Recent ATLAS results from small collision systems

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for the ATLAS Collaboration

13th International workshop on Multiple Partonic Interactions at the LHC

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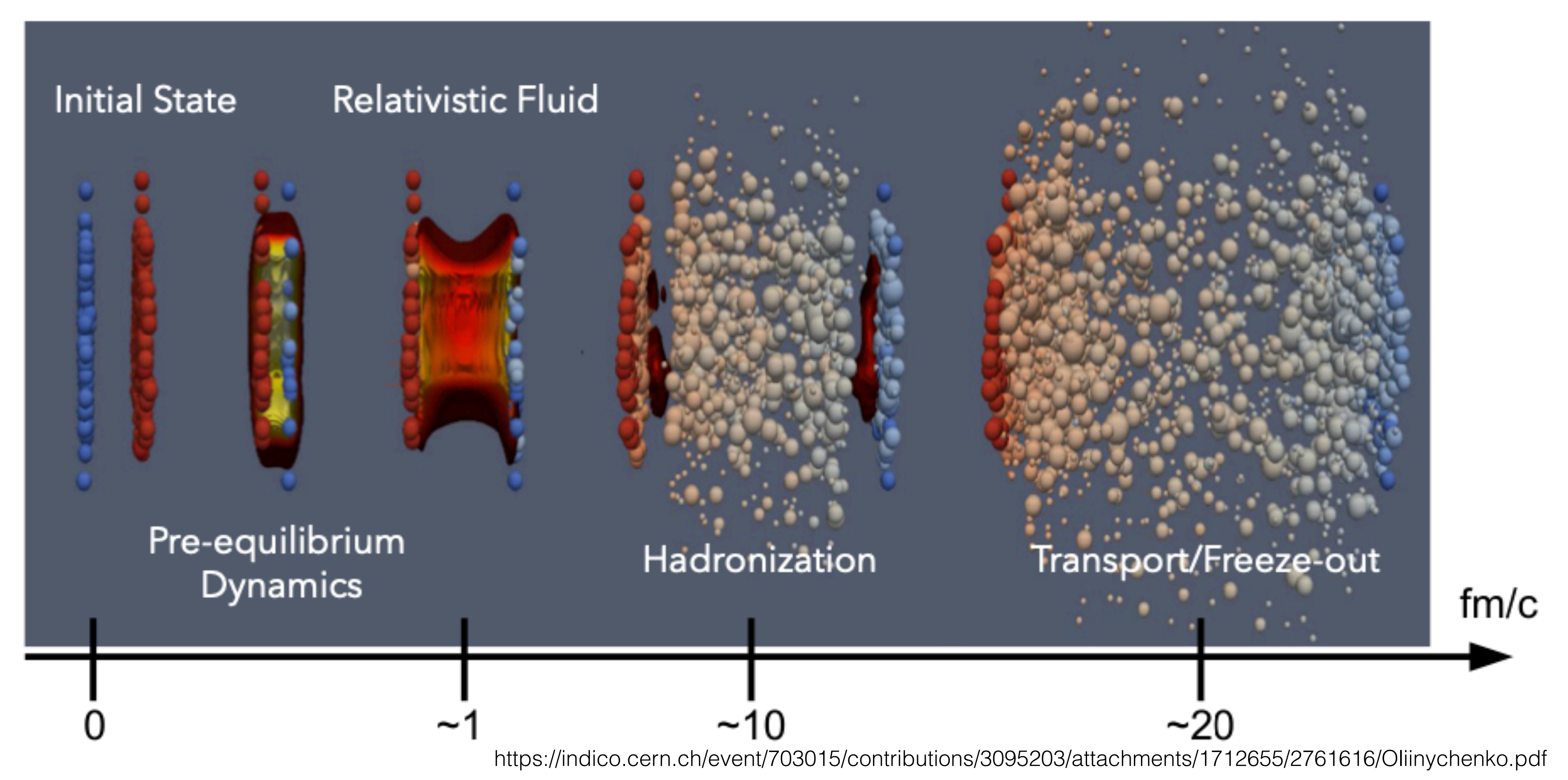
A brief history of flow in heavy-ion collisions

Early results from RHIC program indicated that head on **Au+Au** collisions at 200 GeV behave as a *nearly perfect fluid*.

- Subsequent measurements at **Pb+Pb** collisions at LHC shows similar *fluid nature.*



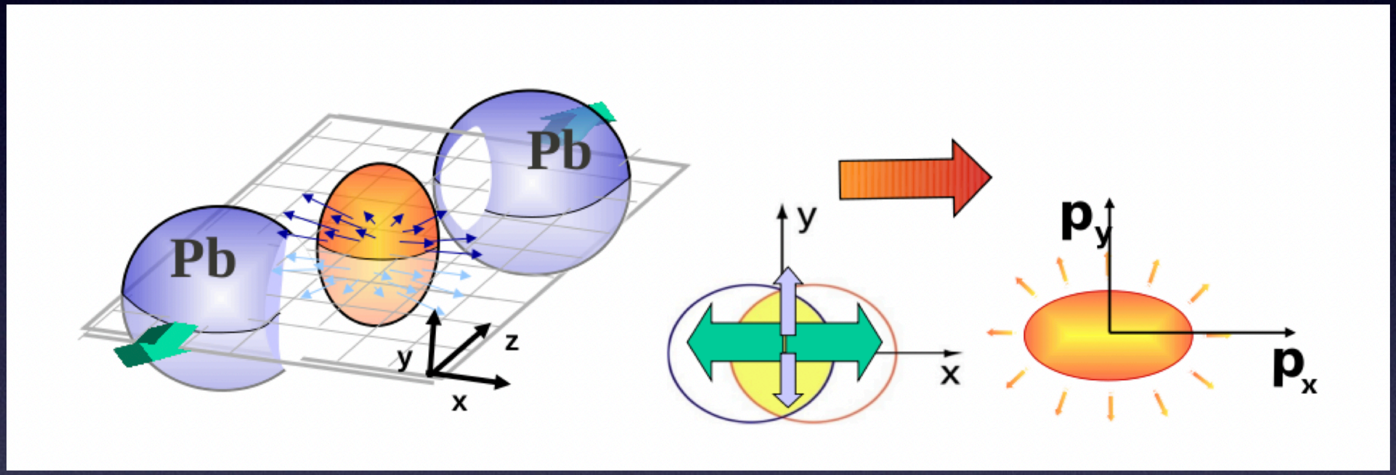
Visualization of the different stages of heavy-ion collisions in a hybrid approach based on *hydrodynamics and hadronic transport* for the initial and final stages.

Flow in the Quark Gluon Plasma (QGP)

Quantifying initial and final state

Pb → ← Pb

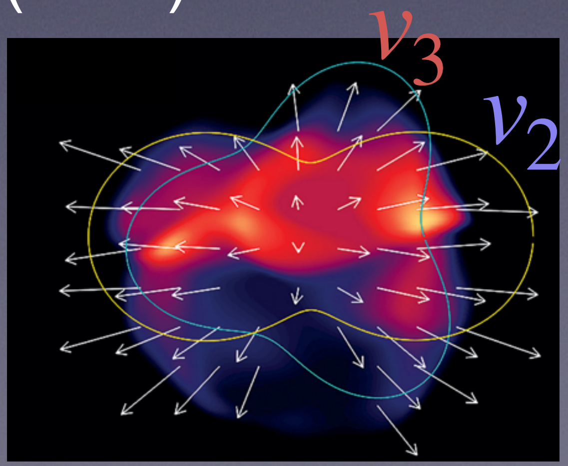
A tiny drop of QGP is created in heavy-ion collisions and it expands like a fluid.



Initial state　　　Final state

Spatial anisotropy in the initial state energy density translates into momentum anisotropy in the final state → v_2 (*Flow*)

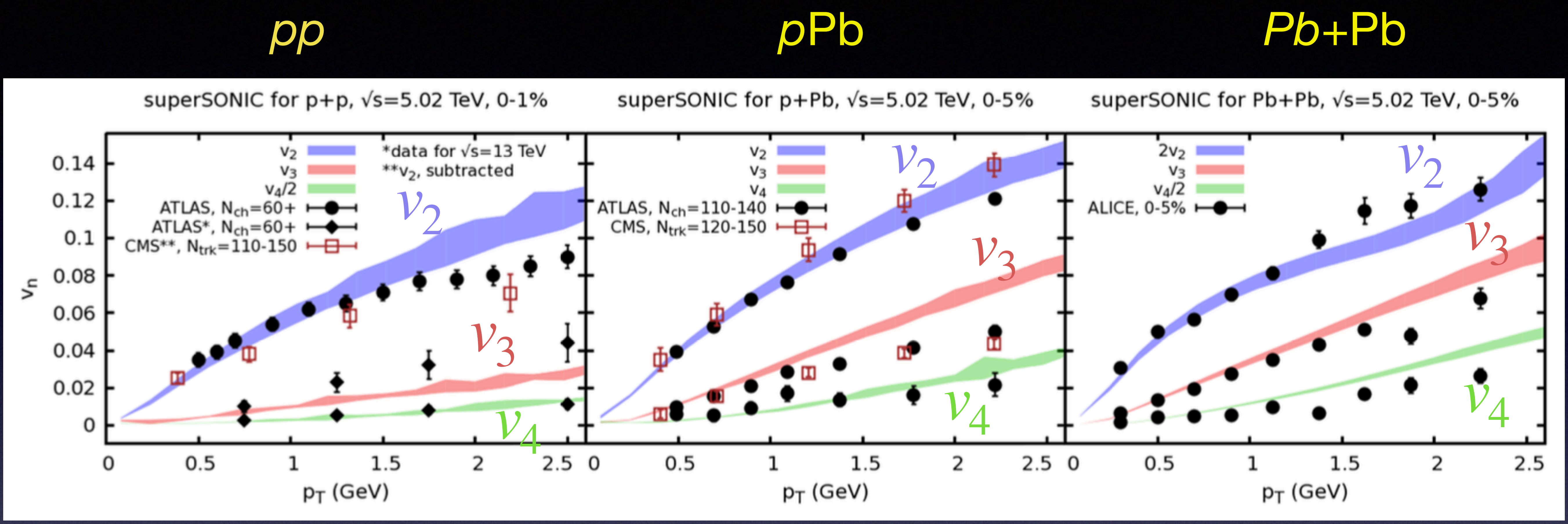
Initial state fluctuations → v_3, v_4 …



Can we observe flow-like signatures in smaller systems like *pp?*

https://cerncourier.com/a/going-with-the-flow/

Can we observe flow in small systems like *pp*, *p*Pb?



