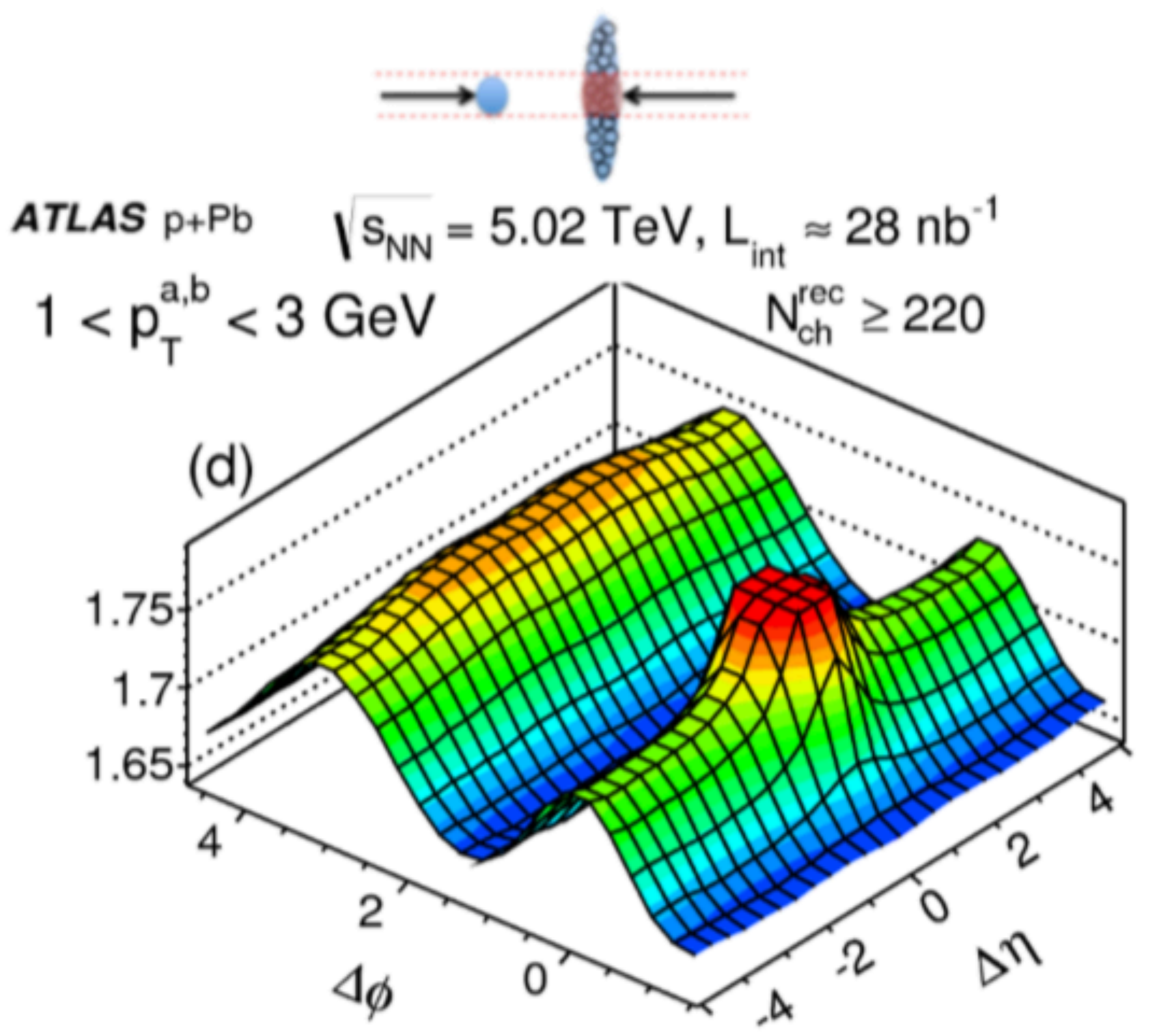
Measurement of the symmetric and asymmetric cumulants with subevent methods in small collision systems with the ATLAS detector

D. Derendarz on behalf of ATLAS collaboration

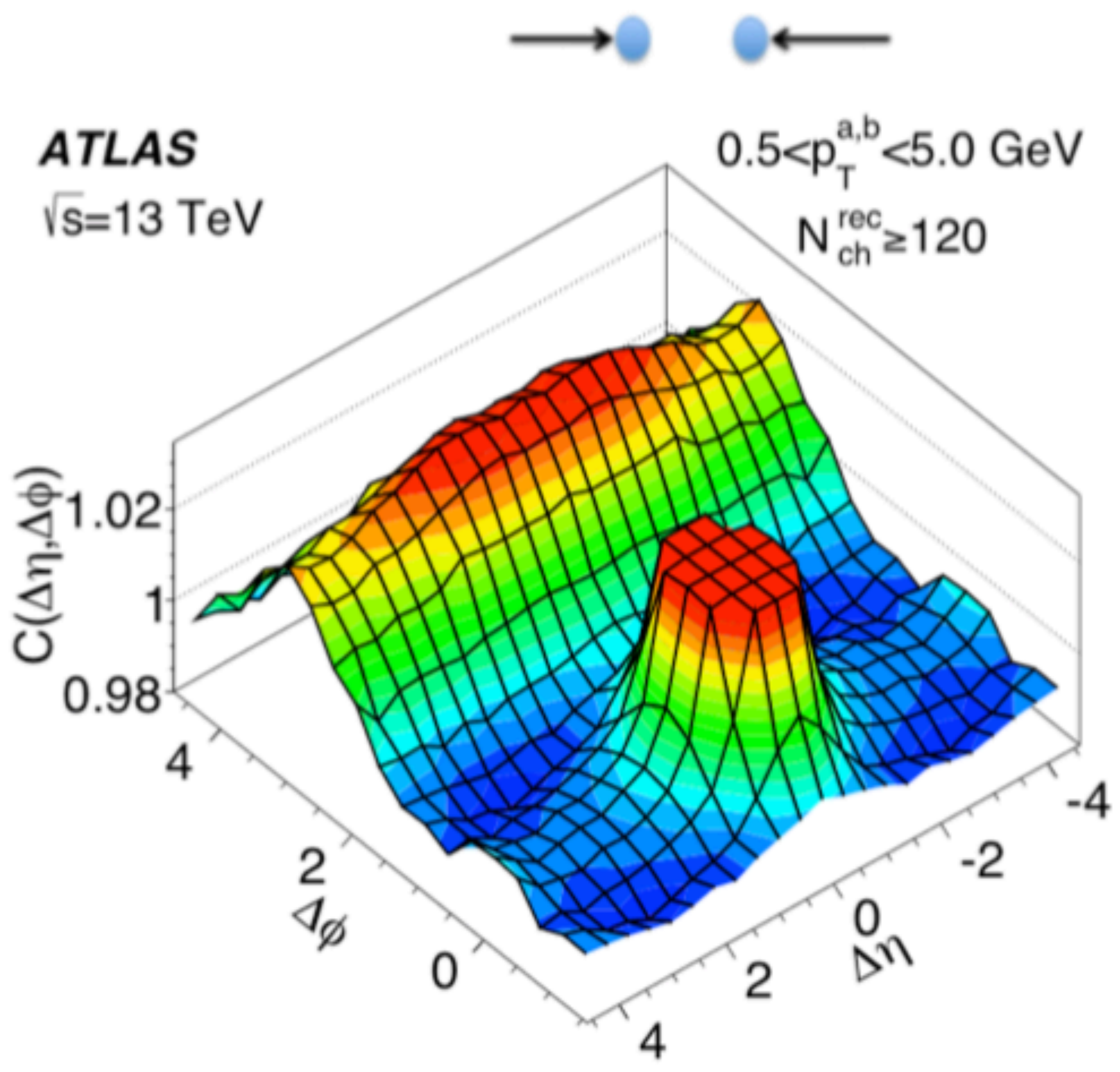
Quark Matter 2018
15/05/2018

Collectivity in small systems



ATLAS, Phys. Rev. C 90, 044906

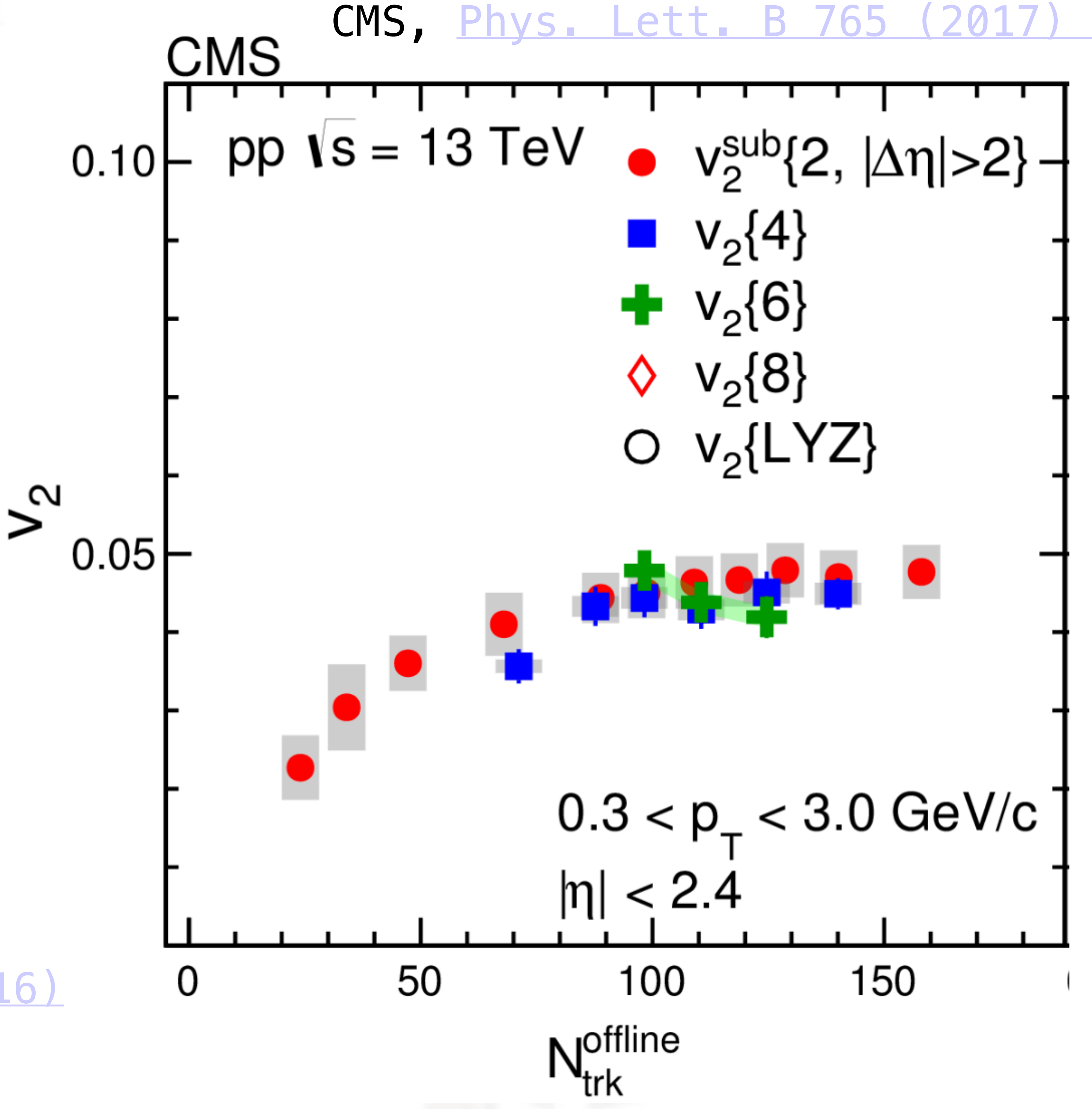
p+Pb ridge



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

p+p ridge

CMS, Phys. Lett. B 765 (2017) 193



p+p v_n

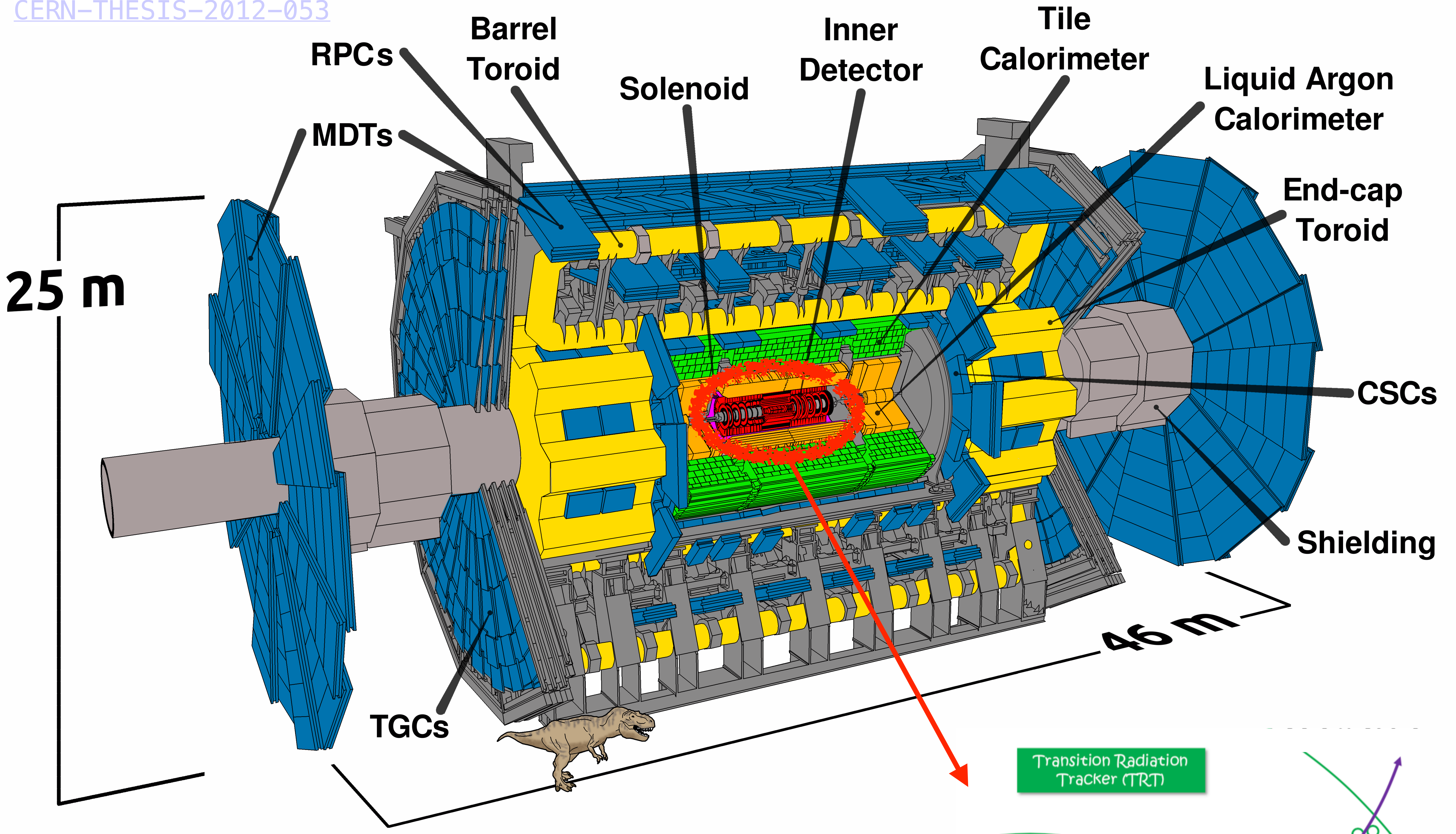
Strongly interacting QGP in small systems?

More detailed probes of collectivity - correlations between flow harmonics?

Clear difference of relative contribution of jets between collision systems - how this affect measurement?

ATLAS detector and dataset summary

CERN-THESIS-2012-053

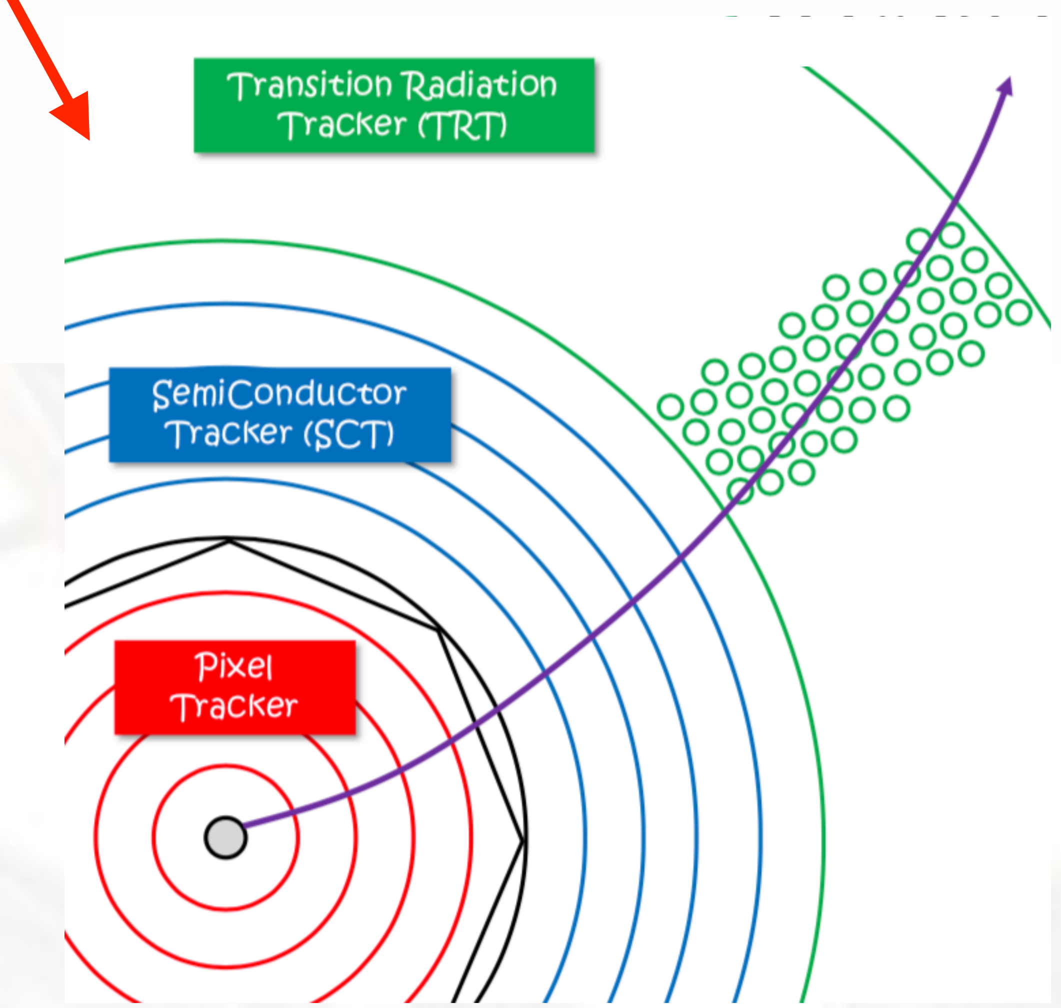


Data sets used:

- **p+p @ 13 TeV**
  - recorded in 2015 & 2016 during low pile-up periods
  - L_{int} = 0.9 pb^{-1}
- **p+Pb @ 5.02 TeV**
  - recorded in 2013 & 2016
  - L_{int} = 28 nb^{-1}
- **Pb+Pb @ 2.76 TeV - peripheral**
  - recorded in 2010
  - the same tracks reconstruction as in p+p, p+Pb
  - L_{int} = 7 μb^{-1}

Inner detector, tracks reconstruction with:

- multi layer silicon pixel & strip (SCT)
- supported by gas straw detector at high lever arm (TRT)
- covering 5 units of pseudorapidity



Cumulants, symmetric cumulants and asymmetric cumulants

- To directly explore collectivity multi-particle correlations are used to measure flow harmonics

$$\langle\langle\{2k\}_n\rangle\rangle = \langle\langle e^{in(\phi_1+\ldots+\phi_k-\phi_{k+1}-\ldots-\phi 2k)}\rangle\rangle = \langle v_n^{2k}\rangle$$

