Measurement of the longitudinal dynamics of collective flow in Pb+Pb collisions with the ATLAS detector

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Quark Matter
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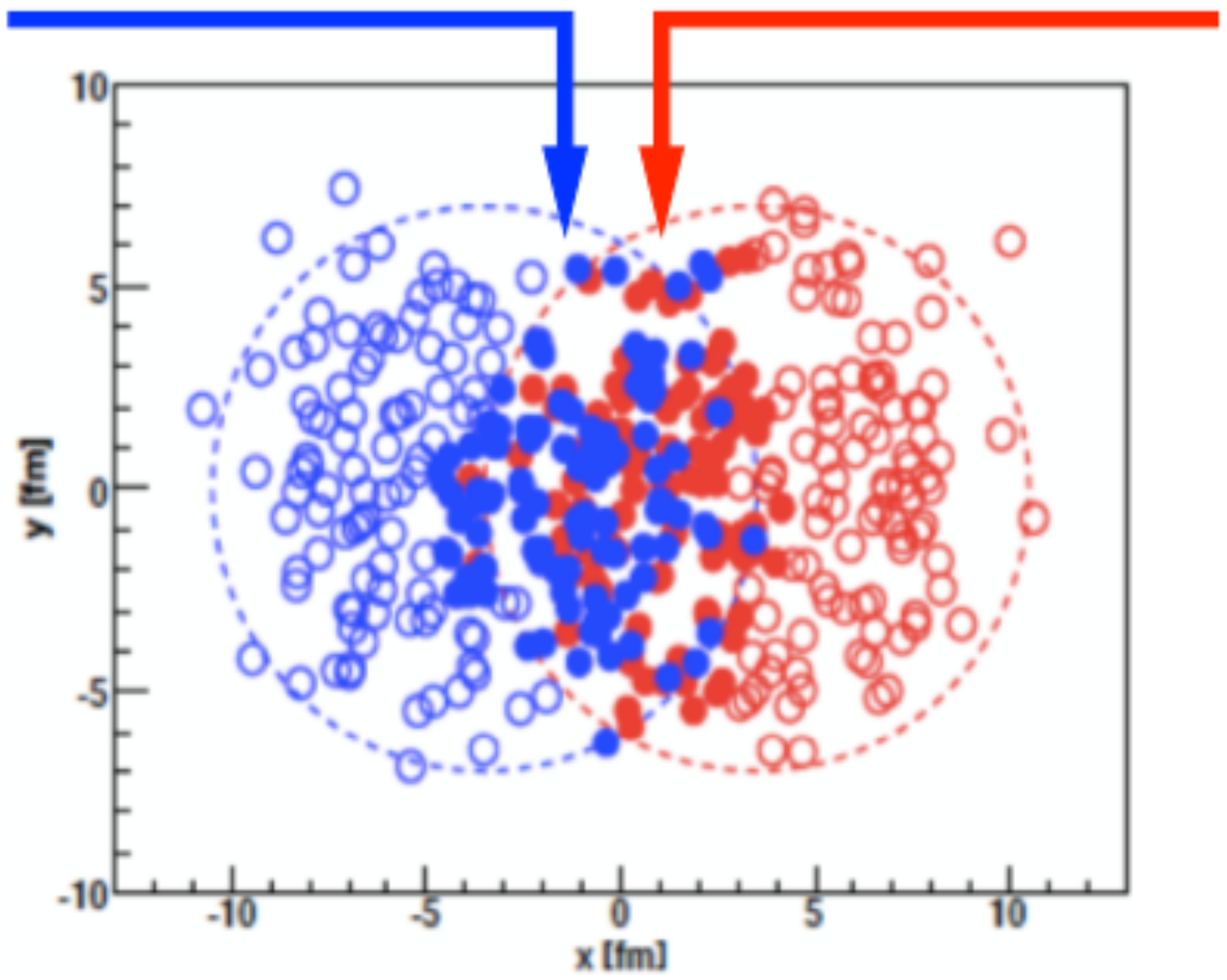
Origin of longitudinal fluctuations

$N^{\mathrm{F}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{F}}_{n} e^{in\Psi^{F}_{n}}$

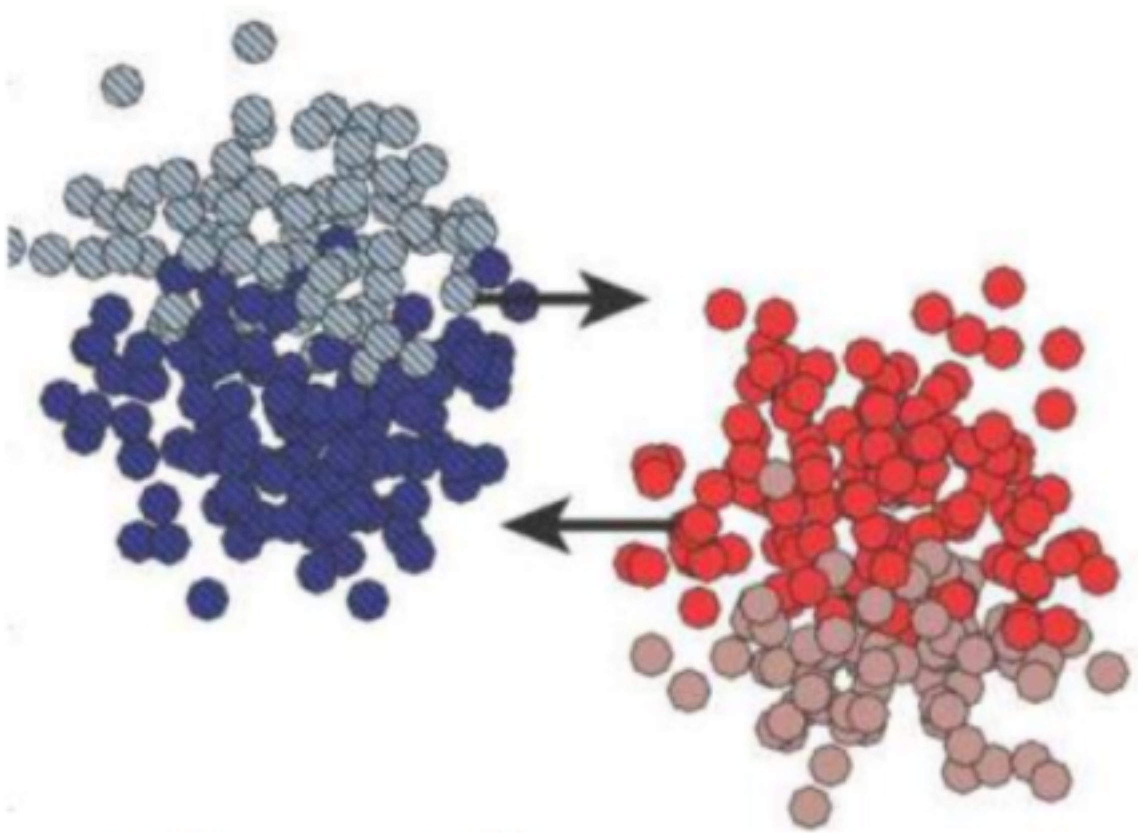


$N^{\mathrm{B}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{B}}_{n} e^{in\Psi^{B}_{n}}$

