UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

HP2024 NAGASAKI

Hard-jet correlations in large and small systems

Riccardo Longo

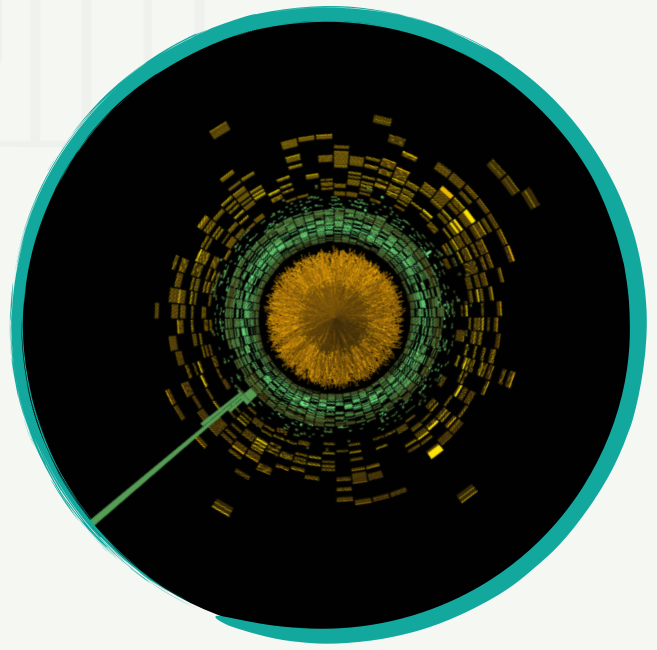
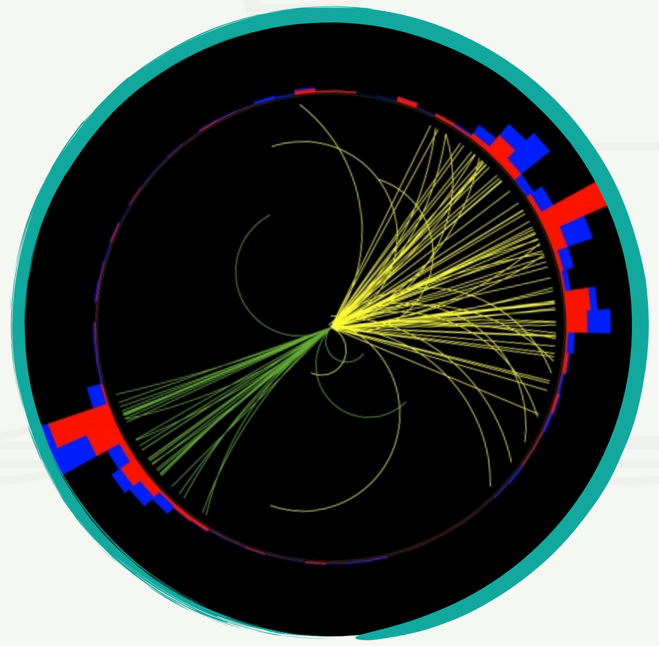
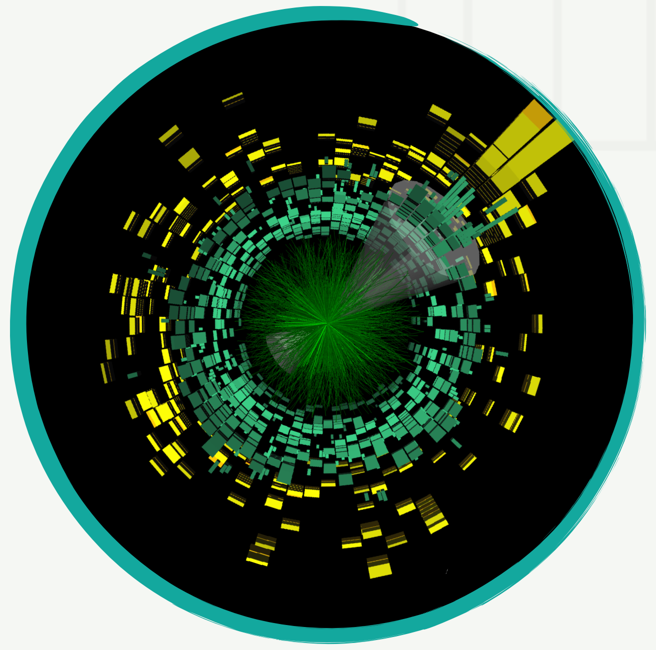
26th September 2024

What is this talk about?

Goal: review recent results using **hard-jet correlations** to better understand the nature of HI collisions (small & large systems)



Boson+jet | **h+jet** | **jet+jet**

Jet overview & HF → see Yaxian's talk

E-E correlator & substructure → see Rithya's talk

A few topic I will cover today

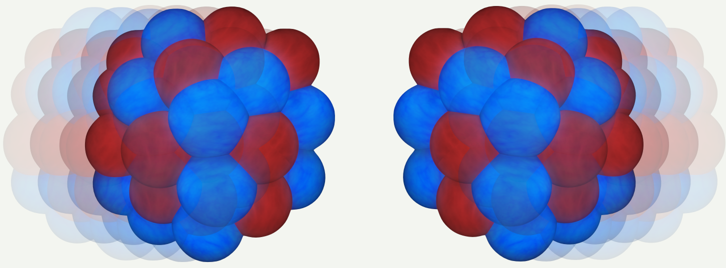
Large Systems

1. Quenching dependence on jets properties
2. Medium response
3. Path-length dependence of E_{loss}

Small Systems

A. E_{loss} in small systems?
B. Relevance of Color Fluctuations
C. nPDF modification

Large Systems



Jet interaction with the medium

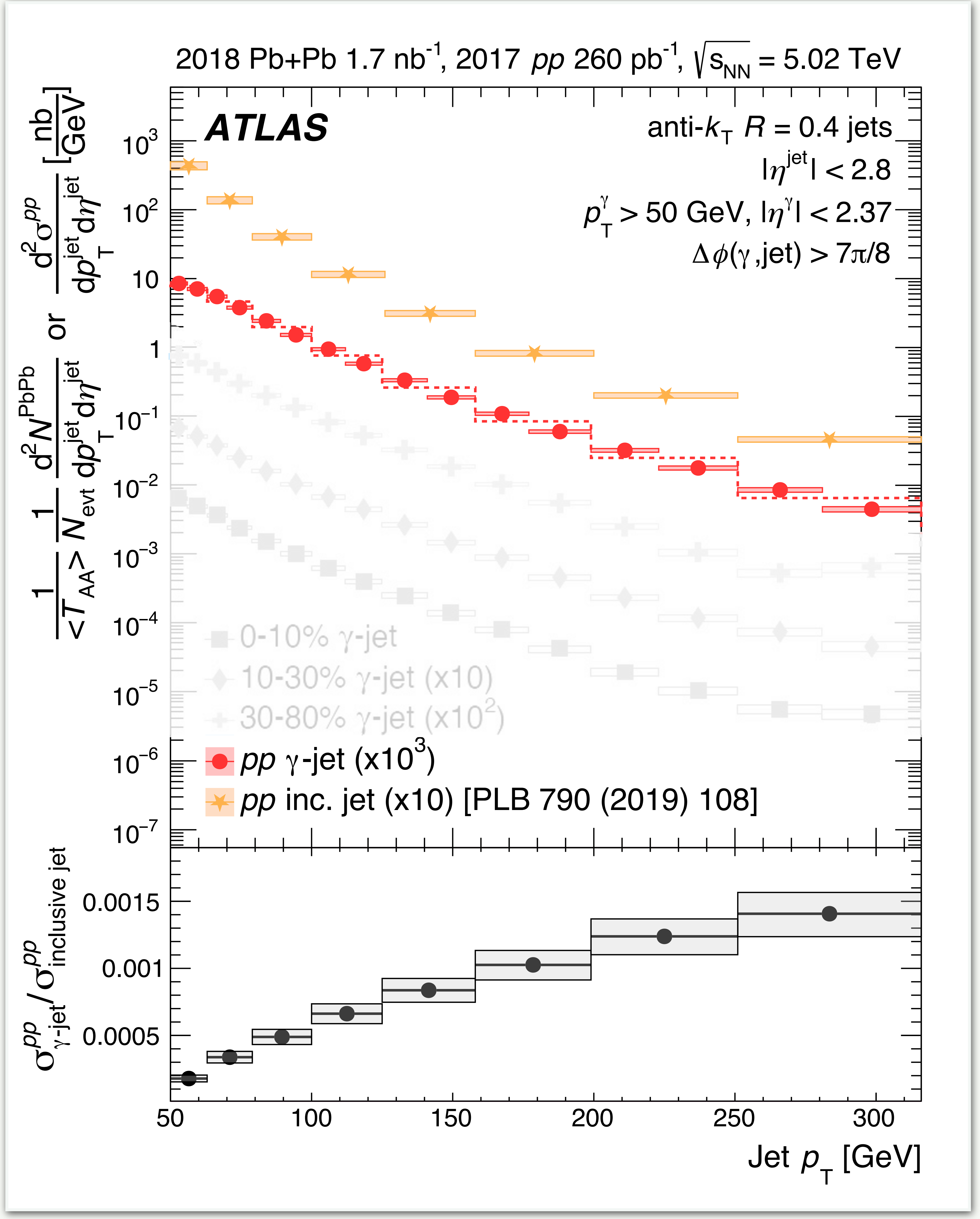
1

How does the quenching depend on jets properties?

Color charge dependence: role of pp p_T spectrum

pp spectra steepness matter!

Inclusive jets in pp have a steeper spectrum compared to **γ-tagged jets**



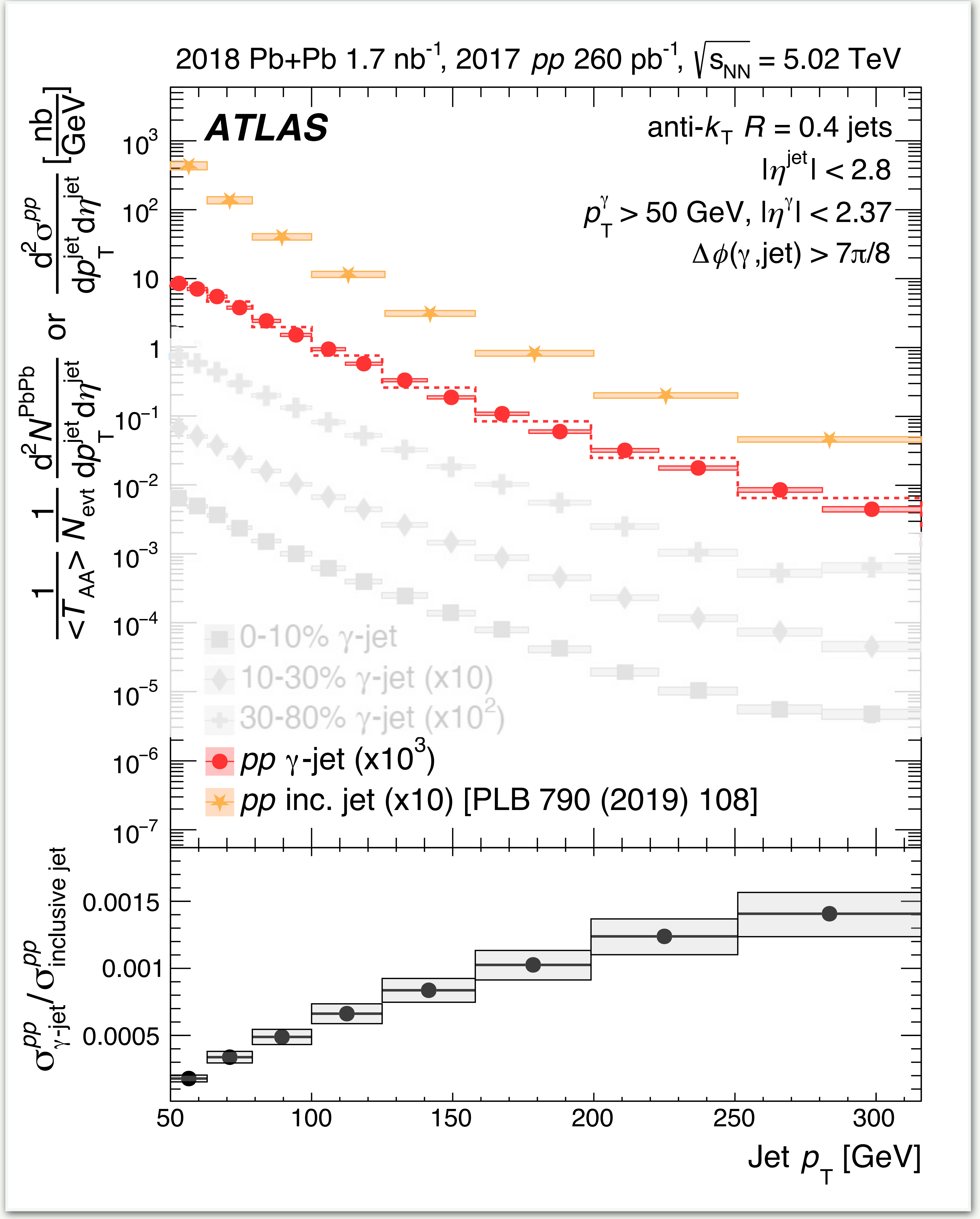
PLB 846 (2023) 138154

Color charge dependence: role of pp p_T spectrum

pp spectra steepness matter!

Inclusive jets in pp have a steeper spectrum compared to **γ-tagged jets**

Assuming the same energy loss in QGP (⟵), lower R_{AA} expected for inclusive jets compared to γ-tagged ones

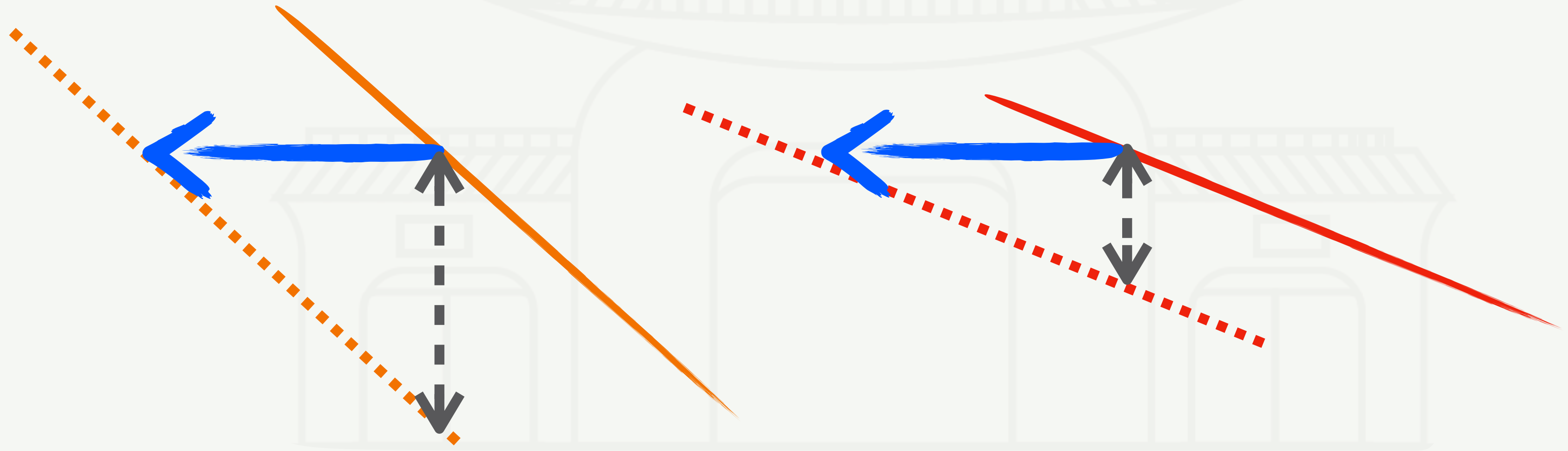


PLB 846 (2023) 138154

— pp spectrum

⋯ quenched spectrum

⟵ ⟶ expected nuclear modification at given p_T

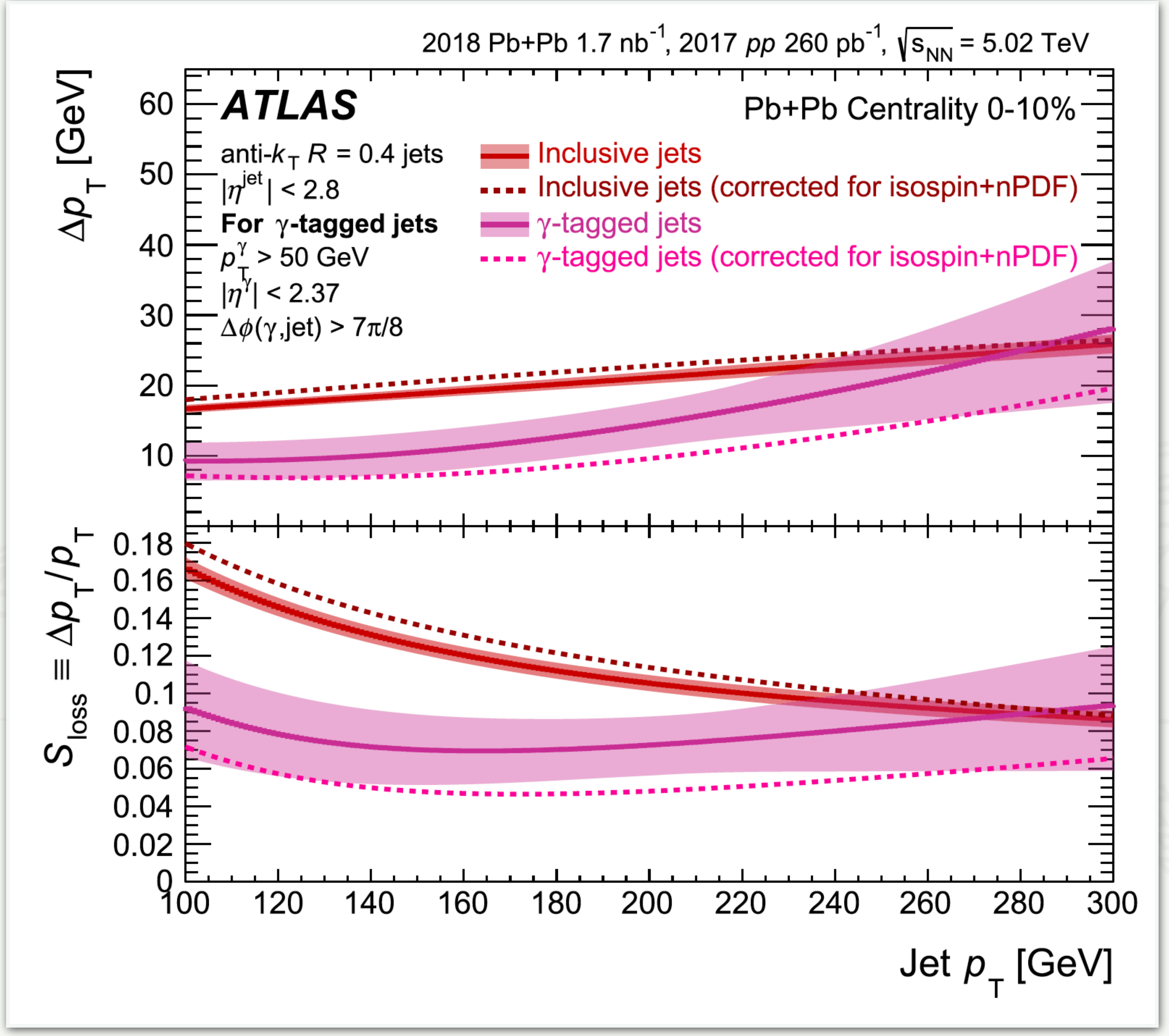


Steeper p_T in pp
↓
larger modification
↓
lower R_{AA}

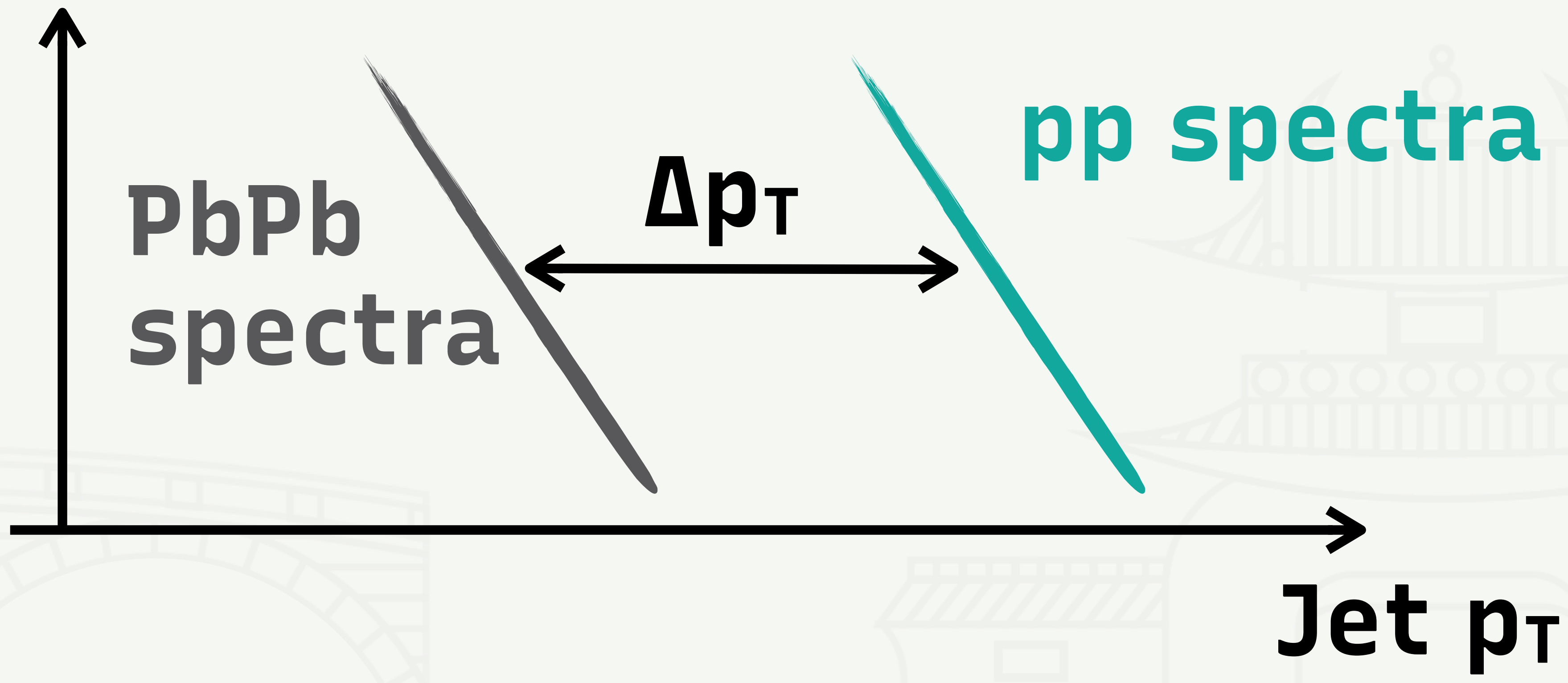
Flatter p_T in pp
↓
smaller modification
↓
higher R_{AA}

Fractional Energy Loss

PLB 846 (2023) 138154

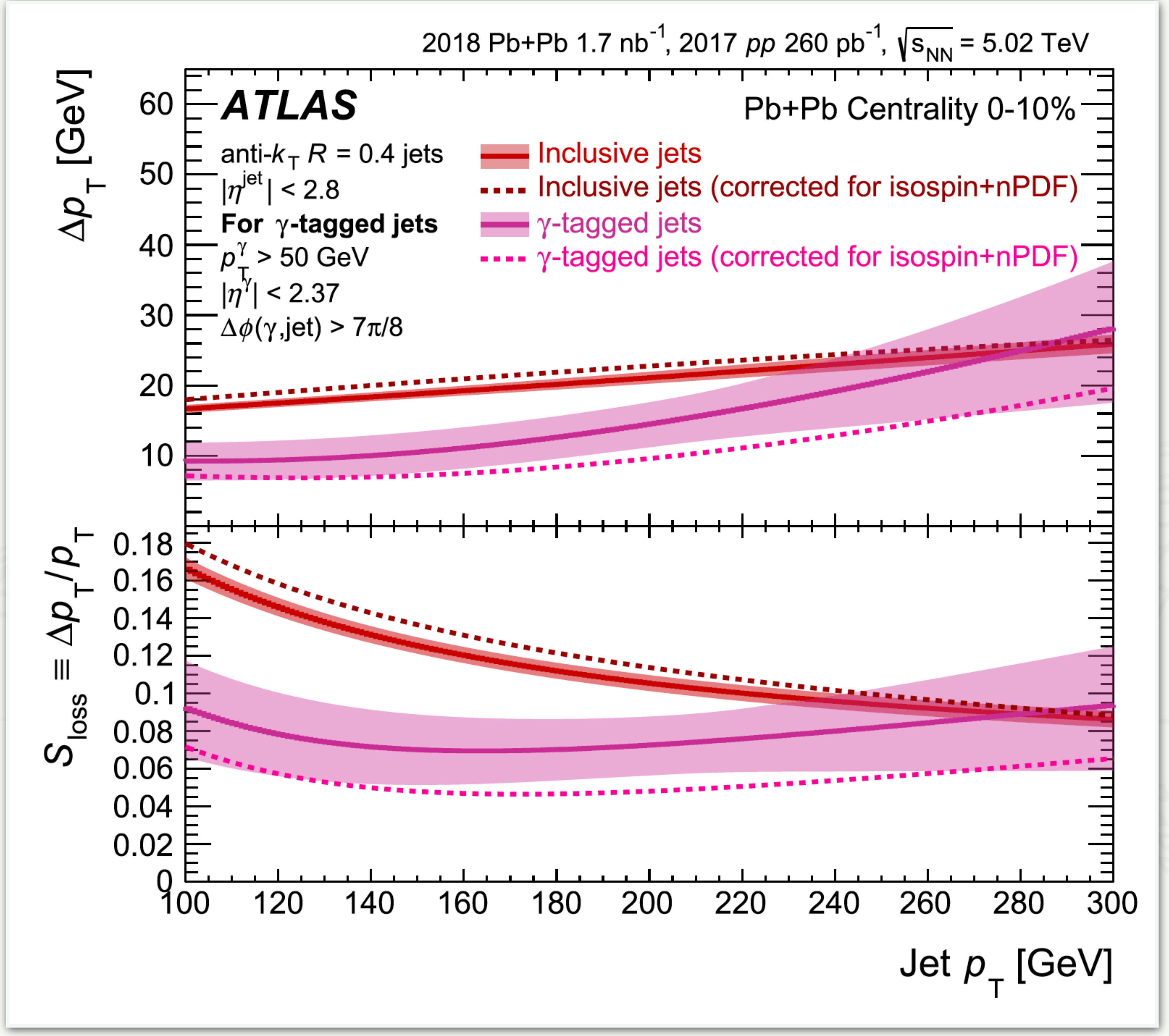


Same approach as PHENIX, **PRC 93 024911 (2016)**

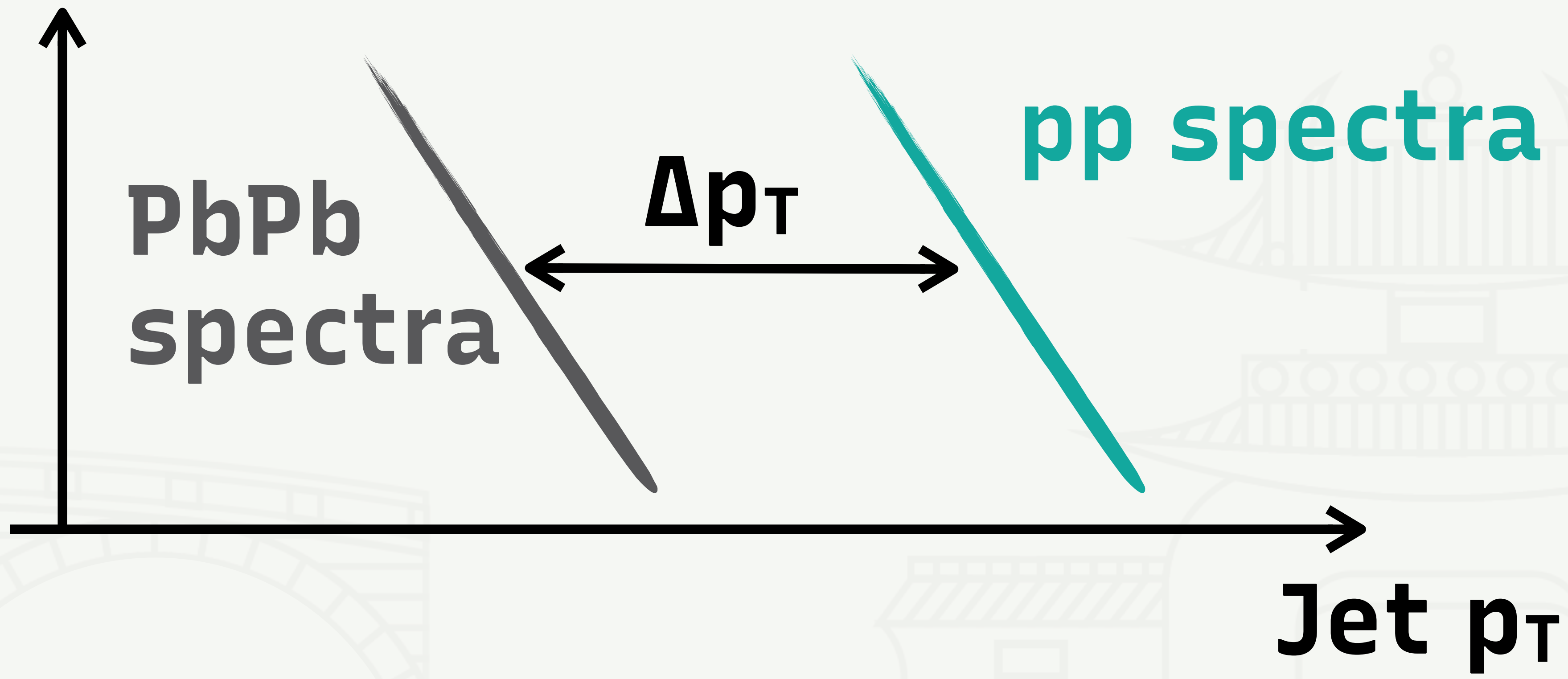


Fractional Energy Loss

PLB 846 (2023) 138154



Same approach as PHENIX, **PRC 93 024911 (2016)**

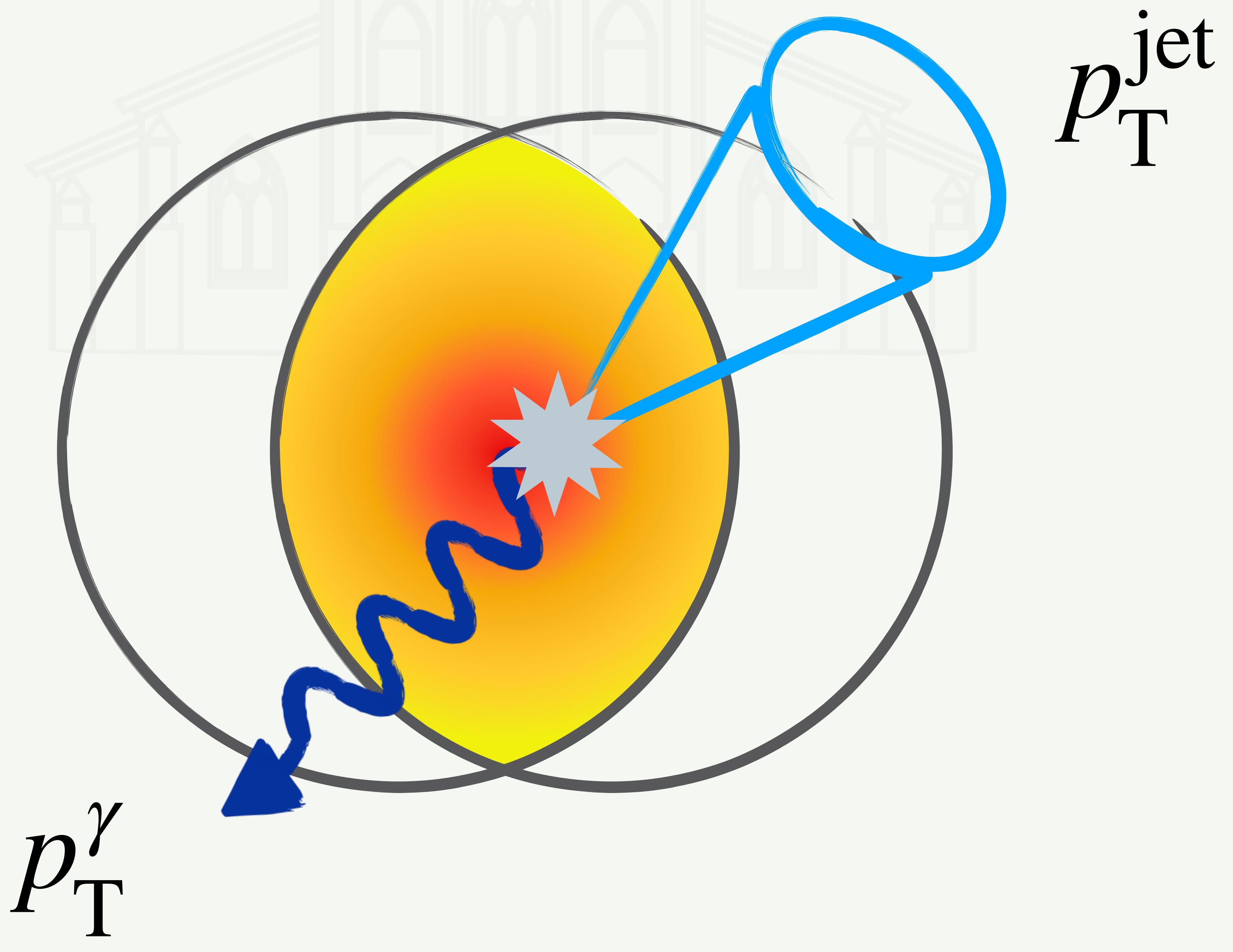


- Remove effects of spectral shape
- Comparison to nPDF and isospin effects
- Significant hints of color-charge dependence of jet energy loss
- For p_T < ~200 GeV, strengthens the case for quark-initiated jets **to lose less energy** than **gluon-initiated** ones

Studies in γ+jet to investigate selection bias

Can the medium distinguish between partons within a jet?

Momentum imbalance $x_{\gamma j} = \frac{p_{\mathrm{T}}^{\mathrm{jet}}}{p_{\mathrm{T}}^{\gamma}}$



Use **high-momentum photons** as proxies for the recoiling parton initiating the jet shower, to **investigate selection biases**

