ATLAS Highlights

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for the ATLAS collaboration

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Advances, Innovations, and Prospects in High-Energy Nuclear Physics

高能核物理进展、创新与展望

CCNU, Wuhan

进展 Advances

- Jet modification and
- Medium response

创新 Innovations

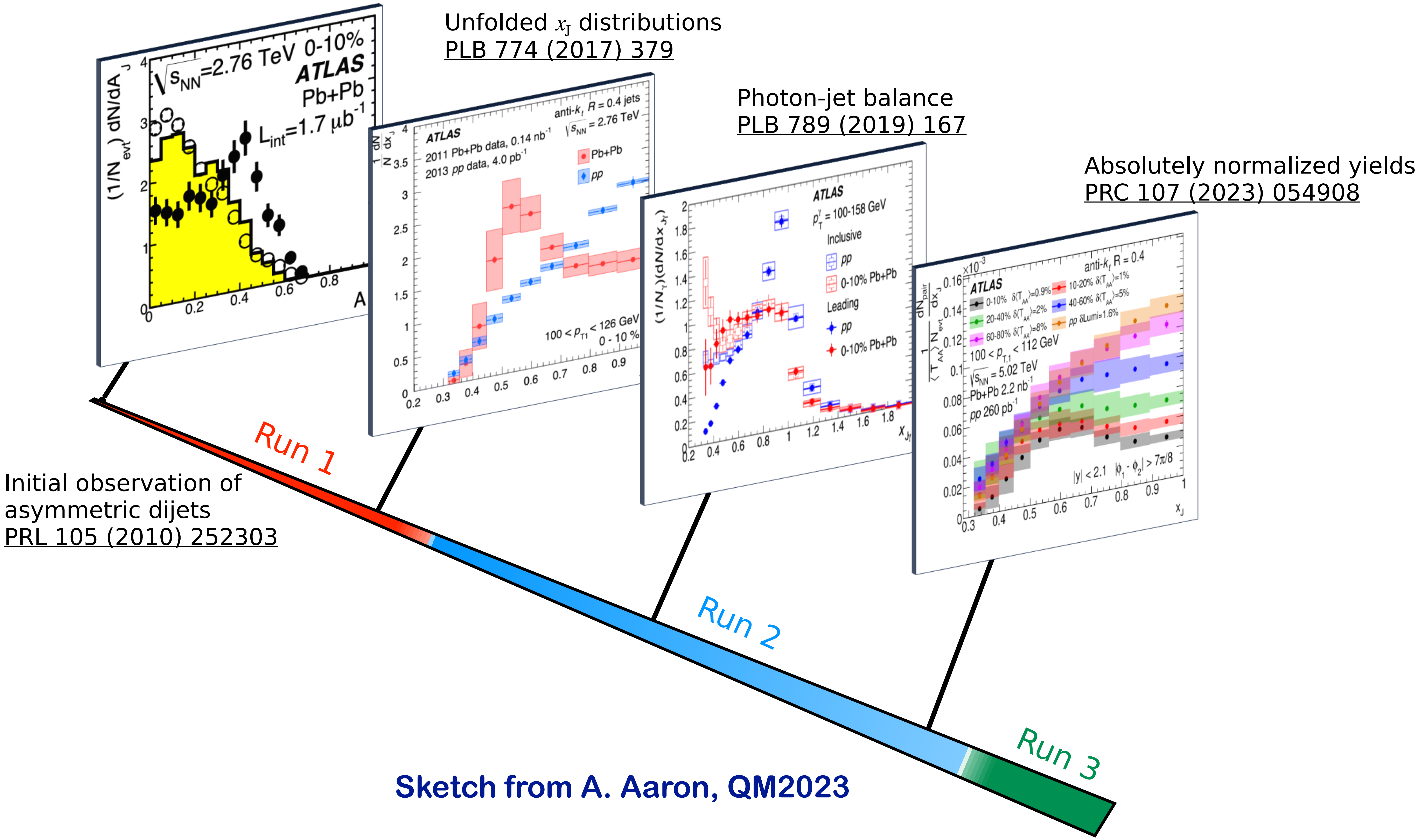
- Dijet for studying centrality bias and nuclear break up
- Improved understanding of photonuclear interactions
- New testing ground for particle physics

展望 Future Perspectives

- New track trigger in Run3
- Exciting heavy ion runs in 2024/2025
- New detector planned for Run4

ATLAS EXPERIMENT

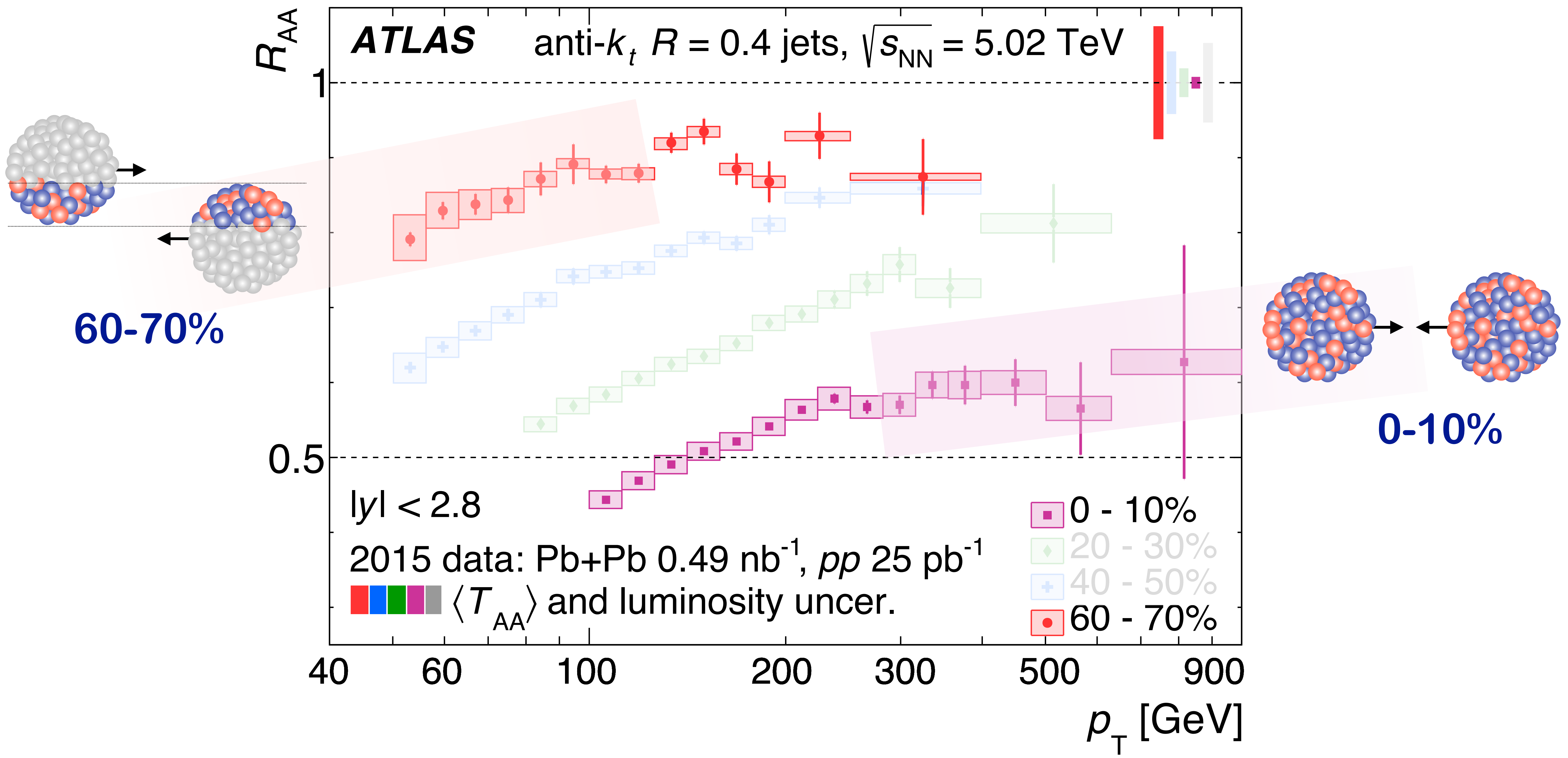
Advances

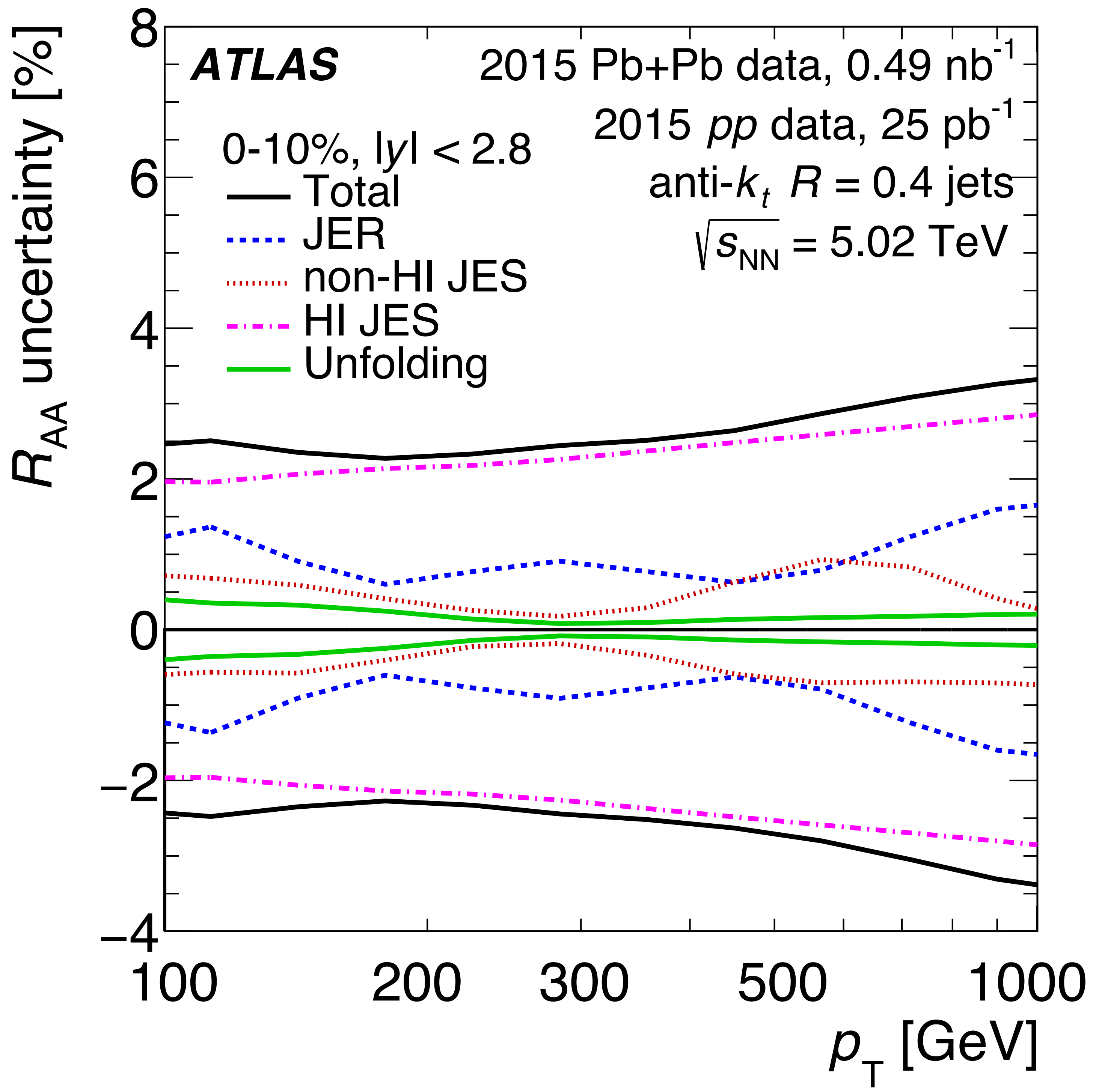


Sketch from A. Aaron, QM2023

Single inclusive jet R_{AA}

PLB 790 (2019) 108

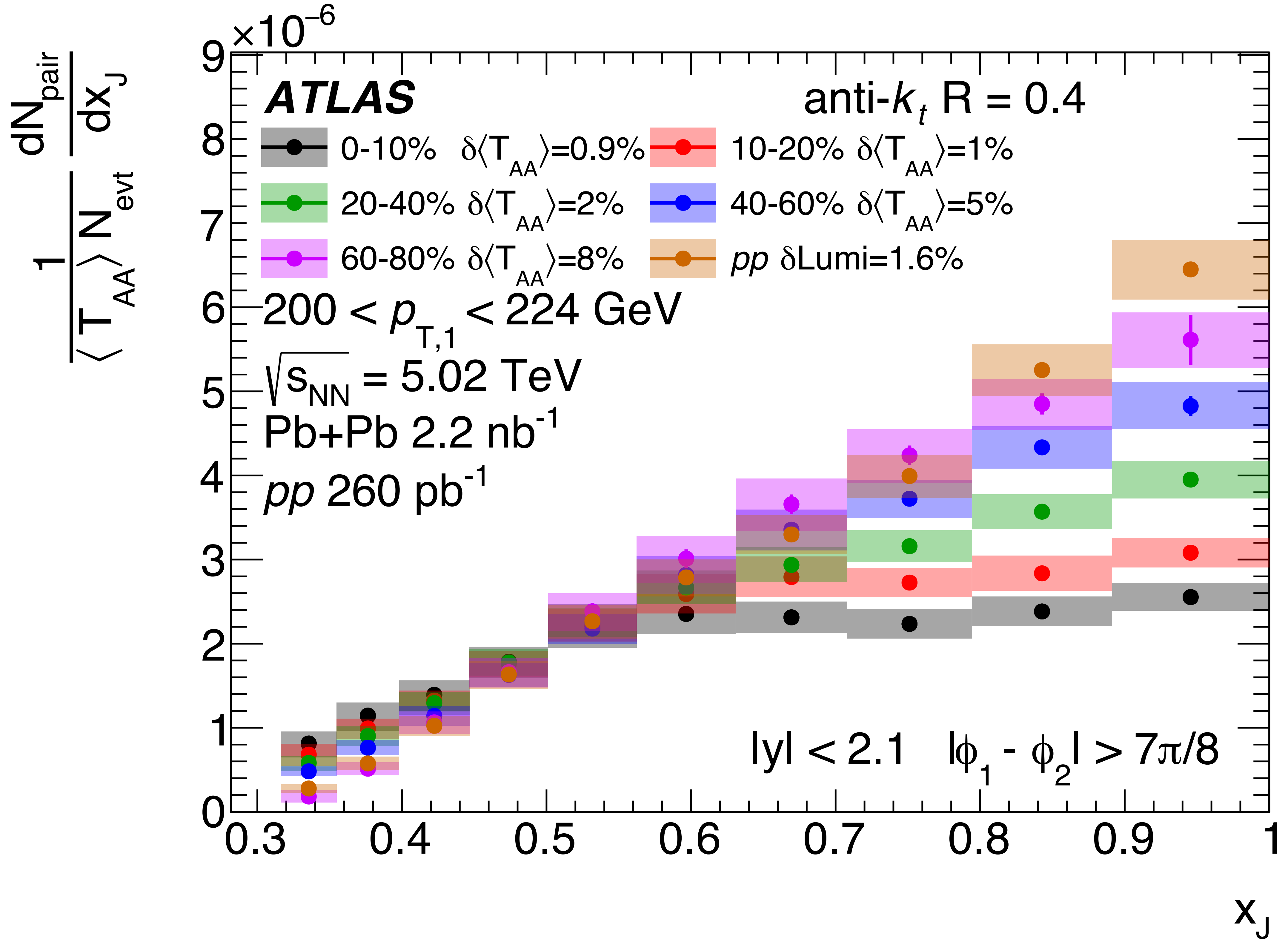




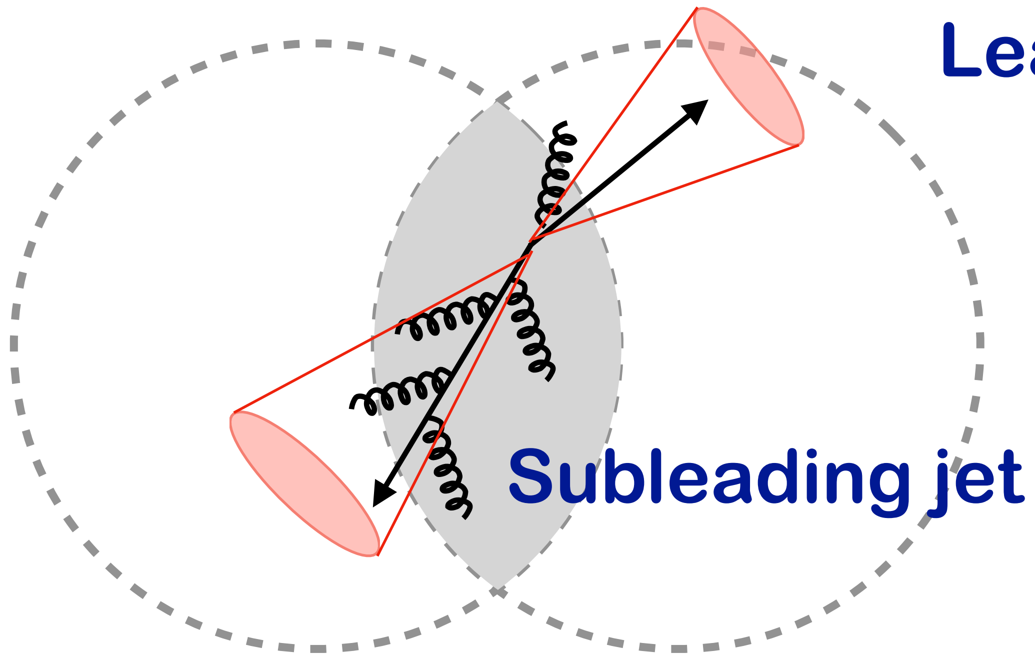
- ATLAS has successfully controlled the single jet R_{AA} systematics to the few-percent level with 2015 data
- Widely used in constraining quenching models

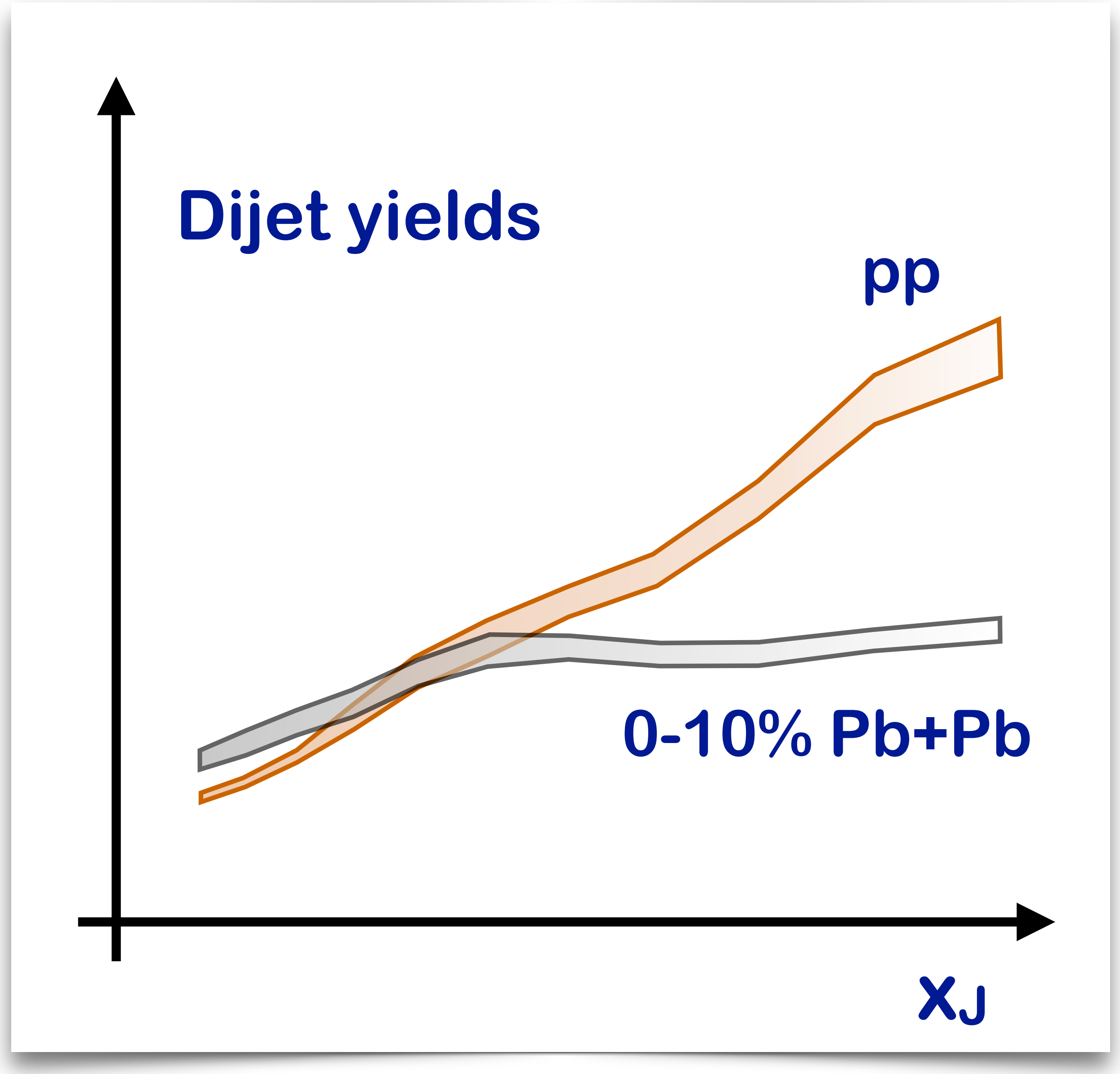
Dijet asymmetry

PRC 107 (2023) 054908



$$x_J = \frac{p_T^{\text{subleading}}}{p_T^{\text{leading}}}$$





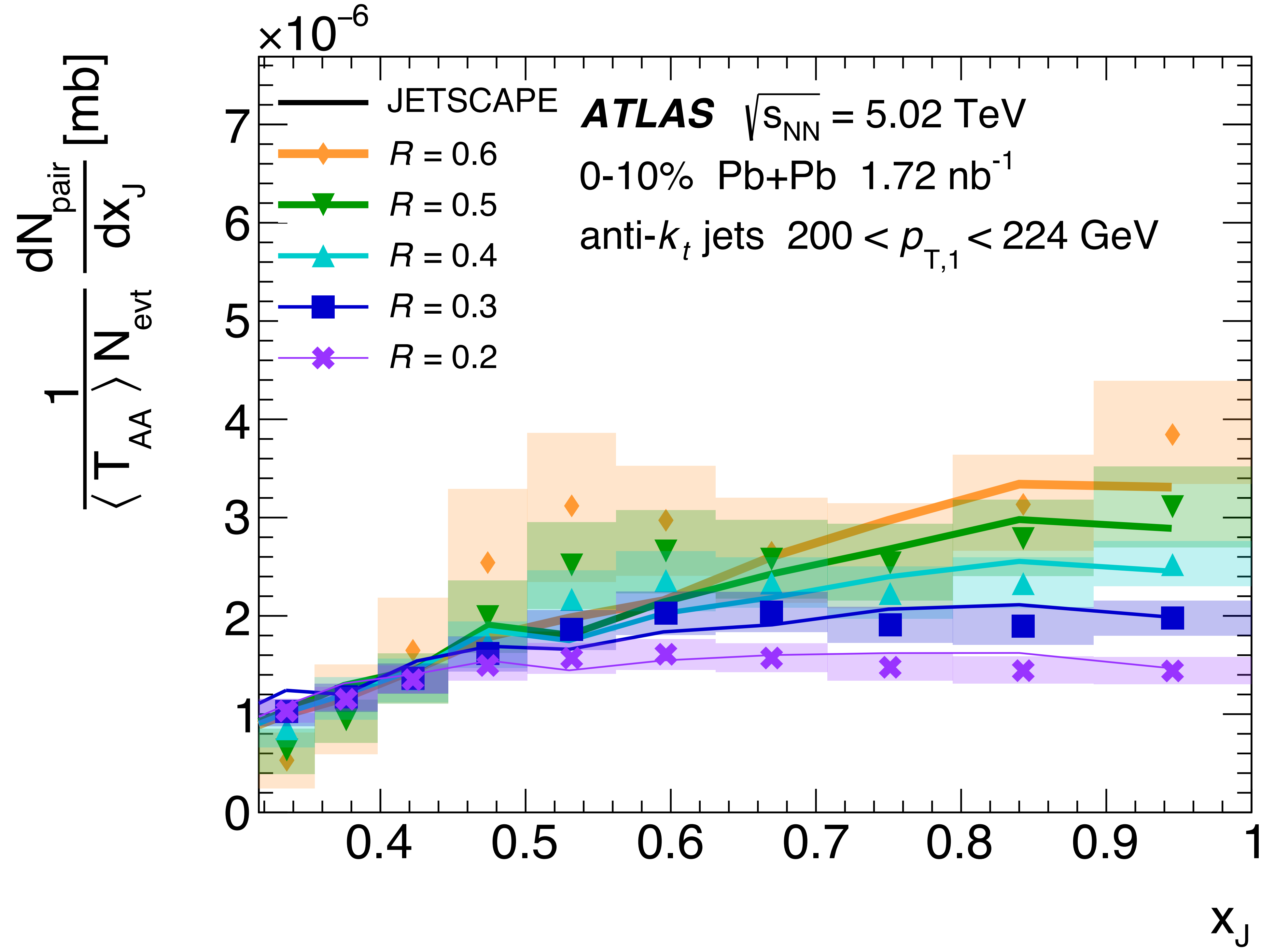
Absolute dijet yield suppression

- Probe the absolute dijet yield suppression and relative suppression between leading and sub-leading jets at the same time

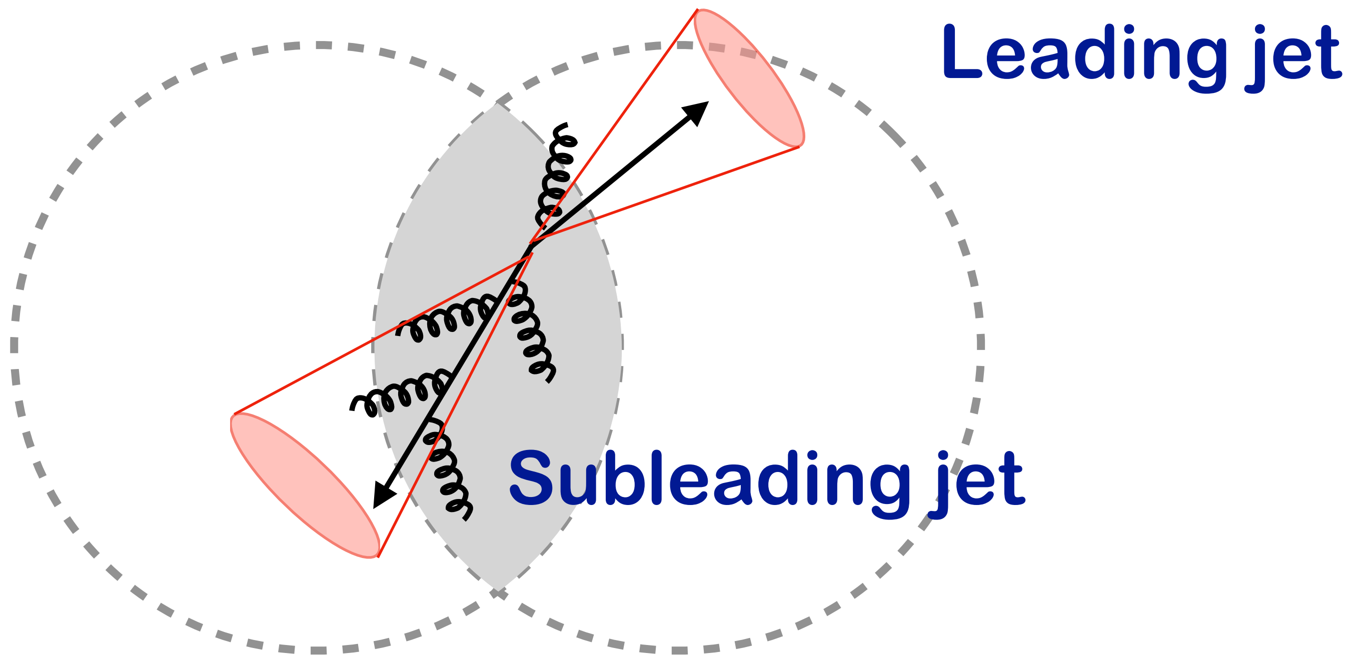
Relative suppression between leading and sub-leading jets