Theory: Physics Letters B 774 (2017) 351–356

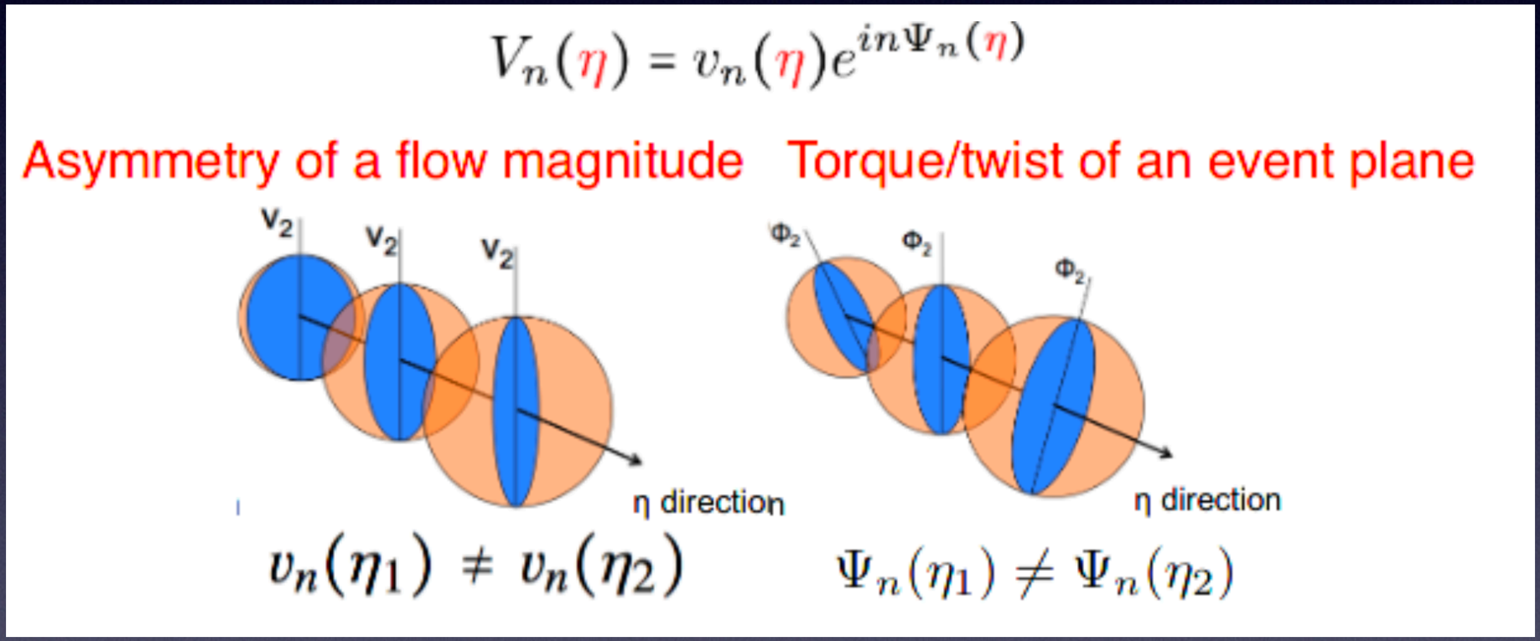
ATLAS: Physical Review C 90, 044906 (2014)

Hydrodynamic models can successfully make predictions for v_2, v_3, v_4 in systems of wide size ranges: *pp*, *p*Pb and Pb+Pb!

Pseudorapidity (η) dependent geometry

Forward (backward) moving nucleons produce particles preferably in the forward (backward) direction, lead to an event- by-event torqued fireball.

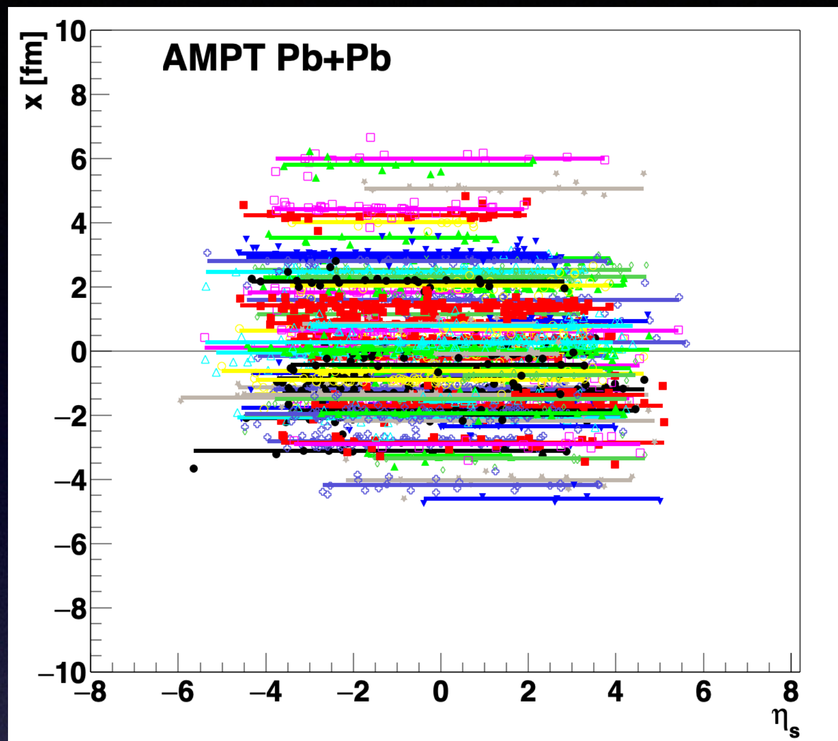
arXiv:1011.3354 *Peter Bozek, Wojciech Broniowski, Joao Moreira*



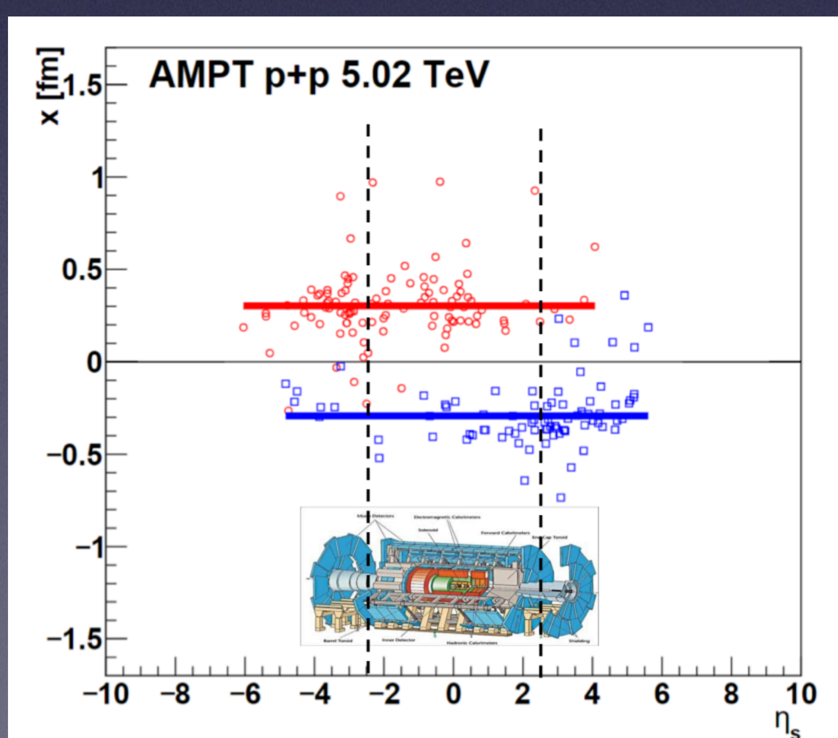
In different η slices, almond geometry (v_n) will be different.

Can we constrain the initial deposition of energy in both the transverse and *longitudinal* directions?

Pseudorapidity (η) dependent geometry - AMPT



http://cdsweb.cern.ch/record/2813842/files/nagle_sqm_atlas_decorrelations_2022.pdf



https://indico.cern.ch/event/895086/contributions/4716148/attachments/2422936/4147716/BSeidlitz_Decor_QM22_Final.pdf

<u>AMPT has string models</u>

Xiang-Yu Wu, Long-Gang Pang, Guang-You Qin, and X-N Wang
Phys. Rev. C **98**, 024913

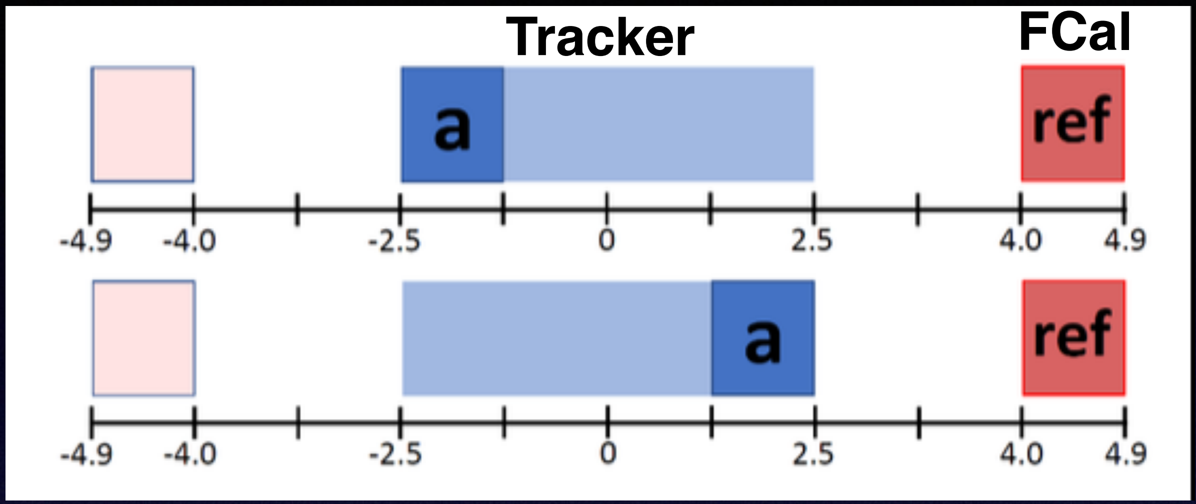
η-dependent geometry from strings in AMPT. AMPT illustrations in large system (Pb+Pb) and small system (pp) are shown.

In p+p AMPT produces a simple geometry with two strings spanning a large rapidity.

Strings span the acceptance of the ATLAS inner detector.

No variation in transverse geometry in different longitudinal slices!
No longitudinal <u>*decorrelation/torque.*</u>

How to quantify longitudinal decorrelation?



