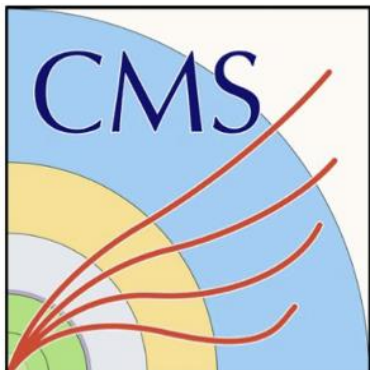


Probing the initial state with dijets in pPb collisions at 8.16 TeV with CMS

Vipul Pant for the CMS Collaboration

vpant4@uic.edu

University of Illinois Chicago



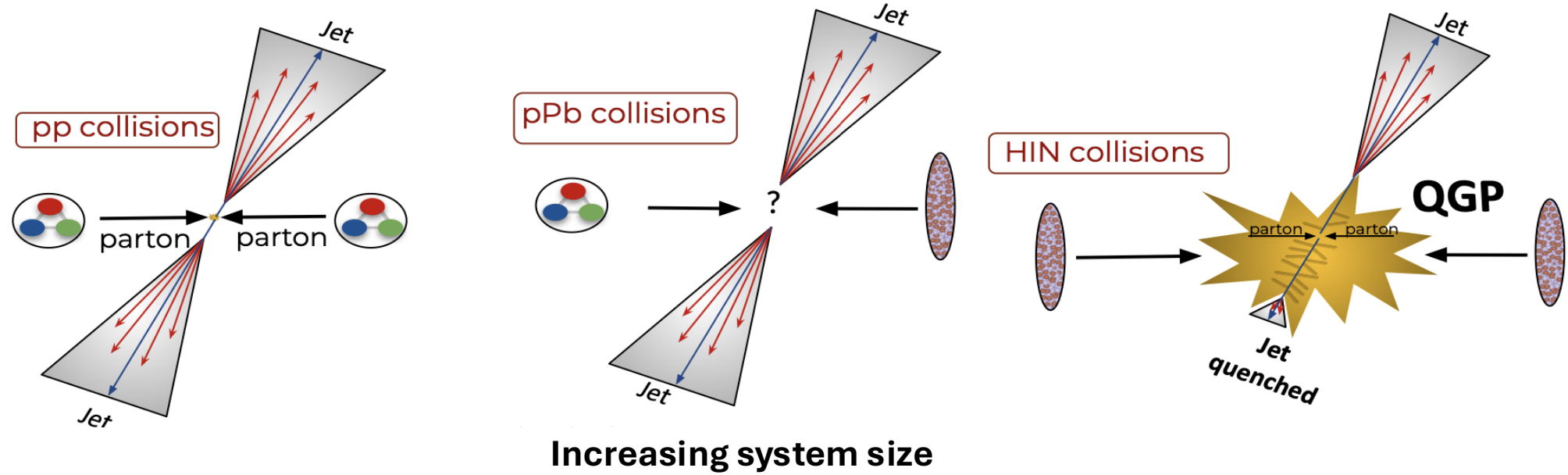
Initial Stages 2025, Taipei, Taiwan
September 9, 2025



Jets as Probes of Initial State

- **Jets as Probes:**

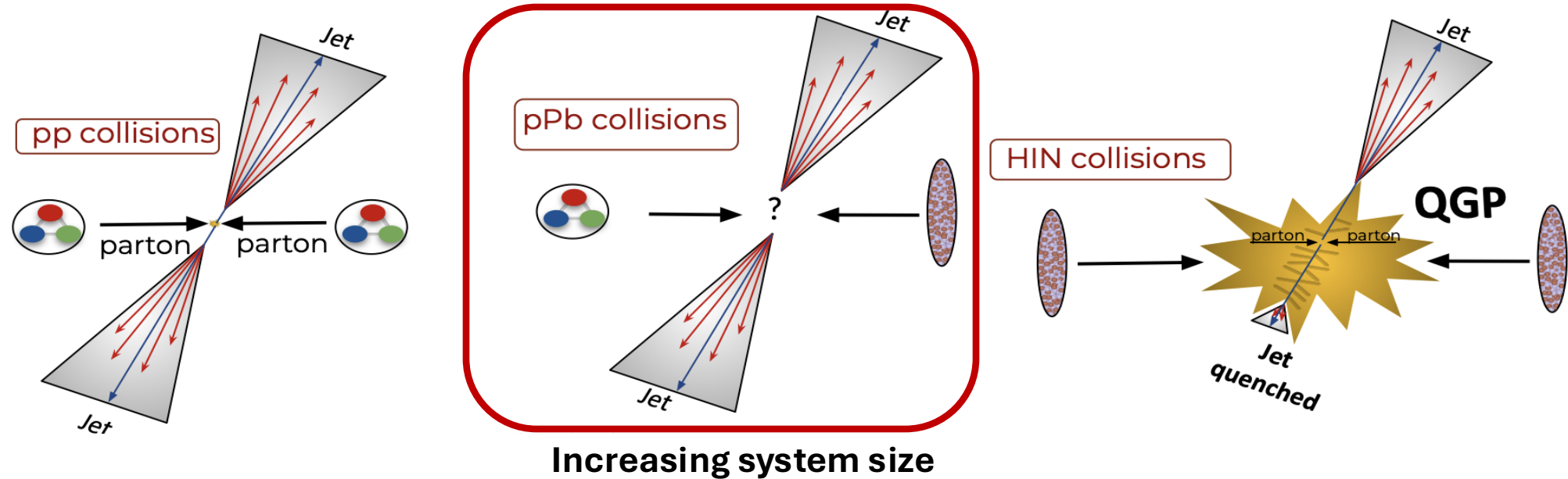
- ❑ Directly probe hard scattered partons in a collision
- ❑ Used as a probe to study jet-quenching in heavy-ion system



Jets as Probes of Initial State

- **Jets as Probes:**

- Directly probe hard scattered partons in a collision
- Used as a probe to study jet-quenching in heavy-ion system

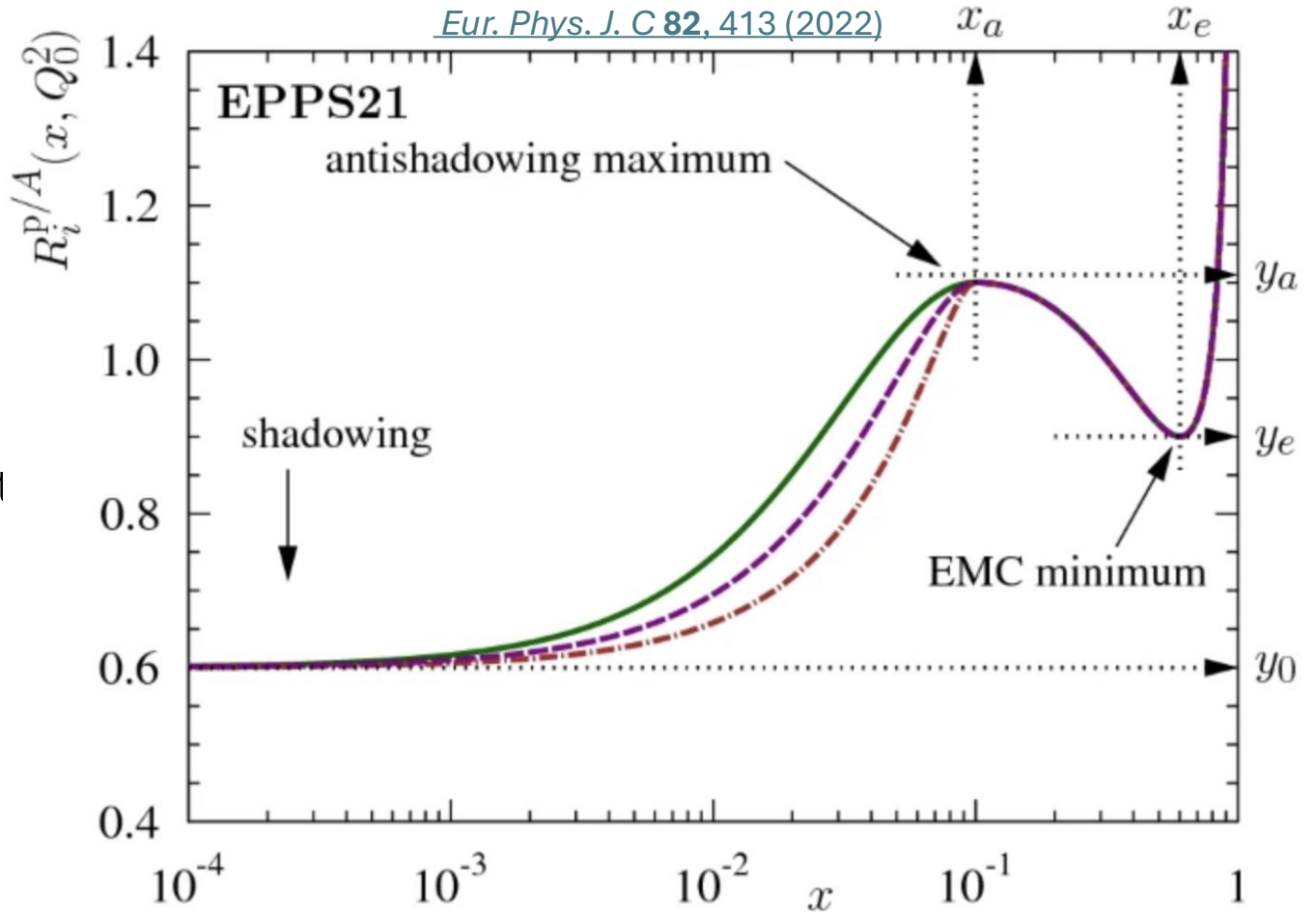


- **Jet measurements in pPb collisions**

- Expected small final state effects
- Sensitive to modifications of nPDFs
- Potential to investigate jet modifications in pPb system

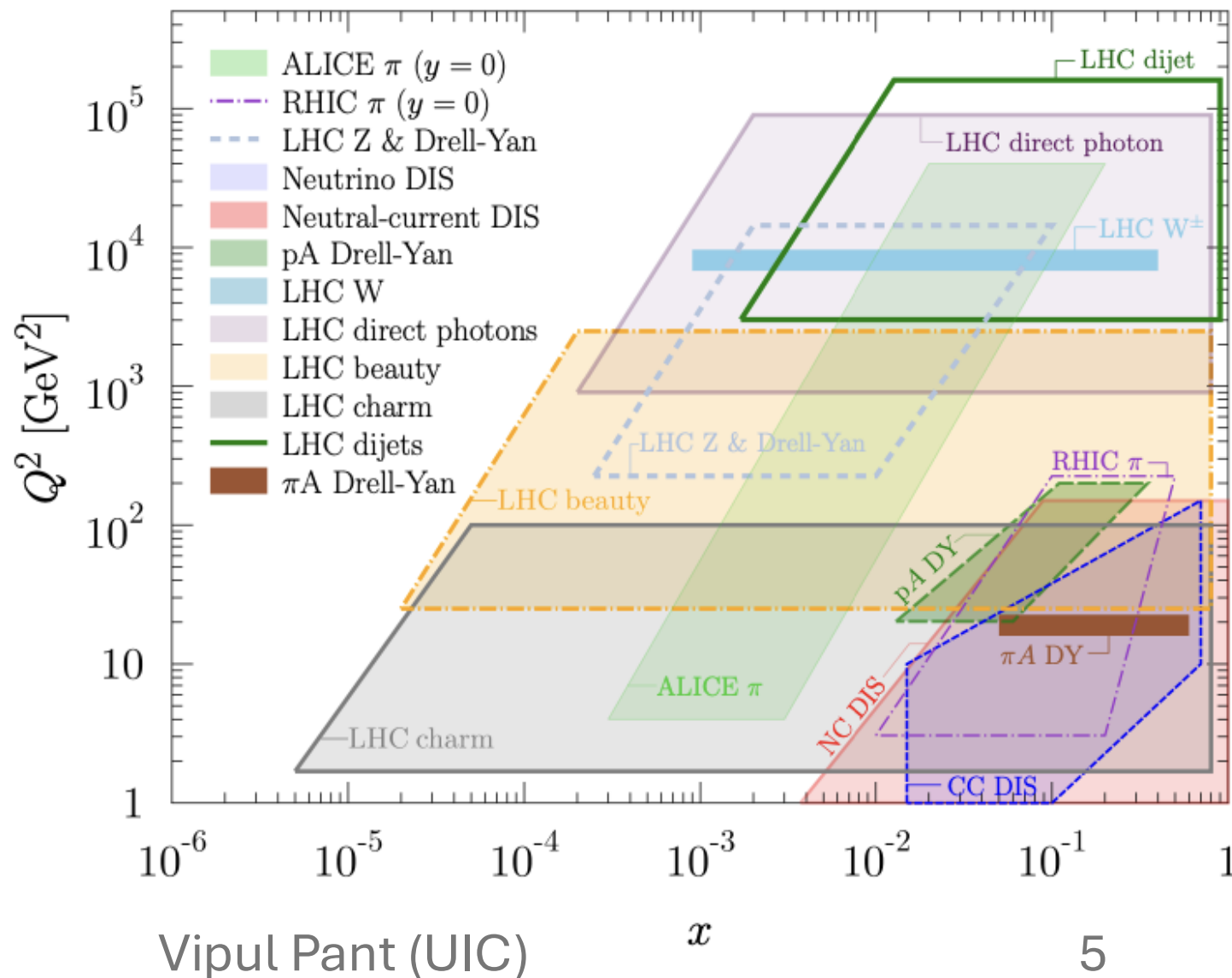
Nuclear parton distributions functions (nPDFs)

