Latest CMS results on jets PbPb and pPb

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CMS Collaboration

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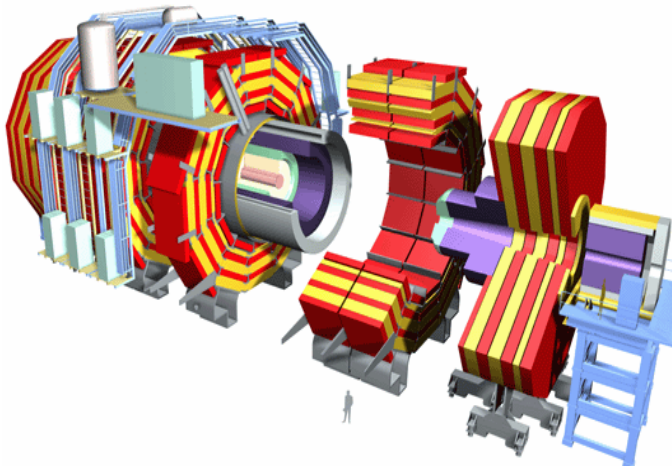
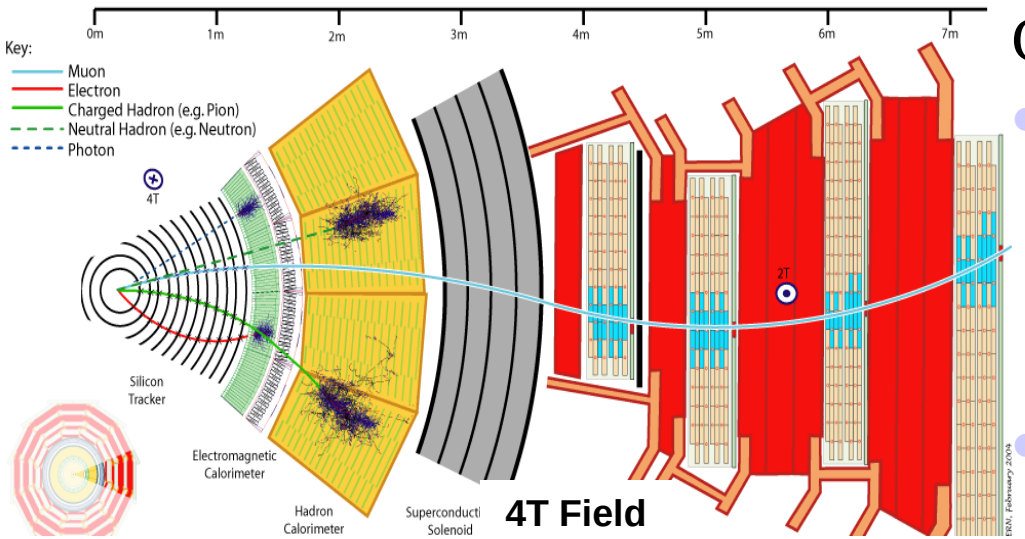
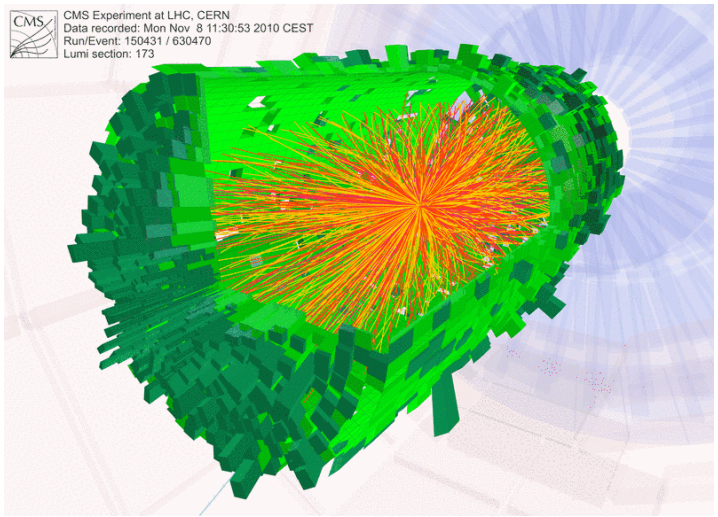


Outline

- Detector Capabilities and Data Samples
- Jets in Heavy Ion Collisions with CMS
  - R_{AA} zoo of jet quenching
  - Jet modifications: jets shapes and fragmentation
- Jets in Cold Nuclear Matter
  - Is there quenching?
  - Calibrating the reference
- Summary and Outlook

Detector Capabilities





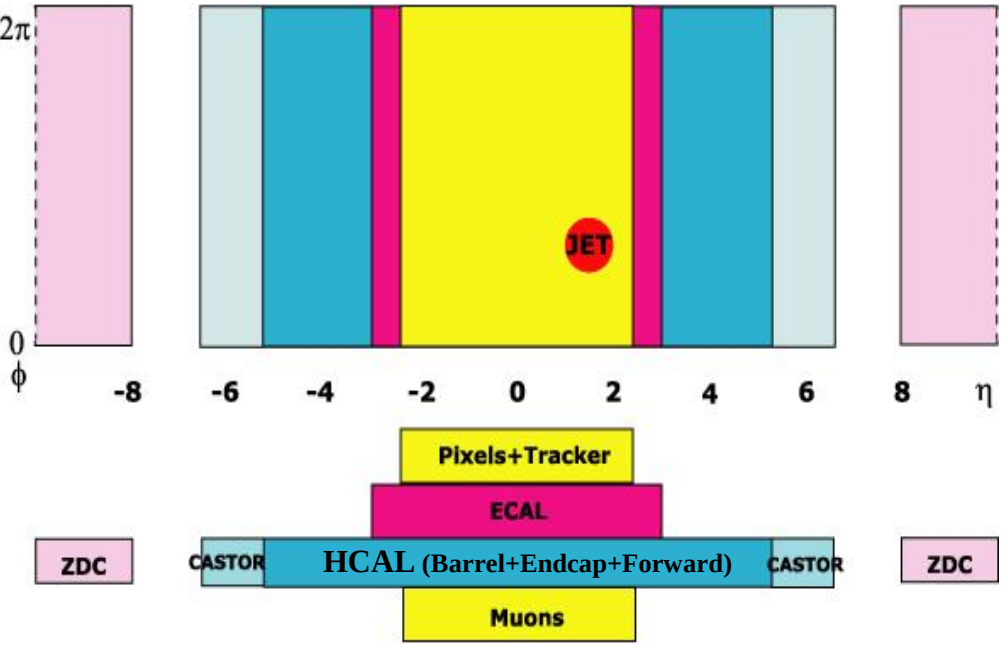
CMS is a multi-layer detector

- Excellent tracking capabilities
  - Momentum resolution of 1-2% to 100GeV/*c*
  - Displaced vertices for Heavy Flavor
- High-granularity calorimetry
  - Directly identifiable jets
  - γ-jet studies
- Unsurpassed muon capabilities
  - Separation of quarkonium states
- High Level Trigger
  - Higher energy reach
  - Ultra-central events
  - Improved J/ψ, Z^0, Υ

Data Samples

This talk's focus – jets @ mid-rapidity

- Large range hermetic coverage is essential for many CMS HI "signature results"

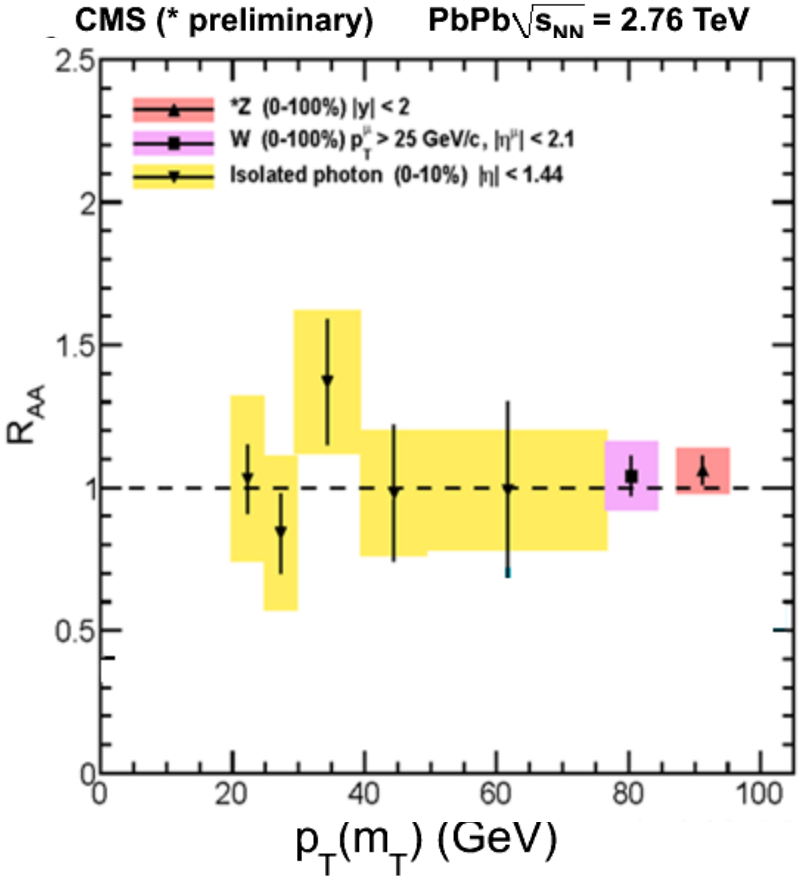


Silicon and μ Tracker	$\|\eta\| \leq 2.4$
ECAL	$\|\eta\| \leq 3$
HCAL	$\|\eta\| \leq 5.2$
ZDC	**Neutrals** $\|\eta\| \geq 8.3$

