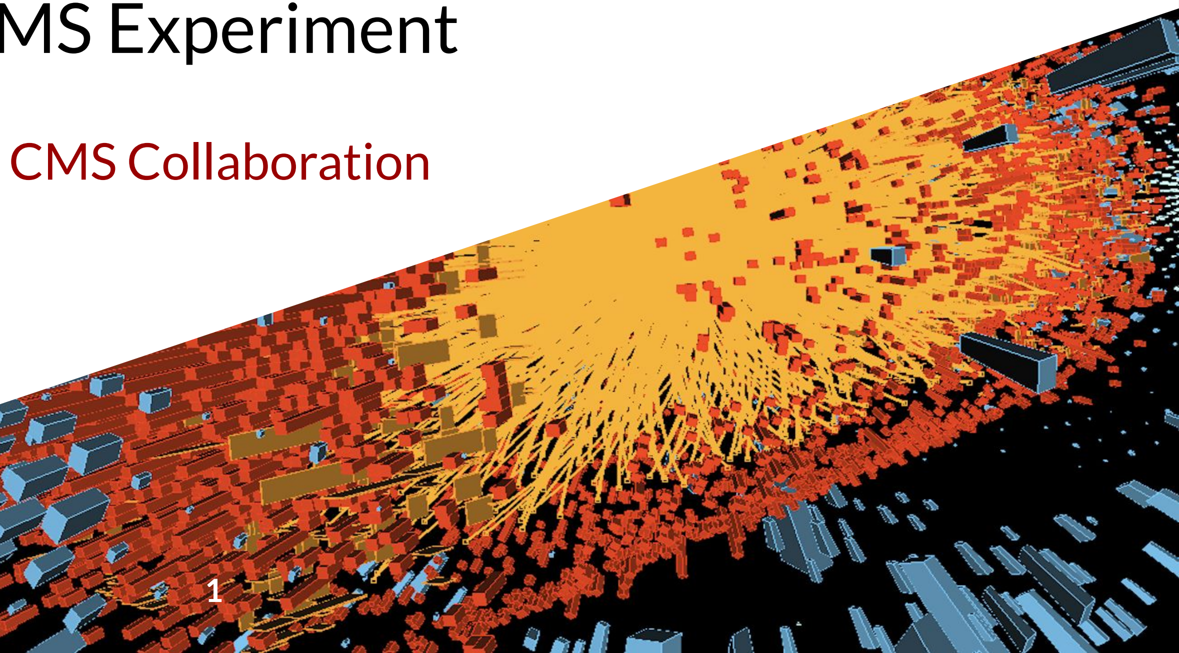
Search for jet quenching using high-multiplicity pPb collisions at the CMS Experiment

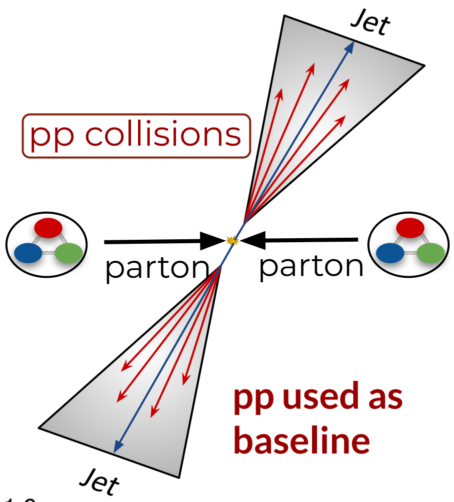
Dener De Souza Lemos for the CMS Collaboration

University of Illinois at Chicago

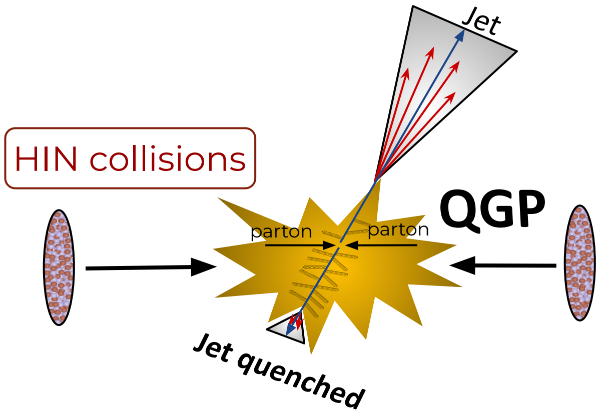
September 24th, 2024



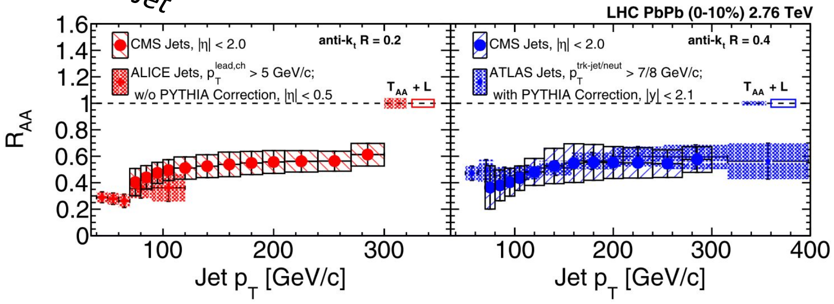
Measurements of jet quenching at CMS



pp used as baseline

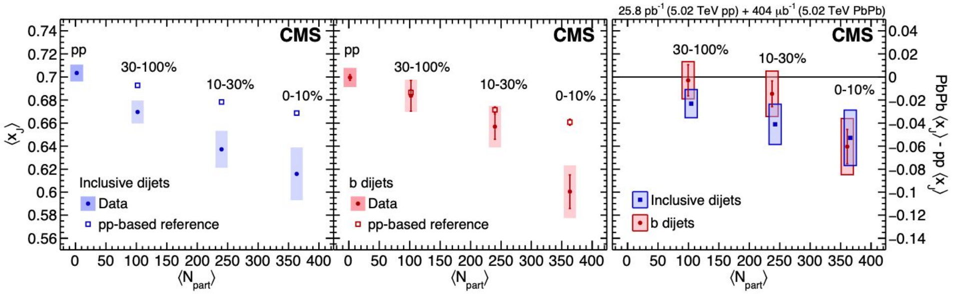


Suppression due to the medium in AA "jet quenching"



$$R_{AA} = \frac{d^2N^{AA}_{\text{jets}}/dp_T\,d\eta}{\langle T_{AA}\rangle d^2\sigma^{pp}_{\text{jets}}/dp_T\,d\eta}$$

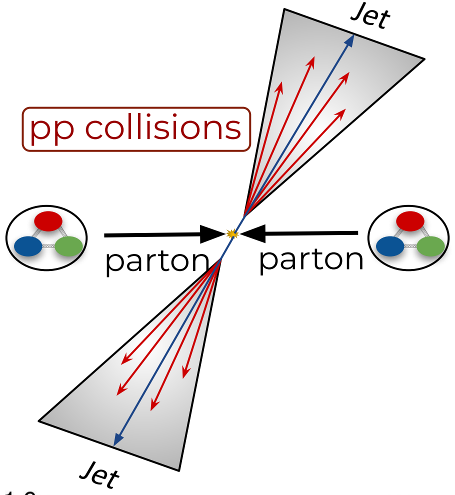
Phys. Rev. C 96 (2017) 015202

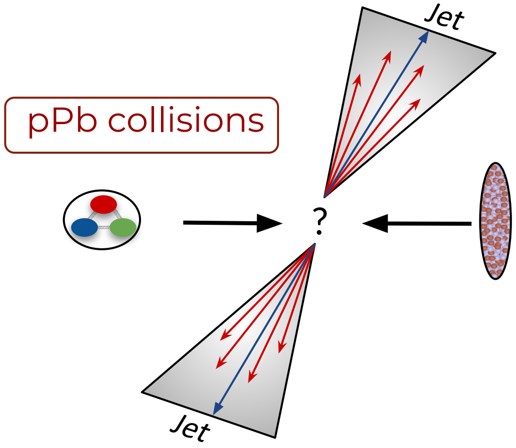


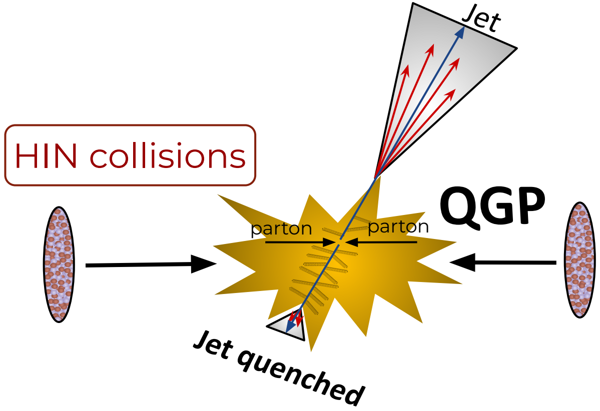
JHEP 03 (2018) 181

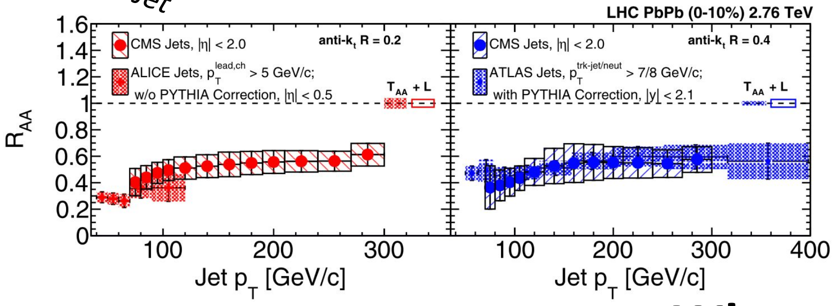
$$x_j = \frac{p_T^{\text{Subleading jet}}}{p_T^{\text{Leading jet}}}$$

