Latest CMS Heavy-Ion Results on Jets

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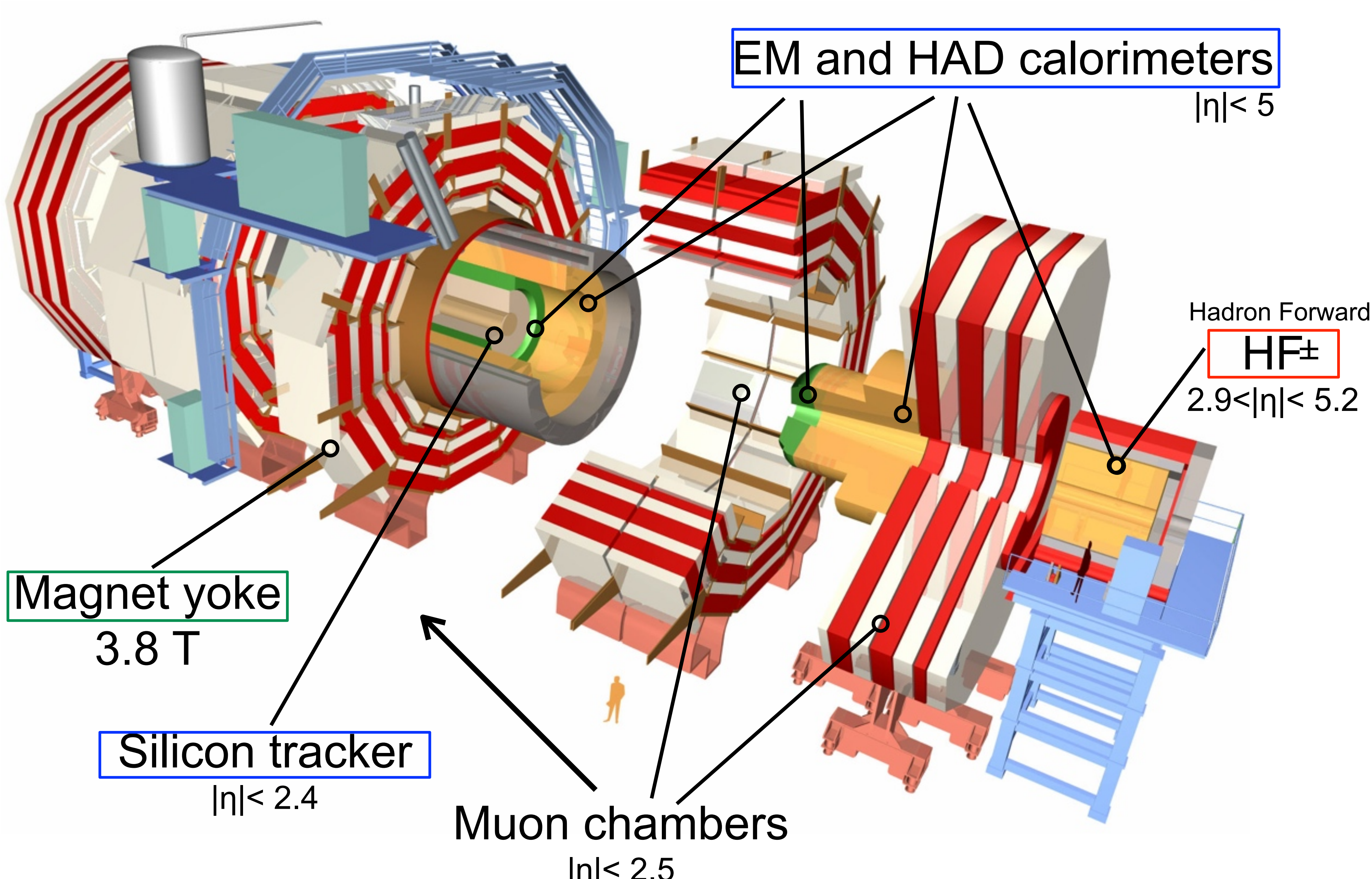
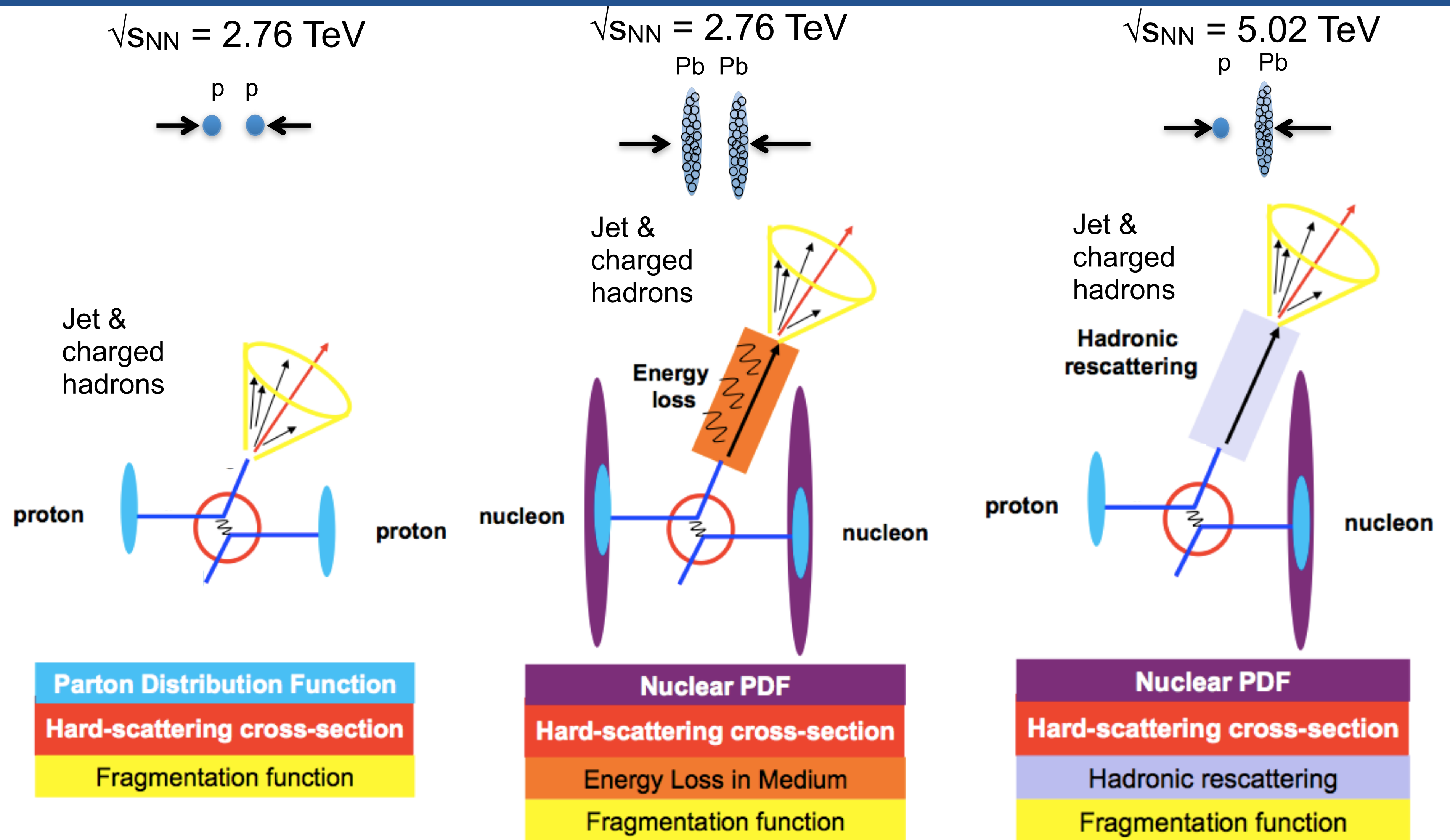
for the CMS Collaboration

LHCP
June 3, 2014

Compact Muon Solenoid (CMS)



What we measure

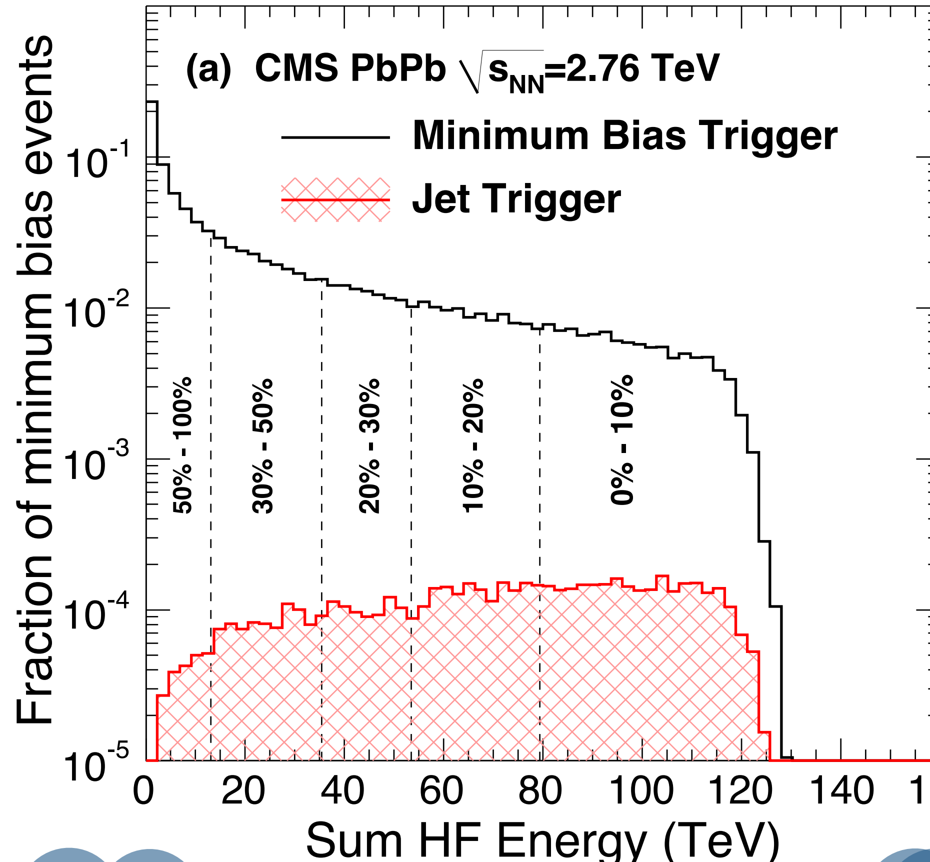


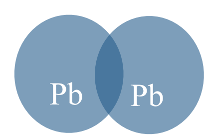
Jets: back-to-back dijets or inclusive, anti-kT algorithm, R=0.3, remove heavy ion underlying event with iterative "pileup" or Voronoi/HF algorithm

