ATLAS v_n results

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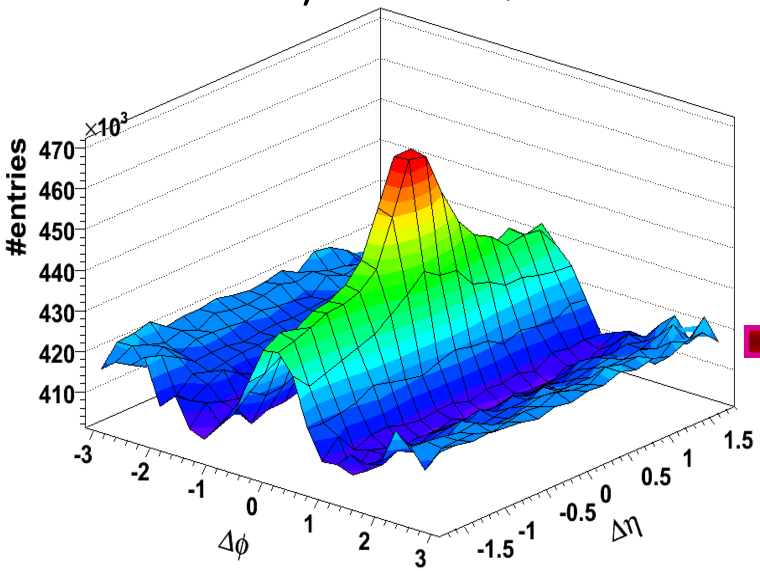
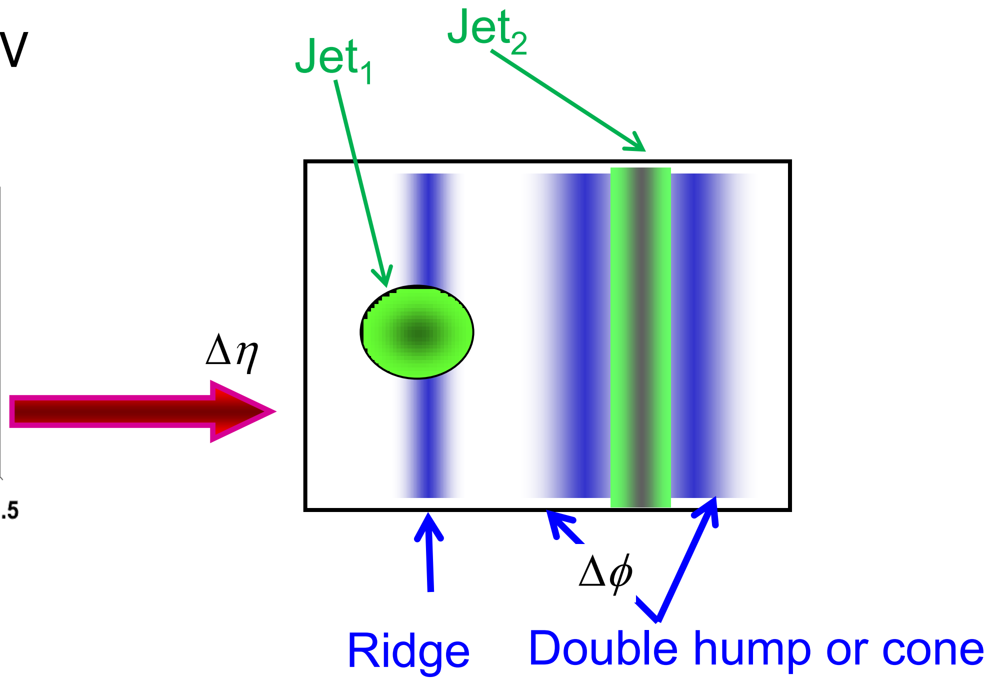
Stony Brook University and BNL

- v_n from event plane method
- v_n from two-particle correlation method
- Comparison between the two methods

Motivation (one of the many)

Long range structure at RHIC
3-4 x 1-2 GeV, Au+Au √s=200 GeV

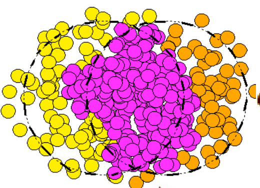




- What is the physics origin of "ridge" and "cone" in 2P correlations?
- Are they due to "jet-medium" interactions or "fluctuation+flow"?

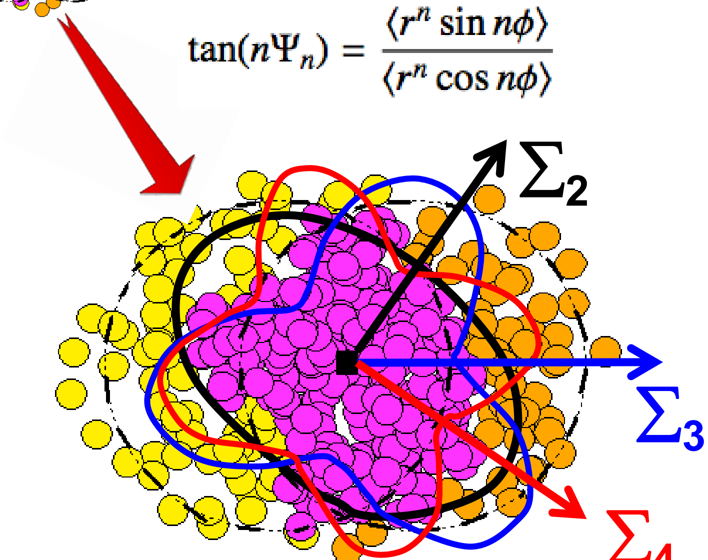
Higher order harmonics in hydro-picture

- Initial spatial fluctuations of nucleons lead to higher moments of deformations, each with its own orientation. Alver, Roland, Staig, Shuryak,
- They are transferred to p_T space by collective expansion
  - Single particle distribution become anisotropic
  - Pairs appear as narrow peak at near-side (all moments are in phase), a broad peak at away-side (out of phase)

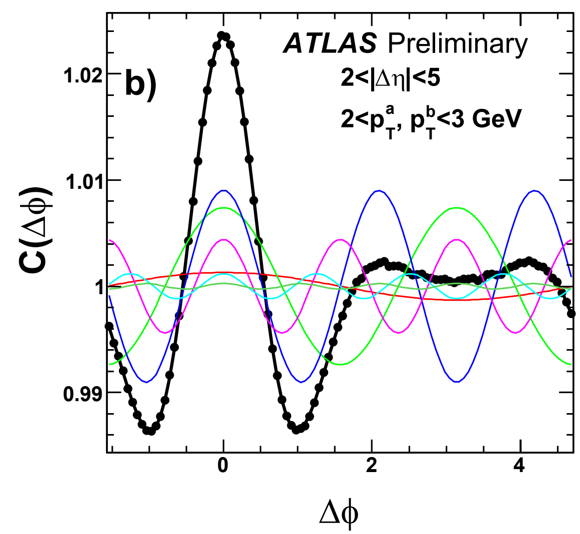


$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi\rangle + \langle r^n \sin n\phi\rangle}{\langle r^n\rangle}}$$

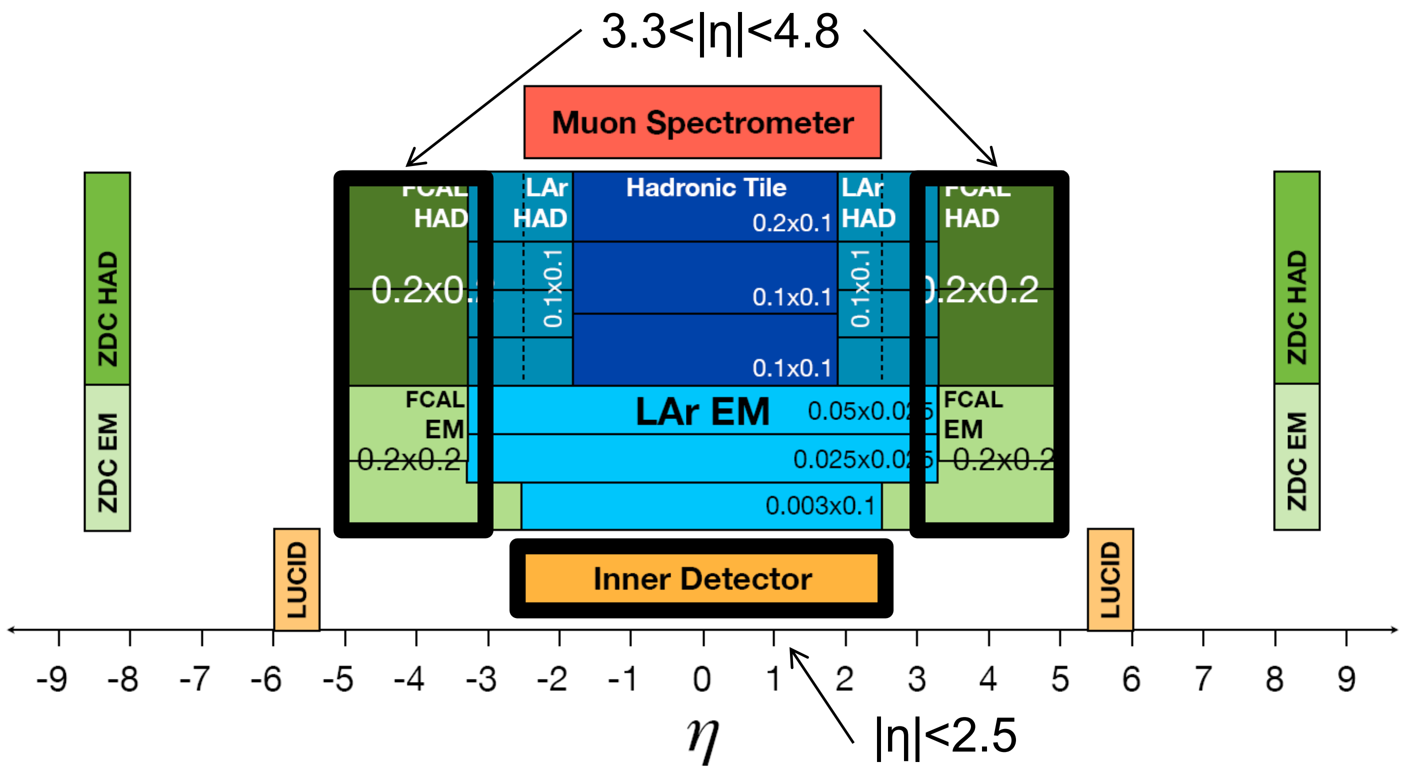
$$\tan(n\Psi_n) = \frac{\langle r^n \sin n\phi\rangle}{\langle r^n \cos n\phi\rangle}$$



Singles:	$\frac{dN}{d\phi} \propto 1 + \sum_n 2\mathrm{v}_n \cos n\left(\phi - \Psi_n\right)$	**EP method**
Pairs:	$\frac{dN}{d\Delta\phi} \propto 1 + \sum_n 2\mathrm{v}_n^a \mathrm{v}_n^b \cos\left(n\Delta\phi\right)$	**2PC method**