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- Recently proposed **symmetric cumulants** (Phys. Rev. C 89, 064904) probe correlations between magnitudes of harmonics of different order v_n and v_m (n!=m) using 4 particle correlations

$$\langle\langle\{4\}_{n,m}\rangle\rangle = \langle\langle e^{in(\phi_1-\phi_2)+im(\phi_3-\phi_4)}\rangle\rangle = \langle v_n^2 v_m^2\rangle$$

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- 3 particle **"asymmetric" cumulant** (ATLAS, Phys. Rev. C 90, 024905) is also sensitive to correlation between v_n harmonics (magnitude v_n and flow phase Φ_n)

$$ac_2\{3\} = \langle\langle\{3\}_n\rangle\rangle = \langle\langle e^{i(n\phi_1+n\phi_2-2n\phi_3)}\rangle\rangle$$
$$= \langle v_2^2 v_4 \cos 4(\Phi_2-\Phi_4)\rangle$$

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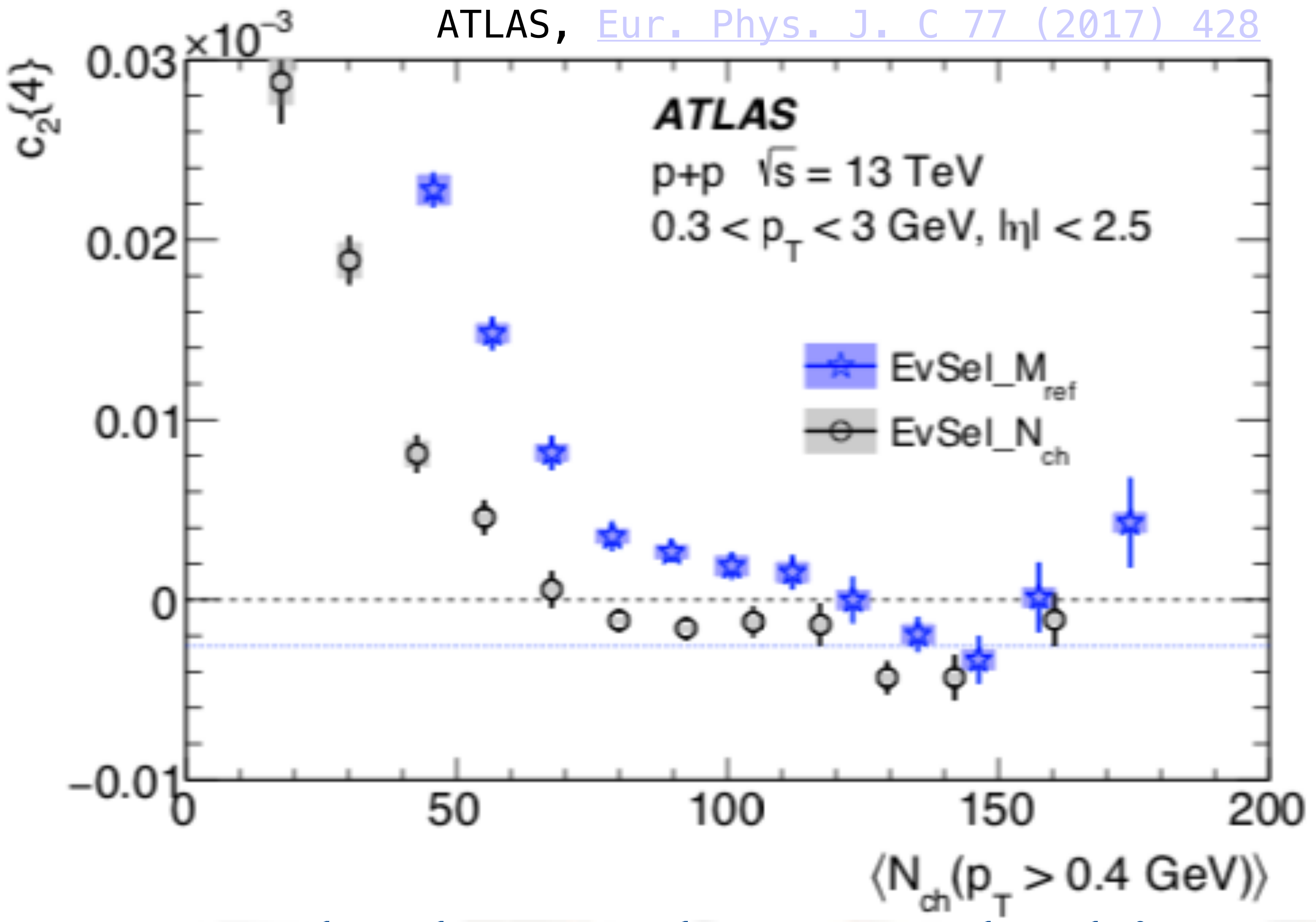
Cumulant measurements in small systems

ATLAS, Eur. Phys. J. C 77 (2017) 428

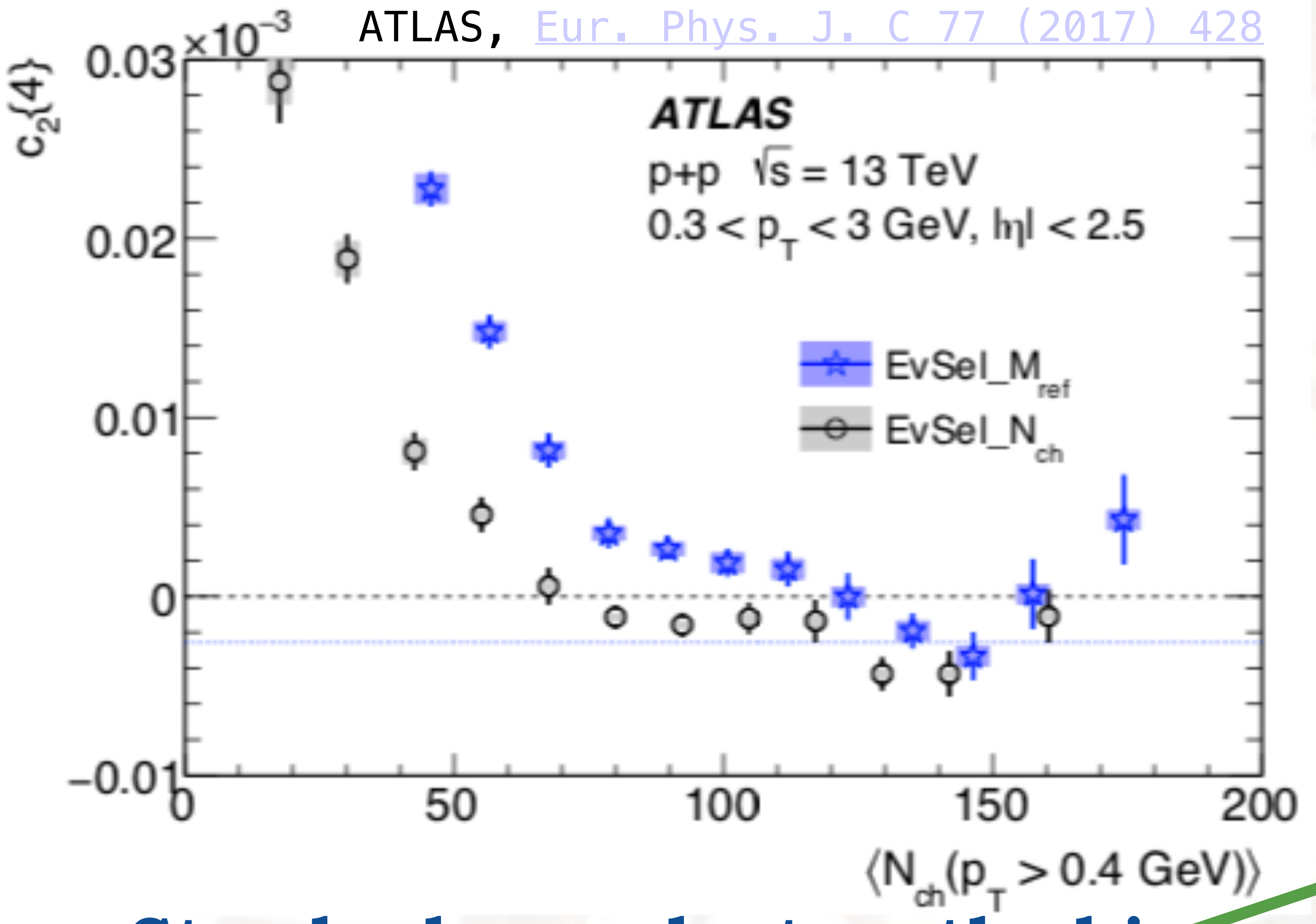


- **Standard cumulant method is sensitive to event class definition**

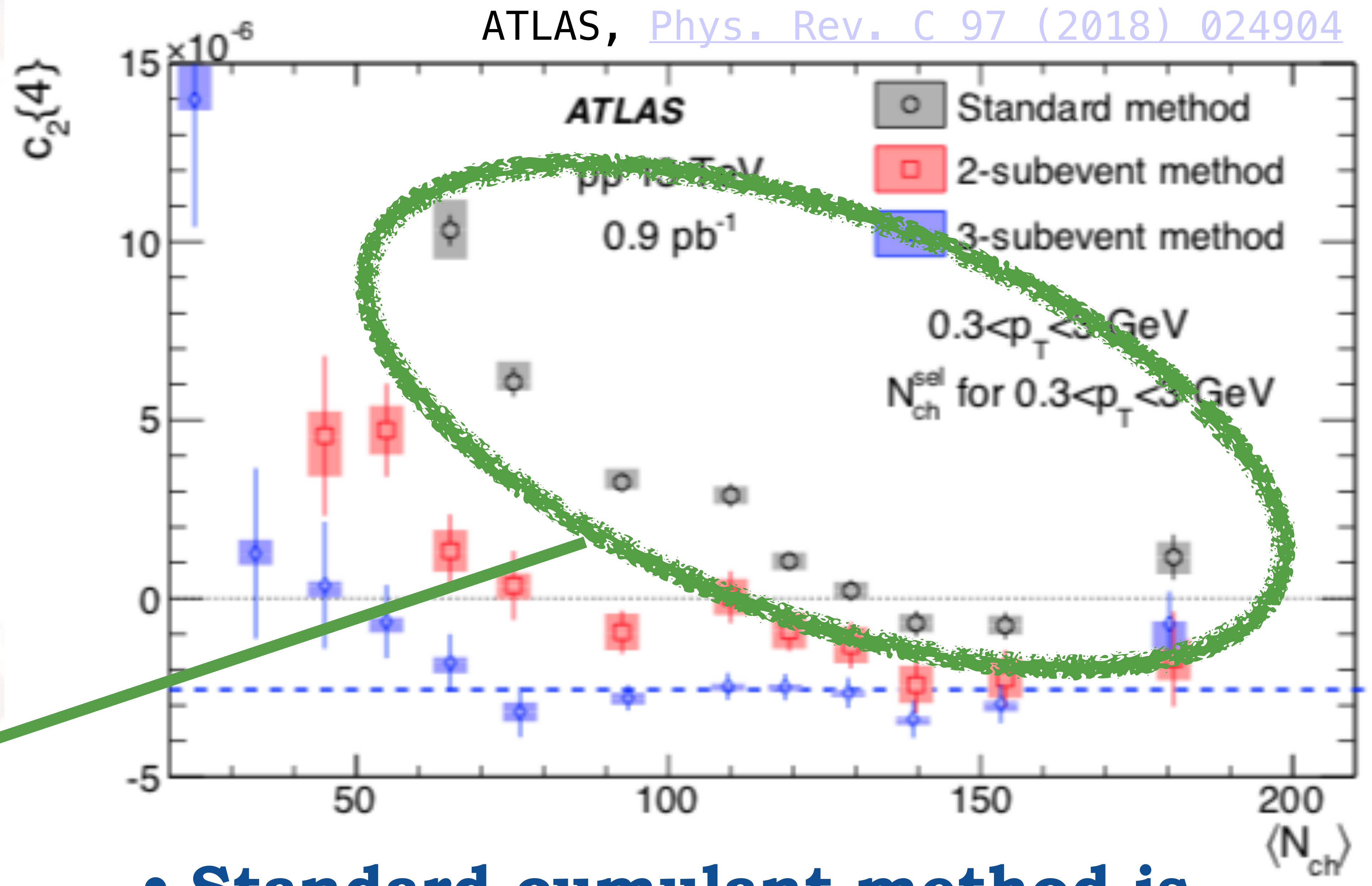
M. Zhou, QM17 talk

Cumulant measurements in small systems

ATLAS, Eur. Phys. J. C 77 (2017) 428

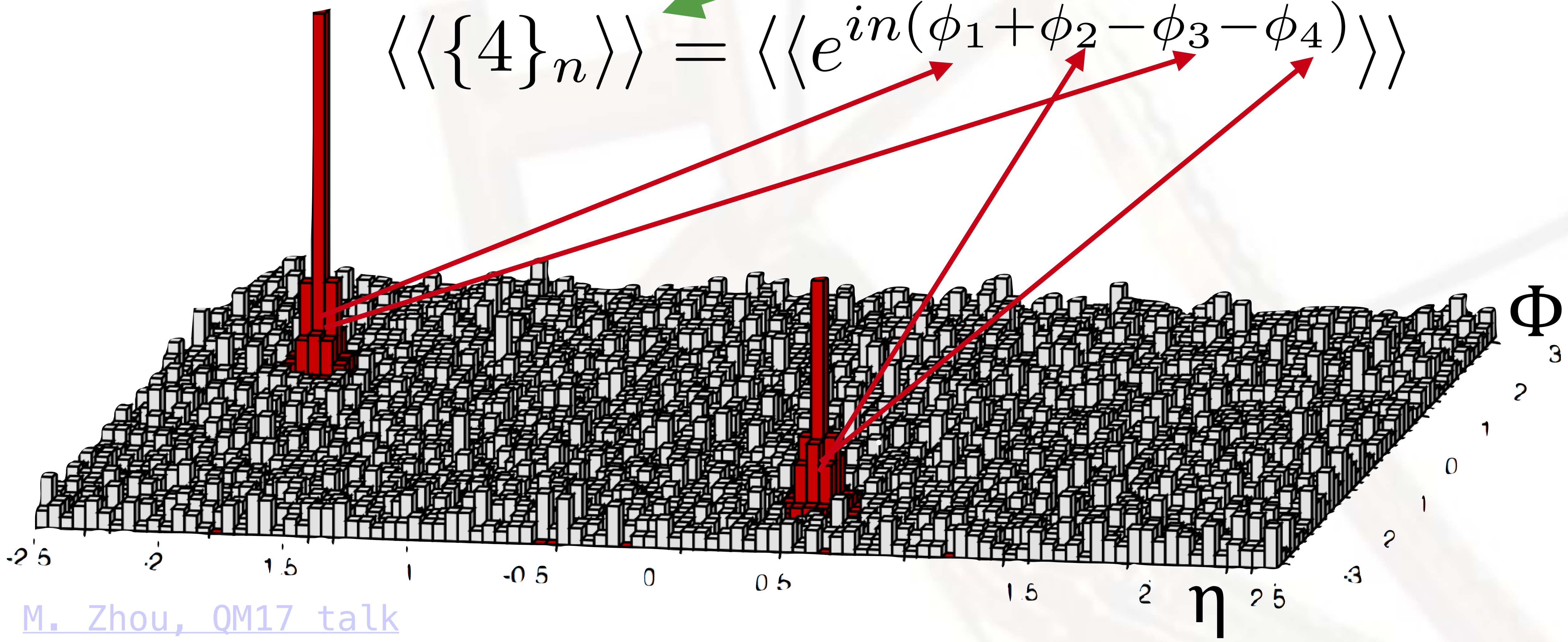


ATLAS, Phys. Rev. C 97 (2018) 024904



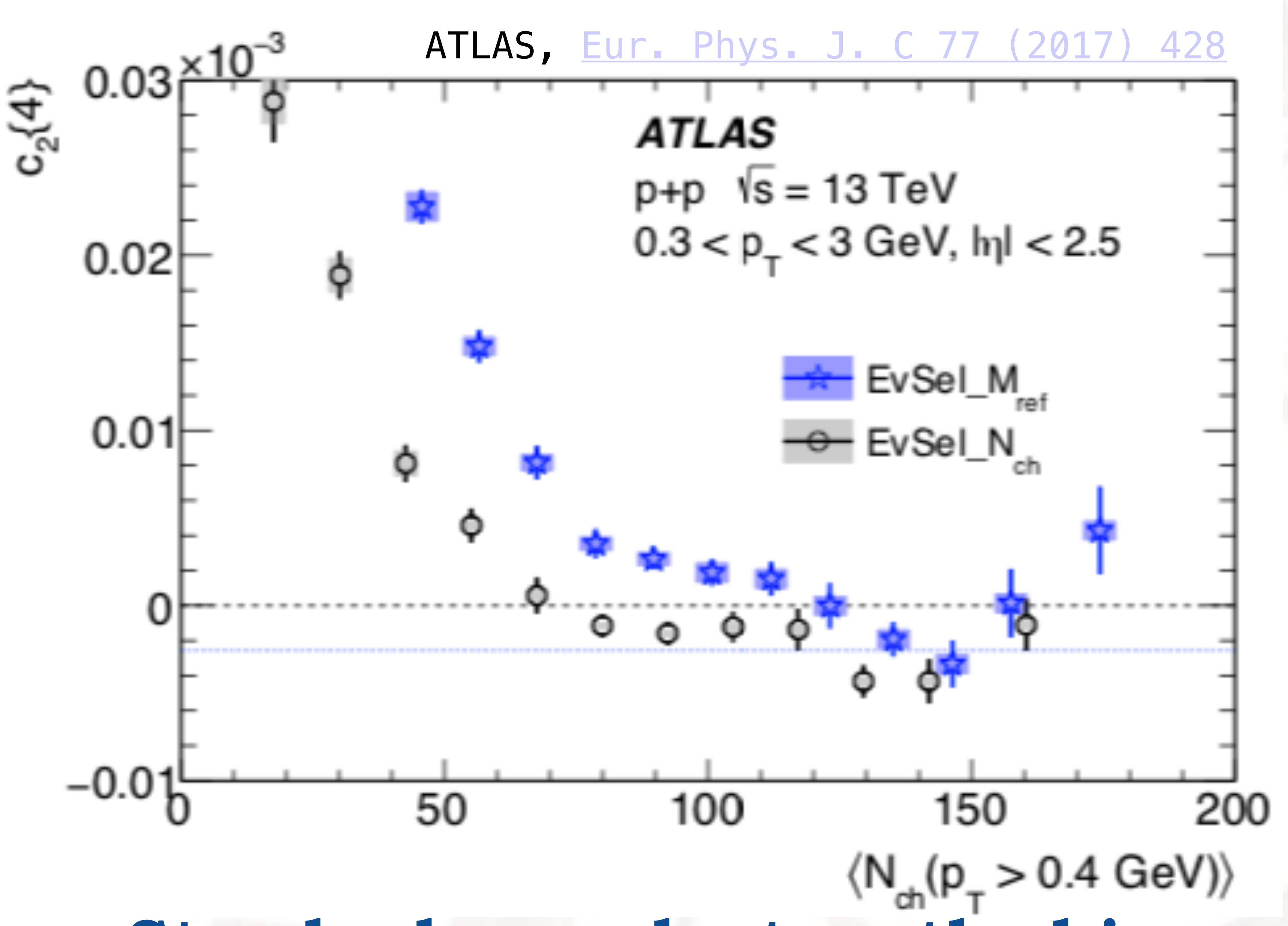
- **Standard cumulant method is sensitive to event class definition**
- **Standard cumulant method is sensitive to non-flow correlations**

