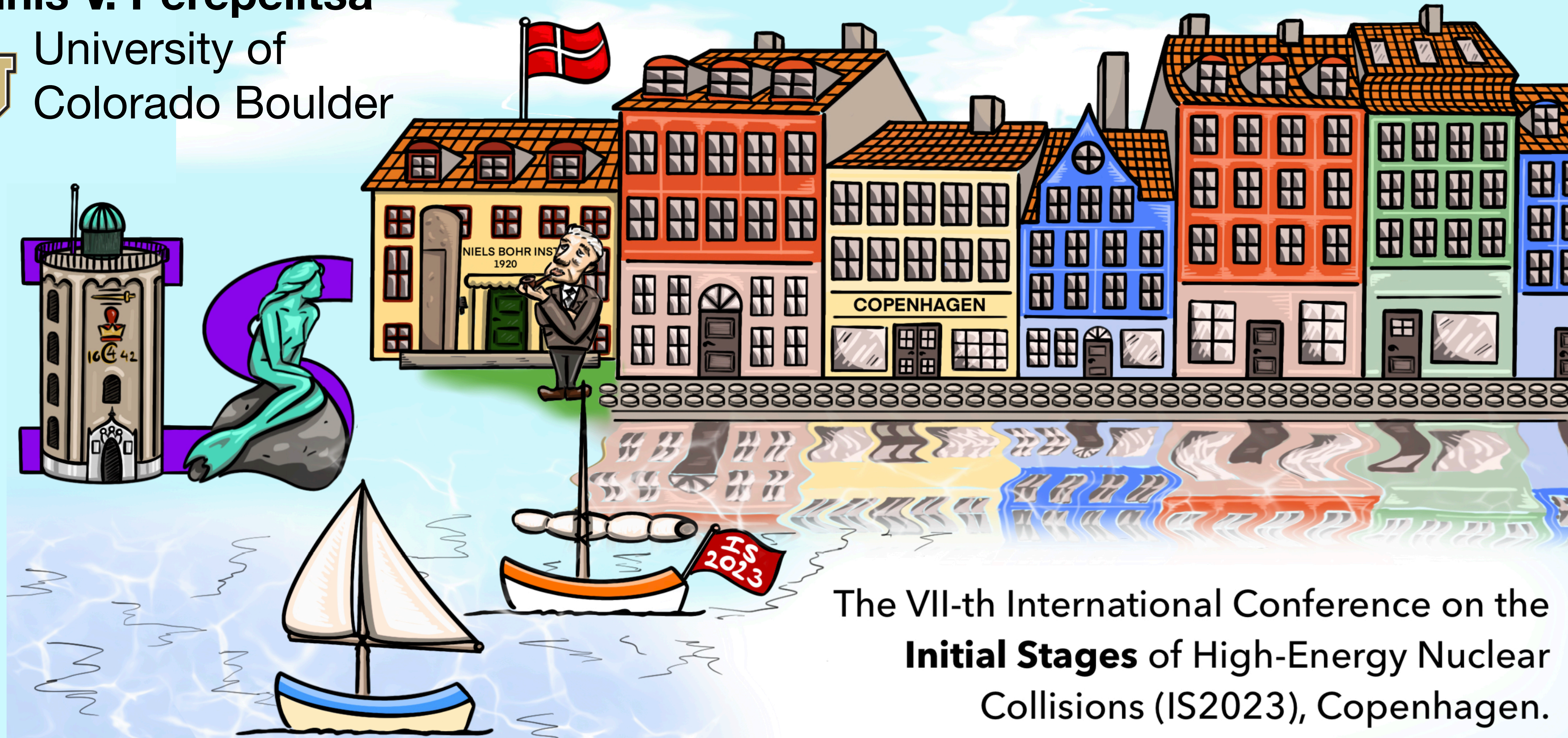


# Overview of ATLAS Results

Dennis V. Perepelitsa



University of  
Colorado Boulder



The VII-th International Conference on the  
**Initial Stages** of High-Energy Nuclear  
Collisions (IS2023), Copenhagen.



# Results at Initial Stages '23

## Initial state of the nucleus:

- $v_n - [p_T]$  correlations in Pb+Pb and Xe+Xe
- $\gamma\gamma \rightarrow \mu^+\mu^-$  in hadronic Pb+Pb collisions
- dijet production in  $\gamma + A$

## Initial state of the proton:

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## Final state effects in small systems:

- Jet-hadron correlations in  $p+Pb$
- Collective behavior in  $pp$  with jets
- Correlation between  $\Upsilon(1,2,3S)$  & UE in  $pp$

## Other highlights:

- Systematic studies of parton energy loss
- $\gamma\gamma \rightarrow \tau\bar{\tau}$  to constrain  $g_\tau - 2$
- ... many more in [ATLAS HI Public Results](#)



Parallel talks by

**Riccardo Longo** (Tue 4:10pm)  
**Peter Steinberg** (Wed 2:20pm)  
**Pengqi (Bill) Yin** (Wed 4:50pm)

Posters by

**Melike Akbiyik**  
**Alexander Milov**

**Somadutta Bhatta**  
**Blair Seidlitz**



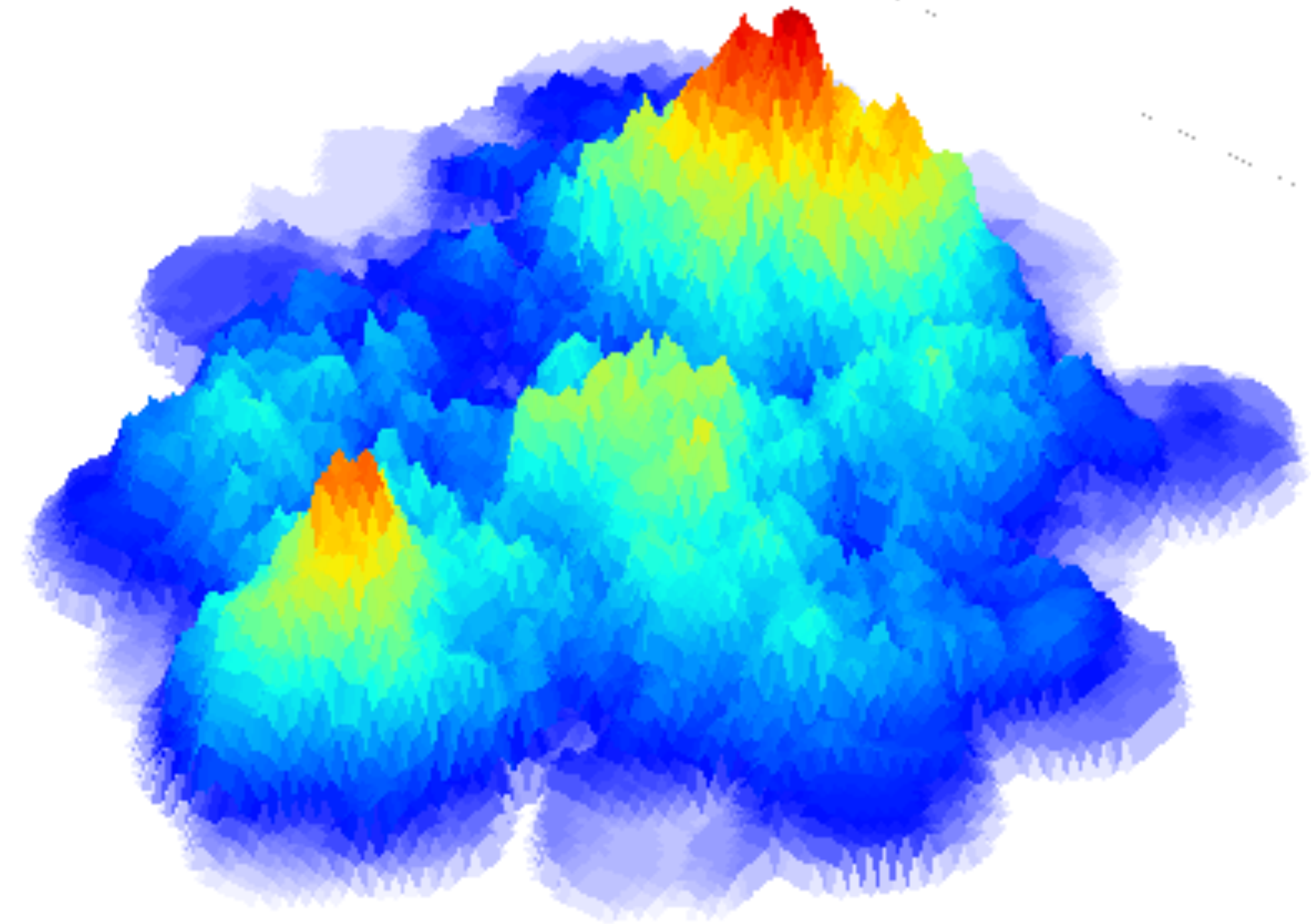


**ATLAS**  
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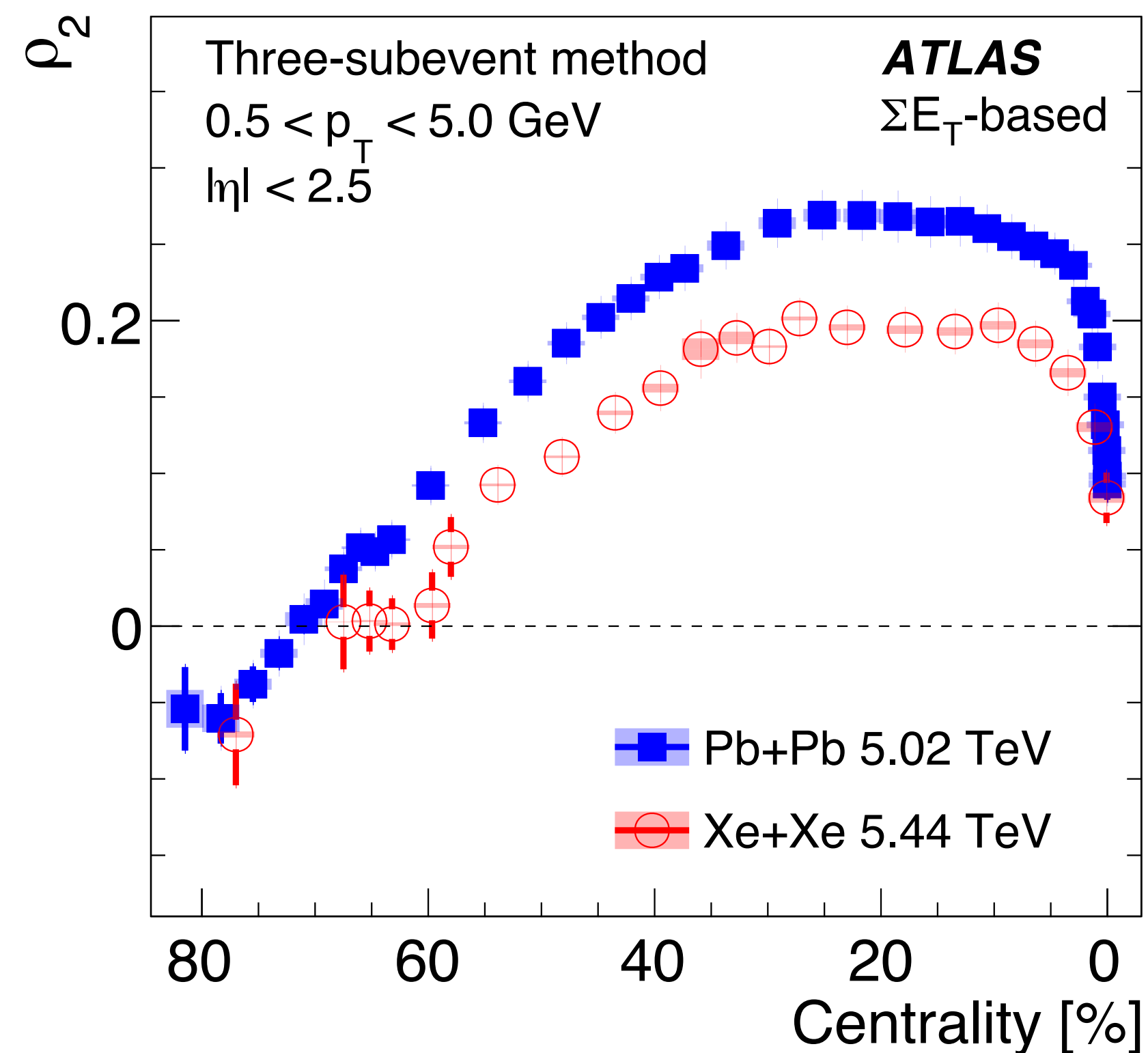
Posters by

**Somadutta Bhatta**

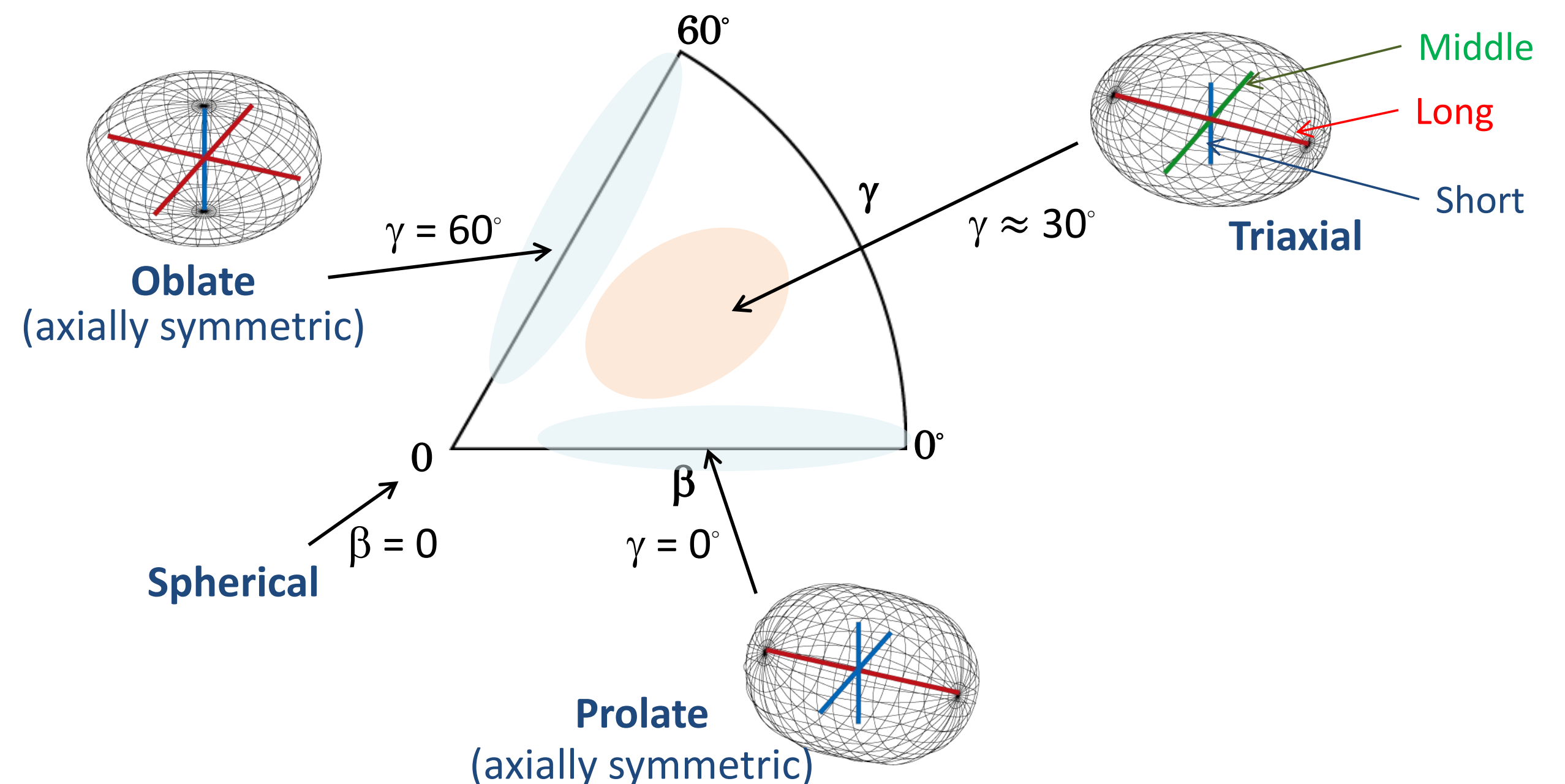


# $v_n - [p_T]$ correlations in Pb+Pb and Xe+Xe

Measure correlation between  $v_{2,3,4}$  magnitude and average  $p_T$  in  
**Xe+Xe** and **Pb+Pb**



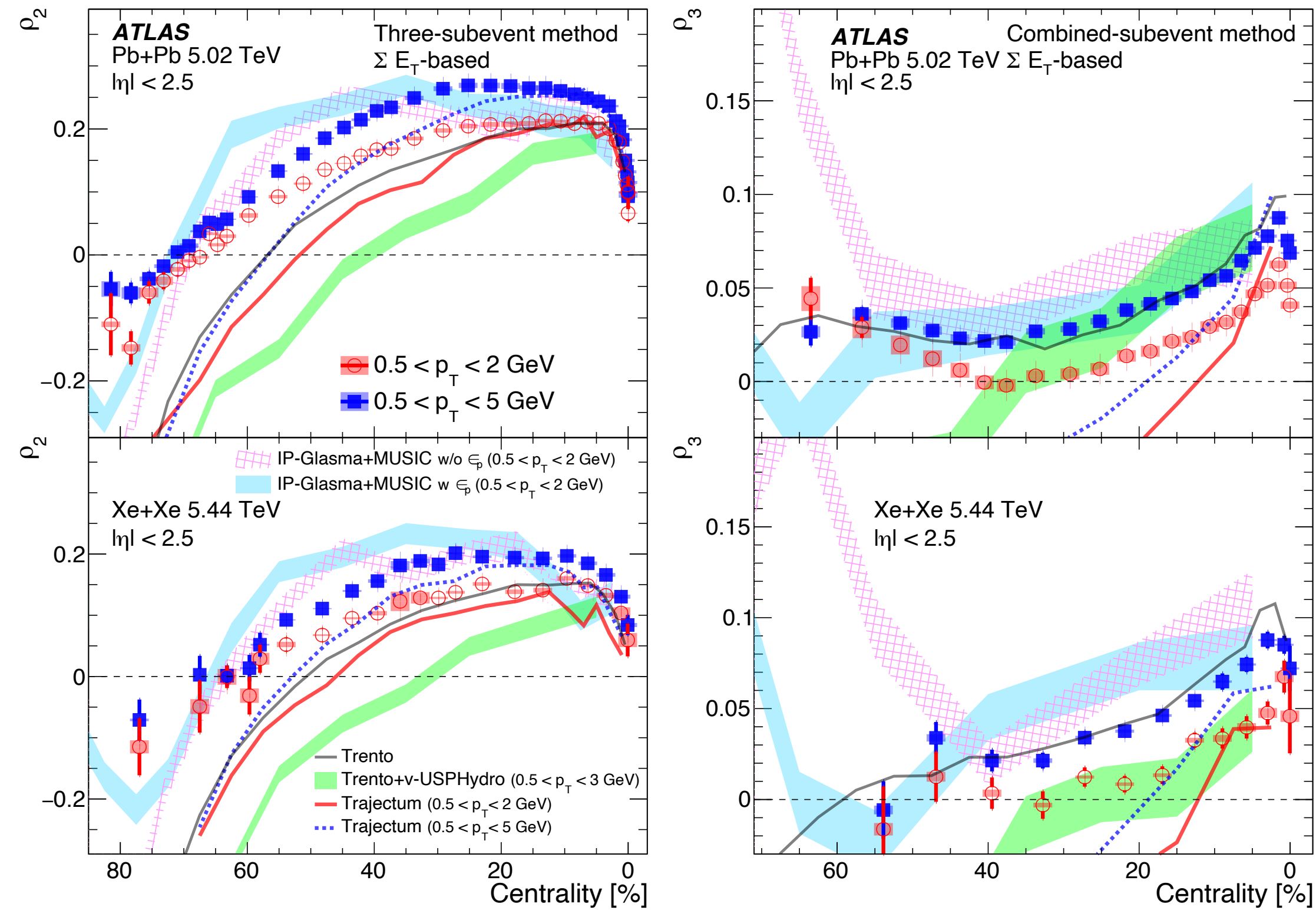
Sensitive to fluctuations in the initial state geometry and thus a good test of IS models



As a bonus, sensitivity to the deformed shape of the colliding nuclei!



# $v_n - [p_T]$ correlations in Pb+Pb and Xe+Xe



Multi-differential comparison to models:

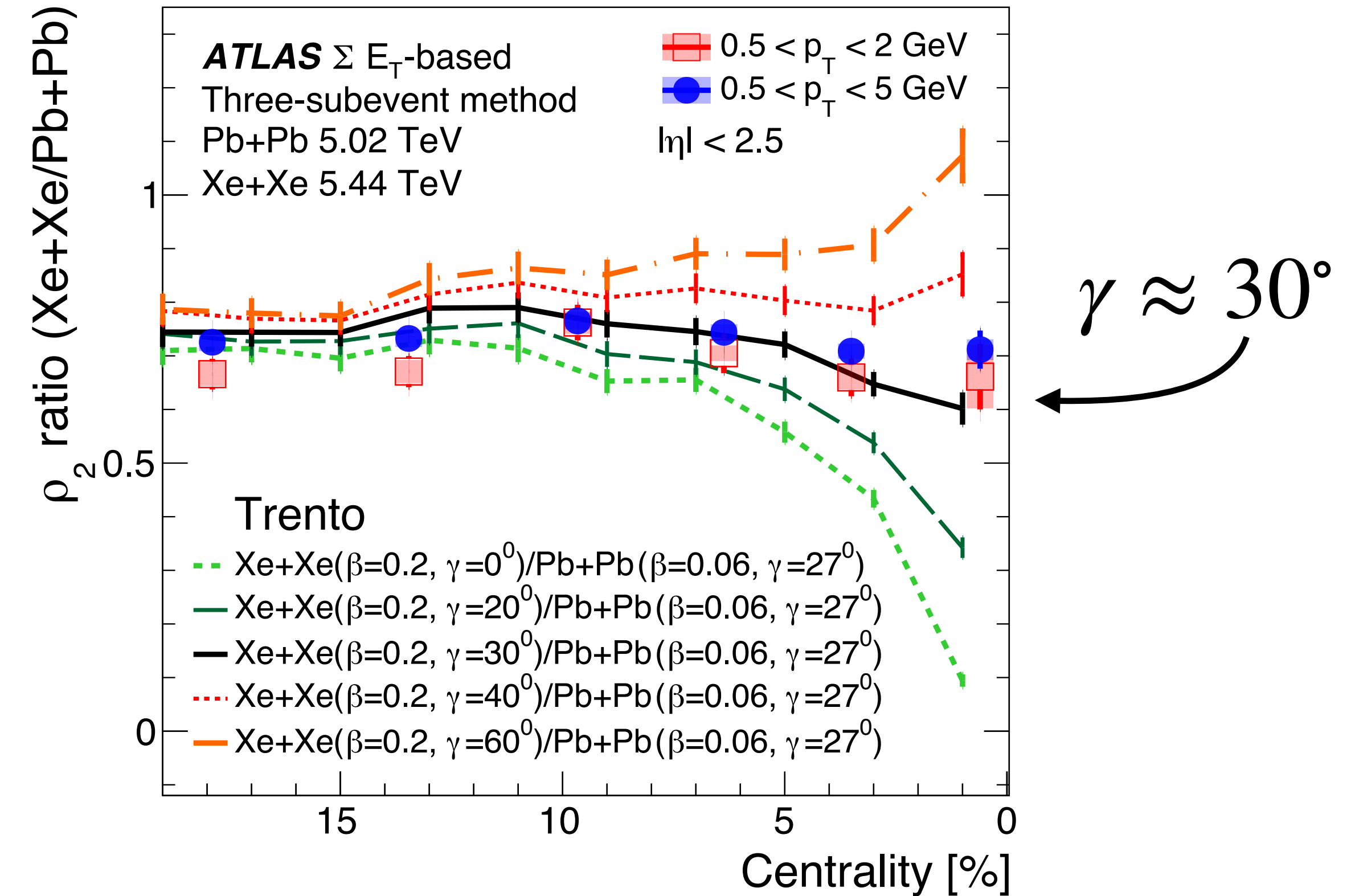
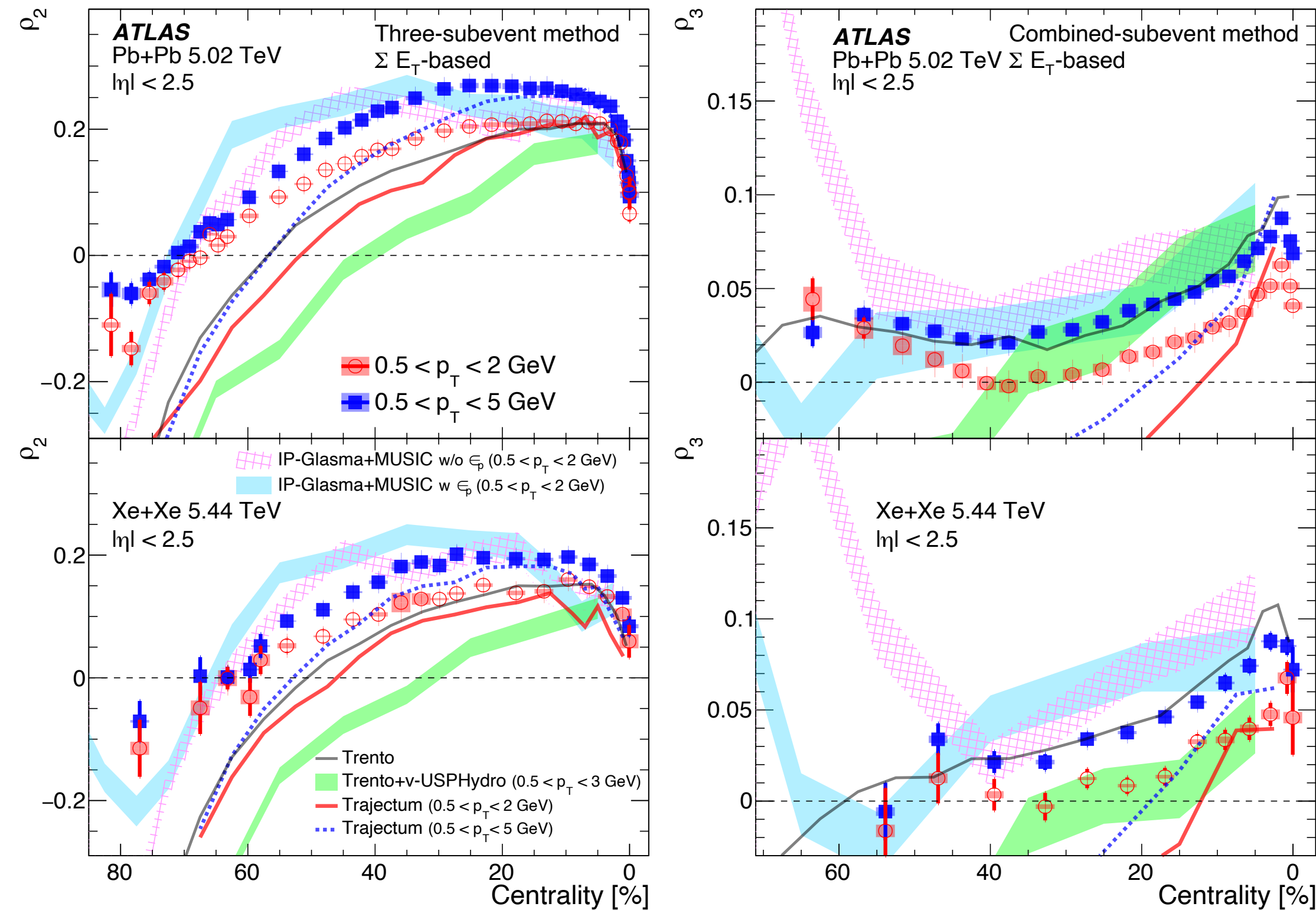
Trajectum/v-USPHydro: Trento IC + 2-D hydro

