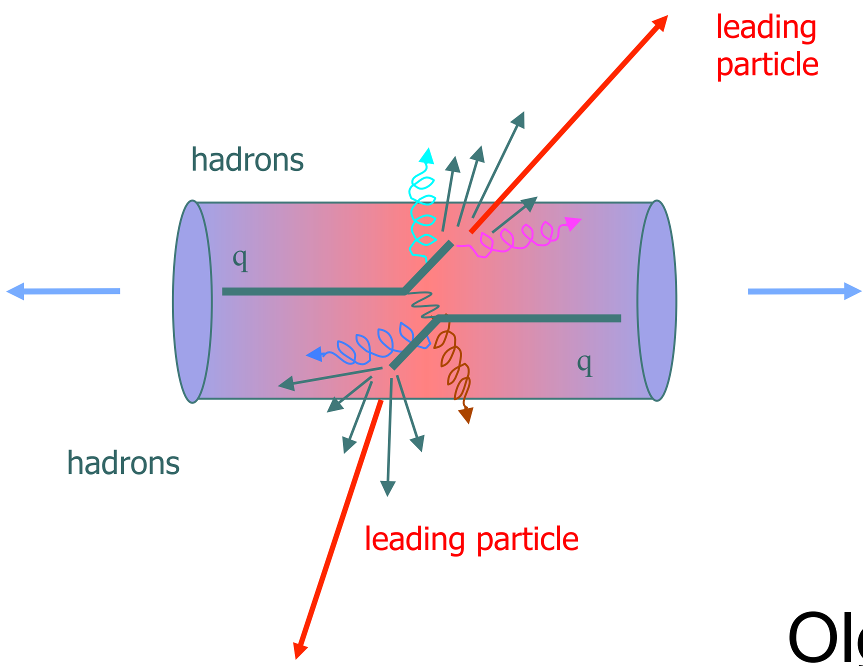
Studies of Jest in QGP Medium with CMS



- Heavy Ion Collisions
- Tomographic medium studies
- Jet quenching – what do we know about it?
- Jet-track correlations for jet studies in QGP

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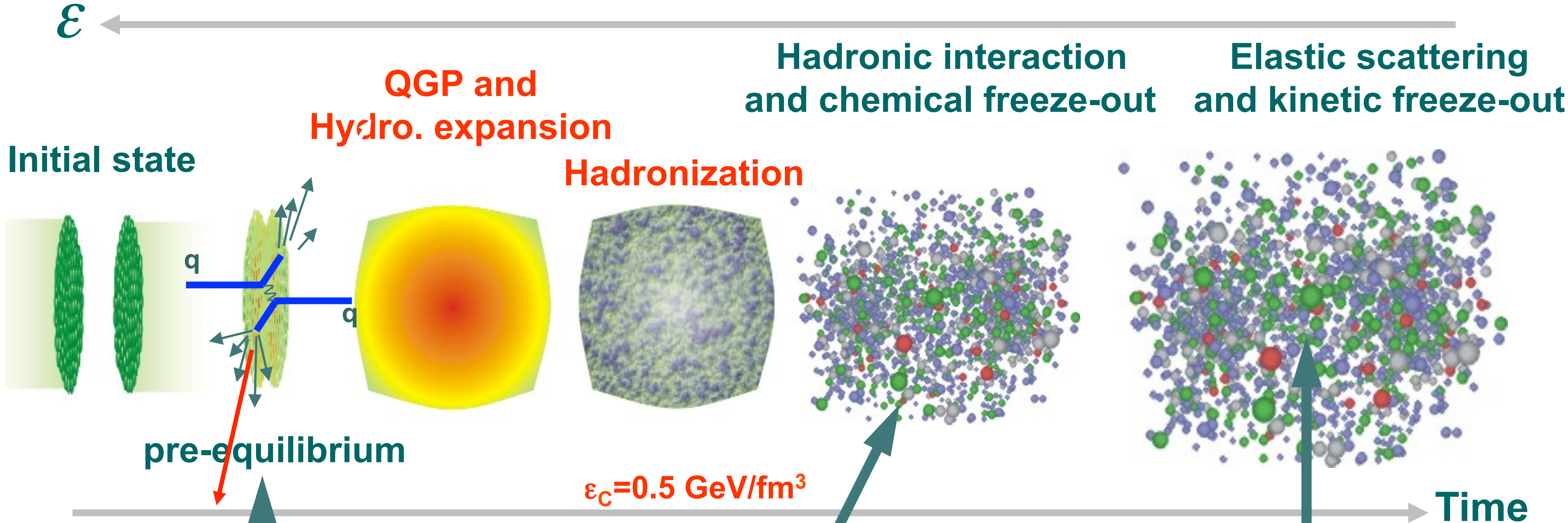
University of Illinois at Chicago

Collision Evolution



99.9% of total yield

Bulk particle distributions

QGP hadronizes in soft hadrons

99.9% of total yield

Source tomography

early state hard scattering-->**jets**

System hadro-chemistry

equilibrium probes

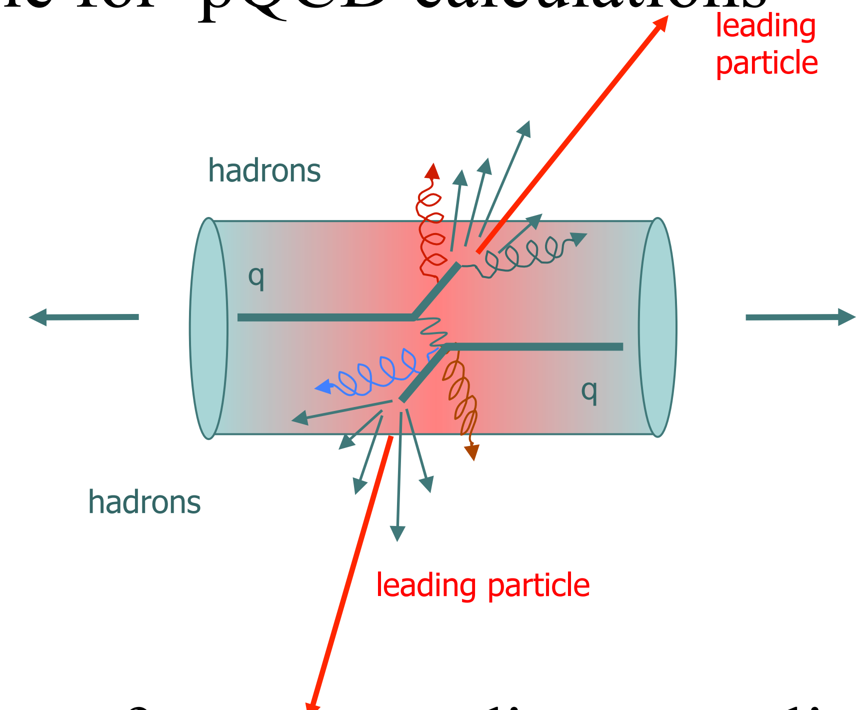
Medium Properties via Jets

What are Jets? In theory: fragmented hard-scattered partons

"Hard" == large scale → suitable for pQCD calculations

Jet Tomography: calibrated probes

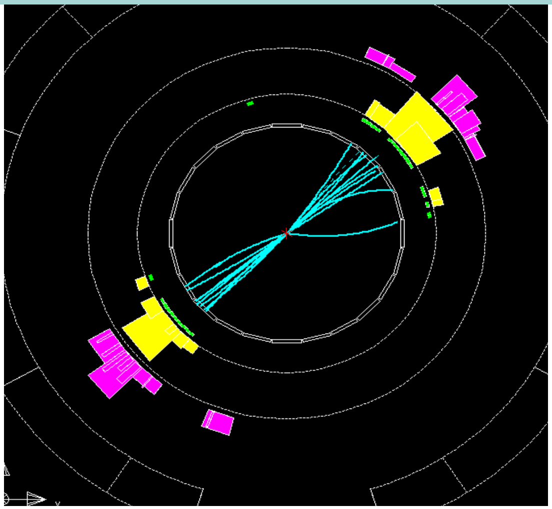
What happens if partons traverse a high energy density colored medium?



