Photon-tagged jet fragmentation functions and jet shapes in pp and PbPb collisions with the CMS detector

Kaya Tatar
Massachusetts Institute of Technology
for the CMS Collaboration

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Introduction

Study modification of parton shower

  Gives info about the dynamics of hot QCD matter

Tools :

  Jet fragmentation function (FF)

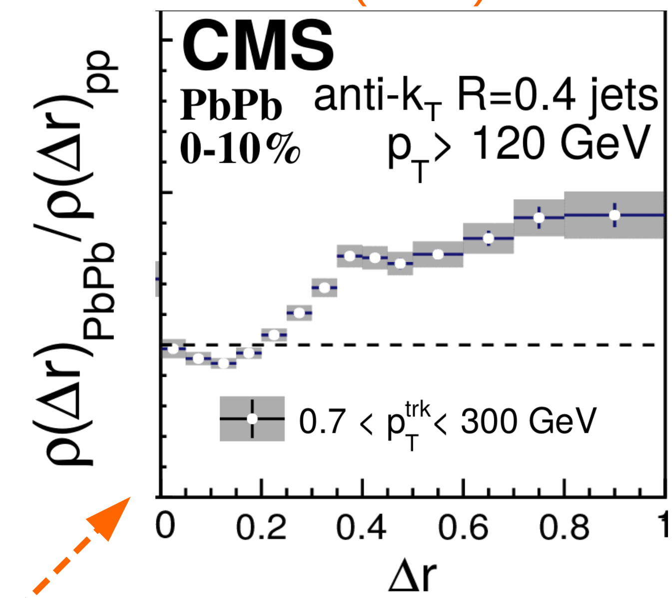
  - Longitudinal distribution of momentum

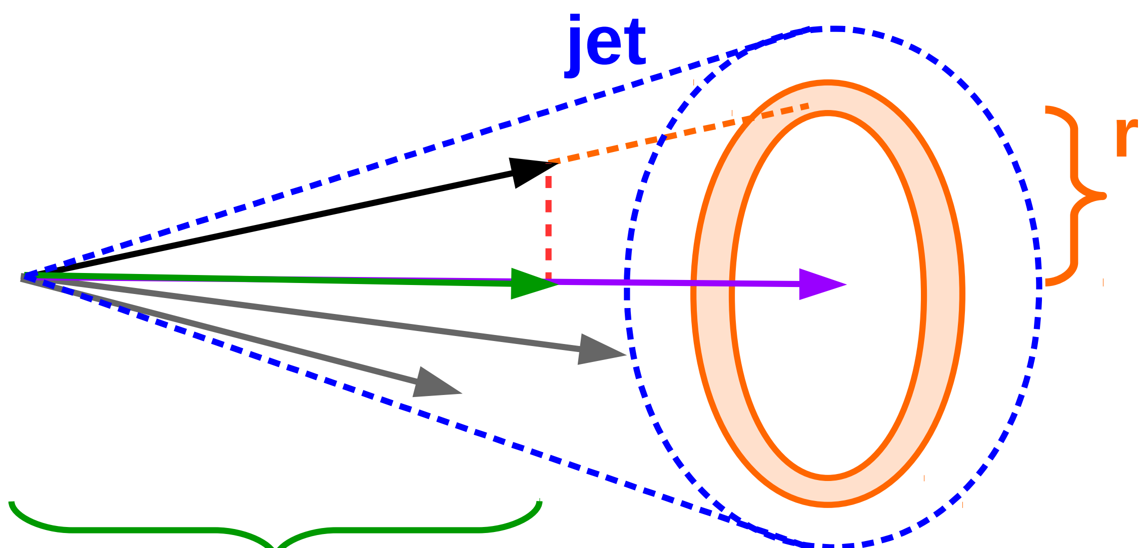
  Jet shapes (JS)

  - Distribution of jet energy in transverse direction

FF and JS provide different, but complementary info

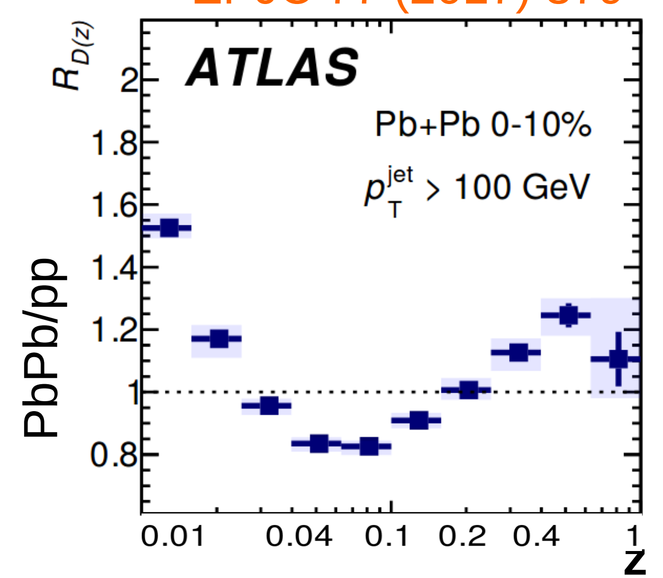
JHEP 05 (2018) 006



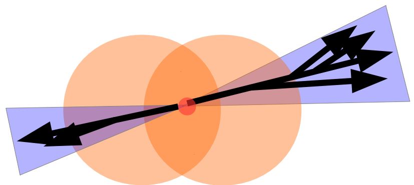


$$z \sim \frac{p_T^{h}}{p_T^{jet}}$$

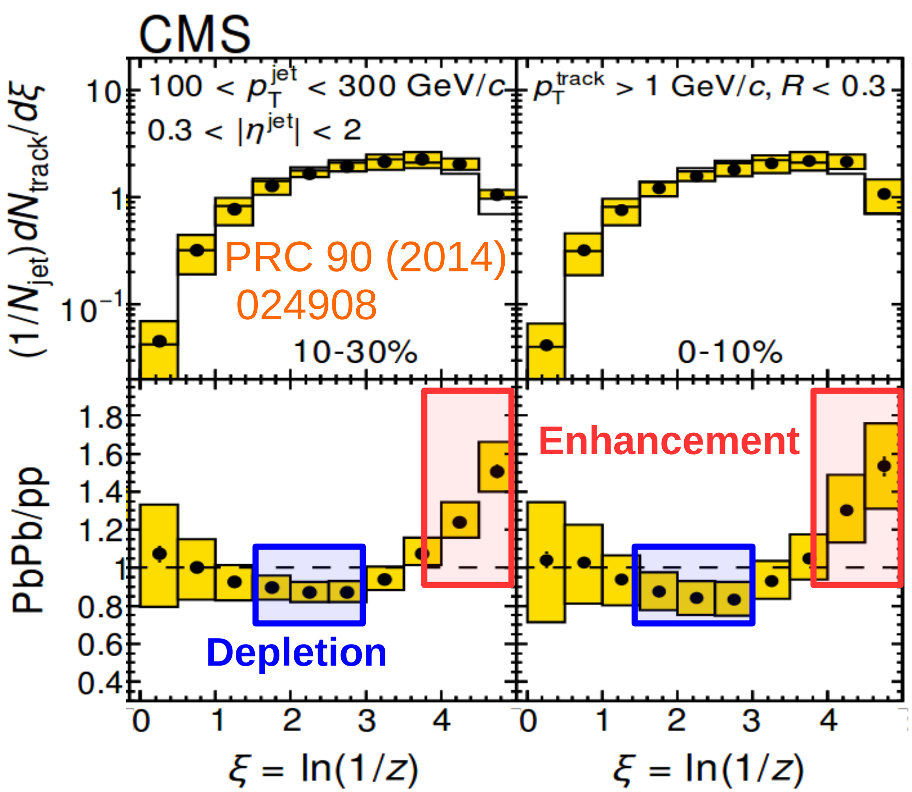
EPJC 77 (2017) 379



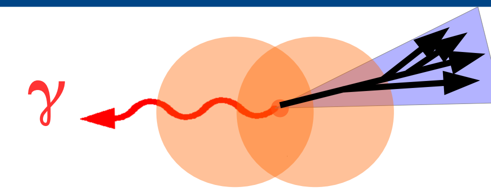
Inclusive jet vs photon+jet



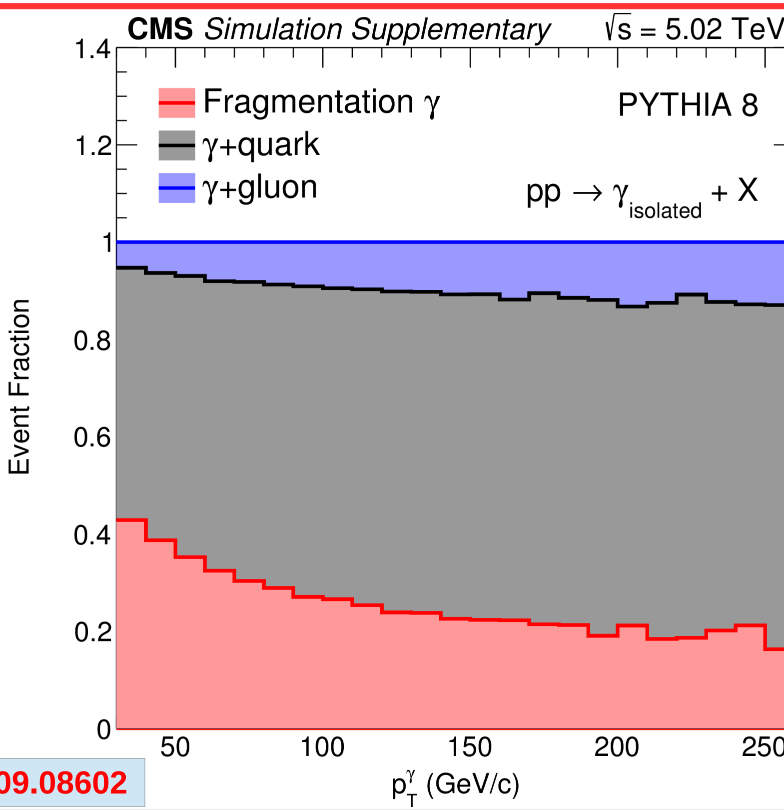
Inclusive jet
Compares samples with different initial states
Produced partons : mix of quarks and gluons



(high ξ – > low-p_T particle)



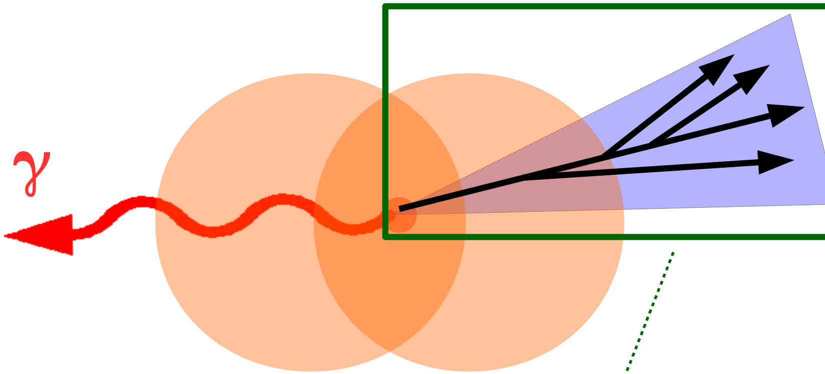
Photon+jet
Photon-tag **controls initial state**
Produced partons : quark fraction enhanced
-- > Probe **quark jet** modification
-- > Insight for gluon modification when combined with inclusive jet



arXiv:1809.08602

Observables : ξ^{jet}

- Take tracks (charged particles) inside the jet cone.
- **Project** the track momentum to **jet axis**.
- Divide jet momentum by the projected track momentum.
- The natural log of this ratio is called ξ^{jet}.

