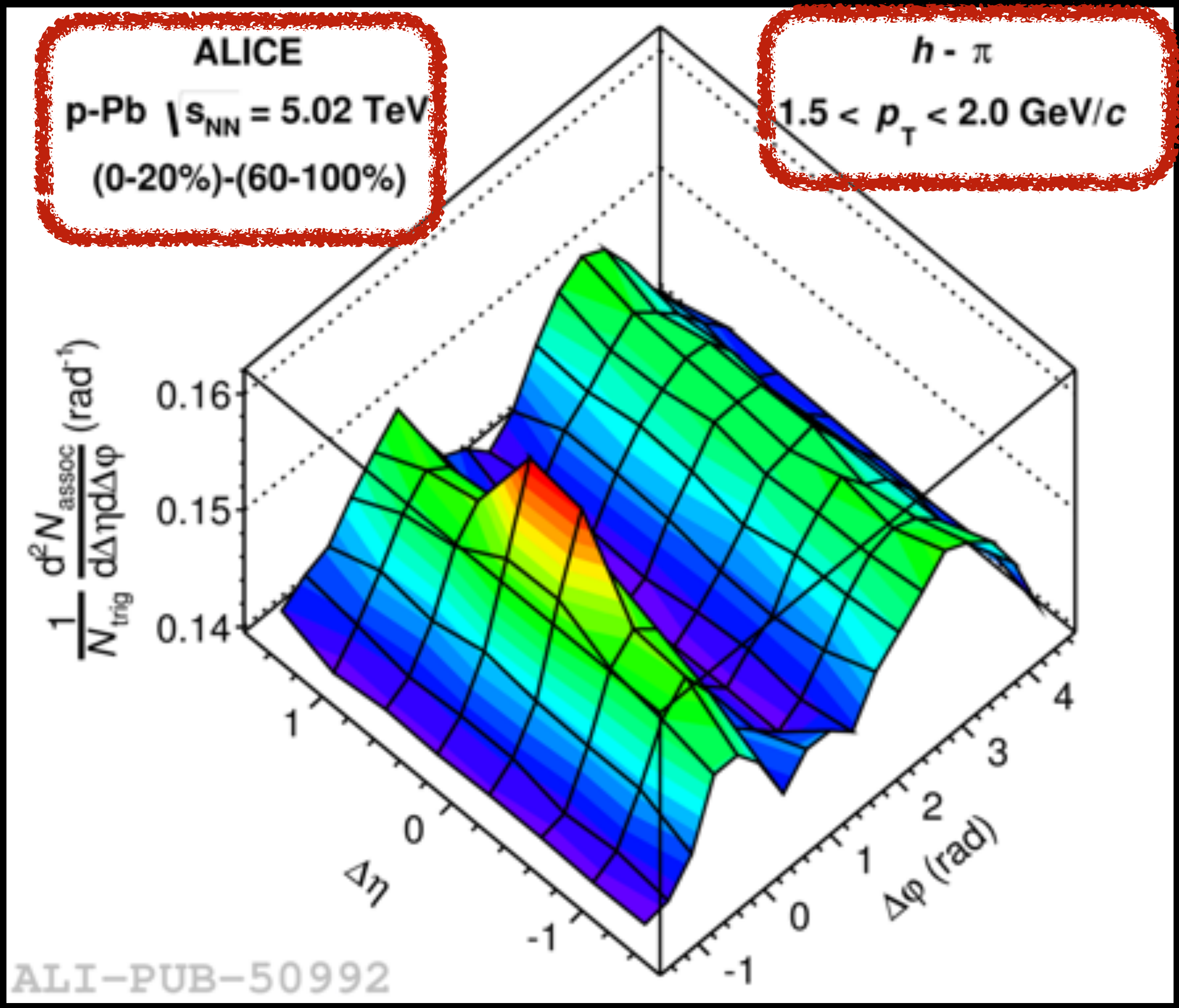


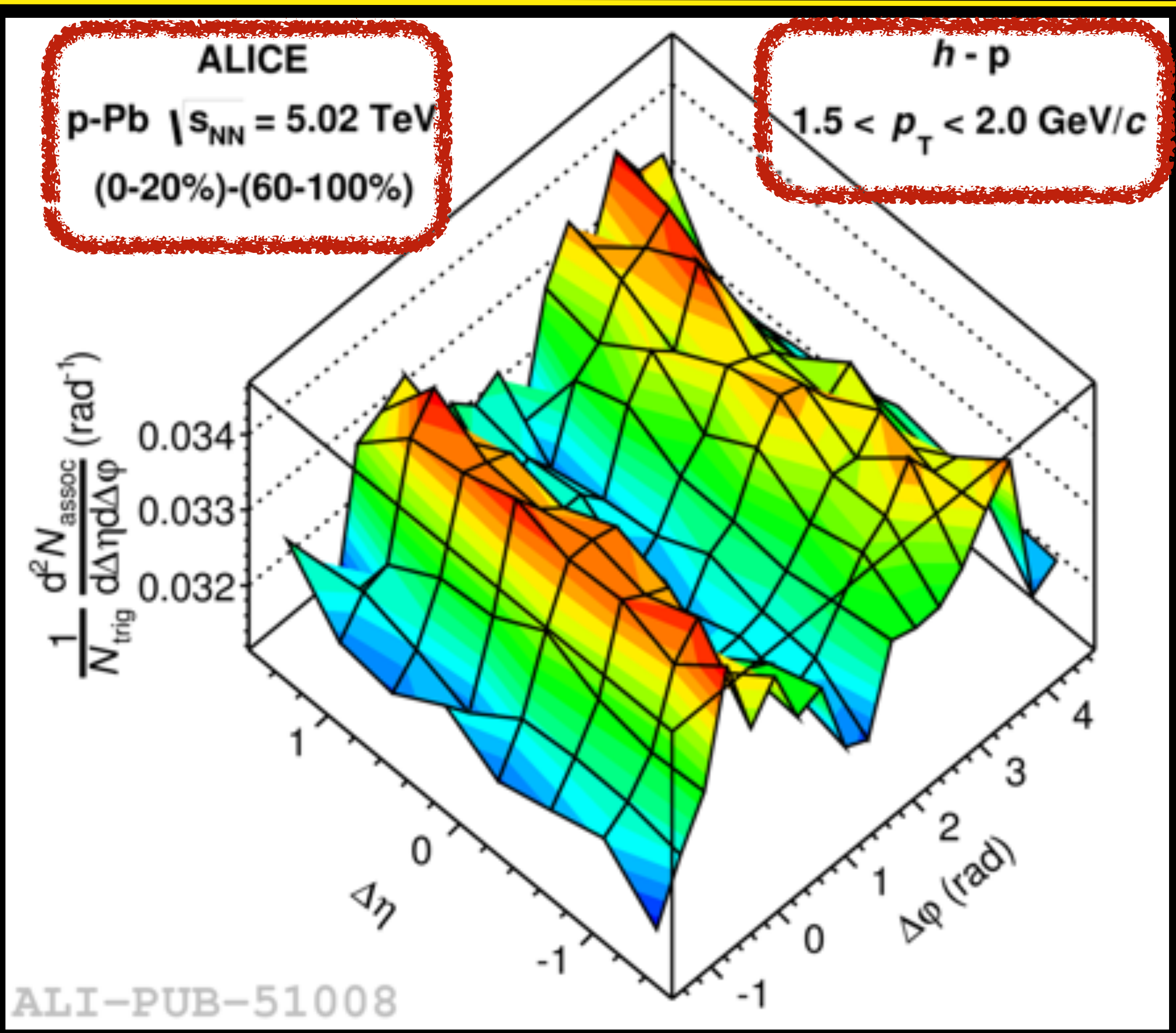
$$\frac{1}{N_{trig}}\frac{dN_{assoc}}{d\Delta\varphi} = a_0 + a_2\cos(2\Delta\varphi) + a_3\cos(3\Delta\varphi)$$

- Fourier decomposition using the 2nd and the 3rd harmonic
- v_2 and v_3 increase with increasing p_T, while exhibiting a mild multiplicity dependence
- In qualitative agreement with hydro and CGC calculations

K.Dusling and R. Venugopalan, arXiv:1302.7018
P. Bozek and W. Broniowski, arXiv:1211.0845

Associated yield per trigger: π-h, K-h, p-h

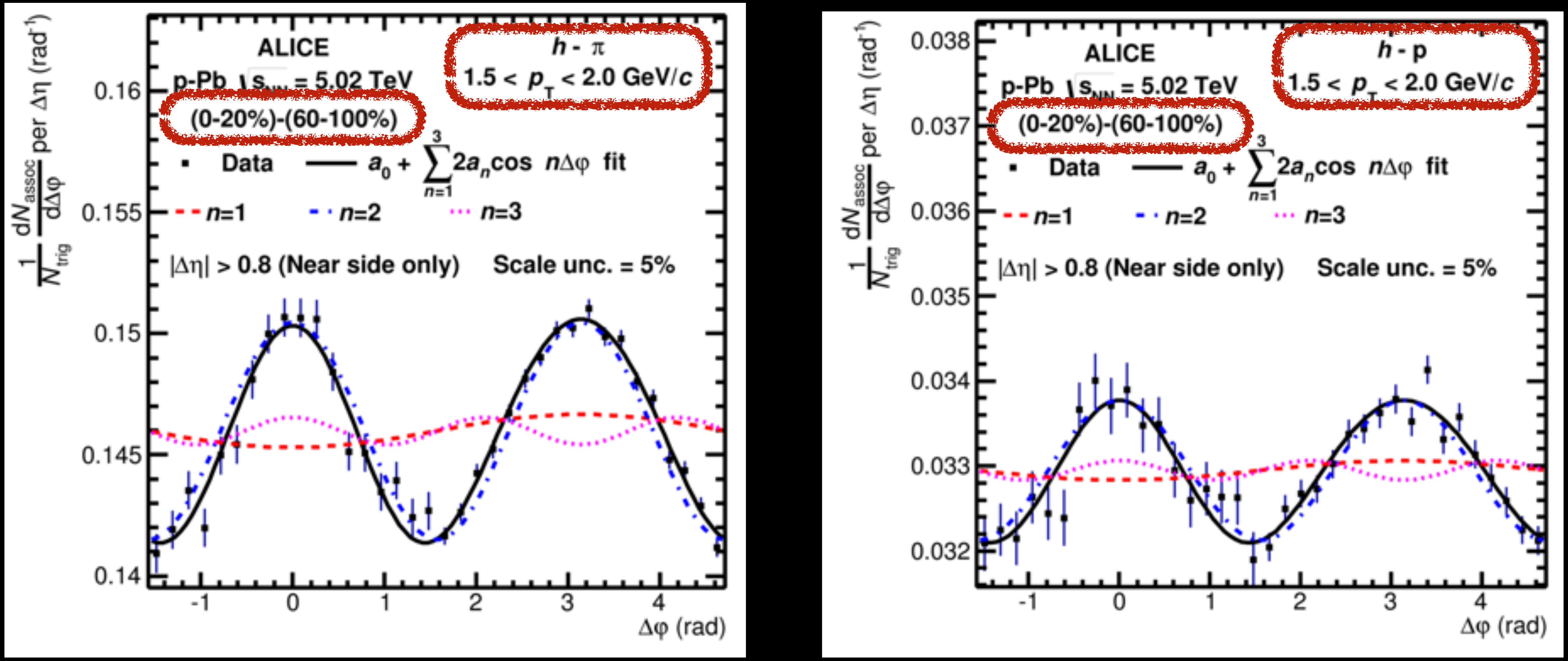




- Similar analysis: charged particle ⇒ "trigger", (π,K,p) ⇒ "associated"
- Jet component reduction: (0-20)% - (60-100)%
- Symmetric ridges in all cases i.e. π-h, K-h, p-h
  - ★ Residual near side jet peak for π-h and to a smaller extent K-h

Leonardo Milano (26/7 Parallel session @ 15:20)

Fourier decomposition

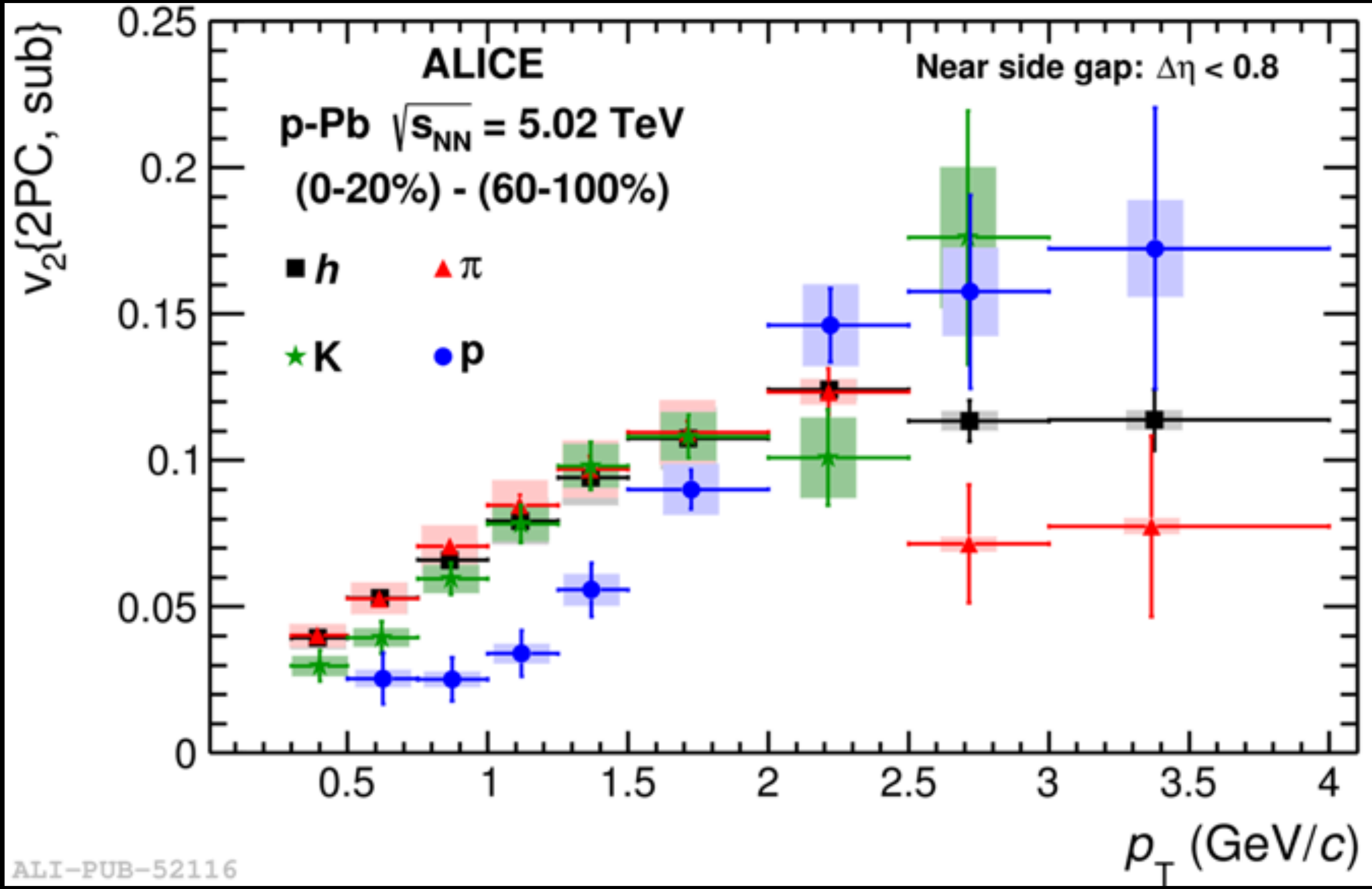


$$\frac{1}{N_{trig}}\frac{dN_{assoc}}{d\Delta\varphi}=a_0+a_1\cos(\Delta\varphi)+a_2\cos(2\Delta\varphi)+a_3\cos(3\Delta\varphi)$$

- After subtraction: symmetric double ridges for h-π, h-K, h-p
- Small contribution from the odd coefficients

Leonardo Milano (26/7 Parallel session @ 15:20)

Results on p_T-differential v_2



- Mass splitting observed in p-Pb collisions!
- Qualitatively similar picture as in Pb-Pb
  - ★ Qualitatively consistent with a system that develops some degree of collective behavior

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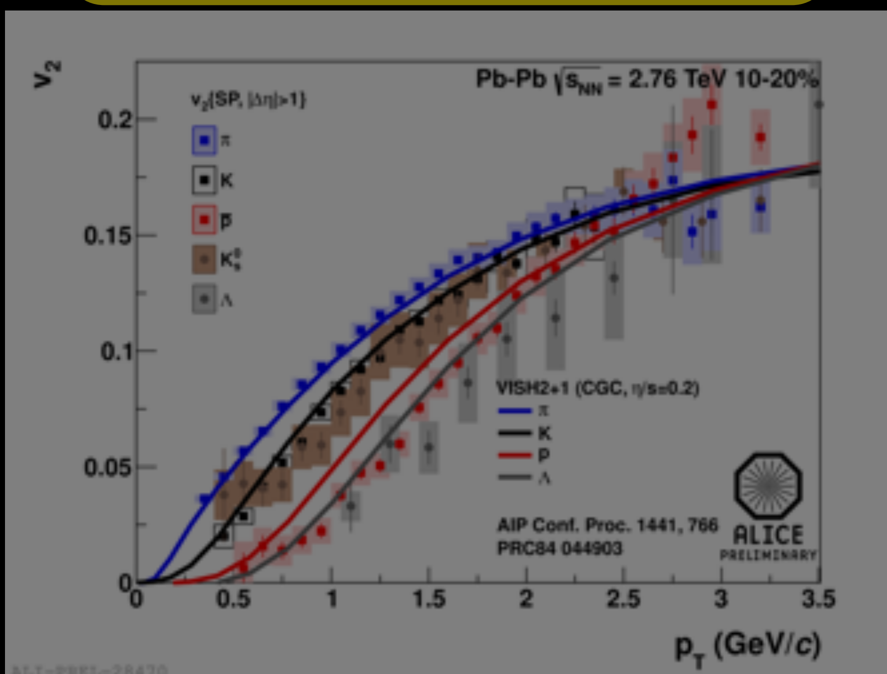

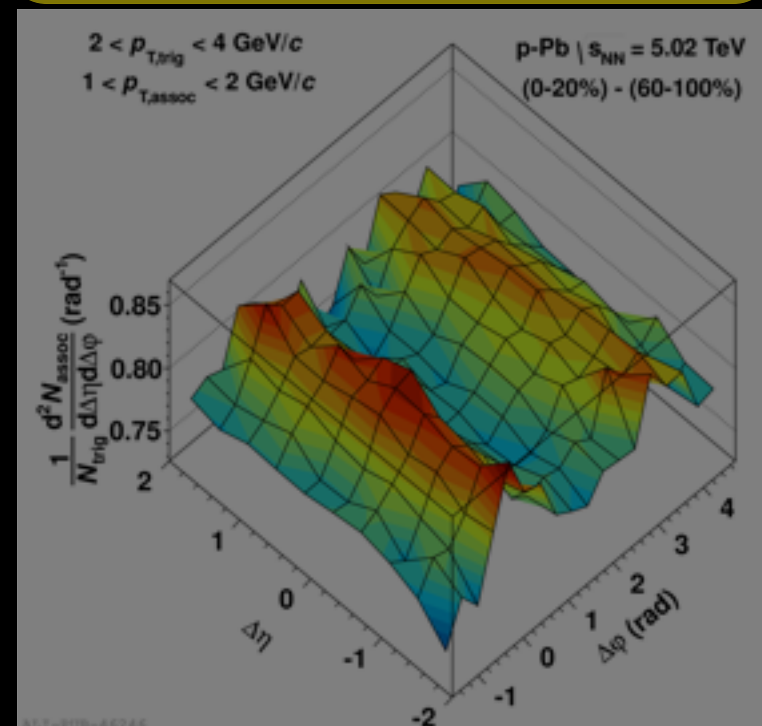

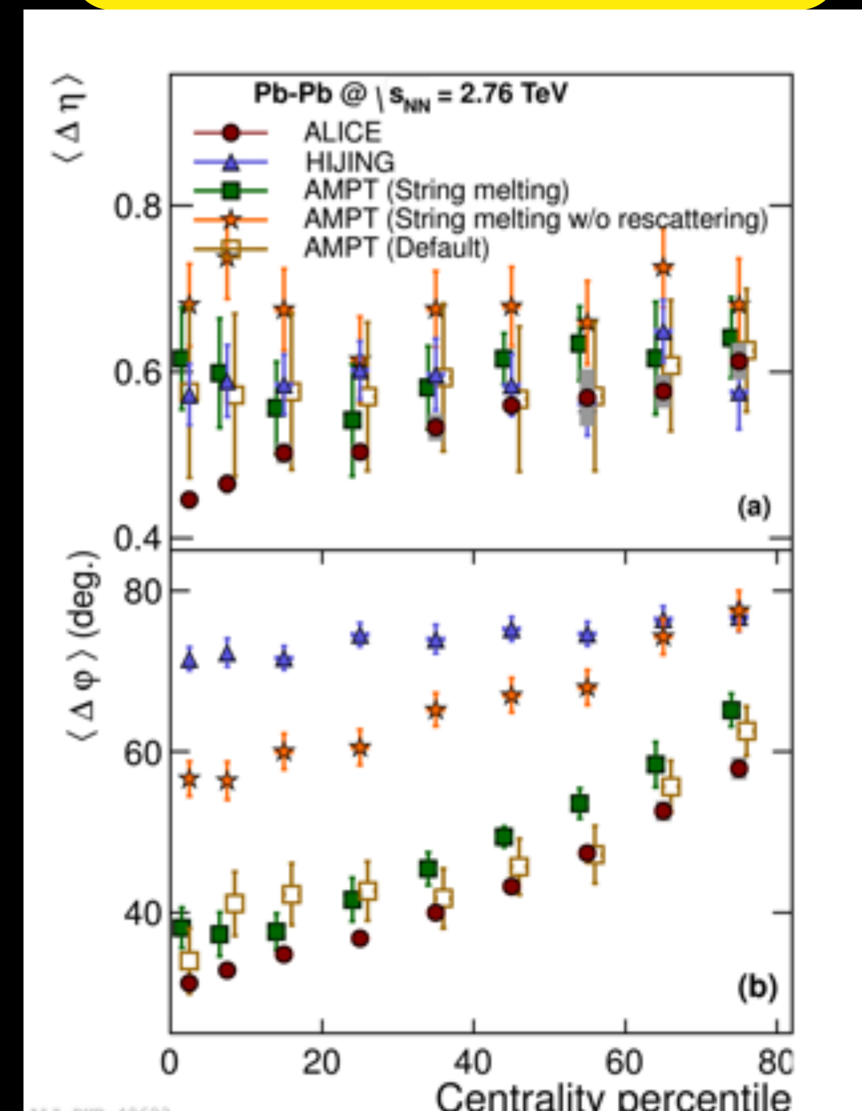

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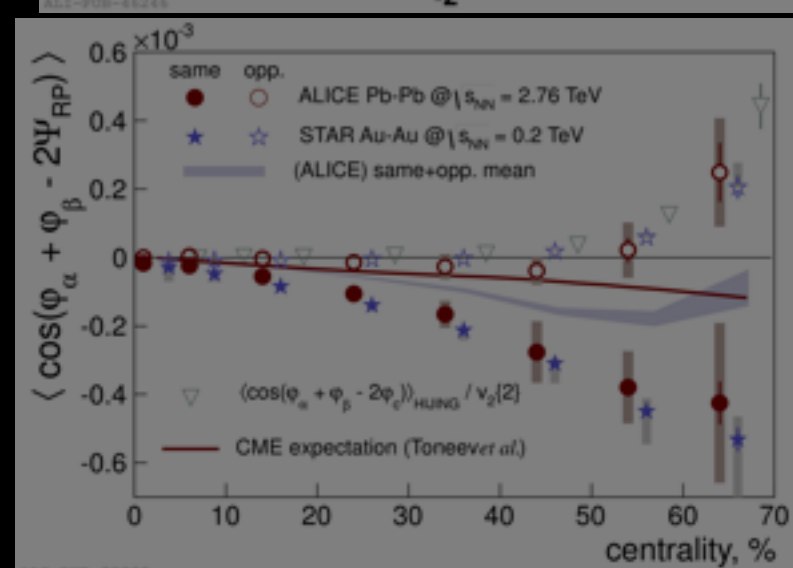