ATLAS Detector



- EP method:
  - Correlate tracks at |η|<2.5 with EP from full FCal in 3.3<|η|<4.8 full FCal method

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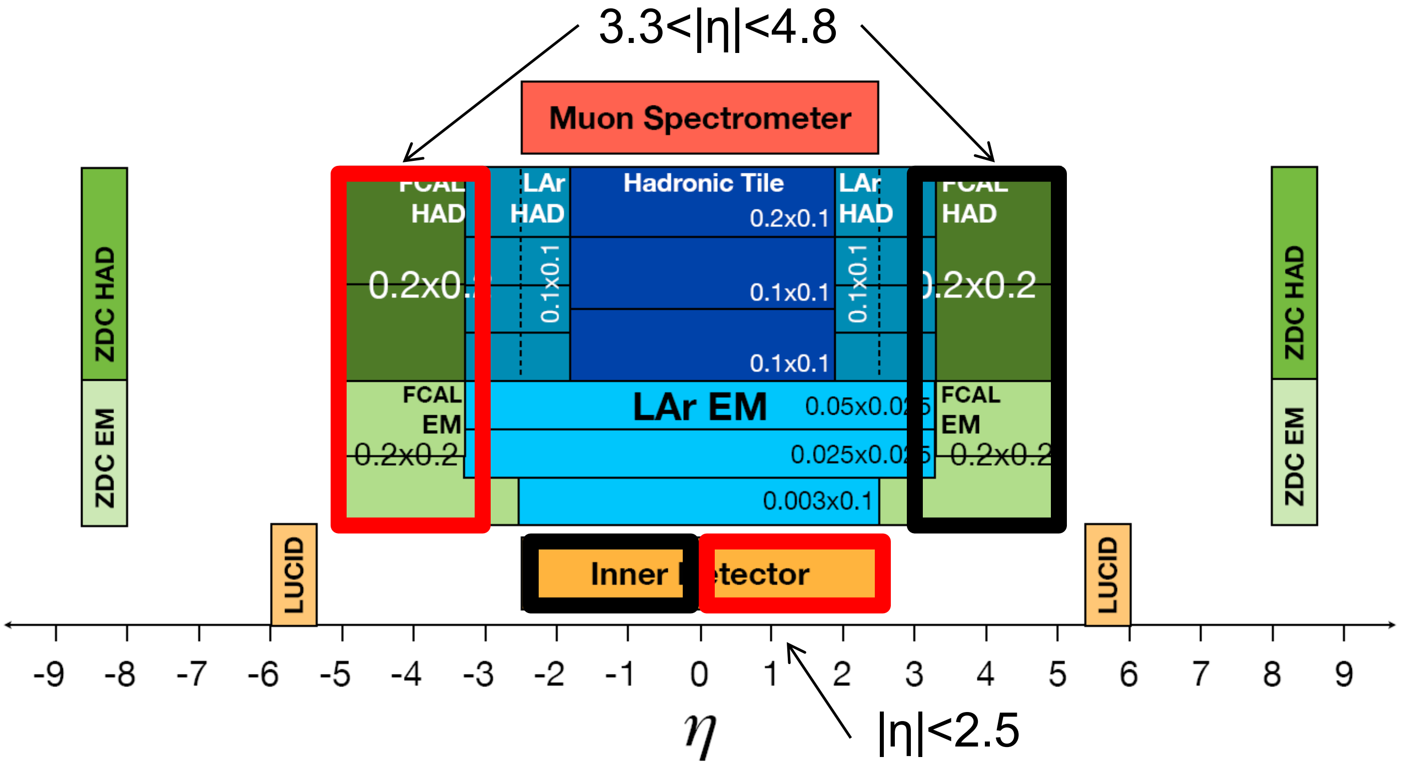
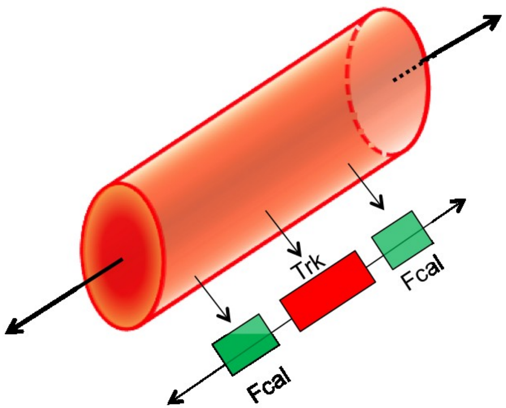
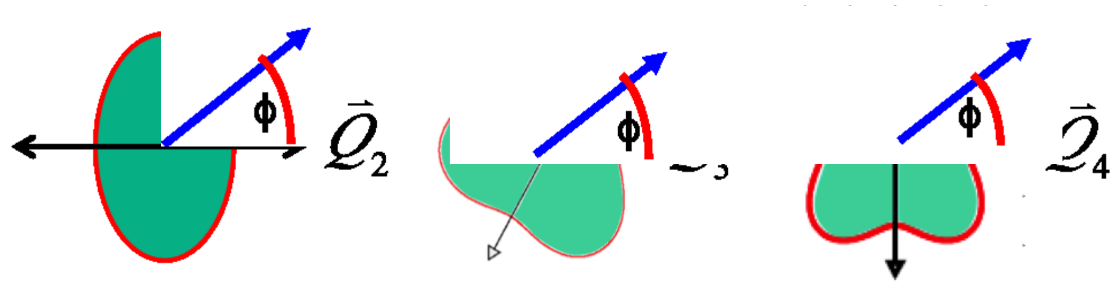


- EP method:
  - Correlate tracks at |η|<2.5 with EP from full FCal in 3.3<|η|<4.8 full FCal method
  - Correlate tracks at η>0 with EP from FCal at η<0 and vice versa $FCal_{P(N)}$ method

    The latter significantly increase the η gap between track and FCal: <Δη> =3→5
- Two-particle correlation method
  - Charged particle pairs with a large rapidity gap, e.g. |Δη|>2.
- 8 μb^{-1} Pb+Pb data from fall 2010 (48 M events)

Event Plane method



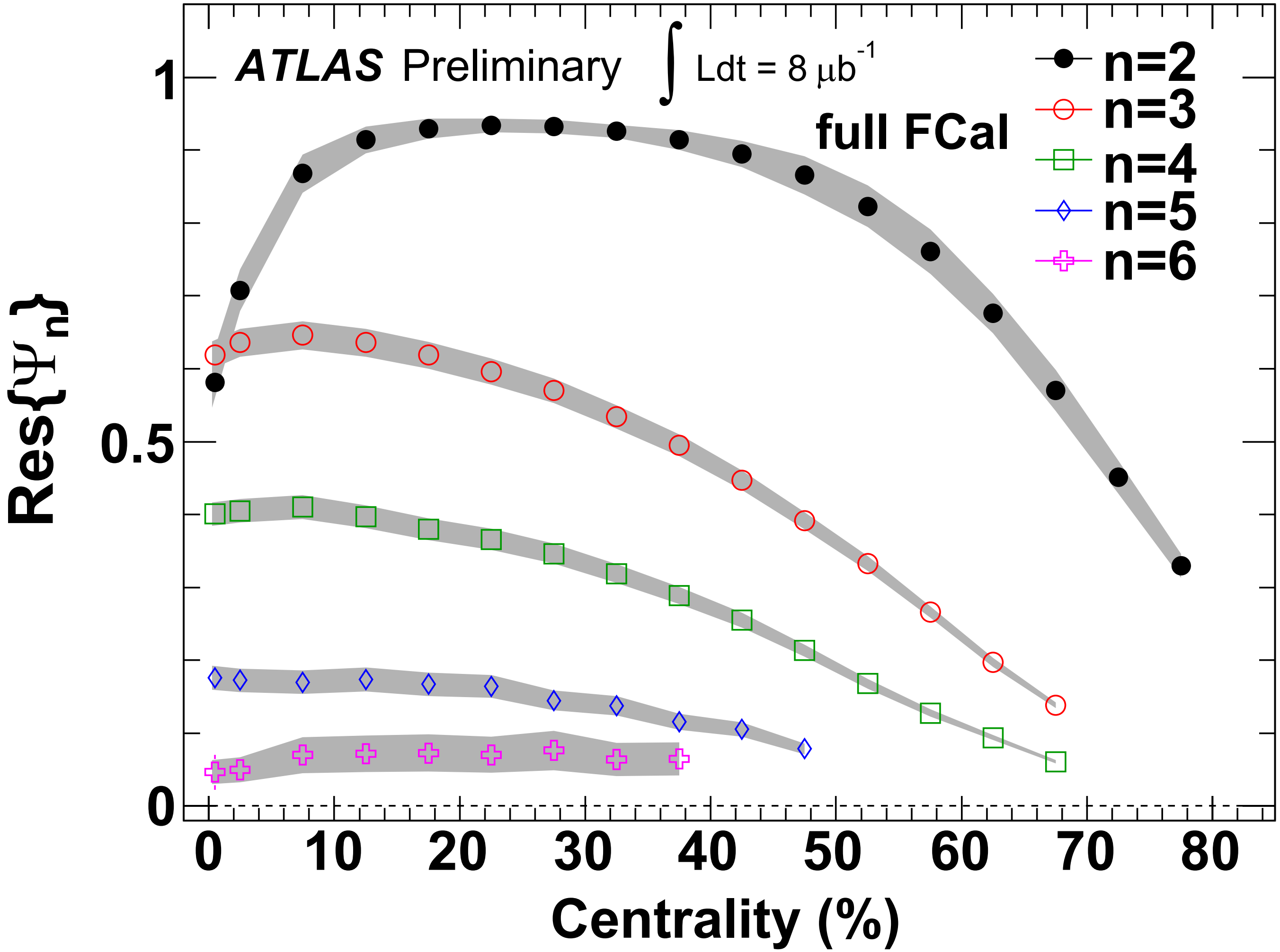


$$v_n = \frac{v_n^{\text{obs}}}{\text{Res}\{\Psi_n\}} = \frac{\langle \cos n(\phi - \Psi_n) \rangle}{\langle \cos n(\Psi_n - \Psi_{\text{RP},n}) \rangle}$$

- v_n^{obs} measured by correlation of tracks with nth flow vector Q_n at FCal
- Followed by a resolution correction

Poskanzer &Voloshin, PRC**58**,1671 (1998)

