Measurements of Longitudinal Decorrelation in small systems with ATLAS

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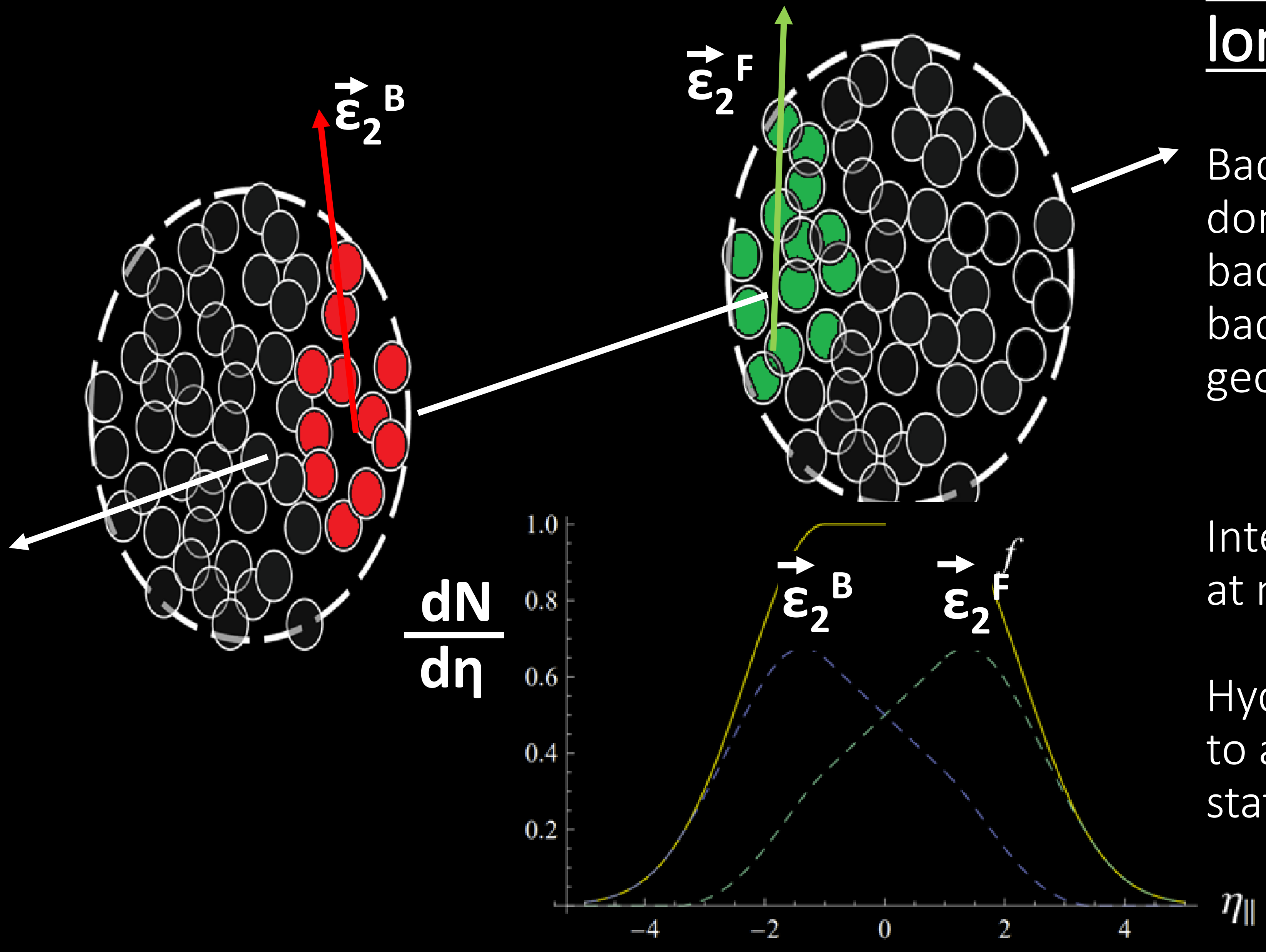
Quark Matter April. 7th , 2022

η-dependent geometry



First models of longitudinal decorrelation

Backwards-going participants dominates backwards going dN/dη and backwards-going initial-state geometry

Interpolation between geometries at mid-rapidity

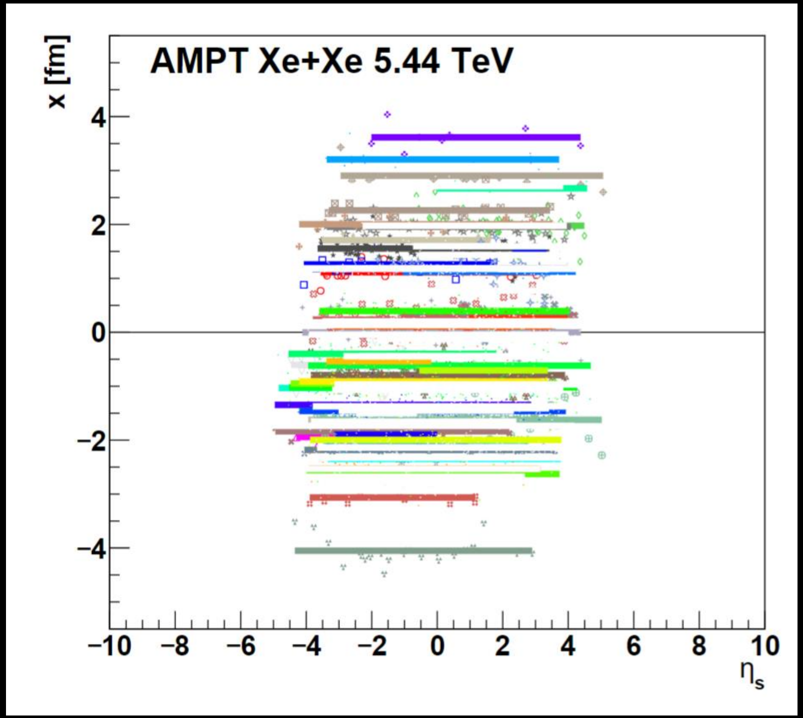
Hydrodynamic expansion gives rise to azimuthally anisotropic final-state momentum

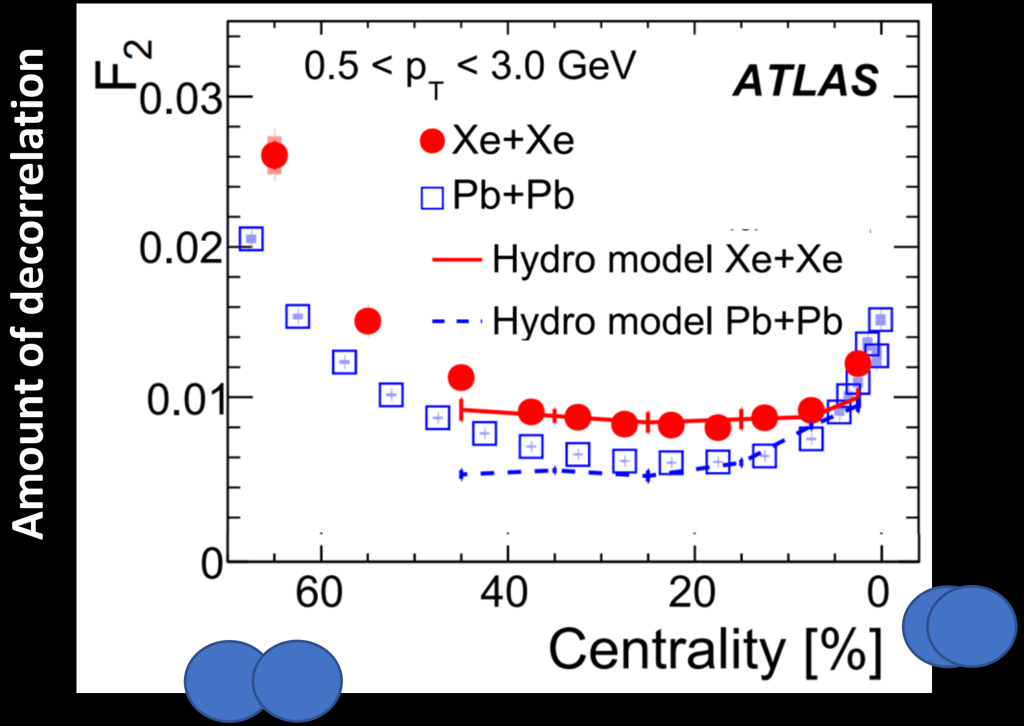
arXiv:1011.3354

String models of longitudinal decorrelation

- String-based MC Glauber models of the initial state simulate these effects out of the box
- Popular models (HIJING/AMPT) produce one string per participant
- String-based initial state + hydro has shown good agreement with previous ATLAS results.