γ-tagged measurement of jet groomed radius and girth

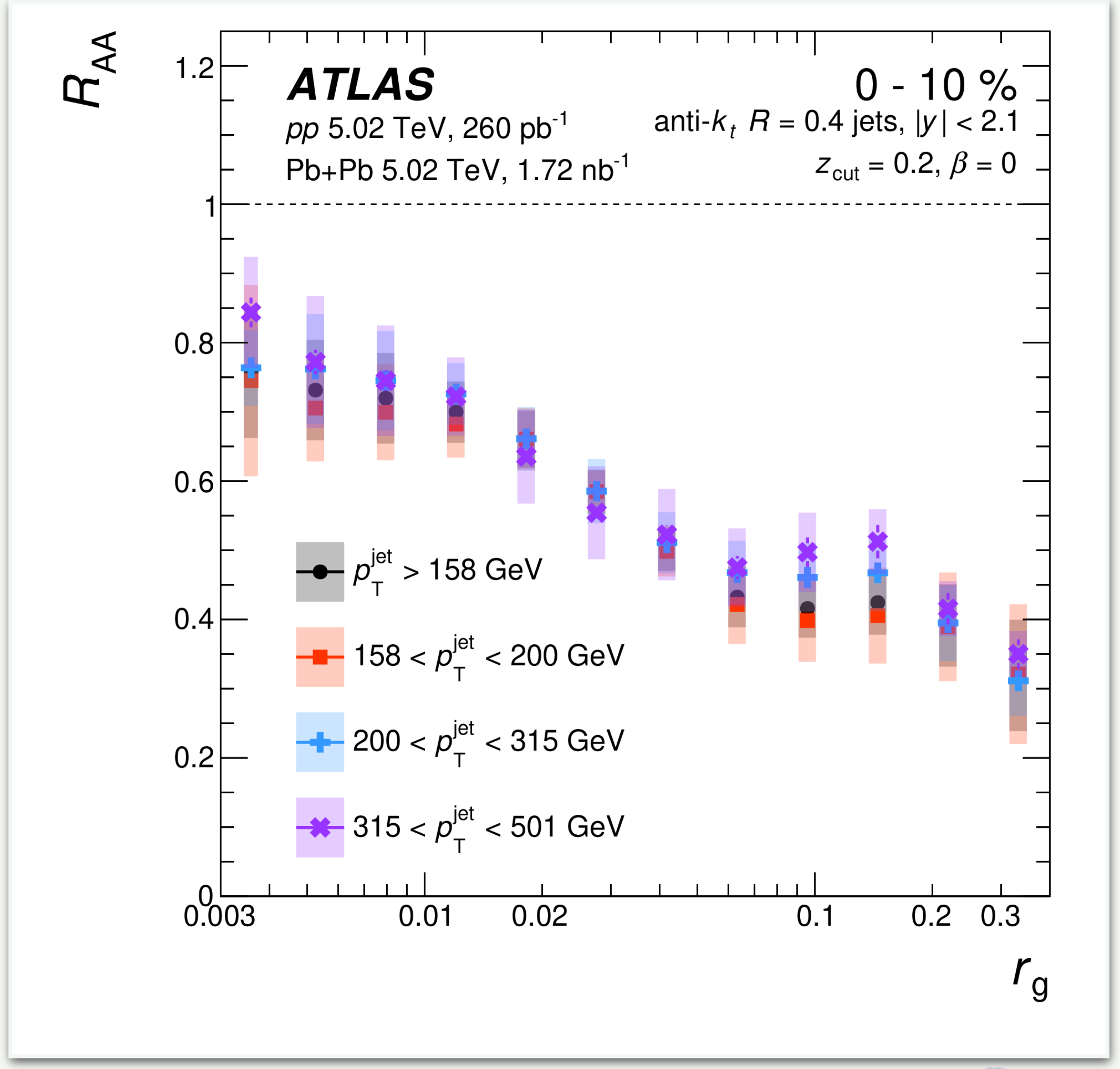
See talk by M.Nguyen

γ-tagged measurement of jet axis decorrelation

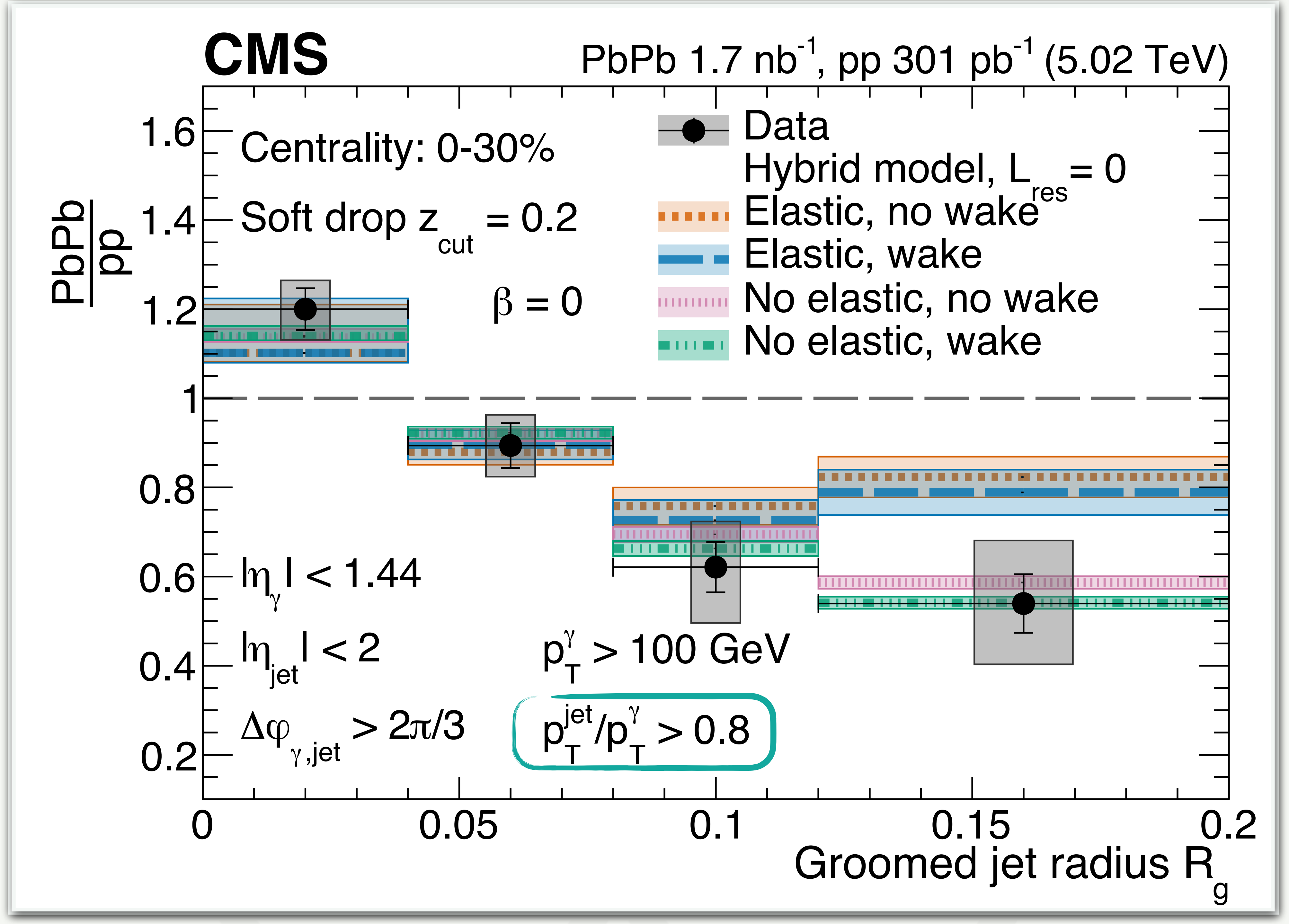
See talk by M.Park

Jet Substructure in γ+jet events vs inclusive

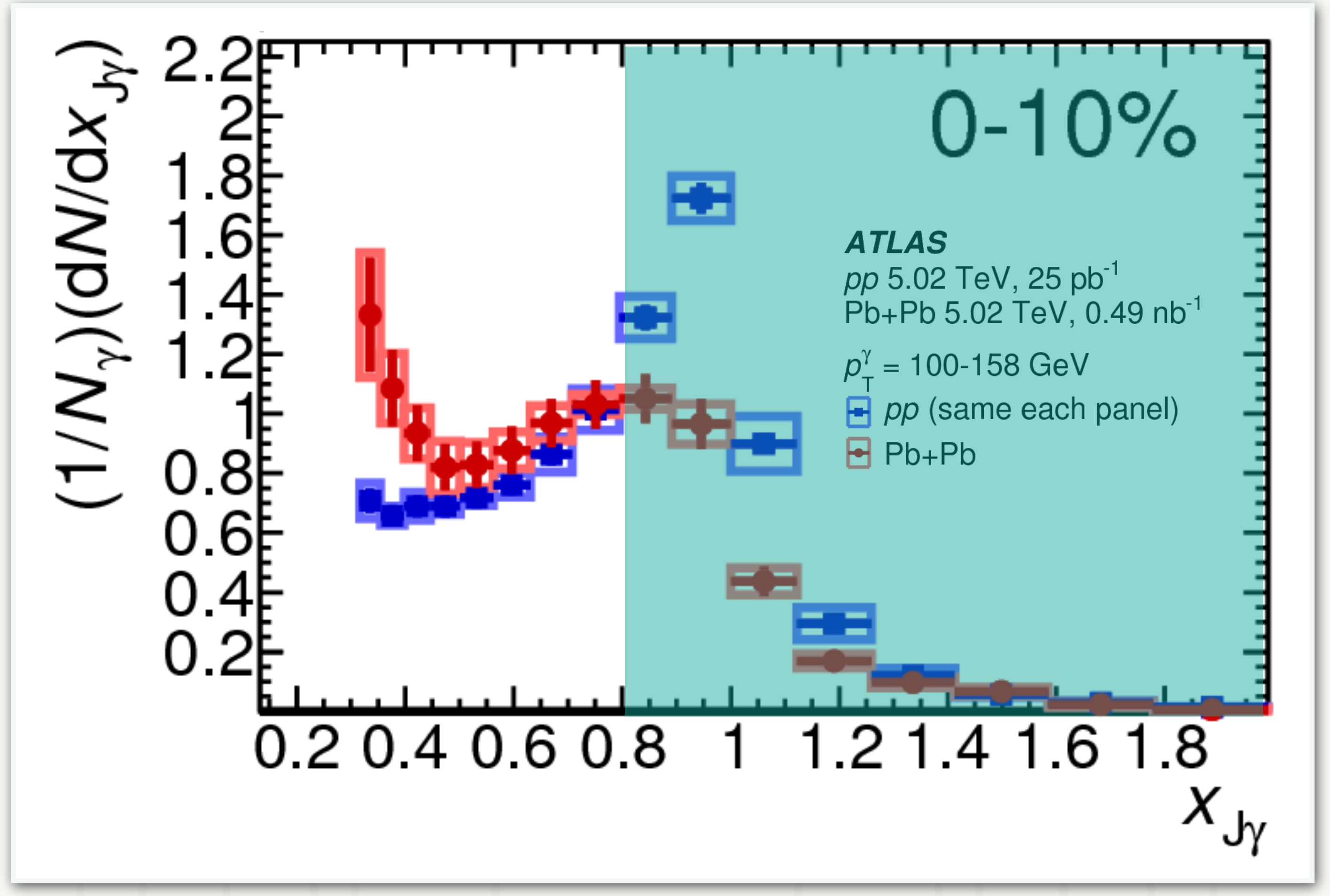
PRC 107 (2023) 054909



arXiv:2405.02737



Phys. Lett. B 789 (2019) 167



Less quenched jet selection: $x_{\gamma j} > 0.8$

ATLAS inclusive jets

See talk by M.Rybar

CMS γ+jets

See talk by M.Nguyen

Complementary ways to study color coherence effects

R=0.4 vs R=0.2

R_{AA} vs Area normalized

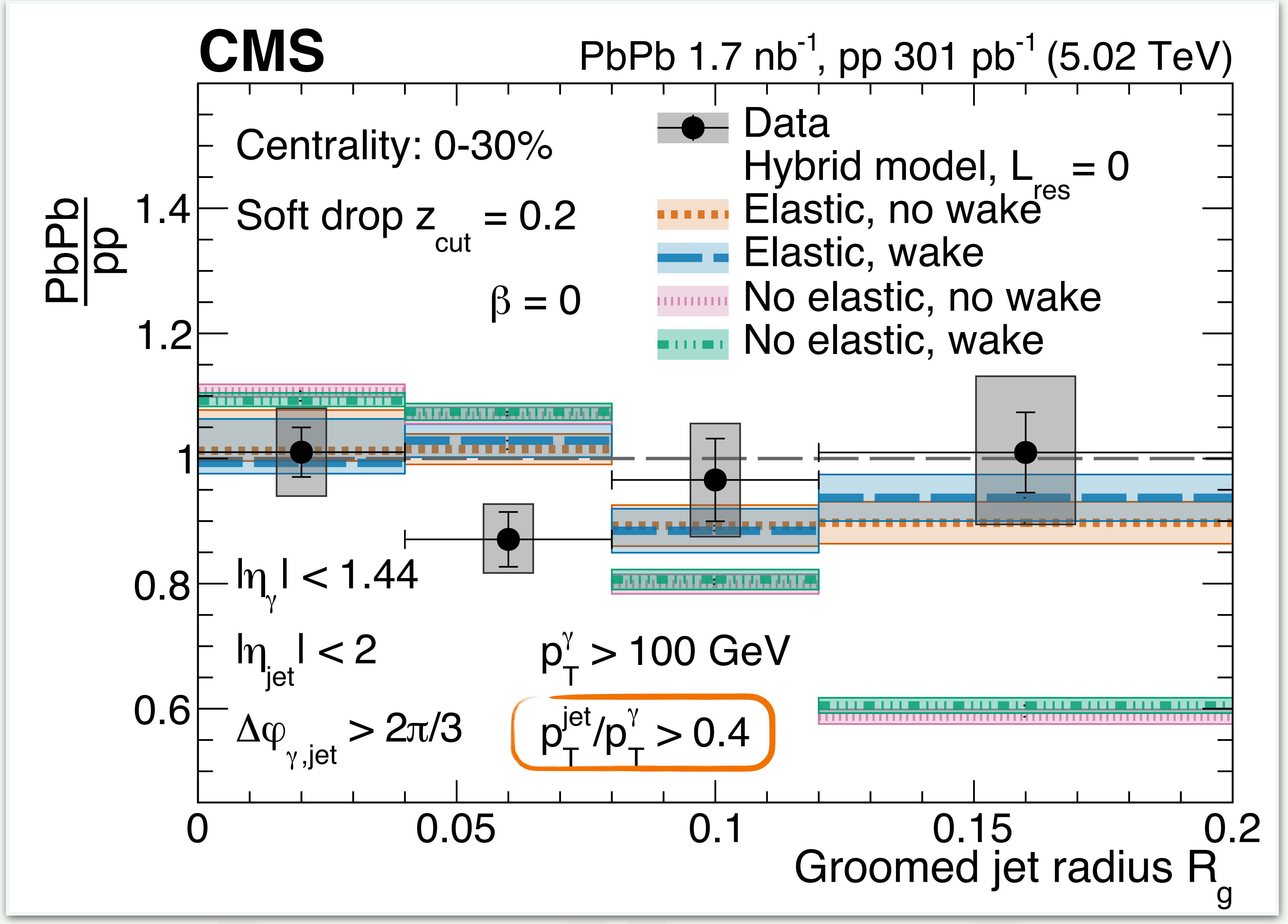
Gluon vs Quark jet dominance

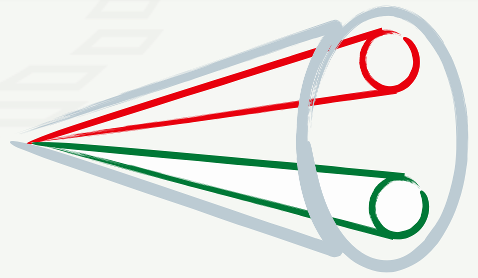
Different p_T ranges

Changing quenching level in γ+jet

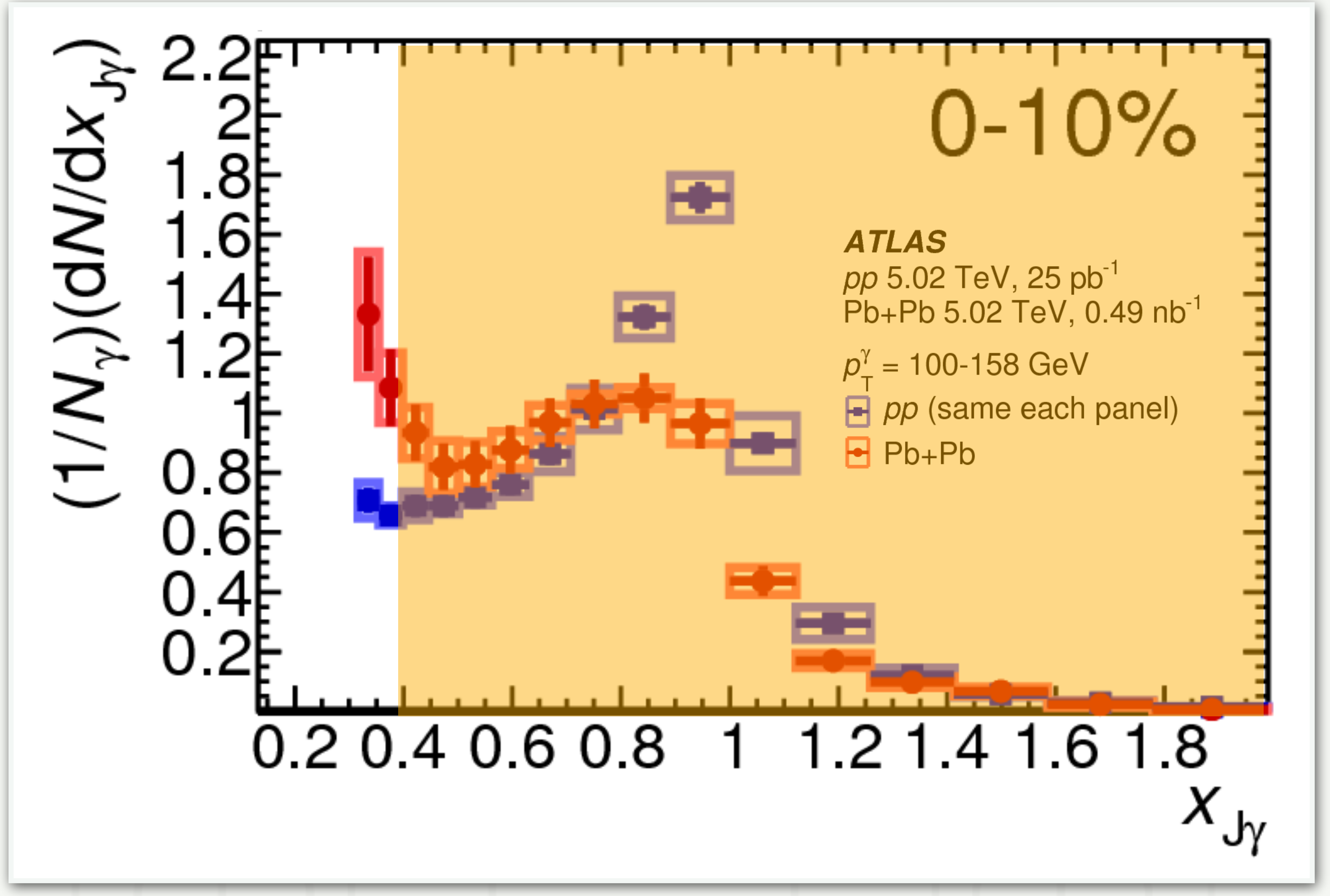
See talk by M.Nguyen

arXiv:2405.02737





Phys. Lett. B 789 (2019) 167



No narrowing observed with less biased selection on $x_{J\gamma}$

Quenched + unquenched jet selection: $x_{\gamma j} > 0.4$

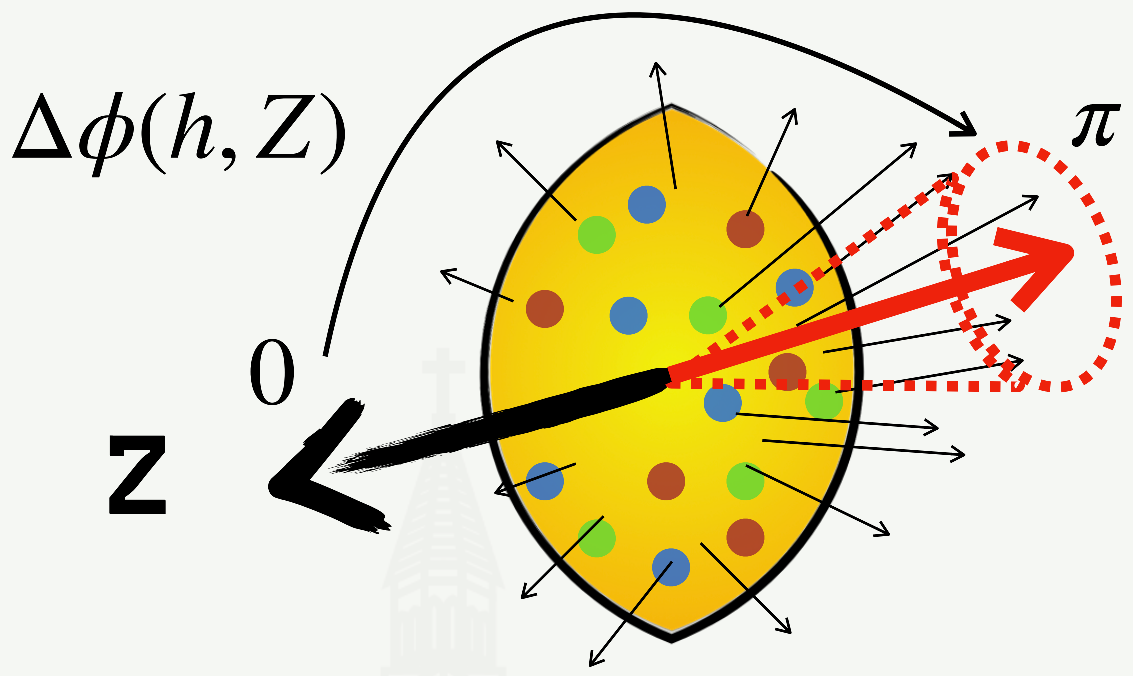
Jet interaction with the medium

What happens to the energy deposited by the jet in the medium?

2

‘Waking’ the medium

See talks by Y.Go and Y.Lee



Experimental measurements with Z-bosons differential in $\Delta\phi$

Duck = jet

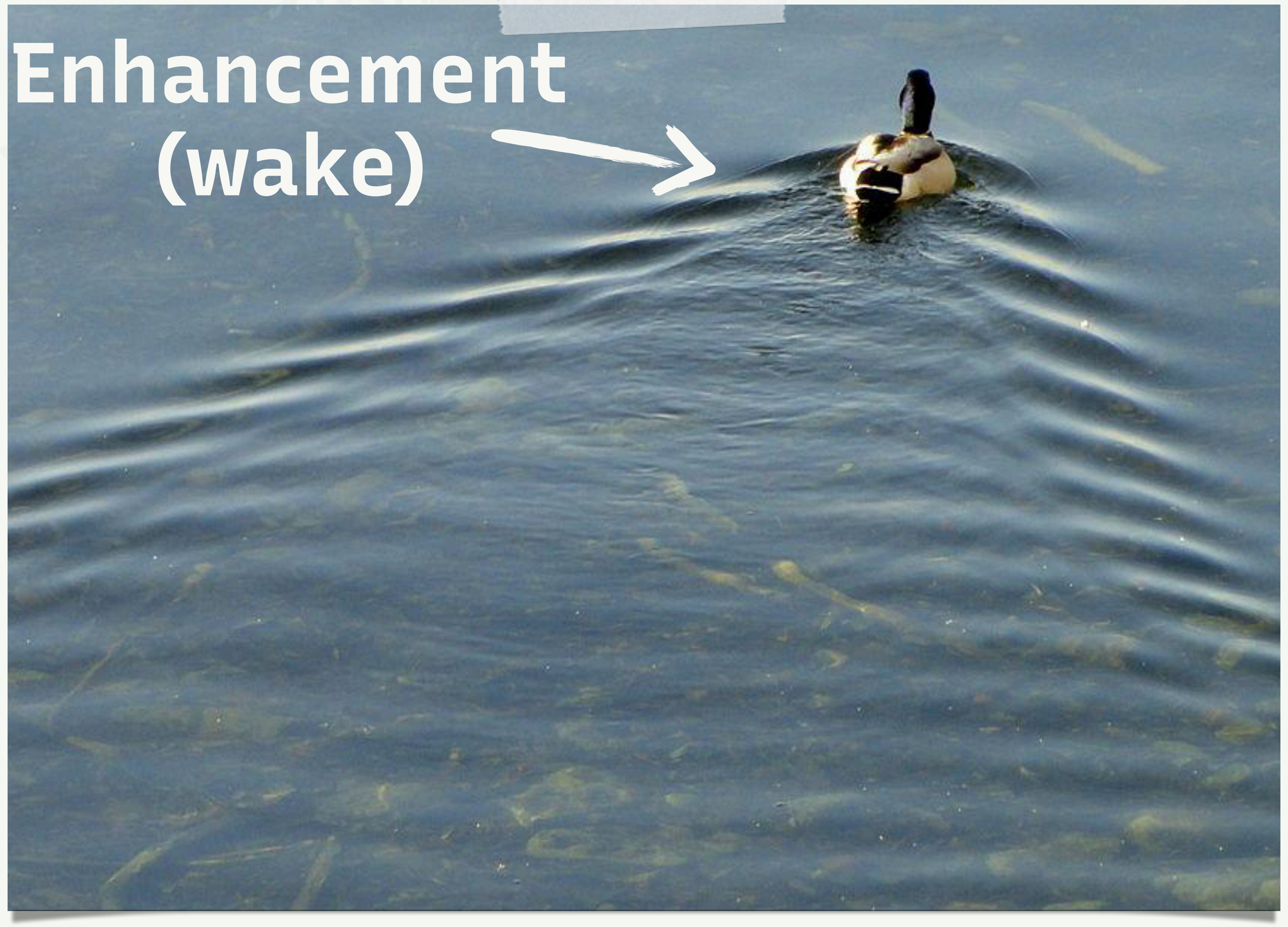
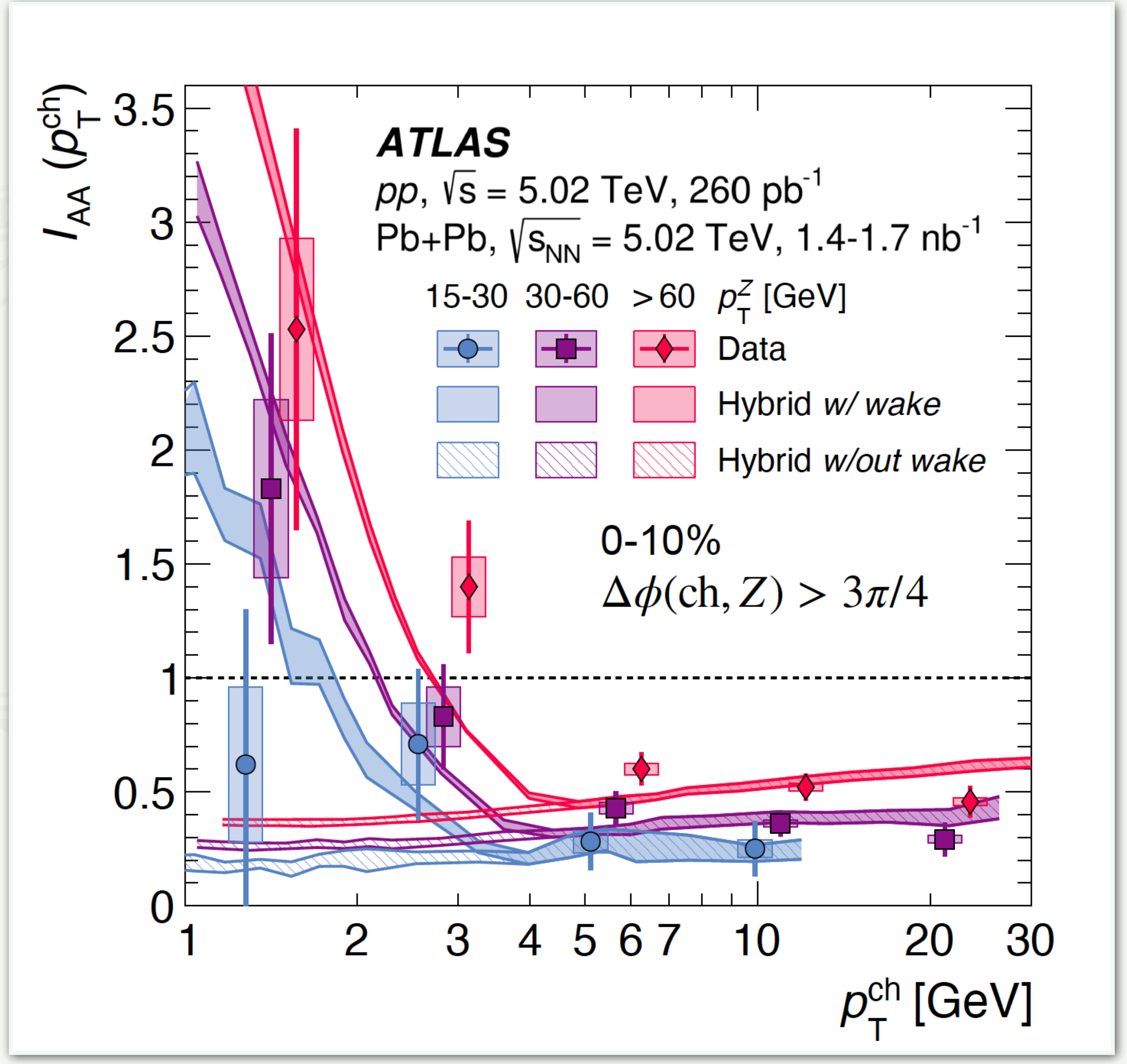
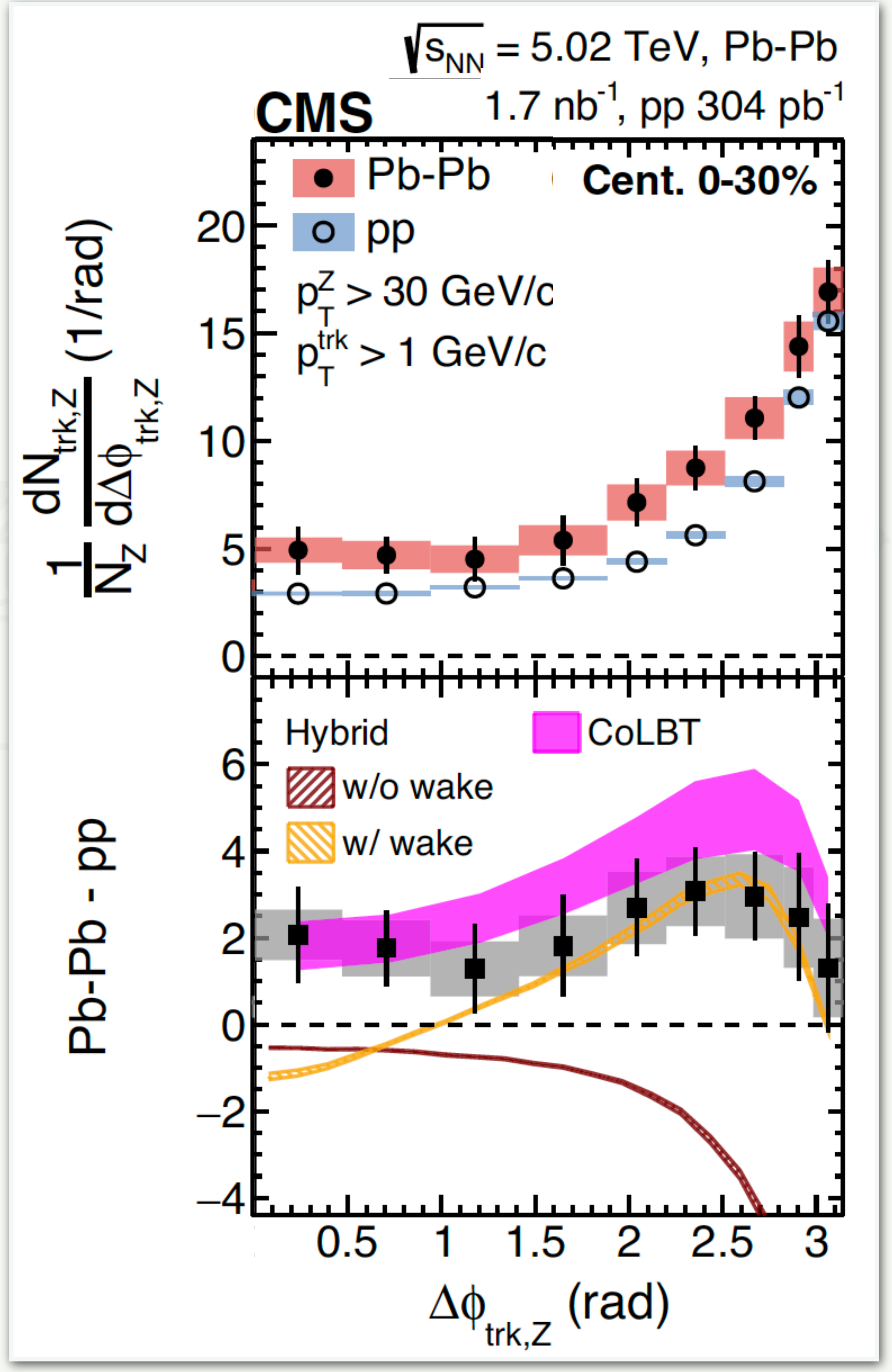


Photo from Y.Lee’s talk



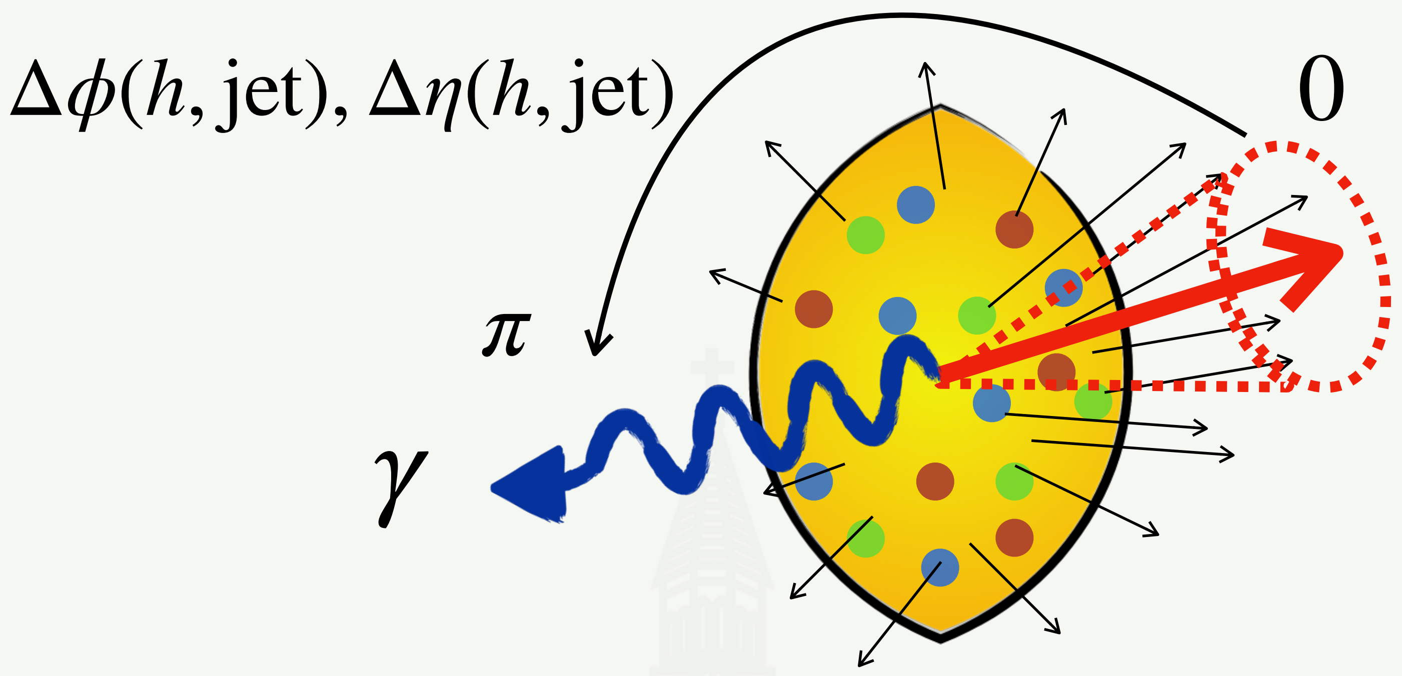
PRL 126 (2021) 072301



PRL 128 (2022) 122301

‘Waking’ the medium [2]

See talks by Y.Go and Y.Lee



Experimental measurements with γ-tagged jets differential in $\Delta\phi$ and $\Delta\eta$

Duck = jet

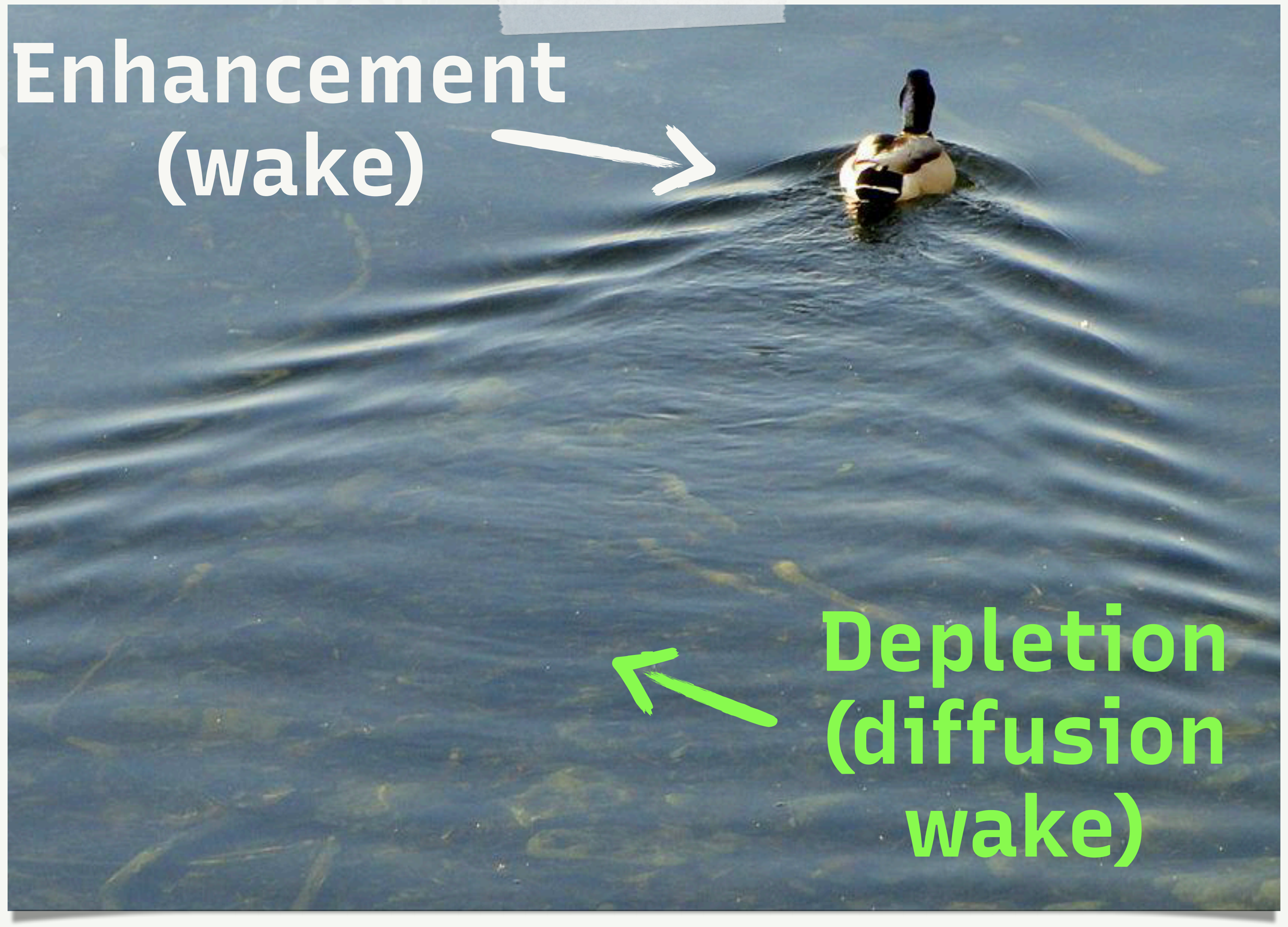
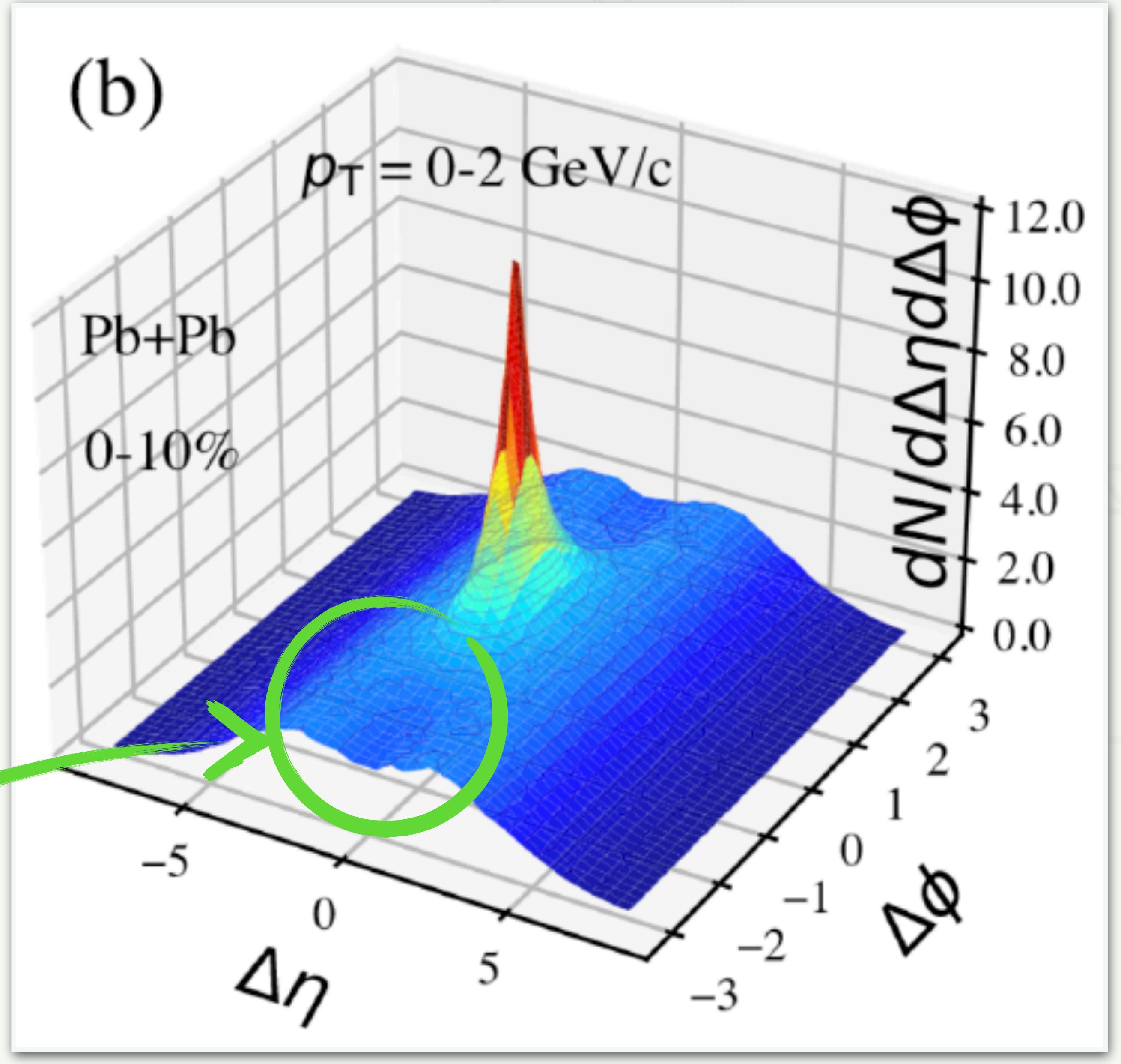


Photo from Y.Lee’s talk

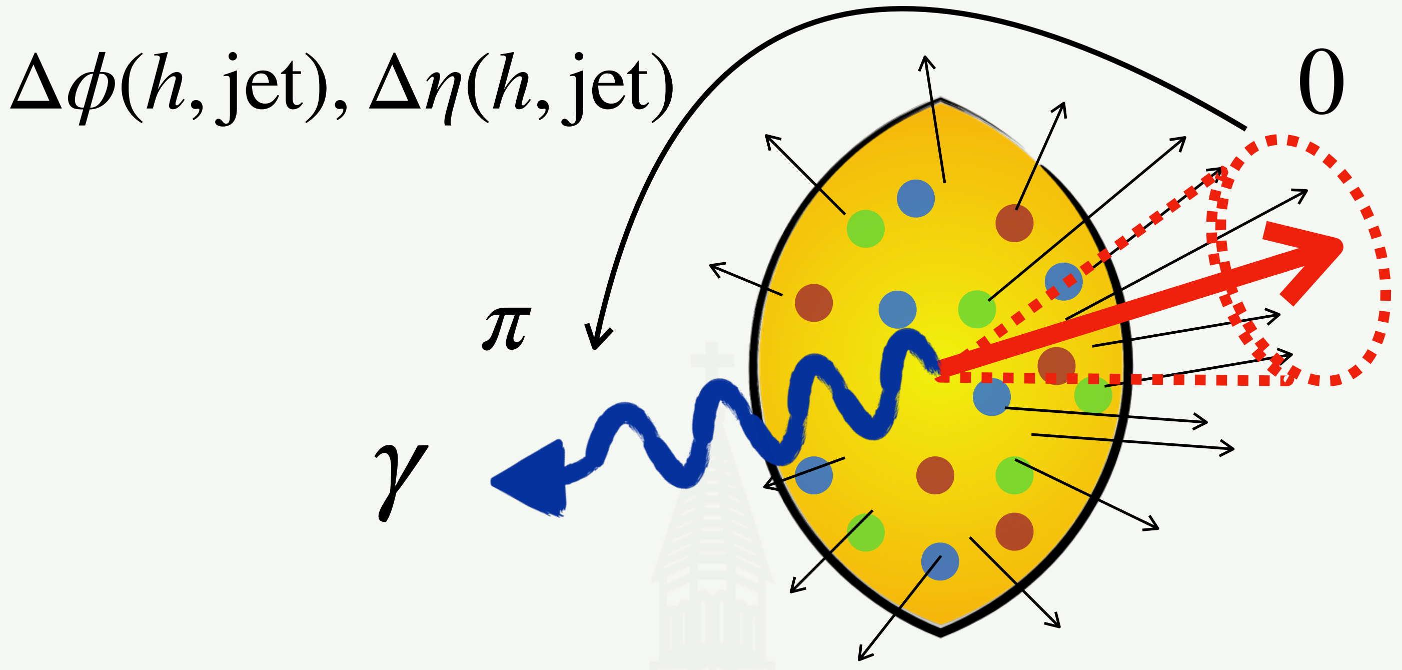
PRL 130, 052301 (2023), CoLBT



Diffusion wake signal expected at $\Delta\phi > \pi/2$ and $\Delta\eta \sim 0$

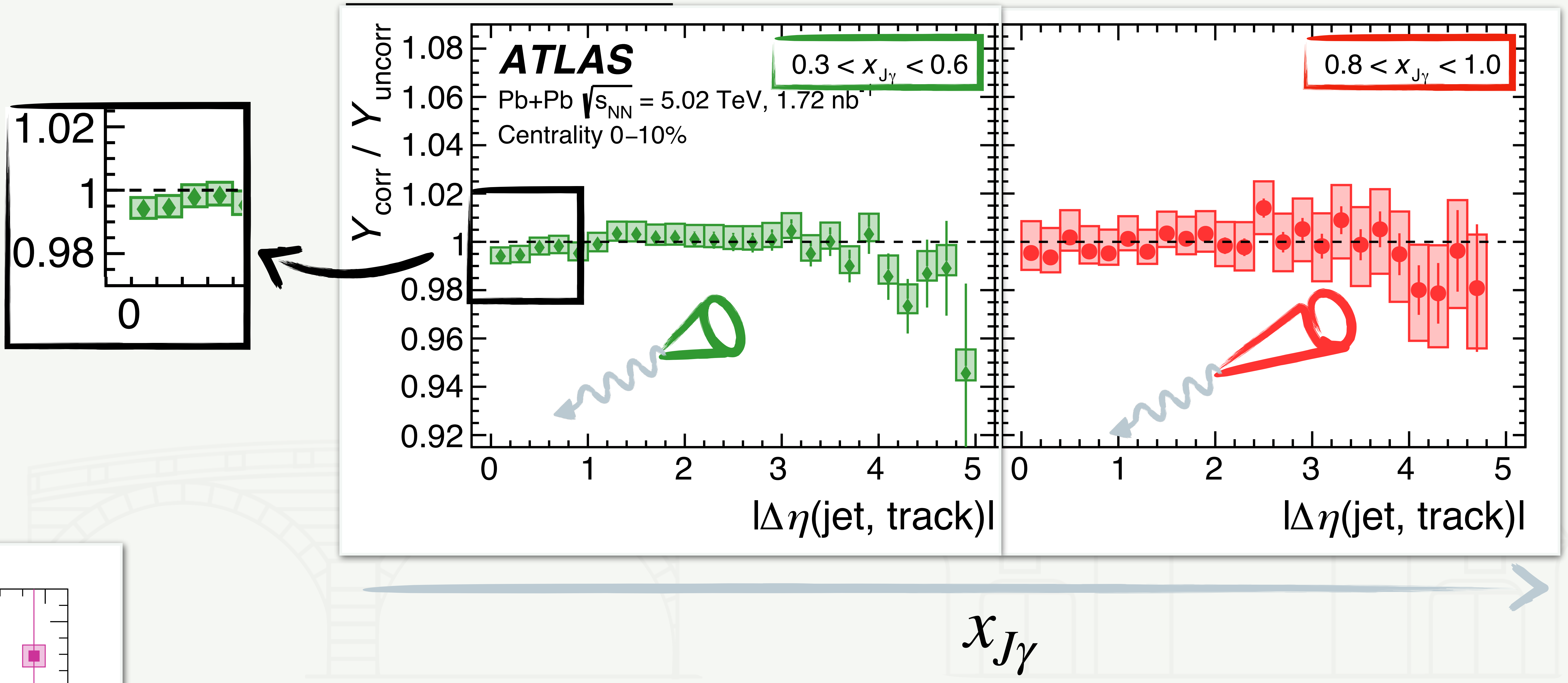
3D jet+tracks in γ+jet

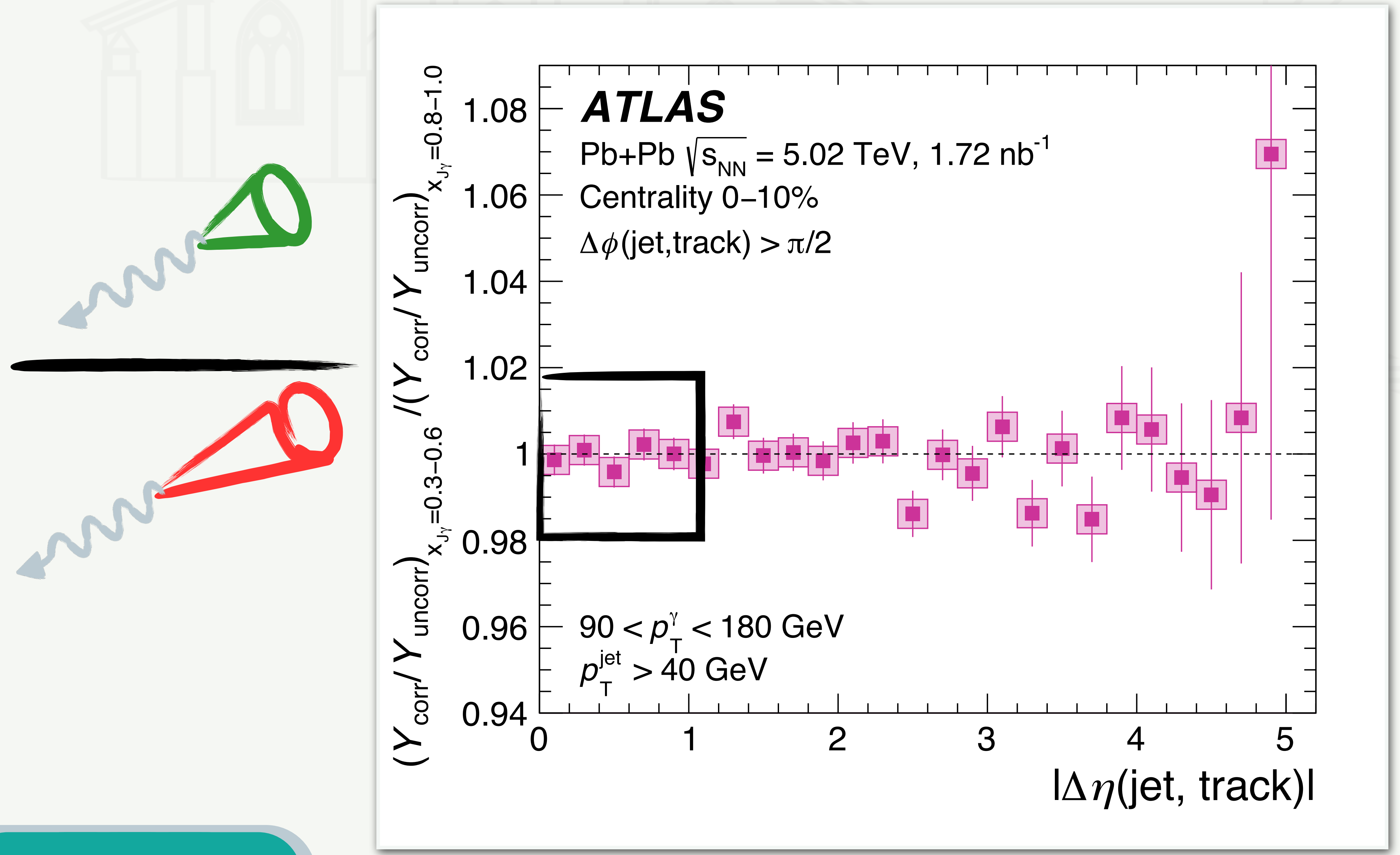
See talk by Y.Go



$Y_{\text{corr}}/Y_{\text{uncorr}}$ shows the relative modification of the bulk medium

arXiv:2408.08599

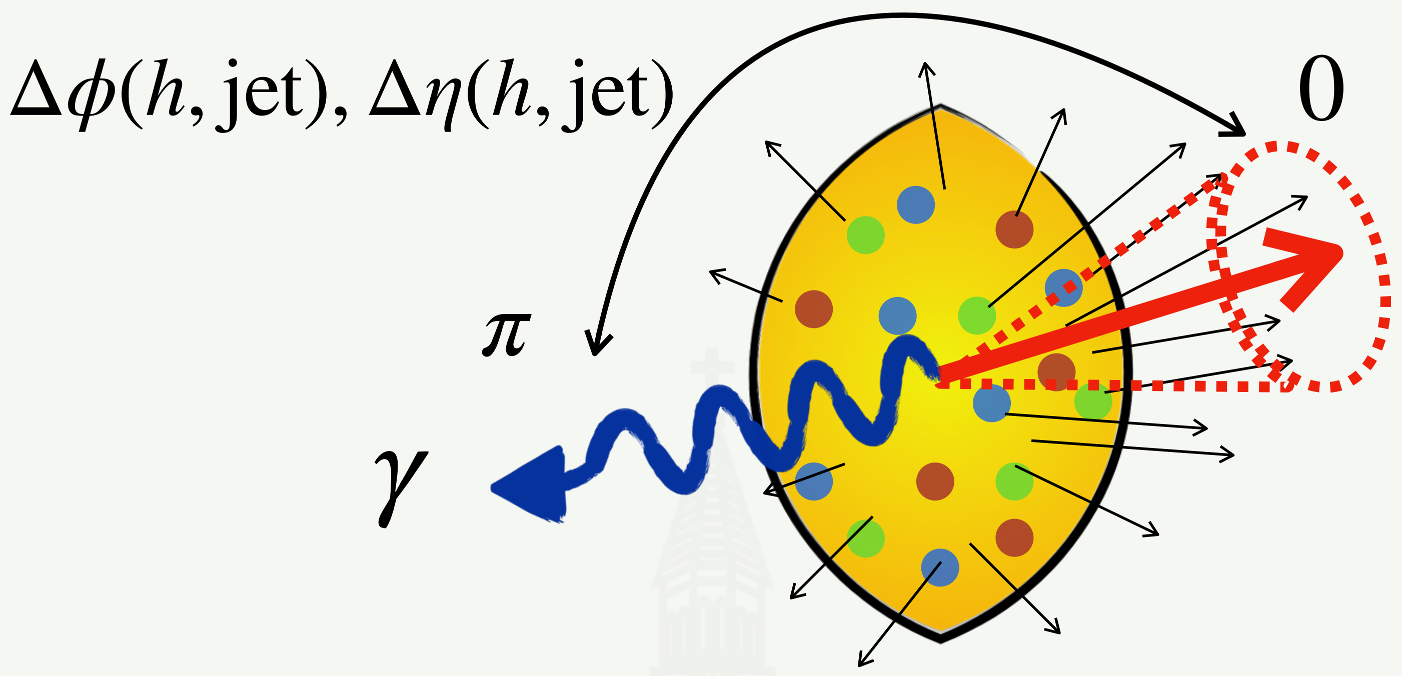




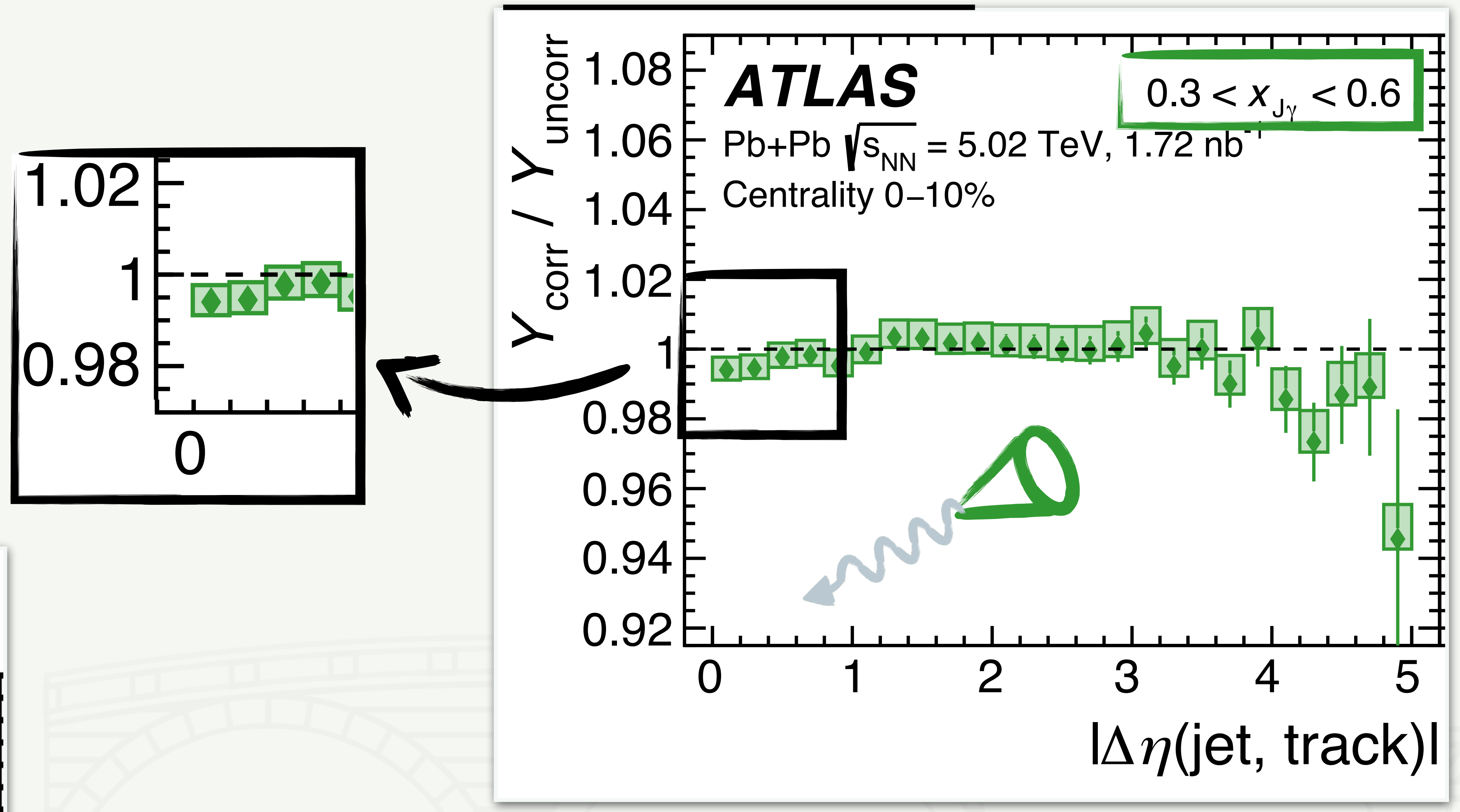
- **3D analysis** of jet-track correlations ($x_{J\gamma}$, $\Delta\phi$ and $\Delta\eta$)
- **Selecting** different **jet energy loss** classes **using** $x_{J\gamma}$
- **No** significant $x_{J\gamma}$ **dependence** of the diffusion wake observed

