Jet-track correlations in PbPb collisions

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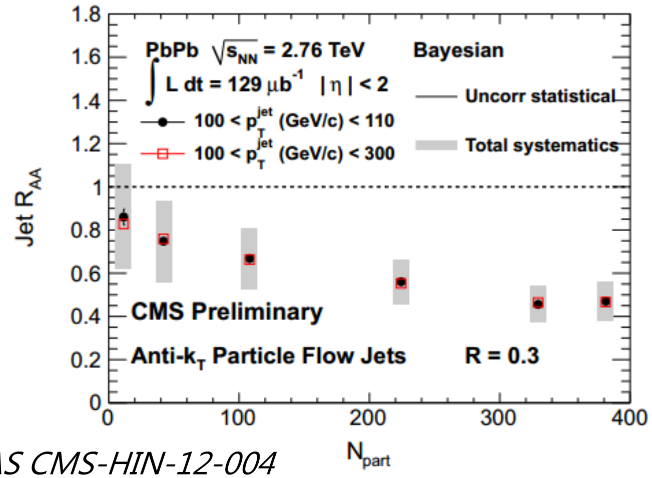
On behalf of the CMS Collaboration

10th International Workshop on High-pT Physics

Sep 9-12, 2014, SUBATECH Nantes

Inclusive jets and Dijets



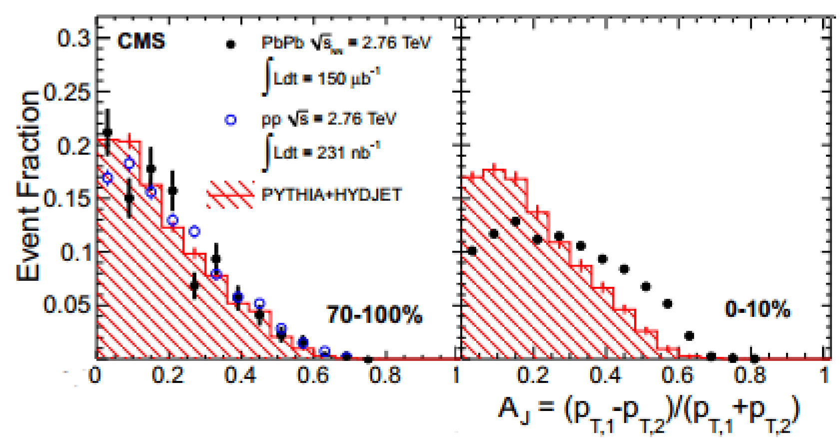
PAS CMS-HIN-12-004

Jet shapes, Fragmentation functions **Inclusive jets**

- Increasing centrality $\Longrightarrow$ Less jets come out of the medium
- Jets that are observed at a given p_T are mostly the ones with little quenching

PLB 712 (2012) 176

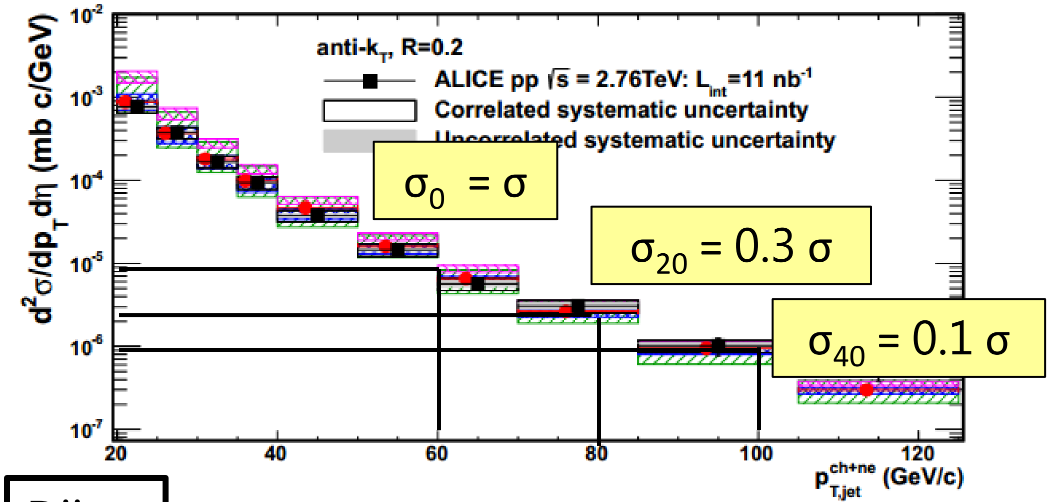
Dijets Missing p_T as a function of ΔR



- Increase in asymmetry of dijet pairs in central events
  - 10% downwards shift of $\langle p_{T,2}/p_{T,1} \rangle$
  - Subleading jet gets quenched (~10 GeV/c) more compared to leading jet
- Tagging quenched jets $\Longrightarrow$ Subleading jets in events with large dijet asymmetry

Inclusive jets and Dijets

Nucl.Phys. A904-905 (2013) 721c-724c



Inclusive jets

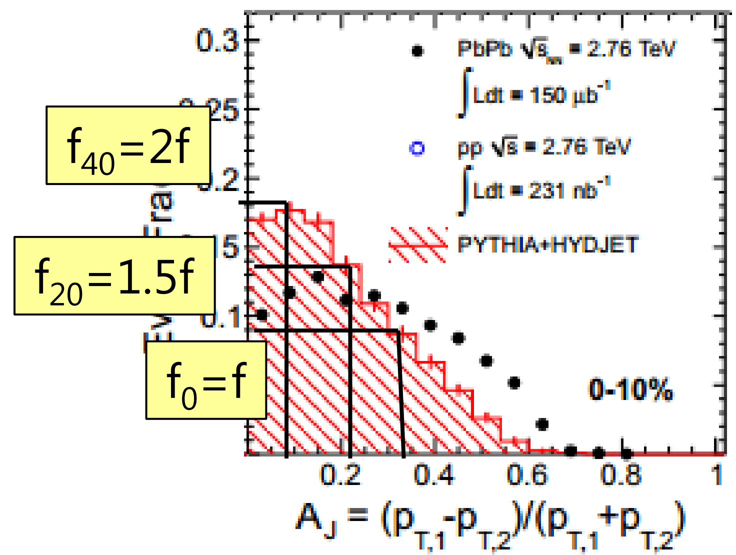
e.g. Fraction of inclusive jets at 60 GeV/c which has lost 20 GeV energy or 40 GeV energy

- $\left(\frac{N_{20}}{N_0}\right)^{inc} = \frac{p_{20}\sigma_{20}}{p_0\sigma_0}$
- $\left(\frac{N_{40}}{N_0}\right)^{inc} = \frac{p_{40}\sigma_{40}}{p_0\sigma_0}$

Dijets

e.g. Fraction of subleading jets with A_J=0.3 ($p_{T,2}$ ~60 GeV) which has lost 20 GeV energy or 40 GeV energy

- $\left(\frac{N_{20}}{N_0}\right)^{dijet} = \frac{p_{20}f_{20}}{p_0 f_0} = \left(\frac{N_{20}}{N_0}\right)^{inc} \frac{\sigma_0 f_{20}}{\sigma_{20} f_0} \approx 5\left(\frac{N_{20}}{N_0}\right)^{inc}$
- $\left(\frac{N_{40}}{N_0}\right)^{dijet} \approx 20\left(\frac{N_{40}}{N_0}\right)^{inc}$



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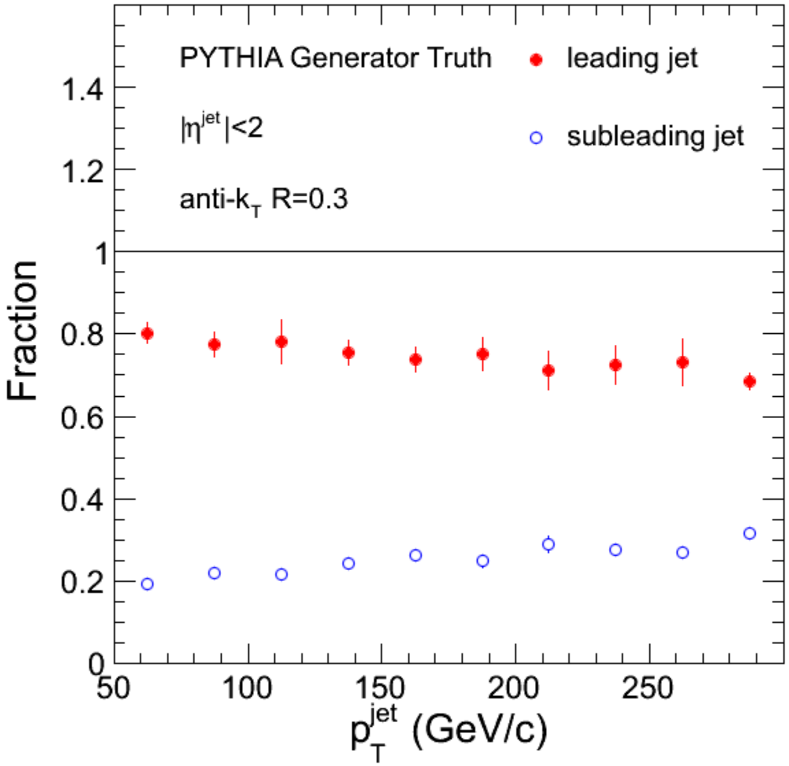
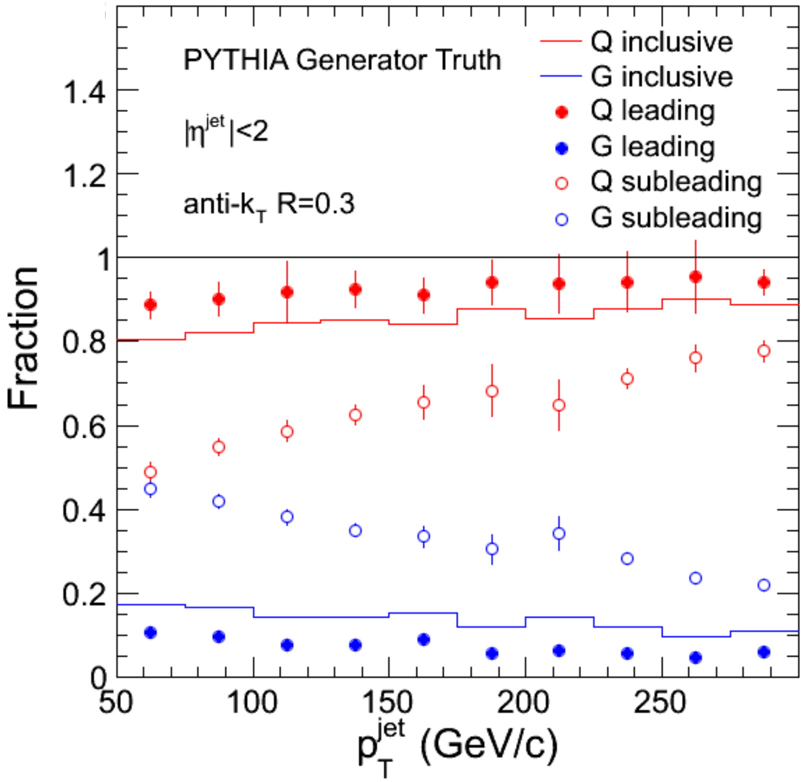
Inclusive jets and Dijets

Fraction of inclusive jets that are leading (subleading) jets



Q/G jet fraction for inclusive/leading/subleading jets



In generator-level PYTHIA:

- Large fraction of inclusive jets are leading jets
- Subleading jets have larger fraction of gluon jets compared to leading and inclusive jets.

Datasets and event selection

DATA

- CoM energy: 2.76 TeV
- Luminosity: 5.3 pb^{-1} for pp, and 150 μb^{-1} for PbPb
- Trigger: A jet with pT > 80 GeV/c

MC

- PYTHIA simulations
- PYTHIA sample embedded into a HYDJET background.

