Experimental approaches to flow and nonflow in small systems

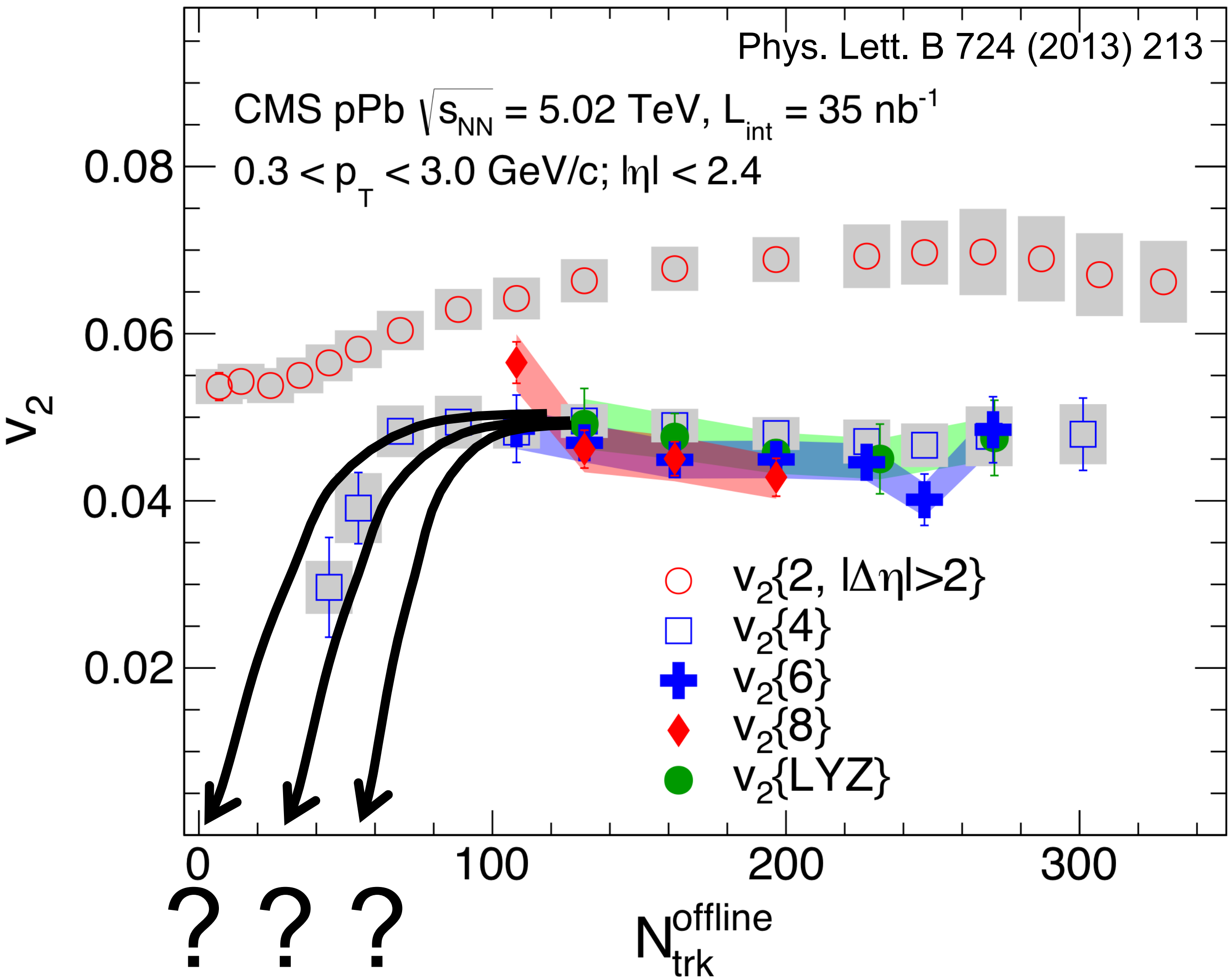
Shengquan Tuo

VANDERBILT UNIVERSITY

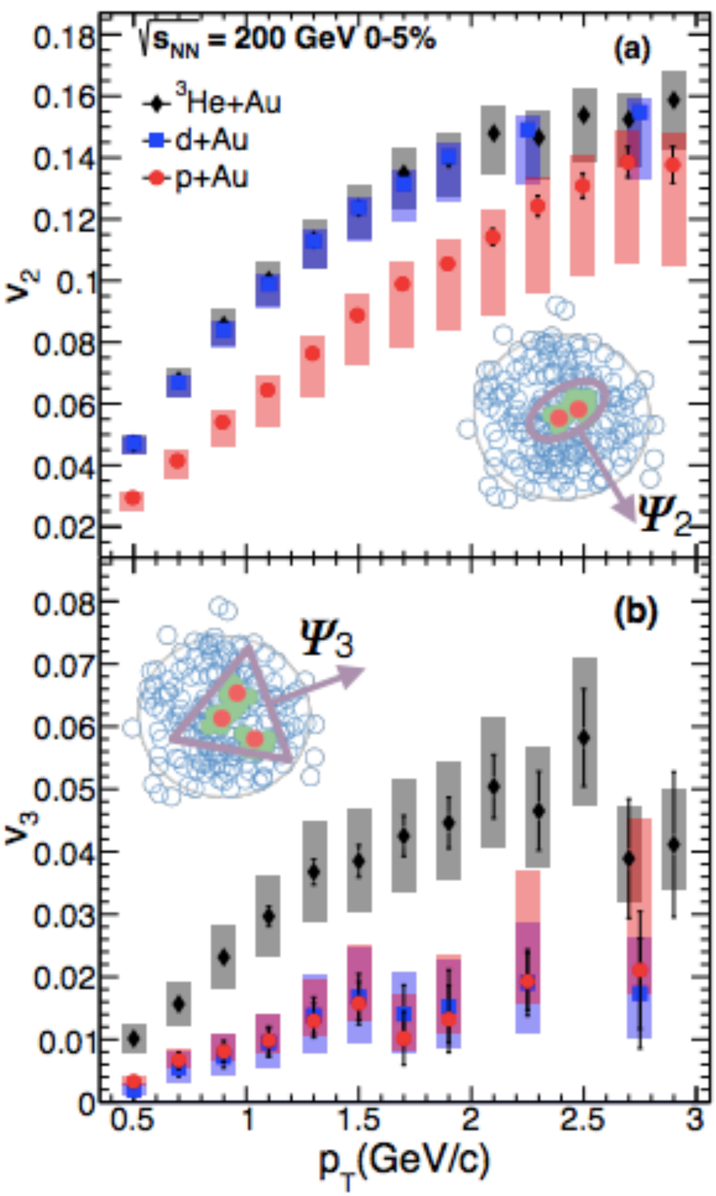
9th Workshop of the APS Topical Group on Hadronic Physics

13-16 April, 2021

Flow in small systems



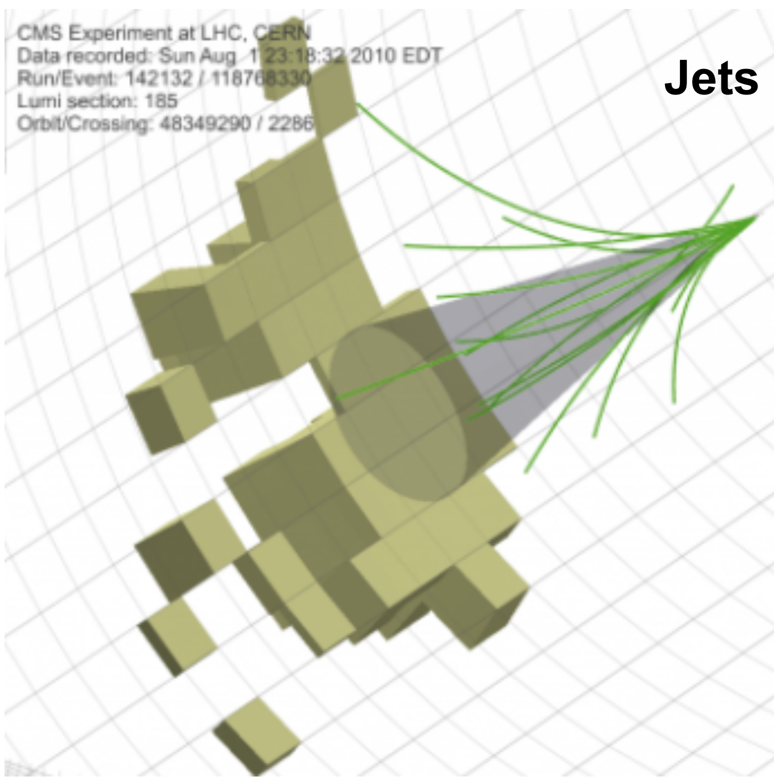
Nature Phys. 15 (2019) 3, 214

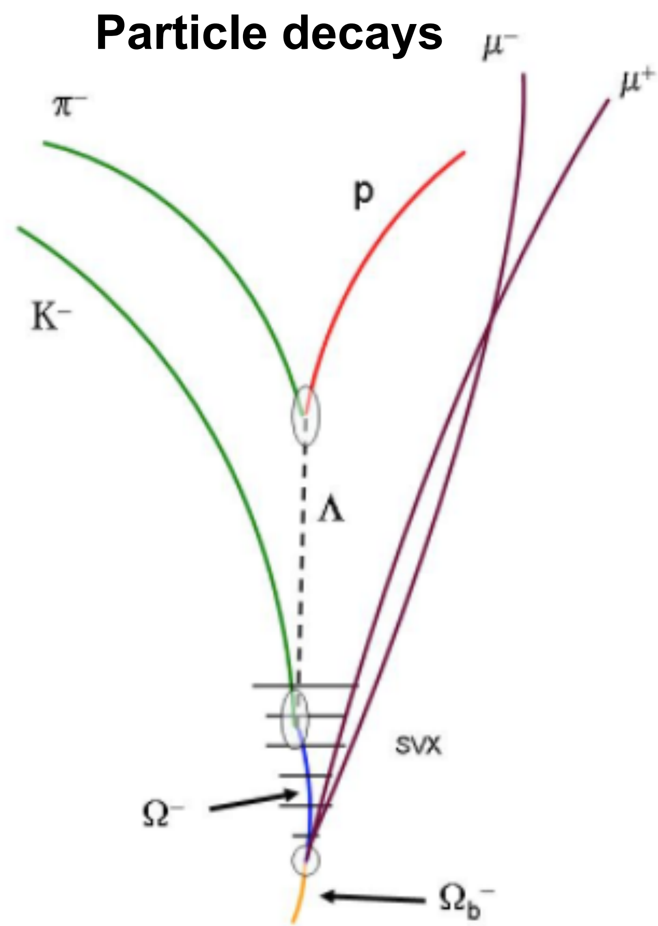


What is the smallest possible droplet of QGP?
How does nonflow affect our understanding of the onset of QGP production?