N. Armesto *et al.*, Phys. Rev. Lett., **93**, (2004) 242301

- Investigate potential changes in the near-side peak shape
- Probe jet broadening when coupled to the longitudinally flowing medium

Marek Bombara (23/7 Parallel session@ 15:20)

Jet shapes in Pb-Pb

N. Armesto *et al.*, Phys. Rev. Lett., **93**, (2004) 242301

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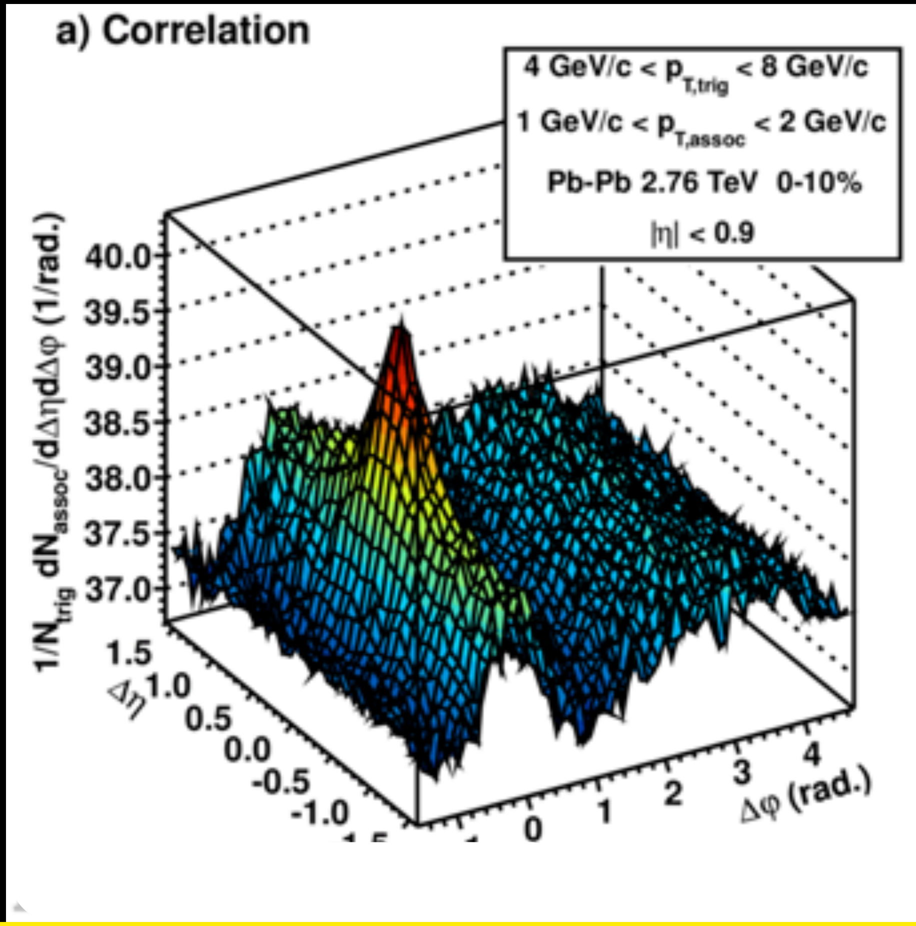

Estimate Δη independent effects by quantifying the long range correlations ($|\Delta\eta| > 1$)

Associated yield per trigger particle from same and mixed events

$$\frac{1}{N_{trig}} \quad \frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi} \quad \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$

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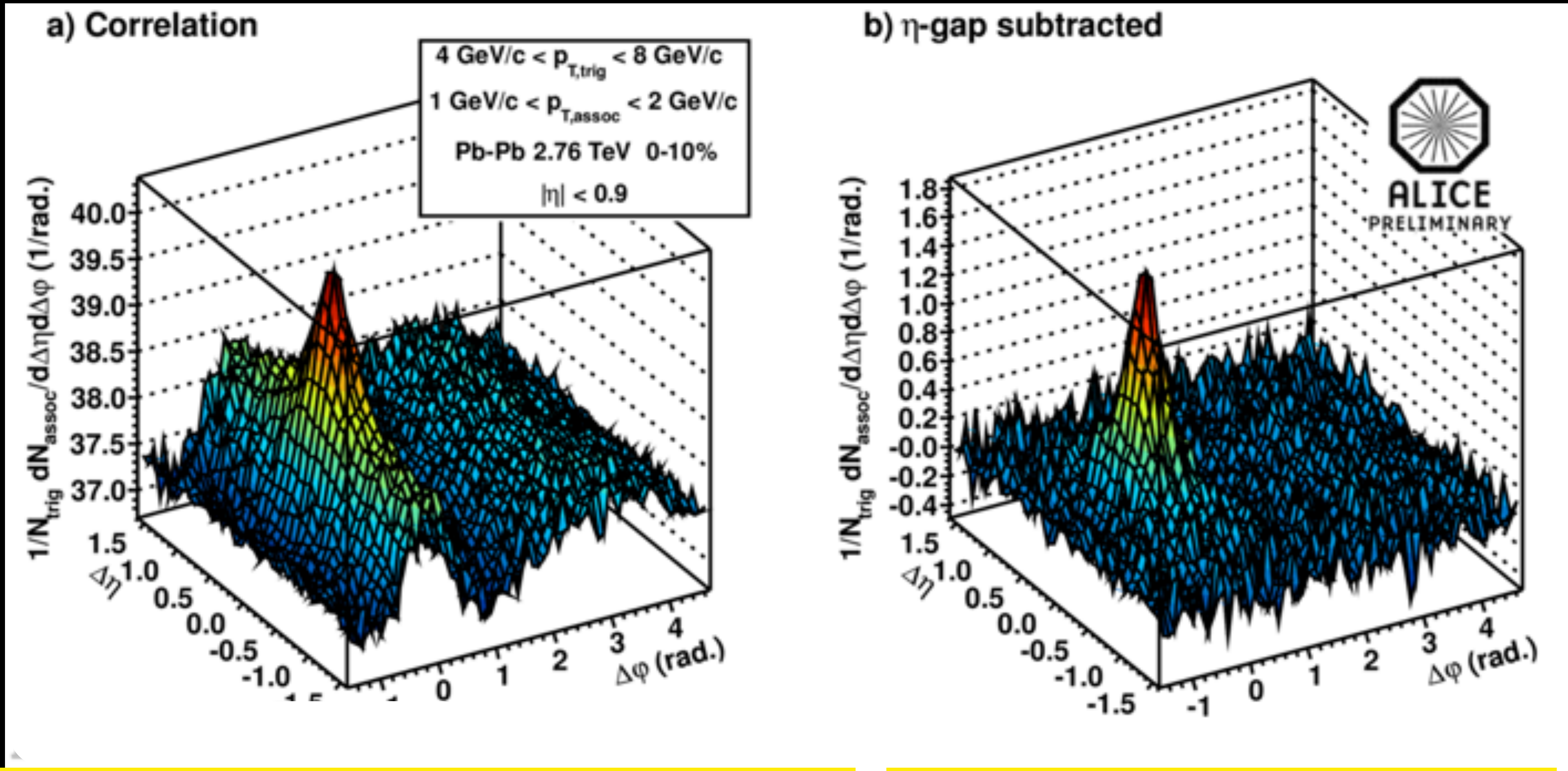

Estimate Δη independent effects by quantifying the long range correlations (|Δη| > 1)

Subtract from short range region (|Δη| < 1)

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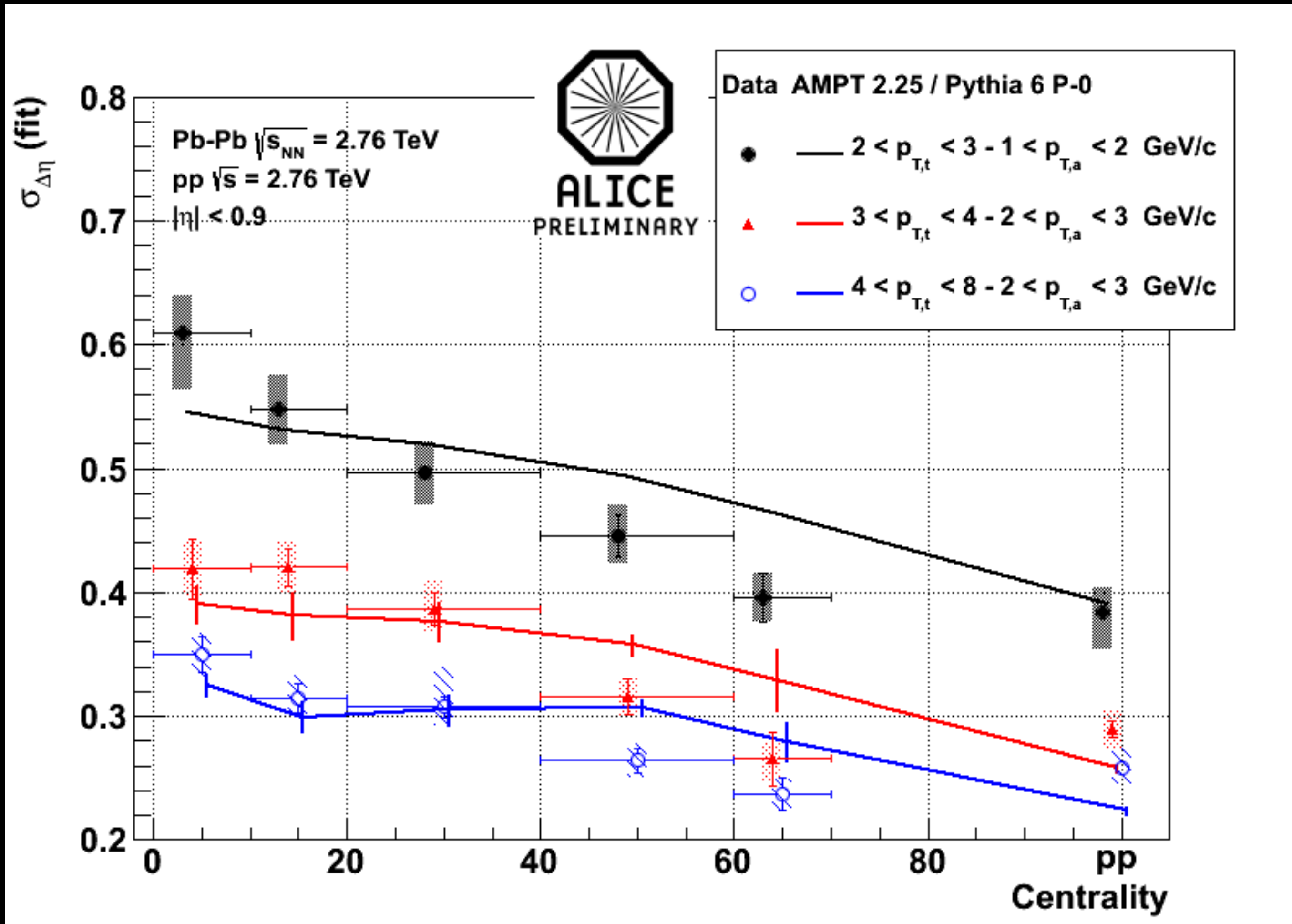

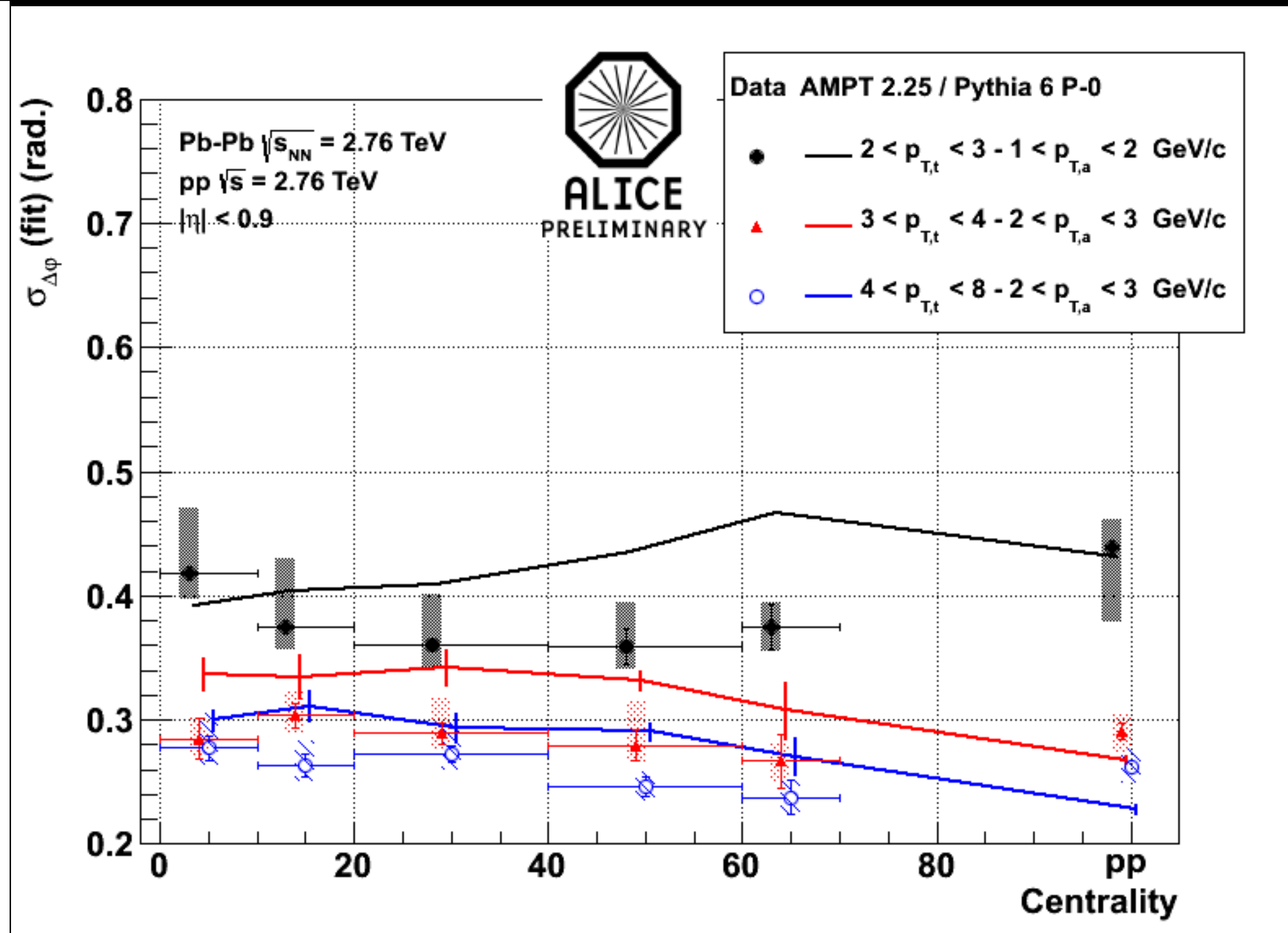

- Significant centrality dependence for $\sigma_{\Delta\eta}$ but mild effect for $\sigma_{\Delta\varphi}$
- AMPT describes fairly well the data points
- Interplay of jets with flow?

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Balance functions in Pb-Pb

S. Bass, P. Danielewicz and S.Pratt , Phys. Rev. Lett. **85**, (2000) 2689

$$B_{+-}(\Delta\eta,\Delta\varphi,p_{T,trig},p_{T,assoc}) = \frac{1}{2}(C_{US}-C_{LS})$$

$C_{US}: C_{+-}, C_{-+}$

$C_{LS}: C_{++}, C_{--}$

$$C_{+-} = \left(\frac{N_{+-}}{N_{+}}\right)/f_{+-}$$

f_{+-} → Detector acceptance and inefficiencies (mixed events or from convolution of single particle distributions)

N_{+-}/N_{+} → particle pair density normalized to the number of trigger particles

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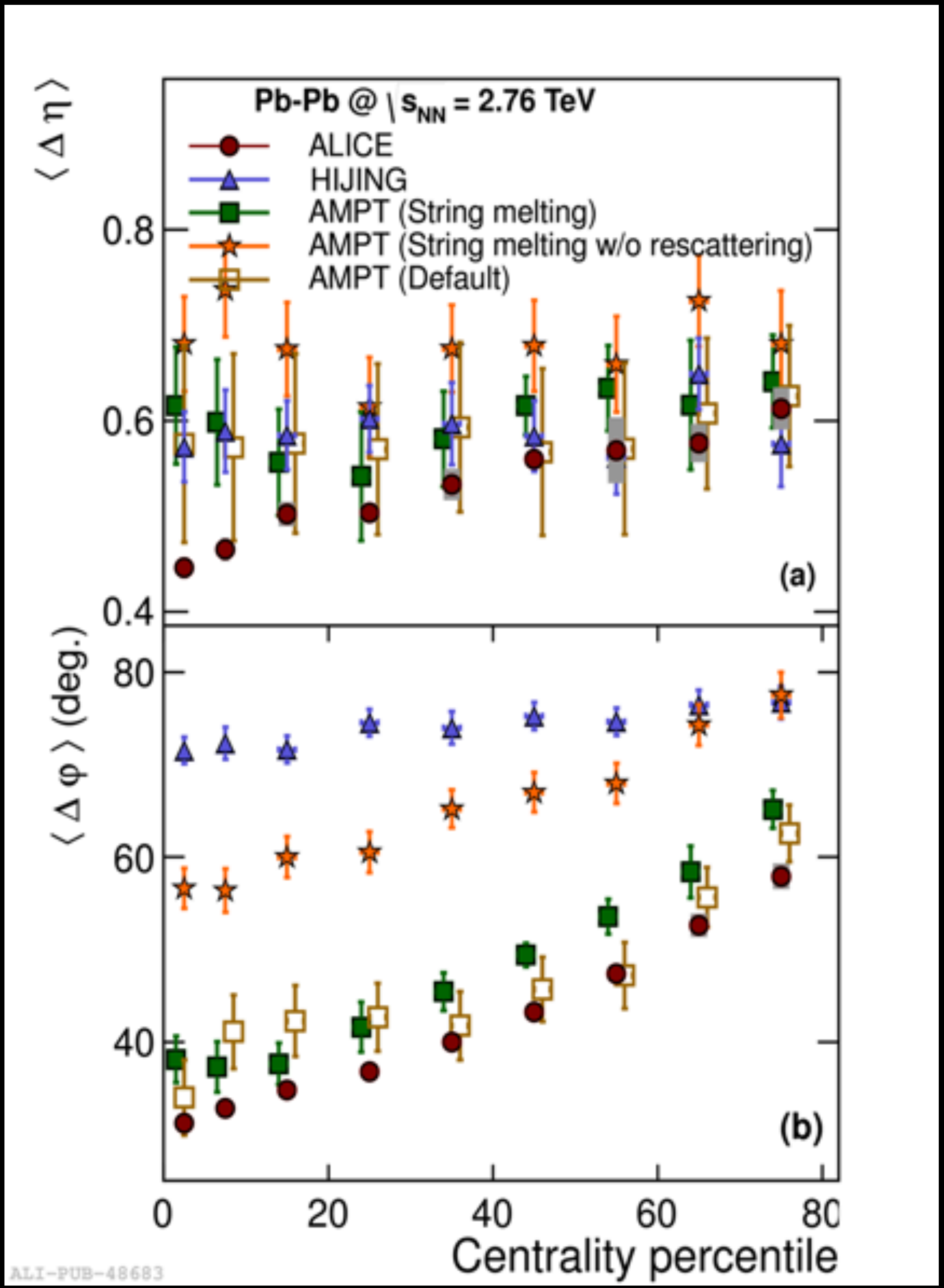
Detector acceptance and inefficiencies (mixed events or from convolution of single particle distributions)

particle pair density normalized to the number of trigger particles

ALICE Collaboration: Phys. Lett. **B723**, (2013) 267



- Width probes the formation time of balancing charges (affected also by radial flow)
- Data: strong centrality dependence
  - Consistent with the idea of late stage creation of charges focused by radial flow
- Models that incorporate collective effects (e.g. AMPT) in quantitative agreement with data (for Δφ)

Outline

Flow results in Pb-Pb

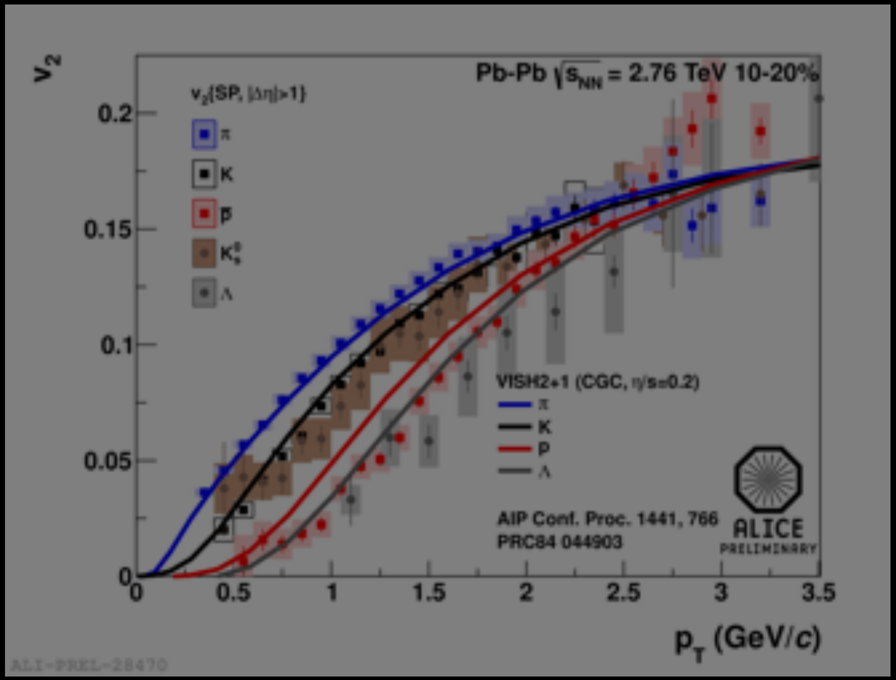
- Directed flow measurements
- Flow fluctuations at high p_T and at forward η
- Symmetry plane correlations
- Identified particle v_2 in Pb-Pb

