Heavy Flavor Jet with CMS

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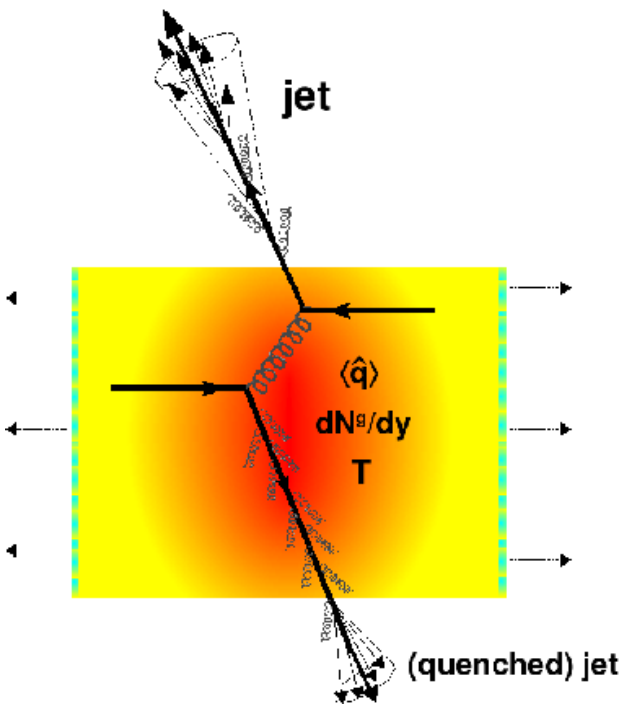
Motivation for heavy flavor jets

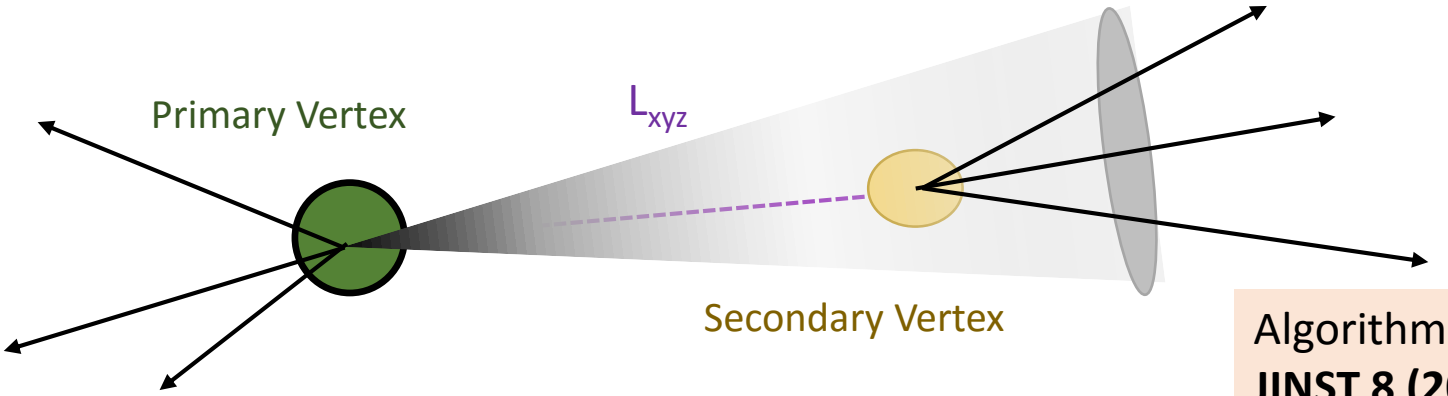
- In PbPb collisions:
  - Energy loss via jet quenching phenomenon.
  - Different interactions in quark-gluon-plasma depend on mass of quark
  - A measurement of heavy flavor jet could provide the info of flavor-dependent energy loss and probe the content of jet quenching



Nucl.Phys. A827 (2009)

- In pPb collisions:
  - Quantification of cold nuclear matter effects for heavy-flavor jet in PbPb.

Heavy flavor jet identification



Algorithms described in :
JINST 8 (2013) P04013

- b quark has long life time and decay length
- The flight distance (L_{xyz}) is used as discriminating variable
- The displacement of jet tracks used as a cross-check
- c jets identification is similar but with additional selection to enhance the c jets purity

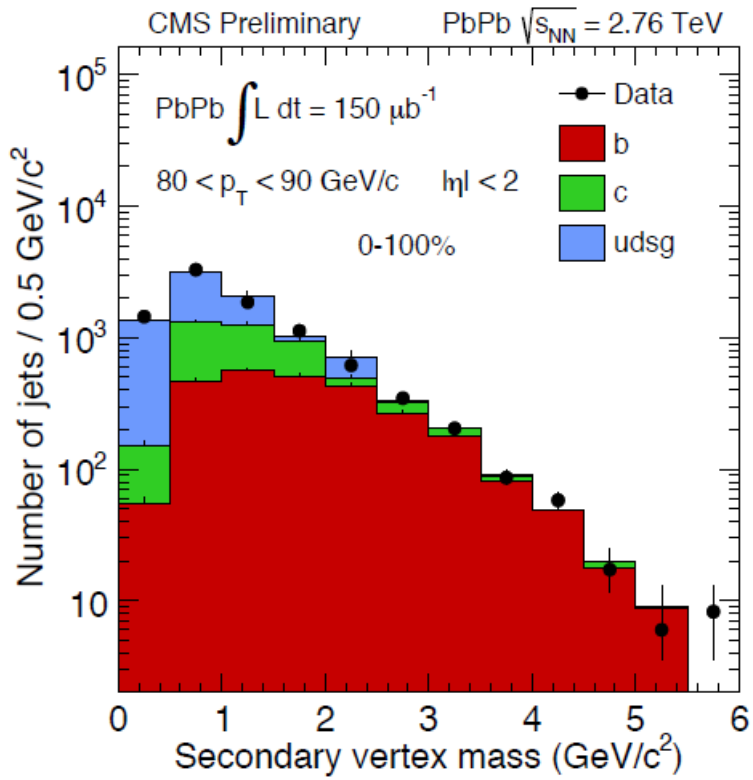
Calculating the heavy flavor jet fraction

$$\varepsilon_b = \frac{C_b f_b^{btag} N_{jets}^{btag}}{f_b^{untagged} N_{jets}^{untagged}} \quad [1]$$

f_b = b-tagging purity
ε_b = b-tagging efficiency
C_b = Fraction of jets with tagger information

