Bottom quark dijet momentum imbalance in PbPb collisions with CMS

4th Heavy Ion Jet Workshop, LLR

Stas Lisniak for CMS collaboration

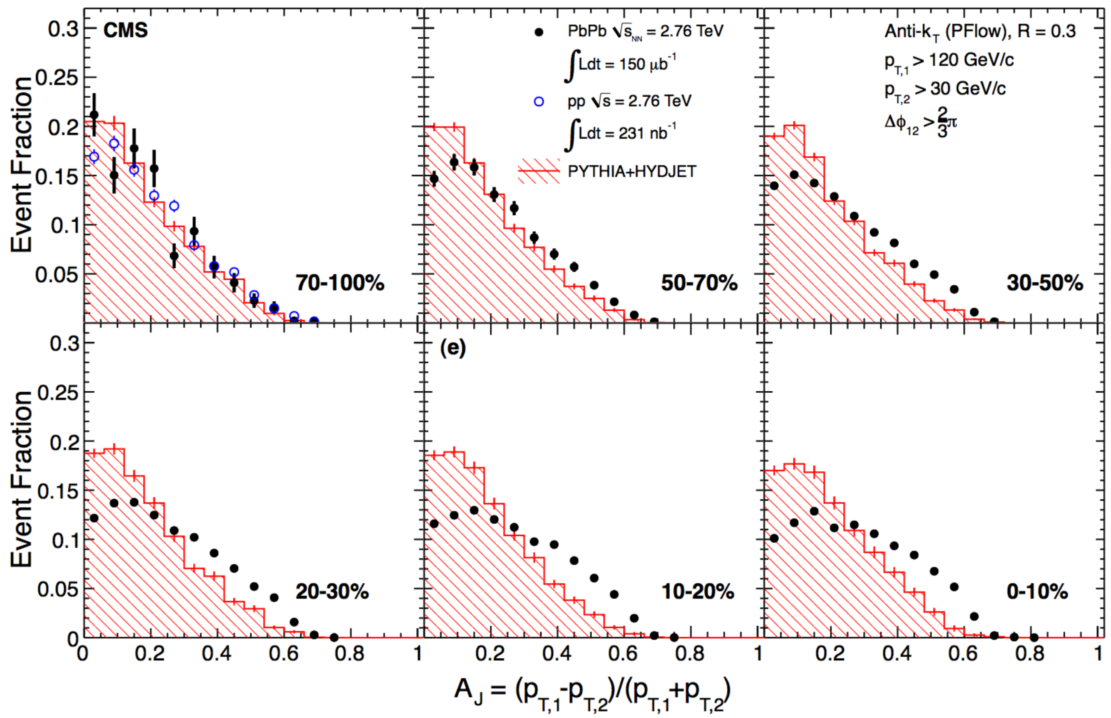
2016/07/26

CMS-HIN-16-005

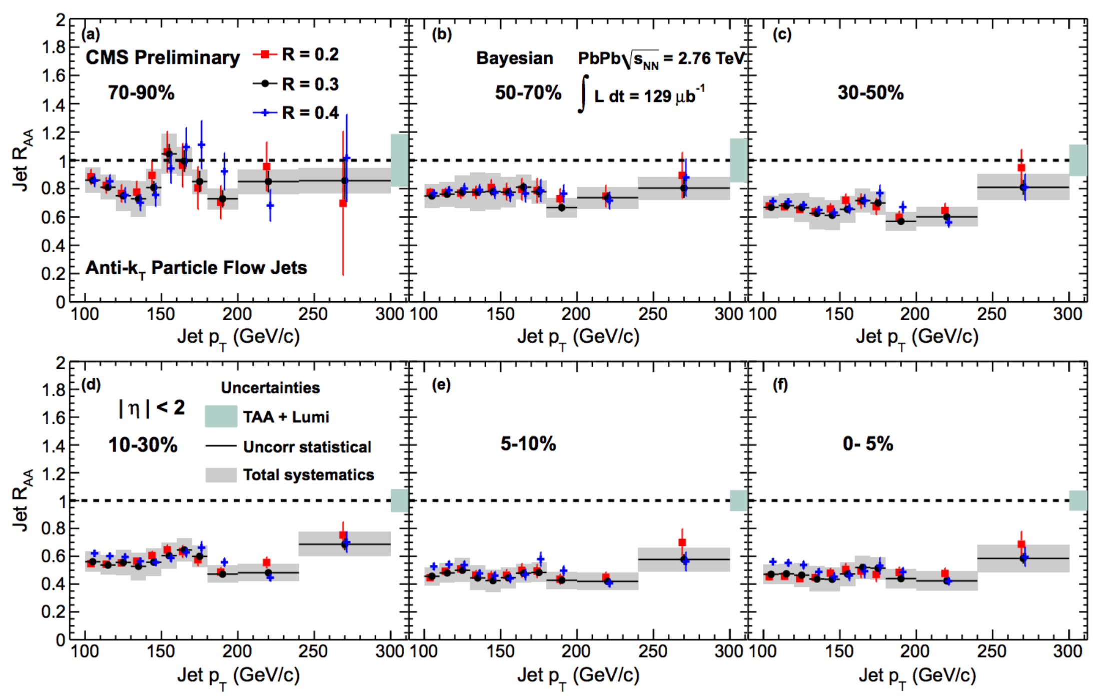
Motivation

Inclusive jets

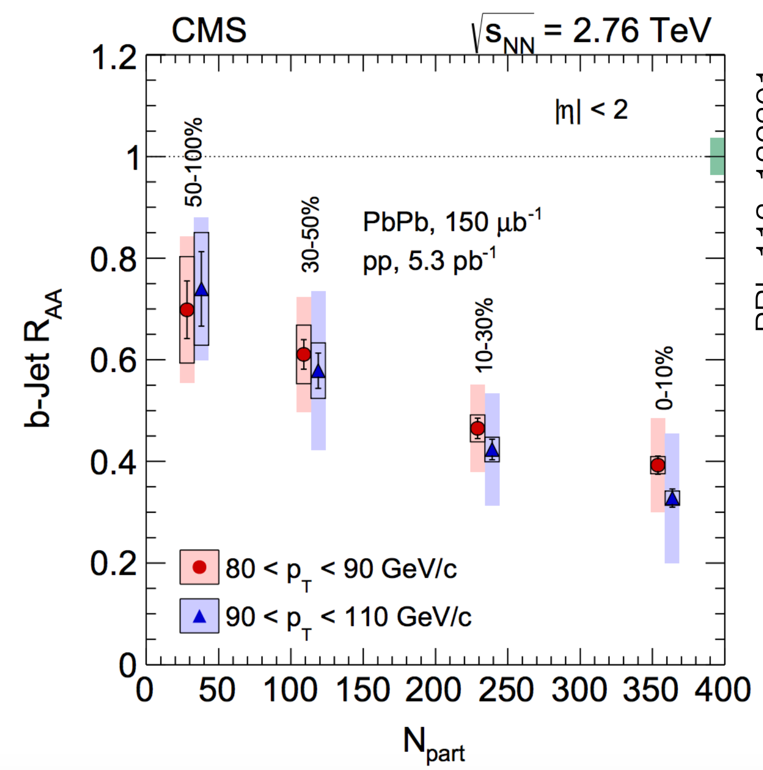
PLB 712 (2012) 176



CMS-PAS-HIN-12-004



b-jets



PRL 113, 132301

b dijet imbalance ?

Dijet momentum imbalance

- anti-k_T Particle Flow R=0.4 jets
- UE subtraction with iterative noise/pedestal subtraction technique

- Dijet selection:

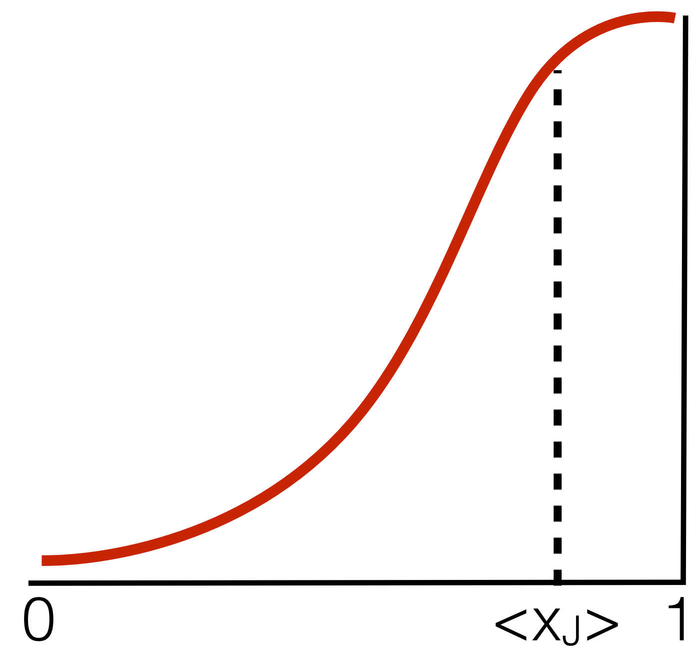
$$|\eta|<1.5$$
$$p_{T,1}>100 \text{ GeV/c}$$
$$p_{T,2}>40 \text{ GeV/c}$$
$$\Delta\phi_{1,2}>2\pi/3$$