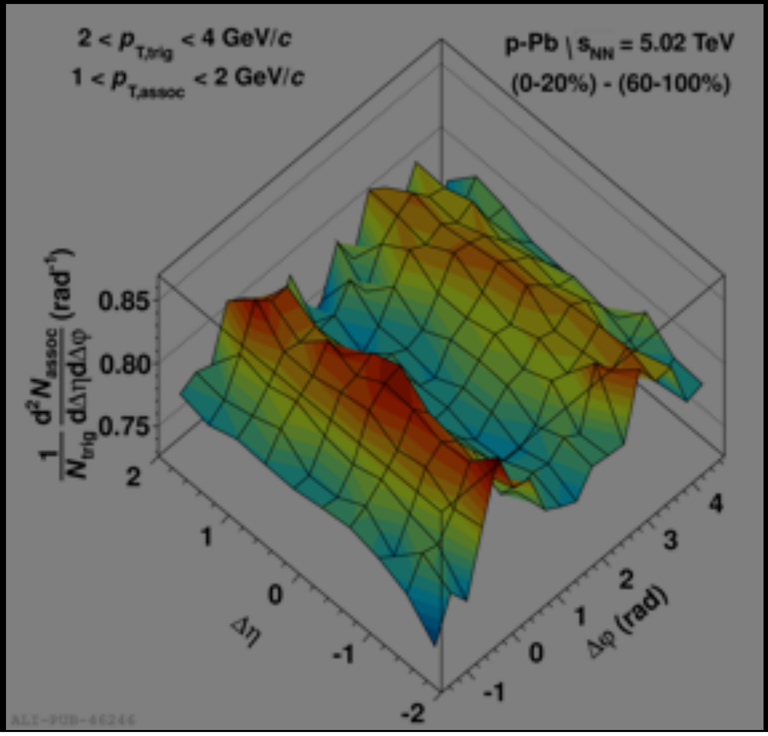
Particle correlations in p-Pb

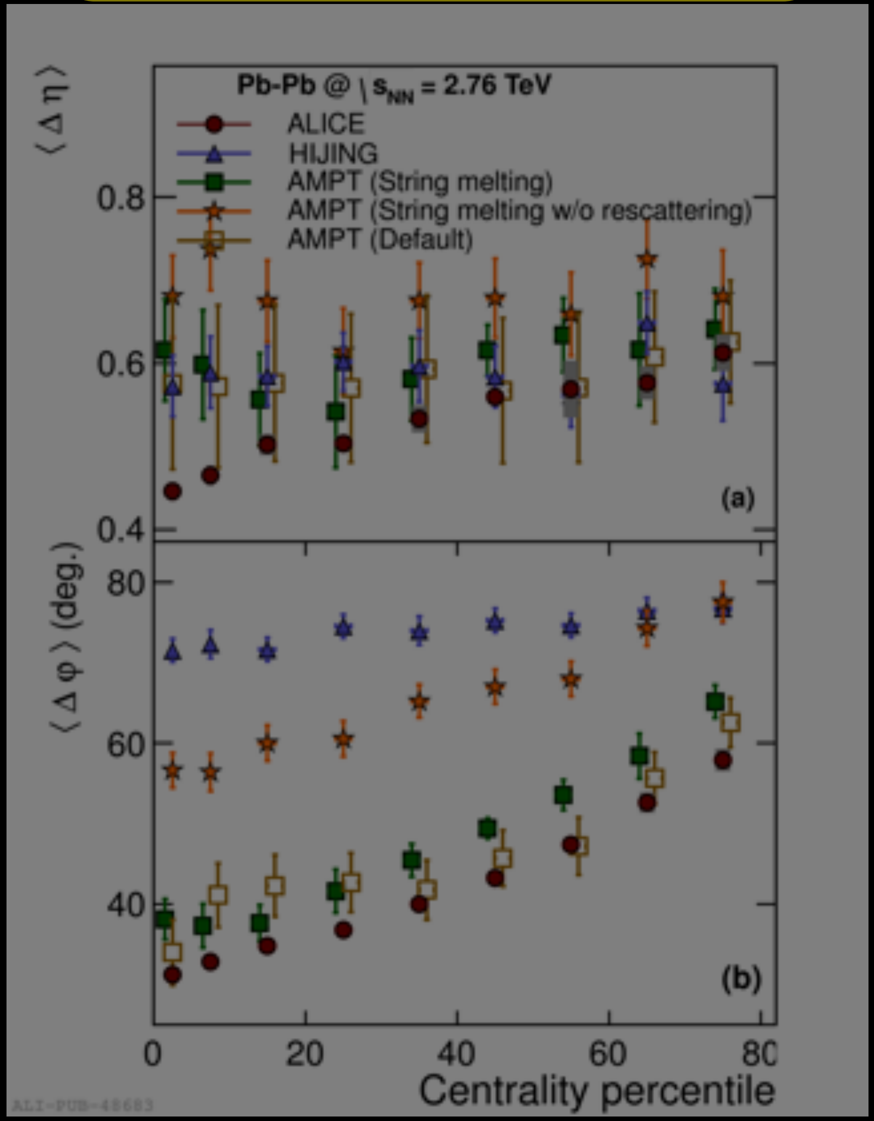
- Double ridge
- Identified particle correlations

Two-particle correlations in Pb-Pb

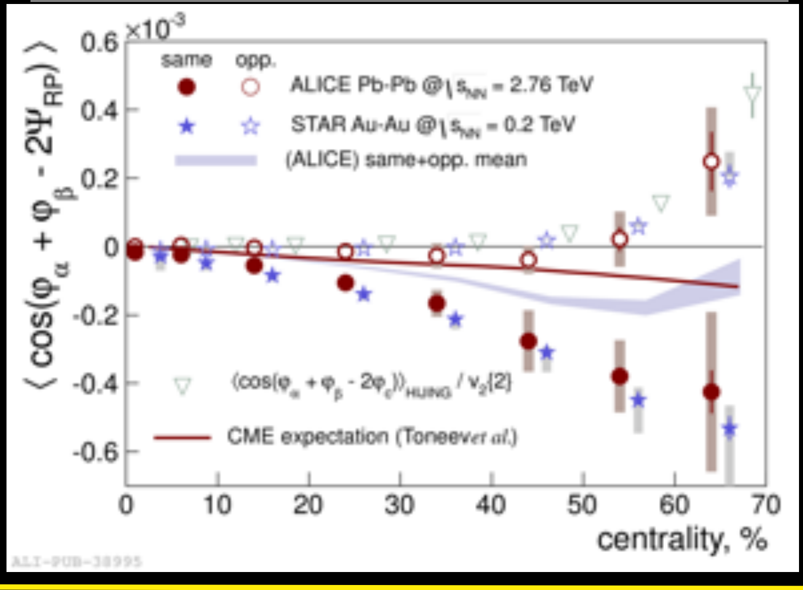
- Jet shape
- Balance functions



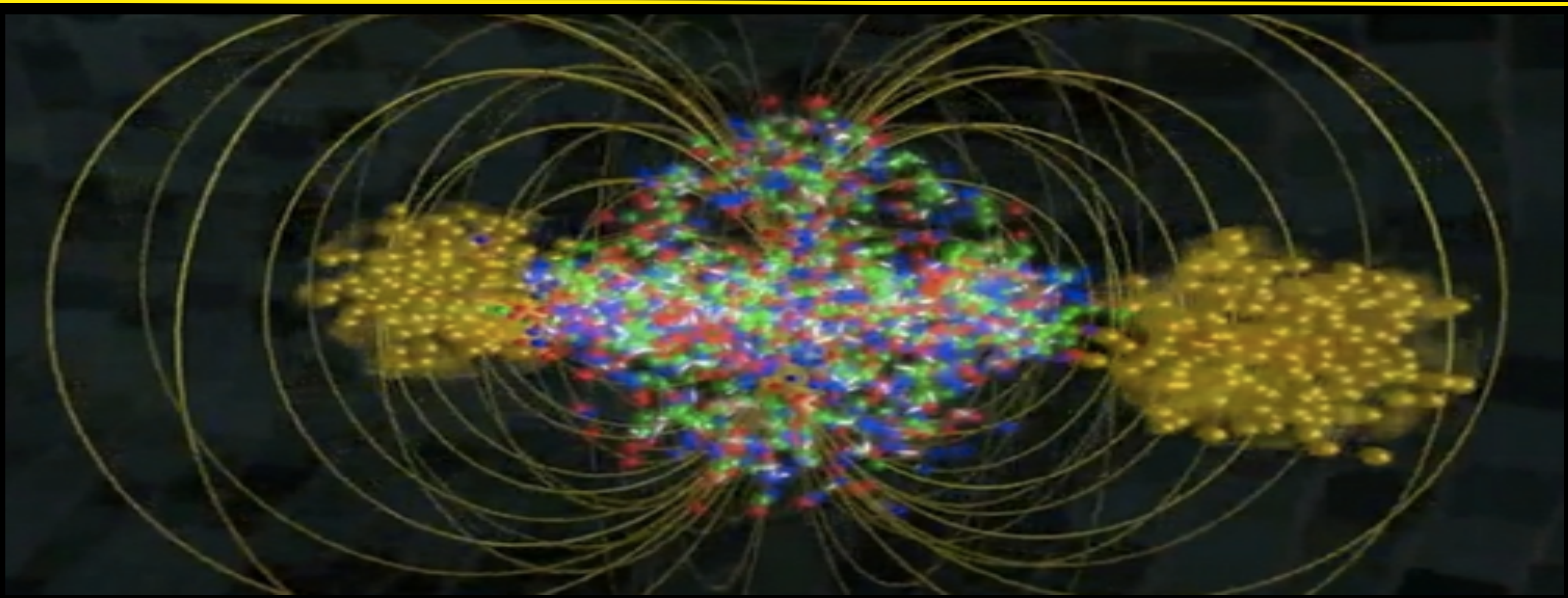




Testing the Chiral Magnetic Effect



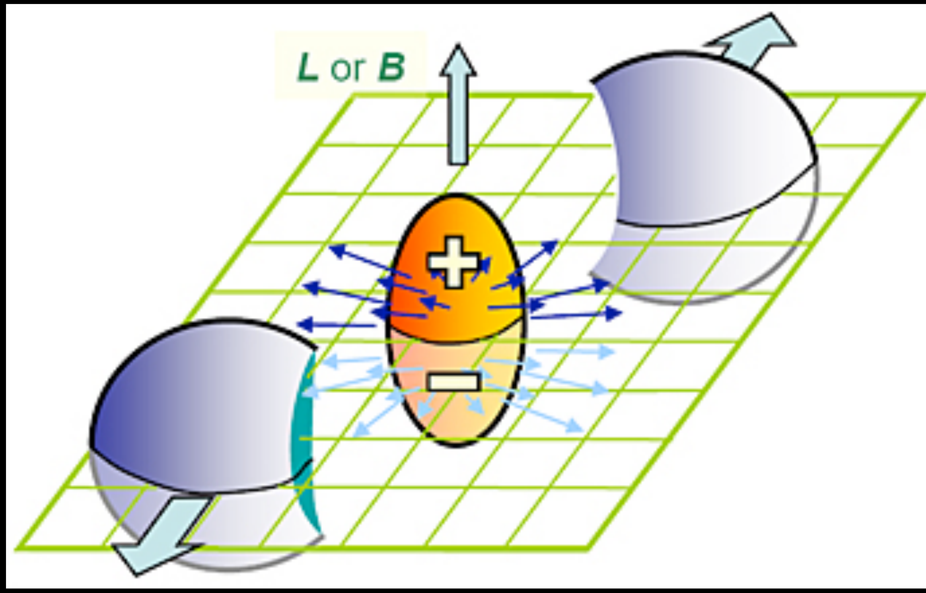
The Chiral Magnetic Effect (CME)



- Ions collide ⇒ strong magnetic field (~10^{17} - 10^{19} G!!!)
- Deconfined phase (if conditions are satisfied)
- Theory: exited QCD vacuum states (domains) ⇒ P and CP invariance locally broken
- Interaction of quarks with these domains and with the magnetic field ⇒spin alignment and development of an E/M current

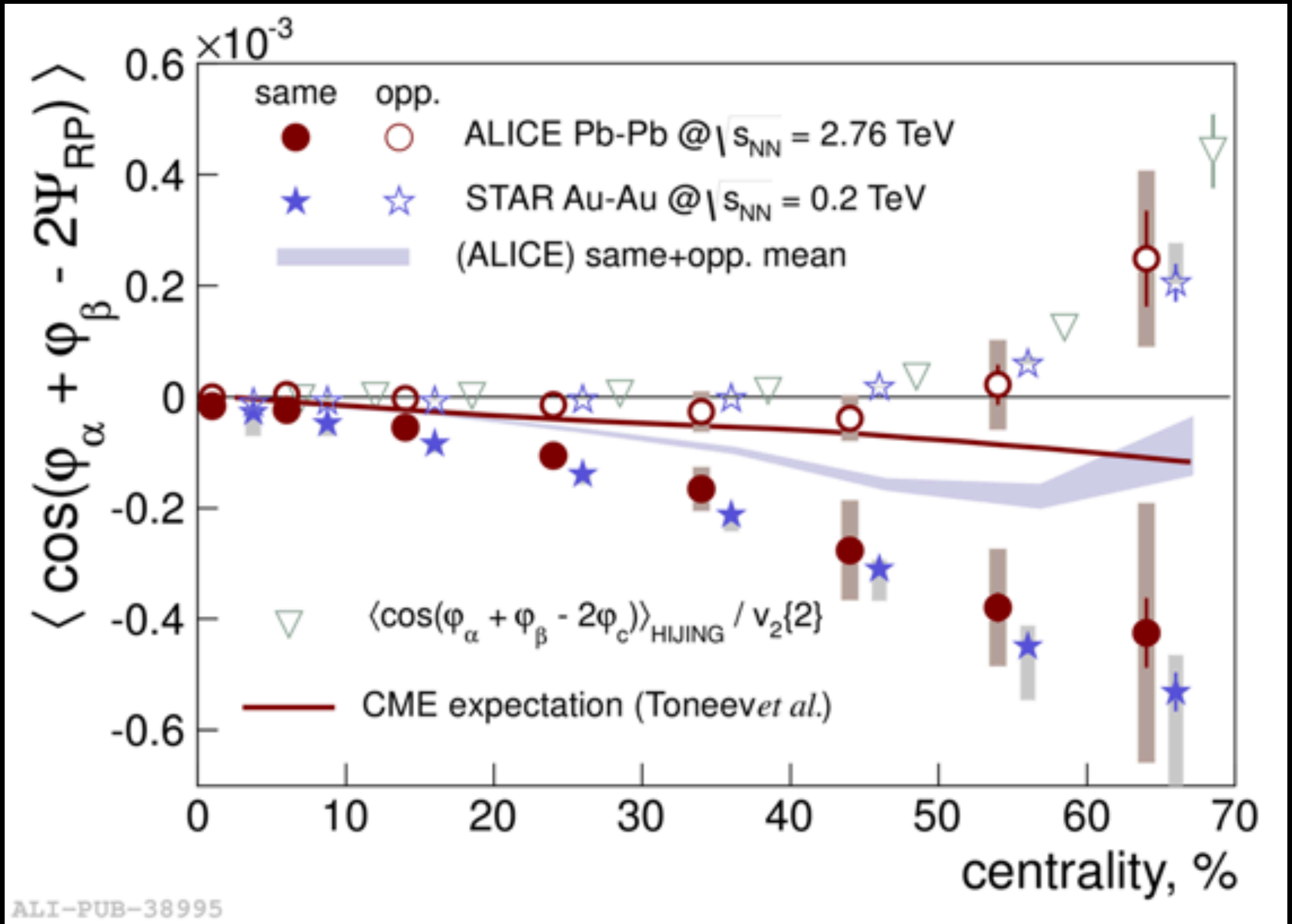
EDM of QCD matter

Experimental consequence: charge asymmetry wrt to Ψ_2



Search for the chiral magnetic effect

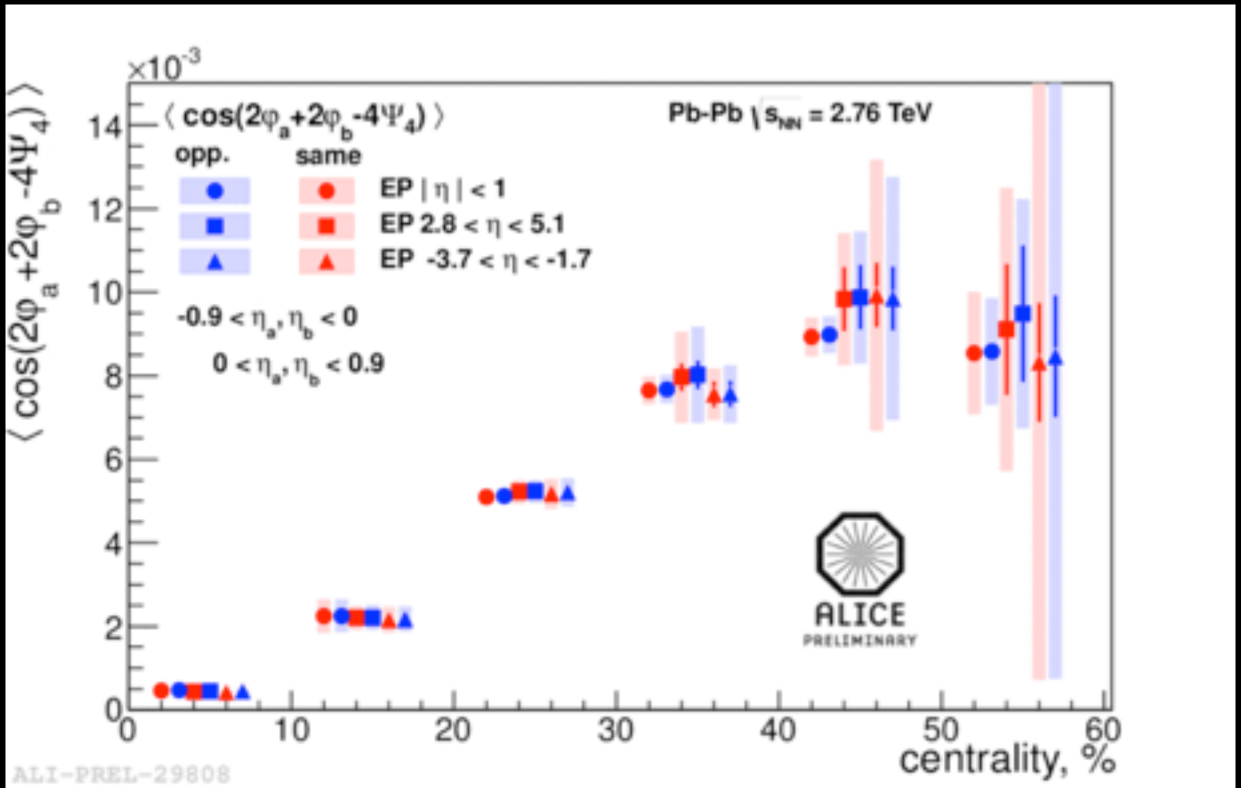
(ALICE Collaboration), Phys. Rev. Lett. **110**, (2013) 012301



- Results in qualitative agreement with the CME expectations
- Homework: disentangle background effects from potential CME signal
  - Background: local charge conservation (balance functions) + v_n modulations

Estimating the background contributions: "double harmonic" correlations

J. Mlynarz (ALICE Collaboration) @ QM2012



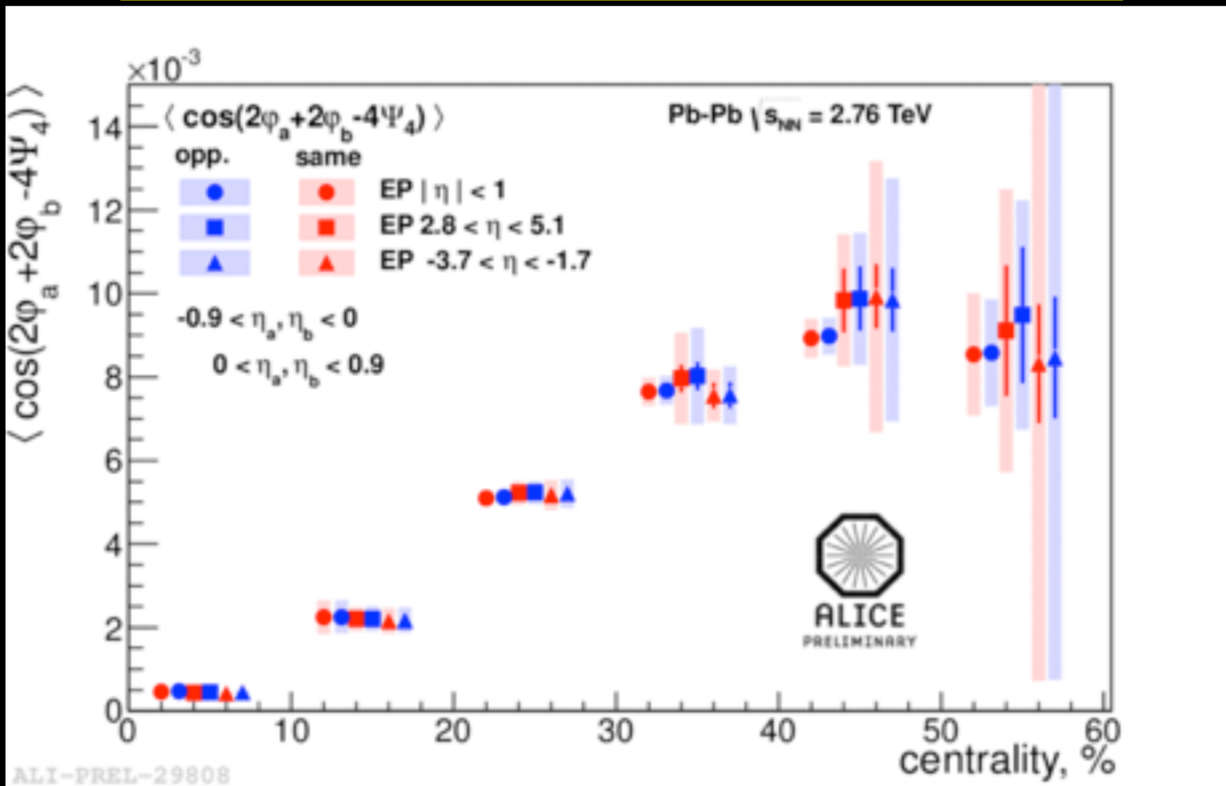
$$\langle \cos(2\varphi_\alpha + 2\varphi_\beta - 4\Psi_4) \rangle$$

