Study of the long-range azimuthal correlations in *pp* and *p*+Pb collisions with the ATLAS detector at the LHC

Krzysztof Wozniak, IFJ PAN, Krakow
for the ATLAS Collaboration

Two particle correlations

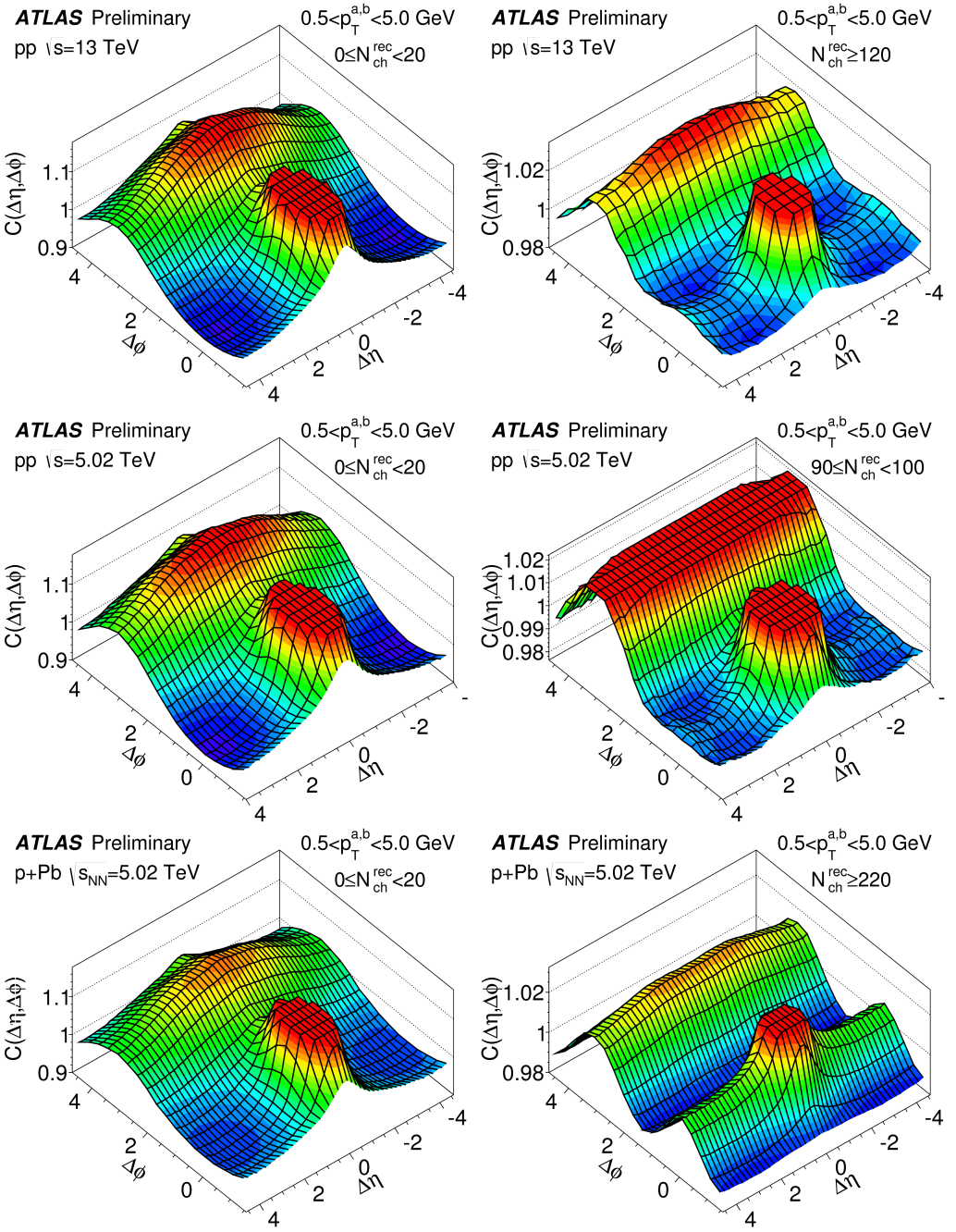
$$C(\Delta\eta,\Delta\phi) = \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

S - number of pairs in the measured events

B - number of pairs in "mixed" events (constructed from tracks from different events with approximately the same multiplicity)

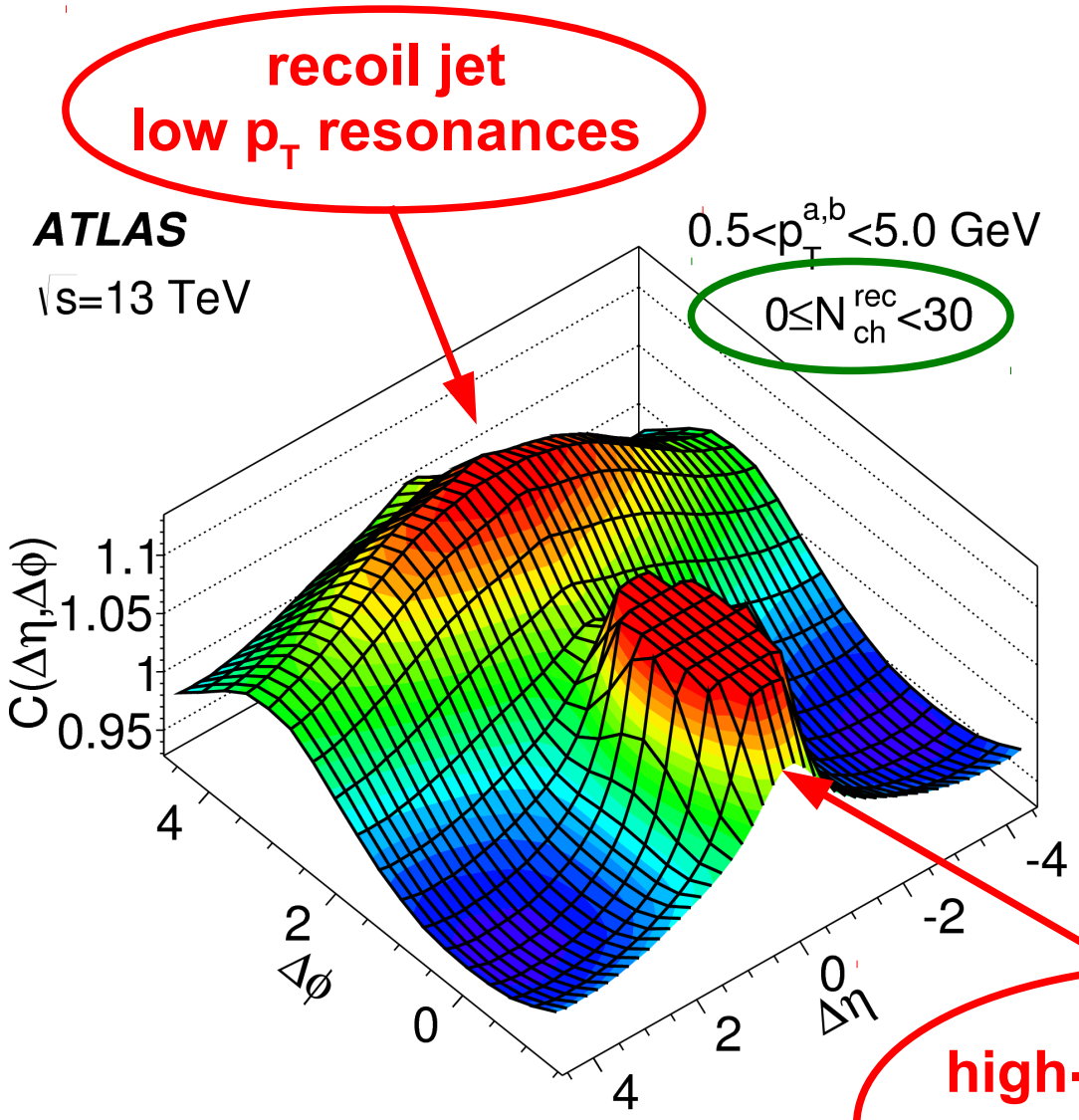
Data:

pp	$\sqrt{s}$ =	**13 TeV**
pp	$\sqrt{s}$ =	**5.02 TeV**
pp	$\sqrt{s}$ =	**2.76 TeV**
***p*+Pb**	$\sqrt{s_{NN}}$ =	**5.02 TeV**