- Nuclear effects on PDFs :
 - ❑ **Shadowing** : depletion in lower x
 - ❑ **Anti-shadowing** : enhancement in intermediate x
 - ❑ **EMC effect** : Depletion in intermediate-high x



Experimental constraints on nPDFs

[Ann. Rev. Nucl. Part. Sci. 2024. 74:1–41](#)

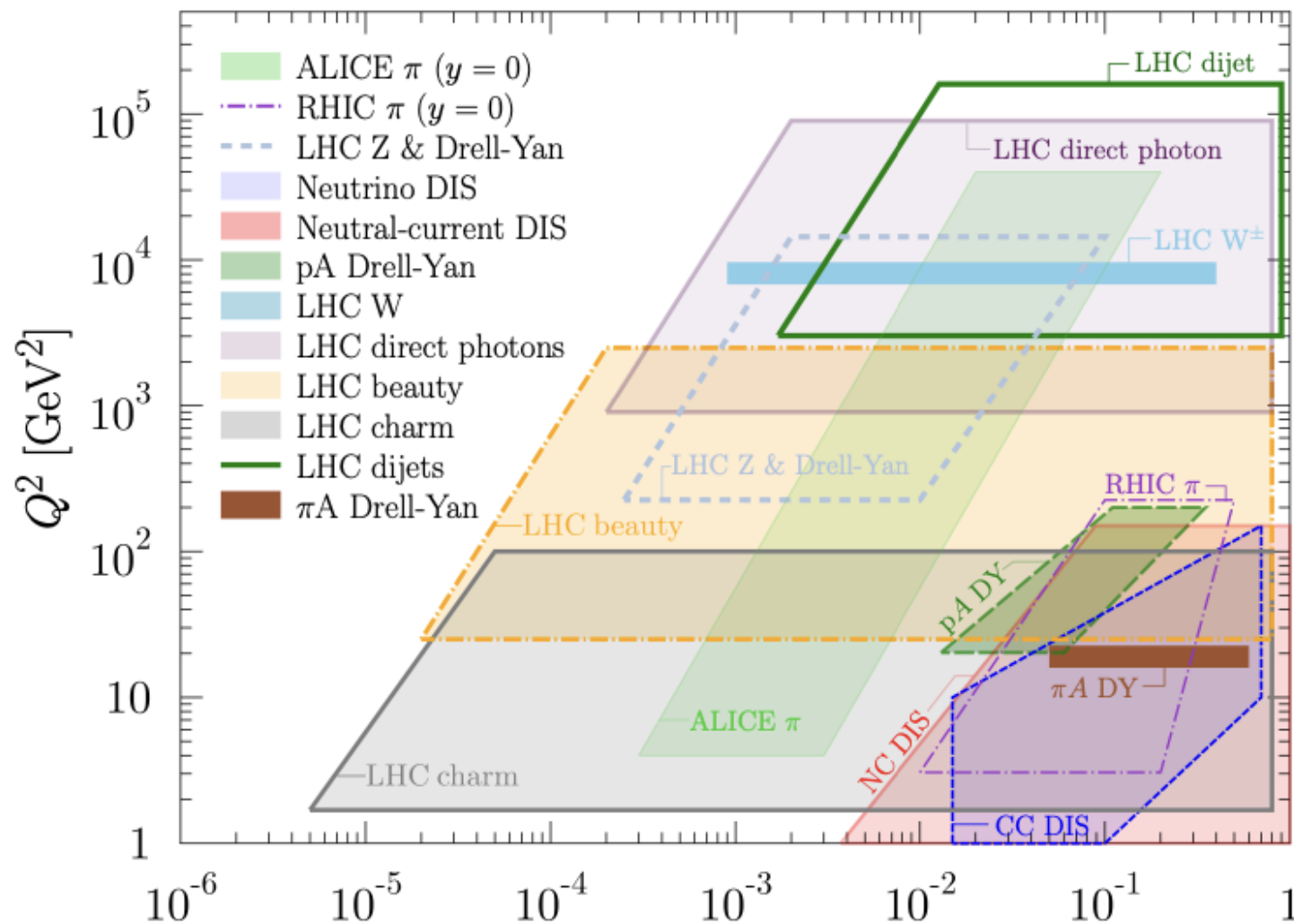


- **Valence quark nPDFs** : DIS , Drell-Yan, LHC electroweak bosons
- **Gluon nPDFs** : Dijets, Heavy flavour measurements
- LHC data significantly expanded x and Q^2 coverage

Experimental constraints on nPDFs

This talk :
Dijets

[Ann. Rev. Nucl. Part. Sci. 2024. 74:1–41](#)



- **Valence quark nPDFs** : DIS , Drell-Yan, LHC electroweak bosons
- **Gluon nPDFs** : Dijets, Heavy flavour measurements
- LHC data significantly expanded x and Q^2 coverage

Dijet measurement at 5.02 TeV

- **Dijet pseudorapidity (η^{dijet})** : sensitive to nuclear PDFs
- η^{dijet} can be directly mapped to different x regimes

$$x_{pb} \approx \frac{2p_T^{dijet}}{\sqrt{s_{NN}}} e^{-\eta_{CM}^{dijet}} \cosh \Delta\eta_{CM}^{dijet}$$

$$\eta_{dijet} = \frac{1}{2} \left(\eta^{\text{leading}} + \eta^{\text{subleading}} \right)$$

$$p_T^{\text{ave}} = \frac{1}{2} \left(p_T^{\text{leading}} + p_T^{\text{subleading}} \right)$$

Dijet measurement at 5.02 TeV

- **Dijet pseudorapidity (η^{dijet})** : sensitive to nuclear PDFs
- η^{dijet} can be directly mapped to different x regimes

$$x_{Pb} \approx \frac{2p_T^{dijet}}{\sqrt{s_{NN}}} e^{-\eta_{CM}^{dijet}} \cosh \Delta\eta_{CM}^{dijet}$$

$$\eta_{dijet} = \frac{1}{2} \left(\eta^{\text{leading}} + \eta^{\text{subleading}} \right)$$

$$p_T^{\text{ave}} = \frac{1}{2} \left(p_T^{\text{leading}} + p_T^{\text{subleading}} \right)$$

Dijet measurement at 5.02 TeV

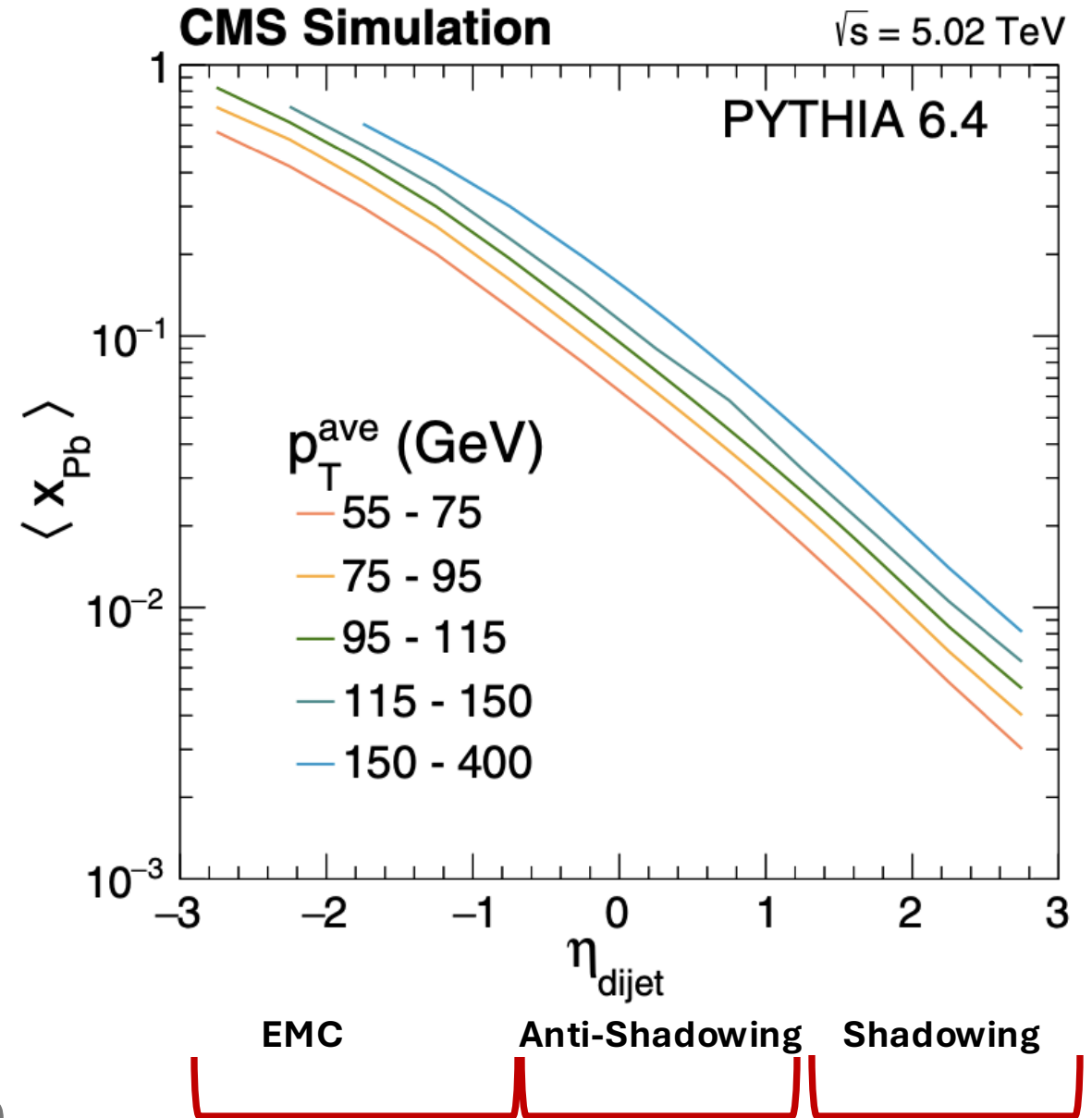
[PRL 121, 062002 \(2018\)](#)

- **Dijet pseudorapidity (η^{dijet})** : sensitive to nuclear PDFs
- η^{dijet} can be directly mapped to different x regimes

$$x_{Pb} \approx \frac{2p_T^{dijet}}{\sqrt{s_{NN}}} e^{-\eta_{CM}^{dijet}} \cosh \Delta\eta_{CM}^{dijet}$$