- Dijet imbalance

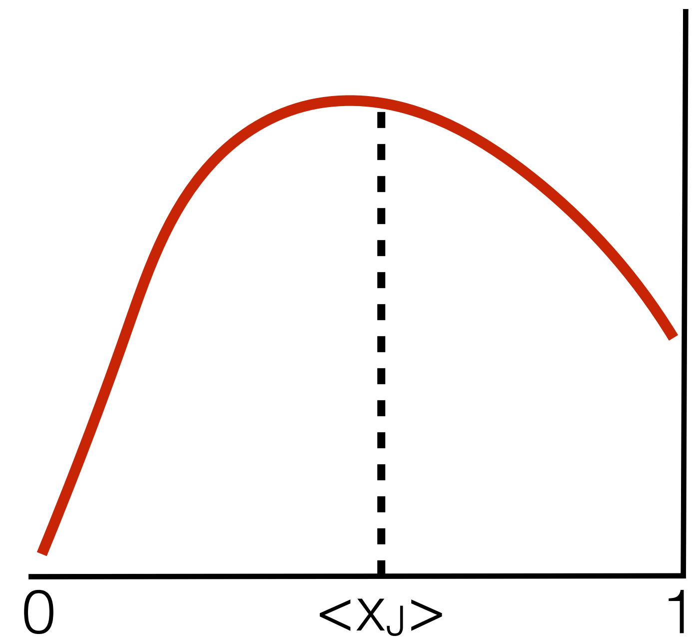
$$x_J = p_{T,2} / p_{T,1}$$

- Dijets are not *perfectly* balanced even in QCD
- +detector resolution effects

balanced x_J

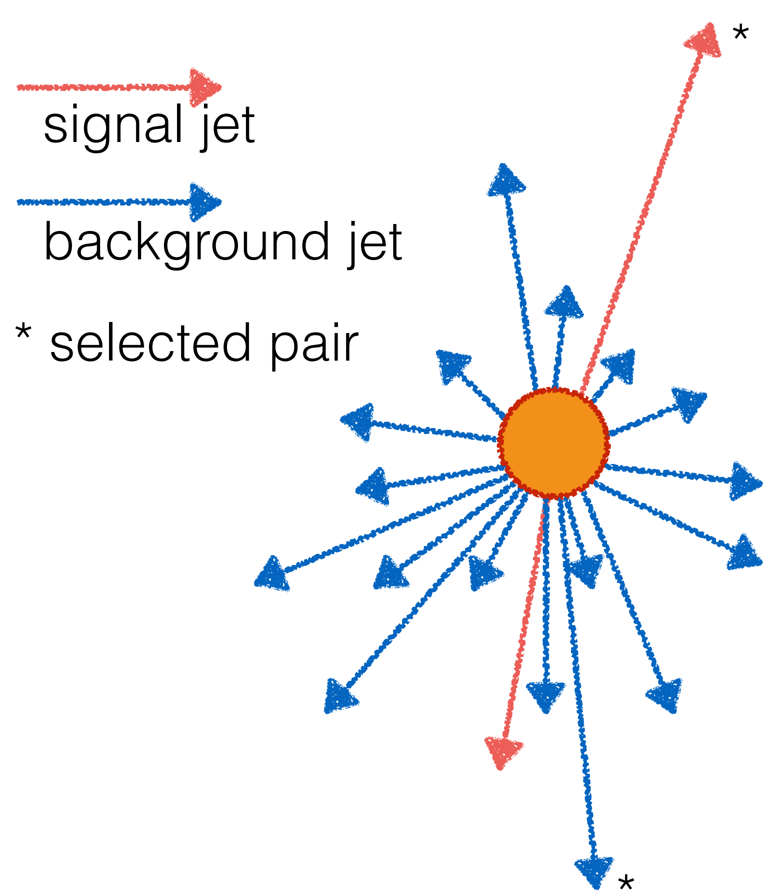


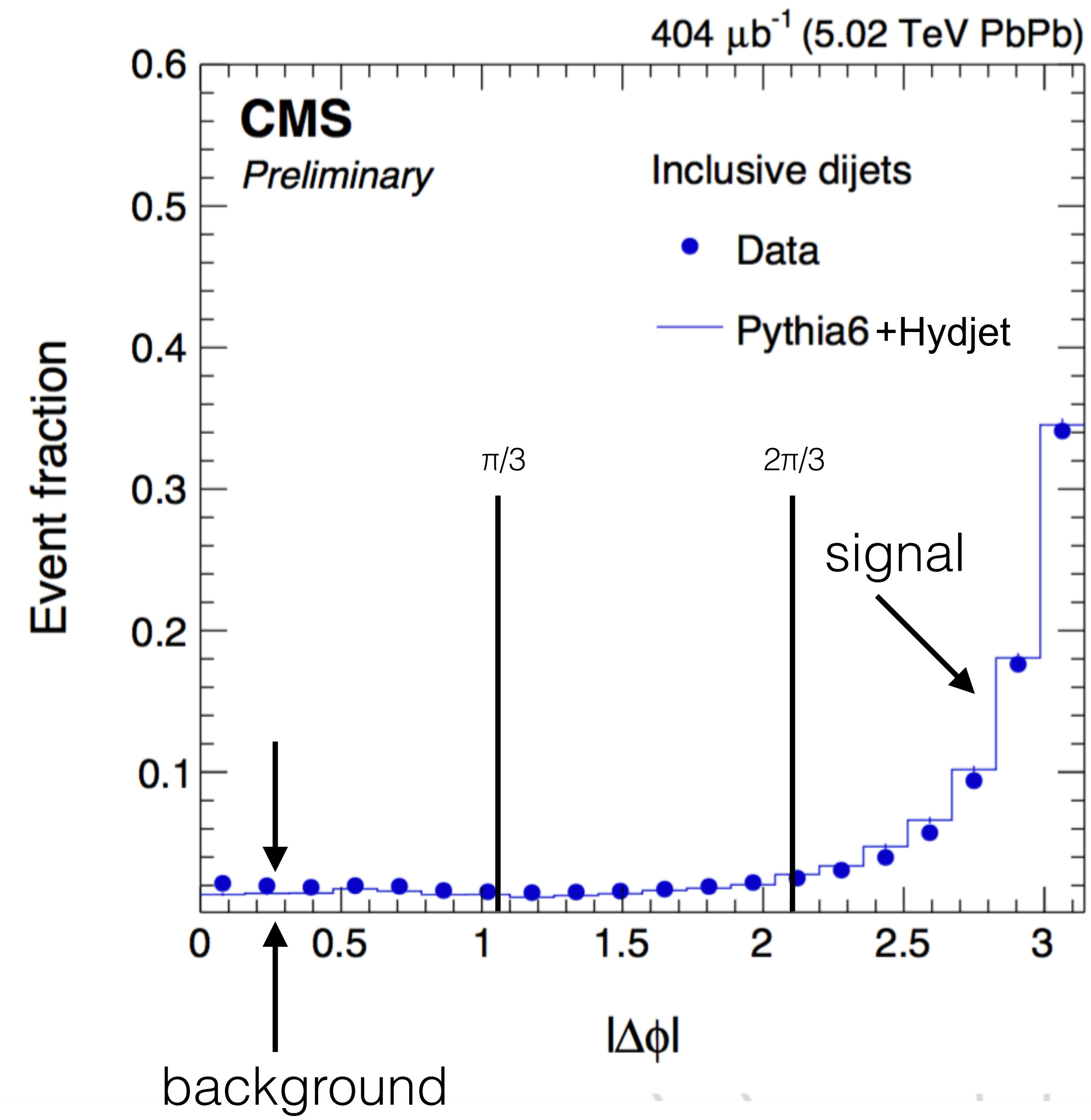
imbalanced x_J



Combinatorial background **subtraction**

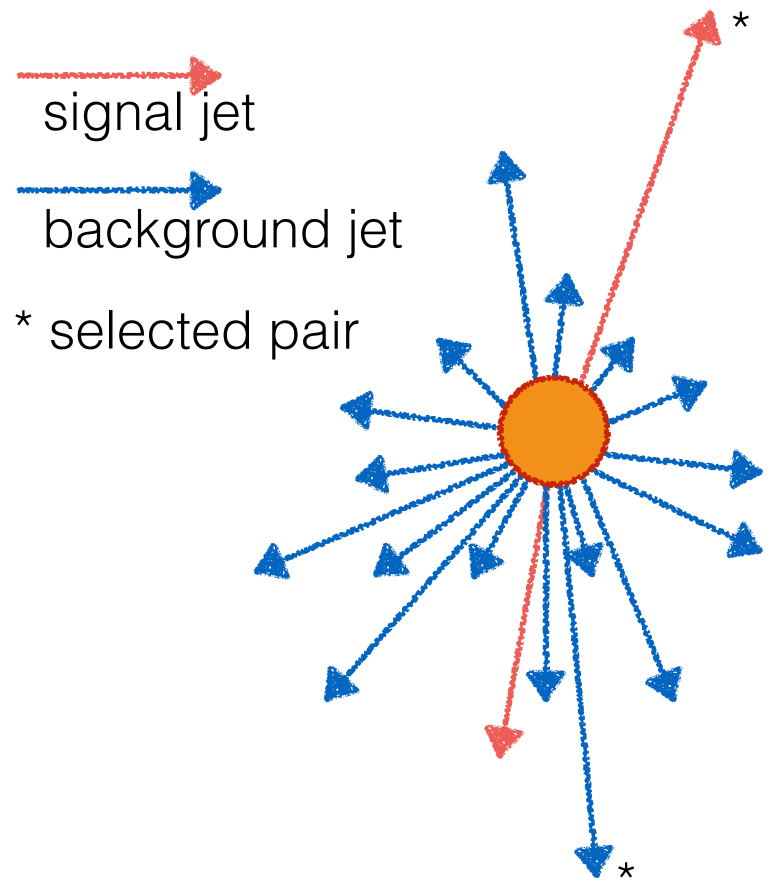
- Combinatorial background jets are uniform in |Δϕ|
- Sometimes the background jet is higher than the true subleading jet
  - true pair is replaced with combinatorial
- We subtract such events with the Δϕ sideband

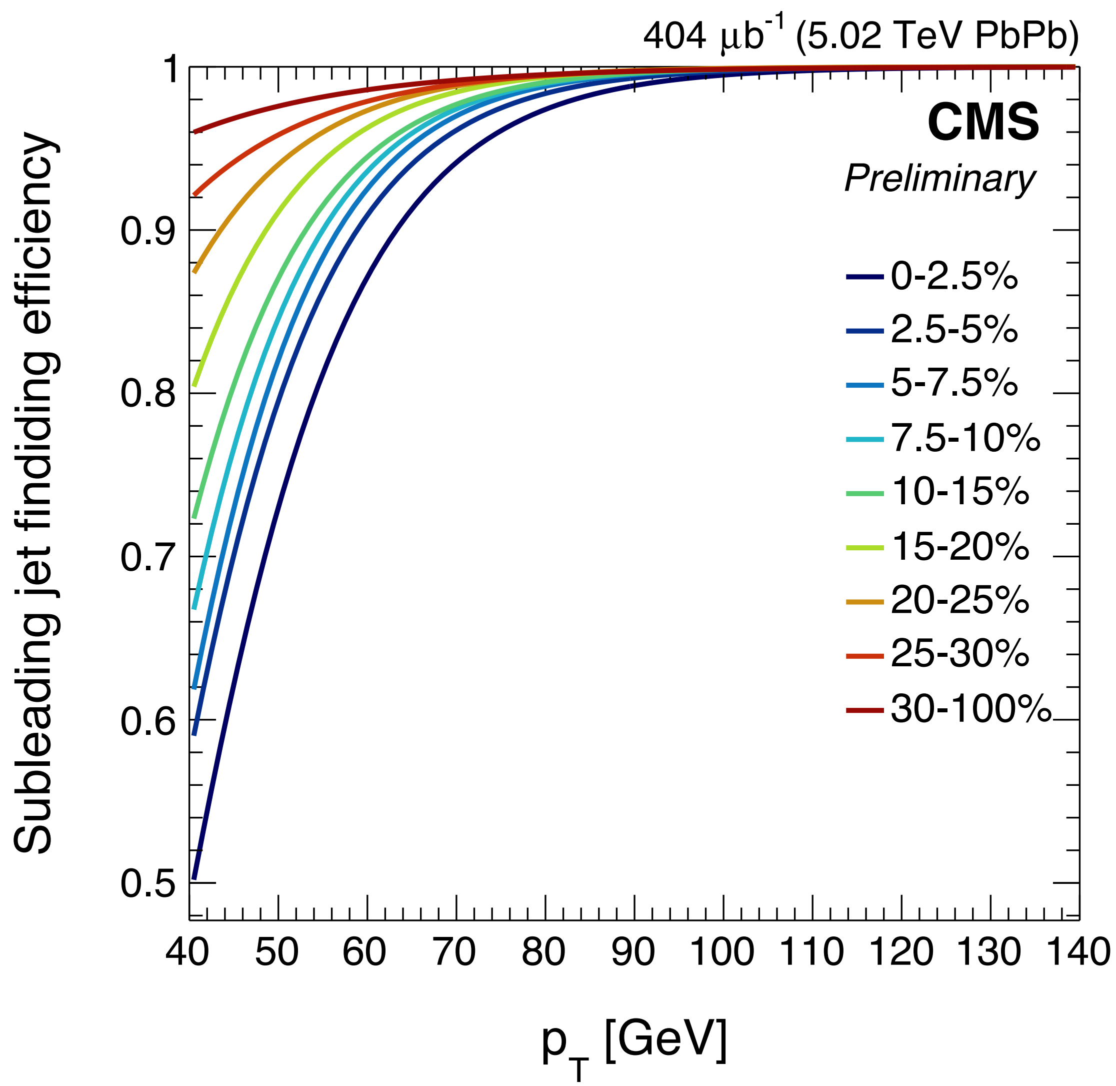




Combinatorial background **correction**

- After subtraction the true pair is lost
- subleading jet finding efficiency can be derived from the spectrum of the background jets
- correction is applied to account for the lost dijets