Inclusive jets

- Inclusive jet selection:
  - $p_T^{jet} > 100$ GeV/c
  - $0.3 < |\eta^{jet}| < 2$
- Charged particles:
  - $p_T > 1$ GeV/c
  - $|\eta| < 2.4$

Dijets

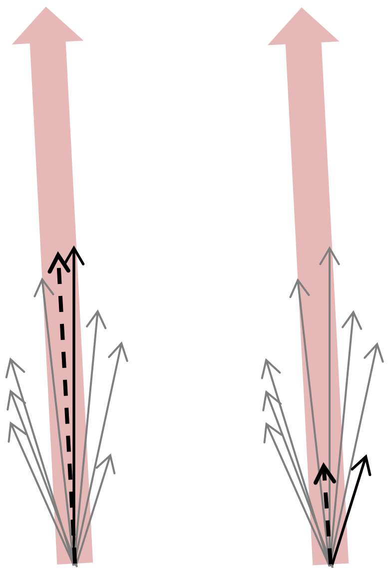
- Dijet selection:
  - $p_{T,1} > 120$, $p_{T,2} > 50$ GeV/c
  - $|\eta_1|, |\eta_2| < 1.6$ (0.5)
  - $\Delta\phi > 5\pi/6$
- Charged particles:
  - $p_T > 0.5$ GeV/c
  - $|\eta| < 2.4$

Inclusive jet measurements

FRAGMENTATION FUNCTIONS

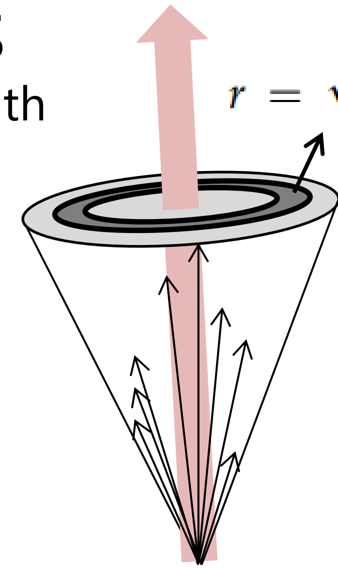
- Number of charged particles per jet with a given value of ξ

$$z = \frac{p_{\parallel}^{\text{track}}}{p^{\text{jet}}}, \quad \xi = \ln\frac{1}{z},$$



Large z small ξ

Small z, large ξ



$$r = \sqrt{(\eta_{\text{track}} - \eta_{\text{jet}})^2 + (\phi_{\text{track}} - \phi_{\text{jet}})^2}$$

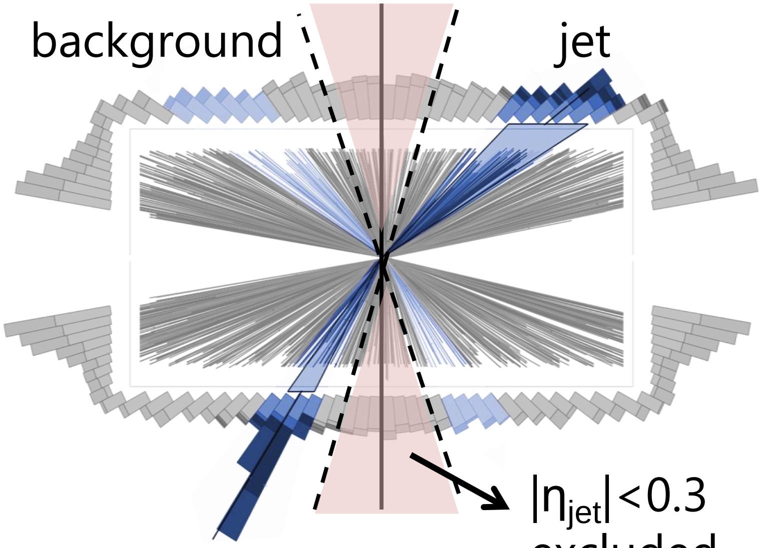
JET SHAPES

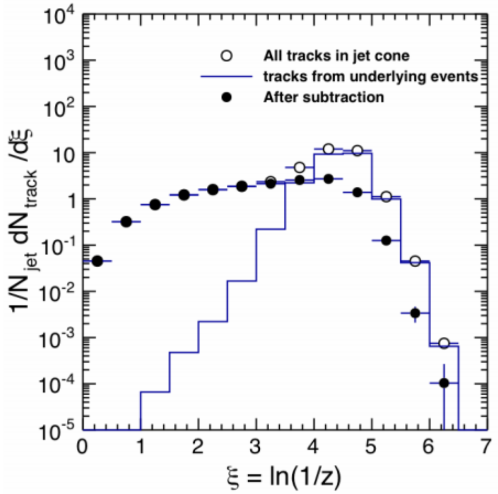
- Scalar p_T sum of charged particles in a slice of r divided by the p_T of the jet

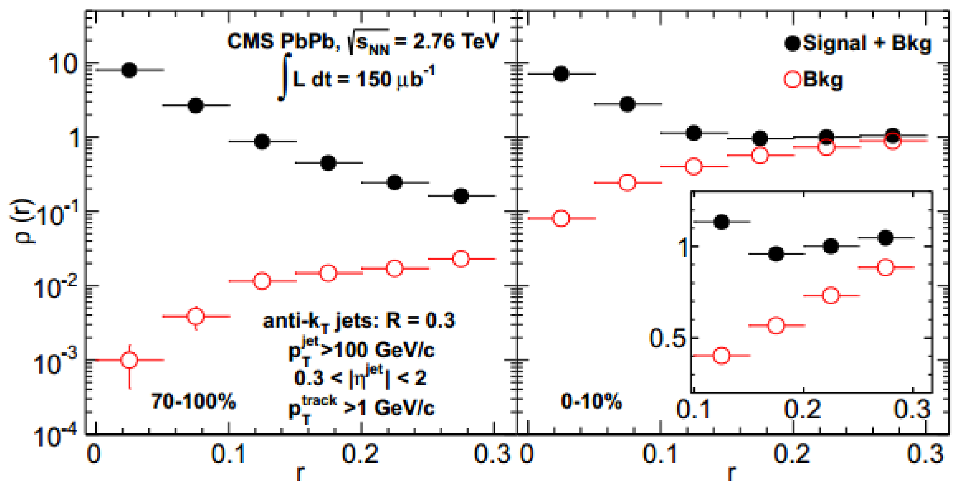
$$\boxed{\rho(r) = \frac{1}{\delta r}\frac{1}{N_{\text{jet}}}\sum_{\text{jets}}\frac{\sum_{\text{tracks} \in [r_a, r_b)} p_{\mathrm{T}}^{\text{track}}}{p_{\mathrm{T}}^{\text{jet}}}}$$

Background subtraction

- Background calculated with η reflection.
- A cone with $\Delta R=0.3$ centered at $\eta_{bkg}=-\eta_{jet}$ and $\varphi_{bkg} = \varphi_{jet}$
- Background is large in central events for $\xi>3$ and $r>0.1$.
- Compared to the estimated background calculated by event mixing with minimum bias events ->systematic uncertainty 5%

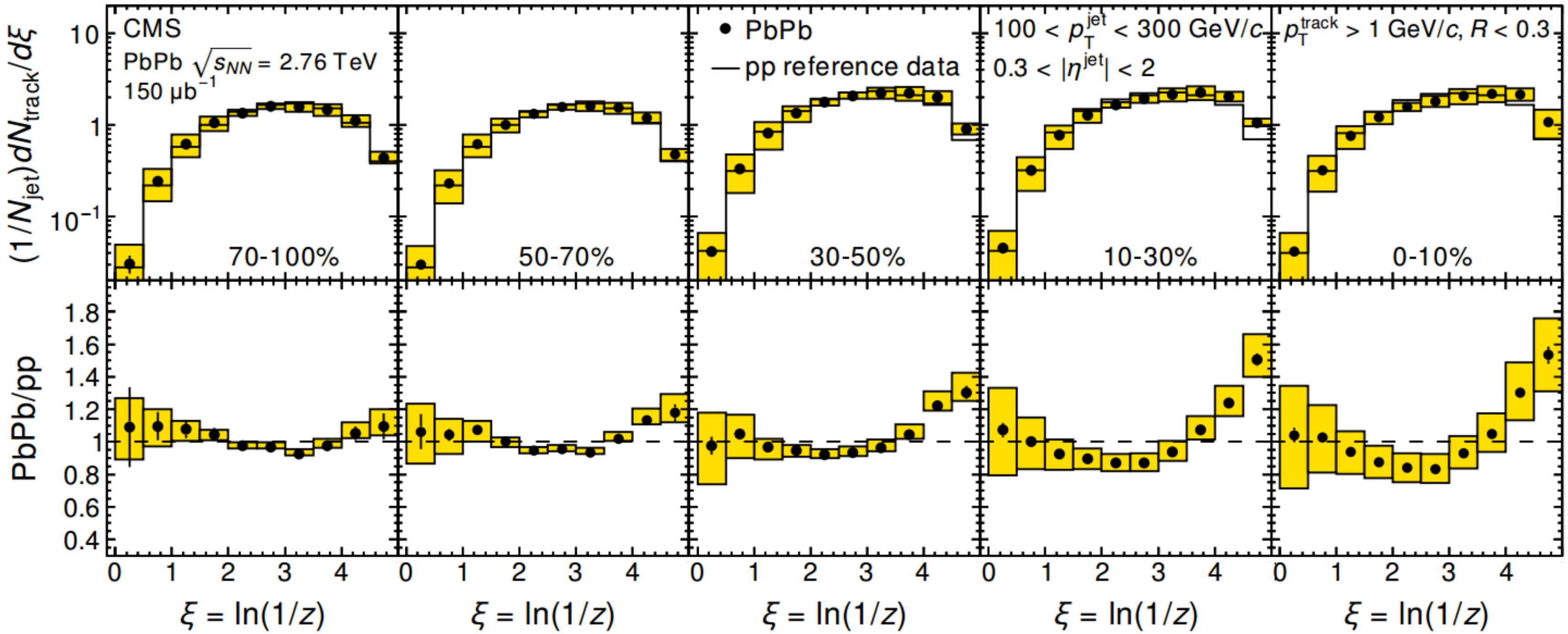






Results - Fragmentation functions

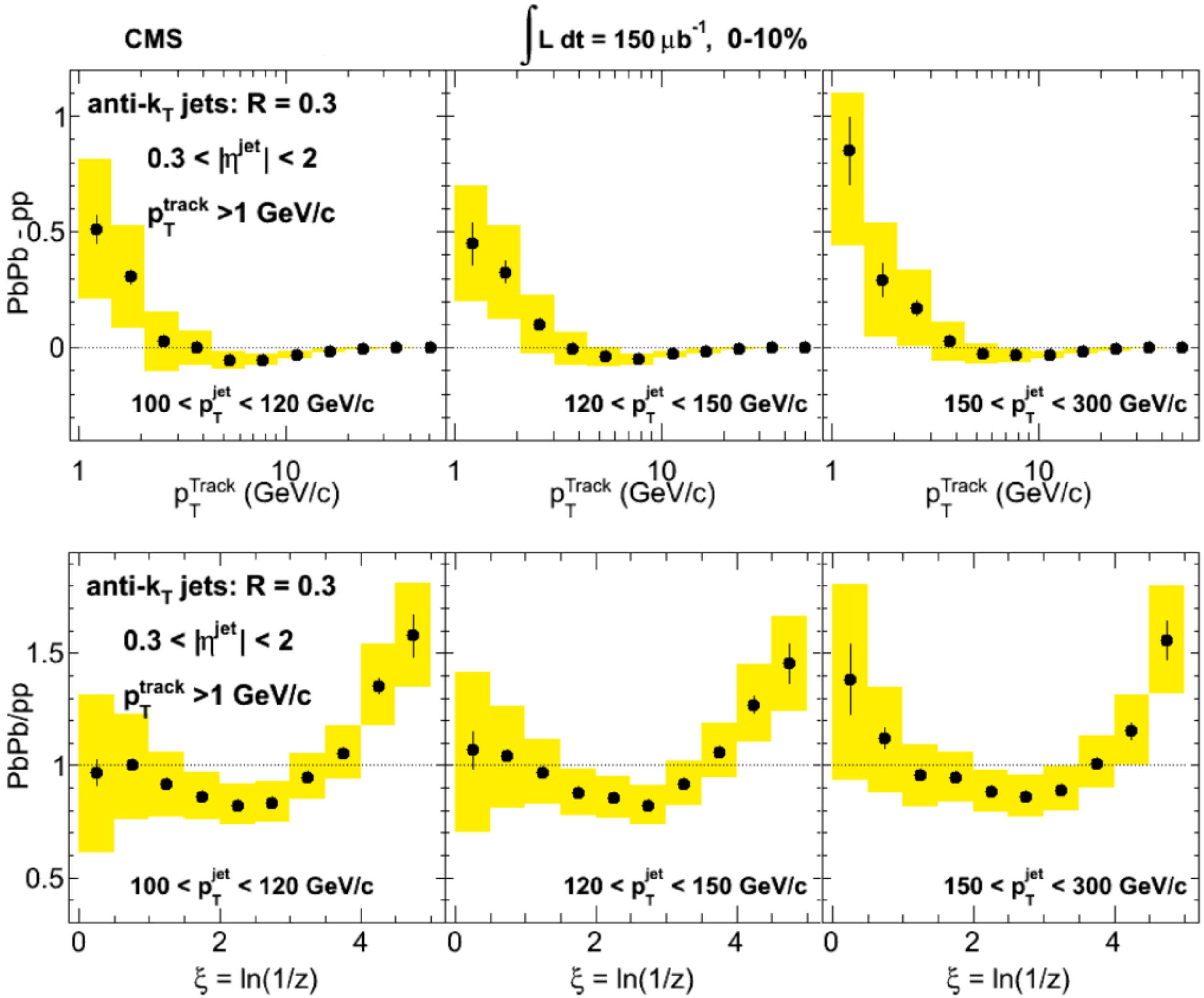
CMS-HIN-12-013 , arxiv:1406.0932



- Enhancement in soft components and reduction in the intermediate range
- Particles' contribution adds up to jet momentum, therefore enhancement and reduction are correlated

