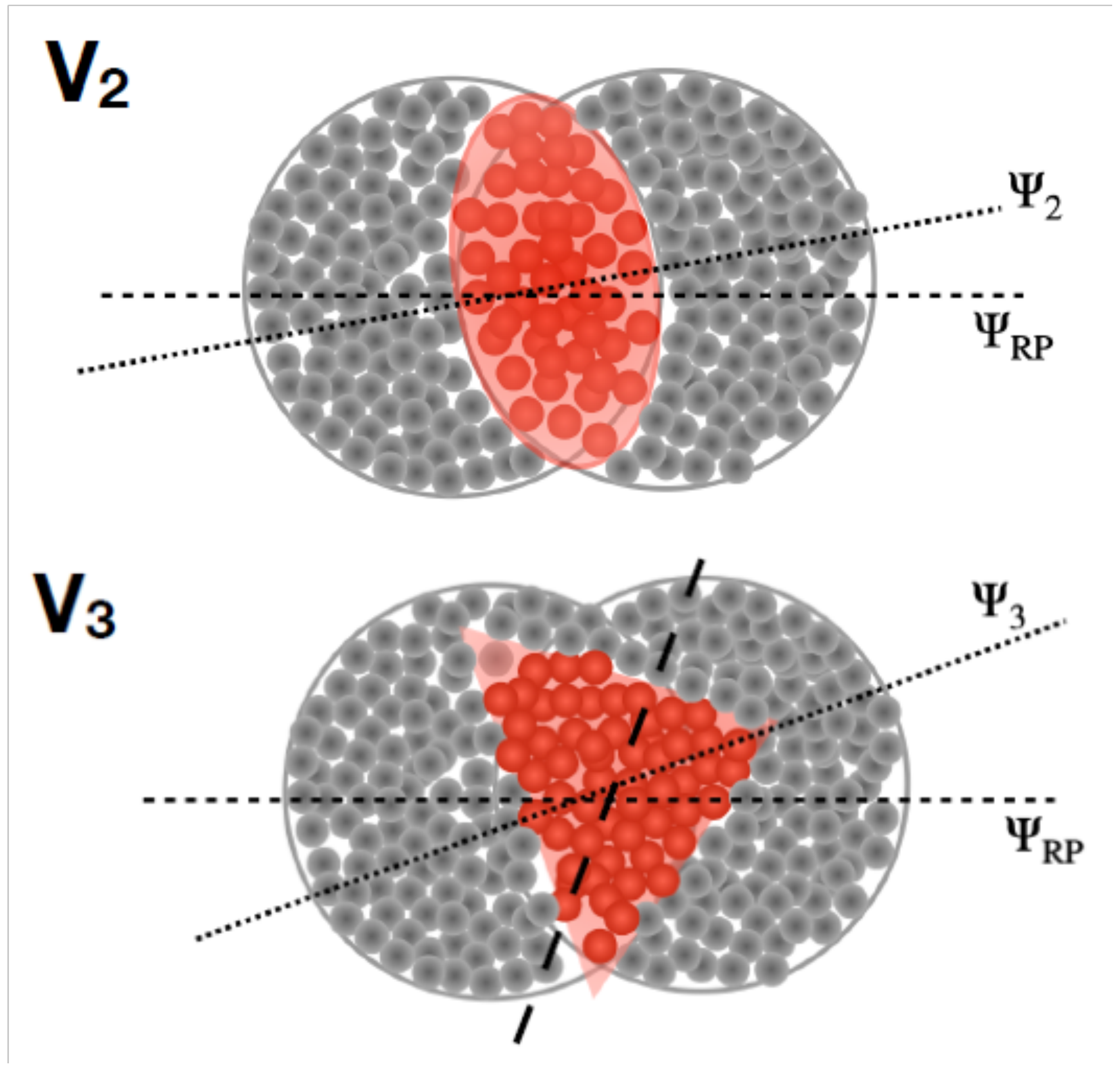
Understanding non-flow effects on multiparticle cumulants in small collision systems using Pythia model

Workshop JCF

Daniel Mihatsch | 14 June 2022

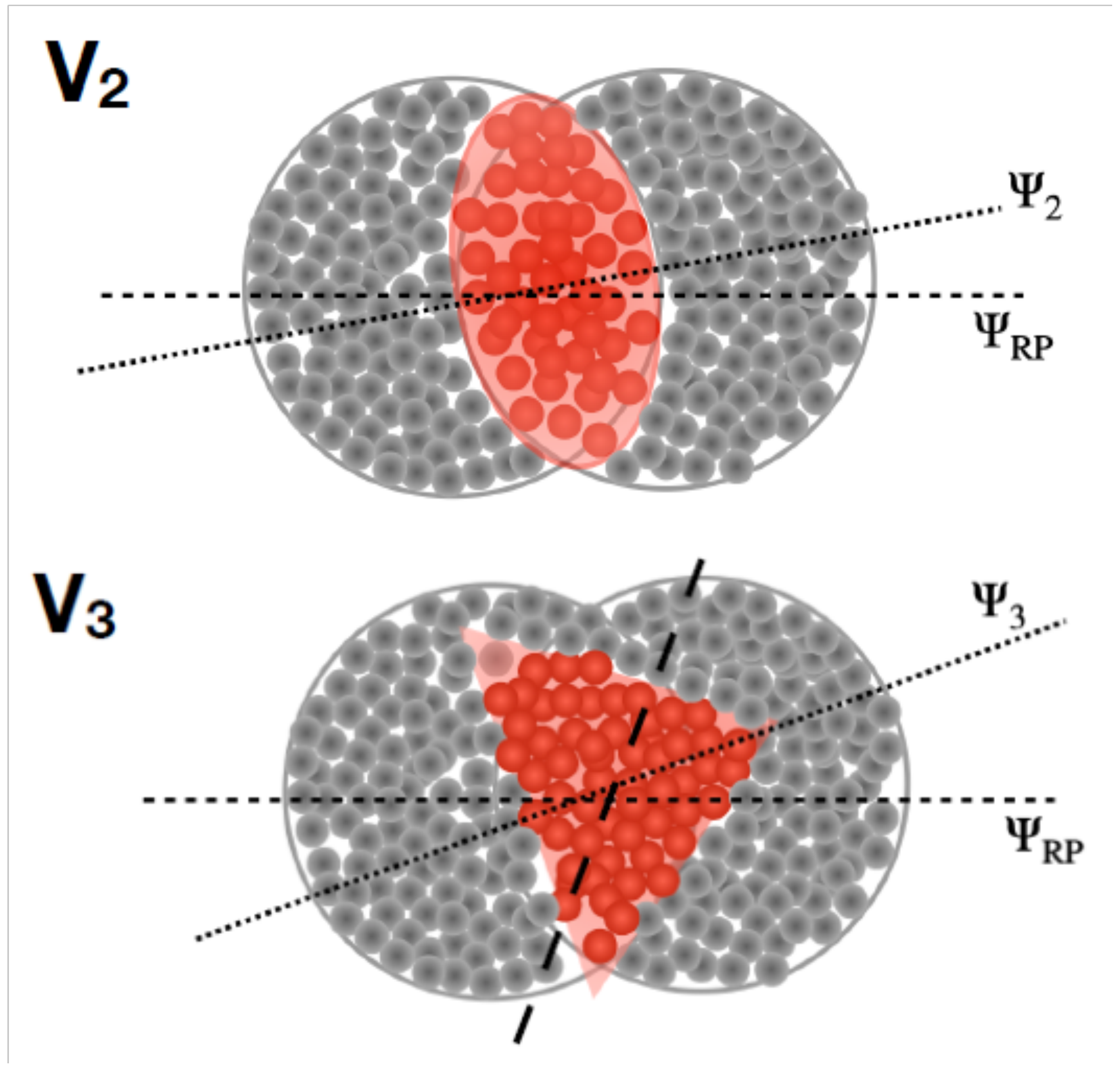
Anisotropic flow

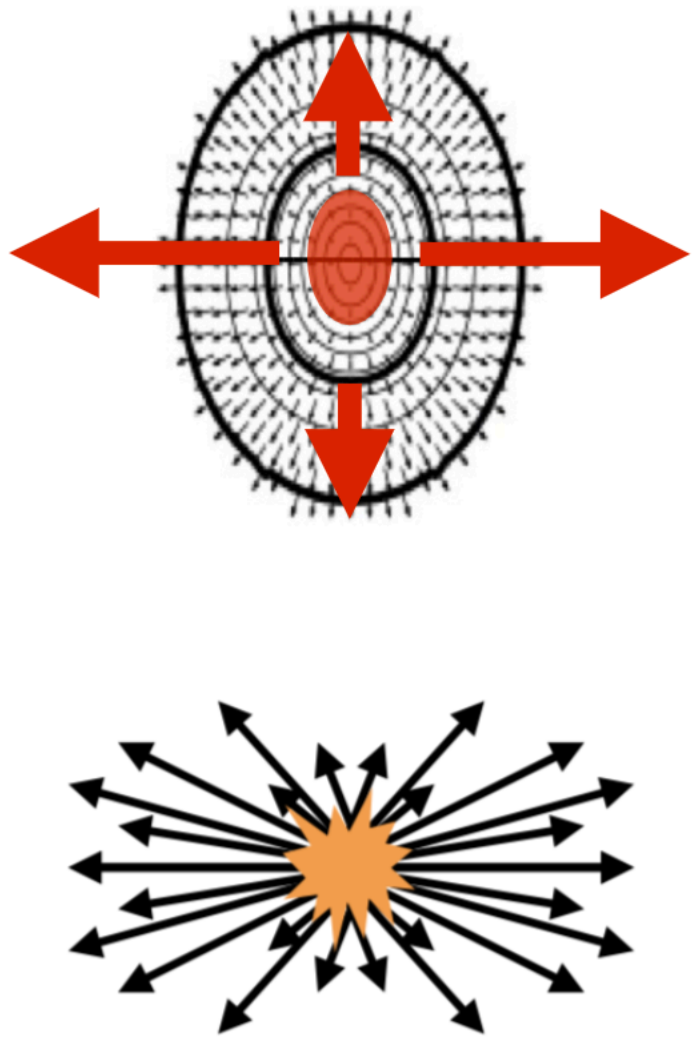
- Initial-state spatial anisotropy (almond-shaped overlap region)



Anisotropic flow

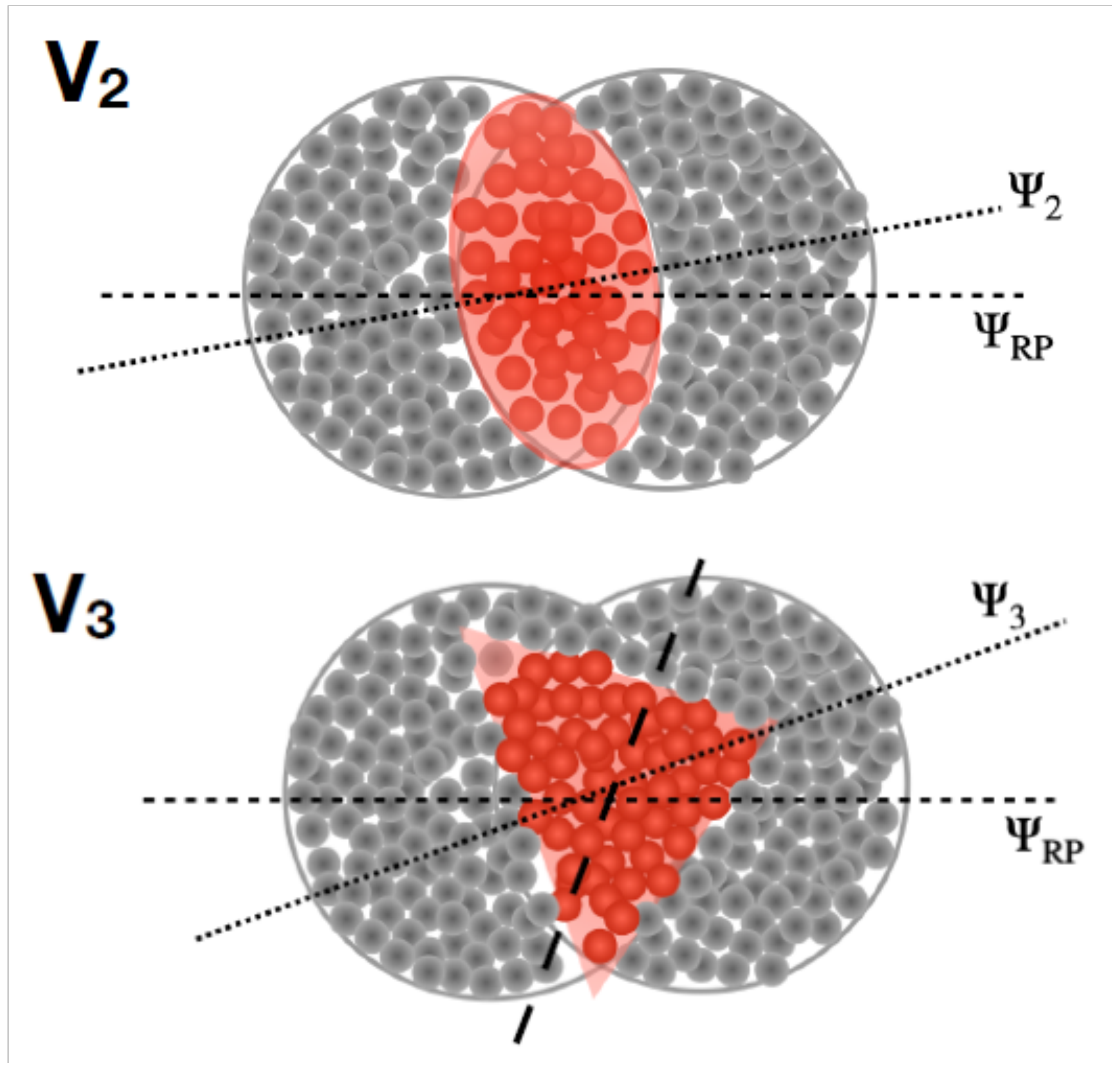
- Initial-state spatial anisotropy (almond-shaped overlap region) -> QGP formation and collective hydrodynamic expansion

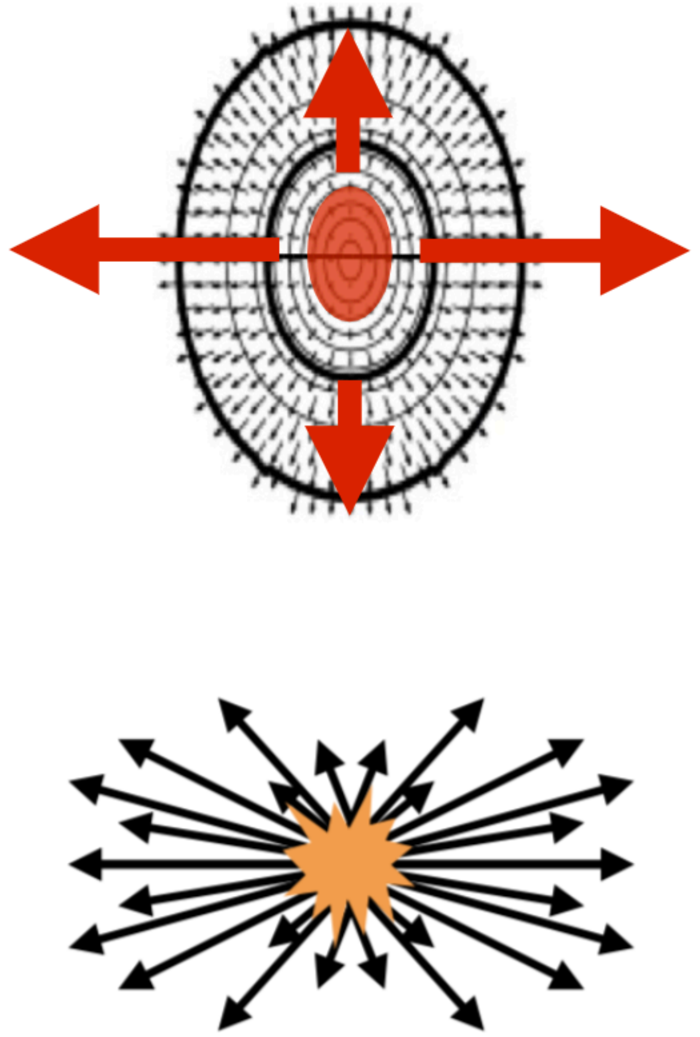


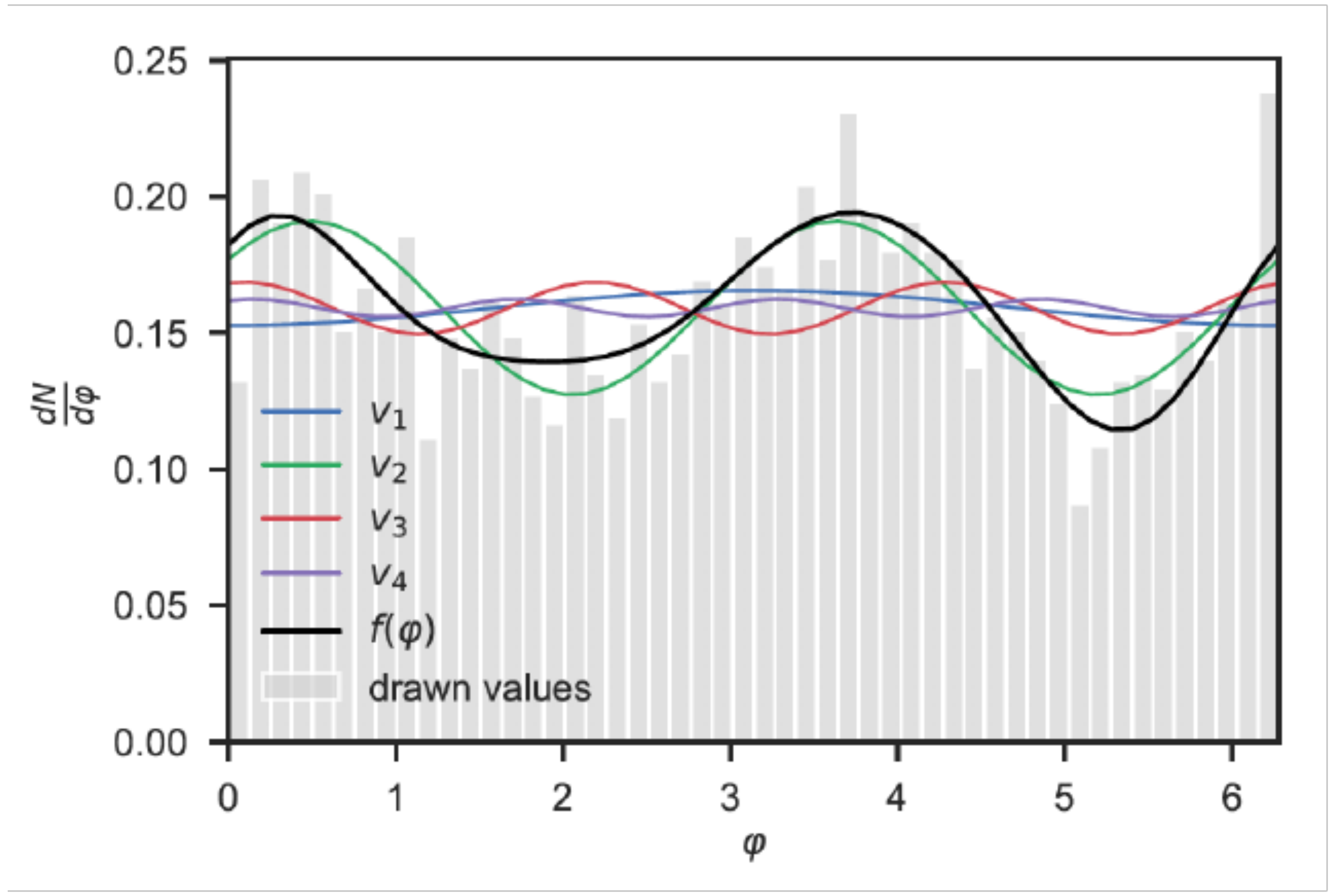


Anisotropic flow

- Initial-state spatial anisotropy (almond-shaped overlap region) -> QGP formation and collective hydrodynamic expansion -> final-state momentum anisotropy characterized by the flow coefficients v_n







