New results on Hard Probes and Heavy Quarks from CMS Heavy Ion Program

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for CMS collaboration

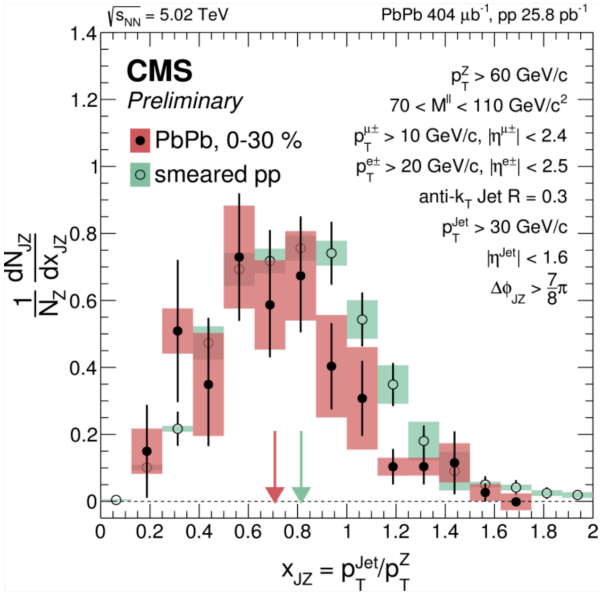
Presented in

LHCP2017, Shanghi
May 18th , 2017

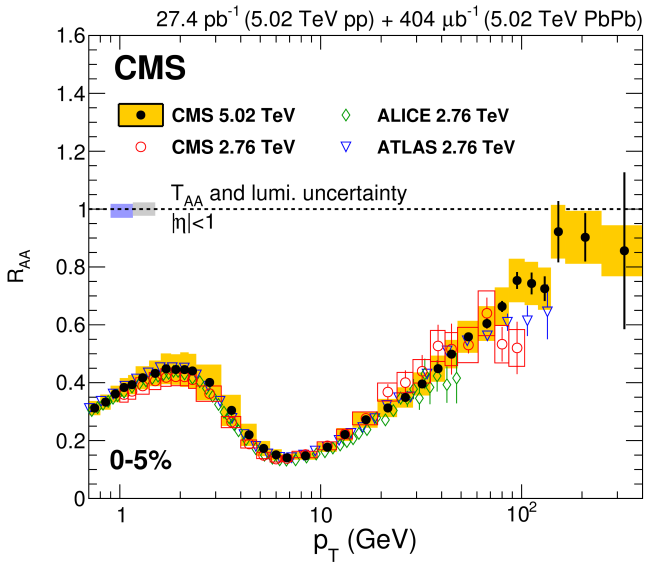
CMS high pT results at LHCP2016

Previously in LHCP2016

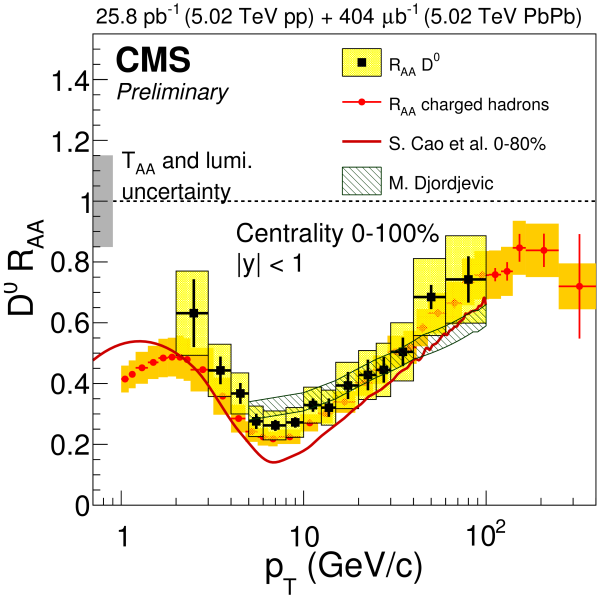
CMS reported on jet quenching results from fresh data at 5 TeV. The collision energy dependence of the medium property was the main interest.



Z-jet correlation



B+ R_{AA}



D^0 R_{AA}

Introduction

This year

New studies were carried out to elaborate the comprehensive picture of jet quenching

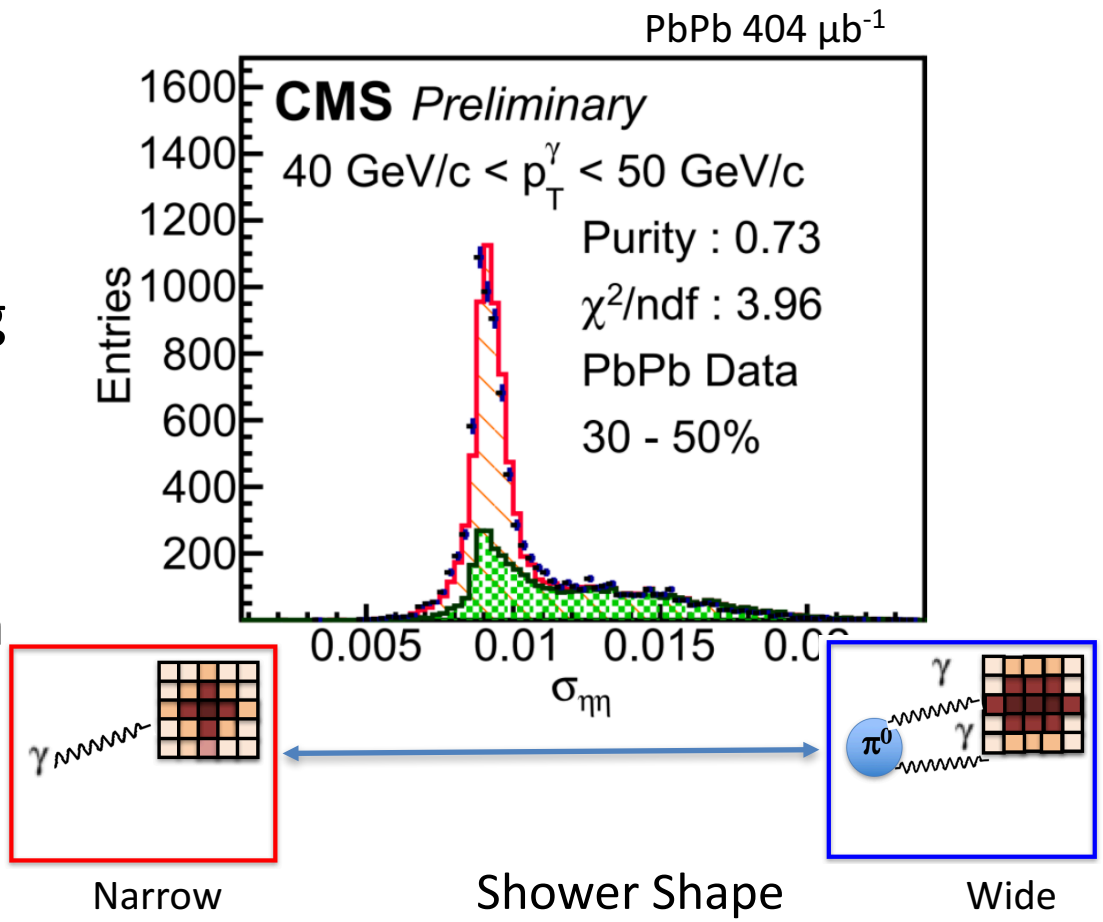
- Photon-jet correlation
- Di-b-jet correlation
- B meson R_{AA}
- Jet splitting Function
- High p_T v_2 and v_3 of D^0

using Run II data at 5.02 TeV

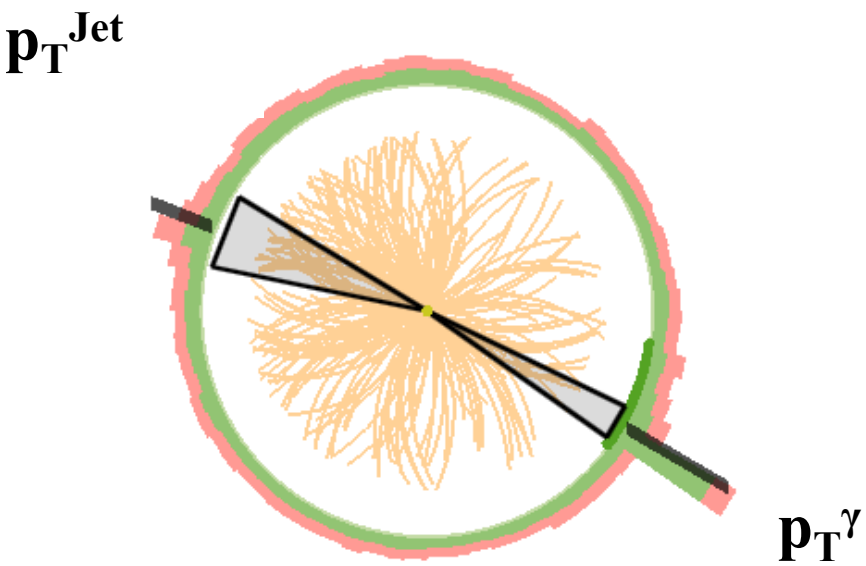
Photon-jet correlation

- Photon tags the momentum information of partner jet before suffering energy loss

- Background photons, mostly from neutral meson decays, are subtracted using shower shape in Ecal



