Detection of jet shower width & survival bias w/ photon-tagged jets

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on behalf of CMS

Hard Probes

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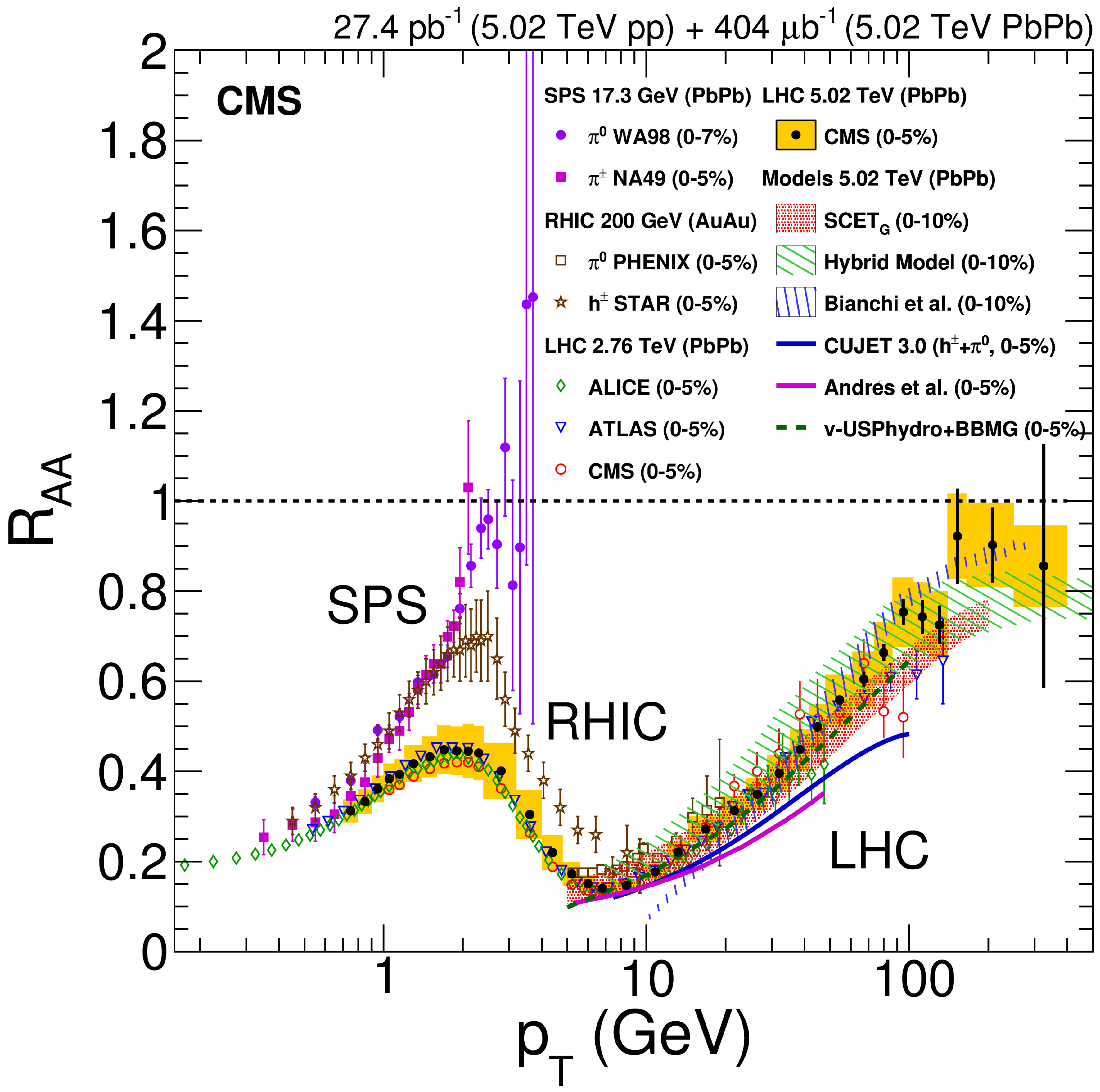
Jet substructure in heavy ions

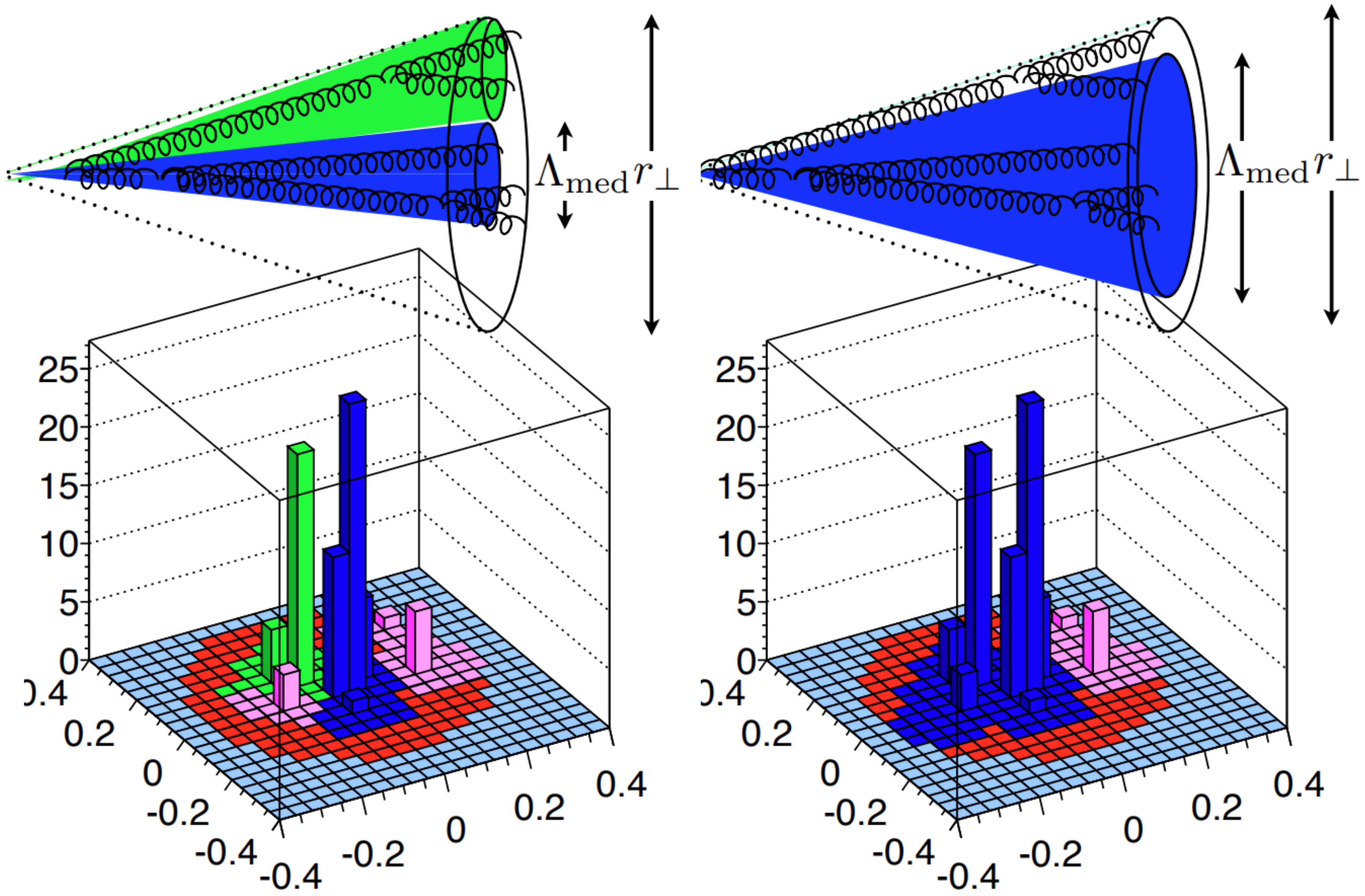
Jet suppression well described over a broad kinematic range by variety of models



CMS, JHEP 04 (2017) 039

Jet substructure techniques can provide additional model discrimination

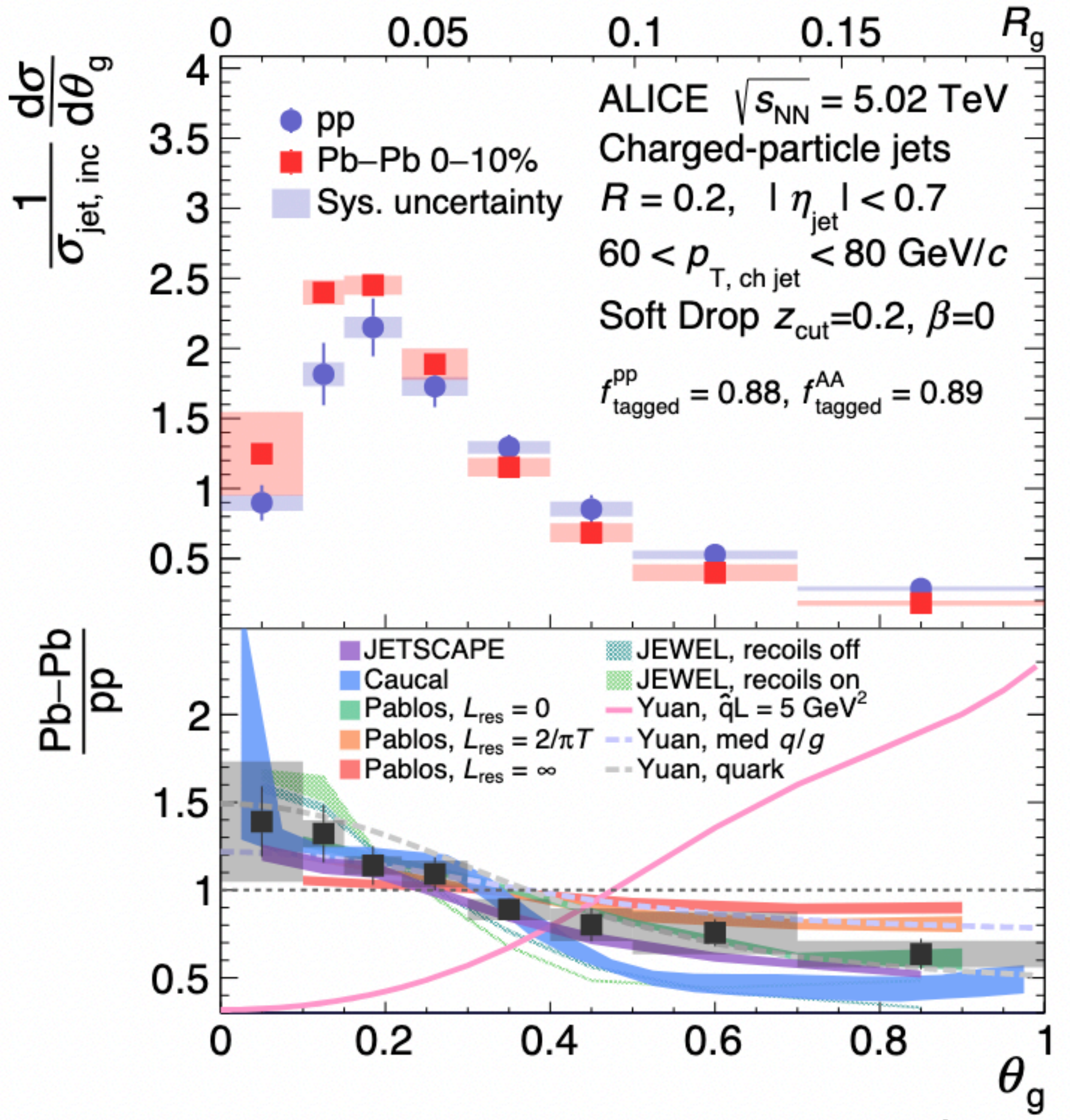
Probe medium resolution scale, where color coherence effects are relevant



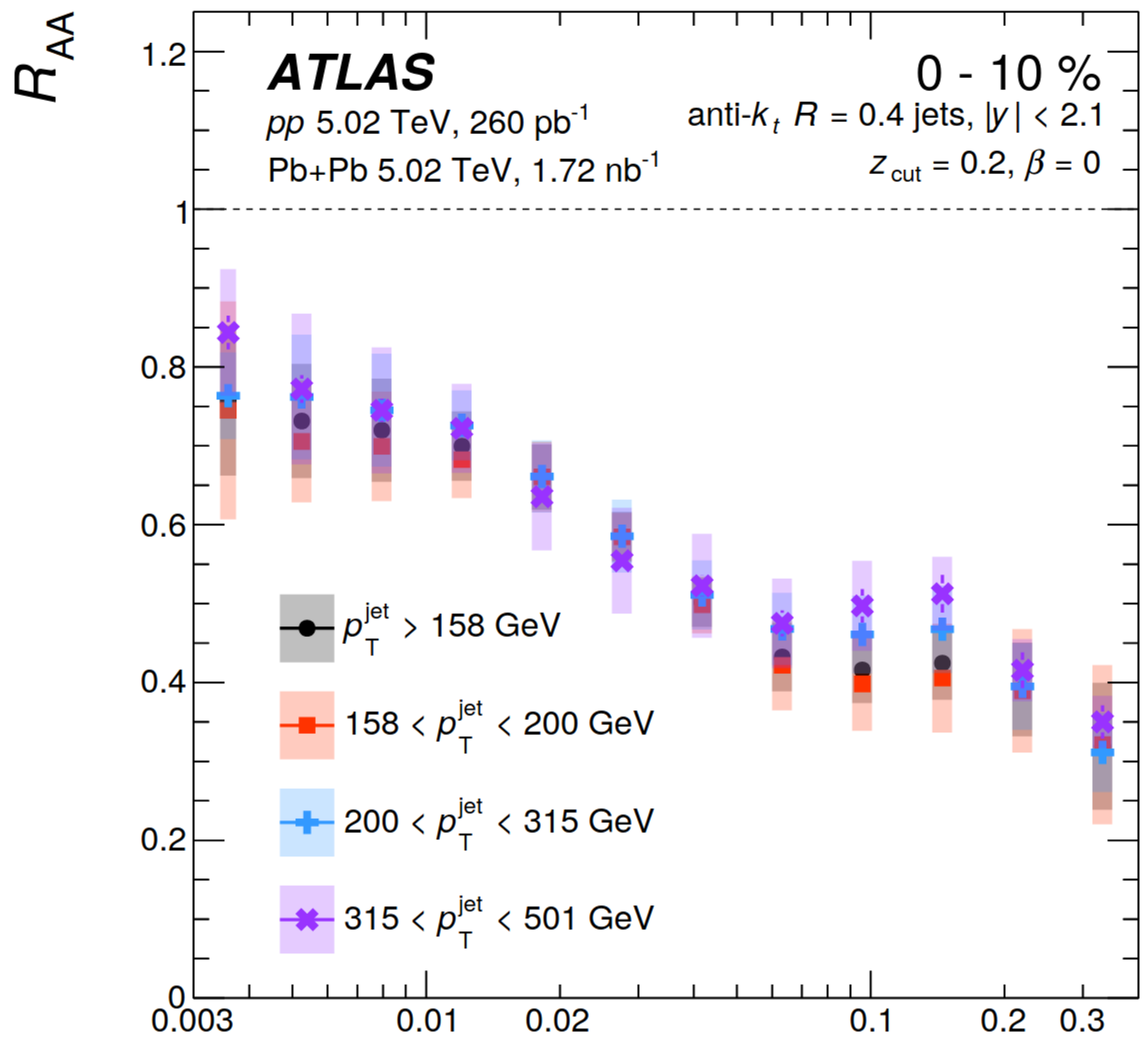
Casalderry-Solana, Mehter-Tani, Salgado, Tywoniuk, PLB 725 (2013) 360