arXiv:2001.04201



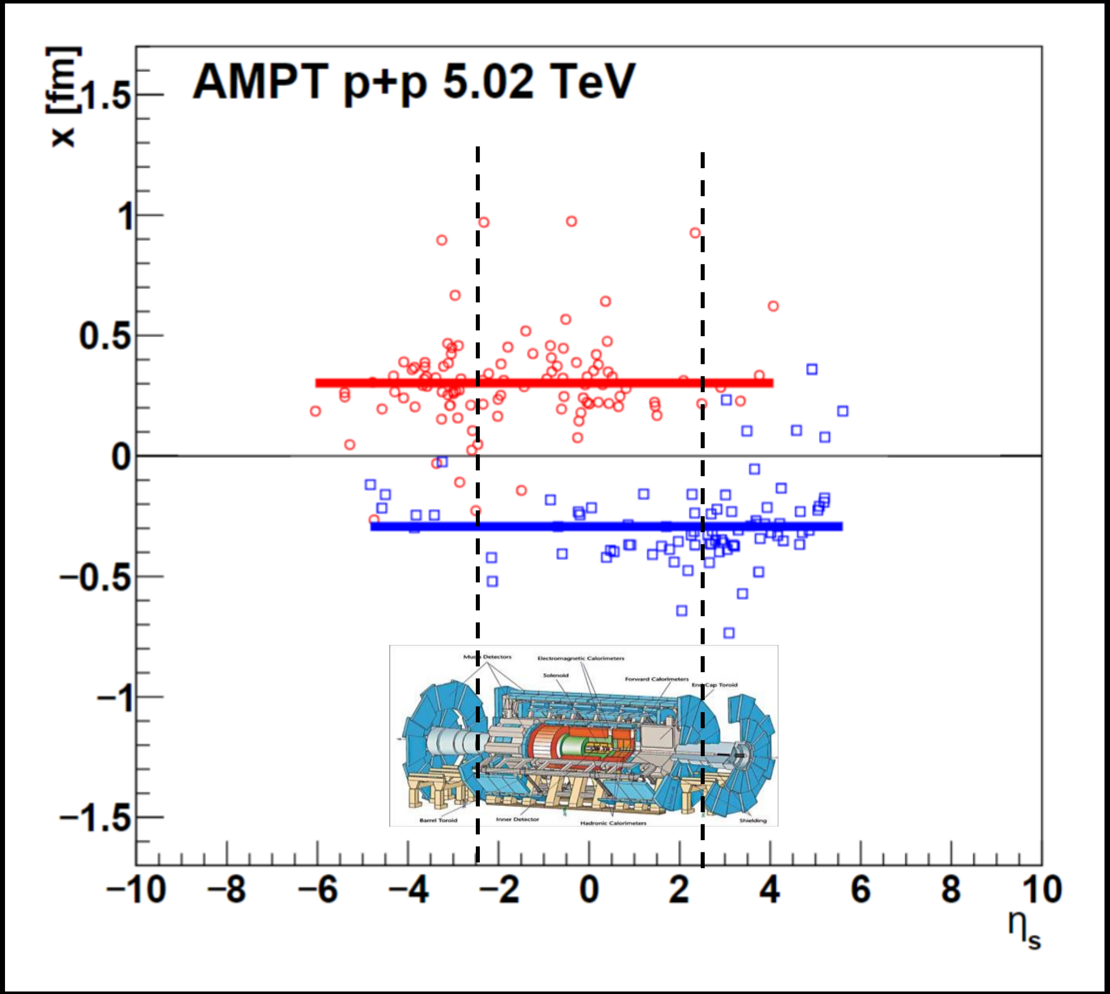


$$v_{2,2} \propto 1 + F_2 \eta$$

String models make straightforward prediction in *pp*

- A string per participant produces a simple model of proton-proton collisions
- Strings span the acceptance of the ATLAS inner detector.
- No variation in geometry
- **No longitudinal decorrelation**

What does data say

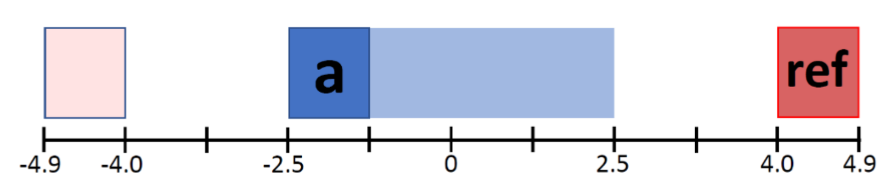


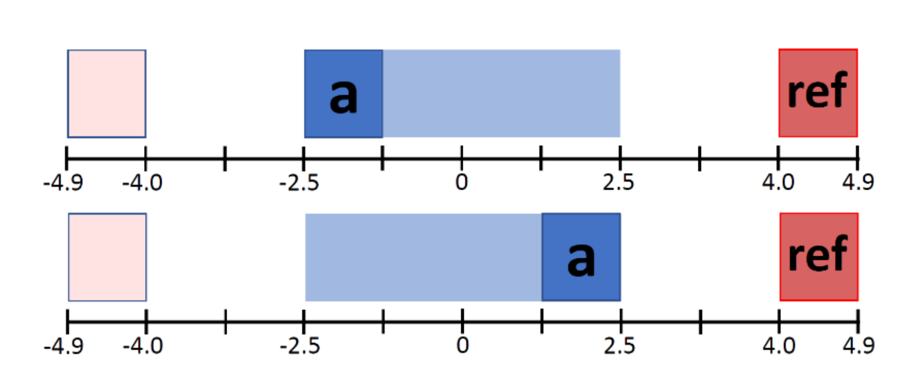
Fundamental constraints on nucleon-nucleon collisions

- Constrains the correlation between initial state
    1. Transverse structure and
    2. Longitudinal energy deposition / initial state momentum structure

- Longitudinal dependence of correlations is of practical importance when
    - **Comparing experimental results with different acceptances**
    - **Comparing theory and data**

Analysis overview





Systems analyzed

***pp* 13 TeV** ***pp* 5.02 TeV** **Xe+Xe 5.44 TeV**

Analysis steps

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

Step 2: measure Fourier moments and perform non-flow subtraction as a function of η^{a}

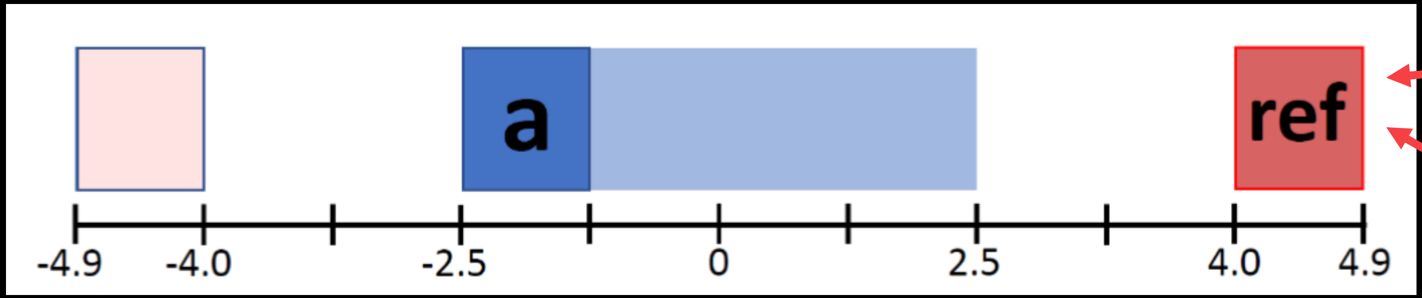
Step 3: construct ratio, $r_{n}(|\eta^{a}|)$