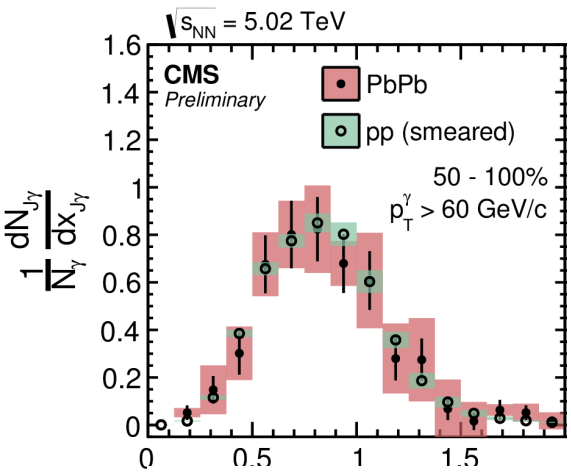
Photon-jet correlation: Momentum ratio



$$x = p_T^{Jet} / p_T^{\gamma}$$

Photon-jet correlation: Momentum ratio

50-100%

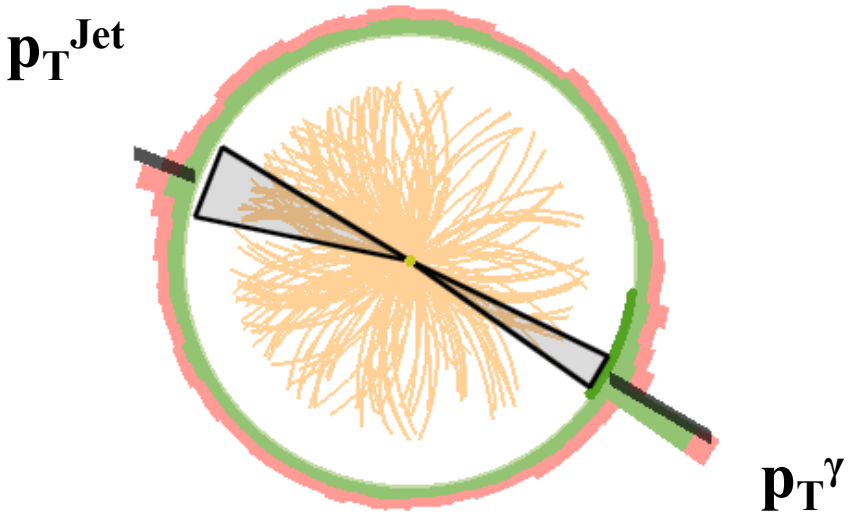


$x = p_T^{Jet} / p_T^{\gamma}$

In peripheral collision

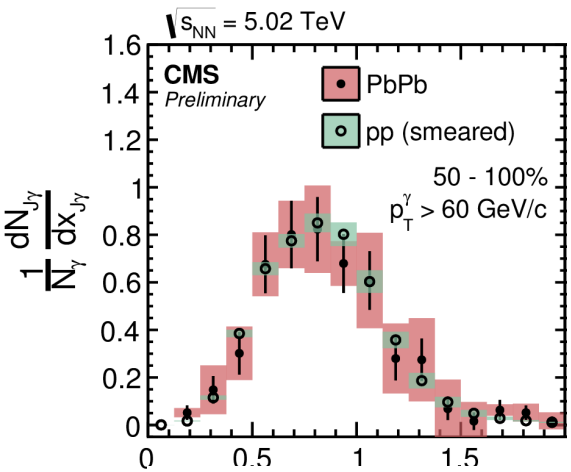
pp jets ≈ PbPb jets

$$x = p_T^{Jet} / p_T^{\gamma}$$



Photon-jet correlation: Momentum ratio

50-100%

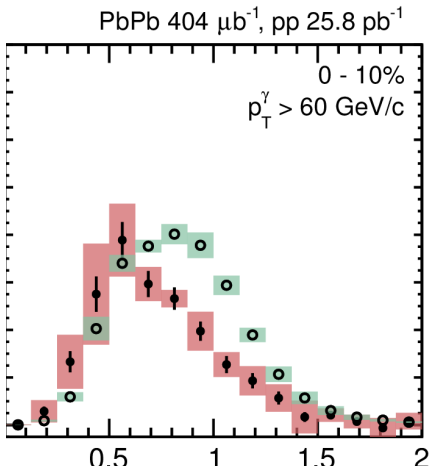


$x = p_T^{Jet} / p_T^{\gamma}$

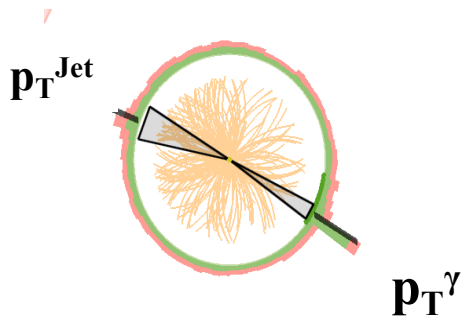
In peripheral collision
PbPb jets ≈ pp jets

