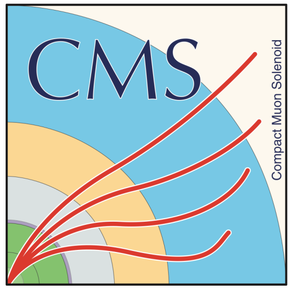
Dead-cone effect in b-jet shapes and the flavor dependence of in-medium shower modifications with the CMS detector

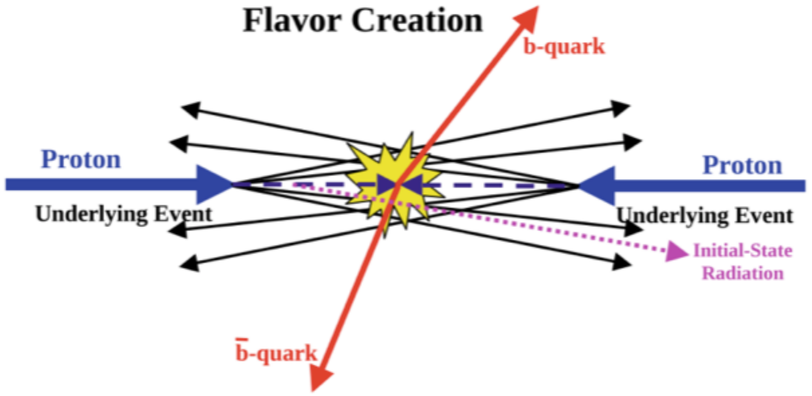
Xiao Wang for the CMS Collaboration
University of Illinois at Chicago

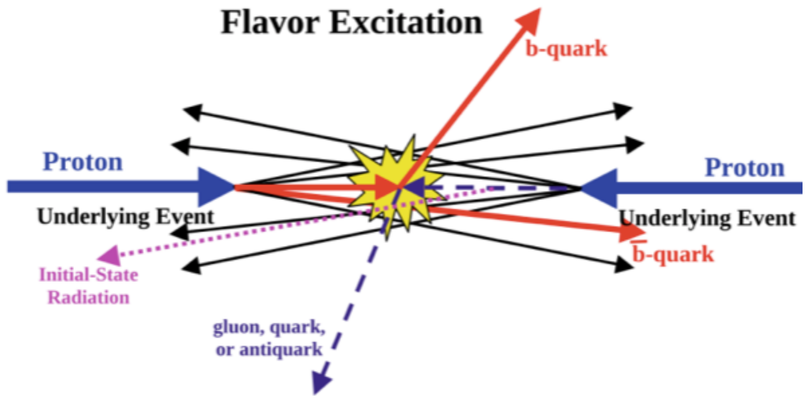
QuarkMatter 2022
Krakov, Poland

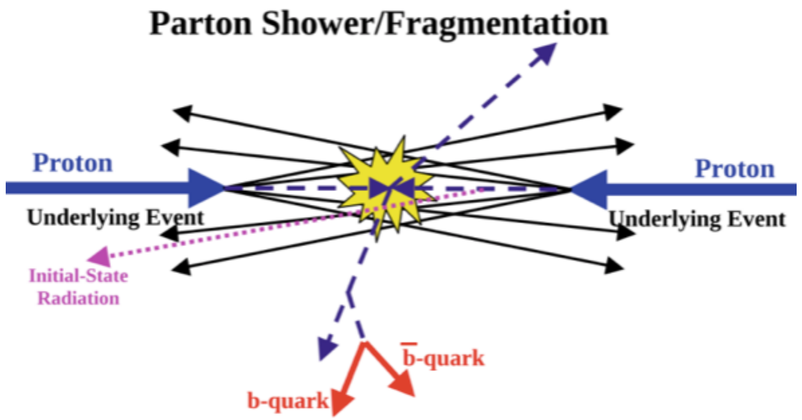


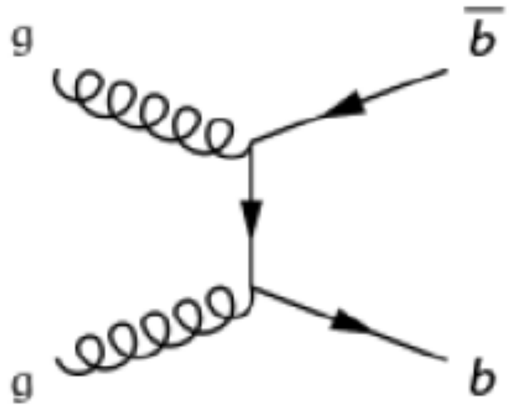
b quark production

- The major three processes of b quark production in hadron collisions









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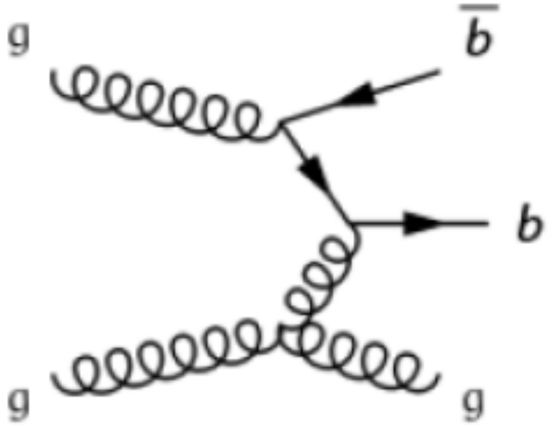

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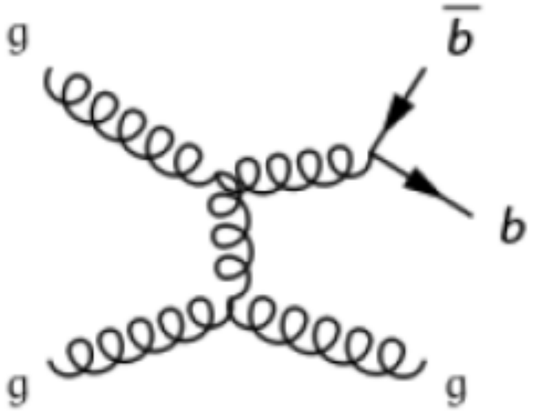
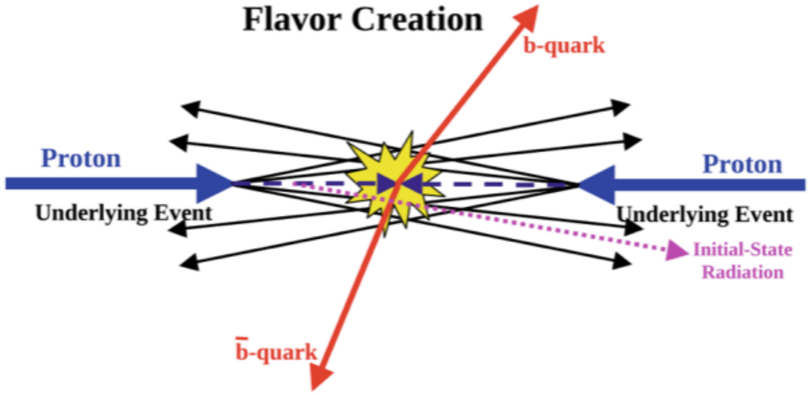
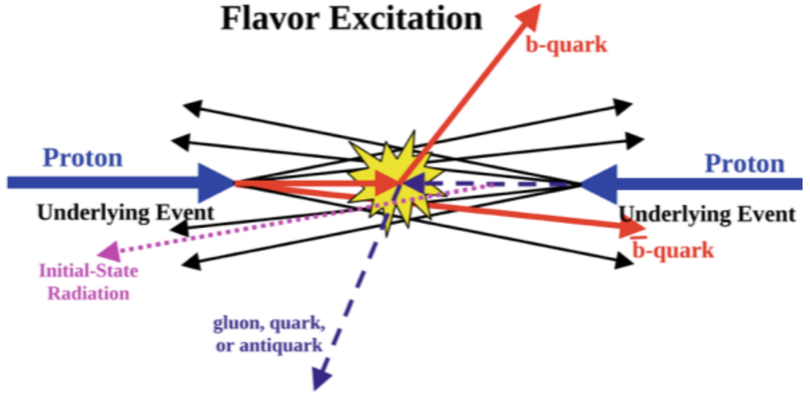