$$N_{jets}^{b} = N_{jets}^{total} \frac{f_b^{btag}}{\varepsilon_b} \quad [2]$$

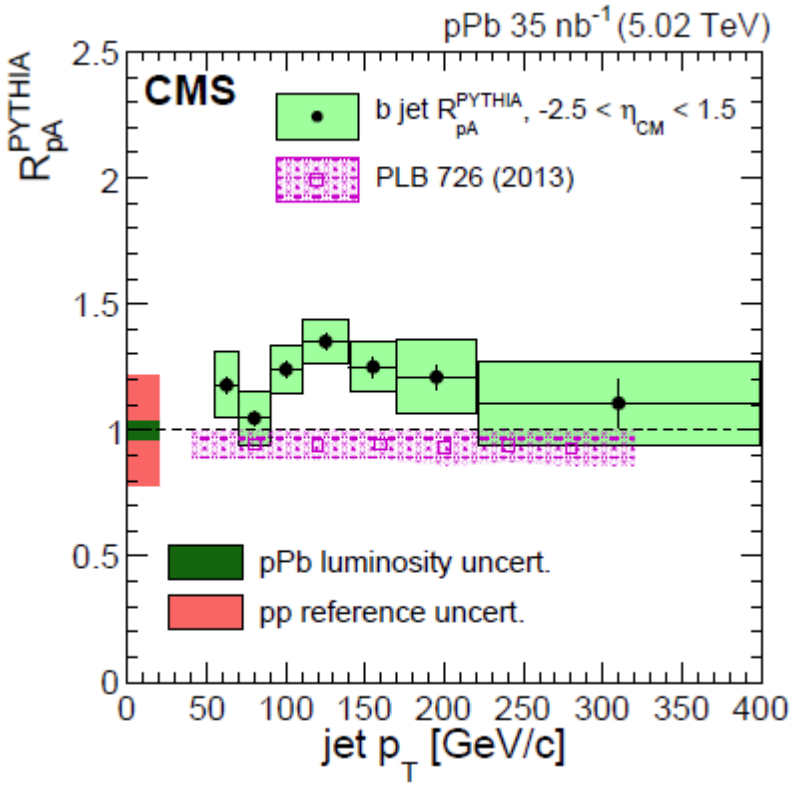
$N^{untagged}$ = All jets
$f_b^{untagged}$ = B-tagging purity of total jet sample



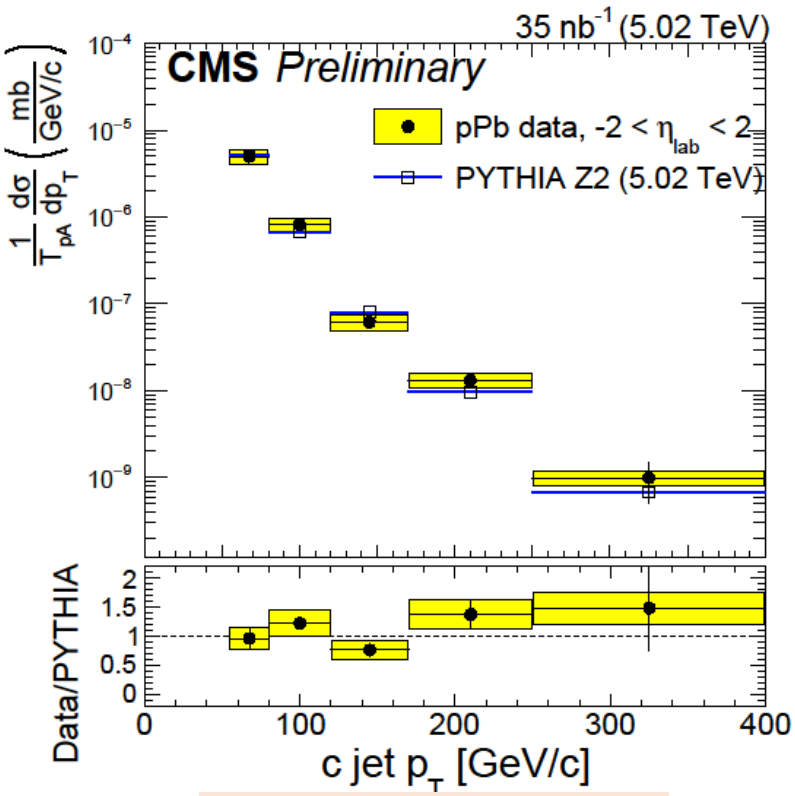
PRL 113:132301(2014)

- Purity calculated via template fits to secondary vertex mass
- Efficiency calculated using template fit before and after flavor tagging

b jet and c jet in 5 TeV pPb collisions



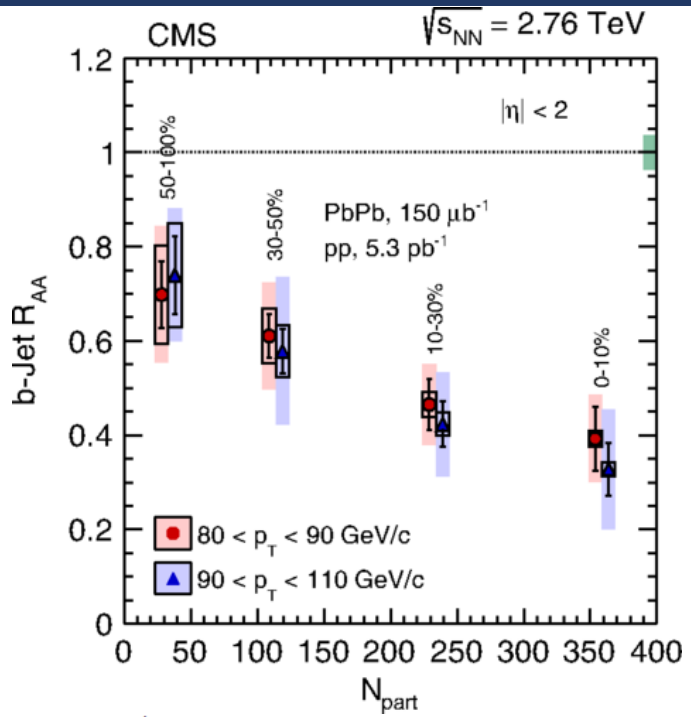
PLB 754:59(2016)

