

# Measurement of the groomed jet radius with photon-jet events in PbPb and pp collisions at 5.02 TeV with CMS

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Massachusetts Institute of Technology  
for the CMS collaboration

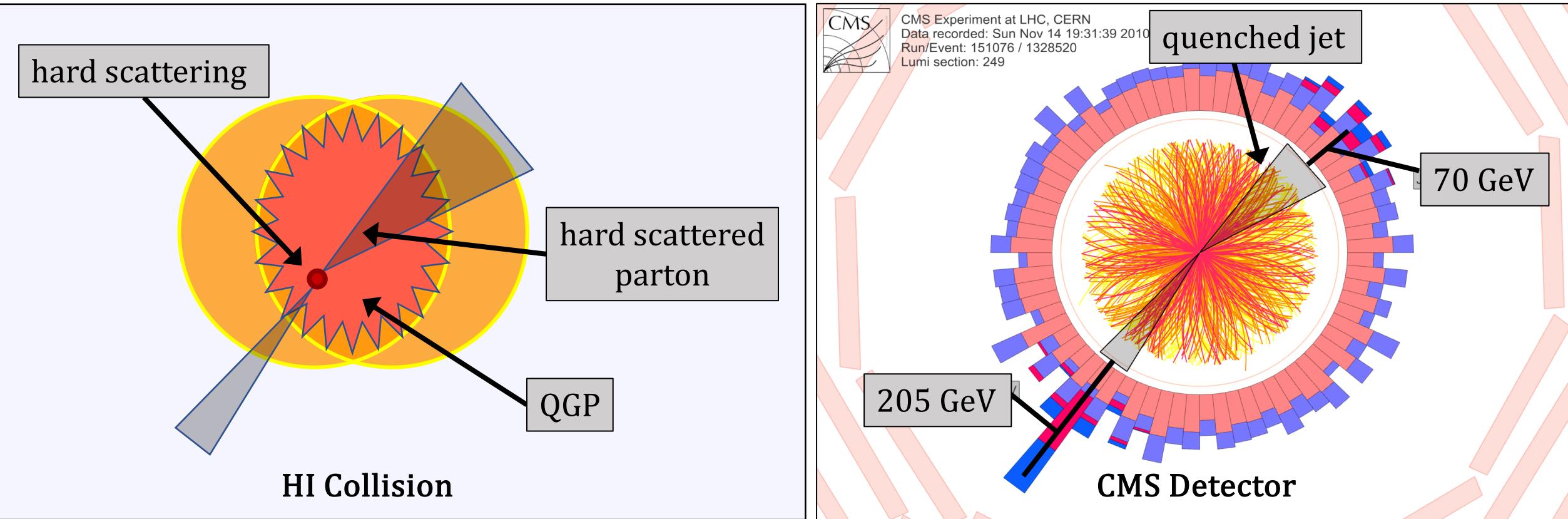
Quark Matter 2023  
September 5, 2023



MITHIG group's work was supported by US DOE-NP



# Jet quenching in heavy ion collisions



- QGP is formed when heavy ions collide
- Hard scattered partons interact with QGP and lose energy → **jet quenching**
- Studies of the quenched jet substructure can probe modifications of the jet shower from QGP interaction

# Jet substructure

- Jet quenching involves modification of the jet radiation pattern
- Jet substructure observables map 4-momenta of jet constituents to physically meaningful observables

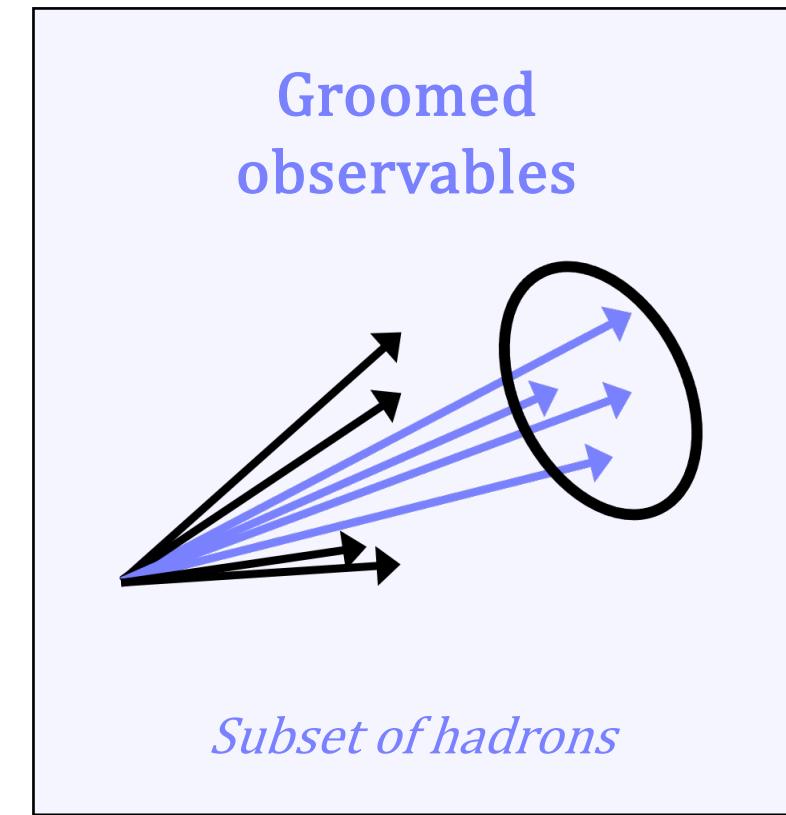
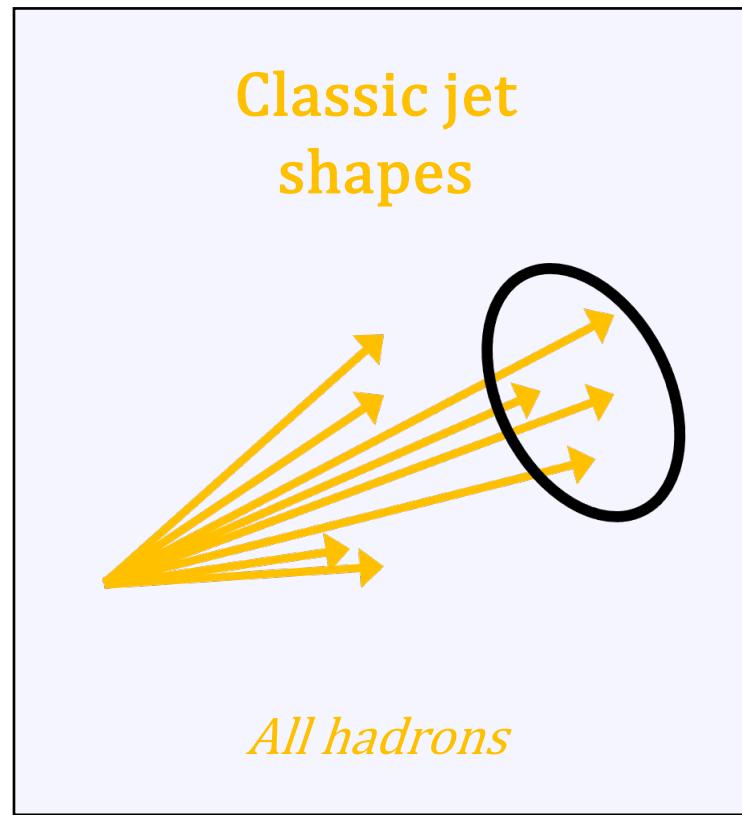
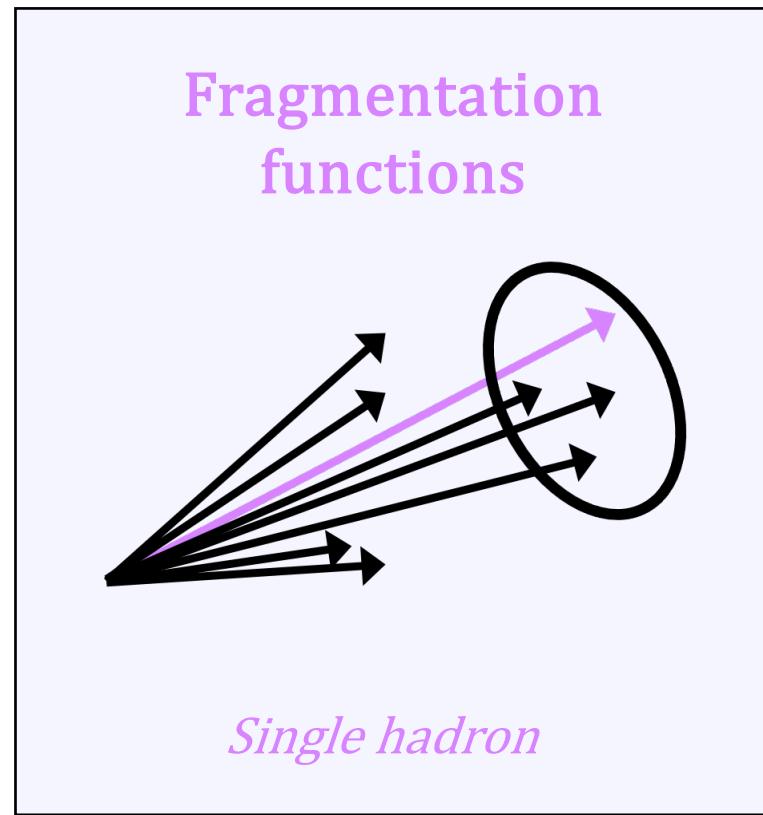
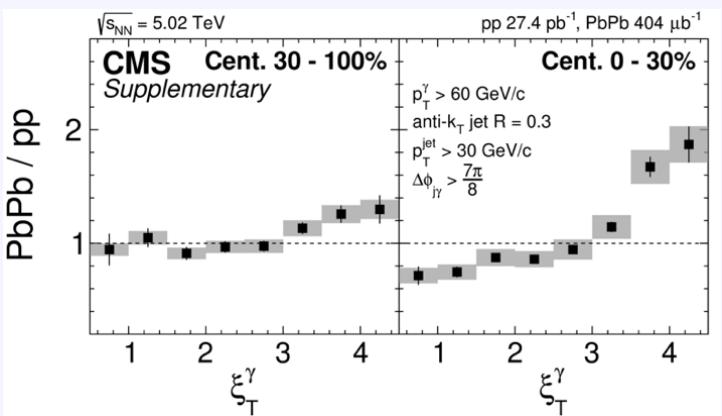