Step 4: Parametrize decorrelation via the slope of $r_{n}(|\eta^{a}|)$

Analysis overview

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

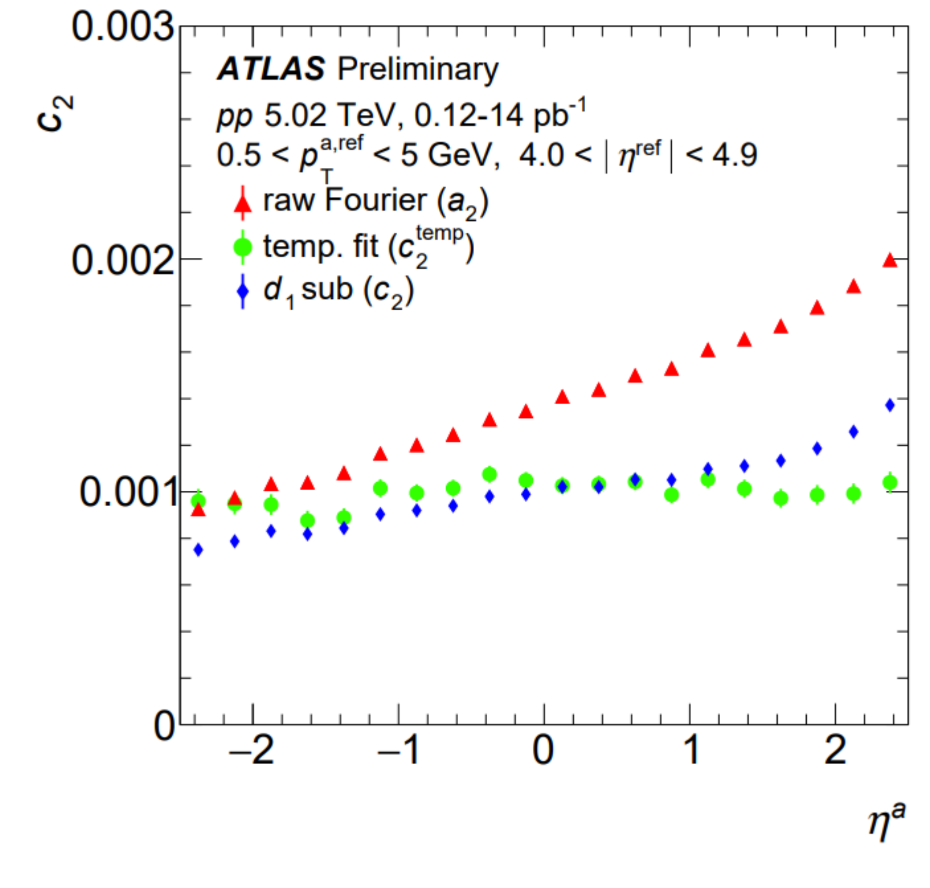
Step 1: Two-particle correlations between Inner detector tracks and forward calorimeter

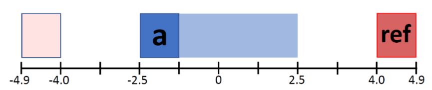


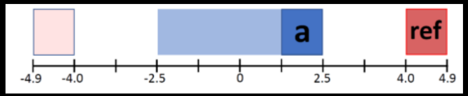
pp: calorimetric cluster

Xe+Xe: calorimetric tower

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







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Raw Fourier moments a_2

$$Y(\Delta\phi, \eta^a) = G\left\{1 + 2\sum_{n=1}^{4} a_n(\eta^a)\cos(n\Delta\phi)\right\}$$

flow **non-flow**

$$Y(\Delta\phi, \eta^a) = G\left\{1 + 2\sum_{n=1}^{4} (c_n(\eta^a) + d_n(\eta^a))\cos(n\Delta\phi)\right\}$$

η-dependent template fit (temp. fit)

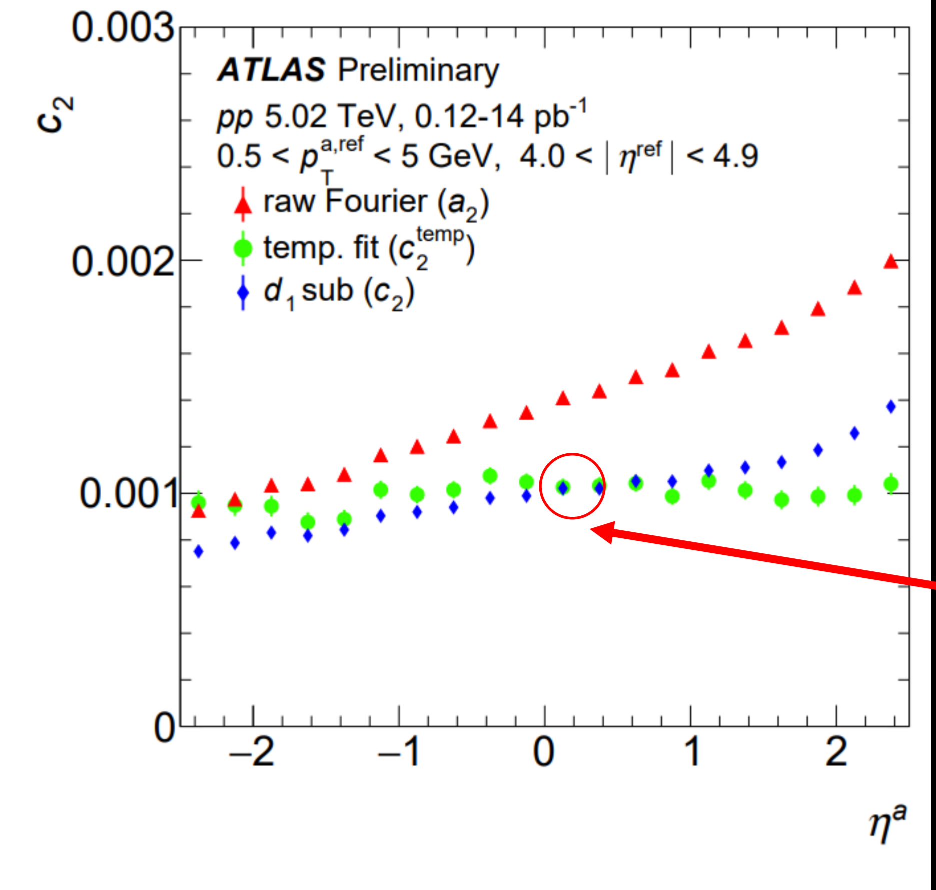
$$Y^{\mathrm{HM}}(\Delta\phi, \eta^a) = F^{\mathrm{temp}}(\eta^a) Y^{\mathrm{LM}}(\Delta\phi, \eta^a) + G^{\mathrm{temp}}(\eta^a)\left\{1 + 2\sum_{n=2}^{4} c_n^{\mathrm{temp}}(\eta^a)\cos(n\Delta\phi)\right\}$$

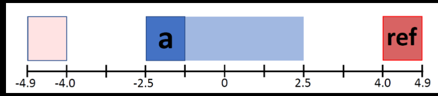
Use low multiplicity 2PC in same η^a slice as a *template* for non-flow

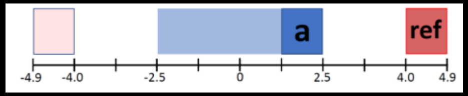
Low multiplicity reference N_{ch} = 40-60

Many assumptions in the template fit – can we compare to another method

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







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d_1 scaling subtraction (d_1 sub.)