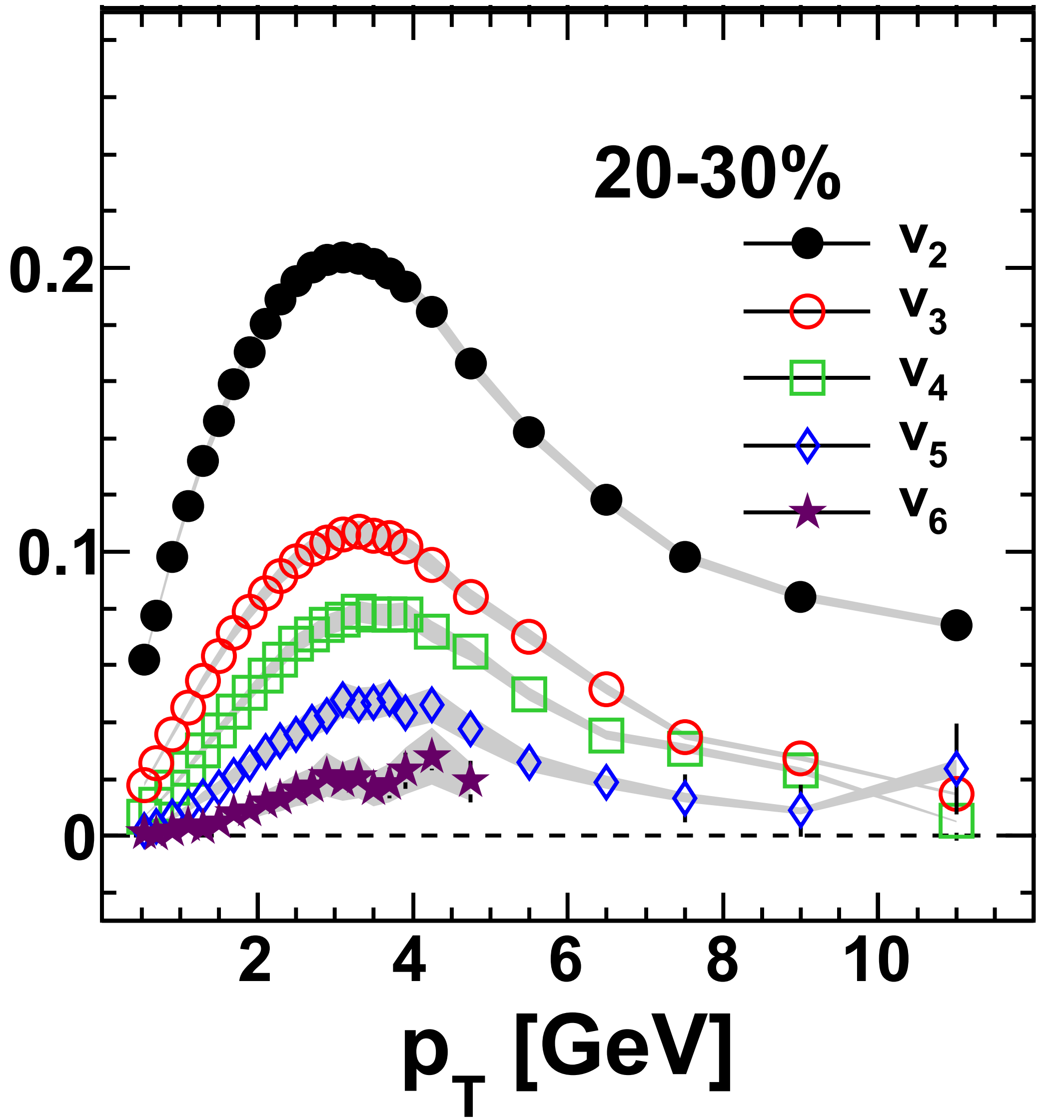
Event Plane Resolution



- Significant resolution for n=2-6 from full FCal.
- Systematic errors estimated via two-sub-event and various three-sub-event methods

$v_n(n, p_T, \eta, \text{cent})$

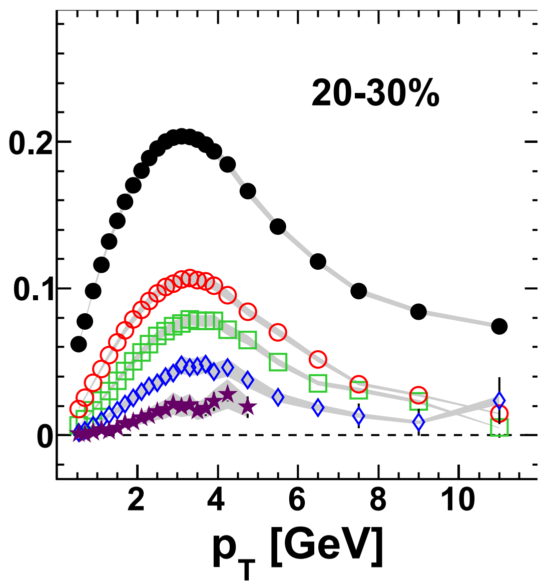
$v_n(n=2\text{-}6)$ vs p_T (0.5-12 GeV)



Similar p_T dependence for all n: rise to 3-4 GeV, then falls

v_n vs p_T

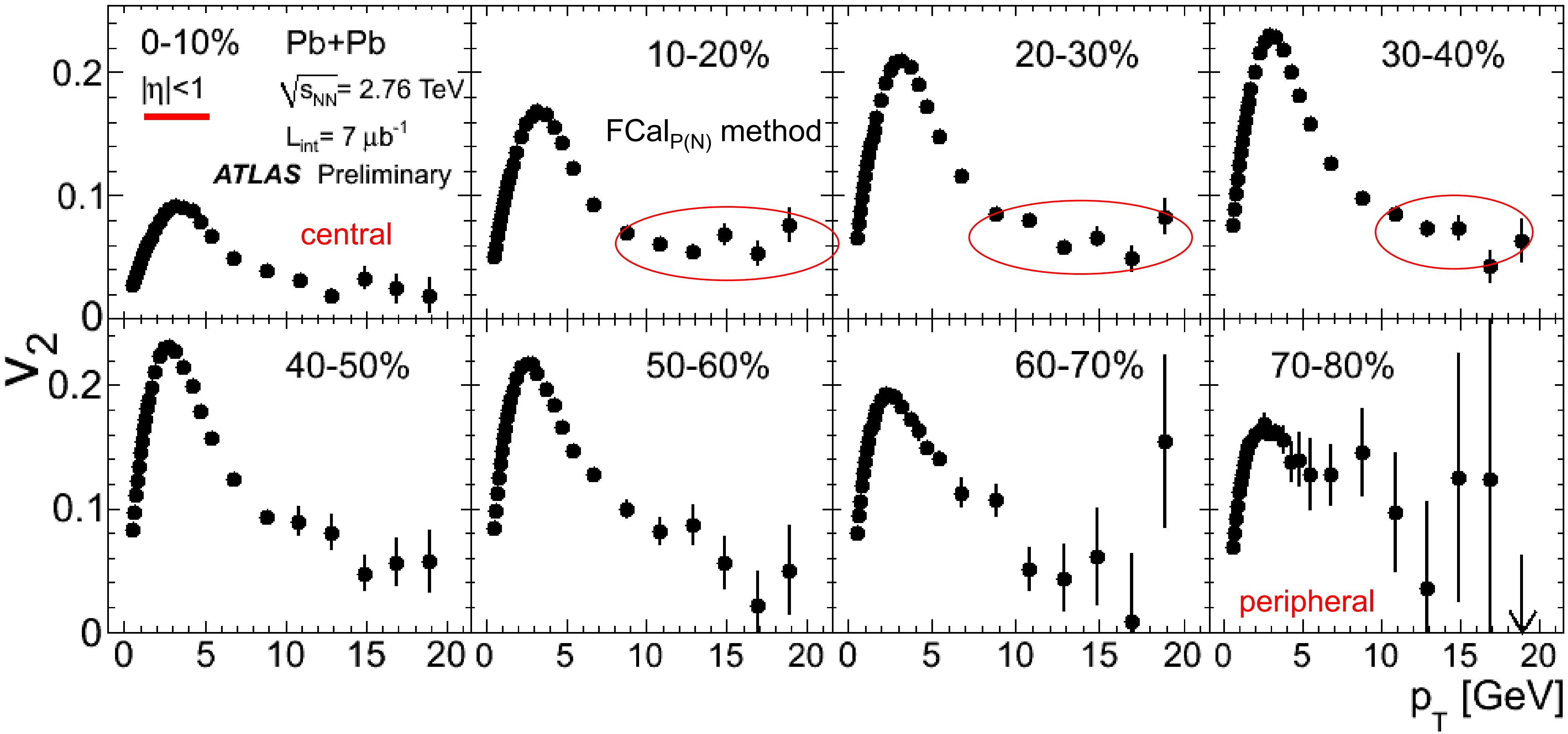
- v_n (n=2-6) vs p_T for several centrality selections



Similar p_T dependence for all n: rise to 3-4 GeV, then falls
v_n (n>2) has steeper slope and may exceed v_2 in central collisions.

v_2 measured out to 20 GeV

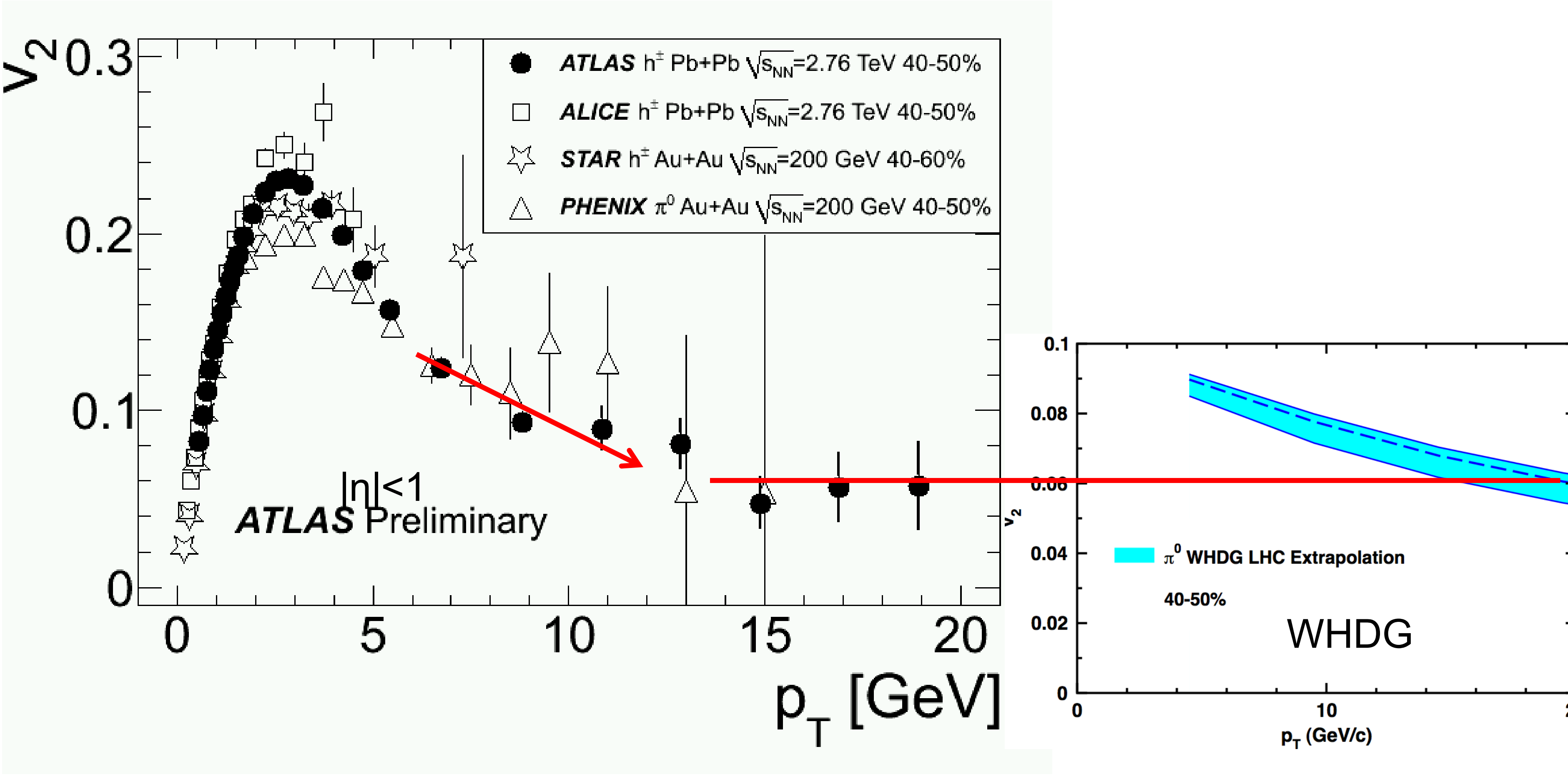
- Charged hadrons, p_T=0.5-20 GeV, mid-rapidity, $|\eta|<1$



Weak p_T dependence beyond 8-10 GeV out to 20 GeV
Important constraint on jet quenching models!