Figure from Jesse Thaler

# Photon-jet substructure

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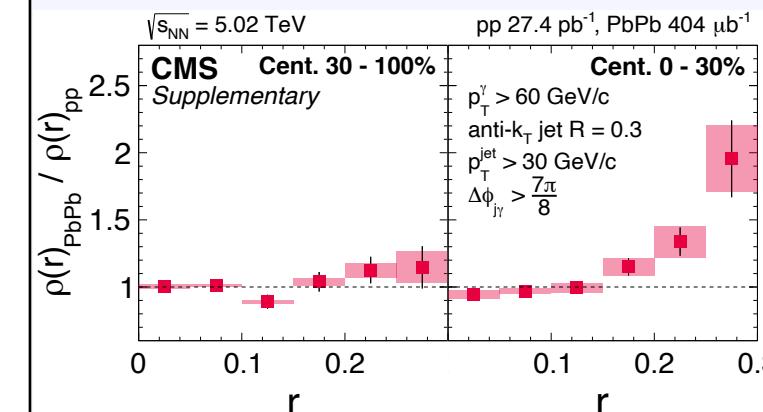
## Fragmentation functions



*Single hadron*

CMS, [PRL 121 \(2018\) 242301](#)

## Classic jet shapes



*All hadrons*

CMS, [PRL 122 \(2019\) 152001](#)

## Groomed observables

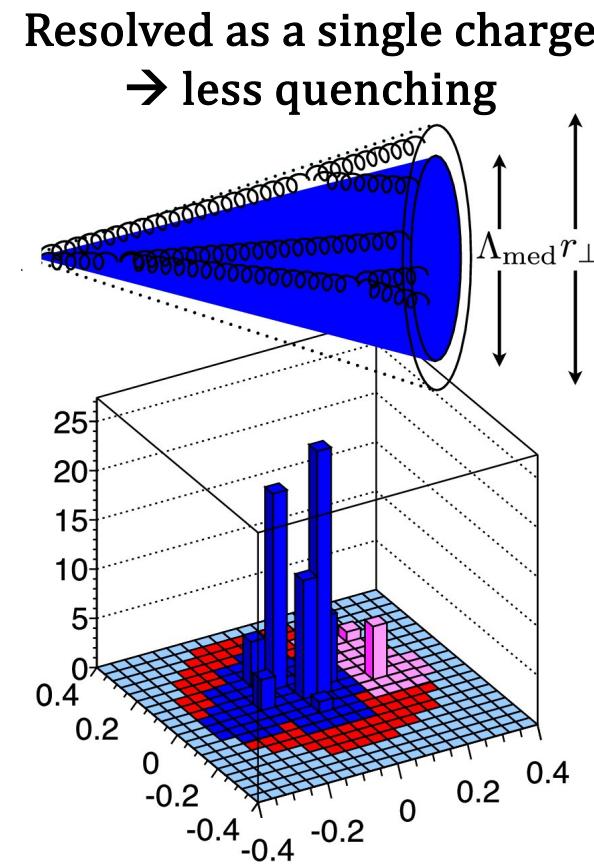
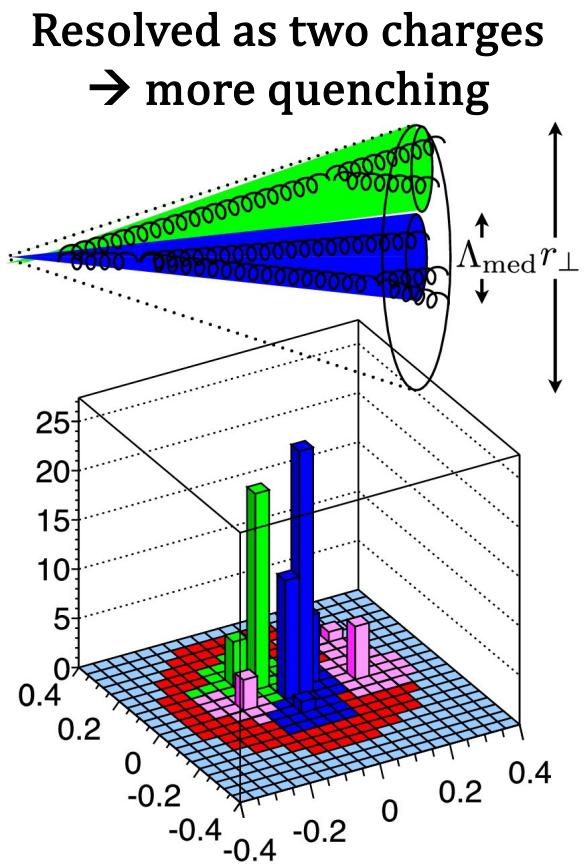


*Subset of hadrons*

CMS, [PAS-HIN-23-001](#)

# Medium resolution length and color coherence

- Depending on medium resolution length, resolve as single charge or multiple charges → **color coherence**
- Emergent property of the QGP due to quantum interference



Diagrams from  
J. Casalderrey-Solana,  
Y. Mehtar-Tani,  
C. A. Salgado,  
K. Tywoniuk,  
[arXiv:1210.7765](https://arxiv.org/abs/1210.7765)

# Soft drop grooming algorithm

- Soft drop (SD) helps control large contribution from underlying event in PbPb
- Jet constituents are reclustered with Cambridge-Aachen (CA)
- The CA jet is clustered iteratively until we find **first** subjet pair that satisfies the **SD condition**

M. Dasgupta, A. Fregoso,  
S. Marzani, G. P. Salam,  
[JHEP09 \(2013\) 029](#)

A. J. Larkoski, S. Marzani,  
G. Soyez, J. Thaler,  
[JHEP 1405 \(2014\) 146](#)

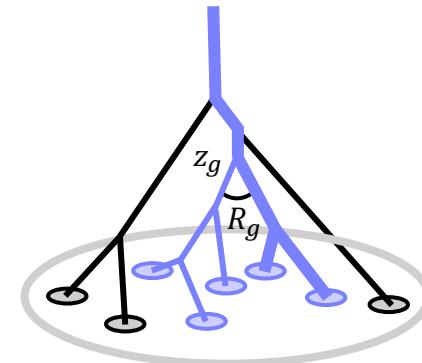
Y. Mehtar-Tani,  
K. Tywoniuk,  
[JHEP04 \(2017\) 125](#)

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$$z_g \stackrel{\text{def}}{=} \frac{\min(p_T^1, p_T^2)}{p_T^1 + p_T^2} > z_{cut} \left( \frac{\Delta R_{12}}{R} \right)^{\beta_{SD}}$$

$$R_g \stackrel{\text{def}}{=} \Delta R_{12}$$



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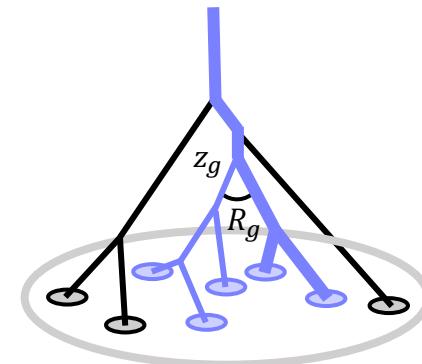
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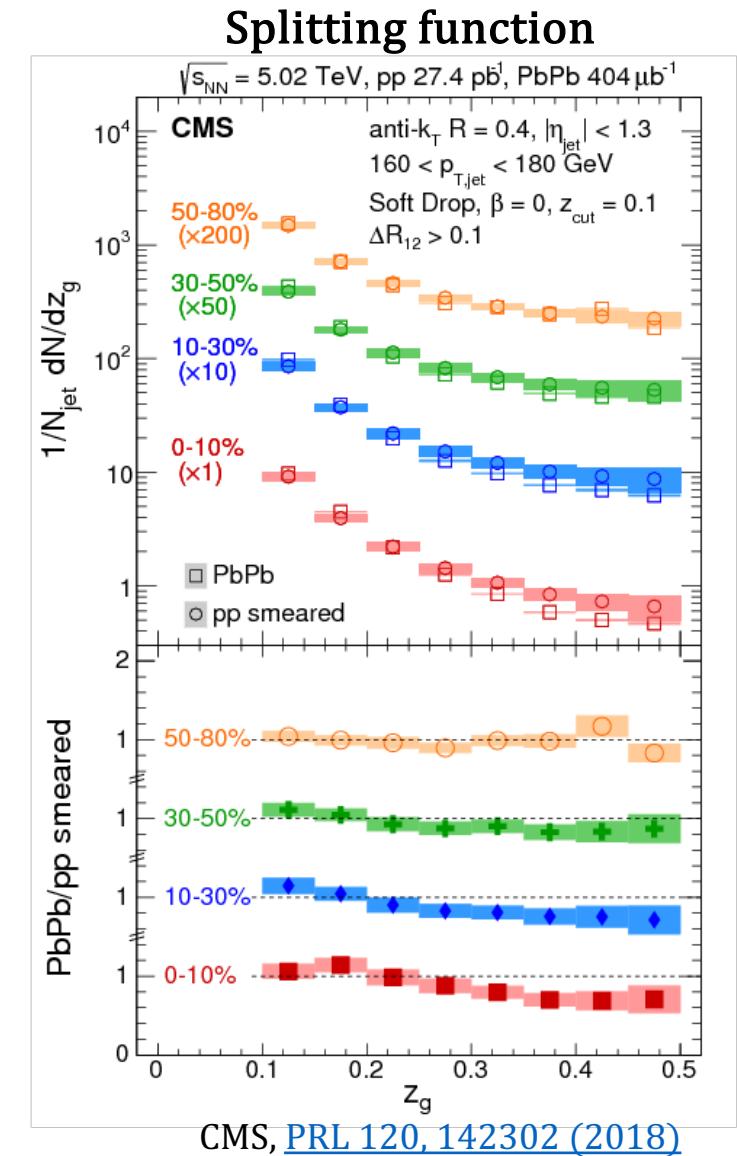
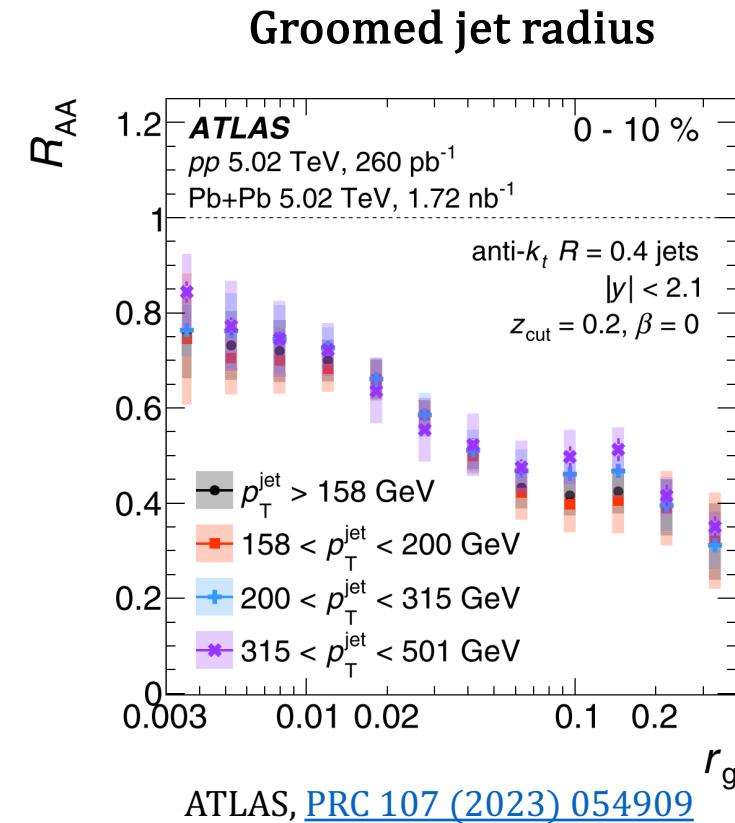
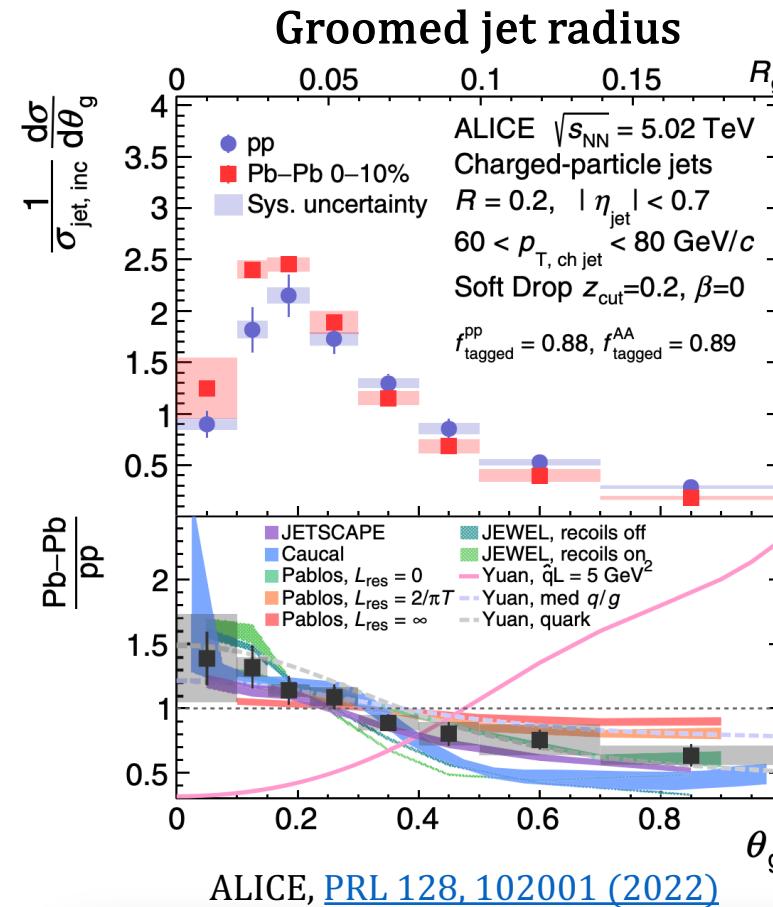
- $\beta_{SD}$  and  $z_{cut}$  are free parameters, set to  $\beta_{SD} = 0$  and  $z_{cut} = 0.2$  in Heavy Ion collisions
- SD subjets are proxy for the hardest  $1 \rightarrow 2$  splitting in jet shower
- $R_g$ , the angular distance of this splitting, can be sensitive to medium resolution length