$$c_2(\eta^a) = a_2(\eta^a) - a_1(\eta^a)\frac{d_2|_{\eta^a=0}}{d_1|_{\eta^a=0}}(1 + [F_2^d - F_1^d]\eta^a)$$

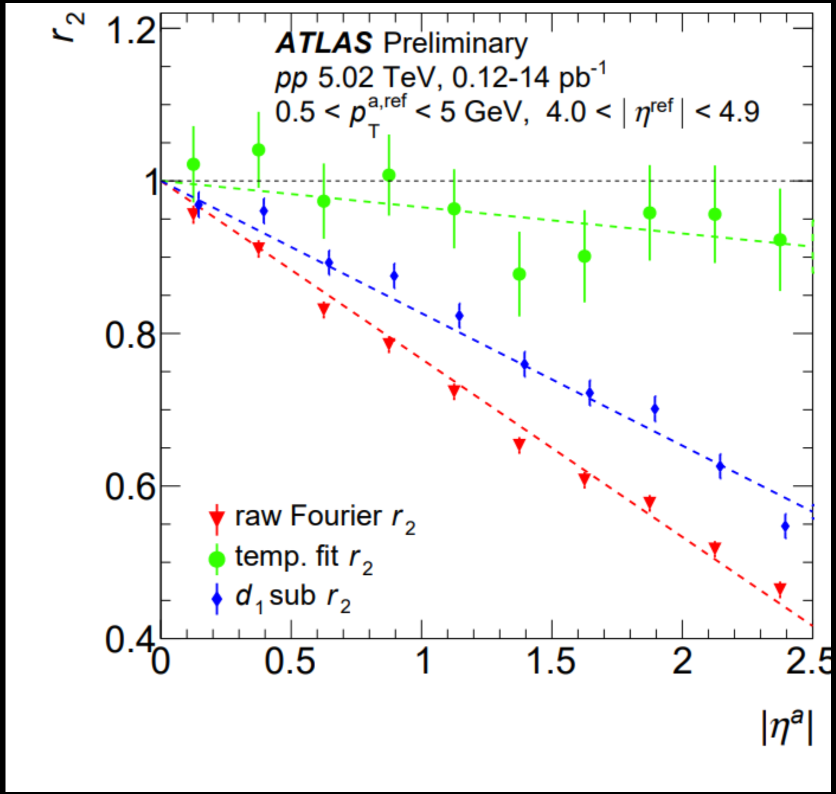
η^a independent non-flow shape
from mid-rapidity template fit results

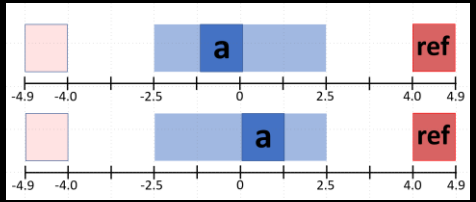
η^a dependent correction
Build in η^a dependence with non-flow model from LM events

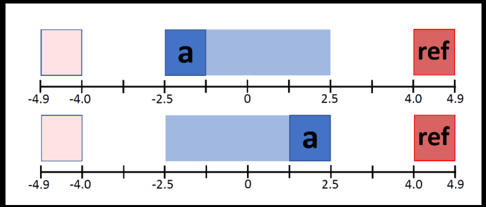
Differences in the subtracted results – will discuss with the full final results

Construct $r_2(|\eta^a|)$ ratio

$$r_2(|\eta^a|) = \frac{v_{2,2}(-|\eta^a|)}{v_{2,2}(|\eta^a|)}$$







Extract the slope of r_2 with linear regression

$$F_n = \frac{\Sigma_i (1 - r_n(\eta_i))\eta_i}{2\Sigma_i \eta_i^2}$$

$$r_n(|\eta^a|) = 1 - 2F_2|\eta^a|$$

This regression is nearly identical to fitting with the above function

F_2 shown as dashed lines

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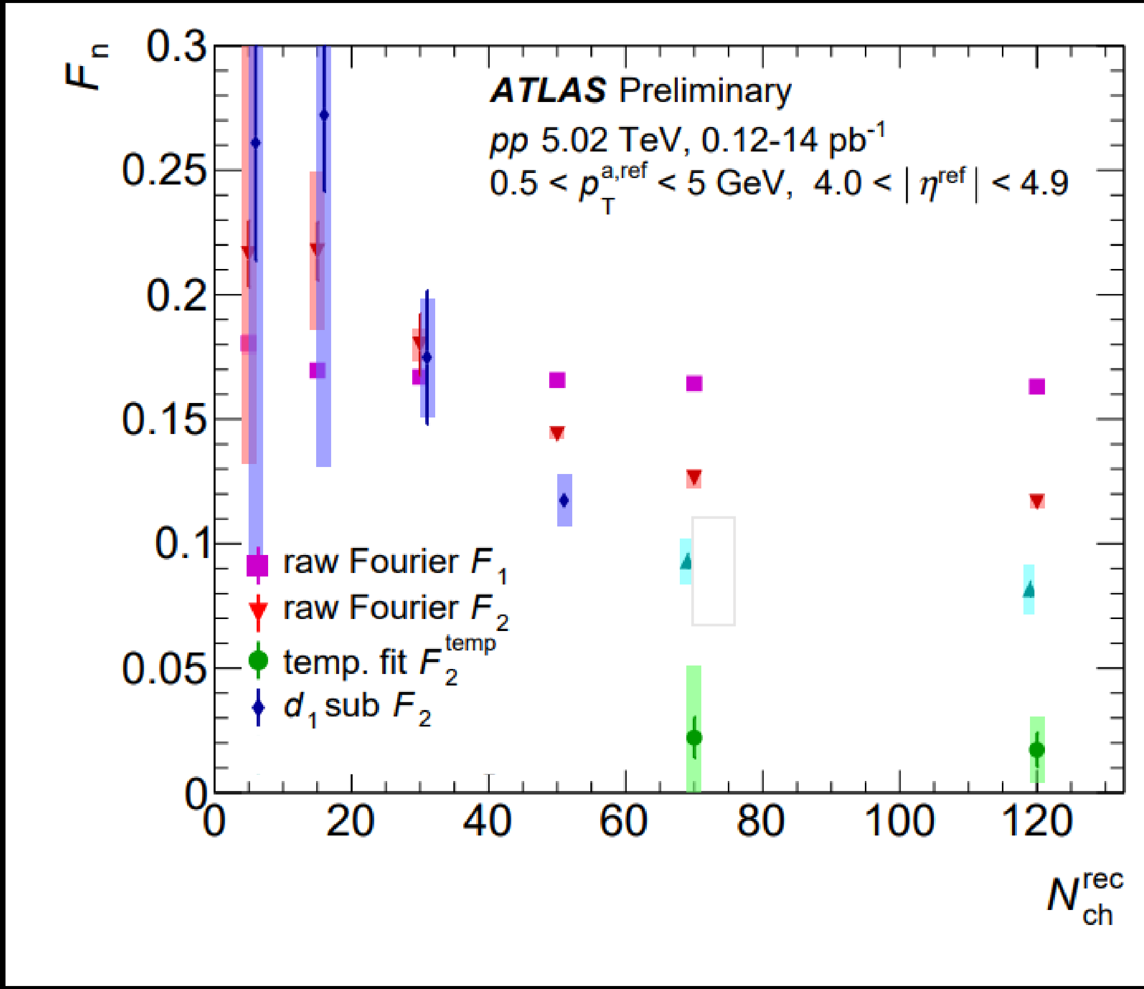
The r_n ratio measures the relative decorrelation between 2 η^a selections

F_2 provides a good description of r_2

Result in 5.02 TeV *pp* collisions



- **Raw Fourier F_2:** a combination of flow and nonflow η^a dependence.
- **Raw Fourier F_1:** the η^a dependence of a_1. Mostly multiplicity independent
- **Template fit F_2**: Subtracts off ~85% of the raw decorrelation.
  - Template N_{ch}=40-60
- ***d_1*-scaling subtracted:** removes 1/4 of the raw decorrelation
  - Defined across the whole N_{ch} range