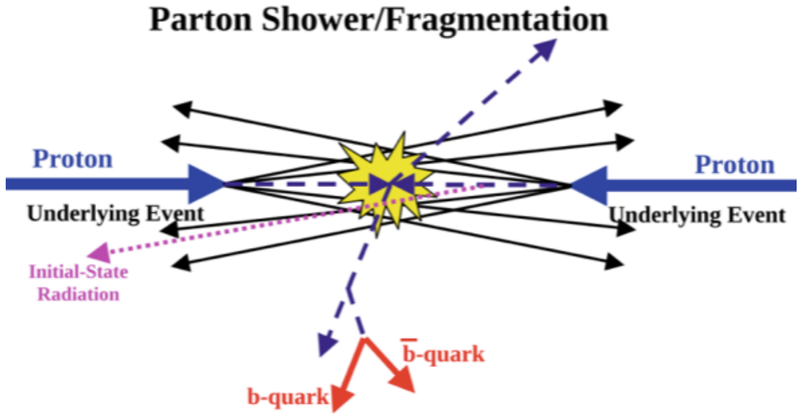
GSP

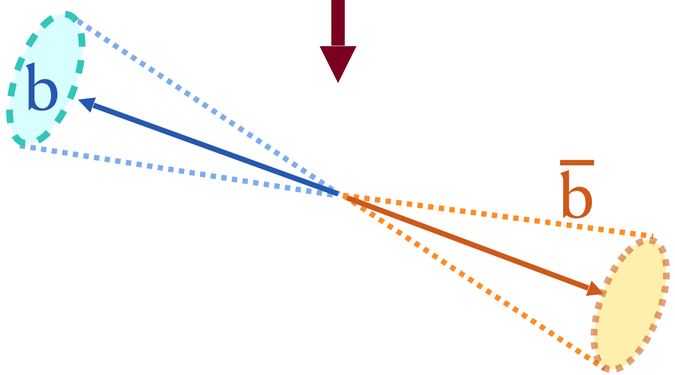
b quark production

- The major three processes of b quark production in hadron collisions

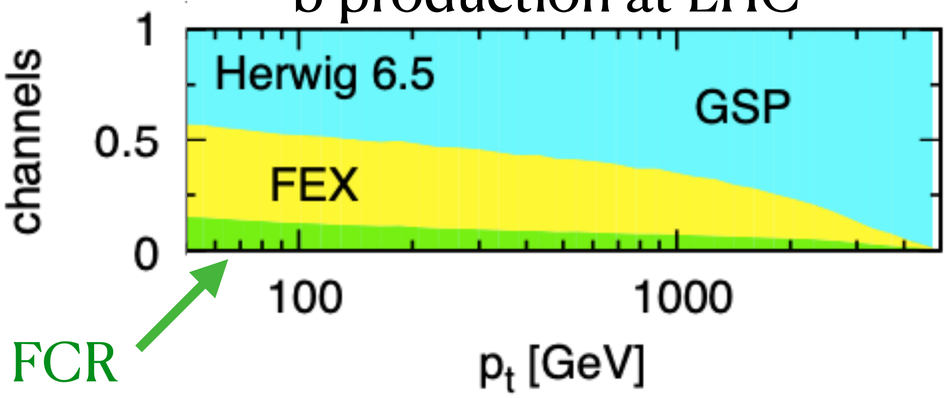




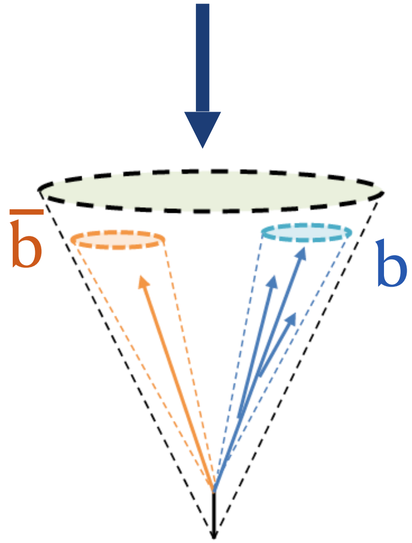




Breakdown of each channel of b production at LHC

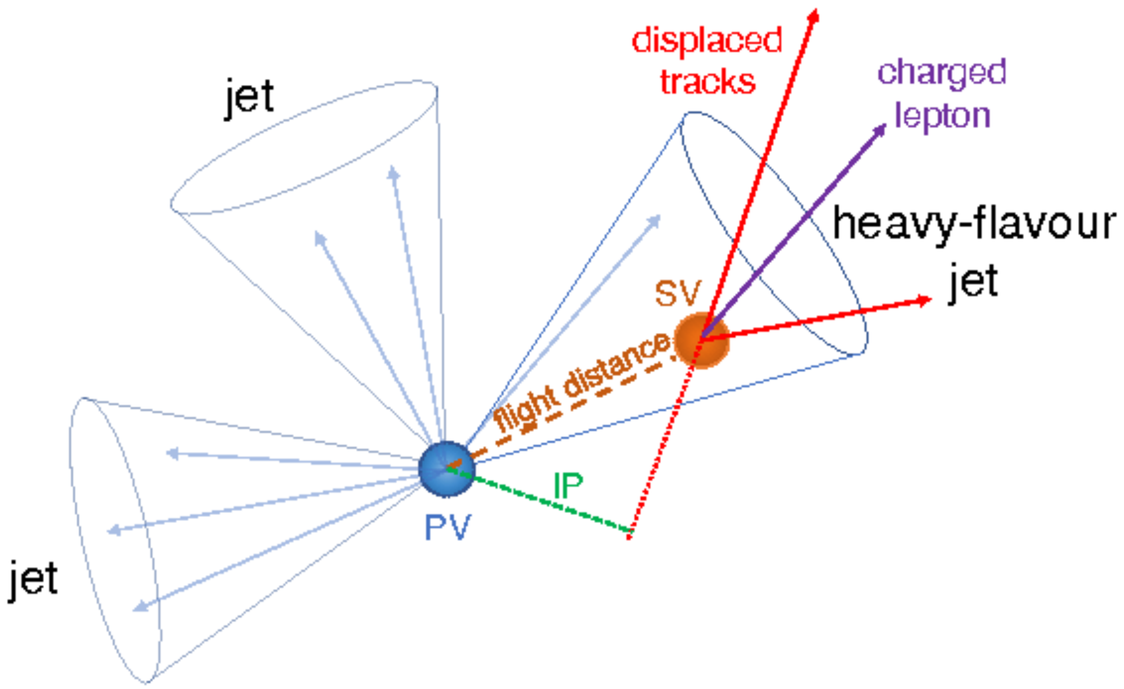


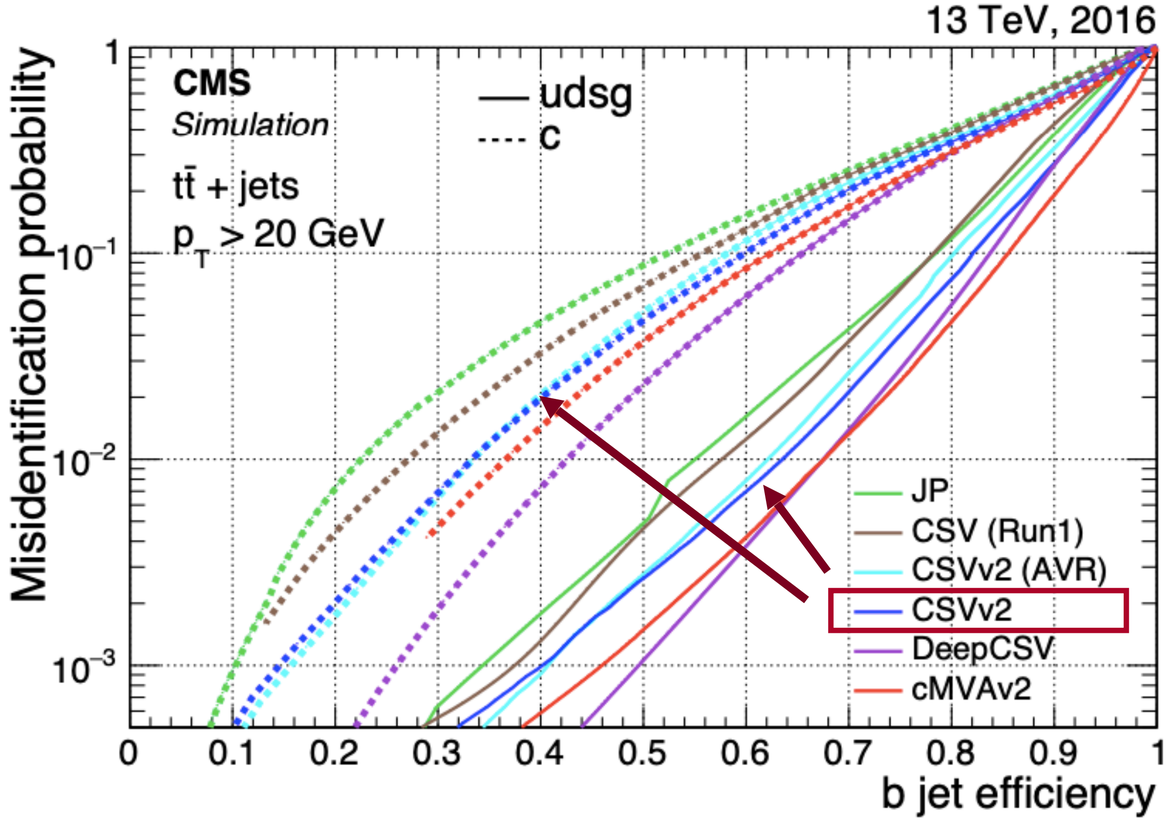
JHEP 026 (2007) 0707



Finding b jets: CMS b-tagging technique

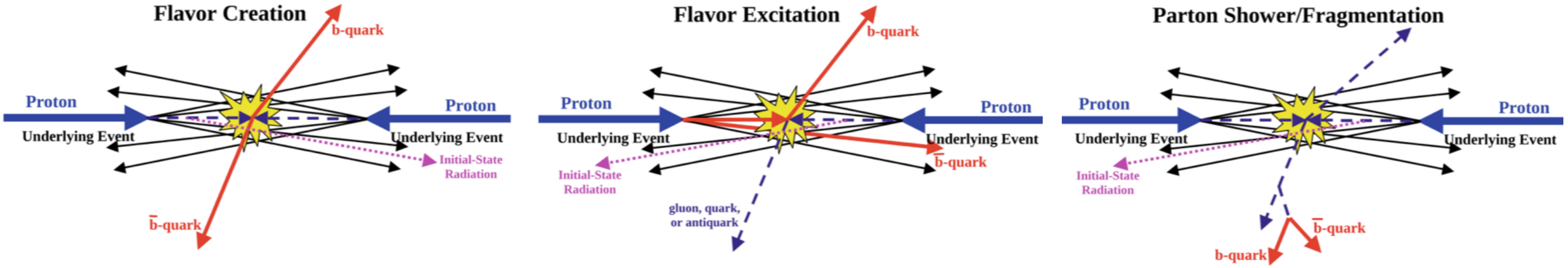
- A multi-variate discriminator (CSVv2) taking the track and secondary vertex (SV) information as input is used for tagging the b jets from data