Substructure with inclusive jets in heavy ions

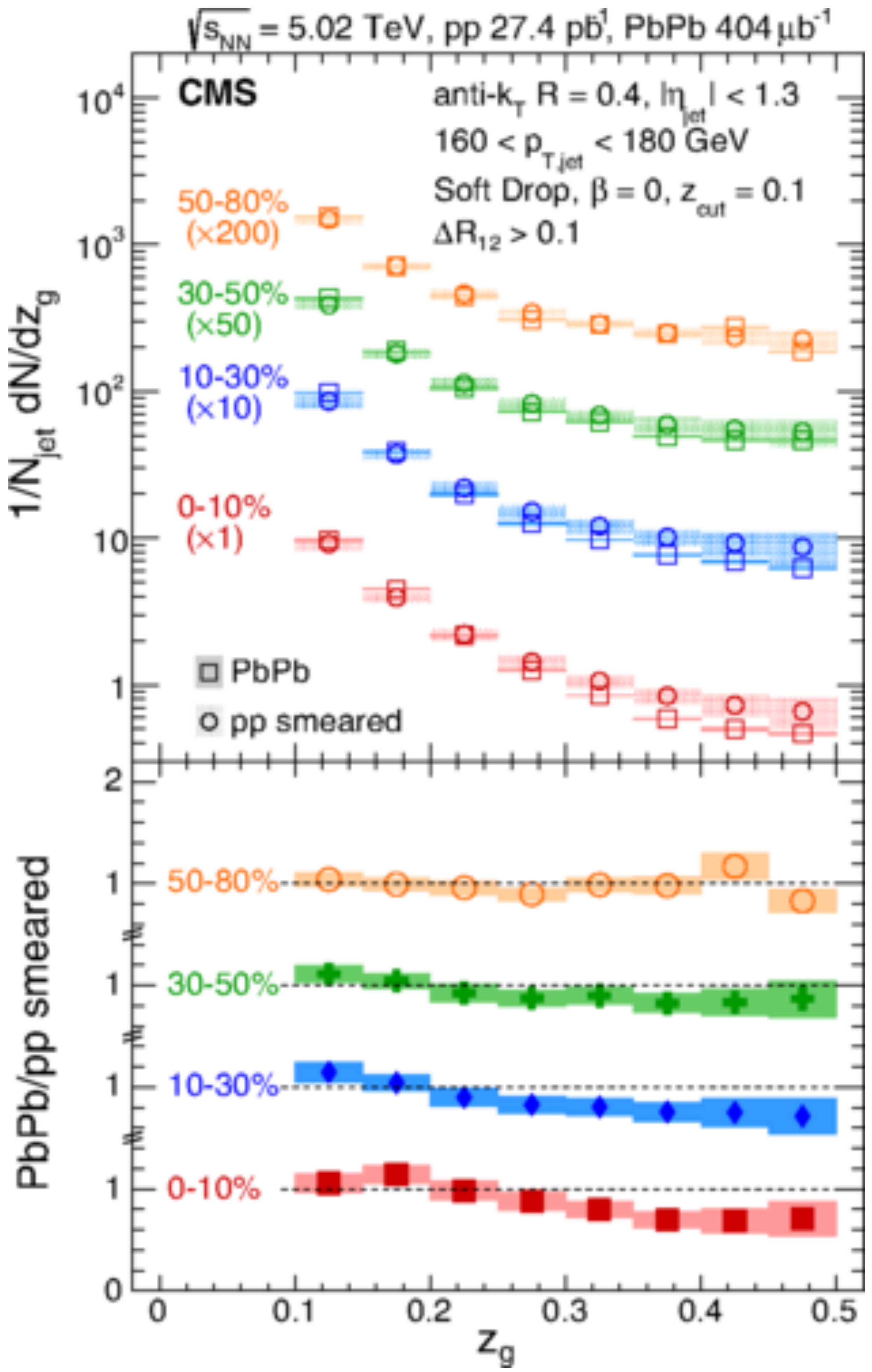
ALICE, PRL 128 (2022) 102001



ATLAS, PRC 107, (2023) 054909



CMS, PRL 120 (2018) 142302



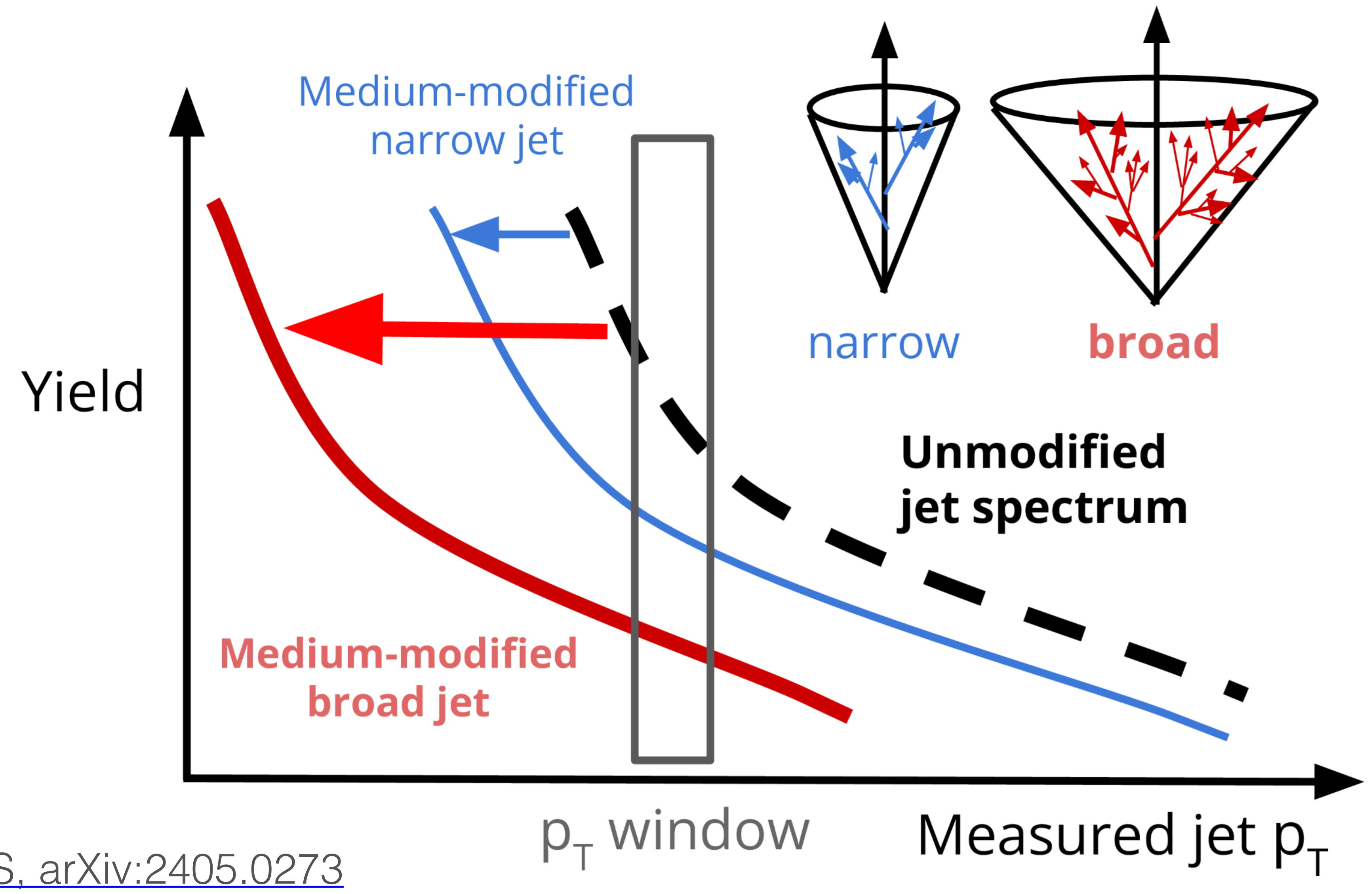
momentum sharing fraction

Comparing (central) PbPb to pp at fixed jet p_T:

- Increasing suppression for large angular separation
- Momentum sharing between prongs more imbalanced
- Are we seeing seeing the effect of the medium resolution scale?

Selection bias in jet quenching

Fixed jet p_T window selects less quenched jets



CMS, arXiv:2405.0273

Possible interplay with jet substructure:

- Quark jets tend to be narrower than gluon jets
- Broader jets may suffer larger quenching
  - At fixed p_T would observe an effective narrowing

Selection bias in jet quenching

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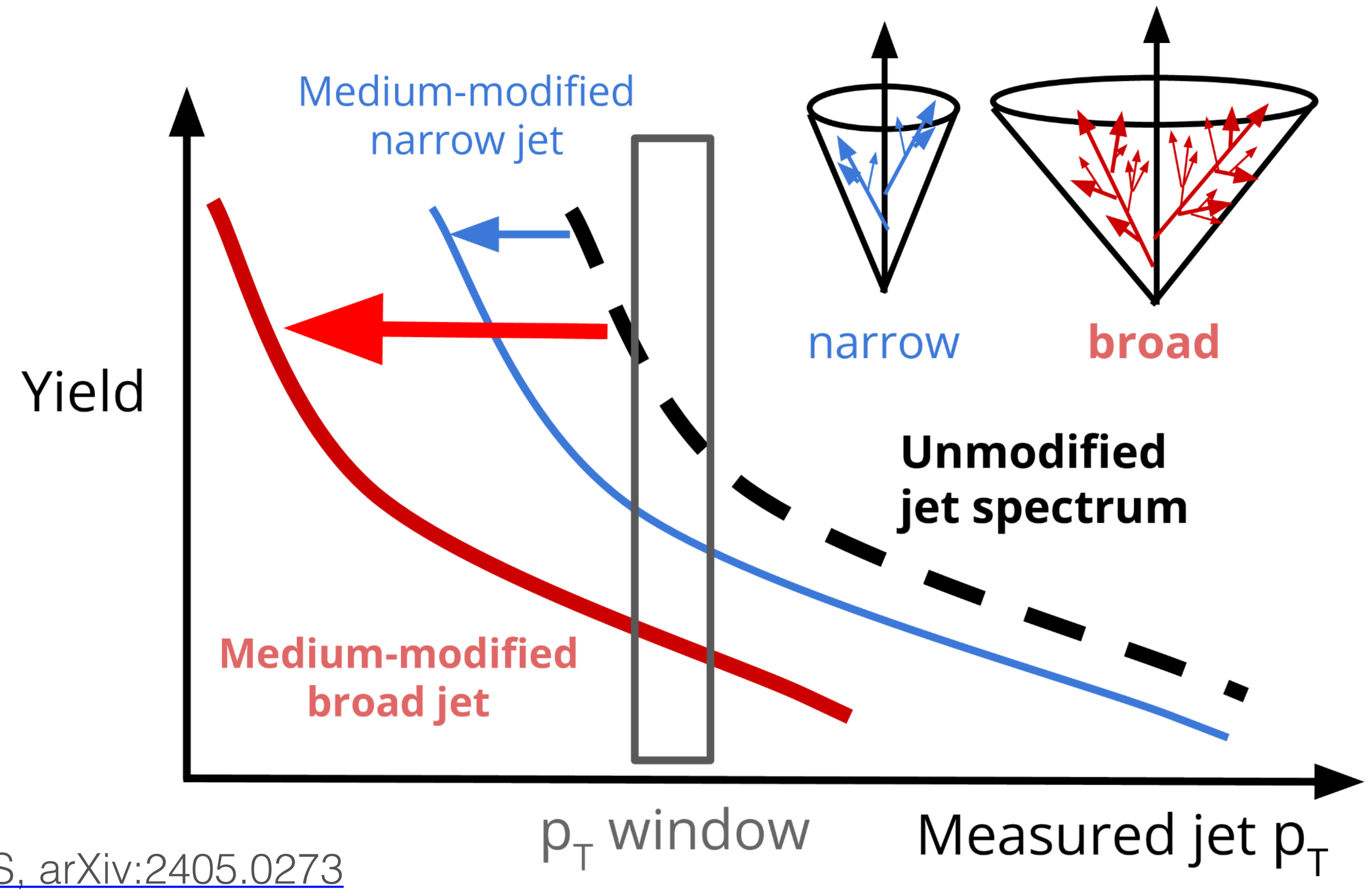

CMS, arXiv:2405.0273

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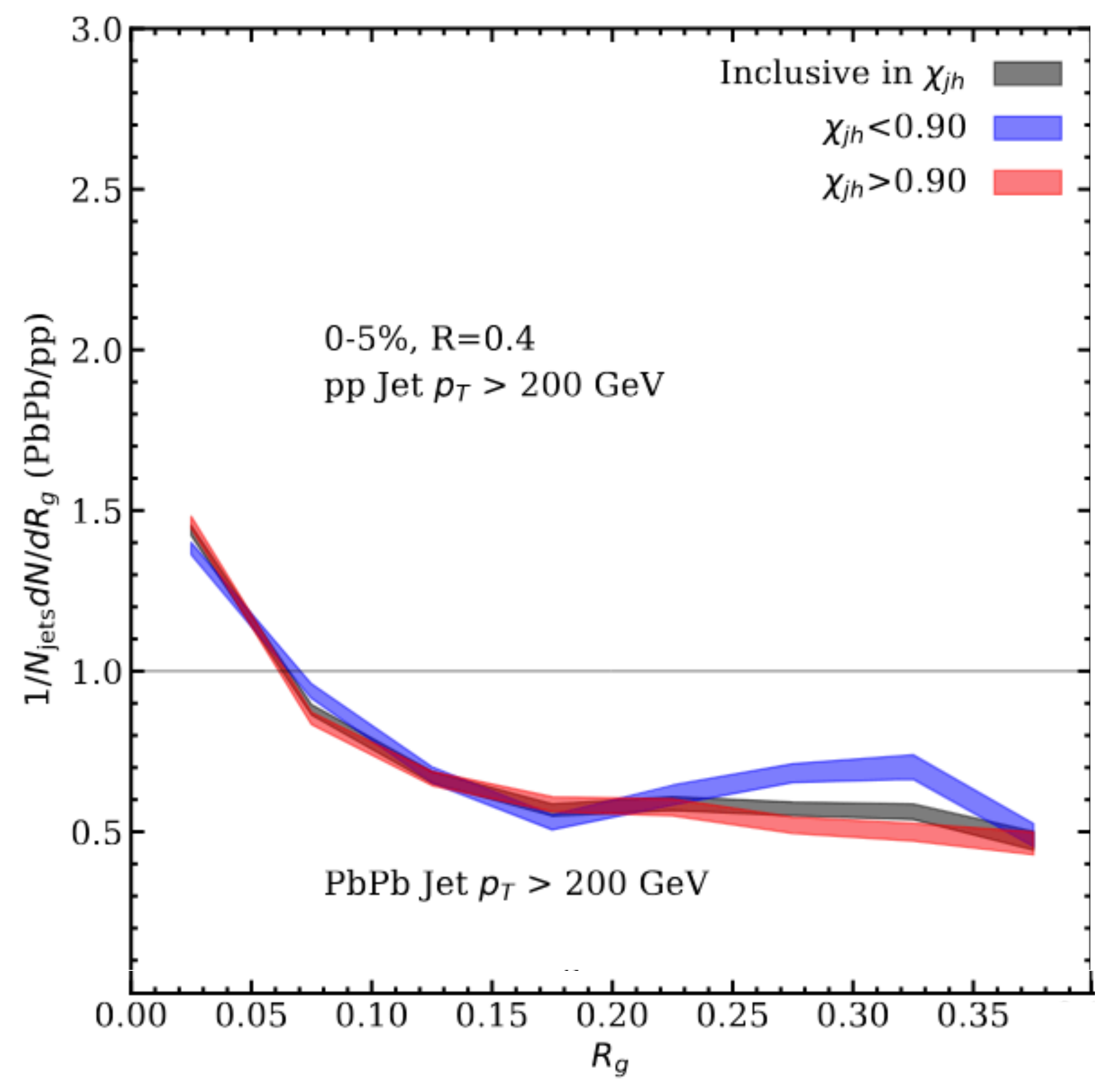
Bias is borne out by model calculations



