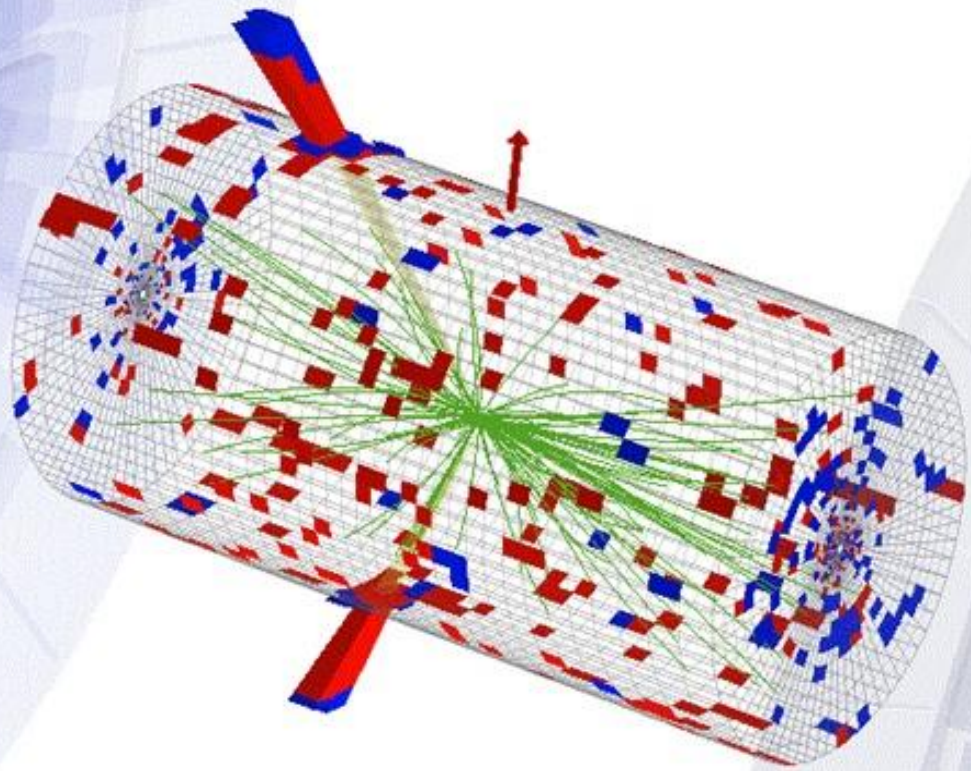


# Dijet Measurements in pPb Collisions

*Doğa Gülhan (MIT)*

*On behalf of the CMS Collaboration*

Jet-HI Workshop, UPMC Paris – July 3rd 2013

# Outline

**INTRODUCTION**

- Use of dijet measurements → Final state interactions
- Use of dijet measurements → Initial state effects
- Centrality in pPb → Tracker based variables
- Centrality in pPb → Forward energy deposit

**RESULTS**

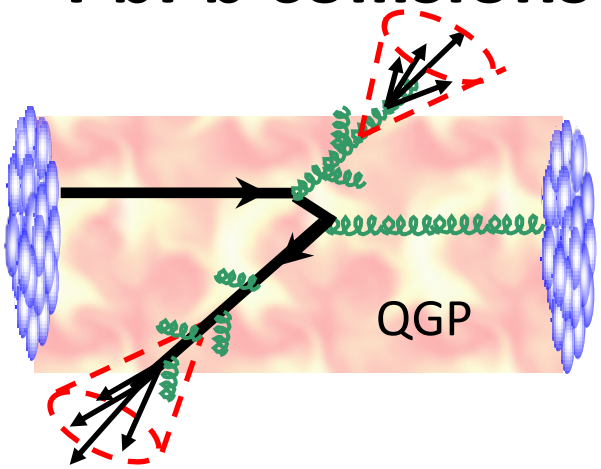
- Dijet $p_T$ ratios and azimuthal correlations
- Dijet pseudorapidity: → Compared to predicted effects in nPDF
- Dijet pseudorapidity: → As function of forward activity

**CONCLUSION**

**FUTURE DIRECTIONS**

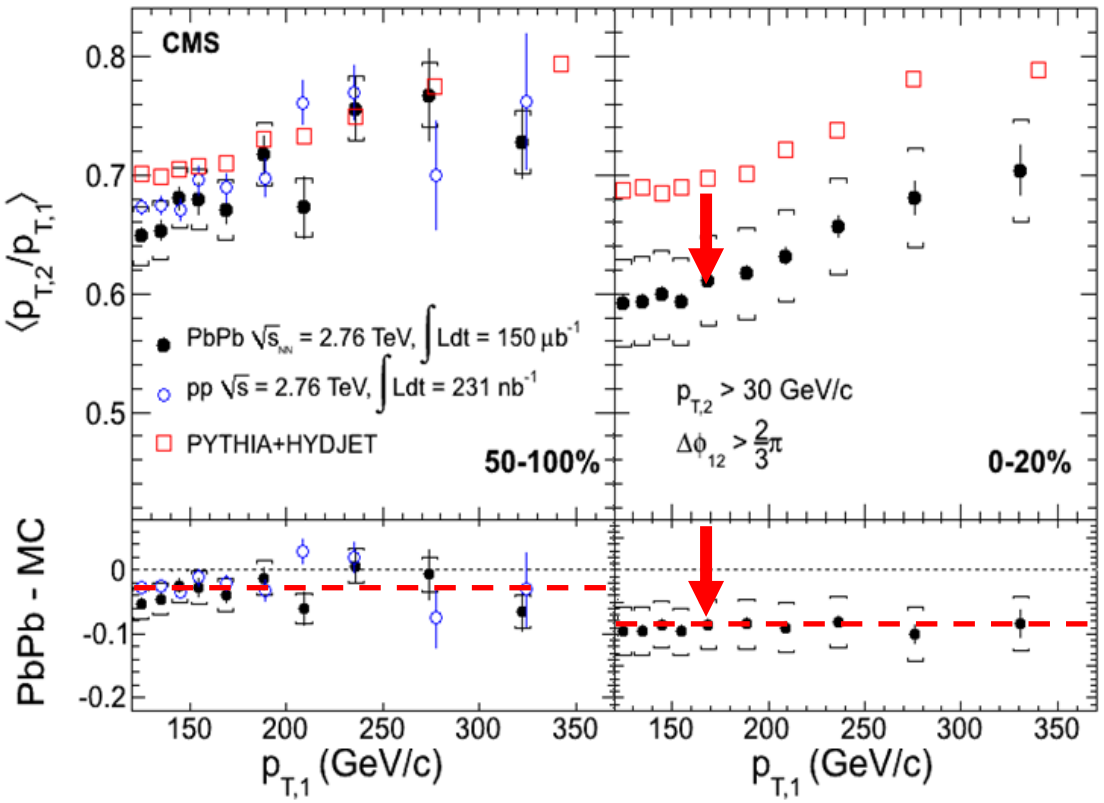
# Dijet production in HI collisions

## PbPb collisions



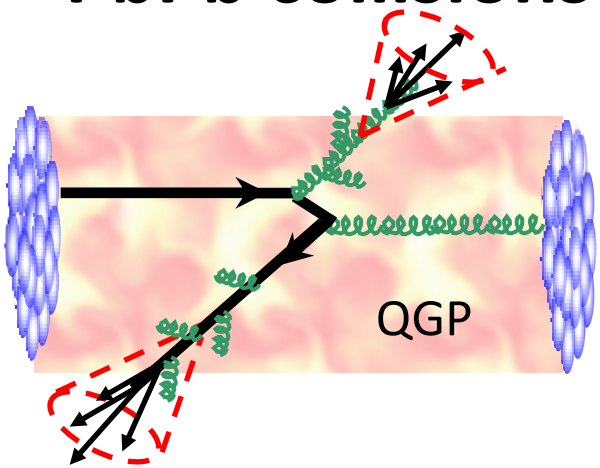

- Jet quenching observed as
  - Pronounced dijet $p_T$ imbalance in central collisions
  - Decreasing dijet $p_T$ ratio as we go to more central collisions (~10%)

PLB 712 (2012) 176



# Dijet production in HI collisions

## PbPb collisions

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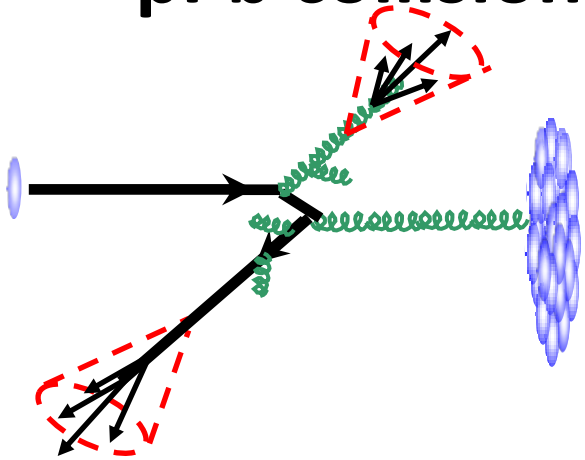
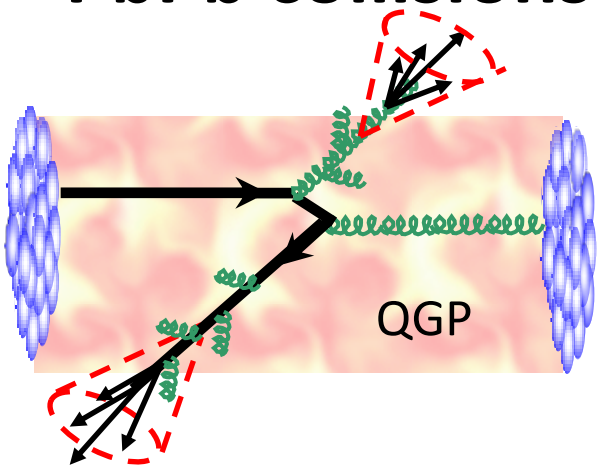
## pPb collisions



- Baseline for PbPb collisions
  - Cold nuclear effects, nPDFs

# Dijet production in HI collisions

## PbPb collisions

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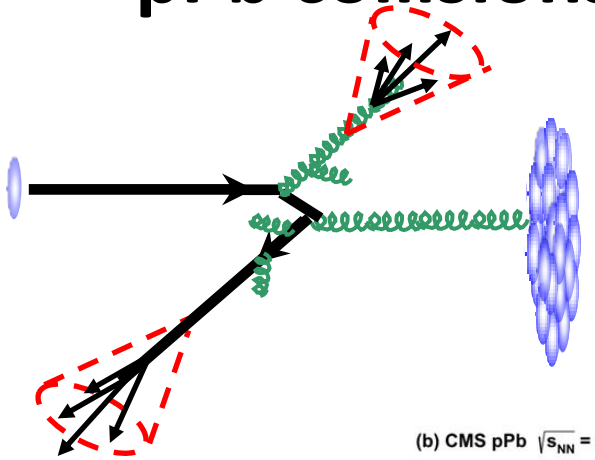
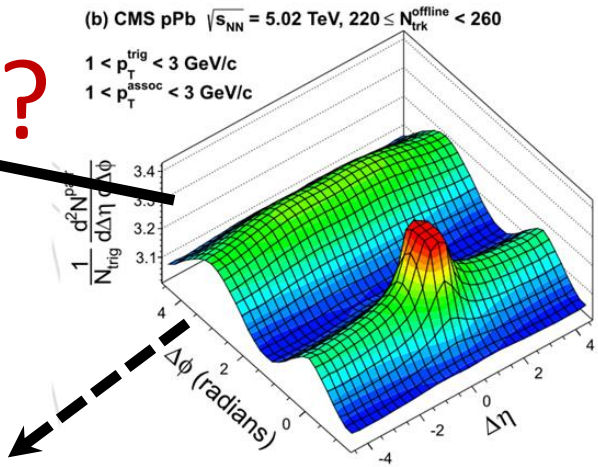
## pPb collisions



- Baseline for PbPb collisions
  - Cold nuclear effects, nPDFs

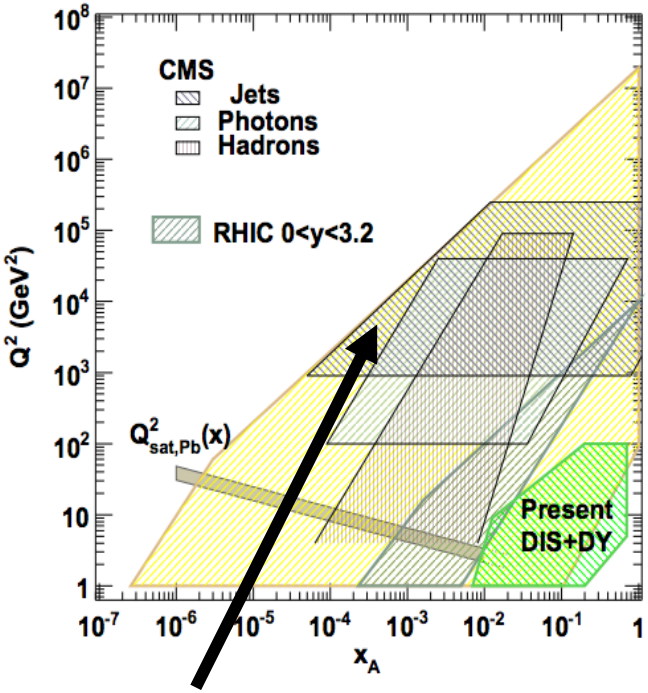
?