Anisotropic flow

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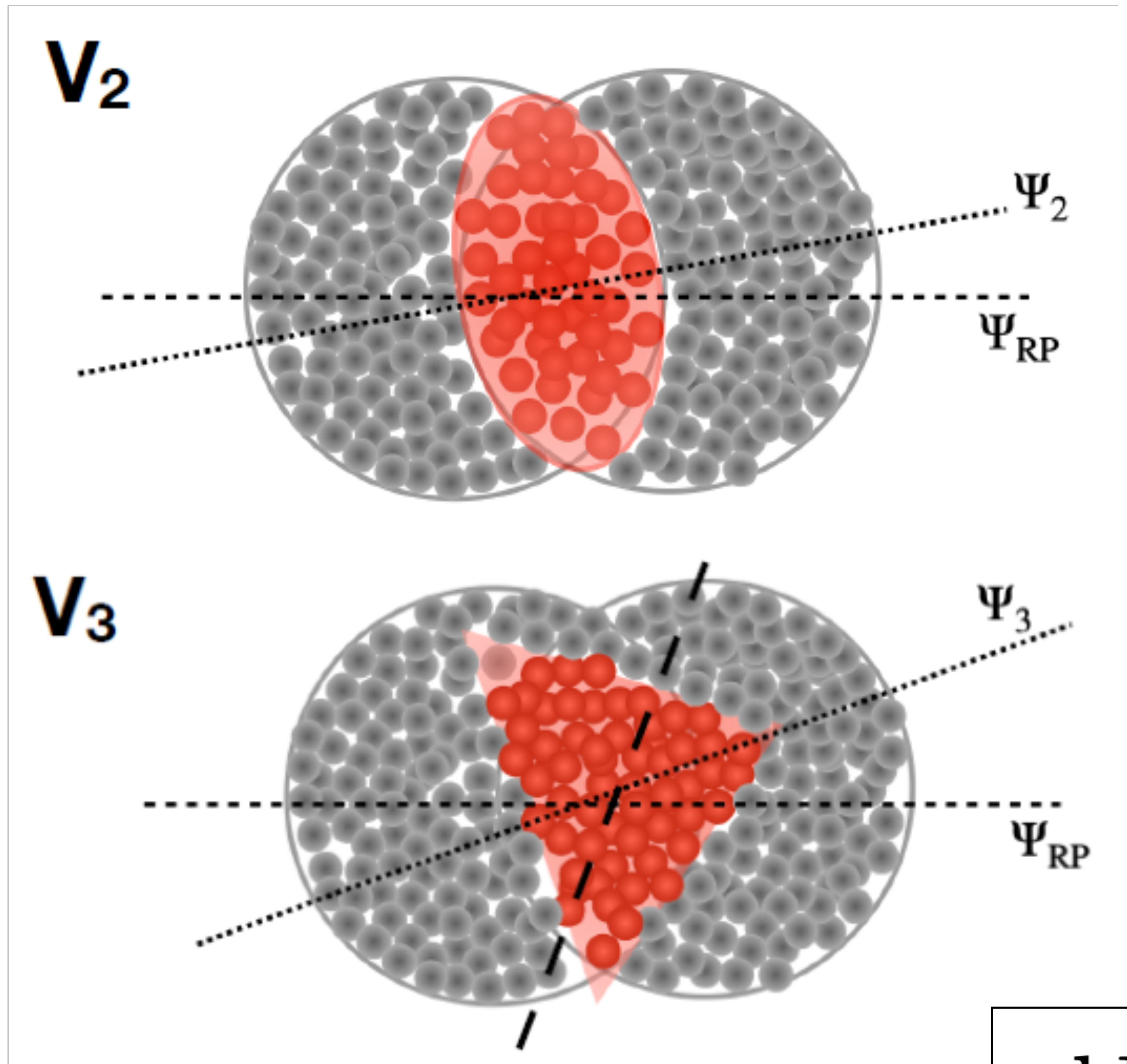
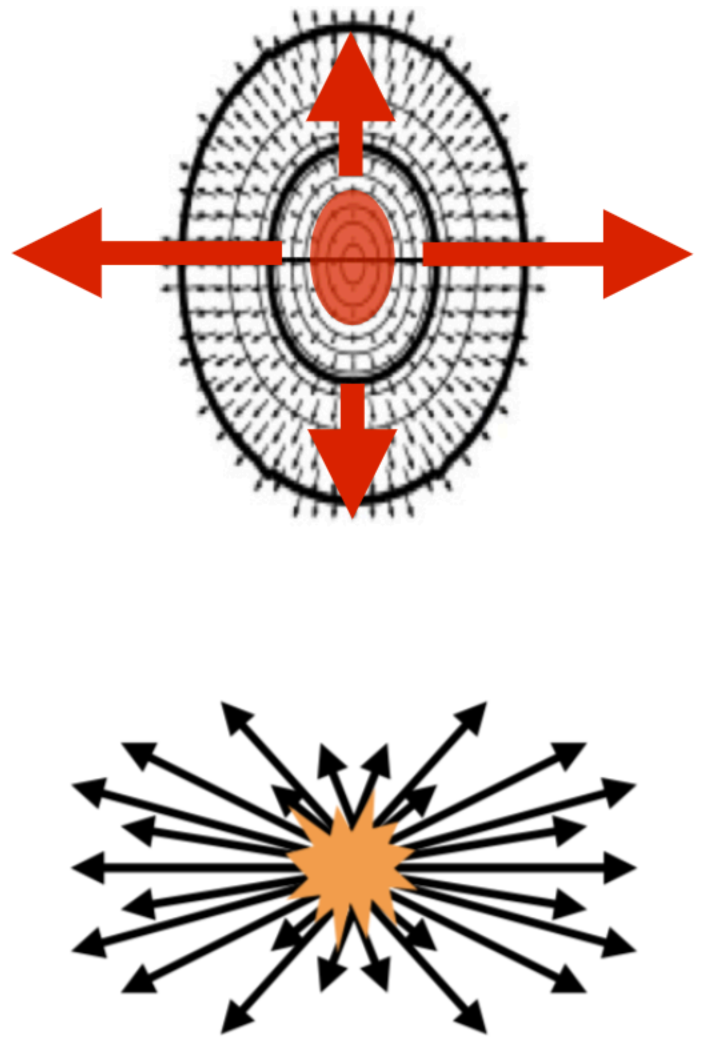
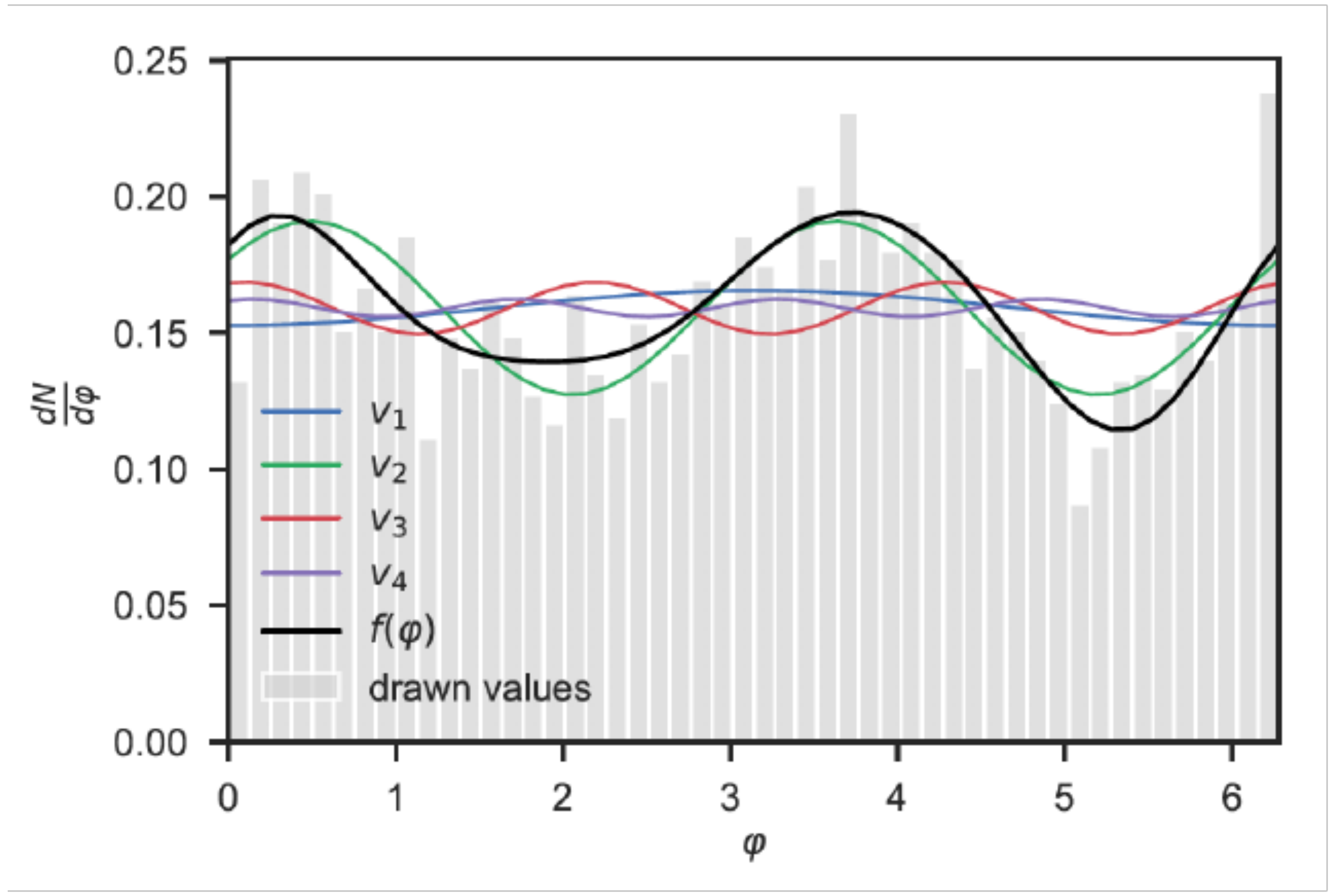




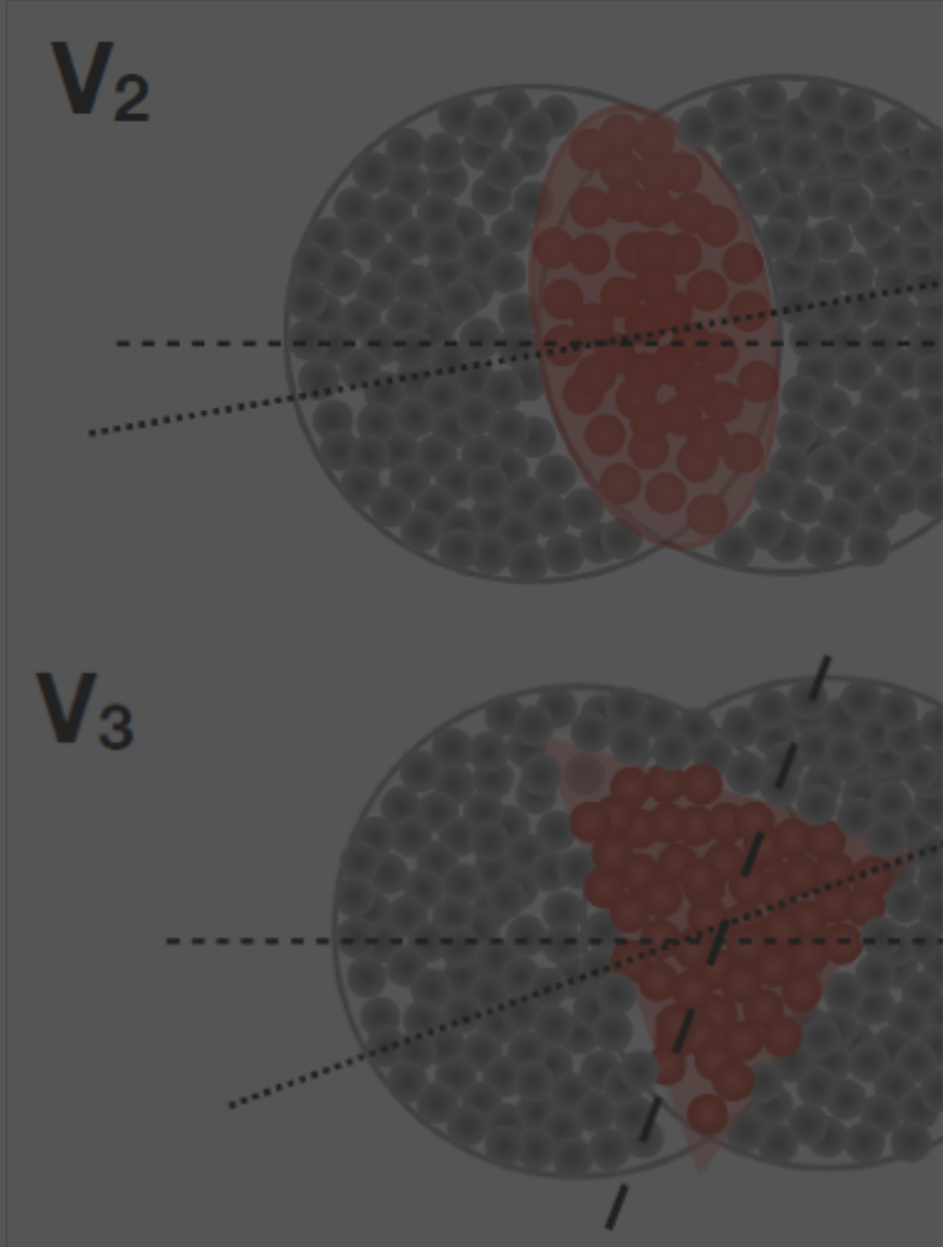


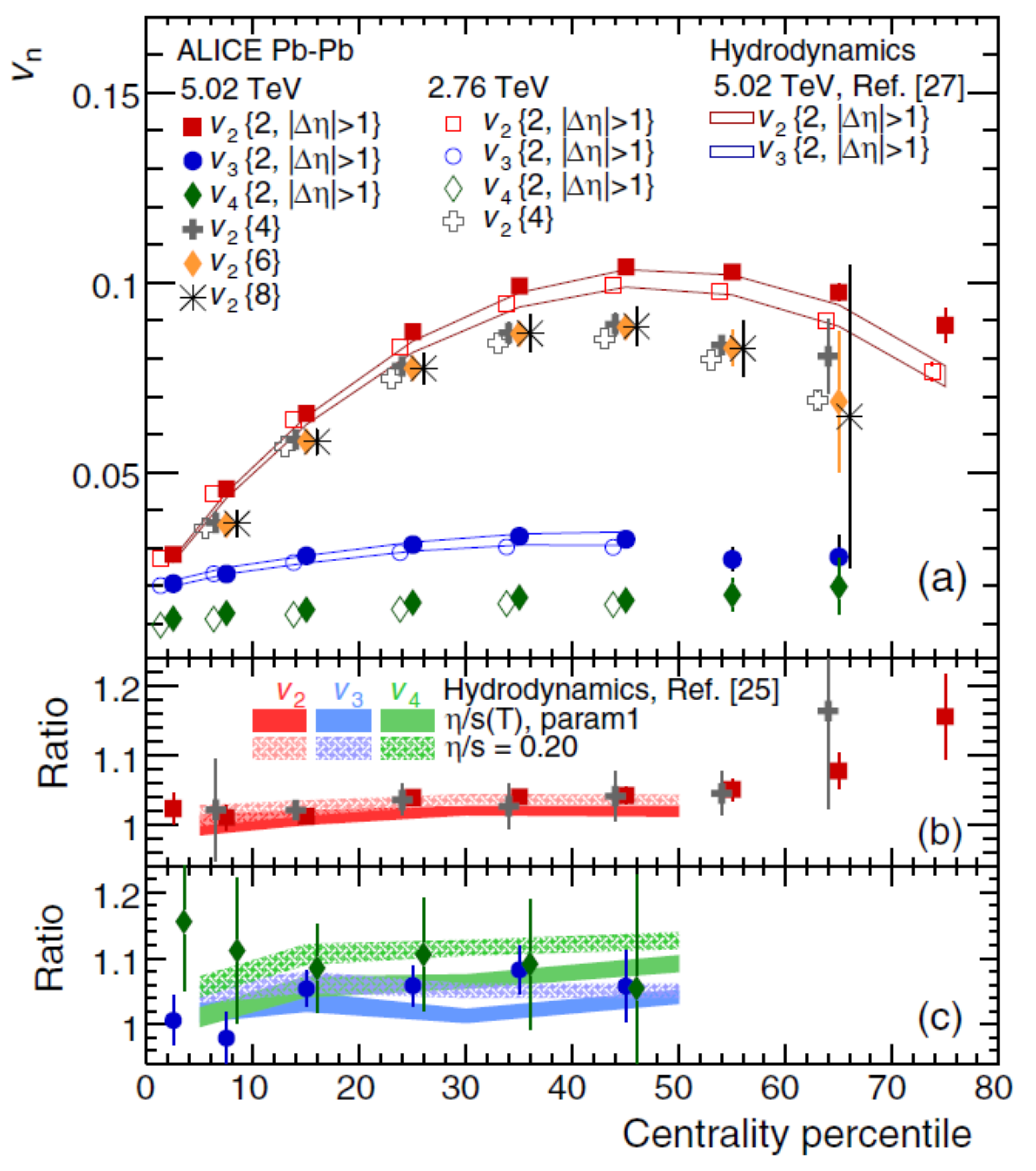
$$\frac{\mathrm{d}N}{\mathrm{d}\varphi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n(\varphi - \Psi_n)\right]$$

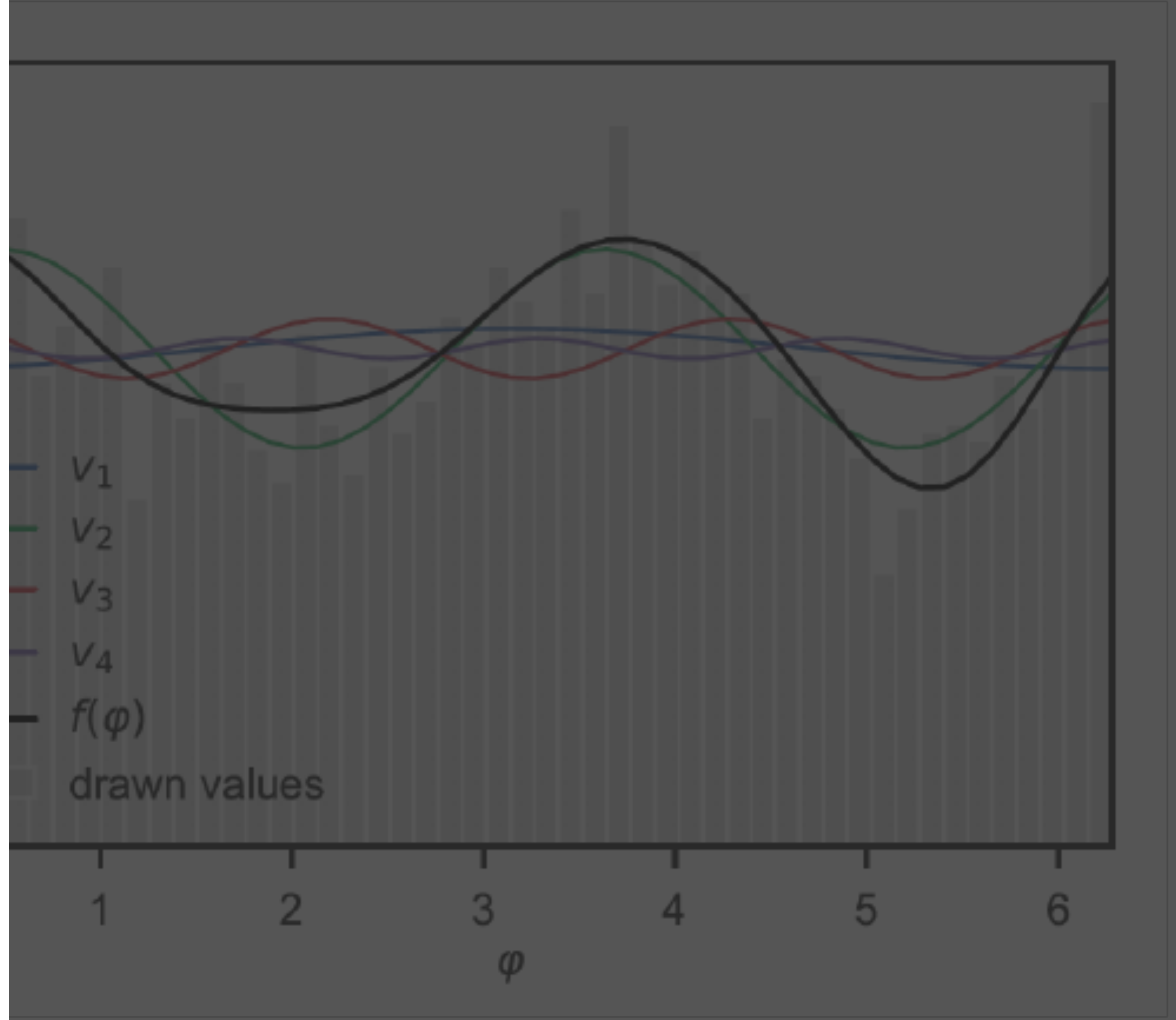
$$v_n = \langle \cos\left[n(\varphi - \Psi_n)\right] \rangle$$

Anisotropic

- Initial-state spatial ...) -> QGP formation and collective hyd... ...tum anisotropy characterized by t...







$$v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle$$

Multiparticle cumulant method

- Symmetry plane Ψ_n cannot be measured precisely -> multi-particle correlations

$$\langle v_n^2 \rangle = \langle\langle \cos[n(\varphi_1 - \varphi_2)] \rangle\rangle \equiv \langle\langle 2 \rangle\rangle$$
$$\langle v_n^4 \rangle = \langle\langle \cos[n(\varphi_1 + \varphi_2 - \varphi_3 - \varphi_4)] \rangle\rangle \equiv \langle\langle 4 \rangle\rangle$$

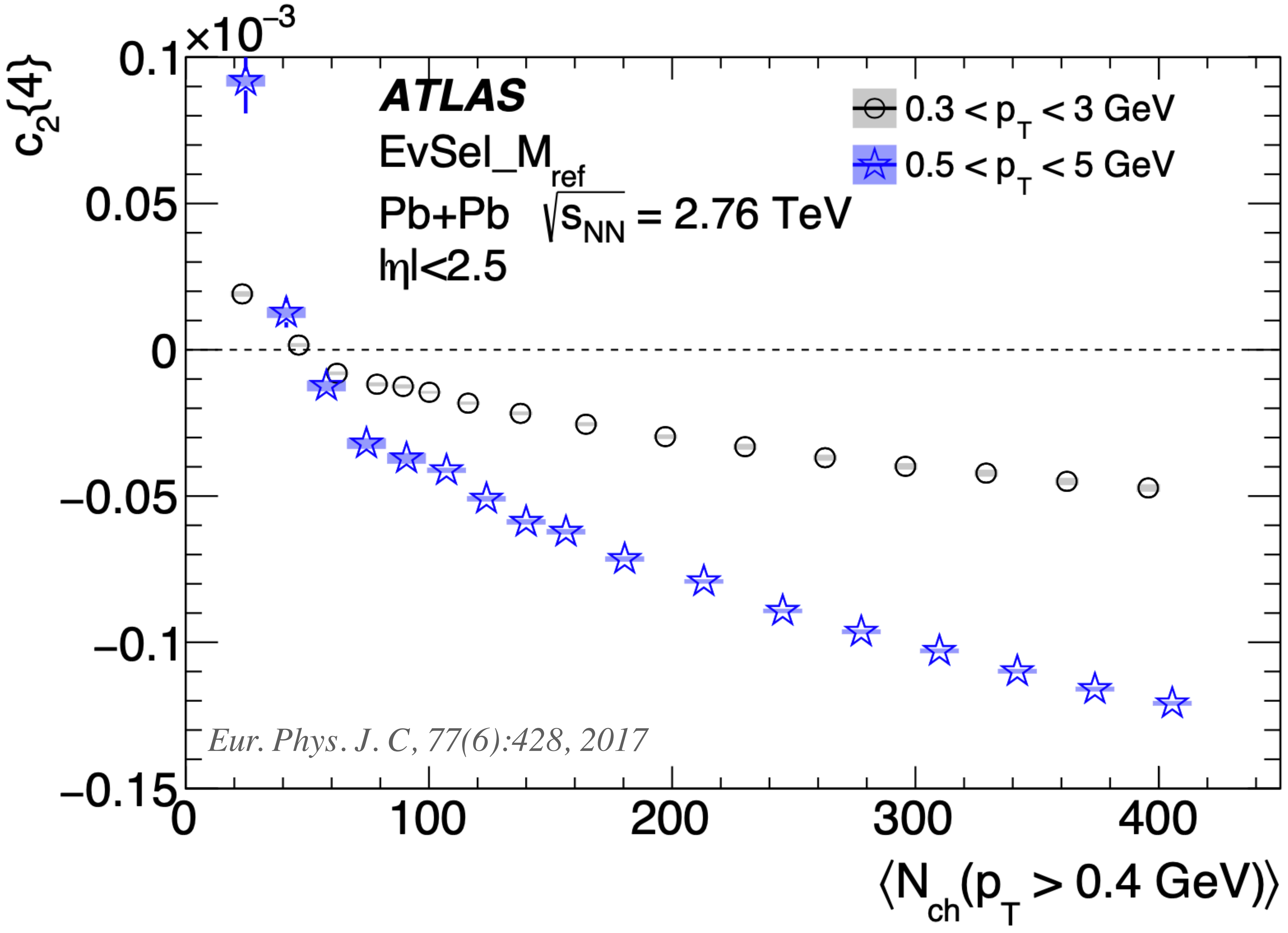
$$c_n\{2\} = \langle\langle 2 \rangle\rangle_{n,-n}$$
$$c_n\{4\} = \langle\langle 4 \rangle\rangle_{n,n,-n,-n} - 2 \cdot \langle\langle 2 \rangle\rangle_{n,-n}^2$$

$$v_n\{2\} = \sqrt{c_n\{2\}} \qquad v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$