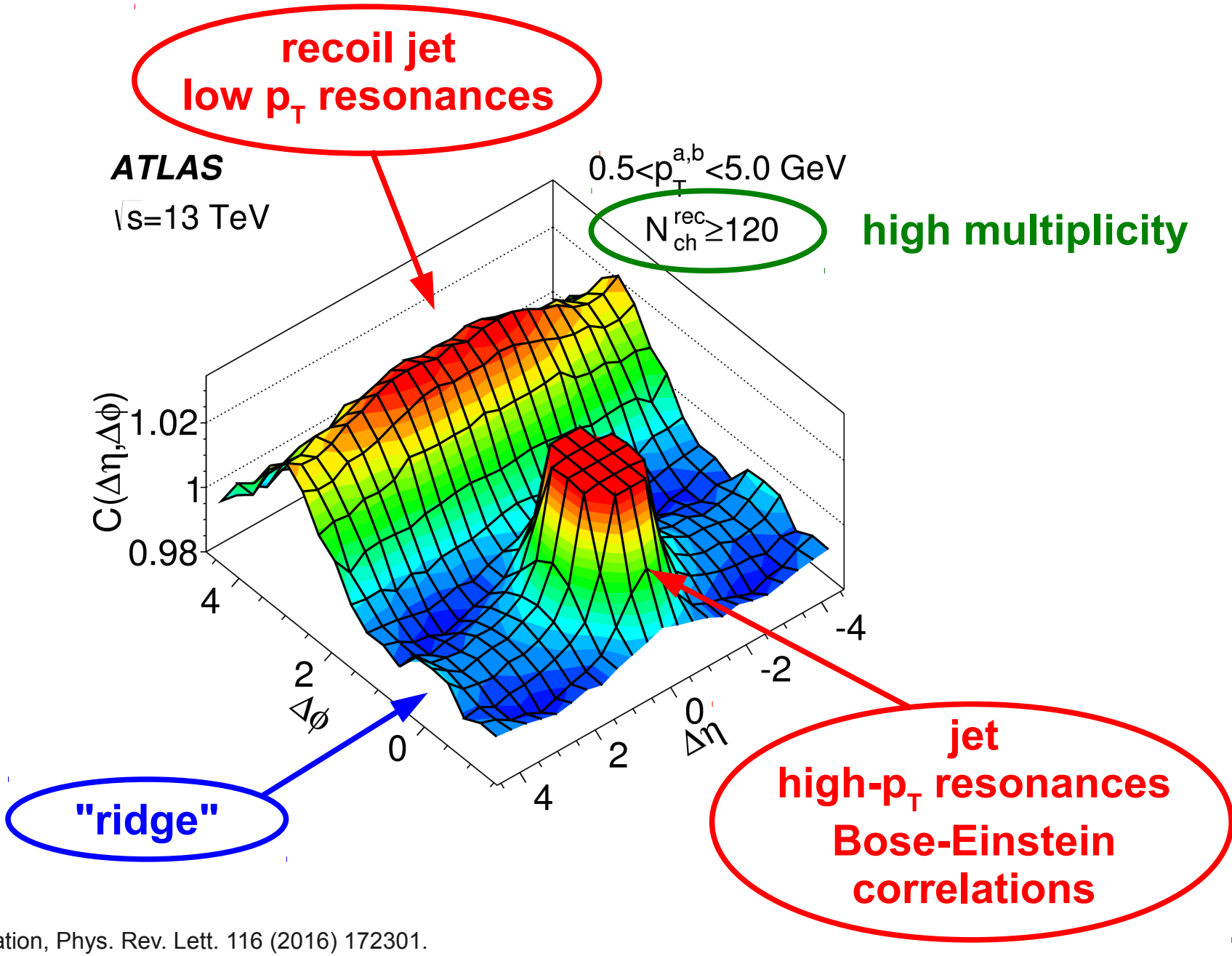
ATLAS Collaboration, Phys. Rev. C 90 (2014) 044906.
ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.
ATLAS Collaboration, ATLAS-CONF-2016-026.

Two particle correlations



ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.

Two particle correlations

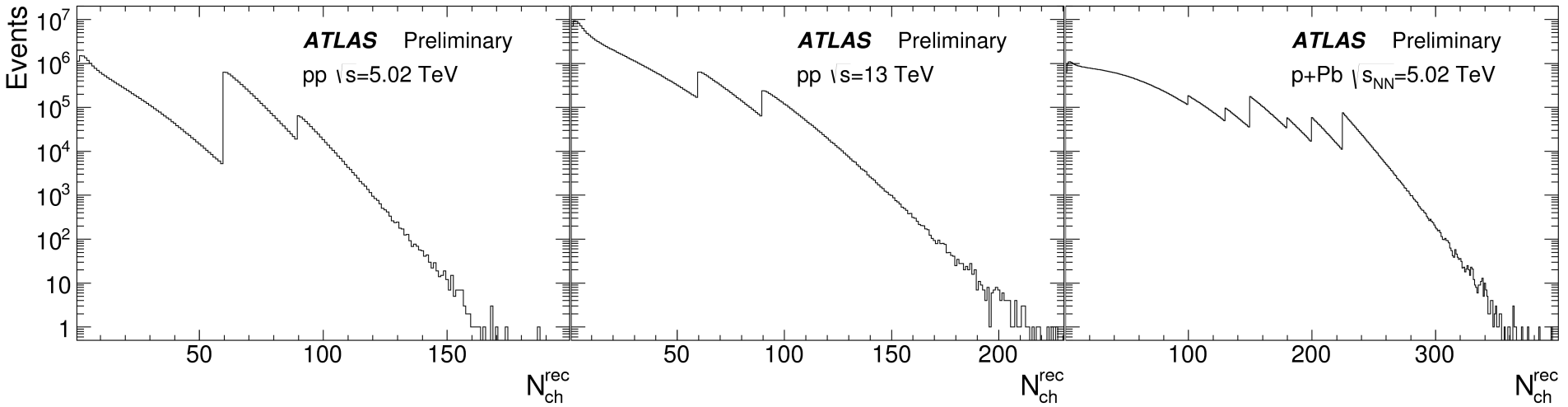


ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.

HMT triggers

For the correlation studies we need unbiased events in the whole multiplicity range:

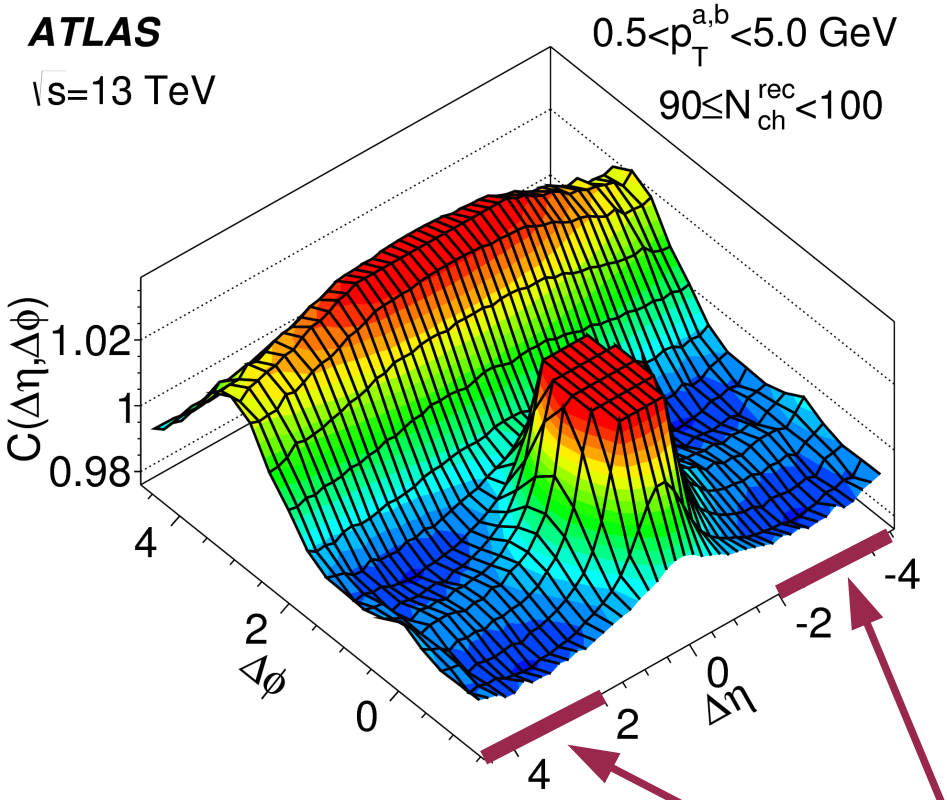
- Minimum Bias events sample is used for low multiplicities
- additional events above some multiplicity thereshold are selected online and registered

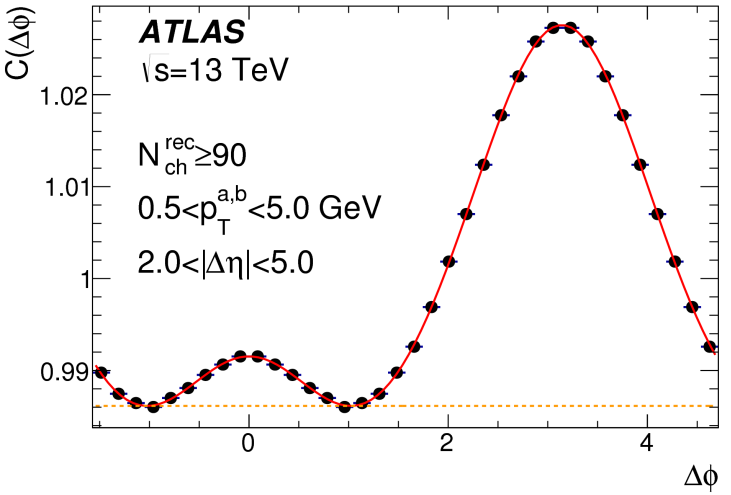


Several **High Multiplicity Triggers** are used to enhance the statistics of events with large number of produced particles

ATLAS Collaboration, Phys. Rev. C 90 (2014) 044906.
ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.
ATLAS Collaboration, ATLAS-CONF-2016-026.