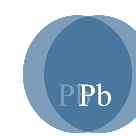
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Centrality in heavy ion collisions

- In PbPb: centrality indicates:
  - ✤ Nuclear overlap
  - ✤ Number of nuclear partonic interactions
- Use the total energy measured in HF, split into percent centrality
- Glauber model of nucleon-nucleon scattering relate measurement to:
  - ✤ $\langle N_{part} \rangle$: average number of participants
  - ✤ $\langle N_{coll} \rangle$: average number of nucleon collisions







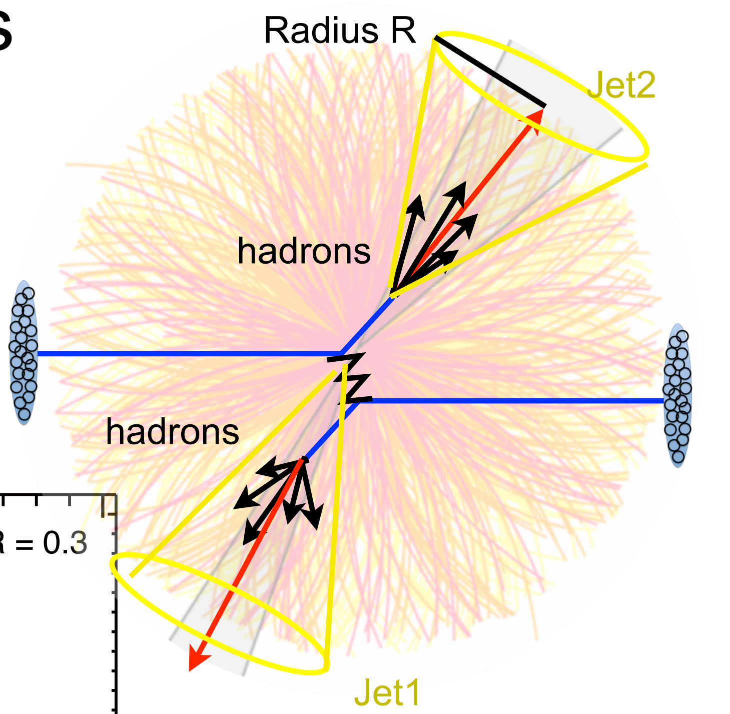
Jet trigger selects more central events

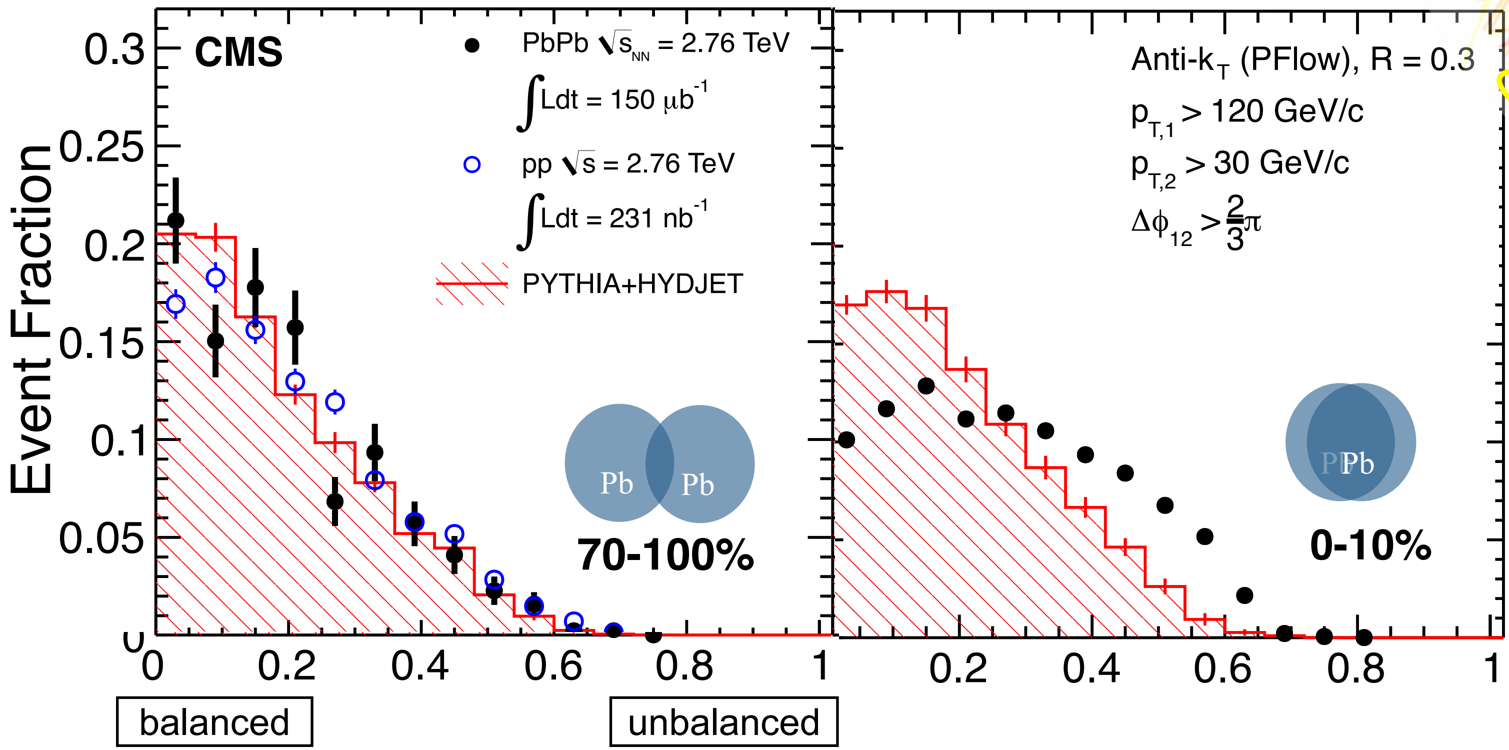
M.L. Miller et al., Glauber modeling in high energy nuclear collisions, Ann. Rev. Nucl. Part. Sci **57** (2007) 205

CMS: PRC 84 (2011) 024906

What we know about jet quenching

- Strongly interacting QGP quenches jets
- In central PbPb collisions, there are more unbalanced dijets than in pp (or Monte Carlo)





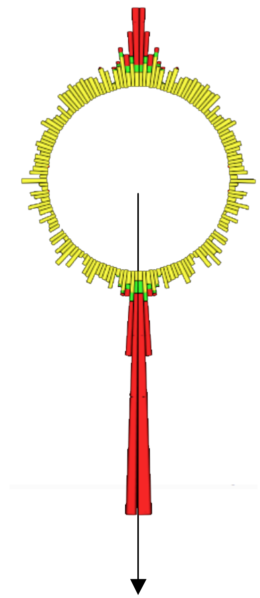
$A_J = (p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$

CMS: PLB 712 (2012) 176

What happened to quenched p_T?

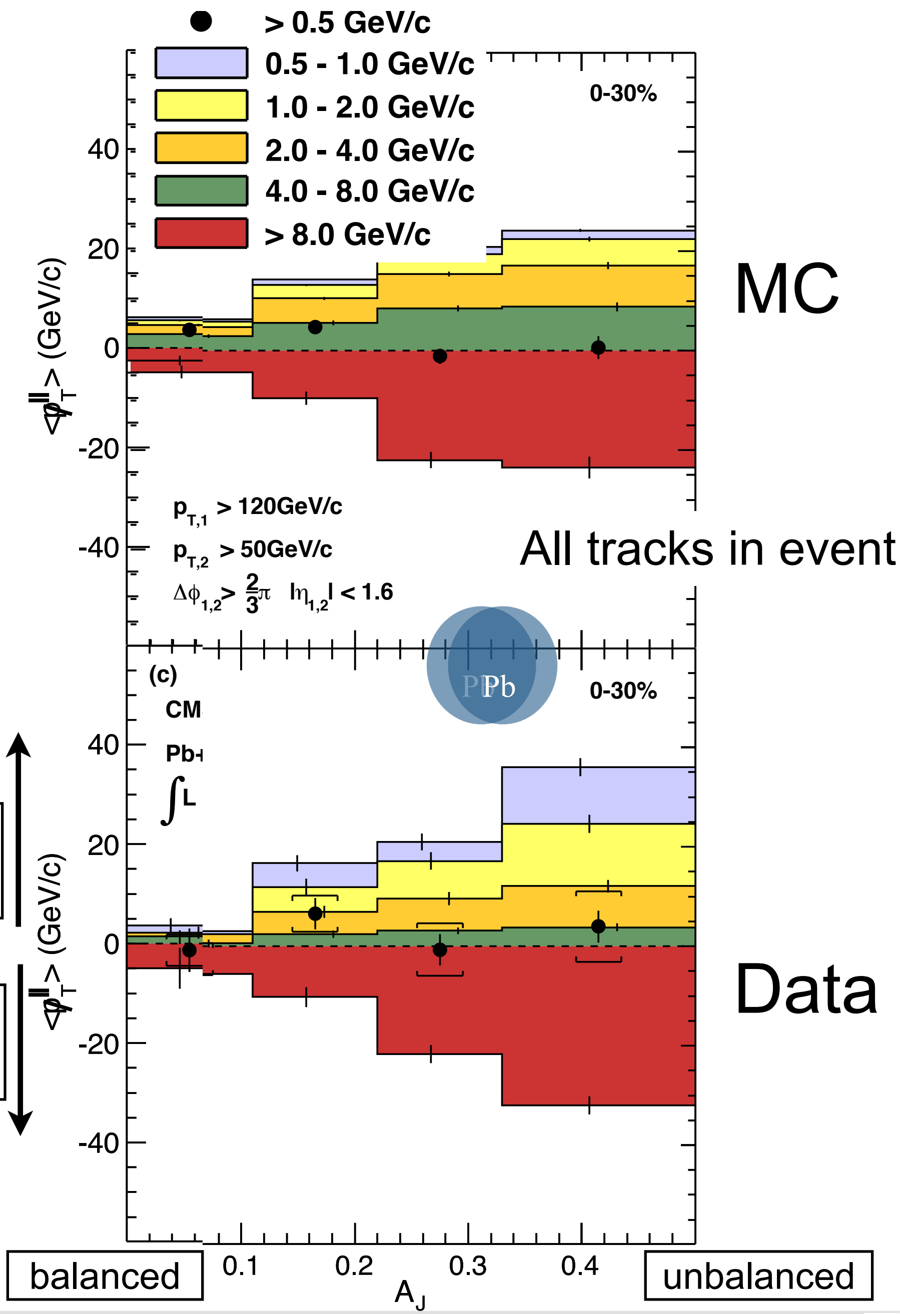
$$\not{p}_T^{||} \equiv \sum_{\text{tracks}} -p_{\mathrm{T,track}} \cos\left(\phi_{\text{track}} - \phi_{\text{leading jet}}\right)$$