- Can see it in simple MC Galuber model picture

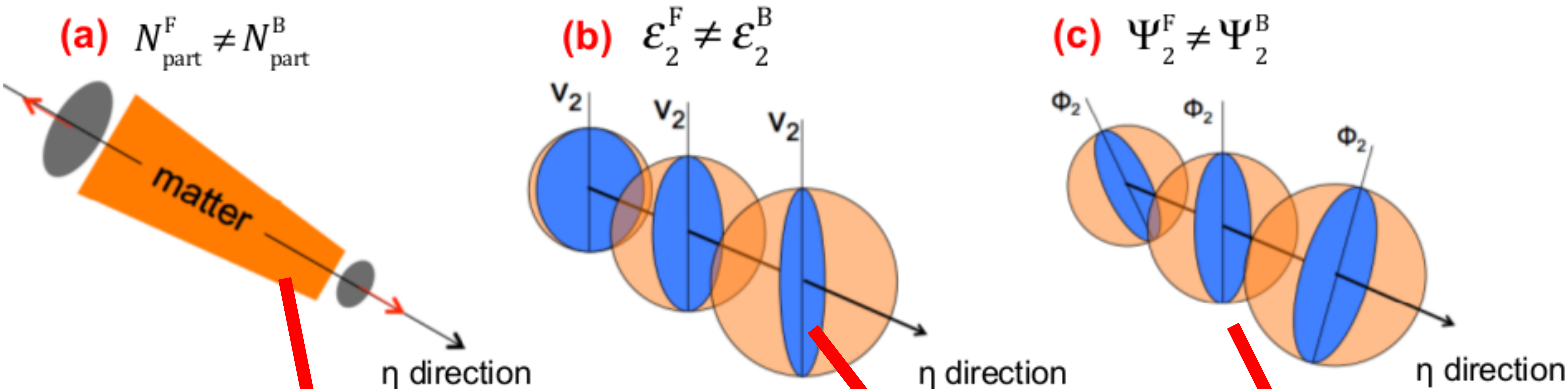
- Forward & backward going participant distributions are not symmetric

$N^{\mathrm{F}}_{\mathrm{part}}$



$N^{\mathrm{B}}_{\mathrm{part}}$

Consequence of longitudinal fluctuations



Event-by-Event Multiplicity Fluctuations along η.

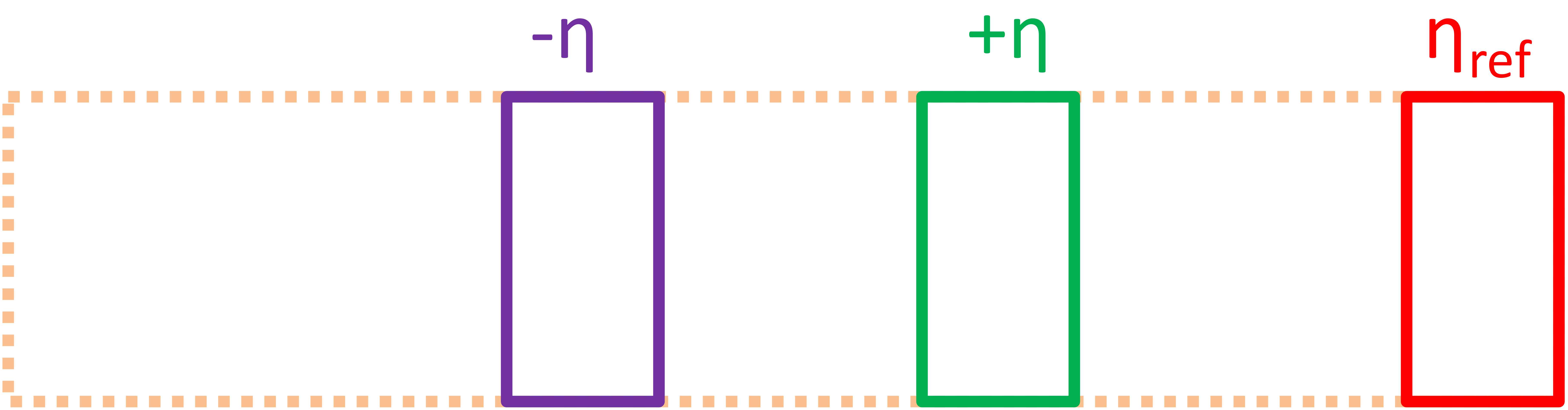
EbE Flow fluctuations, in magnitude and direction along η.

ATLAS Collaboration
arXiv:1606.08170

How to measure de-correlation

Flow Vector $\boldsymbol{q}_n \equiv \dfrac{\sum_i w_i e^{in\phi_i}}{\sum_i w_i} \equiv q_n\, e^{in\Psi_n}$

Correlate k^{th} power of n^{th} order flow-vector (k=1,2,3)



$$\mathrm{r}_{n|n;k} = \frac{\left\langle q_n^k(-\eta)\, q_n^{*k}(\eta_{ref}) \right\rangle}{\left\langle q_n^k(+\eta)\, q_n^{*k}(\eta_{ref}) \right\rangle}$$

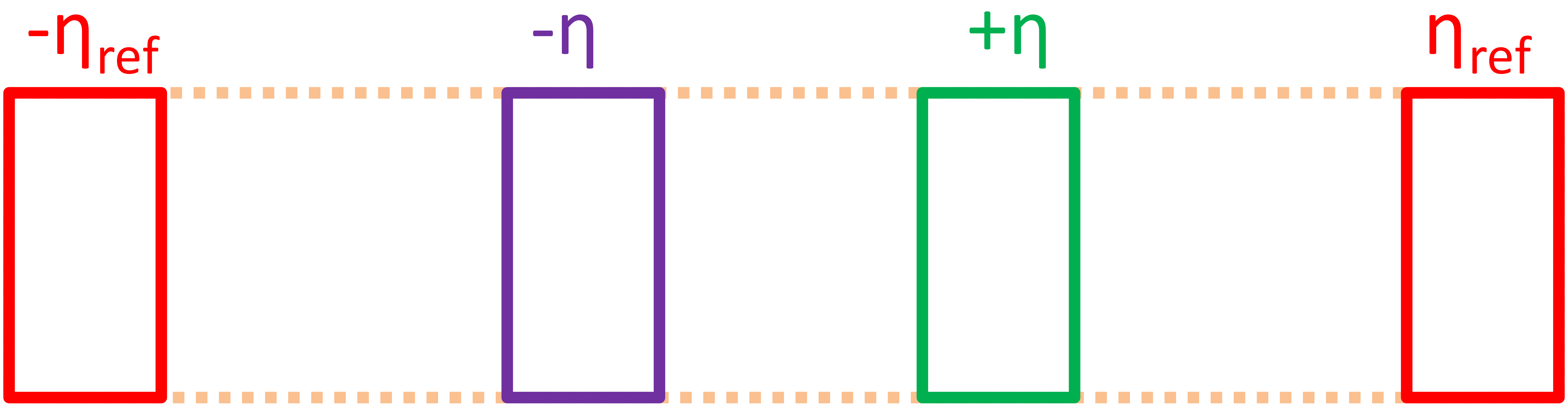
This correlator is sensitive to both, twist as well as magnitude decorrelation

$$\mathrm{r}_{n|n;k} \approx 1 - 2kF_{n;k}^{r}\eta \qquad F_{n;k}^{r} = F_{n;k}^{asym} + F_{n;k}^{twist}$$

CMS: arXiv:1503.01692 (measured k=1 component)

How to measure twist only

Flow Vector $\boldsymbol{q}_n \equiv \frac{\sum_i w_i e^{in\phi_i}}{\sum_i w_i} \equiv q_n \, e^{in\Psi_n}$