**Do we see an onset of this effect in pPb already?**

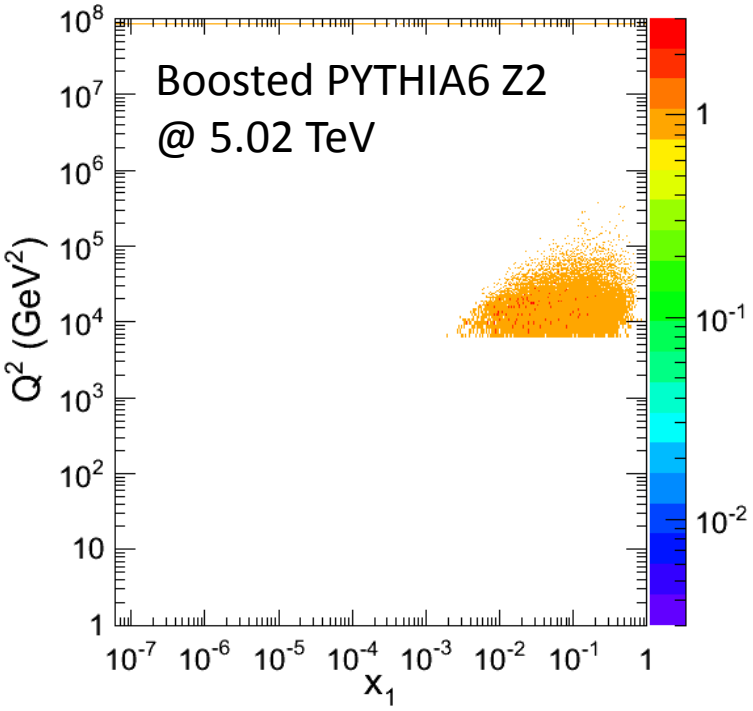
# Probing PDFs

Kinematic reach for CMS,
pPb @ √s = 8.8 TeV (0.1 $pb^{-1}$)




Jets cover high $Q^2$ and $10^{-4}<x<1$.

C.A. Salgado, et. al. J.Phys. G39 (2012) 015010




With the dijet selection of the analysis:

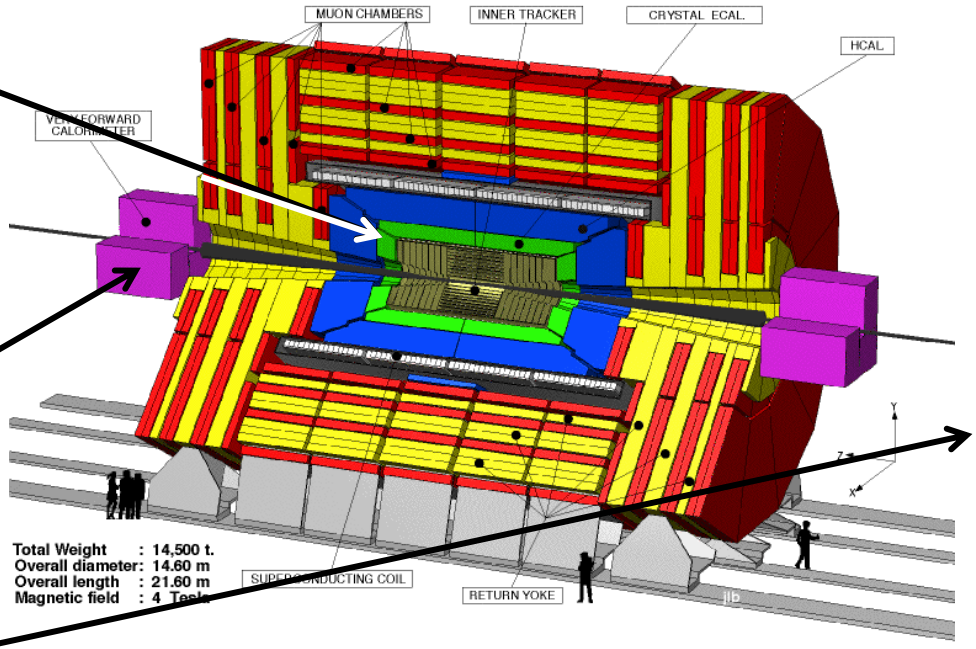
$p_{T,1} > 120$ GeV/c, $p_{T,2} > 30$ GeV/c,
$\Delta\phi_{12} > 2\pi/3$

# Centrality in pPb

# Centrality in pPb

**SEVERAL OPTIONS ARE TESTED**

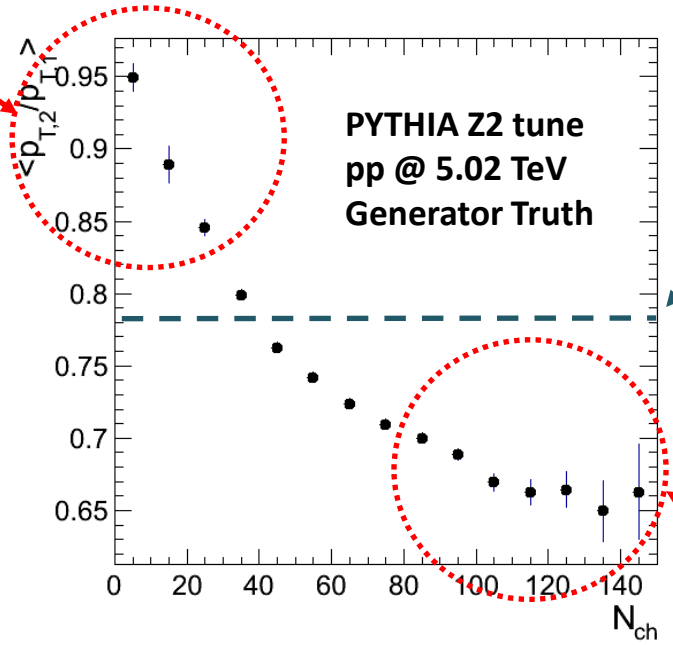
- Tracker based variables (|η|<2.4 )
  - Number of pixel hits,Number of pixel tracks, or number of tracks...
- Forward energy deposit
  - Hadronic forward calorimeter based variables (3<|η|<5.2 )
  - ZDC based variables (|η|>8.5 )



# Tracker based variables

- Introduce bias on number of jets and their fragmentation:

Event less likely to have 3 (or more) jets




Mean value for all generated dijets

Event more likely to have 3 (or more) jets
Each jet means additional $N_{ch}$ ~ 10.

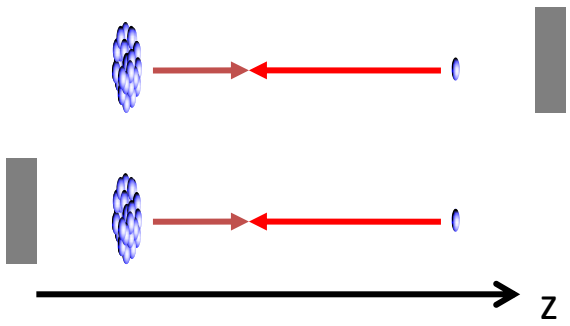
# Variables based on forward energy deposit

- ZDC based variables
  - Doesn't have good enough resolution to go to very high multiplicity events
- Forward calorimeter based variables:

**Final choice:** $E_T$ measured in $4<|\eta|<5.2$

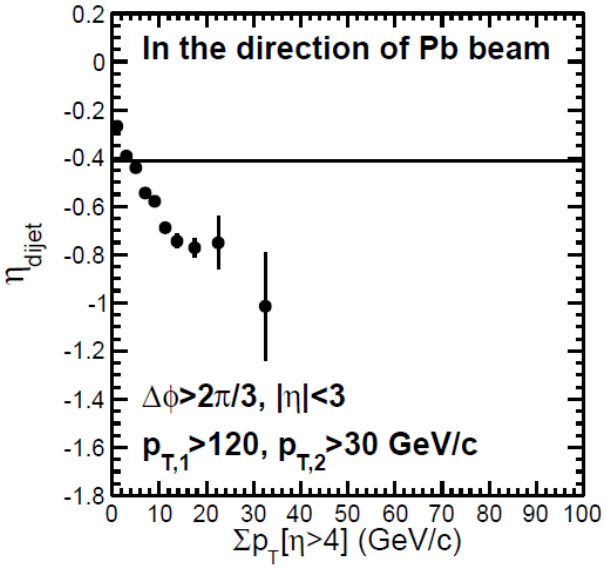

Some other cases:

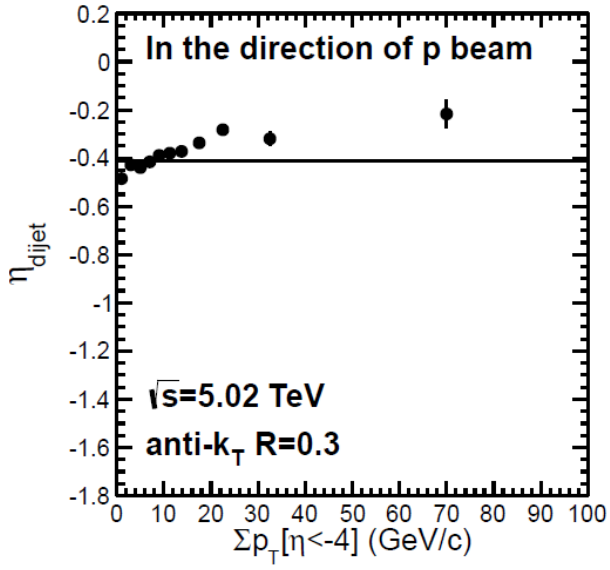
- $E_T$ measured in $4<\eta<5.2$
- $E_T$ measured in $-5.2<\eta<-4$

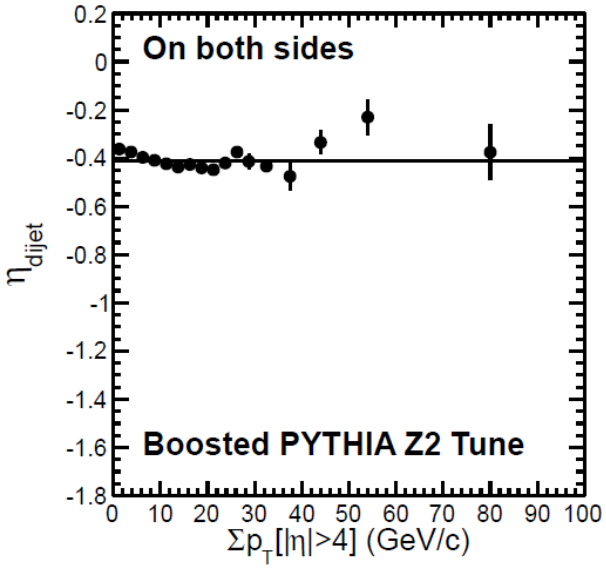


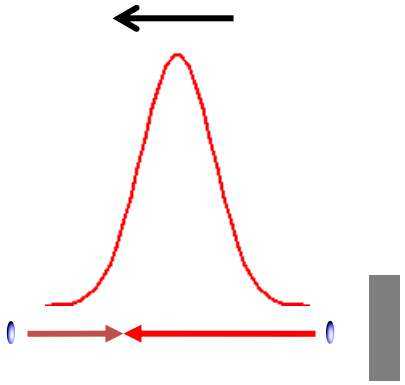
# Variables based on forward energy deposit

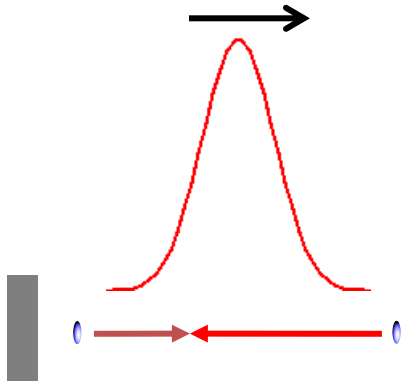
$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$



