Measurements of collectivity in small systems with ATLAS

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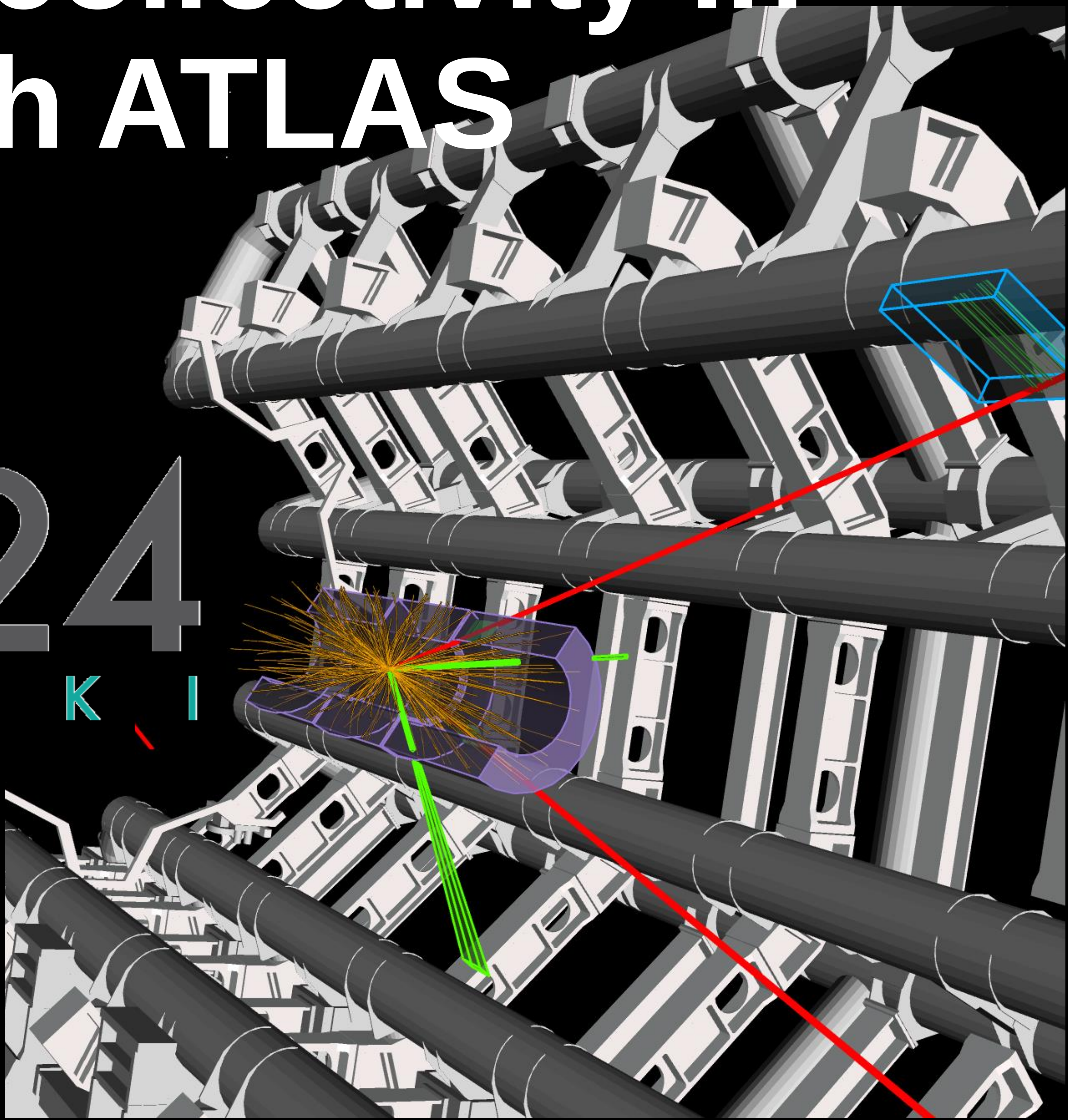
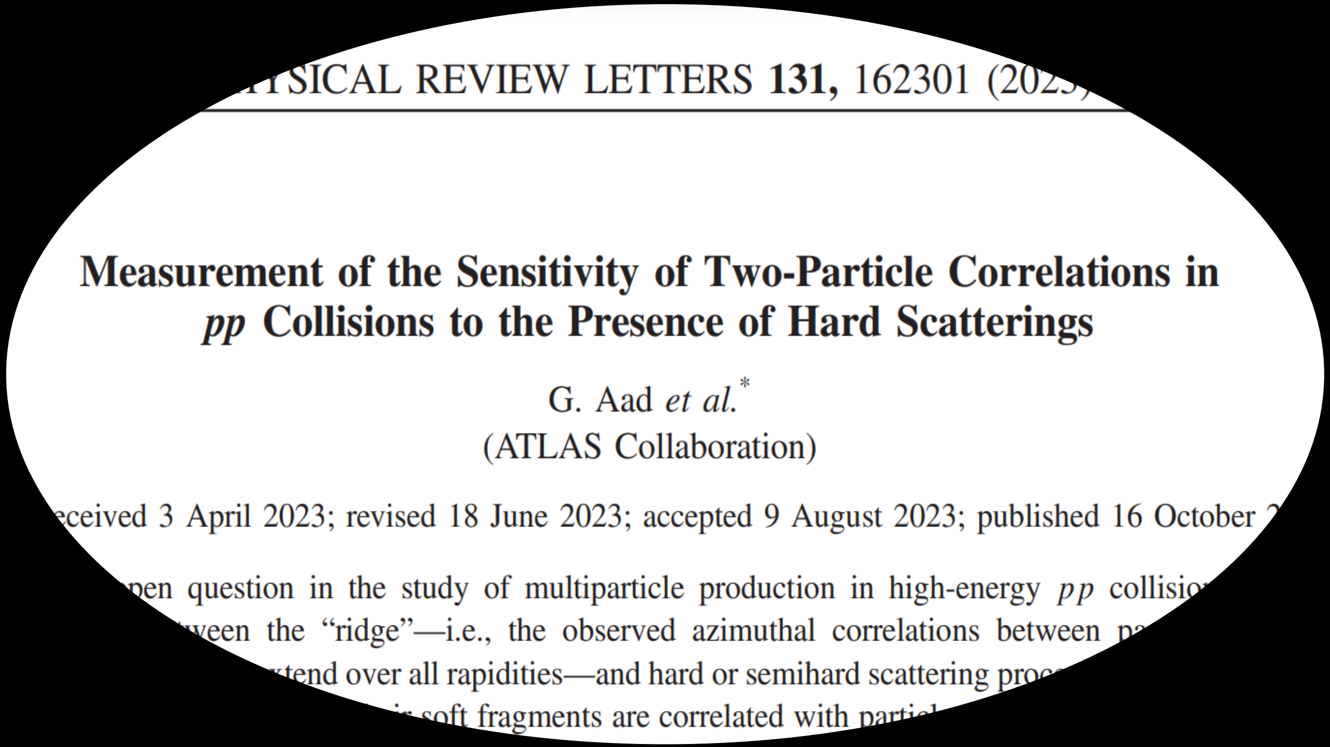
HP2024 NAGASAKI

ATLAS EXPERIMENT

Columbia University IN THE CITY OF NEW YORK



Two measurements in this presentation



YSICAL REVIEW LETTERS **131,** 162301 (202

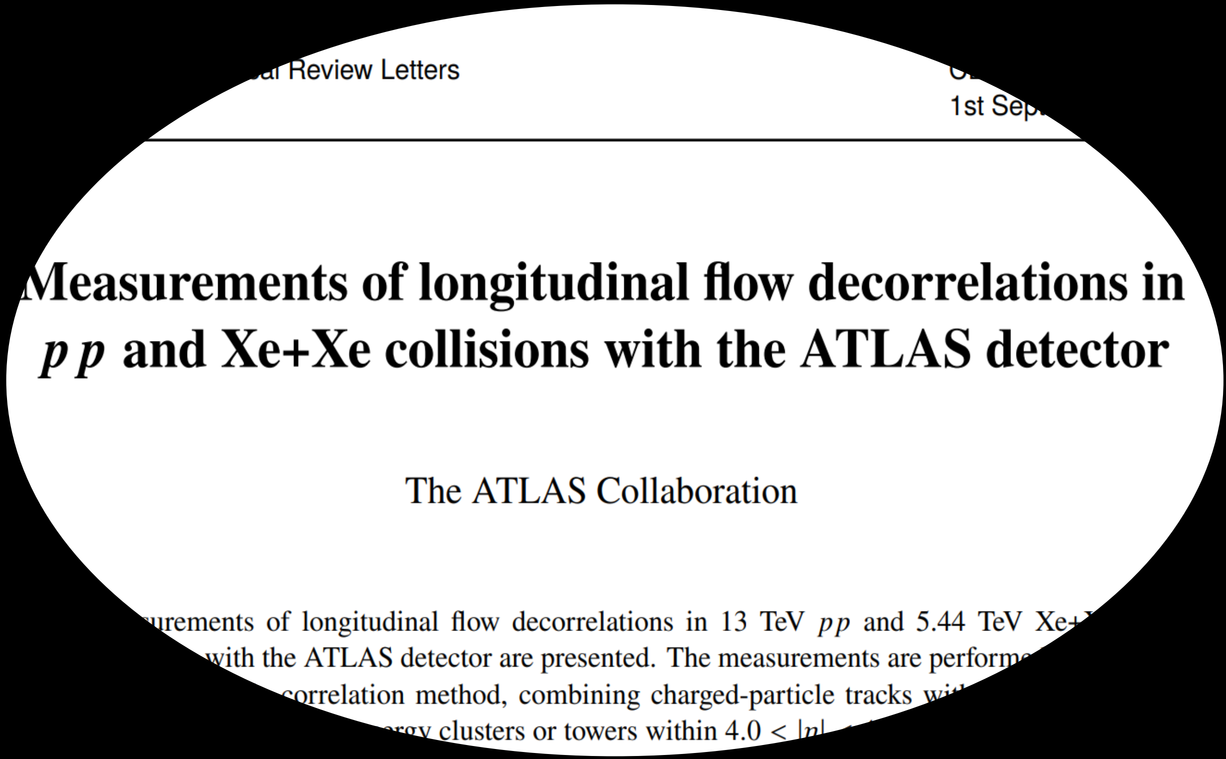
Measurement of the Sensitivity of Two-Particle Correlations in *pp* Collisions to the Presence of Hard Scatterings

G. Aad *et al.**
(ATLAS Collaboration)

eceived 3 April 2023; revised 18 June 2023; accepted 9 August 2023; published 16 October 2

pen question in the study of multiparticle production in high-energy pp collisio
tween the "ridge"—i.e., the observed azimuthal correlations between pa
xtend over all rapidities—and hard or semihard scattering proc
soft fragments are correlated with partic

PhysRevLett.131.162301
arXiv:2308.16745



al Review Letters

1st Sep

Measurements of longitudinal flow decorrelations in pp and Xe+Xe collisions with the ATLAS detector