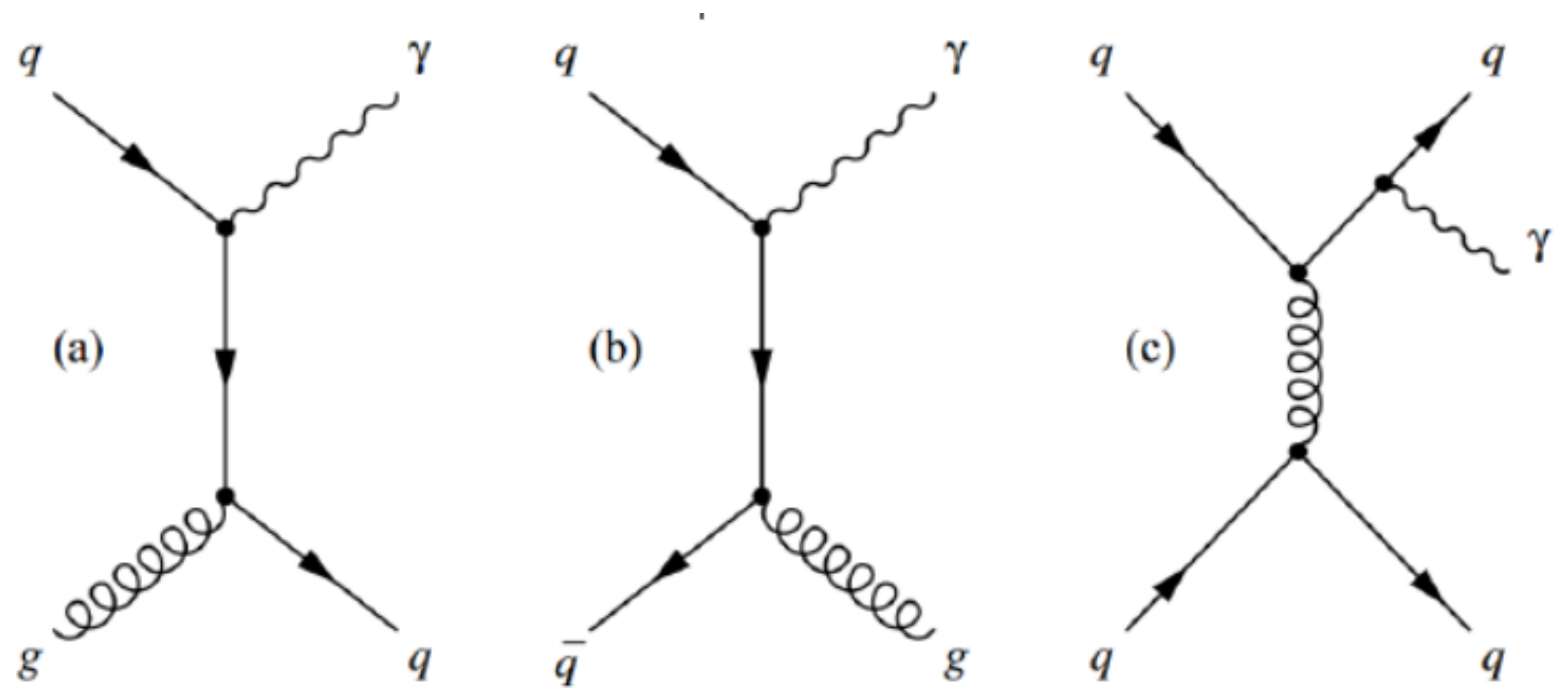
Hybrid model
Unquenched jets
Quenched jets

Yu, Pablos, Tywoniuk, JHEP 21 (2021) 206

Applying experiment-like (post-quenching) jet p_T selection

- ‣ effective narrowing for both quenched & unquenched jets
- ‣ obscures physical broadening effect in this model

Photon-tagged jets



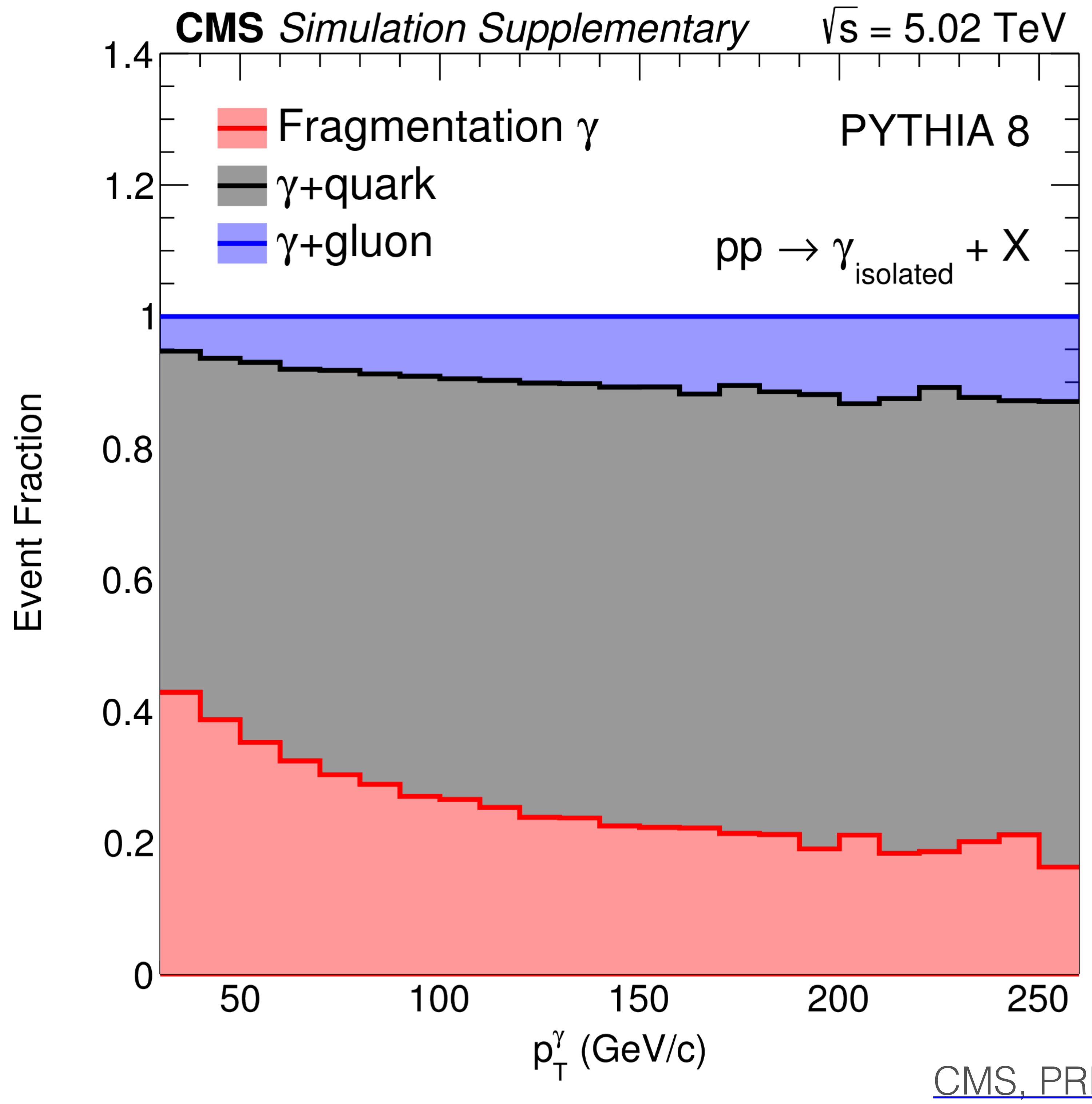
- "Prompt" photons produced at LO in pQCD via
  - Compton scattering: $qg \rightarrow q\gamma$
  - Quark annihilation: $q\bar{q} \rightarrow g\gamma$

➡ Compton scattering dominates in pp collisions

- At NLO parton-to-photon fragmentation

  ➡can reduced with photon isolation

- Large but reducible background from photonic decays of hadrons, e.g., $\pi^0 \rightarrow \gamma\gamma$



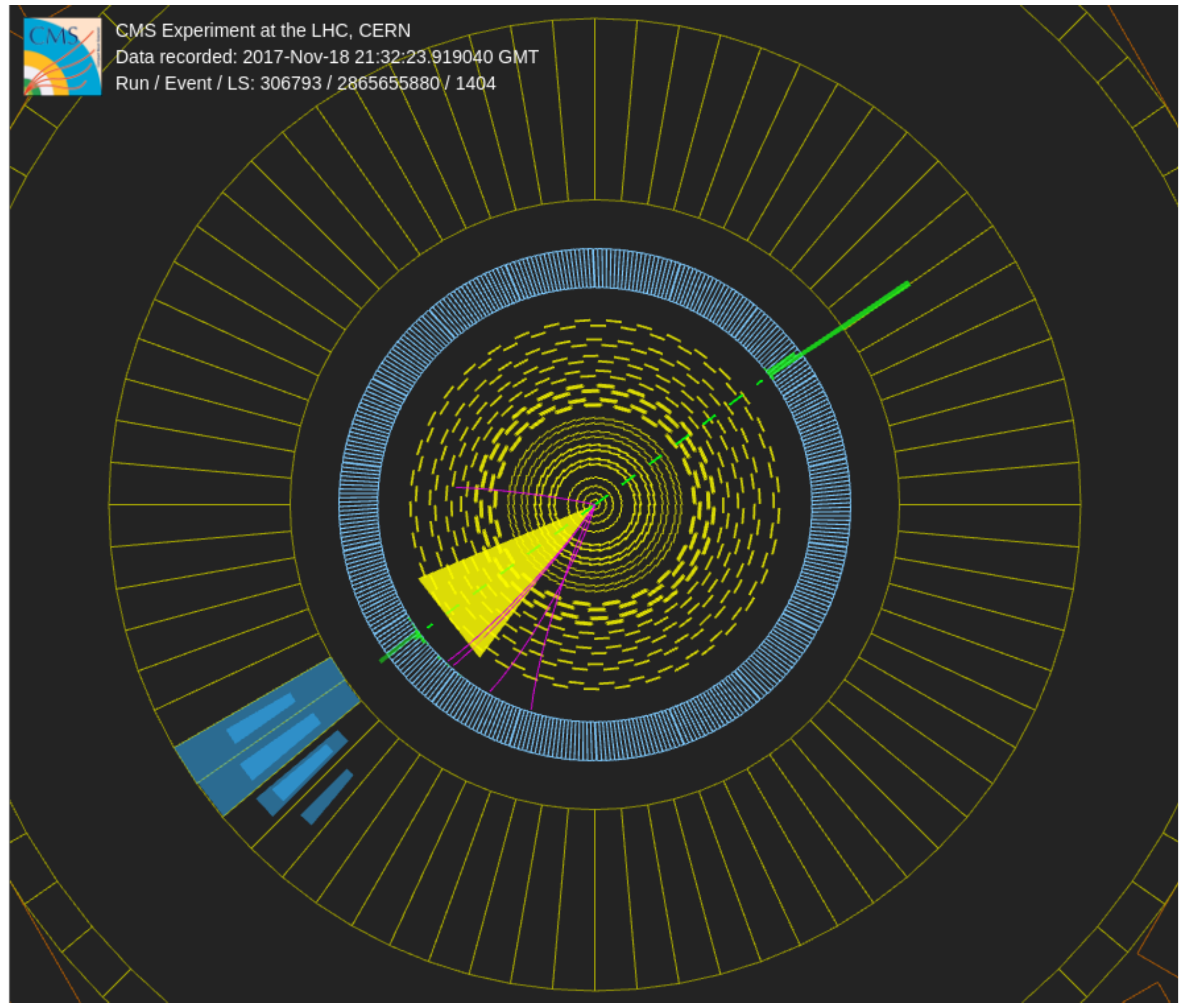
CMS, PRL 122 (2019) 152001

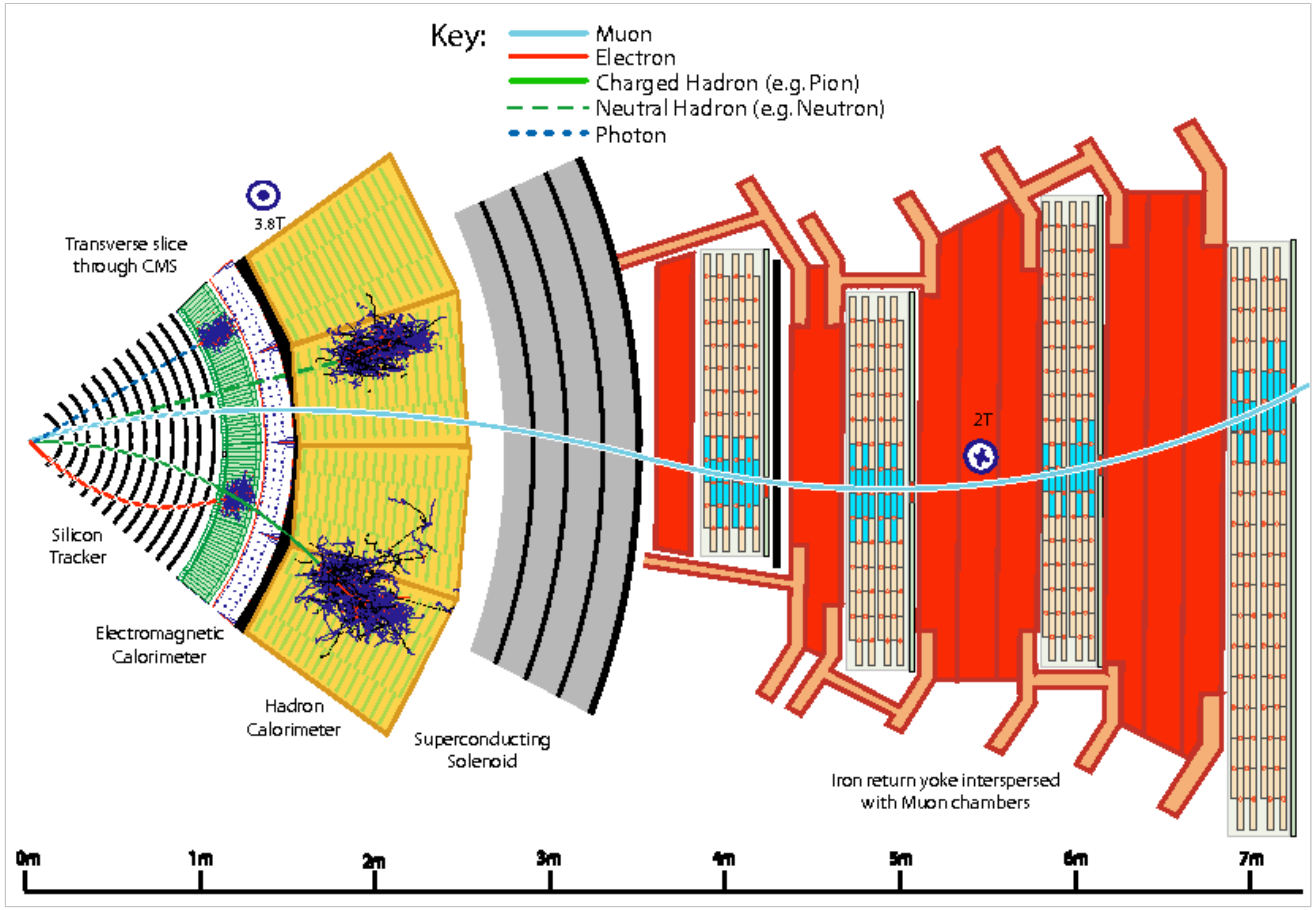
Benefits for jet quenching studies

- Photon fixes recoiling parton kinematics (prior to jet quenching)
- Relatively pure sample of quark jets