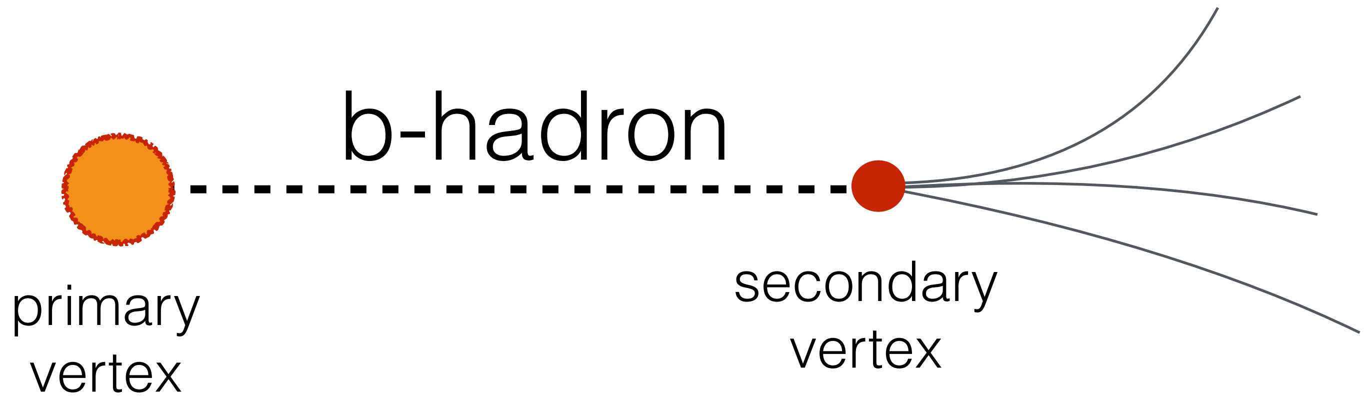
- e.g. 40 GeV jets in most central bin are lost 50% of the time, so we correct x2 whenever we find pair with subleading 40 GeV jet

b-tagging

- we are defining a b-jet as a jet which has b-hadron in the vicinity of jet axis
- b-tagging ≠ b-hadron reconstruction

- there are two ways to perform identification of b-hadrons:
  - weak decay into leptons
  - b-hadron lifetime results in a displaced vertex

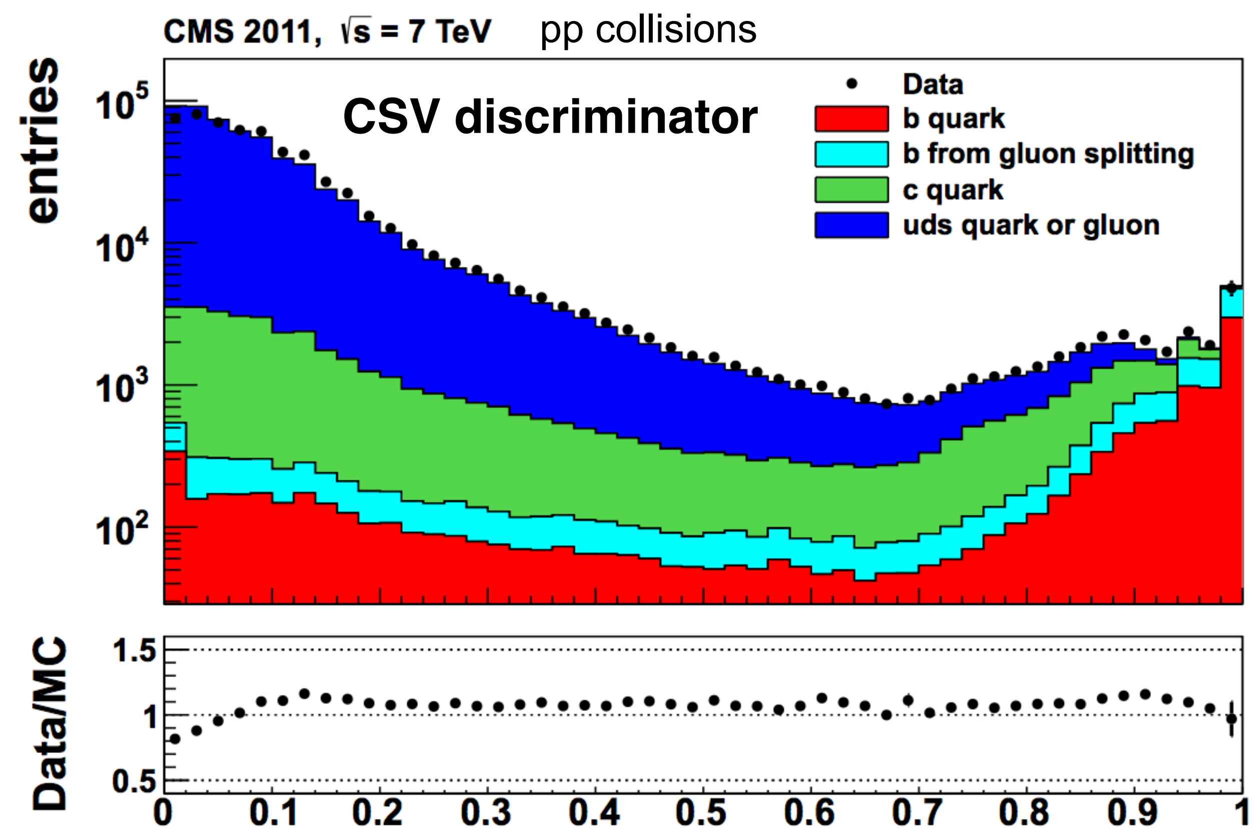
- The tagging of b-jets **in this analysis** is performed with identification of secondary vertex and displacement of tracks in the jet



b-jet discriminator

- Combined Secondary Vertex (CSV) discriminator is constructed from
- the vertex information (if there is one)
    - flight distance significance
    - invariant mass
    - …
- from tracks
    - impact parameter significance
    - …

- Purity = fraction of b-jets in the selection
- Efficiency = fraction of b-jets selected



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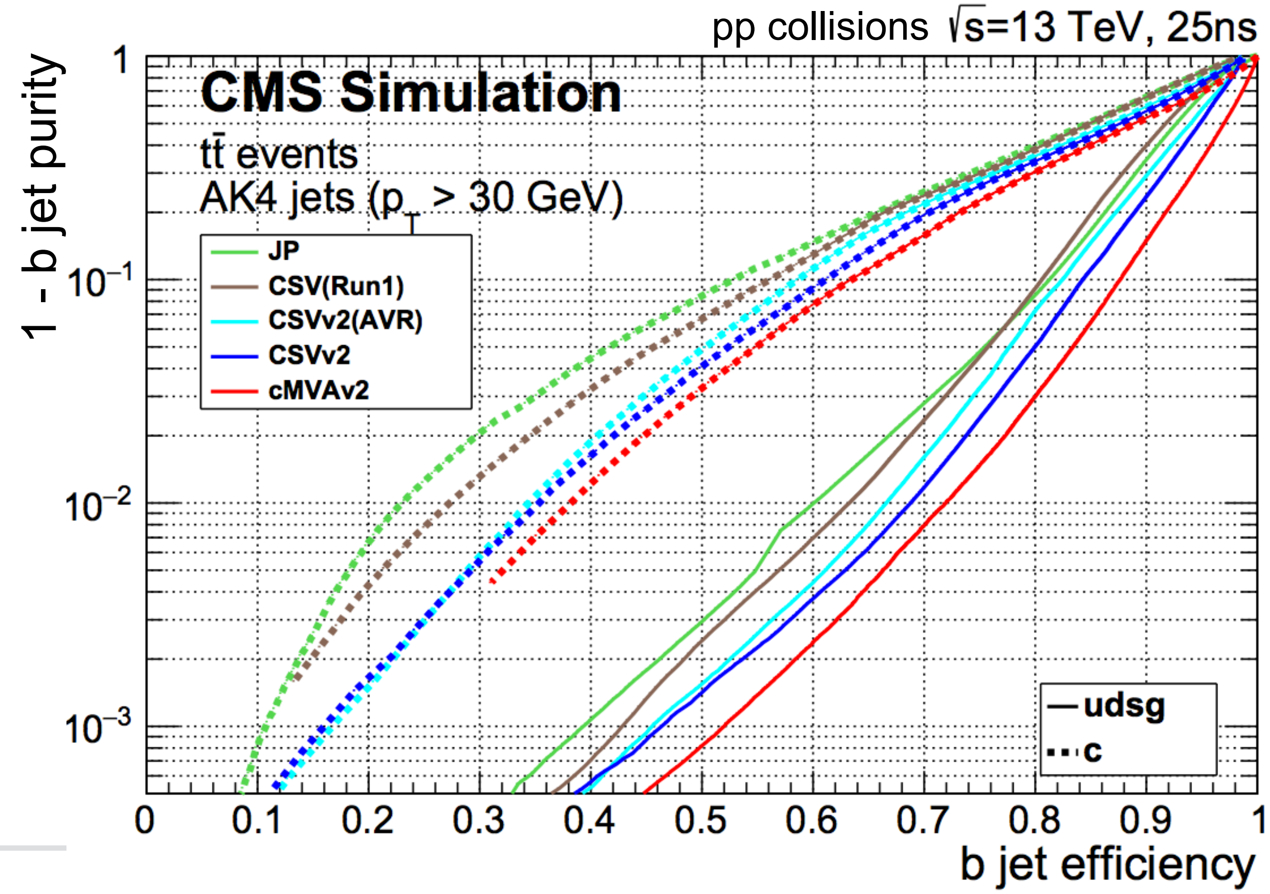
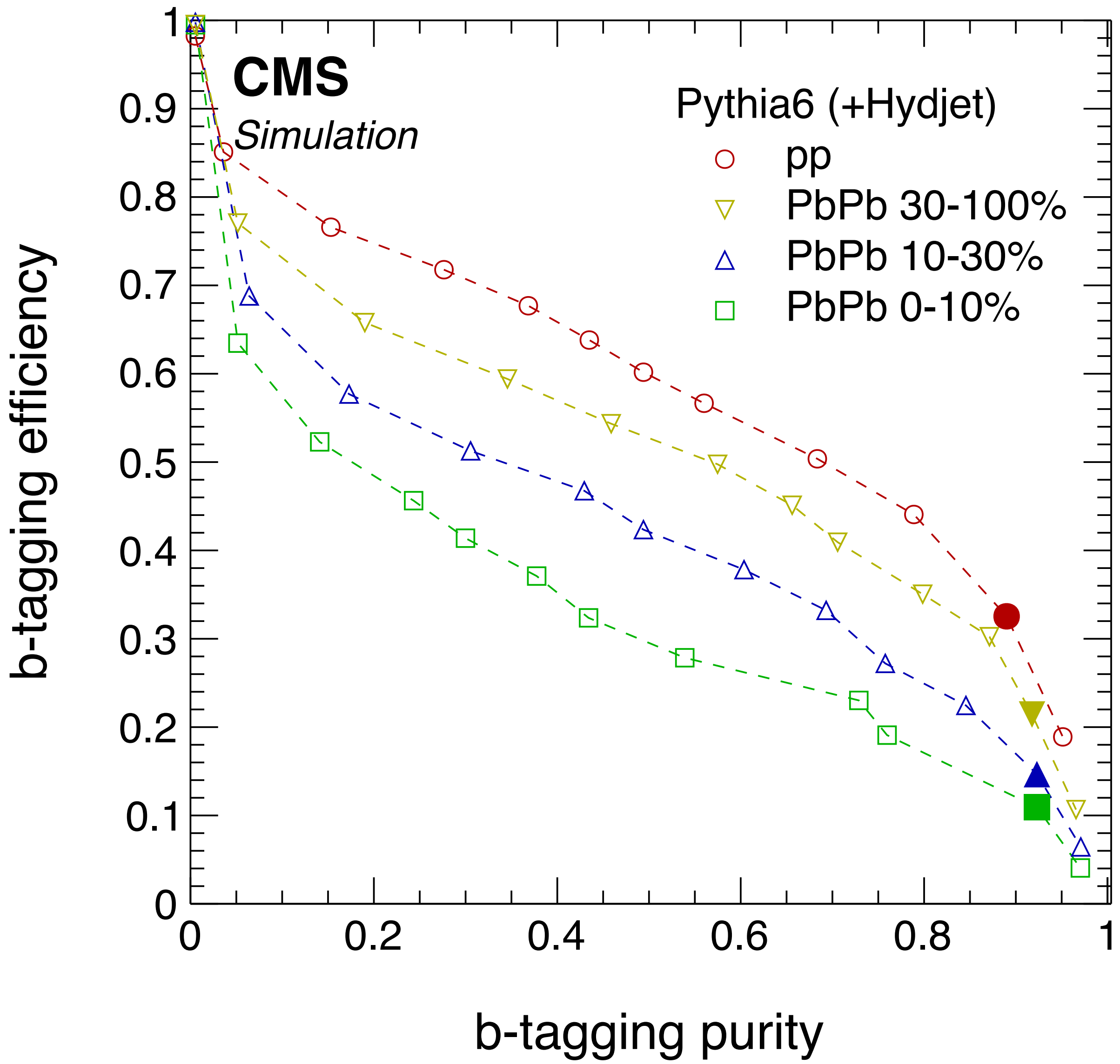