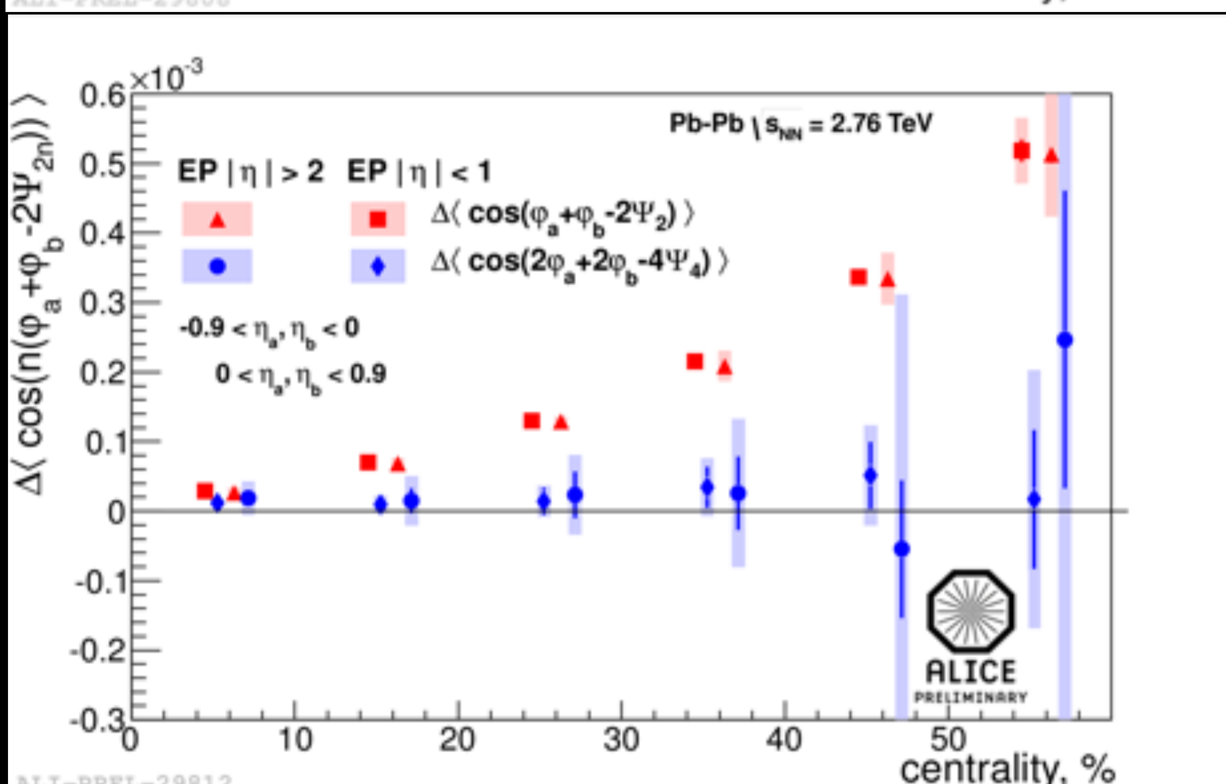
- Charge independent correlations:
  - elliptic flow fluctuations relative to the 4th order symmetry plane
- Charge dependent correlations:
  - no contribution from CME
  - contribution from local charge conservation + v_4

Panos.Christakoglou@nikhef.nl

Estimating the background contributions:"double harmonic" correlations

J. Mlynarz (ALICE Collaboration) @ QM2012





$$\langle \cos(2\varphi_\alpha+2\varphi_\beta-4\Psi_4) \rangle$$

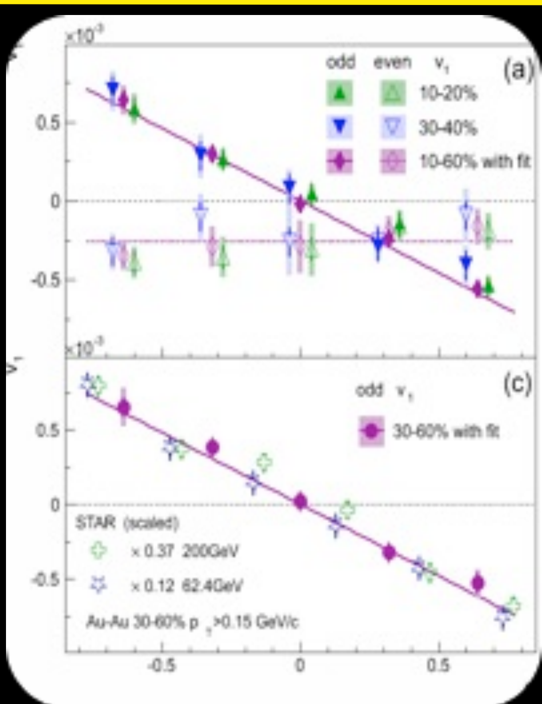
- Charge independent correlations:
  - ★ elliptic flow fluctuations relative to the 4th order symmetry plane
- Charge dependent correlations:
  - ★ no contribution from CME
  - ★ contribution from local charge conservation + v_4

Results show no significant charge dependence within the current (large) statistical and systematic uncertainty ⇒

not significant contribution from background?

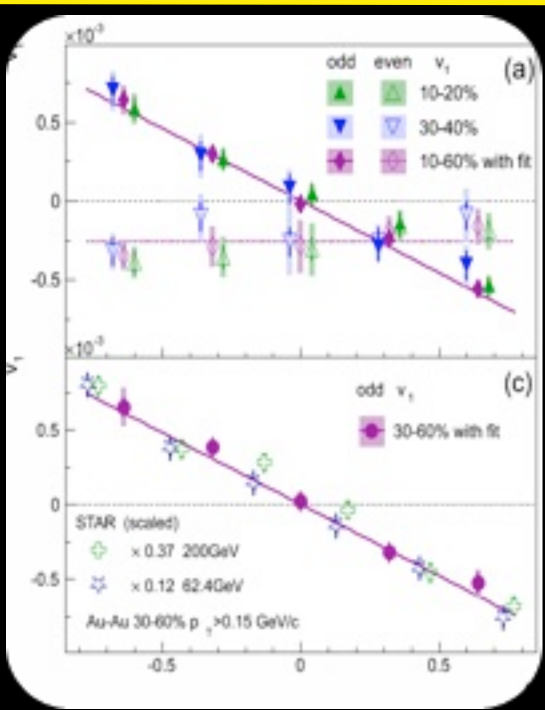
Summary

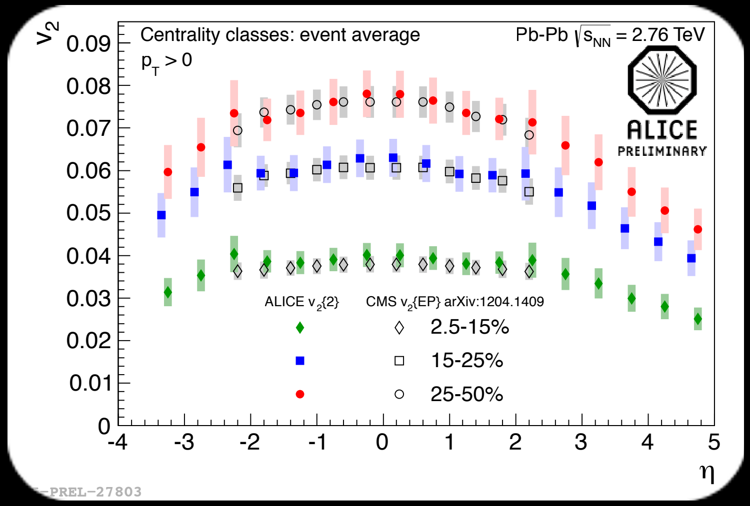
Summary



odd even v_1
(a)
10-20%
30-40%
10-60% with fit
odd v_1
(c)
30-60% with fit
STAR (scaled)
× 0.37 200GeV
× 0.12 62.4GeV
Au-Au 30-60% p_T>0.15 GeV/c

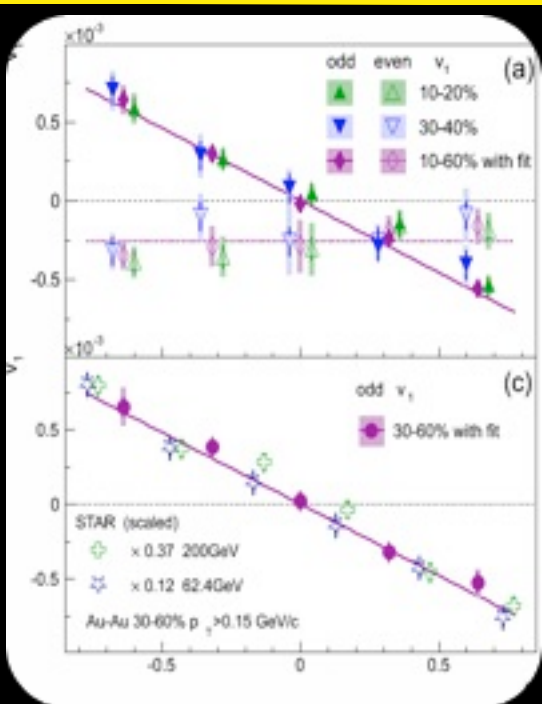
Summary





Panos.Christakoglou@nikhef.nl

Summary


odd even v_1
10-20%
30-40%
10-60% with fit
(a)
(c)
odd v_1
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STAR (scaled)
× 0.37 200GeV
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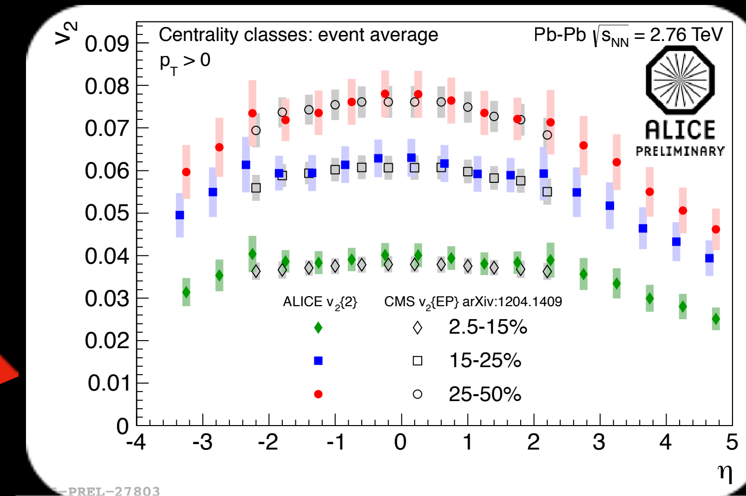
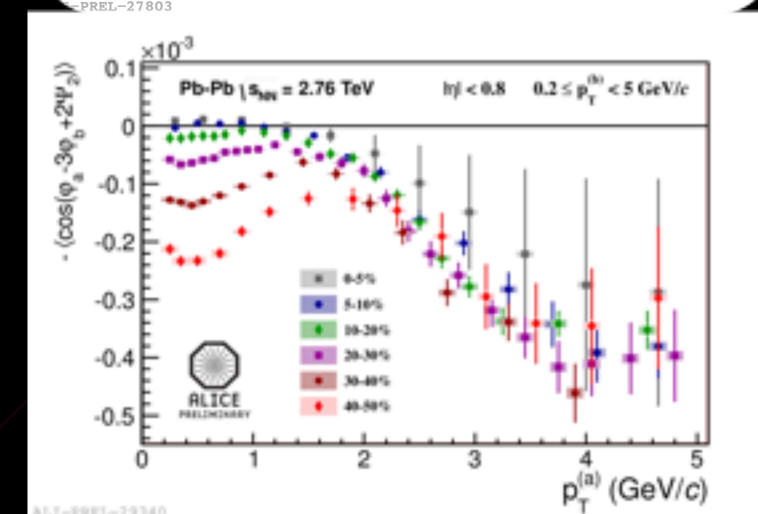
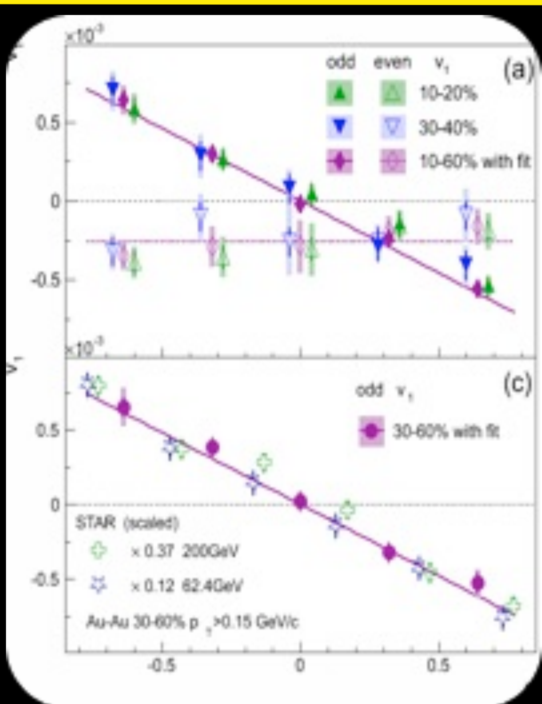

Centrality classes: event average
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$p_T > 0$
ALICE PRELIMINARY
ALICE $v_2\{2\}$
CMS $v_2\{EP\}$ arXiv:1204.1409
2.5-15%
15-25%
25-50%
v_2
η


Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$|\eta| < 0.8$
$0.2 \le p_T^{(b)} < 5$ GeV/c
0-5%
5-10%
10-20%
20-30%
30-40%
40-50%
ALICE PRELIMINARY
$p_T^{(a)}$ (GeV/c)

Summary


odd even v_1
(a)
10-20%
30-40%
10-60% with fit
(c)
odd v_1
30-60% with fit
STAR (scaled)
× 0.37 200GeV
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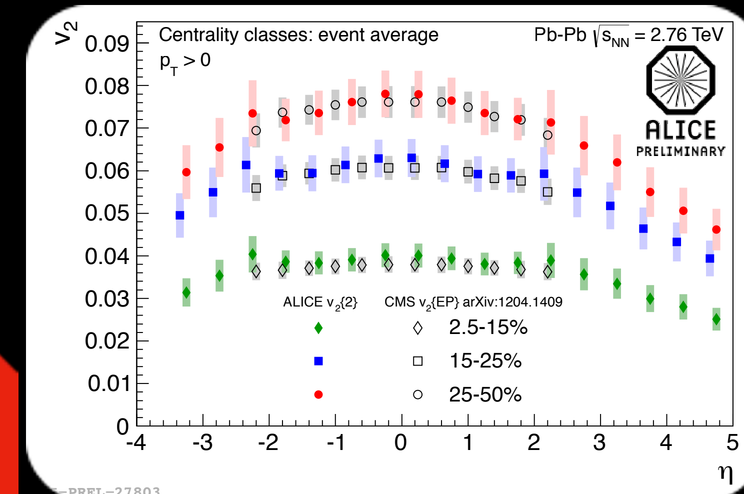
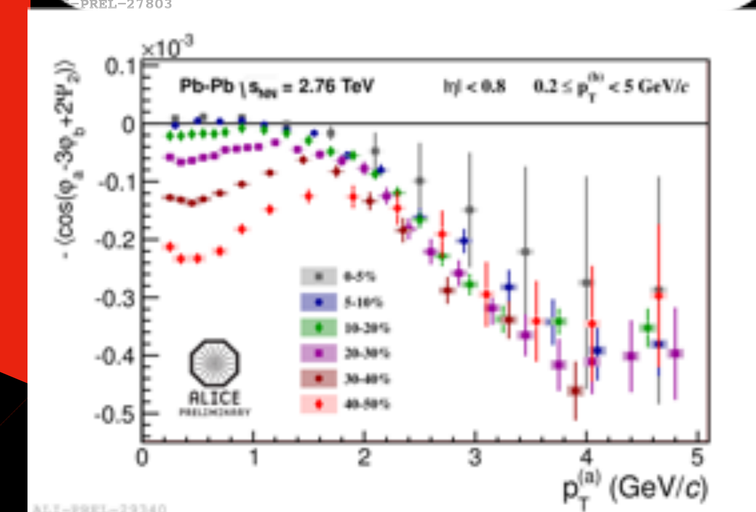
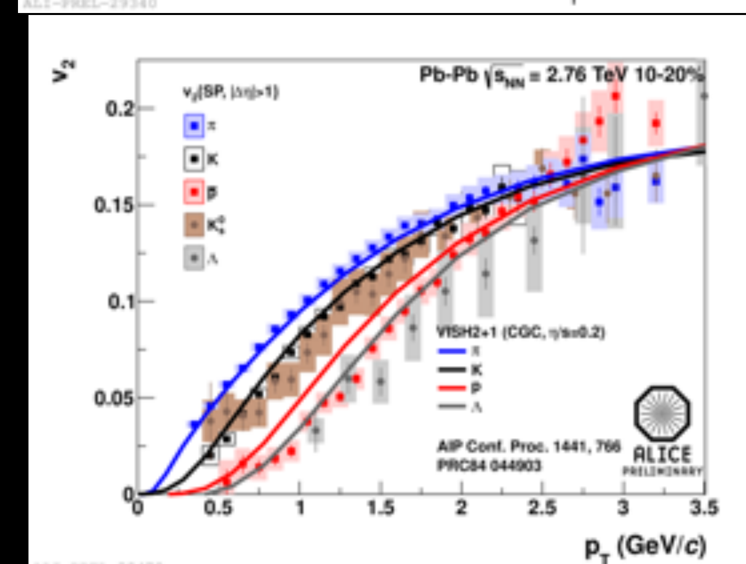
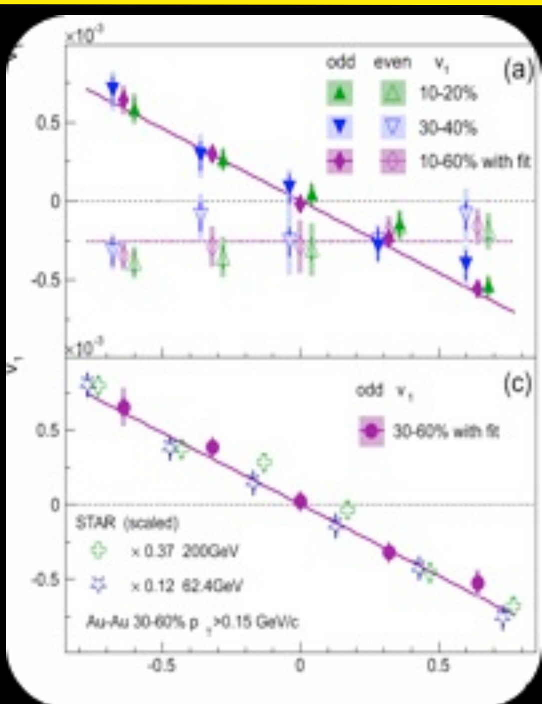
Au-Au 30-60% p_T >0.15 GeV/c


Centrality classes: event average
$p_T > 0$
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE PRELIMINARY
ALICE $v_2\{2\}$
CMS $v_2\{EP\}$ arXiv:1204.1409
2.5-15%
15-25%
25-50%
v_2
η

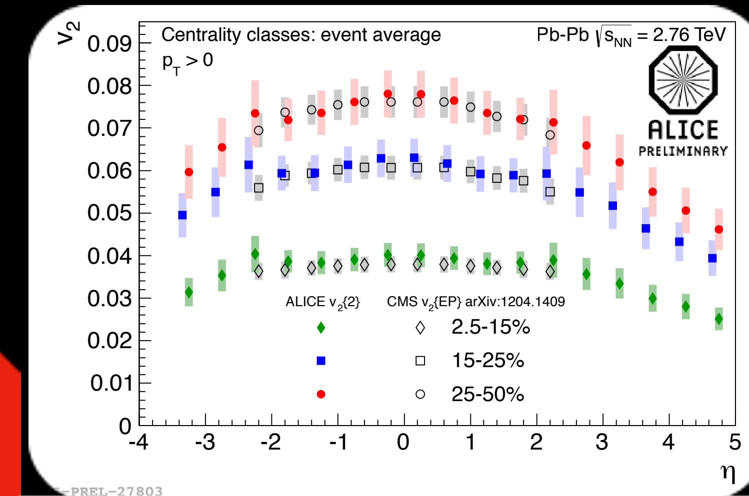

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$|\eta| < 0.8$
$0.2 \le p_T^{(b)} < 5$ GeV/c
$-\langle\cos(\varphi_a - 3\varphi_b + 2\Psi_2)\rangle$
$\times 10^{-3}$
ALICE PRELIMINARY
$p_T^{(a)}$ (GeV/c)


Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV 10-20%
v_2
VISH2+1 (CGC, η/s=0.2)
AIP Conf. Proc. 1441, 766
PRC84 044903
ALICE PRELIMINARY
p_T (GeV/c)

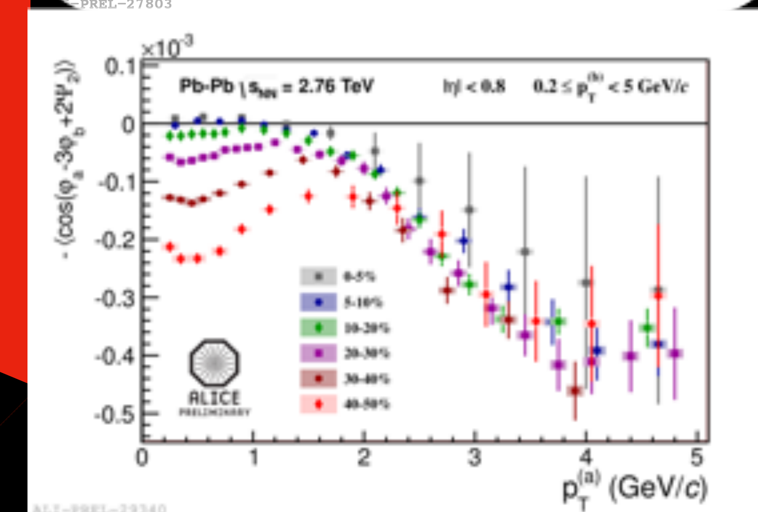
Summary



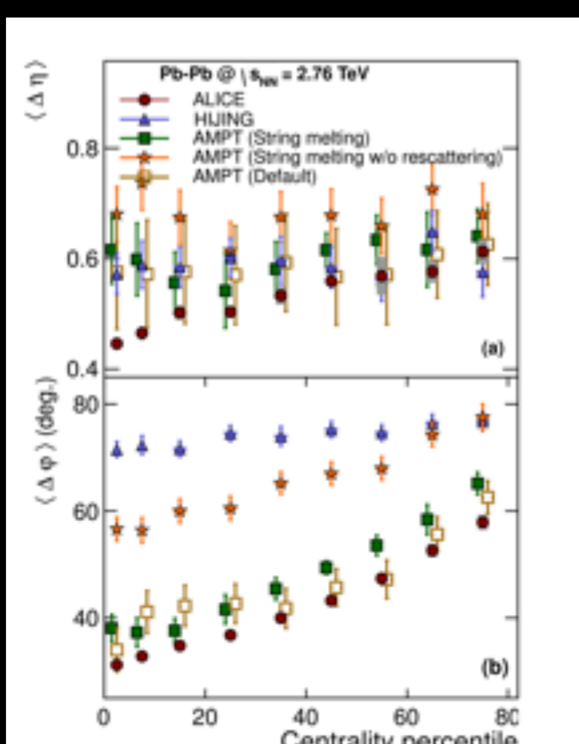
odd even v_1
10-20%
30-40%
10-60% with fit
(a)
odd v_1
(c)
30-60% with fit
STAR (scaled)
× 0.37 200GeV
× 0.12 62.4GeV
Au-Au 30-60% p_T >0.15 GeV/c