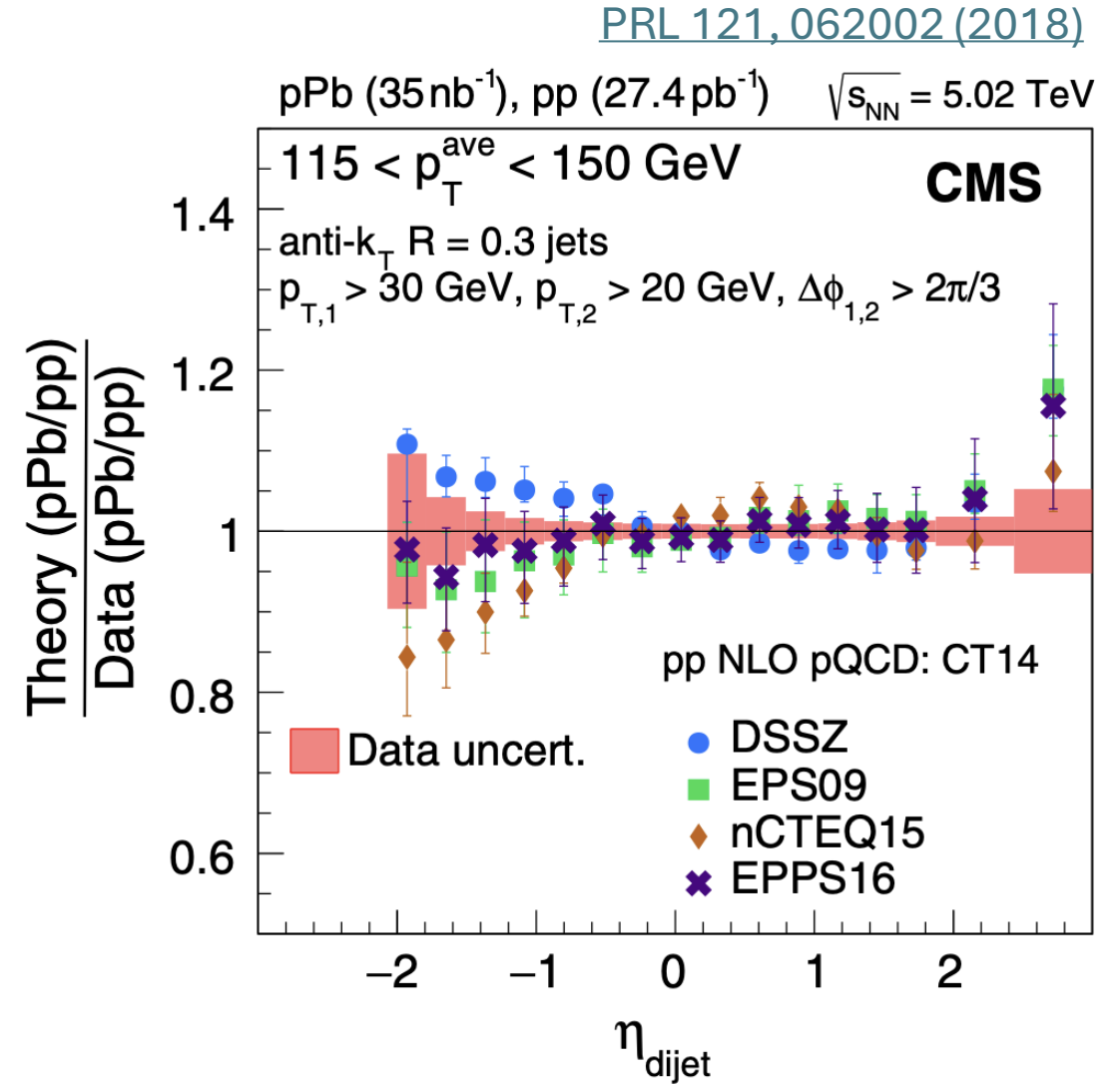
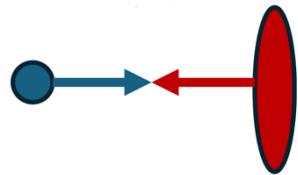
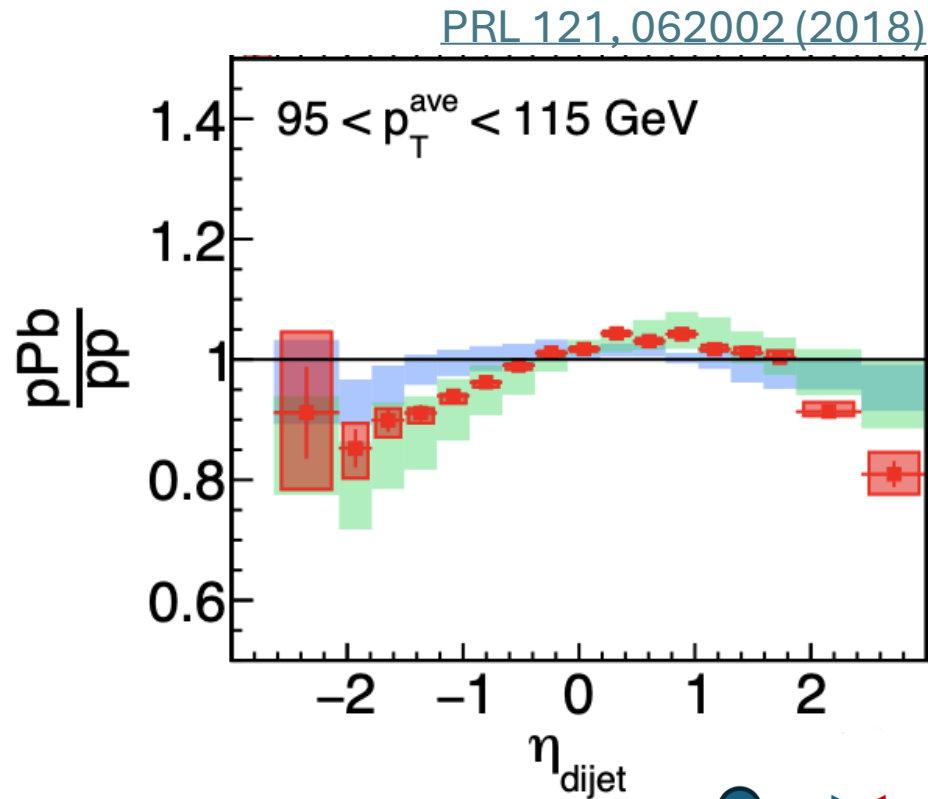
$$\eta_{dijet} = \frac{1}{2} \left(\eta^{leading} + \eta^{subleading} \right)$$

$$p_T^{ave} = \frac{1}{2} \left(p_T^{leading} + p_T^{subleading} \right)$$



Dijet measurement at 5.02 TeV

- Comparison with nPDF showed large deviation in backward and forward region



Dijet measurement at 8.16 TeV

- More luminosity : More differential in Q^2
- Higher collision energy : Probing lower x

Dijet measurement at 8.16 TeV

- More luminosity : More differential in Q^2
- Higher collision energy : Probing lower x

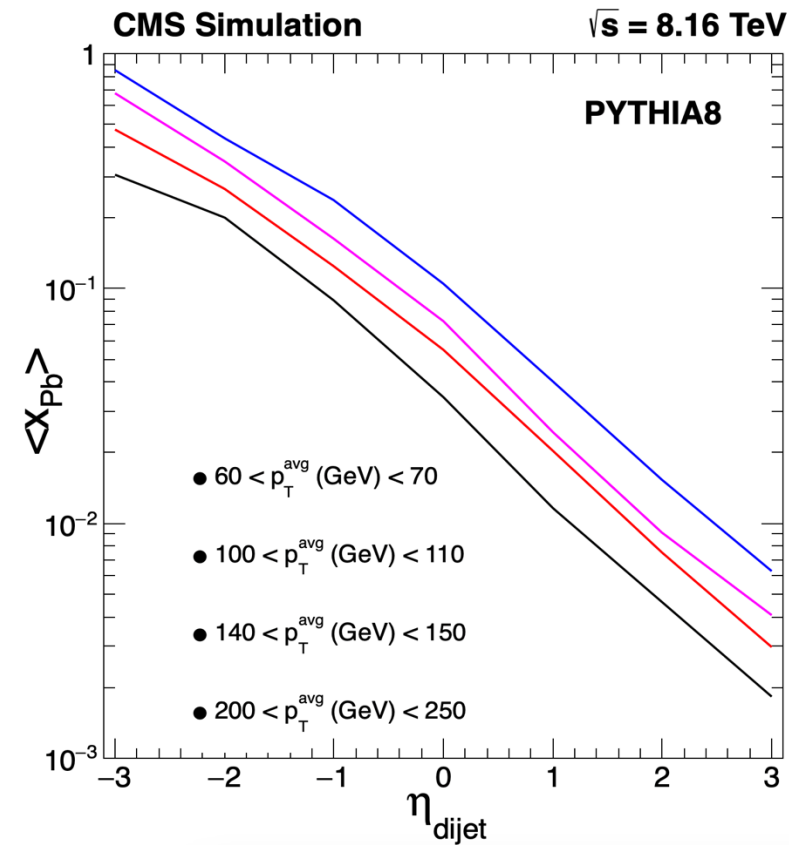
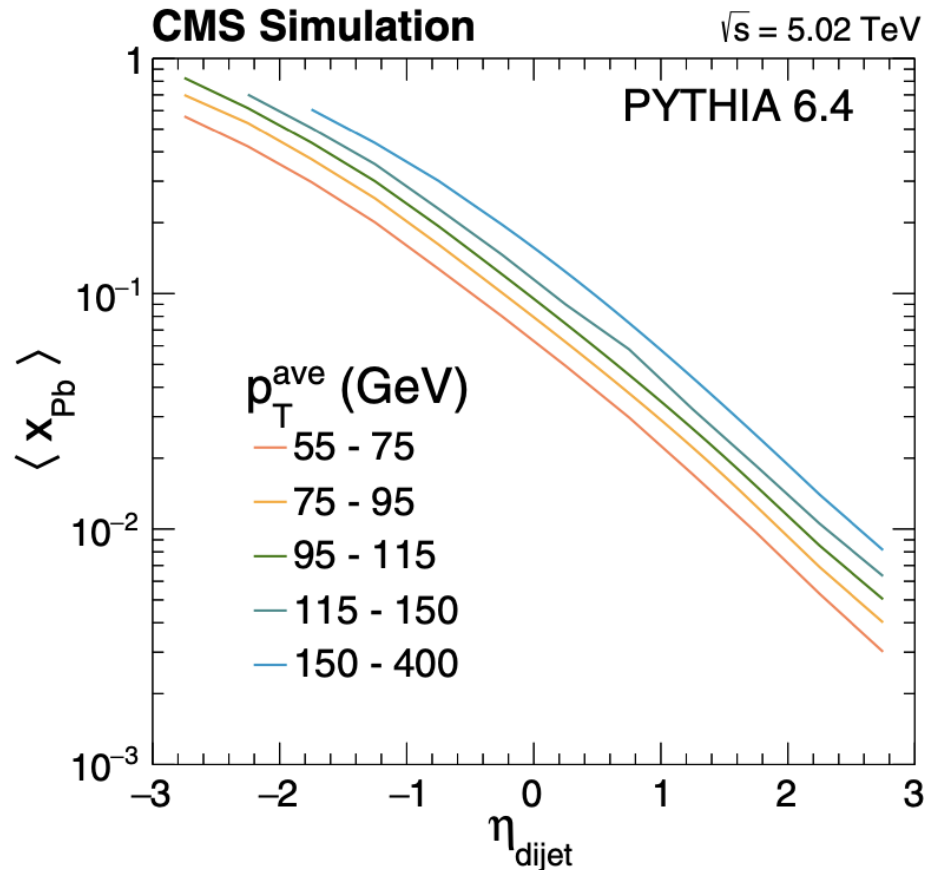
$$x_{Pb} \approx \frac{2p_T^{dijet}}{\sqrt{s_{NN}}} e^{-\eta_{CM}^{dijet}} \cosh \Delta\eta_{CM}^{dijet}$$

Dijet measurement at 8.16 TeV

- More luminosity : More differential in Q^2
- Higher collision energy : Probing lower x

[Eur. Phys. J. C 79, 511 \(2019\)](#)

$$x_{\text{Pb}} \approx \frac{2p_{\text{T}}^{\text{dijet}}}{\sqrt{s_{\text{NN}}}} e^{-\eta_{\text{CM}}^{\text{dijet}}} \cosh \Delta\eta_{\text{CM}}^{\text{dijet}}$$



Dijet measurement at 8.16 TeV

- **Event Selections and trigger**

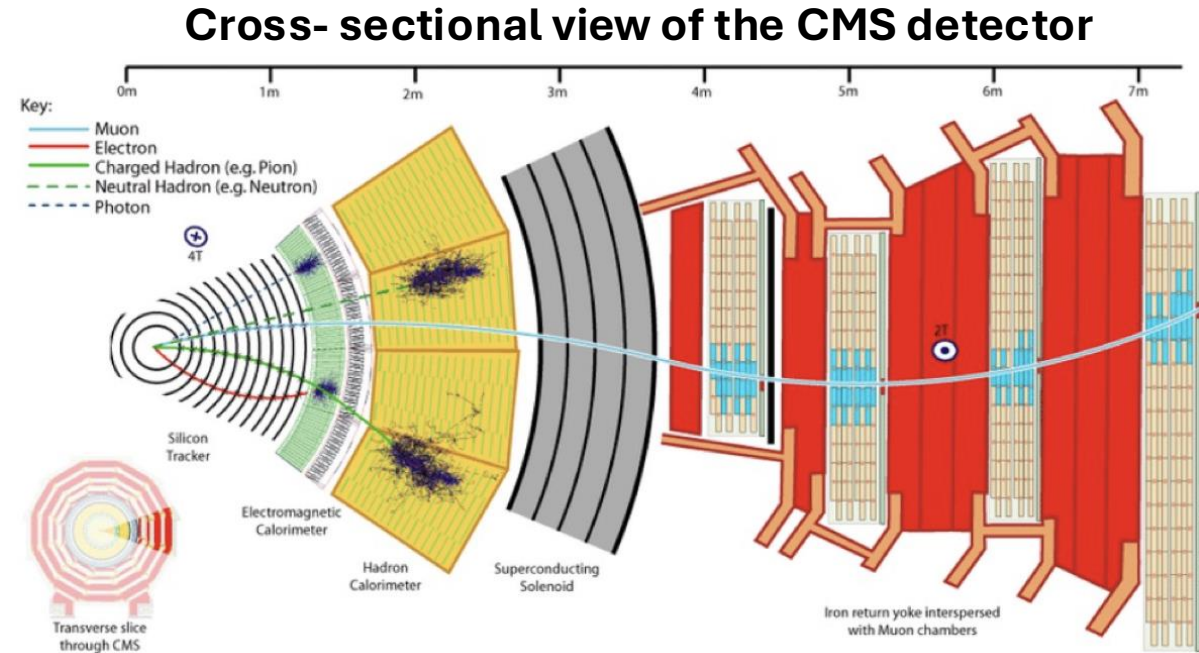
- Triggers : Minbias and jet-triggers
- Leading jet, $p_T > 50$ GeV
- Subleading jet, $p_T > 40$ GeV
- $|\eta^{jet}| < 3$