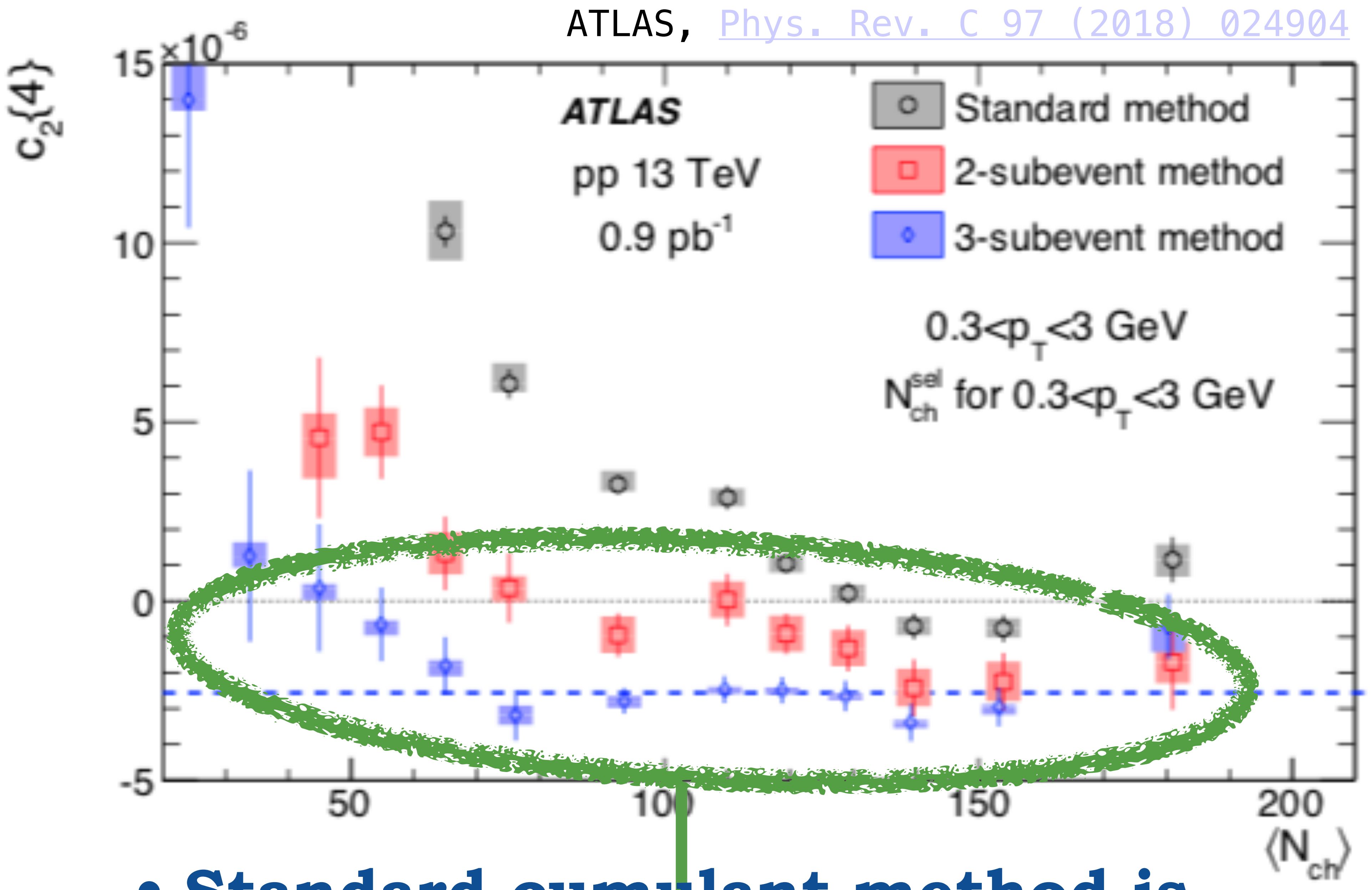
$$\langle\langle\{4\}_n\rangle\rangle = \langle\langle e^{in(\phi_1+\phi_2-\phi_3-\phi_4)}\rangle\rangle$$



M. Zhou, QM17 talk

Cumulant measurements in small systems





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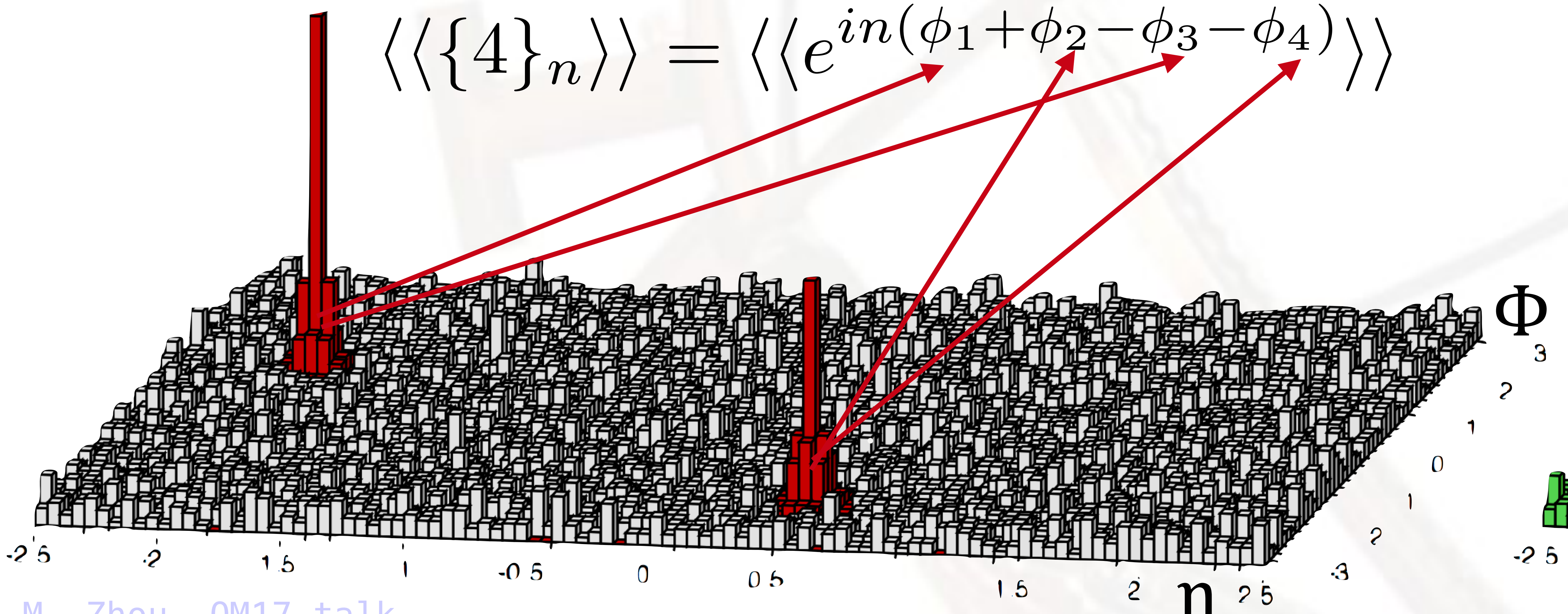
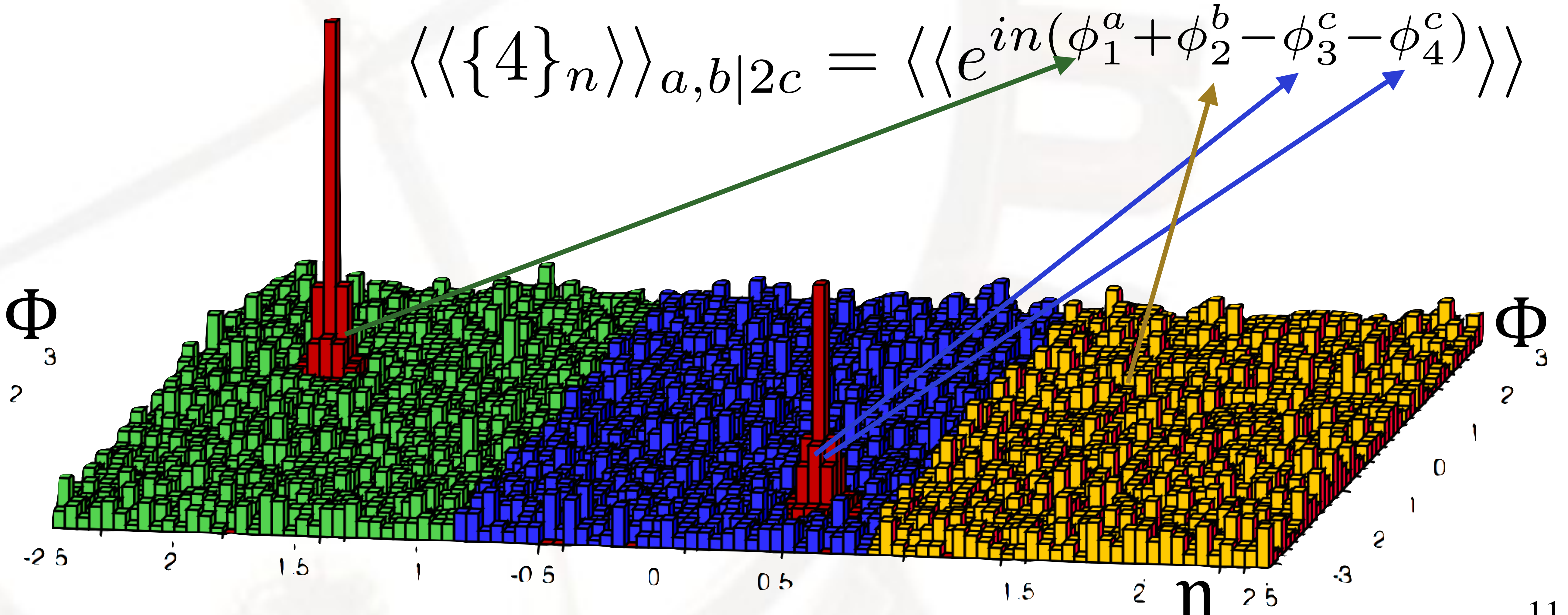
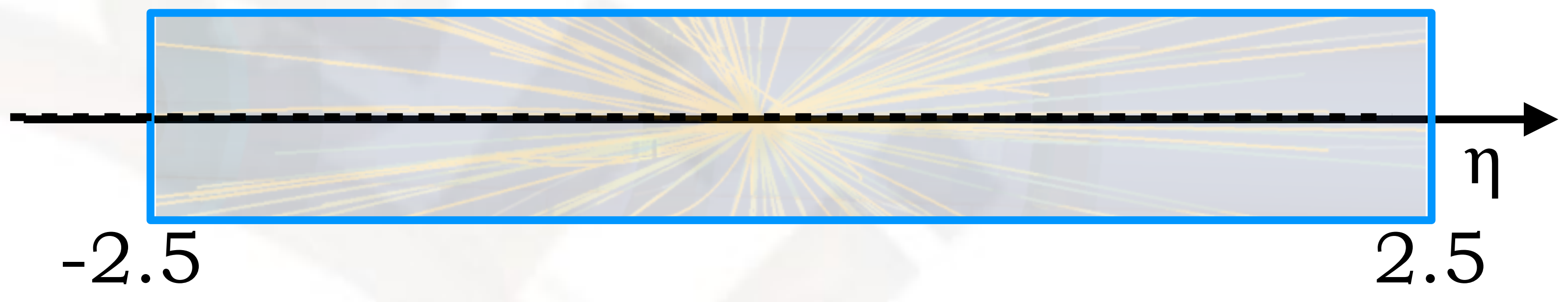




M. Zhou, QM17 talk

Application of subevent method in reducing non-flow

- Standard method



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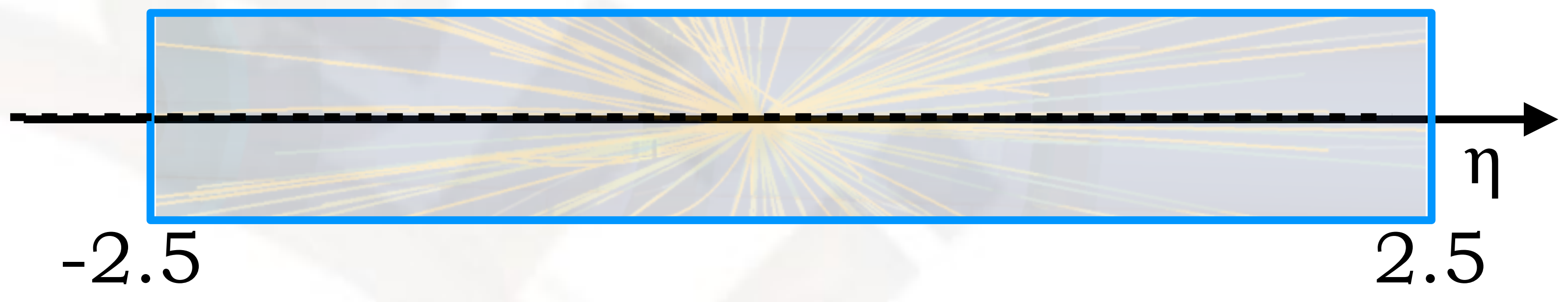

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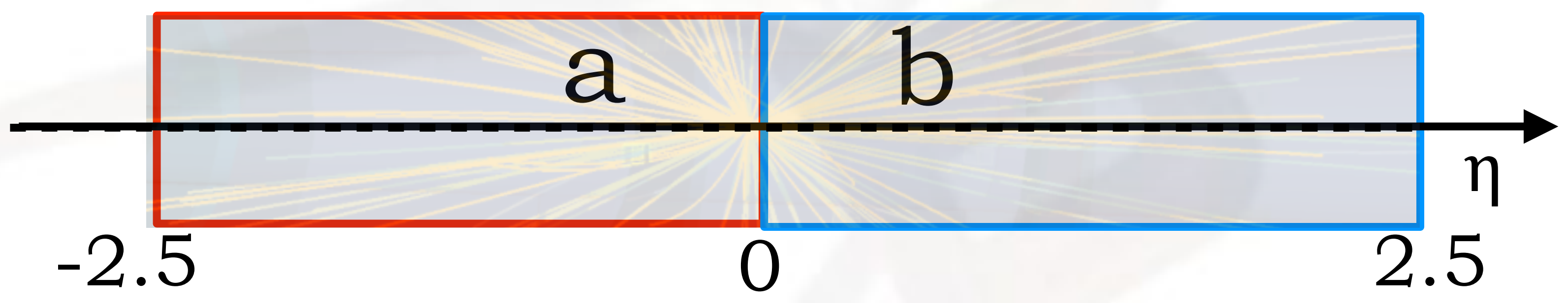
- Two-subevent method



$$ac_n^{2a|b}\{3\} = \langle\langle\{3\}_n\rangle\rangle_{2a|b}$$

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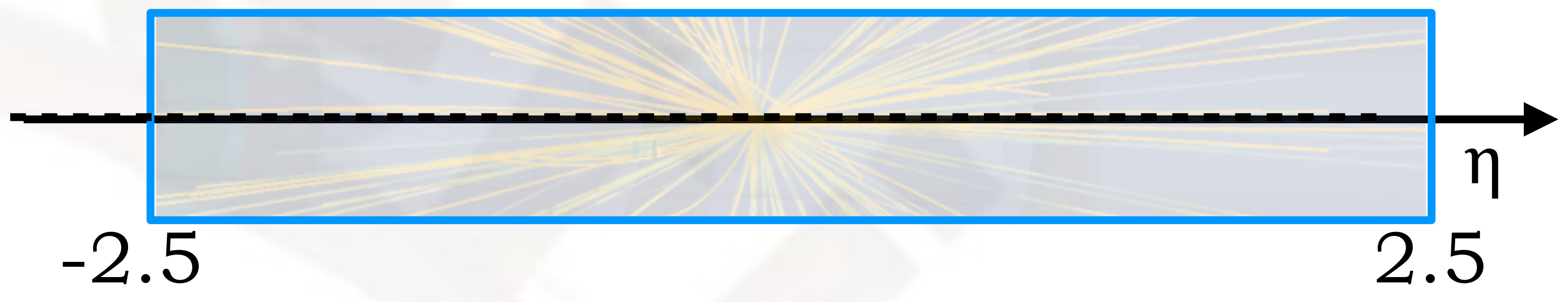

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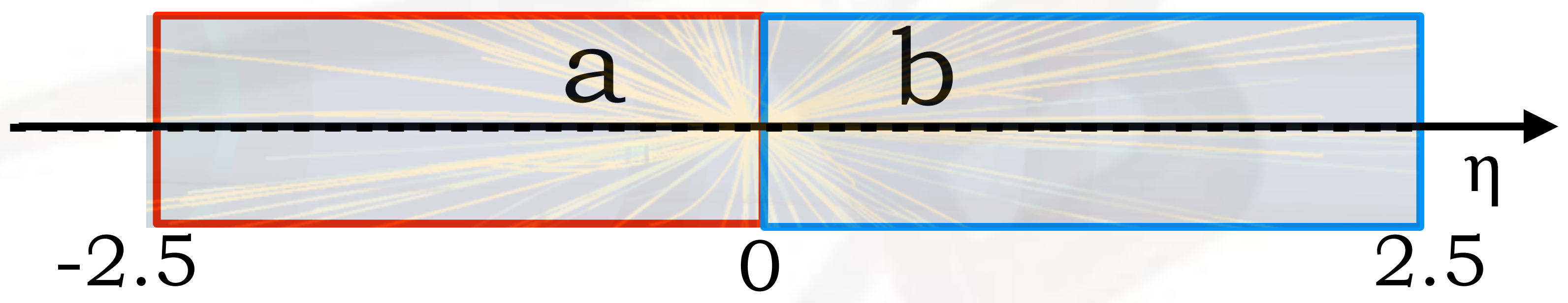

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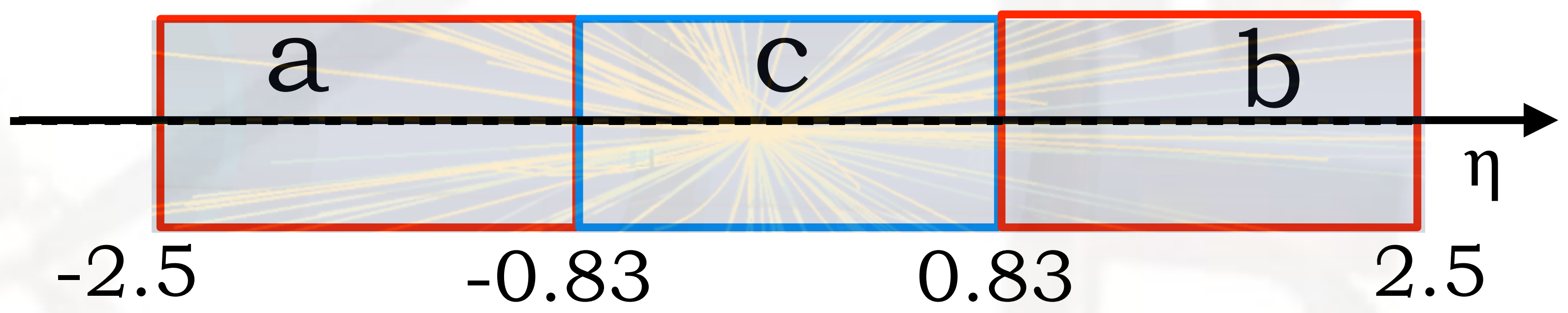
- Three-subevent method



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Application of subevent method in reducing non-flow

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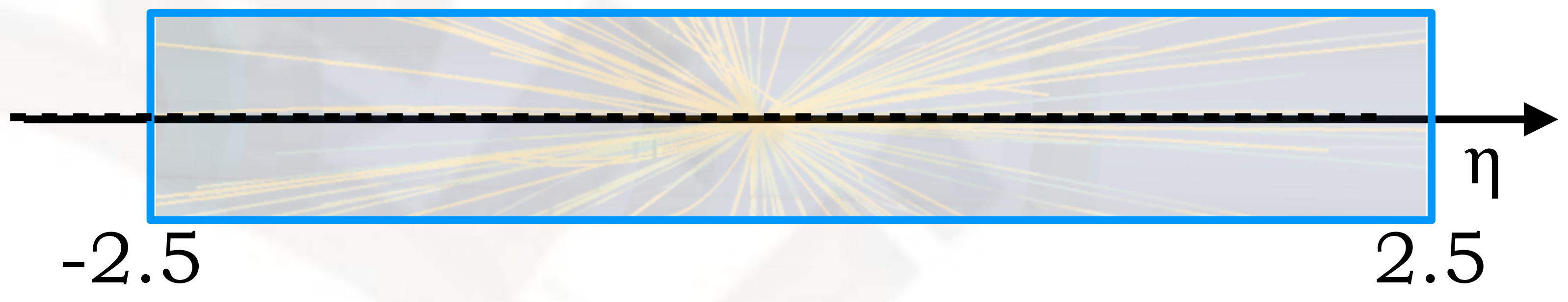

