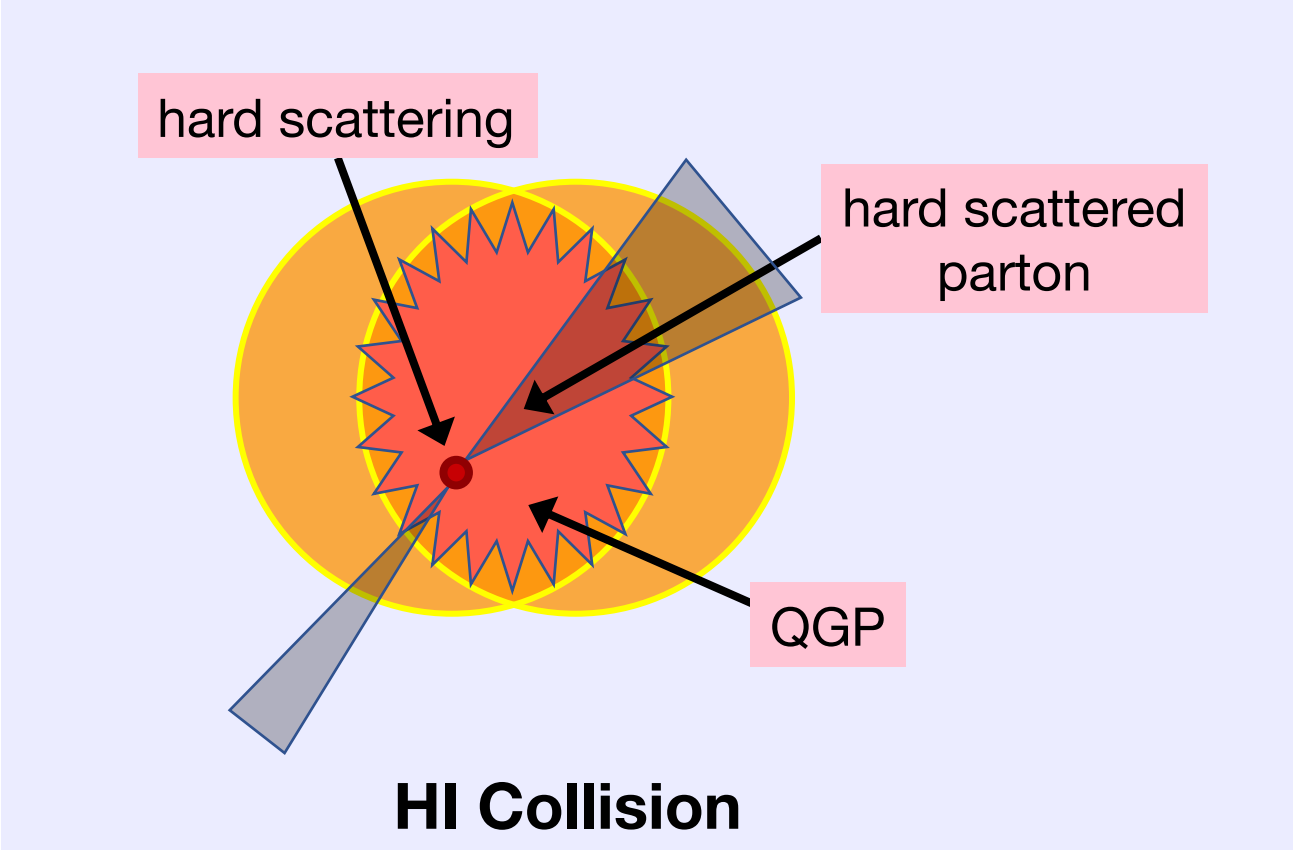
Study of in-medium momentum broadening with photon-jet momentum correlations in PbPb collisions at 5.02 TeV with the CMS experiment

