Search for medium effects using jets from bottom quarks in PbPb collisions

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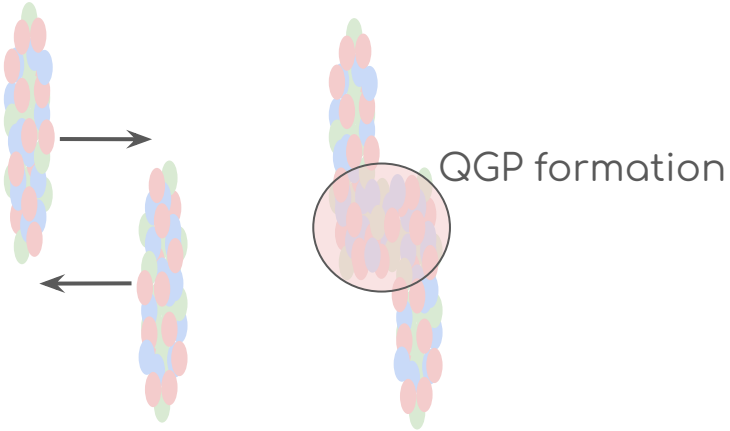
on behalf of the CMS collaboration

Hard Probes 2023

Introduction

Jets as a probe of the Quark-Gluon Plasma (QGP)

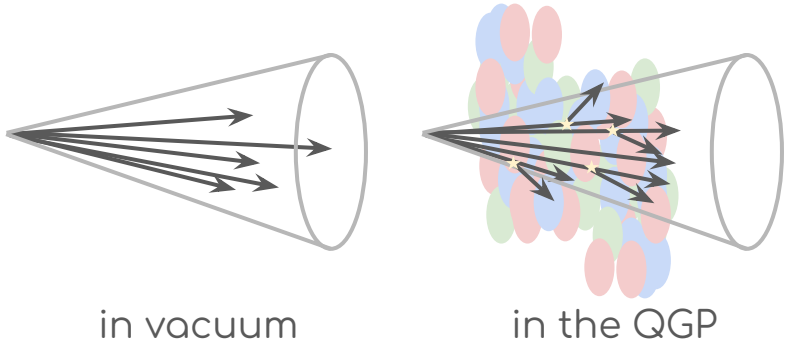
Heavy ion collisions



Collision centrality

Jet constituent - QGP interaction

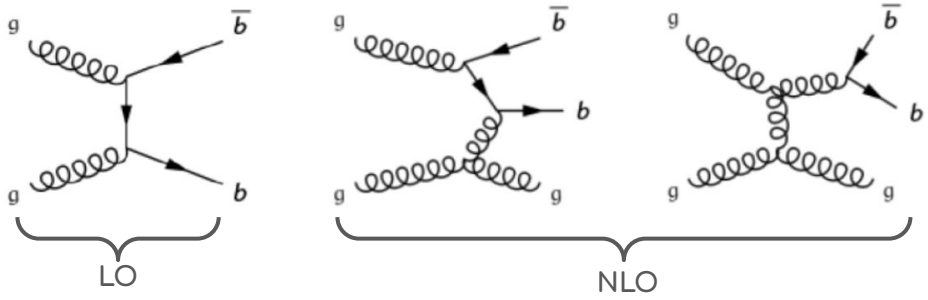
⇒ Jet energy loss (jet quenching)



Flavour, mass, colour dependence ?

Bottom quark jets (b-jets)

Production modes of b quarks

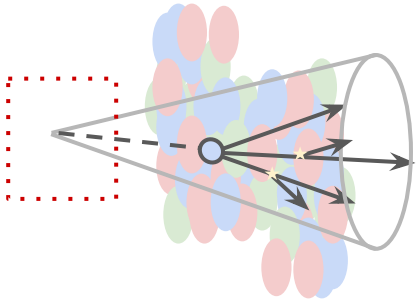


Bottom quark jets are characterized by :

- Hard fragmentation
- Suppression of small angle radiation
- Displaced decay vertex

In heavy ion collisions

b quark produced in the early stage of the collision



Probe the whole medium evolution

Study colour, flavour dependence of QCD processes

Previous b-jet measurements

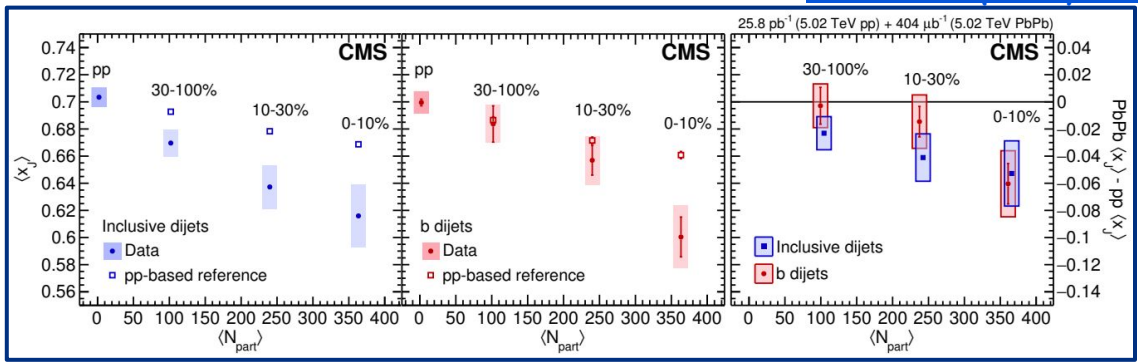
Quenching of b-jets comparable to that of inclusive jets