IP-Glasma+MUSIC: saturation + 3-D hydro



# $v_n - [p_T]$ correlations in Pb+Pb and Xe+Xe

ATLAS, PRC 107 (2023) 054910



Multi-differential comparison to models:

Trajectum/v-USPHydro: Trento IC + 2-D hydro

IP-Glasma+MUSIC: saturation + 3-D hydro

Ratio of  $\rho_2$  in Xe+Xe/Pb+Pb picks out the triaxiality of Xe<sup>129</sup> quadrupole deformation

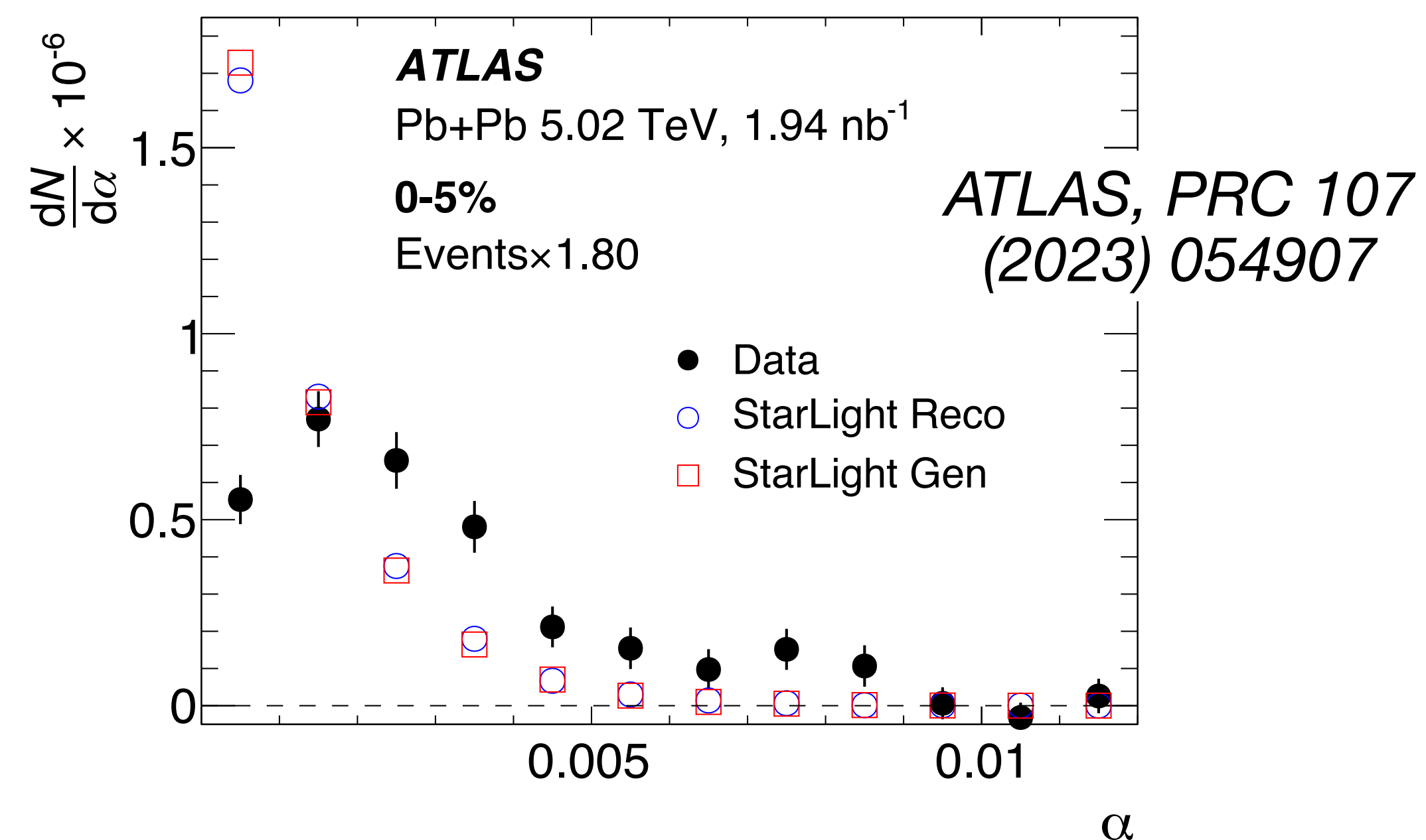
⇒ nuclear structure with heavy ions!



# Initial state of the EM fields around nuclei



$\gamma\gamma \rightarrow \mu^+\mu^-$  processes occurring during a “normal” Pb+Pb collision



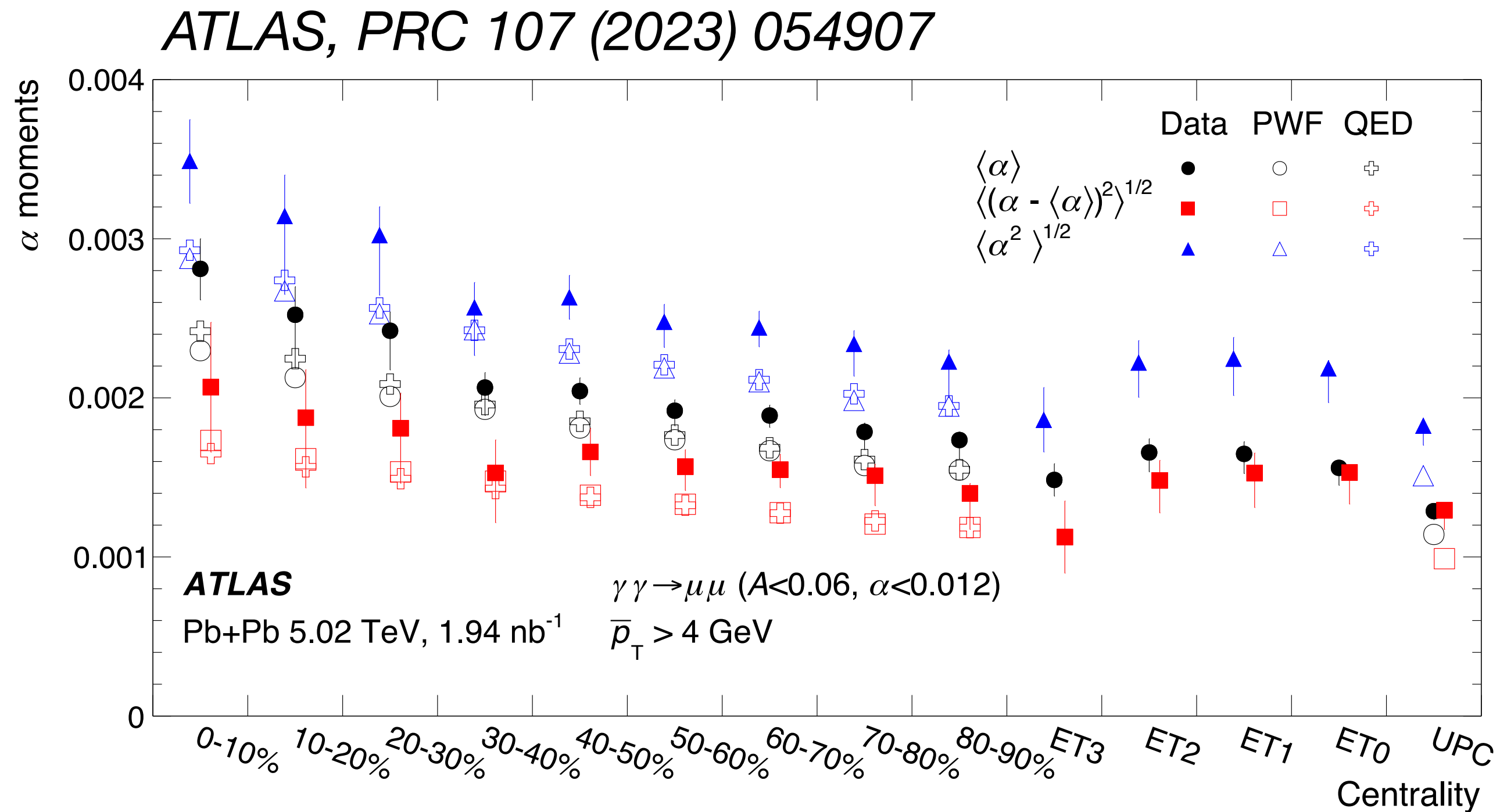
$$\alpha = 1 - \left| \Delta\phi \right| / \pi$$

Di-muon kinematic relationship modified compared to StarLight/UPC data

⇒ investigate origin and test QED models



# Initial state of the EM fields around nuclei



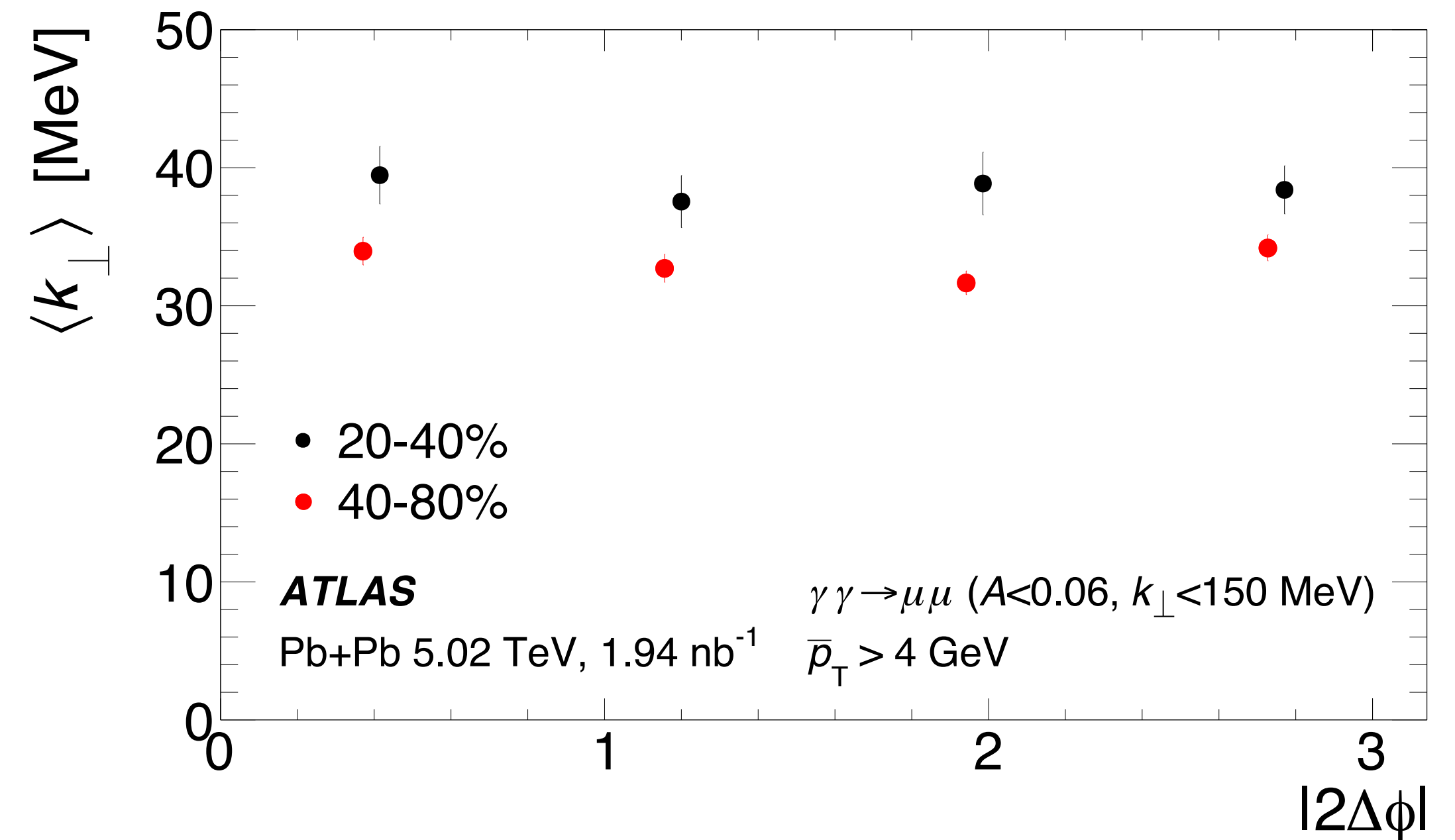
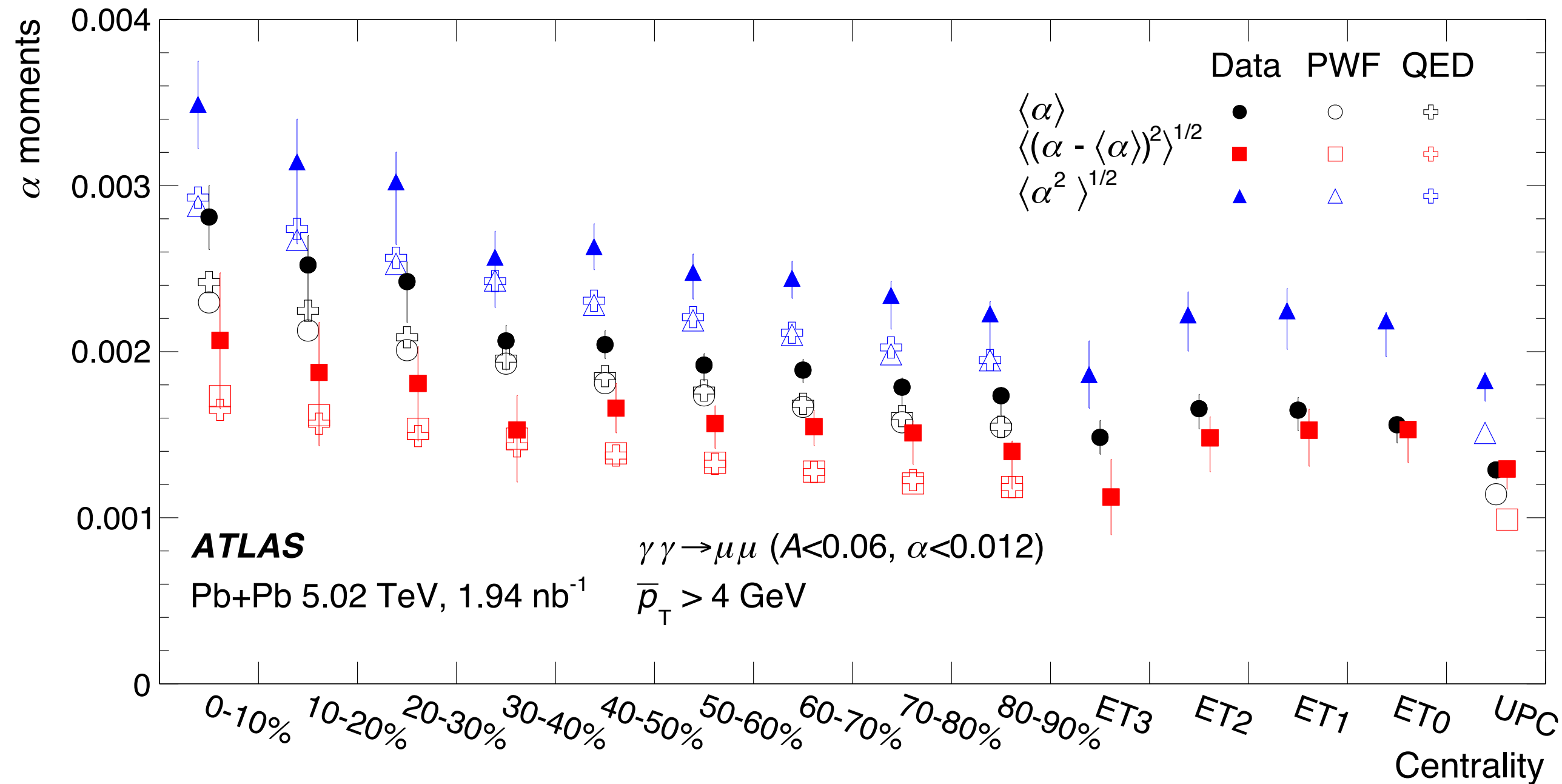
Trends in  $\alpha$  and  $k_{\perp} = \pi\alpha \langle p_T \rangle$  broadening  
reasonably described by QED calculations

⇒ total cross-sections are a challenge



# Initial state of the EM fields around nuclei

ATLAS, PRC 107 (2023) 054907



Trends in  $\alpha$  and  $k_{\perp} = \pi\alpha \langle p_T \rangle$  broadening  
reasonably described by QED calculations  
 $\Rightarrow$  total cross-sections are a challenge

No visible influence from strong  
magnetic fields appearing as a  
modification vs.  $\tanh(y)$  or  $2(\phi - \Psi_2)$



# Dijet production in $\gamma + A$ collisions

Run: 286717  
Event: 36935568  
2015-11-26 09:36:37 CEST  
Pb+Pb,  $\sqrt{s_{NN}} = 5.02$  TeV

$p_T^2 = 60$  GeV

$p_T^1 = 73$  GeV

“Clean” environment for precision probes of  
the nuclear wave function

Access  $(x_A, Q^2)$  “gap” between LHC  $p+A$  and  
fixed target data — 10 years before the EIC!



# Dijet production in $\gamma + A$ collisions

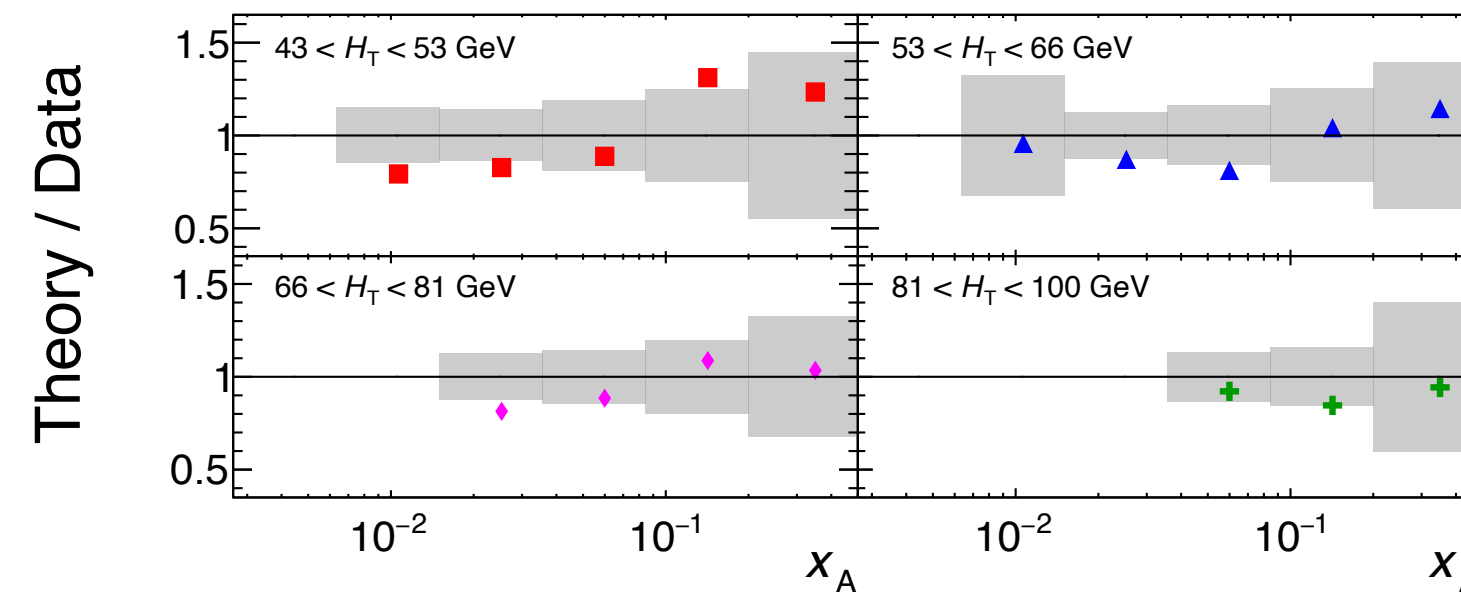
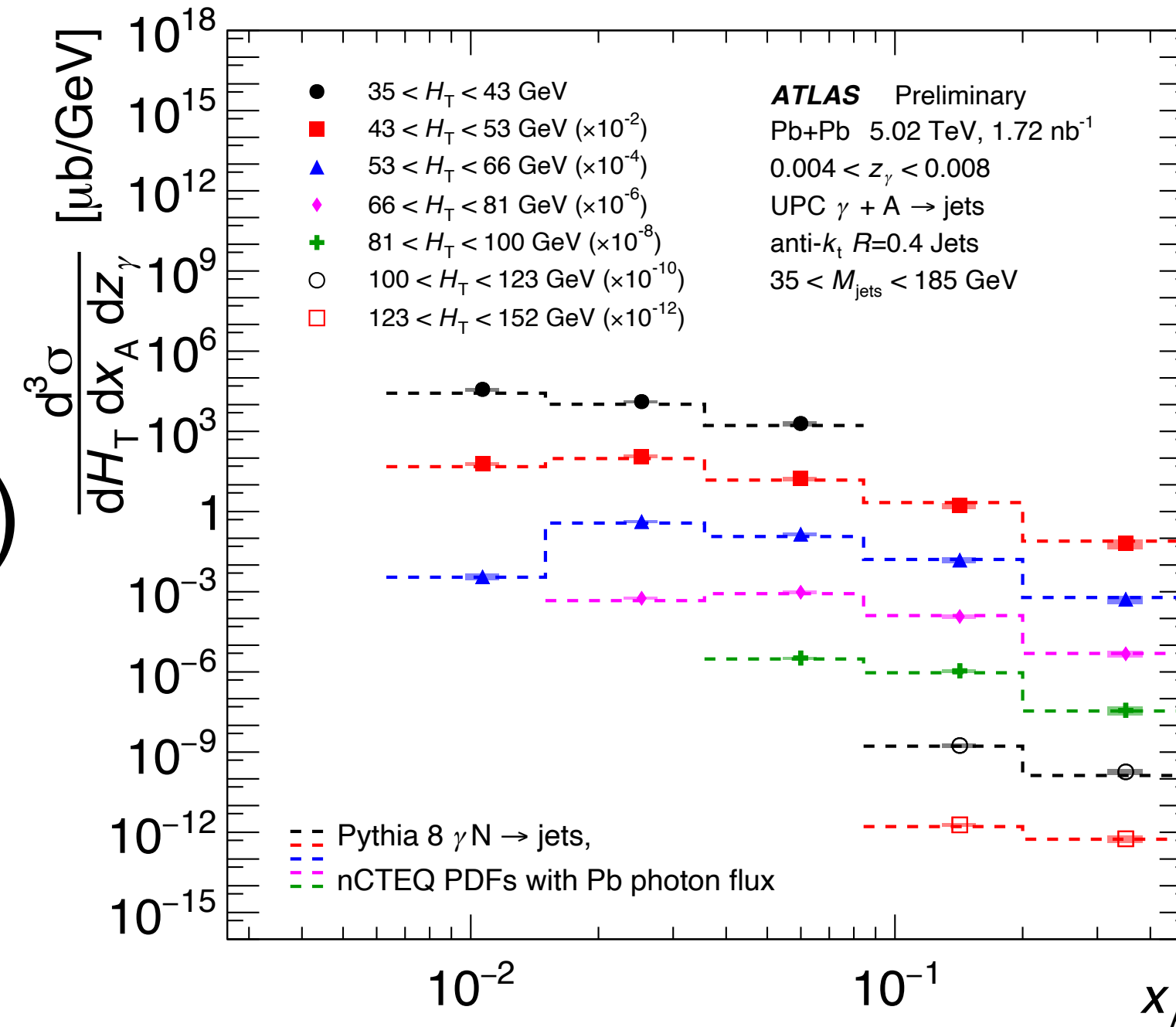
ATLAS-CONF-2022-021

Fully unfolded in:

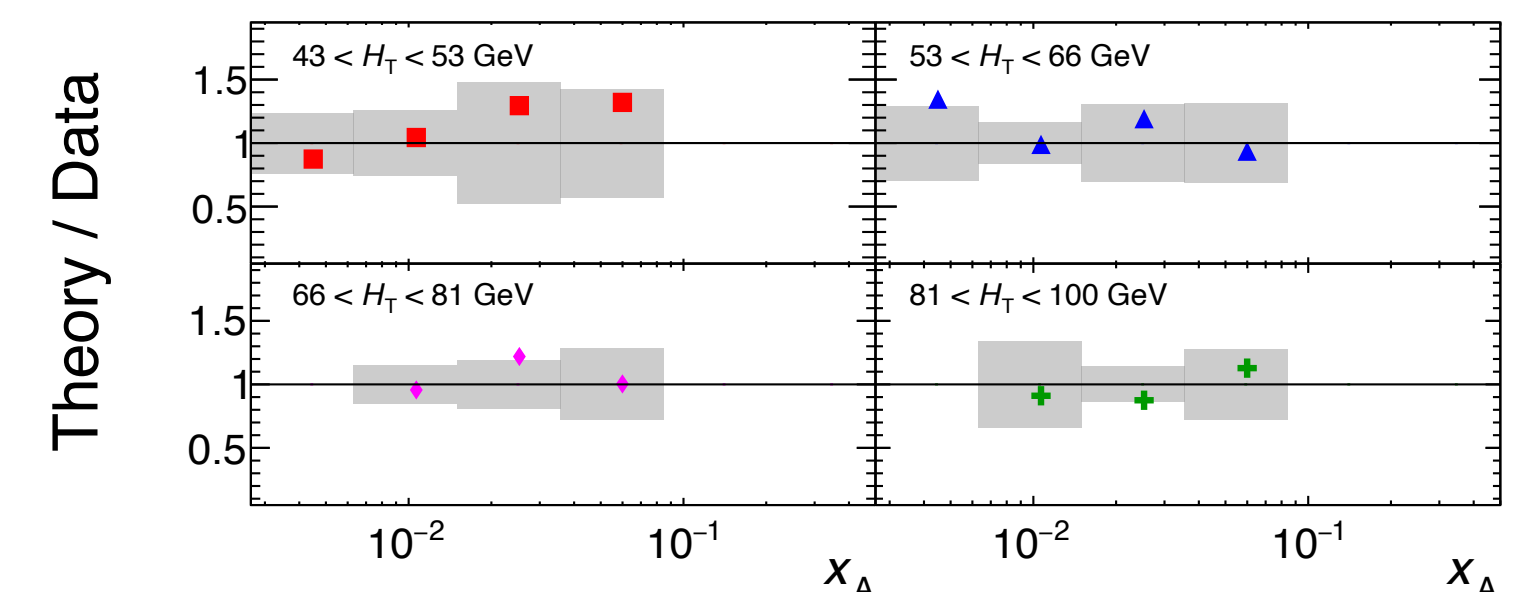
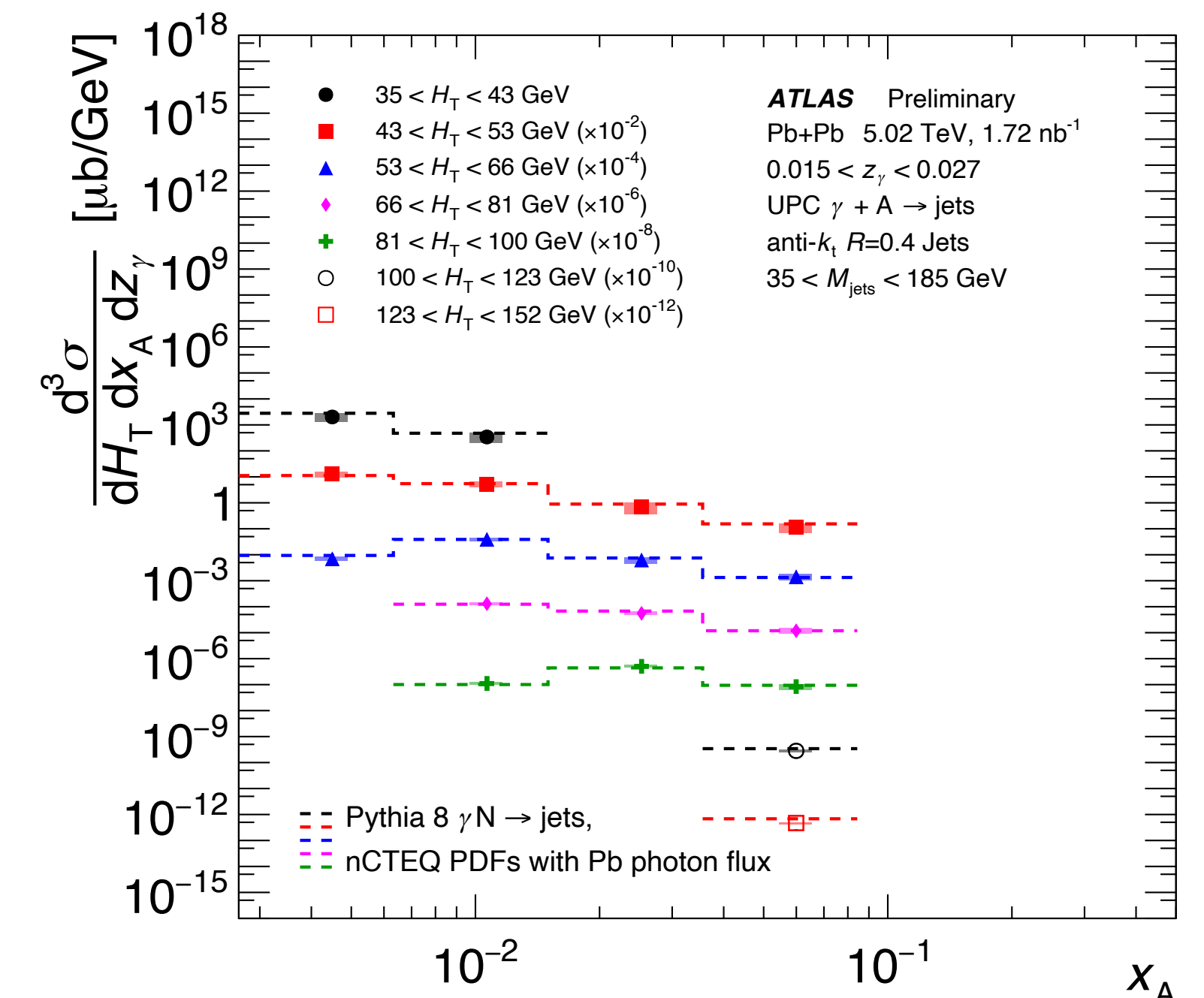
- $x_A$  (Bjorken- $x$  in nucleus)
- $z_\gamma$  (momentum fraction of  $\gamma$  or resolved  $\gamma$  fragment)
- $H_T$  (jet  $E_T$  sum)

