Measurement of centrality and pseudorapidity dependence of elliptic flow in lead-lead collisions at 2.76 TeV with the ATLAS detector

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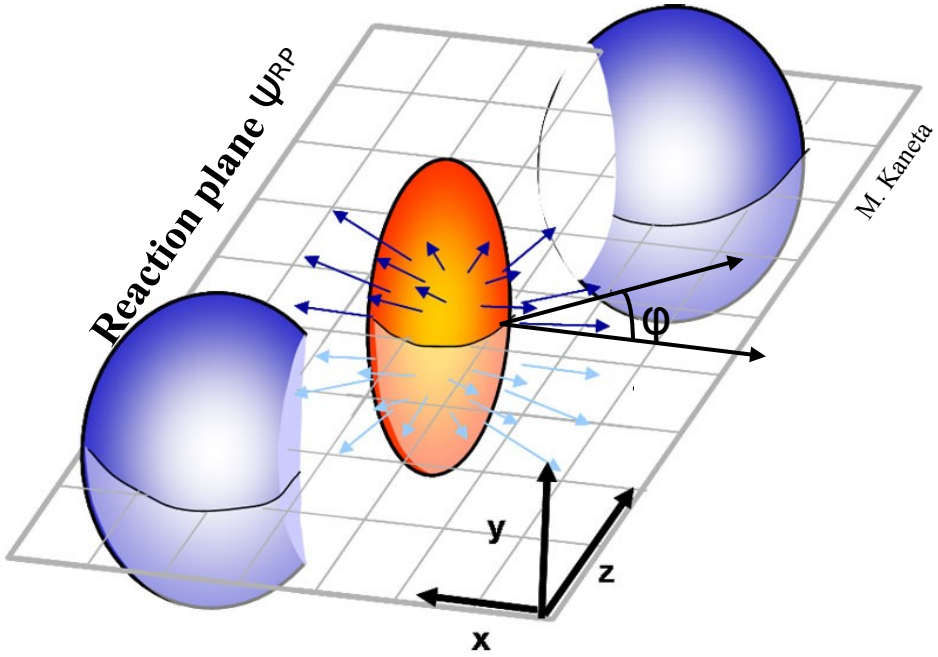
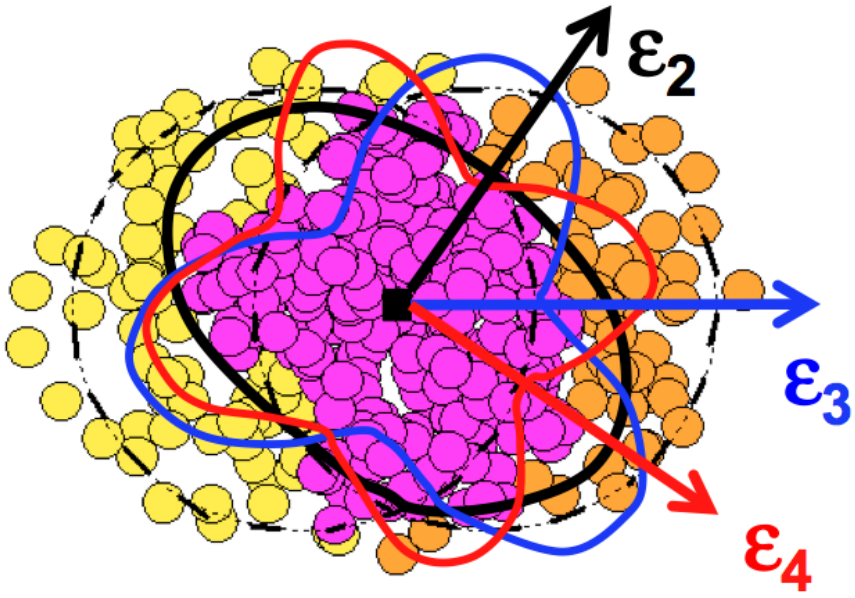
Azimuthal anisotropy in heavy ion collisions





Pressure gradients lead to azimuthal anisotropy

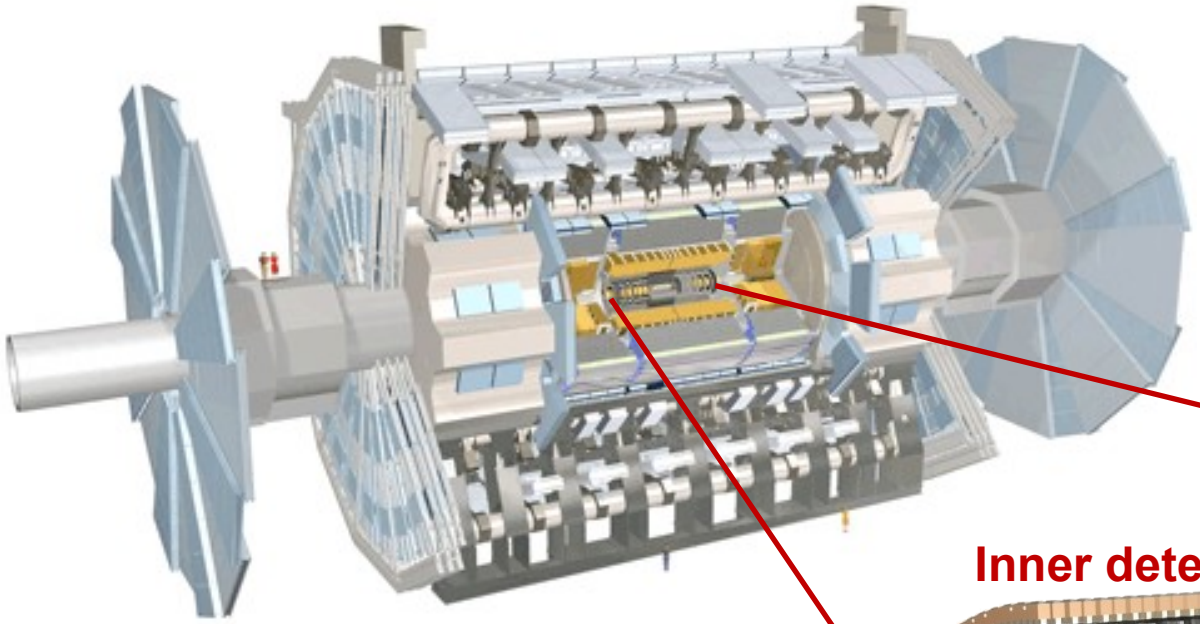
$$\frac{dN}{d\phi} = N_0\left(1 + 2v_1\cos\left(\phi - \Psi_1\right) + 2v_2\cos\left(2\left(\phi - \Psi_2\right)\right) + 2v_3\cos\left(3\left(\phi - \Psi_3\right)\right) + \ldots\right)$$

directed flow — elliptic flow — triangular flow

Fourier harmonics $v_n = \langle \cos\left(n\left(\Phi - \Psi_n\right)\right)\rangle$

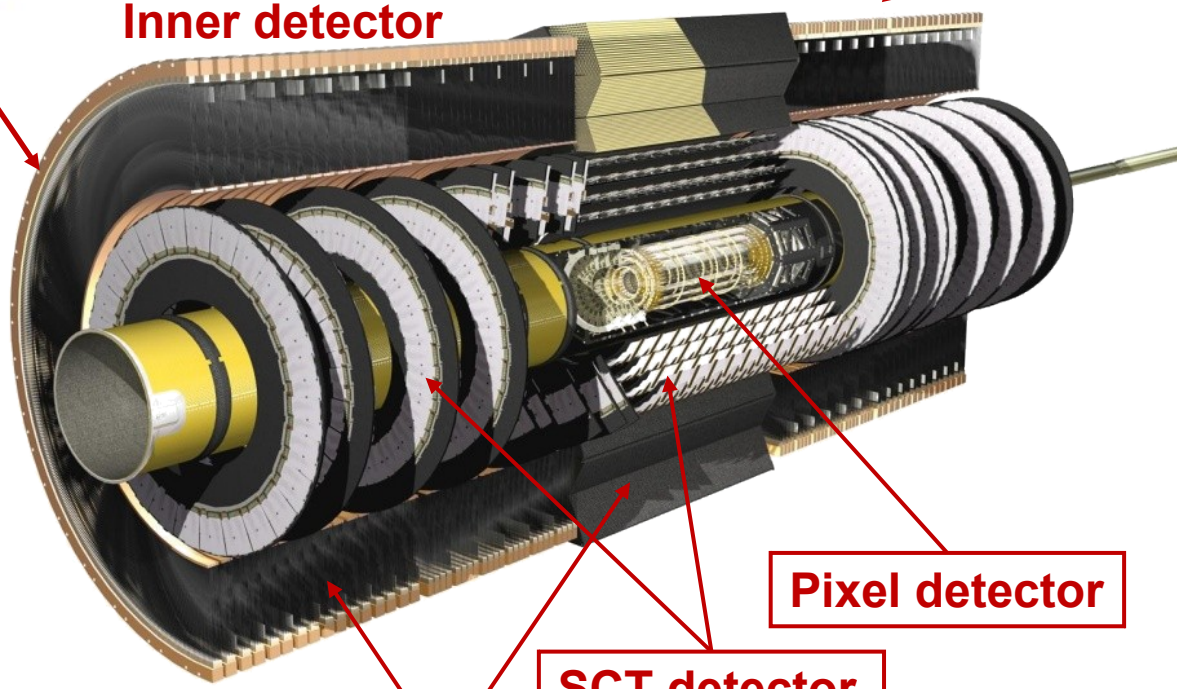
- Initial shape of the interaction region (v_2 - elliptic flow)
- Initial spatial fluctuations of interacting nucleons (higher orders, v_n)

ATLAS detector



The ATLAS Inner Detector is a composite tracking system consisting of silicon and gaseous detectors.