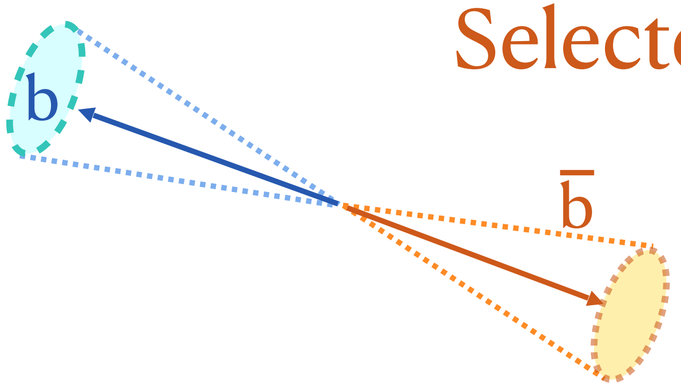


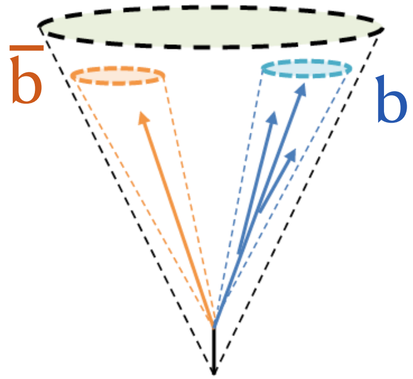
JINST 13 (2018) P05011

b quark production



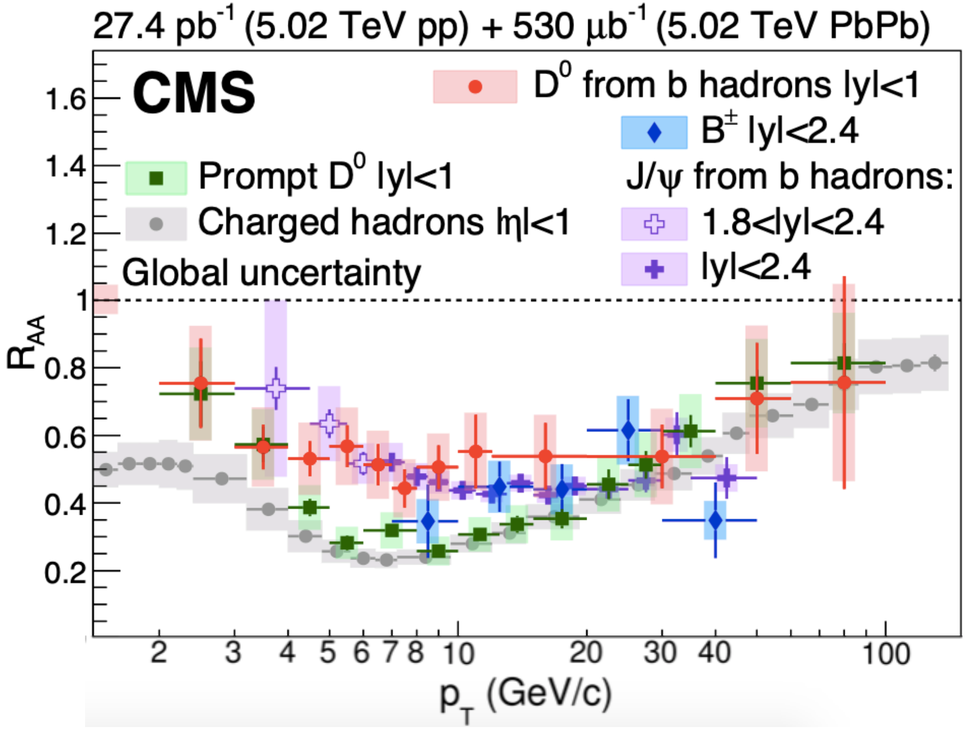
Selected inclusively by b jet CSVv2 tagger



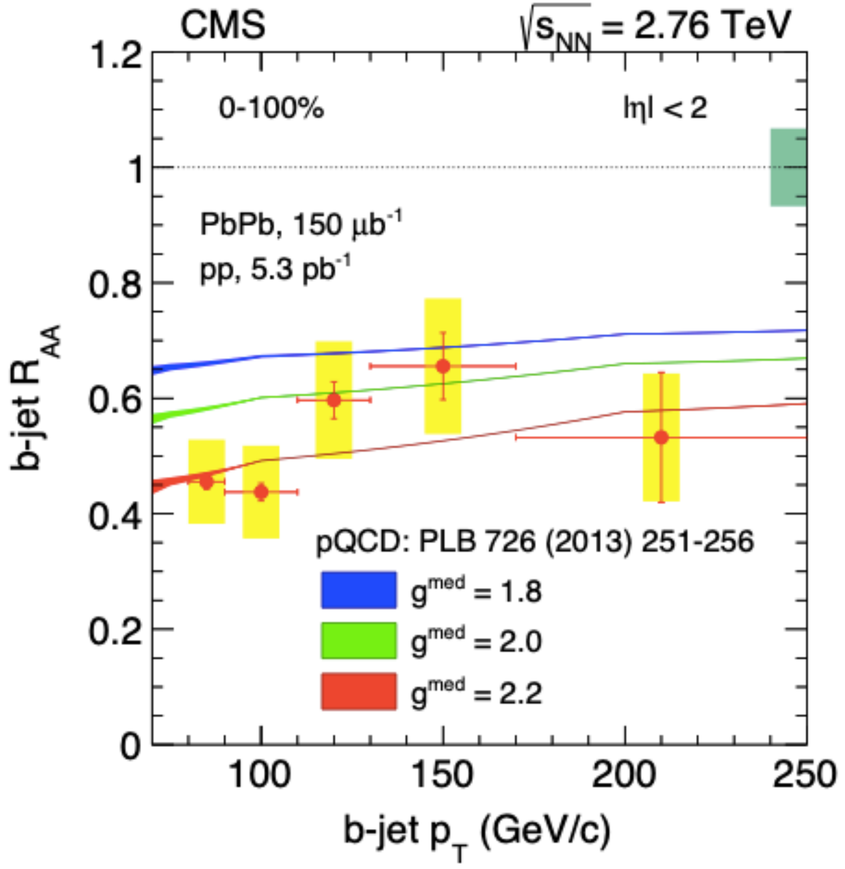


Mass dependence of Energy Loss

- b quarks are expected to lose less energy than light quarks due to the heavy mass:
  - Dead-cone effect
  - Landau-Pomeranchuk-Migdal (LPM) effect



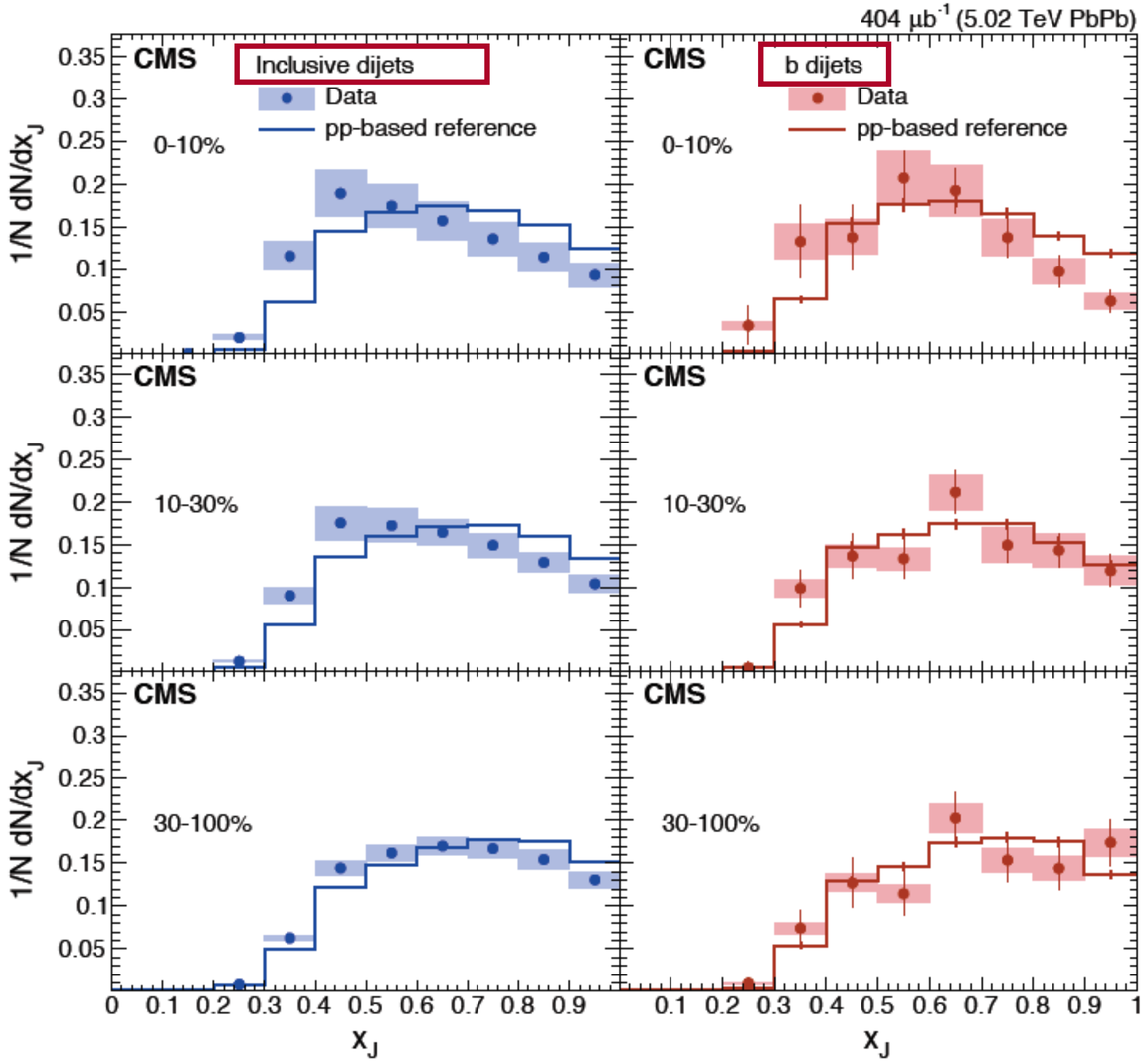
Phys.Rev. Lett. 123 (2019) 022001



Phys.Rev. Lett. 113 (2014) 132301

Mass dependence of Energy Loss

- b quarks are expected to lose less energy than light quarks due to the heavy mass:
  - Dead-cone effect
  - Landau-Pomeranchuk-Migdal (LPM) effect
- No clear picture of how parton showers are modified in the QGP:
  - b jet tomography!