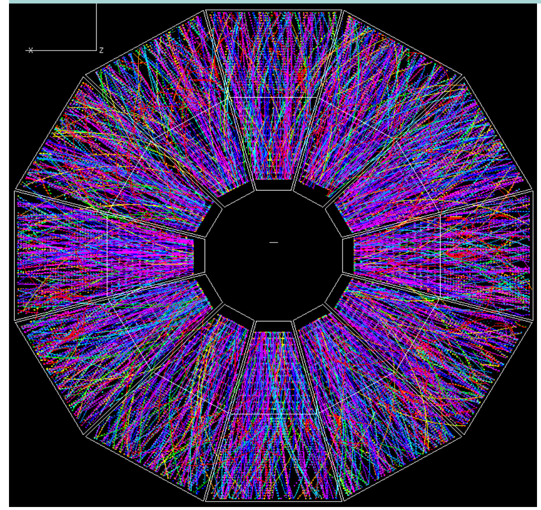
- Jet-medium interactions
- Flavor/color-charge dependence of parton-medium coupling
- In-medium fragmentation/ hadronization

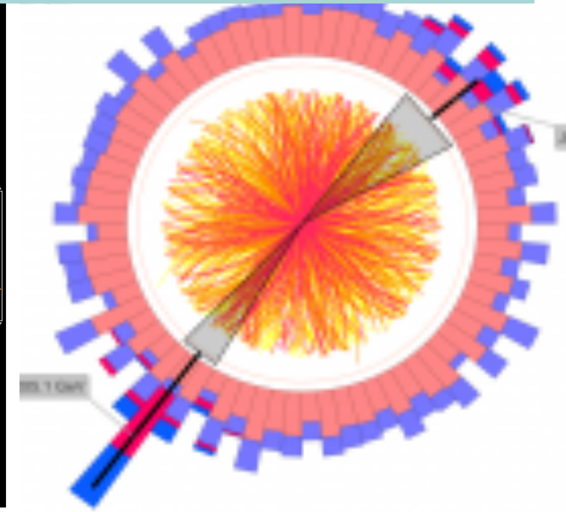
Jets, experimentally

Jets in e^+e^- collision



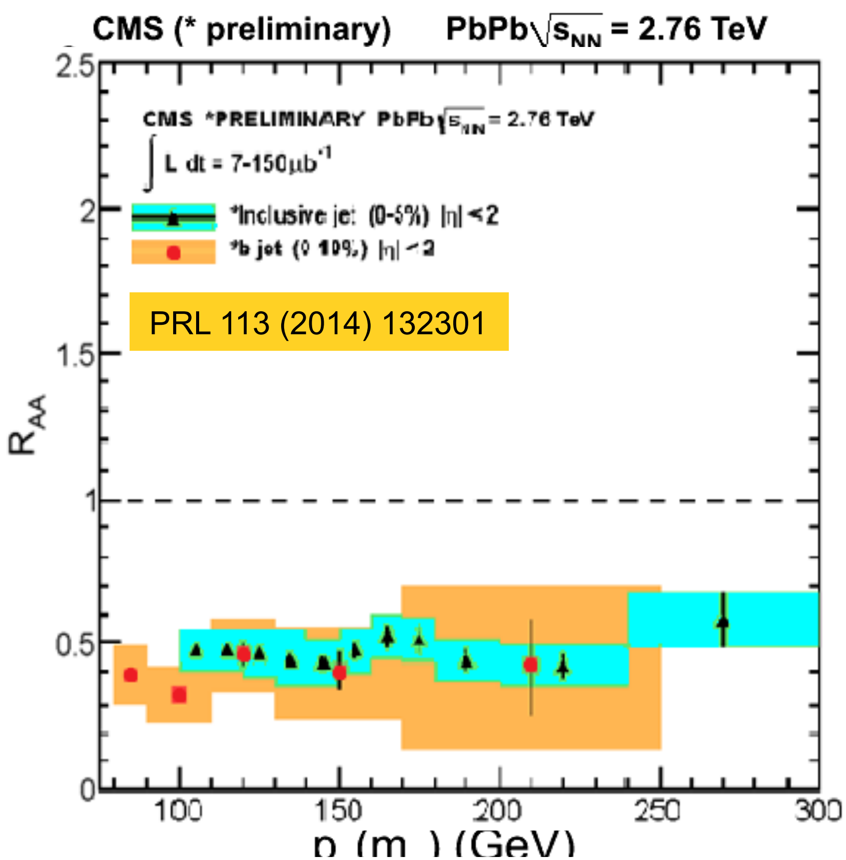
Jets in AA collisions





Spectra/Production rates	Dihadron correlations	Dijets
Pros: *straightforward*	*versatile*	E^{parton}
Cons: *least differential*	*multiple BG sources, no direct E measure*	*ambiguous, fluctuations*

Jets are Quenched



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

- Jet R_{AA}
  - Strong suppression
  - No appreciable p_T dependence

CMS-PAS HIN-12-004

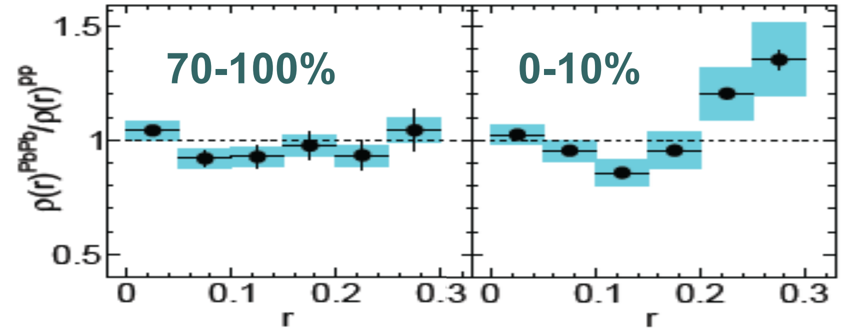
- b-jet suppression, first results:
  - Jet + high mass secondary vertex
  - Jet p_T> 80 GeV
  - Now: differential results on centrality and p_T dependence

Jets are Modified

- Ratio of PbPb to pp jet shapes

  Measuring fractional radial energy distribution (inclusive jets)

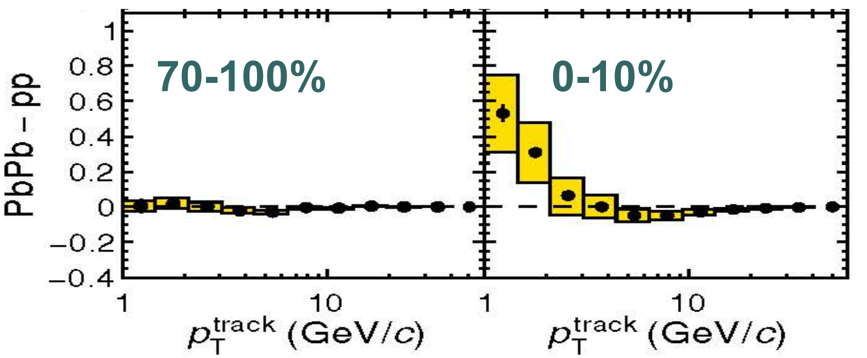
PLB 730 (2014) 243



- PbPb vs pp fragmentation functions

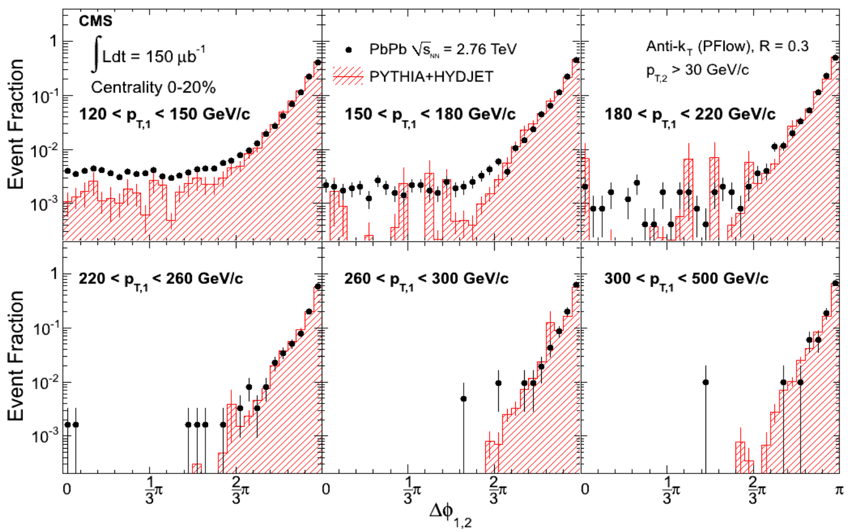
Measuring in-cone track moment distribution projected onto jet axis (inclusive jets)

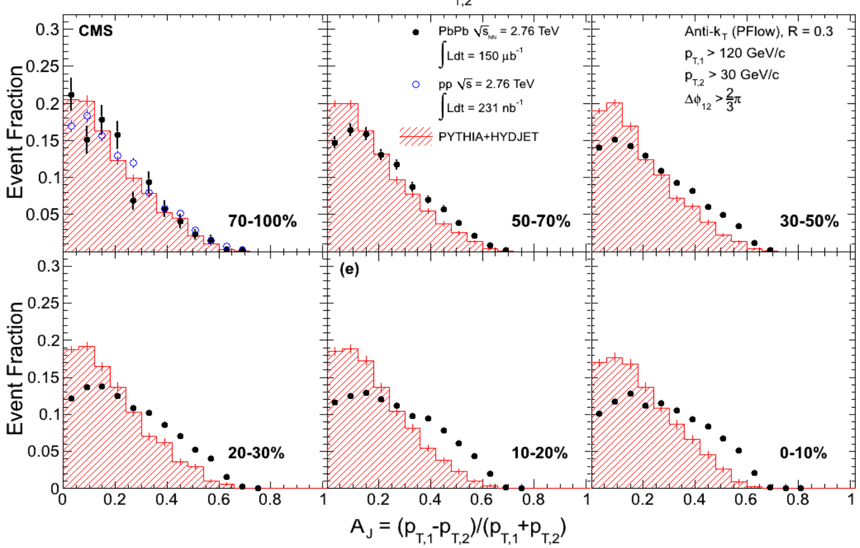
PRC 90 (2014) 024908

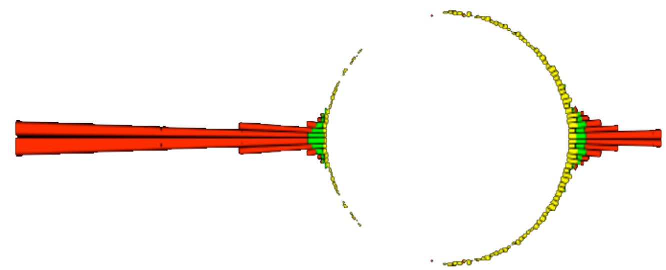


  - Little/no medium effects in peripheral events
  - Enhancement at low p_T / larger r in central collisions