Two particle correlations - $\Delta\phi$ dependence





Integration outside of the jet peak in the range $2 < |\Delta\eta| < 5$

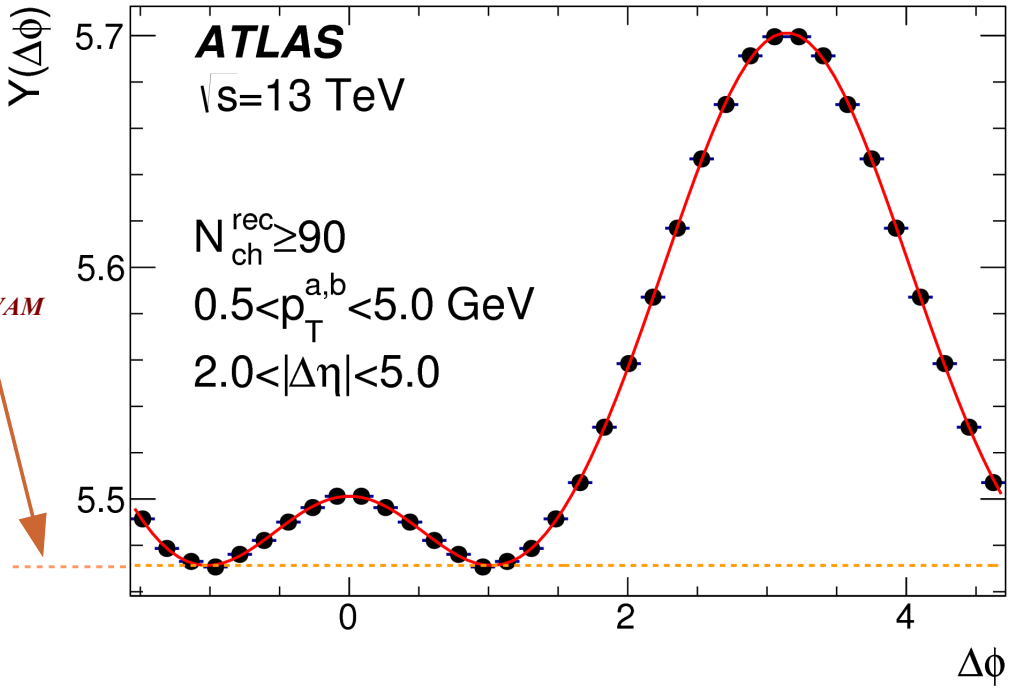
Correlation function still affected by the combinatoric contribution

Per-trigger-particle yield - ZYAM procedure

ZYAM (Zero Yield At Minimum) procedure

$$Y^{corr}(\Delta\phi) = \left(\frac{\int B(\Delta\phi)\ d\Delta\phi}{N^a \int d\Delta\phi} \right) C(\Delta\phi) - b_{ZYAM}$$

From the per-trigger-particle yield a constant pedestal arising from uncorrelated pairs is subtracted



In the analysis of azimuthal correlations in *p*+Pb collision the ZYAM procedure was applied to the peripheral yield only - which was then subtracted from the yields at higher centralities.

However, the assumption that the number of correlated pairs is zero at the minimum may be incorrect in the presence of long range correlations.
Even in the peripheral (or low-multiplicity) collisions the yield may contain a modulated soft component:

$$Y^{periph}(\Delta\phi) = Y^{hard}(\Delta\phi) + G_0[1 + 2v^0_{2,2}\cos(2\Delta\phi)]$$

Per-trigger-particle yield - template fit procedure

Template

$$Y^{templ}(\Delta\phi) = F\,Y^{periph}(\Delta\phi) + Y^{ridge}(\Delta\phi)$$

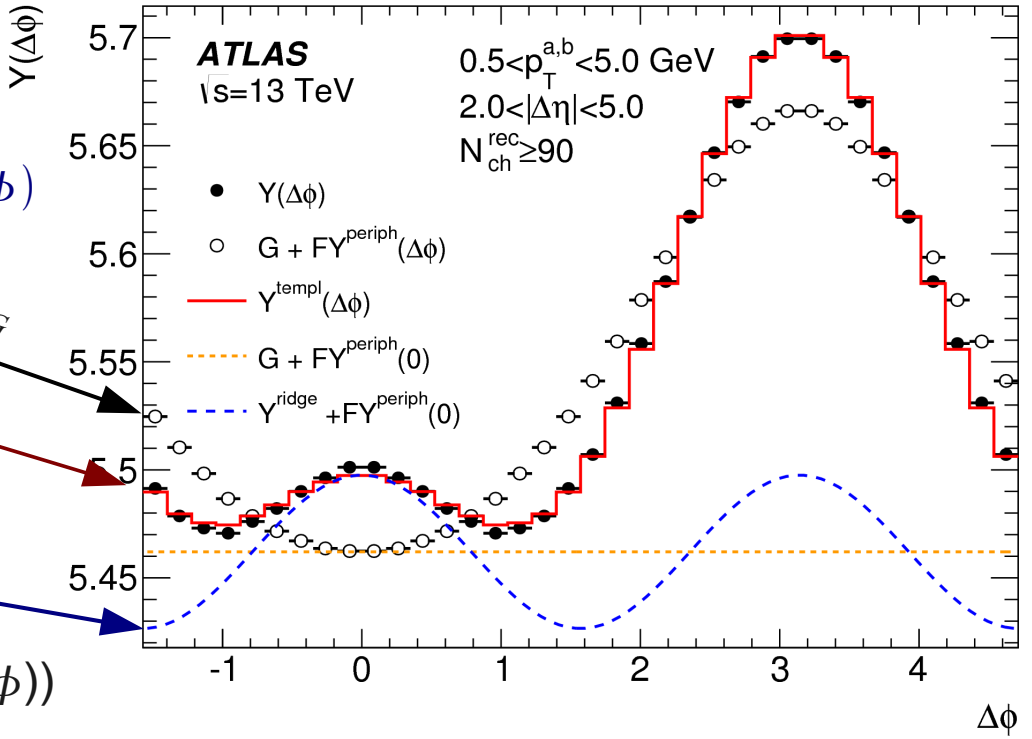
$F\,Y^{periph}(\Delta\phi)+G$

where

$$Y^{ridge}(\Delta\phi) = G[1+2v_{2,2}\cos(2\Delta\phi)]$$

free parameters: F and $v_{2,2}$

(G is fixed by the normalization of $Y(\Delta\phi)$)



Difference between template fit and ZYAM results:

if $Y^{periph}(\Delta\phi) = Y^{hard}(\Delta\phi) + G_0[1+2v^0_{2,2}\cos(2\Delta\phi)]$ *with* $v^0_{2,2}>0$

then ZYAM method subtracts $F\,Y^{hard}(\Delta\phi) + 2F\,G_0 v^0_{2,2}\cos(2\Delta\phi)$

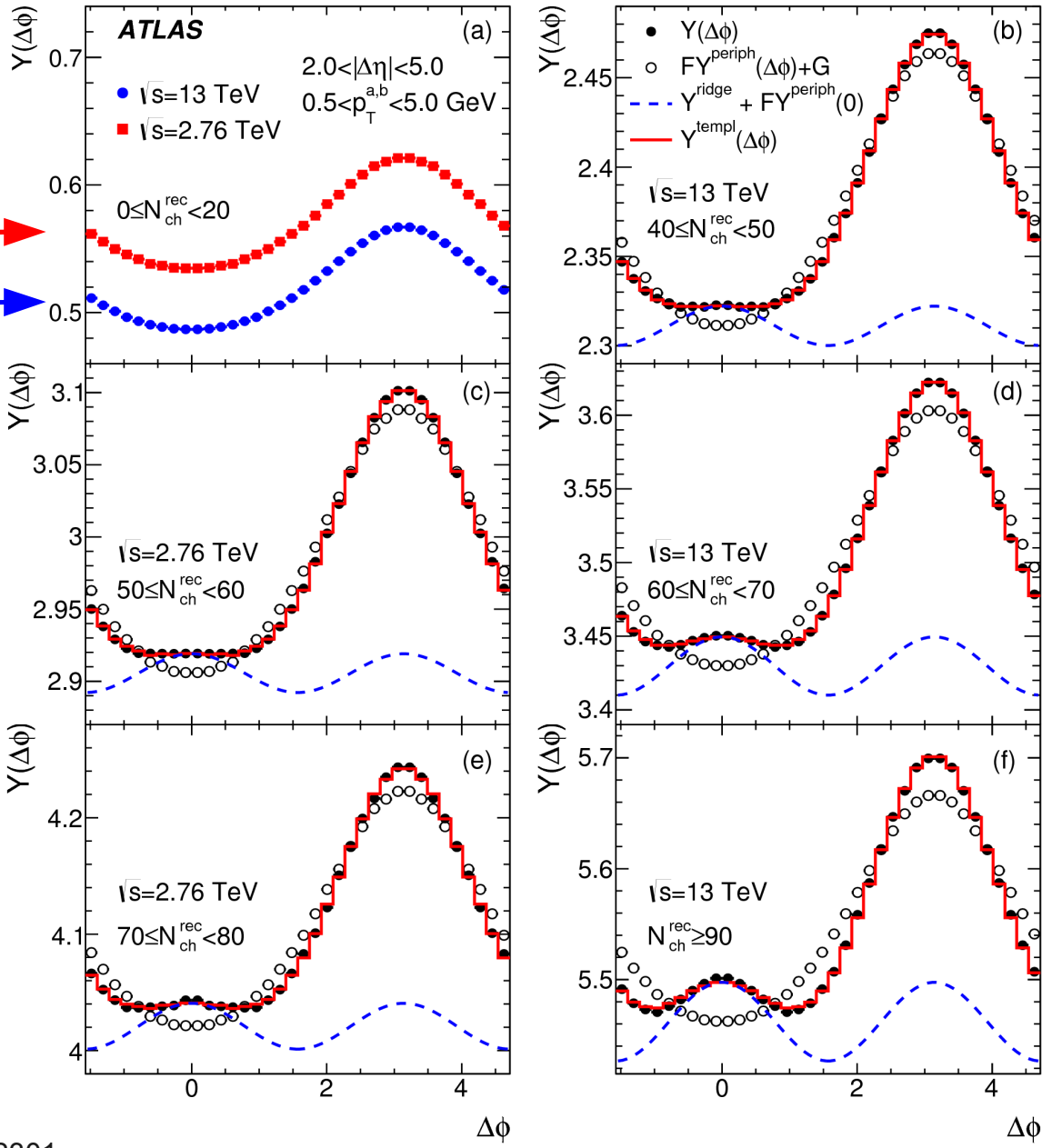
which directly reduces $v^{ZYAM}_{2,2}$

while template method subtracts $F\,Y^{hard}(\Delta\phi) + F\,G_0[1+2v^0_{2,2}\cos(2\Delta\phi)]$