Adam Trzupek, Friday 15:00

Compare to RHIC

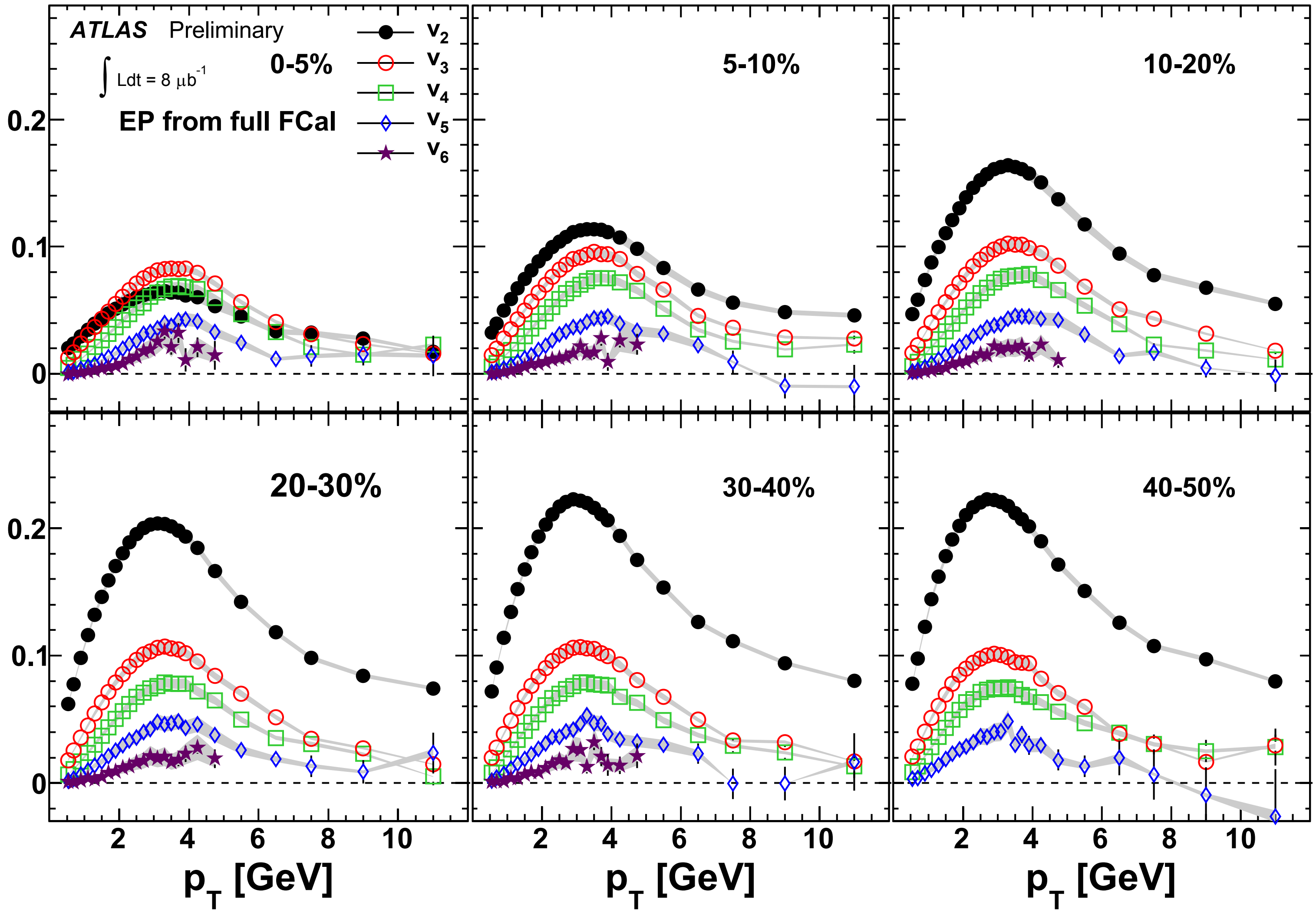


Similar magnitude and p_T dependence in overlapping p_T range

Consistent with pQCD calculations for p_T>10-12 GeV?

Scaling relations between v_n

- Hydrodynamics model suggests different v_n are related, e.g. $v_4 \propto v_2^2$ or $v_4^{1/4} \propto v_2^{1/2}$
- Plot the $v_n^{1/n} / v_2^{1/2}$ (n=3-6) ratio for several centrality selections



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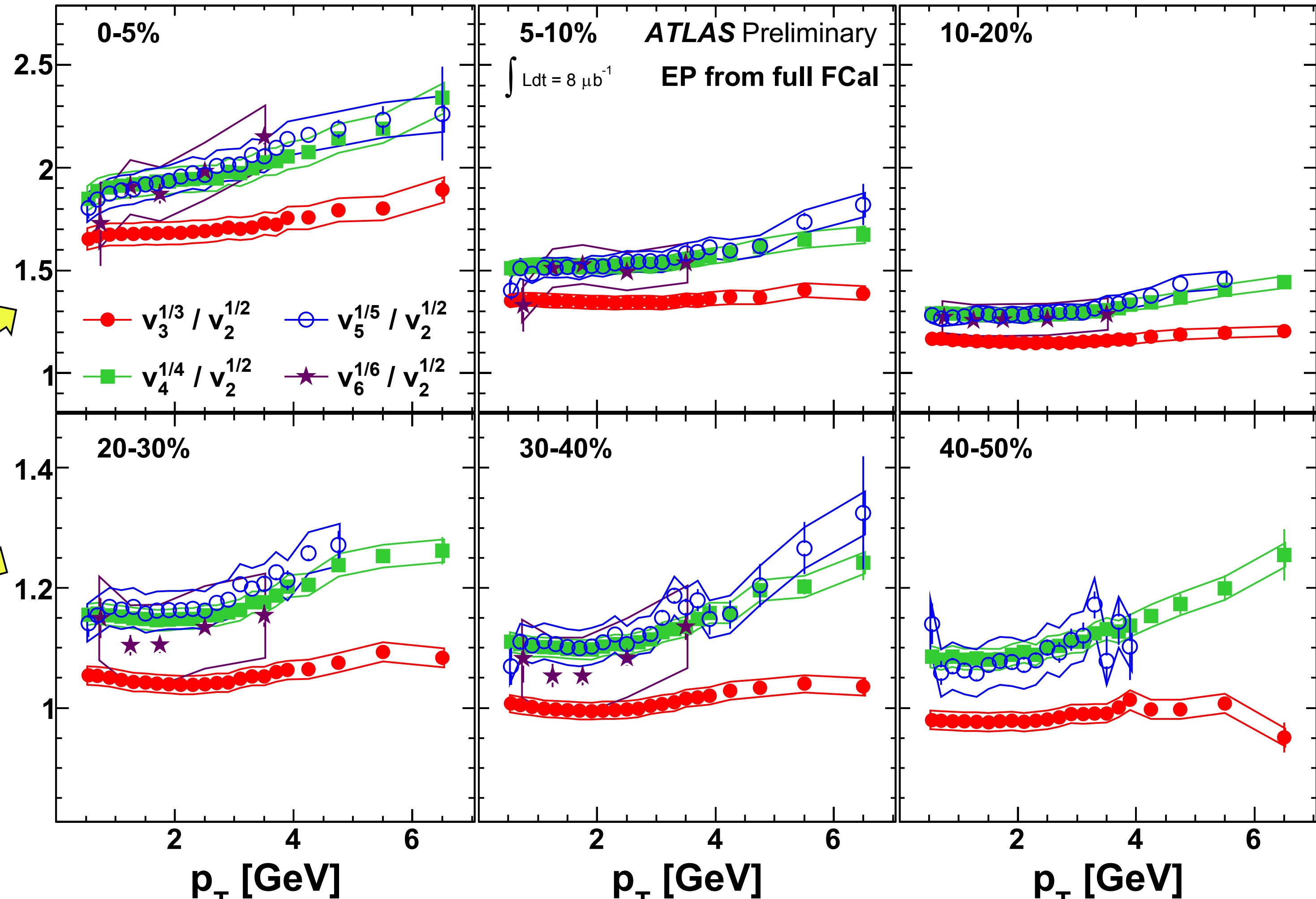
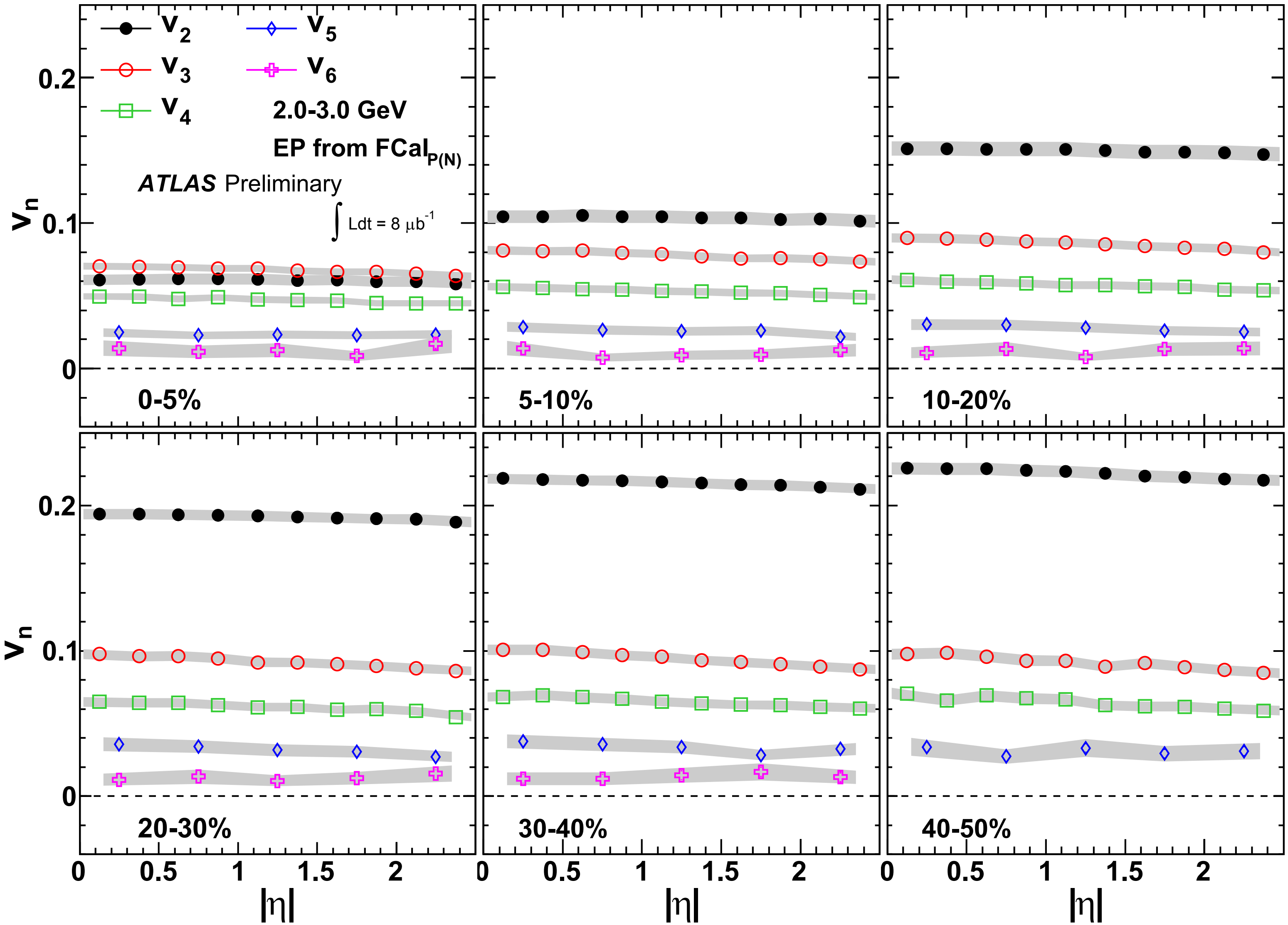
Notice the change of scales