Inner detector

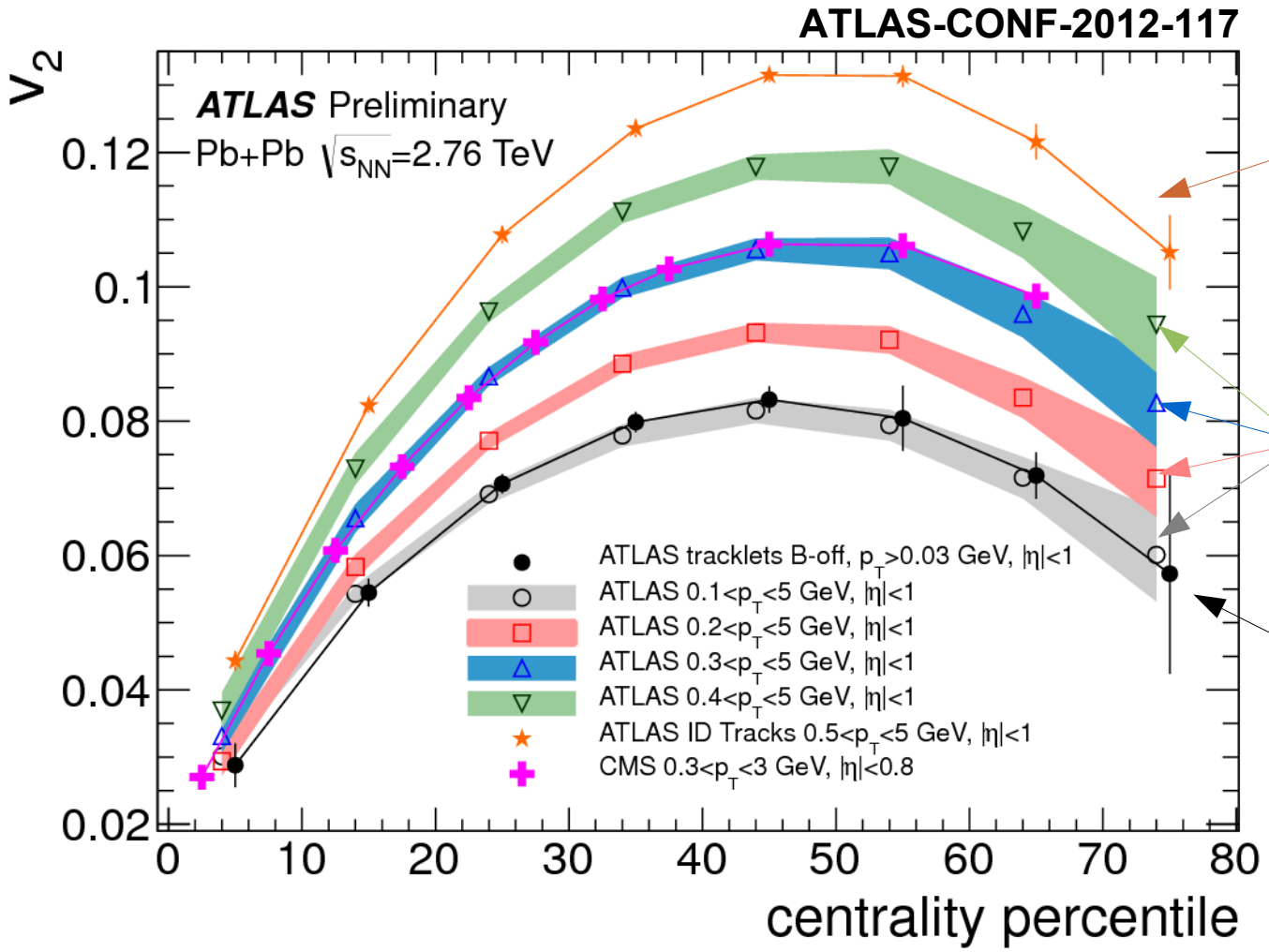


Three tracking techniques:

- ID tracks:
  $p_T > 0.5$ GeV
- Pixel tracks:
  $p_T > 0.1$ GeV
- Two point pixel tracklets (B-off):
  $p_T > 0.03$ GeV

Integrated v_2 down to very low p_T

- Integrated v_2 flow harmonic measured using the EP method
- Reaching low p_T reduces uncertainty on the integrated v_2
- More robust comparison with theoretical model predictions possible



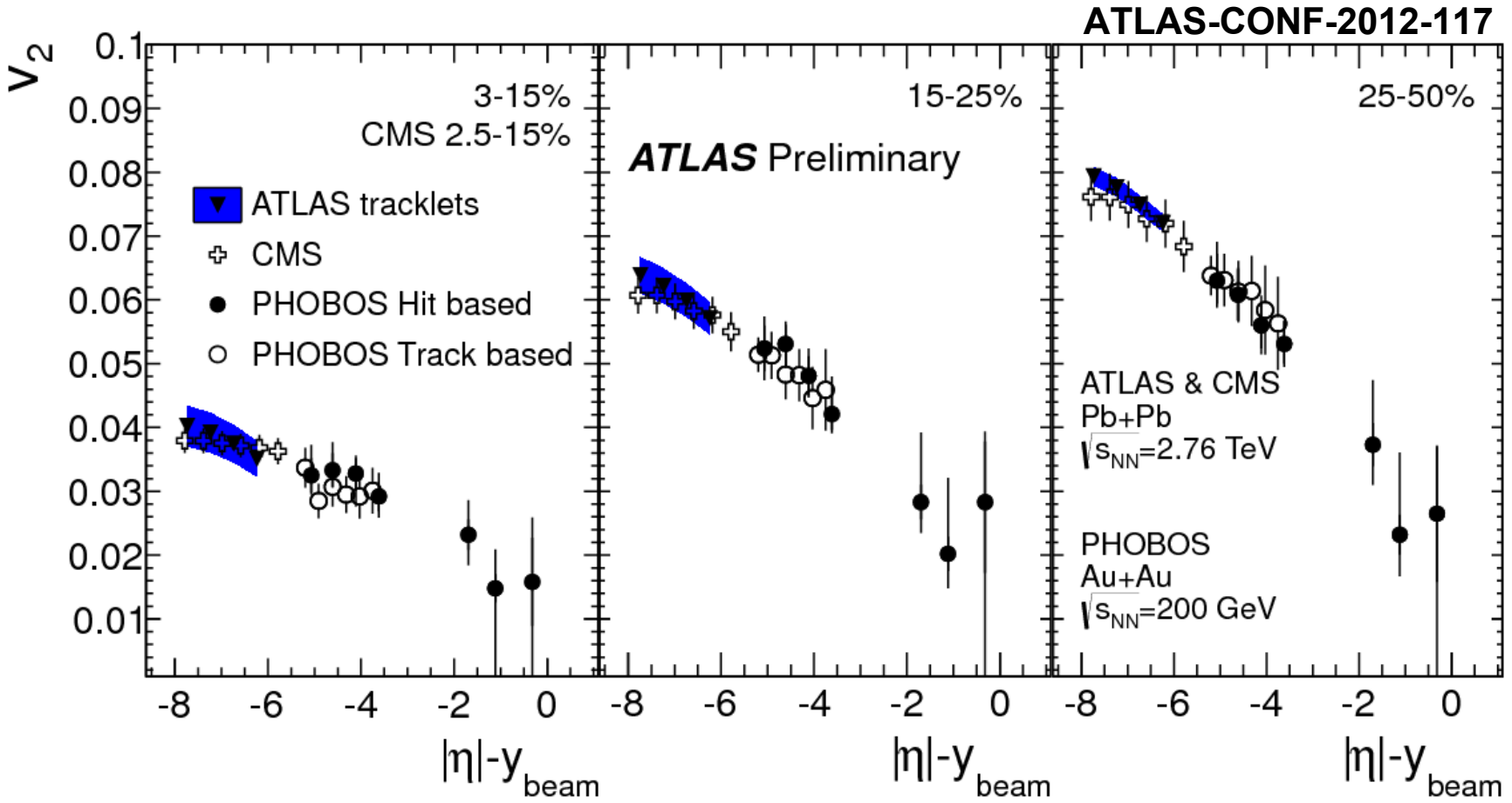
ID tracks $p_T > 0.5$ GeV

Pixel tracks – varied lower integration p_T limit to link ID tracks and tracklets

Tracklets $p_T > 0.03$ GeV

Pseudorapidity dependence of integrated v_2

- $v_2(\eta)$ integrated over p_T, shows weak pseudorapidity dependence
- $v_2(\eta)$ scaling consistent with the trend observed by PHOBOS at RHIC (Phys.Rev.C72:051901,2005)



Elliptic flow with cumulant method

- **Elliptic flow harmonics of charged particles obtained with the cumulant generating function method**
  (N. Borghini, P.M.Dinh and J.Y. Ollitrault Phys.Rev.C 64 (2001) 054901)

- **v_2 measurement (e.g. with the Event Plane method) is distorted by non-flow effects (not related to the initial geometry)**

- **Cumulants of multi-particle (>2) correlations eliminates non-flow contributions**