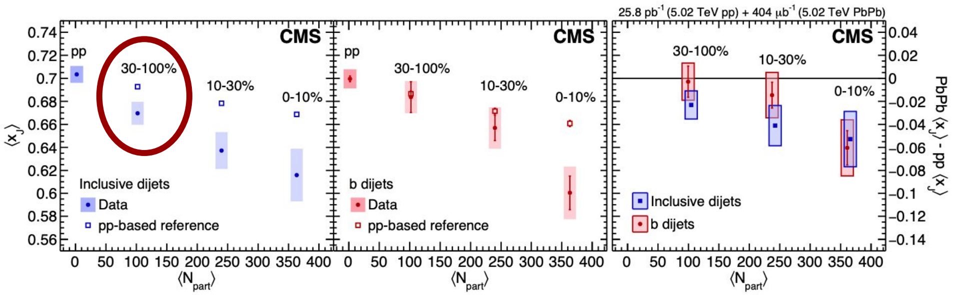
Measurements of jet quenching at CMS











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What about pPb?

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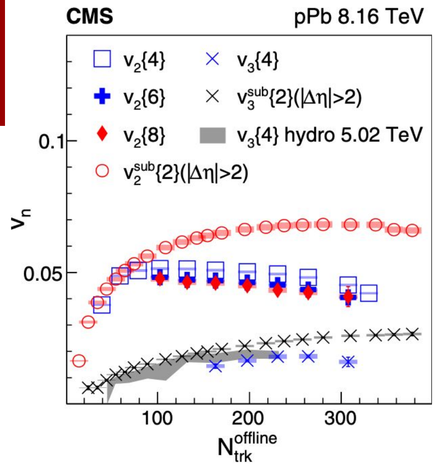
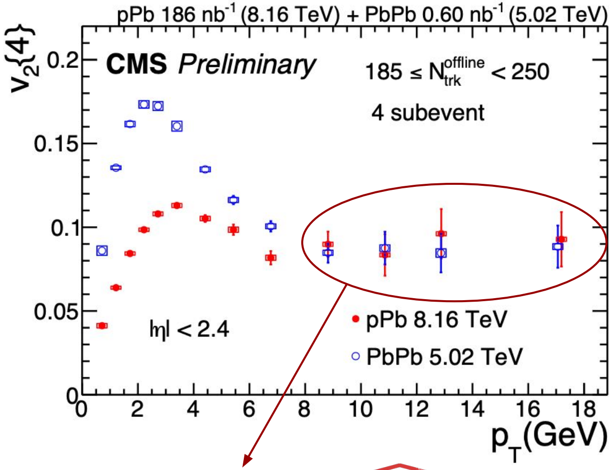
$$x_j = \frac{p_T^{\text{Subleading jet}}}{p_T^{\text{Leading jet}}}$$

Datasets and Monte Carlo simulations

- pPb@8.16 TeV (L = 174.6 nb^{-1})
  - Minimum-bias trigger
    - ~6.4 Billion events in total
    - Multiplicity range: 10 to 185
  - High multiplicity triggers
    - Multiplicity range: 185 to 250
      - ~ 498 Million events in total
    - Multiplicity range: > 250
      - ~ 32 Million events in total
  - Simulations: PYTHIA8+EPOS
    - ~ 22 Million dijet events (all multiplicities)
    - For corrections , unfolding and data comparison



PRC 101, 014912 (2020)



See Rohit's talk

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Analysis workflow

Datasets and Simulations

Jet energy corrections

Selections

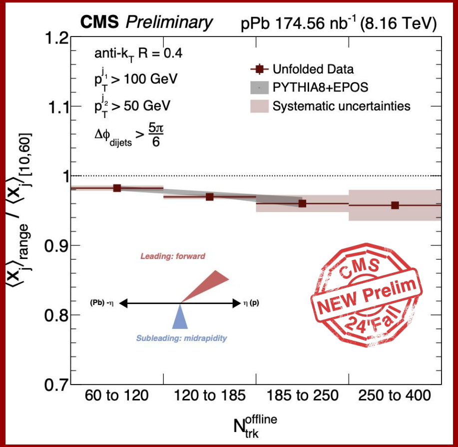
Unfolding

Observables

Systematic uncertainties

(see backup)

Final results

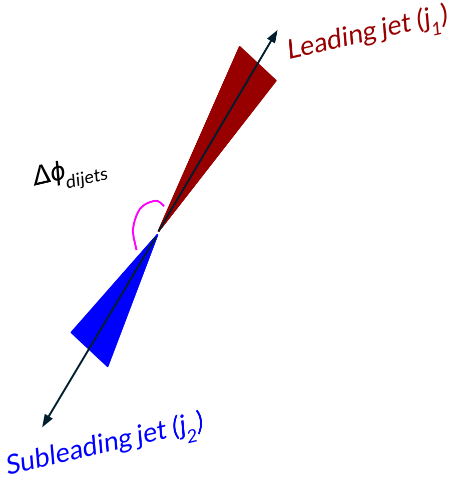


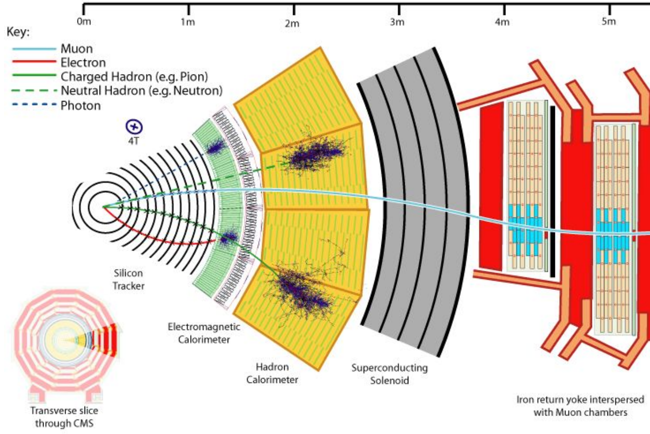
Measurement setup

- Dijet selection
  - Particle Flow
    - anti-k_T jets with R = 0.4
    - $p_T^{j1} > 100$ GeV
    - $p_T^{j2} > 50$ GeV
    - $|\Delta\phi_{dijets}| > 5\pi/6$
- Observable

$$x_j = \frac{p_T^{j_2}}{p_T^{j_1}}$$

- Analysis methods
  - Ratio high-to-low multiplicity (R_{CP}-like)
  - Probe proton and lead directions (η dependency)
  - Apply D'Agostini unfolding to correct for resolution





x_j dependency

- Study of x_j as function of multiplicity and pseudorapidity
  - Multiplicity ranges: [10,60], [60,120], [120,185], [185,250] and [250,400]

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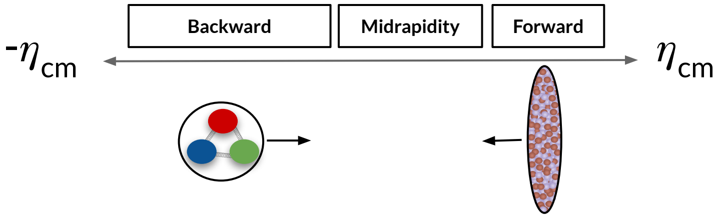
  - Probe jets in both proton and lead directions
    - Midrapidity: $|\eta_{CM}| < 1$
    - Forward (p direction): $1.2 < \eta_{CM} < 2.4$
    - Backward (Pb direction): $-3.3 < \eta_{CM} < -1.2$