which rather changes the G parameter than modifies $v^{templ}_{2,2}$

Per trigger yield - template fit for *pp* at 2.76 and 13 TeV

$Y^{periph}(\Delta\phi)$ 2.76 TeV 13 TeV



Very good description of **Y(Δφ)** by the template fit (red histogram)

open points show non flow contribution

$$F\,Y^{periph}(\Delta\phi)+G$$

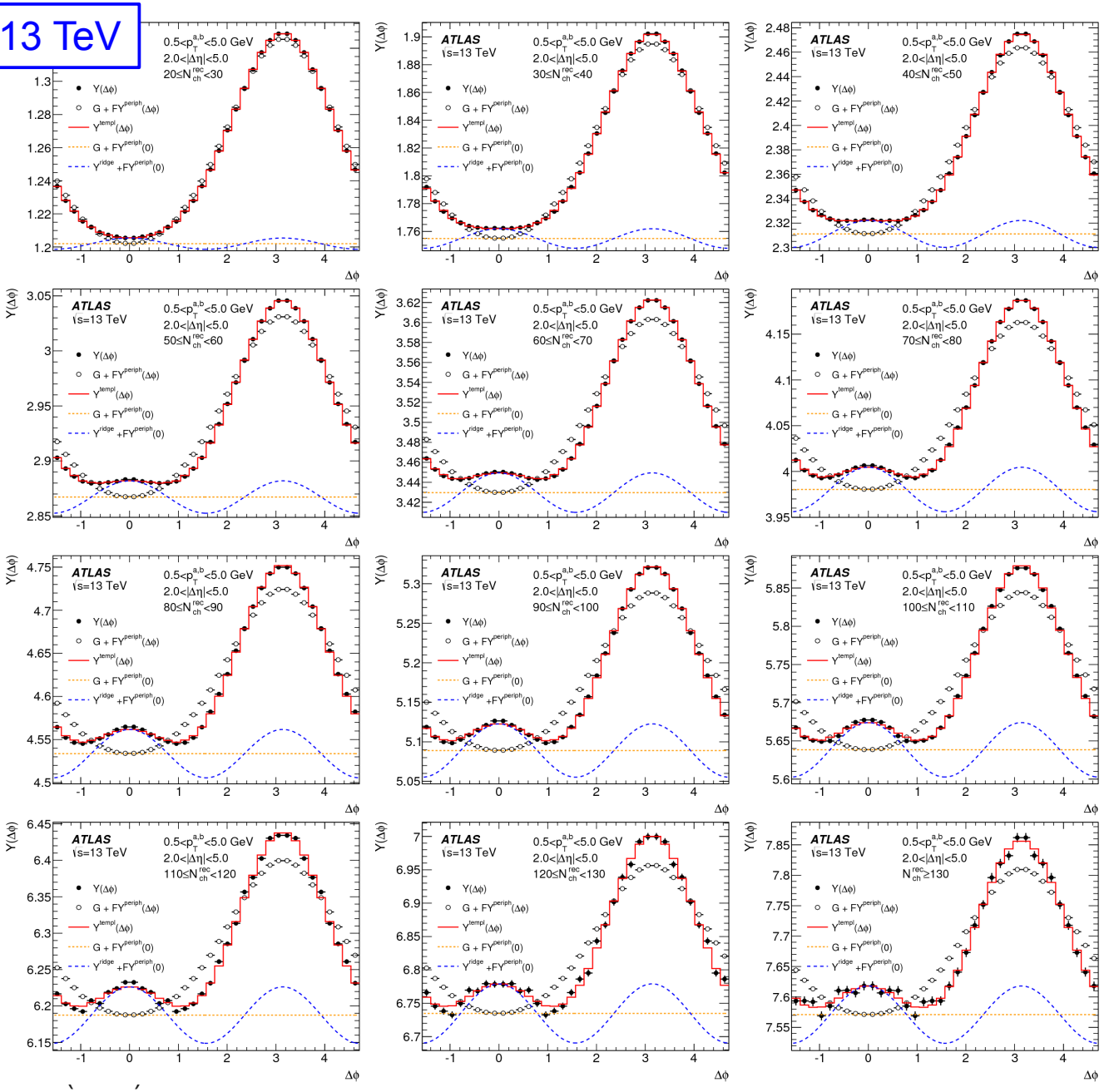
dashed line denotes the "ridge" correlation

$$Y^{ridge}(\Delta\phi) \;+\; F\,Y^{periph}(0)$$

ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.

Per trigger yield - template fit for *pp* at 13 TeV

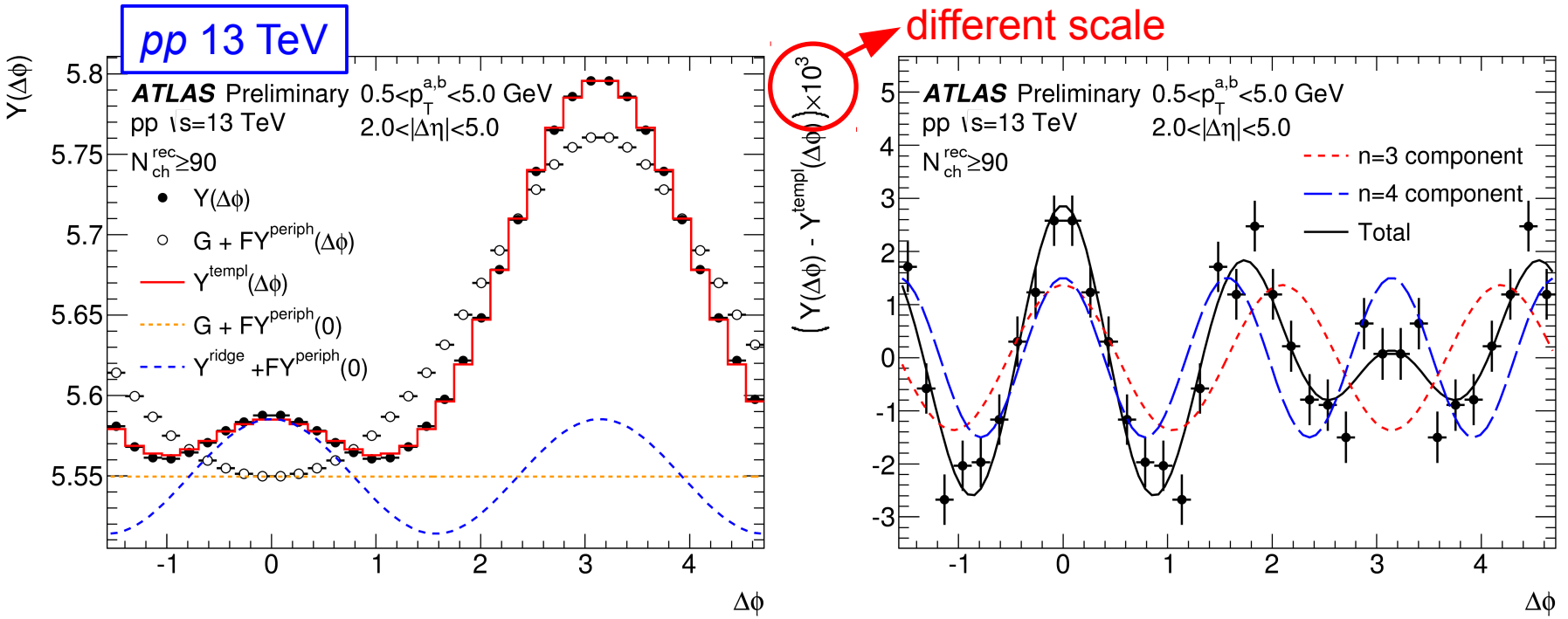
pp 13 TeV



Very good description of
$Y(\Delta\phi)$
by the template fit
in all multiplicity ranges

ATLAS Collaboration, Phys. Rev. Lett

Per trigger yield - subtraction of the fitted template



The small difference between the data points and the fitted template:

$$Y(\Delta\phi) - Y^{templ}(\Delta\phi) = Y(\Delta\phi) - (FY^{periph}(\Delta\phi) + G[1 + 2v_{2,2}\cos(2\Delta\phi)])$$