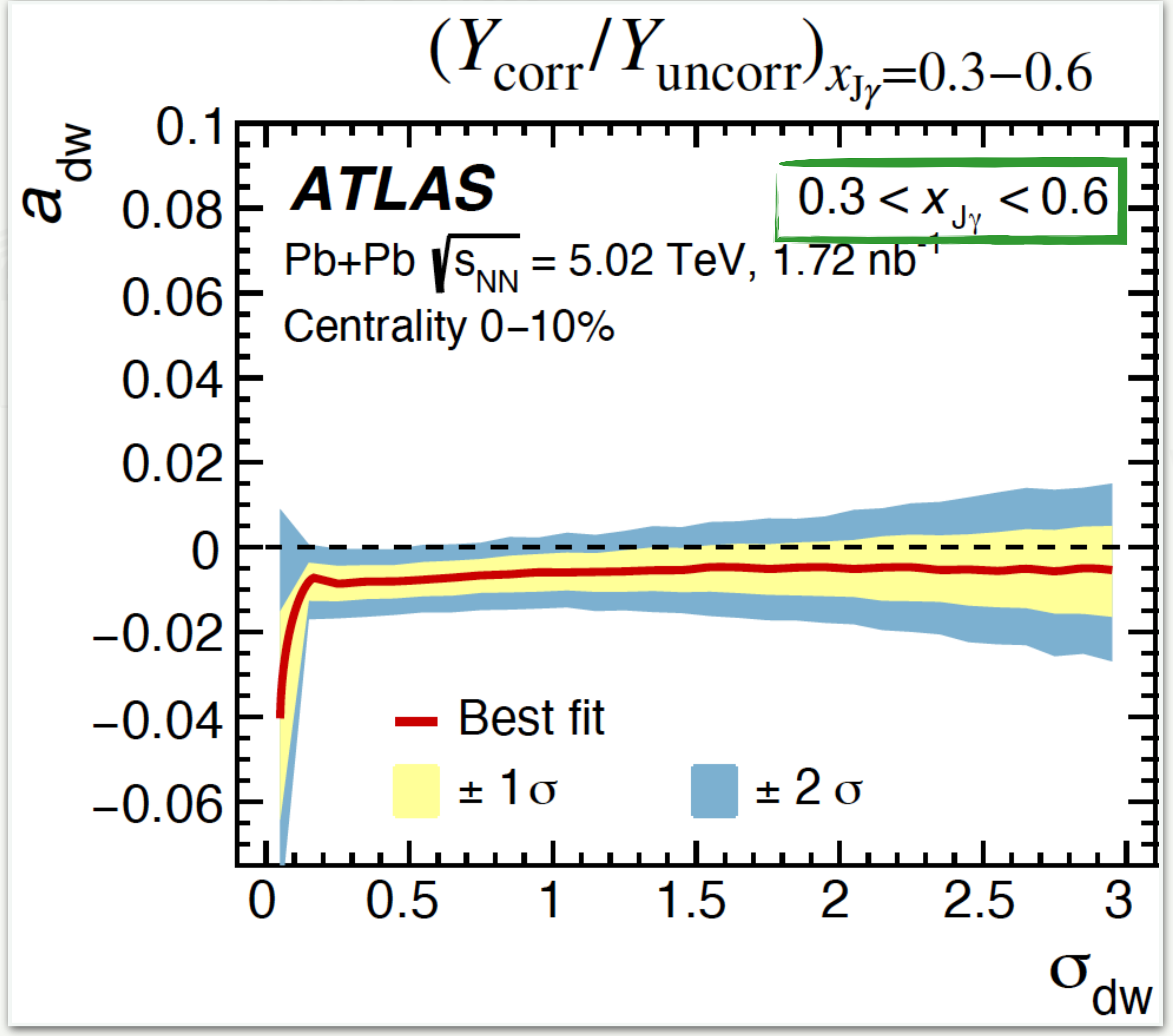
3D jet+tracks in γ+jet: wake constraints

See talk by Y.Go



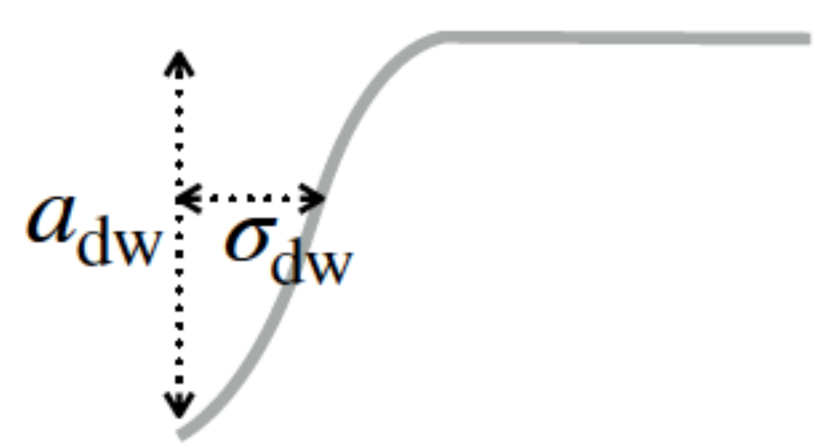
arXiv:2408.08599





Diffusion Wake Amplitude — Diffusion Wake Width

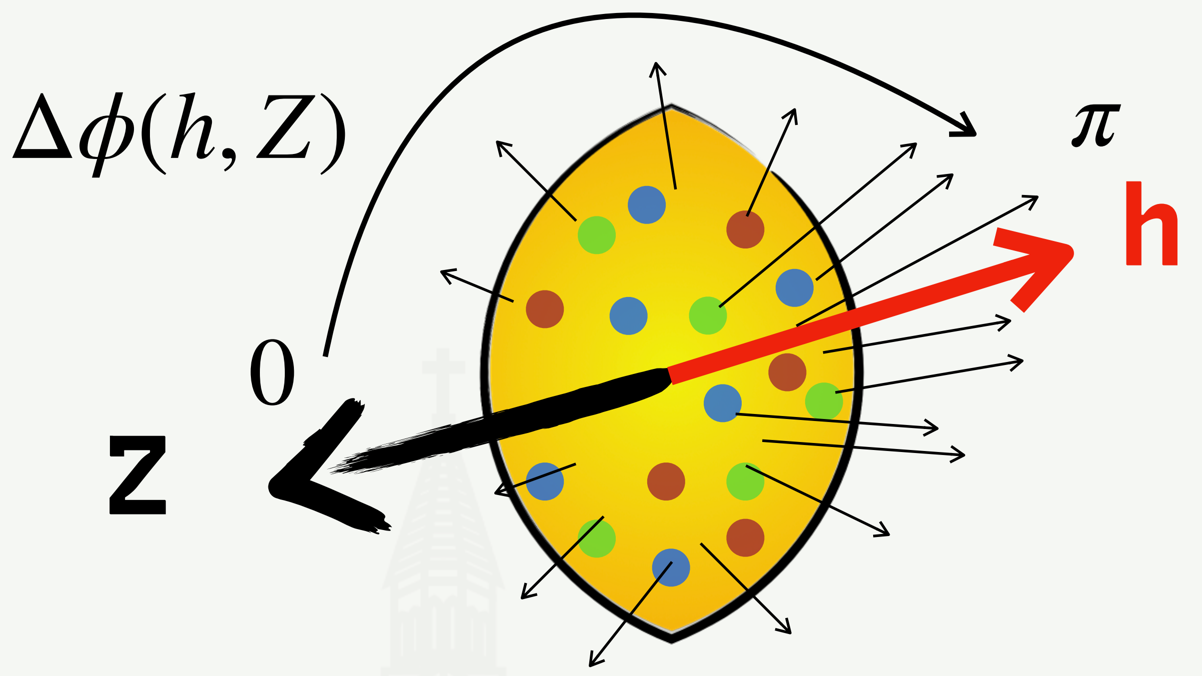
$$a_0 + a_{dw} \cdot e^{-|\Delta\eta(\text{jet,track})|^2/(2\sigma_{dw}^2)}$$

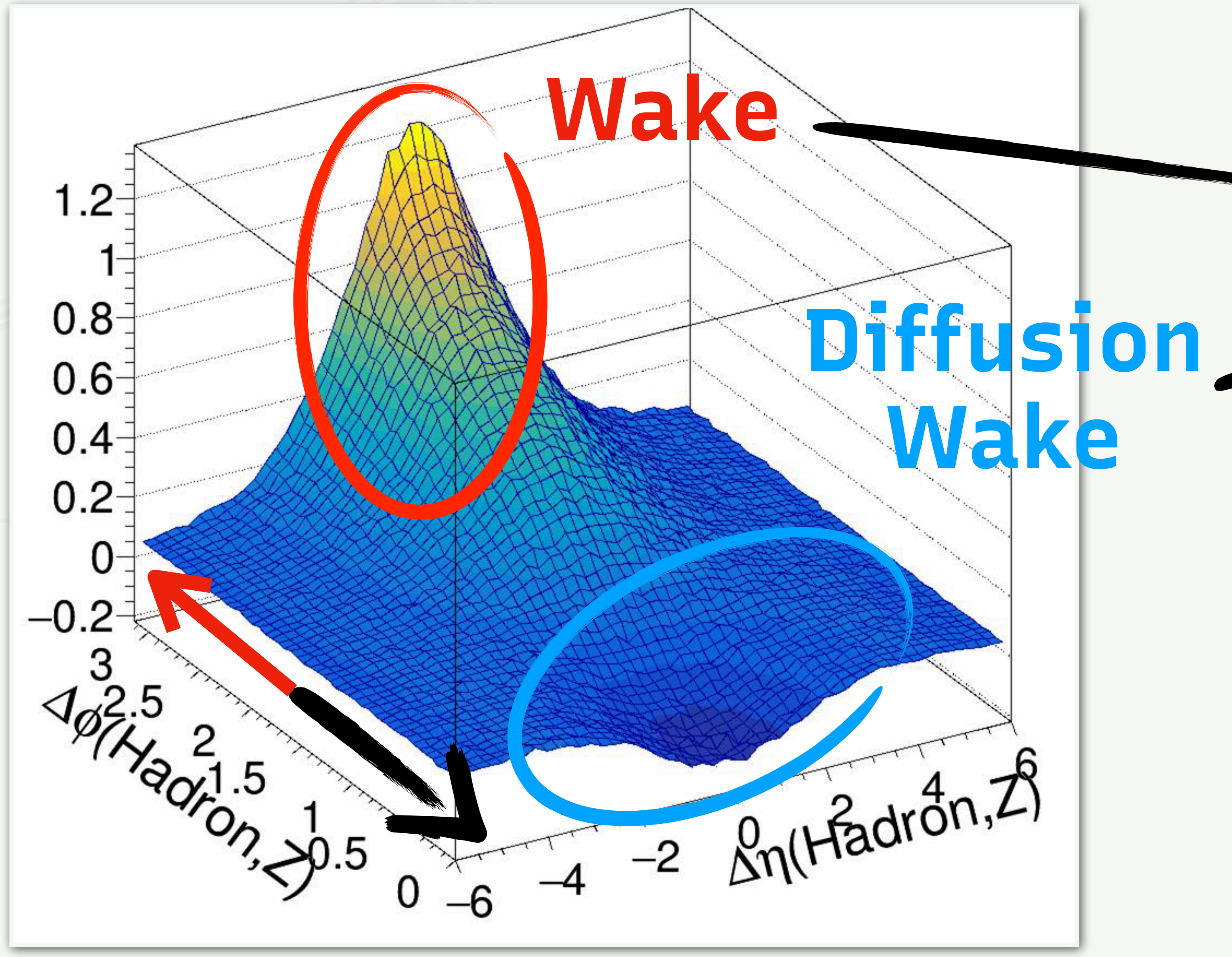


The **best fit** of the **diffusion wake amplitude** for the lowest $x_{J\gamma}$ (highest energy deposition in the medium) is about **0.5-0.8%** for the diffusion wake width range of 0.5-1.0

Search for diffusion wake in Z-tagged events

See talk by Y.Lee





Z and **Wake Hadron** correlation in **Hybrid** model by Pablos, Rajagopal, Lee

Note the different relative magnitudes of the two effects compared to γ+jet CoLBT due to different type of analysis

No jet requirement

allows for contribution from very quenched jets ($x_{J\gamma} \ll 1$)

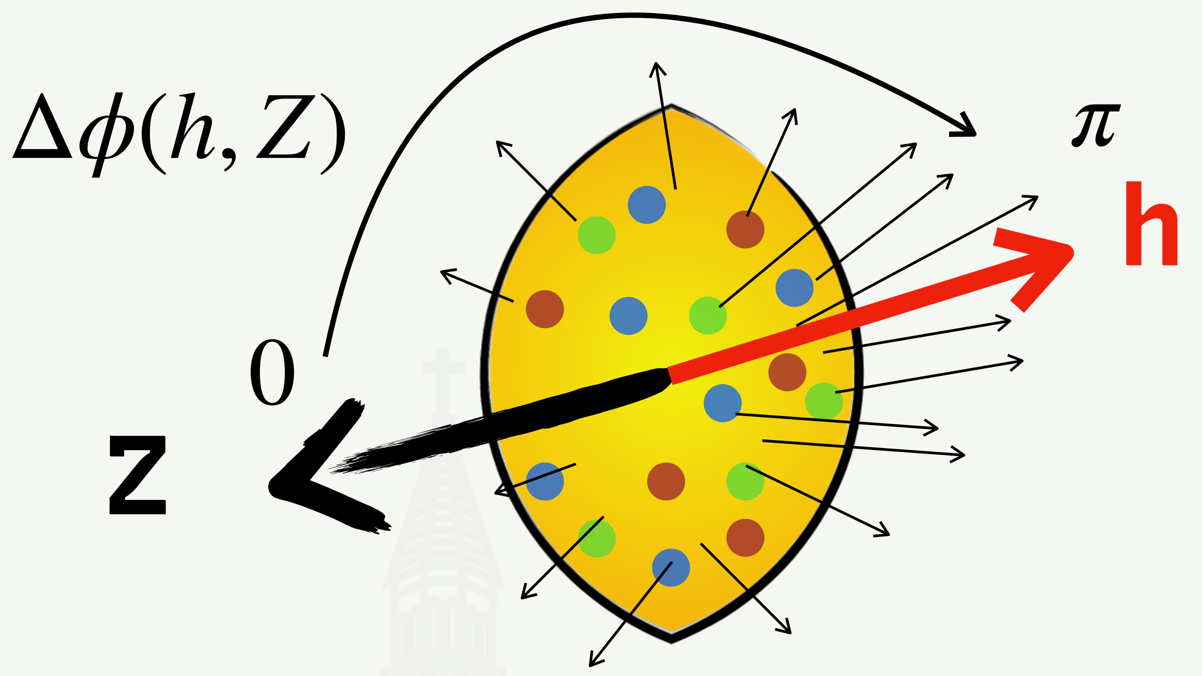
Double differential absolute measurement of $\Delta N_{\rm ch} = S - B$

$$\frac{d\langle \Delta N_{\rm ch}\rangle}{d\Delta\phi_{\rm ch,Z}} \quad \text{or} \quad \frac{d\langle \Delta N_{\rm ch}\rangle}{d\Delta y_{\rm ch,Z}}$$

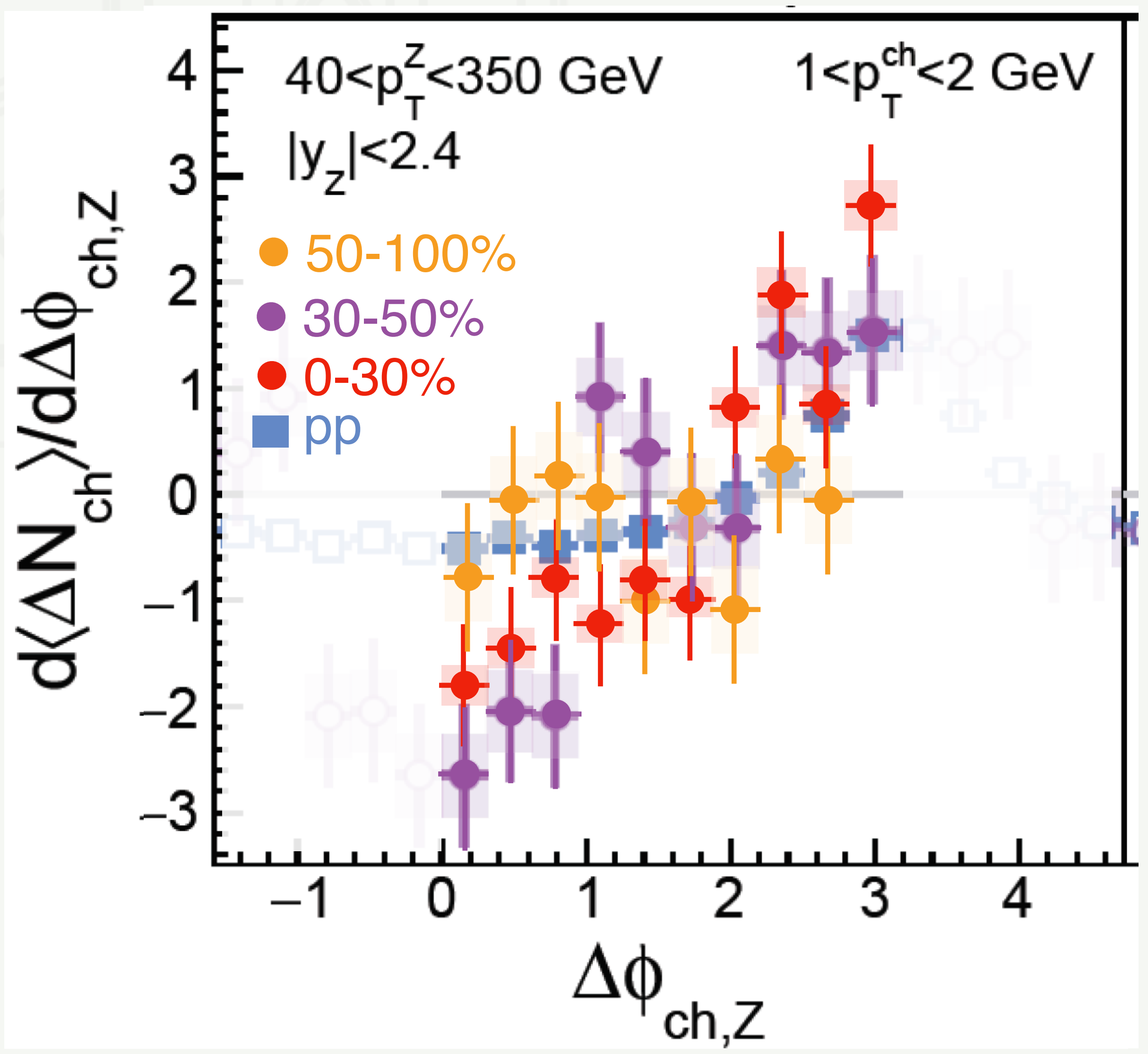
In different selections of $p_{\rm T}^{\rm ch}$

Search for diffusion wake in Z-tagged events

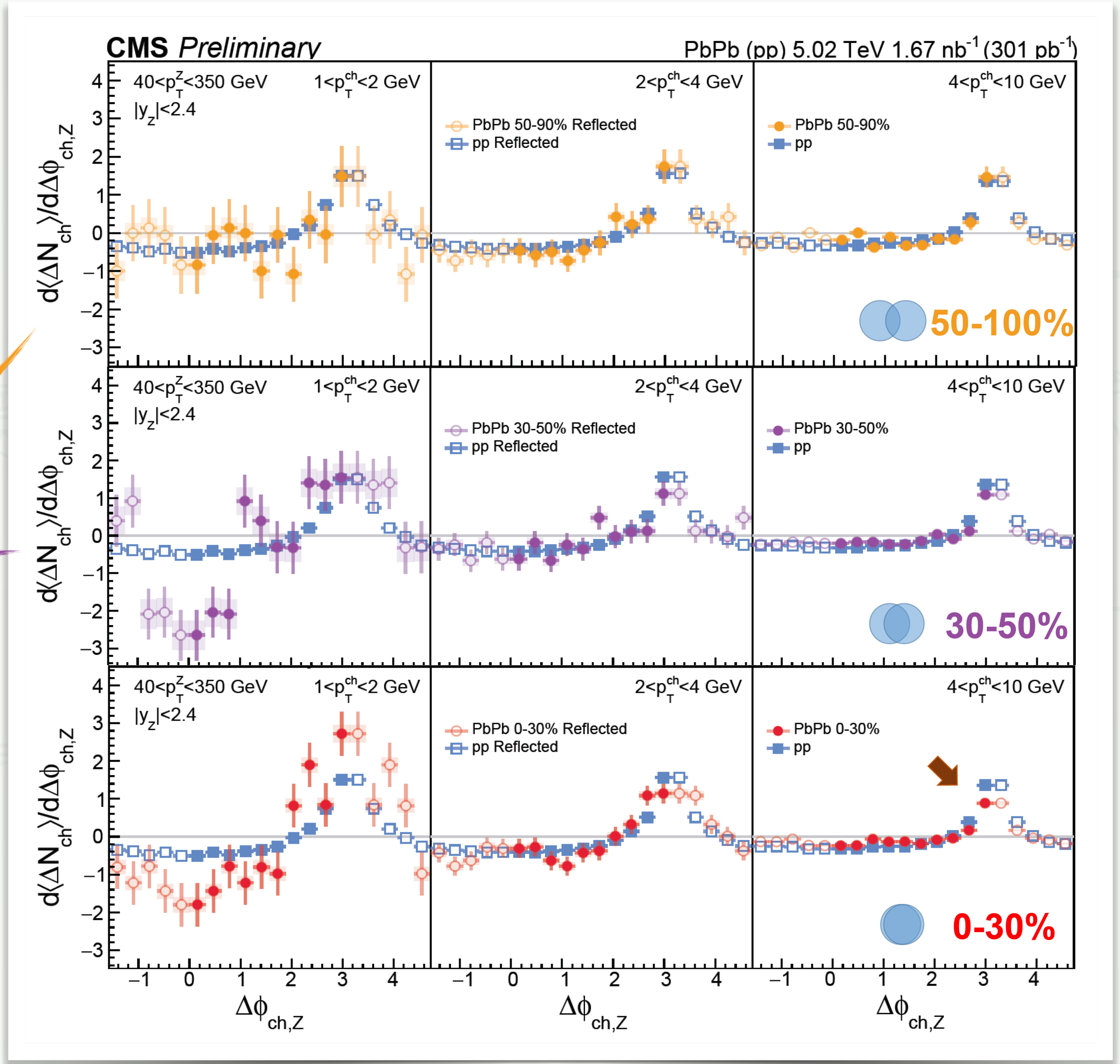
See talk by Y.Lee



Centrality as handle on medium-size



Hadron p_T selection

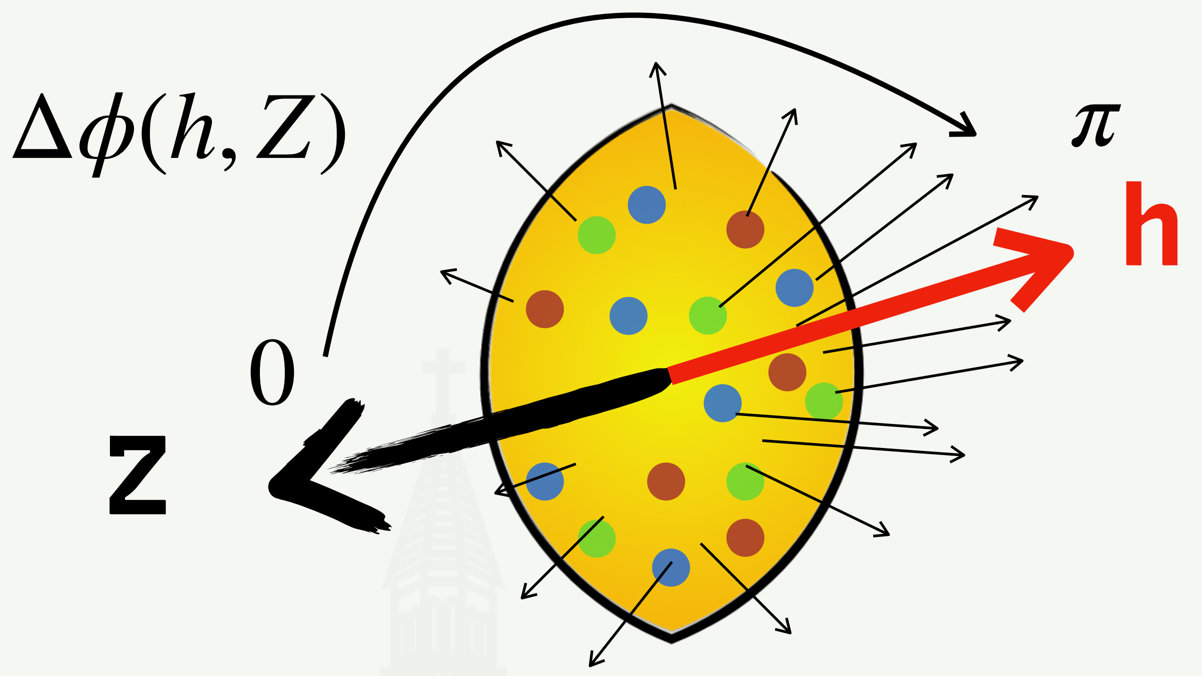


Centrality

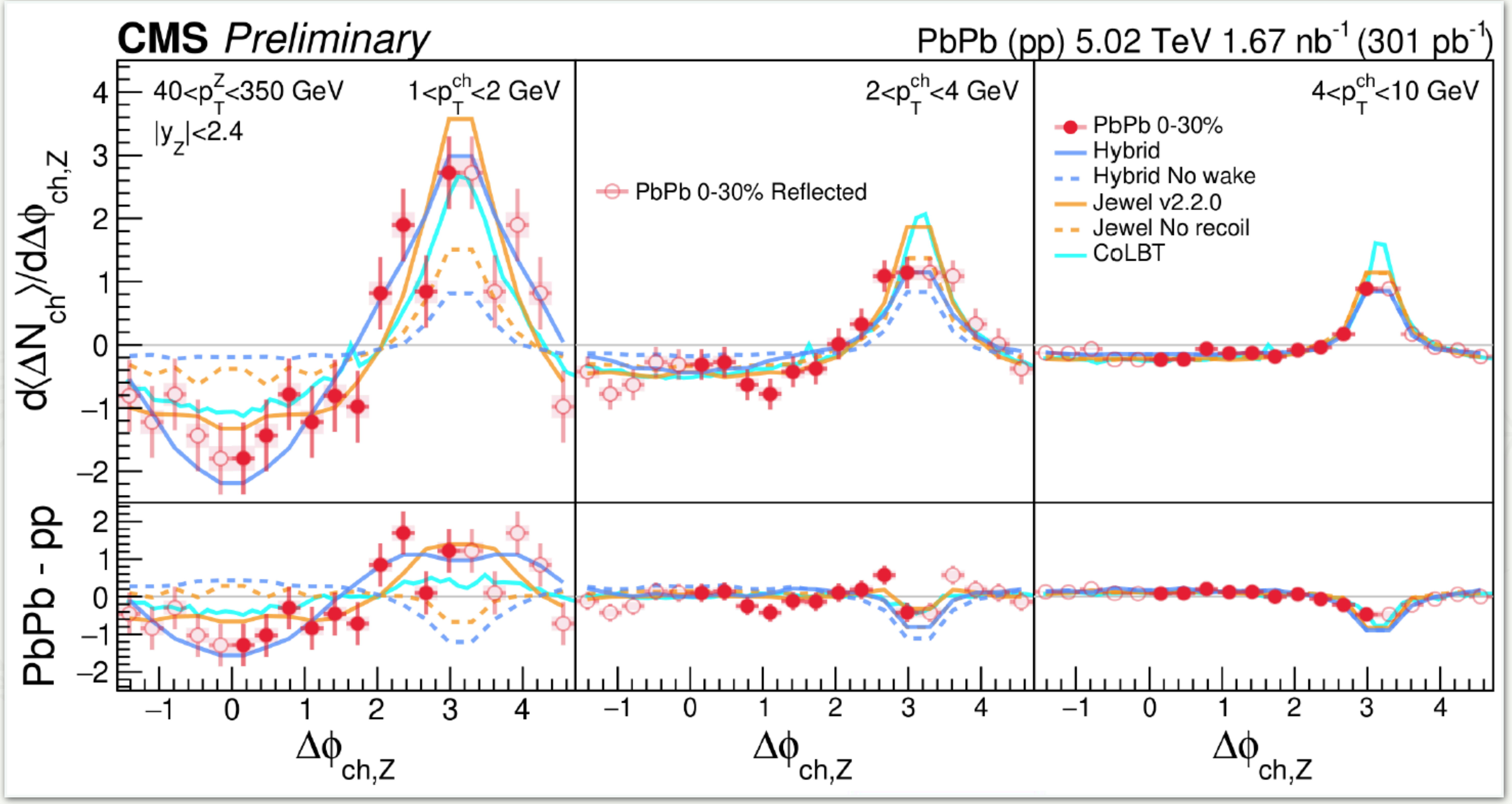
Depletion at $\Delta\phi_{ch,Z}$ ~ 0 in both mid-central & central! Ordering?

Search for diffusion wake in Z-tagged events

See talk by Y.Lee



Hadron p_T selection



Statistically hungry measurements - more to come w/ Run 3 and beyond

Are the γ+jet and Z-h results compatible?

Hybrid w/ wake, CoLBT and JEWEL w/ recoil (solid lines) agree better with the data at low hadron p_T

Microscopic characterization of the QGP

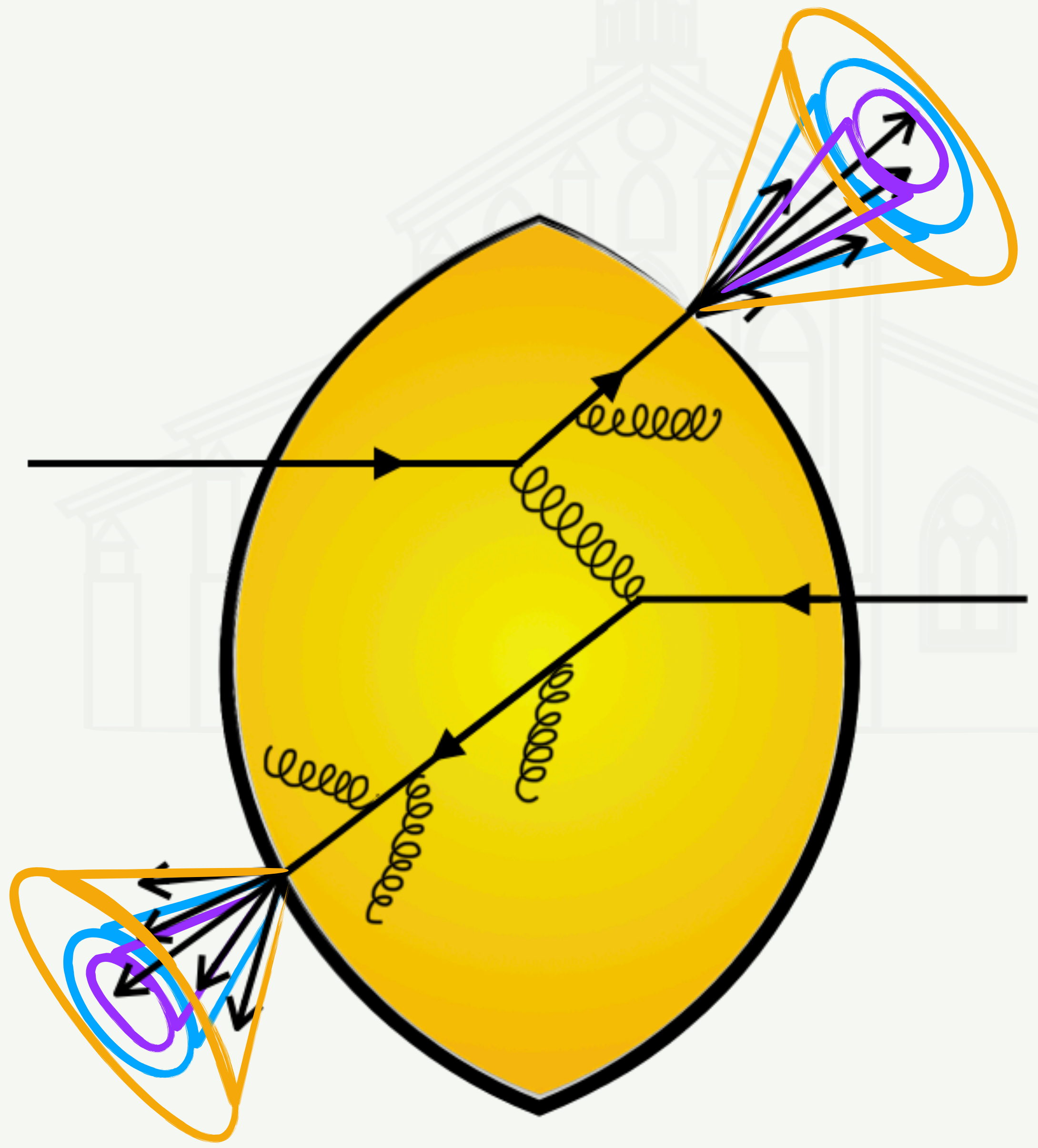
3

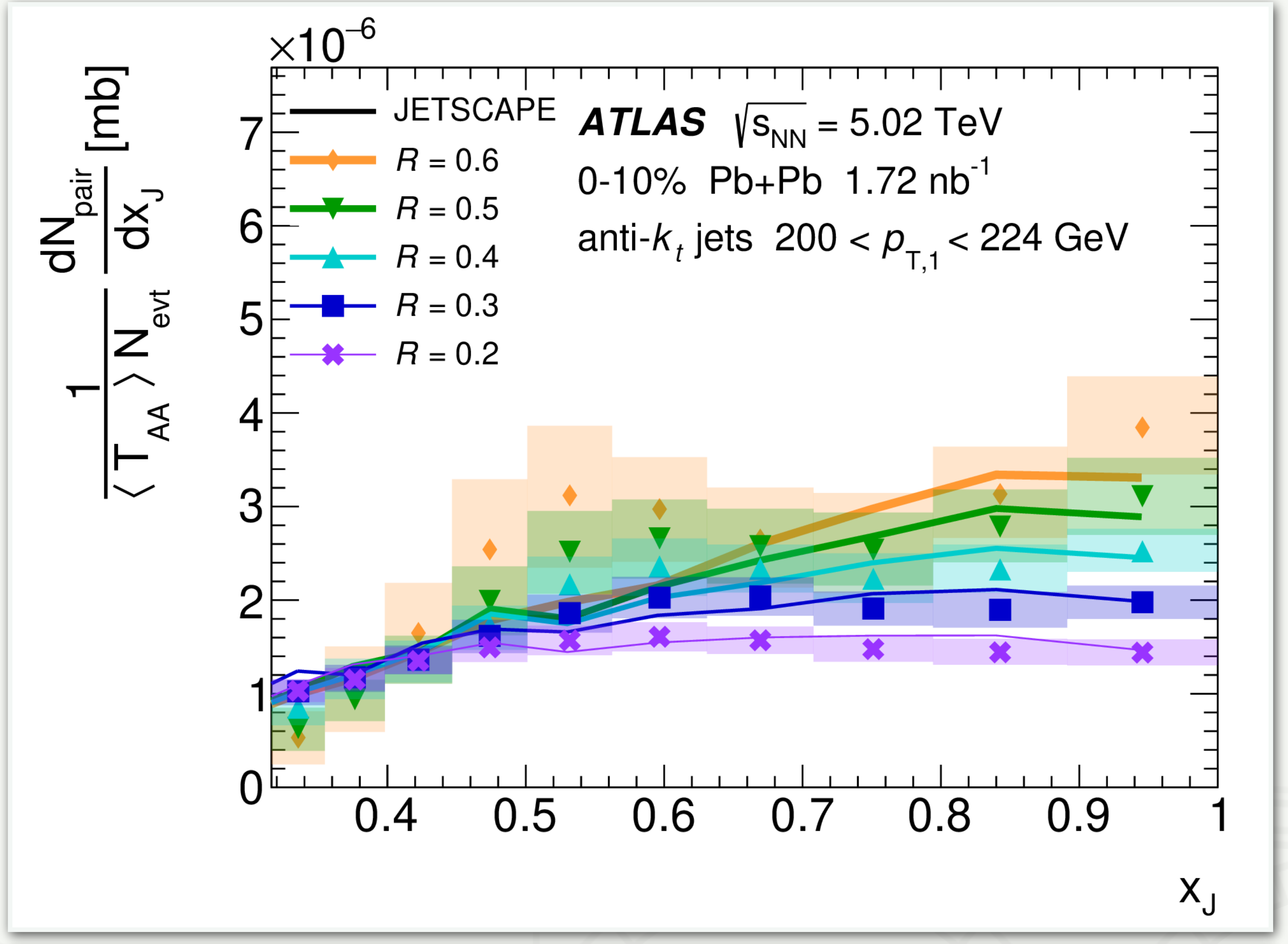
How does the amount of energy lost depend on path length?

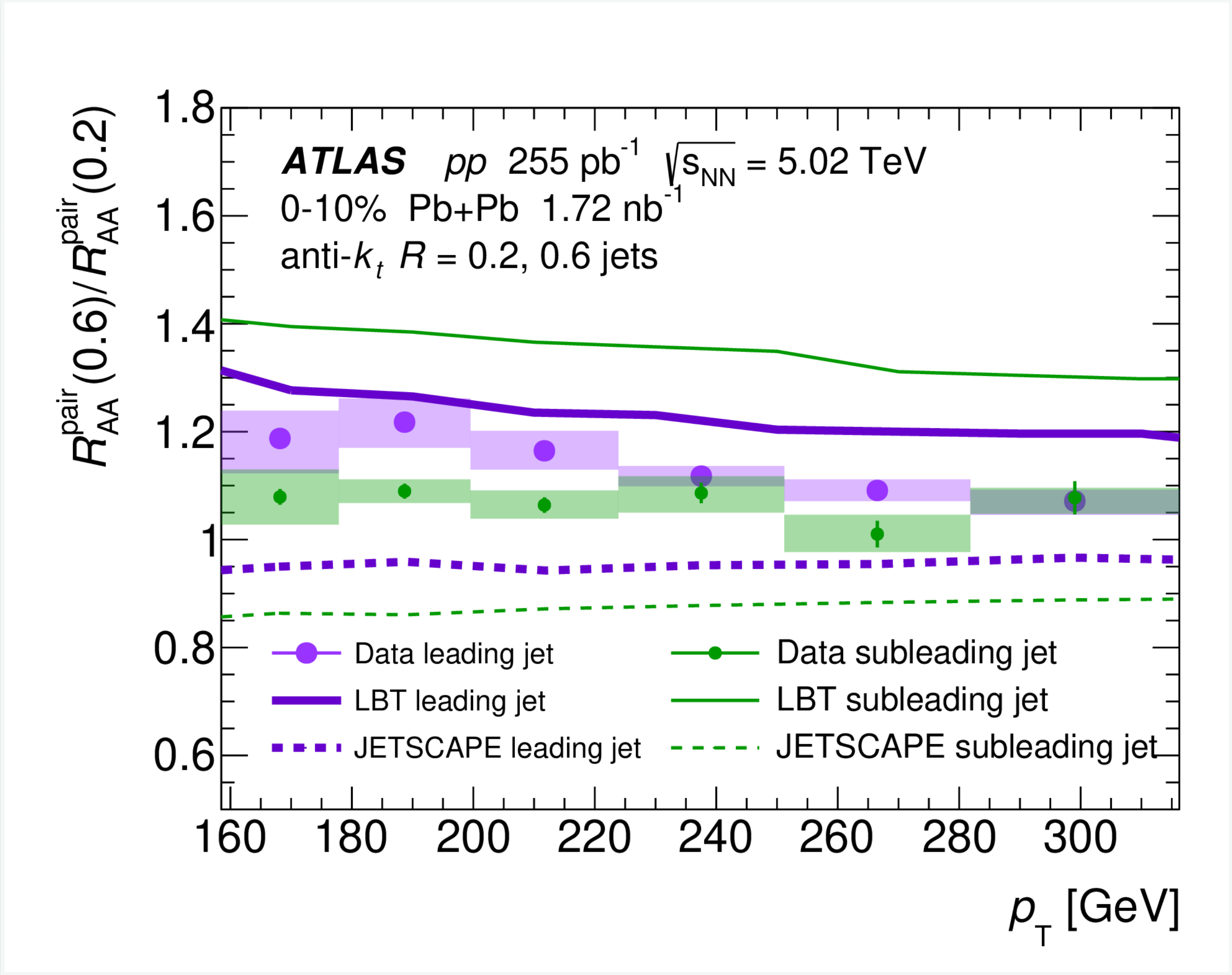
R-scan of dijet asymmetry in Pb+Pb

See talk by A.Sickles & poster by A.Romero

$$x_J = \frac{p_{T,2}}{p_{T,1}}$$







Jet radius

Multi-differential characterization of the dijet asymmetry as a function of jet radius, centrality, p_T, x_J

R_{AA}^{pair} → Dijet nuclear modification factor

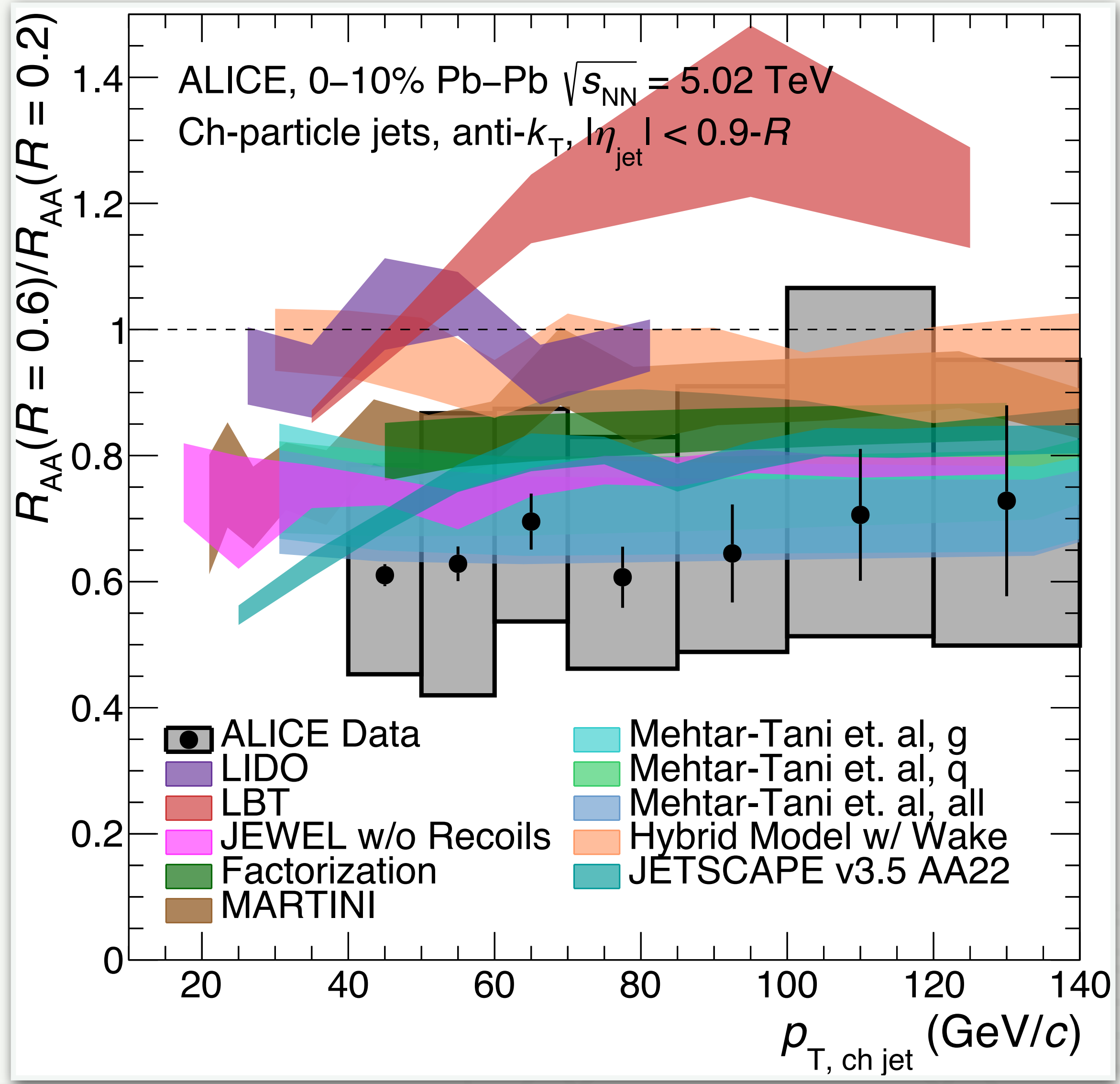
$$\frac{R_{AA}^{pair}(\text{large } R)}{R_{AA}^{pair}(\text{small } R)} > 1$$

For both leading and subleading jets in dijet pair

arXiv:2407.18796

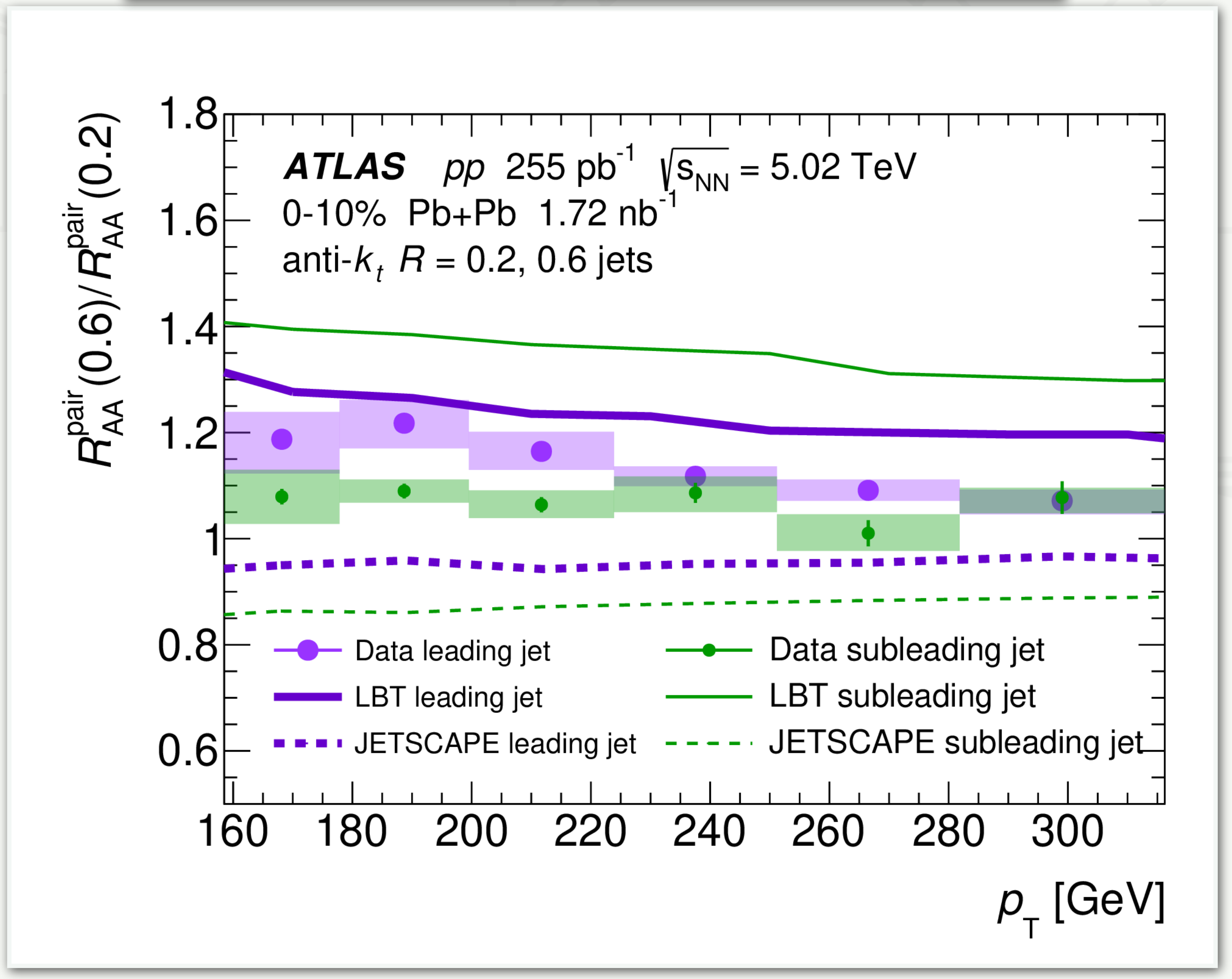
R(0.6)/R(0.2): ALICE inclusive vs ATLAS dijet

PLB 849 (2024) 138412
ALICE Radius dependence of **inclusive jets R_{AA}**



NB: Models ~predict both trends in the two cases

arXiv:2407.18796
ATLAS **Dijet pair R_{AA}**



$$\frac{R^{incl}_{AA}(\ )}{R^{incl}_{AA}(\ )} < 1$$

For inclusive track jets

How do we understand this?