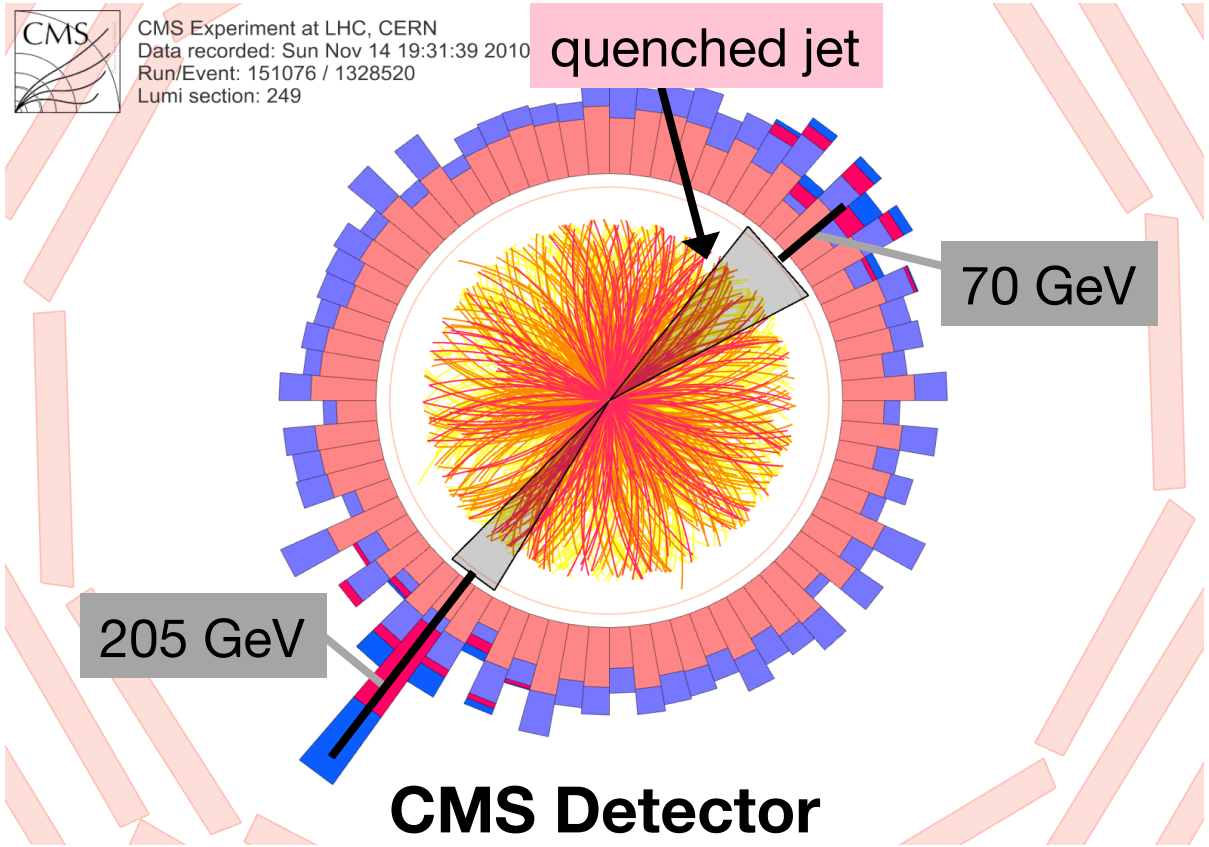
Molly Taylor
Massachusetts Institute of Technology
for the CMS Collaboration