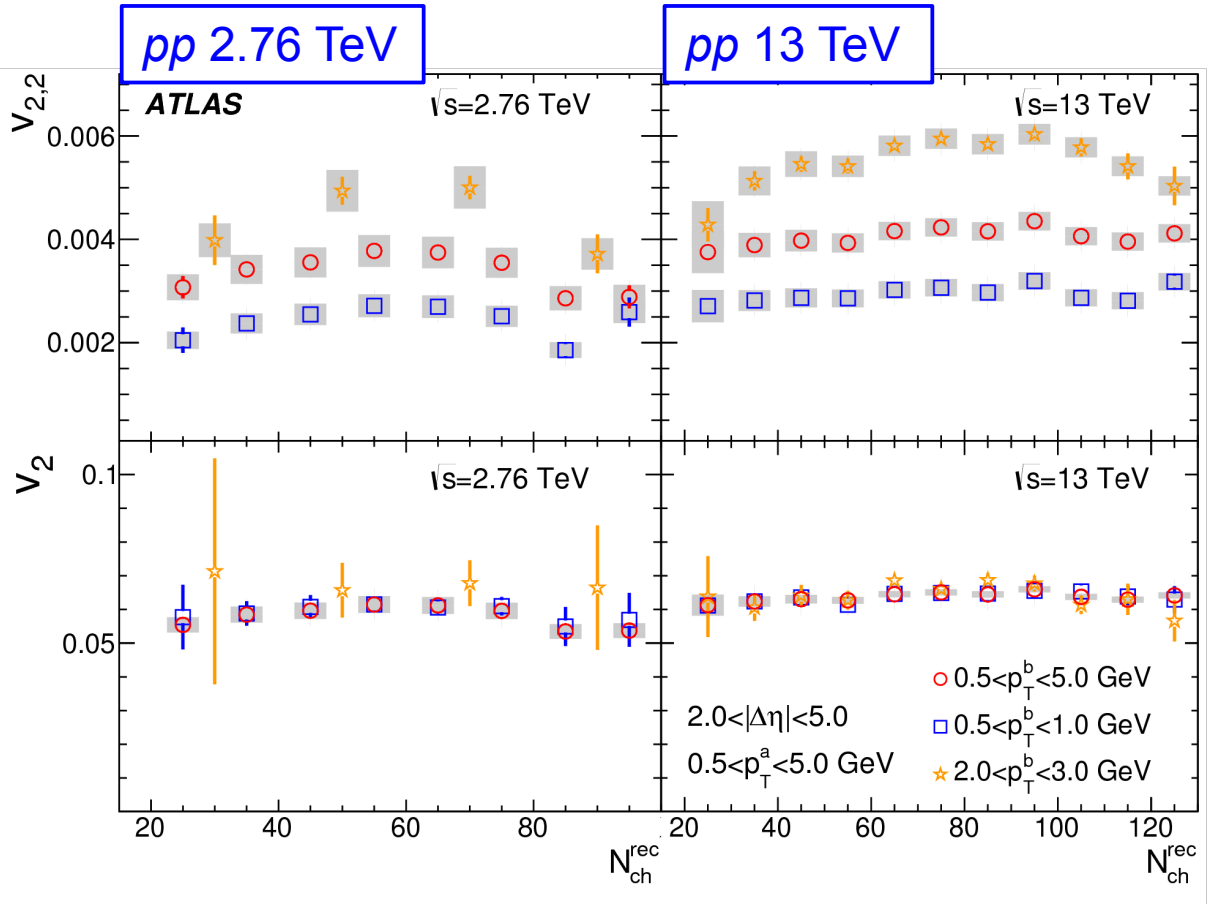
shows oscillations which can be described by higher order components - proportional to $\cos(n\Delta\phi)$ (n>2)

We may use template with higher order terms: $v_{3,3}\cos(3\Delta\phi)$, $v_{4,4}\cos(4\Delta\phi)$

ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.

v_2 from the template fit

$$v_2(p_{T_1}^a) = \frac{v_{2,2}(p_{T_1}^a, p_{T_2}^b)}{\sqrt{v_{2,2}(p_{T_2}^b, P_{T_2}^b)}}$$

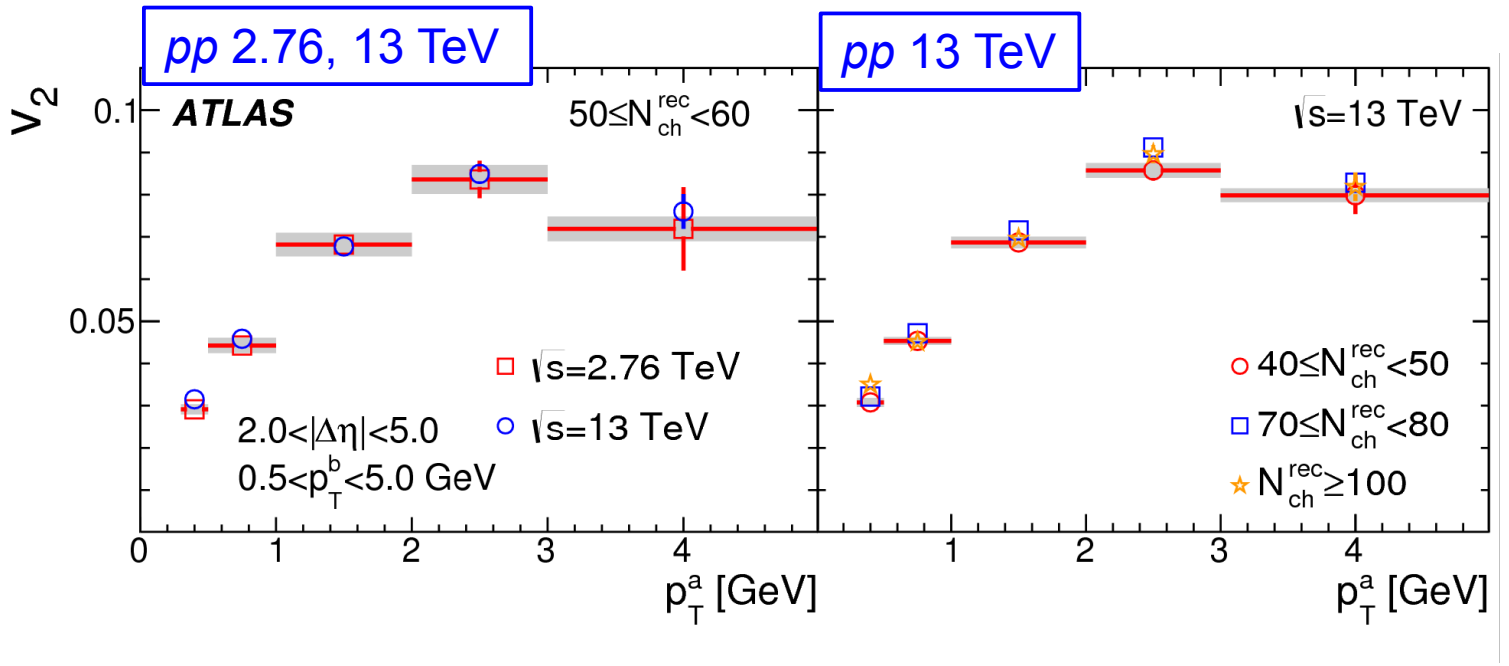


$v_{2,2}$ depends on p_T^b but exhibits factorization, as v_2 does not depend on p_T^b intverval used

v_2 does not depend on event multiplicity or the energy of the *pp* collision

ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.

v_2 from the template fit



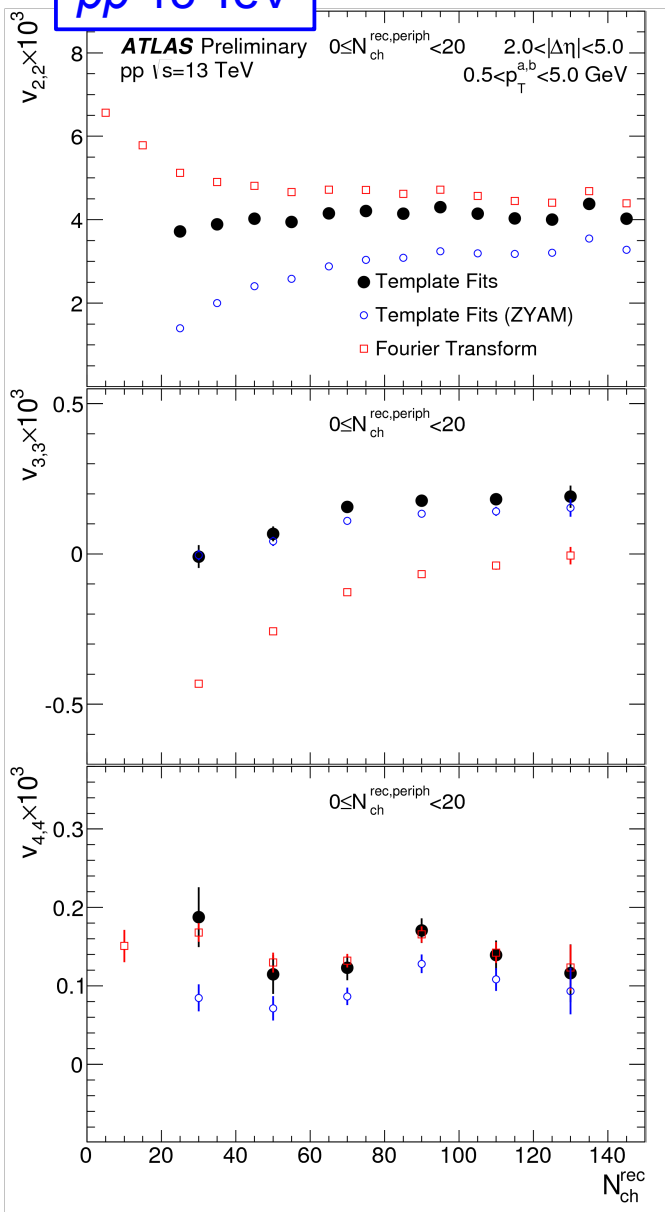
v_2 as a function of p_T^a does not depend on the energy of the *pp* collision

the shape of $v_2(p_T^a)$ does not change with event multiplicity

ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.