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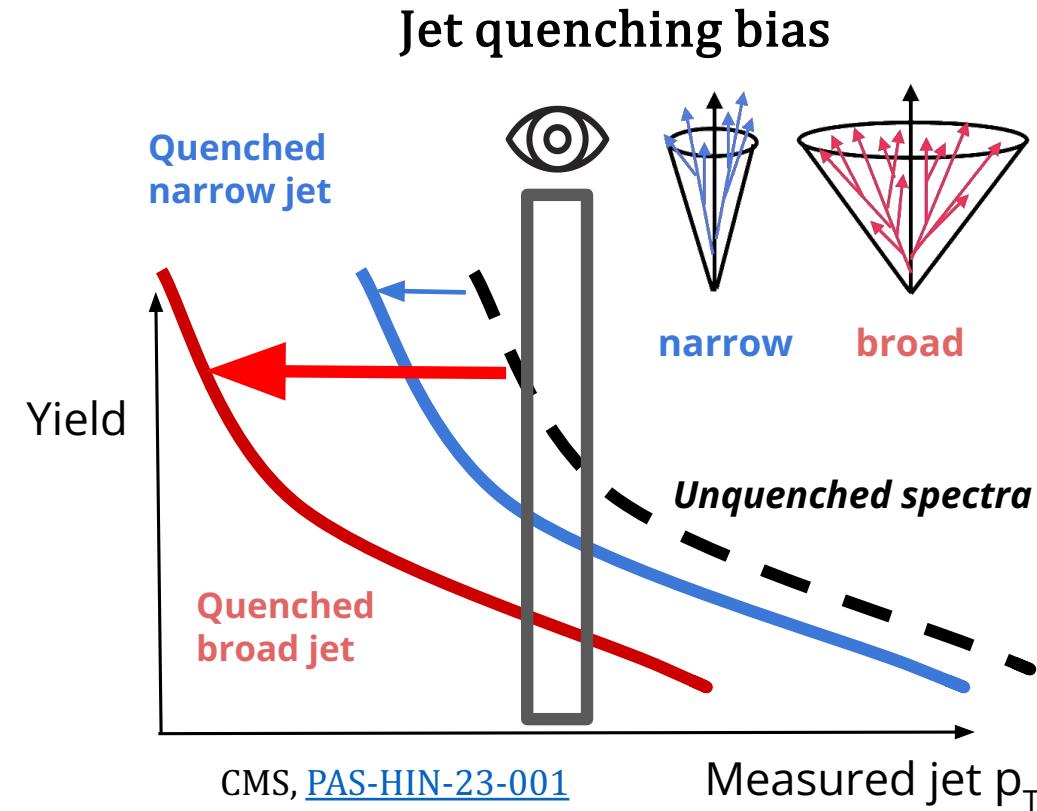
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# Previous measurements in inclusive jet events



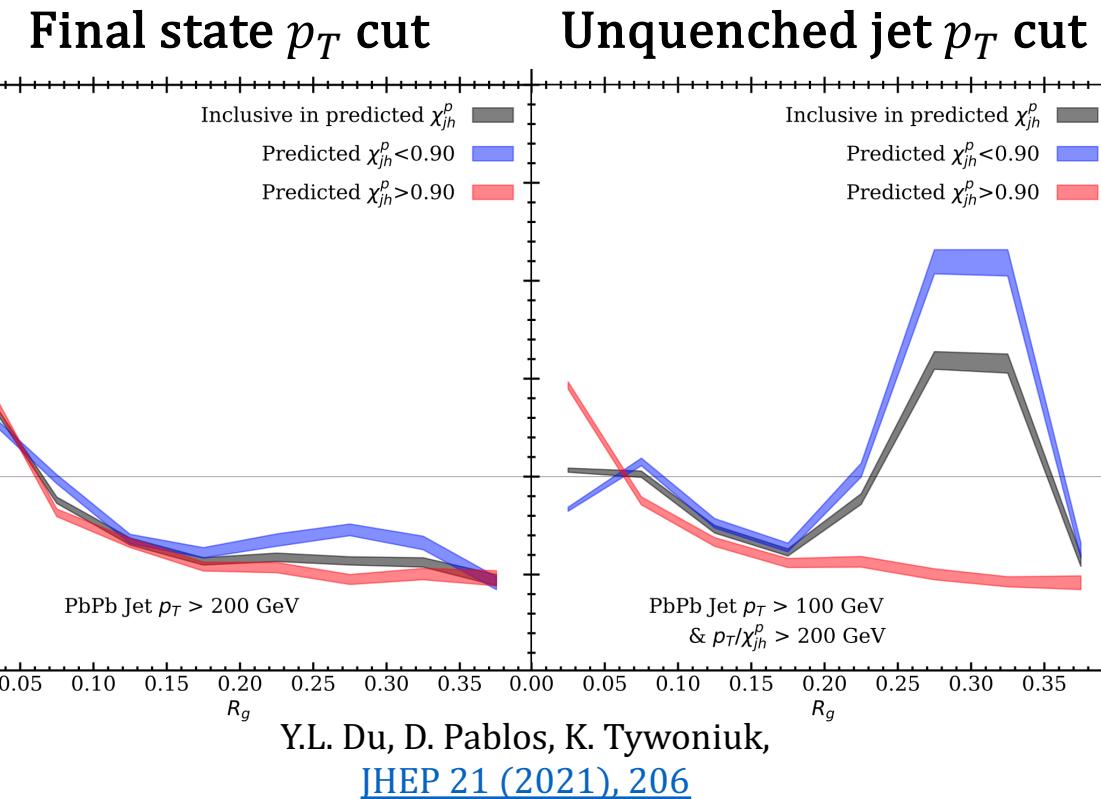
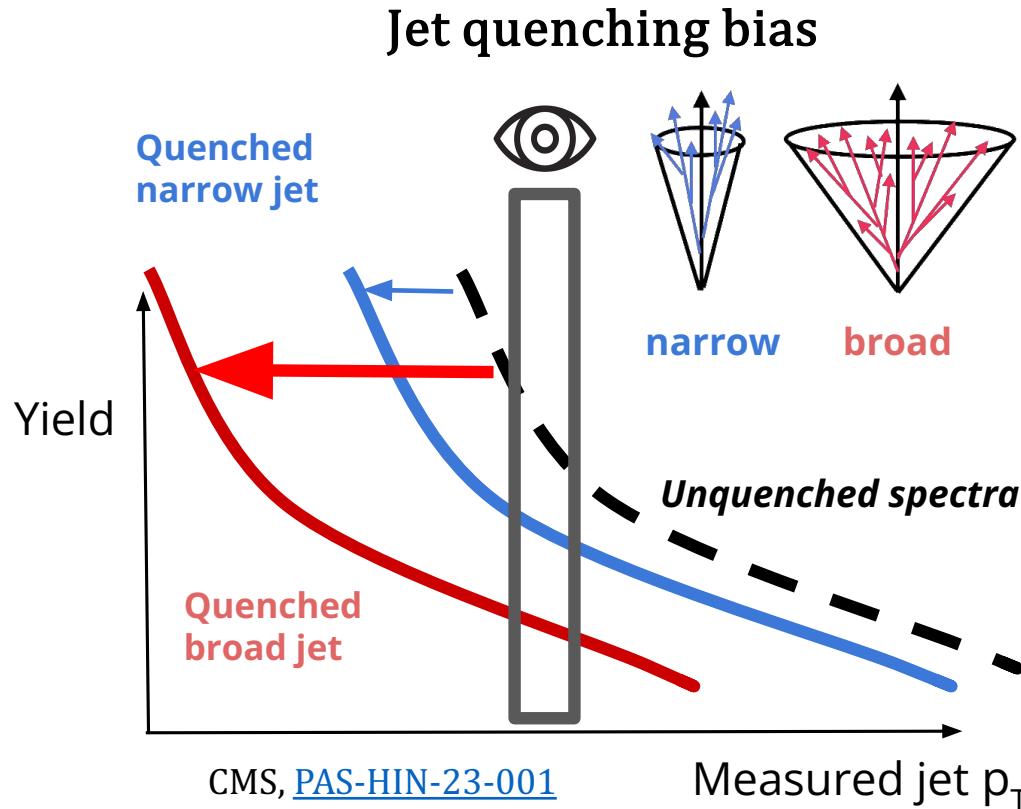
- Broad angular structures are more suppressed in PbPb collisions
- Splitting between branches also becomes increasingly unbalanced
- Is this a consequence of color decoherence?