Systems analyzed

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

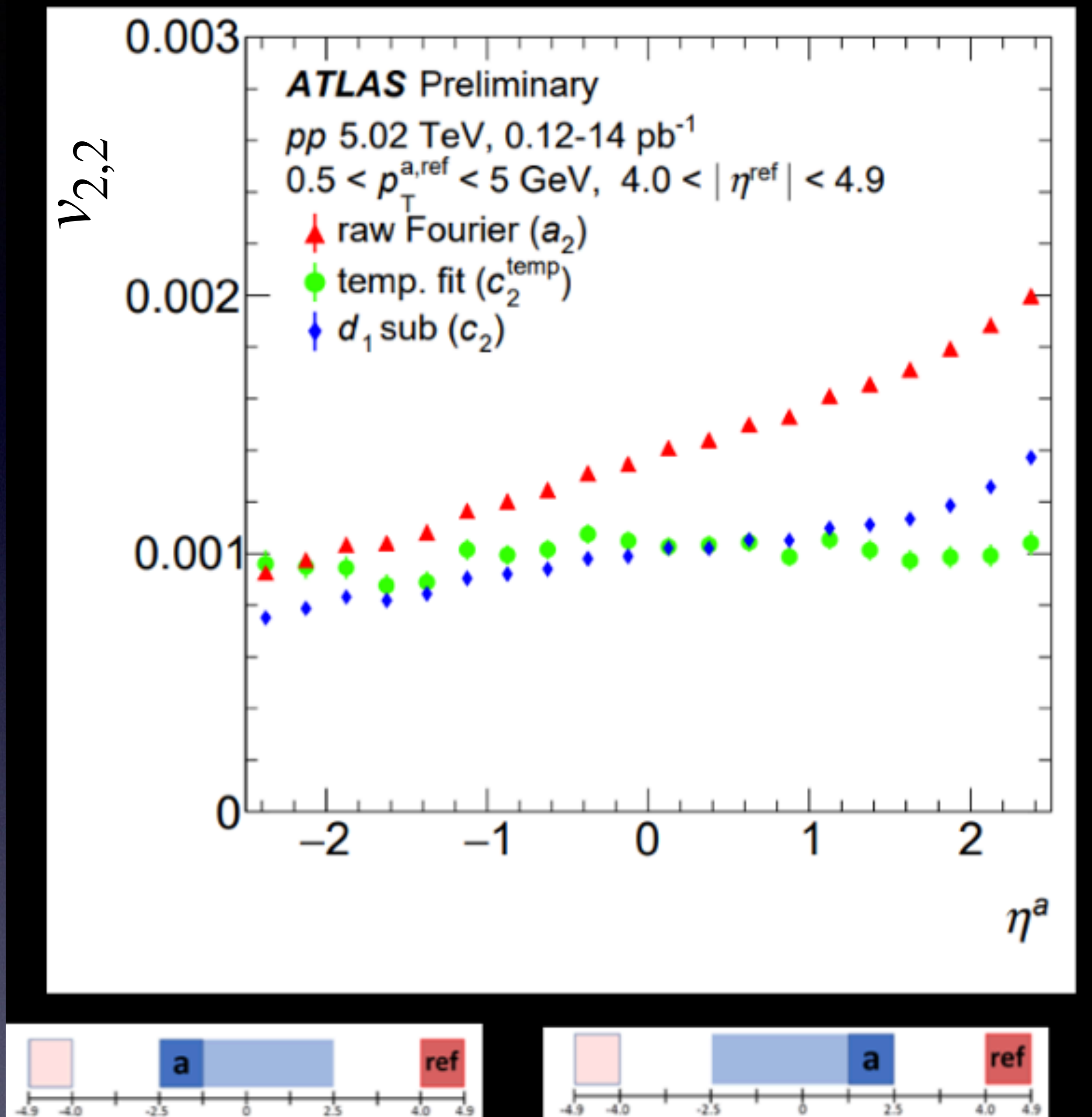
1. Construct two-particle correlation between inner detector tracks ($|\eta| < 2.5$) and $(4.0 < \eta < 4.9)$
2. Measure Fourier moments ($v_{n,n}$) and perform non-flow subtraction as a function of η^a.
3. Calculation of ratio of Fourier moments, $\mathrm{r_n}$

$$\mathrm{r_n}(|\eta^{\mathrm{a}}|) = \frac{\mathrm{v_{n,n}}(-|\eta^{\mathrm{a}}|)}{\mathrm{v_{n,n}}(|\eta^{\mathrm{a}}|)}$$

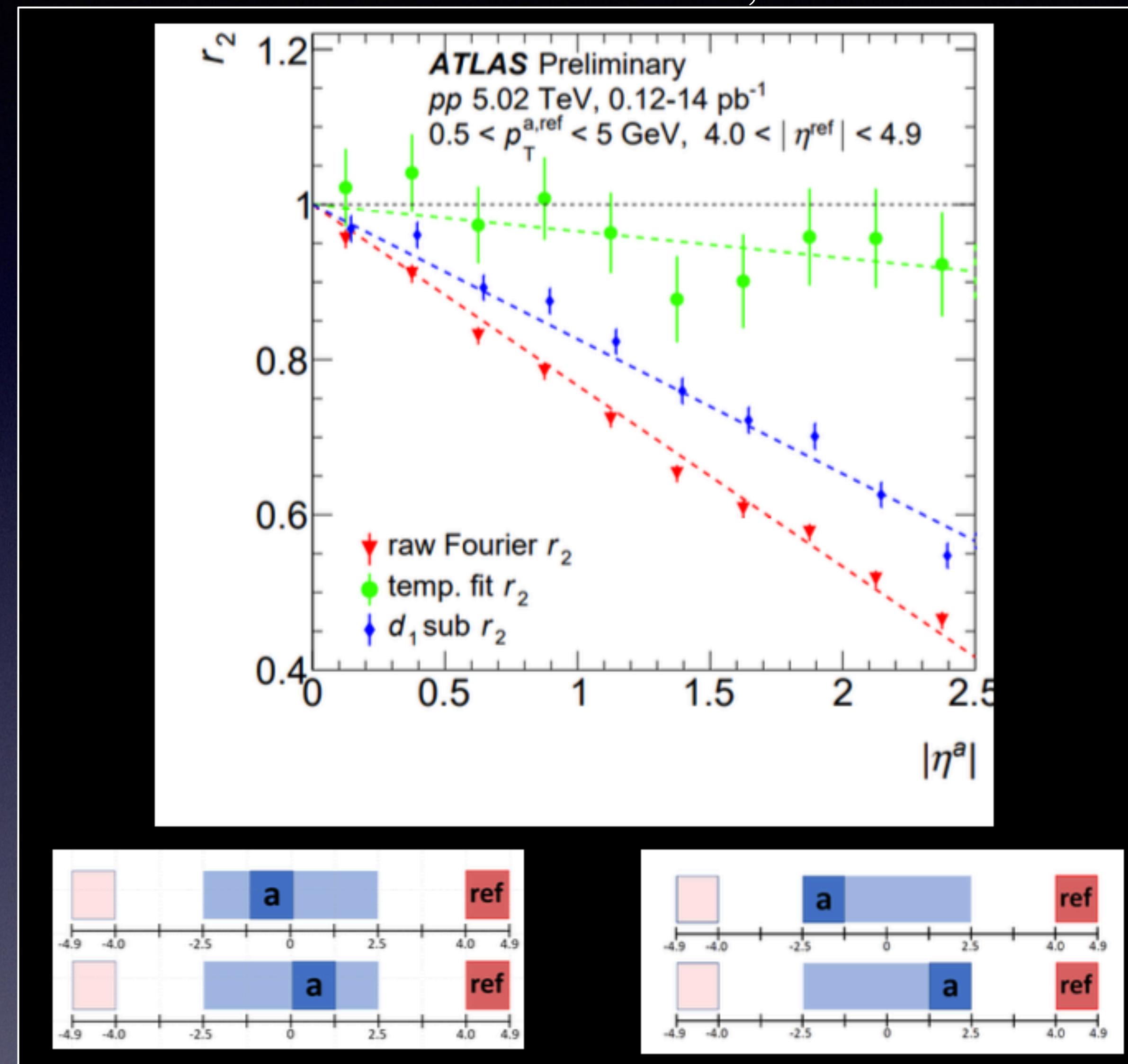
4. Then slope, $\mathrm{F_n}$ measures the strength of longitudinal decorrelation.

$$\mathrm{r_n}(|\eta^{\mathrm{a}}|) = 1 - 2\mathrm{F_n}|\eta^{\mathrm{a}}|$$

Does ATLAS measure decorrelation?



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



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Raw F_2: Combination of decorrelation and η^a-dependent non-flow

Template fit F_2 & d_1 subtraction F_2: Decorrelation after non-flow effects are subtracted.

Does ATLAS measure decorrelation?