- Sum over tracks projected onto the leading jet axis



excess away from leading jet

excess towards leading jet



CMS: PRC 84 (2011) 024906

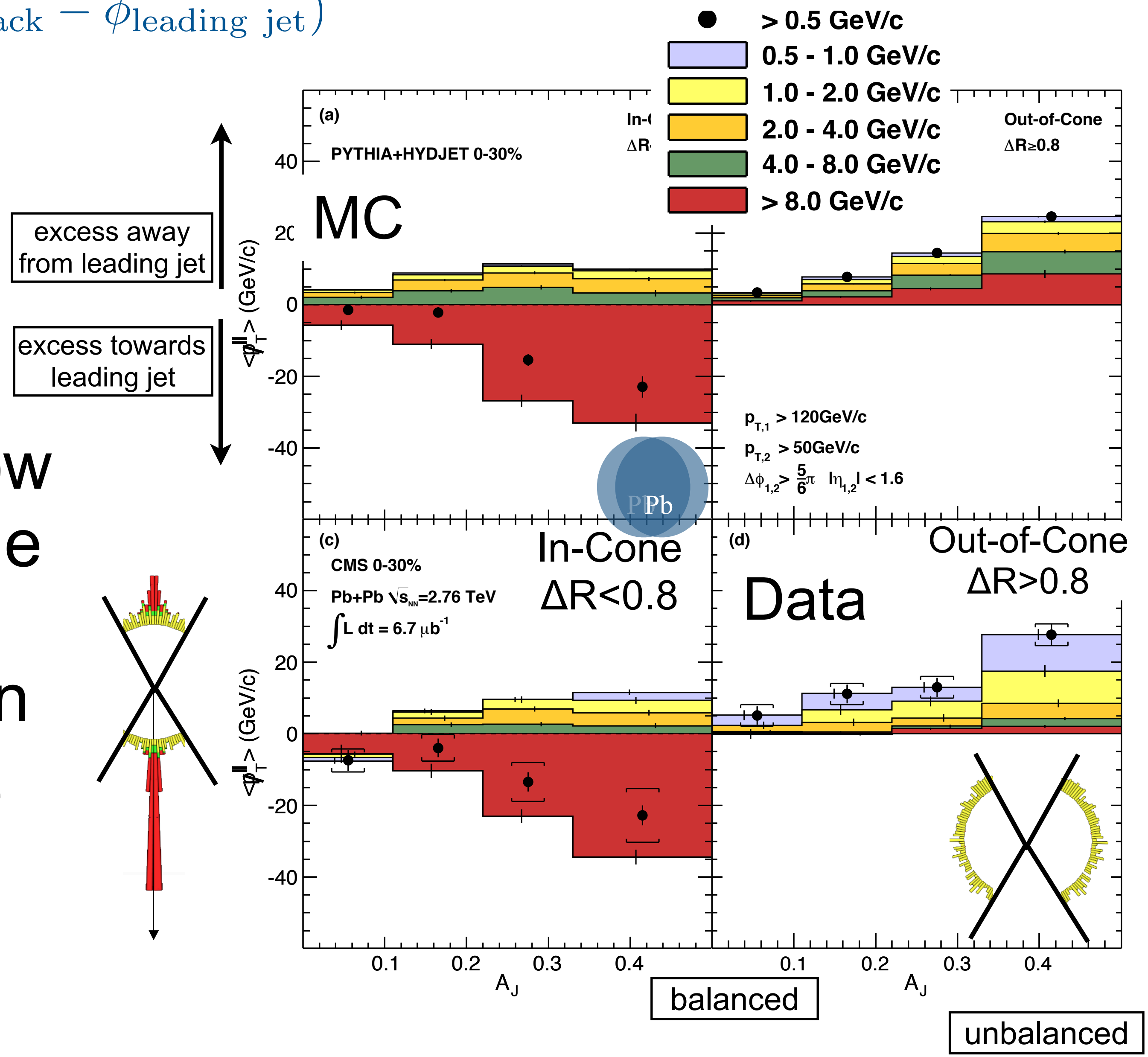
Look around jet cone

CMS: PRC 84 (2011) 024906

$$\not{p}_T^{||} \equiv \sum_{\text{tracks}} -p_{\text{T,track}} \cos\left(\phi_{\text{track}} - \phi_{\text{leading jet}}\right)$$

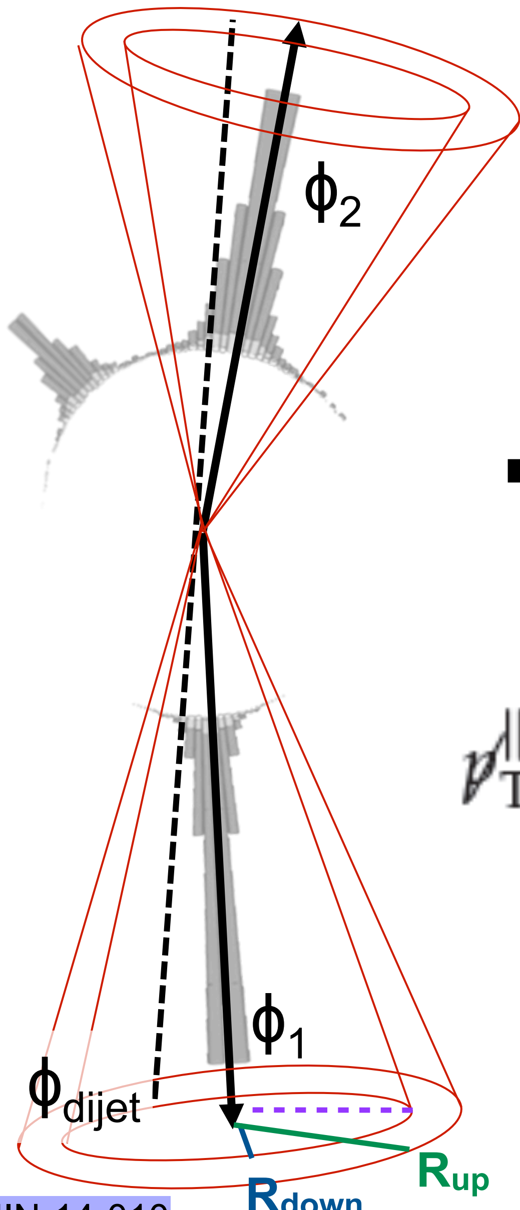
- Sum over tracks projected onto the leading jet axis
- Imbalance in jet cone restored by low p_T tracks outside the cone in the subleading direction

➡ Need a larger cone



Some new measurements

Angular distribution of particles



Direction of the dijet:

$$\phi_{dijet} = ½(\phi_1 + (\pi - \phi_2))$$

- Different than in PRC 84 (2011) 024906
- Provides underlying event cancellation differential in ΔR

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

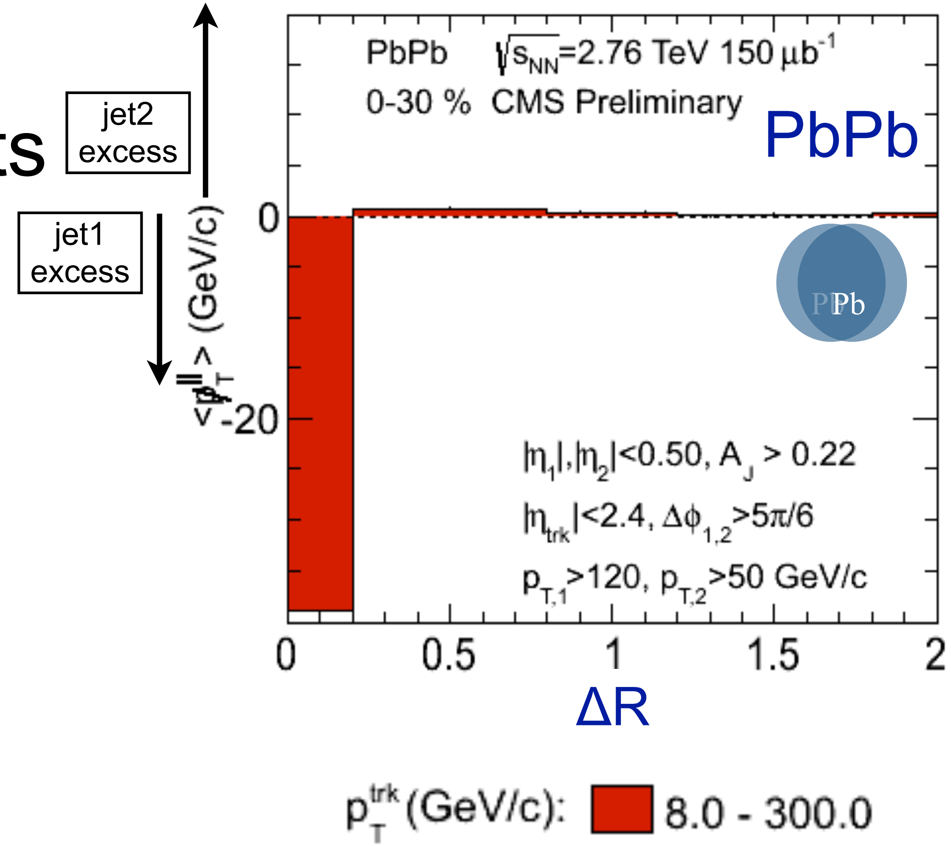
$$p_T^{\|} = \left(\sum_i -p_T^i \cos(\phi_i - \phi_{dijet}) \right) \Big|_{R_{down} < \Delta R < R_{up}}$$