# Jet quenching and the selection bias



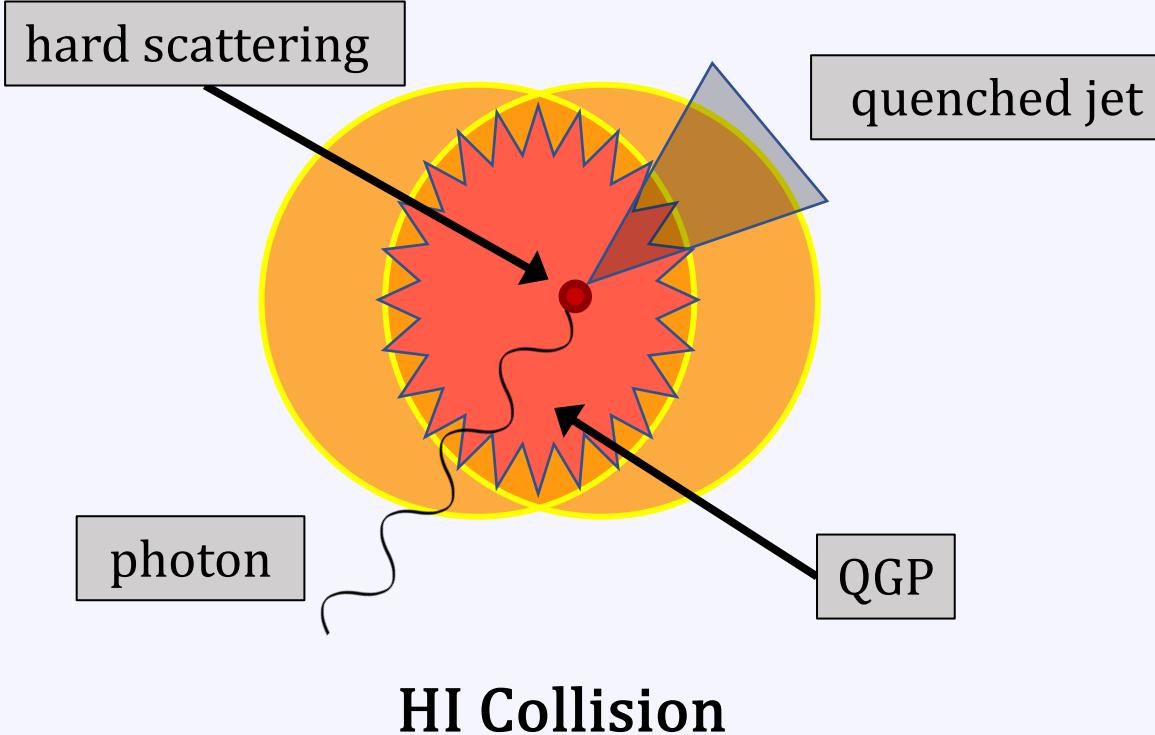
- Quark jets tend to be narrow, gluon jets tend to be broad
- Broader jets are expected to be more quenched than narrower jets
- Potential effect in a measured jet  $p_T$  bin → higher population of narrow jets

# Jet quenching and the selection bias



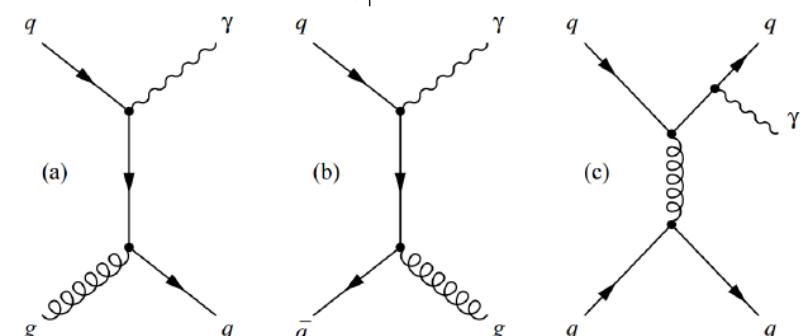
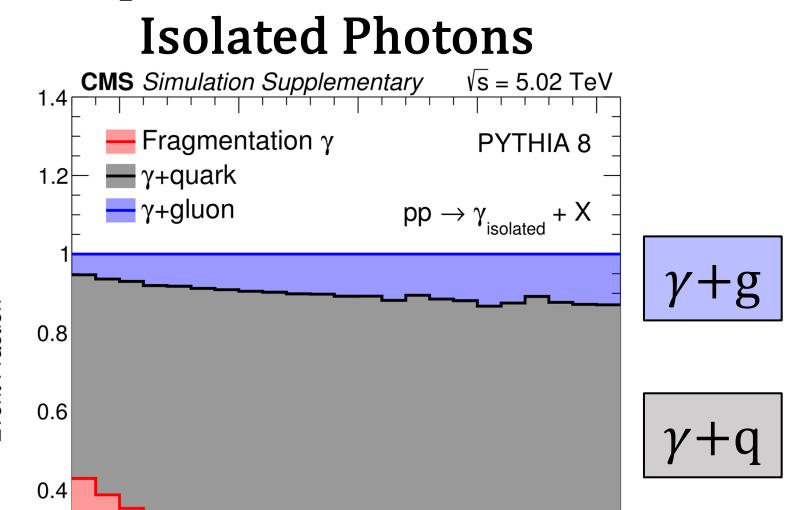
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# Using photon-tagged jets



- Photon does not interact strongly in QGP → tags initial parton  $p_T$
- Less bias from photon selection, compare pp/PbPb with same  $p_T^\gamma$
- Good handle on q/g fraction of recoil parton
- Still some remaining bias from minimum jet  $p_T$  requirement

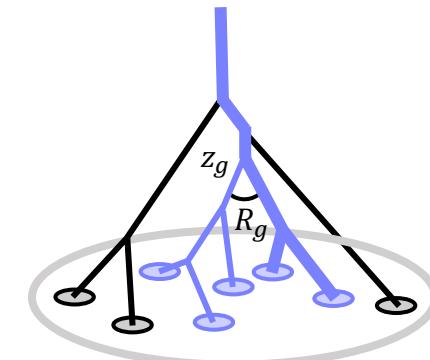
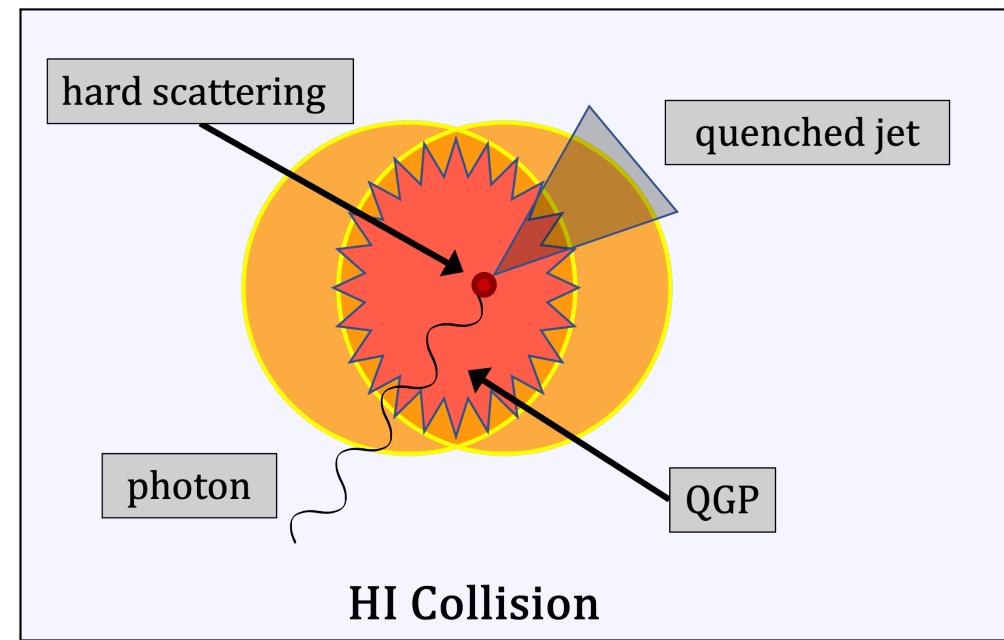
## Composition of Events with Isolated Photons



CMS, [PRL 122 \(2019\) 152001](#)

# Measurement setup

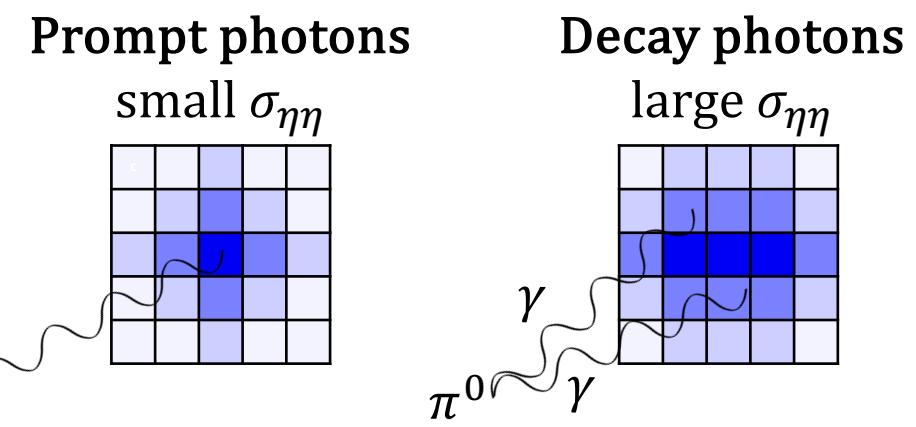
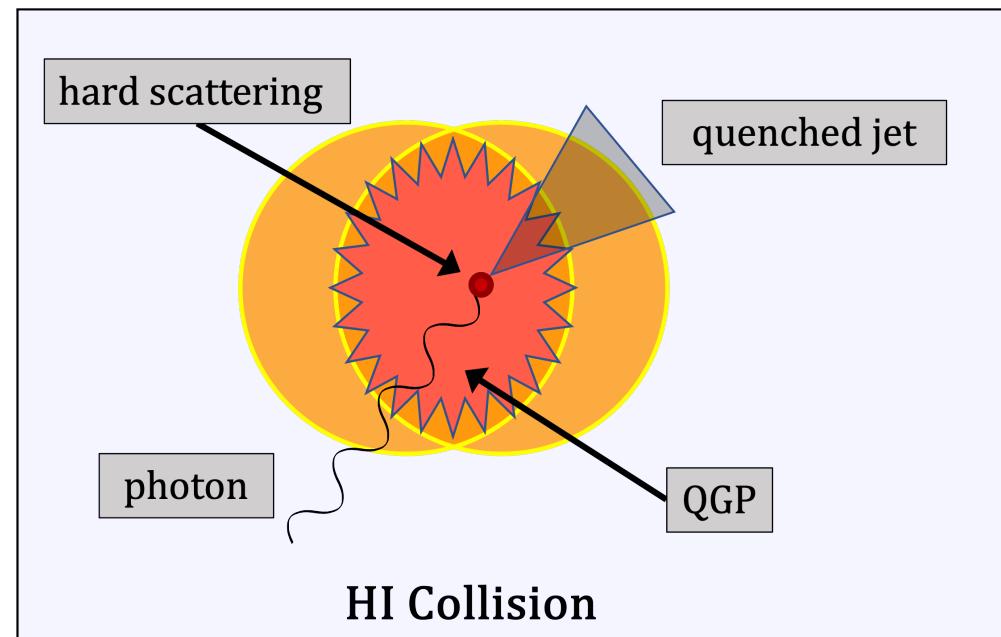
- Isolated photons:  $p_T^\gamma > 100 \text{ GeV}$  and  $|\eta^\gamma| < 1.44$
- Associated anti- $k_T$  jets:  $R = 0.2$ ,  $\phi^{j\gamma} > \frac{2\pi}{3}$ ,  $|\eta^{jet}| < 2$
- Observables:
  - Groomed jet radius  $R_g$  ( $\beta_{SD} = 0$  and  $z_{cut} = 0.2$ )
  - Jet girth  $g = \frac{1}{p_T^{jet}} \sum_i p_T^i \Delta R_{i,jet}$
- Two categories for measurement
  - $p_T^{jet}/p_T^\gamma = x_{j\gamma} > 0.4$  (quenched and unquenched jets)
  - $p_T^{jet}/p_T^\gamma = x_{j\gamma} > 0.8$  (less quenched jets)