$$\frac{R^{pair}_{AA}(\ )}{R^{pair}_{AA}(\ )} > 1$$

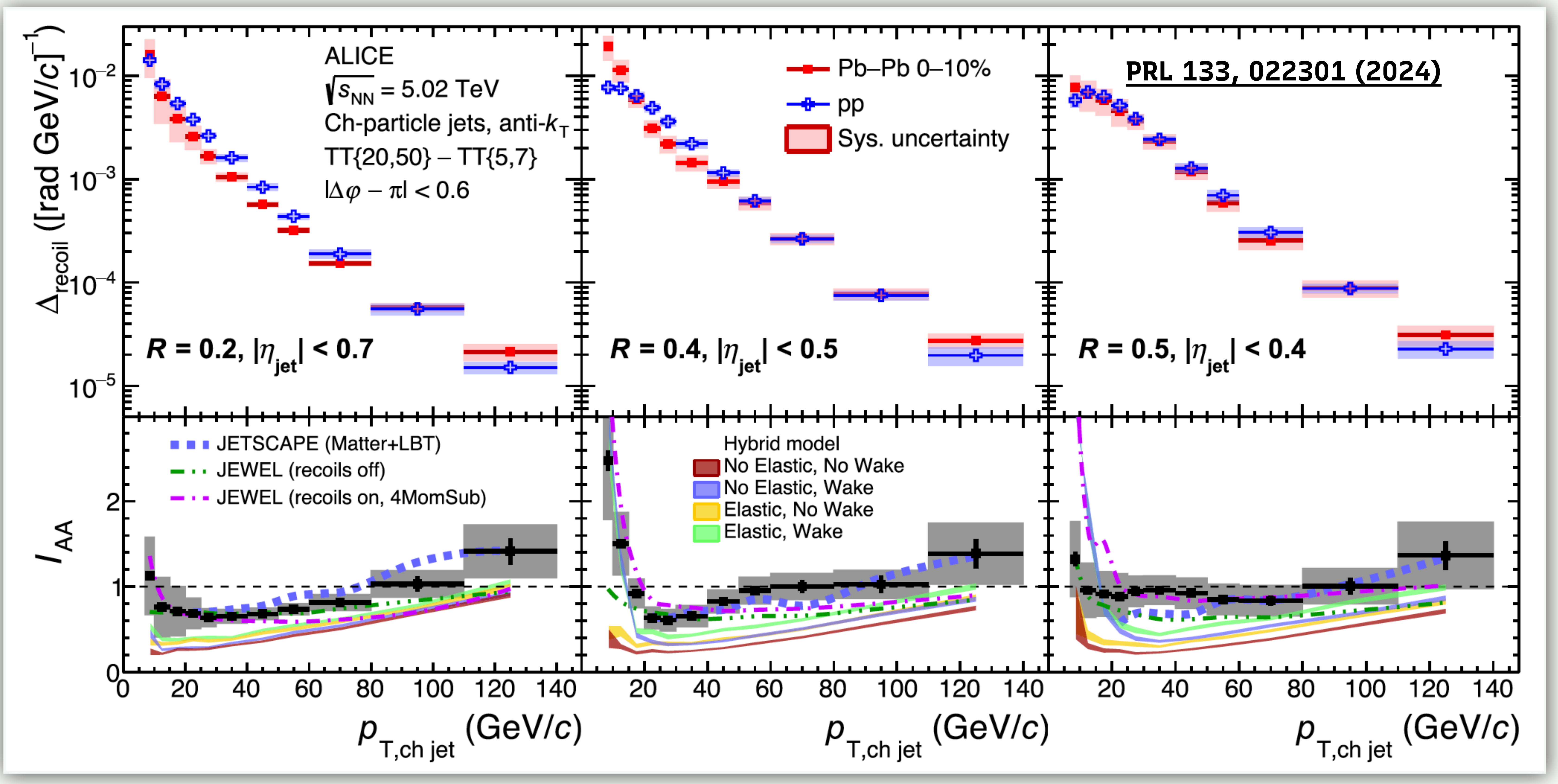
For both leading and subleading jets in dijet pair

Semi-inclusive jet+h in Pb+Pb

See talk by **D.M.Jones**

Jet radius

- Data-driven method to remove the fake jet background
  - Lowest value of p_T reached at LHC, $7 < p_T$ /[GeV] < 140 (track jets)
- **I_{AA} not suppressed for larger R jets**
- Interesting **increase** in the **I_{AA}** observed **at high $p_{T,ch\ jet}$**
  - See **PLB 854 (2024) 138739** and talk by **Y.He**



Azimuthal broadening in jet+h

See talk by D.M.Jones

PRL 133, 022301 (2024)

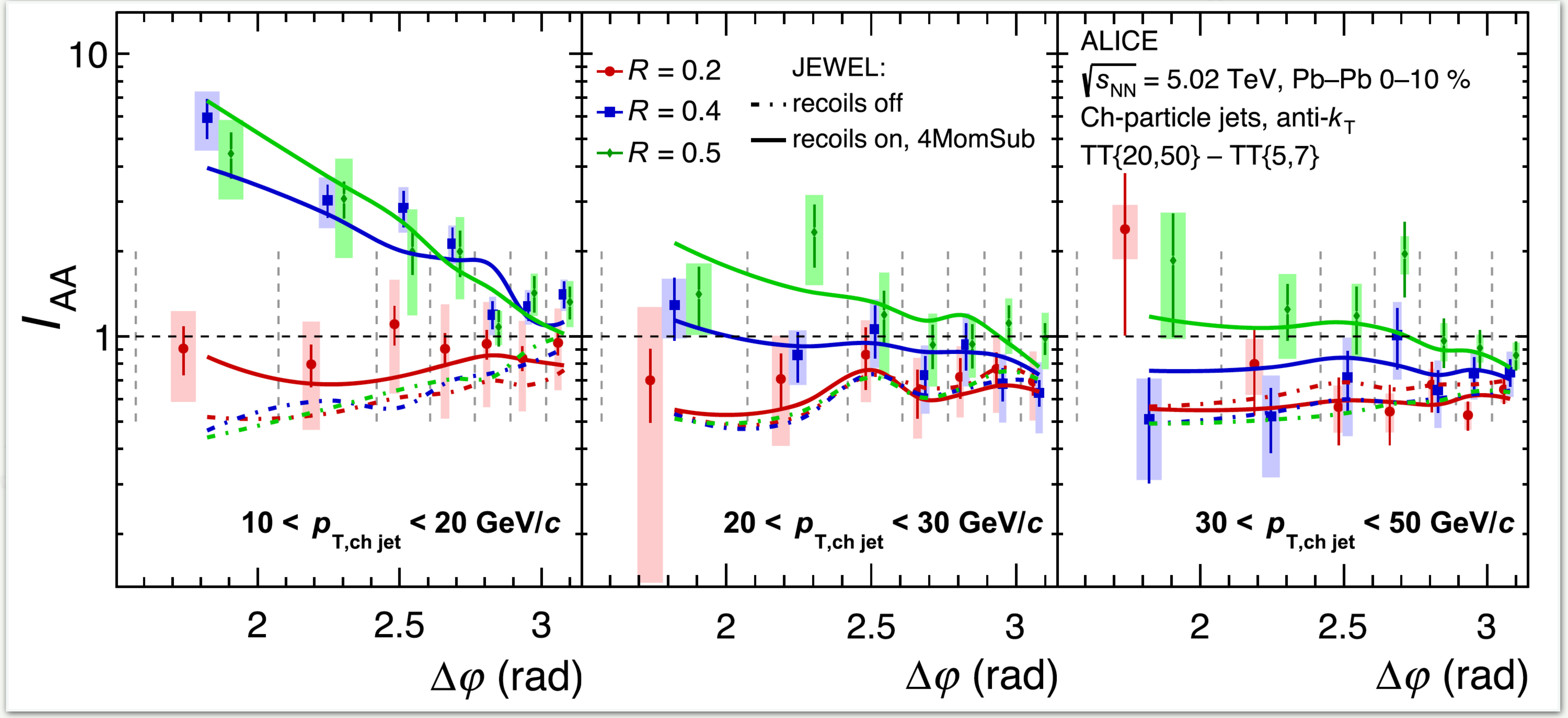
Azimuthal decorrelation at low (< 20 GeV) $p_{T,ch\ jet}$ for R >= 0.4

JEWEL+recoils on describe this data but not inclusive results

Decorrelation due to recapturing of radiation from the wake at larger R?

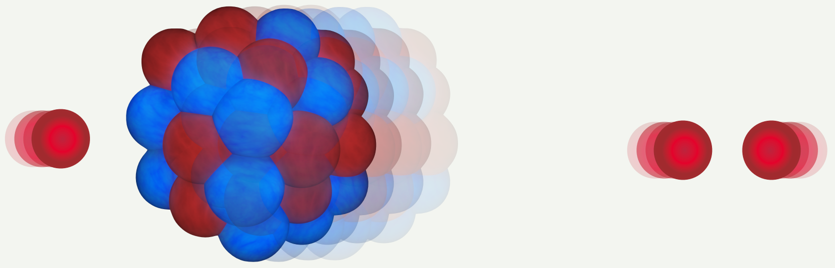
$p_{T,ch\ jet}$ →

Jet radius ↓



Similar measurement also at STAR in π^0 and γ tagged jets, **preliminary for @HP2023**

Small Systems



Small systems - Question A

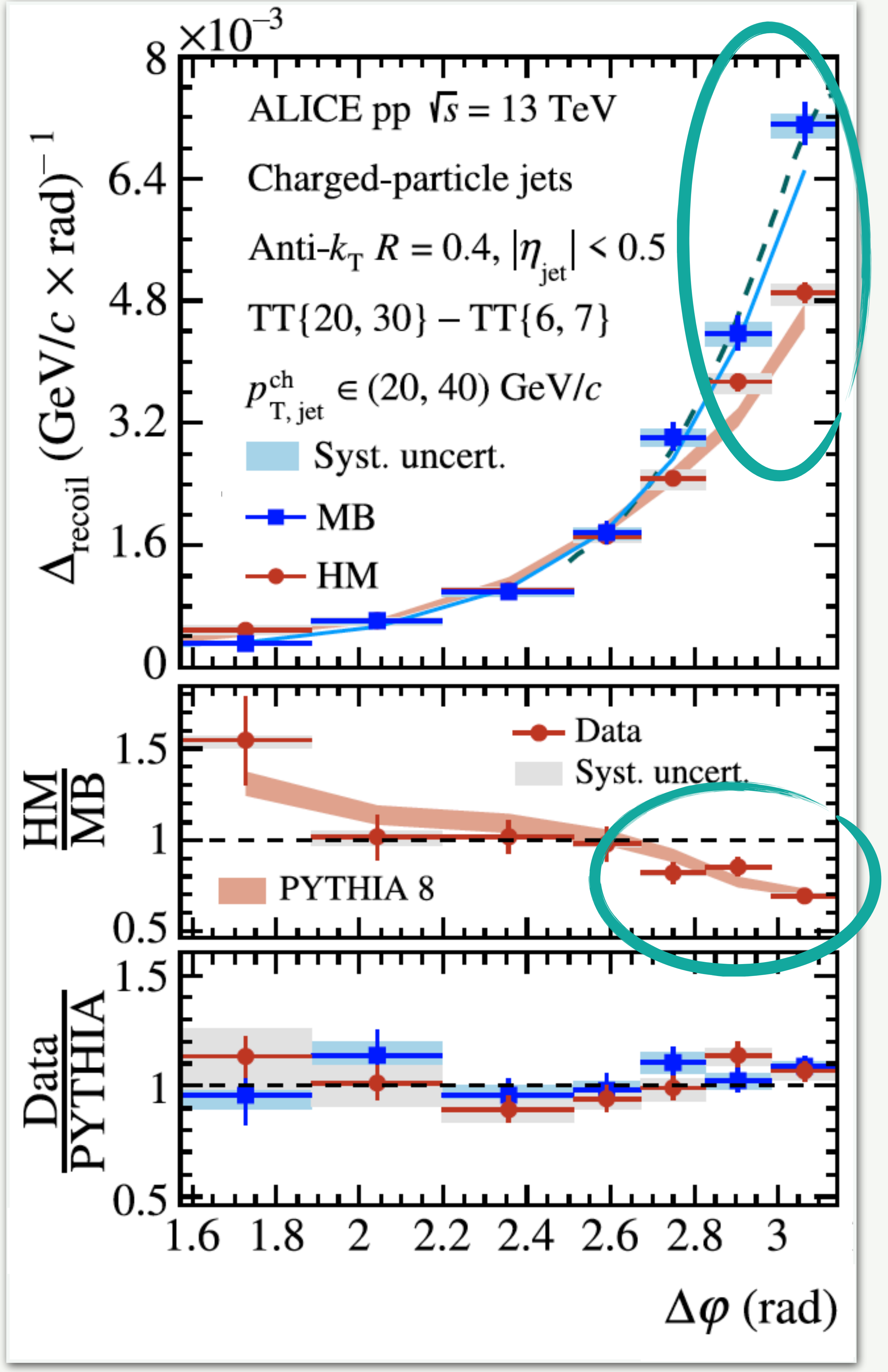
A

Is there evidence of E_{loss} onset in existing small-systems experimental data?

ALICE h+jet in p+p

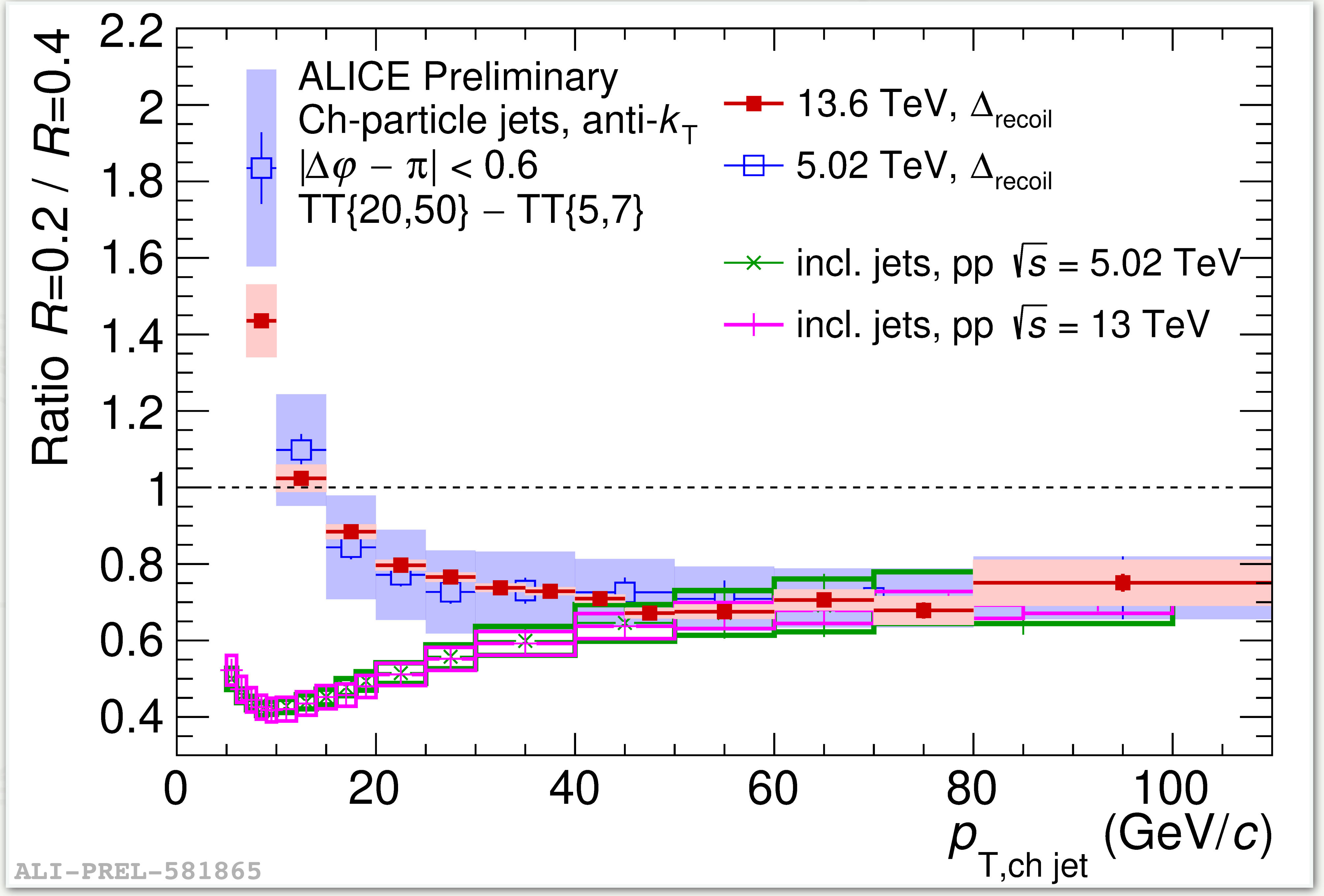
See talk by D.M.Jones & Y.Mao

arXiv:2309.03788



- Semi-inclusive h+jet distributions in High Multiplicity (HM) and Minimimum Bias (MB) p+p collisions

- **Observed suppression of back-to-back h+jet pairs in HM: selection bias** towards **higher order processes** (e.g. **no quenching**)

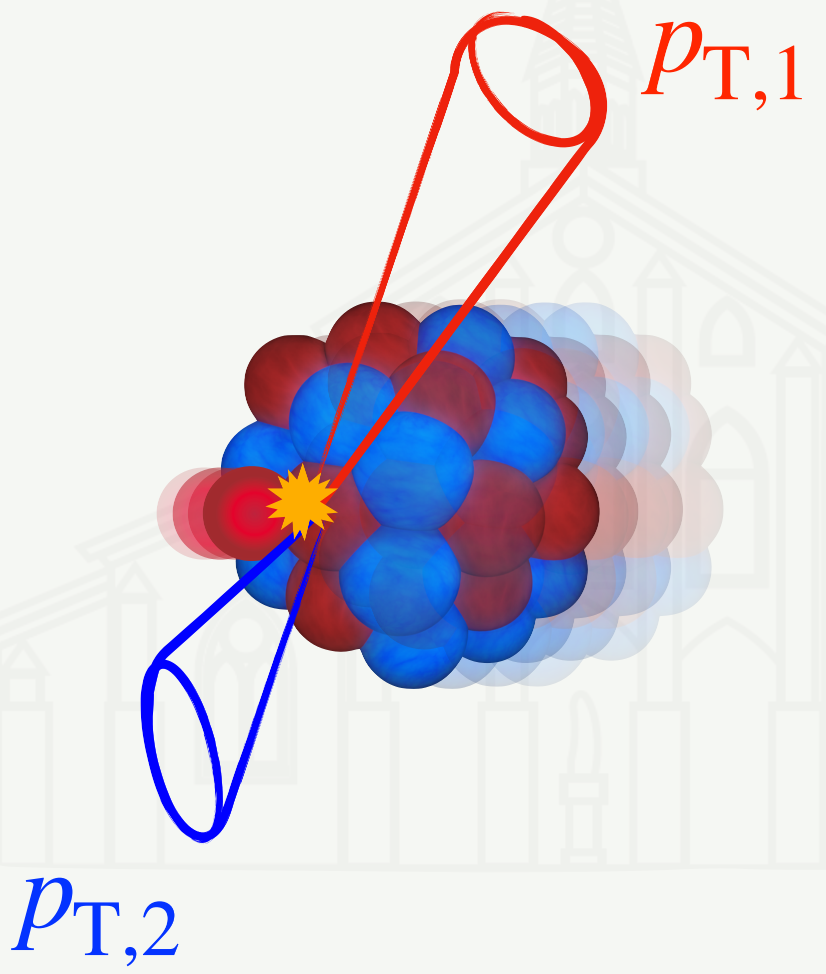


- Fraction of 2022 data vs Run 2 pp reference (50x more): **demonstrates the statistical power of ALICE Run 3 datasets**

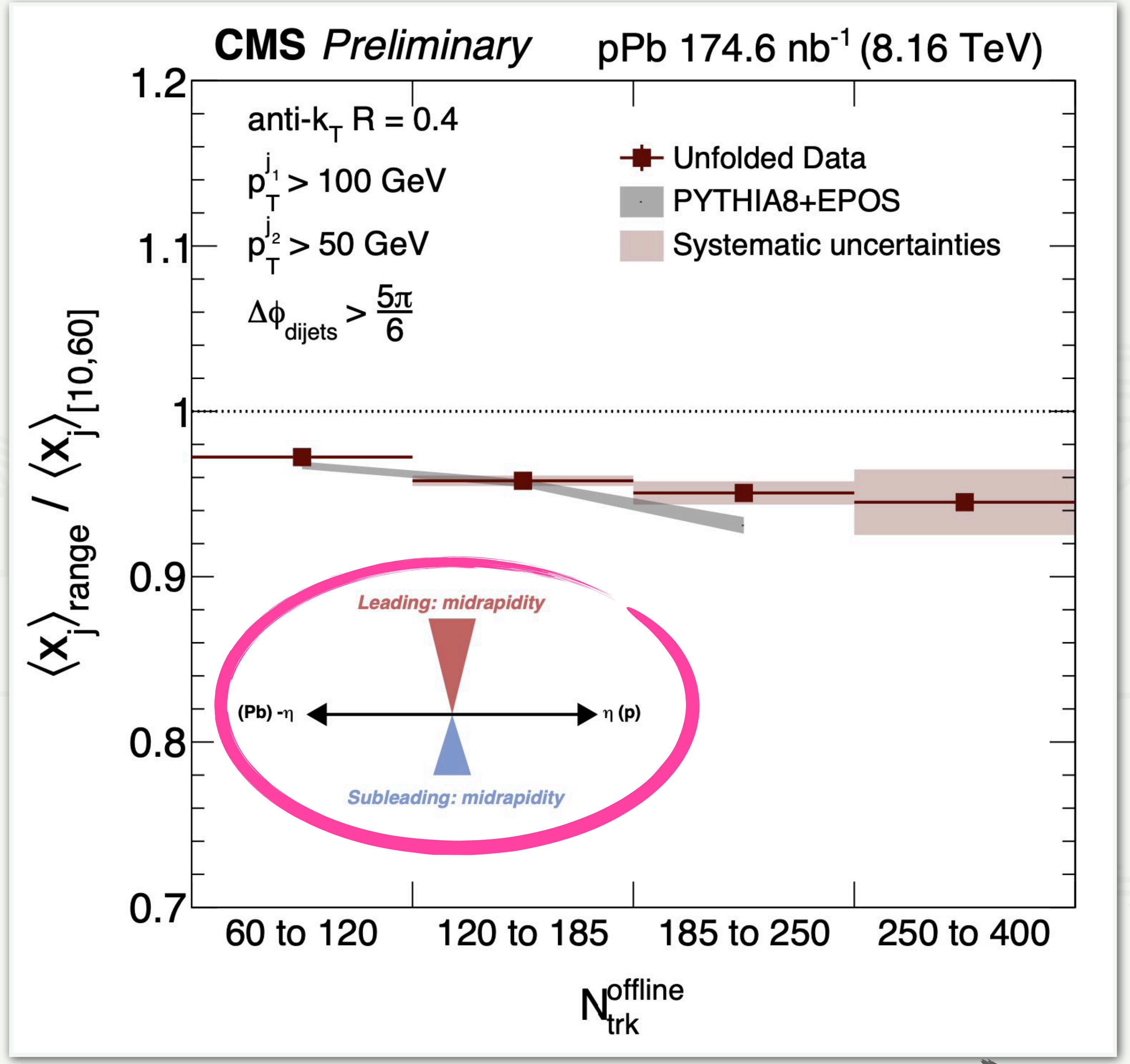
Search for E_{Loss} onset in small systems: LHC p+A

- New results from CMS studying dijet momentum imbalance in p+Pb differentially in rapidity and multiplicity class

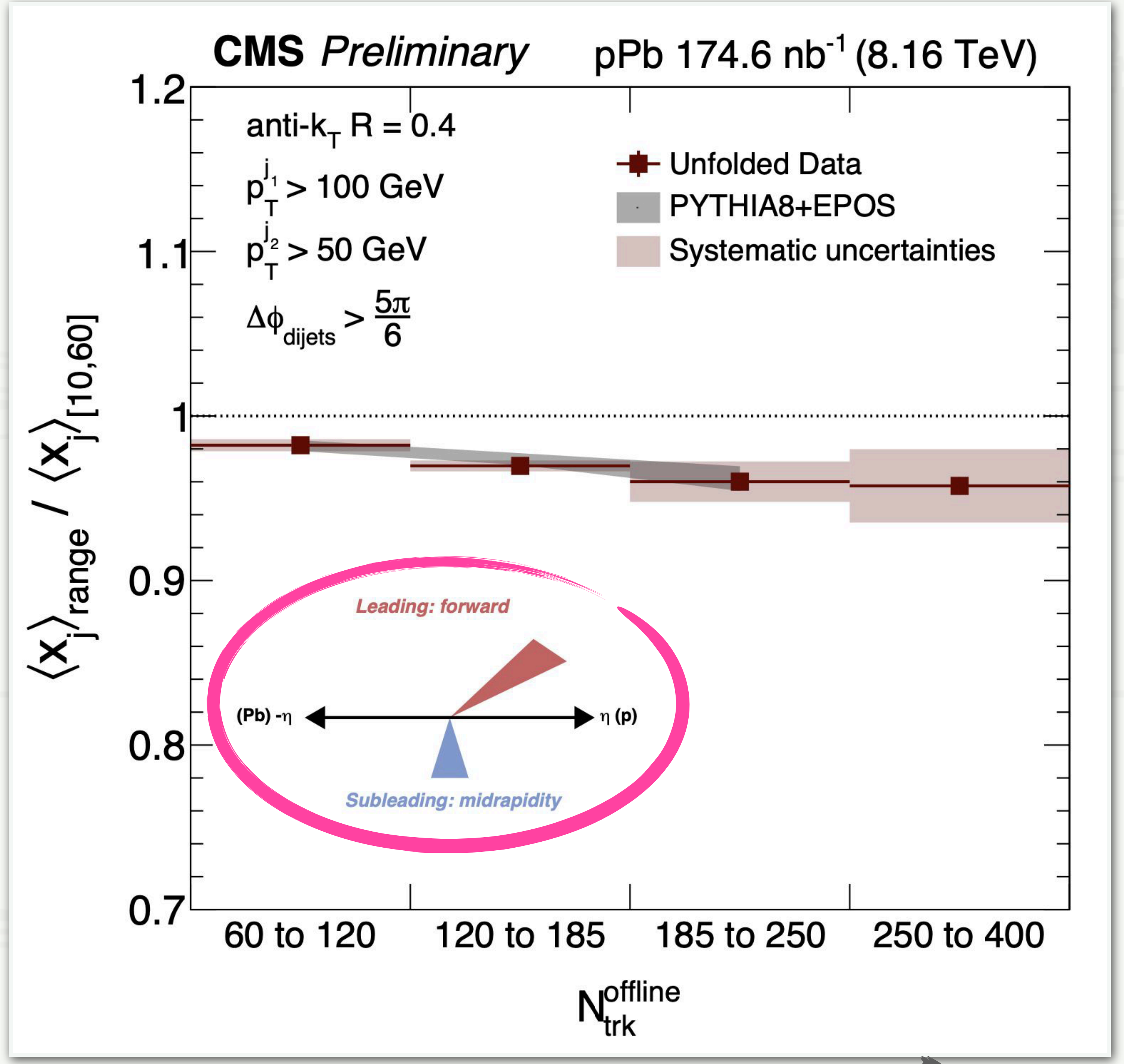
See talk by D.De Souza Lemos



$$x_J = \frac{p_{T,2}}{p_{T,1}}$$



Increasing Event Multiplicity

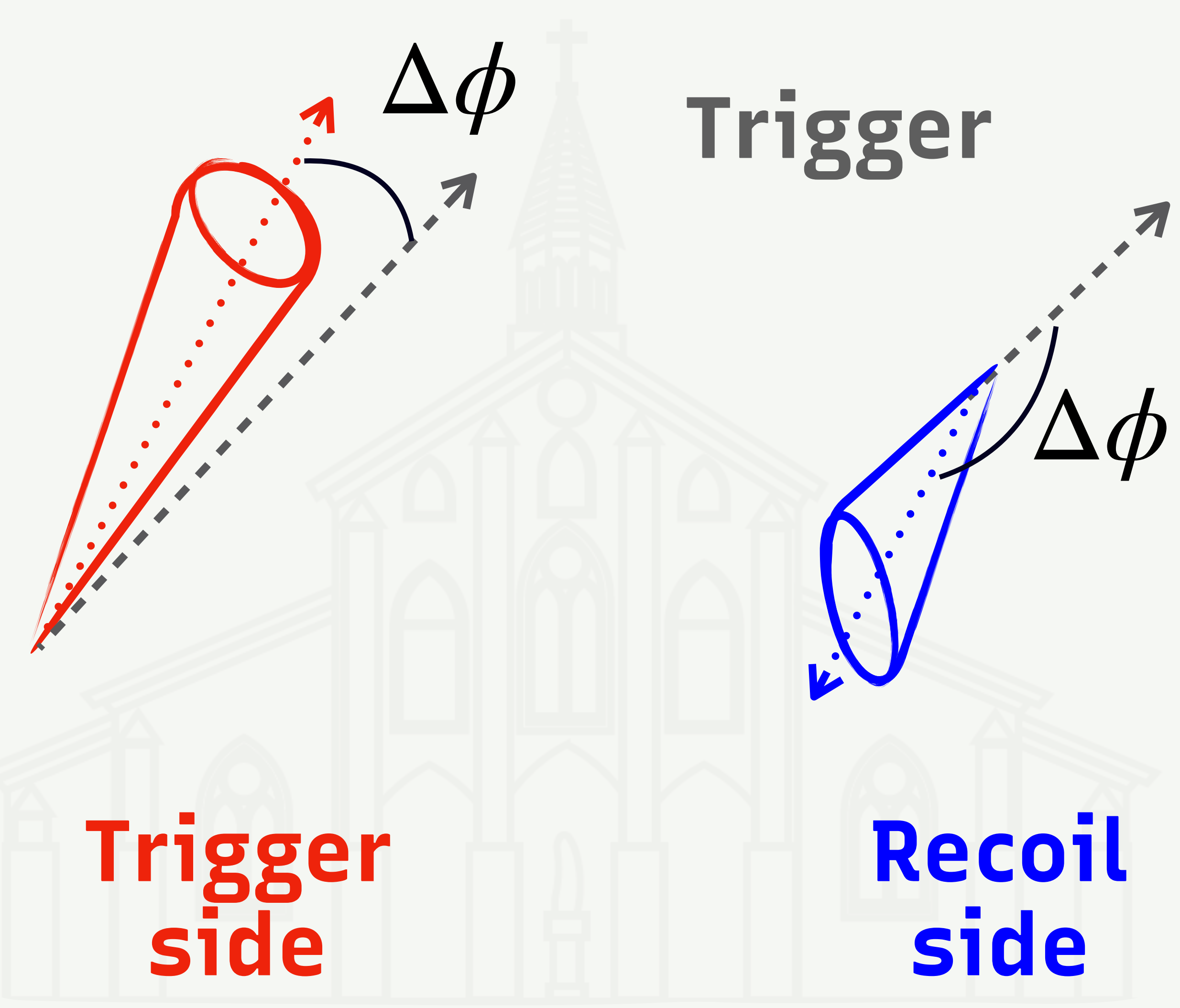


Increasing Event Multiplicity

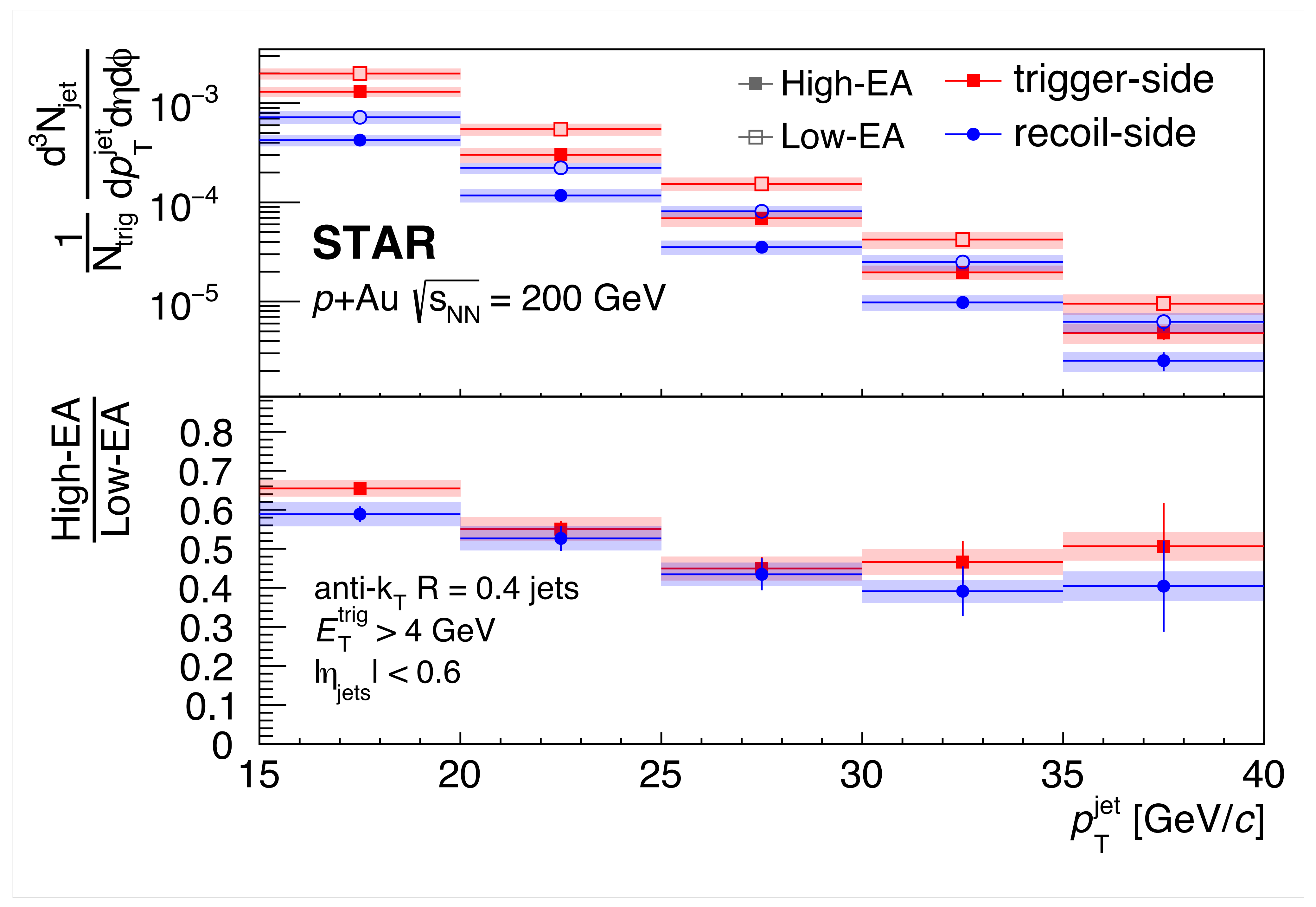
Different dijet η rapidity topology

- Results well described by Pythia8+EPOS MC **(not including E_{loss} effects)**

Search for onset of E_{Loss} in small systems: RHIC



$\Delta\phi < \pi/3$ $\Delta\phi > 2/3\pi$



arXiv:2404.08784

- **h+jet spectra**
  - Comparable suppression for both trigger and recoil side

    → **no evidence of pathlength dependence**

Event activity estimated using the beam-beam counter in the **Au-going direction**

NB: **event activity not robust centrality estimator** in p+A - but used with certain prescriptions in this case

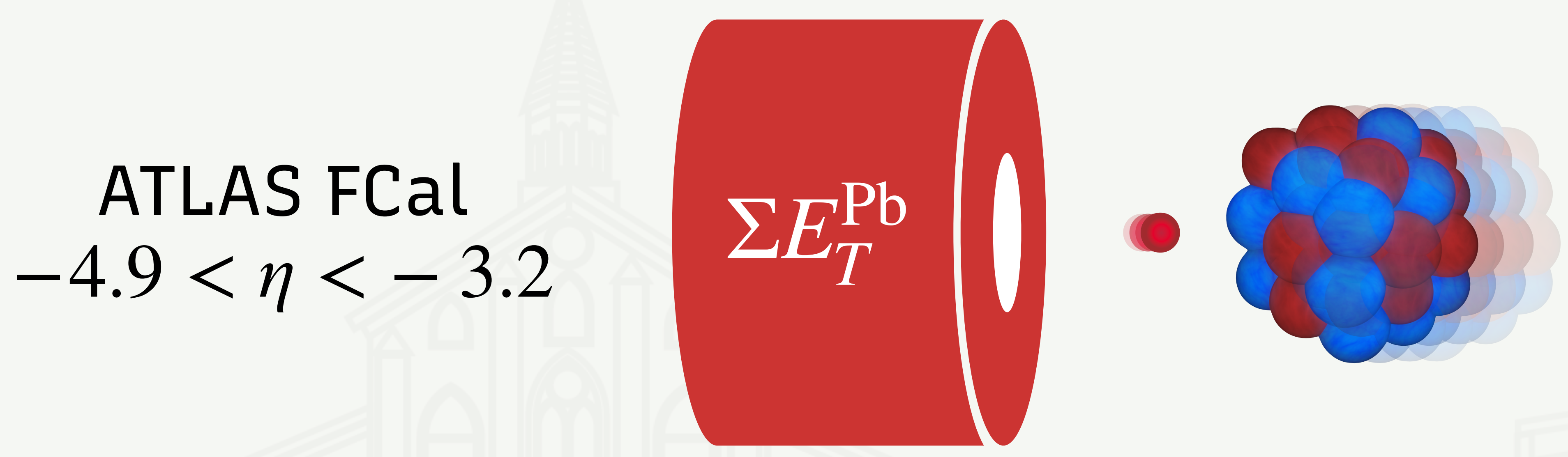
Small systems - Question B

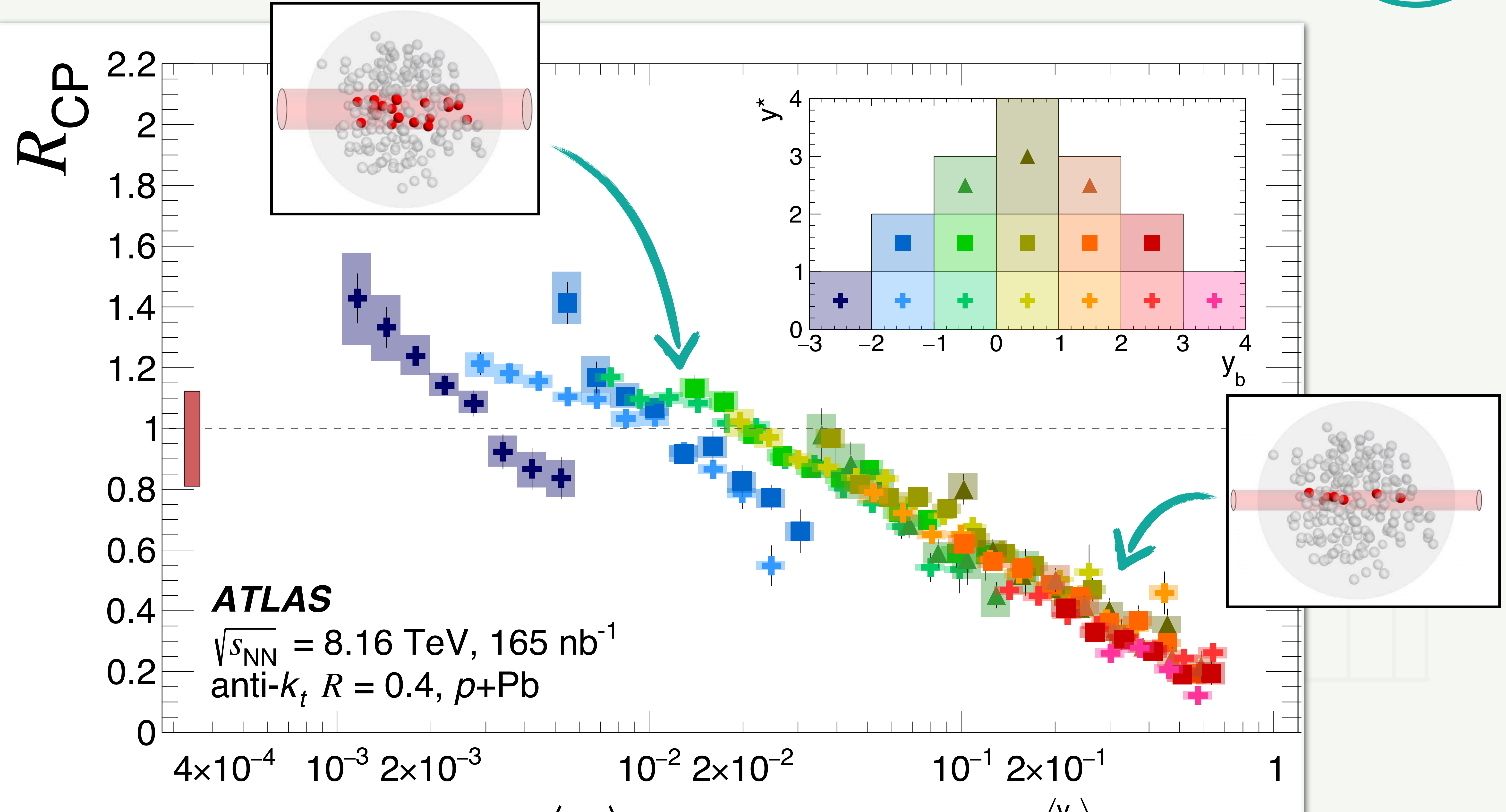
B

How do color fluctuations affect the interpretation of hard scatterings in p+A collisions?

Color fluctuation effects on event activity in p+A

See poster by M.Hoppesch





PRL 132 (2024) 102301 $\langle x_p \rangle \sim (2/\sqrt{s_{NN}}) \times p_{T,Avg} \times e^{\langle y_b \rangle} \cosh(\langle y^* \rangle)$

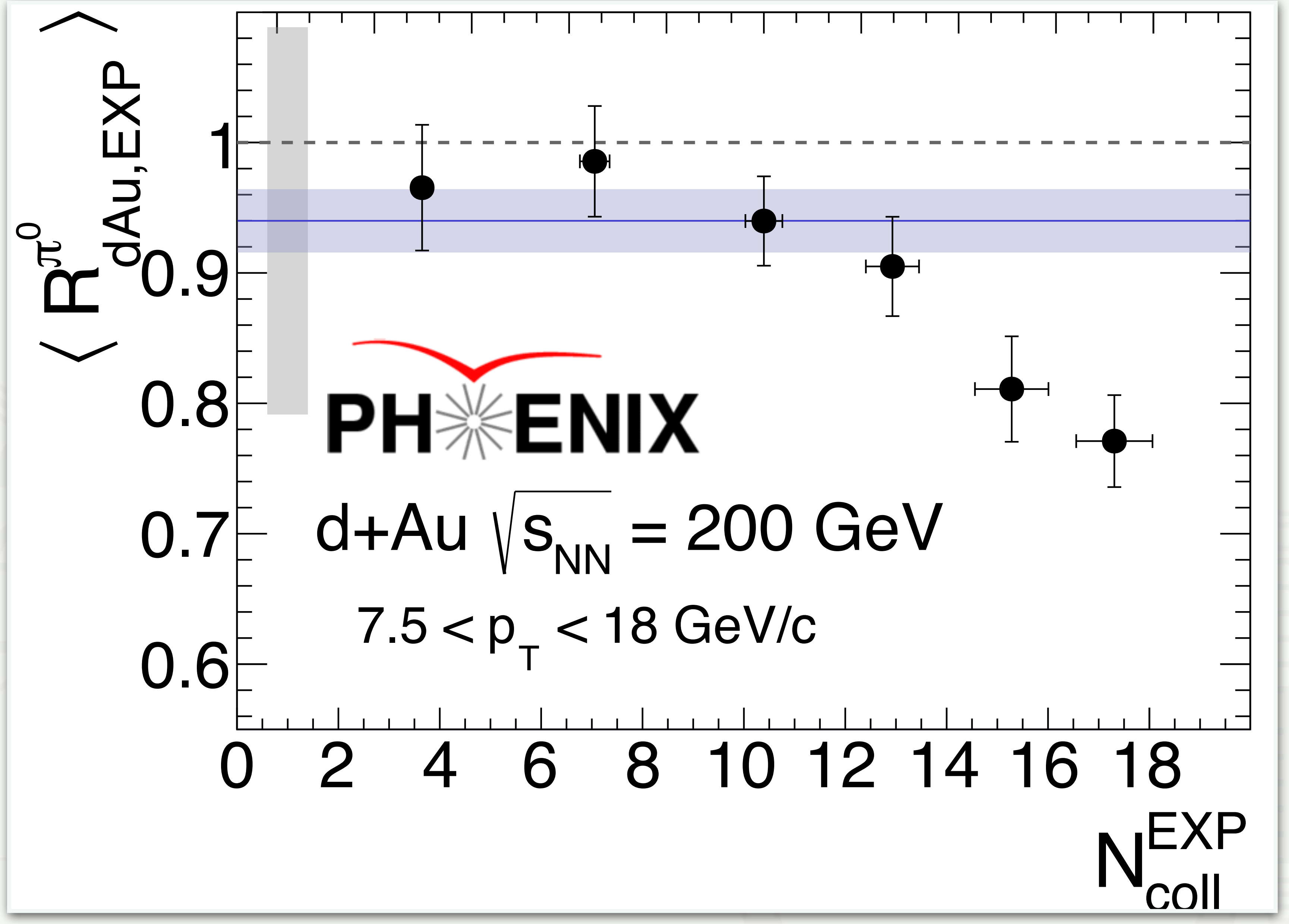
- Centrality defined w/ ΣE_T^{Pb} deposited in Pb-going FCal
- **R_{CP} suppression fully driven by the proton configuration**
- **High-x_p** → Small proton configuration → Lower interaction strength → **Event activity bias**
- Results strongly supportive of **Color Fluctuations (CFs) model, PRD 98 (2018) 071502**

Relevance of CF effects in HI collisions

B Bonus

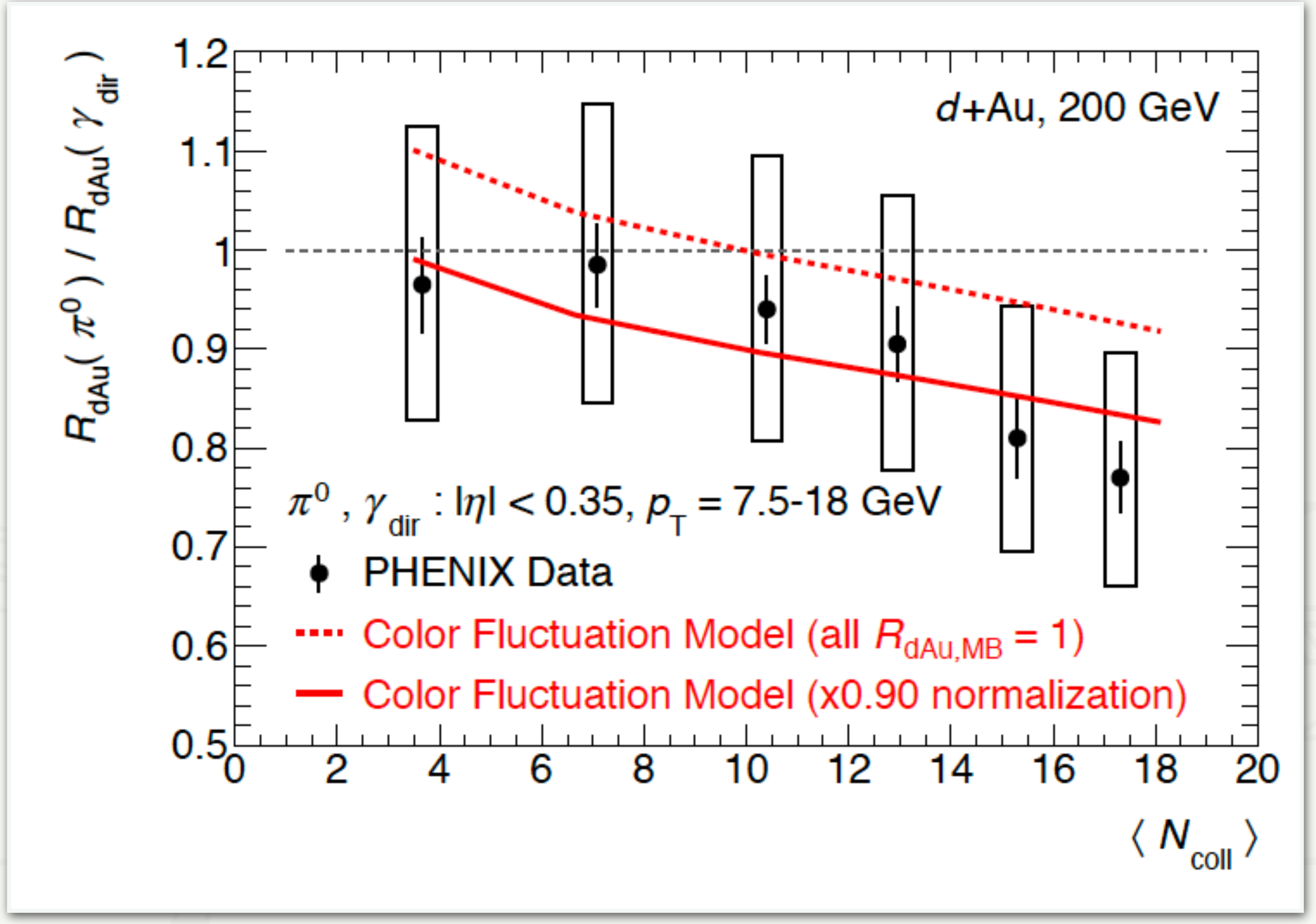
See talk by D.Firak

$$R^{\pi^0}_{dAu,EXP} = \frac{Y^{\pi^0}_{dAu}/Y^{\pi^0}_{pp}}{Y^{\gamma^{dir}}_{dAu}/Y^{\gamma^{dir}}_{pp}}$$