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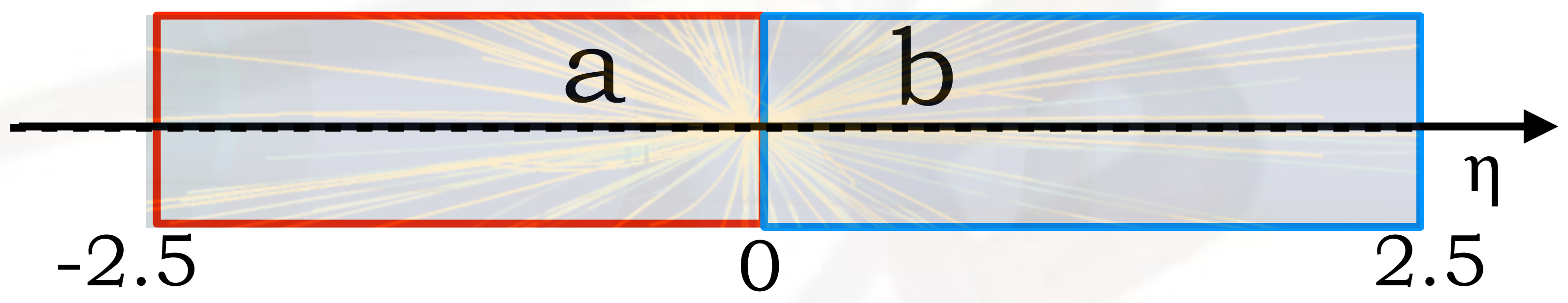

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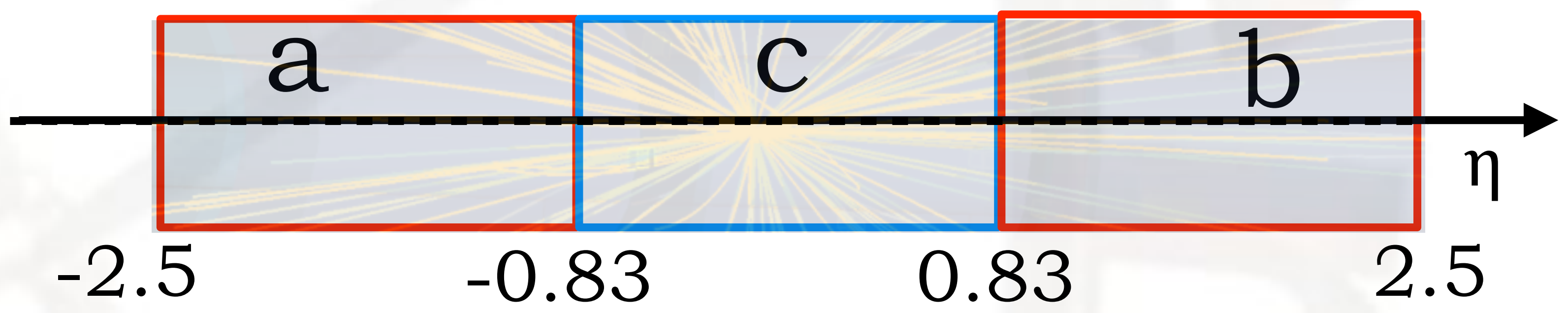

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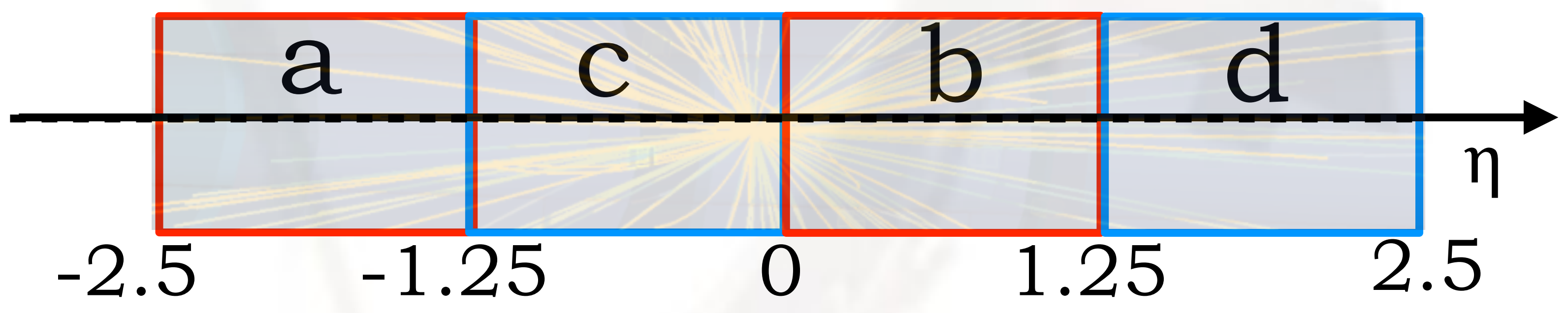
- Four-subevent method



$$sc_{n,m}^{a,b|c,d}\{4\} = \langle\langle\{4\}_{n,m}\rangle\rangle_{a,b|c,d} - \langle\langle\{2\}_n\rangle\rangle_{a|c}\langle\langle\{2\}_m\rangle\rangle_{b|d}$$

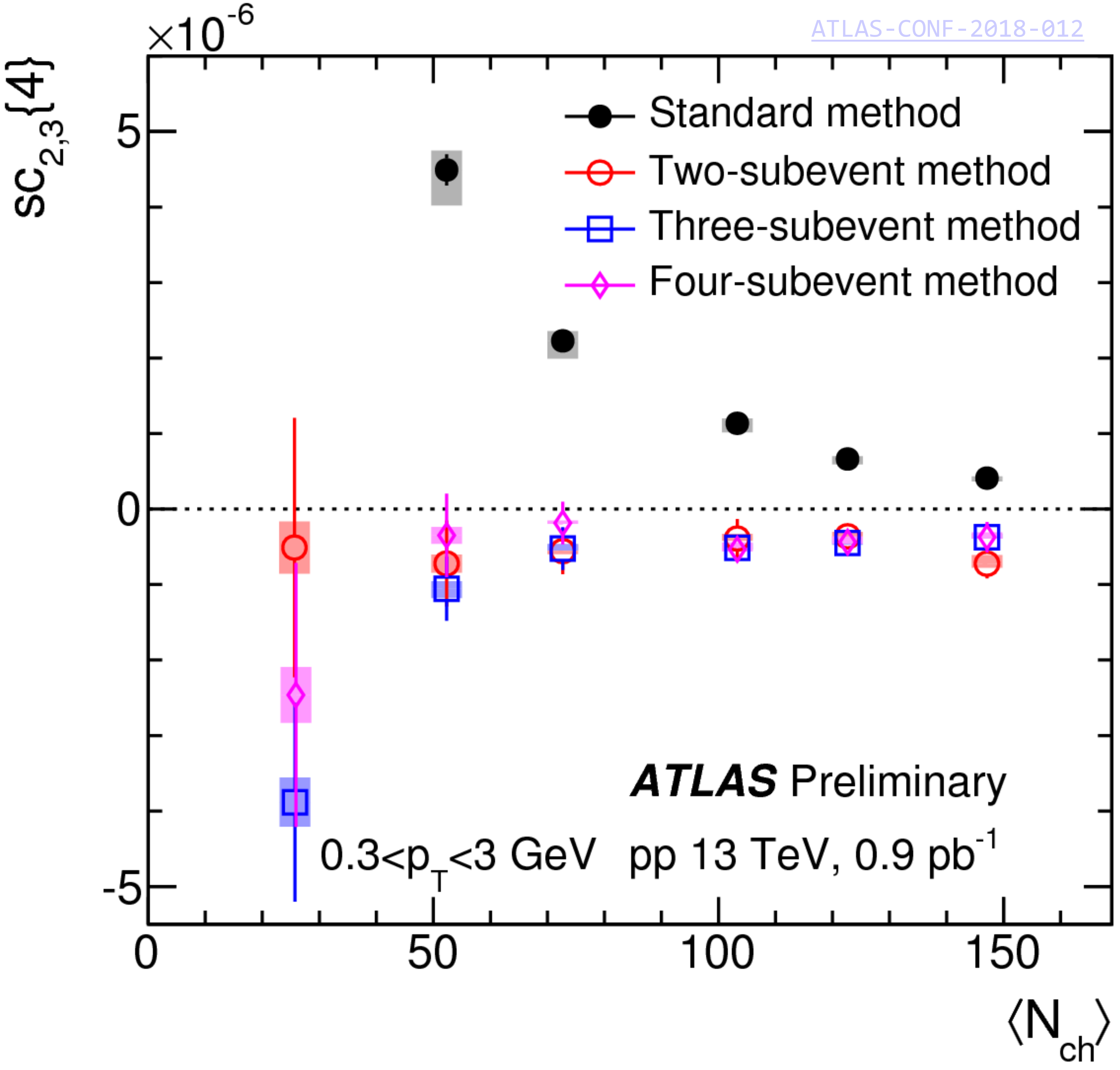
Results for v_2 v_3 correlations ($sc_{2,3}\{4\}$)

Big **difference between standard and subevent** methods for the entire <N_{ch}> range

- **Standard method is dominated by non-flow in p+p**
- Anti-correlation between v_2 and v_3 after removing non-flow
- Consistent results from three- and four-subevents

The same correlation pattern for the $0.5 < p_T < 5$ GeV

$$sc_{2,3}\{4\} = \langle v_2^2 v_3^2 \rangle - \langle v_2^2 \rangle \langle v_3^2 \rangle$$



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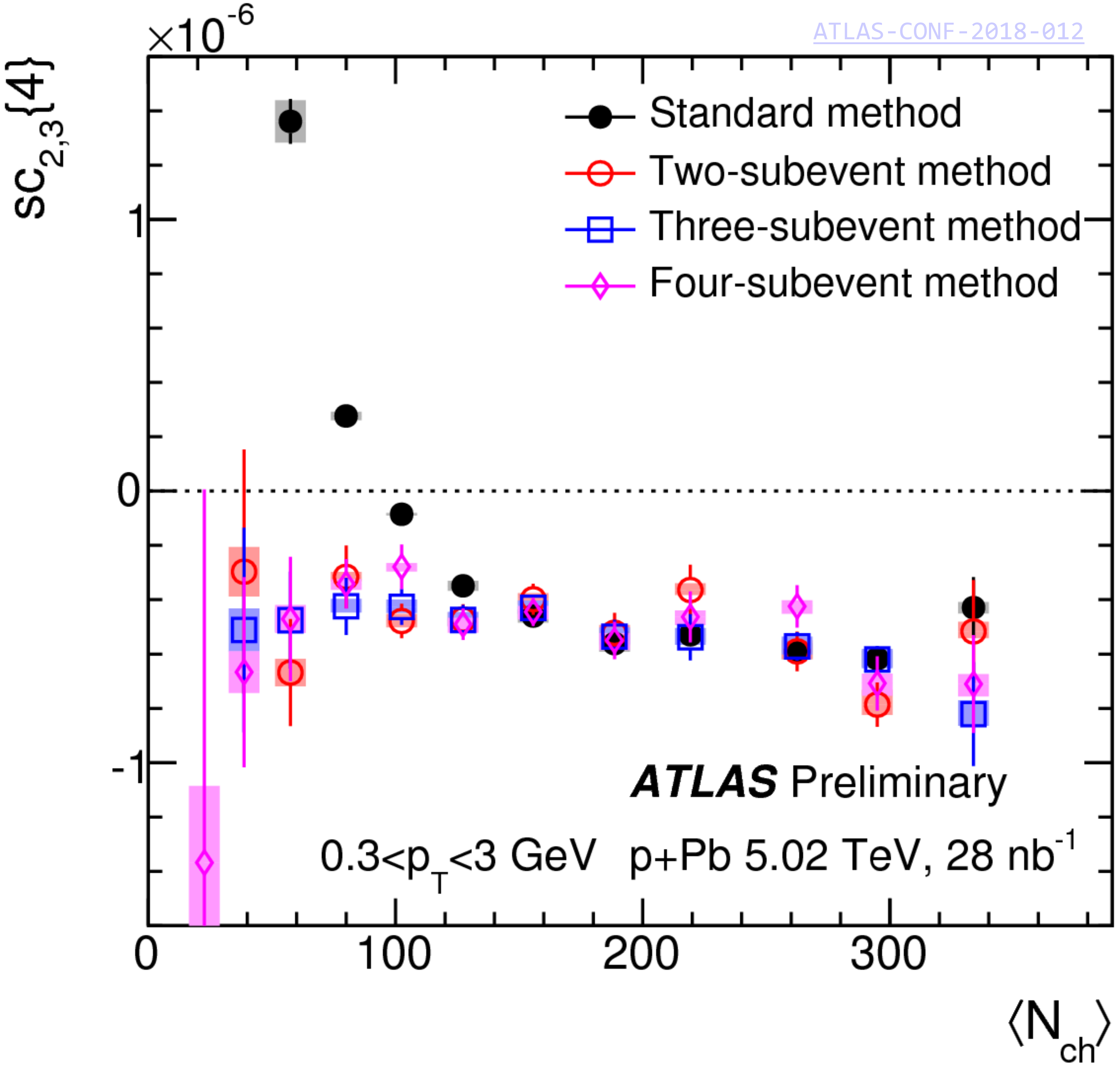
Difference between **standard and subevent** methods for <N_{ch}> below 140

- $sc_{2,3}\{4\}$ change sign around <N_{ch}> = 80 and remains negative
- **Above <N_{ch}> 140** all methods gives consistent results - **genuine long-range correlations**



p+Pb

Results for v_2 v_3 correlations ($sc_{2,3}\{4\}$)

Consistent results between all methods for Pb+Pb collisions

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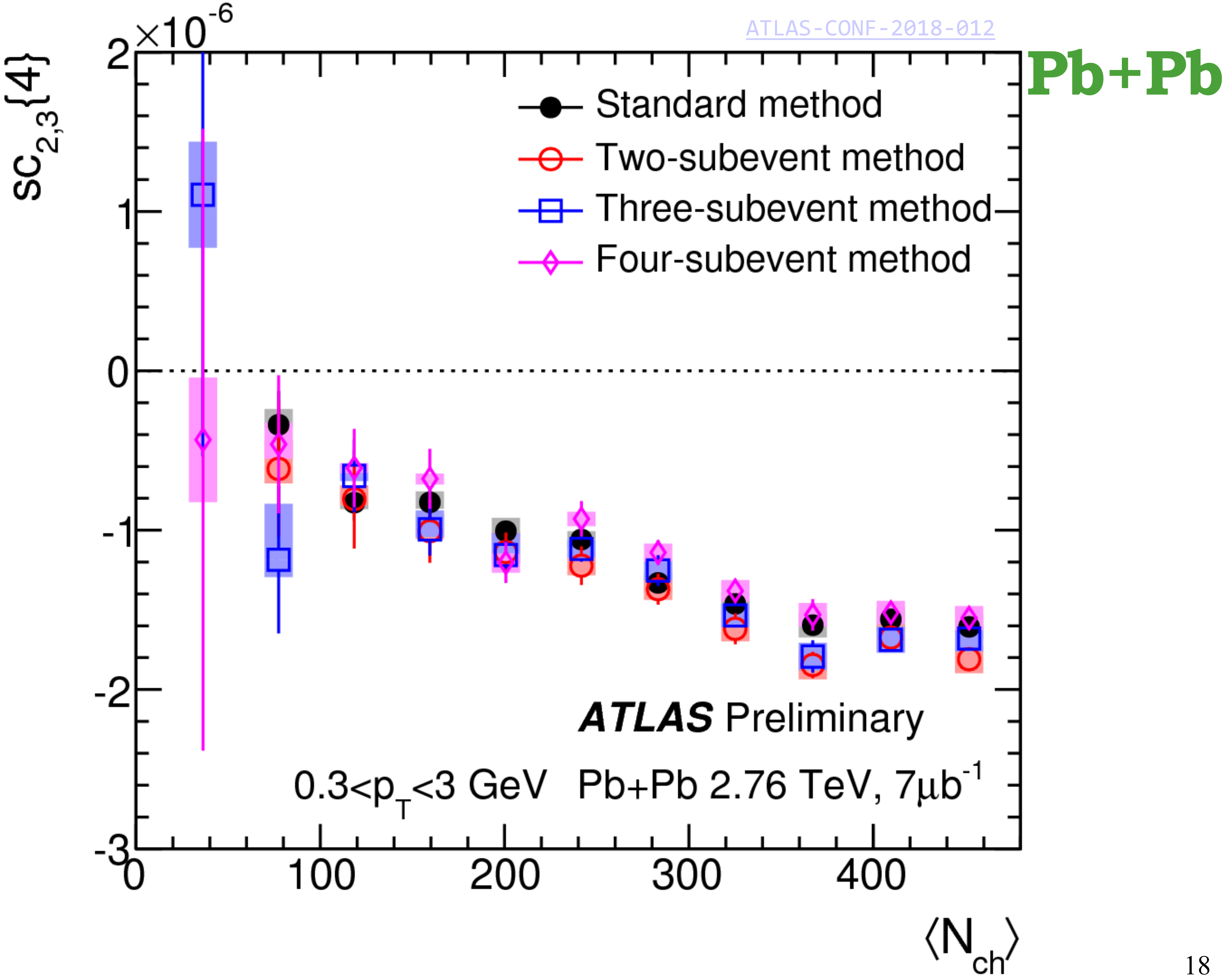

Results for v_2 v_4 correlations ($sc_{2,4}\{4\}$)

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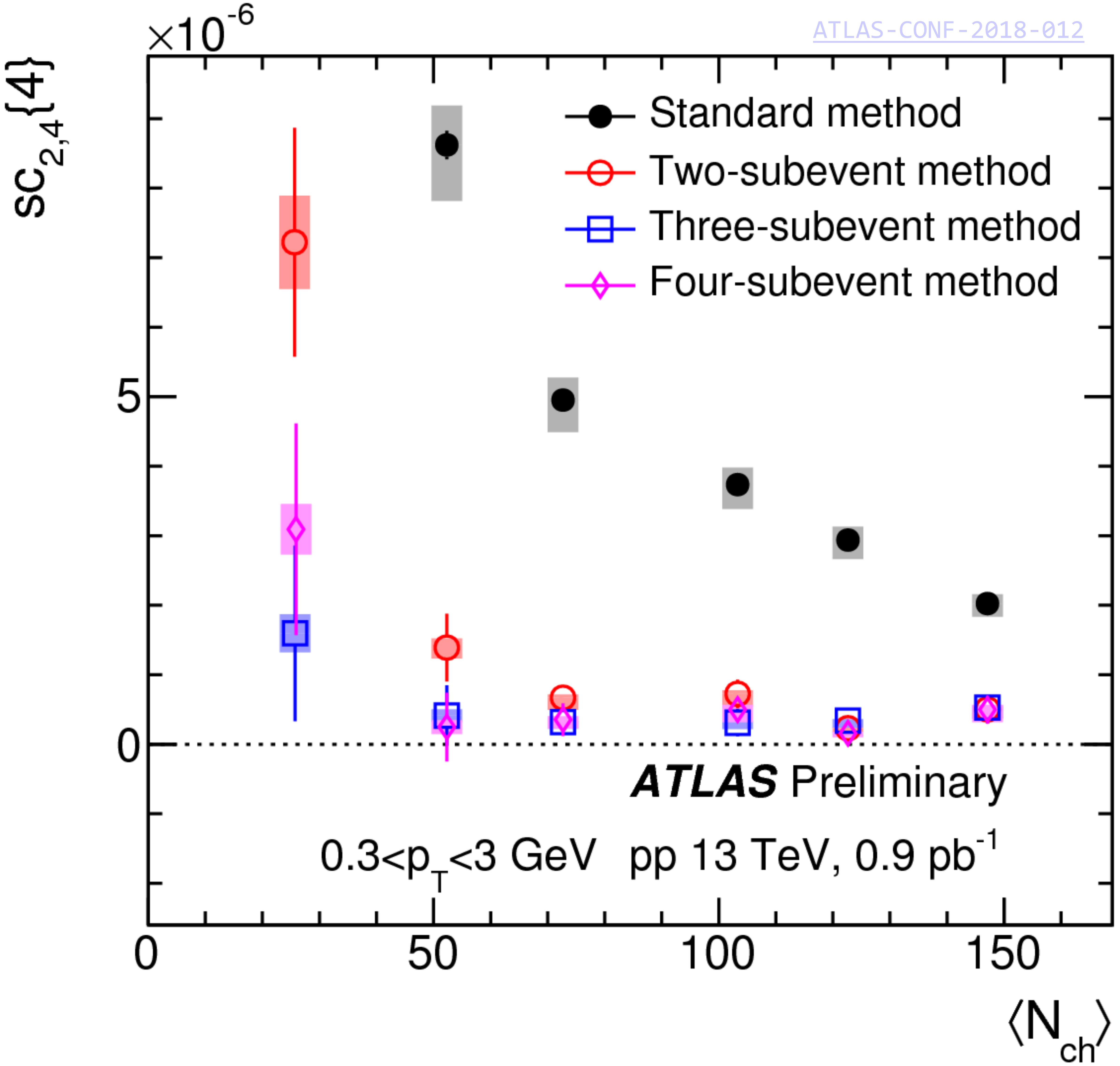
Positive correlation seen by all methods