BTV-15-001

b-tagging in PbPb collisions @ 5 TeV

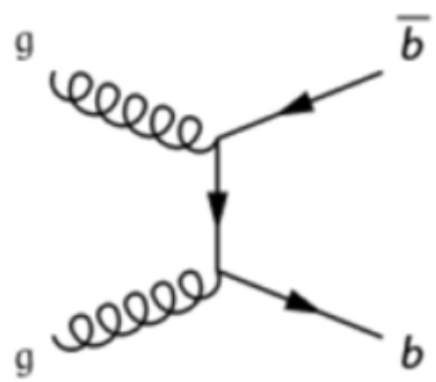
- We use CSV discriminator to identify b dijets
- Working point is selected to obtain 90% pure sample

- Tagging efficiency corrections are applied in
    - centrality
    - p_T
    - η
- ~10% contamination is taken into account as a systematic uncertainty



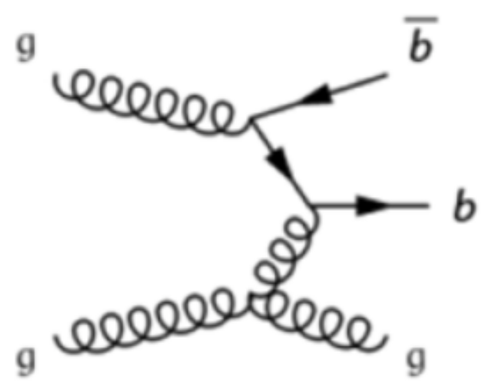
Heavy flavor production

@ NLO



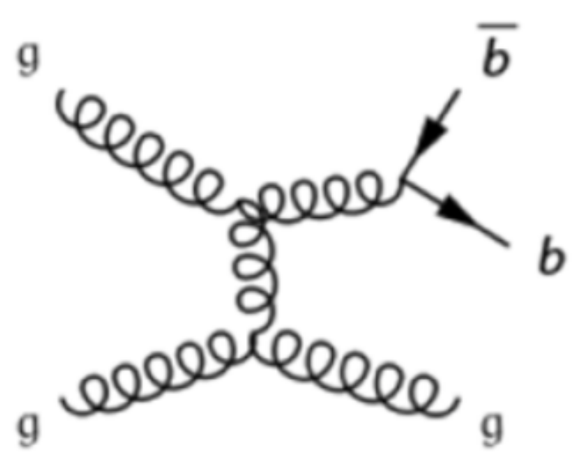
Flavor Creation

- gluon fusion or $q\bar{q}$ annihilation
- heavy quarks are back-to-back



Flavor Excitation

- sea bb pair is excited by gluon or light quark
- heavy quark is back-to-back with light parton



Gluon Splitting

- gluon splits into $b\bar{b}$
- small angle between heavy quarks

Pythia

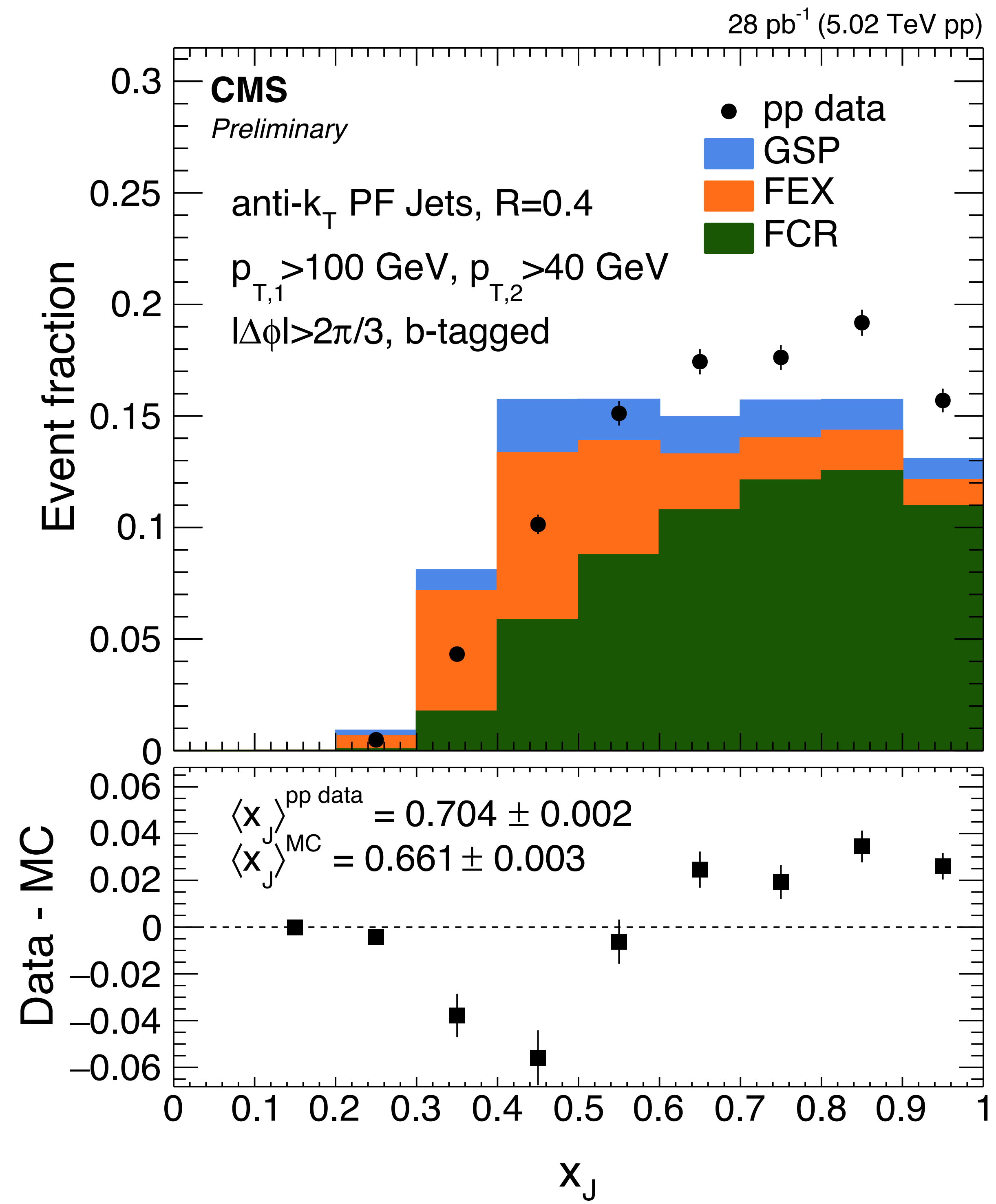
hard scattering

ISR

FSR / parton showering

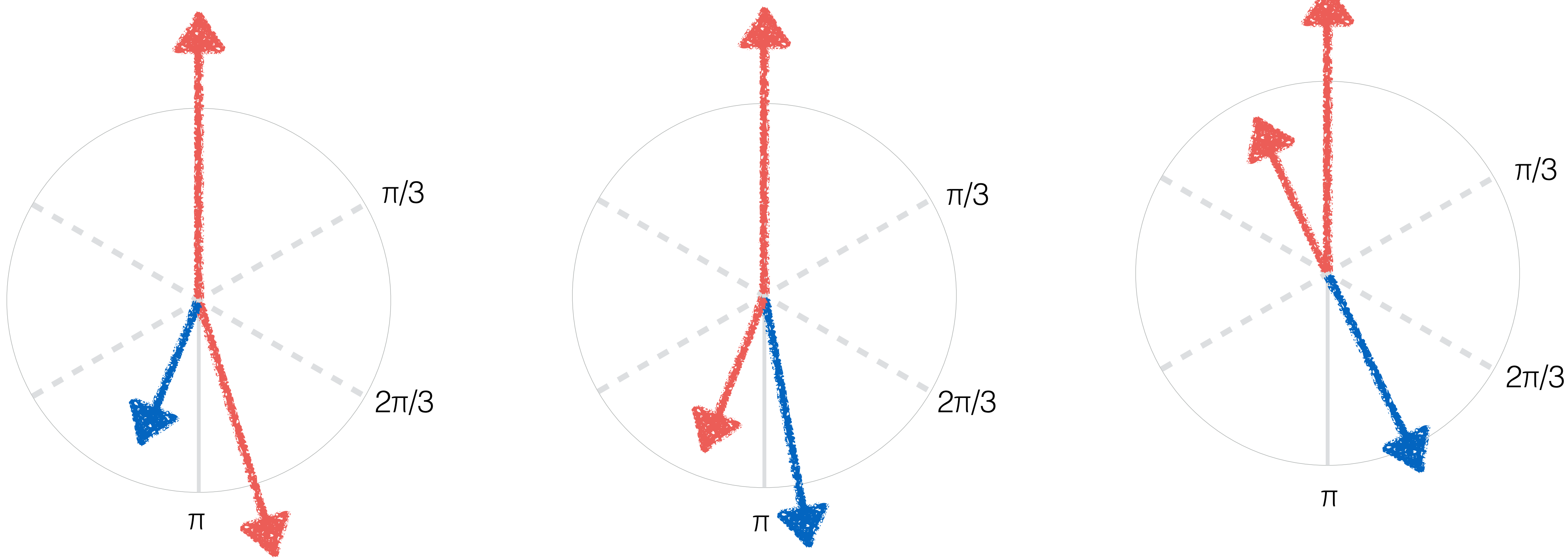
b dijet imbalance in pp

- Pythia6 has poor description of b dijet imbalance
- b dijets from Flavor Excitation (FEX) are more imbalanced than from Flavor Creation (FCR)



Flavor process reweighting

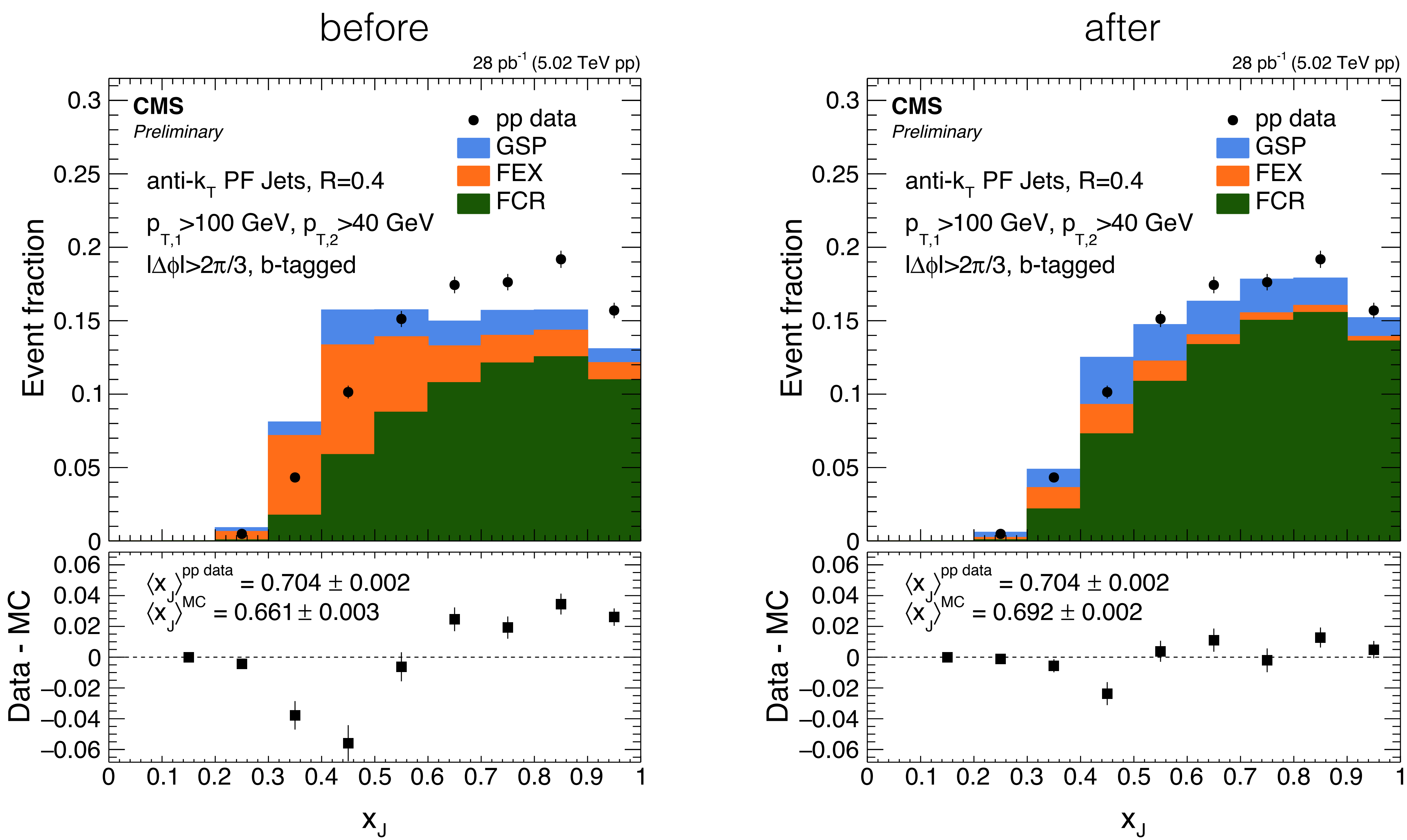
- The two highest pT jets are b-tagged and back-to-back ($|\Delta\phi_{1,2}|>2\pi/3$)
- The first and third highest pT jets are b-tagged and back-to-back ($|\Delta\phi_{1,3}|>2\pi/3$)
- The first and third highest pT jets are b-tagged and nearby ($|\Delta\phi_{1,3}|<\pi/3$)