Hard Probes 2020

June 1, 2020

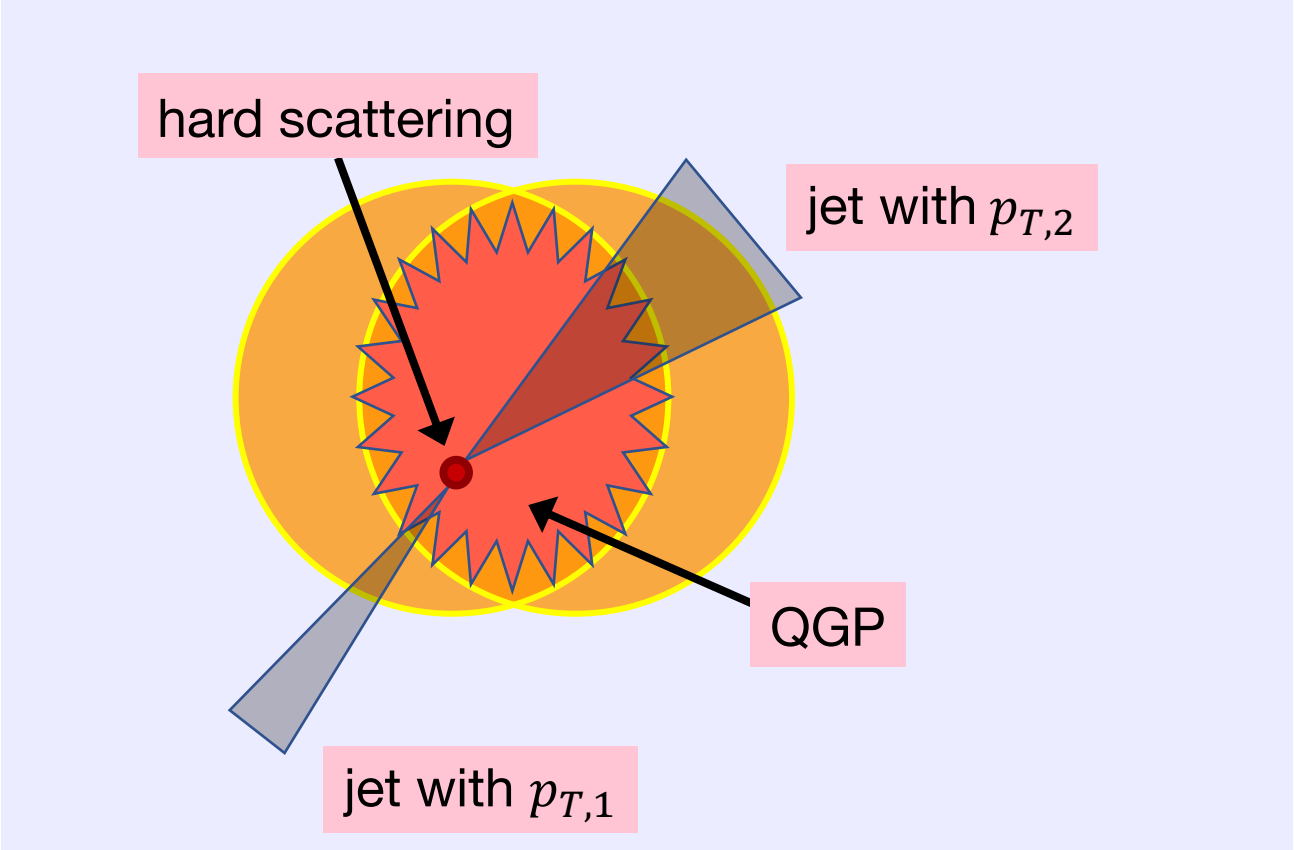
Introduction

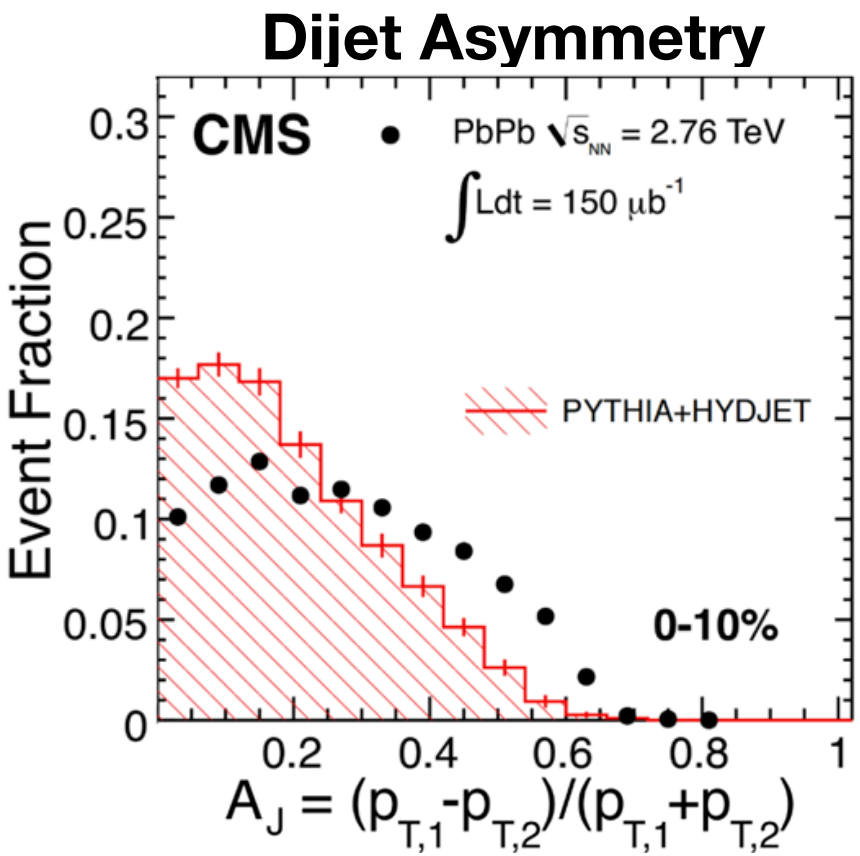




- QGP formed when heavy ions collide
- Hard scattered partons interact with QGP and lose energy => **jet quenching**

Dijet asymmetry





- Dijet measurements show greater asymmetry A_J than PYTHIA in HYDJET
- Asymmetry is evidence of jet quenching