Jet Quenching via Dijets







Di-jets in PbPb:

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

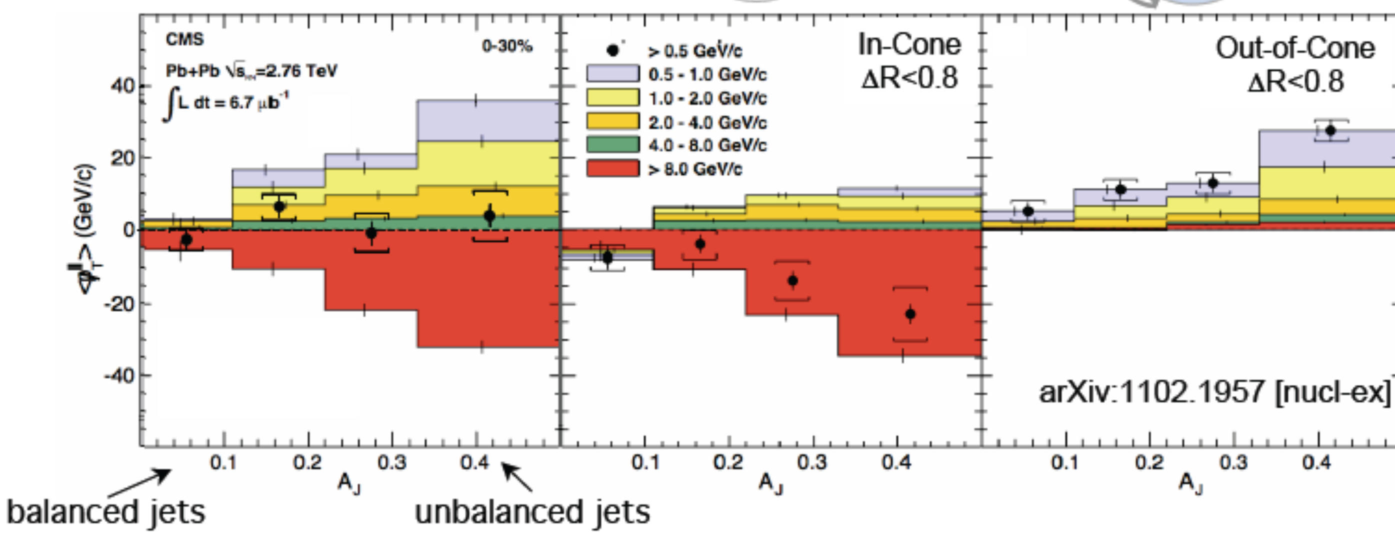
PRC 84 (2011) 024906

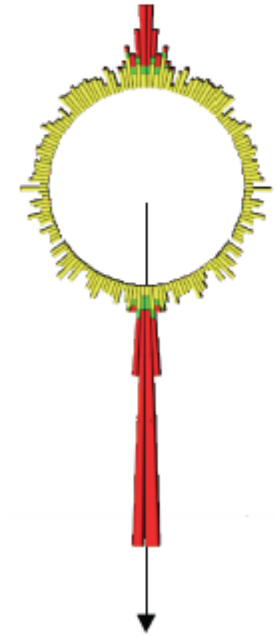
Dijet Energy Balance

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

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

0-30% Central PbPb





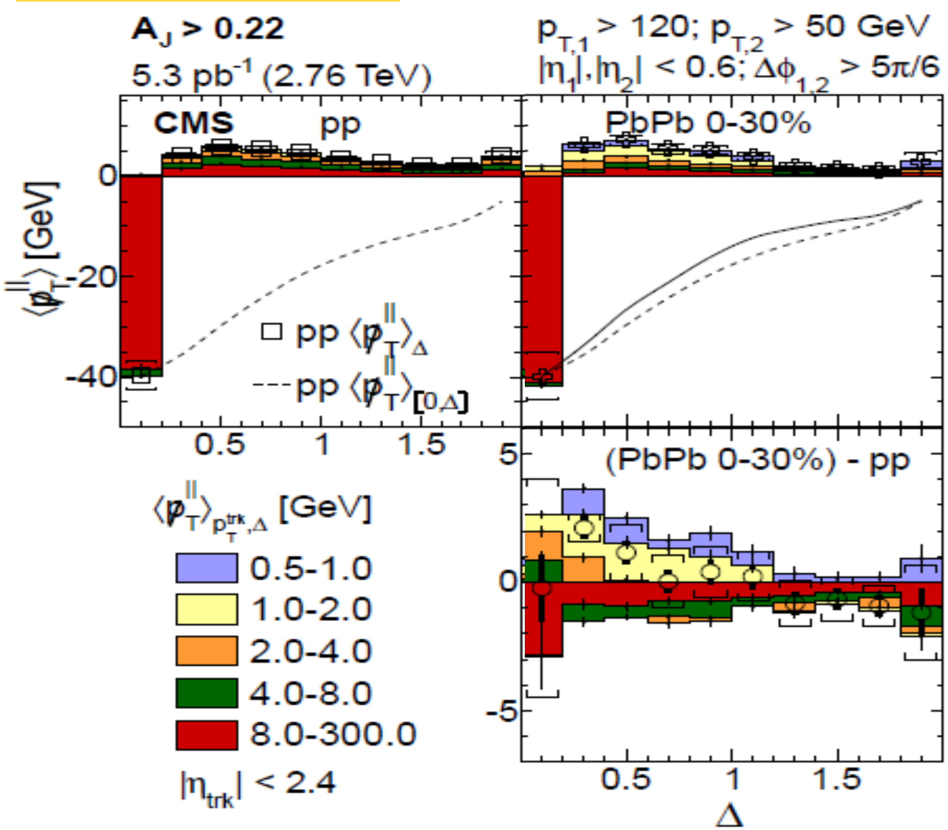
PRC 84 (2011) 024906

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

Momentum “Flow”

Unbalanced dijets (A_J>0.22)

JHEP 01 (2016) 006



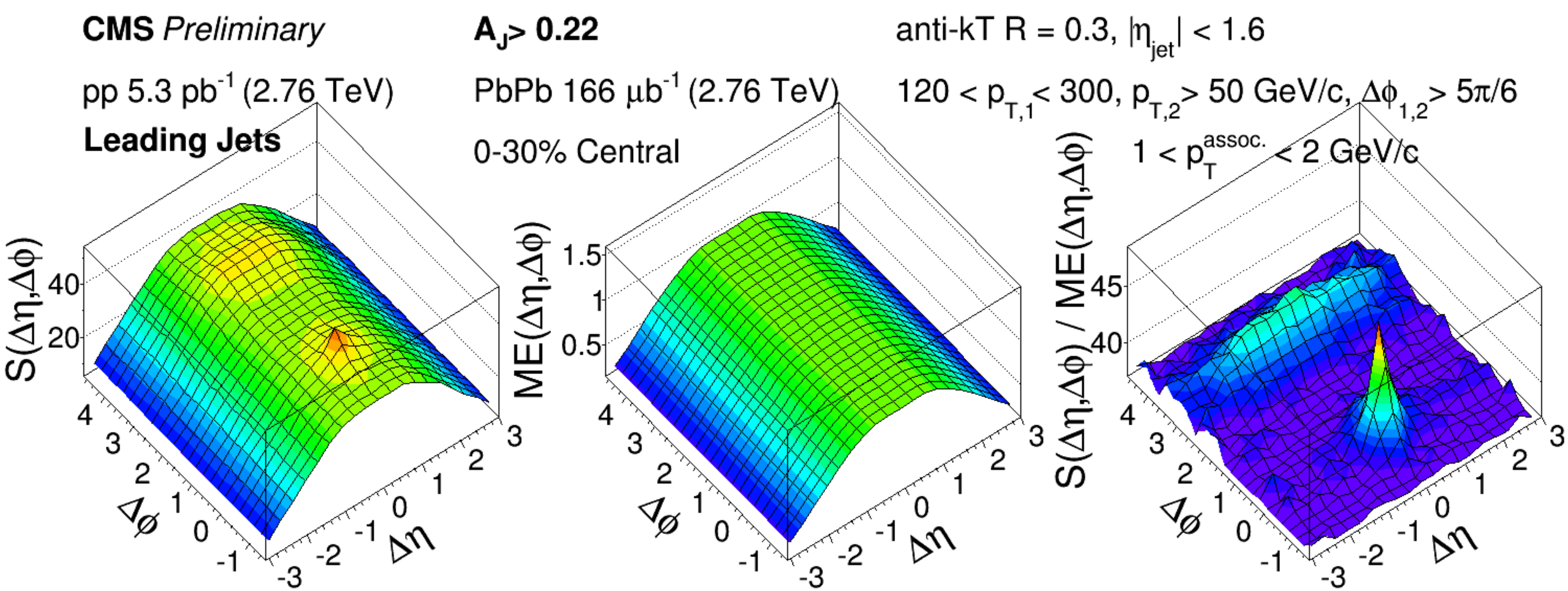
- Energy balance vs , ΔR
- For more unbalanced dijets (A_J>0.22):
  - ~35 GeV missing at high p_T/small ΔR<0.2
  - Extra yields at low p_T / up to large ΔR
- Comparing to pp with same A_J:
  - Change in p_T mix
  - Similar p_T-integrated ΔR shape