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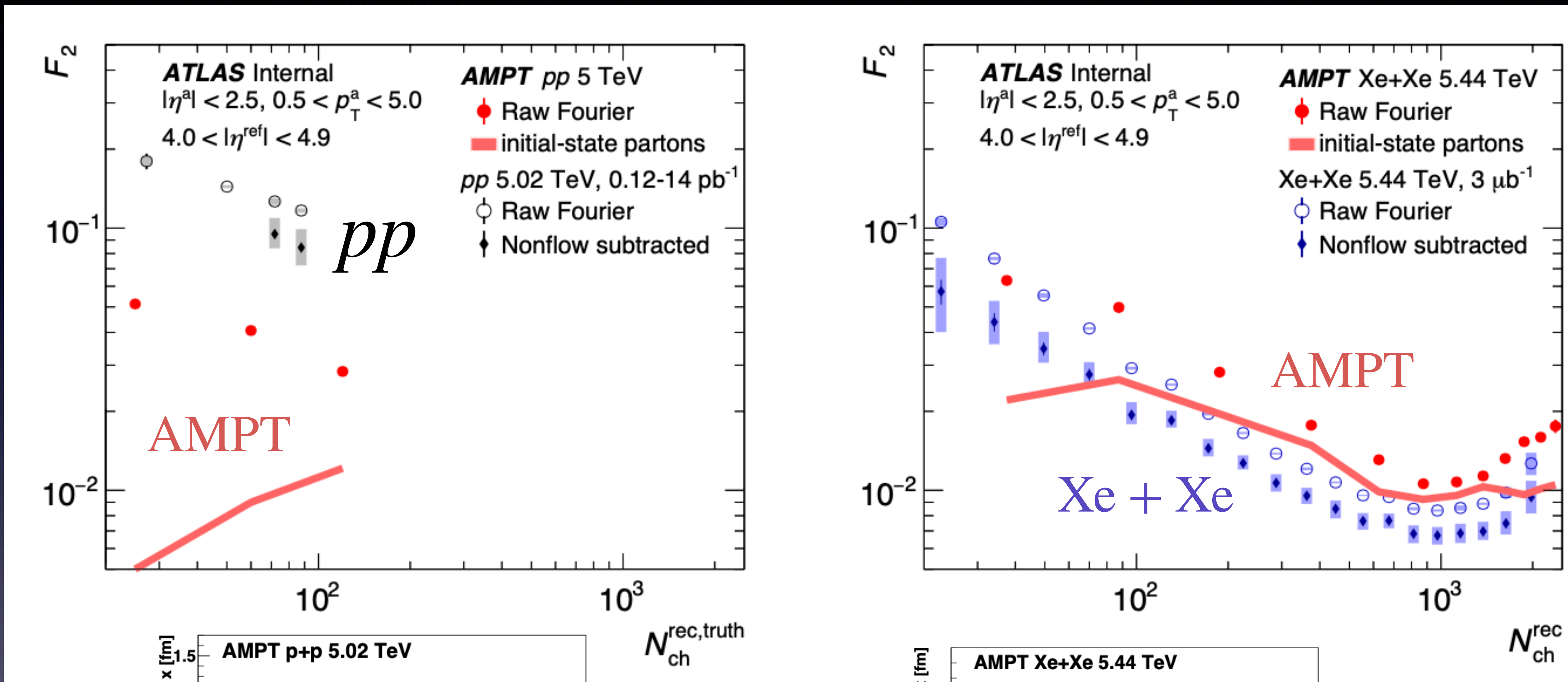
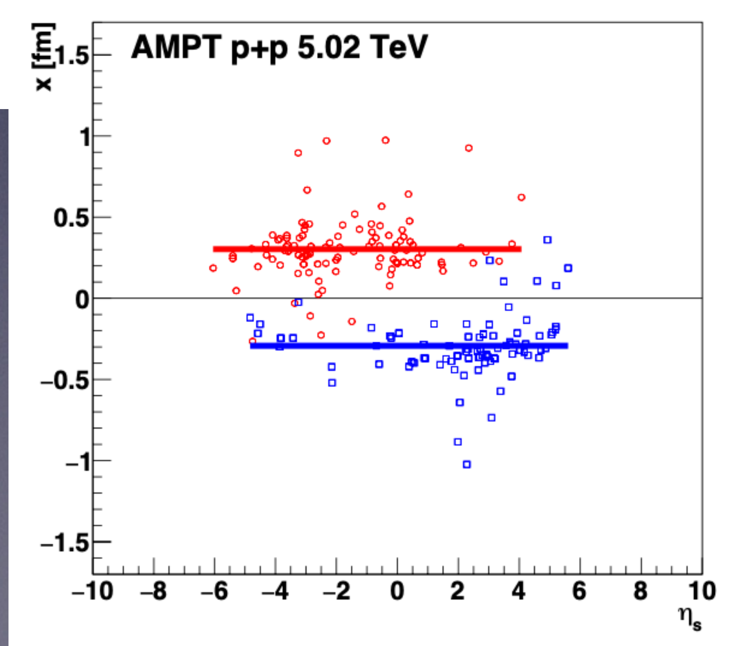
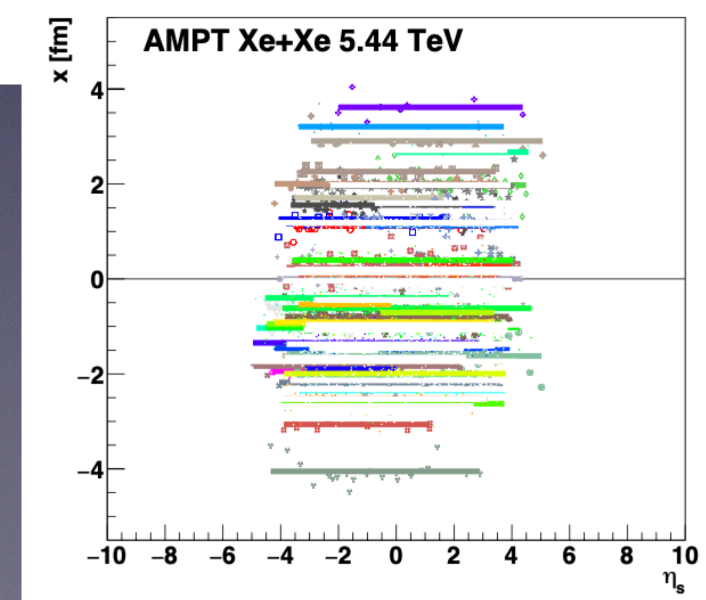
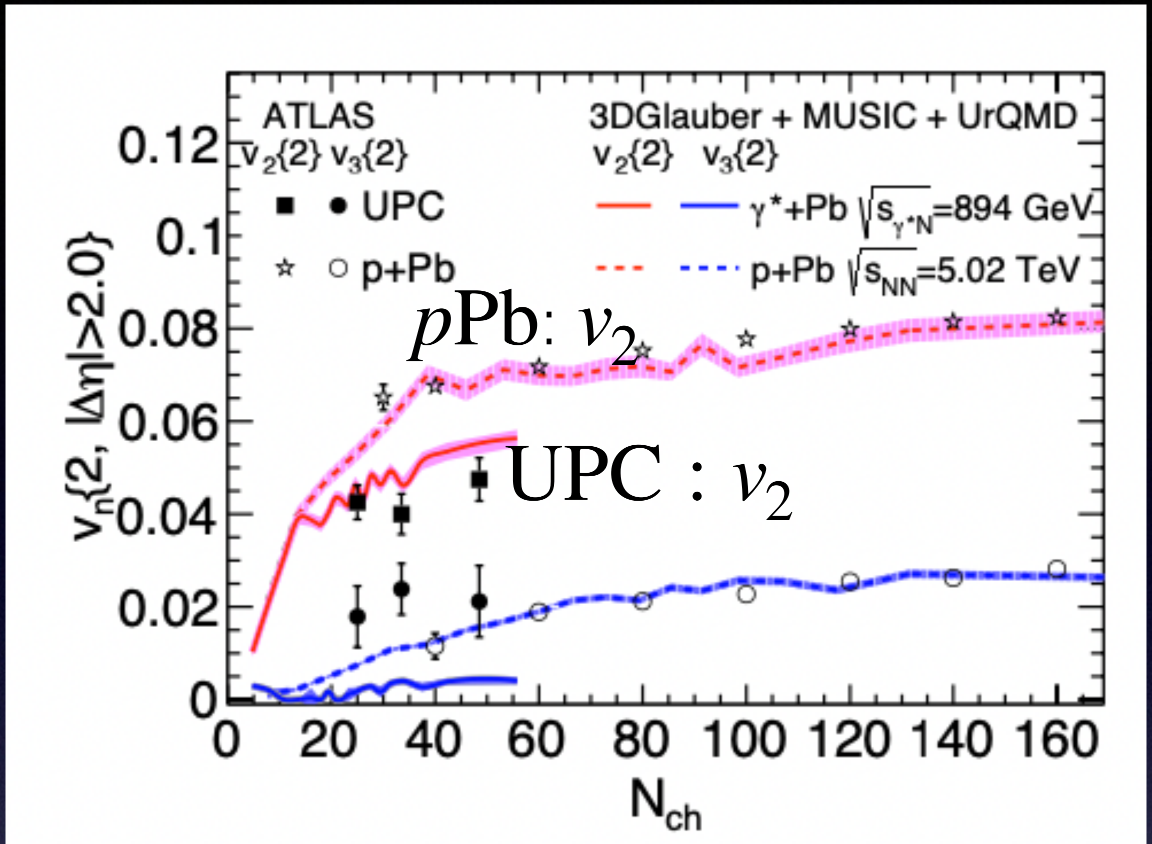
$$r_2(|\eta^a|) = 1 - 2F_2|\eta^a|$$







Flow in Ultraperipheral Collisions

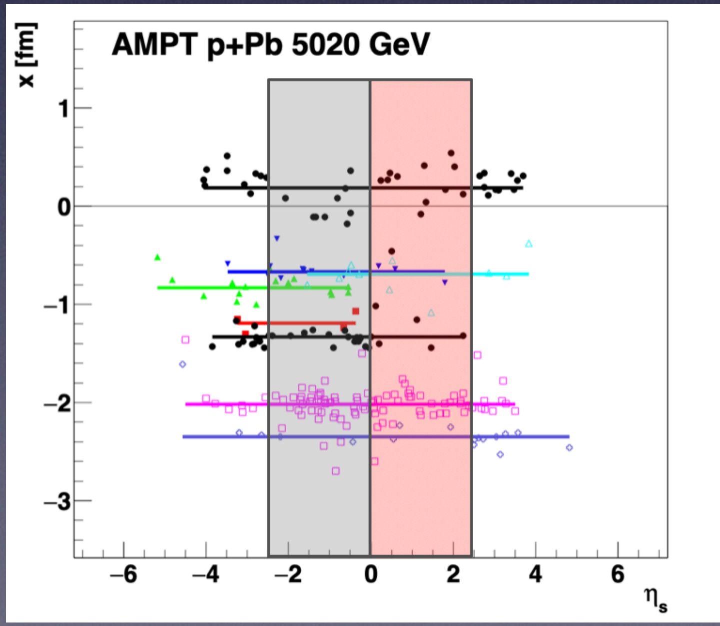


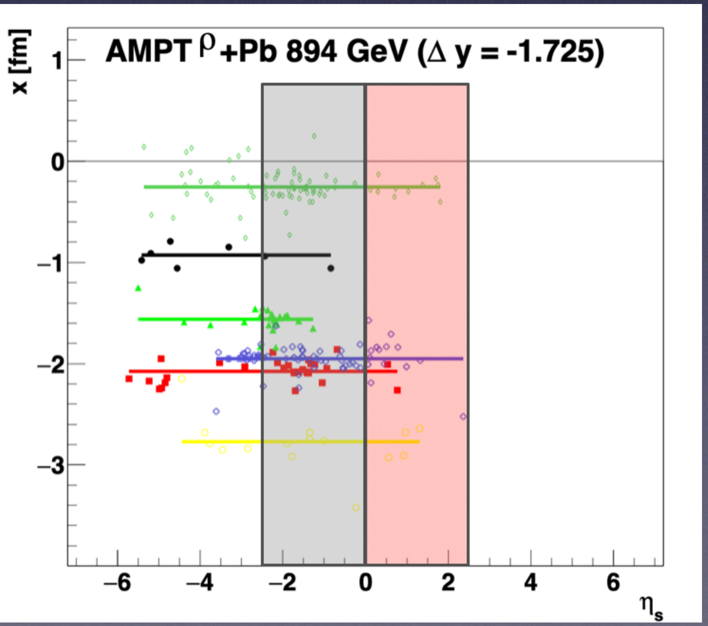
Theory (3+1D framework with hydrodynamics):

arXiv:2203.06094 Wenbin Zhao, Chun Shen, Bjorn Schenke

claims that *elliptic flow hierarchy* between γ^*Pb and pPb is dominated by *longitudinal flow decorrelations.*

AMPT illustrations to show longitudinal decorrelation in γ^*Pb and pPb





ATLAS UPC data:
Physical Review C 104, 014903 (2021)

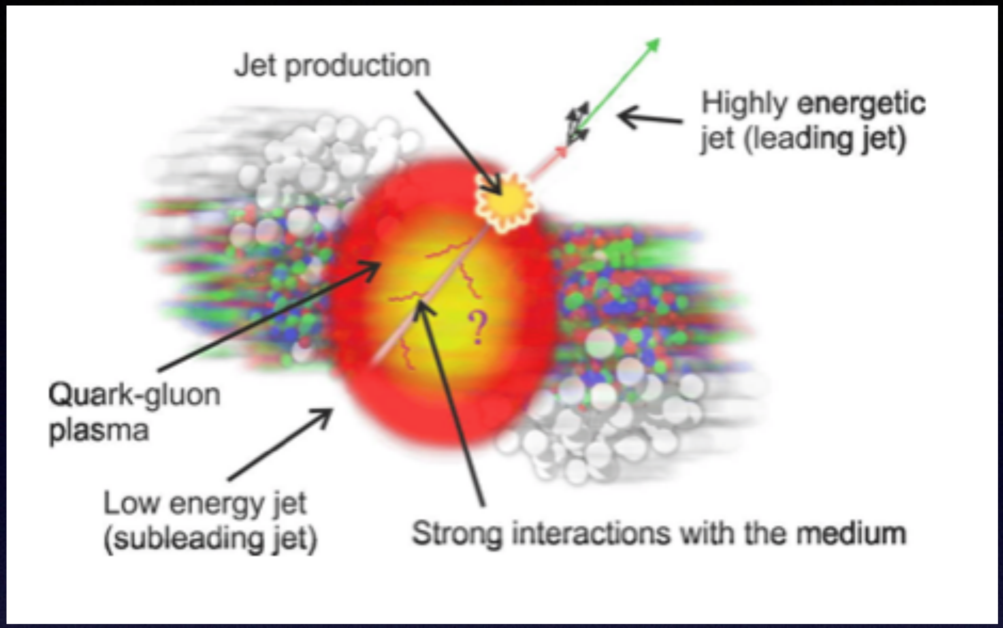
ATLAS pPb data:

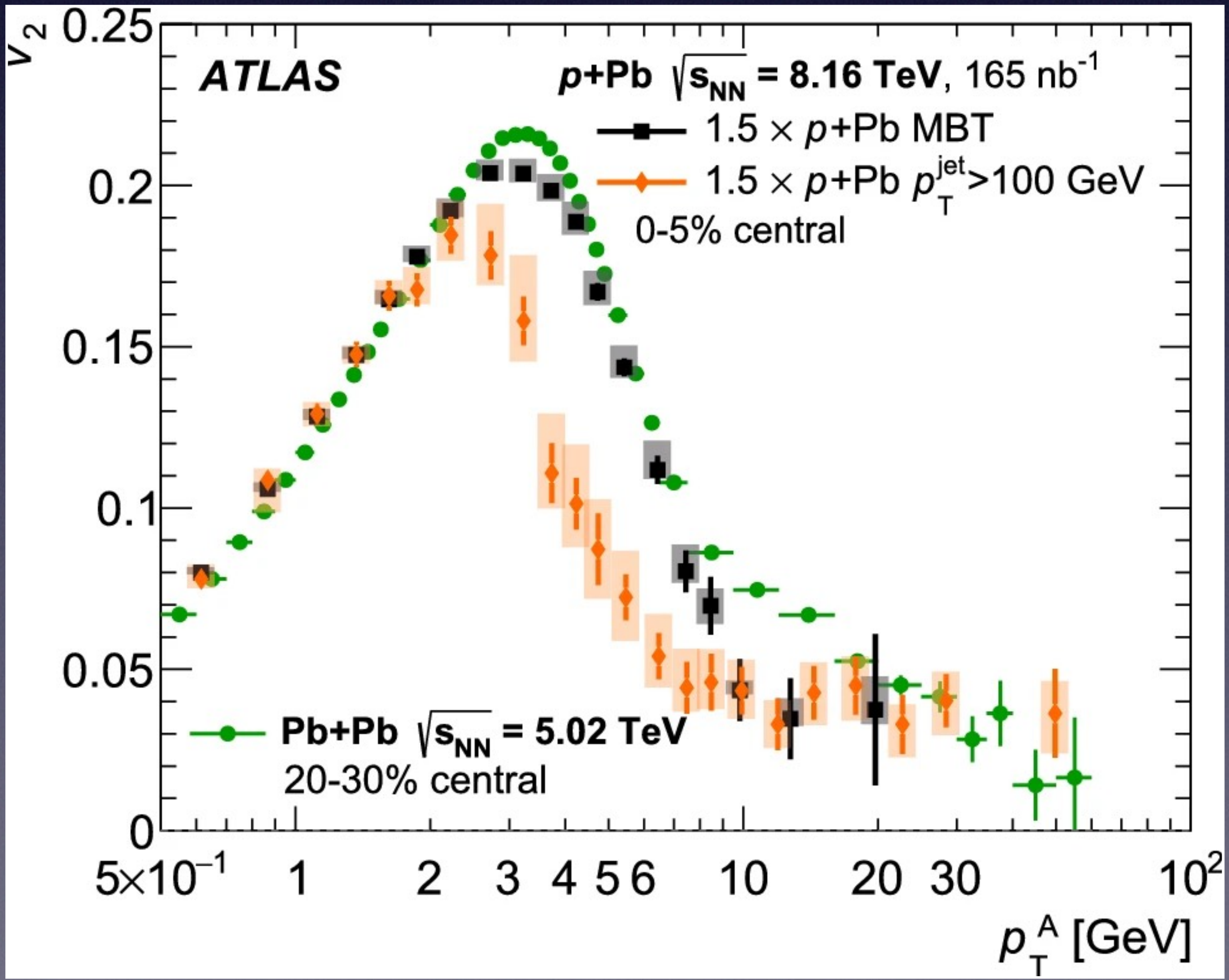
Physical Review C 96, 024908 (2017)

γ*Pb is like ρPb at 894 GeV, but shifted in rapidity
Much larger longitudinal decorrelation!

Why are jet quenching signatures in small system interesting?

Jet quenching = energy loss of high energy partons when traversing the Quark-Gluon Plasma





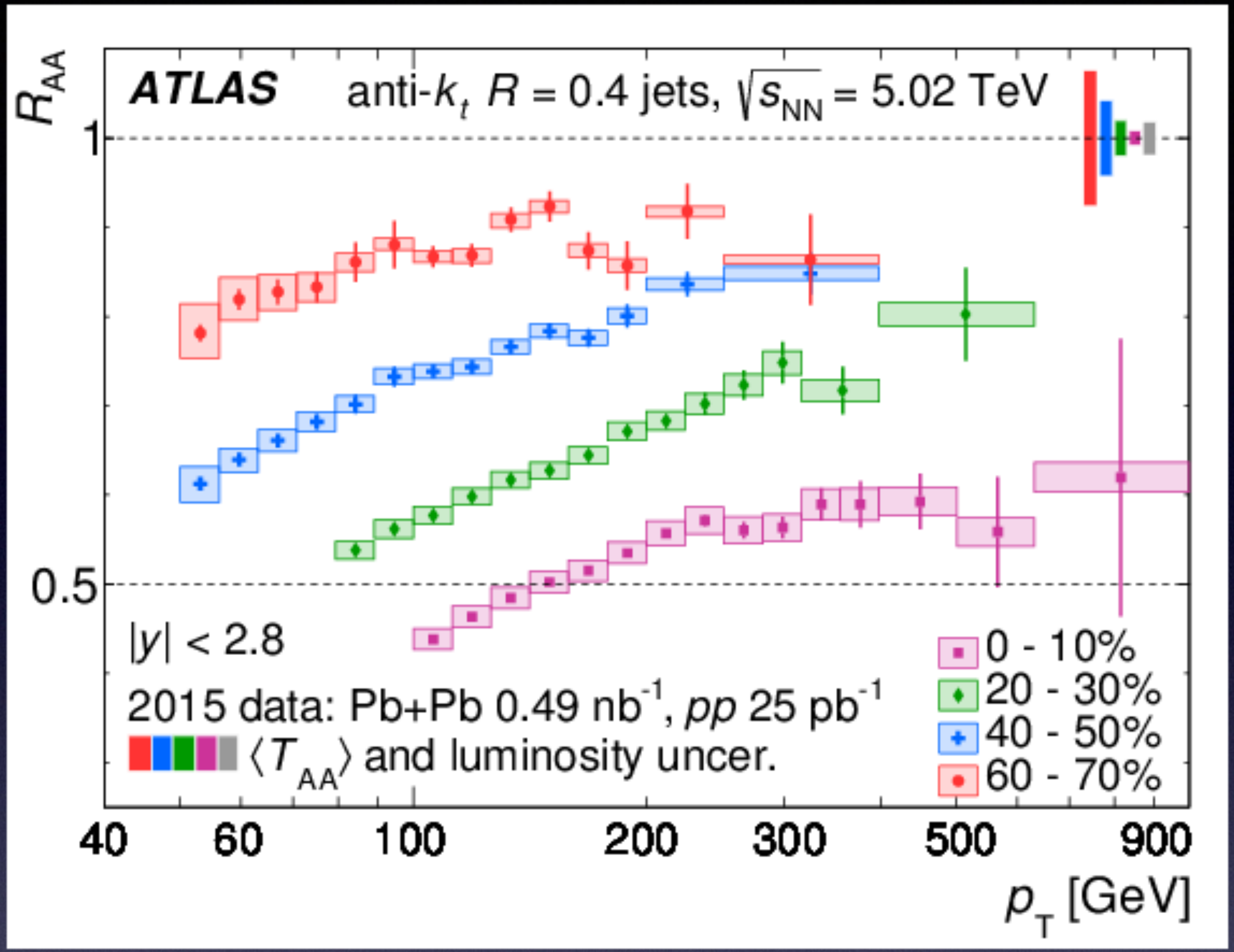
At low p_T, v_2 is interpreted as flow. At high p_T, v_2 in pPb could result from jet-quenching.

Could we look for small quenching effects in pPb?

PHYSICAL REVIEW C 90, 044906 (2014)

Jet quenching in the QGP

Jet quenching observable: $R_{AA} = \frac{Y_{AA}}{Y_{pp}\langle N_{coll}\rangle}$

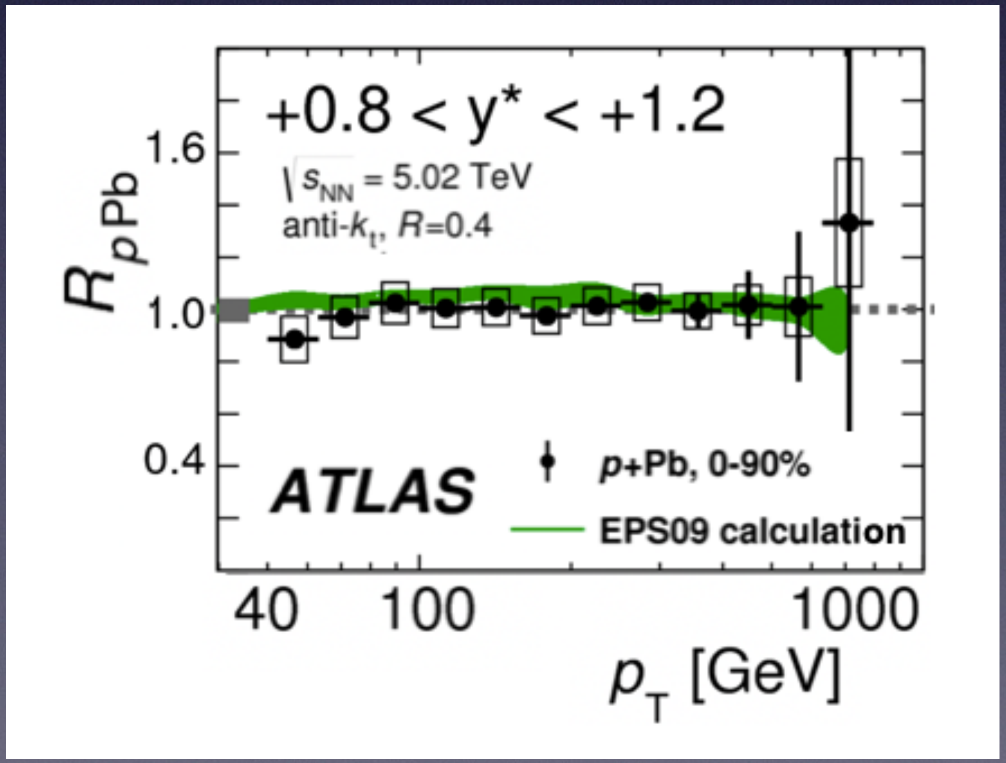


arXiv:1805.05635

Jet quenching confirmed in large system Pb+Pb!