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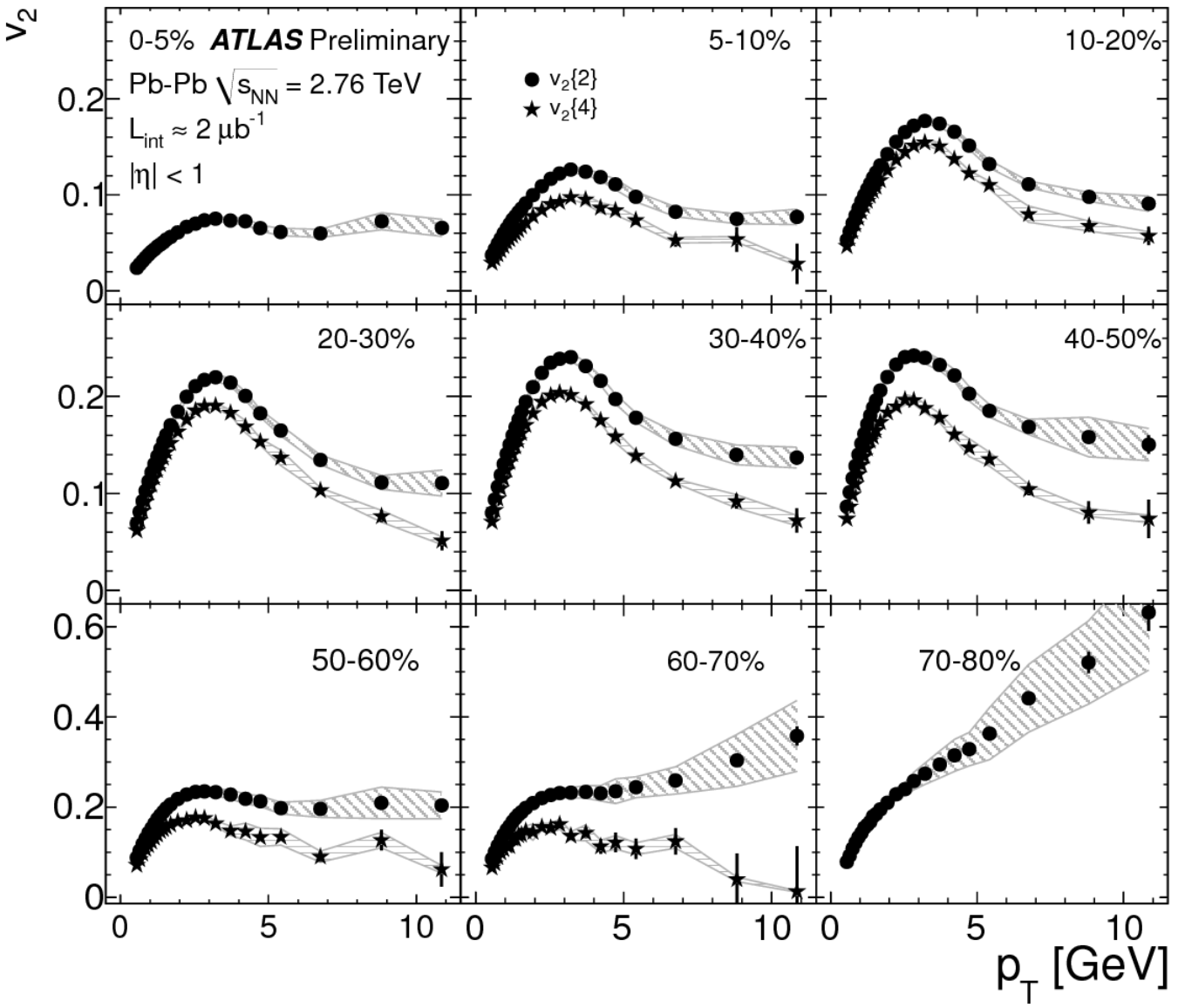

Comparison of $v_2\{2\}$, $v_2\{4\}$ and $v_2\{EP\}$

- Strong reduction of v_2 is observed by using four-particle cumulants
- $v_2\{4\}$ consistent between ATLAS, ALICE and CMS
- The $v_2\{EP\}$ lies between $v_2\{2\}$ and $v_2\{4\}$

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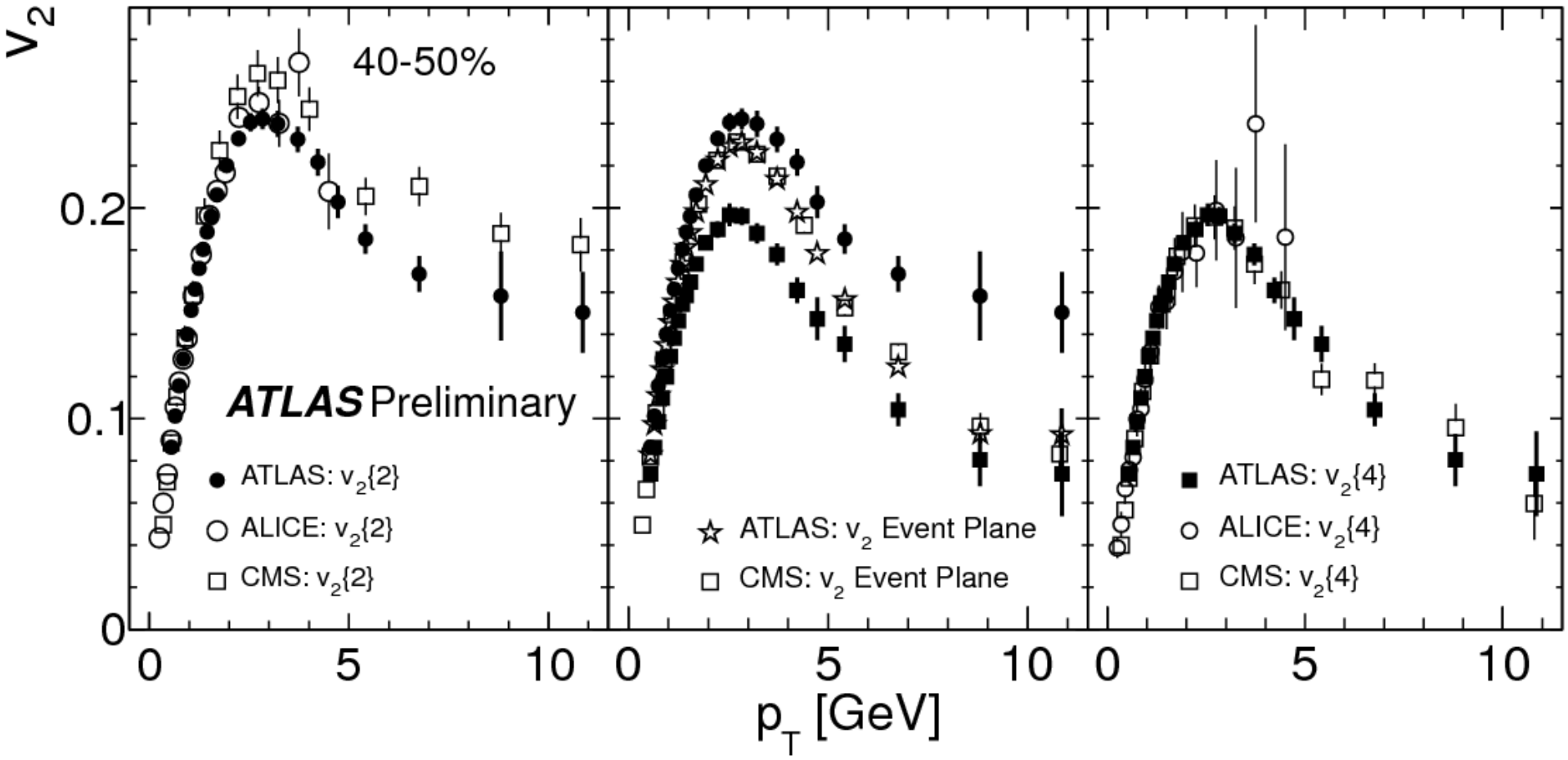
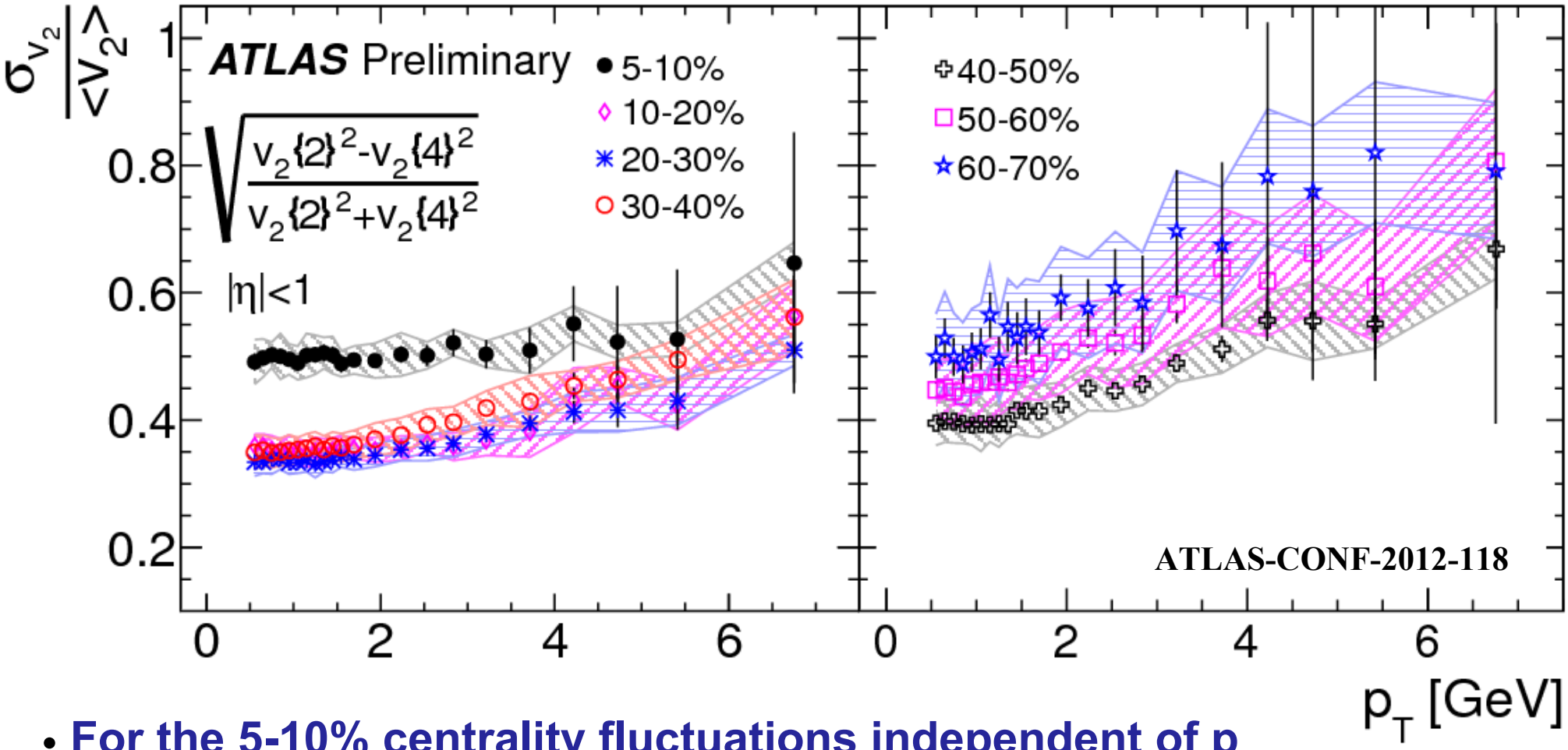