- Relative yield of π^0 to γ^{dir} under the argument both are subject to the same centrality bias (**arXiv:2303.12899**)
- Evidence of jet quenching? (At odds w/ several other measurements at both RHIC and LHC)

See talk by D.Perepelitsa



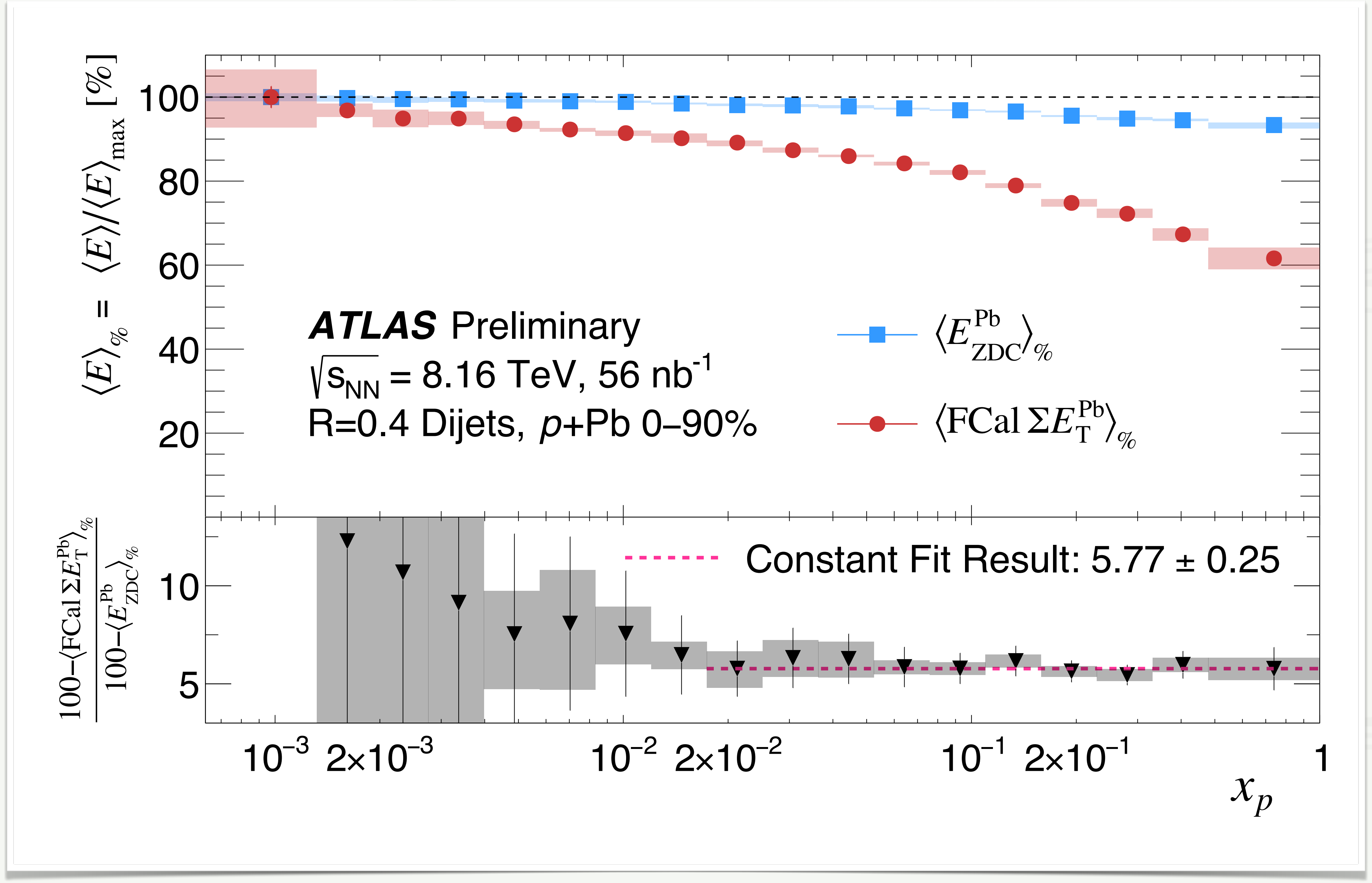
- Same kinematic cuts but π^0 & γ^{dir} have **different x_d distributions**
- Results can be explained w/ color fluctuation model (**Phys. Rev. C 110, L011901**)

Nuclear breakup in p+A collisions w/ dijets

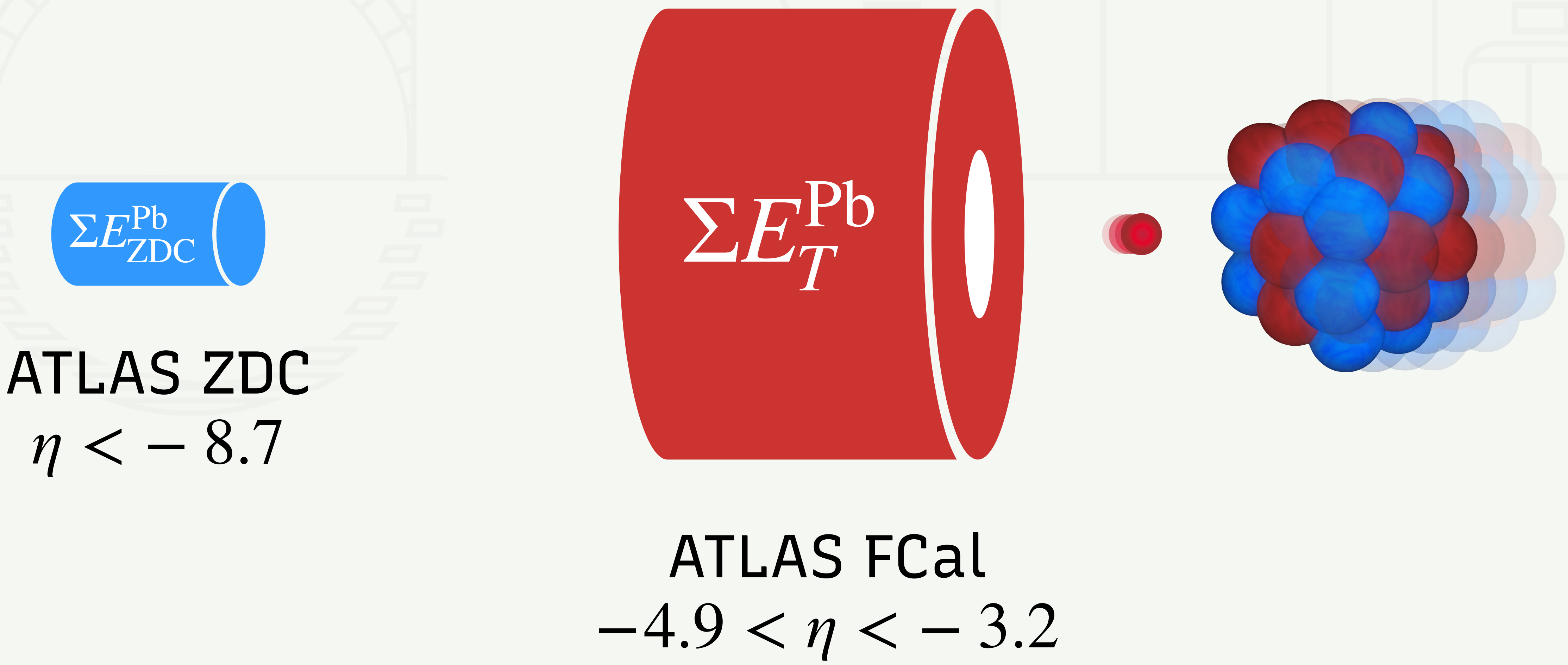
ATLAS-CONF-2024-013

See poster by M.Hoppesch

- Study of energy in the **ZDC** and in the **forward calorimeter in dijet events** to analyze **dependence on the hard-scattering kinematics**



- **~5% difference** between **low** and **high** x_p selections in terms of **ZDC** energy



- **ZDC** energy **~6 times more robust against** dependences on the **hard-scattering kinematics**

Small systems - Question C

C

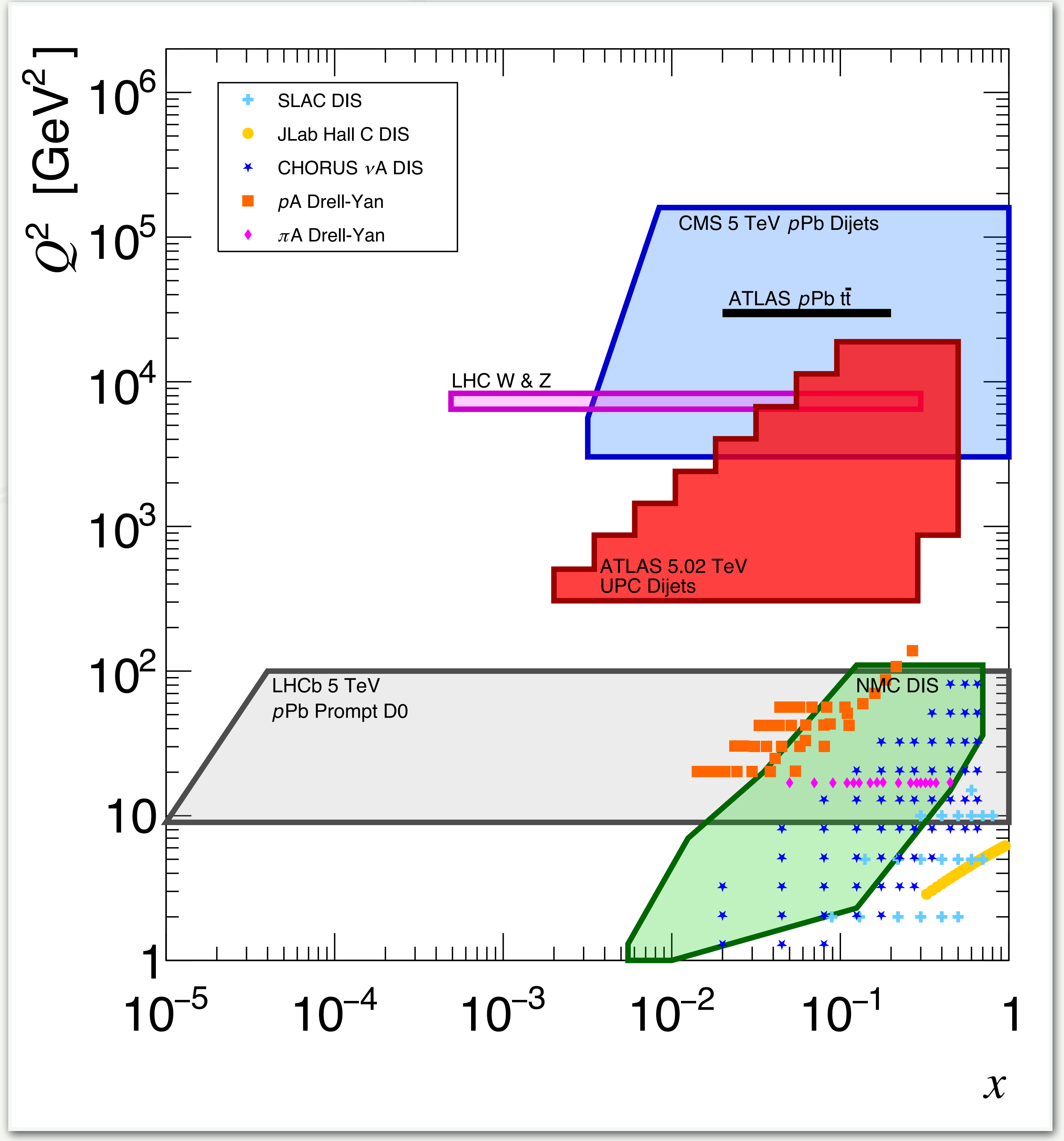
How are parton distribution functions modified in the nuclear environment?

UPC Dijets & nPDFs

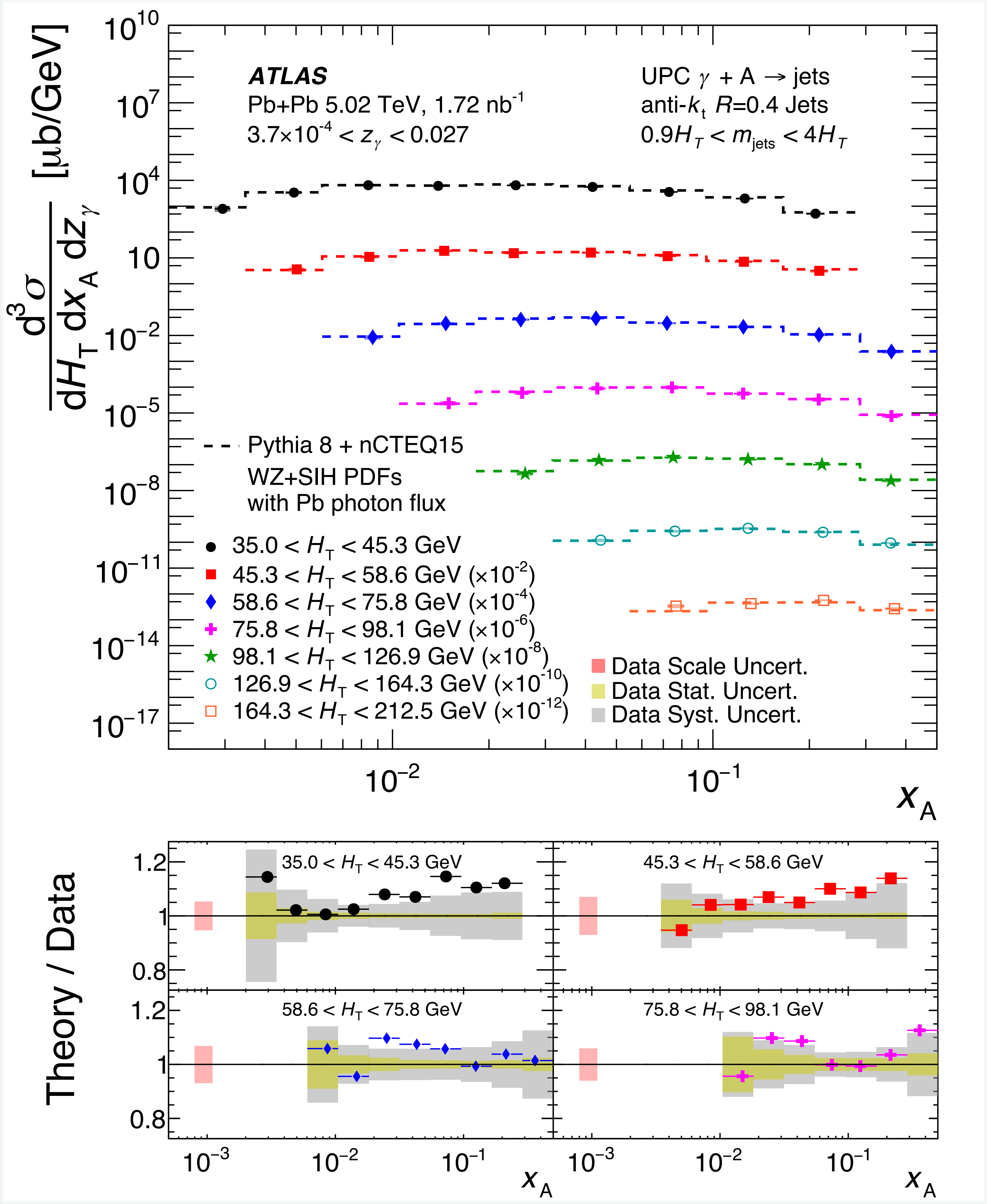
See talk by B.Gilbert

3D unfolded extraction of UPC dijet cross-section in Pb+Pb @ 5.02 TeV

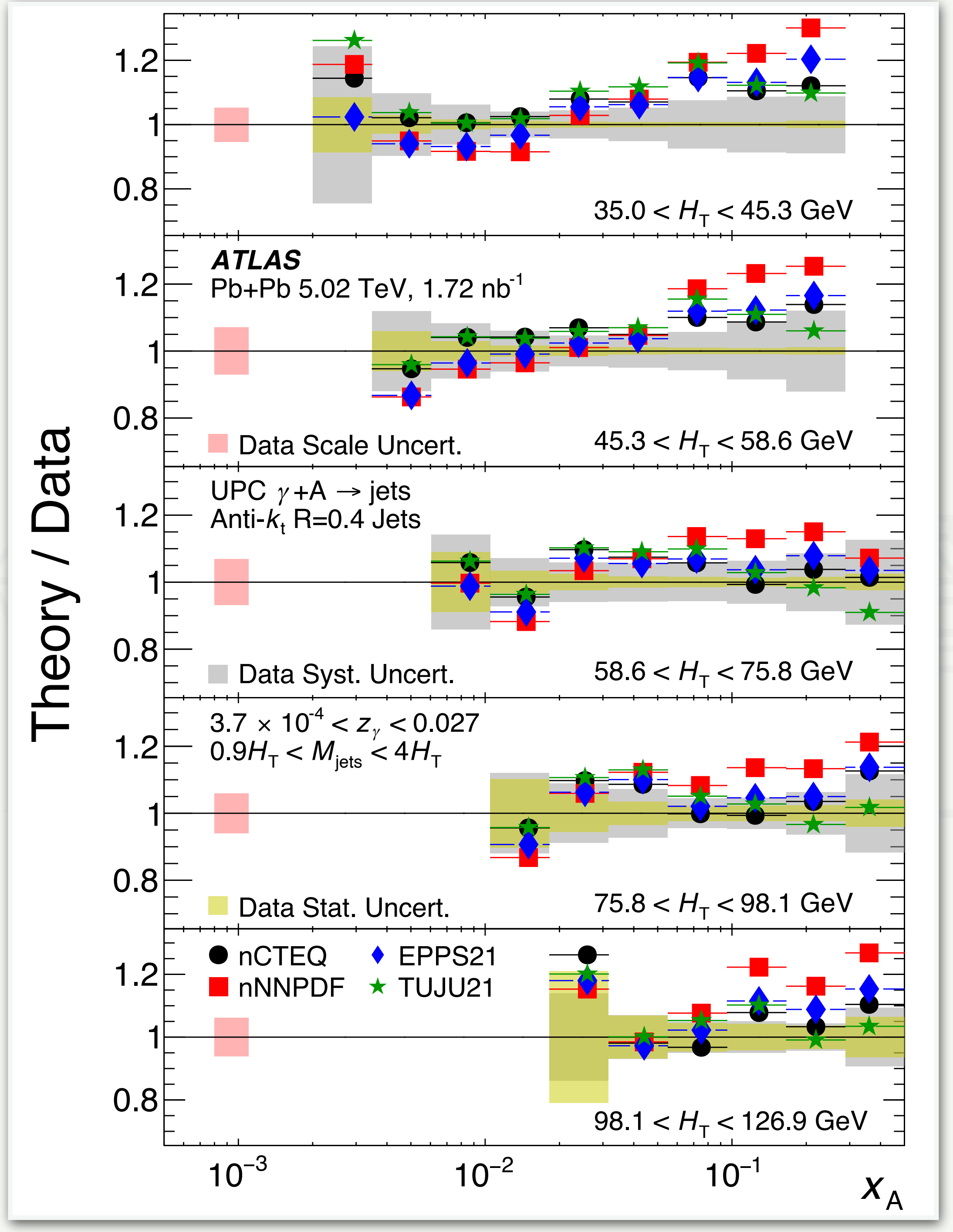
- H_T (hard-scale), z_γ (γ resolution power), x_A (parton momentum fraction in the Pb)



EPPS21 data + UPC dijets



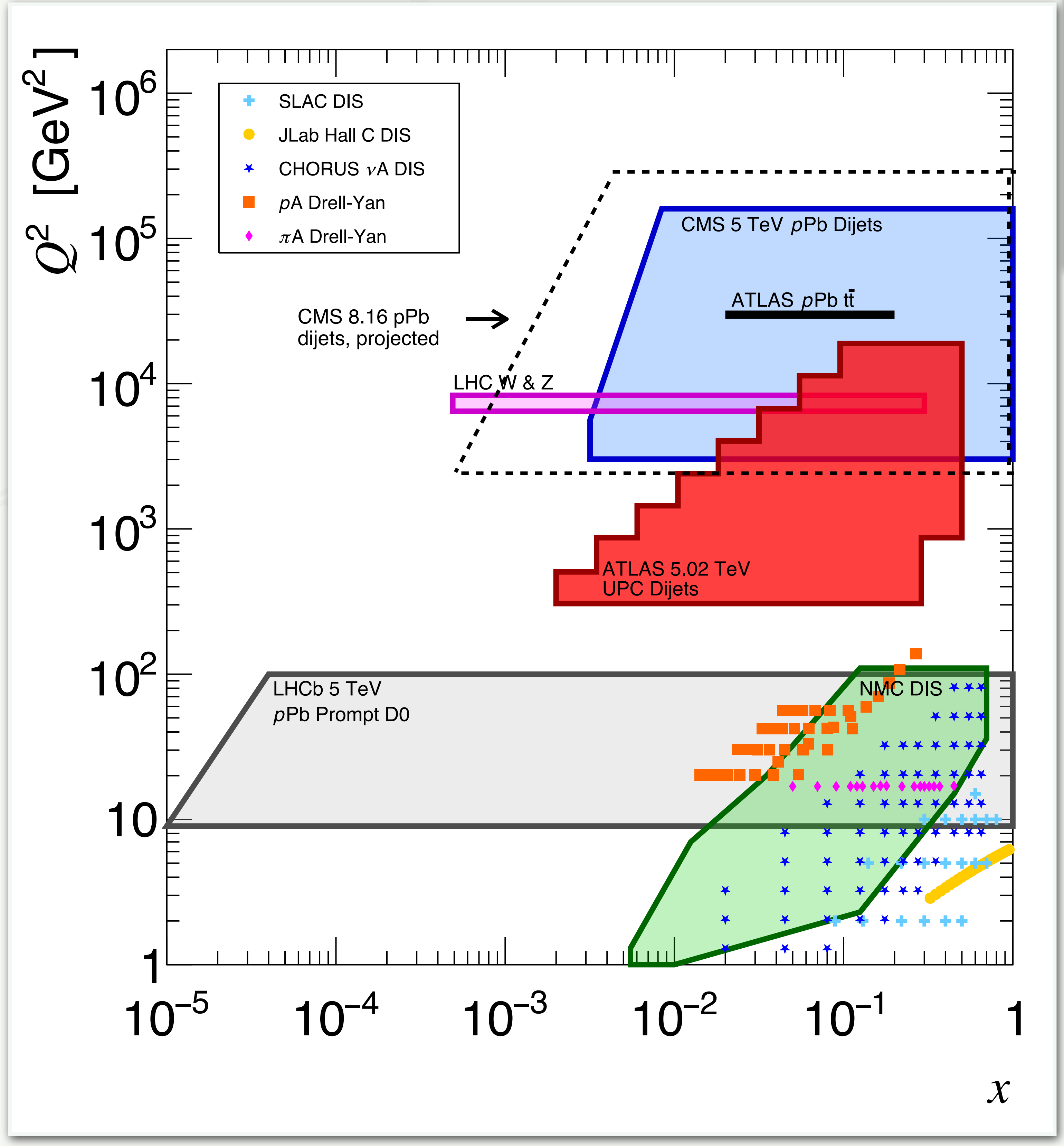
arXiv:2409.11060



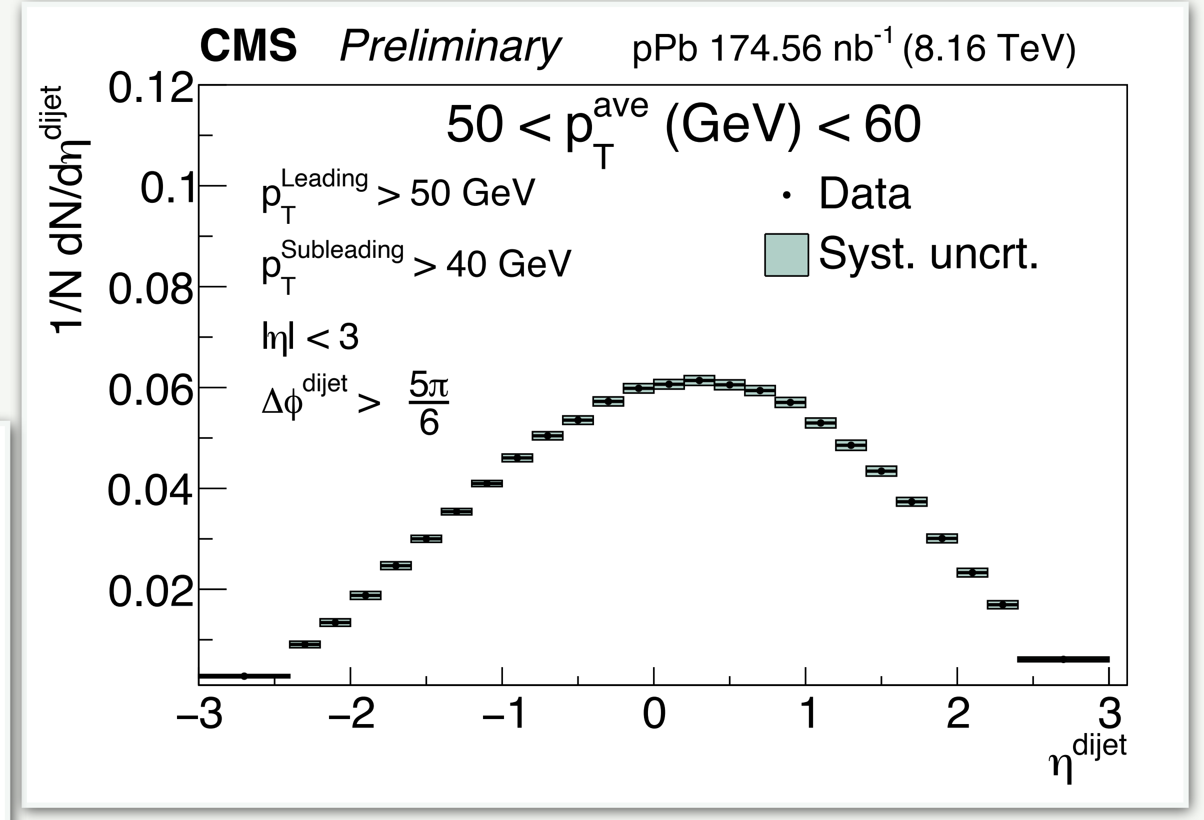
Comparison to different nPDFs in a unique (x,Q2) phase space

Dijets in p+Pb: more CMS & ATLAS data to come

See talk by G.Nigmatkulov

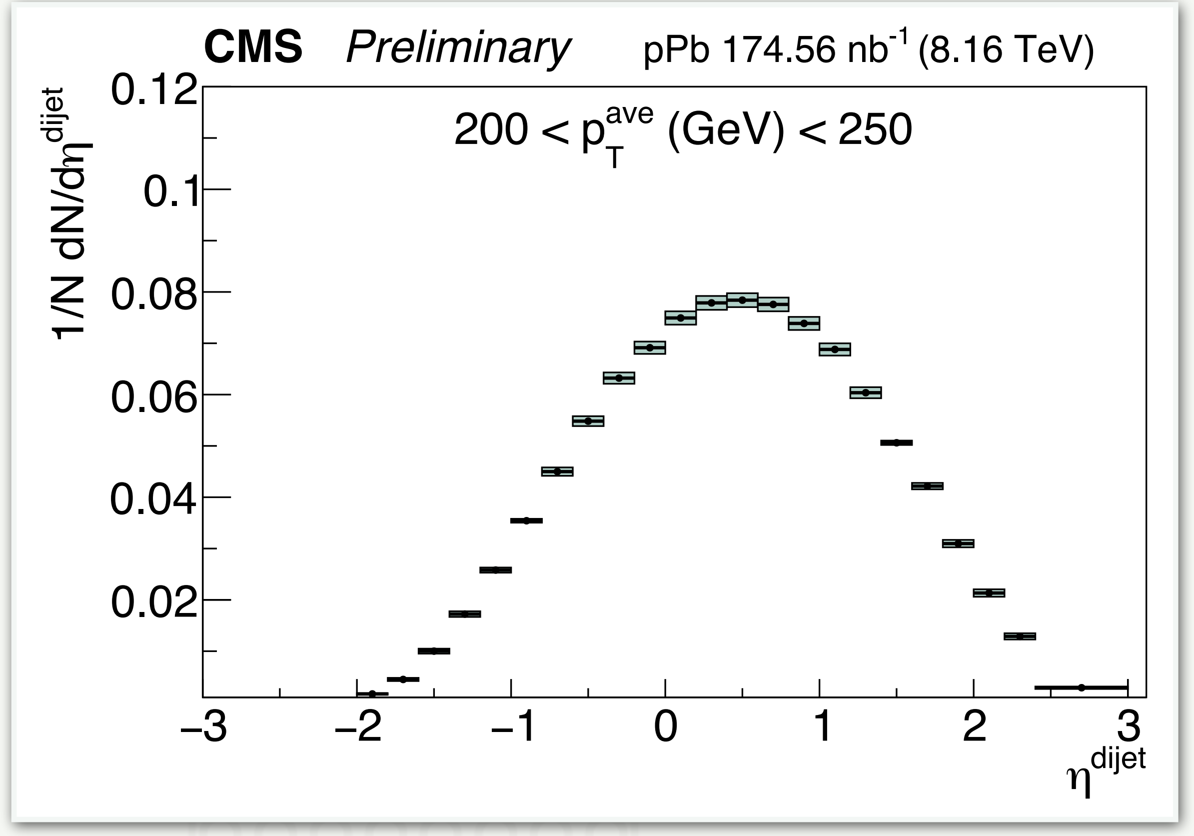


EPPS21 data + UPC dijets + CMS dijets



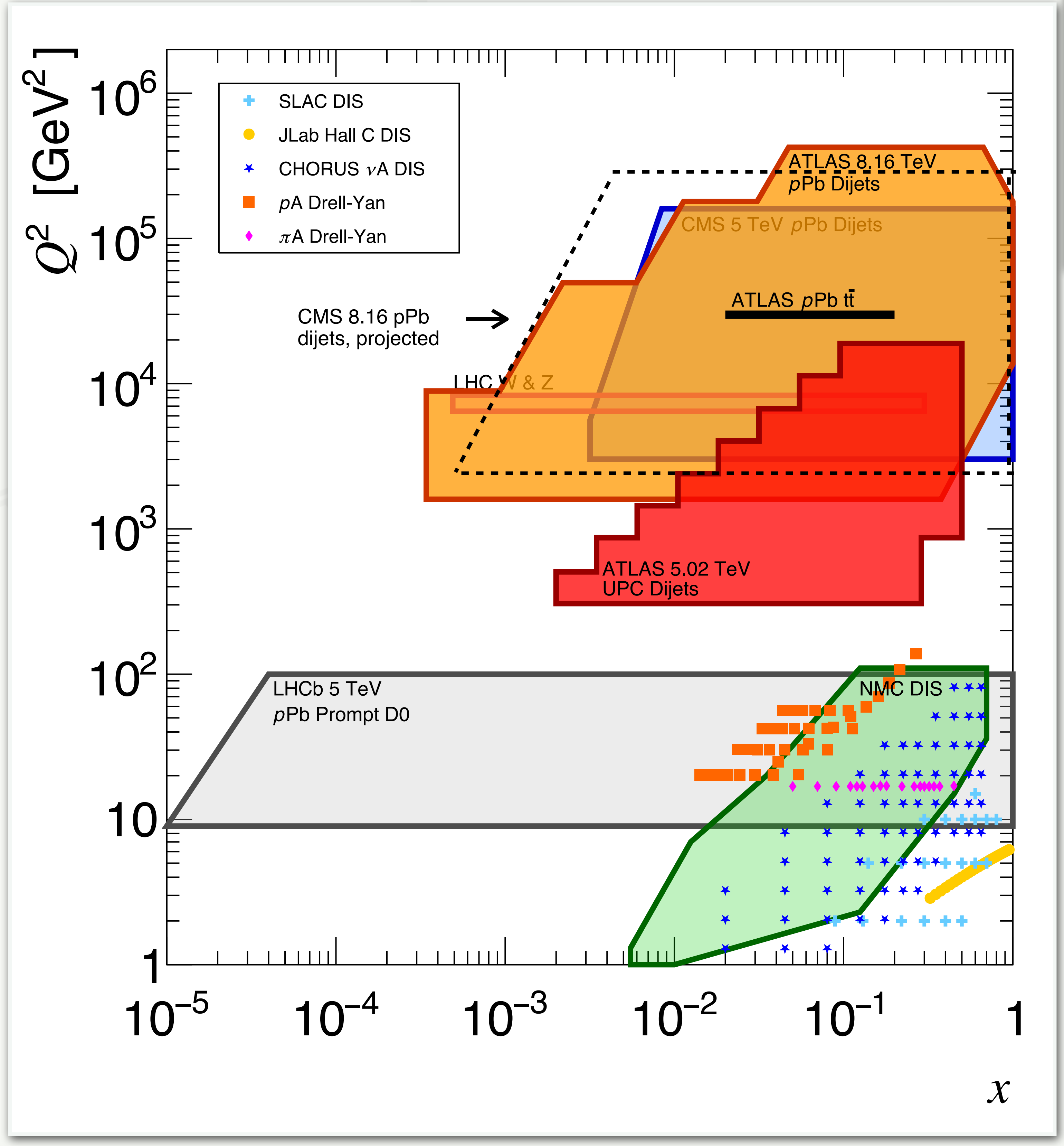
… 14-bins …

$$p_T^{\text{ave}} = \frac{p_{\text{T,Lead}} + p_{\text{T,Sublead}}}{2}$$

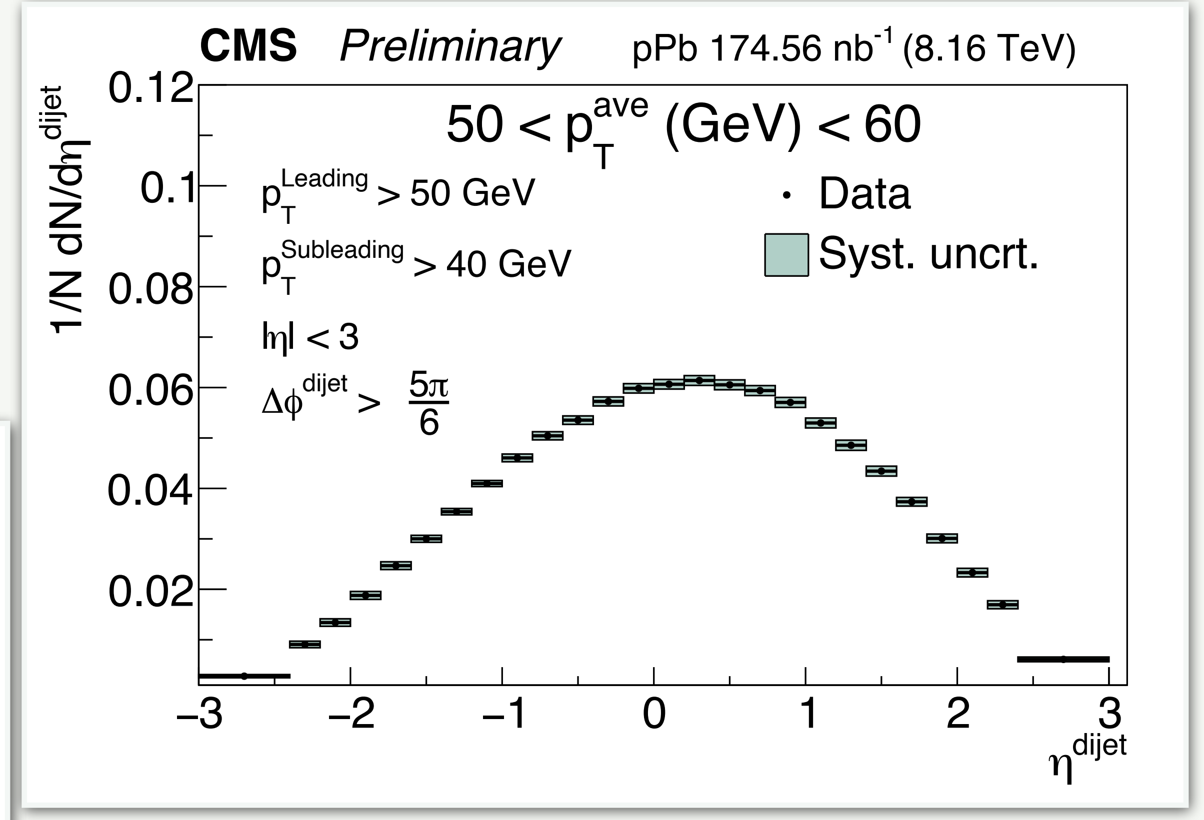


Dijets in p+Pb: more CMS & ATLAS data to come

See talk by G.Nigmatkulov

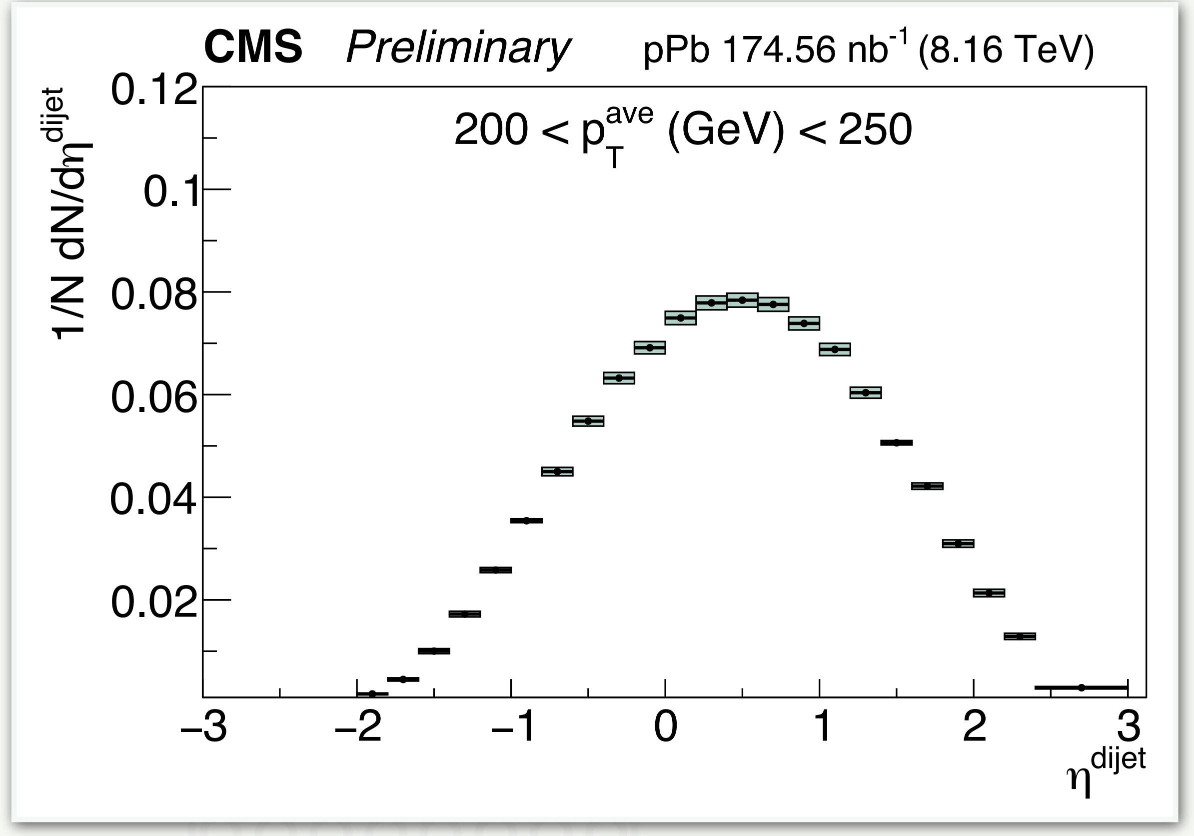


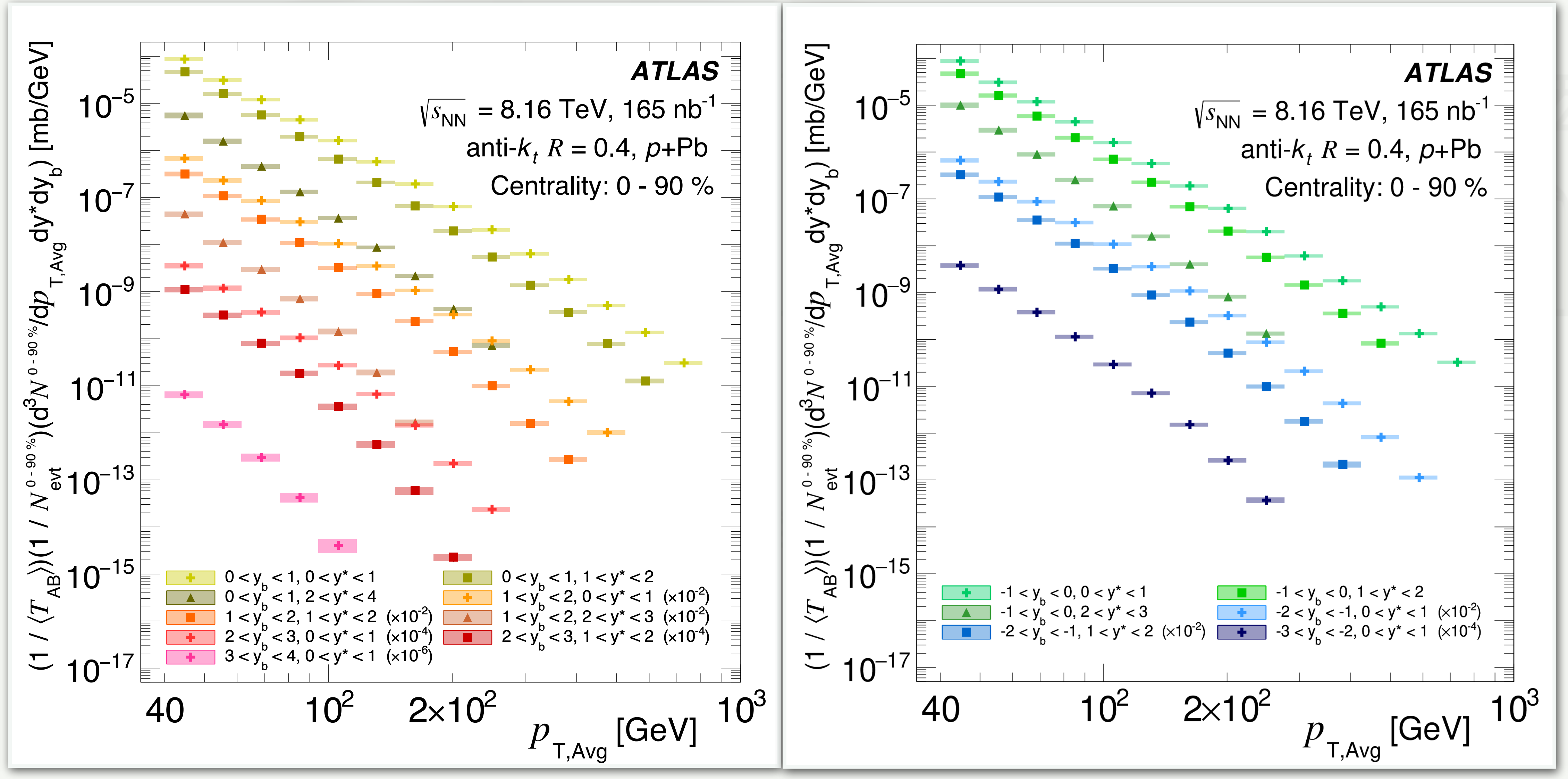
EPPS21 data + UPC dijets + CMS dijets + ATLAS dijets



... 14-bins ...

$$p_T^{ave} = \frac{p_{T,Lead} + p_{T,Sublead}}{2}$$





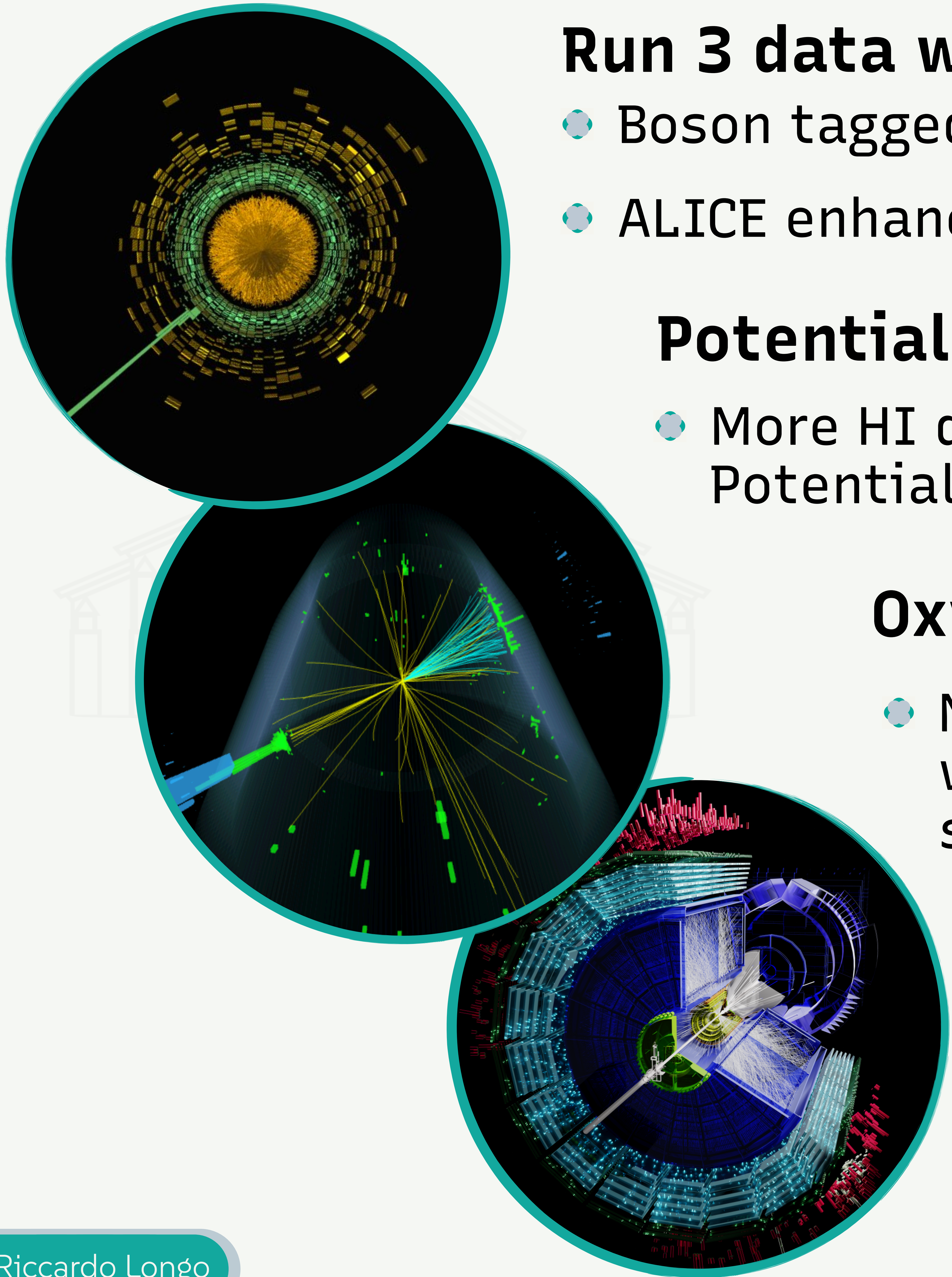
[ATLAS per-event yields, HION-2023-15](#), x-section studies underway

Both results will provide further input to constrain nPDFs down to $x_{Pb} \sim 10^{-4}$!