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

CMS-PAS-HIN-14-010

Missing $p_T^{||}$ for unbalanced dijets

- Sum charged particles for unbalanced (A_J>0.22) dijets in central (0-30%) PbPb
  - ❖ 35 GeV/c of high p_T tracks missing from jet_2 at ΔR=0.2



CMS-PAS-HIN-14-010

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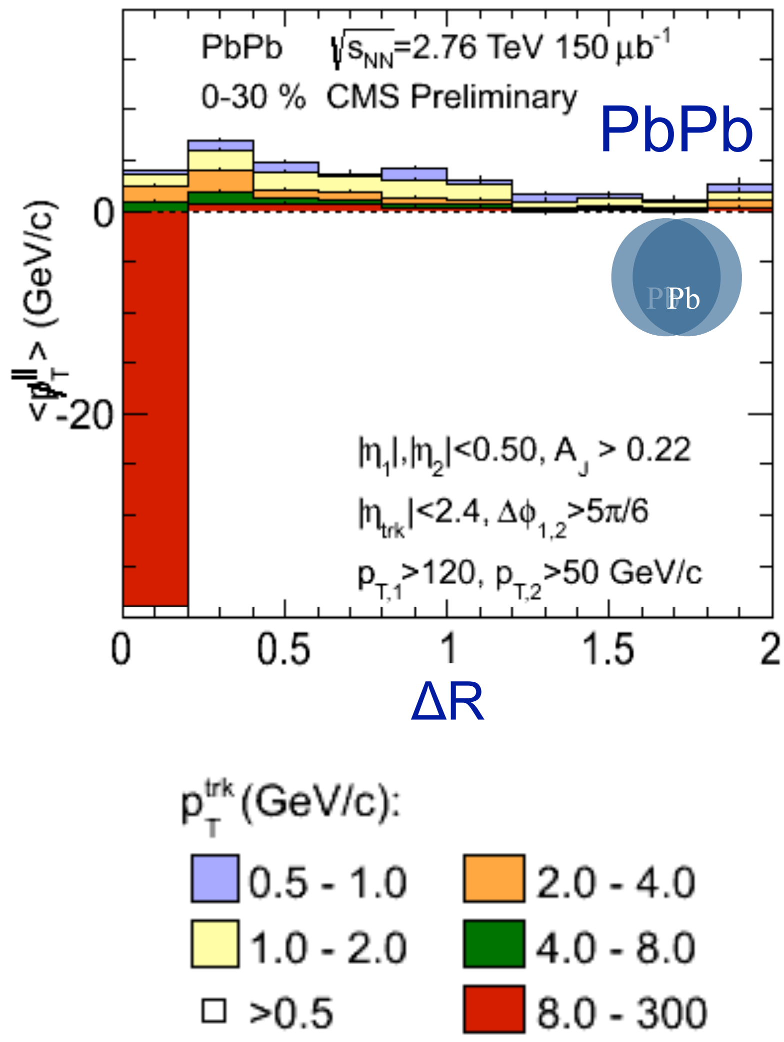
  - ❖ Balanced by low p_T particles up to very large ΔR = 2.0



CMS-PAS-HIN-14-010

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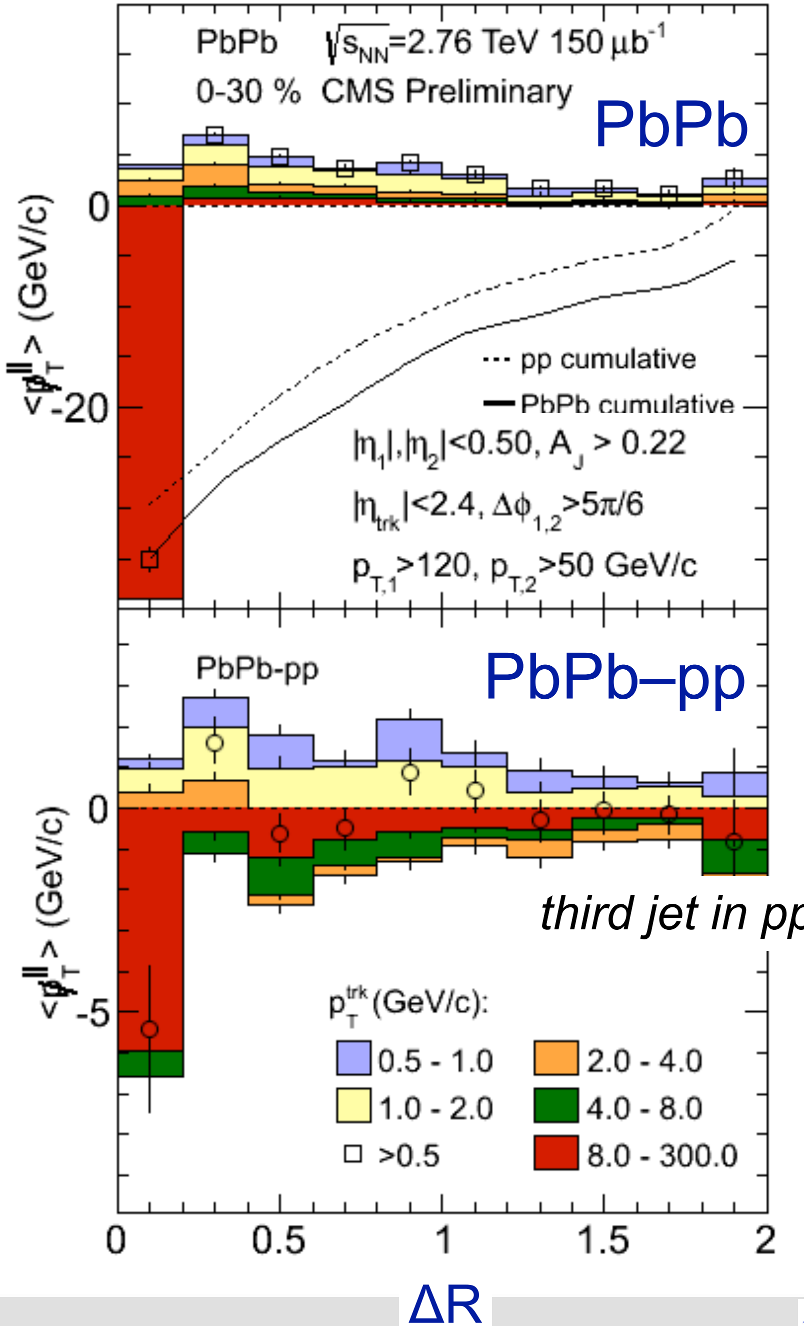
  - ❖ Balanced by low p_T particles up to very large ΔR = 2.0
  - ❖ PbPb -pp: result shows a different p_T distribution



CMS-PAS-HIN-14-010

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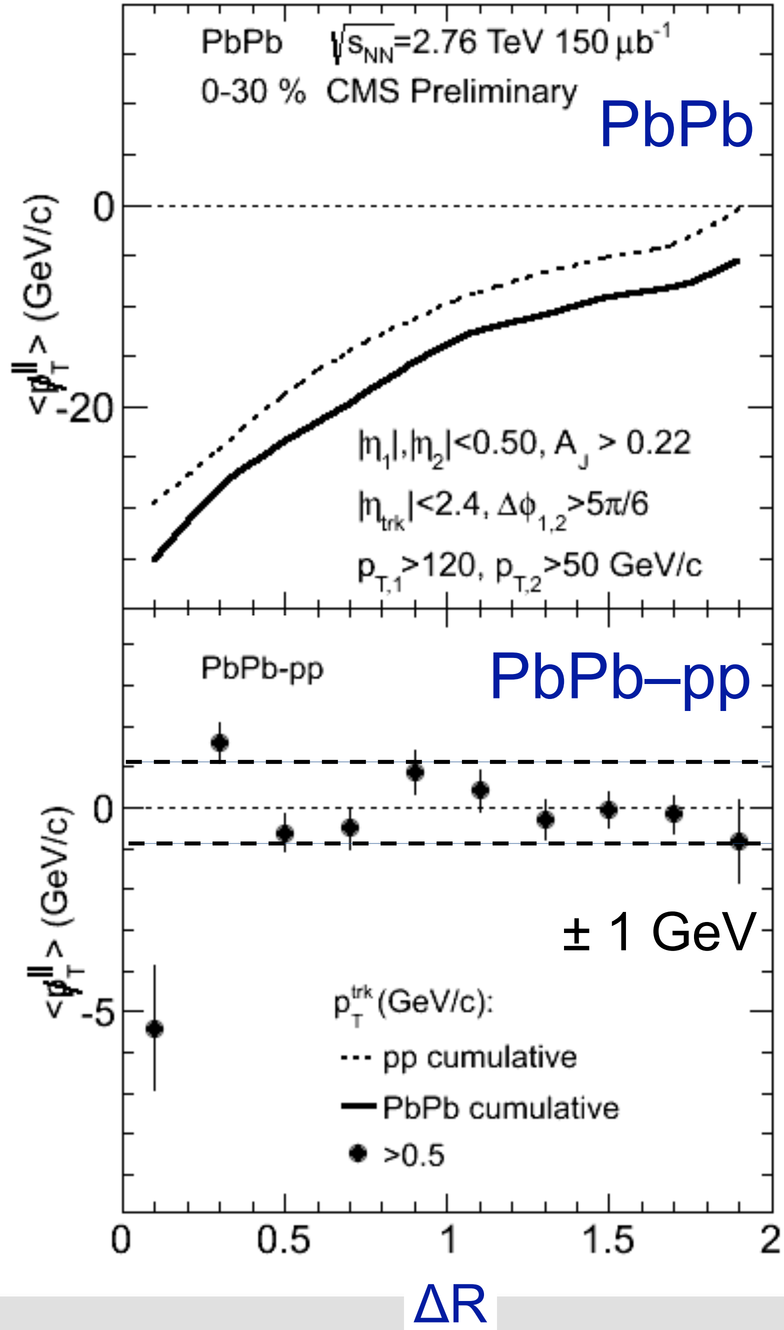
  - ❖ Balanced by low p_T particles up to very large ΔR = 2.0
  - ❖ PbPb -pp: result shows a different p_T distribution
  - ❖ Take the p_T cumulative of all tracks: total angular pattern is similar in PbPb and pp