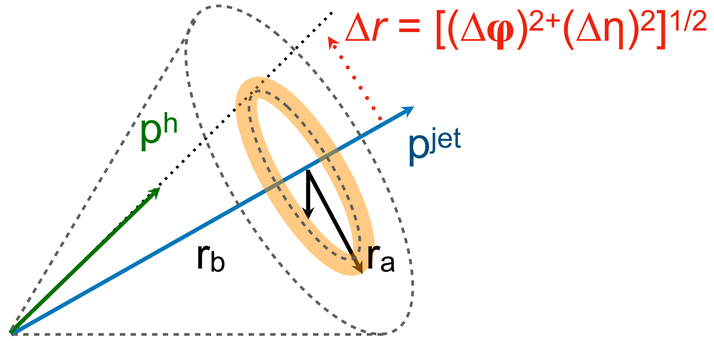
JHEP 03 (2018) 181

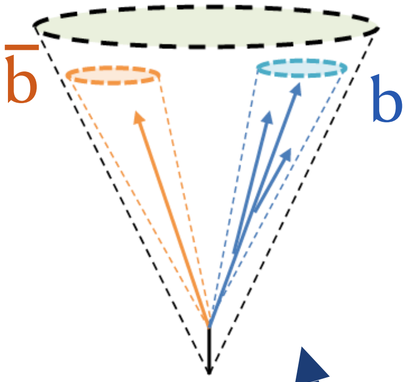
Inclusive b jet shapes

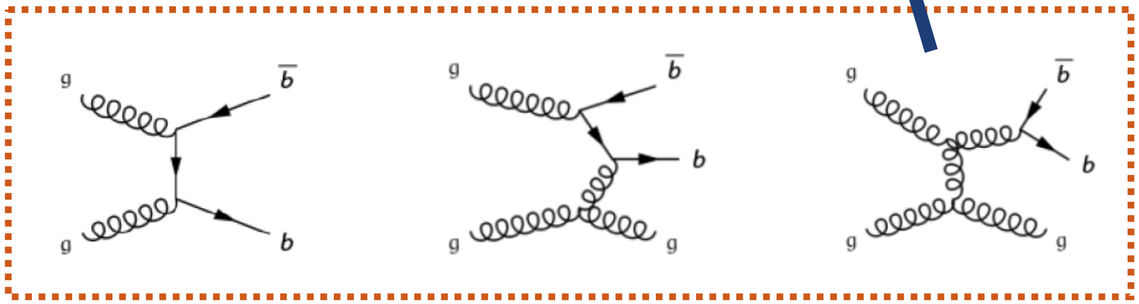
- Inclusive b jet shapes :

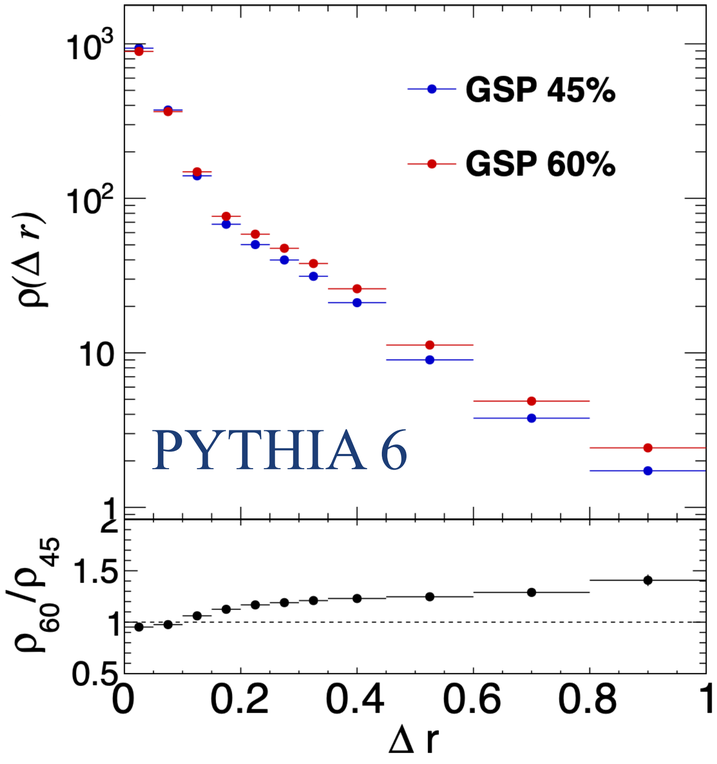
$$\rho(\Delta r) = \frac{1}{\delta r}\frac{\Sigma_{\text{jet}}\Sigma_{\text{trk}\in(\Delta r_a,\Delta r_b)}p_{\text{T}}^{\text{trk}}}{\Sigma_{\text{jet}}\Sigma_{\text{trk}}p_{\text{T}}^{\text{trk}}}$$

  - Sensitive to production processes (b jets from GSP are much broader than b jets from other processes);
  - Sensitive to the parton fragmentation (e.g. dead cone effect, b hadron formation).







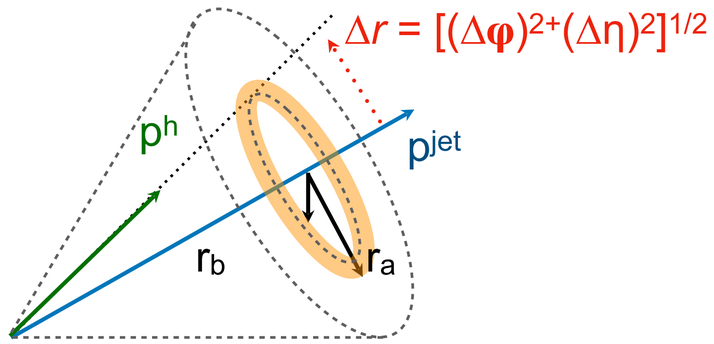


Inclusive b jet shapes

- Inclusive b jet shapes :

$$\rho(\Delta r) = \frac{1}{\delta r}\frac{\Sigma_{\text{jet}}\Sigma_{\text{trk}\in(\Delta r_a,\Delta r_b)}p_{\text{T}}^{\text{trk}}}{\Sigma_{\text{jet}}\Sigma_{\text{trk}}p_{\text{T}}^{\text{trk}}}$$

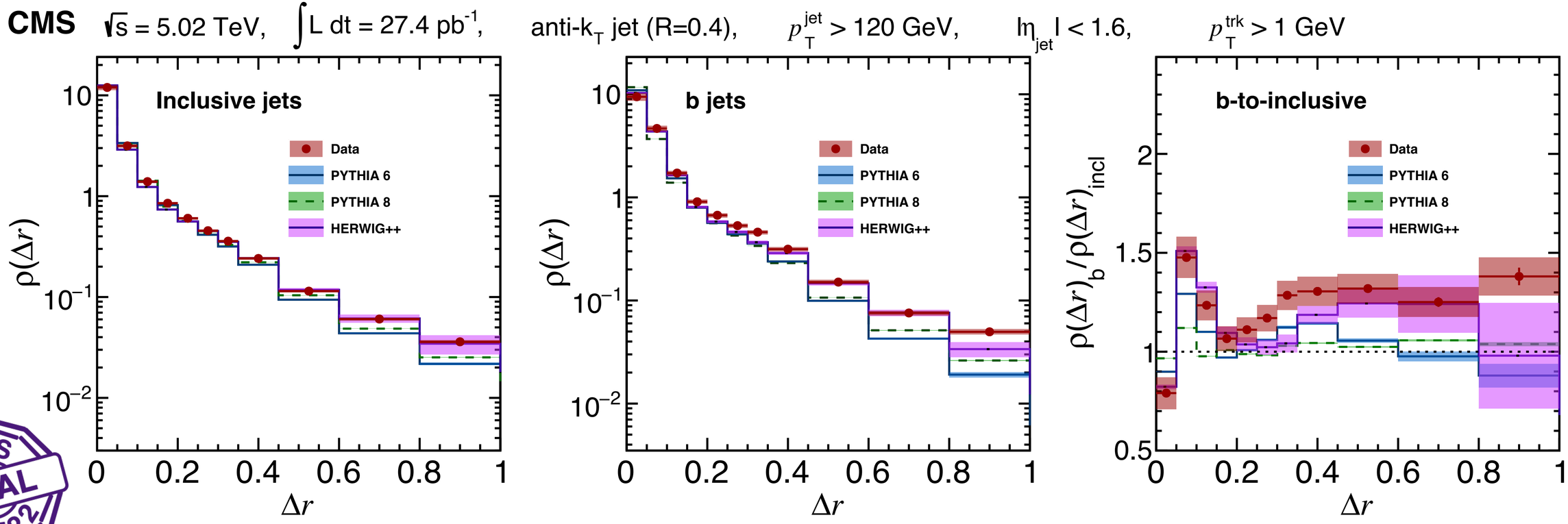
- Kinematic selections:
  - Jets: anti-k_{T}, $R = 0.4$, $p_{\text{T}} > 120$ GeV, $|\eta| < 1.6$
  - Tracks: $p_{\text{T}} > 1$ GeV, $|\eta| < 2.4$



- Analysis Strategy:
  - Select b jet candidates from inclusive jet samples (by using the CSVv2 discriminator);
  - Extract the signal from the jet-track correlation method (extended the measurement up to $\Delta r = 1$)
  - Remove the contamination from mis-identified light jets.
  - Correct reconstruction and background fluctuation effects.

Inclusive b jet shapes in pp collisions

- Inclusive b jet shapes :
  - Sensitive to production processes (b jets from GSP are much broader than b jets from other processes);
  - Sensitive to the parton fragmentation (e.g. dead cone effect, b hadron formation).