Most p_T dependence is linearized in the ratio!

v_n vs pseudorapidity

- v_n (n=2-6) vs η for several centrality selections



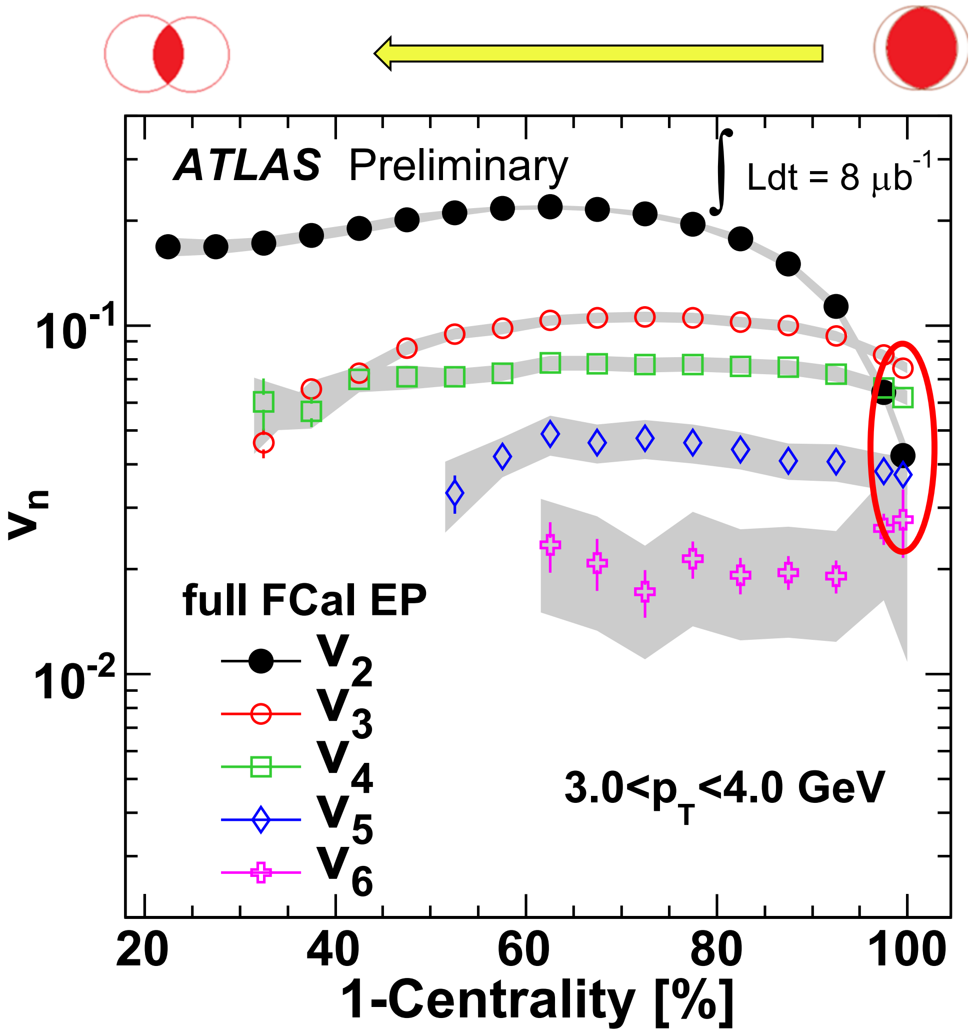
Weak η dependence for all v_n !

v_n vs centrality

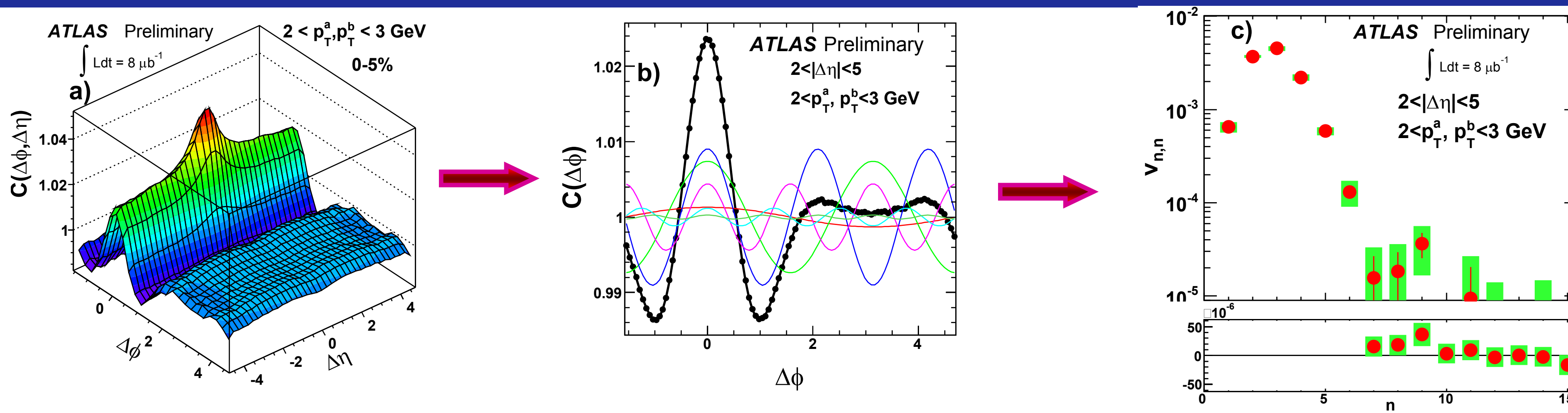
- Plot v_n(n=2-6) vs centrality in 5% centrality steps plus a 0-1% most central bin (the right most point)

Rise to mid-centrality then falls; higher order v_n is flatter

v_3,v_4 even v_5 exceed v_2 at high p_T in most central collisions



Two-particle correlation method



Fourier decompose the 1D Δϕ correlation in given Δη slice

$$\frac{dN}{d\,\Delta\phi} \propto 1 + \sum_n 2\mathrm{v}_{n,n}\cos\left(n\Delta\phi\right) \qquad \mathrm{v}_{n,n} = \left\langle \cos\left(n\Delta\phi\right)\right\rangle$$

No fitting! $v_{n,n}$ calculated directly via DFT for n=1-15

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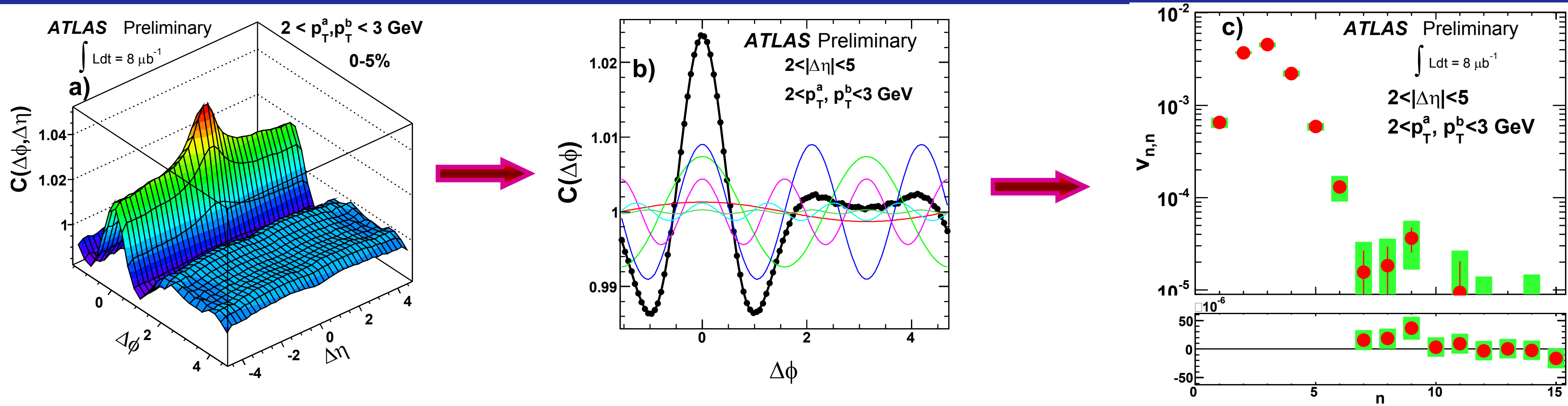

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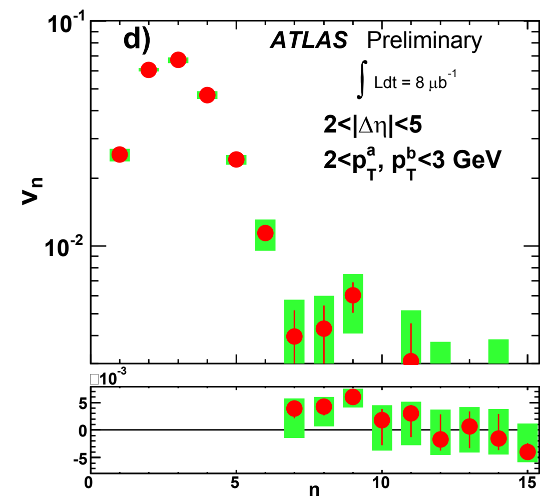