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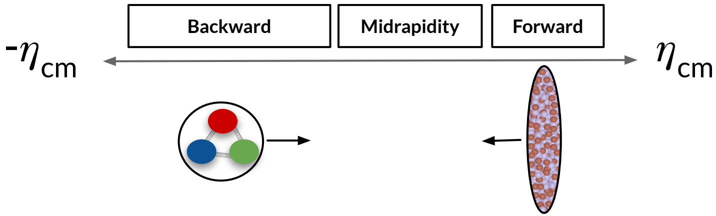
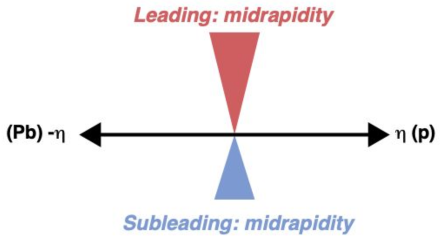
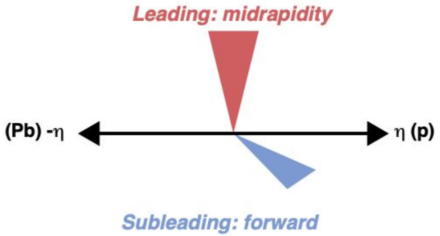
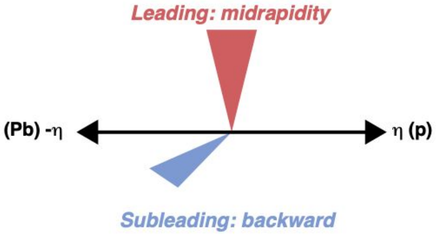
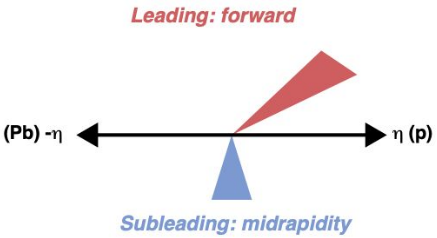


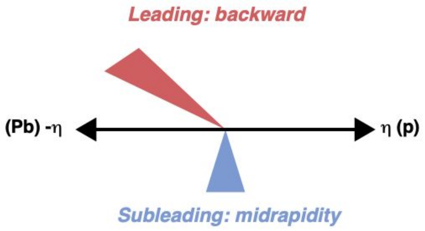
  - Dijet combinations studied:



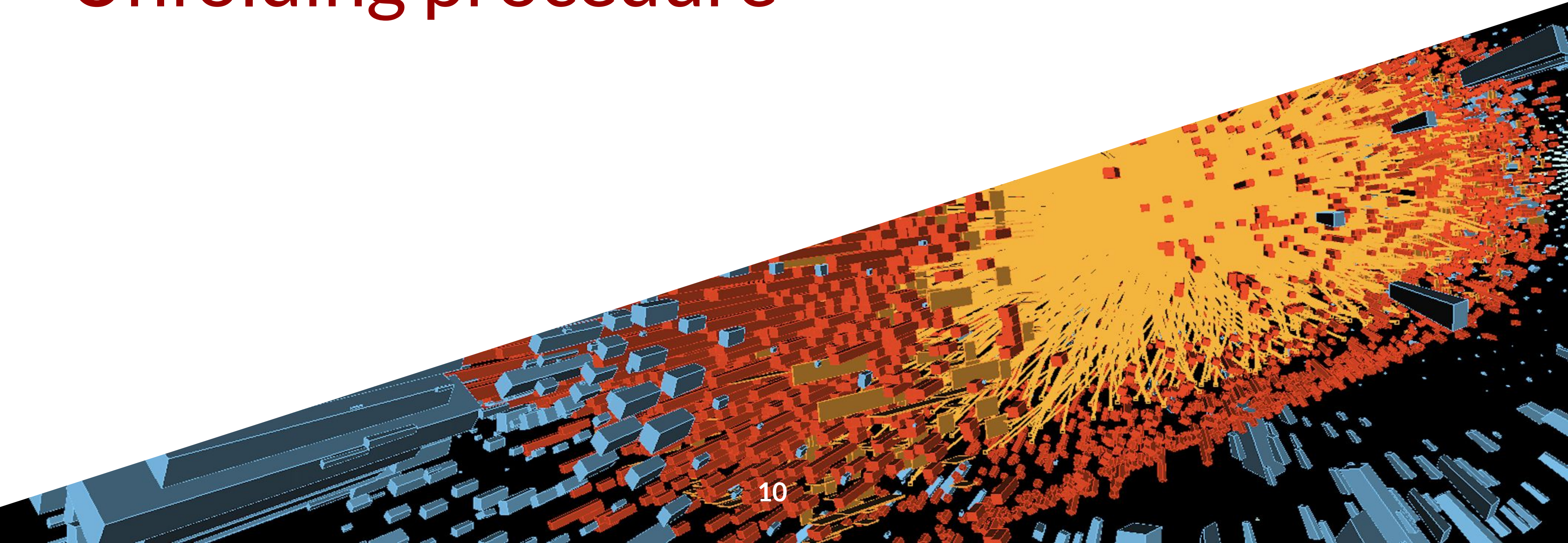








Unfolding procedure



Unfolding x_j

- First x_j unfolding at CMS
  - x_j reconstructed vs x_j generated
    - For each η_{CM} combination
    - In different multiplicity bins
      - [10,60], [60,120] and [>120]
- Effects taken into account in the response matrices
  - Fakes → Negligible
  - Swap → ~20%
  - Missing → ROOUnfold
  - Data/MC differences
    - p_T^{j1} vs p_T^{j2} PDF map applied to the matrices
- Applied with D'Agostini unfolding using ROOUnfold

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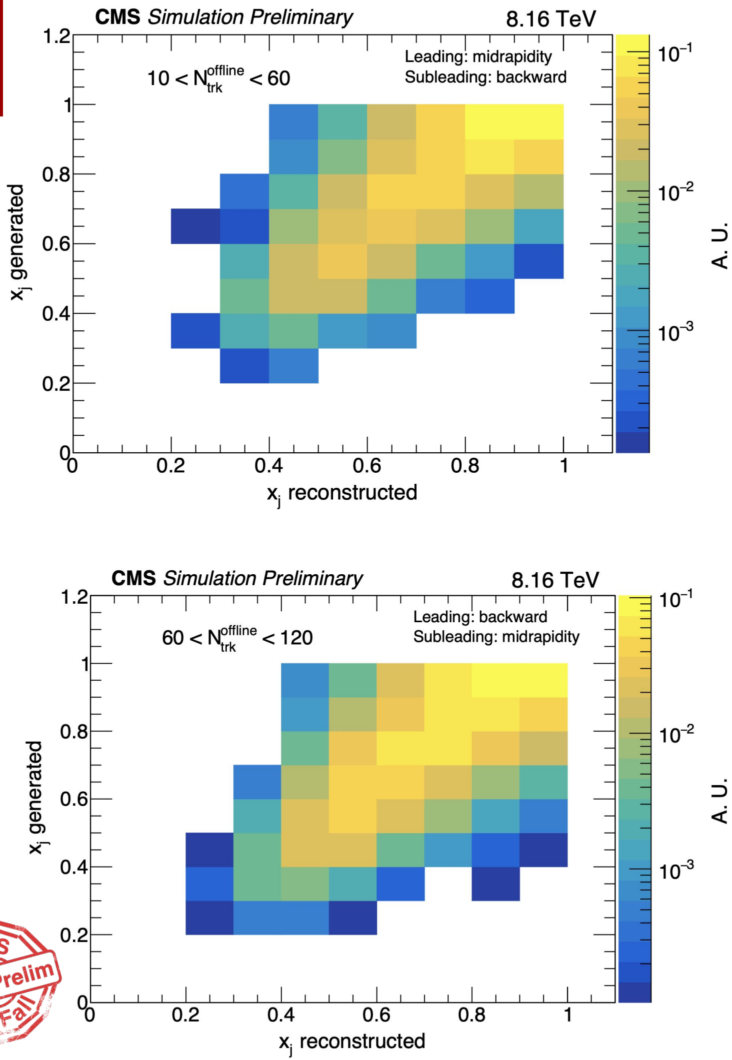

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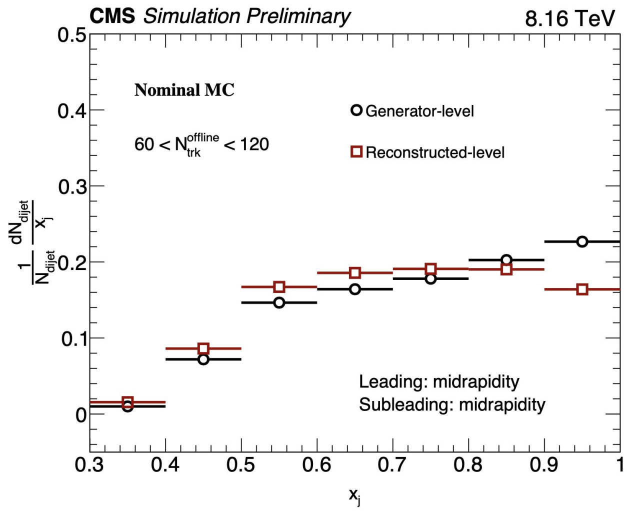
Validate the unfolding procedure at MC (I): prior

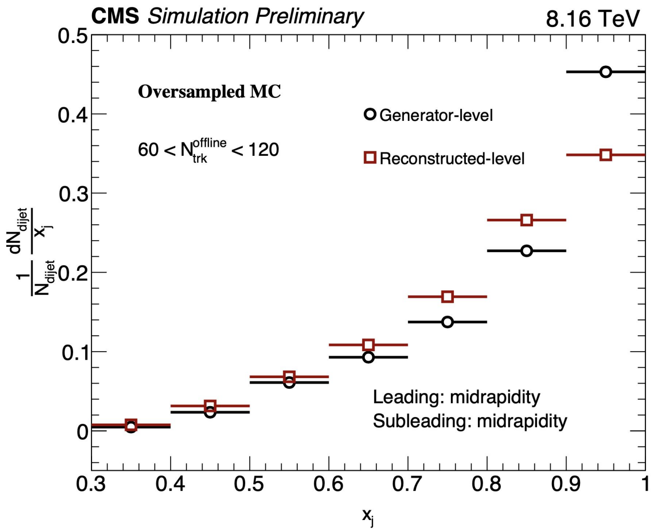
- Data/MC reconstructed pdf(p_T^{j1} , p_T^{j2}) is applied to remove sensitivity to prior shape
- Procedure is tested using an "oversampled MC"
  - Very different prior between the nominal and oversampled test-MC

