Dijet Measurements in pPb Collisions

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On behalf of the CMS Collaboration

IS2013, Illa da Toxa, Spain – Sep 13th 2013

Outline

INTRODUCTION

Data and MC

Centrality in pPb and event classes

Overview of the analysis:

- Major systematics
- Results

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

Comparison to EPS09 nPDF

Dependence on total forward activity

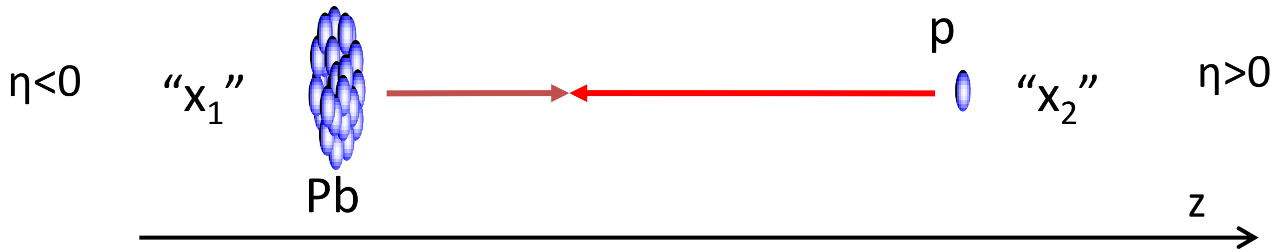
Dependence on Pb (p) side forward activity NEW

SUMMARY

Data and MC

DATA

- High-p_T jet trigger (a jet with p_T > 100 GeV/c)
- Pb ion is going in the positive z direction
- p beam energy 4 TeV, Pb beam energy 1.58 TeV
- Pseudorapidity shift NN center of mass to -0.465



MC

- Boosted PYTHIA pp jets with η_{CoM}= -0.465
- Embedded PYTHIA sample into a HIJING pPb background

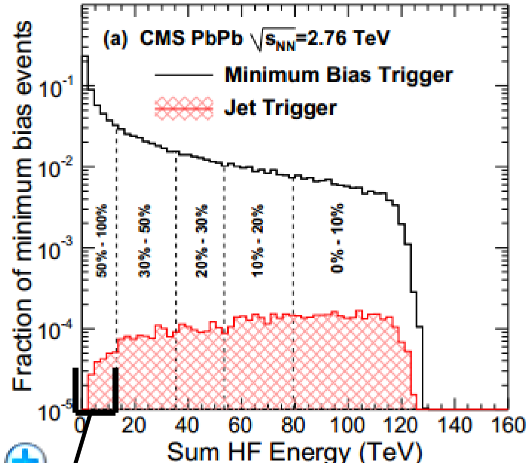
Dijet selection:

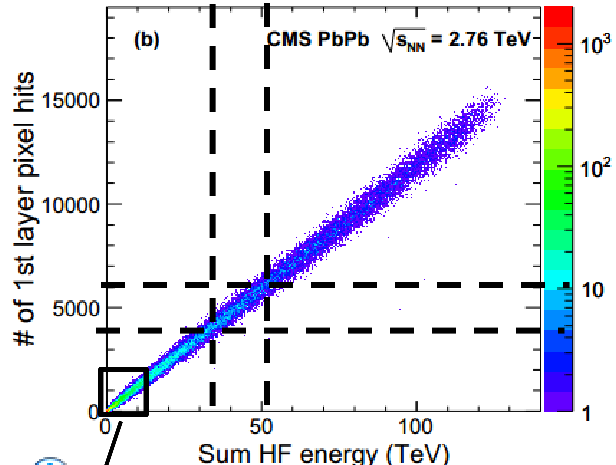
$|\eta| < 3$, $p_{T,1} > 120$ GeV/c, $p_{T,2} > 30$ GeV/c, $\Delta\phi_{1,2} > 2\pi/3$

Centrality in PbPb and pPb

PbPb

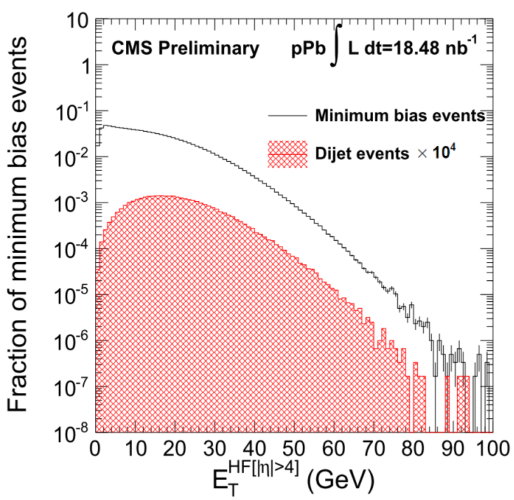
Phys.Rev.C84:024906,2011

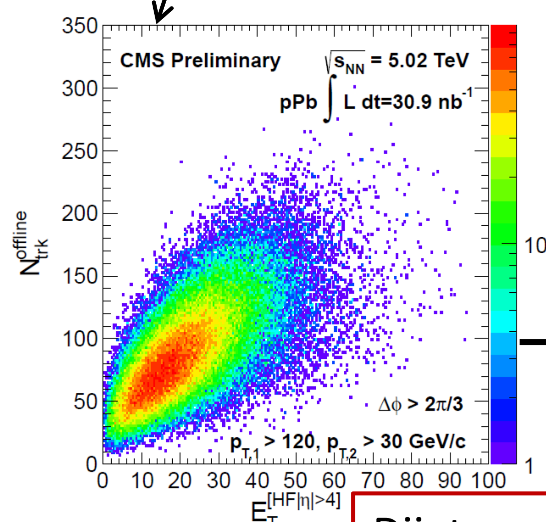




Slicing direction doesn't vary the chosen events significantly.

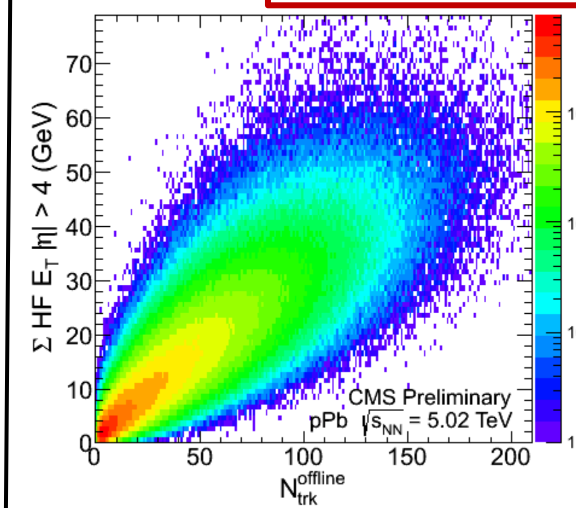
pPb





Dijet events

Minimum bias

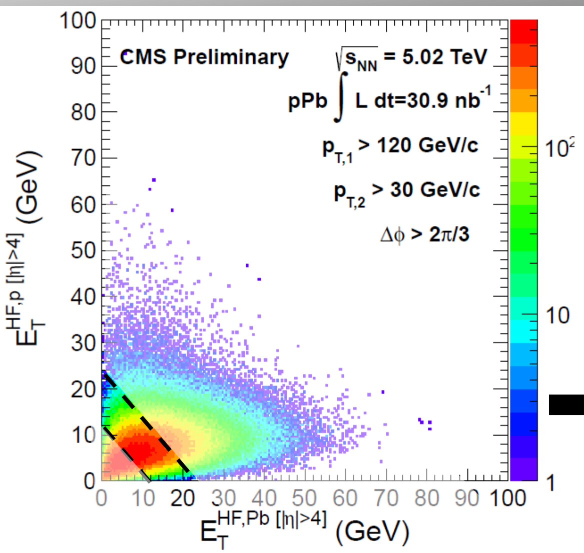


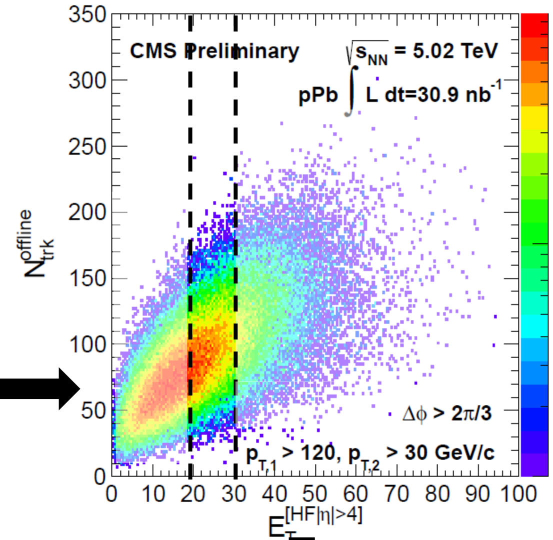
Compared to Minimum bias:

- Dijet N_{trk} and E_T^{HF} biased towards larger values
- Slope is also different: Ntrk≈100 E_T^{HF} ≈20 dijet, 30 GeV MB

Centrality classes in pPb

CMS PAS HIN-13-001

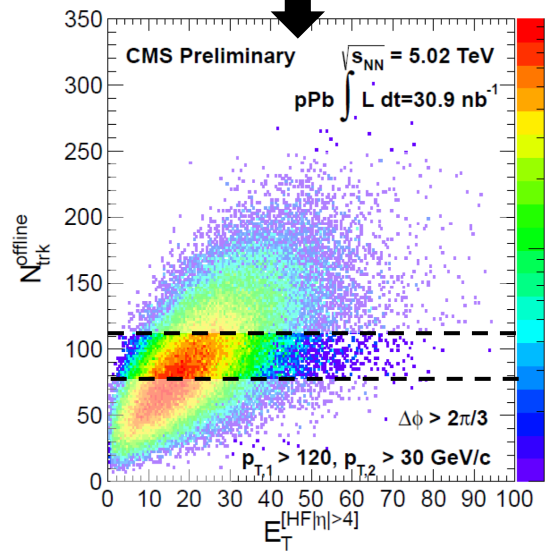


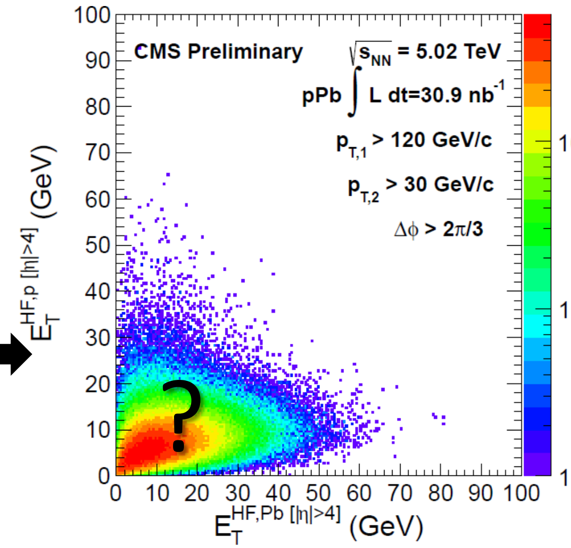


Let us choose one vertical and one horizontal slice which will have same <HF E_T > and same <N_{trk} >

Event activity on Pb side vs event activity on p side

- Correlation is very loose.
- Different trends:
  Proton side E_T energy rise as a function of Pb side energy rise flattens out.





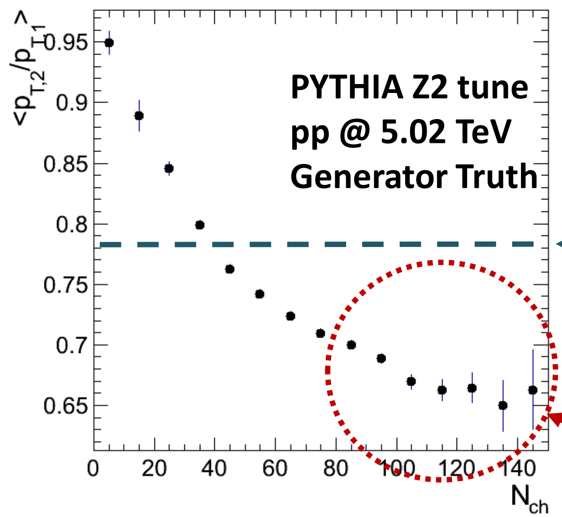
What about peripheral PbPb?