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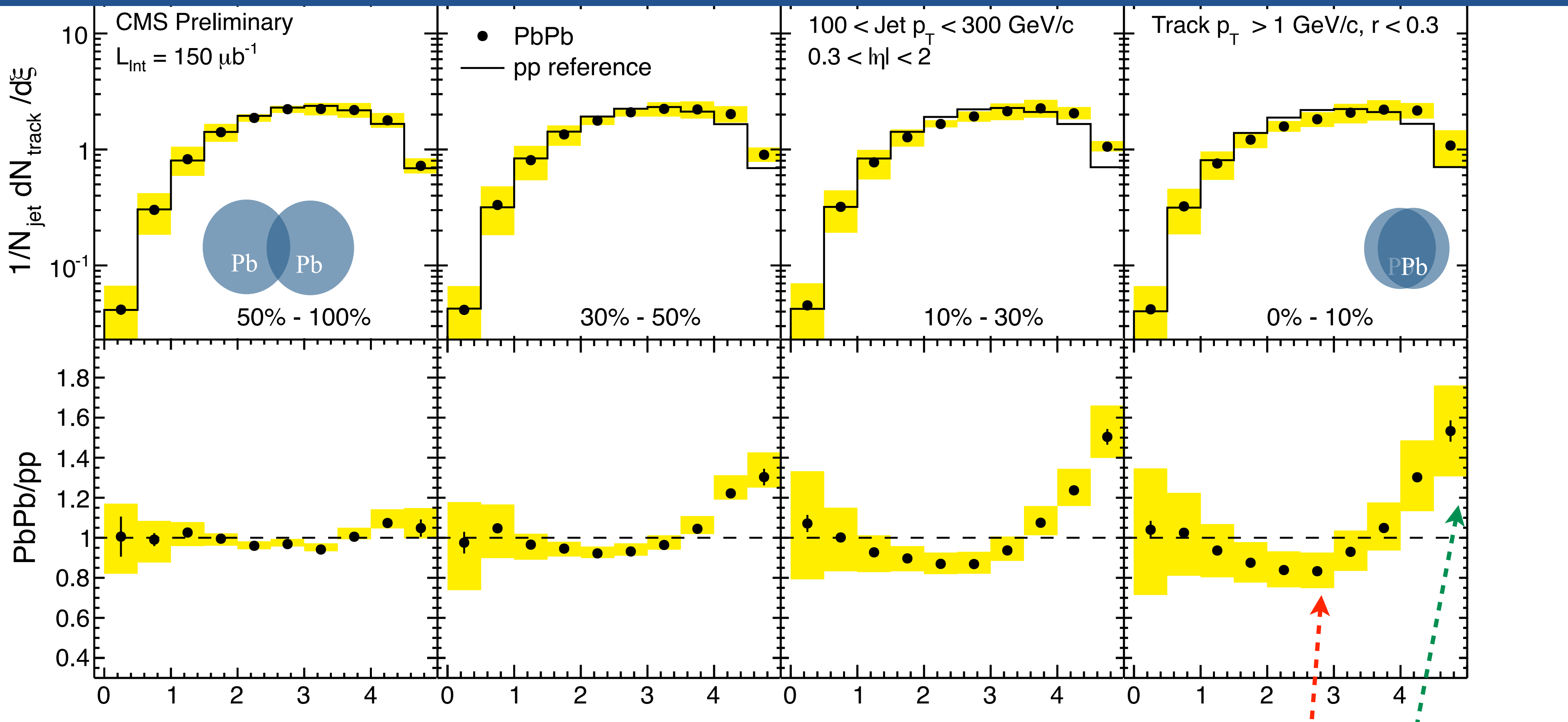
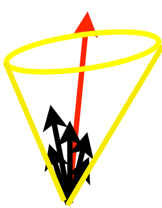
Jet fragmentation function in PbPb



$$\xi = \ln\frac{1}{z}\ ;\ \ z = \frac{p_{\parallel}^{\mathrm{track}}}{p^{\mathrm{jet}}}$$



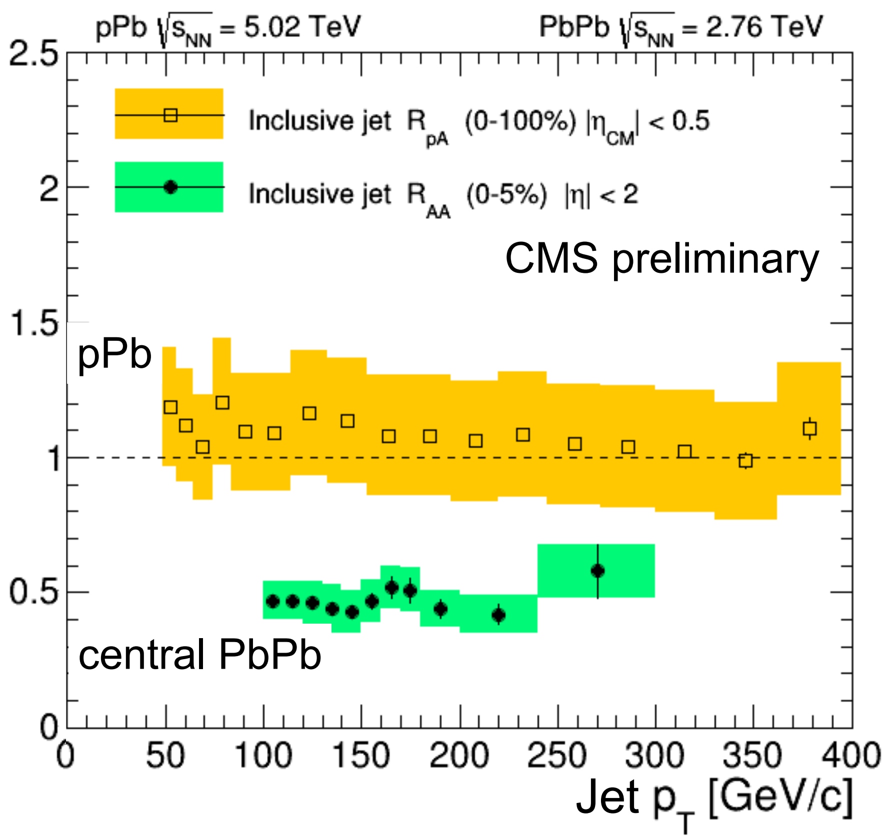
CMS: HIN-12-013-PAS

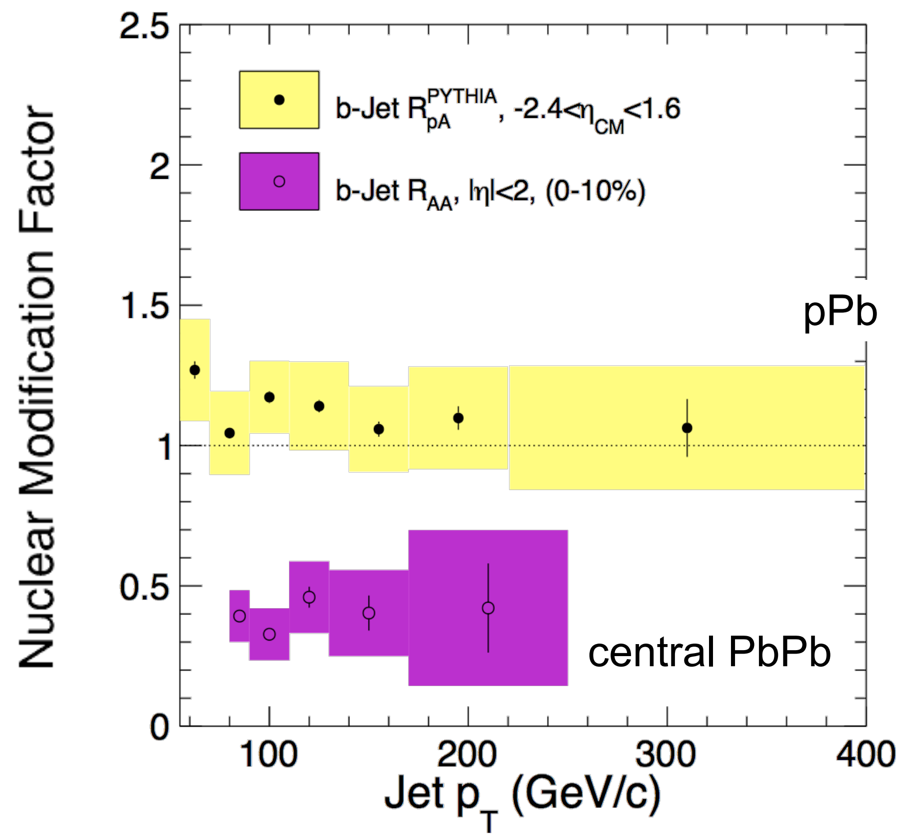
Inside the cone of central PbPb jets: enhancement of low p_T particles in the jet cone, and suppression of intermediate p_T

Jet nuclear modification factor

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

→ How many we measured in PbPb (pPb) / How many we expect if superimpose $\langle N_{coll} \rangle$ pp events?