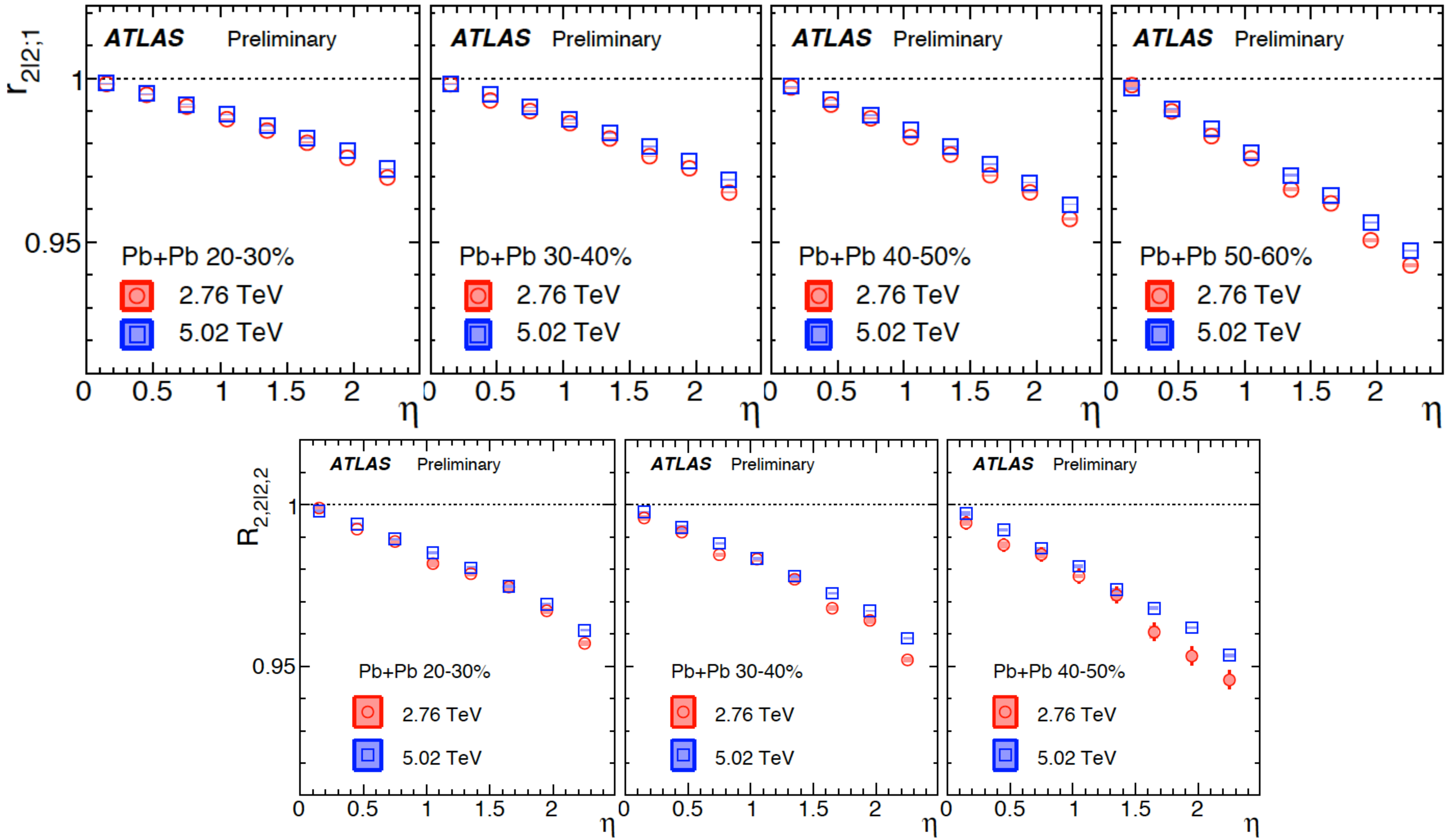


$$R_{n,n|n,n} = \frac{\langle q_n(-\eta_{ref}) q_n(-\eta) q_n^*(+\eta) q_n^*(\eta_{ref}) \rangle}{\langle q_n(-\eta_{ref}) q_n(+\eta) q_n^*(-\eta) q_n^*(\eta_{ref}) \rangle}$$

$$R_{n,n|n,n} \approx 1 - 4F_{n;2}^{twi}\eta$$

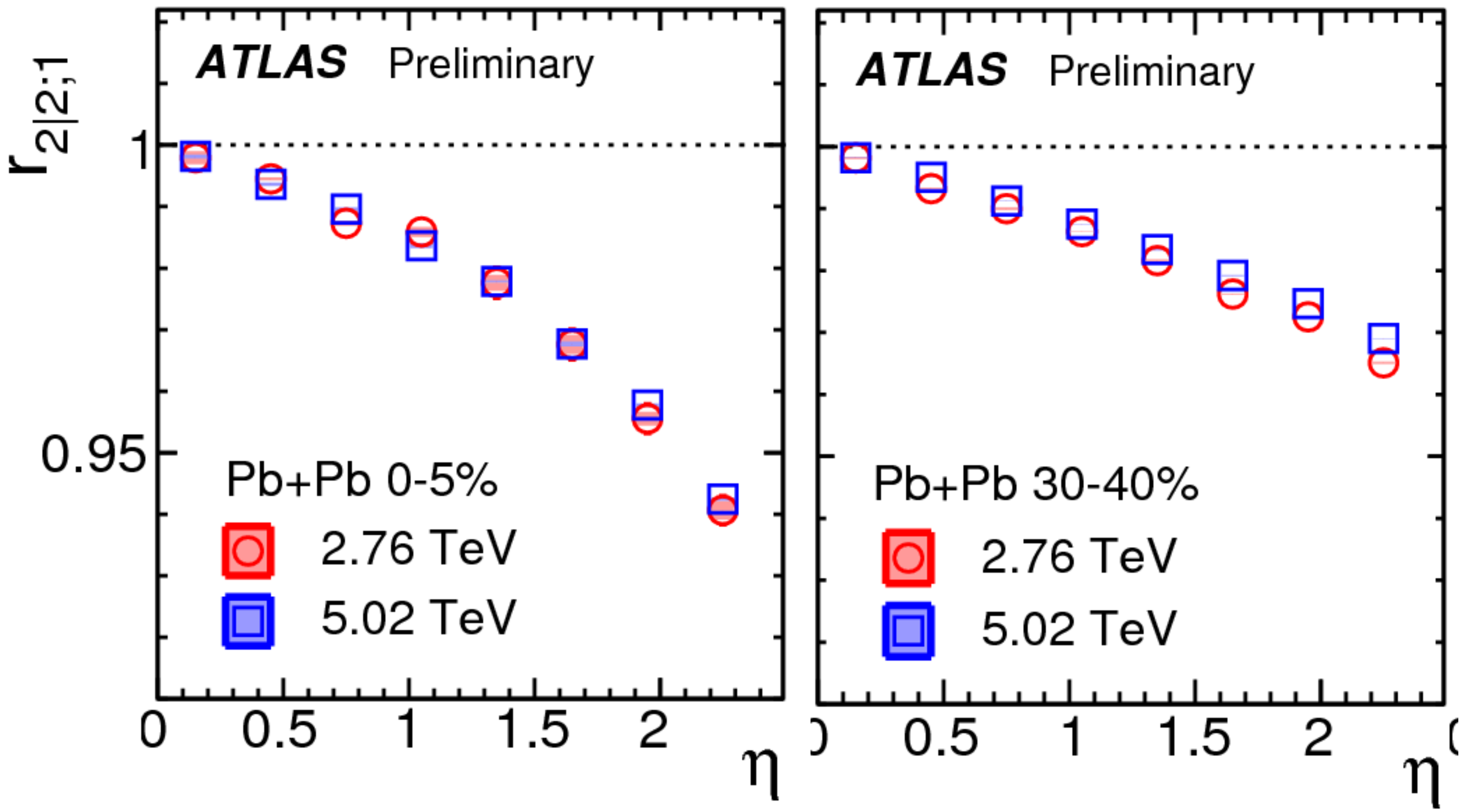
This correlator is sensitive only to the event-plane twist