Decomposing Momentum "flow" for dijet events

- Jets are modified…
  - Strong suppression in jet R_{AA}
  - Softening of jet fragmentation functions
  - Modifications of jet shapes
  - ….
- …and show significant reshuffling of energy in PbPb events compared to pp
- Jets are modified…
  - Strong suppression in jet R_{AA}

Jet-track correlations-I

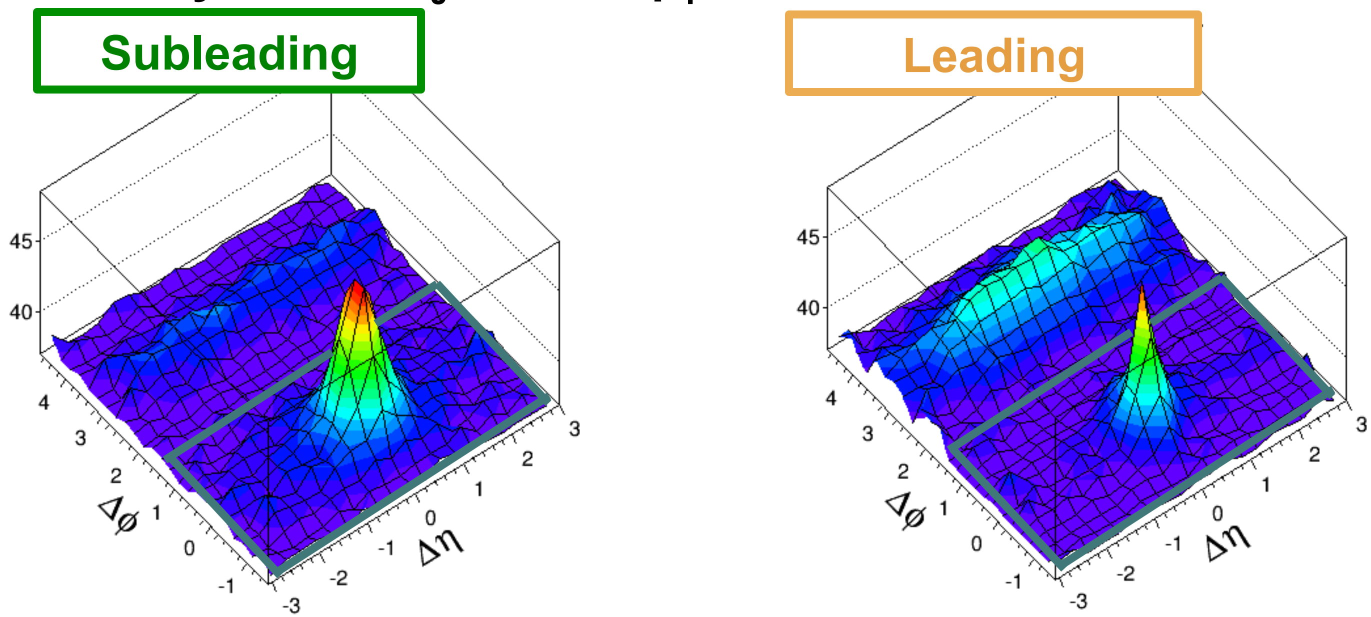
- Construct 2D ΔηΔφ correlations (number or momentum) about each side of dijet
- Correcting for tracking efficiency on per-track basis
- Correct for pair acceptance by mixed event technique
- Correct for background fluctuation, jet swapping, fragmentation bias



Jet-track correlations-II

- Leading and subleading jets are separated on average by $\Delta\varphi_{1,2}=\pi$
- Construct dijet correlations from leading and subleading correlations

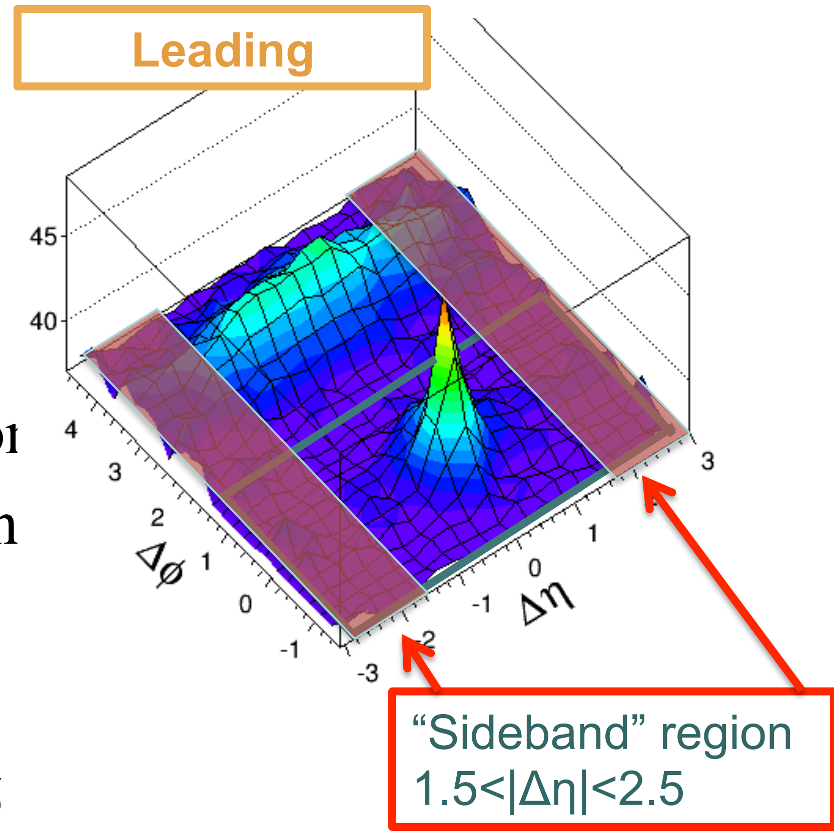
PbPb, Centrality 0-30%, A_J>0.22, 1<$p_T^{assoc.}$<2 GeV/c



- Leading and subleading hemisphere information is taken from (-π/2, π/2) of leading and subleading jet-track correlations, respectively

Separating components

- Use “sideband” method to measure long-range contributions and separate the jet peaks from long range underlying event correlations
- Sideband Δη region 1.5<|Δη|<2.5



- Look at the differences between subleading and leading hemispheres,
-

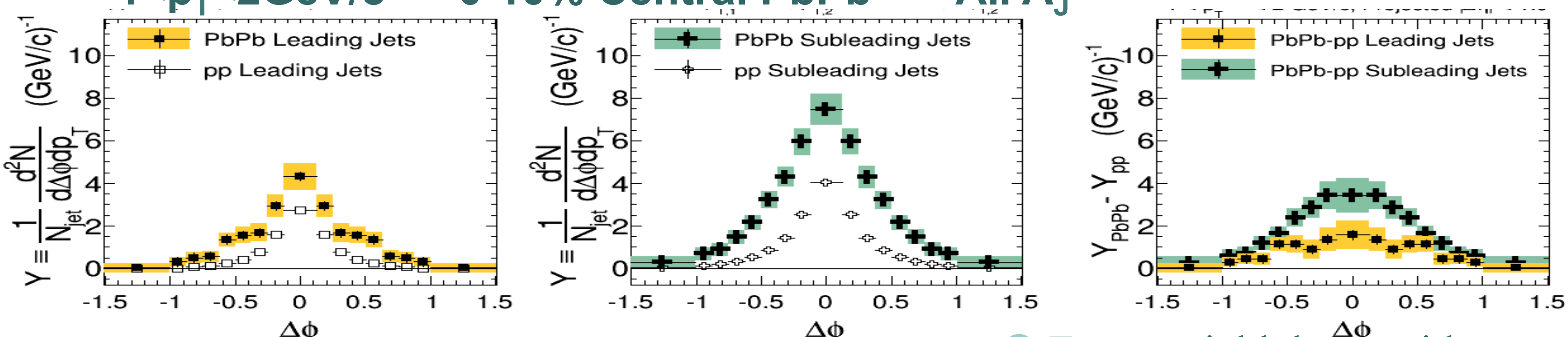
Use “sideband” method to measure lo
separate the jet peaks from long range un