- Hints of flavour dependence
- Need more in-depth studies

Dijet momentum balance

$x_J \sim p_T^{subleading} / p_T^{leading}$

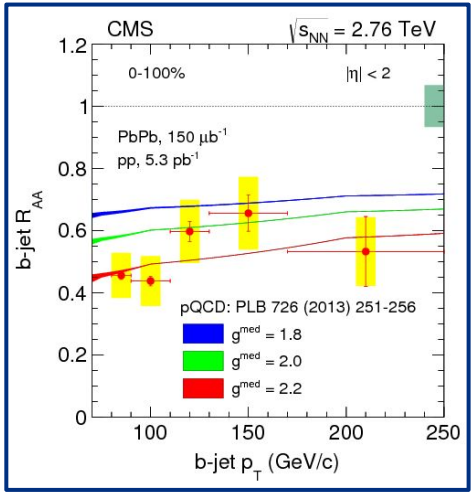
JHEP 03 (2018) 181



Nuclear modification factor

$R_{AA} \sim PbPb / pp$

PRL 113 (2014) 132301



Analysis techniques

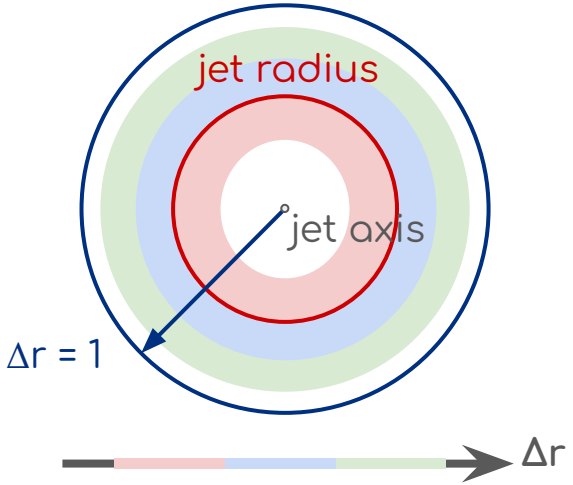
Jet shapes

Transverse jet profile : distribution of charged particle p_T around the jet axis

$$P(\Delta r) = \frac{1}{\Delta r_a - \Delta r_b} \frac{1}{N_{\text{jet}}} \sum_{\text{jets}} \sum_{\substack{\text{trk w/} \\ \Delta r \in (\Delta r_a,\, \Delta r_b)}} p_T^{\text{trk}}$$

Normalized to unity in $\Delta r < 1$

$$\rho(\Delta r) = \frac{P(\Delta r)}{\sum_{\text{jets}} \sum_{\substack{\text{trk w/} \\ \Delta r < 1}} p_T^{\text{trk}}}$$



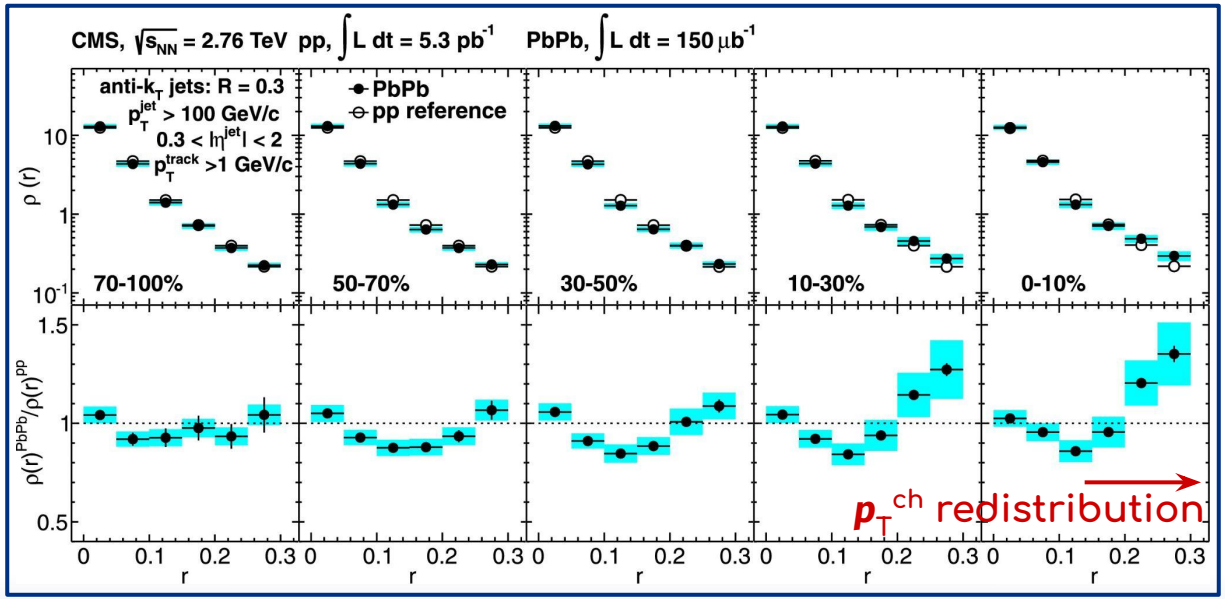
Sensitive to the shower evolution in the QGP

Jet shapes of inclusive jets in pp and PbPb

Measurements restricted in $\Delta r < R^{jet}$:

- Narrowing of jet core in PbPb
- Redistribution to large angles in central PbPb

PLB 730 (2014) 243



Jet shapes of b-jets in pp

The b-jet shape is sensitive to :

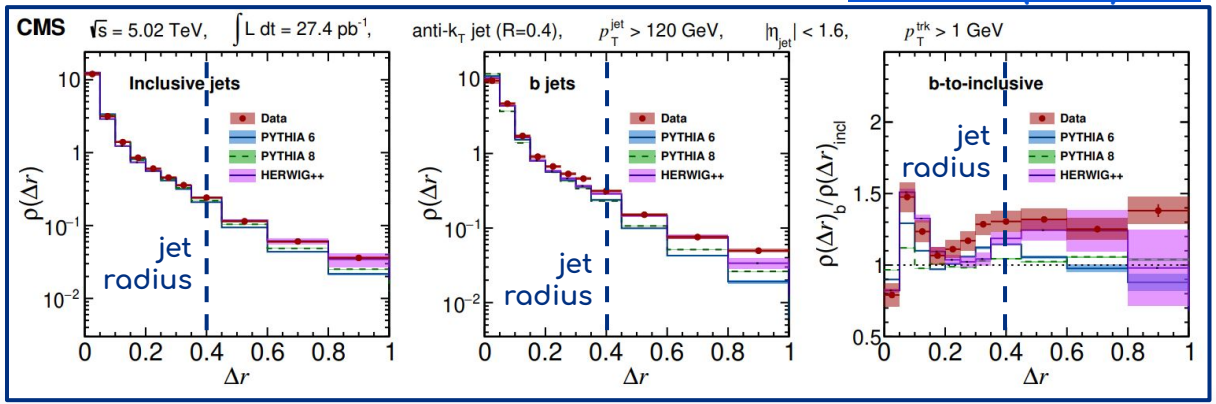
- Very different b-quark fragmentation and hadronization
- The b-hadron decay kinematics