R-dependence of Dijet asymmetry

arXiv:2407.18796



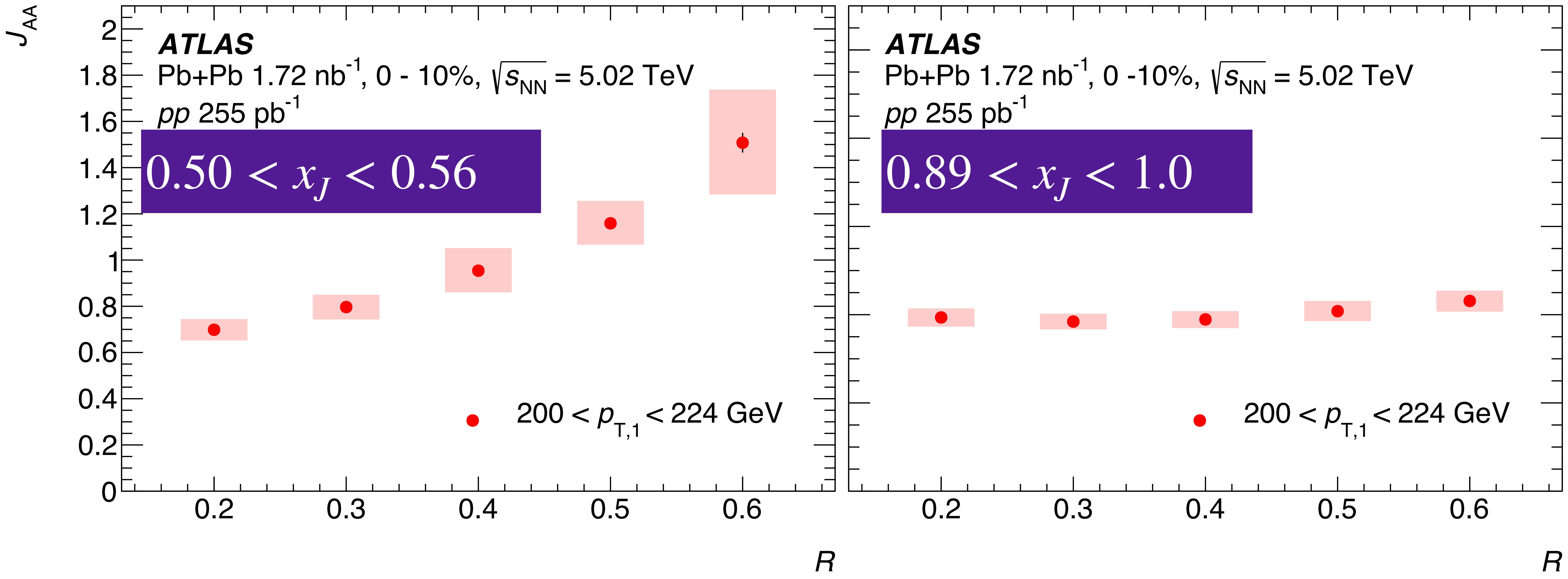
$$x_J = \frac{p_T^{\text{subleading}}}{p_T^{\text{leading}}}$$



- New ATLAS dijet measurements reveal the R-dependence of absolute dijet asymmetry
- While JETSCAPE successfully describes the R-dependence for symmetric dijets, it fails to do so for asymmetric dijets

R-dependence of Dijet asymmetry — cont.

arXiv:2407.18796

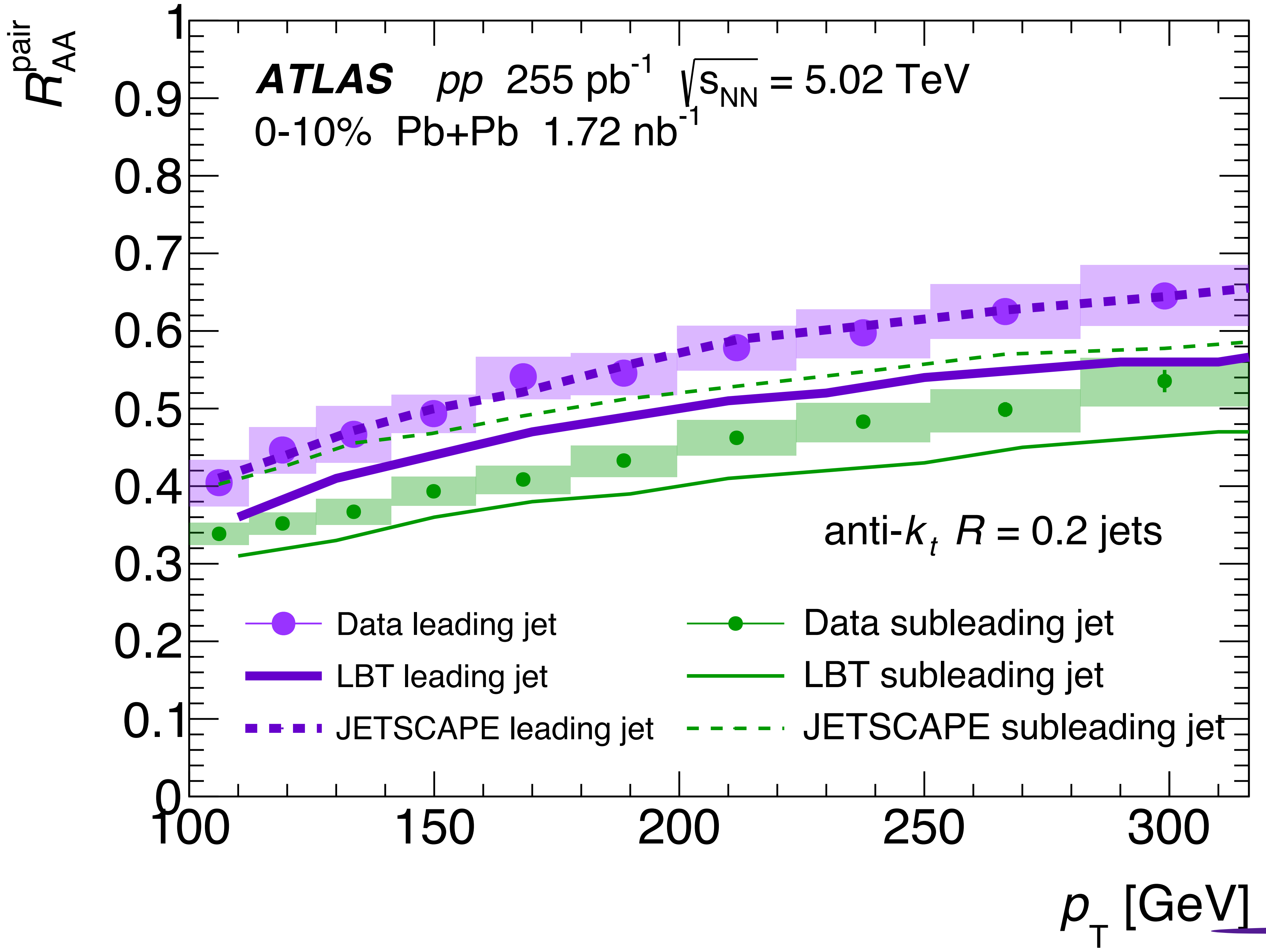


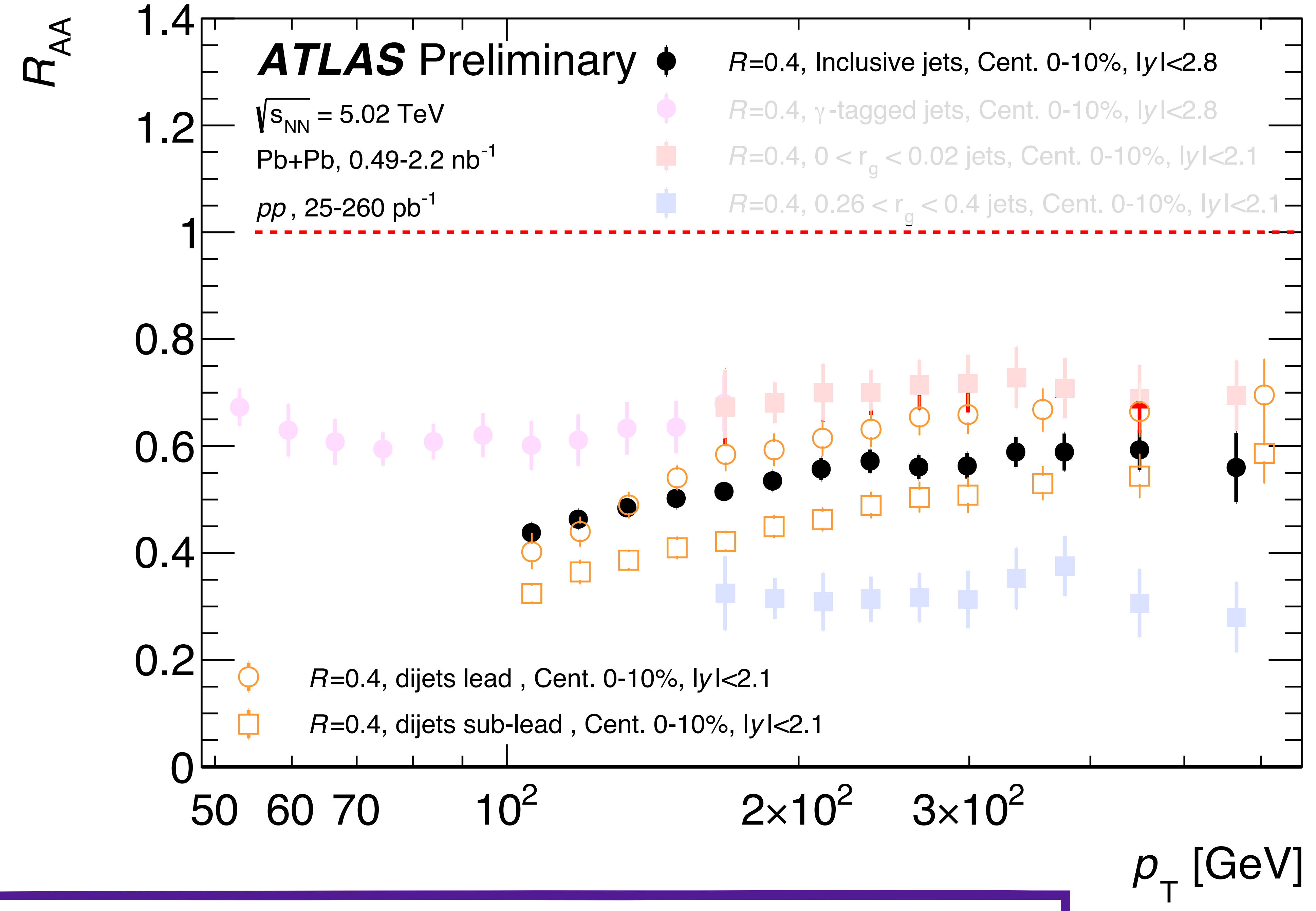
- Strong R-dependence for imbalanced dijets
- Smaller-R dijets are more suppressed

$$J_{AA} = \frac{1}{\langle T_{AA}\rangle N_{evt}^{AA}} \frac{dN_{pair}^{AA}}{dx_J} \Big/ \frac{dN_{pair}^{pp}}{L_{pp} dx_J}$$

Dijet quenching

arXiv:2407.18796
ATL-PHYS-PUB-2022-020

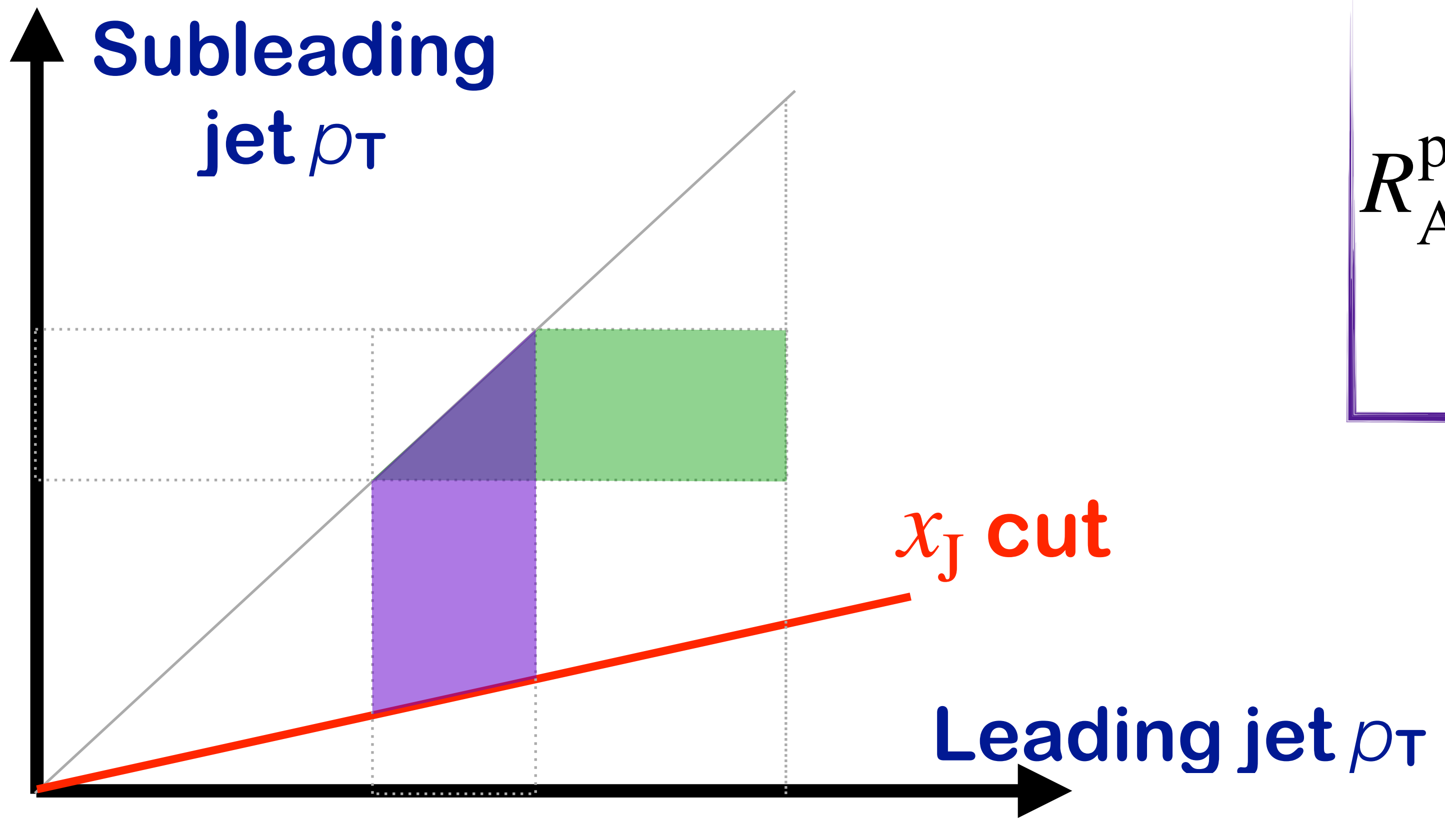




Dijet: leading

Single inclusive

Dijet: sub-leading

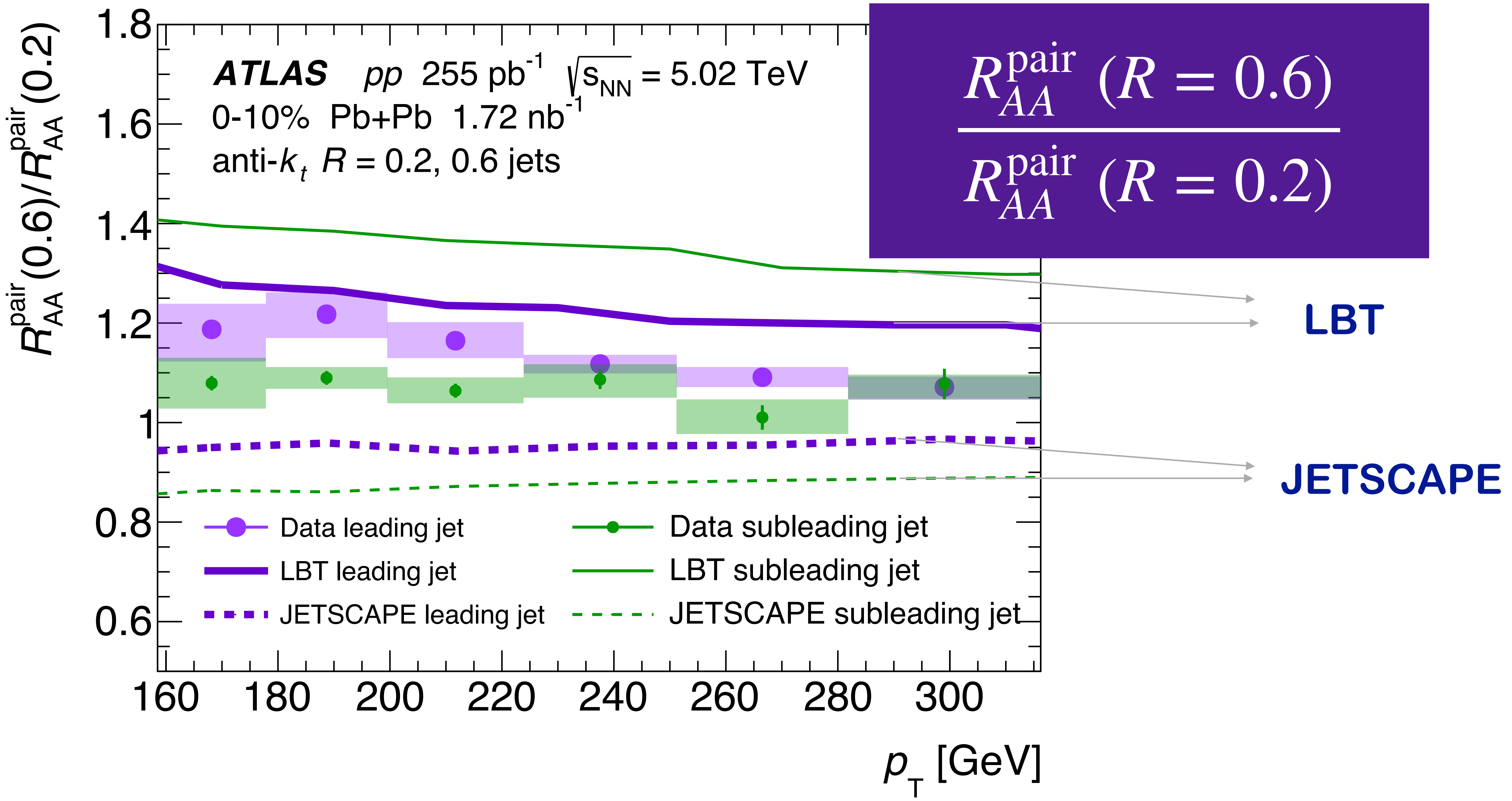


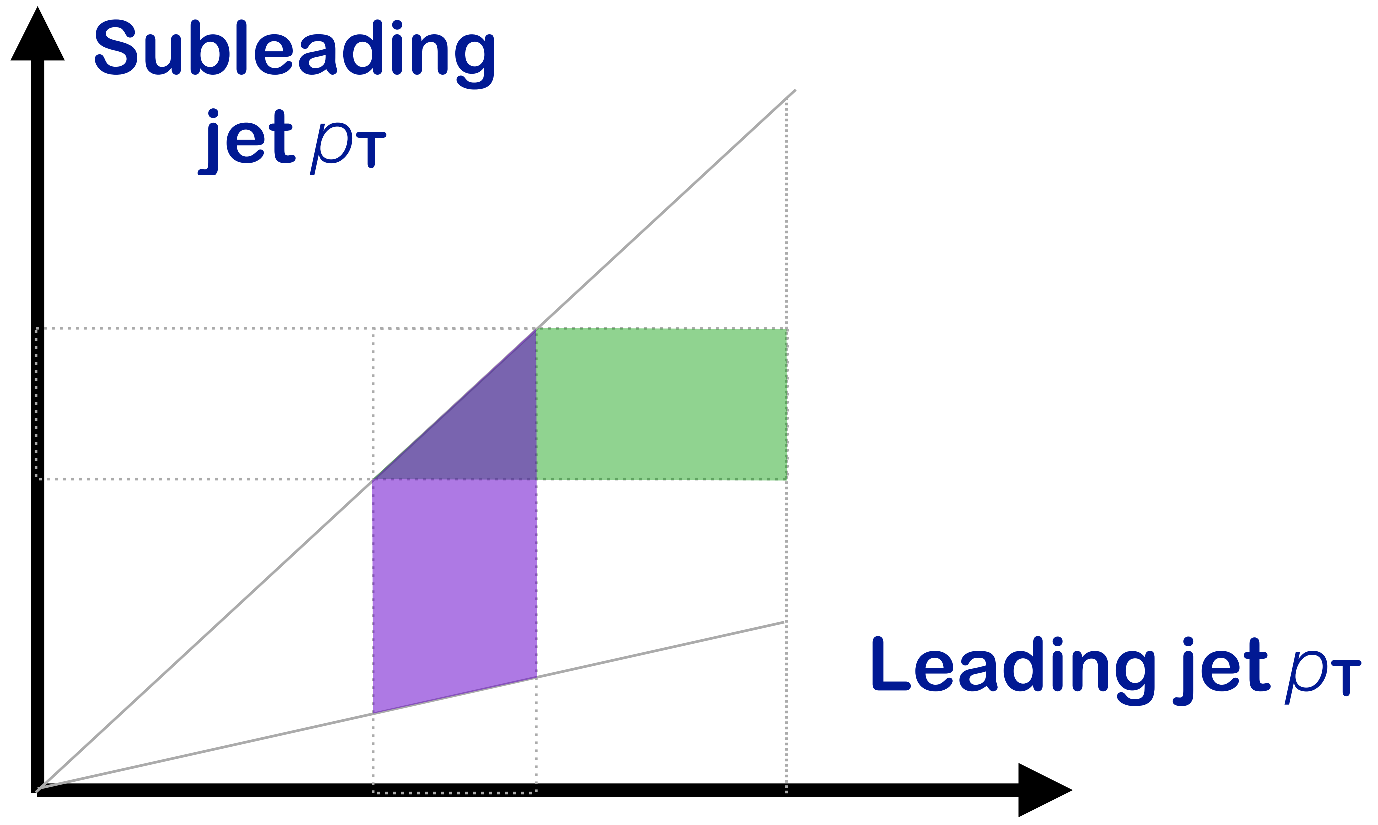
$$R_{\mathrm{AA}}^{\mathrm{pair}}(p_{\mathrm{T},1}) = \frac{\frac{1}{\langle T_{\mathrm{AA}}\rangle N_{\mathrm{evt}}^{\mathrm{AA}}} \int_{0.32\times p_{\mathrm{T},1}}^{p_{\mathrm{T},1}} \frac{\mathrm{d}^2 N_{\mathrm{pair}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T},1}\mathrm{d}p_{\mathrm{T},2}} \mathrm{d}p_{\mathrm{T},2}}{\frac{1}{L_{pp}}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

- Leading and subleading jet $R_{\mathrm{AA}}^{\mathrm{pair}}$ are probing different population of dijet events, useful differential information to improve modeling

R-dependence of dijet quenching

[arXiv:2407.18796](https://arxiv.org/abs/2407.18796)

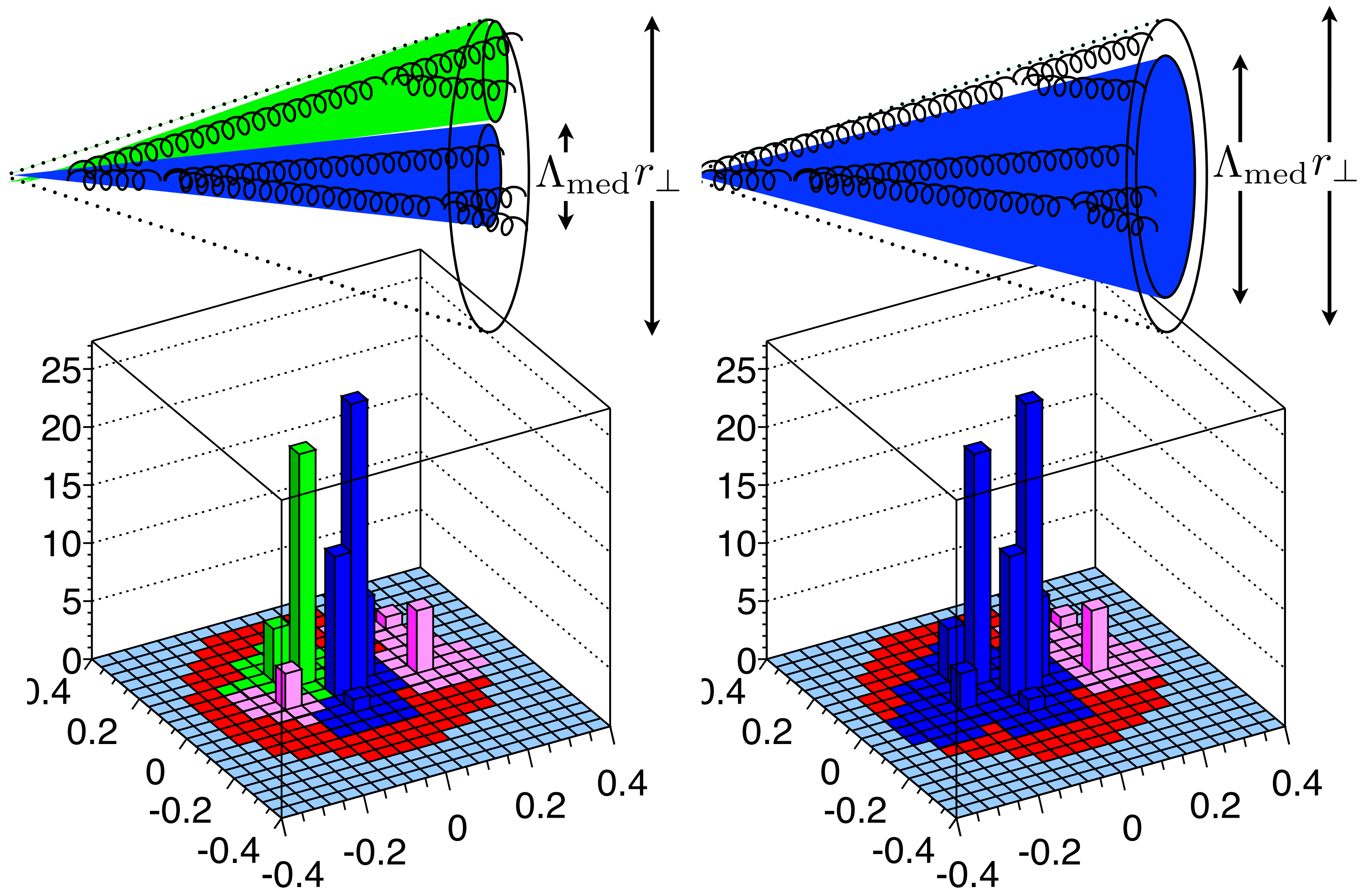




- Smaller R dijets are more suppressed in both regions, bigger difference in leading jet projection
- LBT and JETSCAPE cannot describe the data

