Dijet Measurements in pPb collisions

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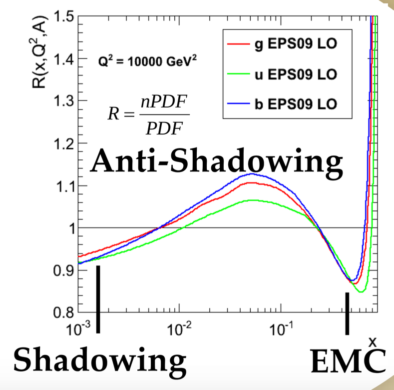
What were we looking for?

Is there jet quenching in pPb?

In pPb collisions flow like properties similar to that in PbPb collisions are observed.[1] In PbPb collisions flow was attributed to formation of QGP, a hot and dense medium where the color deconfinement occurs. Another phenomenon that takes place due to the existence of QGP in PbPb is jet quenching, partons losing their energy as they pass through the plasma. This raises the question whether any final state effects can be observed with jets in pPb collisions.

Nuclear PDF Modifications

The distribution of longitudinal momentum carried by each parton that make up the nucleons in Pb is modified due to interactions with other nucleons surrounding it. This modification has recently been calculated as a function of the position of the nucleons in Pb, using A-dependence of nPDFs.[2]

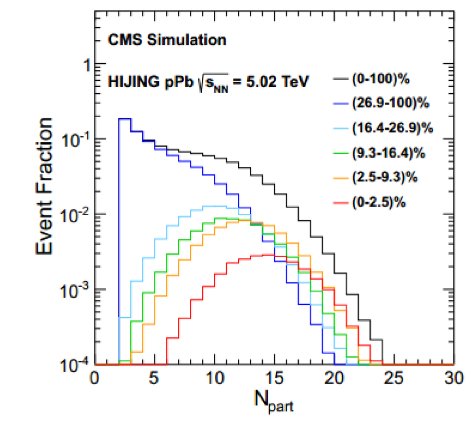


Centrality & Event Classes

If QGP was be formed in pPb collisions, it would most likely form when the number of participant nucleons, N_{part} is large. Therefore we need to choose events with large N_{part}, with the terminology of PbPb collisions this means the most central events. Also, the measurement of impact parameter dependent nPDFs requires a handle on the collision centrality. However, the terminology and the methods used in centrality classification in PbPb collisions are not directly applicable to pPb collisions. This is because of the loose correlation between the final experimental observables and the event geometry.

$E_T^{HF[\|\eta\|>4]}$ range (GeV)	Fraction of DS events	Fraction of dijet events
0-20	73.1%	52.6%
20-25	10.5%	16.8%
25-30	7.1%	12.7%
30-40	6.8%	13.0%
40-100	2.5%	4.9%

Event classes determined according to the forward activity in the event are given in the table above. Corresponding N_{part} distributions for each bin from HIJING simulation are shown in the figure on the right.[3]