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Template fit corrections

	Template fit F_2	d_1-scaling subtracted:
N_{ch}-independent non-flow shape	✓	✓
First moment is all non-flow	✓	✓
N_{ch}-independent mid-rapidity flow	✓	✓
F_n at N_{ch}=0-20 is all non-flow	X	✓
N_{ch}-independent flow decorrelation	✓	X

Template fit corrections

The template fit can be corrected for the violation of
***N_{ch}*-independent flow decorrelation assumption**

$$F_n^{\mathrm{HM}} \approx F_n^{\mathrm{temp}} + \rho \frac{c_n^{\mathrm{LM}}|\eta^a=0}{c_n^{\mathrm{HM}}|\eta^a=0}(F_n^{\mathrm{LM}} - F_n^{\mathrm{temp}})$$

	Template fit F_2	d_1-scaling subtracted:
N_{ch}-independent non-flow shape	✓	✓
First moment is all non-flow	✓	✓
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N_{ch}-independent flow decorrelation	✓	X

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N_{ch}-independent non-flow shape	✓	✓
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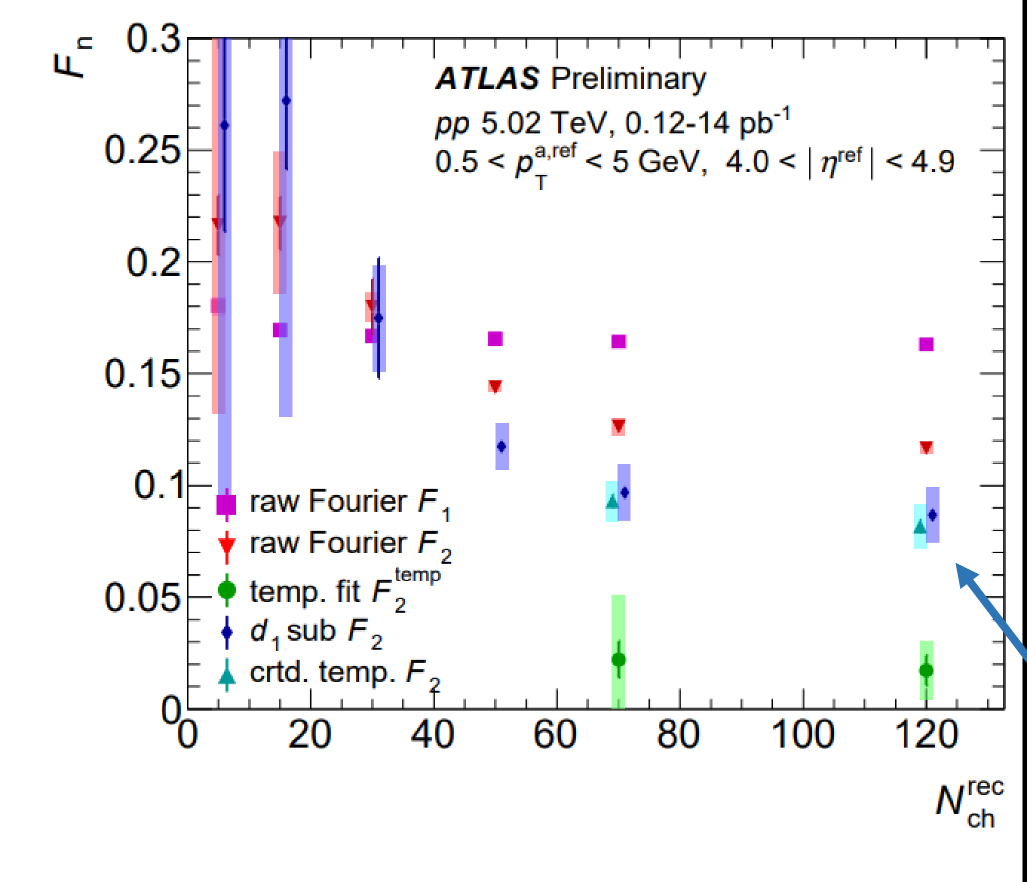
F_n at N_{ch}=0-20 is all non-flow	X	✓
~~N_{ch}-independent flow decorrelation~~	✓	X

Result in 5.02 TeV *pp* collisions



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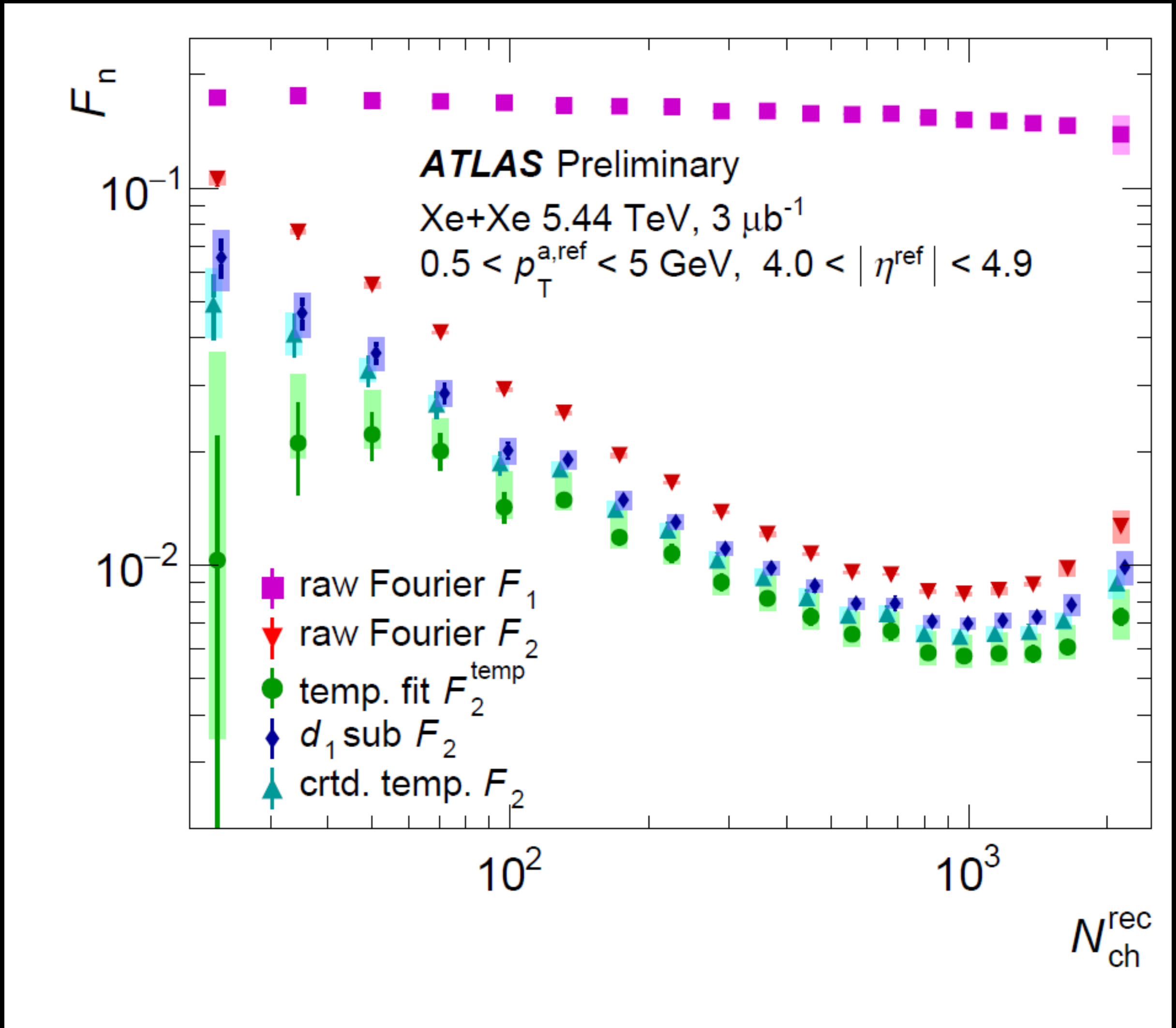
	Template fit F_2	d_1-scaling subtracted:
N_{ch}-independent non-flow shape	✓	✓
First moment is all non-flow	✓	✓
N_{ch}-independent mid-rapidity flow	✓	✓
F_n at N_{ch}=0-20 is all non-flow	X	✓
N_{ch}-independent flow decorrelation	✓	X

The template fit can be corrected for the violation of assumptions with input from the d_1-scaling subtraction

$$F_n^{\mathrm{HM}} \approx F_n^{\mathrm{temp}} + \rho \frac{c_n^{\mathrm{LM}}|_{\eta^a=0}}{c_n^{\mathrm{HM}}|_{\eta^a=0}} \left(F_n^{\mathrm{LM}} - F_n^{\mathrm{temp}}\right)$$

Given results in the d_1 subtraction, the template fit results are understandable

Results in Xe+Xe collisions



First measurement of 70~90% Xe+Xe decorrelation

Analysis differences

- Track-tower correlation
- *pp* reference for template fit and estimation of d_1 sub parameters.