Nonflow correlations

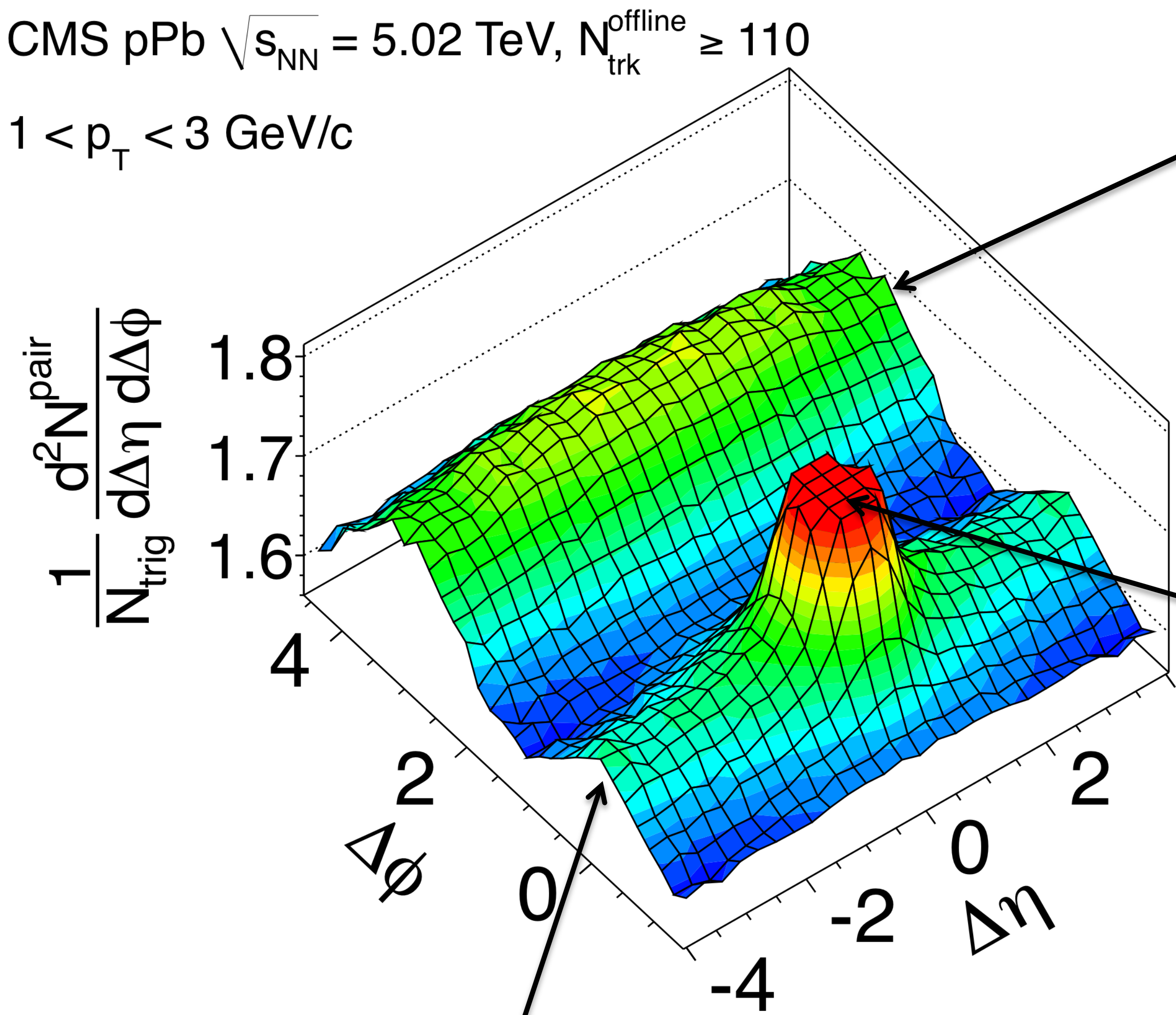
- Flow correlations are global and collective
- Nonflow correlations are local, mostly short range and related to a few particles
    - Correlations due to momentum conservation
    - Particle correlations inside jet cones
    - Particle decays
    - Other quantum correlations