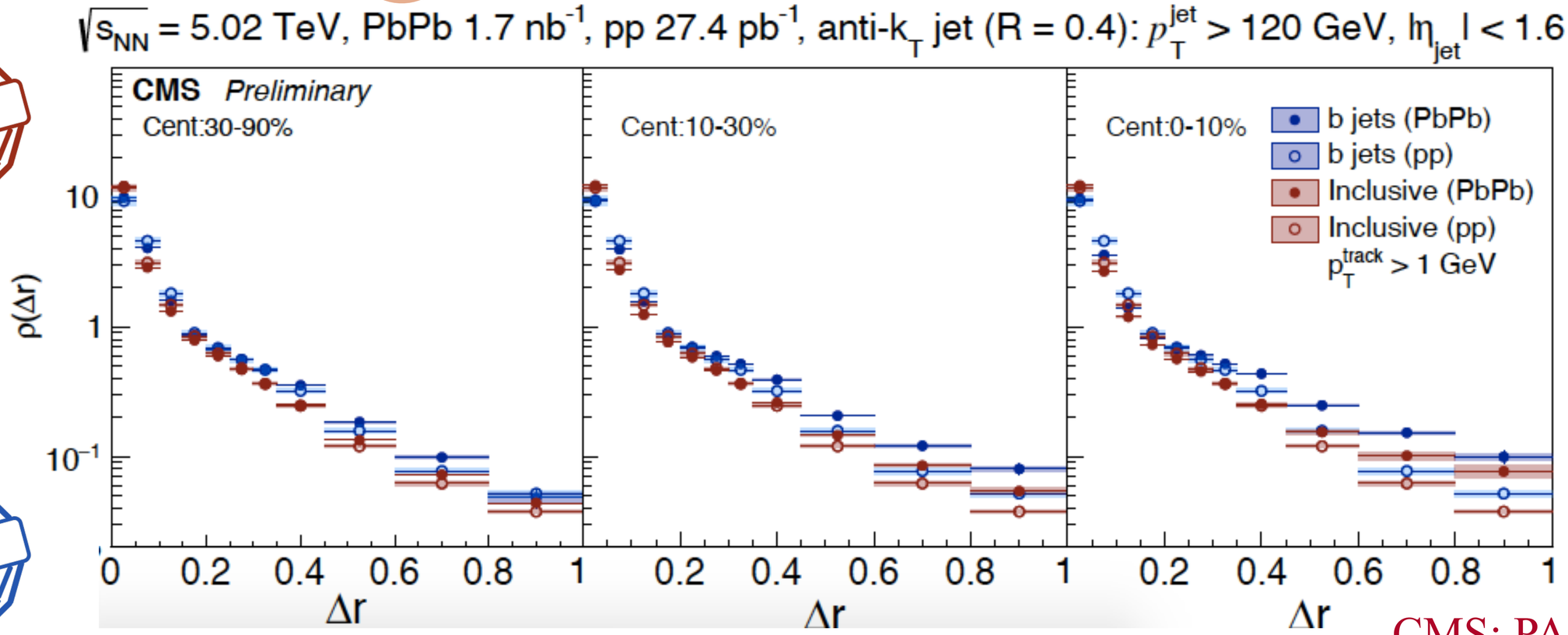


JHEP 05 (2021) 054

Inclusive b jet shapes in PbPb collisions

- Jet shapes are modified in PbPb collisions:

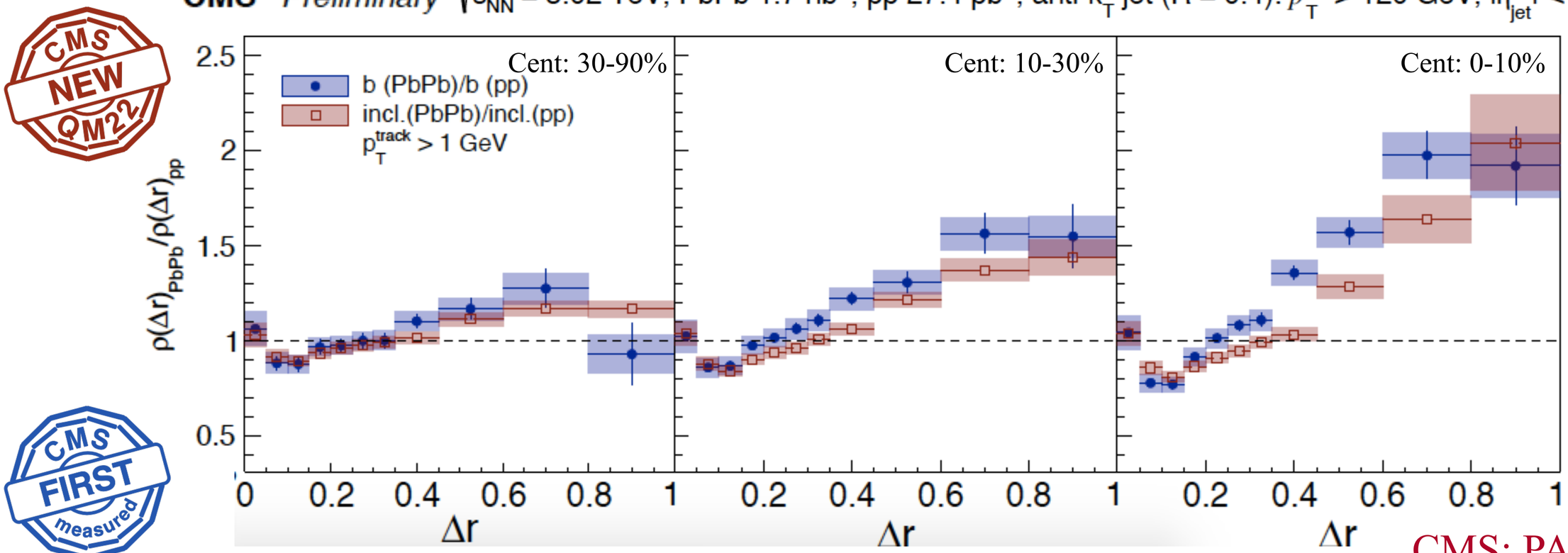
  Both b jet and inclusive jet shapes are broader in PbPb collisions than the pp reference;



CMS: PAS-HIN-20-003

Inclusive b jet shapes in PbPb collisions

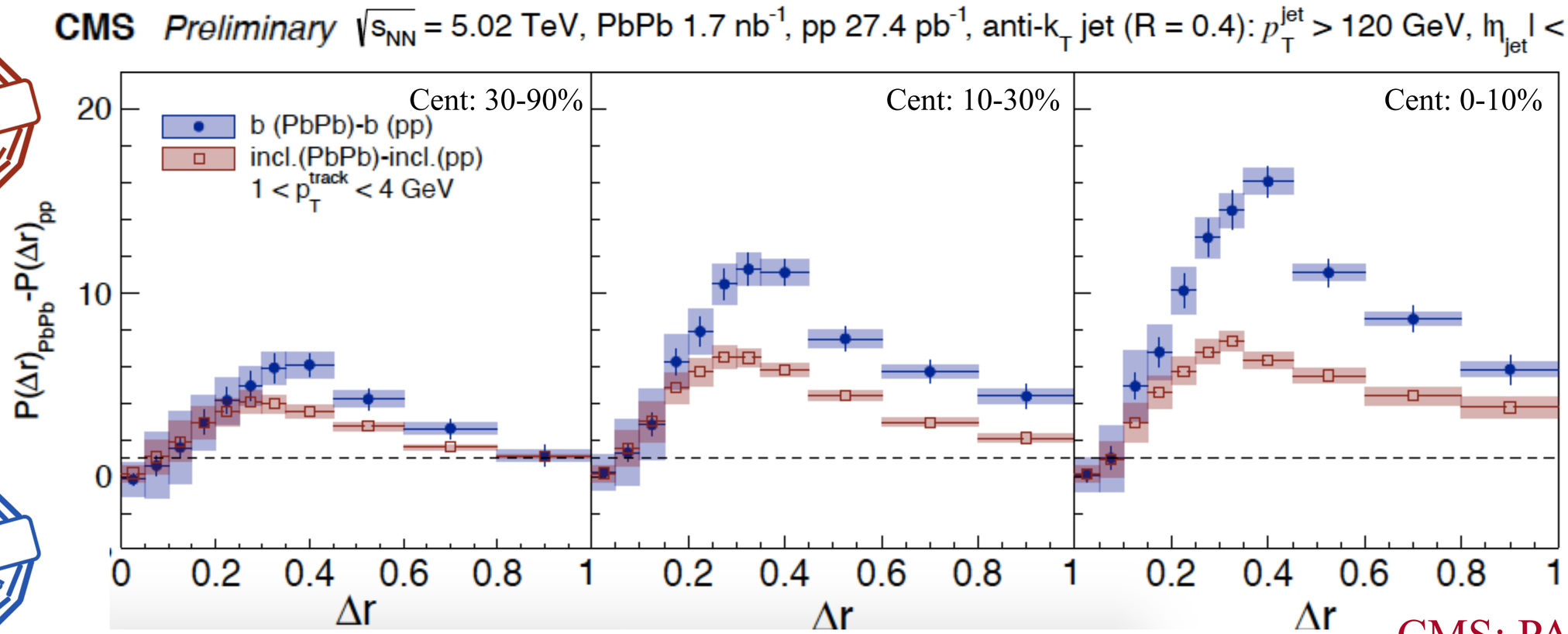
- The jet shape modifications show clear centrality dependence;
- The relative modification of b jets is slightly stronger than that of inclusive jets;