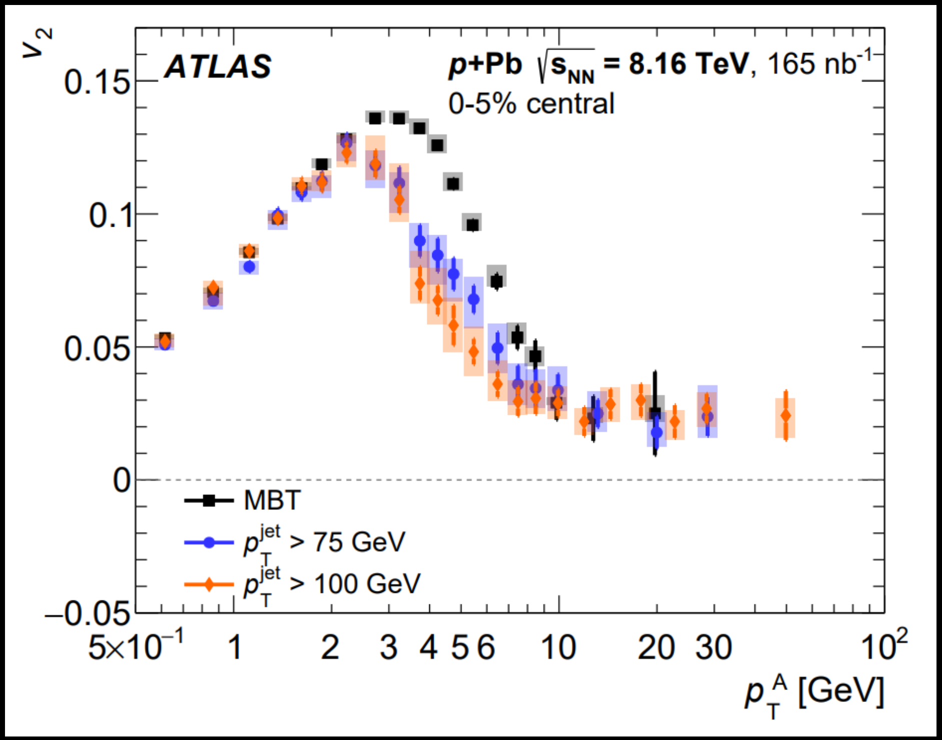
The ATLAS Collaboration

urements of longitudinal flow decorrelations in 13 TeV pp and 5.44 TeV Xe+
with the ATLAS detector are presented. The measurements are performe
correlation method, combining charged-particle tracks wi
rgy clusters or towers within 4.0 < |η|

arXiv:2308.16745

10.1140/epjc/s10052-020-7624-4

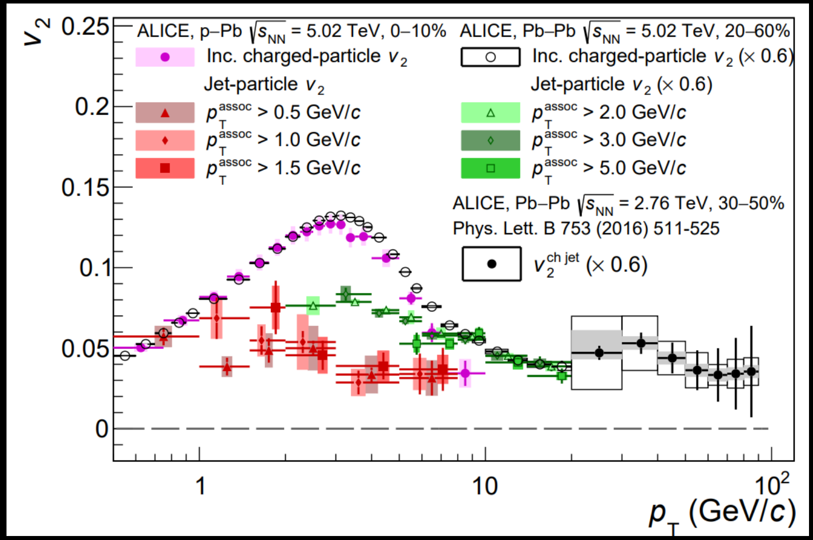
Jet-bulk correlations in small systems



- Measurements in pPb have shown that high-p_T phenomenon are correlated with the underlying event.
- $R_{pPb} \approx 1$
- Suggests another generator of anisotropy, other than something like path-dependent energy loss
- Initial state effects such as TMDs* and CGC correlation?

Today I will present measurements in *pp*

- Cleanly separating jet and the bulk particles
- More sensitivity to initial state effects



* pos.sissa.it/456/164

JHEP 08 (2024) 234

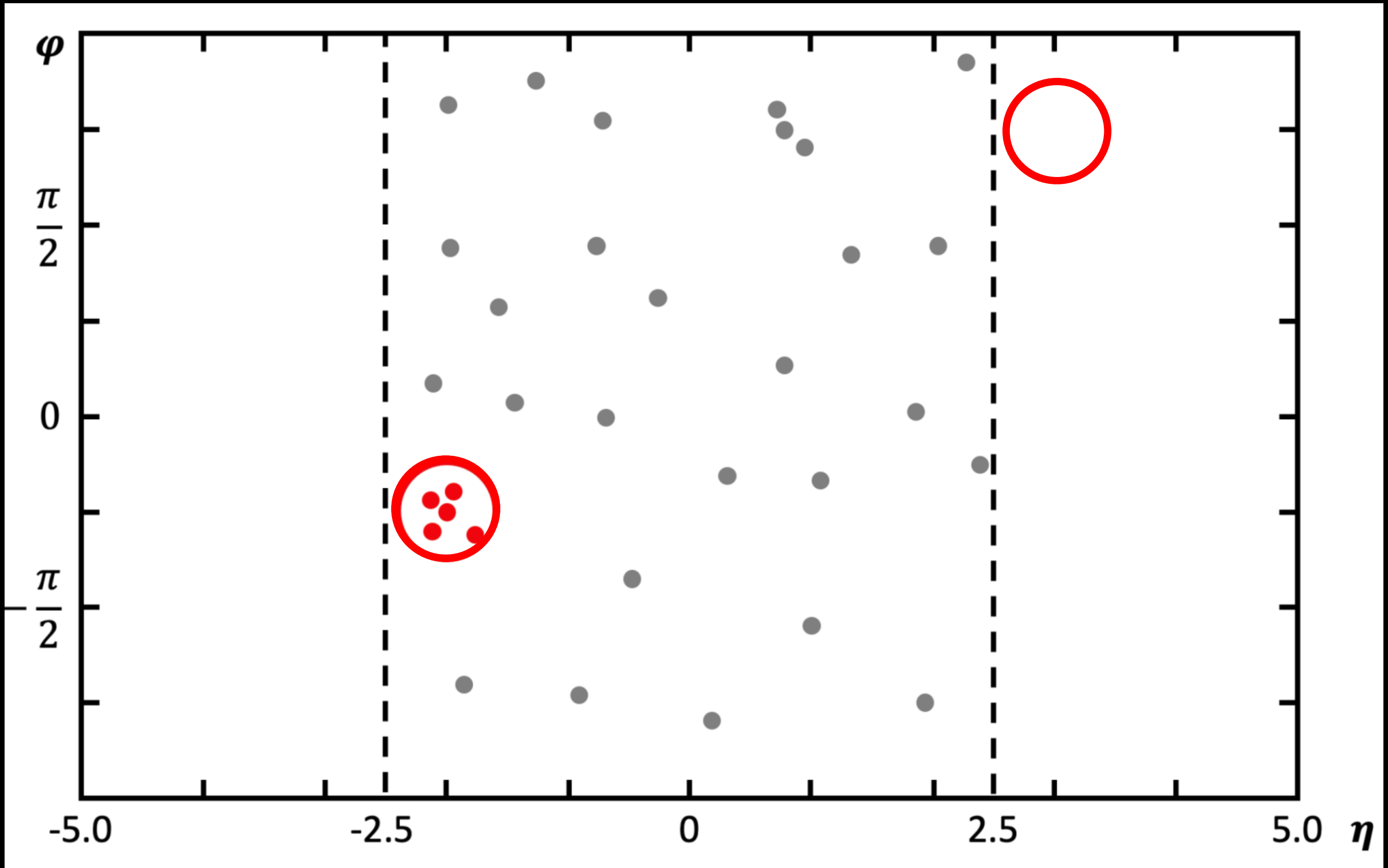
v_2 of underlying event (UE) particles in *pp* collisions

PhysRevLett.131.162301

Identifying jets and jet events

Identify jets

- Particle flow algorithm
- $p_T > 15$ GeV, $|\eta| < 4.5$



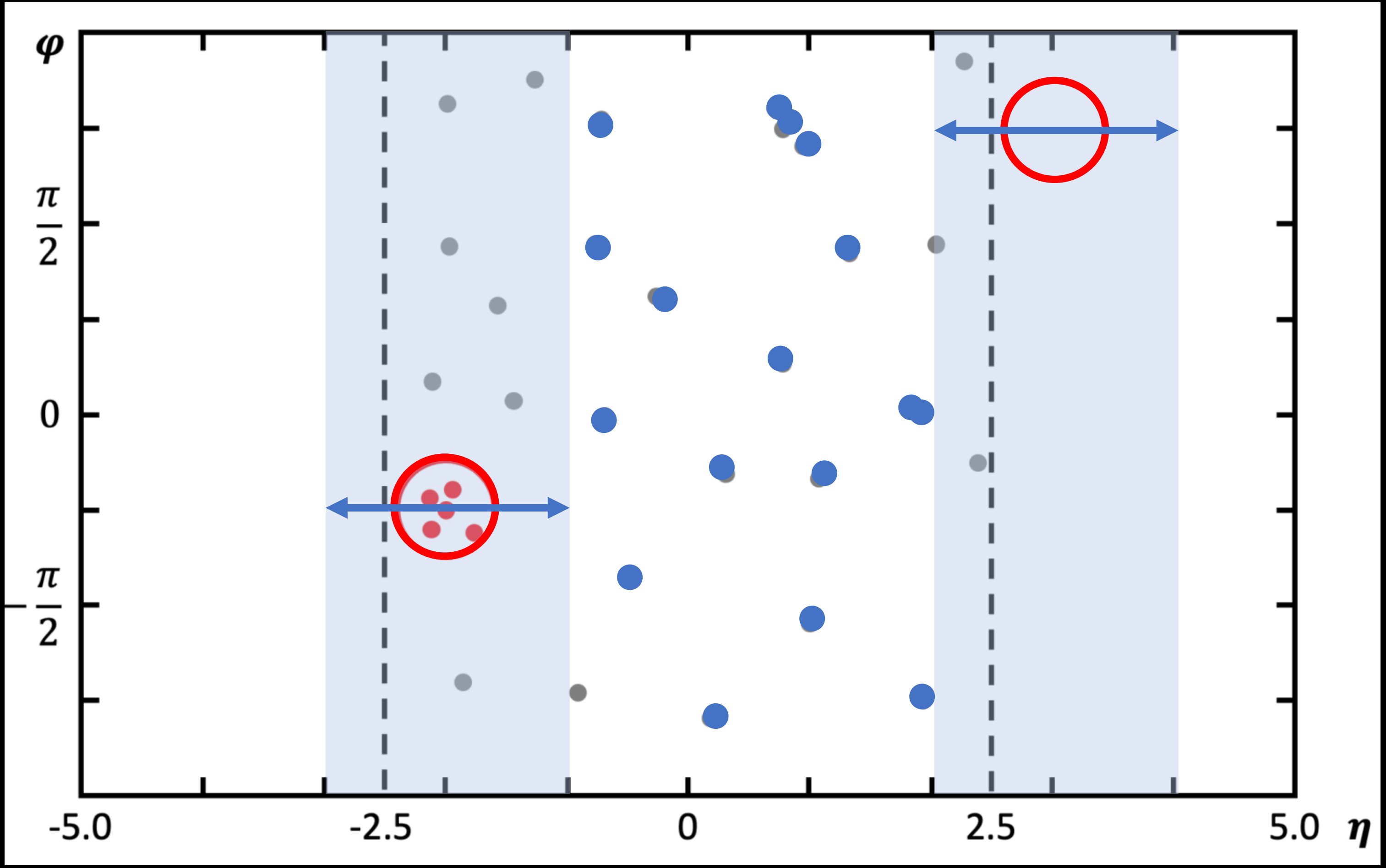
Selecting charged particles in jet events

Identify jets

- Particle flow algorithm
- p_T > 15 GeV, |η| < 4.5

2 Particle correlation

- **Blue-blue correlation**
- Between two charged tracks
- Tracks are NOT near jets $|\Delta \eta_{\text{jet - ch}}| > 1$



Underlying Event correlation (h^{UE}-h^{UE})