Comparison to Monte Carlo generated events :

- Data described reasonably well by hadronization models
- HERWIG++ better at describing large angle production

Extend measurement to large angles using event mixing

JHEP 05 (2021) 054



Event selection and simulation

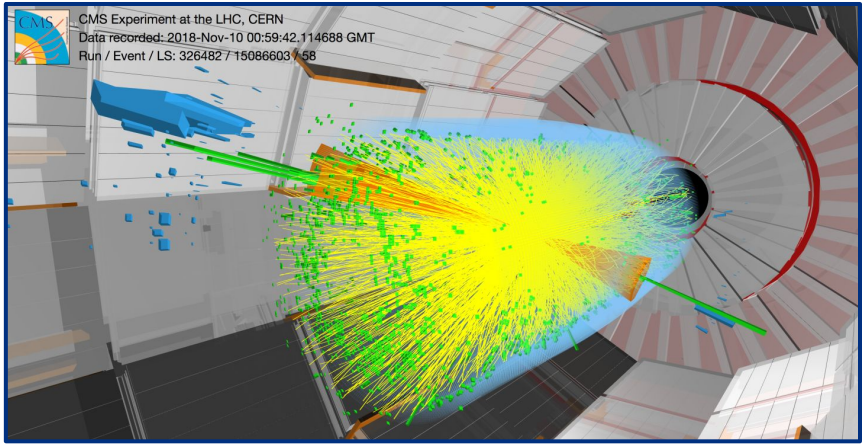
L = 1.69 nb^{-1} of PbPb events at $\sqrt{s_{NN}}$ = 5.02 TeV (CMS 2018) selected with :

- 0.4 anti-k_T jets with online p_T^{jet} > 80 or 100 GeV after underlying event subtraction
- minimum bias, used to correct for jet and track acceptance

Simulated events with :

- PYTHIA8 for the hard processes
- HYDJET for the underlying event contribution
- GEANT4 for the detector response

Used for energy and efficiency corrections

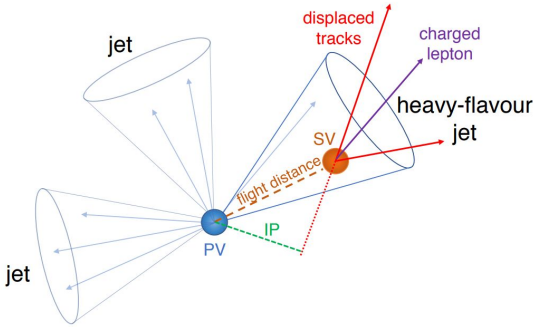


CMS-PHO-EVENTS-2018-010

b-jet selection

The Combined Secondary Vertex (CSV) family of b-taggers rely on :

- Reconstructed secondary vertices
- Large impact parameter tracks
- Soft leptons (e, μ)

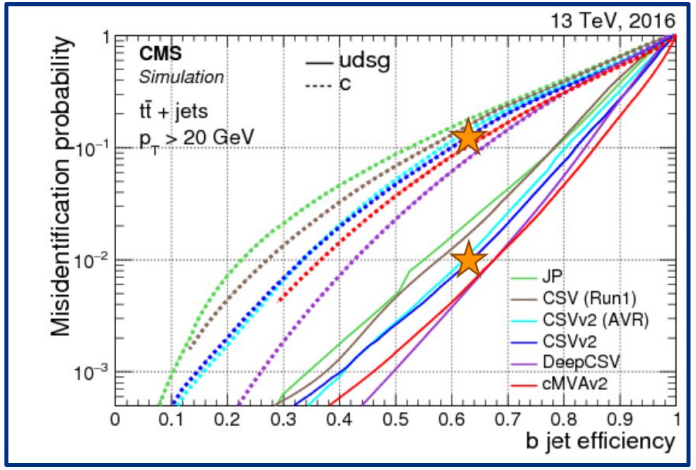


CSVv2 is a multivariate tagger used in early Run 2 analyses

JINST 13 (2018) P05011

- Retrained for PbPb

Working Point
75 % b-jet efficiency
45 % purity



Further light jet decontamination applied using the inclusive jet shape templates (JHEP 05 (2021) 054)

New results

Search for medium effects using jets from bottom quarks in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

accepted by PLB

arXiv:2210.08547

Systematic uncertainties

Leading sources :

- Light jet decontamination of b-jet selection
- Tracking reconstruction efficiency