- manifestation of the nonlinear effects: $v_4 = v_{4L} + \chi_2 v_2^2$
- standard method more affected by di-jet non-flow



p+p

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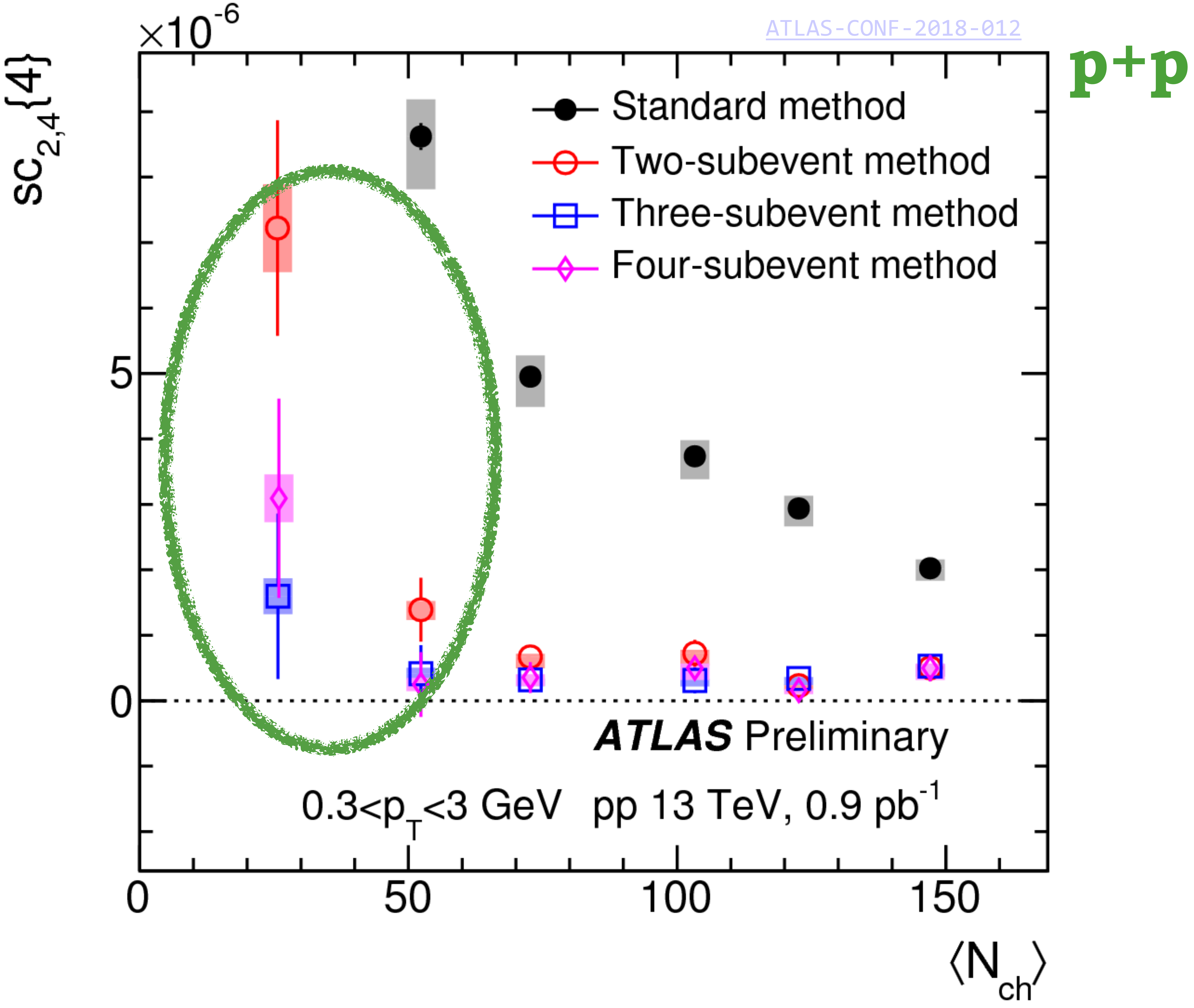
- **small difference** also seen between **two-subevents and three-/four-**subevents at low <N_{ch}>
  - residual non-flow?



Results for v_2 v_4 correlations ($sc_{2,4}\{4\}$)

Positive correlation seen by all methods

- subevents methods are consistent over the full $\langle N_{ch} \rangle$ range

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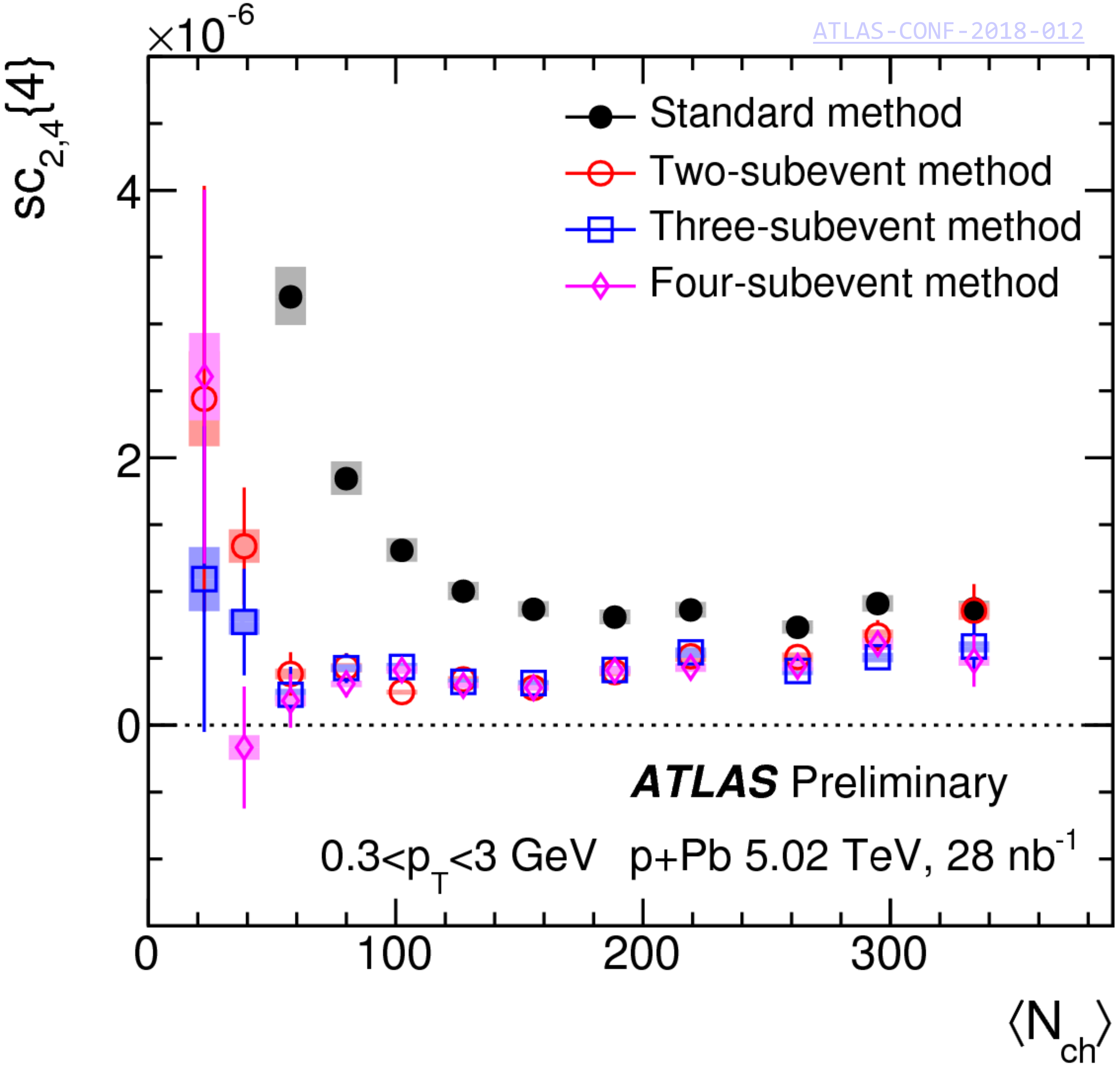

p+Pb

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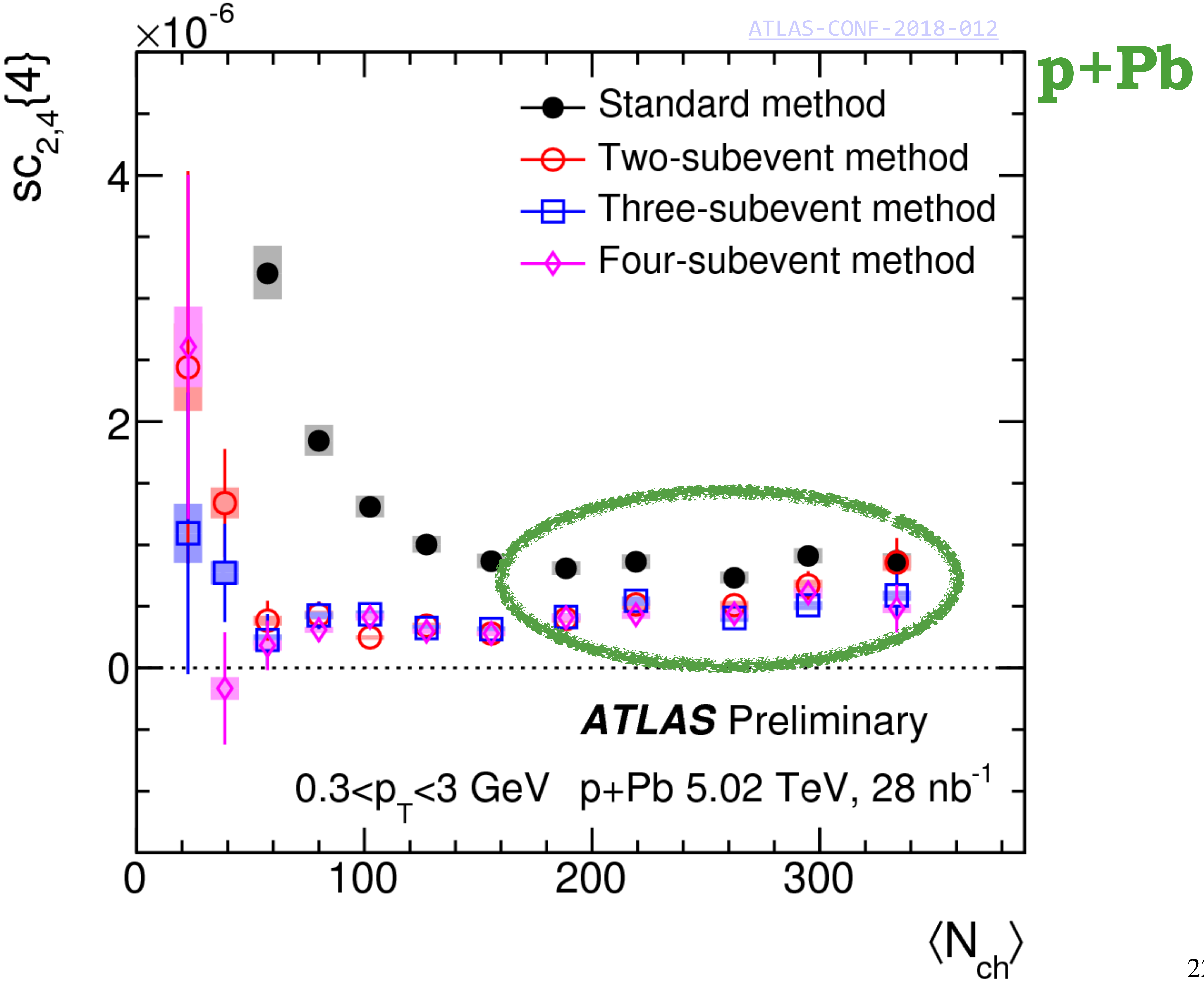
Positive correlation seen by all methods

- subevents methods are consistent over the full <N_{ch}> range
- results from standard method approach subevent results as the <N_{ch}> increase, but not converge
  - posible residual non-flow?



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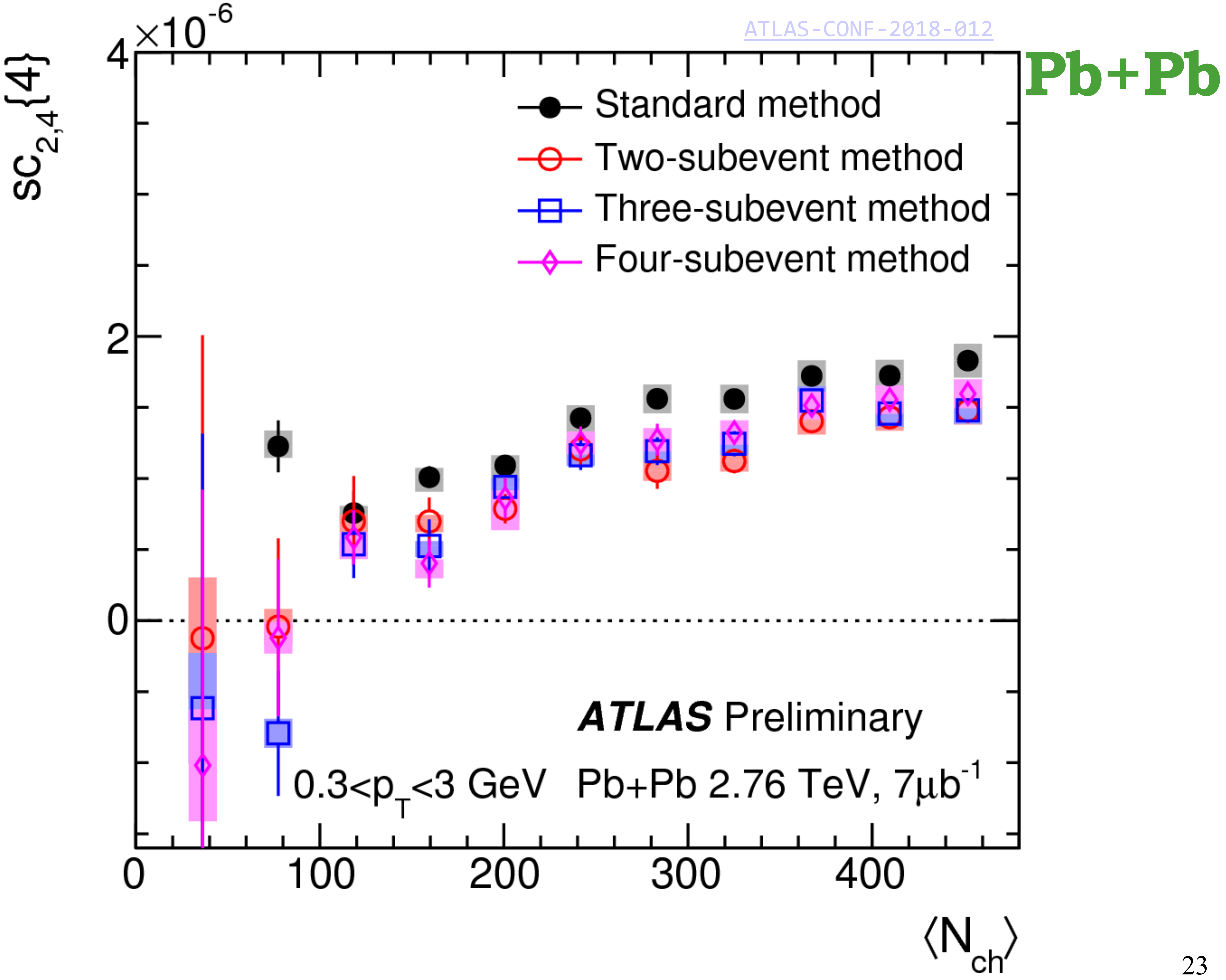

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Positive correlation seen by all methods, with increase of correlations strength as the $\langle N_{ch} \rangle$ increase

- **results from standard method show small systematic difference with respect to subevents**
  - approximately constant with $\langle N_{ch} \rangle$
- possible effect of flow de-correlation?
  - v_4 shows stronger decorrelation effect than the v_3 (Eur. Phys. J. C 76 (2018) 142)

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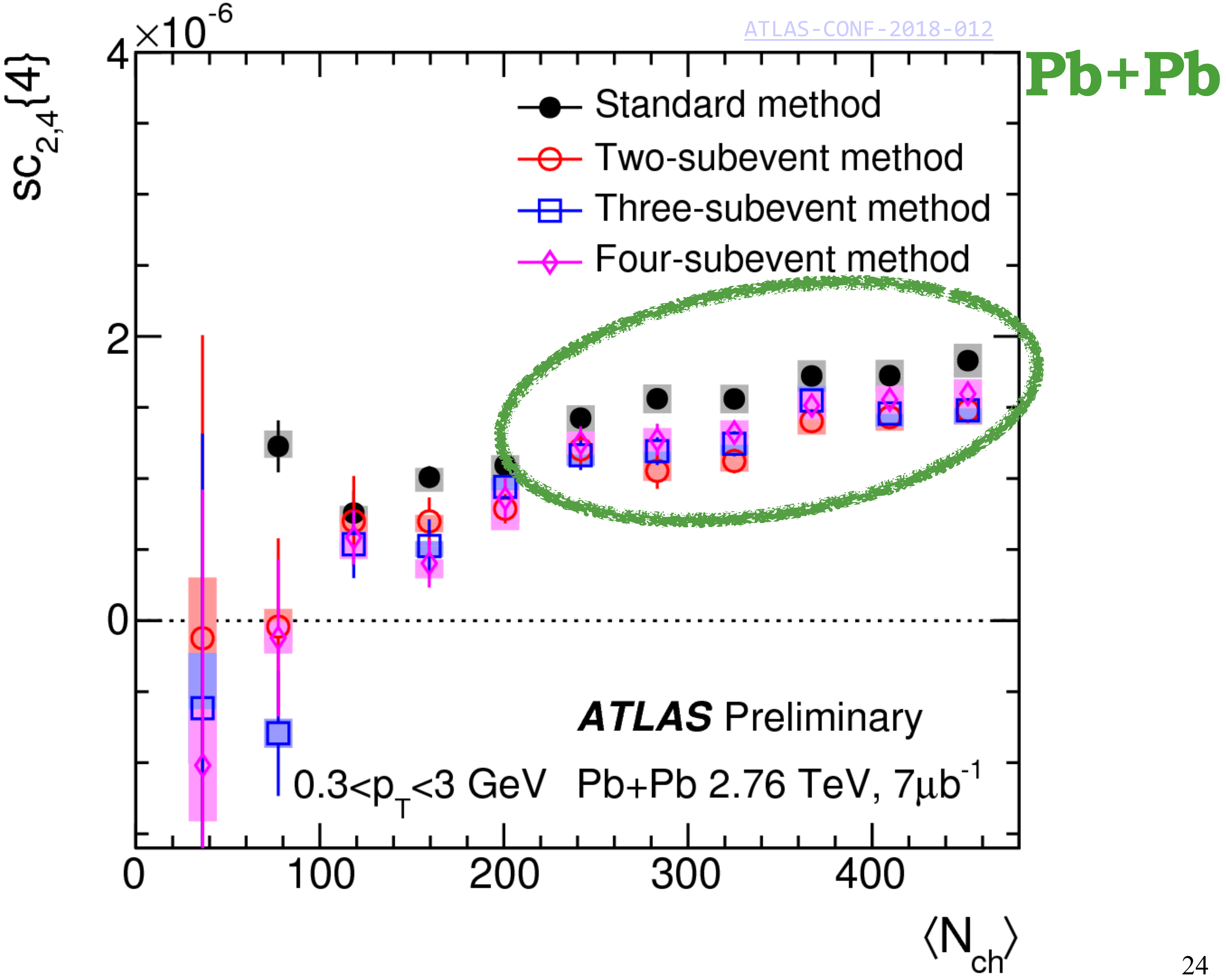

