Dijet production in pPb collisions

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for the CMS Collaboration

pA Physics Workshop

MIT, Cambridge

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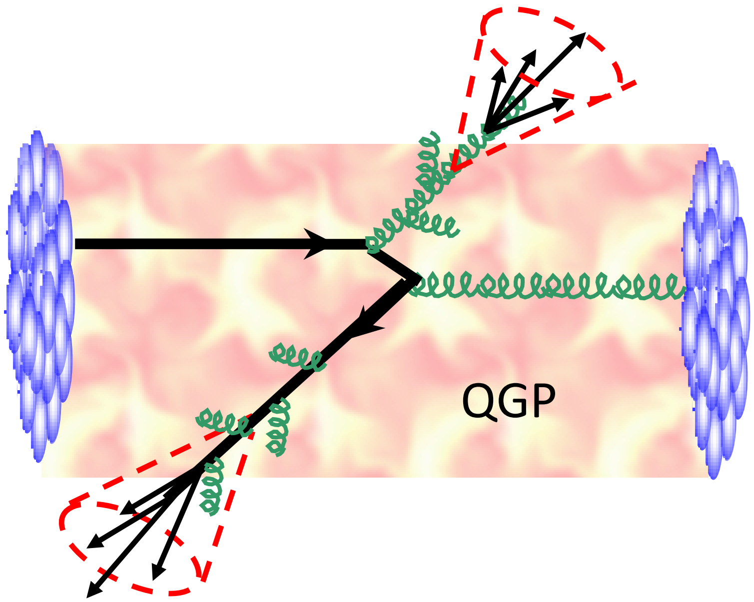
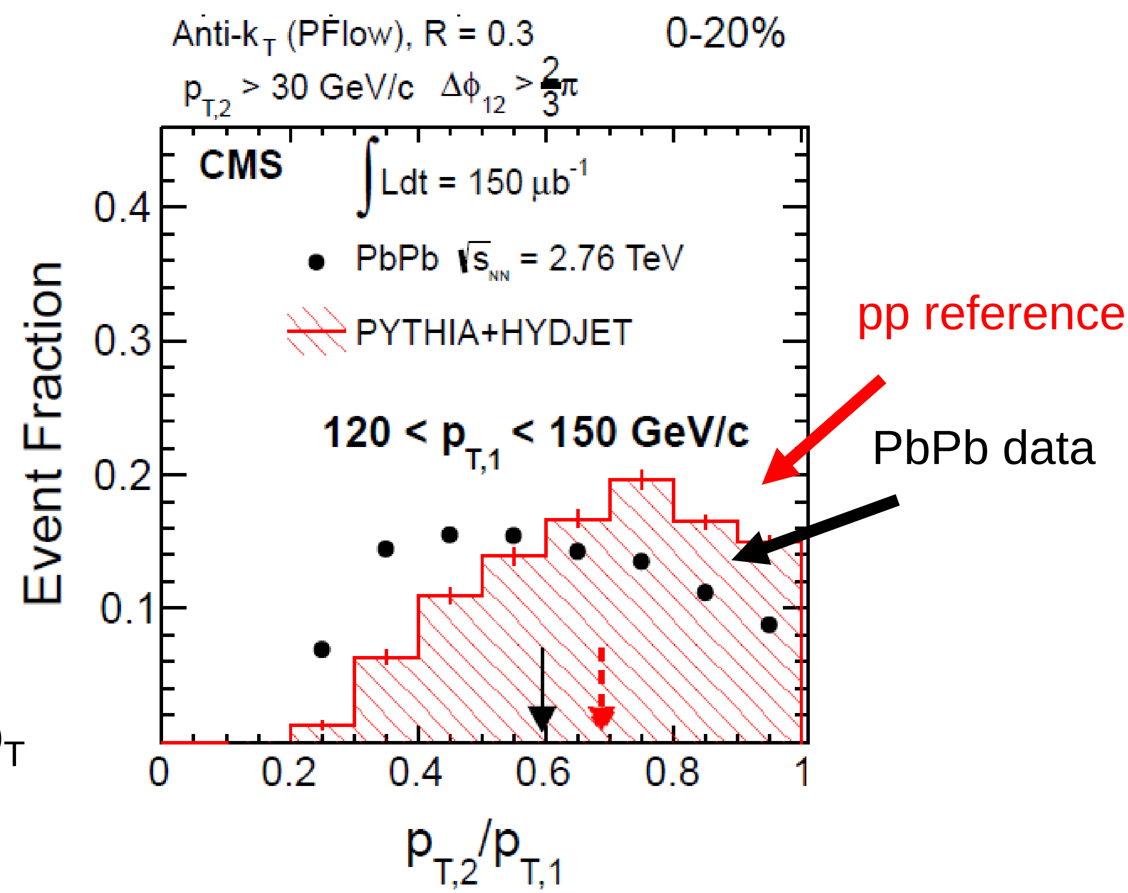
Dijet production in HI collisions

PLB 712 (2012) 176

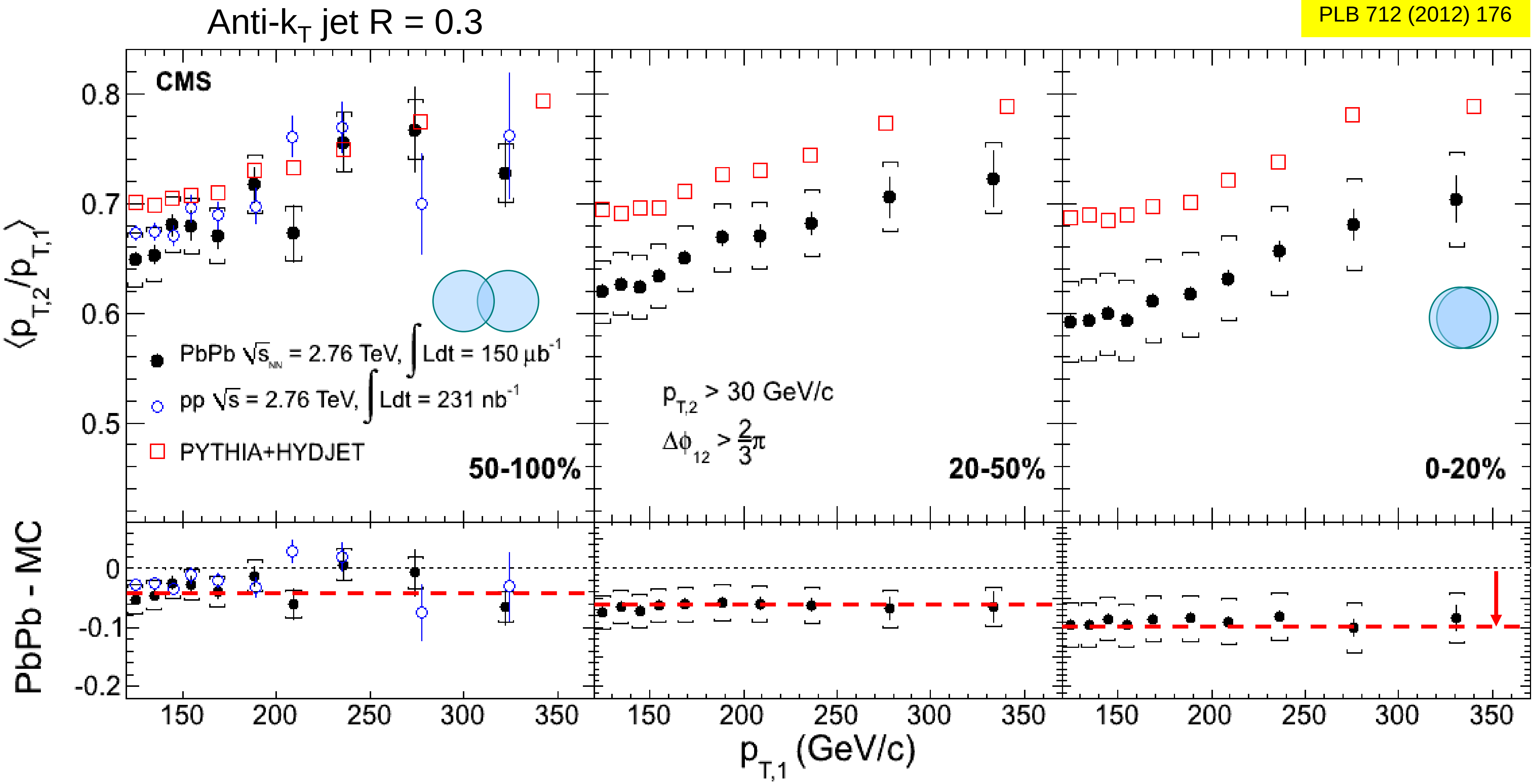




PbPb collisions

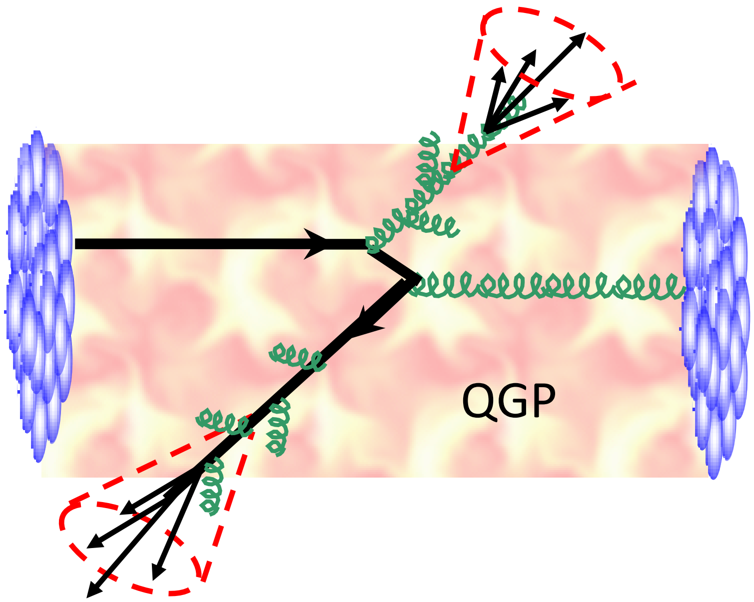
- Jet quenching in PbPb collisions
- Observed as a pronounced dijet p_T imbalance in central collision
- Decreasing dijet p_T ratio as we go to central collisions

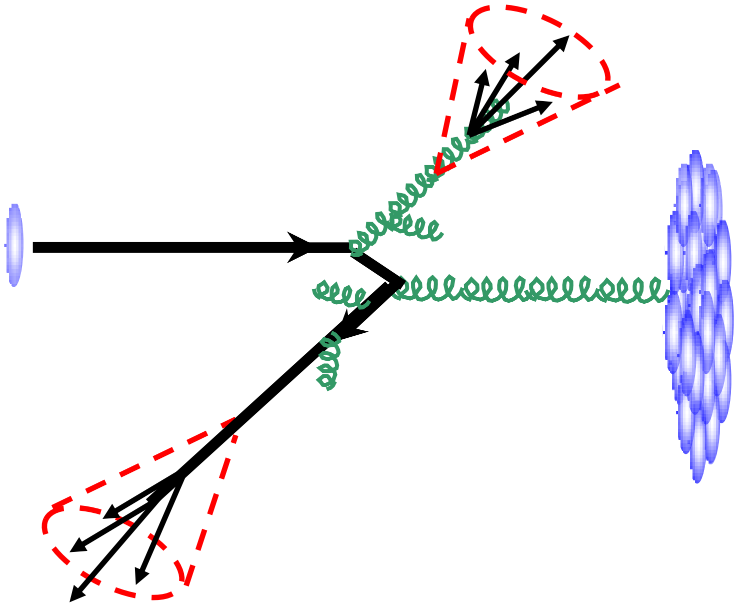
Dijet p_T ratio (imbalance)



- Energy imbalance increases with centrality
  $\langle p_{T2}/p_{T1} \rangle$ decreases as we go to central collisions
- Very high p_T jets are also quenched

Dijet production in HI collisions





PbPb collisions

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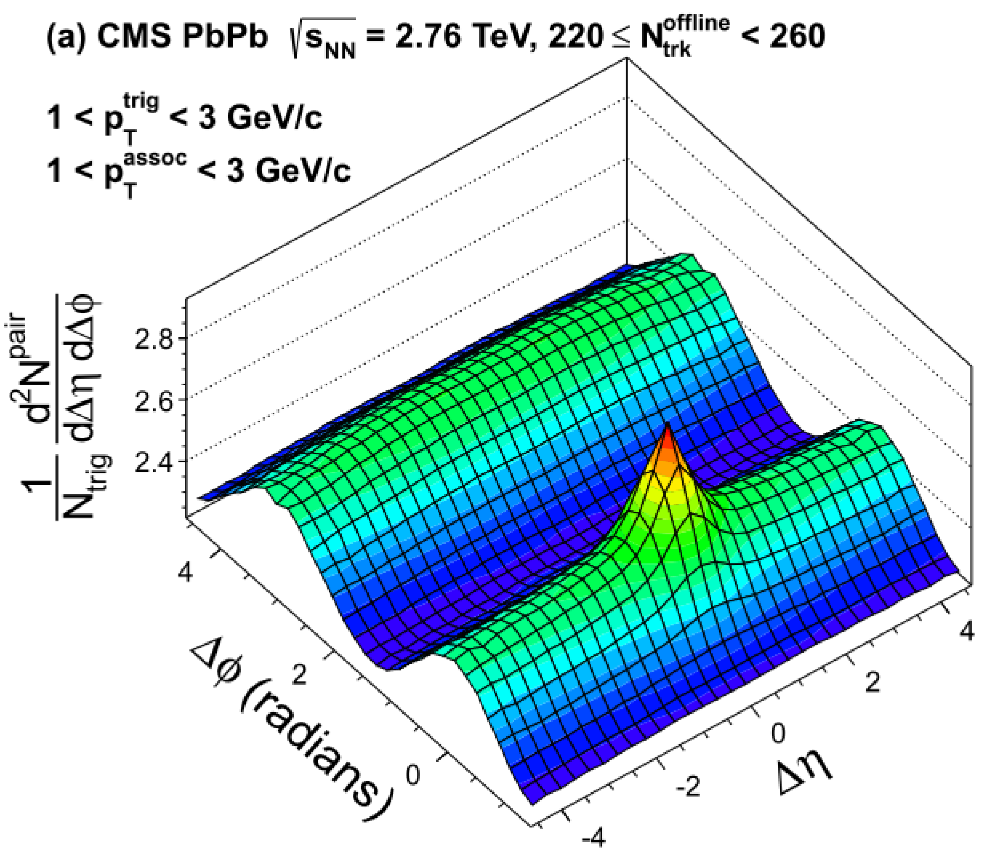
pPb collisions

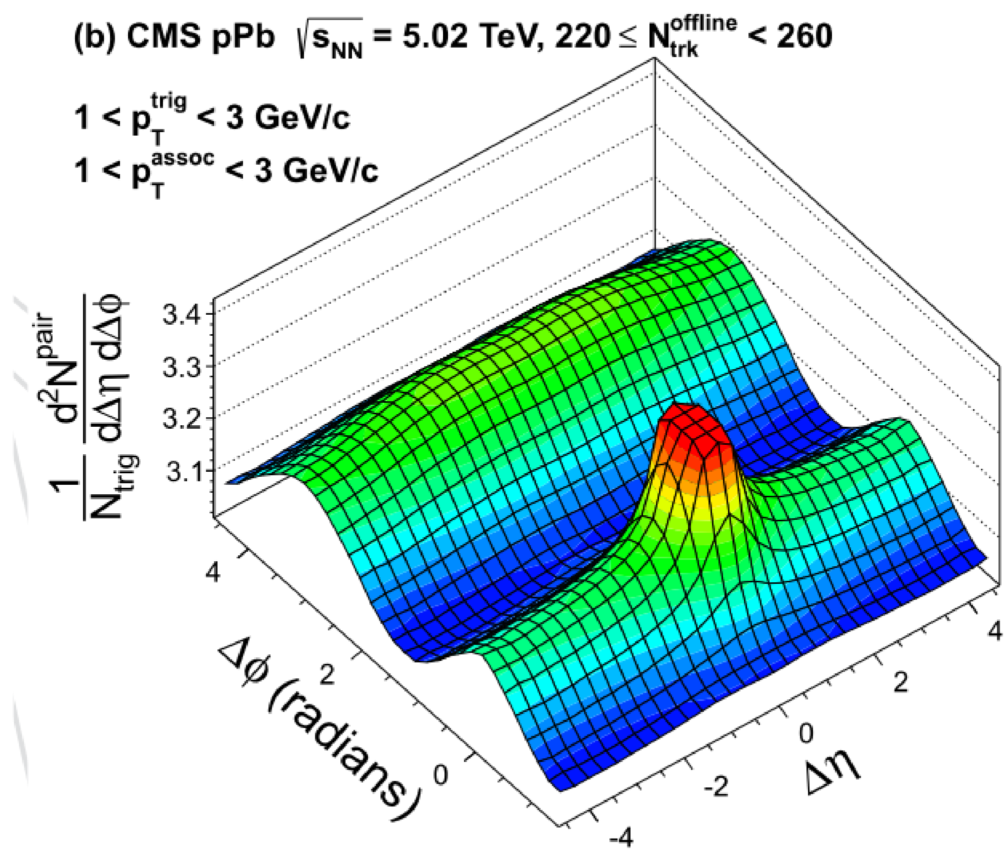
- Baseline for PbPb collisions
- Cold nuclear effects, nPDFs

Two particle correlation in pPb collisions

PbPb

pPb





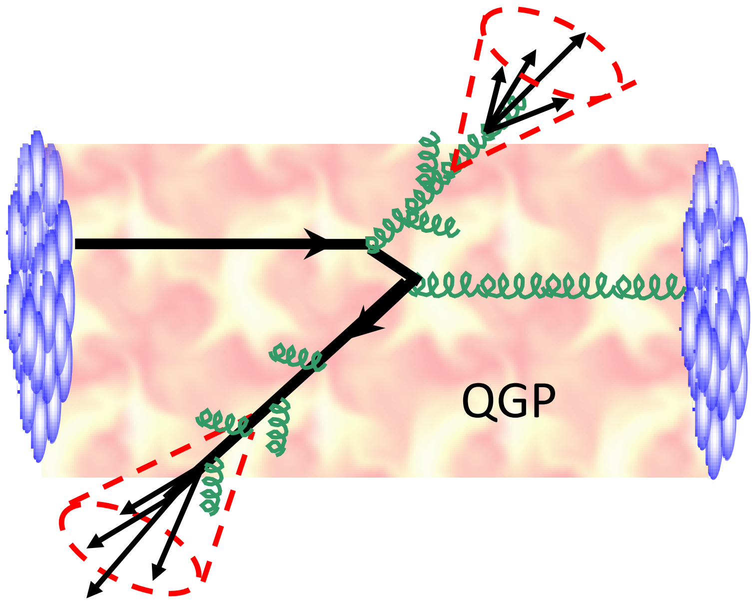
Flow? CGC?