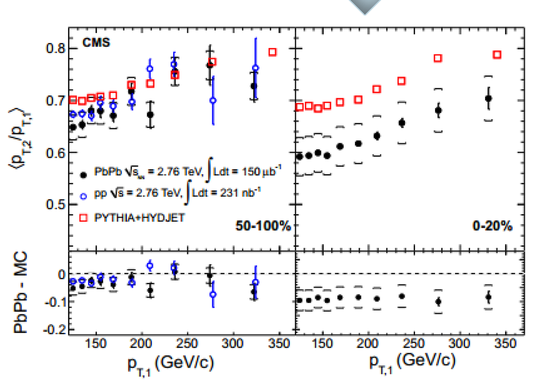
Results

Final state effects

Dijet transverse momentum ratios & azimuthal correlations

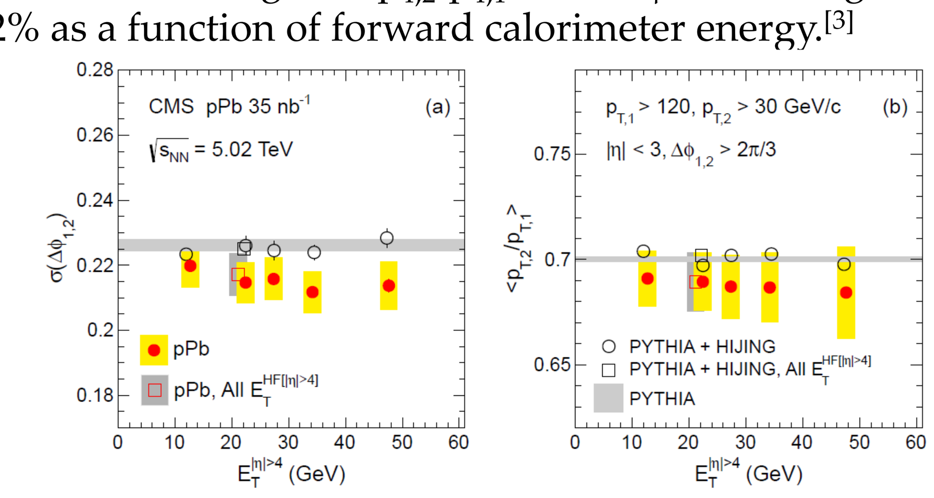
PbPb

Jet quenching is observed as decreasing dijet p_T ratio at more central collisions (10% effect).[5]



pPb

With the current systematic uncertainty, there is no detectable change in $<p_{T,2}/p_{T,1}>$ and $\Delta\phi$ width larger than 2% as a function of forward calorimeter energy.[3]



The values of $<p_{T,2}/p_{T,1}>$ are smaller than MC simulation, but this difference is due to the better jet energy resolution in MC simulation compared to data.

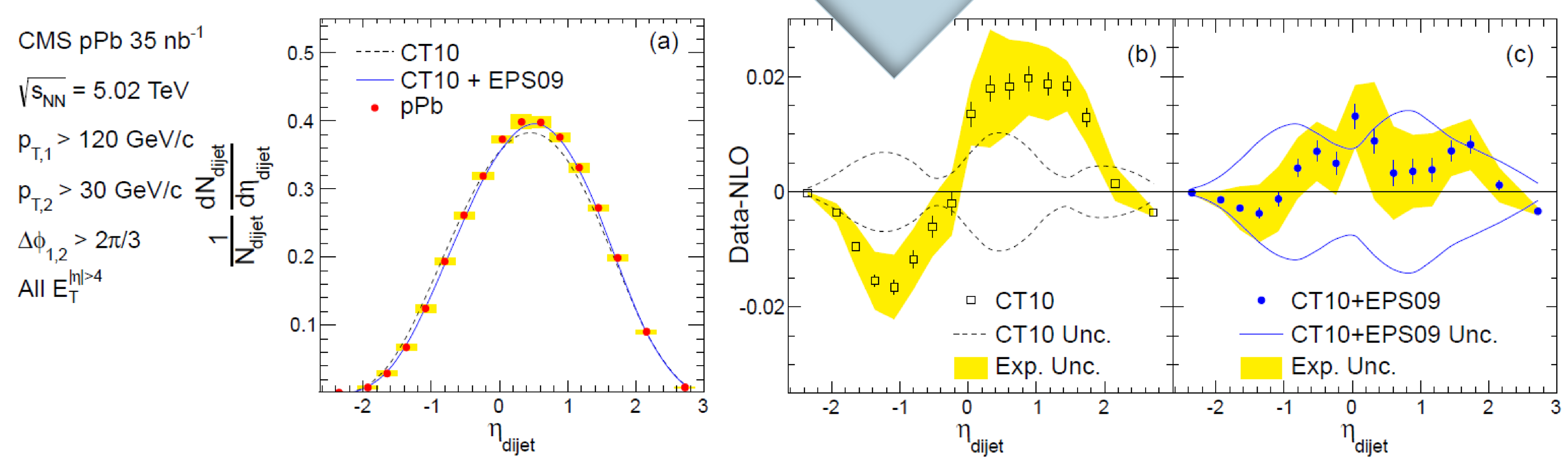
Initial state effects

Dijet pseudorapidity

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

Dijet pseudorapidity is correlated with the parton x of nucleons in Pb. To get possible values of x_{Pb} for a given η_{dijet} one has to integrate over the x_p. Approximately:

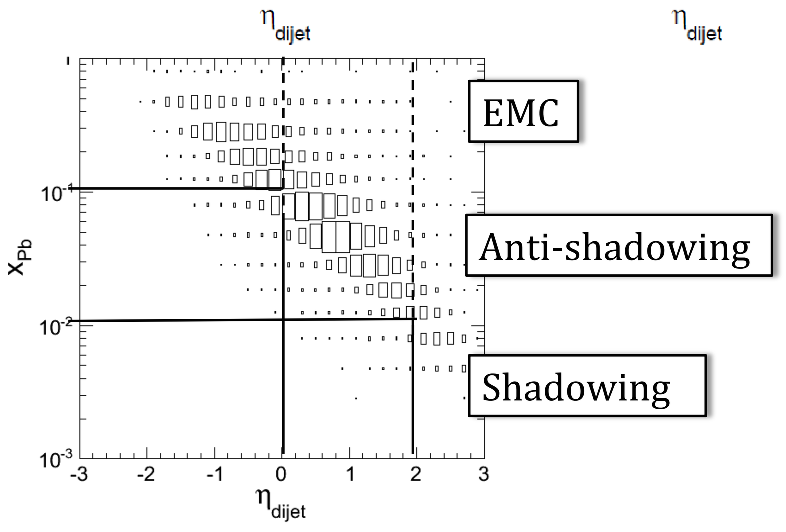
$\eta_{dijet} \approx \log(x_{Pb} / x_p)$.



Comparison to EPS09 nPDF Predictions

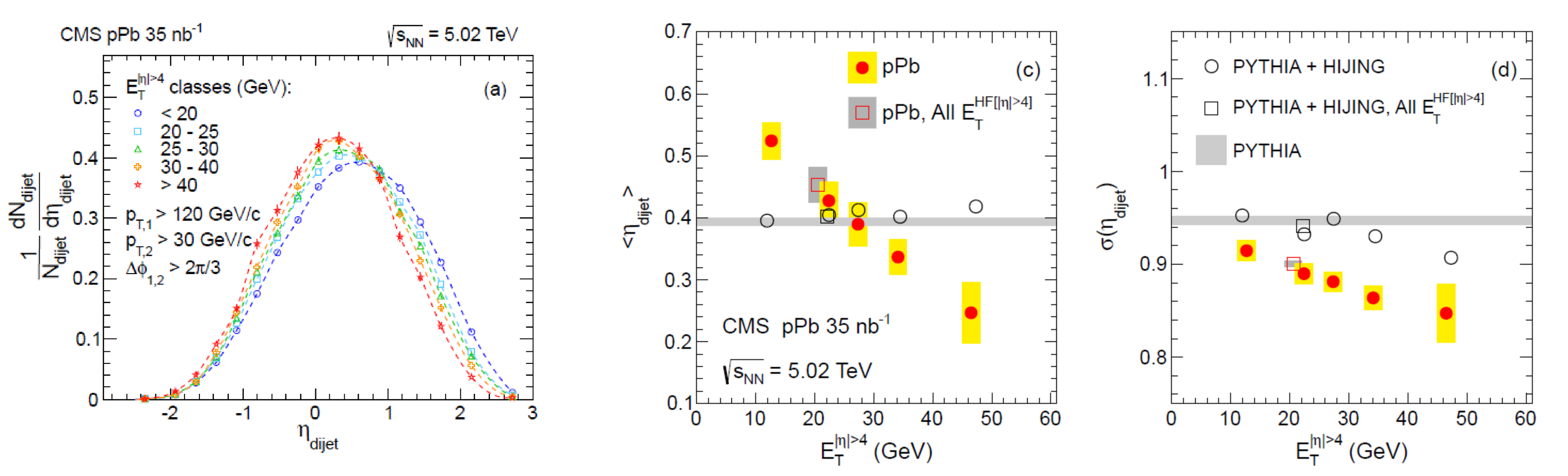
EPS09 collaboration calculated the modification in η_{dijet} distribution for the inclusive centrality measurement.[4] The η_{dijet} for CT10 with EPS09 modification is in better agreement with data compared to CT10 without any nuclear modification (top plot left panel).[3]