Structure of the two particle correlations

Phys. Lett. B 718 (2013) 795

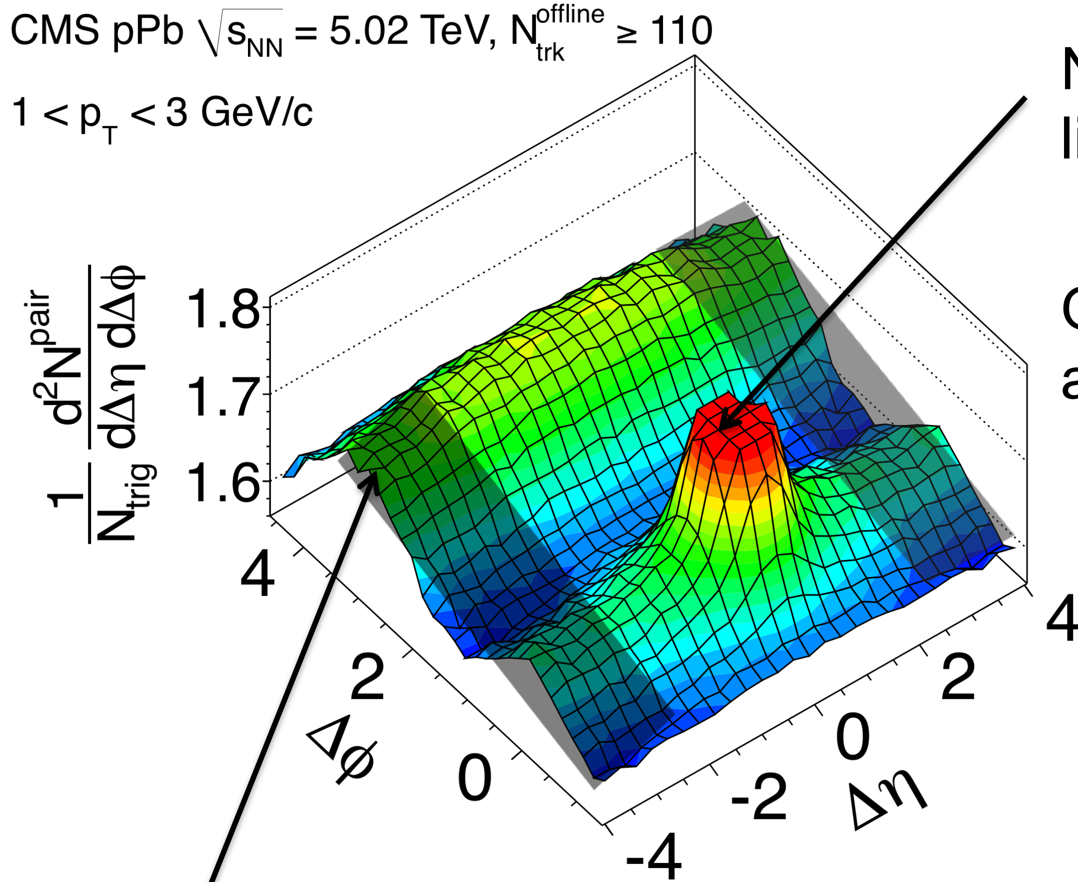


Back to back jets + flow

Nonflow from short range correlations, like inside a jet cone

Long range and near side correlations from flow

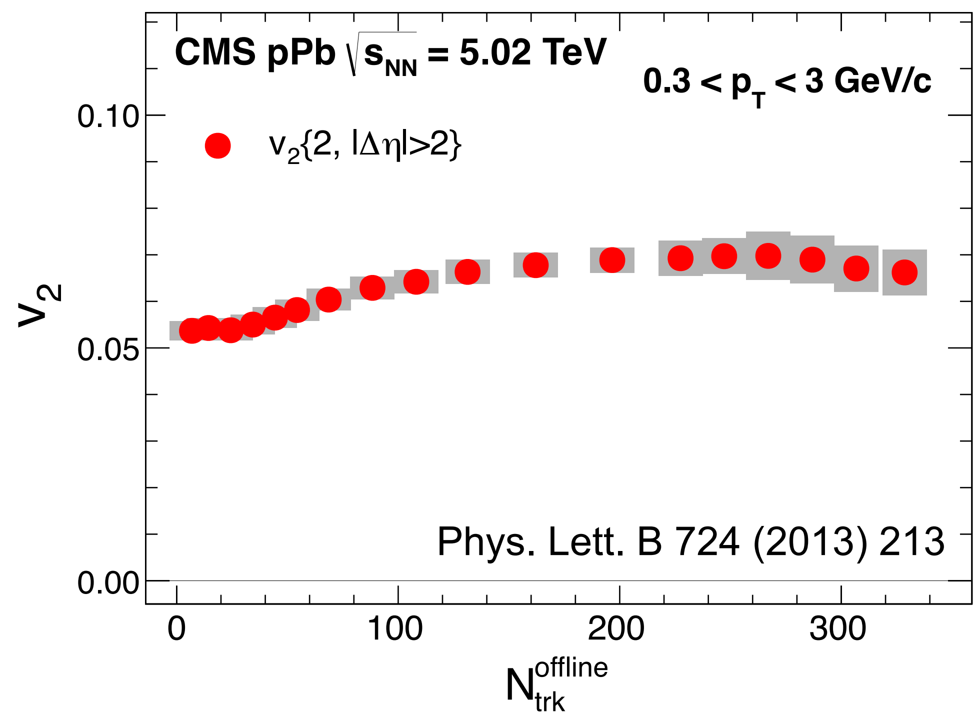
Long range two particle correlations



Nonflow from short range correlations, like inside a jet cone

Only long range correlations (|Δη|>2) are selected to remove this nonflow:

$$\frac{1}{N_{\rm trig}}\frac{dN^{\rm pair}}{d\Delta\phi} = \frac{N_{\rm assoc}}{2\pi}\left[1+\sum_n 2V_{n\Delta}\cos(n\Delta\phi)\right]$$

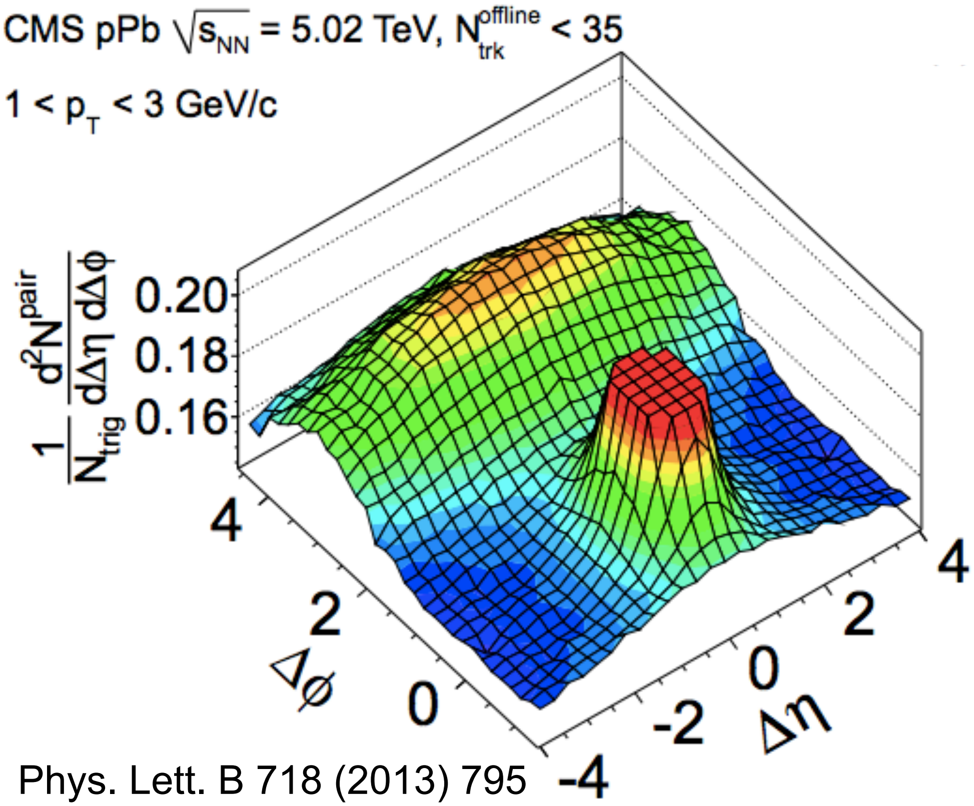


Long range alone is not enough since the nonflow due to back to back jet correlations are not removed

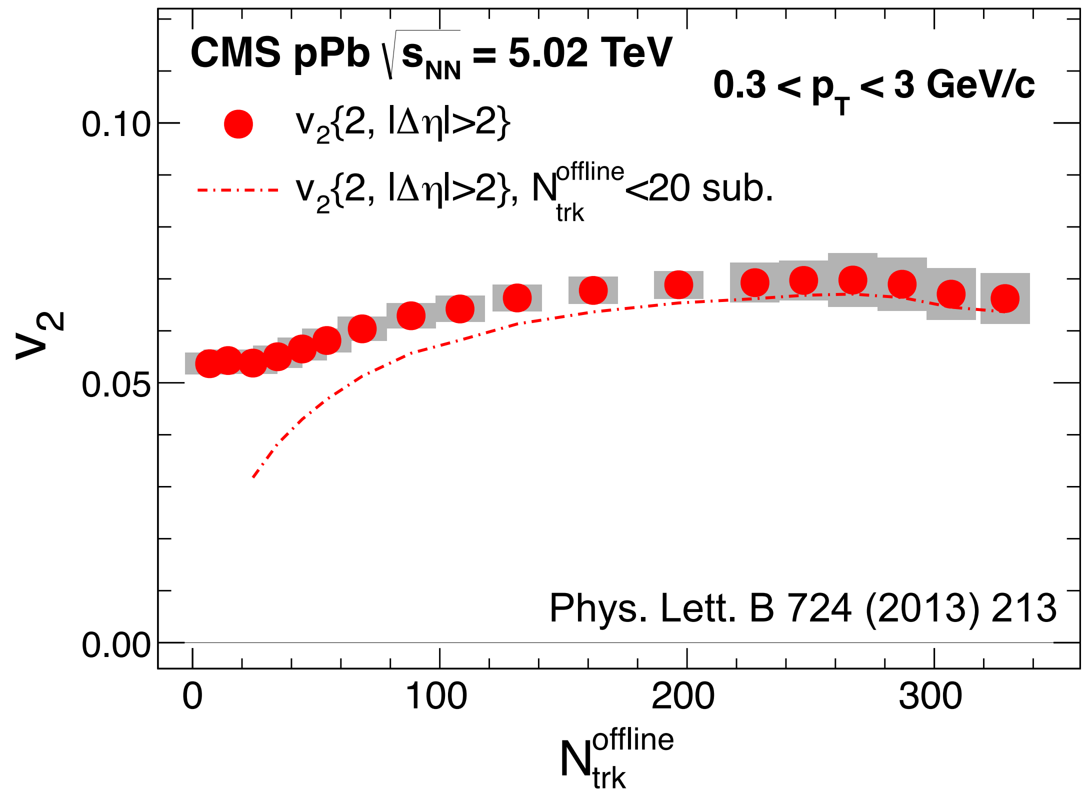
Peripheral subtraction in two particle correlations

Phys. Lett. B 724 (2013) 213

$$V_{n\Delta}^{\mathrm{sub}} = V_{n\Delta} - V_{n\Delta}(N_{\mathrm{trk}}^{\mathrm{offline}} < 20) \times \frac{N_{\mathrm{assoc}}(N_{\mathrm{trk}}^{\mathrm{offline}} < 20)}{N_{\mathrm{assoc}}} \times \frac{Y_{\mathrm{jet}}}{Y_{\mathrm{jet}}(N_{\mathrm{trk}}^{\mathrm{offline}} < 20)},$$

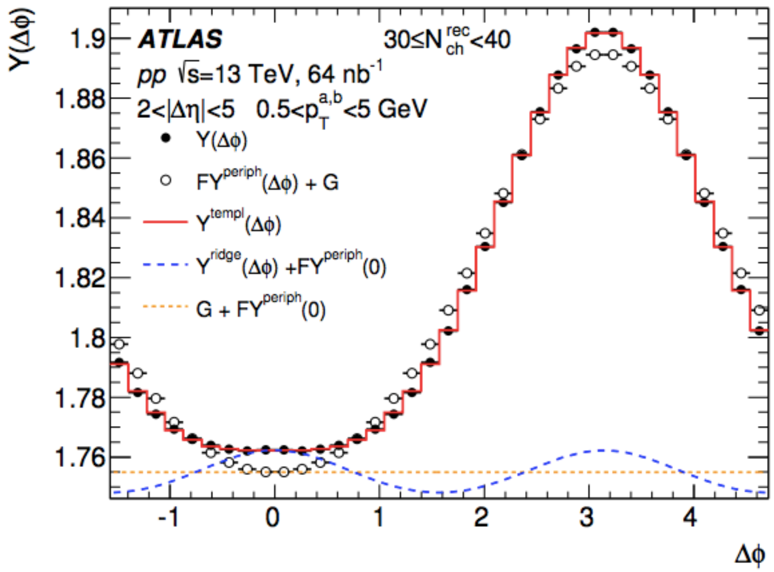


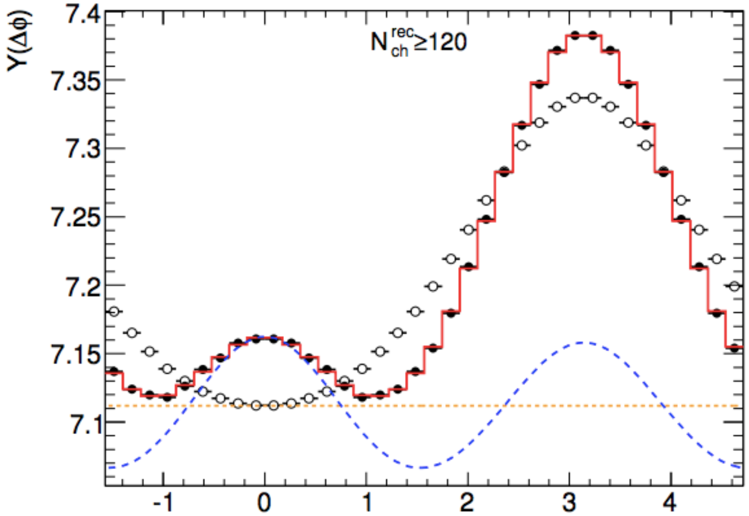
Phys. Lett. B 718 (2013) 795



- Nonflow due to back to back correlations from momentum conservation is removed by subtracting correlations in low multiplicity events, assuming flow is zero there (method is tested in Pythia and HIJING models)
- The effect is large for multiplicity less than 100