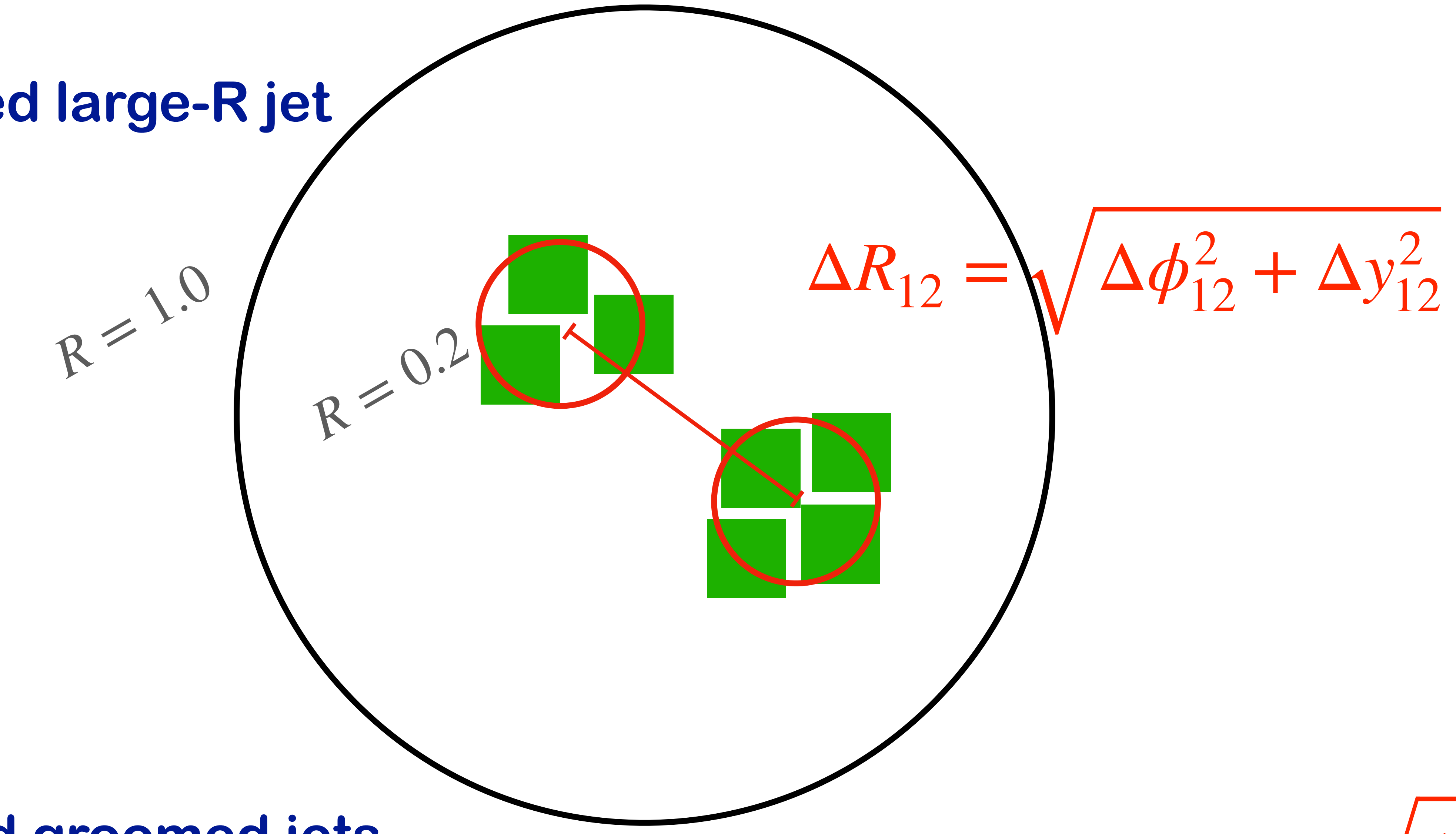
Jet substructure

PRL 131 (2023) 172301
PRC 107 (2023) 054909

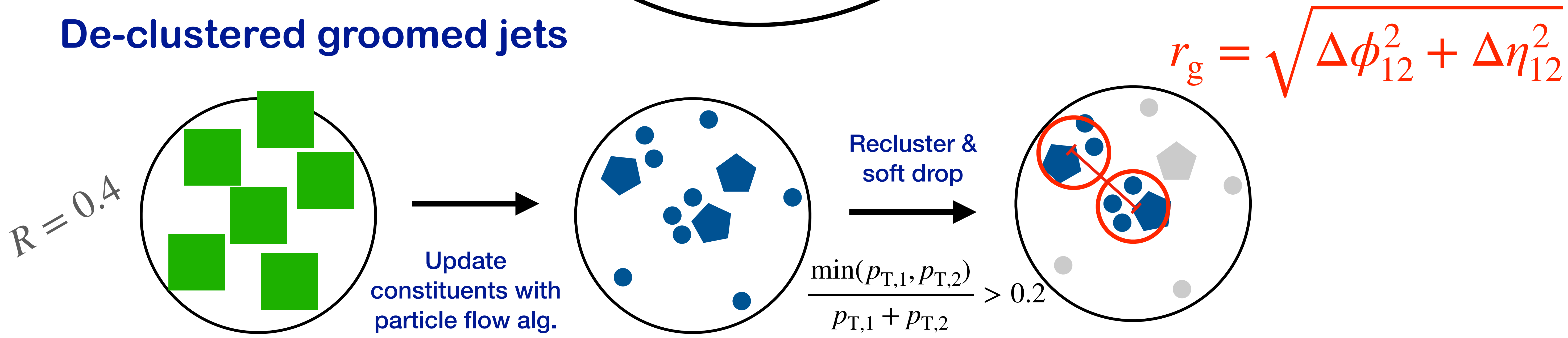


Casalderrey-Solana et al.
PLB 725 (2013) 357

Re-clustered large-R jet



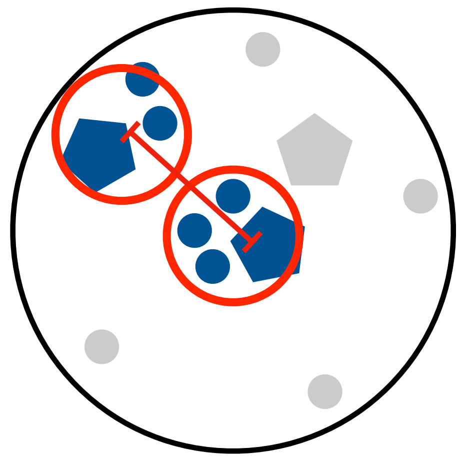
De-clustered groomed jets

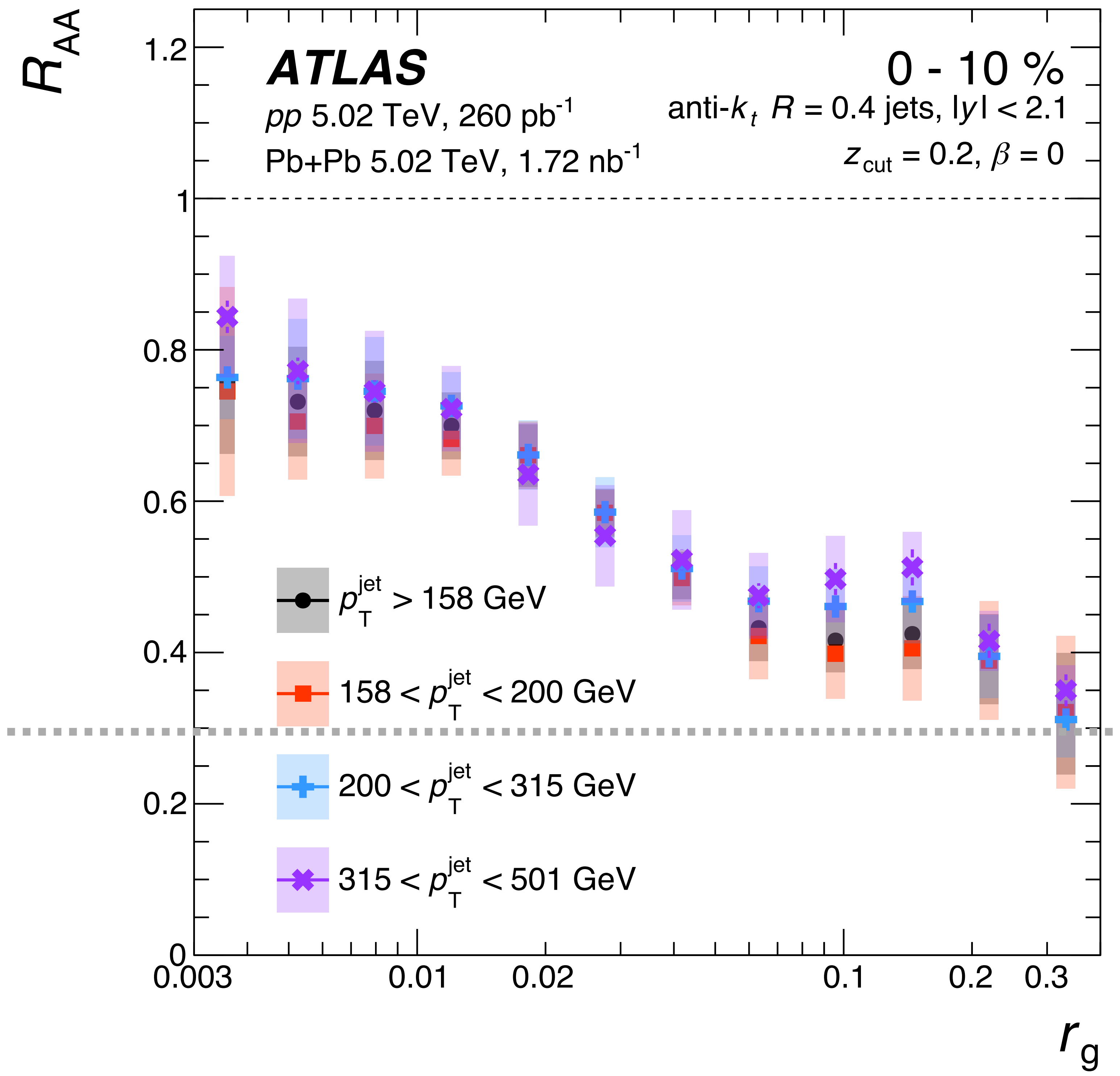


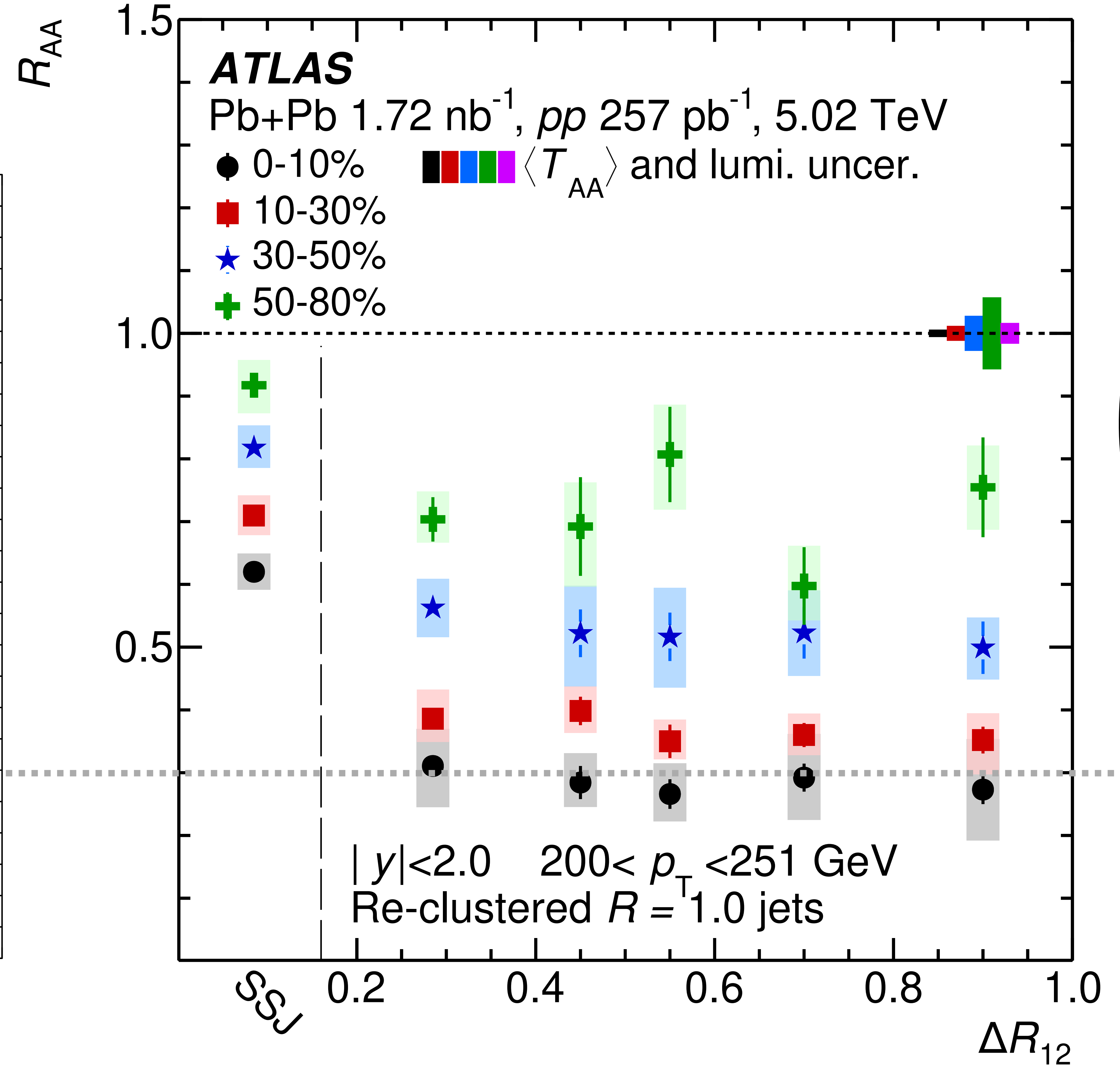
- Color decoherence can be study via hard splitting angle dependence of jet quenching
- Two measurements extracting opening angles between hard splittings in jets at complementing values

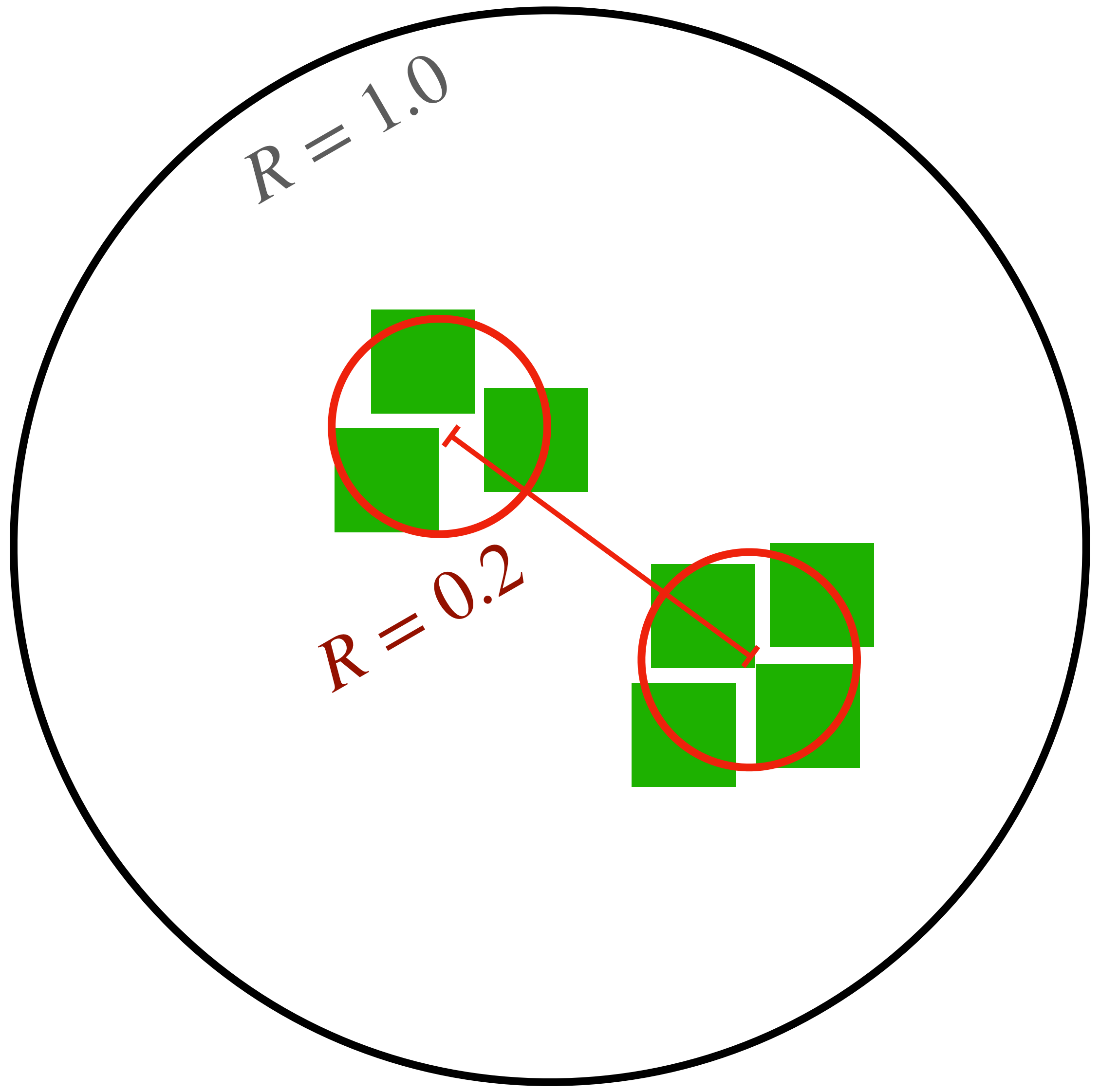
Jet substructure — cont.

PRL 131 (2023) 172301
PRC 107 (2023) 054909





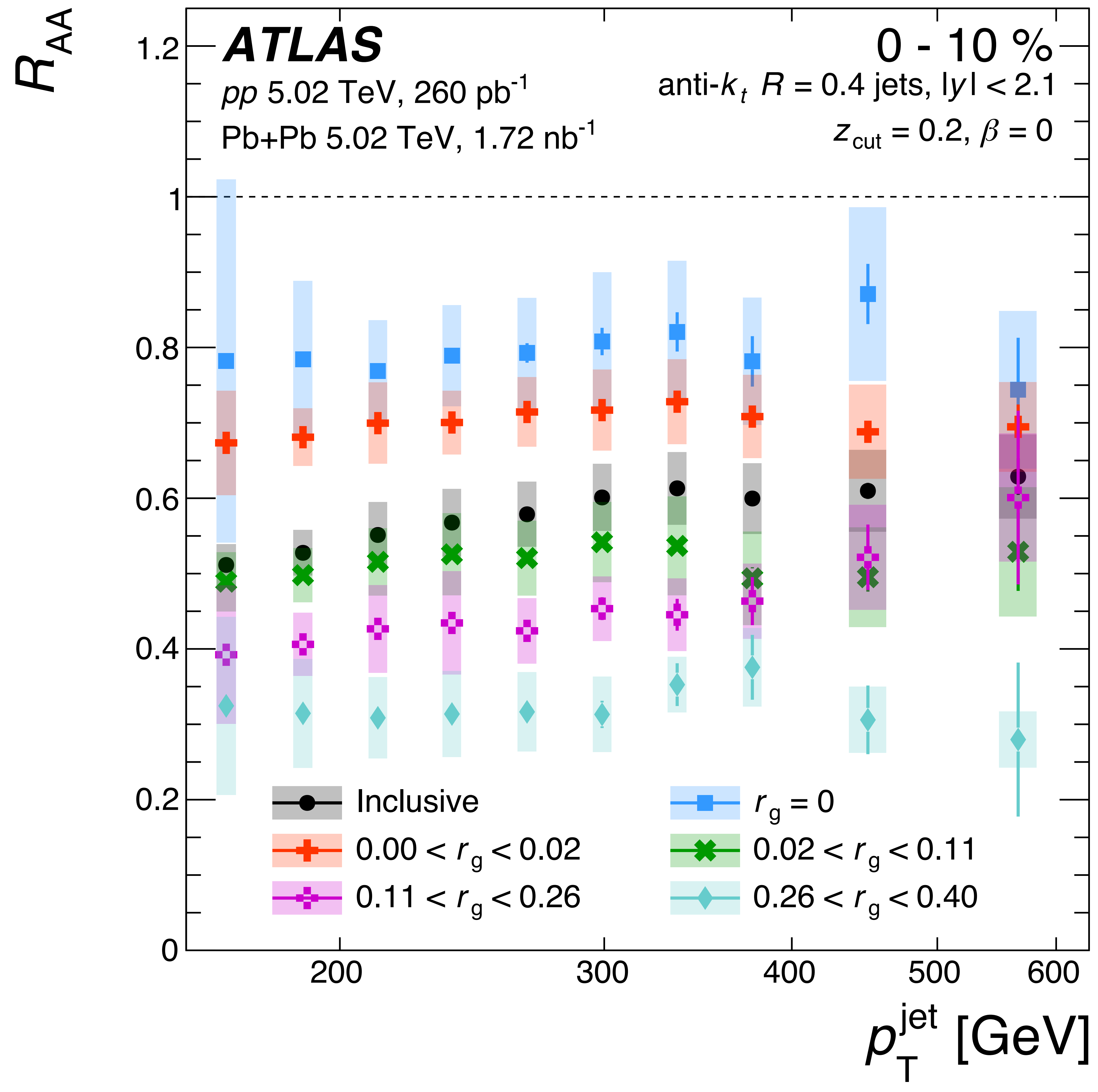




- Decoherence angular scale (**0.1 ~ 0.2**) observed in both de-clustered groomed jets and re-clustered large-R jets: significant larger energy loss above the scale

Jet substructure — cont.

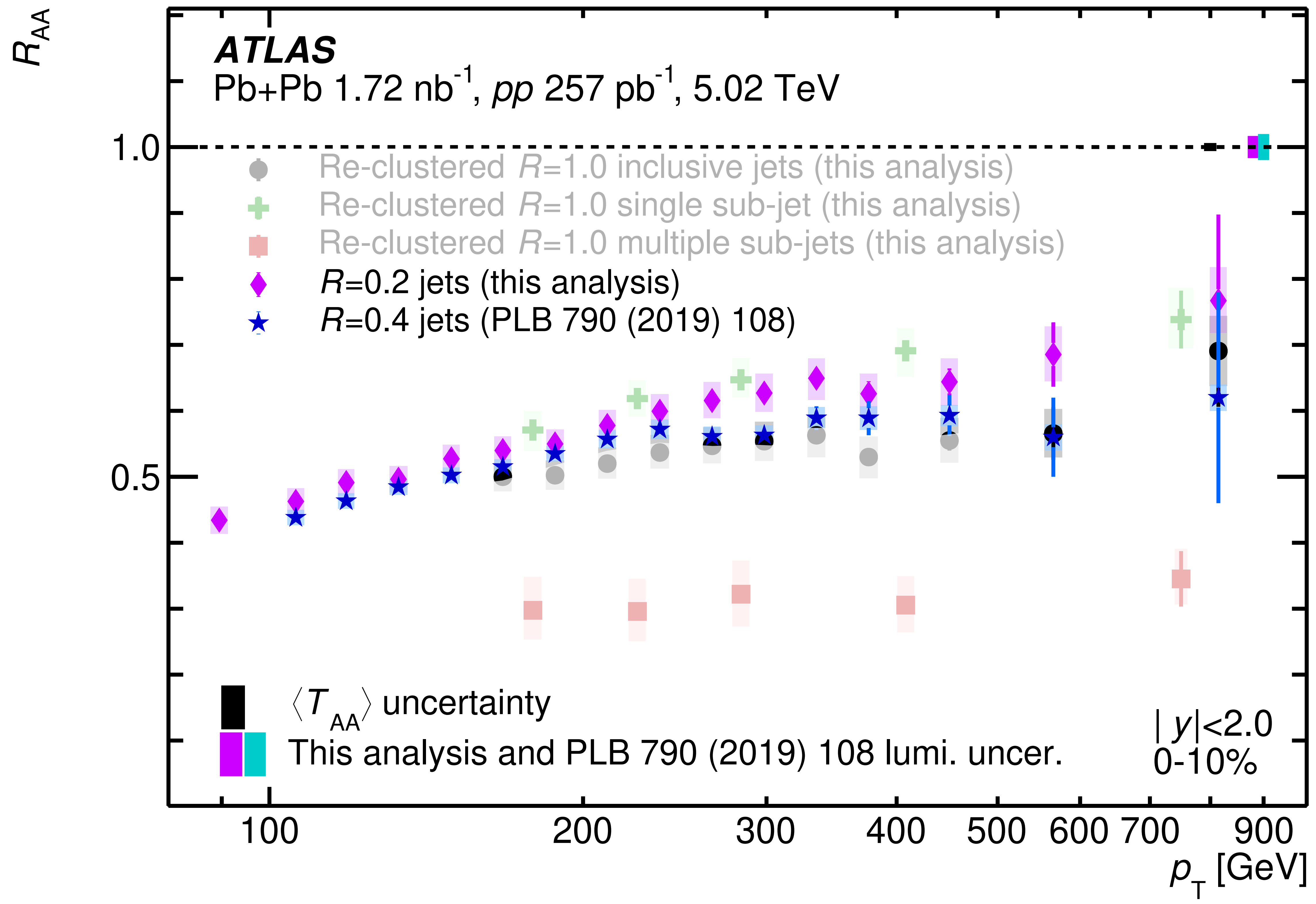
PRL 131 (2023) 172301
PRC 107 (2023) 054909



- Jet energy loss is most directly correlated with the jet substructure not jet p_T

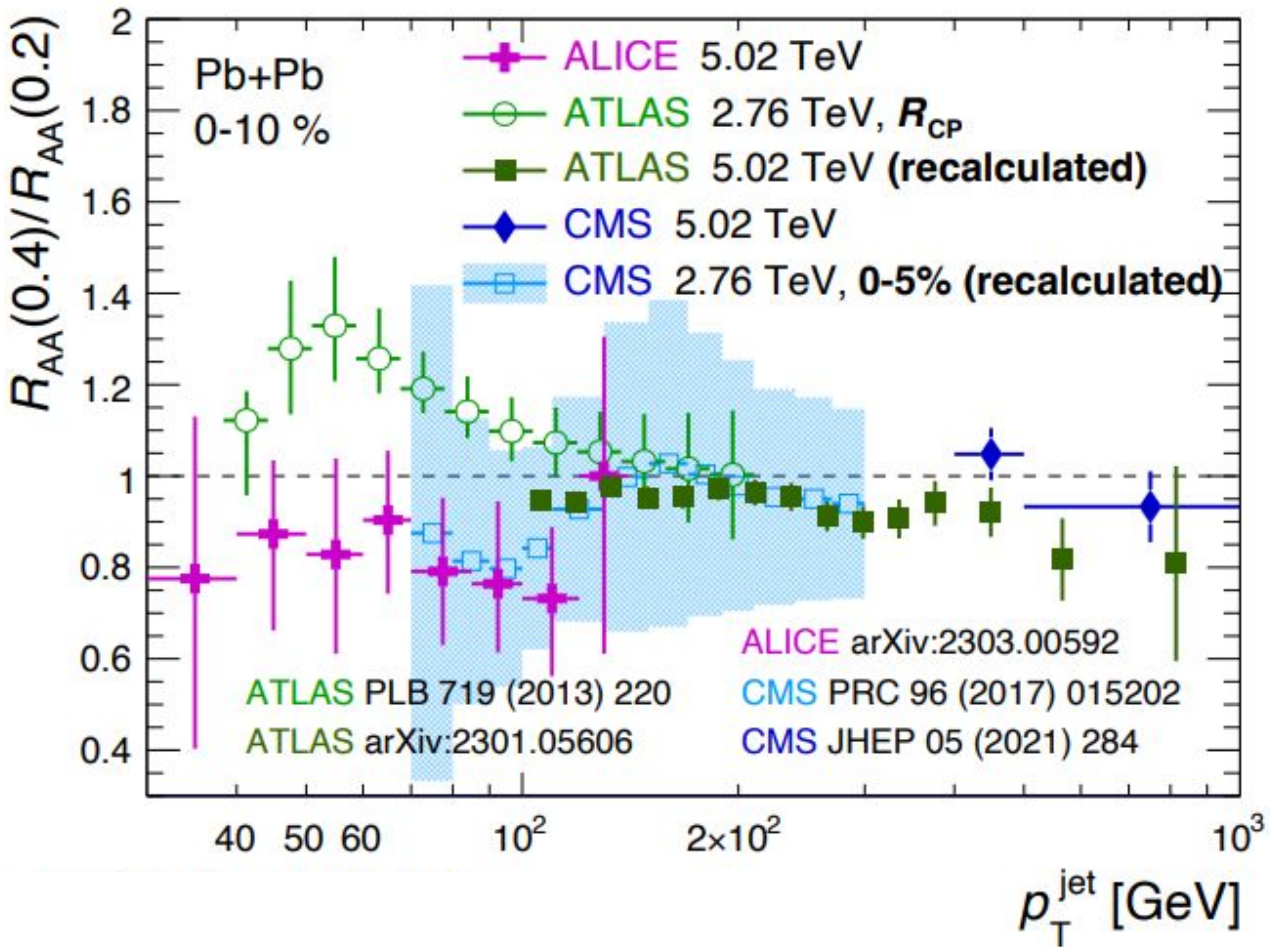
R-dependence of inclusive jet R_{AA}

PRL 131 (2023) 172301



R = 0.2

R = 0.4

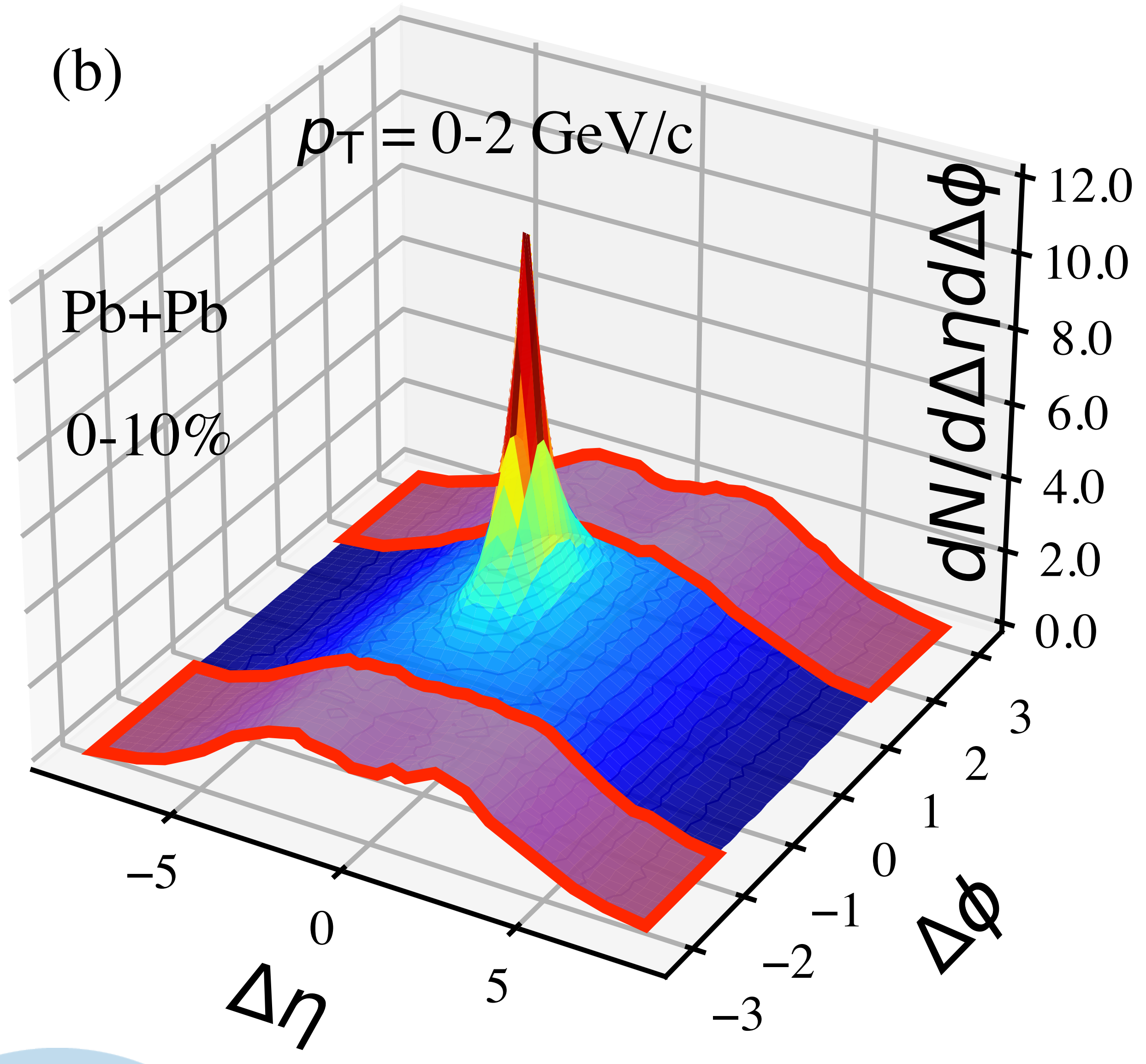


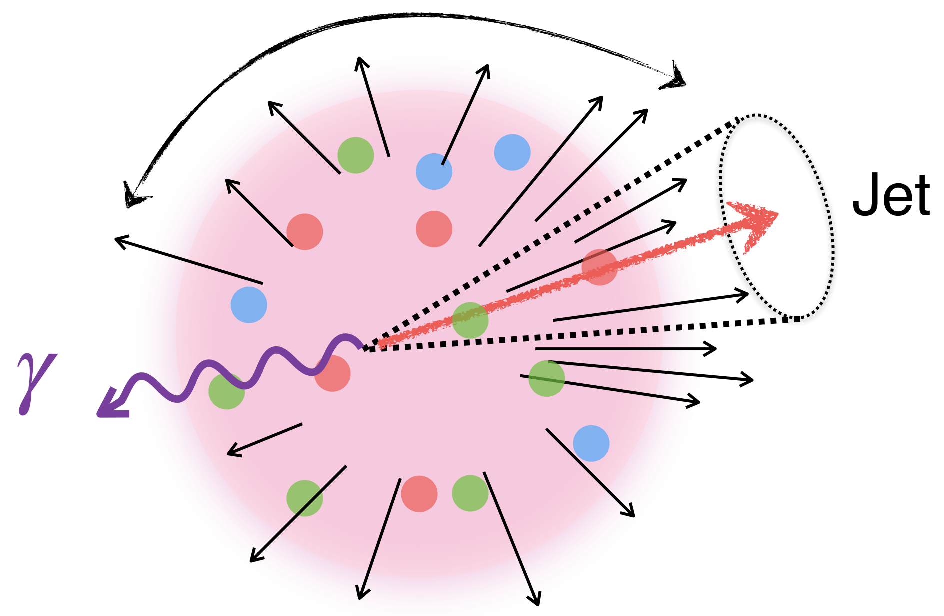
- At $p_T > 100$ GeV, $R = 0.4$ jets are slightly more suppressed than $R = 0.2$ jets, consistency between ATLAS and CMS
- Tension between ATLAS and ALICE at low p_T