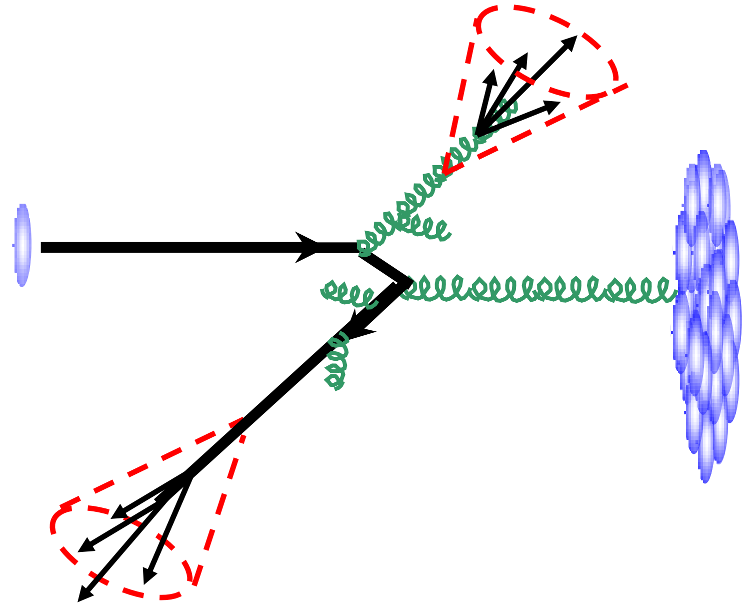
Pilot run data: PLB 718 (2013) 795

2013 pPb data: arXiv:1305.0609

See Wei Li's talk 5/17 2PM

Dijet production in HI collisions





PbPb collisions

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pPb collisions

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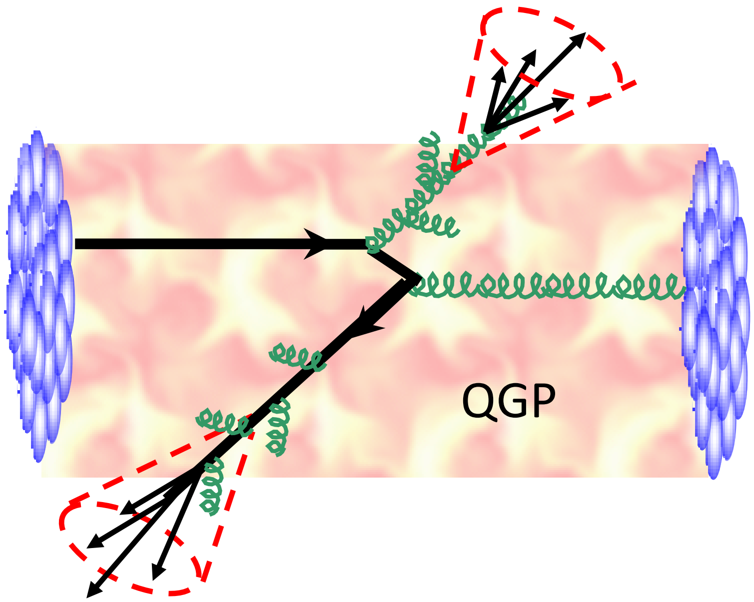
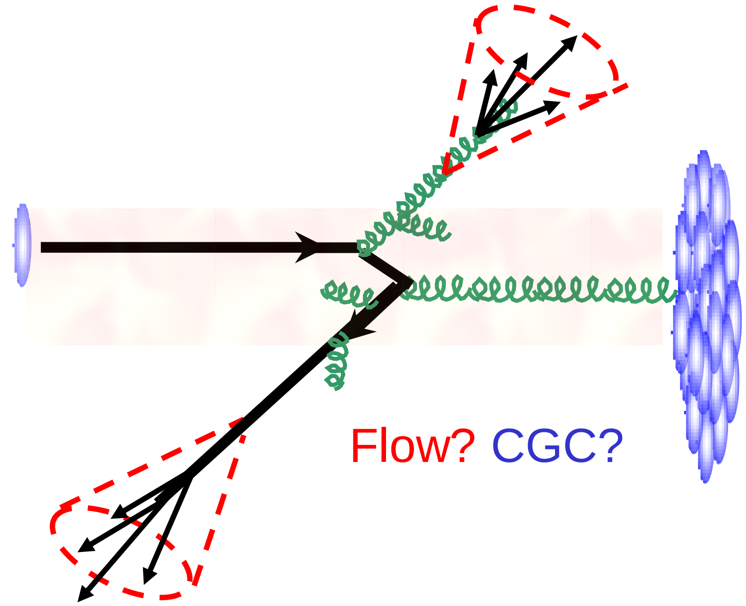
Dijet production in HI collisions





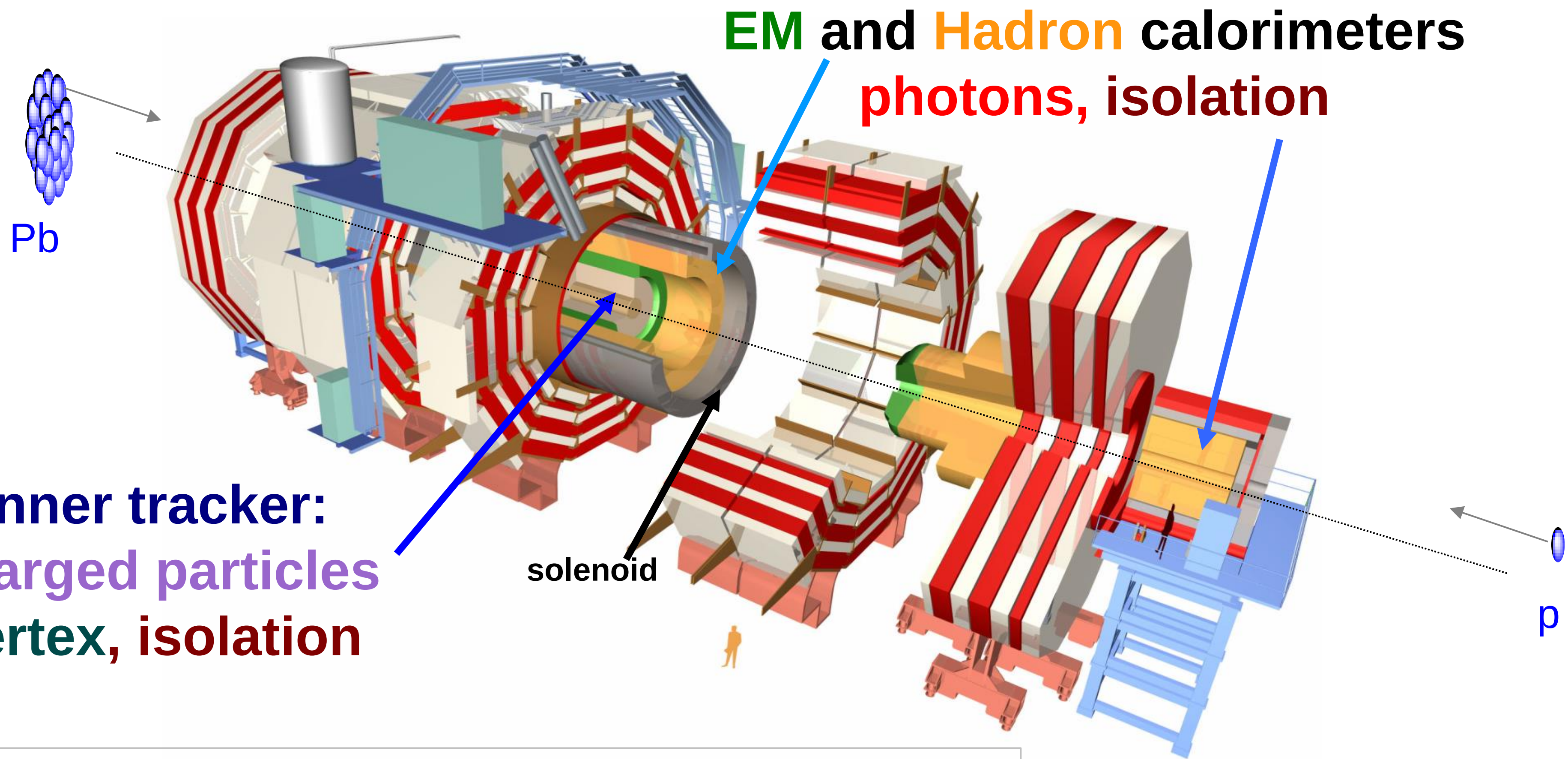
PbPb collisions

- Jet quenching in PbPb collisions
- Observed as a pronounced dijet p_T imbalance in central collision
- Decreasing dijet p_T ratio as we go to central collisions

pPb collisions

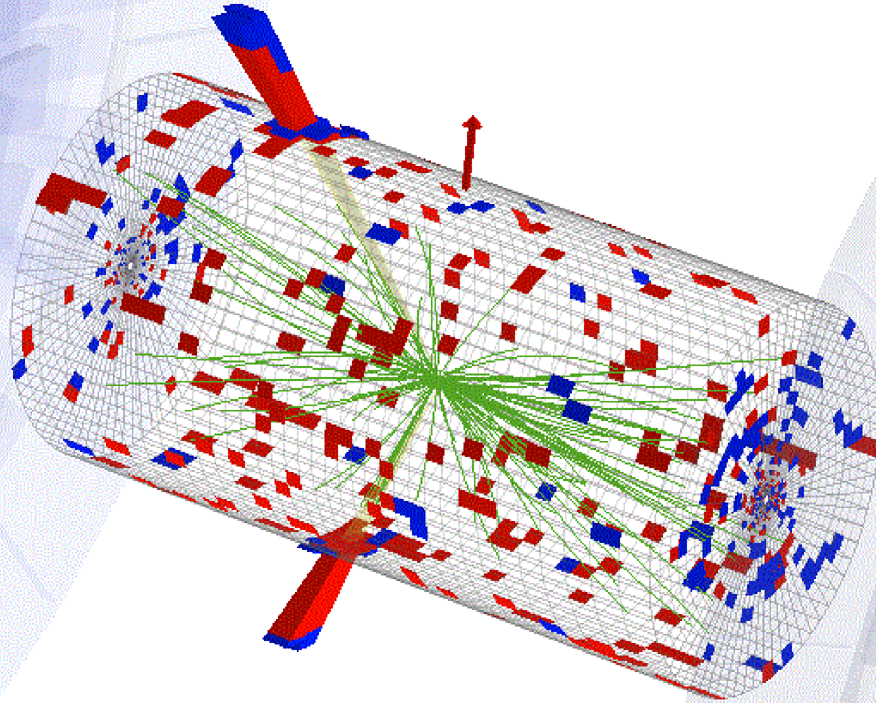
- **Jet quenching in pPb?**
- Baseline for PbPb collisions(?)
- Cold nuclear effects, nPDFs

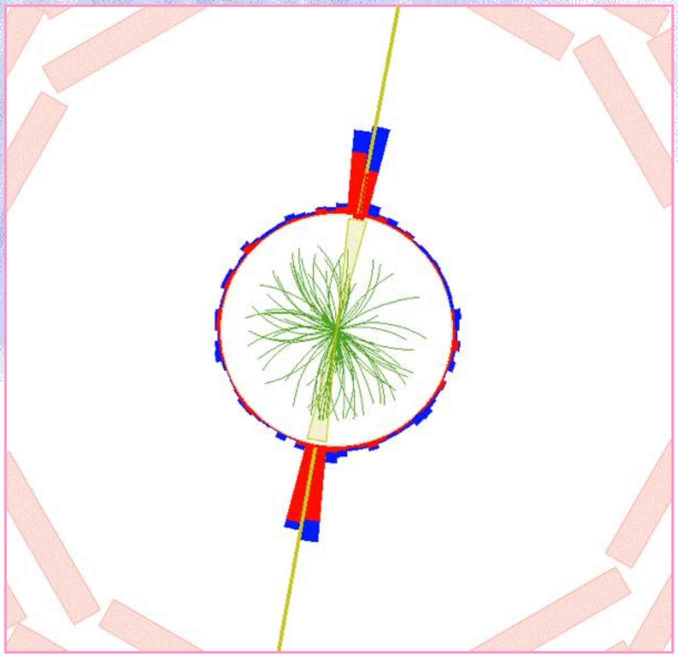
CMS Detector



Detector	Coverage	Jet type
Muon	$|\eta| < 2.4$	
HCAL	$|\eta| < 5.2$	Calojet
ECAL	$|\eta| < 3.0$	Calojet
Tracker	$|\eta| < 2.5$	Particle Flow Jet (track $p_T > 0.15$ GeV/c)

Dijet in pPb collisions recorded by CMS



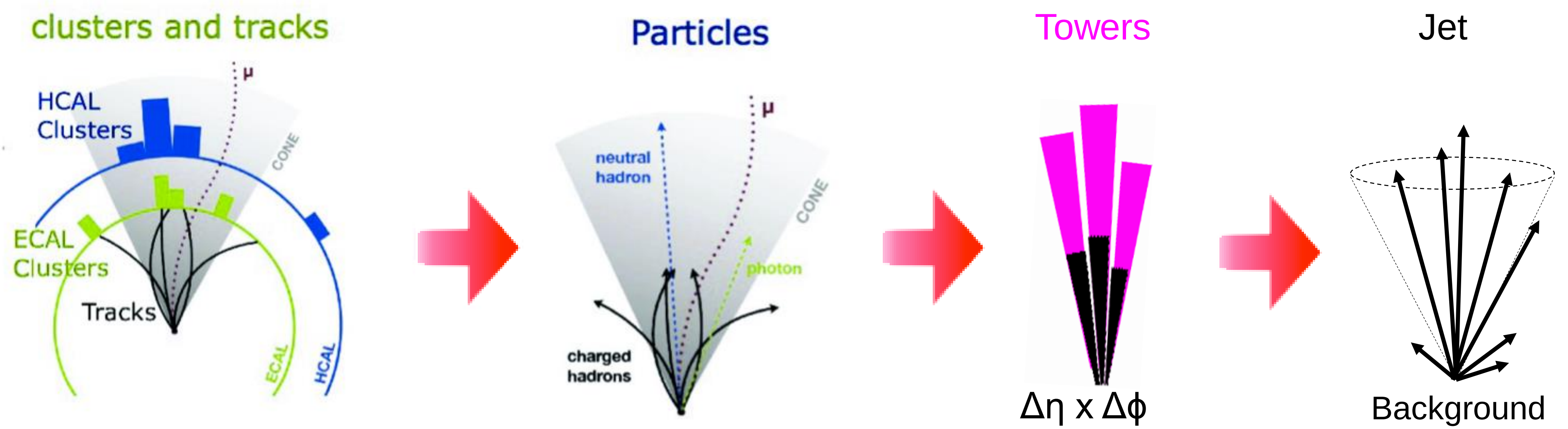


2012 pPb **1 μb^{-1}**
2013 pPb **31 nb^{-1}**

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
- Monte Carlo sample
  - PYTHIA QCD Jets with $\hat{p}_T$ > 30 GeV/c
  - 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

Jet reconstruction



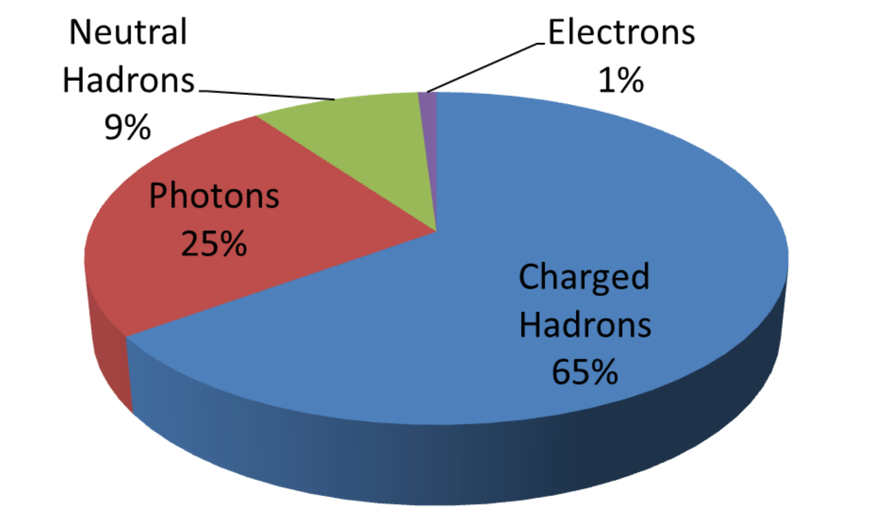
$\Delta\eta \times \Delta\phi$
0.076 x 0.076 in barrel

Background subtraction and jet clustering

Anti-k_T algorithm with R=0.3 is used in this analysis

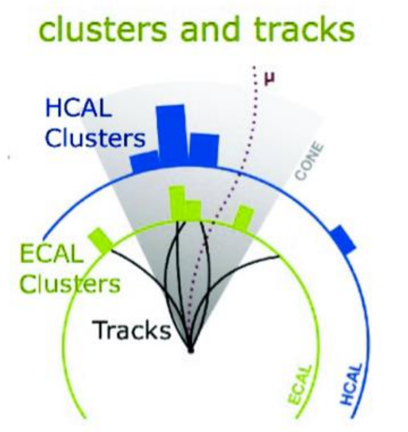
Optimize the use of calorimeter and tracker “Particle Flow” in CMS

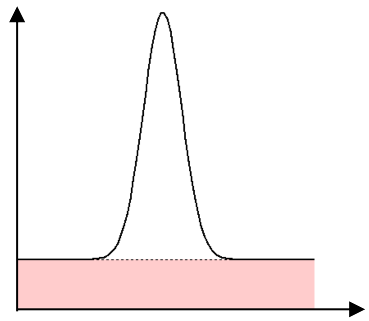
Tracks with p_T > 0.15 GeV/c are used in Particle Flow reconstruction

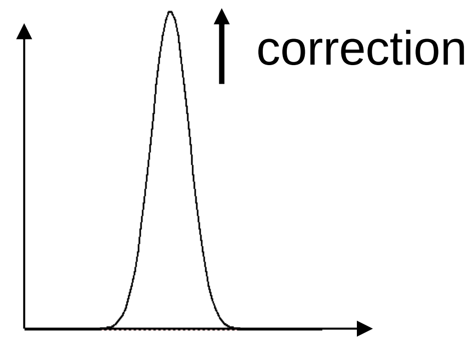


A typical high p_T jet

Jet energy correction







Raw jet energy → Background subtraction → Jet energy correction

Background subtraction: Remove underlying events contribution

Jet energy correction: PYTHIA MC
Residual correction from dijet and photon-jet

- Data-driven jet energy correction from dijet and photon-jet events (method described in **JINST 6 (2011) P11002**)
- Jet with background subtraction used as the main result
- Cross-check with jets without background subtraction

What do we know about jet quenching in pPb collisions?

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

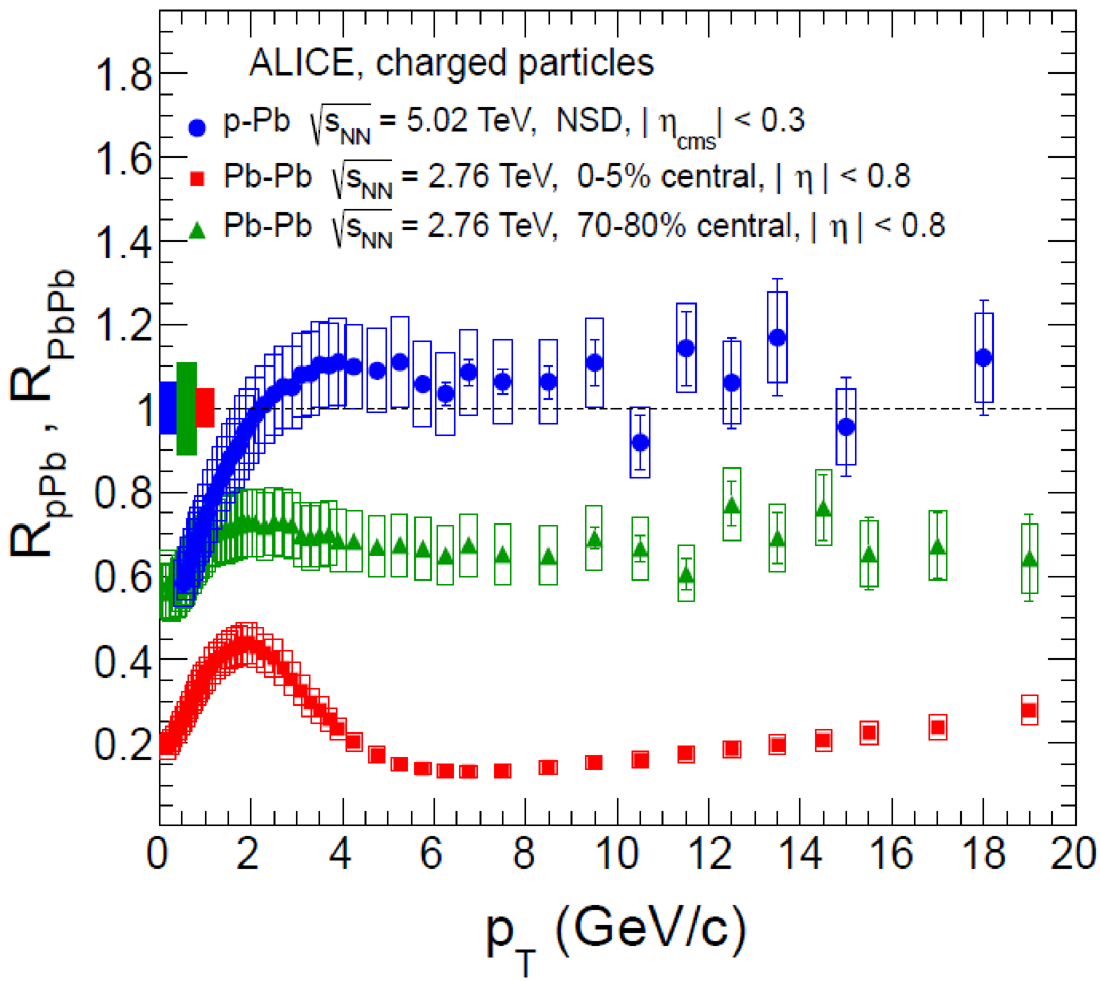
- R_{pPb} ~ 1 from ALICE collaboration

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

→Need to look at high multiplicity event (“central collisions”).