- Results:
  - Leading jet modifications
  - Subleading jet modifications
  - Correlated UE asymmetry

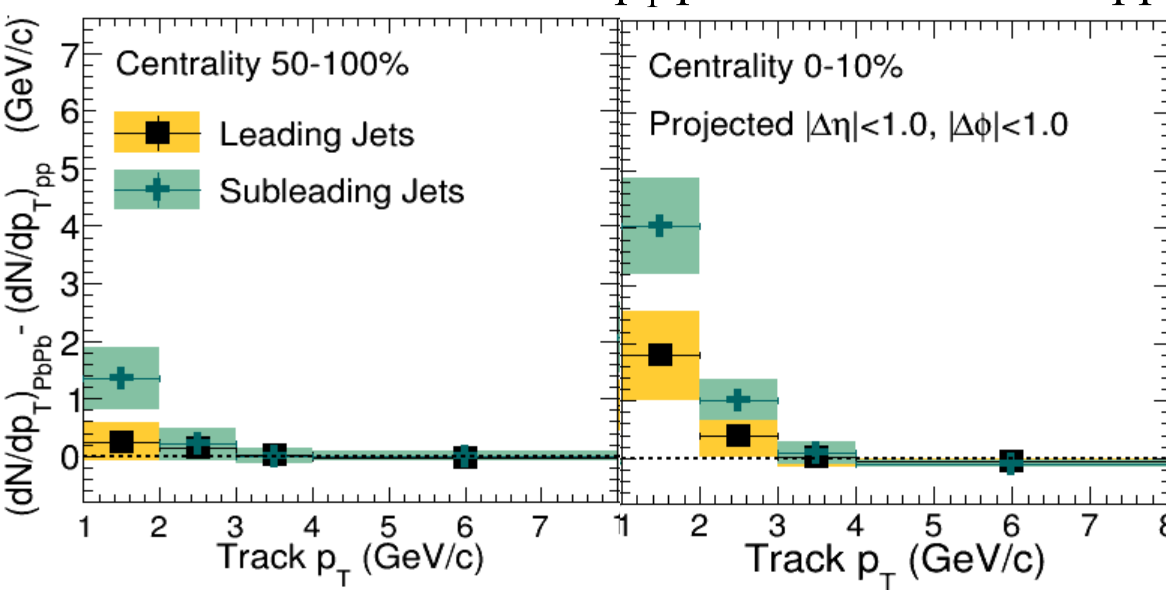
Sideband Δη
region 1.5<|Δη
|<2.5

Number Correlations

$1<p_T<2$GeV/c 0-10% Central PbPb All A_J



- Enhancement of low-p_T particles in PbPb vs pp



- Excess yield drops with p_T, turns into depletion for p_T>8GeV/c
- Larger effects for subleading jets and in central events

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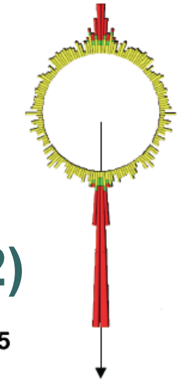
Momentum "flow"

- Hemisphere Momentum Imbalance
  - "Missing p_T" in $\Delta\phi$ (same data!):



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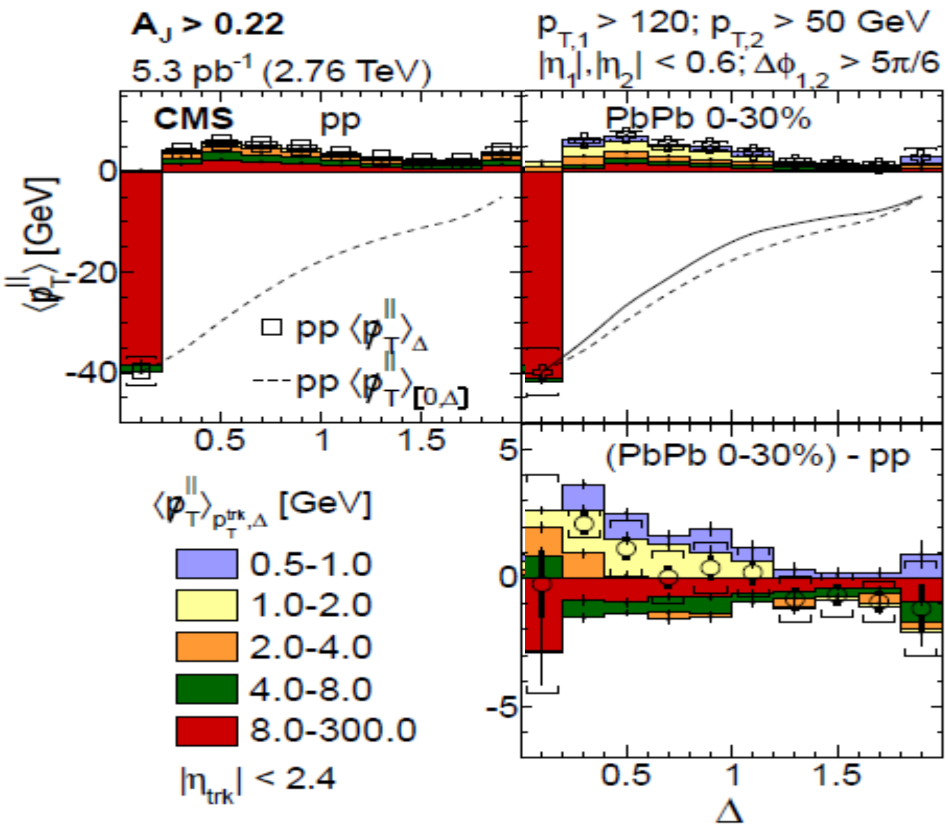
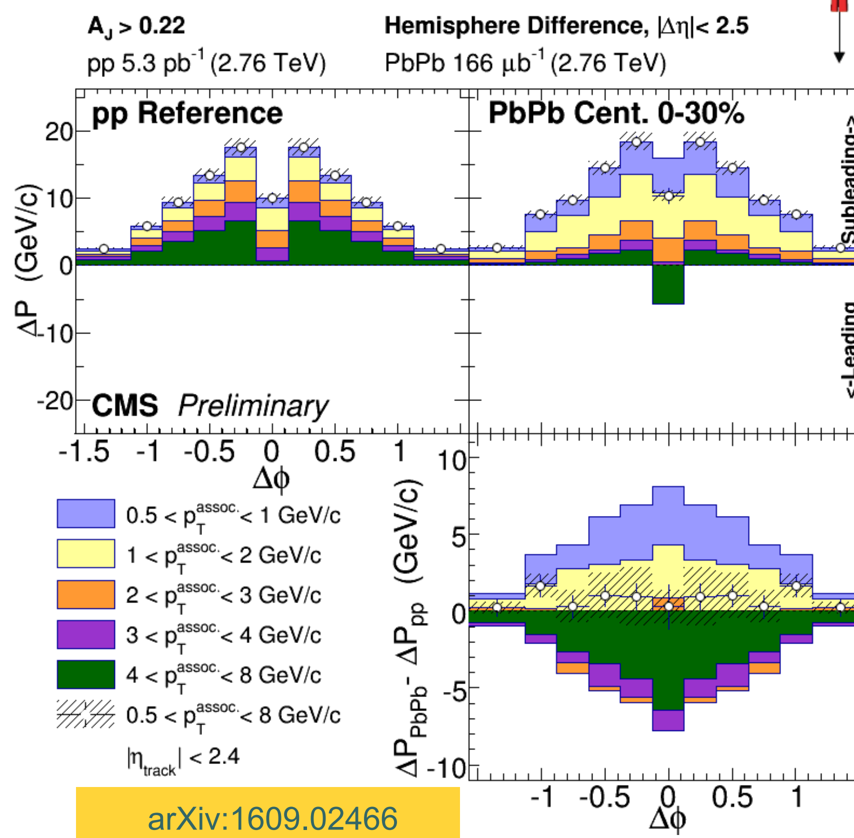