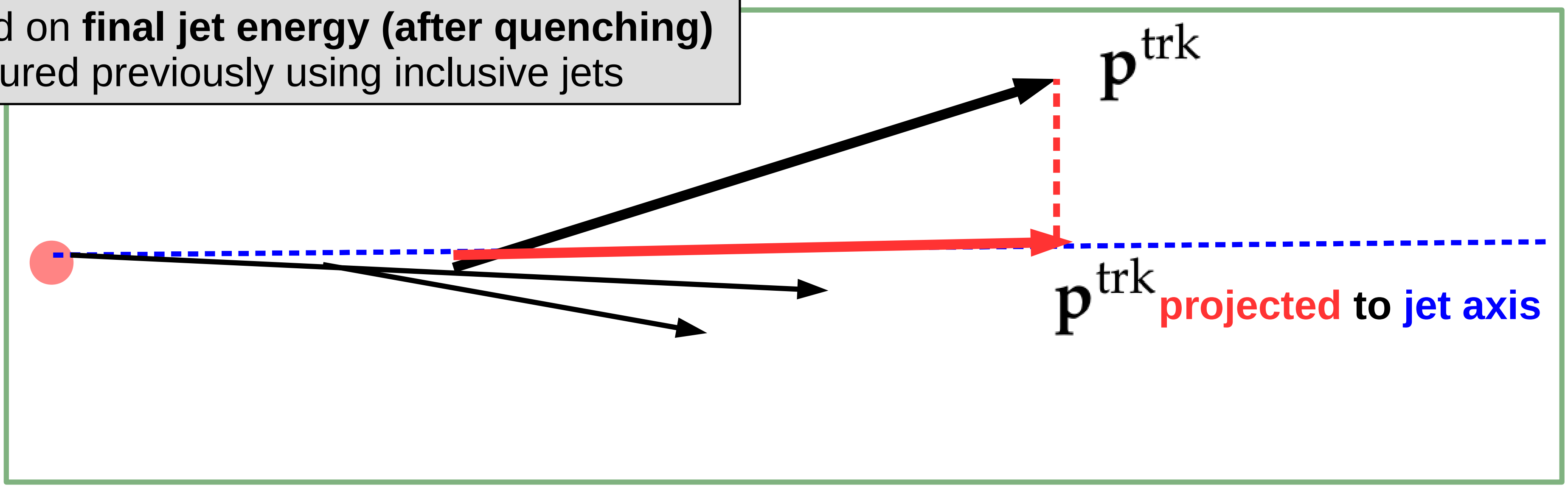


$$\xi^{\text{jet}} = \ln \frac{|\mathbf{p}^{\text{jet}}|^2}{\mathbf{p}^{\text{trk}} \cdot \mathbf{p}^{\text{jet}}}$$

$\mathbf{p}^{\text{jet}}$: 3-momentum vector of the jet

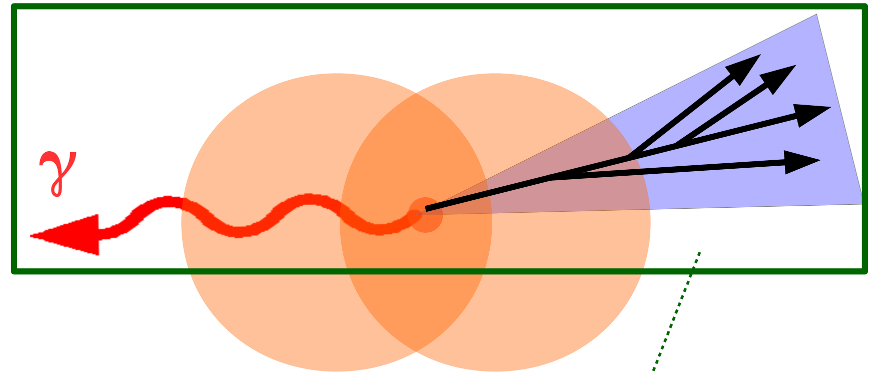
$\mathbf{p}^{\text{trk}}$: 3-momentum vector of the track

- Based on **final jet energy (after quenching)**
- Measured previously using inclusive jets



Observables : ξ_T^γ

- Take tracks (charged particles) inside the jet cone.
- Construct transverse momentum vectors for track and photon
- Invert the track transverse momentum
- Follow the same logic as for ξ^{jet}.

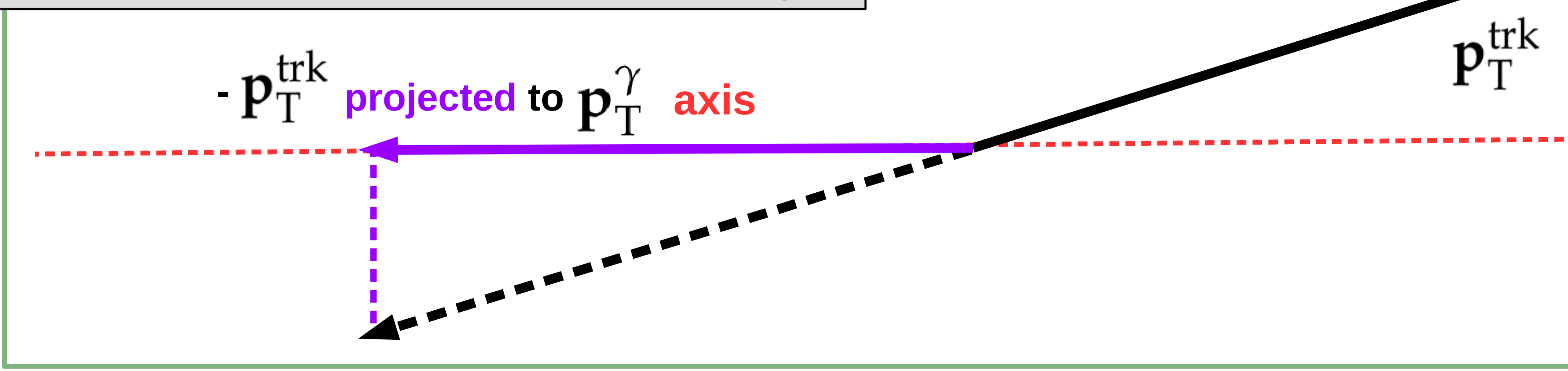


$$\xi_T^\gamma = \ln \frac{-|\mathbf{p}_T^\gamma|^2}{\mathbf{p}_T^{trk} \cdot \mathbf{p}_T^\gamma}$$

$\mathbf{p}_T^\gamma$: transverse momentum vector of the photon

$\mathbf{p}_T^{trk}$: transverse momentum vector of the track

- Based on **photon energy**
- Measured for the **first time** for reconstructed jets



Object Selections

Photons

$p_T^{\gamma} > 60$ GeV/c

$|\eta^{\gamma}| < 1.44$

Jets

anti-k_T, R=0.3

$p_T^{jet} >$ 30 GeV/c

$|\eta^{jet}| < 1.6$

$\Delta\varphi$(photon, jet) $> 7\pi/8$

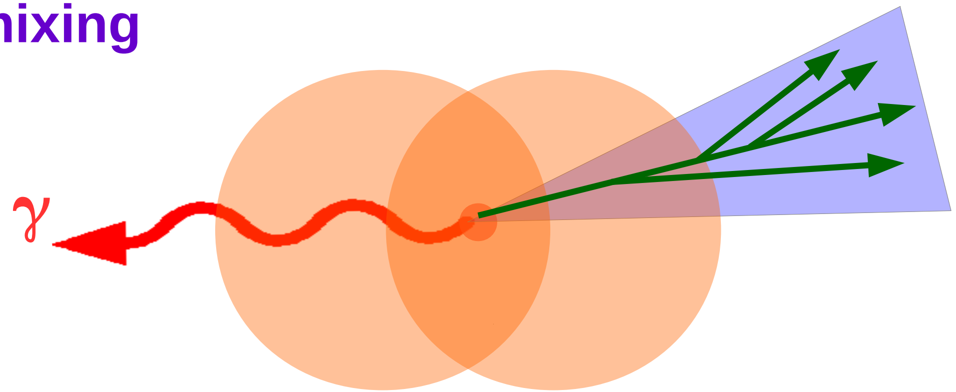
inclusive jets, bkg jets **subtracted via MB event mixing**

Tracks JHEP 04 (2017) 039

$p_T^{trk} >$ 1 GeV/c

ΔR(jet, track) < 0.3

Bkg tracks **subtracted via MB event mixing**



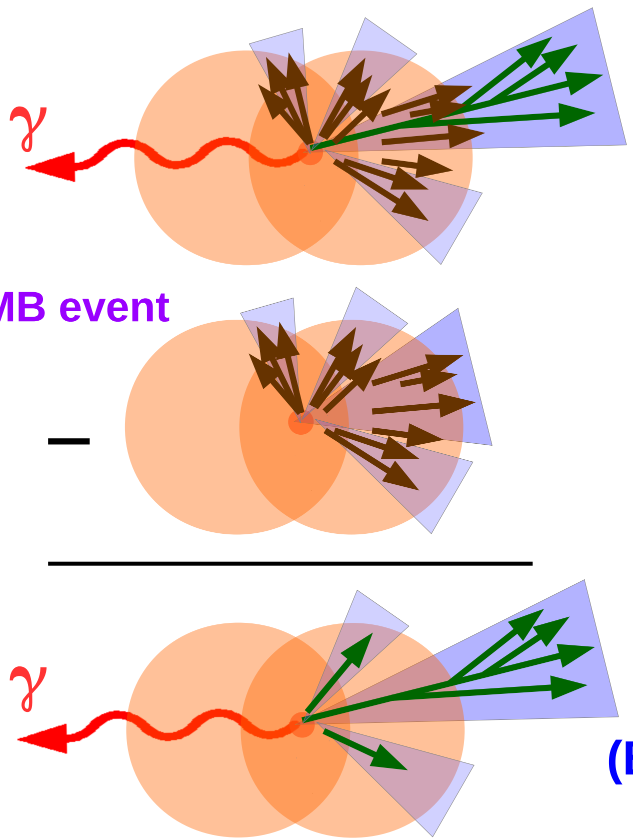
Background sources

- **Tracks from underlying event (UE) –>** Subtracted via Min Bias event mixing
- **Mis-identified (fake) jets –>** Subtracted via Min Bias event mixing
- **photons from neutral meson decays**
  - rejected using shower shape cut, remaining bkg fraction estimated via template fit