How do we classify the events?

PRL 110 (2013) 082302

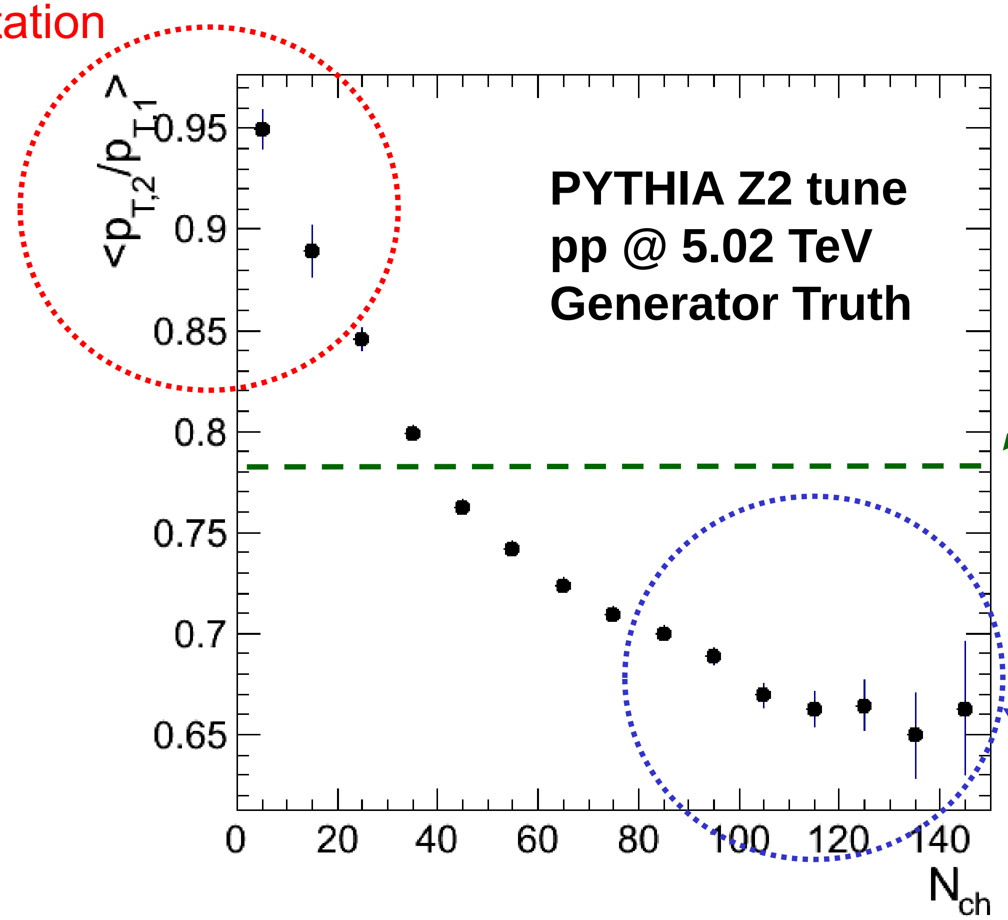


Looking at high multiplicity event

Leading jet $p_{T,1}$ > 120 GeV/c
subleading jet $p_{T,2}$ > 30 GeV/c $|\Delta\varphi_{12}| > 2\pi/3$

N_{ch}: Number of charged particles with $|p_T|>0.4$ and $|\eta|<2.4$

Force "hard" fragmentation



Mean value for all generated dijets

Force "soft" fragmentation

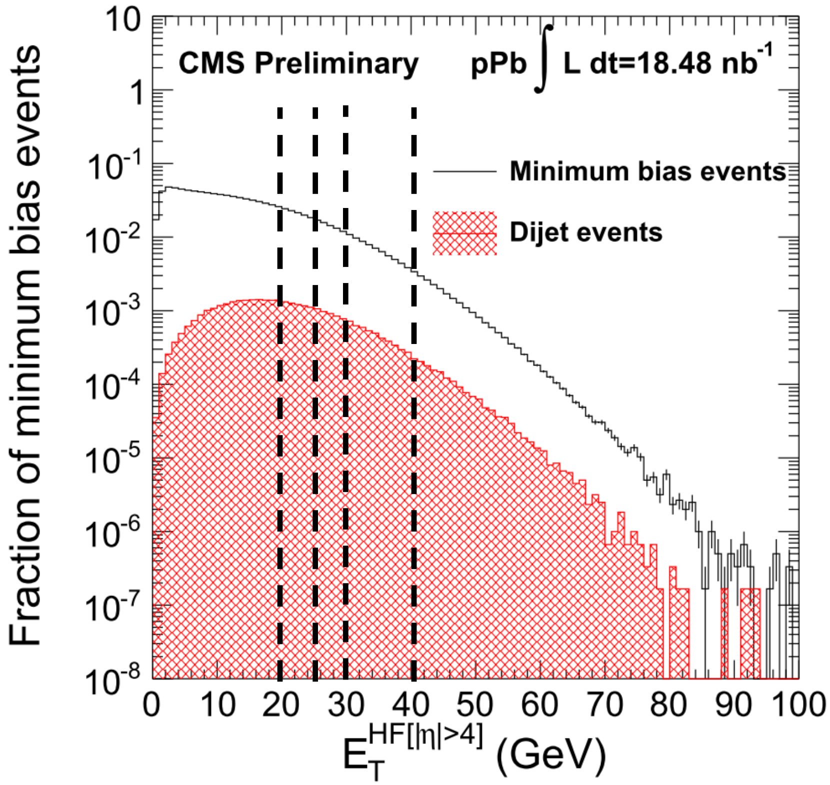
- Number of charged particles produced in pPb << in PbPb
- **Slicing on N_{ch} may cause bias on jet fragmentation pattern**

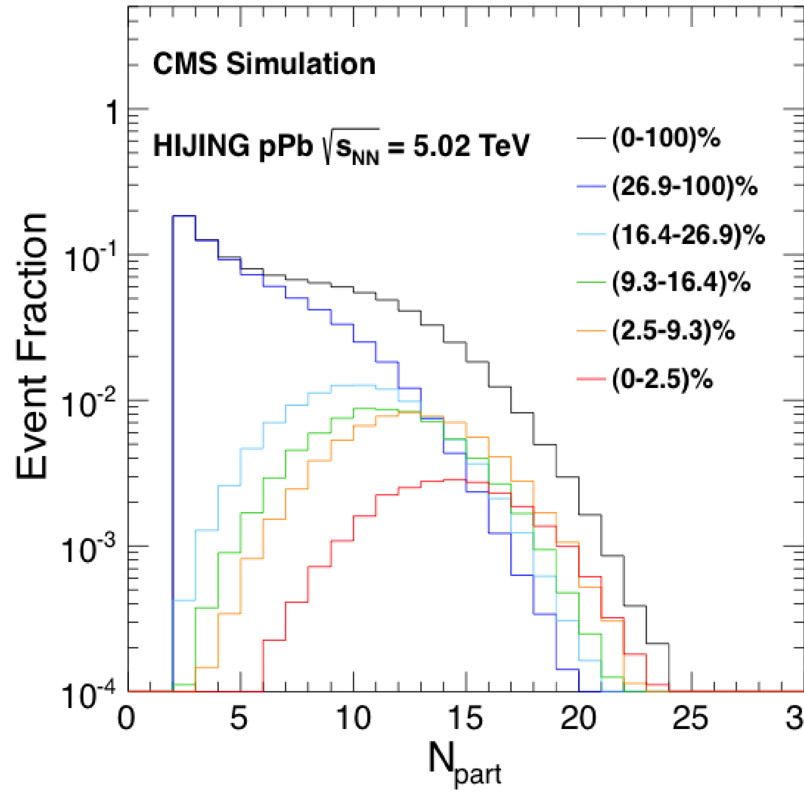
Looking at high multiplicity event

- Several options tested:
  - Tracker based variables:
    - Number of pixel hits
    - Number of pixel tracks, or number of tracks
    - Introduce fragmentation bias as demonstrated before
  - ZDC based variables:
    - Doesn't have good enough resolution to go to very high multiplicity events
- Final choice:

E_T measured in $4<|\eta|<5.2$ by forward calorimeter ($E_T^{HF[|\eta|>4]}$)

Event classes



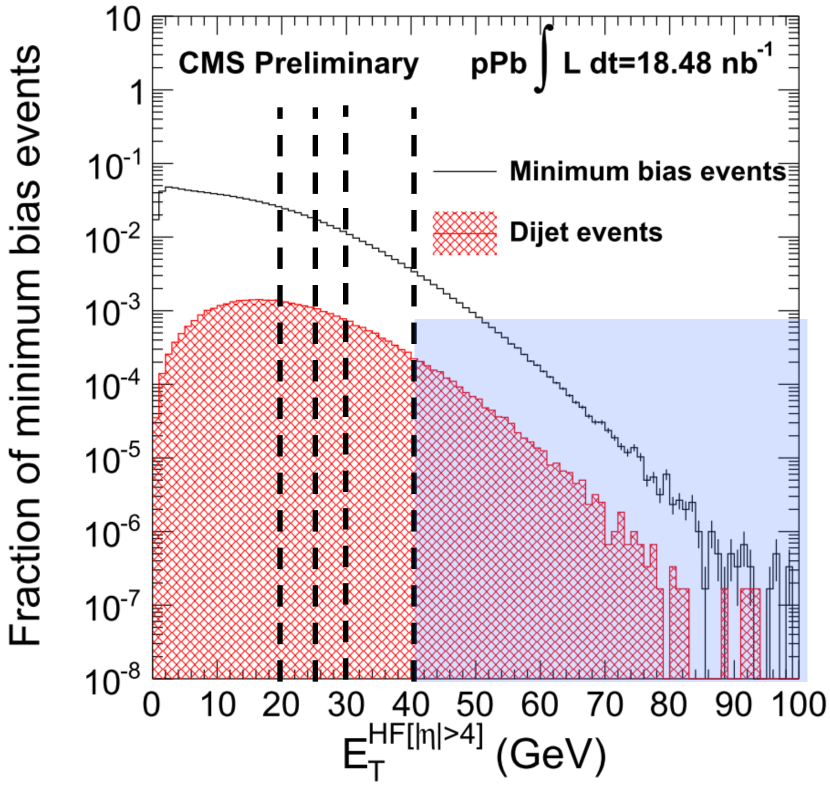


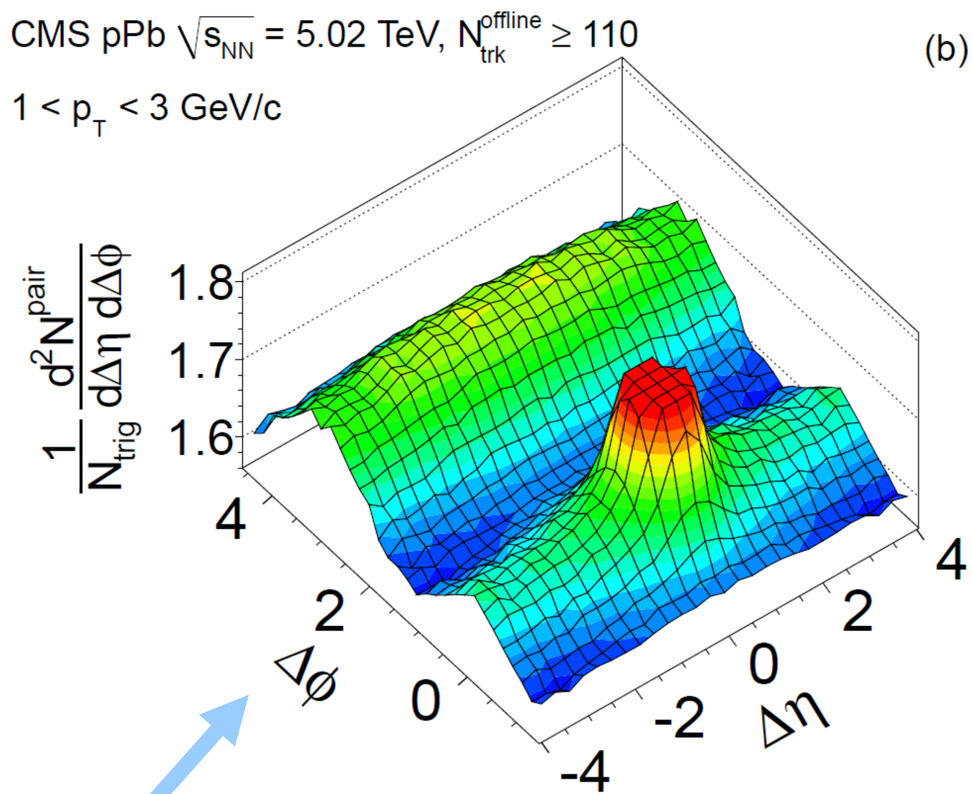
DS selection: at least one particle (proper life time $t > 10^{18}$ s) with E > 3 GeV in the pseudorapidity range -5 < η< -3 and one in the range 3 < η < 5

CMS PAS HIN-13-001

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

Event classes





"**roughly**" correspond to $N_{trk}^{Offline}$>110 bin, given the caveat HF energy is loosely correlated with N

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Dijet p_T ratios

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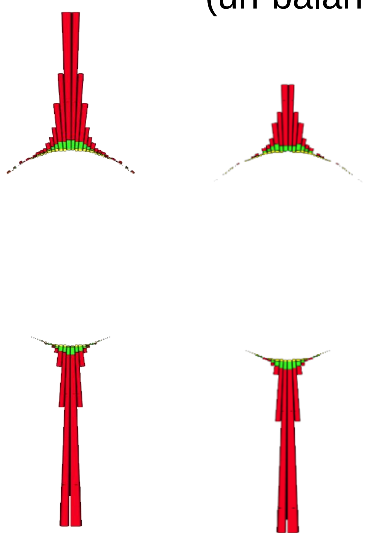
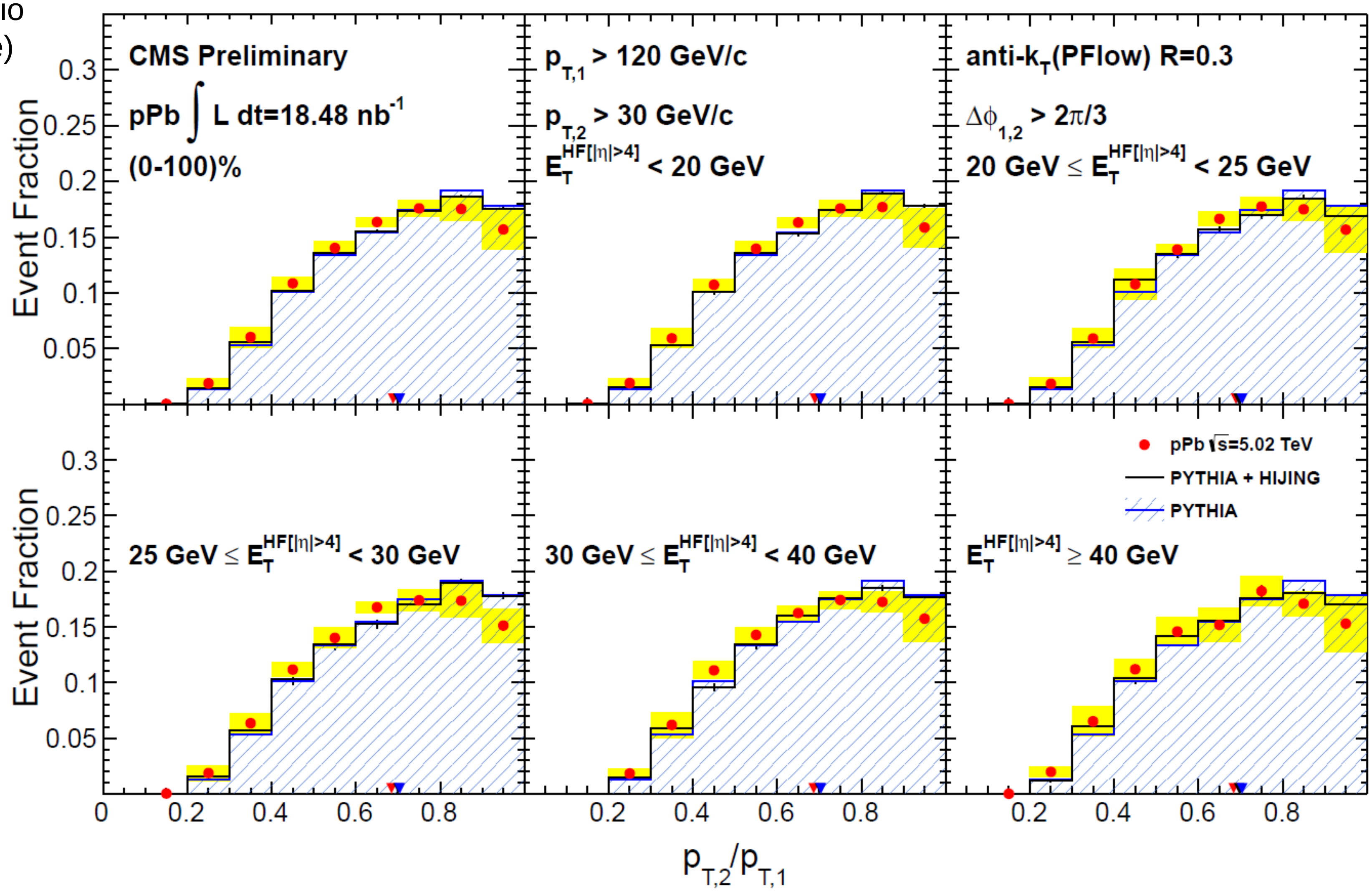
Small p_T ratio (un-balance)



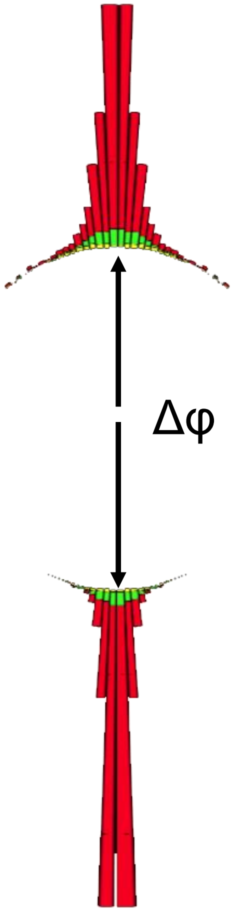
Large p_T ratio (balanced)