Nonflow subtraction with template fitting



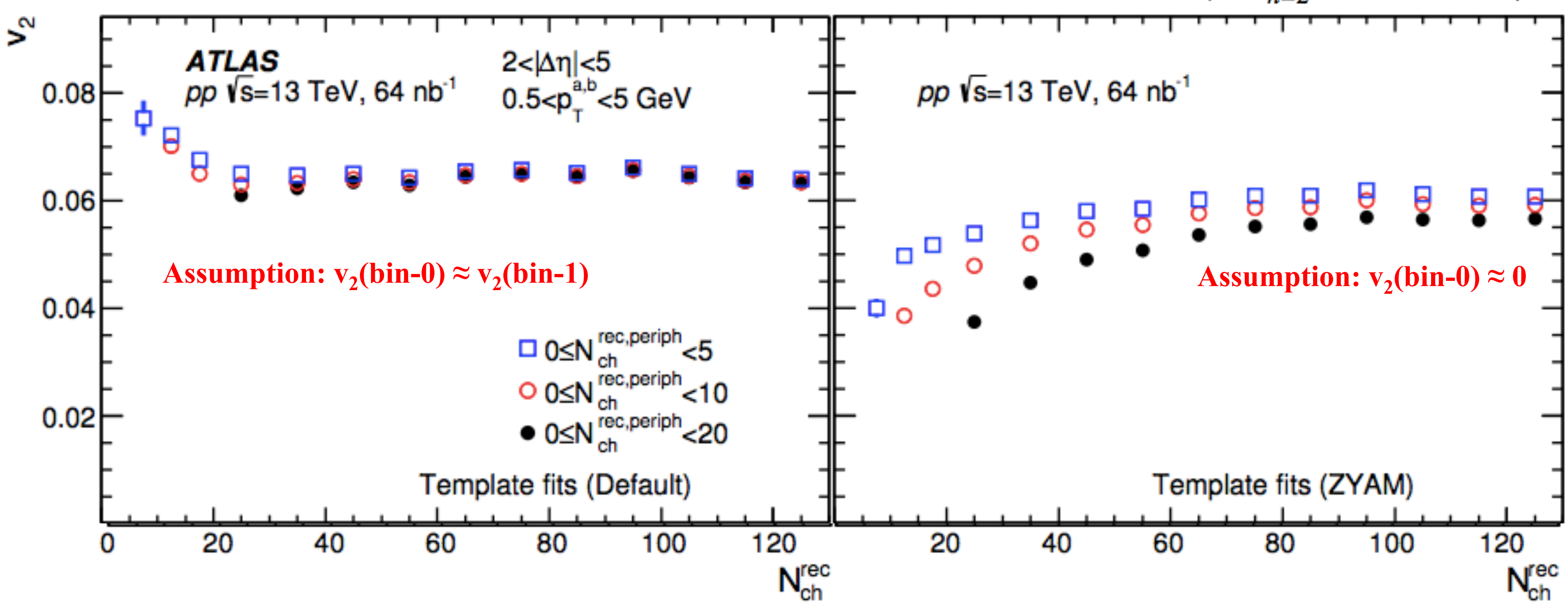


Phys. Rev. C 96 (2017) 024908

Y^{periph} is produced from multiplicity [0, 20).

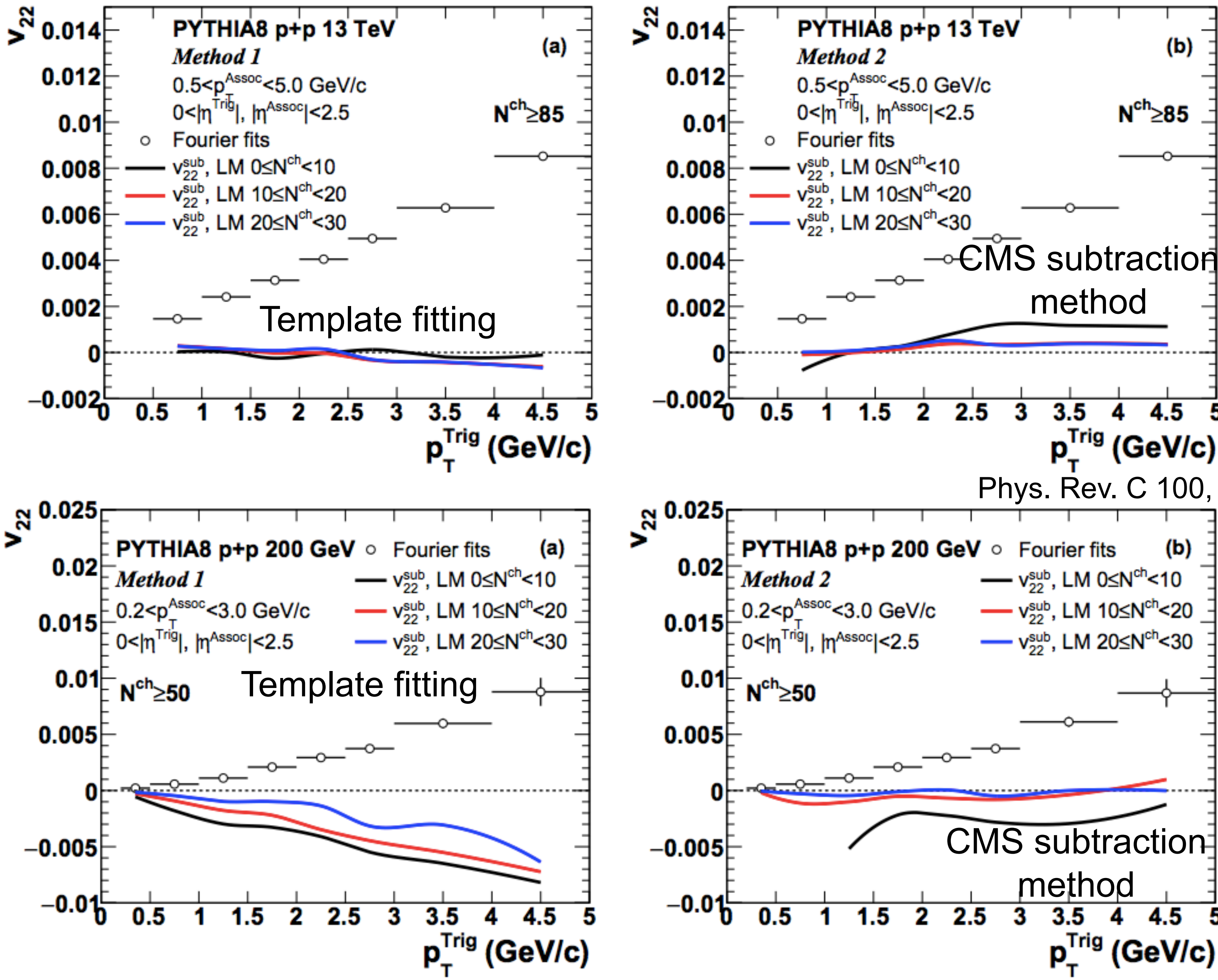
$$Y^{\mathrm{templ}}(\Delta\phi) = Y^{\mathrm{ridge}}(\Delta\phi) + F\,Y^{\mathrm{periph}}(\Delta\phi)$$

$$Y^{\mathrm{ridge}}(\Delta\phi) = G\left(1 + \sum_{n=2}^{\infty} 2v_{n,n}\cos(n\Delta\phi)\right)$$