Background subtraction for tracks

arXiv:1801.04895

isolated-photon+jet event



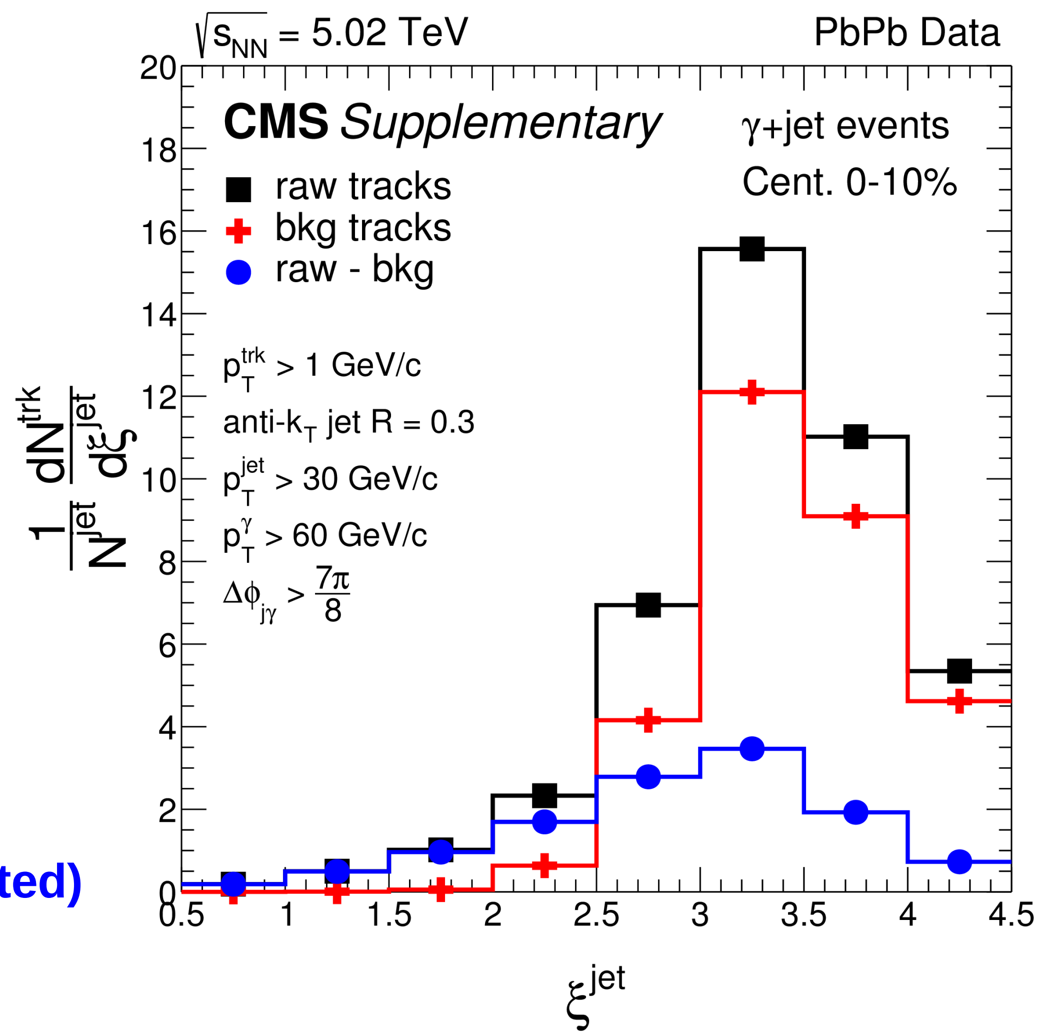
Raw tracks inside jet cone

MB event

–

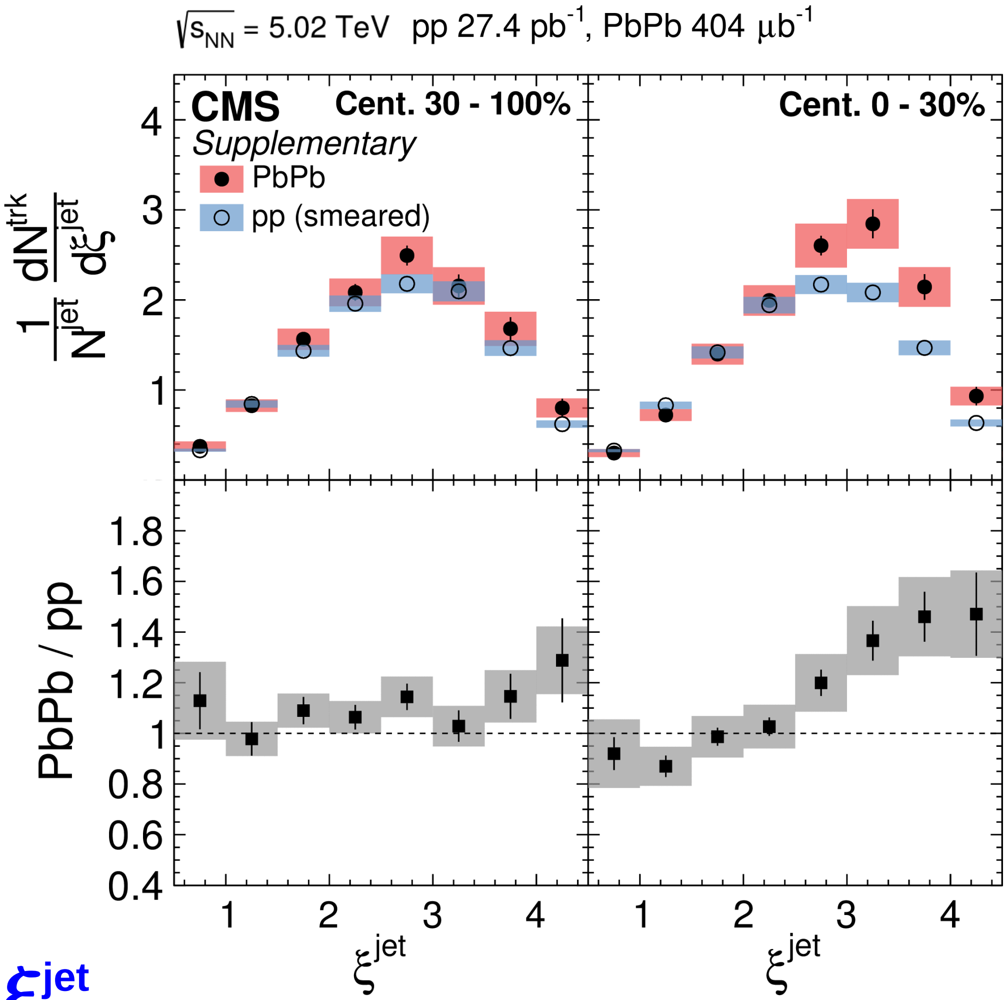
Bkg tracks inside jet cone

Raw – Bkg (Bkg track subtracted)



Results : ξ^{jet} vs ξ_T^{γ}

arXiv:1801.04895

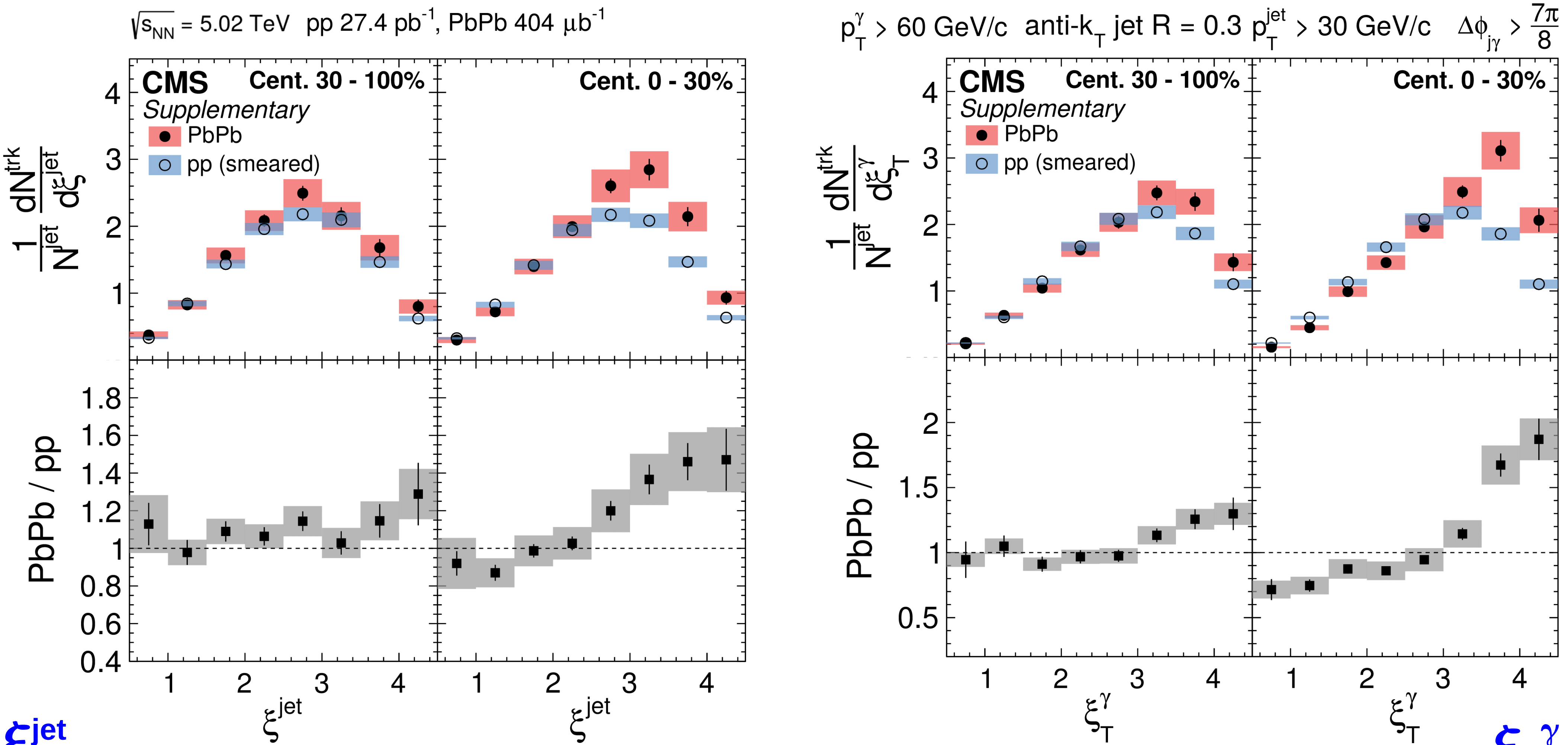


ξ^{jet}

- Based on reconstructed jet energy (energy after quenching)

Results : ξ^{jet} vs ξ_T^{γ}

arXiv:1801.04895



ξ^{jet}

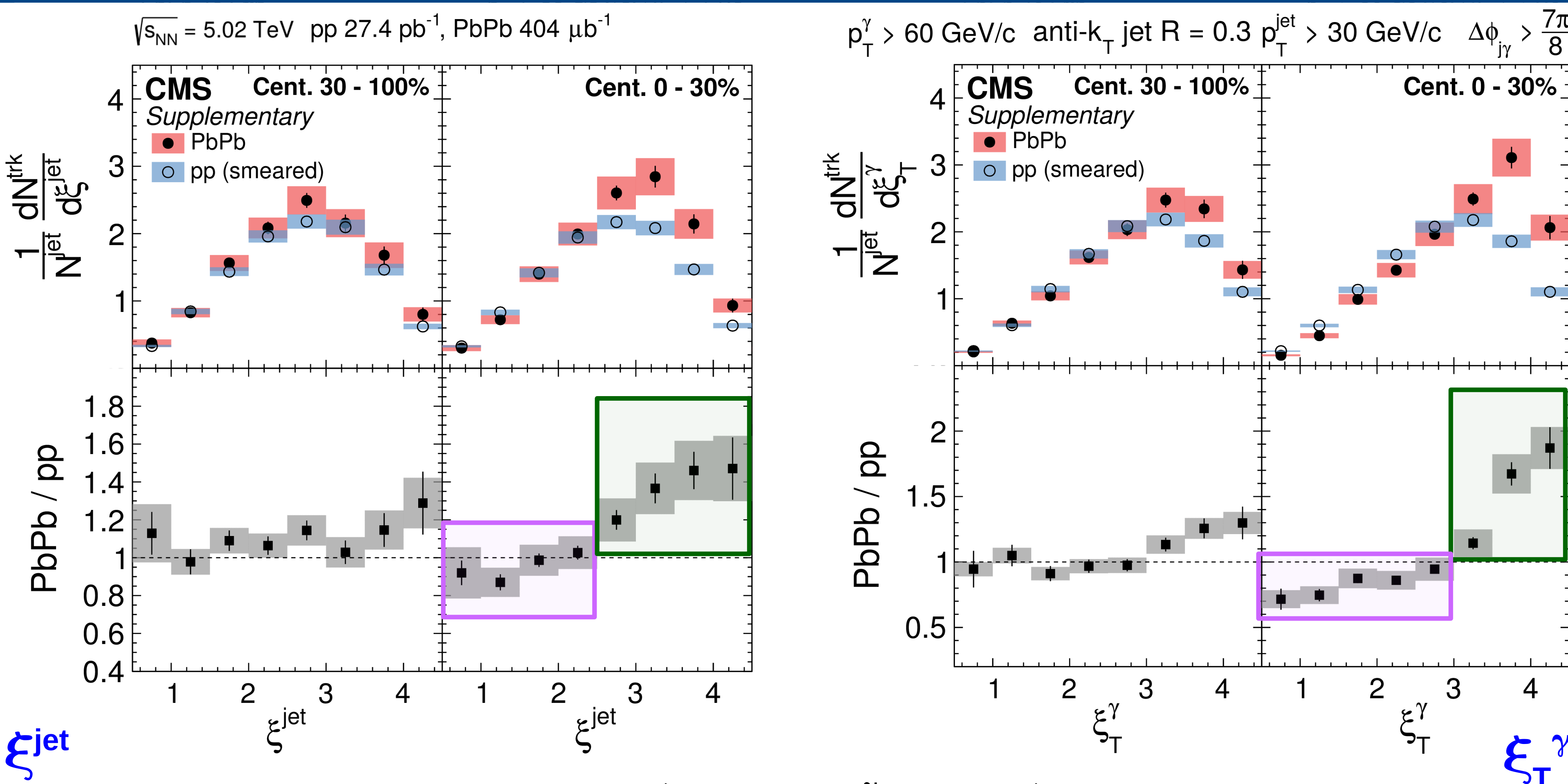
ξ_T^{γ}

- Based on reconstructed jet energy (energy after quenching)
- Based on photon energy

- ξ^{jet} shifted to left compared to ξ_T^{γ}
  - Out-of-cone radiation, photon+multijet

Results : ξ^{jet} vs ξ_T^{γ}

arXiv:1801.04895



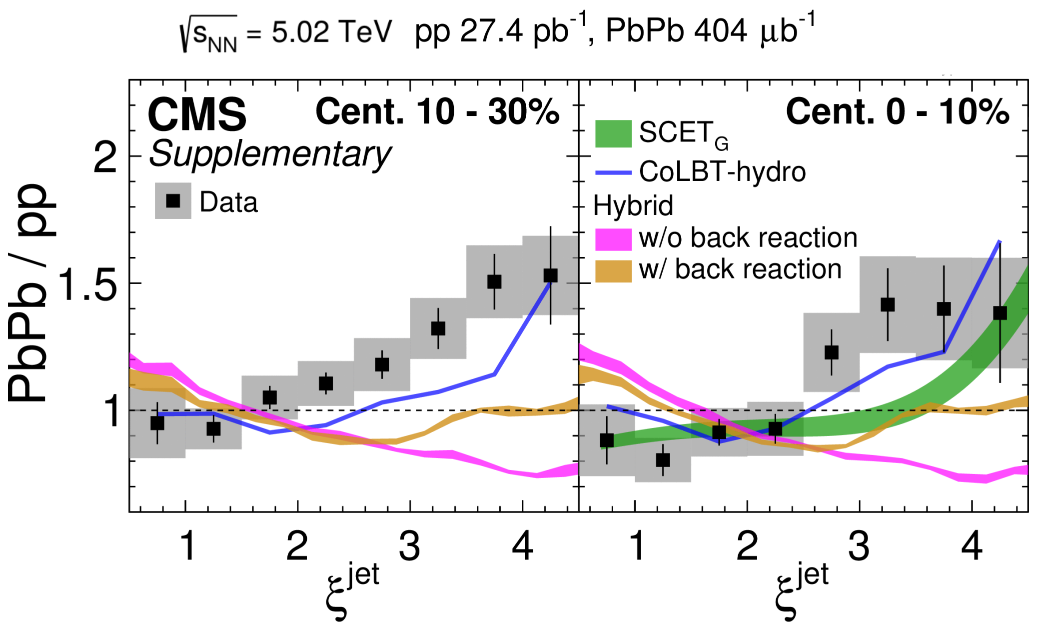
Transition at $\xi^{jet} \approx 2.5$ and $\xi_T^{\gamma} \approx 3$ –> $p_T^{trk} \approx 3$ GeV