Elliptic flow fluctuations (cumulant method)

- **Cumulant method provides a measure of elliptic flow fluctuations** (N. Borghini, P.M.Dinh and J.Y. Ollitrault Phys.Rev. C64 (2001) 054901)

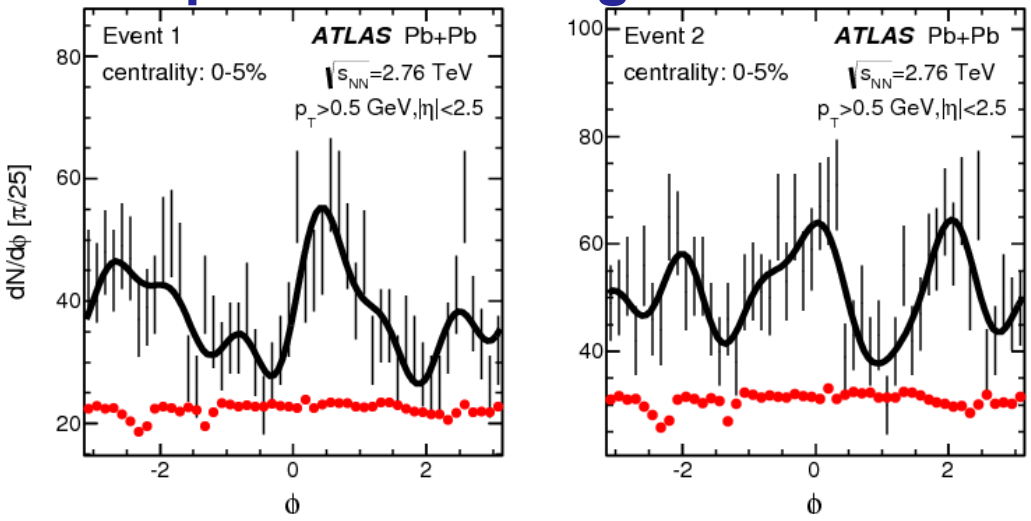


- **For the 5-10% centrality fluctuations independent of p_T**

- **For less central collisions $\sigma_{v_2}/\langle v_2 \rangle$ increases with p_T**

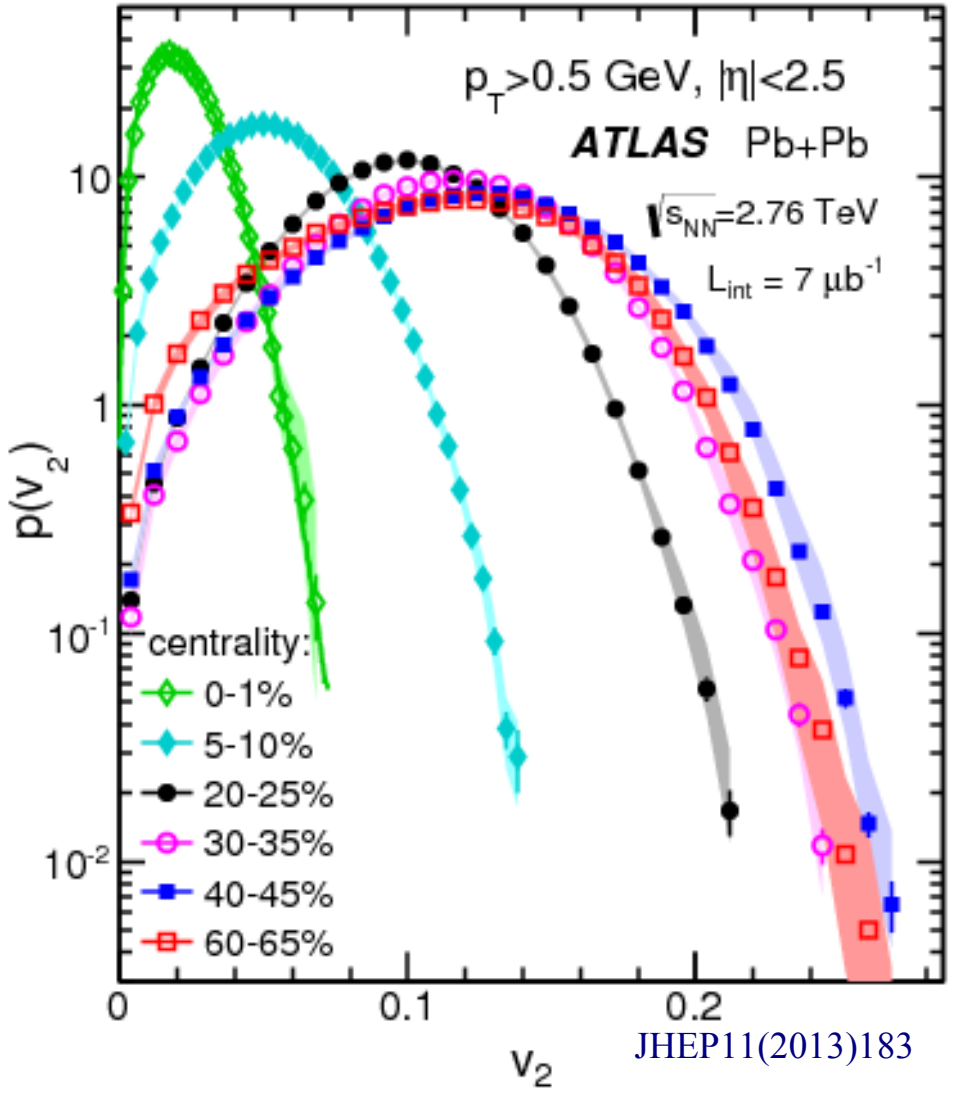
Event – by – Event v_2 in Pb+Pb

Azimuthal distributions of charged particles in single events



- The probability distributions of the EbyE v_2 in several centrality intervals
- v_2 broaden from central to peripheral
- $p(v_2)$ compatible with 2D Gaussian in most central events