Centrality bias & Dijet observables

Each jet means additional N_{ch} ~ 20

CASE 1

Correlation between centrality variable and dijet observable due to the overlaping range of measurement

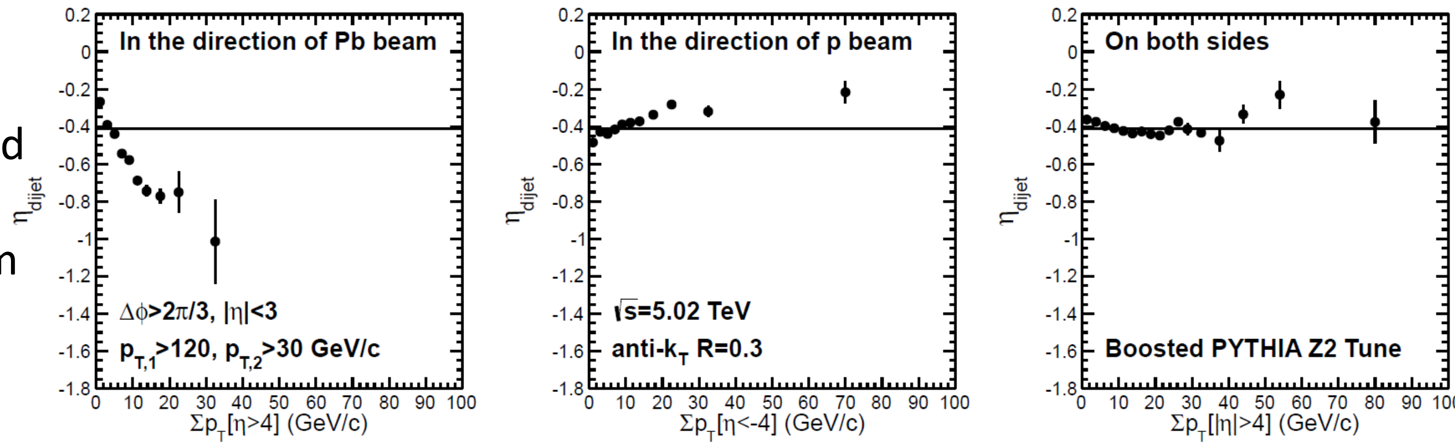


Mean value without N_{ch} selection

Event more likely to have 3 (or more) jets

CASE 2

Correlation between centrality variable and dijet observable due to energy momentum conservation



CASE 3,4… Chance determination of biases is limited by how well MC describes data.

Event Classification

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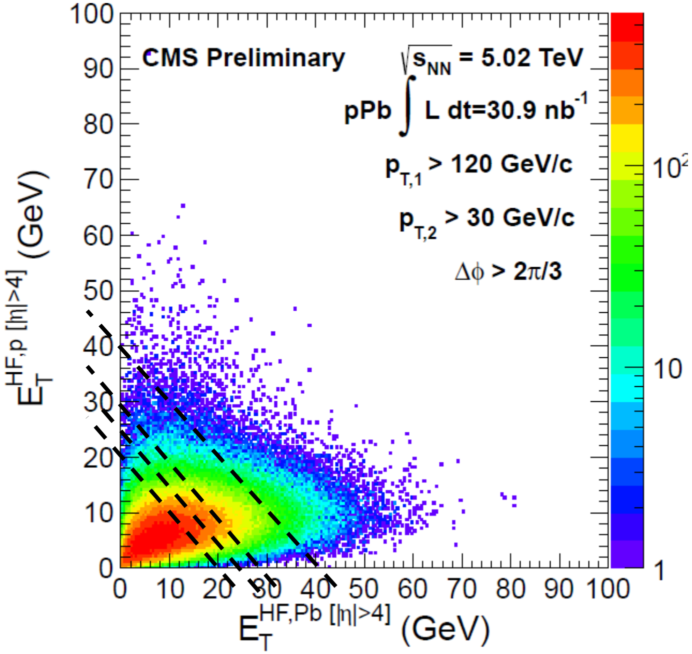
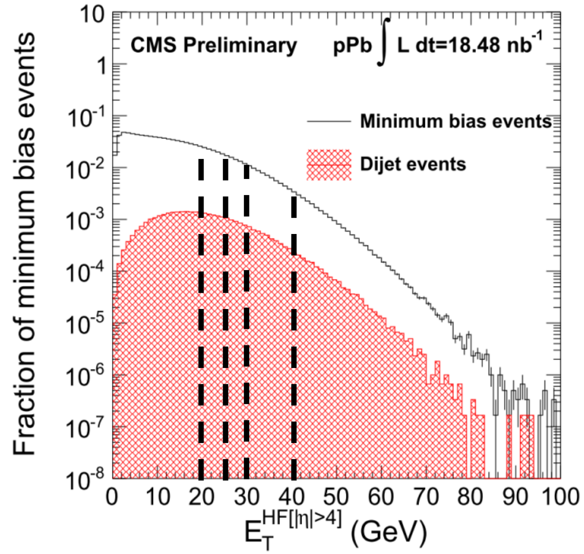




Minimum bias selection:
At least one particle with E>3 GeV in the pseudorapidity range -5 < η< -3 and one in the range 3 < η < 5

$E_T^{HF[\|\eta\|>4]}$ 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

Major systematics

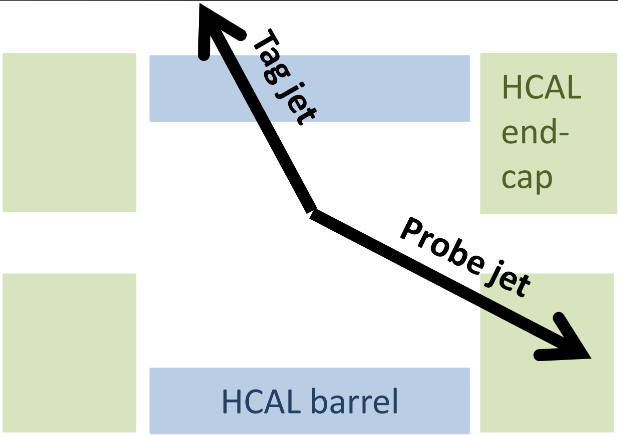
Jet energy scale corrections(JEC):

JEC from MC + Data Driven JEC

↓

Tag & Probe:

at HCAL barrel at HCAL end cap



- Described in JINST 6 (2011) 11002
- Corrects for the calorimeter response difference in data and MC
- Important for this analysis to go forward pseudorapidities.

Forward activity binning:

We quote the change in PYTHIA+HIJING sample with respect to inclusive centrality bin.

Pile-up filter:

Important only for highest activity events. It removes:

- ≈ 2% of minumum bias events
- ≈ 5% of high multiplicity events
- ≈ 4% of dijet events

Overview of the results

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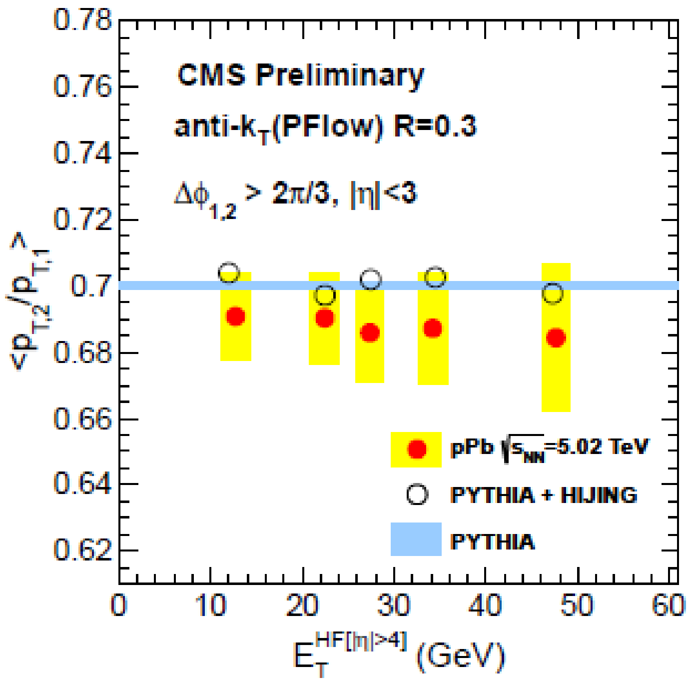

RESULTS

- **No sign of jet quenching (yet?):** We do not observe significant modification in pT ratios of leading and subleading jet. (Any modification <%2)

- **Compared to nPDFs:** Dijet pseudorapidity distribution is modified with respect to MC in a way that is compatible with nPDF predictions
- **Dijet pseudorapidity shift:** Dijet pseudorapidity distribution shifts significantly towards Pb going side as one goes to higher forward activity events

Overview of the results

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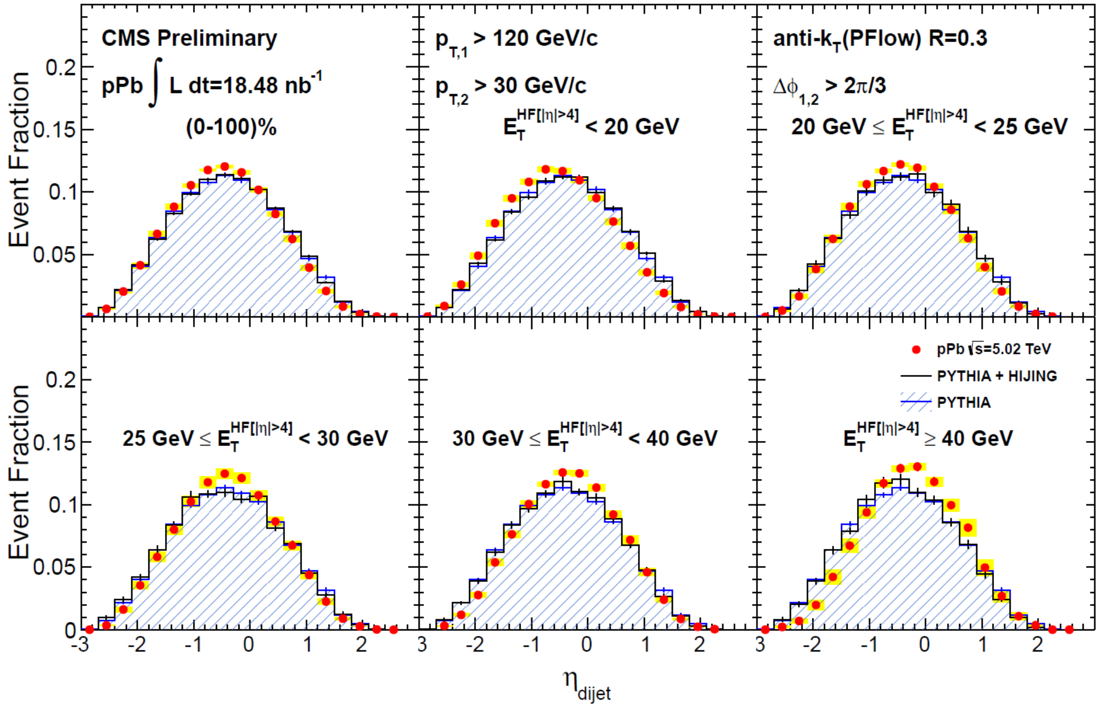

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Comparison to EPS09 predictions