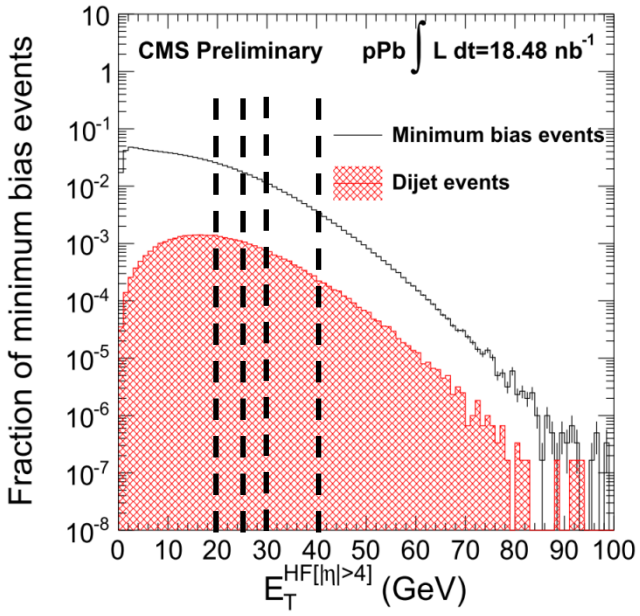



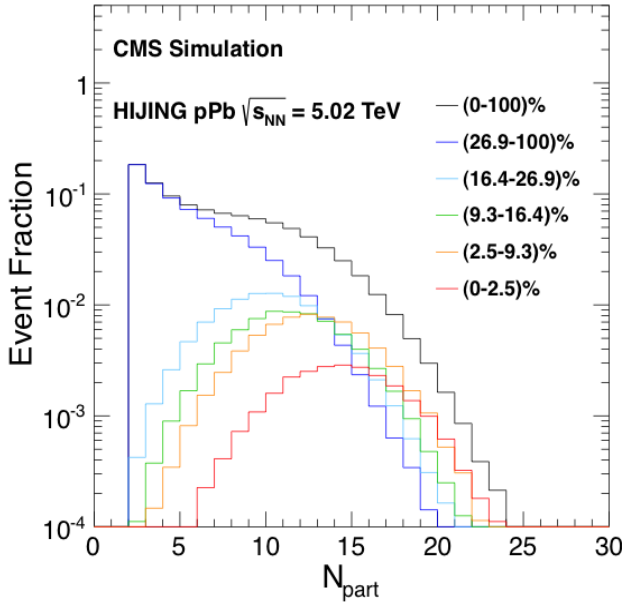


## Energy momentum conservation:

When a large deposit on one side is required the dijet pseudorapidity shifts towards the other direction.

# Event Classes




| $E_T^{HF[\lvert\eta\rvert>4]}$ range (GeV) | Fraction of DS events | Fraction of dijet events | $\langle N_{trk}^{corrected} \rangle$ in DS events |
|---|---|---|---|
| 0-20 | 73.1% | 52.6% | 33±2 |
| 20-25 | 10.5% | 16.8% | 74±3 |
| 25-30 | 7.1% | 12.7% | 88±4 |
| 30-40 | 6.8% | 13.0% | 106 ±5 |
| 40-100 | 2.5% | 4.9% | 135 ±6 |

$N_{part}$ has a weak dependence on forward calorimeter energy in pPb.

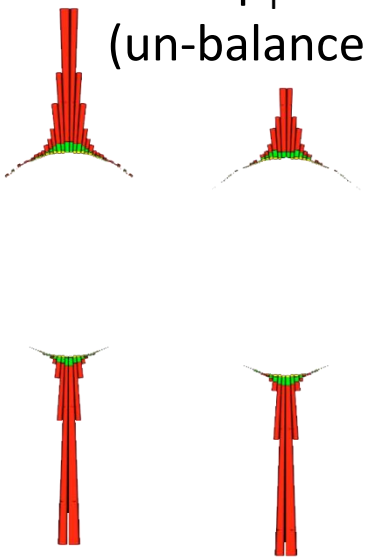
# Results

# Data and MC sample

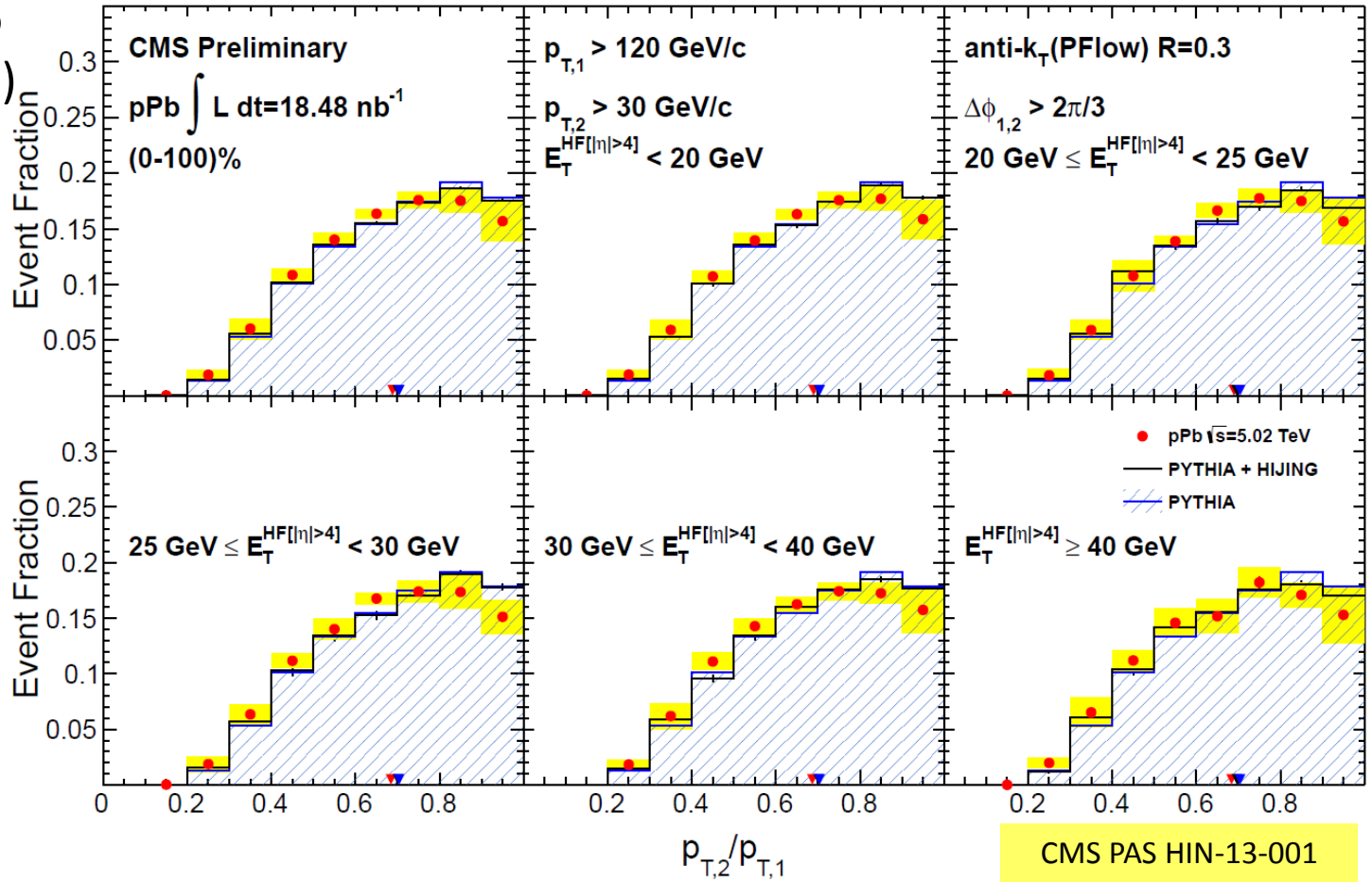
- 2013 pPb dataset analyzed
  - High-$p_T$ jet triggered – Required a jet with $p_T$ > 100 GeV
  - pPb reversed direction after L = 18.48 $nb^{-1}$
  - In this data set, Pb ion is going in the positive z direction
  - Remaining 13 $nb^{-1}$ will be added to the final results.
- Monte Carlo samples
  - Embedded PYTHIA pp jet pairs into a HIJING pPb background
    - pp dijets boosted to η= -0.465 to account for native collision asymmetry
  - Boosted PYTHIA pp jets as reference

# Dijet $p_T$ ratios

Small $p_T$ ratio (un-balanced)



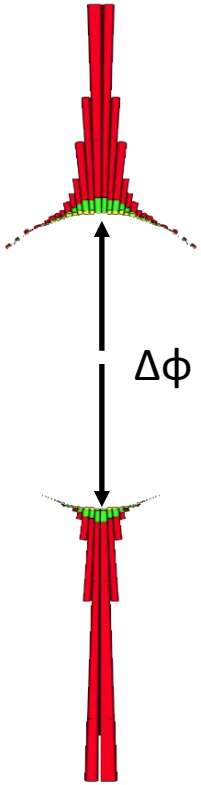
Large $p_T$ ratio (balanced)

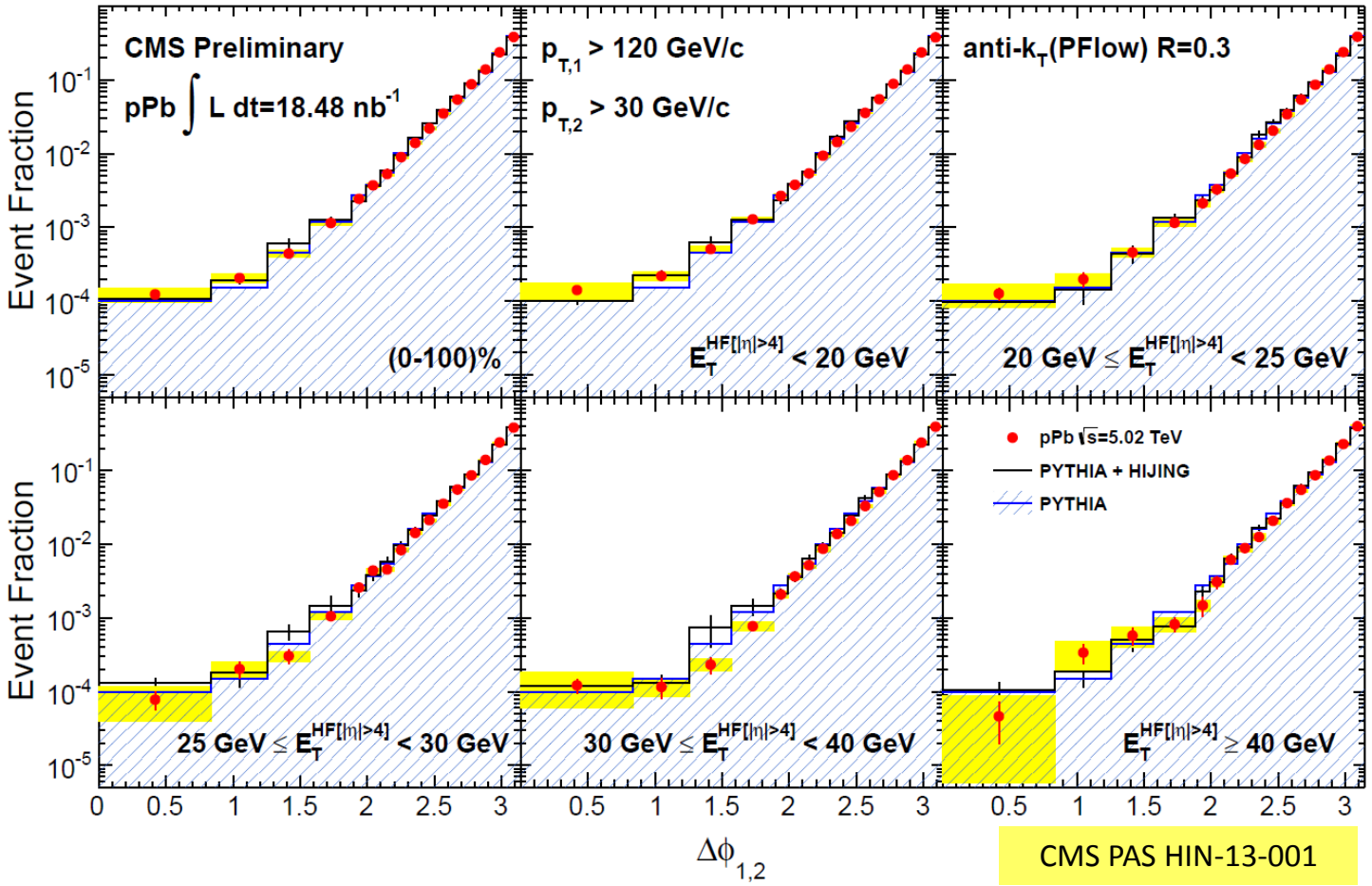



CMS PAS HIN-13-001

- **No modification larger than 2%** is observed in dijet $p_T$ ratio up to $E_T^{HF[|\eta|>4]} > 40$ GeV (top 2.5%)