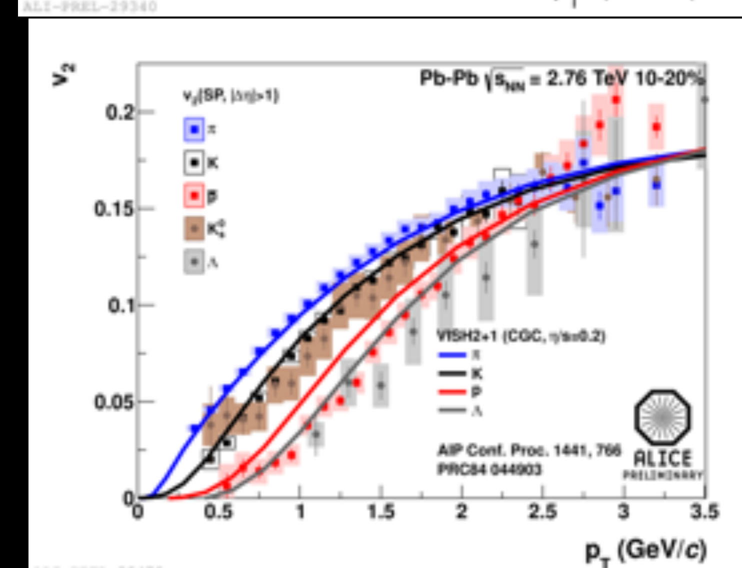
v_2
Centrality classes: event average
p_T > 0
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE PRELIMINARY
ALICE $v_2\{2\}$
CMS $v_2\{EP\}$ arXiv:1204.1409
2.5-15%
15-25%
25-50%
η



Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
|η| < 0.8
$0.2 \leq p_T^{(b)} < 5$ GeV/c
0-5%
5-10%
10-20%
20-30%
30-40%
40-50%
ALICE PRELIMINARY
$p_T^{(a)}$ (GeV/c)

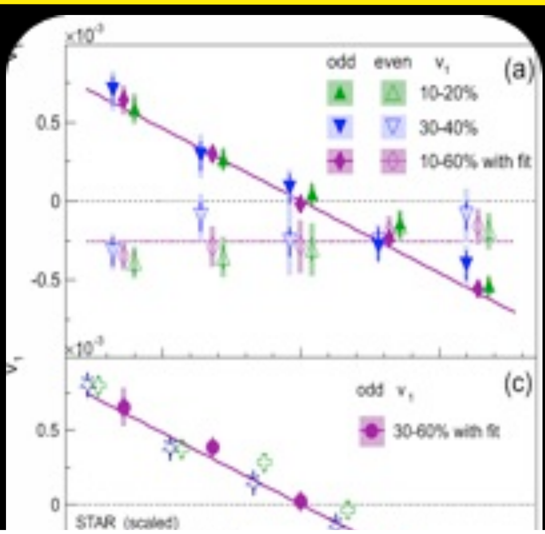


Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE
HIJING
AMPT (String melting)
AMPT (String melting w/o rescattering)
AMPT (Default)
⟨Δη⟩
⟨Δφ⟩ (deg.)
(a)
(b)
Centrality percentile

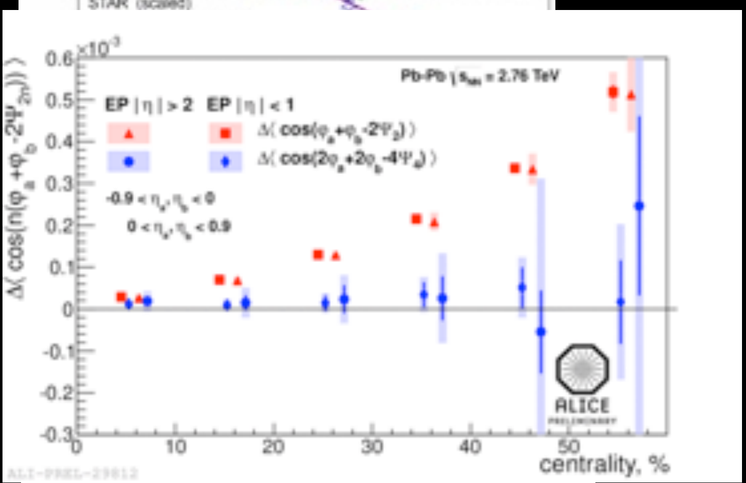


v_2
v_2\{SP, |Δη|>1\}
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV 10-20%
VISH2+1 (CGC, η/s=0.2)
AIP Conf. Proc. 1441, 766
PRC84 044903
ALICE PRELIMINARY
p_T (GeV/c)

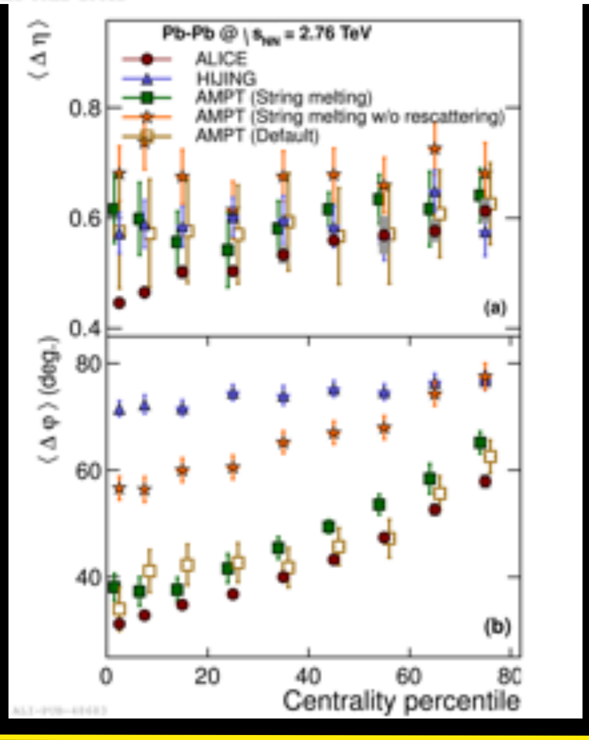
Summary



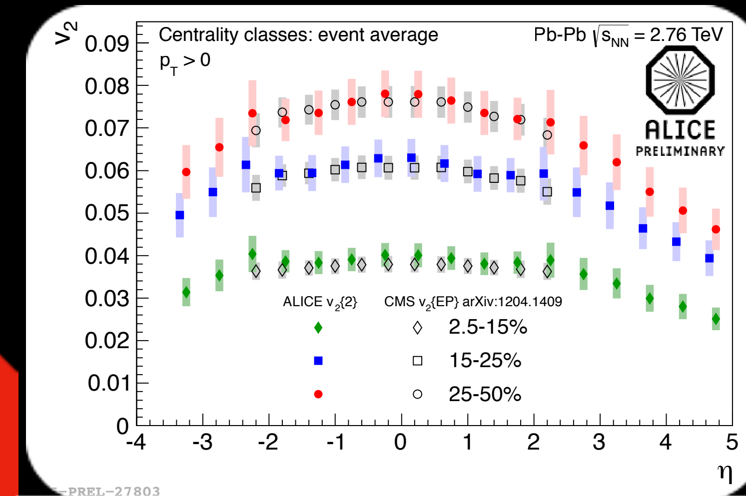
odd even v_1
10-20%
30-40%
10-60% with fit
(a)
(c)
odd v_1
30-60% with fit
STAR (scaled)



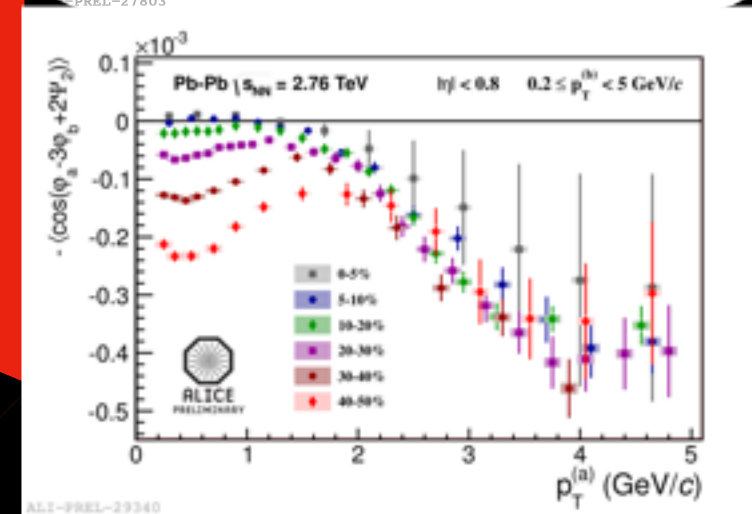
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
EP |η| > 2 EP |η| < 1
centrality, %
ALICE PRELIMINARY



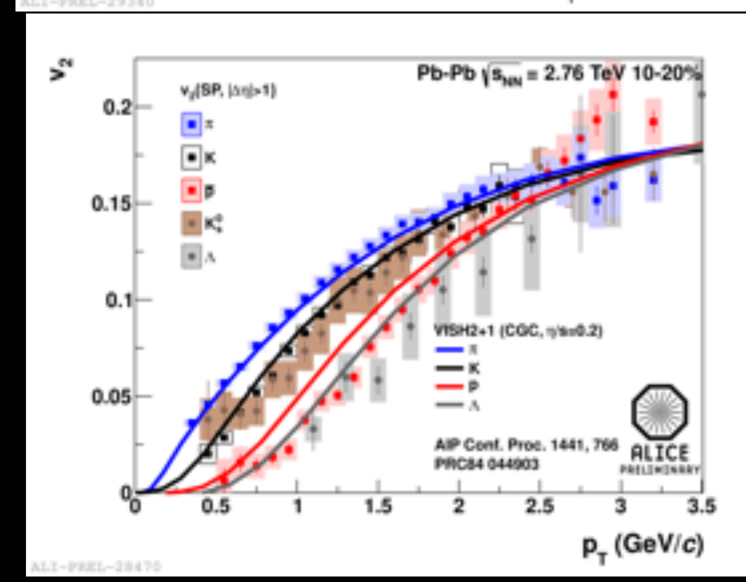
Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE
HIJING
AMPT (String melting)
AMPT (String melting w/o rescattering)
AMPT (Default)
(a)
(b)
Centrality percentile



Centrality classes: event average
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
p_T > 0
ALICE PRELIMINARY
ALICE $v_2\{2\}$
CMS $v_2\{EP\}$ arXiv:1204.1409
2.5-15%
15-25%
25-50%
η

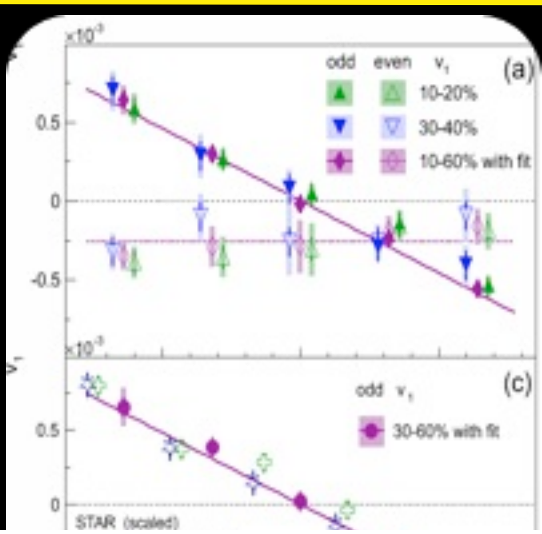


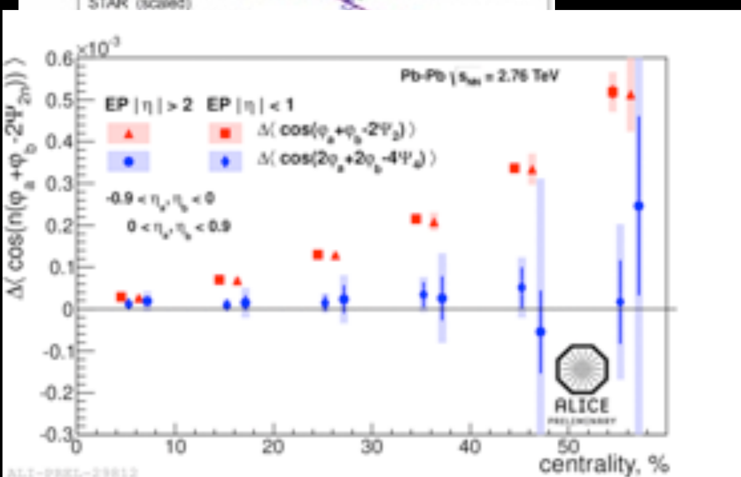
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE PRELIMINARY
$p_T^{(a)}$ (GeV/c)

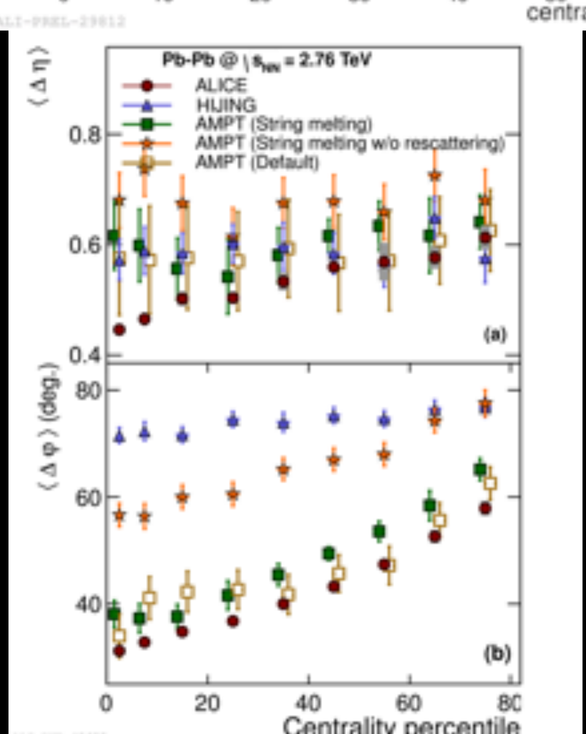


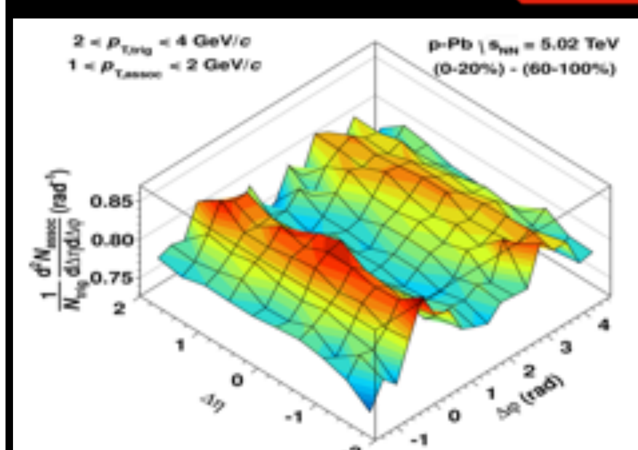
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV 10-20%
ALICE PRELIMINARY
p_T (GeV/c)

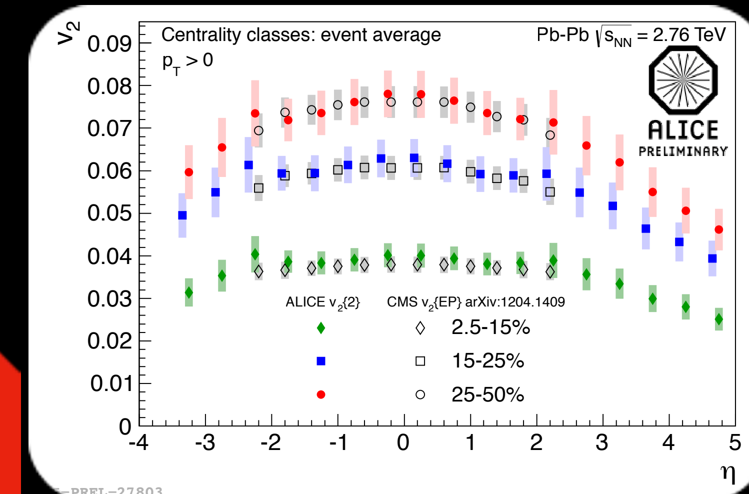
Summary

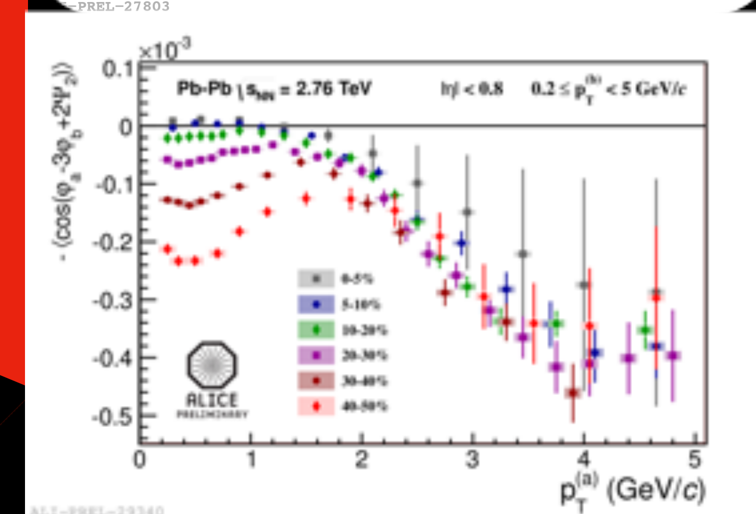

odd even v_1
(a)
10-20%
30-40%
10-60% with fit
odd v_1
(c)
30-60% with fit
STAR (scaled)

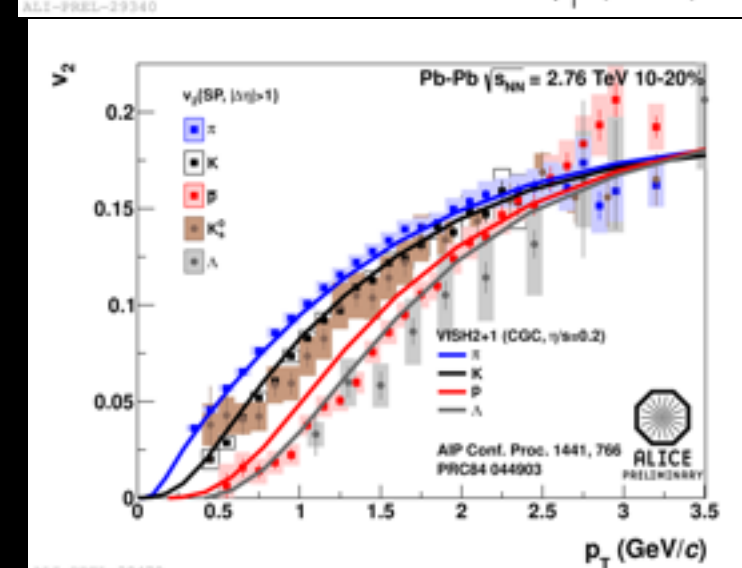

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
EP |η| > 2 EP |η| < 1
$\Delta\langle\cos(\varphi_a+\varphi_b-2\Psi_2)\rangle$
$\Delta\langle\cos(2\varphi_a+2\varphi_b-4\Psi_4)\rangle$
$\Delta\langle\cos(n(\varphi_a+\varphi_b-2\Psi_{2n}))\rangle$
centrality, %
ALICE PRELIMINARY


Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
ALICE
HIJING
AMPT (String melting)
AMPT (String melting w/o rescattering)
AMPT (Default)
⟨Δη⟩
⟨Δφ⟩ (deg.)
(a)
(b)
Centrality percentile

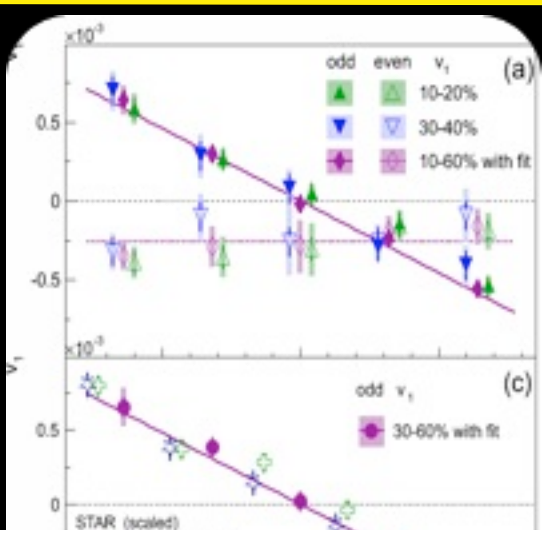

$2 < p_{T,trig} < 4$ GeV/c
$1 < p_{T,assoc} < 2$ GeV/c
p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
(0-20%) - (60-100%)
Δη
Δφ (rad)

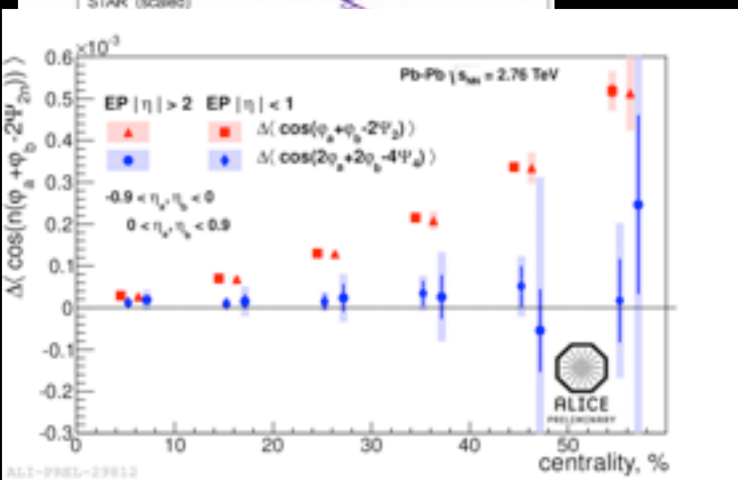

Centrality classes: event average
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$p_T > 0$
ALICE PRELIMINARY
ALICE $v_2\{2\}$
CMS $v_2\{EP\}$ arXiv:1204.1409
2.5-15%
15-25%
25-50%
v_2
η