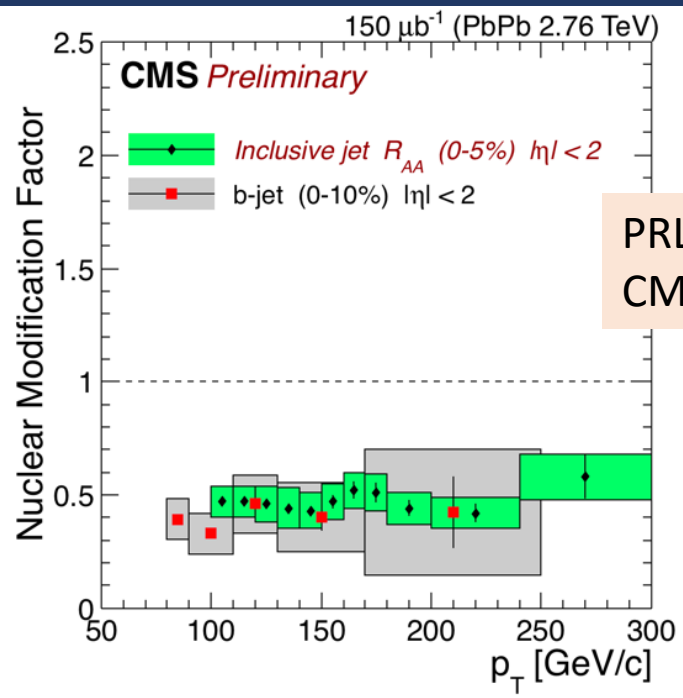


CMS PAS HIN-15-012

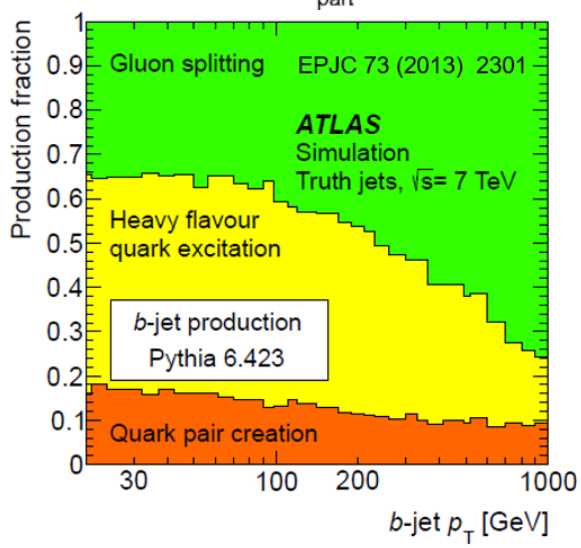
- No enhancement for jets in pPb with respect to pp for heavy flavor jet
- No significant CNM effects in heavy flavor jet production is observed

b jet suppression in 2.76 TeV PbPb collisons





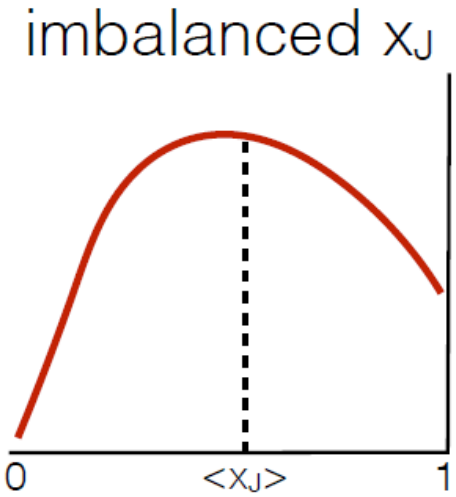
PRL 113:132301(2014) ;
CMS PAS HIN-12-004



- Larger suppression in more central collisions
- Suppression at the level of inclusive jet
- b dijet measurement dominant by flavor creation process might provide more info for energy loss flavor dependence

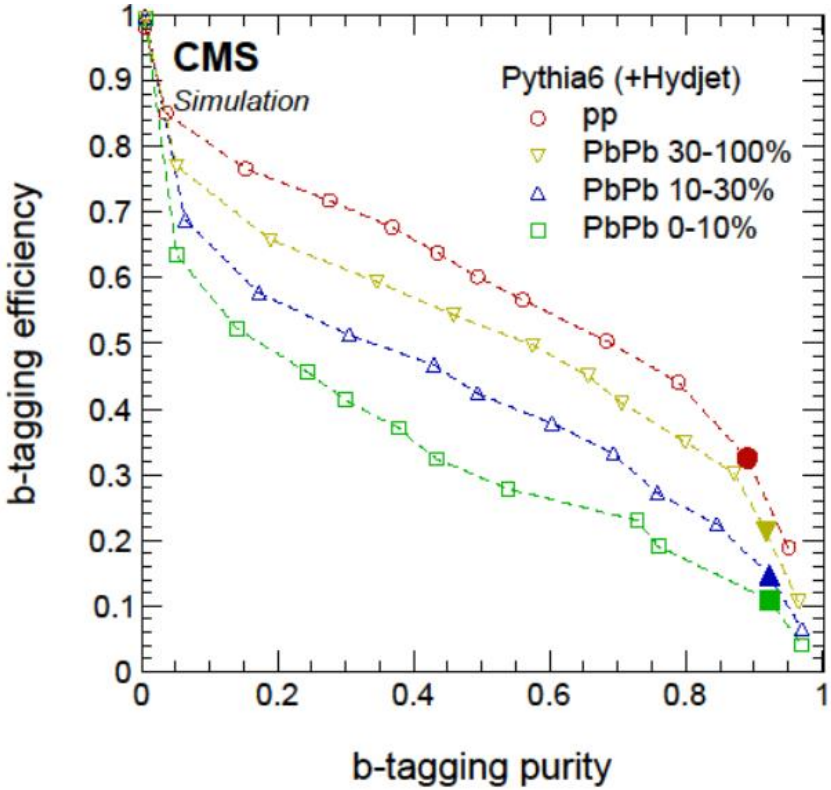
Dijet momentum imbalance measurement

- anti-k_T Particle Flow R=0.4 jets
- UE subtraction with iterative noise/pedestal subtraction
- Dijet selection:
  - $|\eta|<1.5$
  - $p_{T,1}>100$ GeV/c
  - $p_{T,2}>40$ GeV/c
  - $\Delta\phi_{1,2}>2\pi/3$
- Dijet momentum imbalance
  - $X_J=p_{T,2}/p_{T,1}$