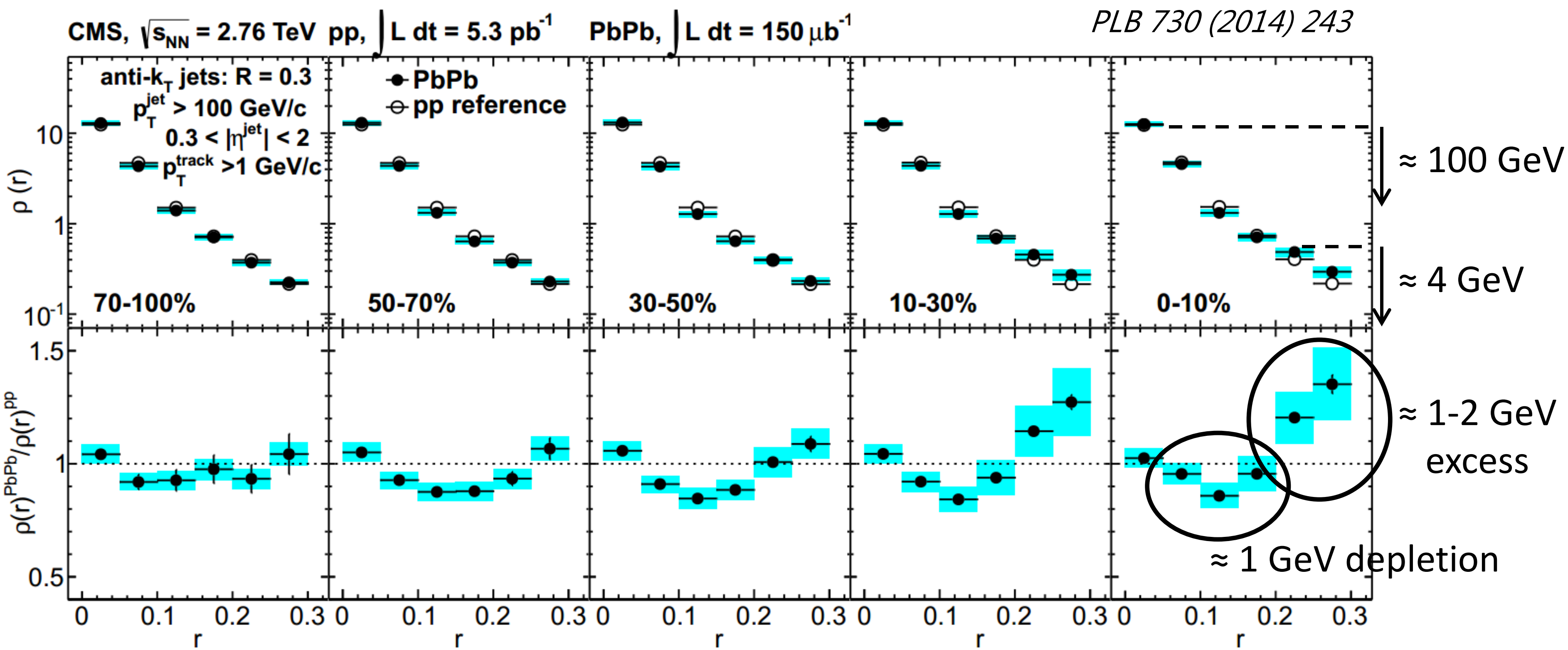
Results - Fragmentation functions

CMS-HIN-12-013 , arxiv:1406.0932



- No significant jet p_T dependence in the modification of fragmentations functions in PbPb.

Results - Jet shapes



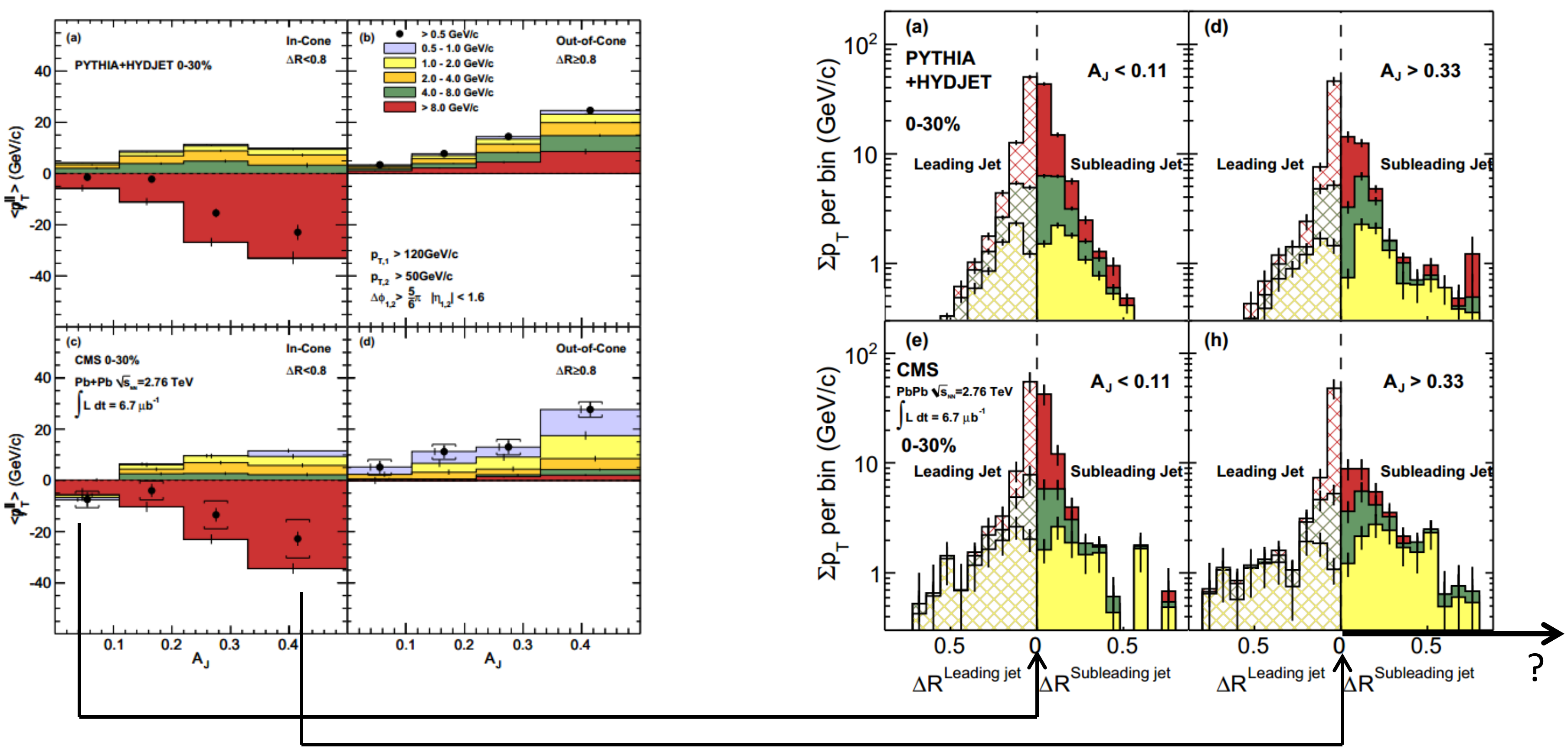
$$\rho(r) = \frac{1}{\delta r}\frac{1}{N_{\text{jet}}}\sum_{\text{jets}}\frac{\sum_{\text{tracks}\in[r_a,\,r_b)} p_T^{\text{track}}}{p_T^{\text{jet}}}$$

Going from peripheral to central events in PbPb:

- Jet core gets narrower
- 1-2 GeV excess of energy density at the skirts of the jet

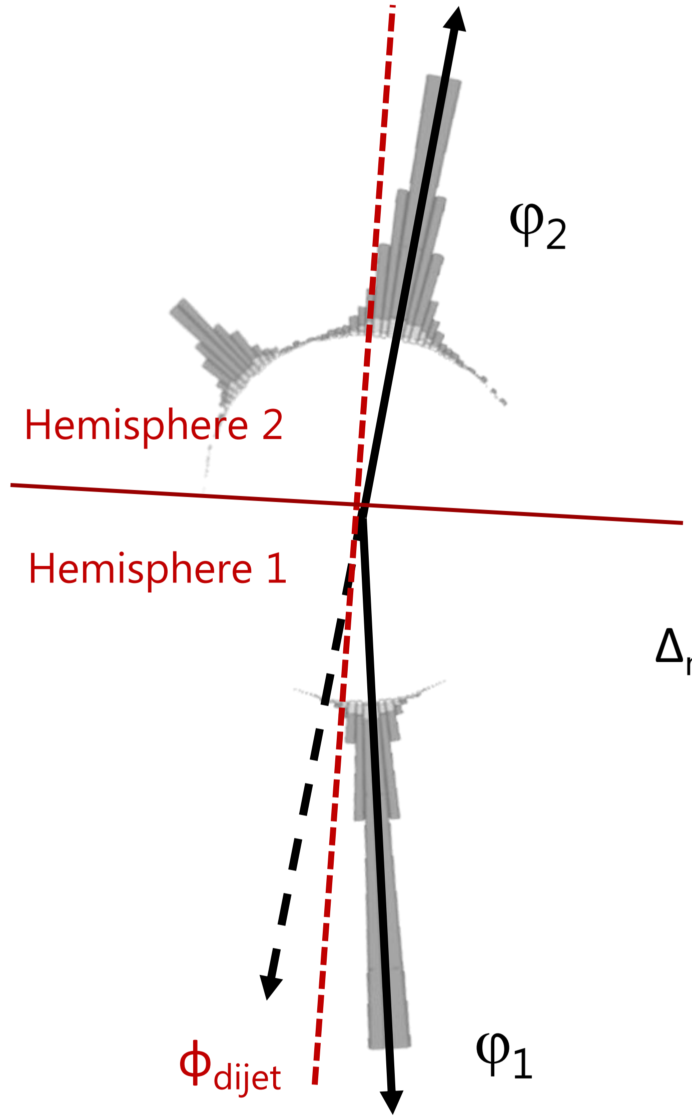
Looking out-of-cone

- In-cone missing p_T is similar in data and MC
- Incone imbalance of the dijet is balanced by low pt particles (p_T < 2 GeV) out-of-the cone in data and harder particles (p_T > 4 GeV) in MC.