Subtracted results suggest non-flow effects at all centralities This assumes

- No modification of nonflow shape
- Non-flow is the only source of first Fourier moment in correlation.

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That was a lot… Want more?

ATLAS EXPERIMENT

ATLAS CONF Note

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3rd April 2022

CERN

Measurements of longitudinal flow decorrelations in 5.02 TeV and 13 TeV pp collisions and 5.44 TeV Xe+Xe collisions with the ATLAS detector

The ATLAS Collaboration

This note presents measurements of longitudinal flow decorrelations in 5.02 TeV and 13 TeV pp collisions and 5.44 TeV Xe+Xe collisions with the ATLAS detector. The measurements are performed using the two-particle correlation method with charged-particle tracks within $|\eta| < 2.5$ and clusters within $4.0 < |\eta| < 4.9$. Due to the larger influence of non-flow effects in small collision systems, template-based subtraction procedures are developed and used in the measurement. The role of these effects is investigated in large systems such as 5.44 TeV Xe+Xe collisions. Flow decorrelations are characterized in terms of the ratio of the correlation coefficients derived from correlations with a large pseudorapidity gap to those with a small pseudorapidity gap, r_n, where n is the flow harmonic moment. The results, quantified as the slope of r_2 as a function of pseudorapidity gap, are reported as a function of charged-particle multiplicity for the pp and Xe+Xe collision systems.

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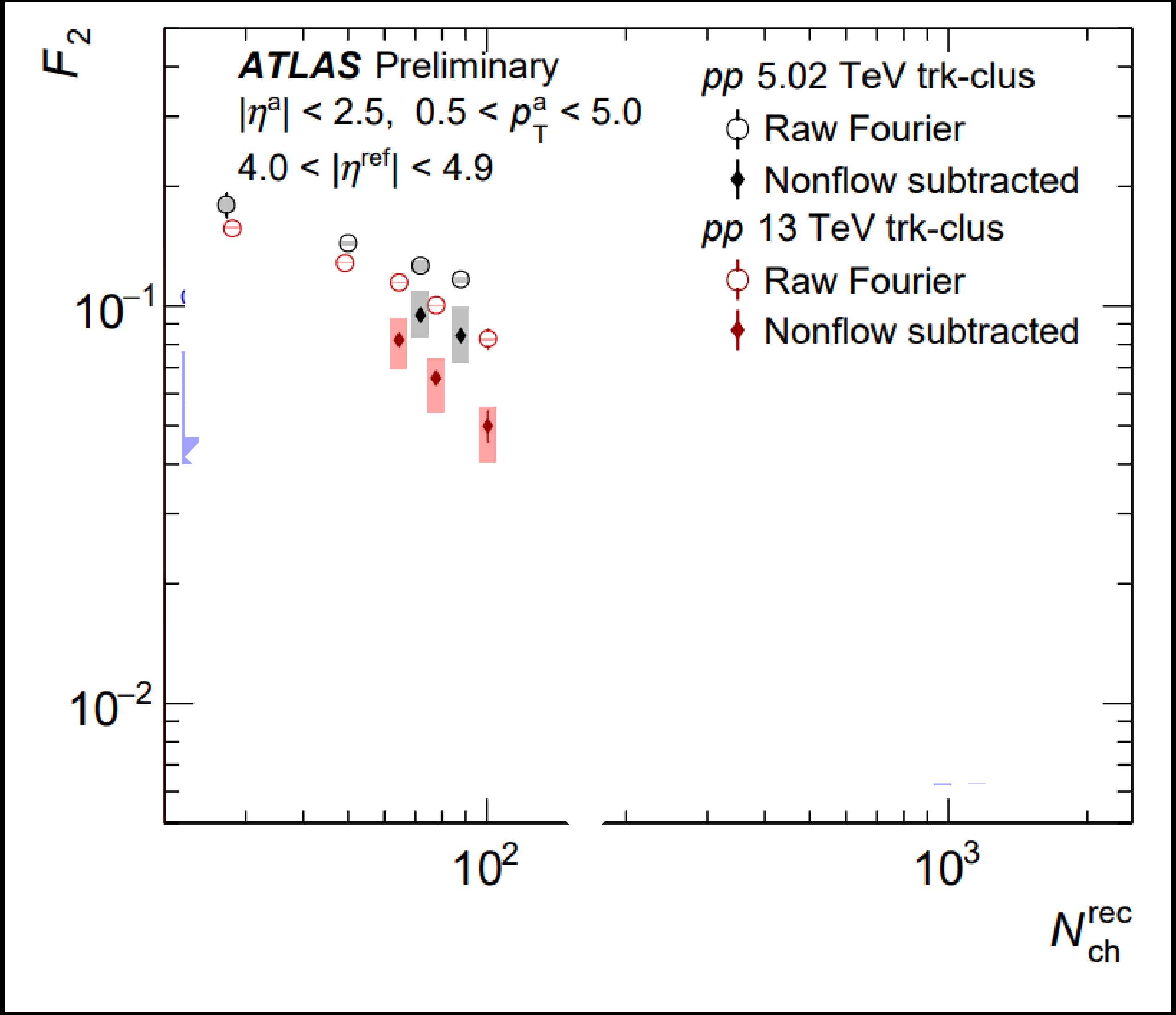
System comparison