The CMS detector

Granular, high resolution ECAL
$\Delta E/E \approx 2\%$ for 100 GeV photons

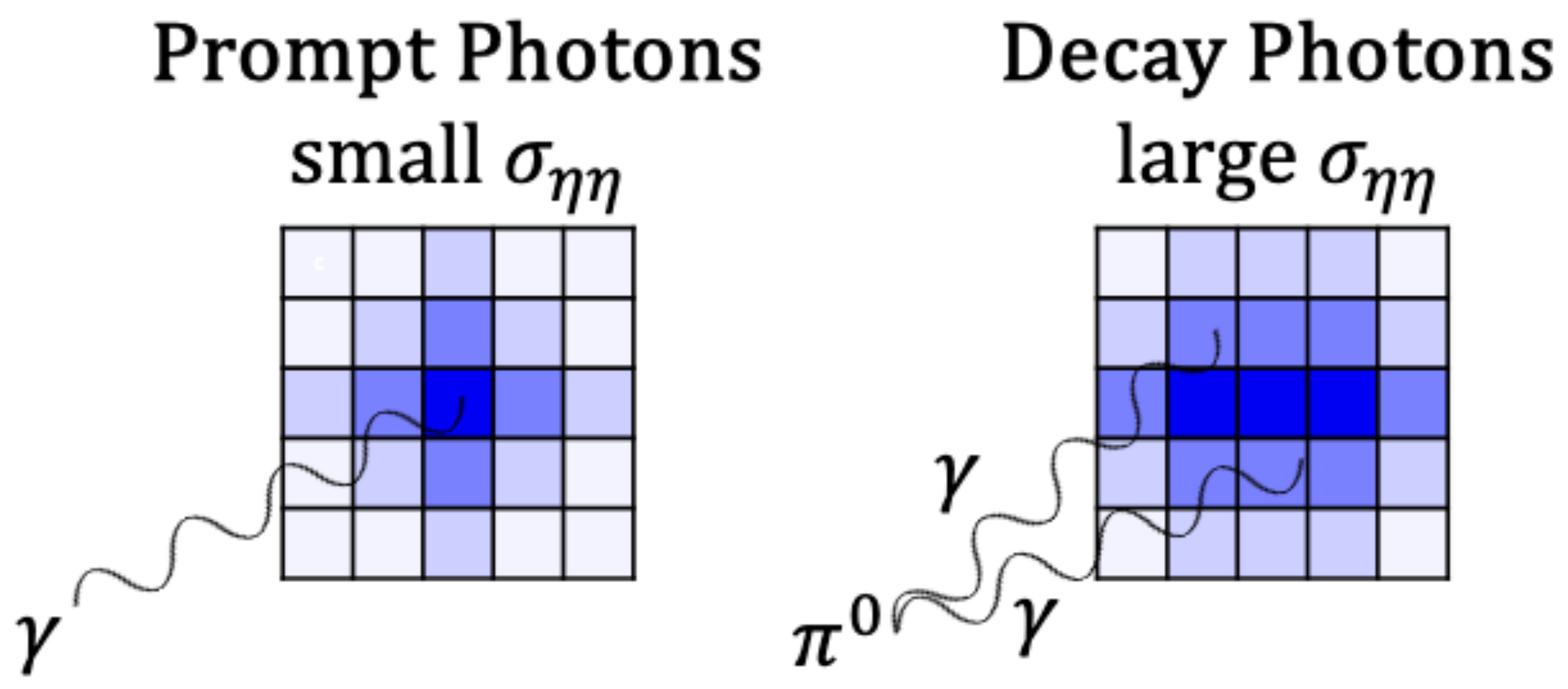




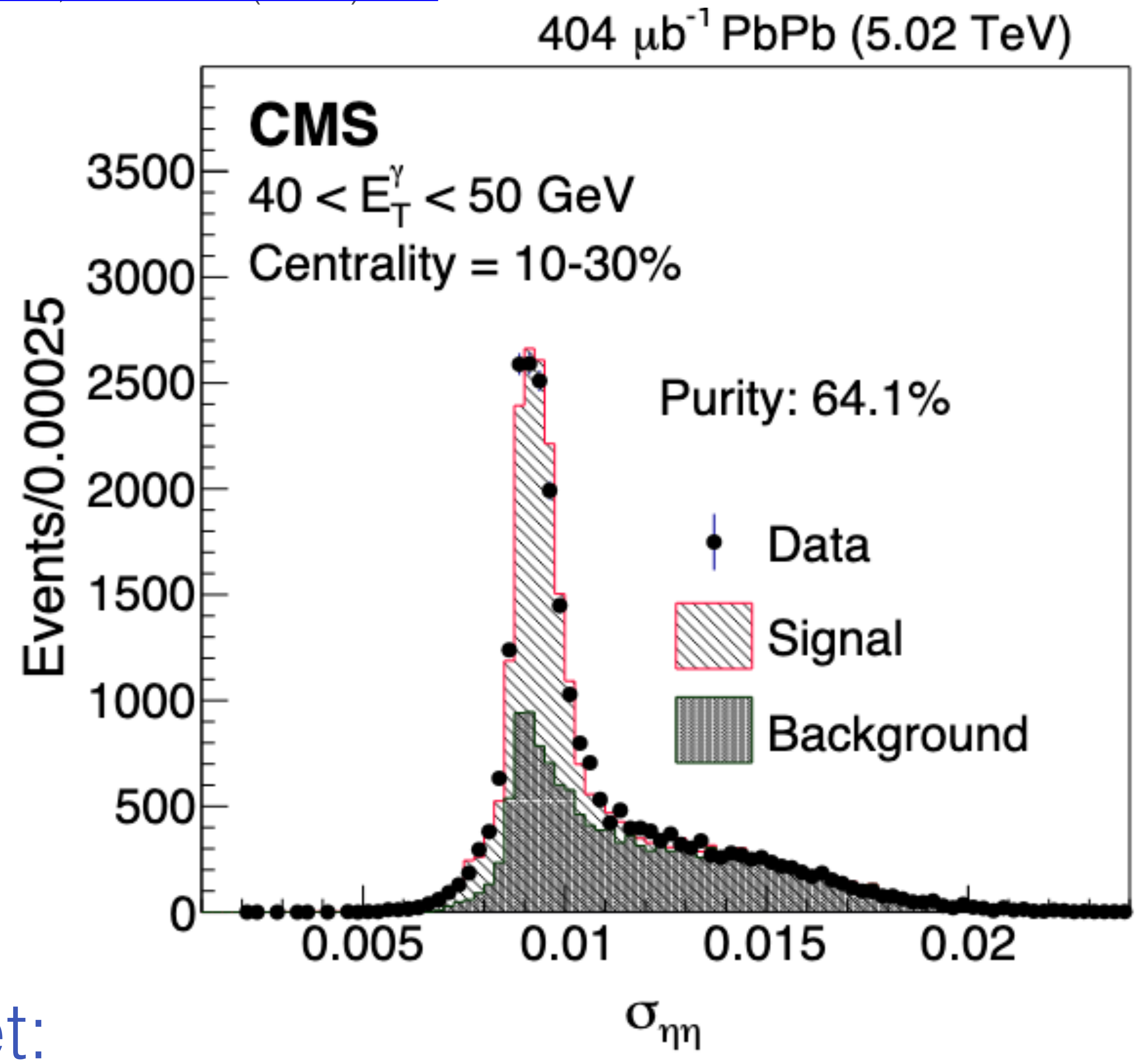
Large acceptance tracking & calorimetry
Inside magnet for precision particle flow
recoil jets fully contained in $|\eta| < 2$

Measurement setup

Photons ID based on
- H/E from HCAL & ECAL
- Shower shape ($\sigma_{\eta\eta}$)
- Isolation from calo & tracks

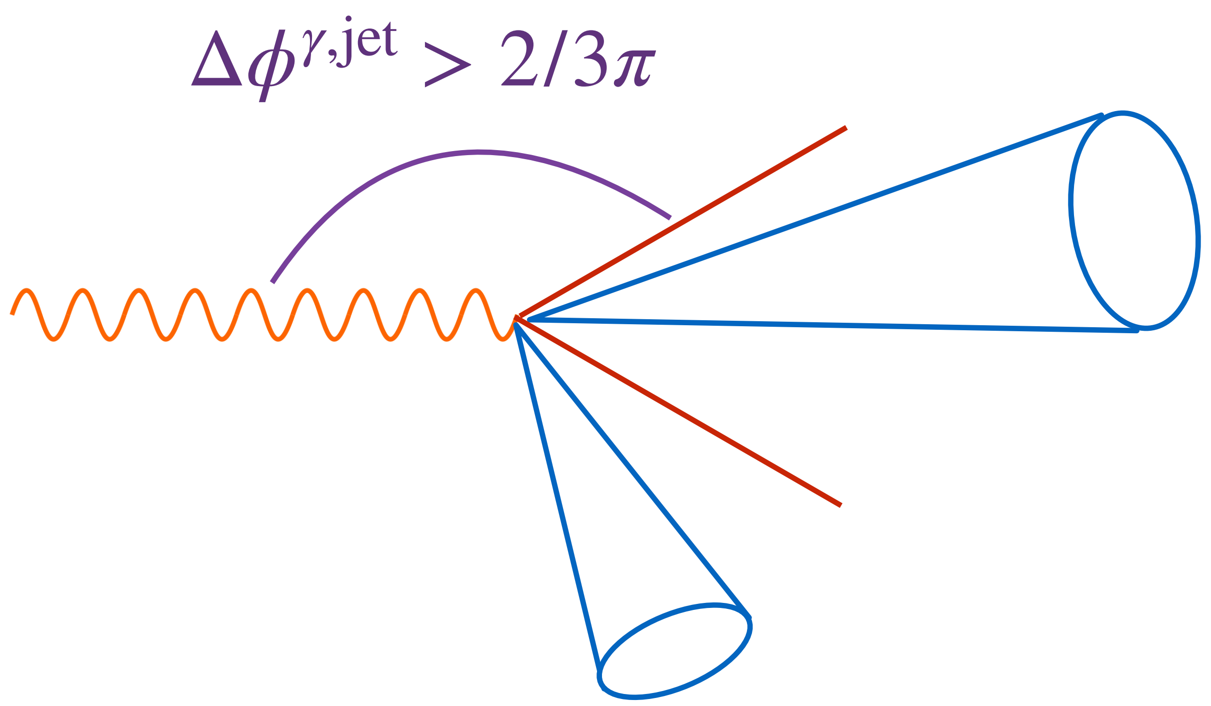


Example from previous analysis
CMS, JHEP 07 (2020) 116



Photon purity extracted w/ template fit
Cross-checked w/ ABCD method

Isolated photons:
- $p_T^{\gamma} > 100$ GeV
- $|\eta^{\gamma}| < 1.44$



Leading recoil jet:
- Anti-k_T, R=0.2
- $|\eta^{\mathrm{jet}}| < 2$

Selections on γ+jet balance:
- $p_T^{\mathrm{jet}}/p_T^{\gamma} > 0.4$: quenched & unquenched recoil jets
- $p_T^{\mathrm{jet}}/p_T^{\gamma} > 0.8$: only less quenched jets