What about small systems like pPb?

Previous ATLAS measurements shows that jet quenching is not observed in pPb.



Phys. Lett. B 748 (2015) 392-413

Can we set precision limits on jet quenching in small collision system?

Constraining jet quenching in small system

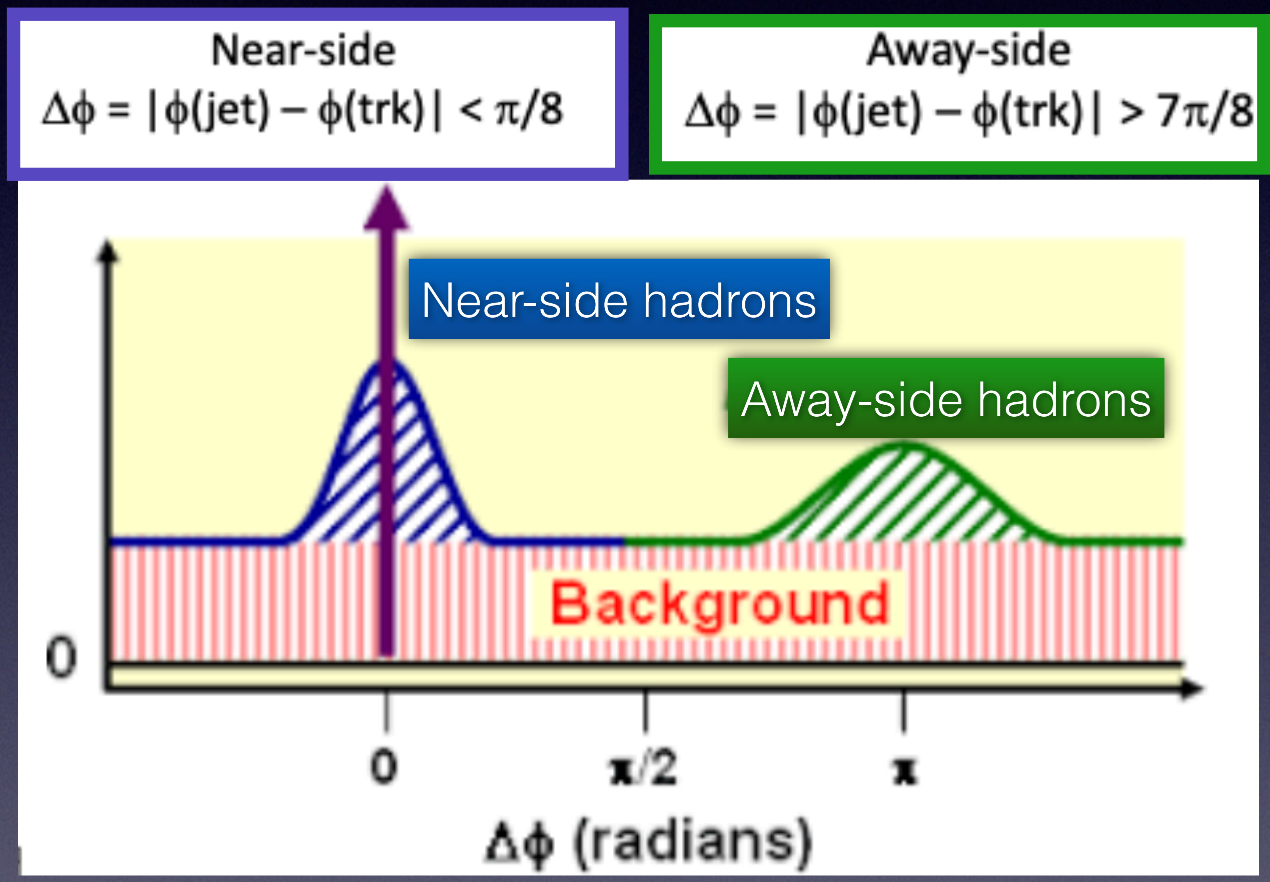
HION-2021-17

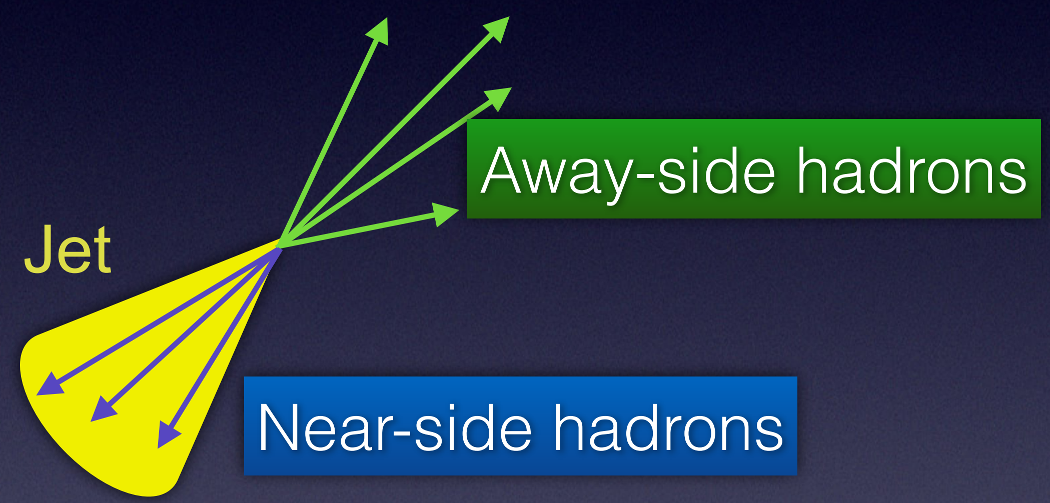
Observable

- Yields of charged hadrons with $p_T > 0.5$ GeV *near and opposite* to jets with $p_T^{jet} > 30$ or 60 GeV.

Systems analyzed

pp 5.02 TeV pPb 5.02 TeV

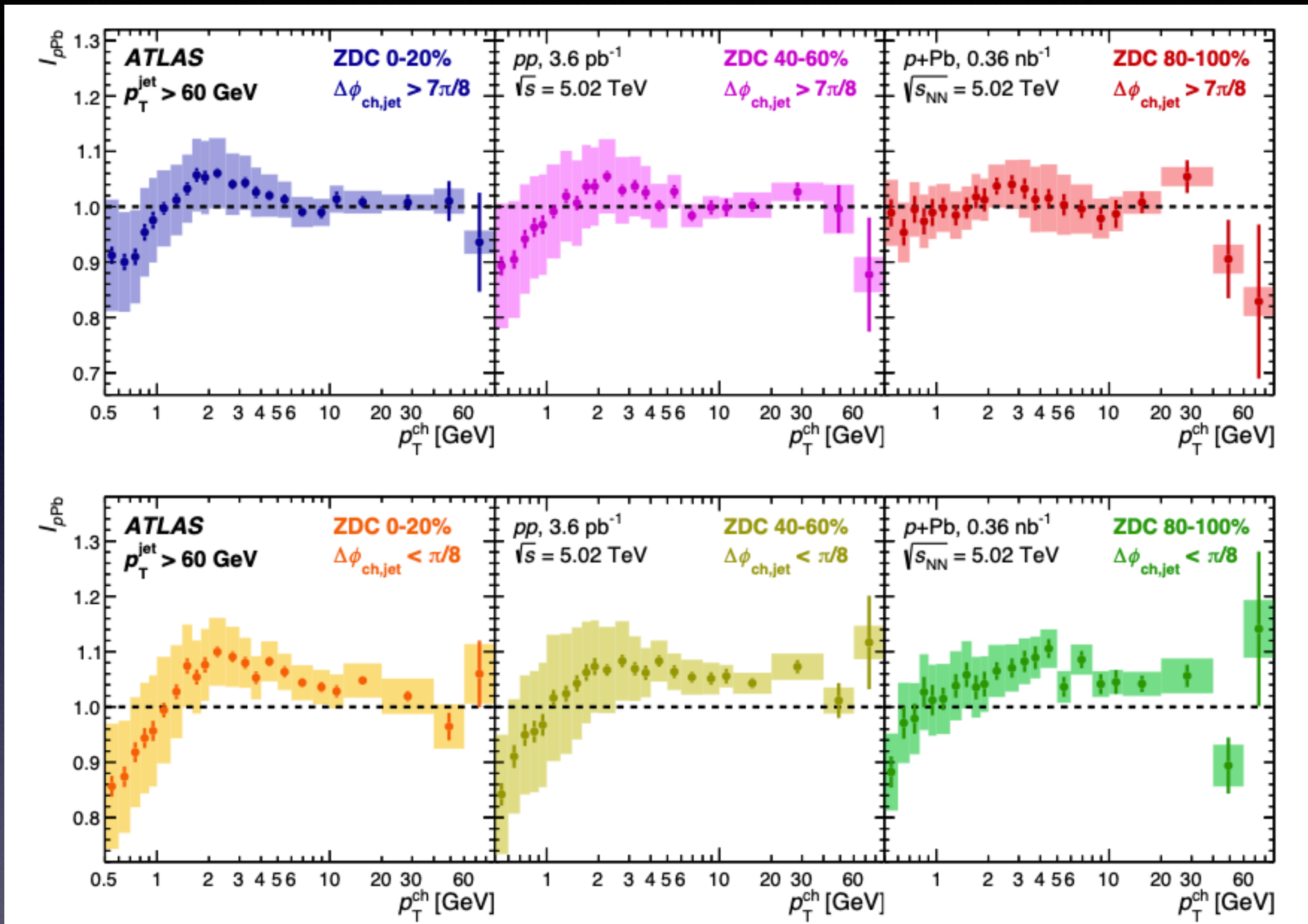


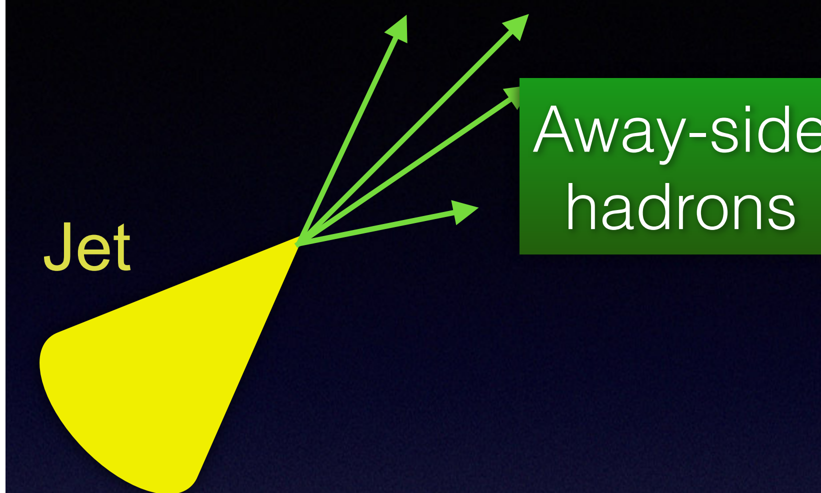


- Ratios of these yields between pPb and pp collisions, $\mathrm{I}_{p\mathrm{Pb}}$.