It is possible to see the agreement in mid-rapidities by looking at the difference of data and theory predictions. Discrepancy in anti-shadowing region < 2.5%, EMC region <5% and data has slightly larger. modification in anti-shadowing and EMC regions compared to CT10+EPS09. The theoretical and experimental uncertainties for the region $|\eta_{dijet}|$>2 it is not possible to make a conclusive statement.[3]



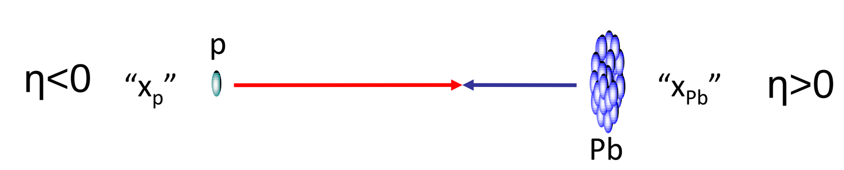
Forward Activity Dependence

Despite the very good agreement between data and predictions accounting the nuclear modification in PDF, if we look at the η_{dijet} distributions differential in forward activity, we see a large systematic shift in η_{dijet} towards the Pb going direction.[3] This shift cannot be explained by the impact parameter variation of nPDF, since any modification at this Q^2 and x is very small. With the dijet selection the kinematic reach of this analysis is Q^2 > 6000 GeV^2 and x>10^{-3} (calculated by Generator Level PYTHIA).



The distribution gets narrower as one goes to larger forward activity events. This trend which is present in MC as well.

Some trials to explain the shift

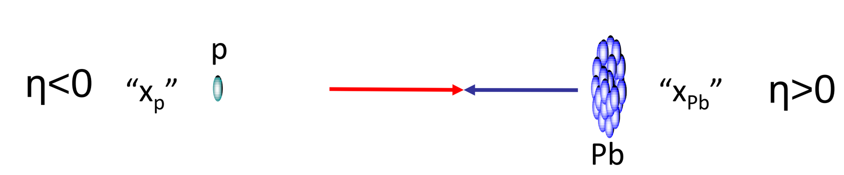


Going to large forward activity ($E_T^{HF[|eta|>4]}$)

- Reduces the energy of hard scattering $E_{JJ} = p_{T,1}\cosh(\eta_1) + p_{T,2}\cosh(\eta_2)$