Flow de-correlation for n=2



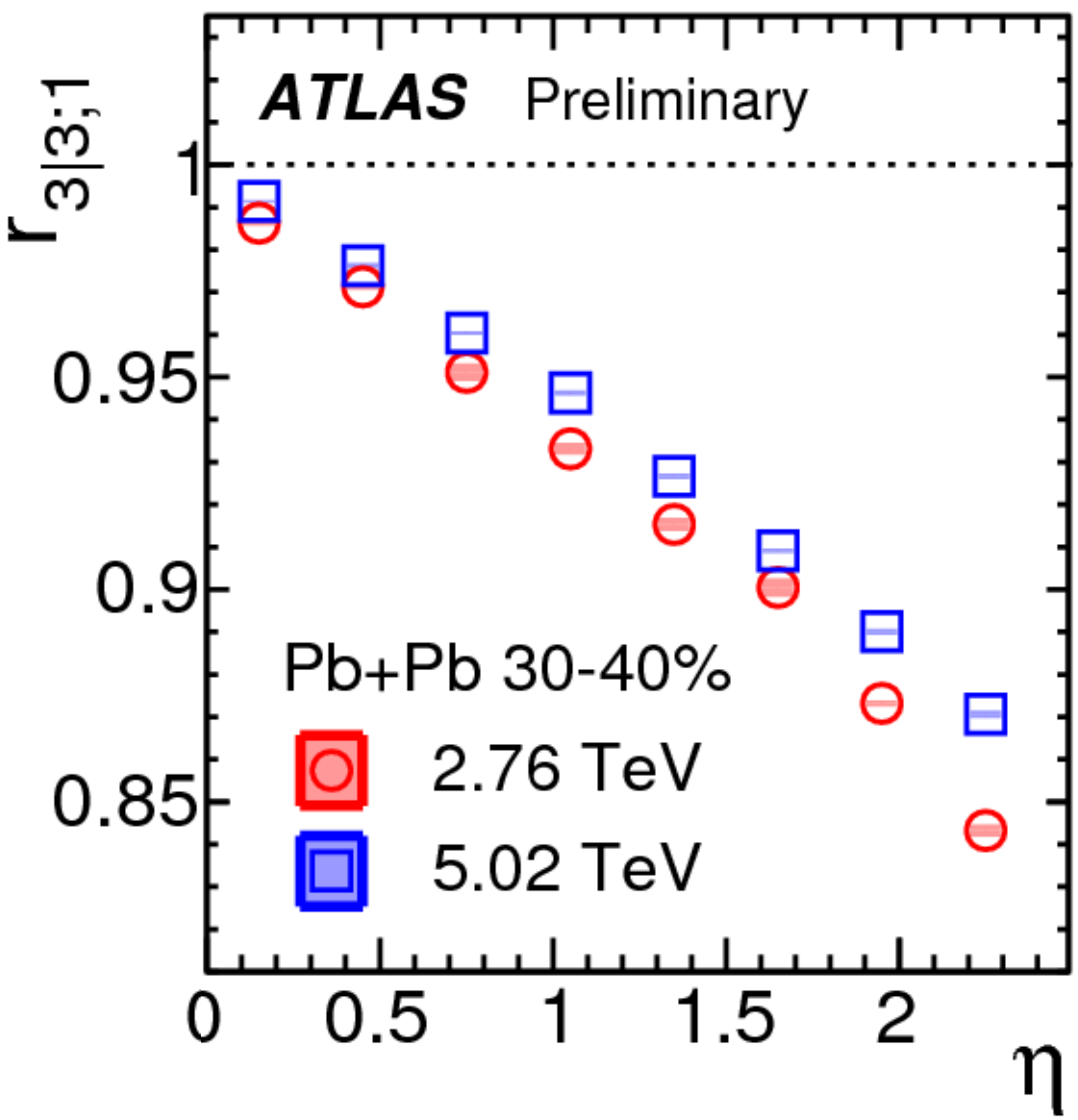
- De-correlations increase linearly with increasing η gap

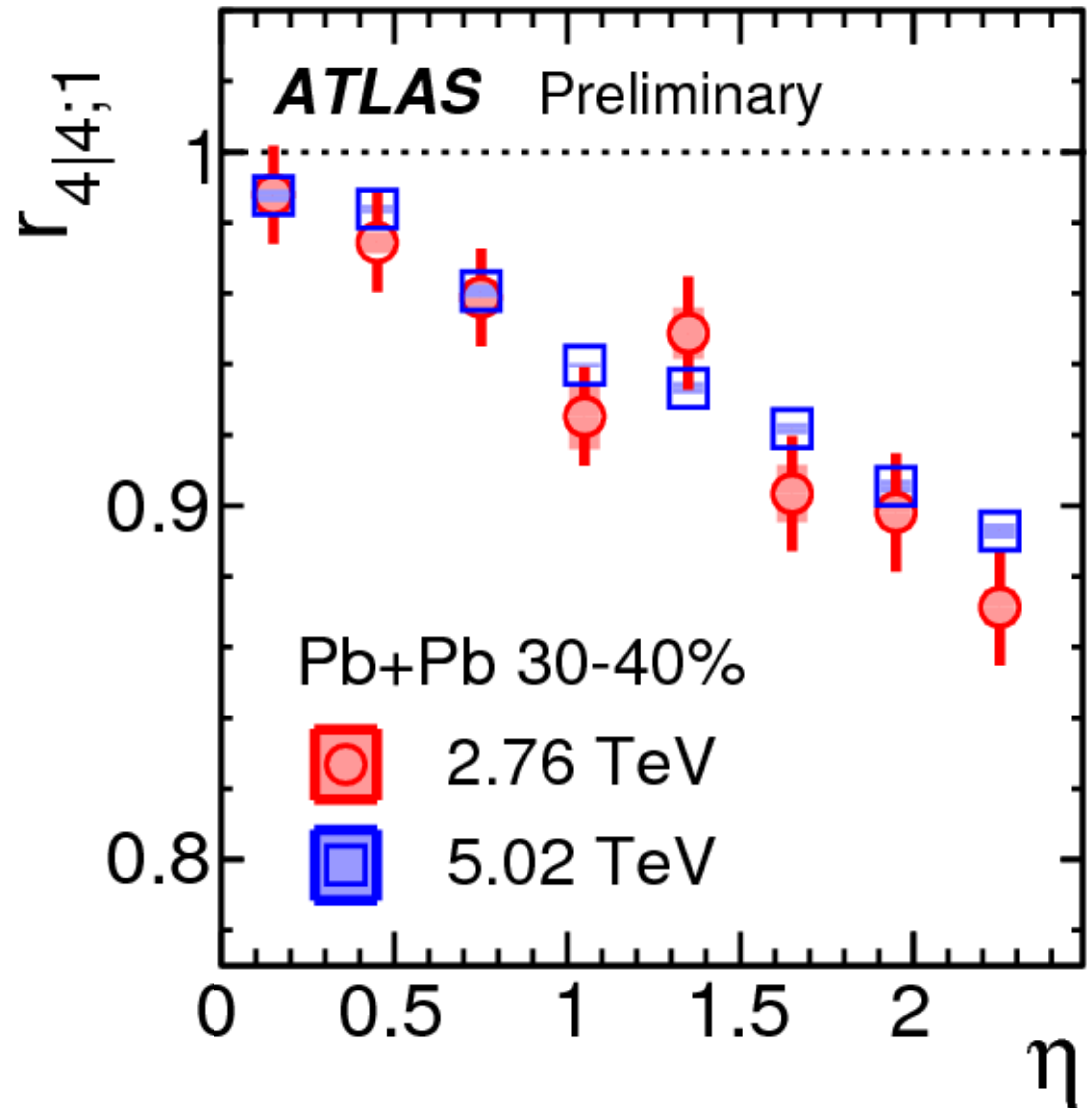
Collision energy dependence for n=2



- Longitudinal de-correlations are smaller at 5.02 TeV as compared to 2.76TeV.
- Shown here for two different centralities
- More boost invariance at higher collision energy.

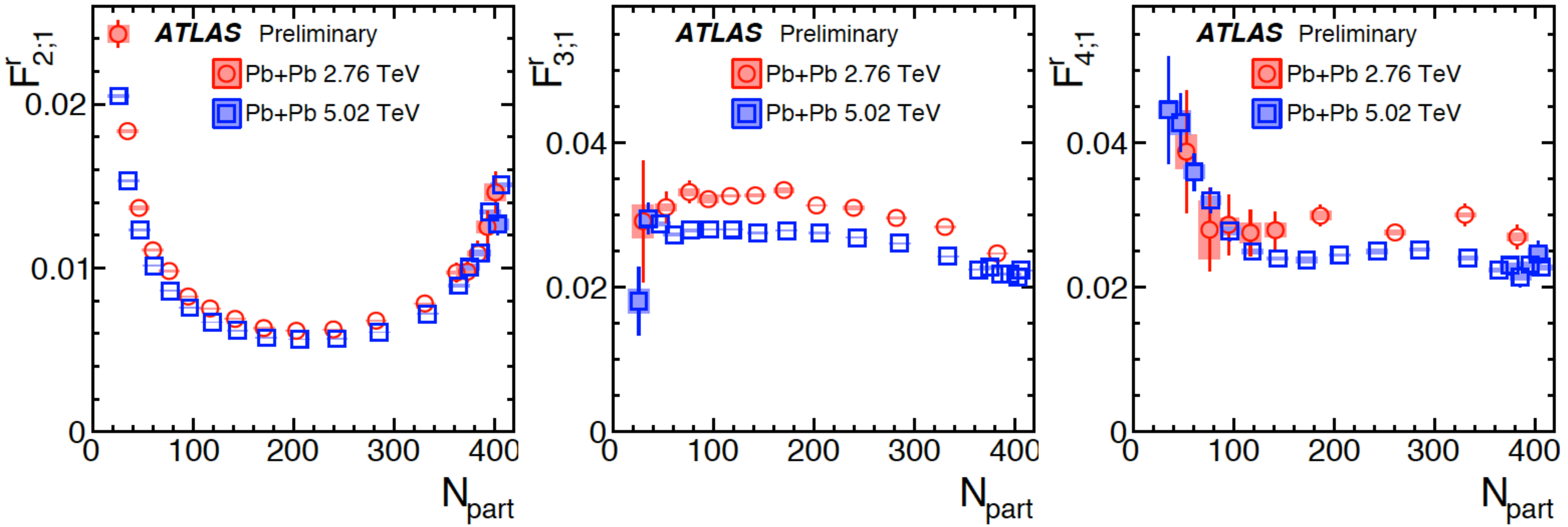
Collision energy dependence for n=3,4





- Comparison for higher order harmonics n=3 (left) and n=4 (right)
- Effect of increased boost -invariance seen more clearly for higher harmonics
- Note that this is relative invariance
- De-correlation is linear for higher order harmonics as well.