In central collision
PbPb jets < pp jets

0-10%



x

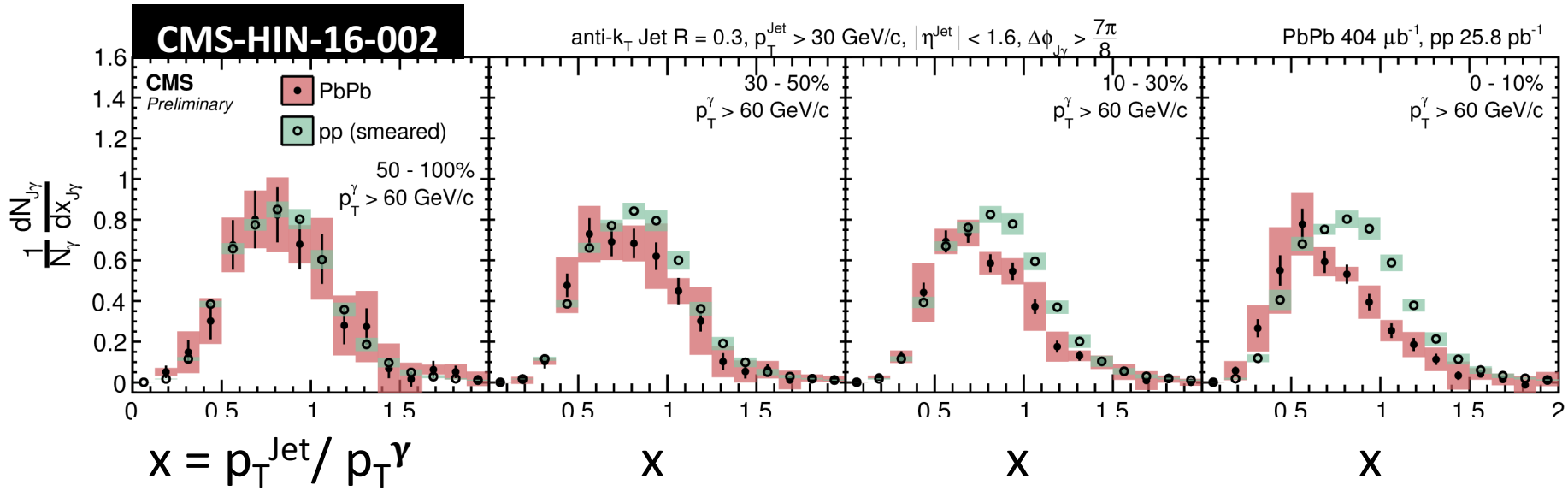


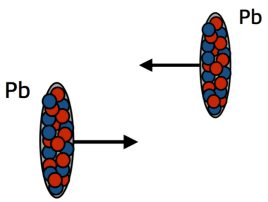
Modification in two aspects

- Number of jet partners*
- Shift of x distribution

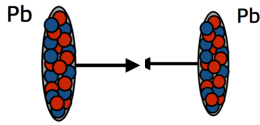
** Jet p_T threshold = 30 GeV/c*

Photon-jet correlation: Momentum ratio

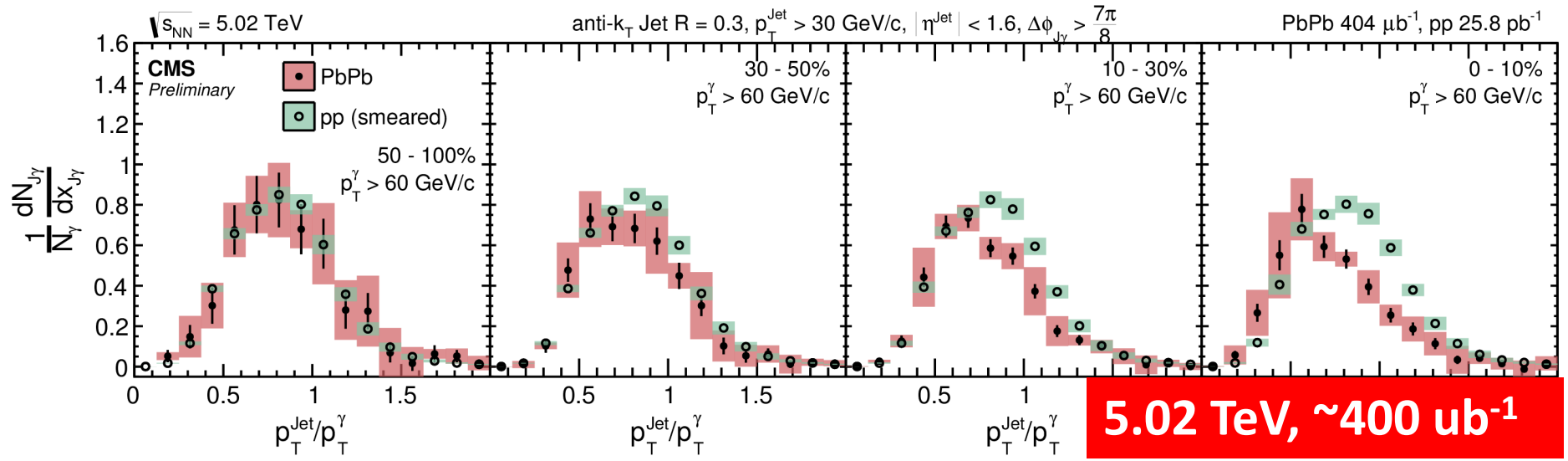




Gradually manifest for higher centrality

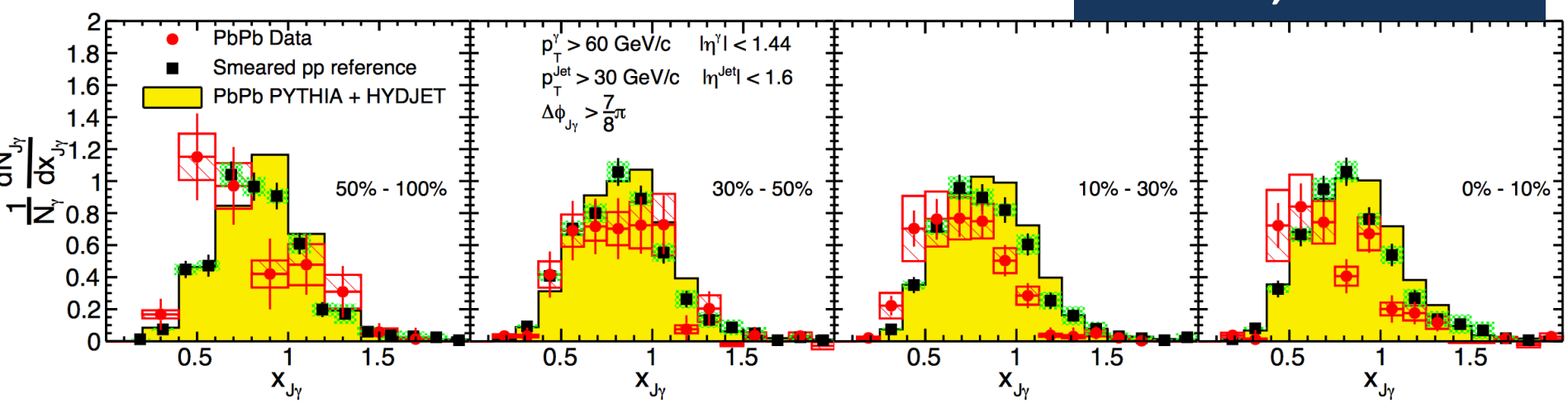


Photon-jet correlation: Momentum ratio

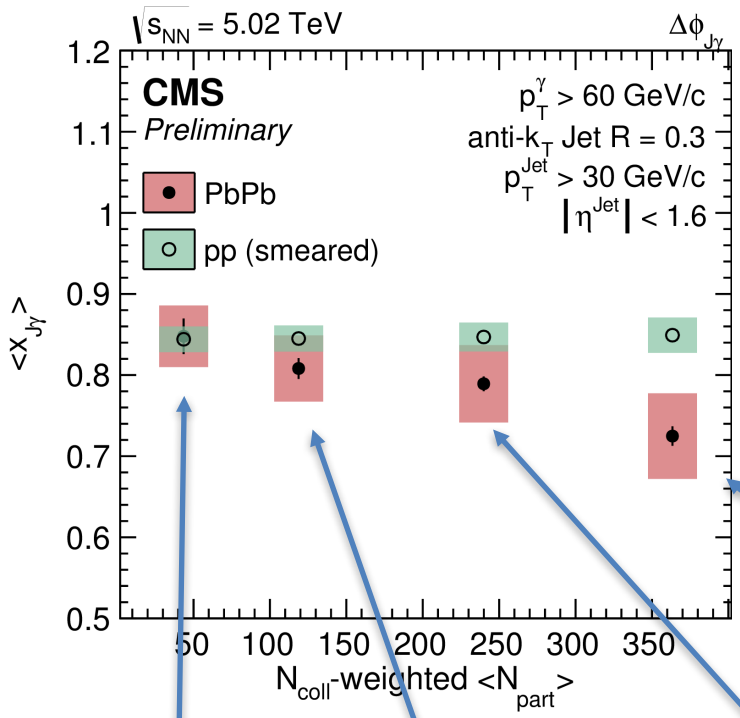


5.02 TeV, ~400 ub^{-1}

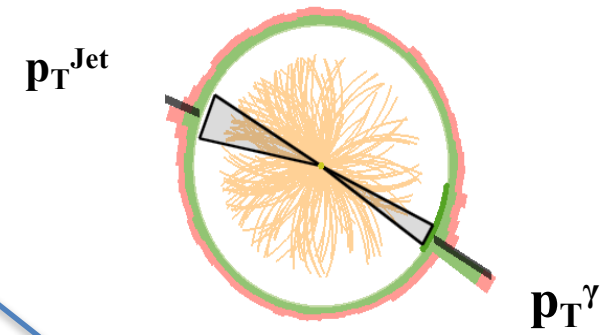
2.76 TeV, ~150 ub^{-1}

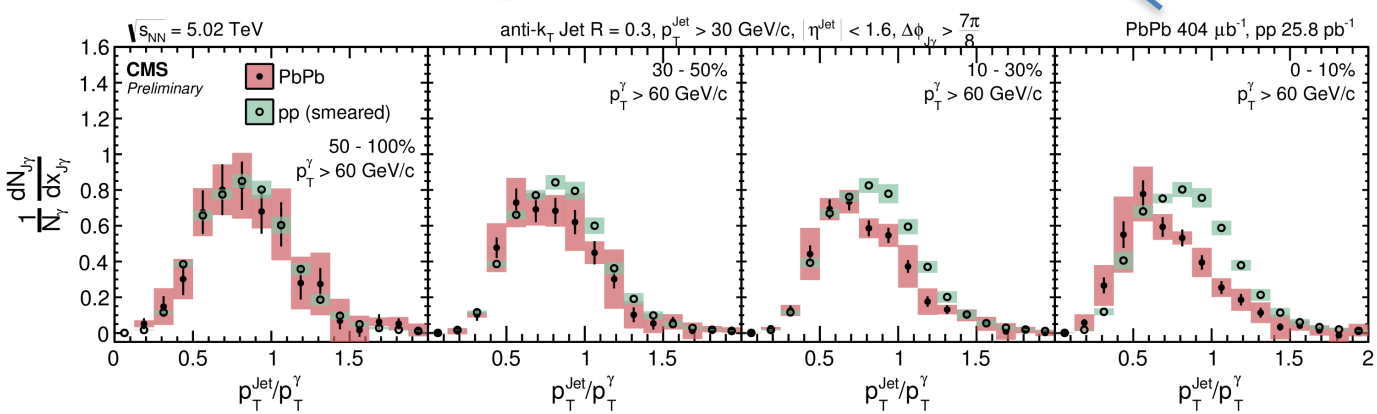


$\langle x_{J\gamma} \rangle$