Category	FCR	FEX	GSP
$\lvert\Delta\phi_{1,2}\rvert>2\pi/3$	**57%**	26%	17%
$\lvert\Delta\phi_{1,3}\rvert>2\pi/3$	11%	**62%**	27%
$\lvert\Delta\phi_{1,3}\rvert<\pi/3$	0%	17%	**83%**

Category	MC	Data
$\lvert\Delta\phi_{1,2}\rvert>2\pi/3$	46%	56%
$\lvert\Delta\phi_{1,3}\rvert>2\pi/3$	49%	37%
$\lvert\Delta\phi_{1,3}\rvert<\pi/3$	5%	7%

Flavor process reweighting



- Result: FCR fraction in analysis selection 50% → 70%
- Pythia overestimates the FEX contribution to back-to-back topologies.
- After reweighting - same data/Pythia agreement as for inclusive jets
- Similar conclusion in CDF PRD71 (2005) 092001

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

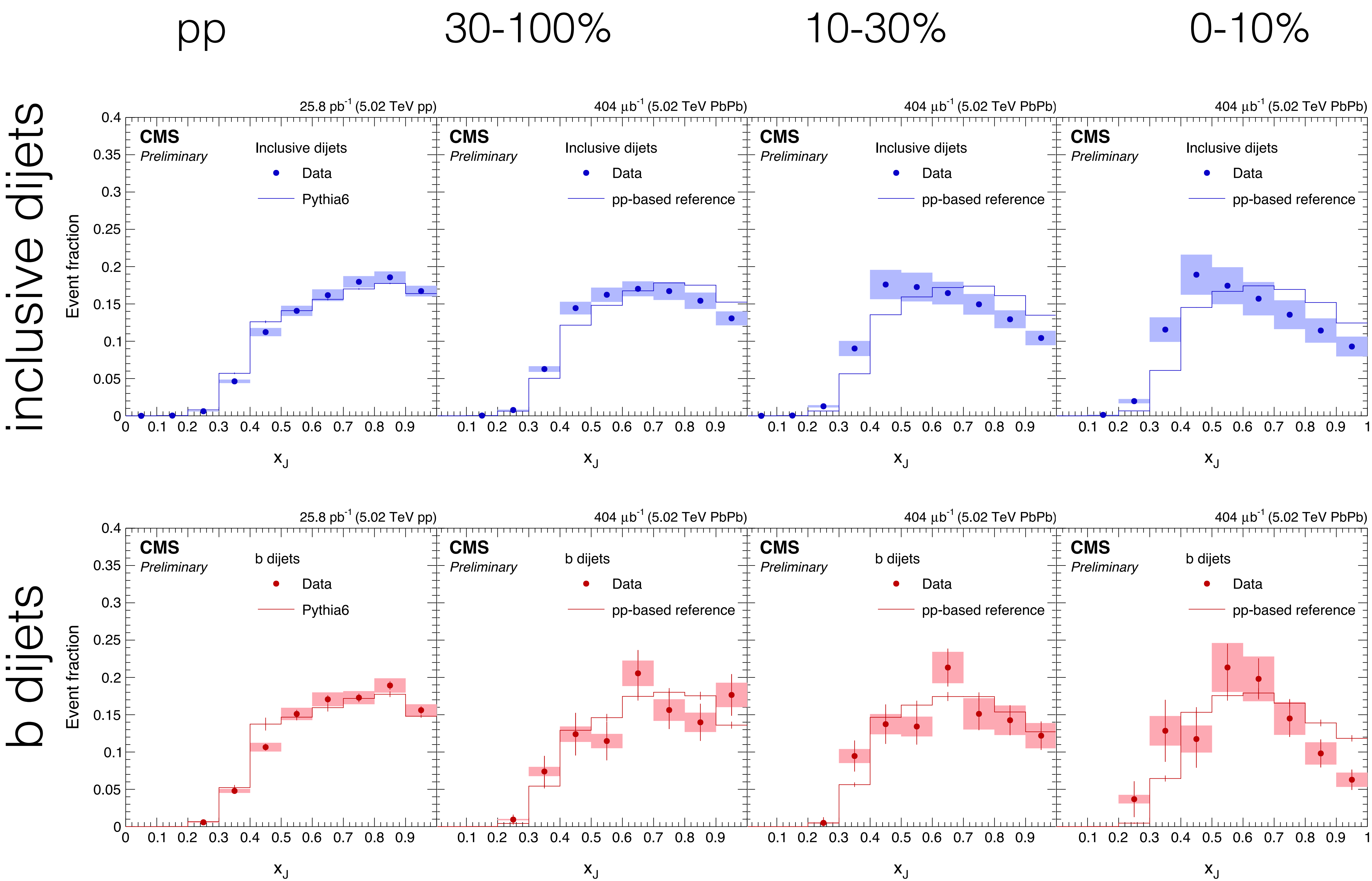
Table 4: Absolute systematic uncertainties on $\langle x_J \rangle$ for inclusive dijets.

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

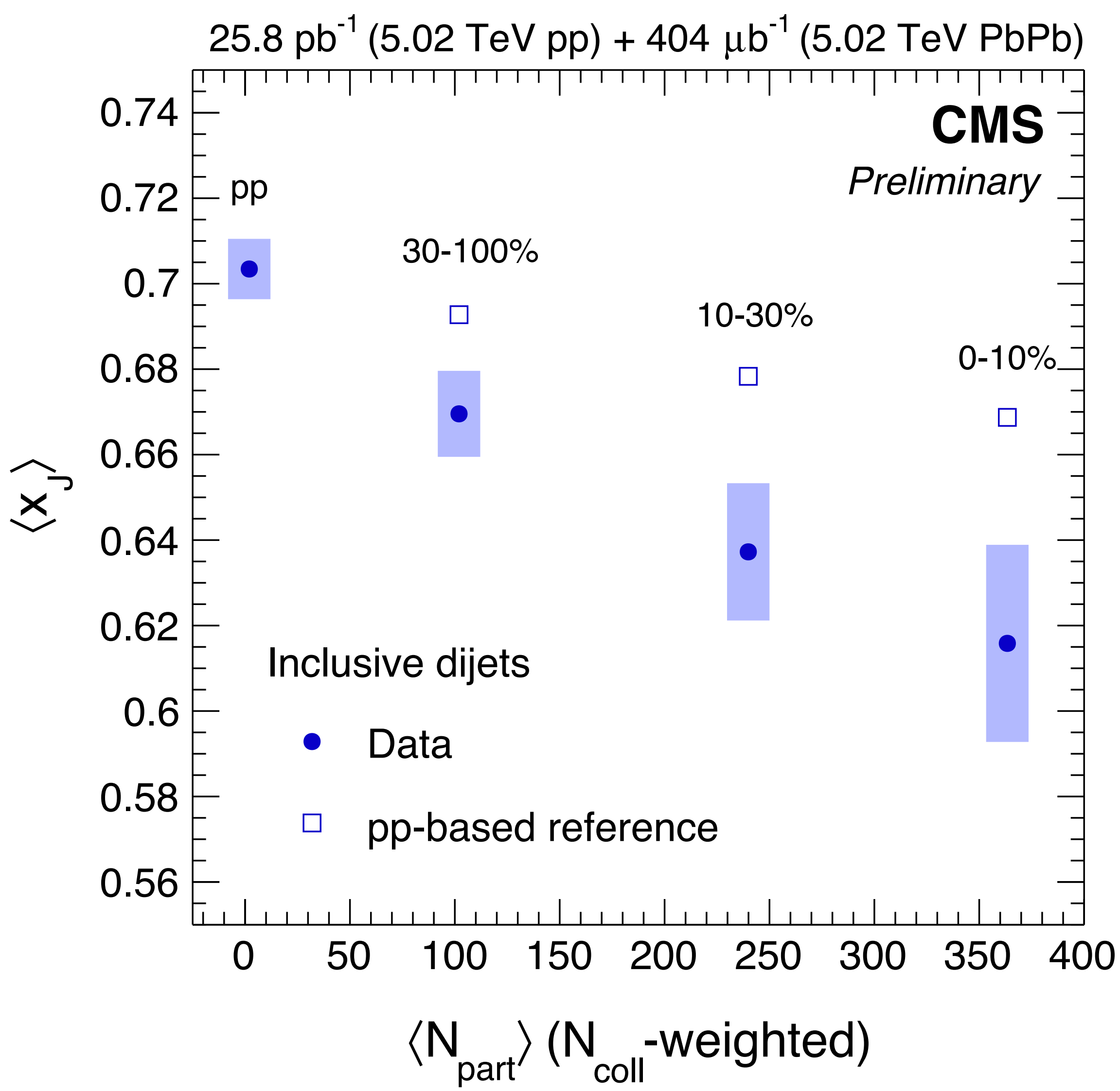
Table 5: Absolute systematic uncertainties on $\langle x_J \rangle$ for b dijets.