One last question...

What's next?

What’s next? [LHC]



Run 3 data will feed statistically hungry measurements

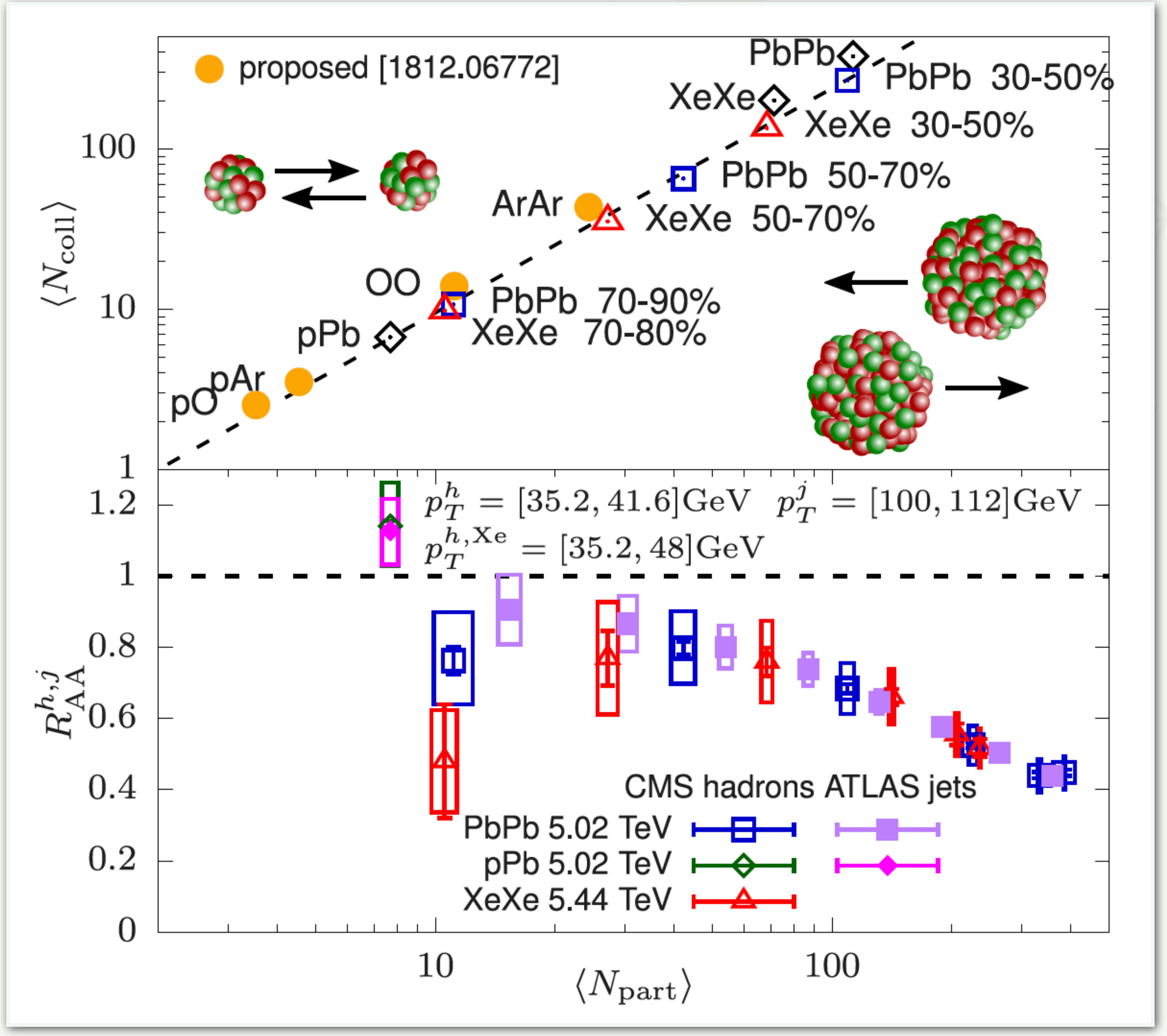
- Boson tagged measurements are on top of the list
- ALICE enhanced capabilities w/ new continous readout

Potential extension of Run 3

- More HI data on the line?
  Potential room for p+A?

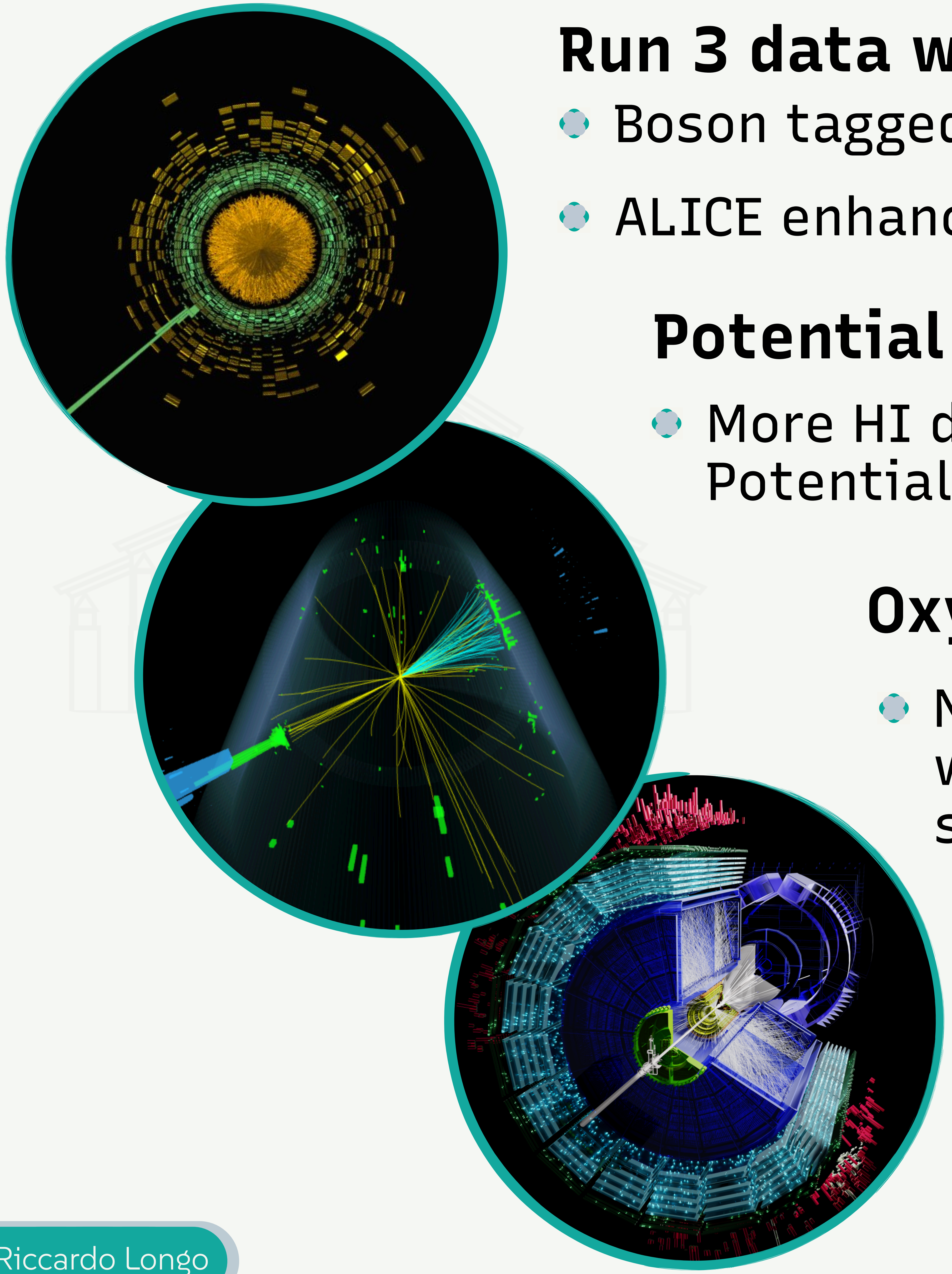
Oxygen is coming!

- Next year O+O and p+O data will open new lands for HI studies at the LHC



A.Huss et al., PRL 126, 192301 (2021)

What’s next? [LHC]



Run 3 data will feed statistically hungry measurements

- Boson tagged measurements are on top of the list
- ALICE enhanced capabilities w/ new continous readout

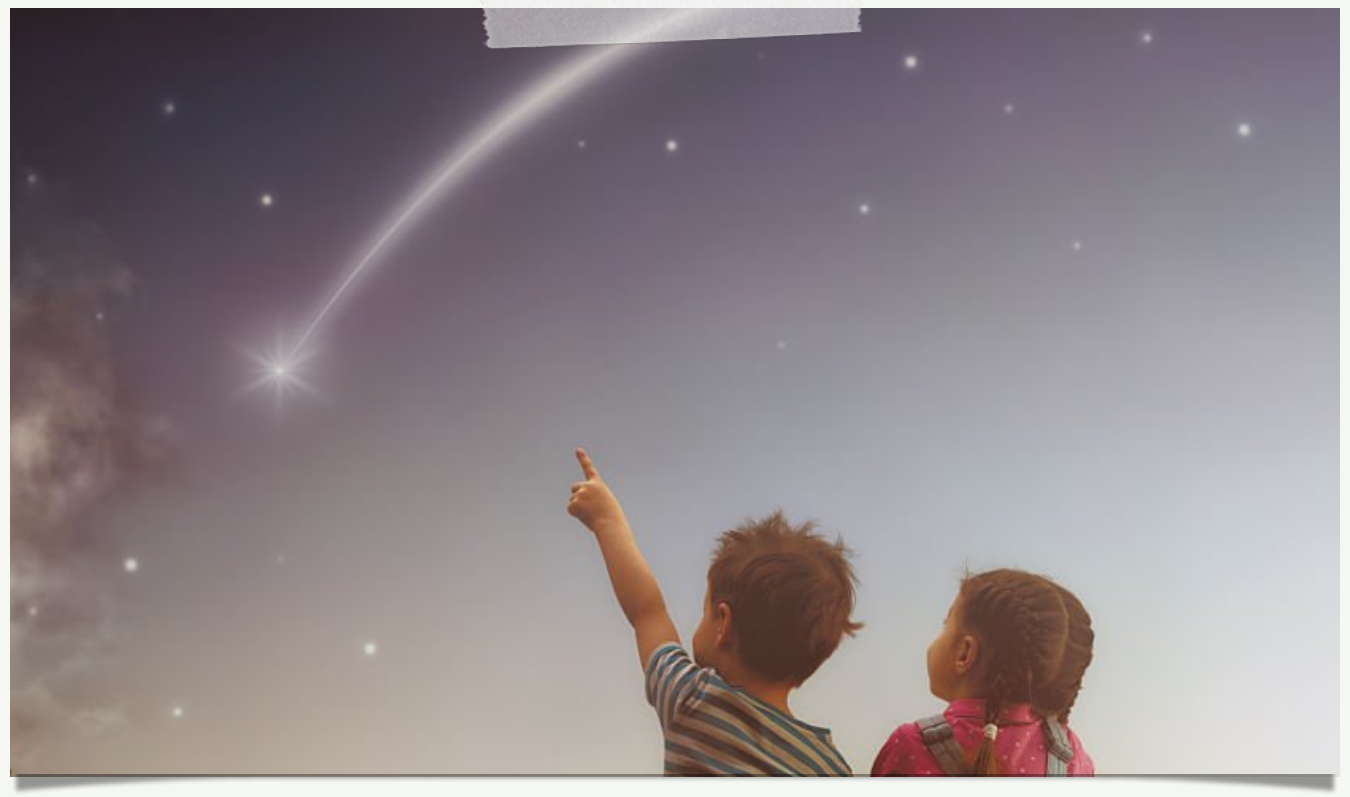
Potential extension of Run 3

- More HI data on the line?
  Potential room for p+A?

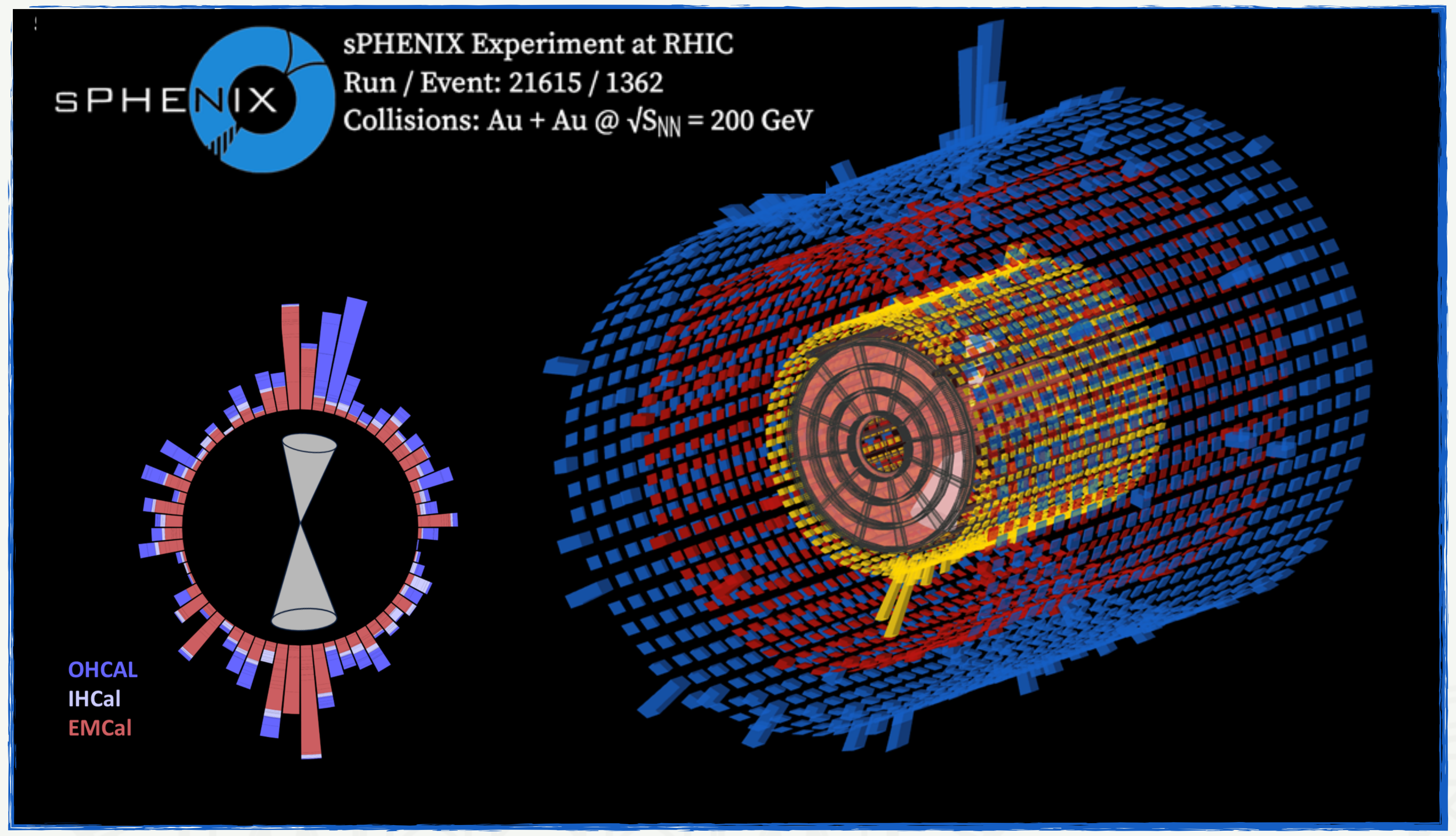
Oxygen is coming!

- Next year O+O and p+O data will open new lands for HI studies at the LHC

Hopefully with a reference run!

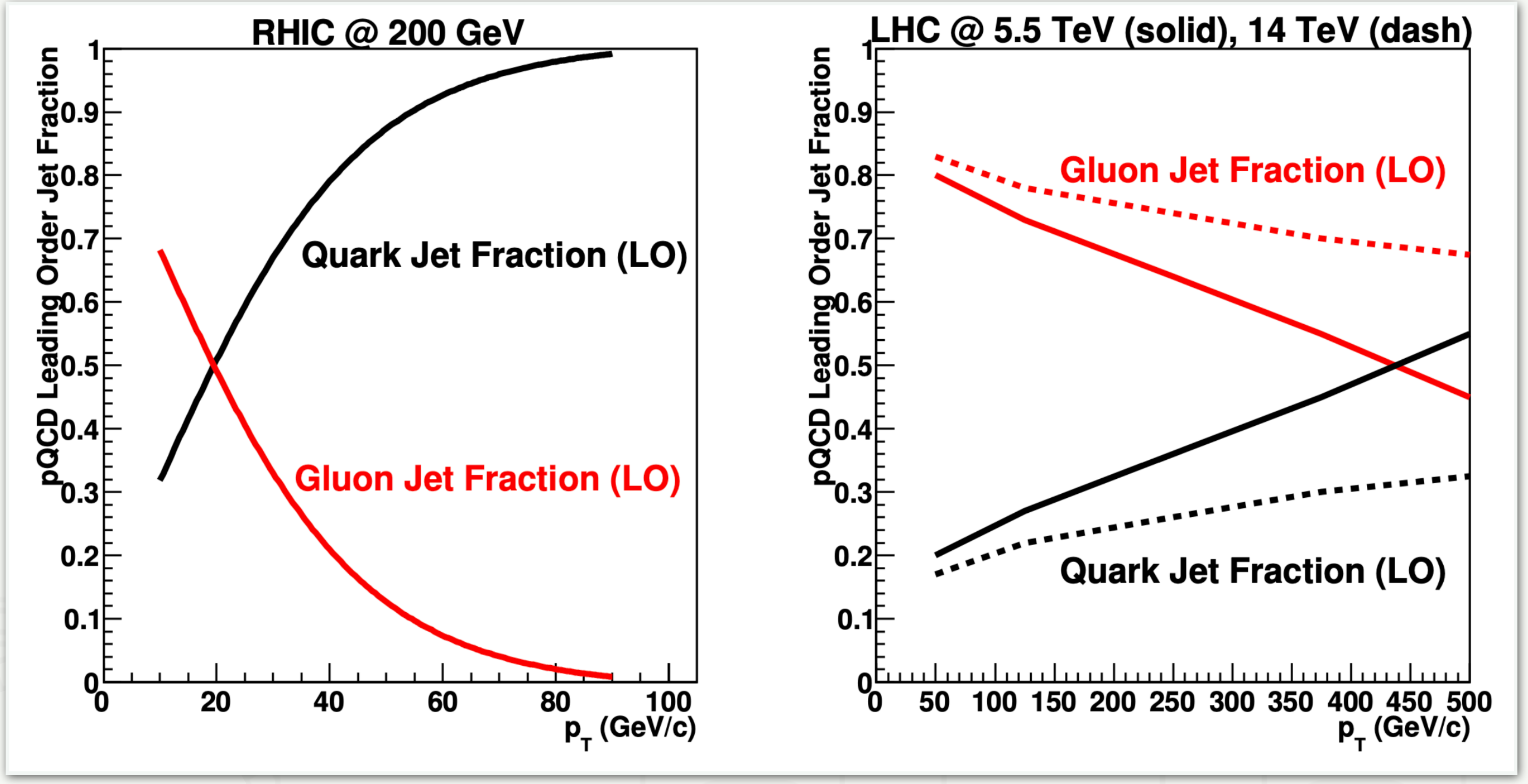


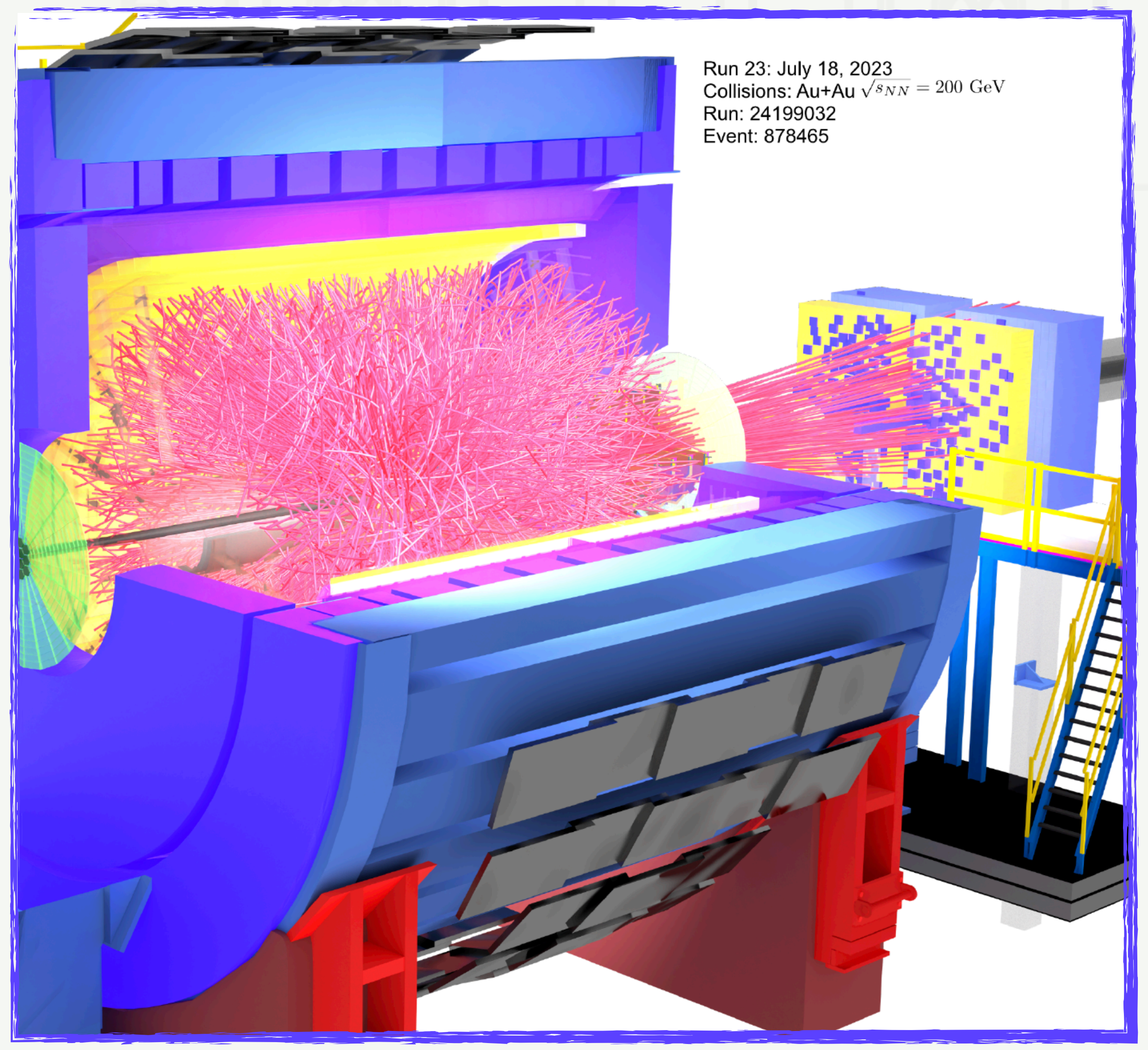
What's next? [RHIC]



sPHENIX is taking data!

arXiv:1207.6378





STAR Forward Upgrade

- Jet probes @ RHIC have very different q/g mixing compared to LHC → Ideal to **study parton energy loss**
- Great opportunities are available for cold nuclear matter studies, color-fluctuations measurements, low-x investigations in **p+Au…** it would be nice to have a **p+Au** run **before RHIC shutdown**!

Summary: Small systems

Searches for E_{loss} onsets

New studies from ALICE (p+p) and CMS (p+Pb) at LHC and STAR (p+Au) at RHIC - still **no signs of E_{loss}.**

Relevance of Color Fluctuations

Emerging feature of p+A collisions @ LHC and RHIC. To be better understood for proper data interpretation

nPDFs

Golden age of Run 2 dijet analyses at LHC: new ATLAS UPC results + CMS & ATLAS p+Pb @ 8.16 TeV analyses next in the pipe

LHC: p+O and O+O next year!

- ➡ Search for the onset of E_{loss} in small systems
- ➡ Study of Oxygen Nuclear Structure

Hope for p+Pb w/ LHC schedule shift?

RHIC: hope for p+Au @ sPHENIX and STAR?

Summary: Large systems

Color charge dependence of E_{loss}

Several advancements in γ-tagged vs inclusive jets studies: ATLAS **S_{Loss}** + CMS jet **substructure** measurements

Medium response to the jets

Exciting results on **diffusion wake** from CMS (Z-tagged hadrons, hints of significant signal) and ATLAS (γ-tagged jets, constraints on small magnitude). Compatibility?

Path-length E_{loss} dependence

New ALICE (ATLAS) **R-dependent** jet+h (dijet asymmetry) **measurements**

LHC: Run 3 high statistic data @ 5.36 TeV (ATLAS+CMS x3-4, **ALICE x20-30!**)

➡ More differential boson-tagged measurements!

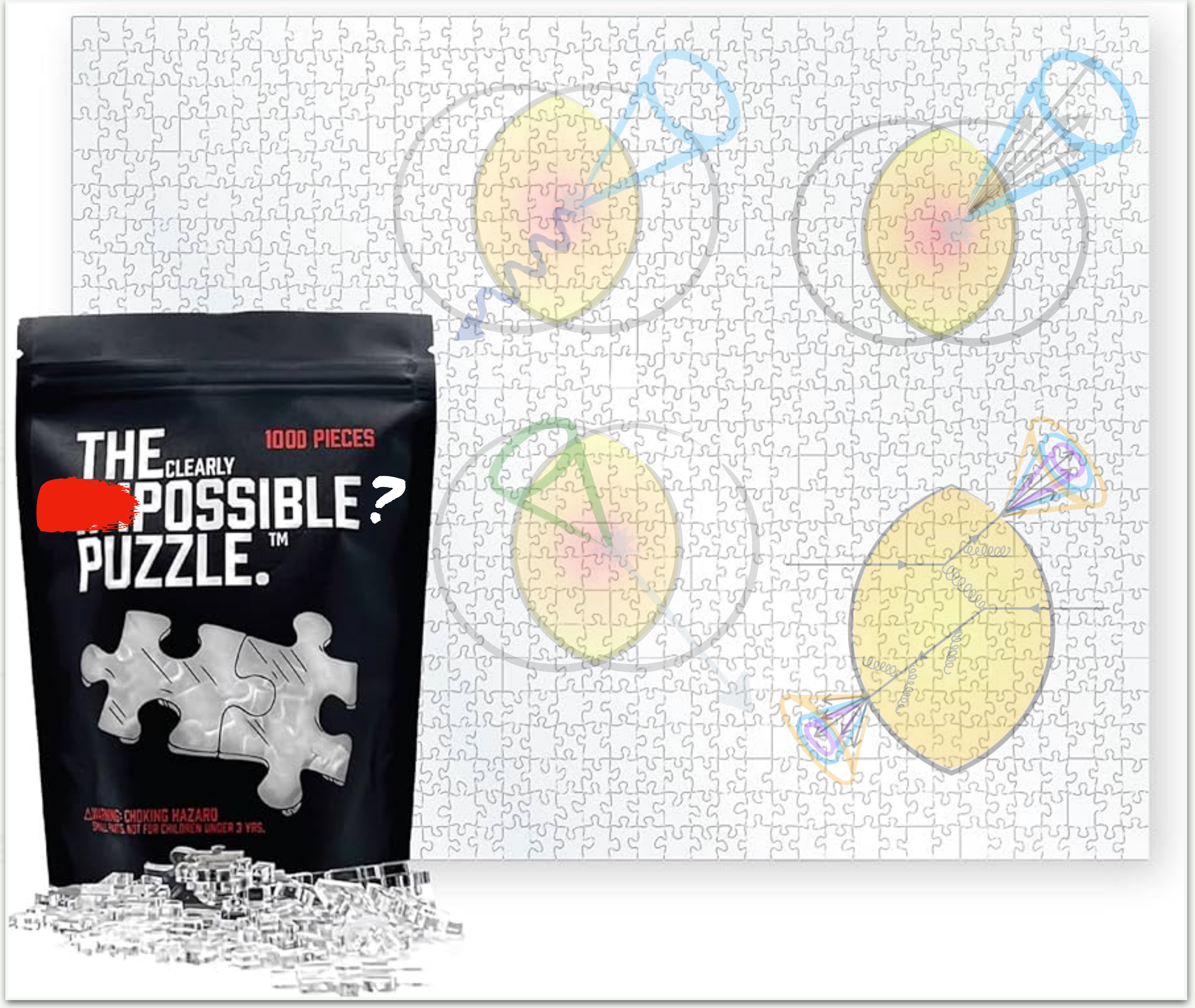
RHIC: sPHENIX (first) data + STAR (new) data!

Large Systems: a last thought ...

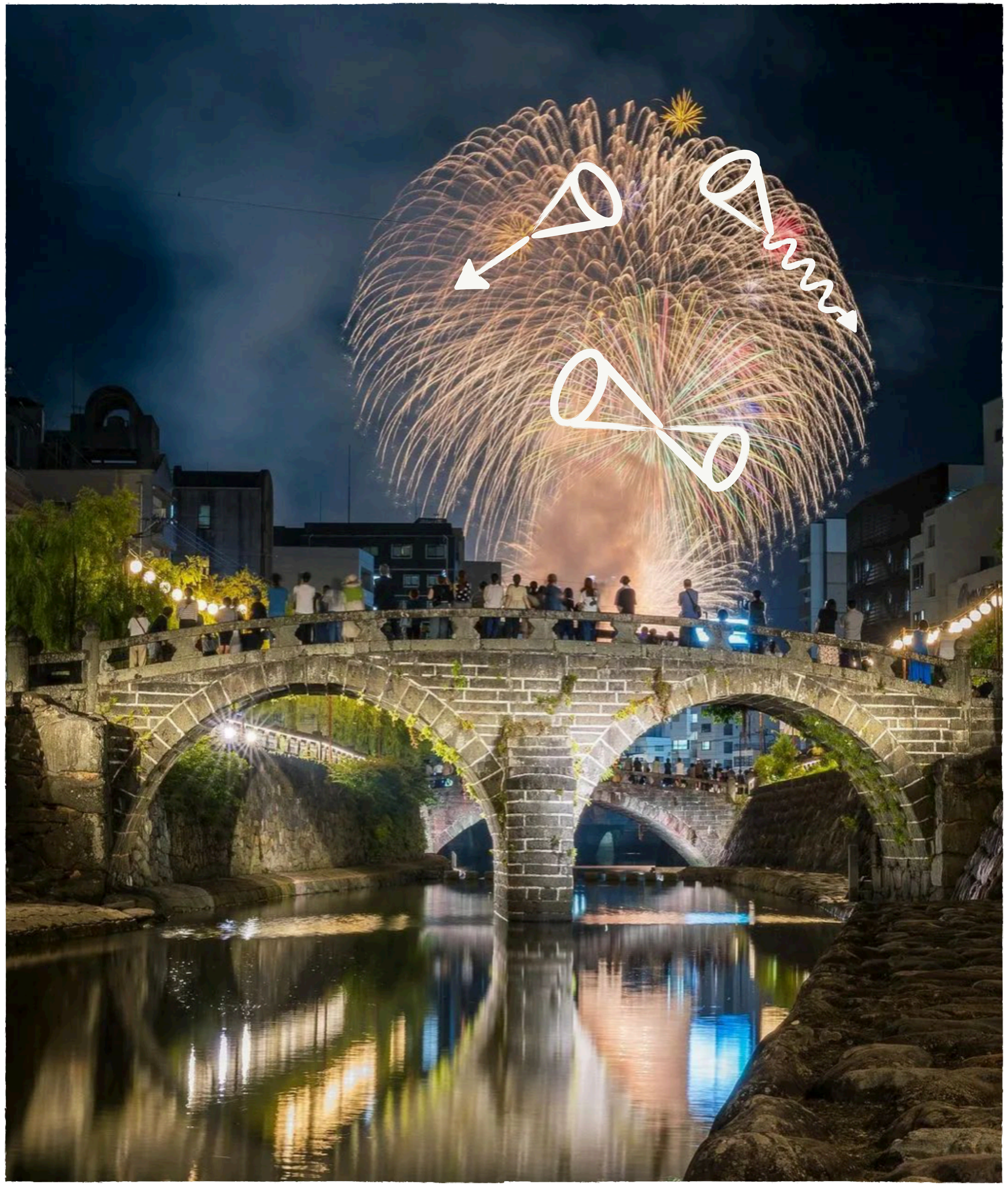
- **Experimental programs at LHC & RHIC keep delivering a copious amount of results -** differential in jet p_T, radius, momentum balance, ... **- to investigate the microscopic nature of the QGP !**
  - This talk contained ~1k new data points from recent analyses (just a narrow selection).
  - Different models capture different trends in different observables
  - ⟹A lot still needs to be done toward a **global understanding** of QGP properties

Large Systems: a last thought …

- **Experimental programs at LHC & RHIC keep delivering a copious amount of results -** differential in jet p_T, radius, momentum balance, … **- to investigate the microscopic nature of the QGP !**
  - This talk contained ~1k new data points from recent analyses (just a narrow selection).
  - Different models capture different trends in different observables
  - $\Longrightarrow$A lot still needs to be done toward a **global understanding** of QGP properties



See the next talk by R.Ehlers!



Thank you for your attention!

Thanks to A.Sickles, M.Rybar, C.McGinn, B.Gilbert, Y.Mao, D.Perepelitsa, D.Hangal, G.Nigmatkulov, Y.Lee, Y.Go, P.Jacobs, P.Steinberg, S.Mohapatra for useful discussions and input for this talk!

Summary of summaries

Large Systems

Color charge dependence of E_{loss}

Several advancements in γ-tagged vs inclusive jets studies: ATLAS S_{Loss} + CMS jet **substructure** measurements

Medium response to the jets

Exciting results on **diffusion wake** from CMS (Z-tagged hadrons, hints of significant signal) and ATLAS (γ-tagged jets, constraints on small magnitude). Compatibility?

Path-length E_{loss} dependence

New ALICE (ATLAS) **R-dependent** jet+h (dijet asymmetry) **measurements**

LHC: Run 3 high statistic data @ 5.36 TeV (ATLAS+CMS x3-4, **ALICE x20-30!**)

- ➡ More differential boson-tagged & dijet measurements!

RHIC: sPHENIX (first) data + STAR (new) data!

Small Systems

Searches for E_{loss} onsets

New studies from ALICE (p+p) and CMS (p+Pb) at LHC and STAR (p+Au) at RHIC - still **no signs of E_{loss}**.

Relevance of Color Fluctuations

Emerging feature of p+A collisions @ LHC and RHIC. To be better understood for proper data interpretation

nPDFs

Golden age of Run 2 dijet analyses at LHC: new ATLAS UPC results + CMS & ATLAS p+Pb @ 8.16 TeV analyses next in the pipe

LHC: p+O and O+O next year!

- ➡ Search for the onset of E_{loss} in small systems
- ➡ Study of Oxygen Nuclear Structure

Hope for p+Pb w/ LHC schedule shift?

RHIC: hope for p+Au @ sPHENIX and STAR?

Backup Slides

3D jet+tracks in γ+jet: wake constraints

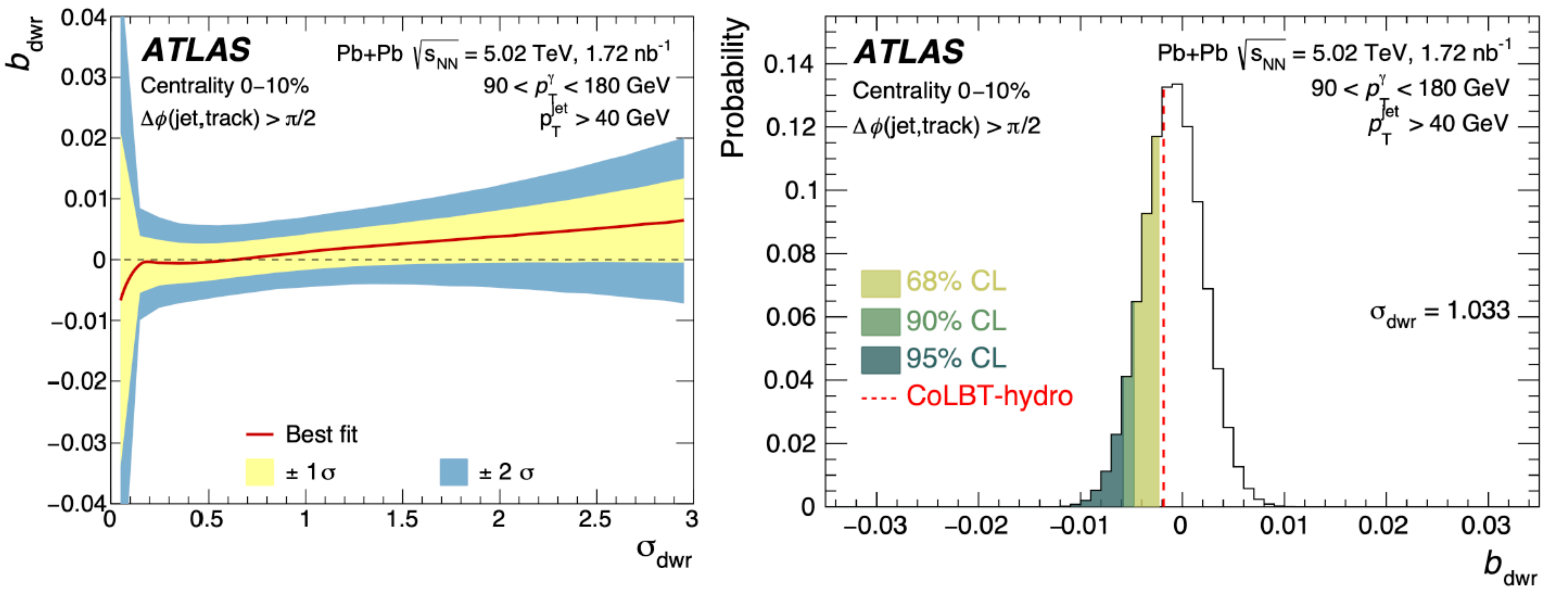
See talk by Y.Go

No significant signal of the diffusion wake found within the current experimental sensitivity

Double Ratio Amplitude — Double Ratio Width

$$b_0 + b_{\mathrm{dwr}} \cdot e^{-|\Delta\eta(\mathrm{jet,track})|^2/(2\sigma^2_{\mathrm{dwr}})}$$

arXiv:2408.08599



Data are used to set upper limits on the magnitude of the diffusion wake effect at different confidence levels.

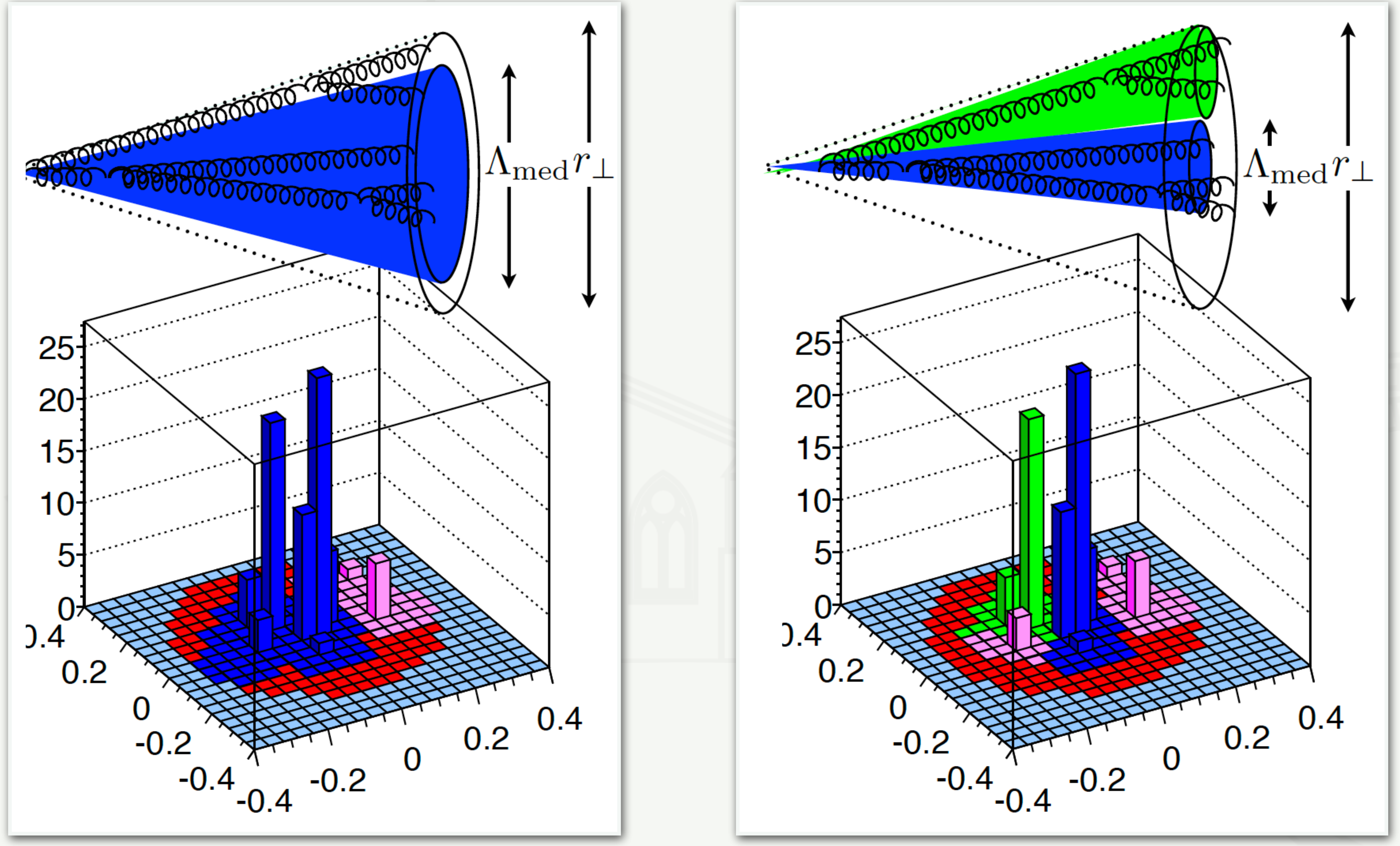
TheCoLBT-hydro theory prediction is consistent with the data within the 68% confidence level upper limit.

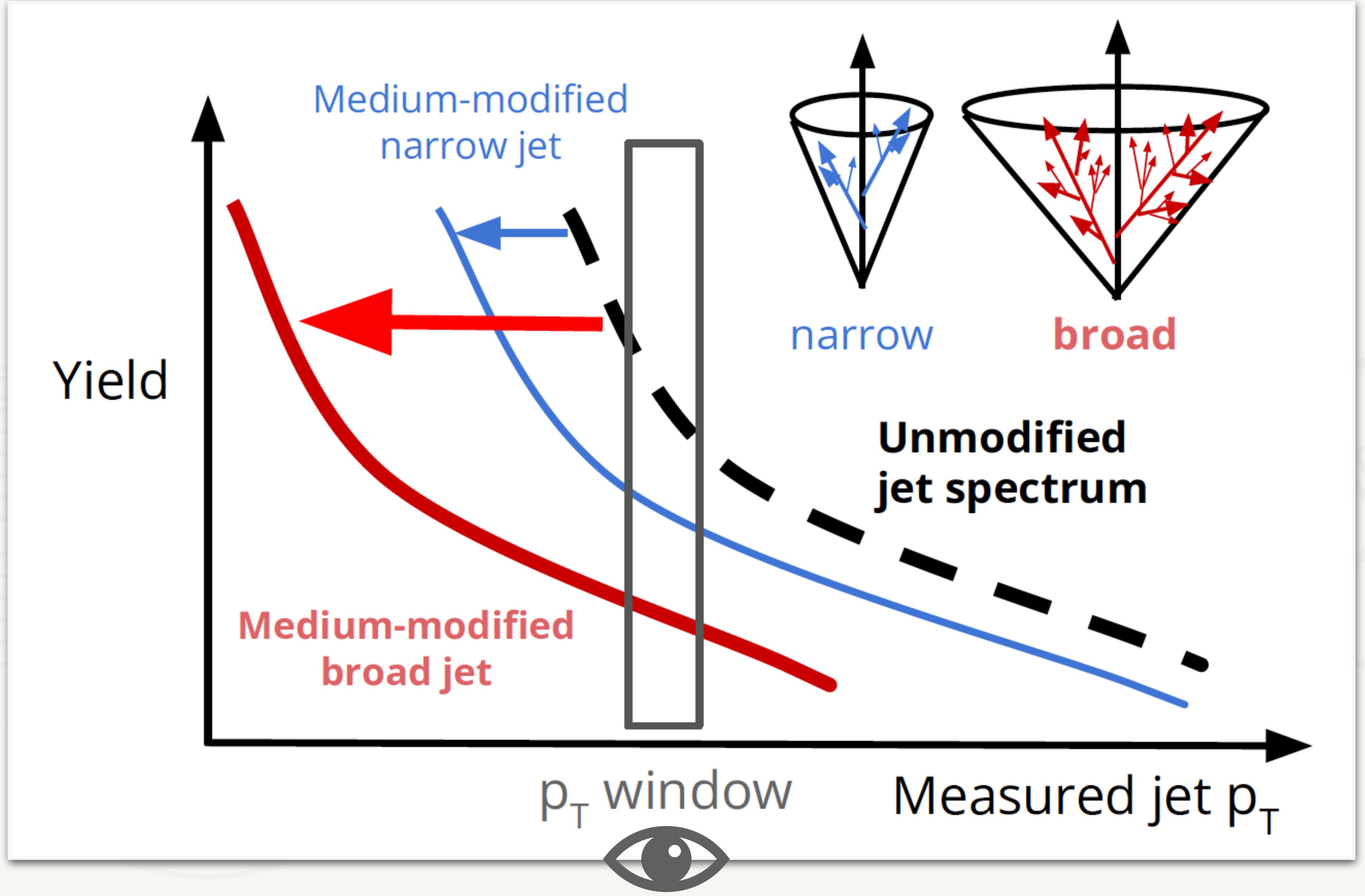
Assuming a double ratio width, σ_{dwr}, given by the CoLBT-hydro model, values of the amplitude b smaller than -0.0023 are excluded at 95% confidence level.

Color coherence effects

Can the medium distinguish between partons within a jet?