$$\mathrm{I}_{p\mathrm{Pb}} = \frac{Y_{p\mathrm{Pb}}(\text{per jet})}{Y_{pp}(\text{per jet})}$$

$\mathrm{I}_{p\mathrm{Pb}}$ results



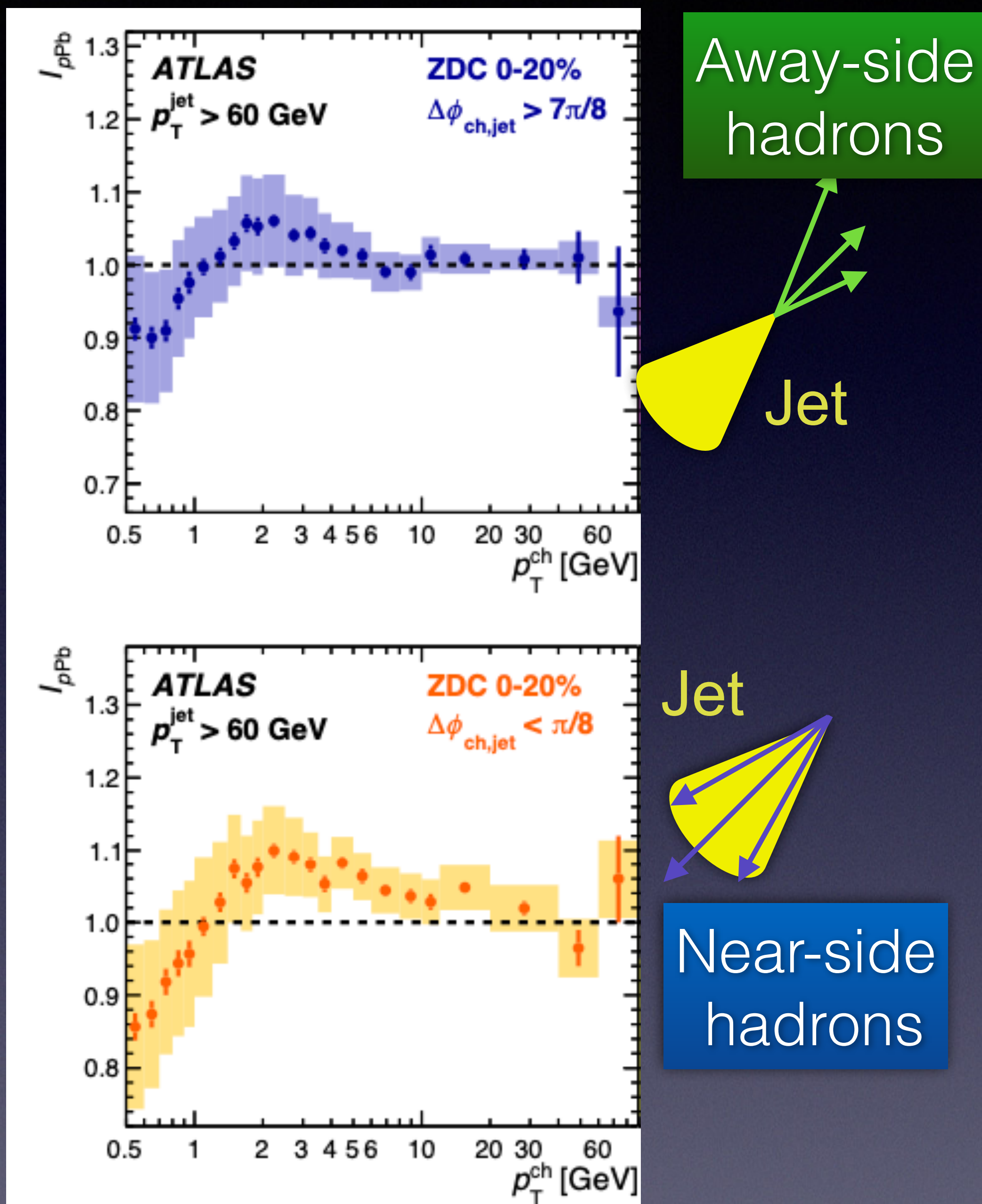


arXiv:2206.01138

Top row: $\mathrm{I}_{p\mathrm{Pb}}$ of charged particles on the away-side of jets with p_T^{jet} > 60 GeV

Bottom row: $\mathrm{I}_{p\mathrm{Pb}}$ of charged particles on the near-side of jets with p_T^{jet} > 60 GeV

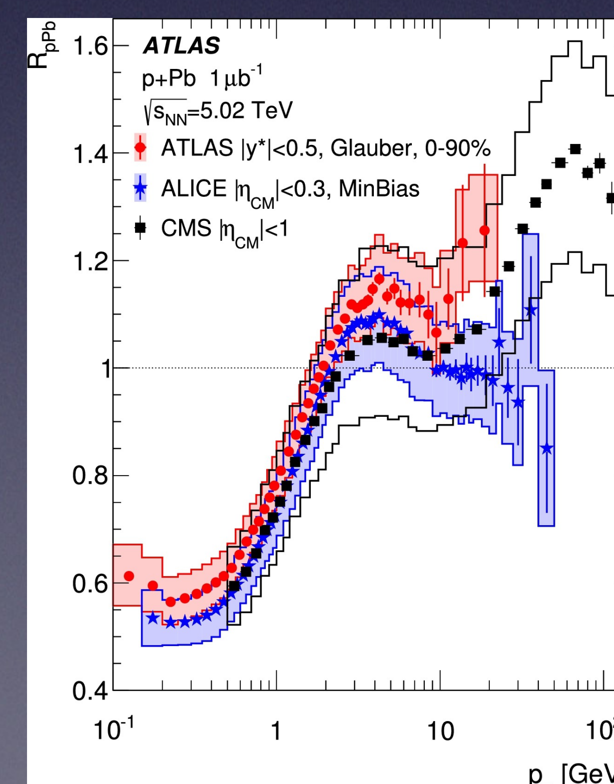
Low p_T: 0.5 - 4 GeV observations



Pattern from 0.5 GeV to 4 GeV is *qualitatively similar between the away- and near-side*.

Enhancement at modest p_T → *"Cronin effect"*

R_{pPb} shows similar pattern, this could be referred to as Cronin effect.

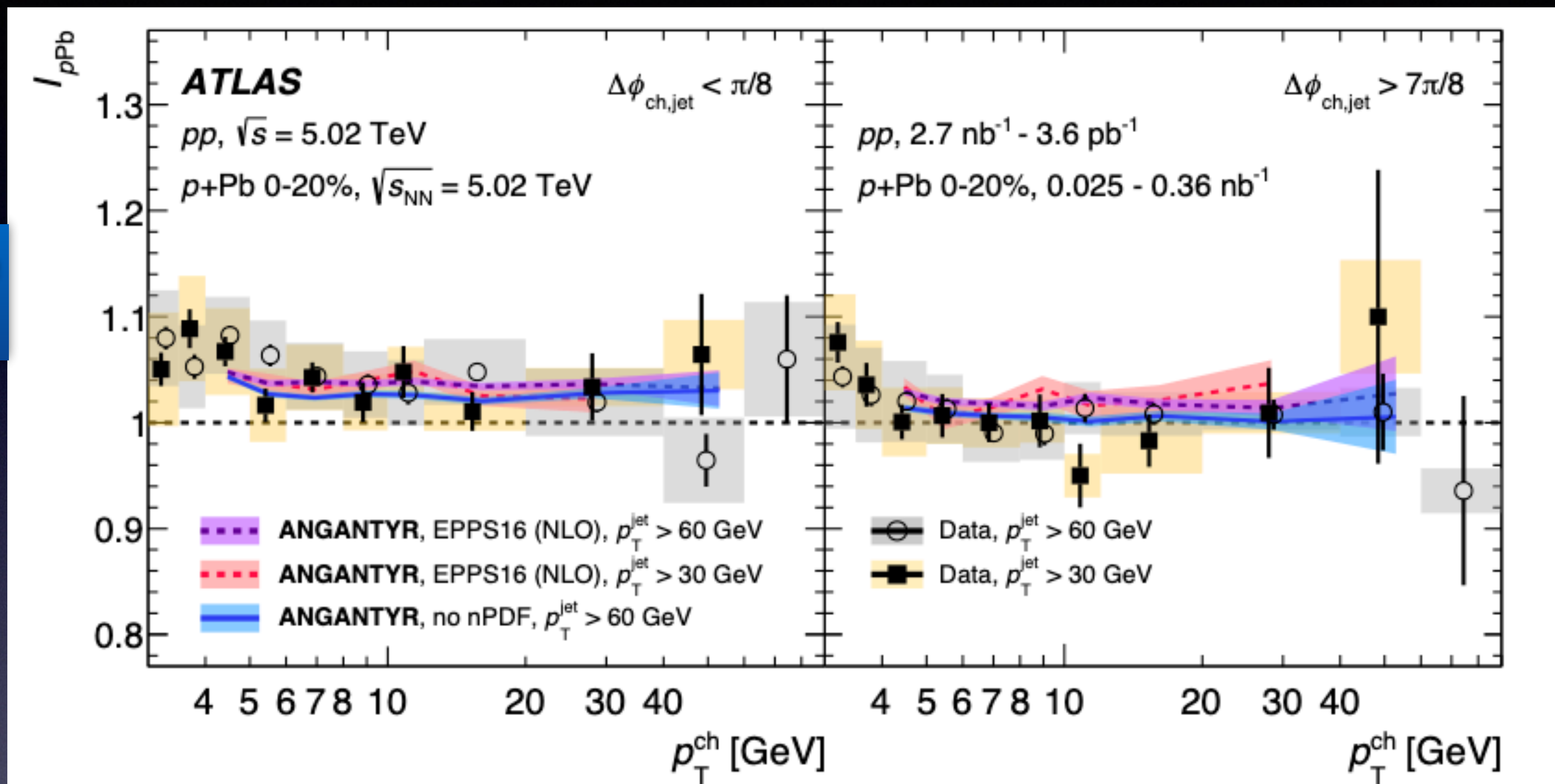


Physics Letters B 763 (2016) 313-336

High p_{T} > 4 GeV observations

Jet

Near-side hadrons



Away-side hadrons

Jet

Theory: JHEP 10 (2018) 134

Angantyr is a Monte Carlo that extends Pythia from pp to $p\mathrm{A}$ and AA.
Angantyr has no jet quenching modeling and is compatible with the data within uncertainties.

Results provide quantitative constraints on the model.