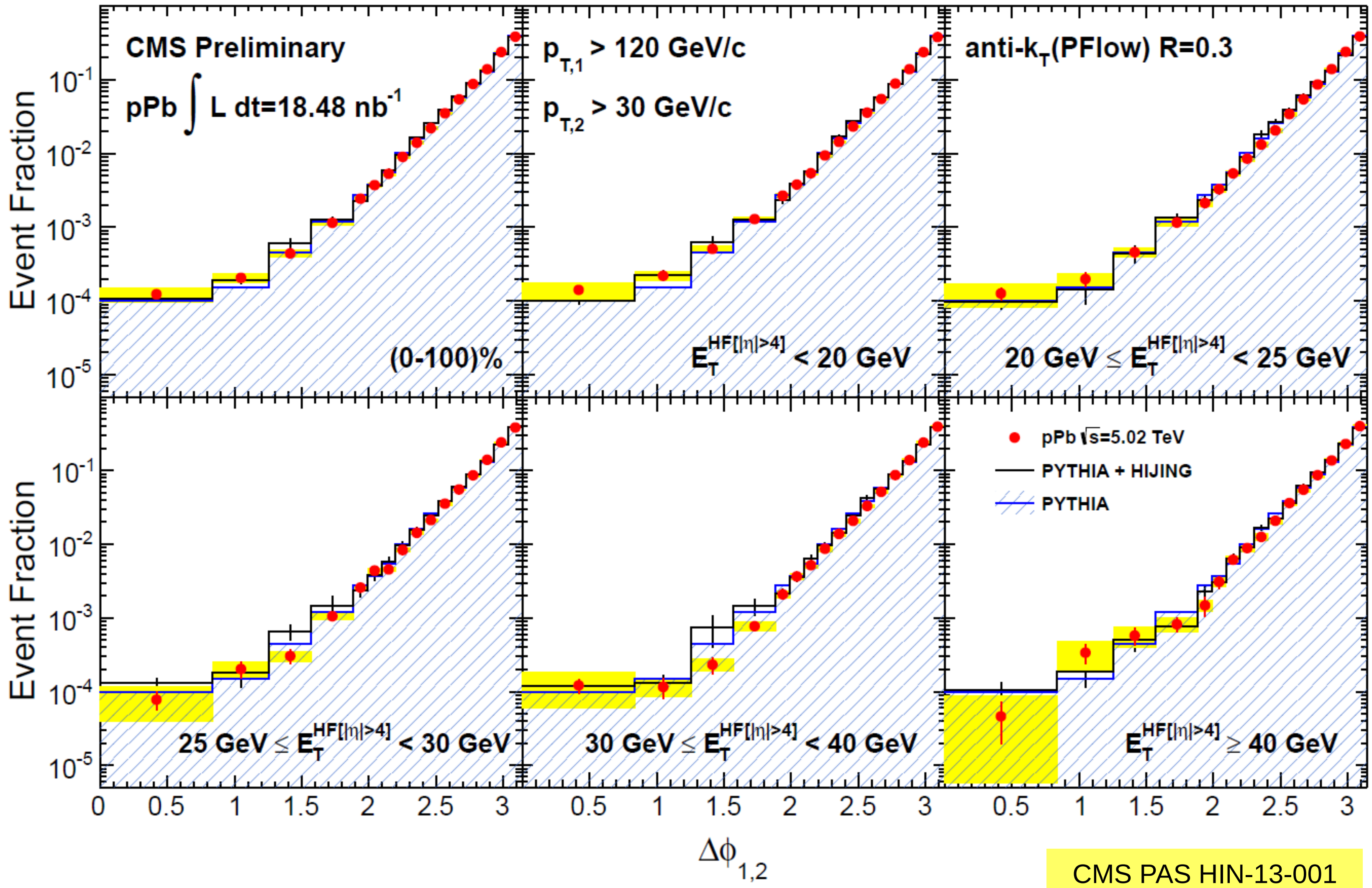


No modification is observed in dijet p_T ratio up to $E_T^{HF[|\eta|>4]} > 40$ GeV (top 0-2.5%)

(Did not have enough statistics to check PbPb collisions in the same $E_T^{HF[|\eta|>4]}$ interval)

Dijet Δφ





Δϕ distribution is unchanged w.r.t. HF energy

Summary of dijet p_T ratio and $\Delta\varphi$

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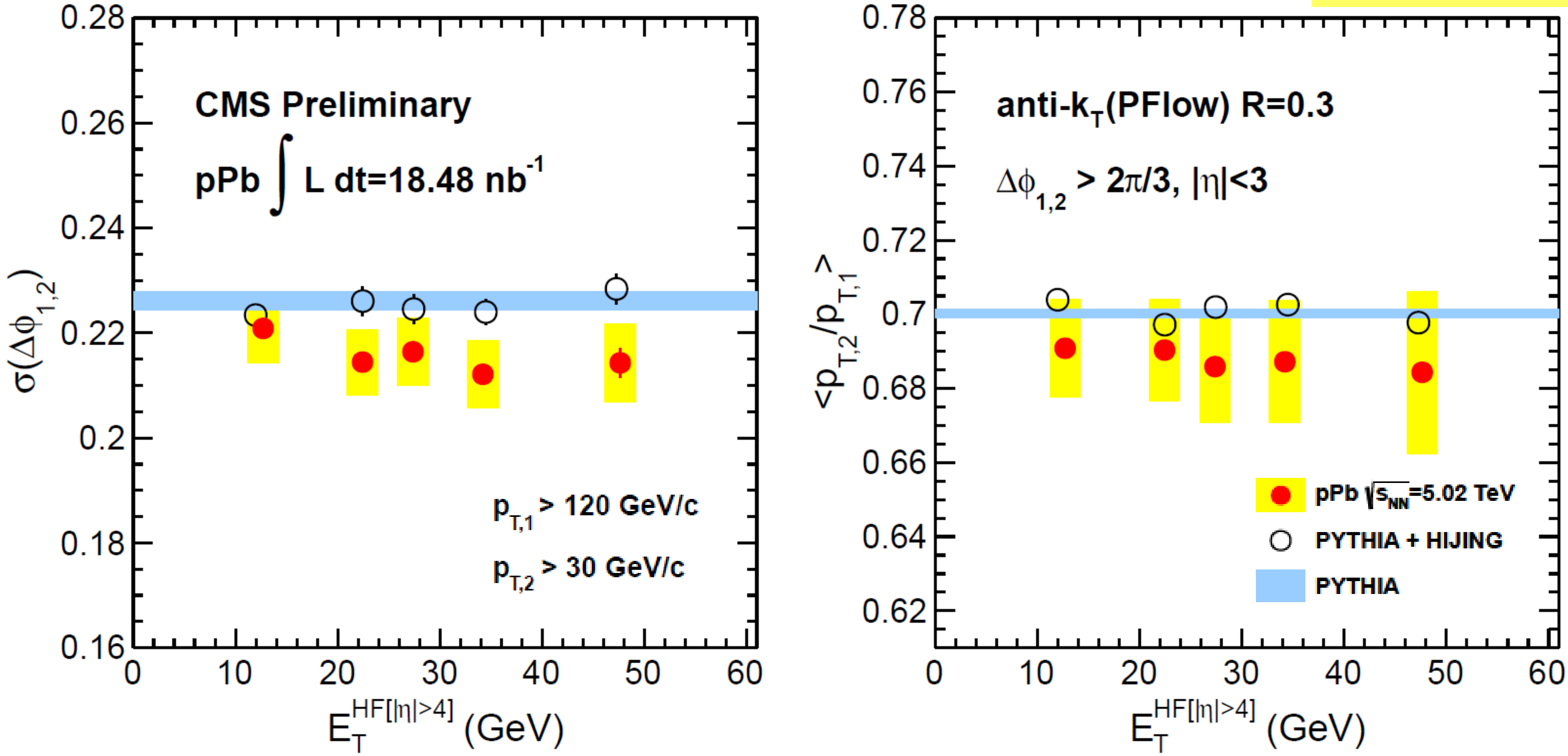
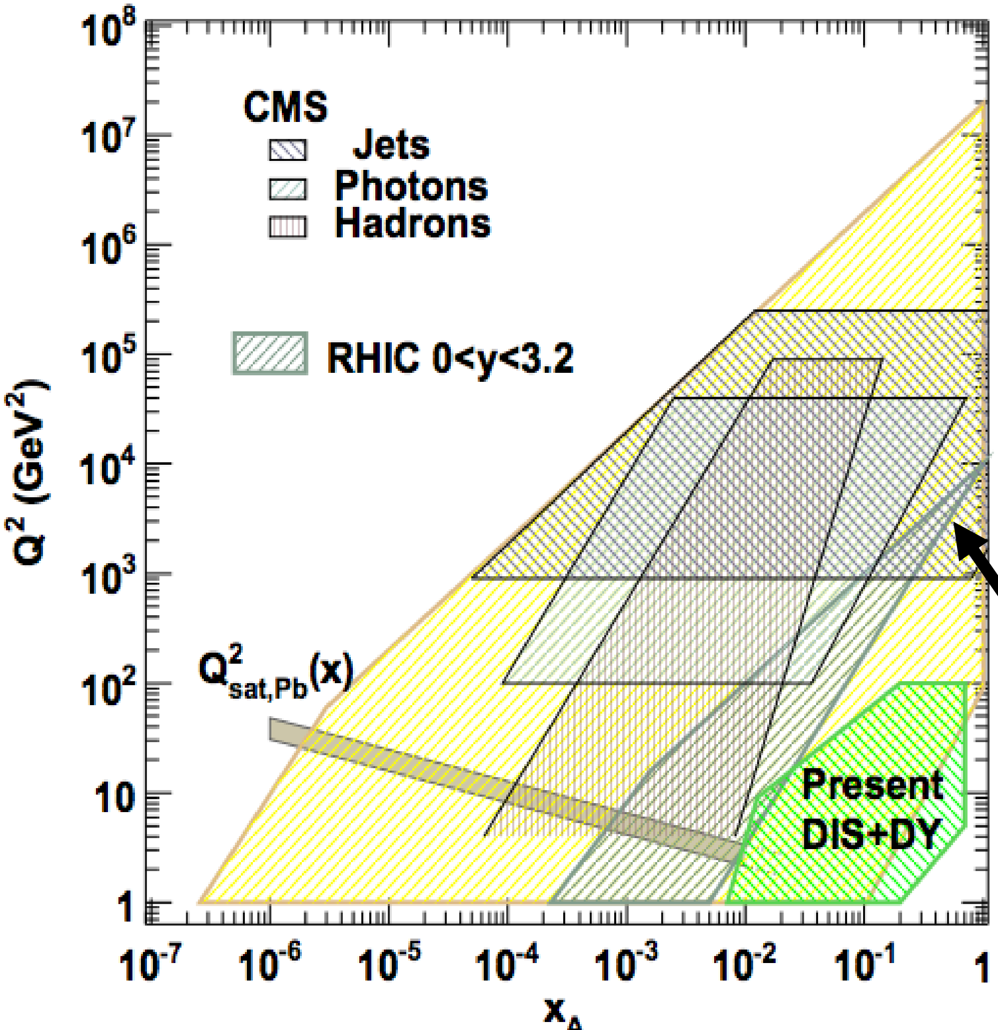


- With the current systematic uncertainty, no detectable change in $\langle p_{T,2}/p_{T,1}\rangle$ and $\Delta\varphi$ width as a function of forward calorimeter energy
- **Establish the basis to use the jets for nPDF determination**

Nuclear Parton Distribution Function

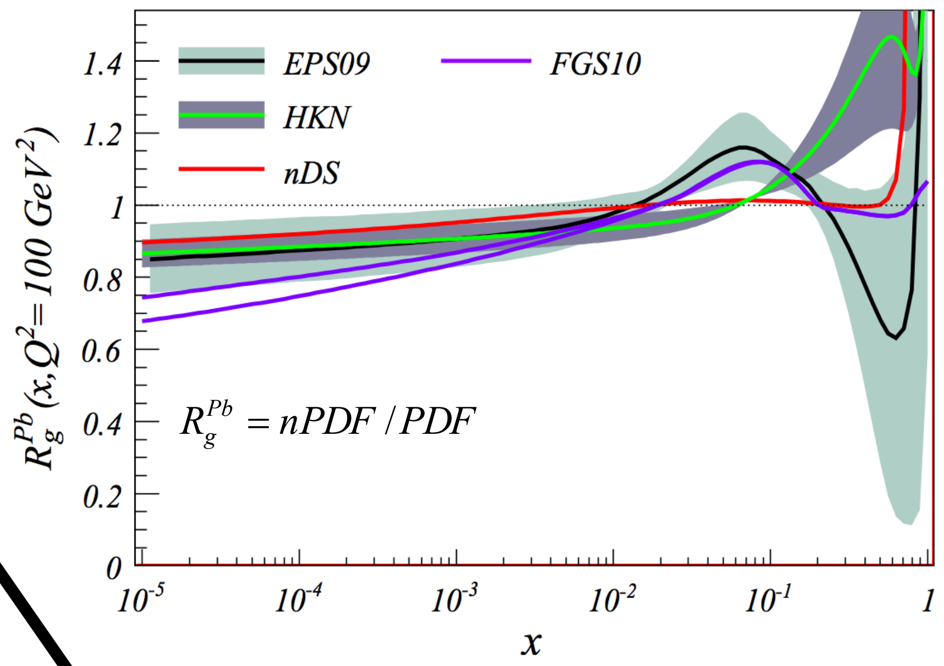
Kinematic reach for CMS, pPb @ √s = 8.8 TeV (0.1 pb^{-1})



C.A. Salgado, et. al.

J.Phys. G39 (2012) 015010

Q^2 = 100 GeV^2

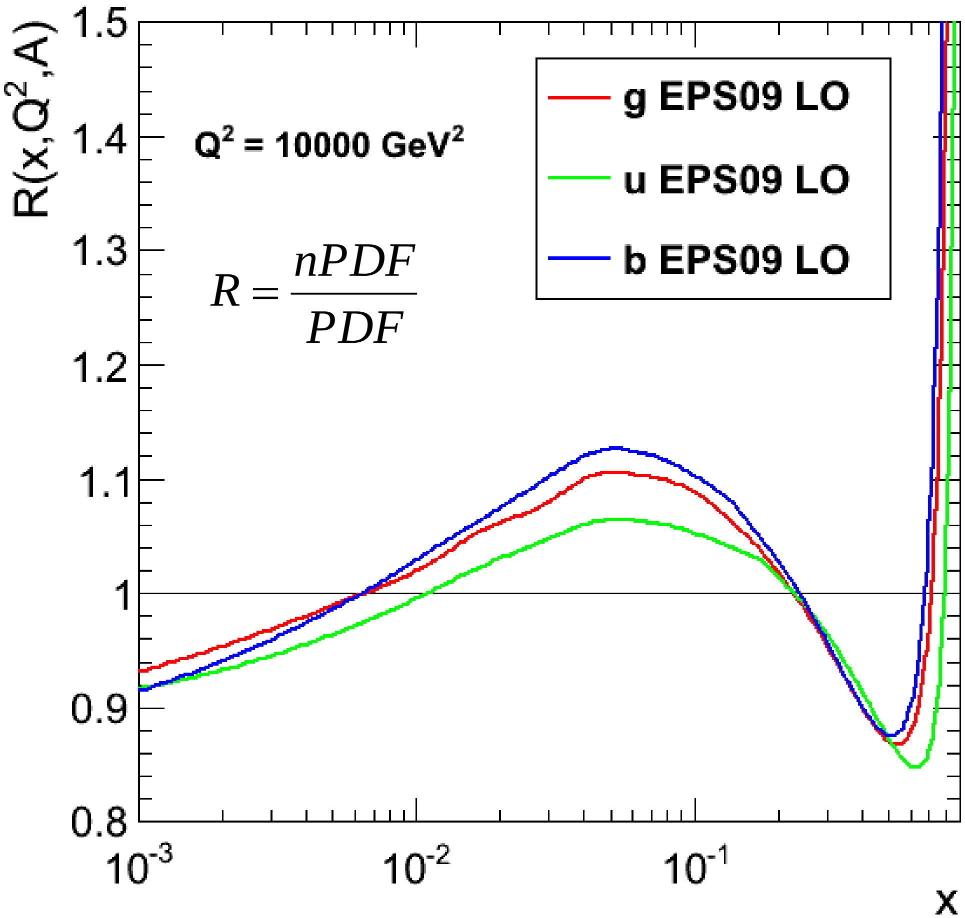


Observables using jets:

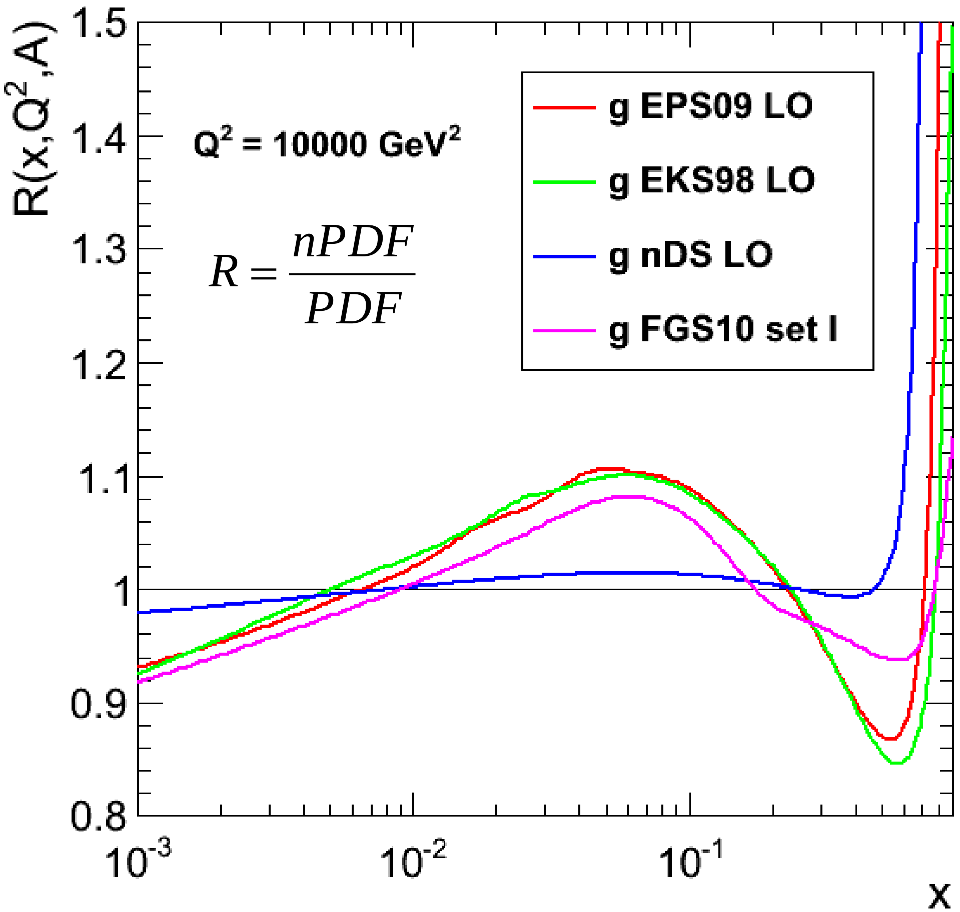
Covers high Q^2 and 10^{-4}<x<1

Nuclear Parton Distribution Function

Gluon and Quark nPDF/PDF in EPS09 LO

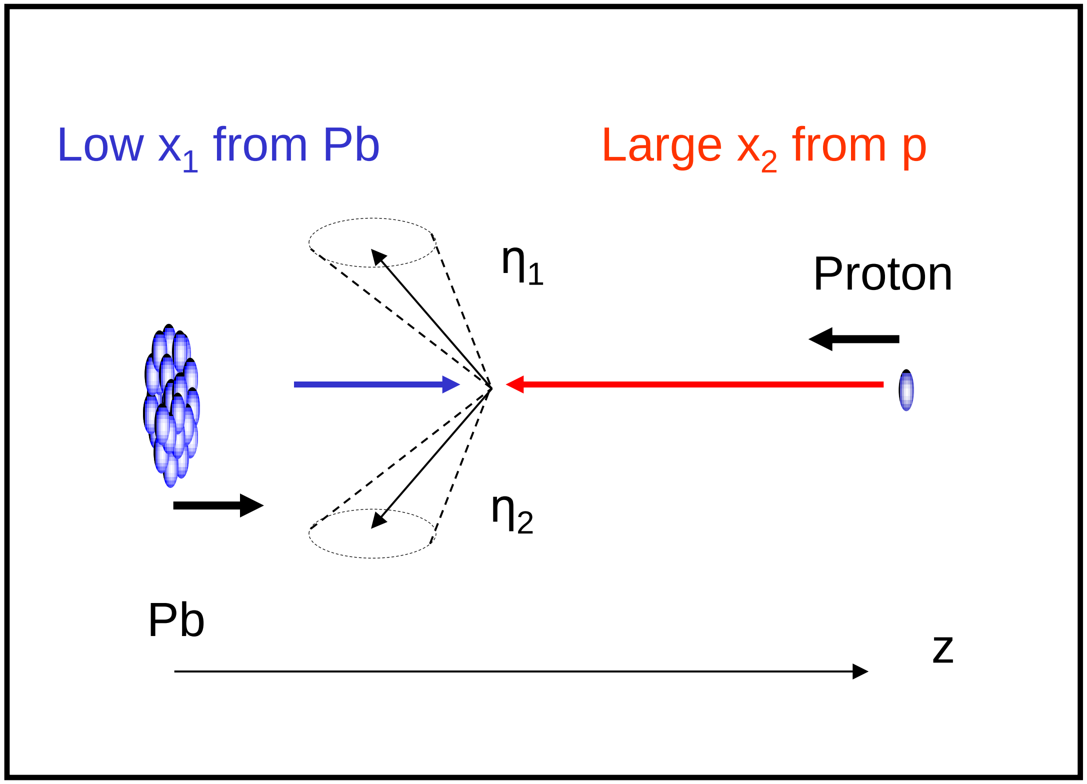


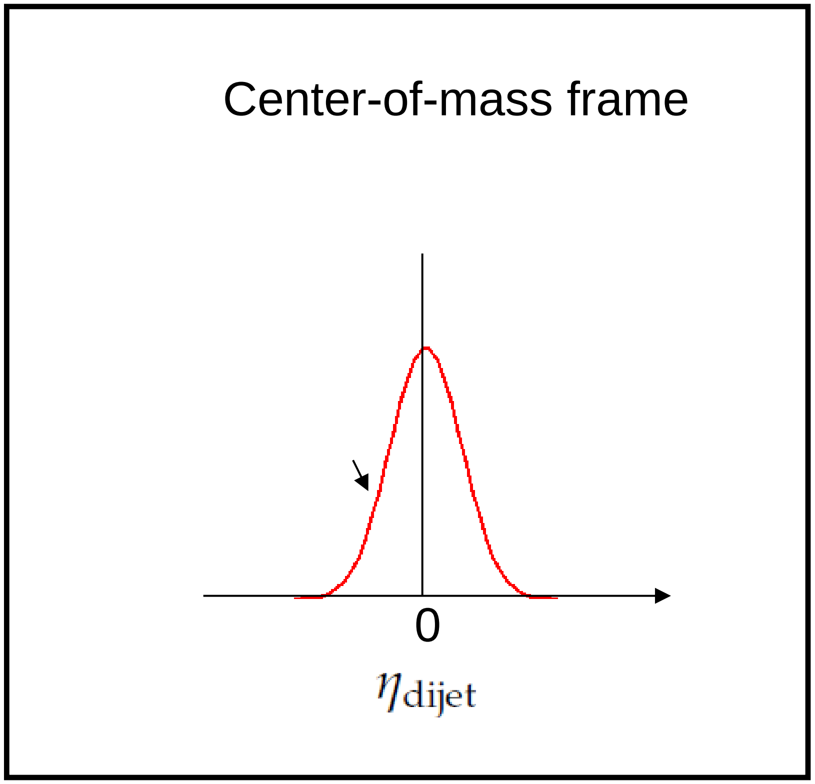
Gluon nPDF/PDF comparison between EPS09, EKS98, nDS and FGS10