Escola, Paukkunen, Salgado. arxiv:1308.6733

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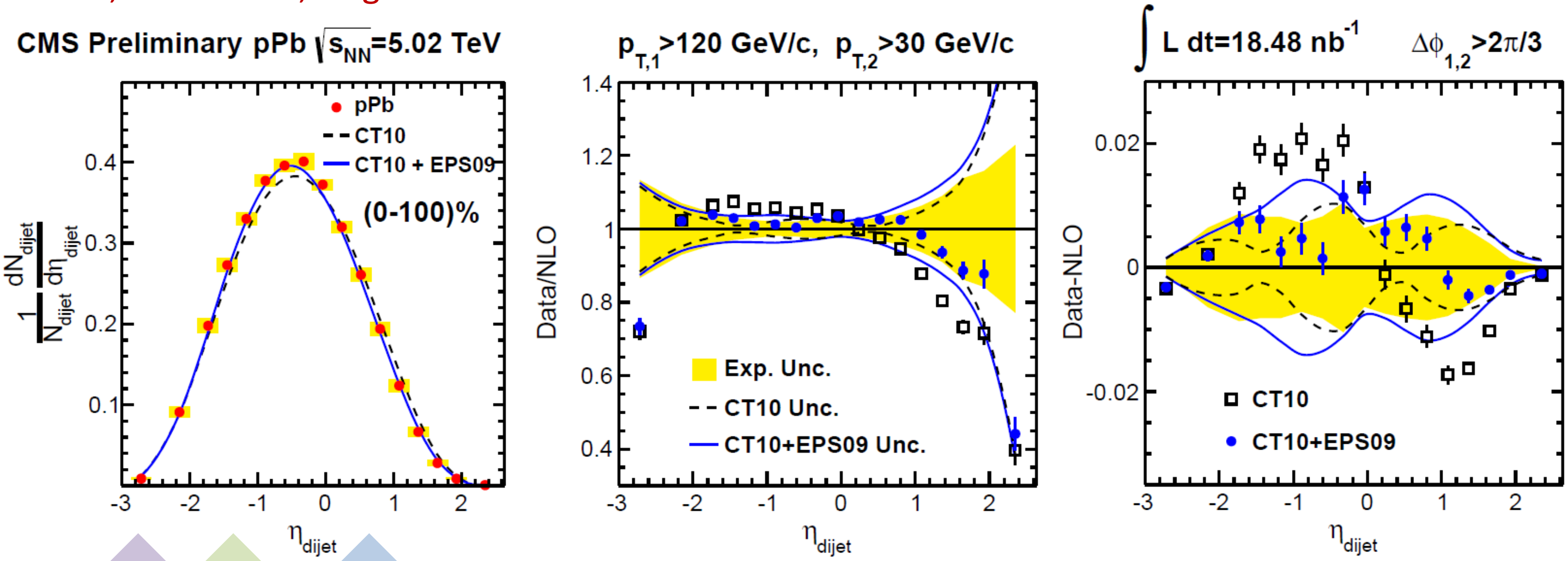
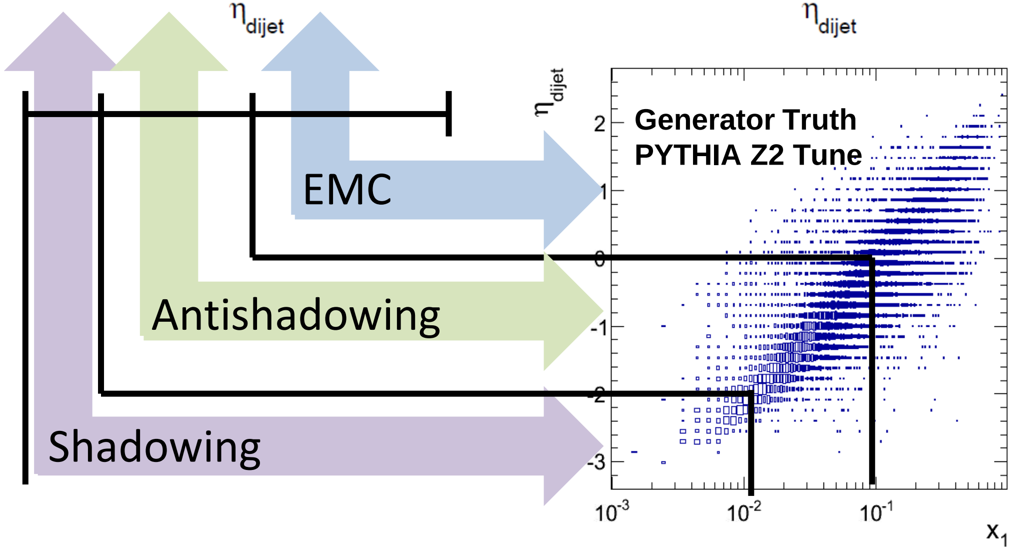
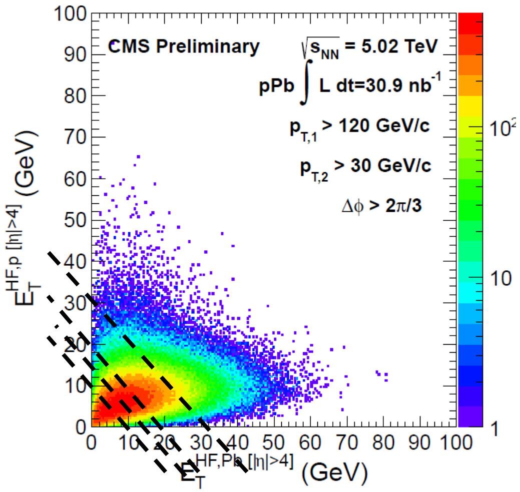
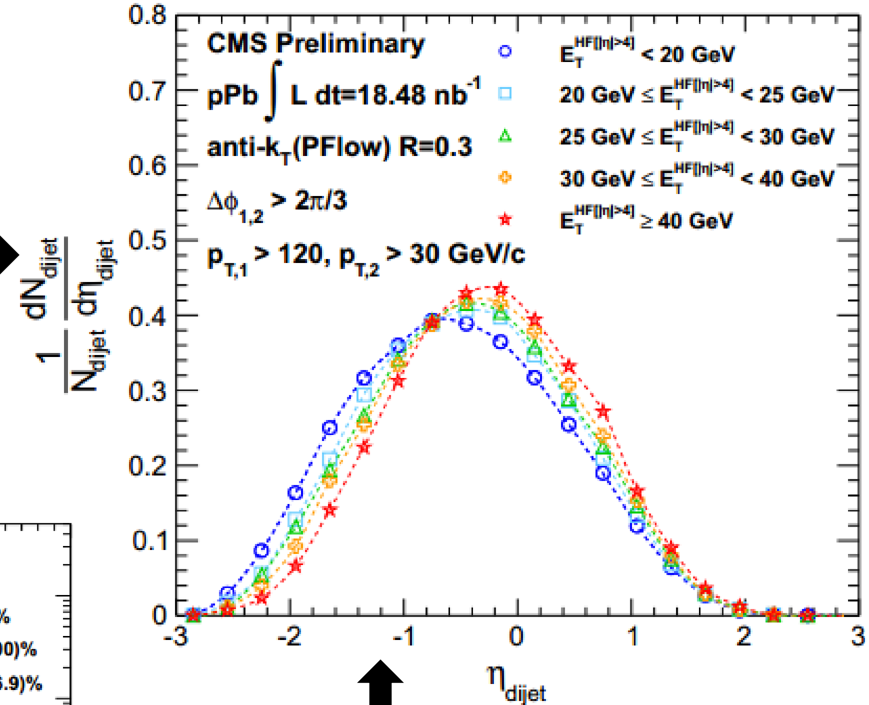


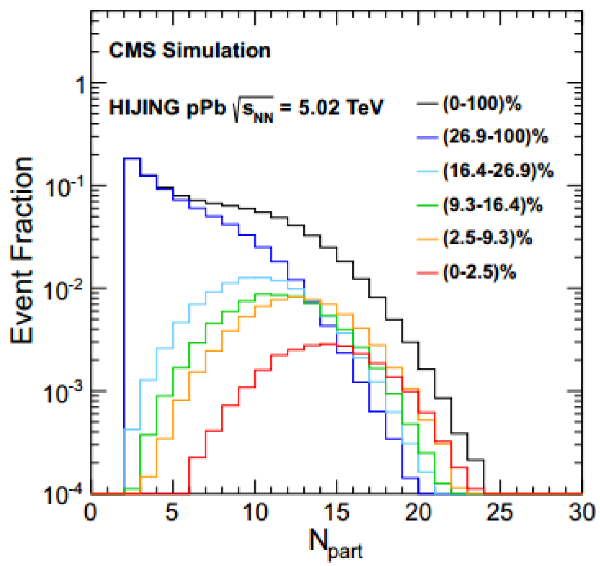


- Agreement between data with EPS09 within systematics.
- Data has slightly larger. modification in anti-shadowing and EMC regions compared to CT10+EPS09. (DSSZ agreement would be worse)
- Large uncertainties in forward region.

Forward activity dependence of η_{dijet}







Going to large HF E_T N_{part} only increases very little

Large variation in dijet pseudorapidity distiribution

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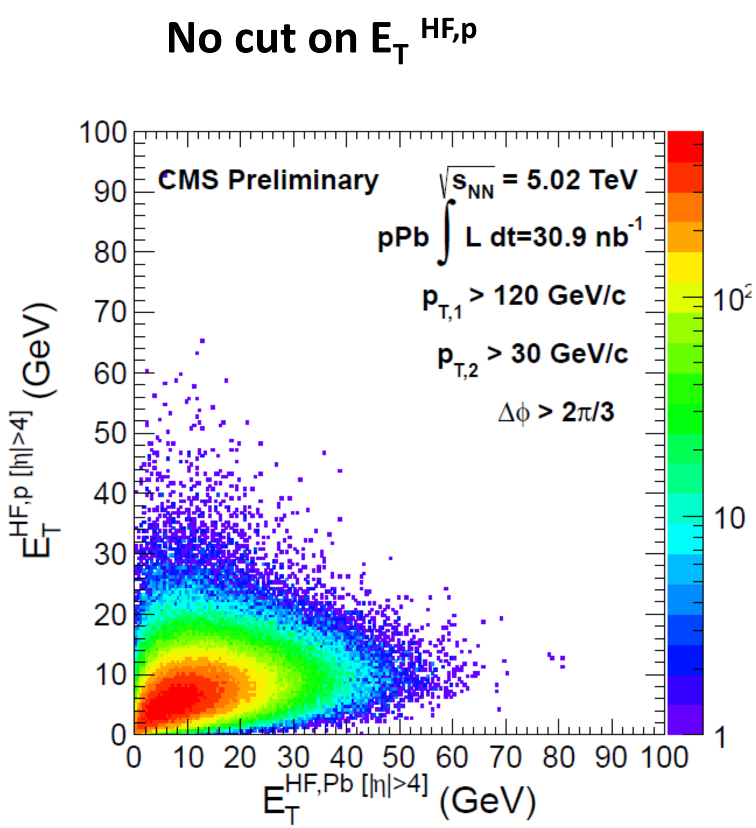
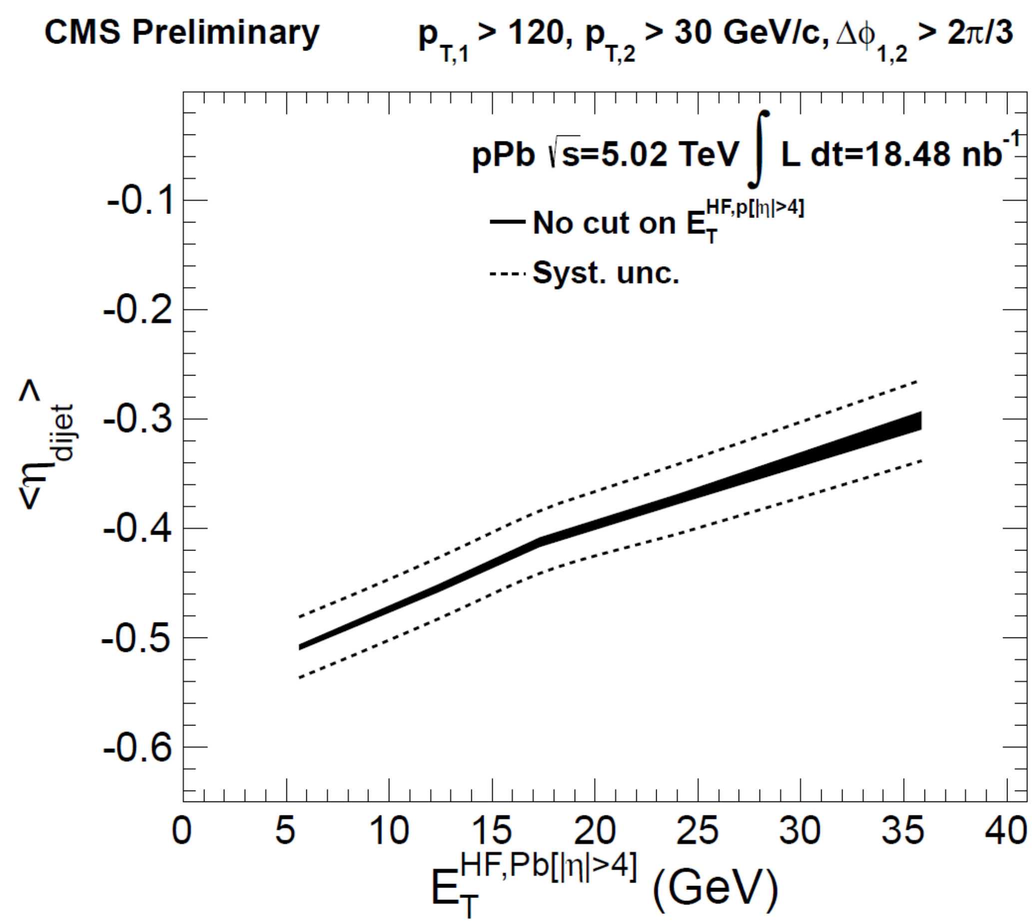
η_{dijet} vs Pb side forward activity





- Shift slightly less compared to the mean dijet eta vs forward activity on both sides. (shift ≈0.2 instead of 0.27)
- Remember from slide 7 that the shift in PYTHIA is in opposite direction, cancellation occurs reducing the effect.