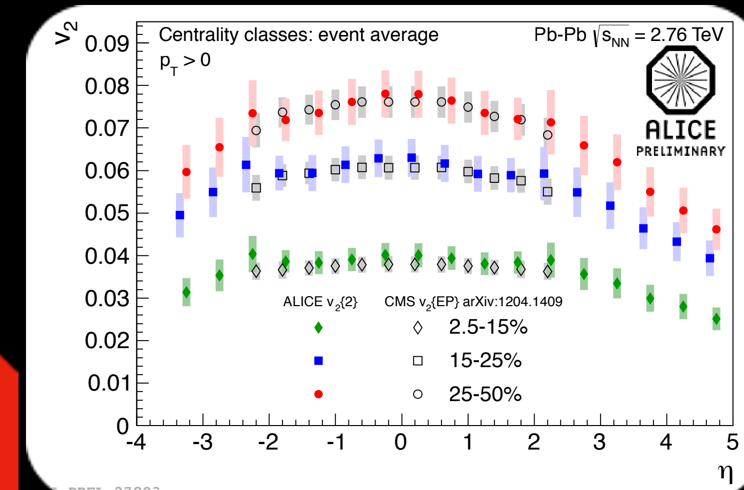

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
|η| < 0.8
ALICE PRELIMINARY
$p_T^{(a)}$ (GeV/c)

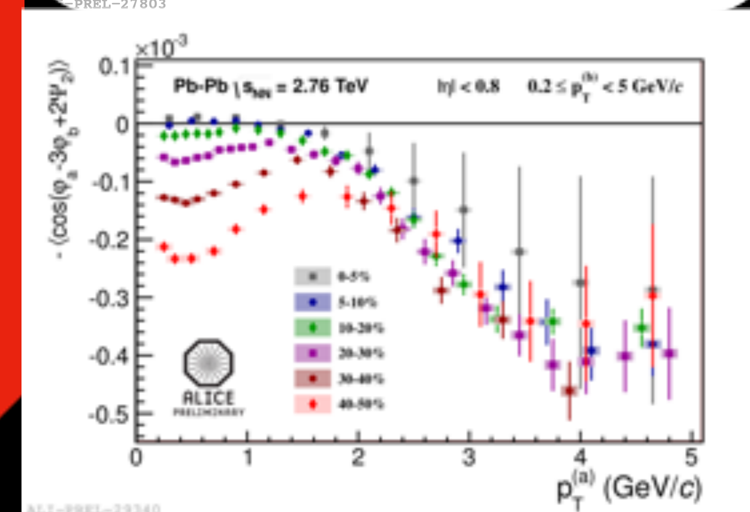

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV 10-20%
v_2
VISH2+1 (CGC, η/s=0.2)
ALICE PRELIMINARY
p_T (GeV/c)

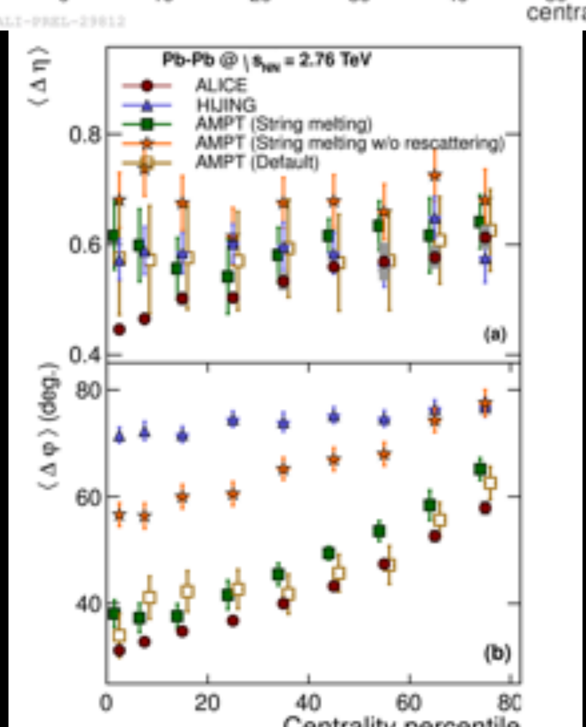
Summary

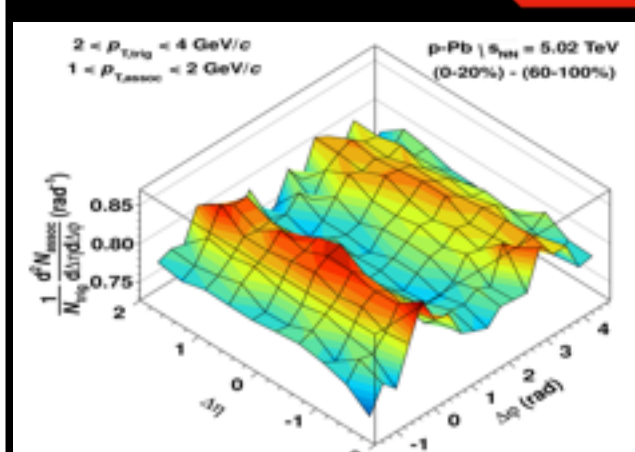

odd even v1
10-20%
30-40%
10-60% with fit
(a)
(c)
30-60% with fit
STAR (scaled)

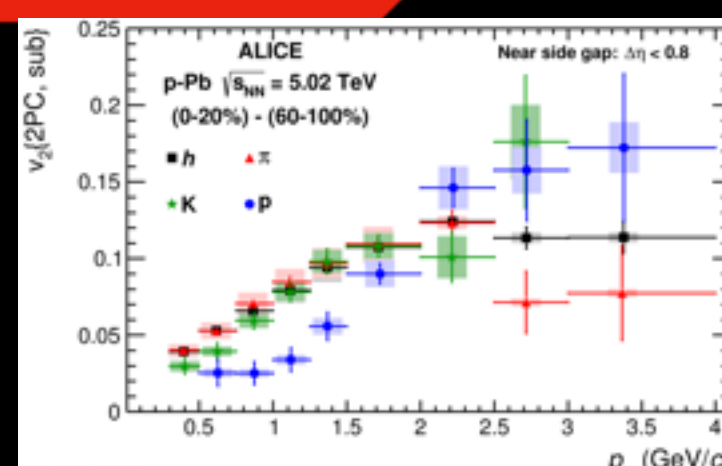

Pb-Pb √sNN = 2.76 TeV
EP |η| > 2 EP |η| < 1
ALICE
centrality, %

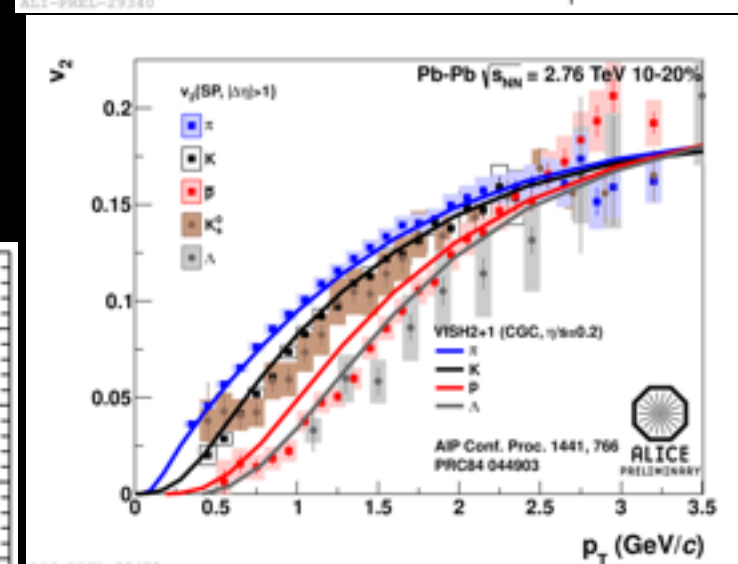

Centrality classes: event average
Pb-Pb √sNN = 2.76 TeV
ALICE PRELIMINARY
2.5-15%
15-25%
25-50%
η


Pb-Pb √sNN = 2.76 TeV
ALICE PRELIMINARY
(GeV/c)


Pb-Pb @ √sNN = 2.76 TeV
ALICE
HIJING
AMPT (String melting)
AMPT (String melting w/o rescattering)
AMPT (Default)
(a)
(b)
Centrality percentile


p-Pb √sNN = 5.02 TeV
(0-20%) - (60-100%)


ALICE
p-Pb √sNN = 5.02 TeV
(0-20%) - (60-100%)
Near side gap: Δη < 0.8
(GeV/c)

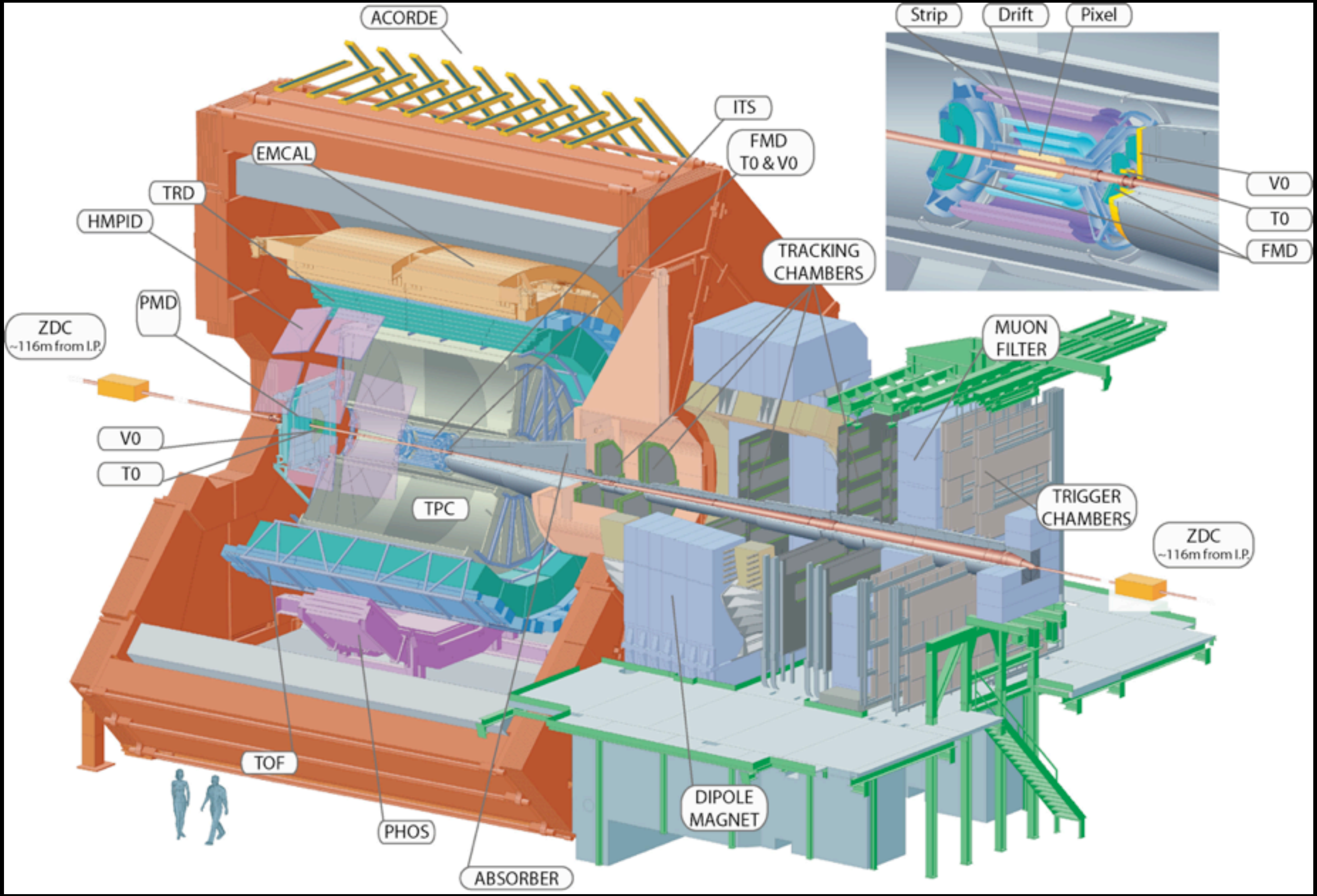

Pb-Pb √sNN = 2.76 TeV 10-20%
VISH2+1 (CGC, η/s=0.2)
AIP Conf. Proc. 1441, 766
PRC84 044903
ALICE PRELIMINARY
(GeV/c)

Summary

ALICE

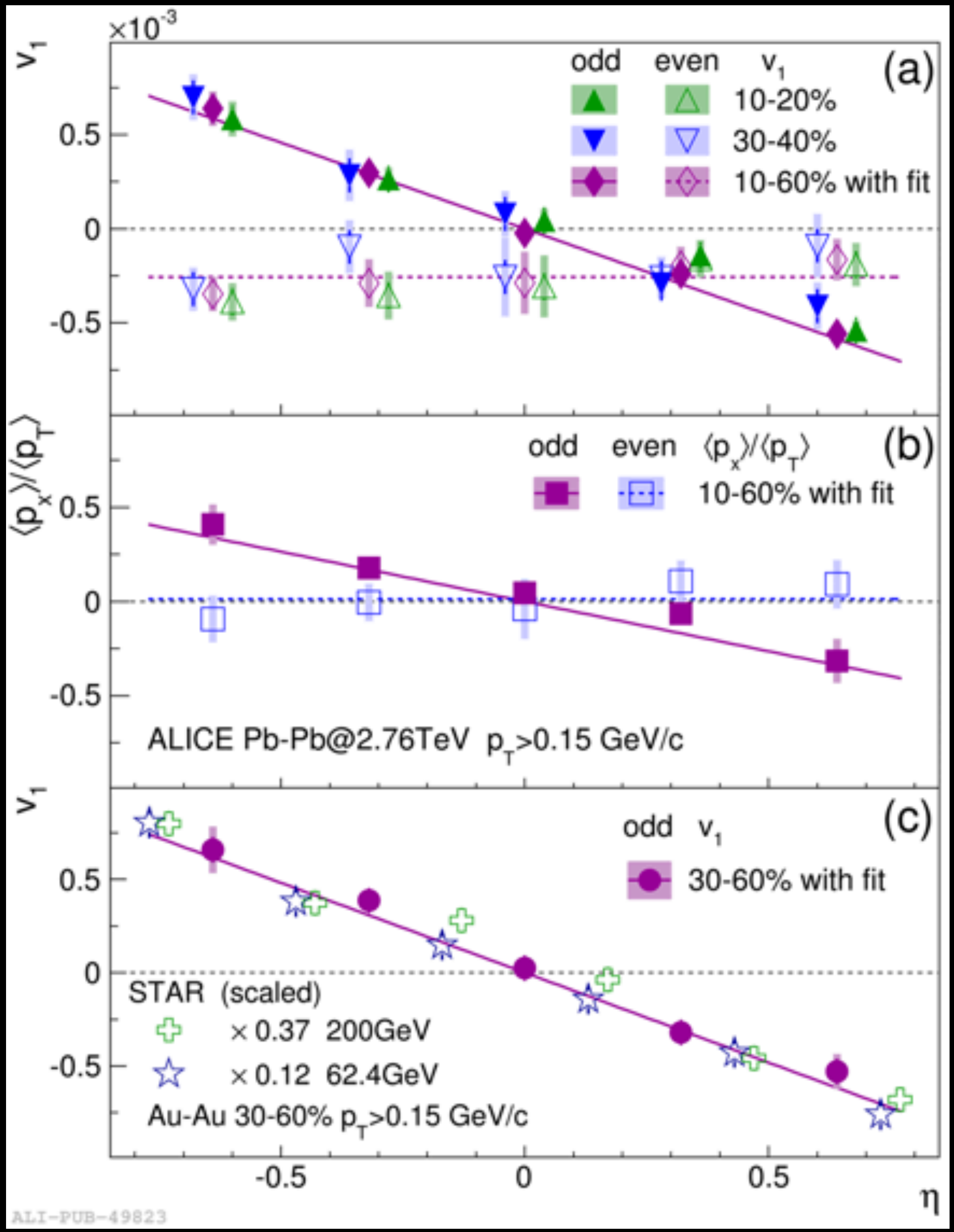
BACKUP

Experimental setup



Directed flow measurement: η dependence

(ALICE Collaboration) arXiv:1306.4145



$$v_1 = \langle \cos(\varphi - \Psi) \rangle$$

$$v_1^{odd}\{\Psi_{SP}\} = \frac{1}{2}\left[v_1\{\Psi_{SP}^p\} + v_1\{\Psi_{SP}^t\}\right]$$

$$v_1^{even}\{\Psi_{SP}\} = \frac{1}{2}\left[v_1\{\Psi_{SP}^p\} - v_1\{\Psi_{SP}^t\}\right]$$

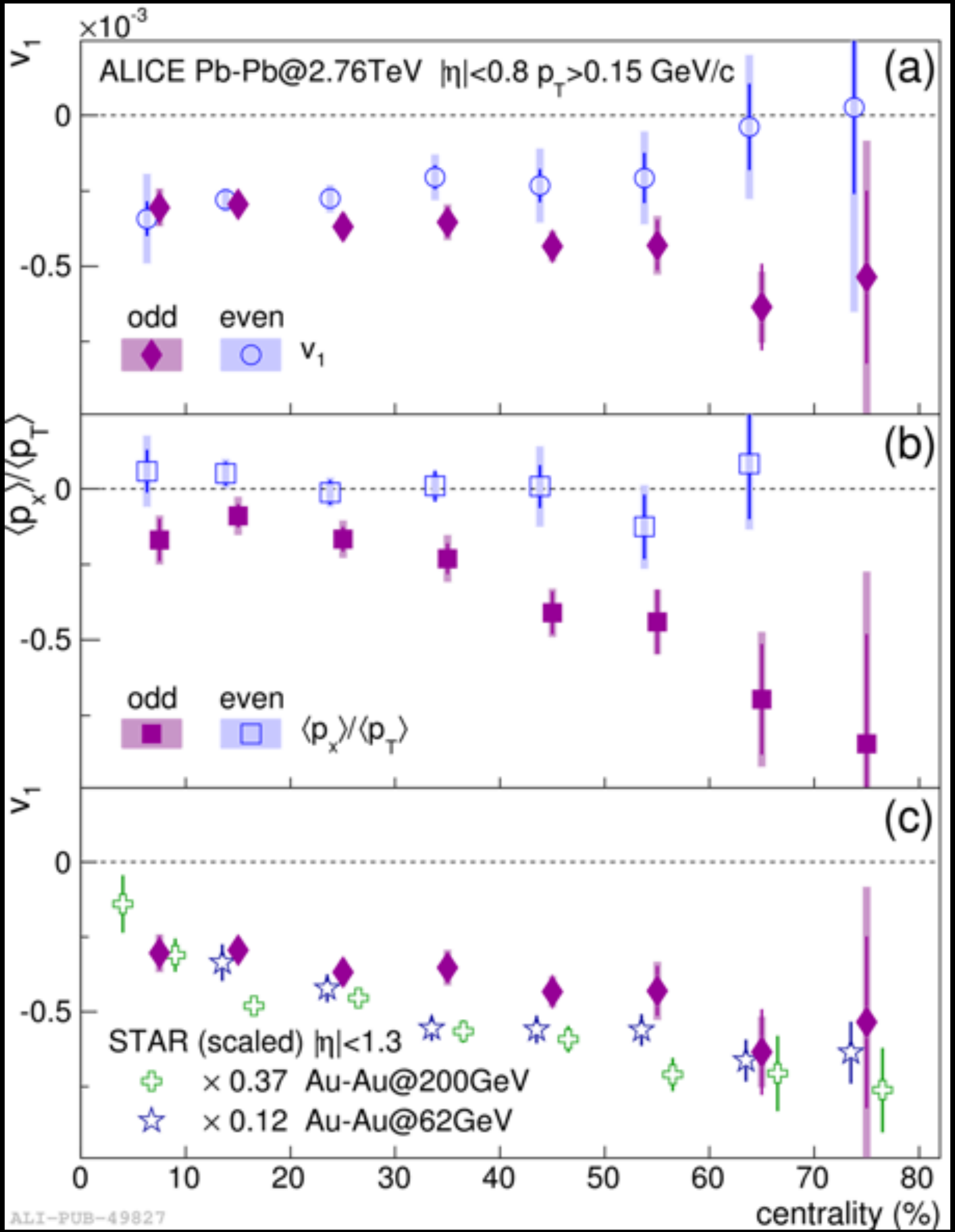
- Measured wrt the spectator deflection
- v_1^{odd} negative slope
  - similar observation @ RHIC but a factor of ~3 smaller magnitude
- v_1^{even} negative with no evident η dependence
- Relative momentum shift:
  - Odd component smaller slope than the v_1^{odd},
  - even component compatible with 0

$$\frac{\langle p_x \rangle}{\langle p_T \rangle} = \frac{\langle p_T \cos(\varphi - \Psi_{SP}) \rangle}{\langle p_T \rangle}$$