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

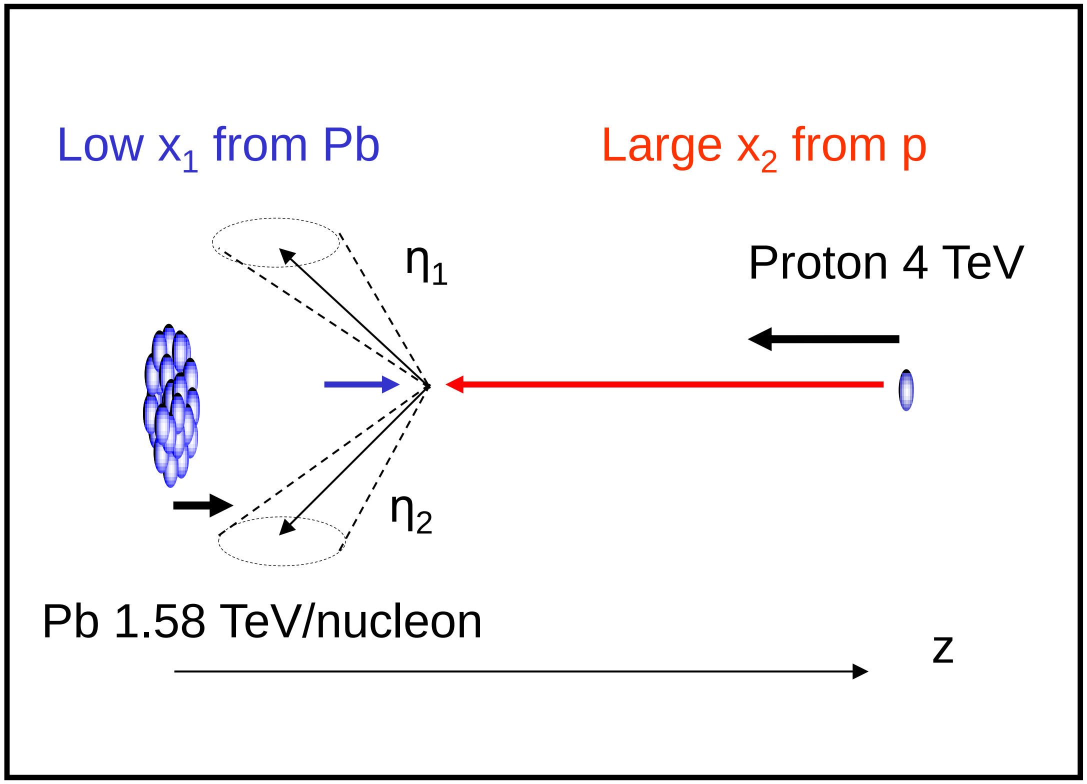
Kinematics in CM frame

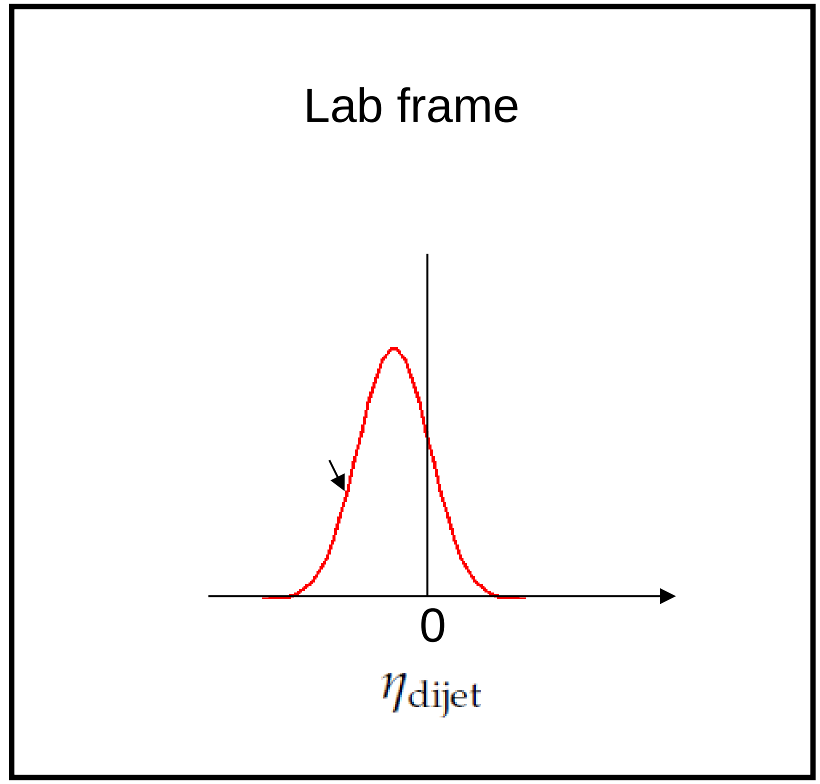




$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$

Kinematics in lab frame





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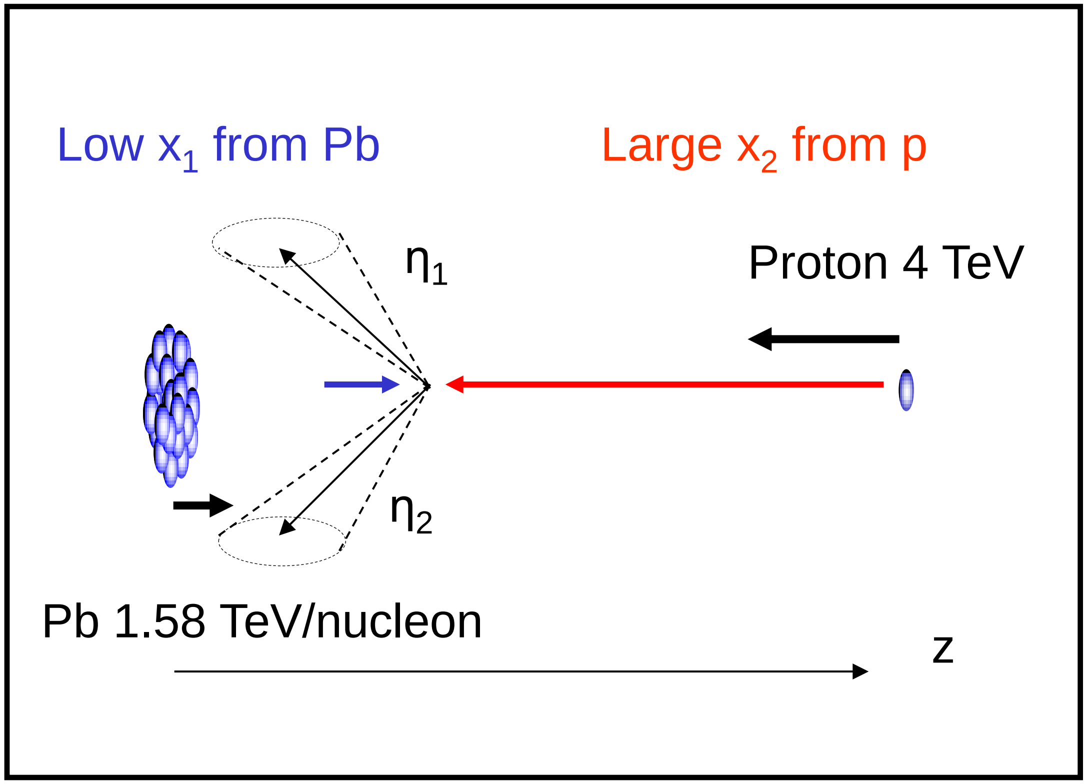
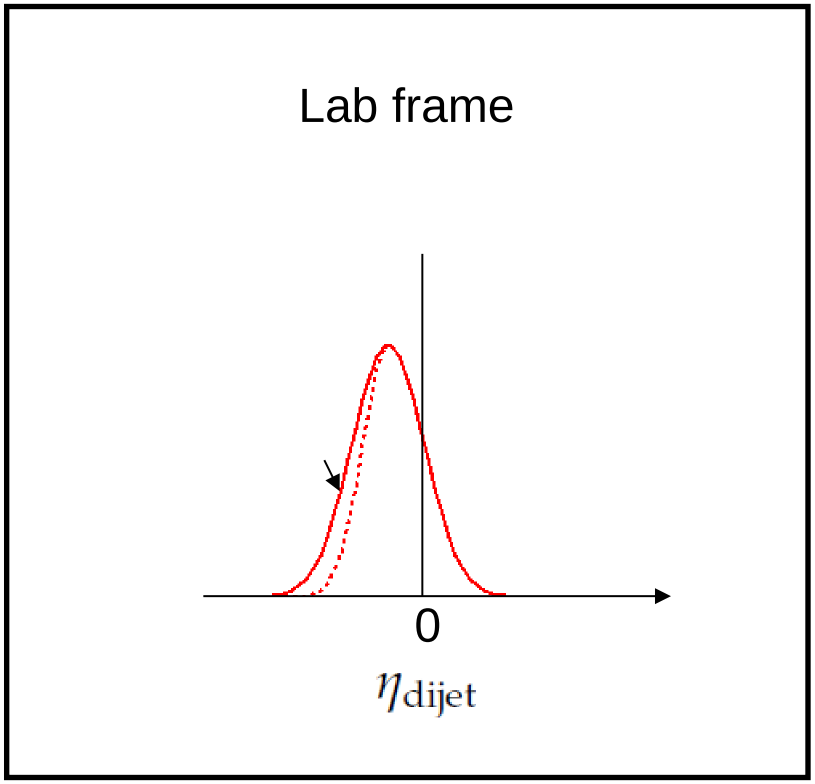


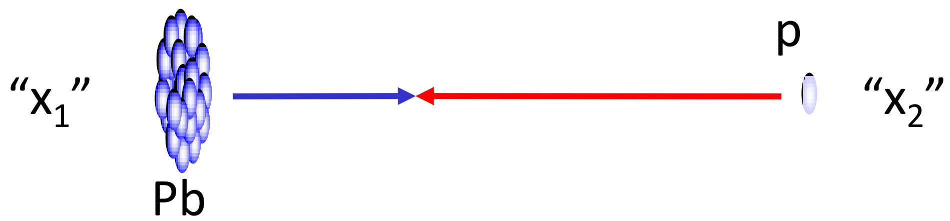


Suppression of low x1 parton from Pb ion
→ Depletion of dijet with $\eta_{dijet} < 0$

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

$x_1 \leftrightarrow \eta_{dijet}$

Leading jet $p_{T,1}$ > 120 GeV/c
subleading jet $p_{T,2}$ > 30 GeV/c
$|\Delta\varphi_{12}| > 2\pi/3$



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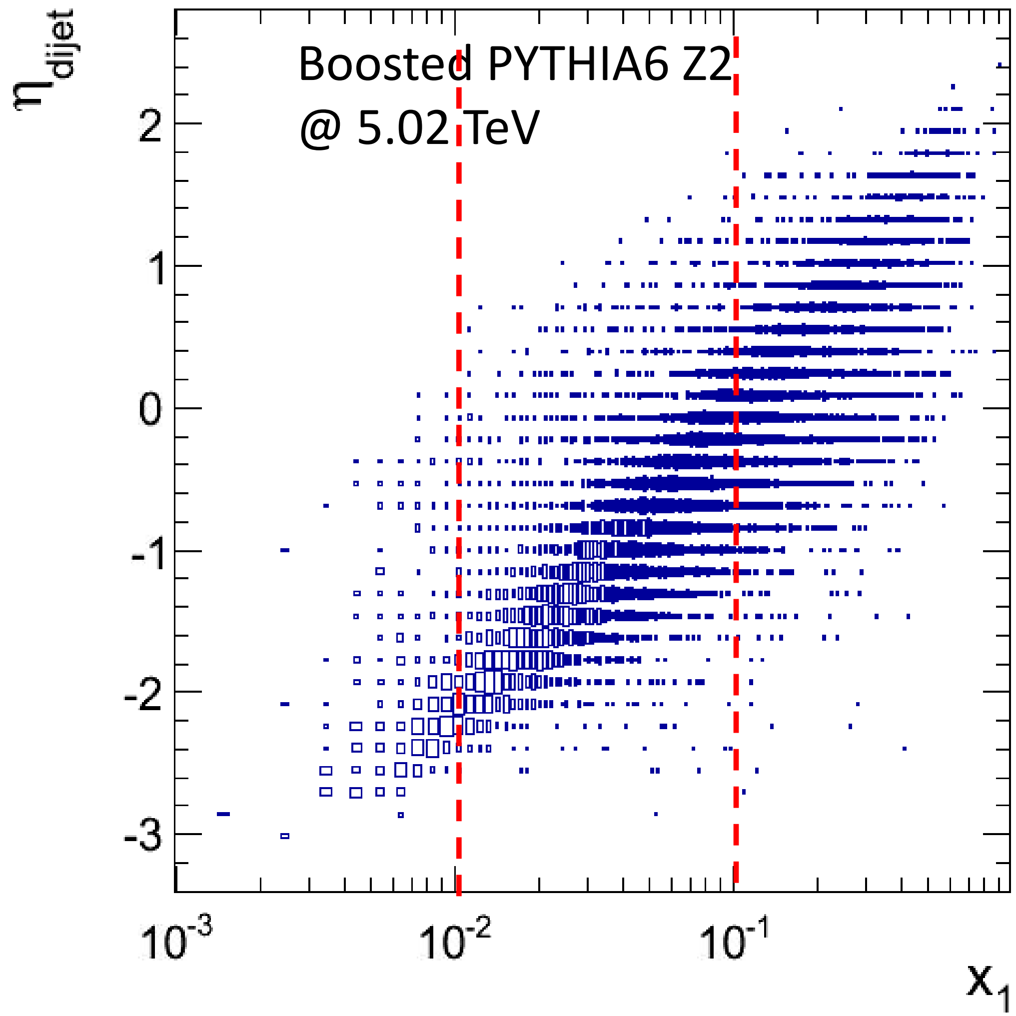
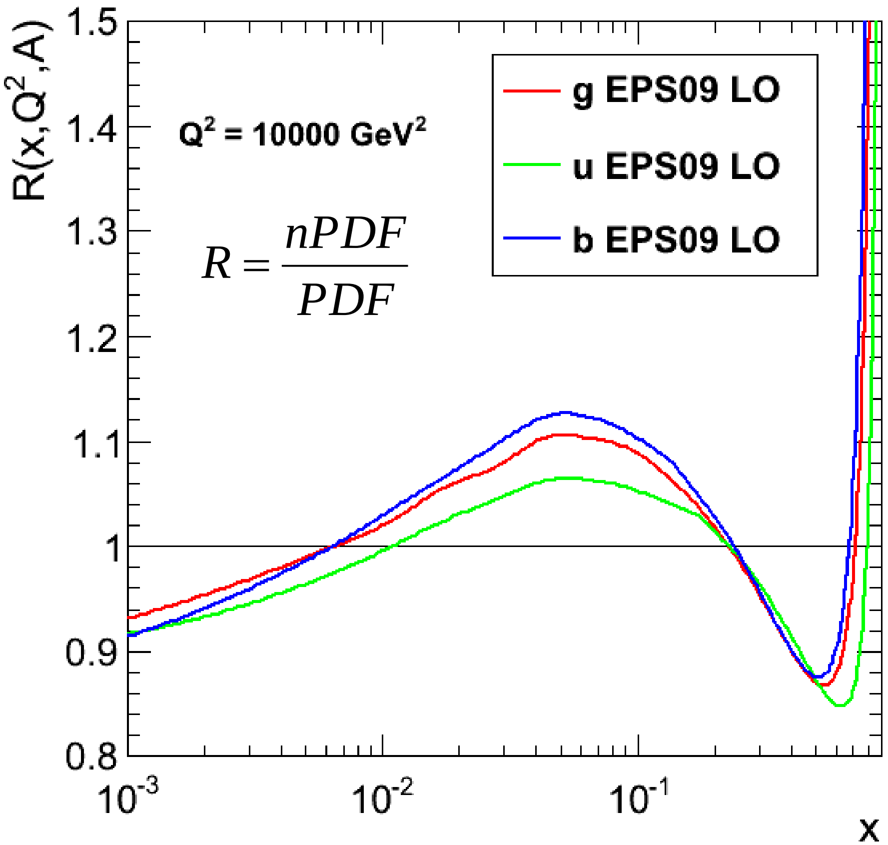