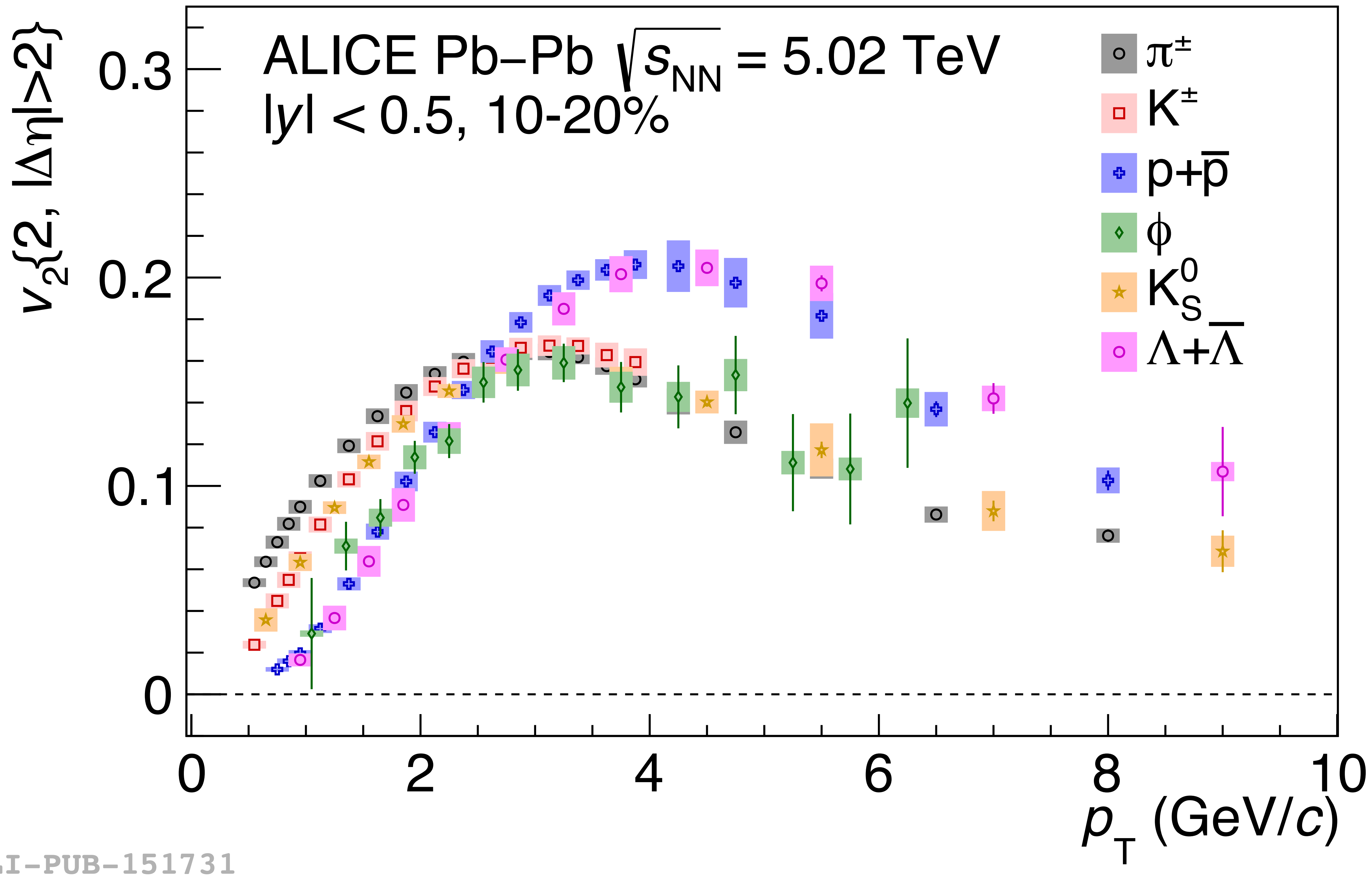
Signs of collectivity in large systems

- Heavy-ion collisions -> collective behaviour (particles are correlated to each other)
- **Collectivity** = "long-range multi-particle correlations"

Negative four-particle cumulant

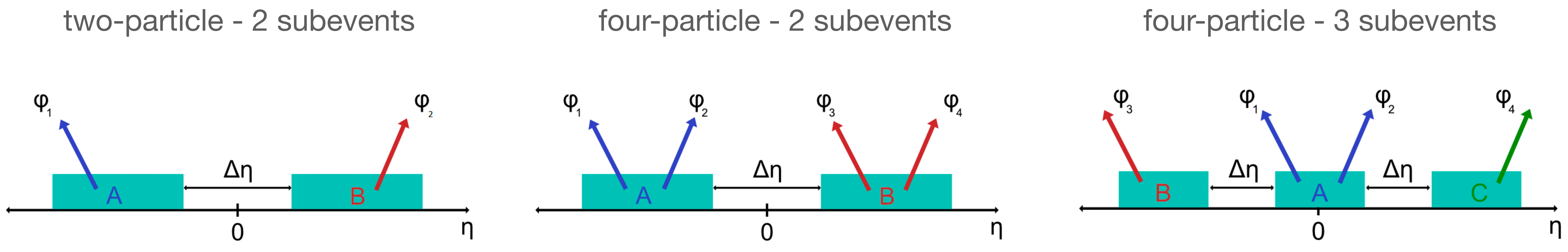


Mass-ordering and baryon-meson splitting in identified flow

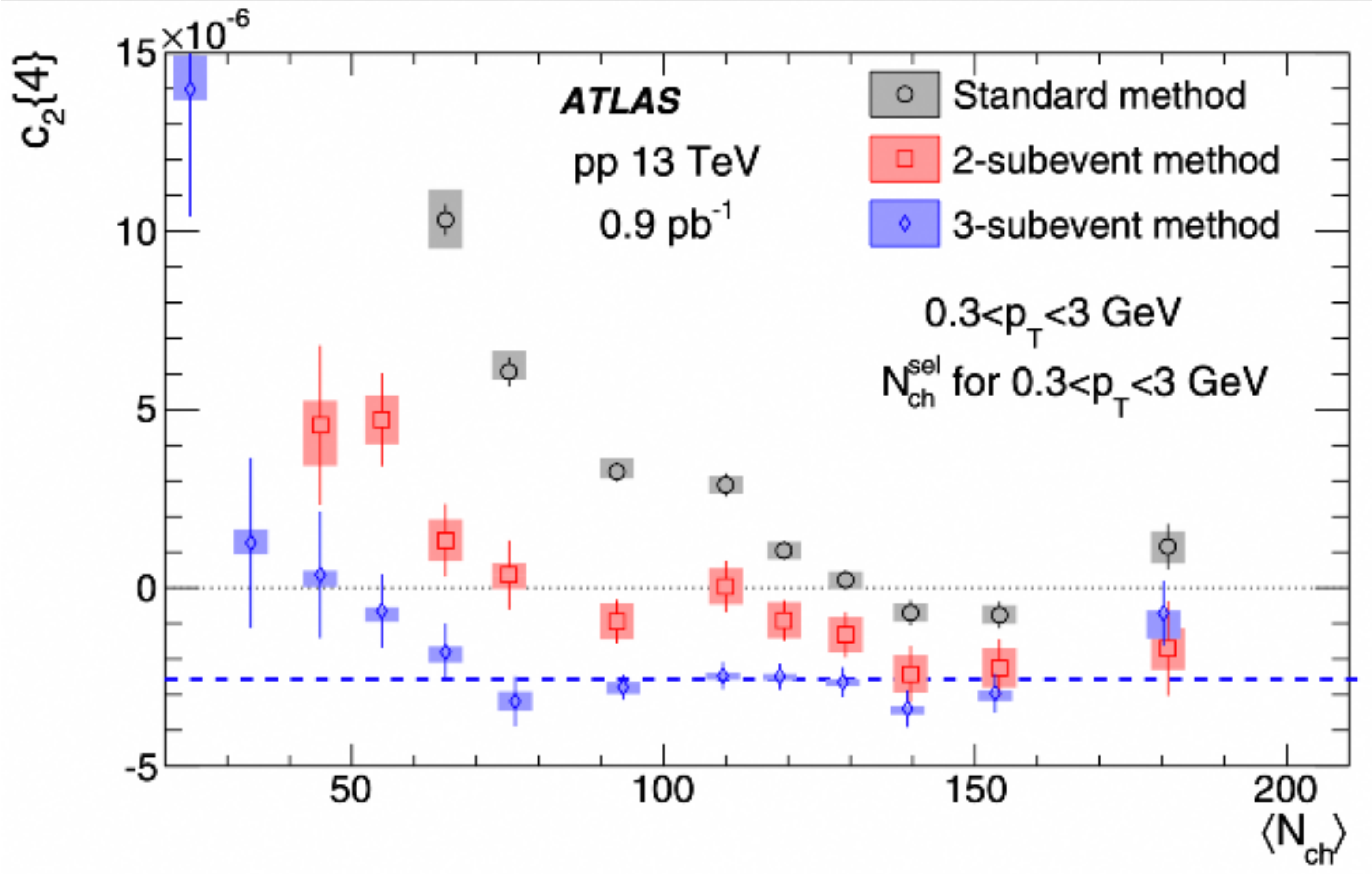


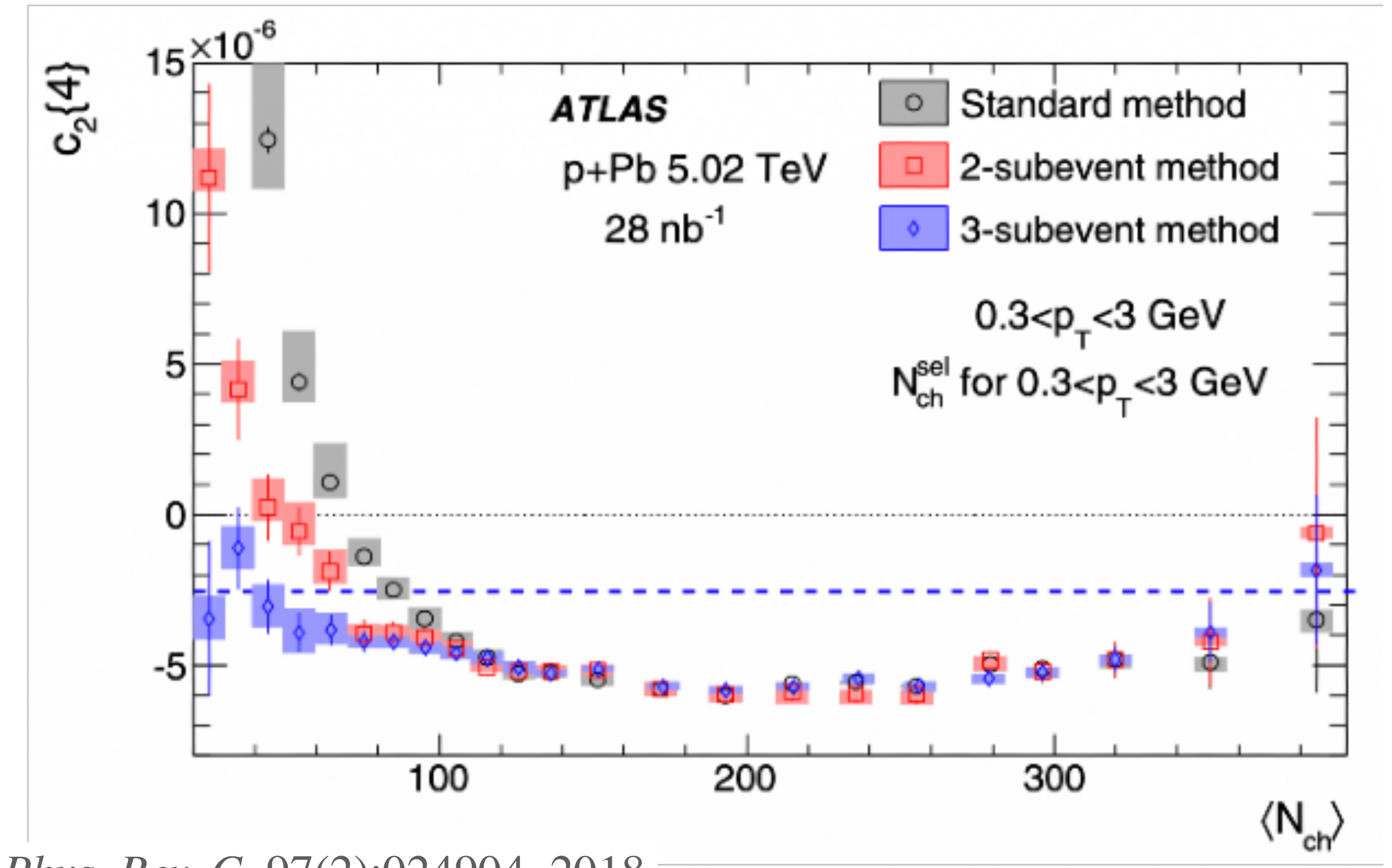
Non-flow suppression

- Measurement of flow is affected by non-flow contamination (mostly short-range correlations) caused by jets, decays, etc. -> increase of the flow signal
- Non-flow can be suppressed by multi-particle correlations (2-particle correlation is more sensitive to non-flow than 4-particle correlation)
- Subevent method - splitting pseudorapidity acceptance into two or more regions separated by η-gap



Hints of collectivity in small systems

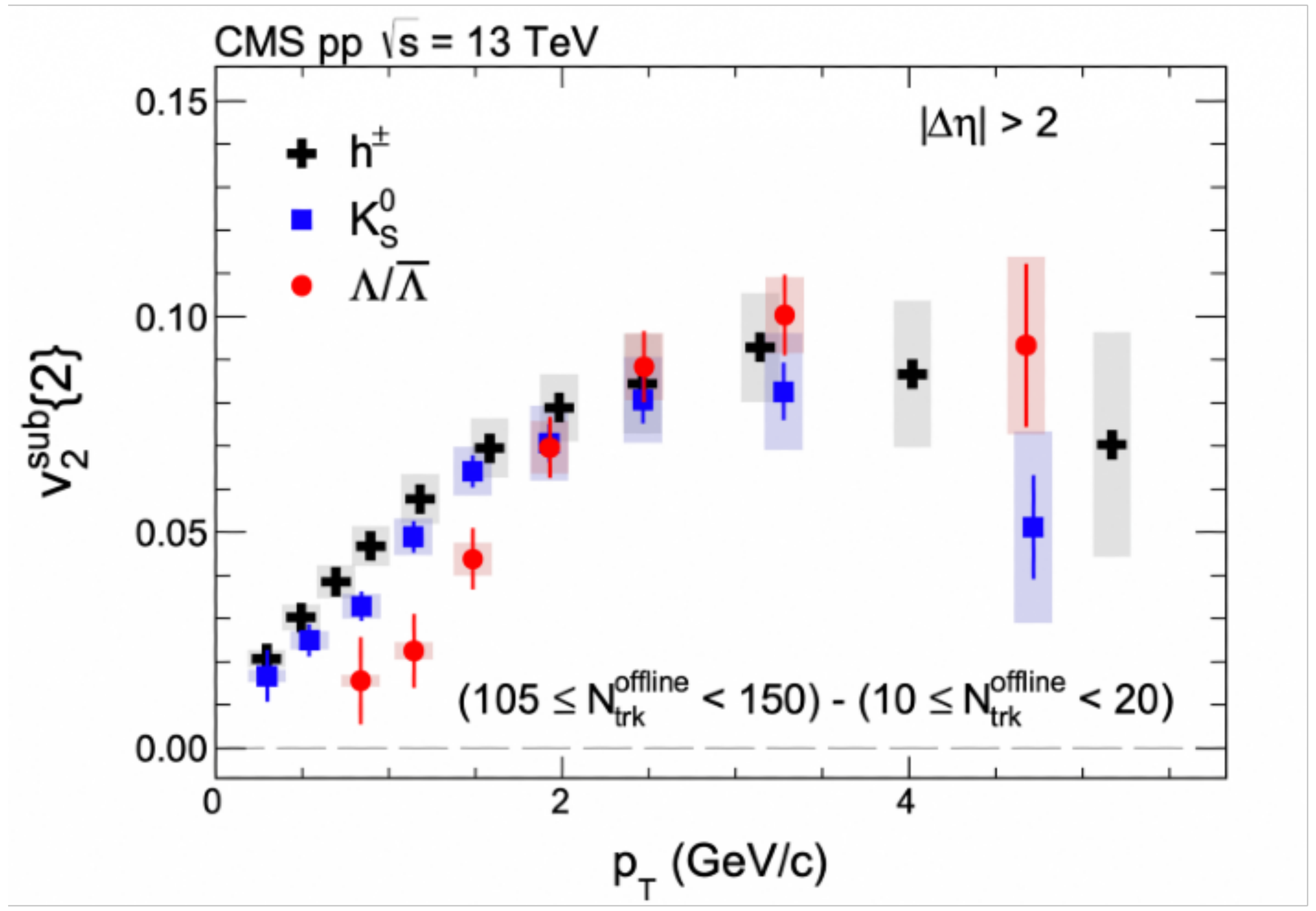




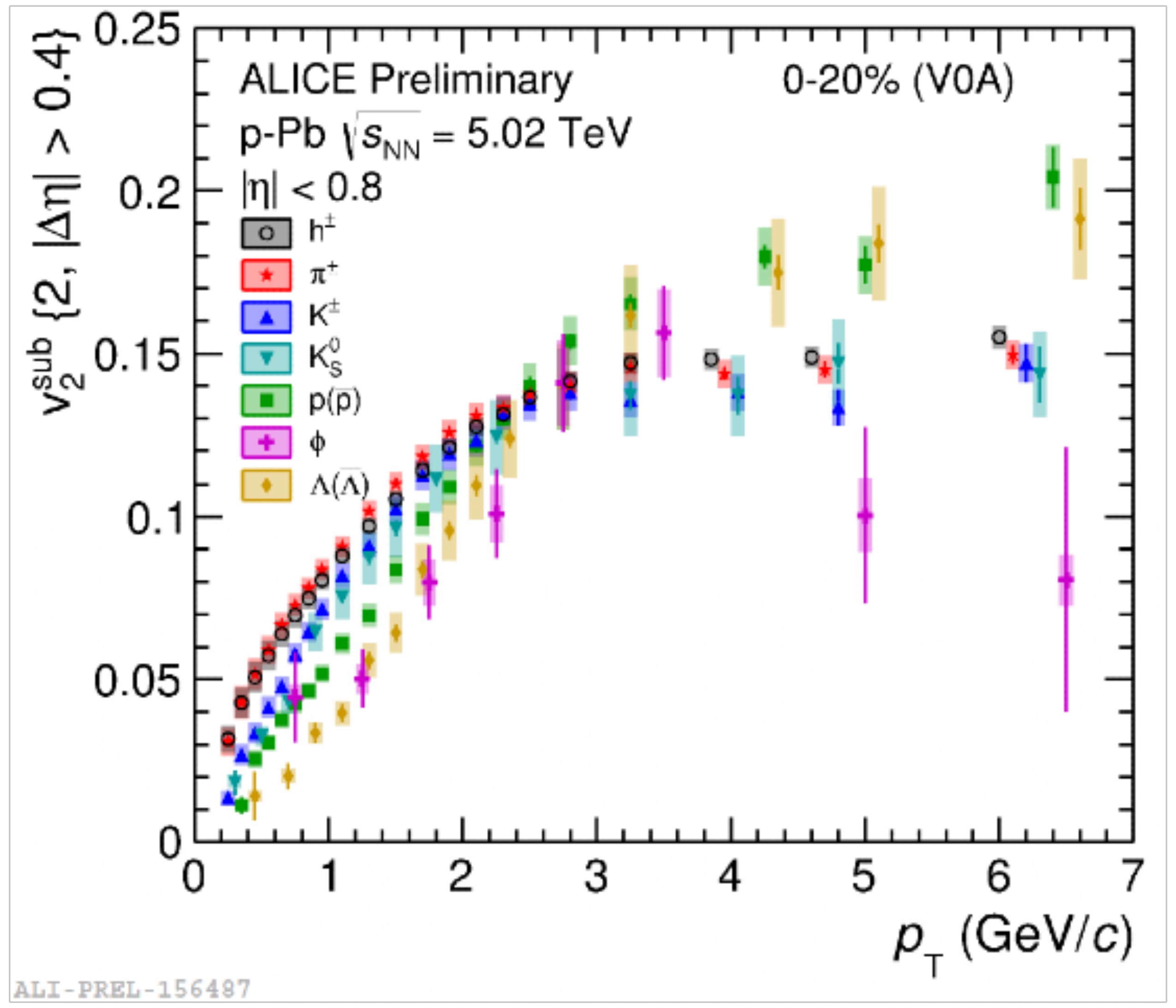
Phys. Rev. C, 97(2):024904, 2018

Negative four-particle cumulant

pp - pPb



Phys. Lett. B, 765:193–220, 2017

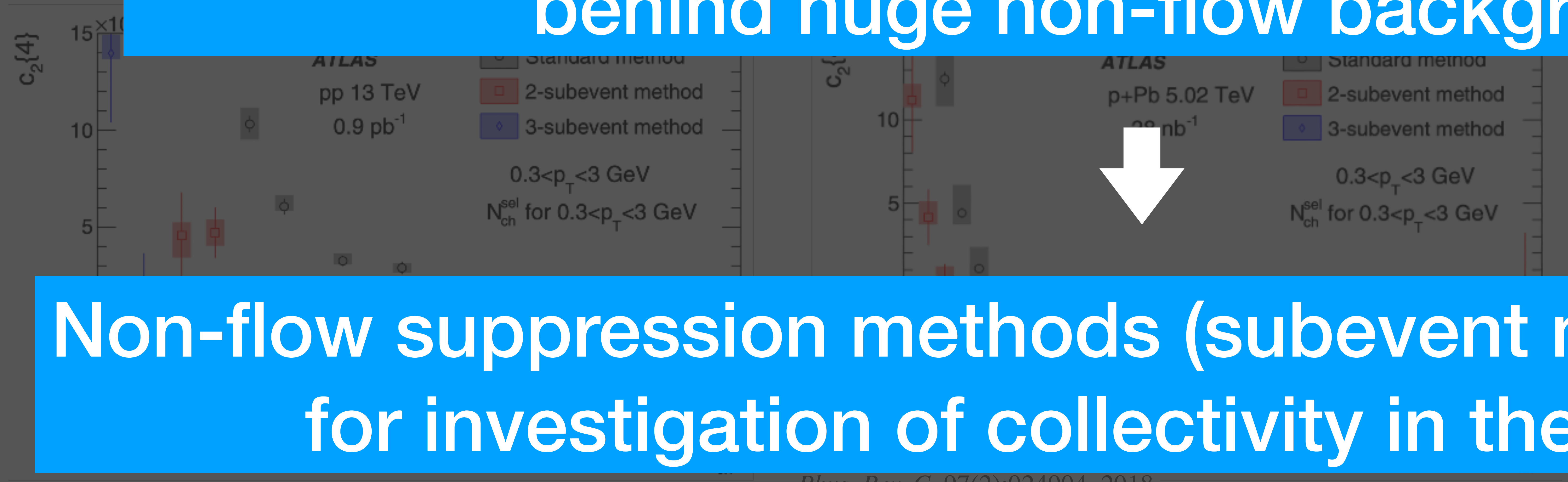


Mass-ordering and baryon-meson splitting in identified flow

pp - pPb

H

Signs of collectivity in small collision systems are hidden behind huge non-flow background



Negative four-particle cumulant

Non-flow suppression methods (subevent method) are crucial for investigation of collectivity in these systems