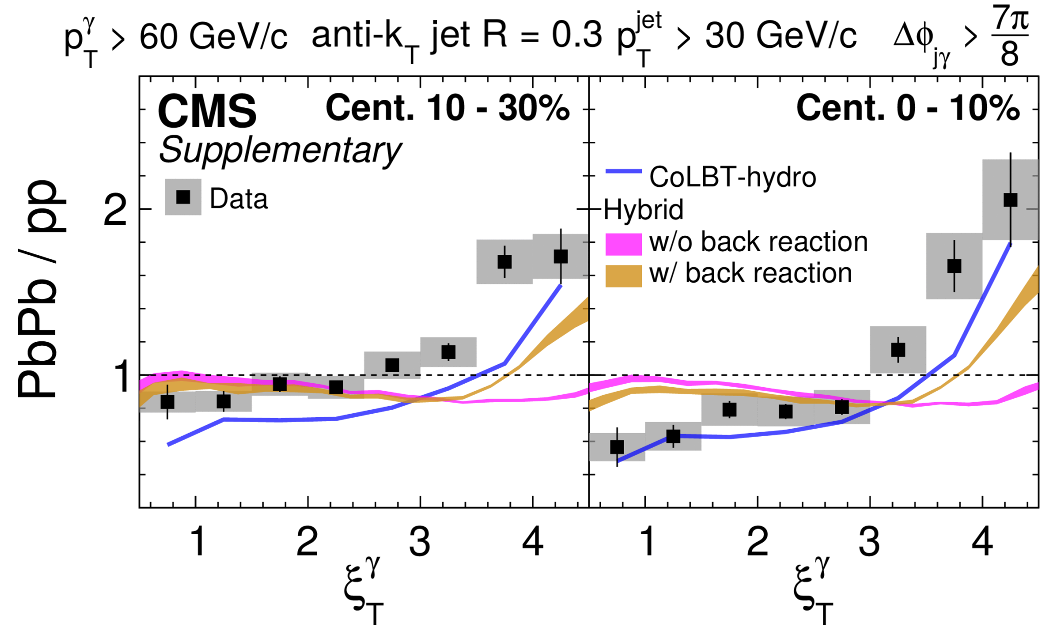
Central PbPb collisions – > **enhancement of low-p_T particles** and a **depletion of high-p_T particles**

ξ_T^{γ} modified stronger compared to ξ^{jet}

ξ^{jet} and ξ_T^{γ} vs Theory

arXiv:1801.04895





SCET$_G$ (JHEP 11 (2016) 155)

- Framework decomposing Soft Collinear and Glabuer models

CoLBT-hydro (Phys. Lett. B, 777 (2018) 86)

- Couples LBT for jet evolution with (3+1)D hydrodynamics
- Combines pQCD approach with hydro simulation of medium

Hybrid (JHEP 1410 (2014) 019, JHEP 1603 (2016) 053)

- Weak coupling : high-Q² processes using pQCD
- Strong coupling : low-Q² interactions between parton shower and medium
- Weak and strong coupling are combined

Turnover at $\xi^{jet} \approx 2.5$ and $\xi_T^{\gamma} \approx 3$ –> $p_T^{trk} \approx 3$ GeV

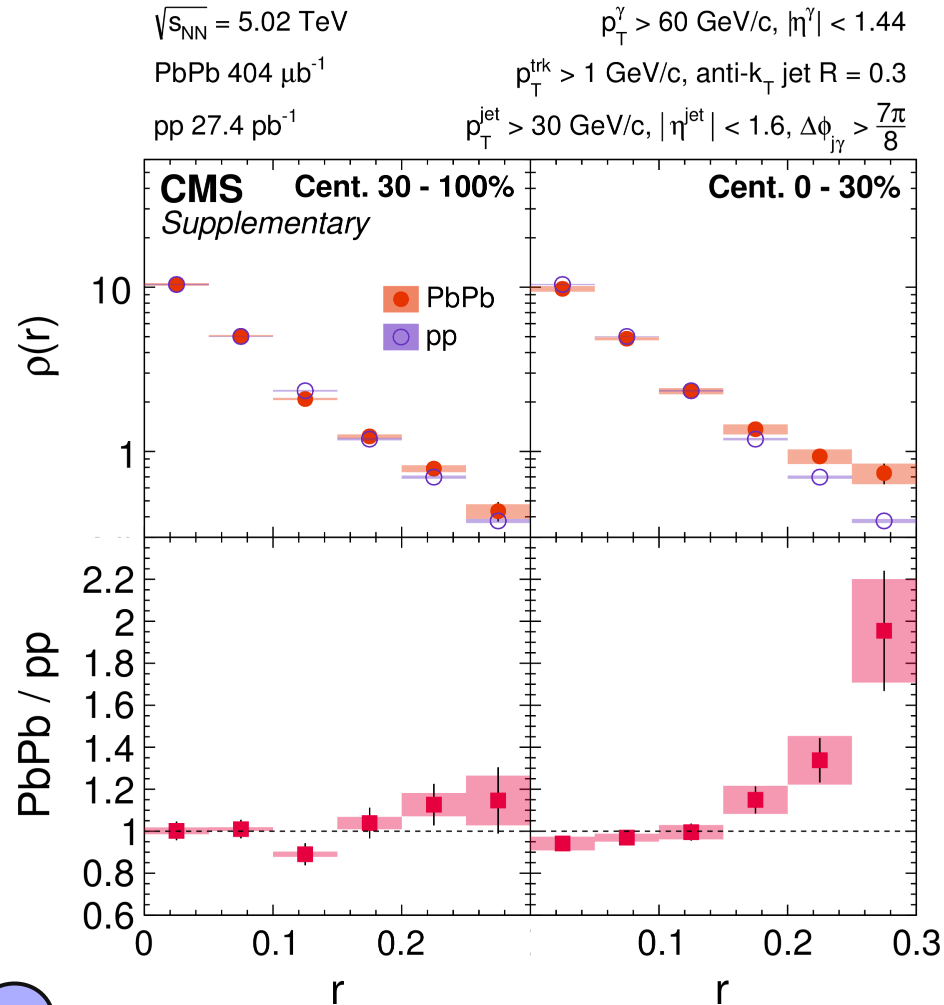
Large enhancement from particles after turnover
-- > Models tend to underpredict this
-- > Medium response important for **CoLBT** and **Hybrid**

Other ingredients considered by theory

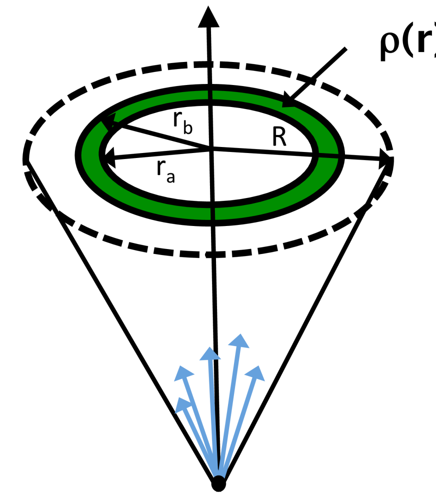
- Medium-induced radiation
- Effects of medium on hadronization

γ-tagged jet shape

arXiv:1809.08602



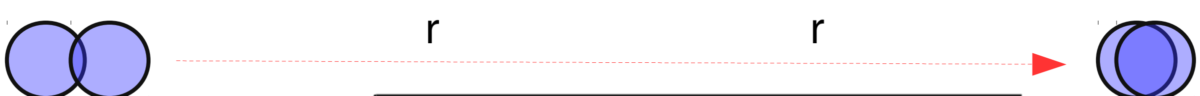
$$\rho(r) = \frac{1}{\delta r}\frac{\sum_{\text{jets}} \sum_{\text{trk}\in[r_a,r_b)} (p_T^{\text{trk}}/p_T^{\text{jet}})}{\sum_{\text{jets}} \sum_{\text{trk}\in[0,r_f)} (p_T^{\text{trk}}/p_T^{\text{jet}})}$$



ρ(r) normalized to unity over **r < 0.3**

Results are corrected for detector resolution, particle reco.

pp results are **NOT** smeared



$$r = \sqrt{(\eta_{\text{track}} - \eta_{\text{jet}})^2 + (\phi_{\text{track}} - \phi_{\text{jet}})^2}$$

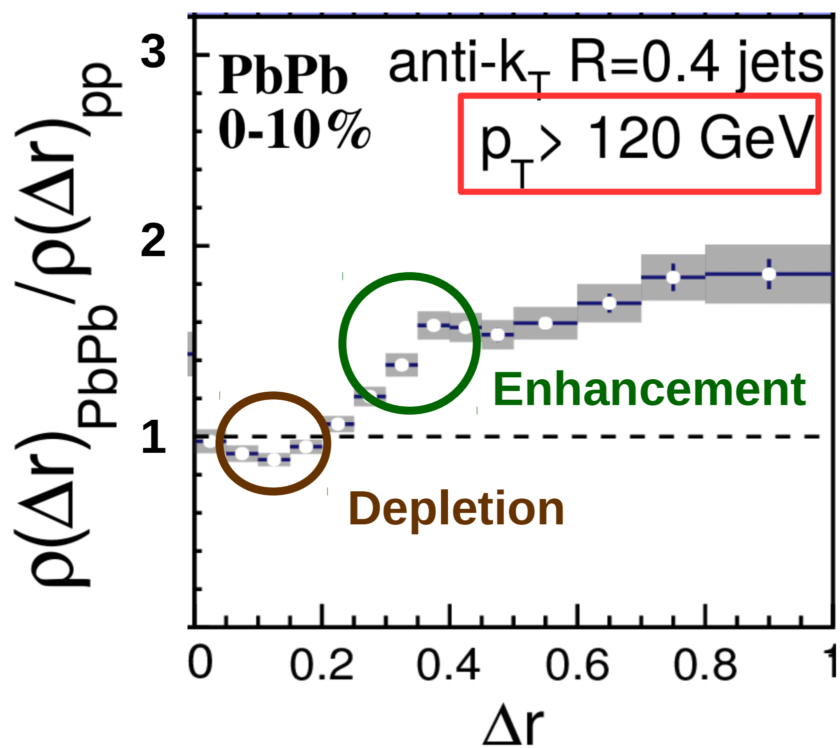
Central PbPb collisions – > a **larger fraction of jet energy** at **large distances** from the jet axis.

inclusive vs γ-tagged jet shape

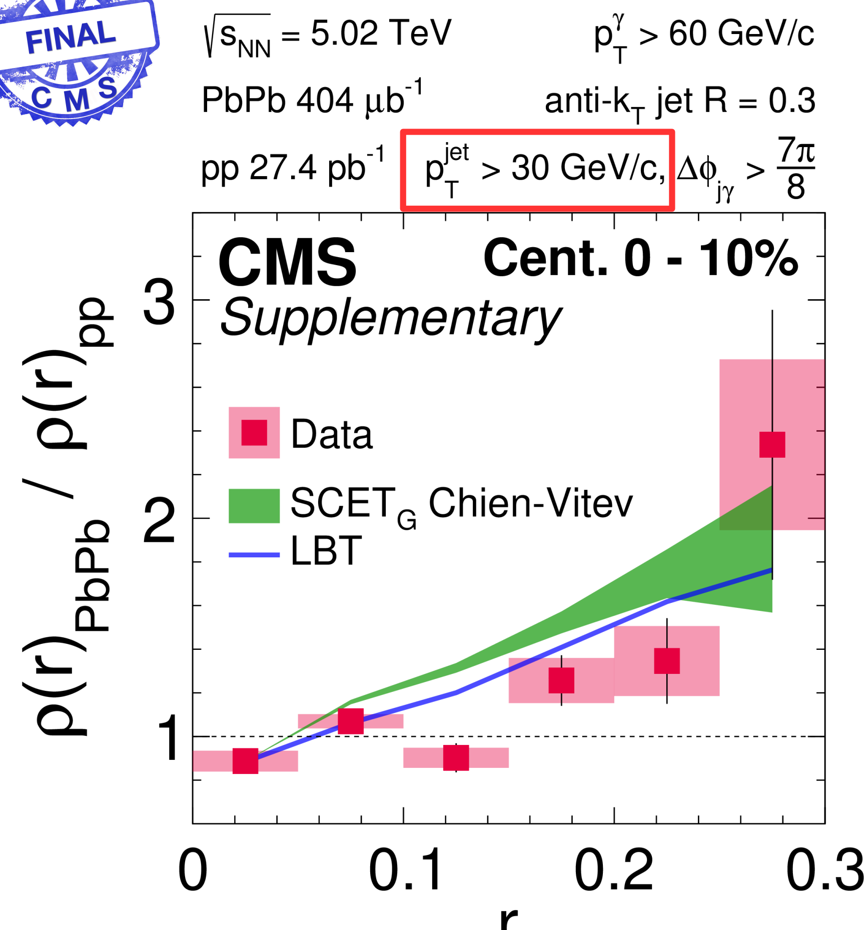
JHEP 05 (2018) 006

arXiv:1809.08602

Inclusive jets



ρ(r) normalized to unity over
r < 1.0 (inclusive jets)
r < 0.3 (γ+jet)



γ+jet :

Larger enhancement at large r. **Smaller depletion** at intermediate r.