CMS: PAS-HIN-20-003

Charged hadron p_T profile of b jets in PbPb collisions

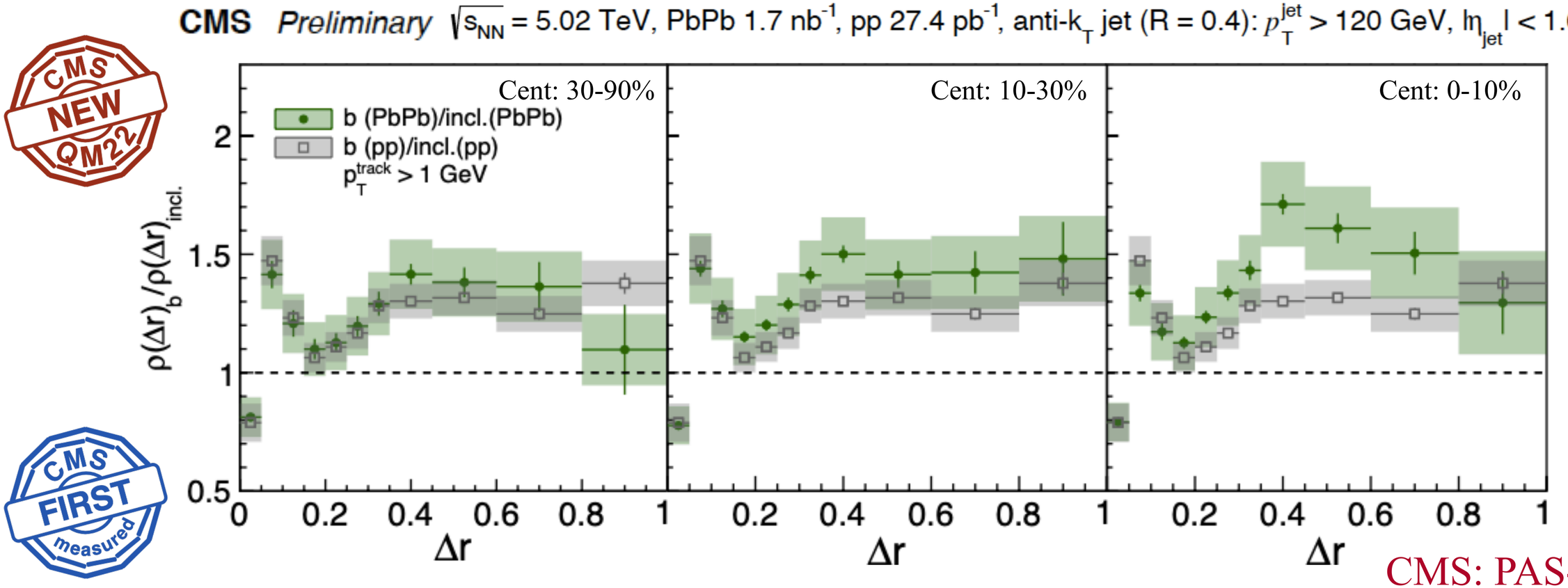
- Charged hadron p_T accumulated around the jet axis: $P(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{\mathrm{jet}}}\Sigma_{\mathrm{jets}}\Sigma_{\mathrm{trk}\in(\Delta r_a,\Delta r_b)}p_{\mathrm{T}}^{\mathrm{trk}}$,
- More p_T from 1 < pT < 4 GeV accumulated around both b and inclusive jets
- The soft p_T accumulation of b jets are stronger than inclusive jets in all centrality bins.



CMS: PAS-HIN-20-003

b-to-inclusive jet shape ratios in PbPb collisions

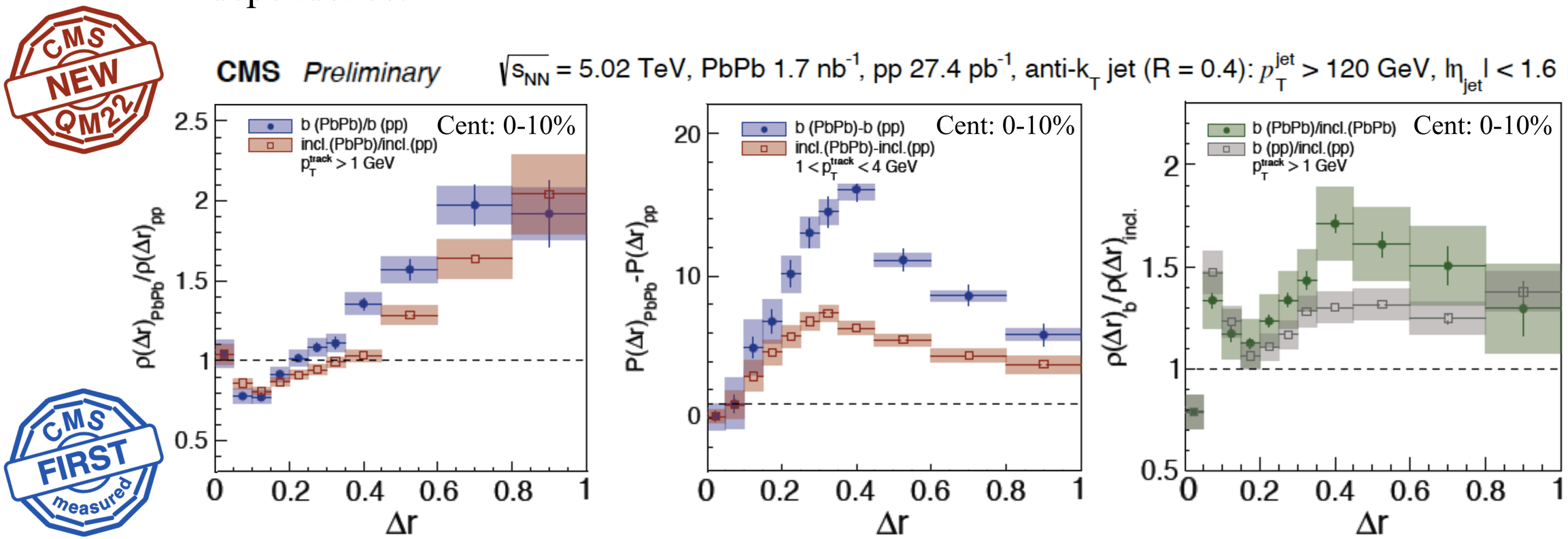
- The relative modification between the b and inclusive jets in large Δr region is getting larger from peripheral to central collisions;
- No obvious centrality dependence observed for the small angle depletion.



CMS: PAS-HIN-20-003

Summary

- The first measurements on the b jet shapes in pp and PbPb collisions are presented:
  - b jets accumulated more soft p_T in large Δr region than inclusive jets;
  - The depletion observed in b-to-inclusive shapes near jet axis shows no centrality dependence.

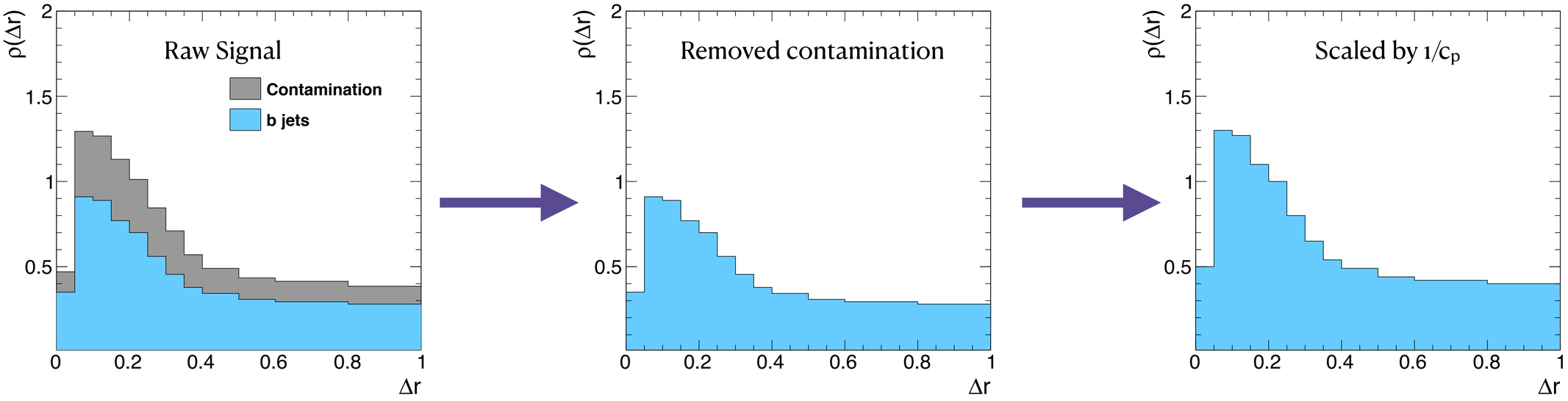


Thanks for your attention!

Remove the contamination

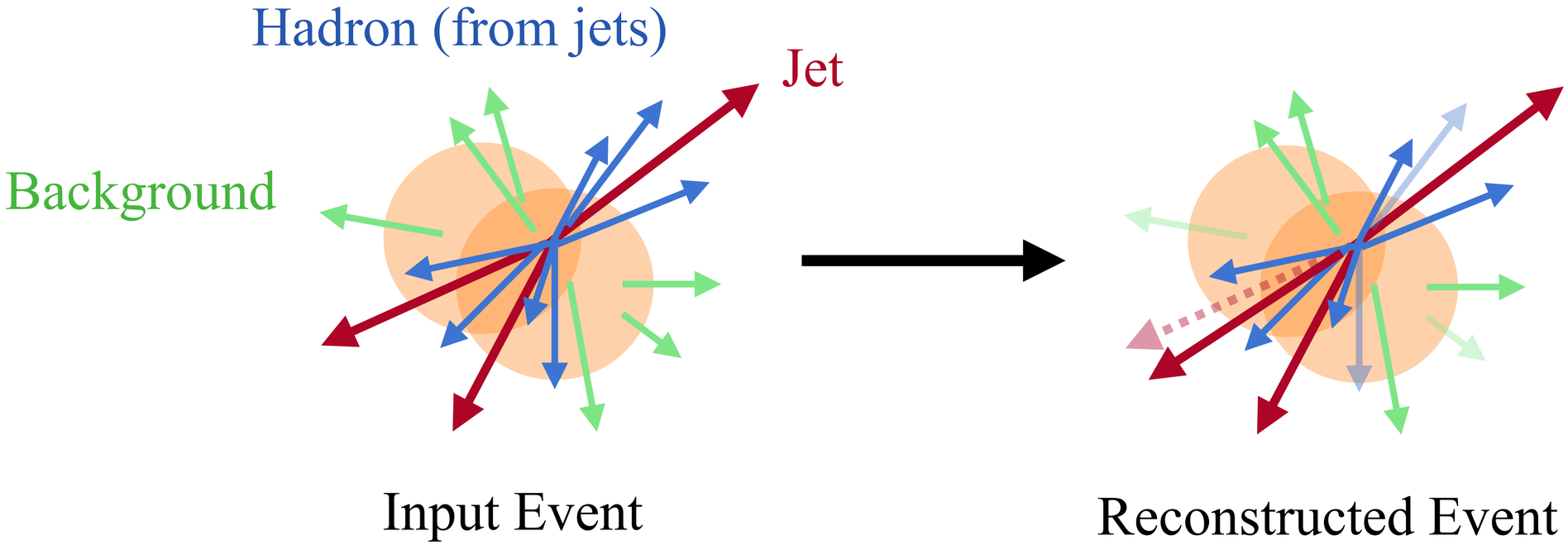
- Remove the contamination from mis-selected light jets based on the formula:

$$S^{*}_{\mathrm{tag}} = \frac{S_{\mathrm{tag}} - (1 - c_p) S_{\mathrm{mistag}}}{c_p}$$