PRC 84 (2011) 024906

Dijet measurements



MULTIPLICITY DIFFERENCE

Direction of the dijet is defined as:

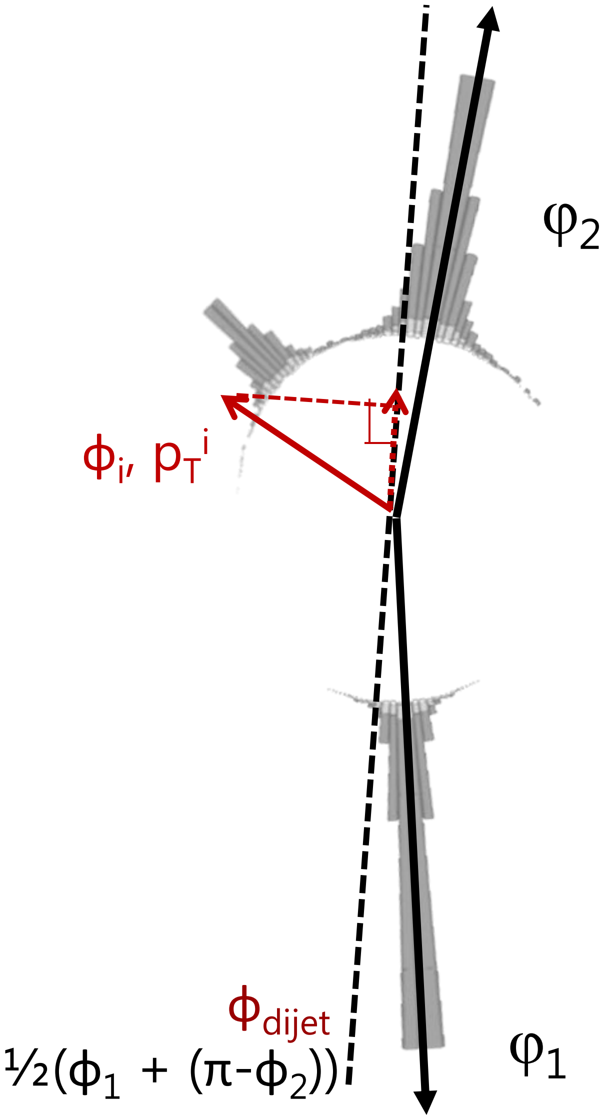
$$\phi_{dijet} = \tfrac{1}{2}(\phi_1 + (\pi - \phi_2))$$

What is the multiplicity of particles that balance the “extra” lost p_T?

Δ_{mult} = Number of charged particles in hemisphere 2 - Number of charged particles in hemisphere 1

Number of charged particles in hemisphere 2	Number of charged particles in hemisphere 1
Subleading jet	Leading jet

Dijet measurements



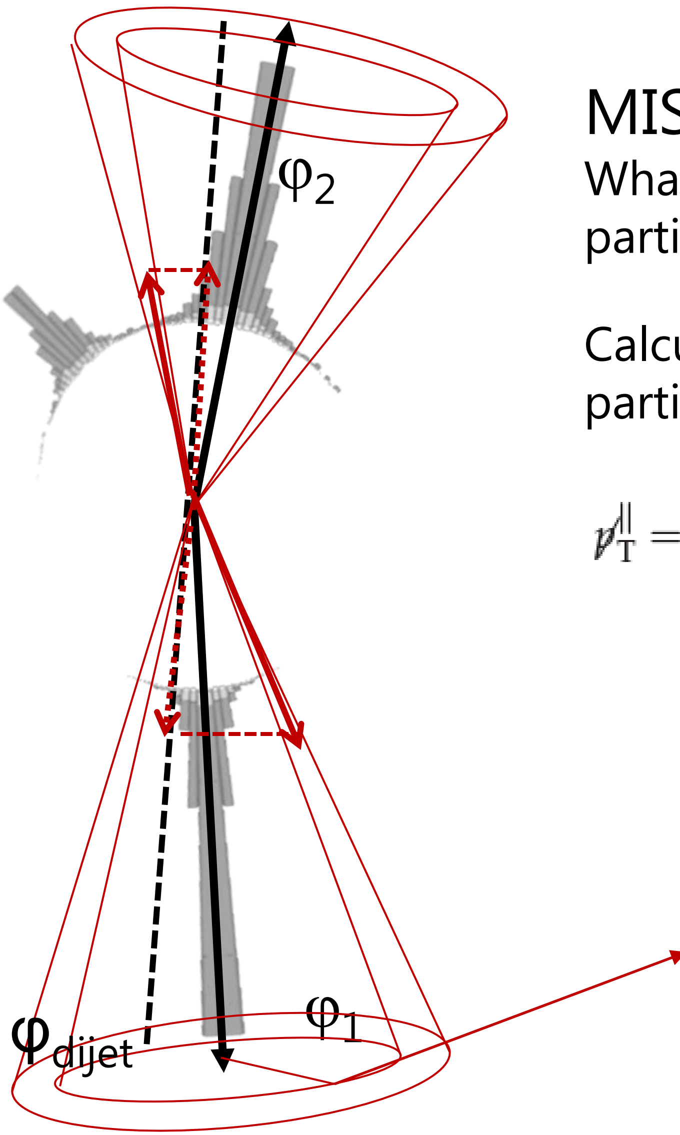
MISSING P_T

What is the multiplicity and spectrum of particles that balance the "extra" lost p_T?

Calculate the missing p_T for charged particles in different p_T ranges

$$\not{p}_{\mathrm{T}}^{\parallel} = \sum_{\mathrm{i}} -p_{\mathrm{T}}^{\mathrm{i}} \cos\left(\phi_{\mathrm{i}} - \phi_{\mathrm{Dijet}}\right)$$

Dijet measurements



MISSING PT VS. ΔR

What is the angular distribution of these particles with respect to the dijet system?

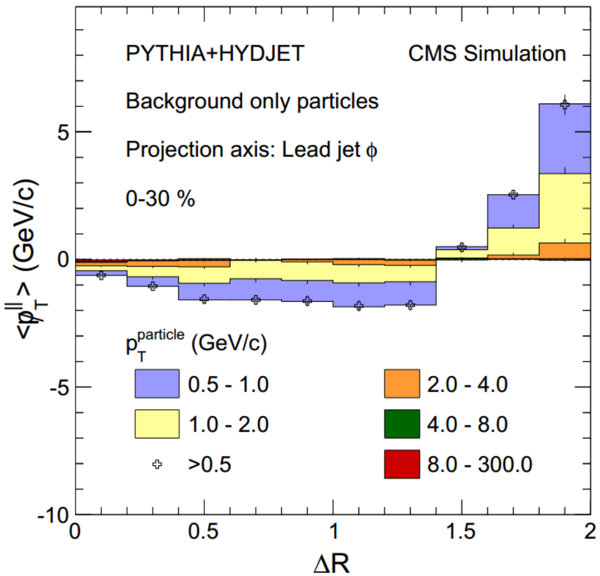
Calculate the missing p_T for charged particles that fall in slices of ΔR

$$\not{p}_{\mathrm{T}}^{\parallel} = \left(\sum_{\mathrm{i}} -p_{\mathrm{T}}^{\mathrm{i}} \cos\left(\phi_{\mathrm{i}} - \phi_{\mathrm{dijet}}\right) \right) \Big|_{R_{\mathrm{down}}<\Delta R<R_{\mathrm{up}}}$$

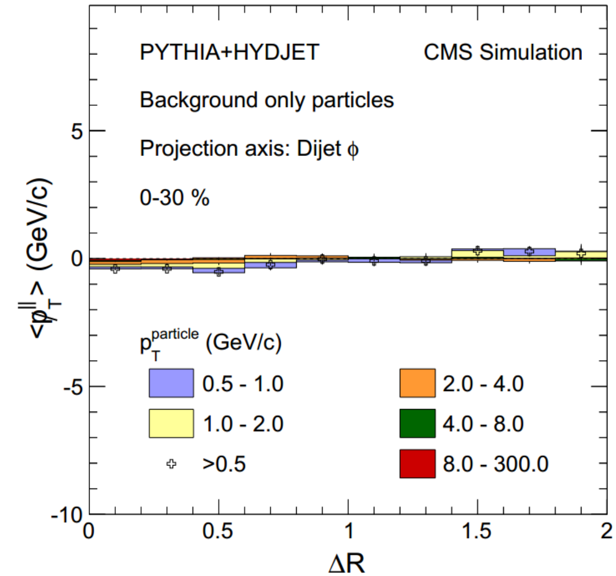
$$\Delta R = \sqrt{\Delta\phi^2_{\mathrm{Trk,jet}} + \Delta\eta^2_{\mathrm{Trk,jet}}}$$

Background cancellation

2011
Projection axis: leading jet



2014
Projection axis: Average dijet direction



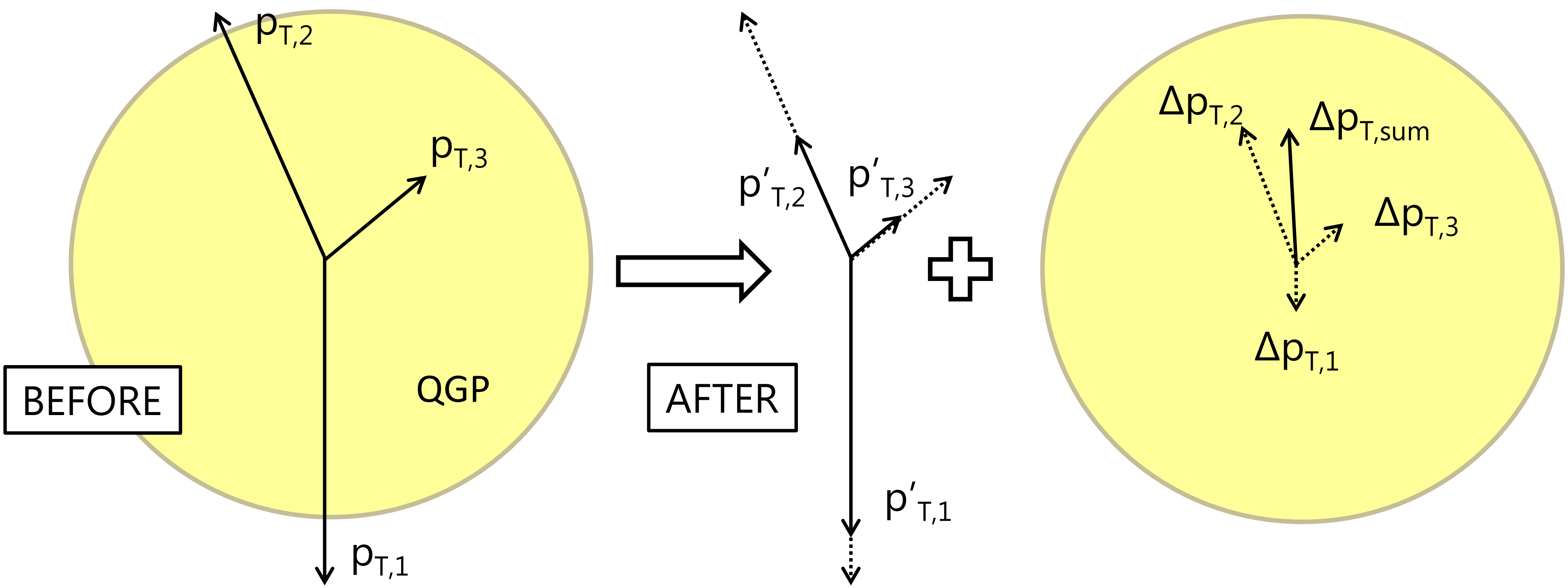
- Current choice of projection axis guarantees cancellation of background due to azimuthal symmetry

Advantage compared to the eta reflection method and the side band subtraction method:

- An effect that is constant as a function of $\Delta\eta$ at a fixed $\Delta\varphi$ can be observed
- Unfortunately, an effect that is constant in $\Delta\varphi$ at a fixed $\Delta\eta$ cannot be observed

Background cancellation

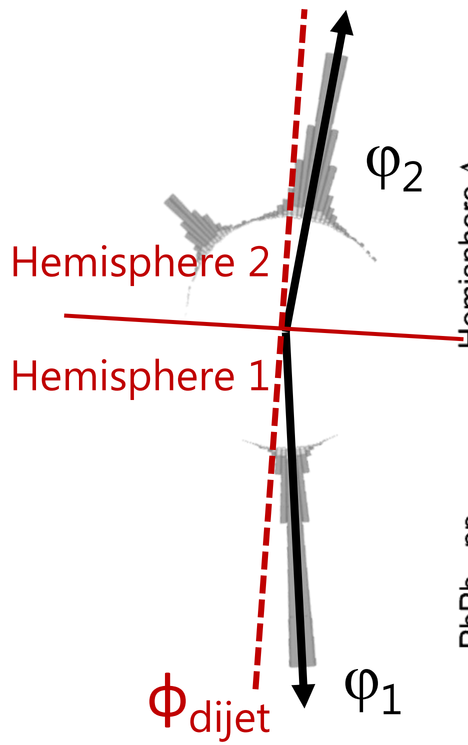
- What part of the momentum which is transferred to the medium can be distributed homogenously in $\Delta\varphi$ with respect to the dijet axis?
- $\Delta p_{T,1} + \Delta p_{T,2} + \Delta p_{T,3} - \Delta p_{T,sum}$