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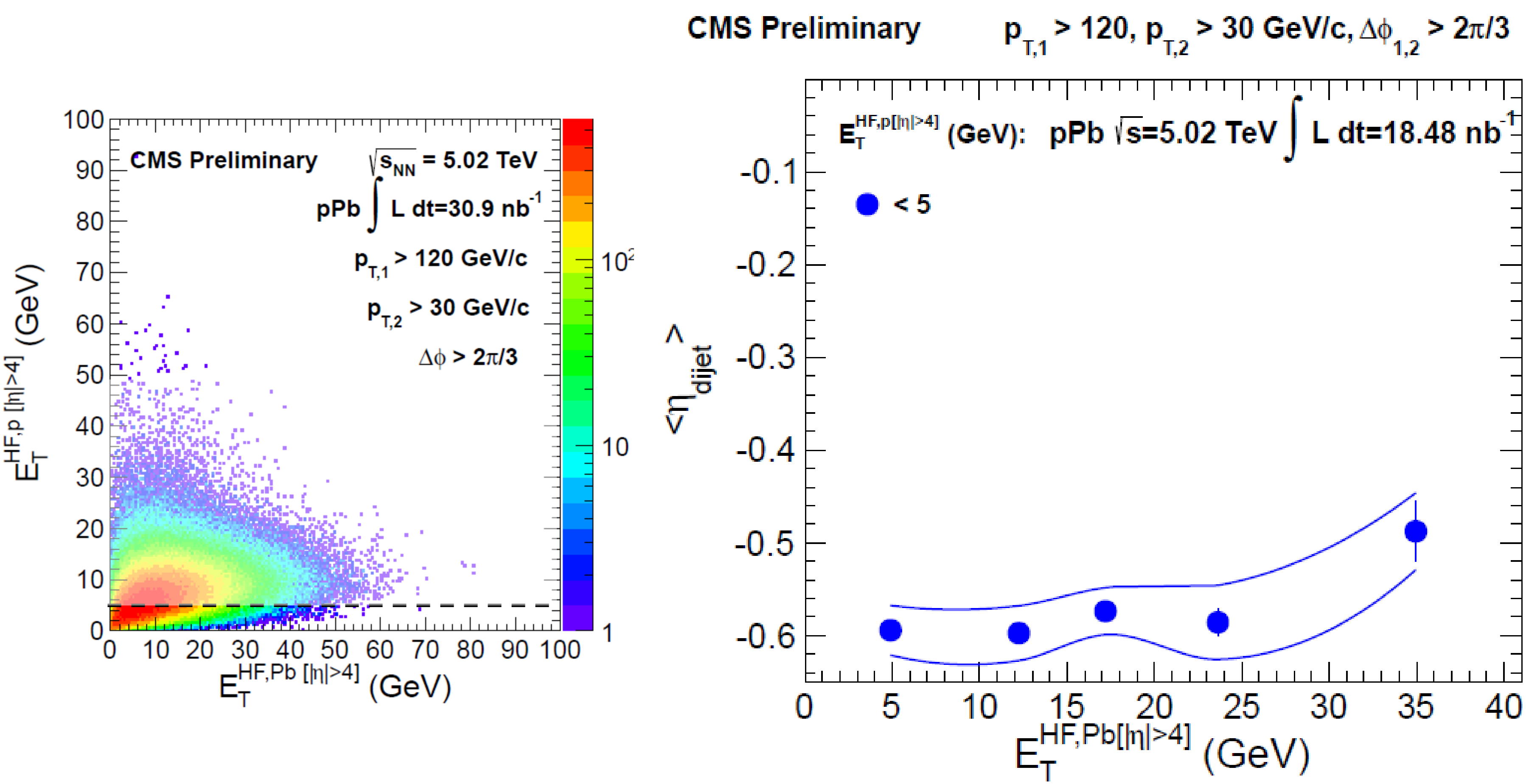
η_{dijet} at fixed proton side forward activity



- When energy on proton size is small $<\eta_{dijet}>$ almost flat as a function of forward activity on Pb side.

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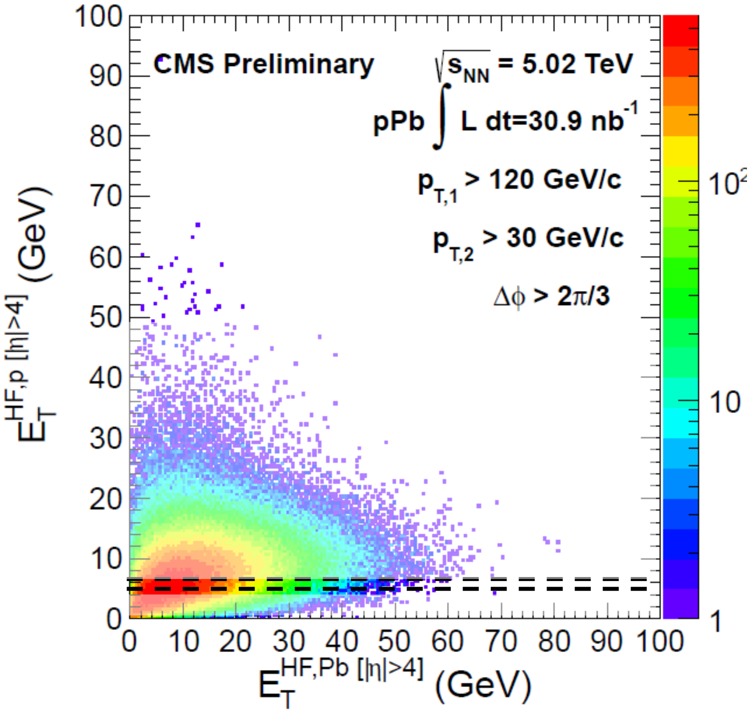

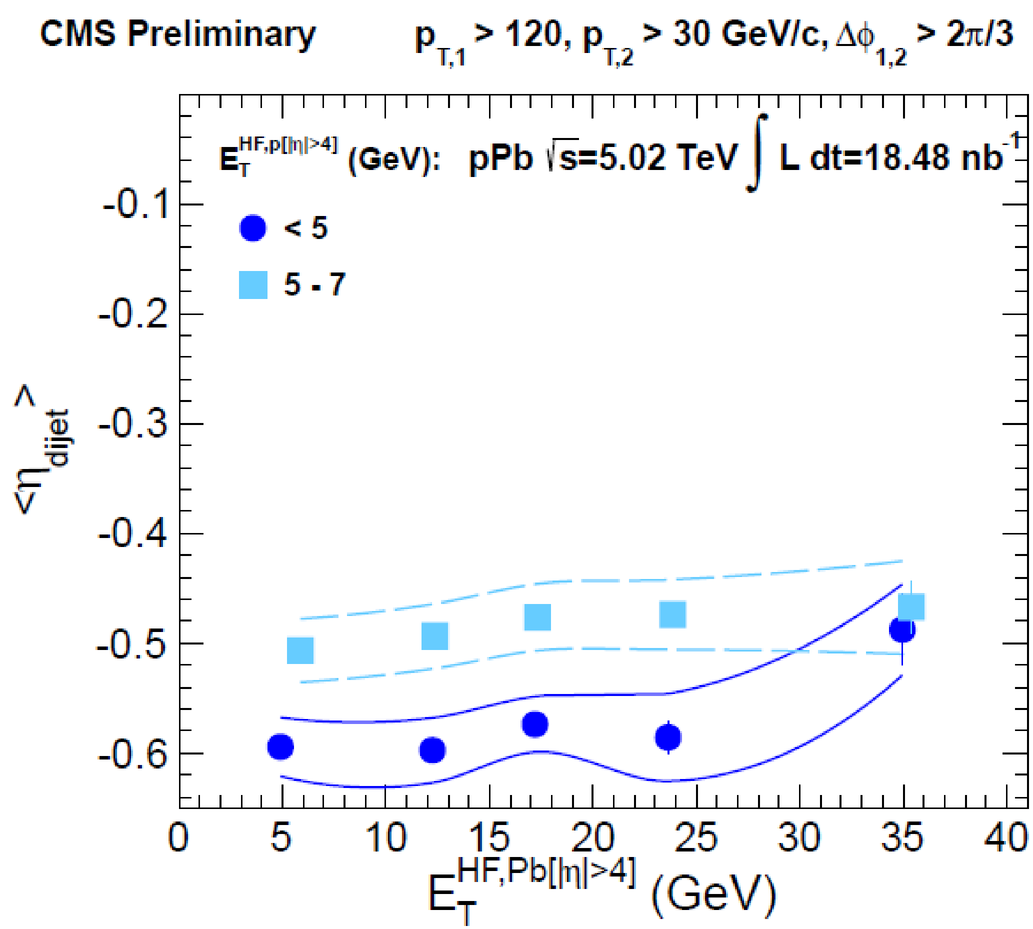

Still flat..

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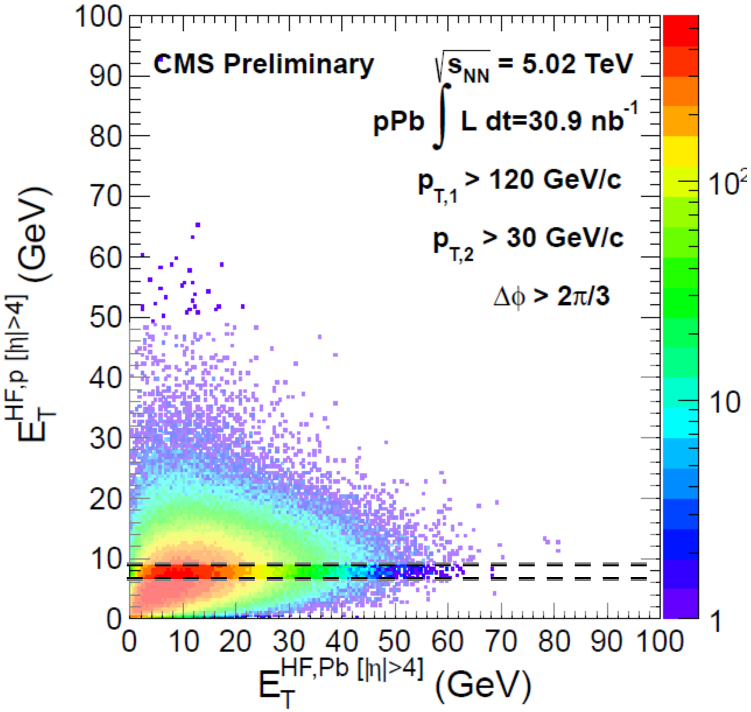
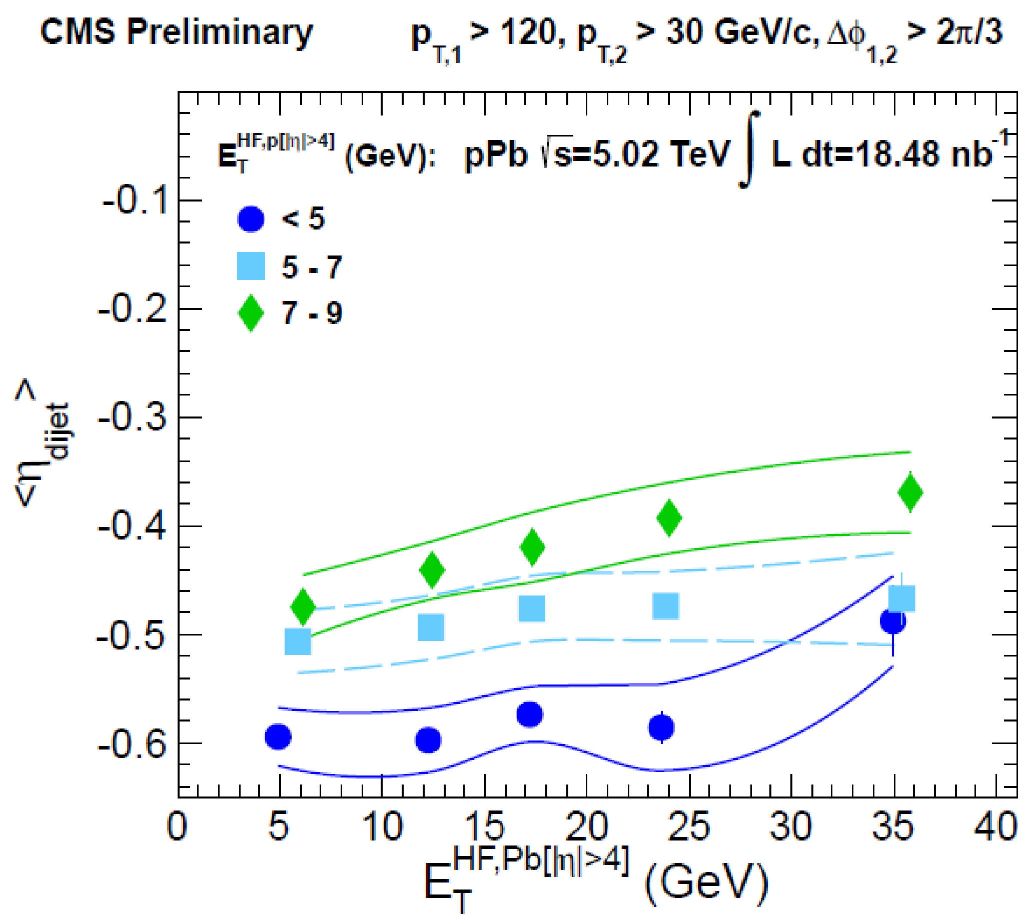
η_{dijet} at fixed proton side forward activity





Slope starts to increase..