Results for v_2 v_4 correlations ($ac_2\{3\}$)

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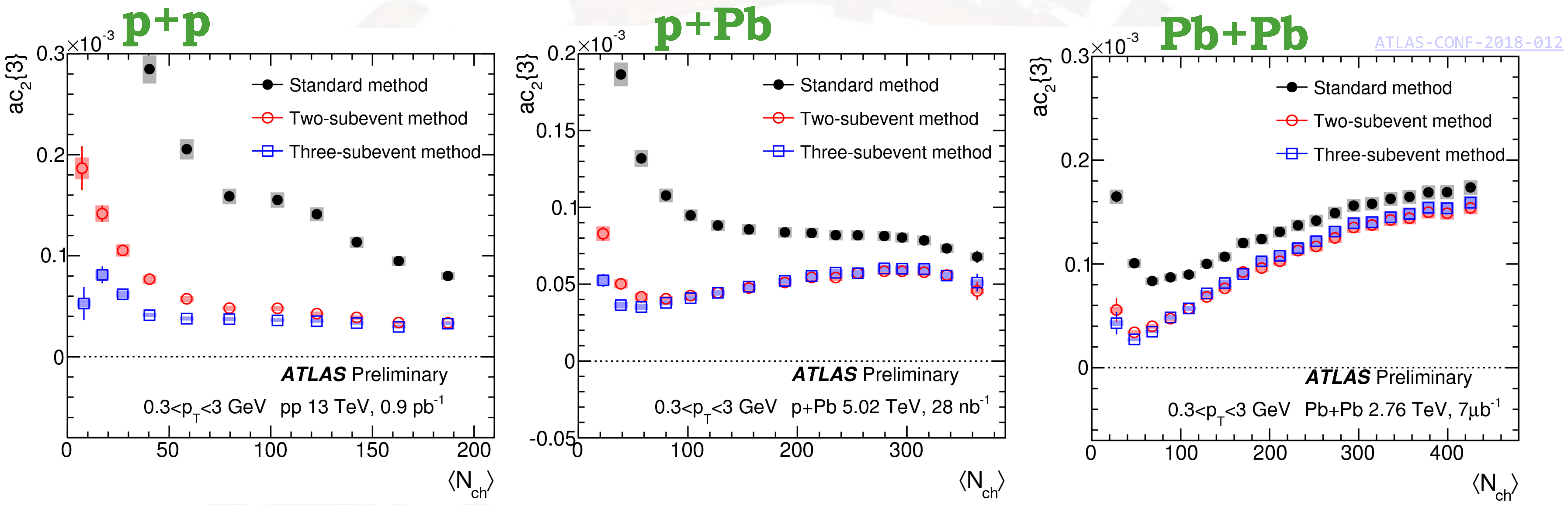

Similar to $sc_{2,4}\{4\}$, $ac_2\{3\}$ measure positive correlation between v_2 and v_4, with the same features:

Results for v_2 v_4 correlations ($ac_2\{3\}$)

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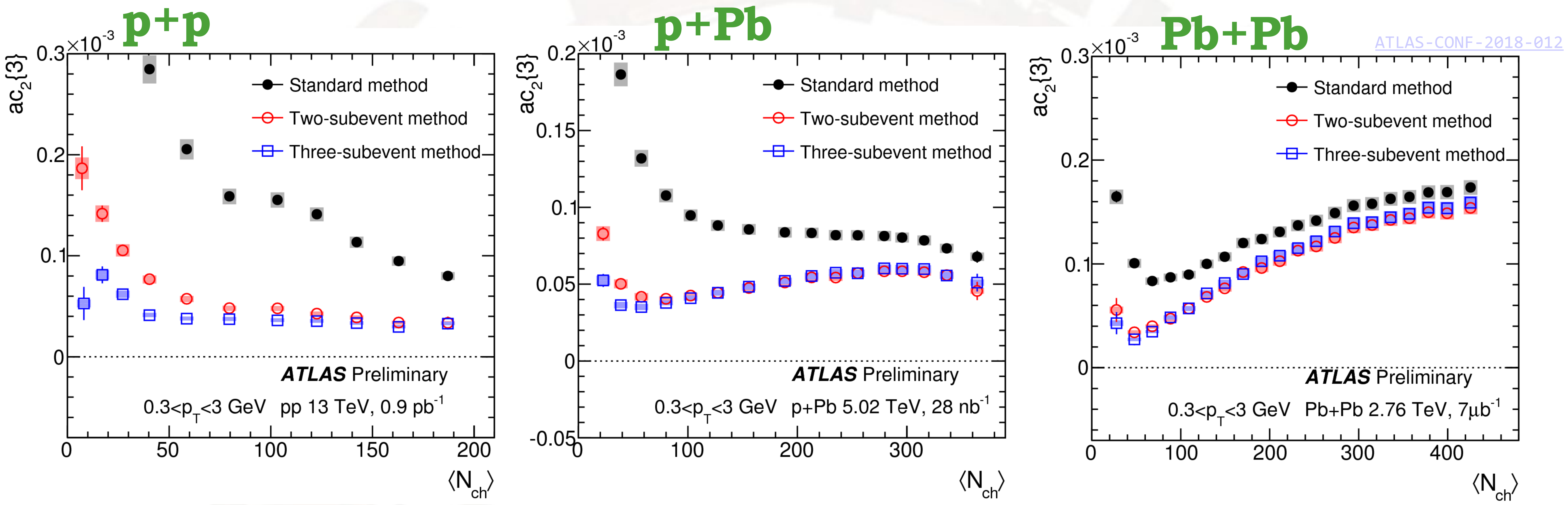

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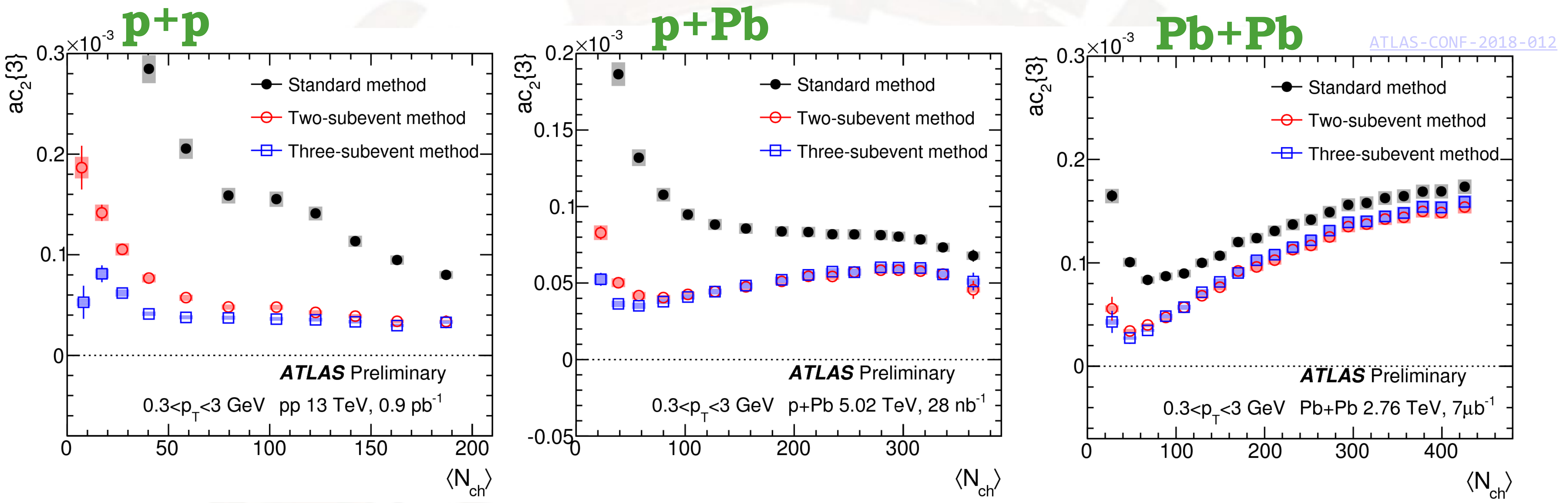

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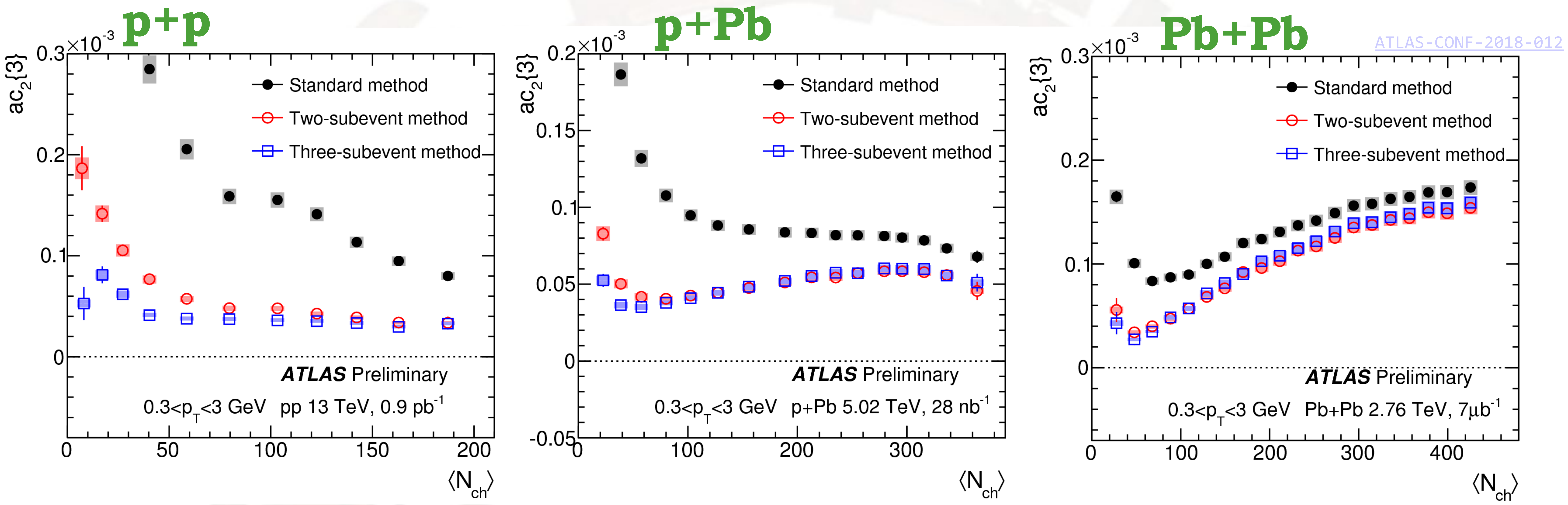

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- standard method more affected by non-flow
- differences between two-subevent and three-subevent at low <N_{ch}>
- standard and subevents method not converge at hight <N_{ch}>

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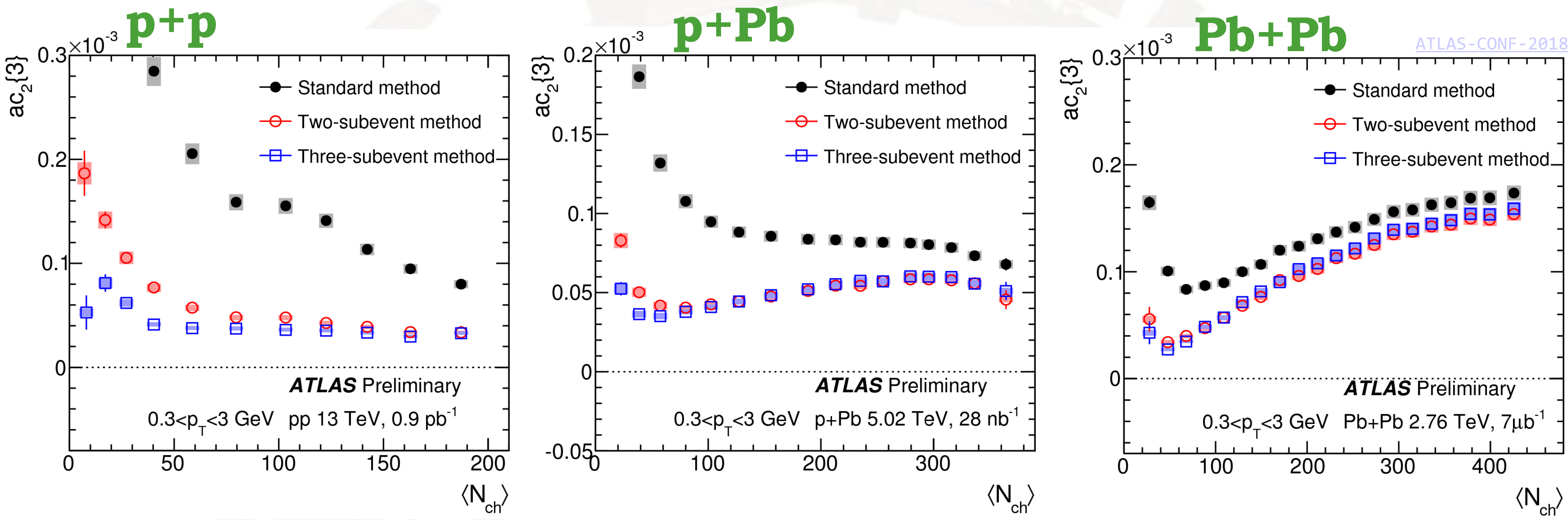
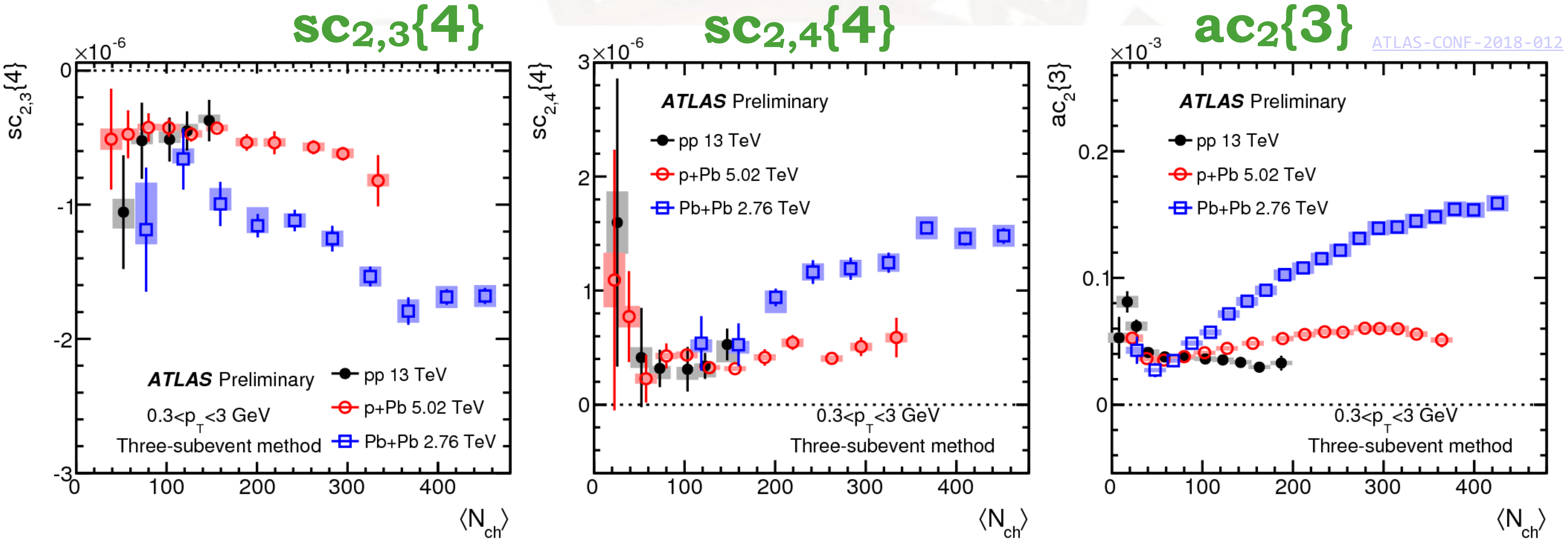


Stronger signal thus better statistical precision

- **Excellent probe of the three particle collective flow**

Comparison between collision systems



- Three-subevent method used for comparison
- **Symmetric cumulants consistent between all three systems in the** $<N_{ch}>$ **range covered by p+p collisions**
- For the p+Pb and Pb+Pb $sc_{2,3}\{4\}$ ($sc_{2,4}\{4\}$, $ac_2\{3\}$) show significant decrease (increase) with $<N_{ch}>$

Normalized symmetric and asymmetric cumulants

Normalized versions of $\mathbf{sc_{n,m}\{4\}}$ and $\mathbf{ac_n\{3\}}$:

- removed dependence on the harmonics magnitude - **focus only on correlation strength**

$$nsc_{2,3}\{4\} = \frac{sc_{2,3}\{4\}}{v_2\{2\}^2 v_3\{2\}^2} = \frac{\langle v_2^2 v_3^2\rangle}{\langle v_2^2\rangle\langle v_3^2\rangle} - 1$$

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$\mathbf{v_n\{2\}^2}$ - obtained from the "improved" **template fit**

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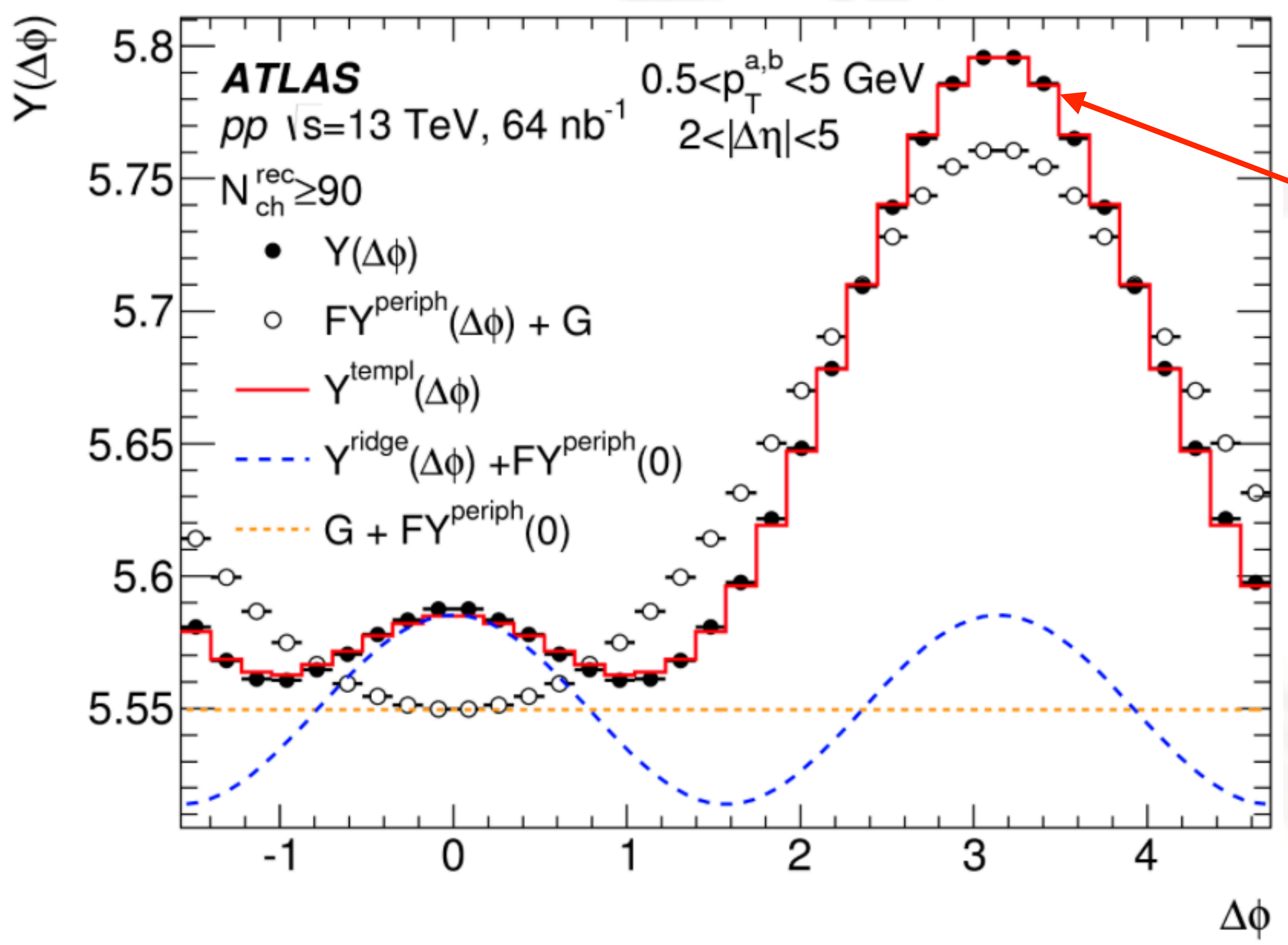

$$Y(\Delta\phi) = FY(\Delta\phi)^{periph} + G(1 + 2\sum_{n=2}^{\infty} v_{nn}\cos n\Delta\phi)$$