Nominal MC
(PYTHIA+EPOS)

Oversampled MC
(PYTHIA+EPOS, no invariant p_T rescale)



very different distributions



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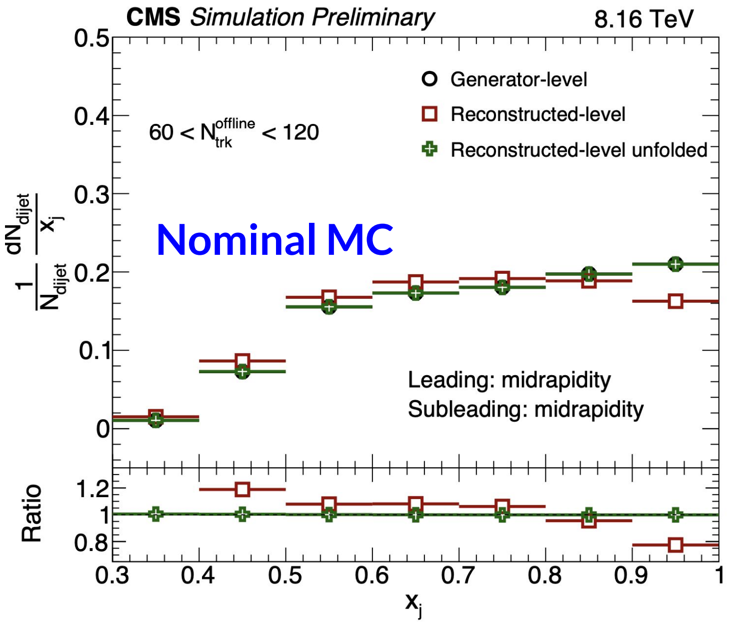
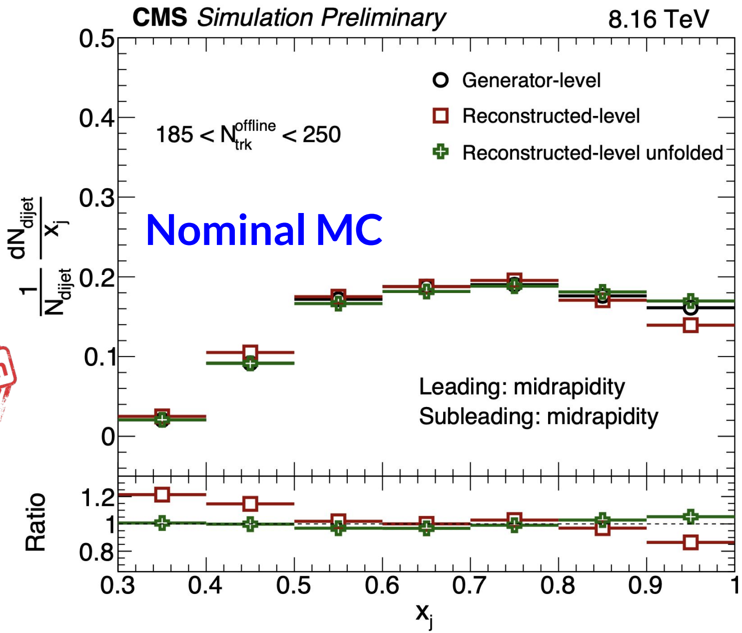
Validate the unfolding procedure at MC (II): closures

- Closures achieved despite drastically different priors
  - Demonstrate the advantage of using the pdf-convoluted response matrices for cases when no reliable Monte Carlo exists





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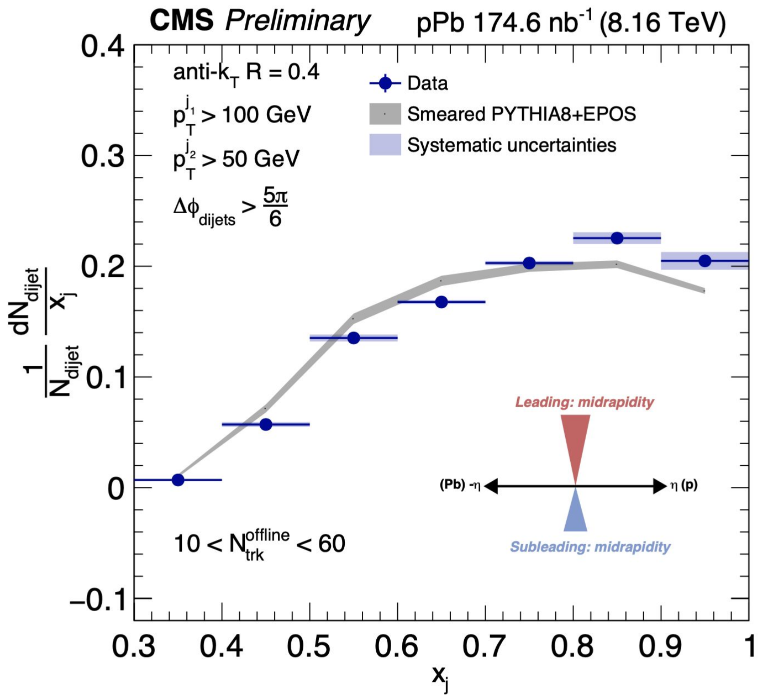
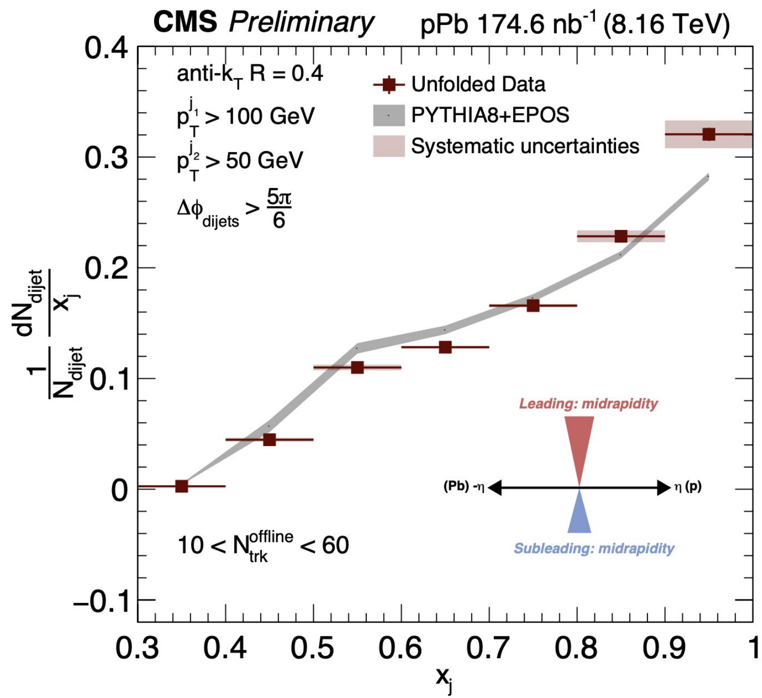
Unfolding x_j – example in data