The results depend on the assumption of v2 in the smallest bin

Nonflow subtraction at different energies



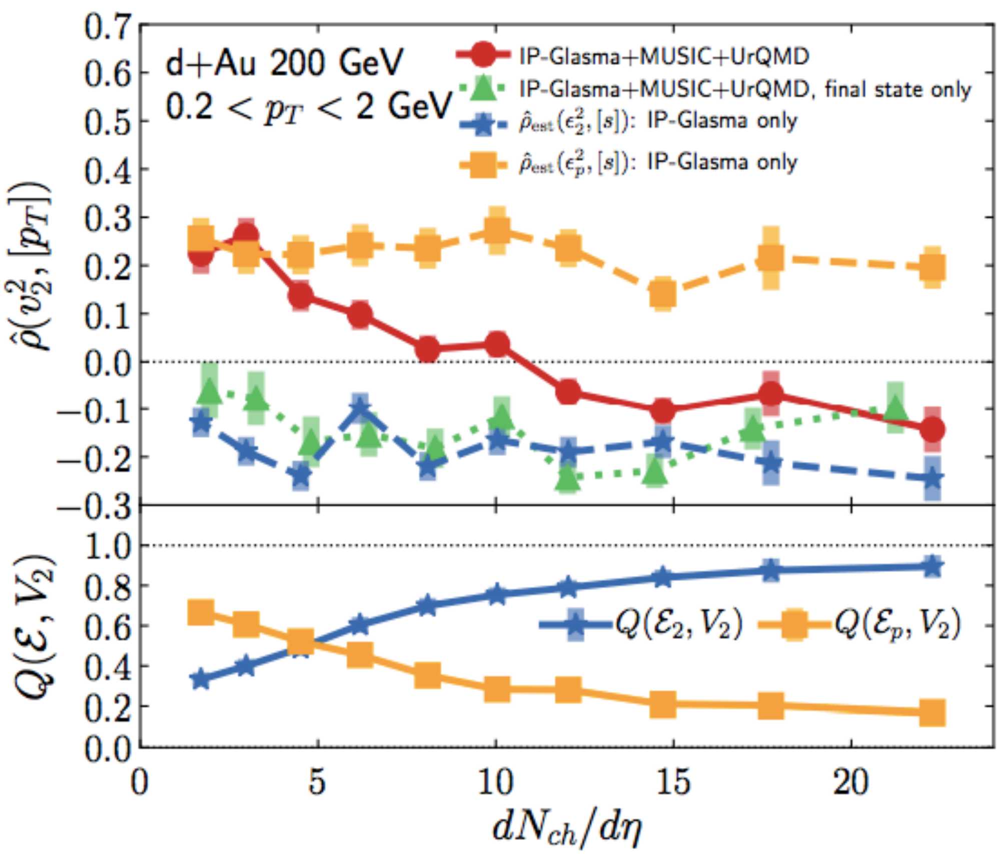
Phys. Rev. C 100, 024908 (2019)

The method behavior depends on collision energies

Two particle flow and <p$_T$> correlations

$$\hat{\rho}(v_2^2, [p_T]) = \frac{\langle \hat{\delta} v_2^2 \, \hat{\delta}[p_T] \rangle}{\sqrt{\langle (\hat{\delta} v_2^2)^2 \rangle \langle (\hat{\delta}[p_T])^2 \rangle}}$$

Phys. Rev. Lett. 125, 192301 (2020)



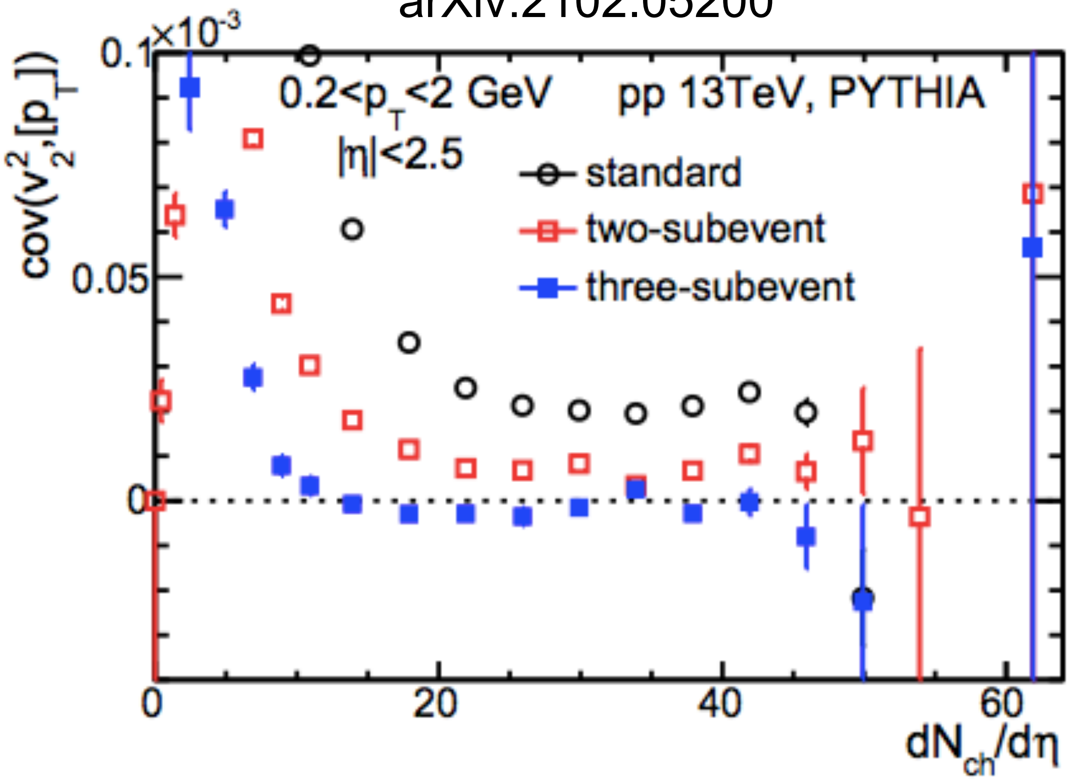
Signature of initial momentum flow from CGC:

- Sign change of the correlator with IP-Glasma + Music + UrQMD
- No sign change without initial momentum anisotropies

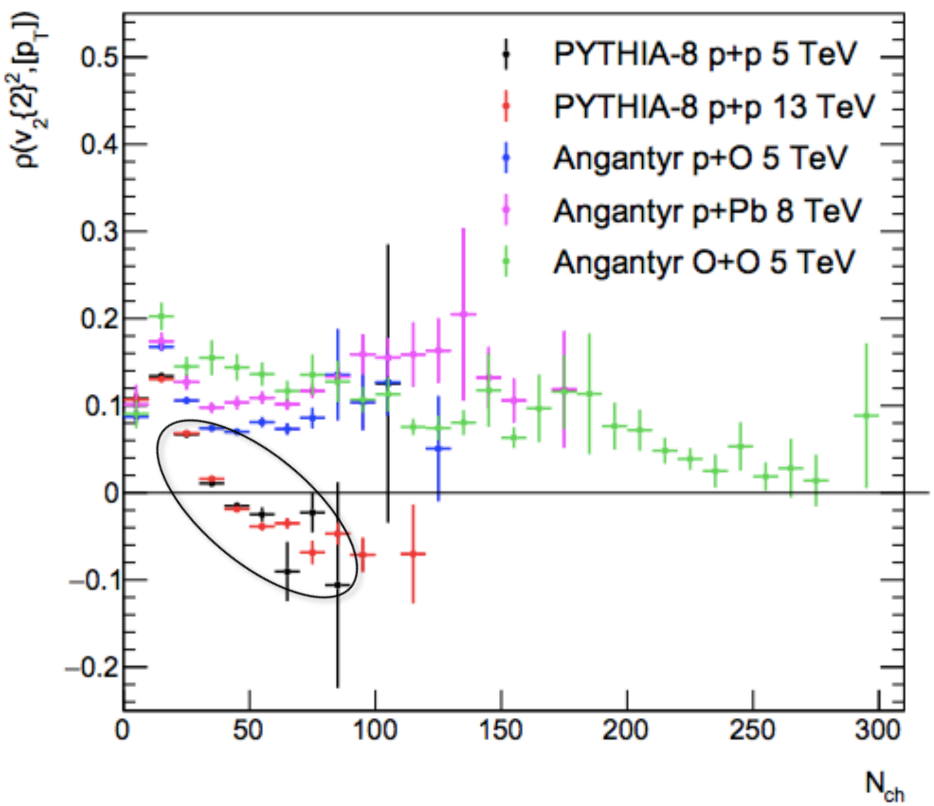
Two particle v2 and <pT> correlations from nonflow

$$\hat{\rho}(v_2^2, [p_T]) = \frac{\langle \hat{\delta} v_2^2 \, \hat{\delta}[p_T] \rangle}{\sqrt{\langle (\hat{\delta} v_2^2)^2 \rangle \langle (\hat{\delta}[p_T])^2 \rangle}}$$