HI Data samples:

- $\sqrt{s_{NN}}$=2.76 TeV PbPb collisions
  - 1st Run – 2010
    L_{int} =13 μb^{-1}
  - 2nd Run – 2011
    L_{int} =150 μb^{-1}
- pp reference – 2013 $\sqrt{s_{NN}}$=2.76 TeV
  L_{int} =5.3 pb^{-1}
- pPb Run – 2012, 2013 $\sqrt{s_{NN}}$=5.02 TeV
  L_{int} =31 nb^{-1}

Binary Scaling and R_{AA}

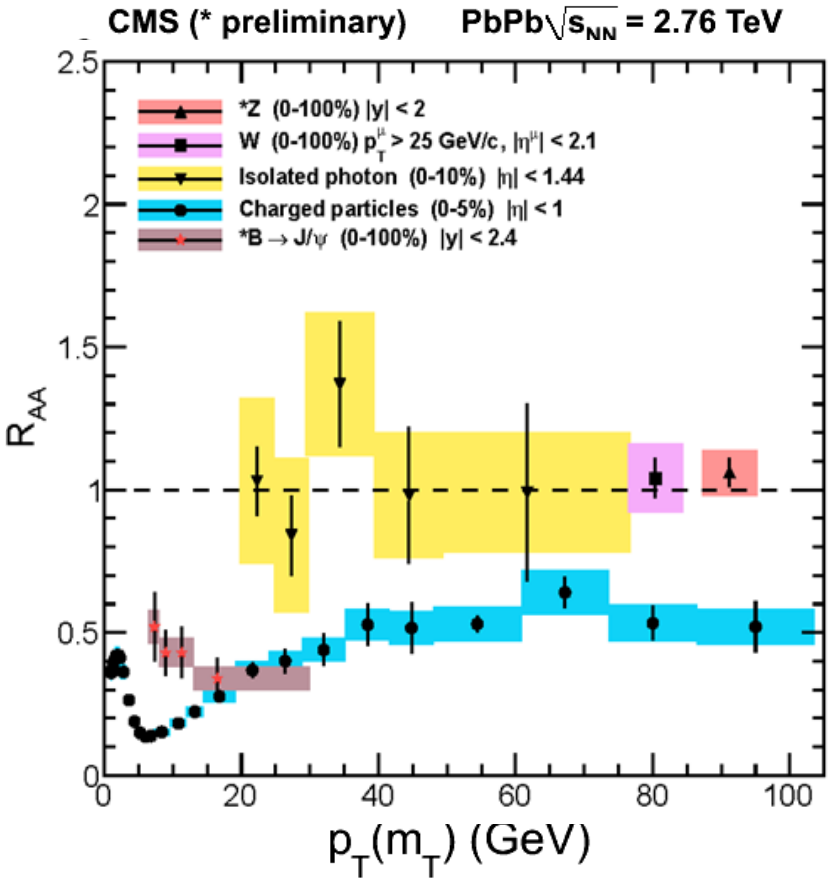


- R_{AA} – the first tool for jet quenching studies

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

- Colorless probes check N_{coll} scaling:
  - Isolated photons — PLB 710 (2012) 256
  - $Z^0 \rightarrow \mu^+\mu^-$ — CMS-PAS HIN-12-008
  - $W \rightarrow \mu\nu$ — PLB 715 (2012) 66

Jet Quenching



CMS-PAS HIN-12-014

HLT in Run 2011:

- Extended reach for charged hadron R_{AA}
- Observed p_T-independence of R_{AA} on $40 < p_T < 100$ GeV constrains the theory

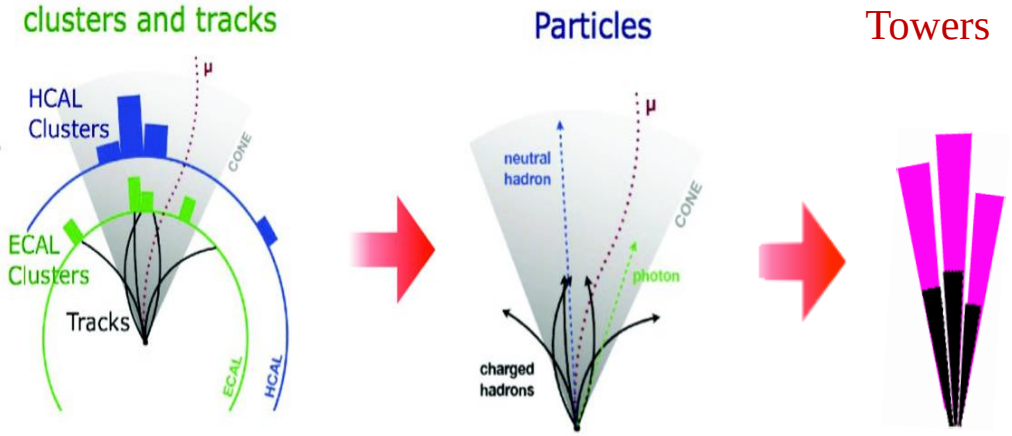
EPJC 72 (2012) 1945

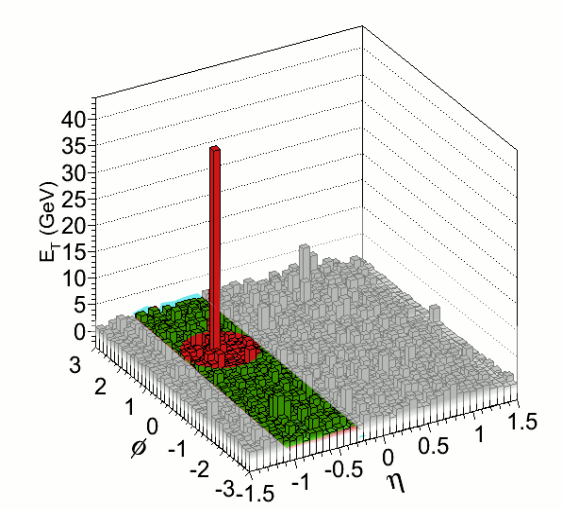
- First b-quark R_{AA} measurement in HI
  Displaced $J/\psi \rightarrow \mu\mu$
- Different suppression for b
  $6.5 < p_T < 30$ GeV

Jet Quenching with…Jets

Jet reconstruction in CMS:

- "Particle Flow" algorithm:
  - Ecal+Hcal+Tracks
  - Anti-k_T with R=0.3
  - Iterative BG subtraction