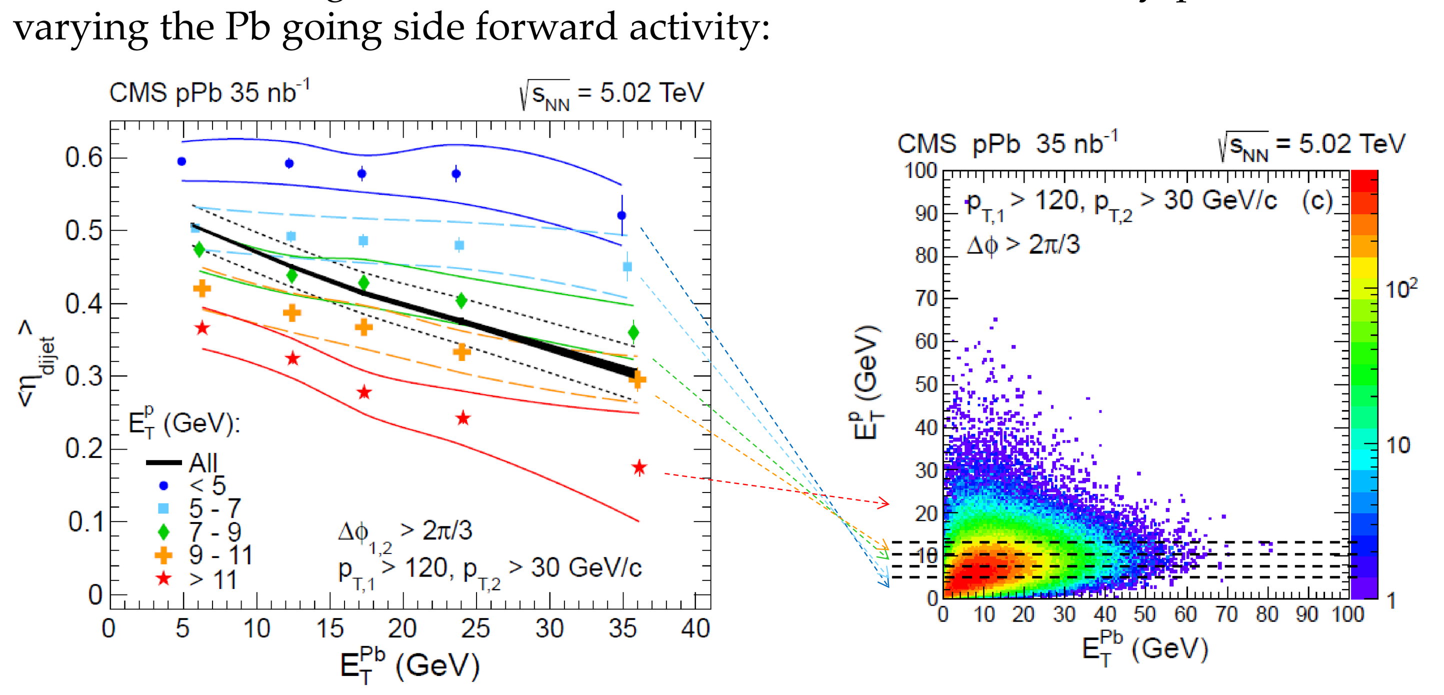
- Pb side energy ↑
- Initial state radiation from Pb nuclei ↑
- Cheap, N_{nuc} >>1

- p side energy ↑
- Initial state radiation from p ↑
- Costly, N_{nuc} =1,
- Shifts PDF of proton to lower x



As a result, ηdijet distribution shifts in the opposite direction of the p beam, and η_{dijet} distribution shifts gets squeezed in mid-rapidities.[6]

This explanation can be tested by fixing proton going side forward energy, therefore choosing events with similar initial state radiation by proton, and varying the Pb going side forward activity:



When the raw energy in the proton going side calorimeter is small, mean ηdijet is approximately constant, when we go to larger proton side activity bins we see that the ηdijet shift is still observed.[3]

What did we find?

No sign of jet quenching (yet?): We do not observe significant modification in p_T 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 events with total higher forward activity.
- The effect that causes the shift gets smaller when proton side forward activity is fixed and Pb side forward activity is varied.

References

[1] Ikka Helenius et al. *"Observation of long-range near-side angular correlations in proton-lead collisions at the LHC"* **PLB 718 (2013) 795**

[2] Ikka Helenius et al. *"Impact-parameter dependent nuclear parton distribution functions: EPS09s and EKS98s and their applications in nuclear hard processes"* **arxiv:1205.5359**, May 2012.

[3] **CMS PAS HIN-13-001. arxiv:1401.4433**

[4] Kari J Eskola et al. *"A perturbative QCD study of dijets in p+Pb collisions at the LHC"* **arxiv:1308.6733**, Aug 2013.

[5] S. Chatrchyan et al. [CMS Collaboration] *"Jet momentum dependence of jet quenching in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV"* **PLB 712 (2012) 176**

[6] Guilherme Milhano, Nestor Armesto. **Jet Workshop**, Paris May 2013