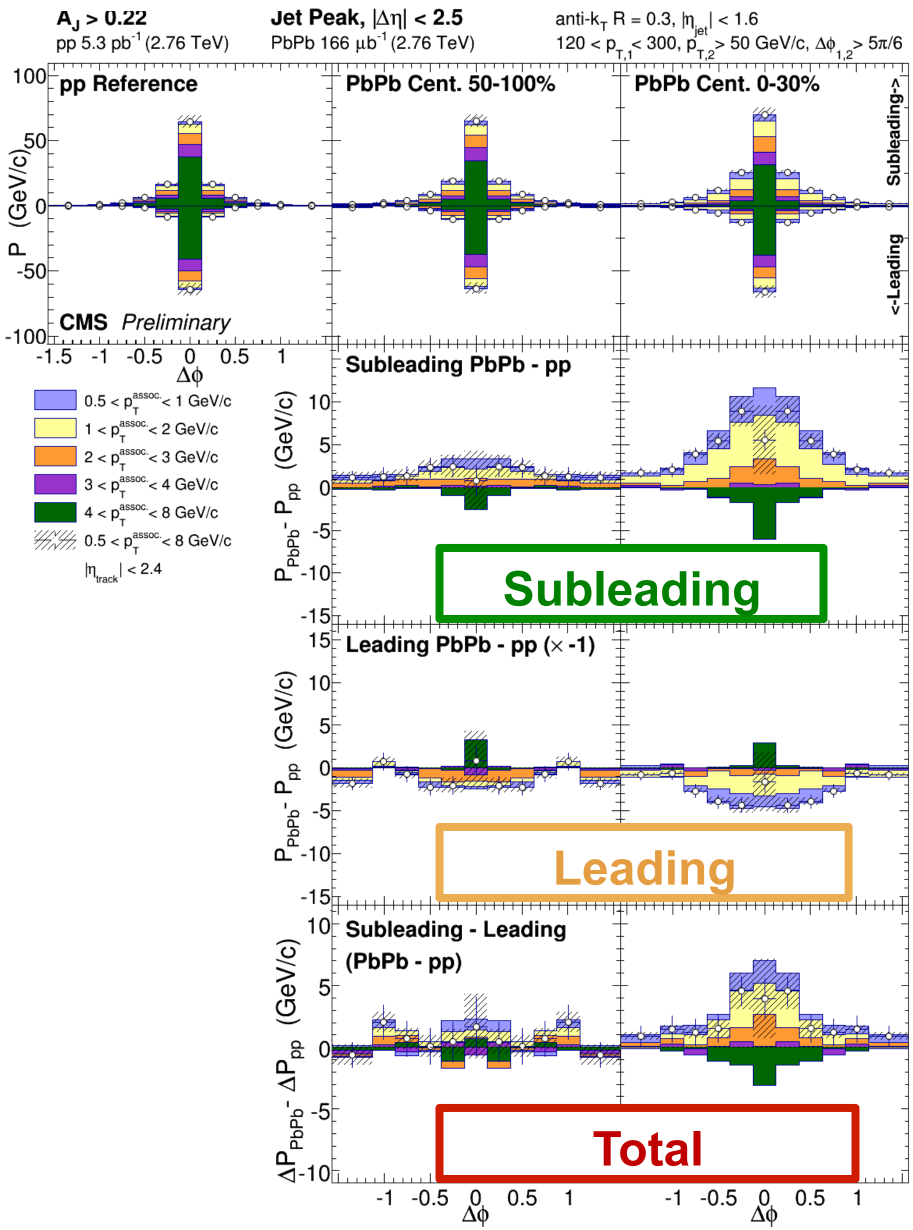
→

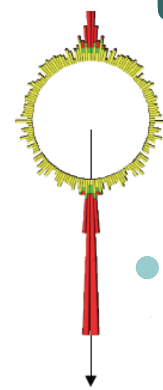
Unbalanced dijets (A_J>0.22)



arXiv:1609.02466

Jet Peaks Contributions





Unbalanced dijets (A_J>0.22)

Same conclusions as from number-correlations:

- low-p_T enhancement, high-p_T depletion, both sides of dijet are affected
- Larger effects for subleading jets and in central events
- Double difference recovers only part of total hemisphere momentum difference
- by $\Delta\varphi \sim 1$

- Somewhat smaller modifications

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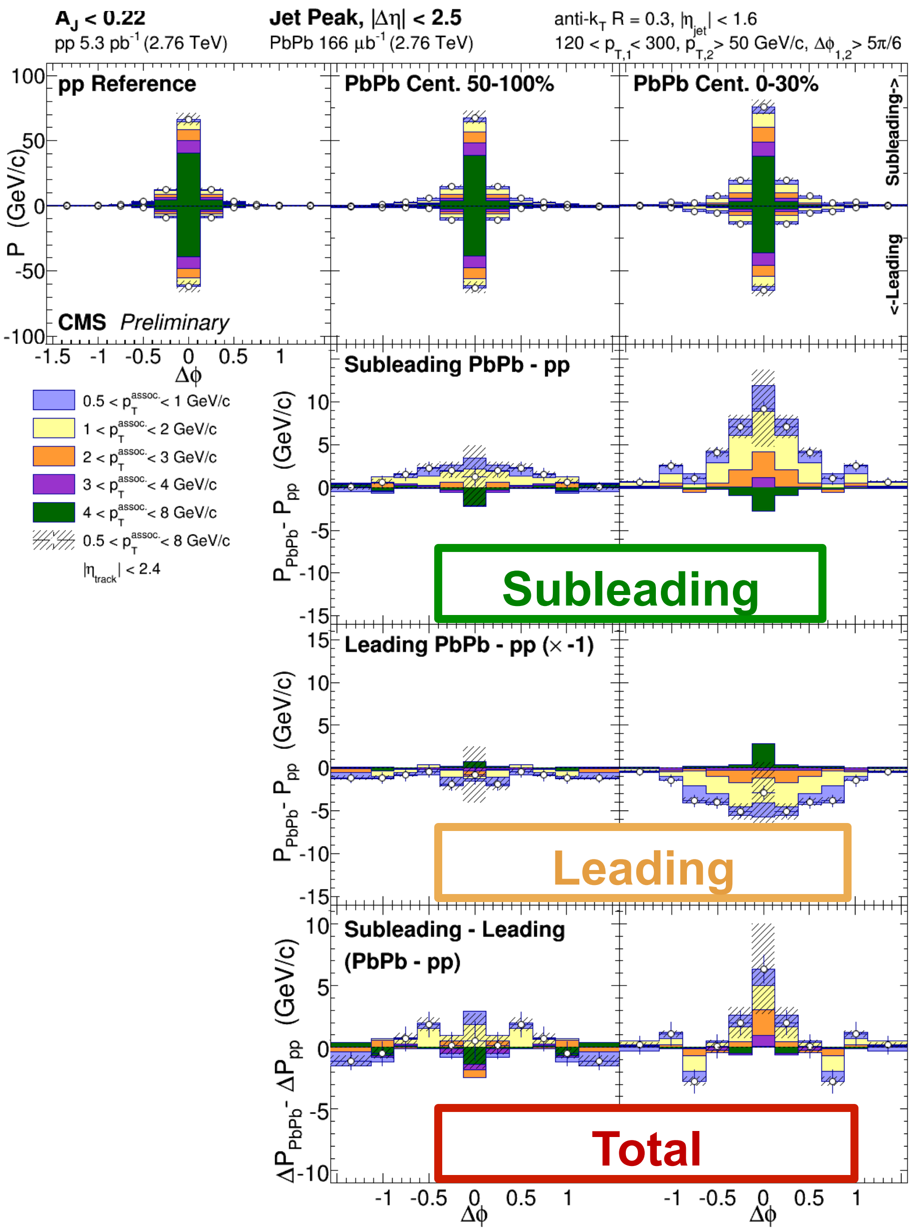
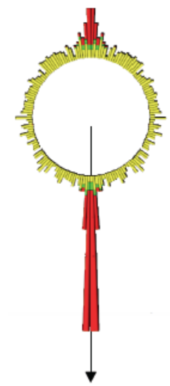
Jet Peaks Contributions





Balanced dijets (A_J<0.22)

Same conclusions as from number-correlations:

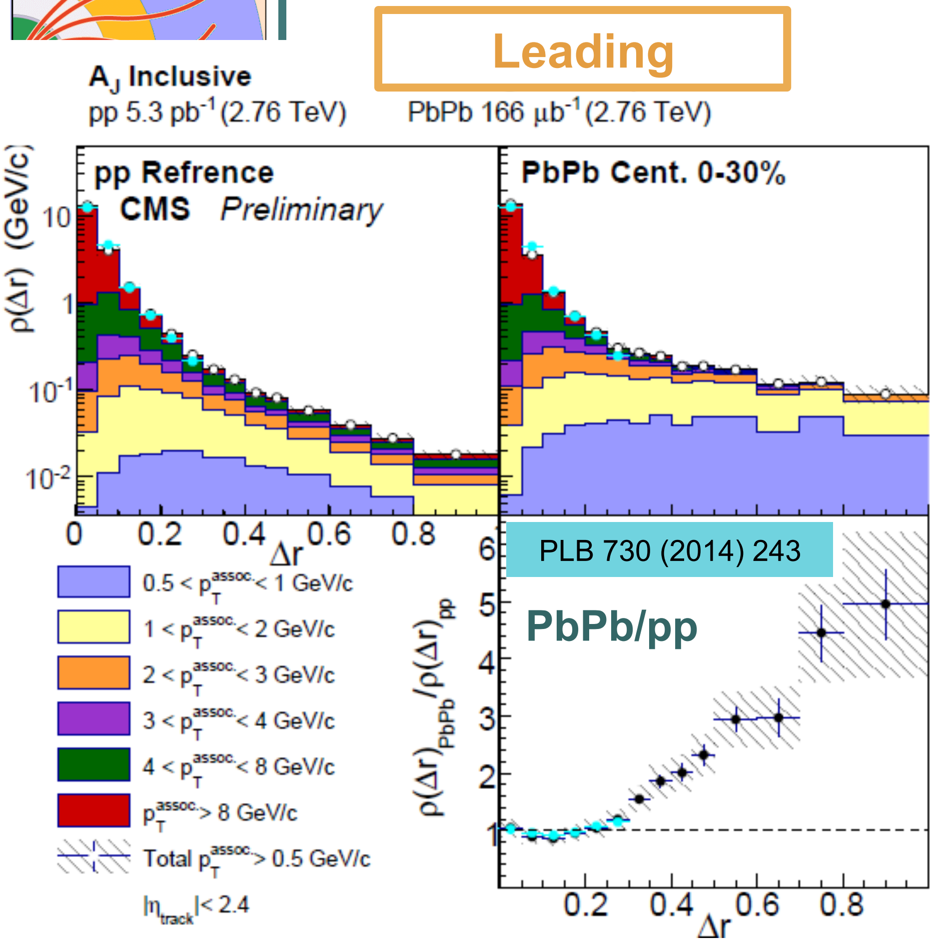
low-p_T enhancement, high-p_T depletion, both sides of dijet are affected

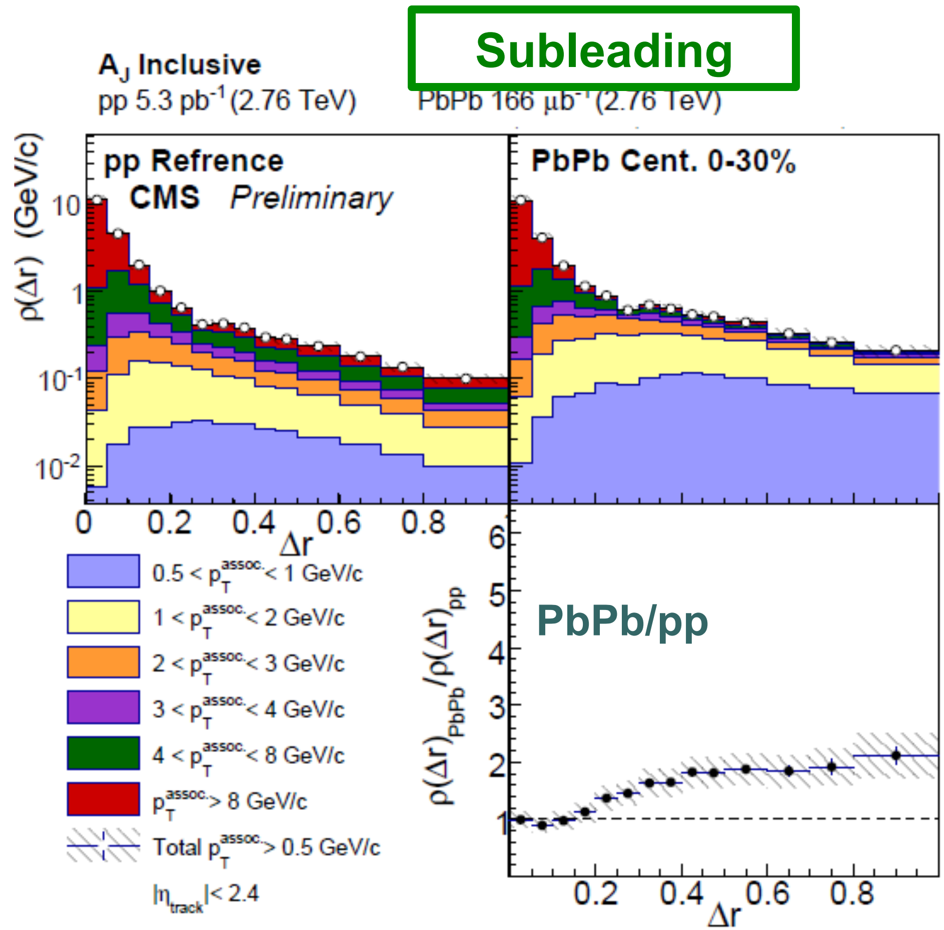
- Larger effects for subleading jets and in central events
- Double difference recovers only part of total hemisphere momentum difference
- Correlated jet-like yield "dies out" by $\Delta\varphi \sim 1$

- Somewhat smaller modifications

arXiv:1609.02466

Jet Shape Modifications

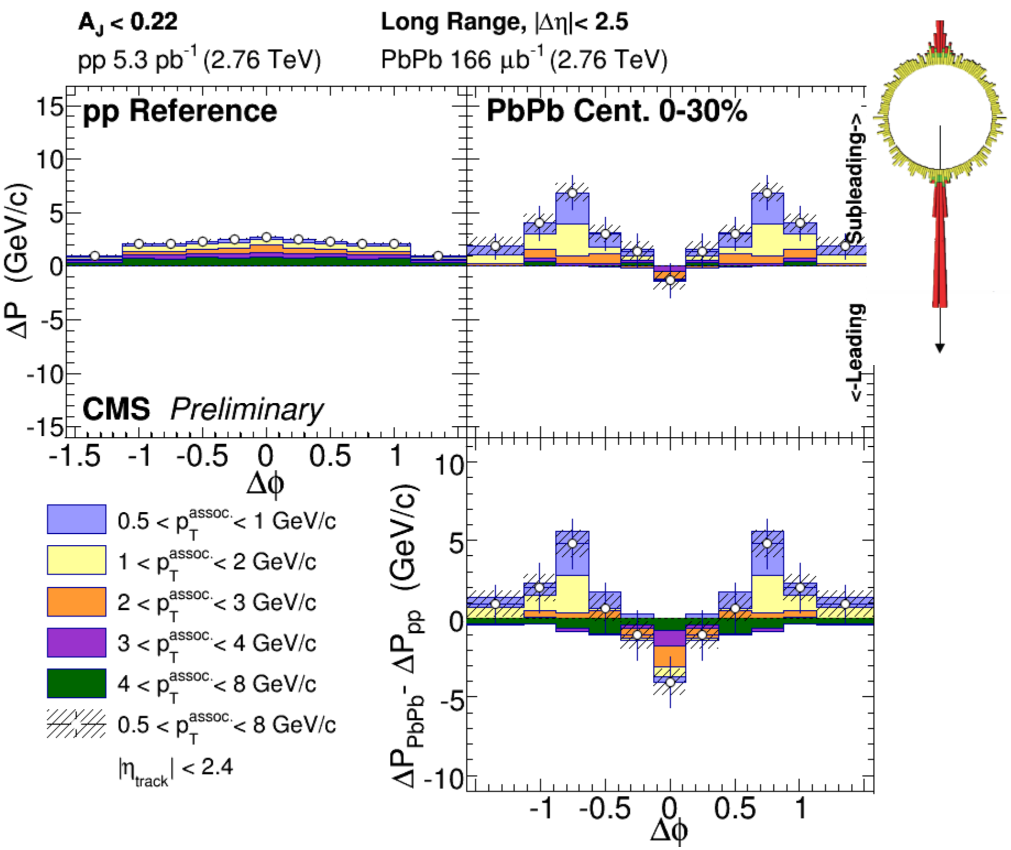




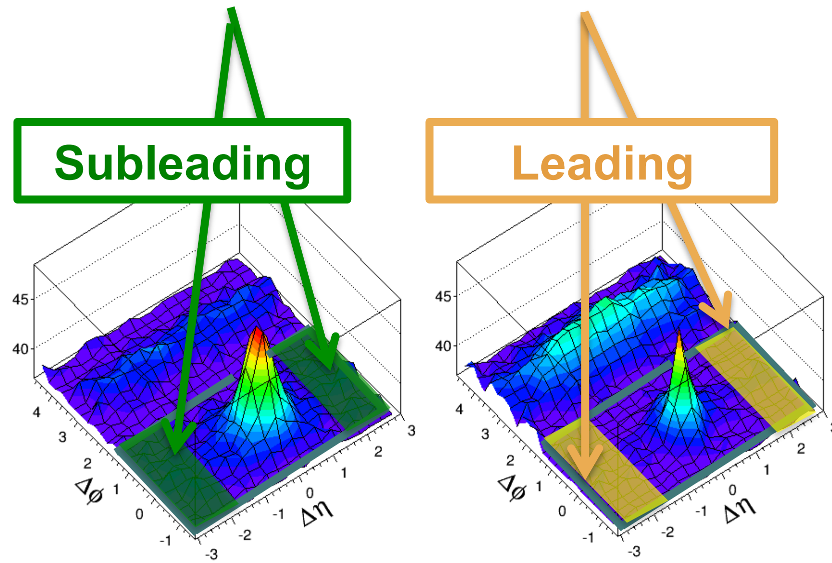
- New measurement of jet shapes up to large radial distances
  - Preserved normalization of previous measurement: set to integrate to unity for p_T>0.5 GeV/c in Δr<0.3