Directed flow measurement: centrality dependence

$v_1 = \langle \cos(\varphi - \Psi) \rangle$

(ALICE Collaboration) arXiv:1306.4145

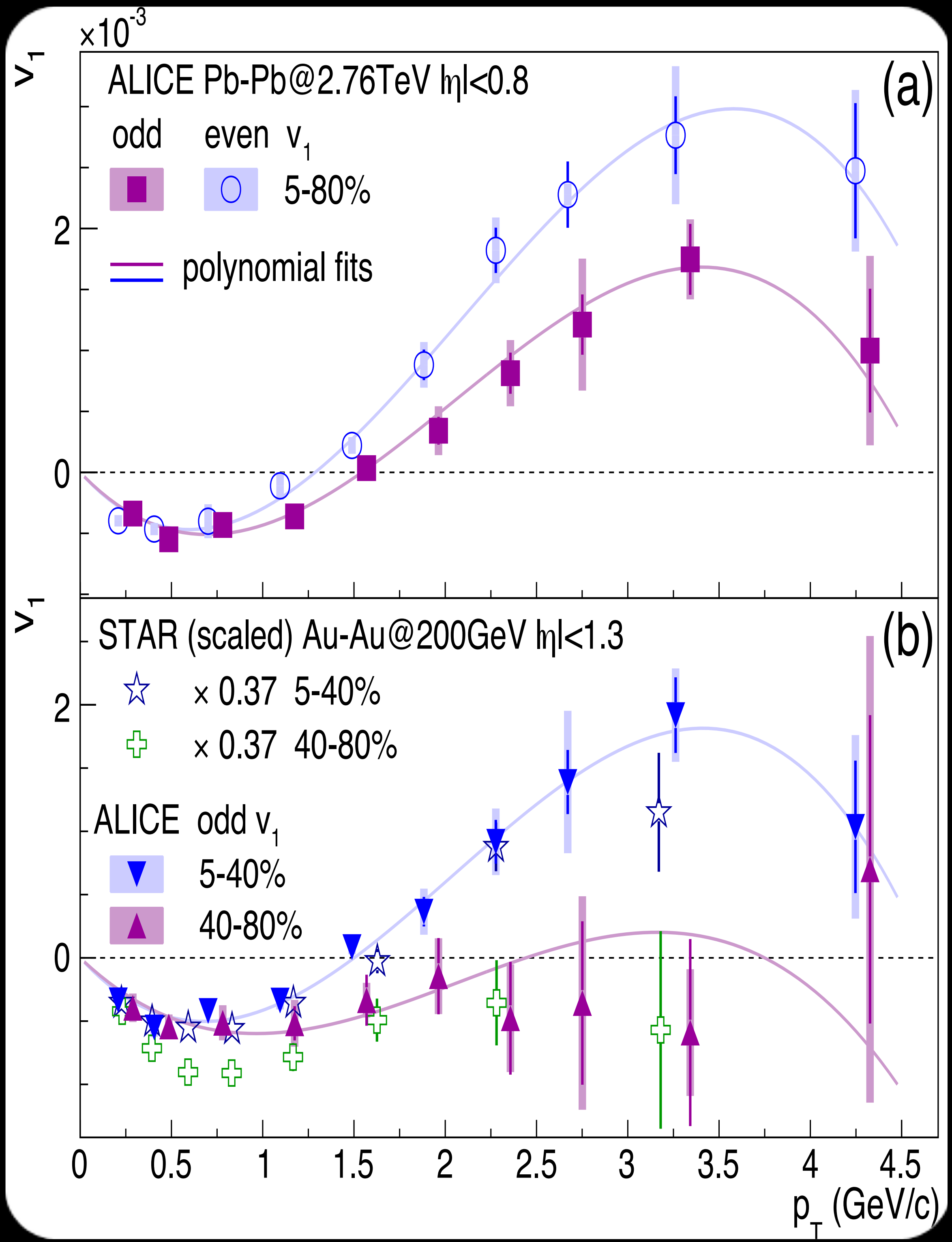


- Odd parts multiplied with -1 for $\eta < 0$
- Mild centrality dependence for both v_1^{odd} and v_1^{even}
- Significantly smaller magnitude of v_1^{odd} compared to RHIC

Directed flow measurement: transverse momentum dependence

$v_1 = \langle \cos(\varphi - \Psi) \rangle$

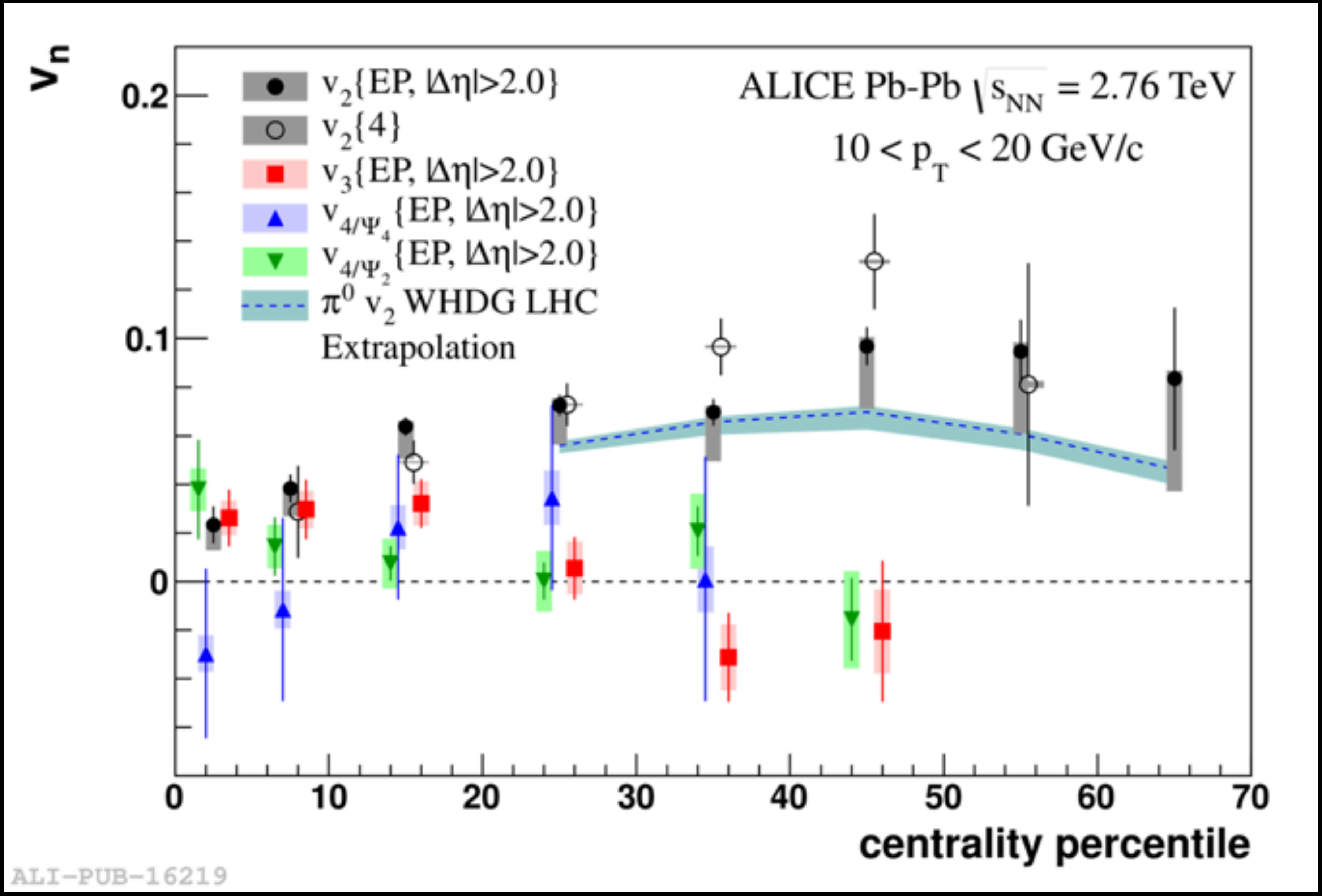
(ALICE Collaboration) arXiv:1306.4145



- Change of sign around 1.2-1.7 GeV/c
- Similar trends compared to RHIC
  - Note the scaling for the RHIC data

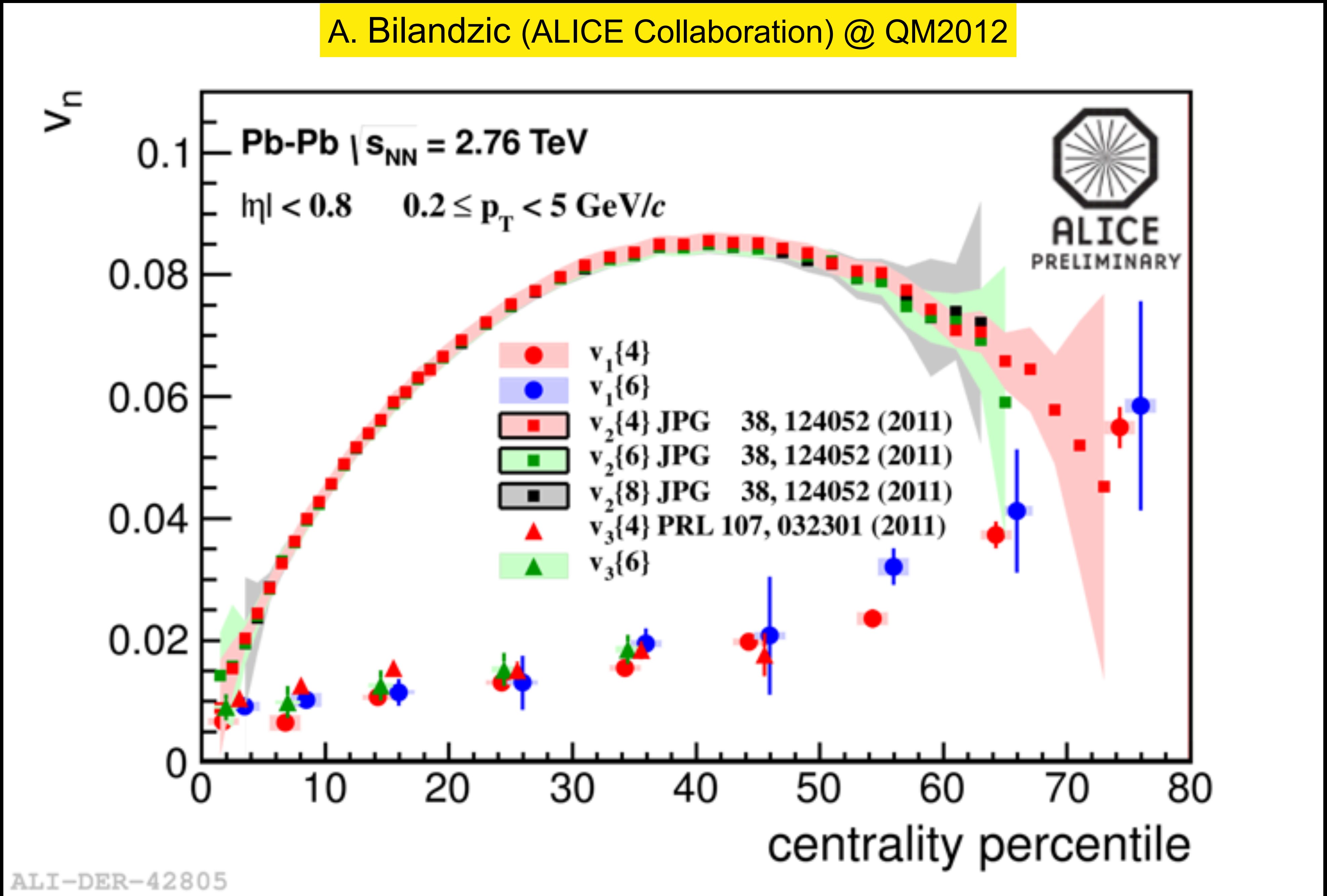
Elliptic flow @ high p_T

ALICE Collaboration: Phys. Lett. **B719**, (2013) 18



Multi-particle correlations: probing the p.d.f. of flow fluctuations

A. Bilandzic (ALICE Collaboration) @ QM2012

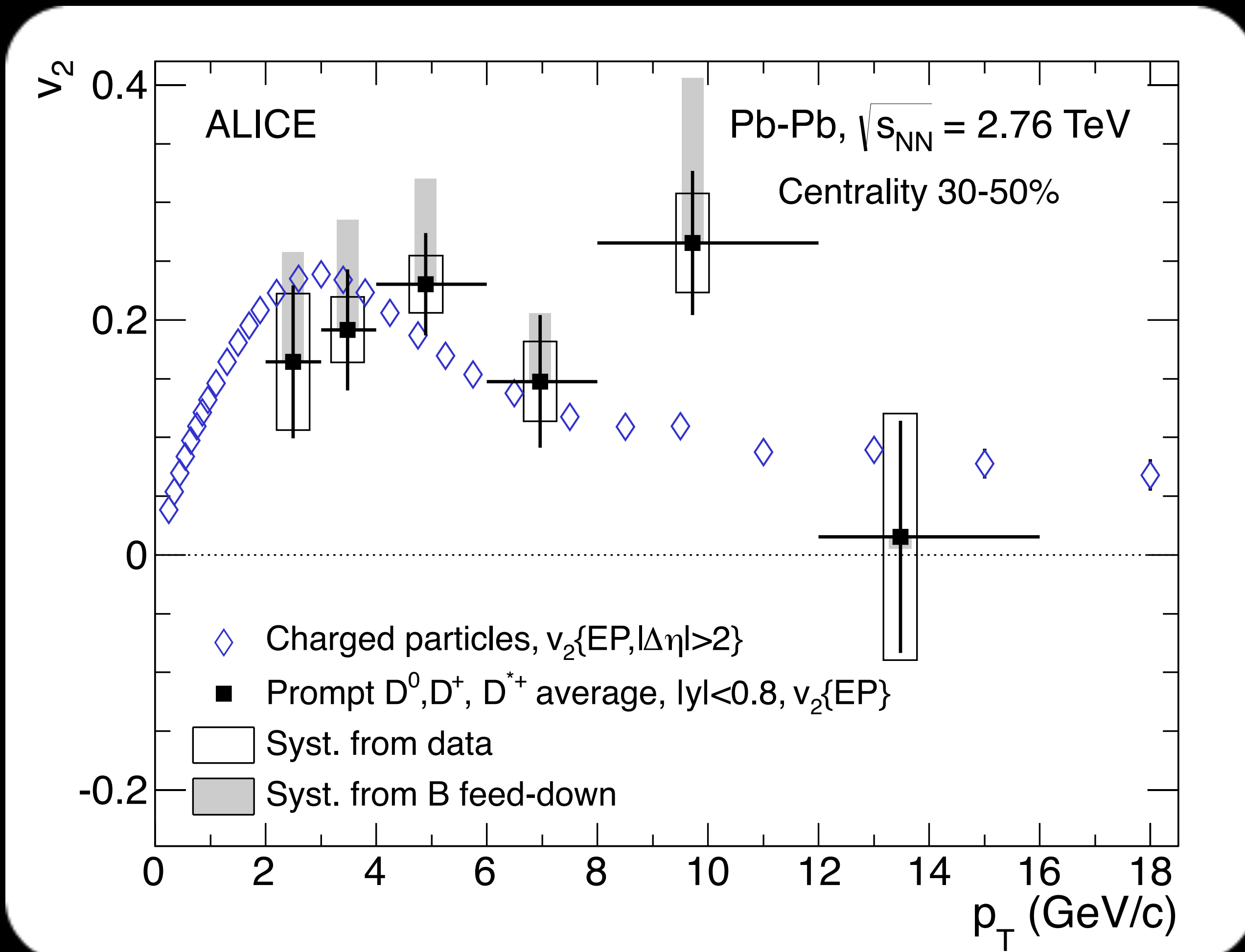


- $v_n\{4\} \approx v_n\{6\} \approx v_n\{8\}$
- Bessel-Gaussian can be considered as a candidate for the p.d.f.

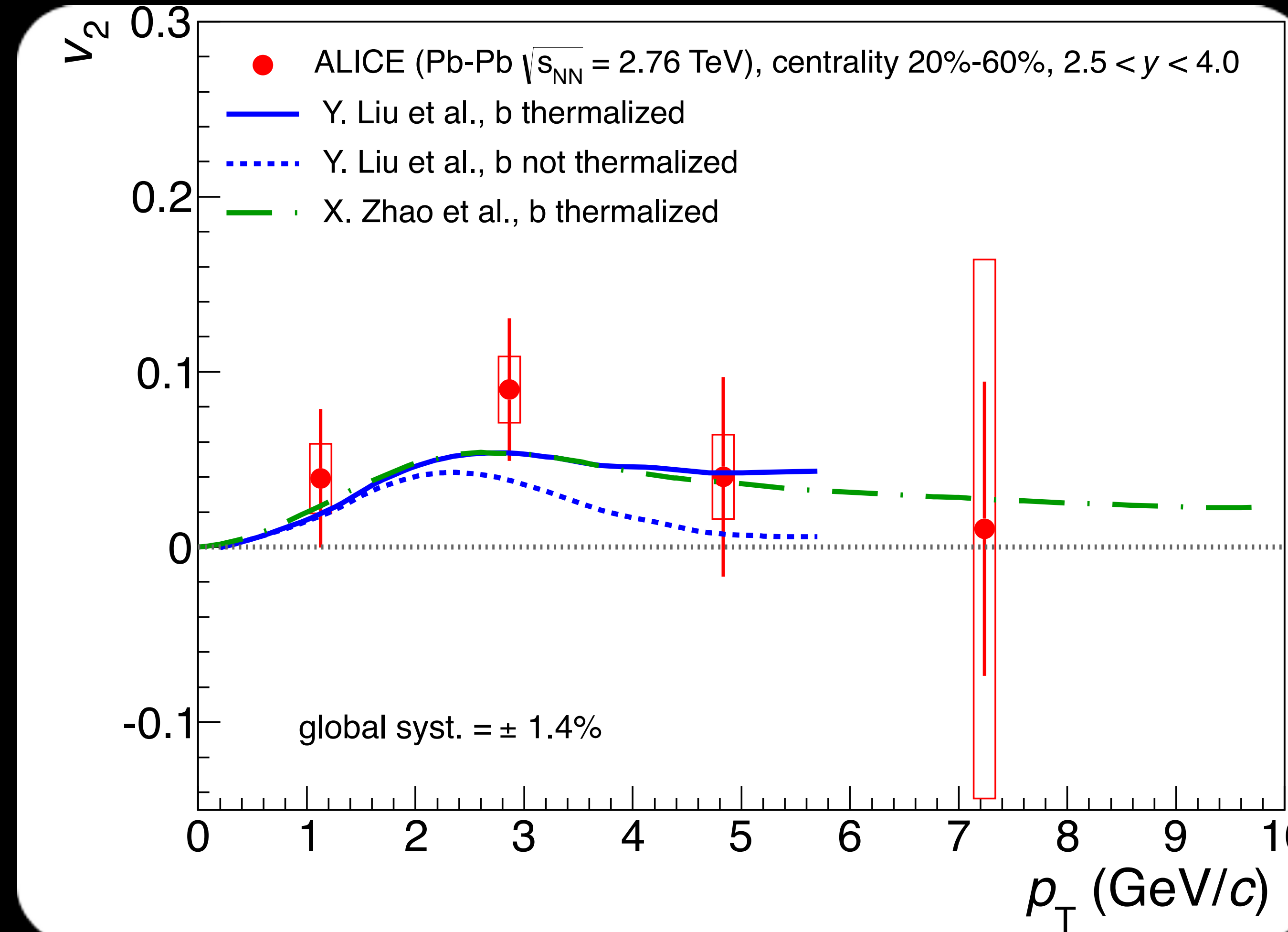
S. Voloshin, Phys. Lett. **B659**, 537 (2008)

Elliptic flow of heavier particles

ALICE Collaboration: arXiv:1305.2707



ALICE Collaboration: arXiv:1303.5880



- Measured elliptic flow with the event plane, scalar product and the q-cumulant methods
- Results for D^0, D^+ and D^{*+}, are in agreement and thus averaged in the plot
- Observed non-zero v_2 for 30-50% and for 2 < p_T < 6 GeV/c (~5.7σ)

- Inclusive J/Ψ v_2 measured in the $\mu^+\mu^-$ channel using the event plane method
- Indication of a non-zero v_2 for 20-60% for 2 < p_T < 4 GeV/c at a level of ~2σ (2.7σ for 2 < p_T < 6 GeV/c for 20-40%)

Elena Bruna (25/7 Parallel session @ 15:20)

Correlations with higher order harmonics

- Let's start from the Fourier series describing the azimuthal distribution of particles
  - ★ a_1: quantifies the charge separation perpendicular to the reaction plane
  - ★ a_n ($n > 1$): higher order coefficients describe the shape in azimuth of the CME

$$\frac{dN}{d\varphi} \sim 1 + 2\sum_{n=1}^{\infty}\{v_n \cos[n(\varphi-\Psi_n)] + a_n \sin[n(\varphi-\Psi_n)]\}$$

- The experimental tool proposed to probe the signal was the two-particle correlator relative to the second order symmetry plane Ψ_2:

$$C_{11}^{\alpha\beta}\{\Psi_2\} = \langle \cos[\varphi_\alpha - \varphi_\beta - 2\Psi_2] \rangle$$

- This correlator can be extended to higher orders:

$$C_{nm}^{\alpha\beta}\{\Psi_k\} = \langle \cos[n\varphi_\alpha - m\varphi_\beta - (n-m)\Psi_k] \rangle$$

- In case of n=m the correlator transforms to the one with no explicit dependence on the symmetry plane:

$$C_n^{\alpha\beta} = \langle \cos[n(\varphi_\alpha - \varphi_\beta)] \rangle$$

- For the case where m=0 and n > 0 the correlator gives the well known flow coefficients relative to the kth order symmetry plane:

$$v_n^{\alpha}\{\Psi_k\} = \langle \cos[n(\varphi_\alpha - \Psi_k)] \rangle$$

Sensitivity to the signal and the background

$$C^{\alpha\beta}_{nm}\{\Psi_k\} = \langle \cos[n\varphi_\alpha - m\varphi_\beta - (n-m)\Psi_k] \rangle$$

- Sensitivity to the CME: $C^{\alpha\beta}_{nm}\{\Psi_k\} \sim (-1)^{n-m} \langle a^\alpha_n a^\beta_n \rangle$

Note: No solid quantitative expectations of the an terms at the LHC from theory; some qualitative expectations for a1 but higher orders are a completely new territory!!!

- Sensitivity to local charge conservation: $\Delta C^{\alpha\beta}_{nm}\{\Psi_k\} = \dfrac{2C^{+-}_{nm} - C^{++}_{nm} - C^{--}_{nm}}{2}$

$$\begin{aligned}\Delta C^{\alpha\beta}_{nm}\{\Psi_k\} = {} & \Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)]\ \cos[(n+m)(\varphi_\beta - \Psi_k)] \rangle - \\ & \Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)] \rangle v_{|n+m|}\{\Psi_k\} + \\ & \Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)] \rangle v_{|n+m|}\{\Psi_k\} - \\ & \Delta\langle \sin[n(\varphi_\alpha - \varphi_\beta)]\ \sin[(n+m)(\varphi_\beta - \Psi_k)] \rangle\end{aligned}$$

$$\begin{aligned}\Delta C^{\alpha\beta}_{nm}\{\Psi_k\} = {} & v^{symm.}_{|n+m|}\{\Psi_k\} + \\ & \Delta C^{\alpha\beta}_{n} v_{|n+m|}\{\Psi_k\} - \\ & v^{asymm.}_{|n+m|}\{\Psi_k\}\end{aligned}$$

Sensitivity to the signal and the background

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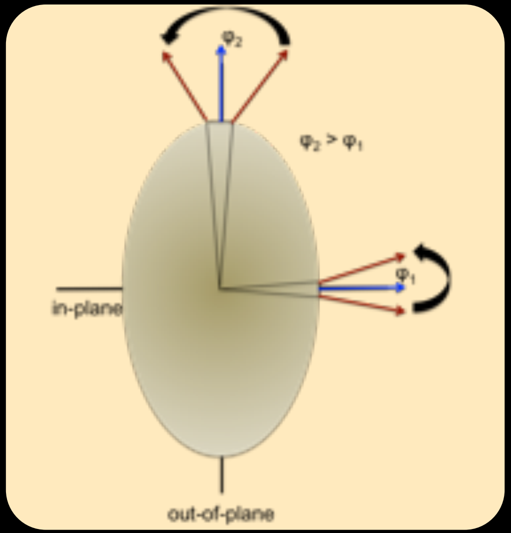
$$\begin{aligned}\Delta C^{\alpha\beta}_{nm}\{\Psi_k\} = &\Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)]\ \cos[(n+m)(\varphi_\beta - \Psi_k)]\rangle - \\ &\Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)]\rangle v_{|n+m|}\{\Psi_k\} + \\ &\Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)]\rangle v_{|n+m|}\{\Psi_k\} - \\ &\Delta\langle \sin[n(\varphi_\alpha - \varphi_\beta)]\ \sin[(n+m)(\varphi_\beta - \Psi_k)]\rangle\end{aligned}$$

$$\begin{aligned}\Delta C^{\alpha\beta}_{nm}\{\Psi_k\} = &v^{symm.}_{|n+m|}\{\Psi_k\} + \\ &\Delta C^{\alpha\beta}_{n} v_{|n+m|}\{\Psi_k\} - \\ &v^{asymm.}_{|n+m|}\{\Psi_k\}\end{aligned}$$

This term quantifies how more tightly correlated the in-plane pairs are wrt the out-of-plane ones



Sensitivity to the signal and the background

$$C^{\alpha\beta}_{nm}\{\Psi_k\}=\langle\cos[n\varphi_\alpha-m\varphi_\beta-(n-m)\Psi_k]\rangle$$

- Sensitivity to the CME: $C^{\alpha\beta}_{nm}\{\Psi_k\}\sim(-1)^{n-m}\langle a^{\alpha}_{n}a^{\beta}_{n}\rangle$

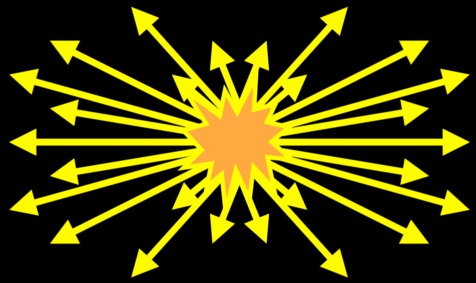
Note: No solid quantitative expectations of the an terms at the LHC from theory; some qualitative expectations for a1 but higher orders are a completely new territory!!!