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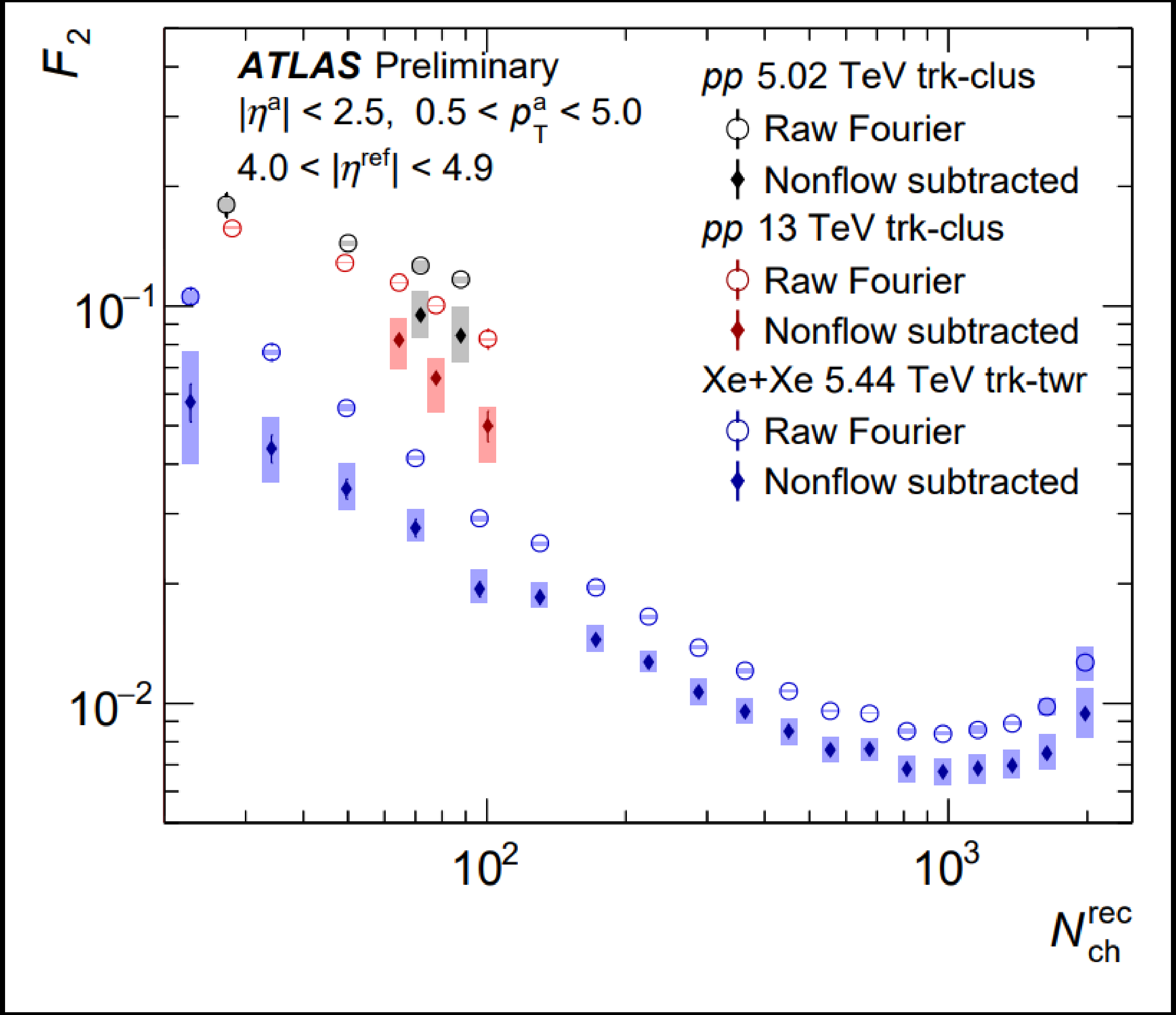
Raw results (open markers)

Non-flow results (solid markers)
Averaged central values of temp fit and crtd temp
Full systematic uncertainty of the two

Larger decorrelation in *pp* than Xe+Xe at similar multiplicities.

Peripheral XeXe and *pp* decorrelation follow a power-law decrease

System comparison



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Raw results (open markers)

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Data to AMPT comparisons

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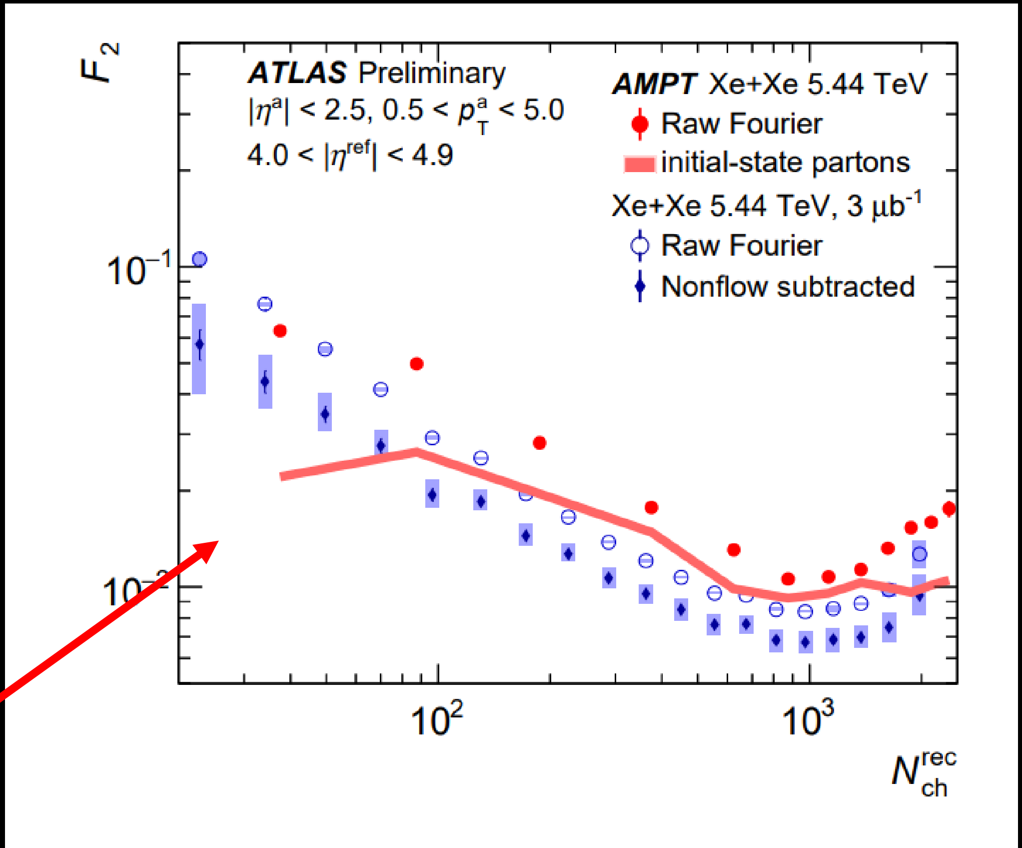

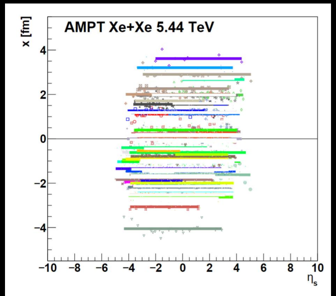

$$r_2(|\eta^a|) = \frac{\vec{\varepsilon}_2(-|\eta_s^a|) \cdot \vec{\varepsilon}_2(\eta_s^{ref})}{\vec{\varepsilon}_2(|\eta_s^a|) \cdot \vec{\varepsilon}_2(\eta_s^{ref})}$$