# Dijet azimuthal correlations

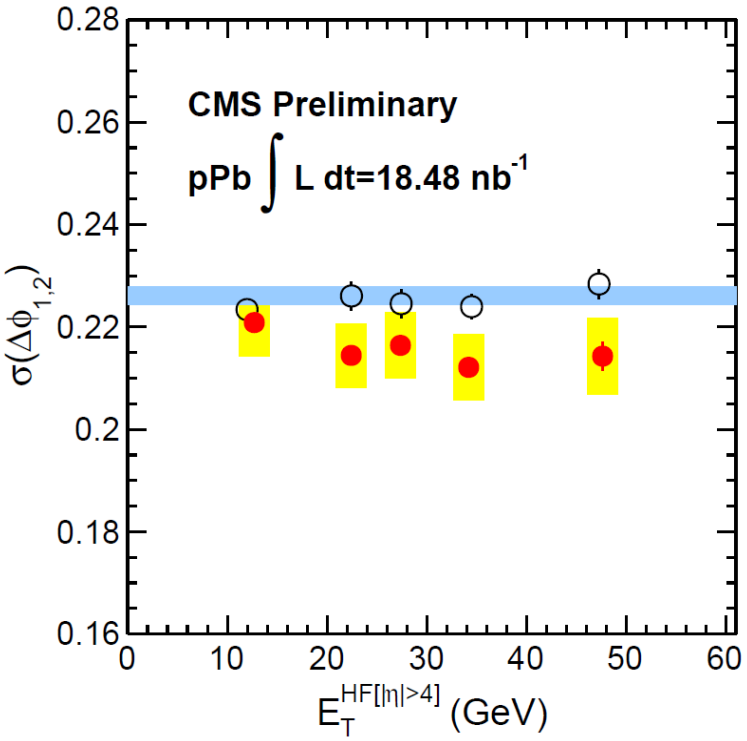


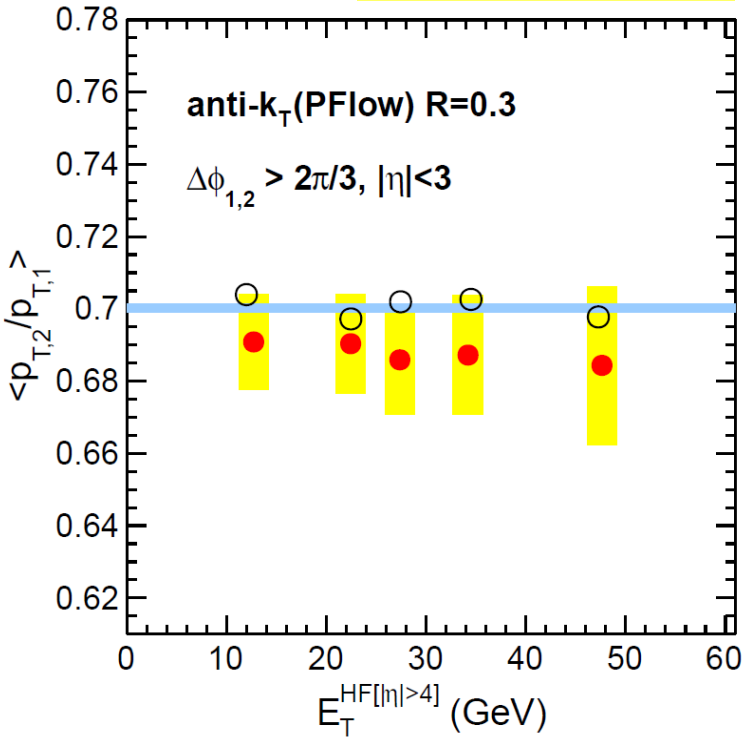




- Δφ distribution **does not change** with HF energy

# Summary of $p_T$ ratios and $\Delta\phi$

CMS PAS HIN-13-001

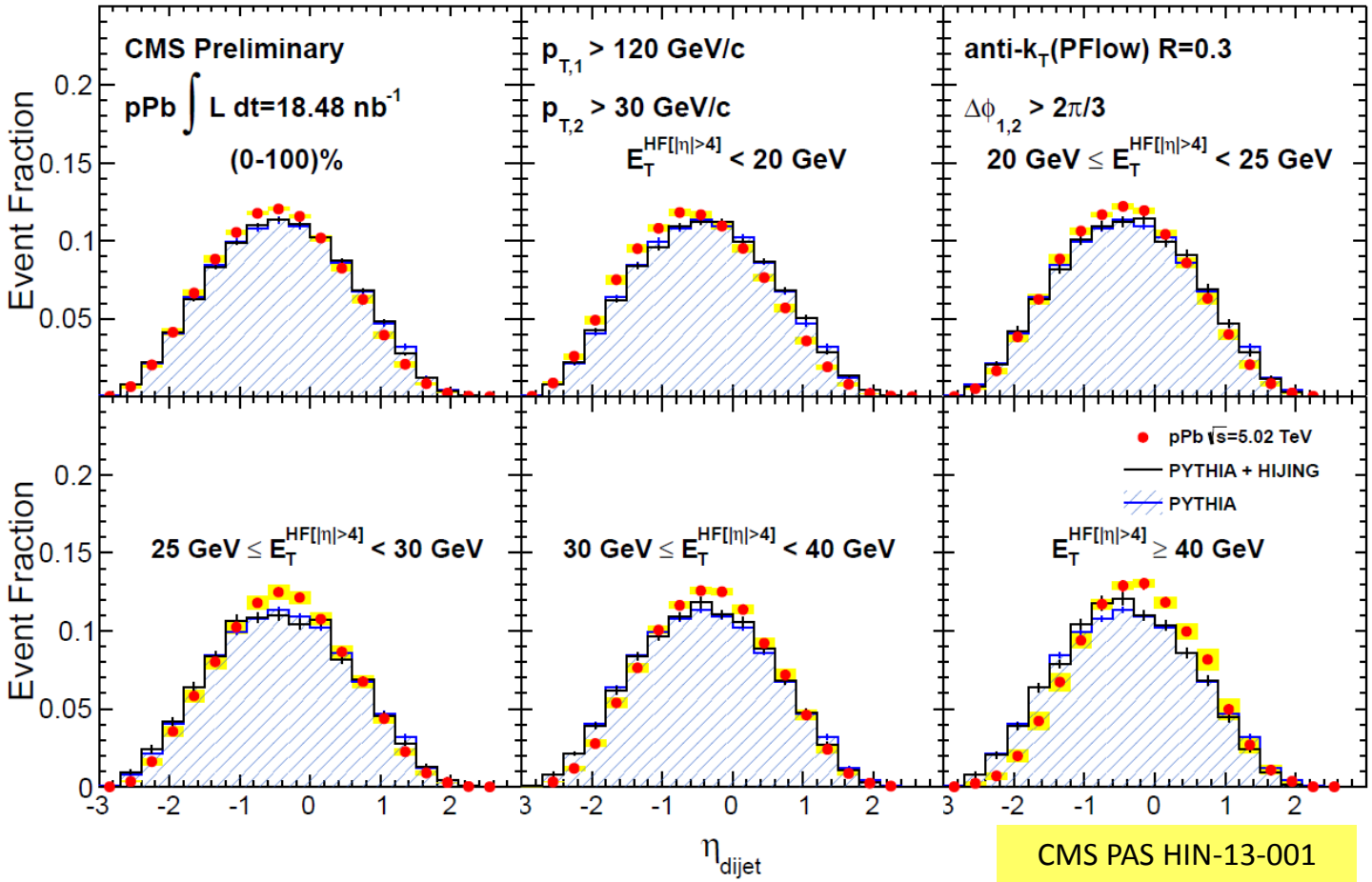



- With the current systematic uncertainty, no detectable change in $\langle p_{T,2}/p_{T,1}\rangle$ and $\Delta\phi$ width larger than 2% as a function of forward calorimeter energy,
- **These results allow us to use jets for nPDF determination.**

# Dijet η

$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$




CMS PAS HIN-13-001

- (0-100)% centrality bin is modified with respect to MC references
- A systematic shift in the positive η direction vs HF energy.

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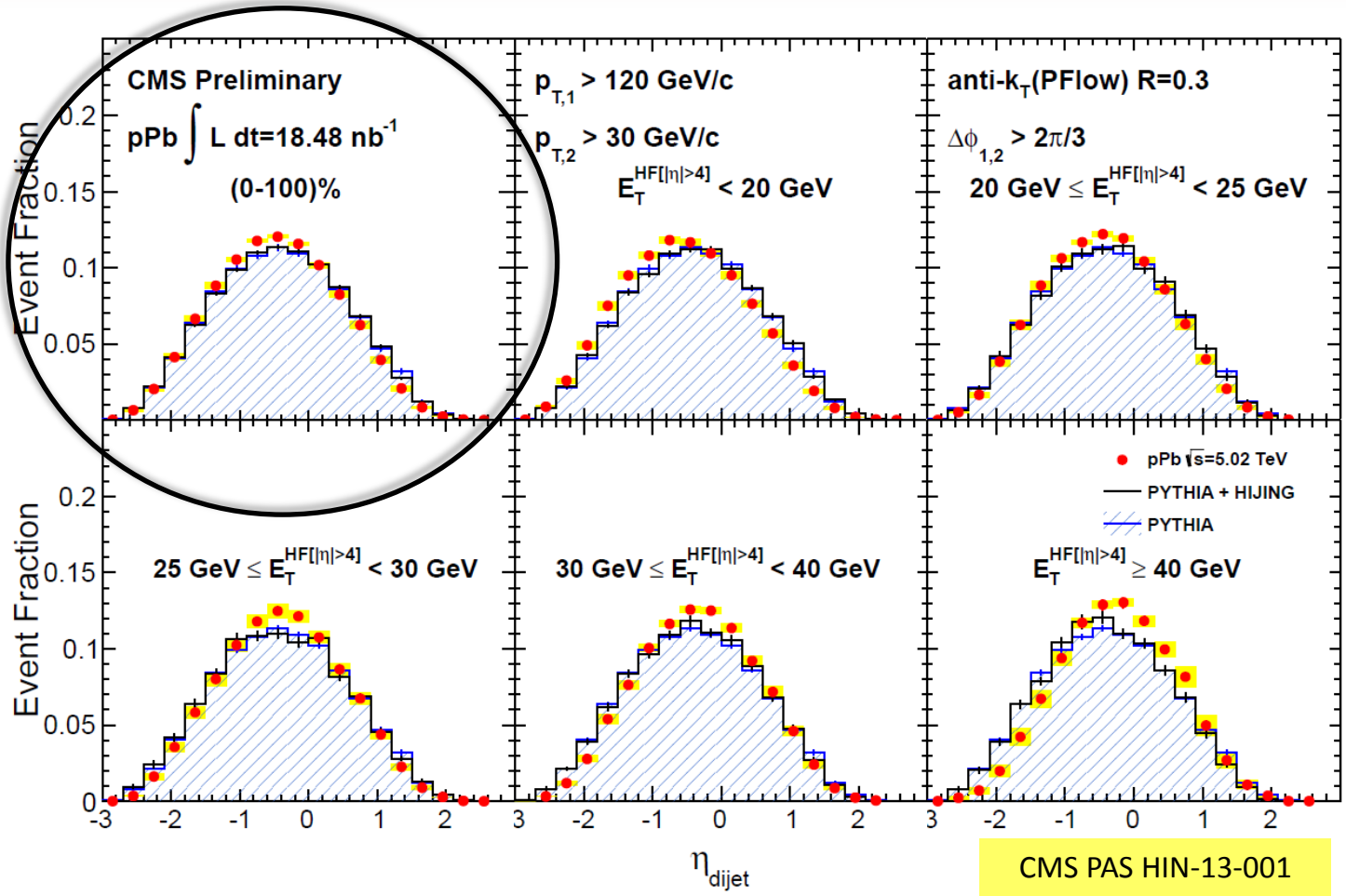