Observables

CMS, arXiv:2405.0273

Soft drop removes soft gluon radiation

- Jets reclustered w/ Cambridge-Aachen algorithm

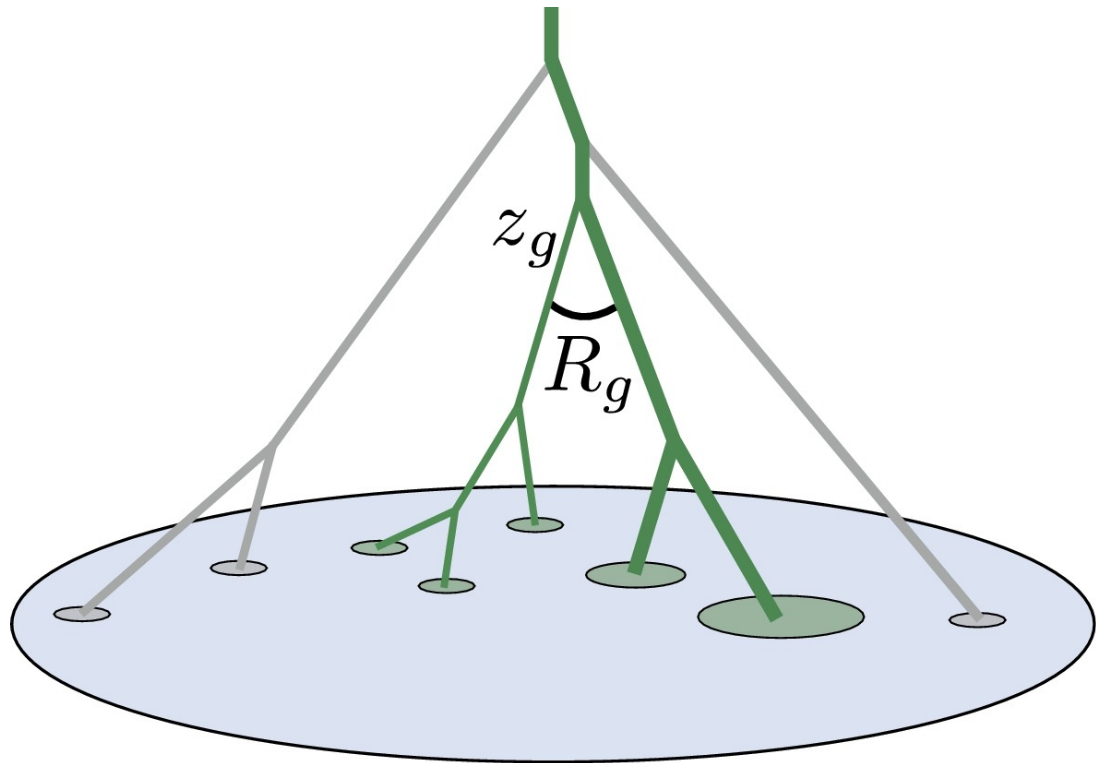


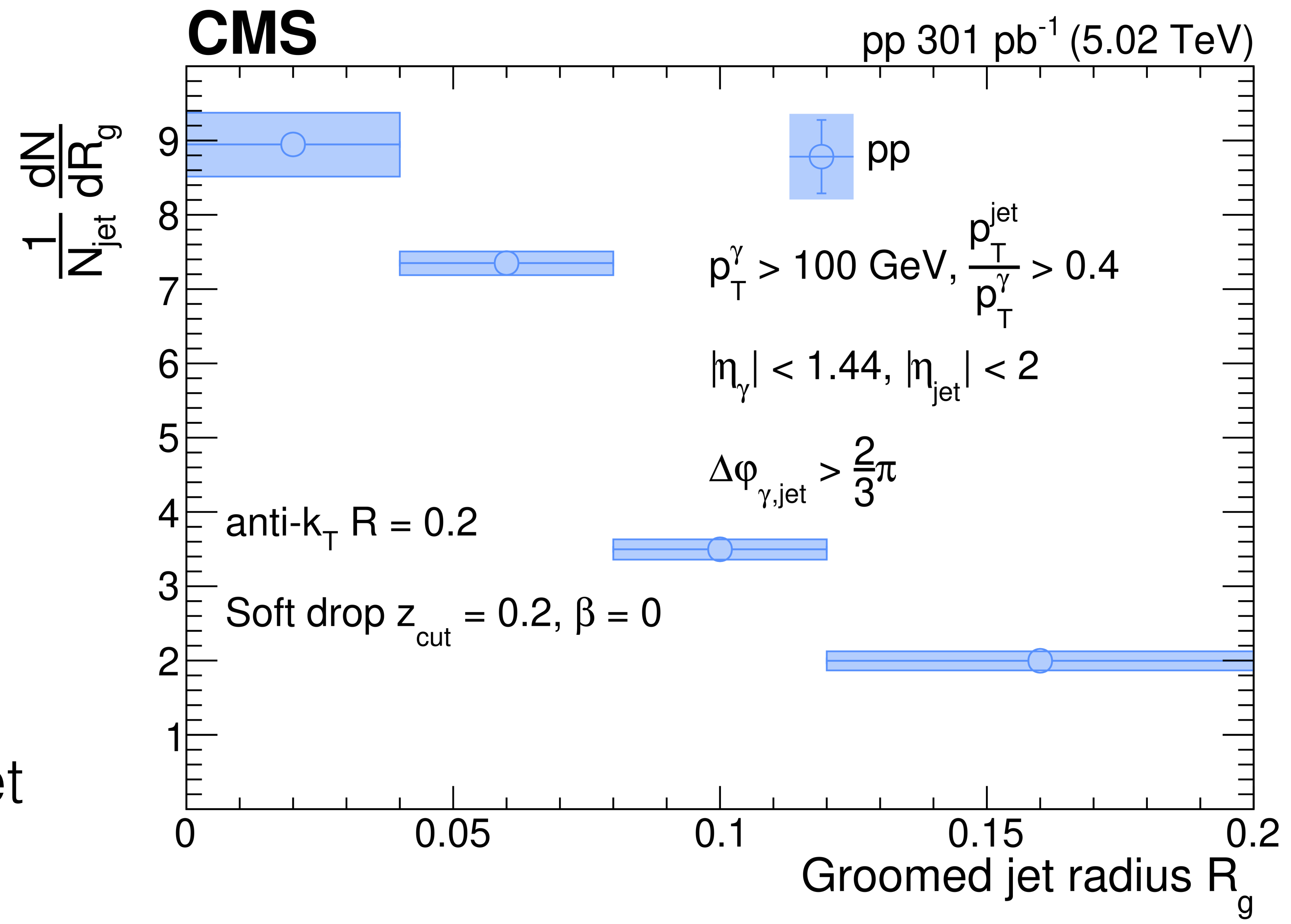
Fig. from Cal et al., PLB 833 (2022) 137390

- CA jet declustered until SD condition is met

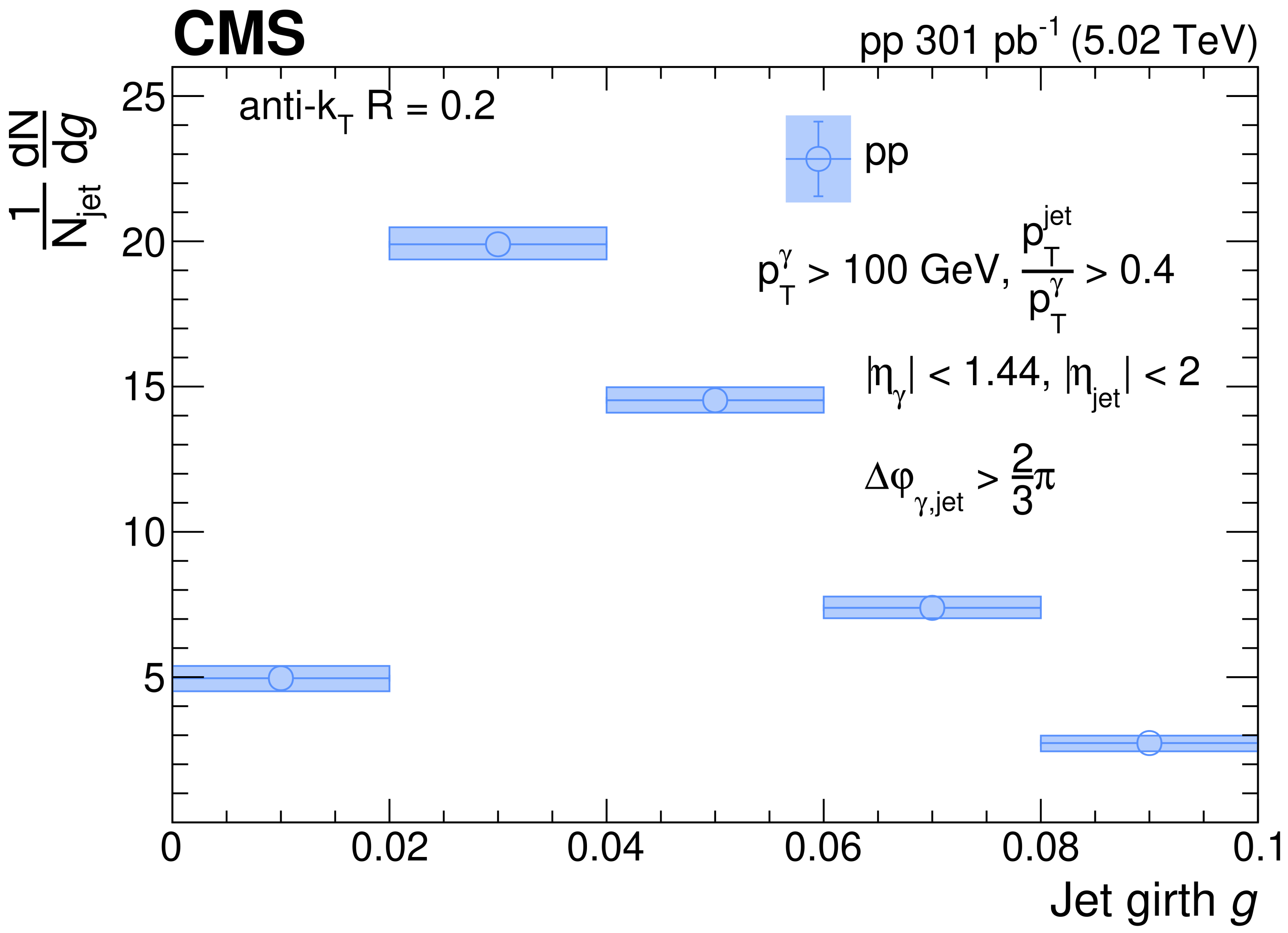
$$z_g \equiv \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut} \left(\frac{R_g}{R}\right)^{\beta}$$

- We choose: β = 0 and z_{cut} = 0.2
  - Subjets are a proxy for the first hard splitting in the parton shower

Groomed jet radius



Jet girth



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

Alternative approach without grooming

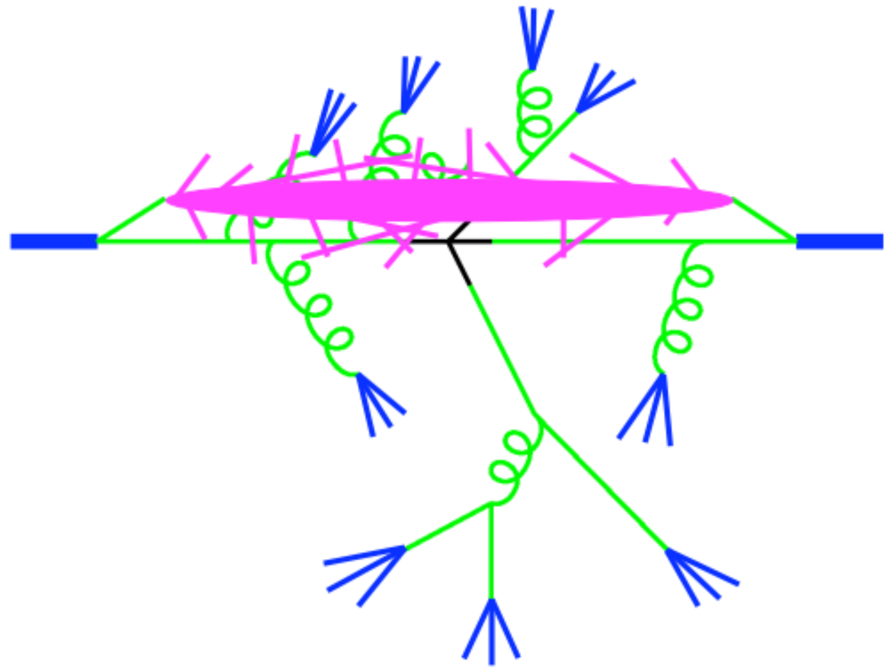
Systematic uncertainties

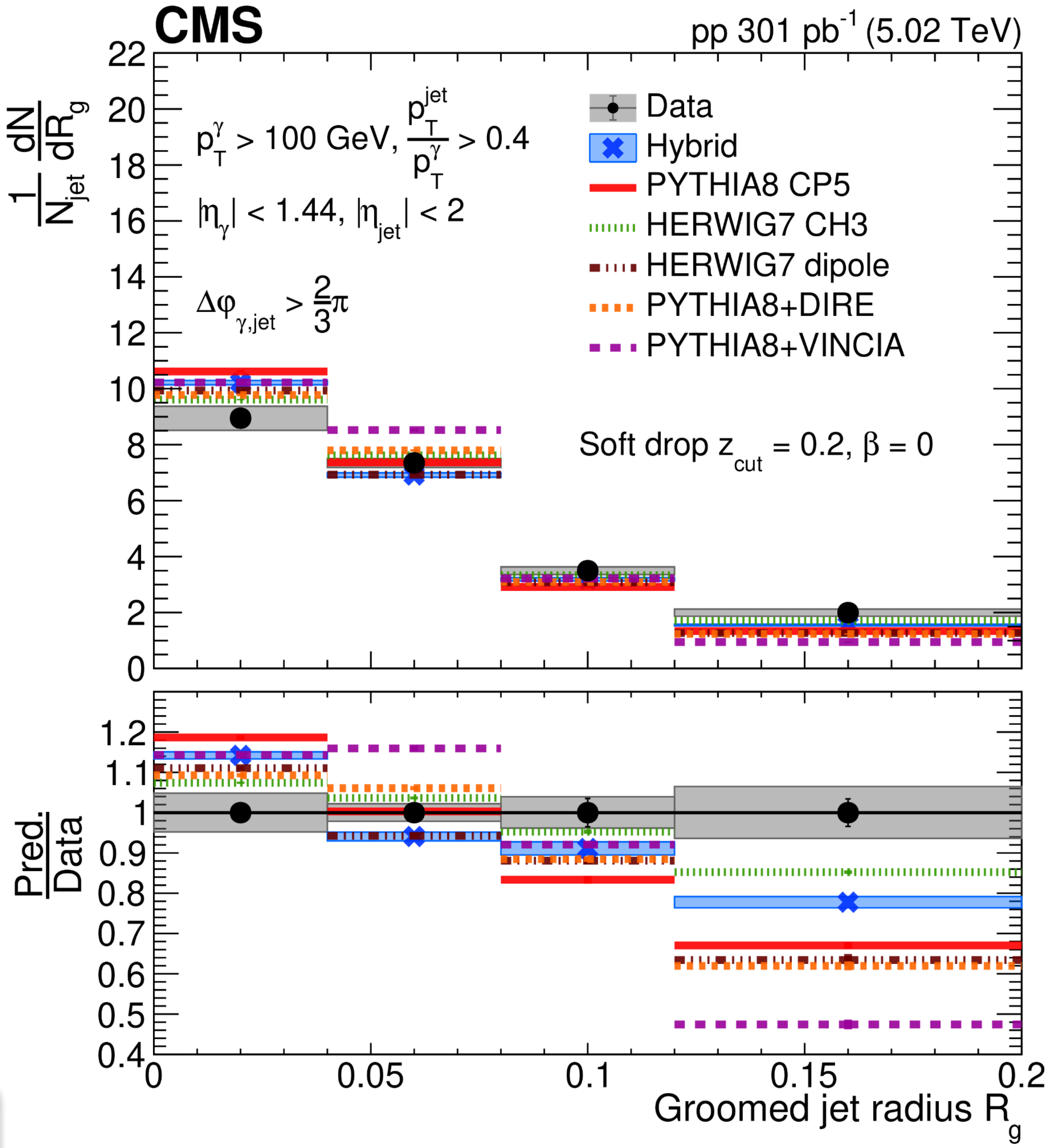
- **MC modeling** (dominant): Addresses modeling of underlying event, parton shower & hadronization. Estimated by comparing Pythia and Herwig. In PbPb quark/gluon reweighted to mimic quenching effect.
- **Jet constituent energy scale** (dominant): Energy of photons & charged hadrons shifted by 1%. Neutral hadrons shifted by 3%.
- **Jet energy scale and resolution**: Derived from dijet and γ+jet balancing studies in pp. Underlying event density in simulation (Hydjet) varied to match data.
- **Photon purity**: Varied background estimation method (template vs. ABCD).
- **Unfolding**: Varied regularization parameter & assumed prior, transfer matrix statistical uncertainties.