Corrections for reconstruction biases

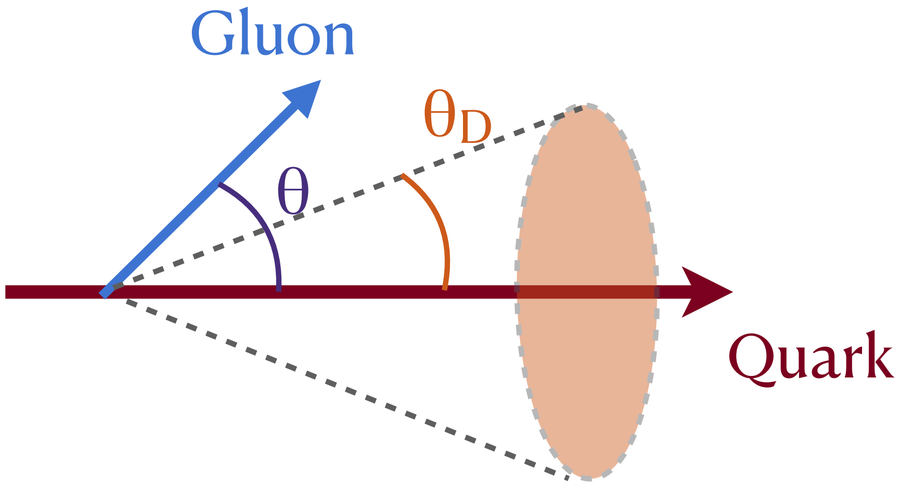
- Reconstruction biases included:
  - Tracking reconstruction efficiency
  - Residual jet fragmentation function bias (included the axis pointing resolution bias)
  - CSVv2 selection bias
  - Background fluctuation bias (for PbPb collisions only)

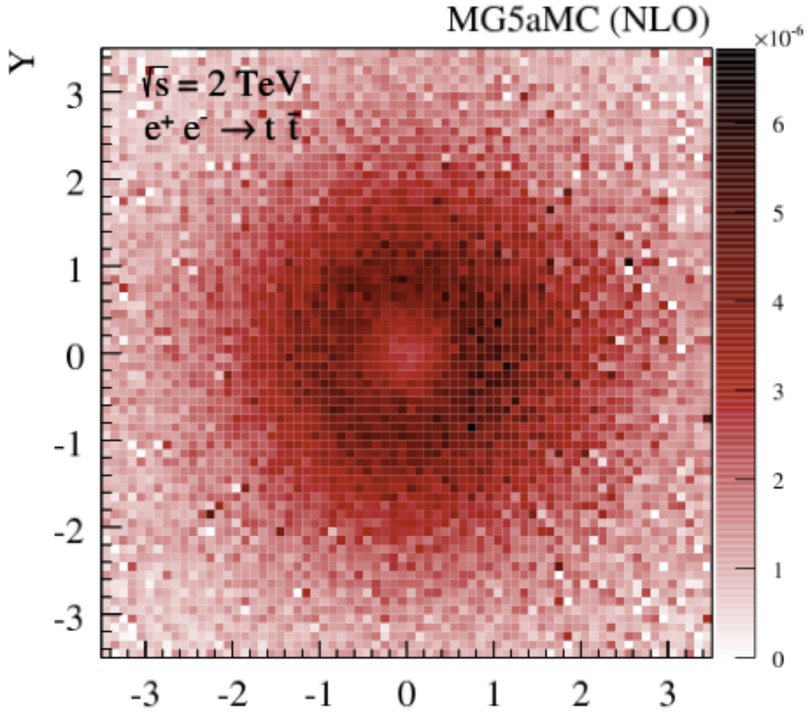


Radiation of b quarks

- The gluon radiation probability from a quark: $\frac{1}{\sigma}\frac{d^2\sigma}{dzd\theta^2} \sim C_F\frac{\alpha_s}{z}\frac{\theta^2}{(\theta^2+\theta_D^2)^2}, \quad \theta_D = \frac{m}{\boldsymbol{p}} \approx \frac{m}{E}.$

- b quarks have a larger gluon radiation dead-cone than light quarks;

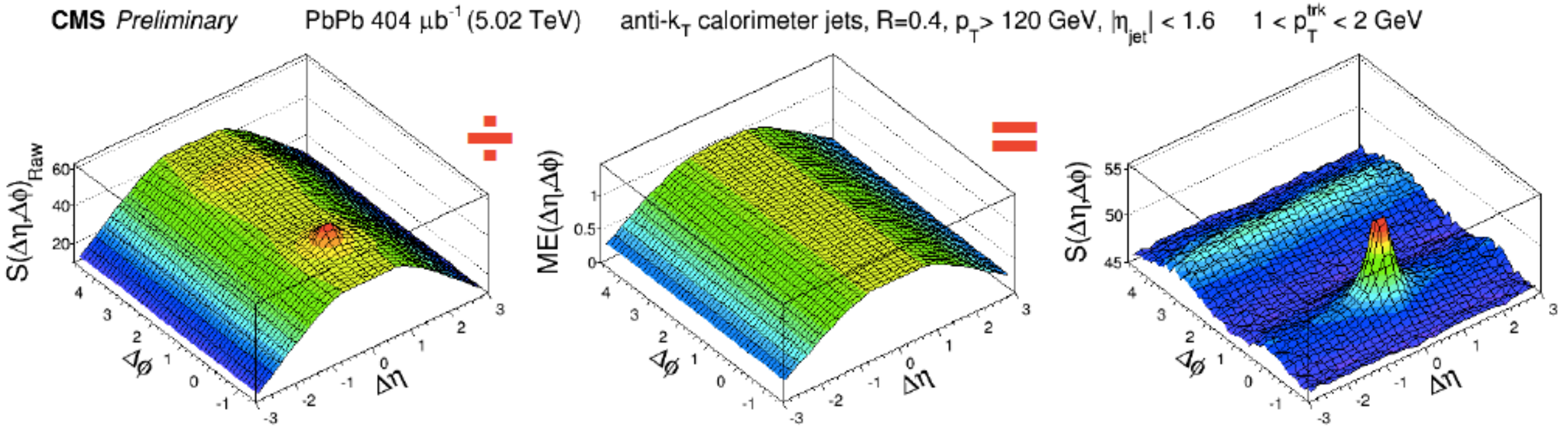




Phys.Rev.D 94 (2016) 5

Correlation method for measuring jet shapes

- Finite jet and track acceptances result in trapezoidal geometry
- Correct for this pair acceptance effect with a mixed-event correction:
  - Jets from sample
  - Tracks from a minimum-bias event matched on centrality and v_z



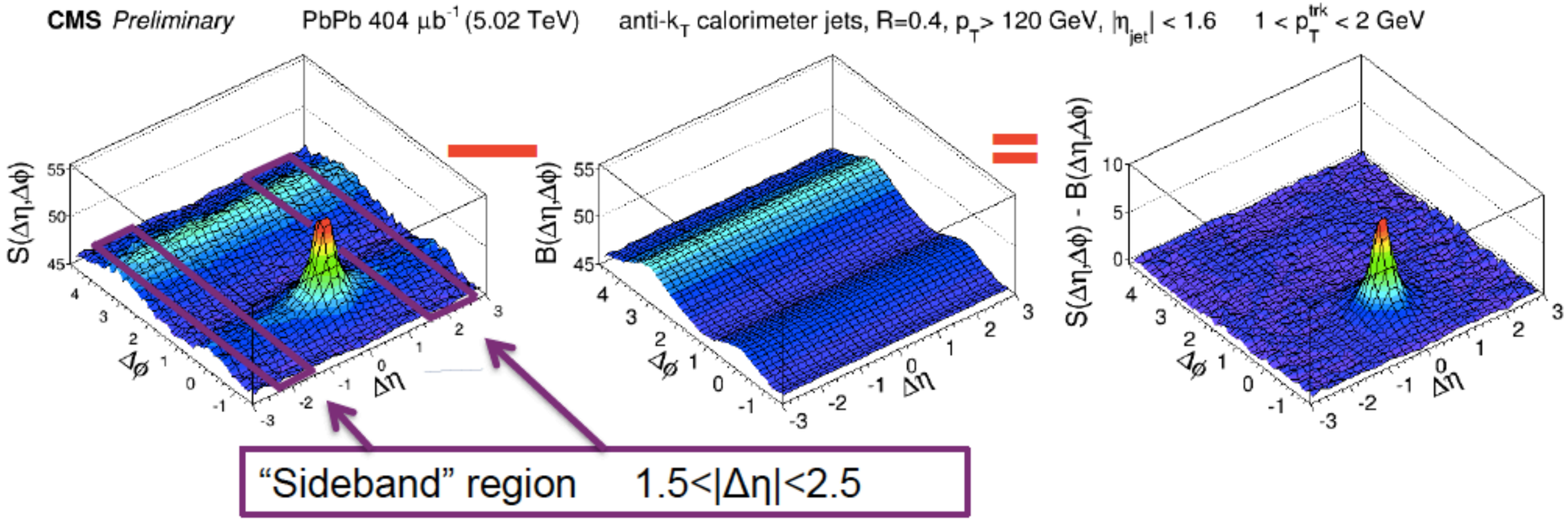
CMS: PAS-HIN-16-020

Correlation method for measuring jet shapes

- Project background (measured on 1.5<|Δη|<2.5) into Δφ
- Propagate this background distribution in 2D
- Subtract from background from signal to yield isolated jet peak