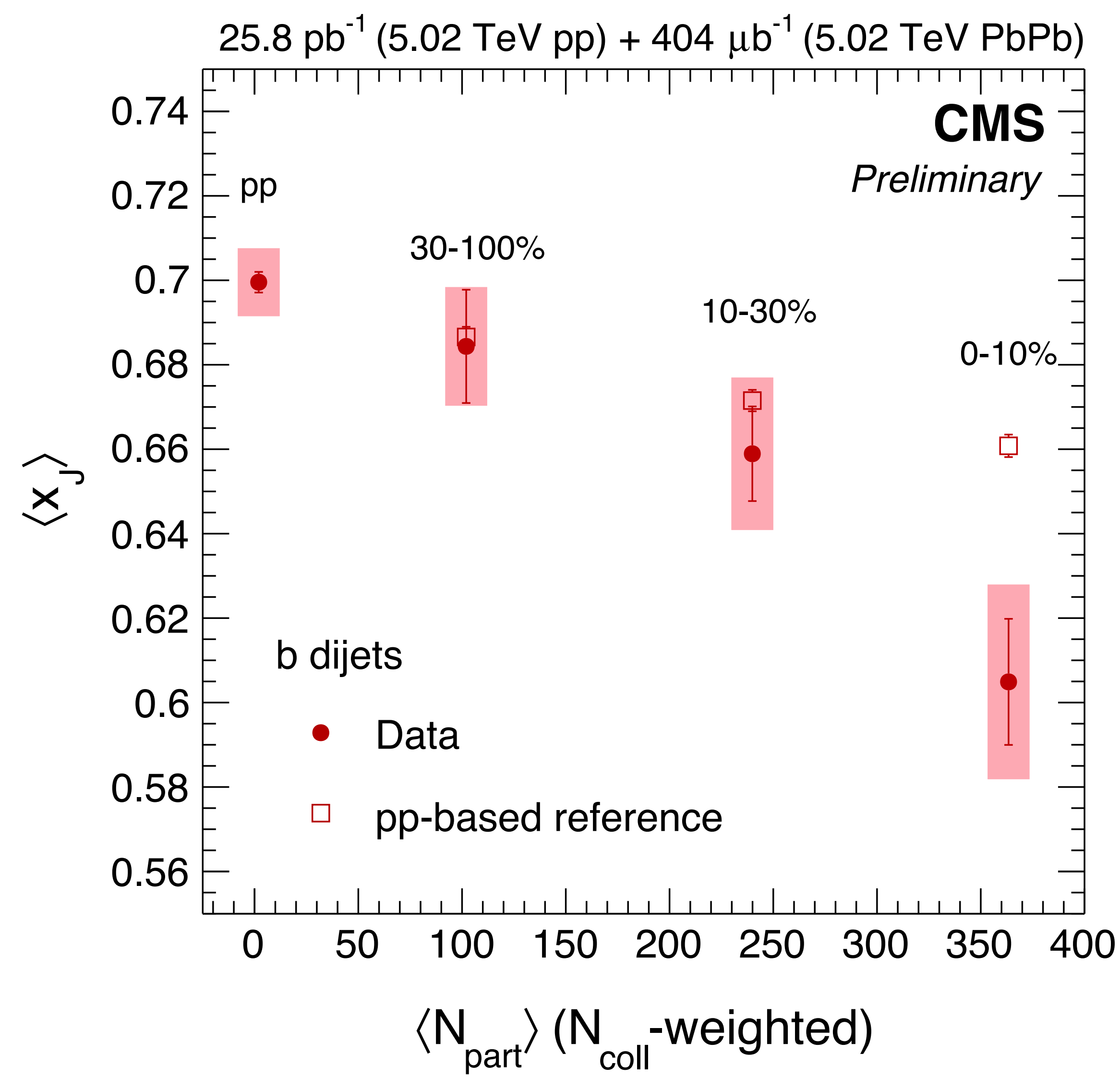
- pp results have been smeared according to the jet resolution in PbPb in order to make data-based reference

Inclusive and b dijet imbalance @ 5 TeV



Results summary

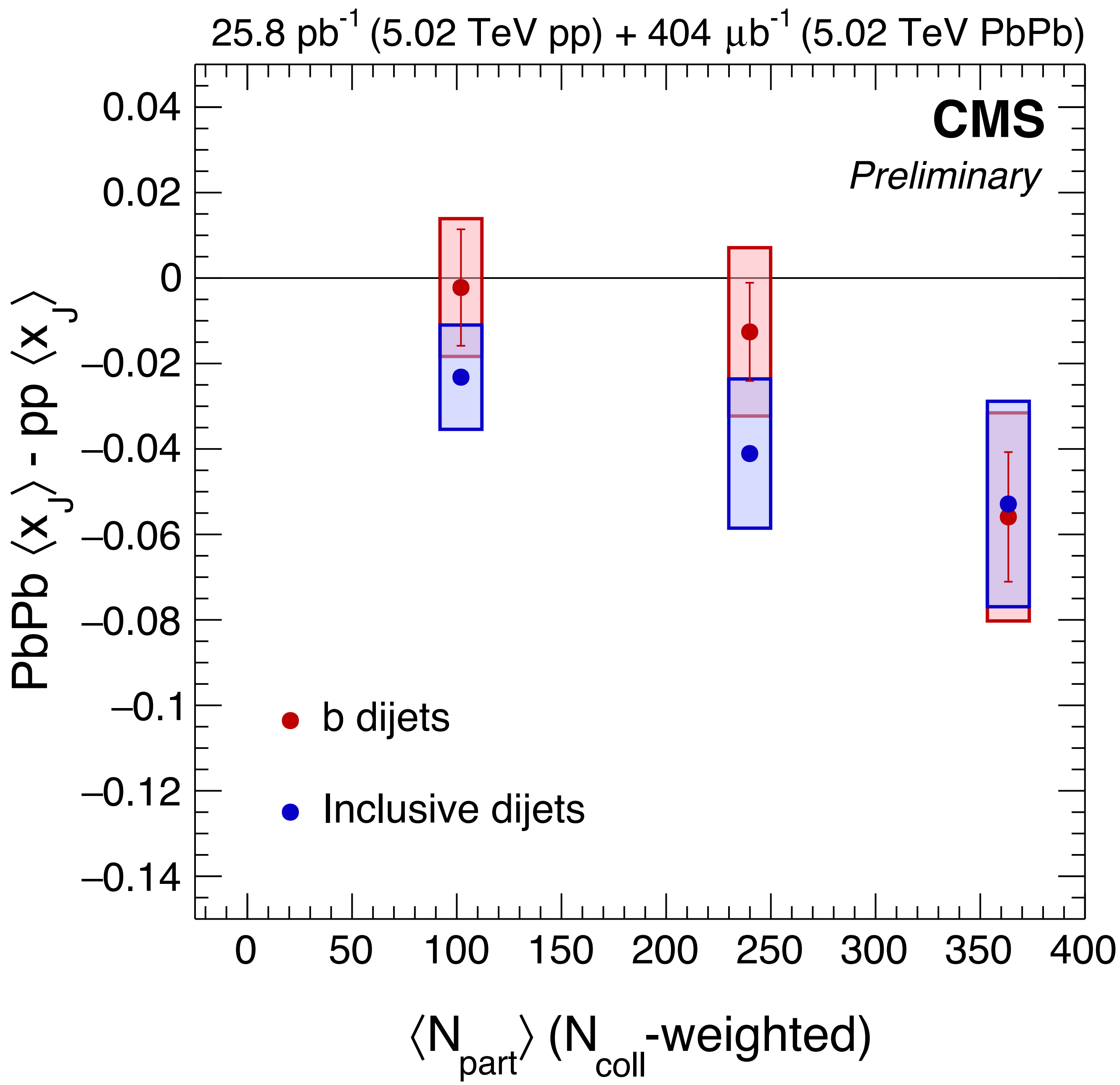




- The increase of imbalance of inclusive dijets from pp to central PbPb collisions has been confirmed @ 5 TeV
- The imbalance of b dijets has been observed for the first time

Conclusions

- Dijet measurement is improved compared to previous results with better treatment of combinatorial background
- b dijet imbalance x_J is described well in pp after flavor process reweighting procedure
- For the first time the imbalance of b dijets is measured
- we observe the imbalance of b dijets on the same level as for non-identified jets

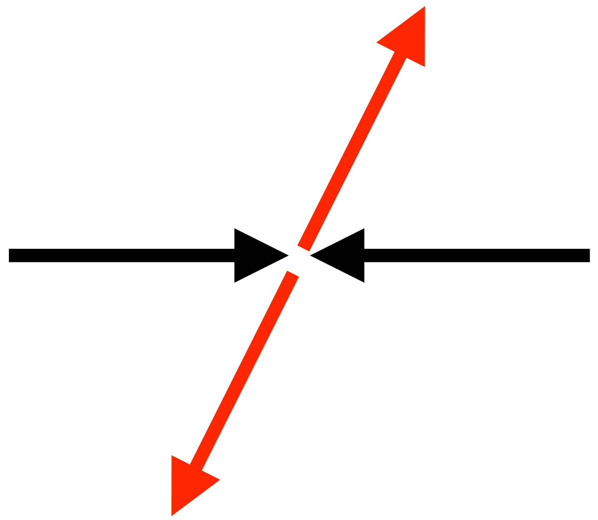


- Back up

heavy quark production @ NLO

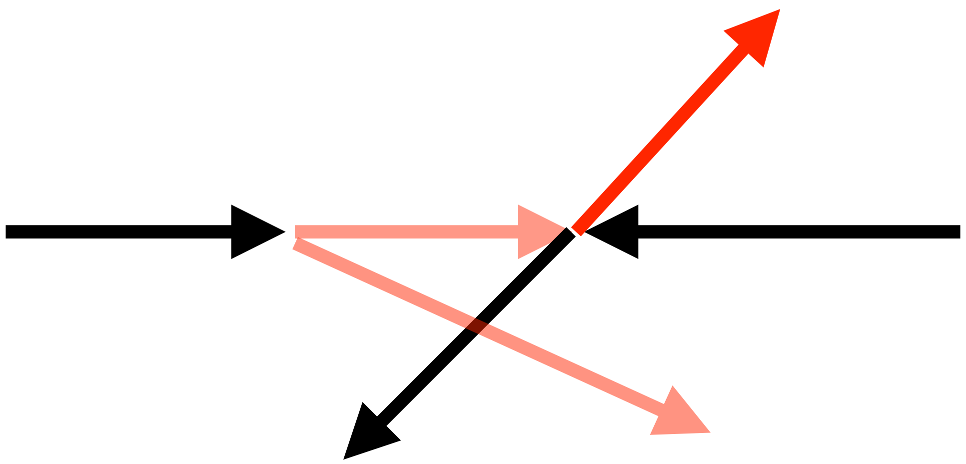
flavor creation (FCR)

2 b-quarks from hard scattering



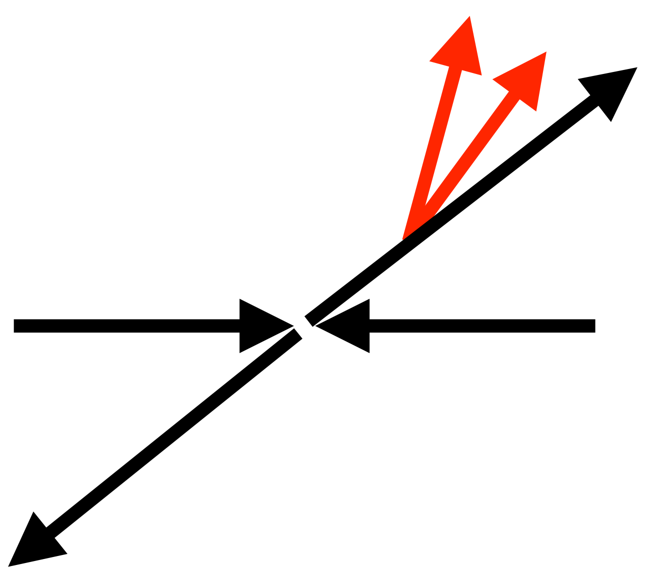
flavor excitation (FEX)