Smeared results



Unfolded results

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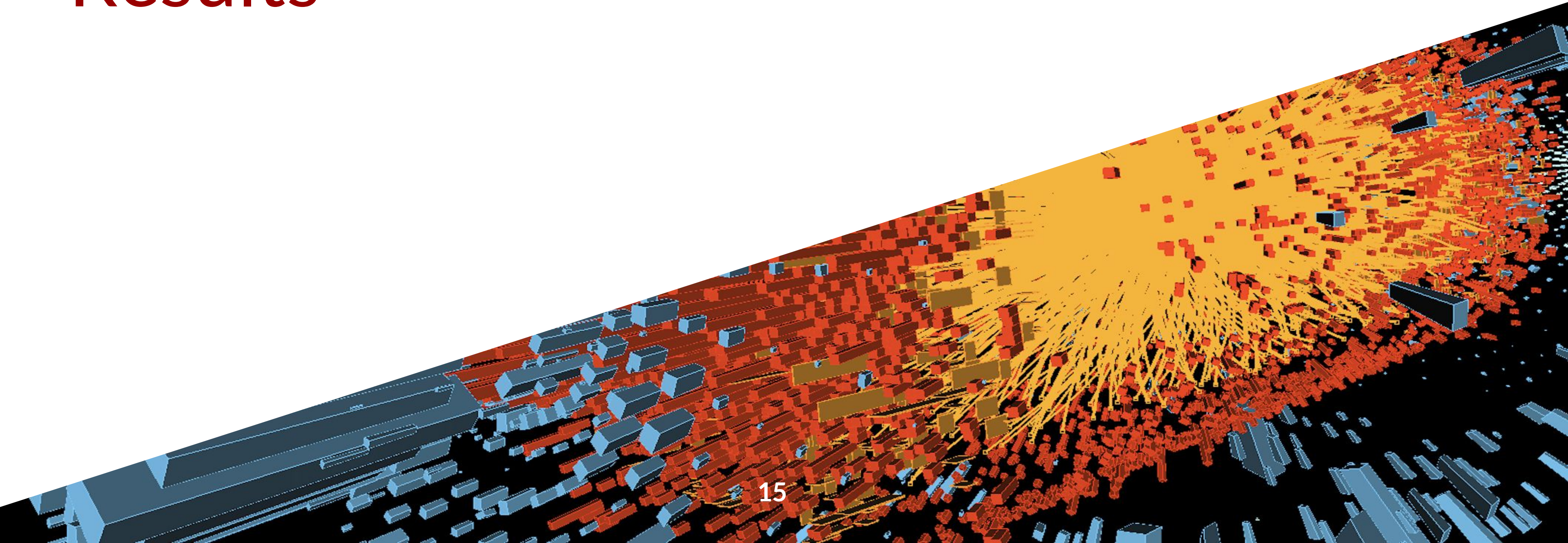
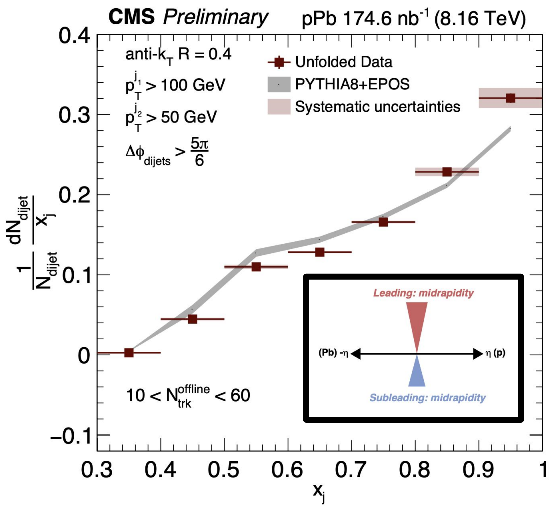
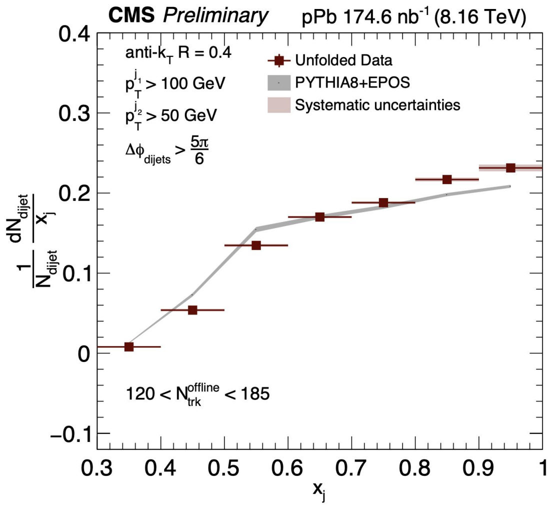
Results

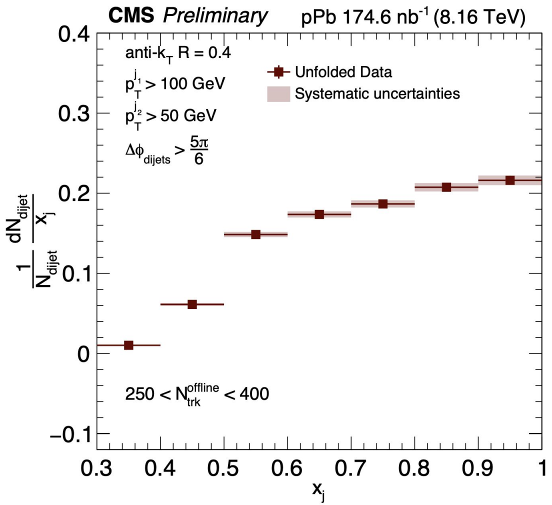


x_j results: multiplicity dependency

- Changes observed in the shapes from low to high multiplicity ranges
  - Especially in $x_j \sim 1$
    - Same behavior for all η combinations
  - Simulations cannot be performed for the highest multiplicity range







Increasing Multiplicity

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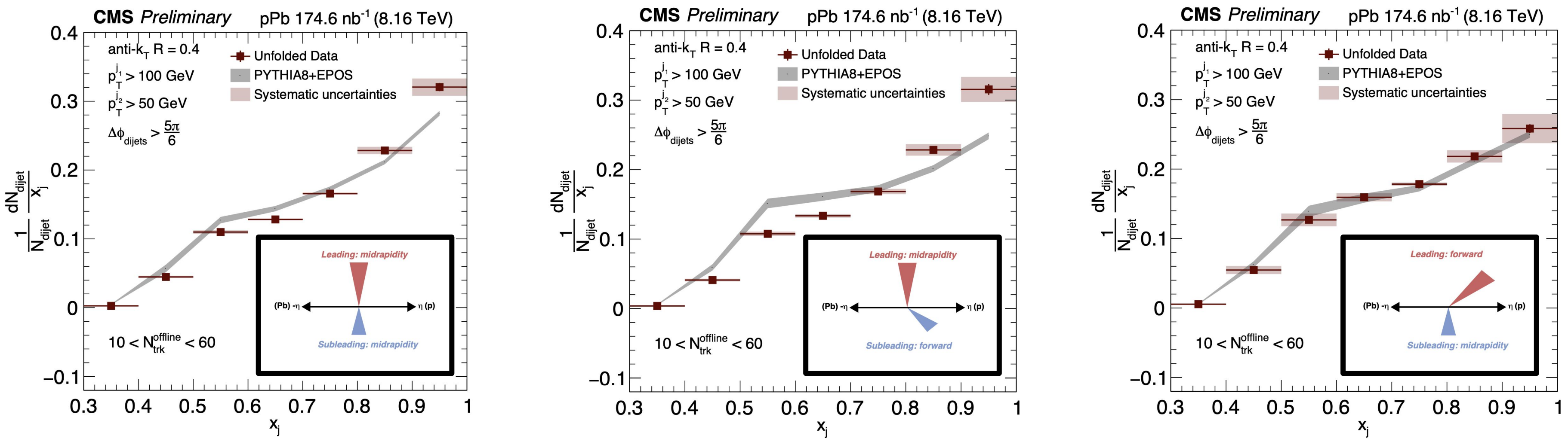
[CMS PAS-HIN-23-010]

x_j results: η dependency (forward)

- Very similar behavior for all different jet combinations
  - Small changes in shapes



x_j results: η dependency (backward)