- Unfolded distributions of v_2



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Elliptic flow fluctuations

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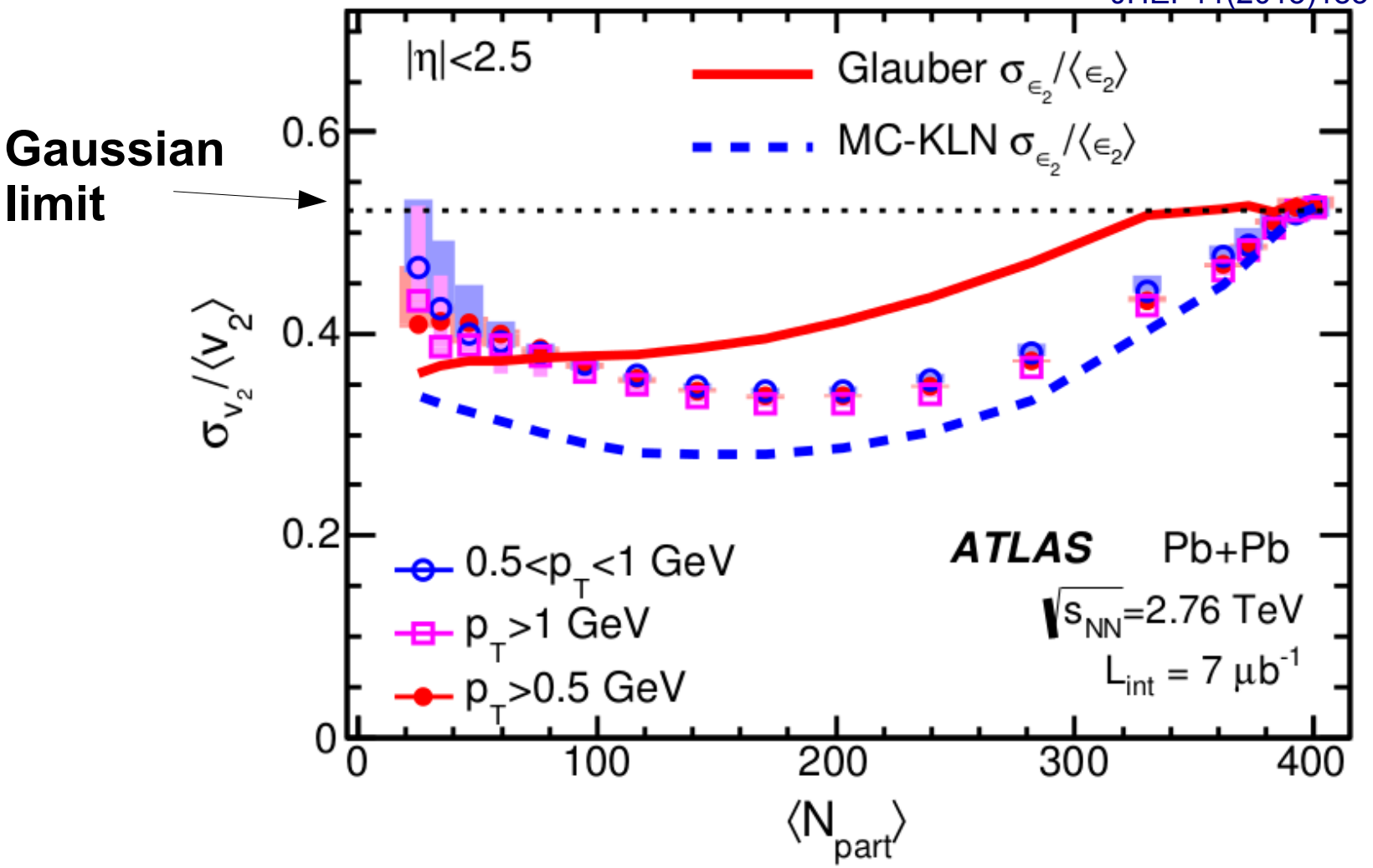


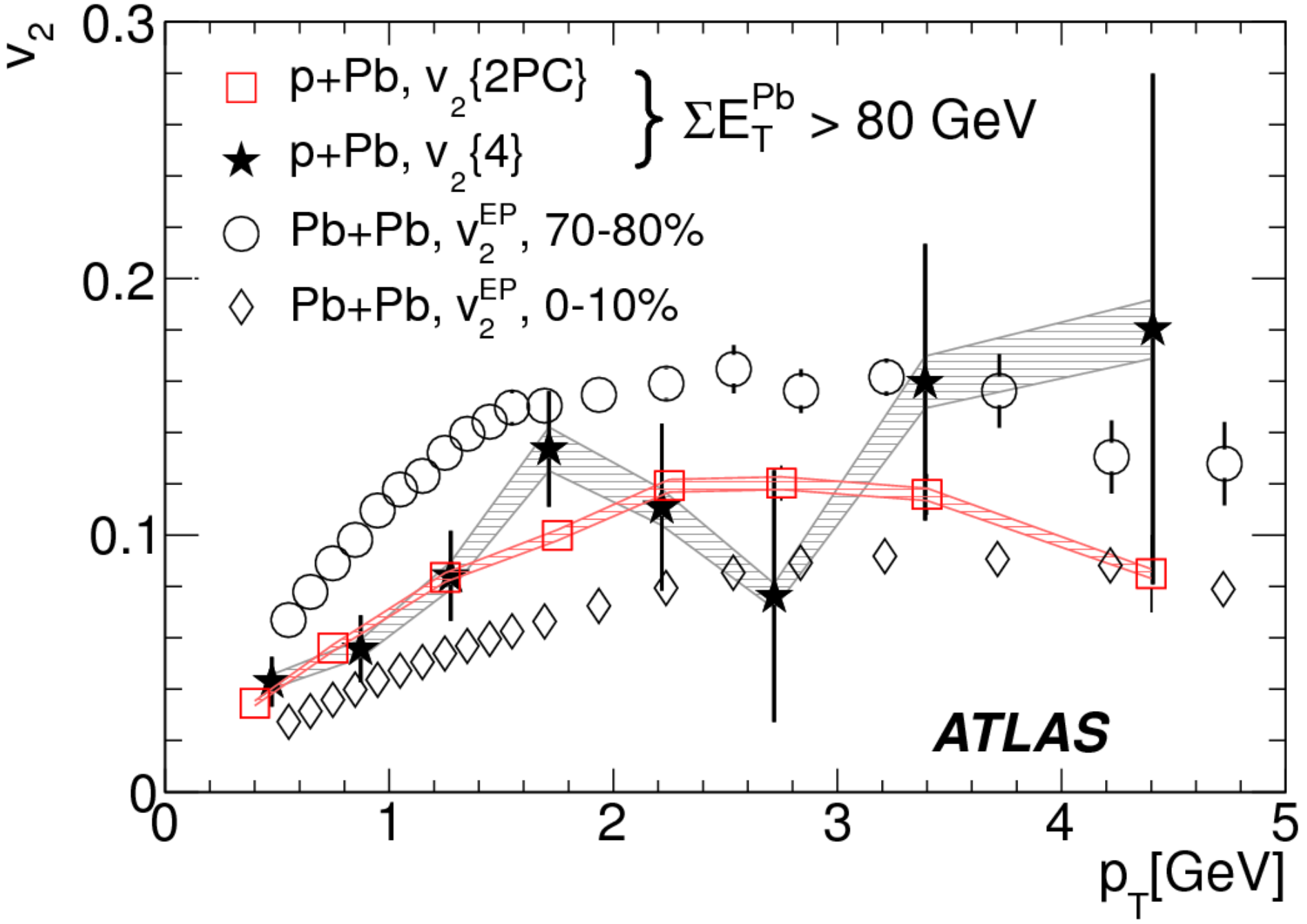
- Fluctuations shows strong centrality dependence
- Same relative fluctuations for different p_T ranges
- Both models fail to describe data across full centrality range – MC-KLN works better in more central and Glauber in more peripheral collisions

Summary

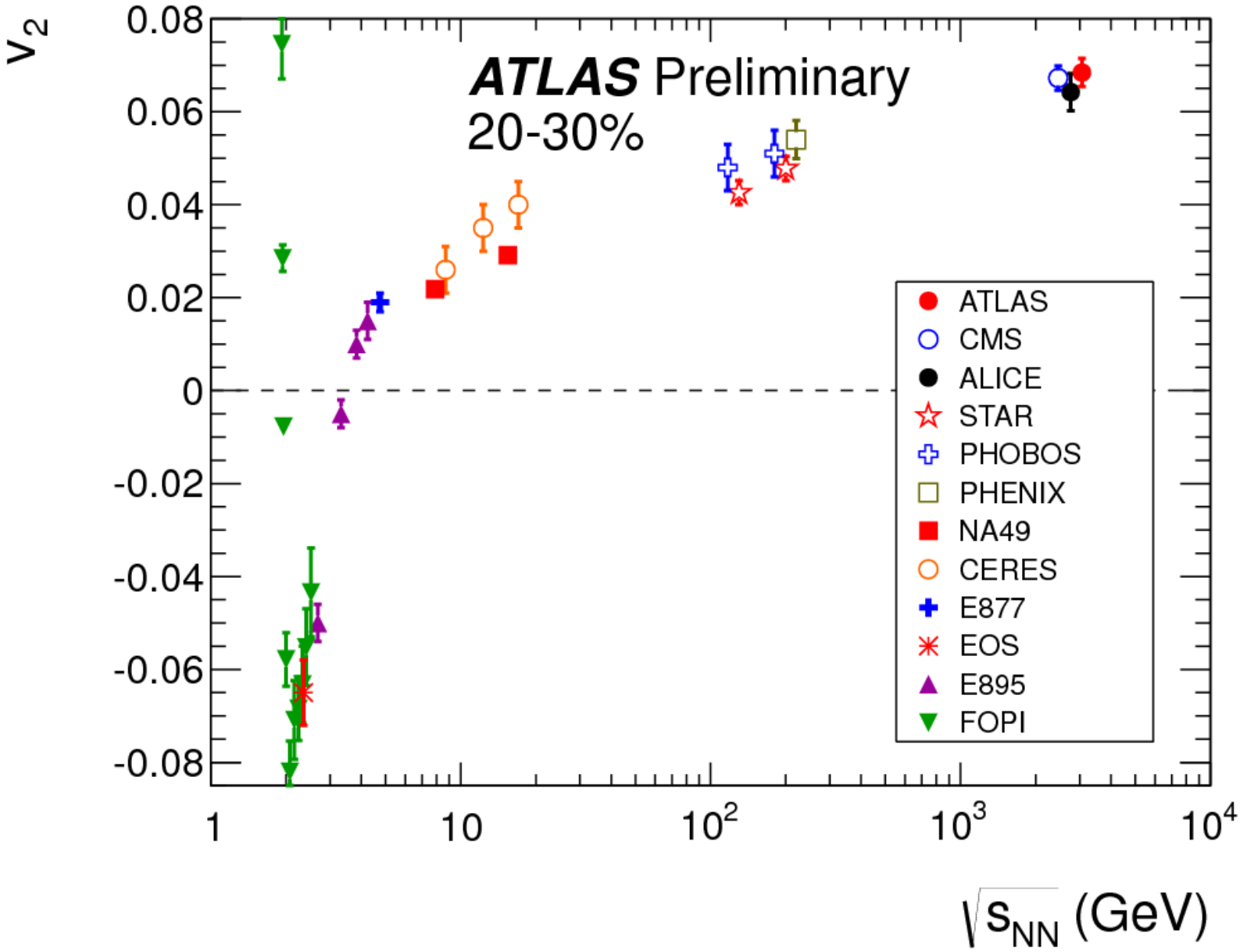
- ATLAS measured integrated v_2 flow harmonic reaching very low p_T
- Elliptic flow $v_2\{2\}$ and $v_2\{4\}$ were measured in broad range of centrality, η ($|\eta|<2.5$) and p_T ($0.5 < p_T < 12$ GeV)
- Relative fluctuations of elliptic flow were obtained from the cumulants and Event-by-Event measurements