CMS PAS HIN-13-001

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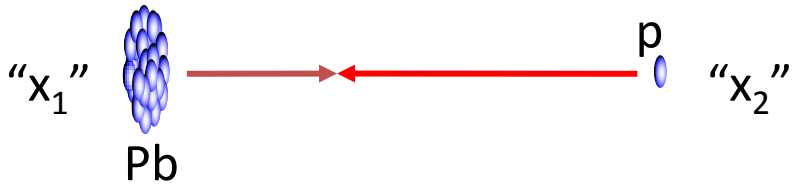
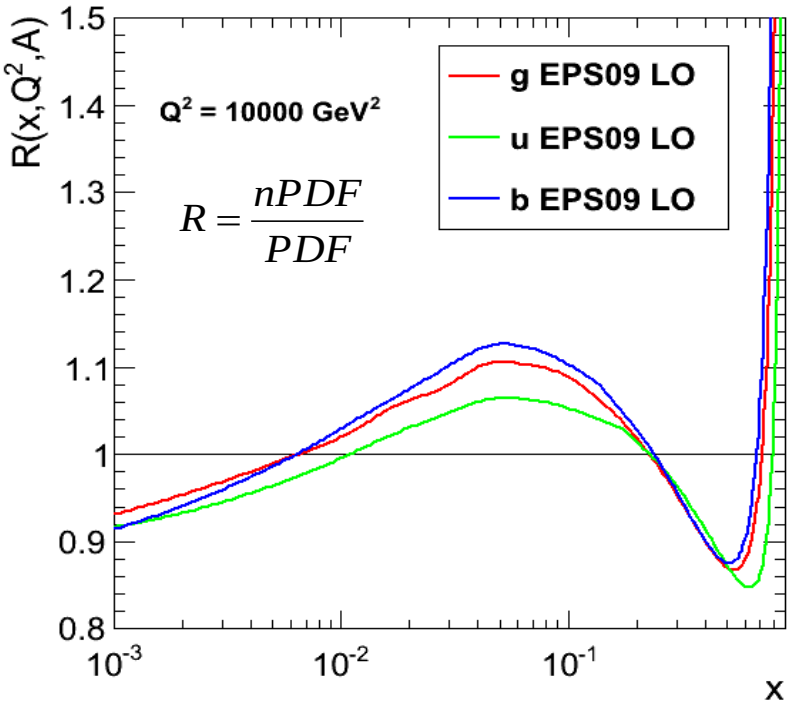
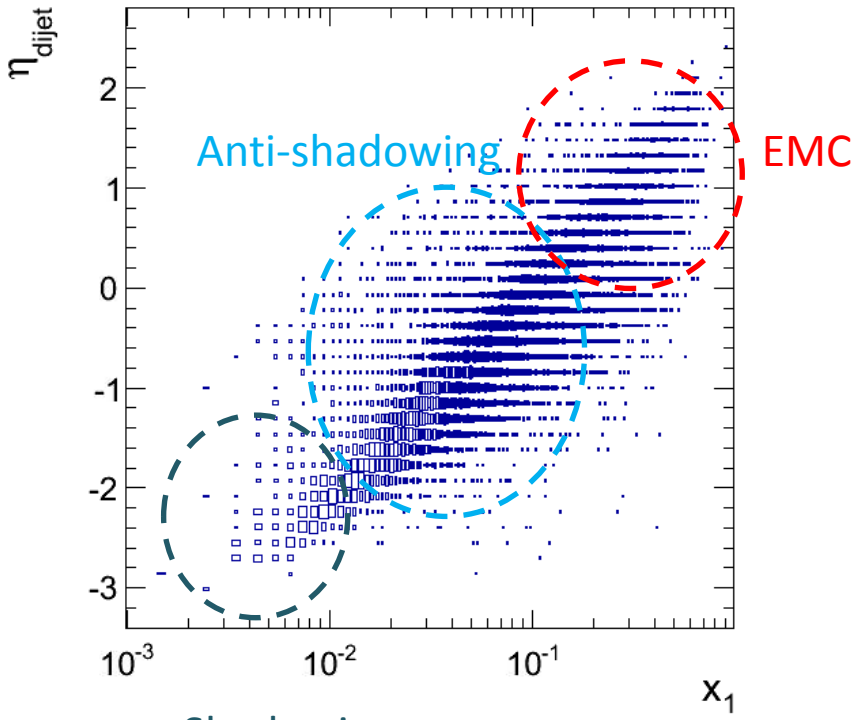
# Dijet η ←→ x



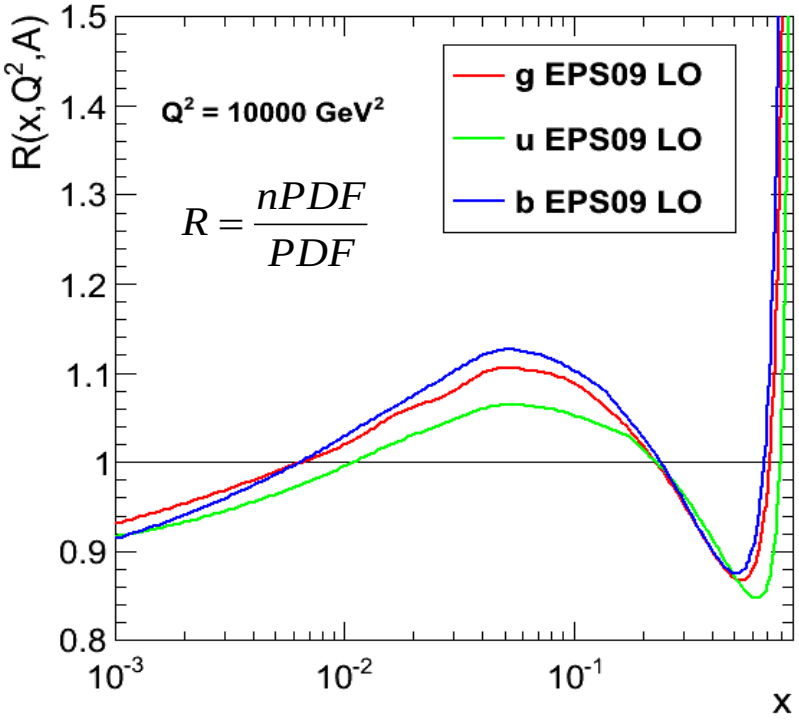

François Arleo and Jean-Philippe Guillet
http://lapth.cnrs.fr/npdfgenerator/

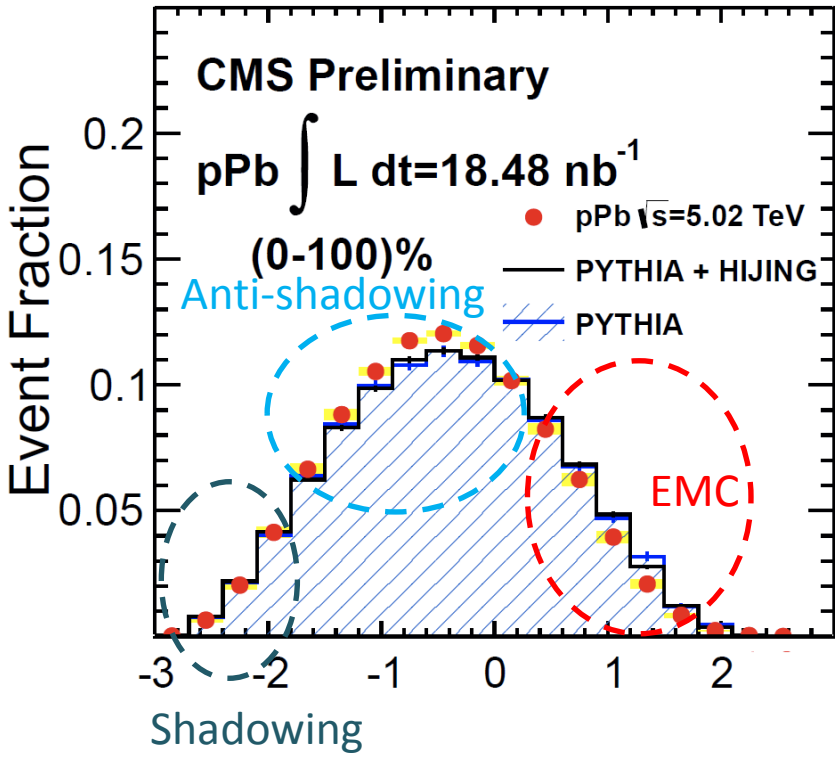



Boosted PYTHIA6 Z2
@ 5.02 TeV



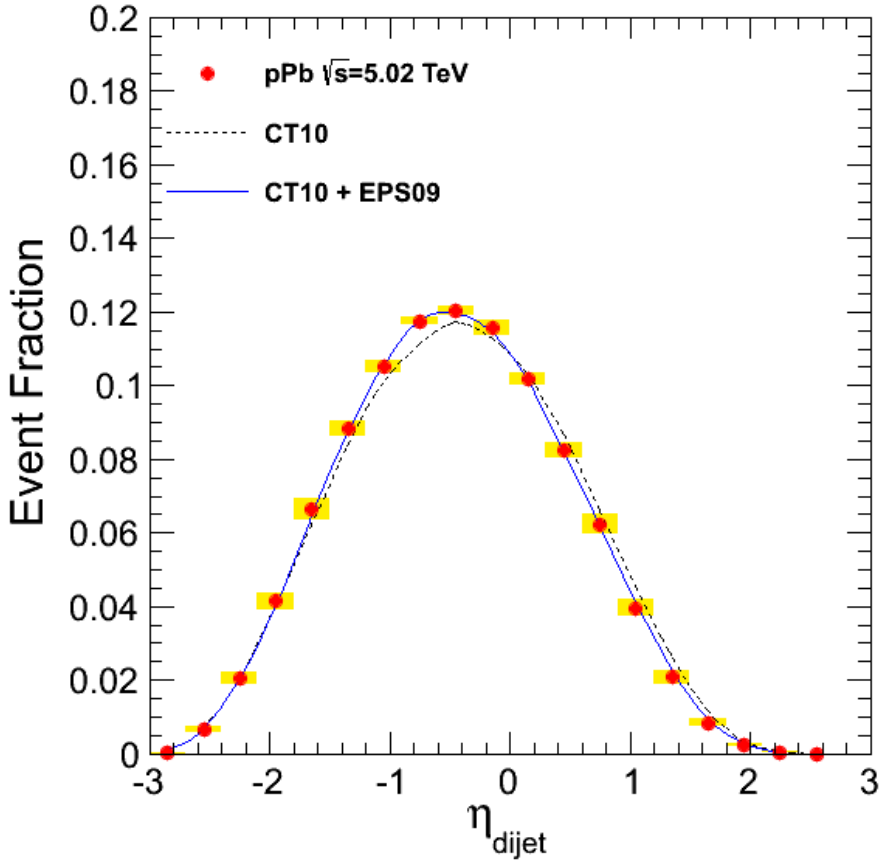
# Comparison to nPDF predictions

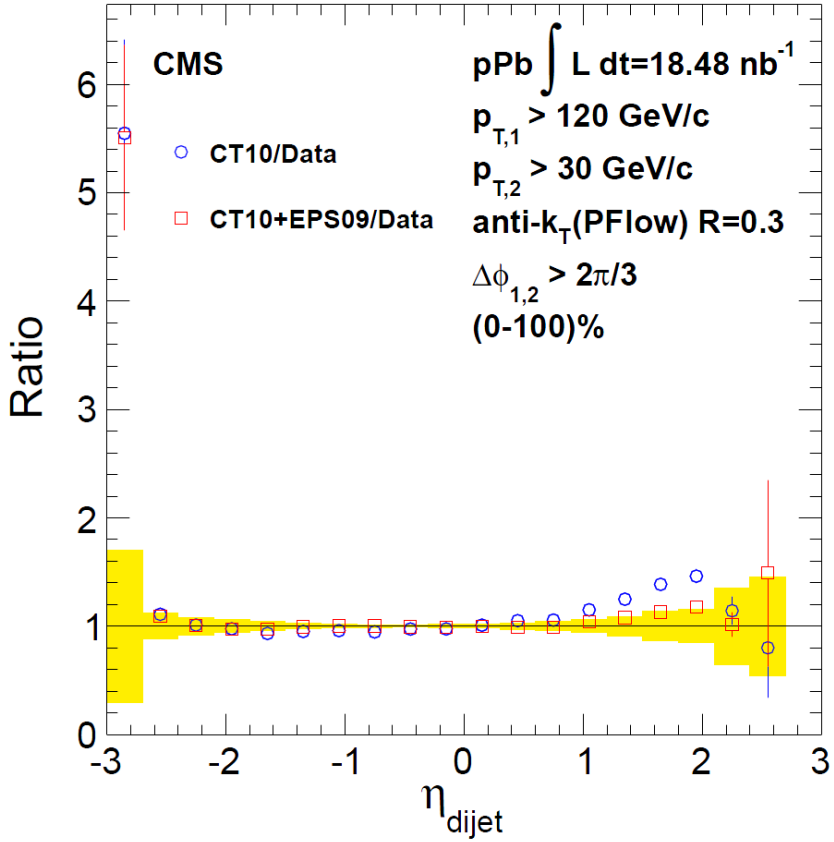



- Observe similar enhancement/suppression in dijet η as predicted for parton x by EPS09 collaboration.