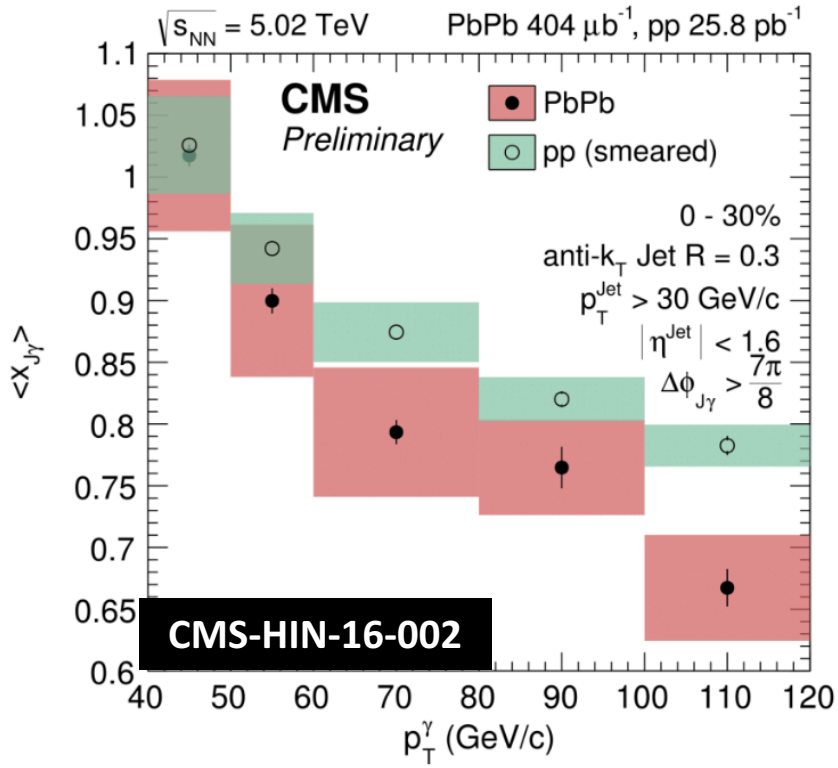


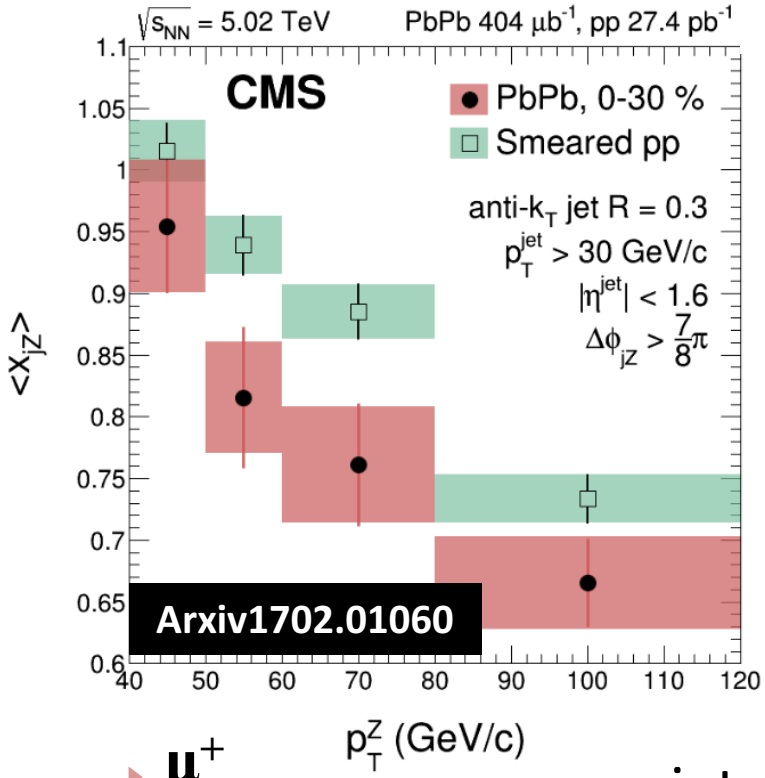
Mean of p_T^{jet} / p_T^{γ}

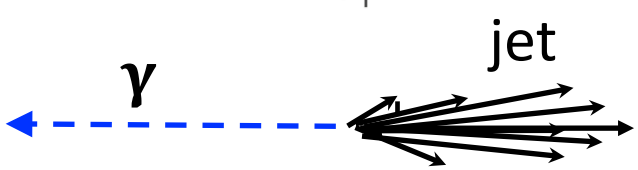


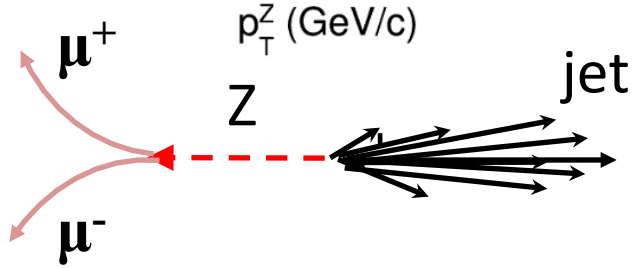


$\langle x_{J\gamma} \rangle$ compared with Z-jet





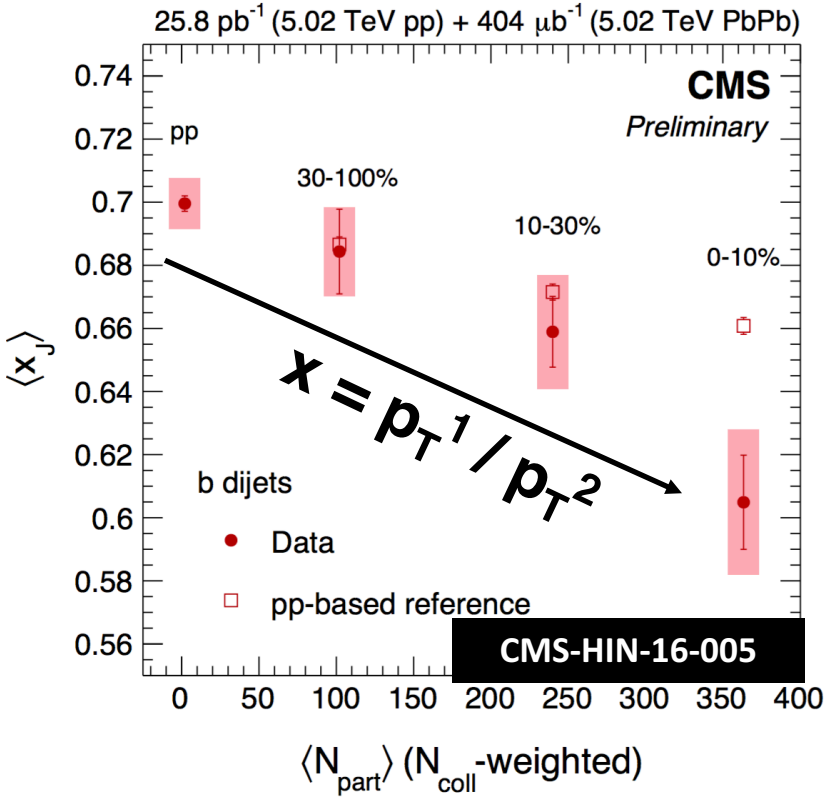


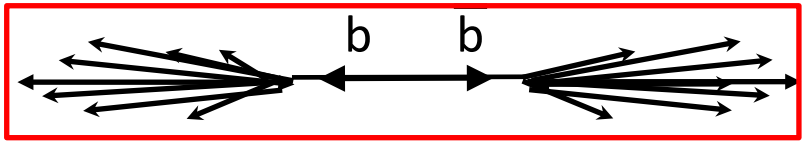


Consistent results in the given statistics

Di-b-jet results in PbPb

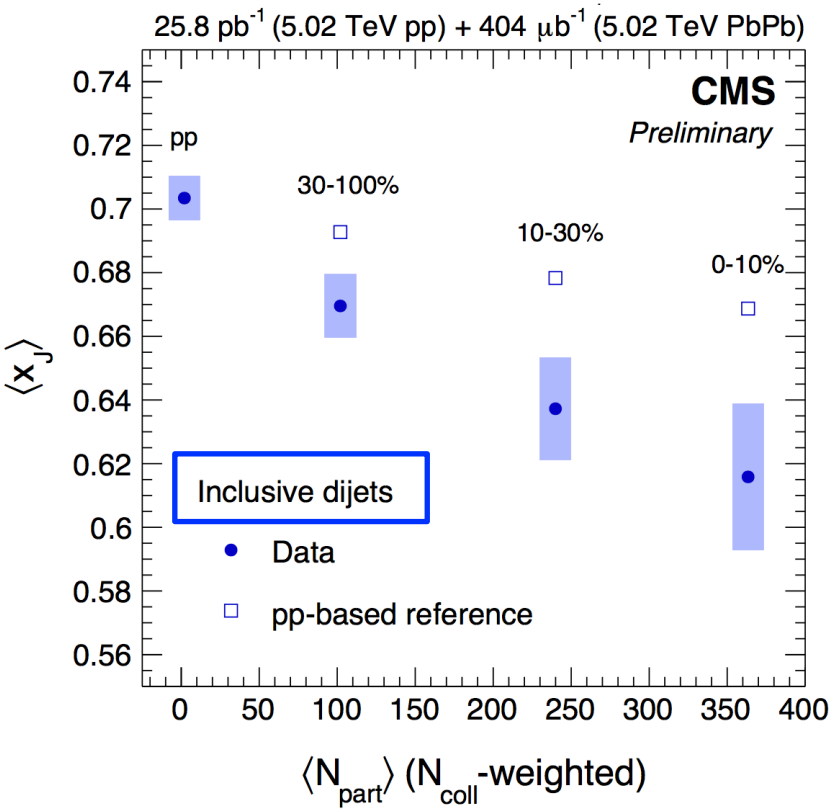
- Imbalance in di-jet reflects path-length through medium and fluctuation of parton energy loss itself
- **The first measurement** of flavor identified di-jet correlation
- Inputs to the modelling of mass and flavor dependence of E-loss