Results of template fit for higher harmonics

pp 13 TeV



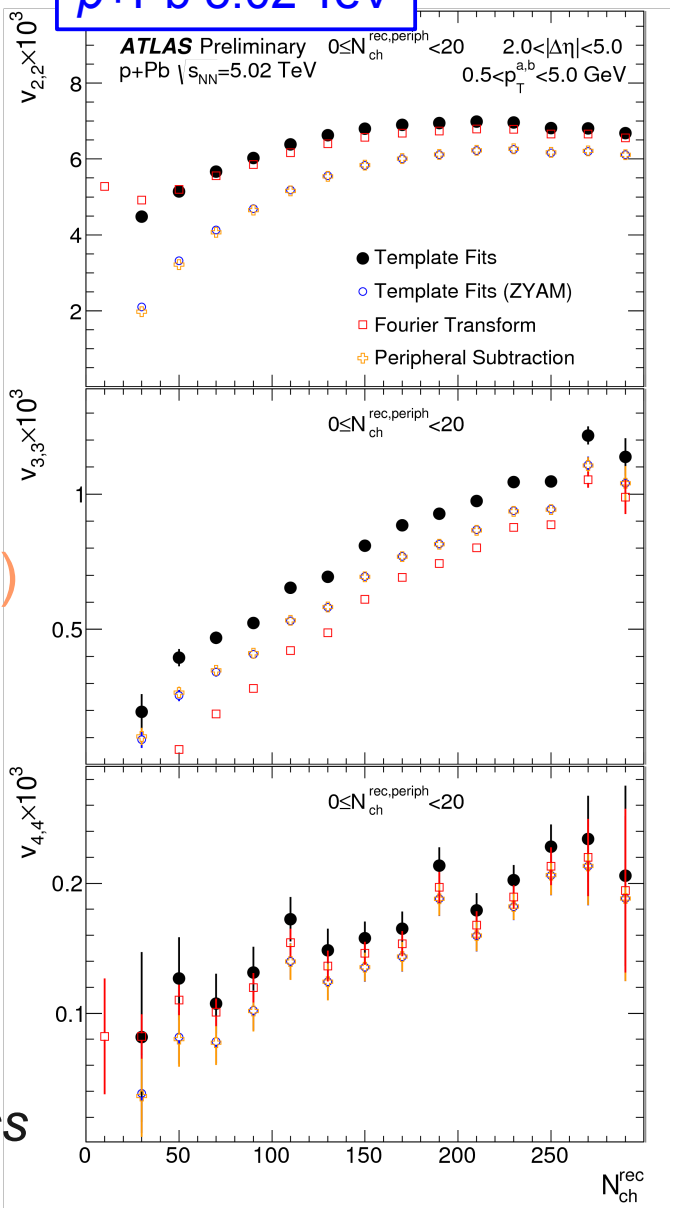
$v_{n,n}$ obtained from:

- **template fit**
- ZYAM
- Fourier transform
- peripheral subtraction (p+Pb)

Template fit gives similar results as the ZYAM method for higer harmonics

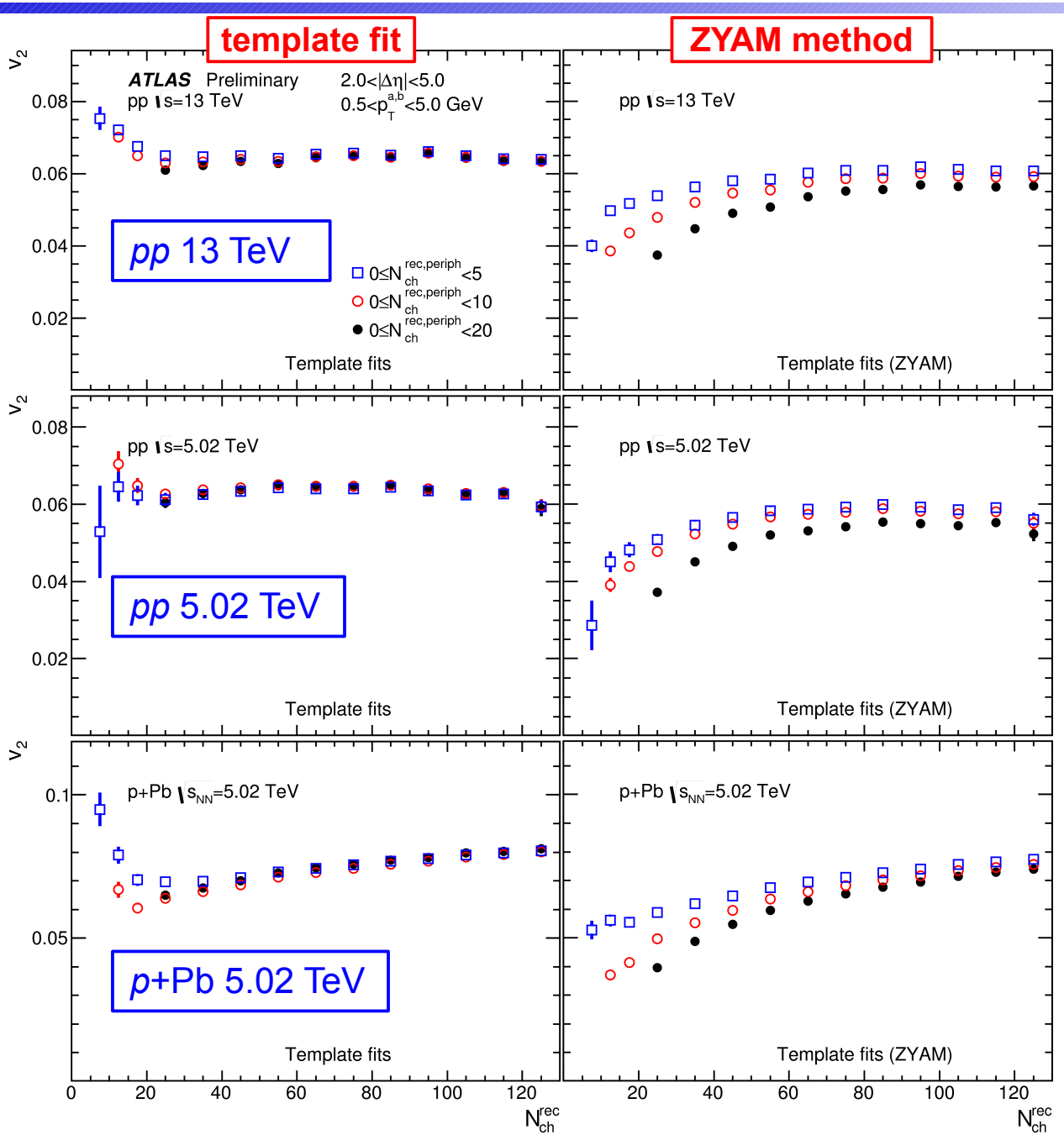
ZYAM method underestimates values of the second harmonics

p+Pb 5.02 TeV



ATLAS Collaboration, ATLAS-CONF-2016-026.

Comparison of template fit and ZYAM method



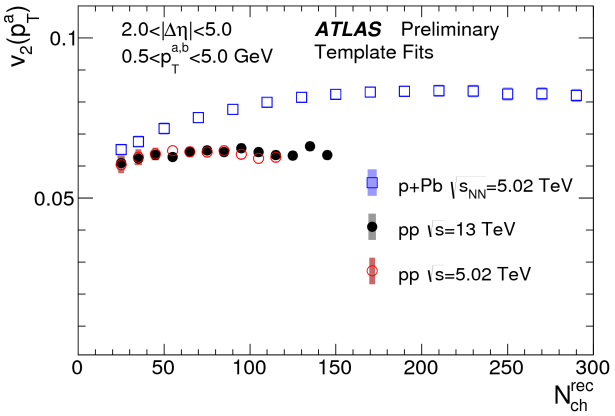
Different definitions of peripheral events

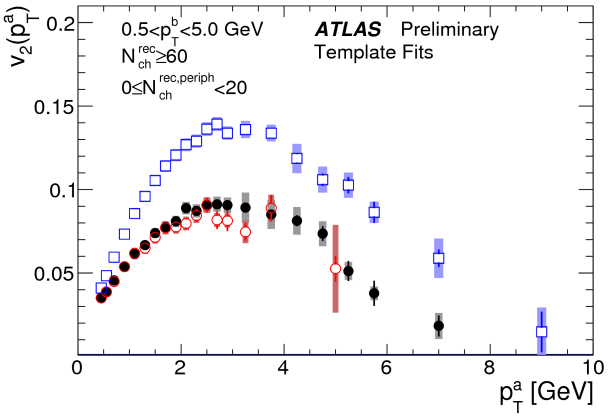
v_2 from **ZYAM method** depends on selection of peripheral sample for subtraction

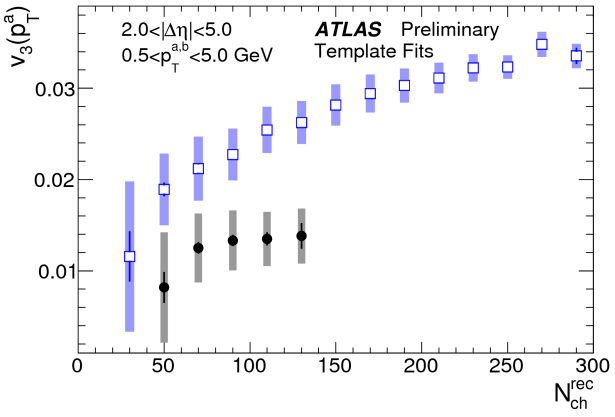
The **template fit method** gives consistent results regardles of the range of multiplicity used in the definition of peripheral events.

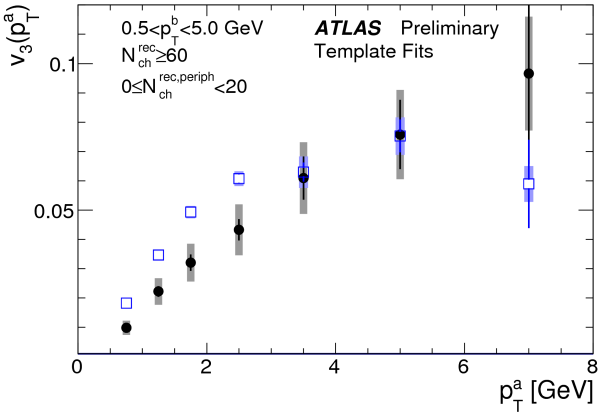
ATLAS Collaboration, ATLAS-CONF-2016-026.