arXiv:2102.05200

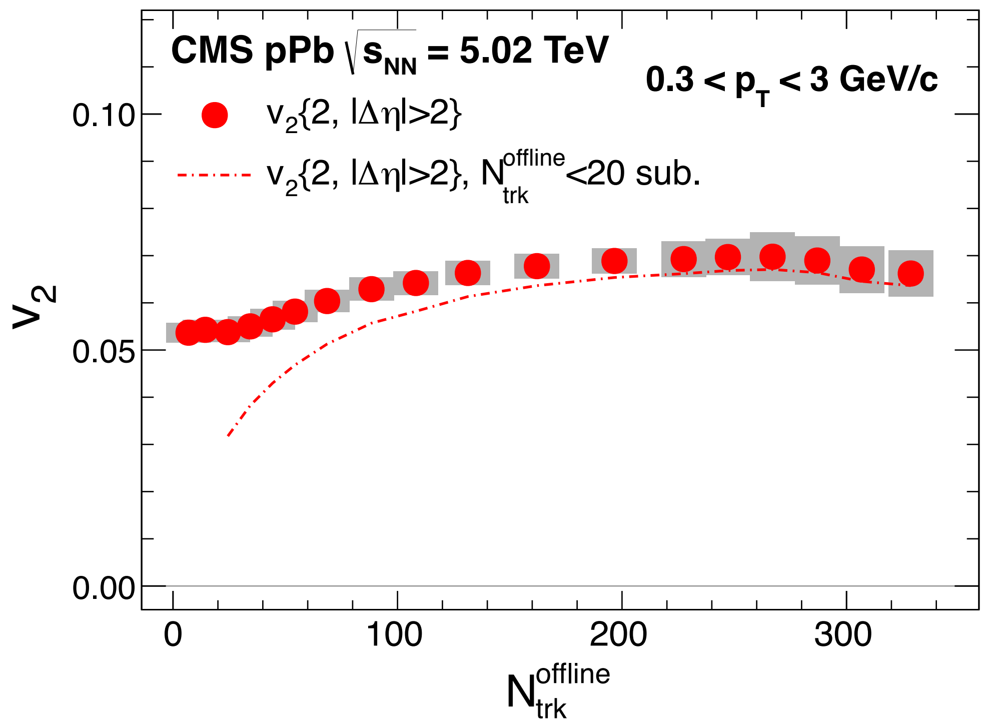


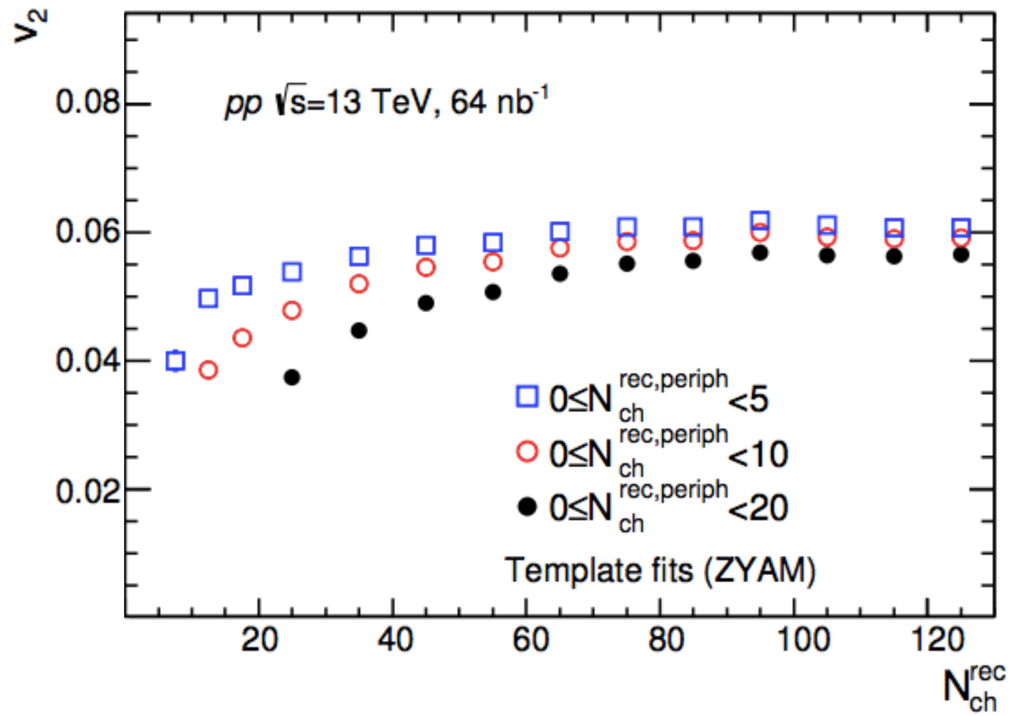
arXiv:2103.01348



- The results from PYTHIA8 already showing sign change
- Subevent method is used for the flow in two particle correlations
- No peripheral subtraction is done

Conclusion for nonflow subtractions in two particle correlations



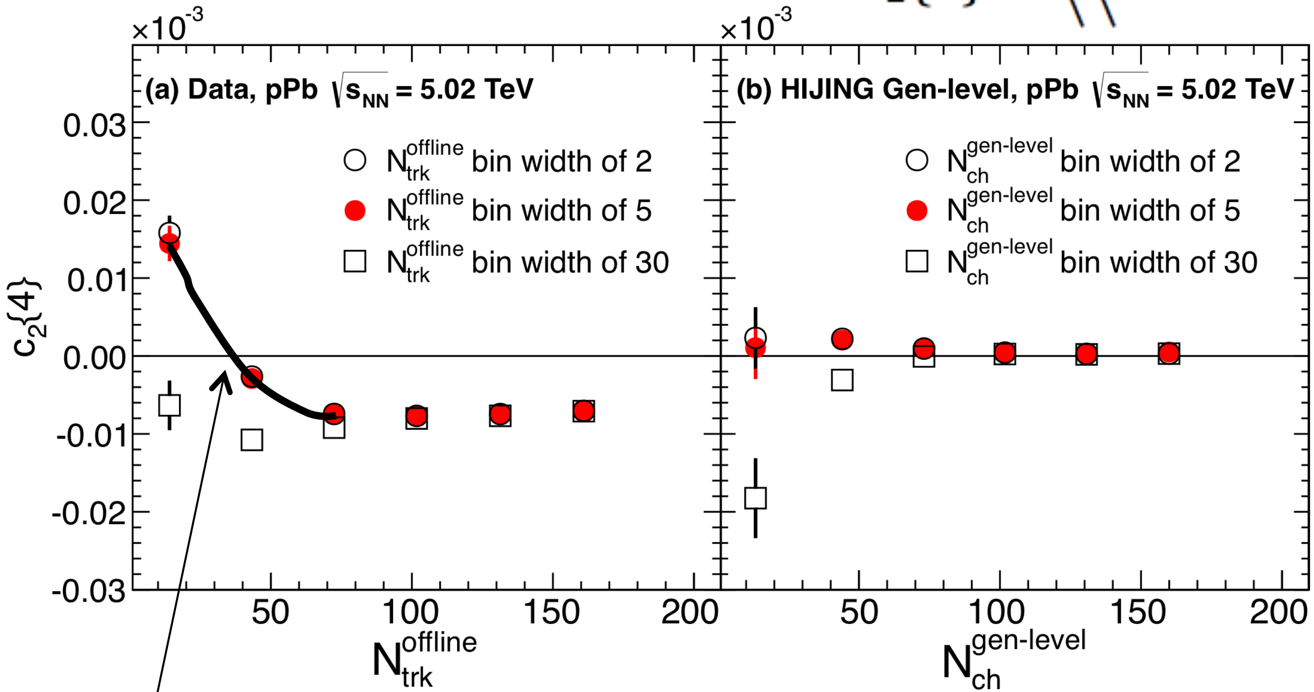


- Must have assumptions about flow in the lowest multiplicity range, model dependent results
- The onset and multiplicity dependence of flow are strongly related to the assumptions

Flow from multiparticle correlations

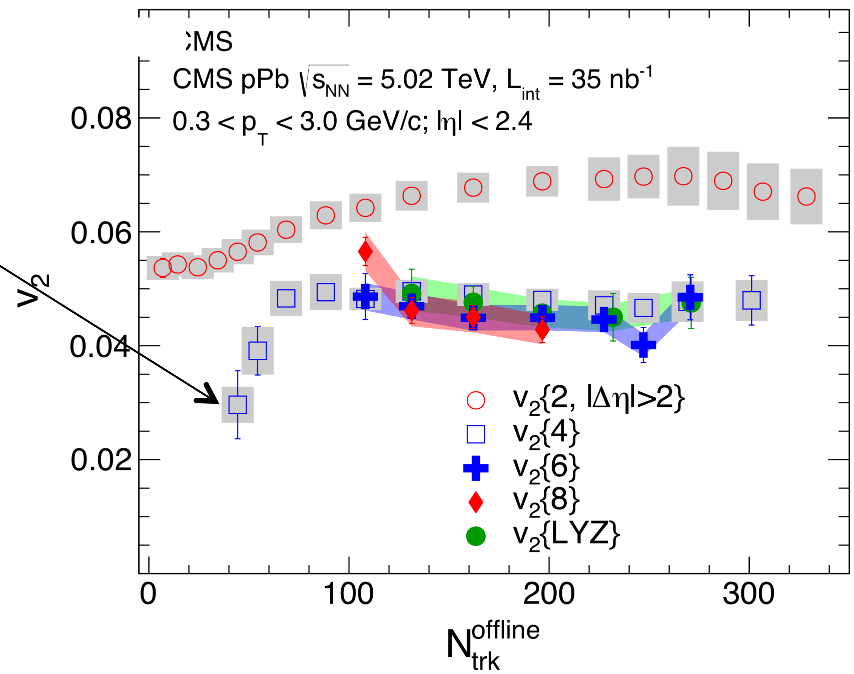
Phys. Lett. B 724 (2013) 213

$$c_2\{4\} = \left\langle\left\langle e^{-2i(\phi_1+\phi_2-\phi_3-\phi_4)}\right\rangle\right\rangle - 2\times\left\langle\left\langle e^{-2i(\phi_1-\phi_2)}\right\rangle\right\rangle^2$$



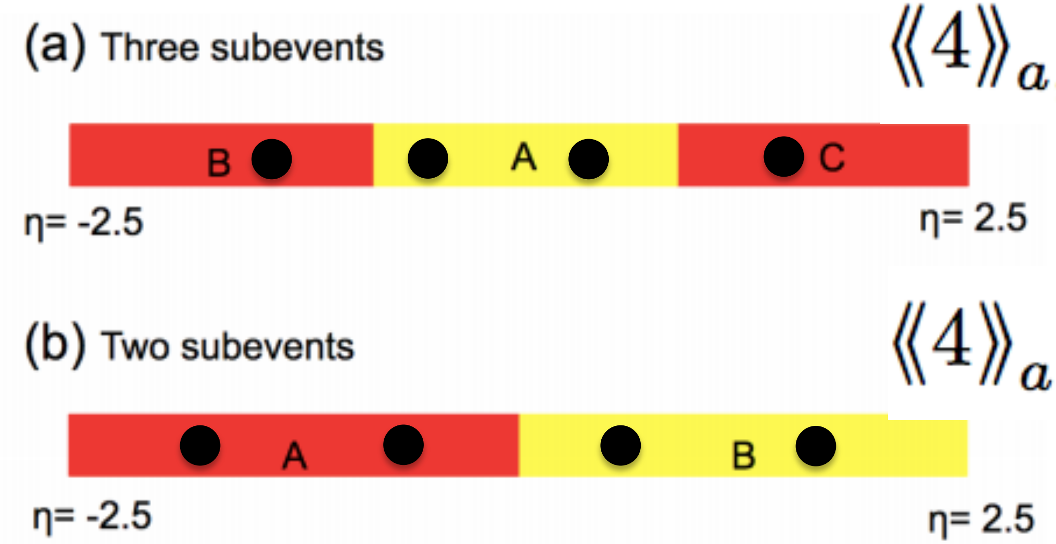
$$v_2^{ref}\{4\} = \sqrt[4]{-c_2\{4\}}$$

Turn-on ?