$v_{n,n}$ is expected to factorize into single v_n for flow

$$v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a)\, v_n(p_T^b)$$

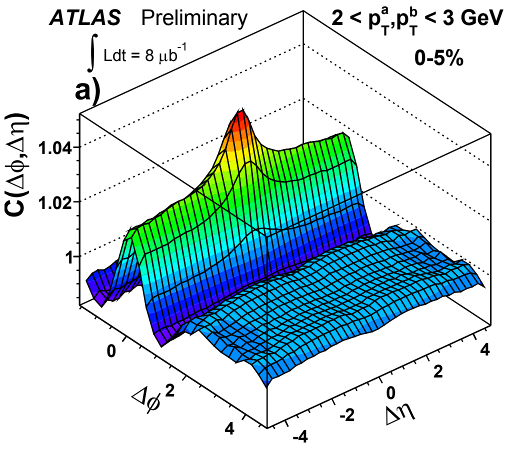
➔ v_n from "fixed-p_T" correlation

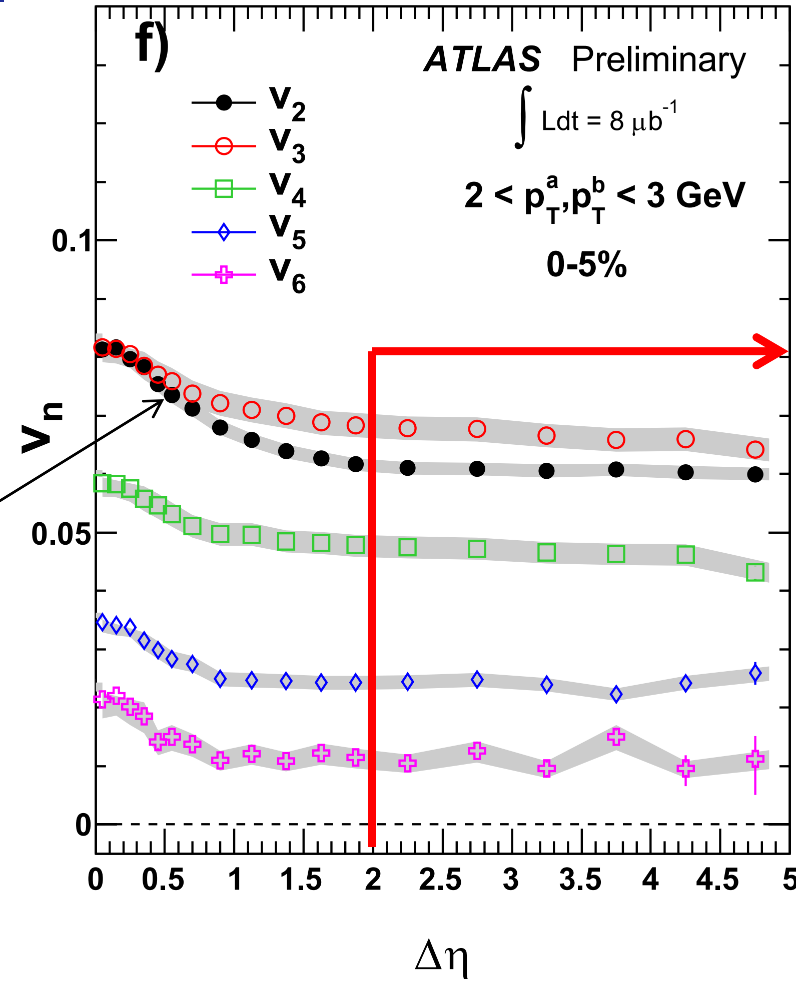
$$v_n(p_T^a) = \sqrt{v_{n,n}(p_T^a, p_T^a)}$$

➔ cross-check via "mixed-p_T" correlation

$$v_n(p_T^b) = \frac{v_{n,n}(p_T^a, p_T^b)}{v_n(p_T^a)}$$

Repeat this for each Δη slice





- v_2-v_6 extracted as a function of Δη.
- Suppress the near-side jet bias with a large Δη gap |Δη|>2

$$v_{n,n}\left(p_T^a,p_T^b\right)=v_n\left(p_T^a\right)v_n\left(p_T^b\right)$$

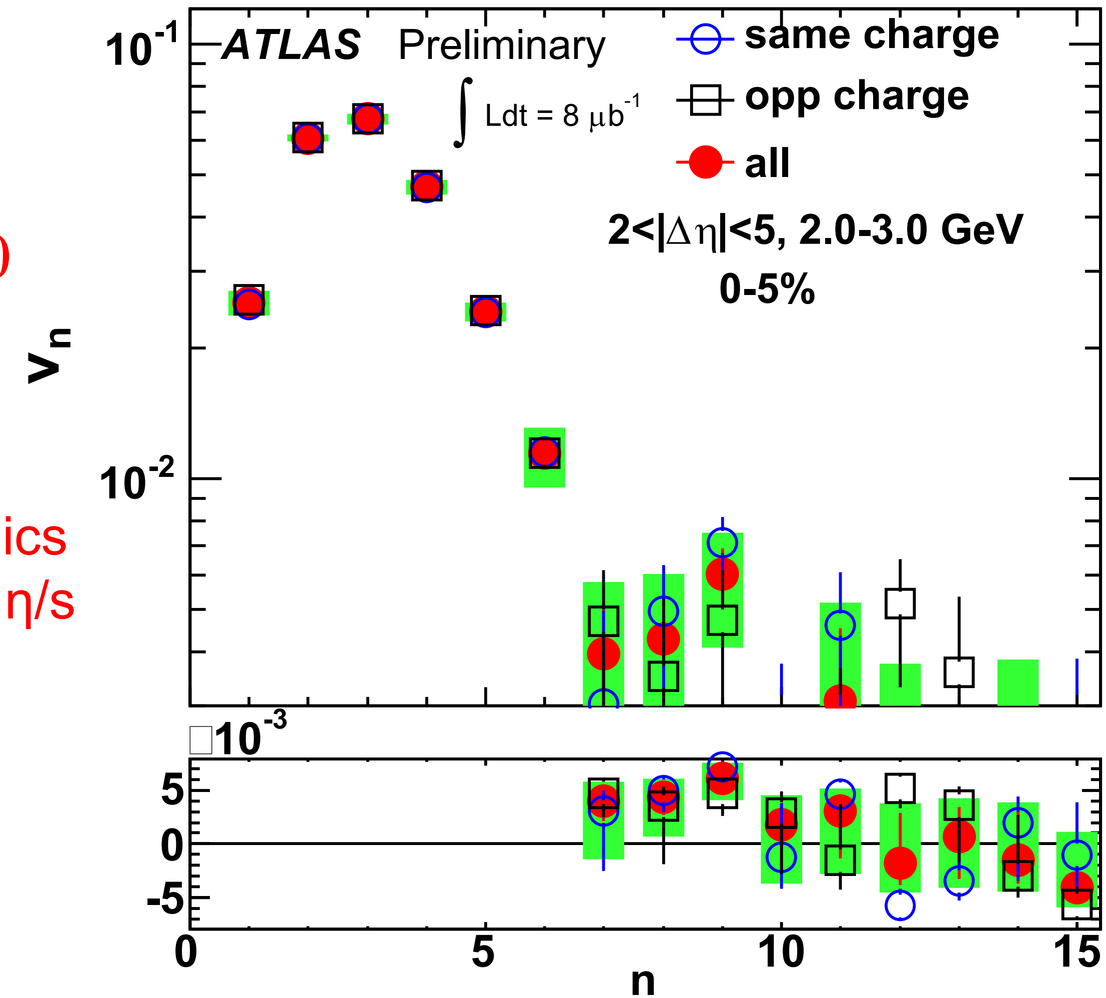
v_2-v_6 obey factorization for |Δη|>2, p_T<3-4 GeV, and in non-peripheral collisions; v_1 does not

Power spectra in azimuth angle

- v_n vs n for n=1-15 in 0-5% most central collisions and 2.0-3.0 GeV

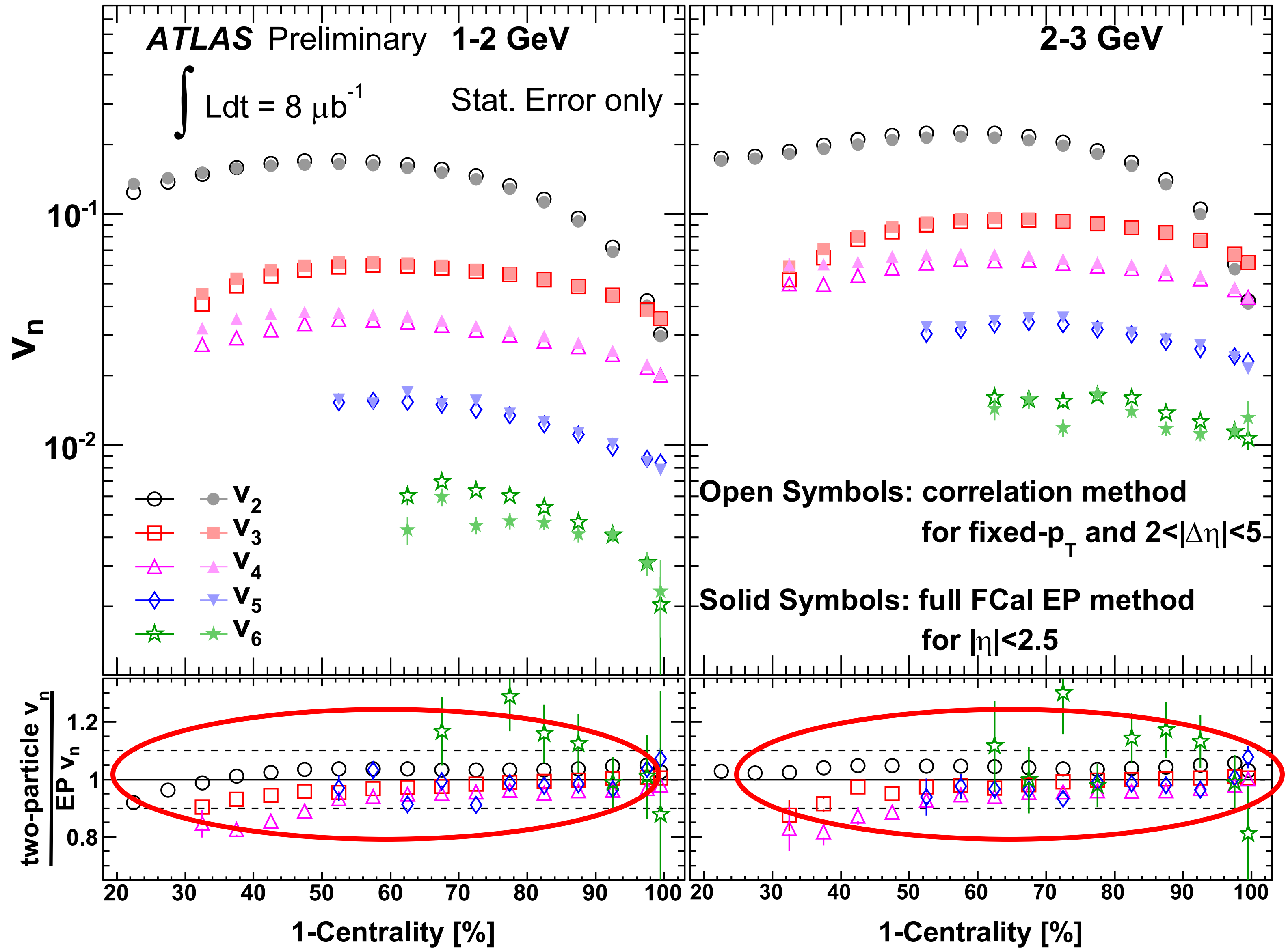
Significant v_2-v_6 signal, higher order consistent with 0

Damping of higher order harmonics provides important constraint on η/s



The error on $v_n=\sqrt{v_{n,n}}$ is highly non-Gaussian

Compare with the Event Plane method



Consistent between the 2PC and full FCal EP method (Similar for $FCal_{P(N)}$).