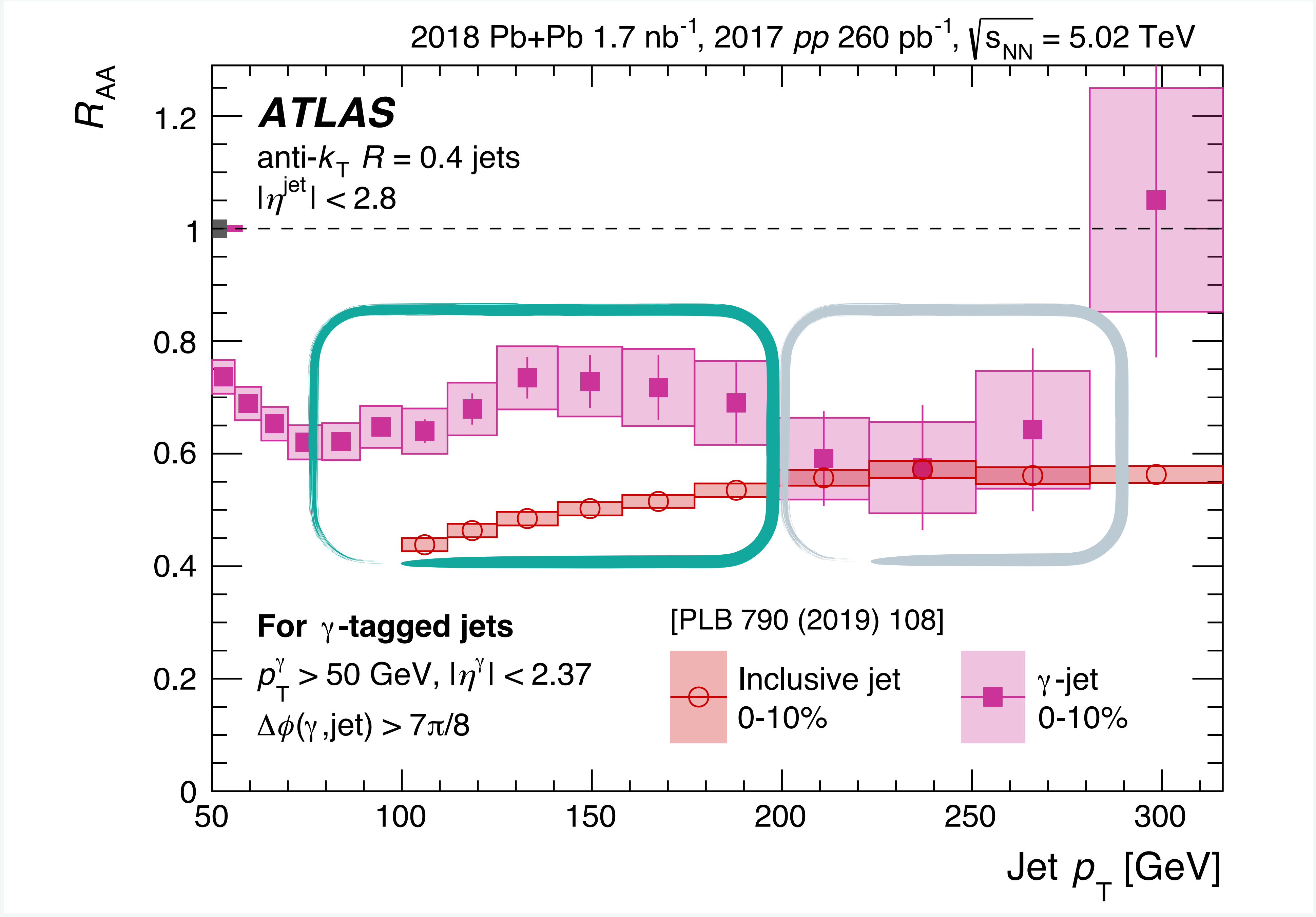
J. Casalderrey-Solana et al., PLB 725 (2013) 357–360





- **Broader structures** more quenched compared to **narrow structures** + **steeply falling jet p_T spectra** → bias towards narrow jets in an observed jet p_T bin

γ+jet vs inclusive jet R_{AA}



PLB 846 (2023) 138154

γ-tagged jets ↔ quark-initiated jets dominance

Inclusive jets ↔ gluon-initiated jets dominance

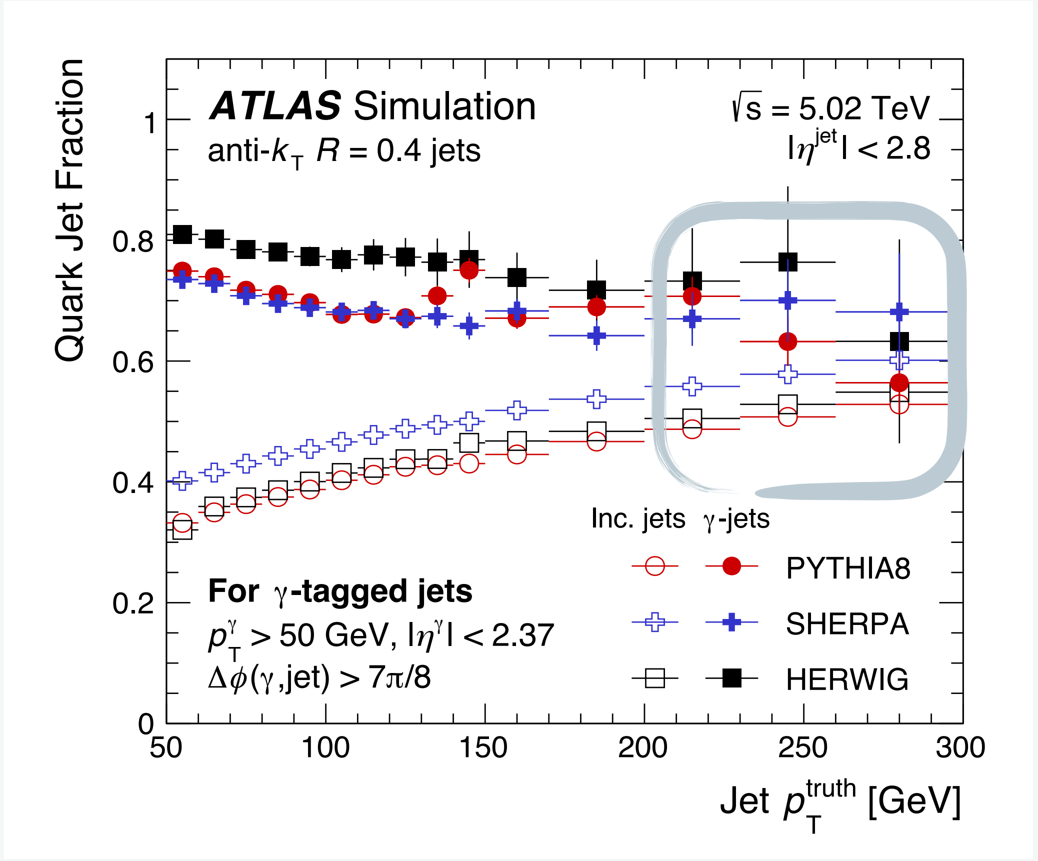
R_{AA} suggests that, For p_T < ~200 GeV, quark-initiated jets lose less energy than gluon-initiated jets

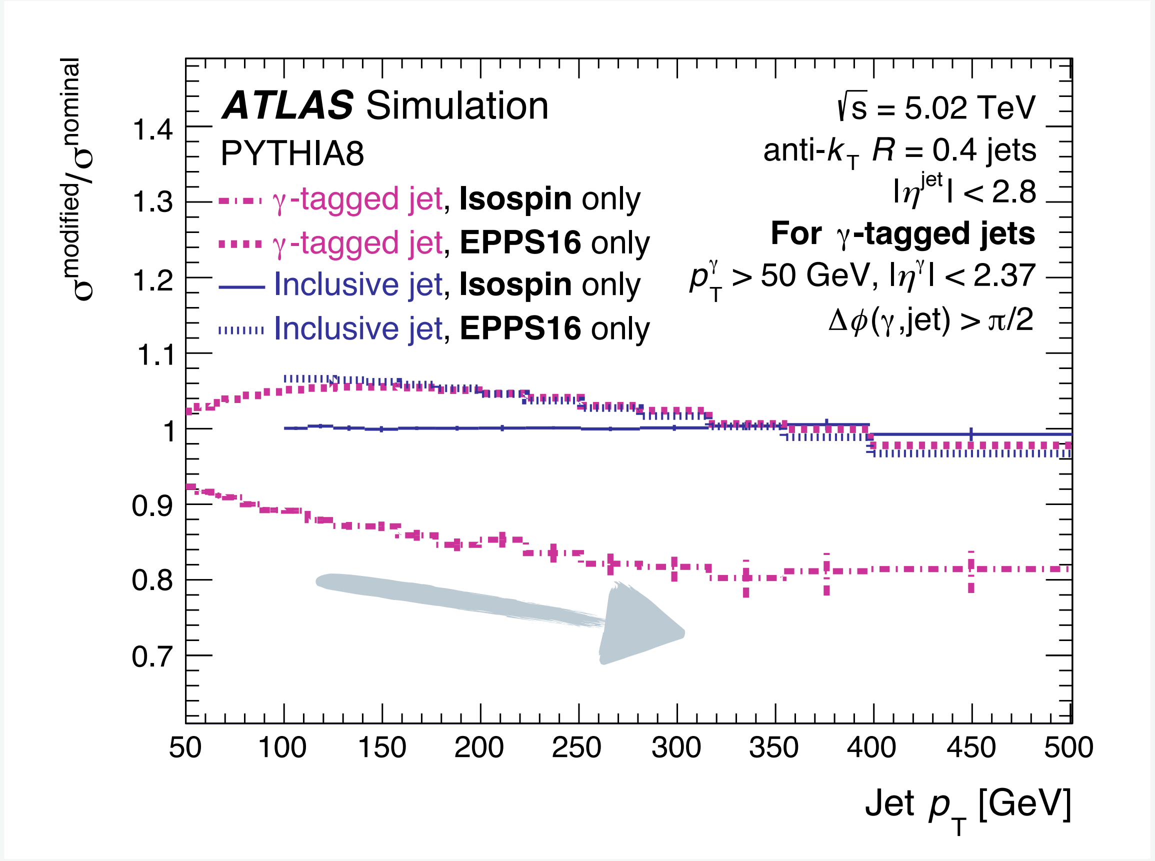
For p_T > ~200 GeV

R_{AA} (γ+jets)

~

R_{AA} (inclusive jets)





Similar quark fraction
+
increasing isospin effect on γ+jet sample

See talk by D.Derendarz

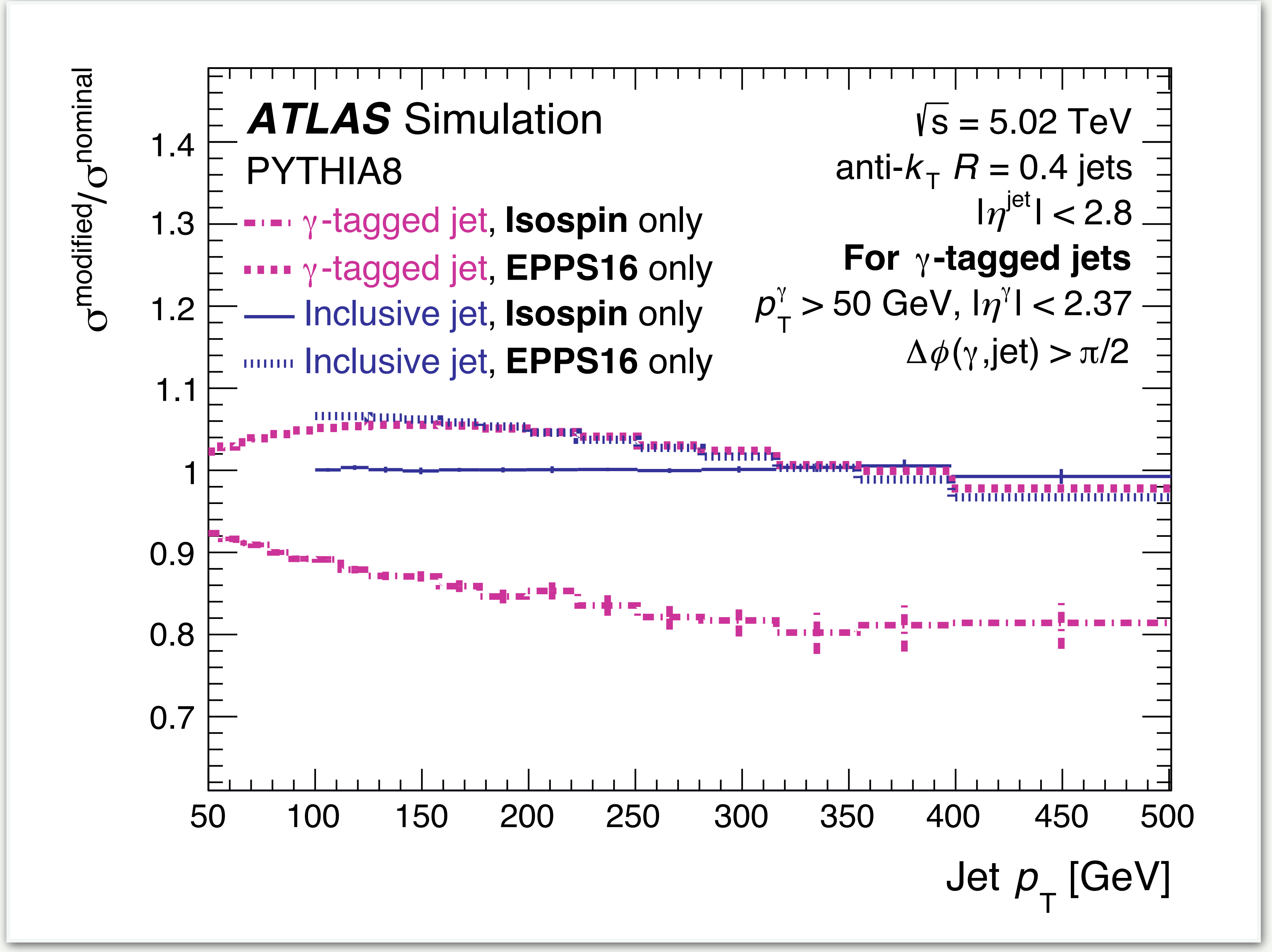
Isospin & nPDF effects

Isospin & nPDF effects matters!

Different mixing of u and d quarks affects γ+jet production
(γ coupling depends on electric charge)

Isospin effects arising from p-n asymmetry of the collision system

Affects **only** **γ-tagged jets**



PLB 846 (2023) 138154

Nuclear modification of PDFs (parameterized via **nPDFs)** can lead to different flavor compositions of the initial state

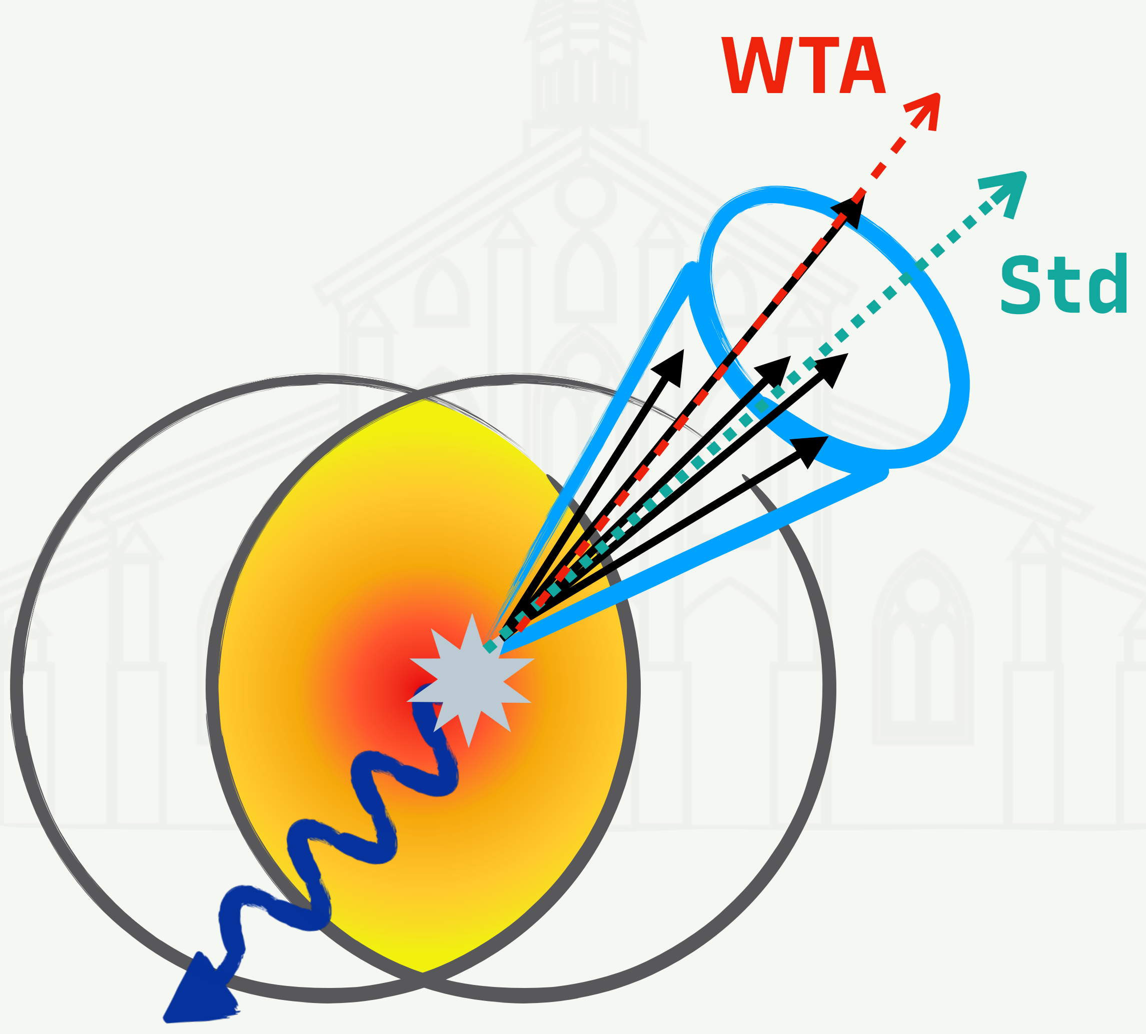
Affects **both inclusive** and **γ-tagged jets**

Jet axis decorrelation in γ+jet events

See talk by M.Park

Jet axis decorrelation

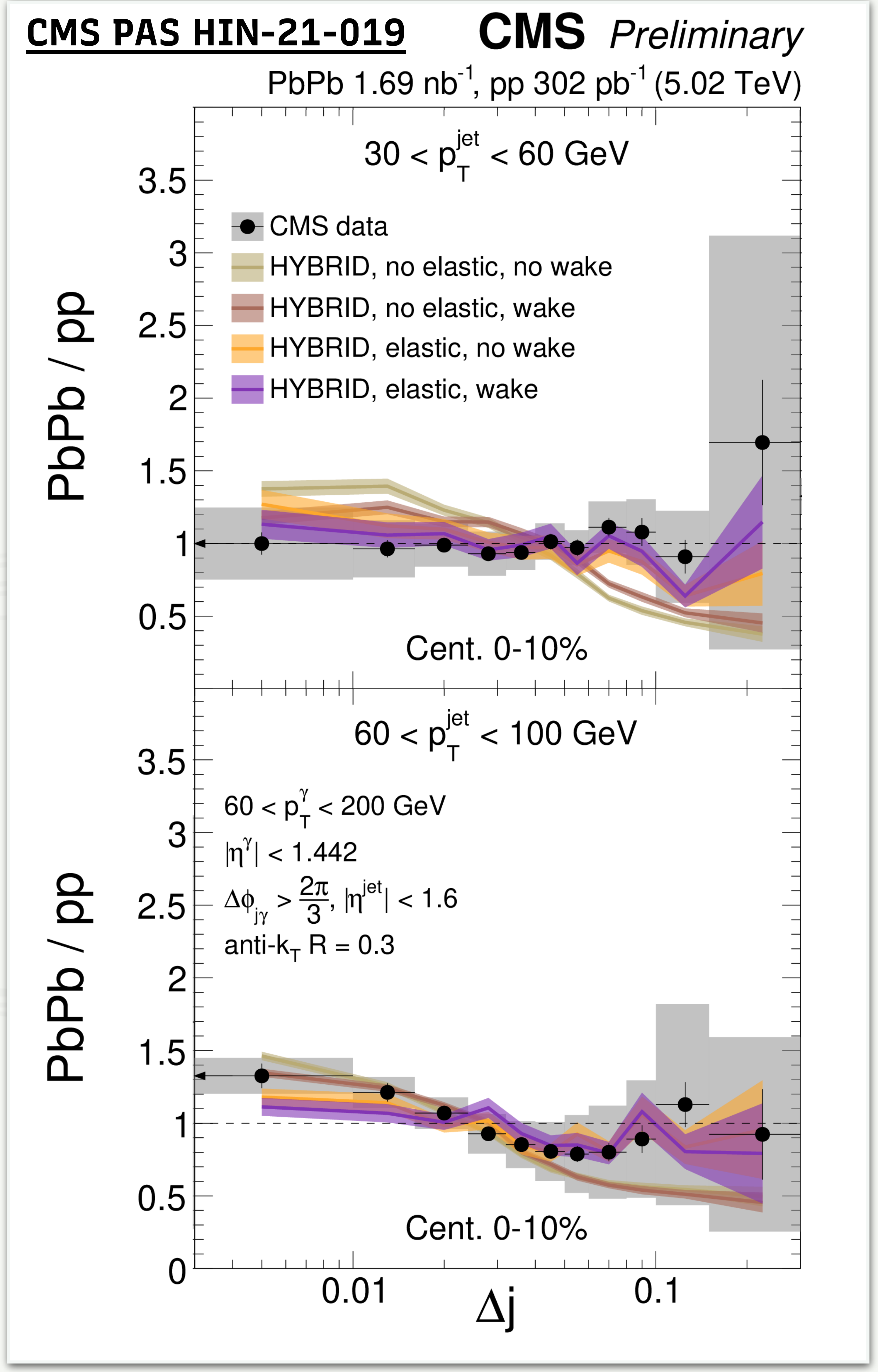
$$\Delta j = \sqrt{(\eta^{\mathrm{Std}} - \eta^{\mathrm{WTA}})^2 + (\phi^{\mathrm{Std}} - \phi^{\mathrm{WTA}})^2}$$



Winner-Takes-All axis less sensitive to soft radiation and medium response

Lower p_T

Higher p_T



- Ratio ~1 for more quenched selections (lower jet p_T)
- Narrowing observed in higher p_T (less quenched) selections
- **Observable is not sensitive to medium wake effects but can provide input on elastic scattering**

Jet axis decorrelation: γ+jet vs jet

See talk by M.Park

Interesting comparison with analogous inclusive measurement done by ALICE

Different model performance in results description

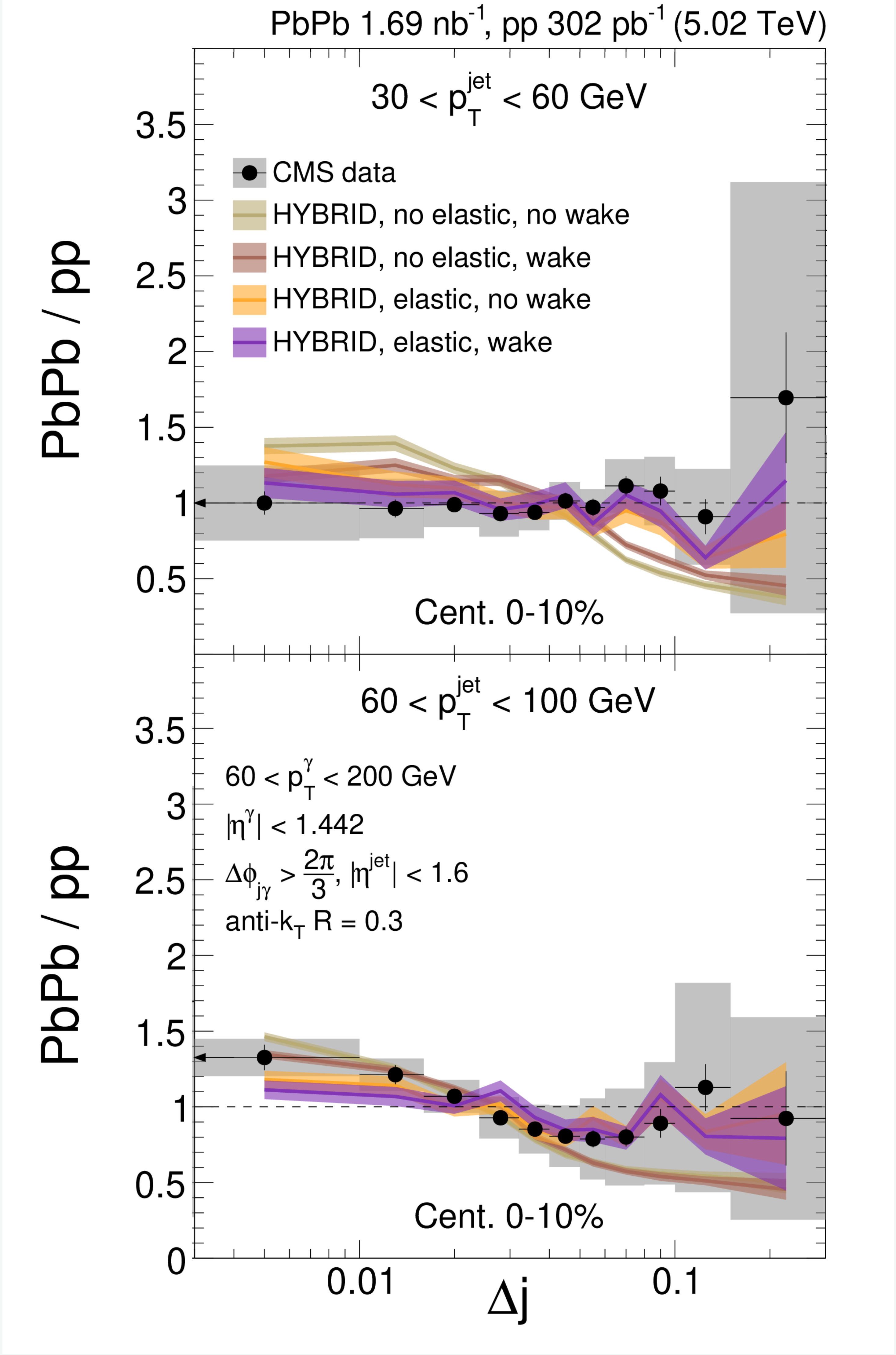
Caveats:

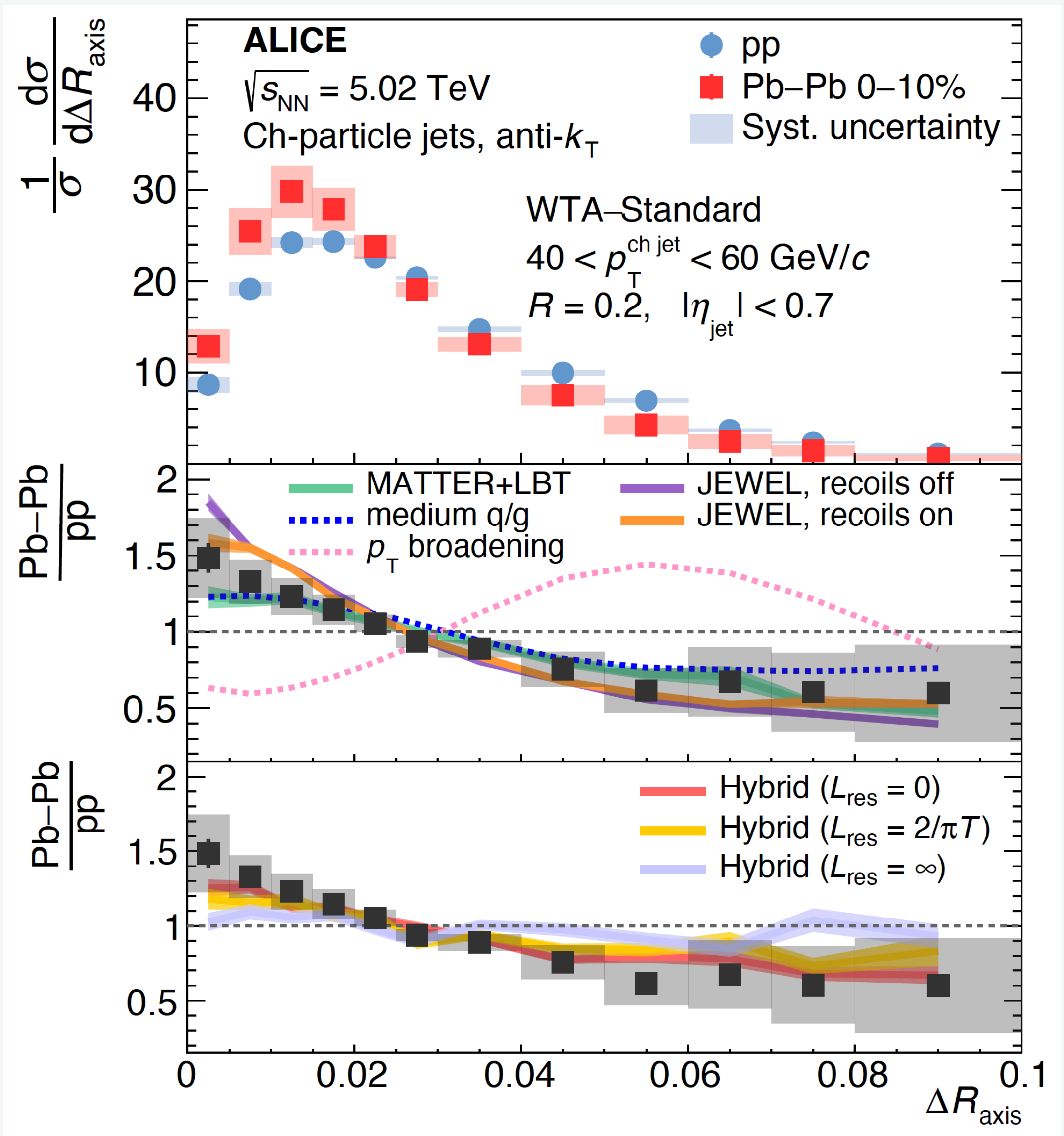
- Inclusive vs γ-tagged
- Different radius (.2 vs .3)
- Track jets vs p-flow jets
- Different rapidity

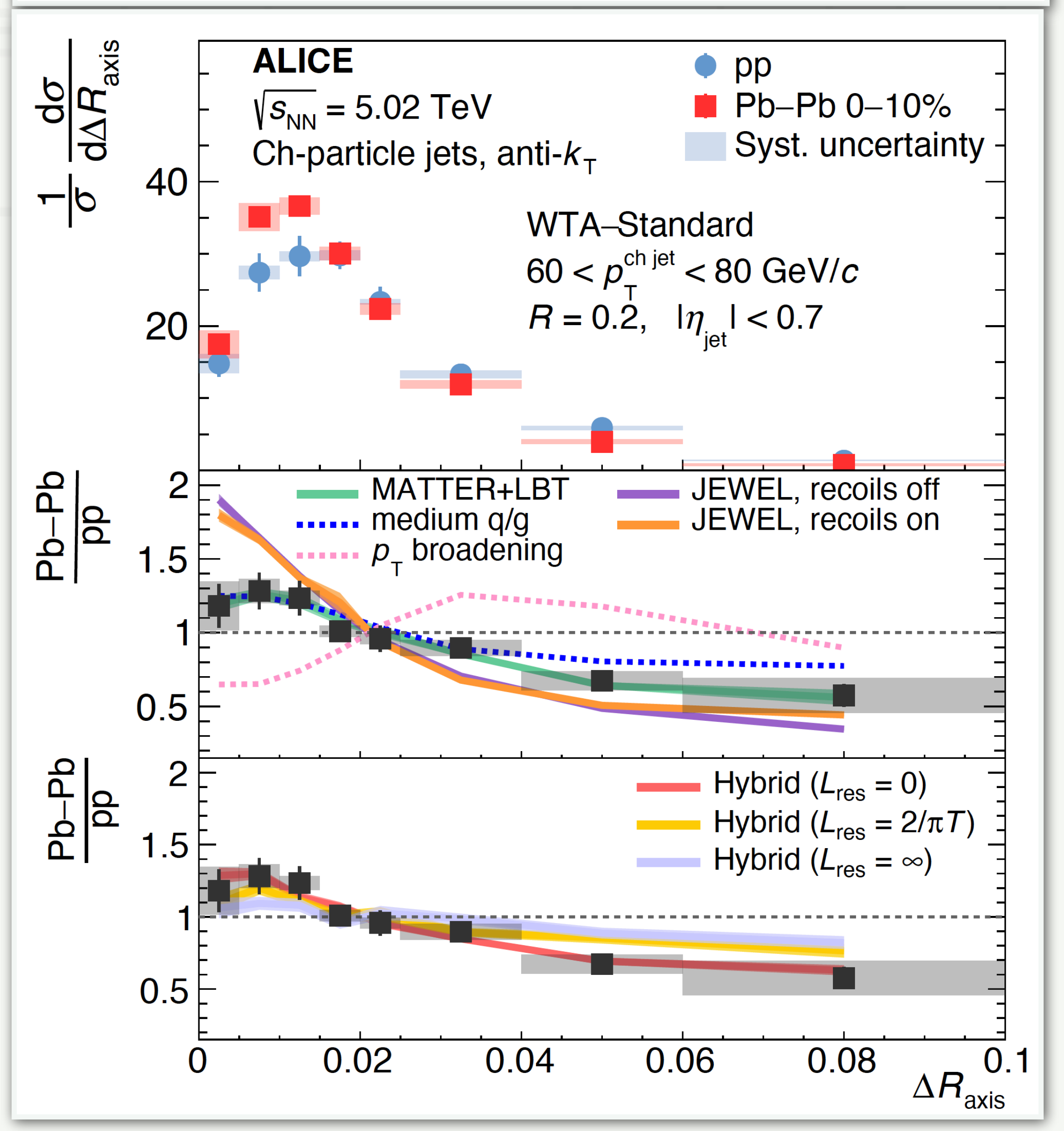
Lower p_T

Higher p_T

CMS PAS HIN-21-019







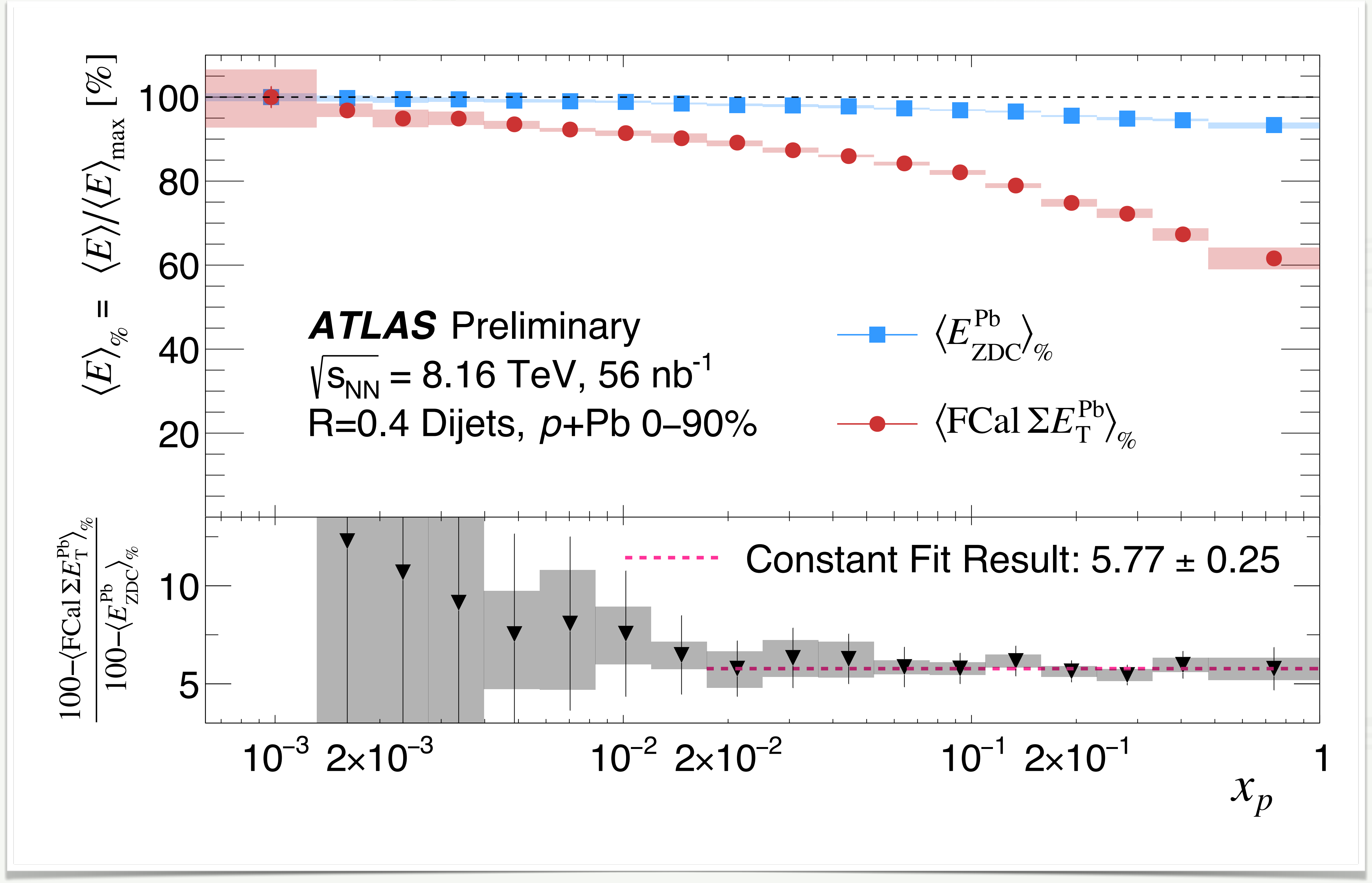
arXiv:2303.13347

Nuclear breakup in p+A collisions w/ dijets

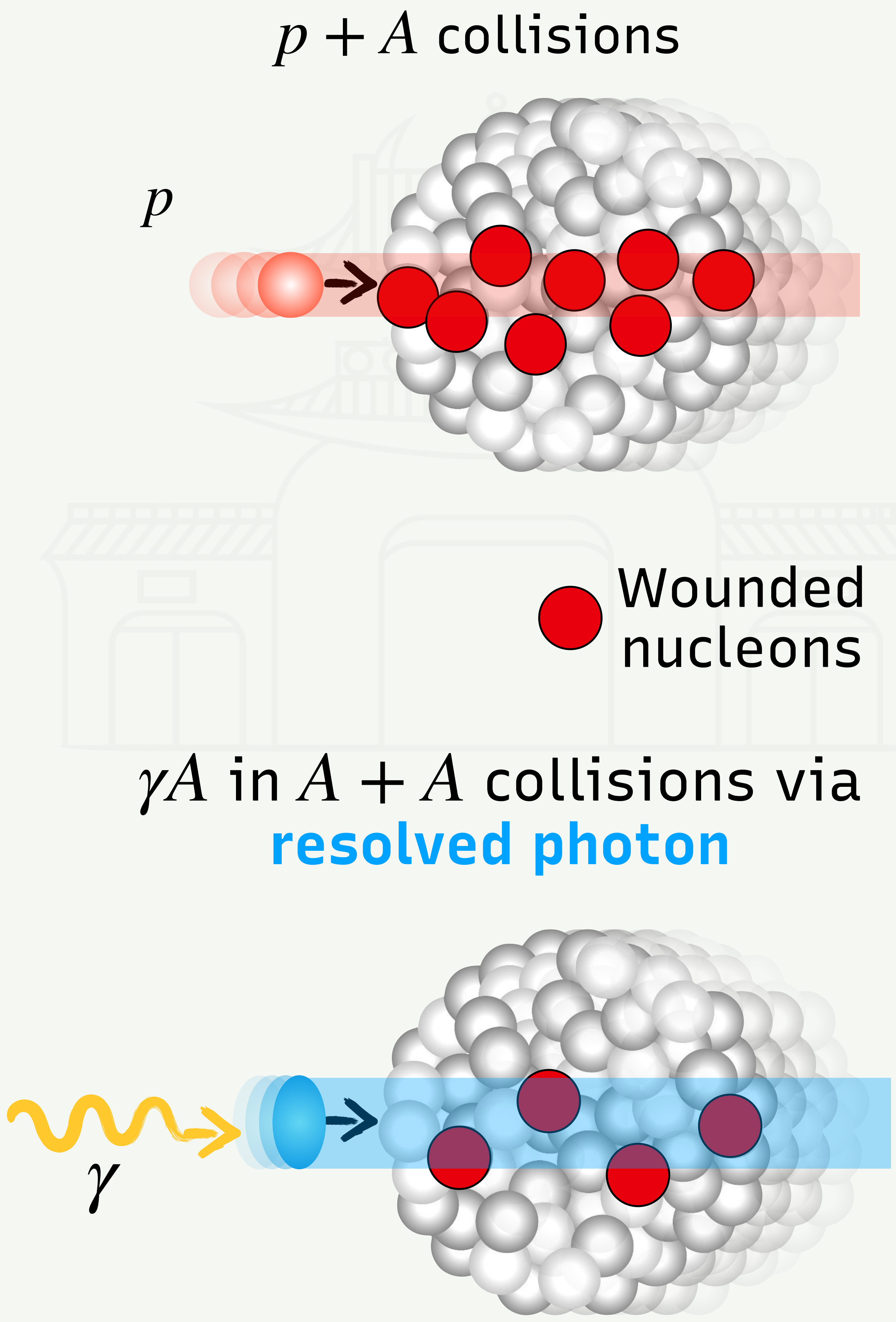
ATLAS-CONF-2024-013

See poster by M.Hoppesch

- Study of energy in the **ZDC and** in the **forward calorimeter in dijet events** to analyze **dependence on the hard-scattering kinematics**



- ~5% difference between low and high x_p selections
- Correlation w/ number of wounded nucleons (as proposed in **PRC 110, 025205 (2024) for resolved UPCs**)?

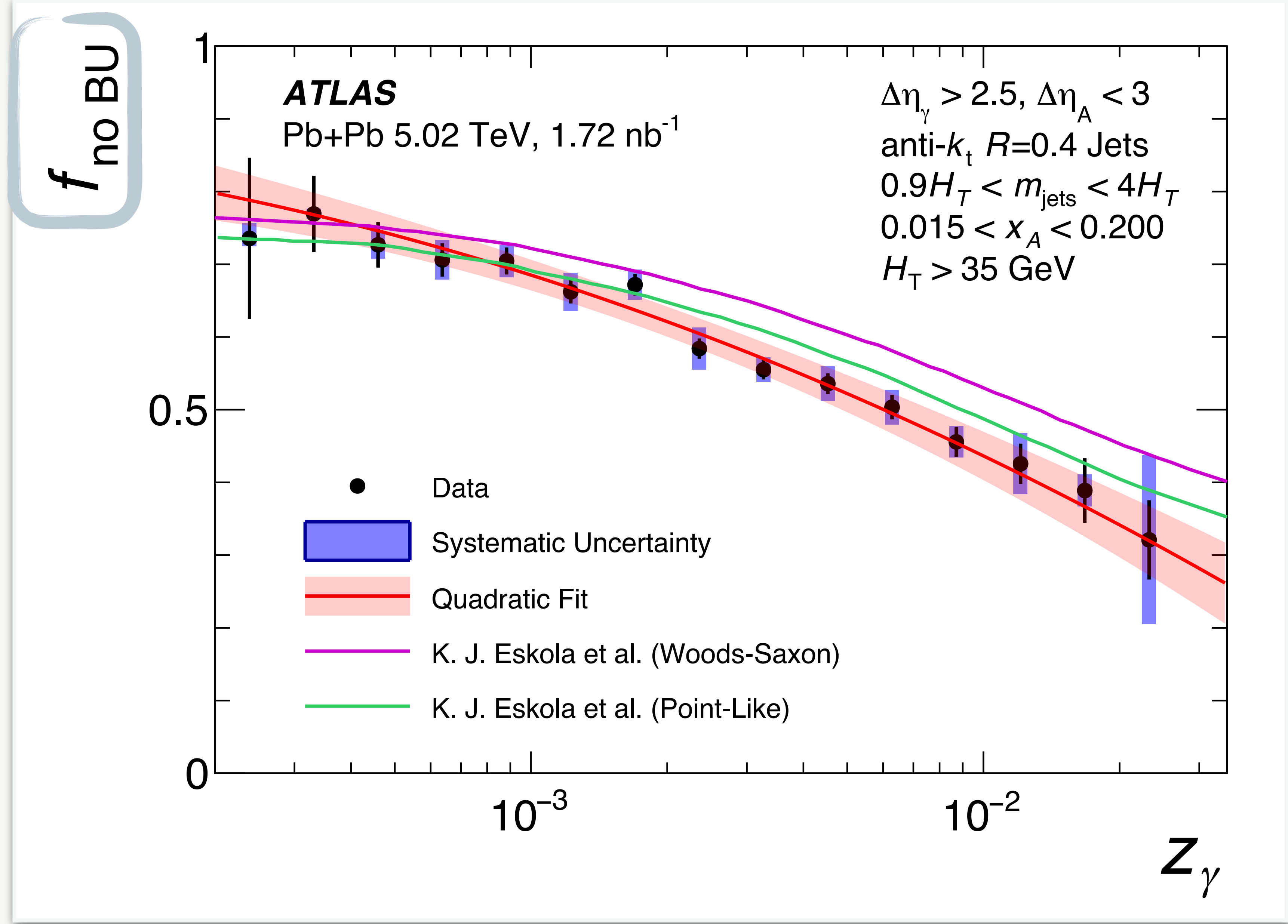


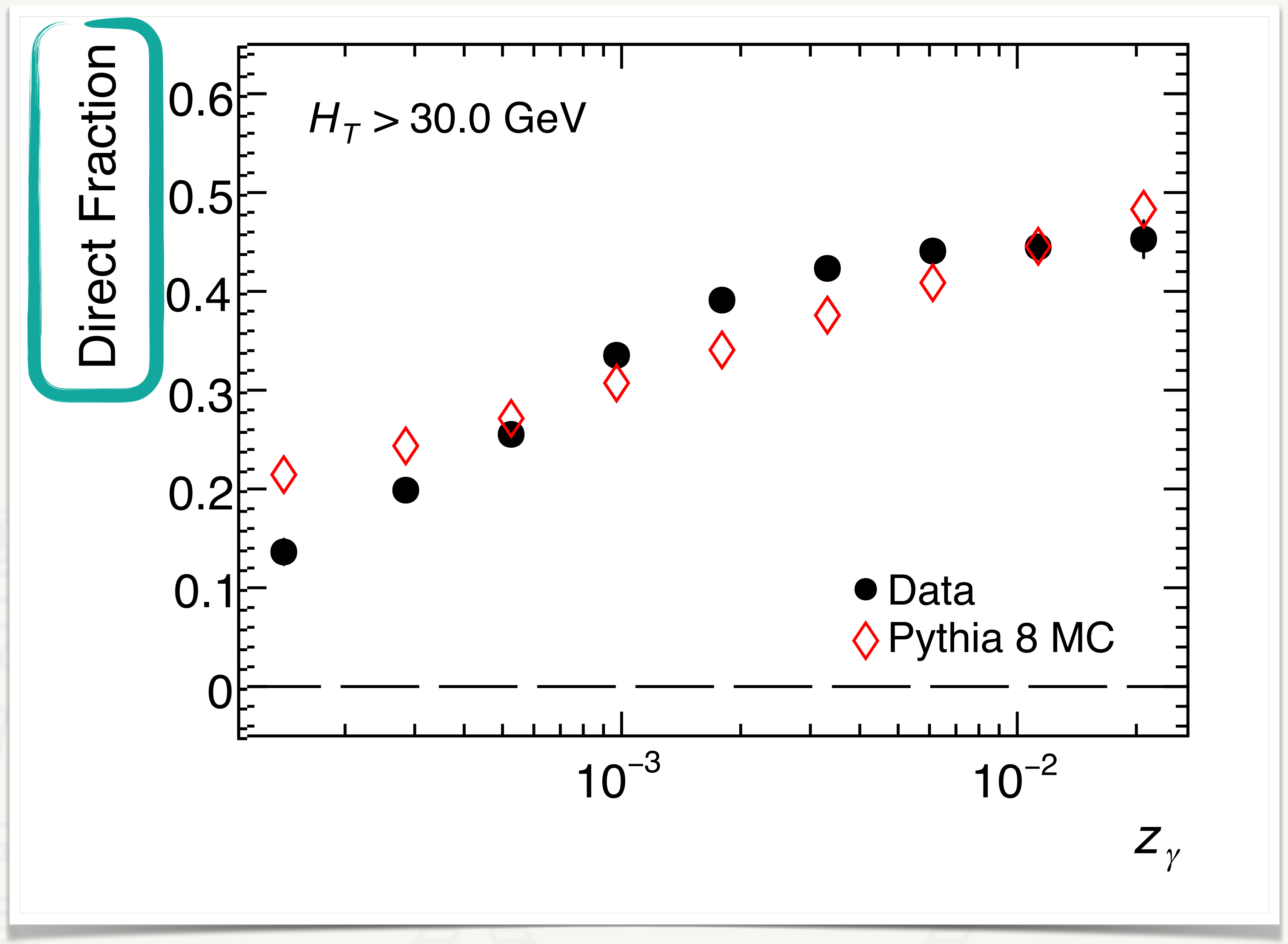
- ZDC energy ~6 times more robust against dependences on the hard-scattering kinematics

UPC Dijets & nuclear breakup

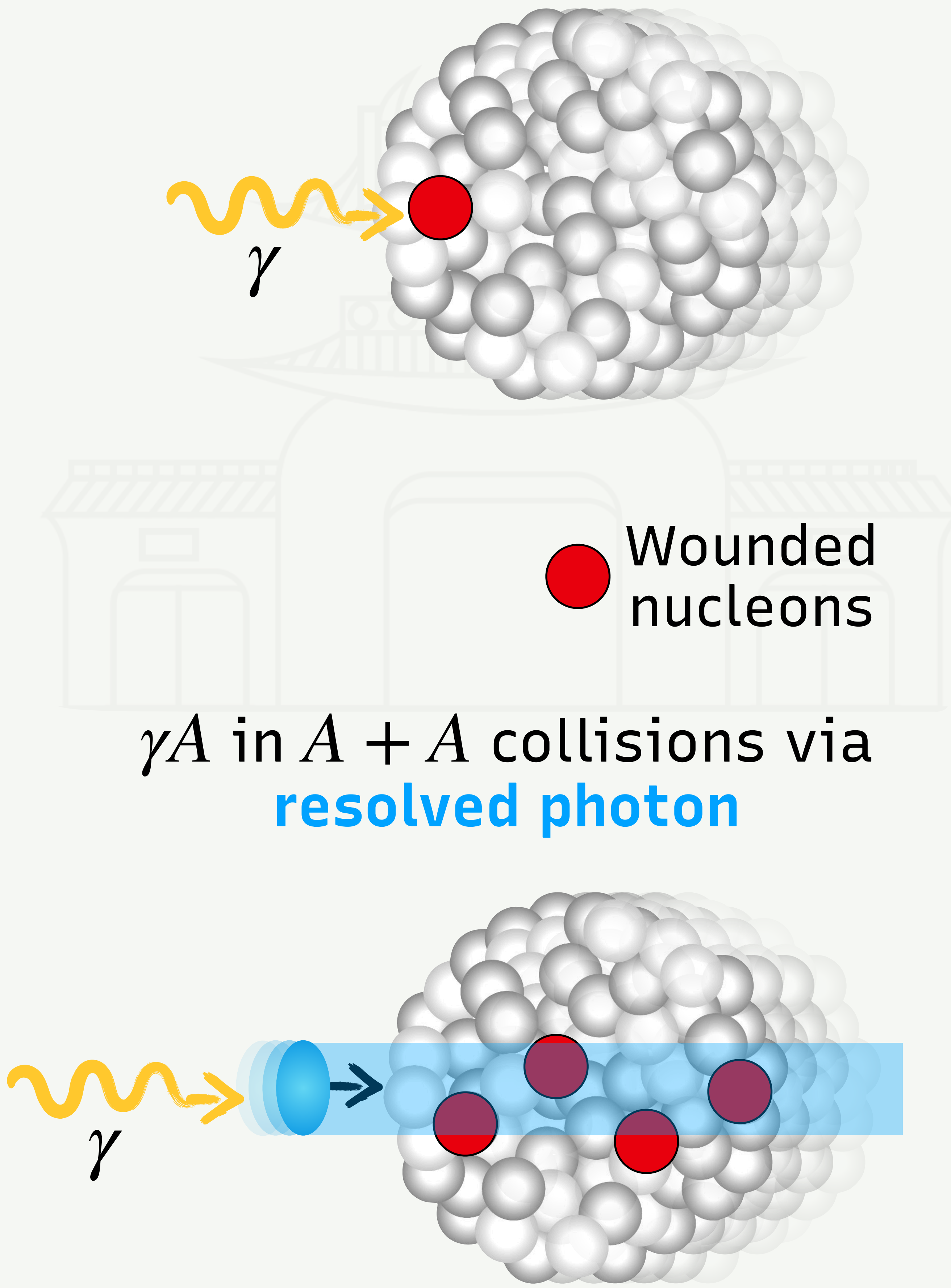
See talk by B.Gilbert

First study of nuclear breakup in UPC dijet events!