- **Dijet selection**

- Azimuth selection: $\Delta\Phi > \frac{5\pi}{6}$

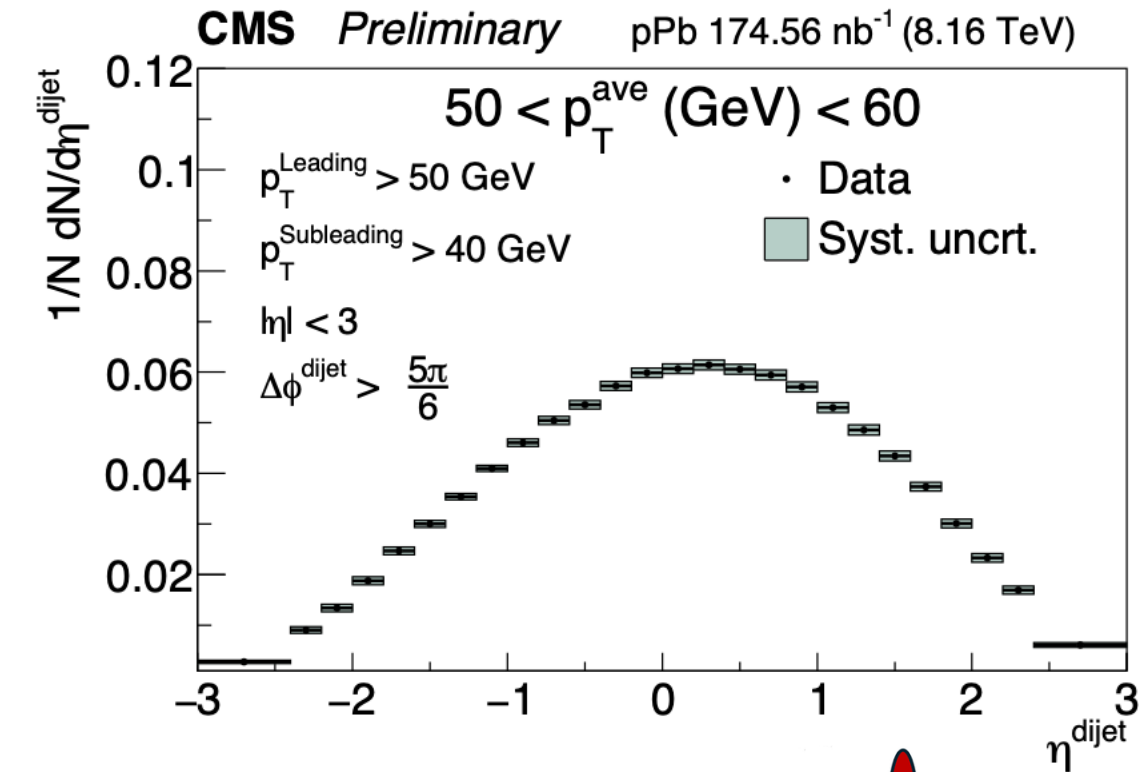
- **Observables** : $\eta_{dijet} = \frac{1}{2} (\eta^{leading} + \eta^{subleading})$

$$p_T^{ave} = \frac{1}{2} (p_T^{leading} + p_T^{subleading}) \text{ (16 bins in } p_T^{ave} \text{)}$$



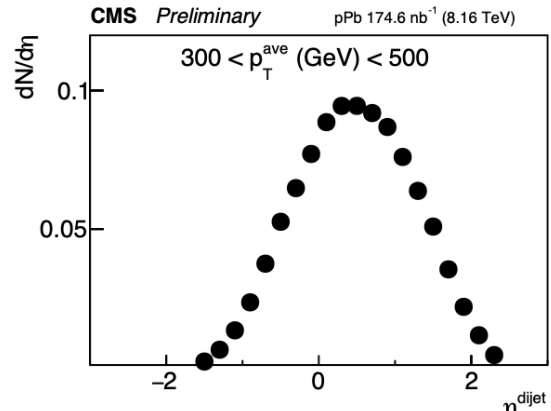
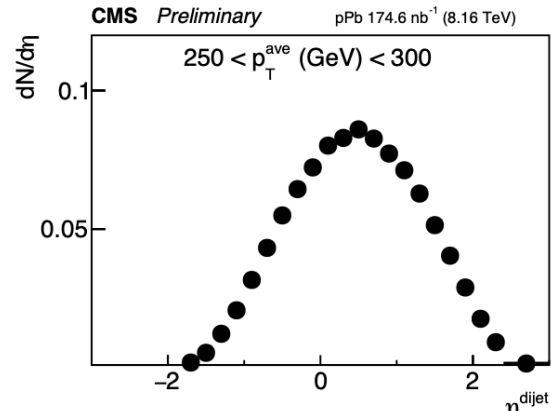
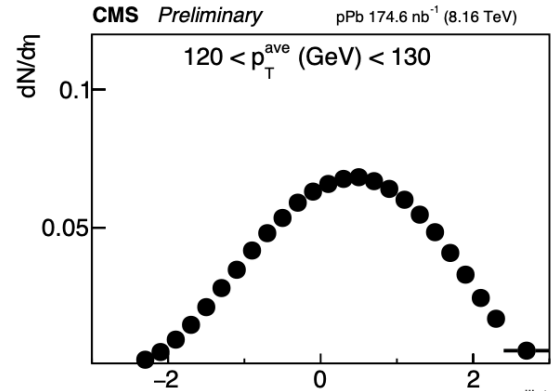
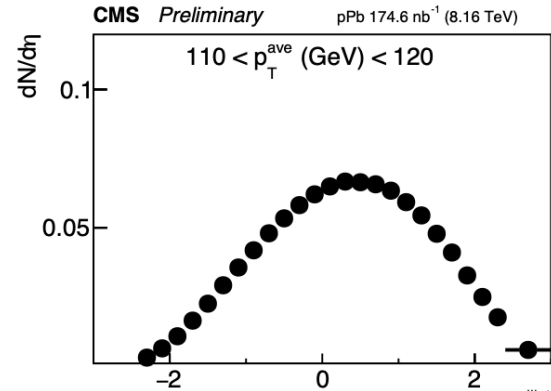
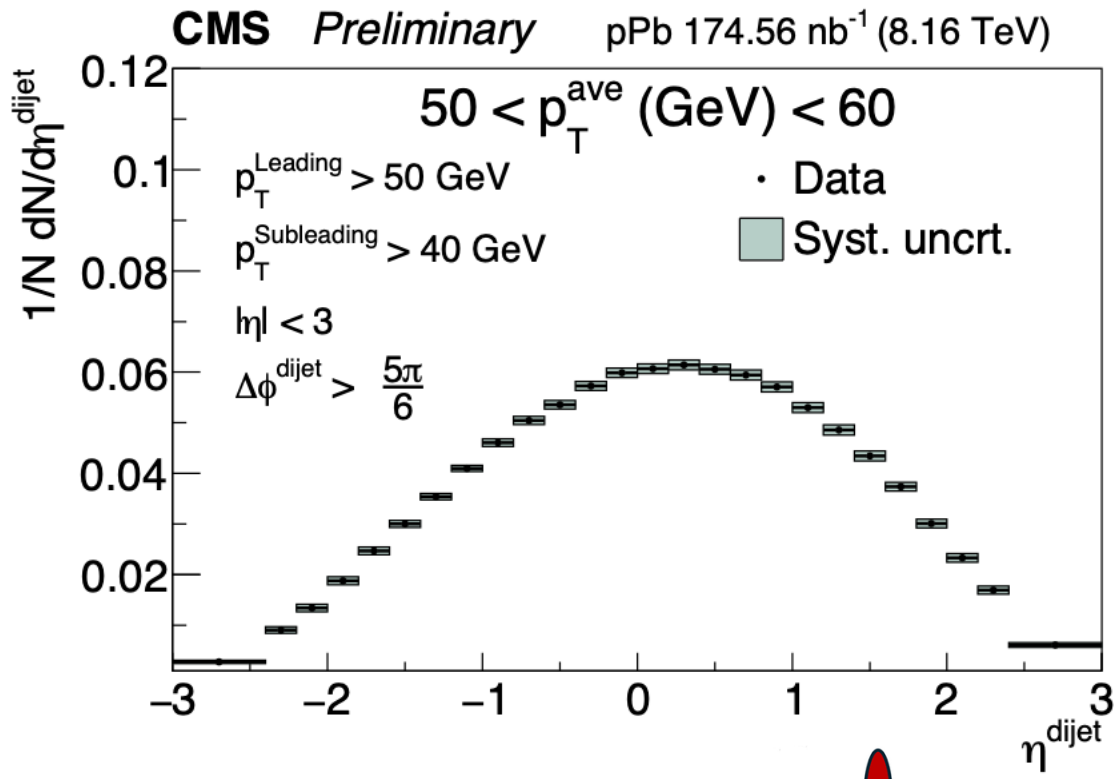
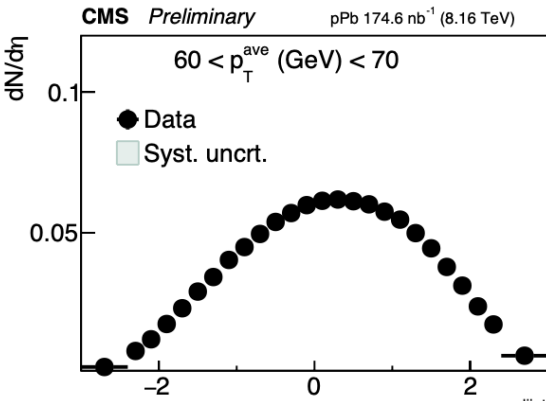
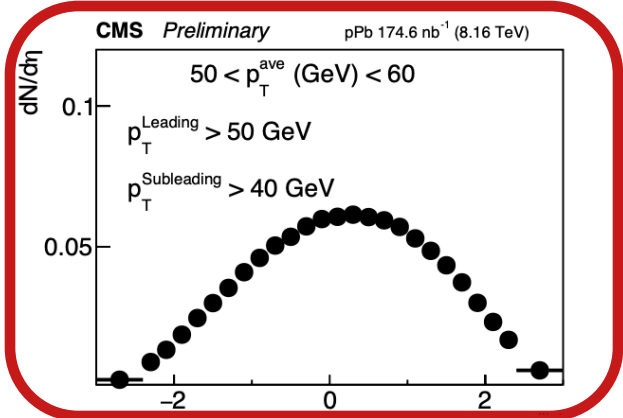
Dijet η distributions in at 8.16 TeV

- Unique and highly constraining set of η_{dijet} for 16 p_T^{ave} intervals



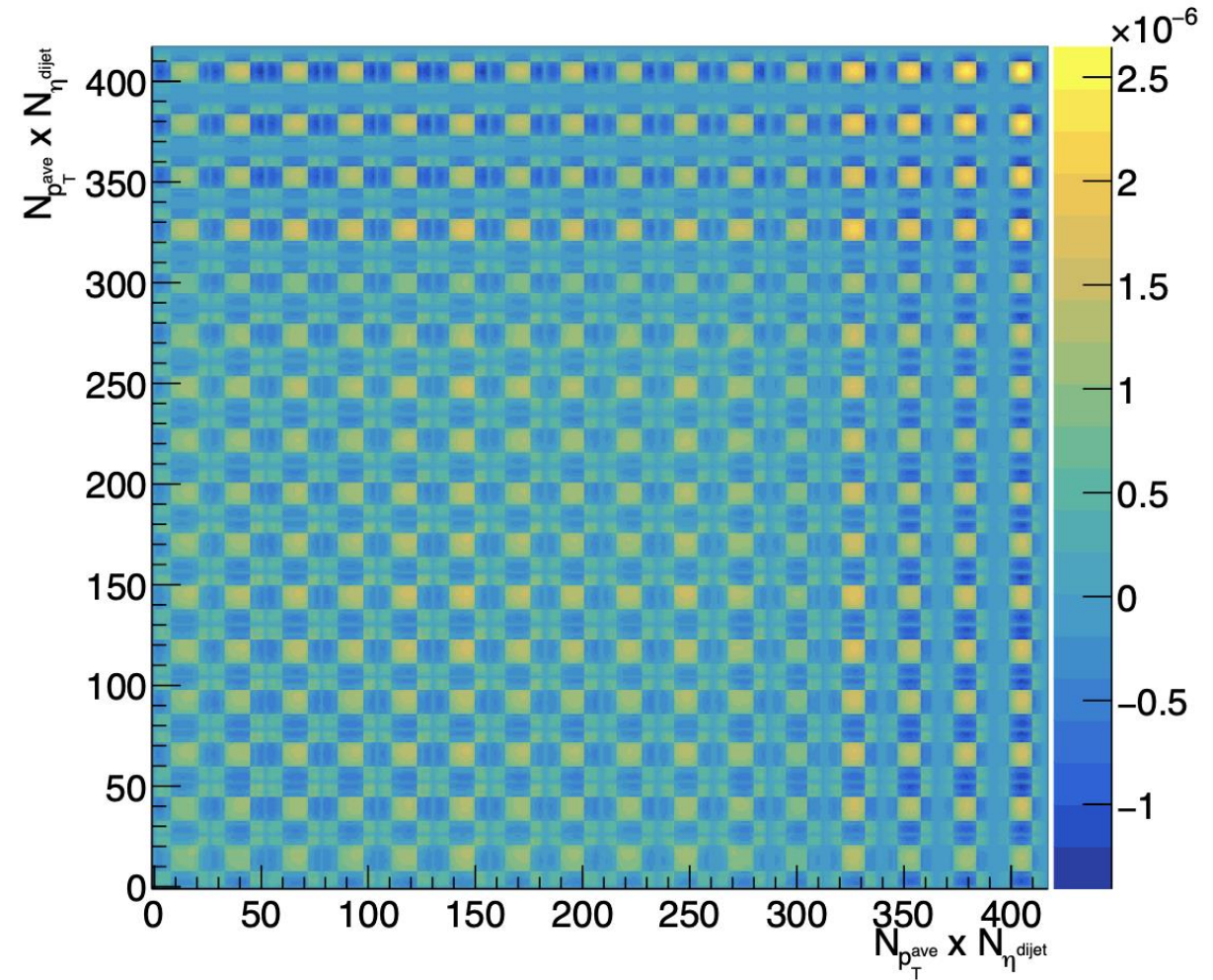
Dijet η distributions in at 8.16 TeV

- Unique and highly constraining set of η_{dijet} for 16 p_T^{ave} intervals



Covariance Matrix

- Covariance matrix containing ~ 100000 unique entries calculated
- Allows fit across full kinematic range