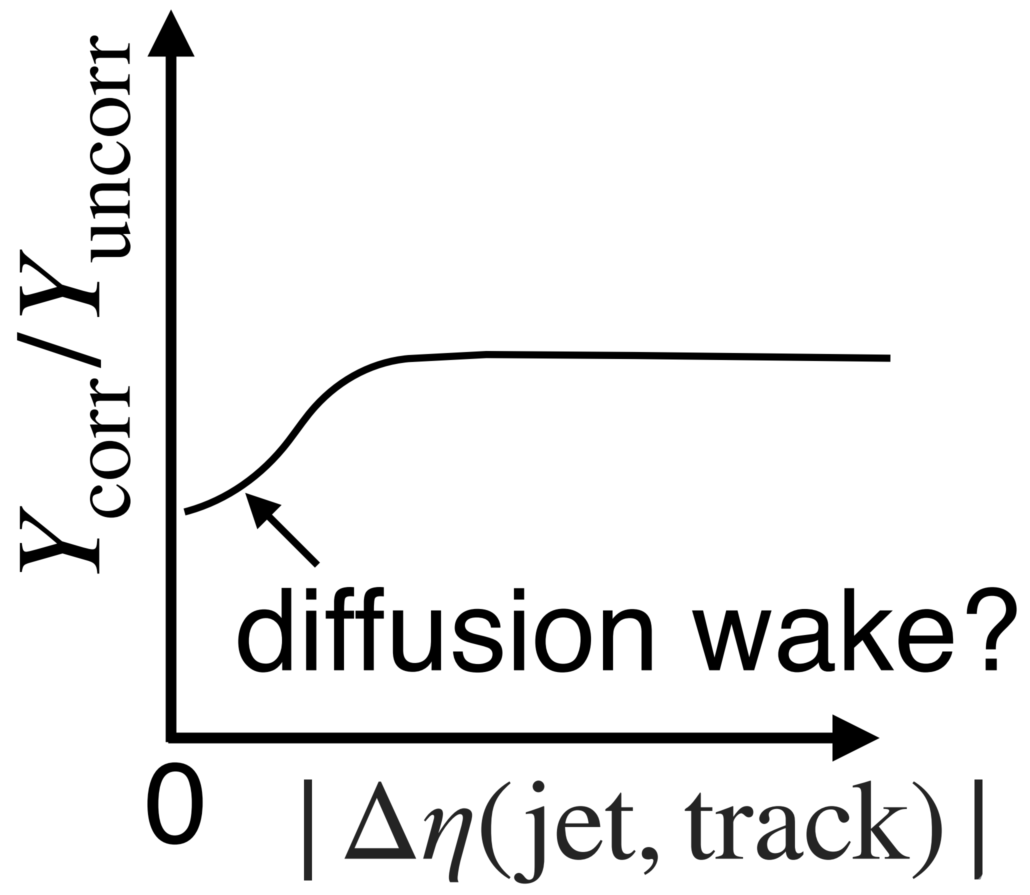
Jet-induced diffusion wake

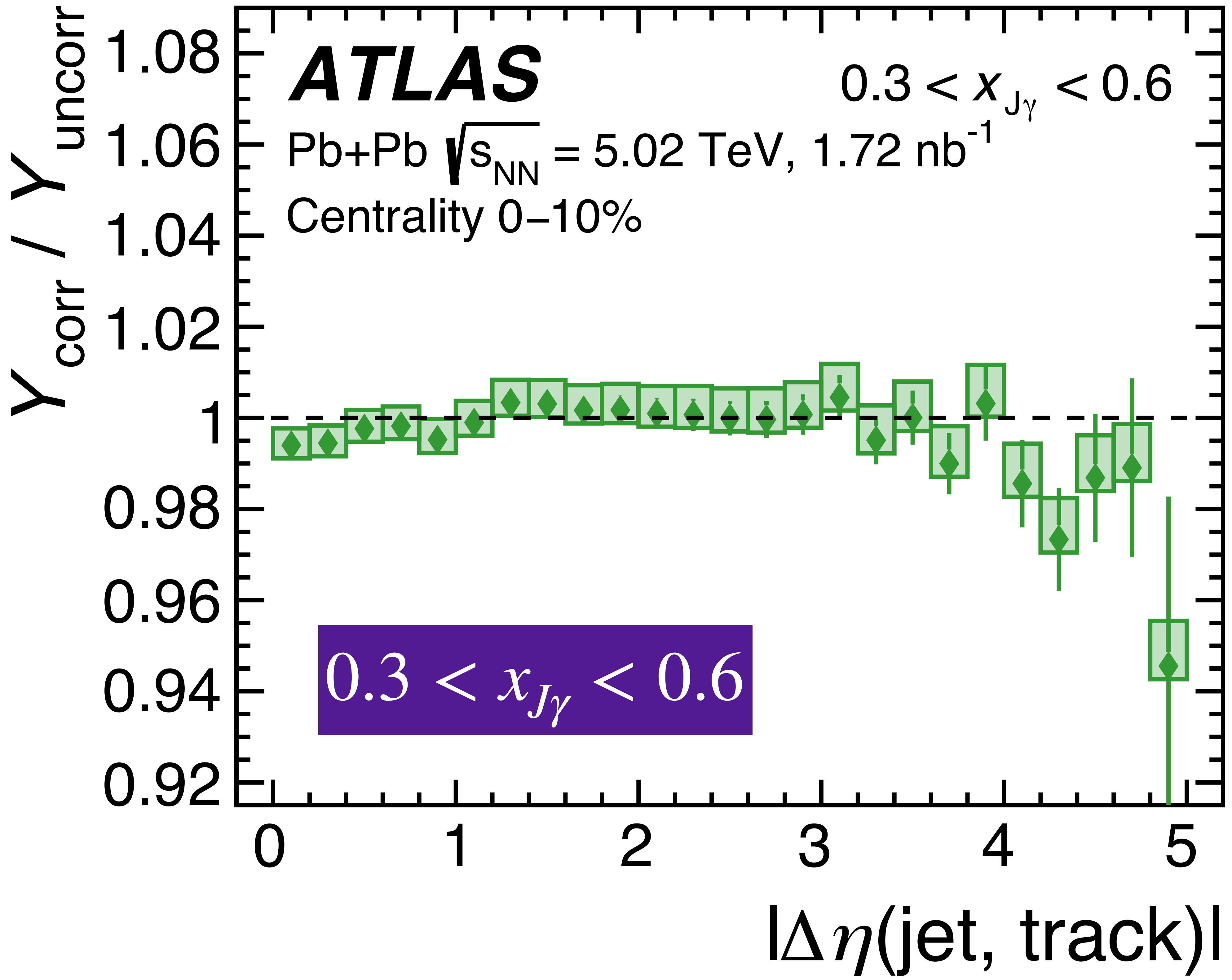
arXiv:2408.08599

Follow proposal of **CoLBT** PRL 130 (2023) 052301 look at photon-jet: depletion in charged particle production opposite to the jet in ϕ





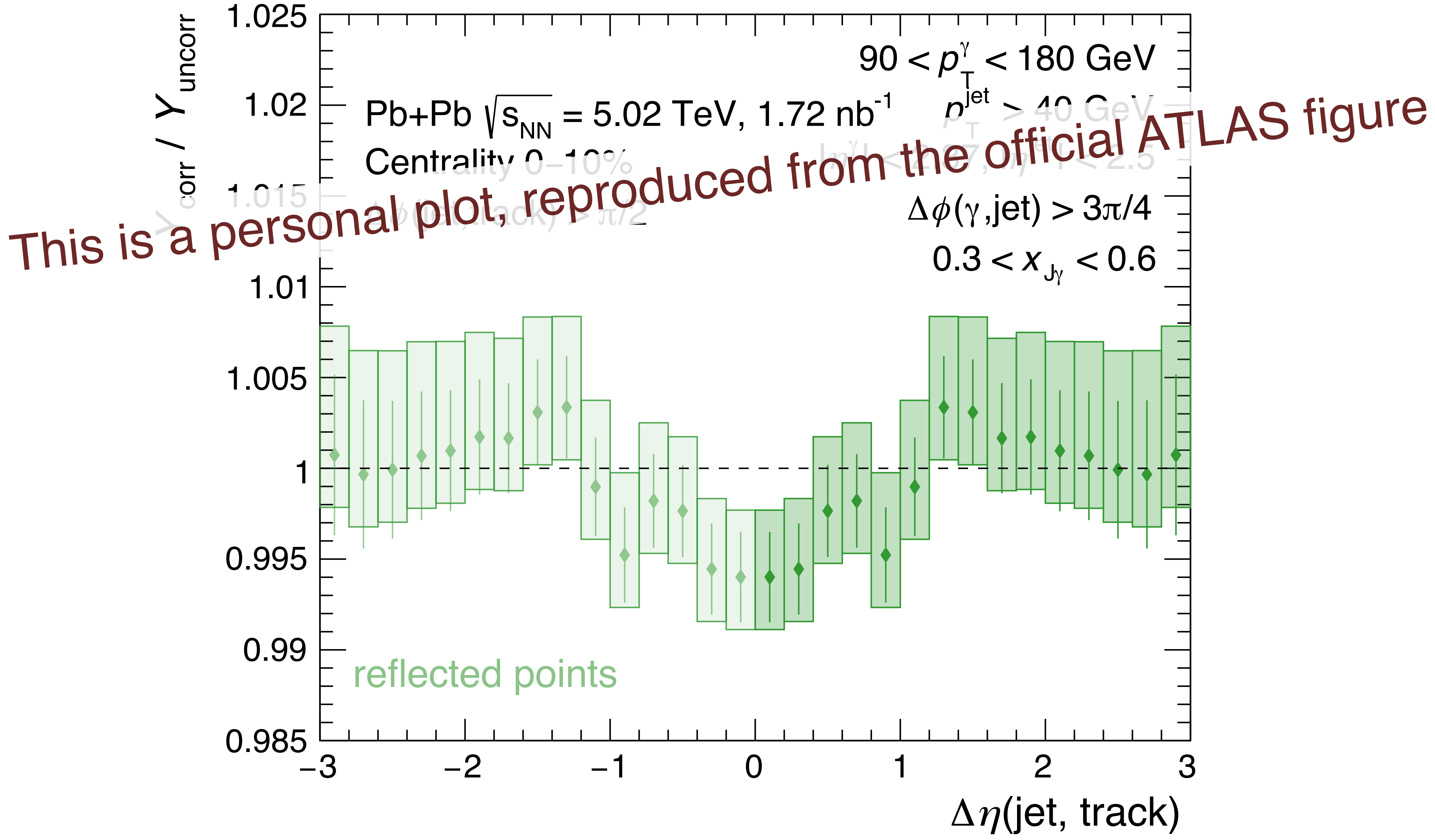


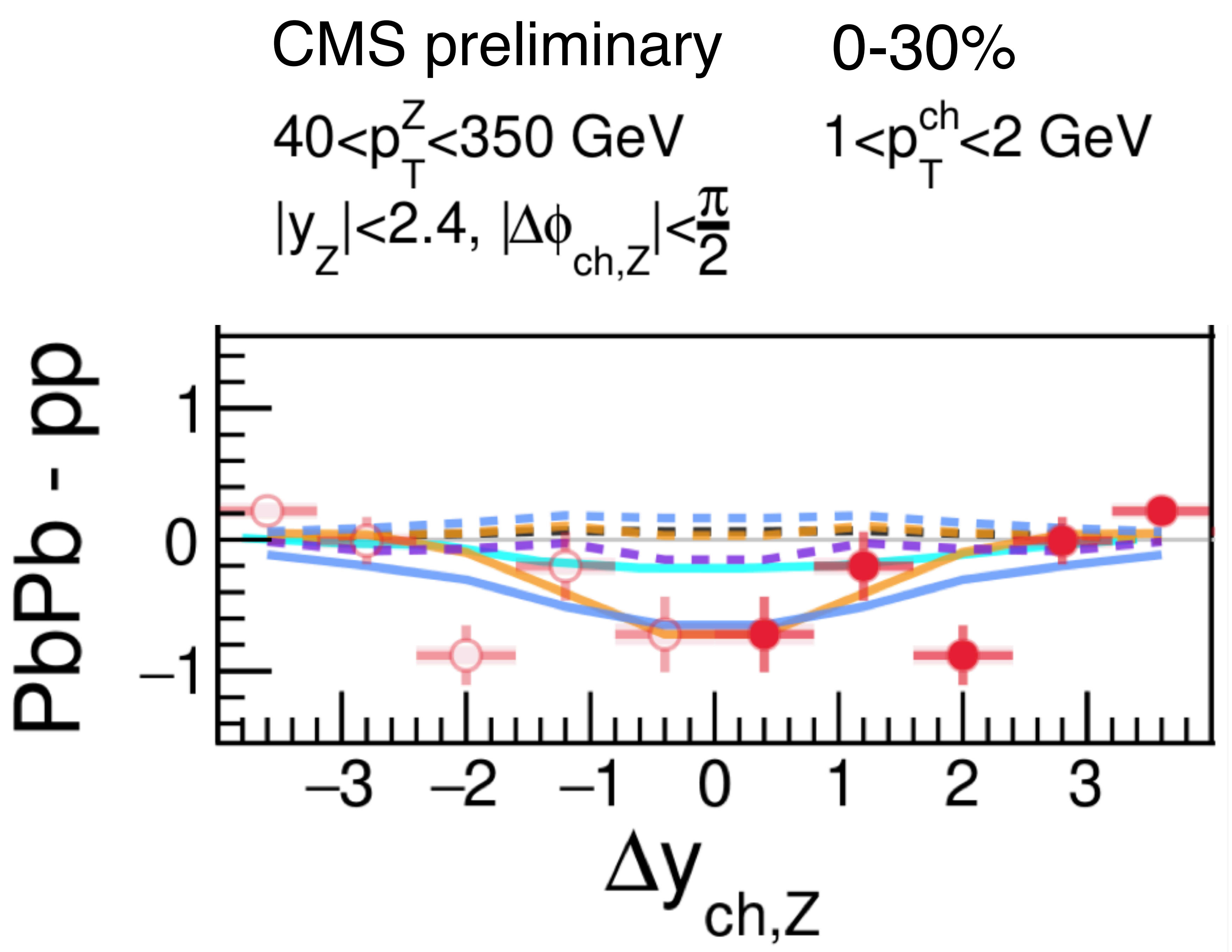


- No significant diffusion wake within the present uncertainties.

Jet-induced diffusion wake — Cont.

arXiv:2408.08599
CMS-PAS-HIN-23-006





- Central value indicates ~0.5% depletion ~ **0.5 particle per unit** reduction due to wake;
- γ+jet sampel contains ~ 20% fragmentation γ
- No obvious inconsistency with CMS Z+jet results

Innovations

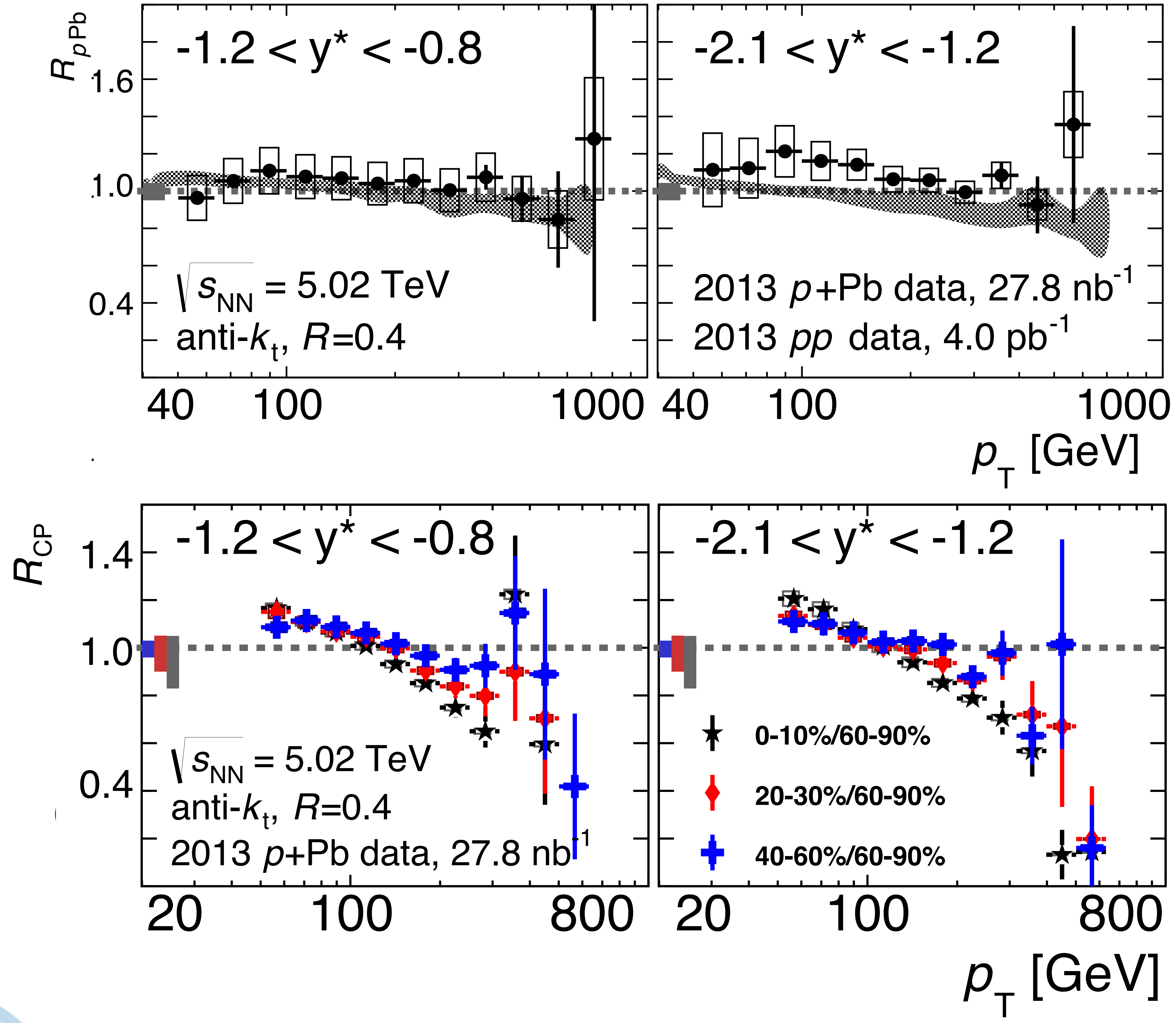
Innovation emerges through dedication and perseverance

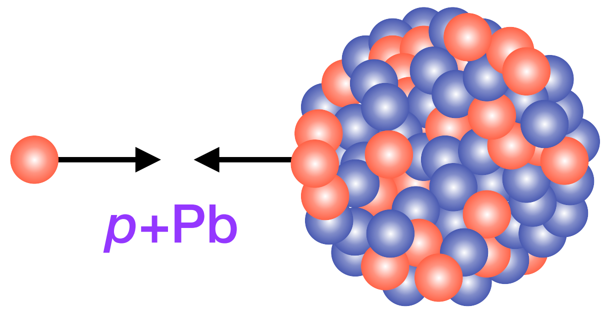
- Enlarge the impact of delivering physics
- Open doors for more sophisticated studies

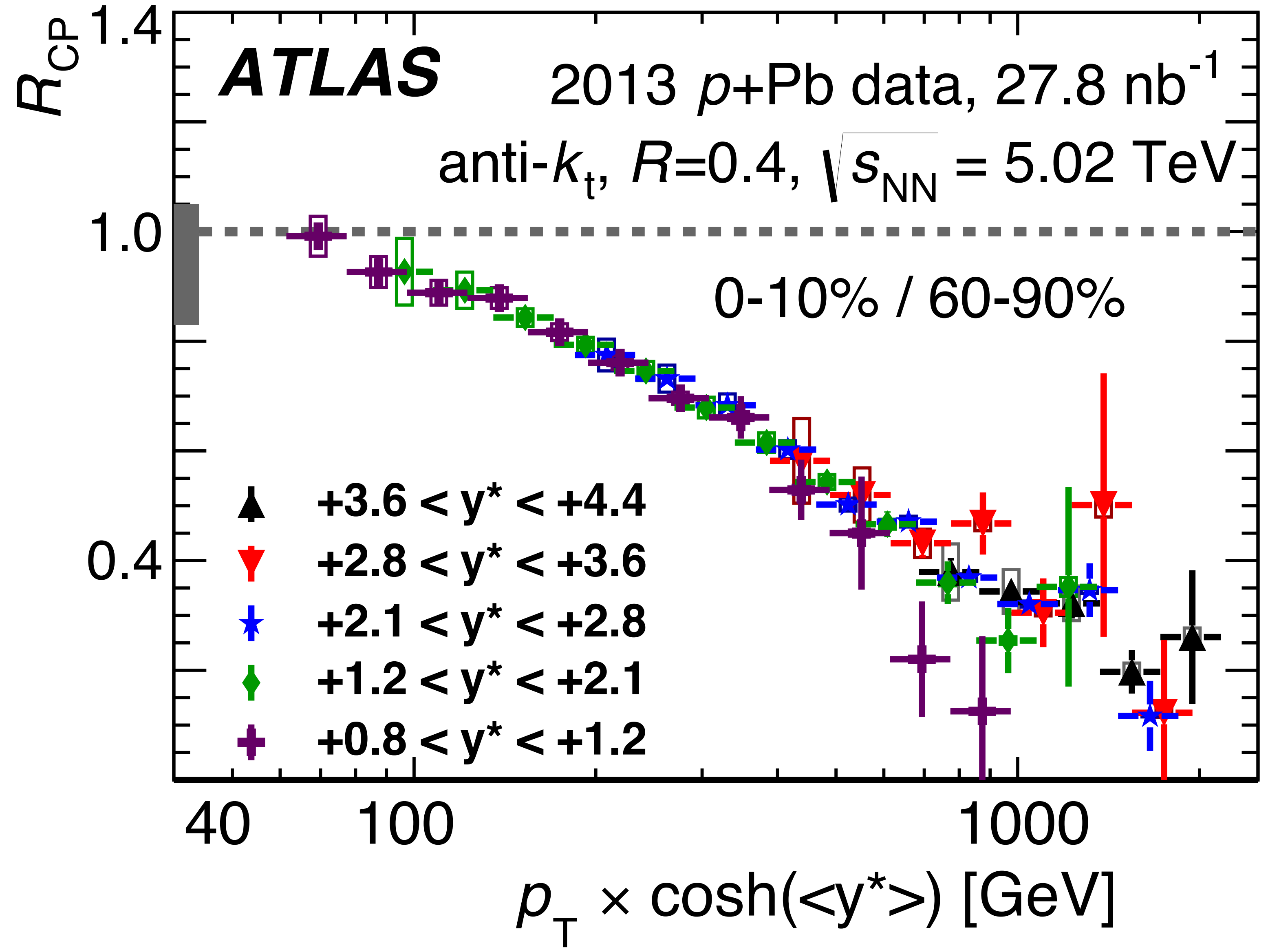
Little parade float by my daughter at age of 3, after seeing Disney Parade

Jet in p+Pb

[PLB 748 (2015) 392](PLB 748 (2015) 392)



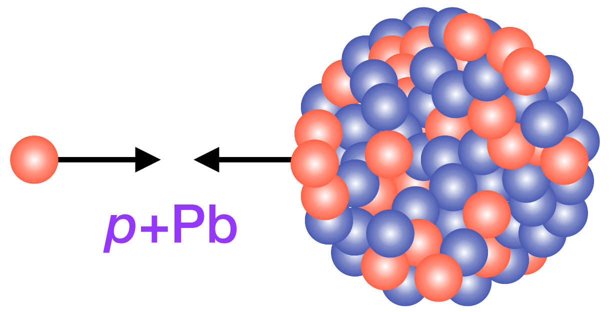




- Run1 ATLAS p+Pb measurements show jet R_{pPb} consistent with unity, while jet R_{CP} decreases with increasing jet p_T and varies with jet rapidity
- Scale with jet energy in proton-going direction indicate the parton kinematics play a key role

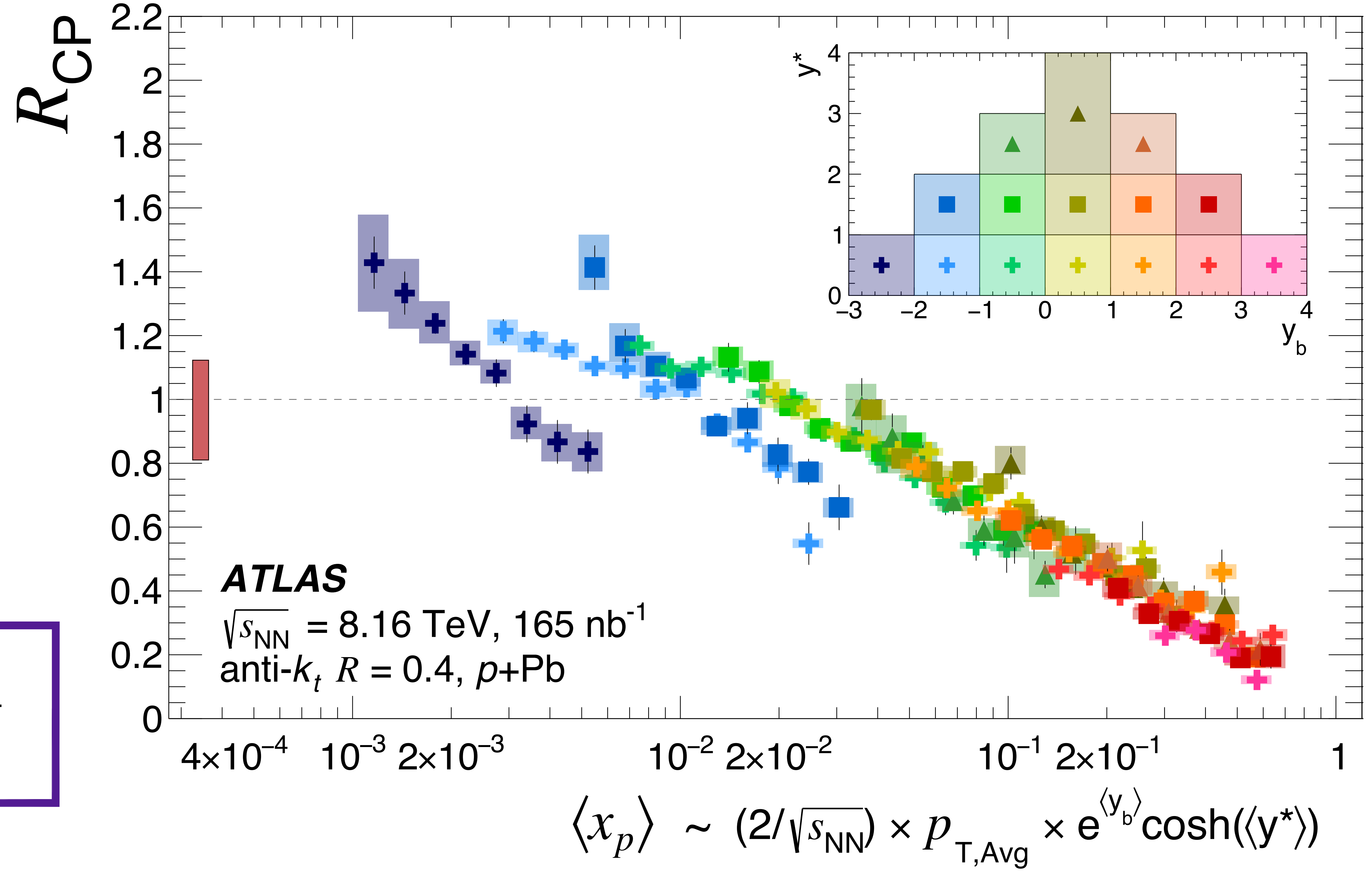
Dijet in p+Pb

PRL 132 (2024) 102301



Dijet events in 8.16 TeV p+Pb data: combined over 20 jet triggers to maximize the kinematic coverage, and performed meticulous jet calibration for improved precision

$$p_{\mathrm{T,Avg}} = \frac{p_{\mathrm{T},1} + p_{\mathrm{T},2}}{2}, \quad y_{\mathrm{b}} = \frac{y_1^{\mathrm{c.m.}} + y_2^{\mathrm{c.m.}}}{2}, \quad \text{and} \quad y^* = \frac{|y_1^{\mathrm{c.m.}} - y_2^{\mathrm{c.m.}}|}{2}$$