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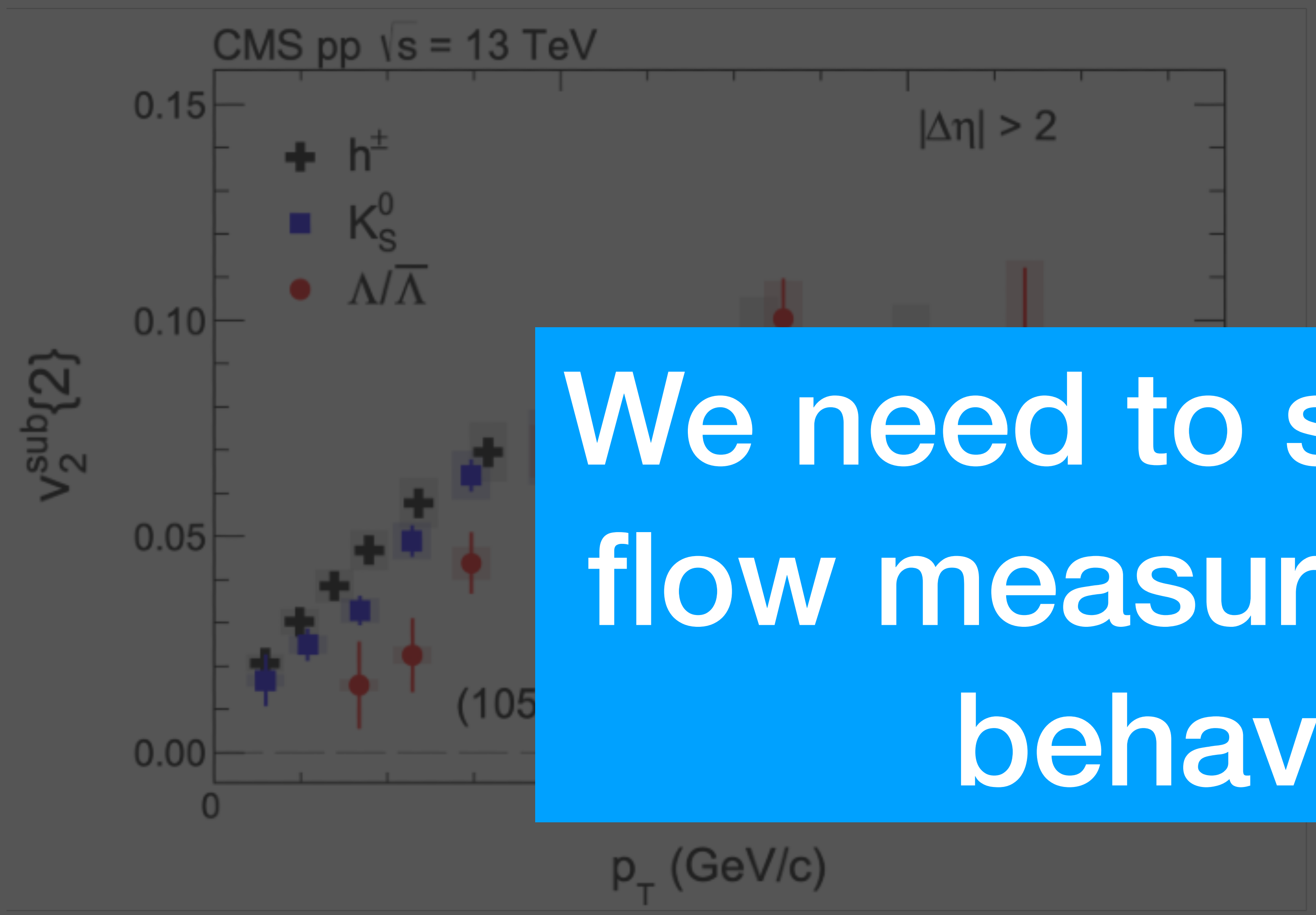
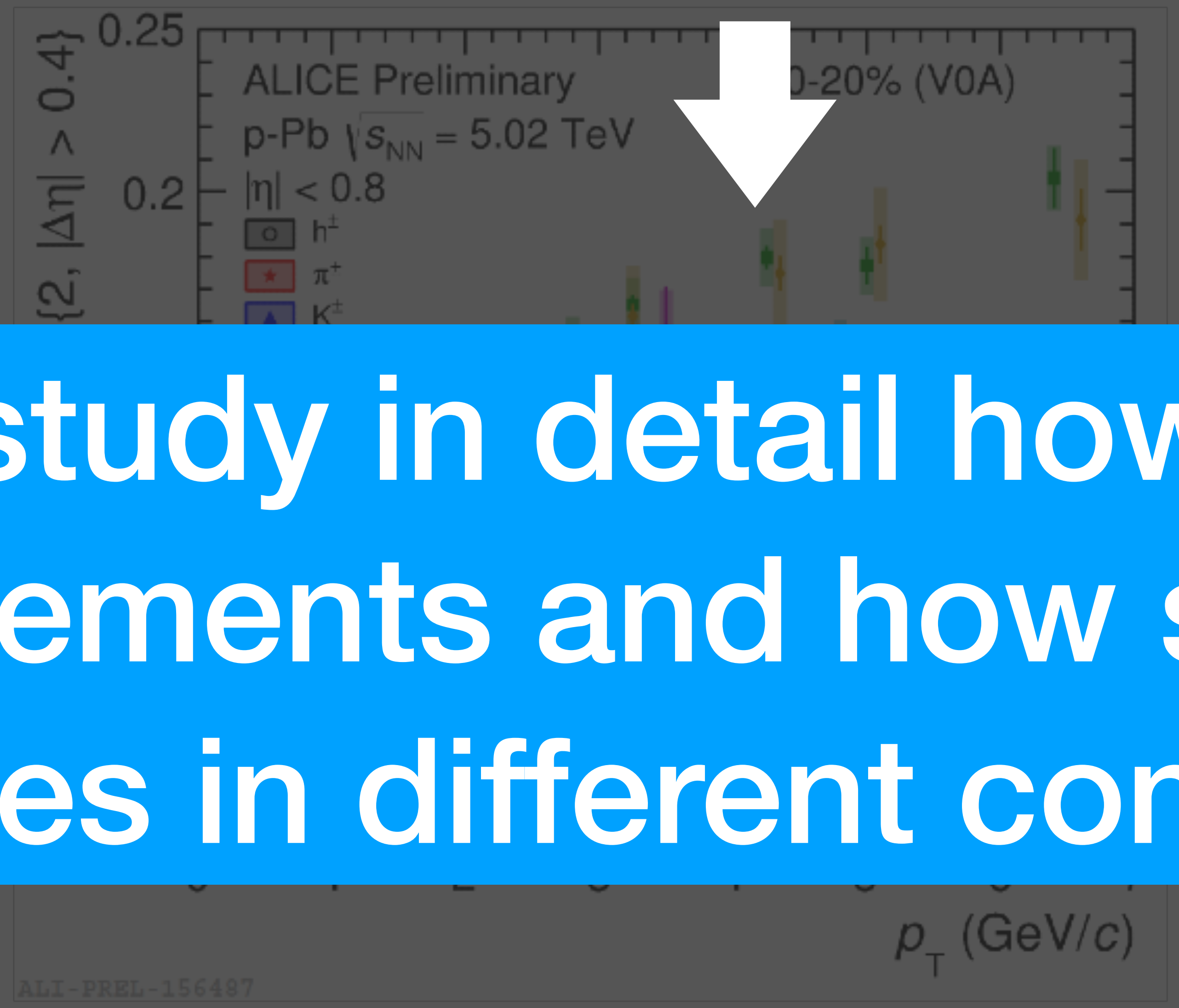




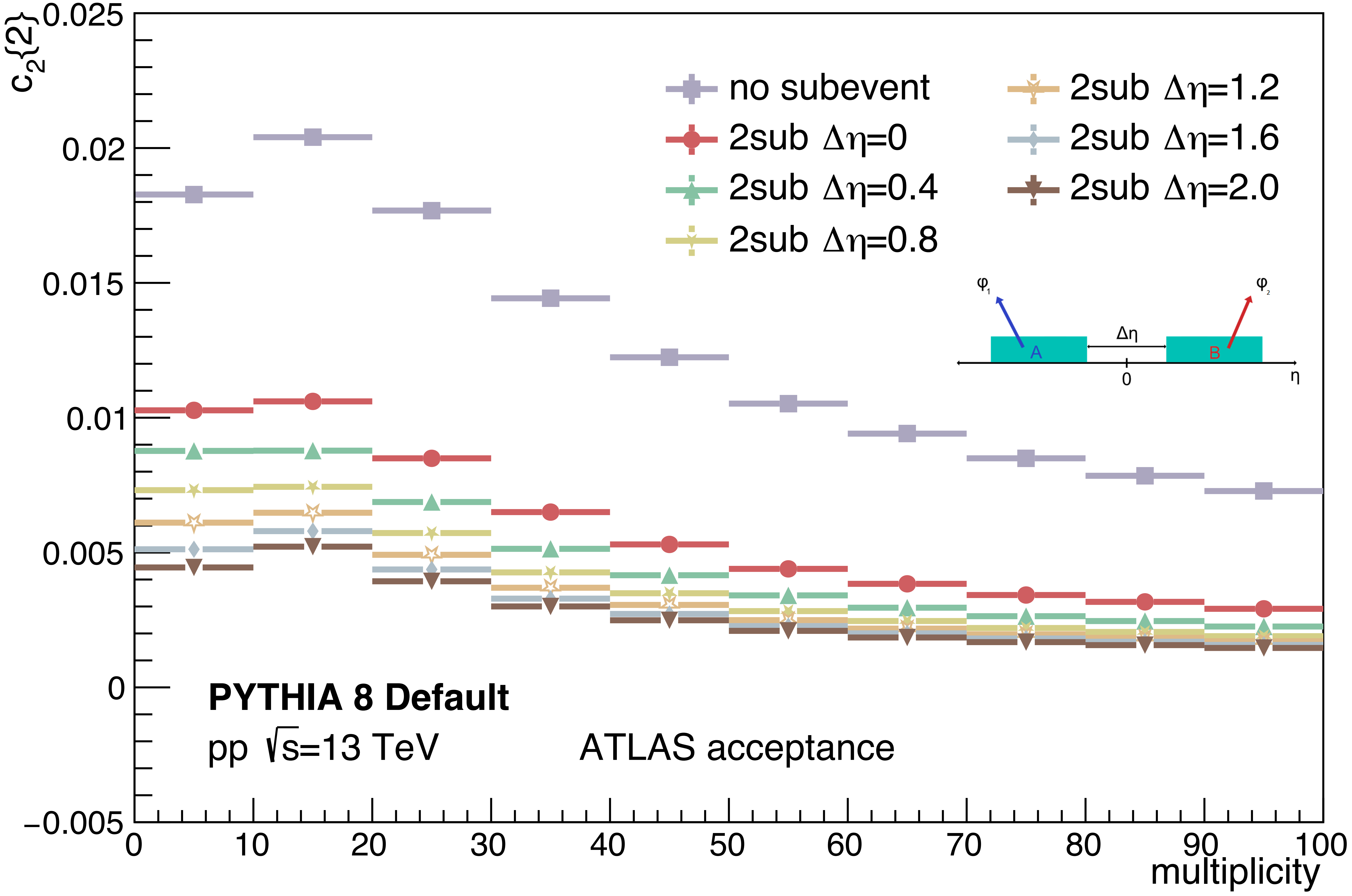
Mass ordering and baryon-meson ... ied flow

We need to study in detail how non-flow affects flow measurements and how subevent method behaves in different configurations

Phys. Lett. B, 765:193–220, 2017

Results - Two-particle cumulant

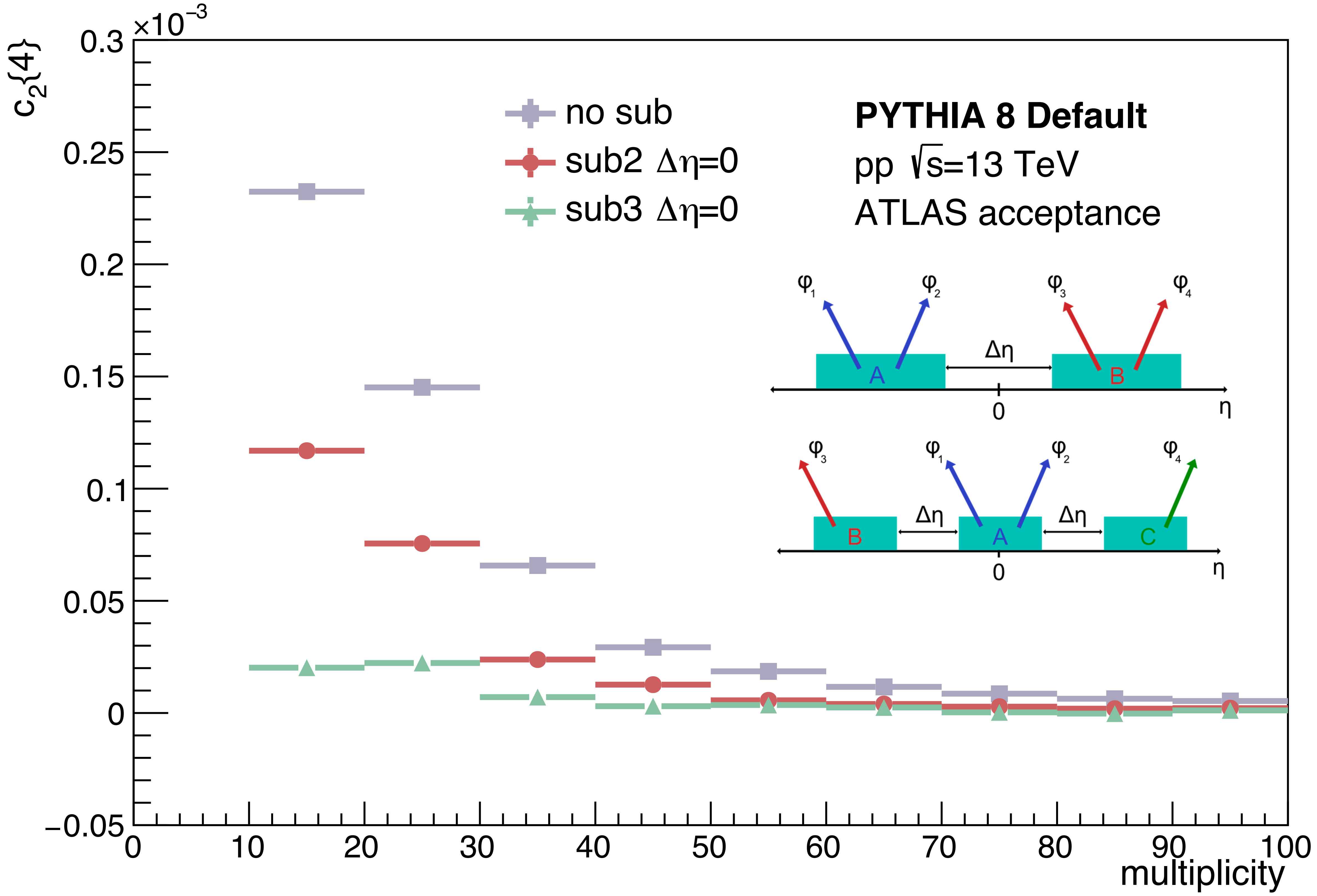
ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$

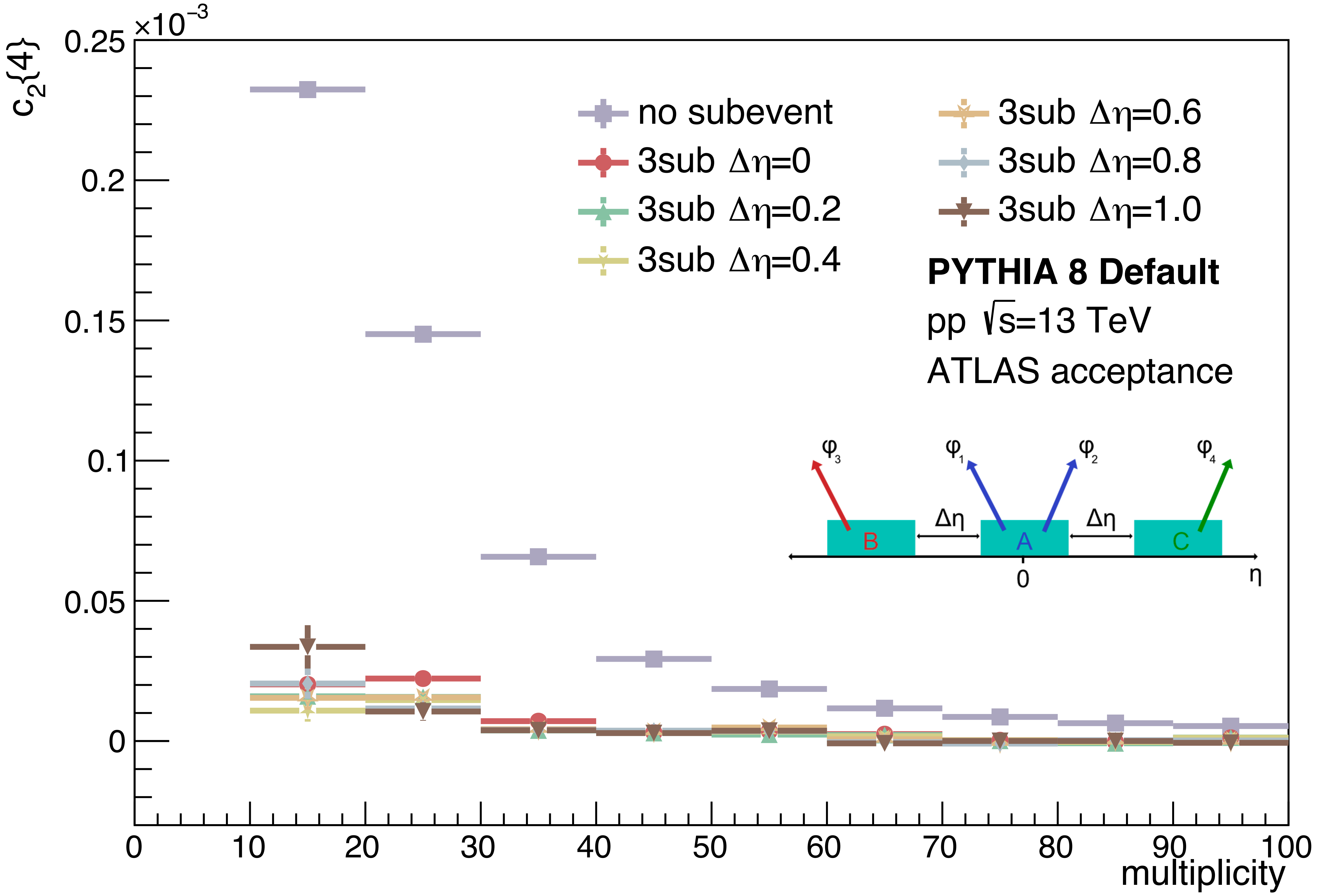


- Bigger η-gap -> better non-flow suppresion

Results - Four-particle cumulant

ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$





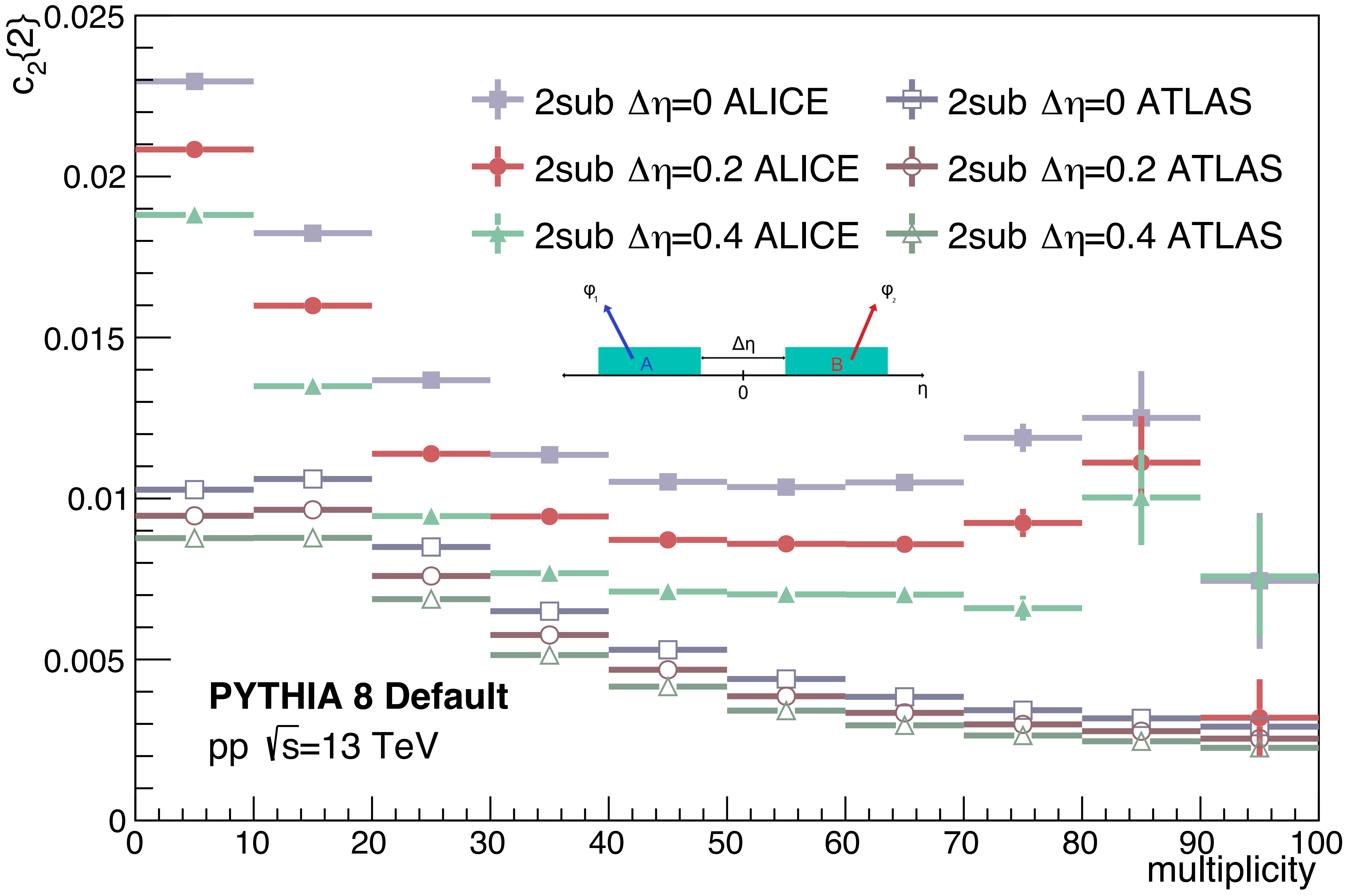
- Cumulant compatible with zero, but not negative
- 3-subevent method suppresses even di-jets

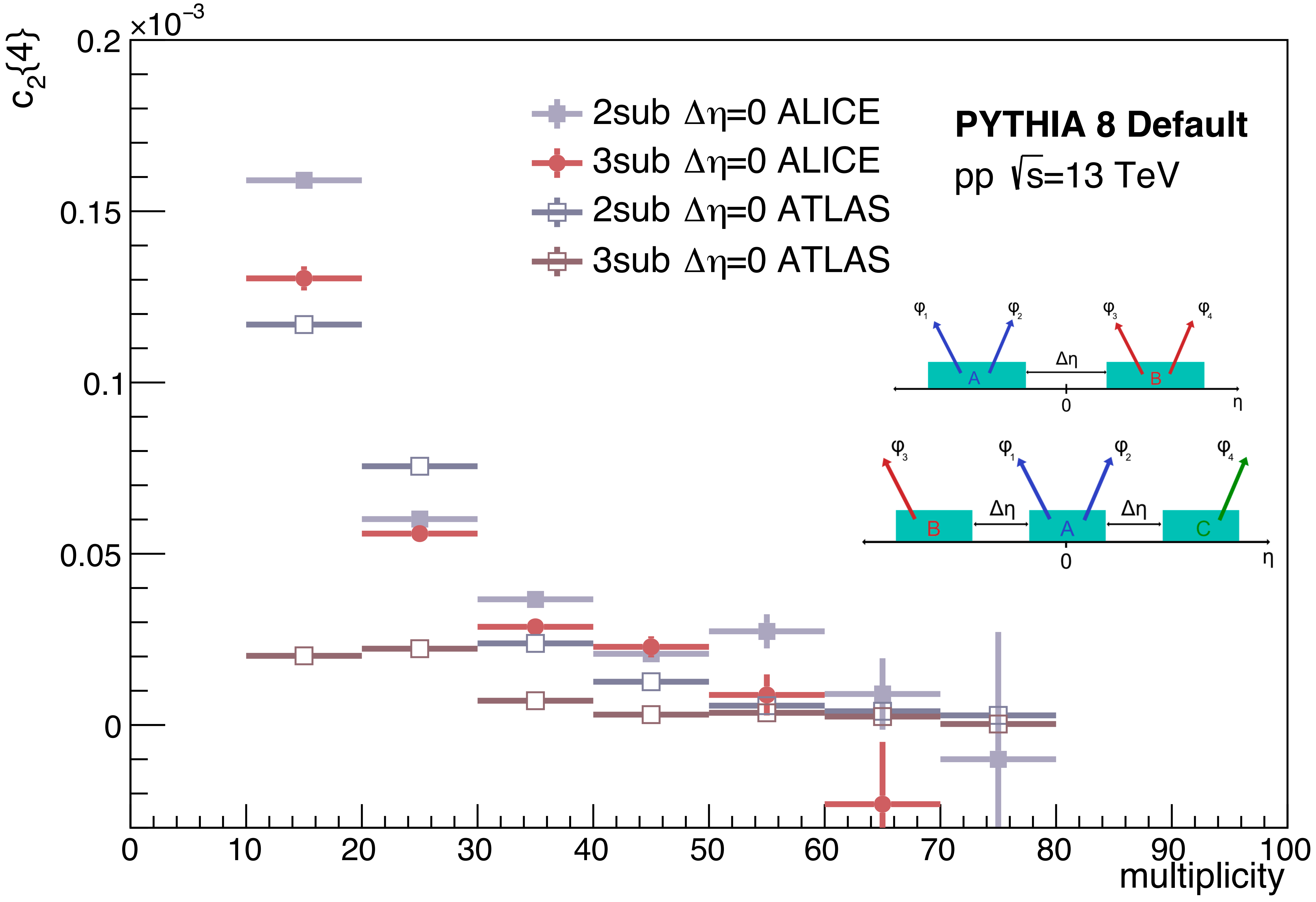
- Increase of signal for larger η-gap due to specific specific selection of particles (possibly due to 3-jets inclusion)