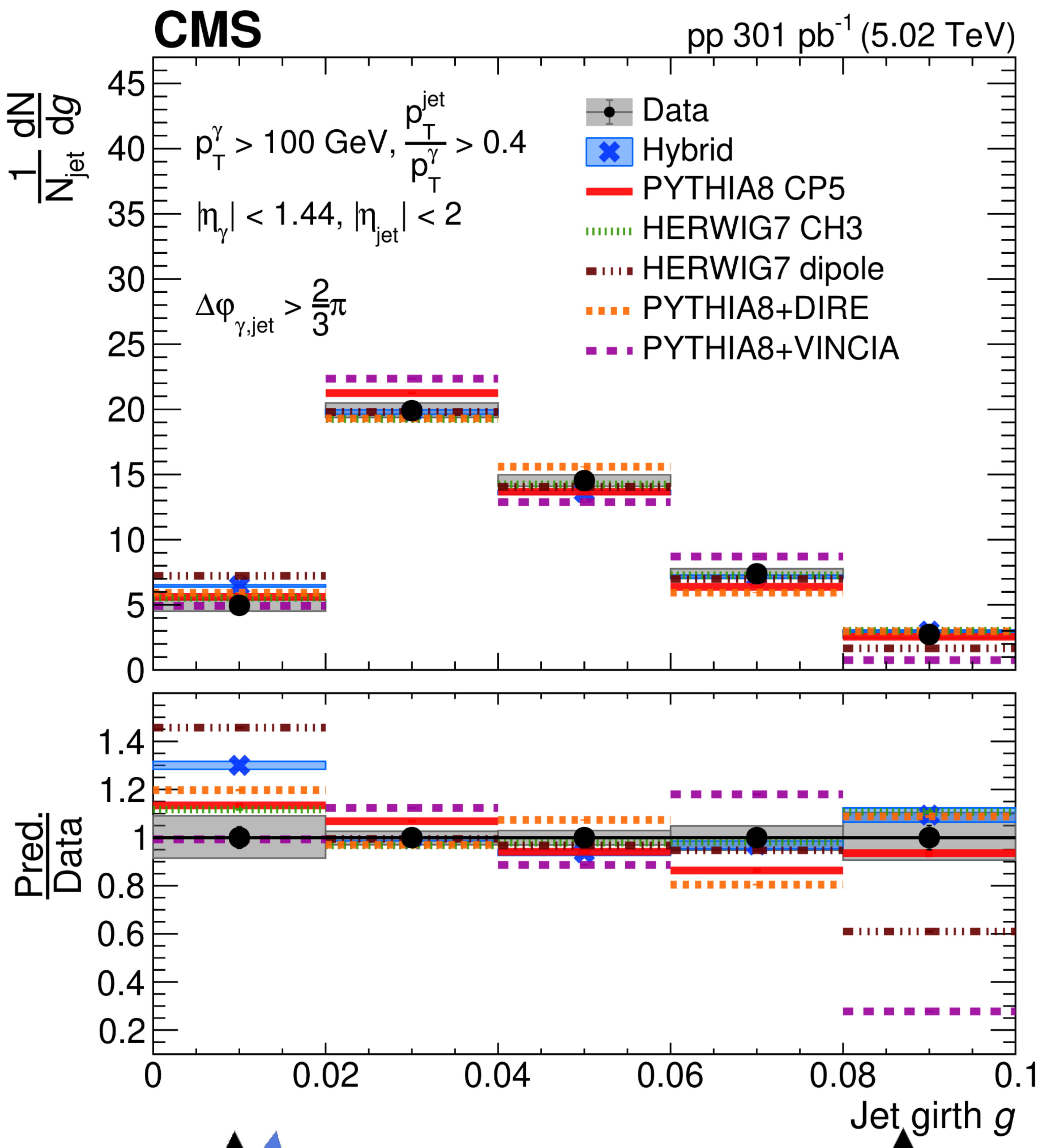
Results in pp collisions

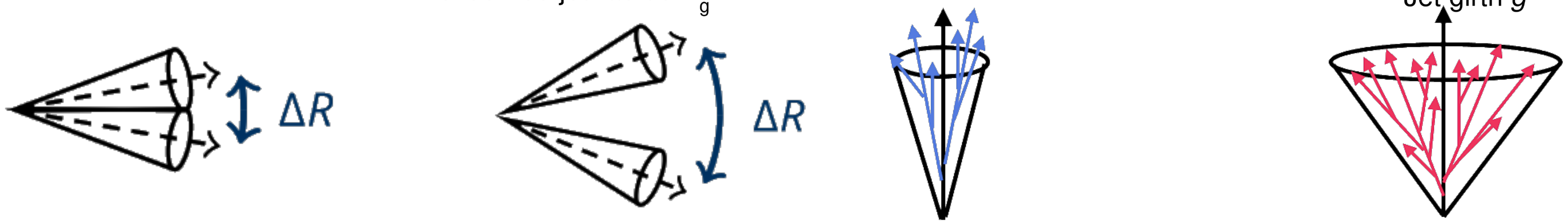
CMS, arXiv:2405.0273

Compared to various models of parton showers, hadronization & underlying event





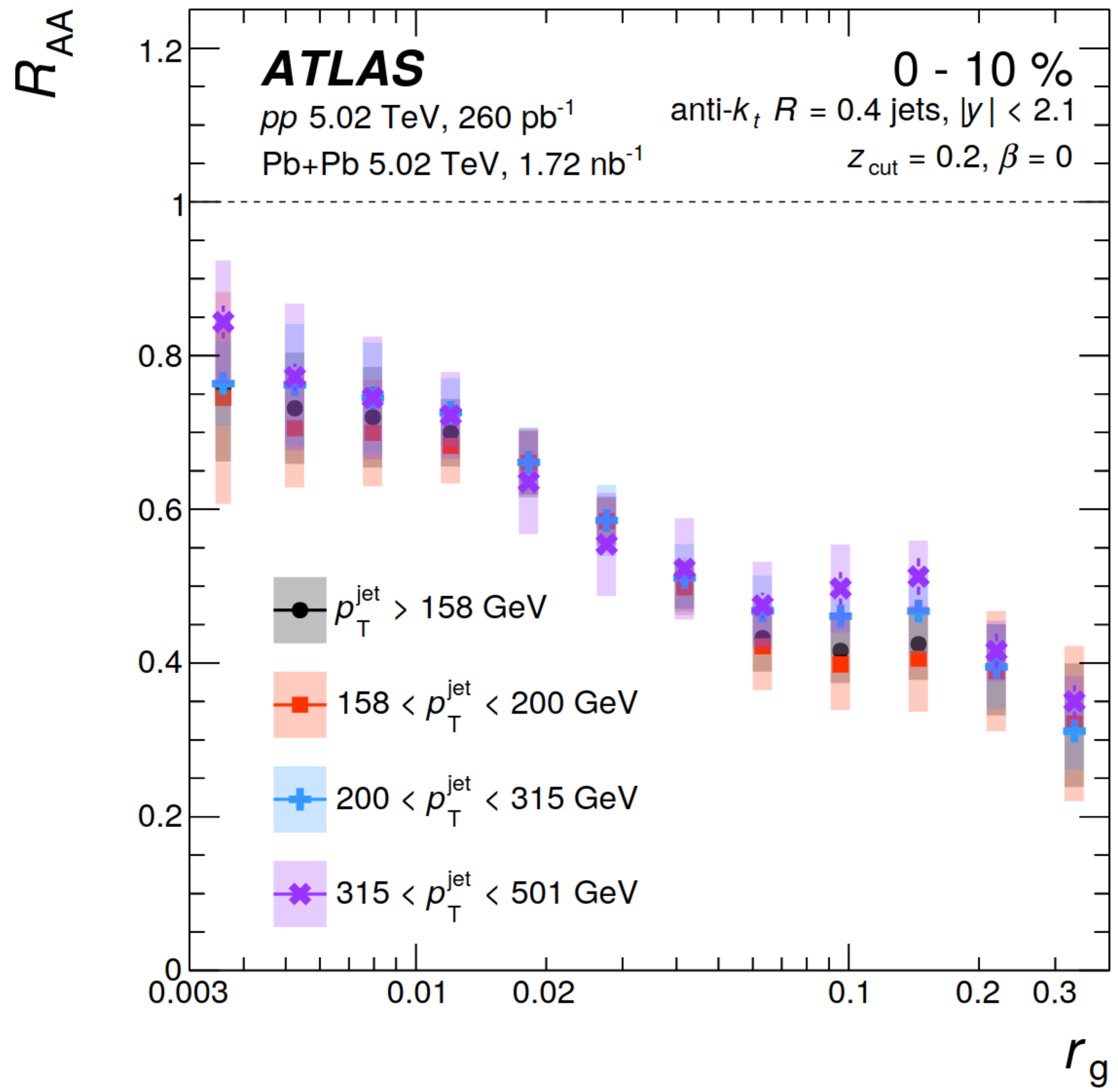




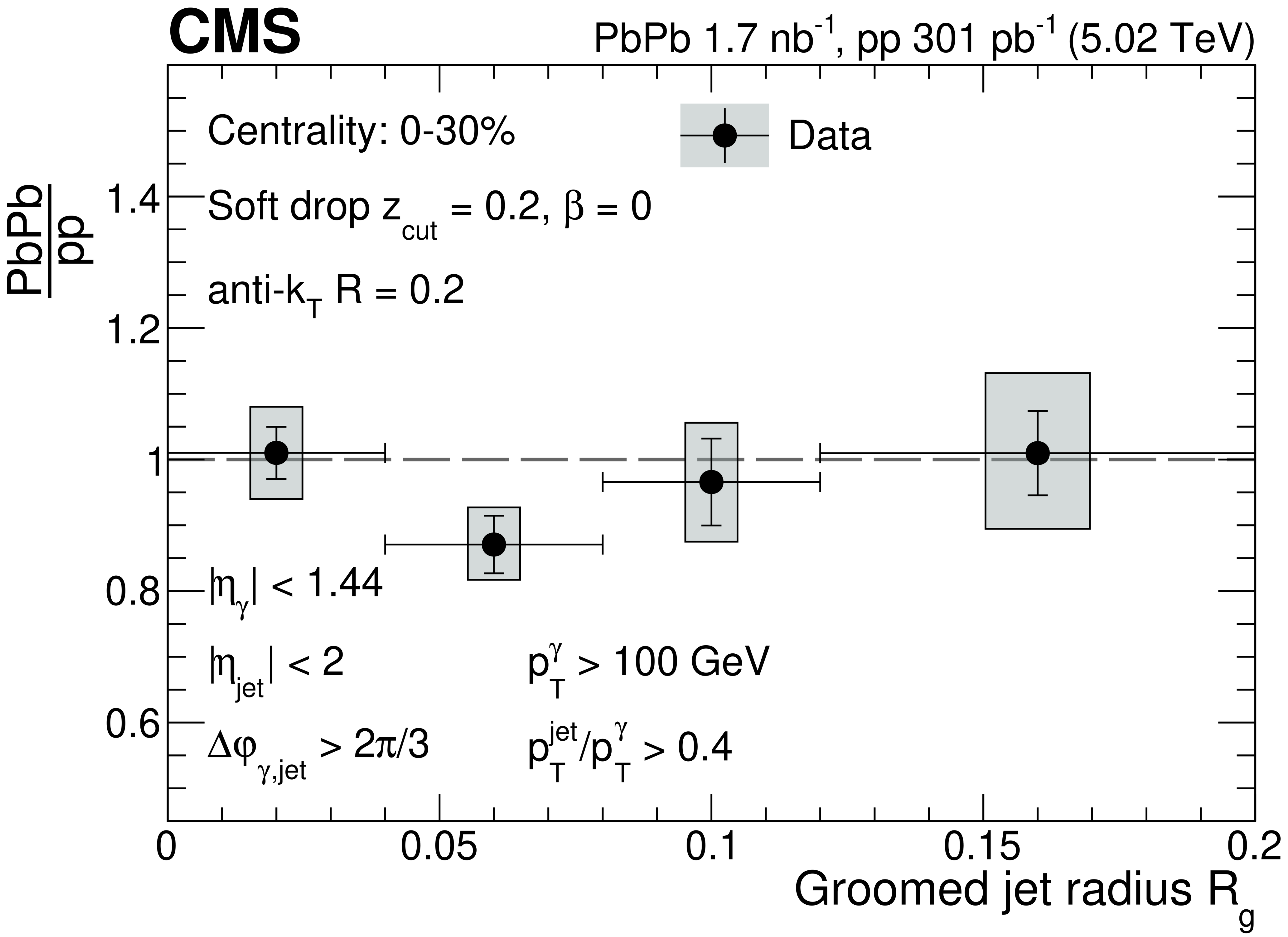
Data/model differences up to factor of 2
→ Vacuum shower model important component for jet quenching calculations