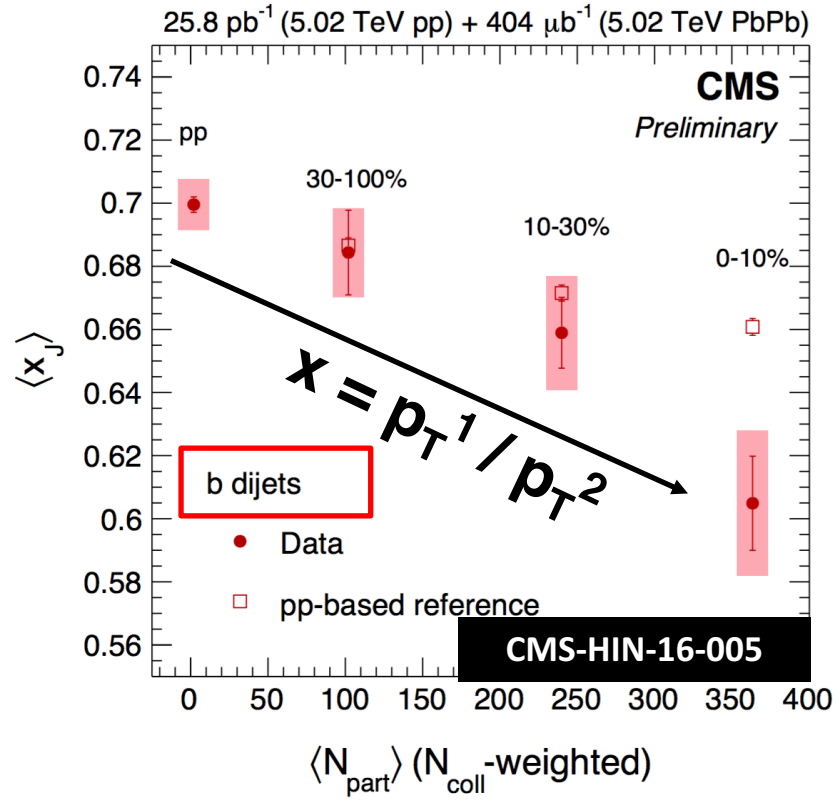


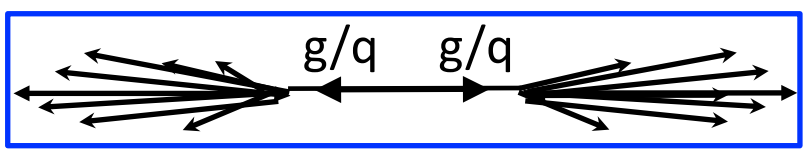


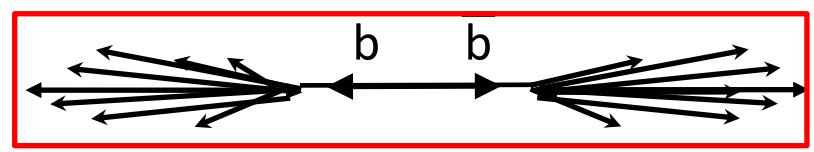
$p_{T,1}$>100 GeV, $p_{T,2}$>40 GeV

Di-b-jet results in PbPb



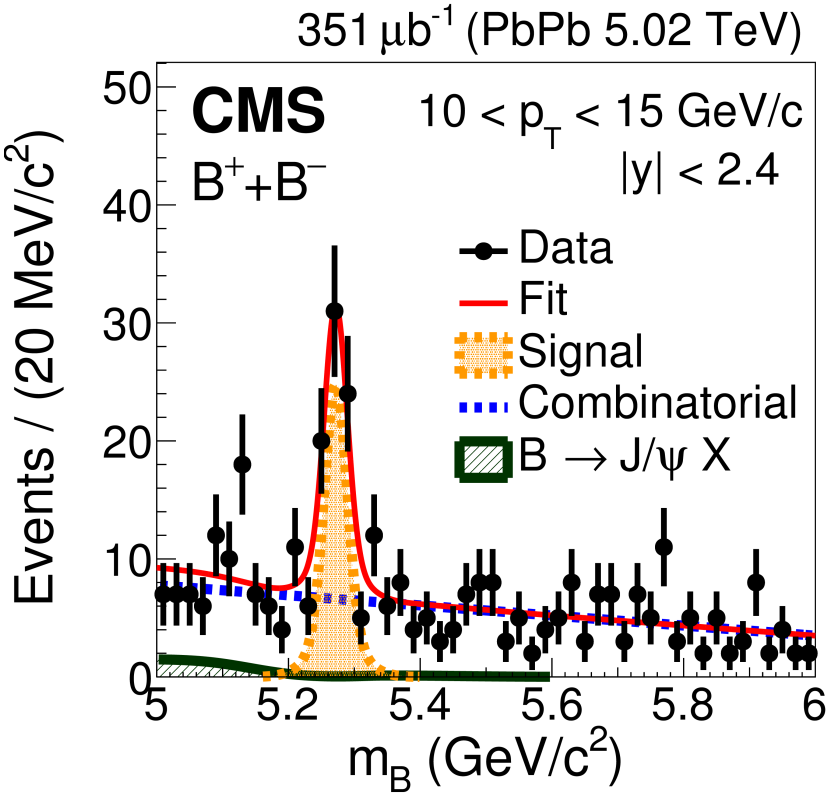




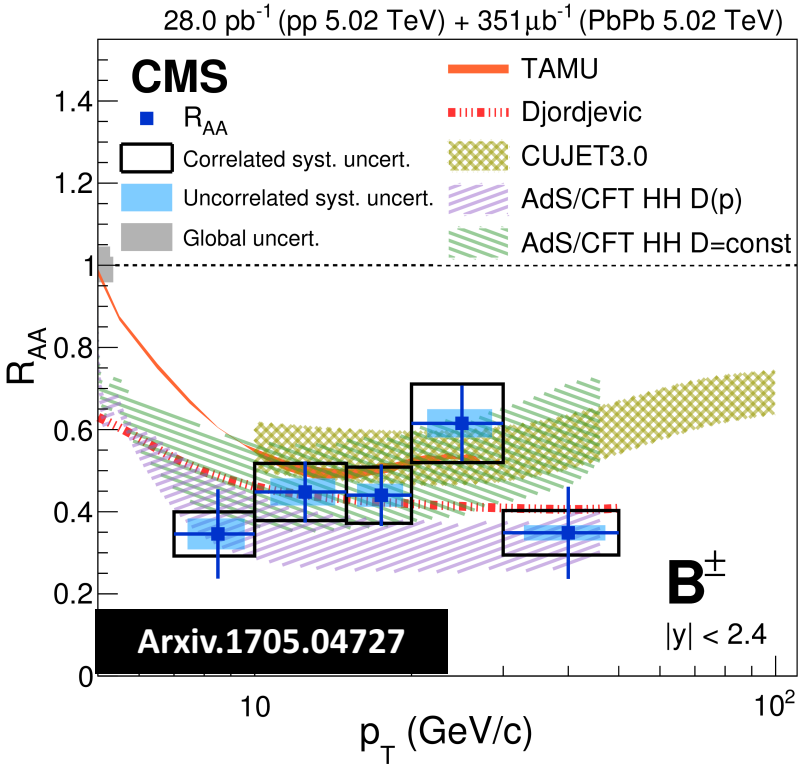


Similar size of momentum imbalance with inclusive dijets

Exclusive B^+ is measured in PbPb



Submitted to PRL

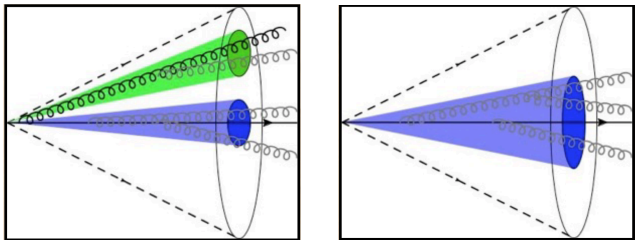


- **The first measurement** of B meson in AA collision
- Suppression by factor of ~2 observed in the minimum bias events for the measured p_T range

Jet Splitting Function

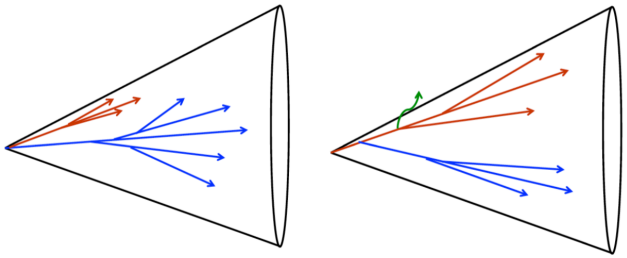
Can the medium resolve jet fragmentation?

- Hard splitting happens before the jet medium interaction
- Would descendent subjets maintain the coherence, or do they loss their links when suffering energy loss?



Collimated jet
+ softer 2nd structure

Two hard structures



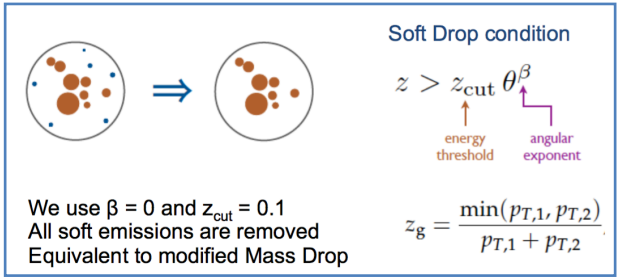
Small z_g

Large z_g

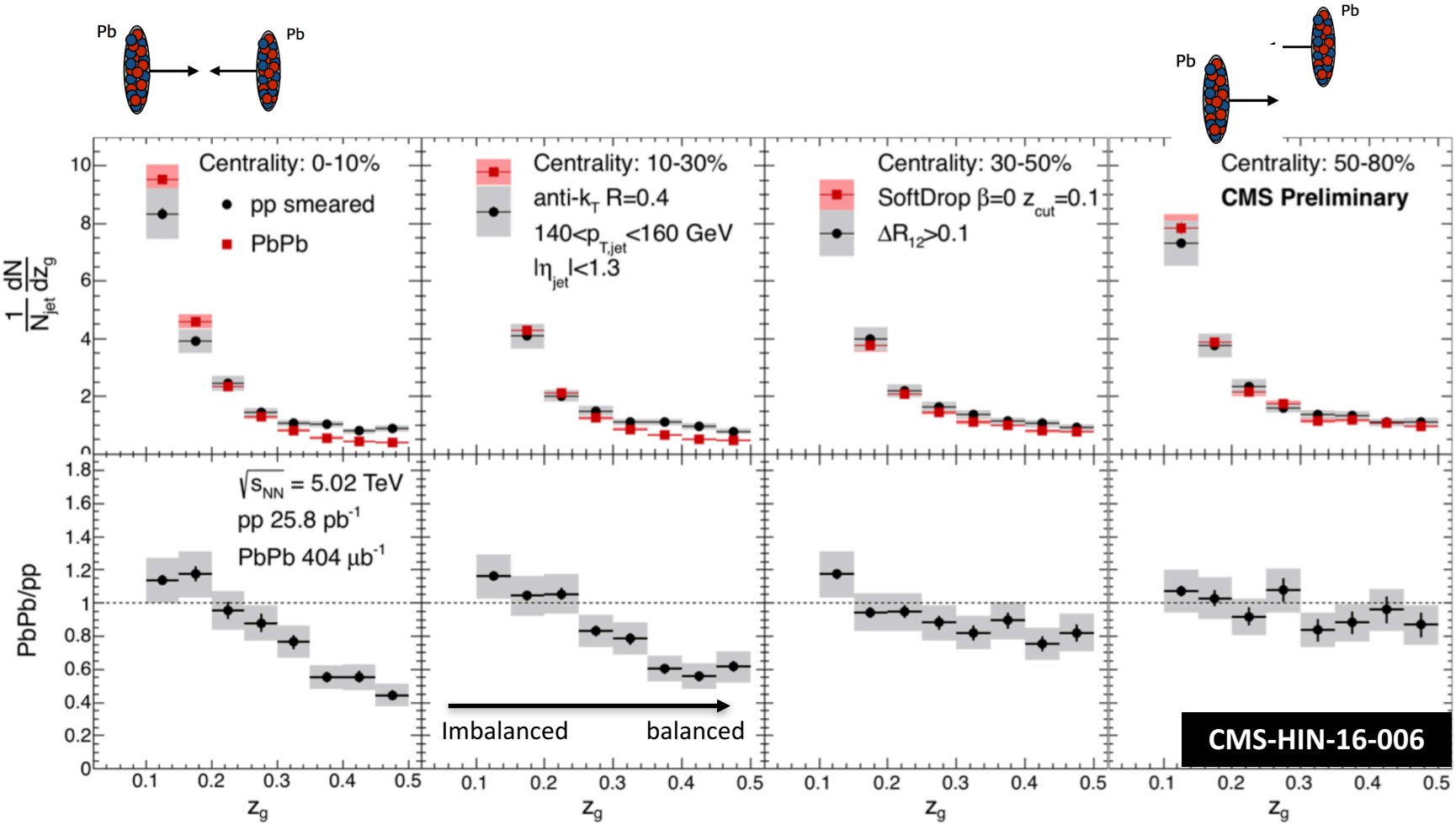
Observable : $z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$