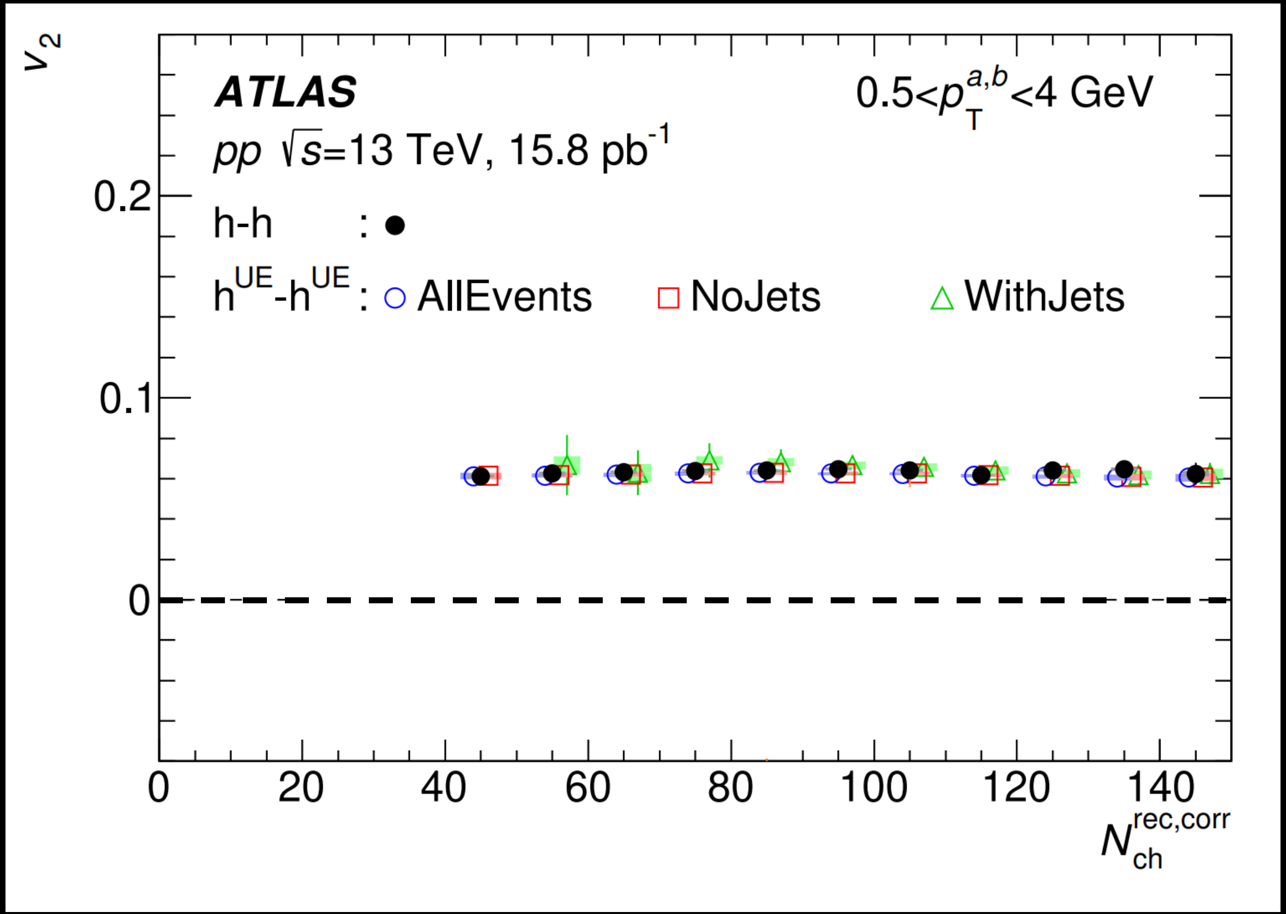
Perform templated-based non-flow subtraction, see backup.

Different event selections shown

- ***h-h***: inclusive, similar to what has been measured for a decade
- **AllEvents**: No event selection (but with the particles away from jets)
- **WithJets**: Only events with at least 1 jet
- **NoJets**: Events with no jets

Regardless of the presence of jets, we observe very similar v_2 as inclusive v_2 measurements

- Weak multiplicity dependence
- V_2~6%



PhysRevLett.131.162301

Correlation of jet particles with the underlying event in *pp*

PhysRevLett.131.162301

Challenge: ensure our identification of jet particles is not biased by the underlying event

UE bias on jets in PYTHIA

consistent p_T cut for calculating jet p_T^G →

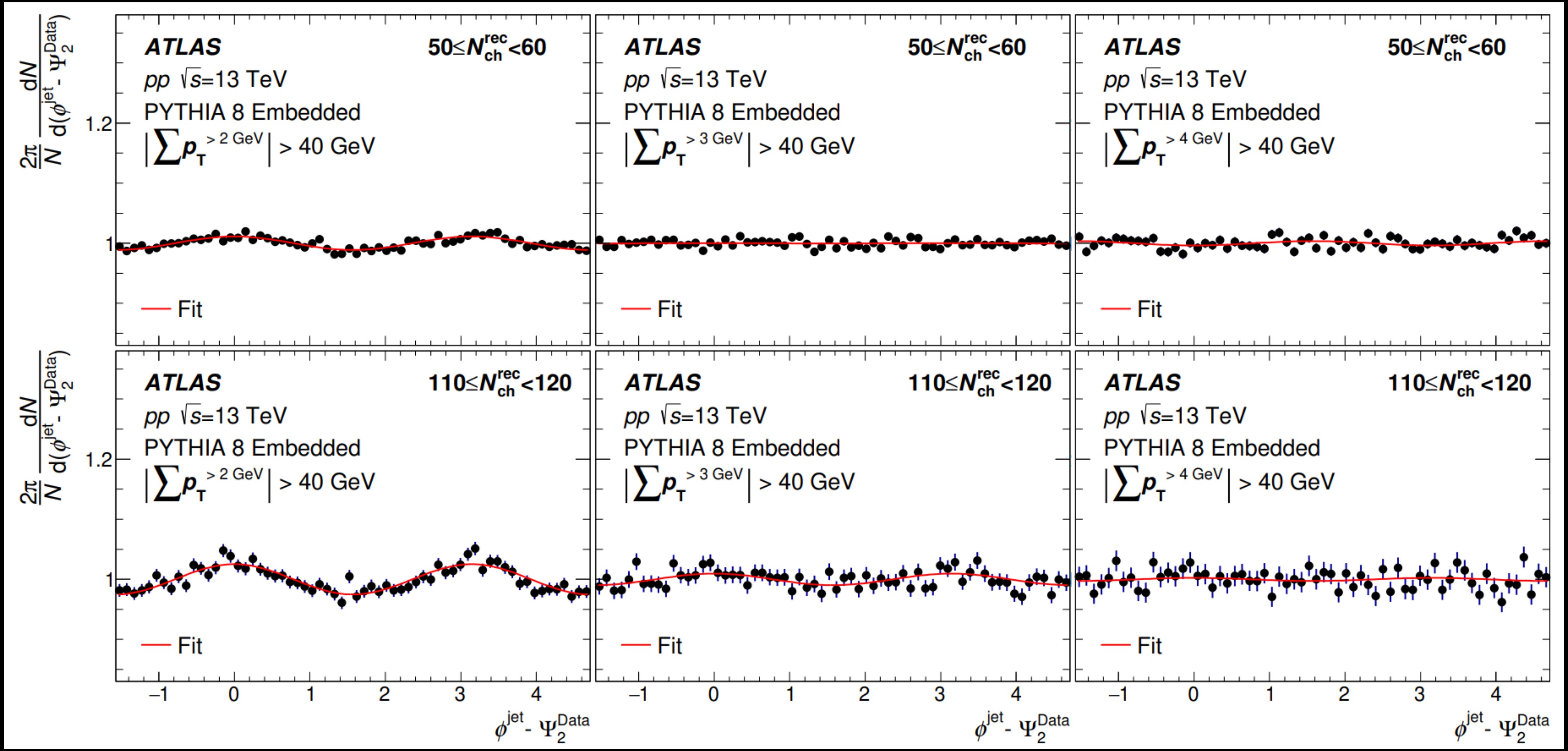
2 GeV 3GeV 4 GeV

Medium UE multiplicity

PYTHIA jet particles embedded into UE data events with no data-jet correlation

but correlation emerges when jets are clustered with UE data particles

Large UE multiplicity



$|\sum p_T^{>4\,GeV}| > 40$ GeV **no artificial correlation of PYTHIA jet with data UE remains**

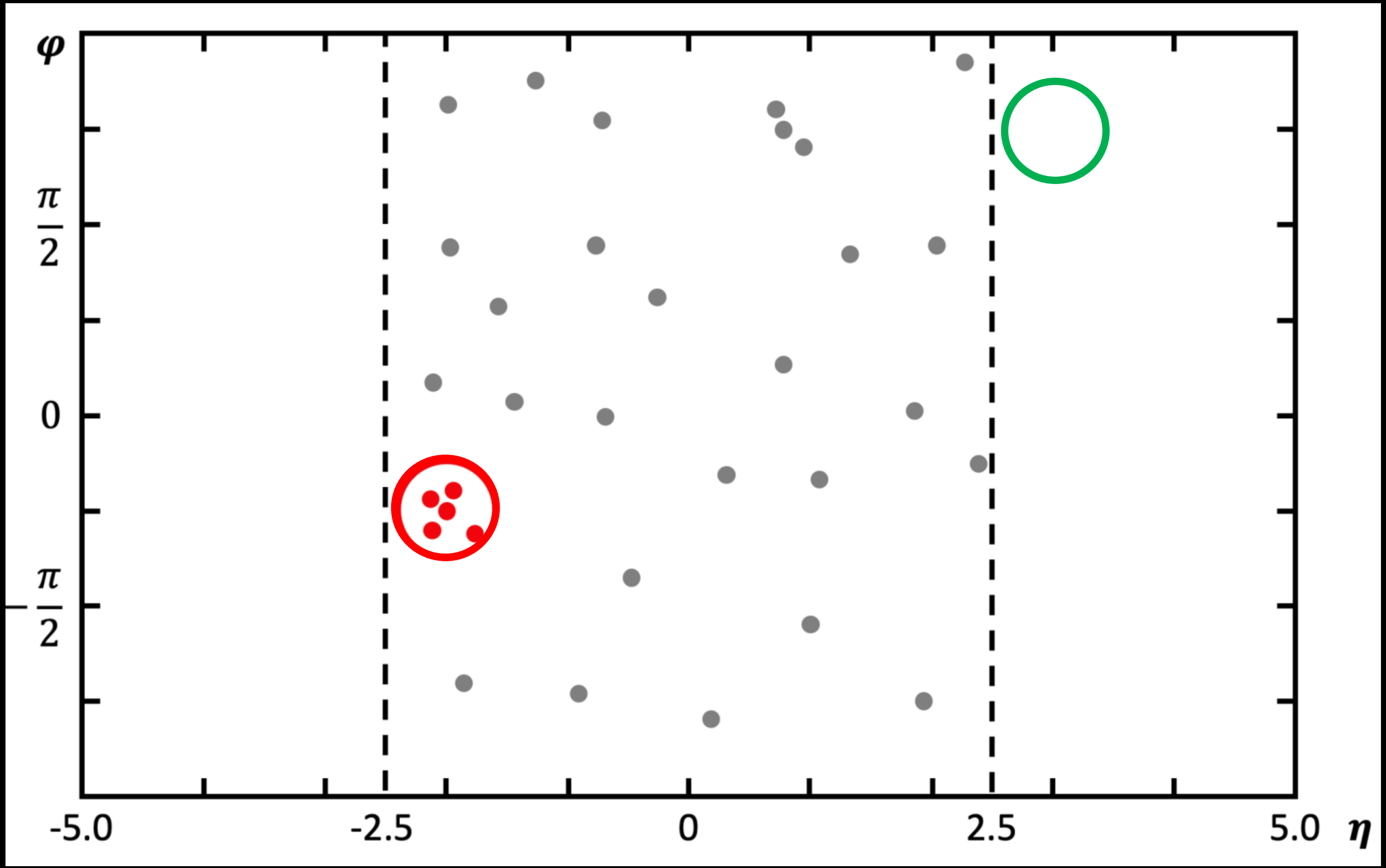
Selecting jets for constituent v_2

constituents of Jets

with $p_T^G > 40$ GeV, $|\eta|<2.1$

Require balancing jet with $p_T^G > 15$ GeV and $\Delta\varphi > 5\pi/6$

reduce non-flow effects in 2PC
clearer separation of jet and UE particles



jets particle – UE correlation

Correlate

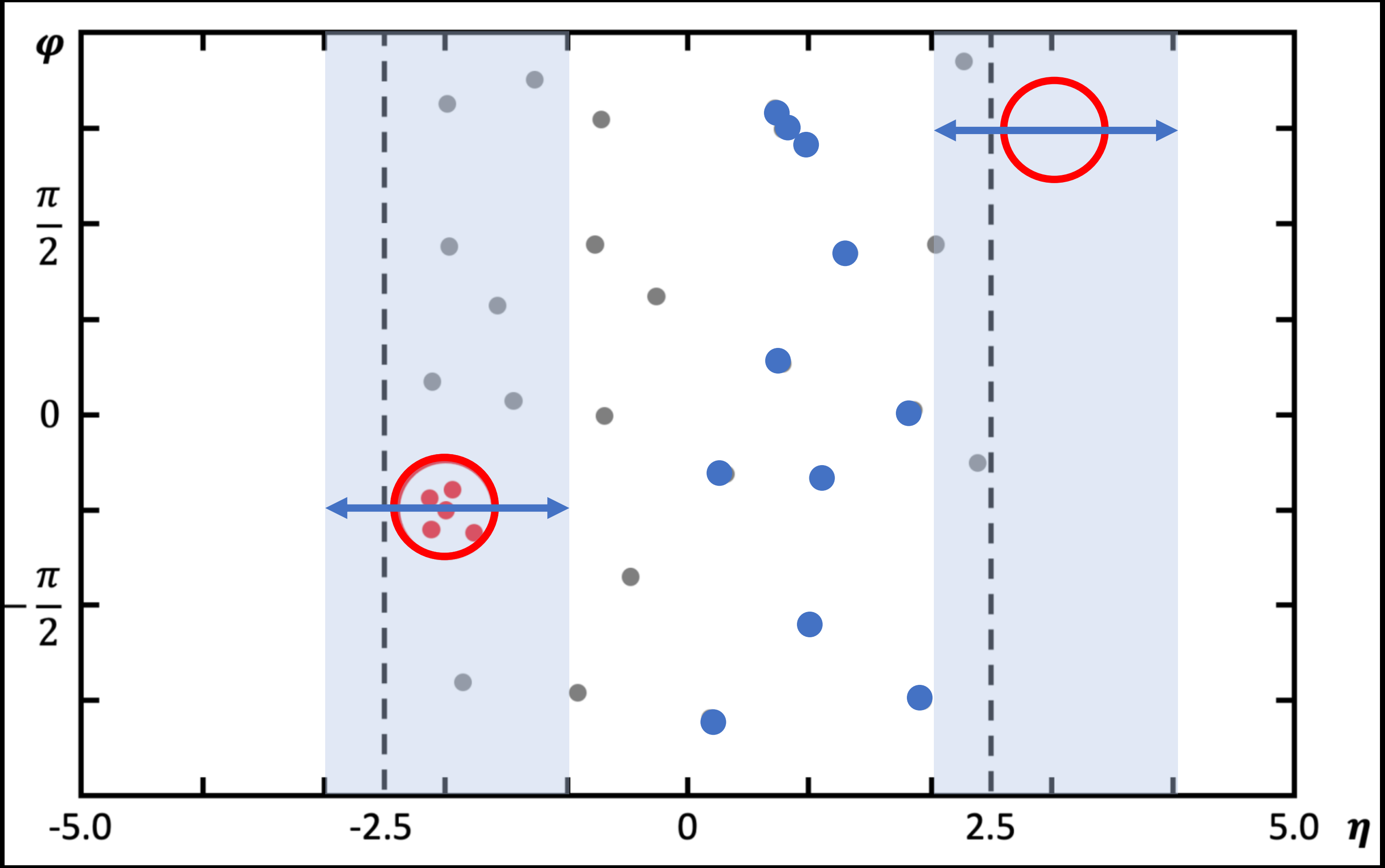
constituents of Jets

- **red particles →**
- Charged particle tracks

with

underlying event particles

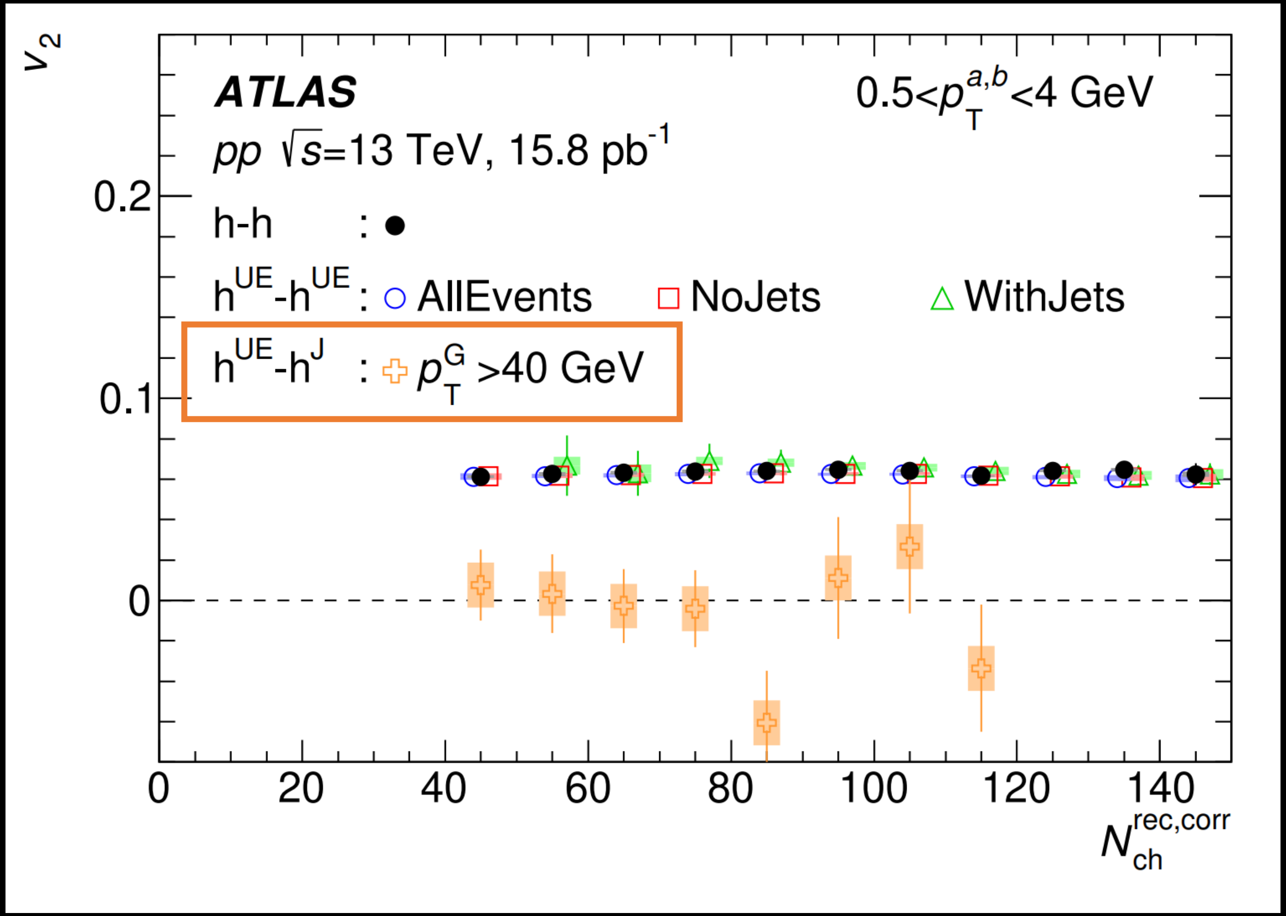
- **Blue particles →**
- away from all jets
- the standard $|\Delta\eta| > 2$



v_2 of jet particles

- Integrated jet particle v_2 consistent with zero

- For multiplicities accessible in *pp* collisions, no jet particle v_2 is observed.

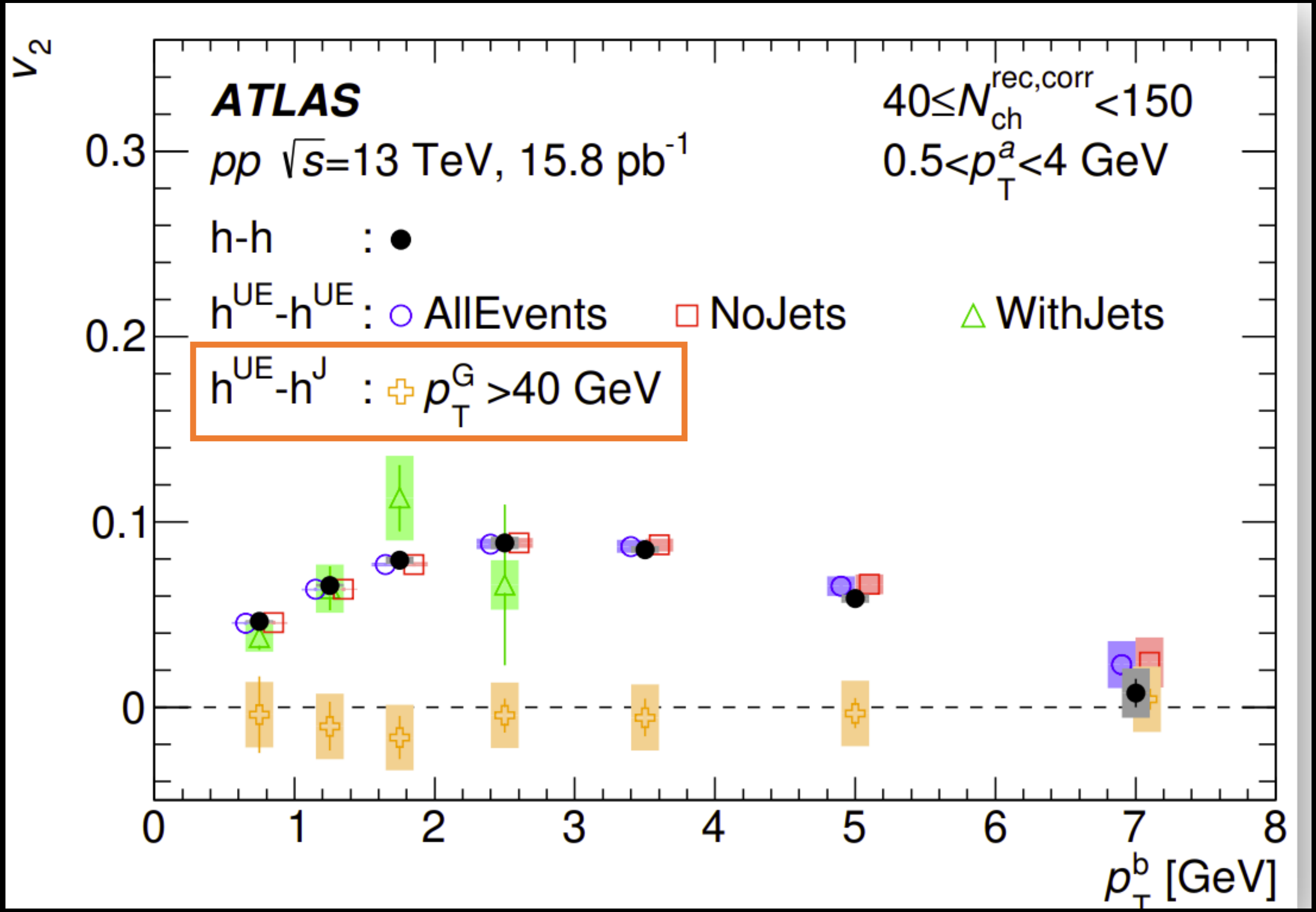


PhysRevLett.131.162301

v_2 of jet particles

PhysRevLett.131.162301

- Jet particle v_2 is consistent with zero within uncertainties



Major conclusions

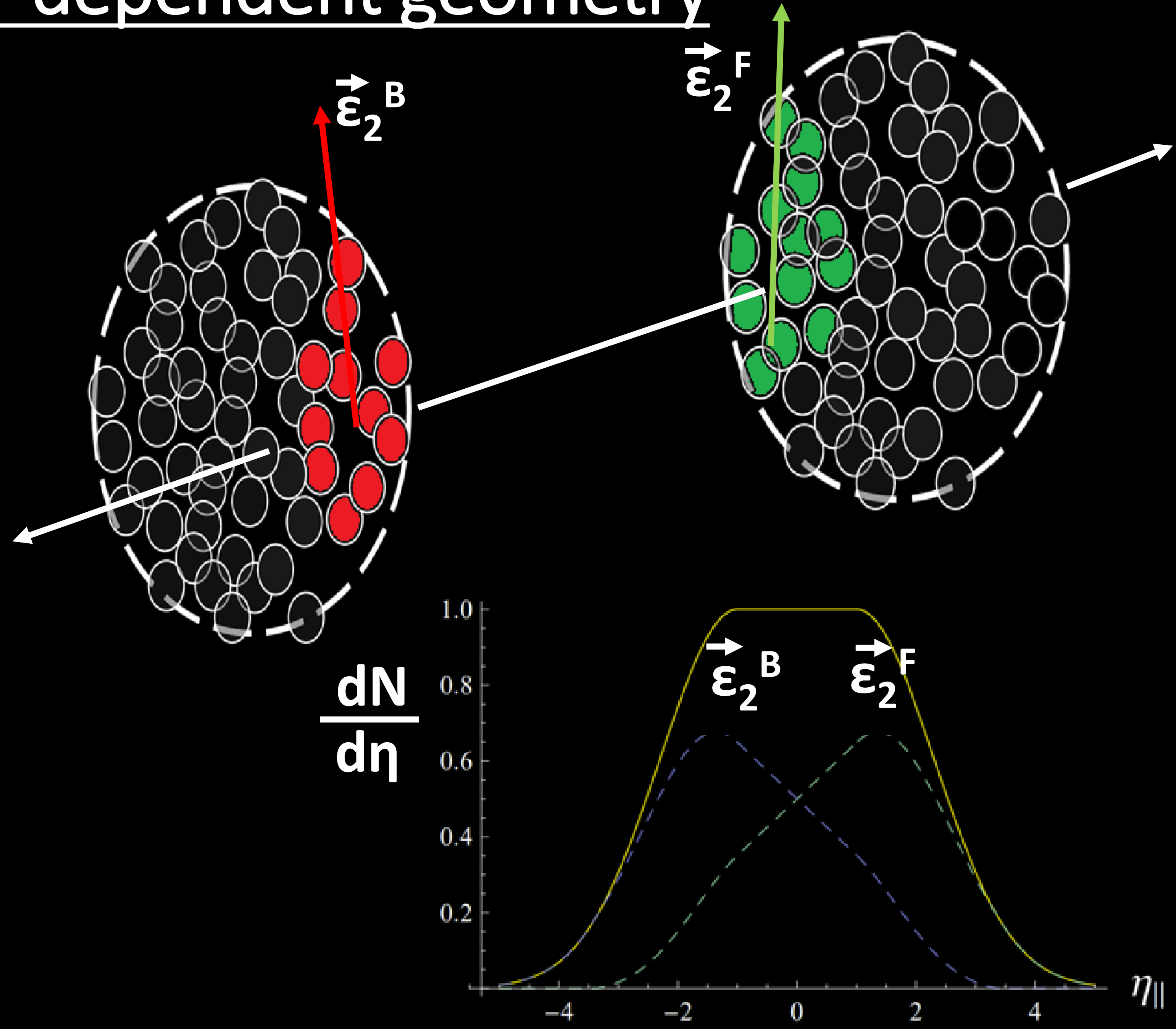
- Jets do not contribute to the ridge signature in *pp* collisions
- Particles arising from jets, even at very low p_T, do not participate in the collective behavior

Diverse consequences, from jet-medium interactions to initial-state momentum anisotropy

Flow decorrelations in small systems

arXiv:2308.16745

η-dependent geometry



First models of longitudinal decorrelation

Backwards-going participants dominates backwards-going dN/dη and backwards-going initial-state geometry $\varepsilon_n{}^B$

$\varepsilon_n{}^B$ and $\varepsilon_n{}^F$ could be different

Interpolation between geometries at mid rapidity

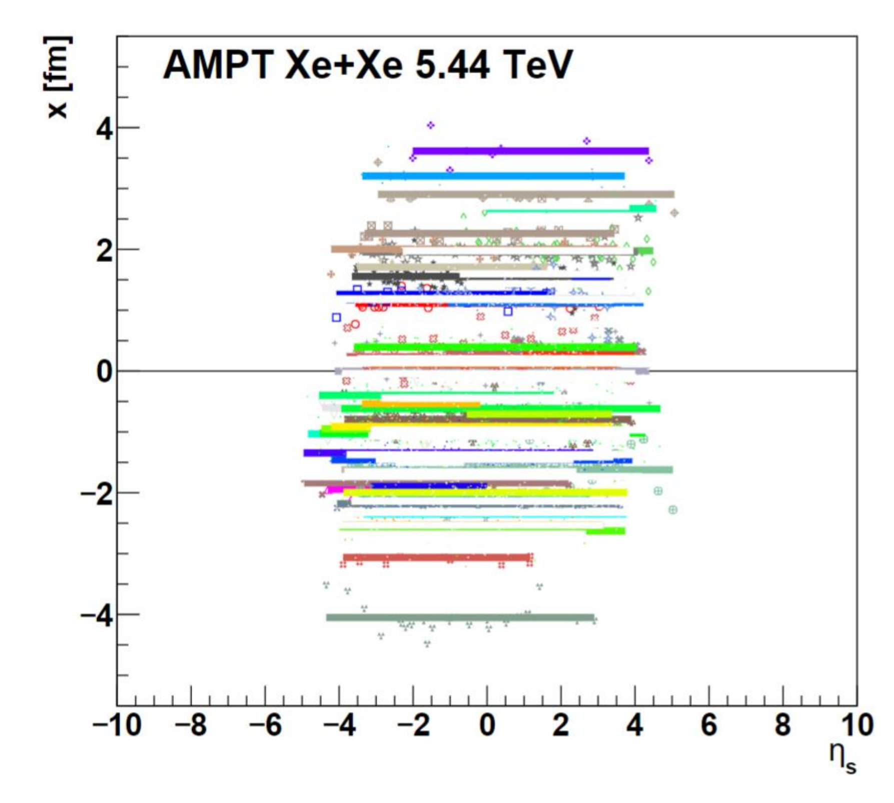
Fluctuation-driven geometry (e.g. ε_3) can vary more

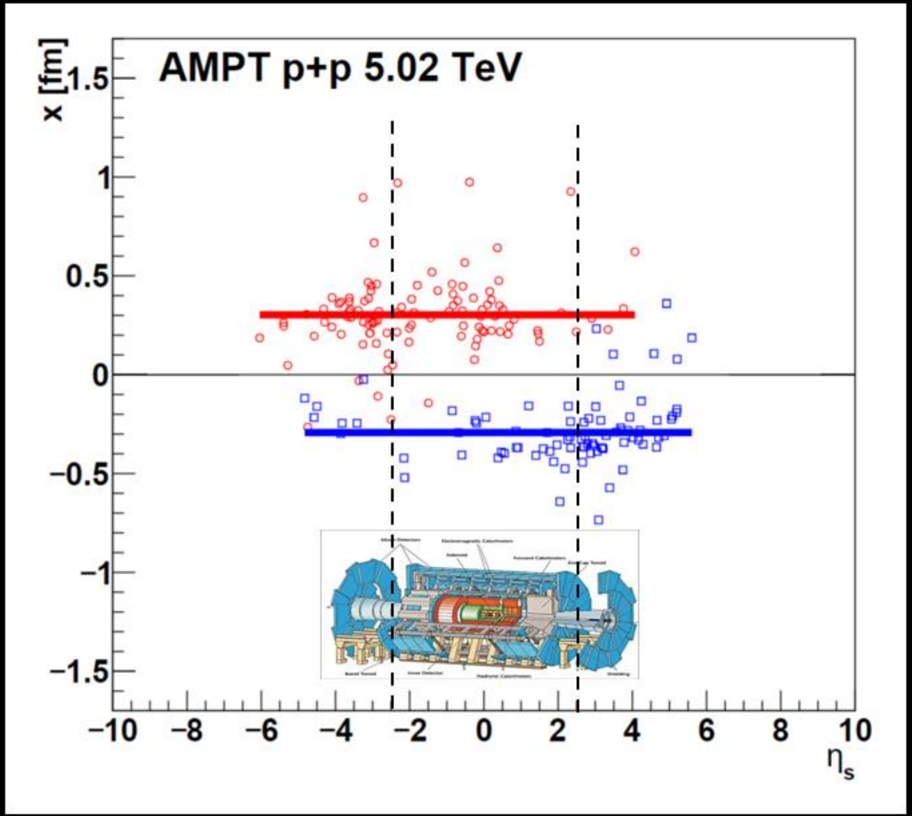
Hydrodynamic expansion gives rise to azimuthally anisotropic final-state momentum

arXiv:1011.3354

String models make straightforward prediction in *pp*

- String-based MC Glauber models of the initial state simulate these effects out of the box in AA
- In *pp*
  - Strings span the acceptance of the ATLAS inner detector.
  - No variation in geometry
  - **No longitudinal decorrelation predicted**





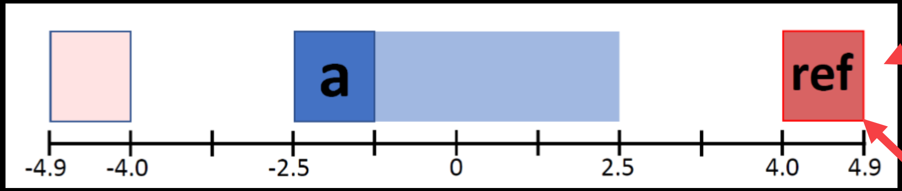
Analysis overview

Systems analyzed

pp **13 TeV** **Xe+Xe 5.44 TeV**

Analysis steps

Step 1: Two-particle correlations between inner detector tracks and forward calorimeter



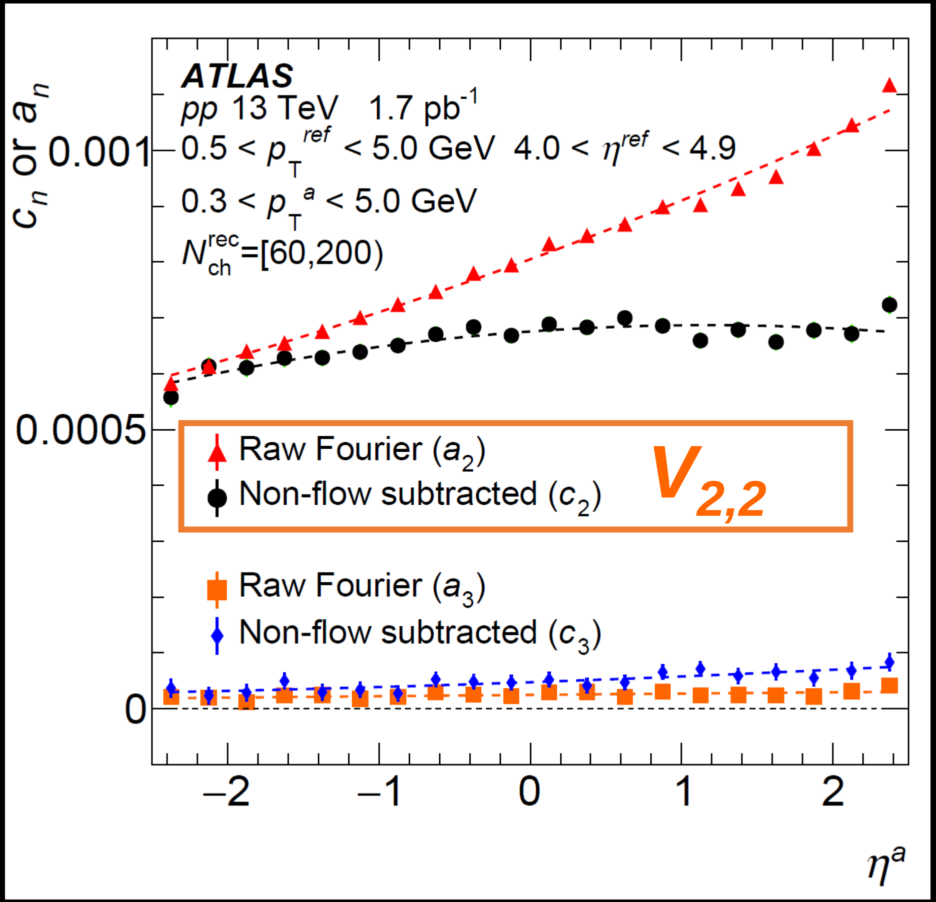
pp: calorimetric clusters

Xe+Xe: calorimetric towers

$$\Delta\phi = \underbrace{\phi^{a}}_{\eta^{a} = [-2.5,2.5]} - \underbrace{\phi^{ref}}_{\eta^{ref} = [4.0,4.9]}$$

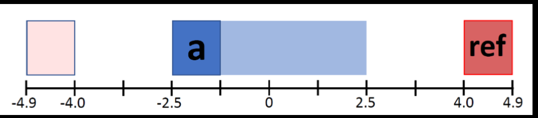
$v_{2,2}(\eta^a)$ and non-flow subtraction

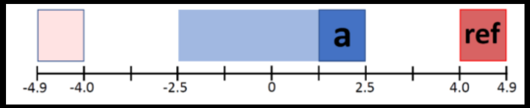
arXiv:2308.16745



Nonflow a_2 is positive

Nonflow a_3 is negative





Raw Fourier a_2: large $da_2/d\eta$

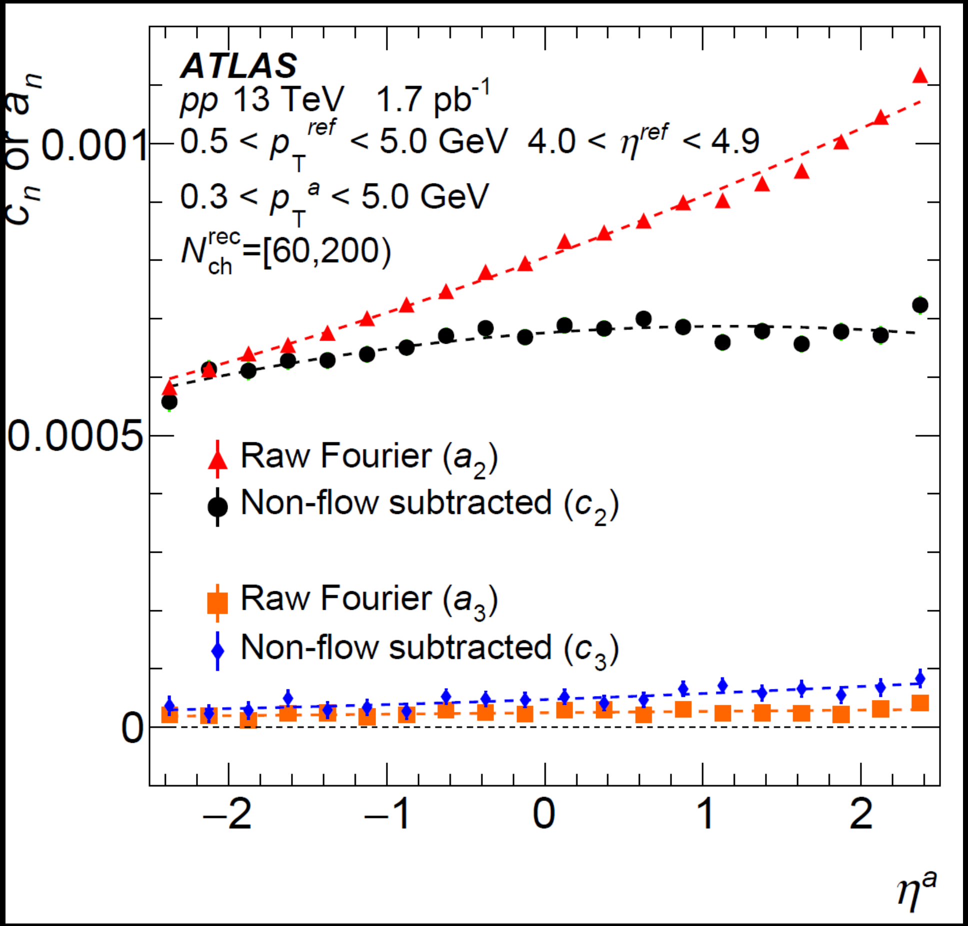
Non-flow subtraction c_2: small $dc_2/d\eta$ with a large subtraction for small gaps and a small correction for large gaps

3rd moment has opposite hierarchy!
Raw Fourier a_3: small $da_3/d\eta$
Non-flow subtraction: : larger $dc_3/d\eta$

Nonflow is a large background for decorrelation measurements

Parametrize dependence of correlation coefficients

arXiv:2308.16745



We characterize the η^a behavior of the correlation coefficients with a fit function,

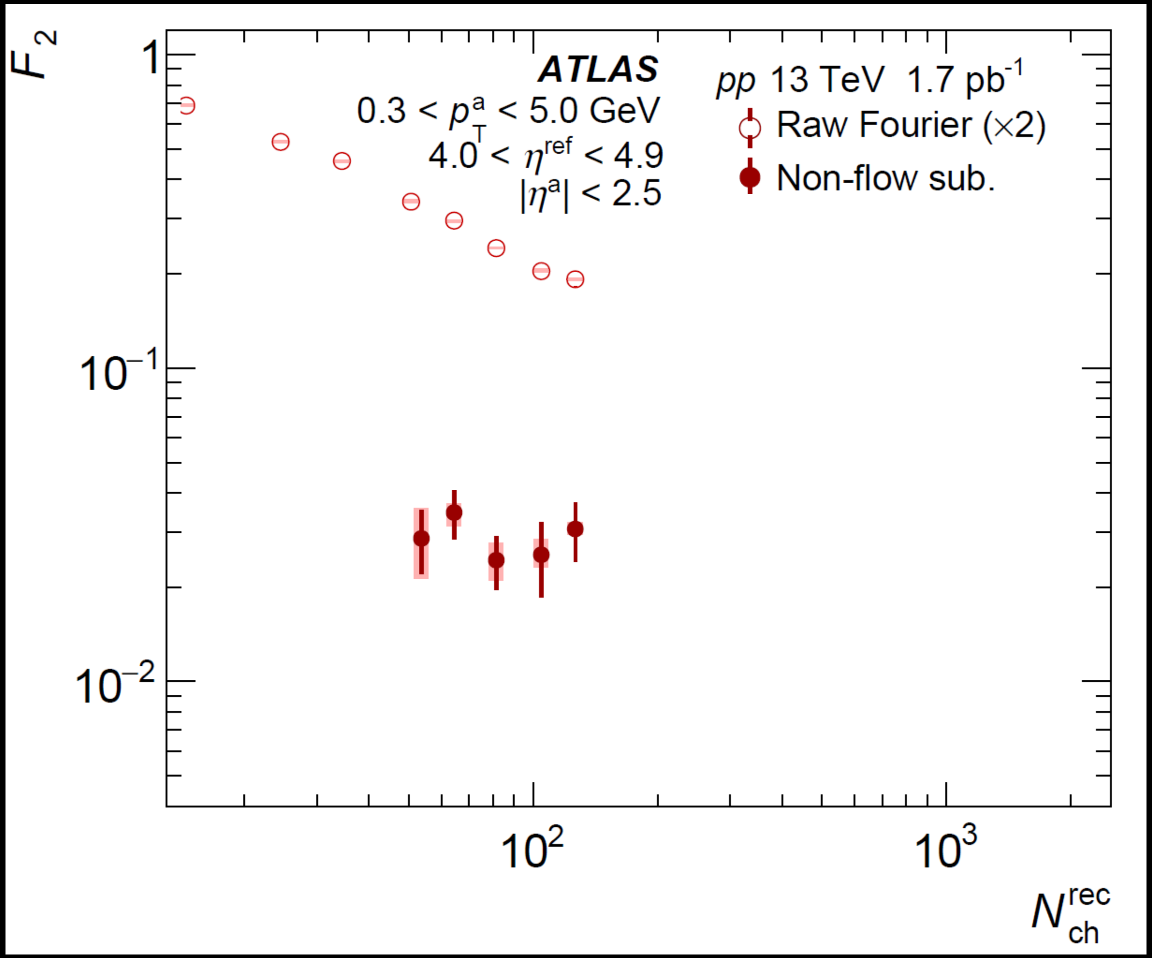
$$A(1 + F_n \times (\eta^a) + S_n \times (\eta^a)^2)$$

Decorrelation observable

F_n is the fractional change in $v_{2,2}$ per a unit rapidity
it characterizes longitudinal decorrelation effects well

F_2 result in 13 TeV *pp*

arXiv:2308.16745



Raw Fourier (x2)

- combination of flow and nonflow
- Nonflow yields a huge fake decorrelation signal of raw F_2 = 0.09-0.4 which varies heavily with multiplicity

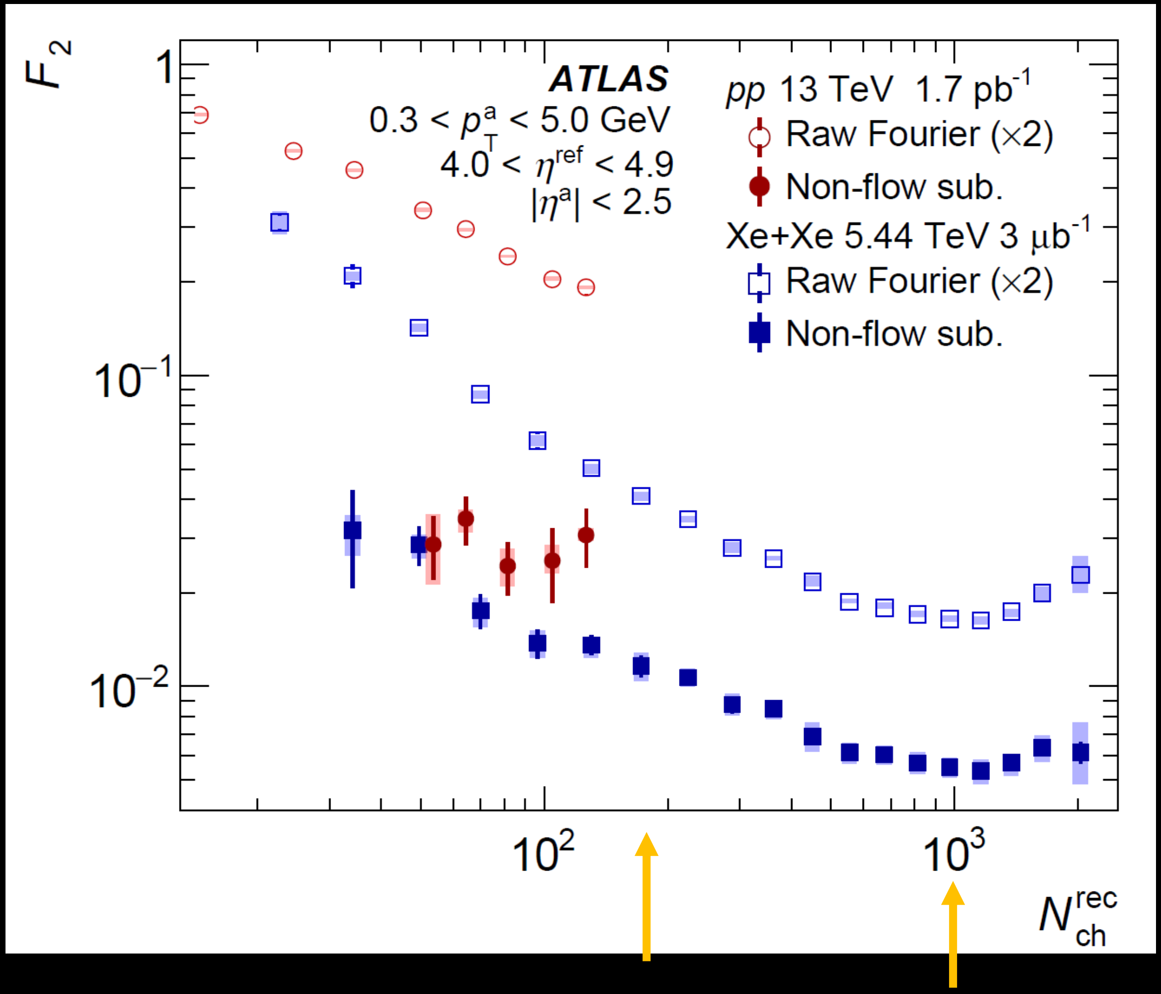
Nonflow subtracted F_2 (solid markers)

- Much smaller, F_2 = 0.02-0.03, which is multiplicity independent

Little change in longitudinal dynamics as a function of multiplicity

F_2 results in Xe+Xe

arXiv:2308.16745



Raw Fourier (x2)

- Extends previous results to peripheral Xe+Xe

Nonflow subtracted F_2

- Nonflow subtraction removes 40-70% of raw decorrelation in peripheral.
- Decorrelation of ~0.03 observed in most peripheral ~80-90% centrality
- We also observe a 30% nonflow effect for more than 50% central

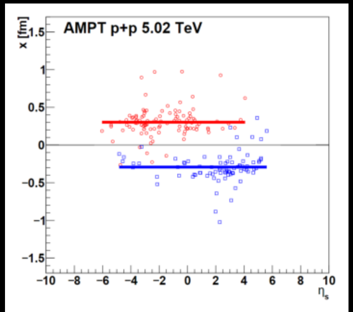
Qualitatively different behavior at the same N_{ch} for *pp* and Xe+Xe

Comparisons to AMPT: *pp*

- AMPT initial state geometric decorrelation F_n is shown and is calculated as follows

$$\vec{\varepsilon}_2(\eta^a)\cdot\vec{\varepsilon}_2(\eta^{ref}) = A(1+F_n\,\eta^a + S_n\,\eta^{a2})$$

- F_2: AMPT predicts an order of magnitude lower F_2 which is N_{ch} dependent
- **Data disfavors models with a small number of long color strings in the initial state**
- **need for sub-nucleonic degrees of freedom.**
- AMPT F_3 which is fluctuation driven agrees better with the data



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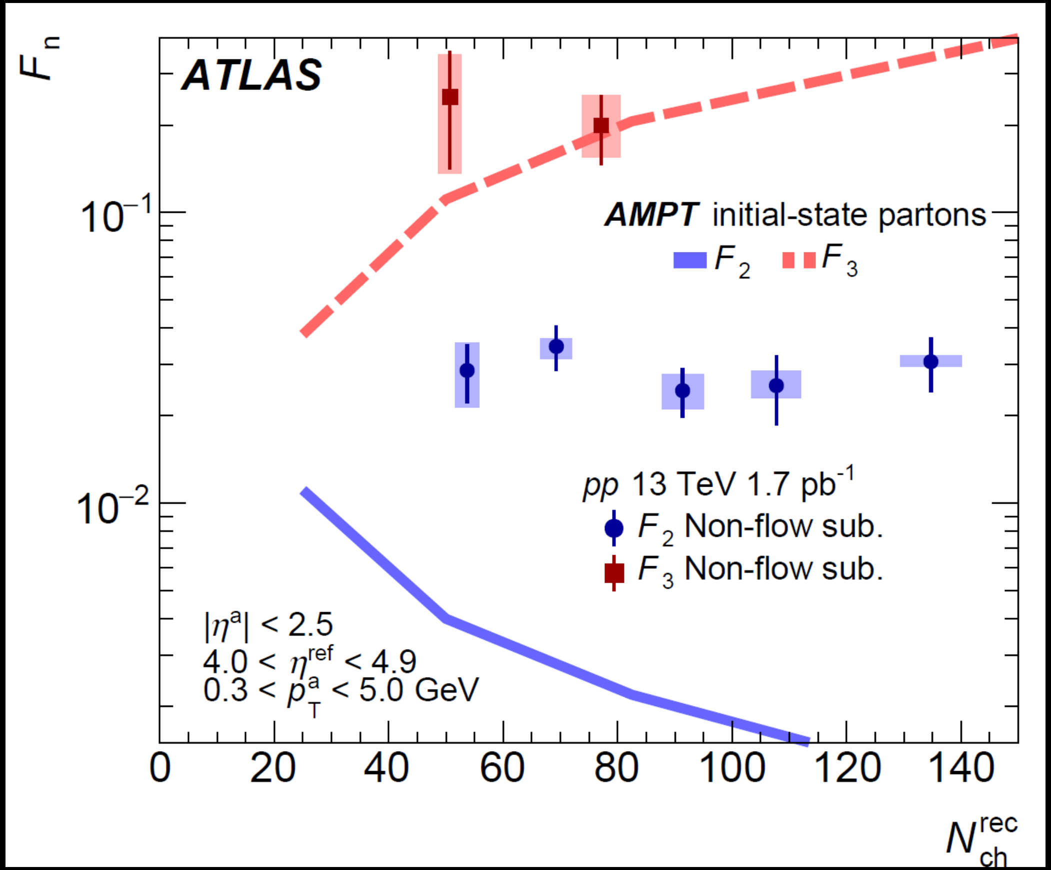
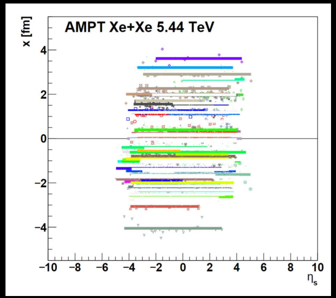


Comparisons to AMPT: Xe+Xe

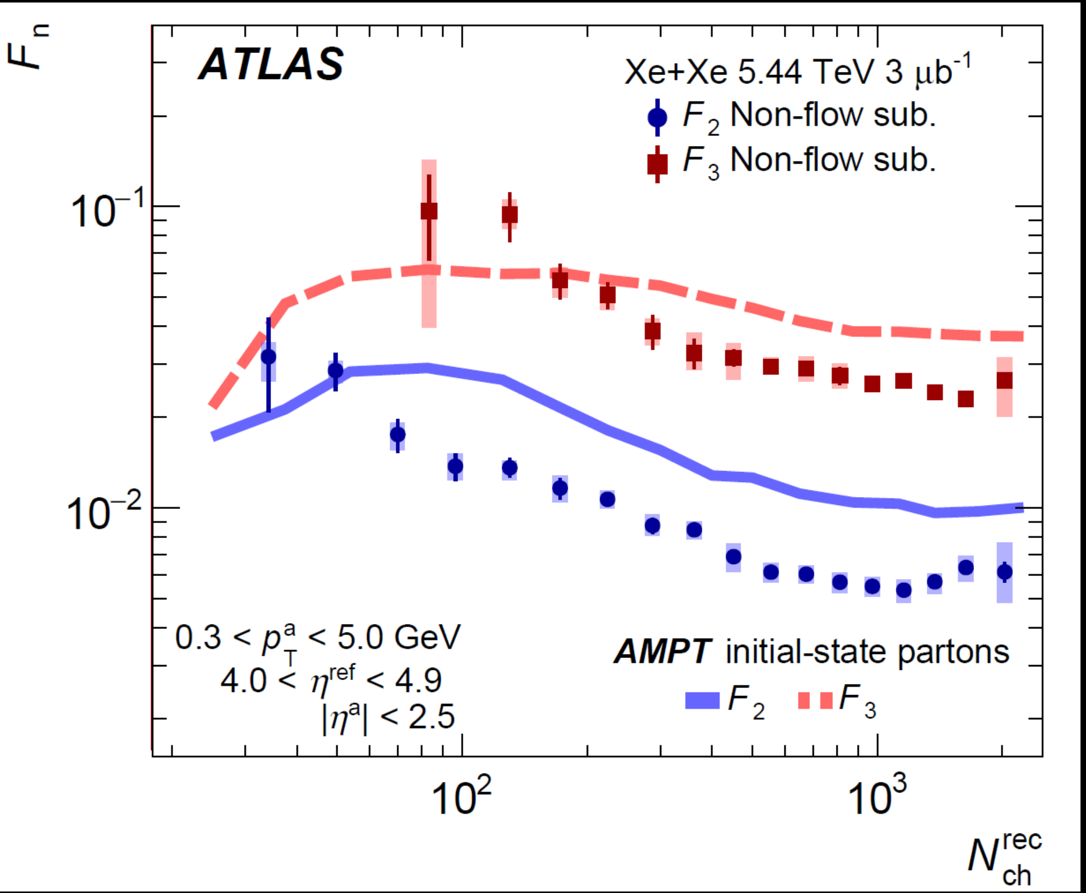


[arXiv:2308.16745](https://arxiv.org/abs/2308.16745)

- AMPT initial state geometric decorrelation F_n is shown and is calculated as follows

$$\vec{\boldsymbol{\varepsilon}}_2(\eta^a)\cdot\vec{\boldsymbol{\varepsilon}}_2(\eta^{ref}) = A(1+F_n\,\eta^a+S_n\,\eta^{a2})$$

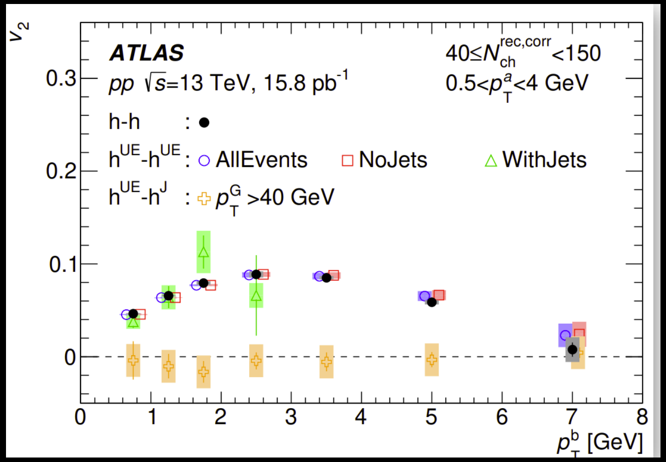
- We observe qualitative agreement with AMPT in Xe+Xe in central and mid central collisions
- A qualitative change in behavior towards smaller decorrelation at low multiplicities is present in AMPT but not in data



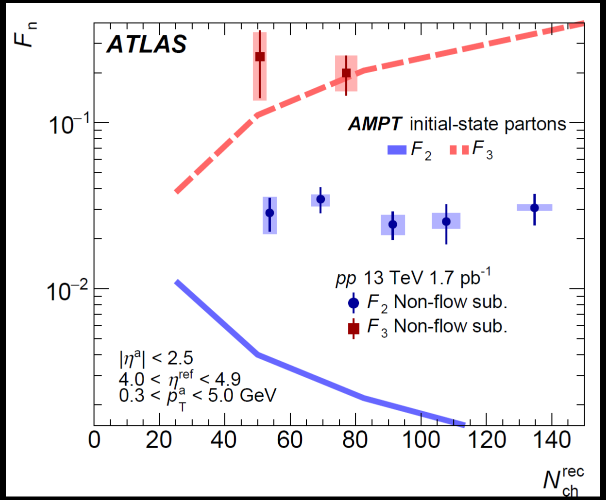
Data indicates sub-nucleonic structure is required to describe peripheral AA and pp

Conclusions

- Jets of > 40 GeV and all their constituents do not participate in the bulk flow in *pp* collisions



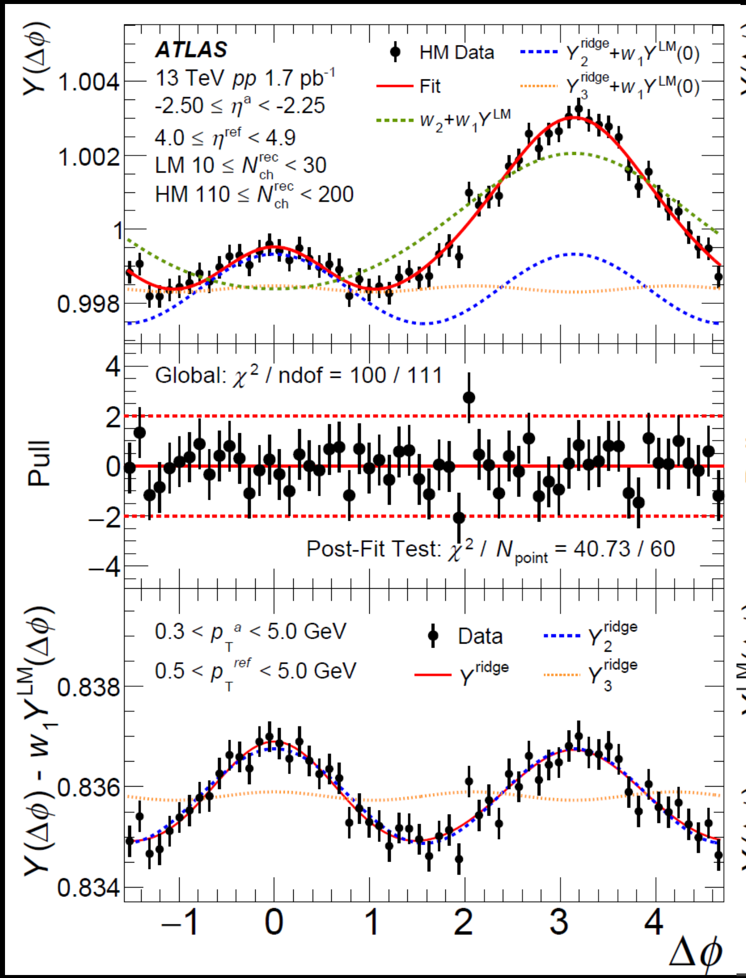
- Detailed measurements of longitudinal decorrelations
  - N_{ch} independent F_n in pp collisions
  - Disfavors initial-state models without sub-nucleonic structure

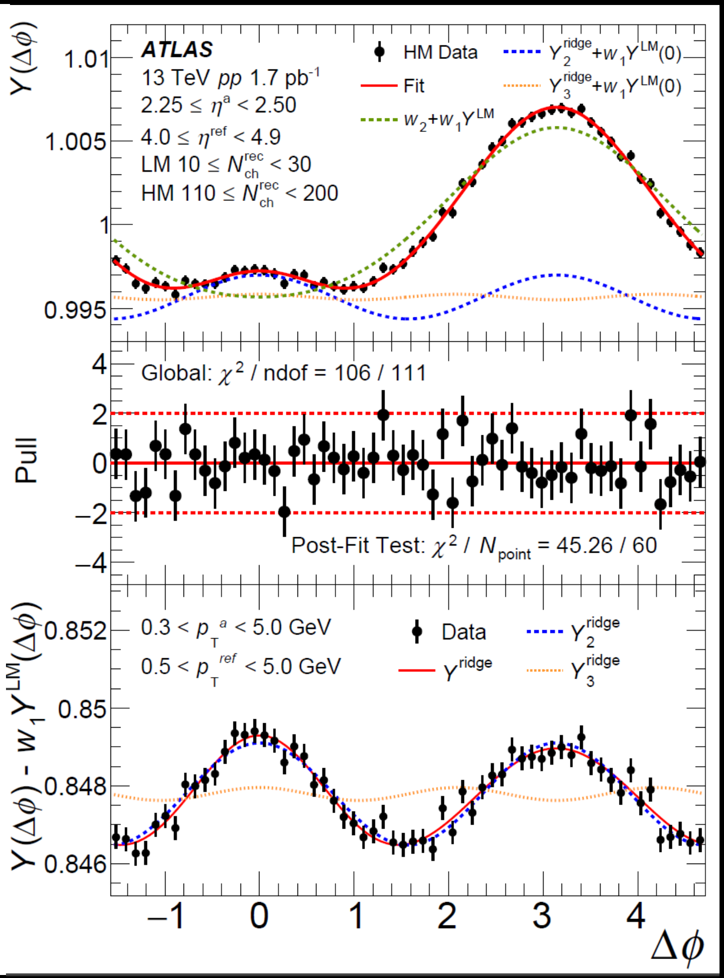


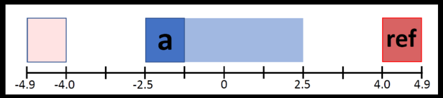
Thank you!

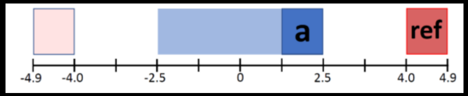
Back up

Correlation functions and template fits









arXiv:2308.16745

Template fit: $c_n(\eta^a)$

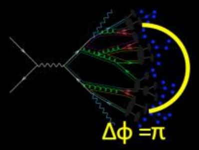
$$Y^{HM}(\Delta\phi) = w_1 Y^{LM}(\Delta\phi) + w_2\left(1 + 2\sum_{n=2}^{4} c_n \cos(n\Delta\phi)\right)$$

Fit:

Low multiplicity correlation

Dominated by nonflow

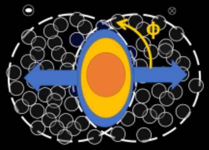
Assumes LM HM nonflow shape



Free Flow moments

Assumes LM HM flow is equal

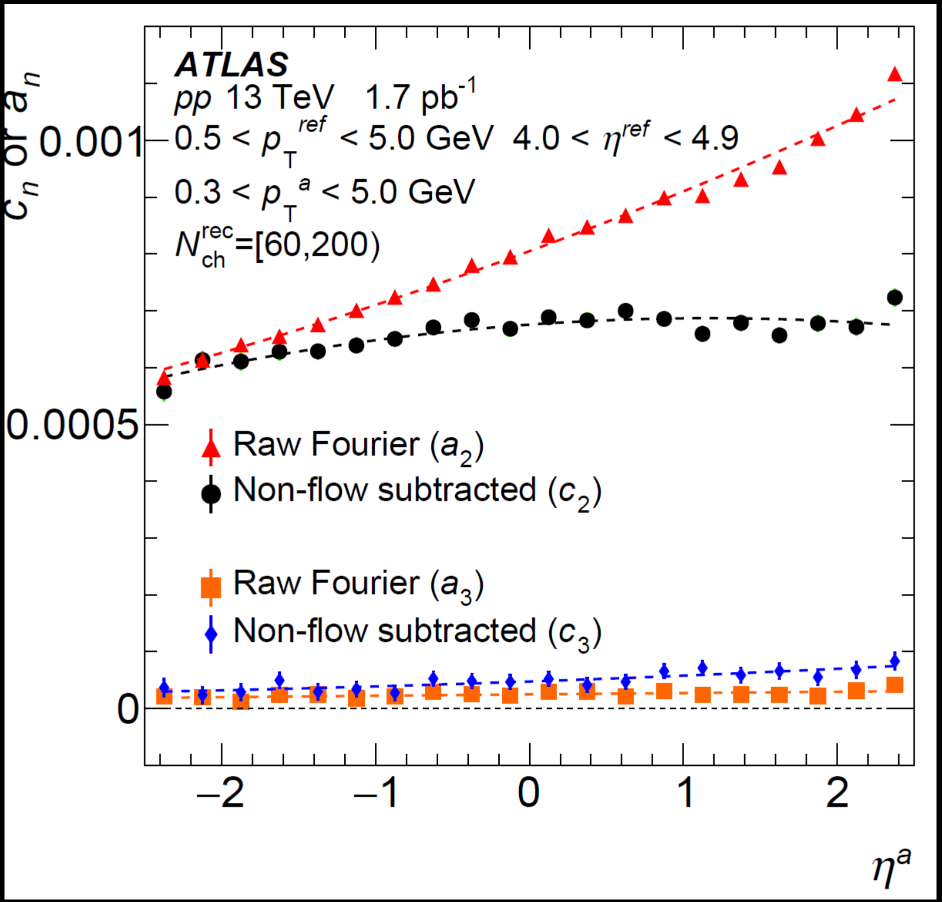
No flow c_1



With assumptions, template fit removes nonflow: $c_n(\eta^a)$

Parametrize dependence of correlation coefficients

arXiv:2308.16745



We characterize the η^a behavior of the correlation coefficients with a fit function,

$$A(1 + F_n \times (\eta^a) + S_n \times (\eta^a)^2)$$

Decorrelation observable

- F_n is the linear fractional change in the correlation coefficient and is the parameter of interest.

Other parameters in the fit

- ***A*** is the mid-rapidity flow and is not of interest
- $\boldsymbol{S_n}$ is an η^a–even function and does not represent decorrelation and is not of interest.
- Data is described by the function well

Past observable

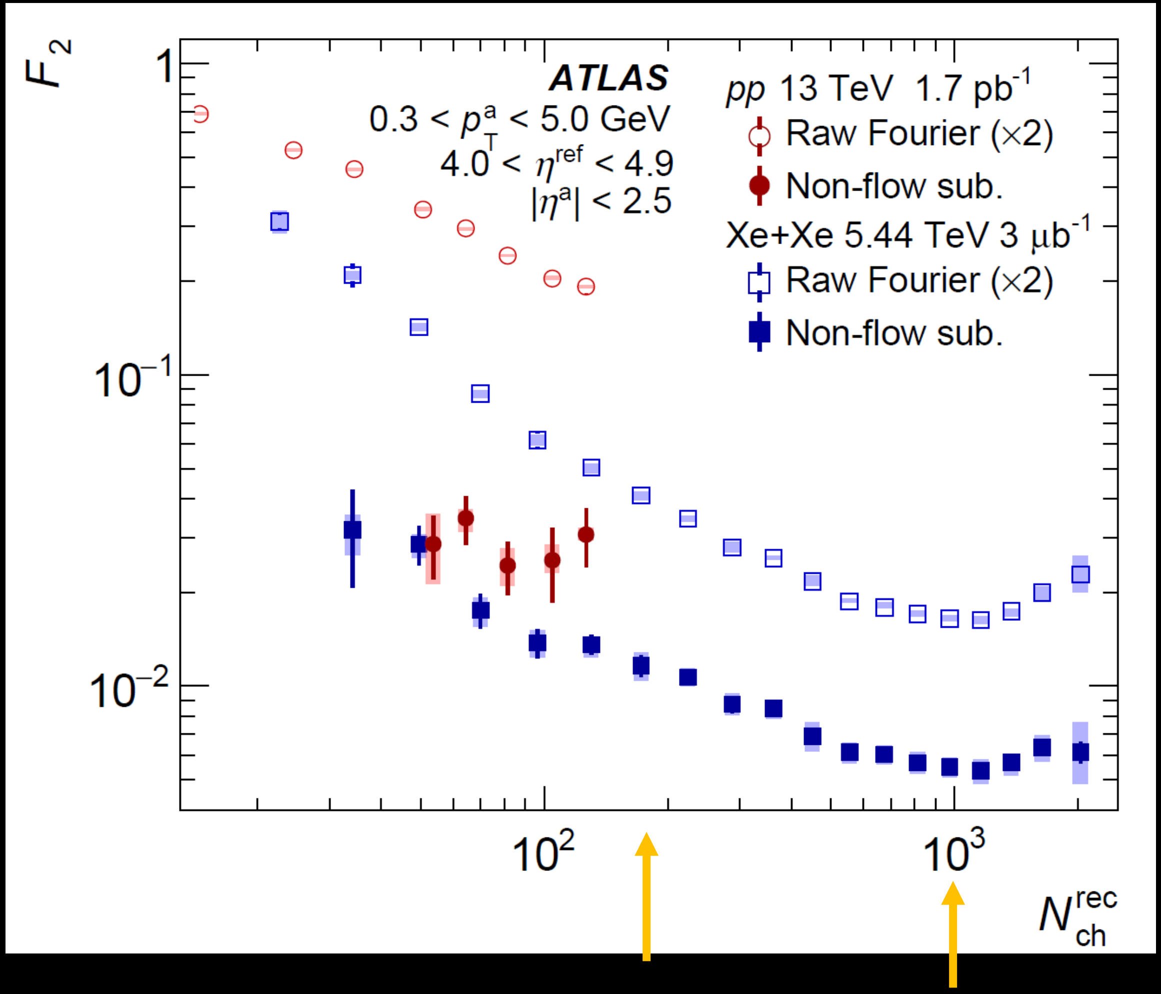
$$r_n(|\eta^a|) = \frac{c_n(-|\eta^a|)}{c_n(|\eta^a|)}$$

$$\approx 1 - 2F_n|\eta^a|$$

F_n is the fractional change in $v_{2,2}$ per a unit rapidity
it characterizes longitudinal decorrelation effects well

F_2 results in Xe+Xe

arXiv:2308.16745



40%

20% central

Raw Fourier (x2)

- Consistent with past results in large systems from ***ATLAS*** and others for centrality > 60%

Nonflow subtracted F_2

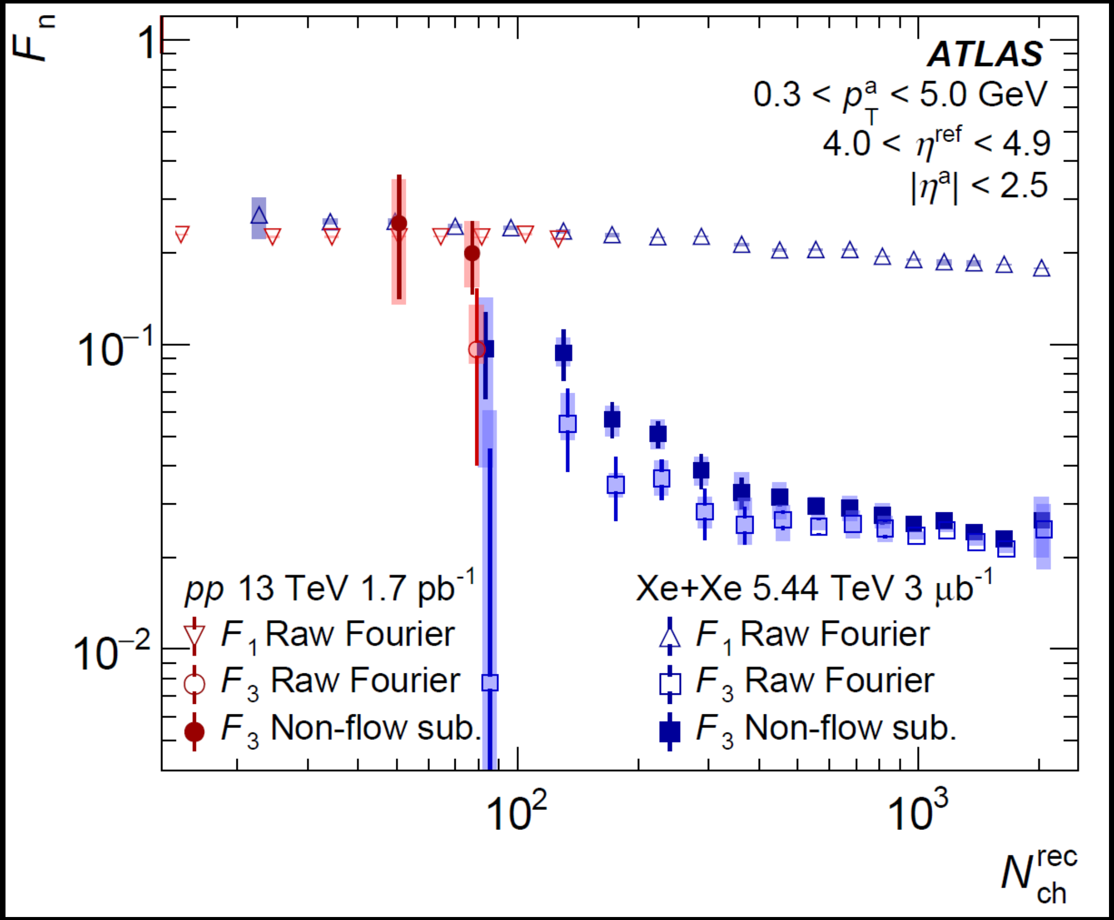
- Nonflow subtraction removes 40-70% of raw decorrelation in peripheral.
- Decorrelation of ~0.03 observed in most peripheral ~80-90% centrality

- We also observe a 30% nonflow effect for more than 50% central
  - Template fit assumption-violating effects such as modification to nonflow shape may cause an overestimate of nonflow effects.
  - but with current available techniques is a significant background in all 2PC and event-plane measurements of decorrelation.

Qualitatively different behavior in the same N_{ch} for *pp* and Xe+Xe

Other moments

arXiv:2308.16745



***F*₃**

- similar qualitative features as 2nd
- Nonflow bias F_3 down but smaller bias because F_3 is generally larger
- Agreement between Xe+Xe within statistical uncertainties for low N_{ch}

***F*₁**

- Completely dominated by nonflow not allowing for subtraction with current methods.
- Very little multiplicity dependence because there is little change in flow/nonflow composition