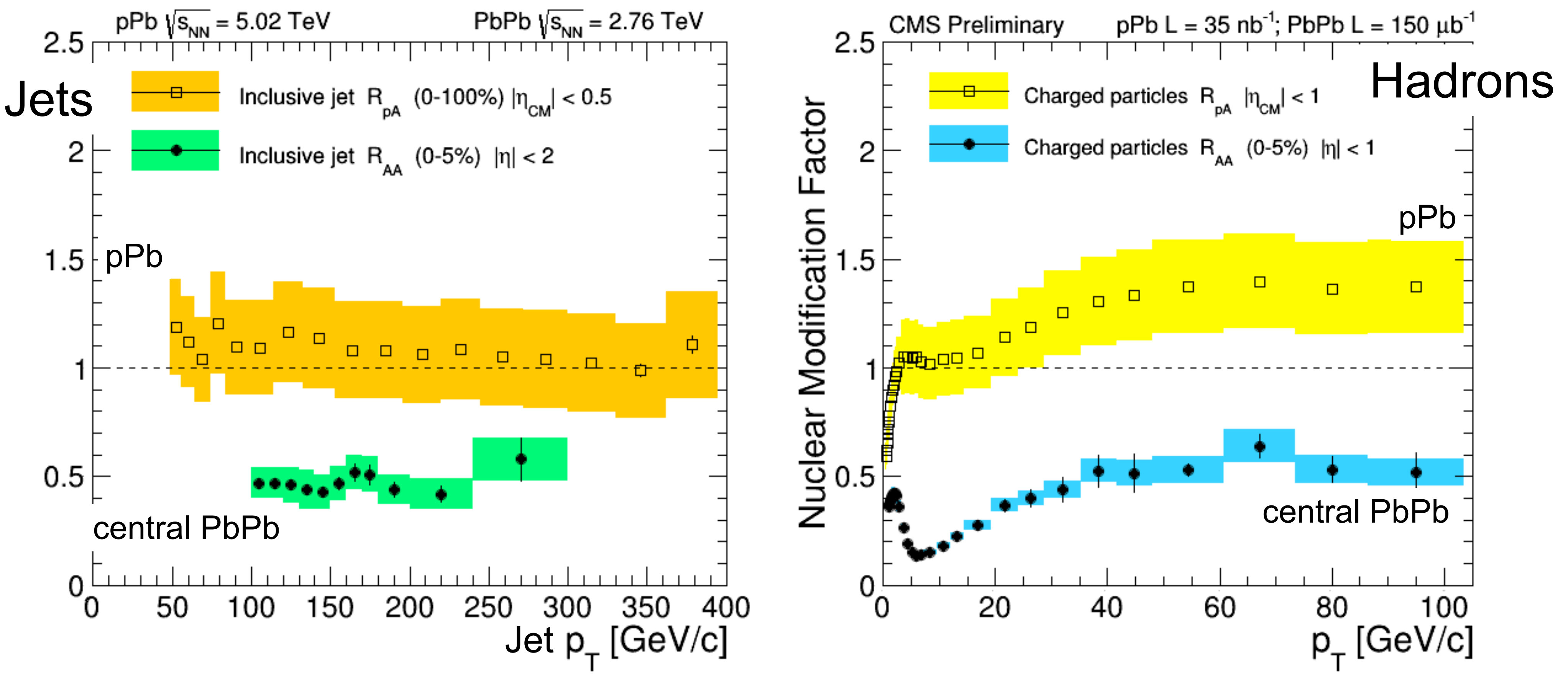




- In ***central*** **PbPb**: inclusive and b-jets show similar suppression in PbPb ($R_{AA} \approx 0.5$)
- In **pPb** (***all centralities***), the inclusive and b-jets have no suppression ($R_{pA} \approx 1$)

CMS-PAS-HIN-14-001 CMS-PAS-HIN-12-004 CMS-PAS-HIN-14-007 arXiv:1312.4198

Charged hadron pPb mystery



- PbPb shows similar suppression at high p_T for charged particles and jets
- Charged particles in pPb for all centralities show enhancement at the p_T
  - ❖ What causes this to affect charged hadrons and not jets?
  - ❖ Need pp data at 5.02 TeV

CMS-PAS-HIN-14-001 CMS-PAS-HIN-12-004 CMS-PAS-HIN-12-017 CMS EPJC 72 (2012) 1945

Summary

- Jets are quenched in central PbPb, not in pPb
- ✳ Charged hadrons show enhancement at high p_T in pPb
- Inclusive jets and b-jets show similar behavior
  - $R_{pPb} \approx 1$
  - $R_{PbPb} \approx 0.5$
- In central PbPb unbalanced dijets are balanced by low p_T tracks (<2 GeV/c) out to ΔR of 2
  - Different jet fragmentation in particle p_T for PbPb and pp
  - Angular pattern of the energy flow of tracks is similar in pp and central PbPb

Backup

Jet p_T scale and resolution comparison

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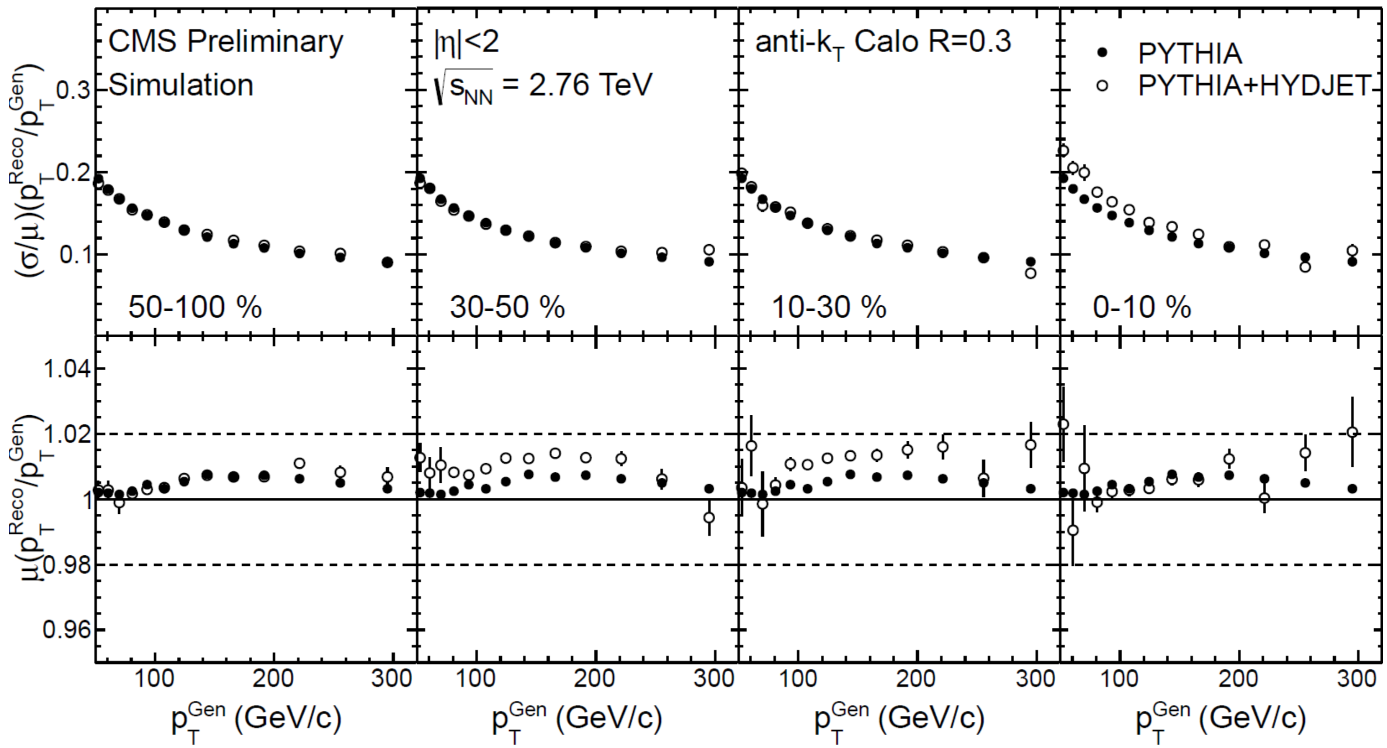
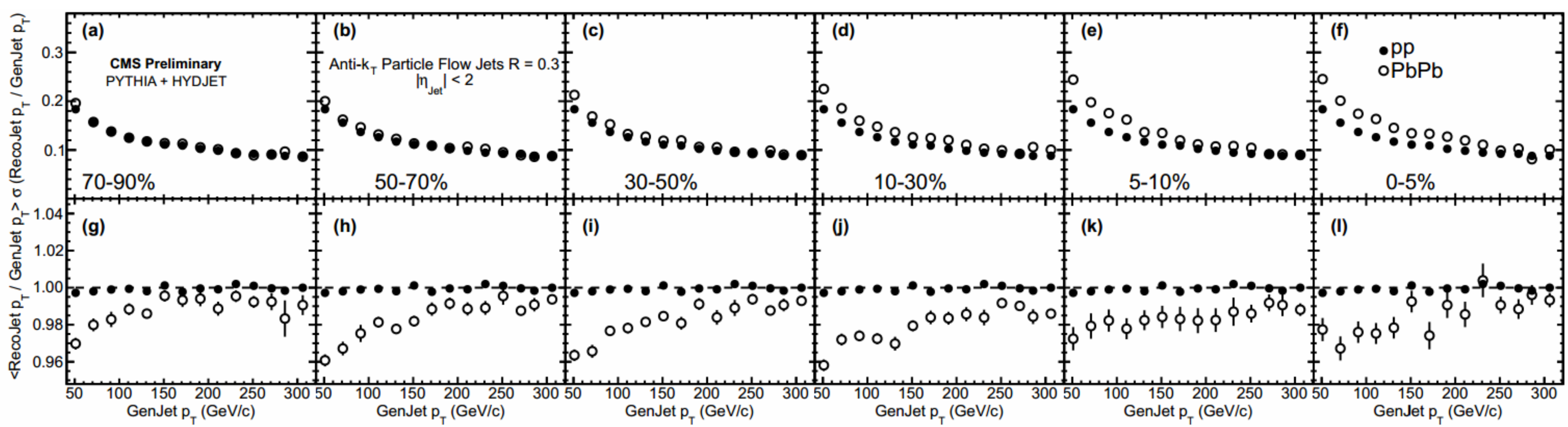