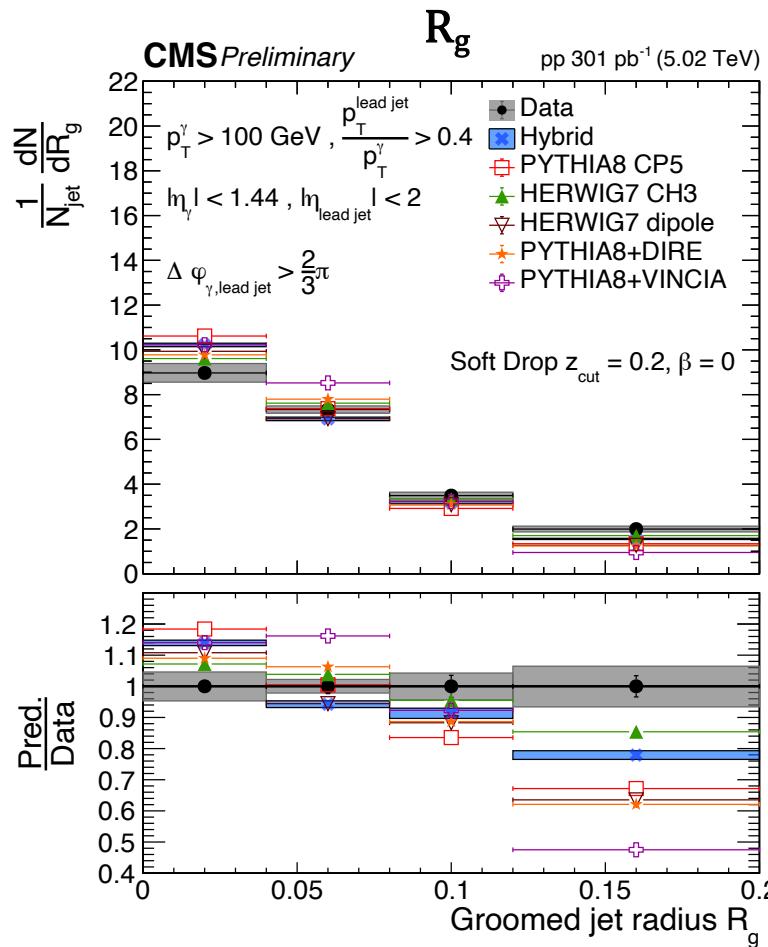
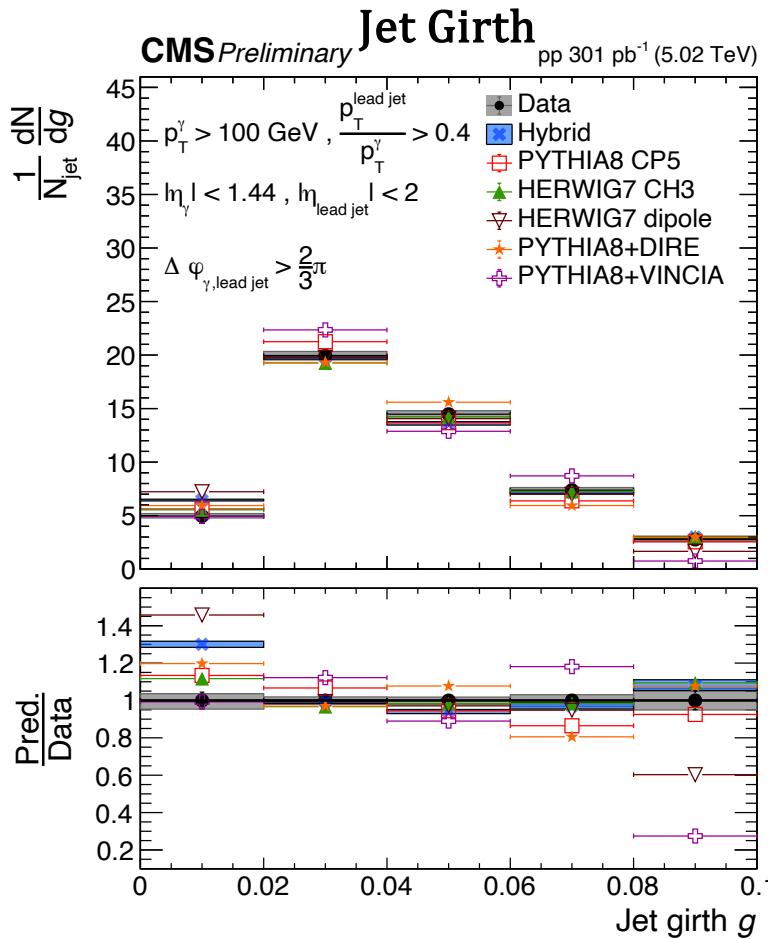
$$g = \frac{1}{p_T^{jet}} \sum_i p_T^i \Delta R_{i,jet}$$

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- Analysis method
  - Subtract contributions from neutral meson diphoton decays with template fits and ABCD method
  - Correct detector resolution effects, acceptance, and efficiency with D'Agostini unfolding



# Results for $x_{j\gamma} > 0.4$ in pp collisions



References in backup

**Data**

**Hybrid**

**HERWIG7 CH3**

**HERWIG7 Dipole**

**PYTHIA8 CP5**

**PYTHIA8 DIRE**

**PYTHIA8 VINCIA**

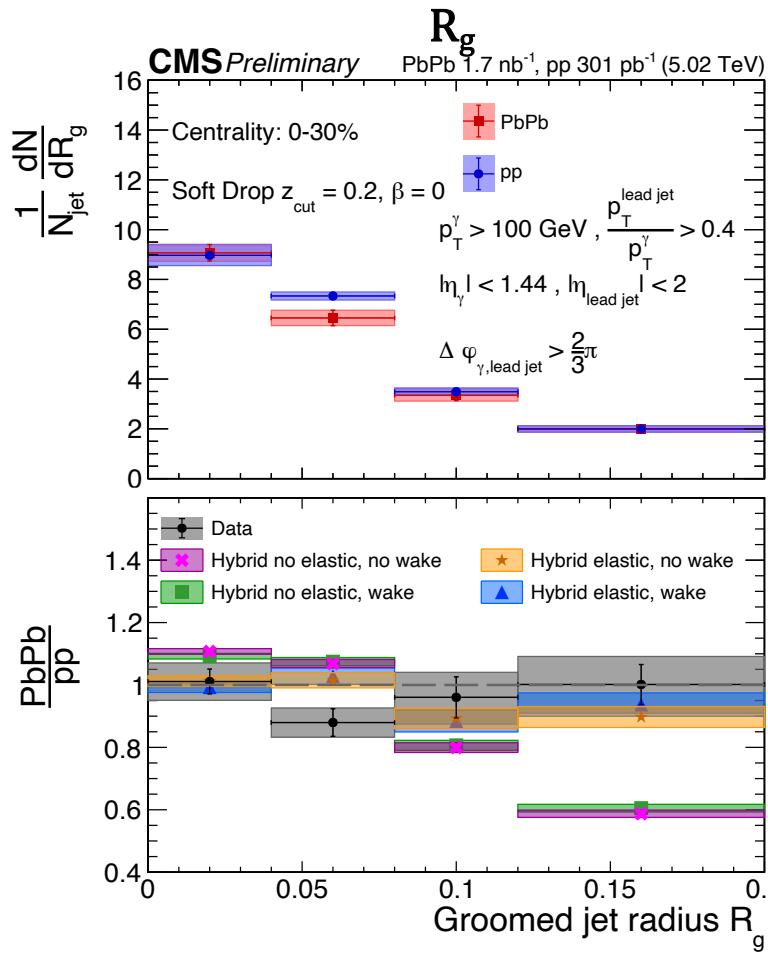
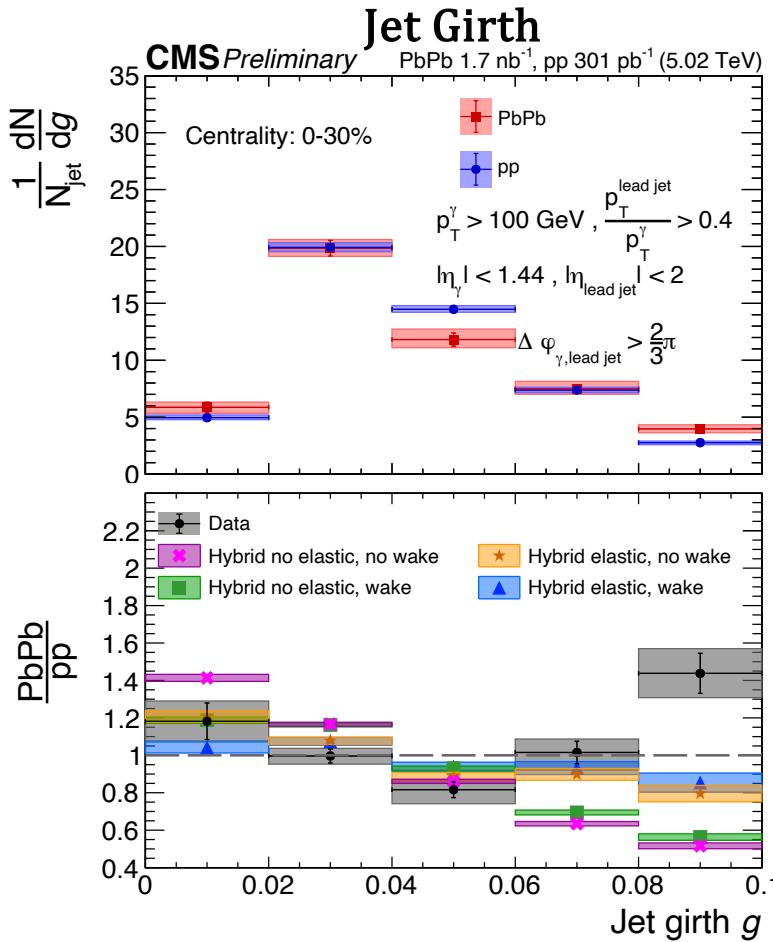
Differences between data and MC simulation by factors of up to 2