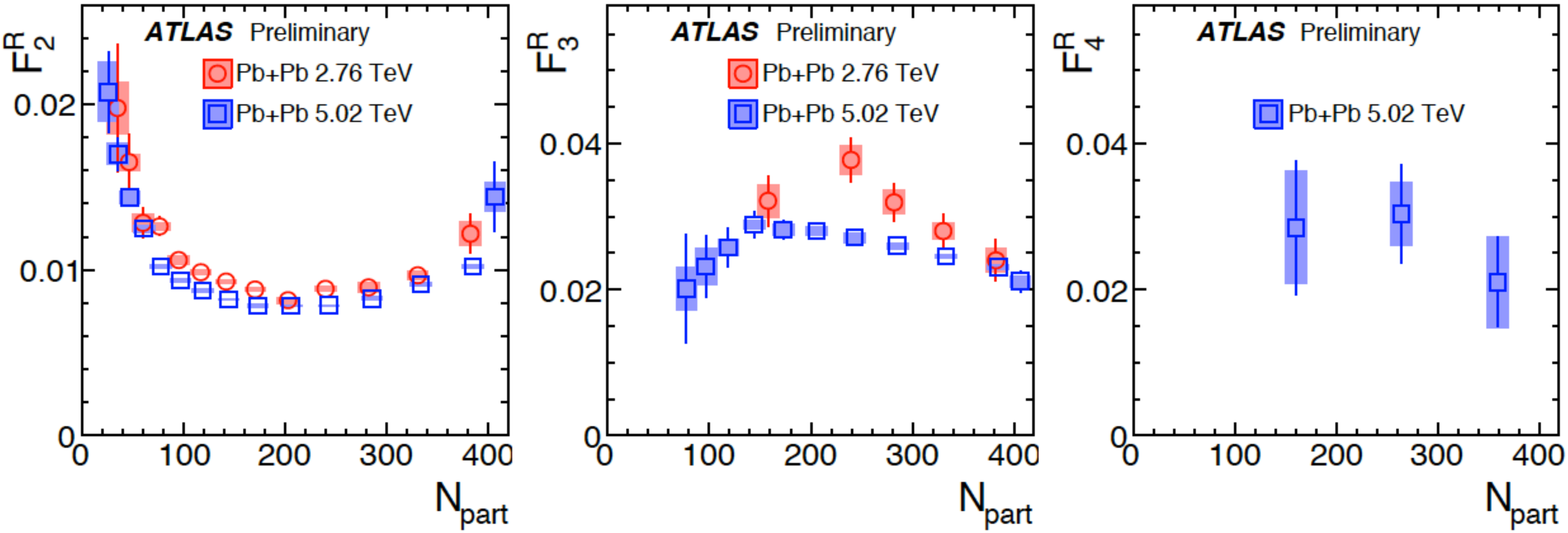
Centrality dependence of slope : $r_{n|n;1}$



$$r_{n|n;1} = 1 - 2F^{r}_{n;1}\eta$$

- For n=2,
  - slope is minimum in mid-central events
  - Magnitude of slope is quite small
- For higher order harmonics
  - Slope significantly larger
  - Some centrality dependence trends are seen

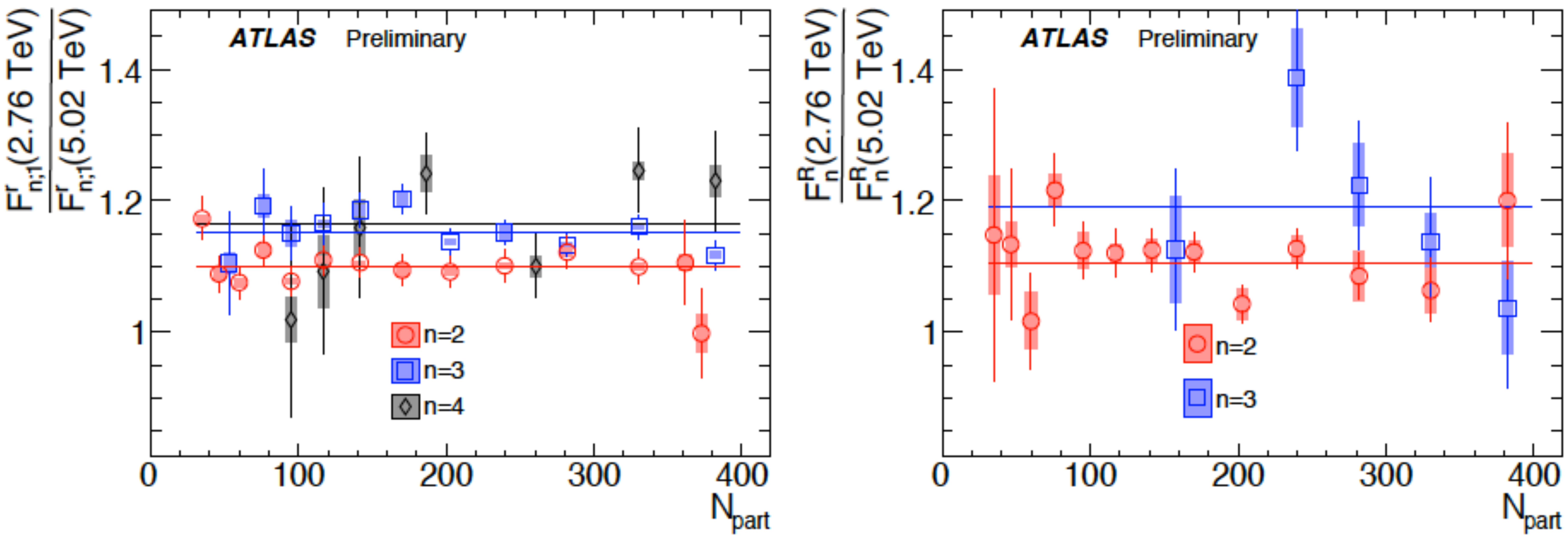
Centrality dependence of slope : $R_{n,n|n,n}$



$$R_{n,n|n,n} \approx 1 - 4F^{twi}_{n;2}\eta$$

- For n=2,
  - slope is minimum in mid-central events
  - Magnitude of slope is relatively small
- For higher order harmonics
  - Slope significantly larger
  - centrality dependent trends seen
- Both cases 5.02 TeV has smaller value than 2.76 TeV