← HF/Voronoi subtraction

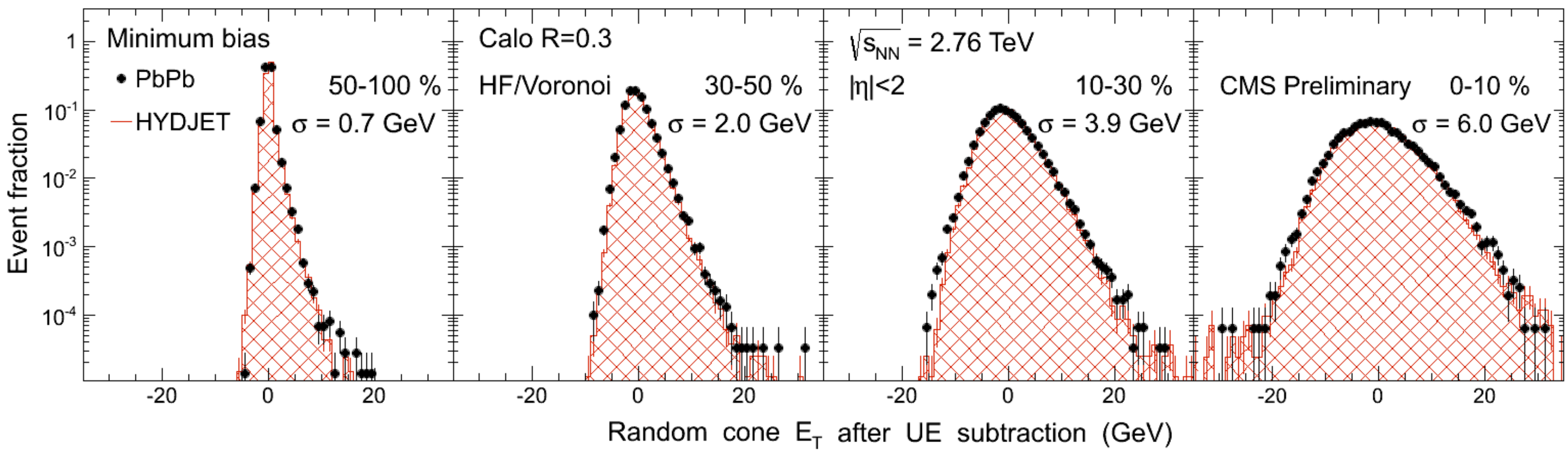
Iterative "pileup" subtraction ↓

CMS-HIN-12-004



Performance of HF/Voronoi 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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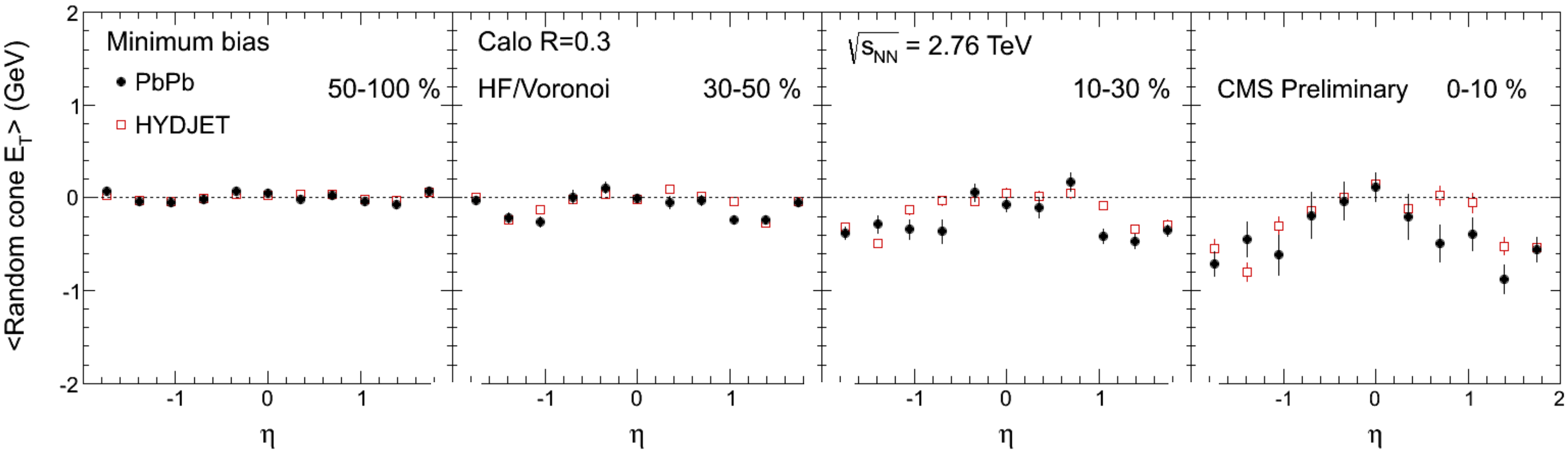
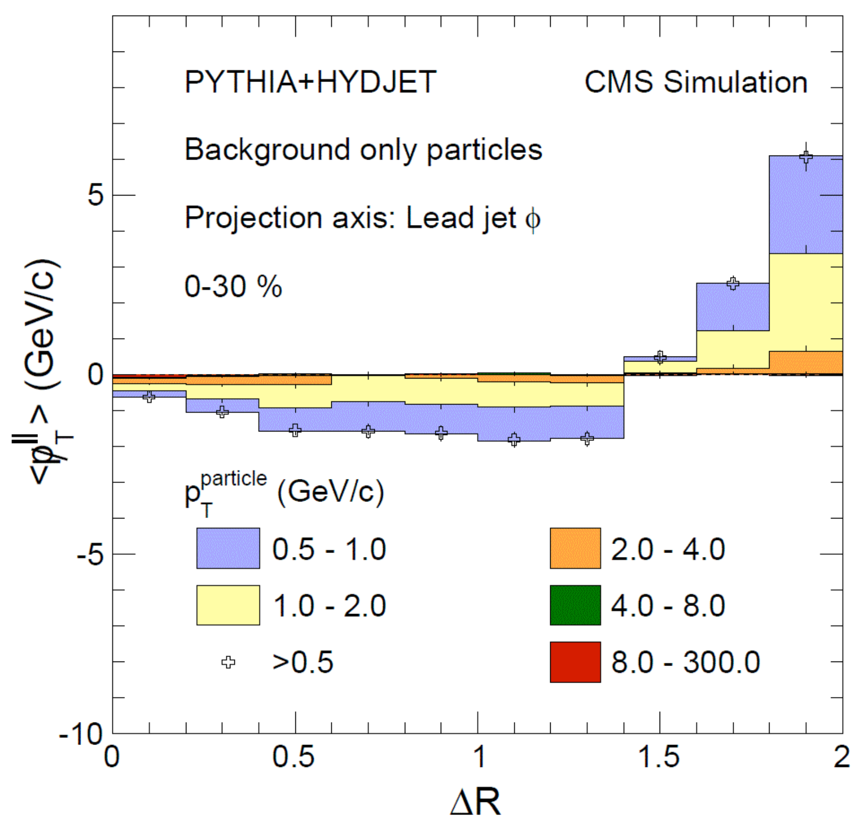
Mean random cone E_T as a function of η:



Deviation from zero <0.5-1 GeV

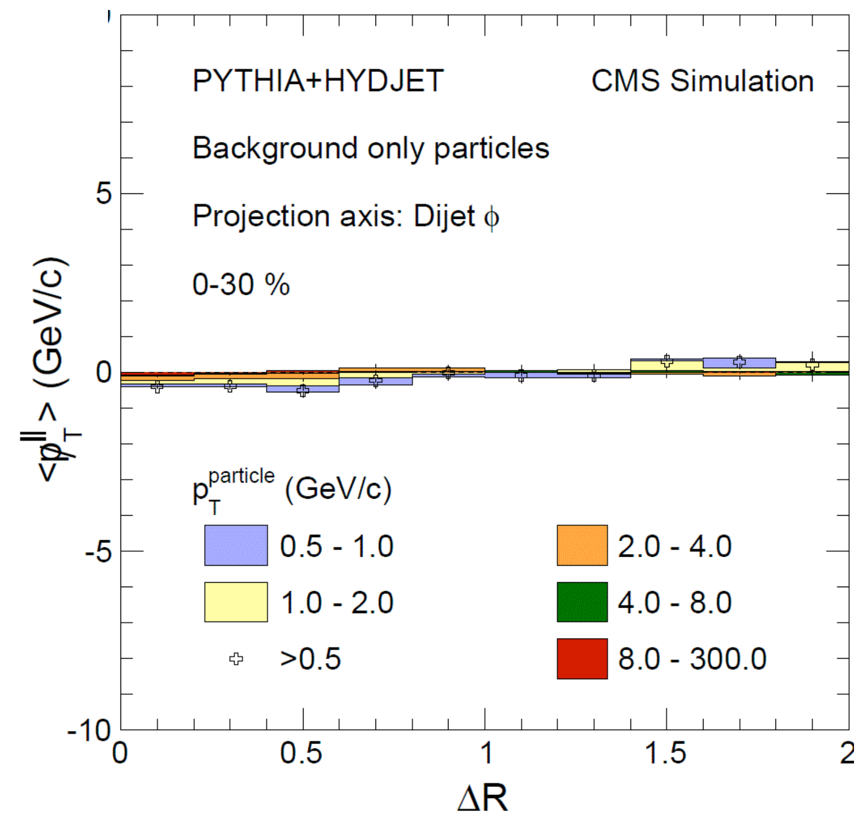
Projection axis choice: PbPb dijet

Leading jet axis



- $\Delta\varphi_{1,2} \neq \pi$ ⟶ Projection of p_T of charged particles in small ΔR near subleading jet is smaller than those near leading jet