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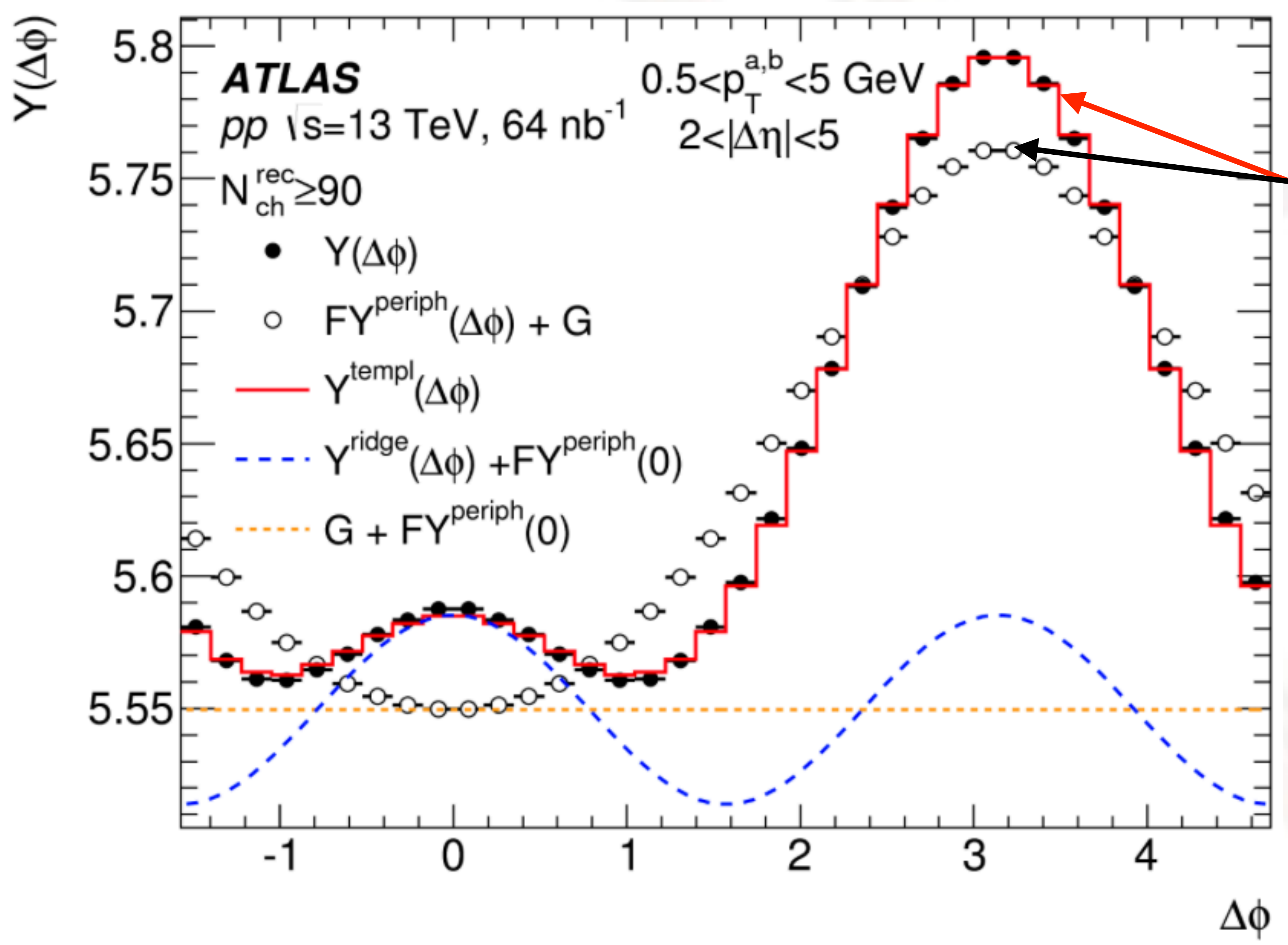

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Scaled peripheral

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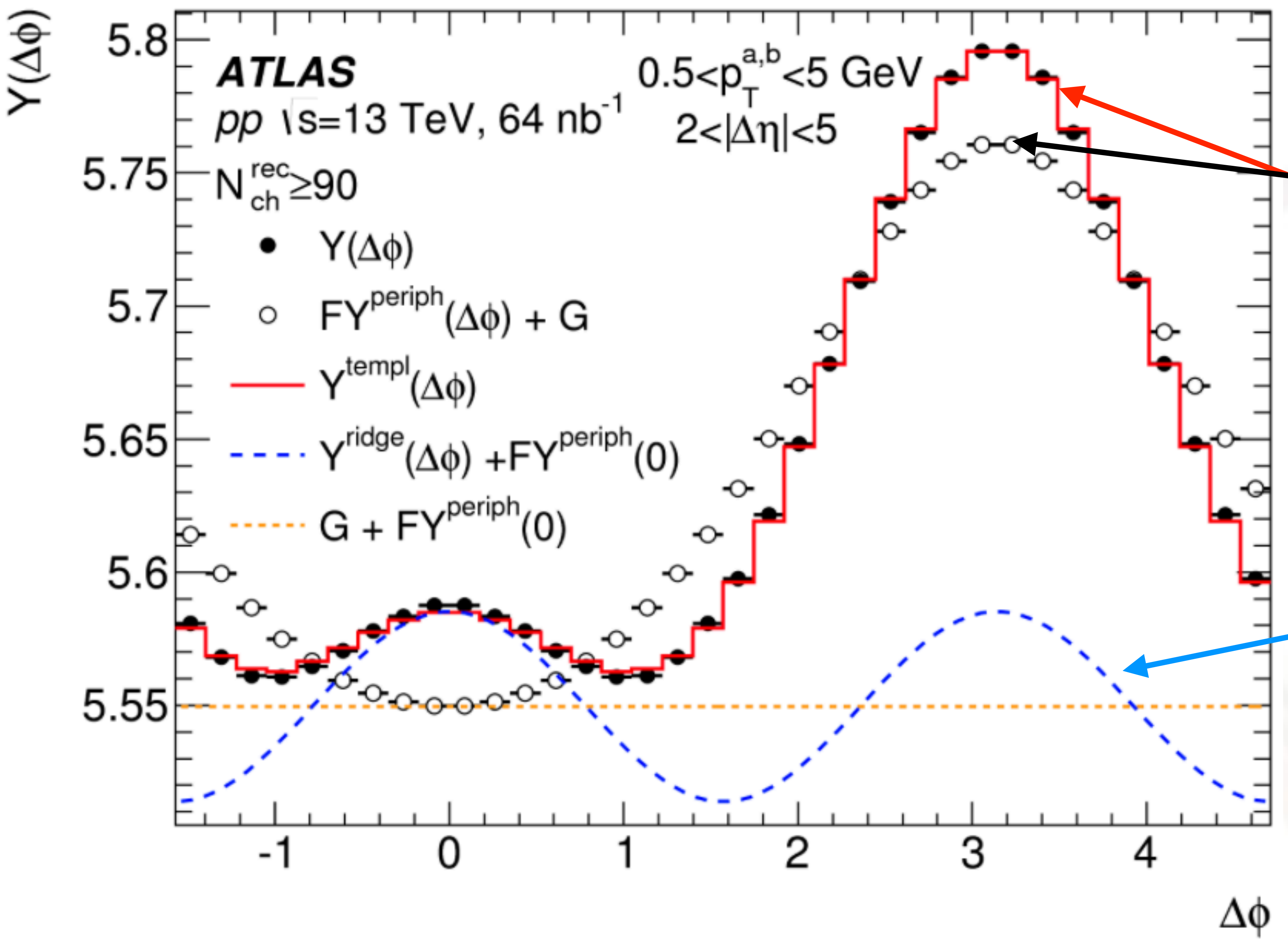

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Scaled peripheral

Flow modulation

Normalized symmetric and asymmetric cumulants

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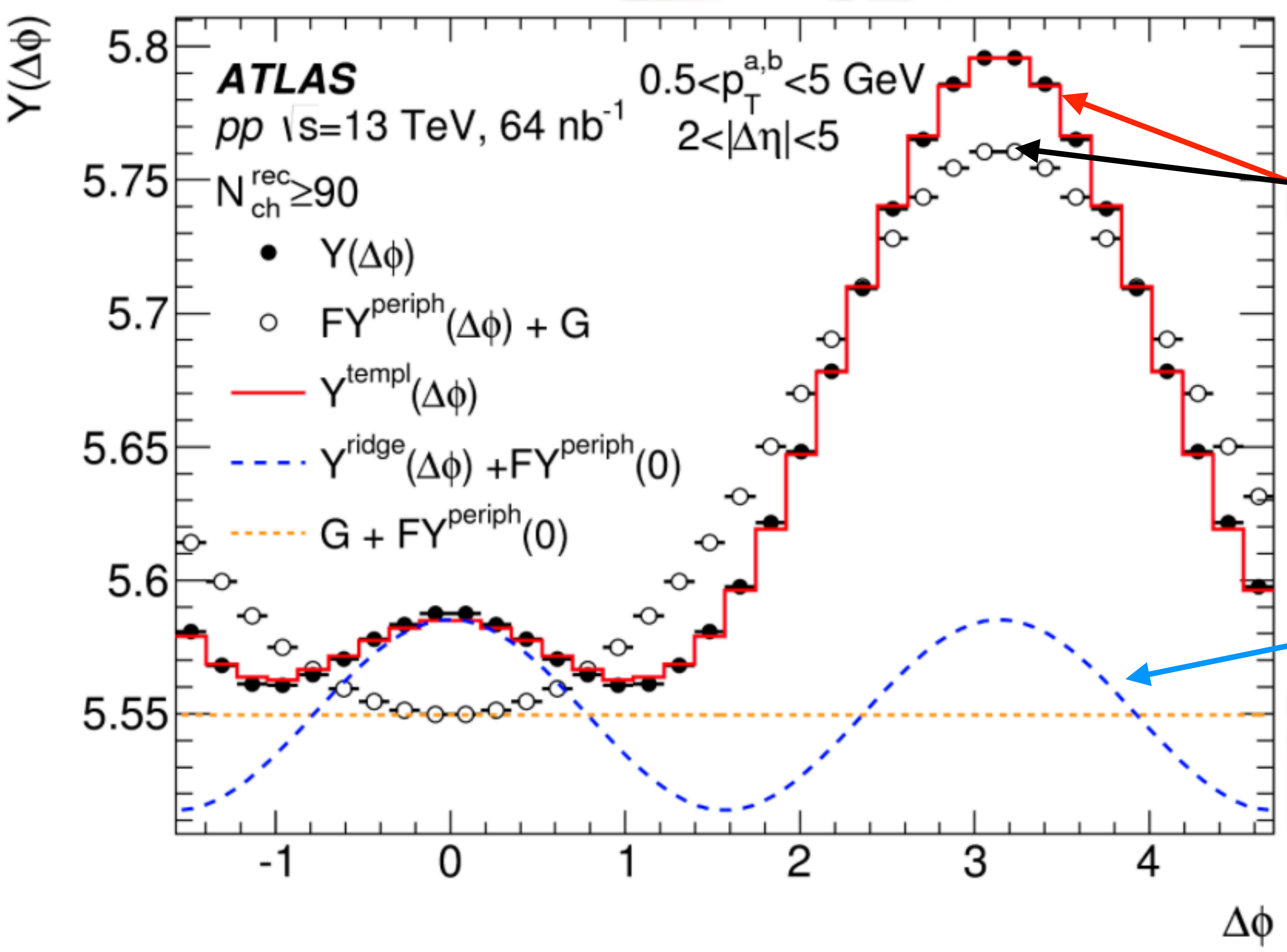

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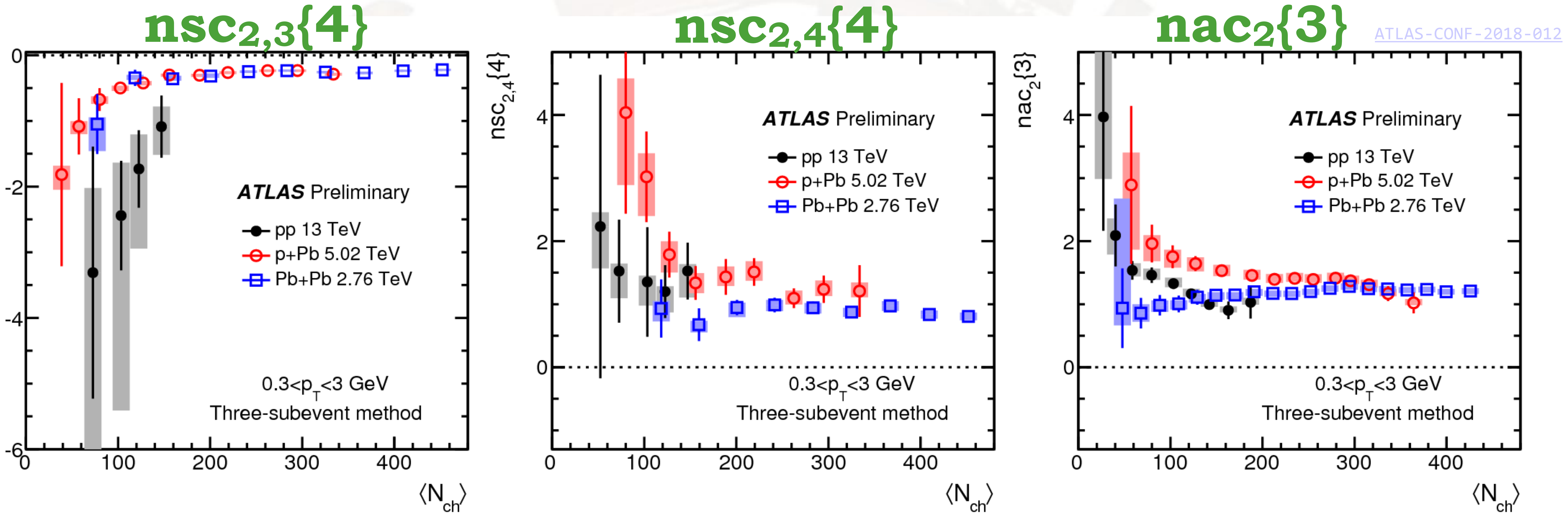
Scaled peripheral

Flow modulation

Improved ≡ corrected for the bias when
$\mathbf{v_n\{2\}^2}$ **change with** $\mathbf{\langle N_{ch} \rangle}$

Comparison between collision systems - normalized



- Most of the <Nch> dependence in p+Pb and Pb+Pb disappear
- **Strength of the correlations between harmonics similar between all systems**

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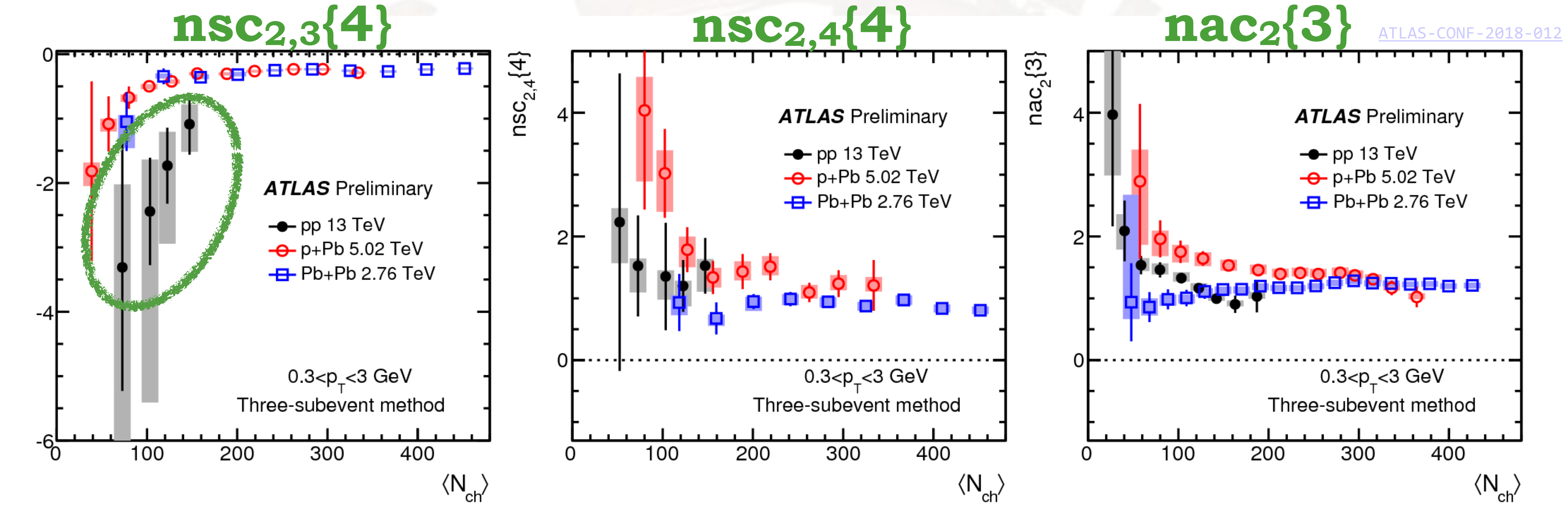


- Most of the <N_{ch}> dependence in p+Pb and Pb+Pb disappear
- **Strength of the correlations between harmonics similar between all systems**
  - **except nsc$_{2,3}${4} - in p+p** much different from p+Pb and Pb+Pb
    - **implying a possible of bias in <v_3> from template fit**

Summary

- ATLAS measured **symmetric and asymmetric cumulants** with standard method and subevent methods **in p+p, p+Pb, peripheral Pb+Pb collisions**
- Results obtained with **standard cumulant method** in small systems are **strongly contaminated by non-flow**
- **Anti-correlation between v_2 and v_3** and **correlation between v_2 and v_4 over all collisions systems**
  - **normalized observables show that the strength of the correlation between harmonics is similar across all systems**
- **Measurements with three- and four- subevents** provide **new evidence for long range azimuthal correlations in pp and p+Pb** systems

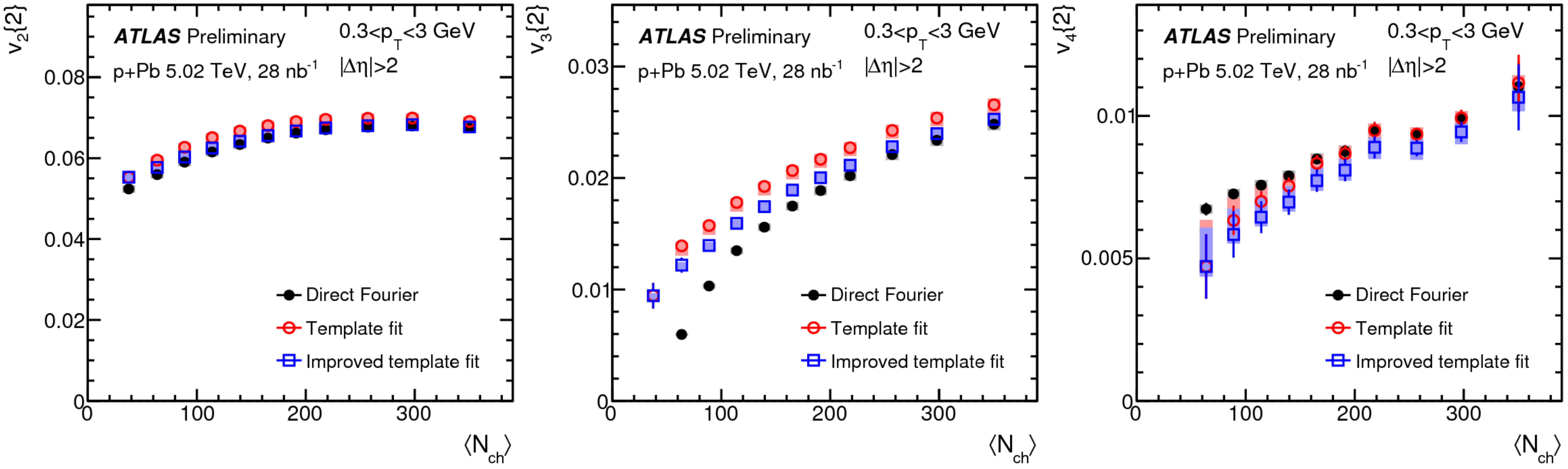
Backup

Improved template fit

Correction for the measured $v_n\{2\}$:

$$v_n\{2\}^2 = v_n\{2,templ\}^2 - \frac{FG^{periph}}{G}(v_n\{2,templ\}^2 - v_n\{2,periph\}^2)$$