1 b-quark from hard scattering



gluon splitting (GSP)

shower, fragmentation

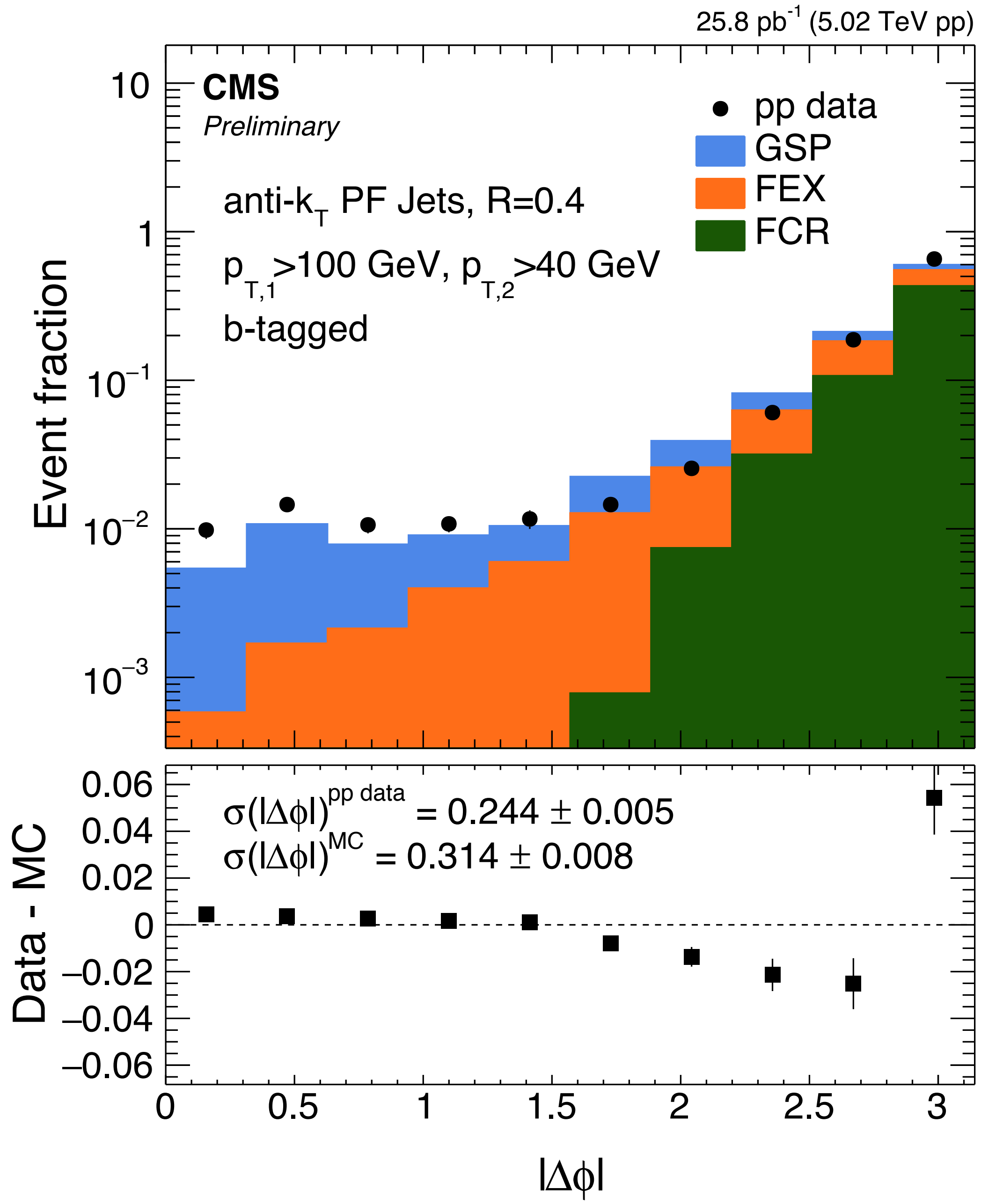


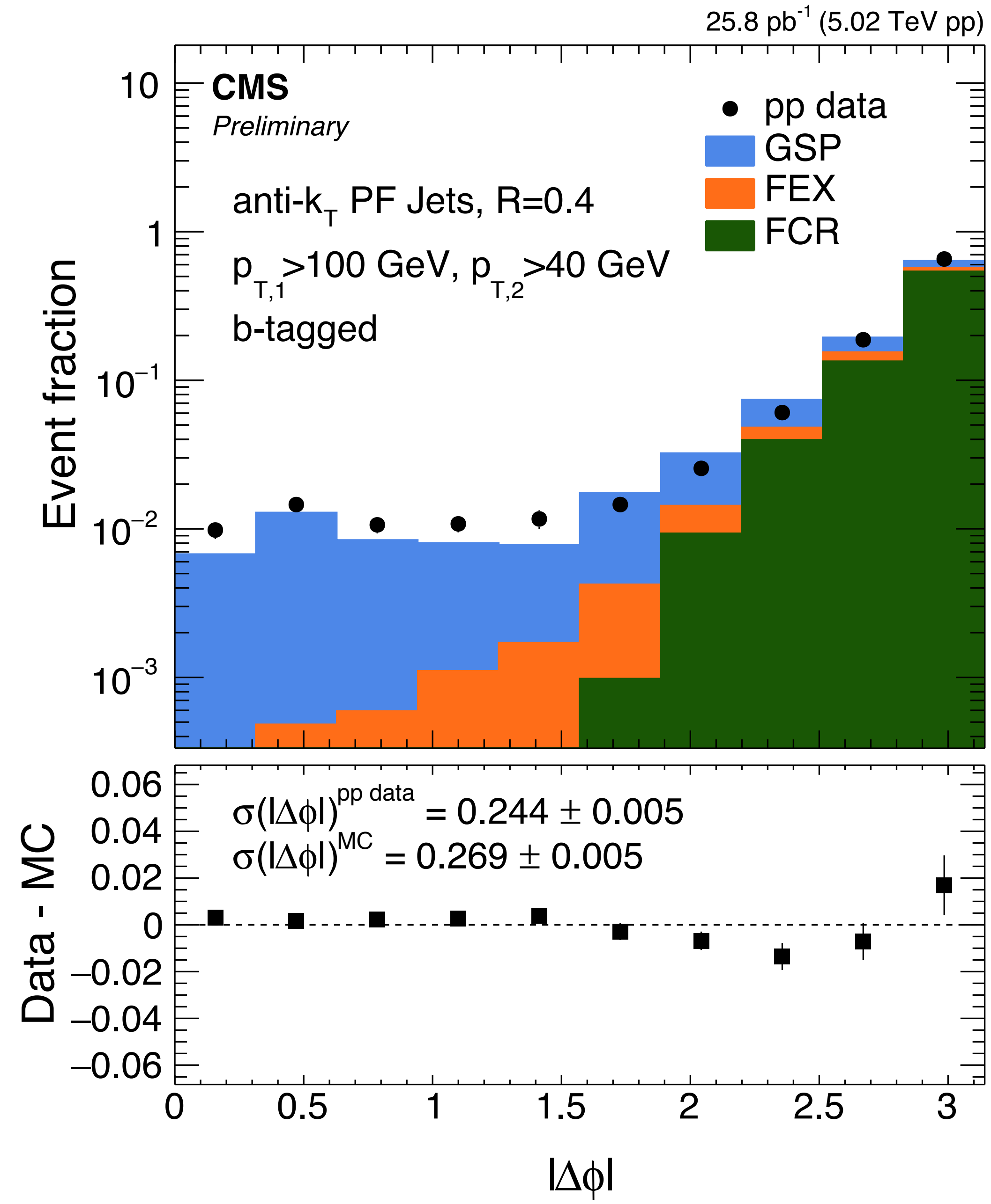
CSV variables

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

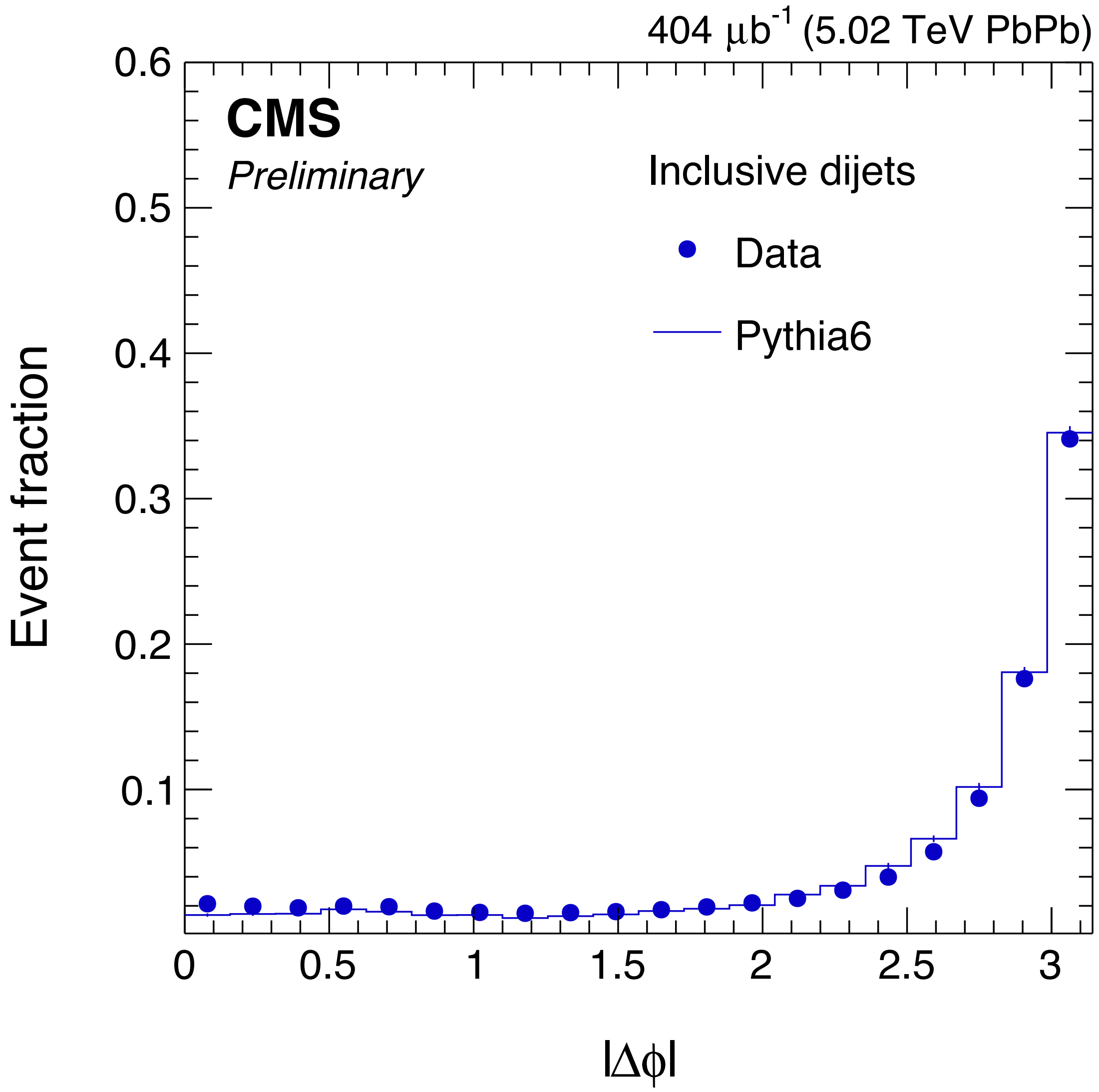
- the vertex category (real, “pseudo,” or “no vertex”);
- the 2D flight distance significance;
- the vertex mass;
- the number of tracks at the vertex;
- the ratio of the energy carried by tracks at the vertex with respect to all tracks in the jet;
- the pseudo-rapidity of the tracks at the vertex with 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