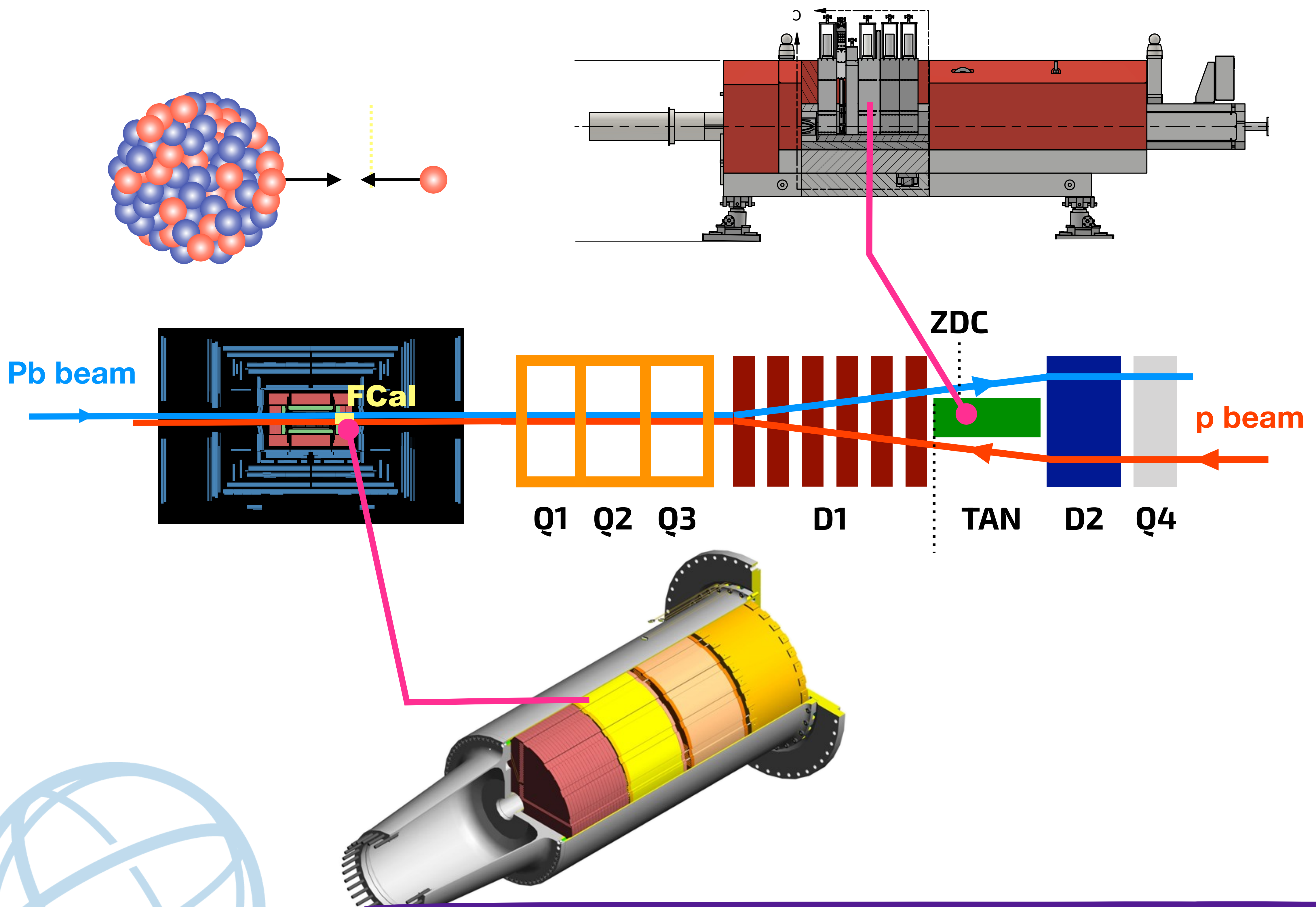


- Striking log-linear dependence of jet R_{CP} on x_{p}
- $R_{\mathrm{CP}}(x_{\mathrm{p}})$ is qualitatively described by the color fluctuations: smaller than average interaction strength at large x_{p}

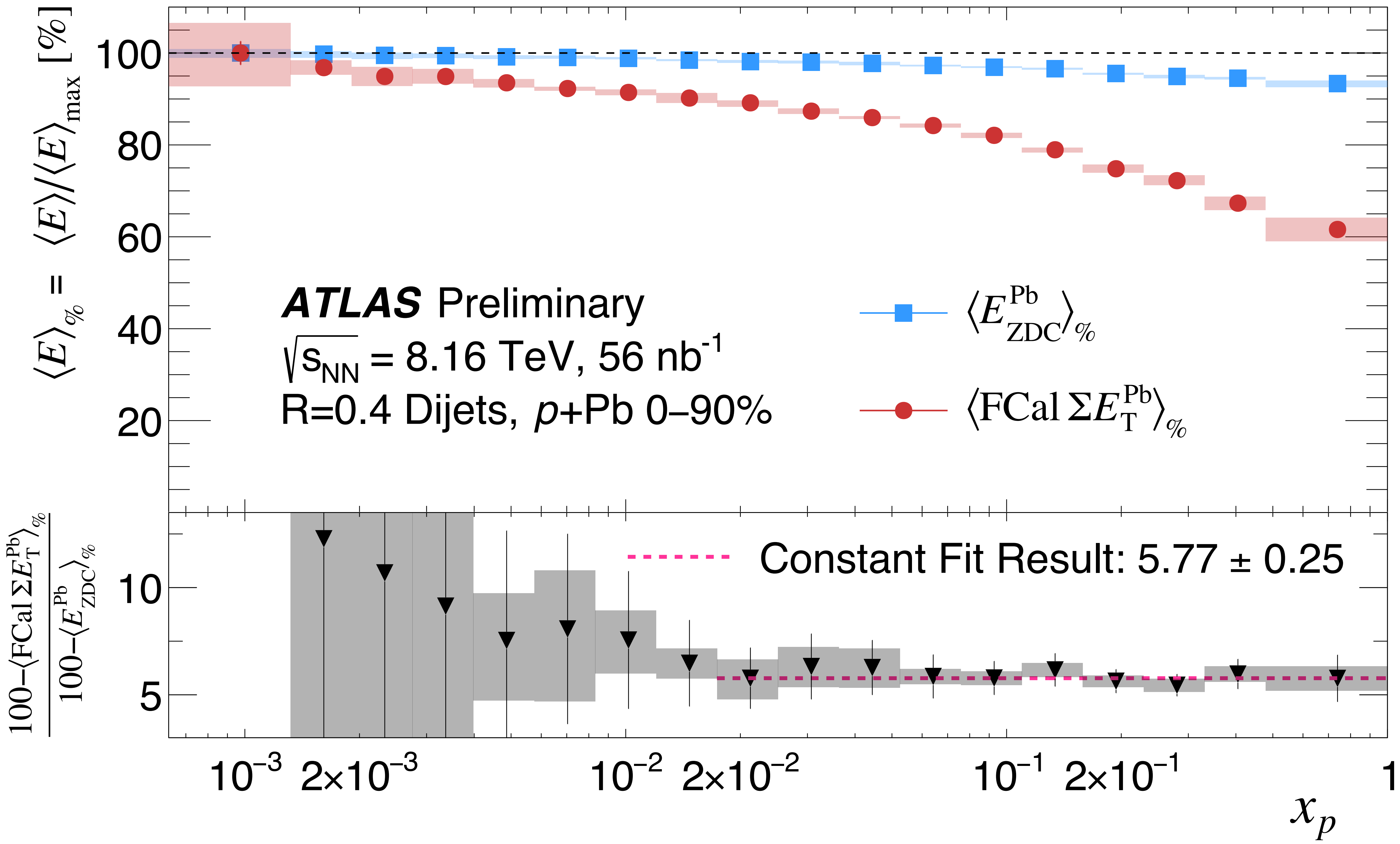
UE vs. nuclear break-ups in p+Pb

ATLAS-CONF-2024-013

Zero-Degree Calorimeter (ZDC)
$\eta > 8.3$, break-up neutrons from nucleus



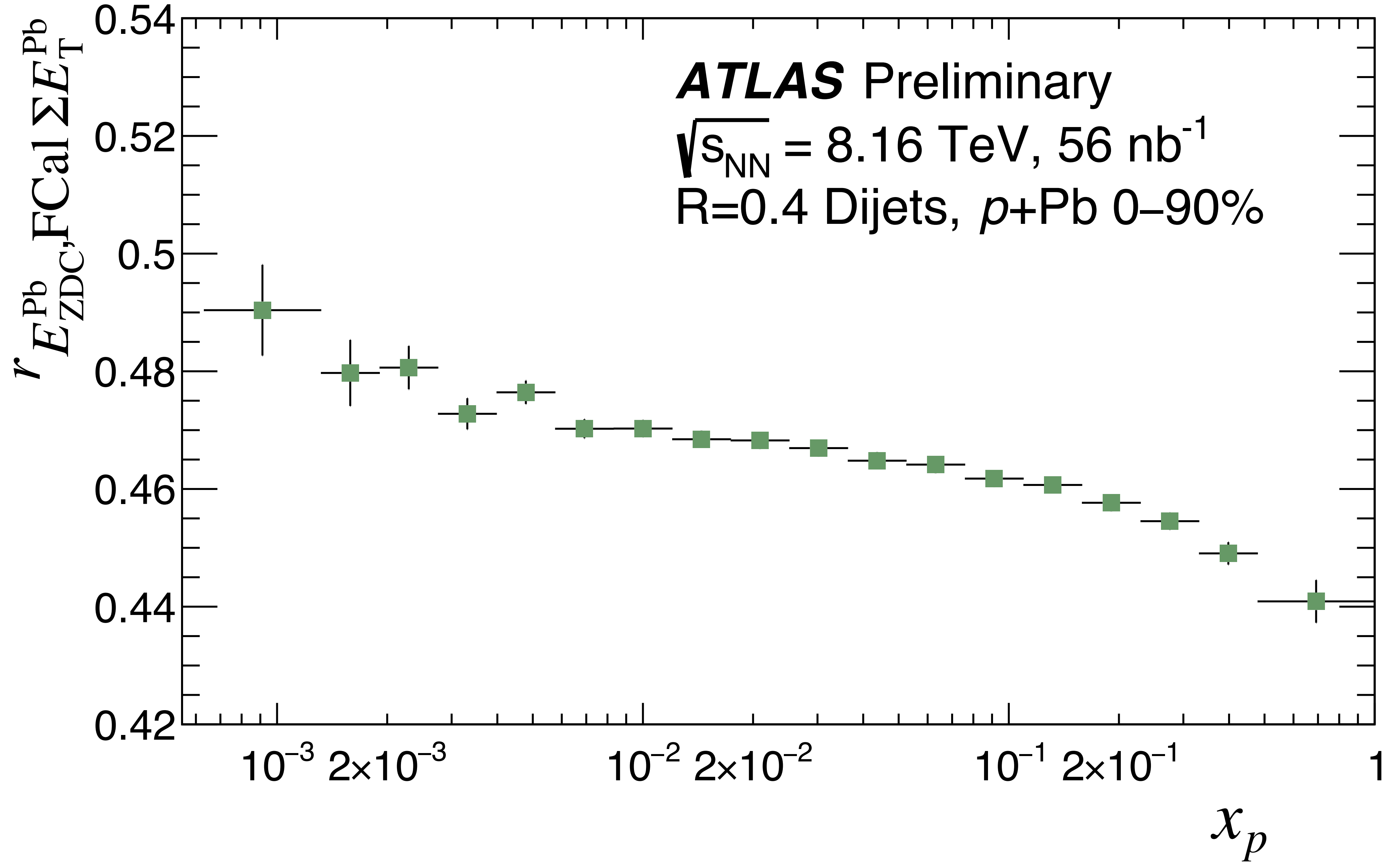
Forward Calorimeter (FCal)
$3.2 < \eta < 4.9$, underlying events activity

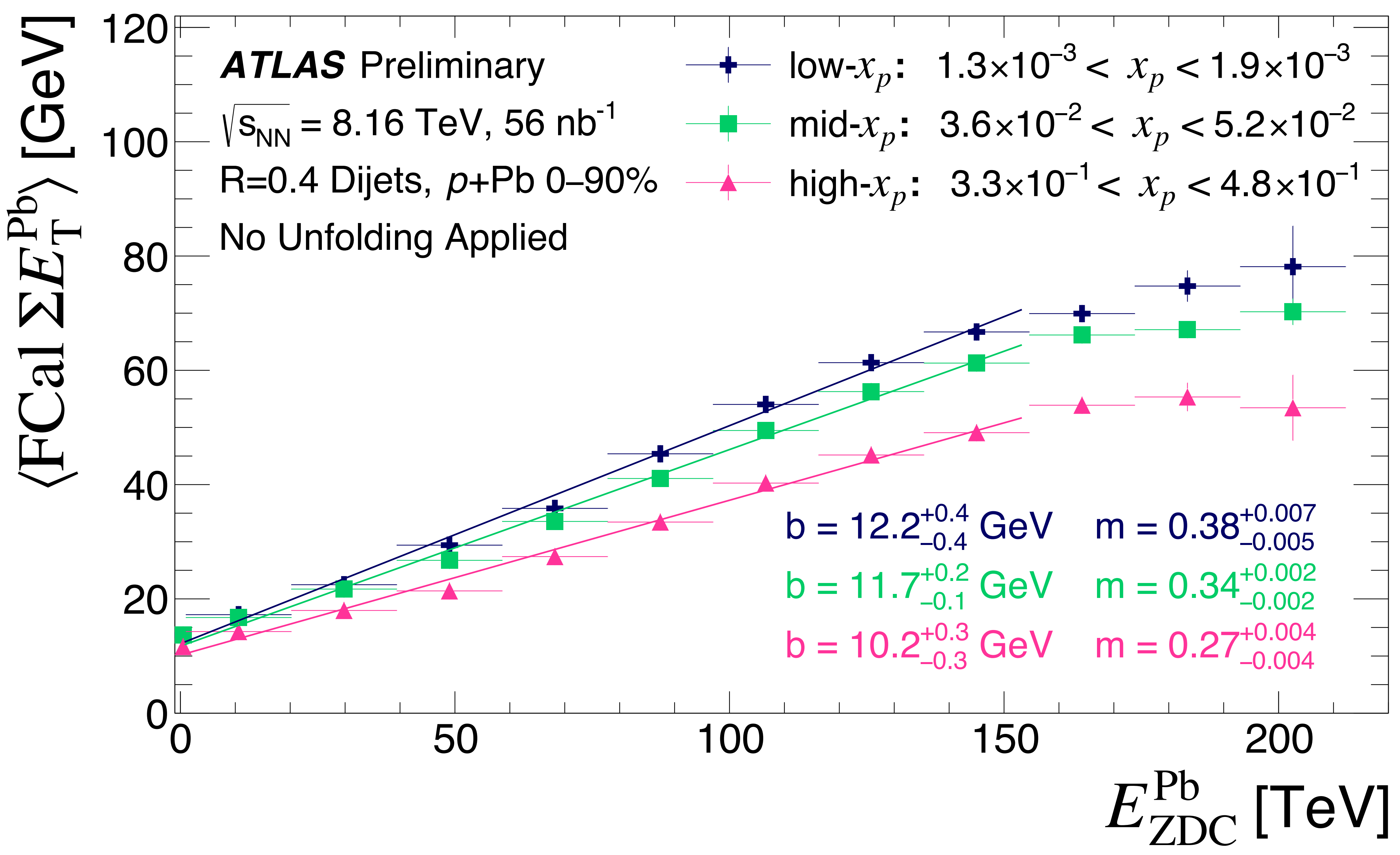


- Decreasing UE energy and break-up neutrons with increasing x_p
- UE is more sensitive to the change in x_p

UE vs. nuclear break-ups in p+Pb — Cont.

ATLAS-CONF-2024-013

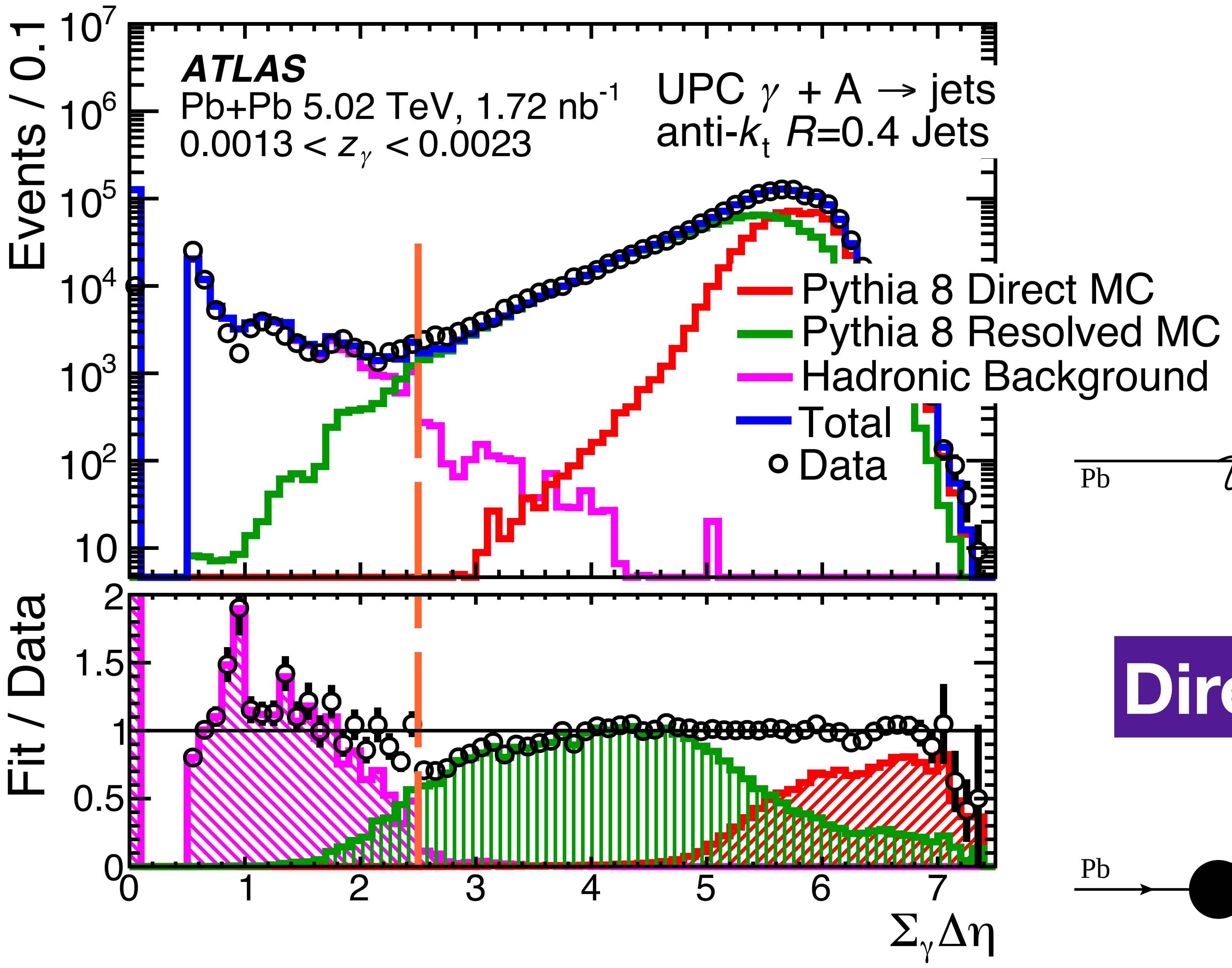




- Correlation between UE energy and break-up neutrons becomes weaker with increasing x_p
- Scaling of UE energy and break-up neutrons at low ZDC energy, fluctuation of break-ups when UE energy saturated
- Offer a new approach to exploring hard-scattering biases in UE based centrality classifications and biases in modeling nuclear break-ups

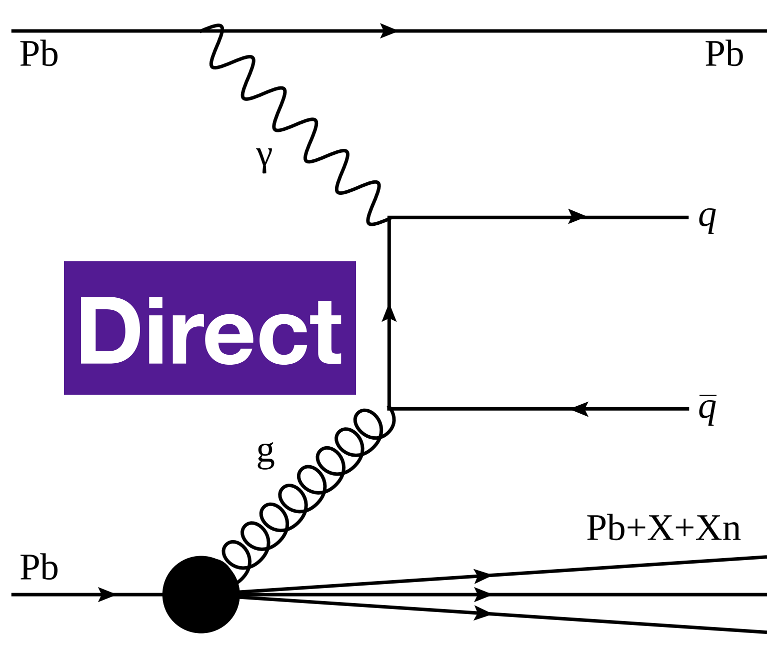
Photonuclear jets

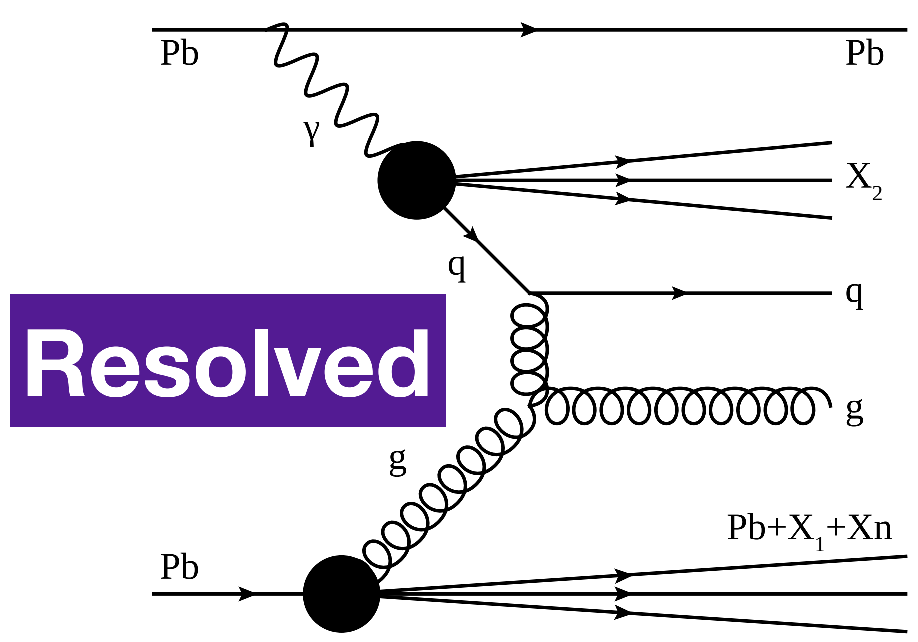
arXiv:2409.11060

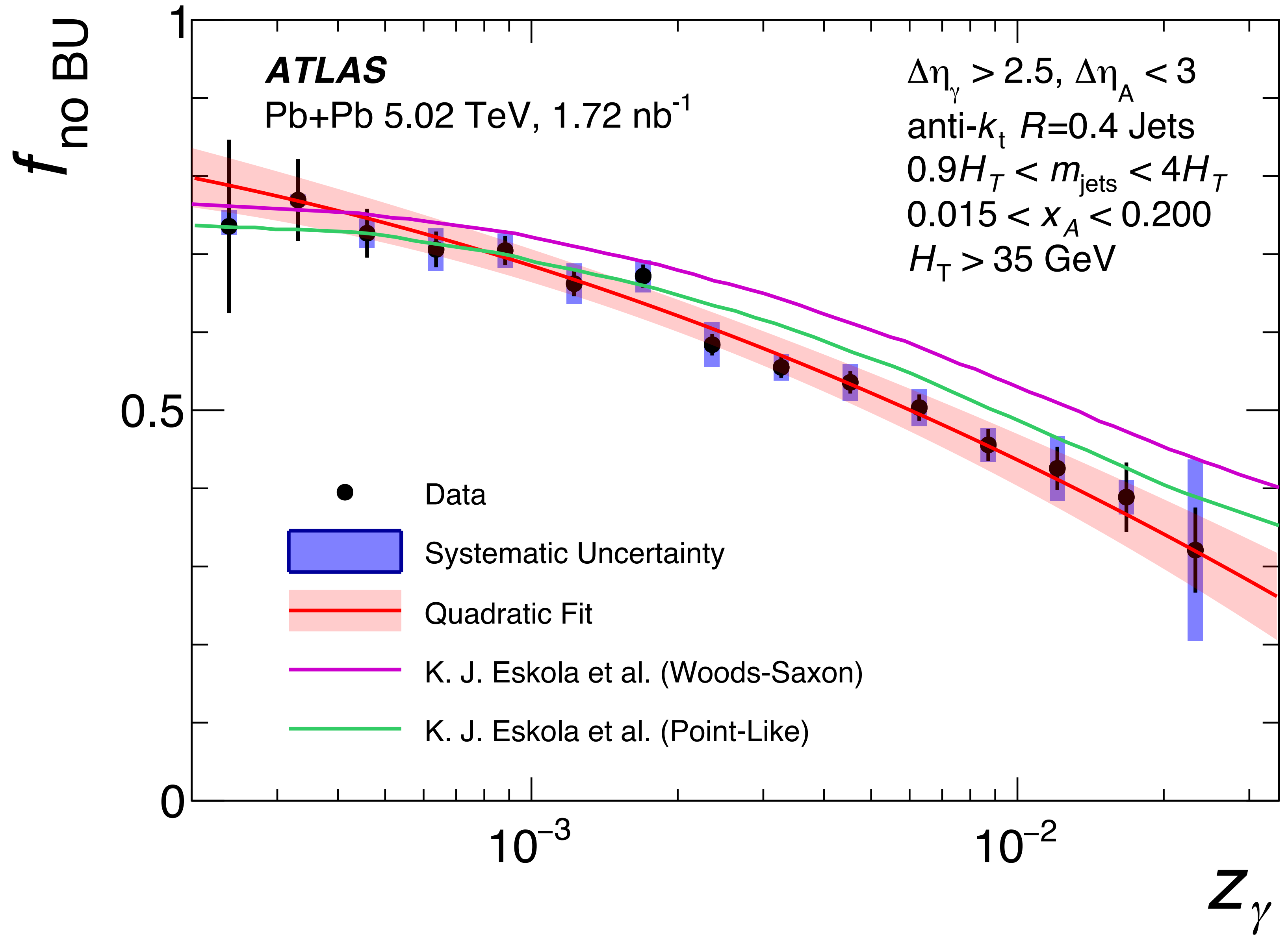


Collected photonuclear events:

- Direct γ+Pb
- Resolved γ+Pb
- Peripheral Pb+Pb





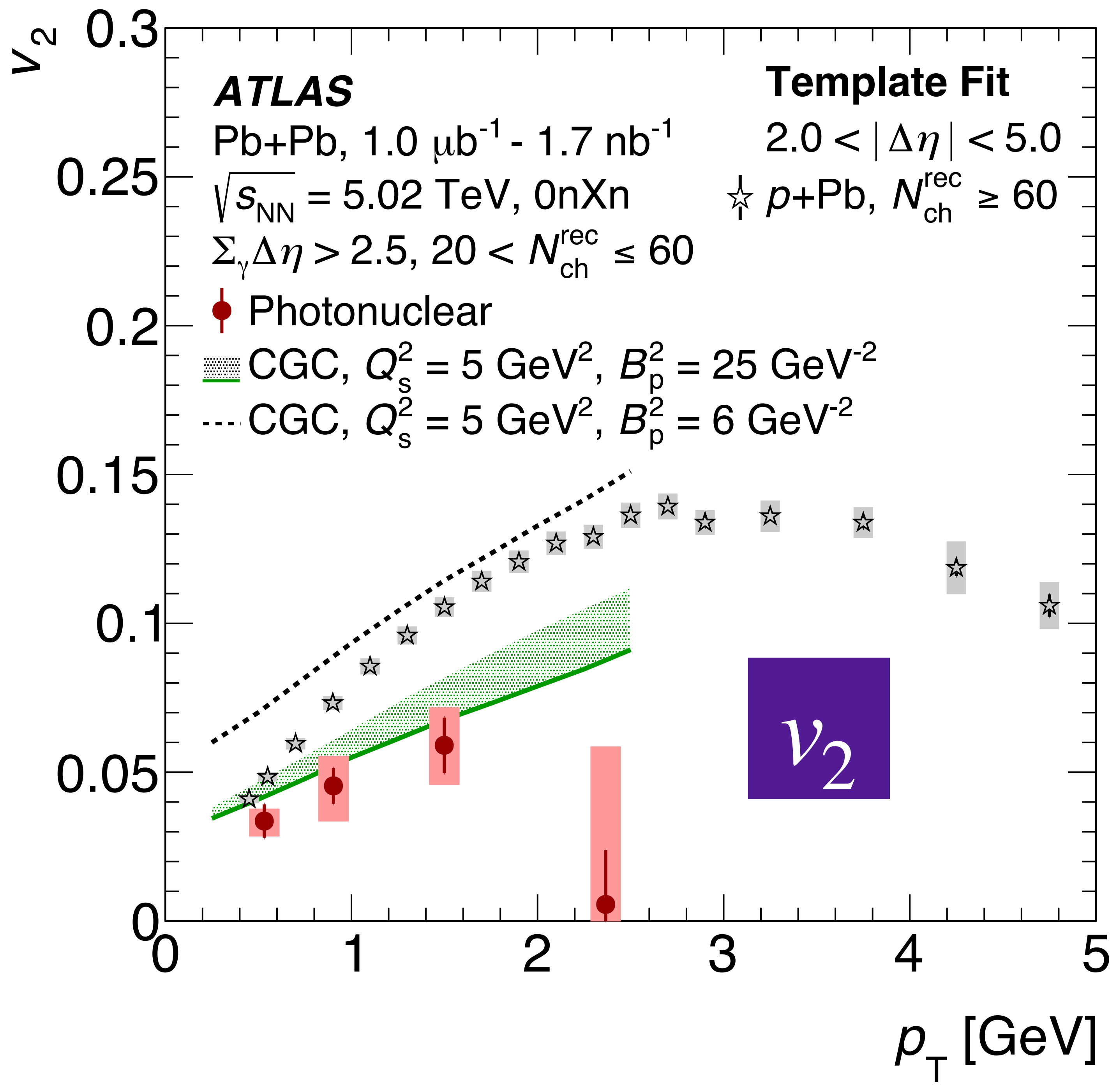


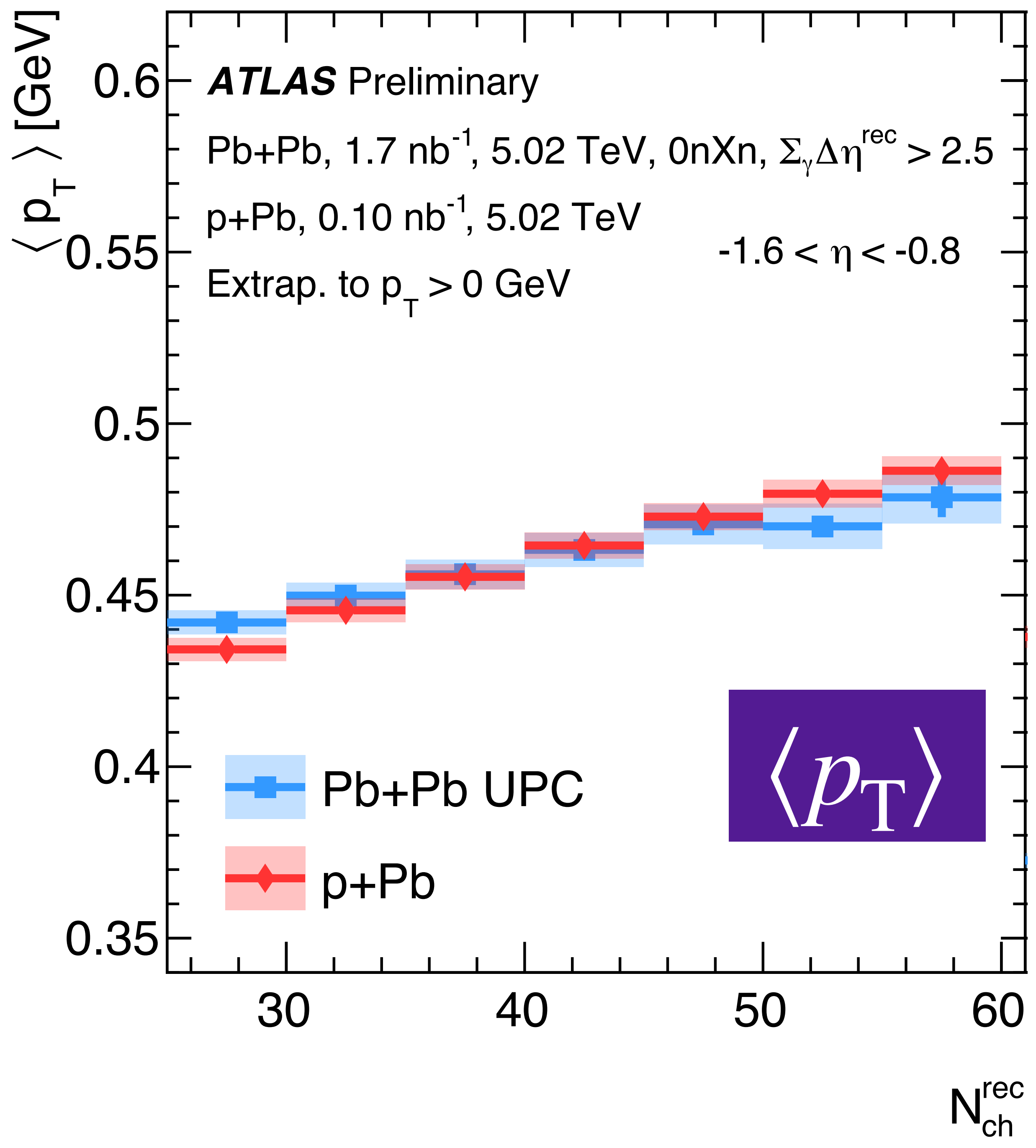
After years of dedicated efforts, we have a better understanding of photonuclear UPCs with jets:

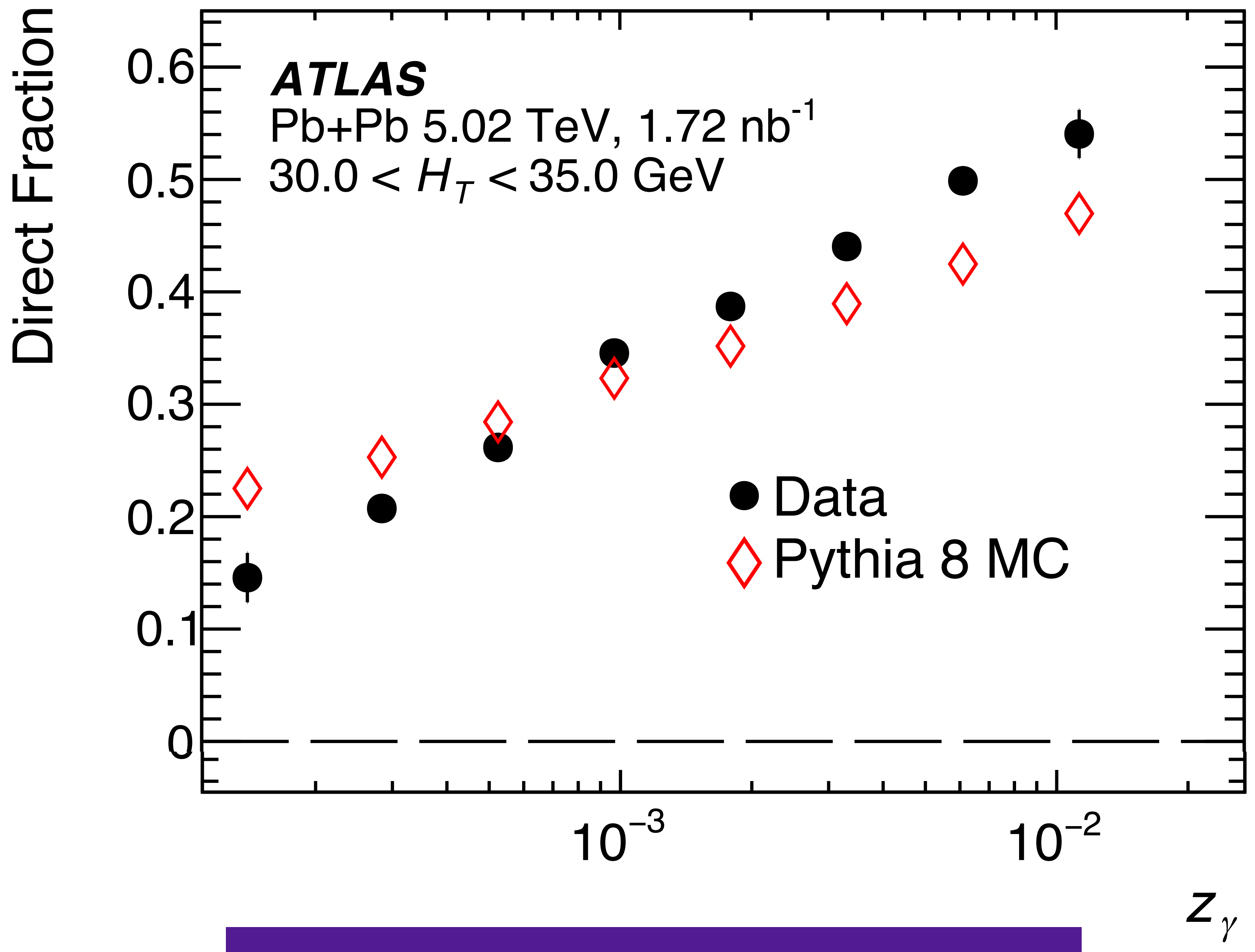
- Achieved well-modeled rapidity gaps that allows us to separate direct from resolved
- Measured break-up corrections to enable direct model comparison
- Extended p-flow jet p_T down to 15 GeV while keep control over systematic

Photonuclear jets - isolate direct γ+Pb

PRC 104 (2021) 014903
ATLAS-CONF-2023-059







$v_2\ (p+\text{Pb}) > v_2\ (\gamma+\text{Pb})$

$\langle p_T \rangle\ (\gamma+\text{Pb}) \approx \langle p_T \rangle\ (p+\text{Pb})$

Direct fraction from the photonuclear jet analysis

- Could be understood as different longitudinal decorrelation and similar radial flow in the hydro picture (Zhao et al PRL 129 (2022) 252302)
- However, direct and resolved processes should be studied separately and it becomes possible

Photonuclear jets - constrain nPDF effects

arXiv:2409.11060

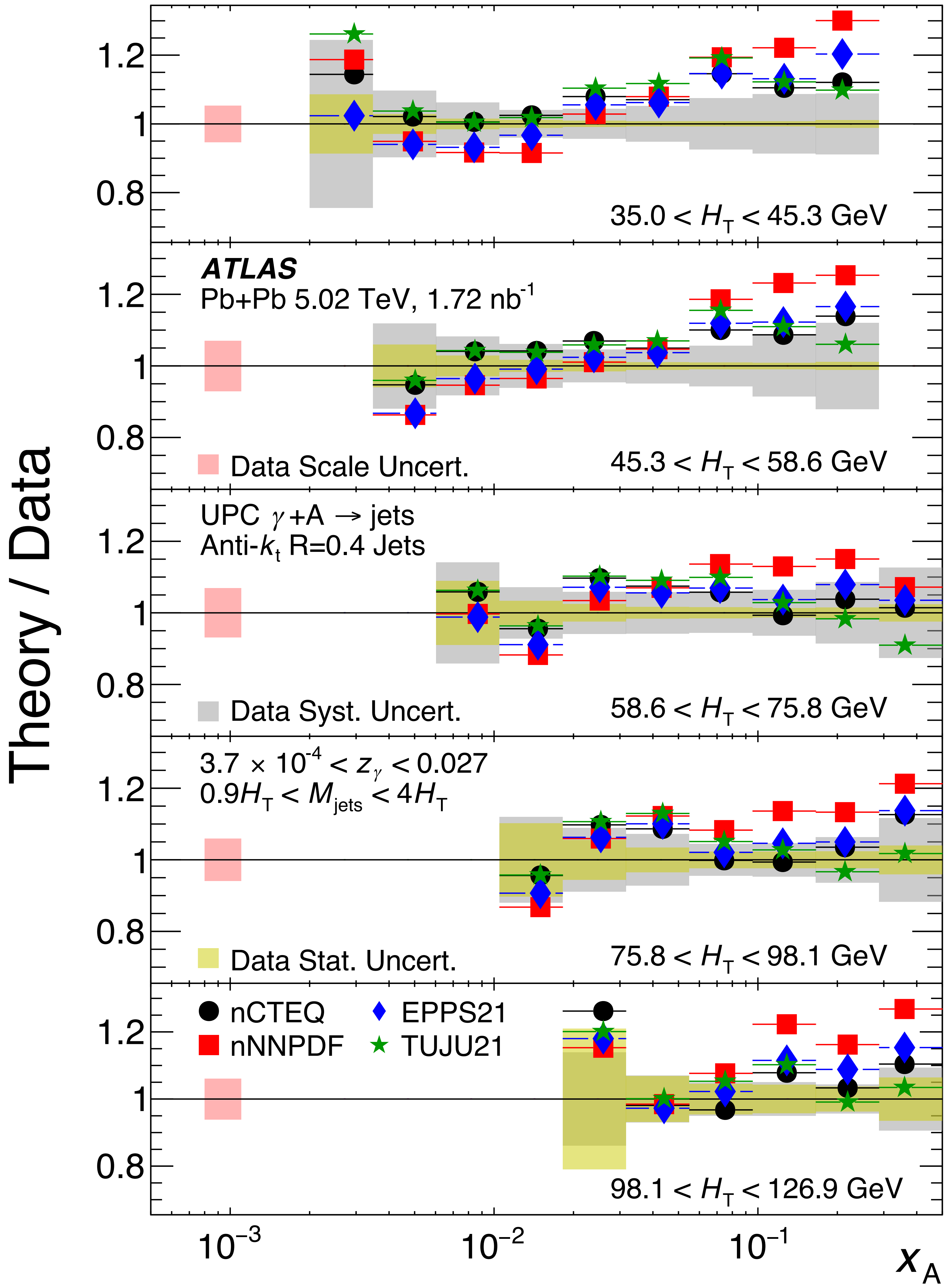
$$H_{\mathrm{T}} \equiv \sum_i p_{\mathrm{T}\,i}$$

$$x_{\mathrm{A}} \equiv \frac{m_{\mathrm{jets}}}{\sqrt{s_{\mathrm{NN}}}} e^{-y_{\mathrm{jets}}}$$

$$z_{\gamma} \equiv \frac{m_{\mathrm{jets}}}{\sqrt{s_{\mathrm{NN}}}} e^{+y_{\mathrm{jets}}}$$

$$m_{\mathrm{jets}} \equiv \left[\left(\sum_i E_i \right)^2 - \left| \sum_i \vec{p}_i \right|^2 \right]^{1/2}$$

$$y_{\mathrm{jets}} \equiv \frac{1}{2} \ln \left(\frac{\sum_i E_i + \sum_i p^*_{z\,i}}{\sum_i E_i - \sum_i p^*_{z\,i}} \right)$$



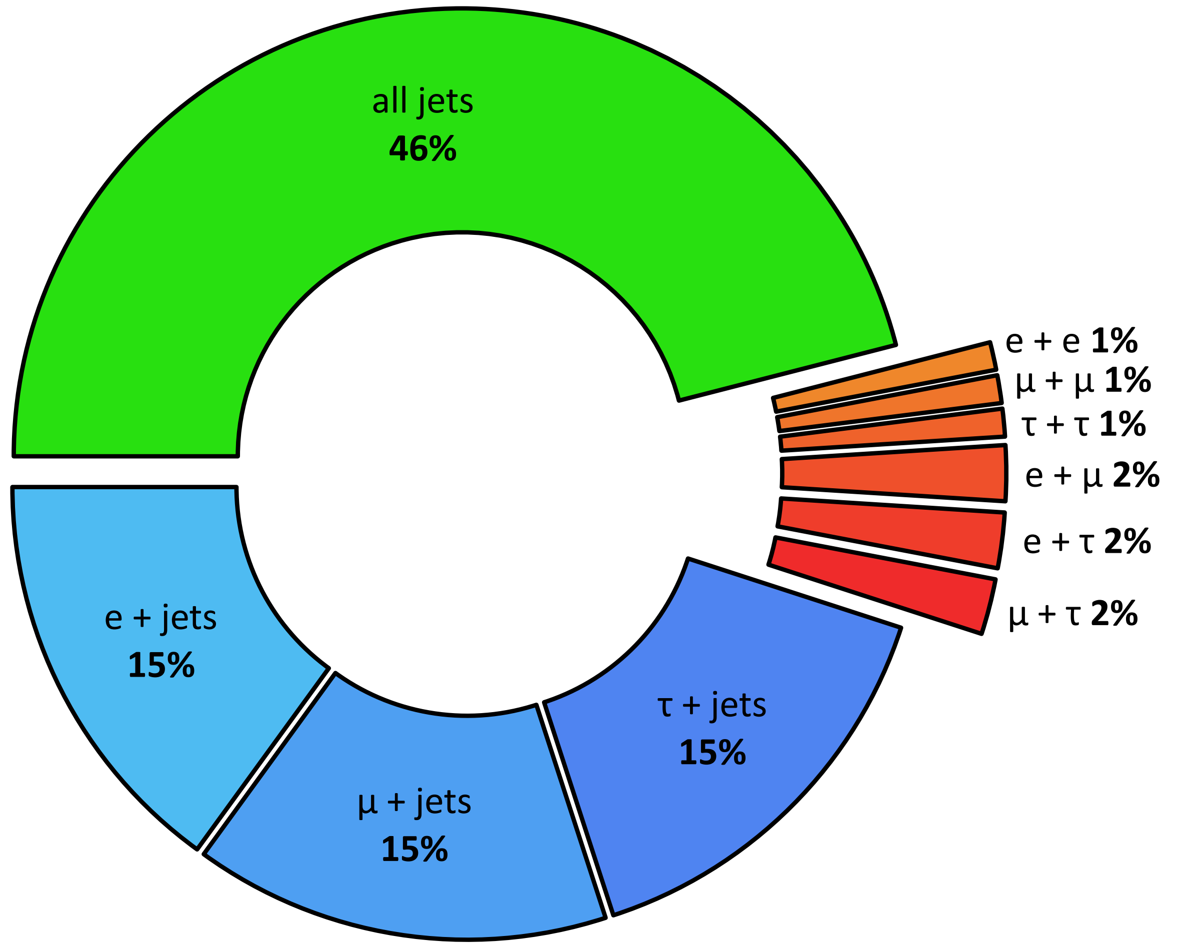
Ratio between measured precise 3D cross-sections and predictions with different nPDF fits, while uncertainties of the photon flux not included:

- **nCTEQ**15 WZ+SIH
- **nNNPDF**3.0
- **EPPS**21
- **TUJU**21

- nCTEQ results typically agree best. At higher H_{T}, the data typically agree well with TUJU
- nNNPDF overpredicts the cross sections at high H_{T} and x_{A}

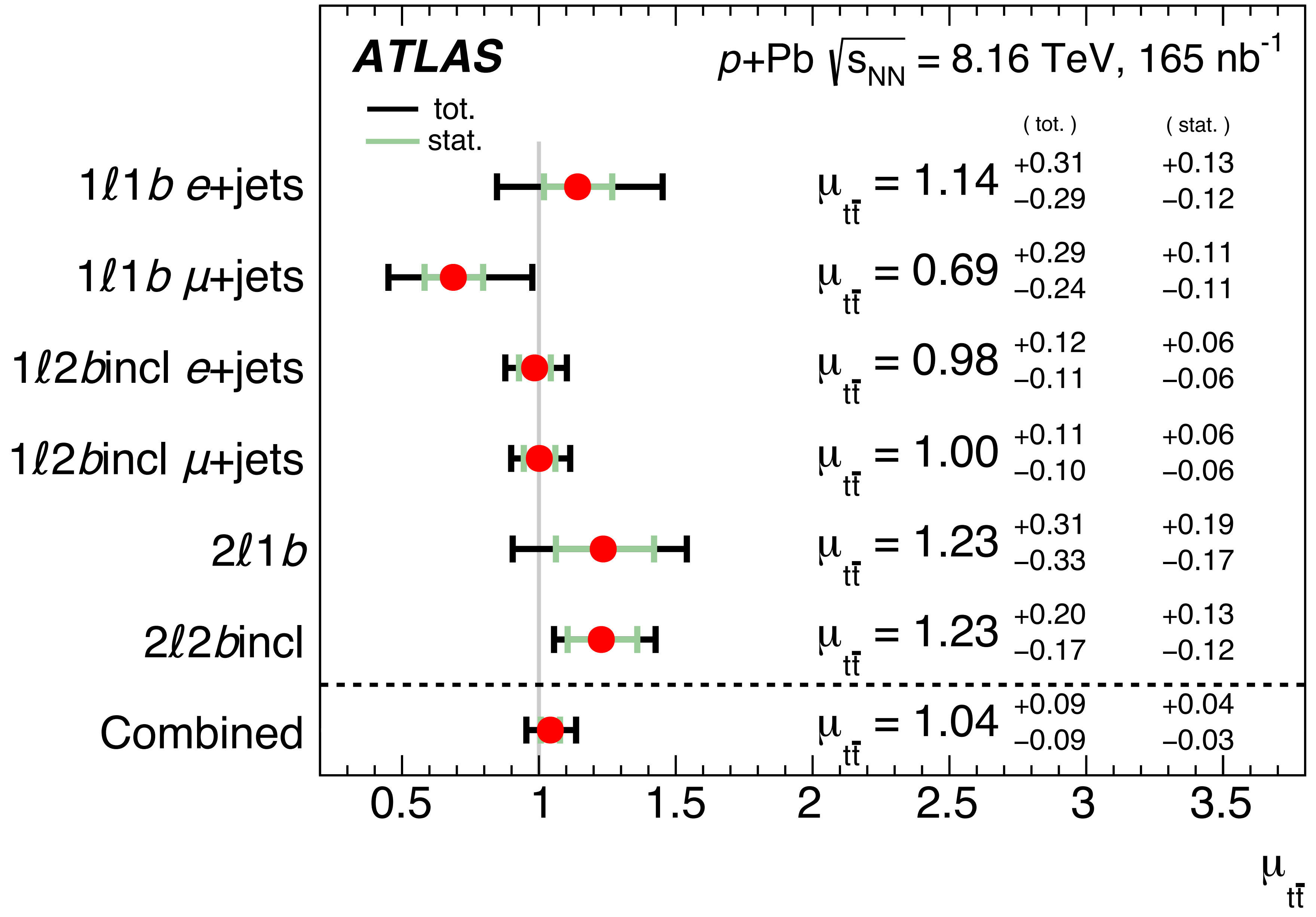
Top pair in p+Pb

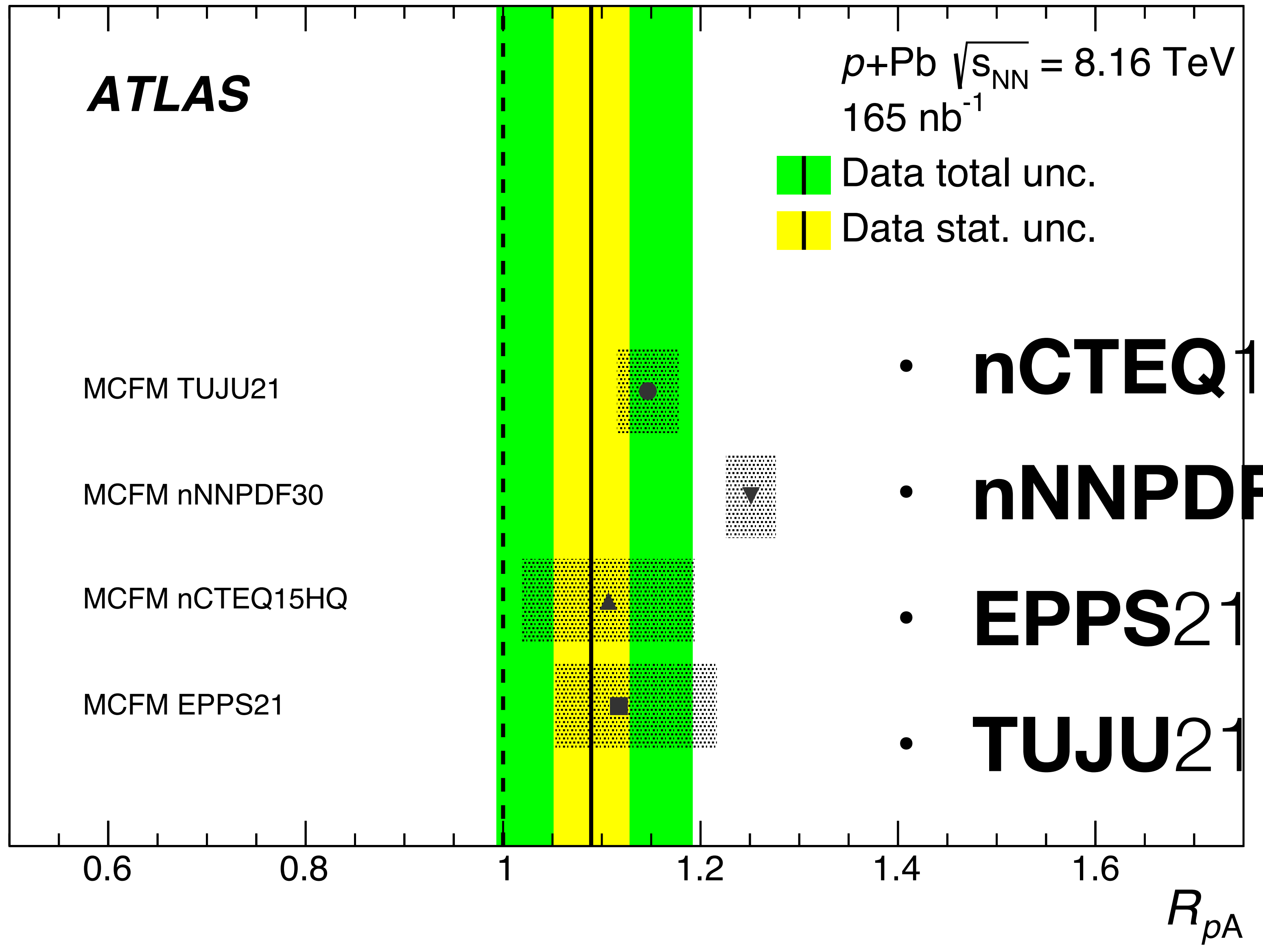
arXiv:2405.05078



$\ell + \textbf{jets}:\quad t\bar{t} \to WbW\bar{b} \to \ell\nu_\ell bq\bar{q}'\bar{b}$

$\textbf{dilepton}:\quad t\bar{t} \to WbW\bar{b} \to \ell\nu_\ell b\ell\bar{\nu}_\ell\bar{b}$

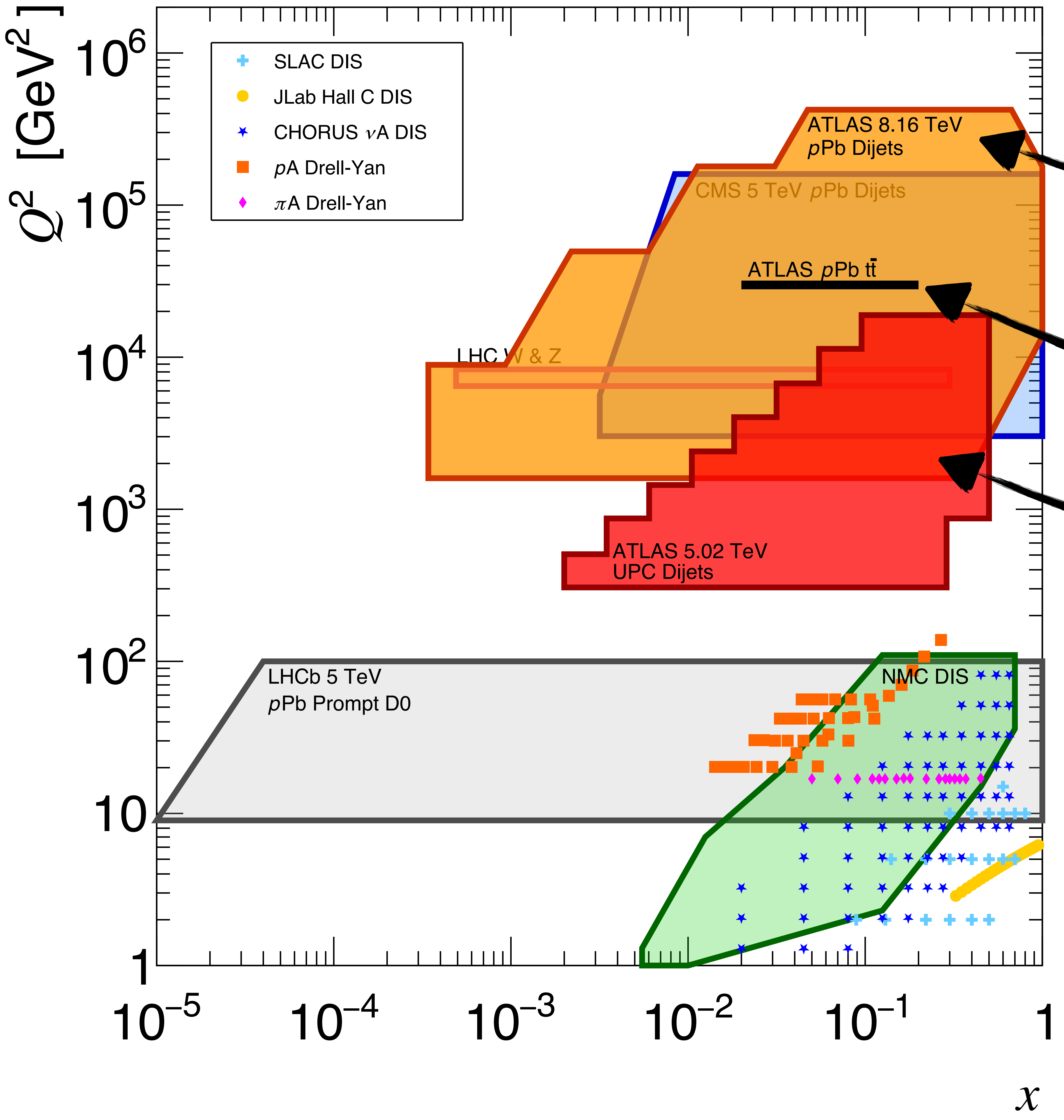




- **nCTEQ**15 HQ
- **nNNPDF** 3.0
- **EPPS**21
- **TUJU**21

- First calibration and use p-flow jets with NN b-tagger in ATLAS heavy ion data
- The $t\bar{t}$ cross section is measured to be $\sigma_{t\bar{t}} = 58.1 \pm 2.0^{+4.8}_{-4.4}$ nb
- Extrapolated $R_{\text{p+Pb}}$ is consistent with unity; nNNPDF overestimates of $t\bar{t}$ $R_{\text{p+Pb}}$