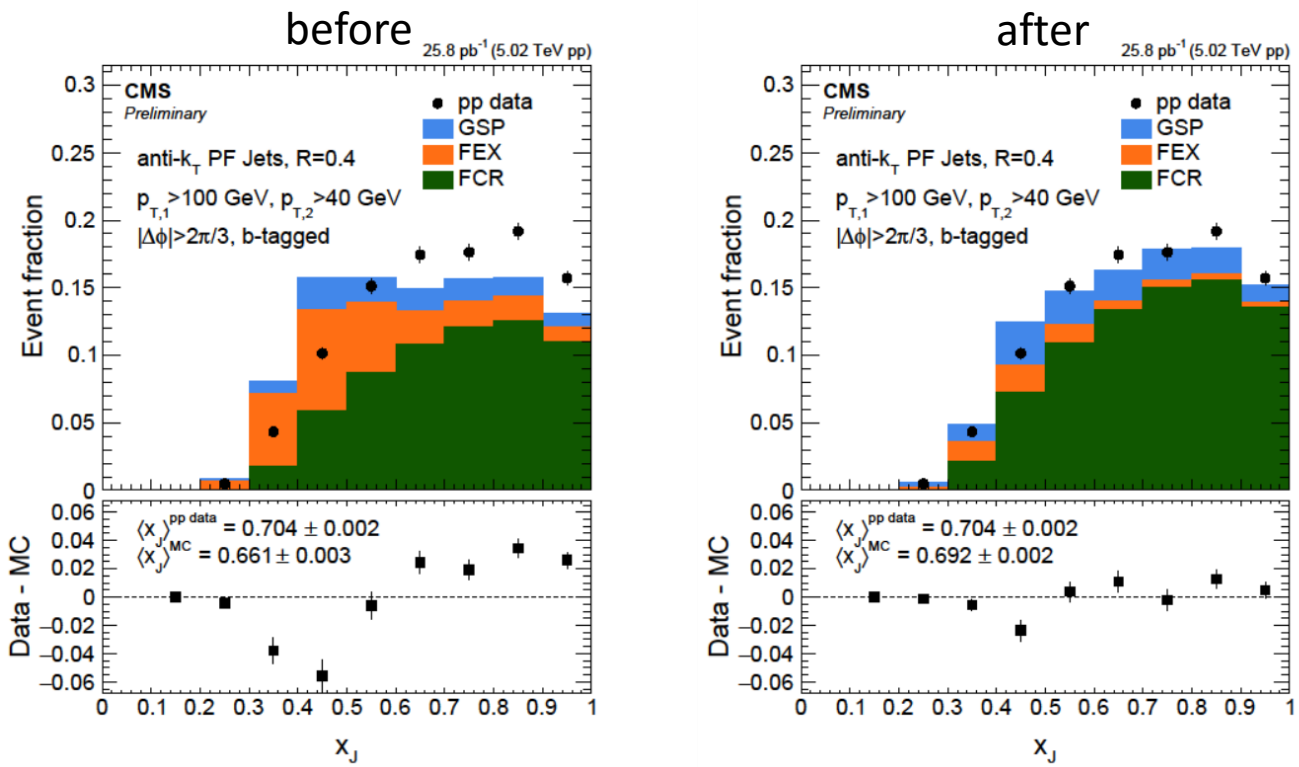
b-tagging in PbPb collisions at 5 TeV

- Combined Secondary Vertex discriminator is constructed by vertex and track information to identify b dijets
- The working point is selected to obtain 90% pure sample
- Tagging efficiency corrections are applied in : p_T , η, Centrality
- ~10% contamination is taken into account as a systematic uncertainty



CMS PAS HIN-16-005 , CDS:2202805

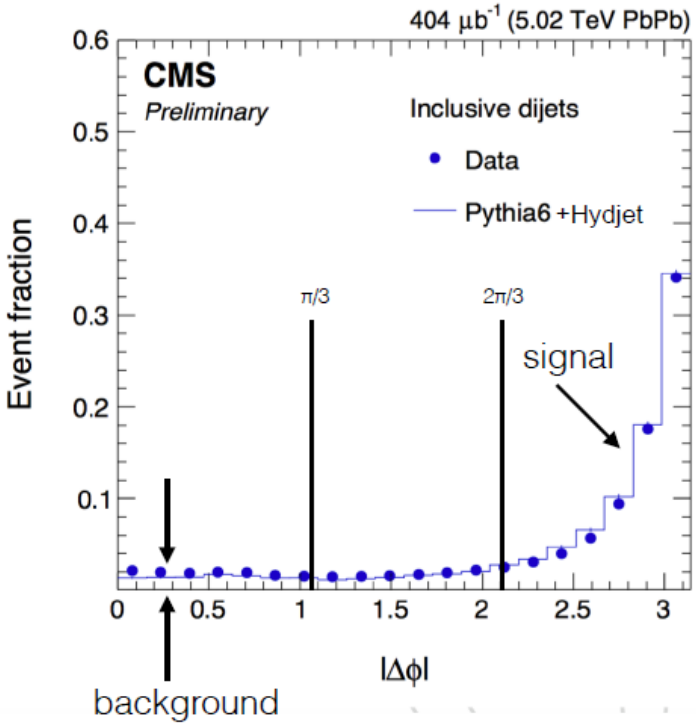
Flavor process reweighting

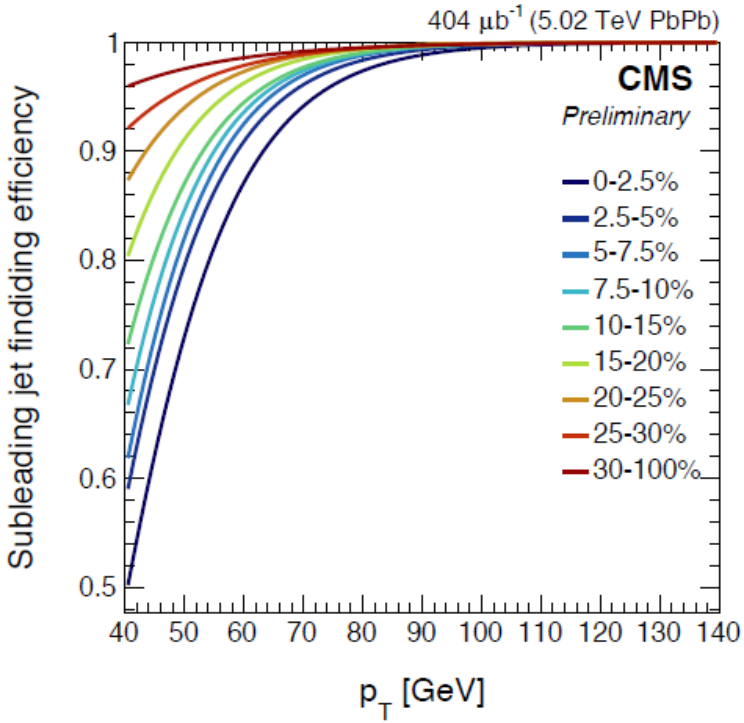


CMS PAS HIN-16-005

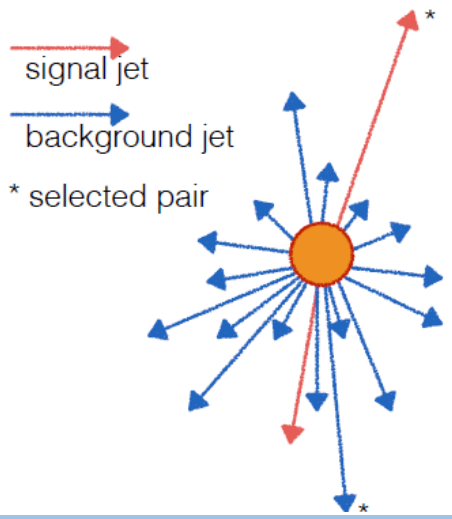
- Data/PYTHIA discrepancy is found in b dijet momentum imbalance.
- After reweighting, Data/PYTHIA in agreement
- FCR in analysis selection 53% ⟶ 70%
- Similar conclusion in CDF PRD71 (2005) 092001