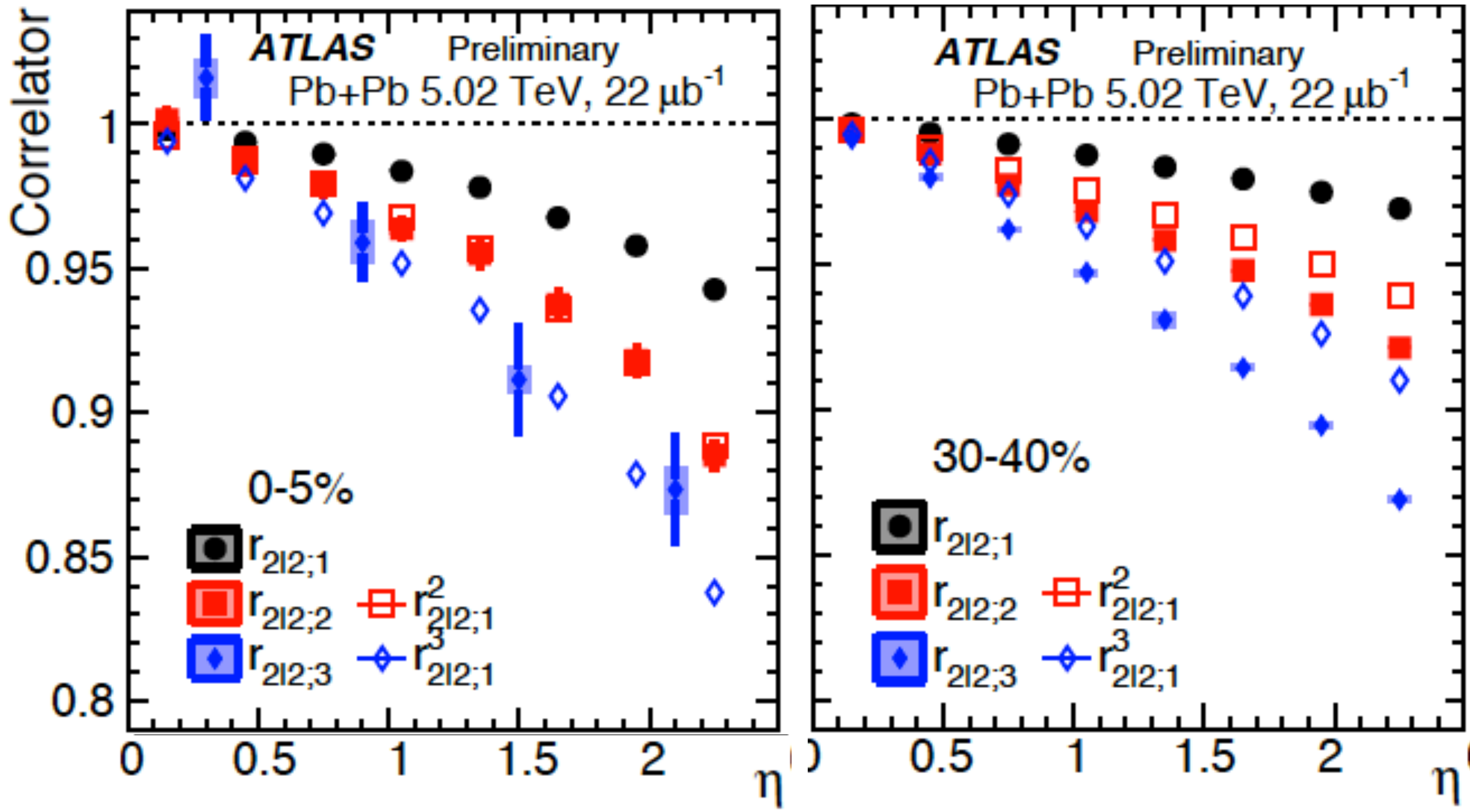
Energy dependence of slope



	$n = 2$	$n = 3$	$n = 4$
$F^{\mathrm{r}}_{n;1}(2.76\ \mathrm{TeV})/F^{\mathrm{r}}_{\mathrm{n};1}(5.02\ \mathrm{TeV})$	1.100 ± 0.010	1.153 ± 0.011	1.17 ± 0.04
$F^{\mathrm{R}}_{n}(2.76\ \mathrm{TeV})/F^{\mathrm{R}}_{\mathrm{n}}(5.02\ \mathrm{TeV})$	1.106 ± 0.027	1.19 ± 0.08	–

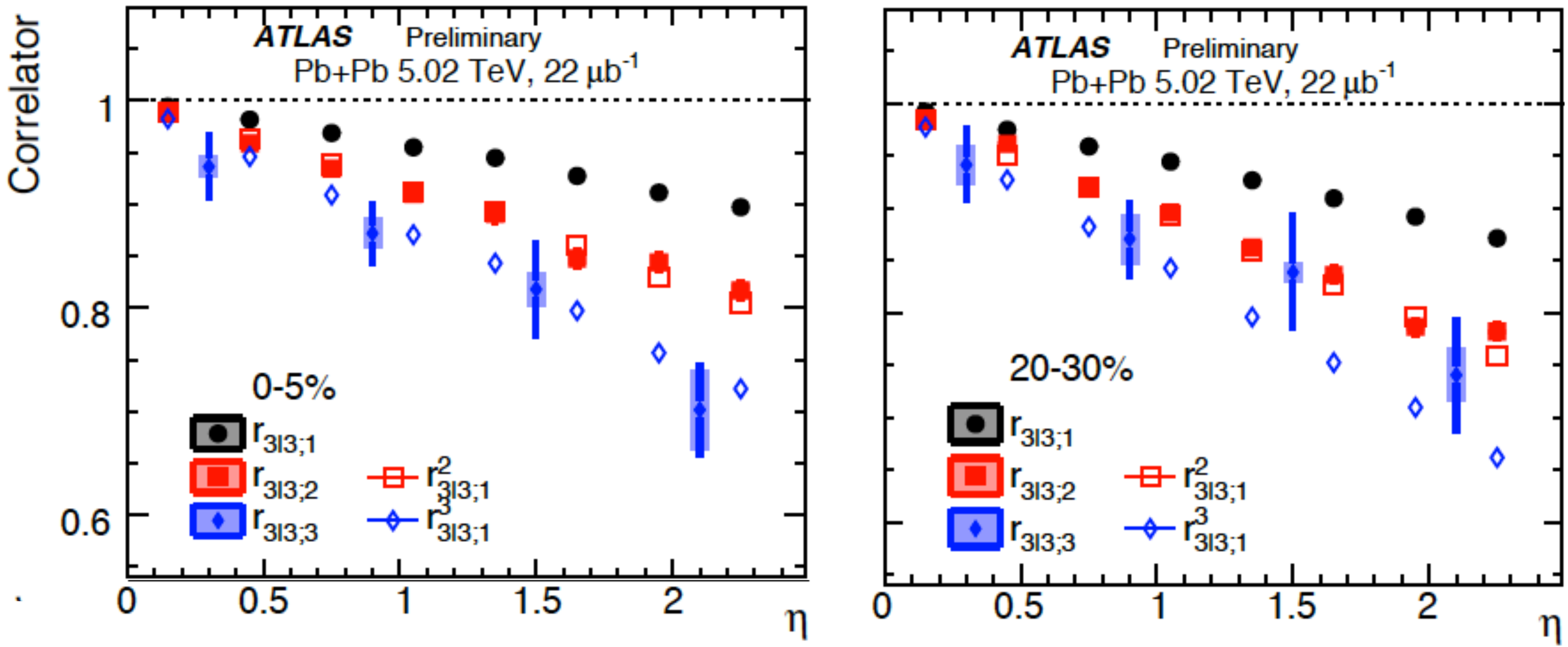
- For n=2 values are 10% higher at 2.76 TeV than at 5.02 TeV
- For n=3,4 the values are ~16% higher
- Ratios are independent of centrality.