- Increased quark fraction (70-80%) ?
- Lower jet p_T threshold (higher fraction of quenched jets) ?

SCET$_G$ [JHEP 05 (2016) 023]

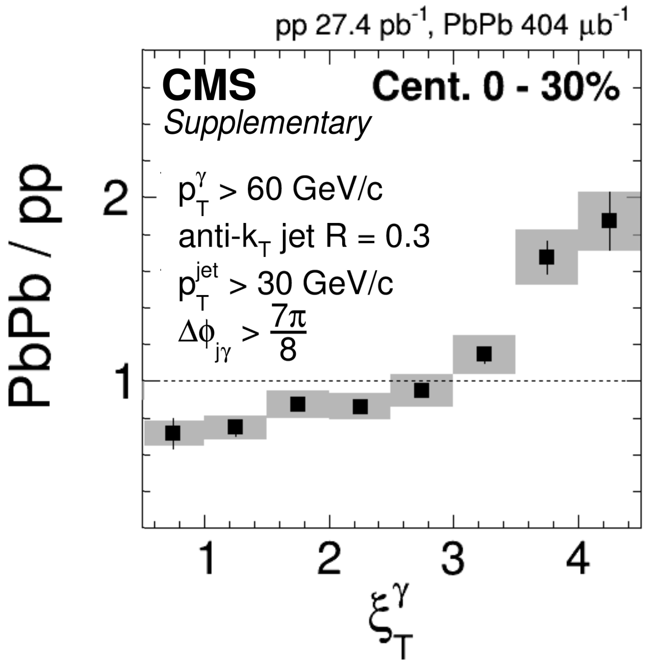
LBT [Phys. Lett. B, 782 (2018) 707]

Models describe data well.

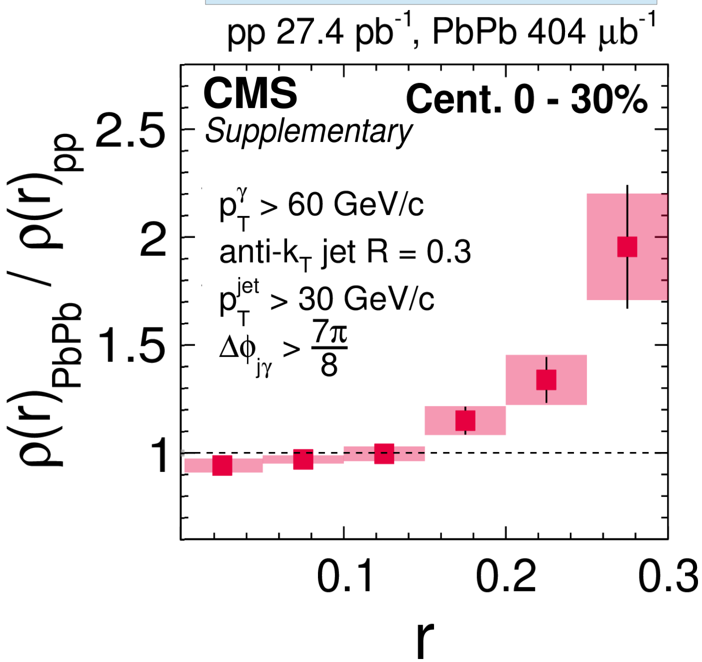
Summary

- FF and jet shapes (JS) measured for jets tagged with isolated-photons.
  - Constrains the **initial parton kinematics** and probes **quark-jet** modification.
- FF modification – > excess of low-p_T particles and depletion of high-p_T particles inside the jet cone.
  - FF observable wrt photon energy – > robust measurement, larger modification
- JS modification – > a larger fraction of jet energy is carried at large distances from the jet axis.
  - No large depletion at intermediate distances.
- Models seem to describe both longitudinal and transverse jet structure.

arXiv:1801.04895



arXiv:1809.08602



Acknowledgements : The MIT group's work was supported by US DOE-NP.

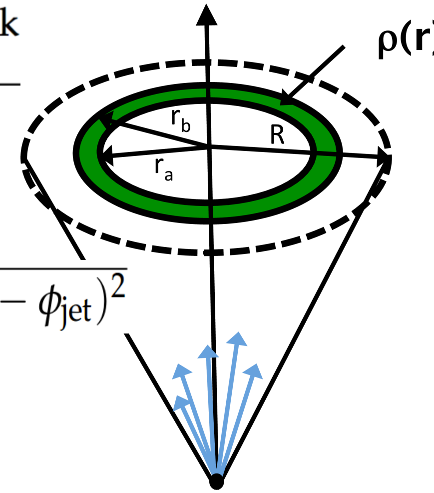
BACKUP

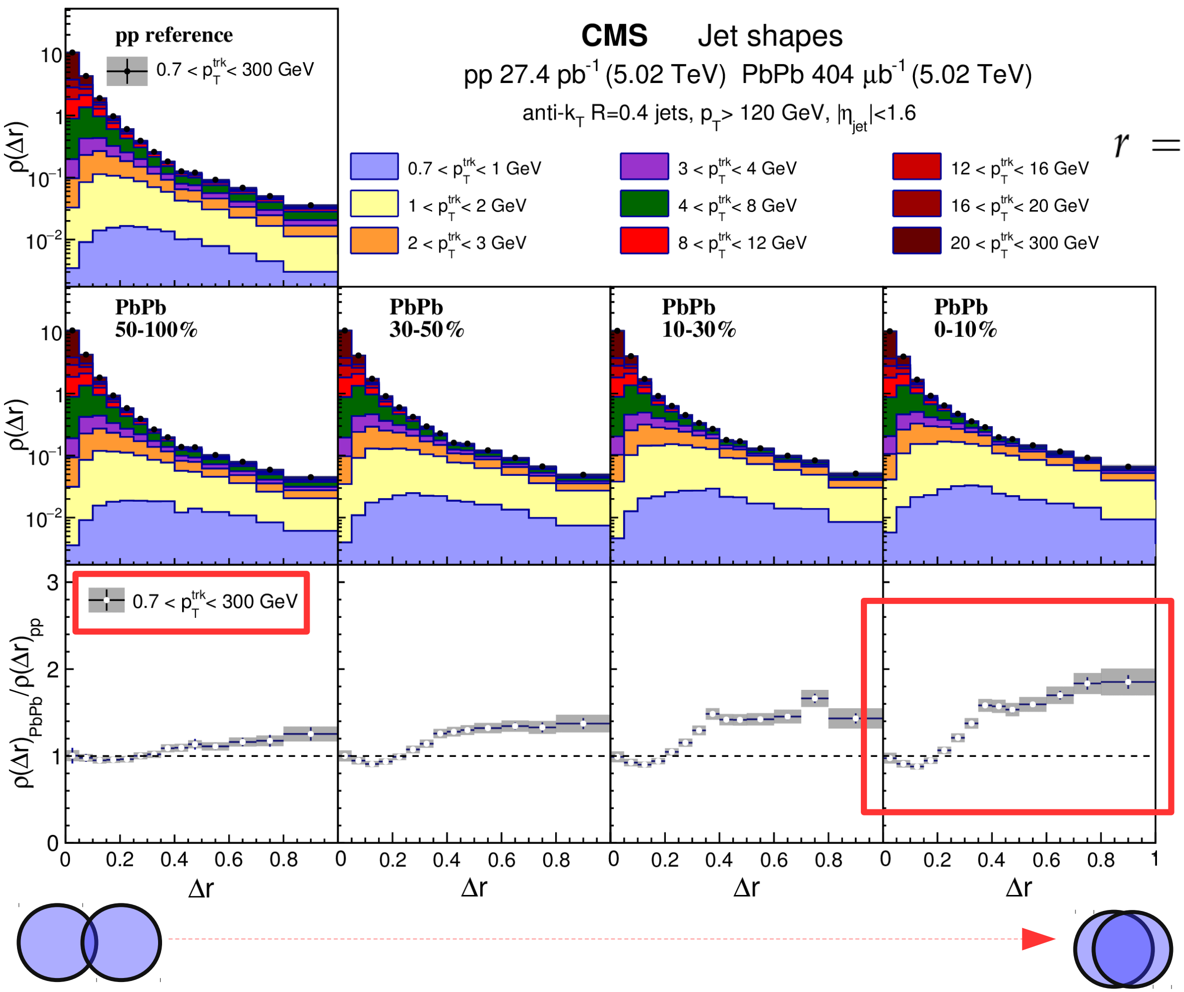
Inclusive jet shape

JHEP 05 (2018) 006

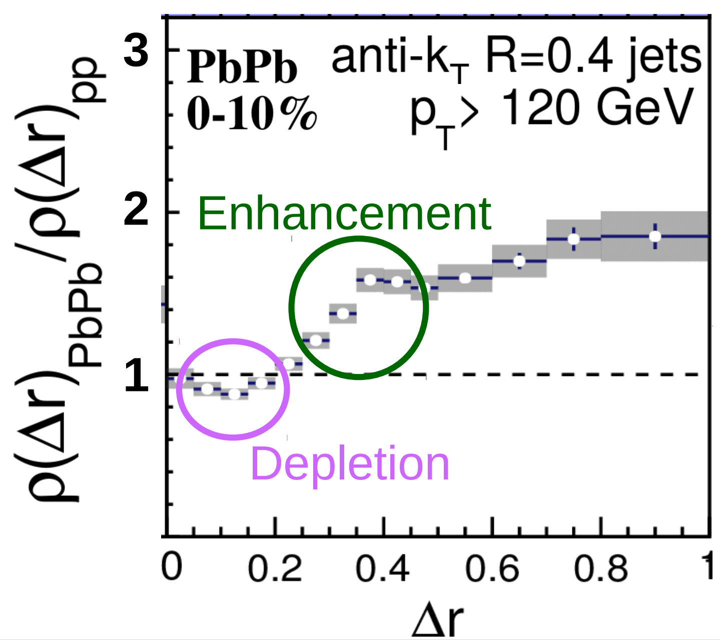
$$\rho(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{\text{jets}}}\Sigma_{\text{jets}}\frac{\Sigma_{\text{tracks}\in(r_a,r_b)}\, p_T^{\text{trk}}}{\Sigma_{\text{tracks}}\, p_T^{\text{trk}}}$$

$$r = \sqrt{(\eta_{\text{track}}-\eta_{\text{jet}})^2 + (\phi_{\text{track}}-\phi_{\text{jet}})^2}$$



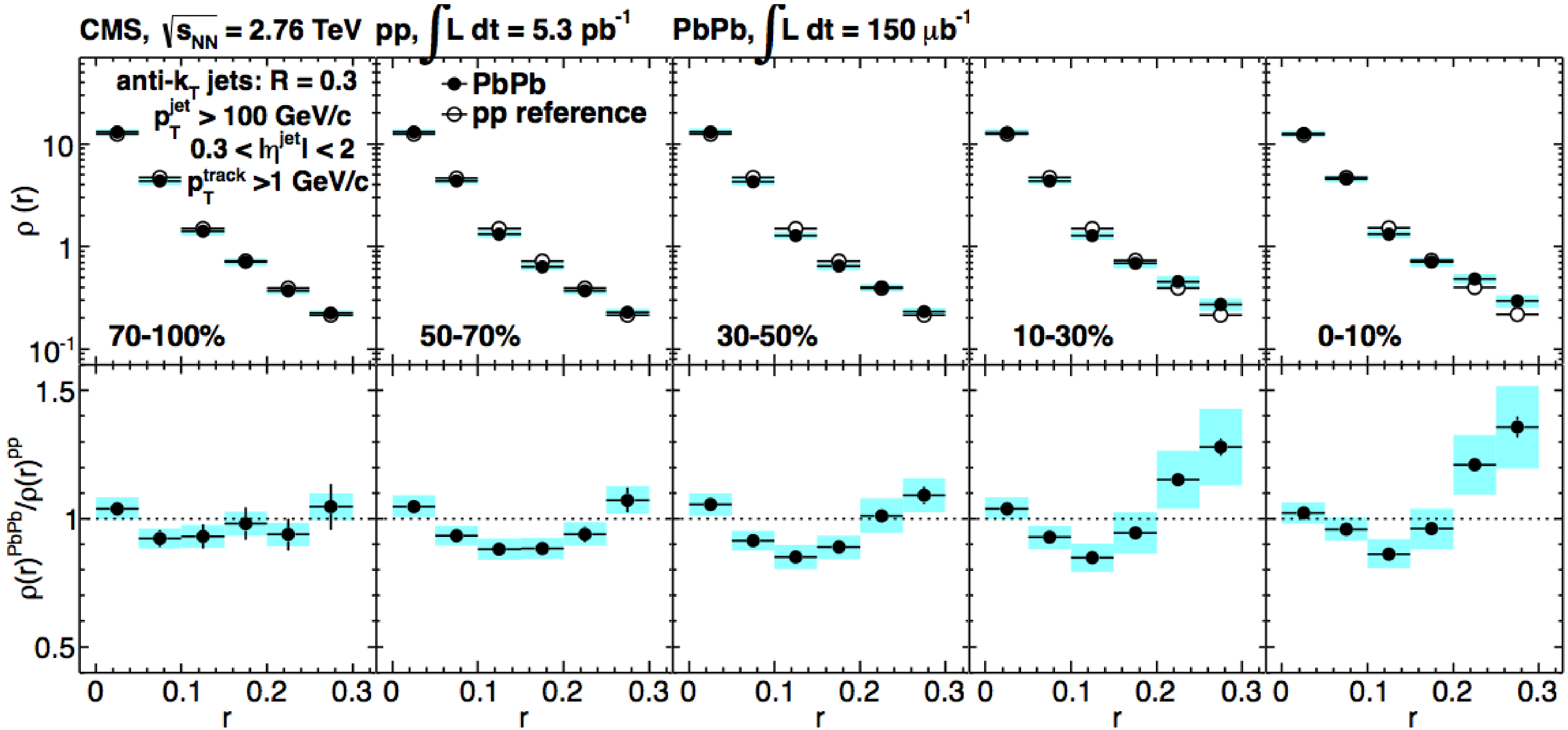


ρ(r) normalized to unity over **r < 1**.