process reweighting Δφ

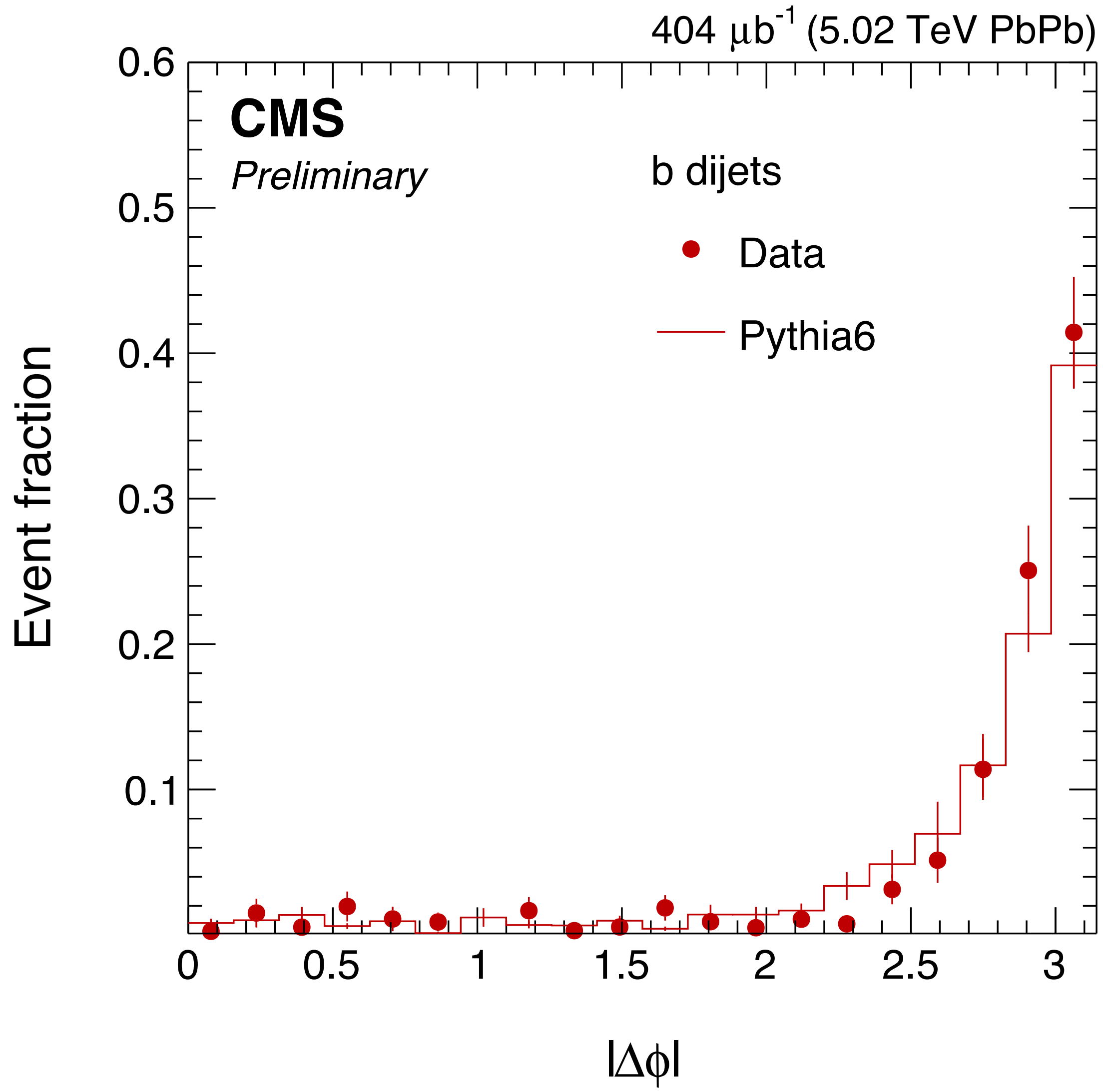




Δϕ 0-10%



404 μb^{-1} (5.02 TeV PbPb)
CMS
Preliminary
Inclusive dijets
Data
Pythia6
Event fraction
|Δϕ|
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
3



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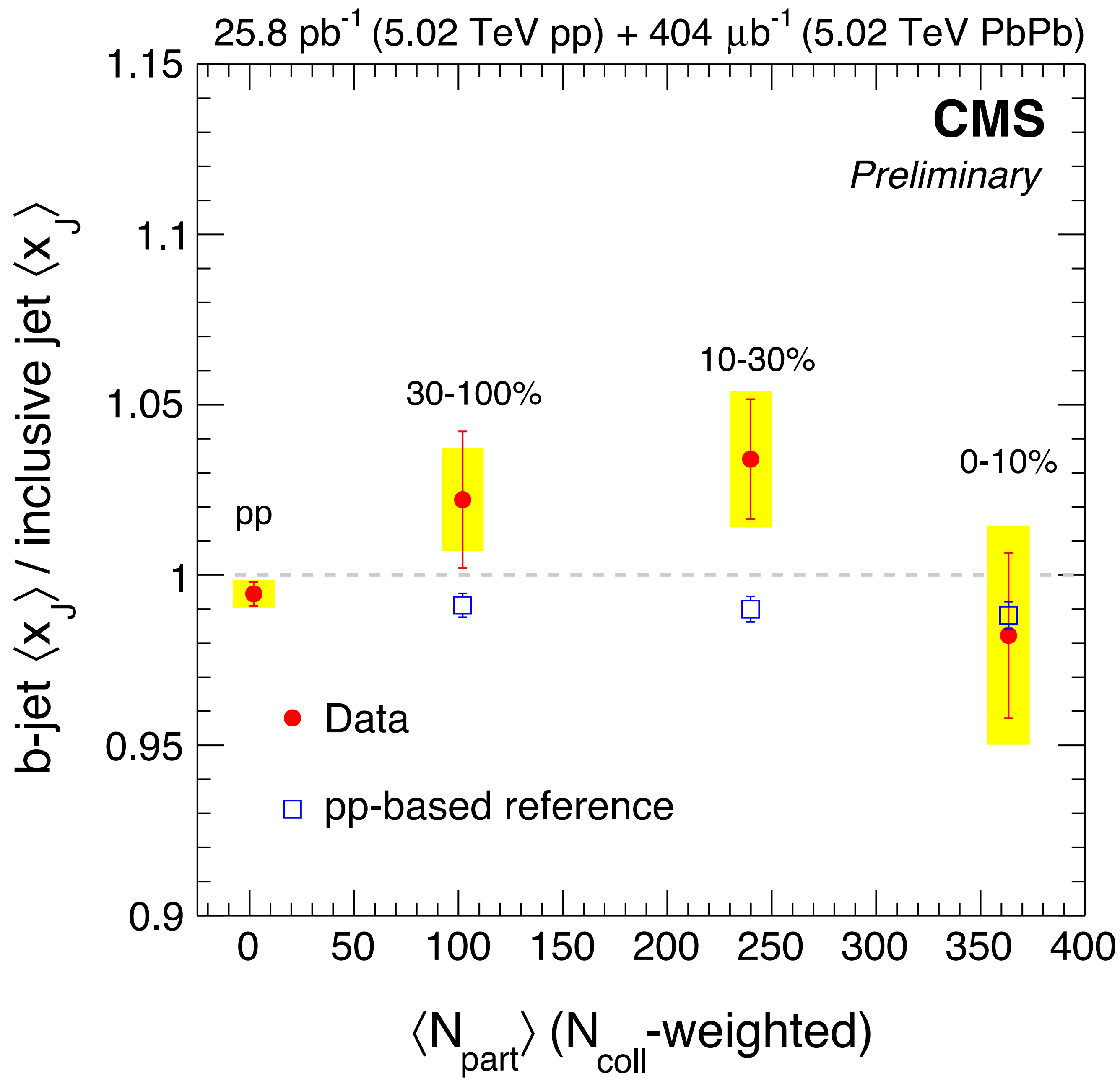
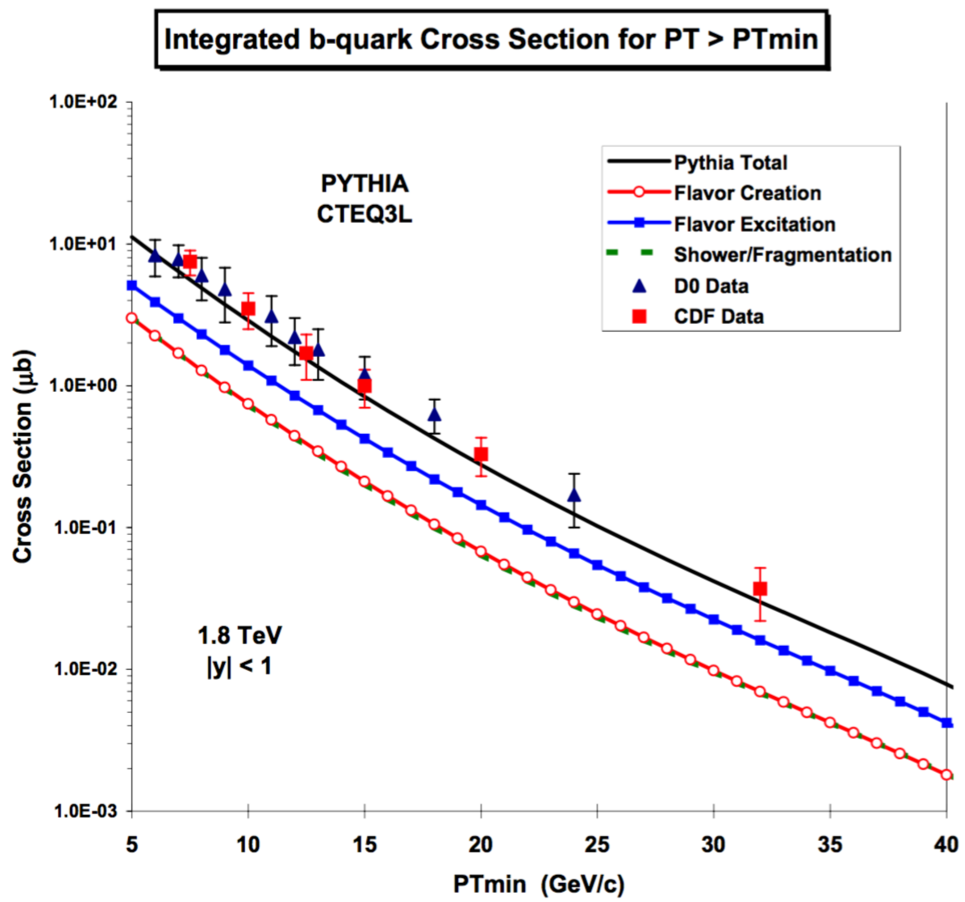
b-jet / inclusive jets

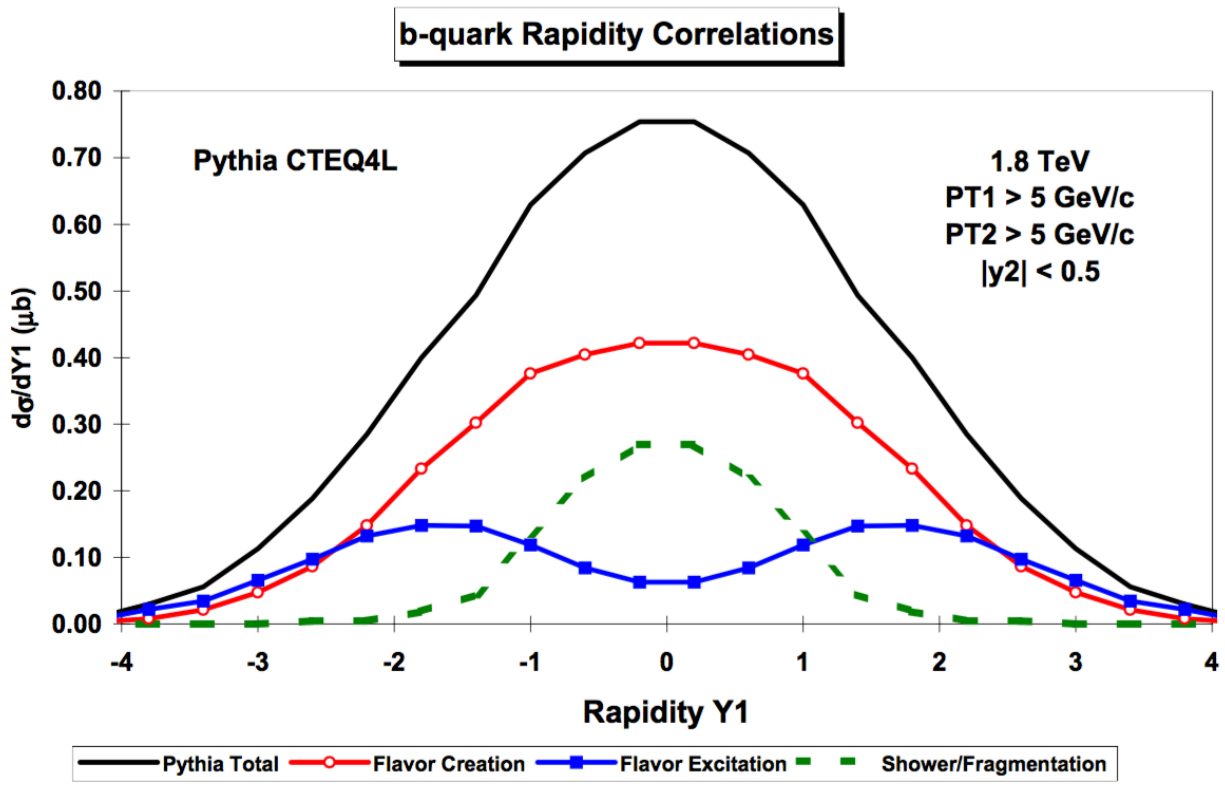


b-quark production in Pythia

arXiv:hep-ph/0201112

ppbar





- The total single b-quark cross section is described well by Pythia 6
- FEX sends recoil quark outside of acceptance region