Status of jet quenching search in pPb

- Medium suppression well observed in AA
- High multiplicity pp & pPb show QGP like behavior
- Quenching in pPb tested before : consistent with negligible medium effects

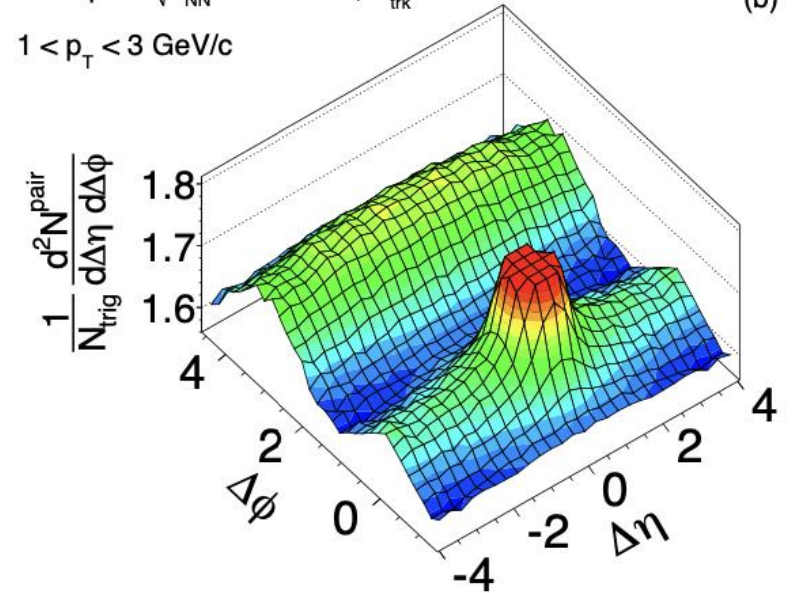
Status of jet quenching search in pPb

- Medium suppression well observed in AA
- High multiplicity pp & pPb show QGP like behavior
- Quenching in pPb tested before : consistent with negligible medium effects

<https://arxiv.org/pdf/1210.5482>

CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{\text{trk}}^{\text{offline}} \geq 110$

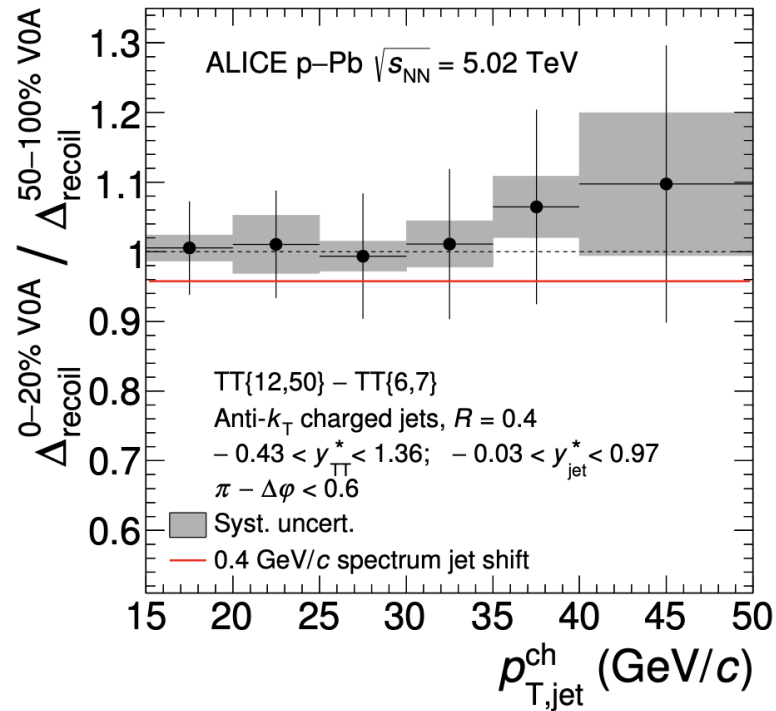
$1 < p_T < 3$ GeV/c



Status of jet quenching search in pPb

- Medium suppression well observed in AA
- High multiplicity pp & pPb show QGP like behavior
- Quenching in pPb tested before : consistent with negligible medium effects

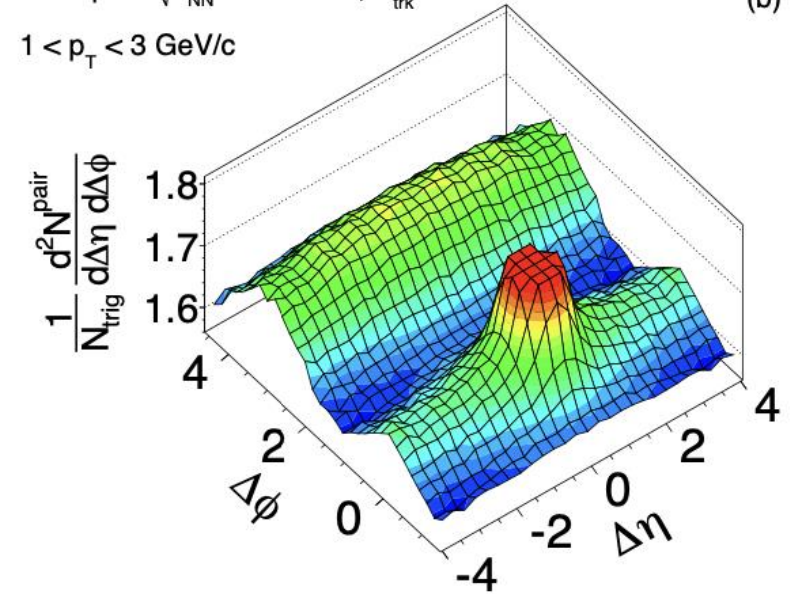
[PLB 783 \(2018\) 95](#)



<https://arxiv.org/pdf/1210.5482>

CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{\text{trk}}^{\text{offline}} \geq 110$

$1 < p_T < 3$ GeV/c



Status of jet quenching search in pPb

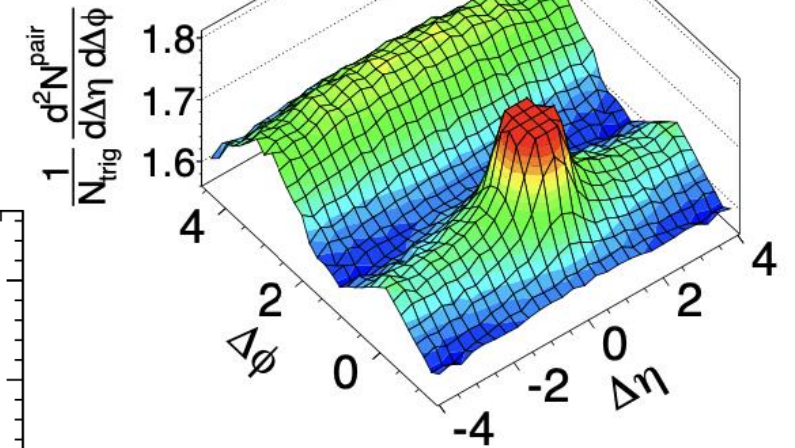
- Medium suppression well observed in AA
- High multiplicity pp & pPb show QGP like behavior
- Quenching in pPb tested before : consistent with negligible medium effects

<https://arxiv.org/pdf/1210.5482>

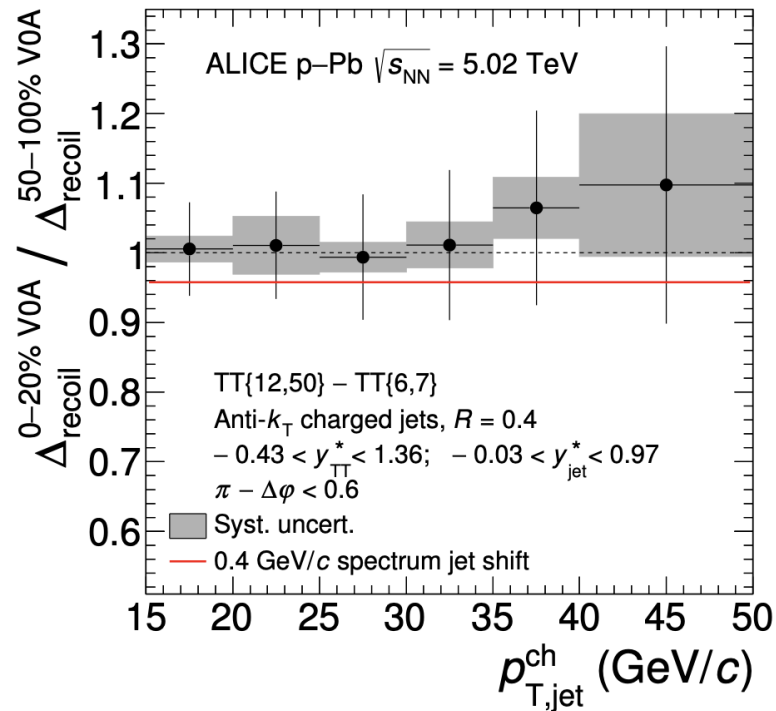
CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{trk}^{offline} \geq 110$

$1 < p_T < 3$ GeV/c

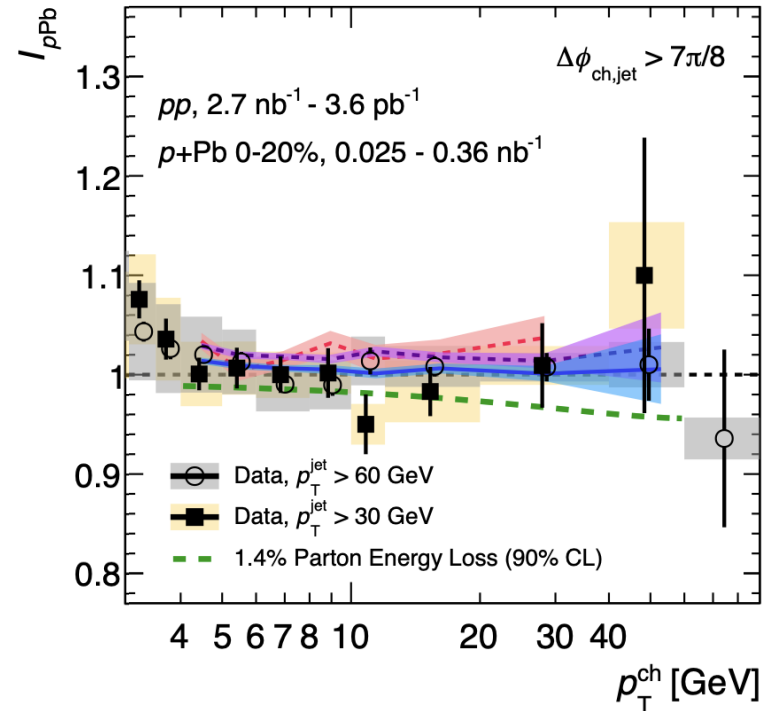
(b)



[PLB 783 \(2018\) 95](#)



[PRL 131 \(2023\) 072301](#)



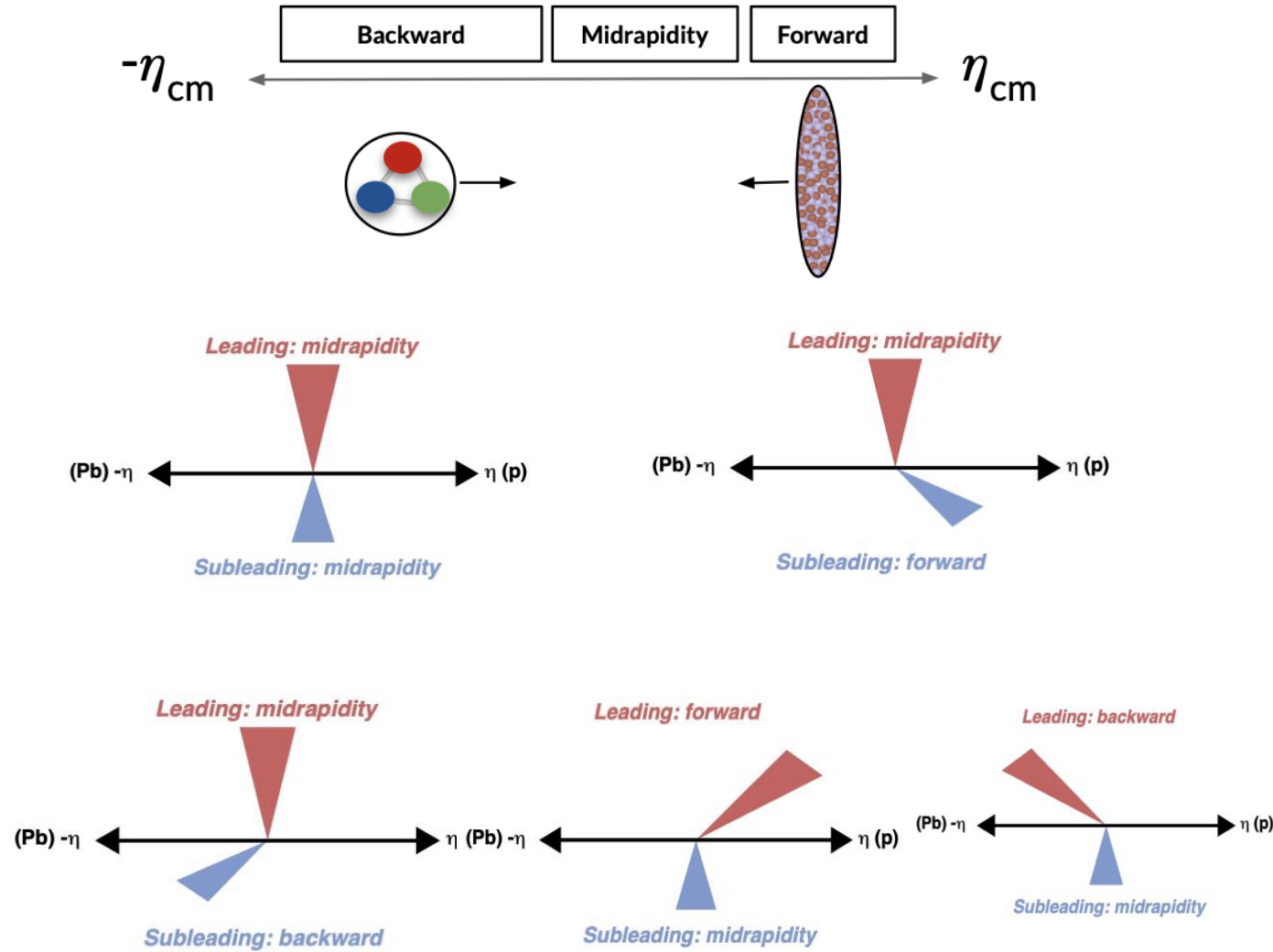
x_j measurement in pPb at 8.16 TeV

- Observable: $x_j = \frac{p_T^{subleading}}{p_T^{leading}}$

- Dijet selection:

- ❑ $R=0.4$
- ❑ $p_T^{j1} > 100 \text{ GeV}, p_T^{j2} > 50 \text{ GeV}$
- ❑ $|\Delta\Phi| > \frac{5\pi}{6}$

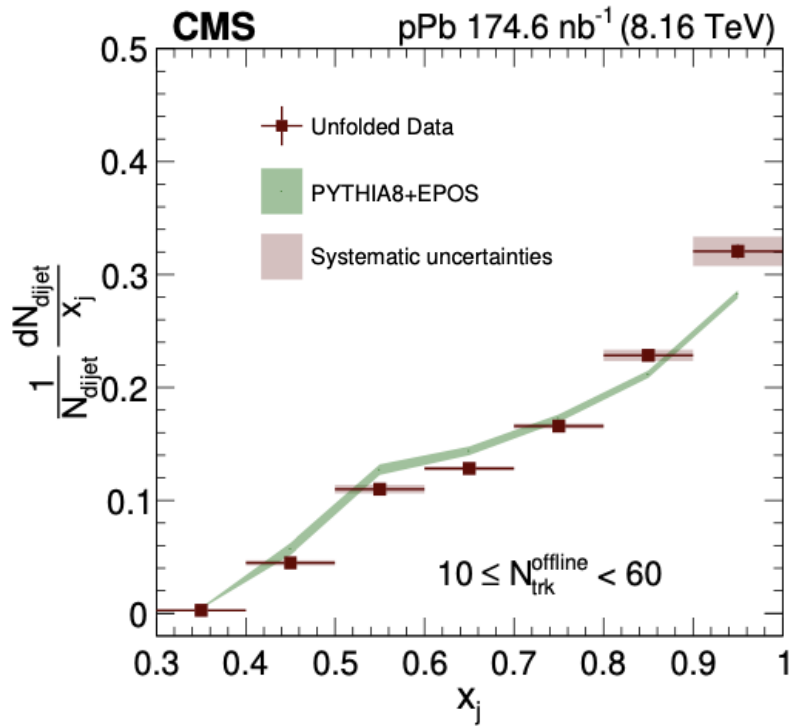
- x_j in six multiplicity classes across $N_{trk} [10,400]$
- Probing distinct x by various dijet rapidity selections



Hard Probes 2024

x_j results : Multiplicity Dependence

- Changes observed in shapes from low to high multiplicity ranges
- Similar behavior observed between **data** and **MC (PYTHIA+EPOS)**

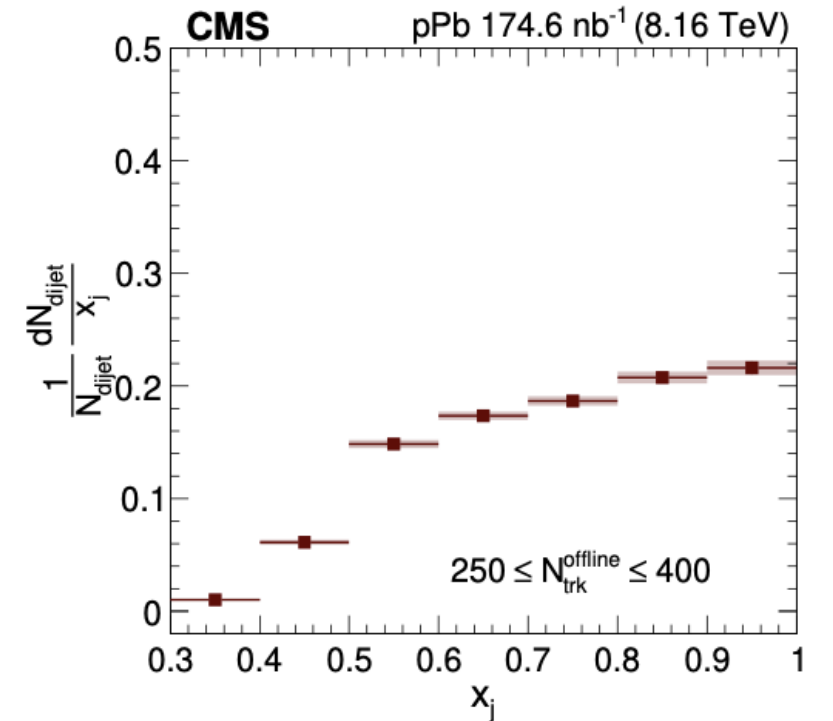
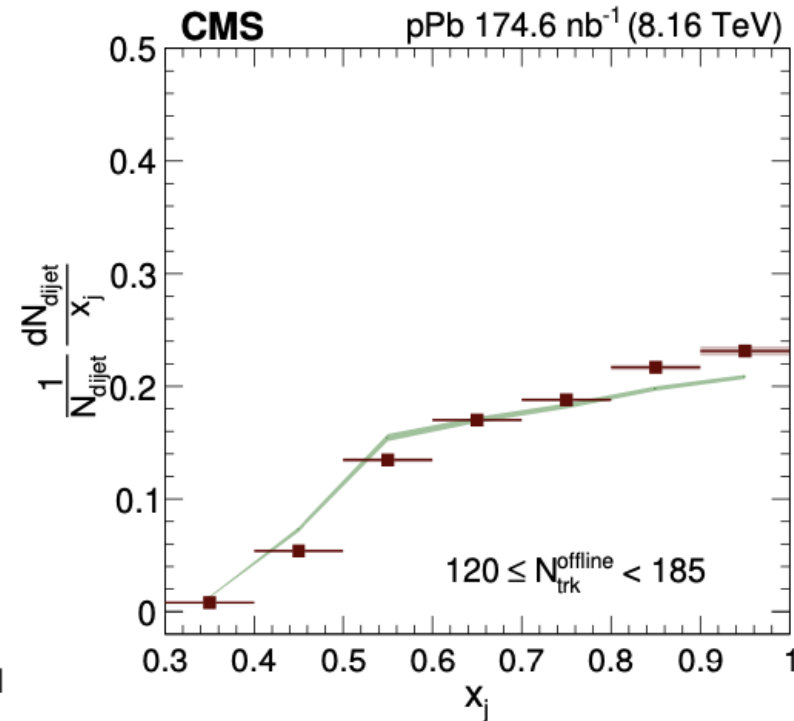
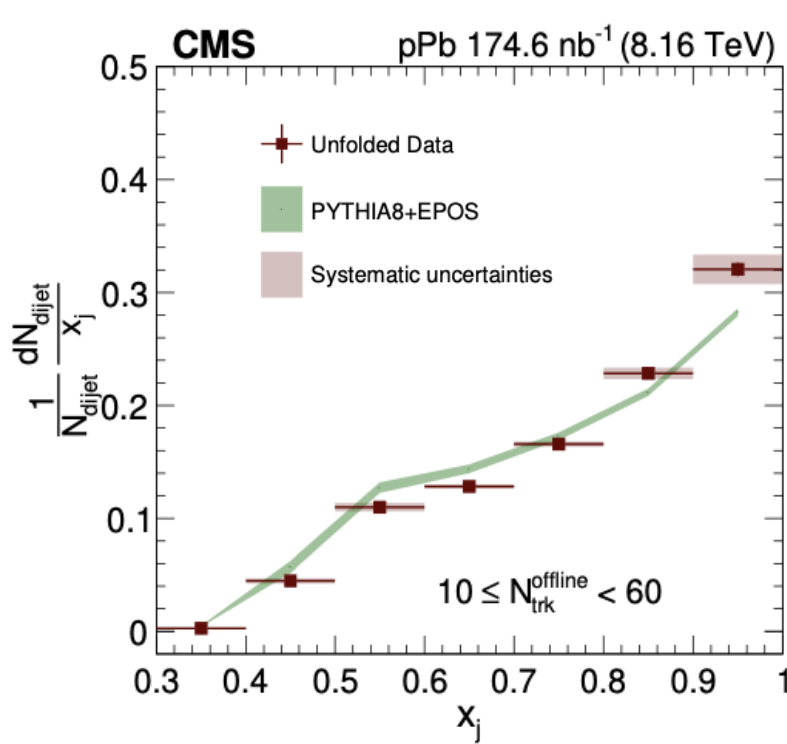


x_j results : Multiplicity Dependence

- Changes observed in shapes from low to high multiplicity ranges
- Similar behavior observed between **data** and **MC (PYTHIA+EPOS)**



[JHEP 2025, 118 \(2025\)](#)



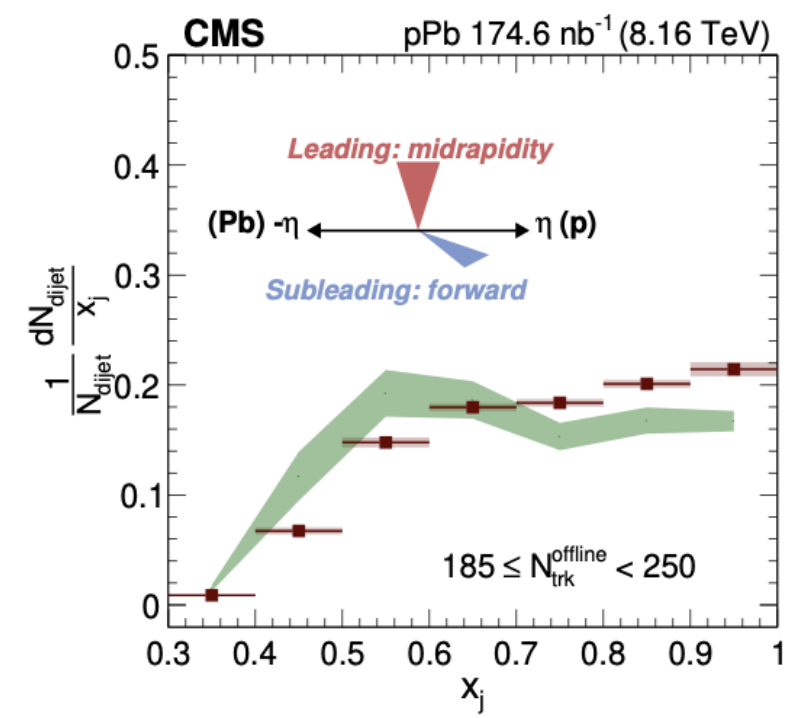
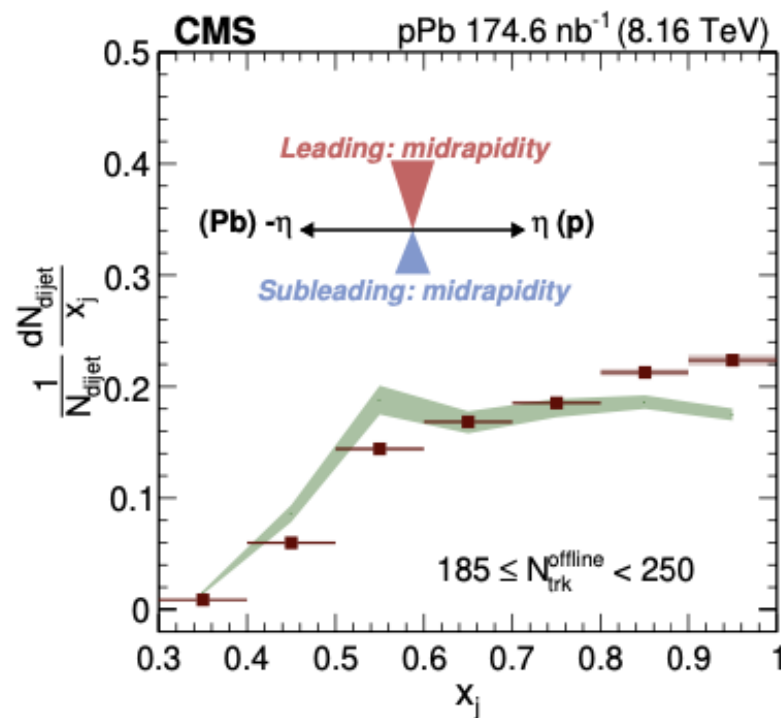
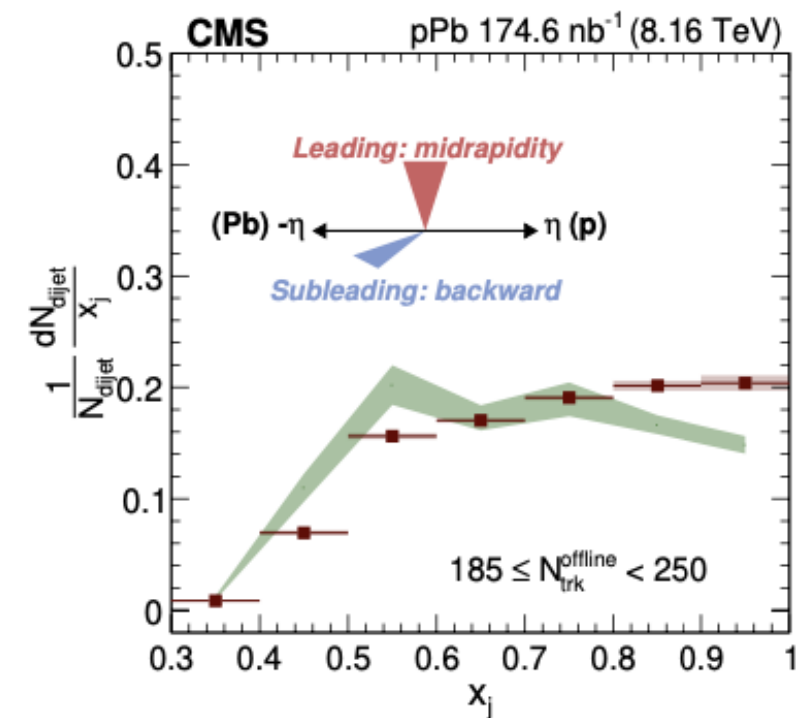
Increasing multiplicity