Jet Grooming by SoftDrop

- Removes soft divergences and remaining backgrounds
- Grooming and sub-jet finding are done simultaneously

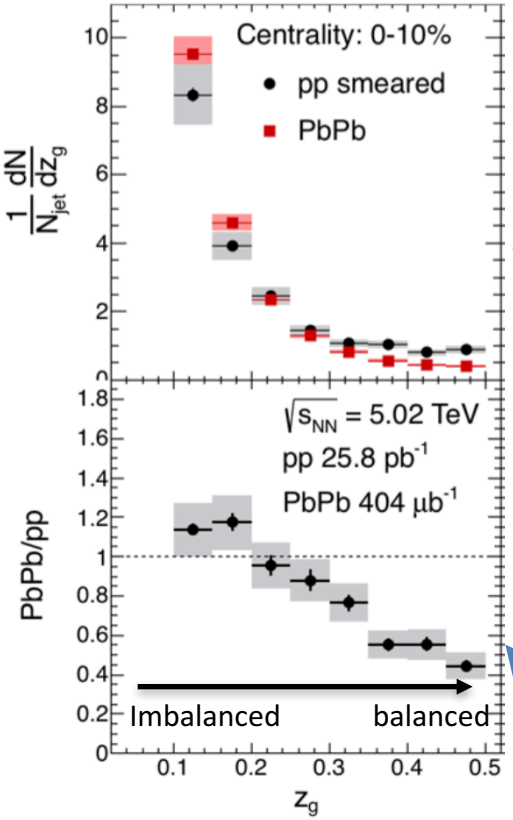


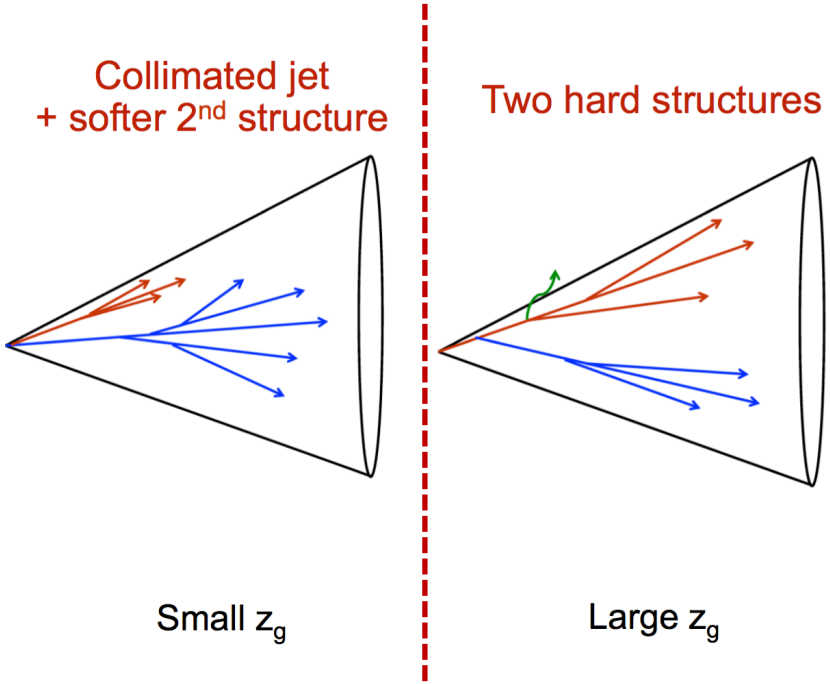
Jet Splitting Function



Compared to pp reference, the two subjets are more imbalanced in central PbPb collisions. The modification is less conspicuous for higher p_T.

Jet Splitting Function





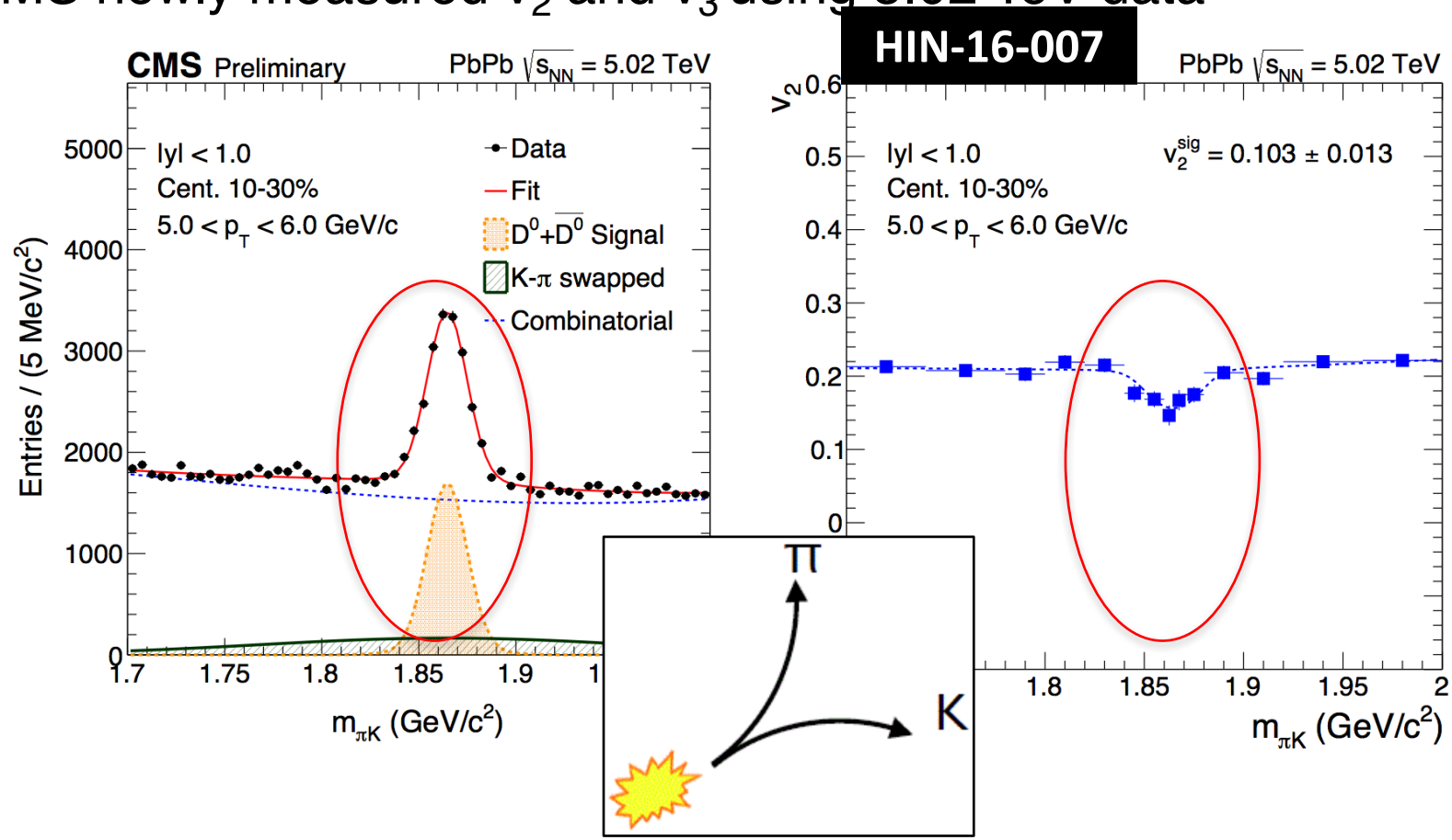
In pp low z_g is dominant, and balanced sub-jets are rare.