Inclusive jets vs γ+jets

ATLAS, PRC 107, (2023) 054909



CMS, arXiv:2405.0273



Narrowing effect observed for inclusive jets is not replicated in γ+jet

Inclusive jets vs γ+jets

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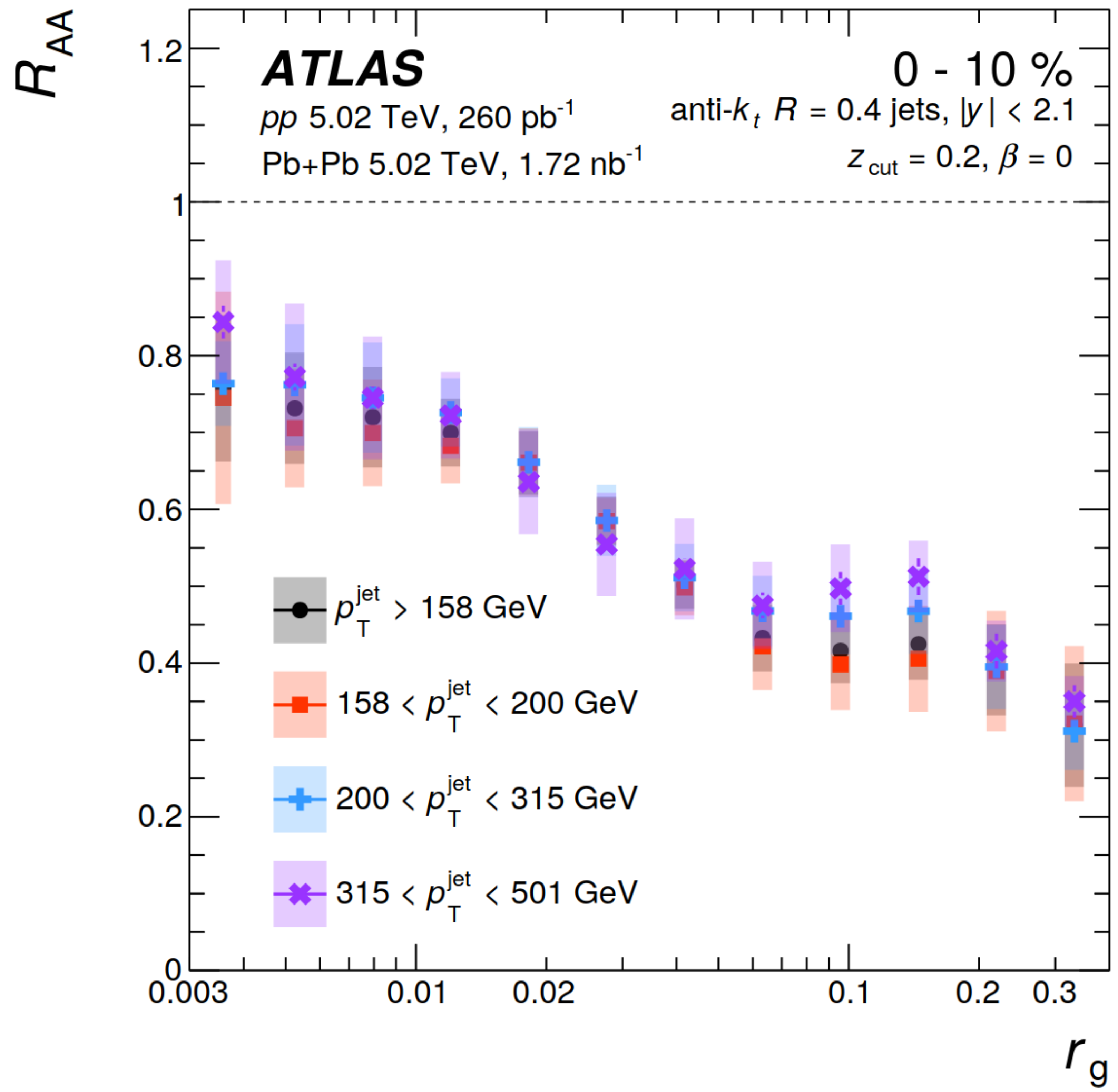
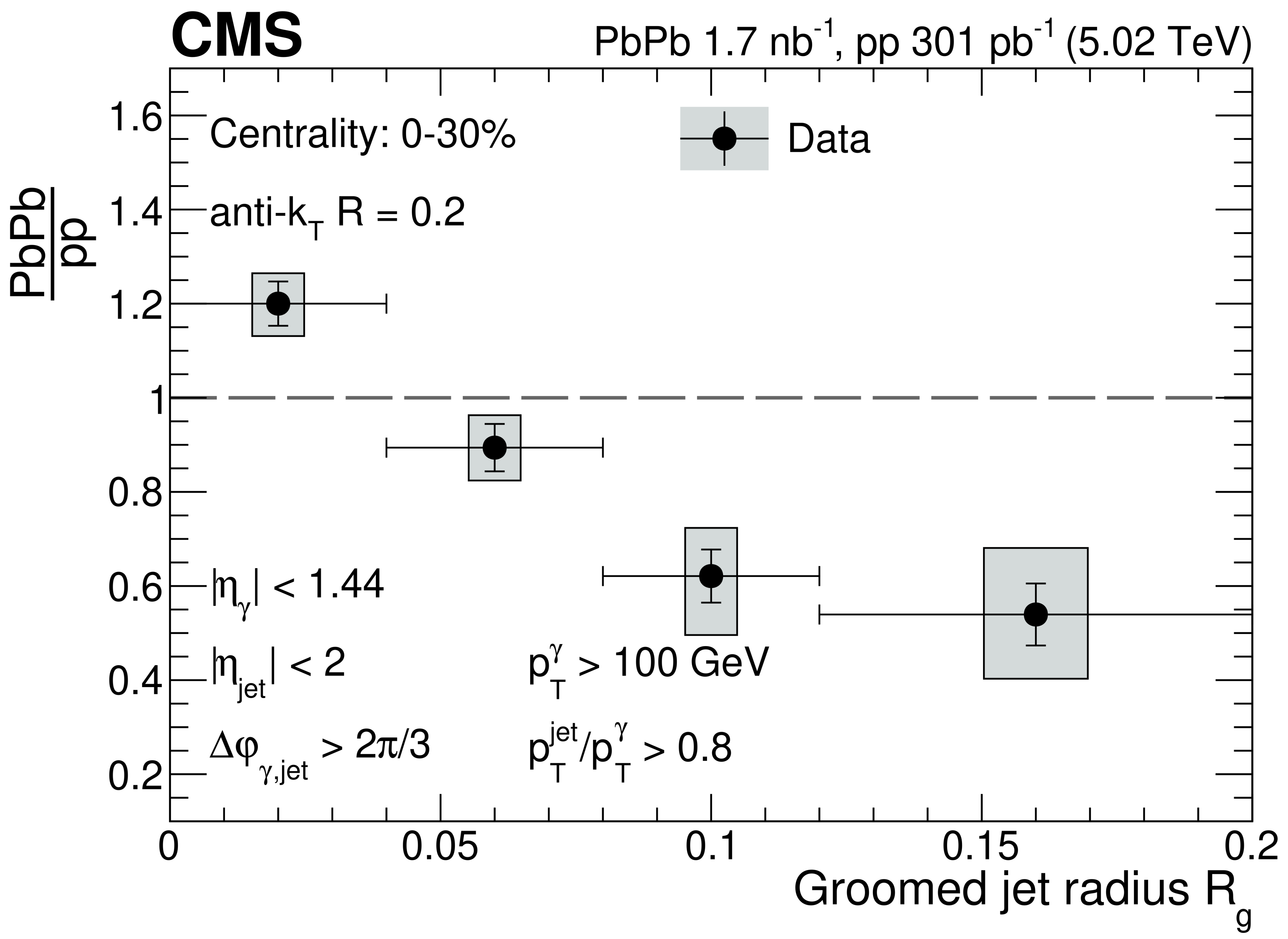
CMS, arXiv:2405.0273





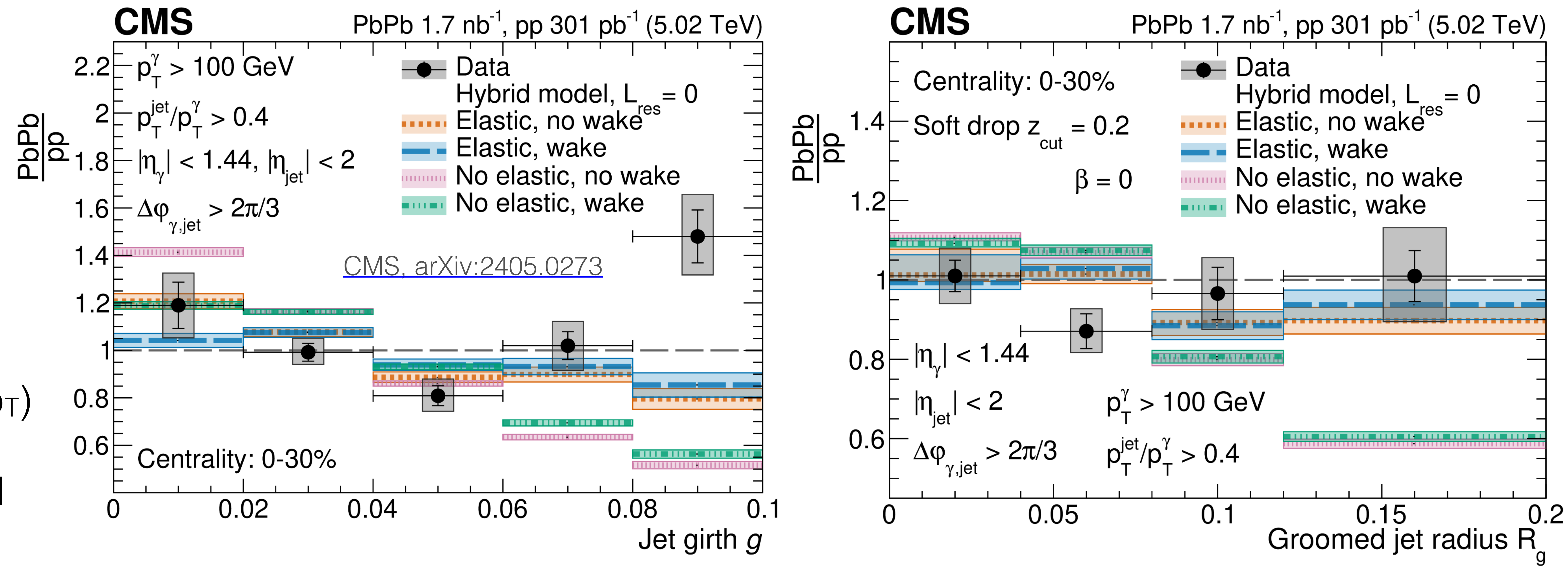
Raising p_T threshold on recoiling jet restores narrowing effect

Quenching model comparison (hybrid)

Hybrid: weak+strong coupling model of jet quenching

Calculations w/o coherence (L_{res} = 0)

- Wake plays no role for these jet kinematics (R, p_T)
- Elastic scattering improves agreement w/ model



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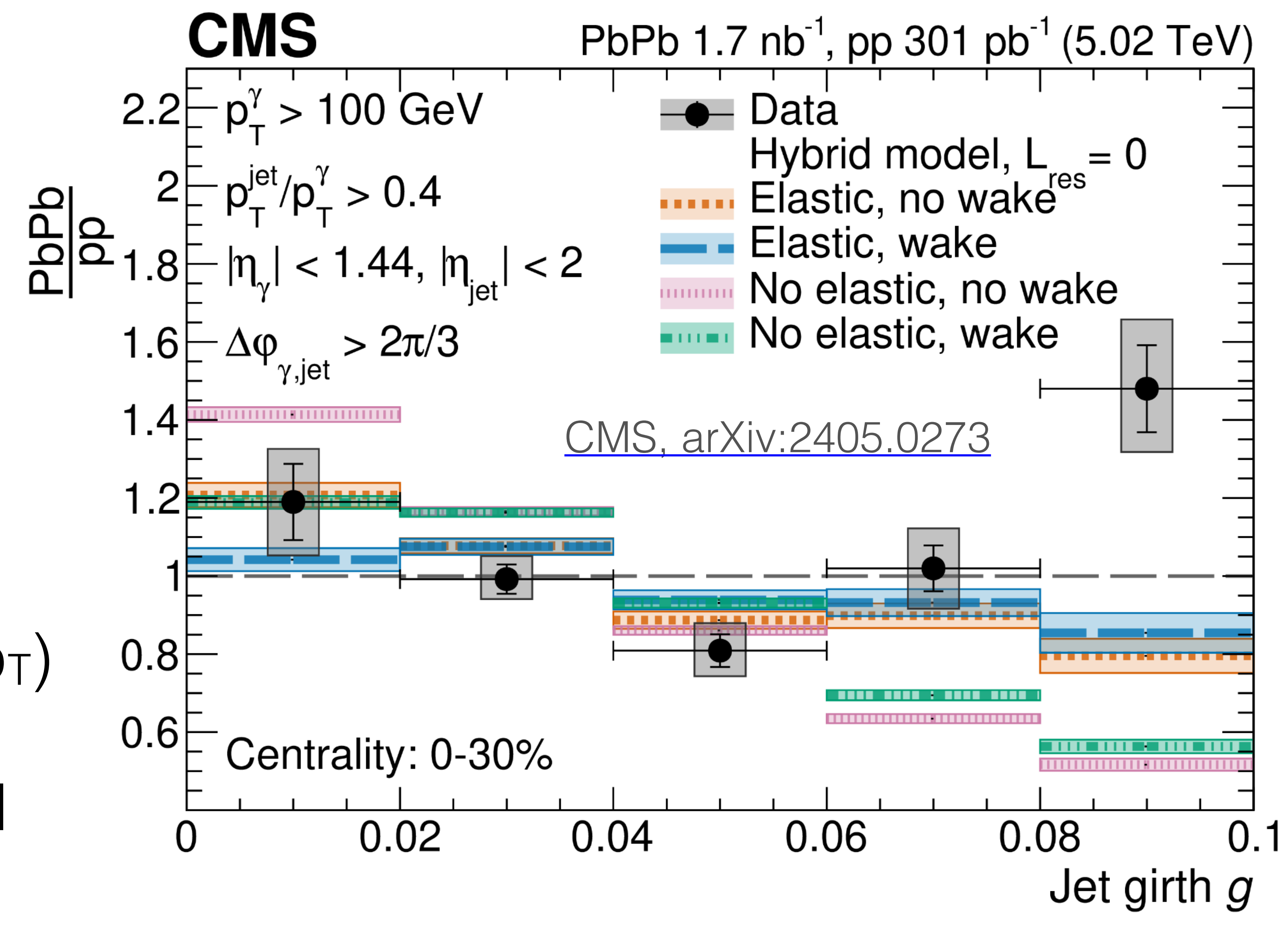
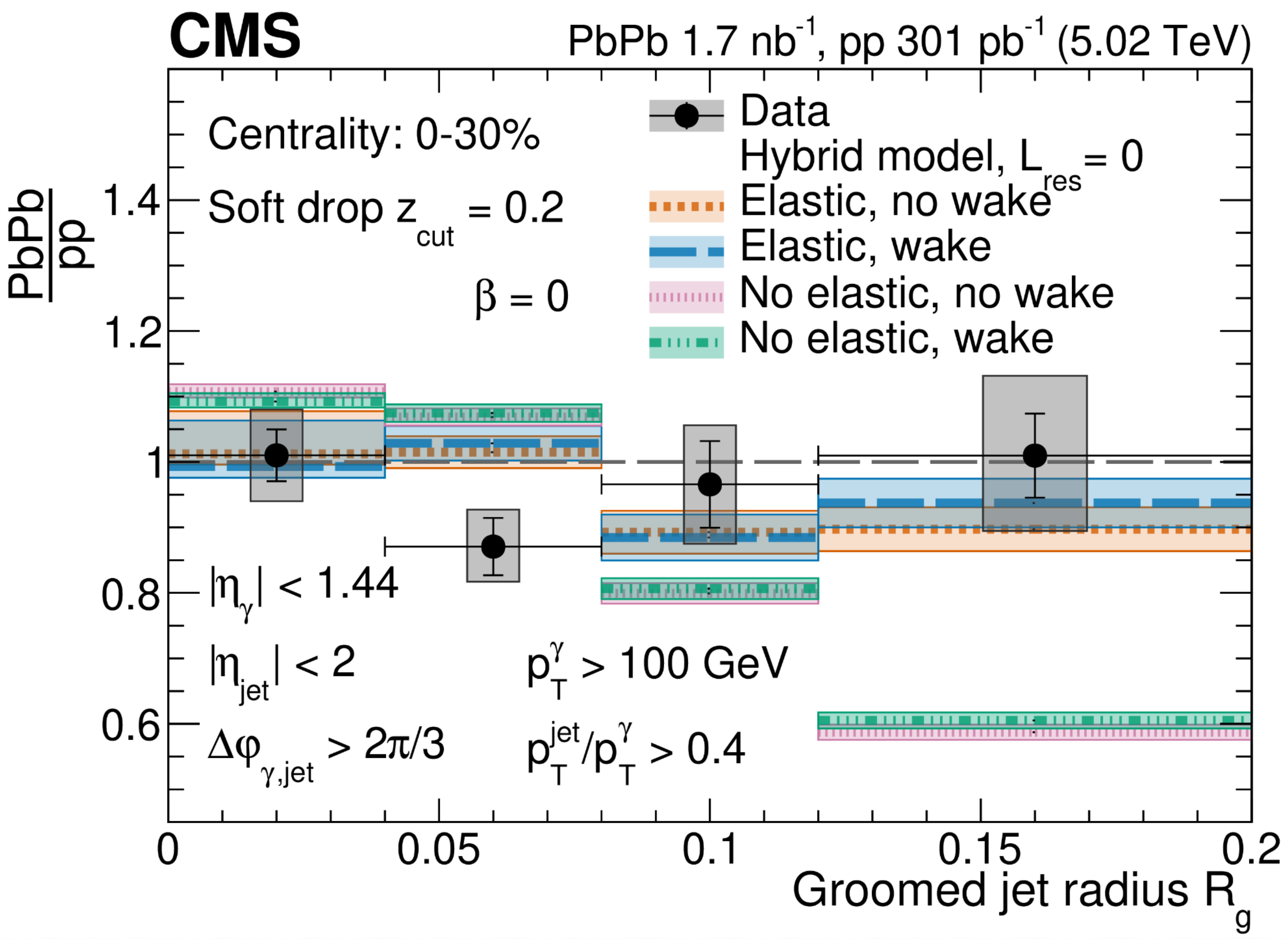
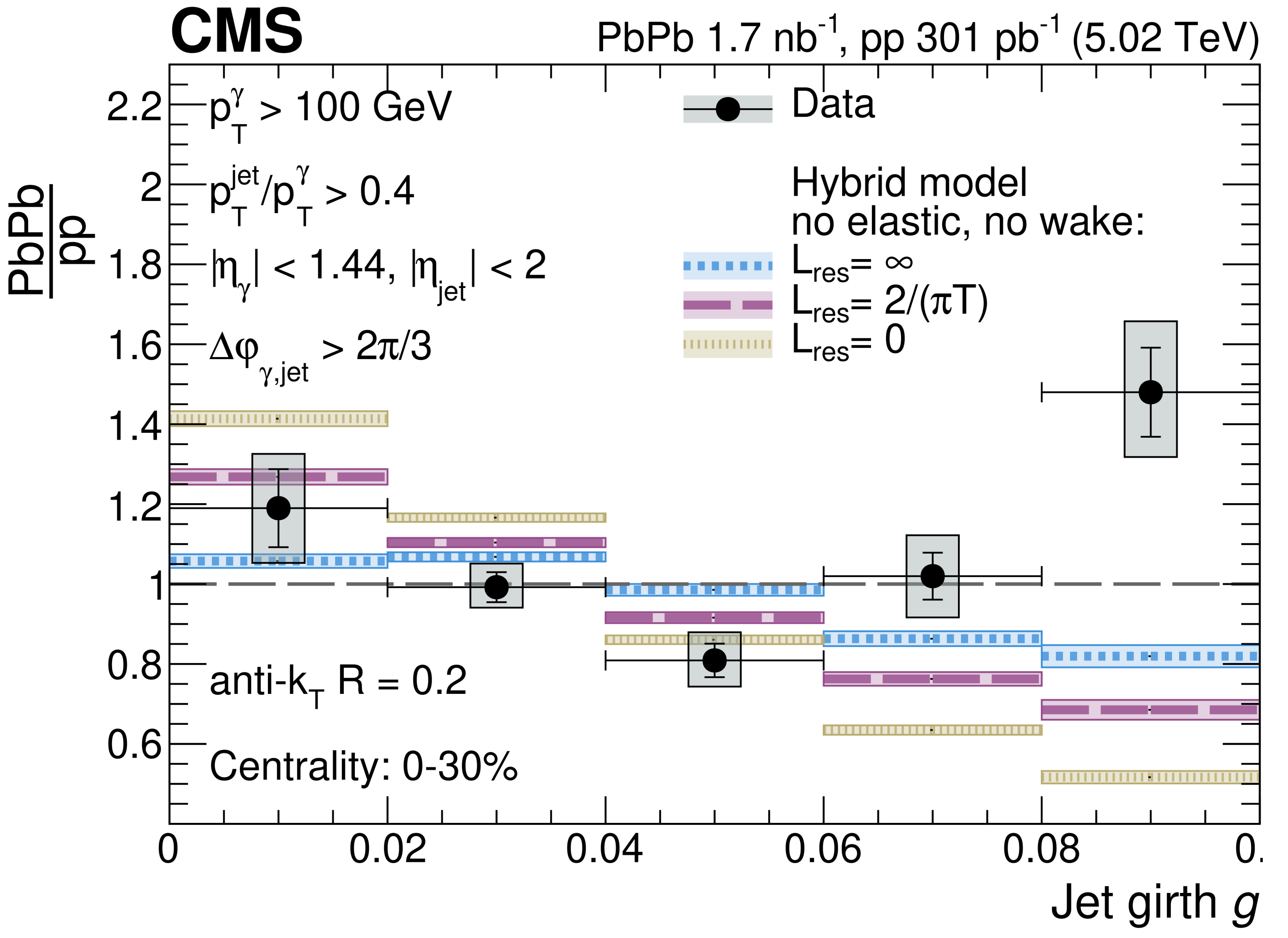
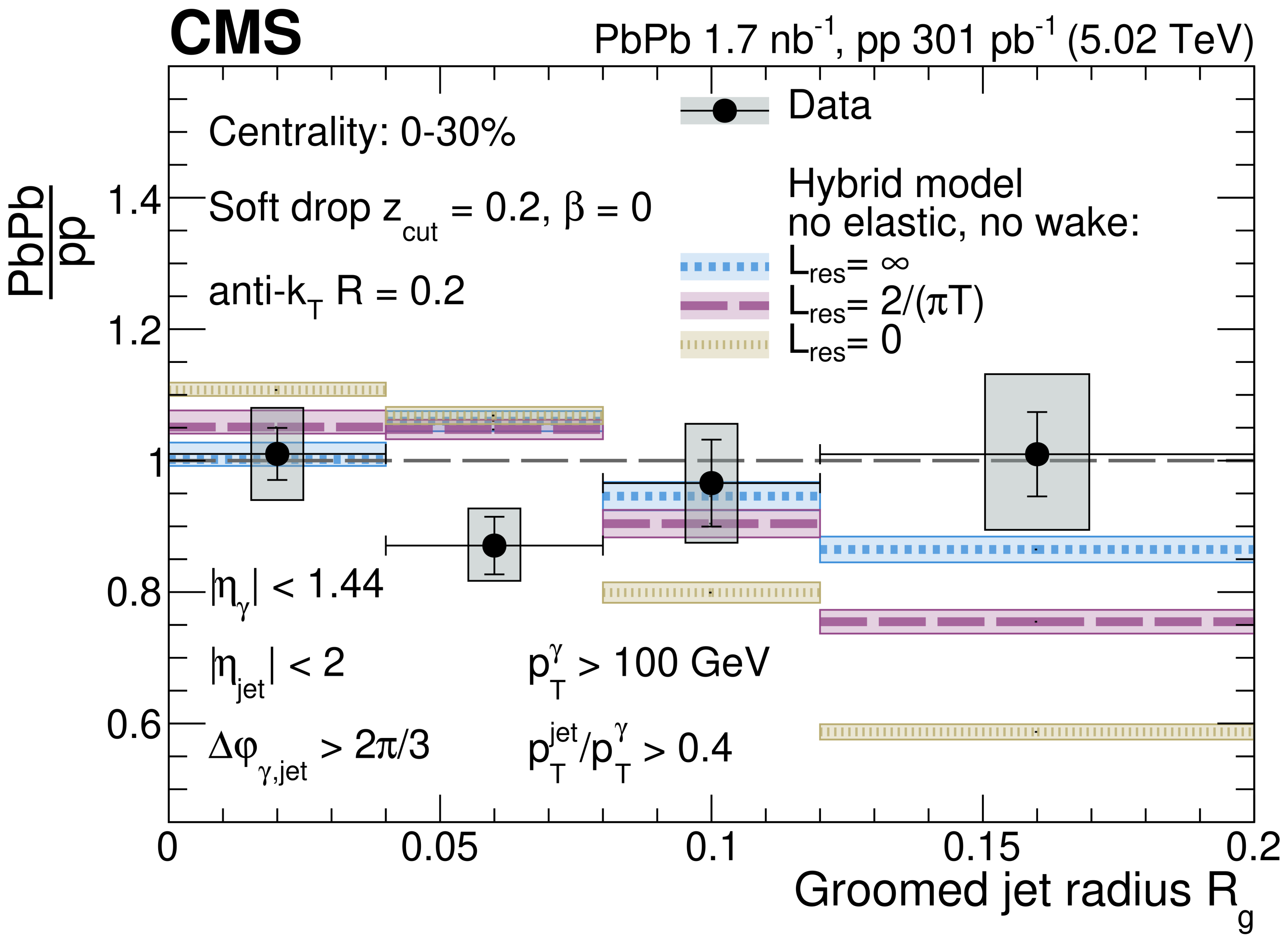