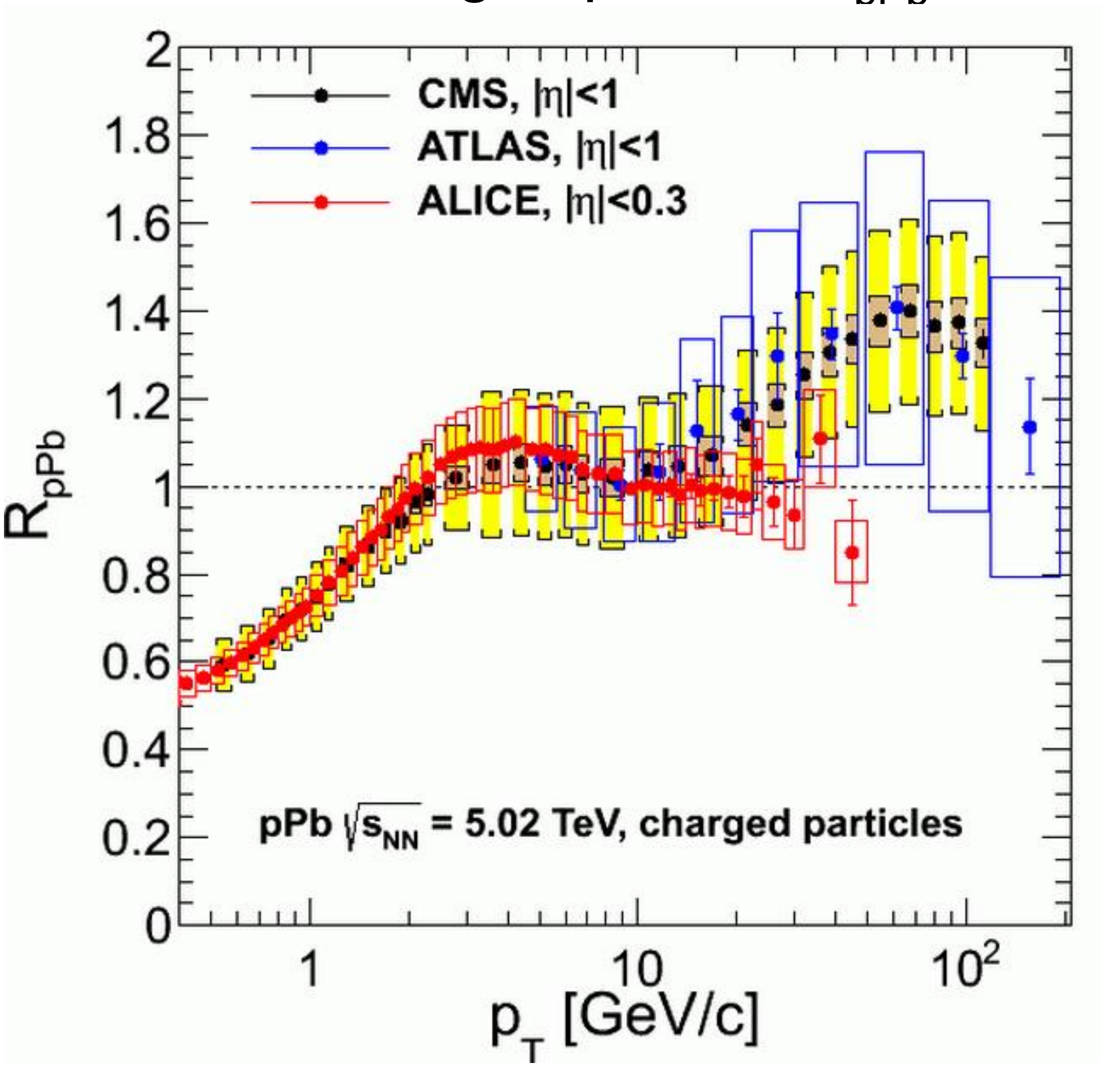
Dijet axis



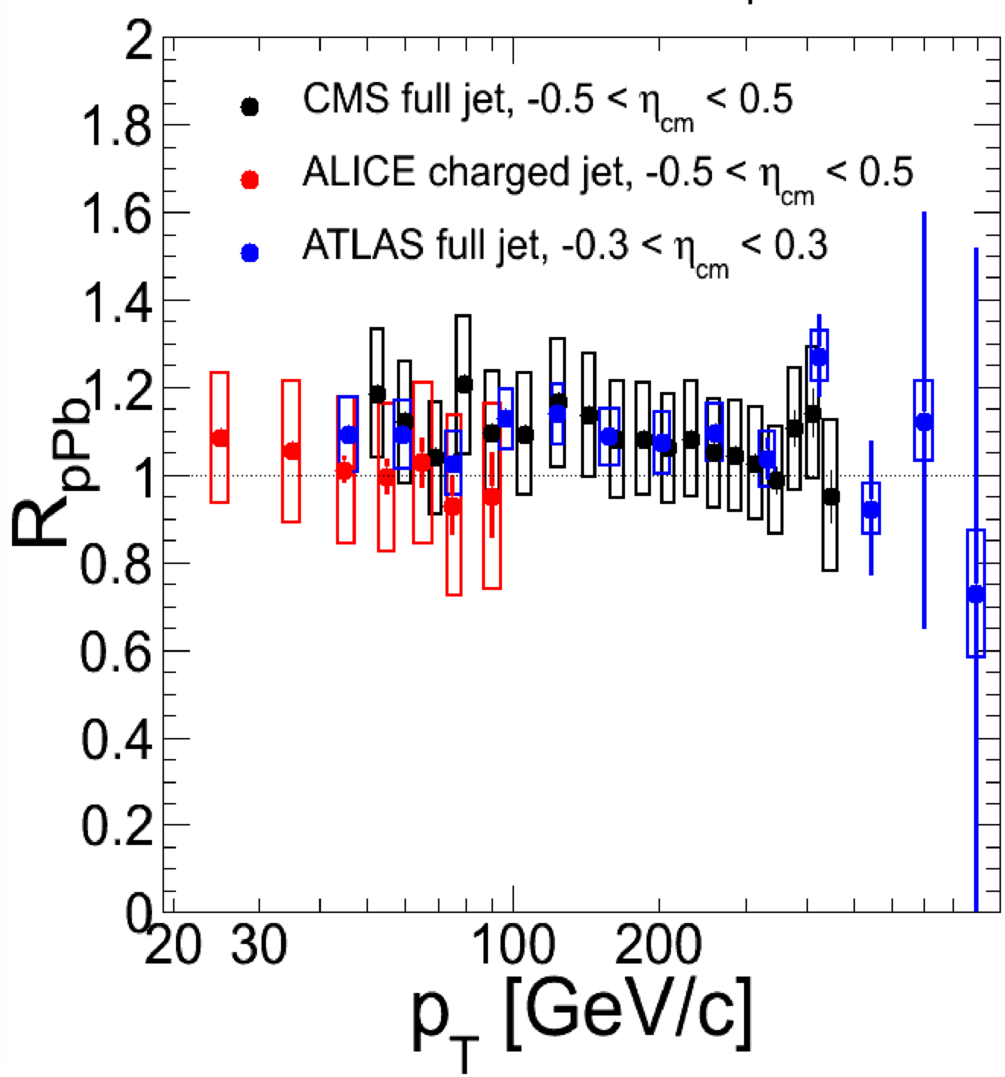
- Restores the symmetry of particles near leading and subleading jet ⟶ UE cancels by azimuthal symmetry

Charged particle and jet R_{pPb} (QM2014)

Charged particle R_{pPb}



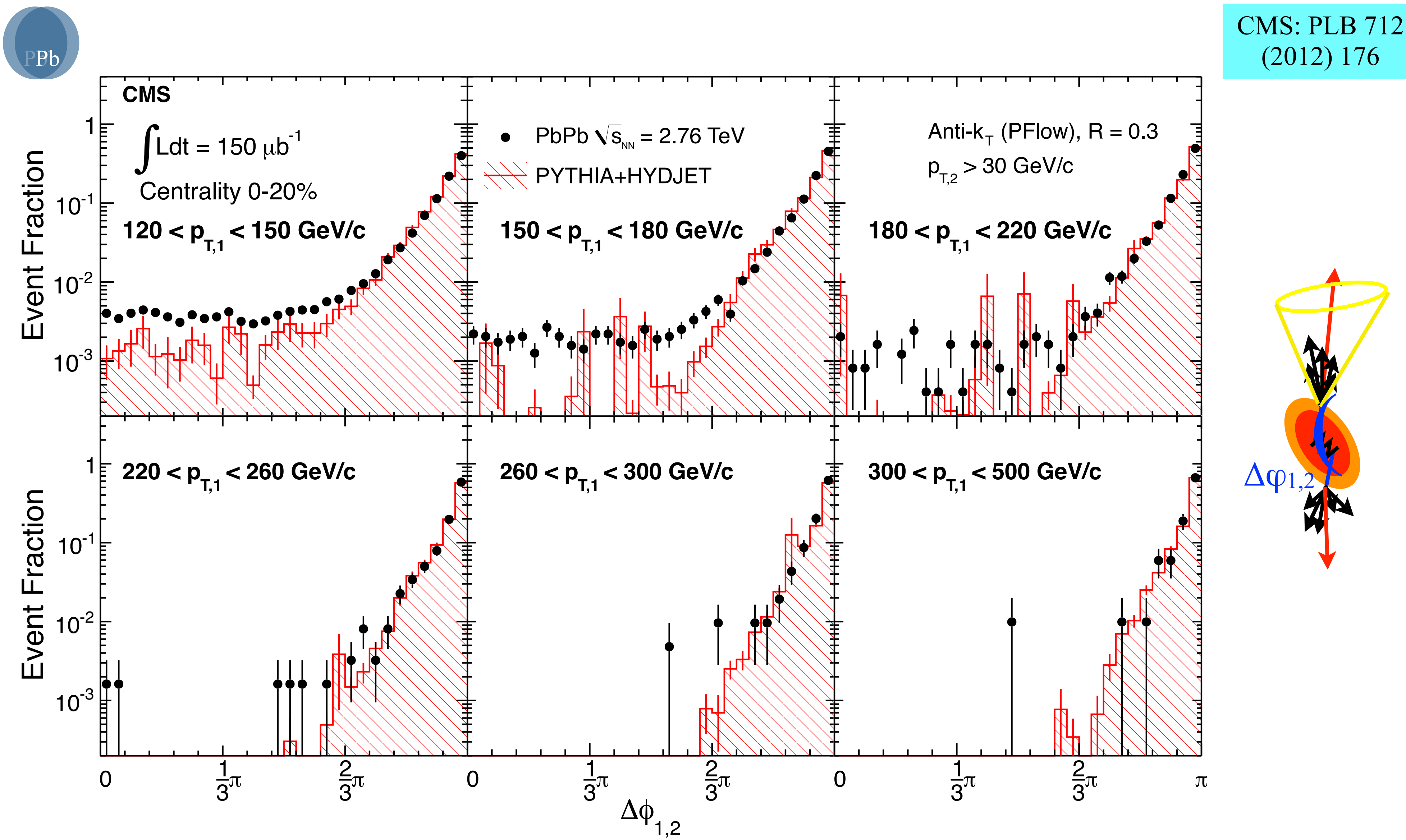
(Charged) Jet R_{pPb}



Yen-Jie Lee QM2014

Do jets get deflected in position?

CMS: PLB 712 (2012) 176



No significant angular decorrelation across different jet $p_{T,1}$