- Sensitivity to local charge conservation: $\Delta C^{\alpha\beta}_{nm}\{\Psi_k\}=\dfrac{2C^{+-}_{nm}-C^{++}_{nm}-C^{--}_{nm}}{2}$

$$\begin{aligned}\Delta C^{\alpha\beta}_{nm}\{\Psi_k\}=&\Delta\langle\cos[n(\varphi_\alpha-\varphi_\beta)]\cos[(n+m)(\varphi_\beta-\Psi_k)]\rangle-\\&\Delta\langle\cos[n(\varphi_\alpha-\varphi_\beta)]\rangle v_{|n+m|}\{\Psi_k\}+\\&\Delta\langle\cos[n(\varphi_\alpha-\varphi_\beta)]\rangle v_{|n+m|}\{\Psi_k\}-\\&\Delta\langle\sin[n(\varphi_\alpha-\varphi_\beta)]\sin[(n+m)(\varphi_\beta-\Psi_k)]\rangle\end{aligned}$$

$$\Delta C^{\alpha\beta}_{nm}\{\Psi_k\}=v^{symm.}_{|n+m|}\{\Psi_k\}+\Delta C^{\alpha\beta}_{n}v_{|n+m|}\{\Psi_k\}-v^{asymm.}_{|n+m|}\{\Psi_k\}$$

This term quantifies how many more balancing pairs there are in-plane wrt the out-of-plane



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Sensitivity to the signal and the background

$$C_{nm}^{\alpha\beta}\{\Psi_k\} = \langle \cos[n\varphi_\alpha - m\varphi_\beta - (n-m)\Psi_k] \rangle$$

- Sensitivity to the CME: $C_{nm}^{\alpha\beta}\{\Psi_k\} \sim (-1)^{n-m} \langle a_n^\alpha a_n^\beta \rangle$

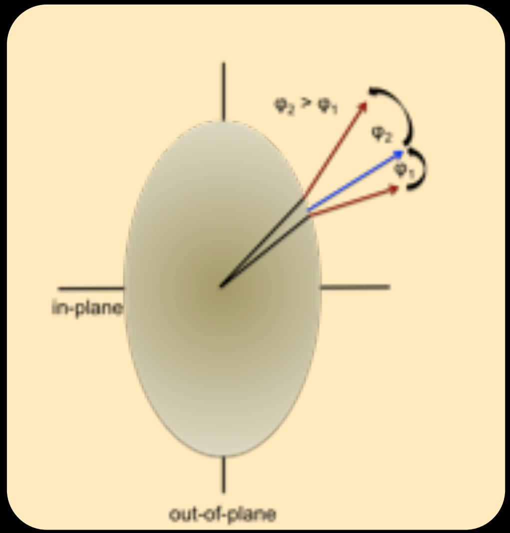
Note: No solid quantitative expectations of the an terms at the LHC from theory; some qualitative expectations for a1 but higher orders are a completely new territory!!!

- Sensitivity to local charge conservation: $\Delta C_{nm}^{\alpha\beta}\{\Psi_k\} = \dfrac{2C_{nm}^{+-} - C_{nm}^{++} - C_{nm}^{--}}{2}$

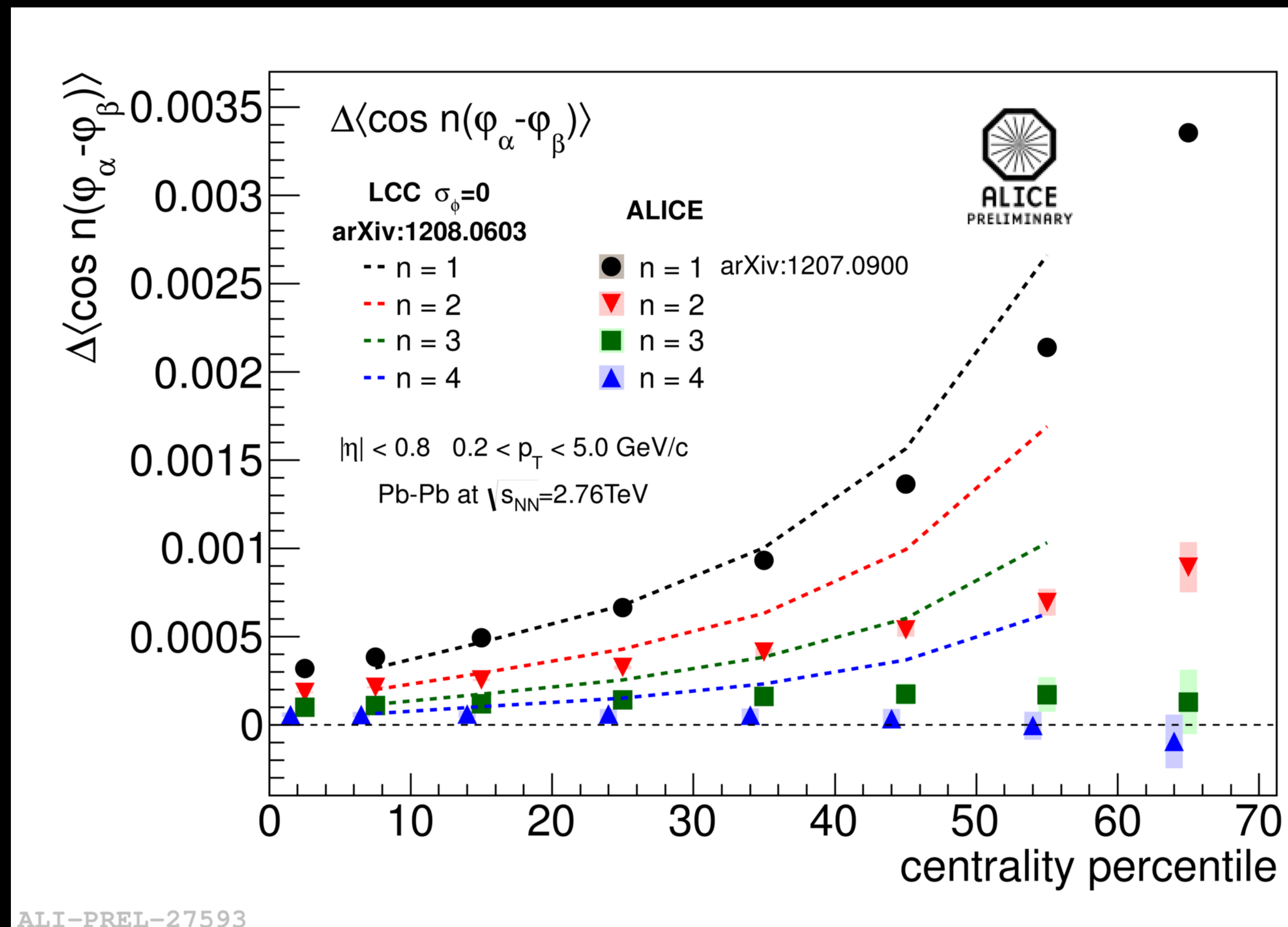
$$\begin{aligned}\Delta C_{nm}^{\alpha\beta}\{\Psi_k\} = &\Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)]\ \cos[(n+m)(\varphi_\beta - \Psi_k)]\rangle - \\ &\Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)]\rangle v_{|n+m|}\{\Psi_k\} + \\ &\Delta\langle \cos[n(\varphi_\alpha - \varphi_\beta)]\rangle v_{|n+m|}\{\Psi_k\} - \\ &\Delta\langle \sin[n(\varphi_\alpha - \varphi_\beta)]\ \sin[(n+m)(\varphi_\beta - \Psi_k)]\rangle\end{aligned}$$

$$\begin{aligned}\Delta C_{nm}^{\alpha\beta}\{\Psi_k\} = &v_{|n+m|}^{symm.}\{\Psi_k\} + \\ &\Delta C_n^{\alpha\beta} v_{|n+m|}\{\Psi_k\} - \\ &v_{|n+m|}^{asymm.}\{\Psi_k\}\end{aligned}$$

This term quantifies how more likely it is for the balancing charge to be emitted towards the symmetry plane wrt the trigger (leading) particle



Higher harmonics of the symmetry plane independent correlator



- Results are compared to a blast wave model tuned to match the published charged particle v2 values at the LHC and the identified particle spectra as reported by ALICE
  - ★ The model generates particle pairs (balanced) at the surface based on an initial separation parameter σ that can be adjusted accordingly (e.g. σ = 0 point-like unlike-sign particle emission)
- Model describes the data for the first harmonic reasonably well (besides the most peripheral classes) but systematically overestimates the centrality dependence for the higher moments.

For further details: Yasuto Hori (for the ALICE Collaboration), “Mixed harmonic charge dependent correlations measured with ALICE” shown @ Quark Matter 2012, Washington DC

Estimating the background contributions: higher harmonics

$$C^{\alpha\beta}_{nm}\{\Psi_k\} = \langle \cos[n\varphi_\alpha - m\varphi_\beta - (n-m)\Psi_k] \rangle$$

- The second harmonic modulation of the balance function wrt Ψ_2

$$\Delta C_{1,1}\{\Psi_2\} = \Delta\langle \cos(\varphi_\alpha + \varphi_\beta - 2\Psi_2) \rangle$$

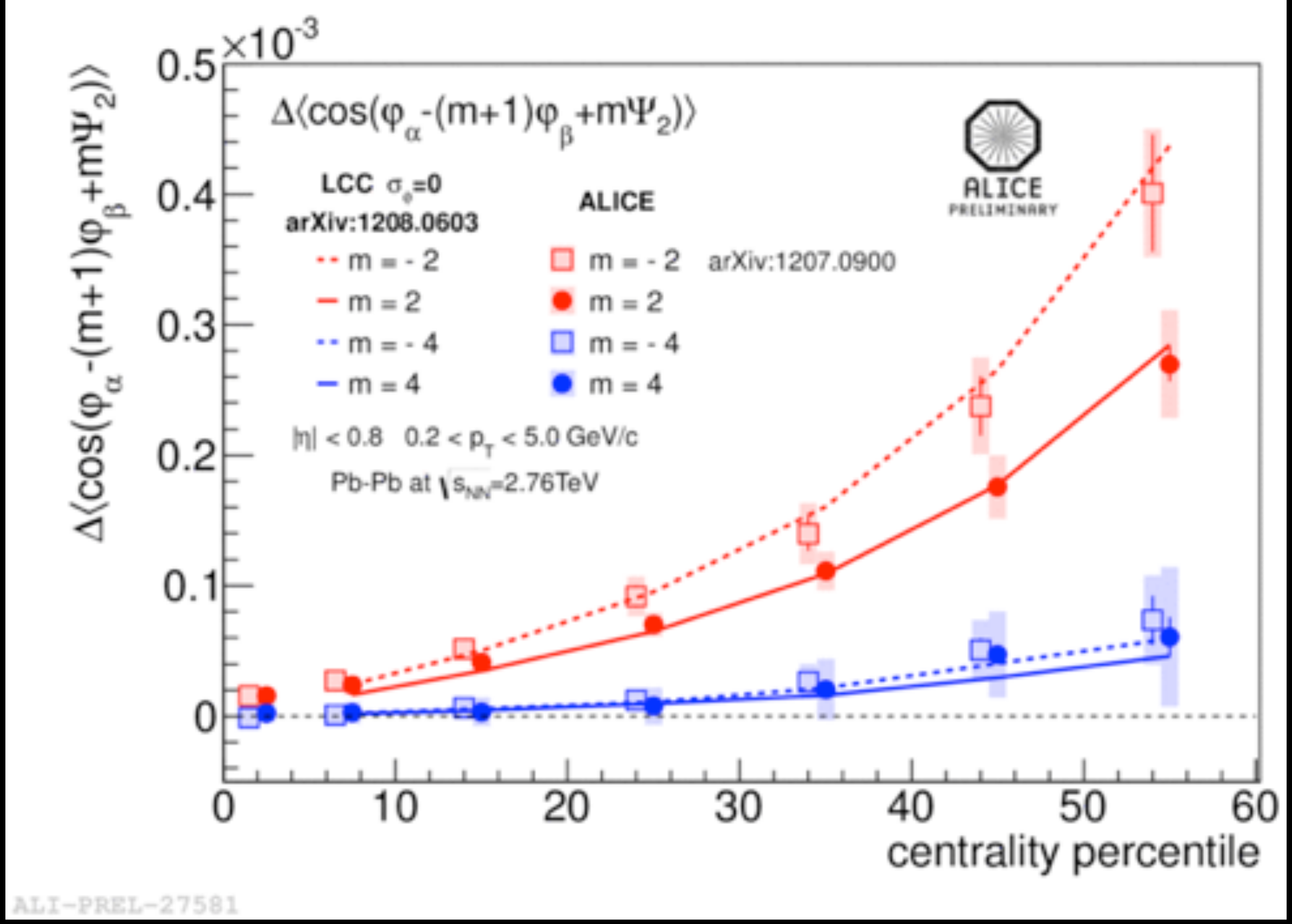
$$\Delta C_{1,3}\{\Psi_2\} = \Delta\langle \cos(\varphi_\alpha - 3\varphi_\beta + 2\Psi_2) \rangle$$

- The fourth harmonic modulation of the balance function wrt Ψ_2

$$\Delta C_{1,-3}\{\Psi_2\} = \Delta\langle \cos(\varphi_\alpha + 3\varphi_\beta - 4\Psi_2) \rangle$$

$$\Delta C_{1,5}\{\Psi_2\} = \Delta\langle \cos(\varphi_\alpha - 5\varphi_\beta + 4\Psi_2) \rangle$$

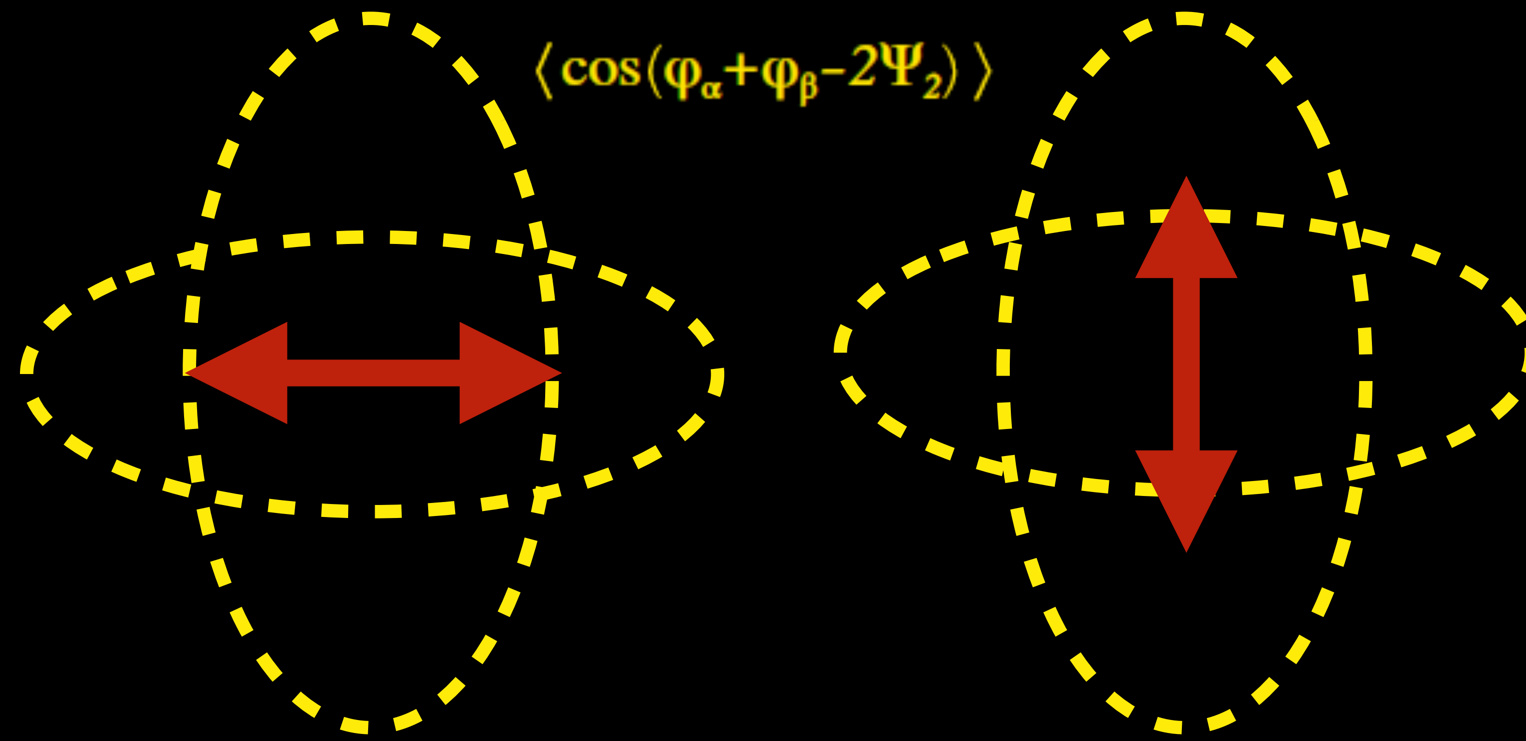
The model reproduces successfully the main features for a set of correlators with different harmonics



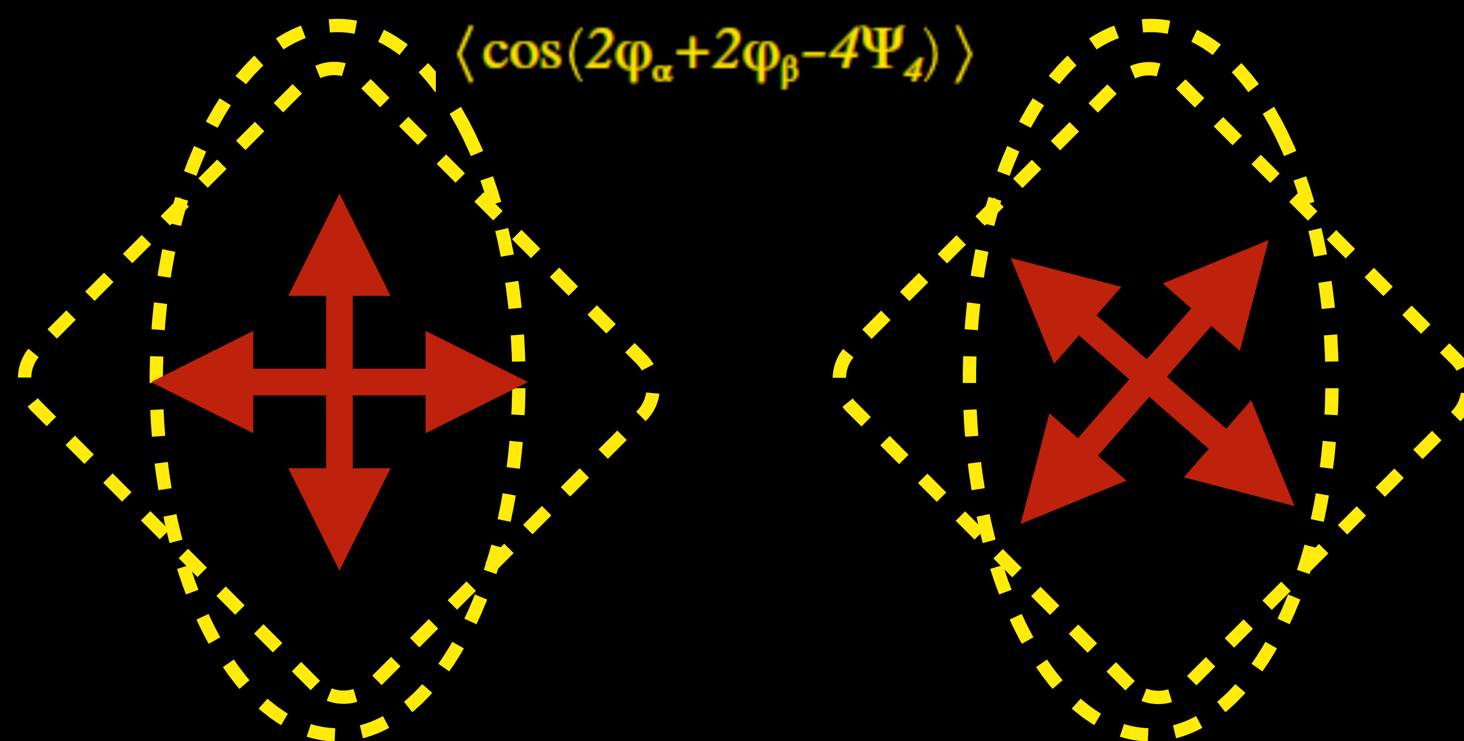
Y. Hori (ALICE Collaboration) @ QM2012

“Double harmonic” correlations

- Charge independent correlations:
  - directed flow fluctuations relative to the 2nd order symmetry plane
- Charge dependent correlations:
  - contribution from CME
  - contribution from local charge conservation + v_2



- Charge independent correlations:
  - elliptic flow fluctuations relative to the 4th order symmetry plane
- Charge dependent correlations:
  - no contribution from CME
  - contribution from local charge conservation + v_4



For further details: Jocelyn Mlynarz (for the ALICE Collaboration), “Charged dependent correlations relative to the 4th harmonic” shown @ Quark Matter 2012, Washington DC