Results - ALICE vs ATLAS

ALICE acceptance
0.3 < pT < 3 GeV
$|\eta| < 0.8$

ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$

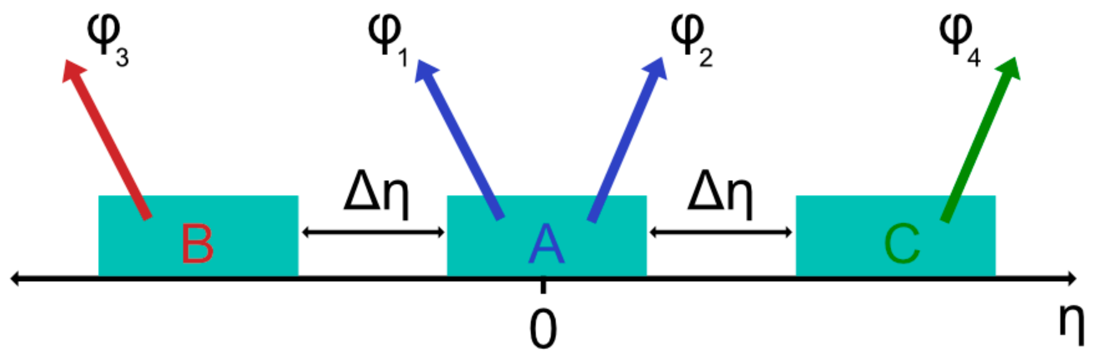




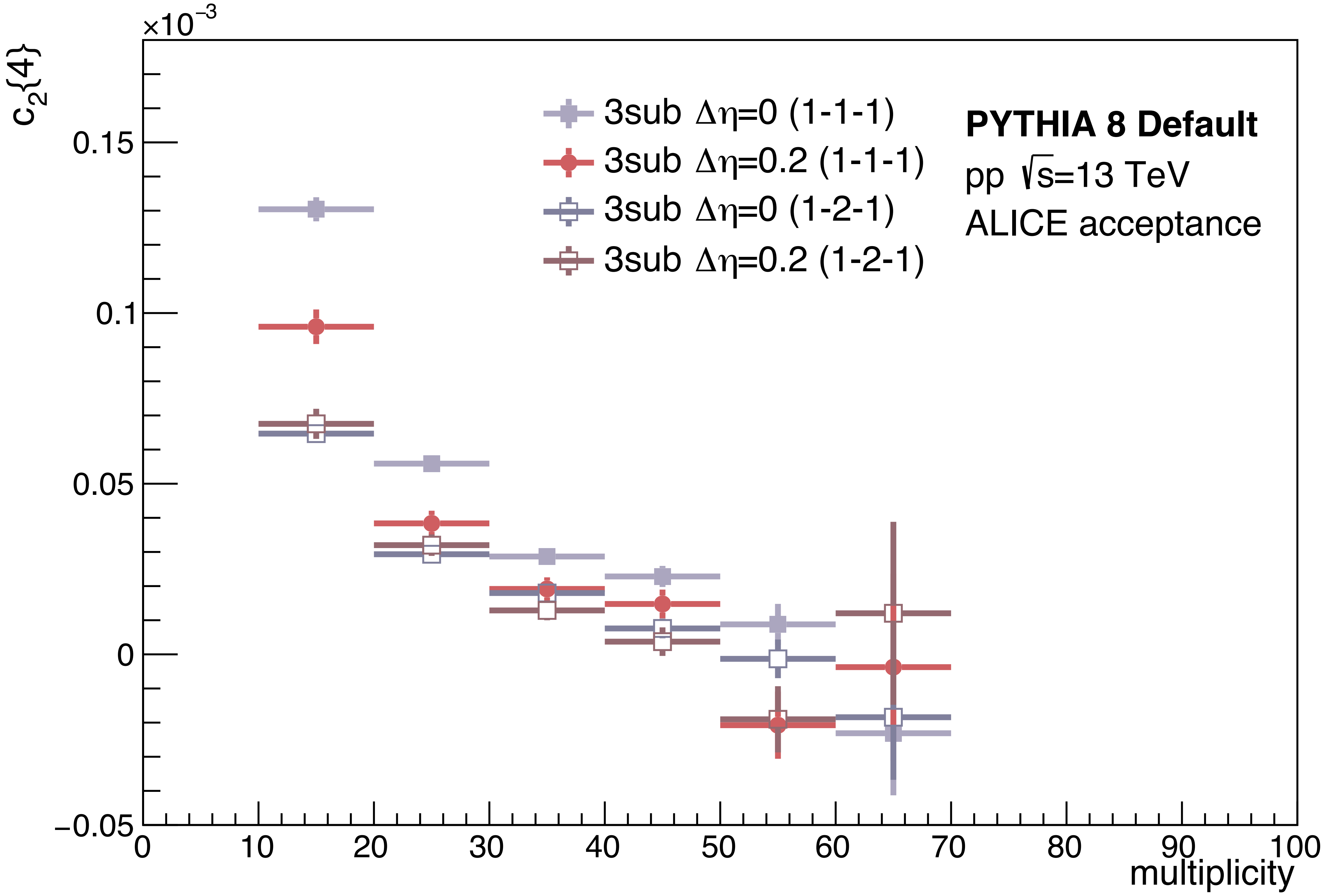
- Smaller acceptance of ALICE -> larger non-flow contamination -> higher cumulants and larger non-flow suppression

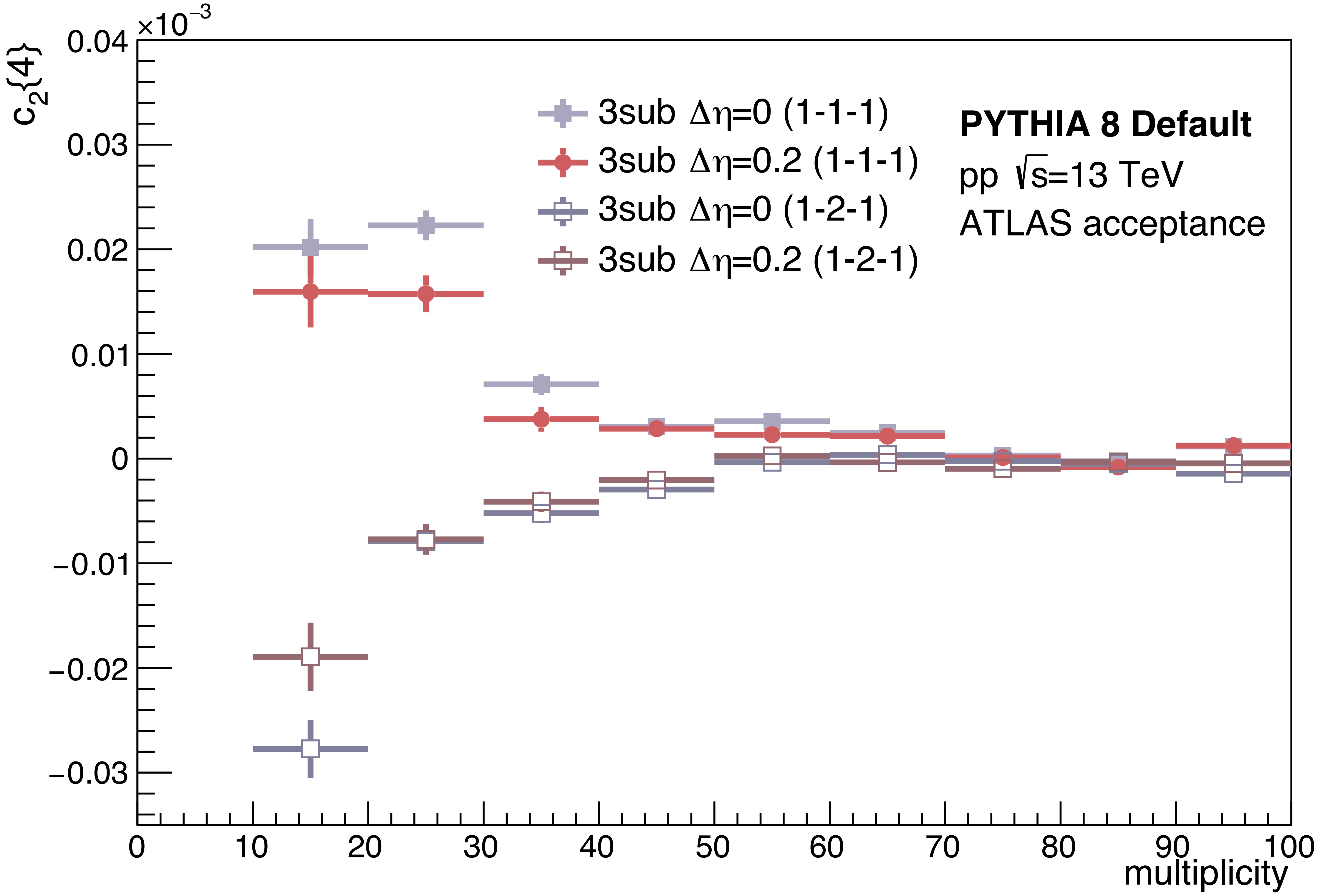
- ATLAS - Larger magnitude of non-flow suppression
- Cumulant compatible with zero, but not negative

Results - 3-subevent method



- Study of two 3-subevent method configurations:
  - (1-1-1) -> all subevents of the same size (ATLAS)
  - (1-2-1) -> middle subevent twice as large as others (ALICE)

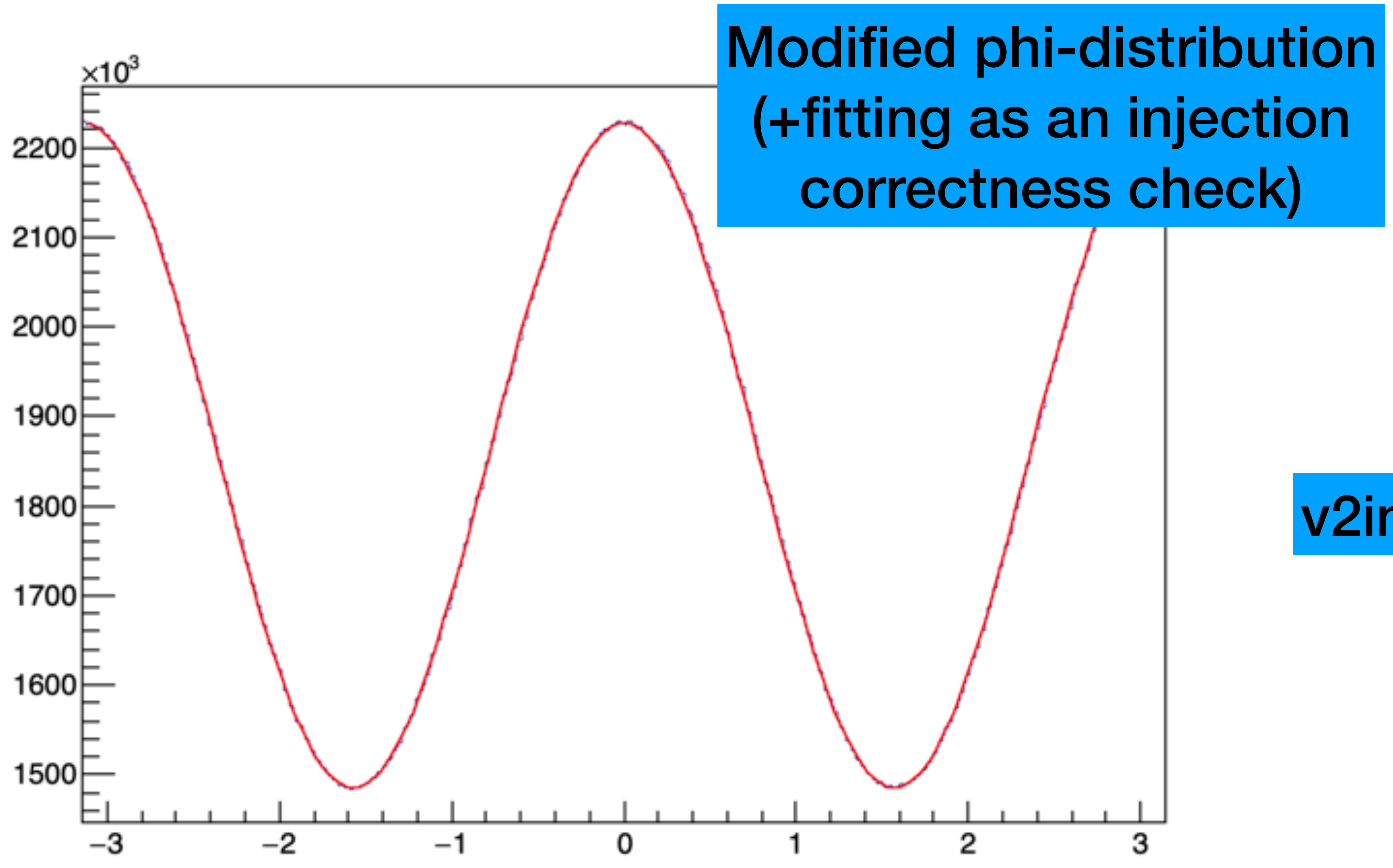


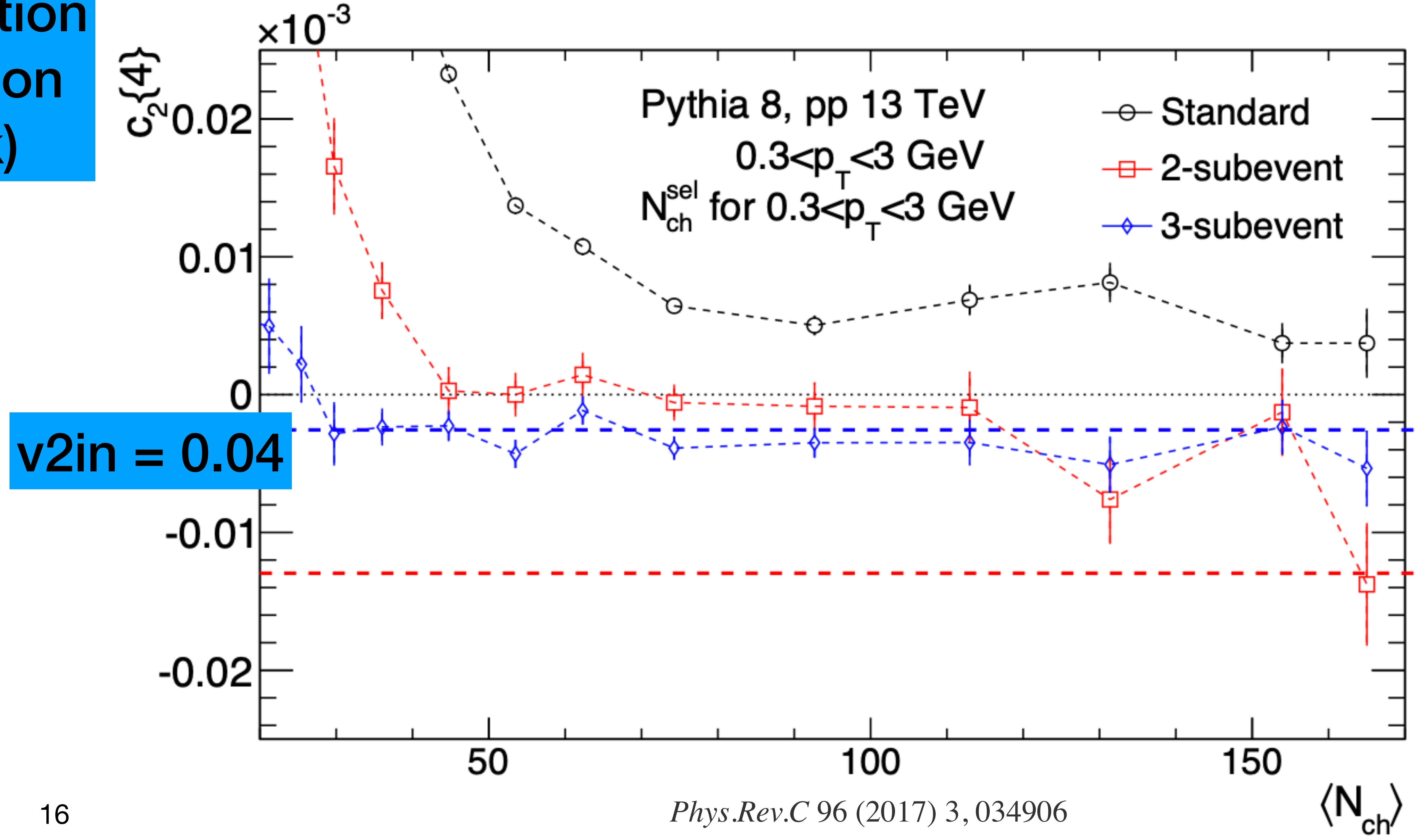


- (1-2-1) - globally lower cumulant -> important difference between these configurations
- Negative values for ATLAS acceptance possibly due to long-range non-flow contamination

Injected elliptic flow

- Method: modification of phi-distribution in order to introduce flow into PYTHIA
  $\varphi = \varphi_0 - \tilde{v}_2 \sin[2(\varphi - \Psi_{RP})]$ -> numeric solution (Newton method)
- Motivation: to study which configuration of subevent method reconstructs introduced flow signal best