# Comparison to nPDF predictions

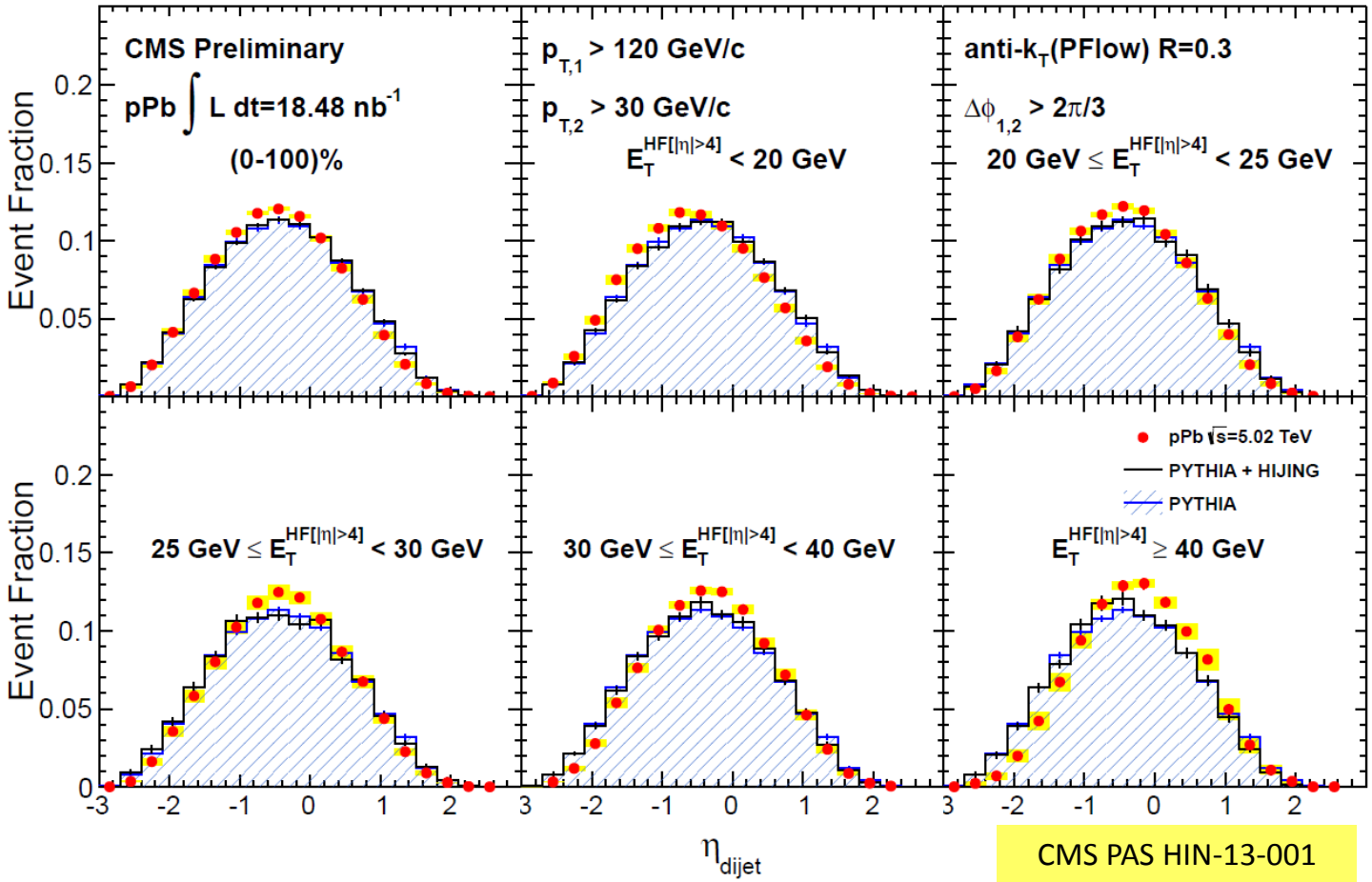



- Agreement between data and EPS09 for dijet η > -2.
- The disagreement at η > -2 is probably due to difference in dijet selection.

# Dijet η

$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$




CMS PAS HIN-13-001

- (0-100)% centrality bin is modified with respect to MC references
- A systematic shift in the positive η direction vs HF energy.

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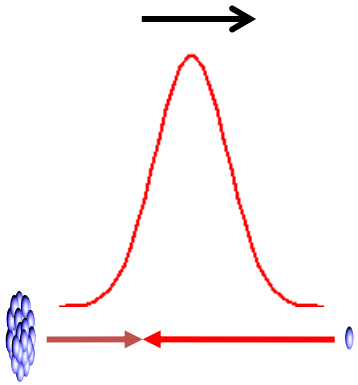
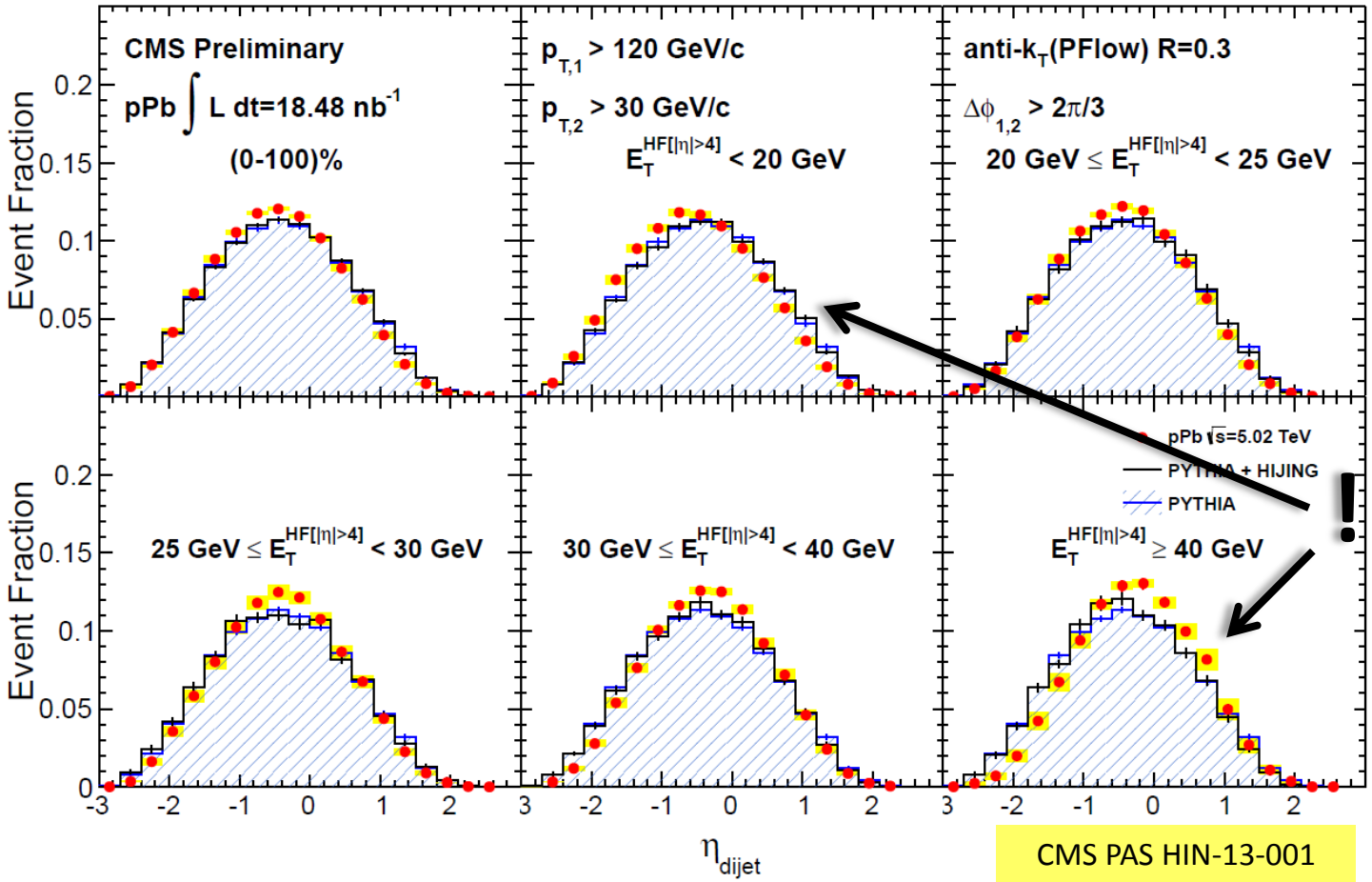
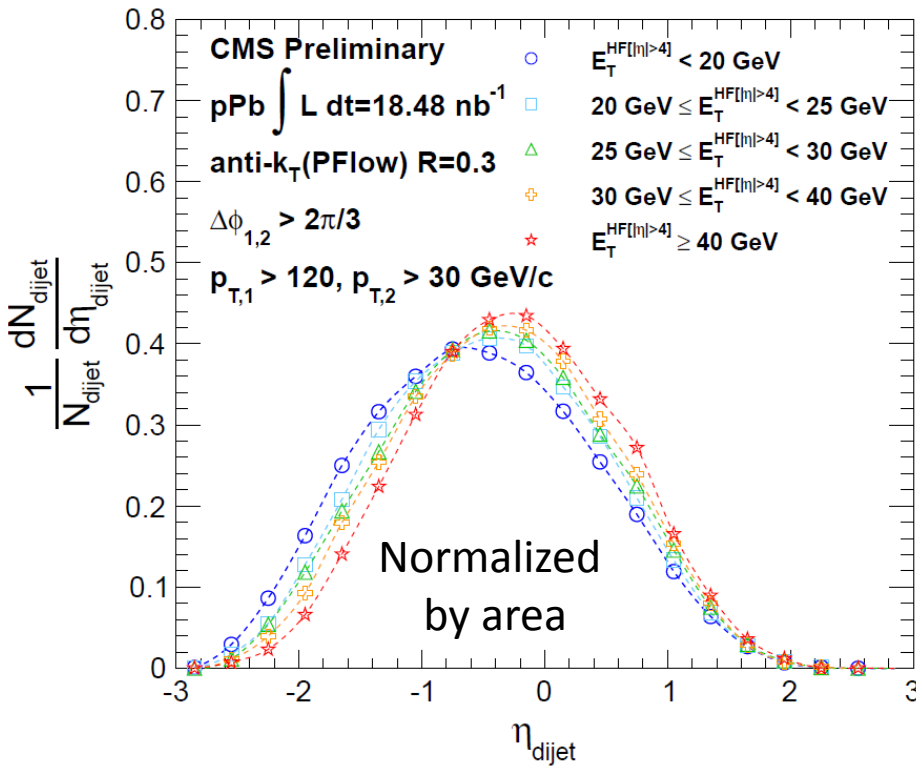


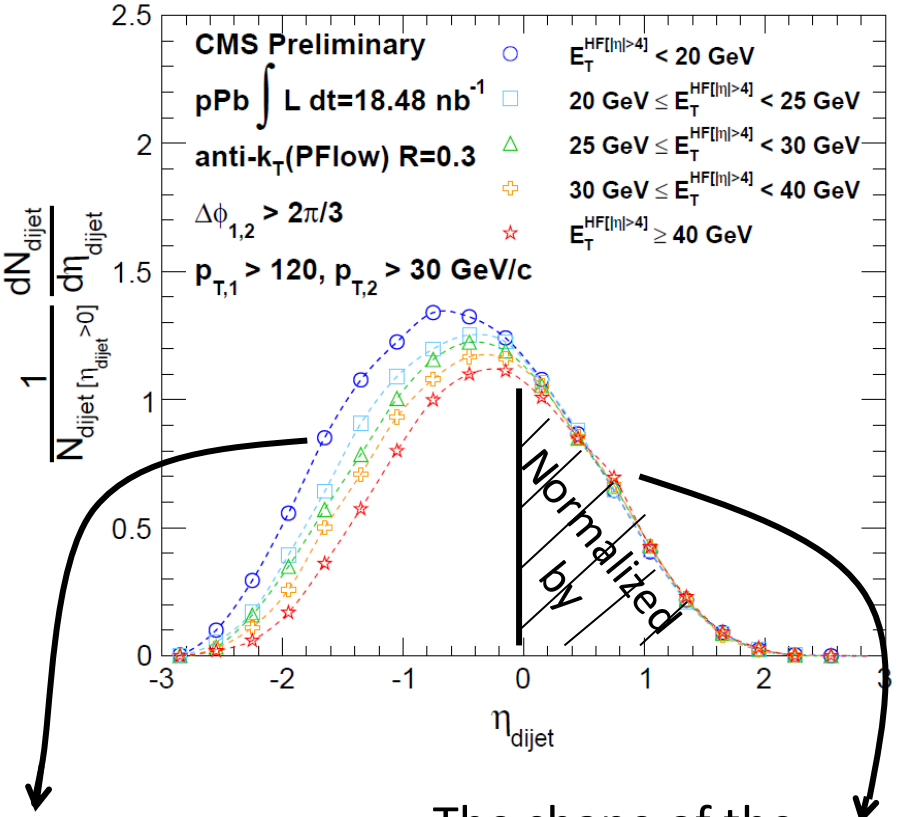



CMS PAS HIN-13-001

- (0-100)% centrality bin is modified with respect to MC references
- A systematic **shift in the positive η direction** vs HF energy.