x_j results : Pseudorapidity Dependence

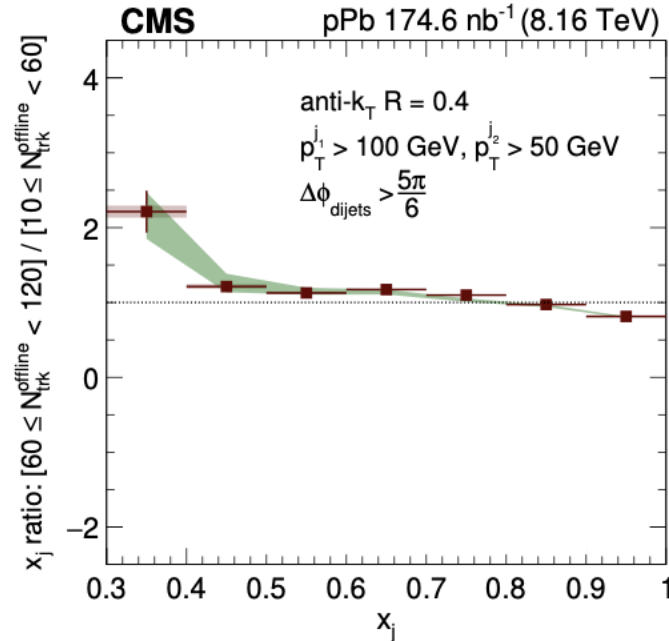
- Very similar behavior for all jet η combinations
- Similar behavior observed between **data** and **MC**

[JHEP 2025, 118 \(2025\)](#)



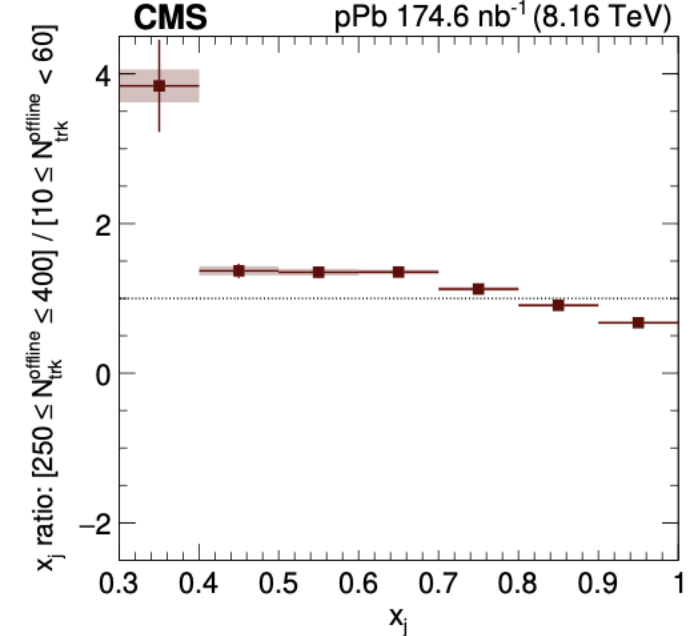
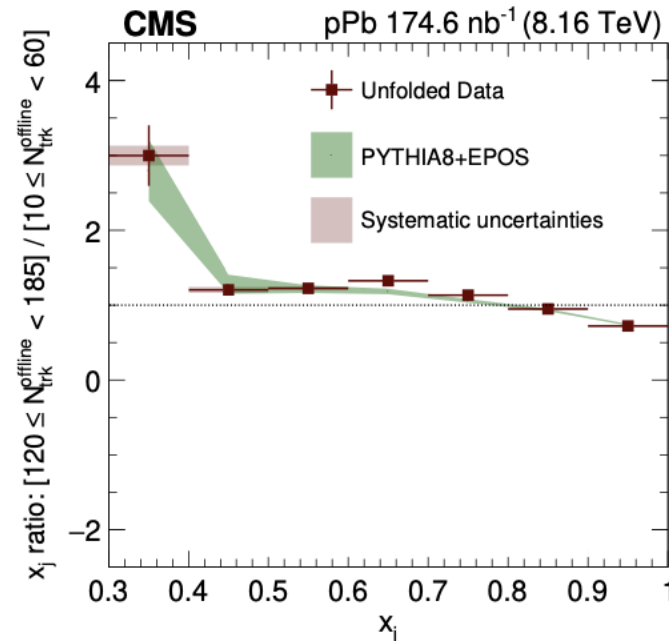
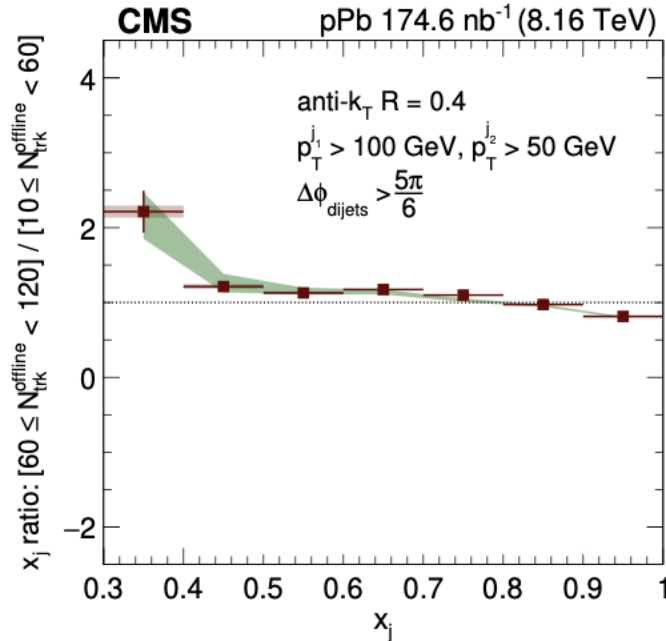
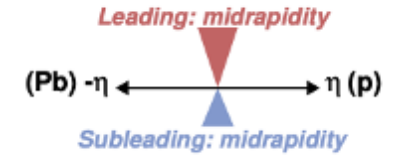
x_j ratio to lower multiplicity range

- Reference multiplicity range : $10 < N_{\text{trk}} < 60$
- Ratio > 1 at low x_j and < 1 for high x_j
- Data well described by PYTHIA+EPOS MC in all multiplicities and η combinations



x_j ratio to lower multiplicity range

- Reference multiplicity range : $10 < N_{\text{trk}} < 60$
- Ratio > 1 at low x_j and < 1 for high x_j
- Data well described by PYTHIA+EPOS MC in all multiplicities and η combinations

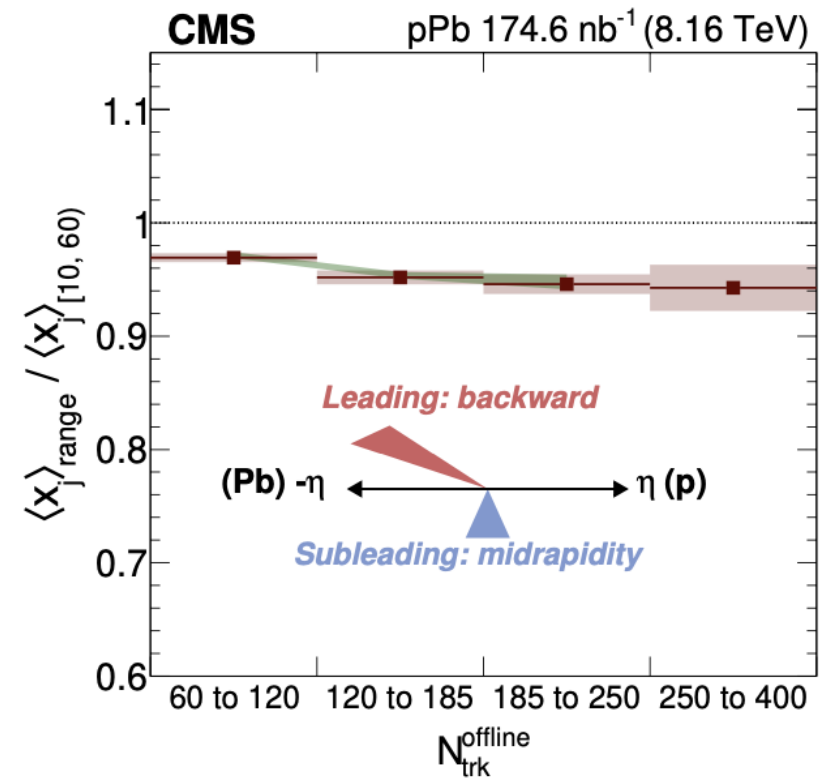
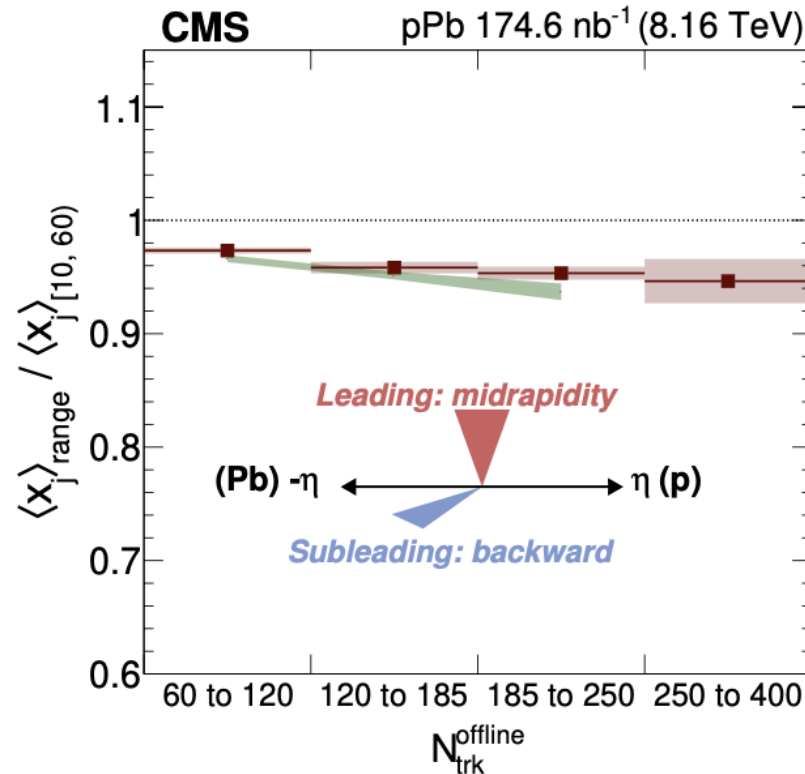
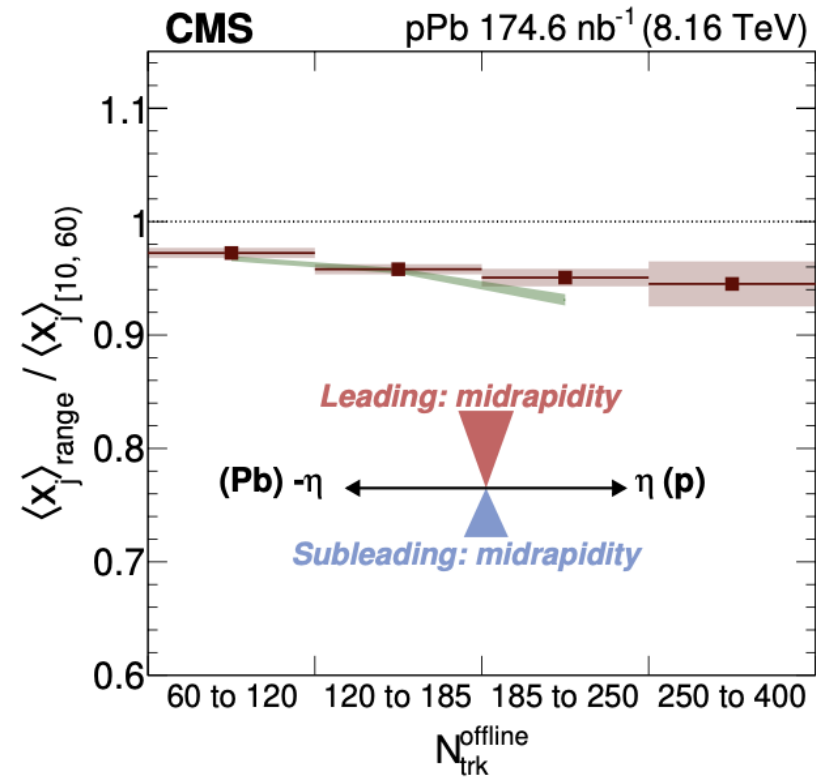