Is there nonflow from multiparticle correlations in small multiplicity?

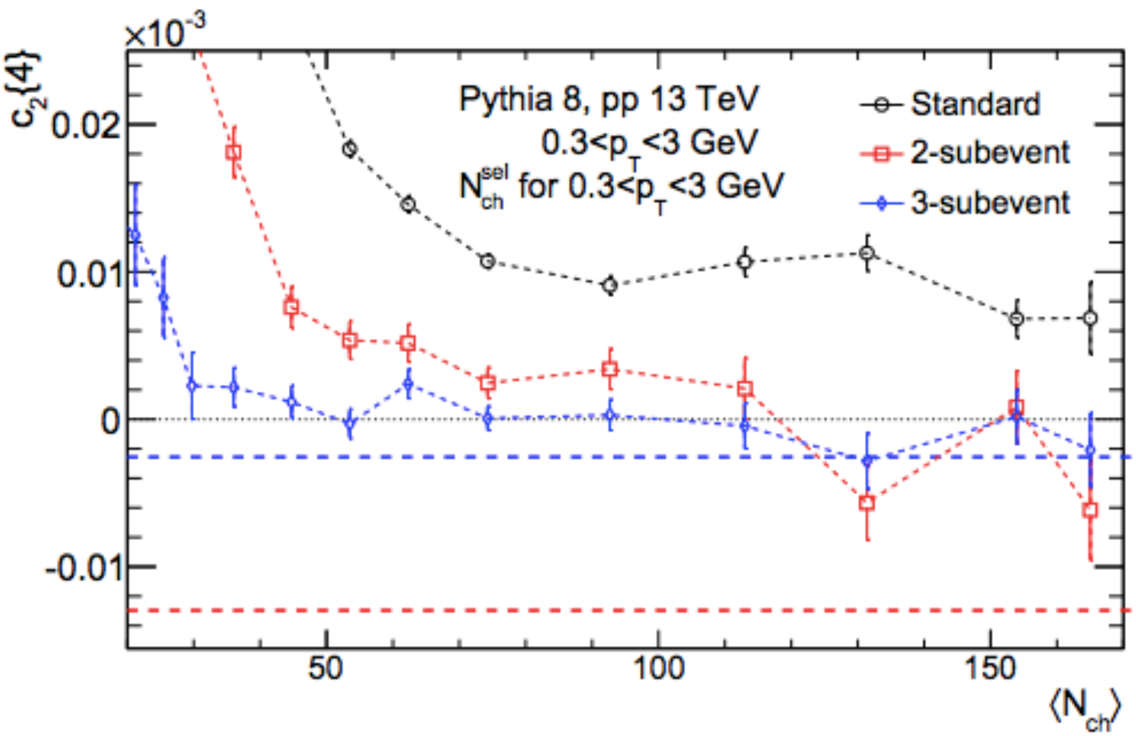
Subevent method with multiparticle correlations



$$\langle\langle 4 \rangle\rangle_{a,a|b,c} \equiv \left\langle\left\langle e^{in(\phi_1^a+\phi_2^a-\phi_3^b-\phi_4^c)} \right\rangle\right\rangle$$

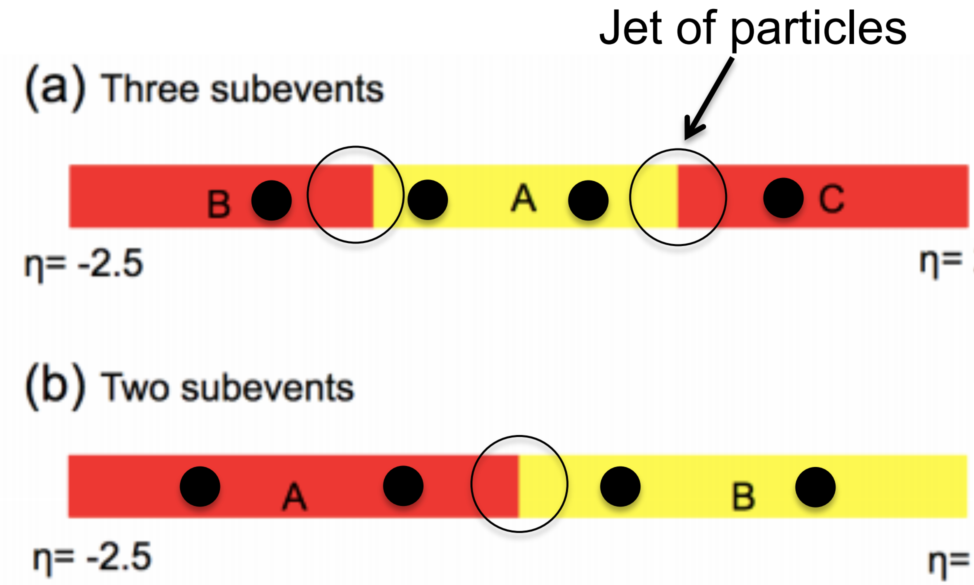
$$\langle\langle 4 \rangle\rangle_{a,a|b,b} \equiv \left\langle\left\langle e^{in(\phi_1^a+\phi_2^a-\phi_3^b-\phi_4^b)} \right\rangle\right\rangle$$

Phys. Rev. C 96, 034906 (2017)



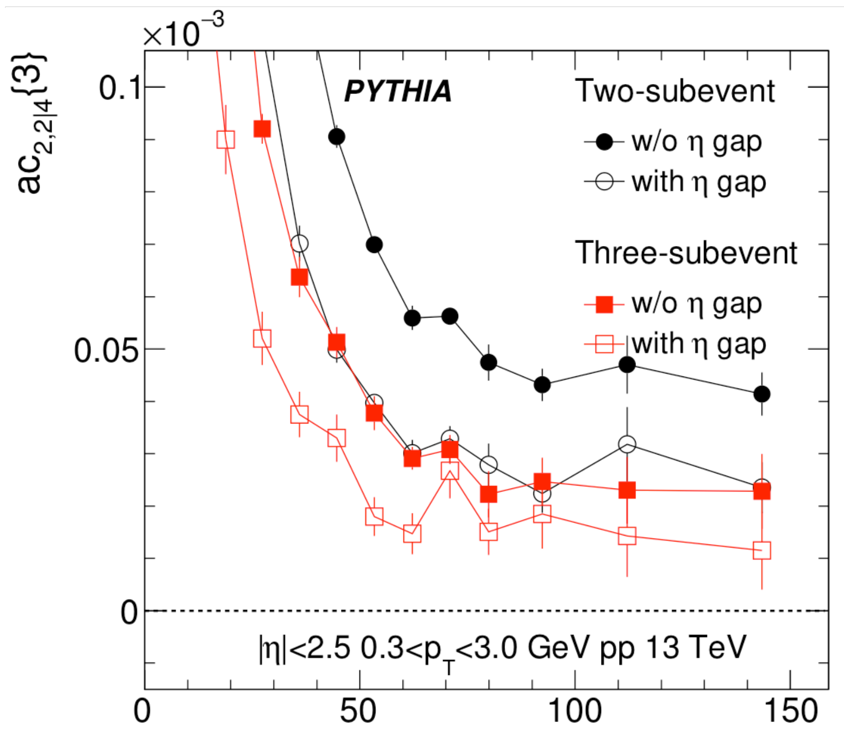
- The standard method has large nonflow contribution in small multiplicity ranges.
- The subevent method works much better

Nonflow in subevent method



$$\langle\langle 4\rangle\rangle_{a,a|b,c} \equiv \left\langle\left\langle e^{in(\phi_1^a+\phi_2^a-\phi_3^b-\phi_4^c)}\right\rangle\right\rangle$$

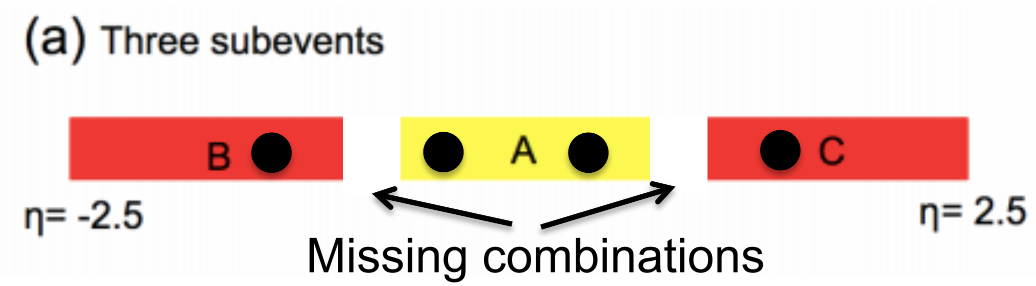
$$\langle\langle 4\rangle\rangle_{a,a|b,b} \equiv \left\langle\left\langle e^{in(\phi_1^a+\phi_2^a-\phi_3^b-\phi_4^b)}\right\rangle\right\rangle$$