Backup slides

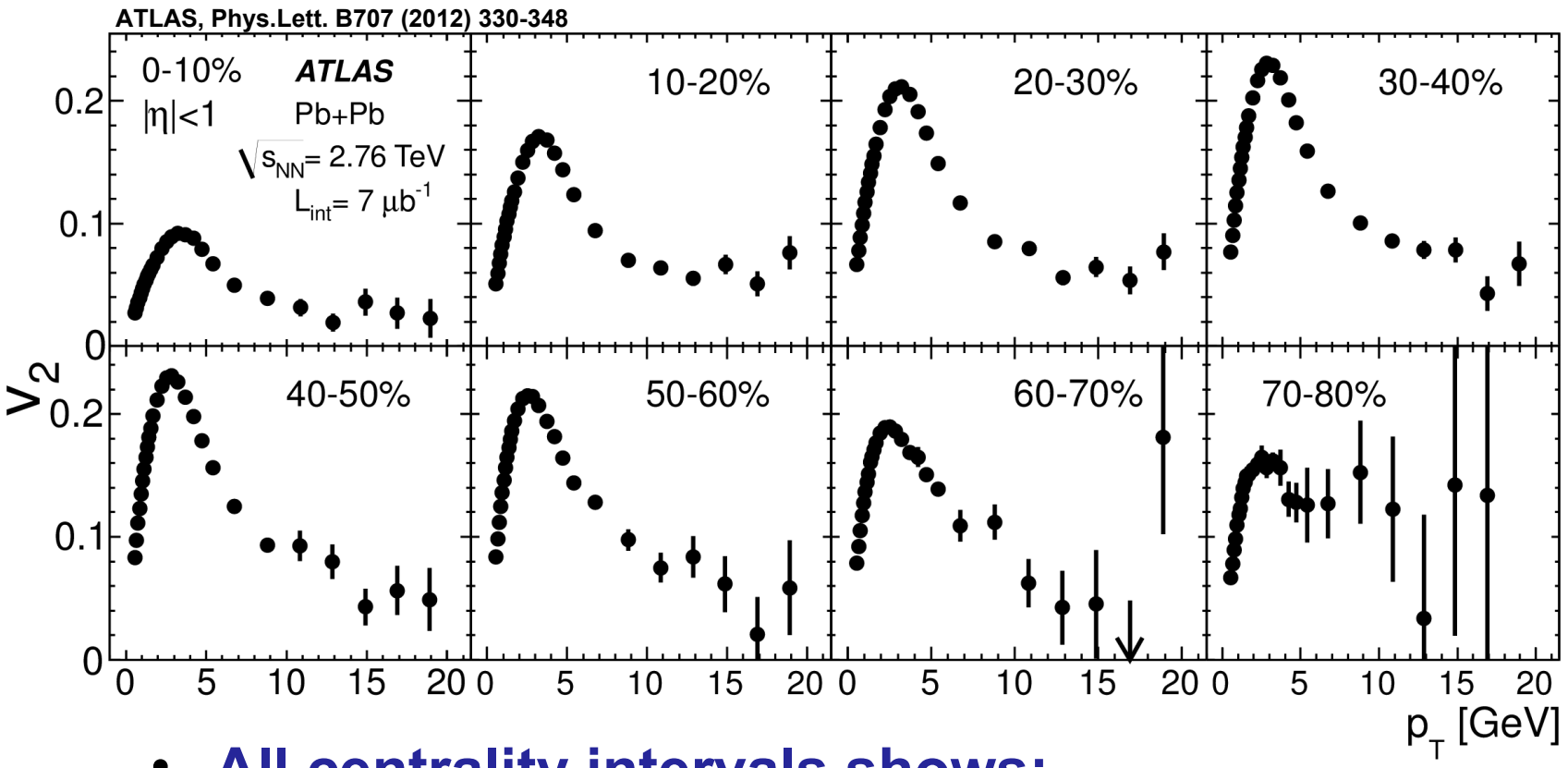
Elliptic flow in p+Pb



Integrated v_2



p_T dependence of the v_2 of charged particles

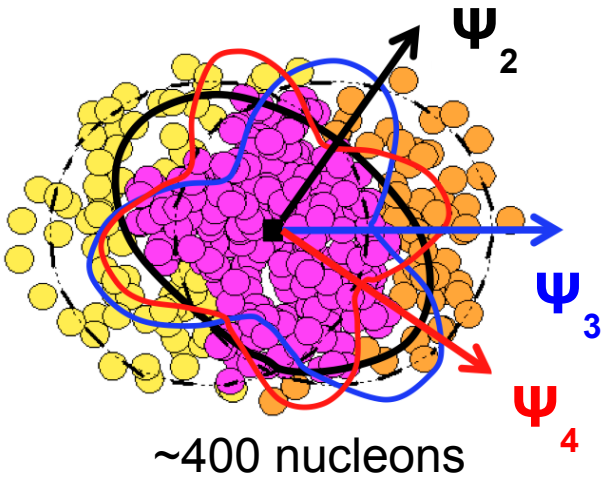


- **All centrality intervals shows:**
  - **Rapid rise in $v_2(p_T)$ up to p_T ~ 3 GeV**
  - **Decrease out to 7-8 GeV**
  - **Weak p_T-dependence above 9-10 GeV**
- **The strongest elliptic flow at LHC is observed in centralities 30-50%**

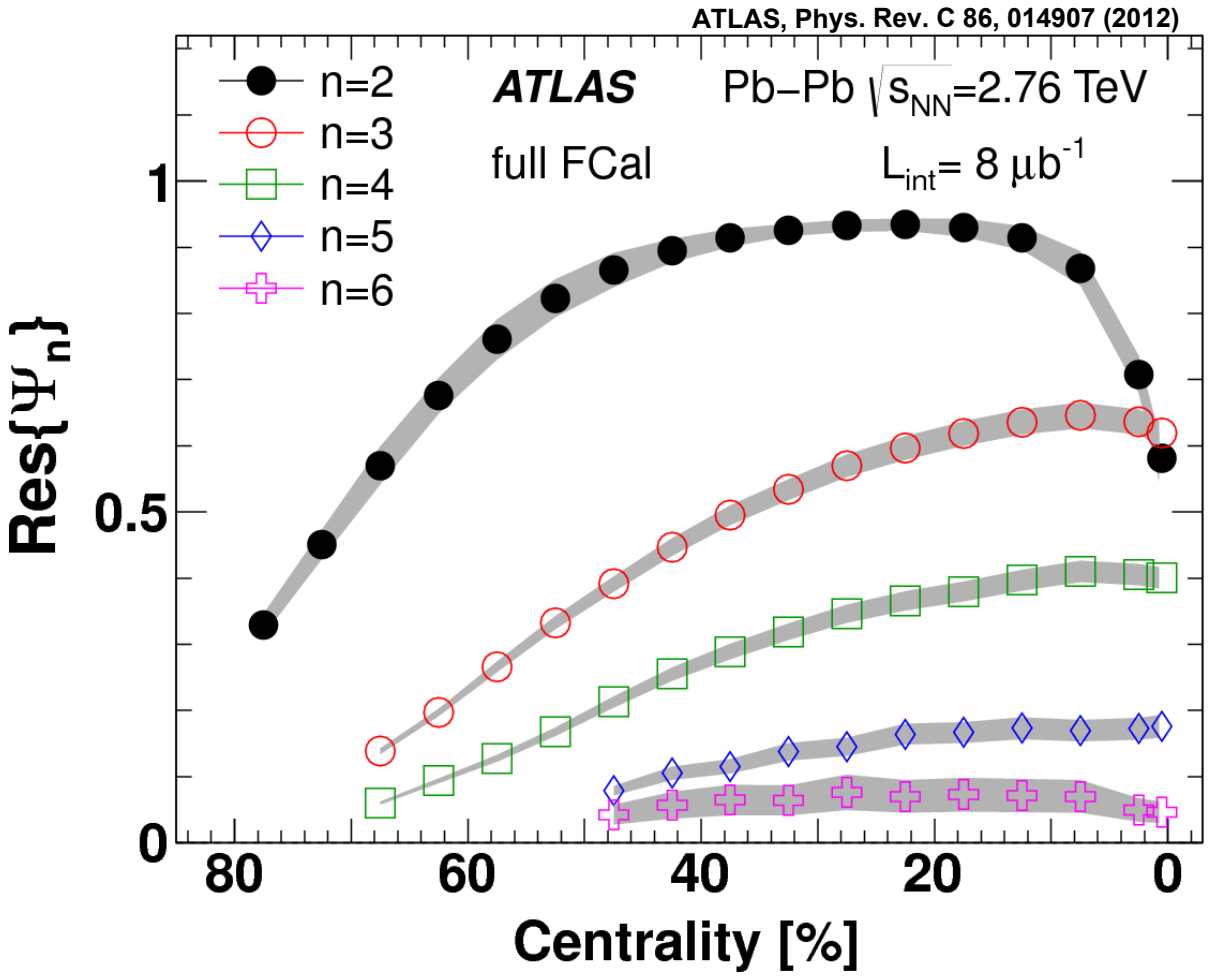
Event plane determination

- **Reaction plane (Ψ^{RP}) is approximated by event plane (Ψ_n^{EP}) measured in FCal:**

$$\Psi_n^{EP} = \frac{1}{n}\tan^{-1}\frac{\sum_i E_{T,i}^{tower} w_i \sin(n\phi_i)}{\sum_i E_{T,i}^{tower} w_i \cos(n\phi_i)}$$