Statistical uncertainties included in the background subtraction

arXiv:2210.08547

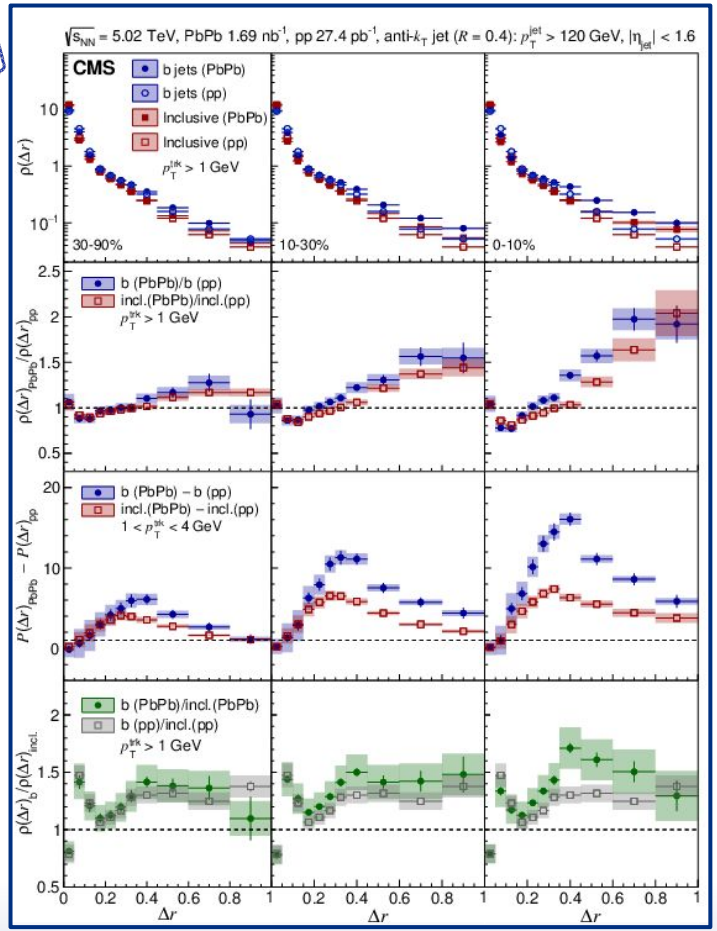
Sources	b jets Centralities			Inclusive jets Centralities		
	30–90%	10-30%	0-10%	30–90%	10–30%	0–10%
Trigger efficiency	3.0	3.0	3.0	3.0	3.0	3.0
Tracking efficiency	5.8	5.8	5.8	5.8	5.8	5.8
Tagging bias corrections	5.0	5.0	5.0	—	—	—
Decontamination procedure	8.0	8.0	8.0	—	—	—
Jet energy scale/resolution	4.2	4.2	4.2	4.2	4.2	4.2
Pair-acceptance corrections	1.0–2.0	1.0–4.0	1.0–5.0	1.0–2.0	1.0–3.0	1.0–4.0
Background subtraction	1.0	2.0	3.0	1.0	2.0	3.0
Total	12.3–12.4	12.3–12.9	12.3 –13.2	7.8–8.0	7.8–8.3	7.8–8.7

Results

arXiv:2210.08547

Overall observed modification :

- PbPb / pp
- b / inclusive



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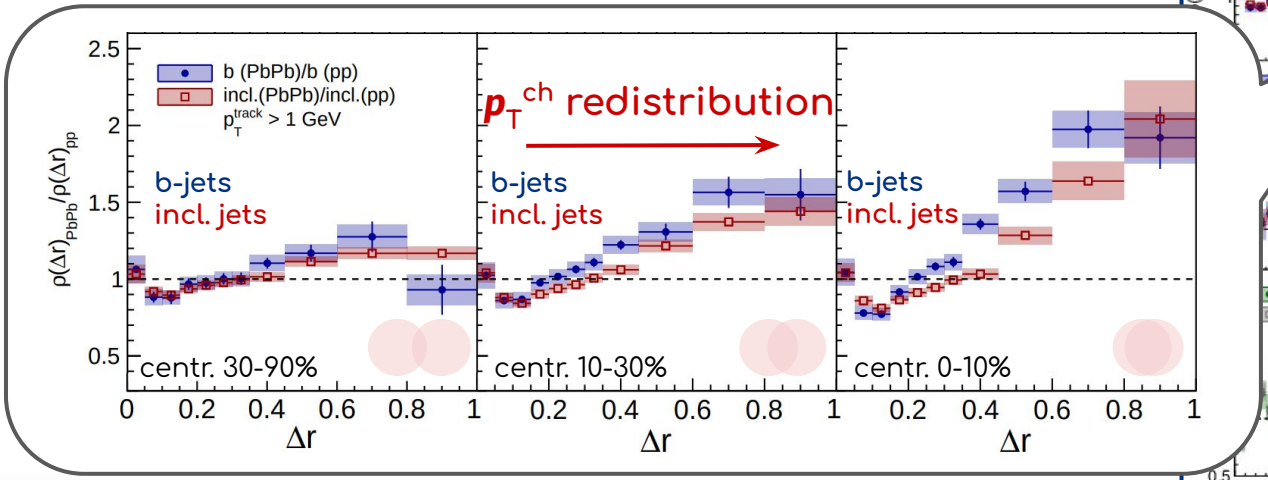
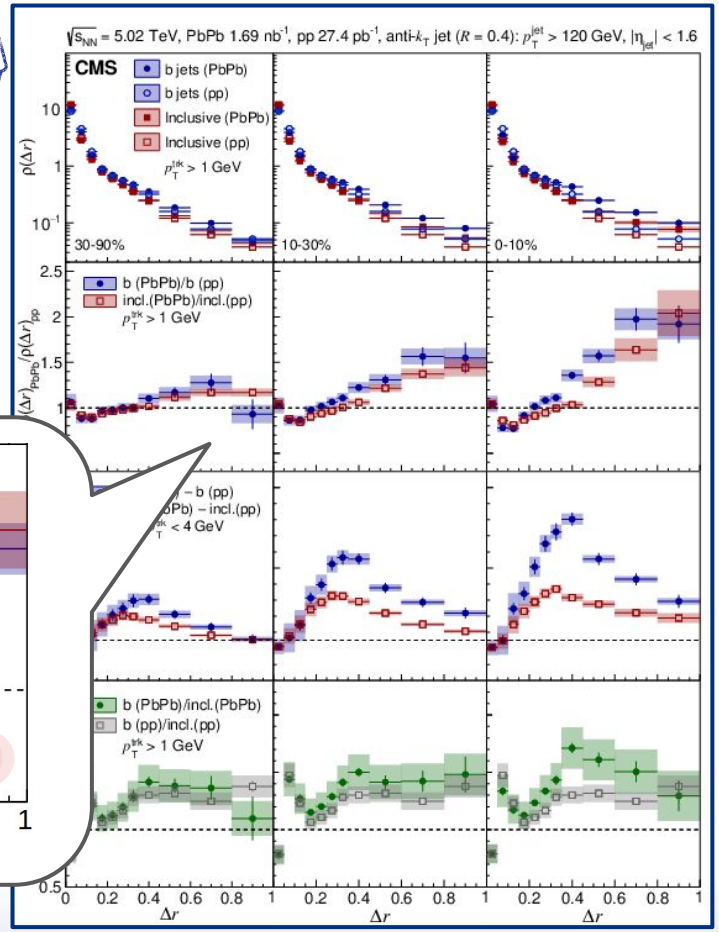
  - p_T^{ch} redistribution towards larger Δr
  - More pronounced in central collisions
  - Agreement with expectations
- b / inclusive