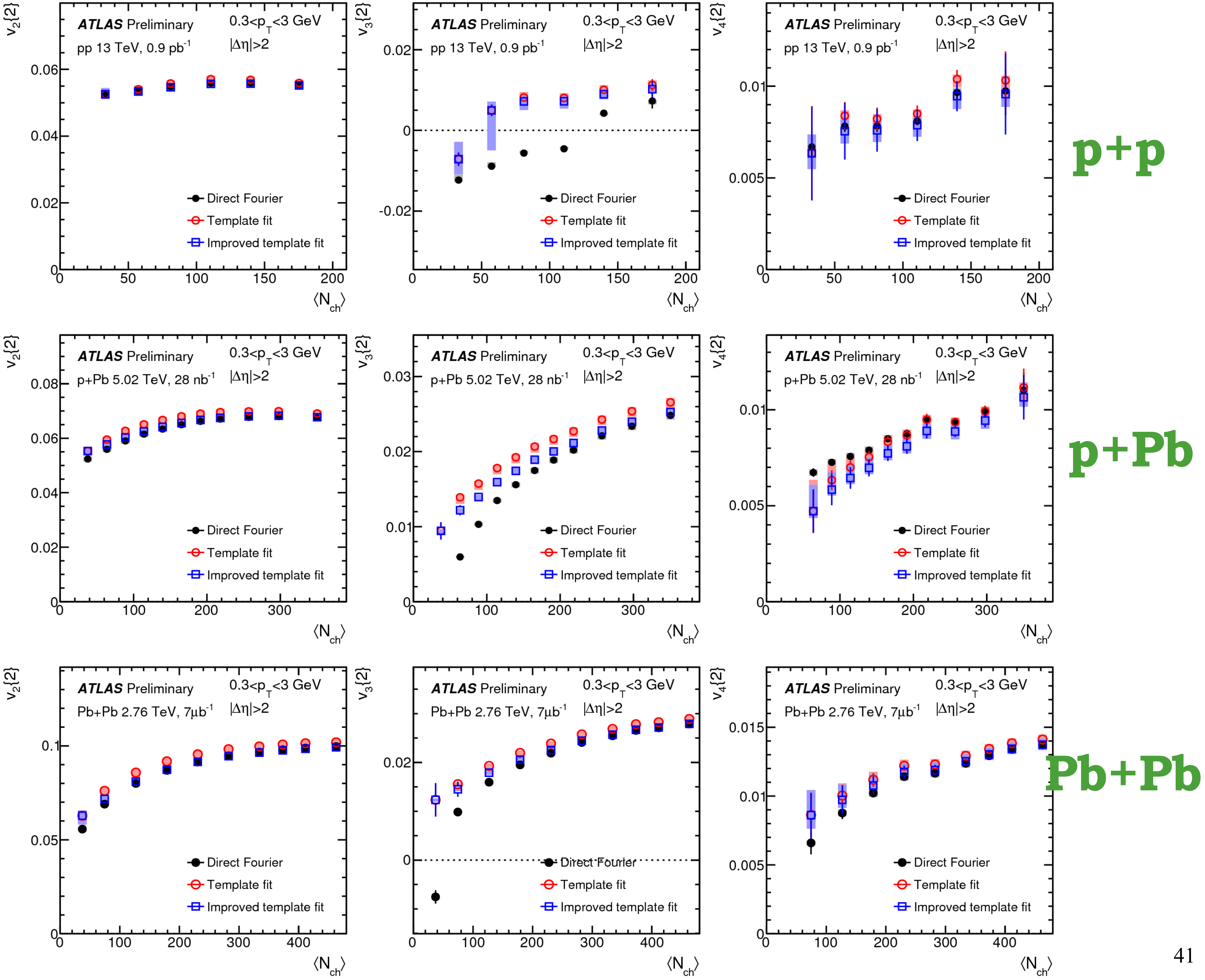
- Correction starts from 3rd <N_{ch}> bin
  - taking $v_n\{2,templ\}$ of the 2nd <N_{ch}> bin as a true $v_n\{2\}$



p+Pb

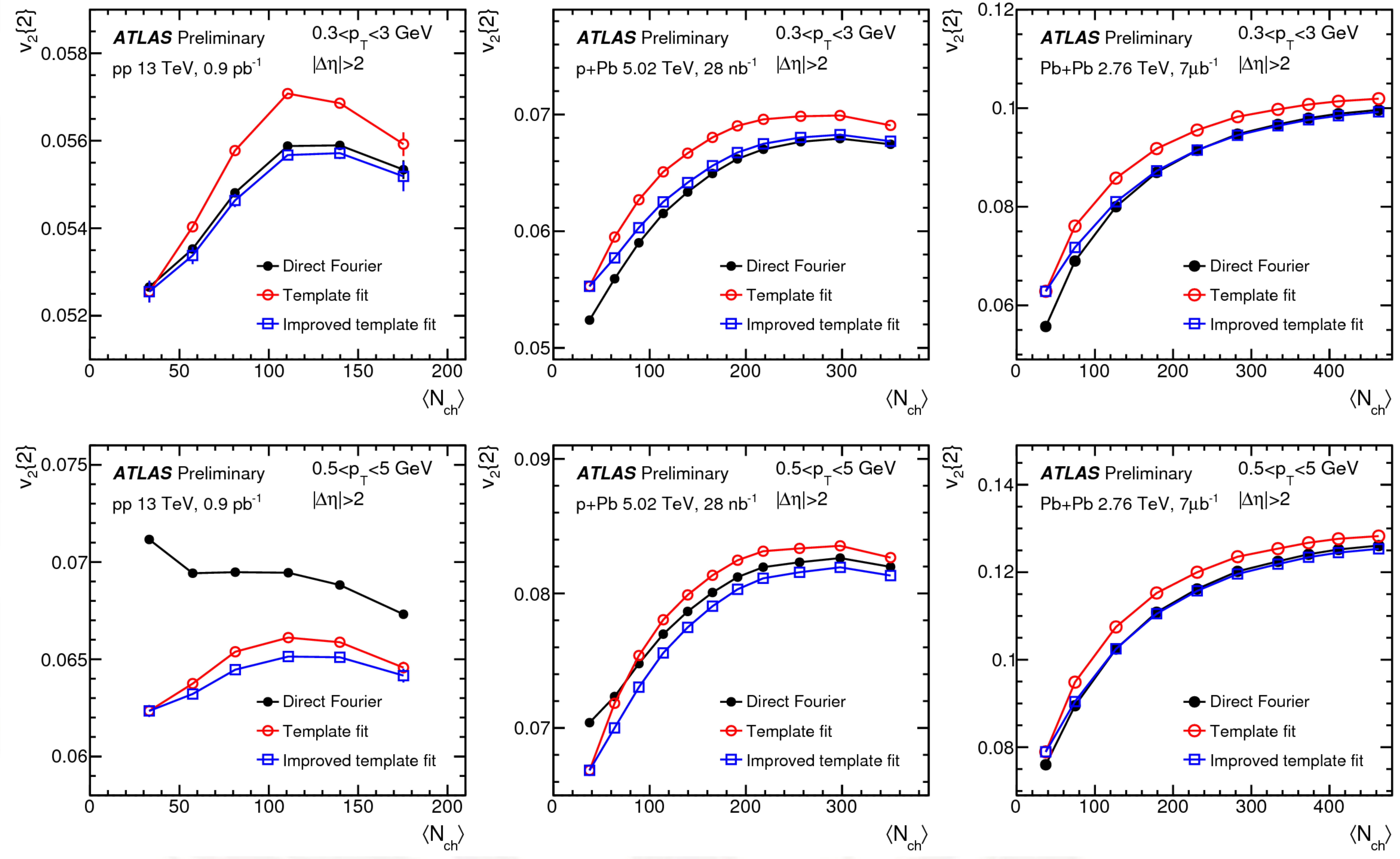
- Small impact on the v_2 and v_4
- More significant difference for v_3 (even more in case od pp collisions)

Improved template fit - all systems

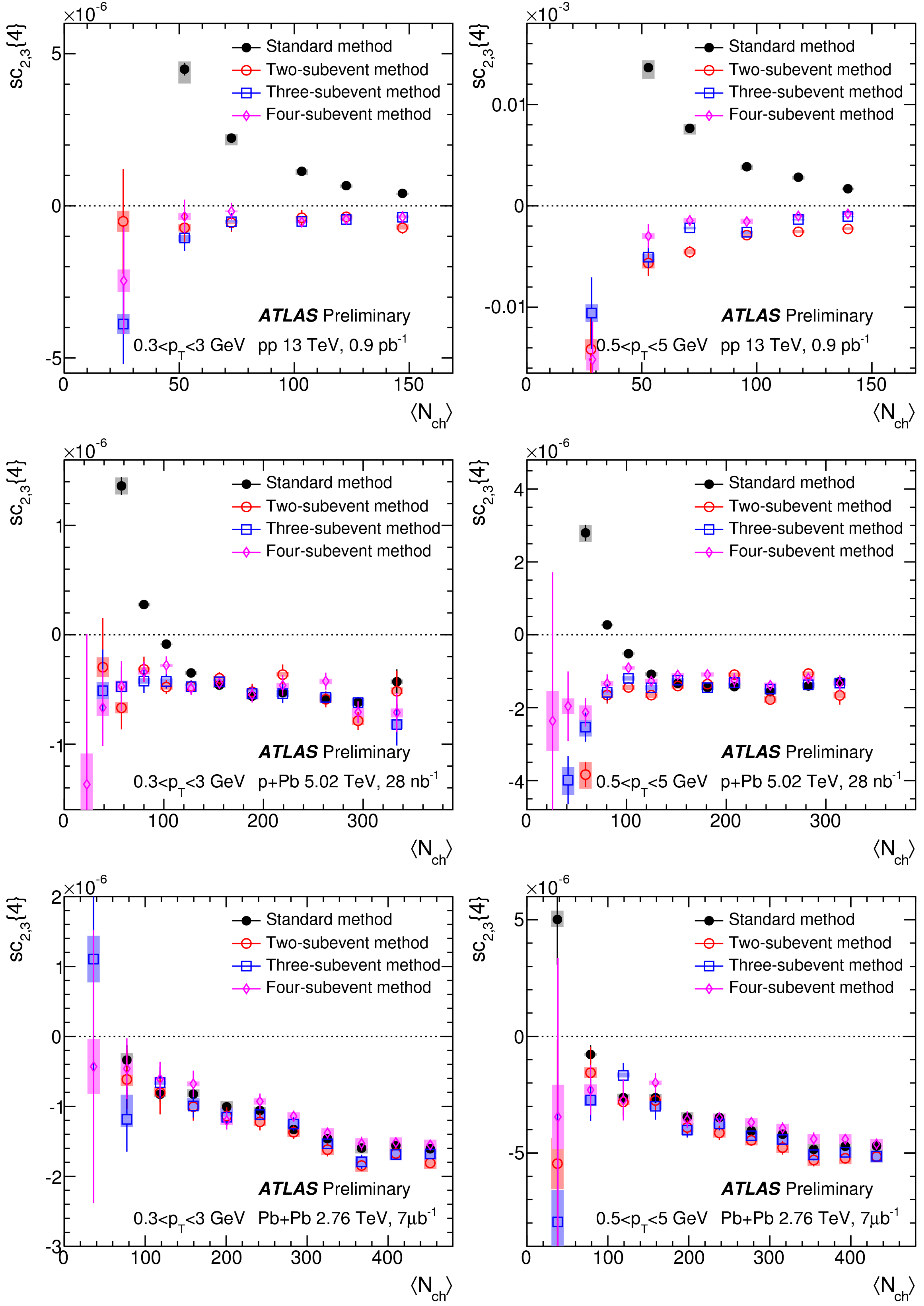


Improved template fit - details for $v_2\{2\}$

p+p **p+Pb** **Pb+Pb**



Comparison of two p_T ranges



p+p

p+Pb

Pb+Pb

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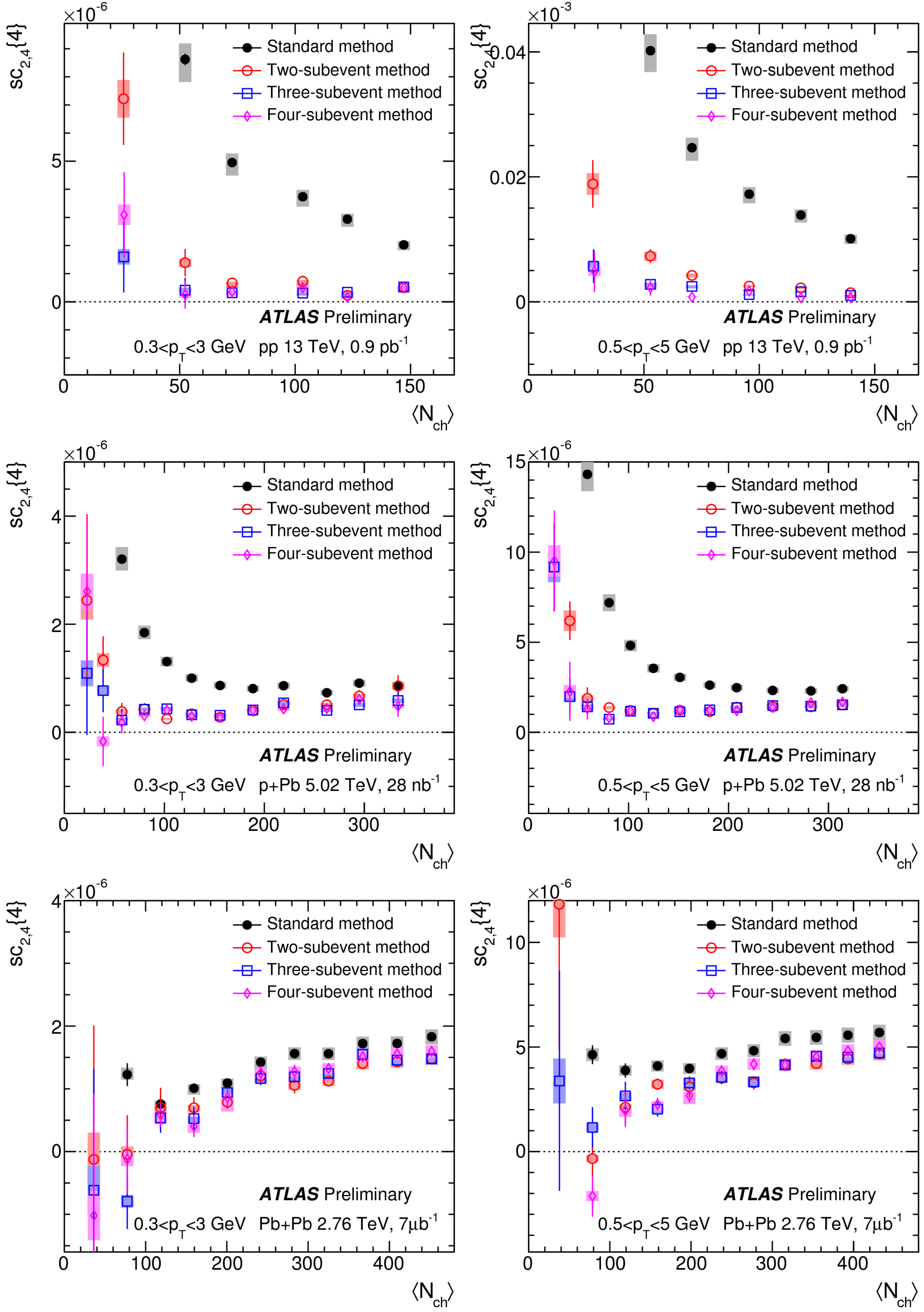

p+p

p+Pb

Pb+Pb

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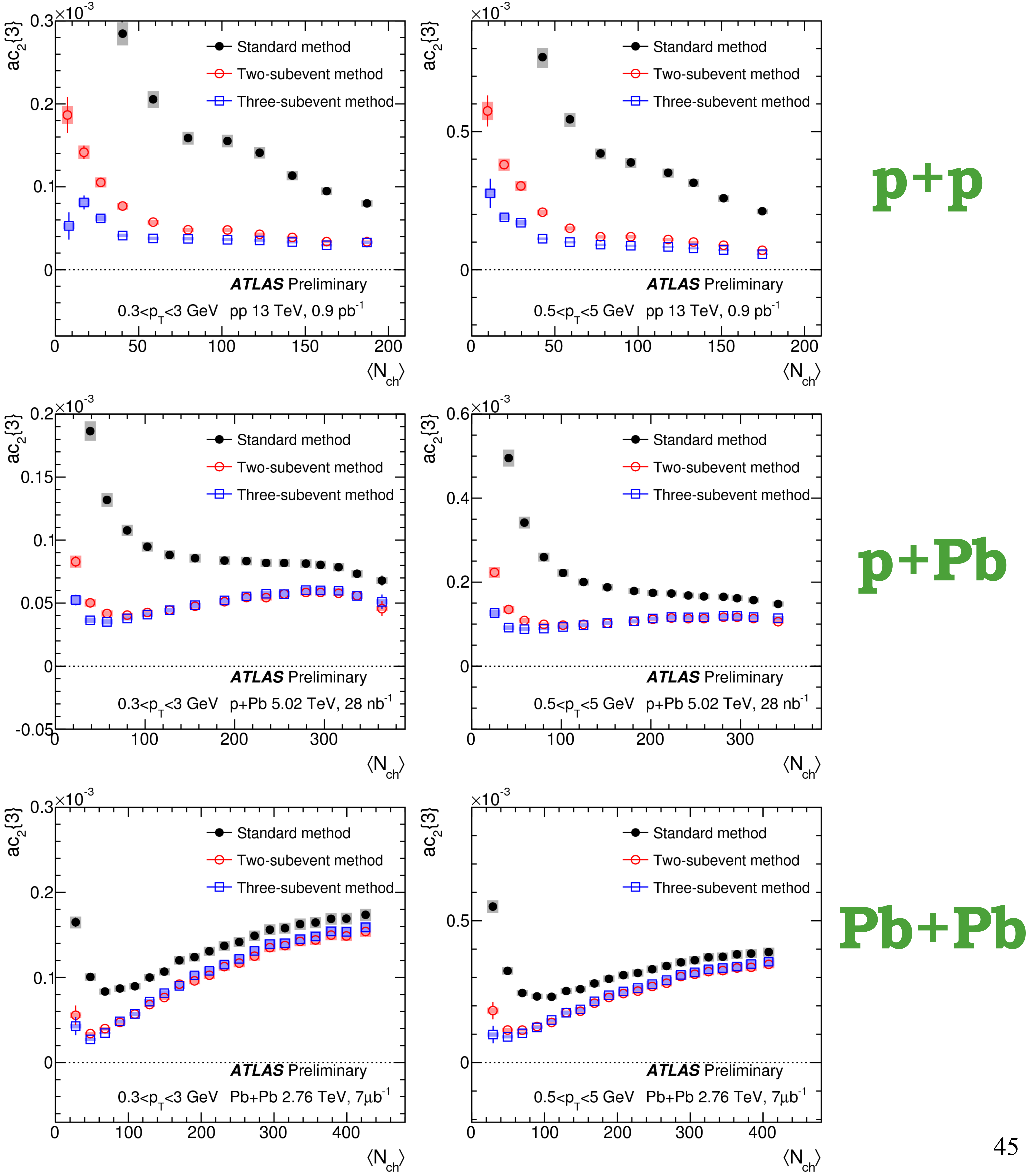

Comparison of correlators