Nuclear modification of parton distribution function



p+Pb dijets

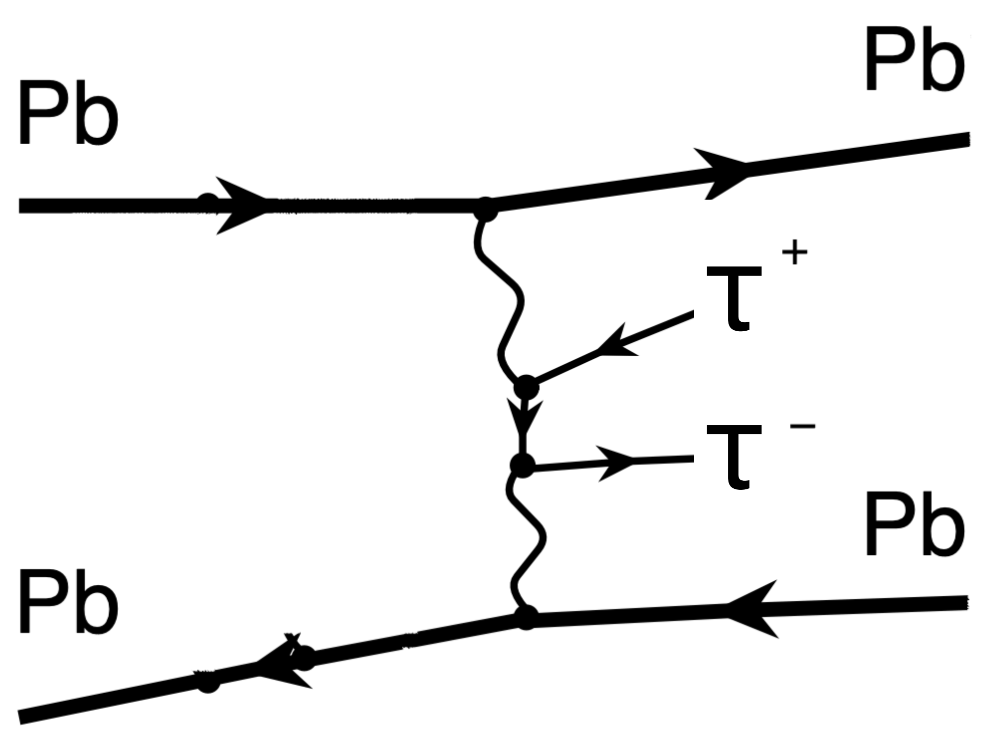
p+Pb $t\bar{t}$

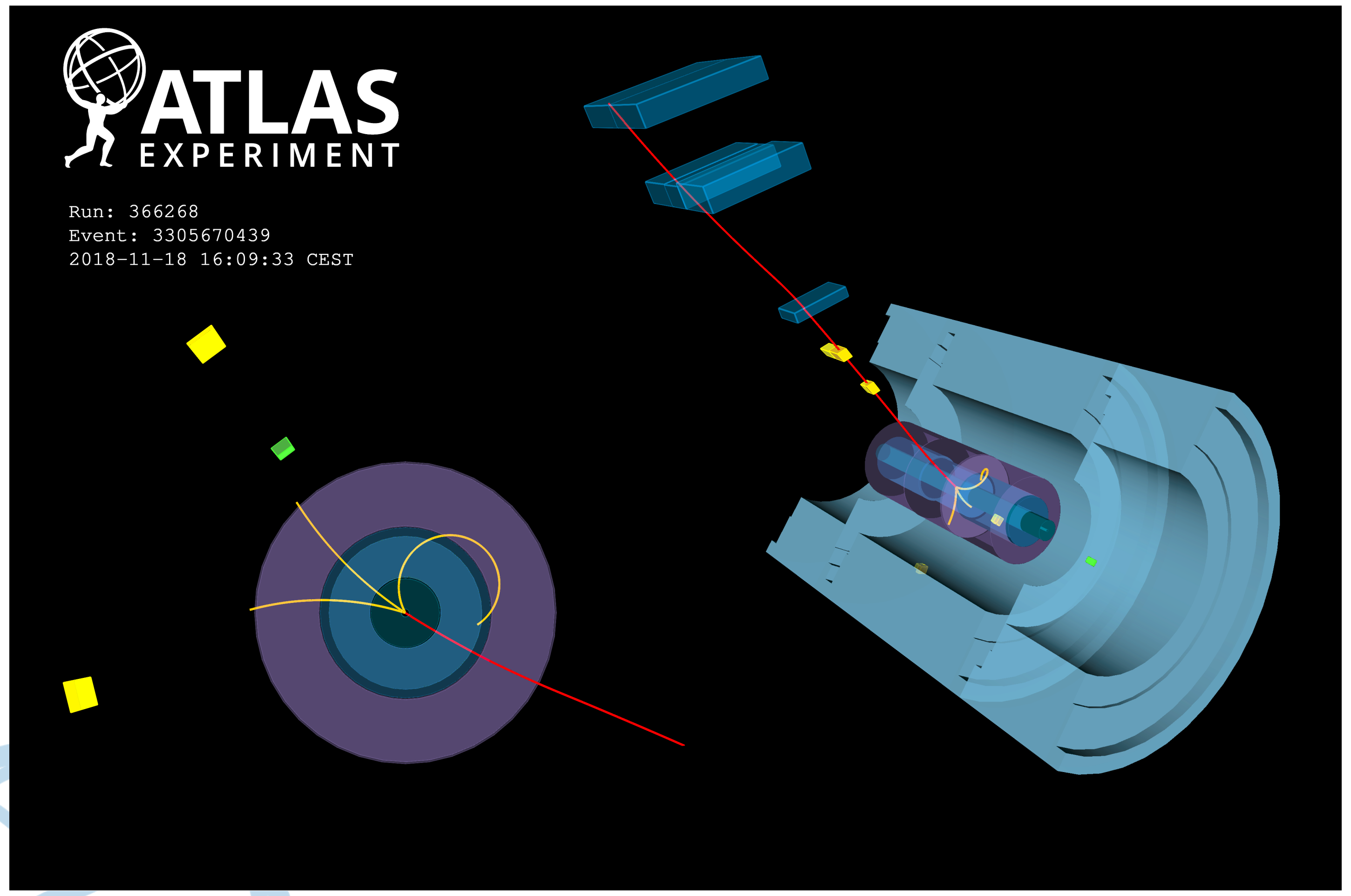
photonuclear jets

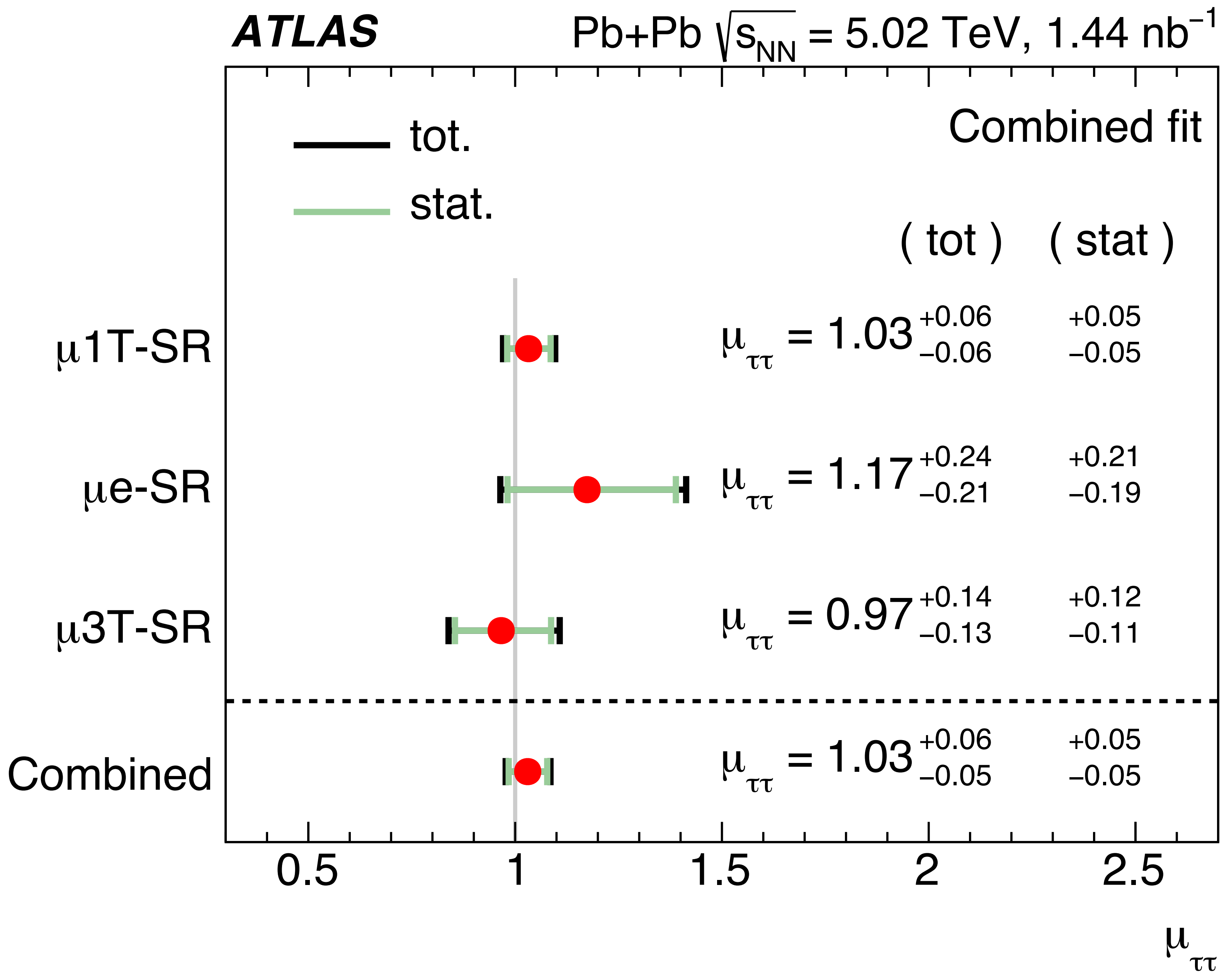
Extend the available data into unexplored regions to investigate nuclear effects on PDFs at high Q^2 across wide x-range

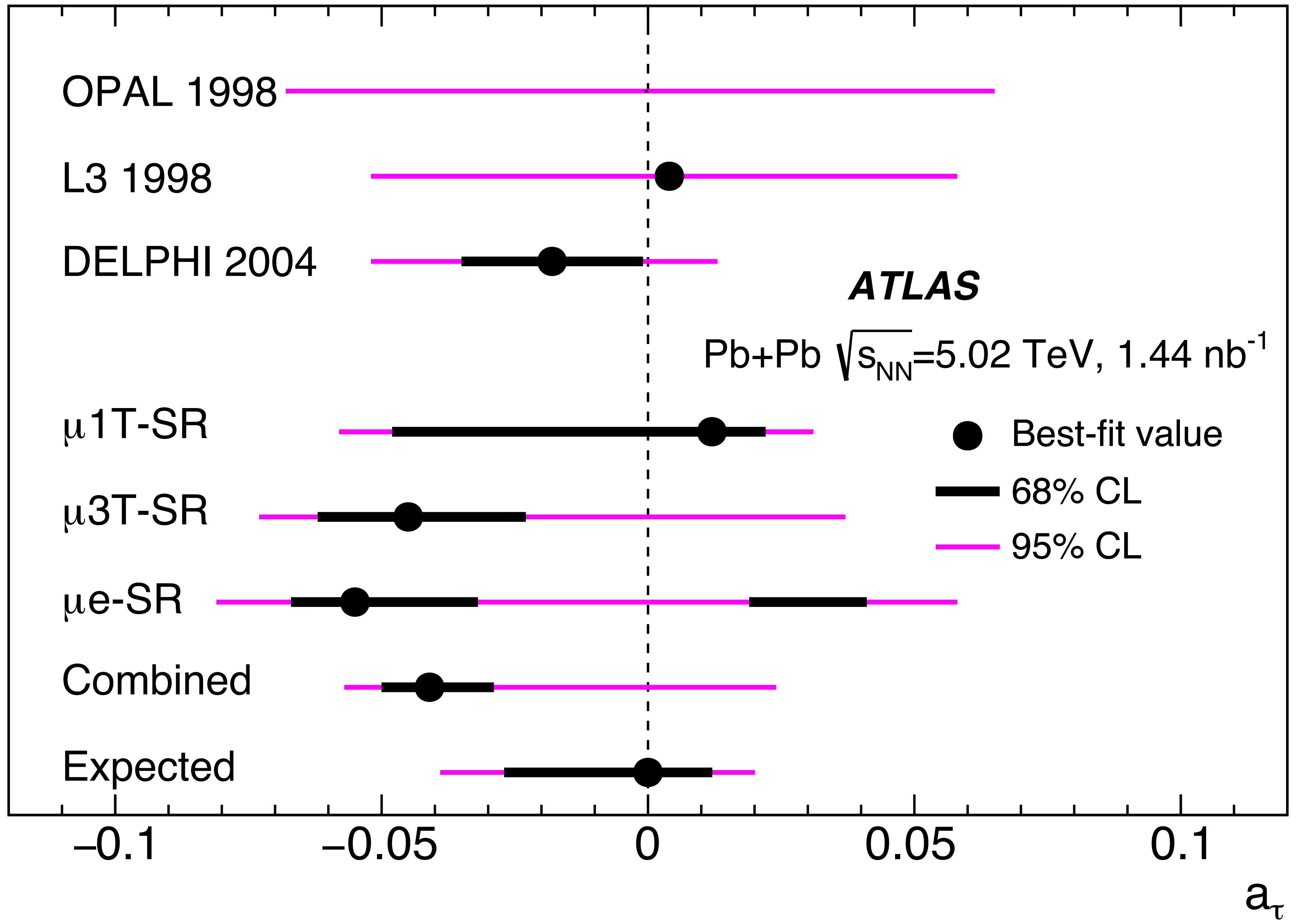
τ anomalous magnetic moment via $\gamma\gamma \to \tau\tau$

PRL 131 (2023) 151802





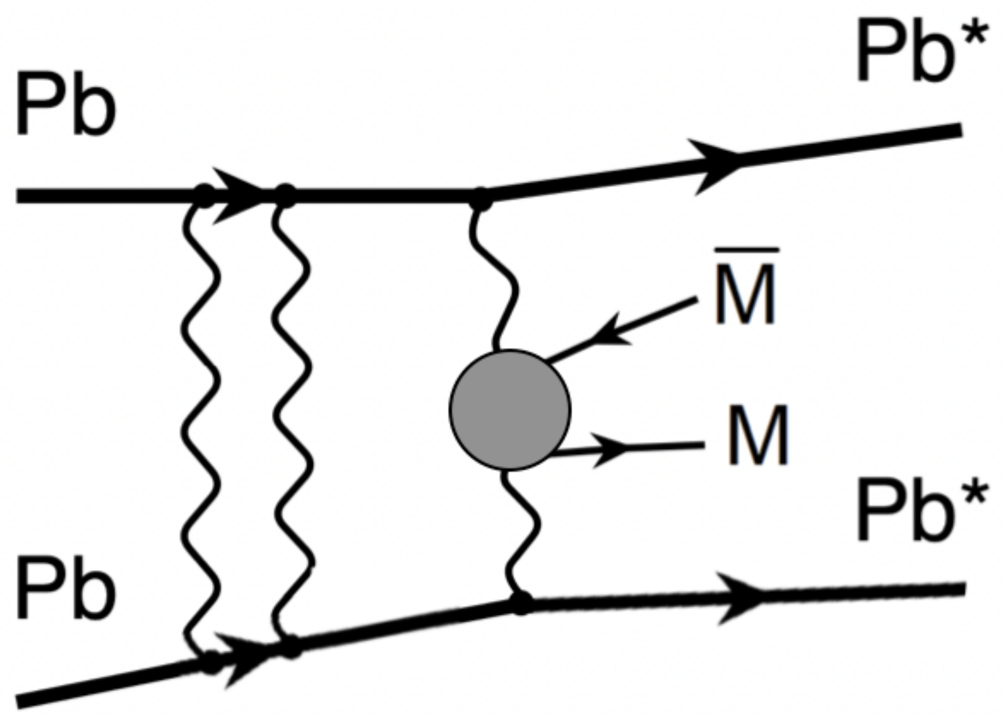


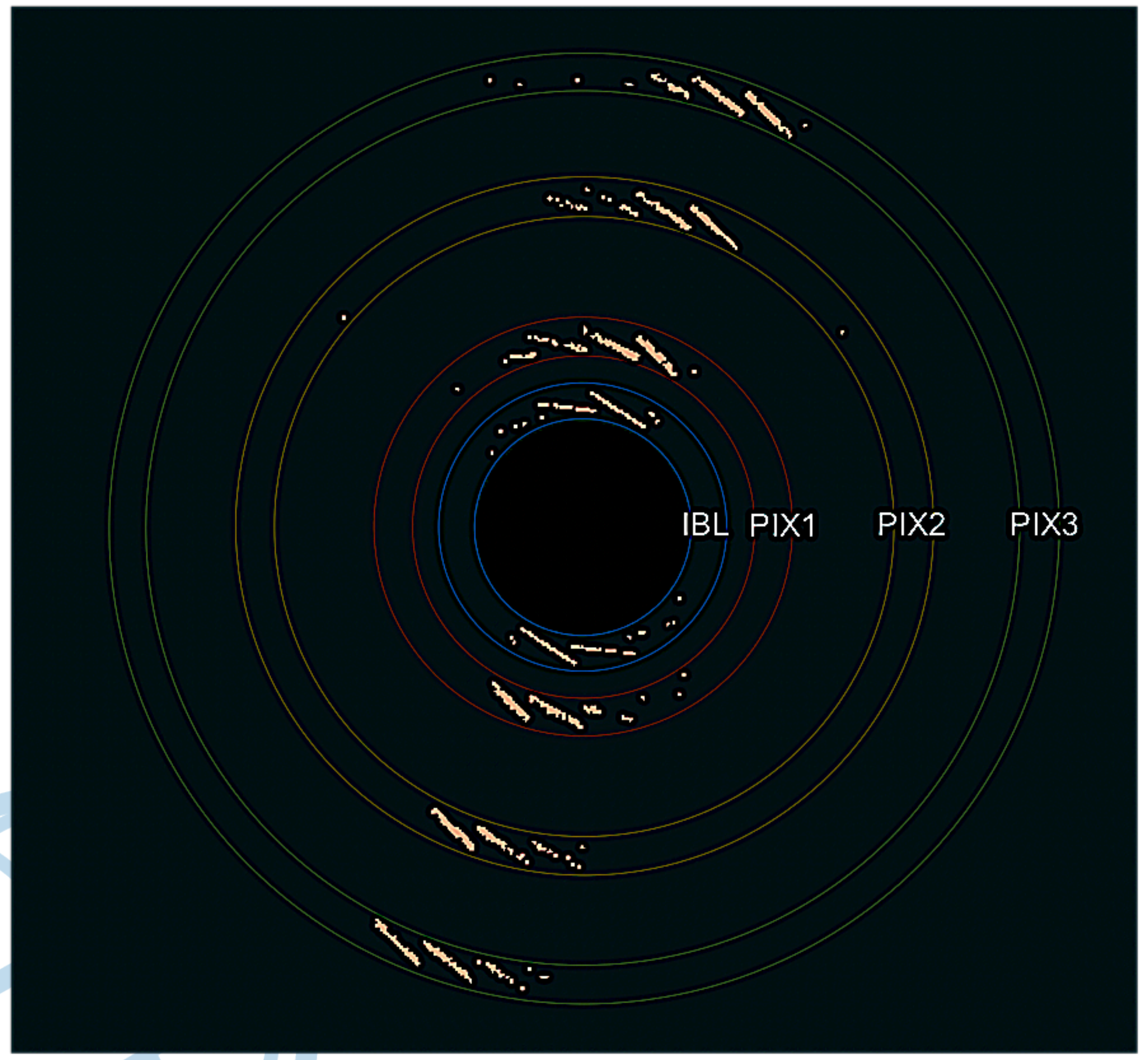


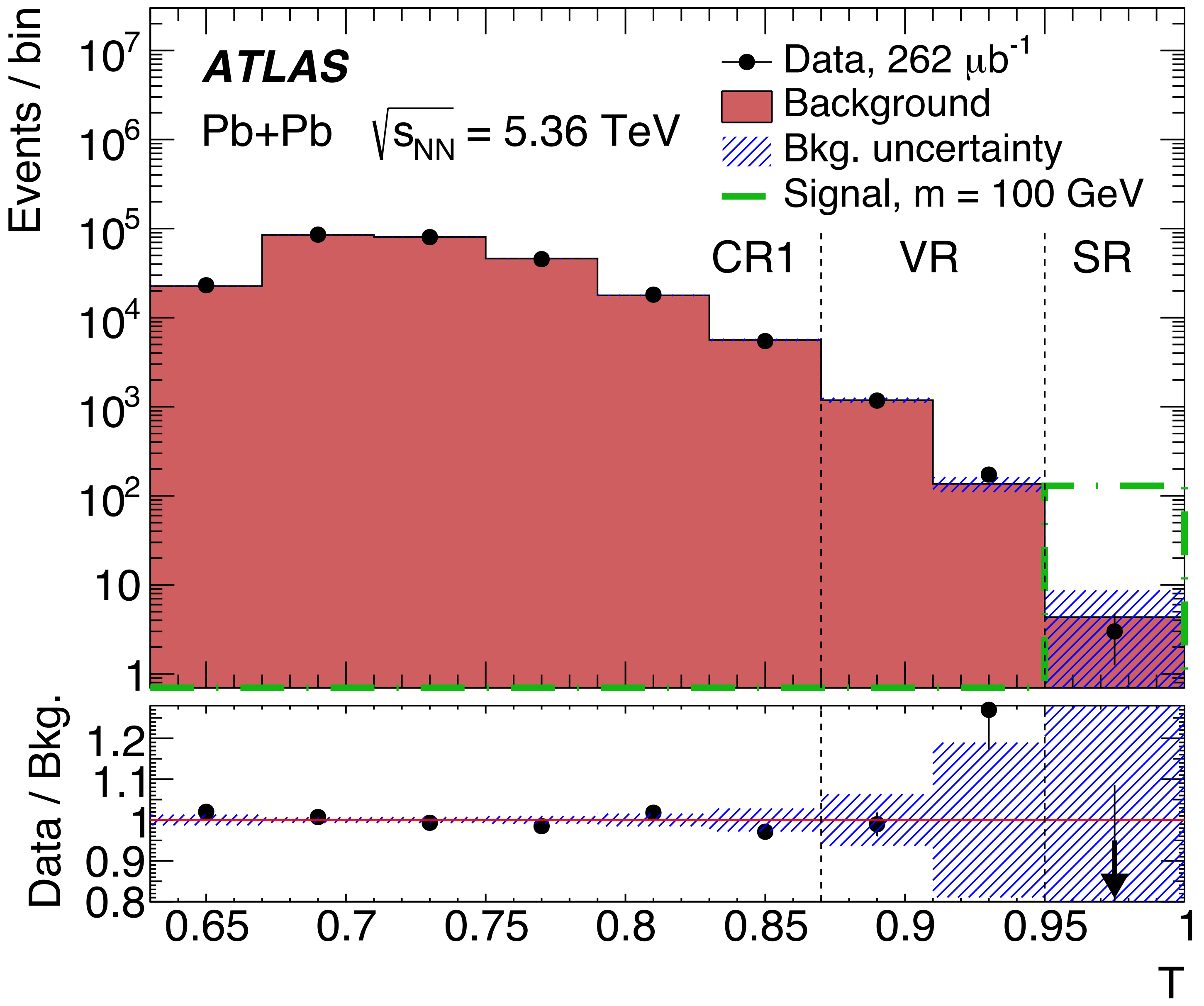
- Study (low-energy) taus for the first time in nuclear collisions
- No nuclear breakup required using ZDC to suppress hadronic background
- Constraints on a_τ extracted from the interaction strength is competitive with those observed at LEP (DELPHI)