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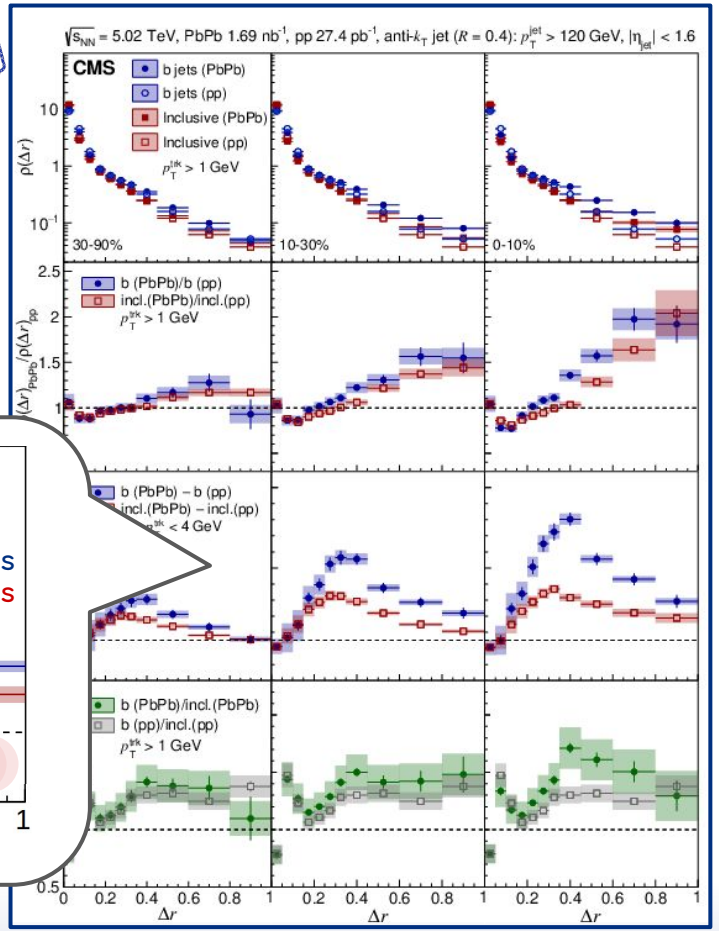
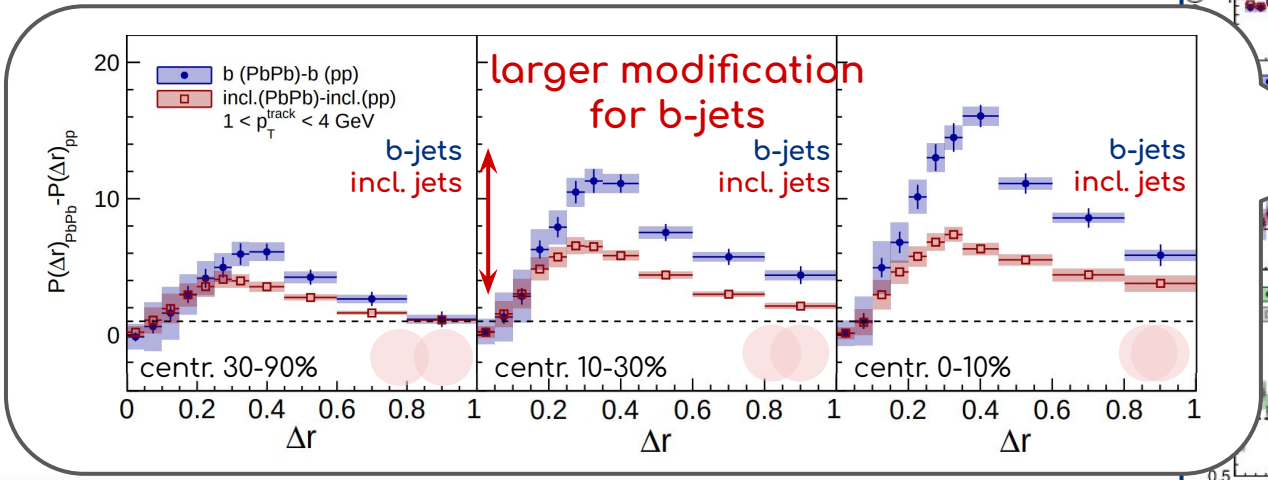