Ready for input to global nPDF fits after:

- ➡ Final results with reduced jet energy uncertainties
- ➡ Modeling of nuclear breakup probabilities



Low- $z_\gamma \Rightarrow$  access high- $x_A$

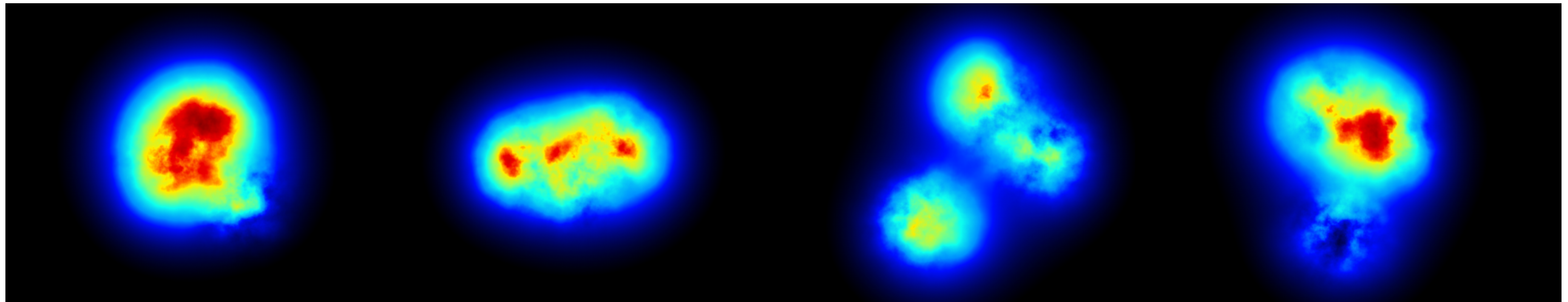


High- $z_\gamma \Rightarrow$  access low- $x_A$

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## Initial state of the proton:

- Flow decorrelations in  $pp$  (and Xe+Xe)
- Correlation between “centrality” and dijet kinematics in  $p+Pb$



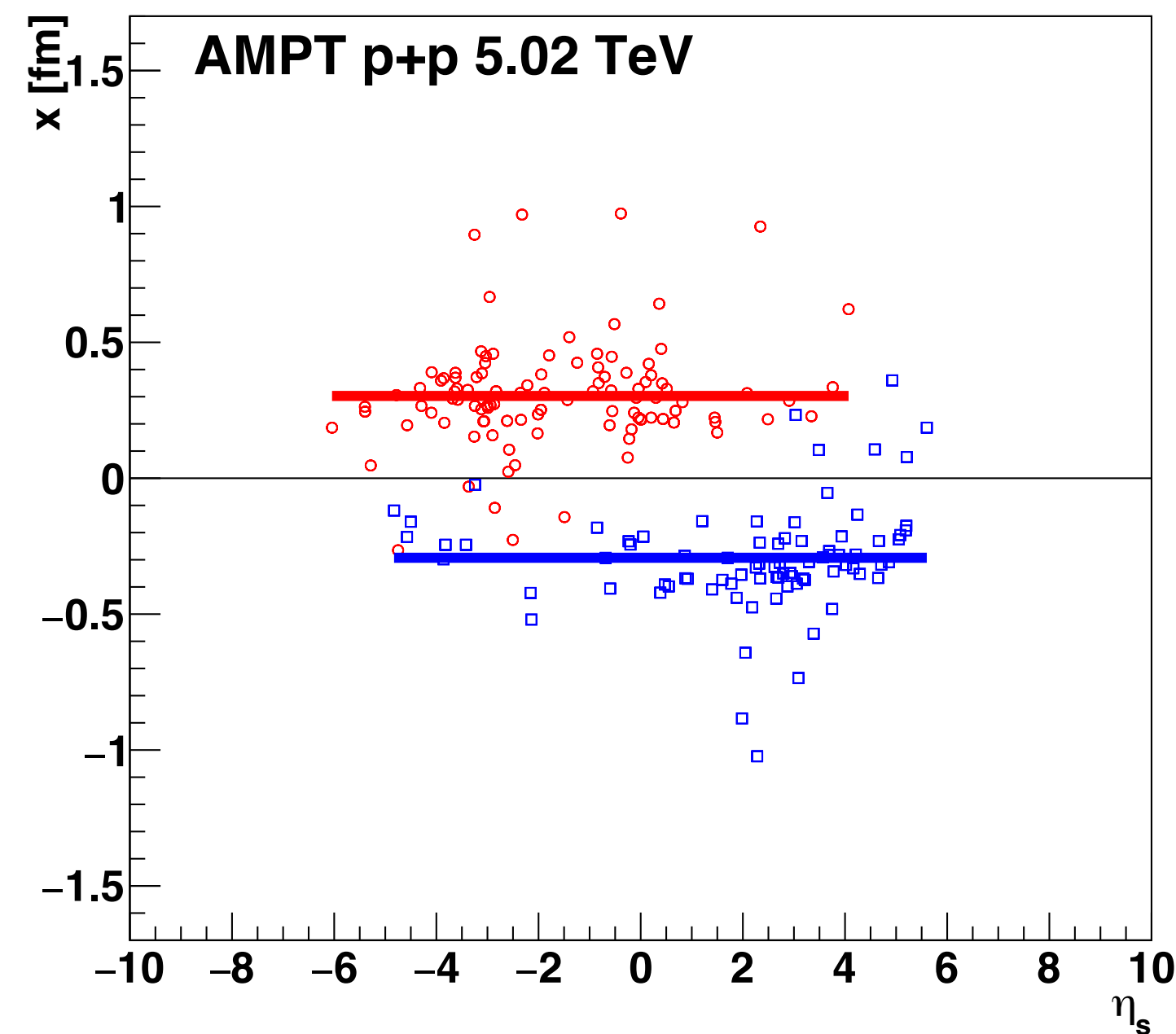
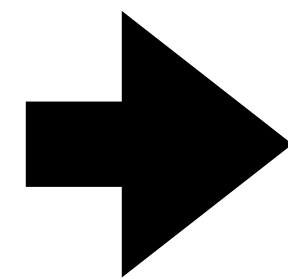
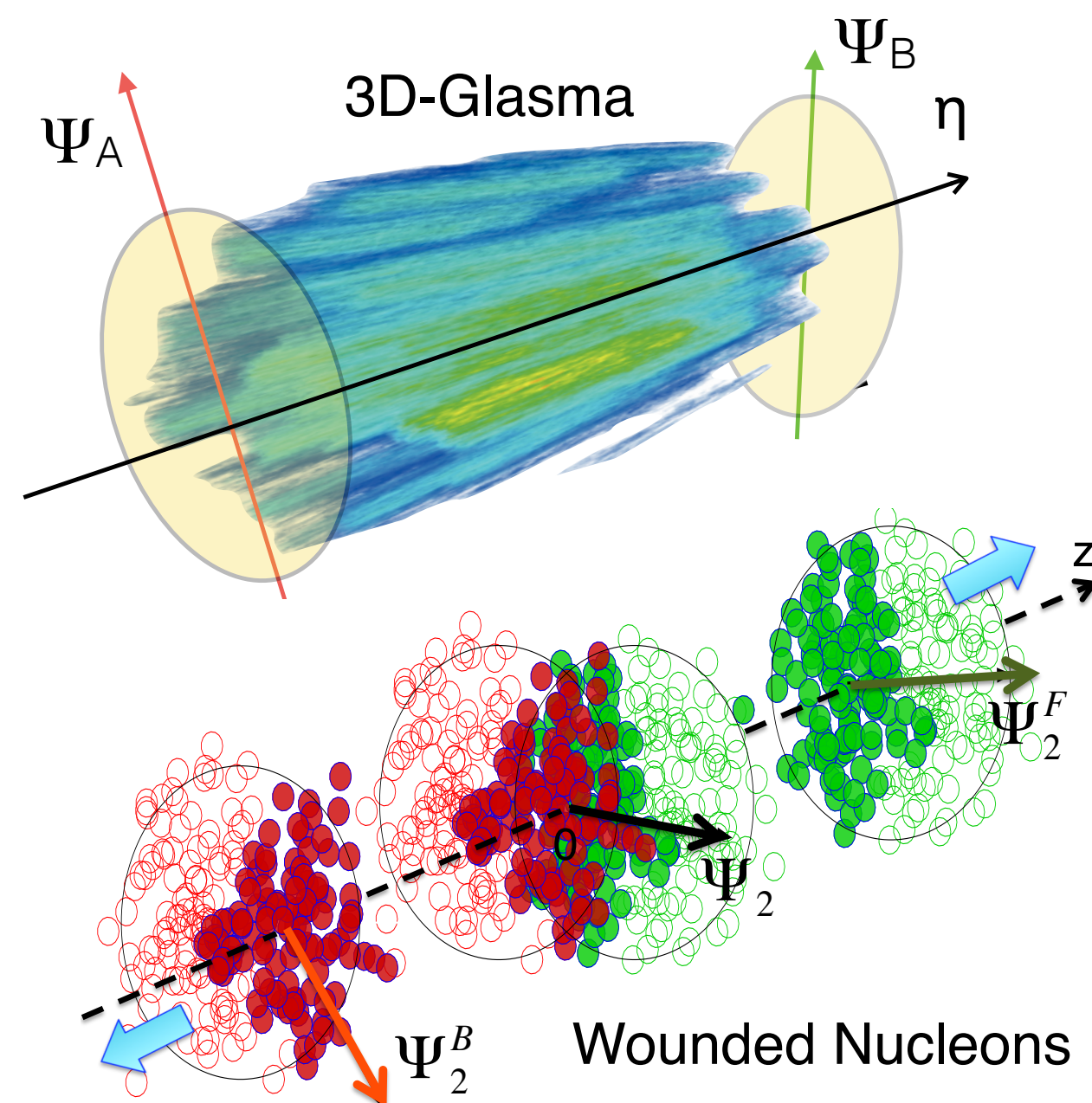
Parallel talks by  
**Riccardo Longo** (Tue 4:10pm)

Posters by  
**Blair Seidlitz**



# 3-D initial state of a proton-proton collision

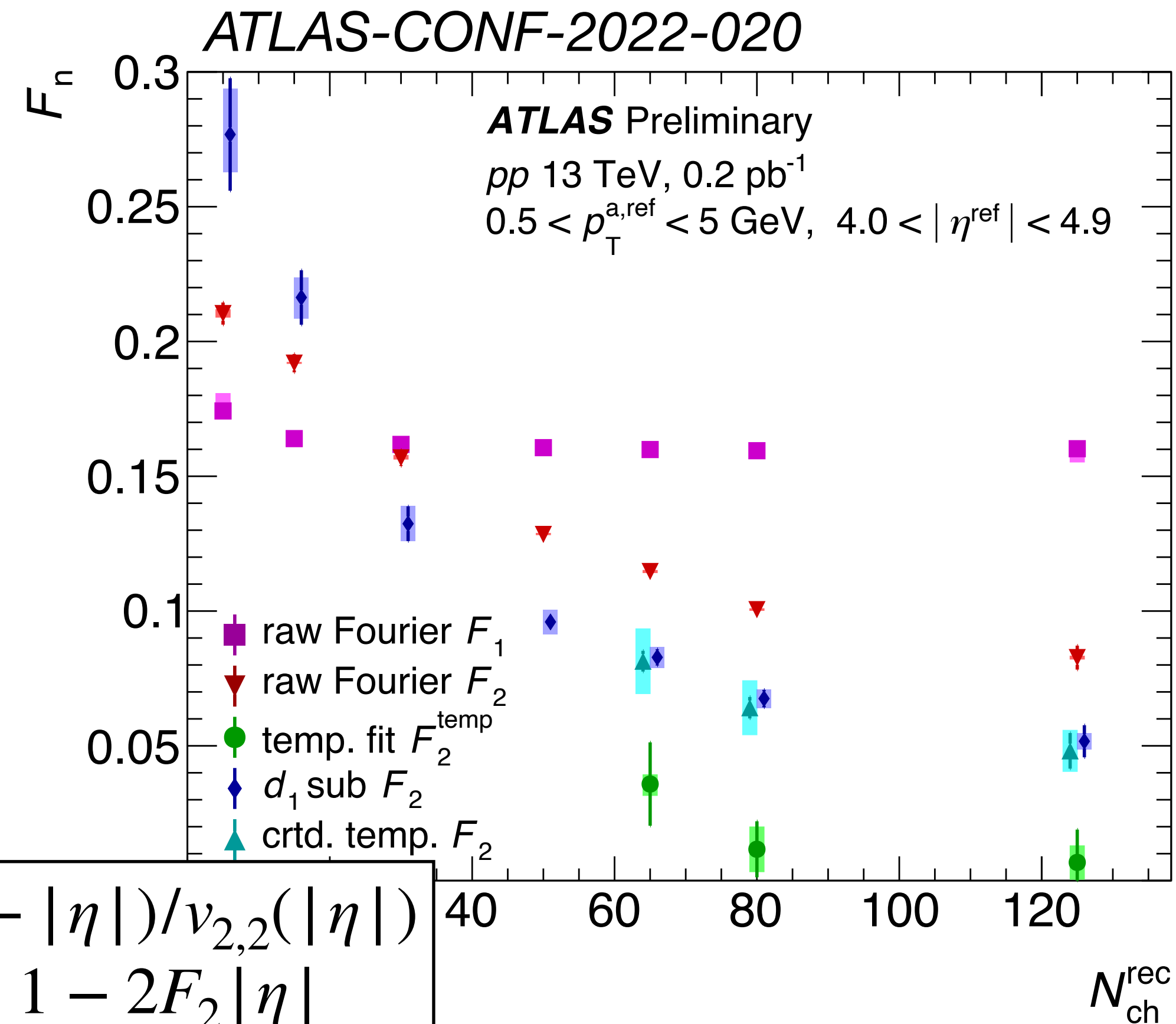
- What is the correlation between the longitudinal energy deposition and (initial state) momentum structure in small systems?



In a simple 2-string model,  
no particular  $\eta$ -dependence  
to  $\Psi_2$  or  $|v_2|$

- Key input for: understanding exotic systems with C.O.M. offset ( $\gamma + A$ ), comparing experiments with different acceptance (RHIC small systems), etc.

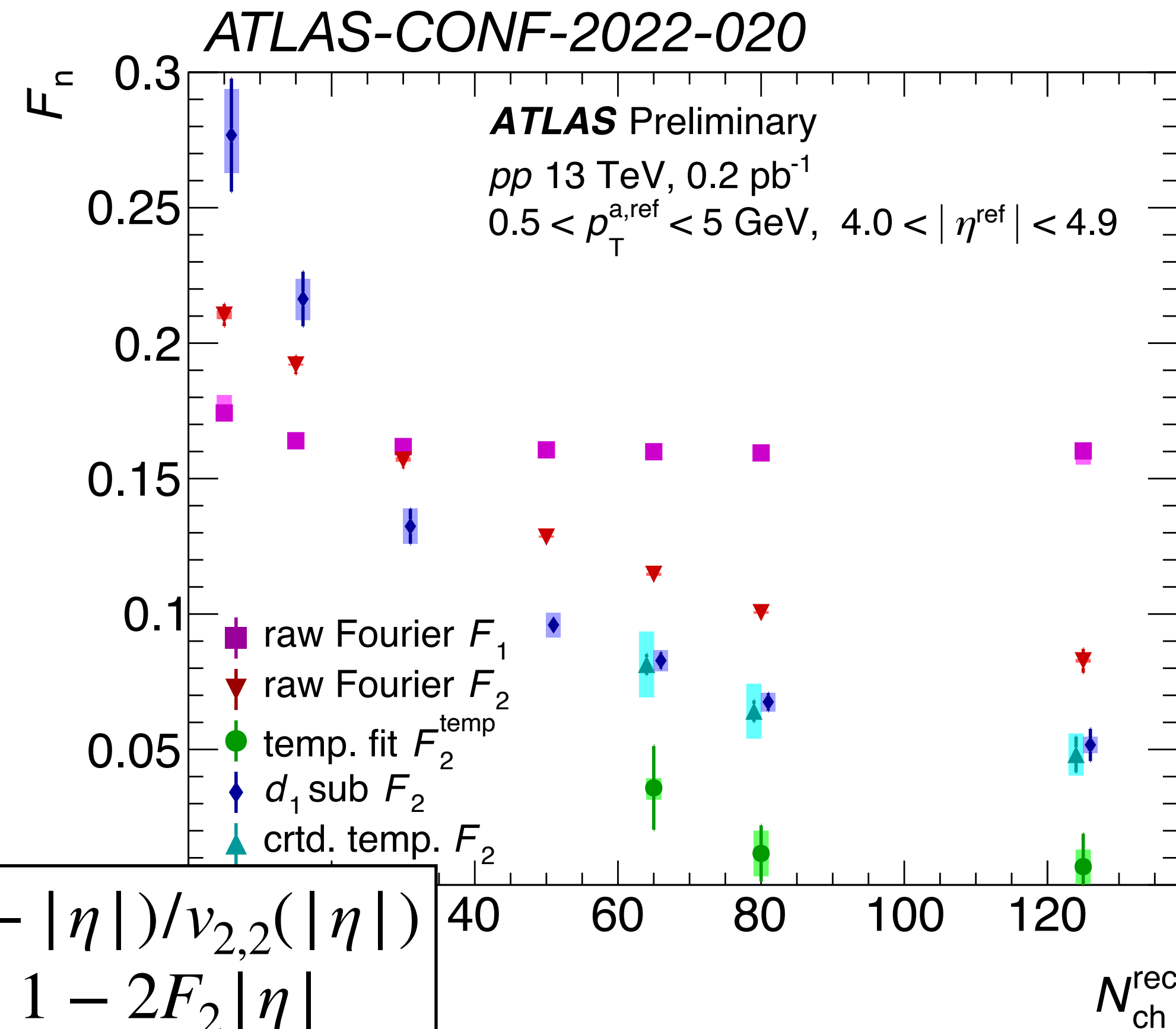
# 3-D initial state of a proton-proton collision



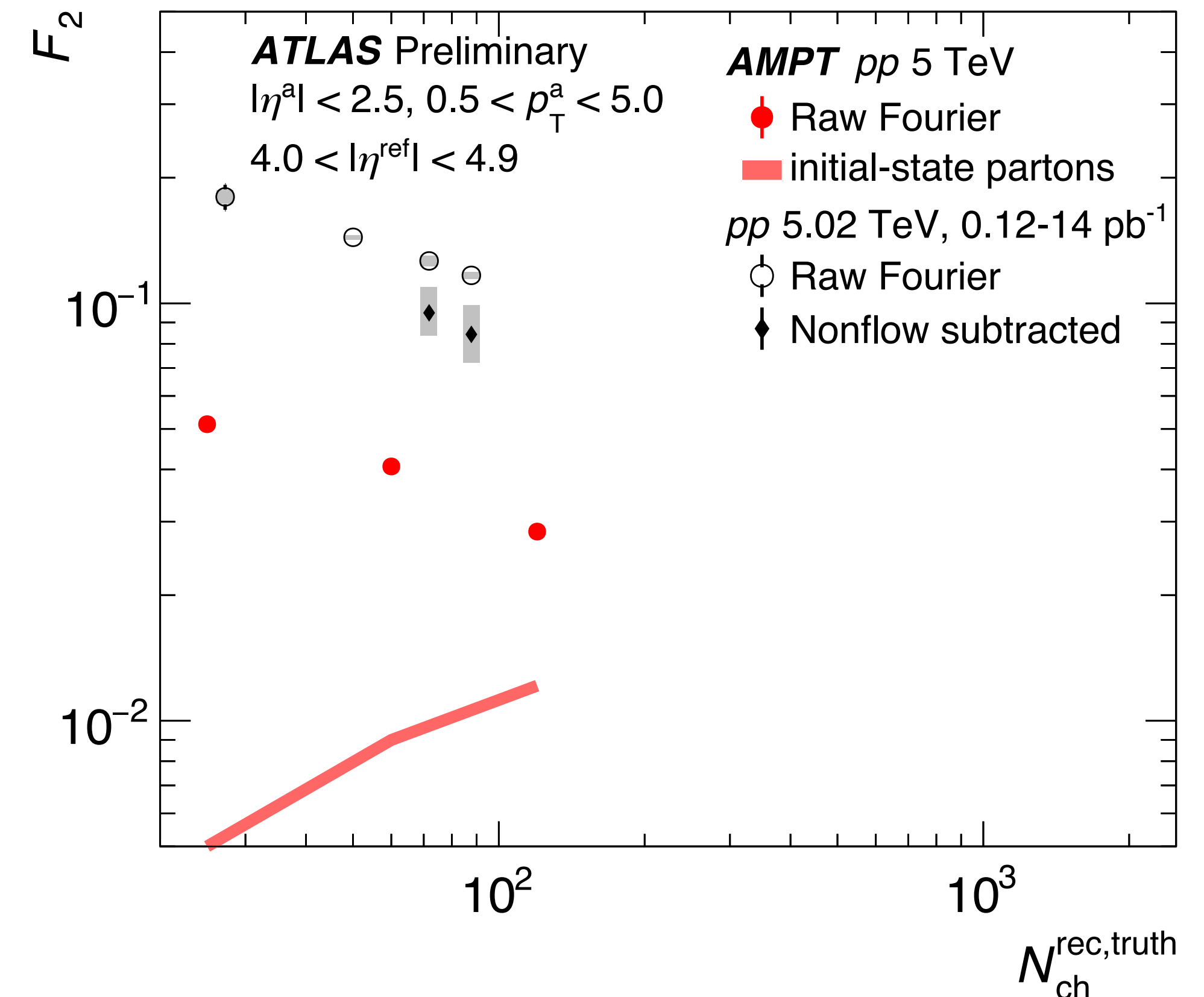
First measurement of  $F_2$  in  $pp$  collisions -  
 magnitude sensitive to assumptions in  
 non-flow subtraction methods (● ▲ ◆)



# 3-D initial state of a proton-proton collision

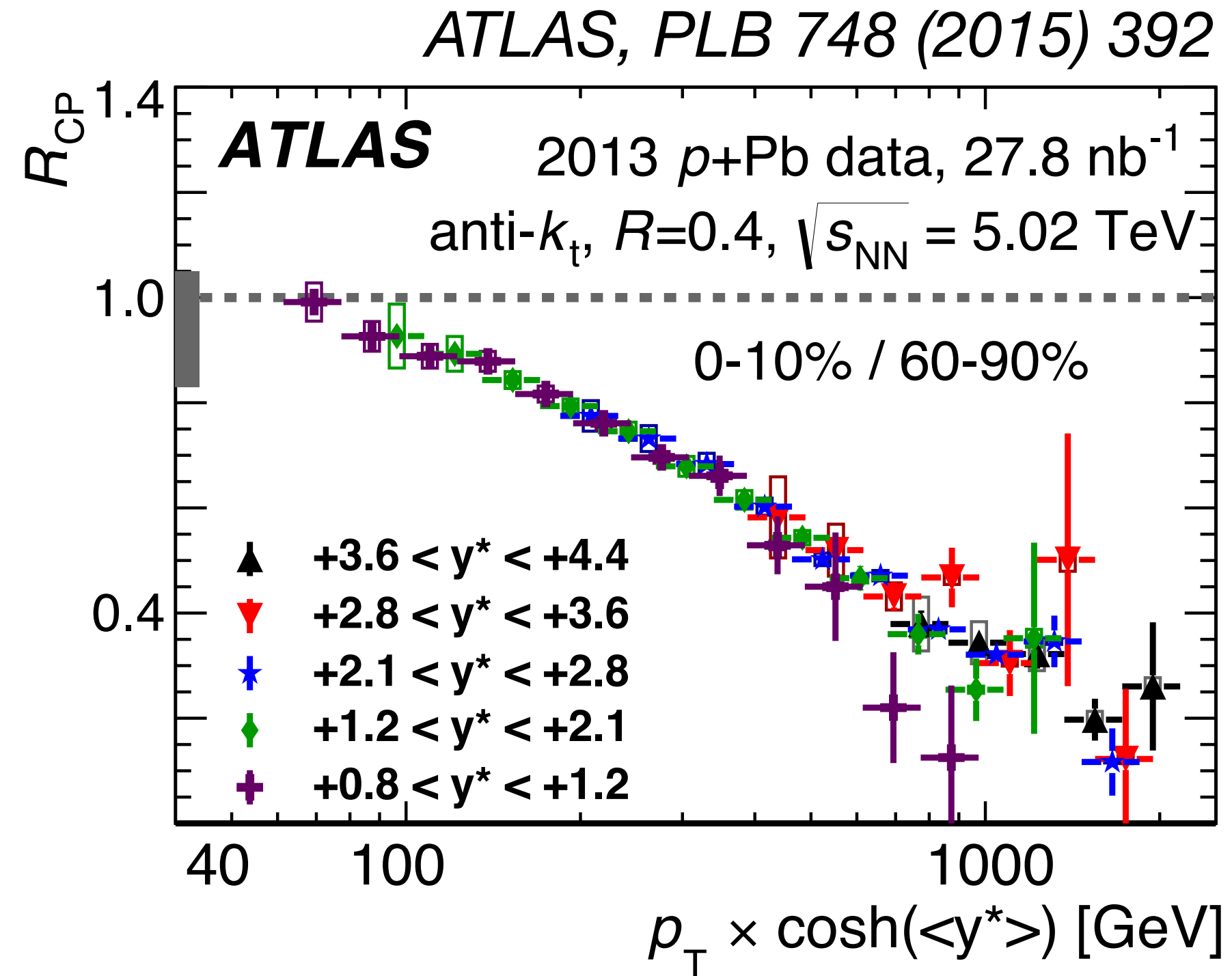


First measurement of  $F_2$  in  $pp$  collisions -  
 magnitude sensitive to assumptions in  
 non-flow subtraction methods (● ▲ ◆)