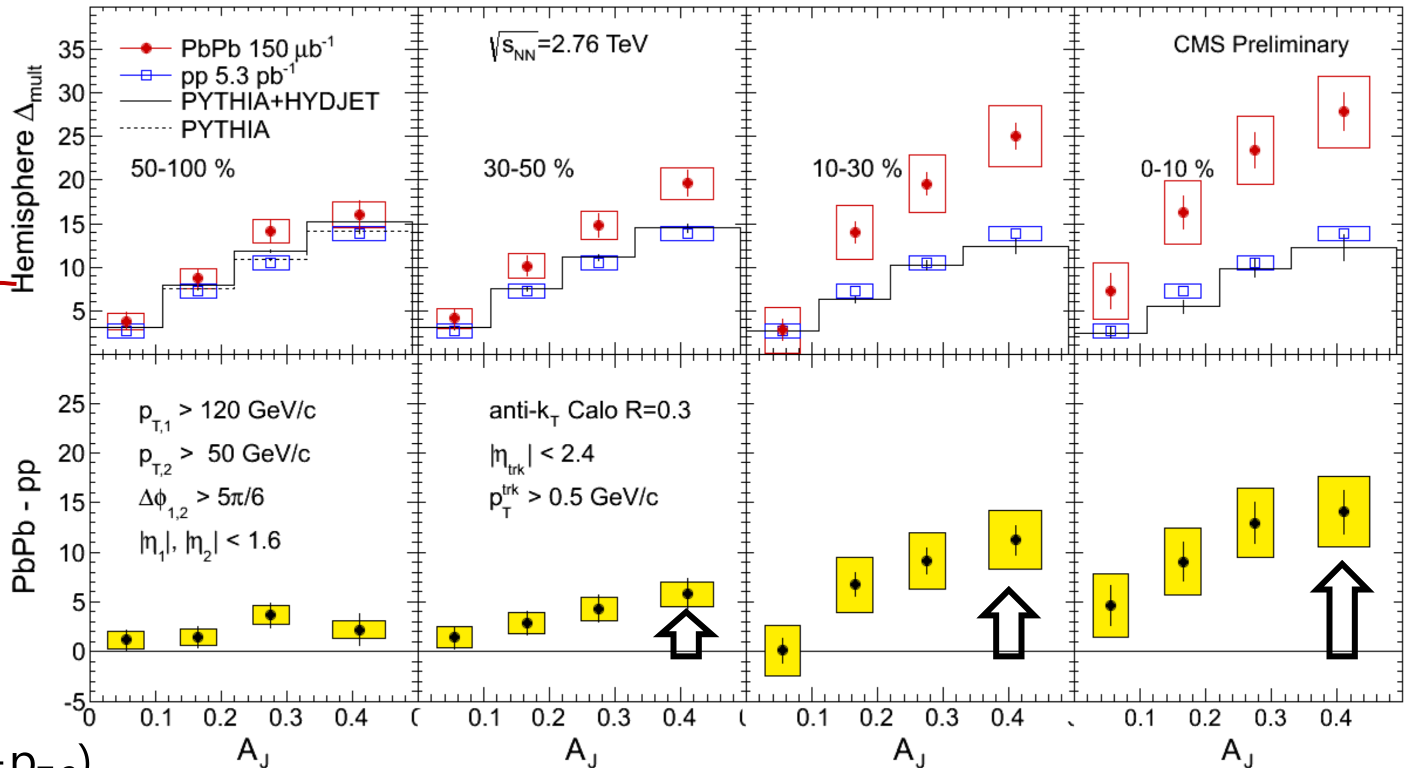


The vectoral sum of momentum after quenching
=
The vectoral sum momentum before quenching

Results - Multiplicity difference

CMS-PAS-HIN-14-010



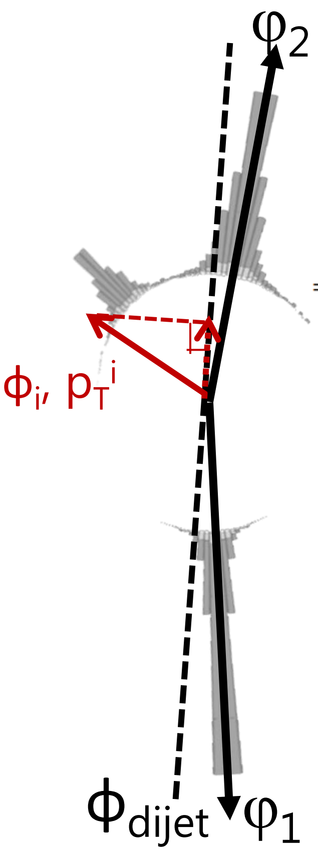


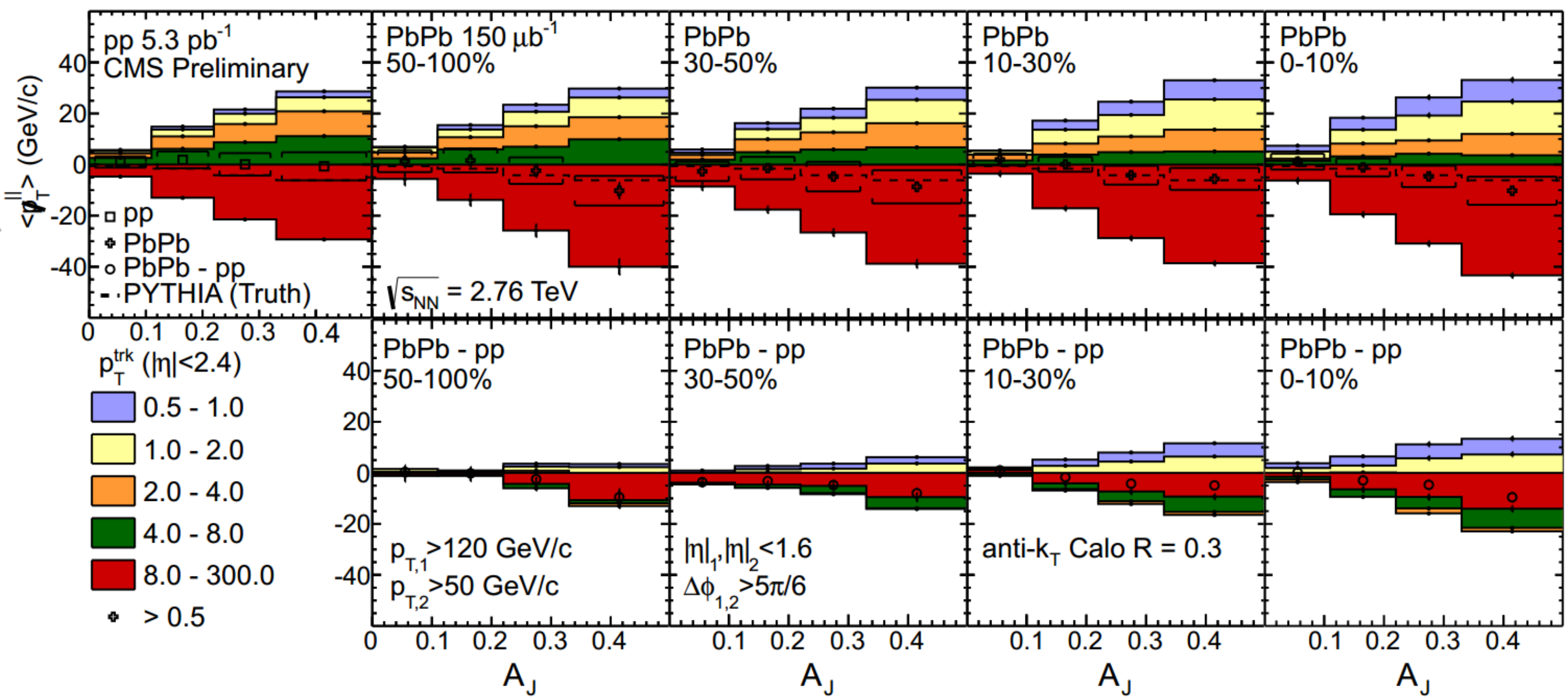
$A_J = (p_{T,1}-p_{T,2})/(p_{T,1}+p_{T,2})$

- Multiplicity difference (in acceptance) increases as a function of A_J
- The increase is larger in PbPb
- The enhancement in PbPb compared to pp increases with centrality.
  - Large A_J, 0-10% $\longrightarrow$ 15 extra particles

Results - Missing p_T vs. A_J

CMS-PAS-HIN-14-010

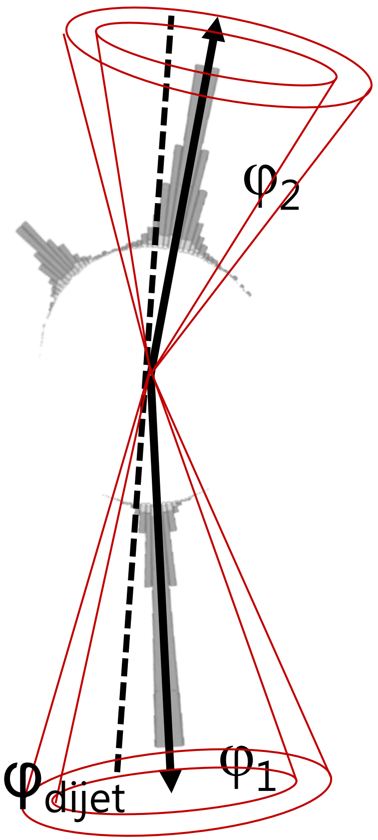


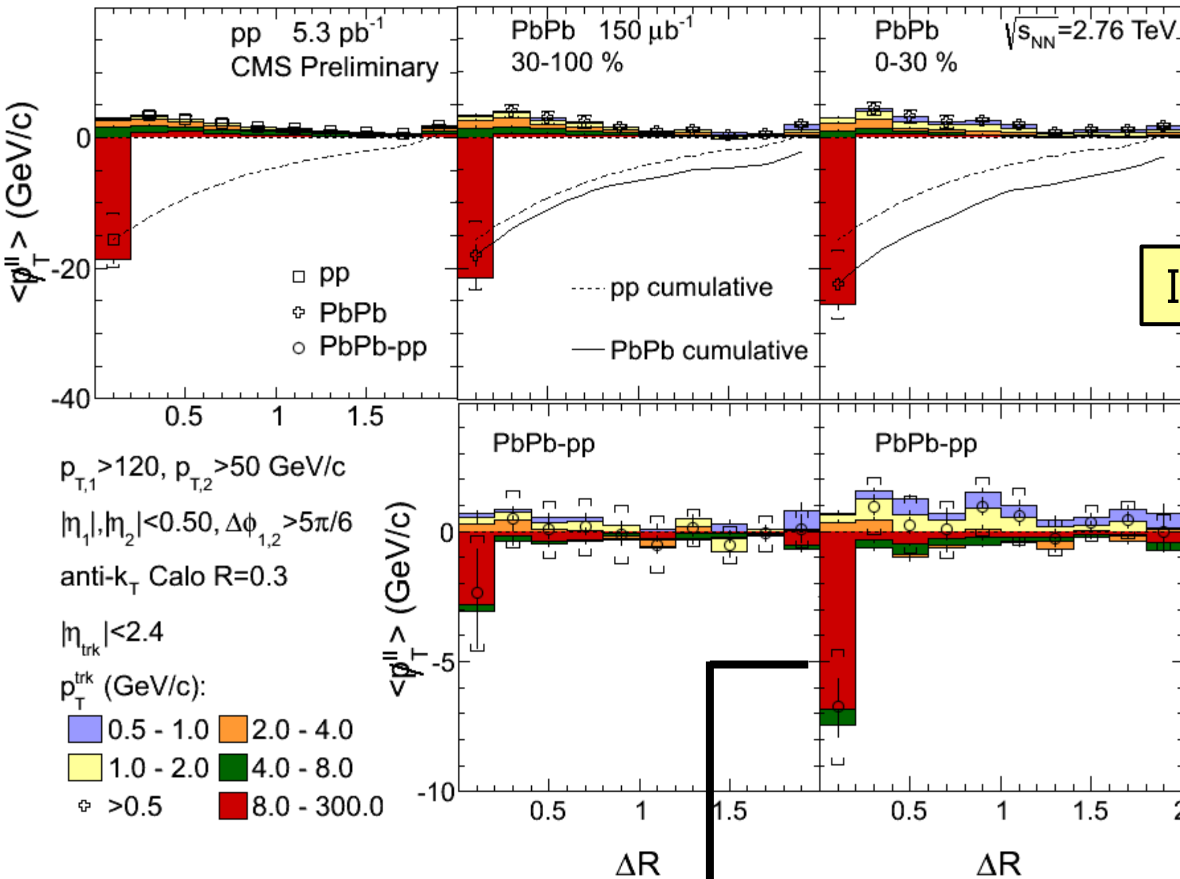


- Access to high p_T particles increases as a function of A_J
- In pp ⟶ Balanced by 2-8 GeV/c particles
- In PbPb ⟶ Balanced by particles with p_T < 2 GeV/c