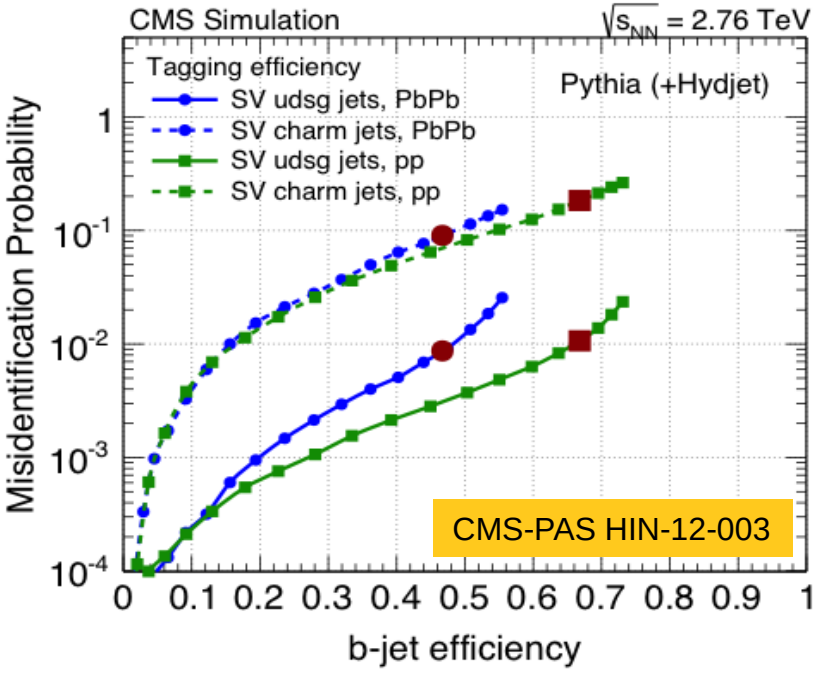


Jet studies in CMS:

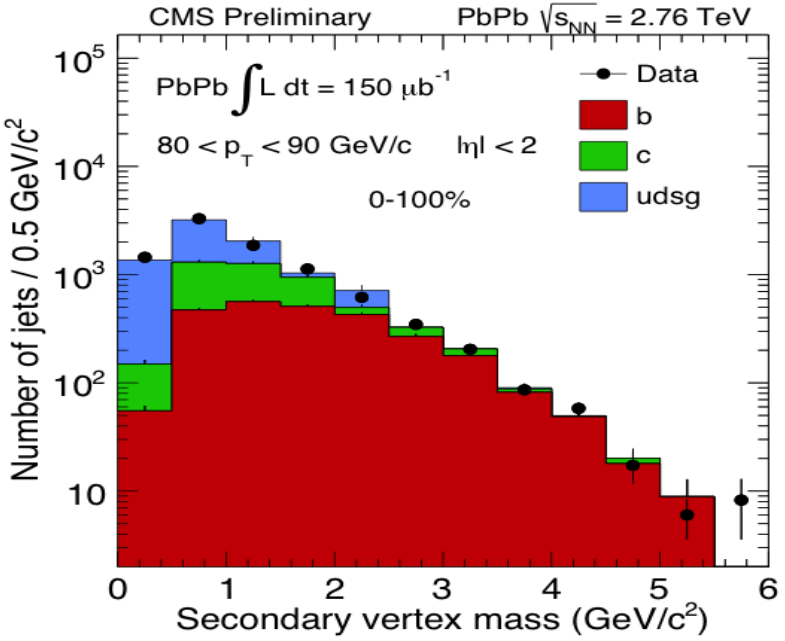
- R_{AA}
- Dijet correlations, energy (im)balance
- Fragmentation functions
- Jet shapes
- b-jets
- γ-jet correlations
- …

Jet b-tagging

- Lifetime τ^b~1.5 ps → decay vertex displacement [mm-cm]
- Secondary vertex position is used as a tagging variable
- Alternative tagger – track impact parameter – performance cross-check

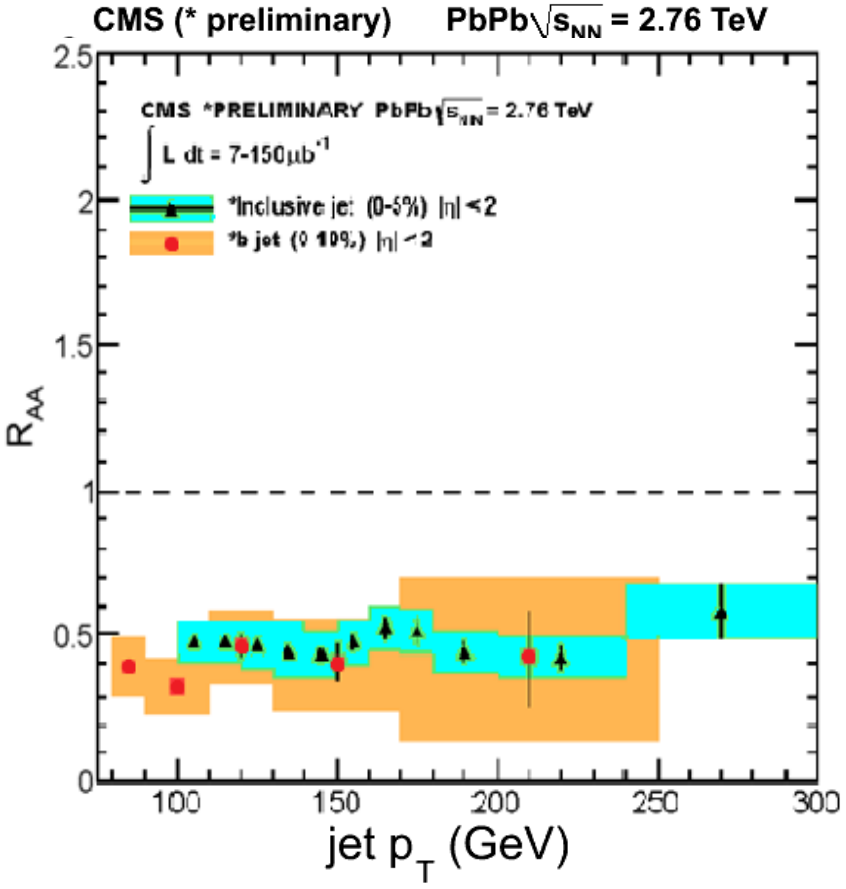


b-tagging efficiency ~45% for PbPb



b-tagging purity ~30% for PbPb

Jet Quenching via Jets



CMS-PAS HIN-12-003

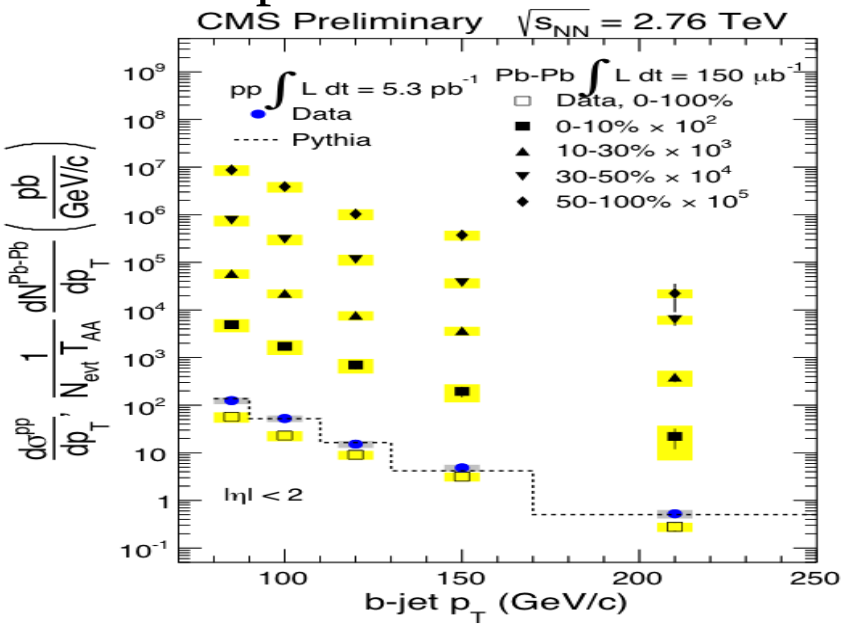
- Jet R_{AA}
  - 2011 – up to 300GeV
  - Strong suppression
  - No appreciable p_T dependence