Higher order decorrelations: v_2



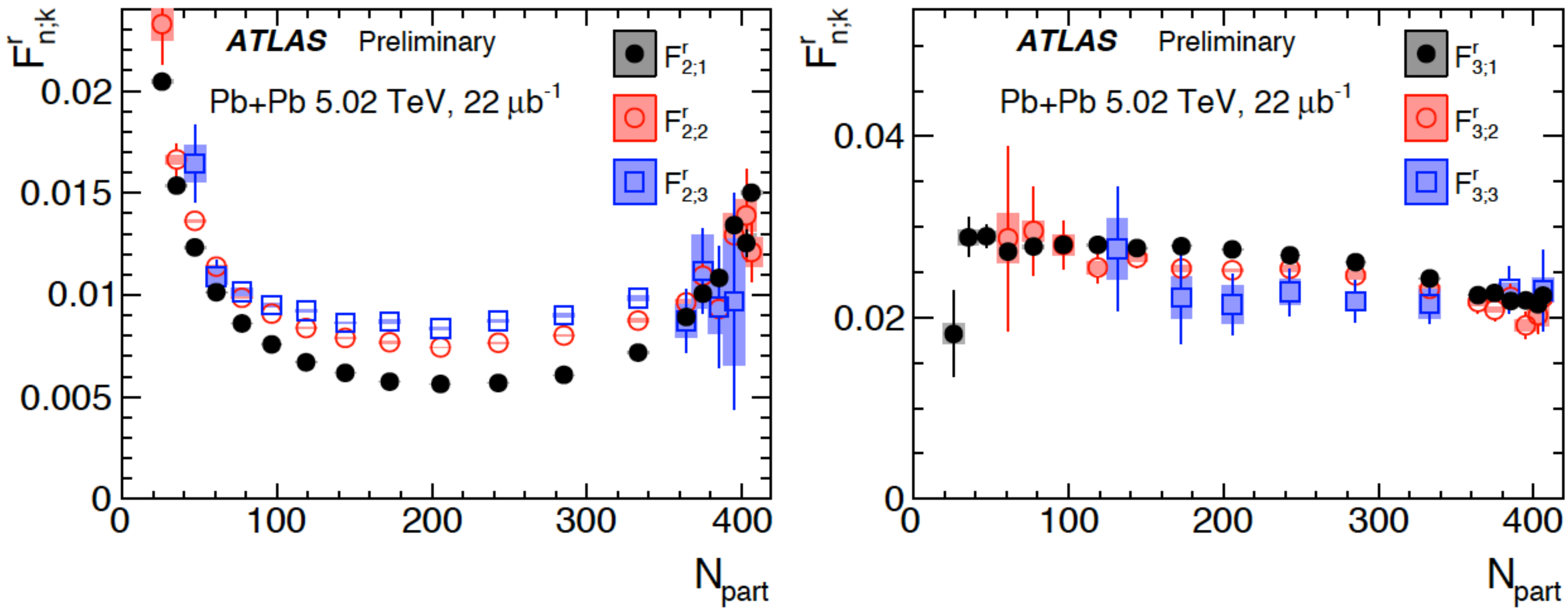
- Also study decorrelation for k^{th} power of flow-vector
- Expect (for fluctuations driven v_n) $r_{n|n;k} \approx r^k_{n|n;1}$
- For n=2 this scaling holds in central events only

Higher order decorrelations: v_3



- Also study decorrelation for k^{th} power of flow-vector
- Expect (for fluctuations driven v_n) $r_{n|n;k} \approx r^{k}_{n|n;1}$
- For n=3 this scaling holds everywhere

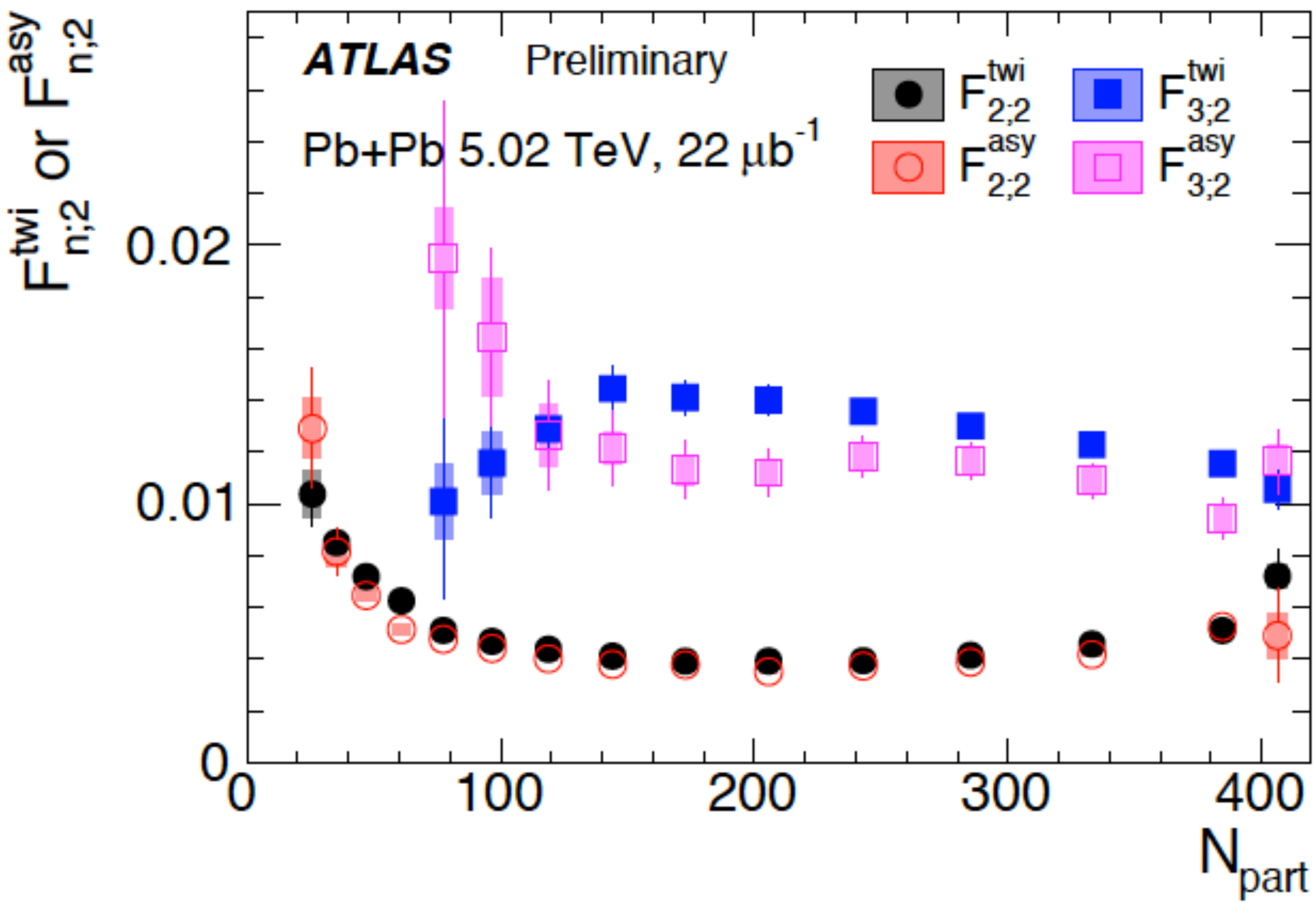
Slopes for higher order decorrelations



$$r_{n|n;k} \approx 1 - 2kF^r_{n;k}\eta$$

- Also study decorrelation for k^{th} power of flow-vector
- Higher power shows larger slope for *n*=2 (accounting for factor of *k*)
- For n=3 slopes are consistent (after removing trivial factor of *k*)

EP twist vs v_n-magnitude asymmetry



- The contributions of twist and rotation to flow de-correlation are quite comparable for both 2nd and 3rd order harmonics

Correlations in the de-correlations!

- Are the de-correlations for different order harmonics correlated?