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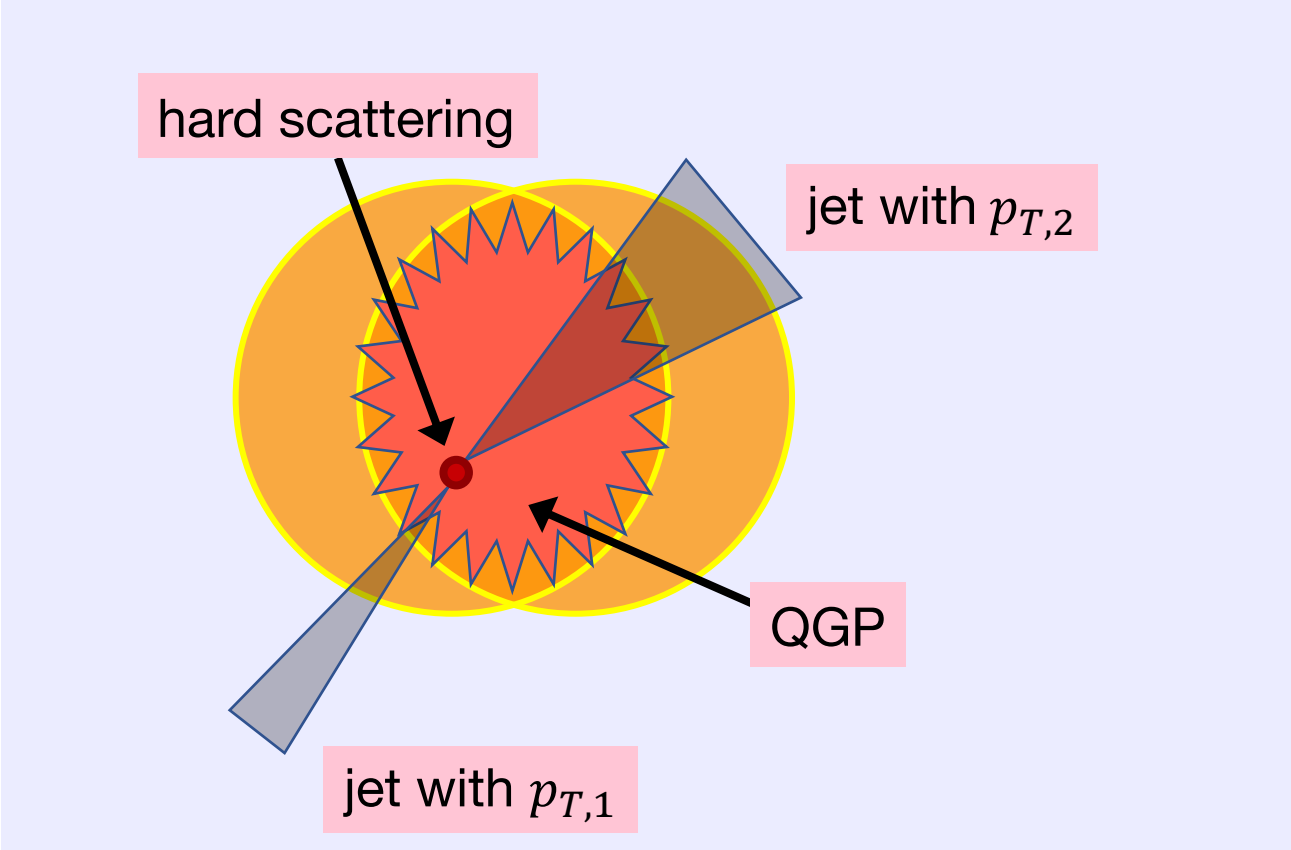