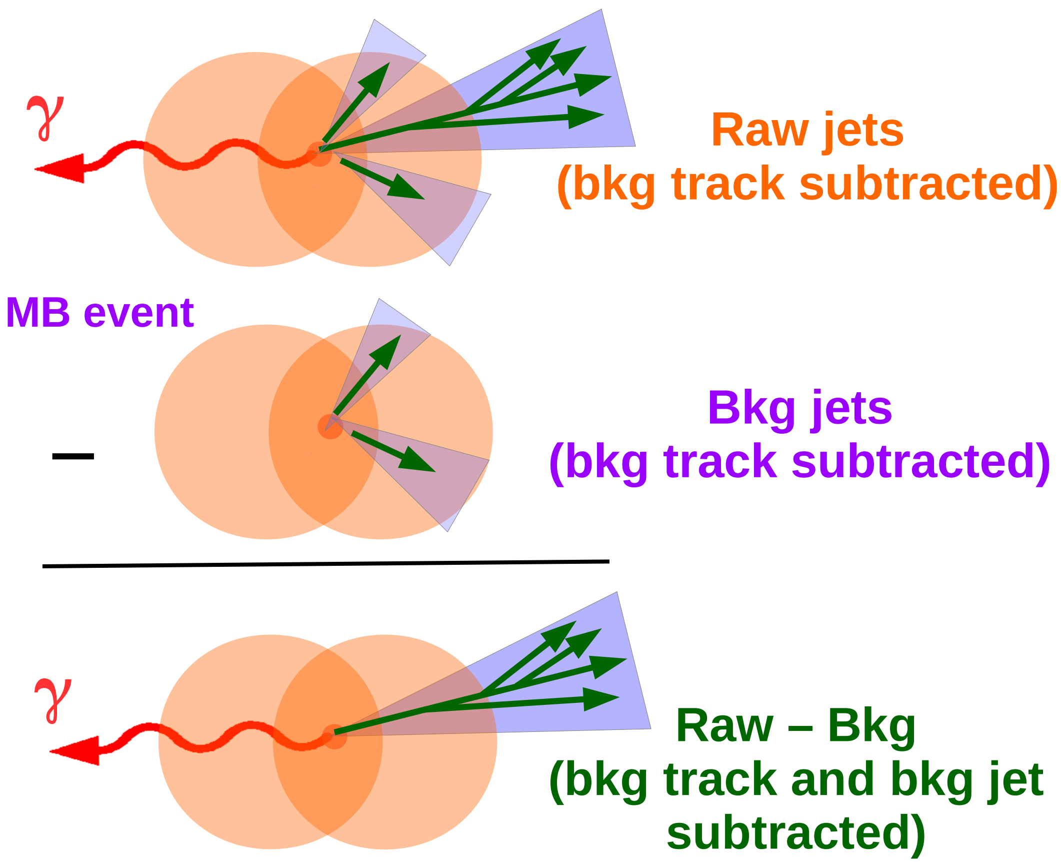
Inclusive jet shape

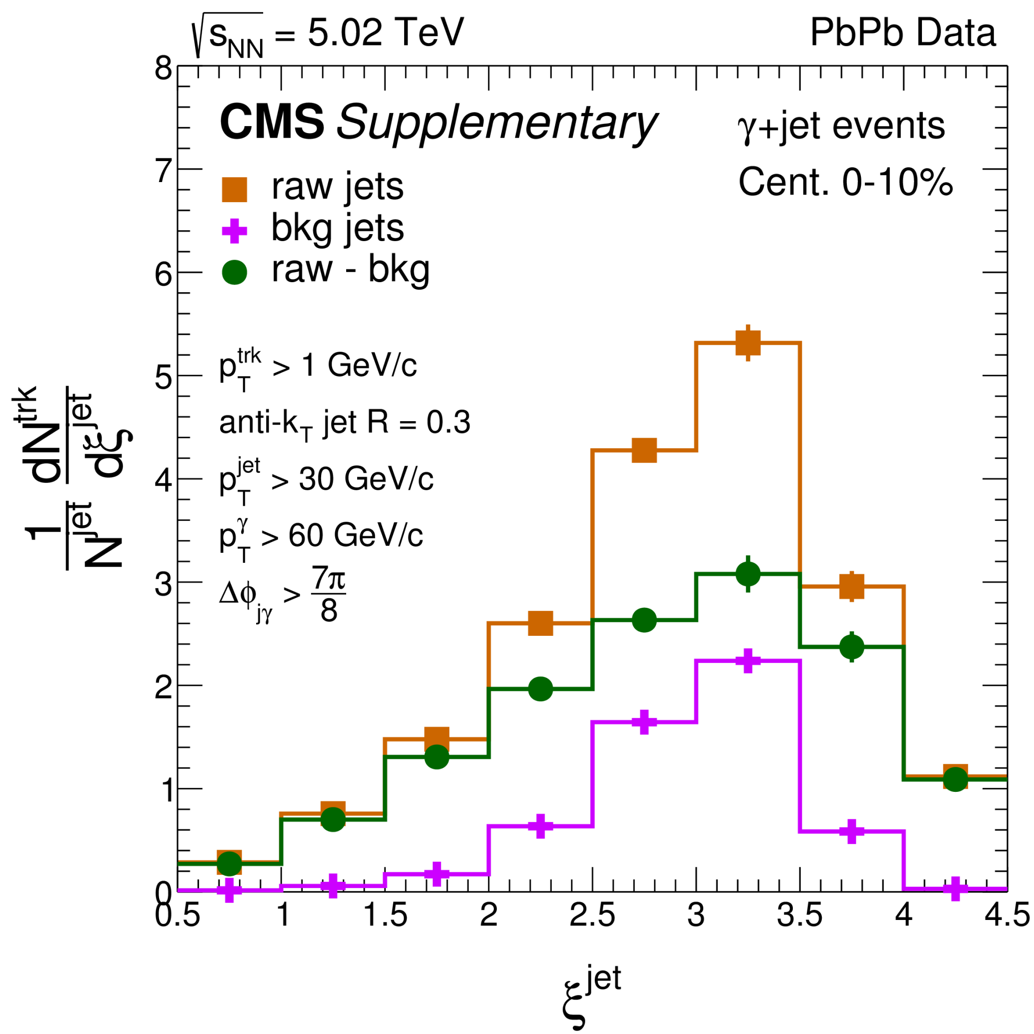
Phys. Lett. B 730 (2014) 243



$$r = \sqrt{(\eta_{\text{track}} - \eta_{\text{jet}})^2 + (\phi_{\text{track}} - \phi_{\text{jet}})^2}$$

Bkg subtraction for jets



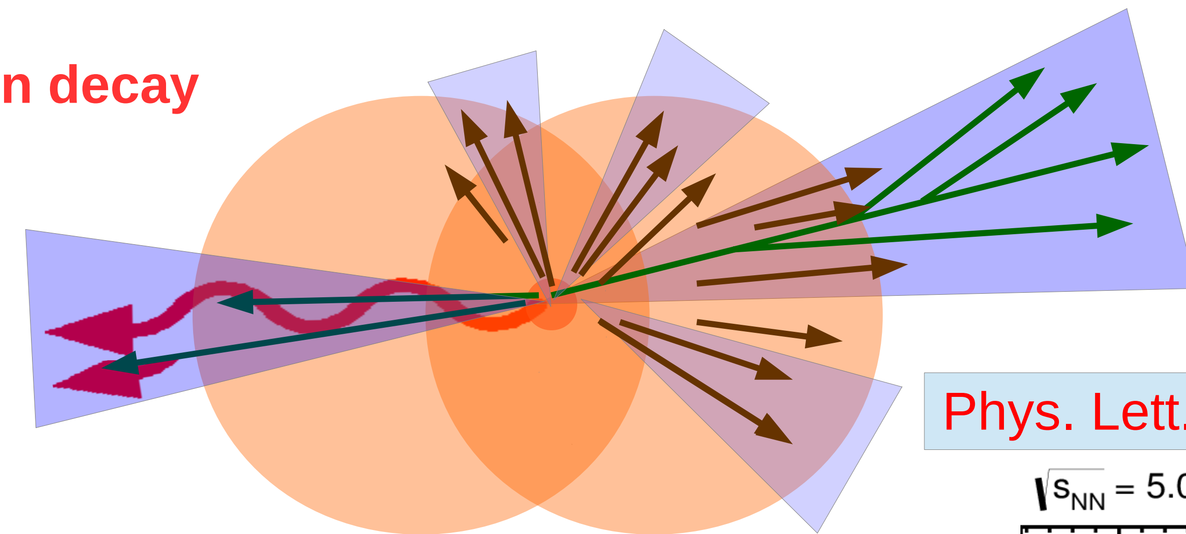


Analysis – bkg photons

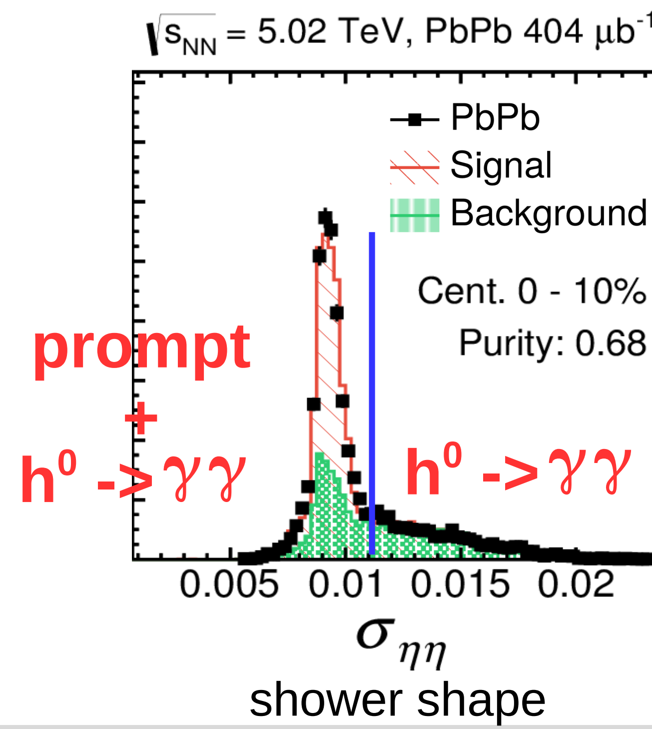
- Observables are constructed using photons, jets and tracks.