Combinatorial background subtraction & correction





CMS PAS HIN-16-005

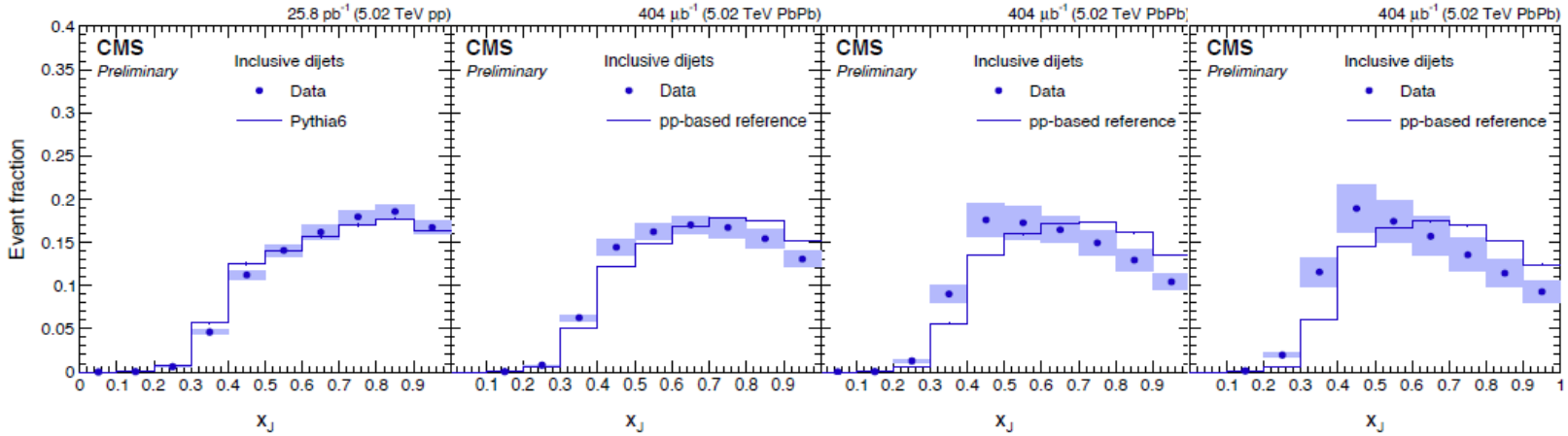


- Combinatorail background removed with sideband method

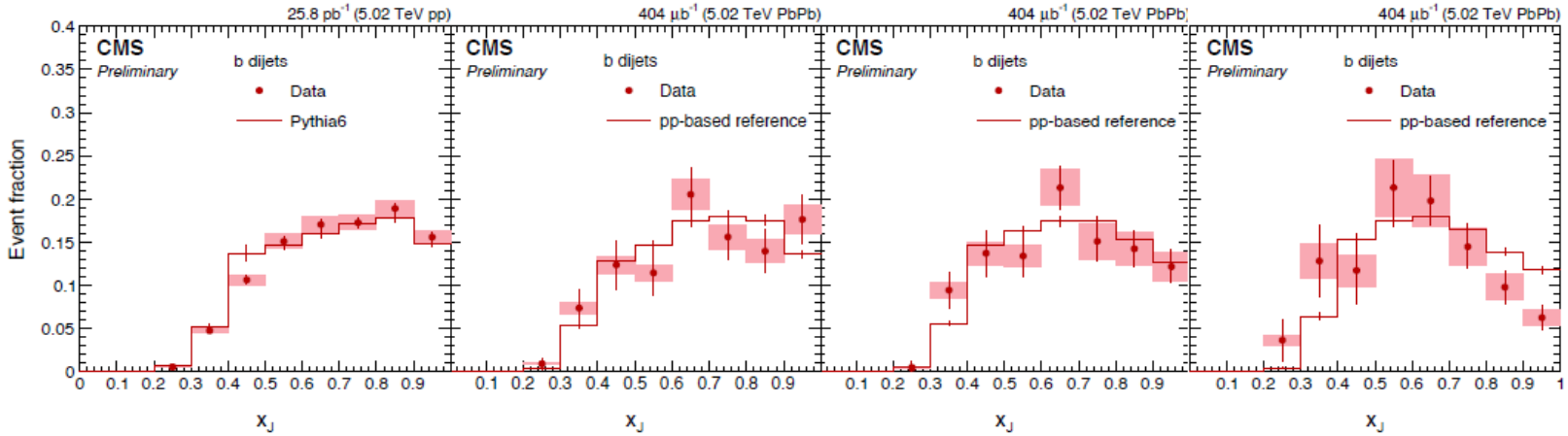
Inclusive and b dijet imbalance in 5 TeV PbPb collisions