arXiv:1609.02466

Long-range contributions



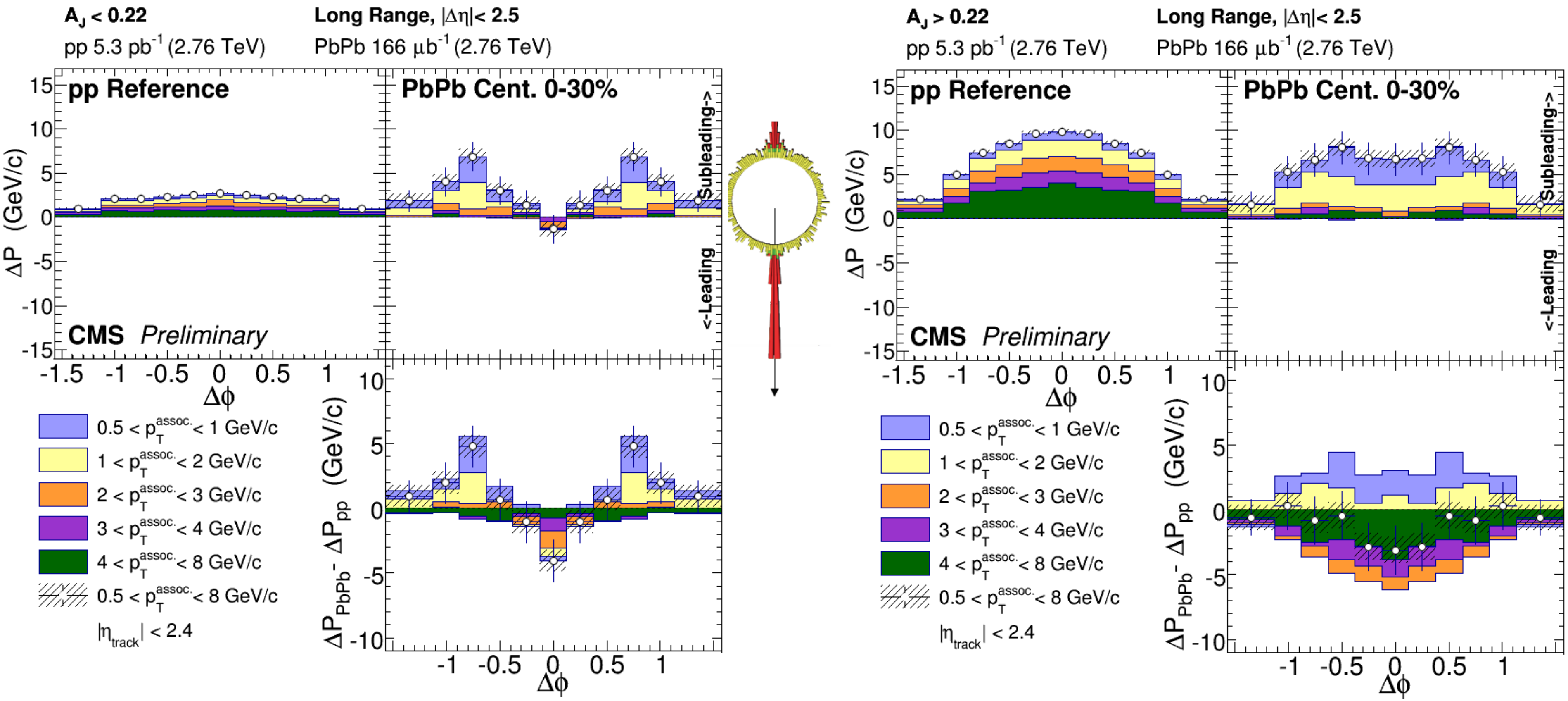
Long range difference
Subleading – Leading



arXiv:1609.02466

- Long range subleading–leading asymmetry
  measured on the region 1.5<|Δη|<2.5, propagated over full range |Δη|<2.5
- Excess of soft hadron p_T on subleading side relative to leading

Long-range contributions



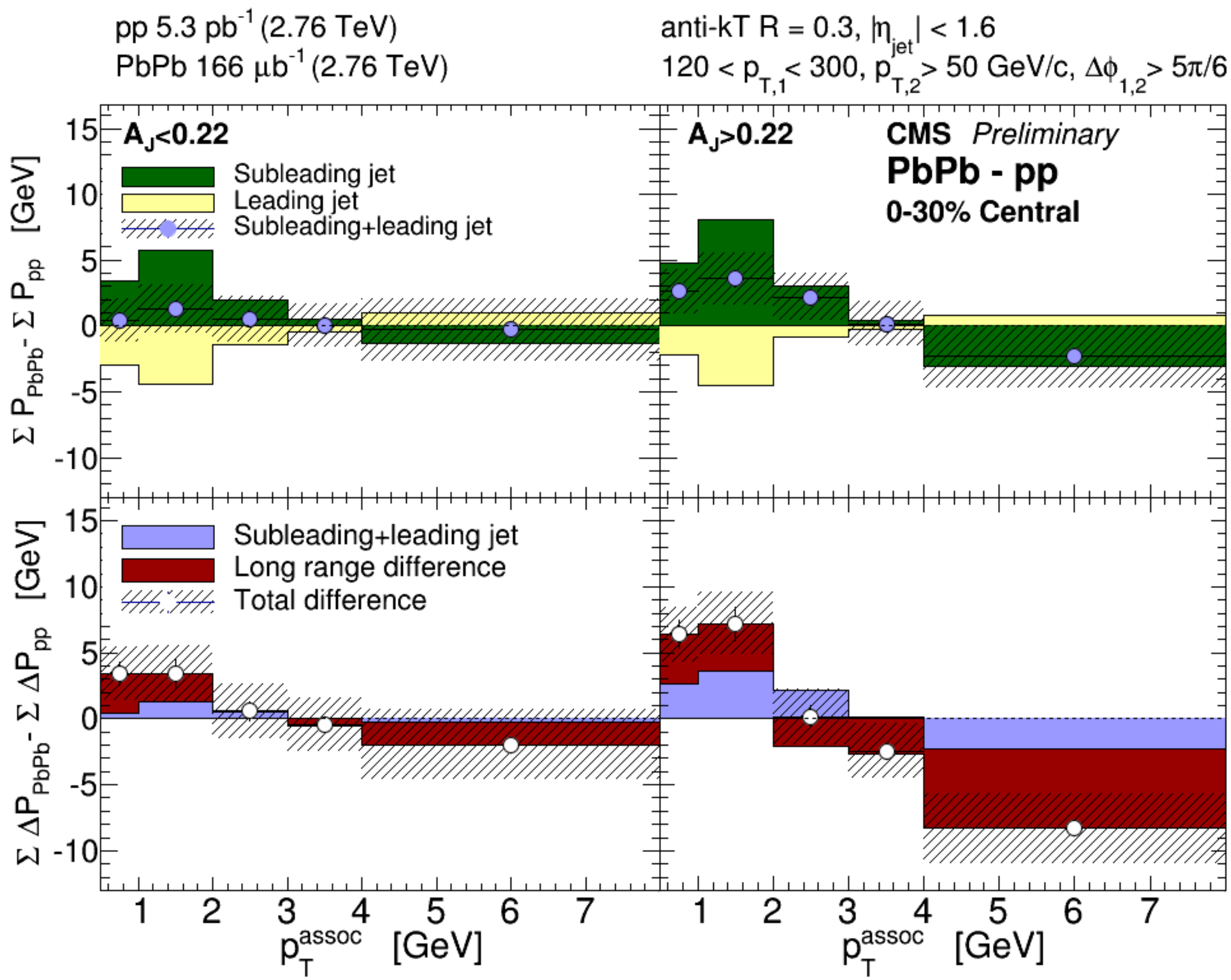
- Long range subleading–leading asymmetry
  - pp: unbalanced dijets are accompanied by a long range excess of yield on the subleading side (momentum conservation/3-jet events)
  - Central PbPb: disappearance of high-p_T long range asymmetry, growth of low-p_T long range asymmetry

arXiv:1609.02466

Decomposing energy balance

Jet-peak differences PbPb – pp →

Total differences PbPb – pp →



- 30% central PbPb vs pp differences:
  - Top: subleading and leading jet modifications
  - Bottom: total jet-related contribution and long-range asymmetry

arXiv:1609.02466

Summary

- Jet-track correlation allow to study jet modifications in associated particle yields and momenta out to large relative angles. The technique allows to decompose energy balance contributions for dijets

- <u>PbPb vs pp</u>: excess of correlated yields in particles below 2 GeV/c; small depletion in high-p_T region

- <u>pp vs PbPb</u>: subleading-side high-p_T excess for unbalanced dijets in pp collisions is absent in central PbPb data: smaller fraction of 3-jet events in unbalanced dijets from PbPb

- New large-Δr jet shape measurements for leading jets and subleading jets