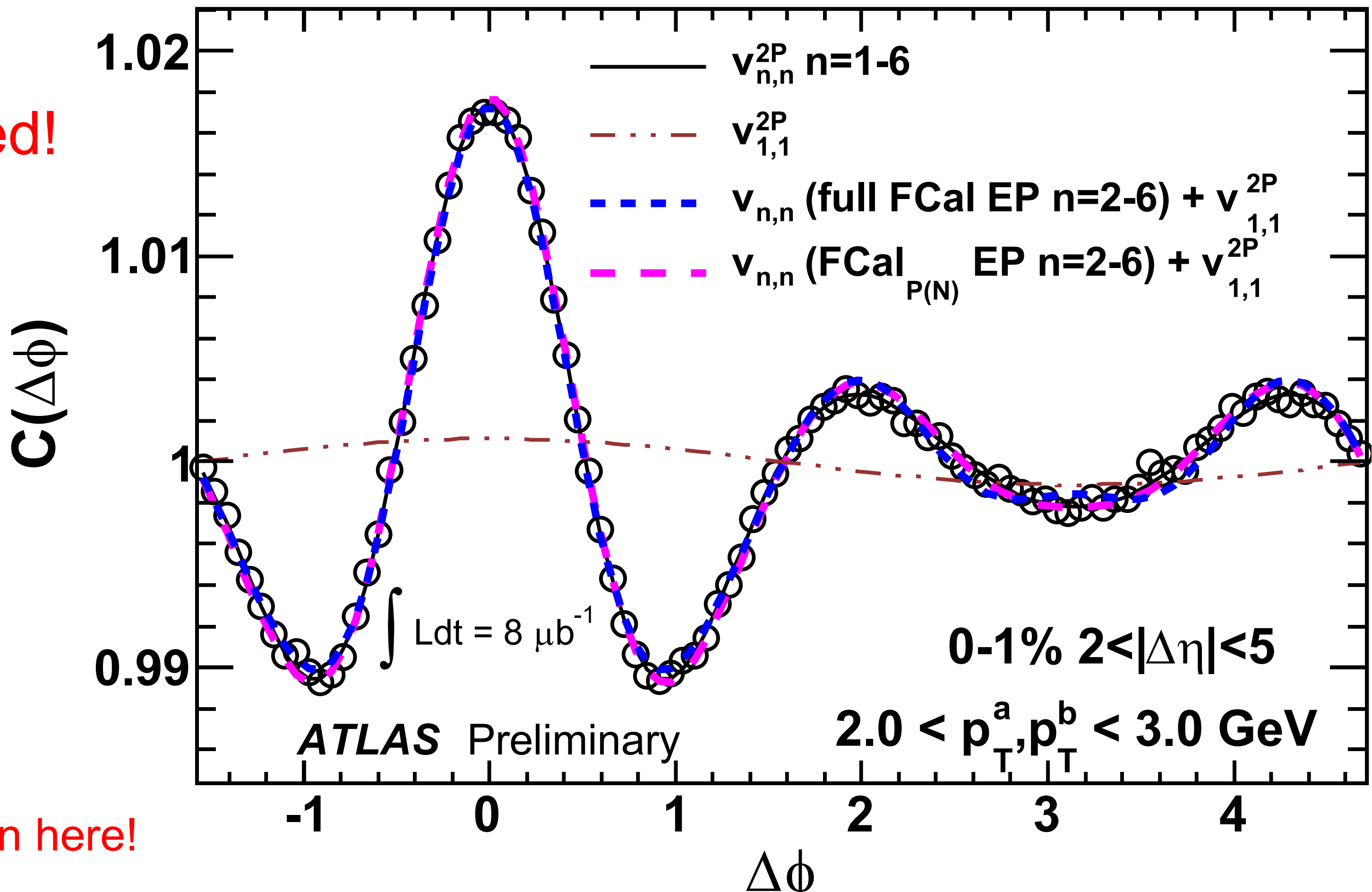
Reconstruct 2PC from Event Plane v_n

$$C(\Delta\phi) = b^{2P}\left(1 + 2v_{1,1}^{2P}\cos\Delta\phi + 2\sum_{n=2}^{6} v_n^{EP} v_n^{EP}\cos n\Delta\phi\right)$$

From 2PC method

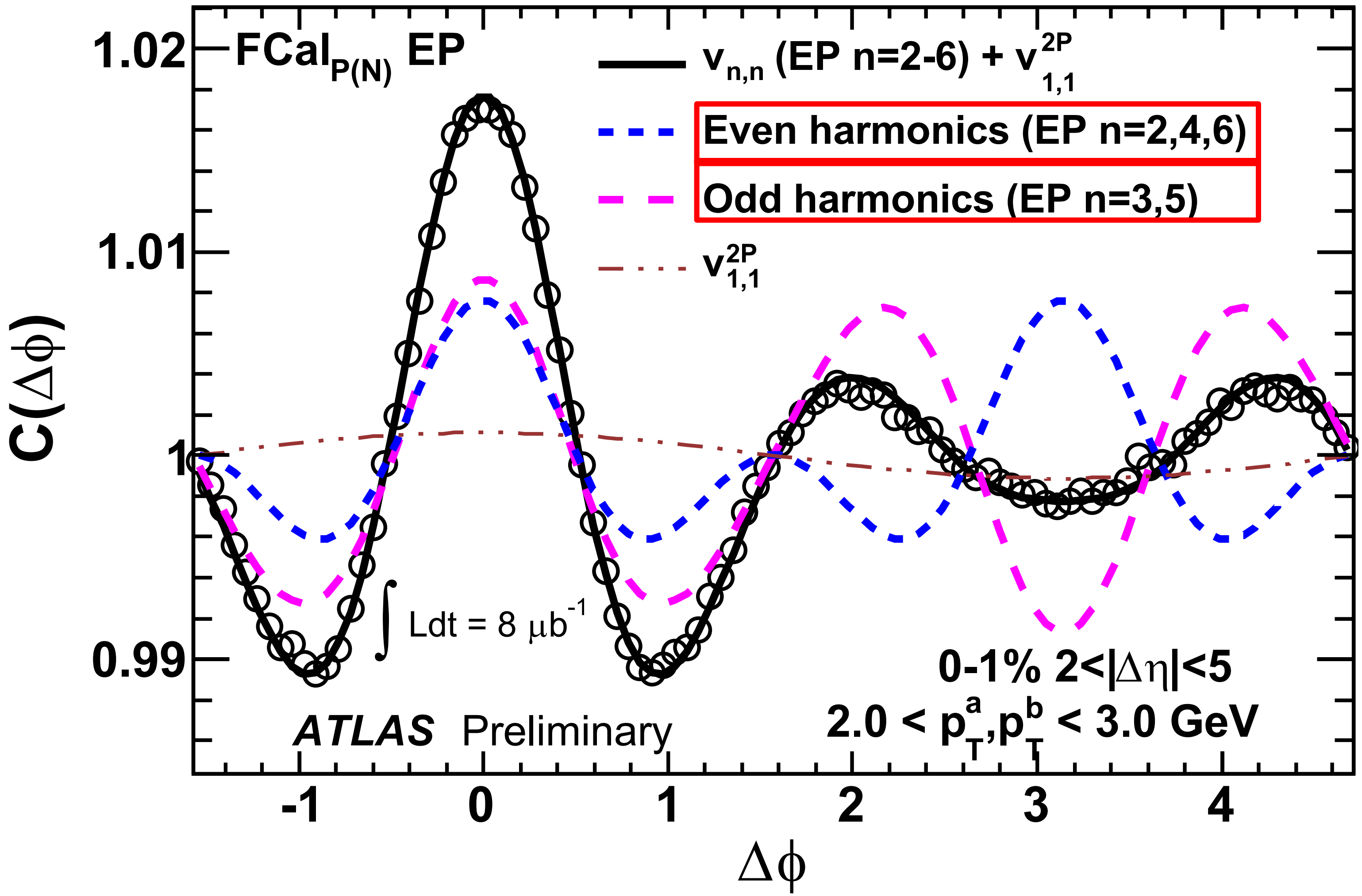
From EP method

well reproduced!



NO ZYAM subtraction here!

Contribution from odd and even harmonics



Away-side shape is due to interplay between odd and even harmonics!