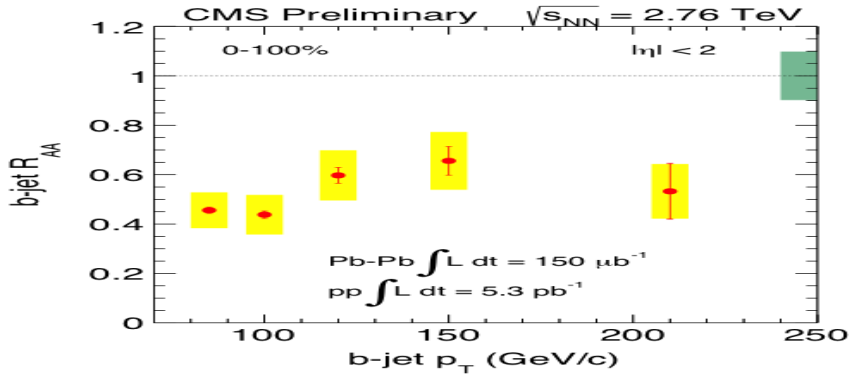
CMS-PAS HIN-12-004

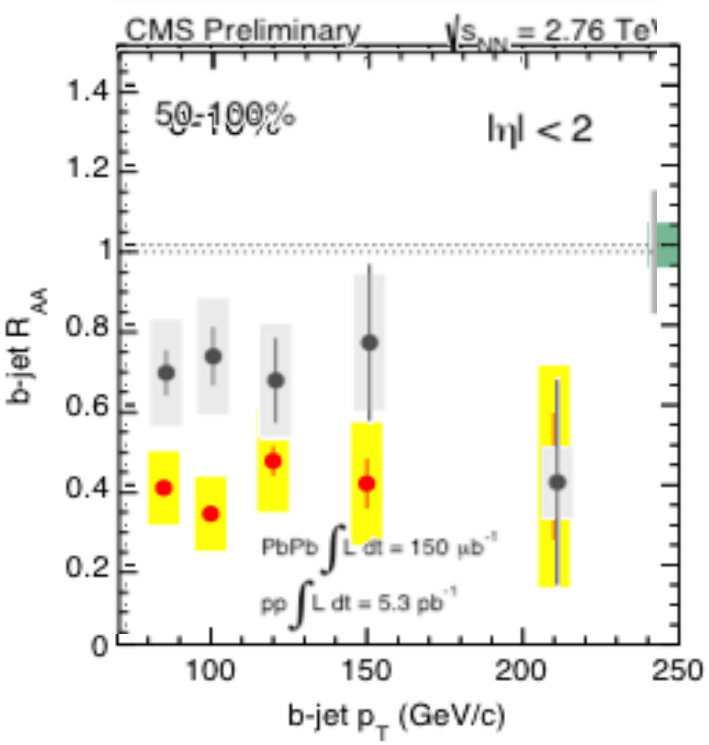
- First observation of b-jet suppression – QM-2012
  - Jet + high mass secondary vertex
  - Jet p_T> 80 GeV
  - New results on centrality and p_T dependence

Jet quenching with b-jets

- b-Jet Spectra

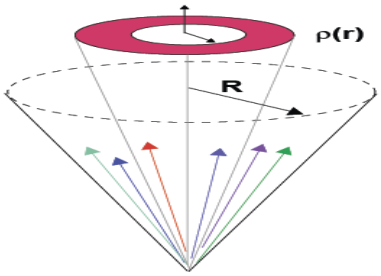






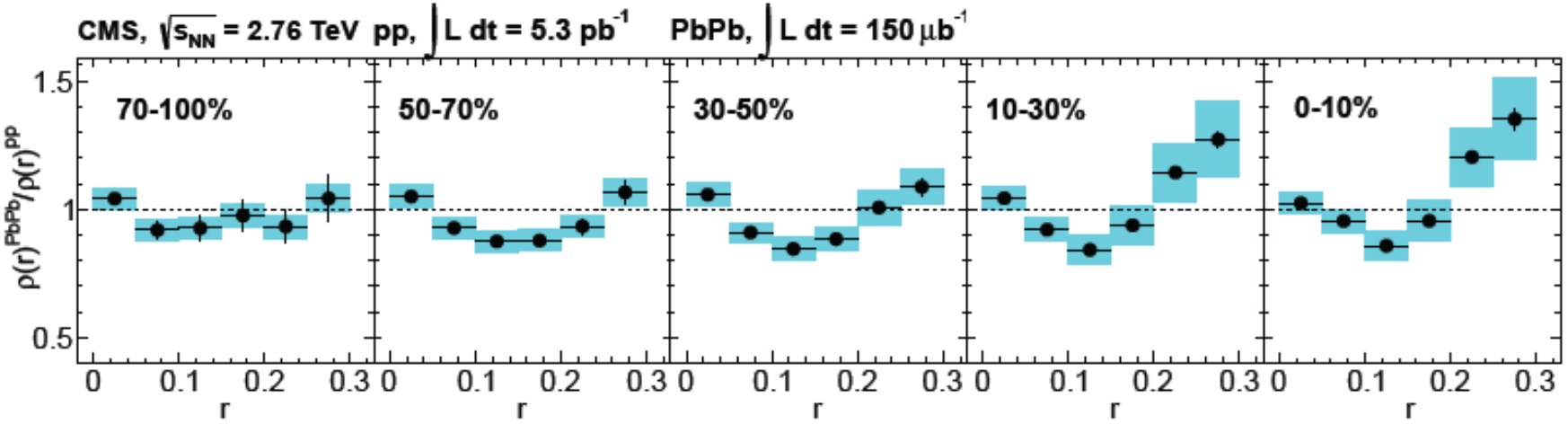
- b-jet suppression
  - Extends up to highest p_T studied
  - Increasing with centrality

Jet Modifications-I



Measuring fractional radial energy distribution (inclusive jets)

- Ratio of PbPb to pp differential jet shapes

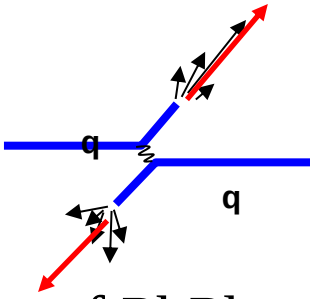


  - Little/no medium effects in peripheral events
  - Enhancement at large *r* in central collisions

Caution: large-*r* enhancement ≠ large-angle-only radiation

PLB 730 (2014) 243

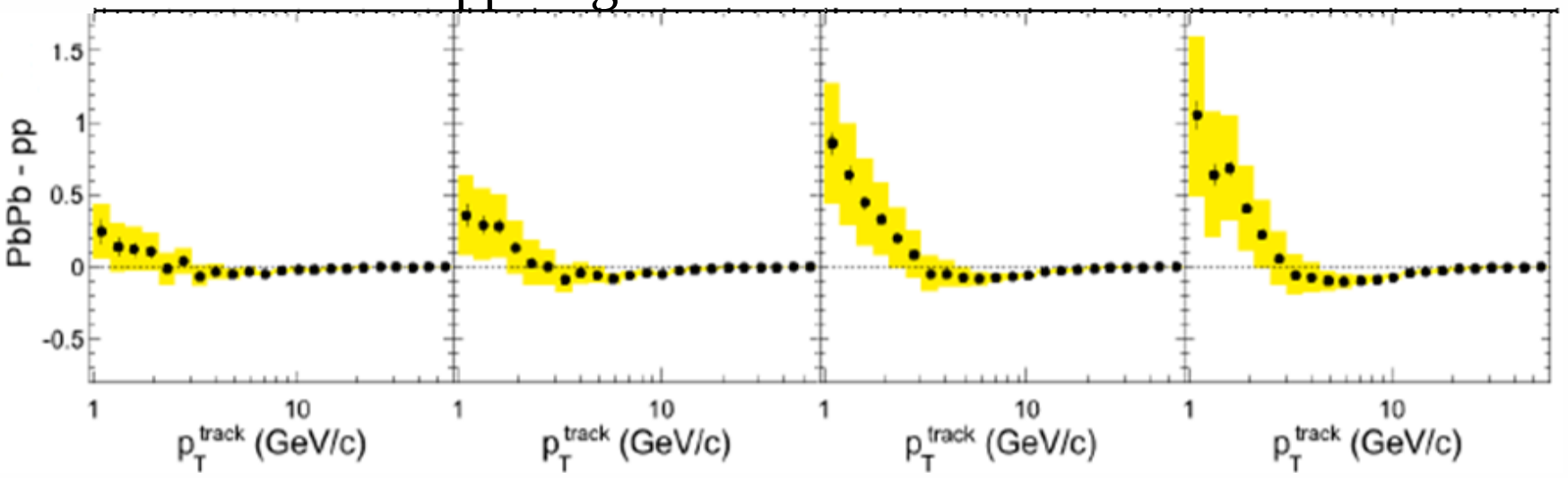
Jet Modifications-II



Measuring in-cone track moment distribution projected onto jet axis (inclusive jets)