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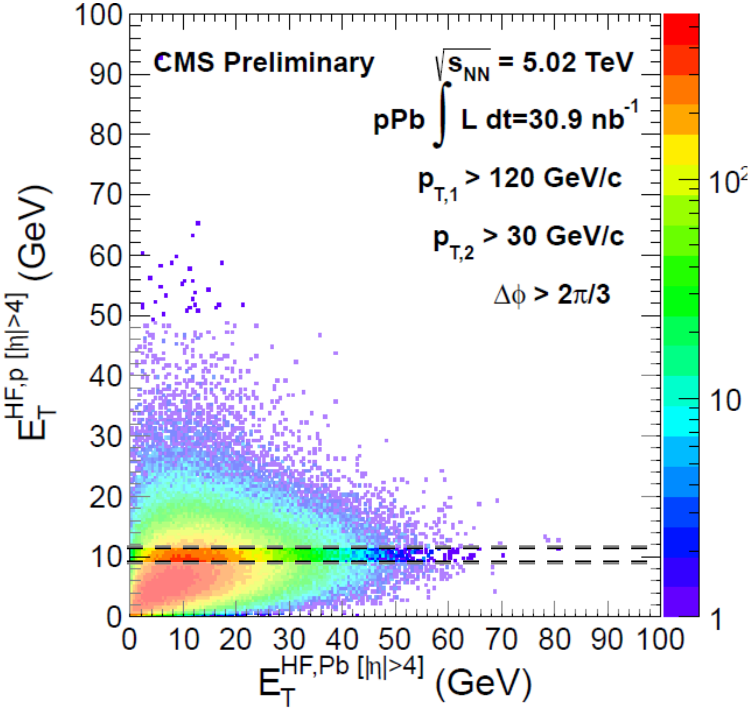
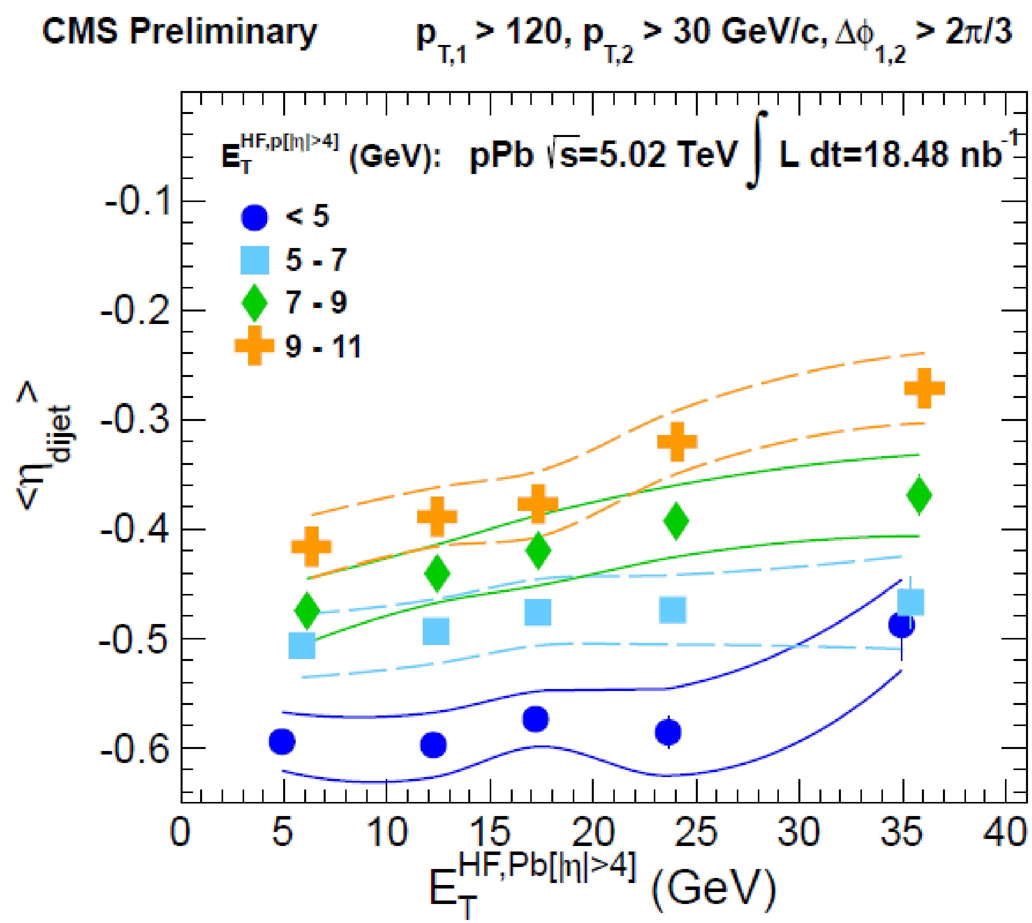
η_{dijet} at fixed proton side forward activity





Slope increases even more..

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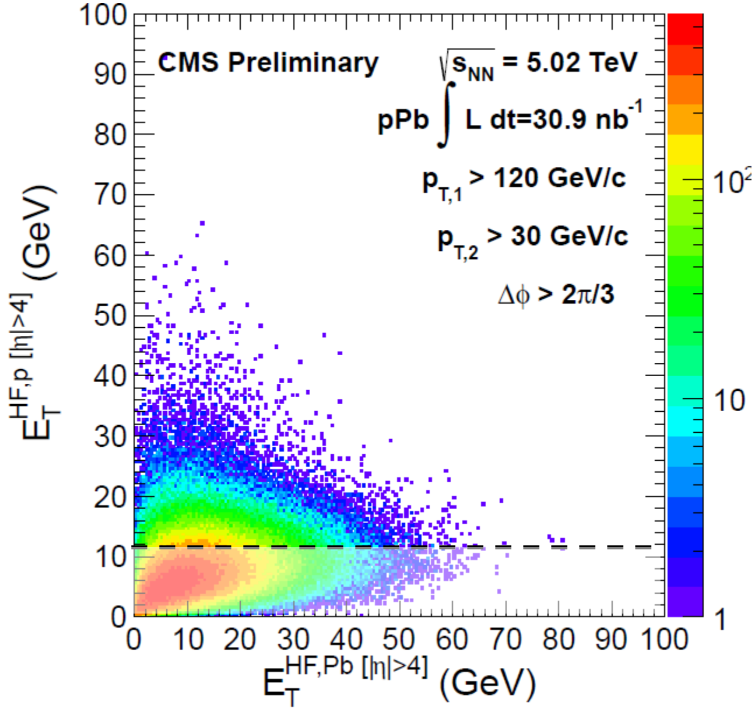
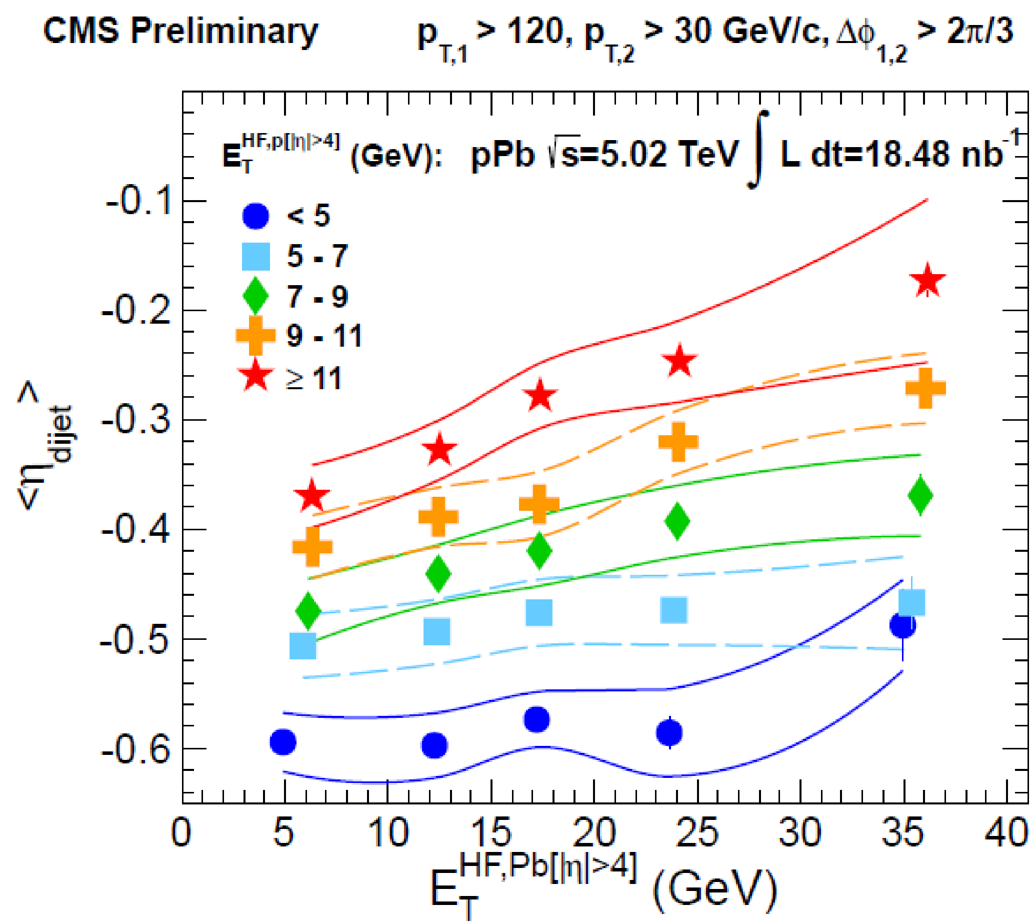
η_{dijet} at fixed proton side forward activity





And even more..

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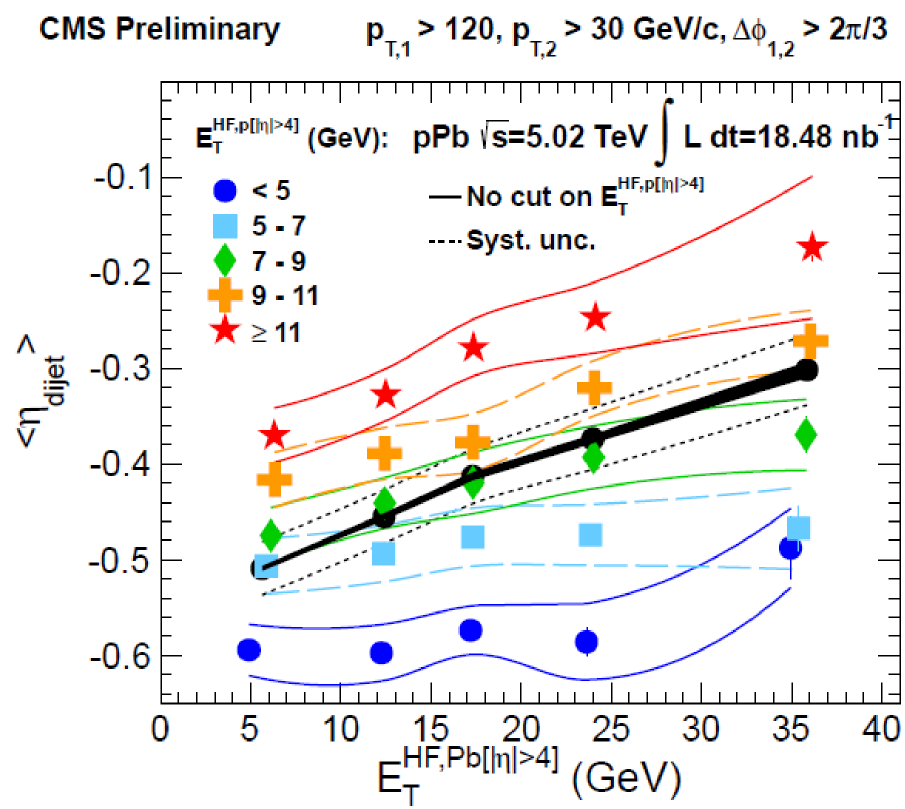
η_{dijet} at fixed proton side forward activity



When proton side energy is fixed the slope of the mean dijet η vs $E_T^{HF,Pb}$ gets smaller (compare any set of colored points with black curve, black curve shows larger shift)

Does this mean that the shift in dijet η is because of the indirect requirement of large $E_T^{HF,p}$ in the large $E_T^{HF,p}$ + $E_T^{HF,Pb}$ bin? **But** we observe the shift event when the proton side activity is fixed (e.g. Red and orange points)

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Summary

Centrality in pPb

- Different analyses are sensitive to different (physics) biases
- Biases that show up with jet observables can teach us good lessons about the nature of pPb collisions with high (low) event activity.