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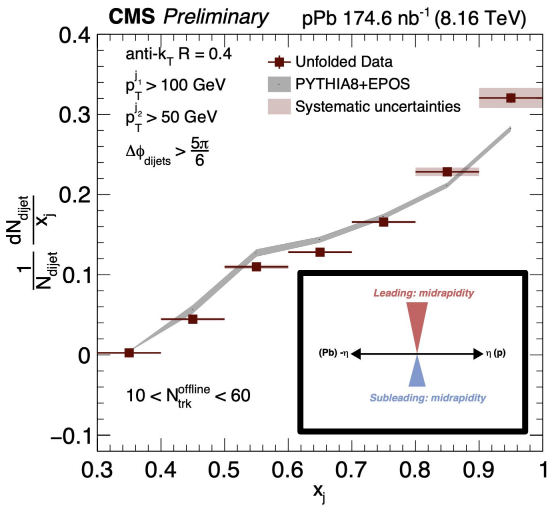
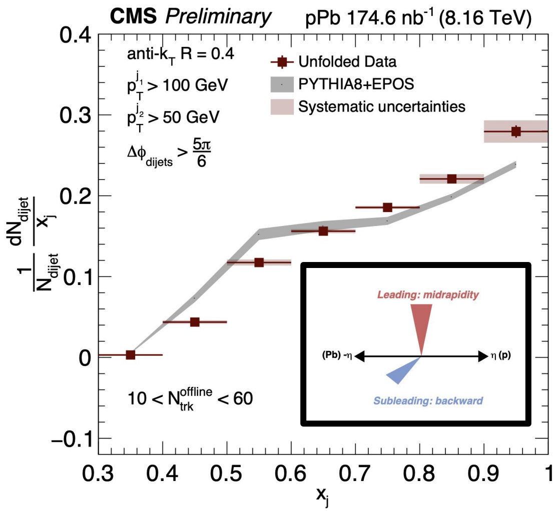
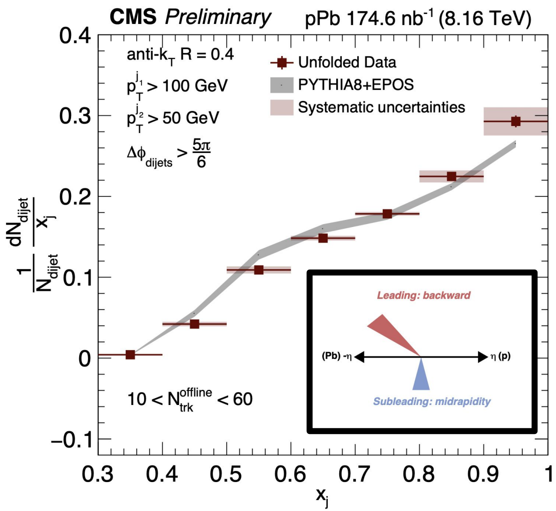
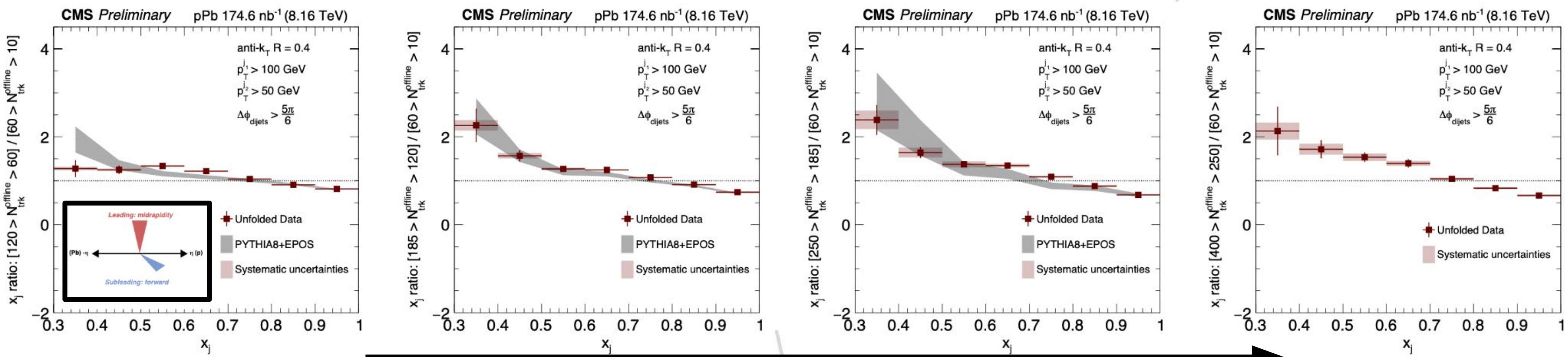






x_j ratio to lower multiplicity range

- Useful for cancellation of systematics
- Ratio > 1 at low x_j and < 1 for high x_j
  - Possible effects: multijets contribution, energy-momentum conservation, among others
- Data well described by PYTHIA8+EPOS MC in all multiplicities and η combinations
  - **PYTHIA8+EPOS do not include energy loss mechanism**



Increasing Multiplicity

Other η combinations in the backup

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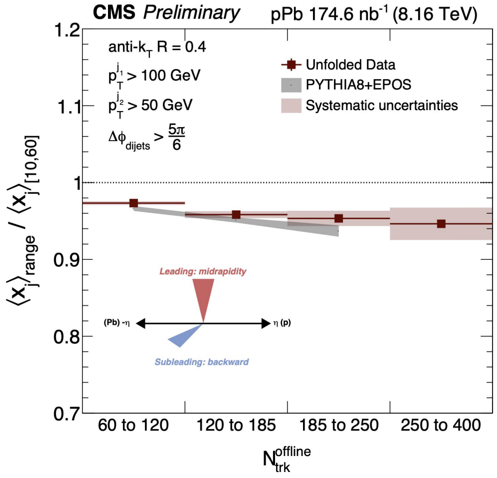
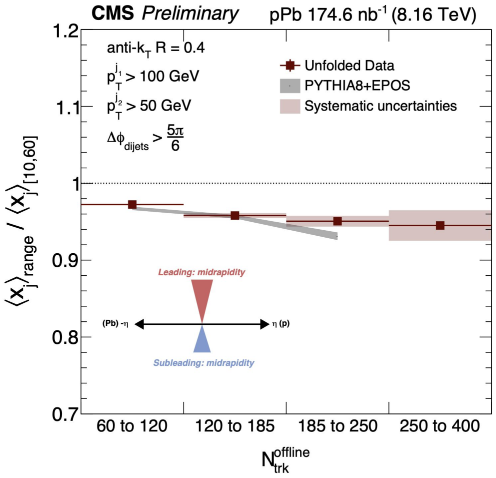
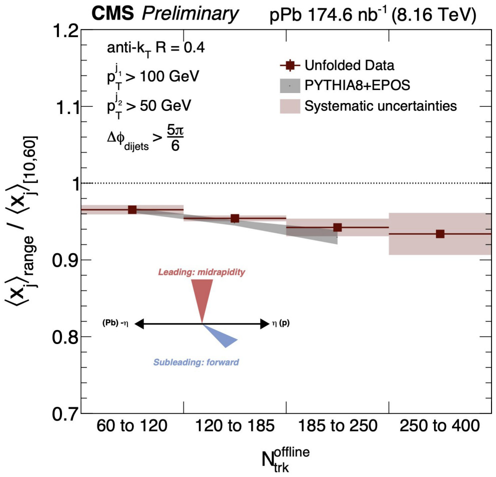
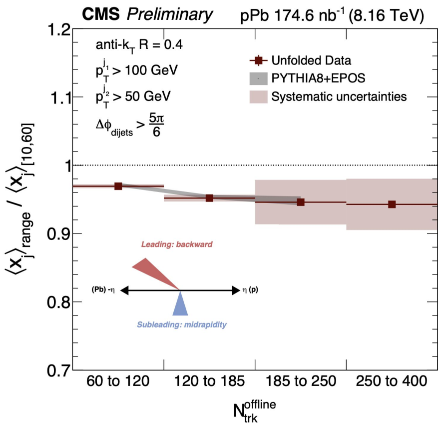
Average x_j : ratio high-to-low multiplicities

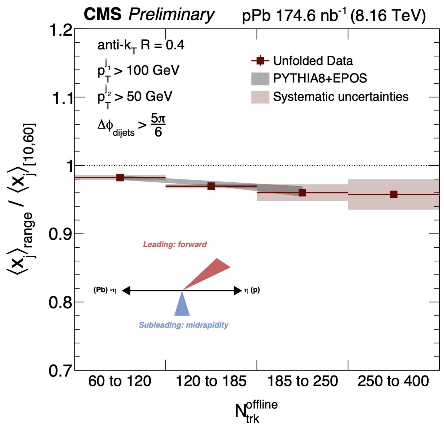








- ➢ **Ratio decrease with multiplicity**
- ➢ **Overall good data/mc agreement**
  - ○ **Indicates no presence of energy loss!**



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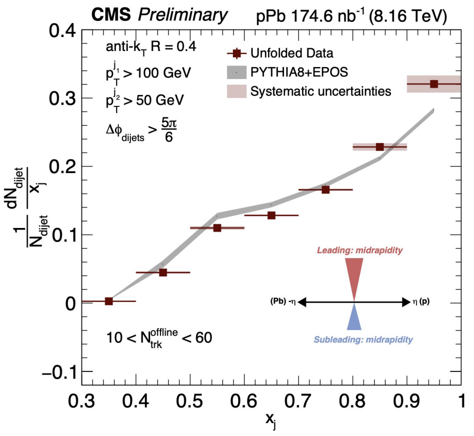
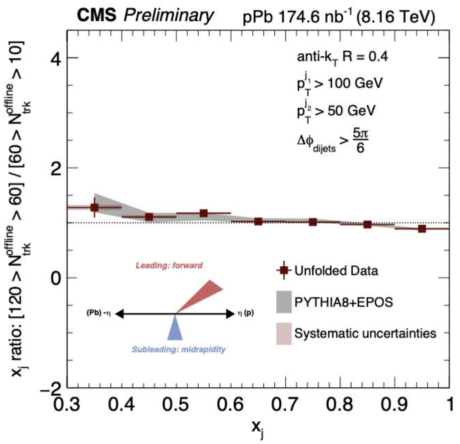
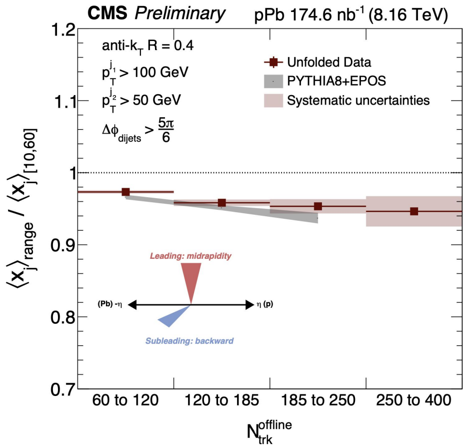
Summary

- ➤ First measurement of unfolded x_j using high multiplicity triggers (strongest flow regime)
  - ⇨ No modifications observed at high multiplicity for any configuration of jet-jet geometry
    - ➔ Deviations from 1 observed, possible effects:
      - ⇨ Energy-momentum conservation, multijets, among others
    - ➔ Well described by PYTHIA8+EPOS (no energy loss)