Best global description by HERWIG7 CH3, which has angular-ordered showering to account for color-coherence

Consistent with other jet substructure measurements

CMS, [PAS-HIN-23-001](#)

# Results for $x_{j\gamma} > 0.4$ in pp and PbPb collisions



Data

Hybrid no elastic, no wake

Hybrid no elastic, wake

Hybrid elastic, no wake

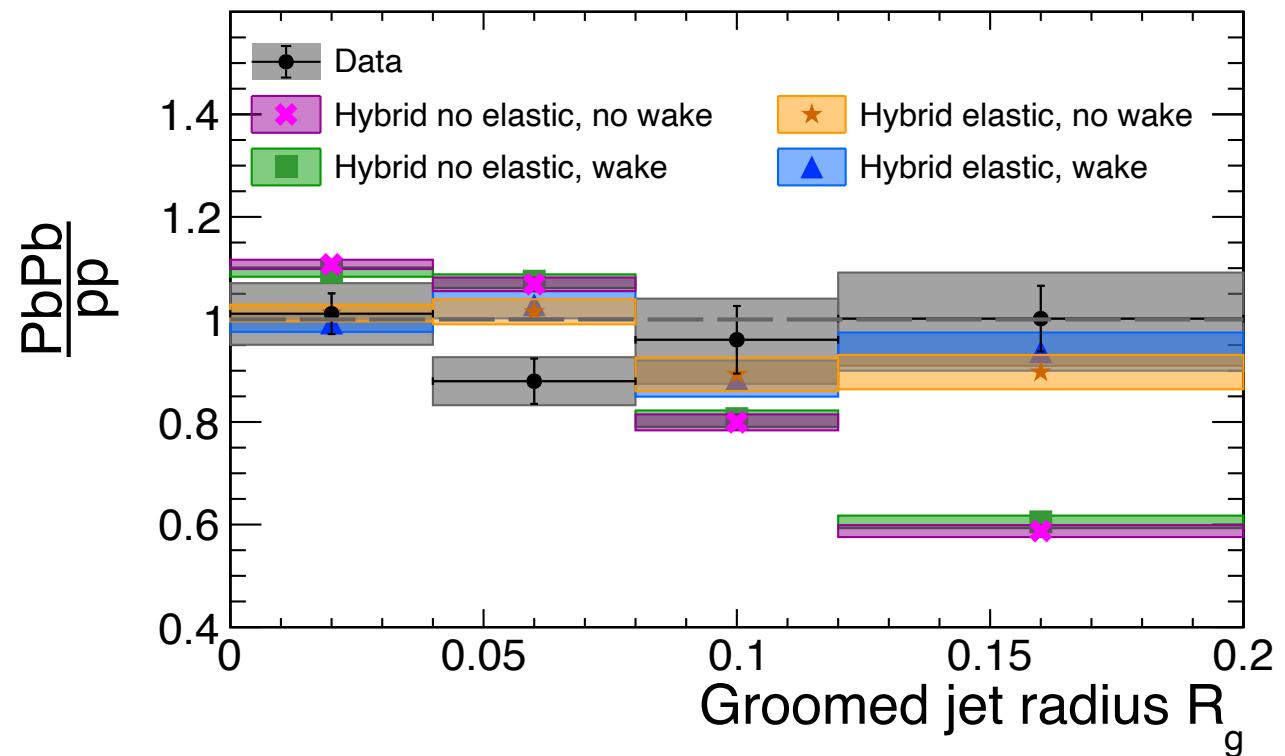
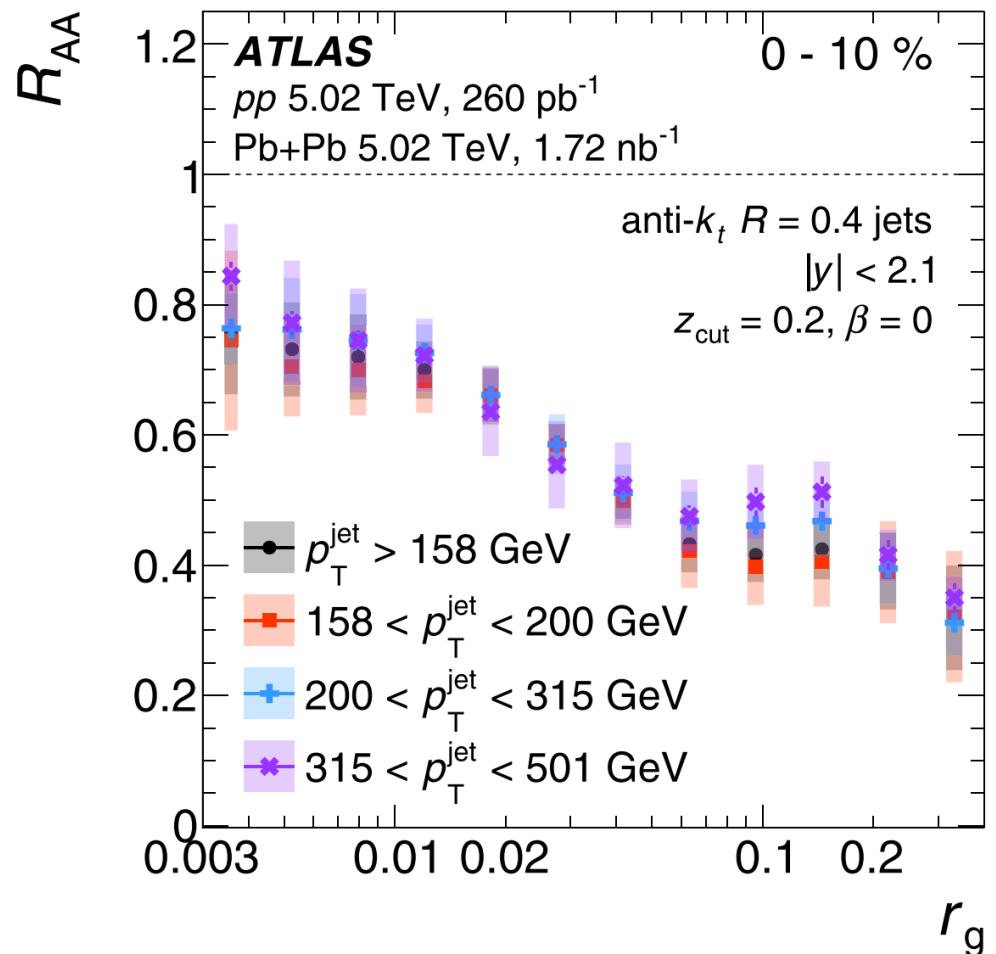
Hybrid elastic, wake

No narrowing seen in PbPb collisions compared to pp collisions in photon-jet events, in events where there is more jet quenching

Z. Hulcher, D. Pablos, K. Rajagopal, [arXiv:1405.3864](https://arxiv.org/abs/1405.3864)

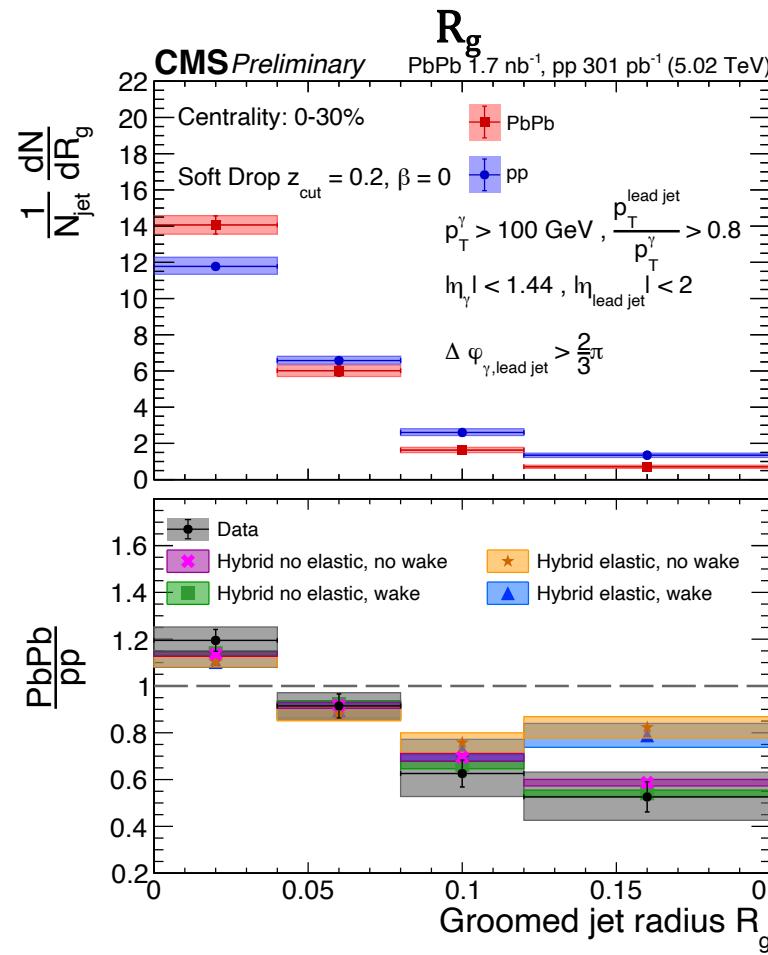
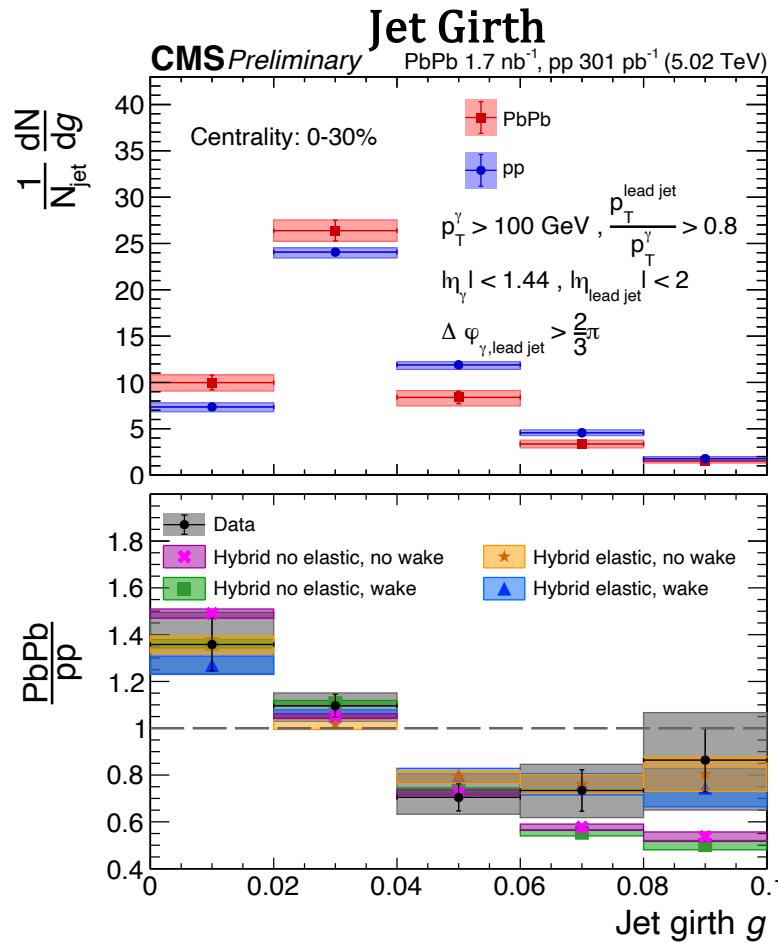
CMS, [PAS-HIN-23-001](#)