Translation from η_{dijet} to x_1



Result on η_{dijet}

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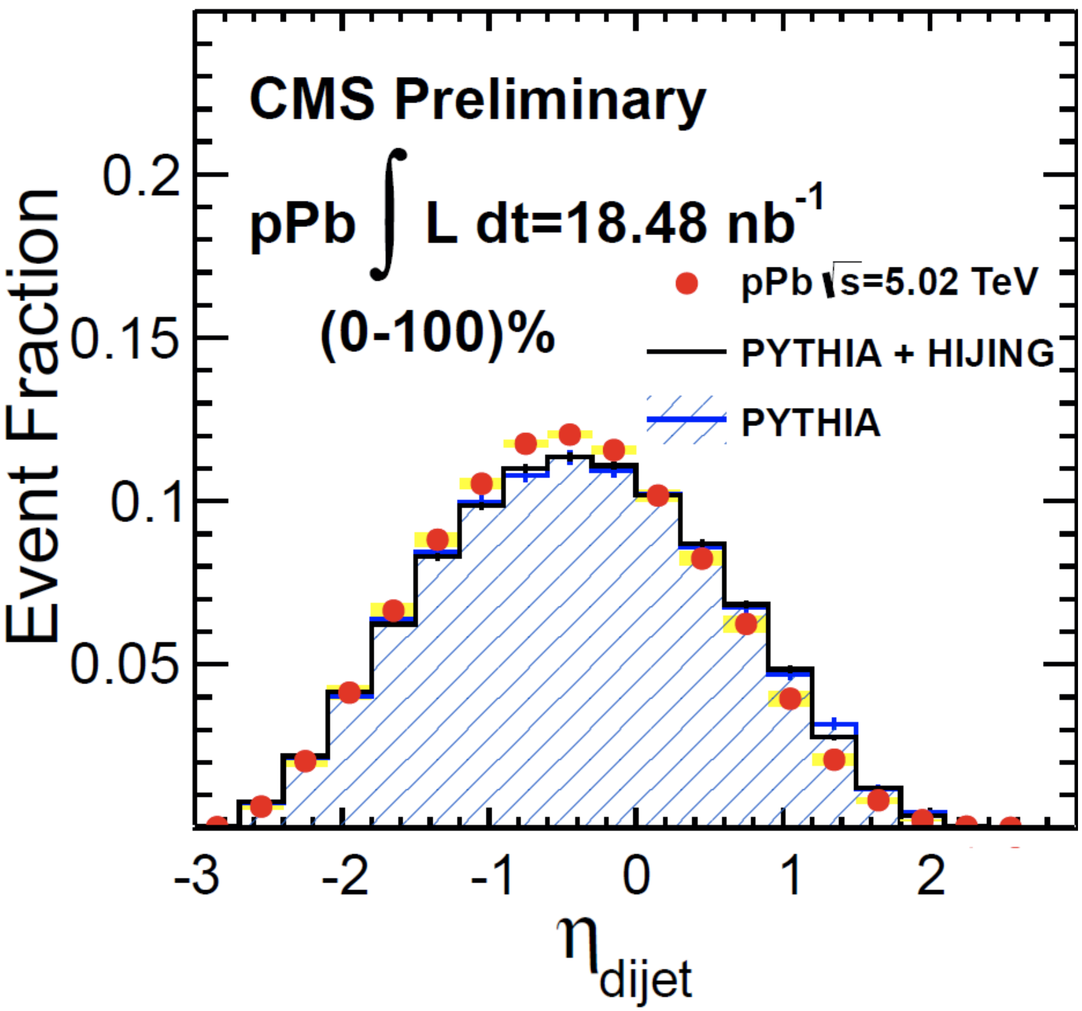
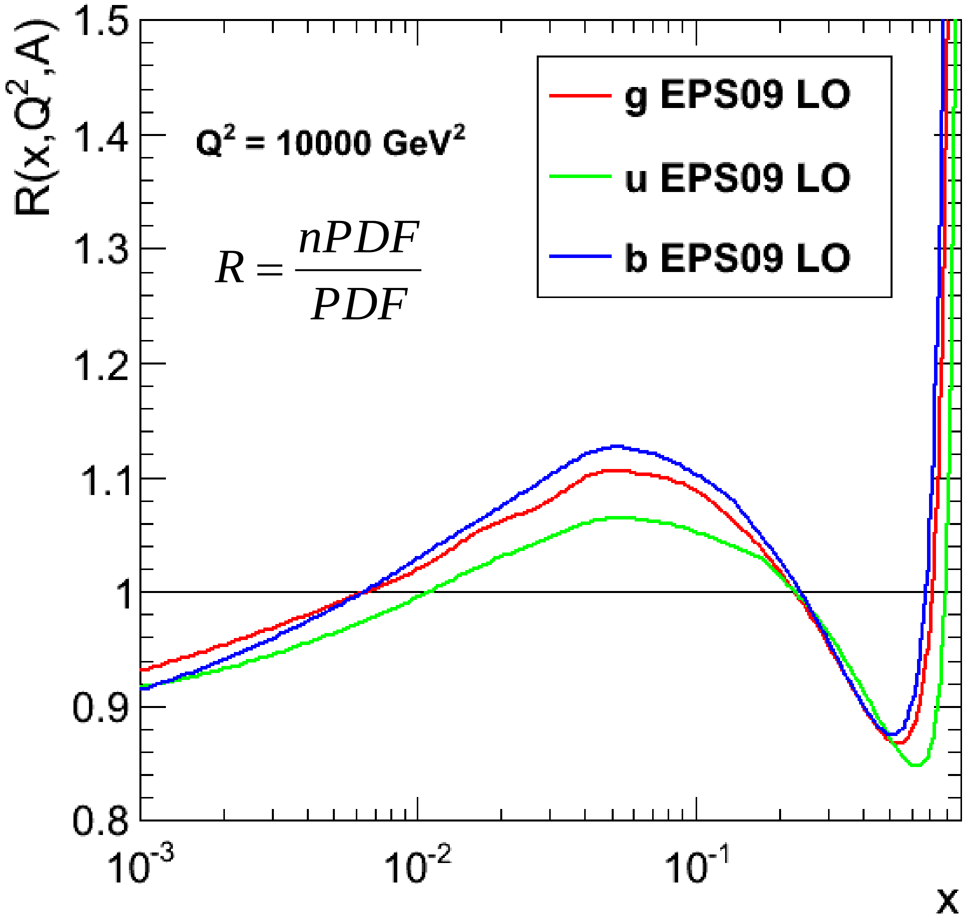
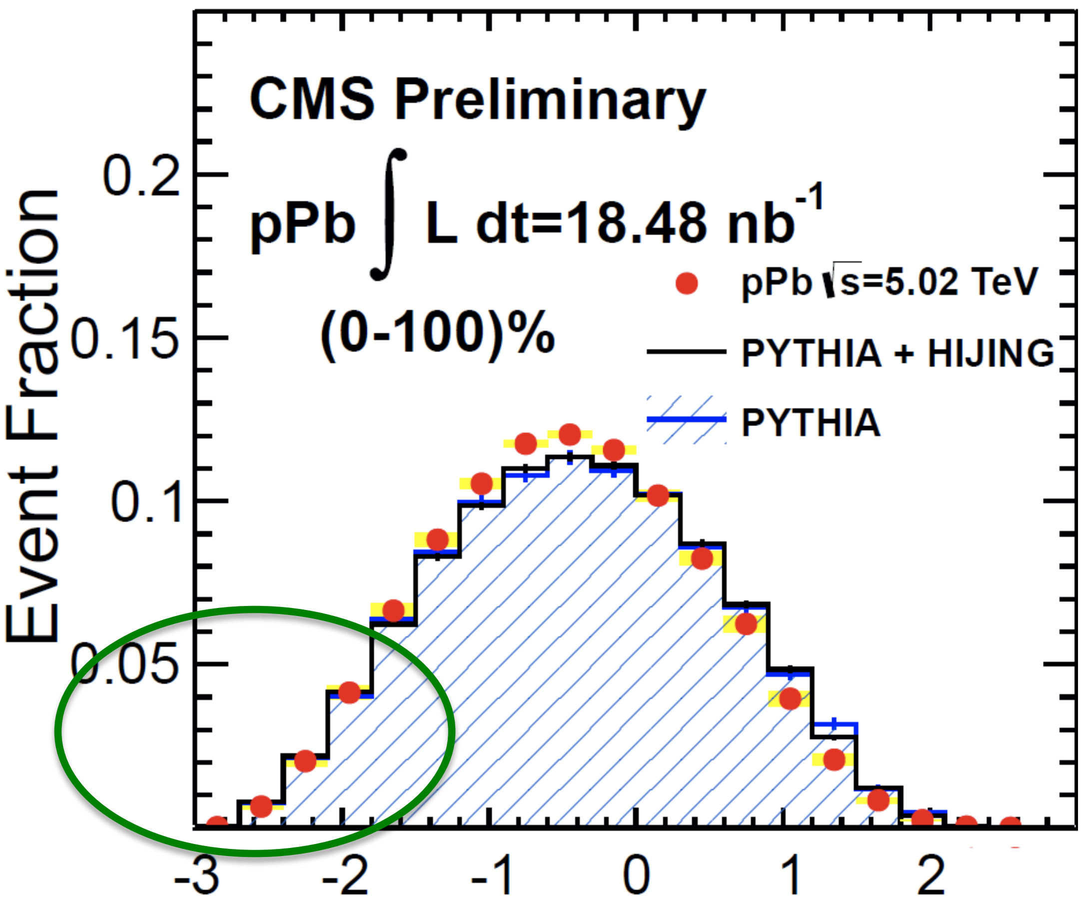




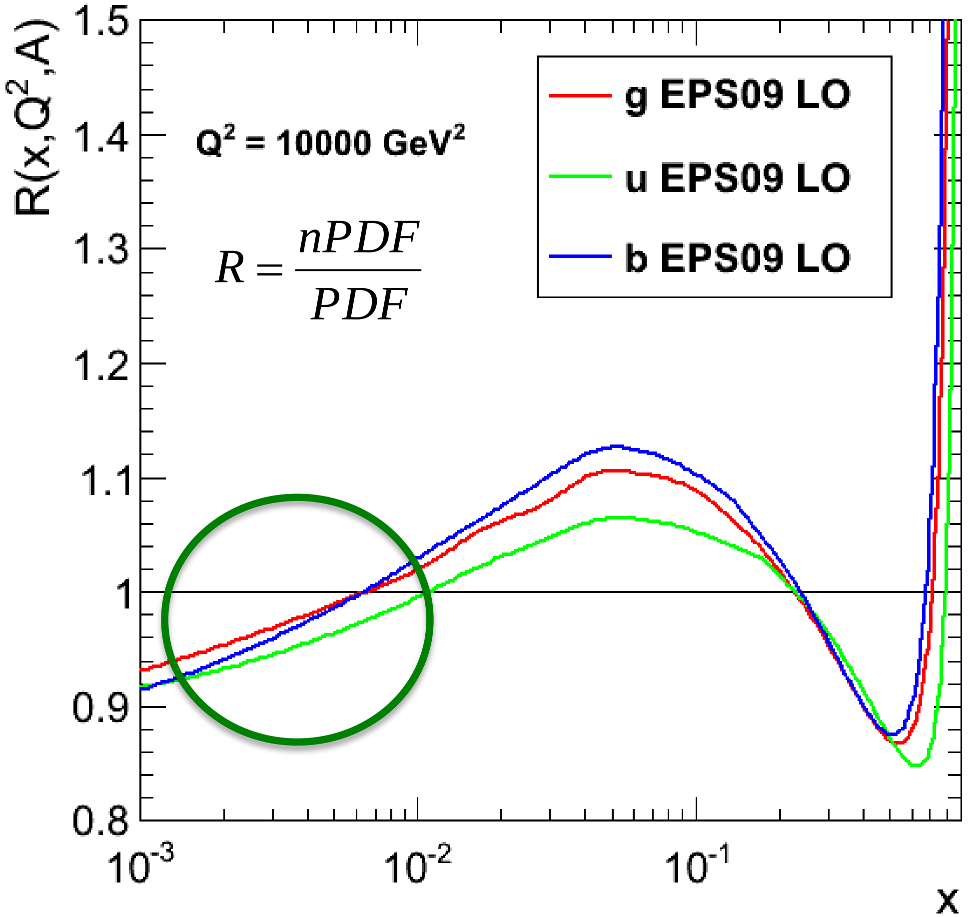
$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$

Result on η_{dijet}

CMS PAS HIN-13-001



Shadowing

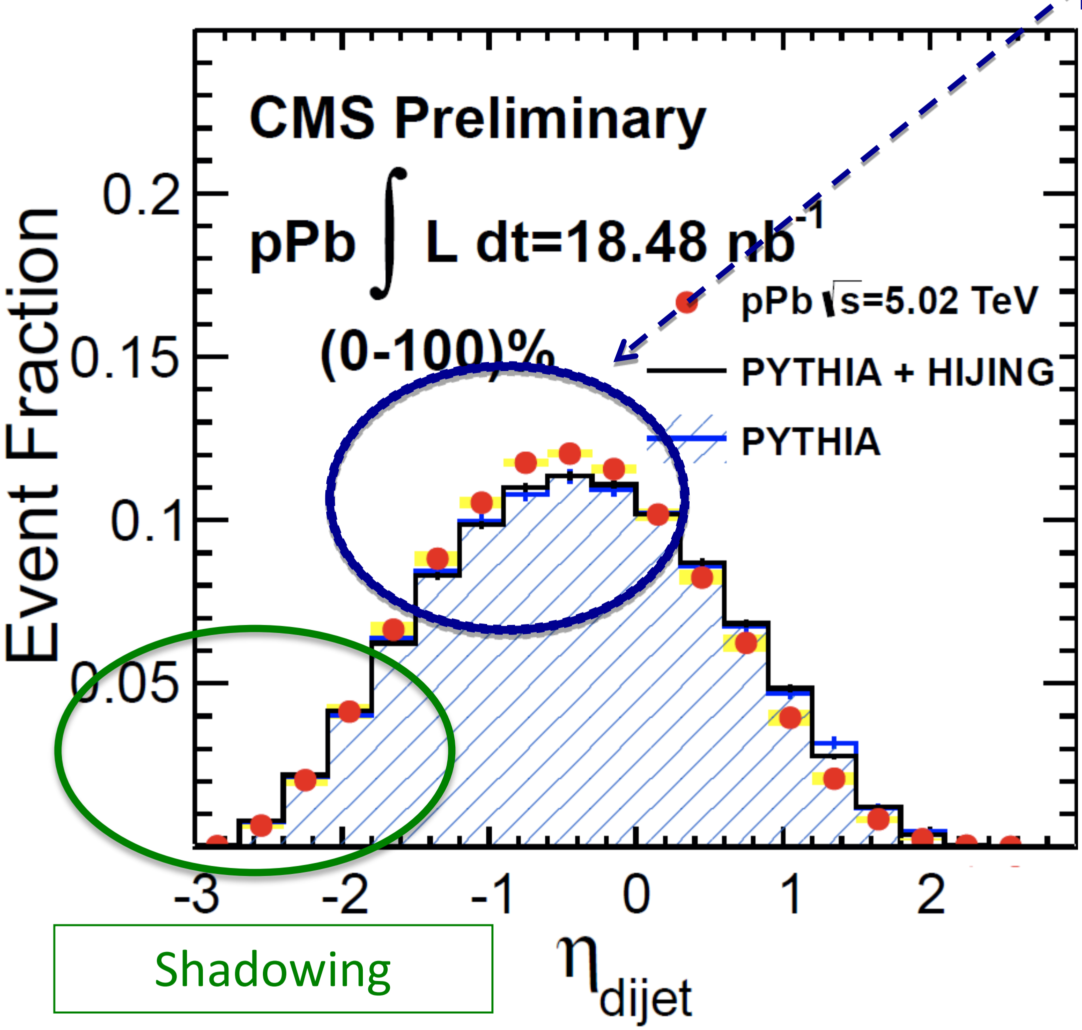


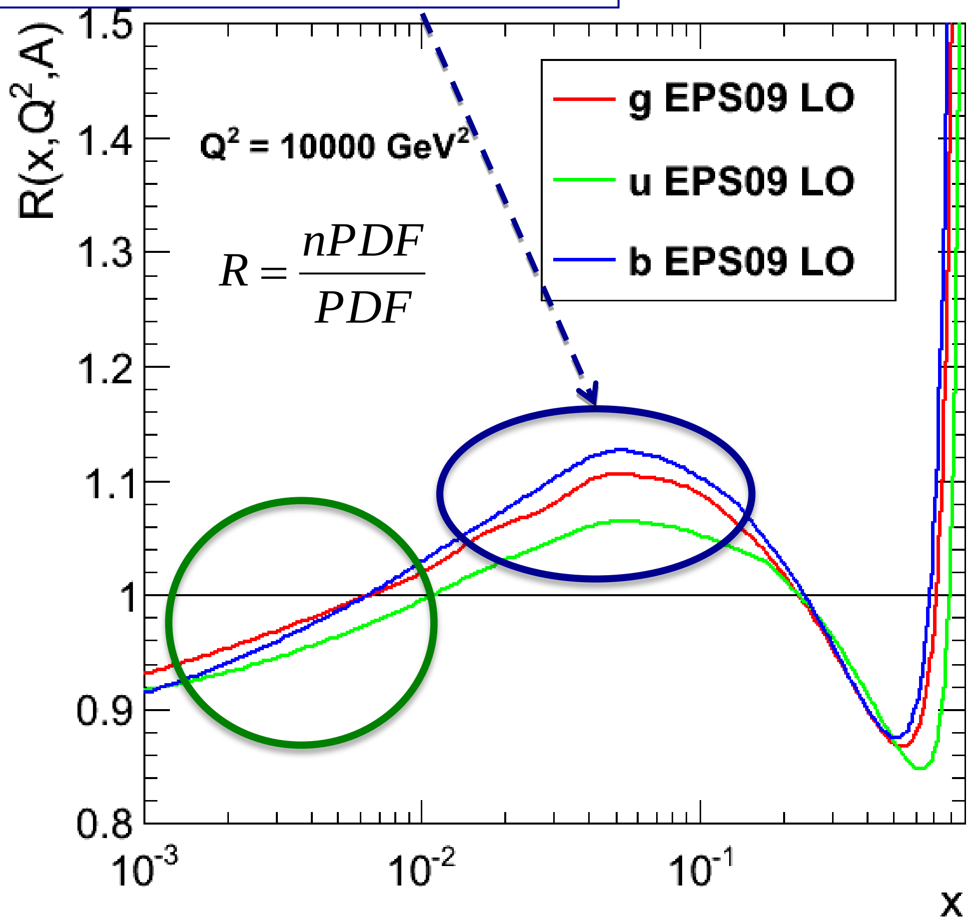
$$R = \frac{nPDF}{PDF}$$

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

Result on η_{dijet}

CMS PAS HIN-13-001





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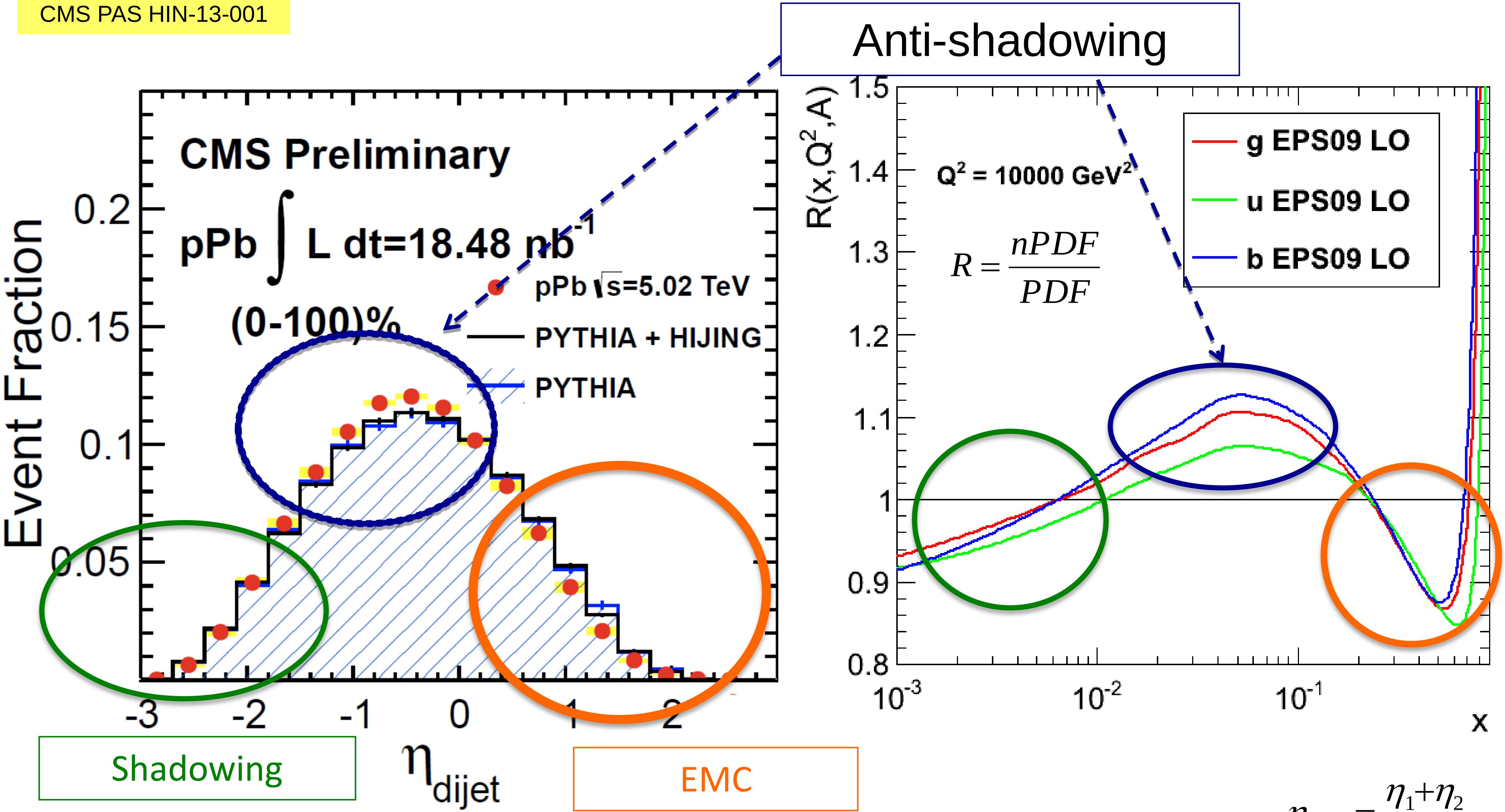
Result on η_{dijet}