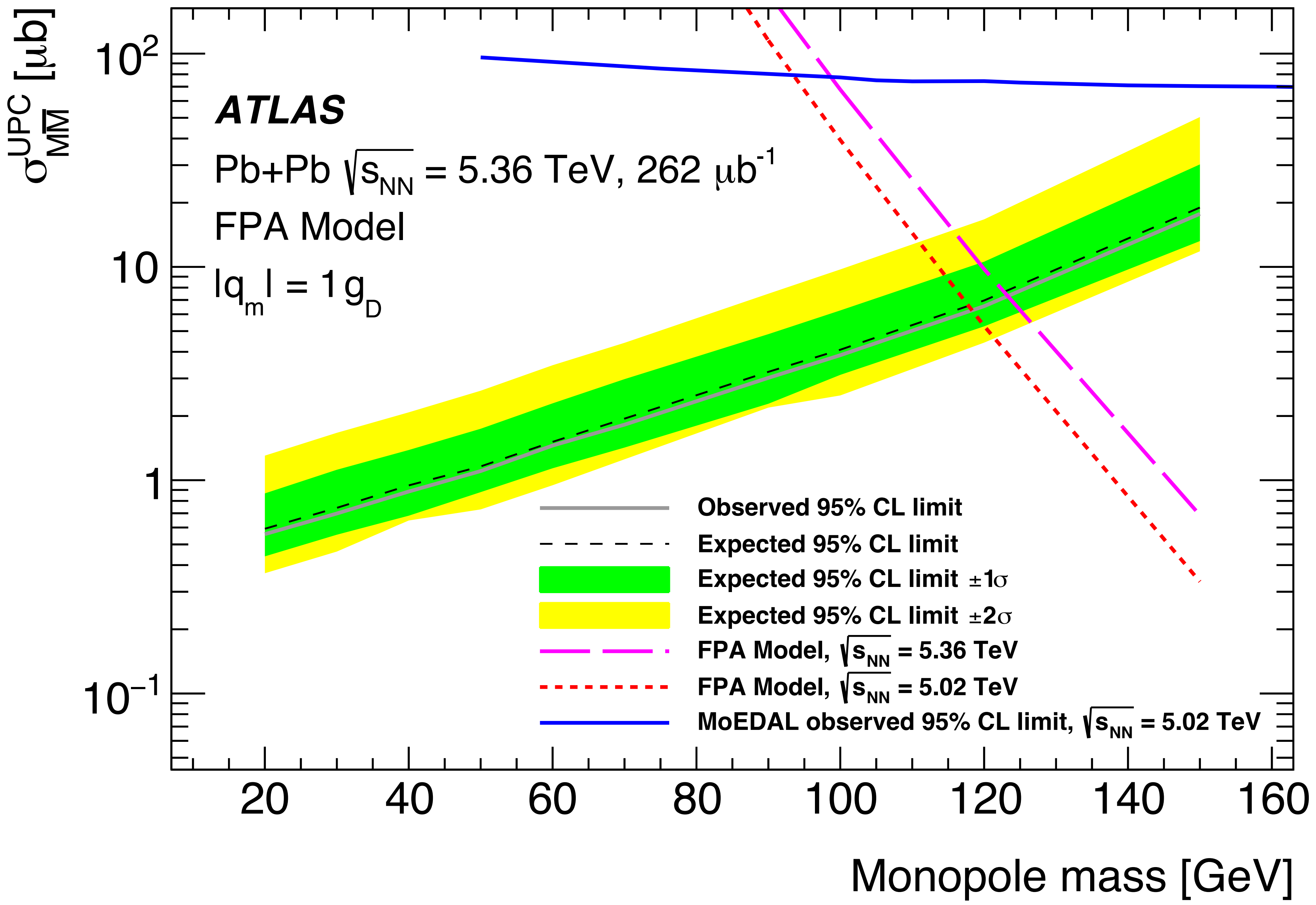
Magnetic monopoles via $\gamma\gamma \rightarrow M\bar{M}$

arXiv:2408.11035



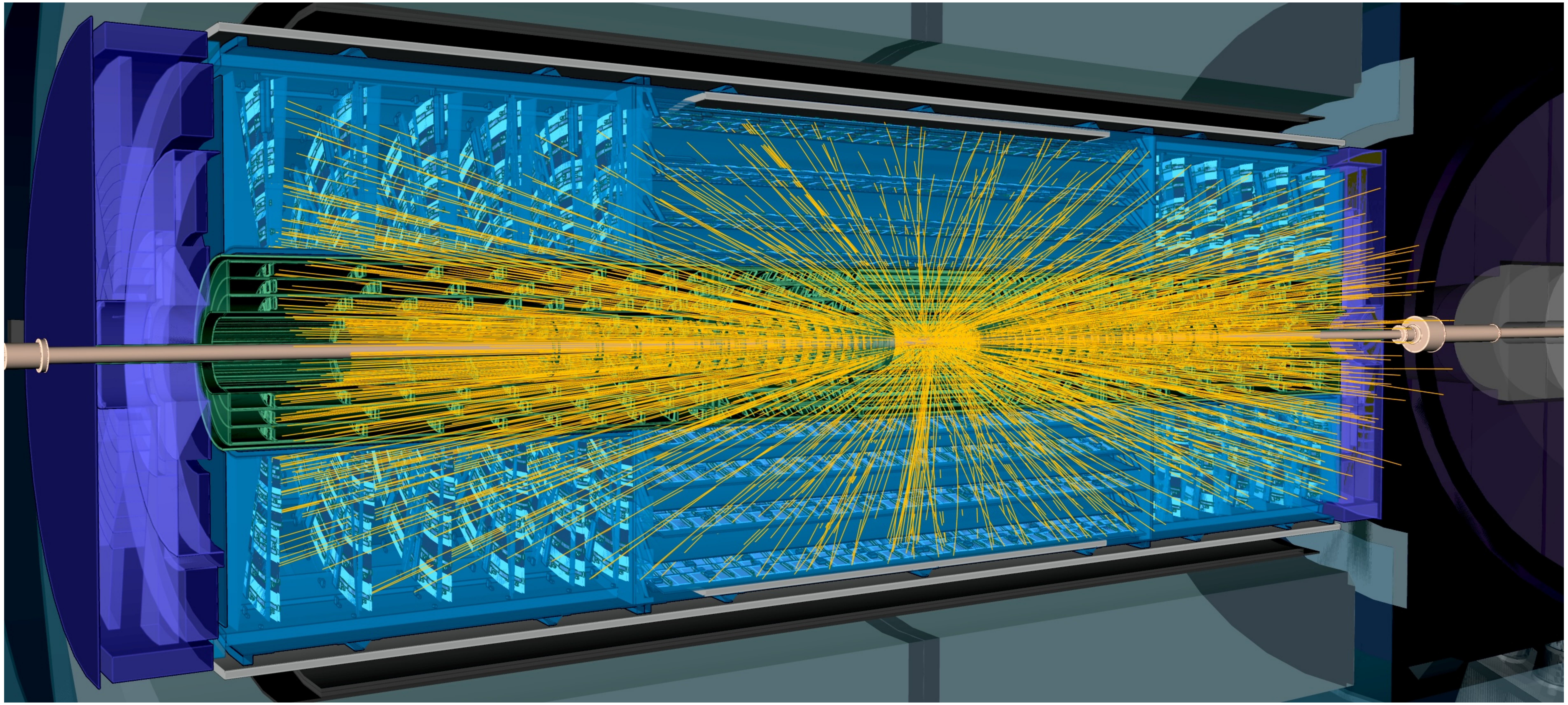






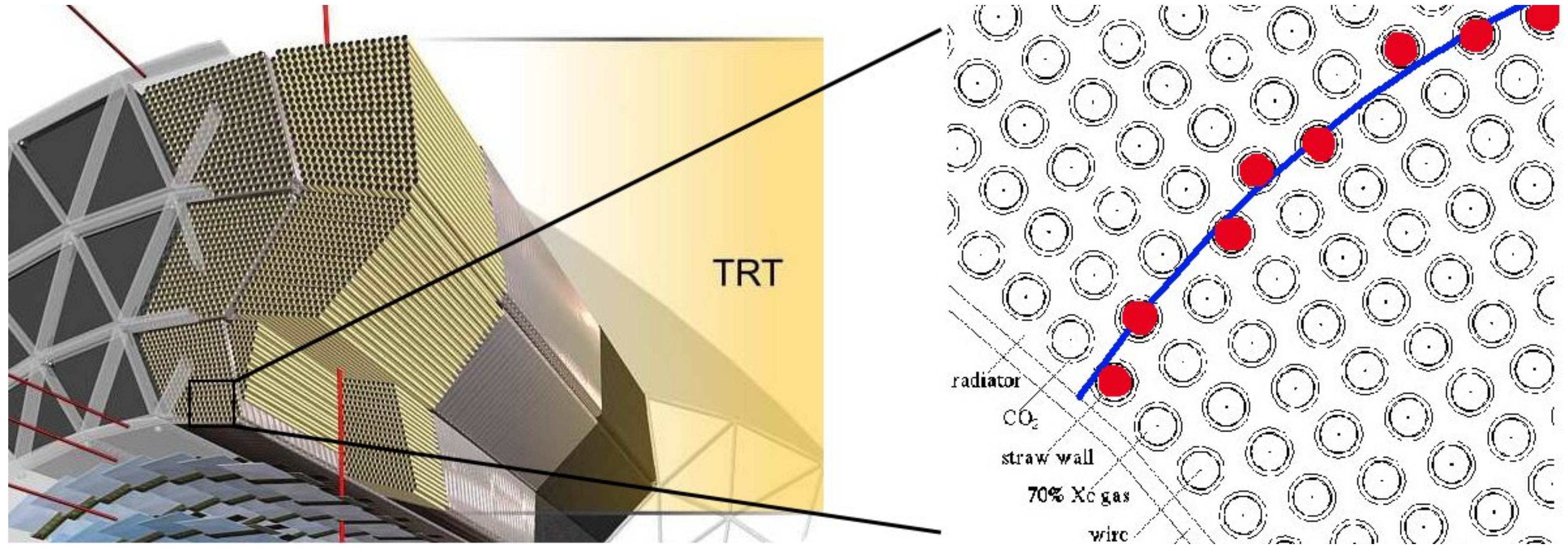
- Magnetic monopoles via the Schwinger mechanism in UPCs. First ATLAS analysis using Run3 heavy ion data
- 3 events in SR, consistent with background estimate (4 ± 4)
- Better limits compared to dedicated MoEDAL experiment (Nature 602 (2022) 63), achieve up to x8 improvement at masses below 120 GeV

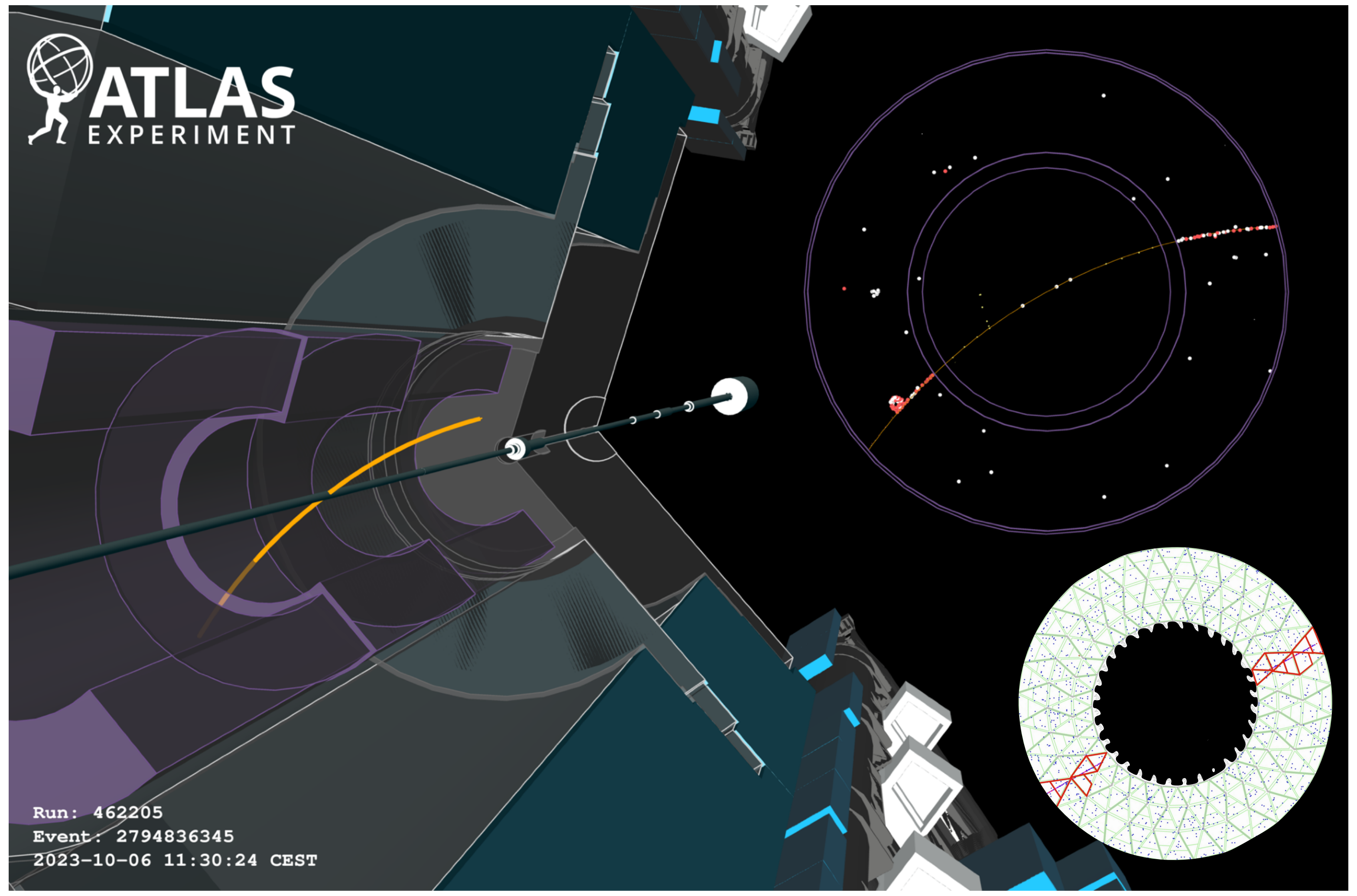
Future Perspectives



The ATLAS ITk for Run 4: the new all-Si tracker

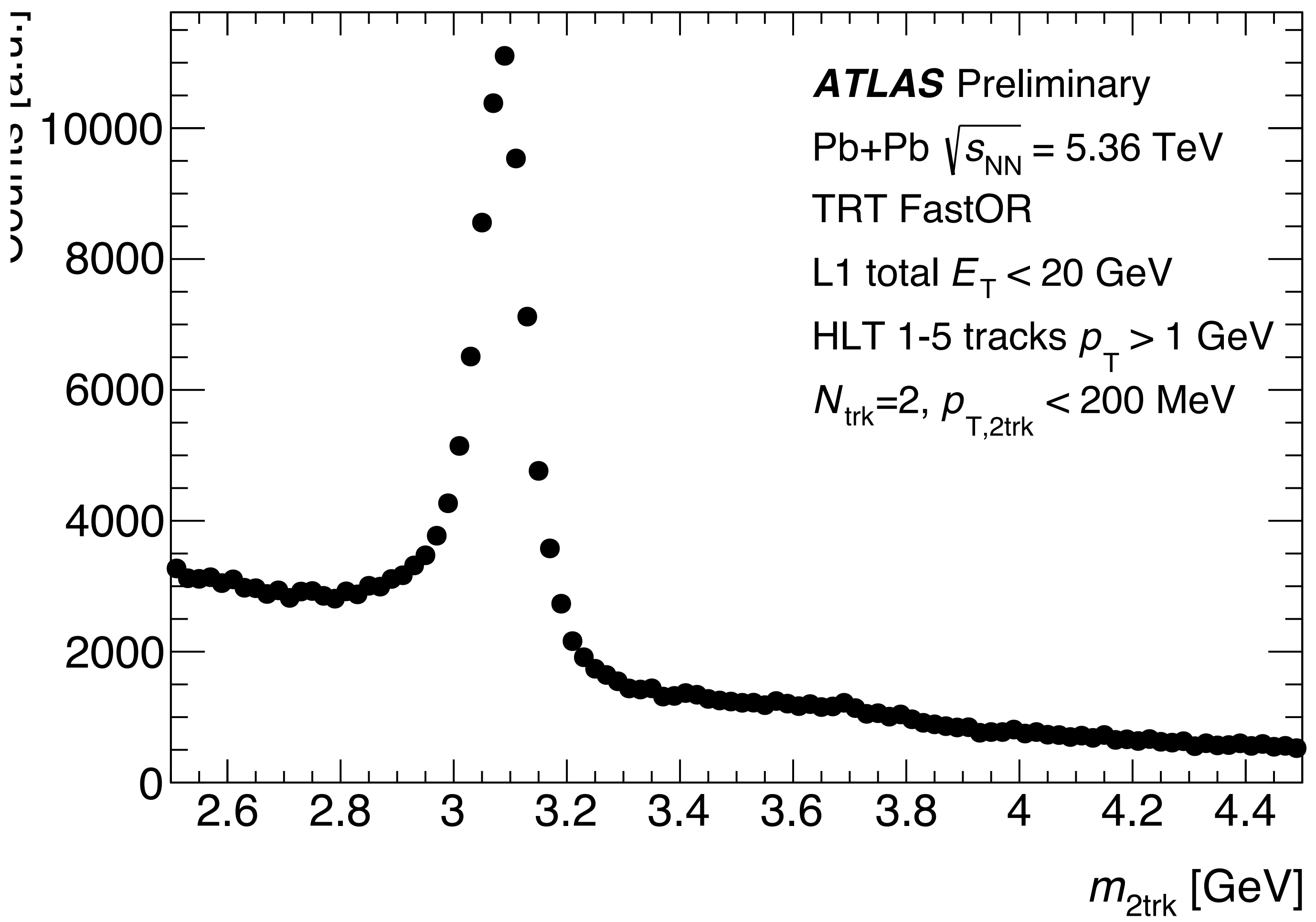
Run3 new L1 track trigger



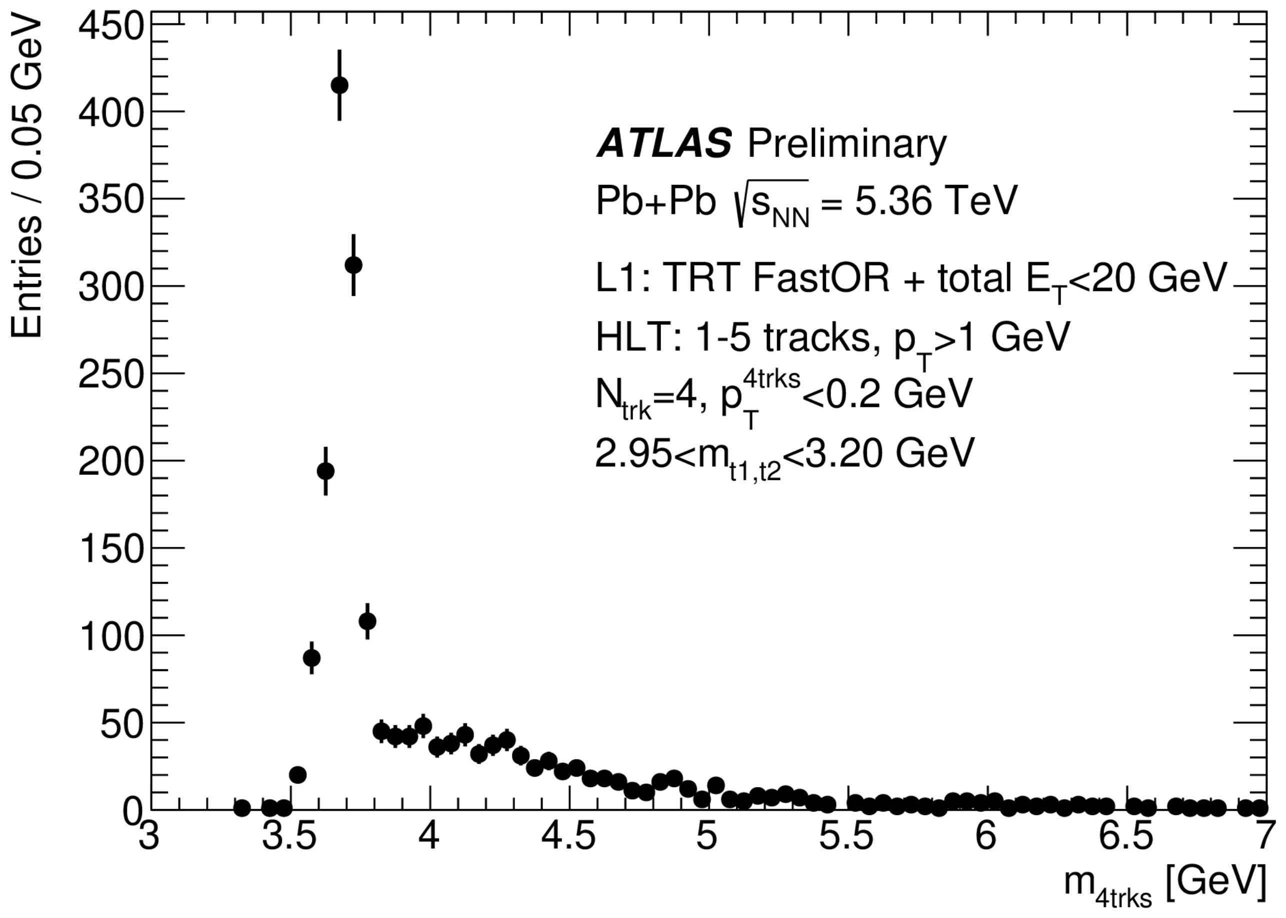


TRT triggered UPC event with two tracks

Two tracks

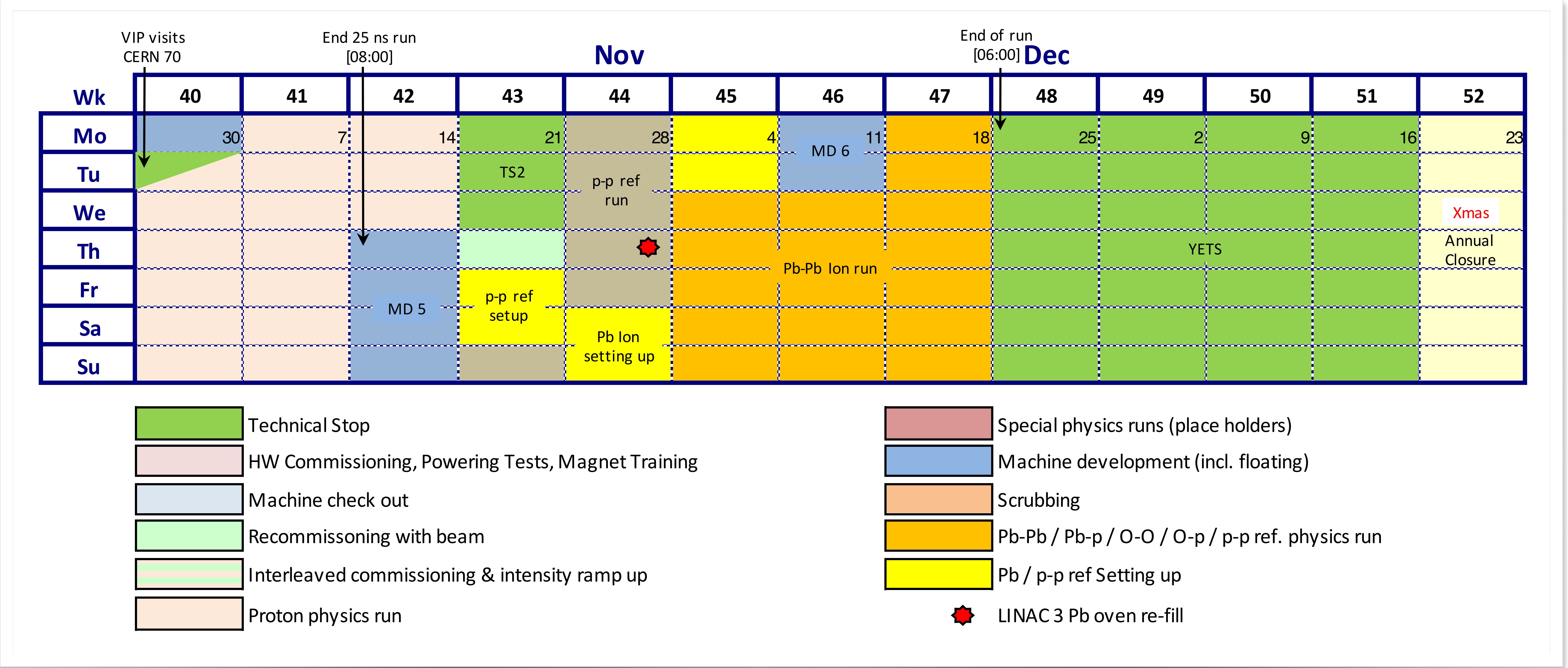


Four tracks

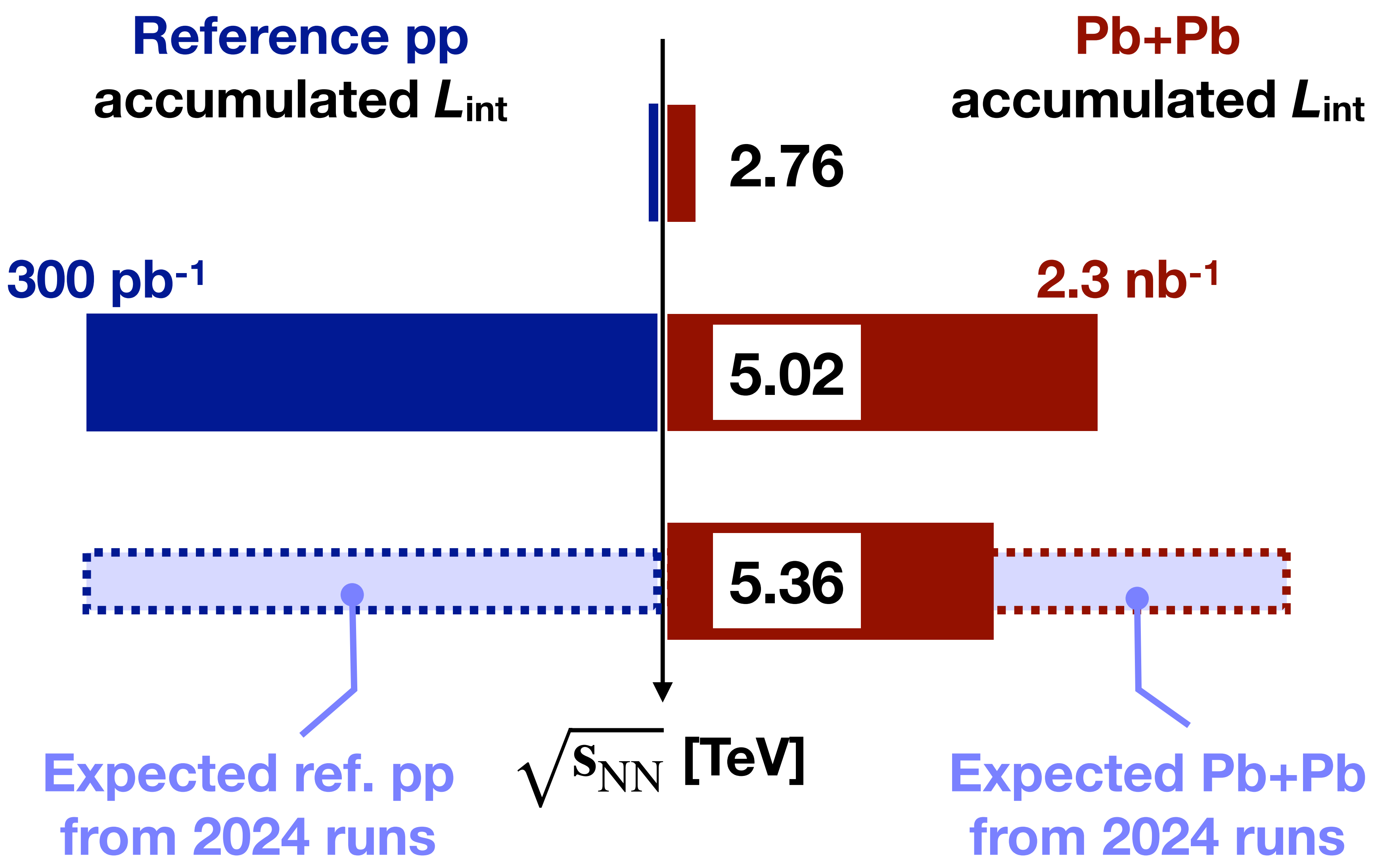


- Newly commissioned TRT trigger (L1 track trigger running at MHz level!)
- In combination with ZDC and total energy triggers, it allow us accumulate large UPC samples with various track multiplicities for exclusive J/ψ and other hadron spectroscopy researches

Heavy ion operations in 2024 and beyond



LHC 2024 schedule as of September 18

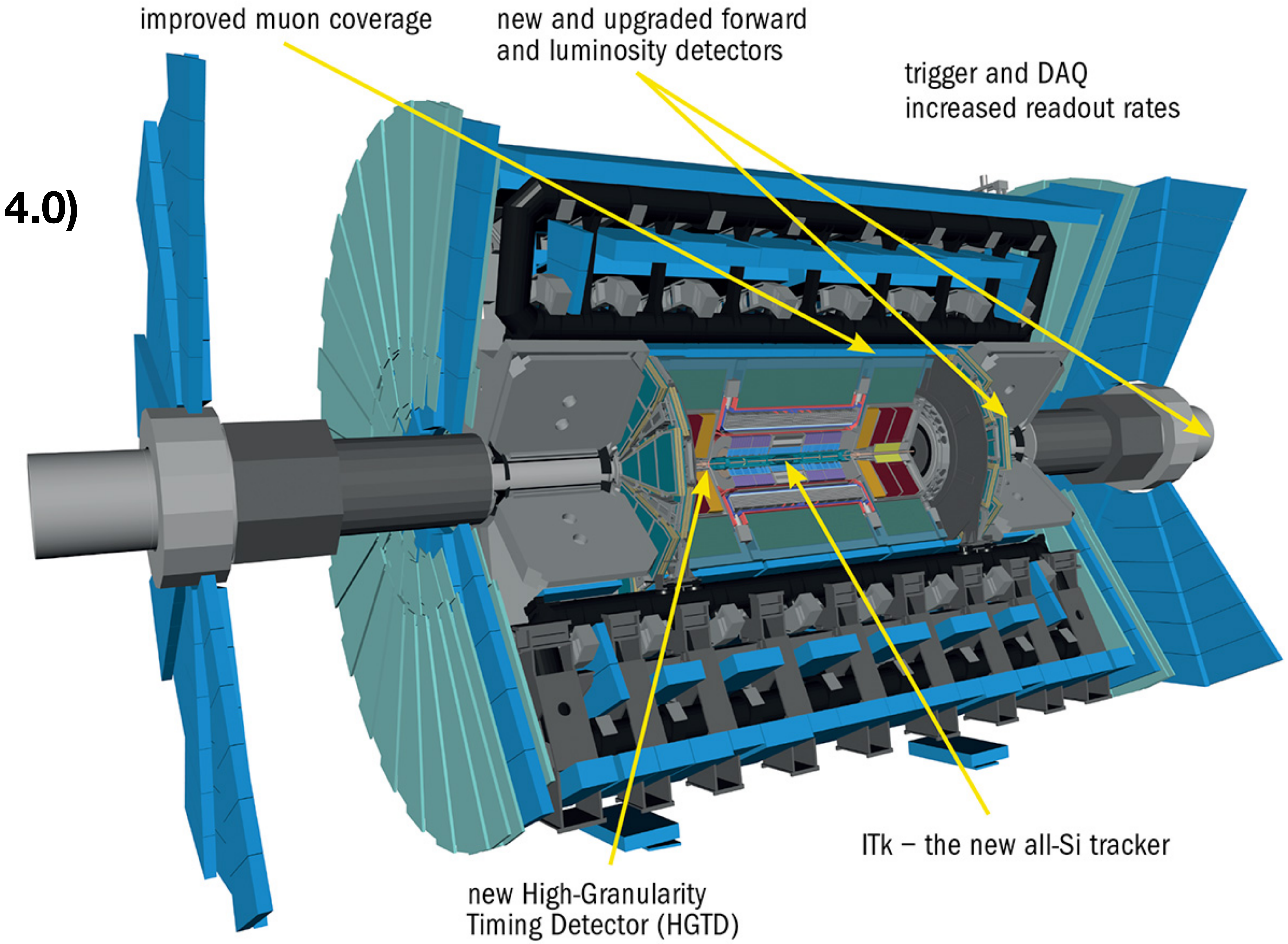


- 2024 target: pp reference > 300 pb^{-1}, Pb+Pb > 1.5 nb^{-1}
- If Run 3 gets extended, possible to collect 6 nb^{-1} Pb+Pb data by the end of Run 3

Phase-II ATLAS

An upgraded ATLAS (> 2030s)

- **High-granularity, high-coverage tracker (2.5 → 4.0)**
- **New ZDC (same as CMS Phase-II ZDC)**
- **High-granularity timing detector**
- Replaced muon chambers
- New and upgraded forward and luminosity detector
- Improved trigger, high-performance software & computing, deeply embedded machine learning



Summary

Advances

- Advancement in several jet measurements:
  - Unveal physics phenomenon — color coherence
  - Challenged jet quenching models — differential dijet R_{AA}

Innovations

- Well-studied measurements — p+Pb dijet, photonuclear jets — paved the way for more sophisticated future studies
- Combining of heavy ion data with general SM studies strengthens collaboration with the broader particle physics community

Future Perspectives

- New track trigger and exciting data taking in 2024/2025/2026
- New sub-detectors and various upgrades for HL-LHC
- Collaborative efforts across experiments to address open questions, such as the R-dependence of p_T jets …