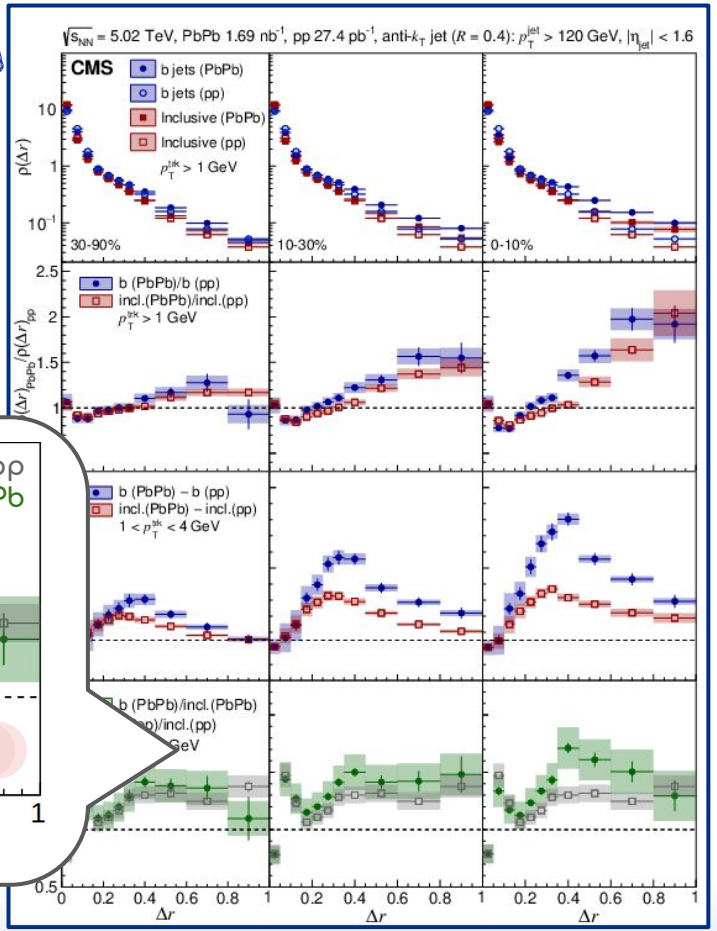


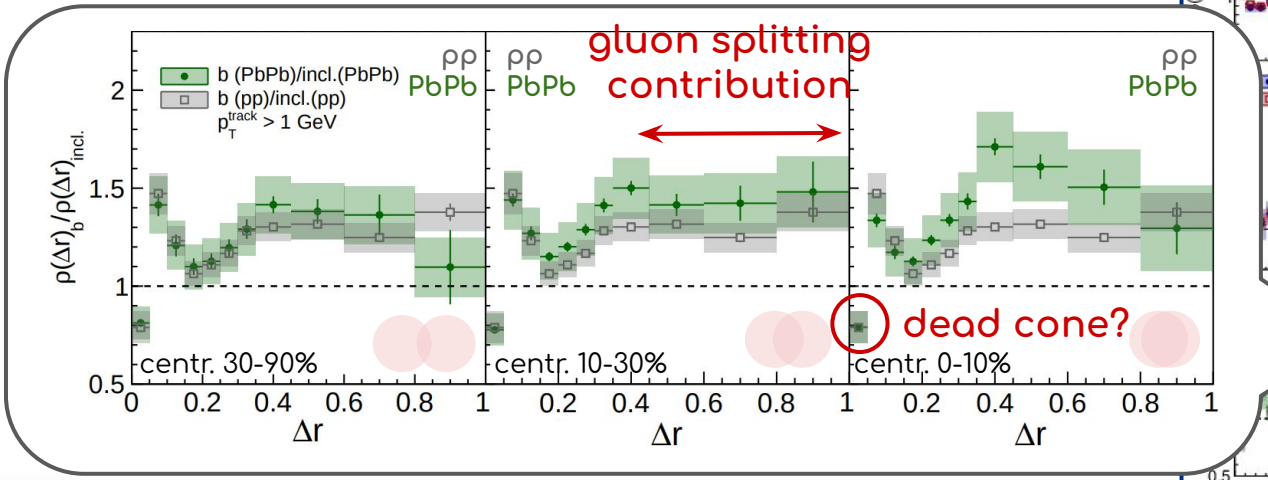
Results

arXiv:2210.08547

Overall observed modification :

- PbPb / pp
- b / inclusive
  - Broader shape for b-jets
  - Suppression in b-jets at very low Δr



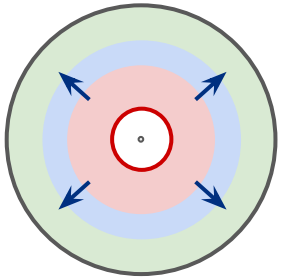


Conclusion

Summary

Jet shapes of b-jets
with respect to inclusive jets

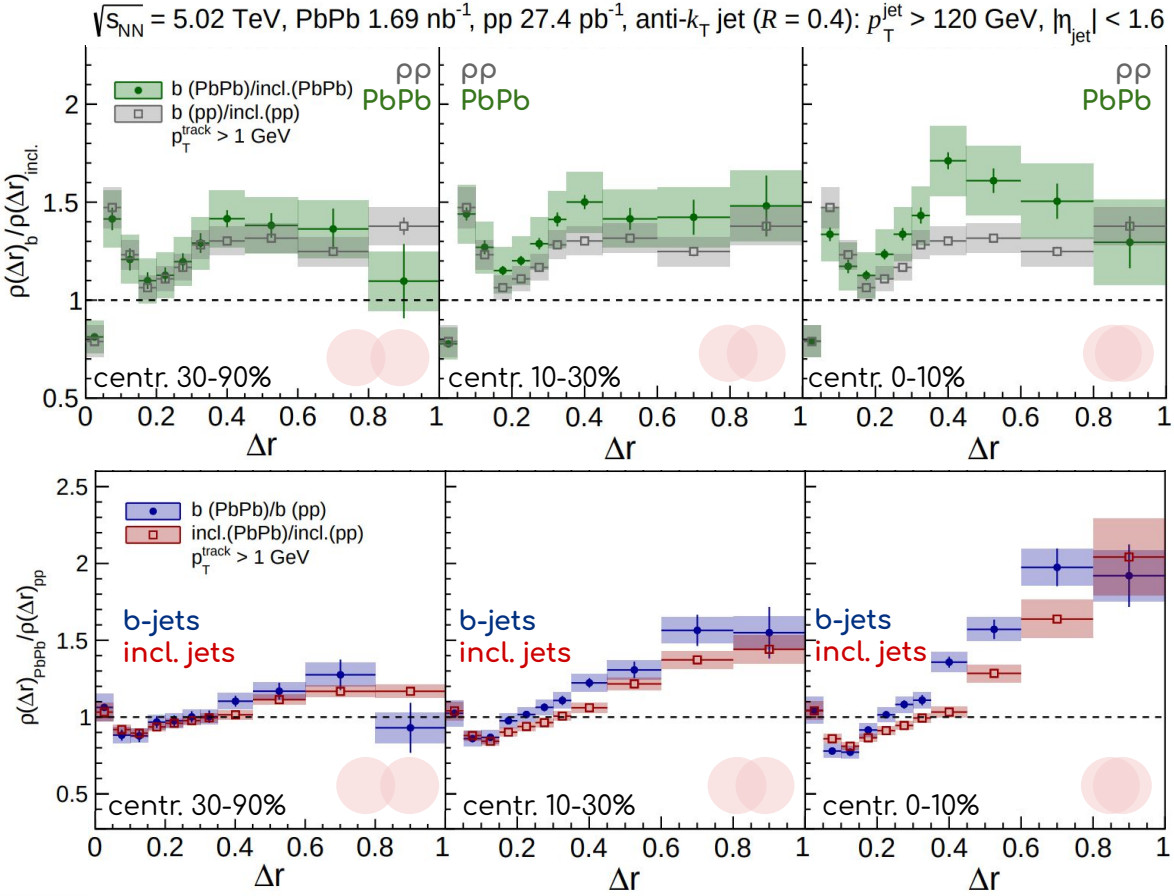
- Suppression at **small** angles
- Broader energy distribution