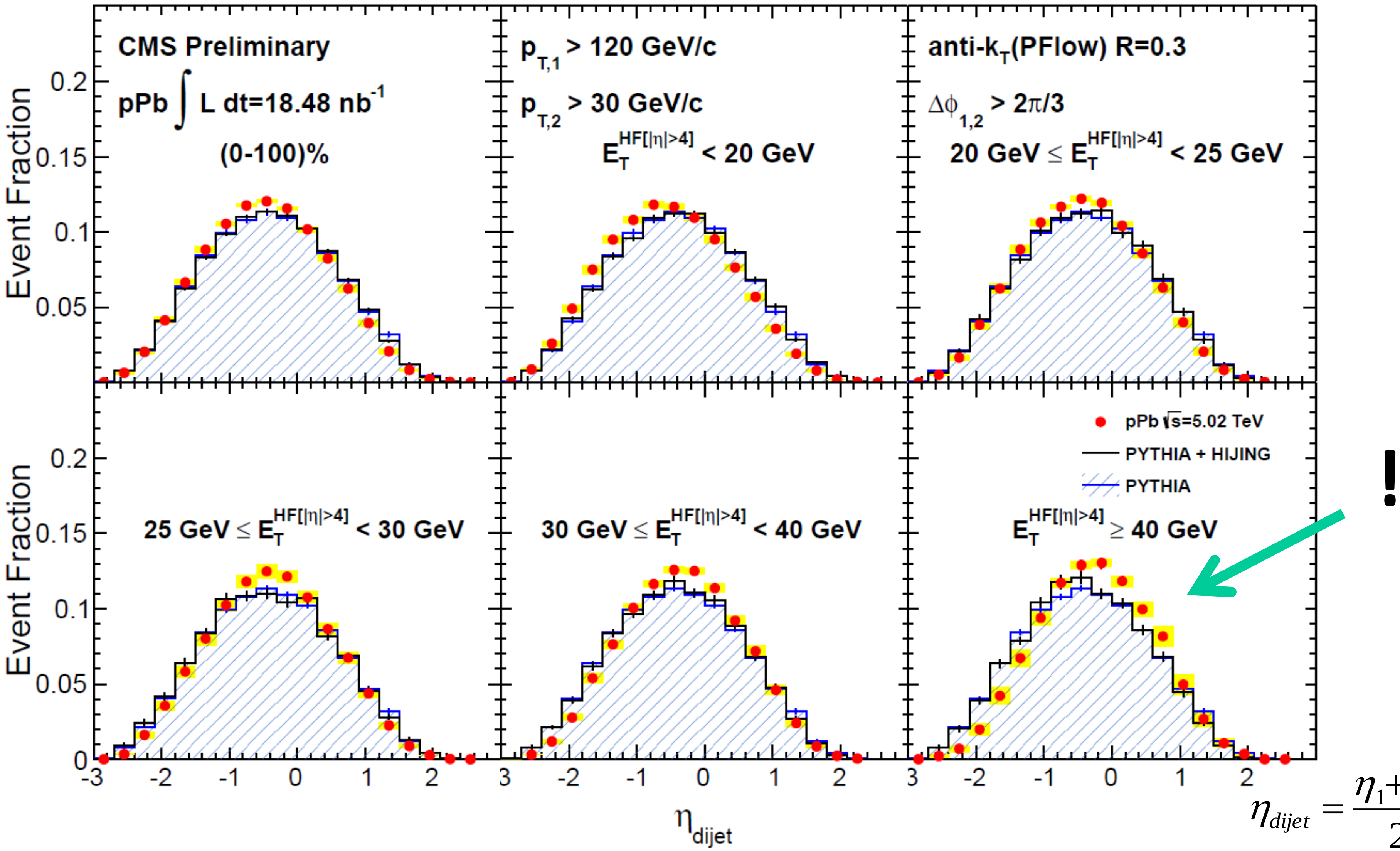
CMS PAS HIN-13-001



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

- Observe similar enhancement/suppression in dijet η as predicted for parton x

Dijet η v.s. forward calorimeter energy

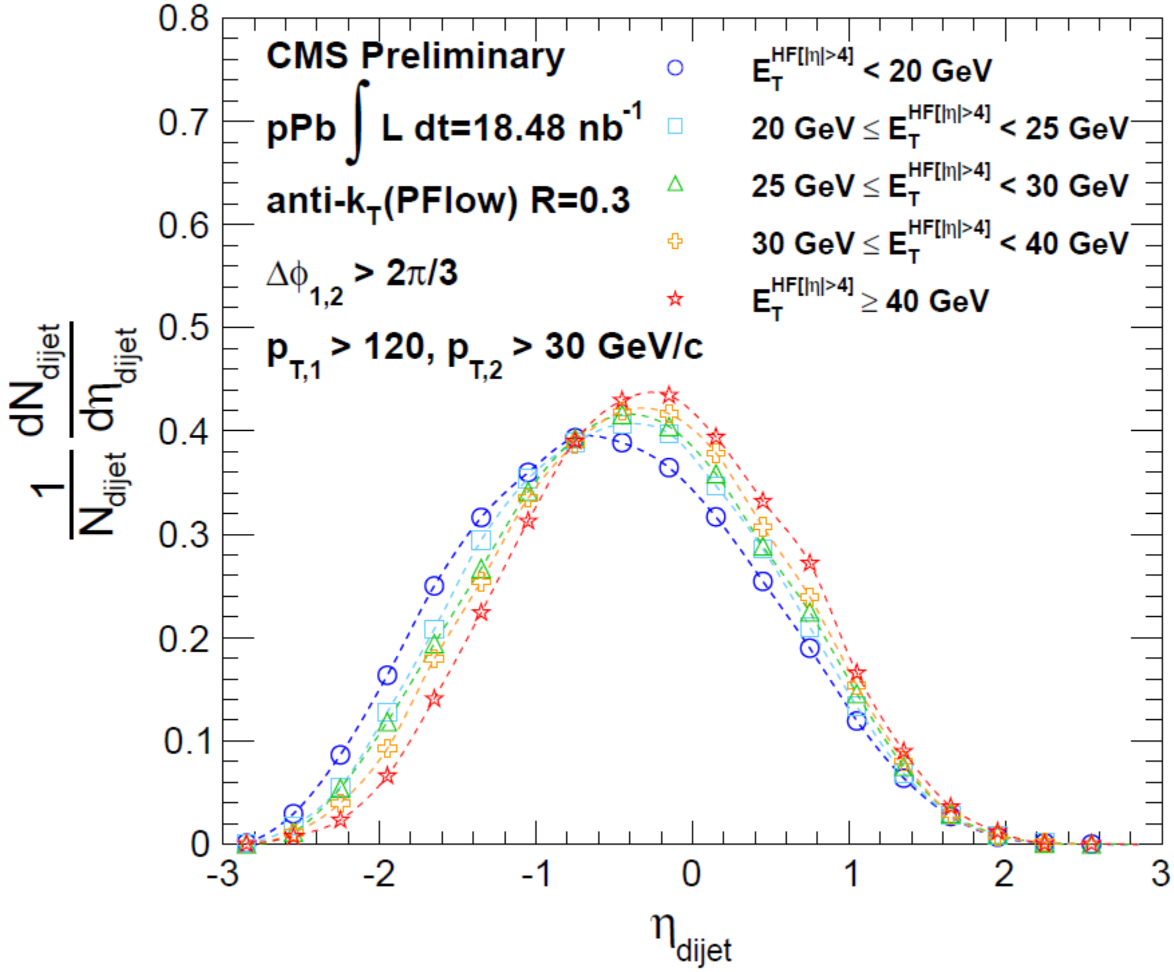


$$\eta_{dijet} = \frac{\eta_1+\eta_2}{2}$$

- η_{dijet} distributions plotted against PYTHIA references
- A systematic shift in the positive η direction vs HF energy

Dijet η in different event clases

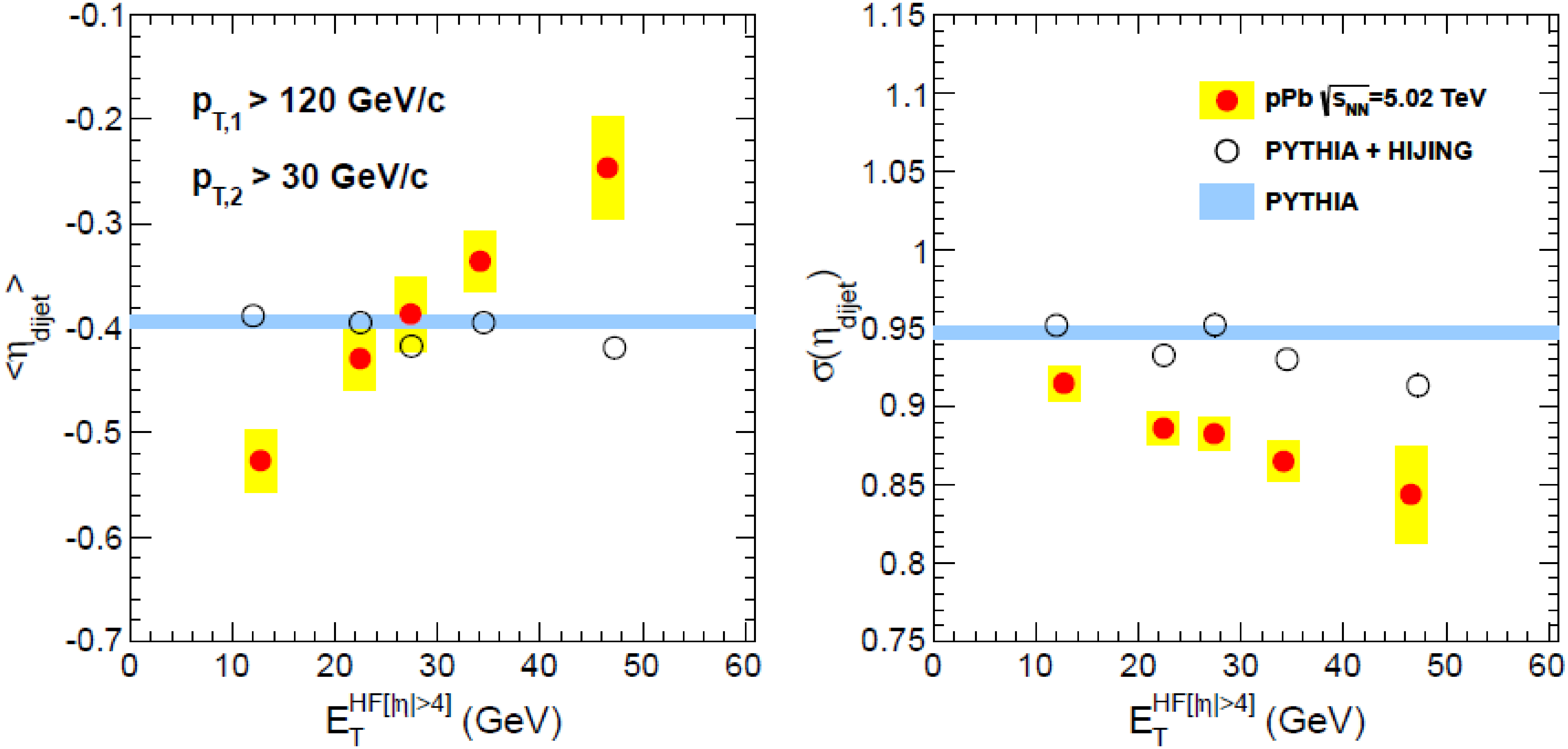
Normalized by N_{dijet}



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

The η_{dijet} distribution is evolving as a function of forward calorimeter energy

Results from dijet η measurements



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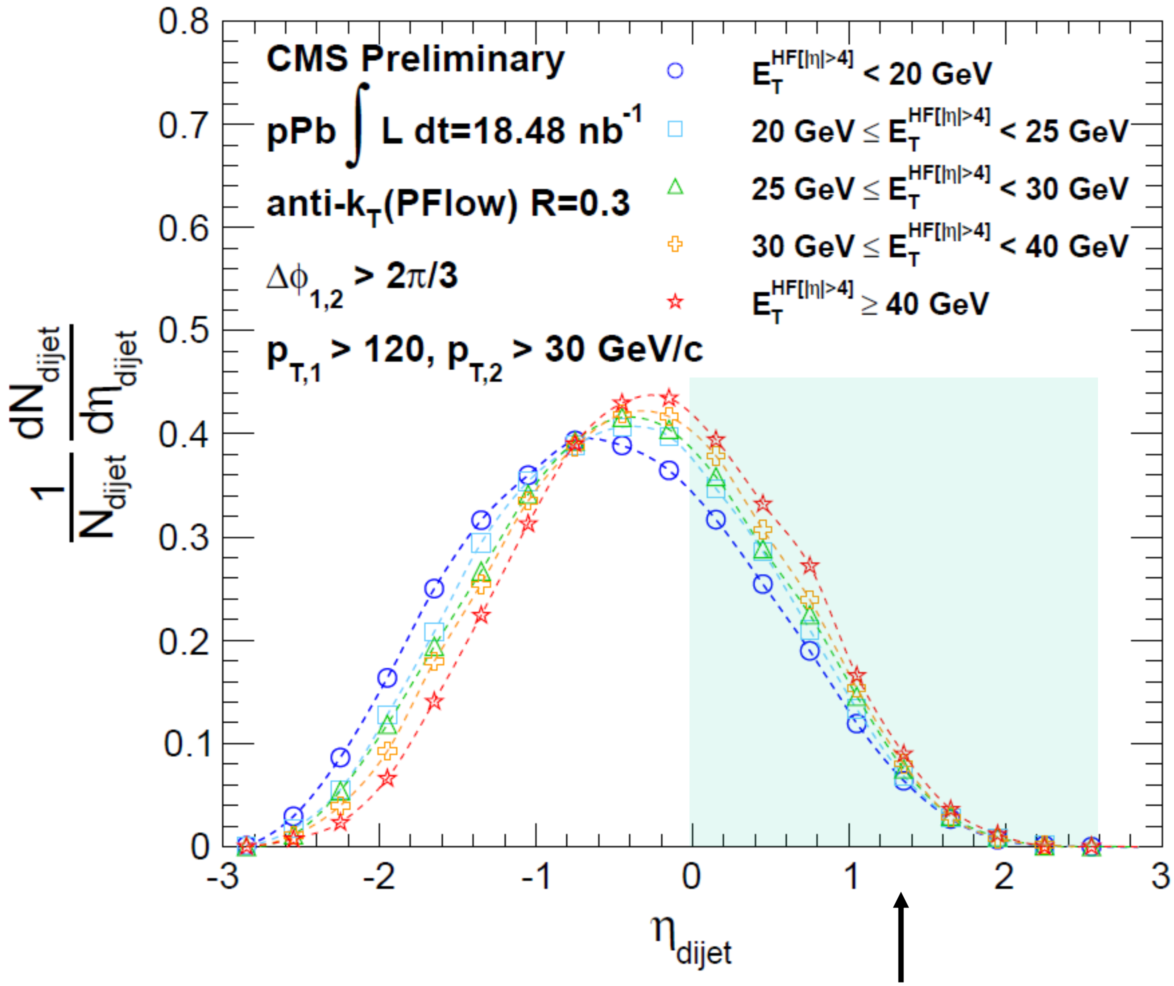
- Mean of η_{dijet} increases v.s. forward calorimeter energy
- Width of η_{dijet} decreases v.s. forward calorimeter energy

Dijet η in different event classes

CMS PAS HIN-13-001

Normalized by N_{dijet}



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

If we normalize the distribution by the area in the interval $\eta_{dijet} > 0$

Dijet η in different event classes

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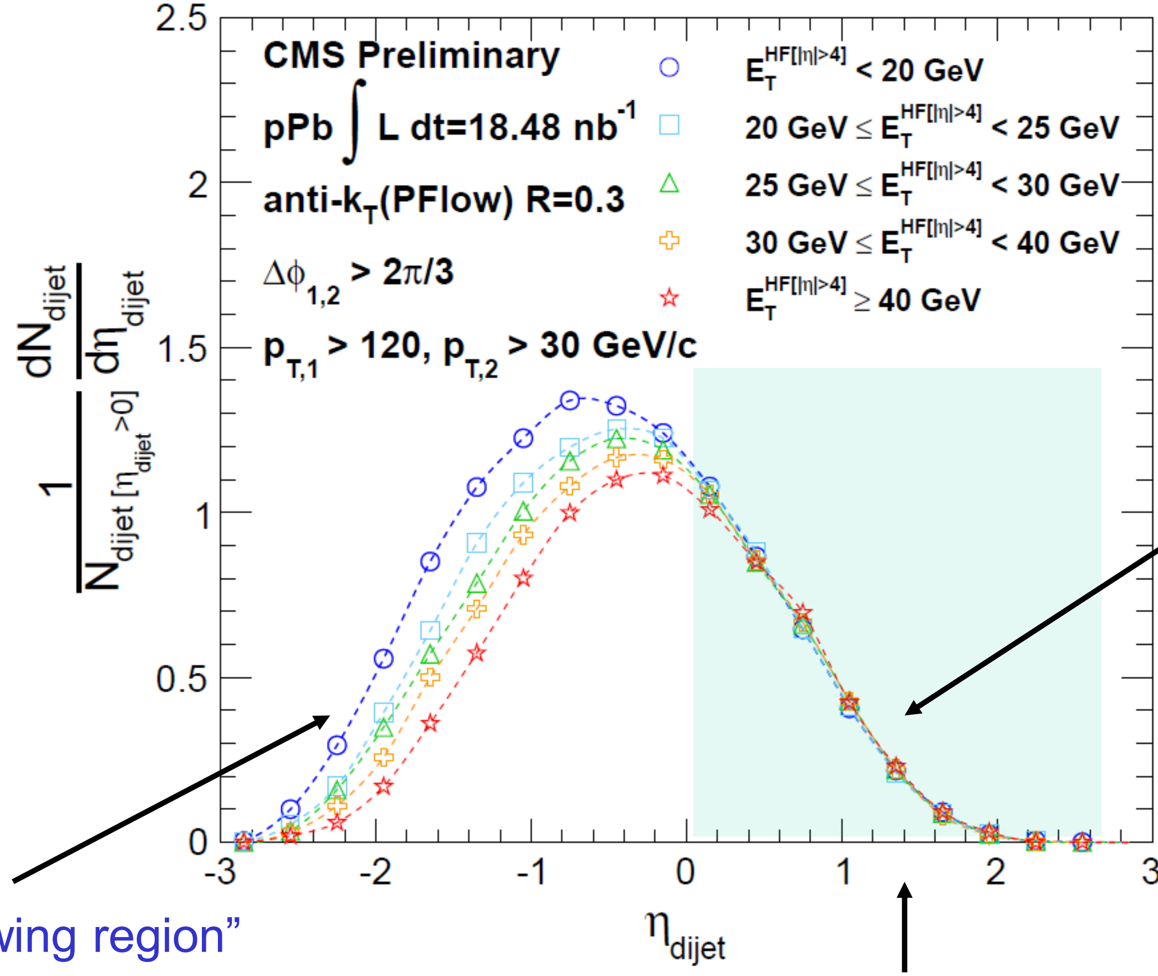
Normalized by N_{dijet} with $\eta_{dijet}>0$



The same shape in "EMC region"?