Please check CMS PAS-HIN-23-010

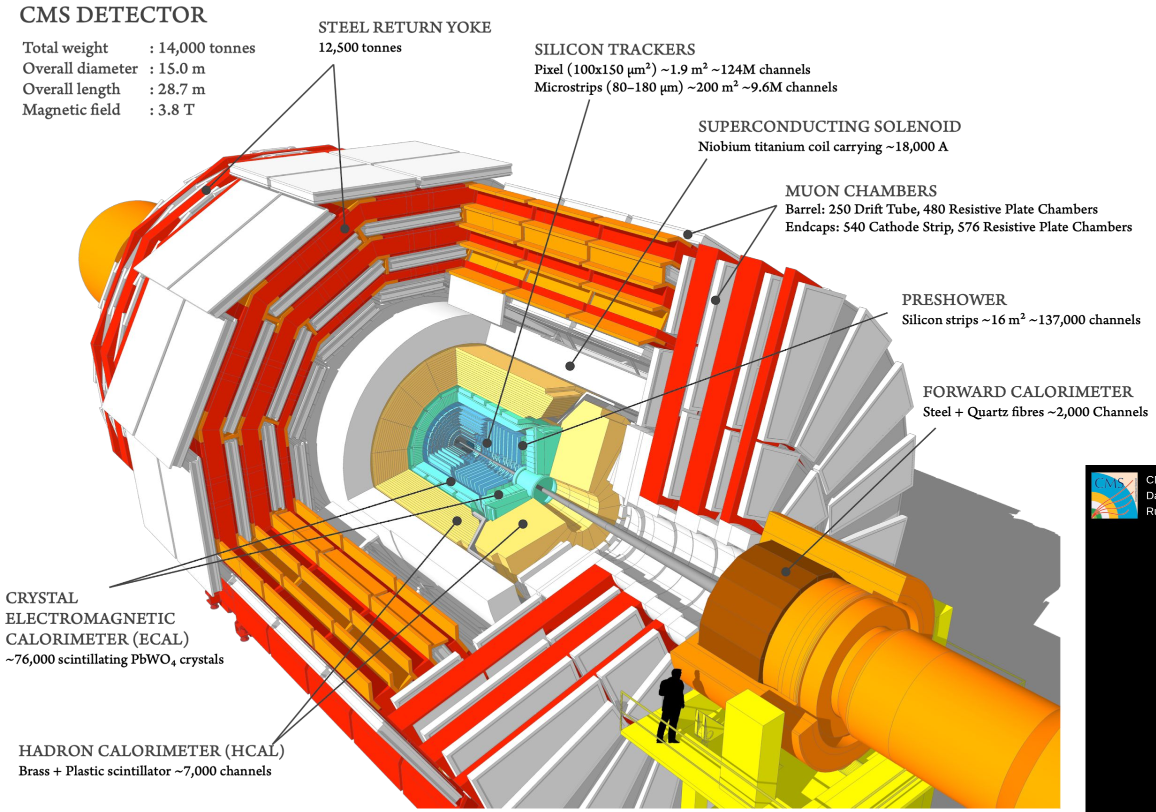
Thank You

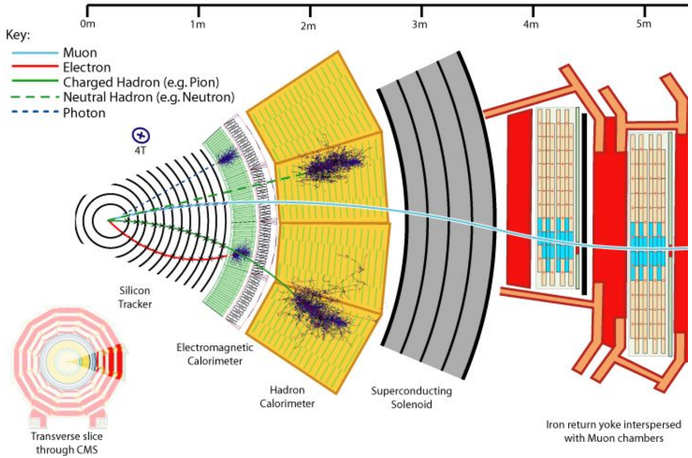
The work of the UIC HENP group is supported by the DOE-NP grant

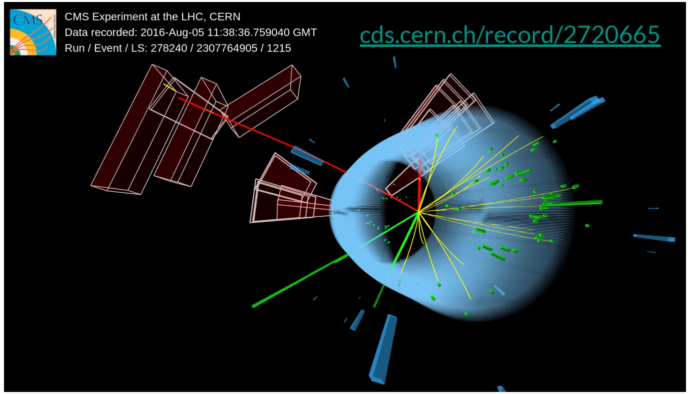
Backup


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2010-Nov-08 10:22:07.828203 GMT(11:22:07 CEST)
Run / Event: 150431 / 541464
(c) CERN 2009. All rights reserved.
http://iguana.cern.ch/ispy

The CMS detector



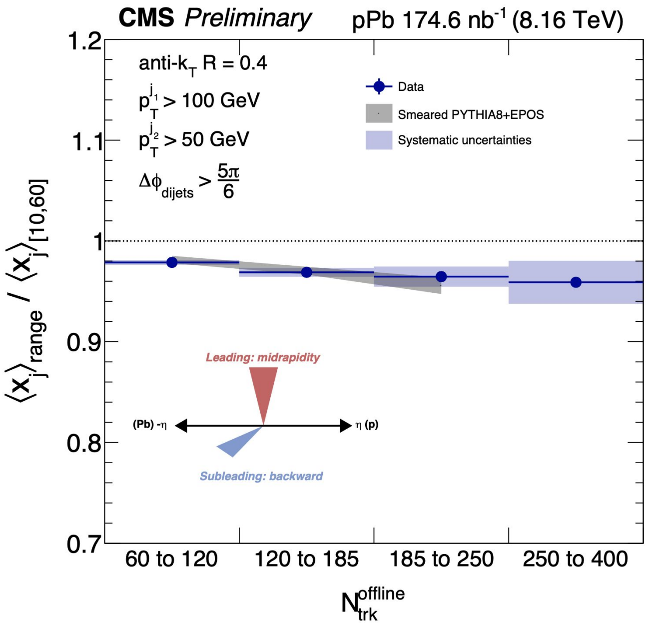


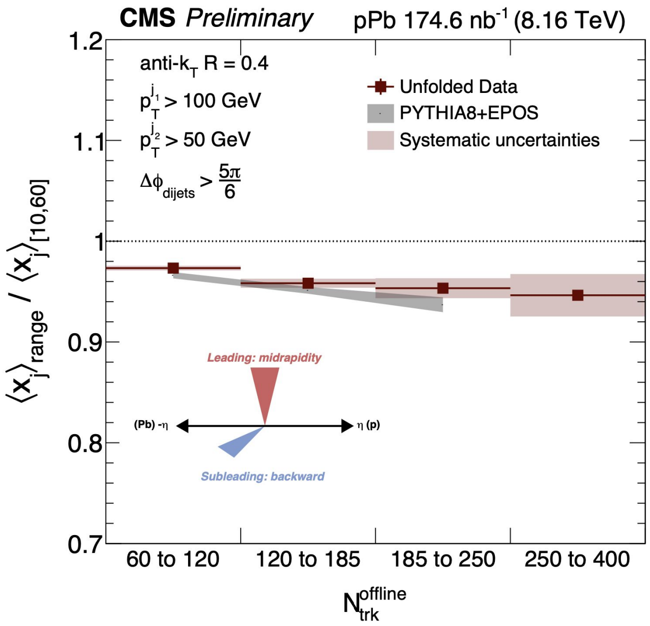


Sources of systematic uncertainties

- Sources of systematics accounted here
  - *Trigger bias:* comparison of distributions between MB and HM triggers
  - *Pileup removal:* different PU rejection event selection criteria are used as systematics
  - ***JES***: shift jet p_T in data based on the uncertainties of jet energy corrections
  - ***JER***: jet p_T is smeared in MC to account for the uncertainties in data-to-simulation differences.
  - *Underlying events:* a jet-area-based background subtraction method is applied As an alternative to the constituent subtraction method
  - *Unfolding:* Five iterations were used to perform the unfolding. Four and six iterations are used as the systematic uncertainty.
- JER and JES are dominant sources of systematics