Significantly larger decorrelation  
 in  **$pp$  data** than a naive two-  
 string picture (**AMPT**)

# Centrality-dependent jet production in $p$ +Pb

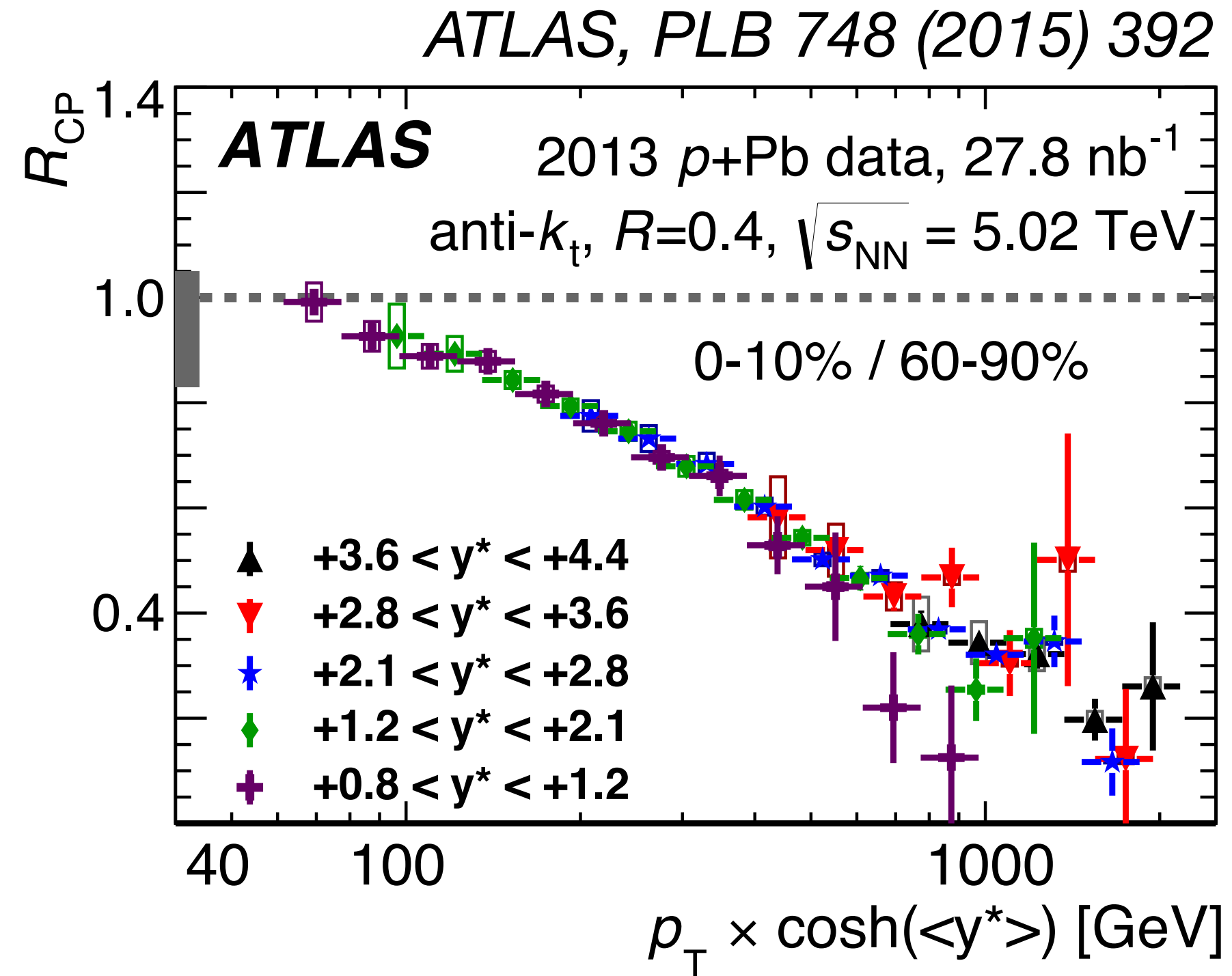


Min bias  $R_{pPb} = 1$ , but very strong “centrality” dependence of inclusive jets in Run 1  $p$ +Pb

Magnitude scales with total jet energy at forward rapidity (i.e. Bjorken- $x$  in proton,  $x_p$ ?)



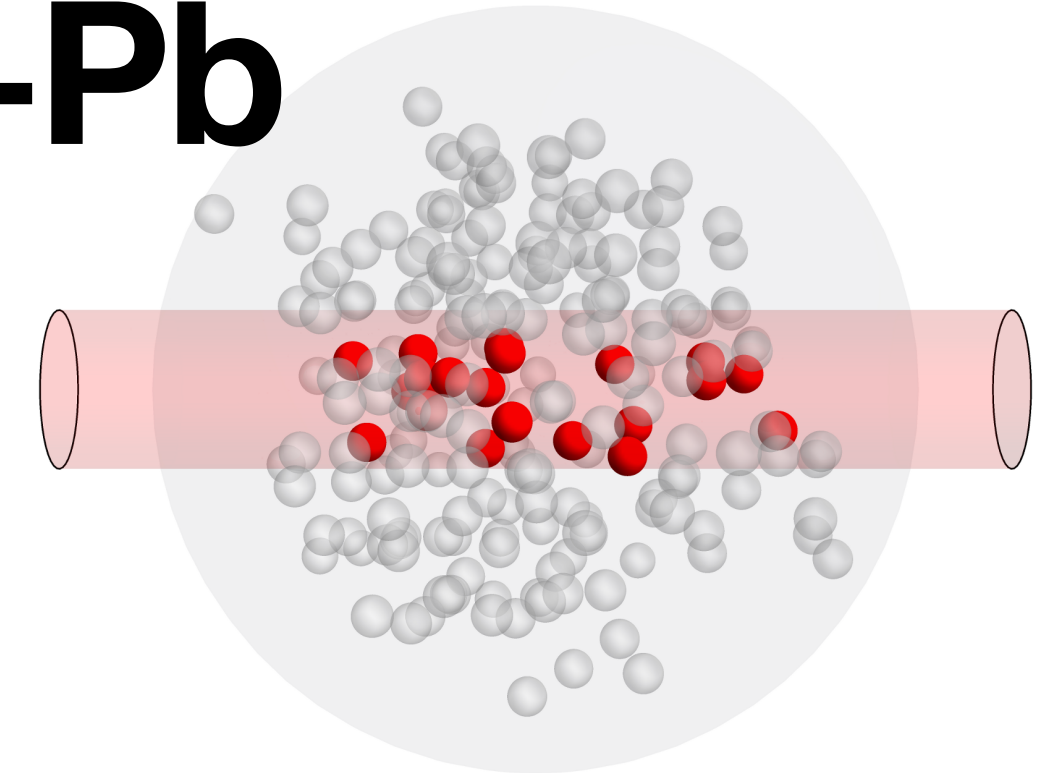
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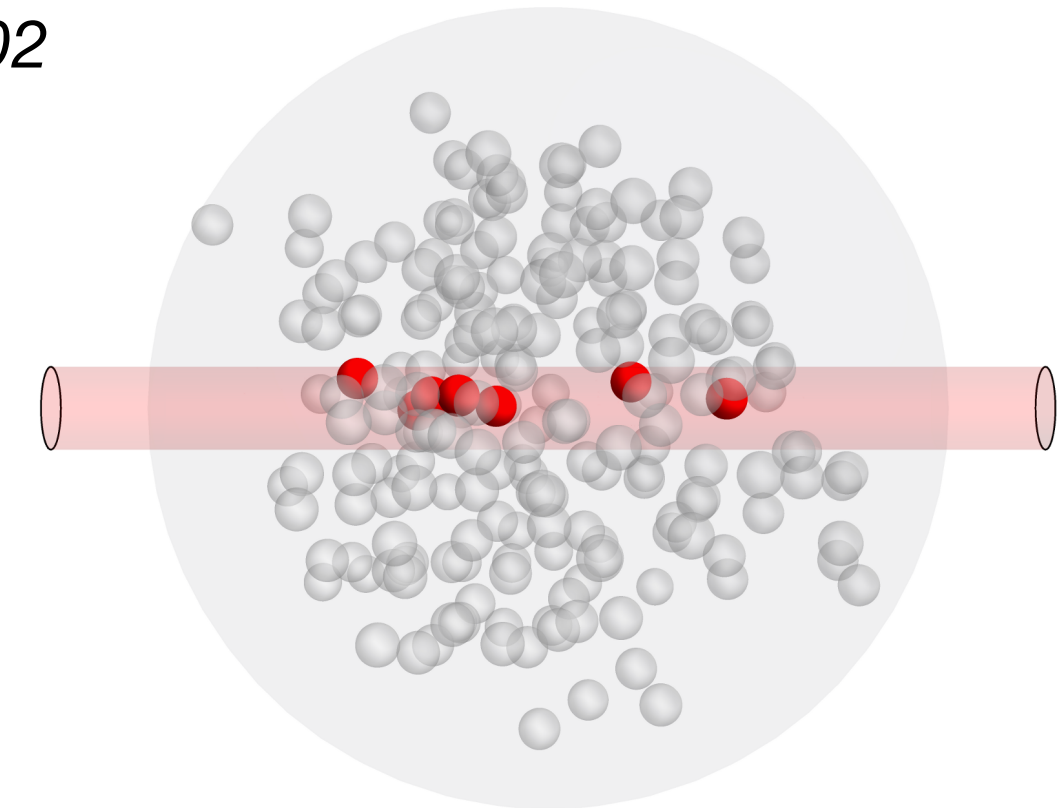
Magnitude scales with total jet energy at forward rapidity (i.e. Bjorken- $x$  in proton,  $x_p$ ?)

“typical”  
proton



Alvioli et al, PRD  
98 (2018) 071502

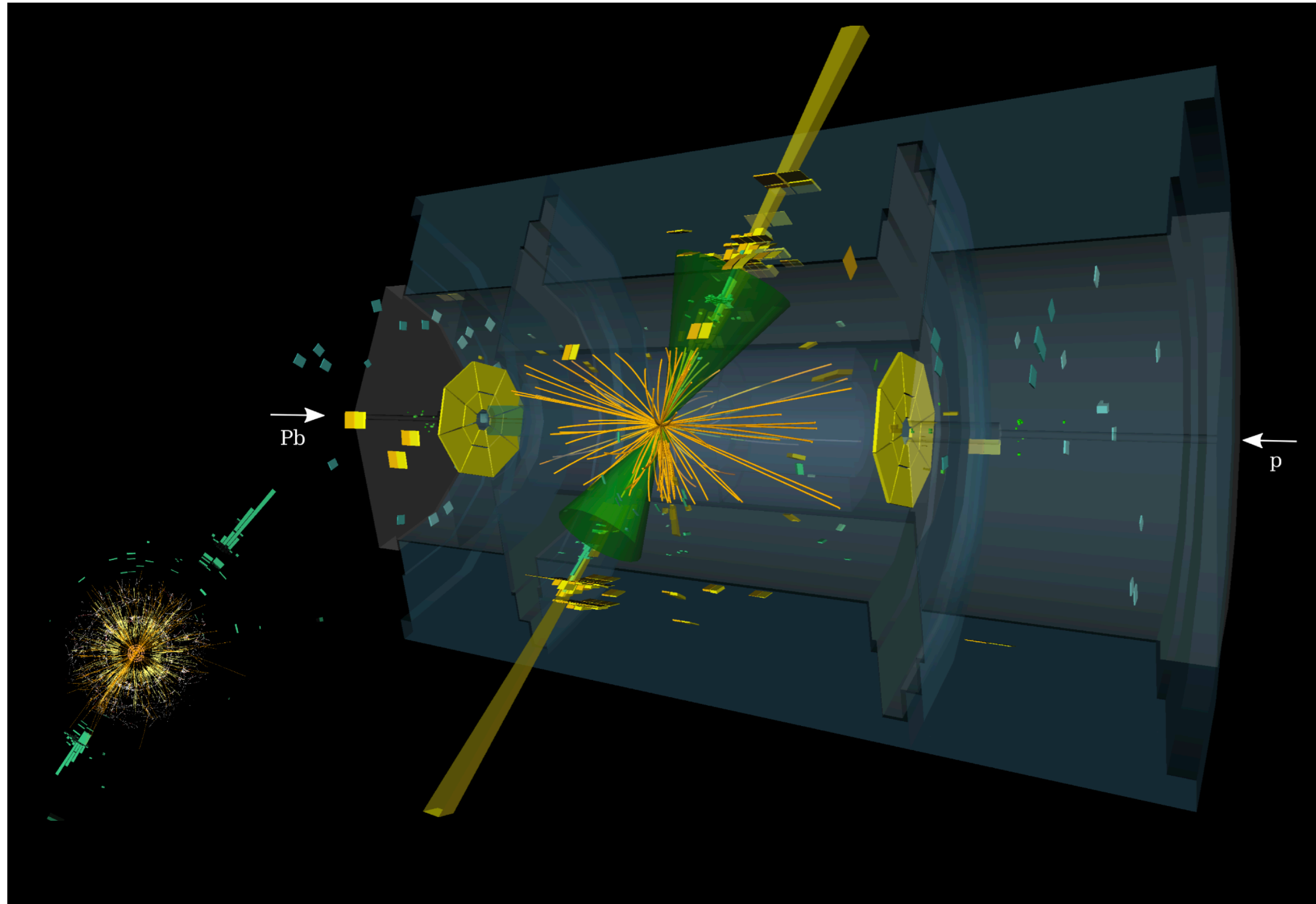
proton configuration  
with large- $x$  parton



Potential physical mechanism:  
a proton with large- $x$  ( $\gtrsim 0.1$ ) parton  
is “small” and strikes fewer nucleons

Central yield  $\downarrow$ , Peripheral yield  $\uparrow$   
(0-100%  $R_{pPb}$  unmodified)

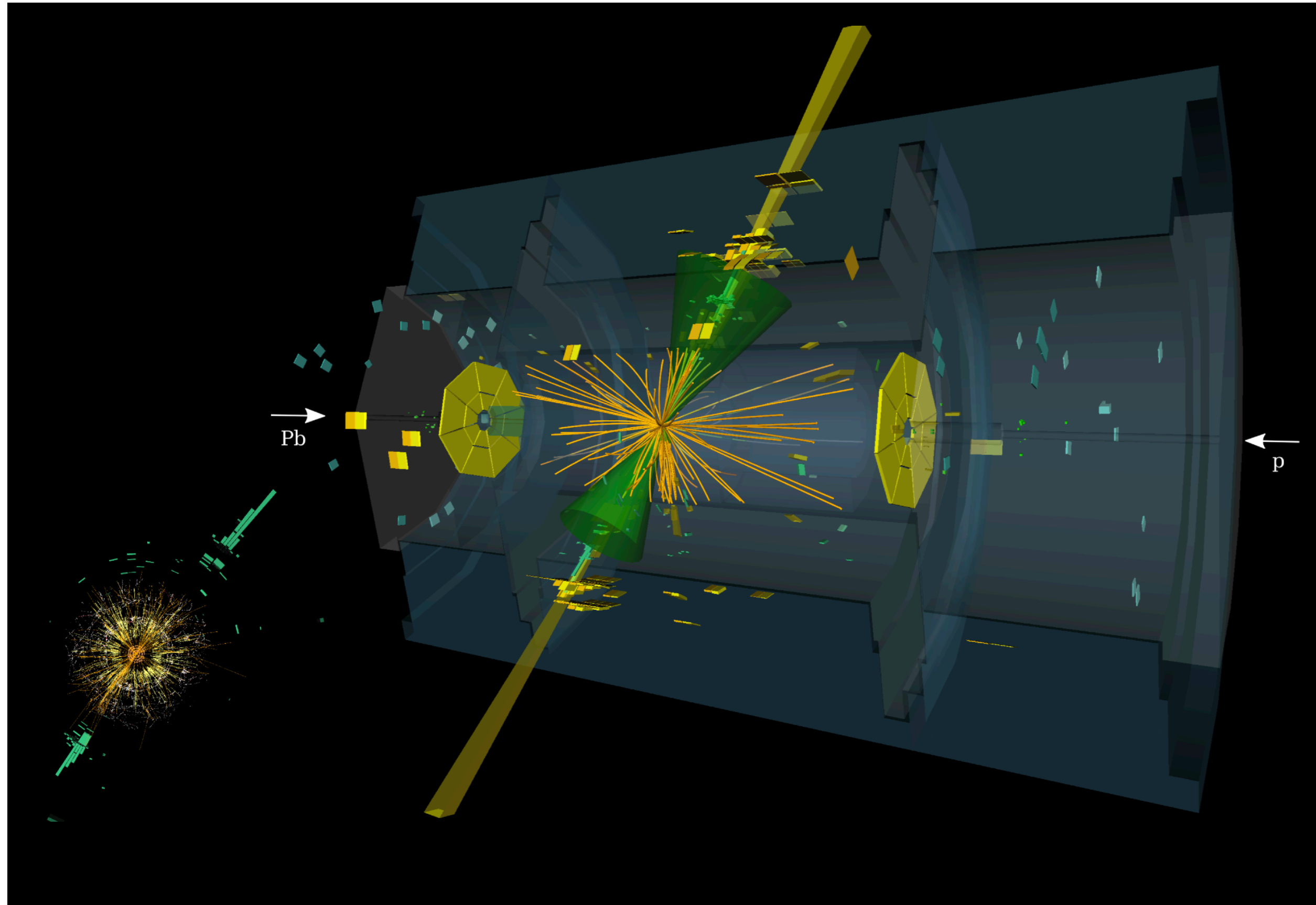
# Centrality-dependent $d\bar{i}$ -jet production in $p$ +Pb



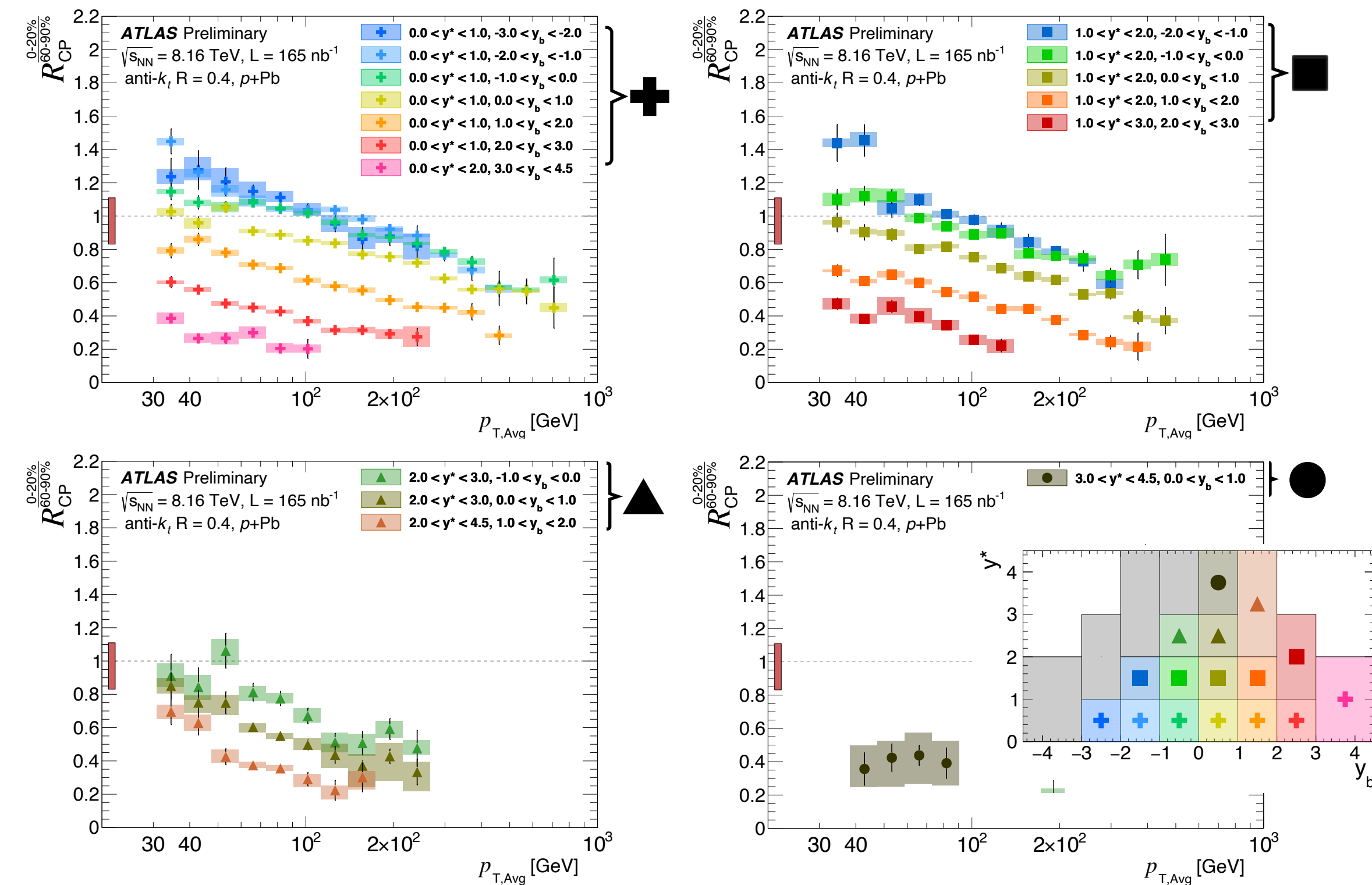
Repeat measurement, reconstructing the two leading jets and estimating tree-level  $(x_p, x_{\text{Pb}}, Q^2)$  in each event



# Centrality-dependent $d\bar{d}$ -jet production in $p$ +Pb



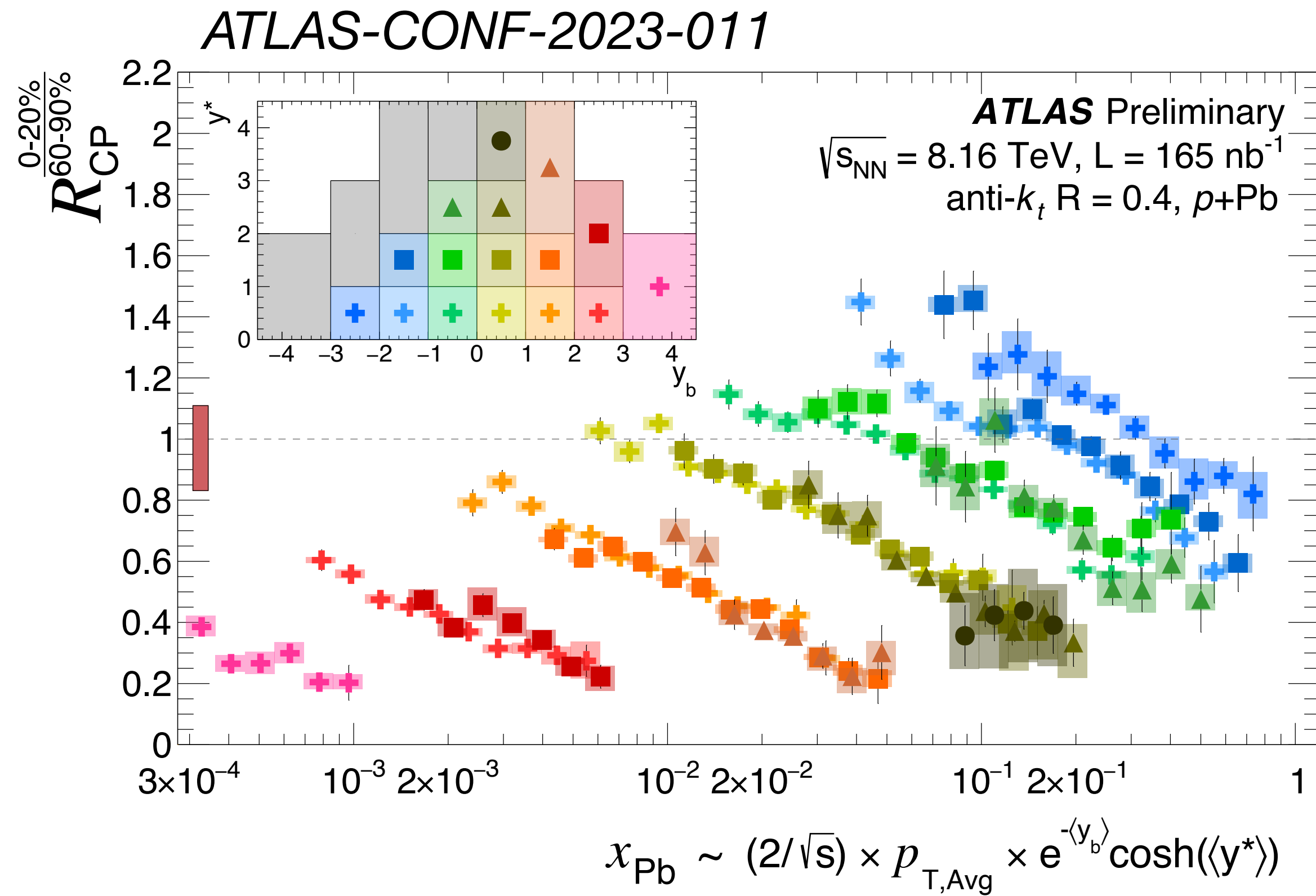
ATLAS-CONF-2023-011



Repeat measurement, reconstructing the two leading jets and estimating tree-level  $(x_p, x_{Pb}, Q^2)$  in each event

Perform differential scan in  $2 \rightarrow 2$  parton-parton kinematics to map out this physics in detail!