Evolving "shadowing region"

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

If we normalize the distribution by the area in the interval $\eta_{dijet} > 0$

Summary and Outlook

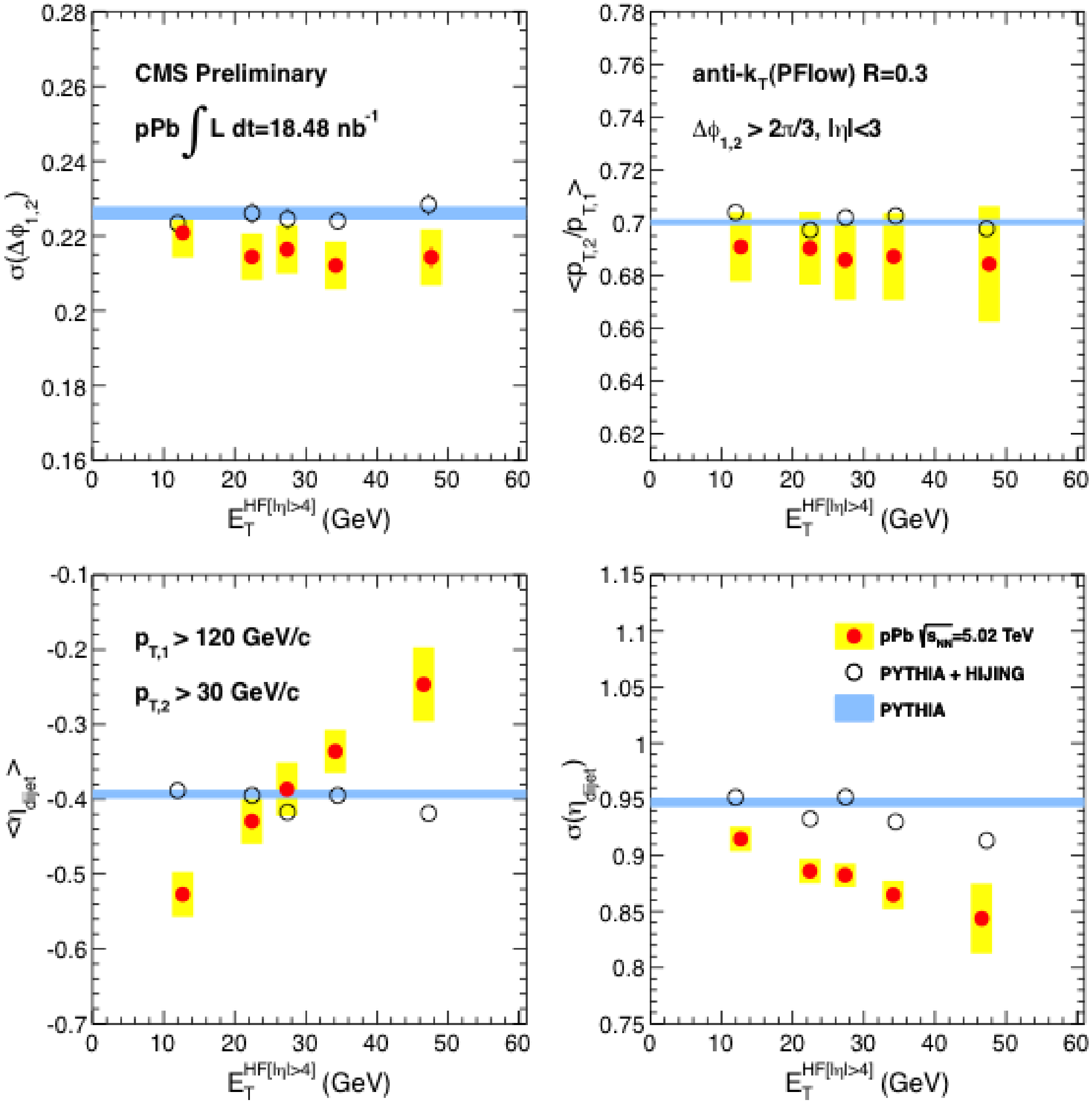
- Centrality determination:
  - Need a common definition of event selection between RHIC and LHC experiments
  - Physics may depend on the way you classify the event: "top 0-2.5%" may mean quite different events depending on the centrality variable you choose
- Jet quenching in pPb collisions:
  - No significant modification observed in dijet p_T ratio and azimuthal angle correlation
- Dijet pseudorapidity distributions:
  - Provide strong constraints for nPDF determination
  - Interesting trend in η_{dijet} v.s. forward calorimeter energy is observed in the shadowing and EMC regions
- Future measurements:
  - Dijet pseudorapidity distributions in bins of dijet mass M_{jj}
  - Inclusive jet & b-jet p_T spectra in different pseudorapidity intervals
  - Photon-jet p_T balance and pseudorapidity distributions

Backup slides

Results from dijet η measurements

Δϕ distributions constant vs HF

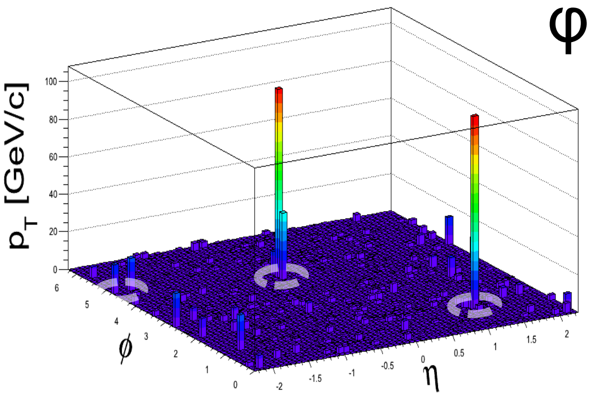
p_T ratio is constant vs HF

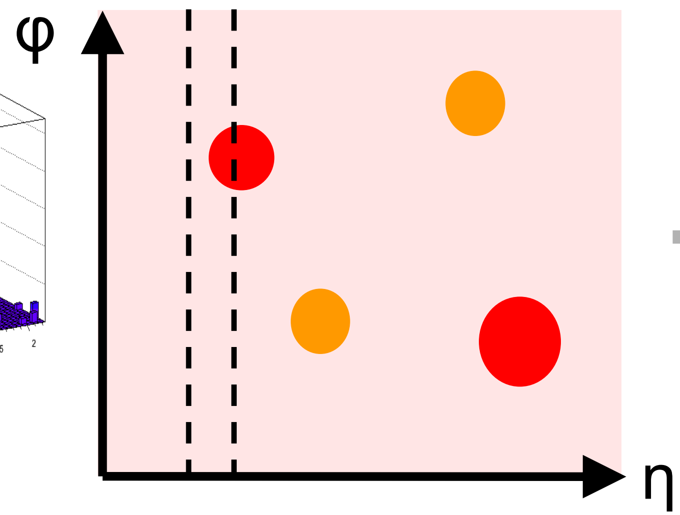


Dijet η shifts toward positive direction vs HF energy

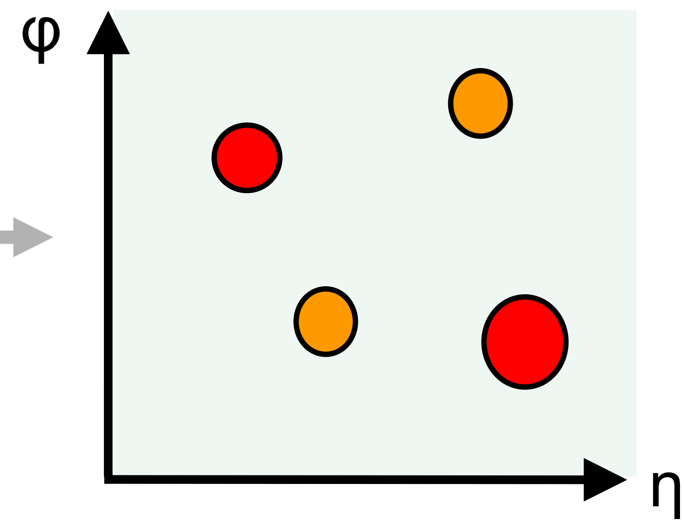
Dijet η gaussian widths become narrower vs HF

Background Subtraction

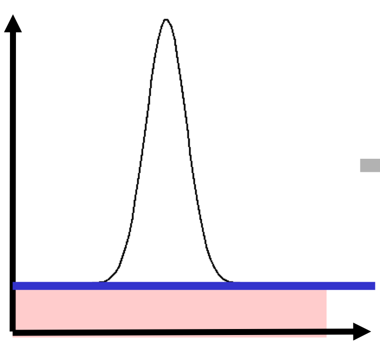




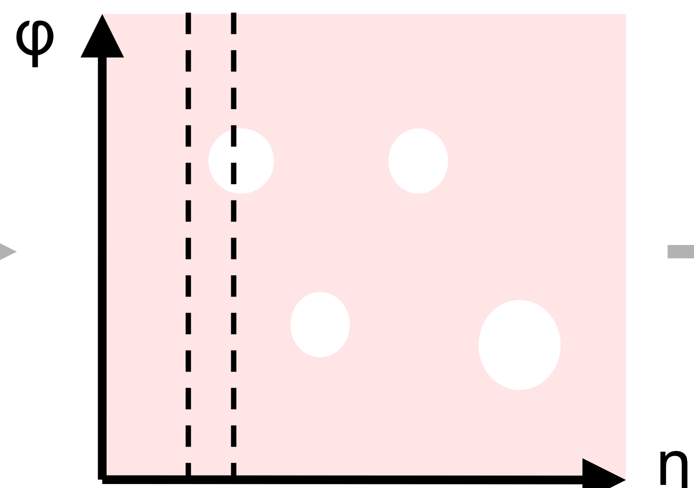
1. Background energy per tower calculated in strips of η. Pedestal subtraction



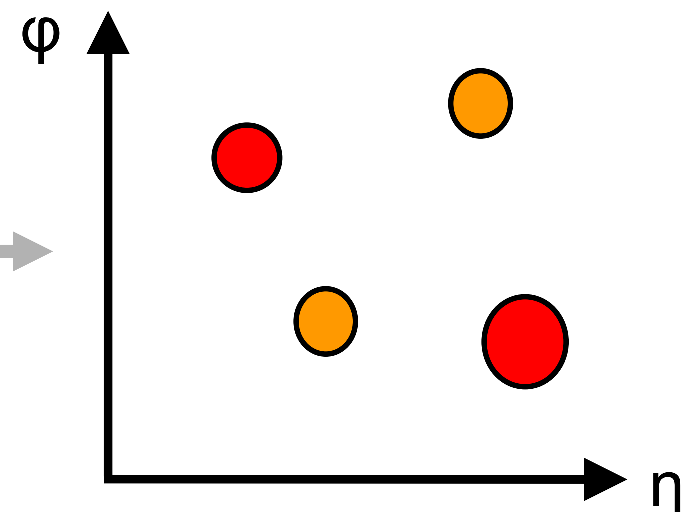
2. Run anti k_T algorithm on background subtracted towers



Background level

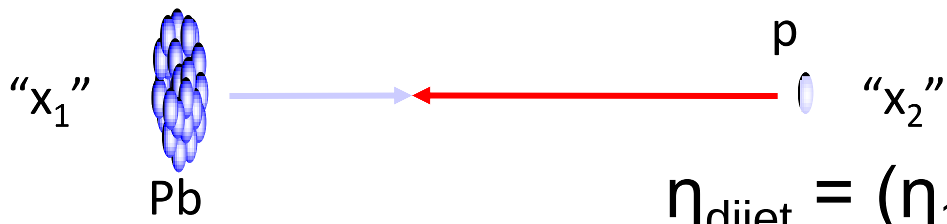


3. Exclude reconstructed jets
Recalculate the background energy

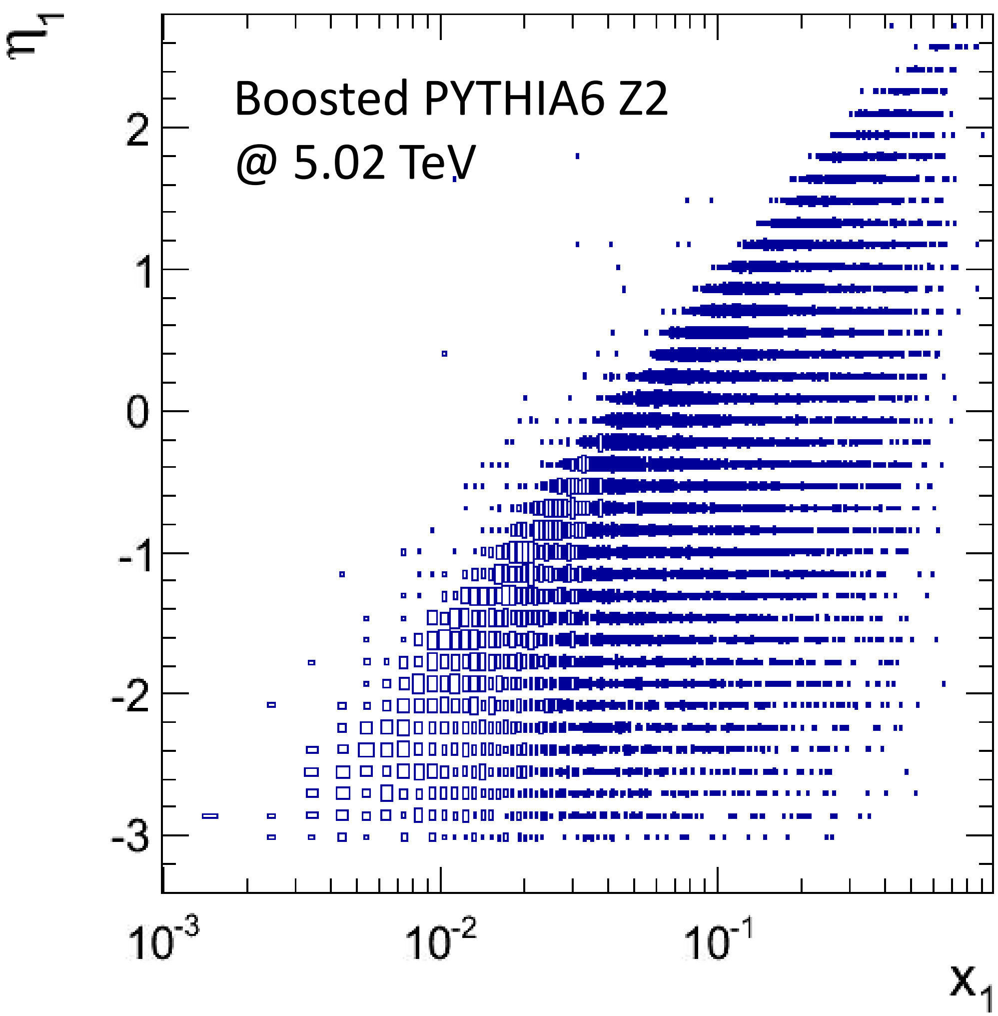


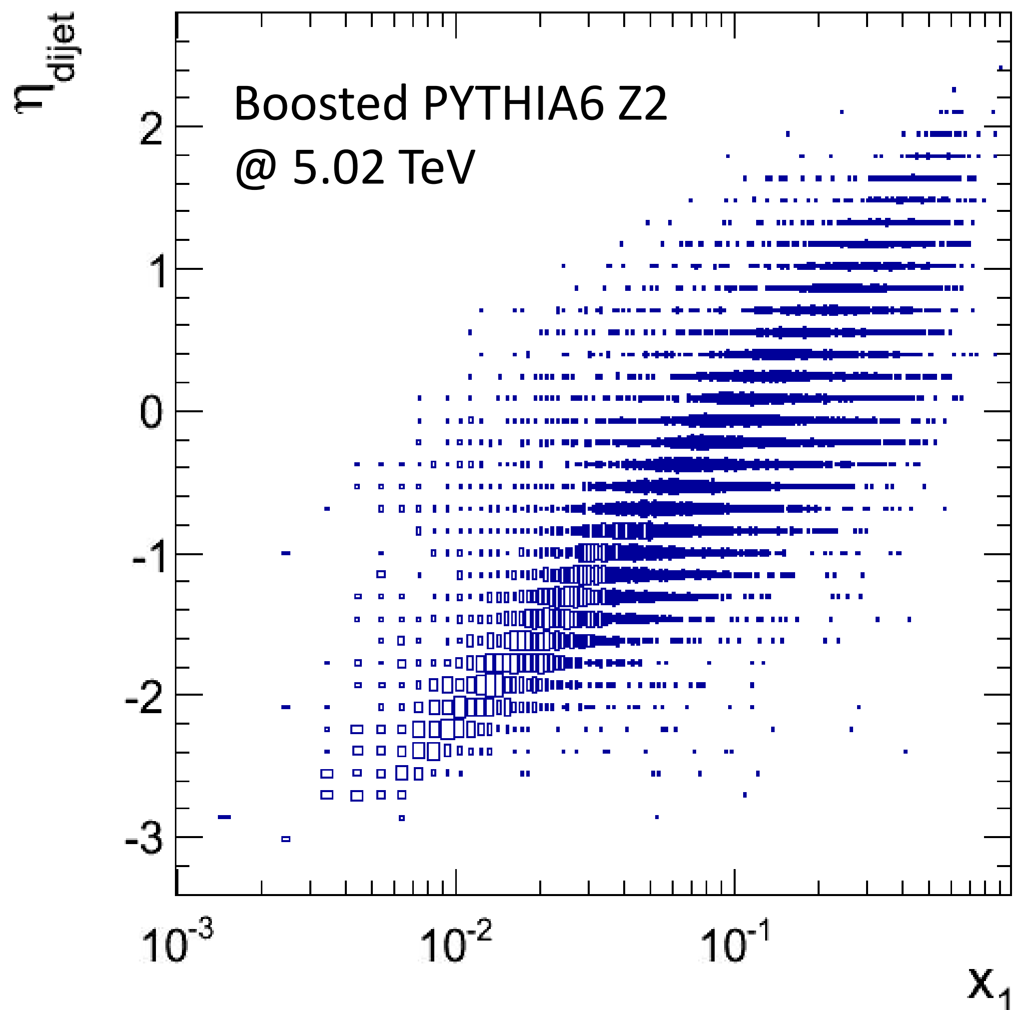
4. Run anti k_T algorithm on background subtracted towers to get final jets

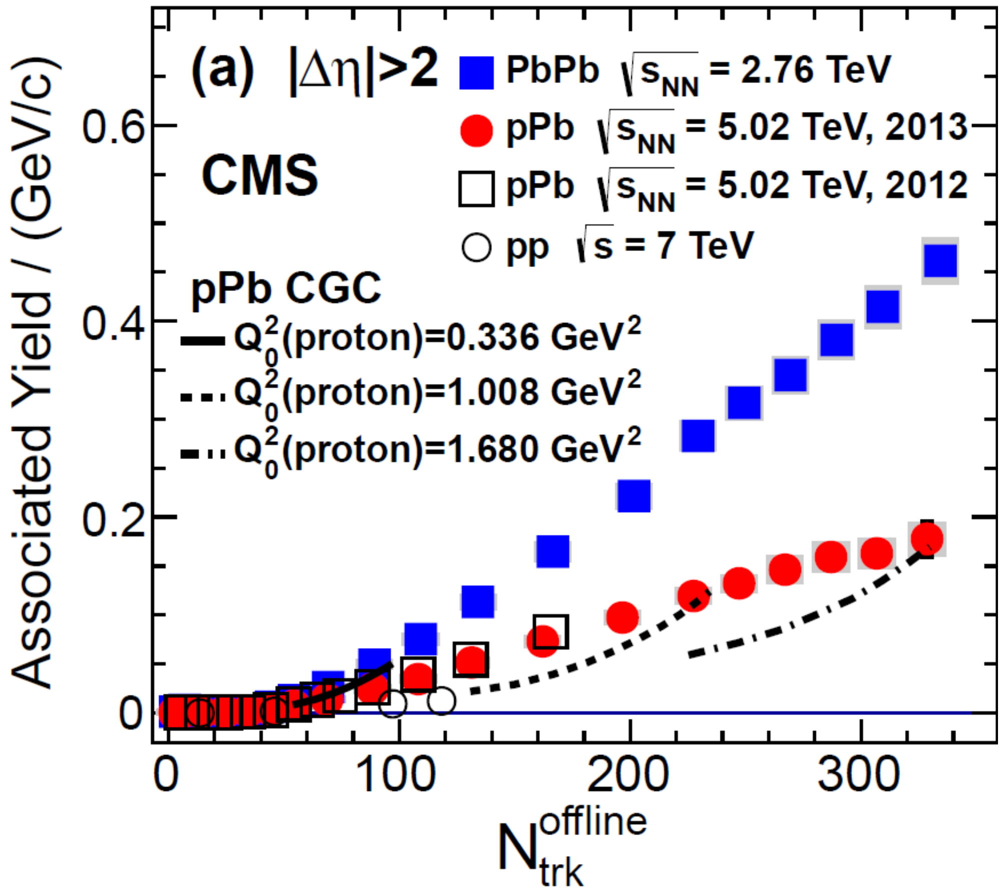
Mapping



$$\eta_{dijet} = (\eta_1 + \eta_2)/2$$







(a) |Δη|>2
CMS
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
pPb $\sqrt{s_{NN}}$ = 5.02 TeV, 2013
pPb $\sqrt{s_{NN}}$ = 5.02 TeV, 2012
pp $\sqrt{s}$ = 7 TeV
pPb CGC
Q_0^2(proton)=0.336 GeV^2
Q_0^2(proton)=1.008 GeV^2
Q_0^2(proton)=1.680 GeV^2
Associated Yield / (GeV/c)
$N_{trk}^{offline}$