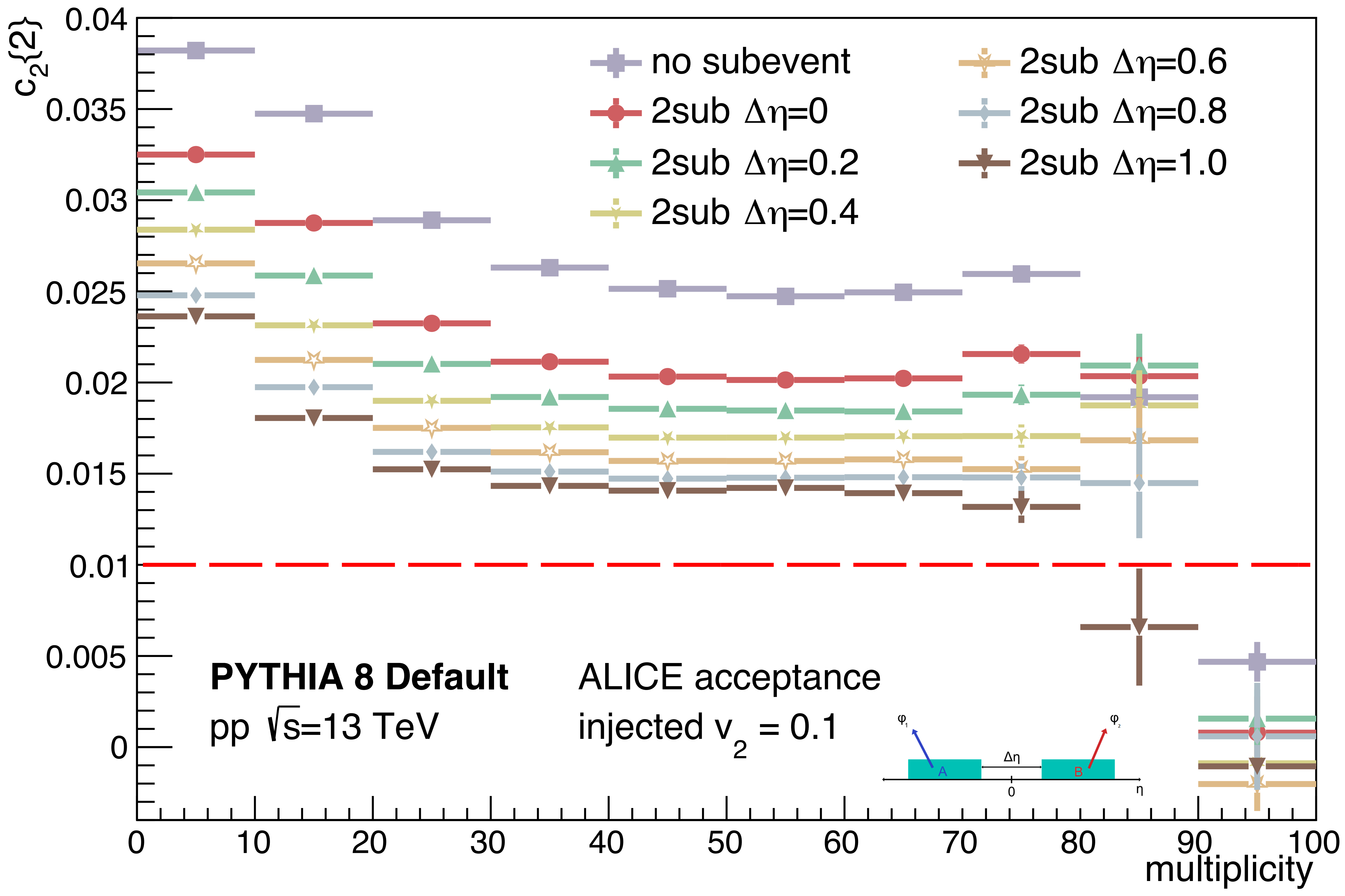


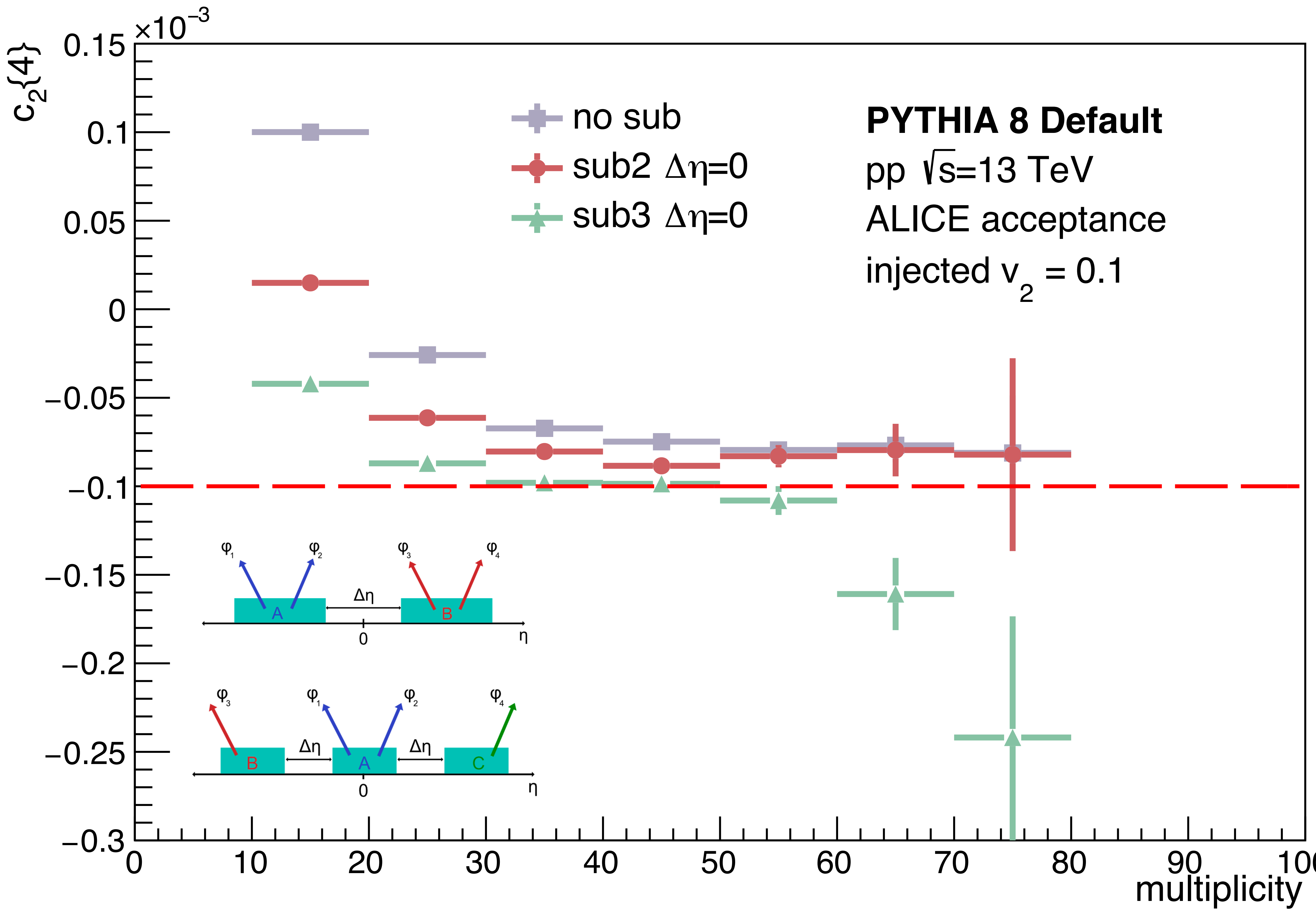


Phys.Rev.C 96 (2017) 3, 034906

Results - Injected flow ALICE

ALICE acceptance
0.3 < pT < 3 GeV
$|\eta| < 0.8$

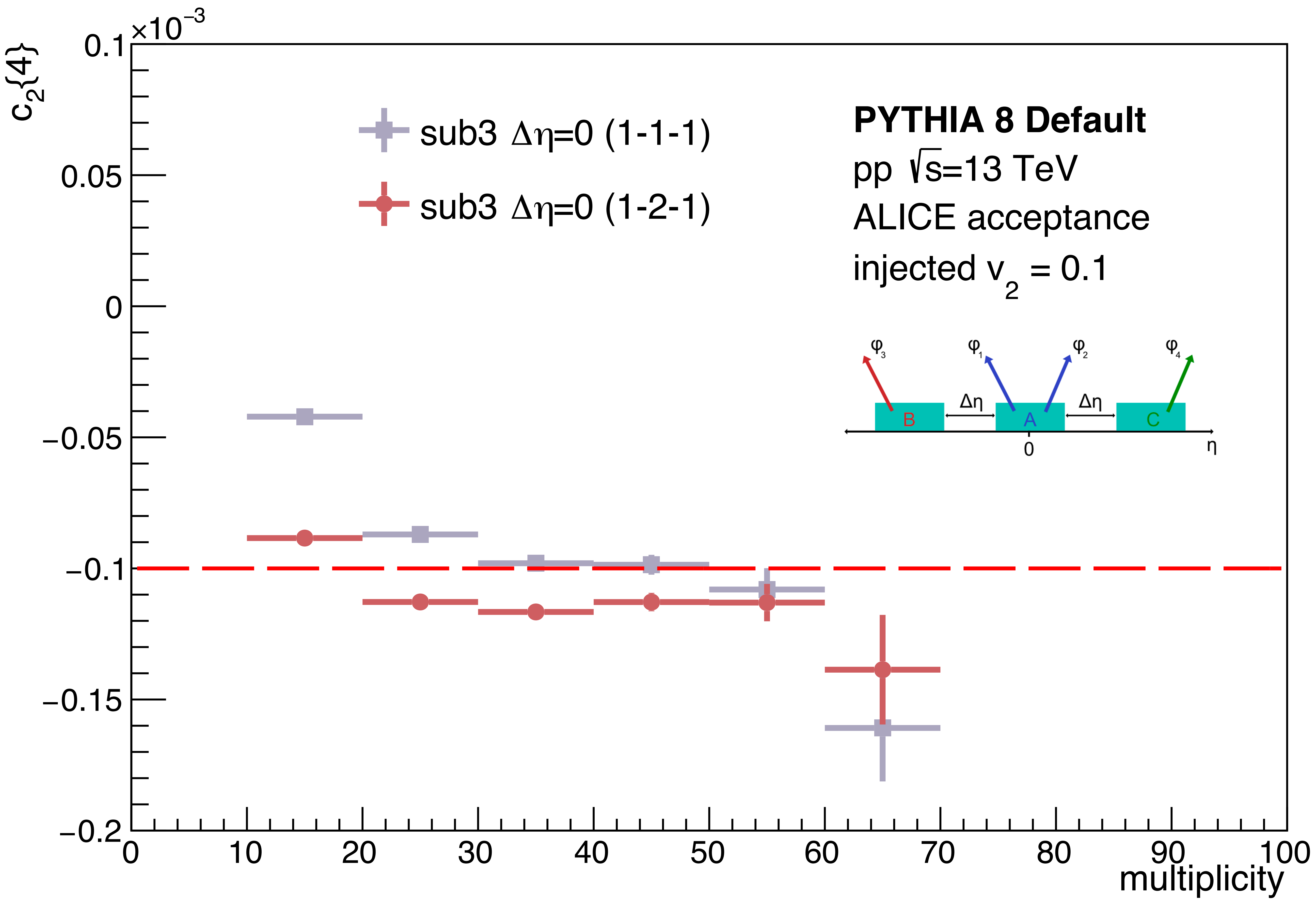




- Two-particle cumulant: remaining non-flow contamination even for the biggest η-gap
- Four-particle cumulant: bins 30-60 compatible with injected flow signal, low multiplicity events contaminated by non-flow

Results - Injected flow ALICE

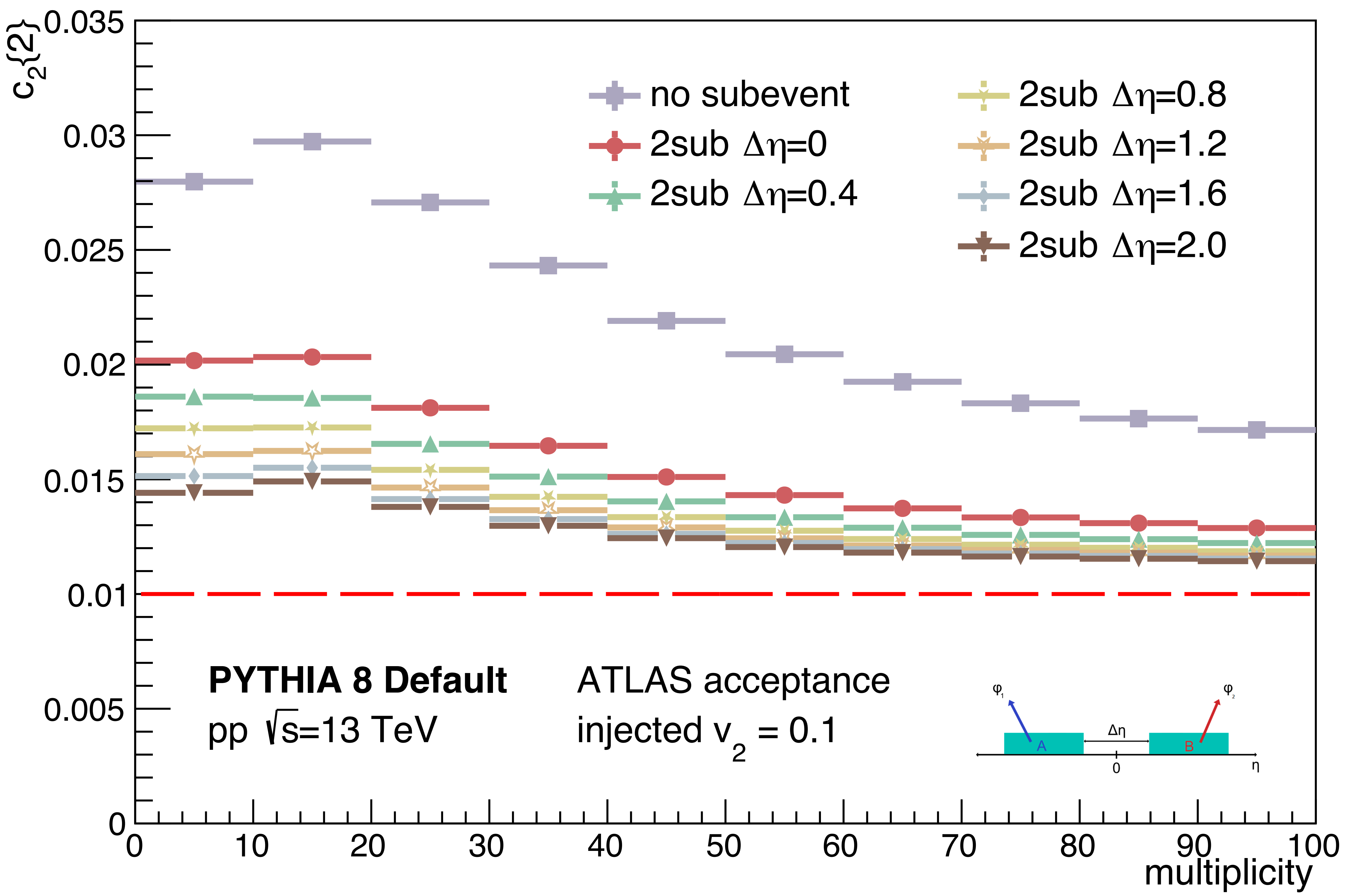
ALICE acceptance
0.3 < pT < 3 GeV
$|\eta| < 0.8$

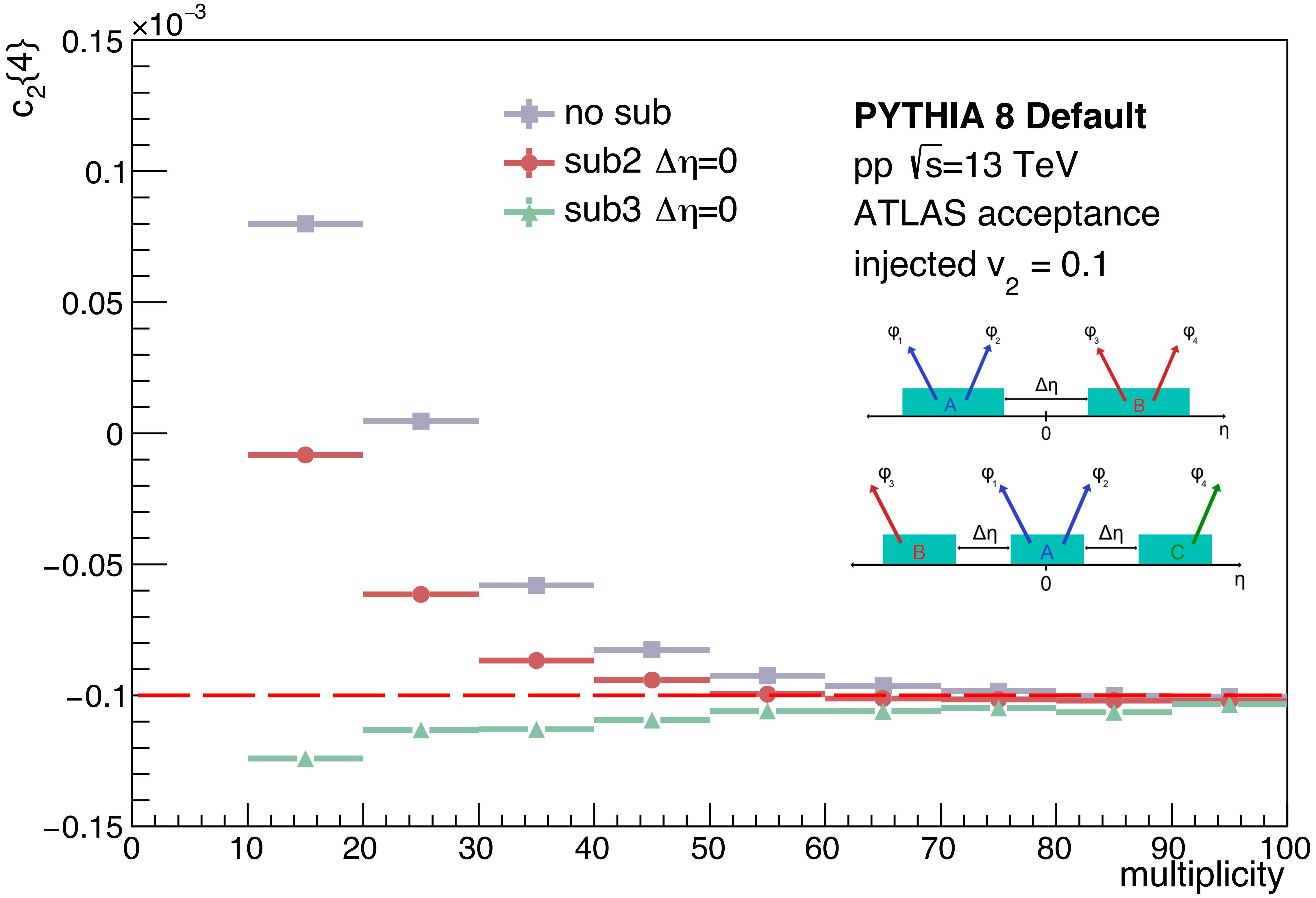


- (1-2-1) configuration underestimates injected signal
- Both configurations show sudden decrease of signal in high multiplicity collisions -> large uncertainties

Results - Injected flow ATLAS

ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$

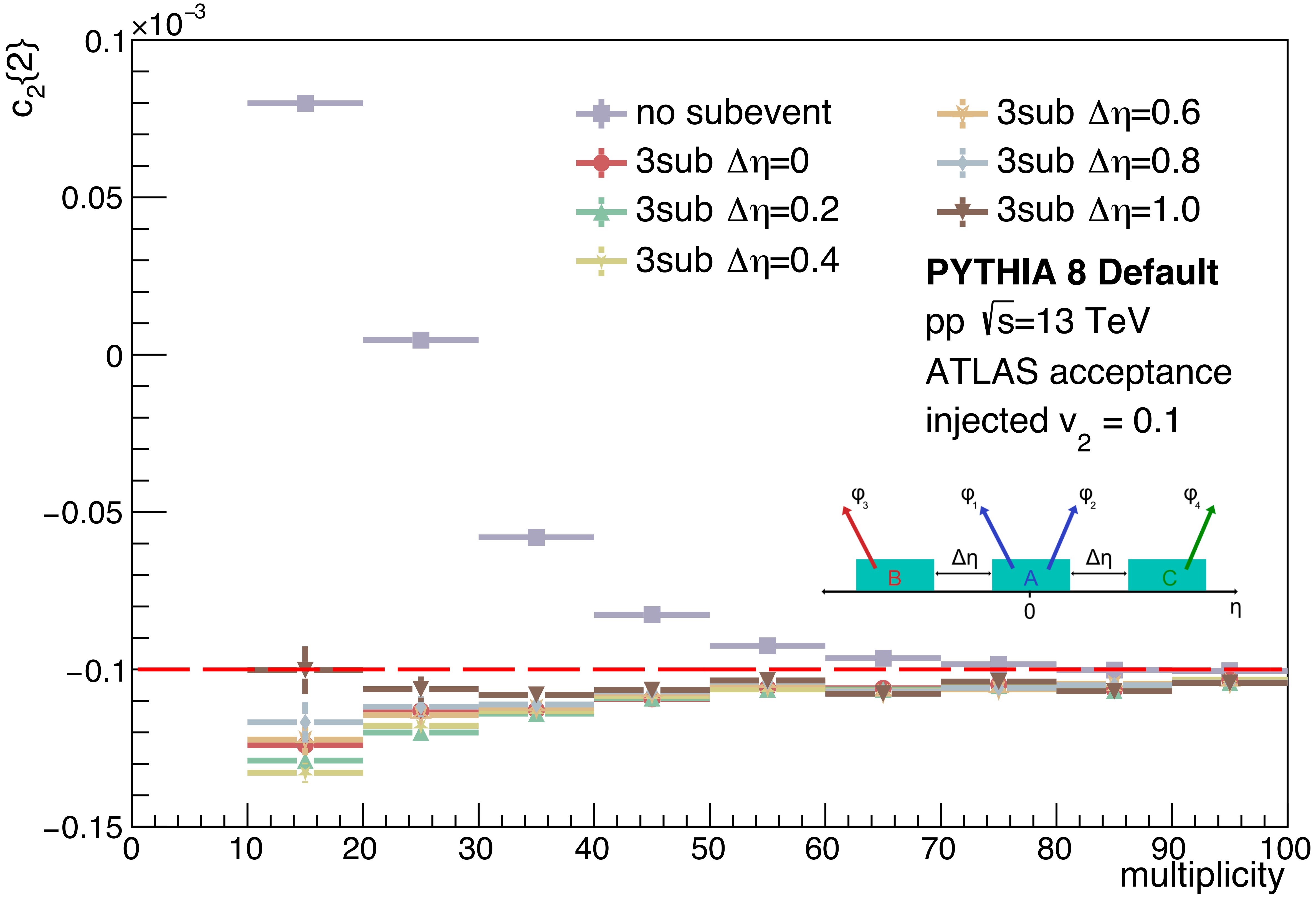


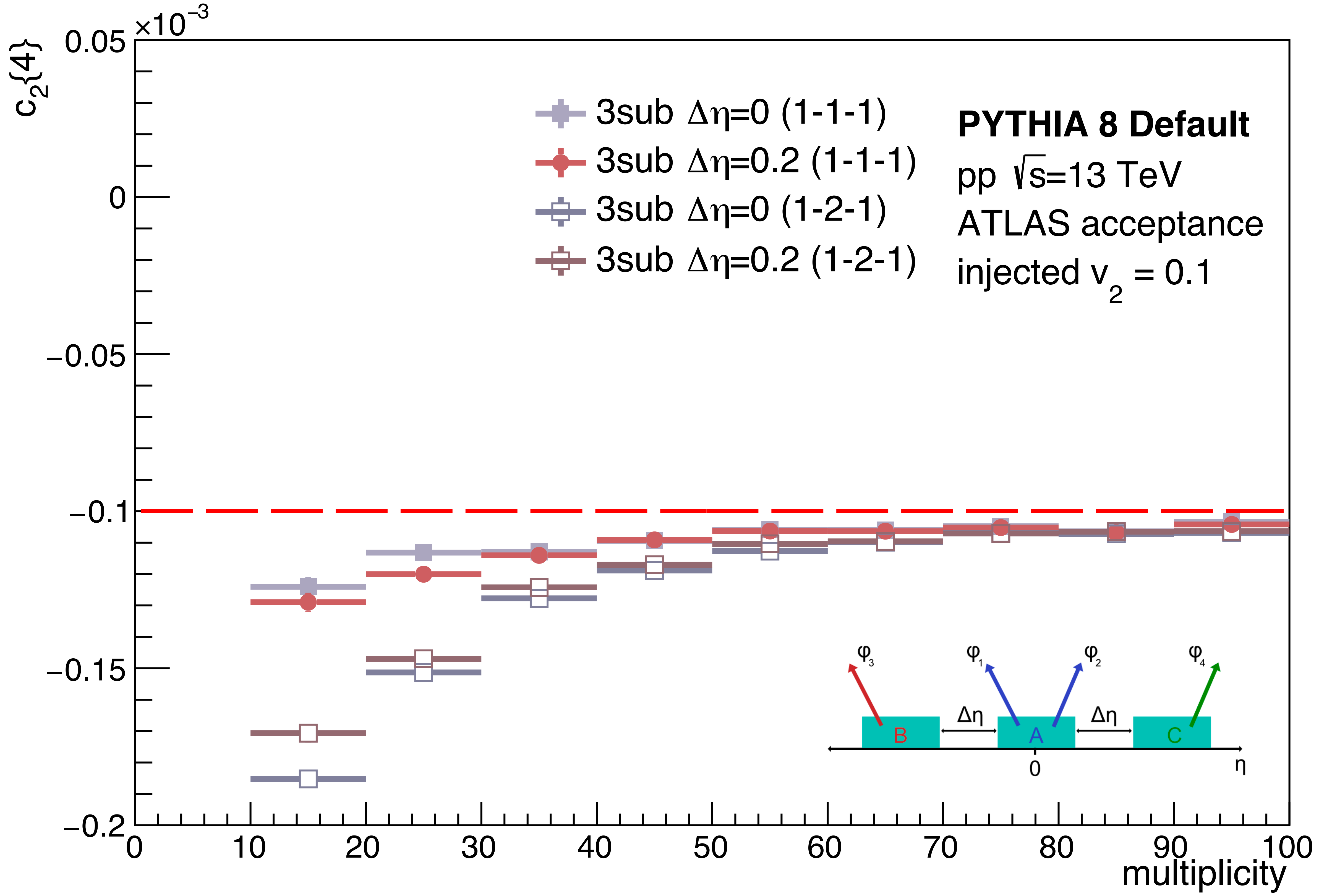


- Two-particle cumulant: similar non-flow contamination as in ALICE results
- Four-particle cumulant: injected signal reverted the trend for 3-subevent method in low multiplicity collisions -> to be investigated

Results - Injected flow ATLAS

ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$





- The size of η-gap is "compensating" signal decrease -> to be investigated
- Decreasing trend for 3-subevent method is even stronger for (1-2-1) configuration

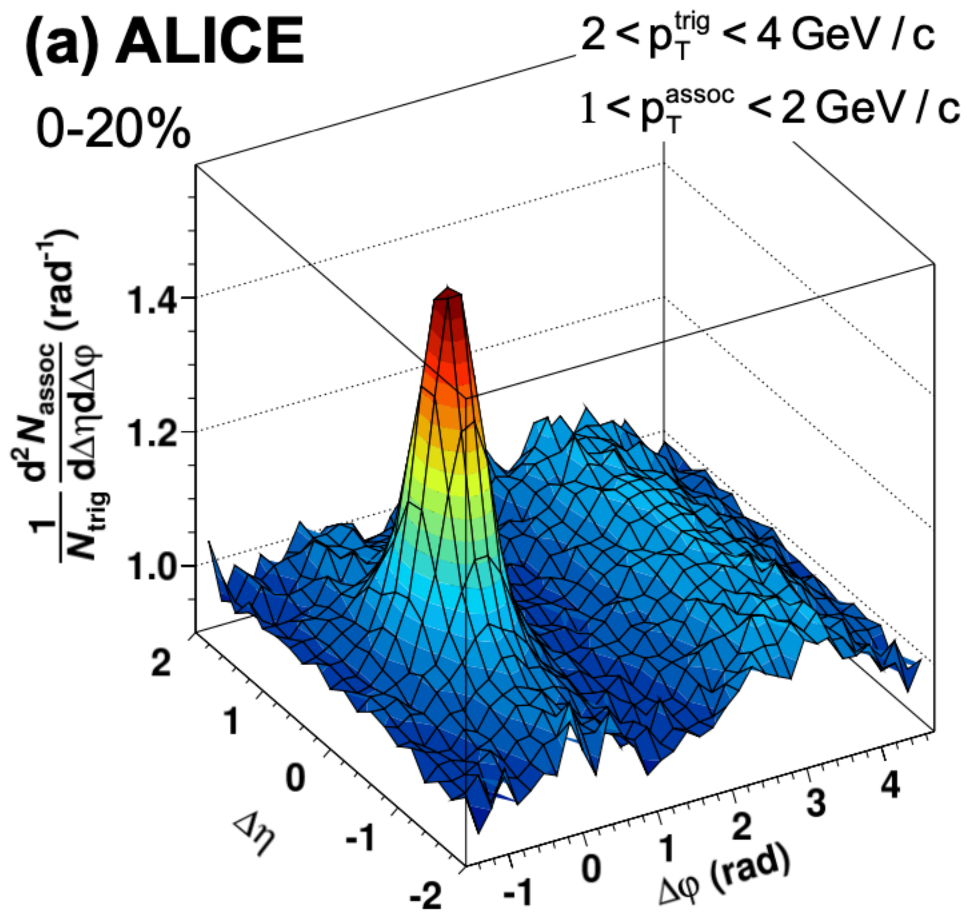
Conclusion

- Subevent method - larger non-flow suppression with larger η-gap
- Comparison of ATLAS and ALICE acceptances - smaller acceptance leads to higher cumulants due to larger non-flow contamination
- Different configurations of 3-subevent method have significant impact on cumulants
- Injected flow
    - 2-subevent method cannot fully suppress non-flow signal in measurement of two-particle cumulant
    - (1-2-1) configuration of 3-subevent method underestimates injected flow signal
- **Outlook** - influence of jets on the method of multi-particle cumulants