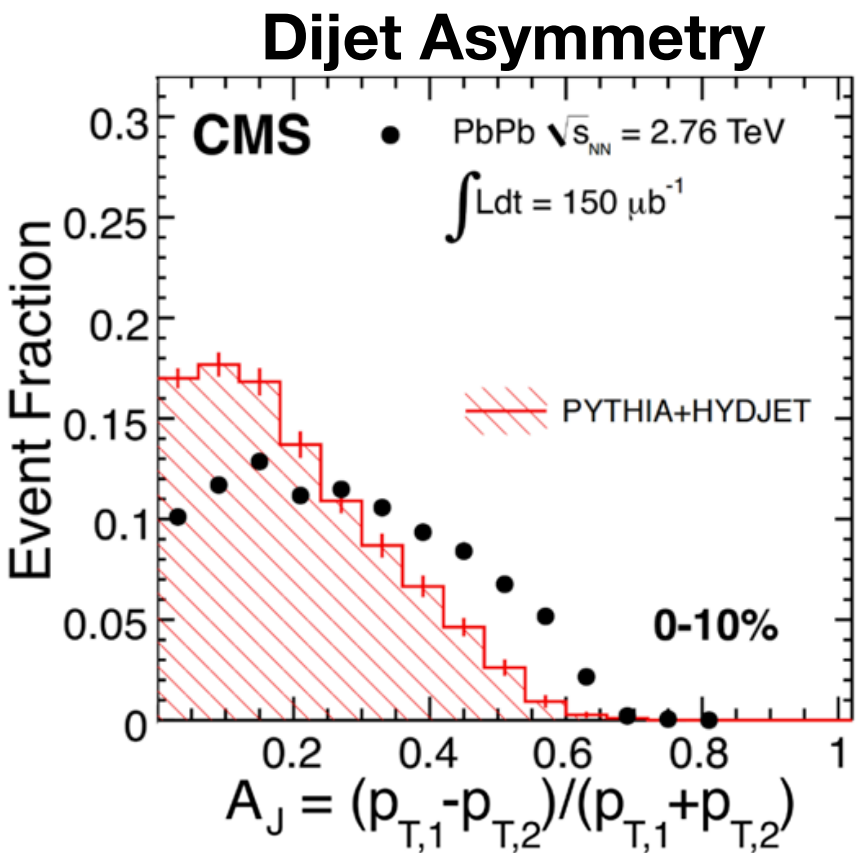
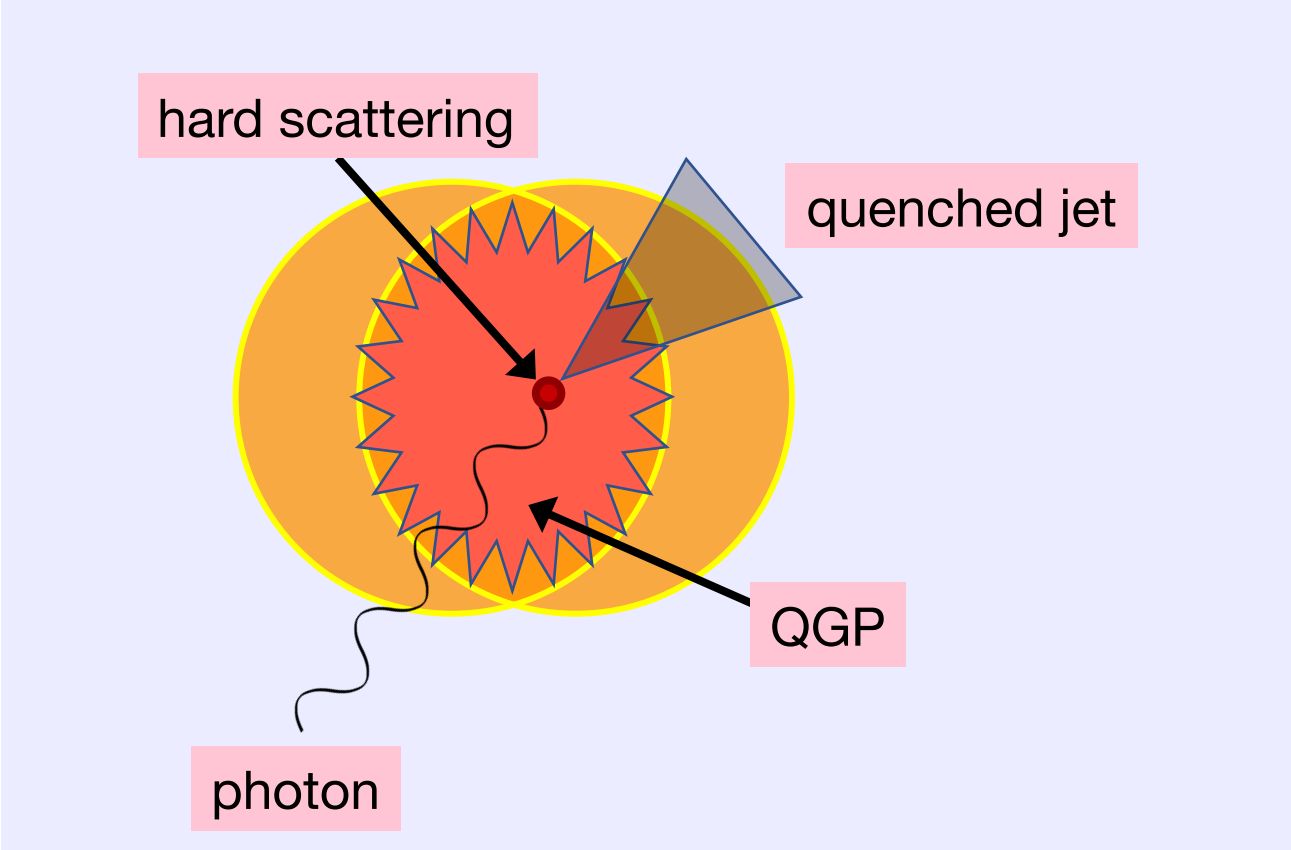
Dijet asymmetry