Phys. Lett. B 792, 138 (2019)

- When jets are landed on subevent boundaries, some remaining nonflow can't be removed
- Need η gaps between subevents

Looping method



- Need to study correlations vs. η gap
- Run out of statistics quickly
- Any solutions?
- The idea behind Q-cumulant method is to avoid using nested loops

$|\Delta\eta_{ij}|>\eta$ gap

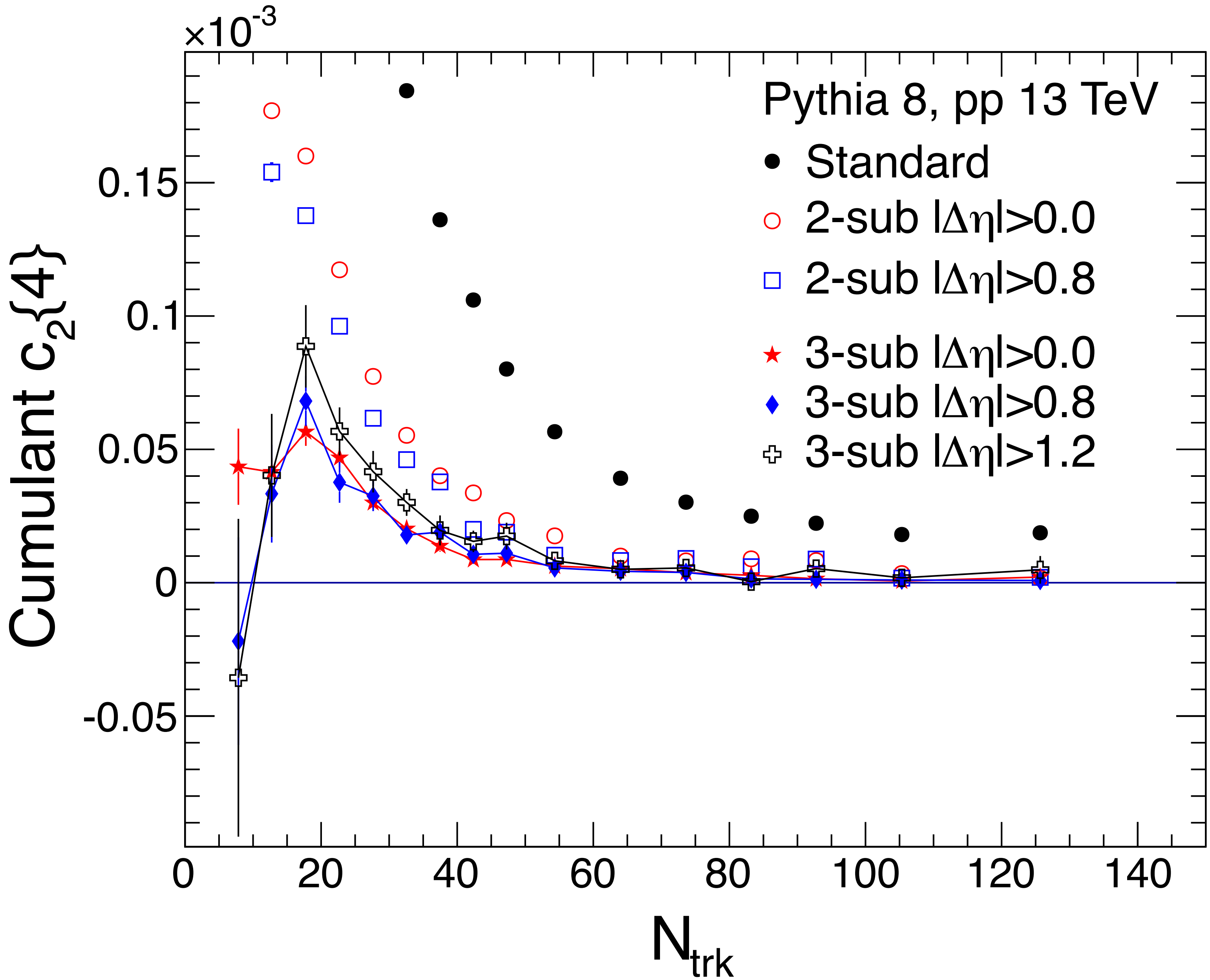
- If we just loop over particle azimuthal angles, it is very easy to study the η gap dependence
- Also with much better statistics since it keeps all possible combinations

$$\langle 4\rangle_{n,n|n,n} \equiv \frac{1}{\binom{M}{4}4!}\sum_{\substack{i,j,k,l=1\\(i\neq j\neq k\neq l)}}^{M} e^{in(\phi_i+\phi_j-\phi_k-\phi_l)}$$

Time complexity:

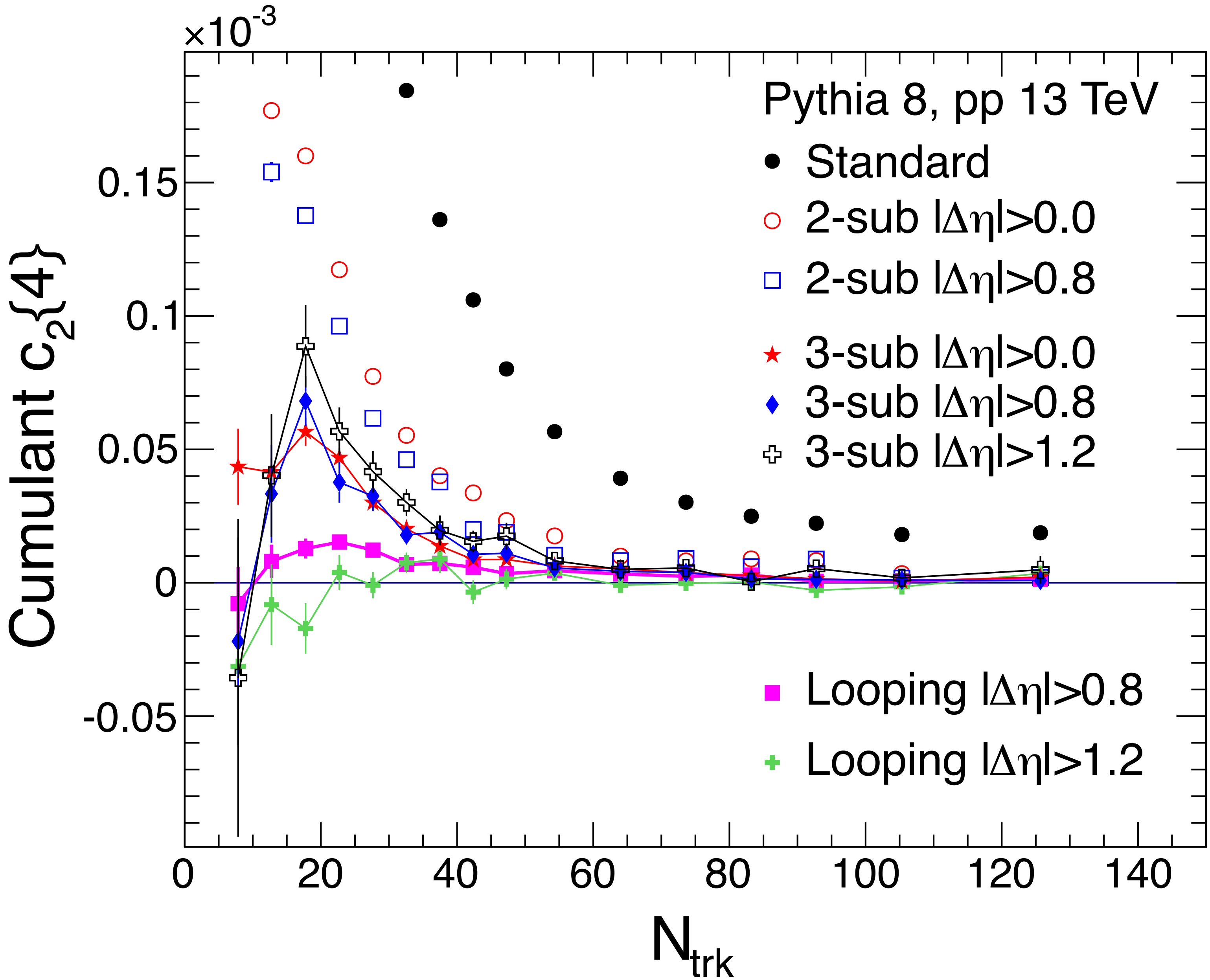
- $O(N_{trk}{}^{n})$, for n particle cumulant with N_{trk} total number of particles per event
- The 8 particle cumulant in an event with 1000 particles will take ~1 billion years
- However, our interest is in the small system with N_{trk} less than 100
- It takes a few seconds to calculate the 4 particle cumulant with N_{trk}=100
- It could be much faster after applying η gaps between particles

Subevent and looping method



- Nonflow is less as more subevents are applied

Subevent and looping method



- Nonflow is less as more subevents are applied
- The looping method remove most of the nonflow

Summary

• Nonflow has to be carefully subtracted for flow study in small systems

• The current subtraction methods in two particle correlations need assumptions about flow in the lowest multiplicity range and the results are model dependent

• Multiparticle correlations with subevent and looping methods are better for dealing with nonflow