Increasing multiplicity



$\langle x_j \rangle$ ratio to lower multiplicity range

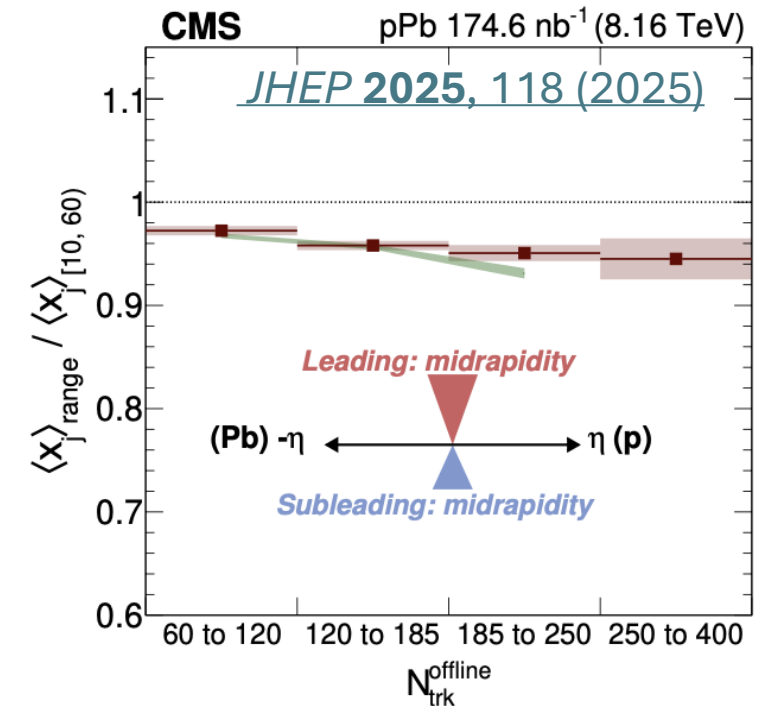
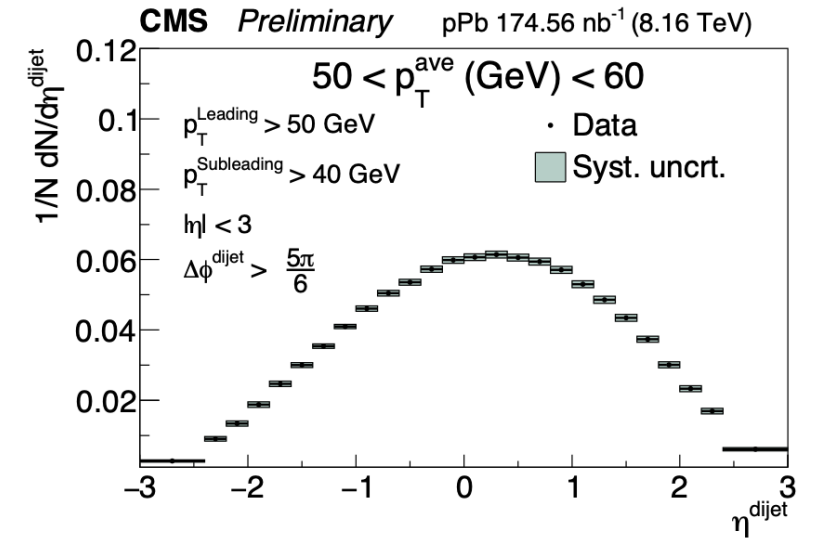
- Ratio decreases with multiplicity
- Overall good data/MC agreement
- Energy loss constrained to be less than 1.26% at the one-sided 90% CL



Summary

- Dijet η provide important constraints on gluon nPDFs
- Highly constraining sets of η_{dijet} measured in pPb collisions at 8.16 TeV
- Dijet p_T imbalance measured in pPb collisions at 8.16 TeV
- No modifications observed for any configuration : dijets are clean probes of the initial state

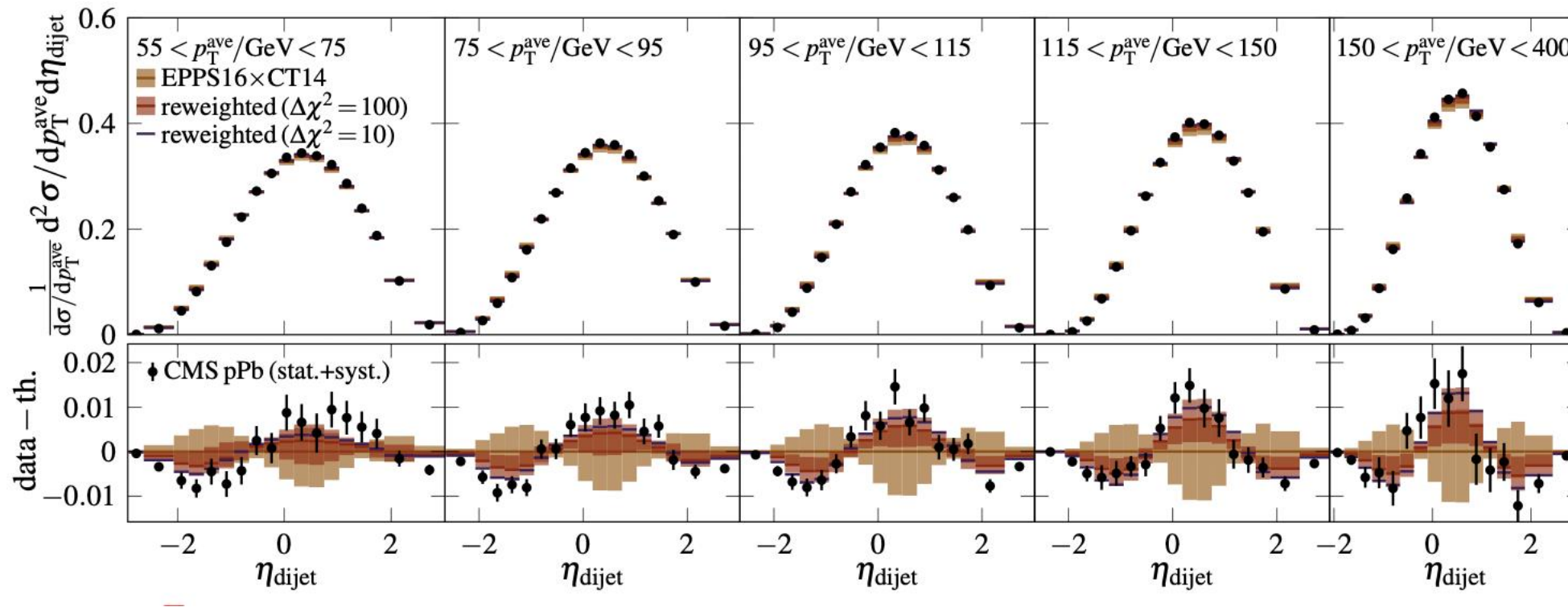
HIN-24-014-PAS



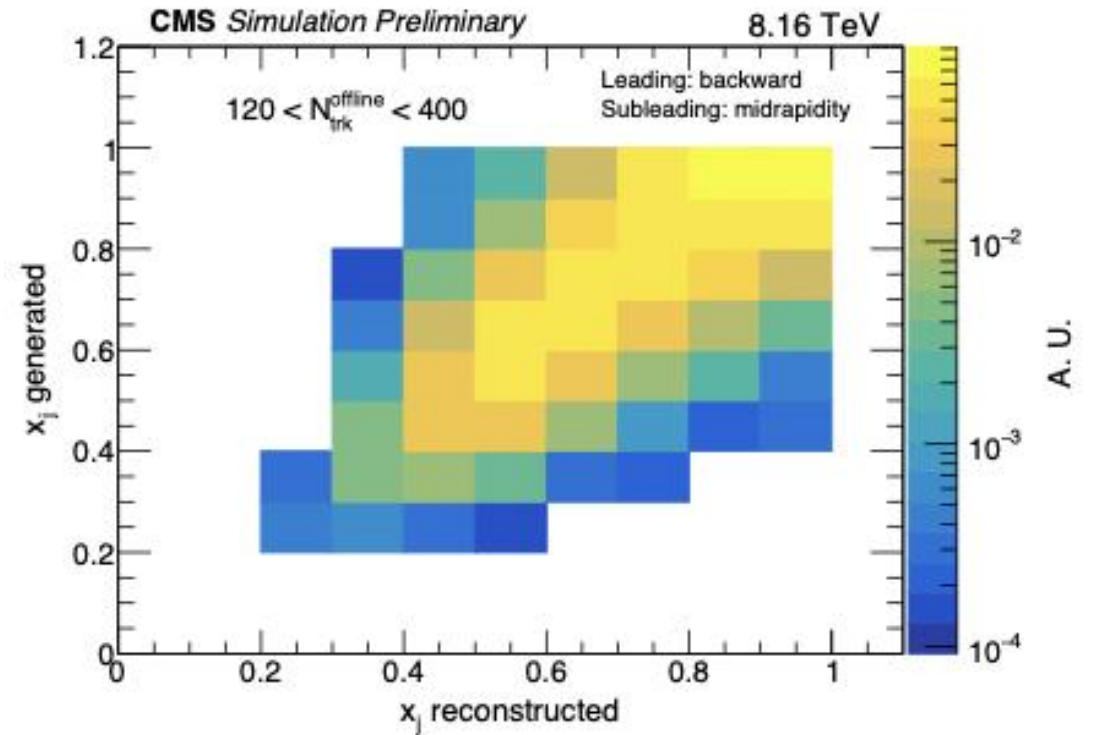
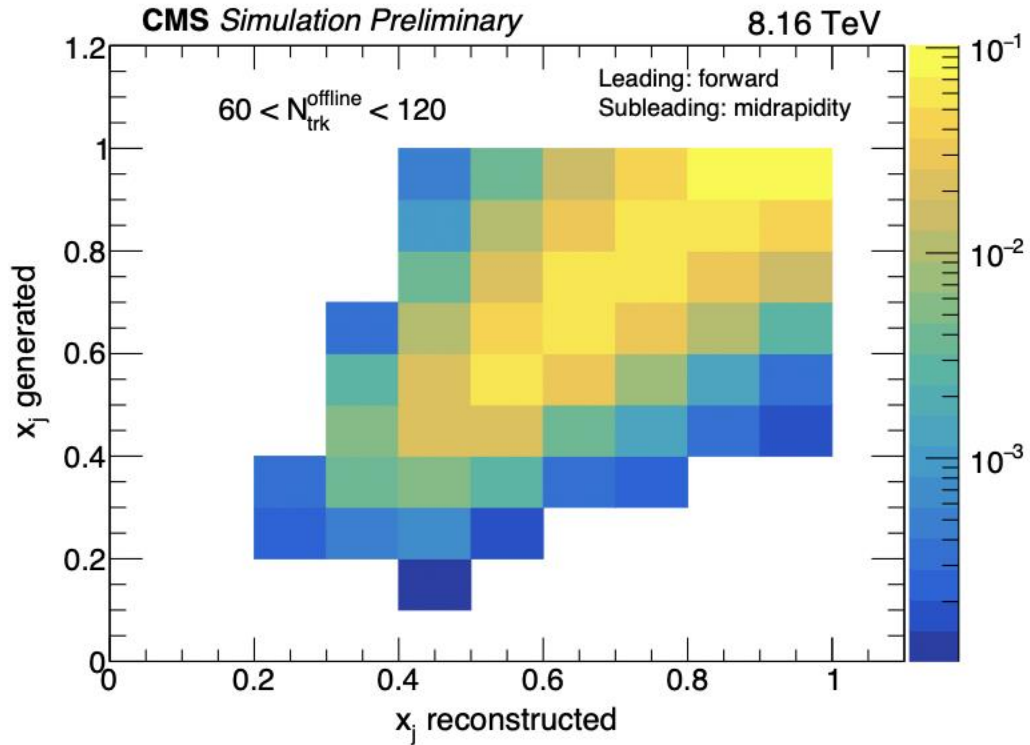
BACK UP

nPDF reweighting

Eur. Phys. J. C **79**, 511 (2019)



x_j unfolding response matrices



x_j distribution in pp collisions