Varying coherence length

- L_{res} = 0: incoherent limit
- L_{res} = $2/(\pi T)$: intermediate
- $L_{res} \rightarrow \infty$: coherent limit

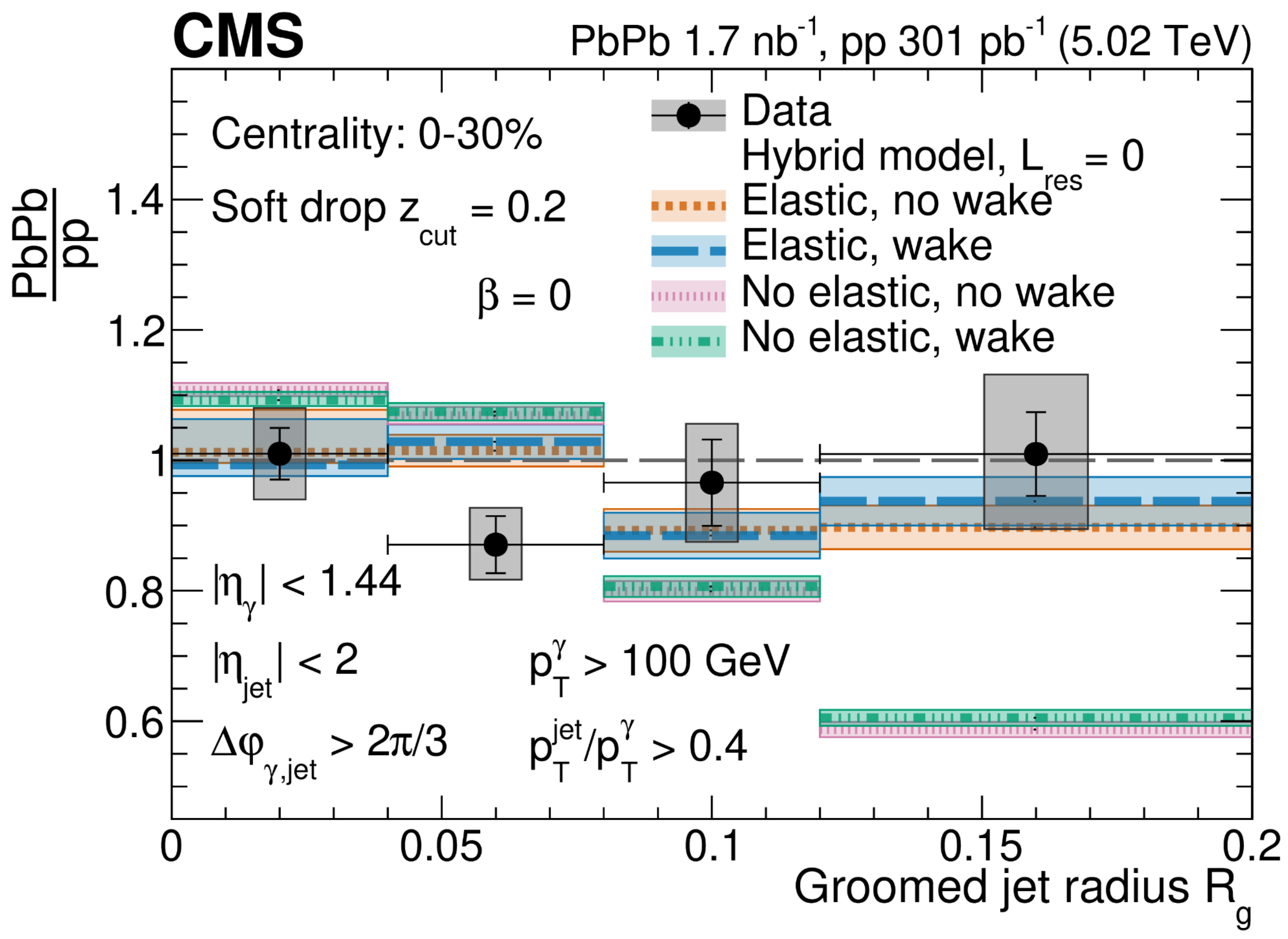




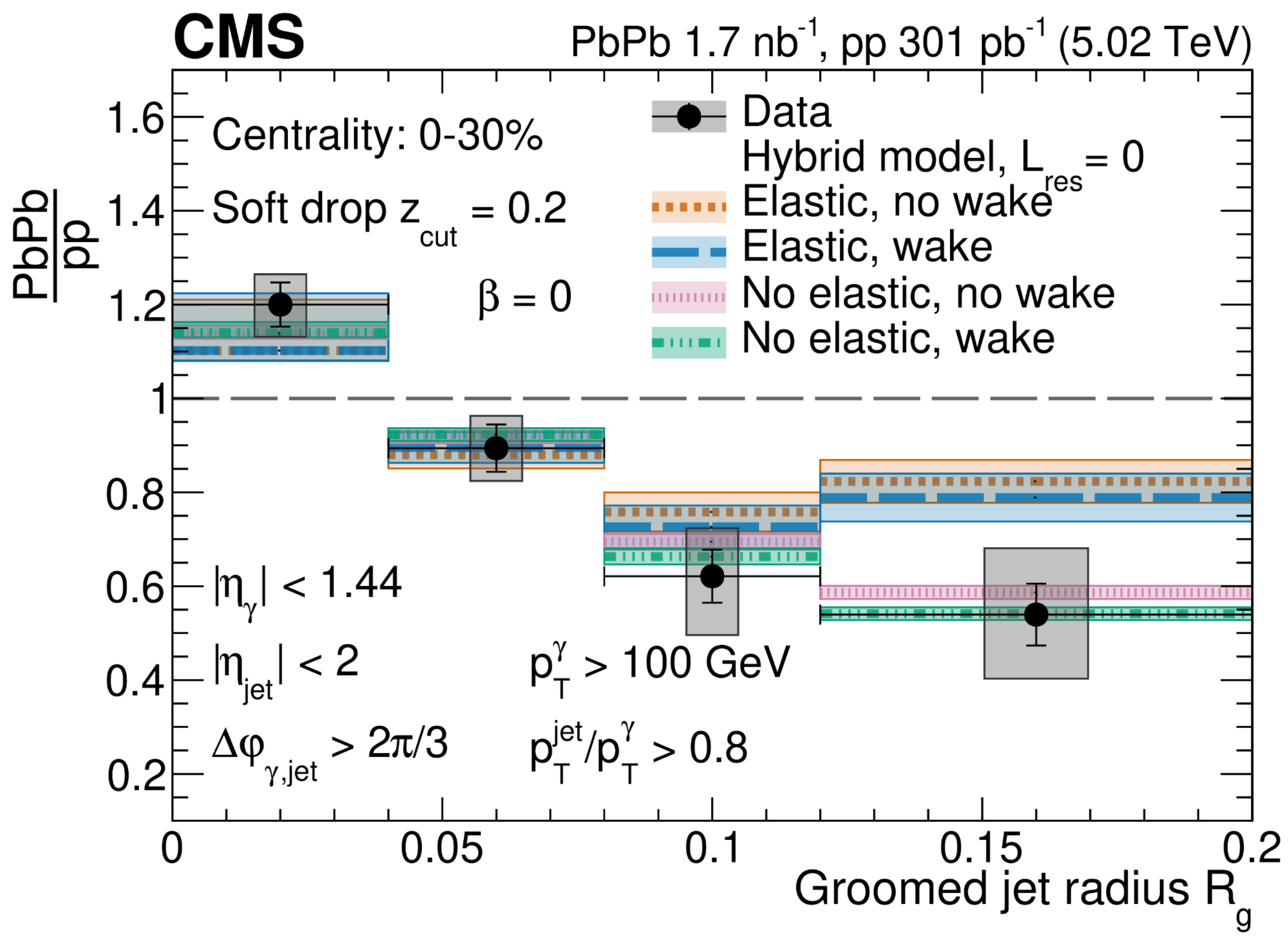
Summary

- Groomed jet radius and girth measured in γ+jet events in pp and PbPb
  - Leading recoil jet from $p_T > 100$ GeV photons studied for two selections:

$x_{\gamma j} > 0.4$ (w/ quenched jets):
no narrowing observed



$x_{\gamma j} > 0.8$ (less quenched jets):
narrowing is restored



CMS, arXiv:2405.0273