Signal + Background

Signal Only

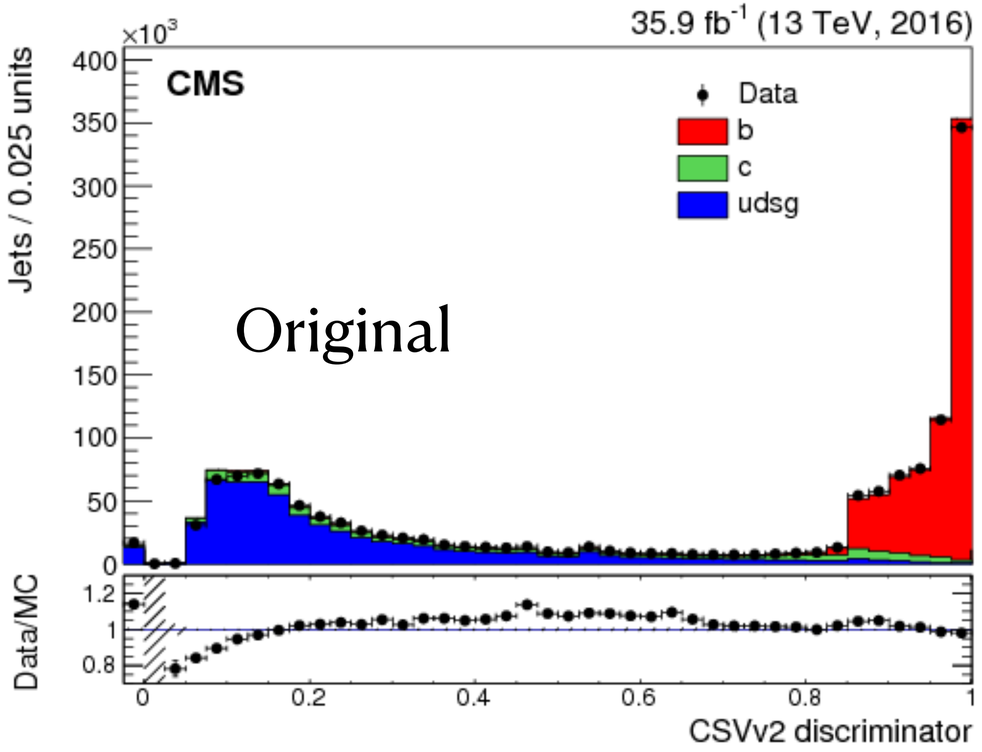


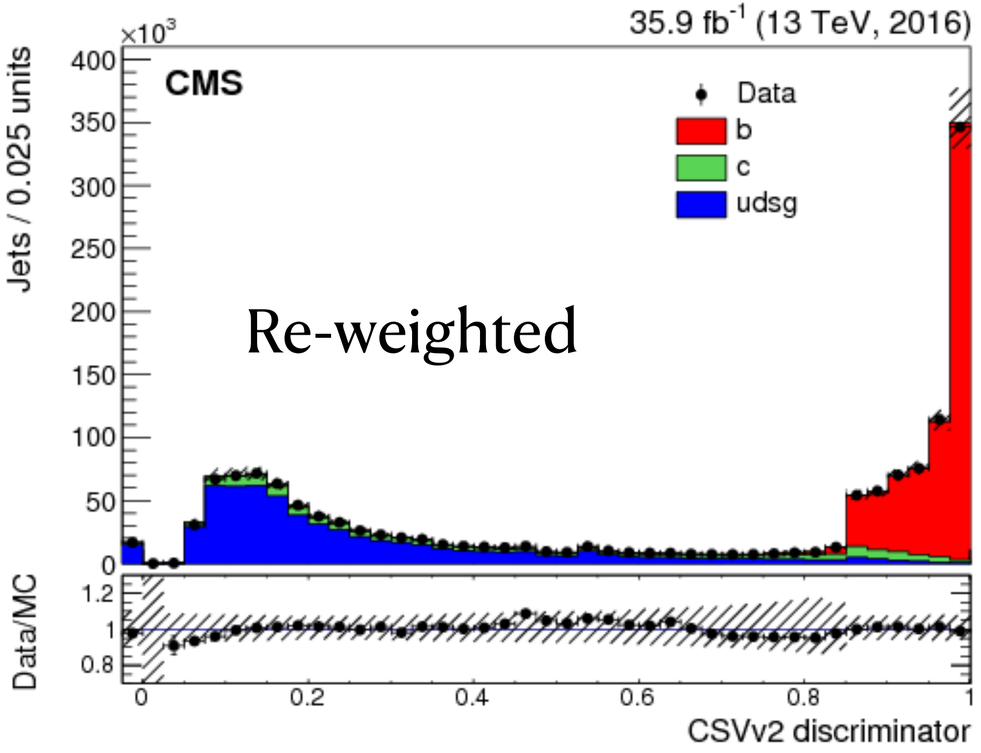
- Finally: apply two MC-based corrections for jet reconstruction biases

CMS: PAS-HIN-16-020

Example of the validation of the scale factor reweight method on top pair events

- Reweighted samples have a better agreement with data in control region (2 jets tagged in 4 jet events)

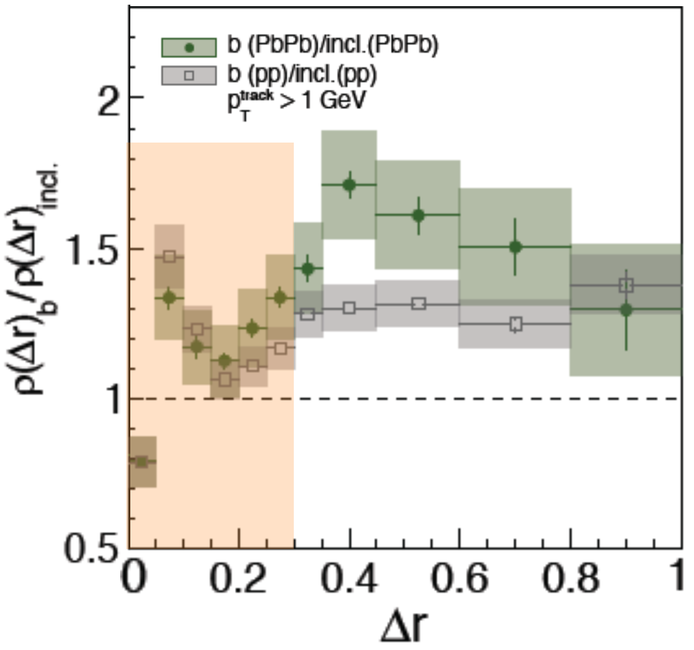


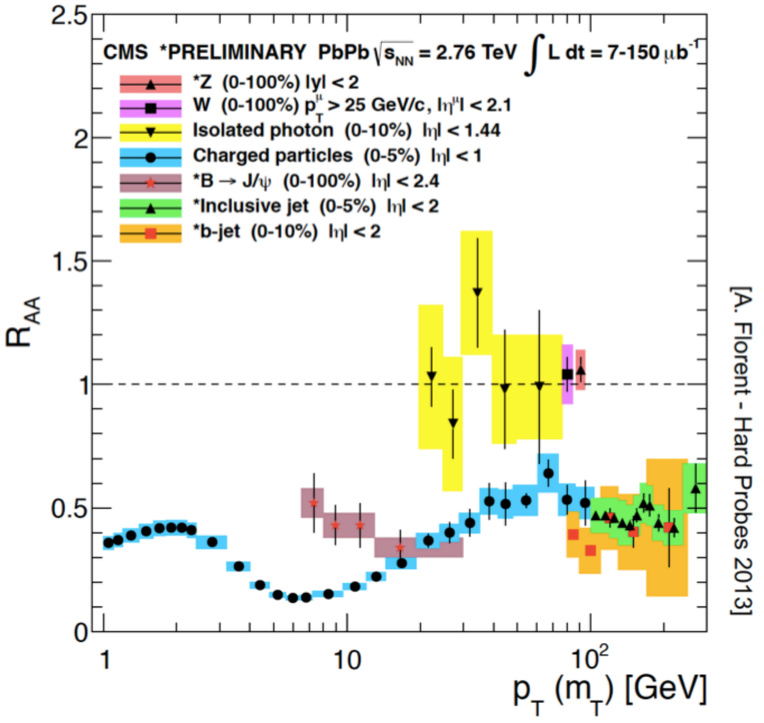


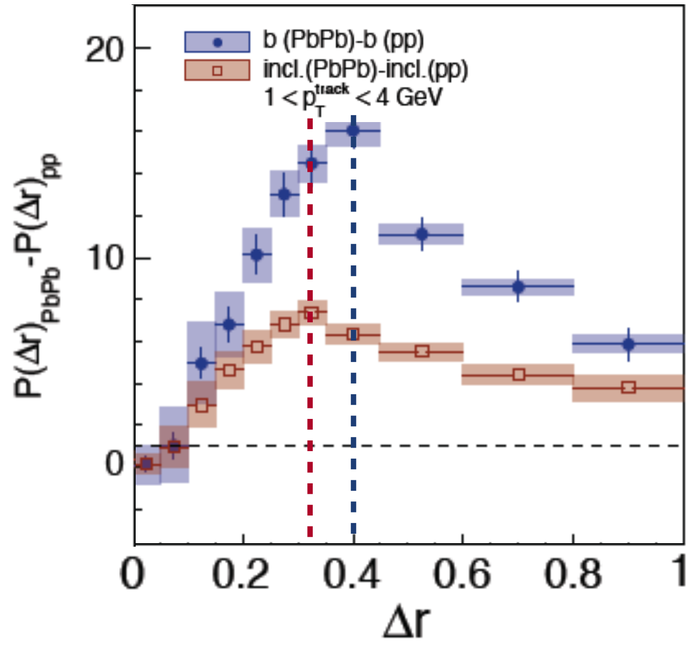
JINST 13 (2018) P05011

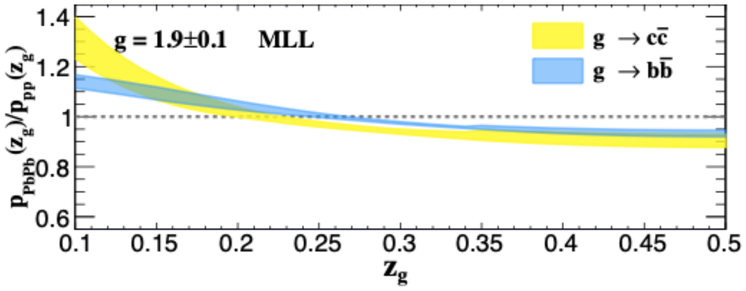
Future Exploration

- A hint that the substructure of GSP b jets is very different from the one from light flavor GSP jets?
- An explanation for the R_{AA} of b jets is similar to inclusive jets when R is small?









Phys.Lett.B 793 (2019)