Dijet pseudorapidity distributions

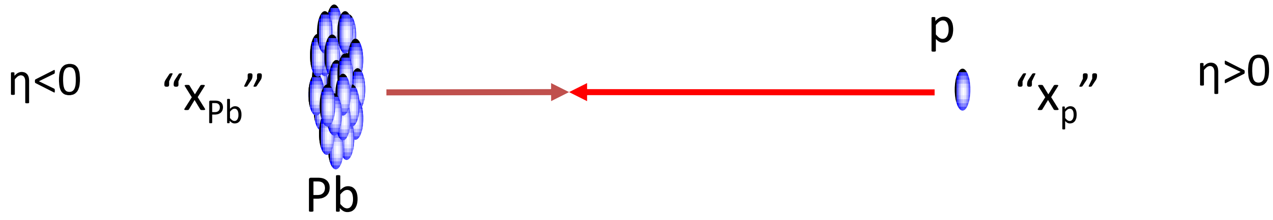
- Compared to nPDFs:
  - Dijet results can be used to constrain nPDF’s.
  - NLO+EPS09 and data comparison has improved agreement with respect to NLO and data comparison in EMC and anti-shadowing regions.
    - Discrepancy in anti-shadowing region < 2.5%, EMC region <5%.

- Dijet pseudorapidity as a function of activity:
  - Large systematic shift which cannot be explained with impact parameter dependence of nPDFs.
  - The effect that causes the shift gets smaller when proton side forward activity is fixed and Pb side forward activity is varied. Is this energy momentum conservation again or something more (related to initial state radiation/fluctuations in proton size or jet quenching)?

BACK-UP

Initial State Radiation

Milhano, Armesto. Jet workshop, UPMC, Paris

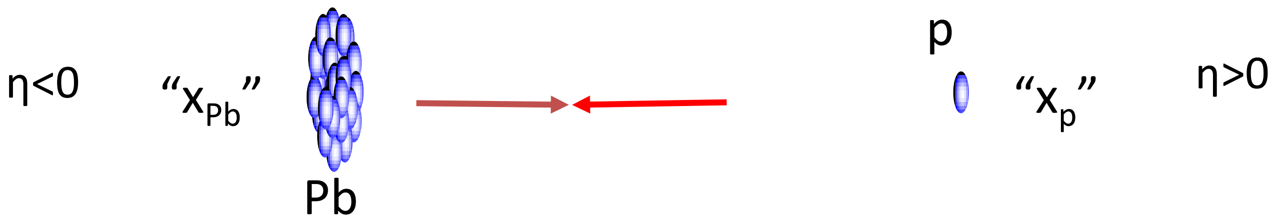


Going to large HF energy

Reduces the energy of hard scattering, $E_{JJ} = p_{T,1}\cosh(\eta_2) + p_{T,1}\cosh(\eta_2)$

Pb side HF energy ISR ↑
Cheap N_{nuc} >>1

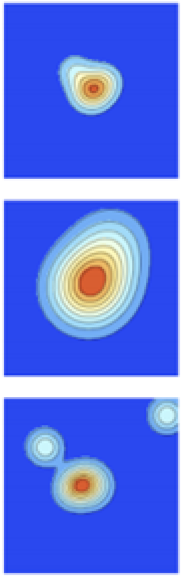
Proton side HF energy ISR ↑
Expensive N_{nuc} =1
Shifts PDF of proton to lower x values



Squezes the dijet η distribution

Shifts dijet η distribution in Pb going direction

Fluctuating initial state

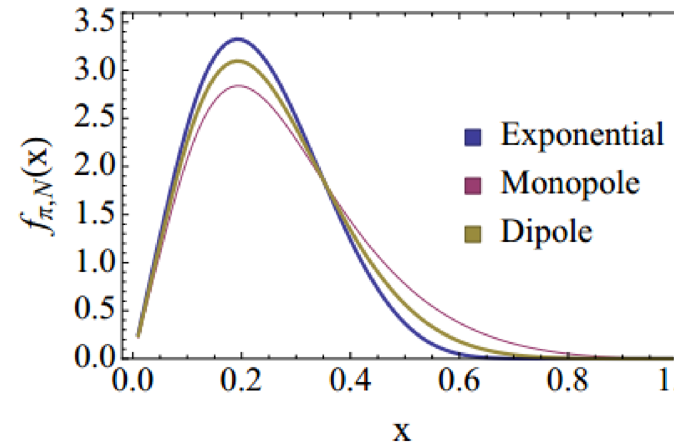


Coleman-Smith, Müller. arXiv:1307.5911

N_π	$P(N_\pi)$	$\int dx\, P_{\bar{q}}(x, Q\vert N_\pi)$
0	0.889	2.292
1	0.104	0.747
2	0.00618	0.068
3	0.00024	0.0027
4	7.17×10^{-6}	

→ Highest forward activity bin 2.5% minimum bias events of events. → Events with ~1 pion

(Over) Simplified calculation



$\eta_{dijet} \approx \log(x_{Pb}/x_p)$

$x_p \rightarrow 0.8 \cdot x_p : \eta_{dijet} \rightarrow \log(x_{Pb}/ 0.8 \cdot x_p) = \log(x_{Pb}/ x_p) + 0.01$

$x_p \rightarrow 0.2 \cdot x_p : \eta_{dijet} \rightarrow \log(x_{Pb}/ 0.2 \cdot x_p) = \log(x_{Pb}/ x_p) + 0.7$

Averaging these(Of course in reality the weights are not equal)

$\eta_{dijet} \rightarrow \eta_{dijet} + 0.36$

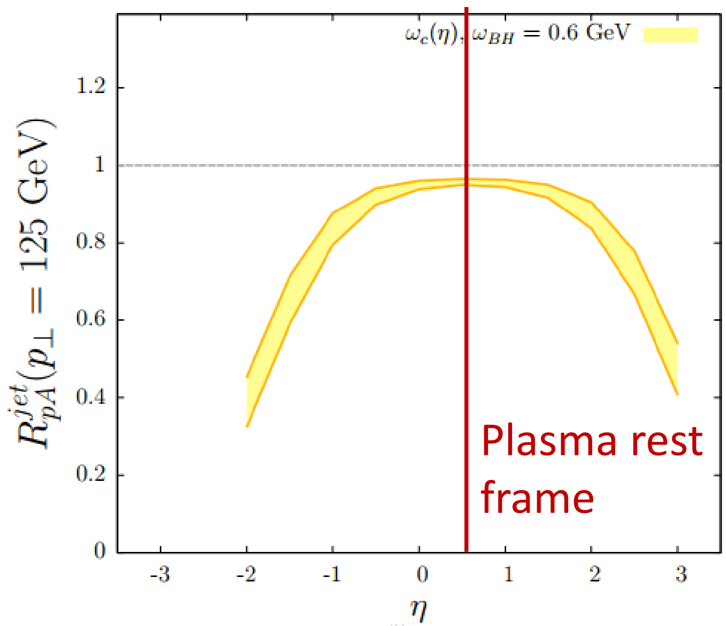
$$\langle x_\pi \rangle = \frac{\int_0^1 x f_{\pi,N}(x)\, dx}{\int_0^1 f_{\pi,N}(x)\, dx} = 0.234.$$

Largest contribution to the shift comes from hard scattering of parton's of pions rather than proton's.

Quenching(?)

Tywoniuk, Casalderrey. IS2013, Illa da Toxa, Spain

- Hard scattering CoM and plasma CoM are not the same.
  - Plasma CoM is moving towards Pb going direction, because of multiple collisions.
- Plasma is much larger in longitudinal direction than in transverse direction, so jets get quenched least if they go transverse in plasma rest frame.

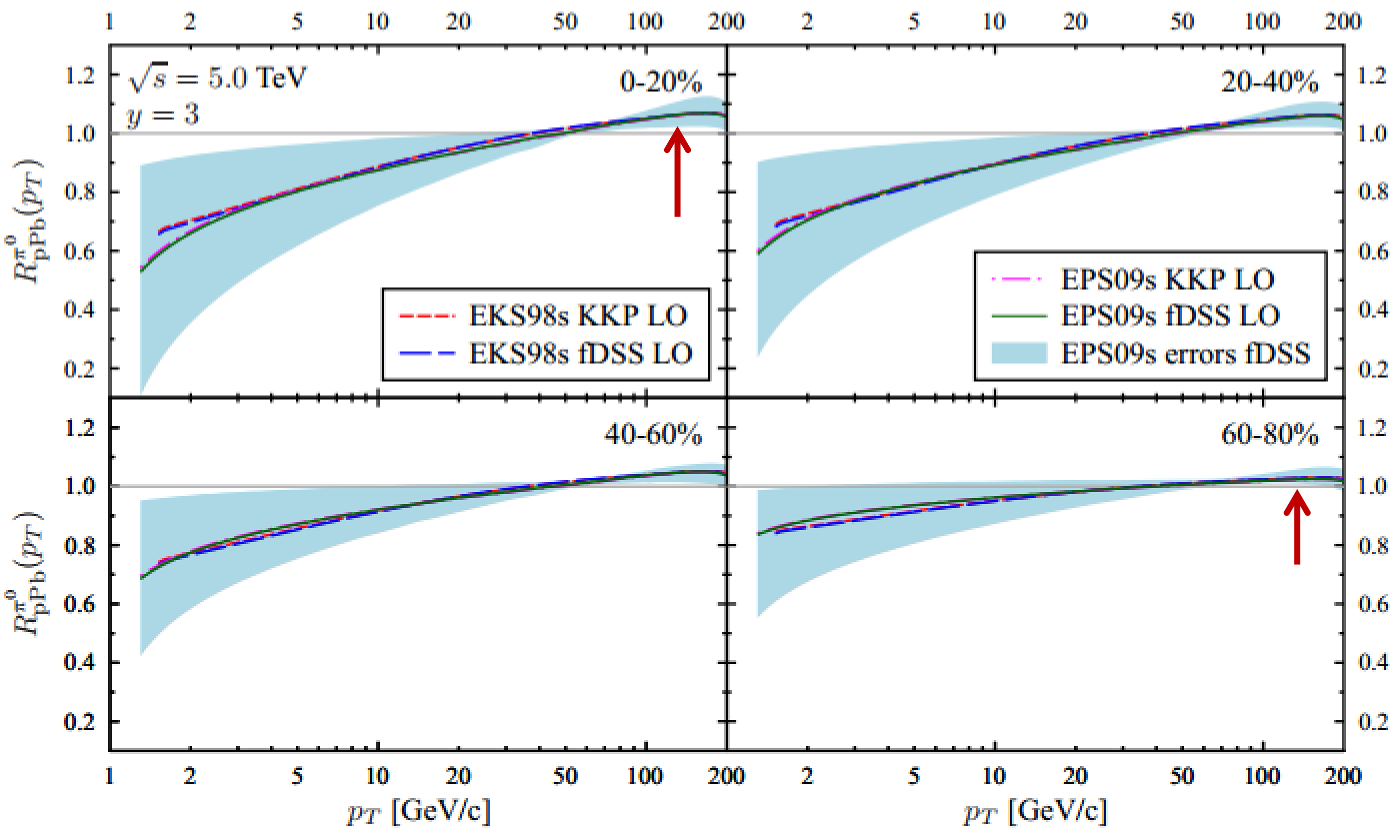


Reduces jets symmetrically around plasma rest frame

↓

Shifts dijet η distribution

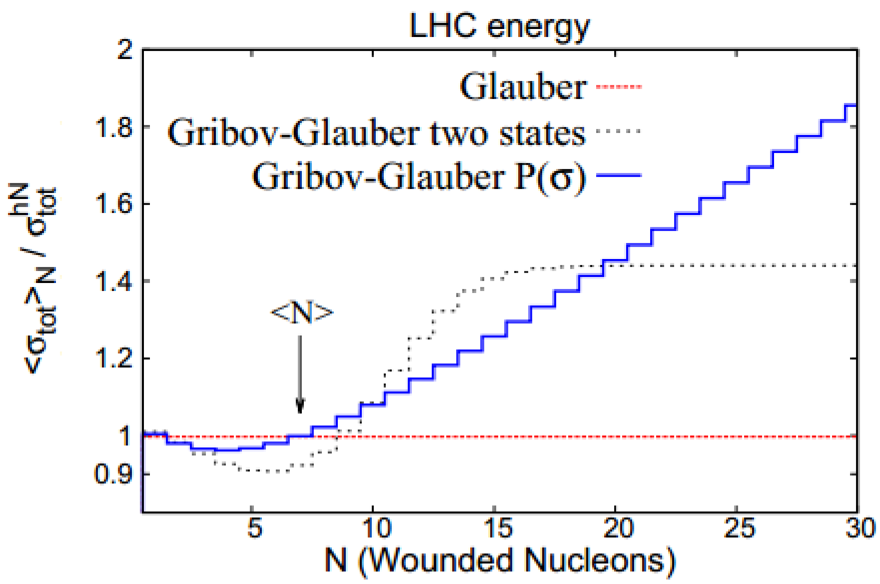
Impact parameter dependent nPDFs



At high p_T and y=3 small modification as a function of centrality. Change by going from 0-20% to 60-80% is <5%.