# Comparison of $x_{j\gamma} > 0.4$ with ATLAS $R_g$ measurement



Large  $R_g$  suppression seen in inclusive jets is not observed in photon-tagged jets

# Results for $x_{j\gamma} > 0.8$ in pp and PbPb collisions



Data

Hybrid no elastic, no wake

Hybrid no elastic, wake

Hybrid elastic, no wake

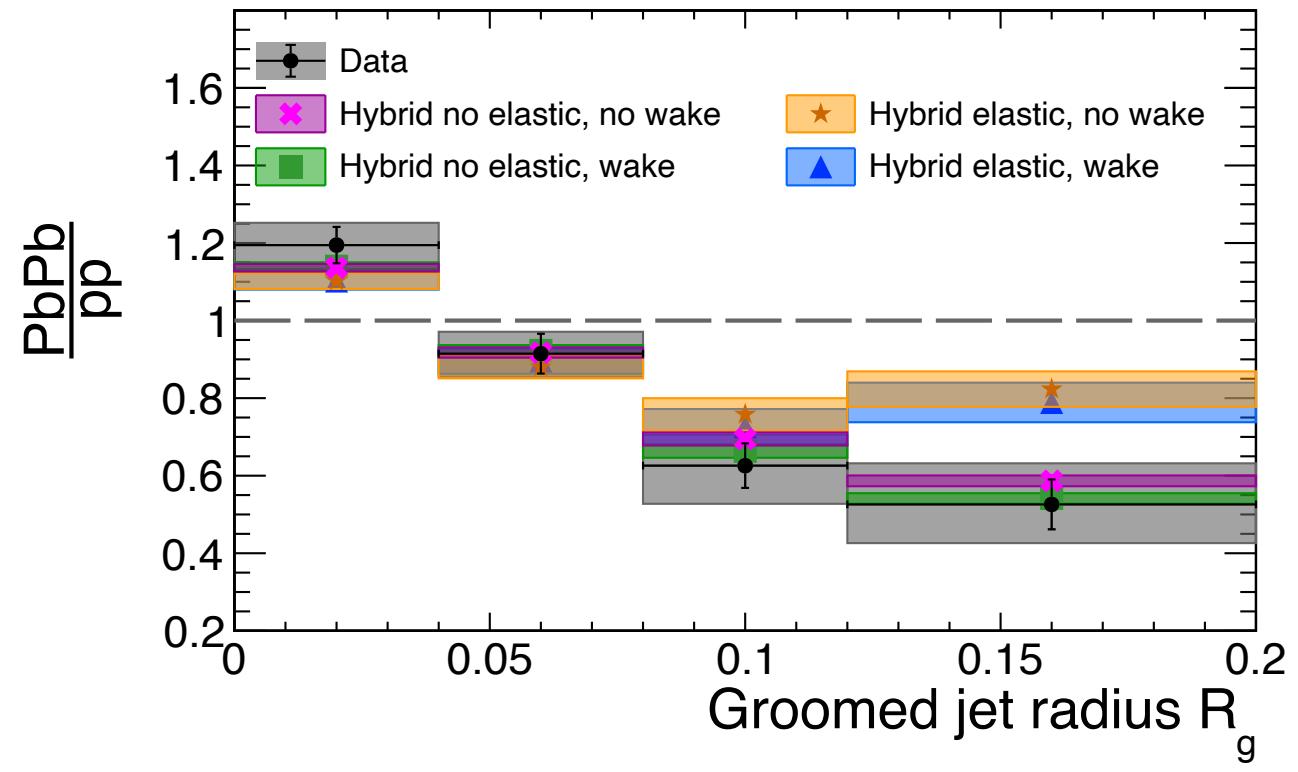
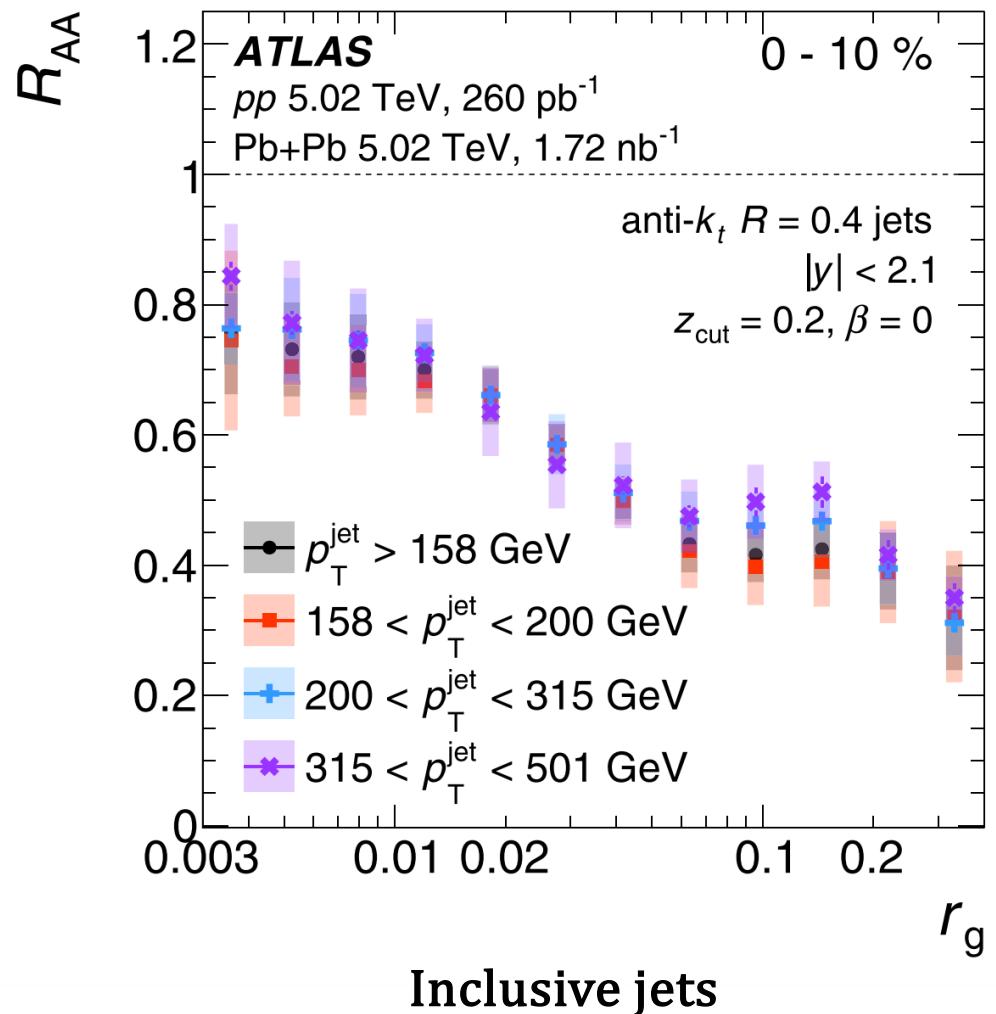
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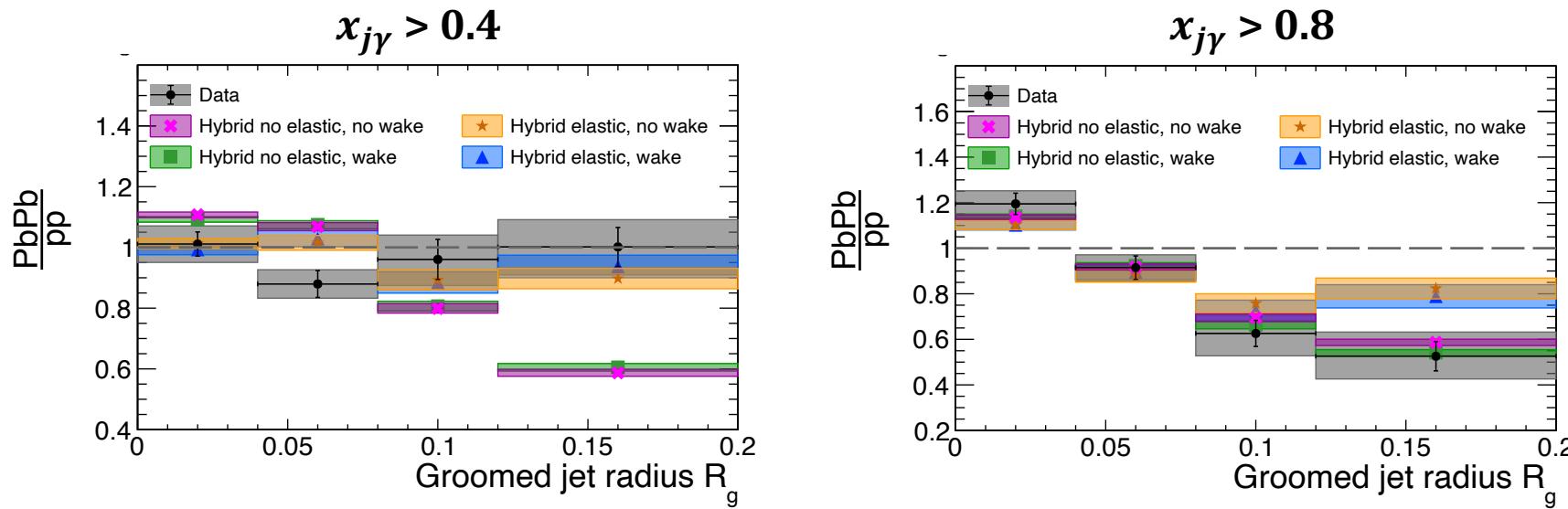
# Comparison of $x_{j\gamma} > 0.8$ with ATLAS $R_g$ measurement