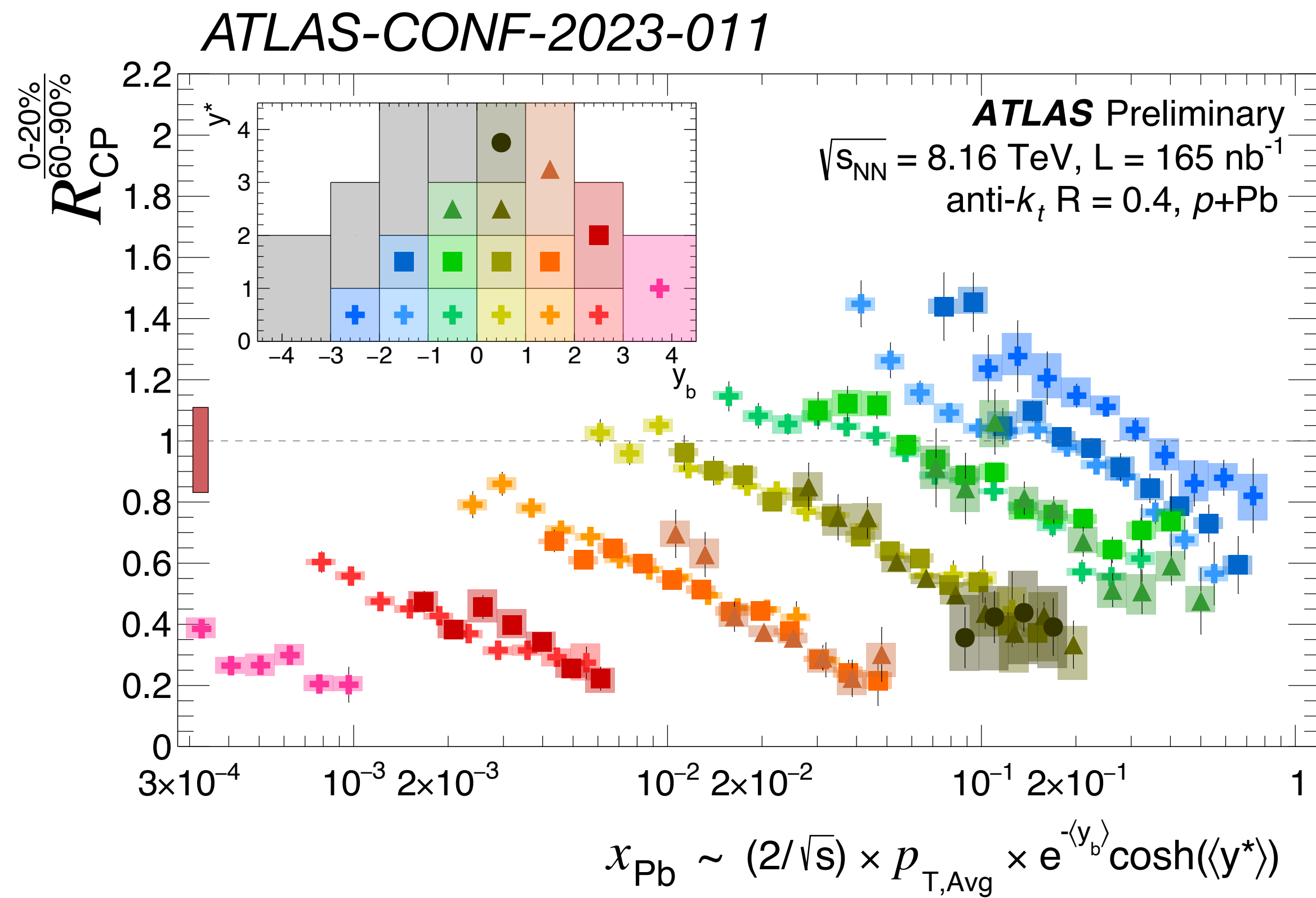
# Centrality-dependent $d\bar{d}$ -jet production in $p$ +Pb



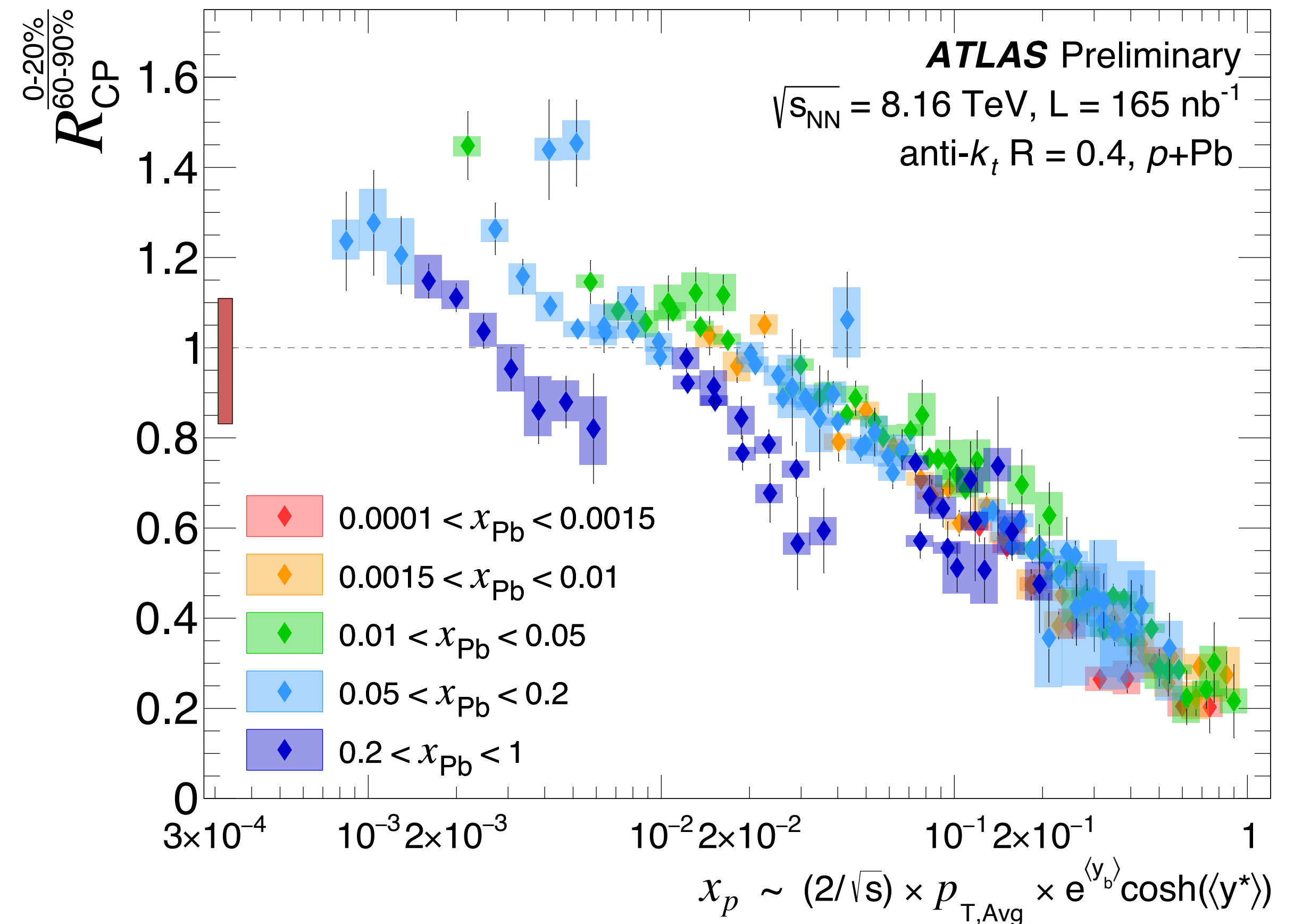
Plot dijet  $R_{\text{CP}}$  in different kinematic regions vs.  $x_{\text{Pb}} \Rightarrow$  no clear pattern, not an (initial state) nuclear effect



# Centrality-dependent $d\bar{d}$ -jet production in $p$ +Pb



Plot dijet  $R_{CP}$  in different kinematic regions vs.  $x_{Pb} \Rightarrow$  no clear pattern, not an (initial state) nuclear effect



Fix  $x_{Pb}$ , check dependence on  $x_p \Rightarrow$  physics effect originates in the initial momentum state of the proton

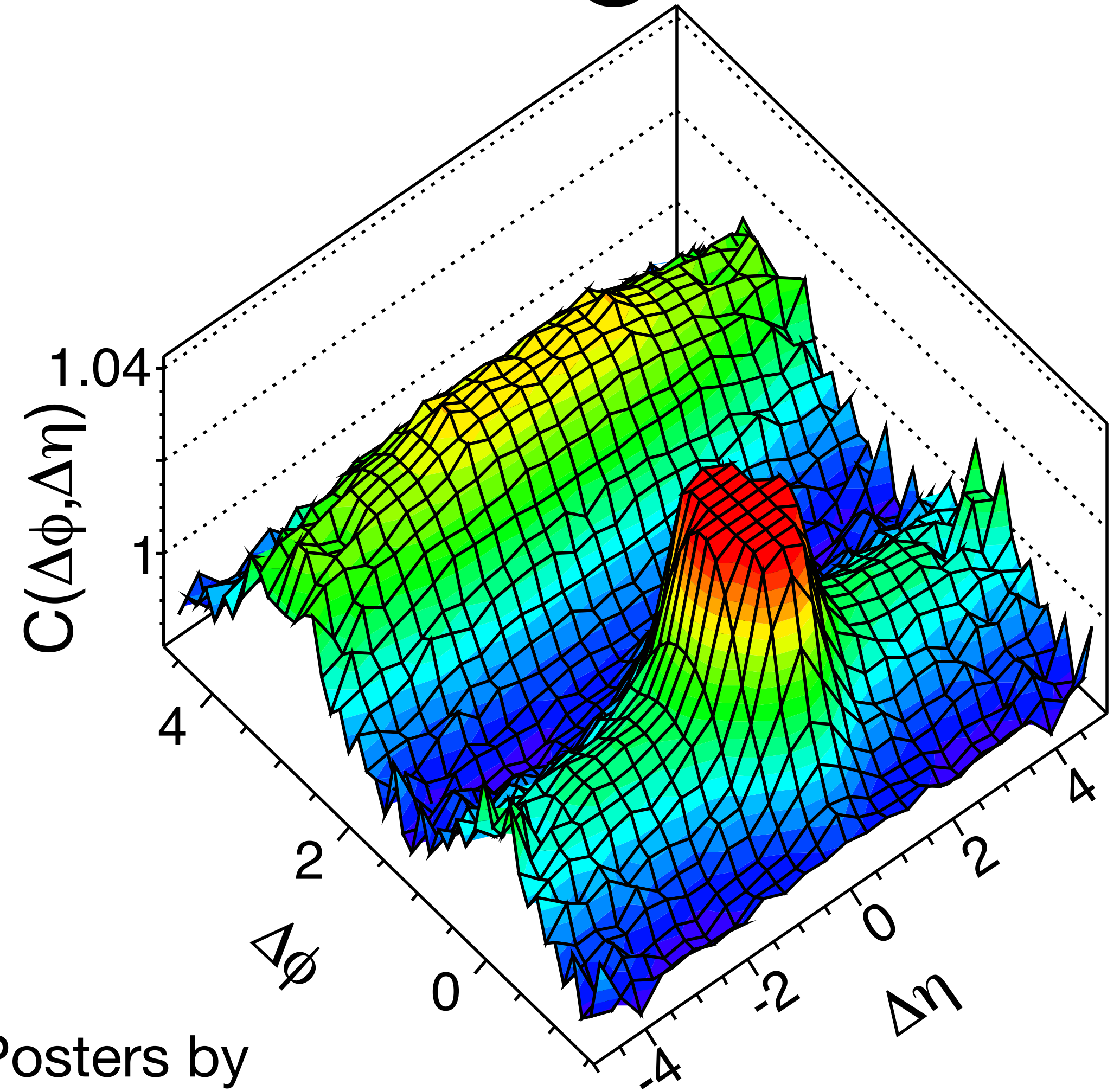
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## Final state effects in small systems:

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- Correlation between  $\Upsilon(1,2,3S)$  & UE in  $pp$



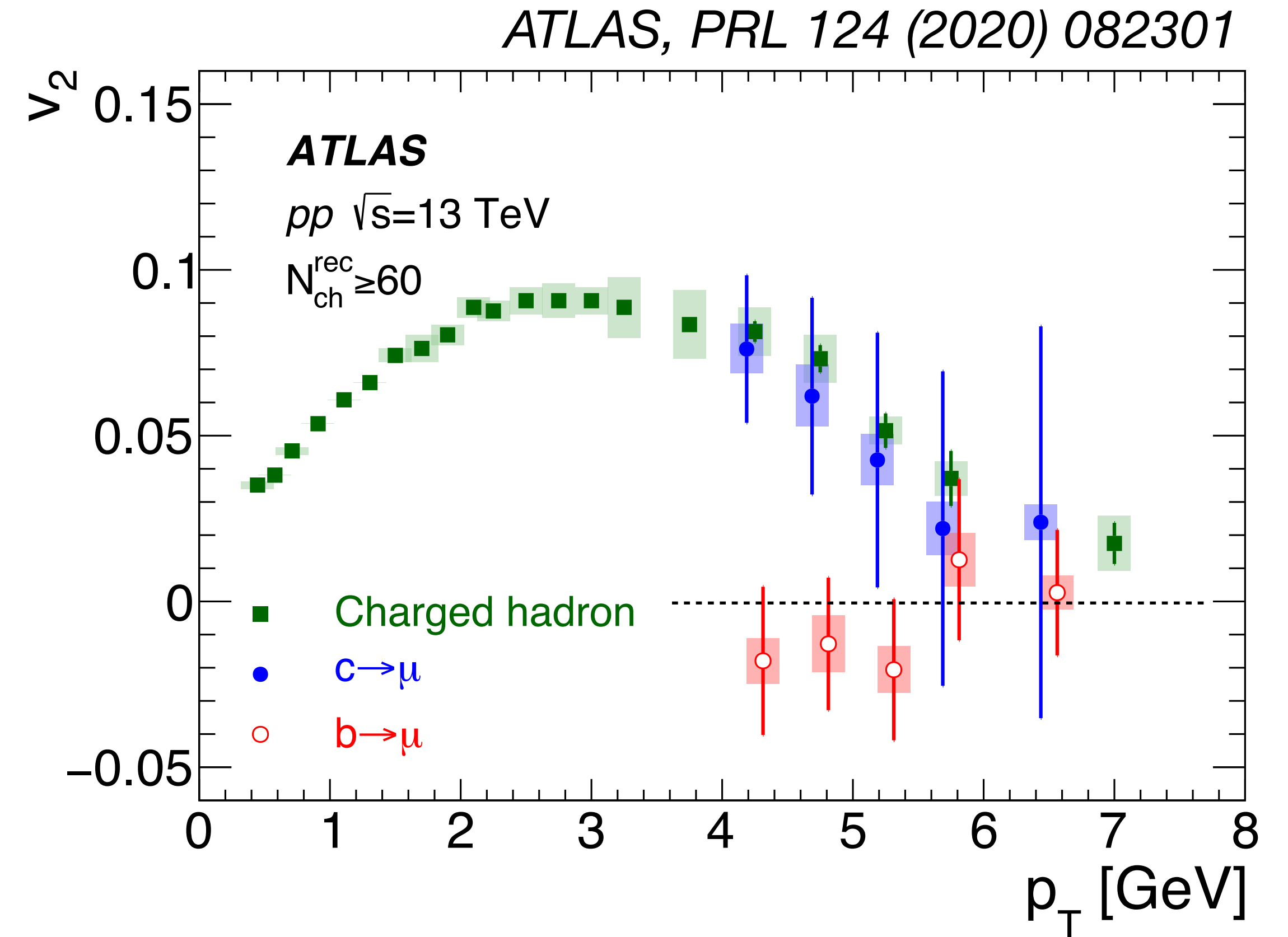
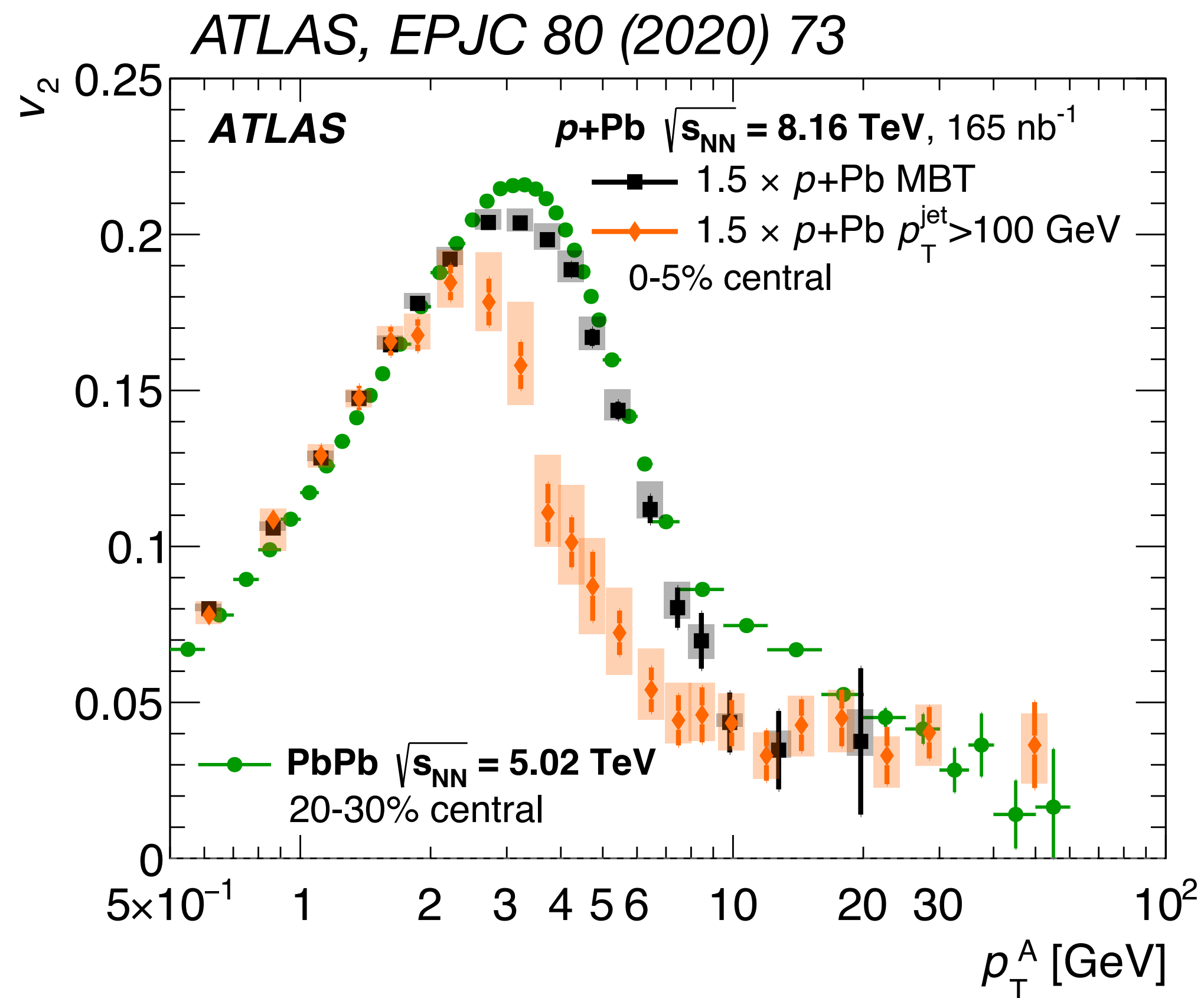
Parallel talks by  
**Pengqi (Bill) Yin** (Wed 4:50pm)



Posters by  
**Alexander Milov**



# Final state effects on hard probes in $p+A/pp$ ?



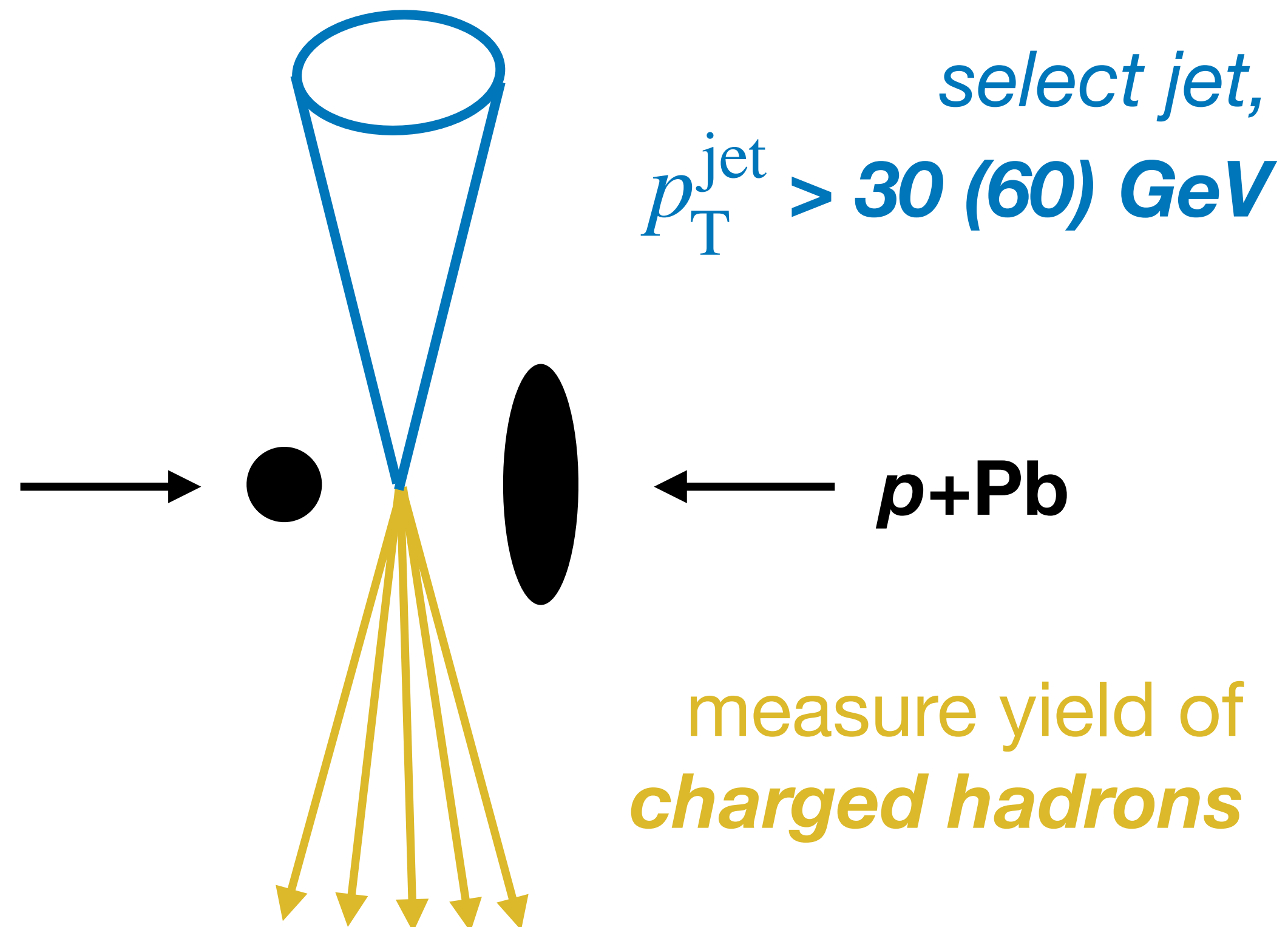
Charged particle  $v_2$  in **p+Pb events** remains non-zero out to 50 GeV

Heavy **charm quarks** flow in  $pp$  (... but **bottom quarks** do not)

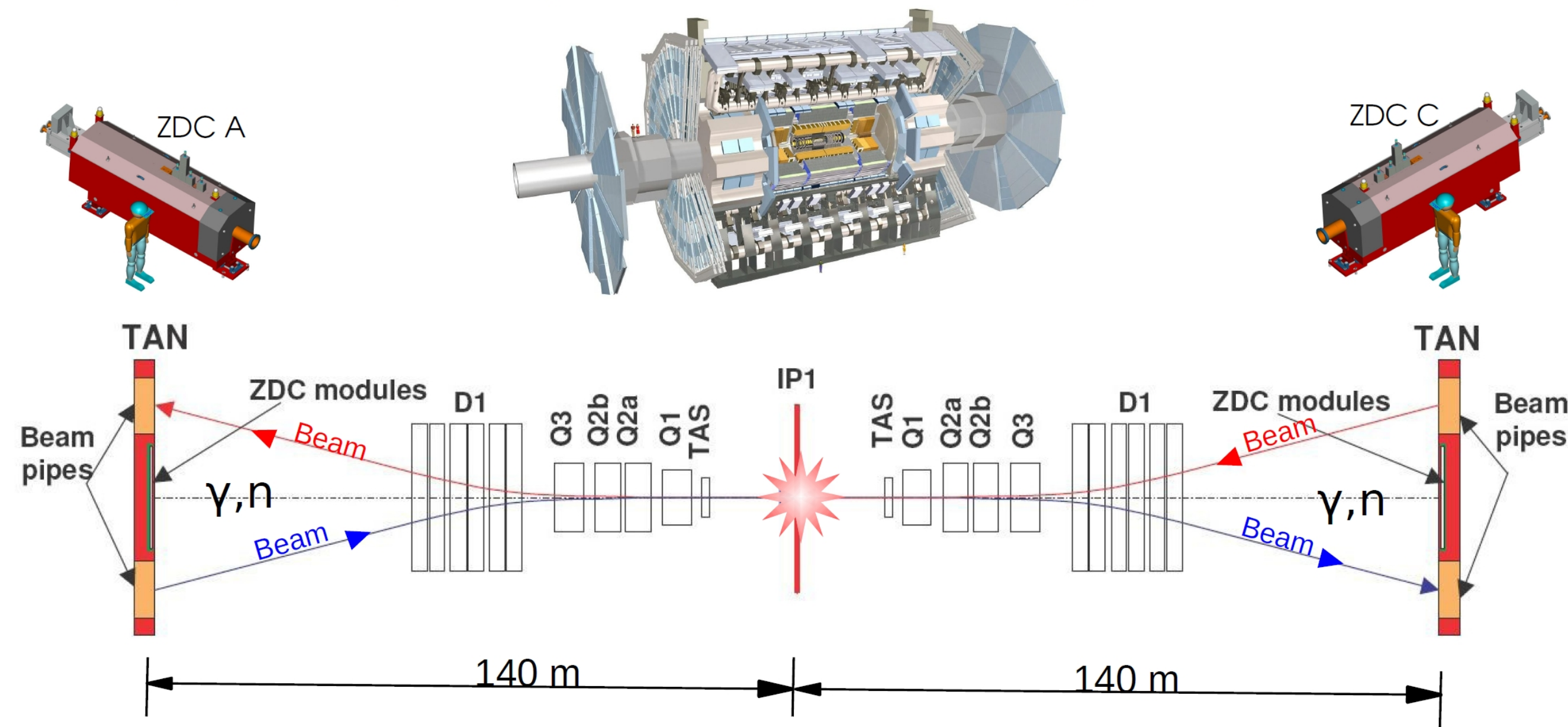
➡ New ATLAS measurements to explore effects on hard partons in small systems

# Jet+h in $p$ +Pb: measurement design

We have limits on out-of-jet-cone  $\Delta E$  - what about hadrons in the jet?