pp | PbPb 30-100% | PbPb 10-30% | PbPb 0-10%

Inclusive dijets



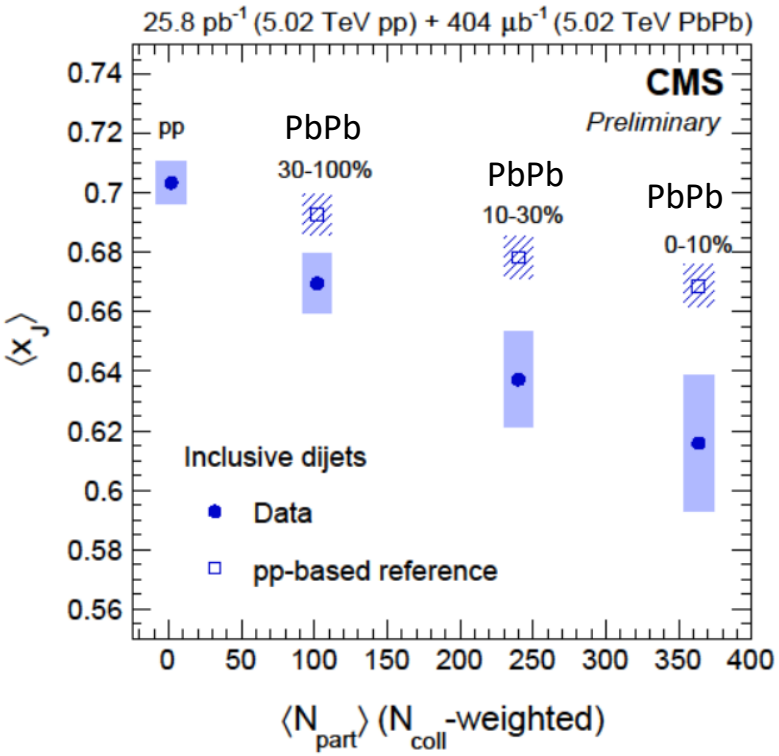
b dijets



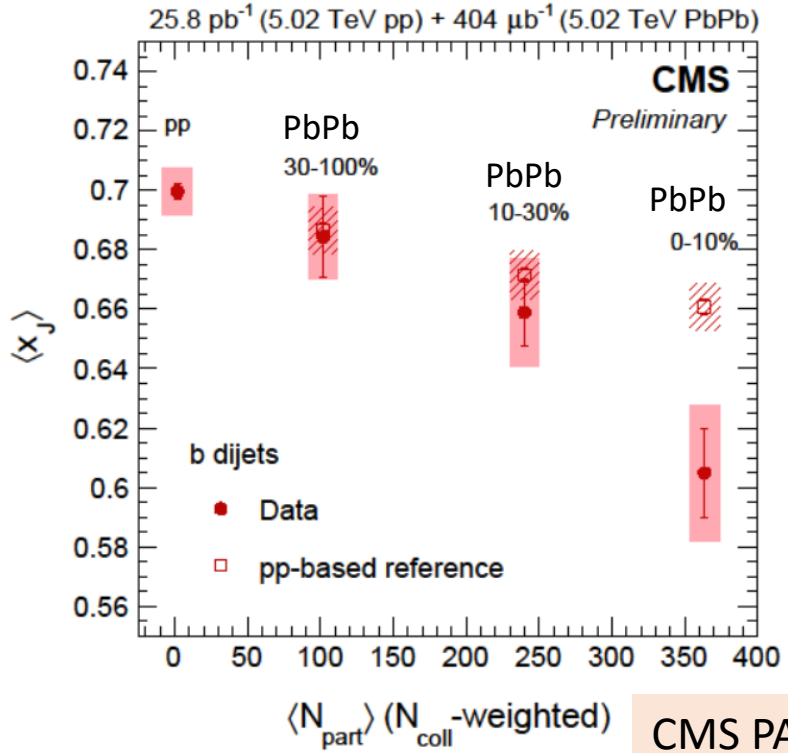
CMS PAS HIN-16-005

Dijet results summary

Inclusive dijet



b dijet



$Xj=p_{T,2}/p_{T,1}$

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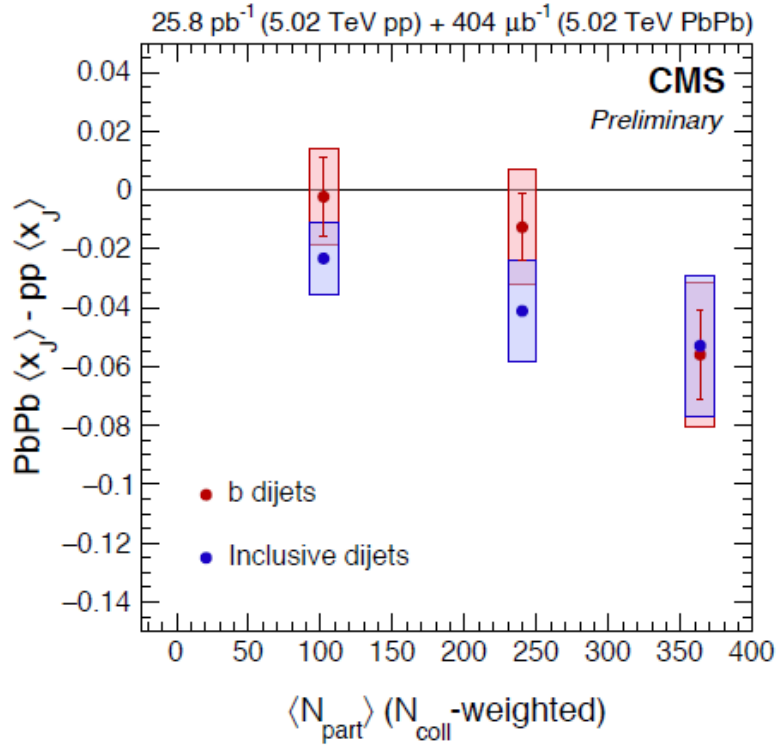
- The imbalance of b dijets has been observed for the first time
- The increase of imbalance of inclusive dijets from pp to central PbPb collisions has been confirmed at 5TeV
- Inclusive dijet and b dijet imbalance are within uncertainty

Summary

- Both b jets and b dijets measurement in PbPb collisions are on the same level as inclusive jet
  - No significant flavor-dependent energy loss is observed
- b jets and c jets R_{pA}^{PYTHIA} measurement in pPb collision are consistent with unity
  - No significant CNM effects is observed



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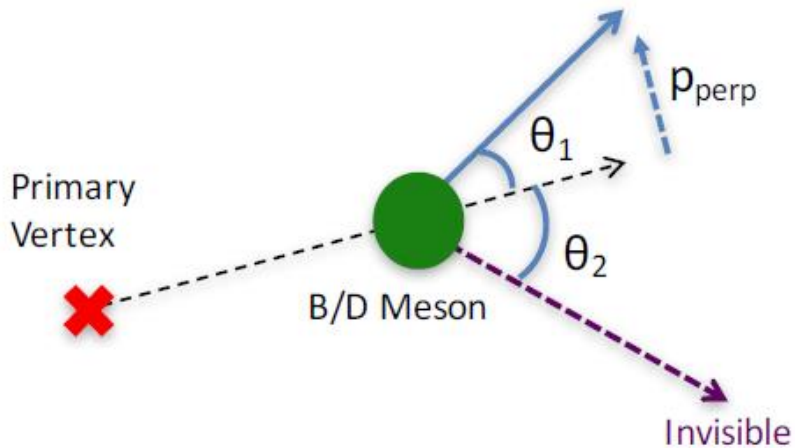
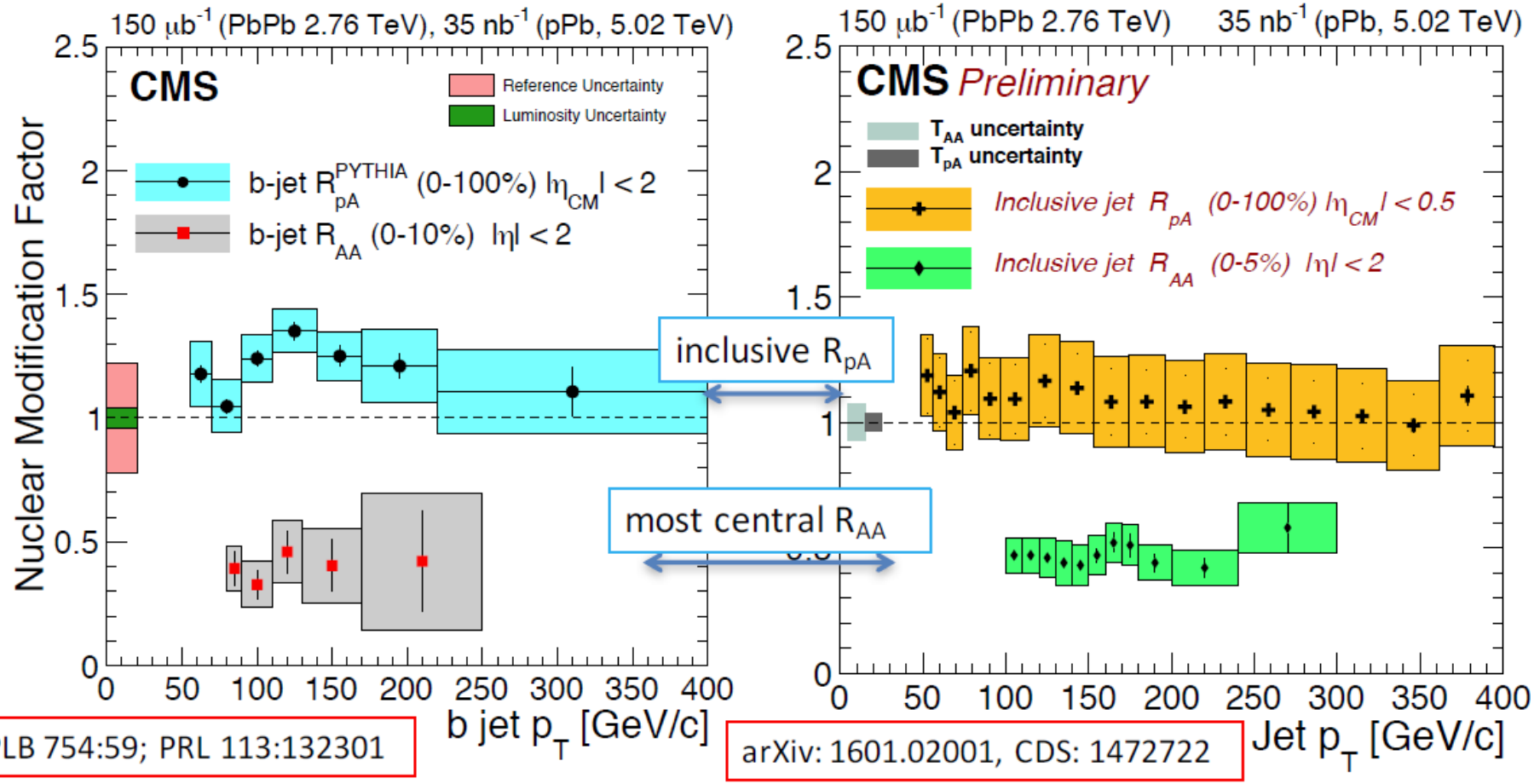
Back Up

Identifying Charm-Jet



- C-Tagging uses 3-prong secondary vertex to lower the misidentification rate wrt to light Jets.
- Use Corrected Secondary Vertex Mass:
  - $M_{corr} = \sqrt{M^2 + p^2 sin^2\theta_1} + psin\theta_1$
- Attempts to restore Mass from missing energy.