Large  $R_g$  suppression seen in inclusive jets is observed in photon-tagged jets with more bias

# Summary

- Measured groomed jet radius and jet girth in photon-tagged jet events in PbPb and pp collisions
- Looked at photon-tagged jet events with  $pT \gamma > 100$  GeV and two different setups:
  - $x_{j\gamma} > 0.4$  [quenched and unquenched jets]: **no narrowing is observed**
  - $x_{j\gamma} > 0.8$  [less quenched jets]: **narrowing is observed**
- Only Hybrid model with Molière scatterings describes the data for  $x_{j\gamma} > 0.4$



# Backup

# Prompt photon production

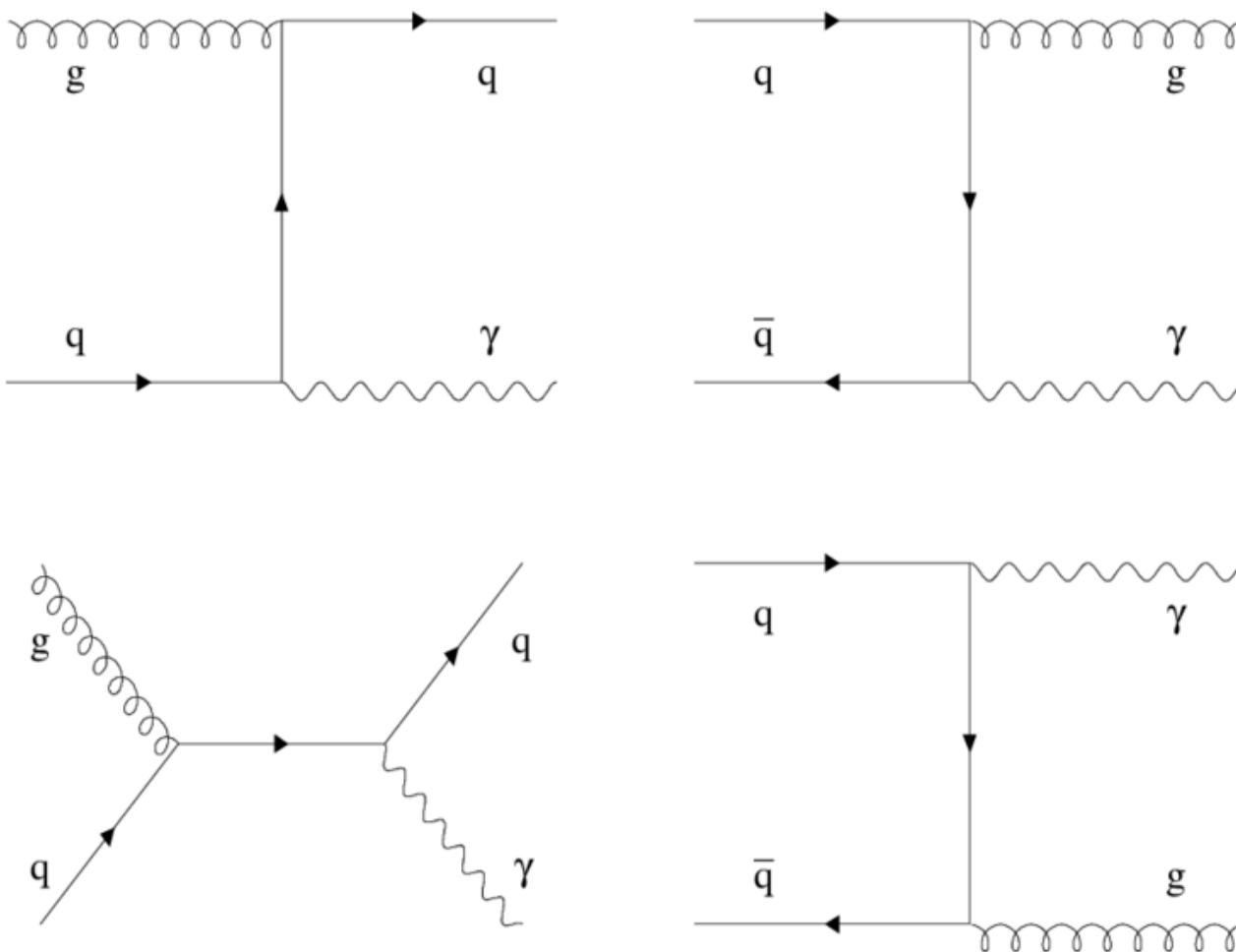


Figure: [PLB 317 \(1993\) 250256](#)

# Systematic uncertainties

Dominant systematics:

- **MC modelling:** quantifies uncertainty in the underlying event, parton shower and hadronization models
  - PbPb: compare reweighted PYTHIA8 with a modified q/g fraction to nominal PYTHIA8
  - PP collisions: compare PYTHIA8 to HERWIG7.
- **Jet constituent energy scale:** quantifies impact of individual PF candidate energy calibrations
  - Shift 4-momenta of charged hadron and photon PF candidates by  $\pm 1\%$  at detector level
  - Shift 4-momenta of neutral hadron PF candidates by  $\pm 3\%$  at detector level

Subdominant systematics:

- Jet energy corrections (JEC)
- Jet energy resolution (JER)
- Unfolding regularization bias
- Response matrix statistics
- Photon purity estimation
- Centrality determination

# Model references

**Hybrid** Z. Hulcher, D. Pablos, K. Rajagopal, [arXiv:1405.3864](#)

**HERWIG7 CH3** CMS, [arXiv:2011.03422](#)

**HERWIG7 Dipole** J. Bellm, S. Gieseke, D. Grellscheid, et al, [arXiv:1512.01178](#)

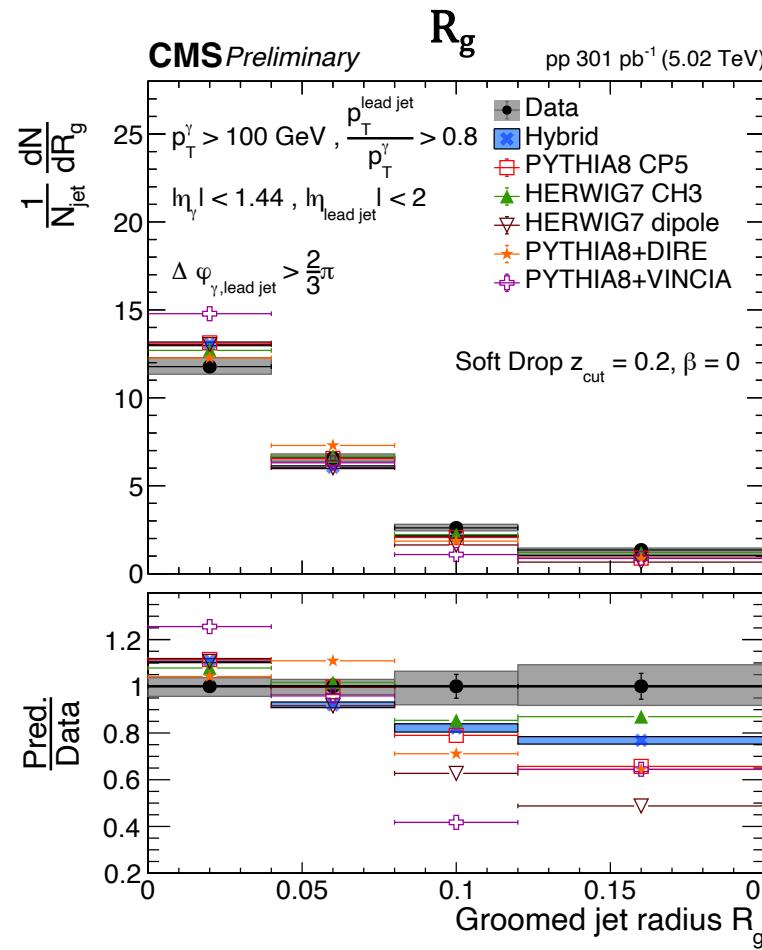
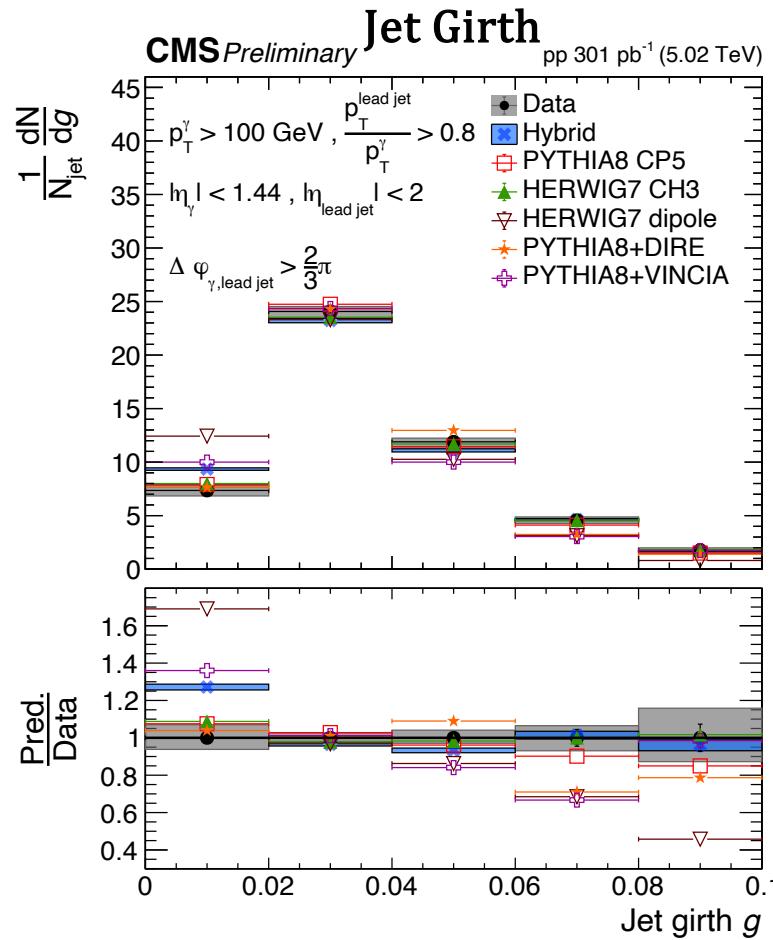
**PYTHIA8 CP5** CMS, [arXiv:1903.12179](#)

**PYTHIA8 DIRE** S. Höche, S. Prestel, [arXiv:1506.05057](#)

**PYTHIA8 VINCIA** W. Giele, D. Kosower, P.Skands, [arXiv:0707.3652](#)

CMS, [PAS-HIN-23-001](#)

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