$\xi=\ln(z)$, $z = p_{||}(\text{track})/p(\text{jet})$

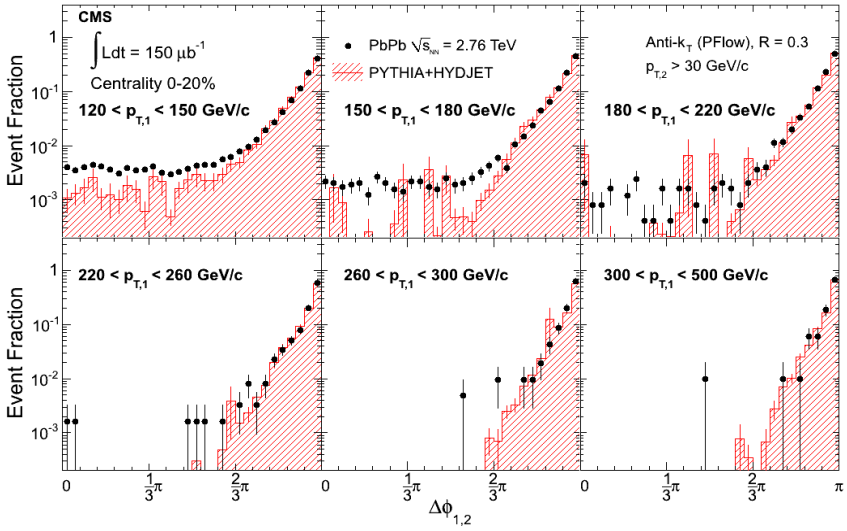
- Ratio of PbPb to pp fragmentation functions

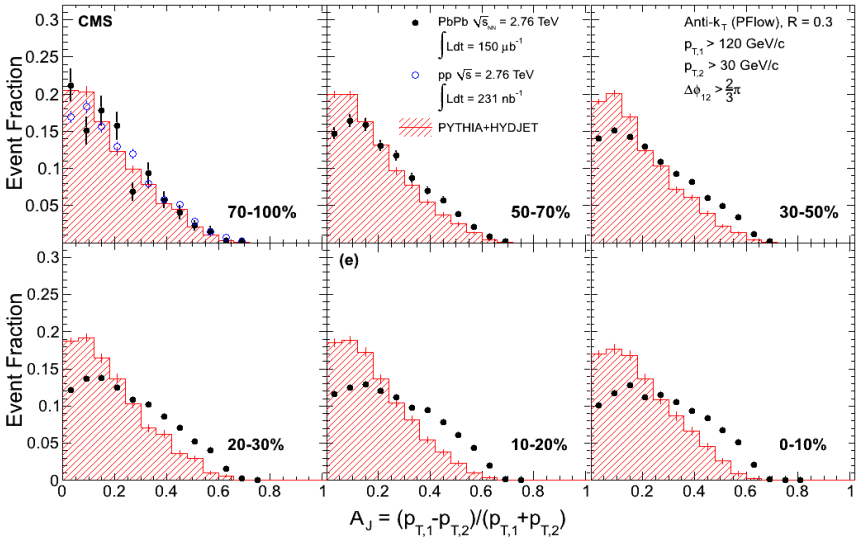


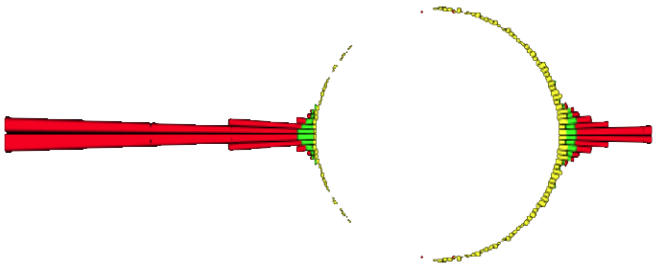
- Vacuum-like fragmentation in peripheral collisions
- Excess of soft hadron yields; most pronounced in central events

CMS-PAS HIN-12-013

Dijets in PbPb





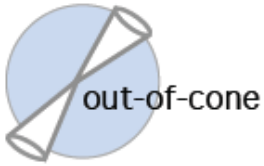


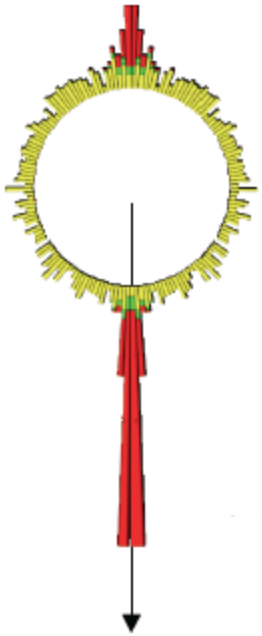
- Remain back-to-back
- Fraction of imbalanced dijets grows with collision centrality
- Larger differences at lower jet p_T

Dijet Energy Balance

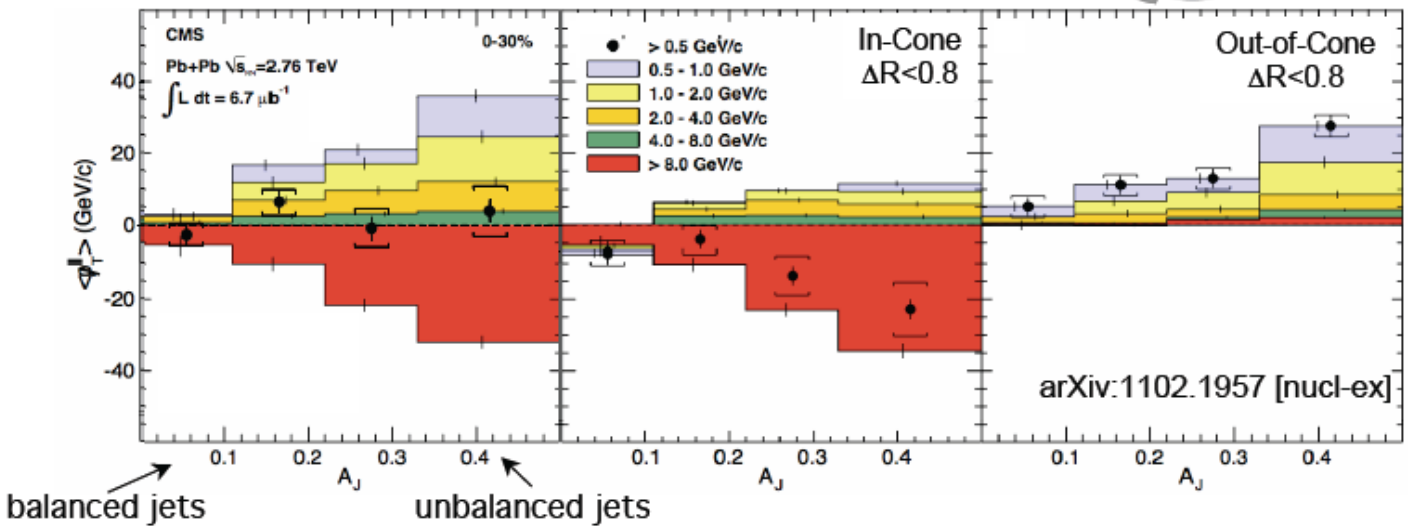
- Missing $p_T^{\parallel}$: $\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$

$$A_j = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$





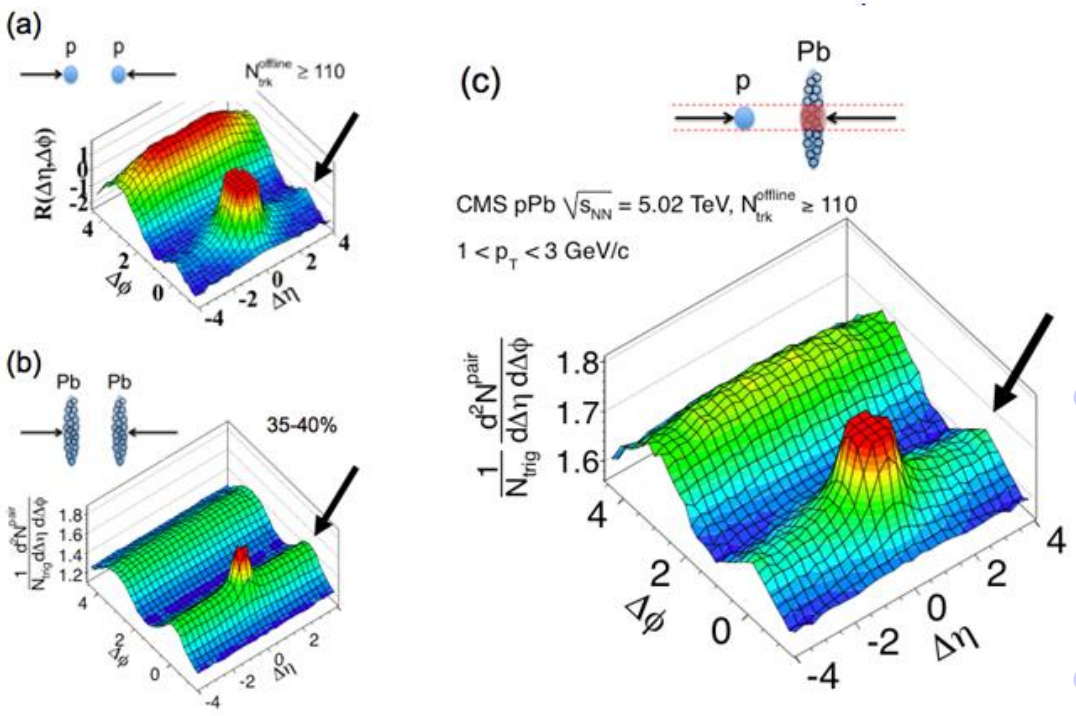
0-30% Central PbPb



- Momentum balance is preserved over the entire event
- "Missing" p_T in hard sector is balanced by soft hadrons away from jet-axis