Data to AMPT comparisons

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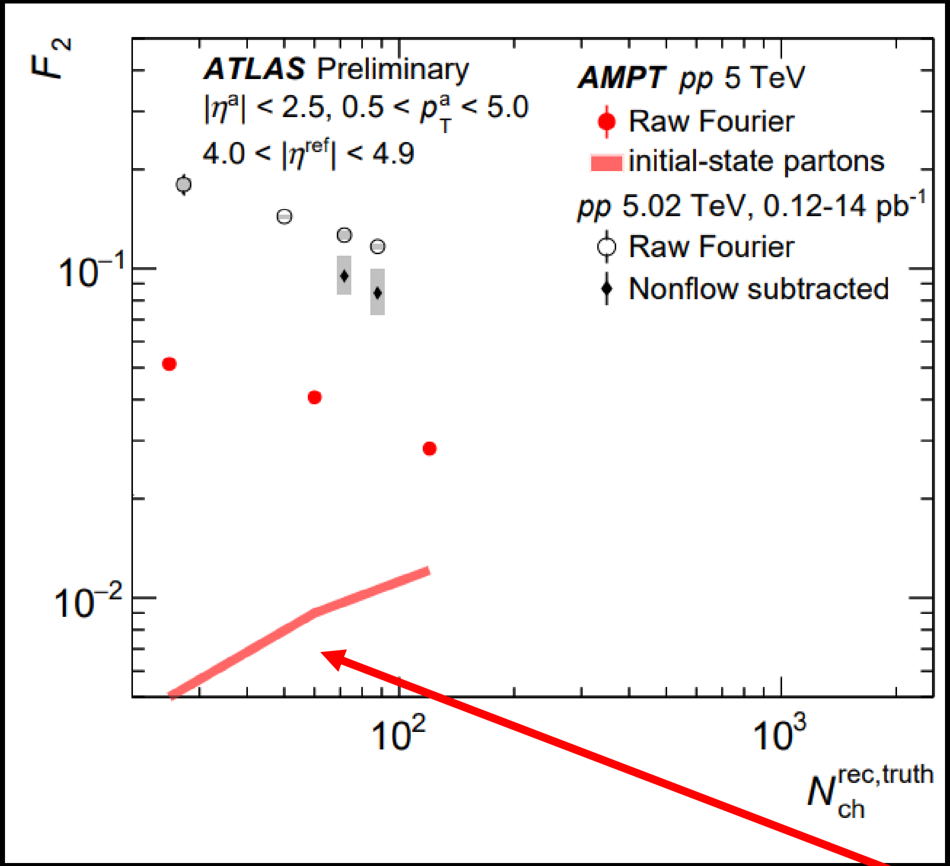
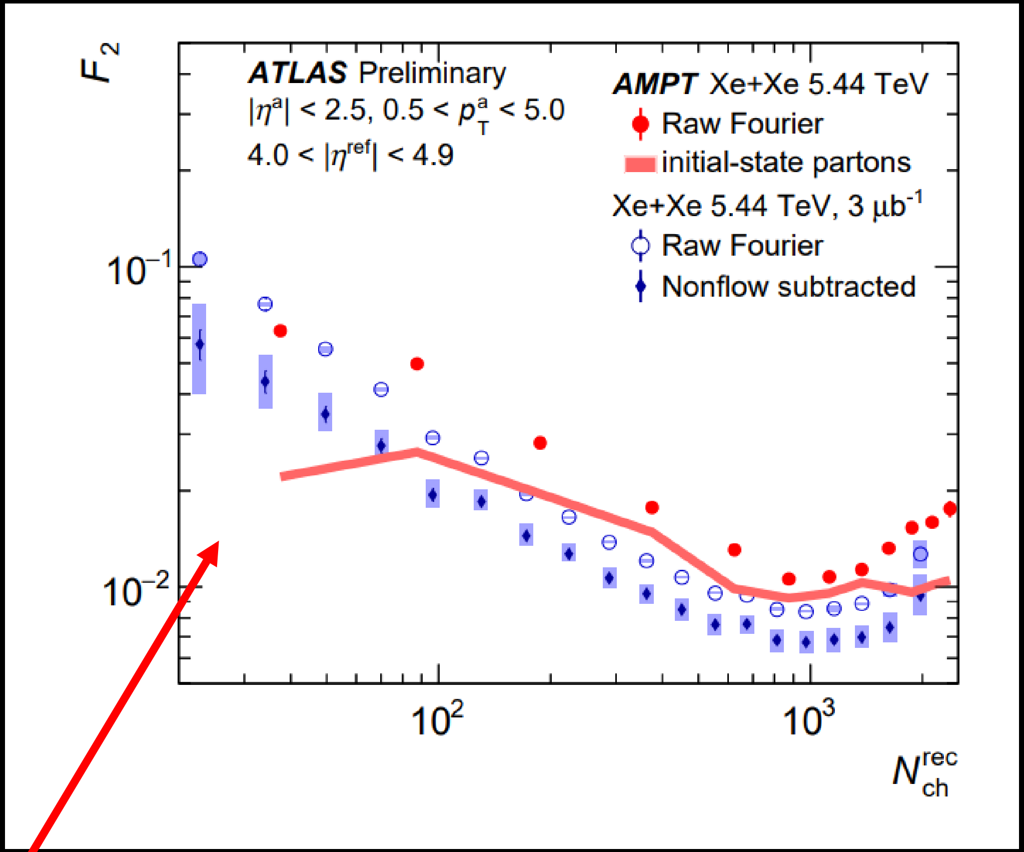
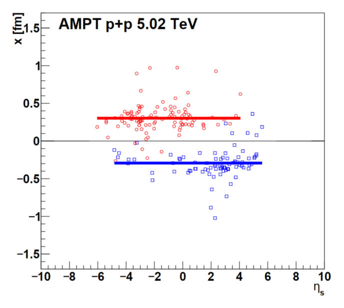
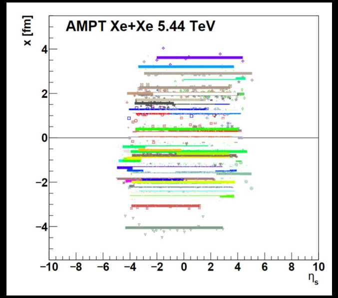






$$r_2(|\eta^a|) = \frac{\vec{\varepsilon}_2(-|\eta_s^a|)\cdot\vec{\varepsilon}_2(\eta_s^{ref})}{\vec{\varepsilon}_2(|\eta_s^a|)\cdot\vec{\varepsilon}_2(\eta_s^{ref})}$$

Low number of strings leads to small geometric decorrelation



Disfavors a *pp* initial-state model with a low number of long strings

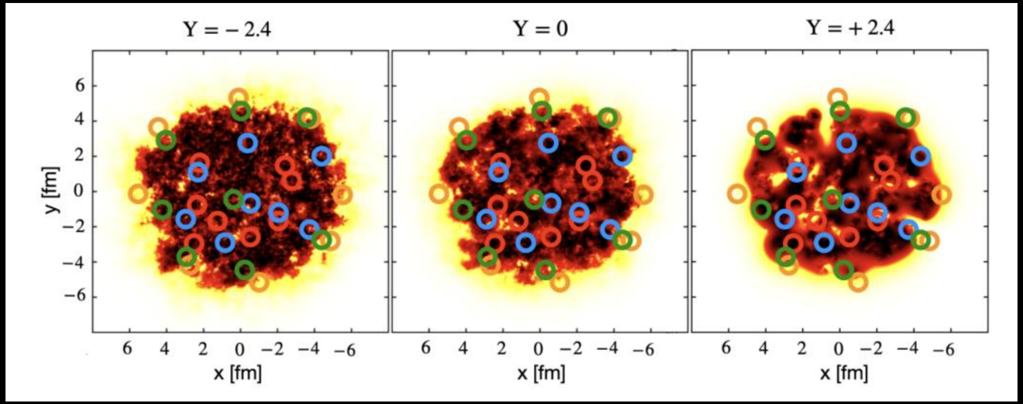
What I showed you

- First measurement of longitudinal decorrelation in pp and peripheral Xe+Xe
- *pp* has larger decorrelation than Xe+Xe at similar multiplicities
- Results are sensitive to non-flow subtraction methodology
- Disfavors string models of the initial state where a nucleon-nucleon collision is simulated by a low number of long strings.

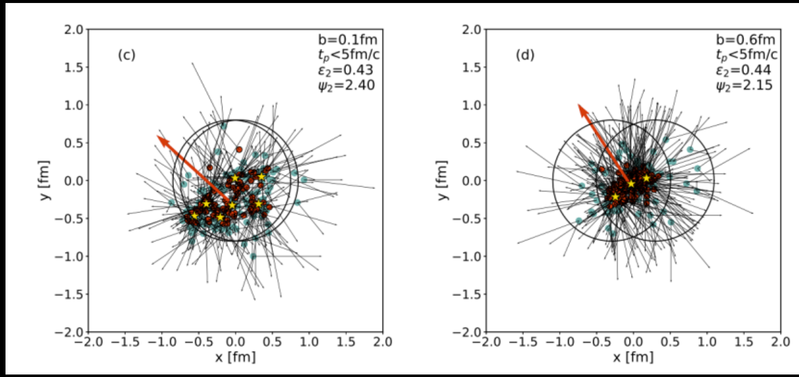
What's next: a new (precision) world

- Part of a push towards a full precision-oriented discription of collective QCD physics
- Discriminate between final and initial state effects
  - Recent work show very large initial-state azimuthal anisotropic decorrelation
  - arXiv:2201.08864
  - arXiv:2109.03512 (pure hydro)
- Future measurements of
  - multi-particle decorrelation – less sensitive to non-flow effects.
  - Photonuclear decorrelation

IP-Glasma+MUSIC+UrQMD Schenke et al arXiv:2201.08864



AMPT+PYTHIA Zhang et al. arXiv:2104.05998



★ Constituent quark collision ↑ ψ_2 Parton: loc. ● Vel. ↑

Thank you