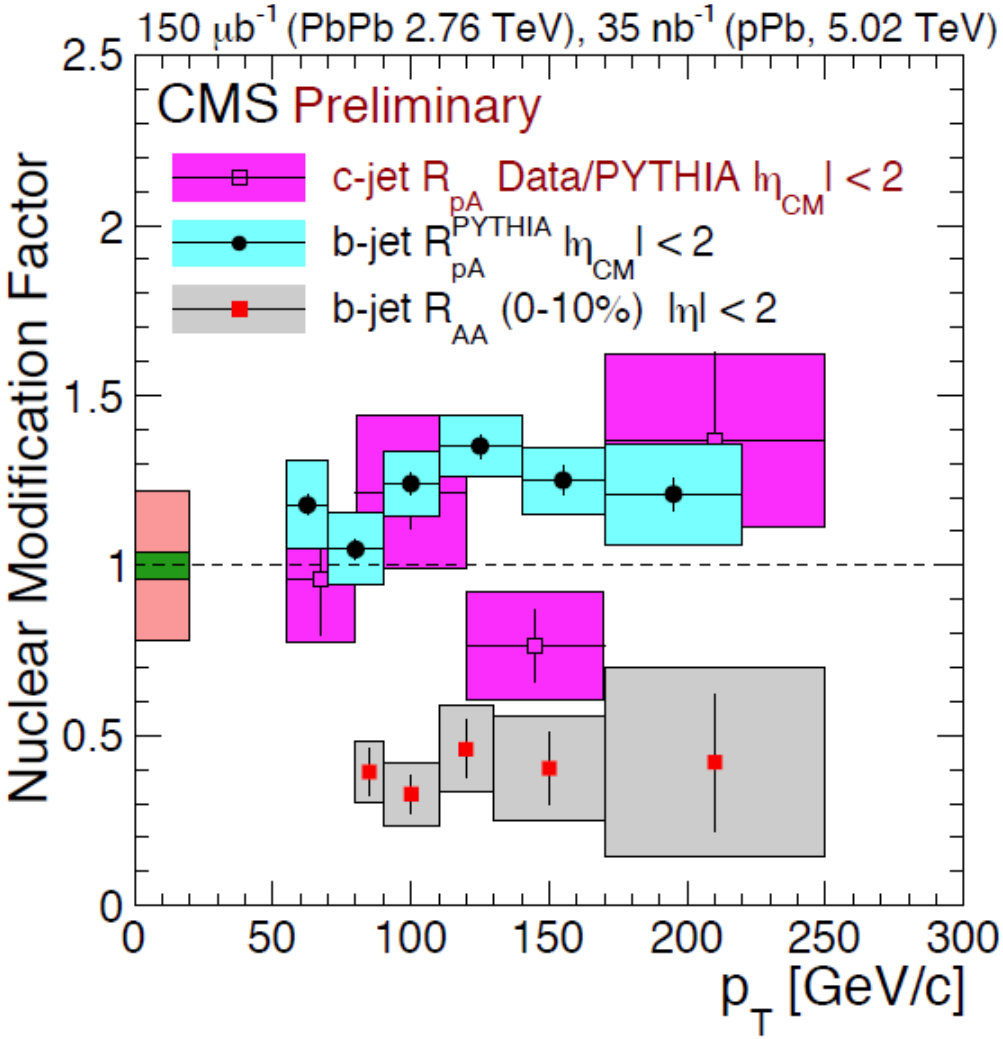
Comparison to Inclusive-Jets



PLB 754:59; PRL 113:132301

arXiv: 1601.02001, CDS: 1472722

R_{AA} & R_{pA} summary



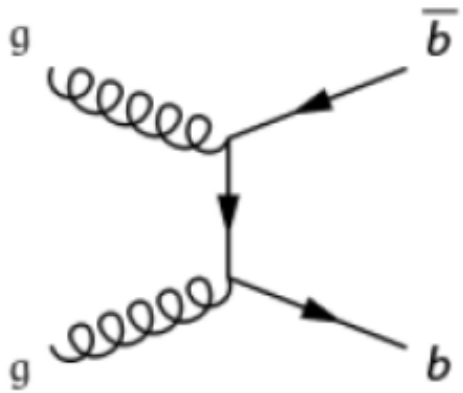
- Parton mass-dependent effects are small at high-p_T – consistent with pQCD prediction.
- No siginificant Flavor-dependent energy loss has been found.
- Rpa Result consistent with pQCD predictions of small CNM effects.

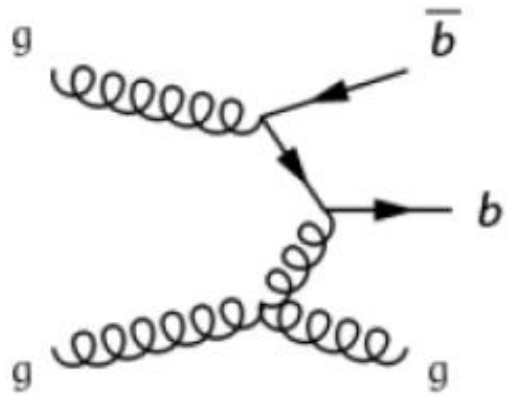
CSV varibles

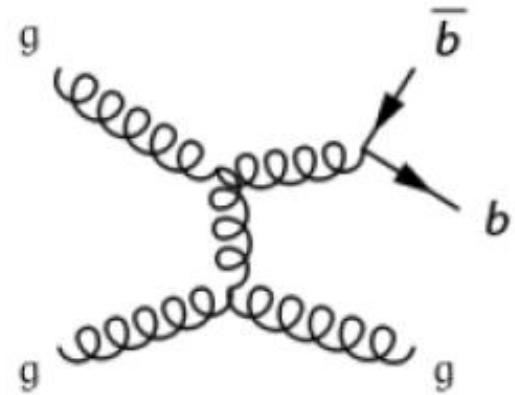
The following set of variables with high discriminating power and low correlations is used:

- the vertex category (real, “pseudo,” or “no vertex”);
- the 2D flight distance significance;
- the vertex mass;
- the number of tracks at the vertex;
- the ratio of the energy carried by tracks at the vertex with respect to all tracks in the jet;
- the pseudo-rapidity of the tracks at the vertex with respect to the jet axis;
- the 2D IP significance of the first track that raises the invariant mass above the charm threshold of 1.5 GeV when subsequently summing up tracks ordered by decreasing IP significance;
- the number of tracks in the jet;
- the 3D signed IP significances for each track in the jet

b jet Production Mechanism







Flavor Creation (FCR)