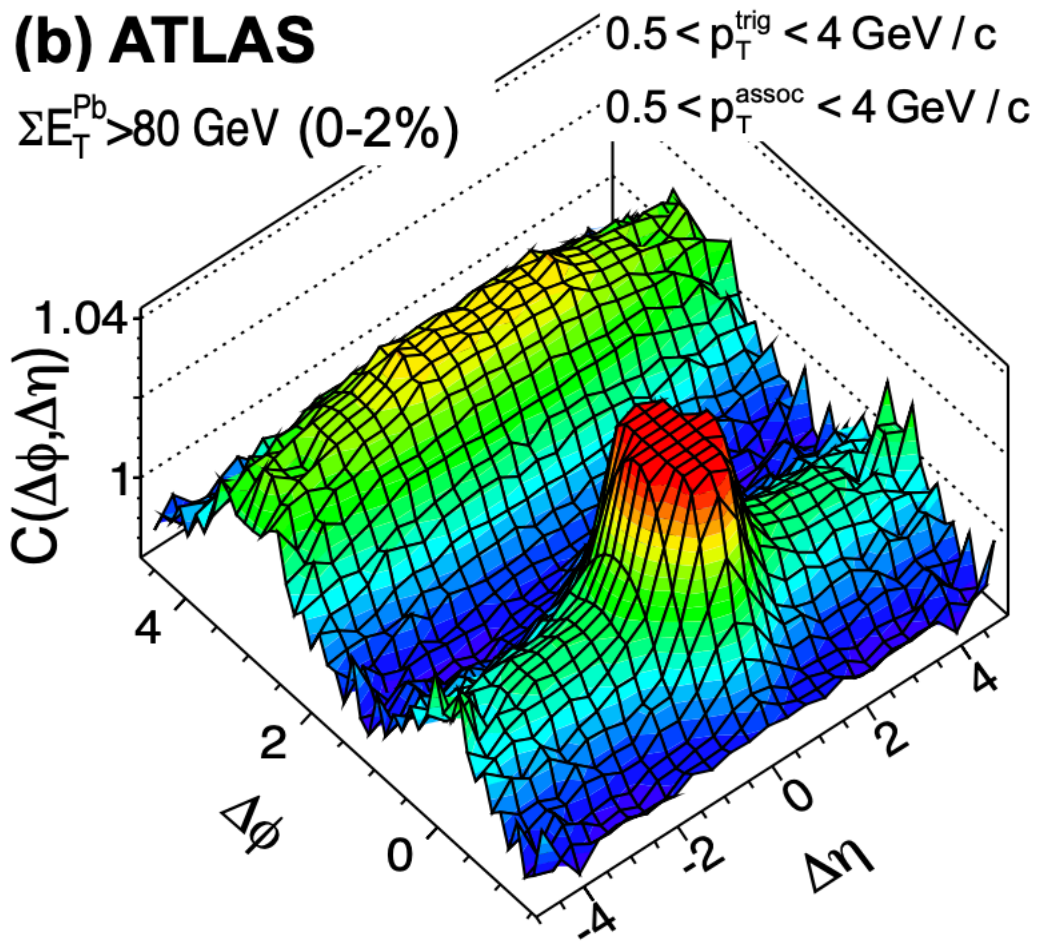
Backup

Hints of collectivity in small systems

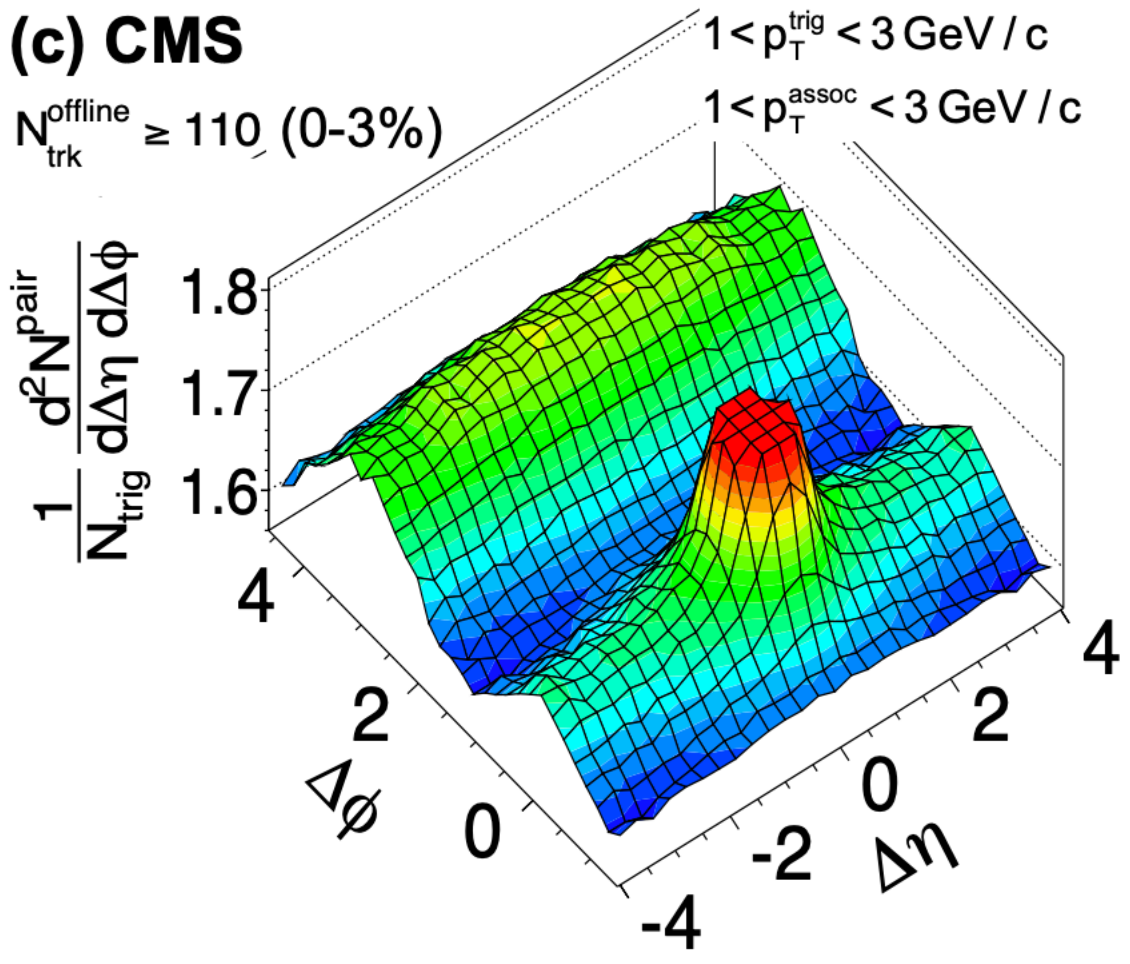
pPb $\sqrt{s_{NN}}$ = 5.02 TeV at the LHC



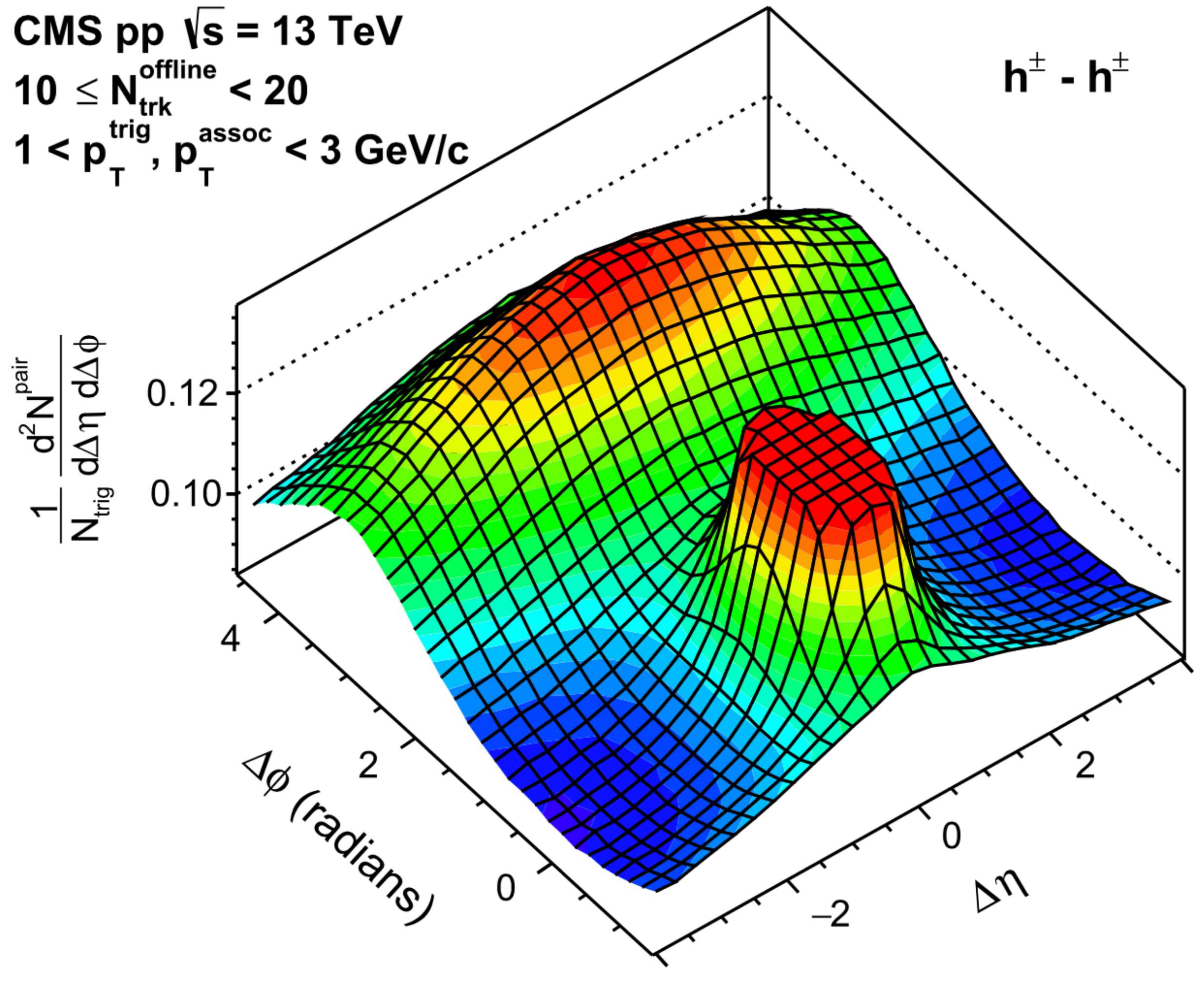
Phys. Lett. B, 719:29–41, 2013

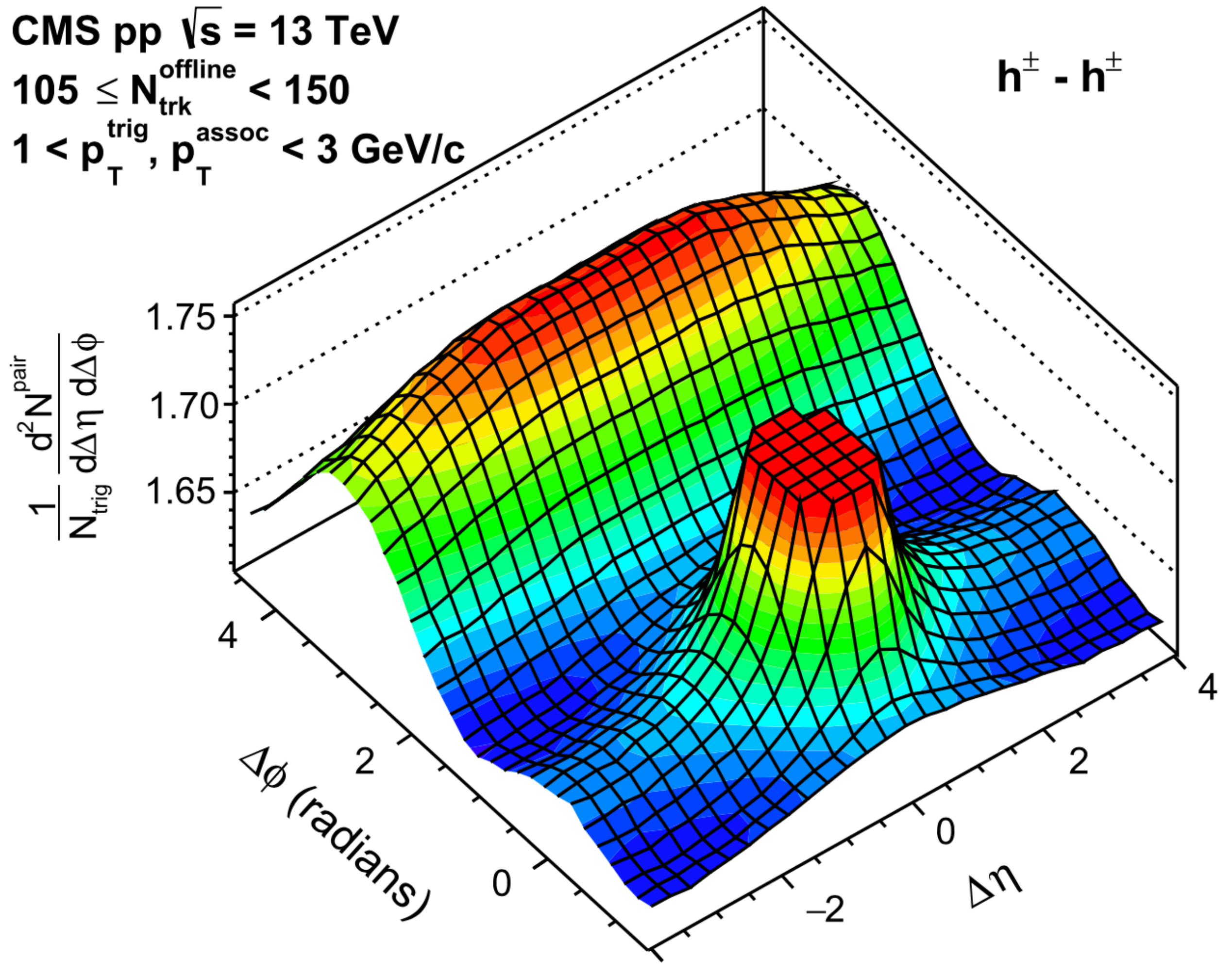


Phys. Rev. Lett., 110(18):182302, 2013



Phys. Lett. B, 718:795–814, 2013





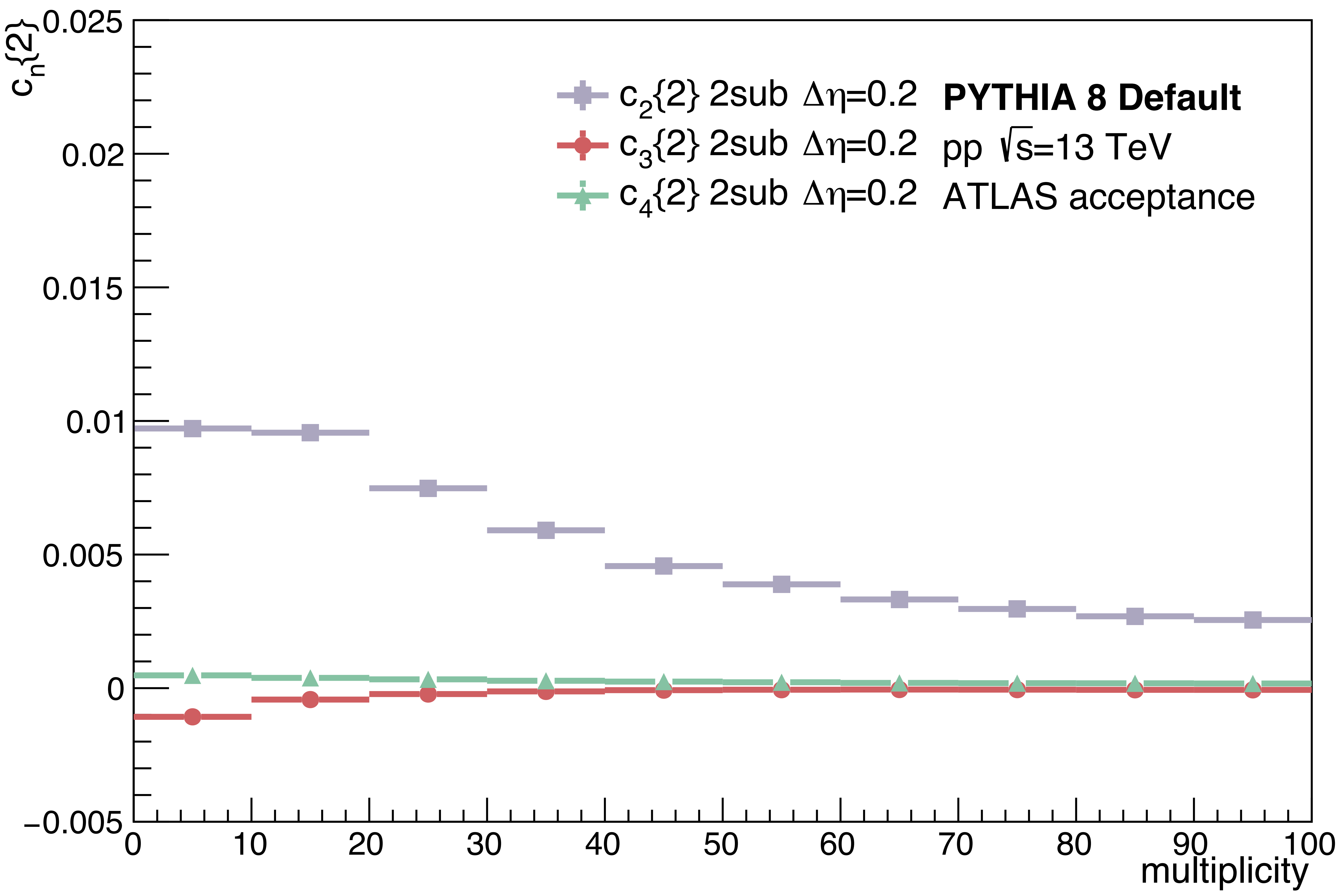
Phys. Lett. B, 765:193–220, 2017

high-multiplicity pPb collisions
ALICE - ATLAS - CMS

Near-side ridge
in two-particle correlations

pp collisions
low vs high multiplicity

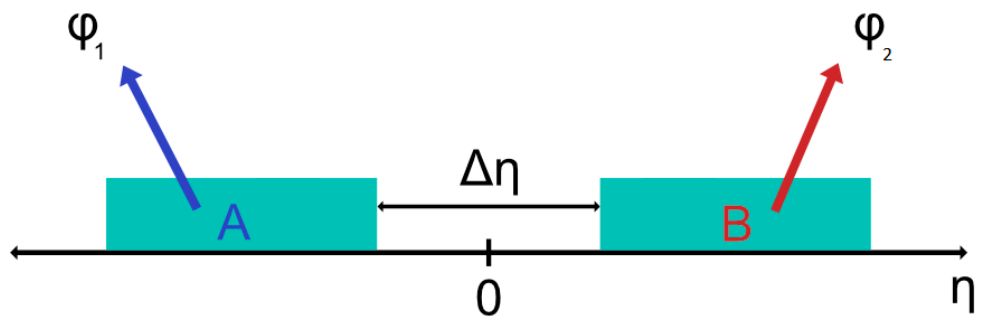
Backup results - Two-particle cumulant



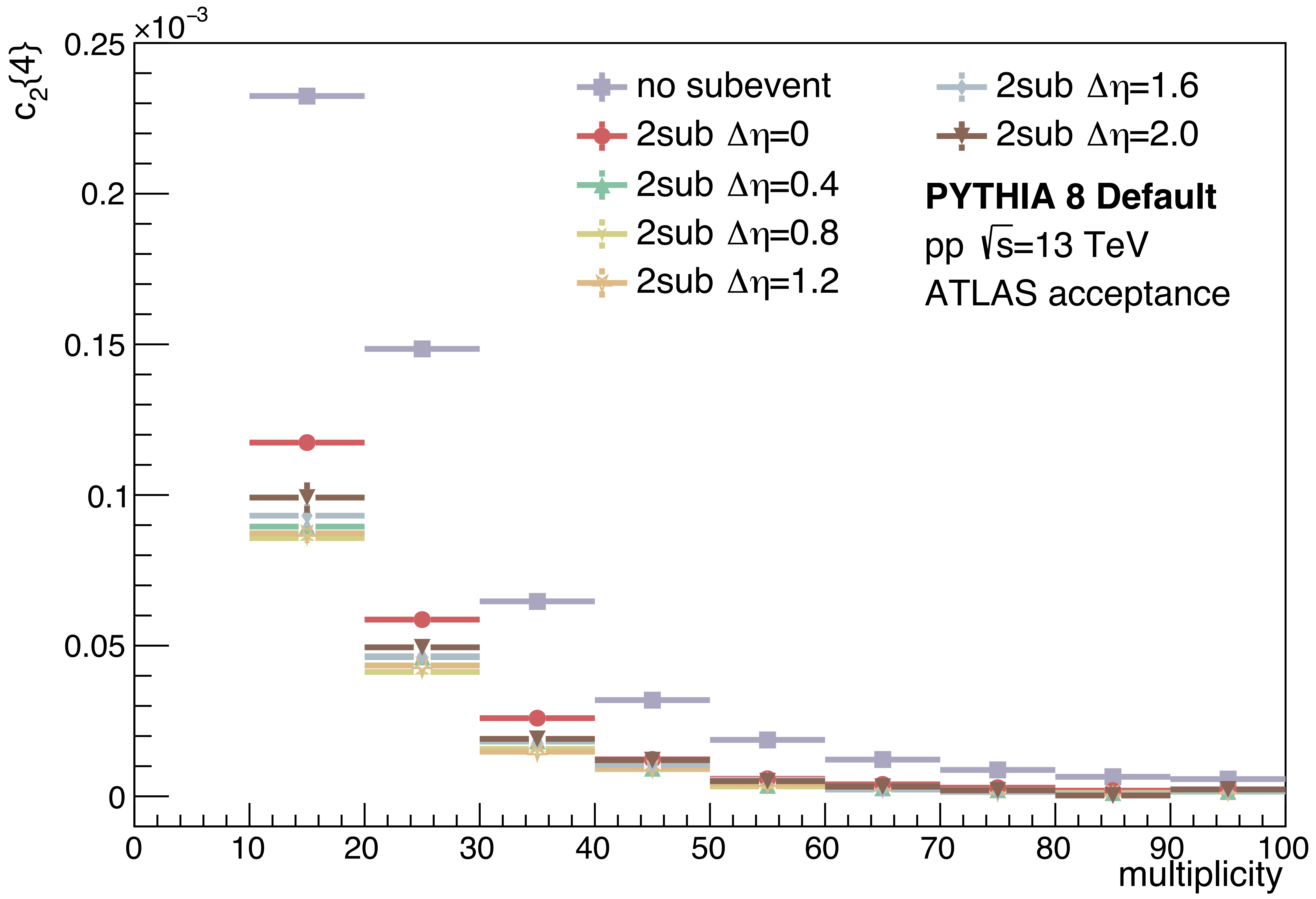
ATLAS acceptance

0.3 < pT < 3 GeV

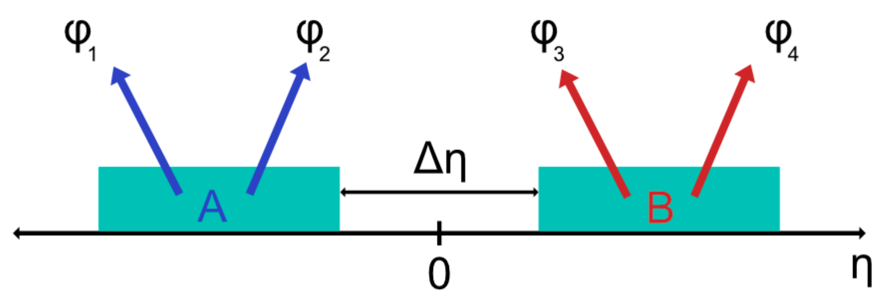
$|\eta| < 2.5$



Backup results - Four-particle cumulant



ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$



Generic Framework

$$Q_{n,p} = \sum_{k=1}^{M} w_k^p e^{in\varphi_k}$$

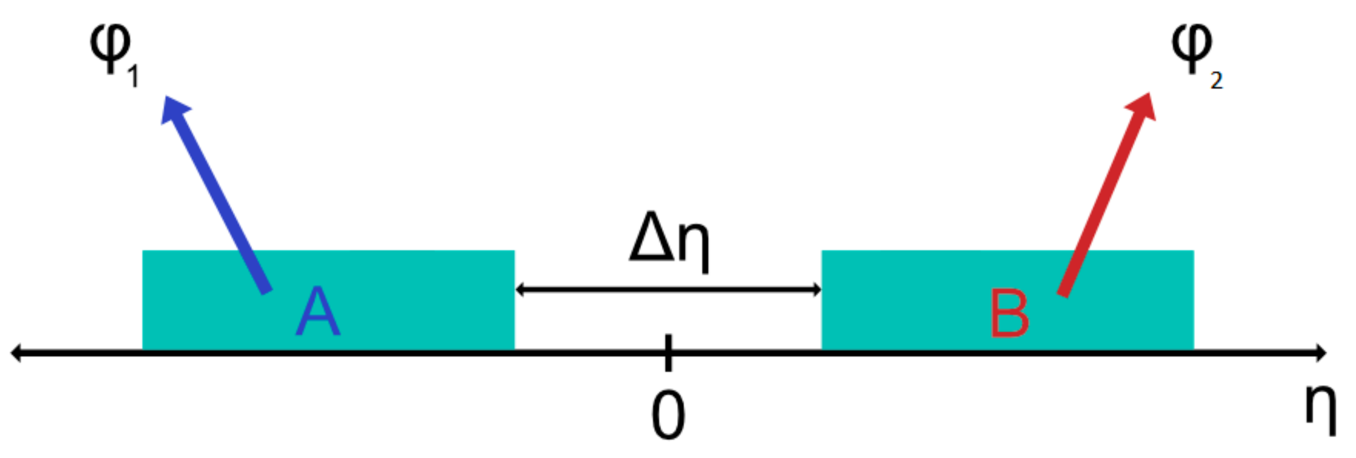
$$\langle m \rangle_{n_1,n_2,\ldots,n_m} = \langle e^{i(n_1\varphi_1+n_2\varphi_2+\ldots+n_m\varphi_m)} \rangle = \frac{N\langle m \rangle_{n_1,n_2,\ldots,n_m}}{D\langle m \rangle_{n_1,n_2,\ldots,n_m}} = \frac{N\langle m \rangle_{n_1,n_2,\ldots,n_m}}{N\langle m \rangle_{0,0,\ldots,0}}$$