γA in $A+A$ collisions via **direct photon**



γA in $A+A$ collisions via **resolved photon**

$f_{\text{no BU}}$ = Fraction of events where photon emitting nucleus does not break up

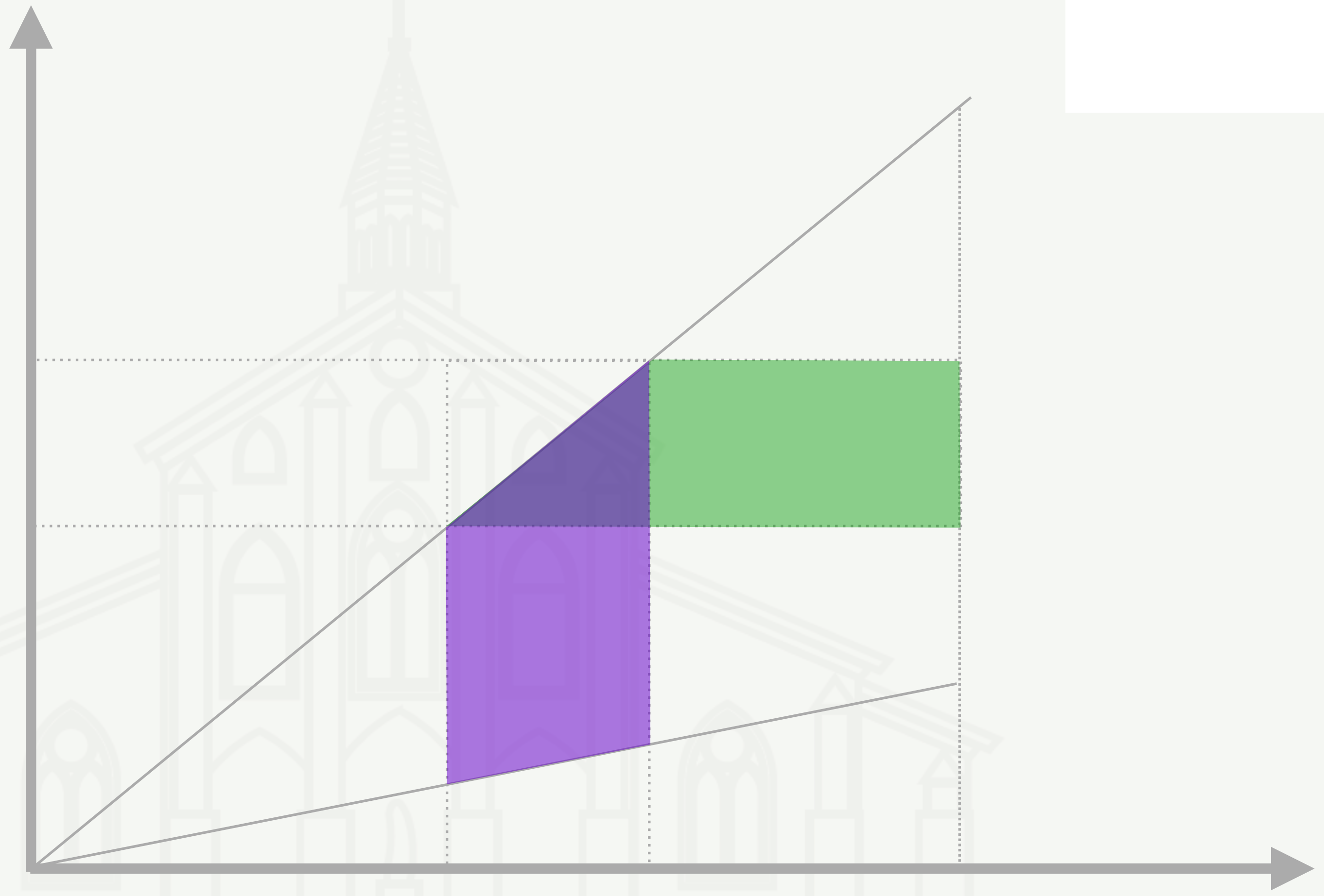
Fraction of direct photon UPCs as a function of photon energy

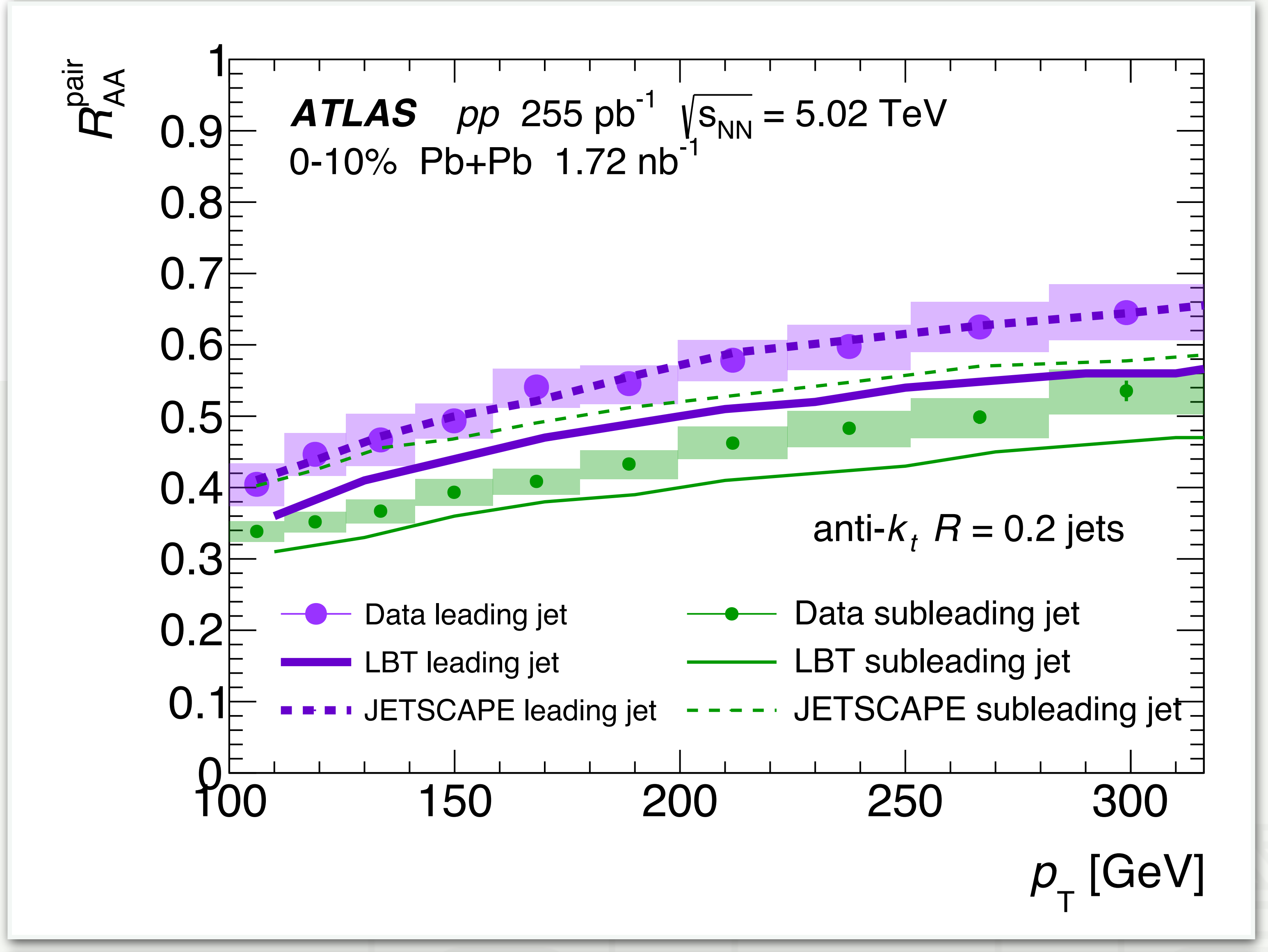
arXiv:2409.11060

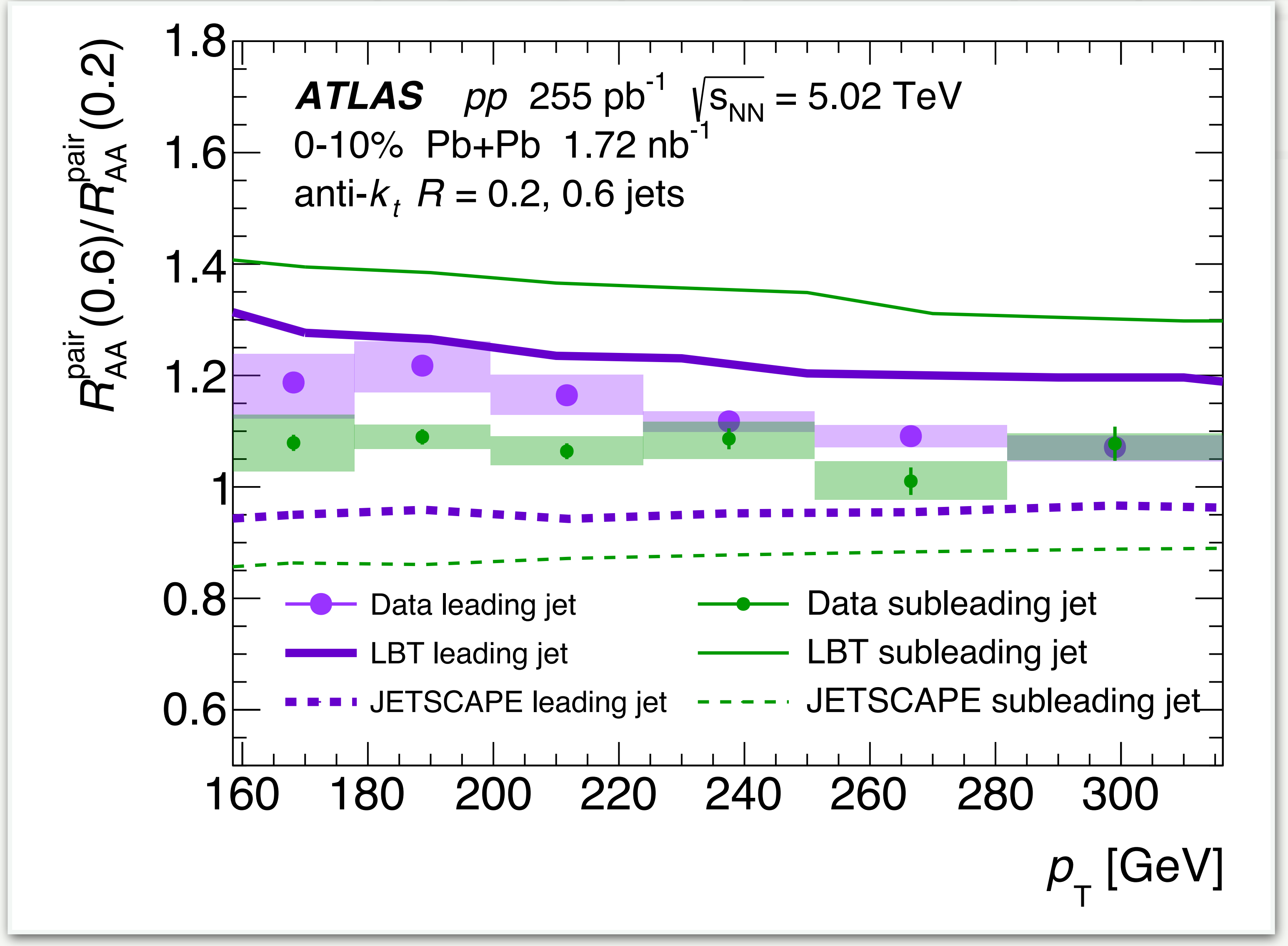
R dependence of jet quenching

See talks by Q.Hu & A.Sickles

$$R_{AA}^{pair}(p_{T,1}) = \frac{\frac{1}{\langle T_{AA}\rangle N_{evt}^{AA}} \int_{0.32\times p_{T,1}}^{p_{T,1}} \frac{d^2 N_{pair}^{AA}}{dp_{T,1}dp_{T,2}} dp_{T,2}}{\frac{1}{L_{pp}} \int_{0.32\times p_{T,1}}^{p_{T,1}} \frac{d^2 N_{pair}^{pp}}{dp_{T,1}dp_{T,2}} dp_{T,2}}$$





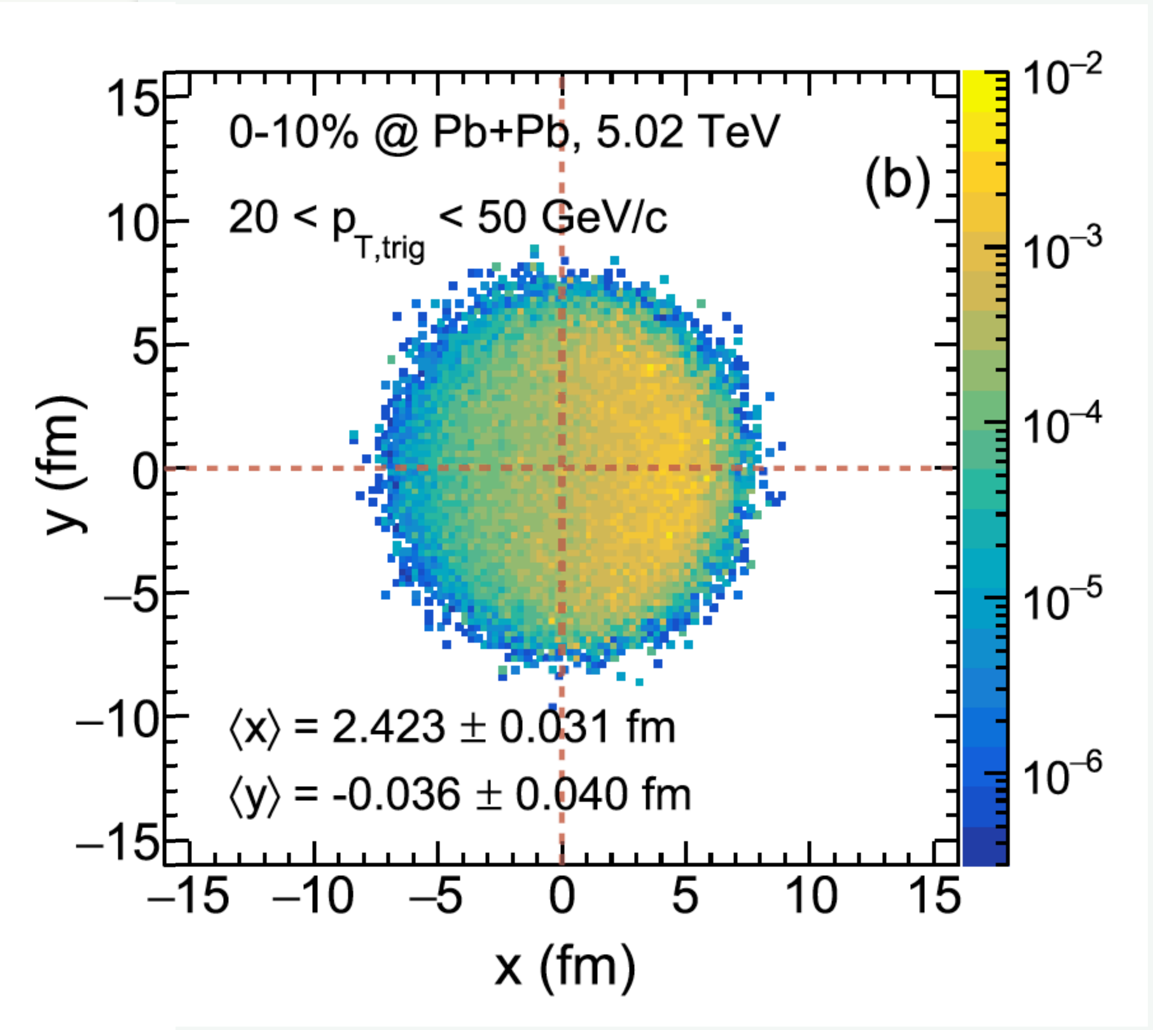


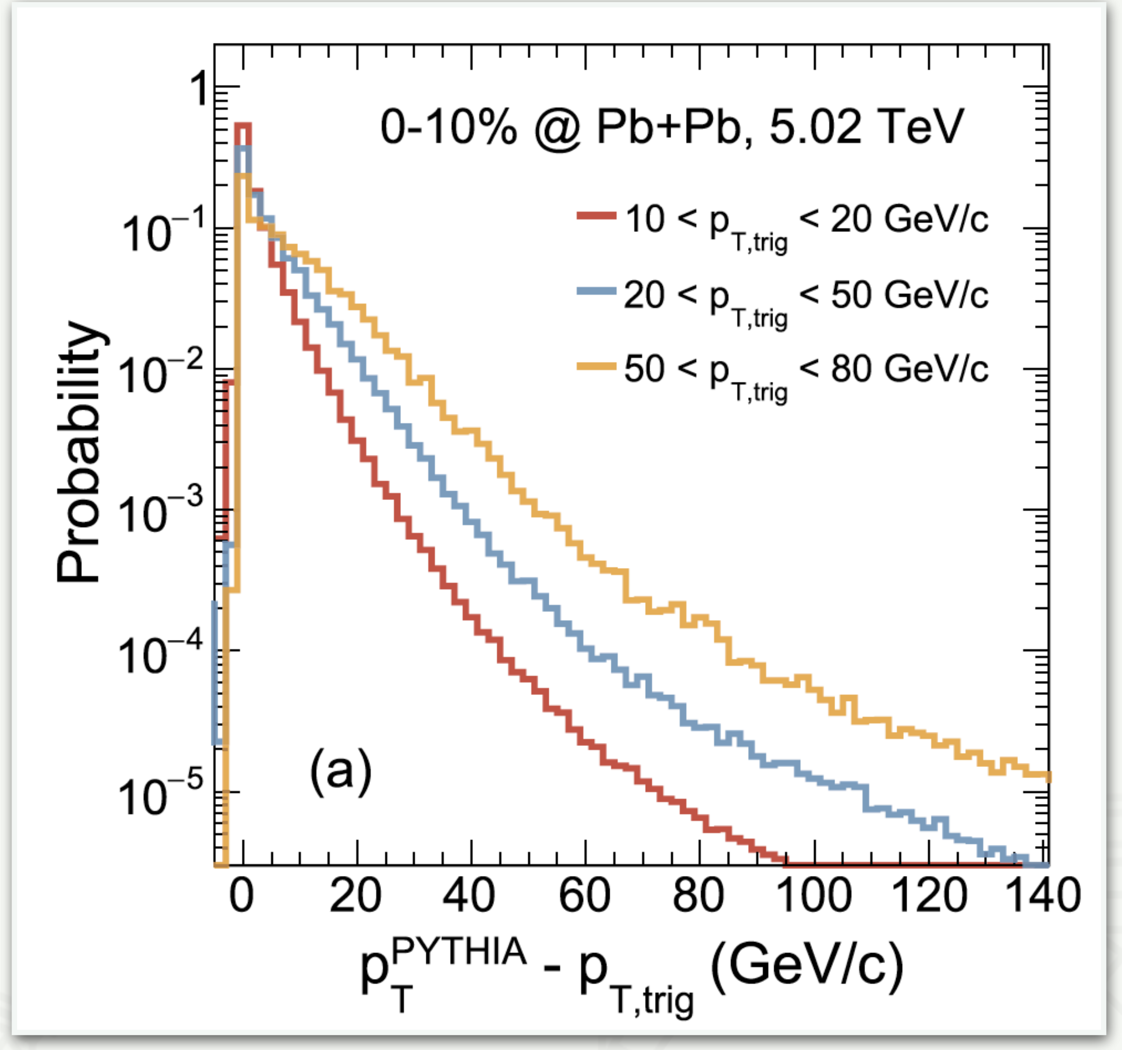
- Leading and subleading jet R_{AA}^{pair} are probing different population of dijet events, useful differential information to improve modeling
- Smaller-R dijets are more suppressed

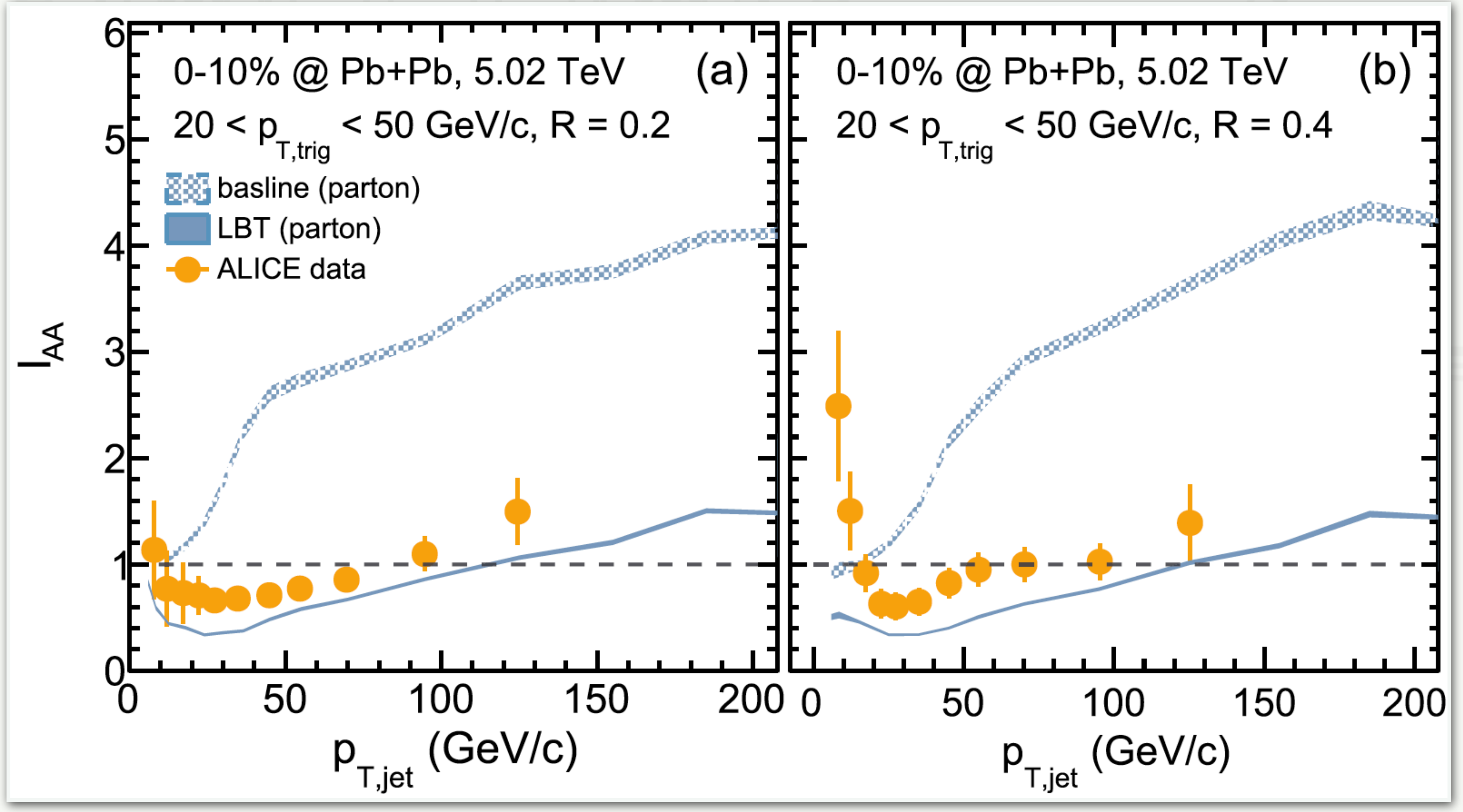
Deciphering the I_{AA} in jet+h

See talk by Y.He

Phys. Lett. B 854 (2024) 138739

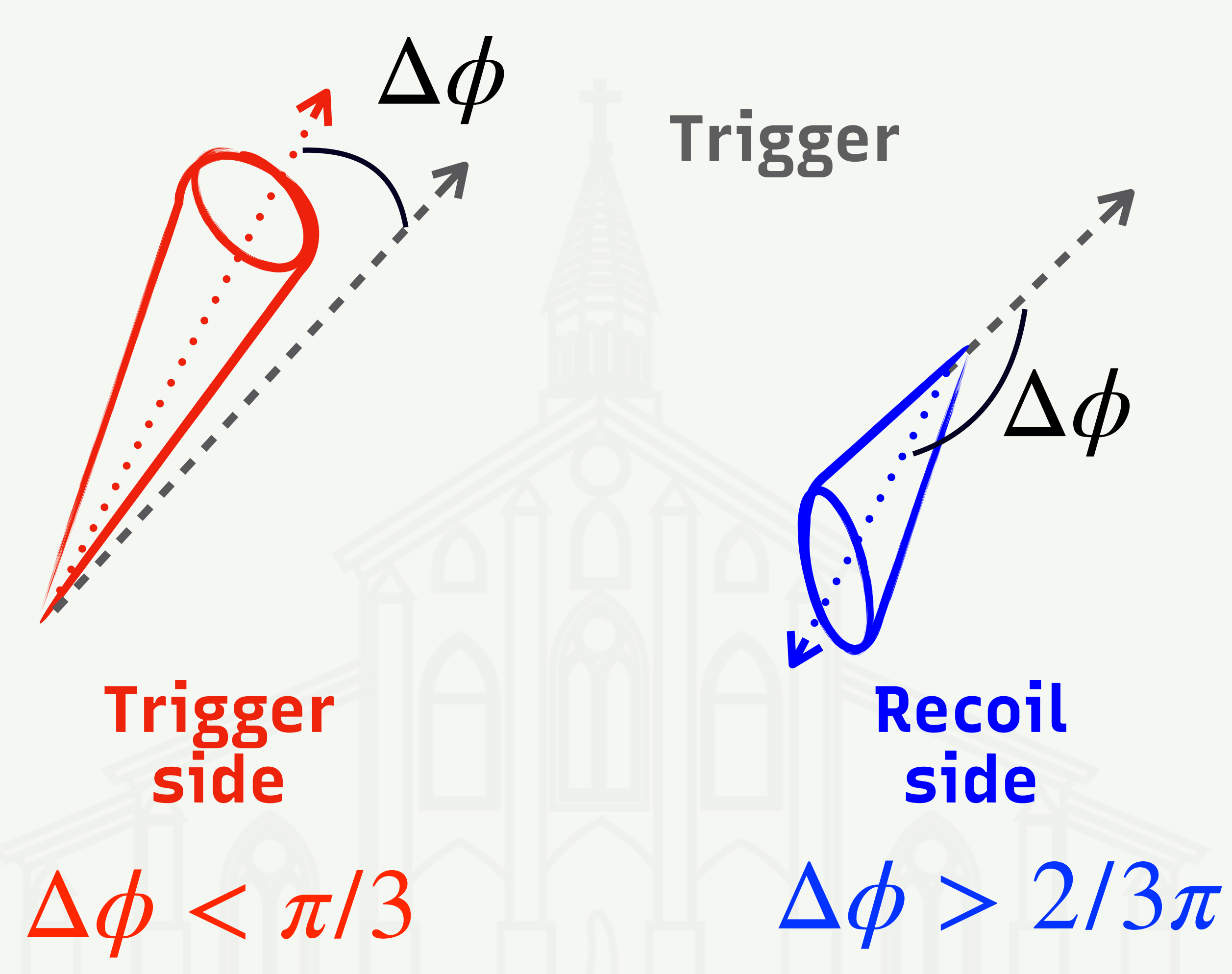






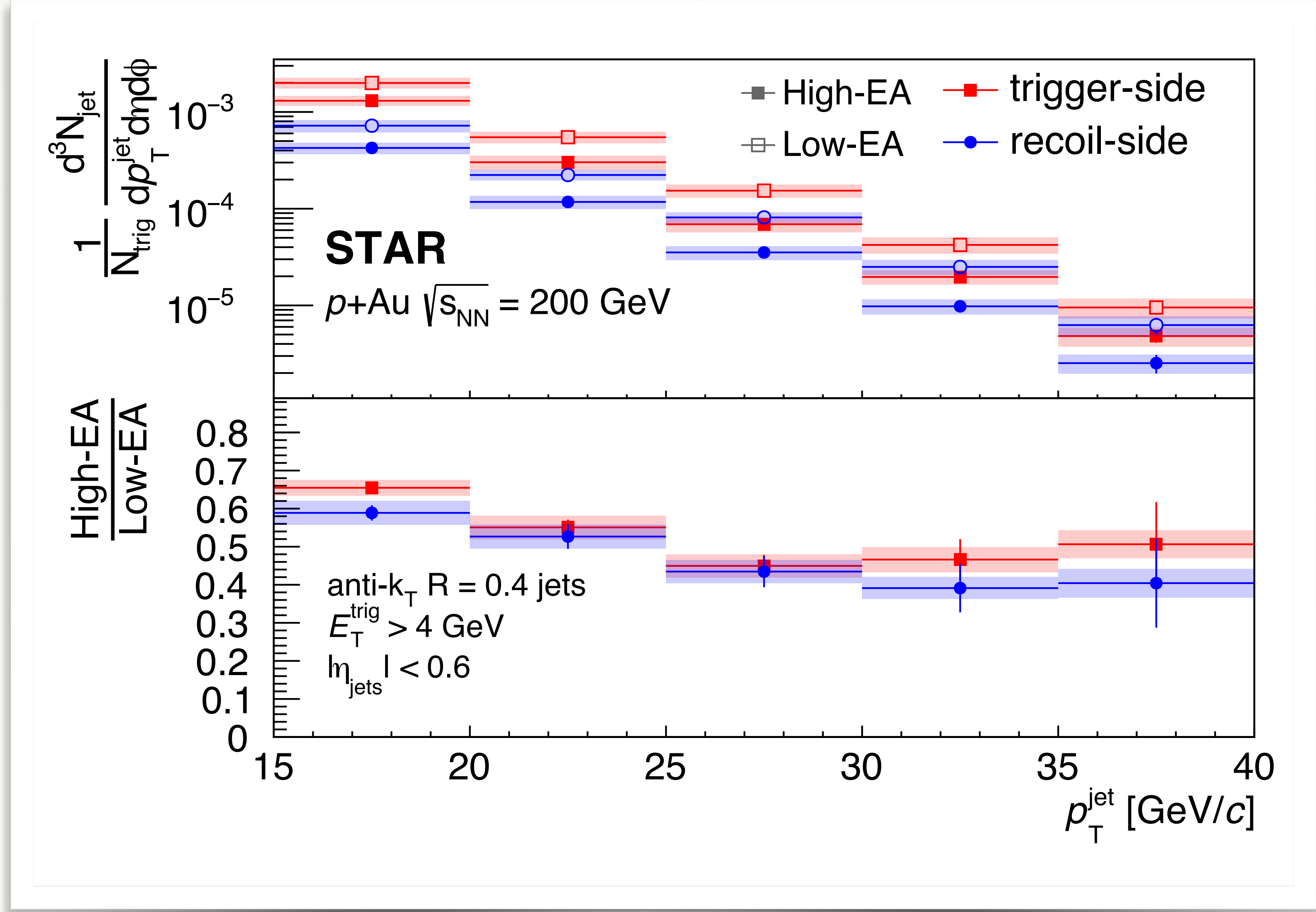
- Surface bias for hadron triggers: still, relevant fraction of trigger hadron experiencing relevant energy loss
- Isolate the effect of surface bias by building a true 'baseline' using hadron triggers with energy loss but no jet quenching on the other side
- **Results provide a qualitative explanation for $I_{AA} > 1$ observed by ALICE**

Search for onset of E_{Loss} in small systems: RHIC

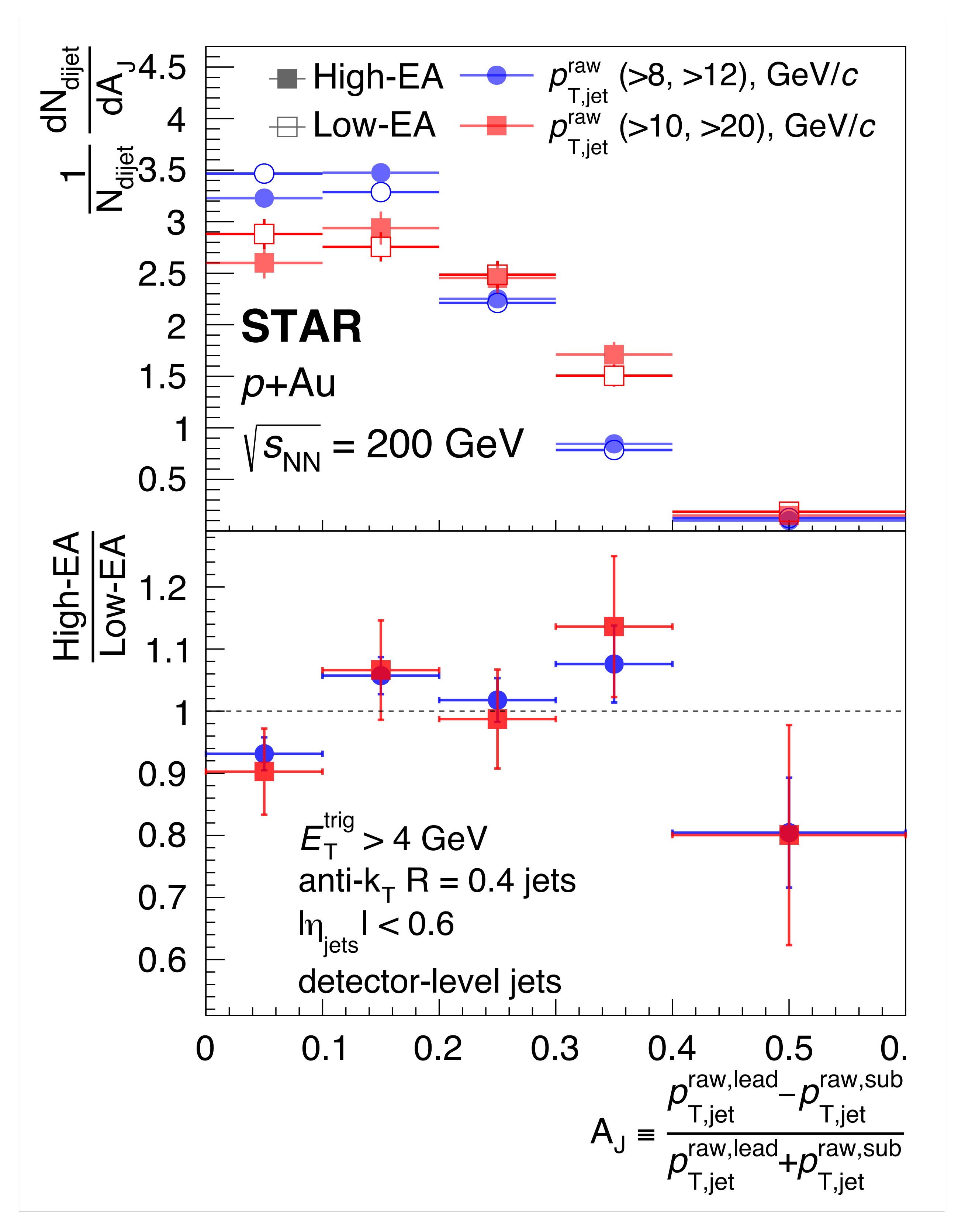


NB: **event activity not robust centrality estimator** in p+A - but used with certain prescriptions in this case

arXiv:2404.08784

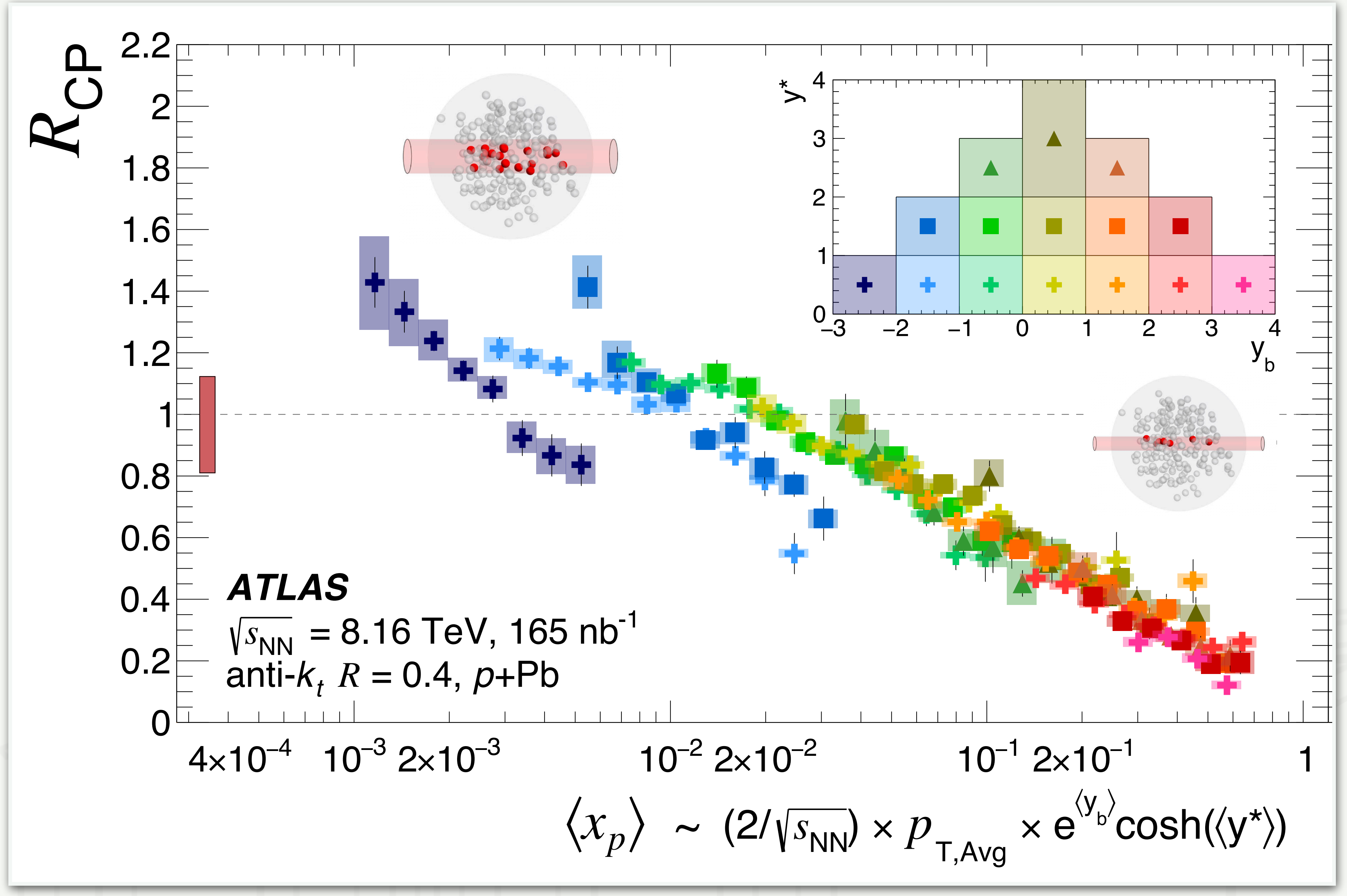


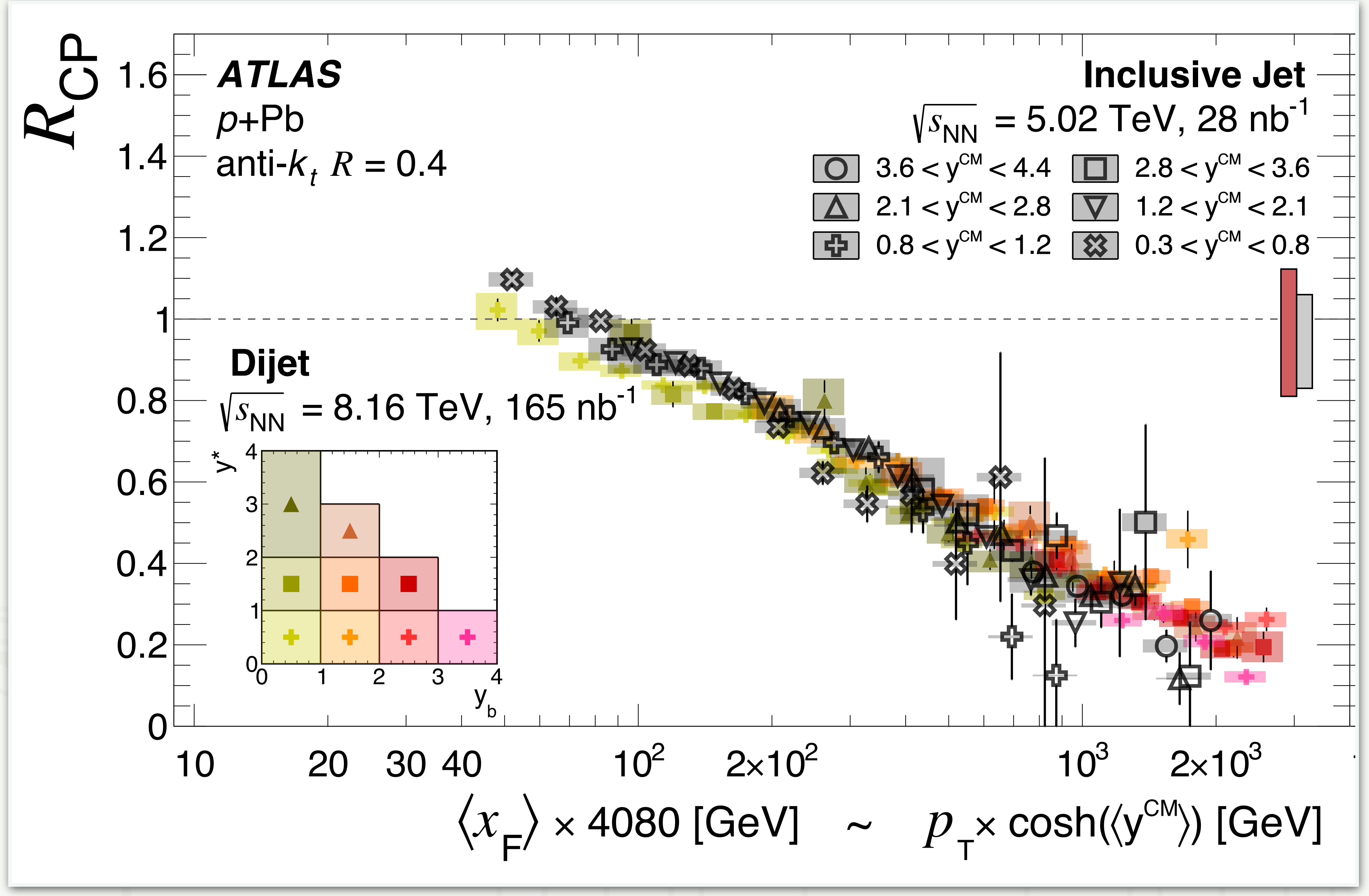
- **Semi-inclusive jet spectra**
  - Comparable suppression for both trigger and recoil side → **no evidence of pathlength dependence**



- **Dijet asymmetry**-like analysis in different p+Au event activity classes
  - **No 'centrality' dependence**

Color fluctuation effects on event activity in p+A





$$x_p - x_{Pb} = x_F = \frac{2p_z}{\sqrt{s_{NN}}} \sim \pm 2\frac{p_T \times \cosh y^{CM}}{\sqrt{s_{NN}}} \rightarrow \pm \frac{\sqrt{s_{NN}}}{2} \times x_F \sim p_T \times \cosh y^{CM}$$

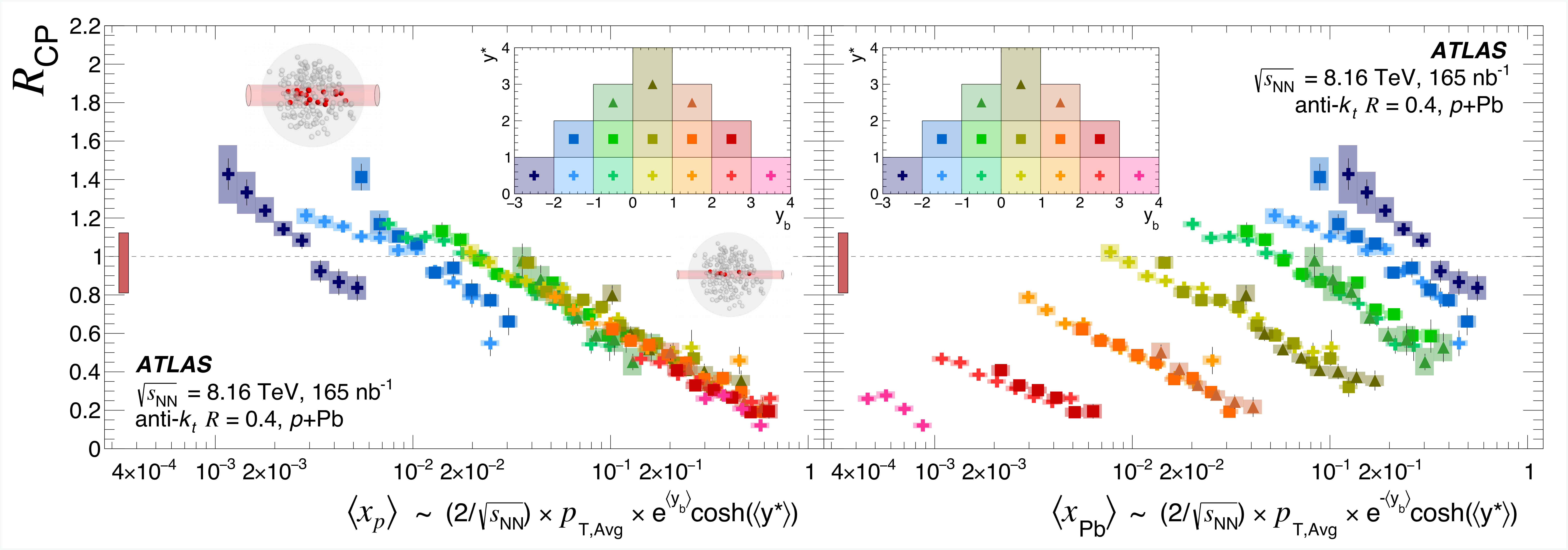
Initial state definition ($x_p - x_{Pb}$) — **Final state definition** ($x_F = \frac{2p_z}{\sqrt{s_{NN}}}$)

Assuming

$$m_T = \sqrt{m^2 + p_T^2} \sim p_T \qquad \sinh y^{CM} \sim \pm \cosh y^{CM} \text{ if } |y^{CM}| \gg 0$$

Comparison between the two measurements achieved via x_F

Color fluctuation effects on event activity in p+A



- **Full picture -** x_p and x_{Pb}
- **Anti-shadowing region shows interesting trends**