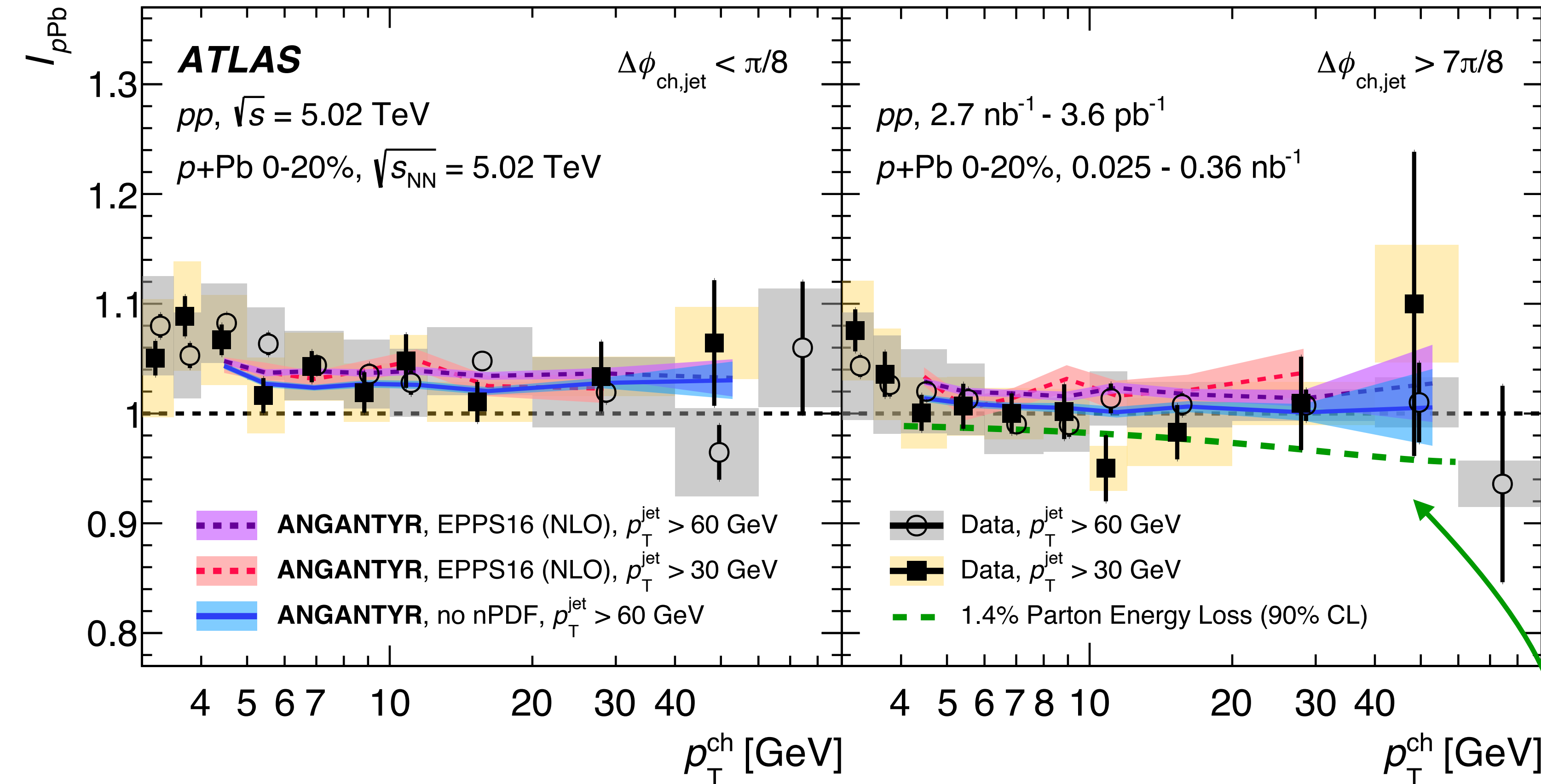
Can't use traditional multiplicity-based centrality for a precision  $E$ -loss search  
 $\Rightarrow$  use ZDC to select central events





# Jet+h in $p$ +Pb: excluding energy loss scenarios...

ATLAS, nucl-ex/2206.01138, in press PRL



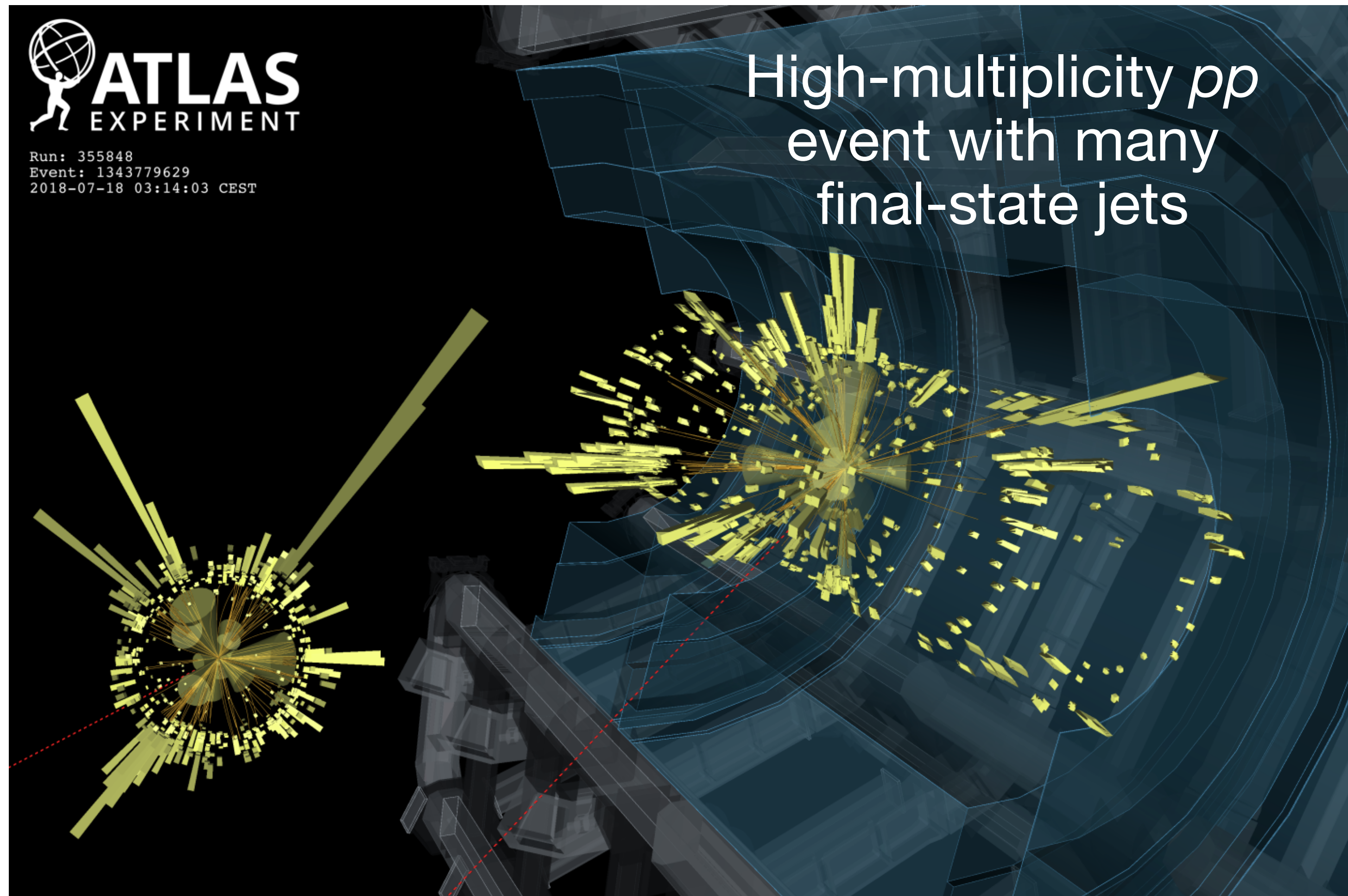
$I_{p\text{Pb}}$  = ratio of per-jet yield  
in central  $p$ +Pb /  $pp$

Small enhancement on the  
near side (left), predicted  
by Angantyr (no QGP)

No significant modification  
on the away side (right)

$\Delta E/E = (-0.2 \pm 0.5) \%$ , with  $|\Delta E/E| < 1.4 \%$  at 90% confidence level

# Interaction between soft and hard processes in $pp$



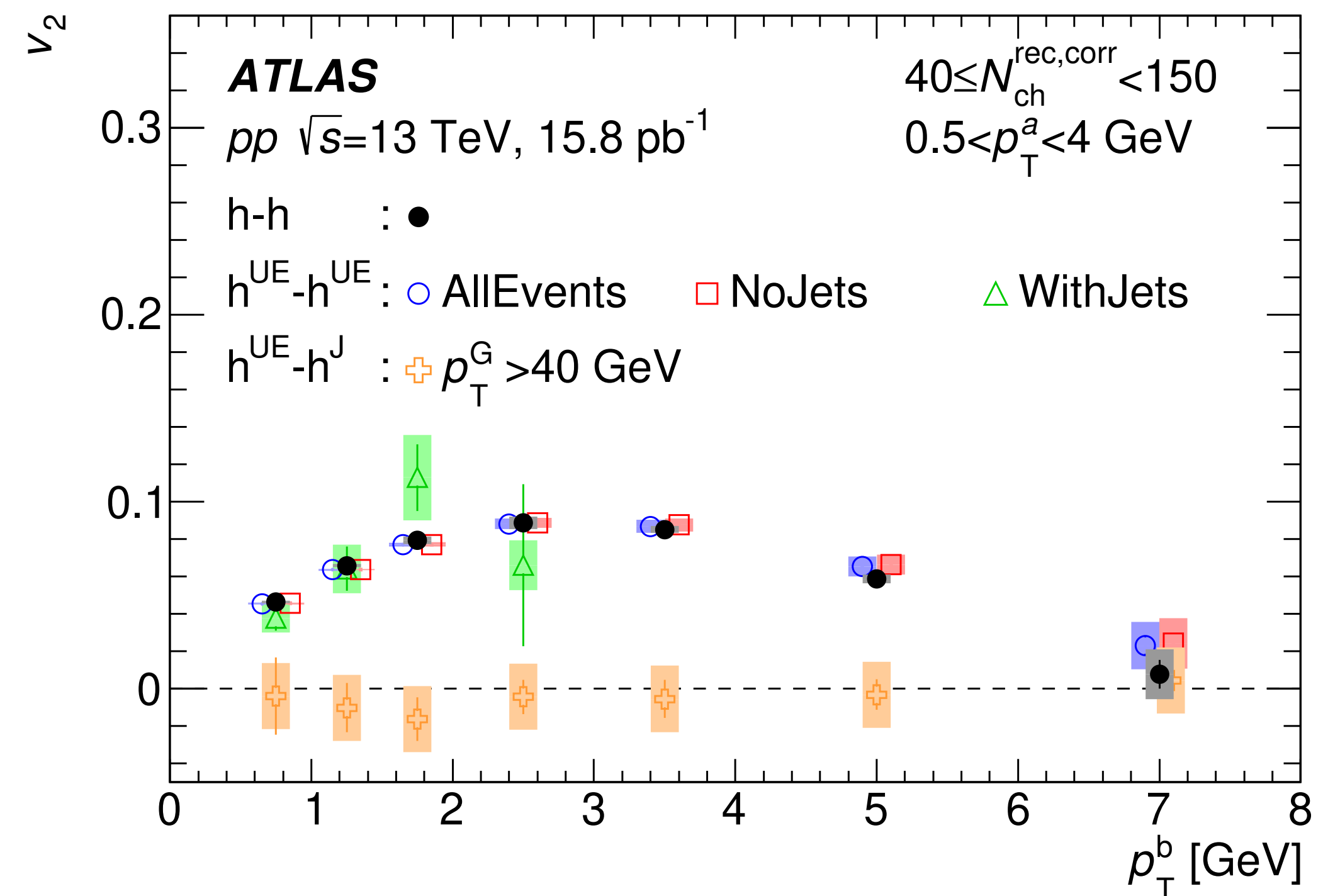
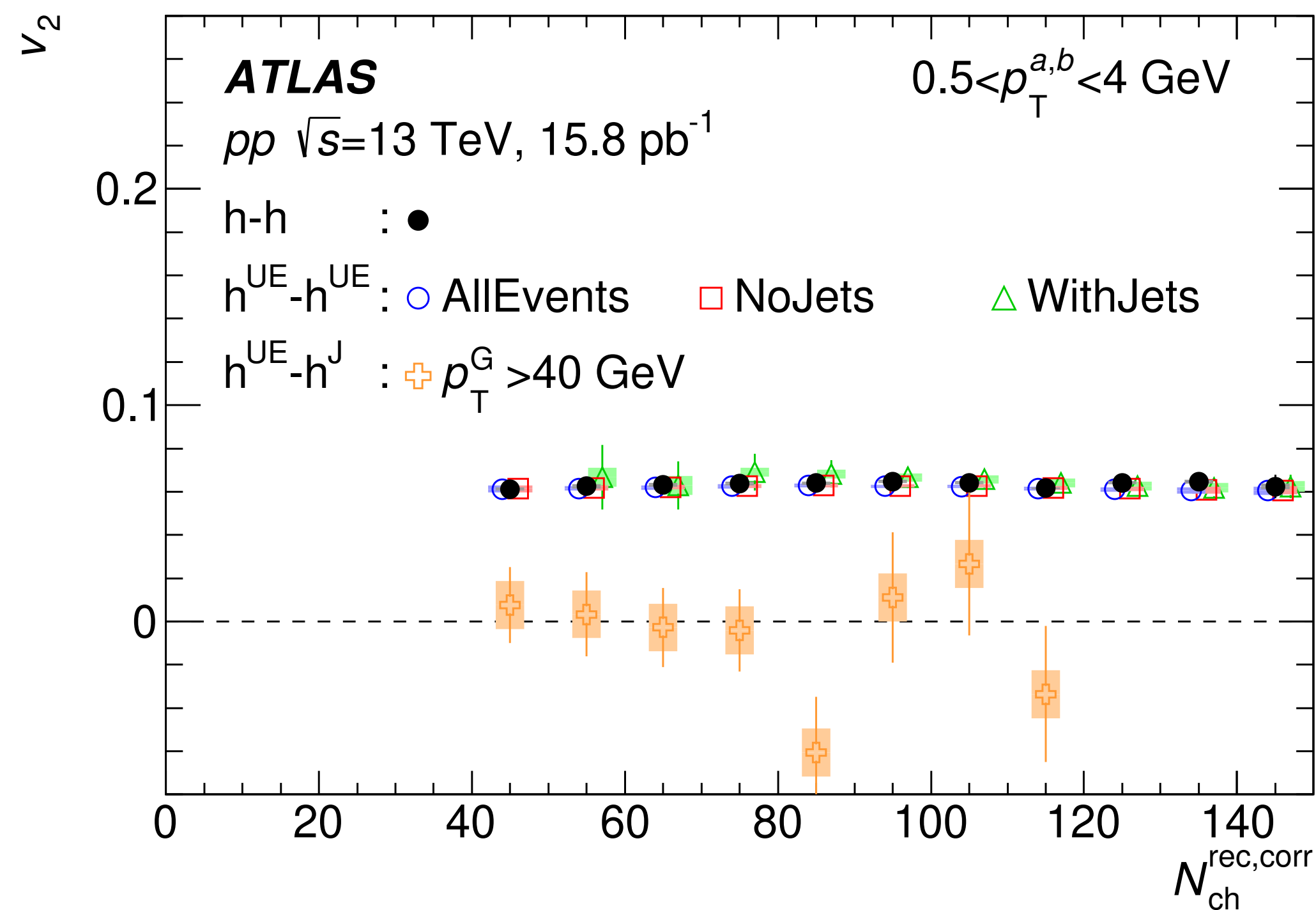
Question #1: does the presence of a hard scattering affect the collective behavior?

Question #2: do jet fragments themselves participate in collective behavior?



# Interaction between soft and hard processes in $pp$

ATLAS, nucl-ex/2303.17357, sub PRL

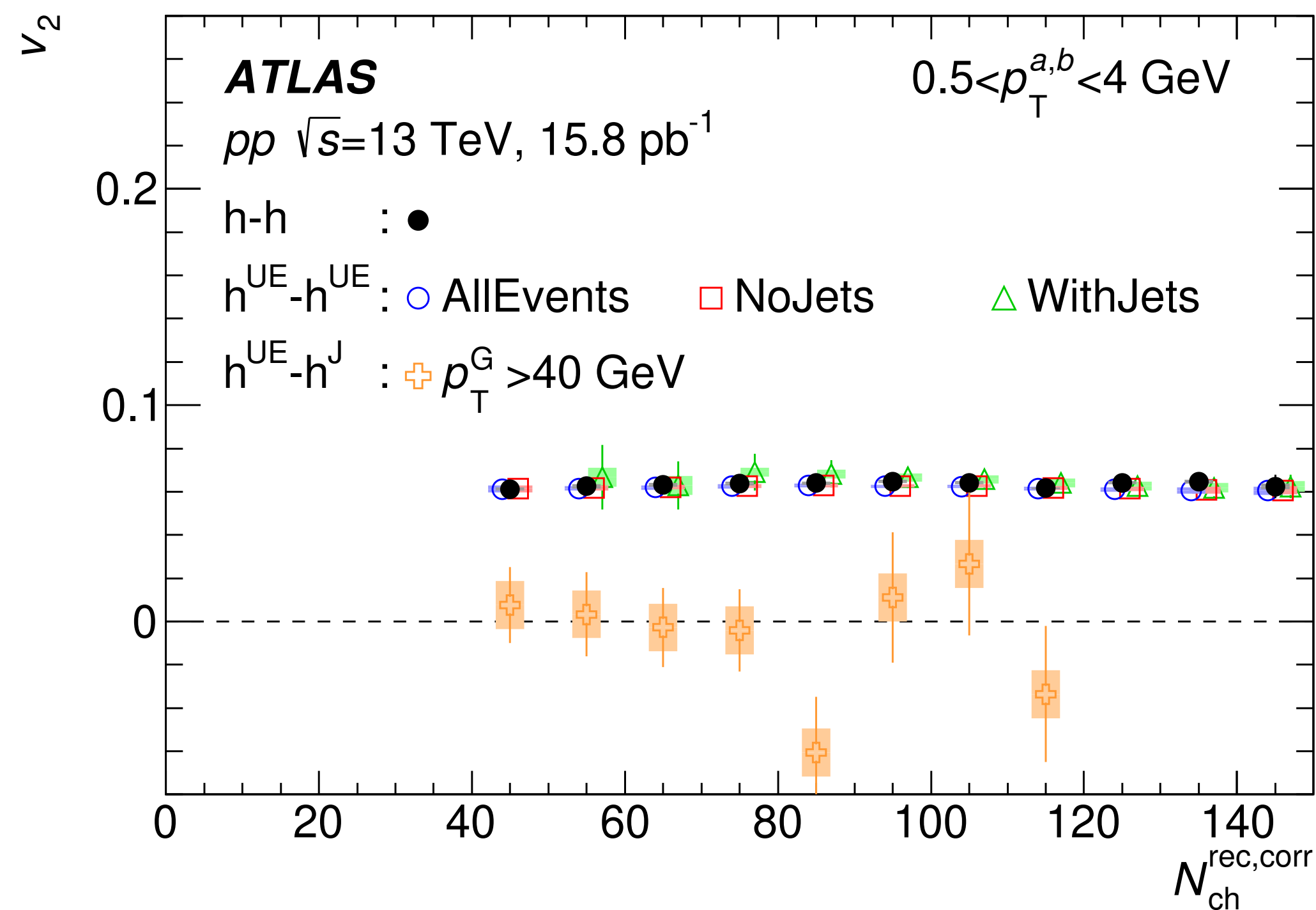


**Nominal  $v_2$  values are unaffected if one **excludes** or **includes** jet events**

➡ similar lack of sensitivity seen in, e.g., Z-boson  $pp$  events

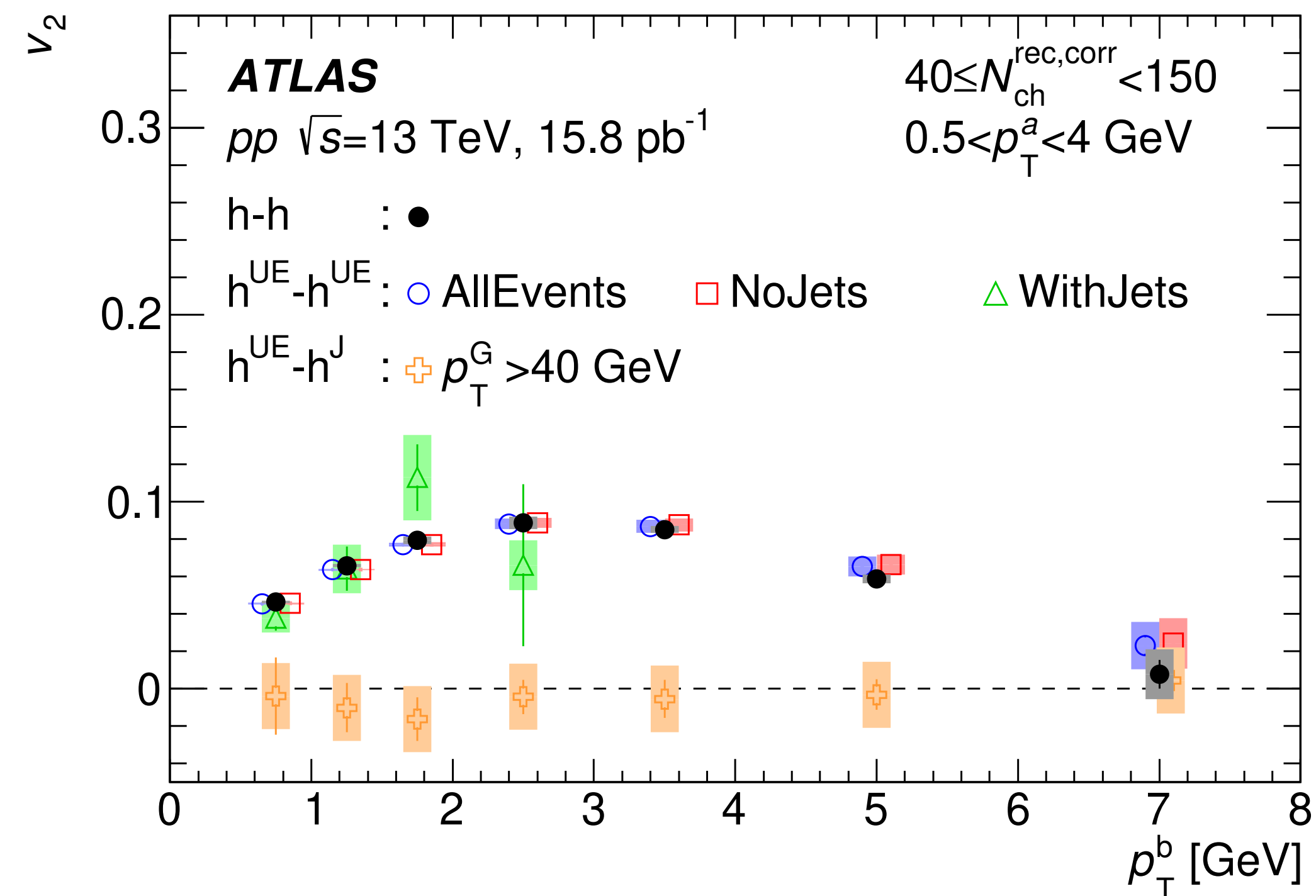
# Interaction between soft and hard processes in $pp$

ATLAS, nucl-ex/2303.17357, sub PRL



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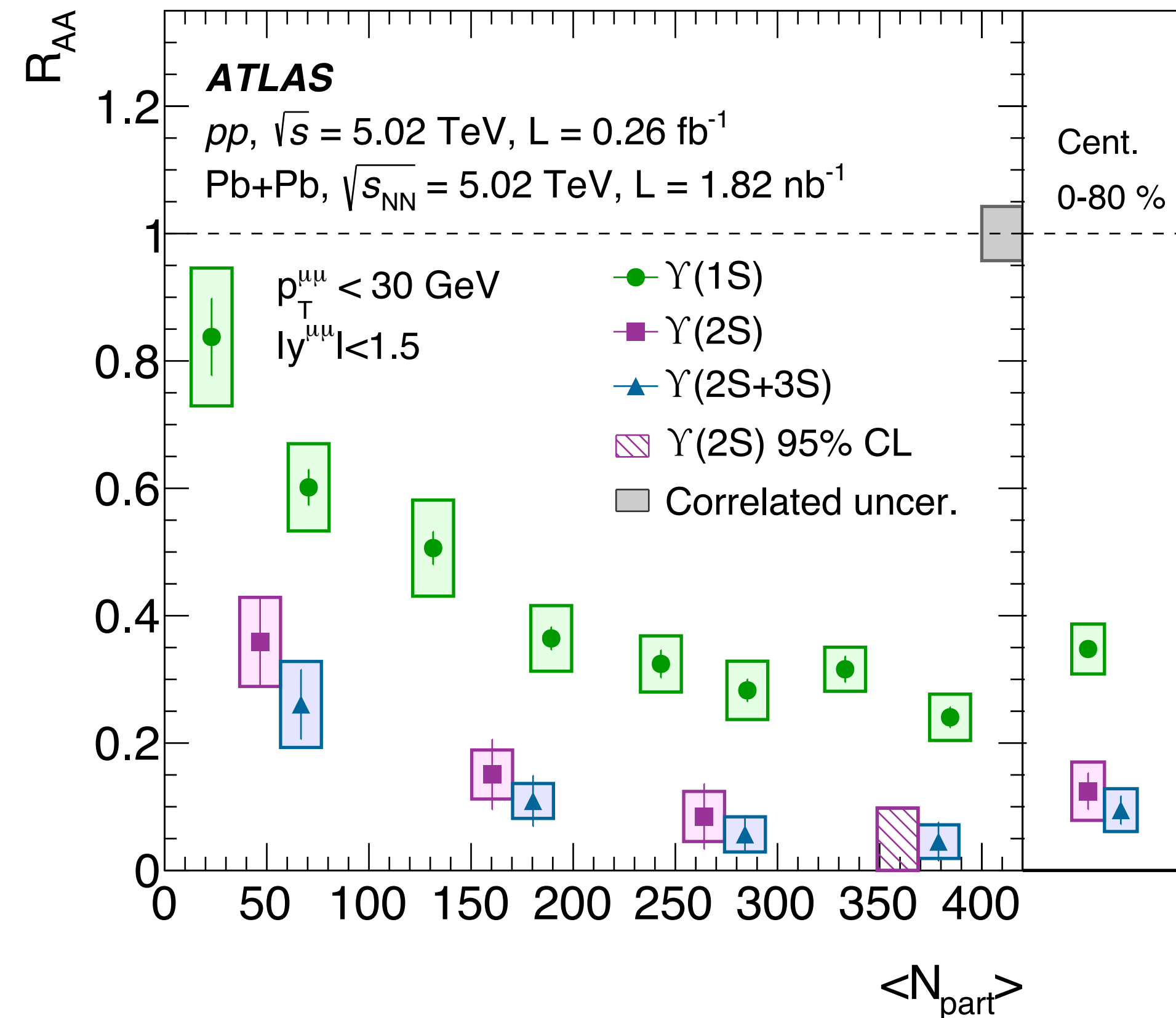
However,  $v_2$  for **hadrons from jet fragmentation** consistent with zero!

➡ (nominally) different than what was observed at high- $p_T$  in  $p+\text{Pb}$ ...