# Different choices of normalization

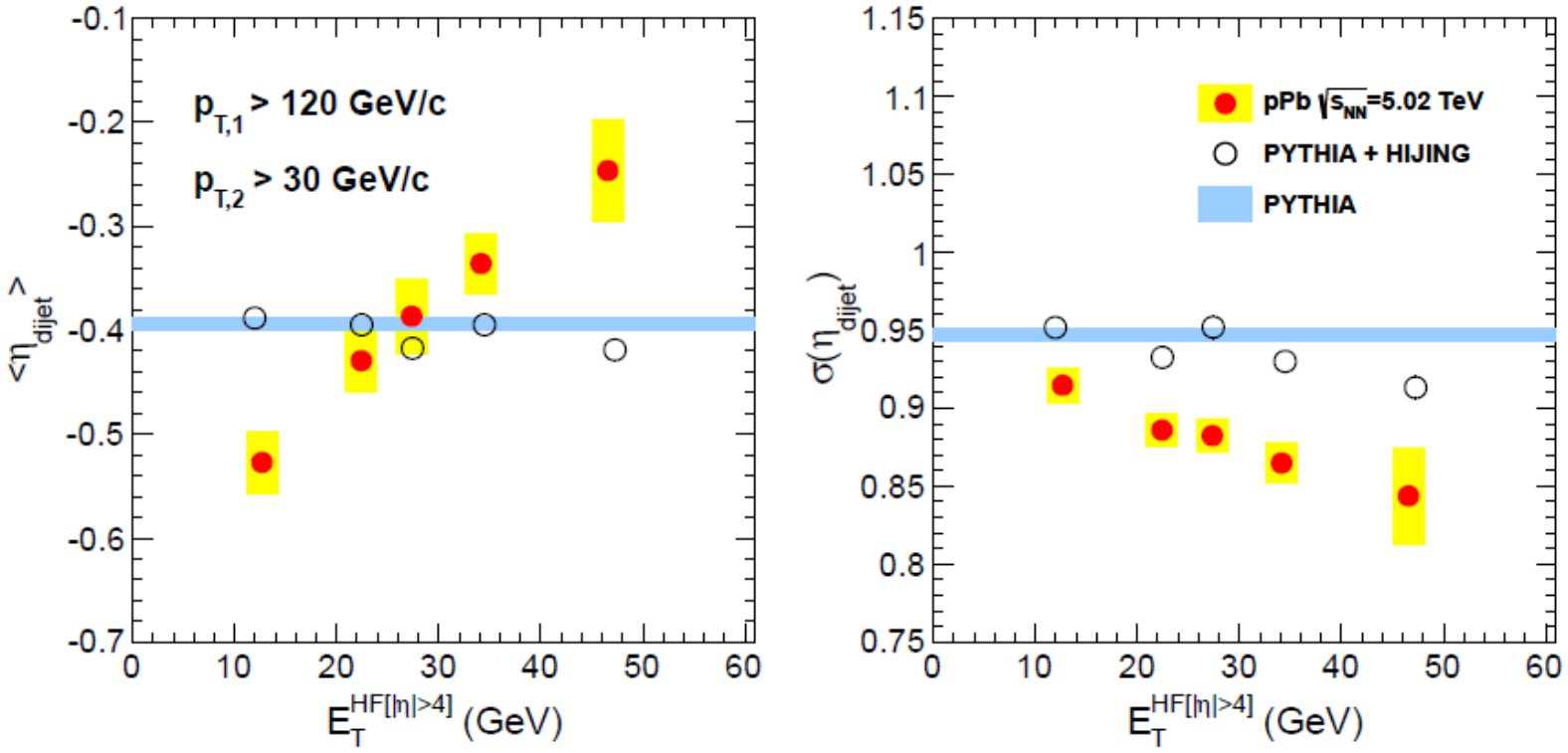



Evolving behavior

The shape of the distribution does not change for dijet η > 0. (EMC region)

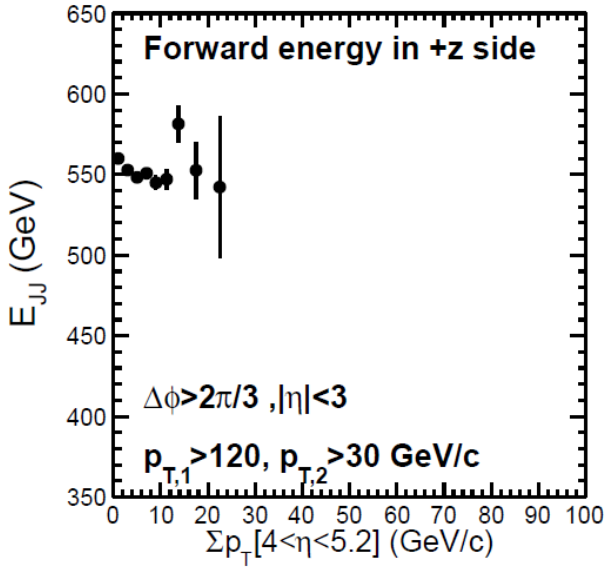
# Summary of dijet η

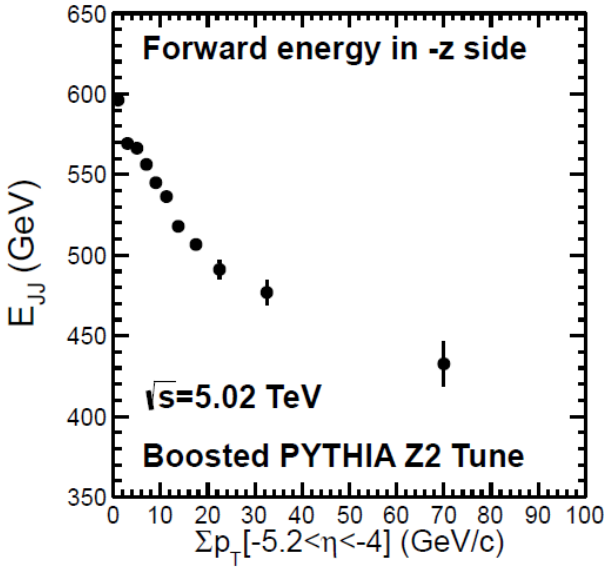


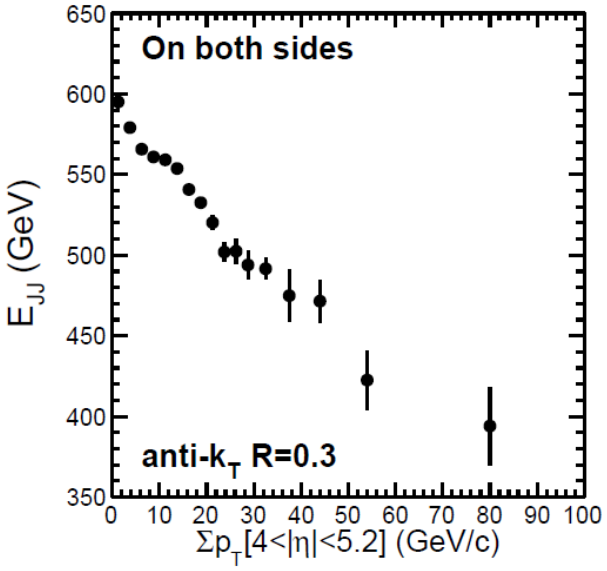

- Mean of $\eta_{dijet}$ increases v.s. forward calorimeter energy
- Width of $\eta_{dijet}$ decreases v.s. forward calorimeter energy (also in MC reference)

# Bias due EM conservation?

Why does the dijet pseudorapidity get narrower by increasing forward energy?



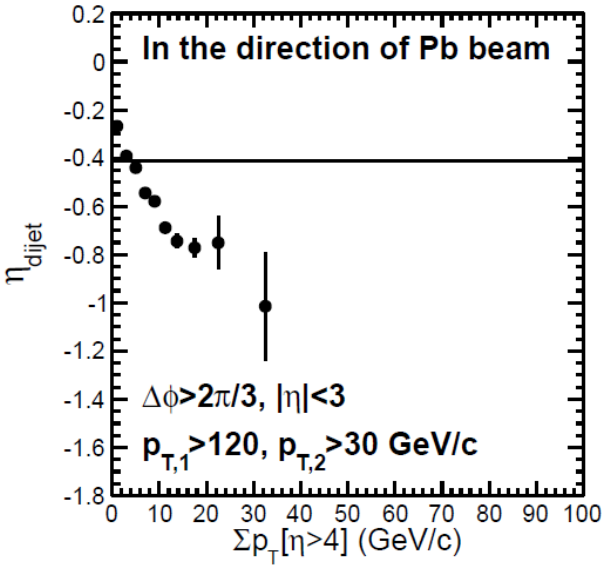

$$E_{JJ} = p_{T,1}\cosh(\eta_2) + p_{T,1}\cosh(\eta_2)$$

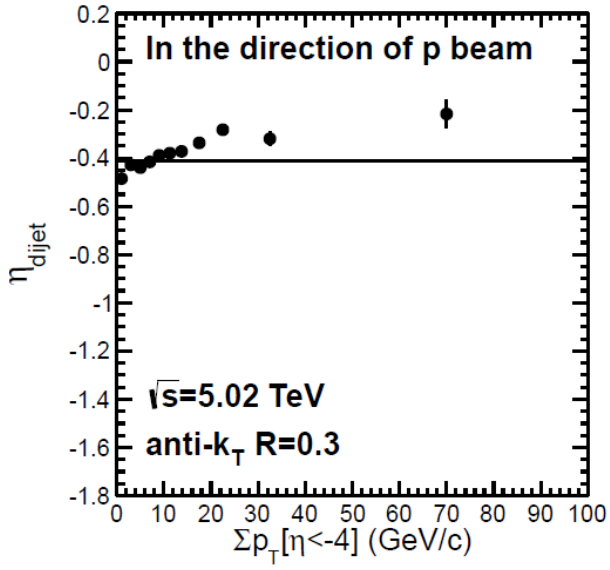
As forward energy in the event increases the energy that is left to dijet pair decreases.

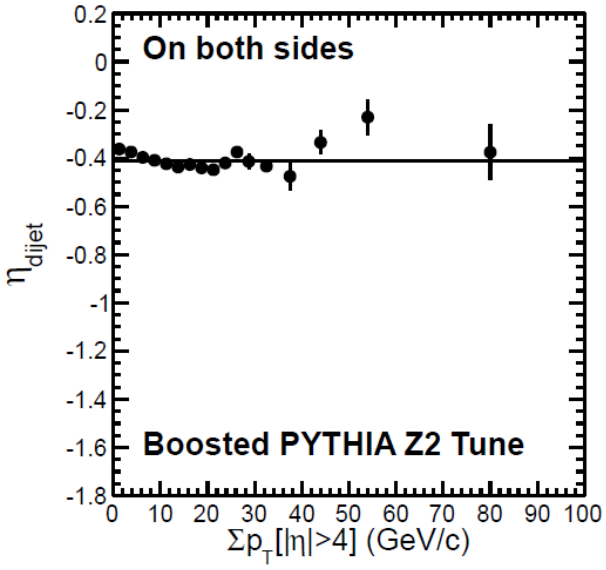
This trend is smaller if you look at +z side. Why ?

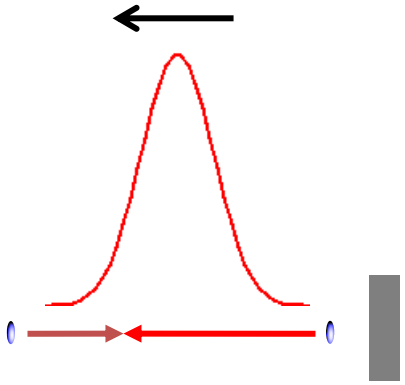
# Variables based on forward energy deposit

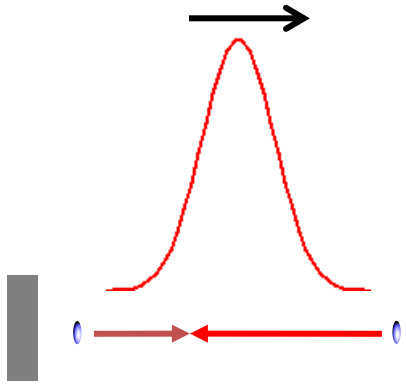
$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$