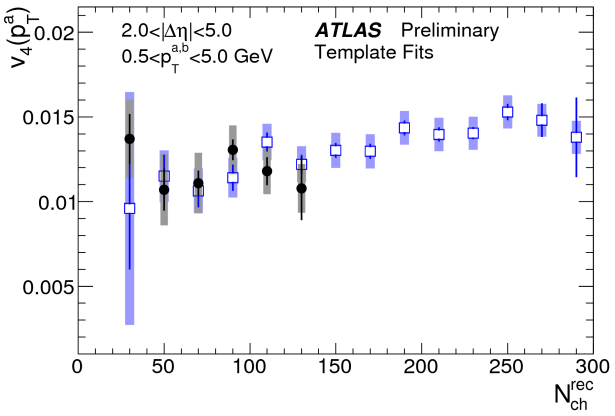
Results of template fit for higher harmonics

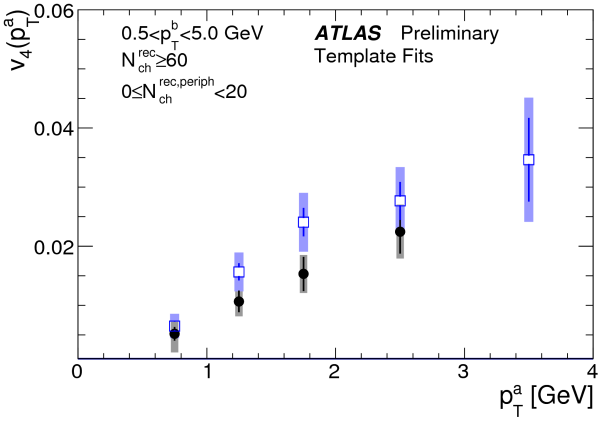












ATLAS Collaboration, ATLAS-CONF-2016-026.

$$v_2^{pp} < v_2^{p+Pb}$$

for *pp* collisions:

v_2, v_3, v_4 do not depend on charged particle multiplicity, and

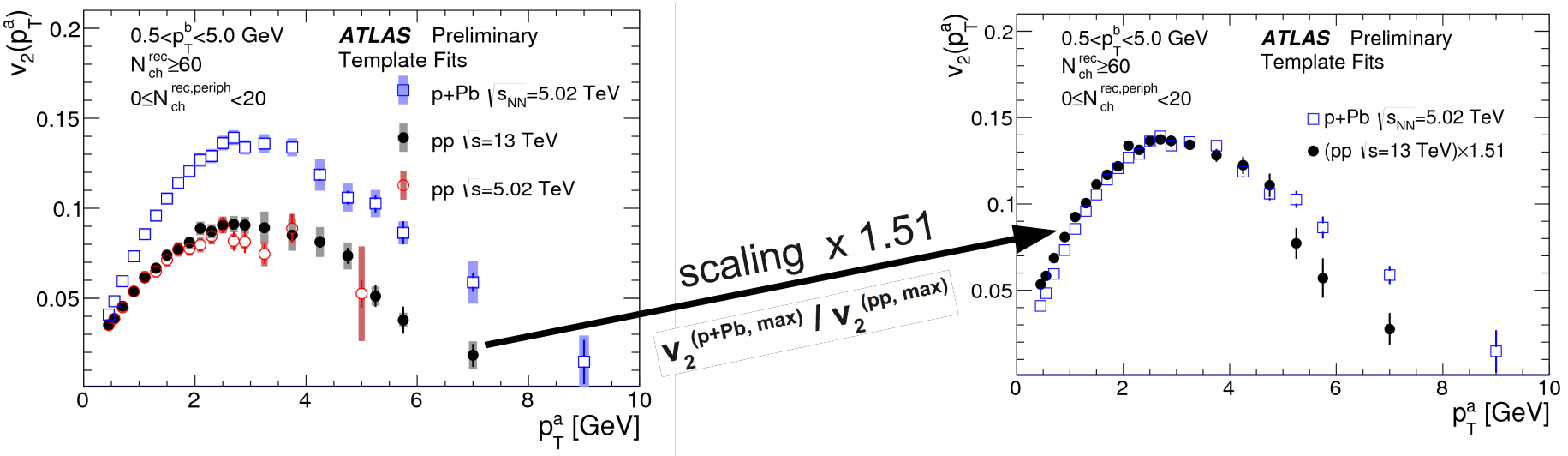
$$v_2 \gg v_3 > v_4$$

for *p*+Pb collisions:

v_2, v_3, v_4 increase with increasing multiplicity, and:

$$v_2 \gg v_3 \gg v_4$$

v_2 in *pp* and *p*+Pb collisions

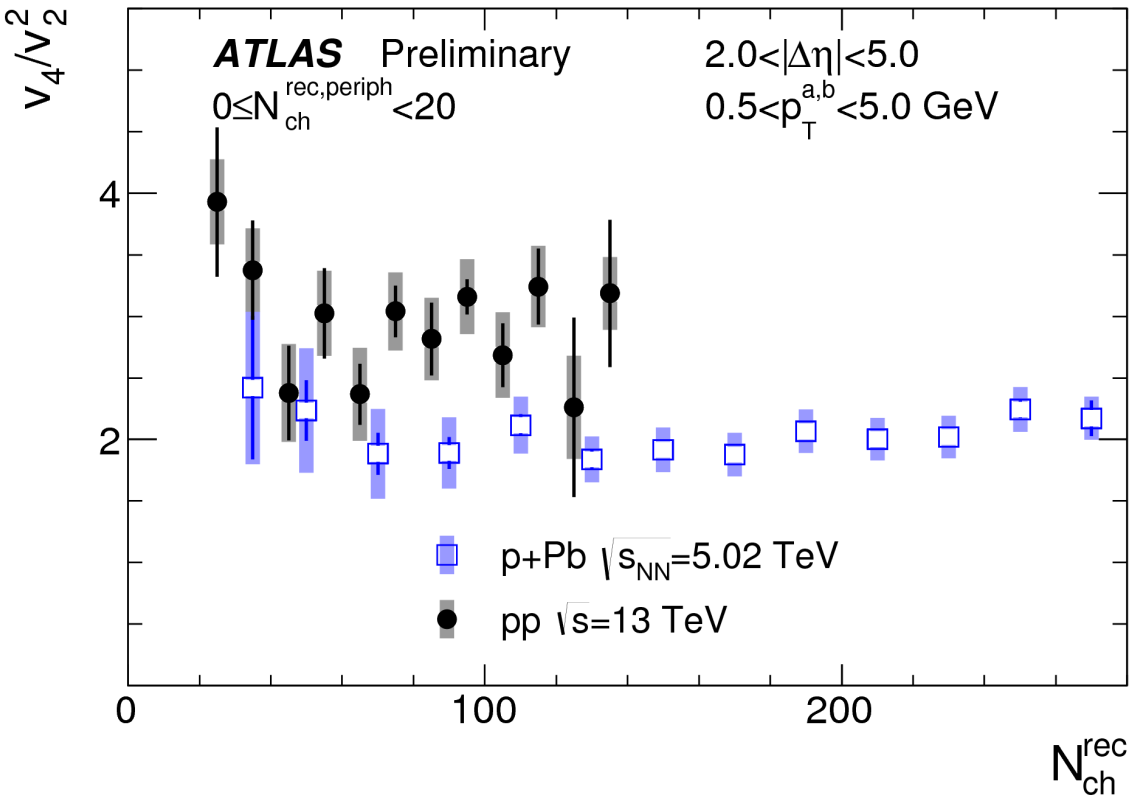


Although the magnitude of v_2 is different in ***pp*** and ***p*+Pb** collisions, **the shape of $v_2(p_T)$ is similar**.

However, after scaling by the ratio of the maximal v_2 in the systems considered, for low p_T the v_2 values are larger in *pp* collisions while for p_T >5 GeV they are lower.

ATLAS Collaboration, ATLAS-CONF-2016-026.

v_4 and v_2^2 comparison



The ratio v_4 / v_2^2 does not change with multiplicity even if v_2 and v_4 increase with increasing multiplicity (in *p*+Pb collisions).

Values of v_4 / v_2^2 are higher in ***pp*** than in ***p*+Pb** collisions - this may be related to stronger non-linear coupling between v_2 and v_4

ATLAS Collaboration, ATLAS-CONF-2016-026.

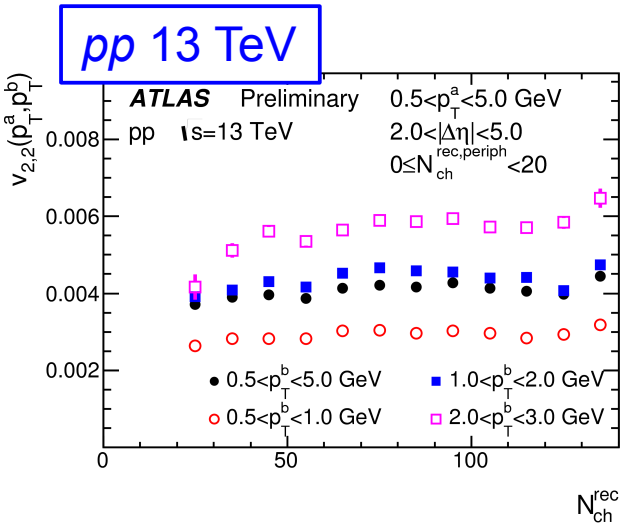
Summary

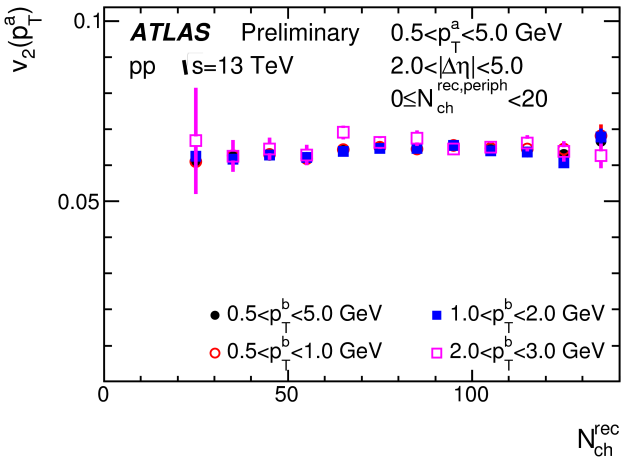
- new template fit method used to obtain flow harmonics gives results independenf of selection of peripheral events used to subtract non flow correlations
- in *pp* collisions:
  - extracted v_2 does not depend on energy of *pp* collisions
  - the dependence of v_2 on transverse momentum of trigger particle is similar for different multiplicities
  - v_2, v_3, v_4 do not change with increasing multiplicity
- in *p*+Pb collisions v_2, v_3, v_4 increase with multiplicity
- the $v_2(p_T)$ shape is similar in *pp* and *p*+Pb collisions
- the ratio v_4 / v_2^2 is independent of multiplicity, and higher for *pp* collisions than for *p*+Pb collisions