(Out of) Control Samples

- Ridge, flow(?) harmonics in all systems…



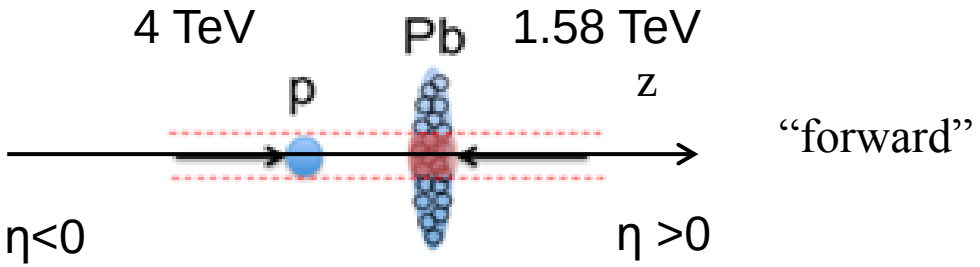
- 2010
  ridge discovered in pp,
  high multiplicity events
  JHEP 1009 (2010) 091
- 2012 Pilot pPb Run
  ridge in high multiplicity events
  PLB 718 (2013) 795
- 2013
  high order anisotropies
  PLB 724 (2013) 213

Multiplicity vs. Centrality

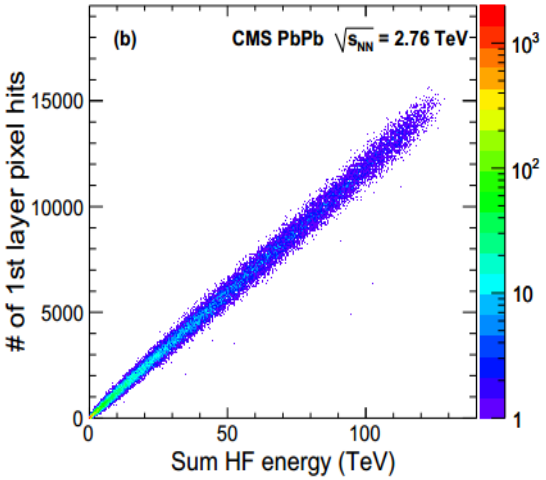
pPb Sample:

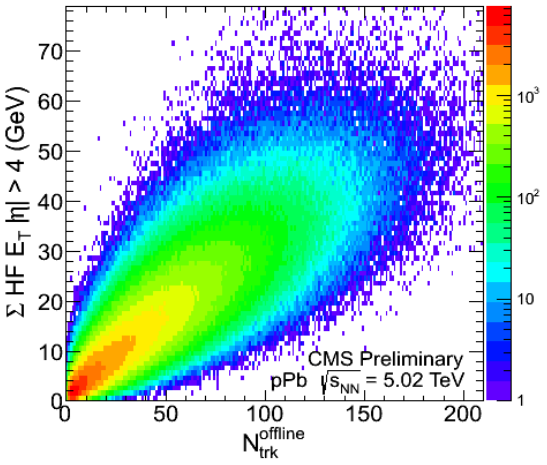
$\sqrt{s_{NN}}$=5.02 TeV

η_{cm}=0.465



- Event Selection
  - PbPb
  - pPb





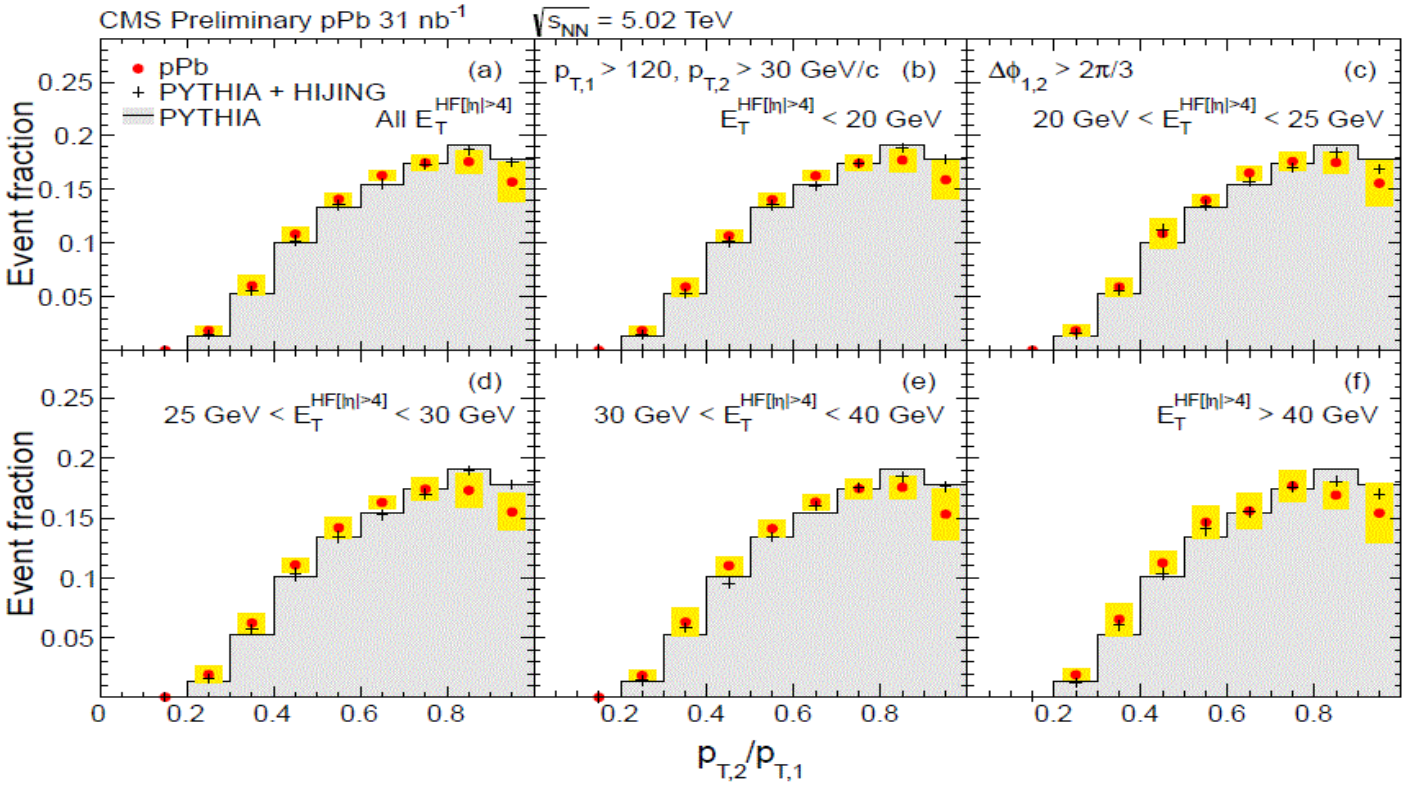
pPb minbias:
Double-**S**ided selection
one particle E>3 GeV in each
-5 < η< -3 & 3 < η < 5.