- Calculate mixed harmonic decorrelators between harmonics n=2 and n=3

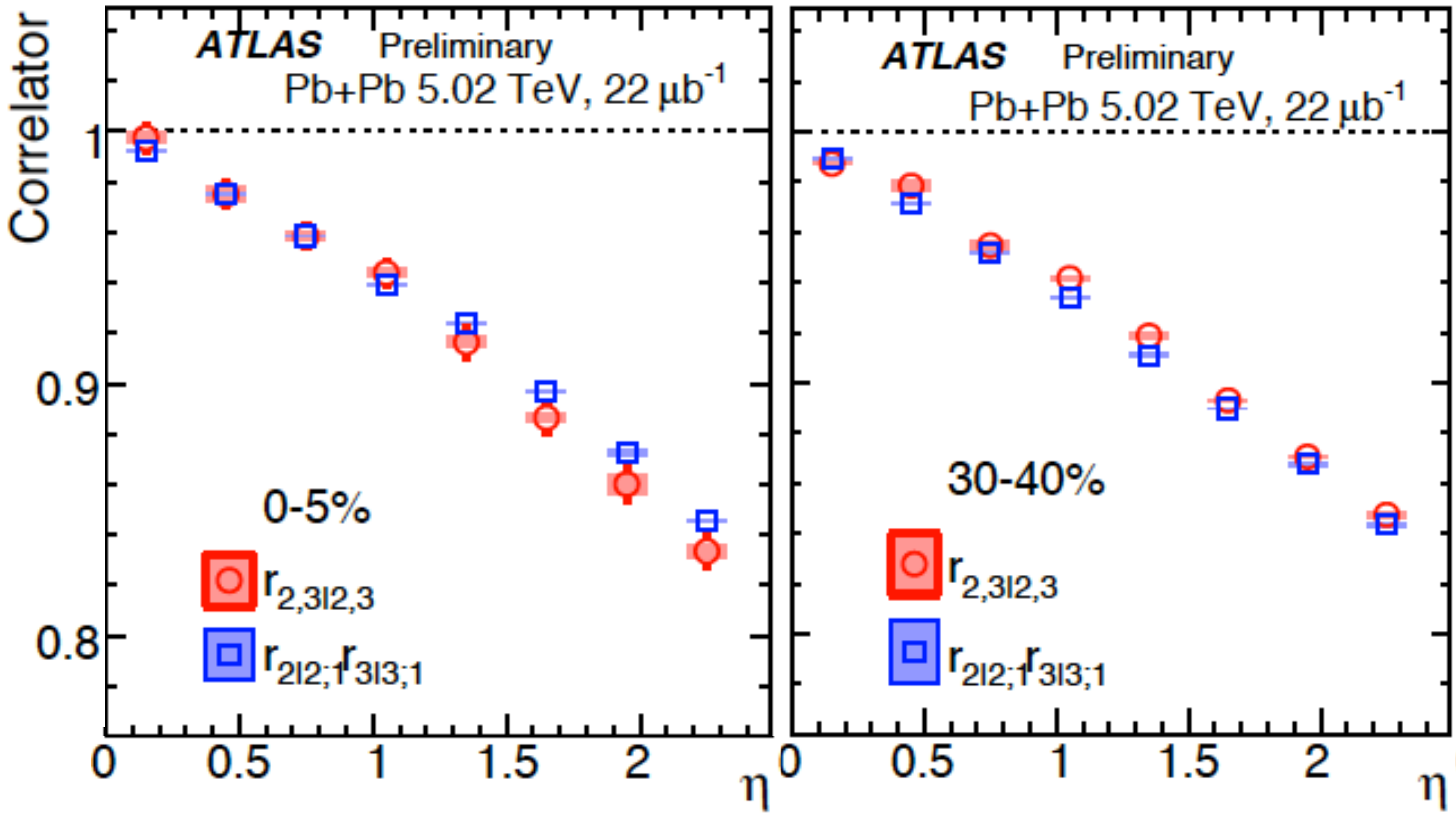
$$r_{2,3|2,3} = \frac{\langle q_2(\eta_{ref}) q_2^*(-\eta) q_3(-\eta_{ref}) q_3^*(+\eta) \rangle}{\langle q_2(\eta_{ref}) q_2^*(+\eta) q_3(-\eta_{ref}) q_3^*(-\eta) \rangle}$$

If decorrelations are uncorrelated then:

$$= \frac{\langle q_2(\eta_{ref}) q_2^*(-\eta) \rangle}{\langle q_2(\eta_{ref}) q_2^*(+\eta) \rangle} \frac{\langle q_3(-\eta_{ref}) q_3^*(+\eta) \rangle}{\langle q_3(-\eta_{ref}) q_3^*(-\eta) \rangle}$$

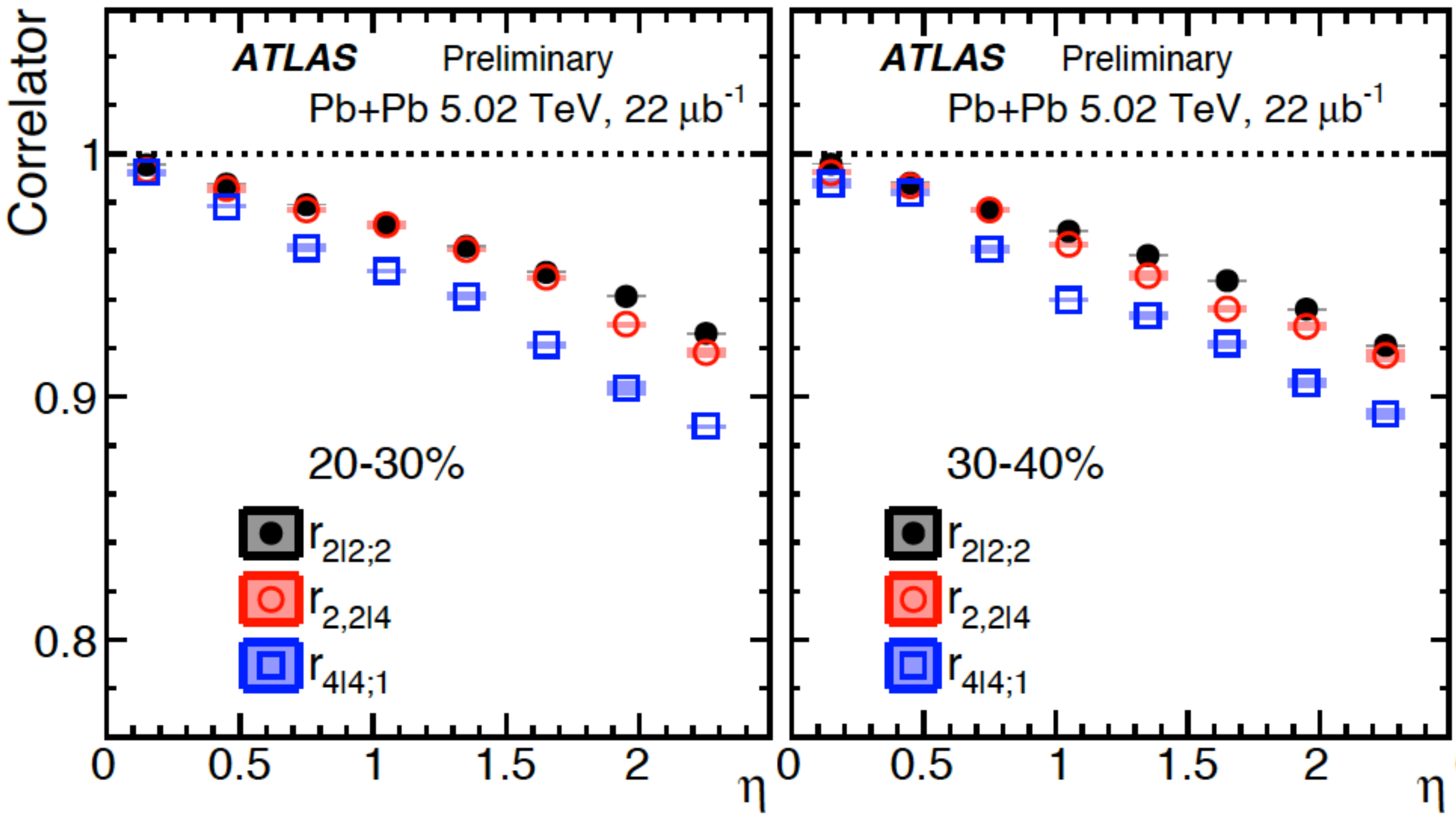
$$= \quad r_{2|2;1} * r_{3|3;1}$$

Correlations in the de-correlations: v_2, v_3



- Compare "correlated de-correlator" $r_{2,3|2,3}$ with product of decorrelations $r_{2|2;1} * r_{3|3;1}$
- Decorrelations for v_2 and v_3 are uncorrelated!

Correlations in the de-correlations: v_2, v_4



- Compare "correlated de-correlator" $r_{2,2|4}$ with de-correlator $r_{2|2;2}$ and also with $r_{4|4;1}$
- Observe non-linear response ($v_4 \propto v_2^2$) in de-correlation

Summary

- Measured Longitudinal flow decorrelations
  - Decorrelations increase linearly with η-gap

- Decorrelations larger for higher order harmonics
- Centrality dependence observed

- Decorrelations 10-16% smaller at 5.02 TeV compared to 2.76 TeV

- Separated EP angle fluctuations and magnitude fluctuations
  - Approximately equal magnitude of the two effects

- Also studied correlations in the decorrelations
  - Independent for v_2 and v_3
  - Correlated between v_2 and v_4

For more results see: **ATLAS-CONF-2016-105, ATLAS-CONF-2017-003**
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults