Measurement of collective dynamics in pp, Xe+Xe, and Pb+Pb collisions with the ATLAS detector

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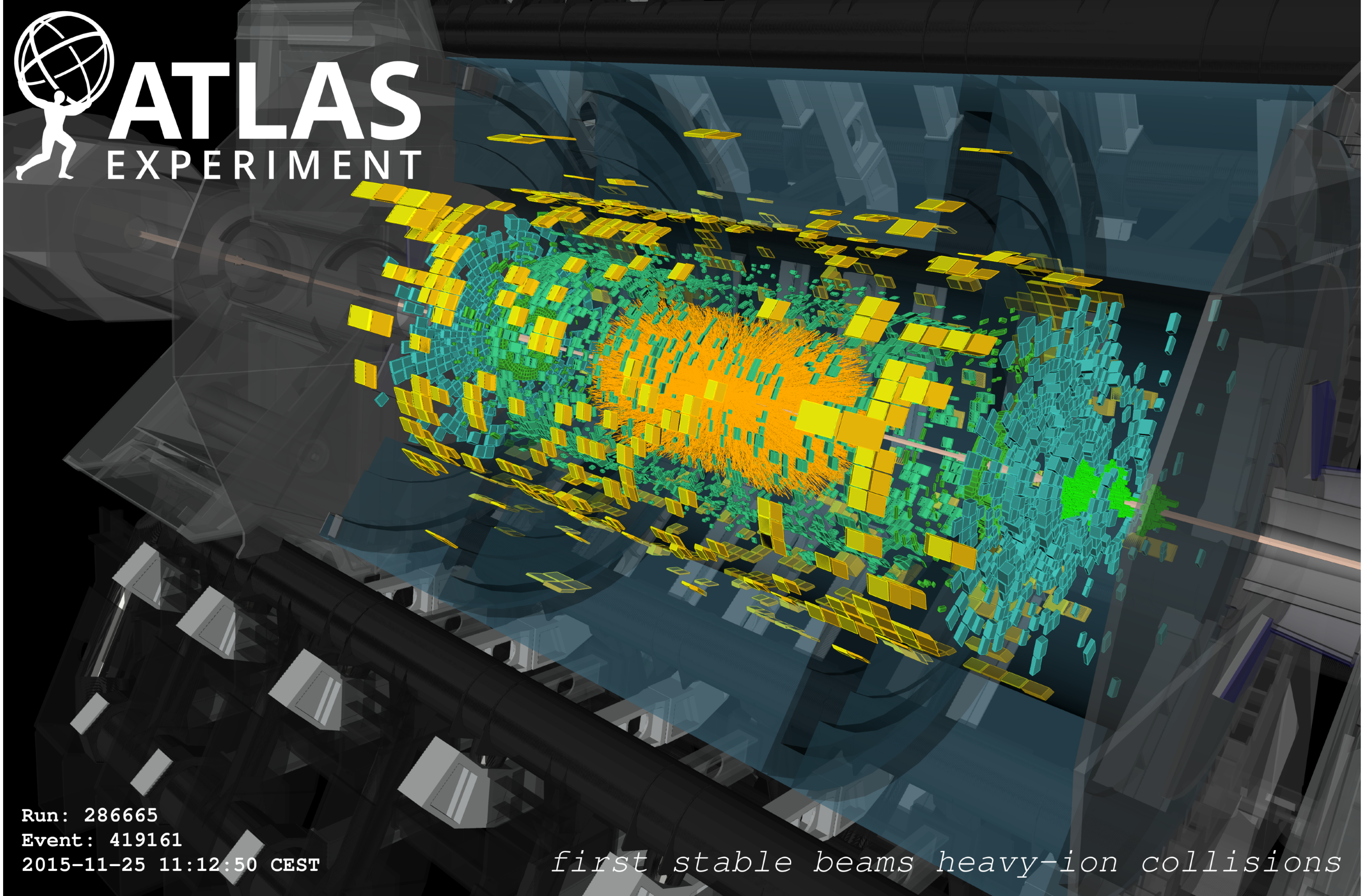
on behalf of the ATLAS Collaboration

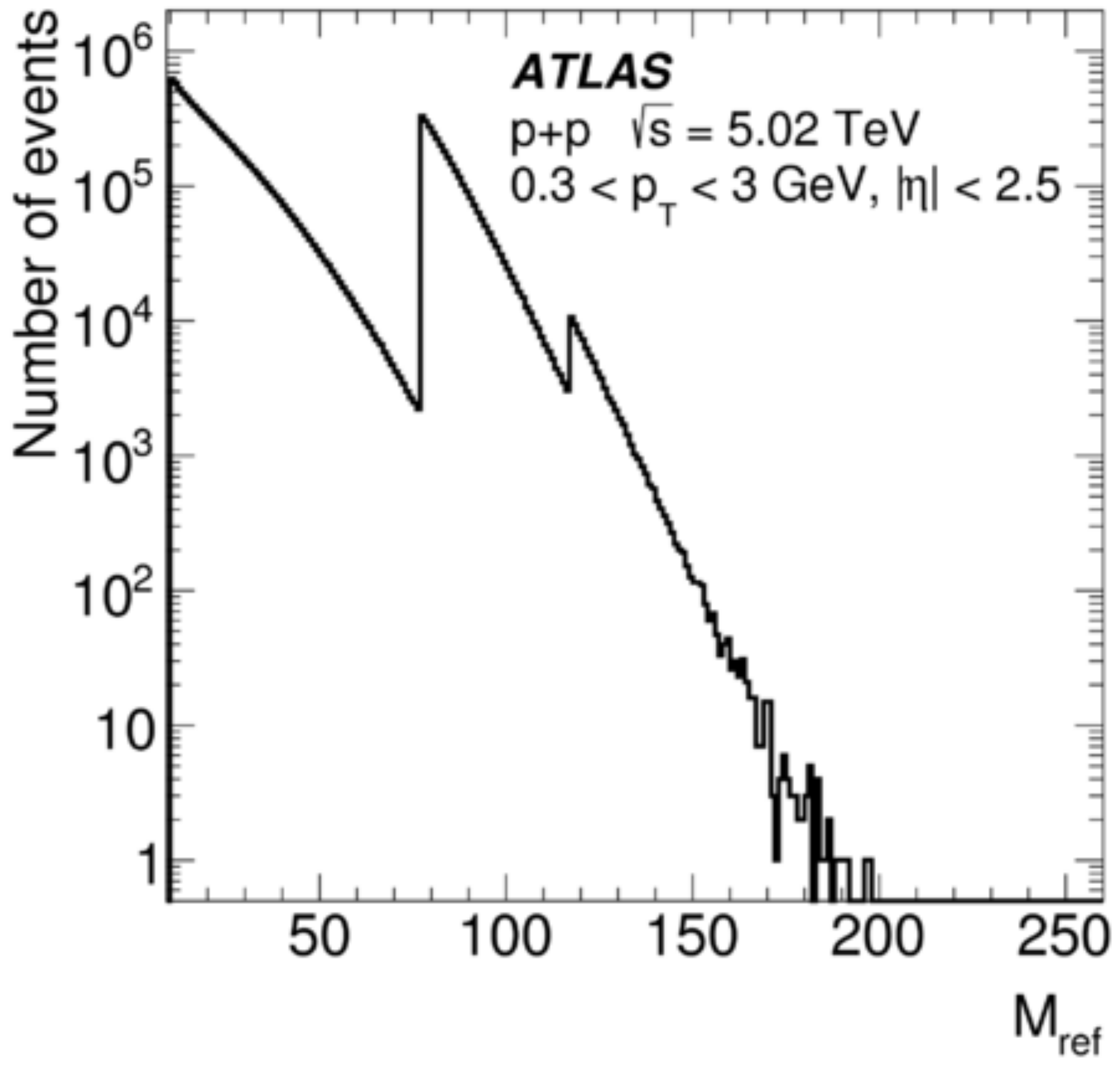
The collision initial stage through correlation measurements

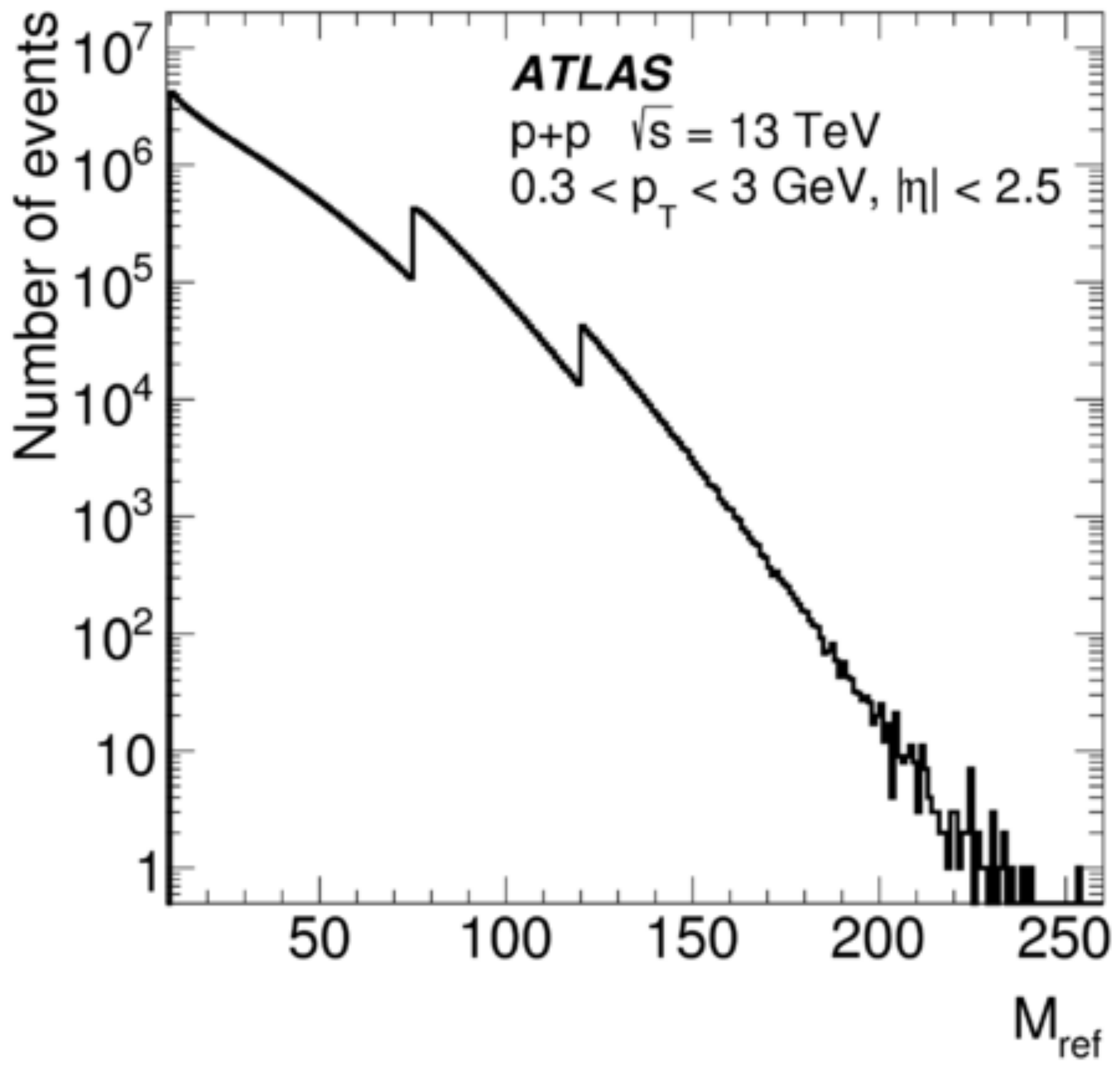
- Correlation measurements provide strong constraints on initial conditions
  - nuclear shapes, fluctuations, longitudinal profile collision profile

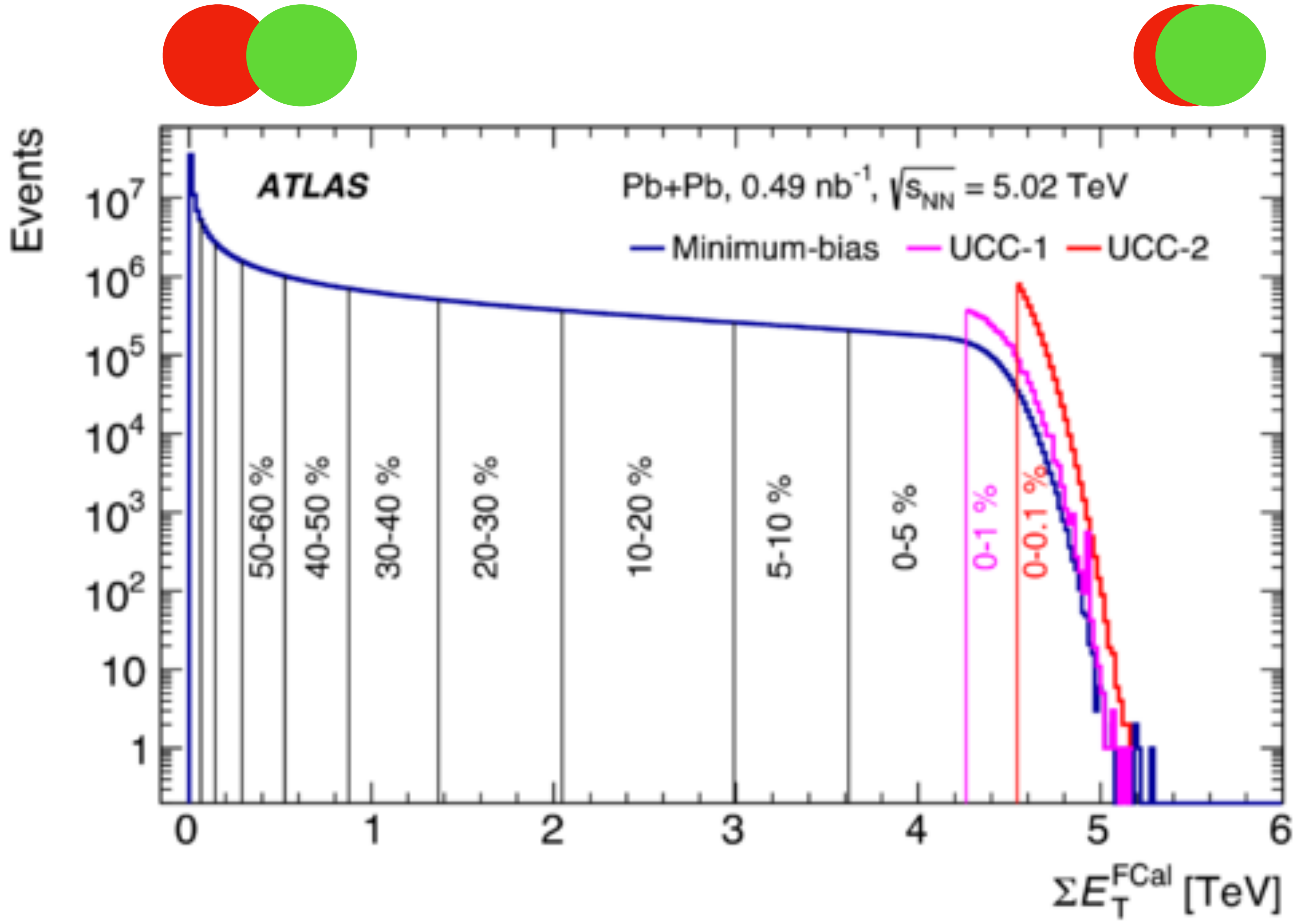
- Results are invaluable input to precise modelling and even have impact outside the field (low energy nuclear physics)


ATLAS
EXPERIMENT
Run: 286665
Event: 419161
2015-11-25 11:12:50 CEST
first stable beams heavy-ion collisions

Datasets





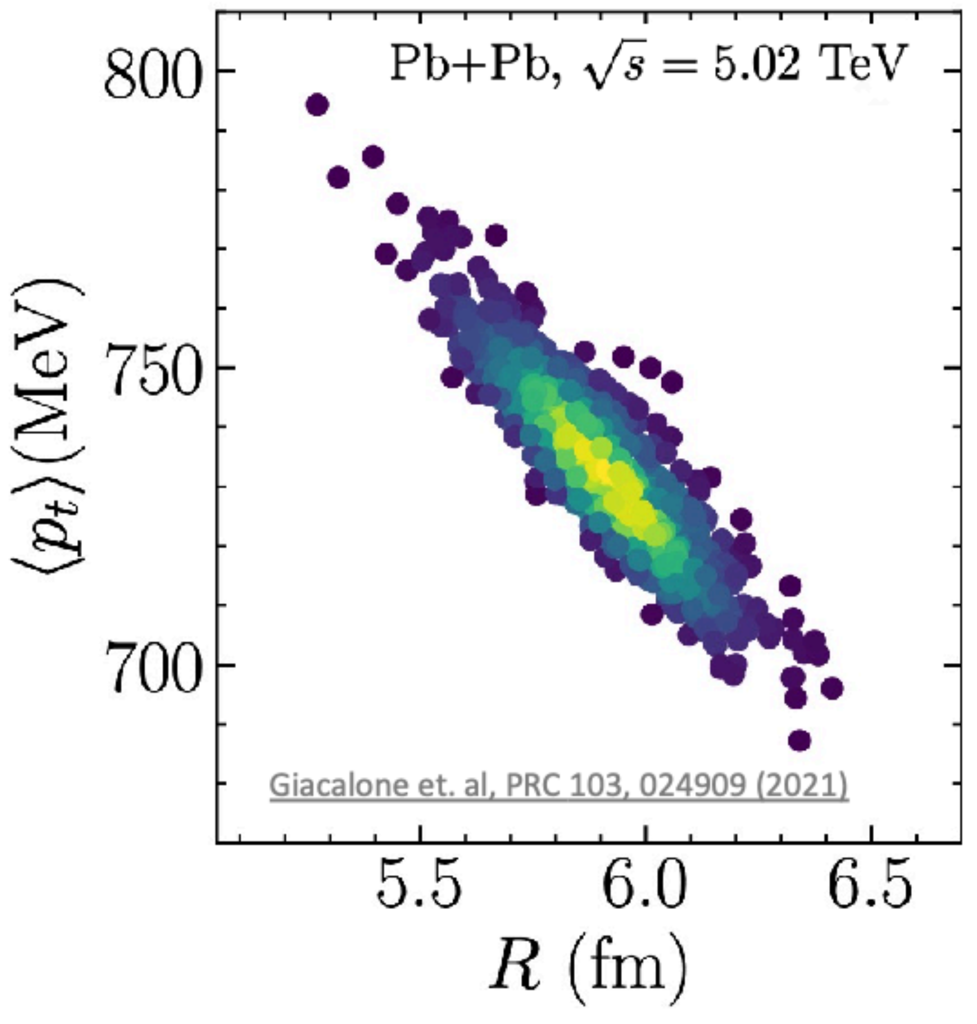


- Measurements possible thanks to specialised datasets enhancing statistics at high multiplicity or low centrality percentile

Shape-size correlation

- The initial collision state shapes & sizes can be correlated due to:
  - Fluctuations
  - Nuclear shapes

How can we measure $\dfrac{cov(\epsilon_n^2, \delta R)}{\sqrt{var(\epsilon_2^n)\ var(\delta R)}}$?



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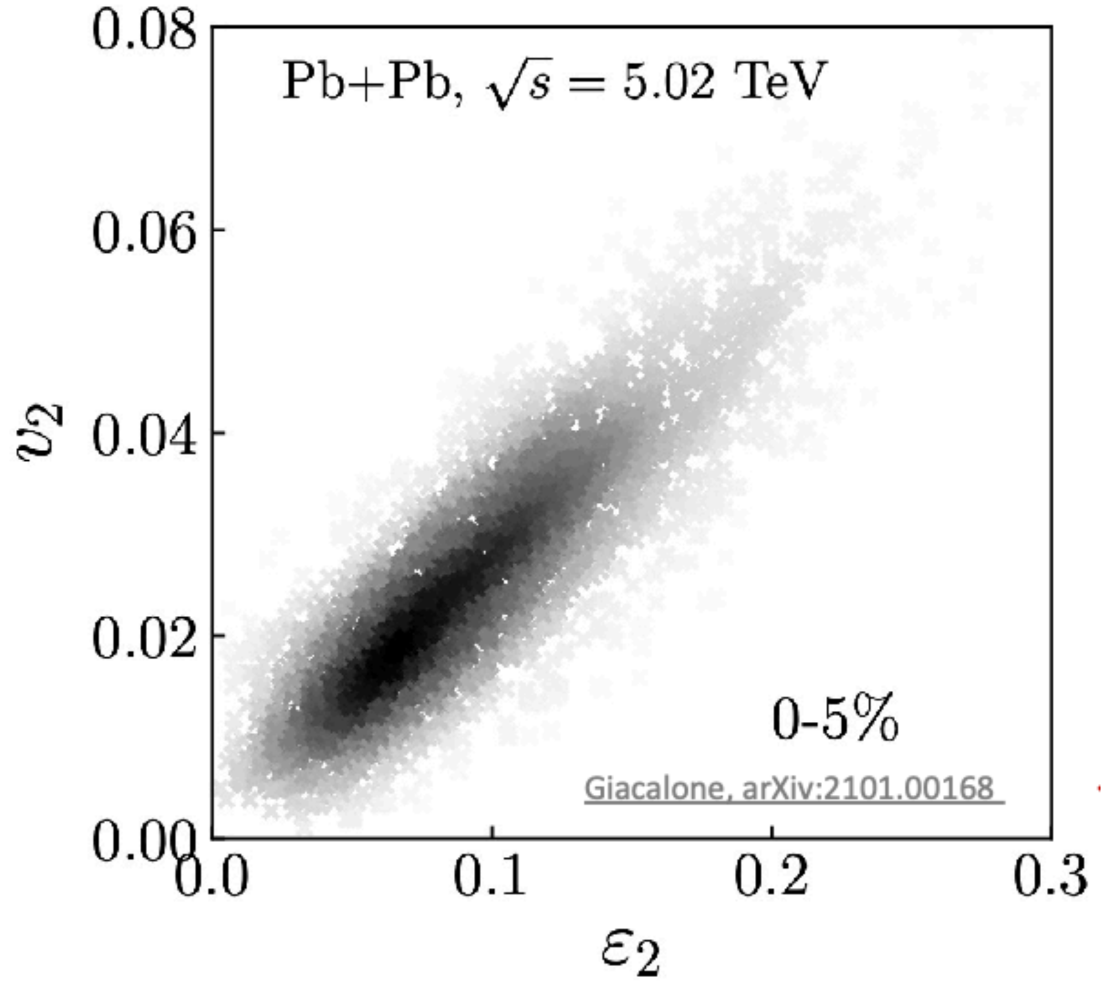


Azimuthal anisotropy in an event

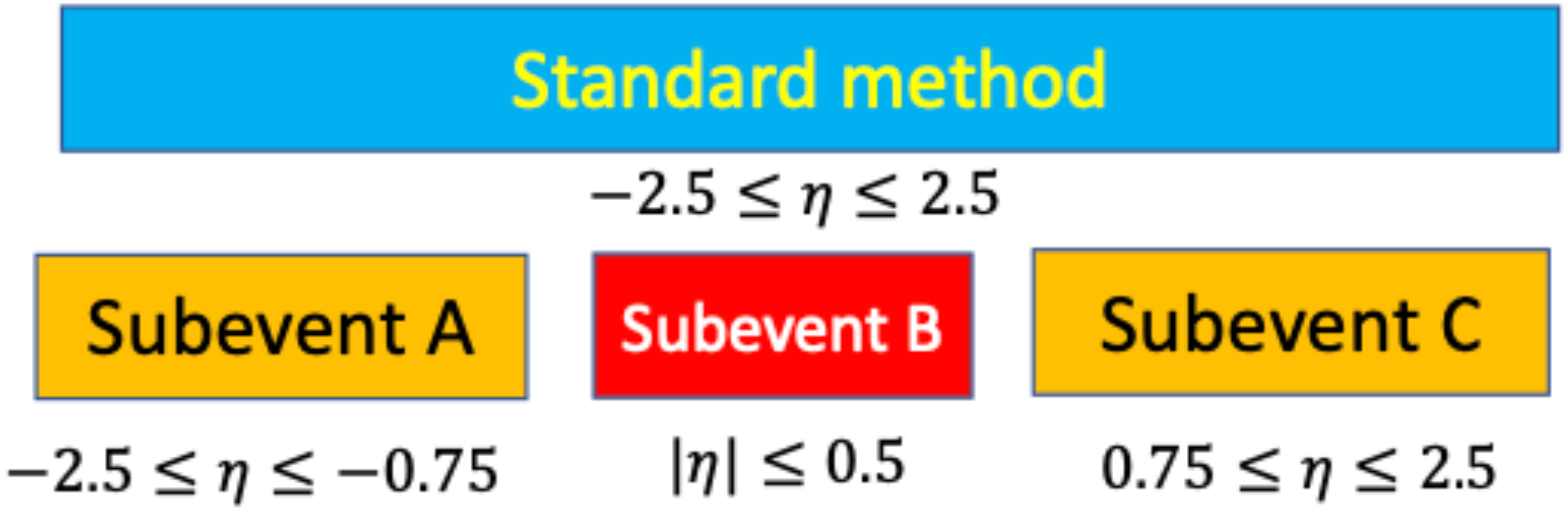
Mean particles momentum in event

$$\rho(v_n^2, \delta p_T) = \frac{cov(v_n^2, \delta p_T)}{\sqrt{var(v_2^n)\ var(\delta p_T)}}$$

Data & method details

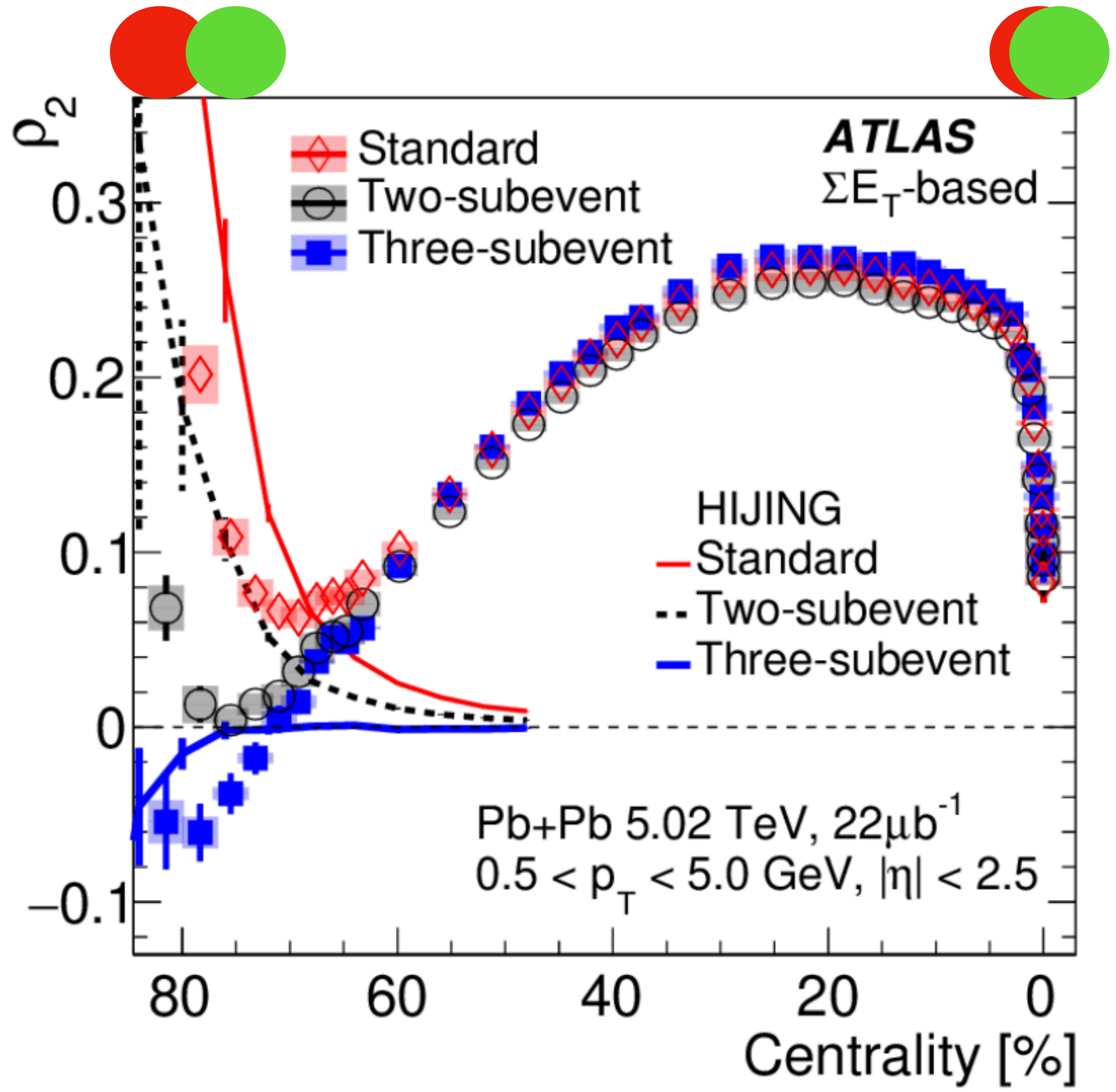
$$\rho(v_n^2, [p_T]) = \frac{cov(v_n^2, [p_T])}{\sqrt{var(v_2^n)\ var([p_T])}}$$

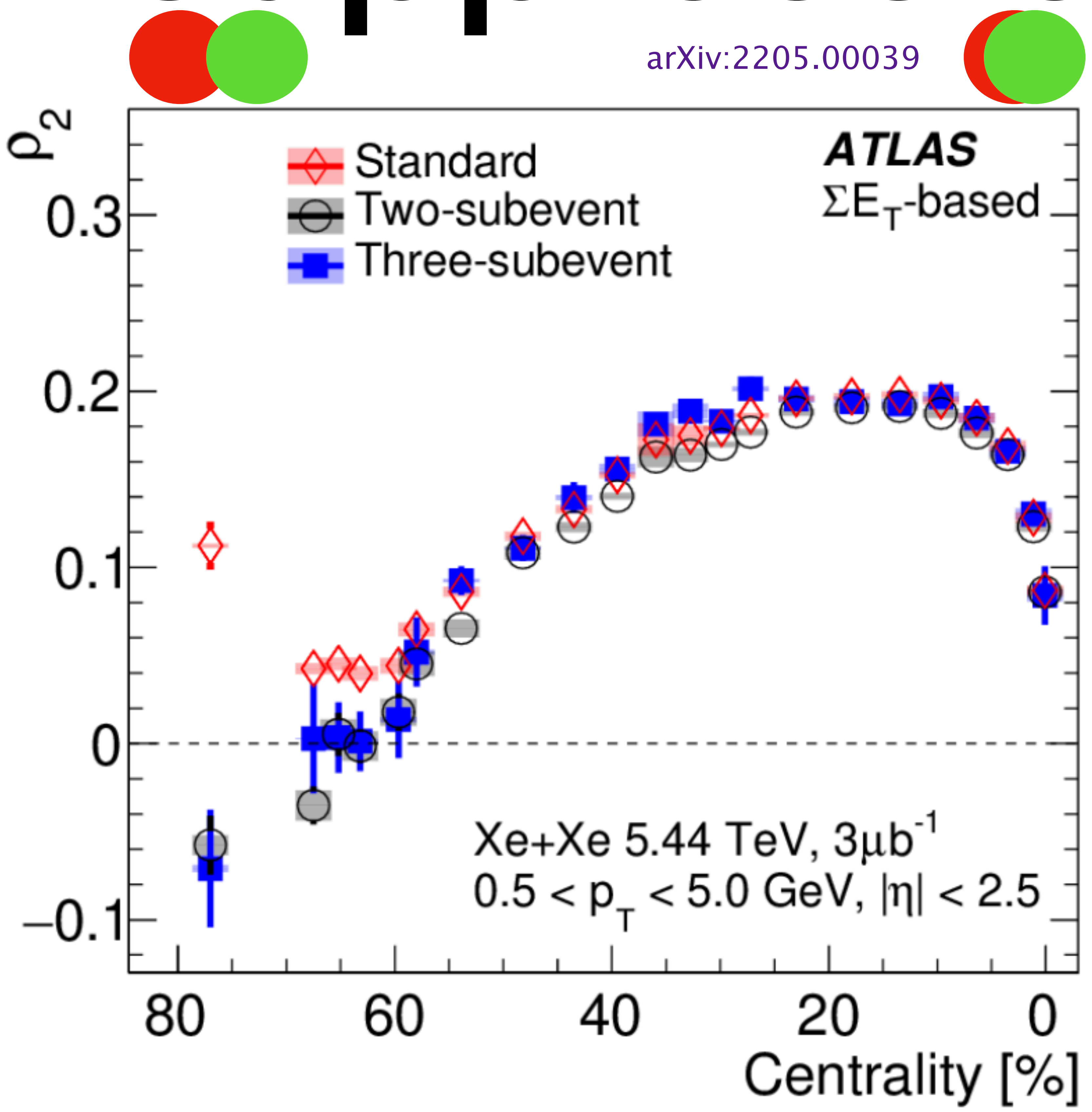
- Pb+Pb data @ 5 TeV
- Xe+Xe # 5.4 TeV
  (~x10 smaller stat. —> novel methodology)



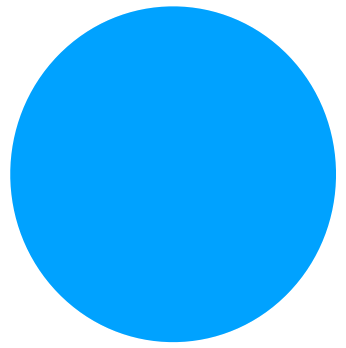
- Standard: (re)use all particles - no η gap - significant non-flow
- 2SE: A&C - significant gap in v_n, stat. lost
- 3SE: A&C for v_n measurements, B for $[p_T]$ - used stat. assured gaps —> non-flow reduced
- Combined: avg. 2SE & 3SE

Non-flow suppression

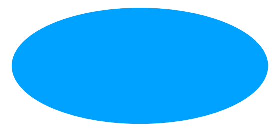




Positive ρ



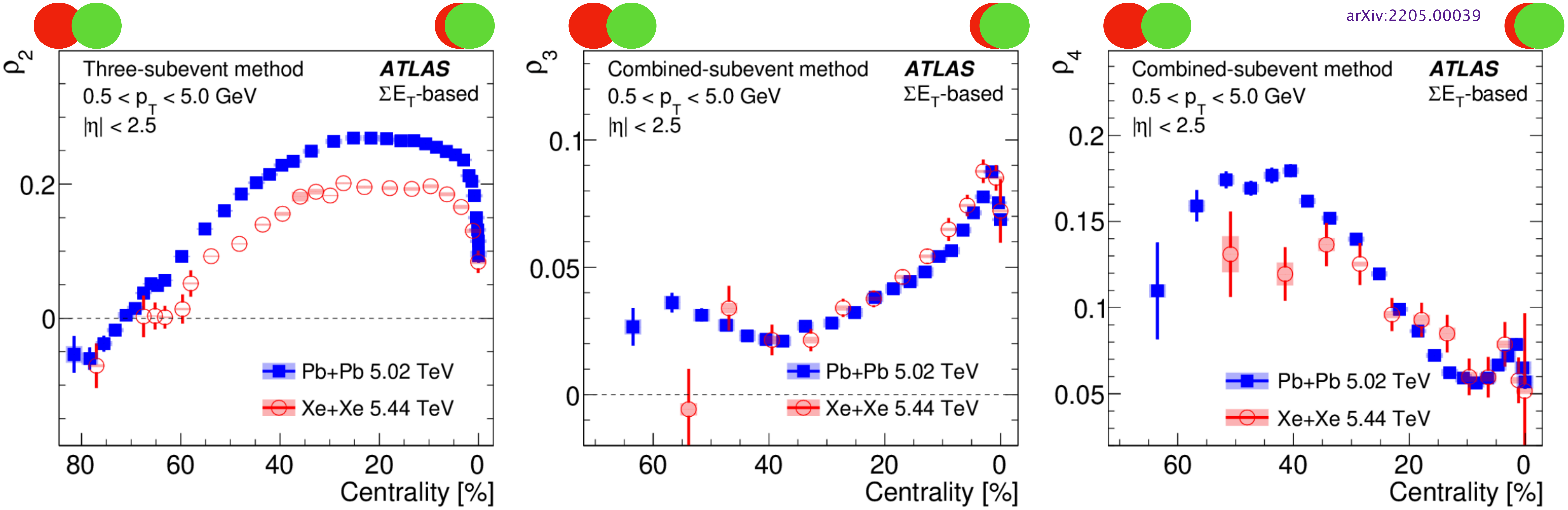
Larger size = smaller flow



smaller size = larger flow

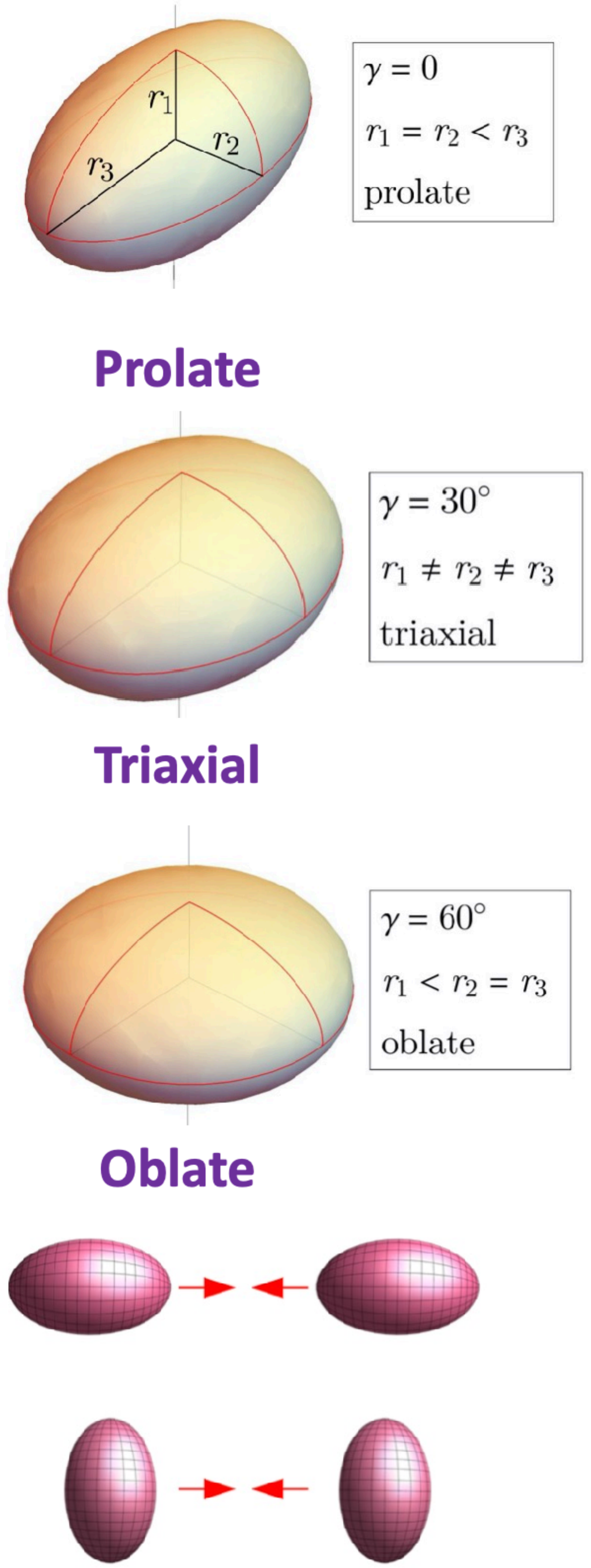
- The 2SE suppresses the non-flow relatively well, statistical fluctuations smaller compared to 3SE
- Also distinct response in Hijing

Systems comparison



- Due to geometric factor $\rho_2^{PbPb} > \rho_2^{XeXe}$, ρ_3 and ρ_4 are comparable

Precise probe of nuclear shape



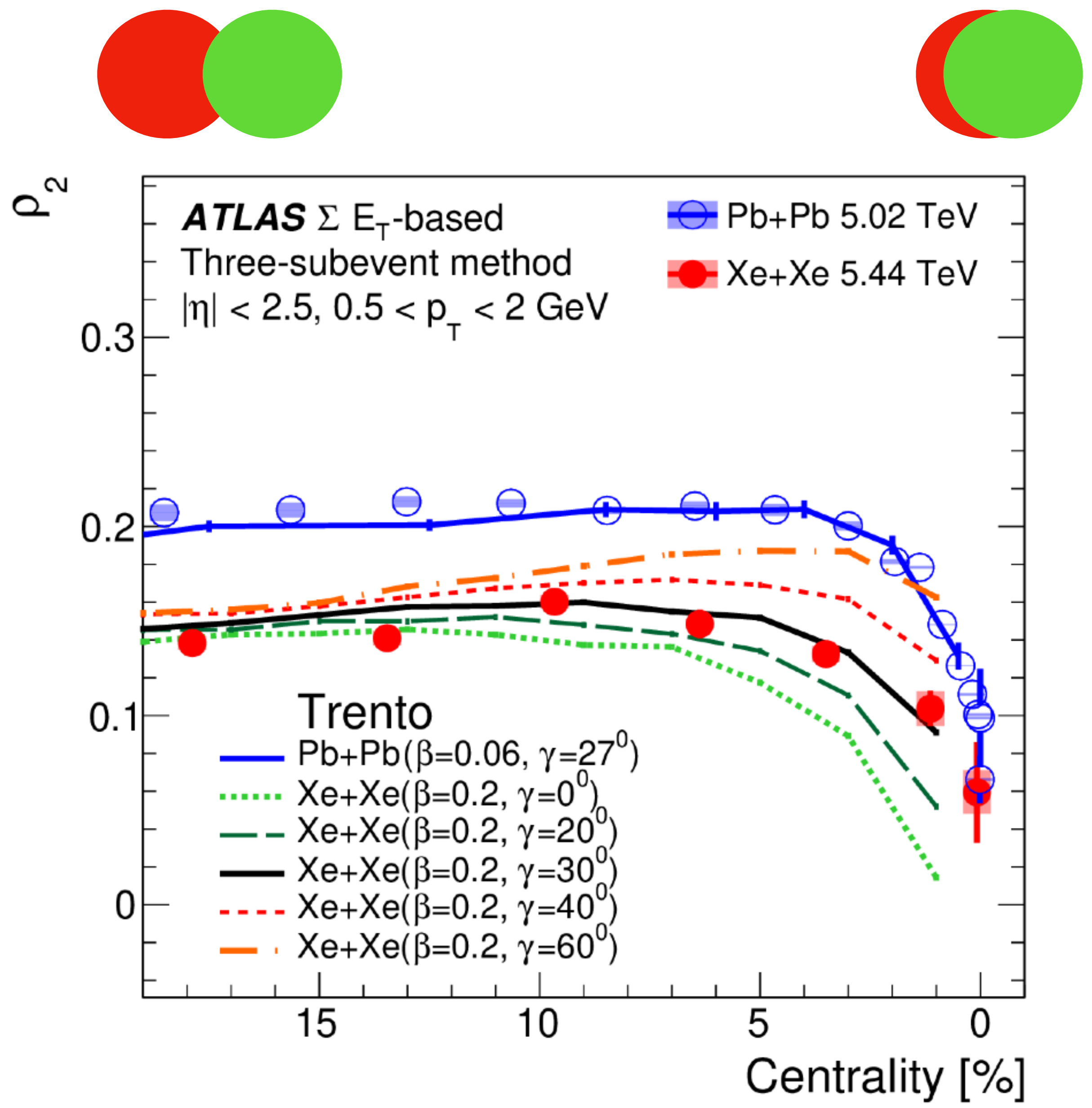
- Input to a precise initial state modeling
- Relevant to understand energy spectra of odd-mass nuclei

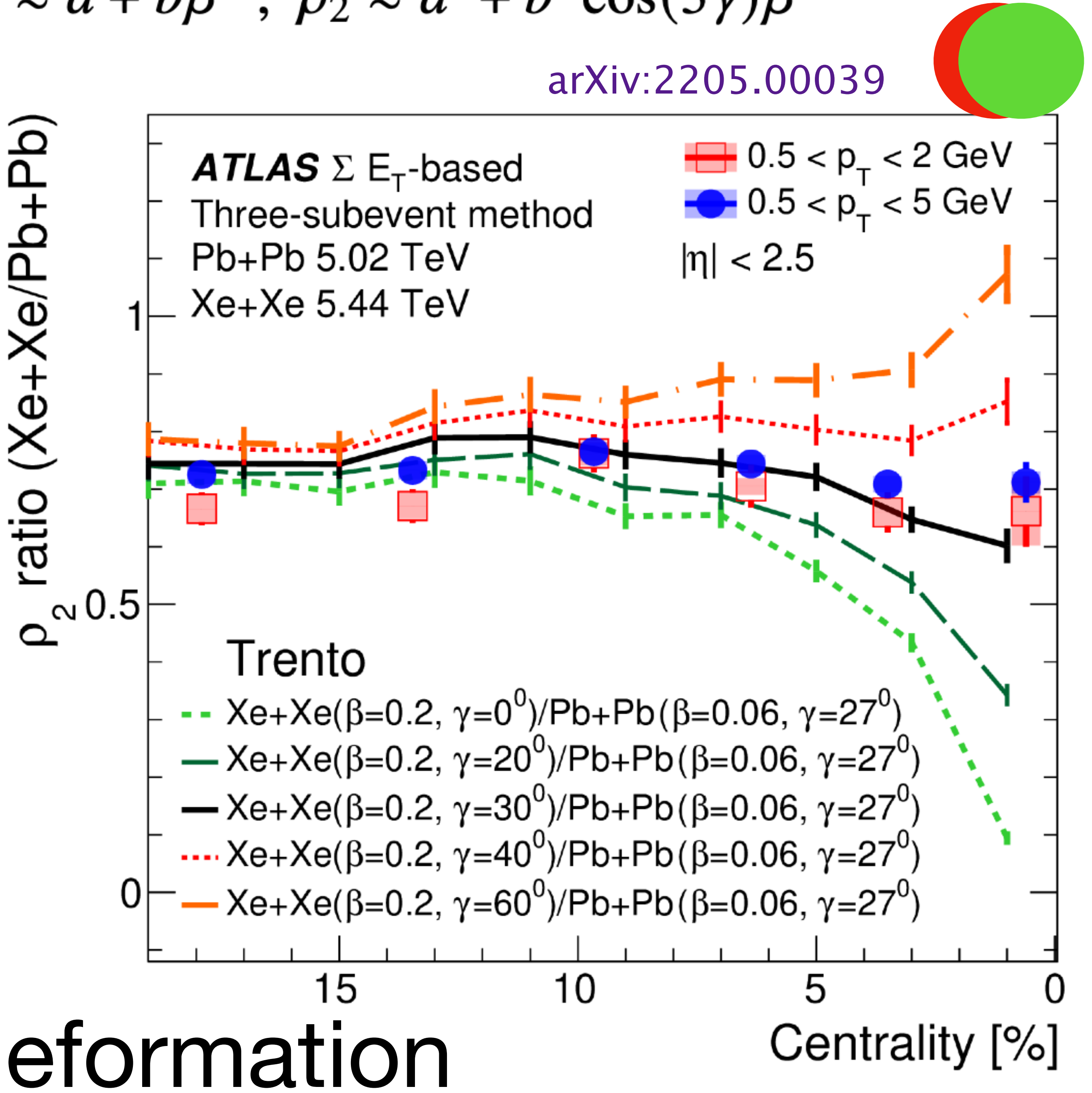
$$R(\theta,\phi) = R_0(1 + \beta(cos\gamma Y_{20}(\theta,\phi) + sin\gamma Y_{22}(\theta,\phi)))$$

R_0 - radius, γ, β- quadrupole deformation parameters

$v_2^2 \approx a + b\beta^2$, $\rho_2 \approx a' + b' \cos(3\gamma)\beta^3$

arXiv:2205.00039

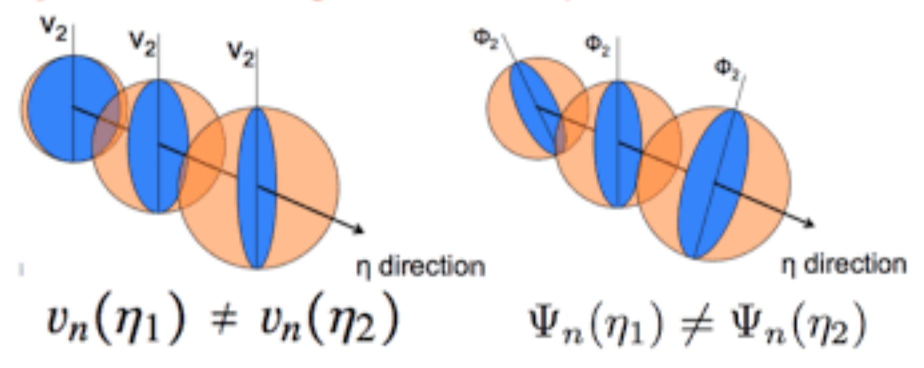




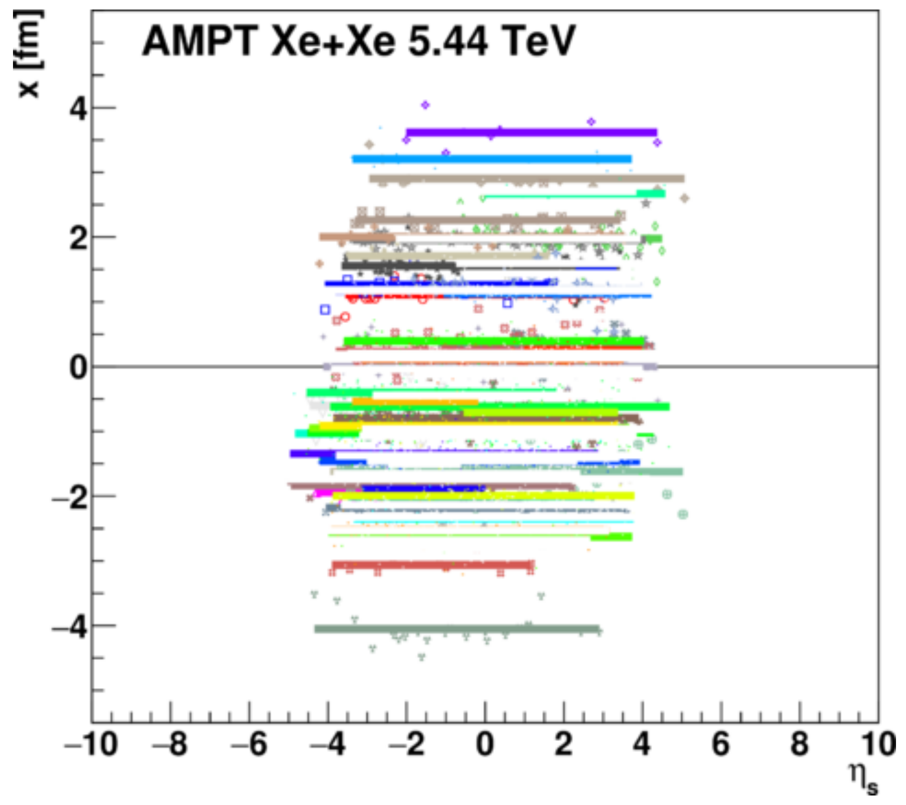
- Great sensitivity to fine shape deformation

Longitudinal flow de-correlations

- In the precise era the longitudinal evolution of the correlations can not be neglected —> a nontrivial evolution confirmed for Pb+Pb and Xe+Xe already - good modeling



- Expected due to different geometric configurations of forward and backward going participants - also present in the models with strings like AMPT



- Small systems are challenging, e.g. in AMPT approach - strings “longer” than rapidity span in ATLAS —> no longitudinal evolution?

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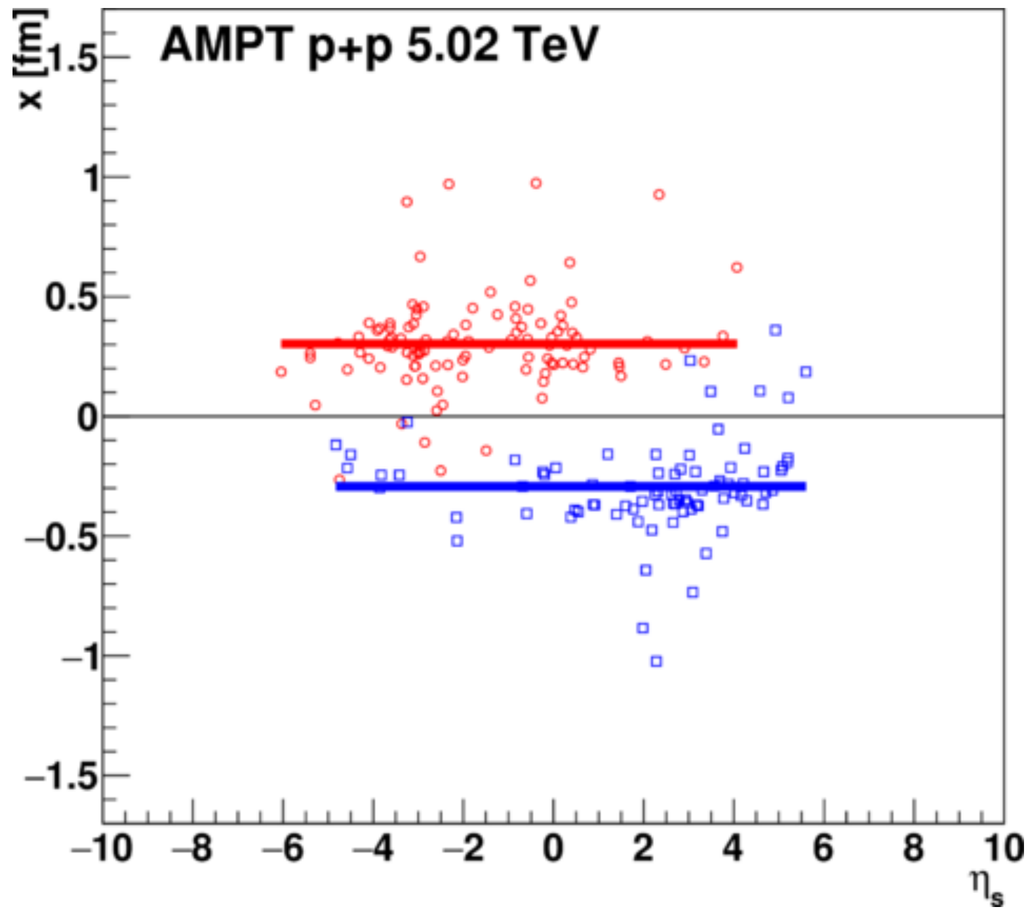

Measurement technique

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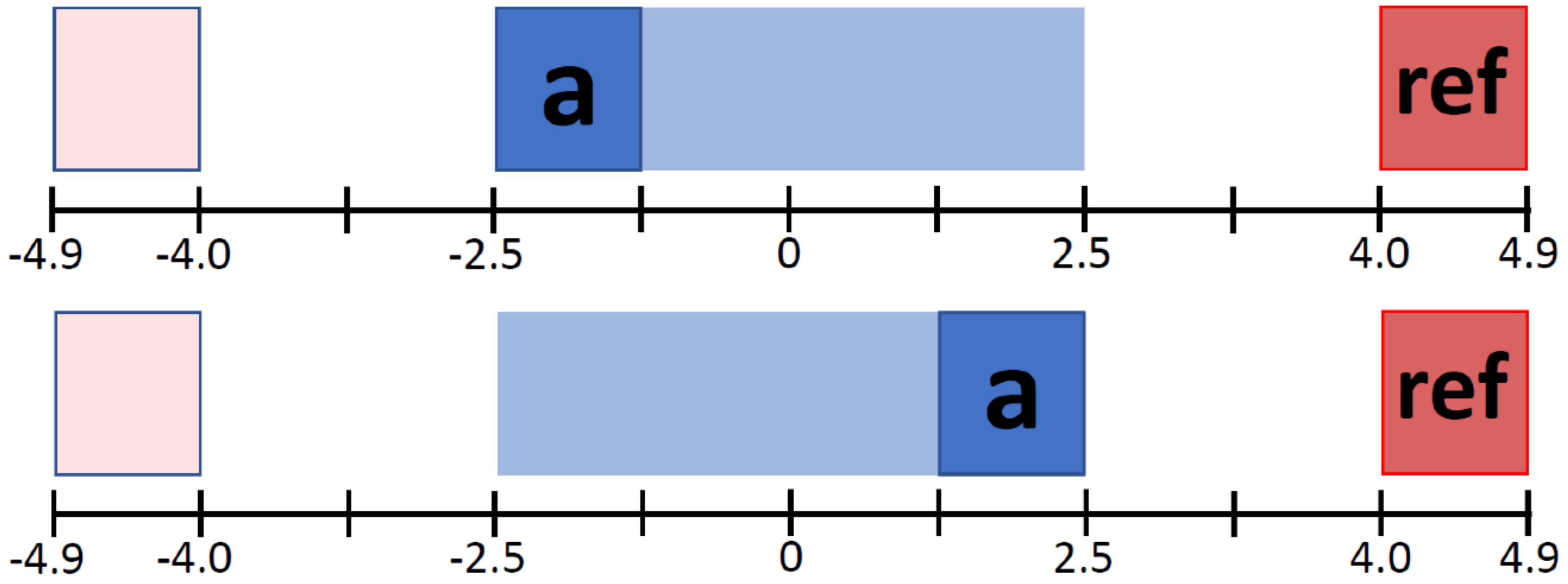
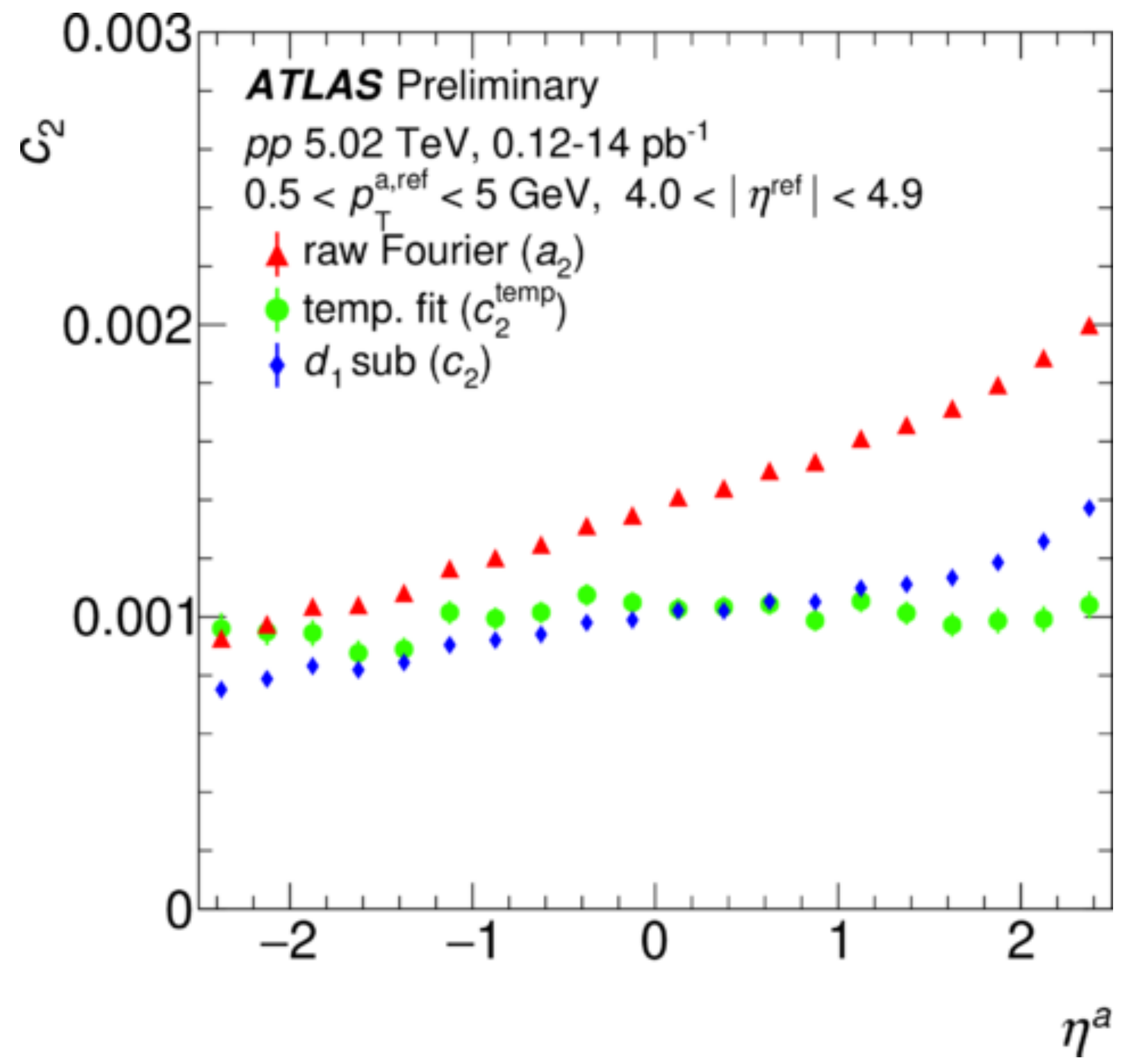
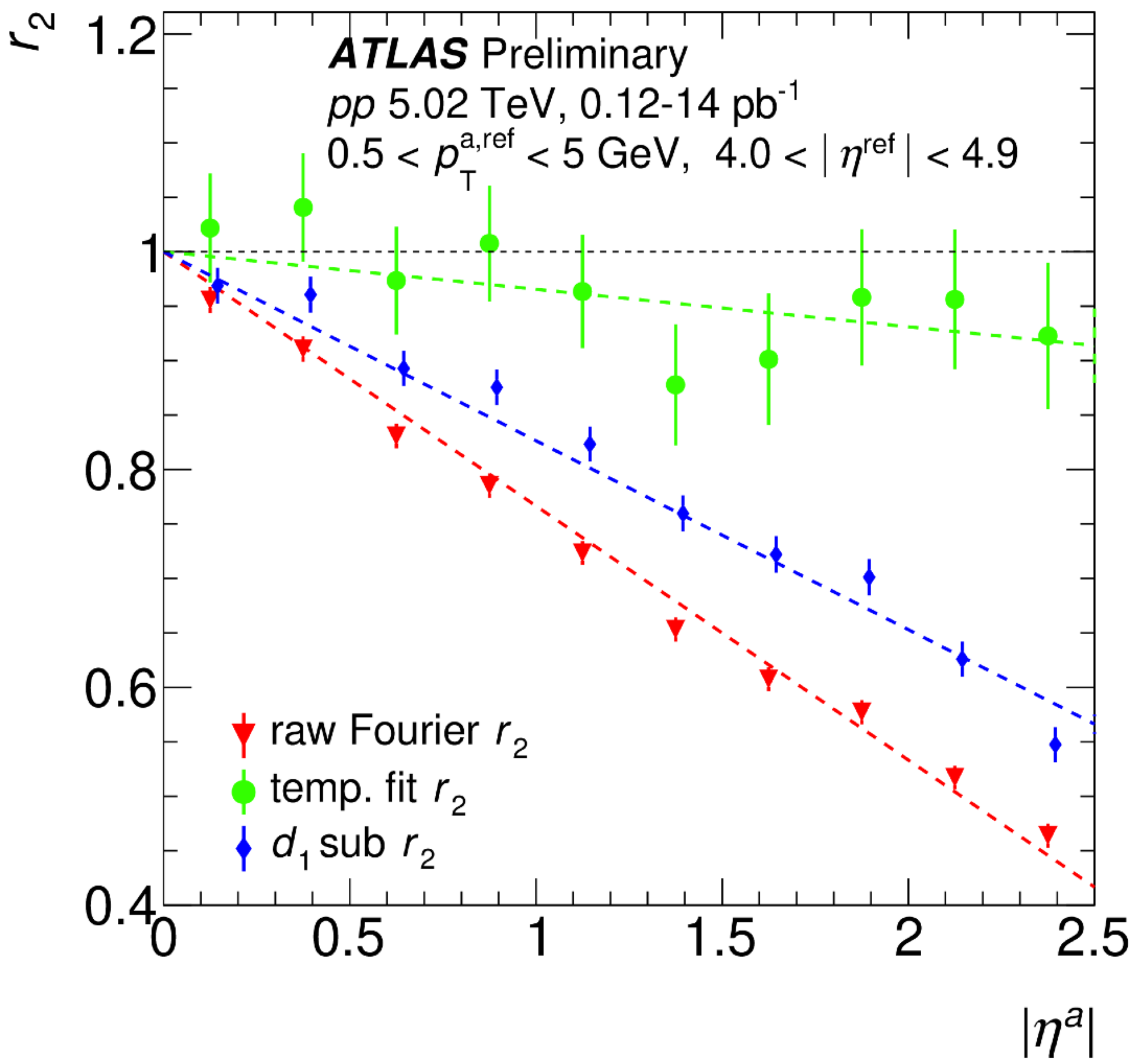
- p-p @5&13 TeV
- Xe+Xe @5.4 TeV







- Steps:
  —> 2PC objects (track & cluster/tower) azimuthal correlation in $\Delta\phi$
  —> Fourier moments —> non flow subtraction
  —> construct $r_2(|\eta|) = v_{2,2}(-|\eta|)/v_{2,2}(|\eta|)$
  —> slope of $r_2(|\eta|)$ via linear regression

Small system (p-p) results

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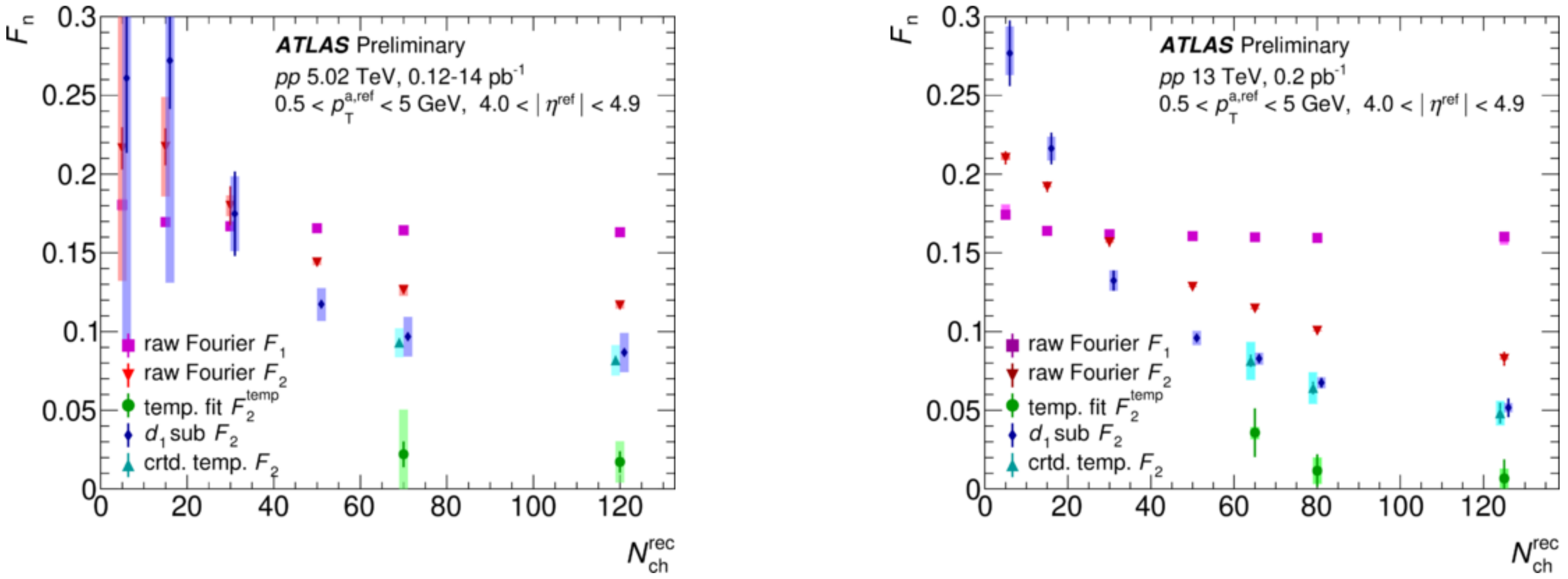
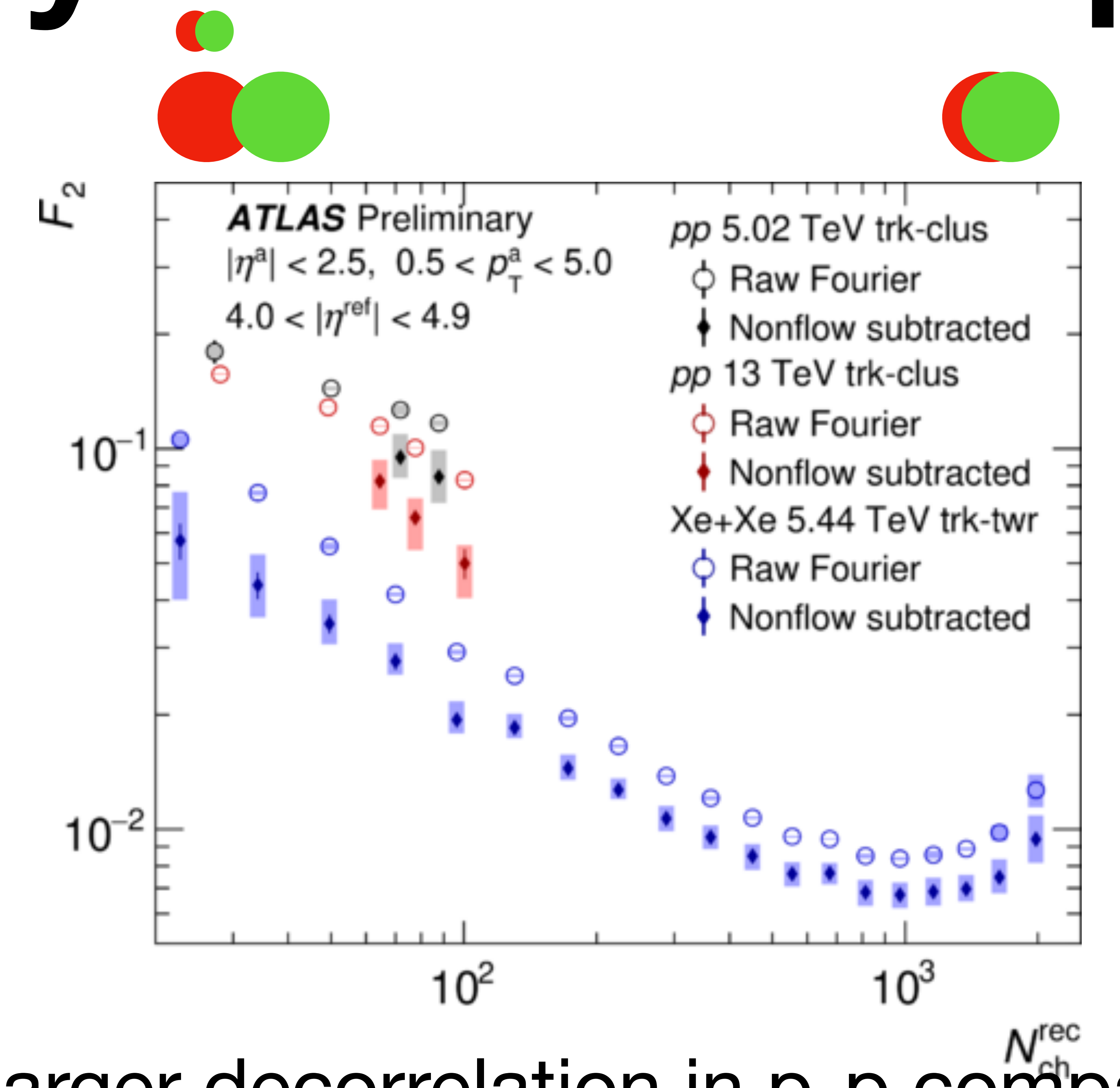
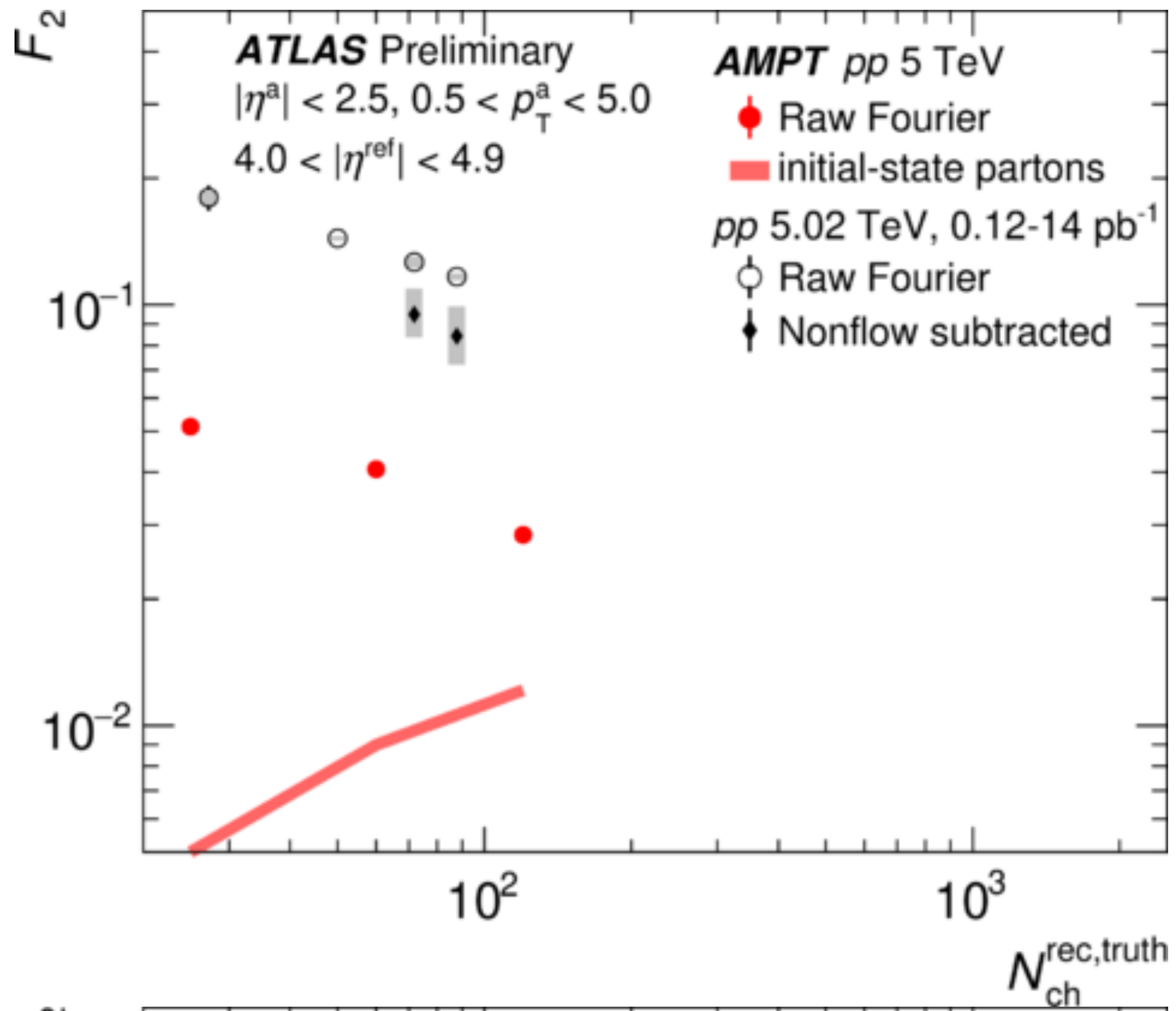
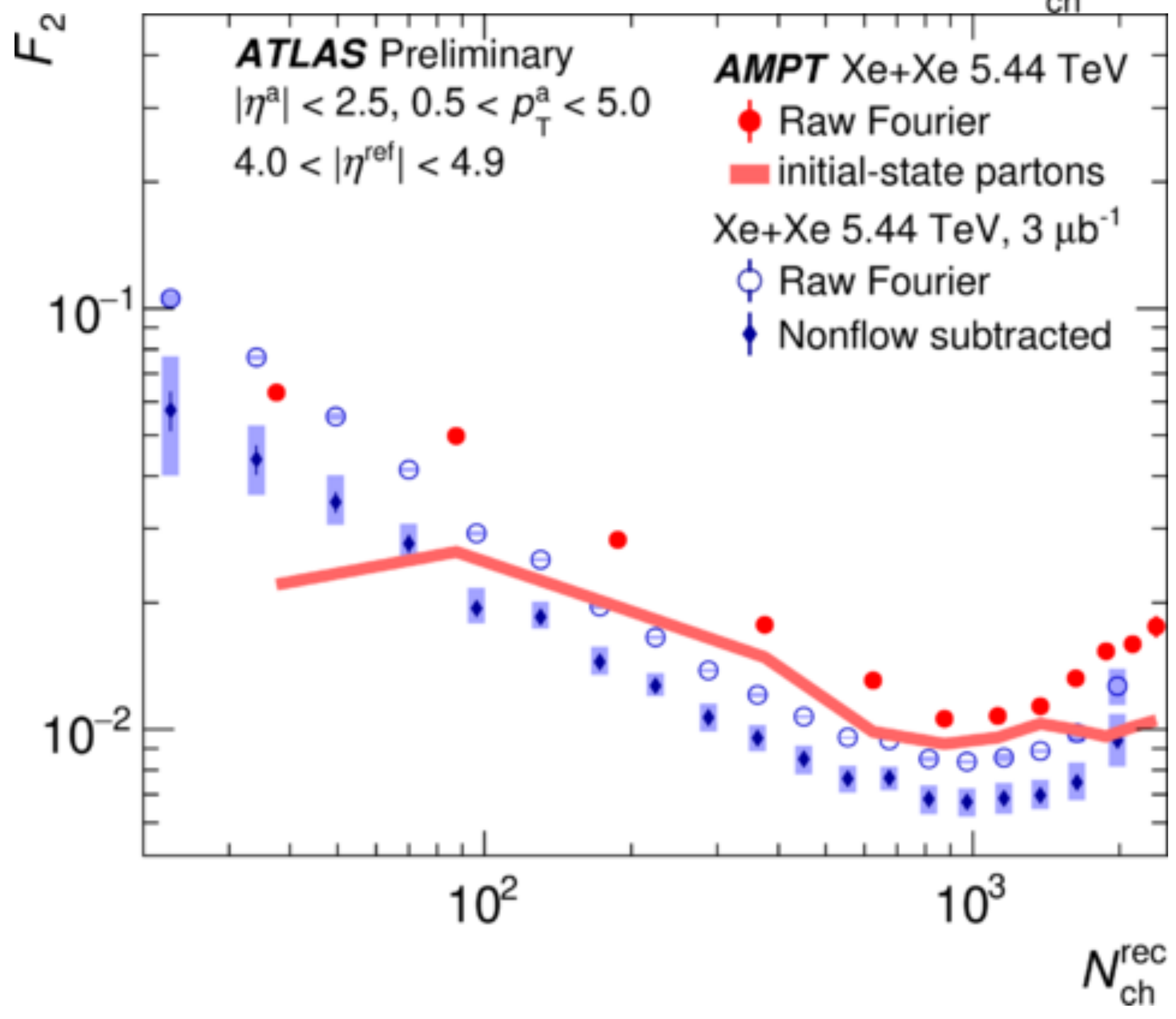


- Measurement needs elaborate non-flow subtraction technology - several results obtained with different levels of contamination
- Corrected results: (blue & magenta) indicate significant variation of flow with η distance, the effect is ~flat with high multiplicity

Systems comparison







- Larger decorrelation in p-p compared to Xe+Xe
- Reasonable modeling (by AMPT) of Xe+Xe data, discrepancy in p-p disfavours two strings picture of p-p collisions

Summary

- ATLAS experiment measured $v_n - [p_T]$ correlation for Xe+Xe in comparison to Pb+Pb
  - Observed differences (ratio) allowed to pin down subtleties of nuclear shapes (Xe nuclei triaxiality) that were measured for the first time
- Longitudinal decorrelation measurement in p-p & Xe+Xe
  - Challenges assumptions about non-flow contributions
  - Significant decorrelation observed in p-p (not expected in AMPT strings model)

Outlook for Run 3:
ready to take large datasets