Summary

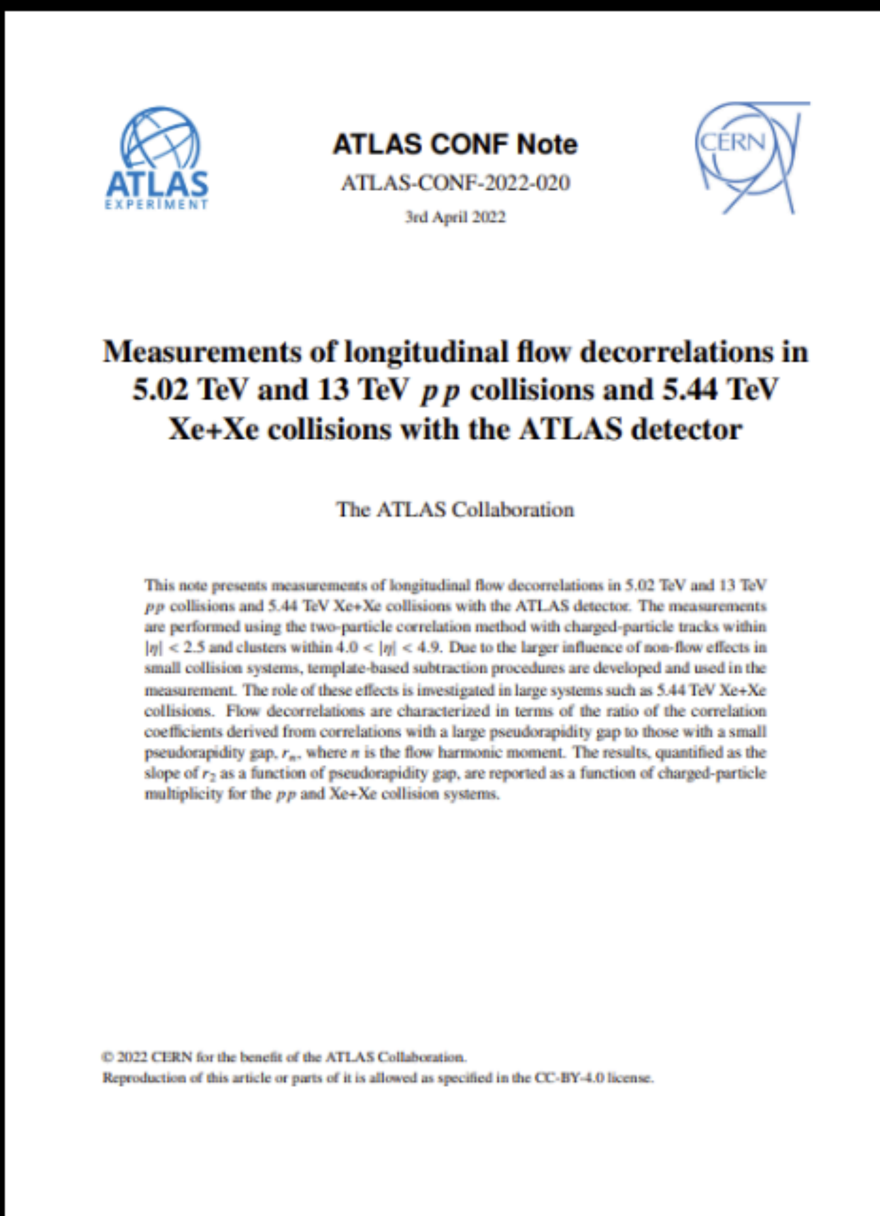
Interesting results published by ATLAS on small systems in heavy-ion collisions.

- Small systems test the limit of Quark-Gluon Plasma formation.
- Longitudinal decorrelation in collision systems is key to learn 3D energy depositions along with understanding of non-flow contributions.
- Effects of jet quenching in $p\mathrm{Pb}$ collisions constrained to be very small.

Thank you!

BACK UP

Longitudinal flow decorrelation in *pp*



ATLAS CONF Note

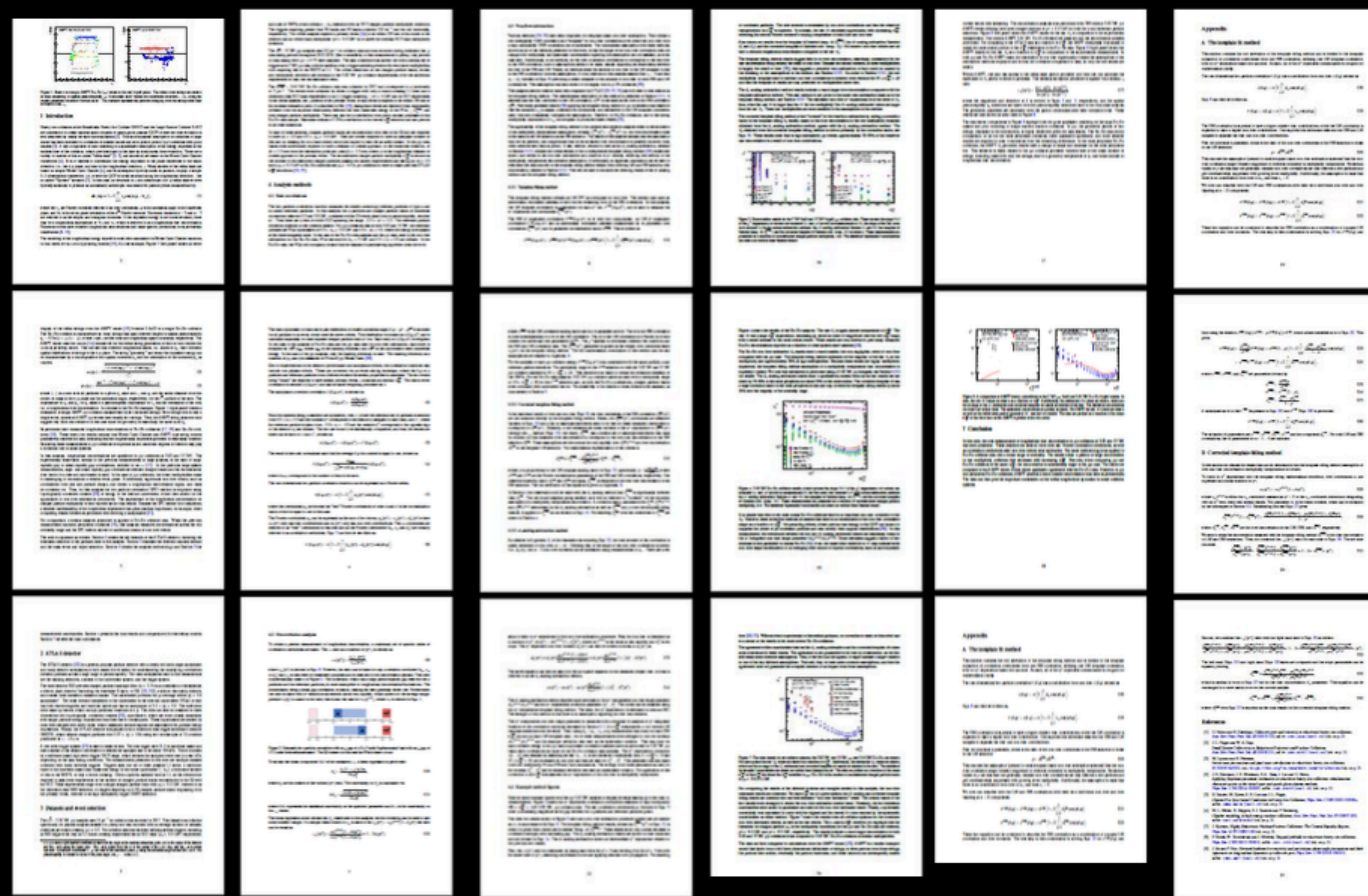
ATLAS-CONF-2022-020

3rd April 2022

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

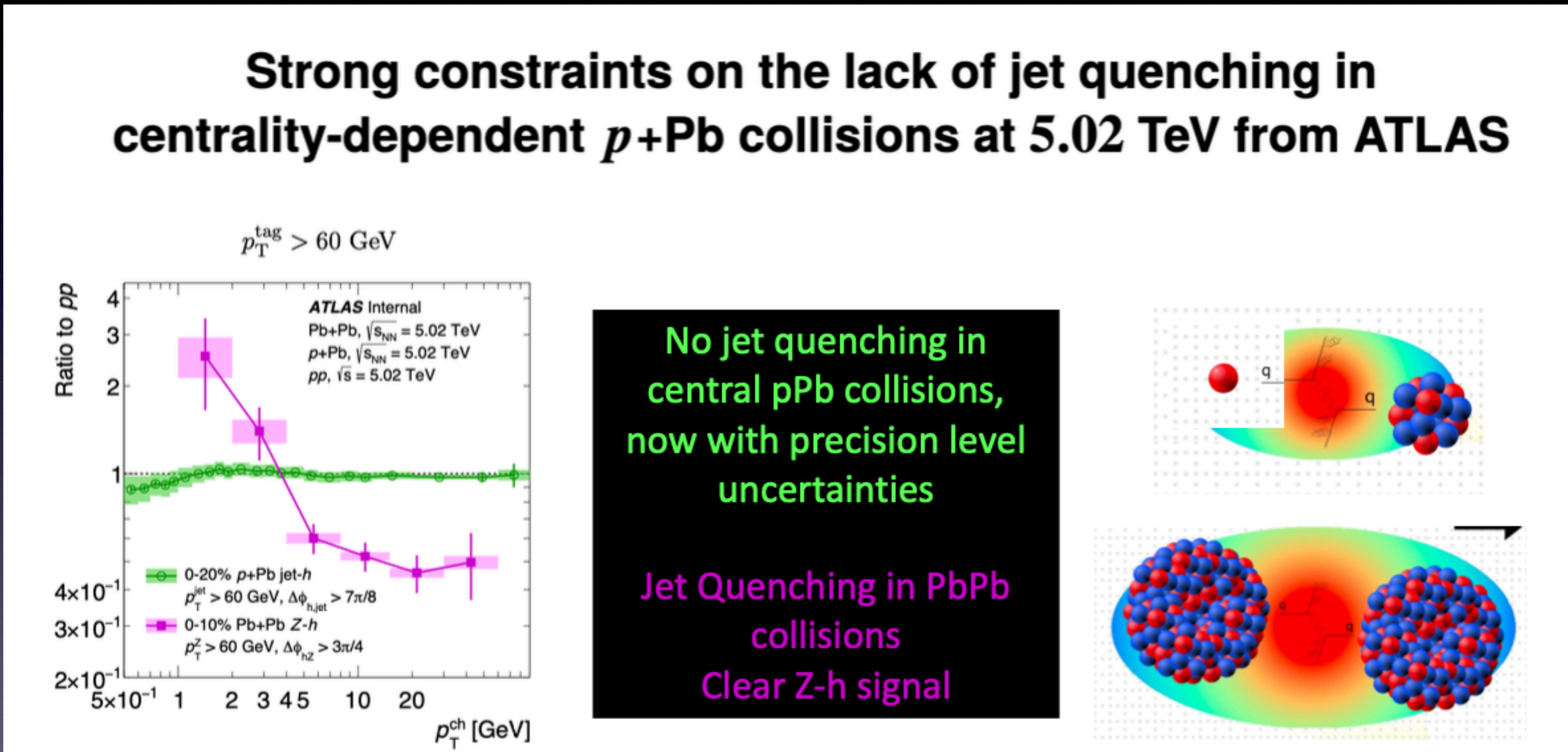
The ATLAS Collaboration

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.



CONF-HION-2020-04

Constraints on jet quenching in pPb



arXiv:2206.01138 HION-2021-17