Results - Missing p_T vs. ΔR

CMS-PAS-HIN-14-010





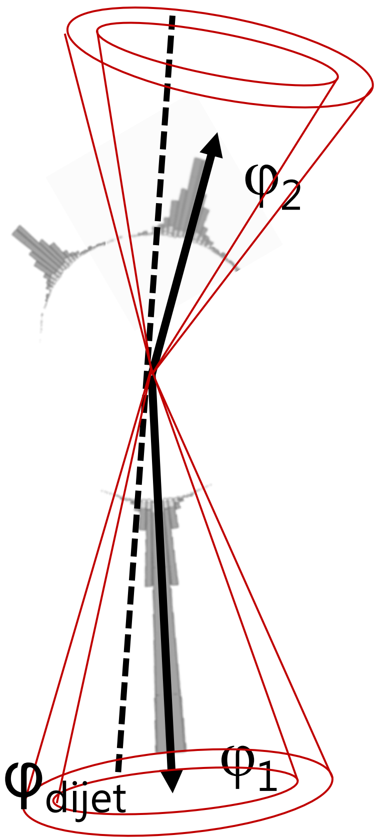
Inclusive A_J

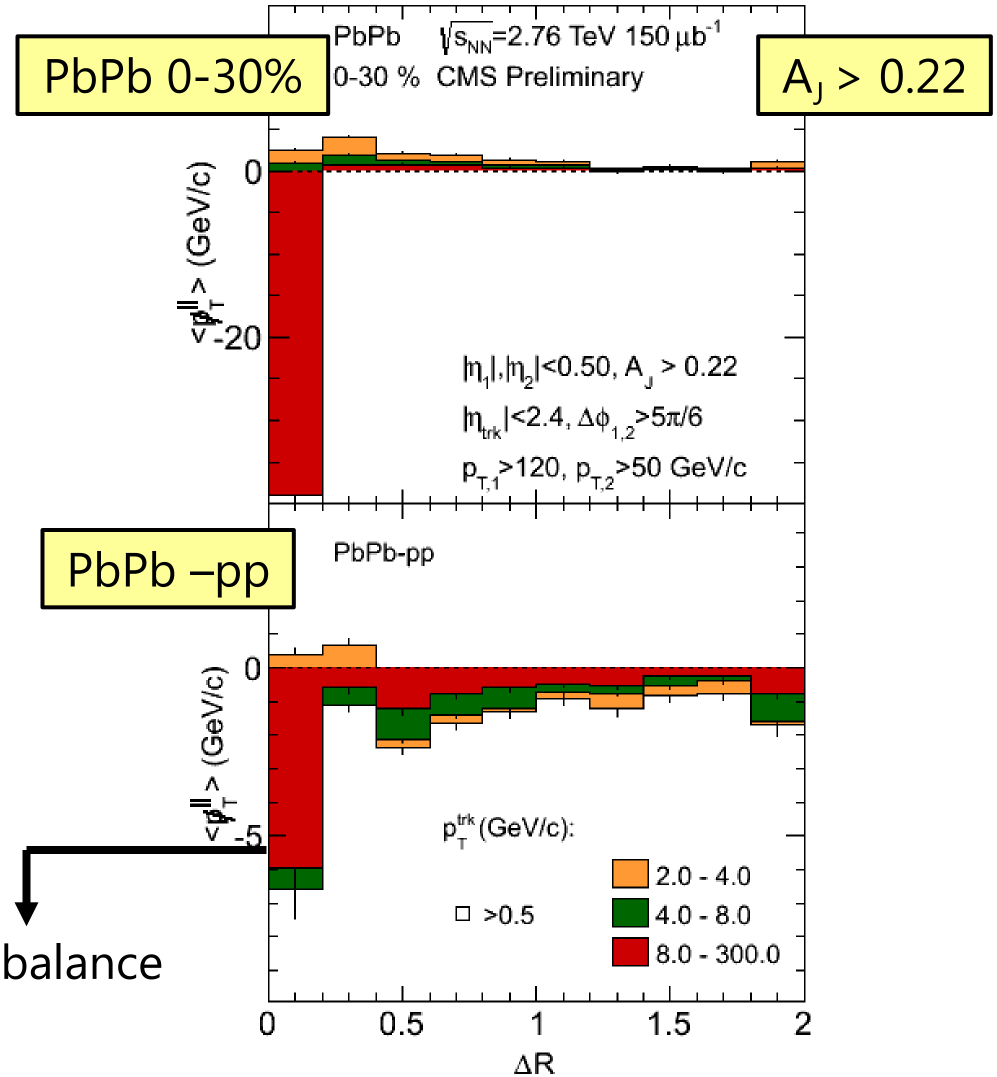
High p_T imbalance at small ΔR

Balanced by low p_T particles in subleading jet direction
Extends upto large ΔR

Results - Missing p_T vs. ΔR

CMS-PAS-HIN-14-010

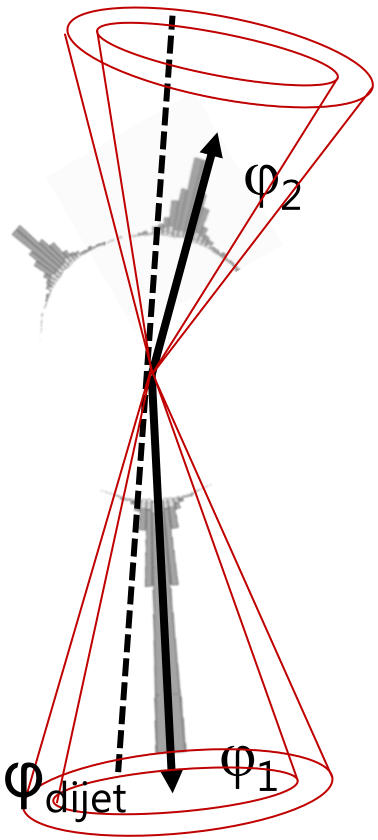


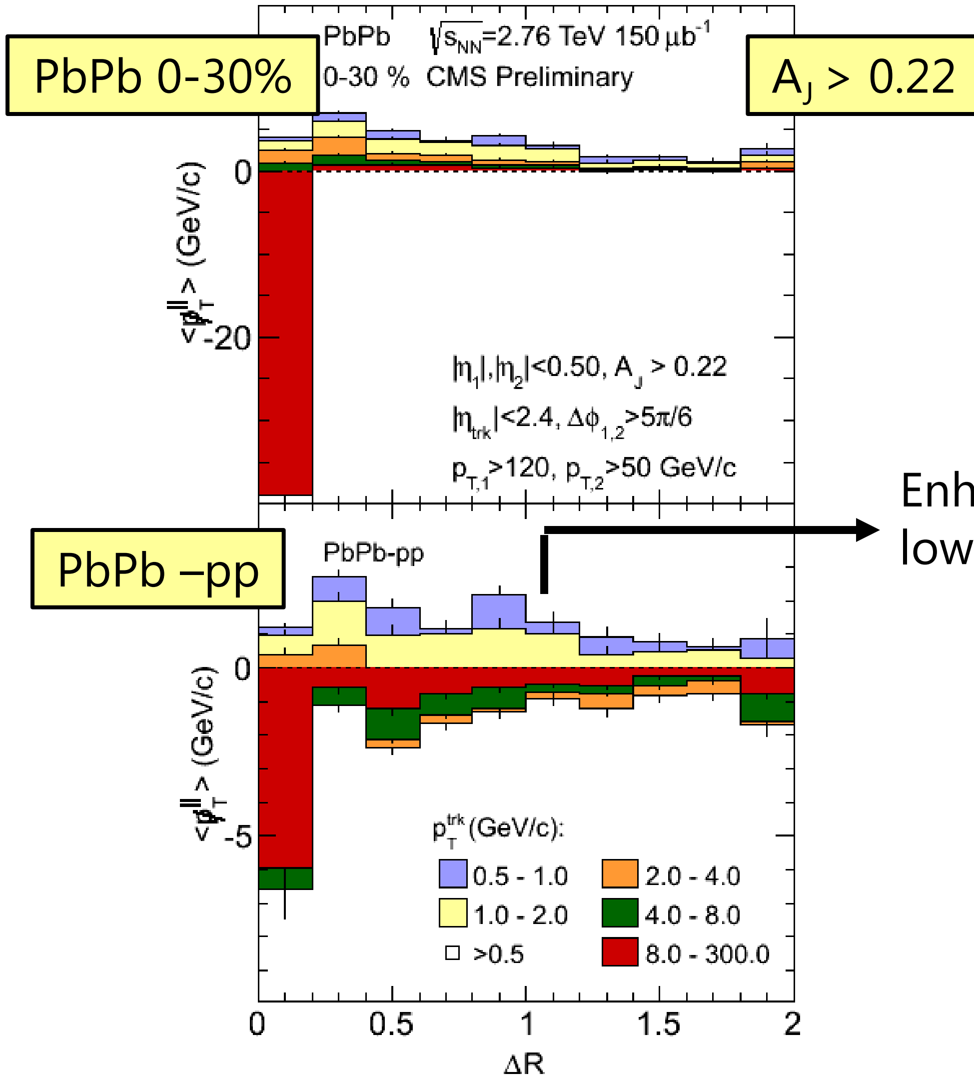


Larger imbalance in PbPb

Results - Missing p_T vs. ΔR

CMS-PAS-HIN-14-010





Enhancement of low p_T particles

Results - Missing p_T vs. ΔR

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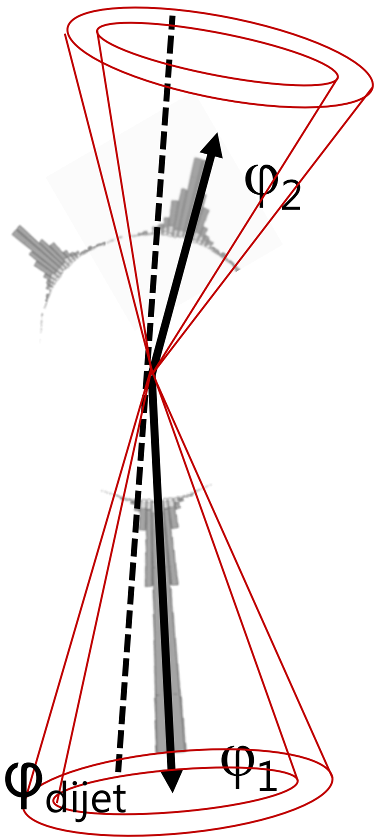
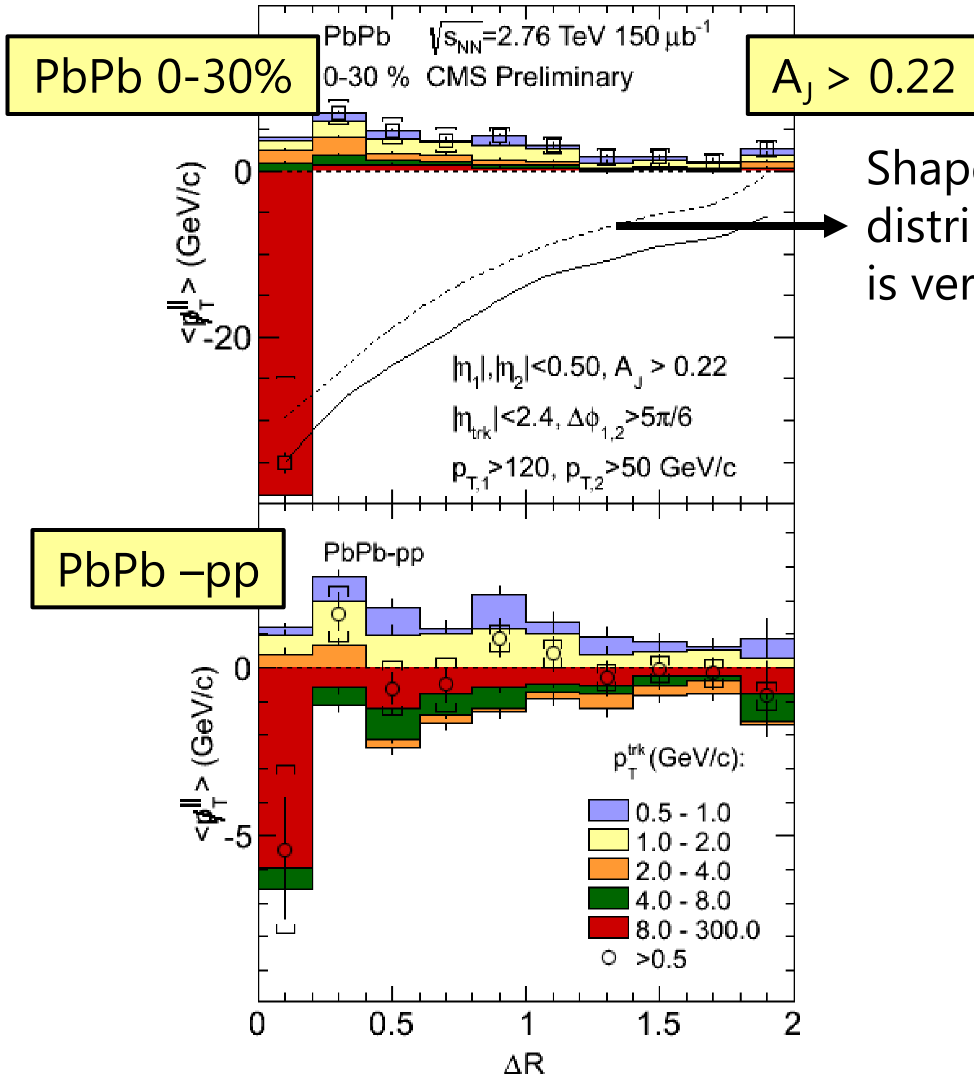