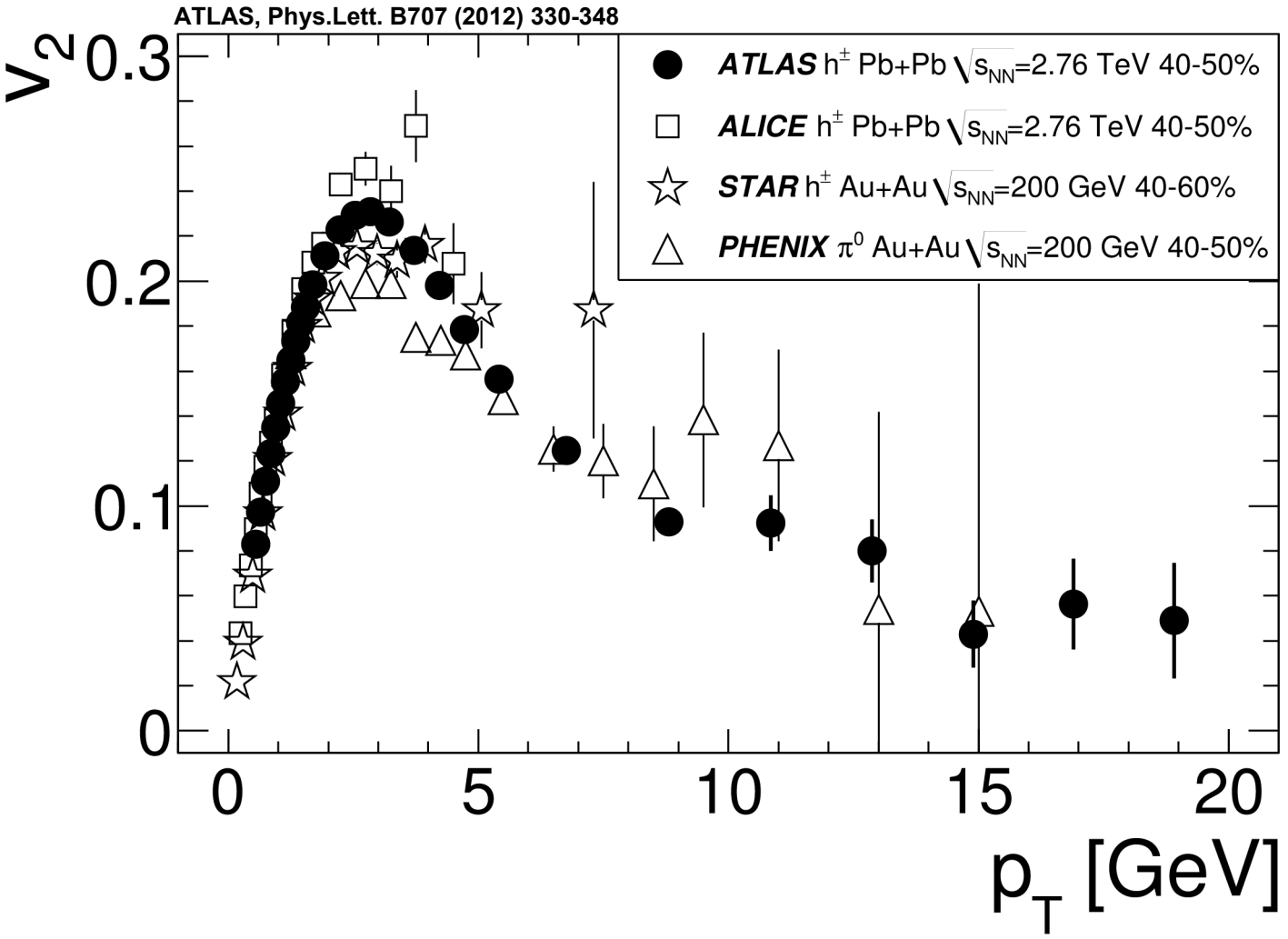
~400 nucleons



- **The event plane resolution correction factor R is obtained using two-sub event and various tree-subevent method**
- **Significant resolution for harmonics n=2 – 6**
- **Resolution corrected harmonics:**

$$v_n = \langle \cos\left(n\left(\Phi - \Psi_n\right)\right)\rangle / R$$

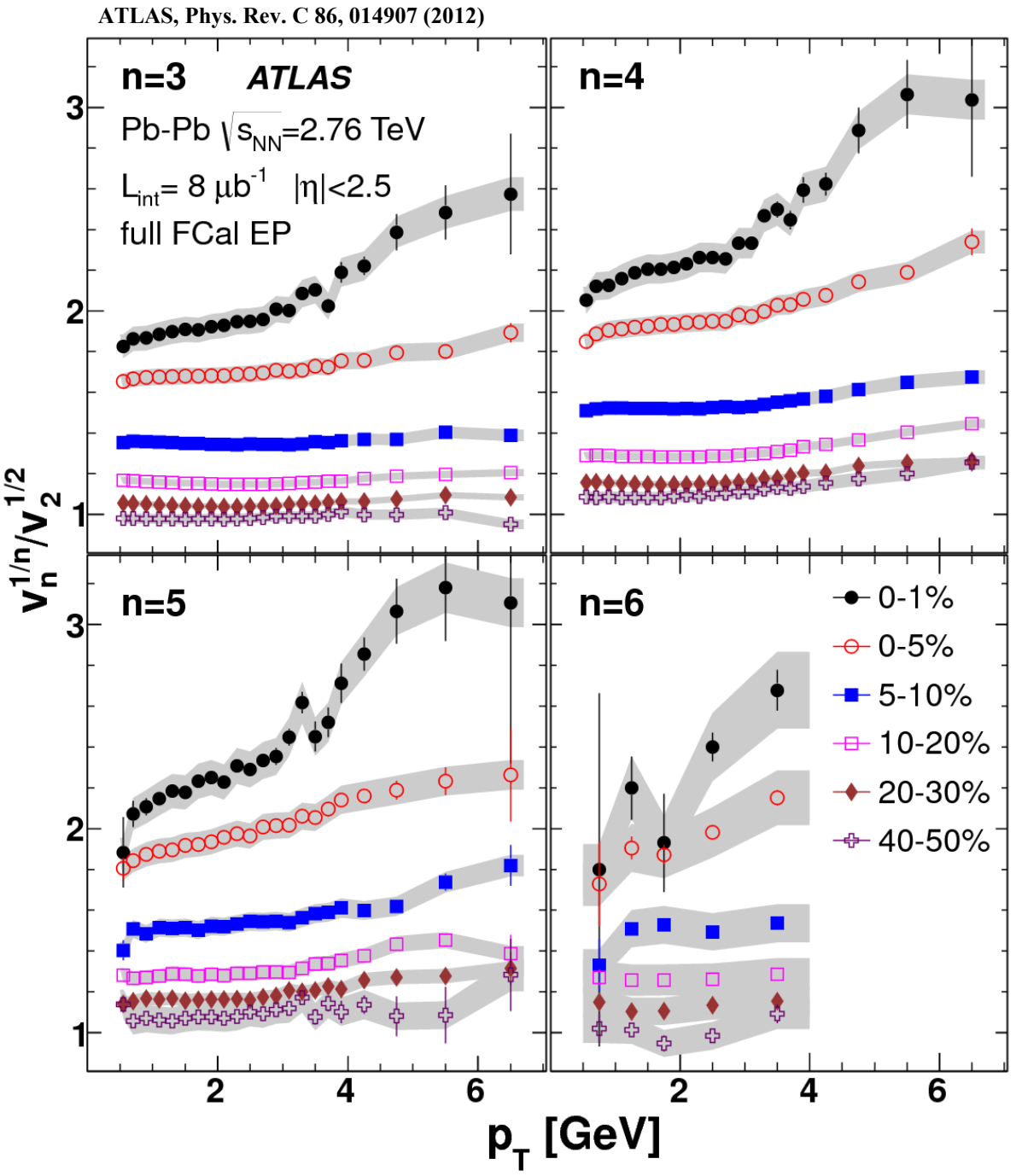
Comparison with ALICE and RHIC experiments