Modifications in the medium

- Similar for inclusive and b-jets
- Redistribution to **larger** angles
- Centrality-dependent

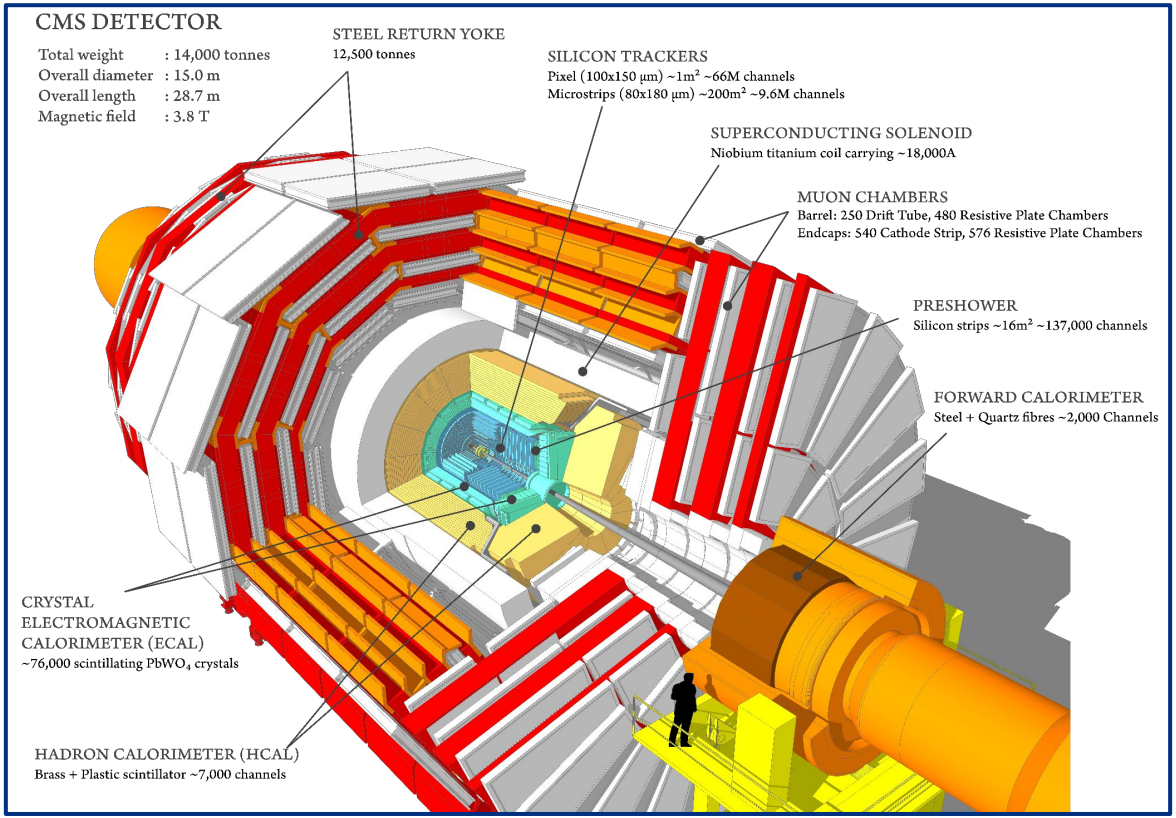
arXiv:2210.08547



Thank you all for your attention!

Backup

The CMS experiment



cms.cern

Object reconstruction

Charged particles :

- Hit information in $|\eta^{trk}| < 2.4$
- Keep tracks with $p_T^{trk} > 1$ GeV
- 60 - 90 % tracking efficiency

Jets :

- Reconstructed from PF candidates with R = 0.4 anti-k_T algorithm
- Energy correction from simulation
- Underlying event subtraction in PbPb
- Redefinition of jet axis by the winner-takes-all scheme (leading constituents)

Event mixing

Motivation

Correct for the jet - track pair acceptance

Result

ME : Reference correlation containing only detector and acceptance effects

S : Corrected yield

Technique

2D jet - track $\Delta\eta$ - $\Delta\varphi$ matrix normalized by N_{jets}
⇒ Per-jet averaged distribution

$$RS(\Delta\eta, \Delta\phi) = \frac{1}{N_{\text{jets}}} \frac{\mathrm{d}^2 N^{\text{same}}}{\mathrm{d}\Delta\eta \mathrm{d}\Delta\phi}$$

Associate tracks from one event to jets from a different event

$$ME(\Delta\eta, \Delta\phi) = \frac{1}{N_{\text{jets}}} \frac{\mathrm{d}^2 N^{\text{mix}}}{\mathrm{d}\Delta\eta \mathrm{d}\Delta\phi}$$

Correct the per-jet yield

collinear
max acceptance

$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{\text{jets}}} \frac{\mathrm{d}^2 N}{\mathrm{d}\Delta\eta \mathrm{d}\Delta\phi} = \frac{\boxed{ME(0,0)}}{ME(\Delta\eta, \Delta\phi)} RS(\Delta\eta, \Delta\phi)$$