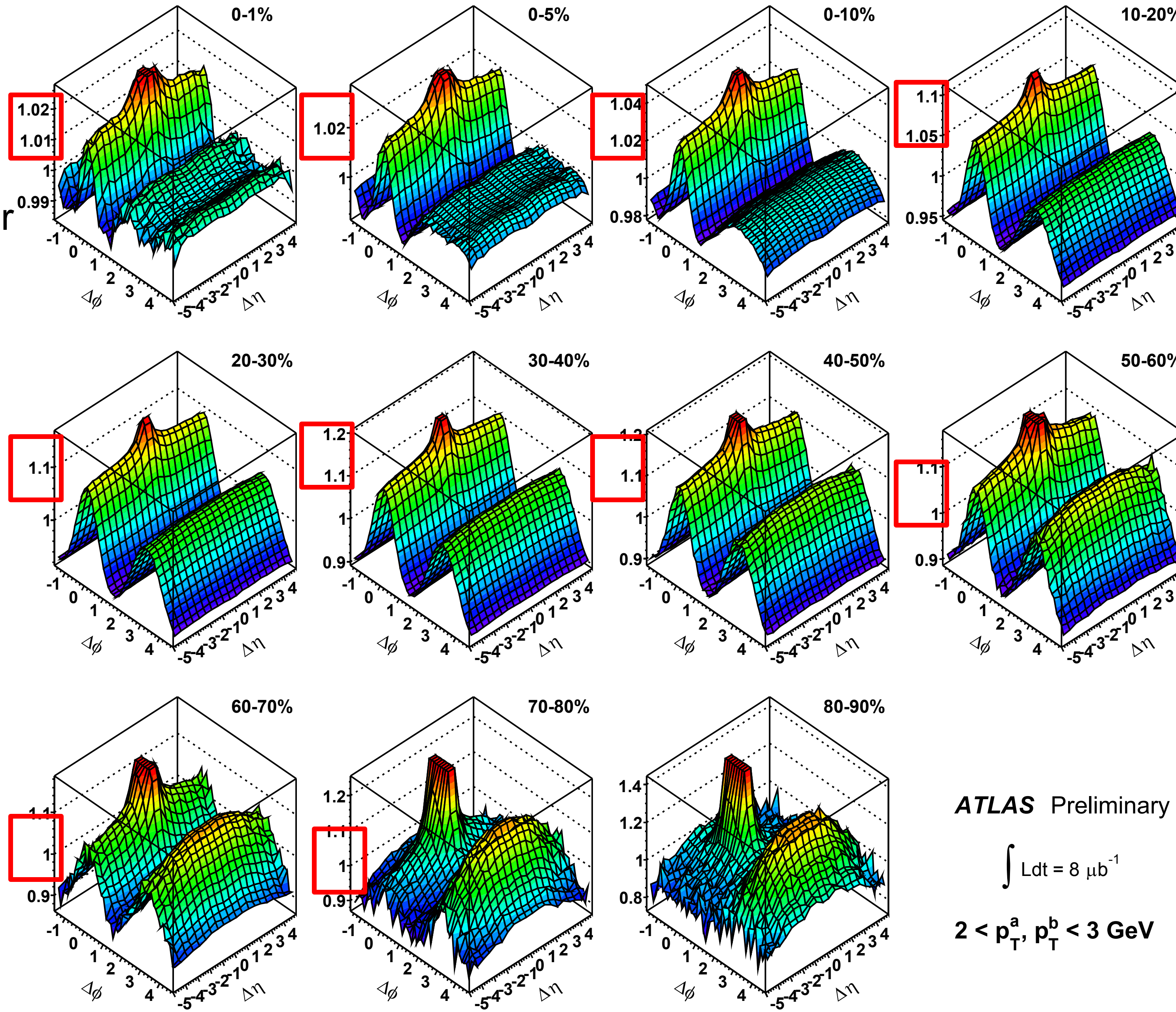
So where is the away-jet contribution?

Rise and fall of “ridge/cone”—Centrality evolution

Pay attention to how long-range structures disappear and clear jet-related peaks emerge on the away-side

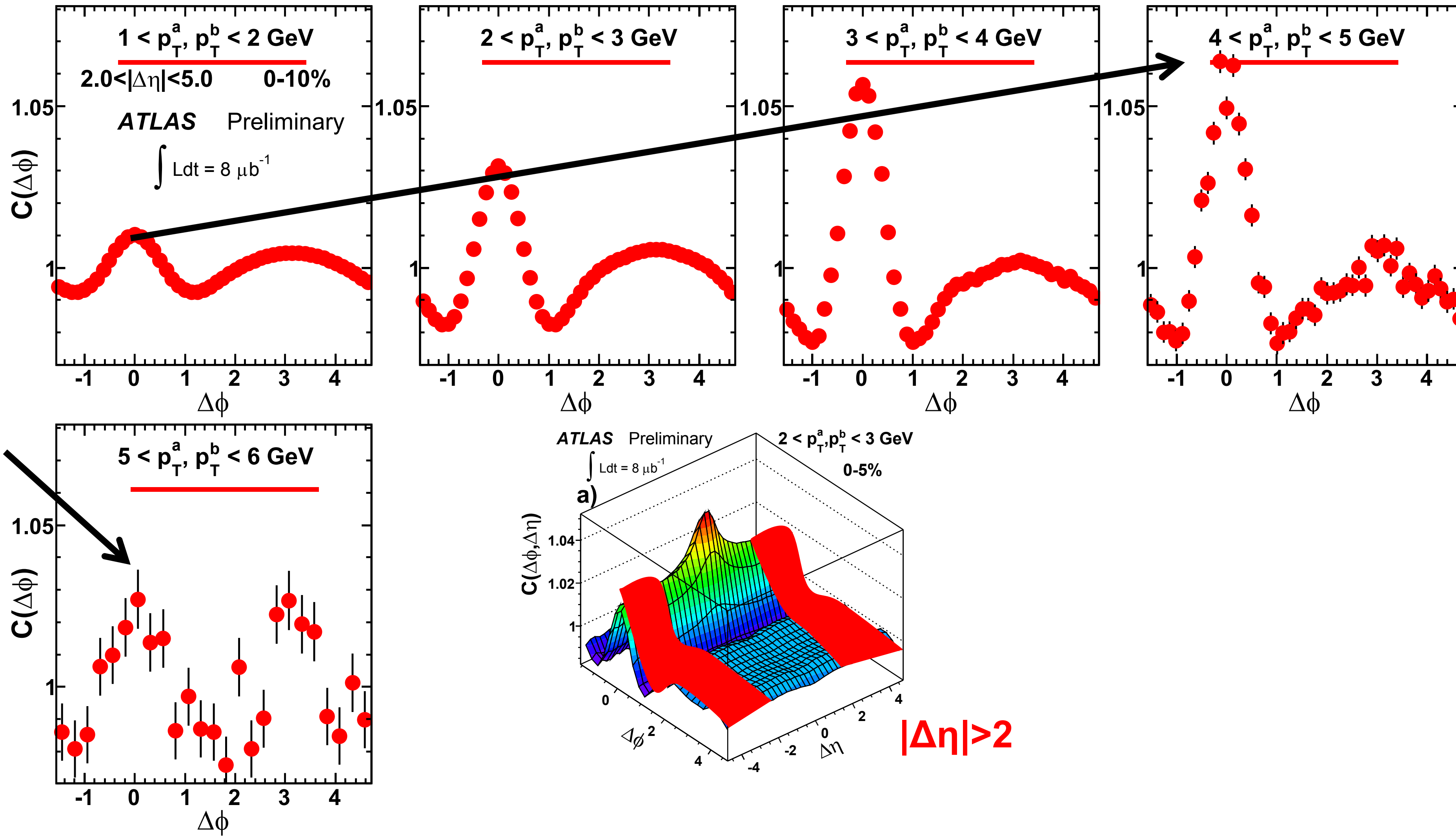
Strength of soft component increase and then decrease

Near-side jet peak is truncated from top to better reveal long range structure



Rise and fall of "ridge/cone"—p_T evolution

- select the long range components with $|\Delta\eta|>2$ and see how it evolves with p_T



Strength of long range components first increase to 4-5 GeV then decrease
Clear away jet emerges in 6-8 GeV range

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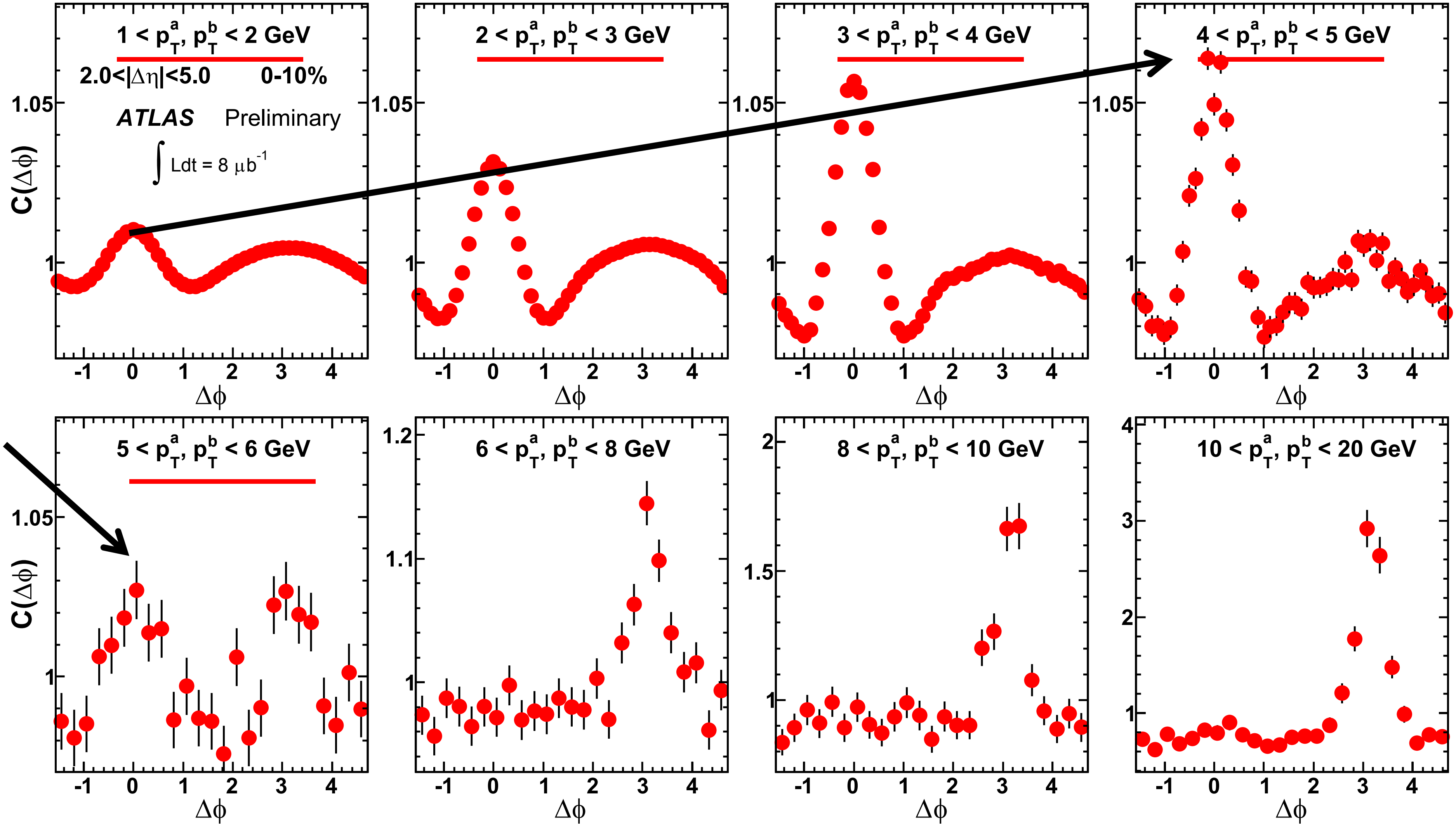

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Conclusion

- We extracted the v_2-v_6 via both EP and 2P correlation methods
- Significant v_2-v_6 are observed from EP, they show similar dependence on η, p_T and centrality, and follow an interesting scaling relation

$$v_n^{1/n} \propto v_2^{1/2}$$

- Consistent with results from 2P correlation with $|\Delta\eta|>2$ cut at low p_T
- The long range "ridge" and "cone" structures in two-particle correlation function at low p_T can be explained by v_2-v_6 and a momentum conservation term (v_1).
- The initial geometry fluctuations, together with small viscosity of medium are likely responsible for these higher coefficients.

This measurement can help elucidate the nature of these fluctuations and better constrain the transport properties.

Adam Trzupek, Friday 15:00
Poster Soumya Mohapatra #7

A 30p note is publicly available
http://cdsweb.cern.ch/record/1352458