- Dijet selection biases up E_T^{HF} values

Dijets in pPb

CMS-PAS-HIN-13-001
arXiv:1401.4433

- Systematic studies of sub-leading to leading jet p_T ratios

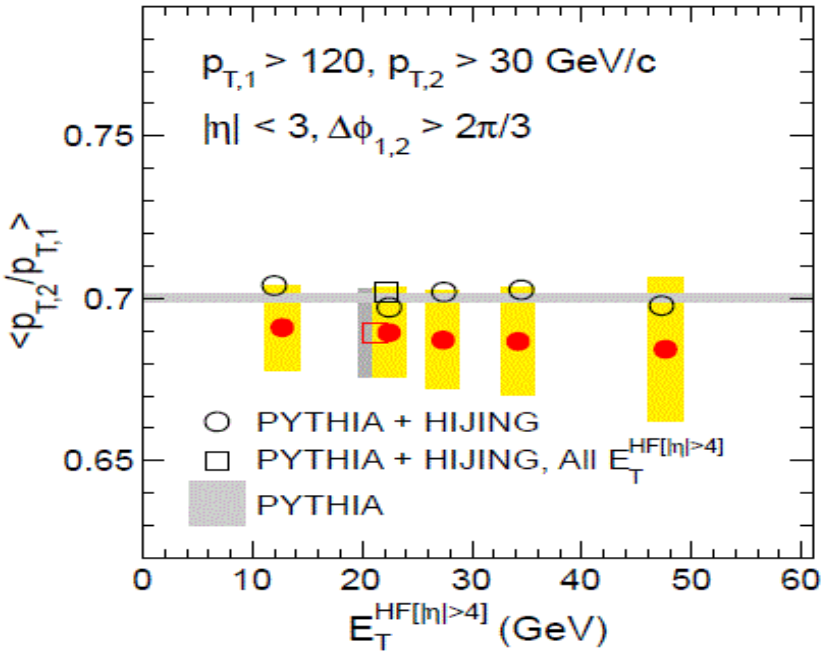


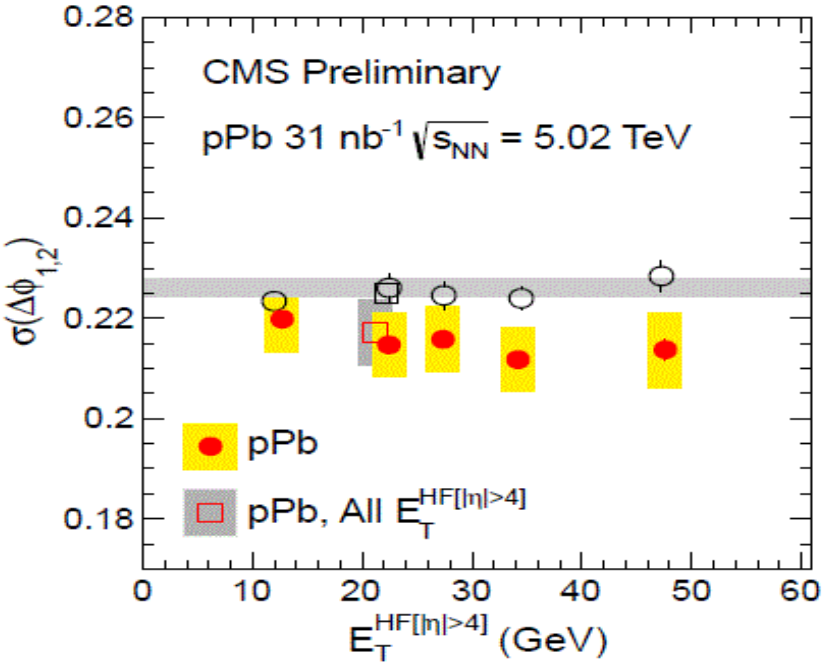
- Final state effects (if any) are less than 2%

Dijets in pPb

CMS-PAS-HIN-13-001
arXiv:1401.4433

- Forward activity dependence

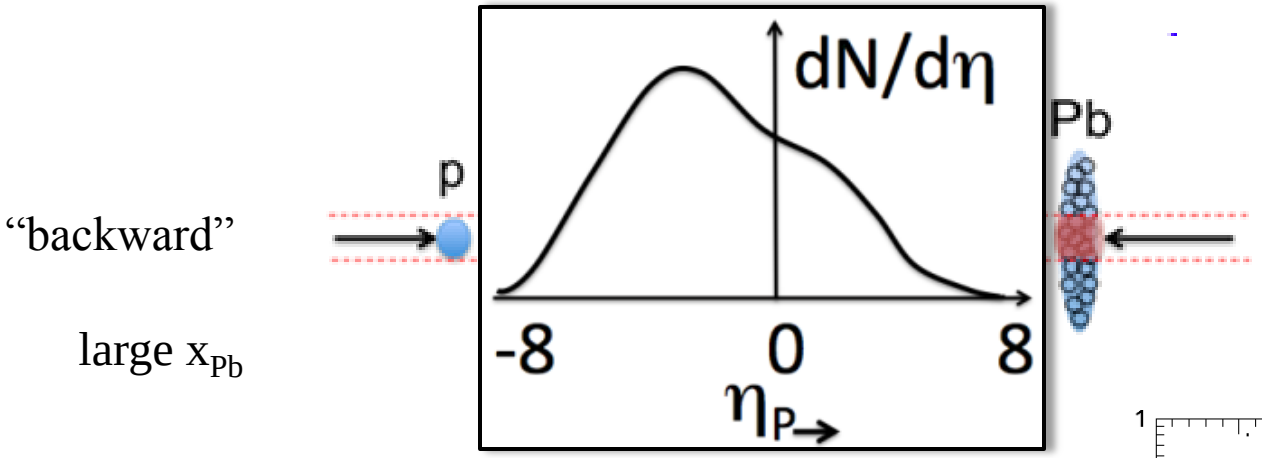


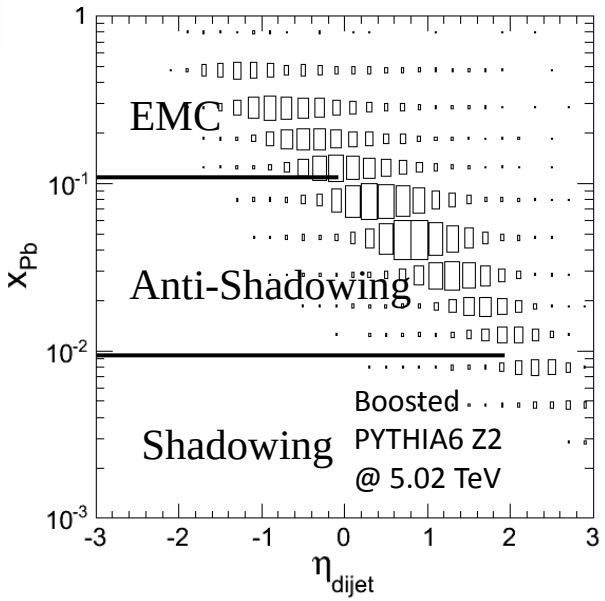


- No evidence for jet quenching:
  - No azimuthal decorrelation (but it was not there in PbPb at comparable event activity)
  - No momentum imbalance

Probing Initial State Effects

- Collision Kinematics



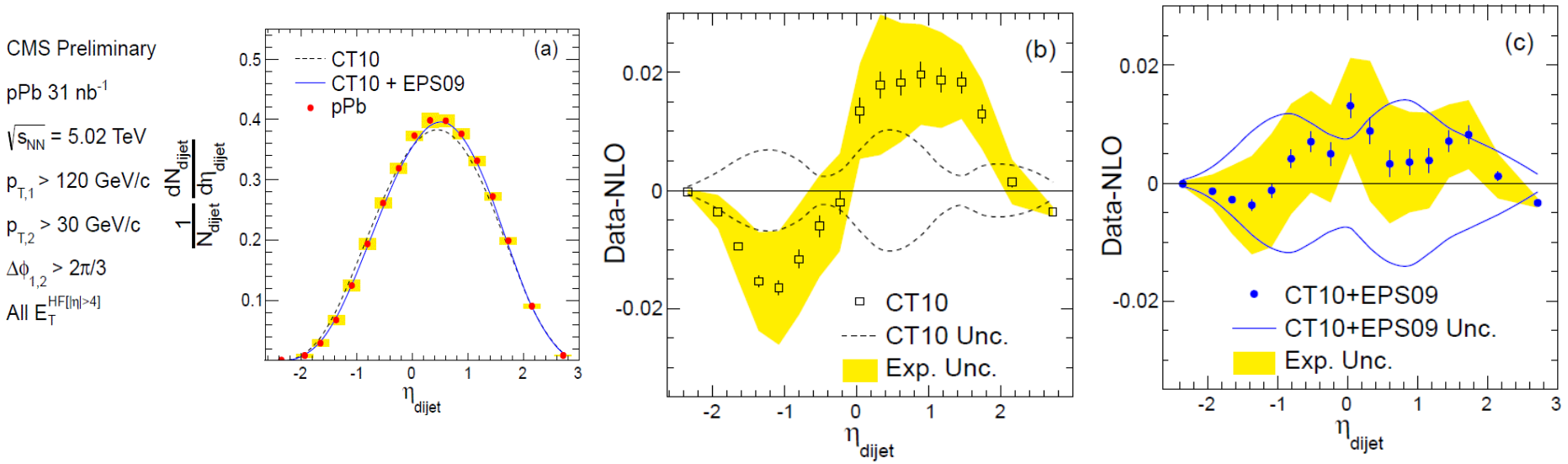


- Dijet η distribution correlated with x_{Pb}
- Measure forward activity dependence of dijet pseudorapidity:

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

Model predictions

- Comparison with EPS09 Escola,Paukkunen,Salgado, arxiv:1308.6733

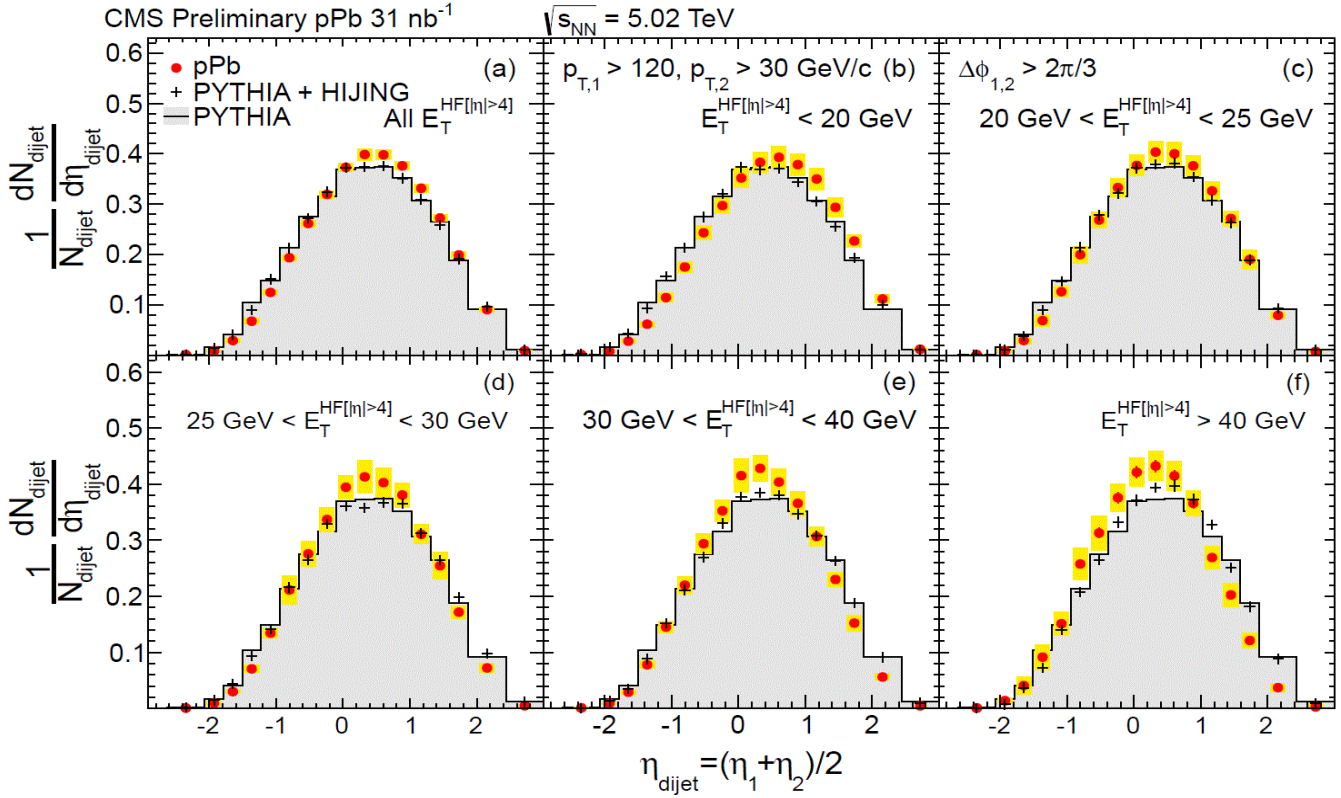


- Large discrepancies between the measured dijet η distribution and CT10 proton PDF
  - Signs of EMC, anti-shadowing and shadowing effects
- Data are consistent with EPS09 nPDF predictions

CMS-PAS-HIN-13-001
arXiv:1401.4433

Dijet η distribution

- Dijet pseudorapidity distribution

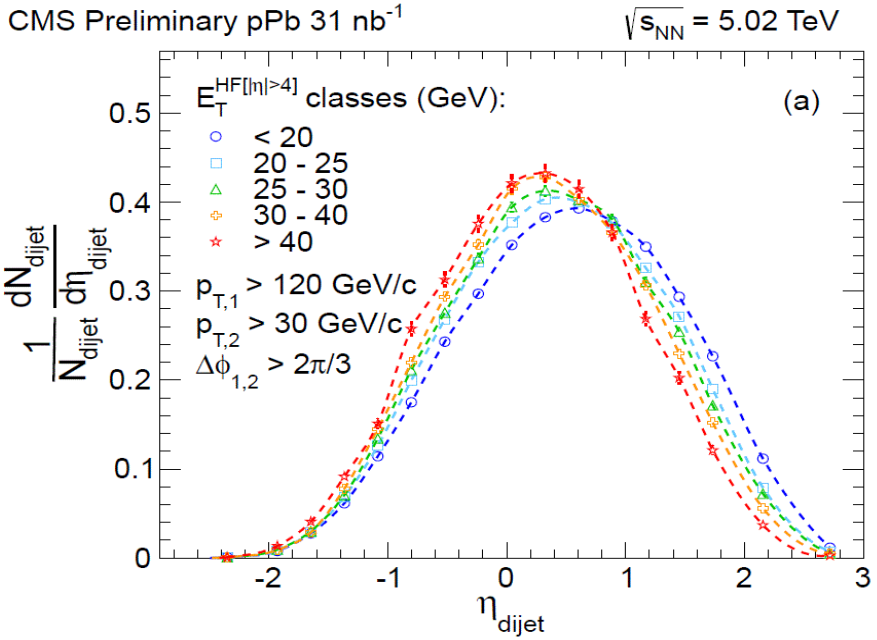


- Dijet pseudorapidity shift towards Pb-going side

CMS-PAS-HIN-13-001
arXiv:1401.4433

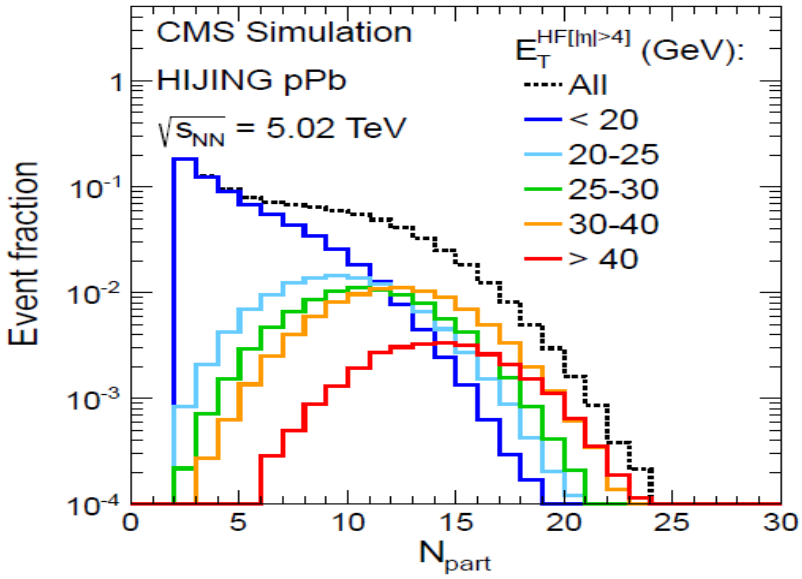
η_{dijet} Shift

η_{dijet} vs. Forward Activity



Significant shift

N_{part} vs. Forward Activity



Little changes

- Not likely to be driven by impact parameter dependence of nPDF

CMS-PAS-HIN-13-001
arXiv:1401.4433

Summary

PbPb

2011 HI Run fully profited from HLT capabilities, improving CMS physics reach

- Updated results of Jet quenching in a variety of measurements
  - Non-suppression of colorless probes
  - Strong suppression for charge hadrons up to 100 GeV/c & jets to 300 GeV
  - Medium-induced modification of jet shapes and fragmentation
  - b-jet suppression similar to light-flavor jets

pPb

2012/2013 pPb data provide new reference for cold nuclear matter studies

- Ridge/ high-order azimuthal anisotropies
- No jet quenching/suppression in pPb data
- Modification of nPDF; needs further work constraining these modifications