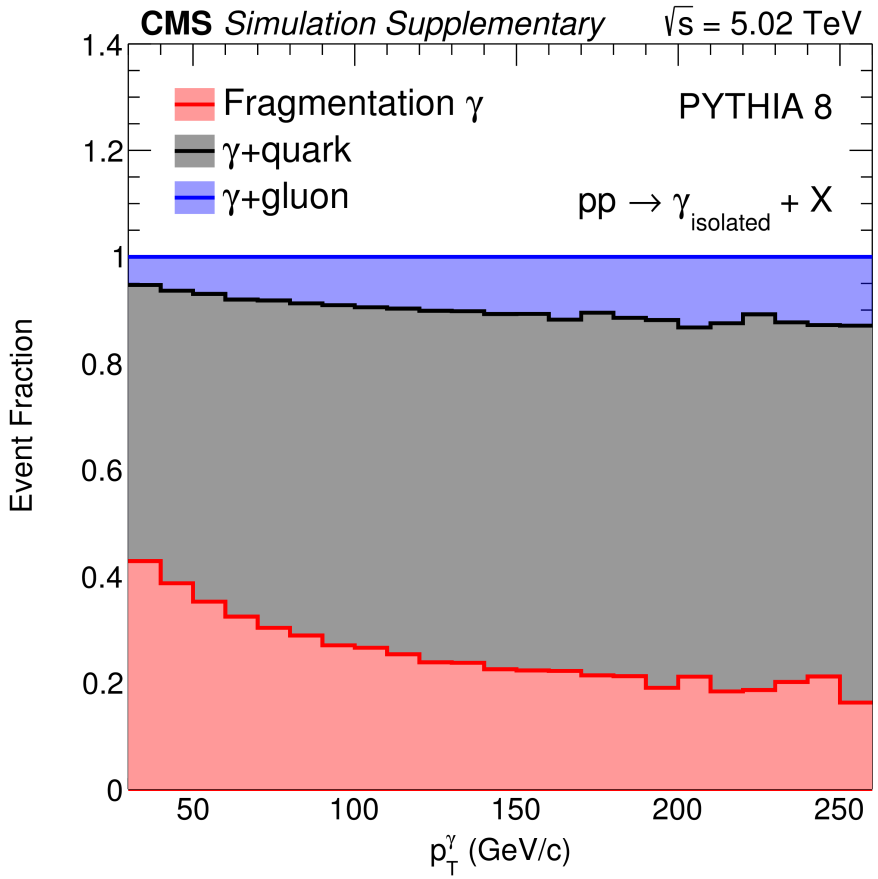




- Dijet measurements show greater asymmetry A_J than PYTHIA in HYDJET
- Asymmetry is evidence of jet quenching – **but both jets lose energy**
- "Surface bias" from requirement that $p_{T,1}$ > 120 GeV/c, $p_{T,2}$ > 30 GeV/c

Photon-tagged jets





- Photon does not interact strongly with QGP => tags initial recoil parton p_T
- No surface bias from photon selection
- Good handle on quark/gluon fraction of recoil parton

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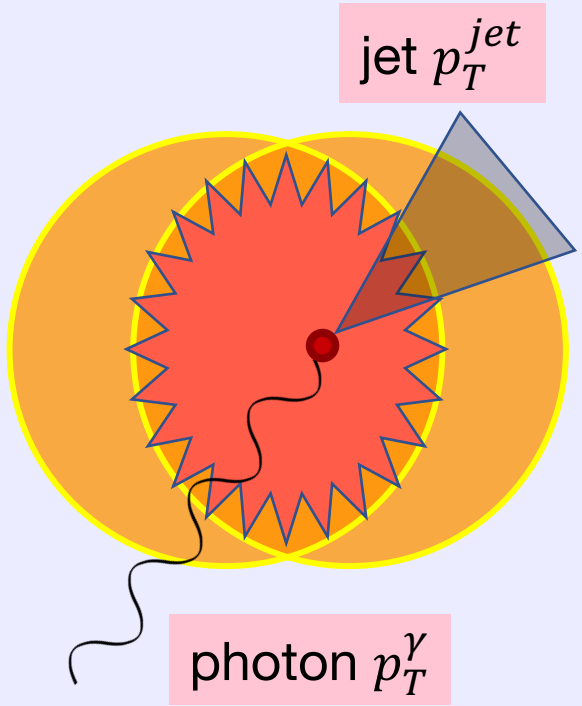
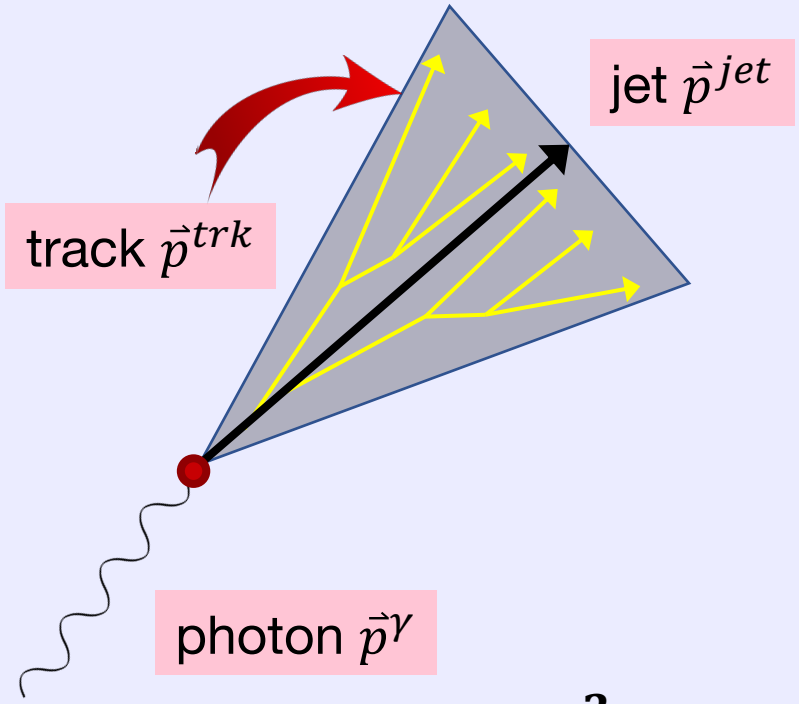
Observables