Neutral meson decay

$h^0 \to \gamma\gamma$



Phys. Lett. B 785 (2018) 14



Background source

photons from neutral meson decays

- rejected with shower shape cut
- 2 photons are reconstruced as single with a **wider shower shape**
  - dominates the sideband region : $0.011 < \sigma_{\eta\eta} < 0.017$

Energy weighted width of shower : $\sigma_{\eta\eta}$

$$\sigma^2_{\eta\eta} = \frac{\sum_i^{5\times5} w_i(\eta_i - \eta_{5\times5})^2}{\sum_i^{5\times5} w_i}, \qquad w_i = \max(0, 4.7 + \ln\frac{E_i}{E_{5\times5}}),$$

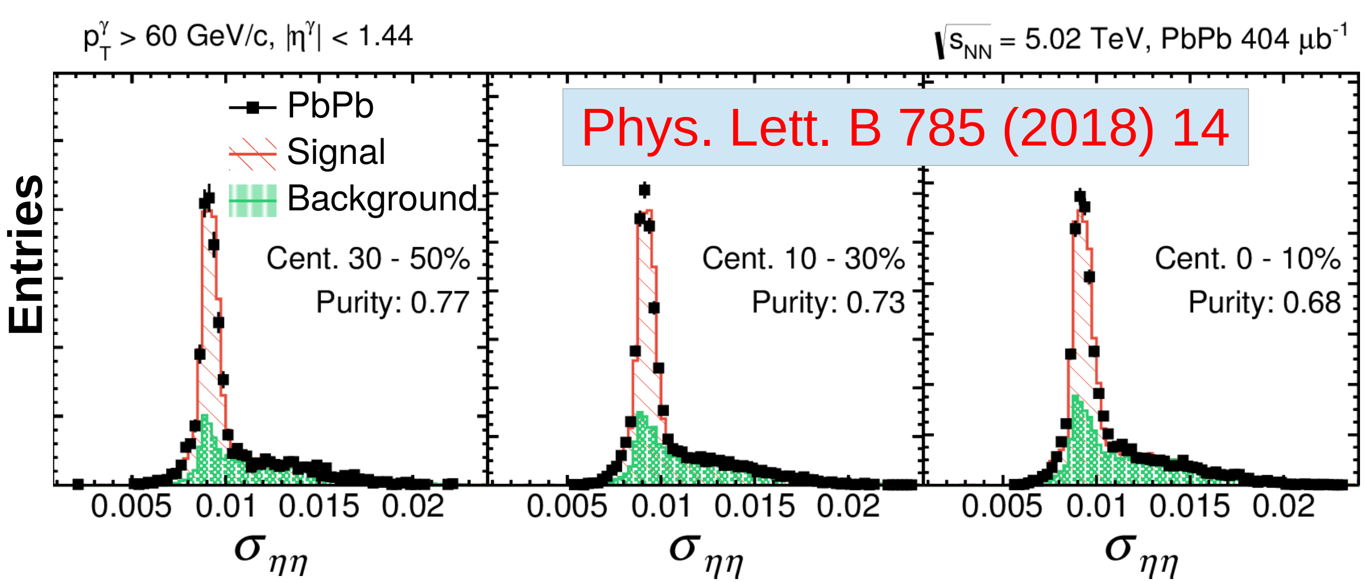
Background from photons

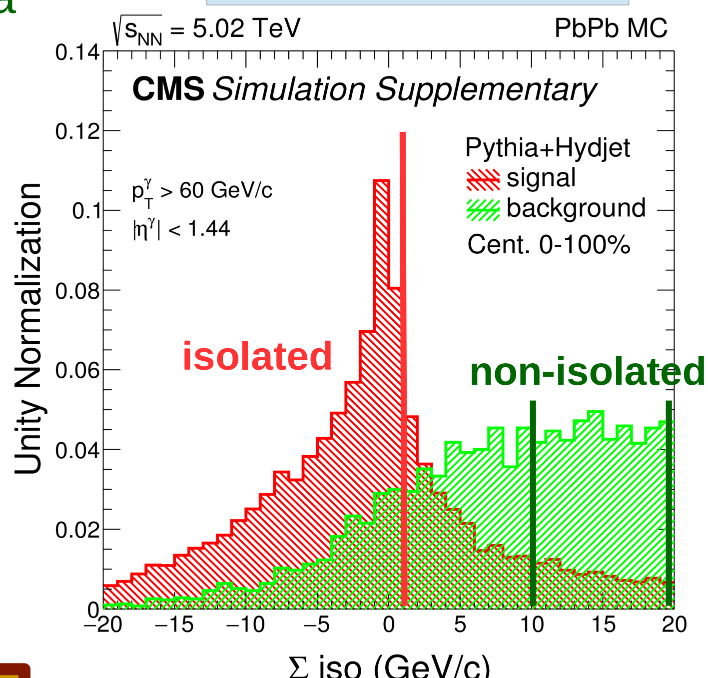
- $\sigma_{\eta\eta}$ < 0.01 selects narrow shower shape, supresses background from neutral meson decays, however there is still contamination.
- Purity = fraction of the prompt photons among candidates
  - Estimated using template fit method. Fit the distribution for $\sigma_{\eta\eta}$ < 0.01 with

Signal (prompt photon) template from MC with isolated photon events

Bkg (neutral meson) template from non-isolated photons in data

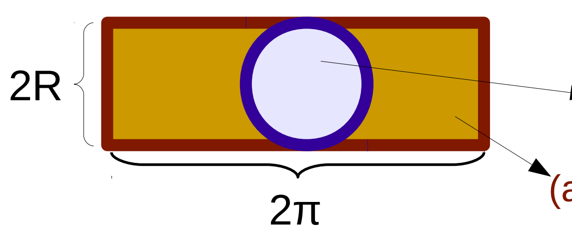
arXiv:1801.04895





$$\sigma^2_{\eta\eta} = \frac{\sum_i^{5\times5} w_i(\eta_i - \eta_{5\times5})^2}{\sum_i^{5\times5} w_i}$$

$$w_i = \max(0, 4.7 + \ln\frac{E_i}{E_{5\times5}})$$



Σ iso =

(tot energy in a cone of R=0.4 around the photon) -

(ave. energy from a strip of 2π x 2R)

Smearing jet spectra

- **Jet energy resolution** and **jet angular resolution** differ between pp and PbPb due to underlying event
  - Estimate relative resolution between pp and PbPb using simulations
  - Smear jet spectra in pp using this relative resolution
- Smearing **jet energy**
  - Parametrize jet energy resolution via

$$\sigma\left(\frac{p_T^{RECO}}{p_T^{GEN}}\right)=\sqrt{C^2+\frac{S^2}{p_T^{GEN}}+\frac{N^2}{(p_T^{GEN})^2}}$$

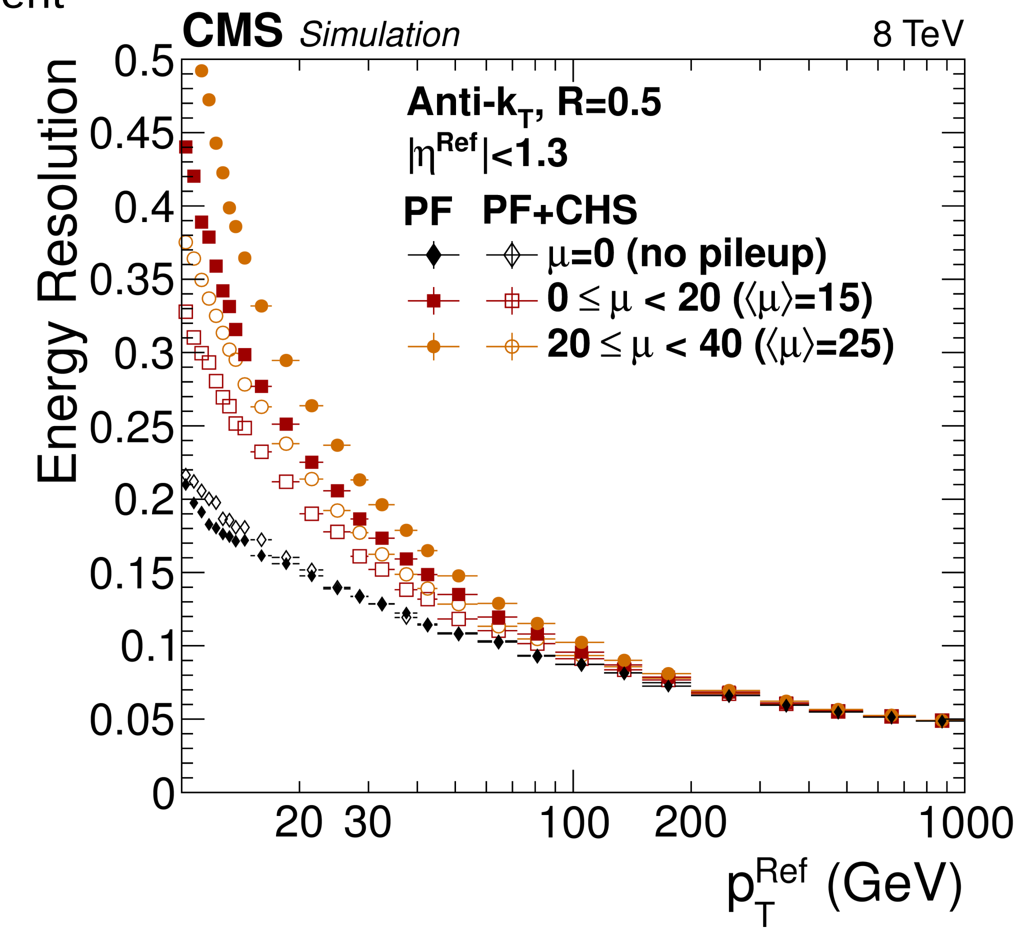
  - Fit C, S and N parameters and apply relative resolution via

$$\sigma_{rel}=\sqrt{(C_{PbPb}^2-C_{pp}^2)+\frac{(S_{PbPb}^2-S_{pp}^2)}{p_T^{GEN}}+\frac{(N_{PbPb}^2-N_{pp}^2)}{(p_T^{GEN})^2}}$$

- Smearing **jet azimuthal angle**
  - Use same parametrization as in jet energy resolution
  - Apply relative resolution in the same fashion

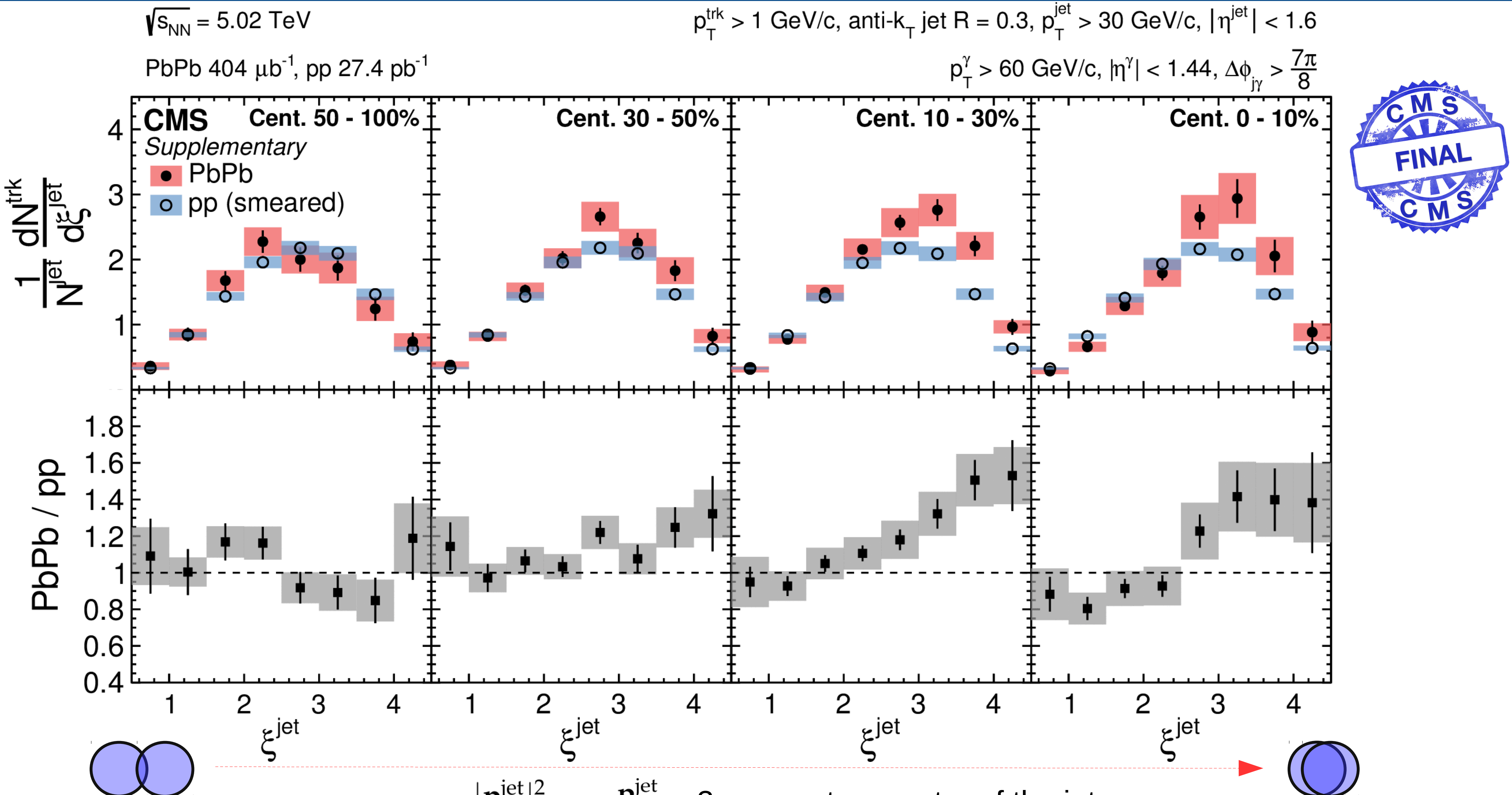
$$\sigma\left(\left|\phi^{RECO}-\phi^{GEN}\right|\right)=\sqrt{C^2+\frac{S^2}{p_T^{GEN}}+\frac{N^2}{(p_T^{GEN})^2}}$$