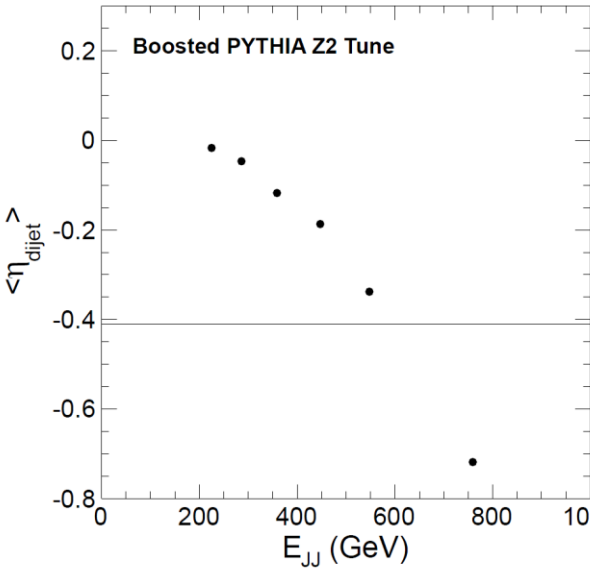


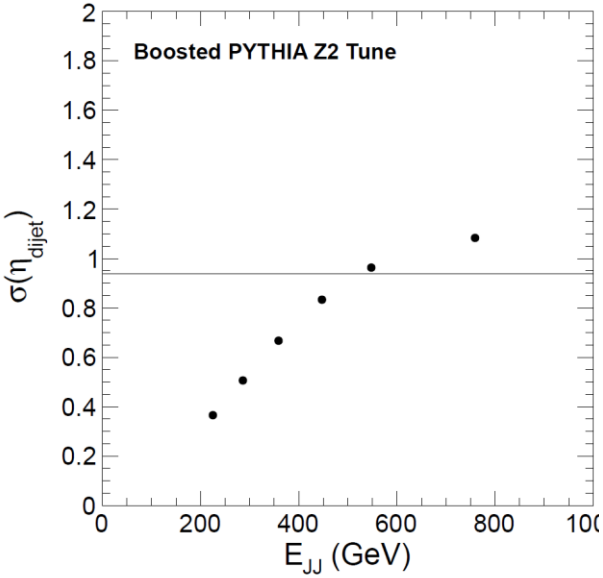
## Energy momentum conservation:

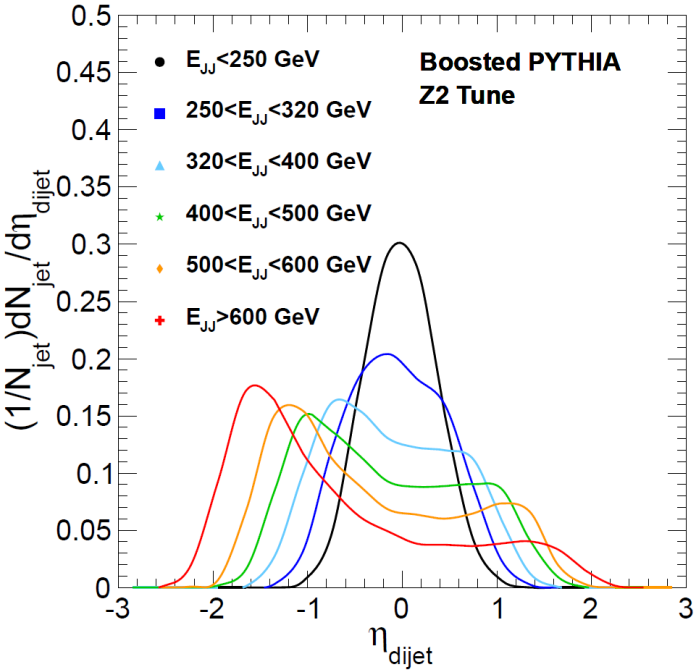
When a large deposit on one side is required the dijet pseudorapidity shifts towards the other direction.

# Bias due EM conservation?

Does this also result in a shift?




$E_{JJ} = p_{T,1}\cosh(\eta_2) + p_{T,1}\cosh(\eta_2)$

Could be the case? How much of an effect?

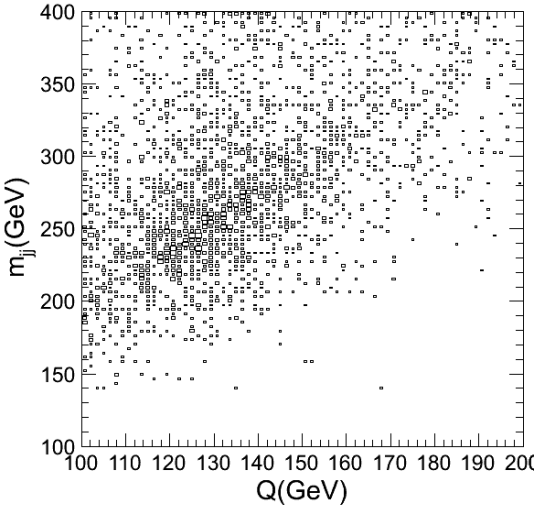
# Conclusions

- It is very difficult to distinguish collisions with different impact parameter/$N_{part}$ in pPb.
- No significant jet quenching in pPb collisions:
  - Any modification dijet $p_T$ ratio and azimuthal angle correlation is < 2%.
- **PDF modifications**
  - Dijet pseudorapidity distribution is sensitive to nPDF for $x > 10^{-3}$ and $Q^2 > 5000$.
  - Dijet pseudorapidity v.s. forward calorimeter energy show an interesting trend

# Looking forward

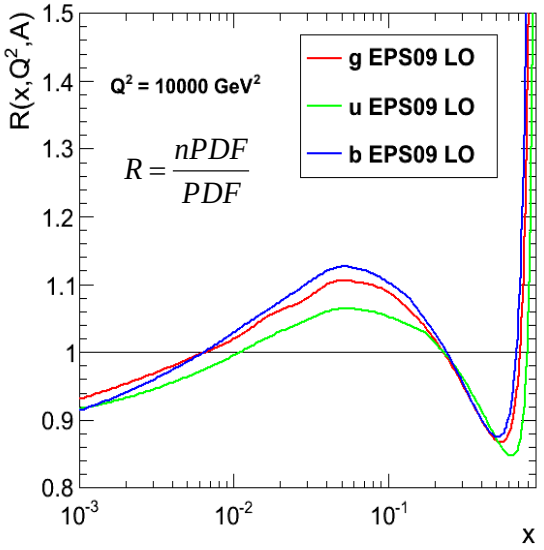
# nPDF measurements with dijets

- Inclusive centrality dijet pseudorapidity measurement proved to be useful to constraint nPDFs, so we can go further:
  - $Q^2$ dependence of nPDF
  - Going to lower x
  - Impact parameter dependence of nPDF:
    - Is there a way to isolate nPDF effects on dijet pseudorapidity as a function of forward activity?
    - Is there a way around complicated centrality biases?



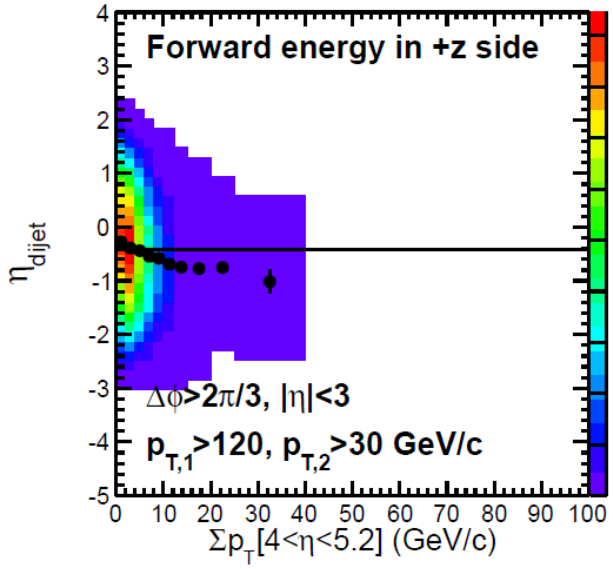
# Using different probes

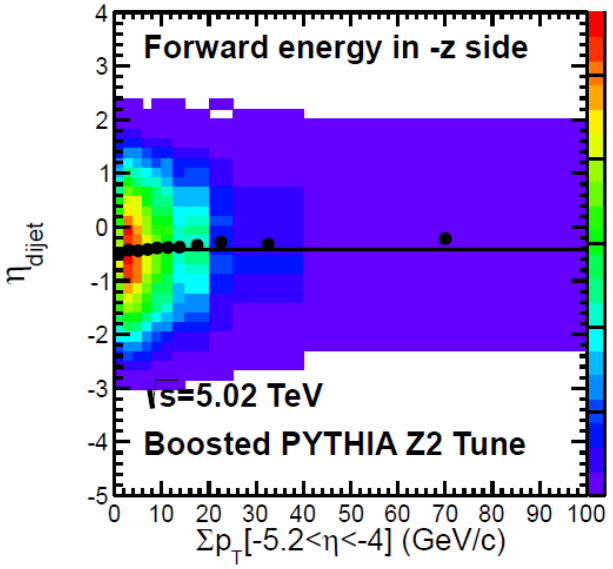
- Quark-gluon nPDF:
  - Gamma-Jet measurements.
  - More elaborate quark-gluon jet discrimination
- Flavor dependence of nPDF's.
  - b-jets: With current 31 $nb^{-1}$ data O(1000) of di-b-jets

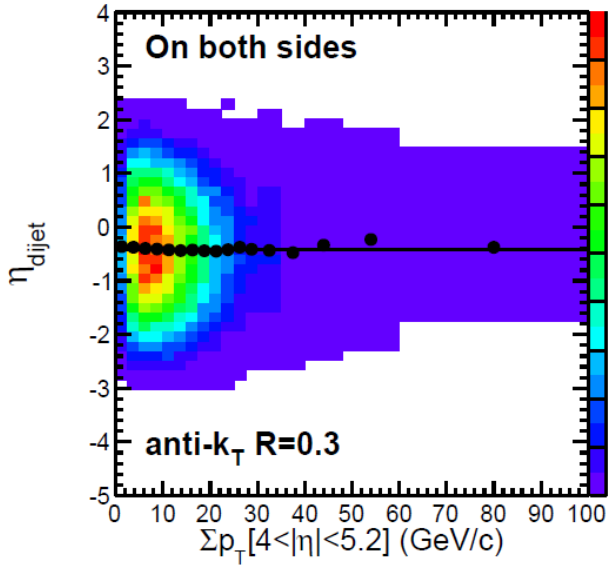


# Back-up

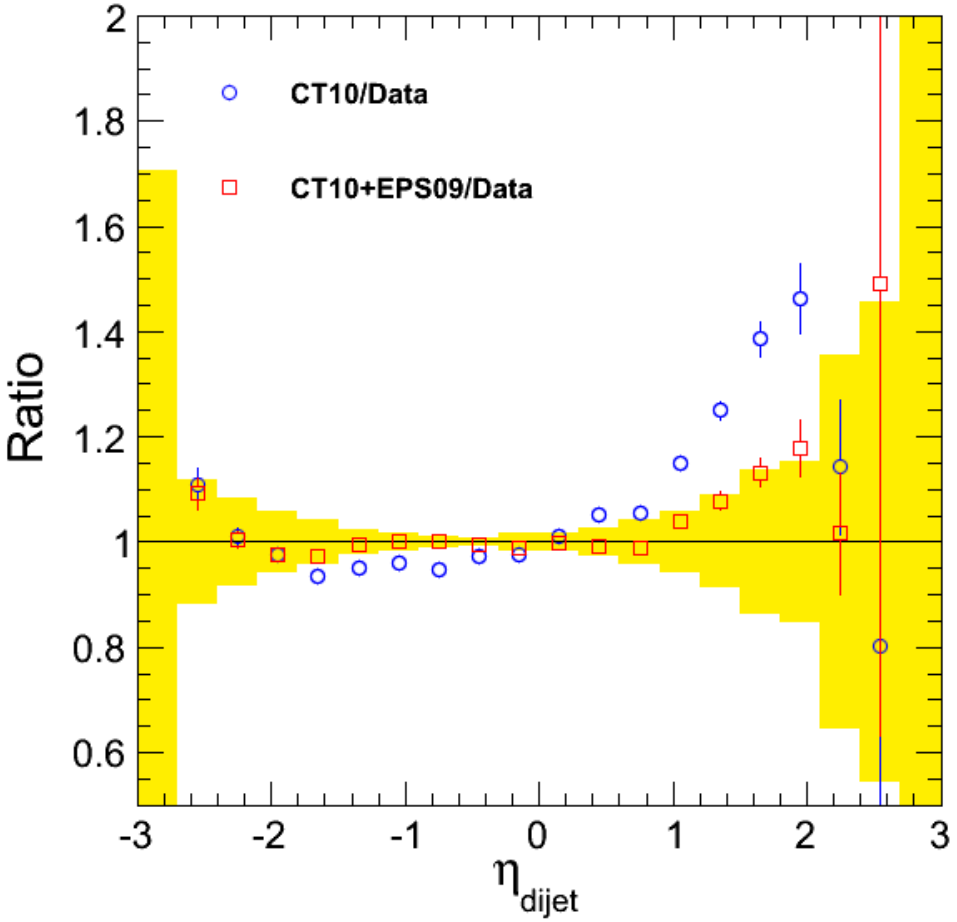
# Centrality and forward energy



# EPOS comparison (v2)



# What do we know about jet quenching in pPb collisions?

PRL 110 (2013) 082302

$$R_{pPb} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{pPb} / dp_T d\eta}{d^2 \sigma_{pp} / dp_T d\eta}$$

$R_{pPb}$ ~ 1 from ALICE collaboration

No strong modification of high $p_T$ charged particle spectra in NSD 0-100% pPb collisions.

We need to look at high multiplicity events ("central collisions").

**How do we classify the events?**