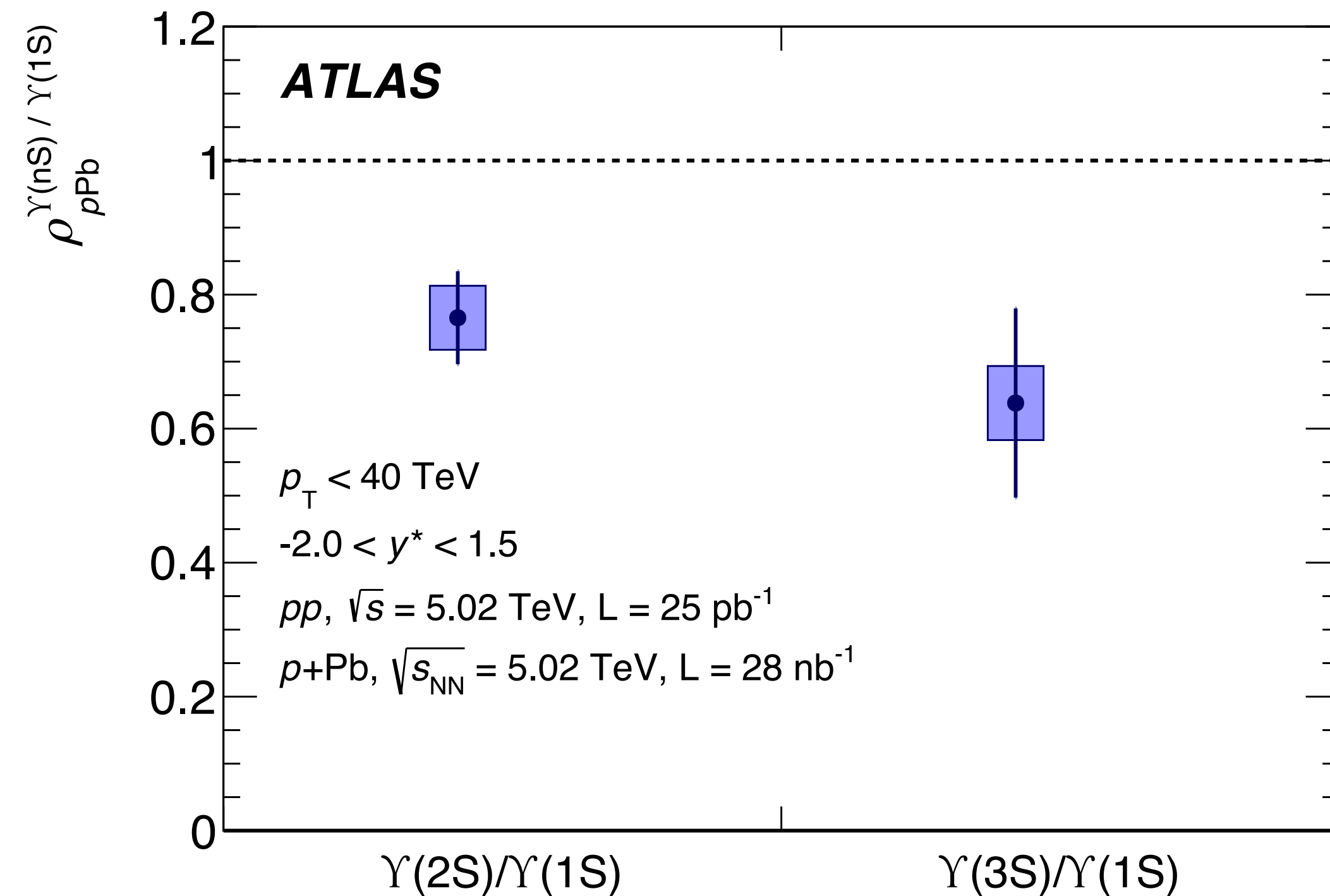


# Upsilon suppression vs. system size

ATLAS, PRC 107 (2023) 054912



ATLAS, EPJC 78 (2018) 171



Sequential suppression of excited  $\Upsilon$  states in Pb+Pb and  $p$ +Pb collisions

➡ study correlation b/w  $\Upsilon$  states and event multiplicity in 13 TeV  $pp$

# Upsilon suppression in ... $pp$ ?

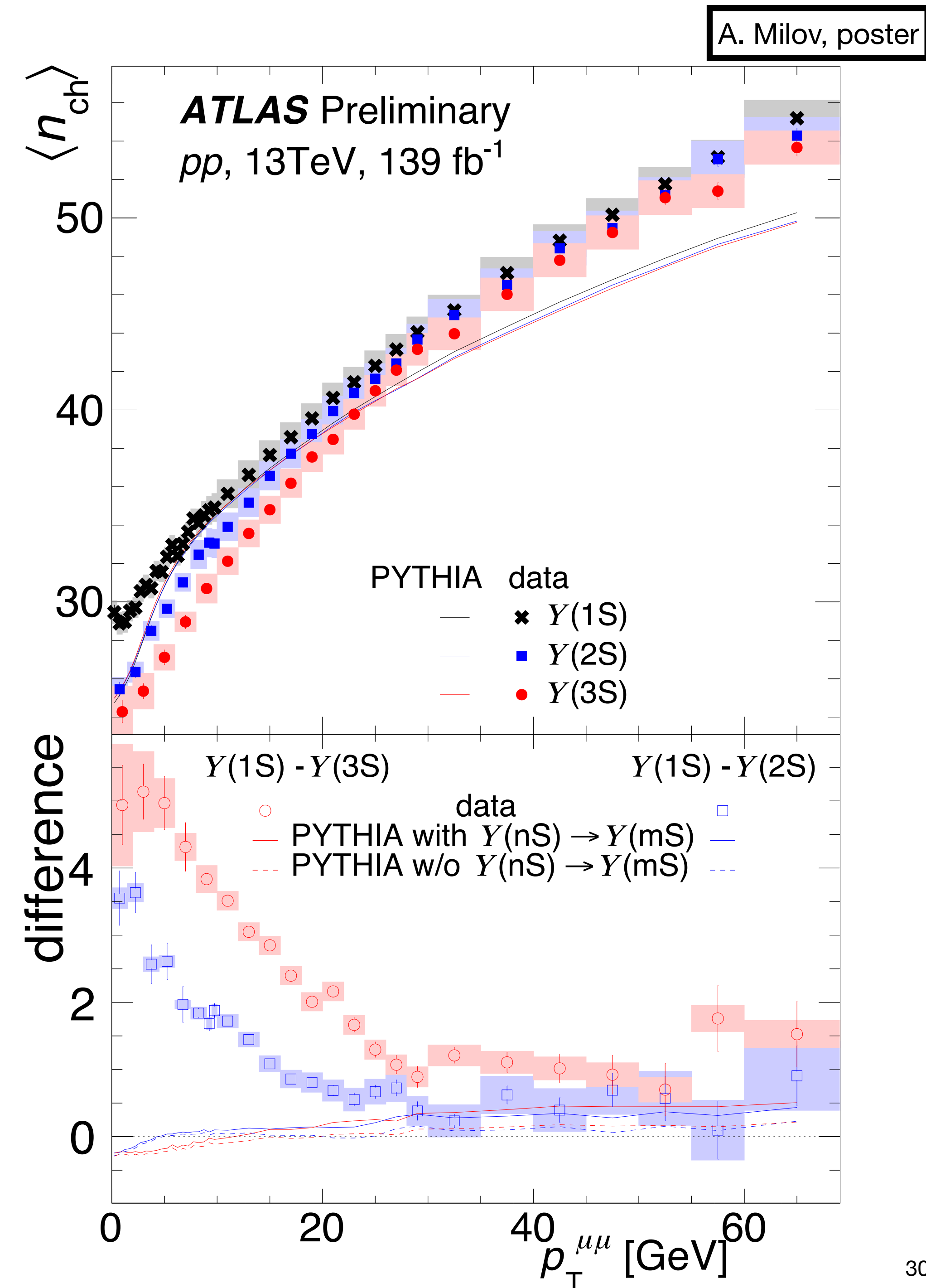
Rather than  $\Upsilon$  yield as a function of  $N_{\text{ch}}$ , study  $\langle N_{\text{ch}} \rangle$  as a function of  $\Upsilon p_{\text{T}}$  for **1S**, **2S**, **3S**

For  $p_{\text{T}}^{\Upsilon} < 30$  GeV, the **1S** is accompanied by more charged particles than the **2S** (and **2S** > **3S**)

“Sequential suppression” as in Pb+Pb?

Non-trivial soft QCD (e.g. color reconnection) physics?

Something to learn about  $\Upsilon$  production mechanisms?

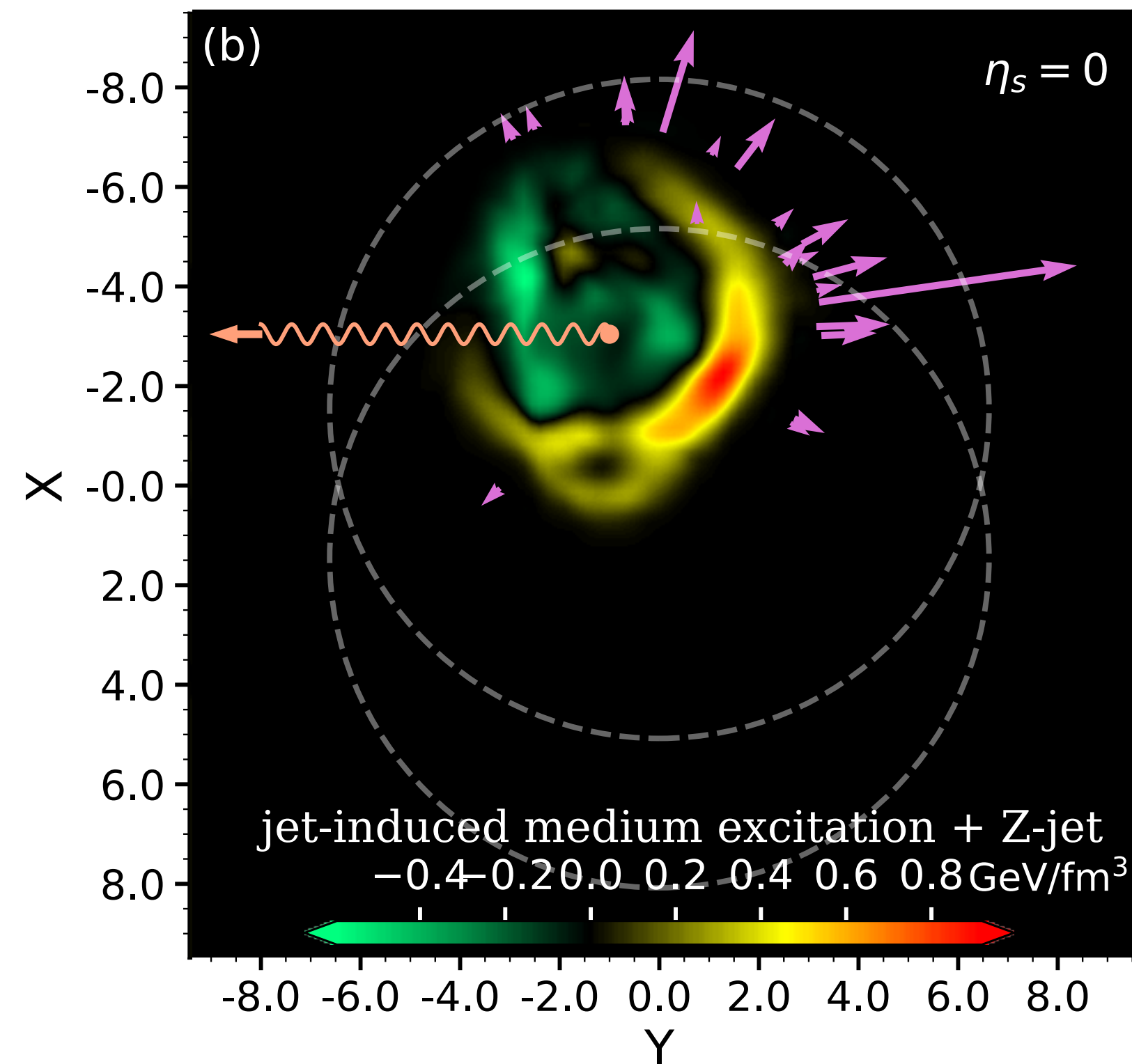






**ATLAS**  
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# Results at Initial Stages '23



## Other highlights:

- Systematic studies of parton energy loss
- $\gamma\gamma \rightarrow \tau\bar{\tau}$  to constrain  $g_\tau - 2$
- ... many more in ATLAS HI Public Results

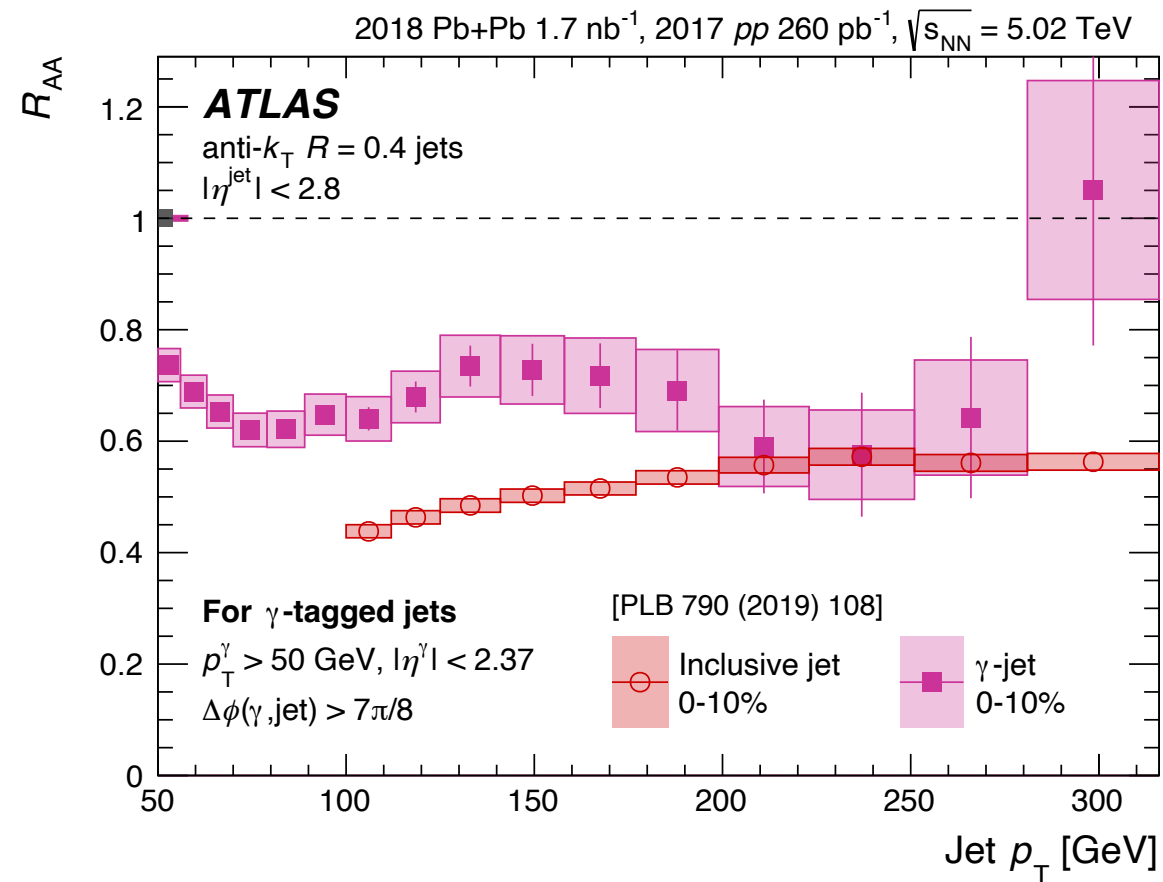


Parallel talks by  
**Peter Steinberg** (Wed 2:20pm)

Posters by  
**Melike Akbiyik**

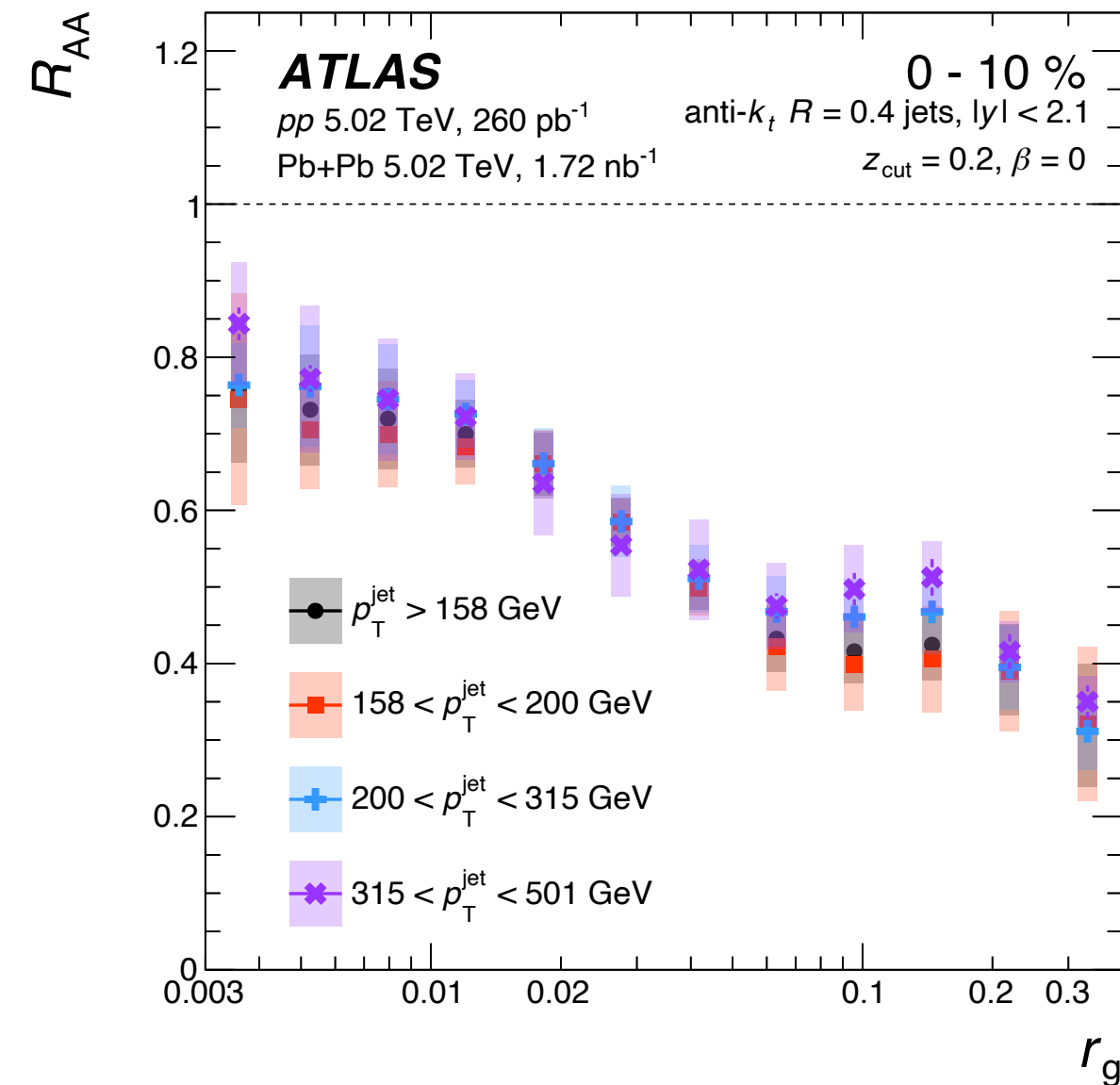
# Systematics of parton energy loss

ATLAS, nucl-ex/2303.10090



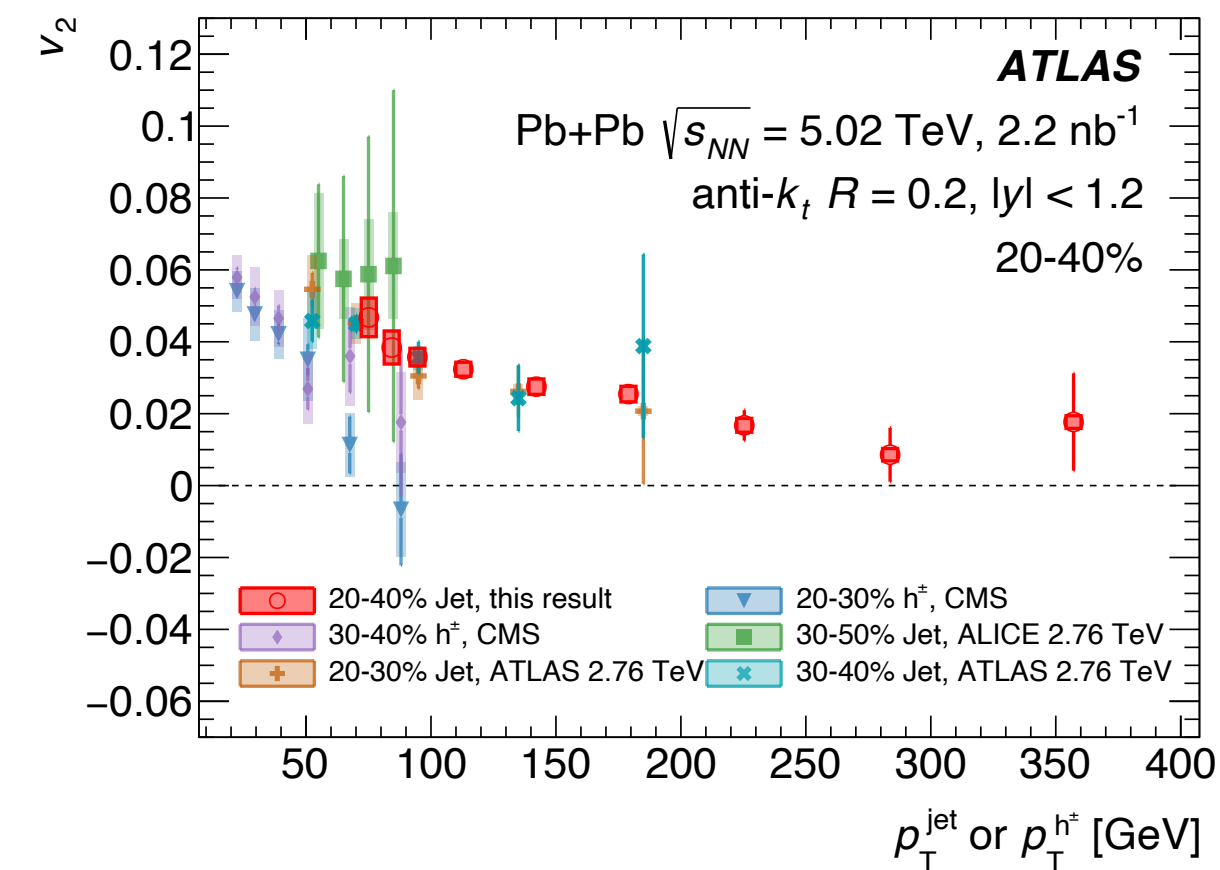
Color  
charge?

ATLAS, PRC 107 (2023) 054909



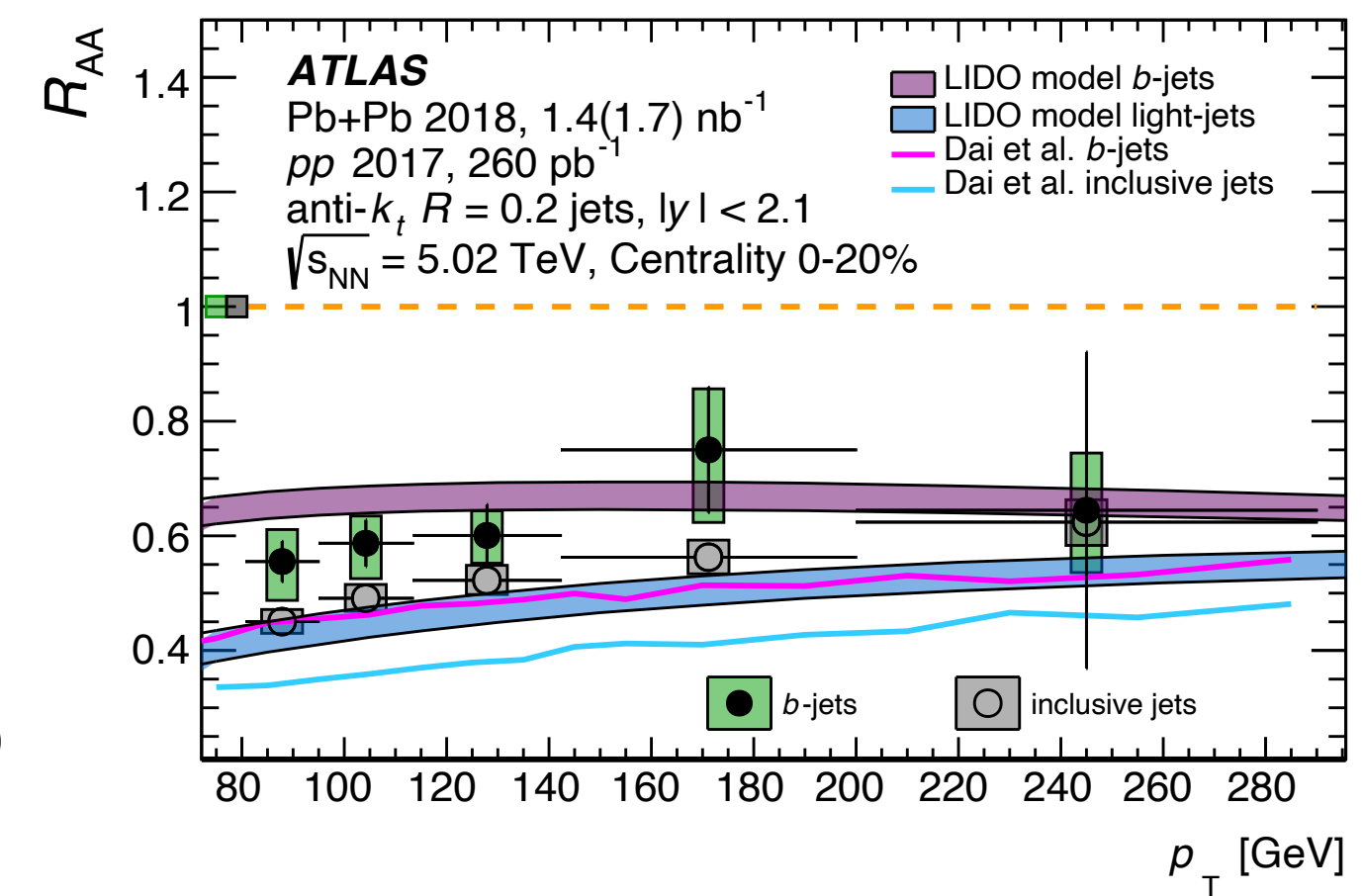
Prong  
structure?

ATLAS, PRC 105 (2022) 064903



Path length vs.  
fluctuations?

ATLAS, EPJC 83 (2023) 438

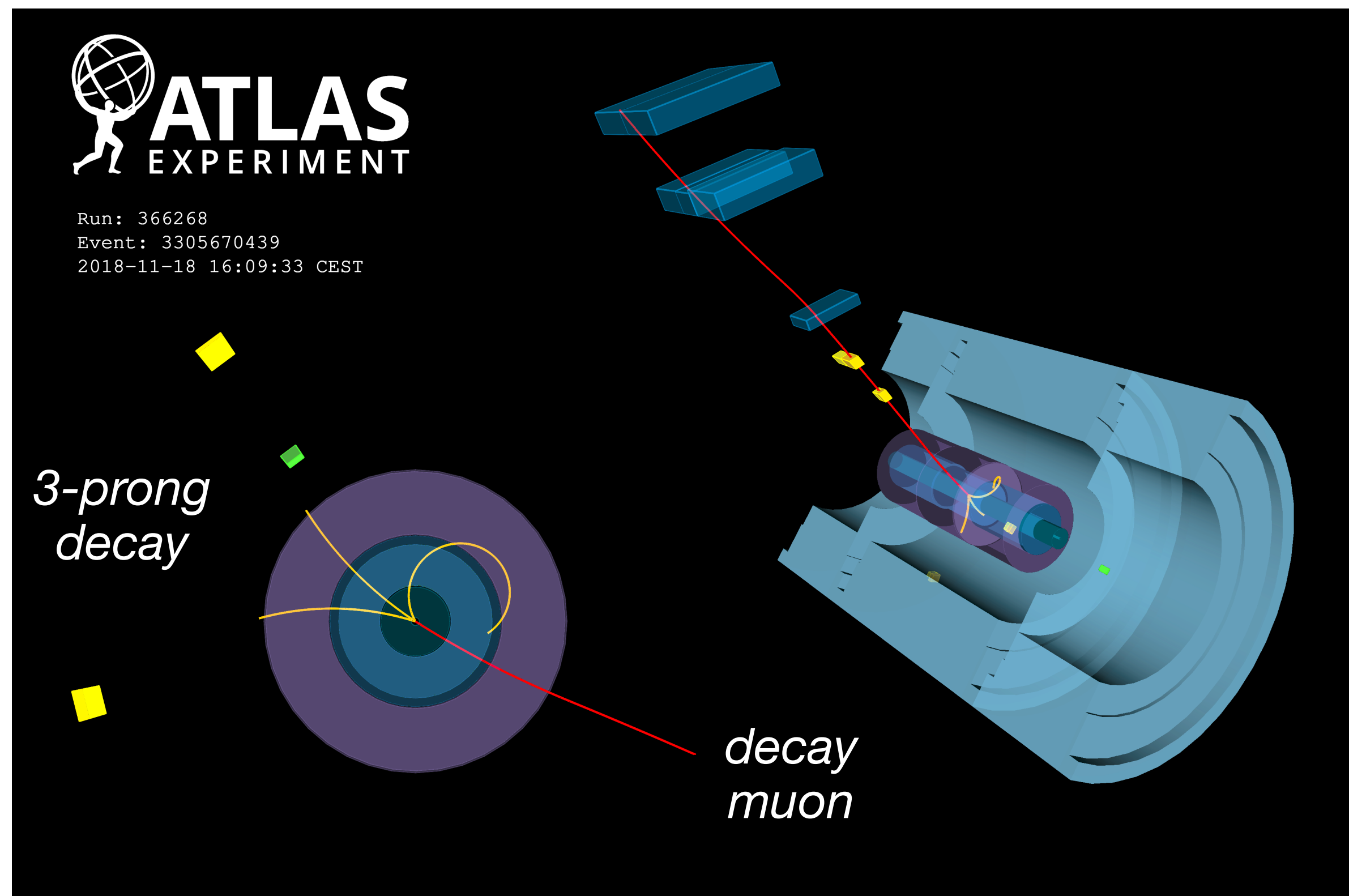


Parton  
mass?