ATLAS Collaboration, ATLAS-CONF-2016-026.

v_2 from the template fit

$$v_2(p_{T_1}^a) = \frac{v_{2,2}(p_{T_1}^a, p_{T_2}^b)}{\sqrt{v_{2,2}(p_{T_2}^b, P_{T_2}^b)}}$$



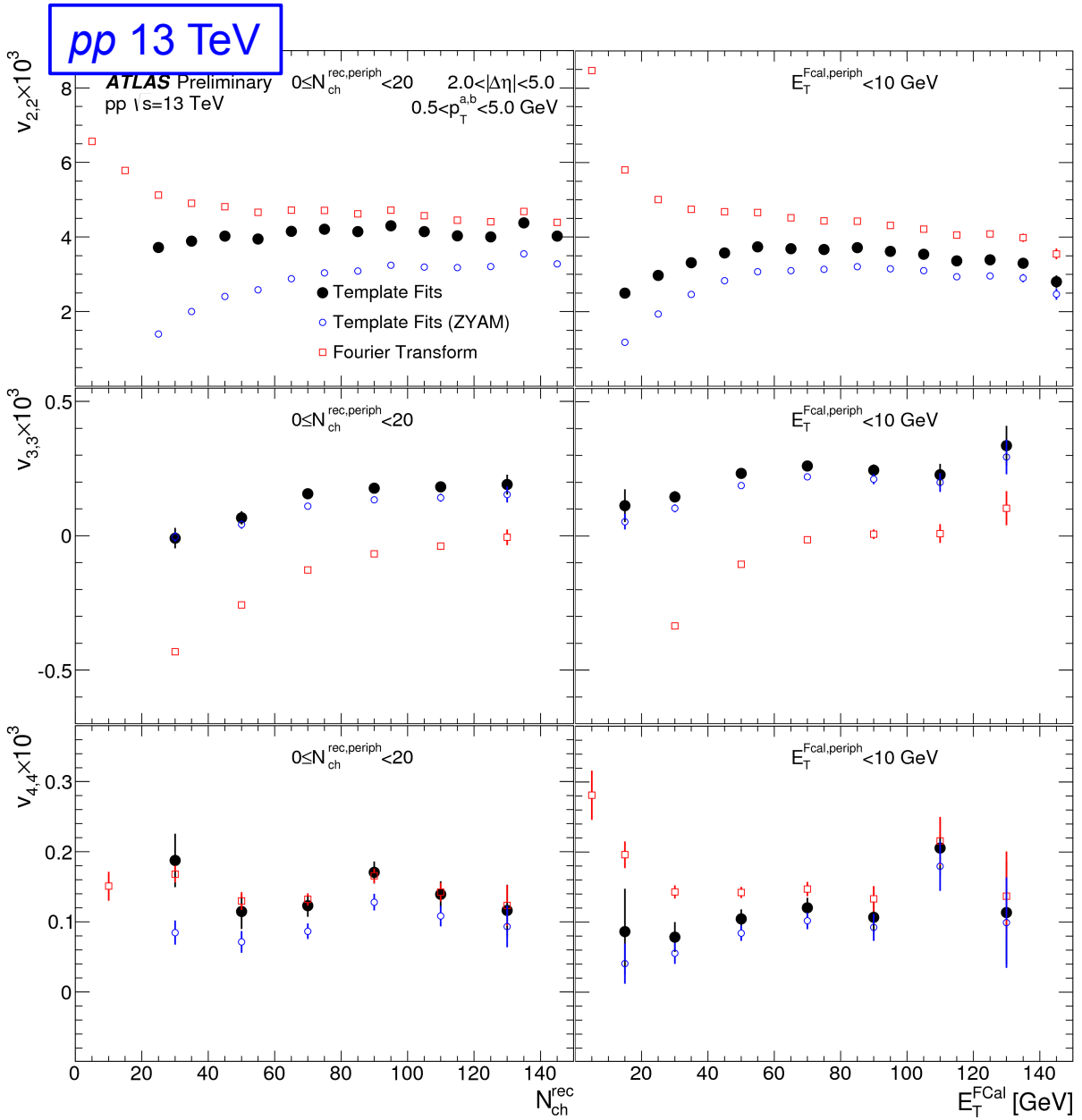


$v_{2,2}$ depends on p_T^b but exhibits factorization, as v_2 does not depend on p_T^b interval used

v_2 does not depend on event multiplicity or the energy of the *pp* collision

ATLAS Collaboration, Phys. Rev. Lett. 116 (2016) 172301.

Results of template fit for higher harmonics - *pp* at 13 TeV



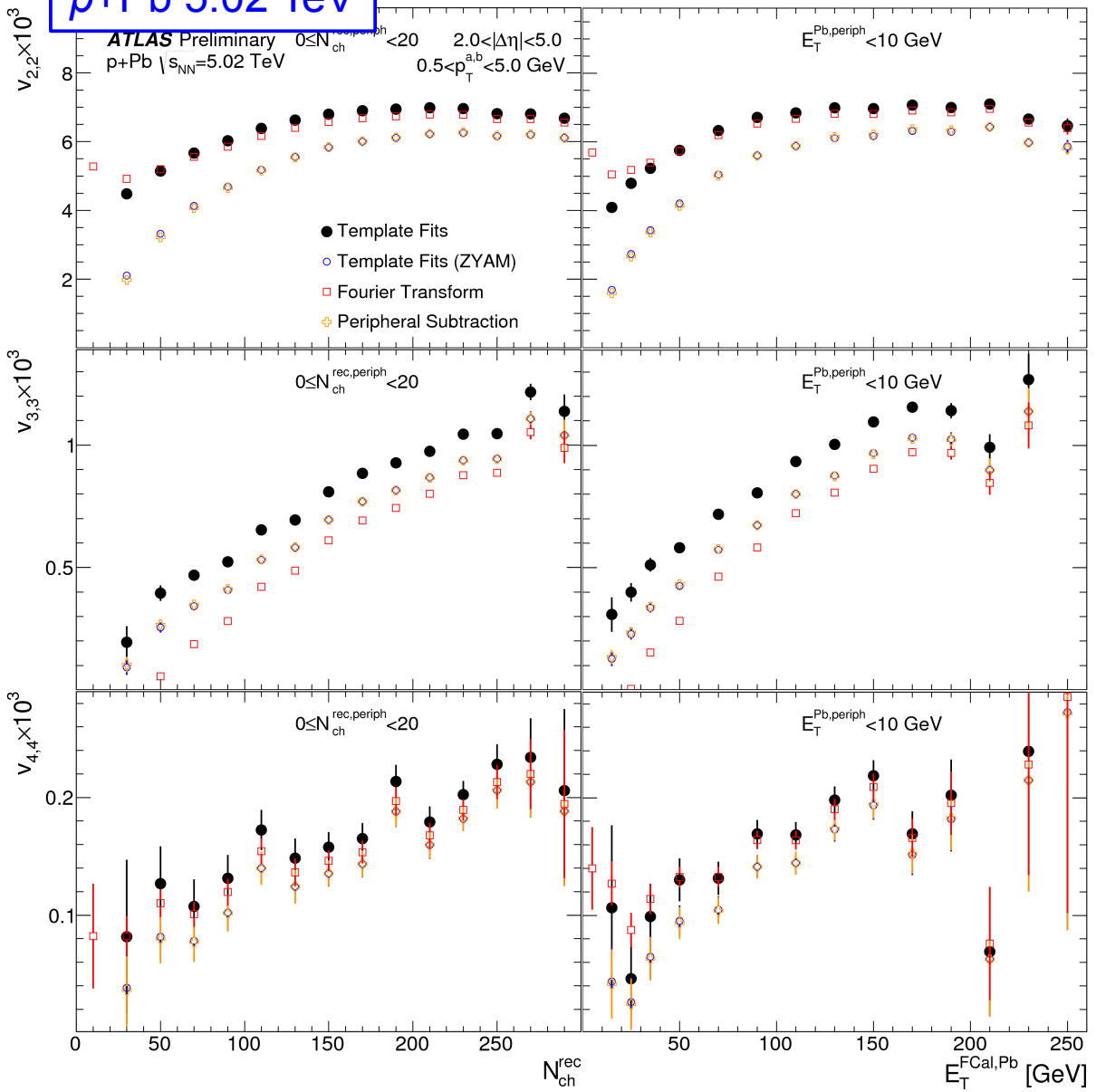
ATLAS Collaboration, ATLAS-CONF-2016-026.

$v_{n,n}$ as a function of:

- multiplicity
- energy in the forward calorimeters

Results of template fit for higher harmonics - *p*+Pb at 5.02 TeV

p+Pb 5.02 TeV



ATLAS Collaboration, ATLAS-CONF-2016-026.

$v_{n,n}$ as a function of:

- multiplicity
- energy in the forward calorimeters