$$N\langle 2 \rangle_{n_1,n_2} = Q_{n_1,1}Q_{n_2,1} - Q_{n_1+n_2,2},$$

$$N\langle 3 \rangle_{n_1,n_2,n_3} = Q_{n_1,1}Q_{n_2,1}Q_{n_3,1} - Q_{n_1+n_2,2}Q_{n_3,1} - Q_{n_2,1}Q_{n_1+n_3,2} - Q_{n_1,1}Q_{n_2+n_3,2} + 2Q_{n_1+n_2+n_3,3},$$

$$N\langle 2 \rangle_{n_1,n_2} = Q^A_{n_1,1}Q^B_{n_2,1}$$

$$\begin{aligned} N\langle 4 \rangle_{n_1,n_2,n_3,n_4} = {} & Q_{n_1,1}Q_{n_2,1}Q_{n_3,1}Q_{n_4,1} - Q_{n_1+n_2,2}Q_{n_3,1}Q_{n_4,1} \\ & - Q_{n_2,1}Q_{n_1+n_3,2}Q_{n_4,1} - Q_{n_1,1}Q_{n_2+n_3,2}Q_{n_4,1} + 2Q_{n_1+n_2+n_3,3}Q_{n_4,1} \\ & - Q_{n_2,1}Q_{n_3,1}Q_{n_1+n_4,2} + Q_{n_2+n_3,2}Q_{n_1+n_4,2} - Q_{n_1,1}Q_{n_3,1}Q_{n_2+n_4,2} \\ & + Q_{n_1+n_3,2}Q_{n_2+n_4,2} + 2Q_{n_3,1}Q_{n_1+n_2+n_4,3} - Q_{n_1,1}Q_{n_2,1}Q_{n_3+n_4,2} \\ & + Q_{n_1+n_2,2}Q_{n_3+n_4,2} + 2Q_{n_2,1}Q_{n_1+n_3+n_4,3} \\ & + 2Q_{n_1,1}Q_{n_2+n_3+n_4,3} - 6Q_{n_1+n_2+n_3+n_4,4}. \end{aligned}$$



Workflow

Generate pp collisions in PYTHIA (non-flow model)
-> 2 billion events for default configuration

↓

Store the output in TTree

↓

Compute correlations and save them (TProfiles)

↓

Compute cumulants

↓

Draw final results

Multiplicity

ALICE acceptance
0.3 < pT < 3 GeV
$|\eta| < 0.8$

ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$

Multiplicity is consistently counted according to ALICE multiplicity

Data subsets and statistics

Collisions generated in subsets of 500 000 events

Each subset is divided into 10 more “statistical” subsets (4 000 x 10 subsets)

Correlations are computed for each subset separately

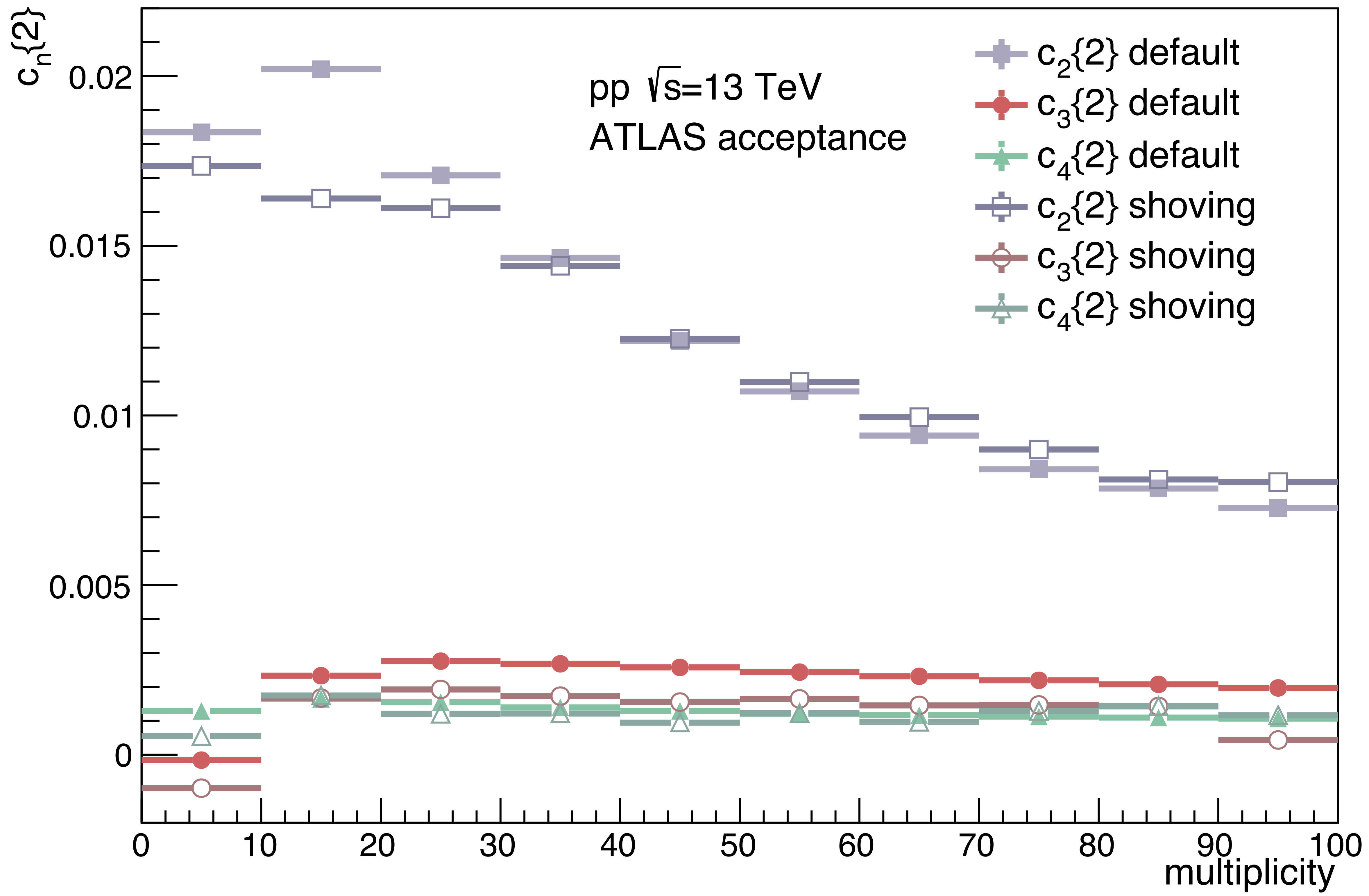
Subsets (4 000) are merged -> resulting dataset still contains 10 “statistical” subsets

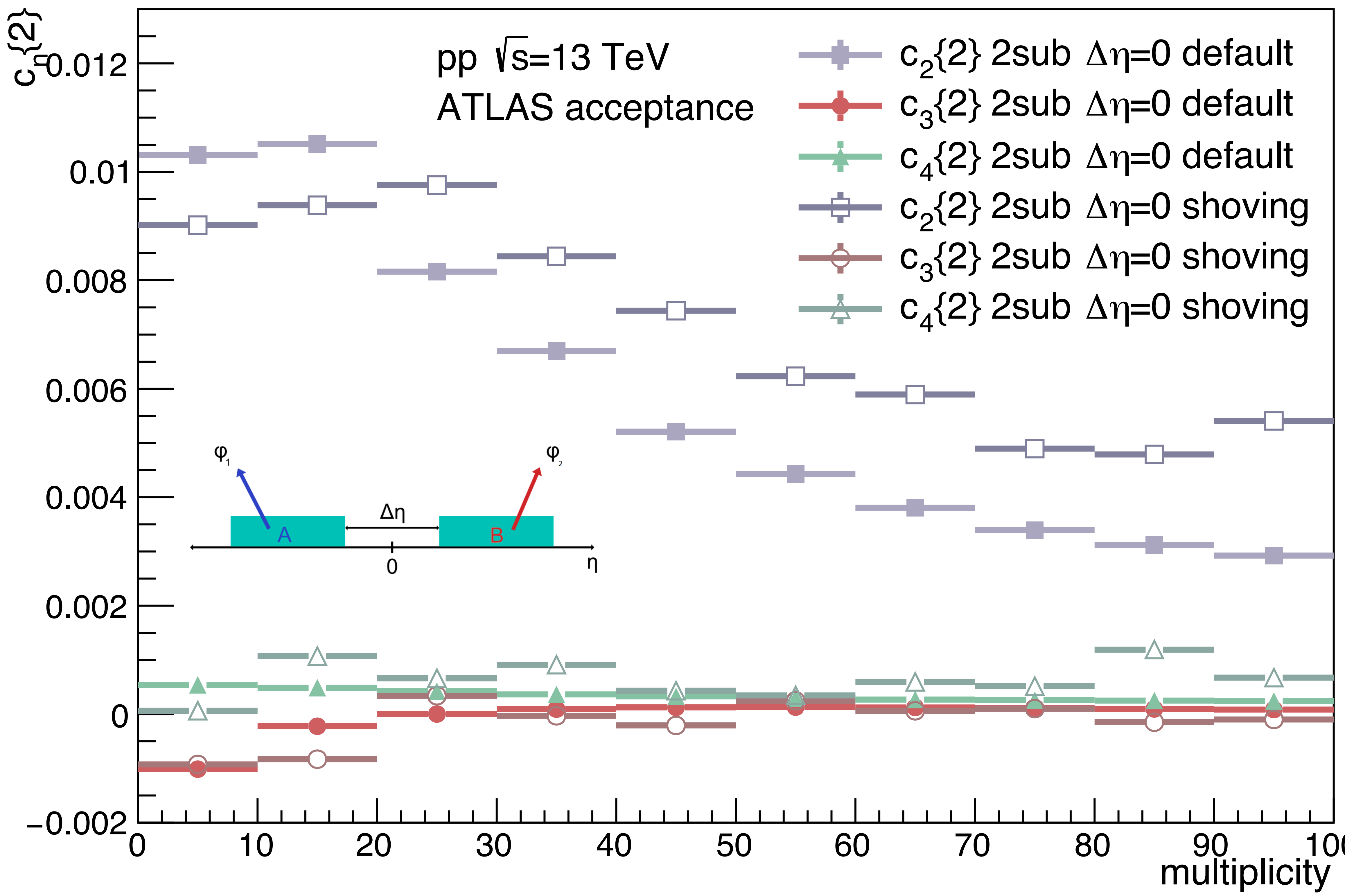
Final cumulants are computed from merged dataset and errors as a standard deviation of values from 10 subsets

Results - Shoving mechanism

ATLAS acceptance
0.3 < pT < 3 GeV
$|\eta| < 2.5$

- Repulsive interaction between Lund strings resulting in momentum boost



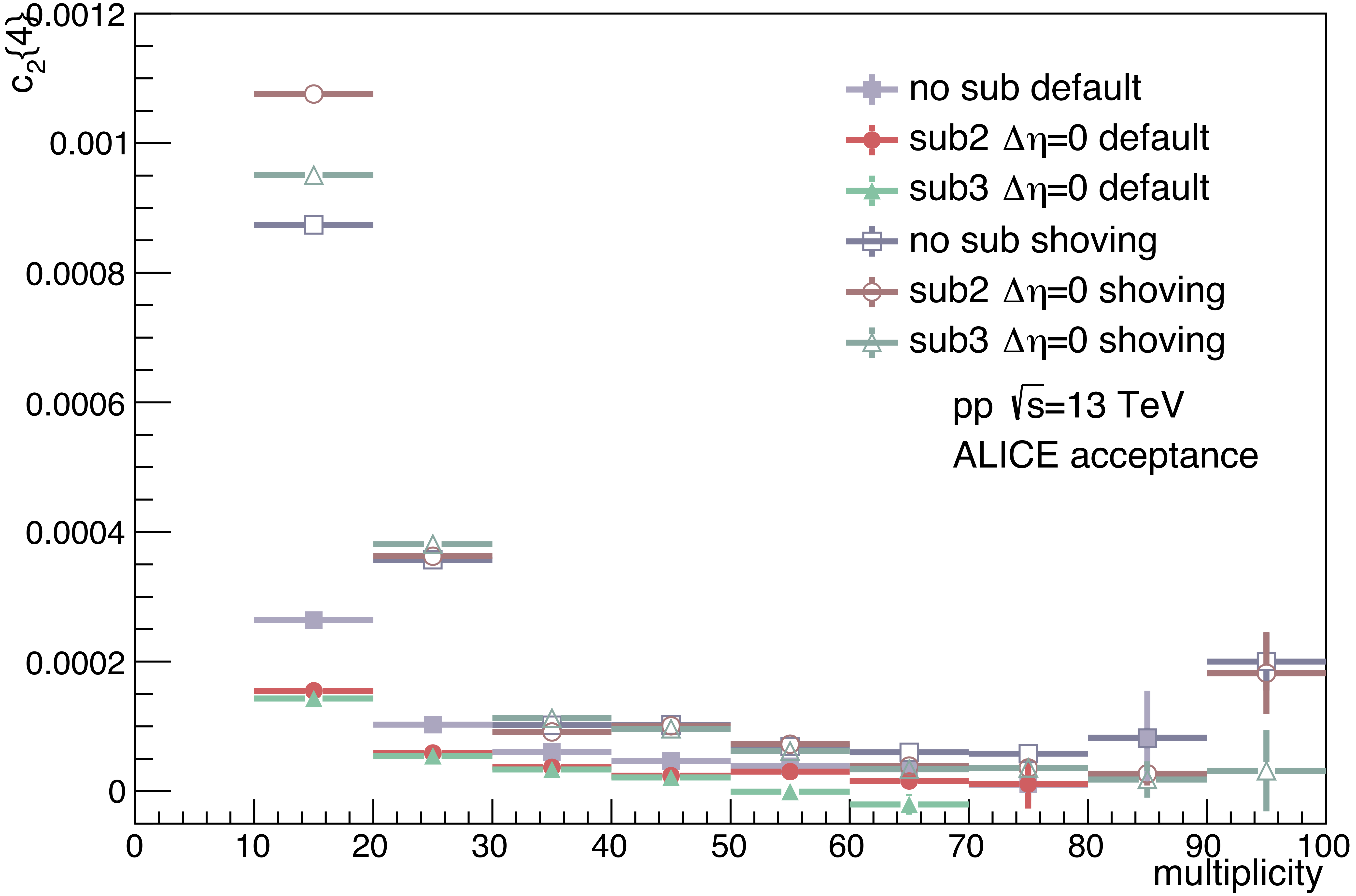


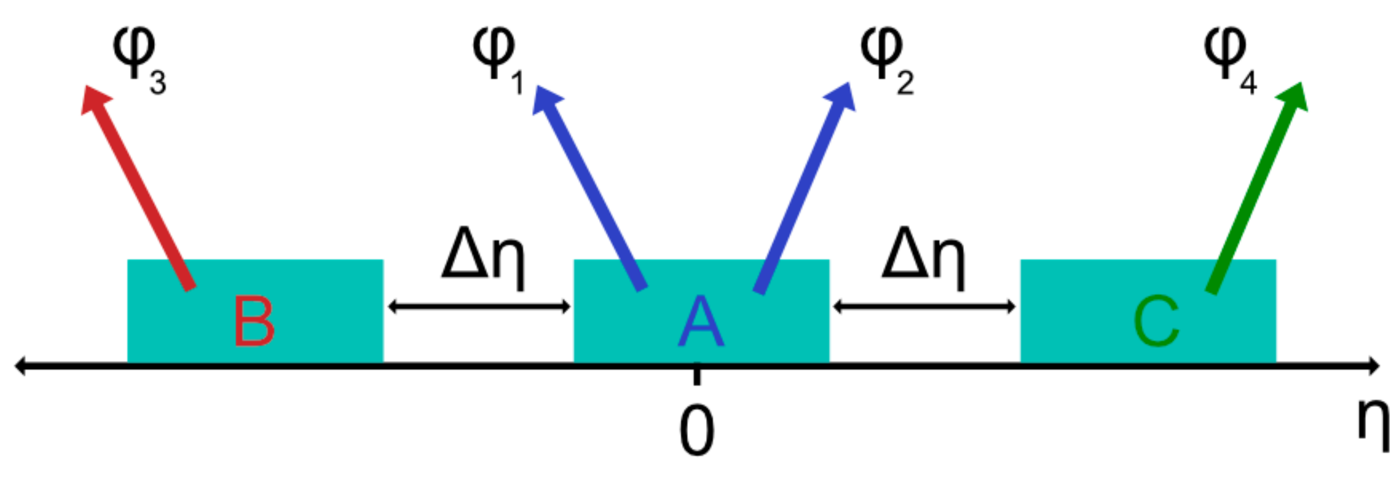
- Magnitude ordering (c2 > c3 > c4)
- Multiplicity dependence of c2
- Higher cumulants for default due to large non-flow

- Non-flow suppression due to subevent method -> effect of shoving can be seen

Results - Shoving mechanism

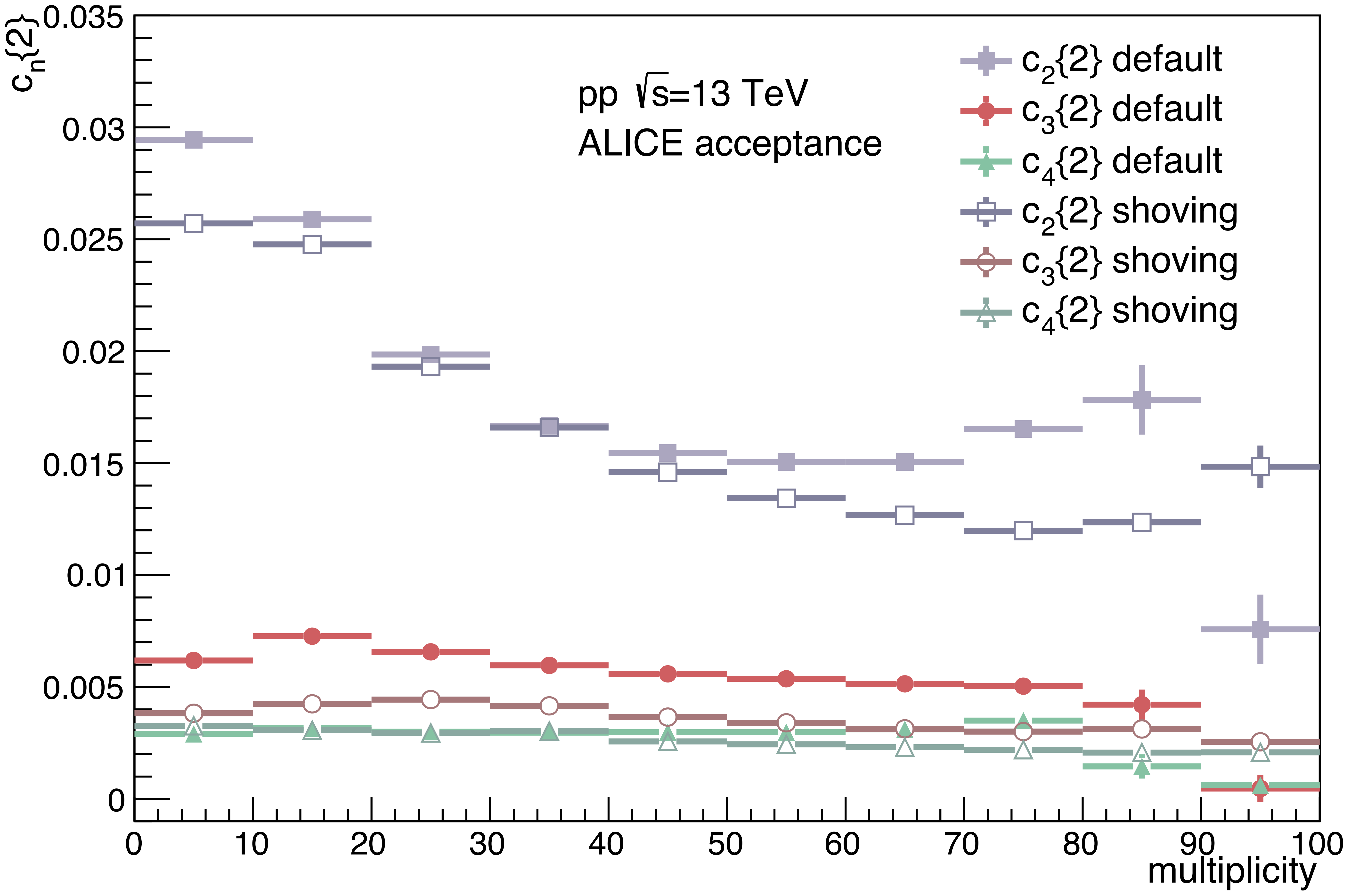
ALICE acceptance
0.3 < pT < 3 GeV
$|\eta| < 0.8$





- Significant multiplicity dependence for low-multiplicity events
- Cumulant compatible with zero, but not negative -> disagreement with naive expectation of adding collectivity with shoving mechanism
- Generally larger cumulant for shoving -> non-flow contamination

Backup results - Shoving mechanism



ALICE acceptance

$0.3 < pT < 3$ GeV

$|\eta| < 0.8$