In PbPb, this tendency is even enhanced

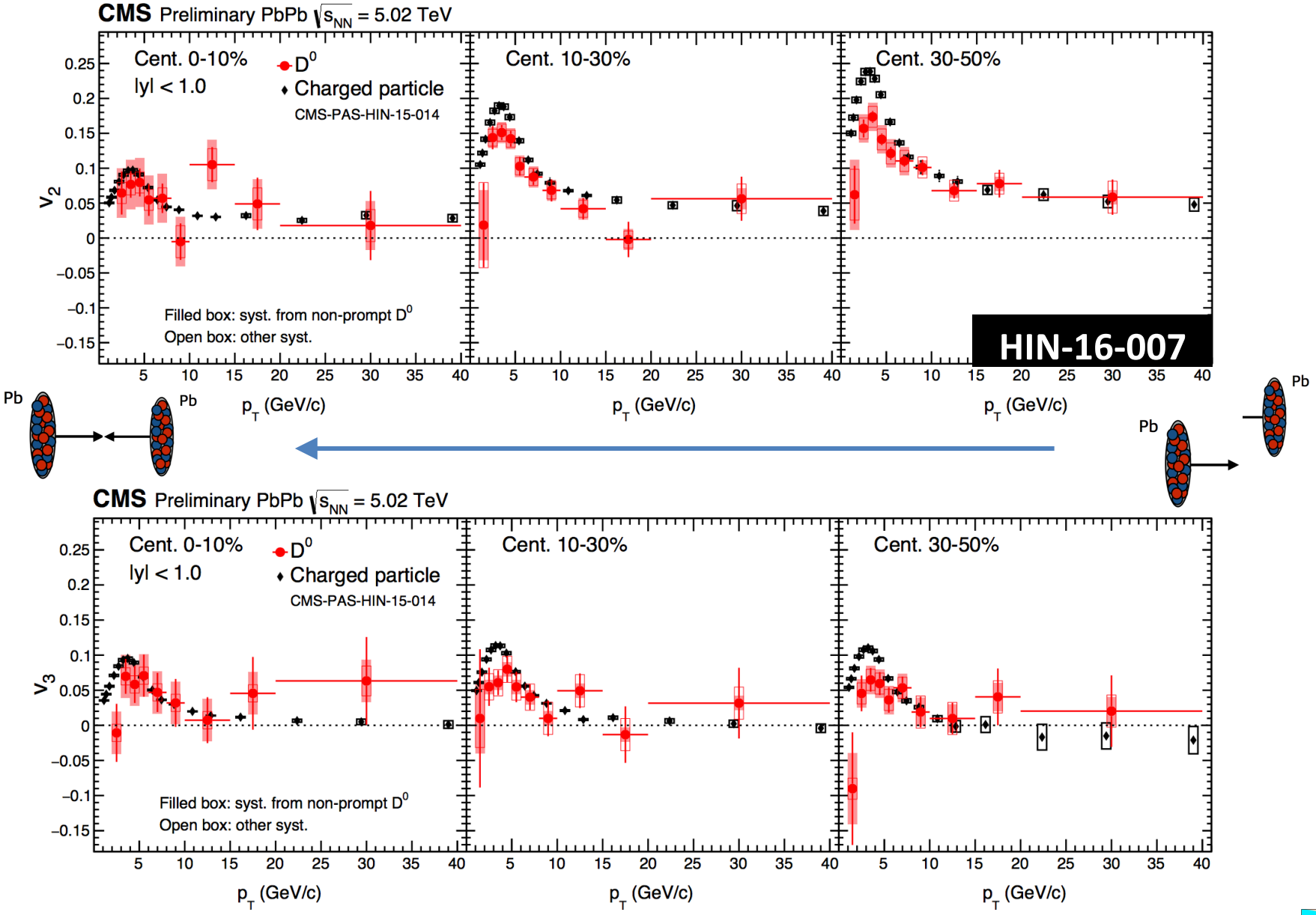
➔ Medium discriminates jet splitting patterns by inflicting different suppression

High p_T v_2 and v_3 of D^0

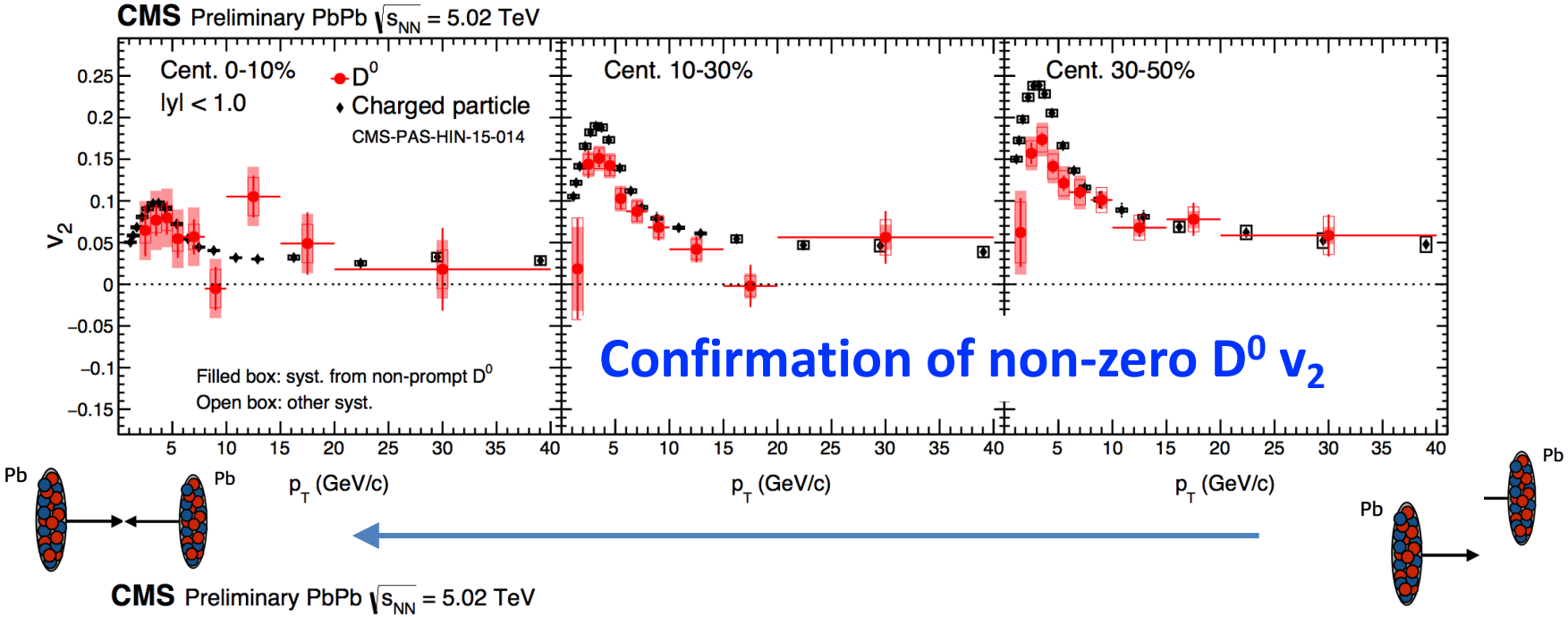
- Further aspect of heavy quark energy loss in medium
- ALICE measured of v_2 of D^0 at 2.76 TeV; the result was compatible with charged particle v_2
- CMS newly measured v_2 and v_3 using 5.02 TeV data