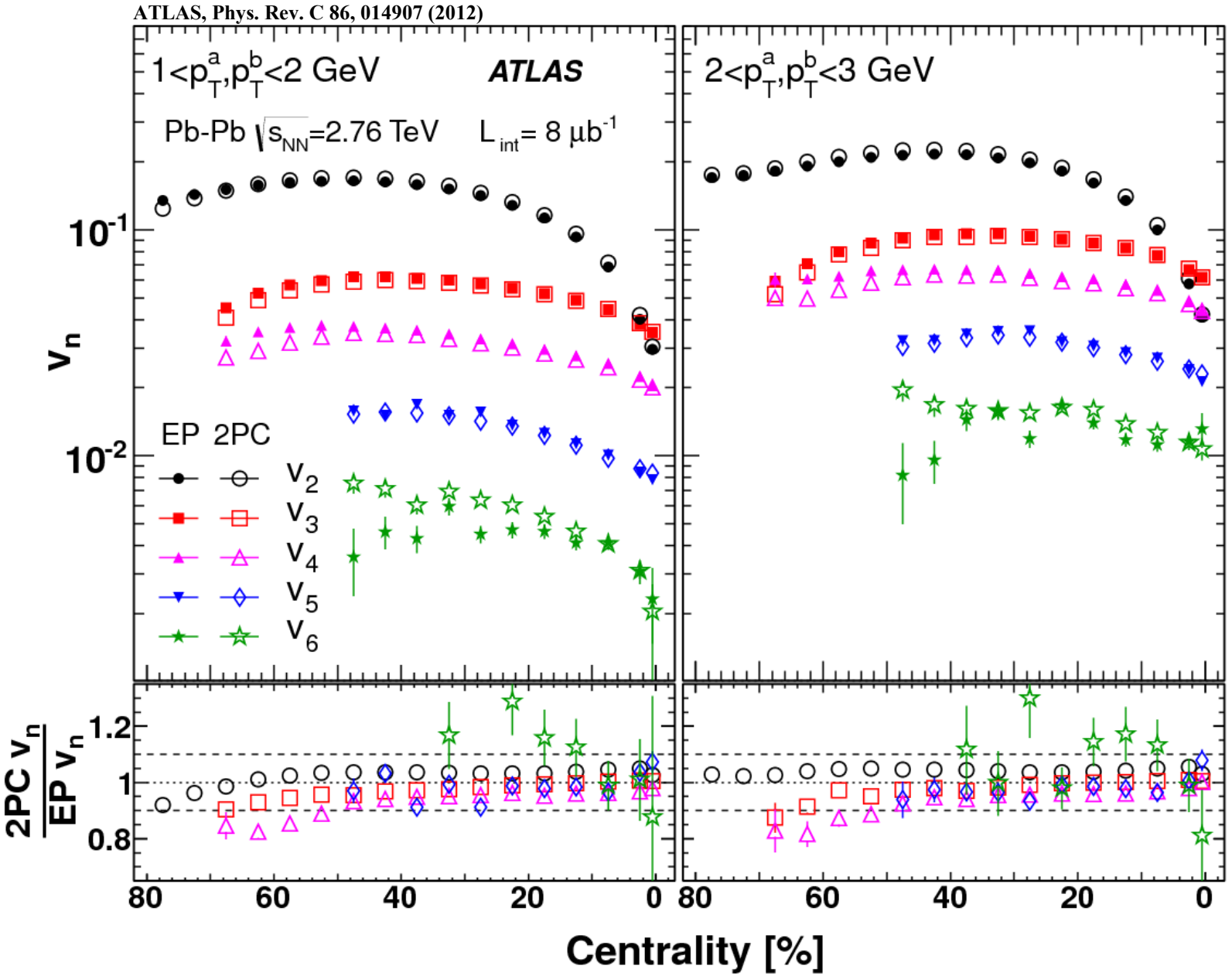
- **All data sets are quite consistent for both low and high p_T**

Higher order harmonics scaling

- Hydrodynamics model suggests scaling $v_4 \sim v_2^2$ (PHENIX PRL 105, 062301 (2010))
- The p_T-dependence of the $v_n^{1/n}/v_2^{1/2}$ (n=3-6) ratio for several centrality selections
- Weak p_T-dependence of the ratio except 5% most central events
- Ratio for n=3 systematically lower than for n=4, 5



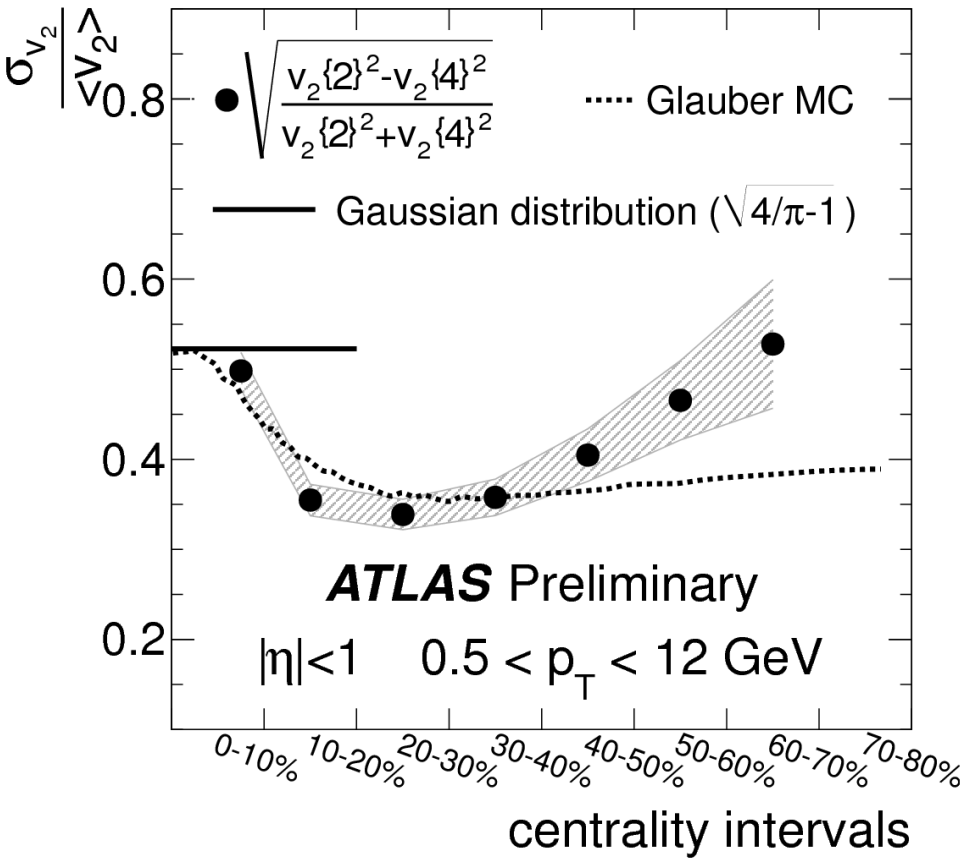
Two particle correlation vs EP results



Good agreement between both methods in the selected kinematical range (p_T 1-3 GeV, 2<|η|<5)

Elliptic flow fluctuations

W. Broniowski, M. Rybczyński, P. Bożek arXiv:0710.5731



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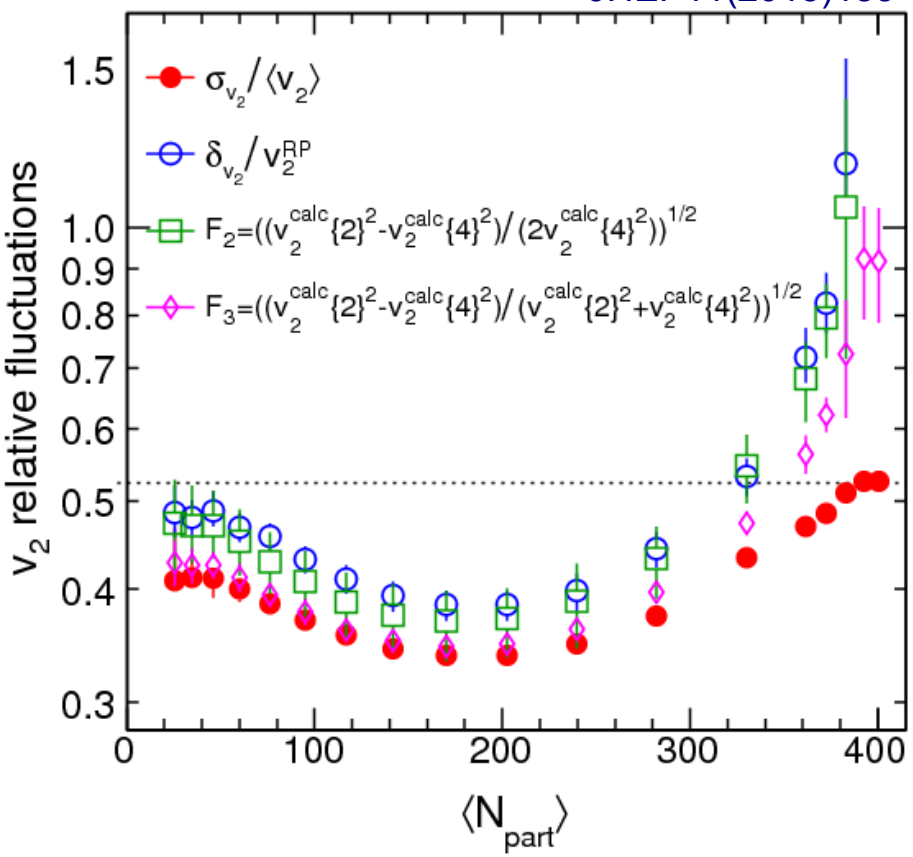

- **Fluctuations shows strong centrality dependence**
- **$\sigma_2/\langle v_2\rangle$ agrees with the Glauber MC model prediction with the exception of the peripheral collisions**
- **Consistent results from cumulants and EbyE measurement**