JINST 12 (2017) P10003



γ-tagged jet FF - ξ^{jet}

arXiv:1801.04895



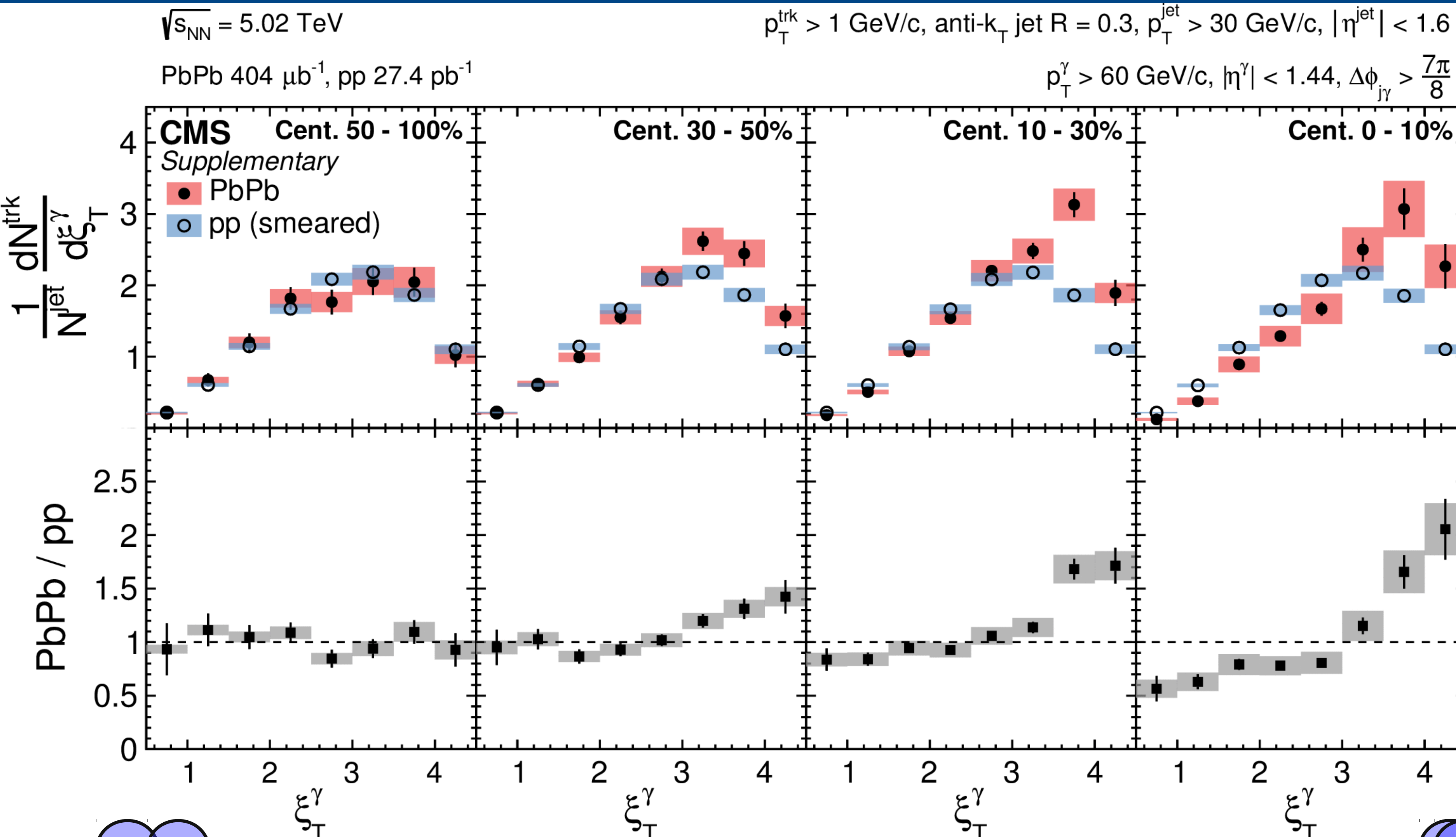
$$\xi^{jet} = \ln \frac{|\mathbf{p}^{jet}|^2}{\mathbf{p}^{trk} \cdot \mathbf{p}^{jet}}$$

$\mathbf{p}^{jet}$: 3-momentum vector of the jet

$\mathbf{p}^{trk}$: 3-momentum vector of the track

γ-tagged jet FF - ξ_T^{γ}

arXiv:1801.04895



$$\xi_T^{\gamma} = \ln \frac{-|\mathbf{p}_T^{\gamma}|^2}{\mathbf{p}_T^{trk} \cdot \mathbf{p}_T^{\gamma}}$$

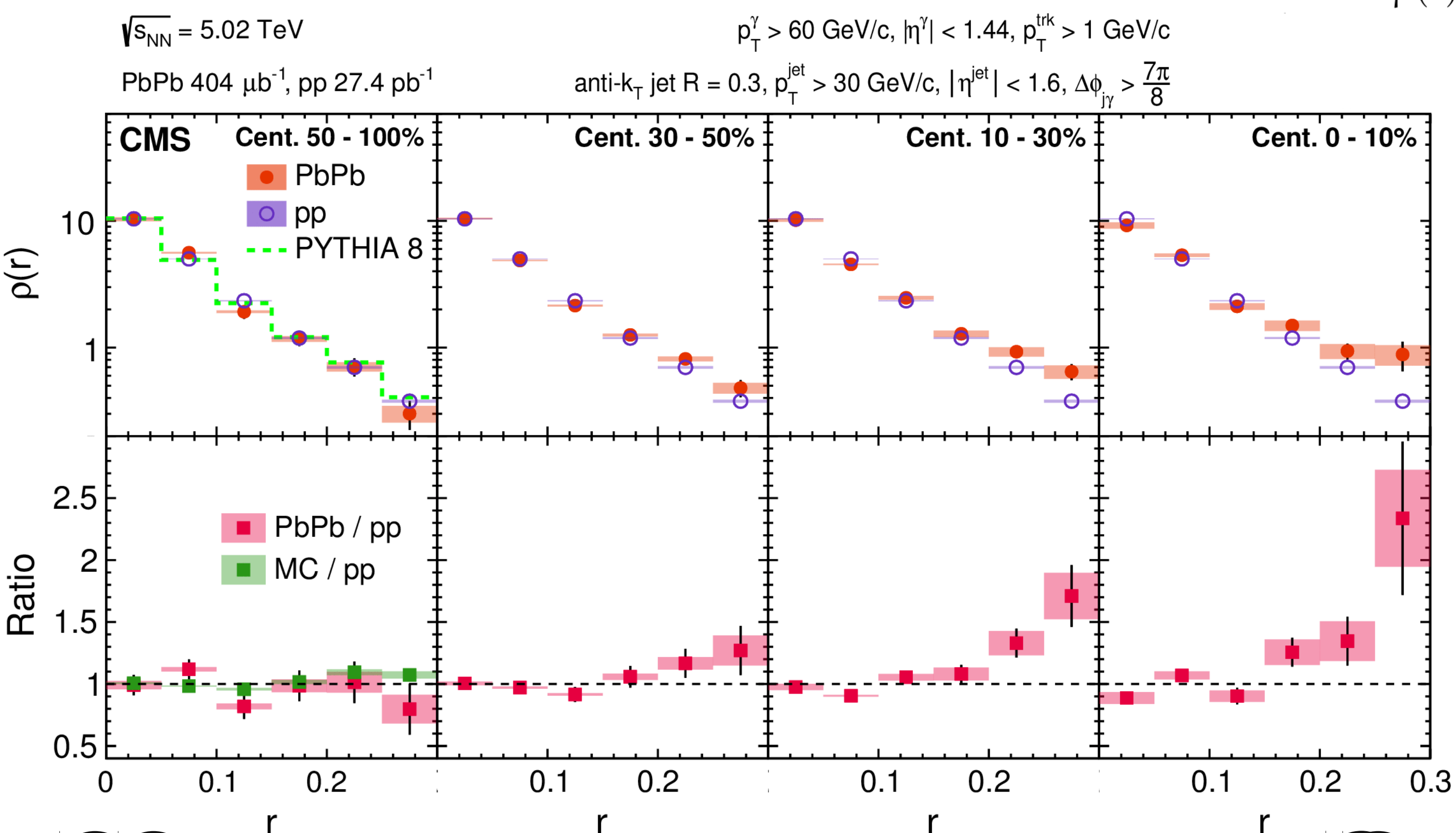
$\mathbf{p}_T^{\gamma}$: transverse mom. vector of the photon

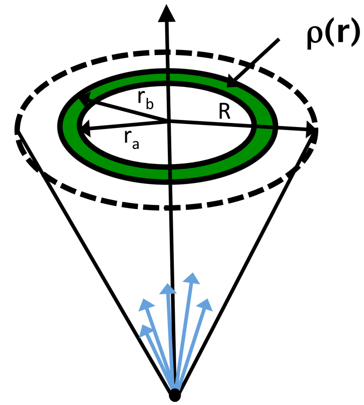
$\mathbf{p}_T^{trk}$: transverse mom. vector of the track

γ-tagged jet shape

arXiv:1809.08602

$$\rho(r) = \frac{1}{\delta r} \frac{\sum_{\text{jets}} \sum_{\text{trk} \in [r_a, r_b)} (p_T^{\text{trk}} / p_T^{\text{jet}})}{\sum_{\text{jets}} \sum_{\text{trk} \in [0, r_f)} (p_T^{\text{trk}} / p_T^{\text{jet}})}$$





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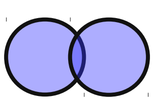
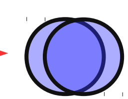
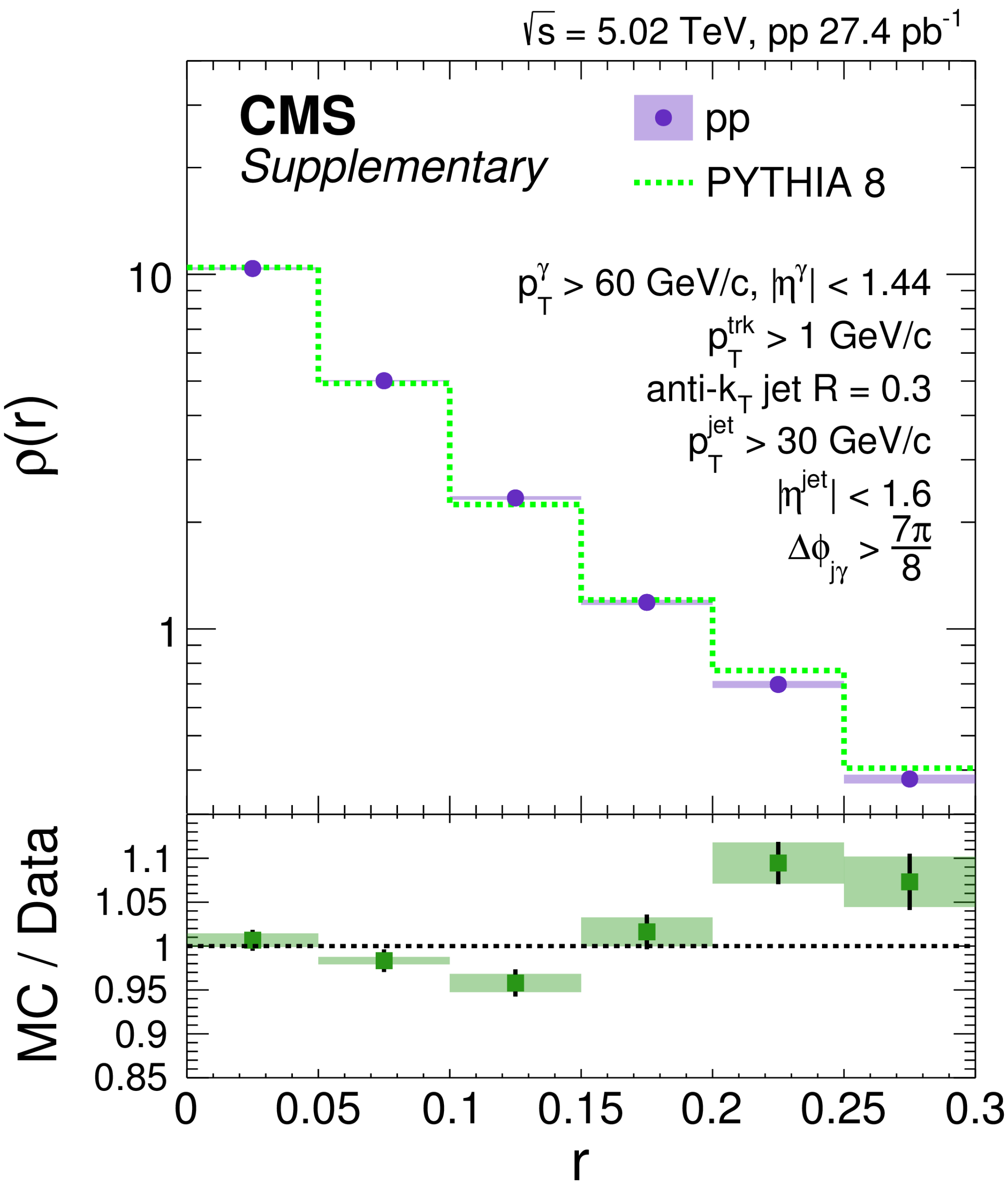
pp results are **NOT** smeared.





$$r = \sqrt{(\eta_{\text{track}} - \eta_{\text{jet}})^2 + (\phi_{\text{track}} - \phi_{\text{jet}})^2}$$

γ-tagged jet shape : pp vs MC



arXiv:1809.08602