Average x_j : ratio high-to-low multiplicities





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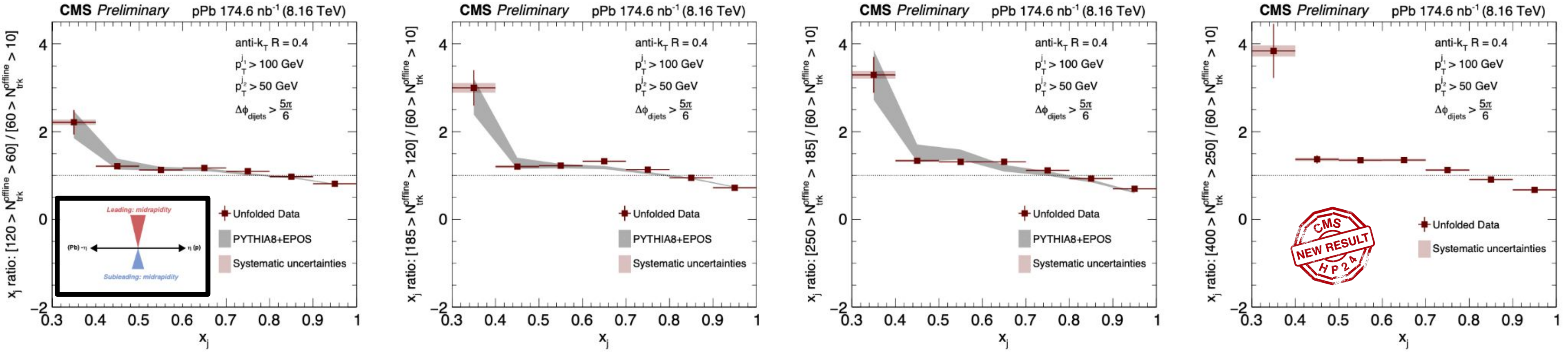

Increasing Multiplicity

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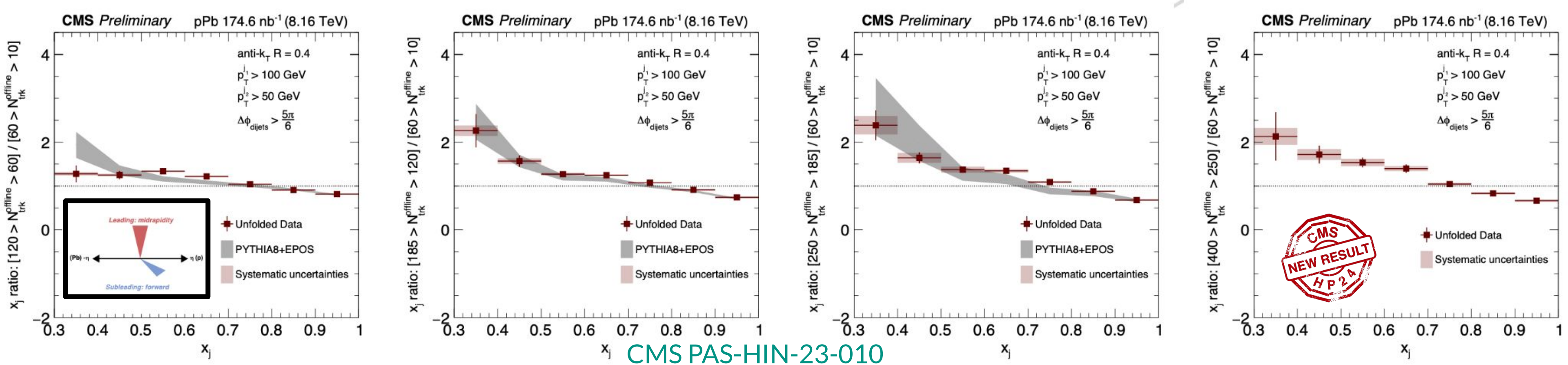
x_j ratio to lower multiplicity range (II)



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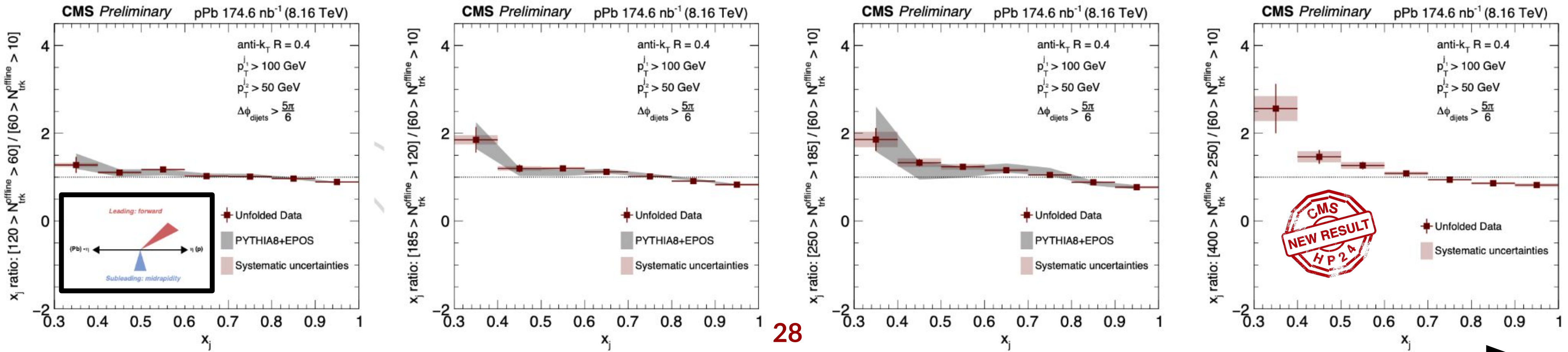
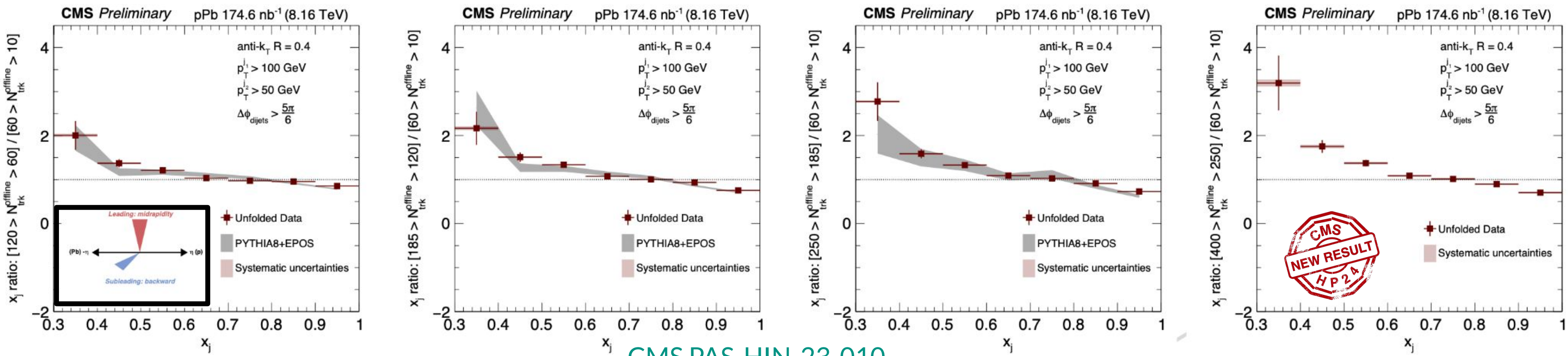
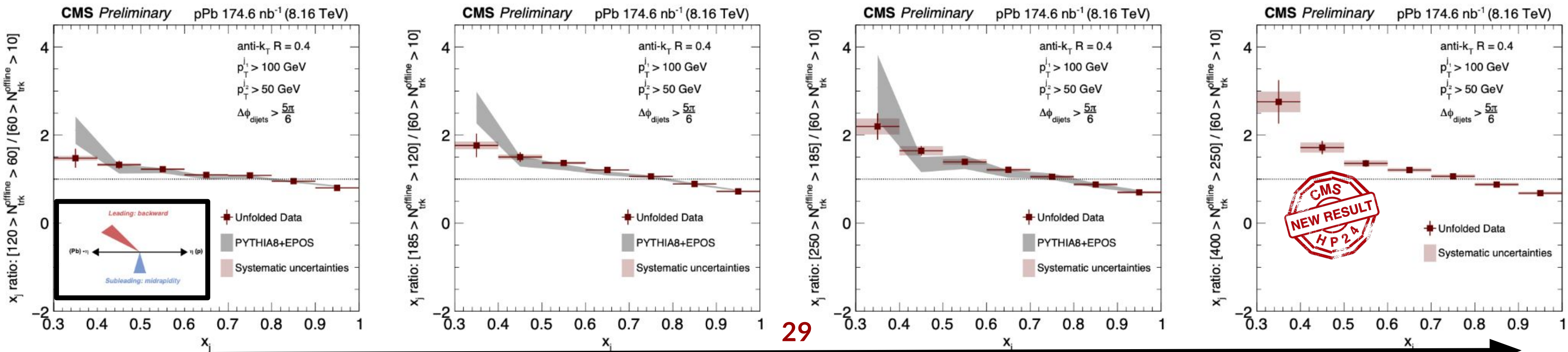


Increasing Multiplicity

x_j ratio to lower multiplicity range (III)



[CMS PAS-HIN-23-010]



Increasing Multiplicity