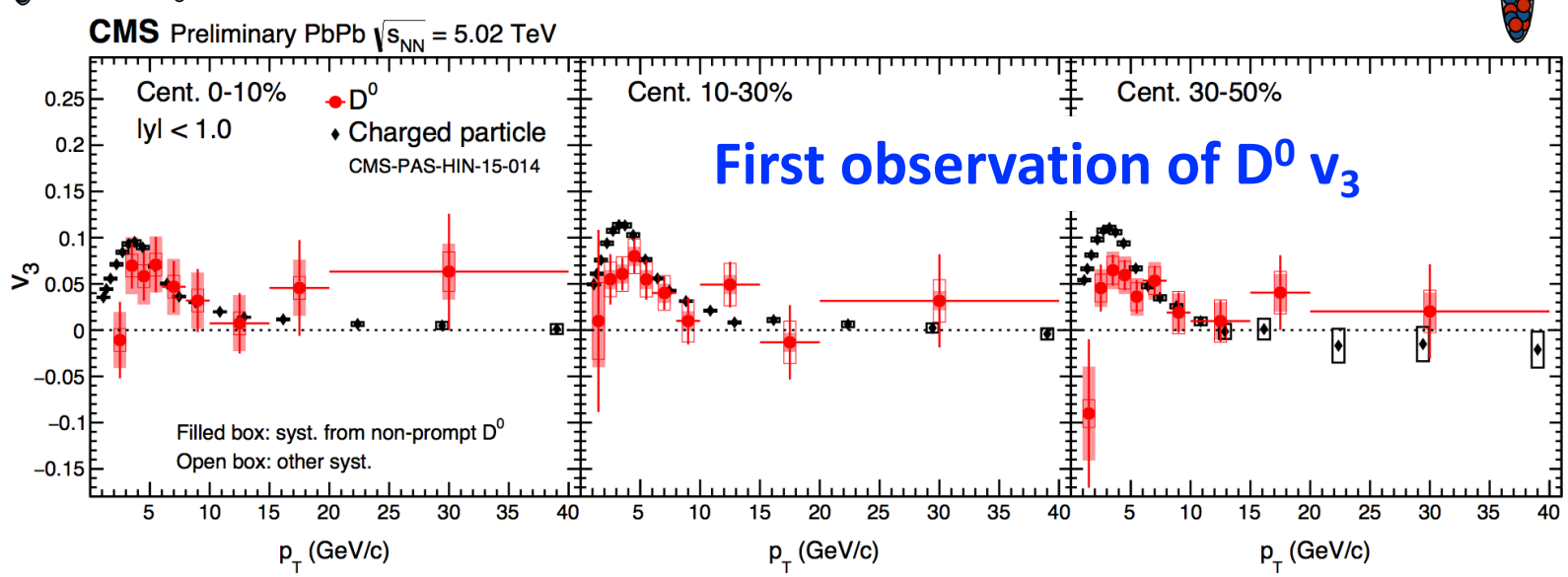


High p_T v_2 and v_3 of D^0

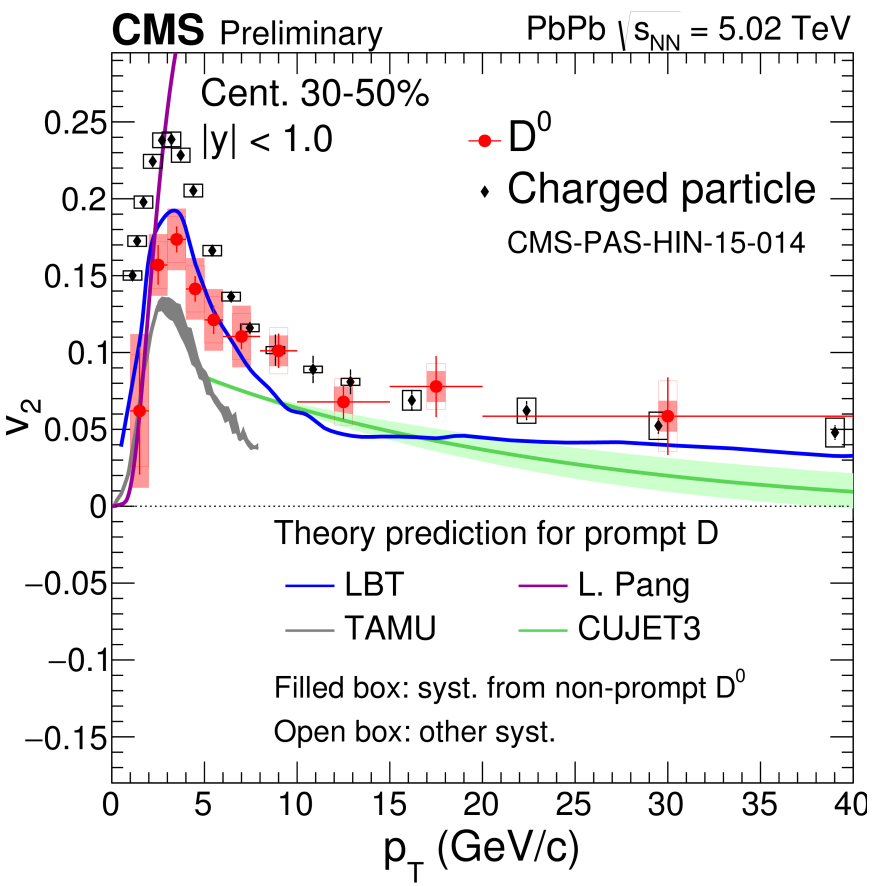


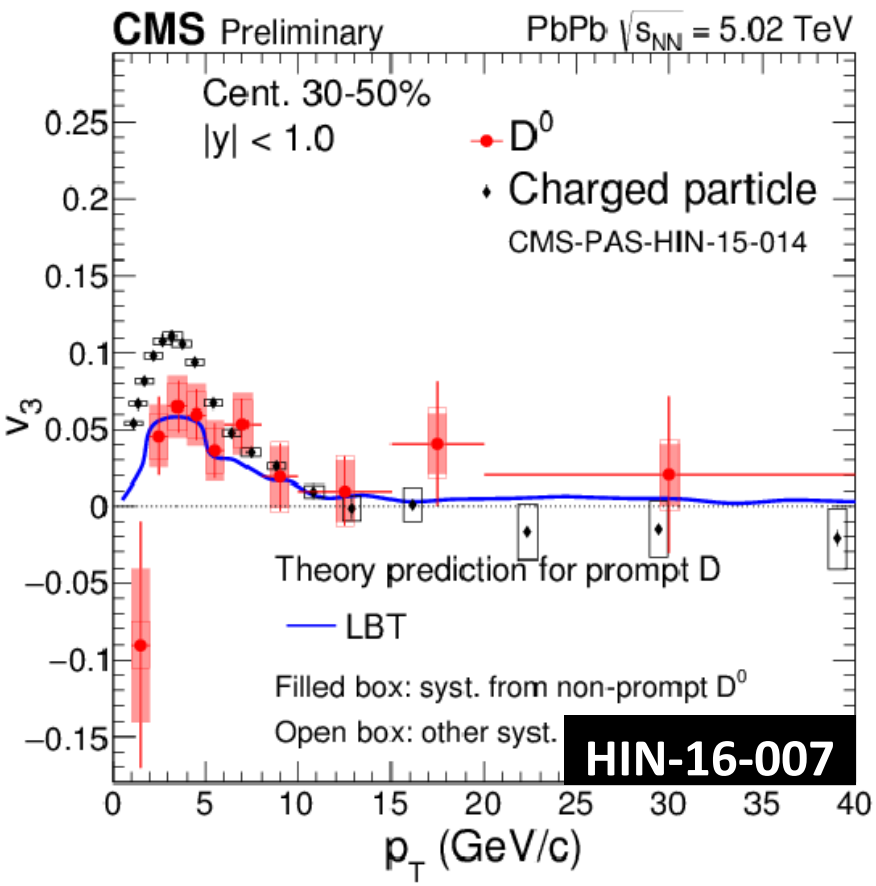
High p_T v_2 and v_3 of D^0





Comparison with models





Calculation of Linearized Boltzman Transport model fairly agrees with the measured v_2 and v_3 [PRC 94 014909 (2016)]

- pQCD transport model
- Lost energy is used for re-heating the medium

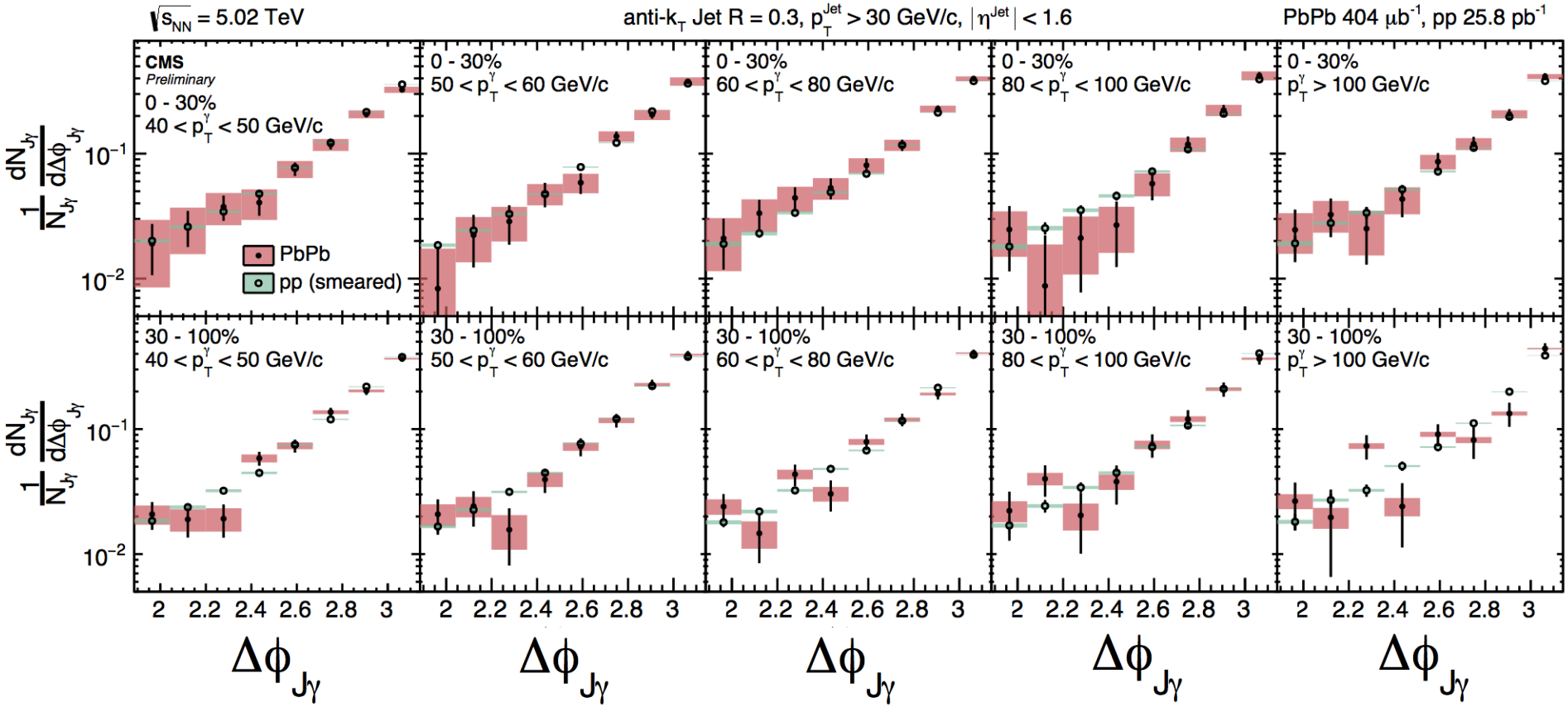
Conclusion

- **Plenty of new results using Run II data at 5.02 TeV!**

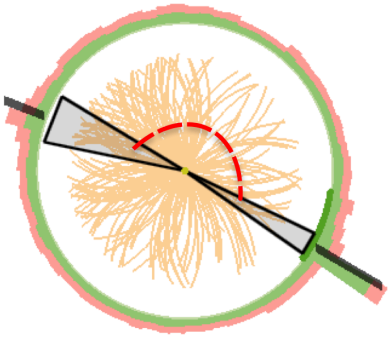
- **Photon-jet correlation**
  - provides the most direct evidence of parton energy loss by interaction with medium
- **Di-b-jet correlation & B meson R_{AA}**
  - Input for modelling the mass and flavor dependence of energy loss
- **Jet splitting function**
  - Medium has the eye for the hard split of jets
- **High p_T v_2 and v_3 of D^0**
  - Confirmation of flow of charm and the first measurement of v_3

BACKUP

Photon-jet correlation: Azimuth angle



CMS-HIN-16-002



No broadening of recoiled jet observed in the measured p_T and centrality bins