- Gluon fusion or $q\bar{q}$ annihilation
- Heavy quarks are back-to-back

Flavor Excitation (FEX)

- Sea $b\bar{b}$ pair is excited by gluon or light quark
- Heavy quark is back-to-back with light parton

Gluon Splitting (GSP)

- Gluon splits into $b\bar{b}$
- Small angle between heavy quarks

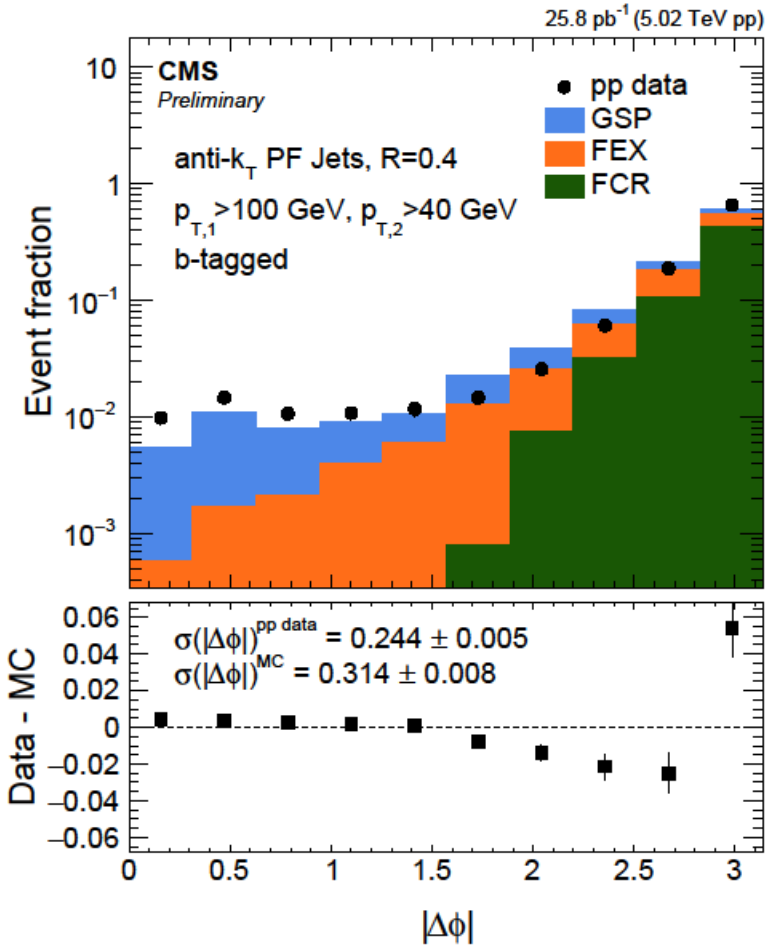
Flavor process reweighting

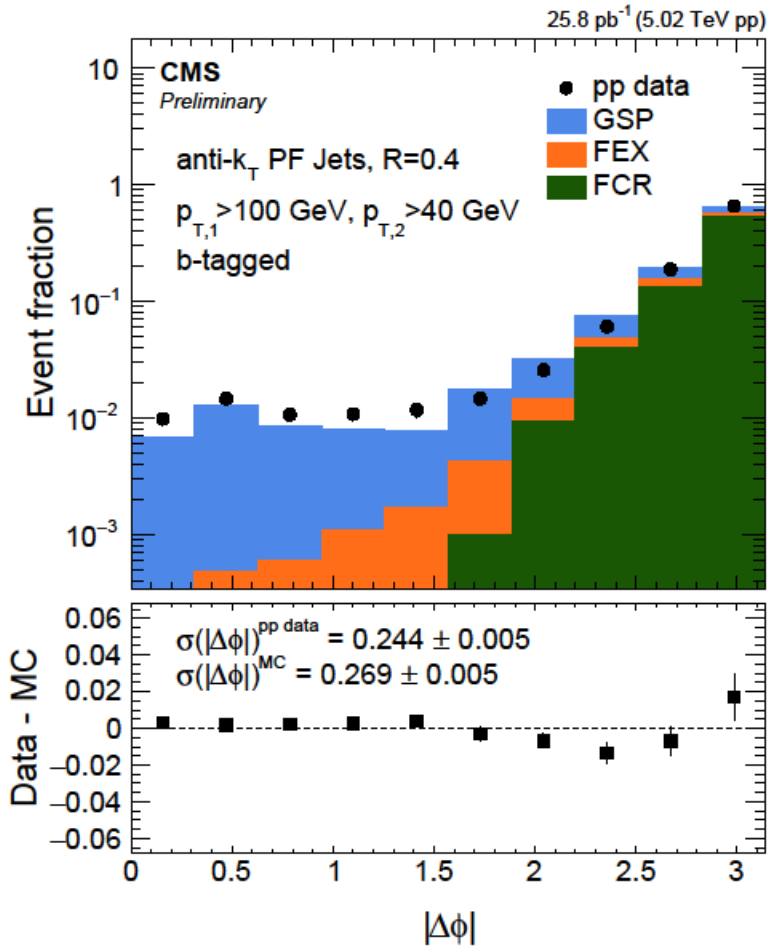
- Reweight the flavor process based on the difference of MC and Data in three Categories:
  - $|\Delta\phi 1,2|>2\pi/3$: The two highest p_T jets are b-tagged and back-to-back
  - $|\Delta\phi 1,3|>2\pi/3$: The first and third highest p_T jets are b-tagged and back-to-back
  - $|\Delta\phi 1,3|<\pi/3$: The first and third highest p_T jets are b-tagged and nearby

Category	FCR	FEX	GSP
$\|\Delta\phi 1,2\|>2\pi/3$	57%	26%	17%
$\|\Delta\phi 1,3\|>2\pi/3$	11%	62%	27%
$\|\Delta\phi 1,3\|<\pi/3$	0%	17%	83%

Category	MC	Data
$\|\Delta\phi 1,2\|>2\pi/3$	46%	56%
$\|\Delta\phi 1,3\|>2\pi/3$	49%	37%
$\|\Delta\phi 1,3\|<\pi/3$	5%	7%

Dijet Δϕ after reweighting





Dijet systematic uncertainties:

Source	pp	30-100%	10-30%	0-10%
Combinatorial subtraction	-	0.001	0.006	0.014
Subleading jet finding	-	0.002	0.004	0.004
Energy scale	0.001	0.006	0.010	0.013
Jet resolution	0.007	0.008	0.010	0.012
total	0.007	0.010	0.016	0.023

Table 4: Absolute systematic uncertainties on $\langle x_J \rangle$ for inclusive dijets.

Source	pp	30-100%	10-30%	0-10%
Combinatorial subtraction	-	0.008	0.008	0.008
Subleading jet finding	-	0.002	0.004	0.004
Tagging efficiency	0.002	0.003	0.003	0.009
Signal mistagging	0.002	0.004	0.006	0.006
Jet energy scale	0.001	0.006	0.010	0.013
Jet resolution	0.007	0.008	0.010	0.012
total	0.008	0.014	0.018	0.023

Table 5: Absolute systematic uncertainties on $\langle x_J \rangle$ for b dijets.

- pp results have been smeared according to the jet resolution in PbPb in order to make data-based reference