Light jet decontamination technique

Motivation

Improve b-tagged jet purity in data

Technique

Partially data driven

≈ b

≈ light

$$S_{\text{decont}}(\Delta\eta, \Delta\phi) = \frac{S_{\text{tag}}(\Delta\eta, \Delta\phi) - (1 - c_{\text{purity}})S_{\text{mistagged}}(\Delta\eta, \Delta\phi)}{c_{\text{purity}}}$$

$\rho \cdot b = tag - (1 - \rho) \cdot light$

$tag = \rho \cdot b + (1 - \rho) \cdot light$

Evaluation methods of systematic uncertainties

Trigger efficiency :

- Repeated the analysis with $p_T^{jet} > 60$ GeV trigger

Tracking efficiency :

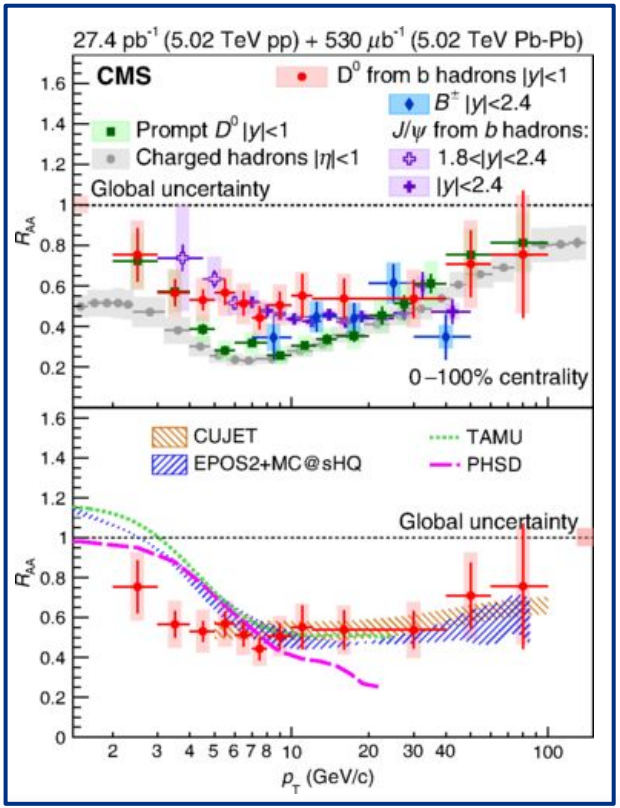
- Data-to-simulation differences estimated from a D meson decay study
- Additional comparison of b-jet to inclusive tracks

Tagging bias corrections :

- Variation of gluon splitting fraction
- Negative tagging method for purity

Related results

PRL 123 (2019) 022001



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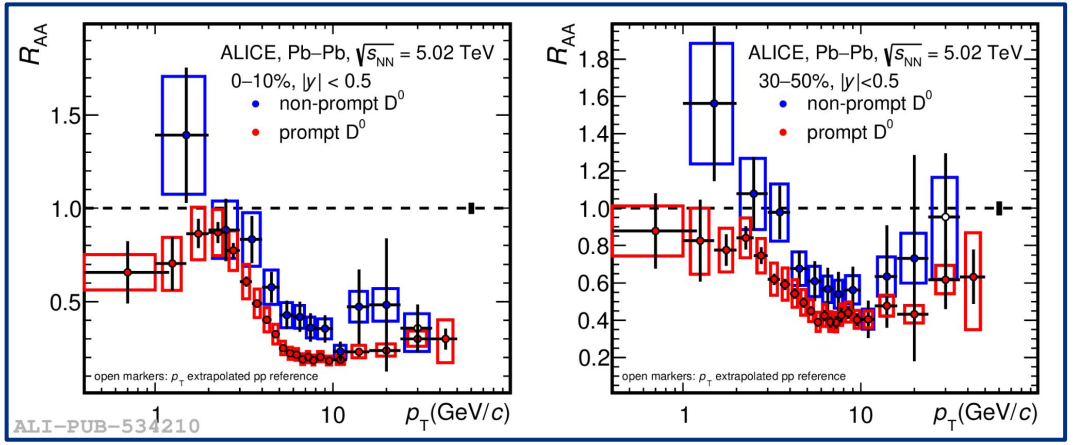

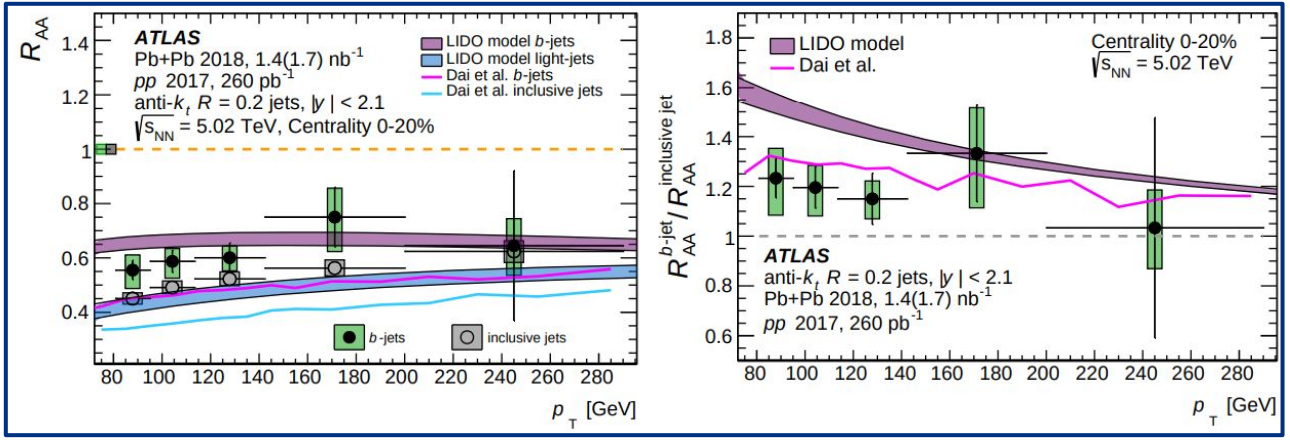

arXiv:2204.13530