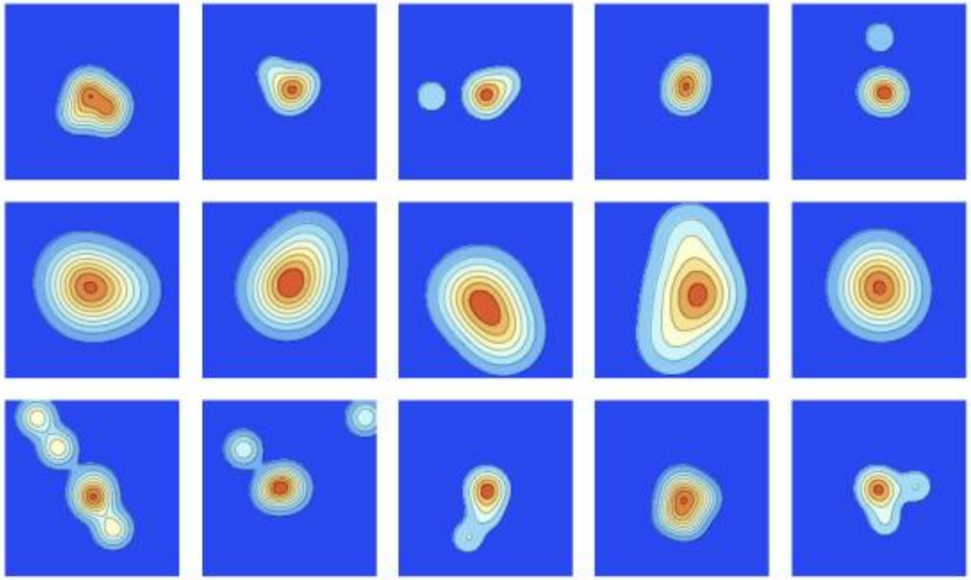
Initial state fluctuations

arXiv:1301.0728



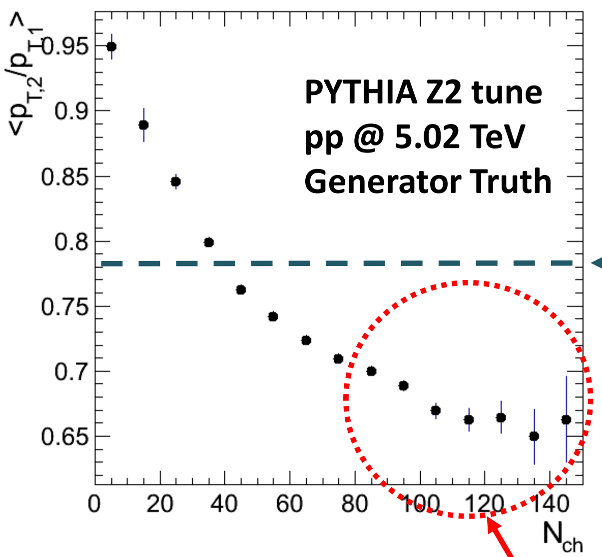
We should keep in mind investigations to explain ridge observed in high multiplicity pPb events, since nPDF can be modified with these processes.

arXiv:1307.5911



Centrality bias with N_{ch}

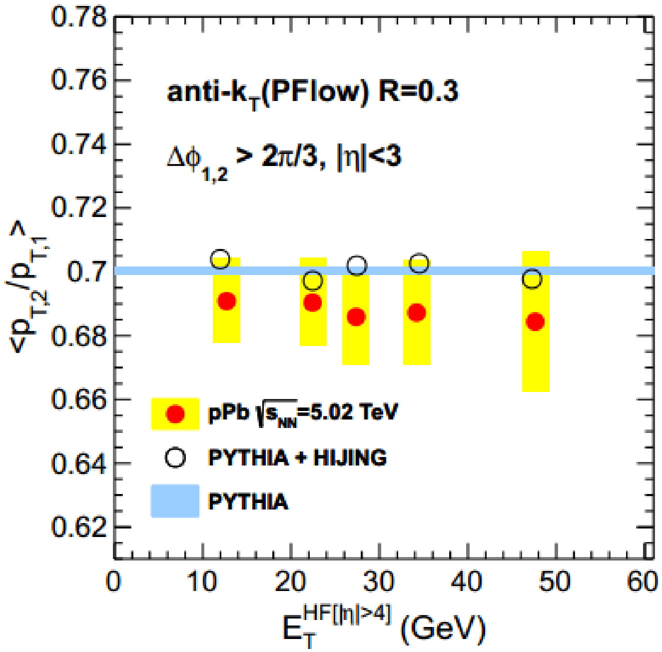
Each jet means additional N_{ch} ~ 20

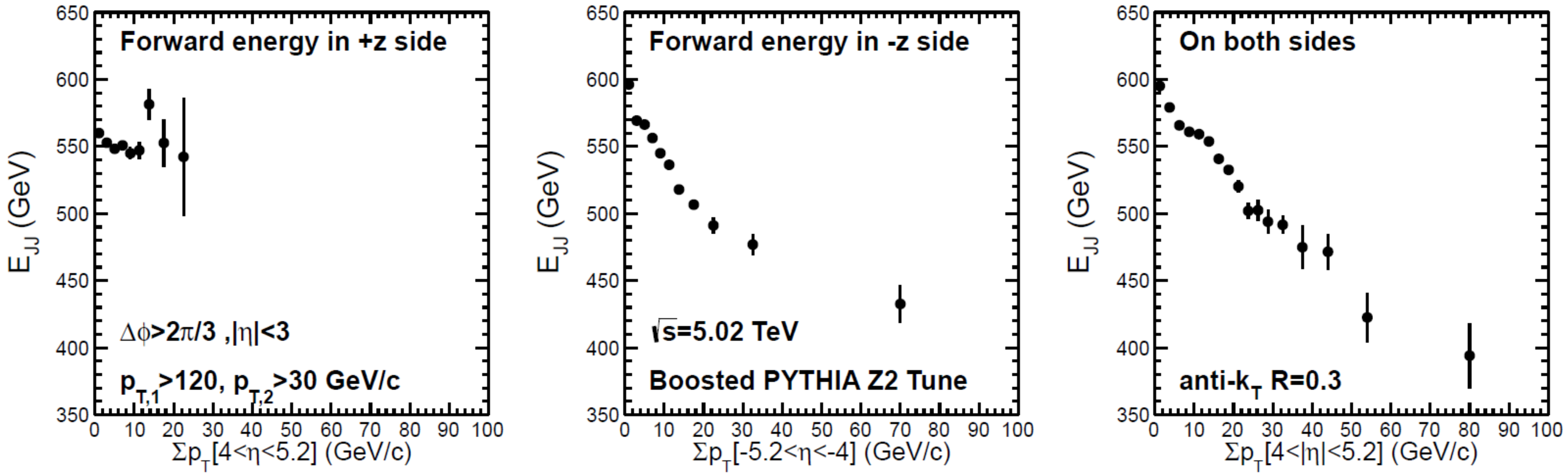


Mean value without N_{ch} selection

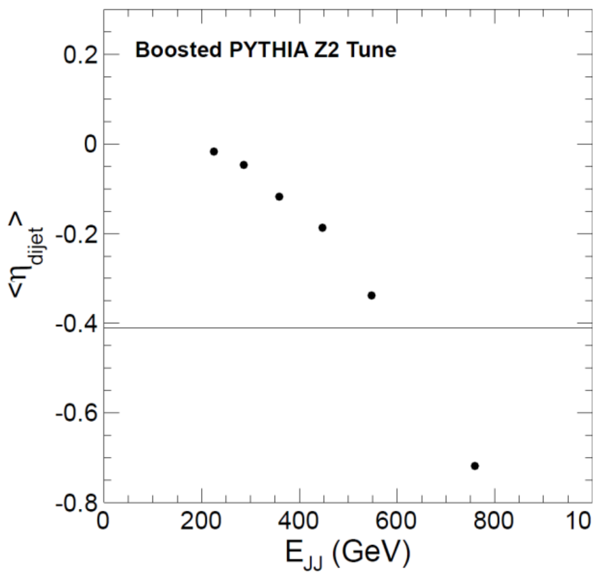
Event more likely to have 3 (or more) jets

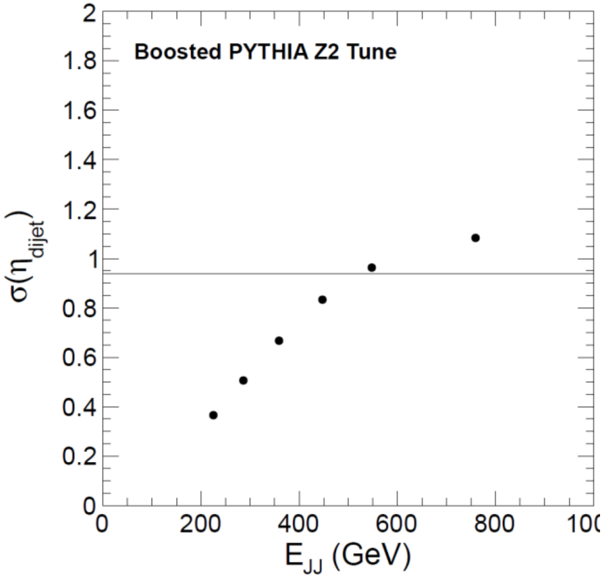
Compare to flat PYTHIA+HIJING points

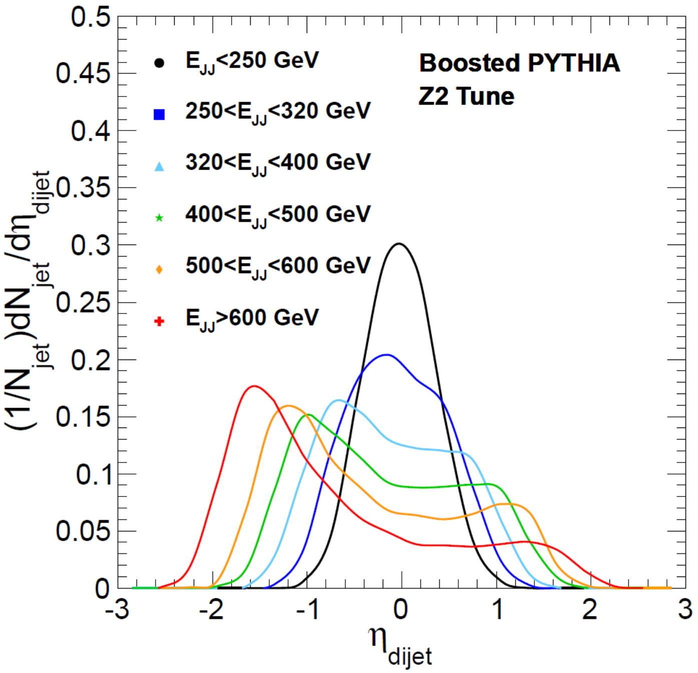



Forward energy in +z side
Δφ>2π/3 ,|η|<3
p_T,1>120, p_T,2>30 GeV/c
E_JJ (GeV)
Σp_T[4<η<5.2] (GeV/c)
Forward energy in -z side
√s=5.02 TeV
Boosted PYTHIA Z2 Tune
E_JJ (GeV)
Σp_T[-5.2<η<-4] (GeV/c)
On both sides
anti-k_T R=0.3
E_JJ (GeV)
Σp_T[4<|η|<5.2] (GeV/c)