Shape of the balancing distribution in pp and PbPb is very similar

Summary

Inclusive jets

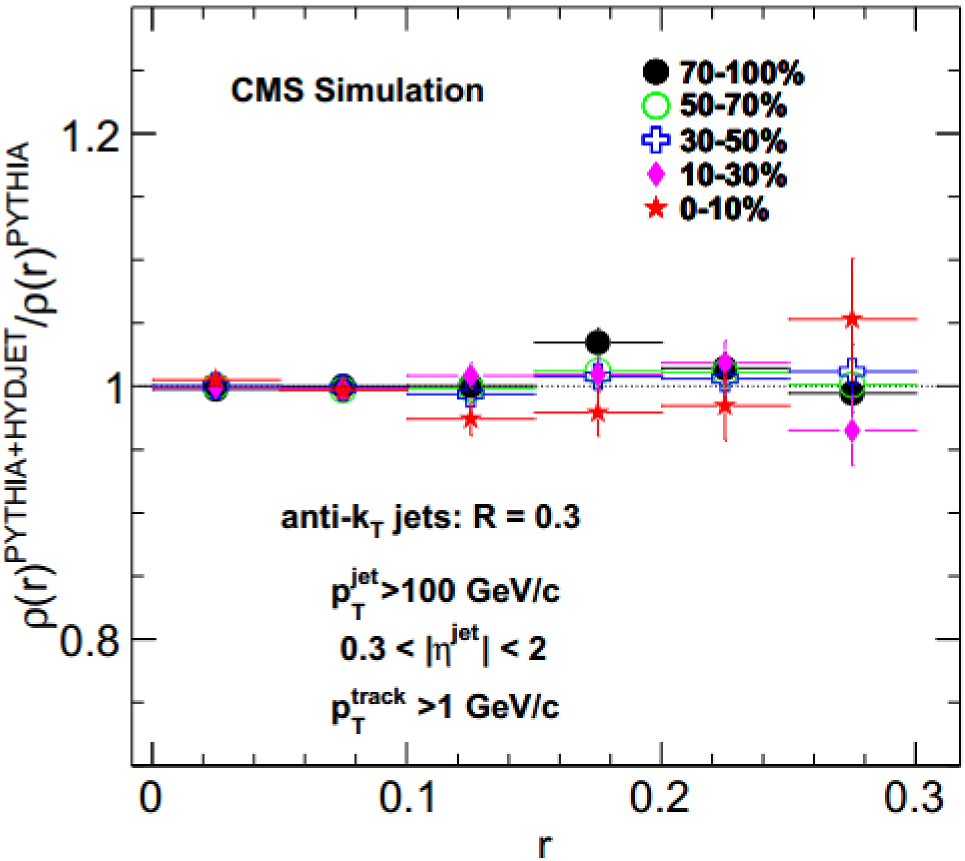
- CMS results provide detailed information about modification of momentum flow inside the jet cone
  - Fragmentation functions in PbPb show an enhancement of charged particles with large ξ and small p_T
  - Jet shapes in PbPb are narrower in the core region of the jet but broader at its edge

Dijets

- The dijet in-cone momentum imbalance is compensated by:
  - PbPb: Low p_T charged particles (0.5-2 GeV/c)
  - pp: Particles in the p_T = 2-8 GeV/c range
- A larger multiplicity of associated particles is seen in PbPb compared to pp.
- The effect persists upto ΔR=1.8

BACK-UP

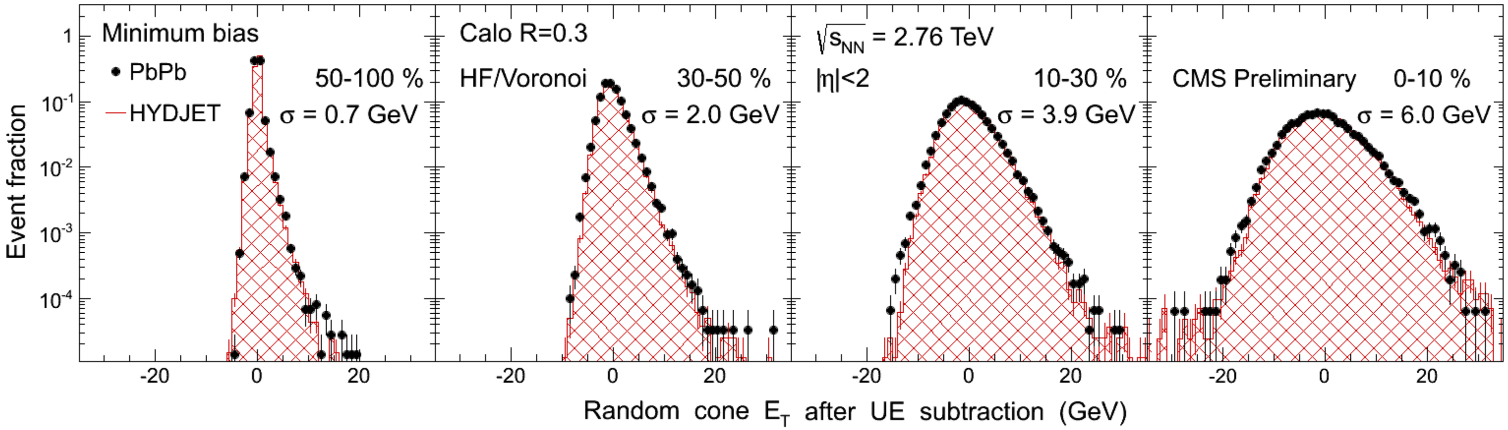
Background subtraction



- Background subtraction uncertainty in on jet shapes in bins of centrality

Performance of UE subtraction

Sum of E_T of UE subtracted calo towers that fall in R=0.3 in random directions in MB events:



Good agreement between data and MC

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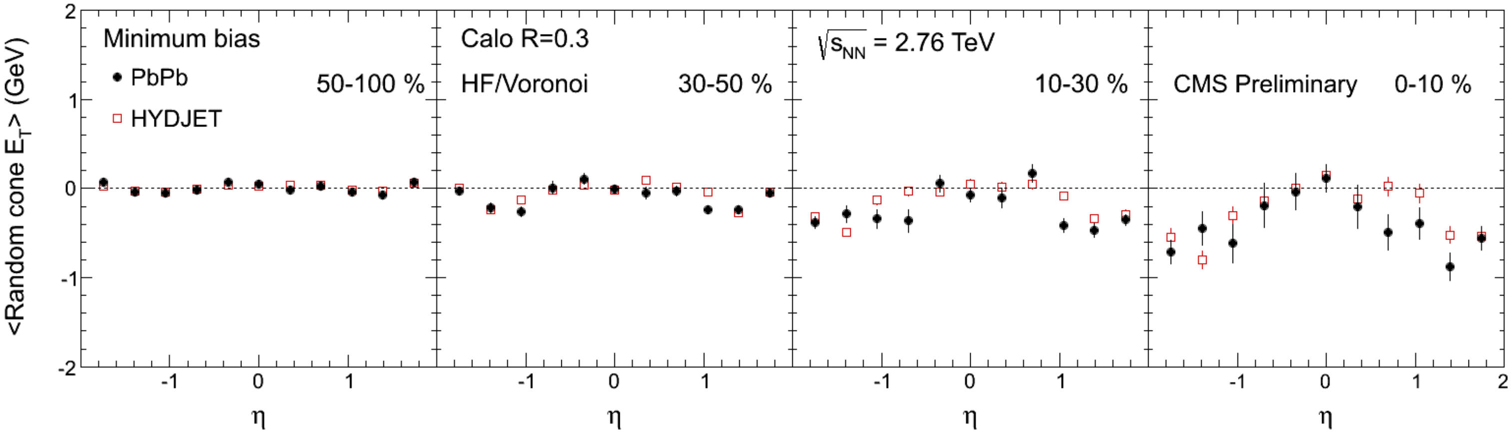
Mean random cone E_T as a function of η:

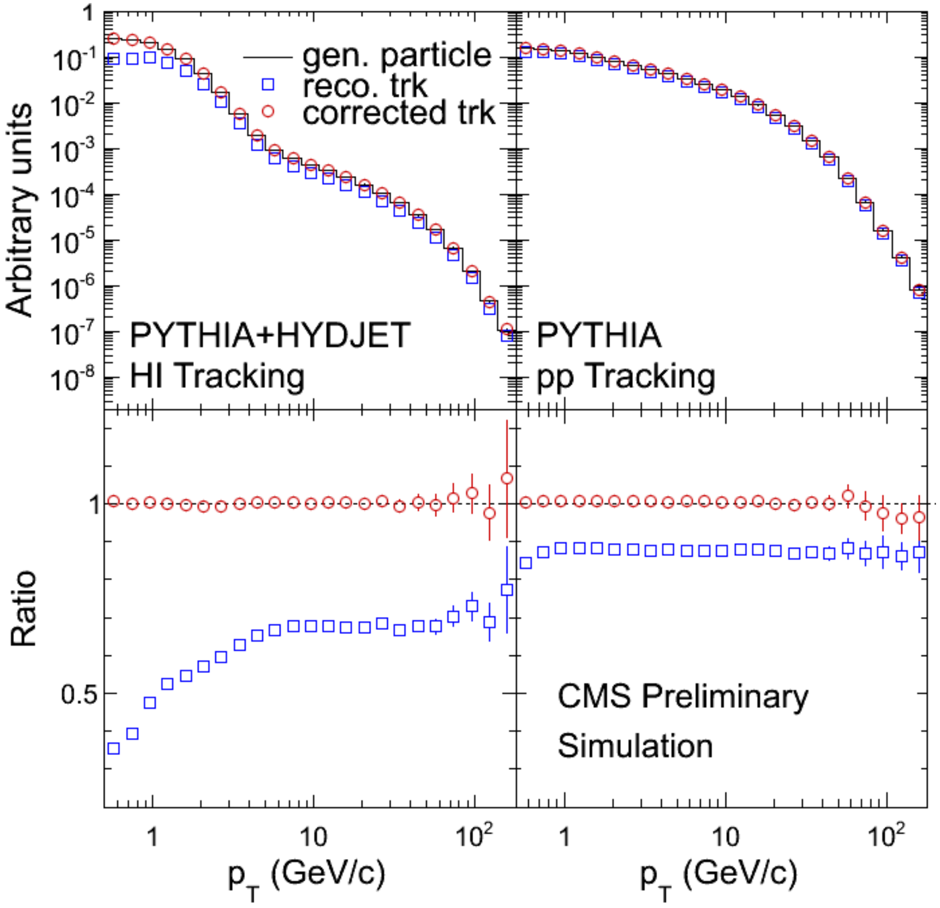


Deviation from zero <0.5-1 GeV

Track corrections

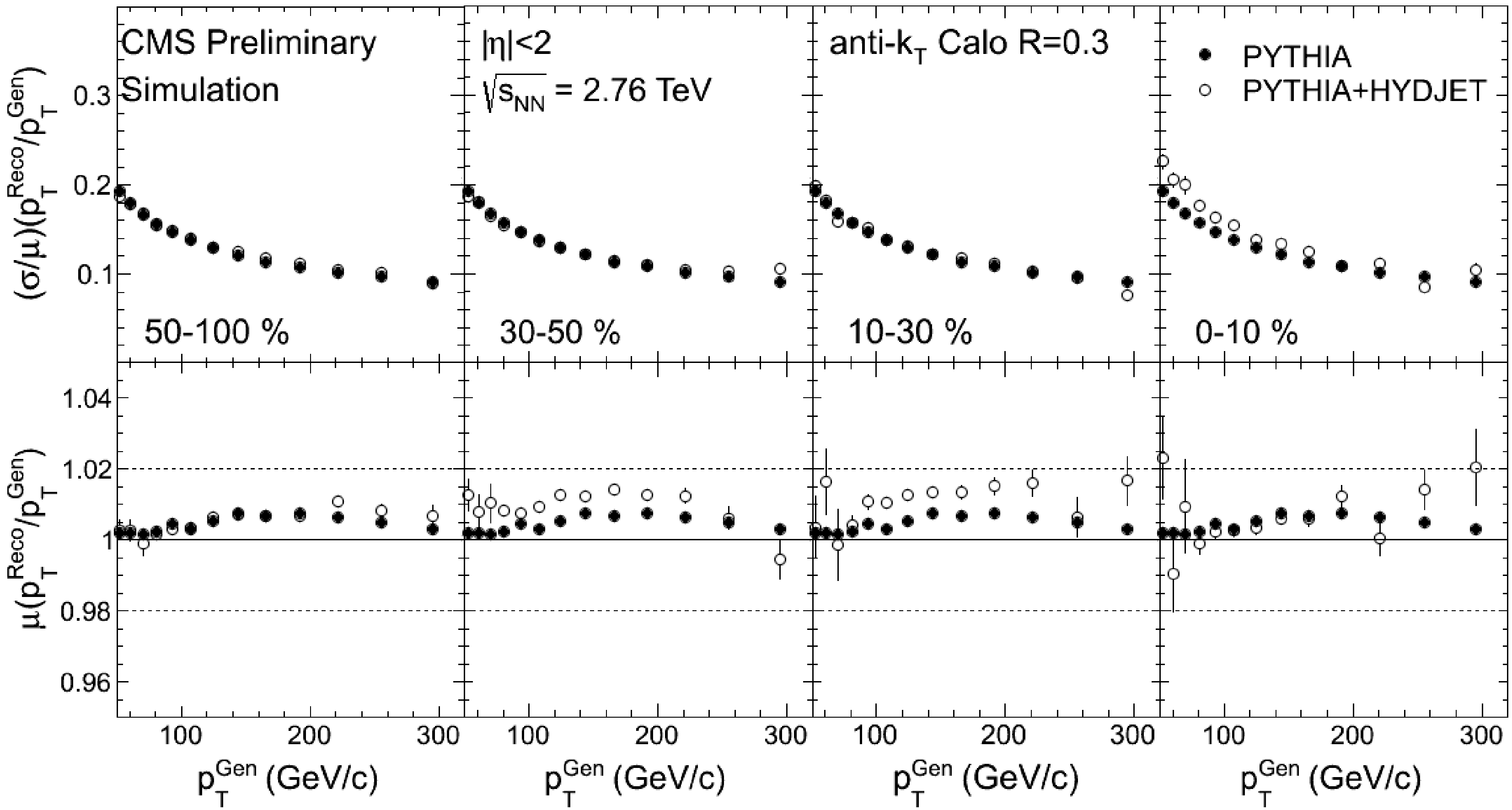
CMS-PAS-HIN-14-010

- Tracks are corrected for reconstruction efficiency, fake rate (both in pp and PbPb) and secondary particles (in pp).
- After the corrections reconstructed track distributions agree with generator-level charged particle distributions in:
  - η
  - φ
  - p_T
  - Distance to a jet axis
  - centrality



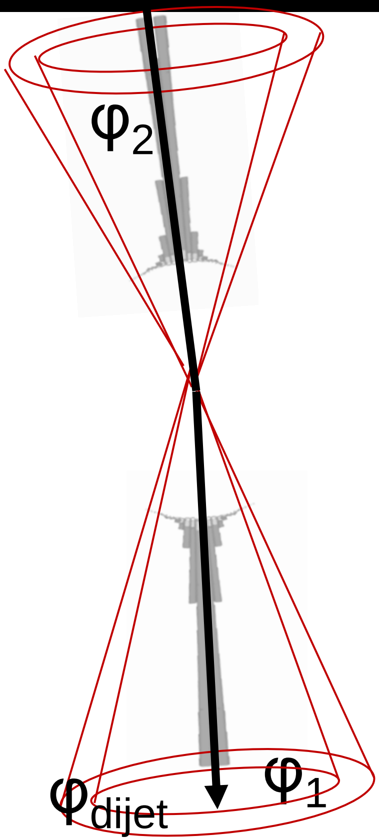
Jet corrections

CMS-PAS-HIN-14-010



- Jet p_T scale is calculated within 2% accuracy.

Results - Missing p_T vs. ΔR



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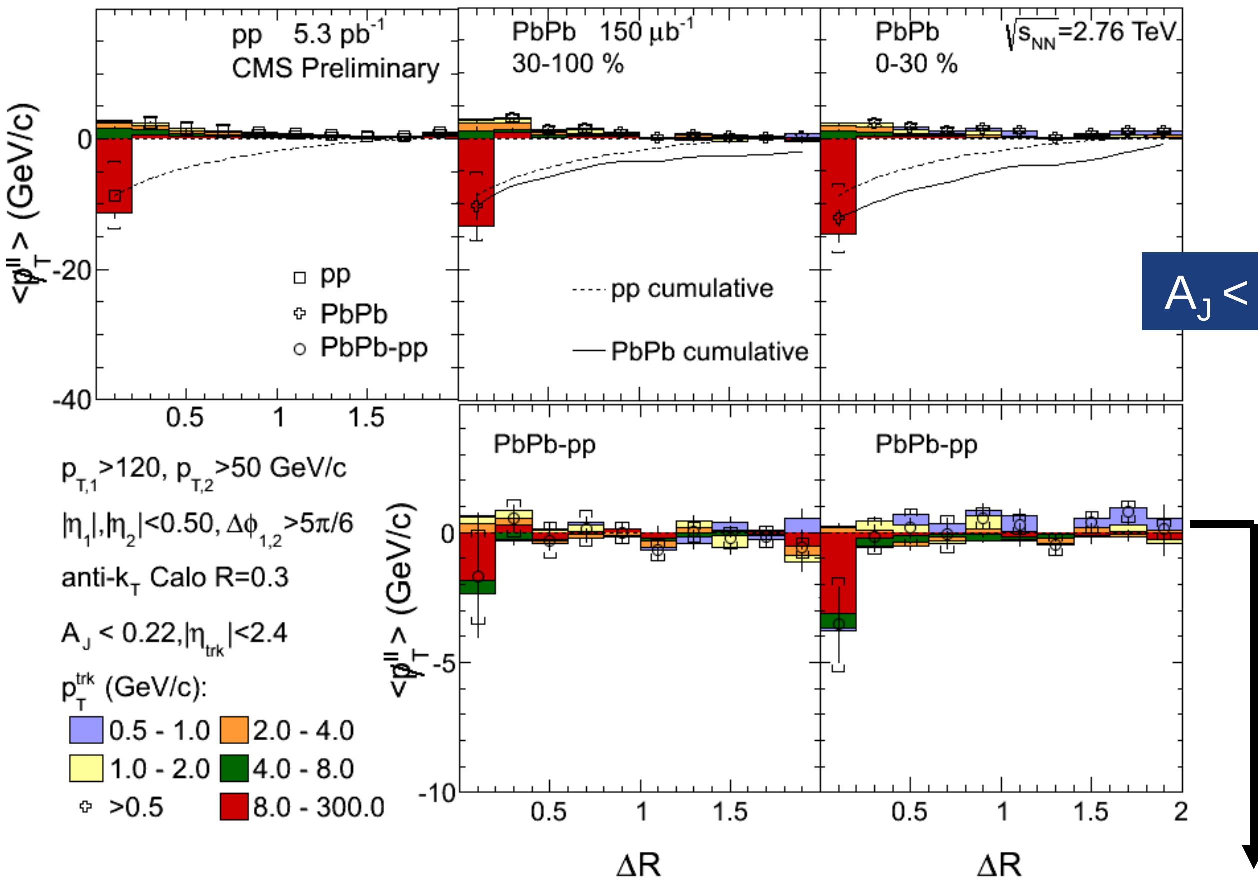

$A_J < 0.22$

Already small enhancement of low p_T charged particles

Results - Missing p_T vs. ΔR

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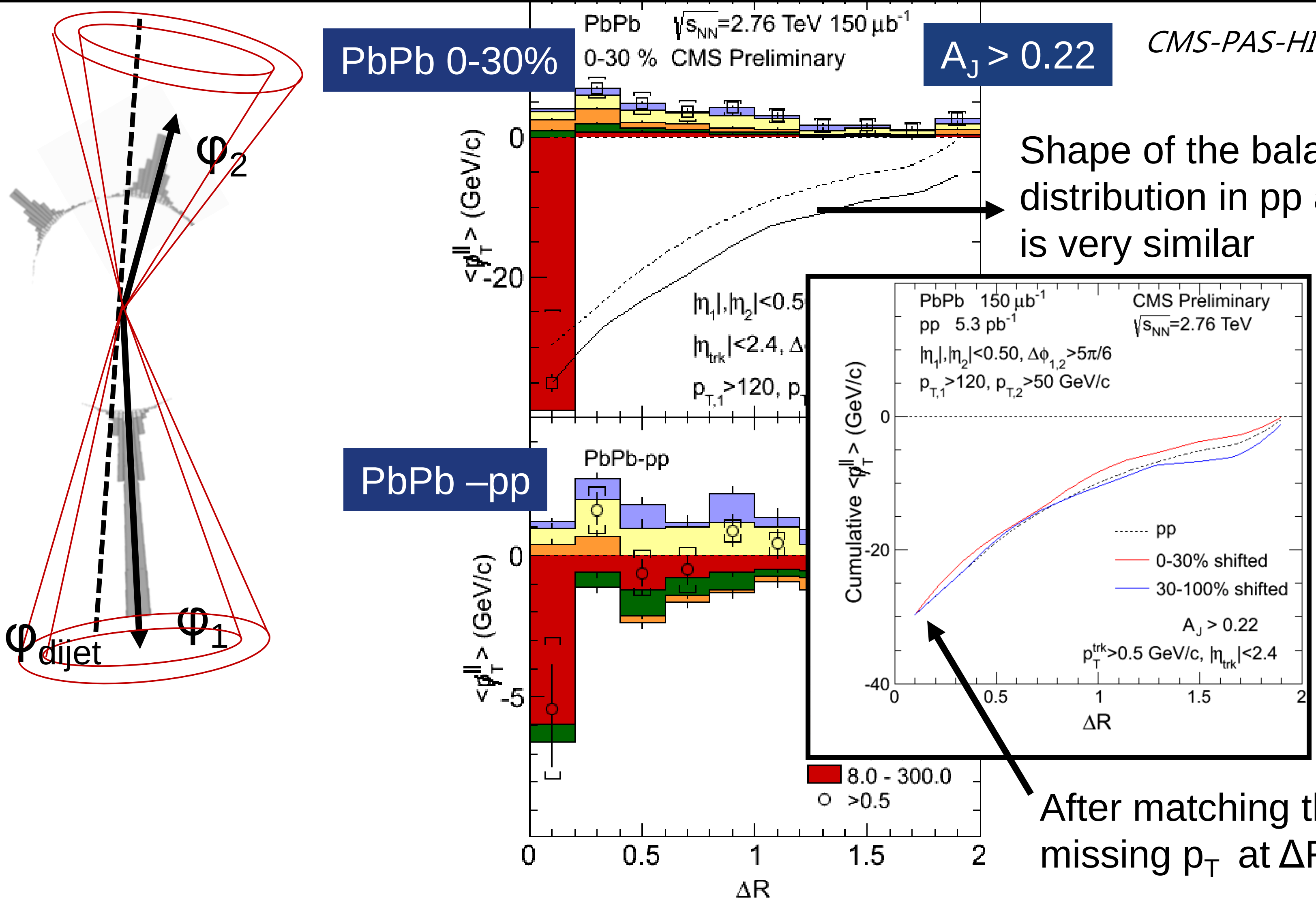

Shape of the balancing distribution in pp and PbPb is very similar

After matching the missing p_T at ΔR<0.2