Campaign of measurements in ATLAS to **isolate what controls the physics**

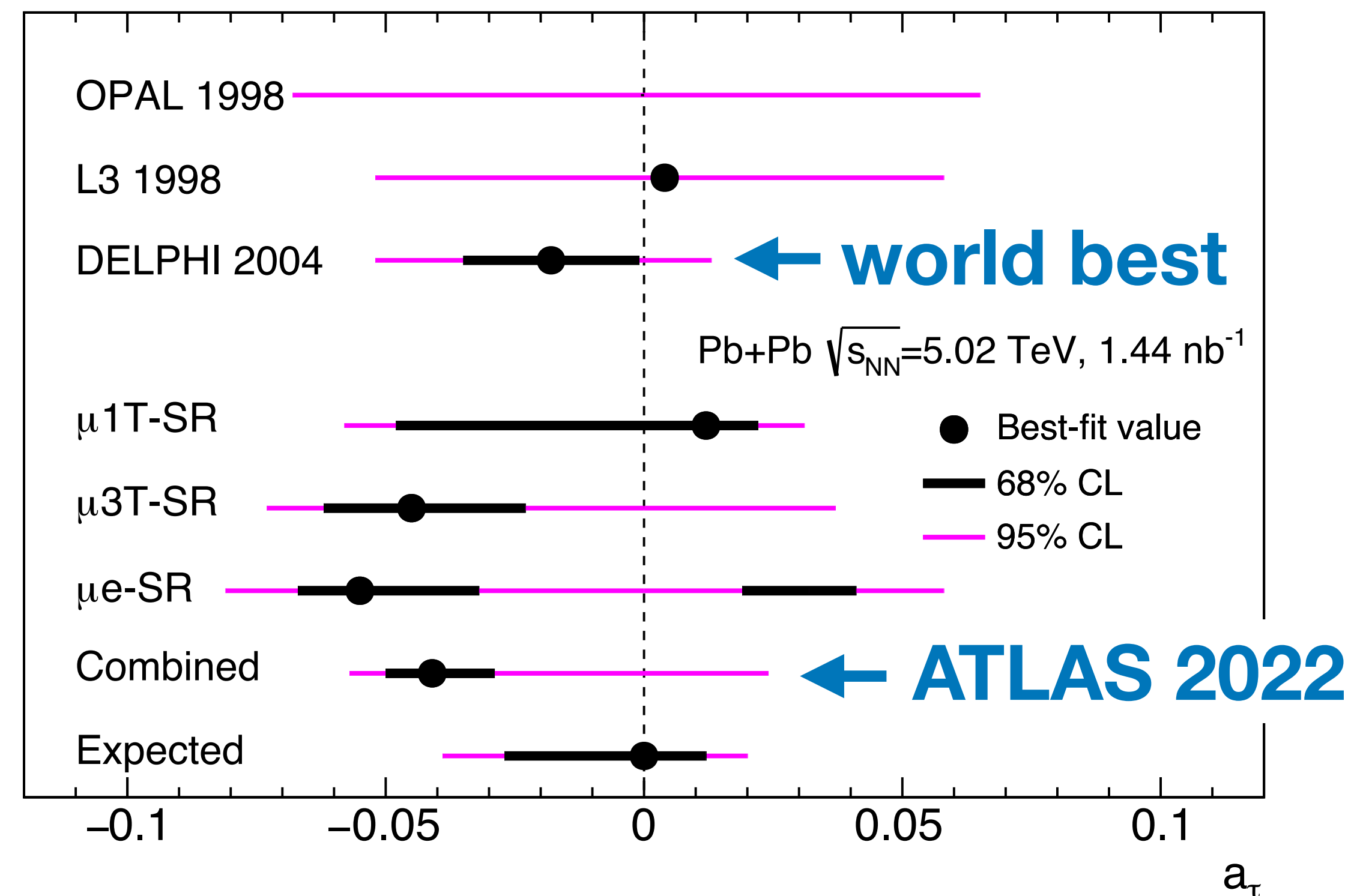


# $\gamma\gamma \rightarrow \tau\bar{\tau}$ to constrain $g_\tau - 2$



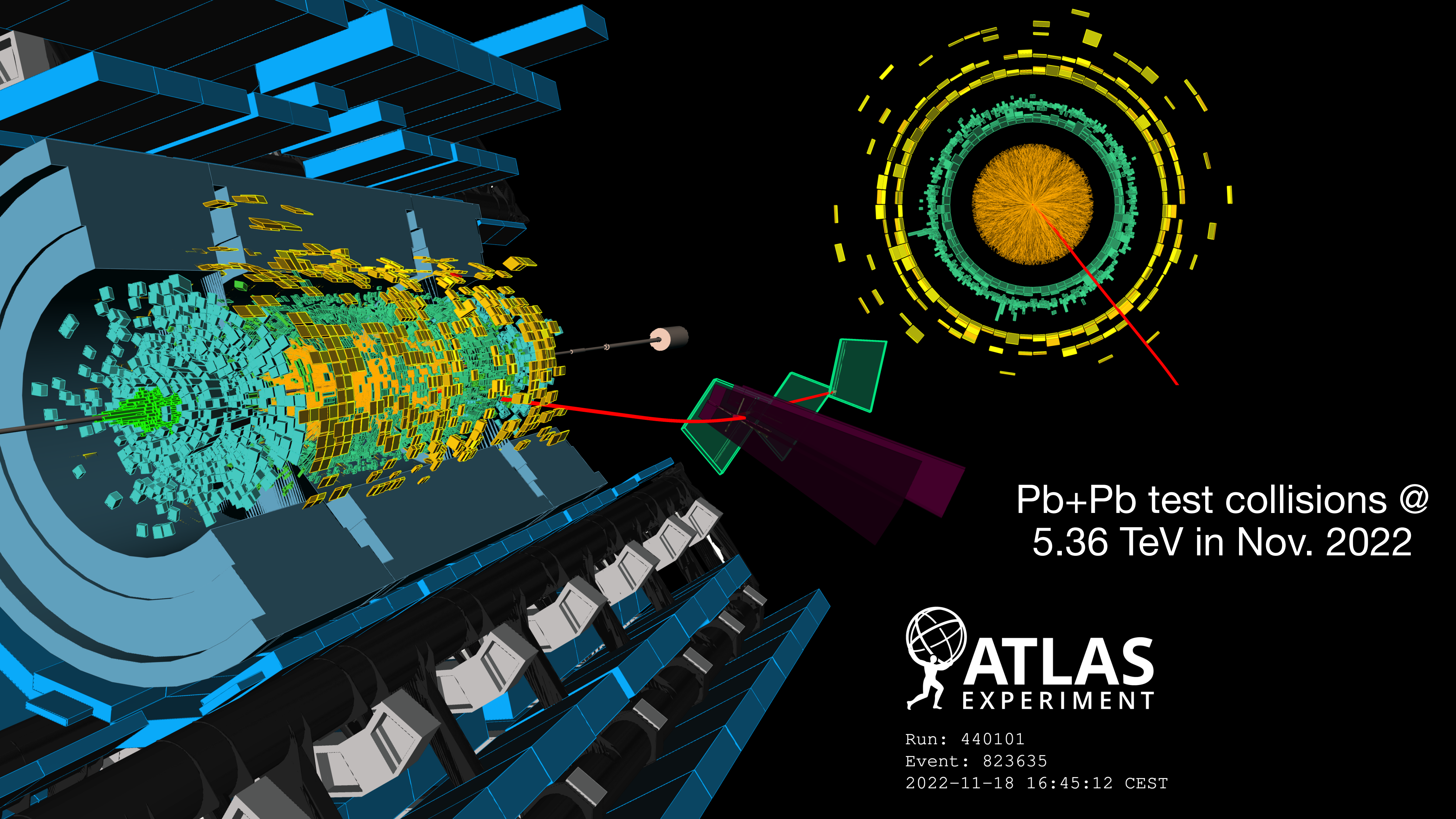
Leverage the clean **initial state** of UPC events to make precision measurement of how the tau couples to photons

ATLAS, hep-ex/2204.13478, in press PRL



Measurement in 2018 Pb+Pb data is immediately competitive with world best, and is stat. (not syst.) limited





Pb+Pb test collisions @  
5.36 TeV in Nov. 2022

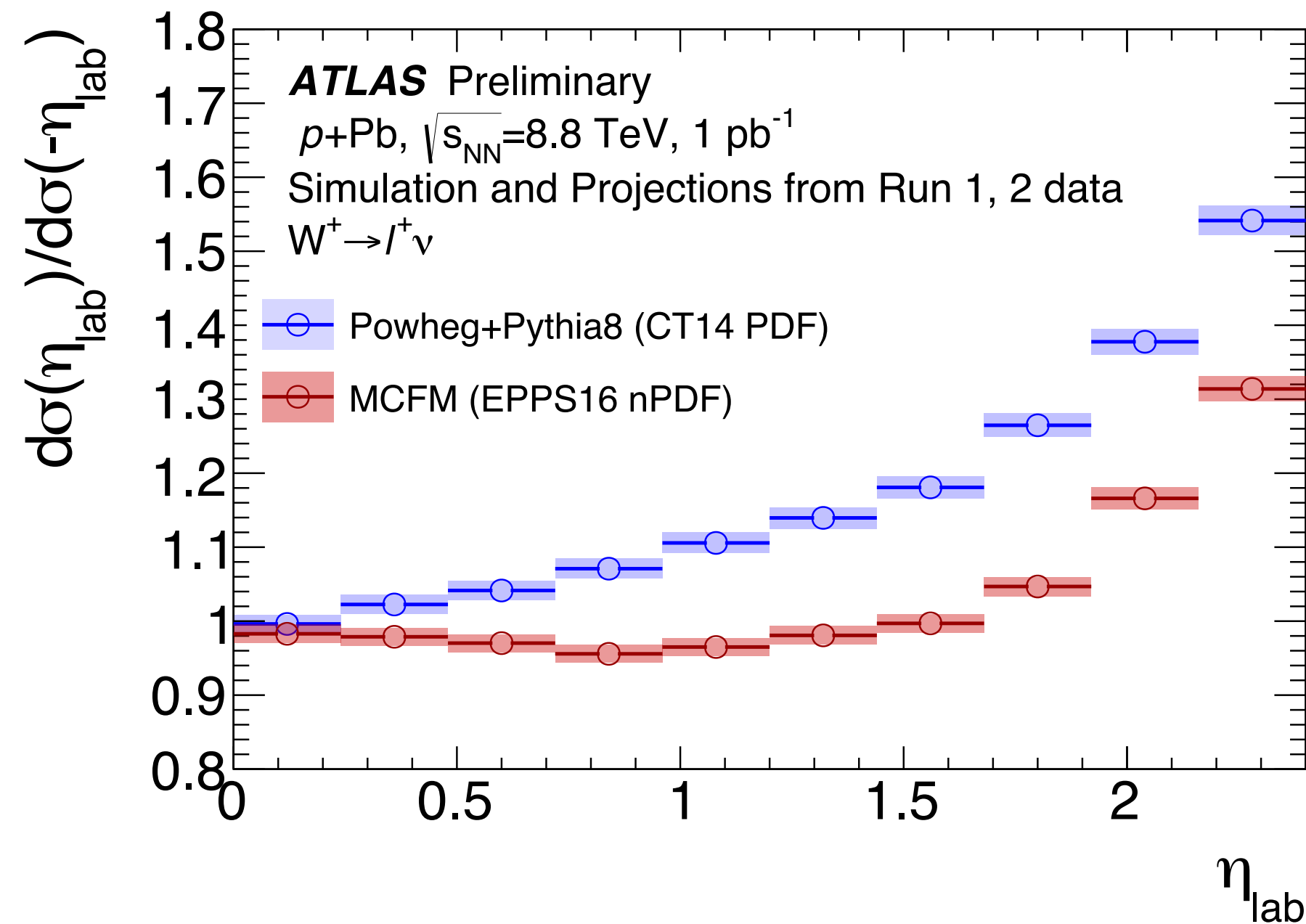


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Event: 823635  
2022-11-18 16:45:12 CEST

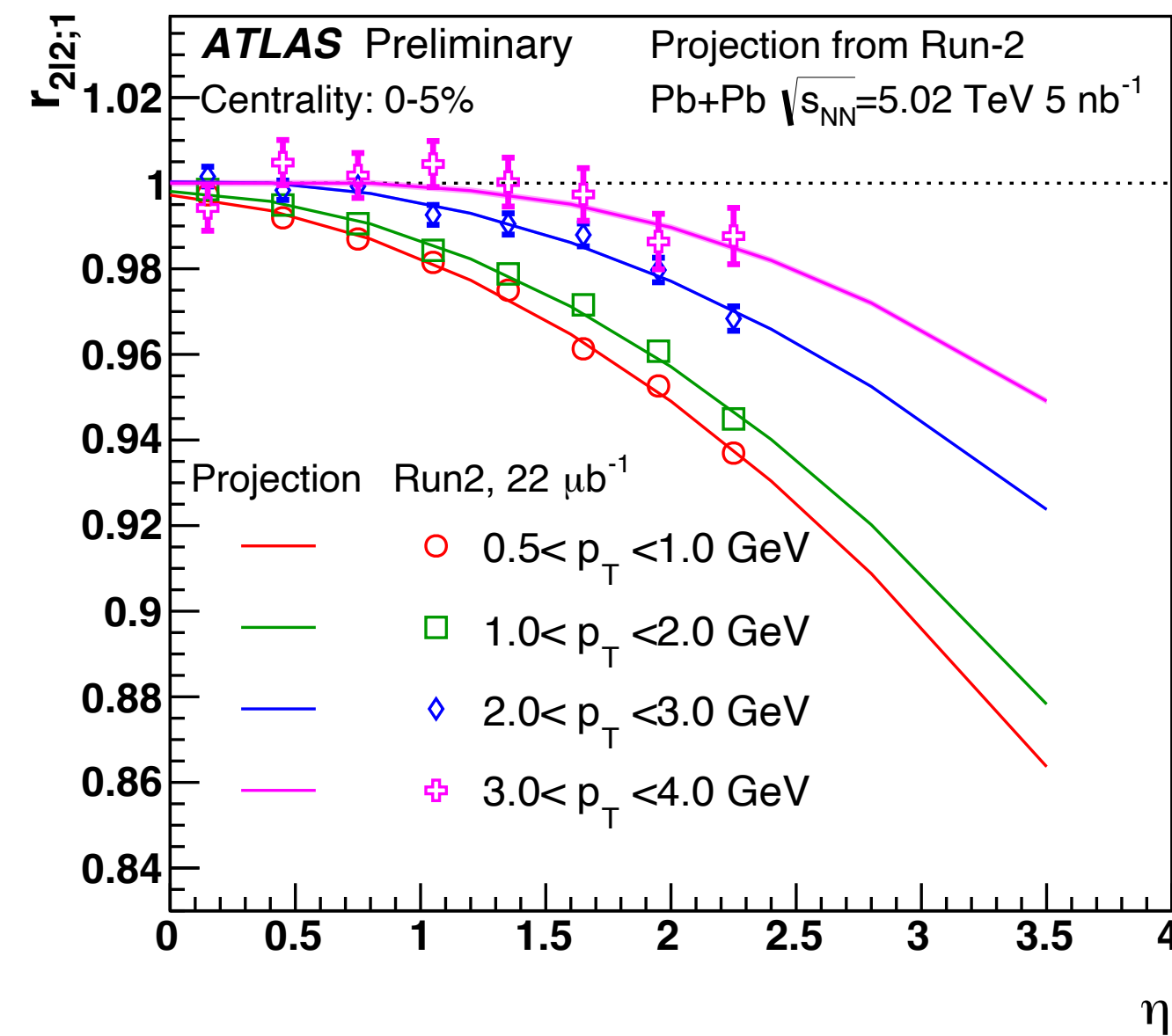


# Plans during LHC Run-3

Many potential measurements in the HL-LHC era for Initial Stages topics:

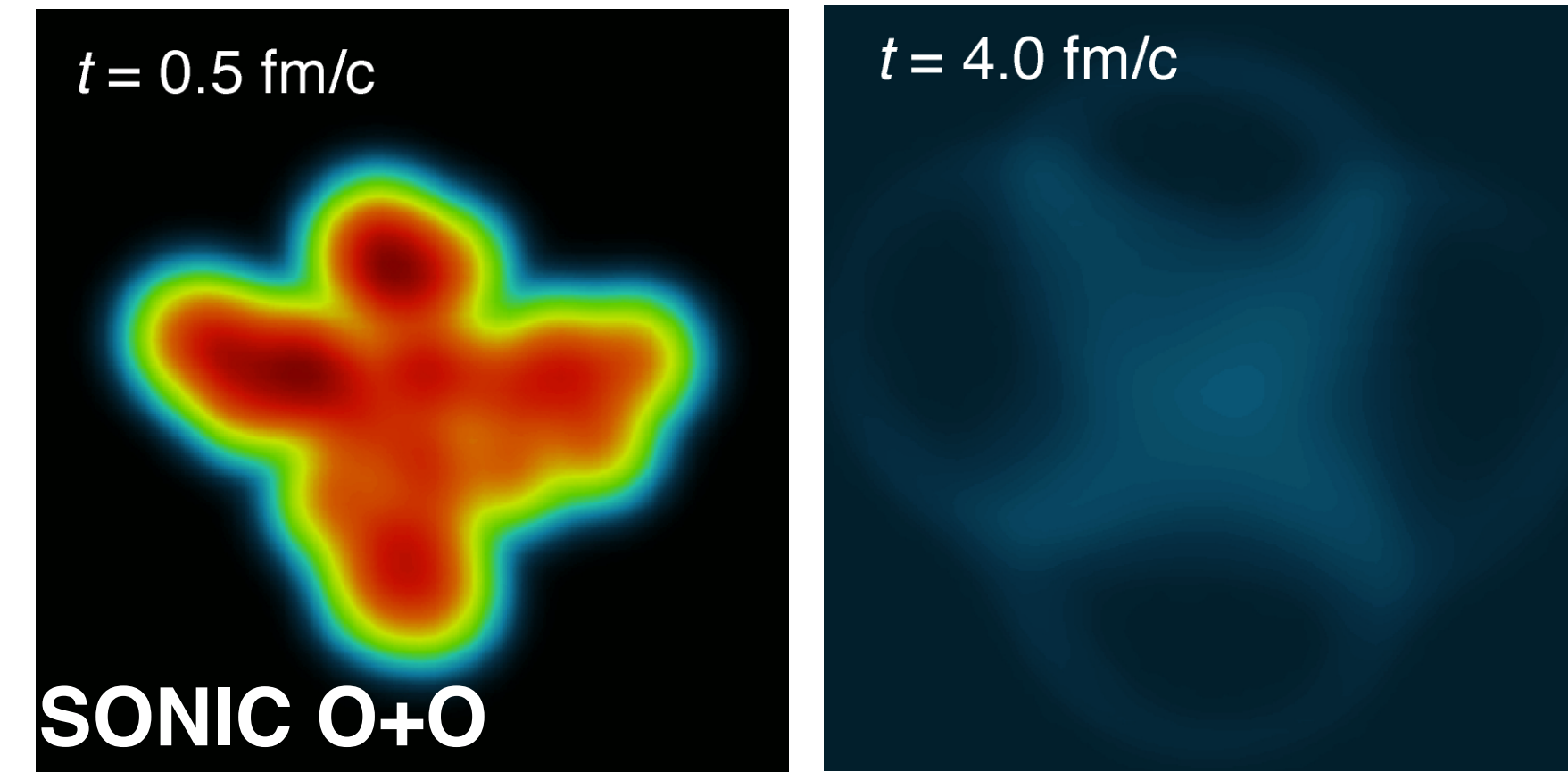


Precision EW-based probes of nPDFs



Statistics-limited soft physics measurements

Lim et al, PRC 99 (2019) 044904



O+O and  $p+O$  - explore small systems with a novel geometry

# Results at Initial Stages '23

## Initial state of the nucleus:

- $v_n - [p_T]$  correlations in Pb+Pb and Xe+Xe
- $\gamma\gamma \rightarrow \mu^+\mu^-$  in hadronic Pb+Pb collisions
- dijet production in  $\gamma + A$

## Initial state of the proton:

- Flow decorrelations in  $pp$  (and Xe+Xe)
- Correlation between “centrality” and dijet kinematics in  $p+Pb$

## Final state effects in small systems:

- Jet-hadron correlations in  $p+Pb$
- Collective behavior in  $pp$  with jets
- Correlation between  $\Upsilon(1,2,3S)$  & UE in  $pp$

## Other highlights:

- Systematic studies of parton energy loss
- $\gamma\gamma \rightarrow \tau\bar{\tau}$  to constrain  $g_\tau - 2$
- ... many more in [ATLAS HI Public Results](#)



Parallel talks by

**Riccardo Longo** (Tue 4:10pm)  
**Pengqi (Bill) Yin** (Wed 4:50pm)  
**Peter Steinberg** (Wed 2:20pm)

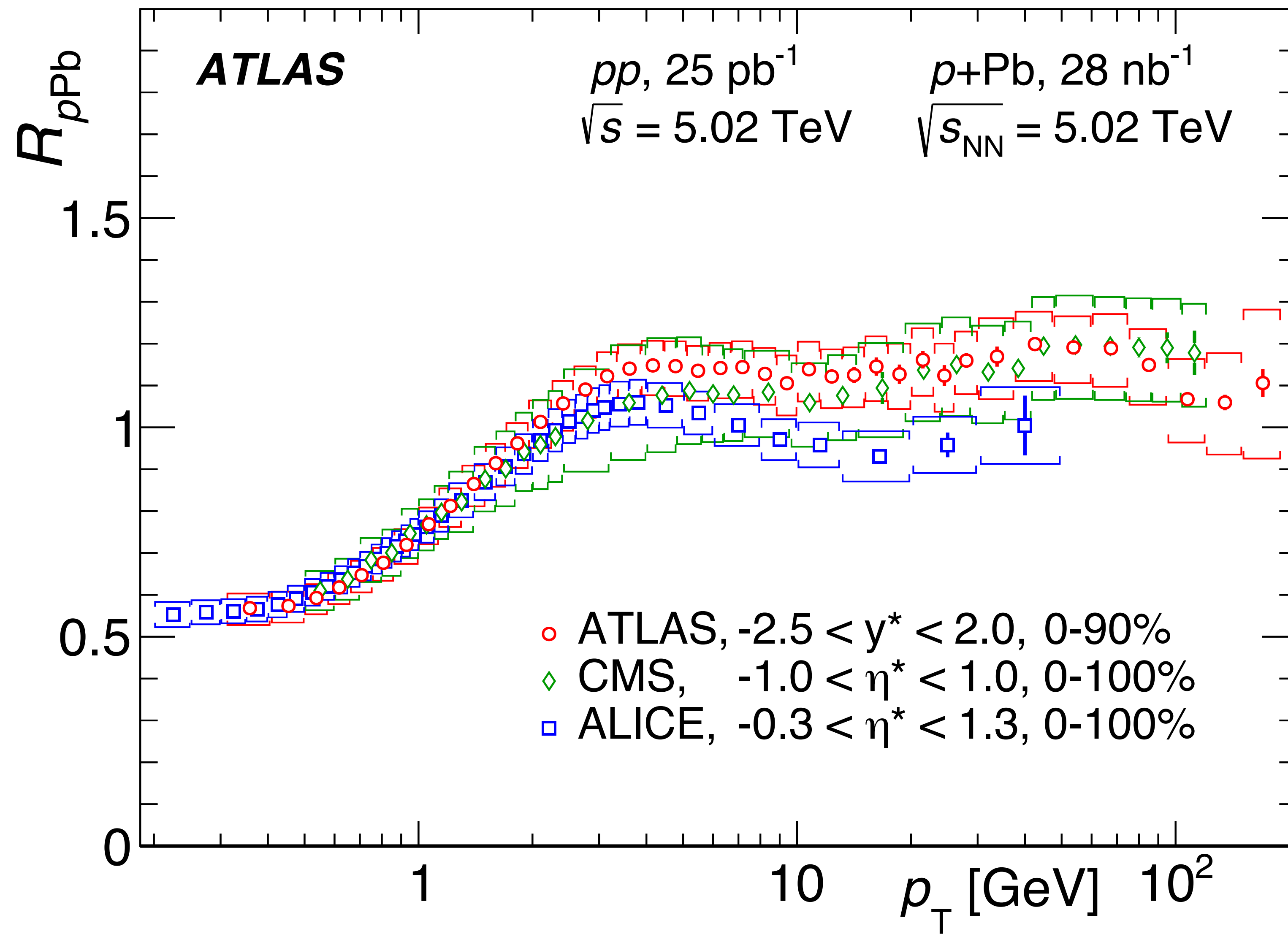
Posters by

**Melike Akbiyik**  
**Alexander Milov**

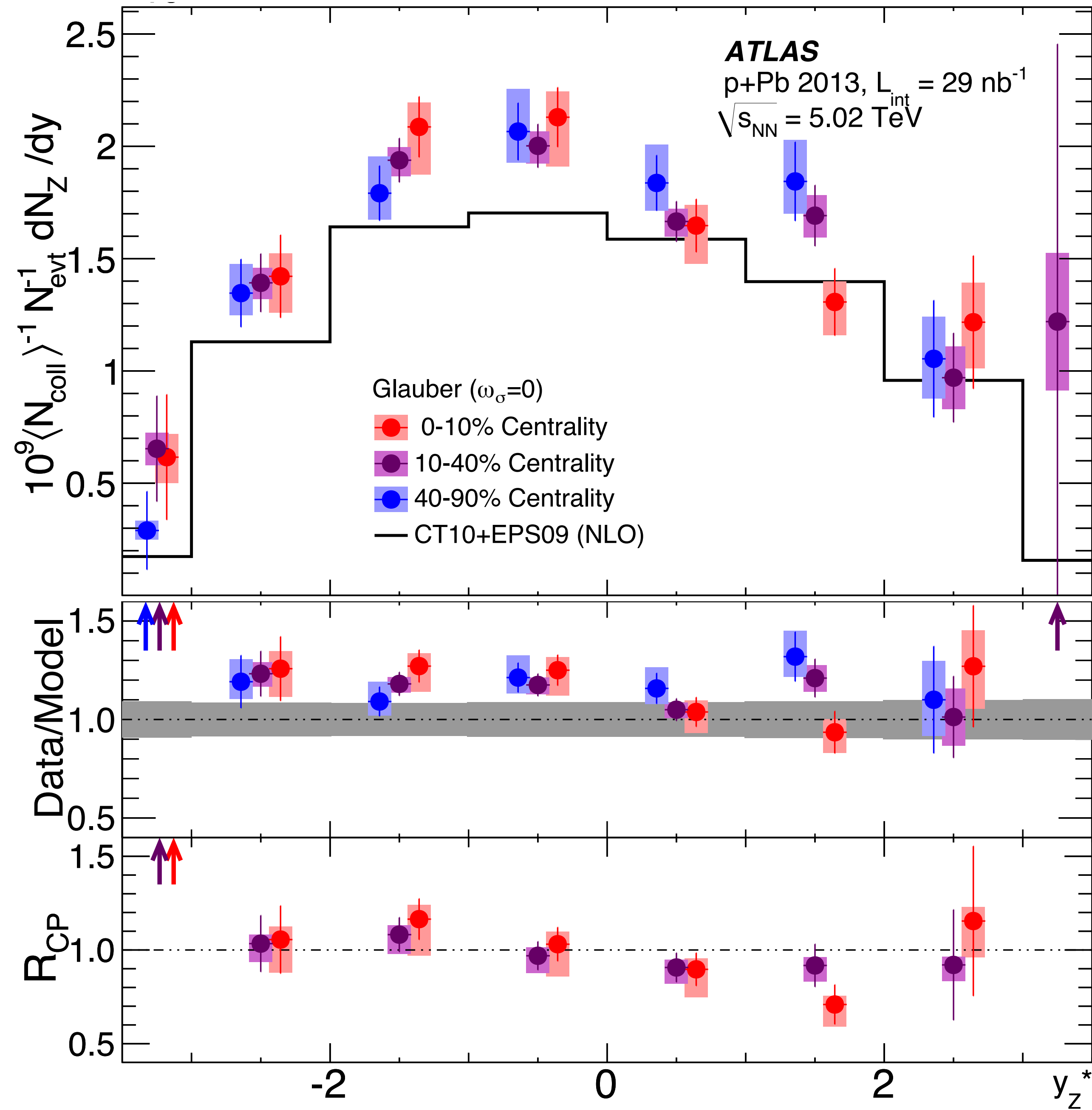
**Somadutta Bhatta**  
**Blair Seidlitz**







# ATLAS, PRC 92 (2015) 044915







Rally in Copenhagen, February 2022



Ukrainian embassy in Copenhagen, March 2022