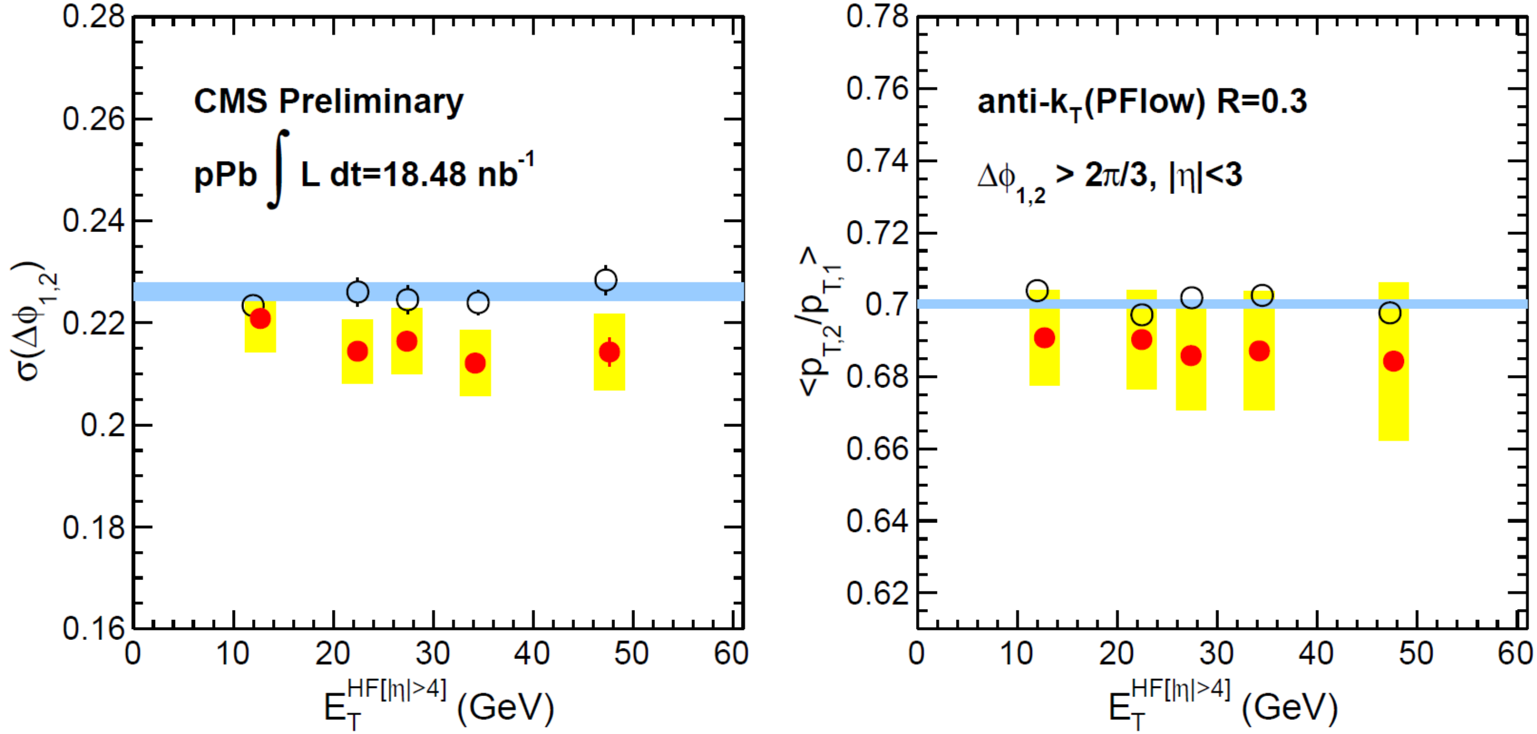
With and mean vs dijet energy







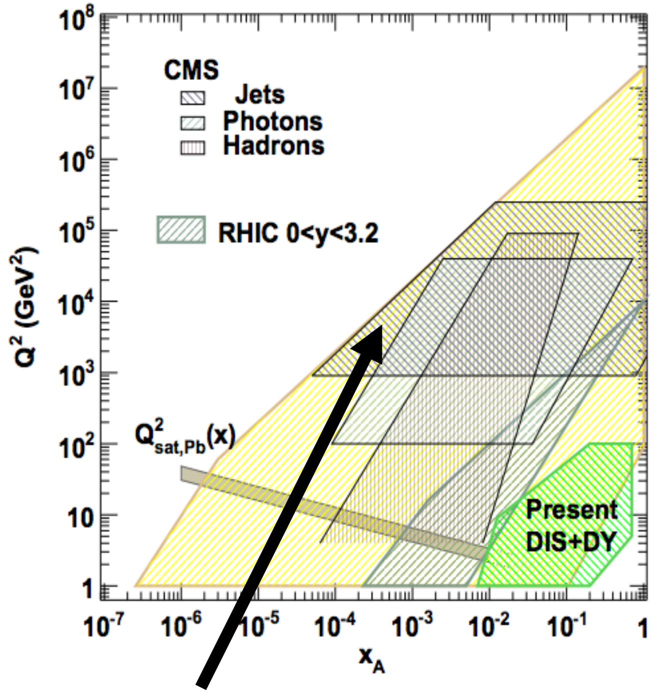
Final state interactions

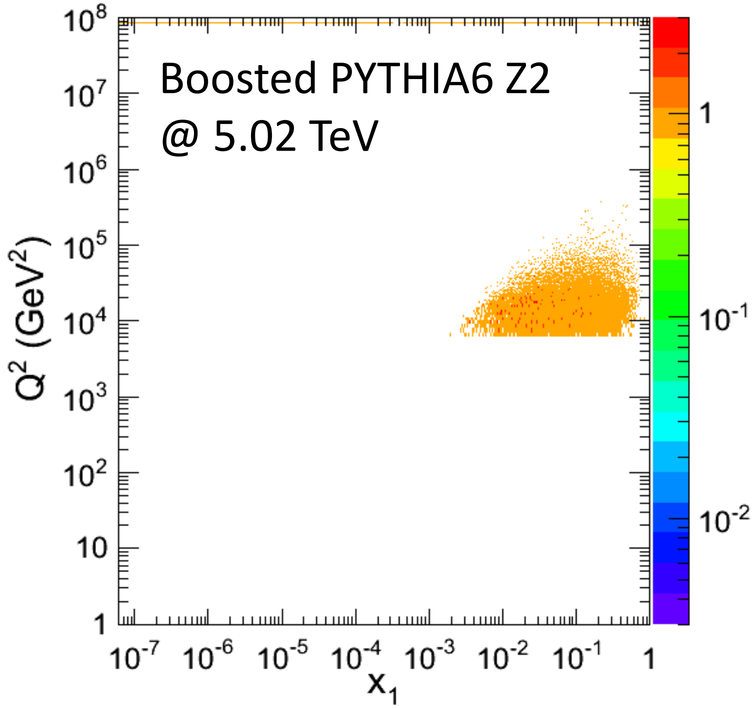


$$\frac{1}{N_{\mathrm{dijet}}}\frac{dN_{\mathrm{dijet}}}{d\Delta\phi_{1,2}} = \frac{e^{(\Delta\phi-\pi)/\sigma}}{\left(1-e^{-\pi/\sigma}\right)\sigma}.$$

Probing PDFs

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





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

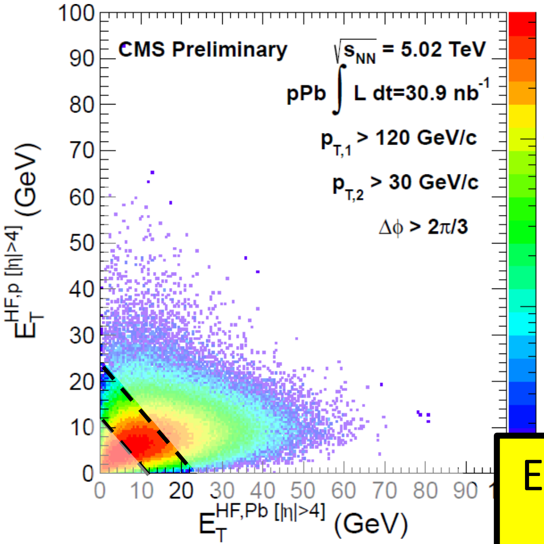
C.A. Salgado, et. al. J.Phys. G39 (2012) 015010

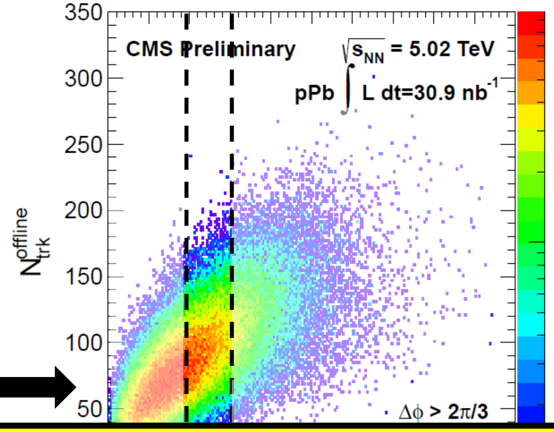
With the dijet selection of the analysis:

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

Centrality classes in pPb

CMS PAS HIN-13-001



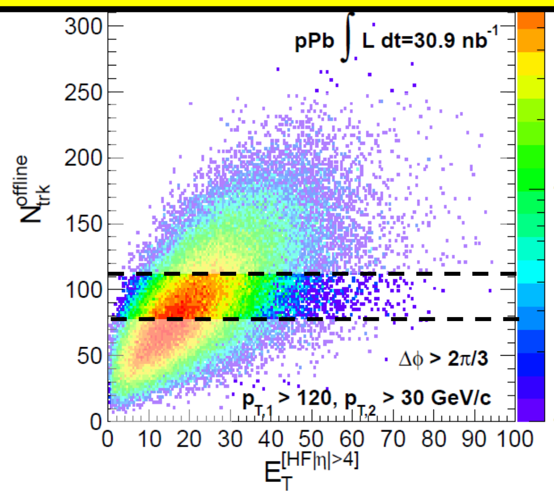


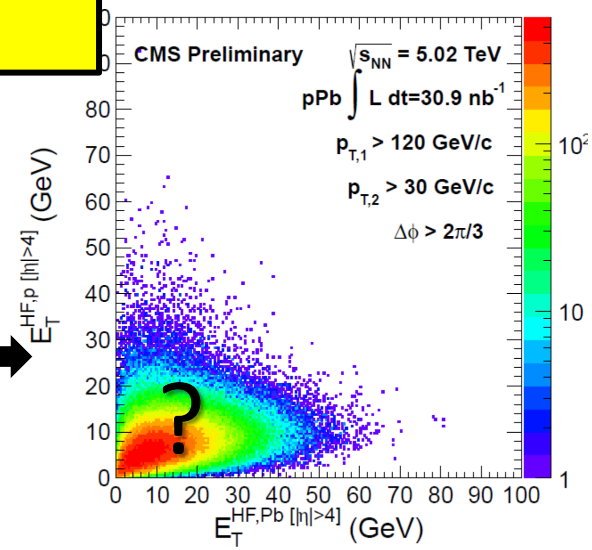
Let us choose one vertical and one horizontal slice which will have same <HF E_T > and same <N_{trk} >

EACH CENTRALITY VARIABLE CAN GIVE US A DIFFERENT PIECE OF INFORMATION
WE SHOULD LOOK AT AND SHOW AS MANY AS POSSIBLE

Event activity on Pb sid
event activity on p side

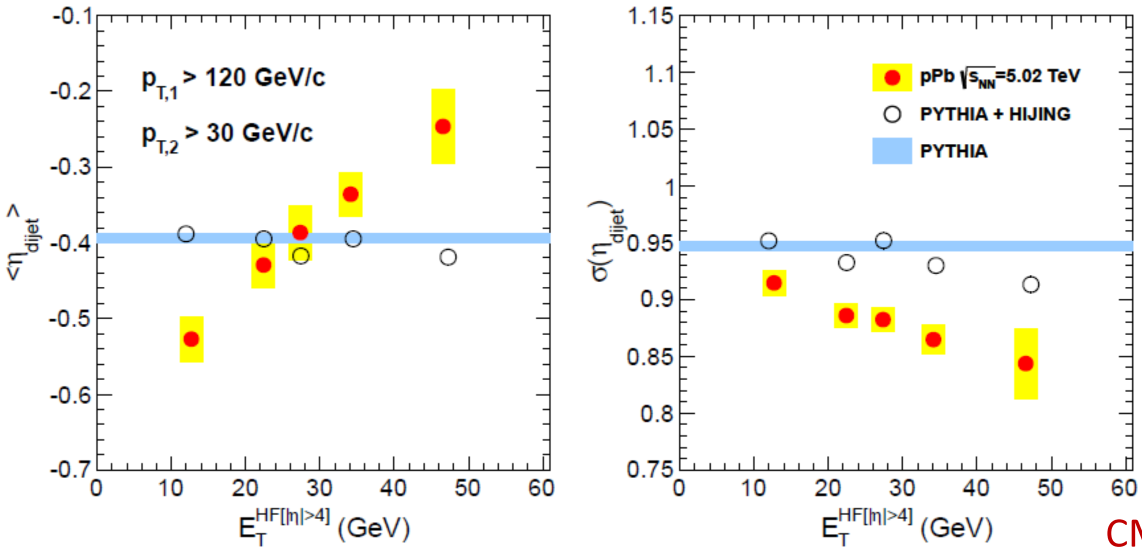
- Correlation is very loose.
- Different trends:
  Proton side E_T energy rise as a function of Pb side energy rise flattens out.





What about peripheral PbPb?

Forward activity dependence of η_{dijet}



CMS PAS HIN-13-001

- The shift we observe of magnitude ≈ 0.27 in $<\eta_{dijet}>$.
- Remaining centrality biases:
  - Looking at PYTHIA+HIJING:
    - Slight shift in dijet eta towards smaller η_{dijet} (in the opposite direction of the shift in data)
    - Narrowing of dijet eta
  - Not included in PYTHIA+HIJING: Interaction of signal and background event, initial state fluctuations…