Momentum Imbalance



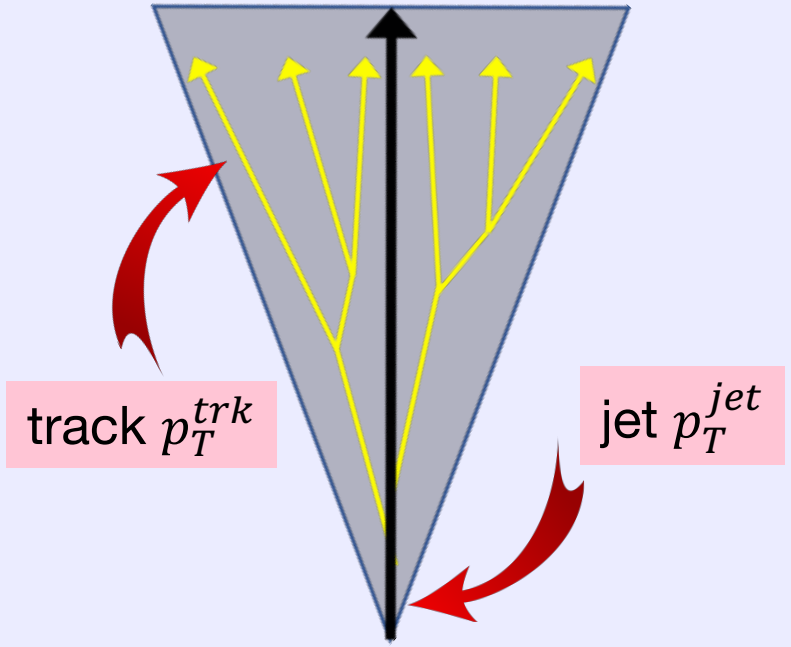
$$x_{jet,\gamma} = p_T^{jet}/p_T^{\gamma}$$

Fragmentation Function



$$\xi^{jet} = \ln \frac{\left|\vec{p}^{jet}\right|^2}{\vec{p}^{trk} \cdot \vec{p}^{jet}}$$

Jet Shape



$$r = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

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

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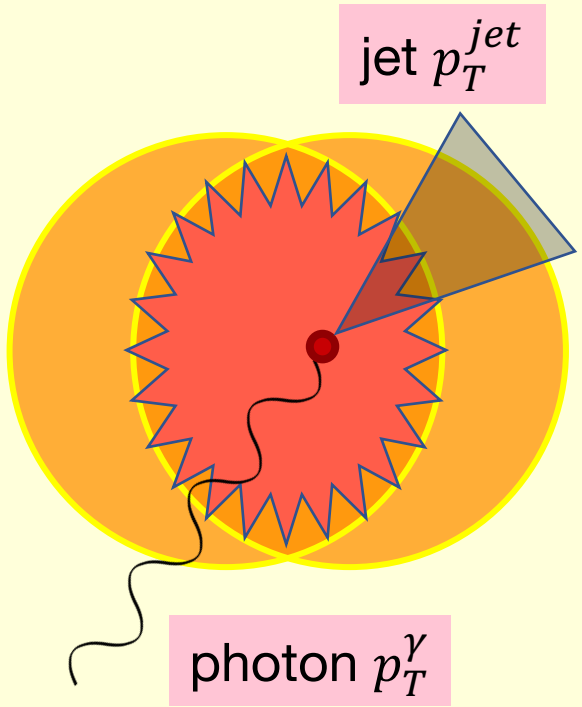

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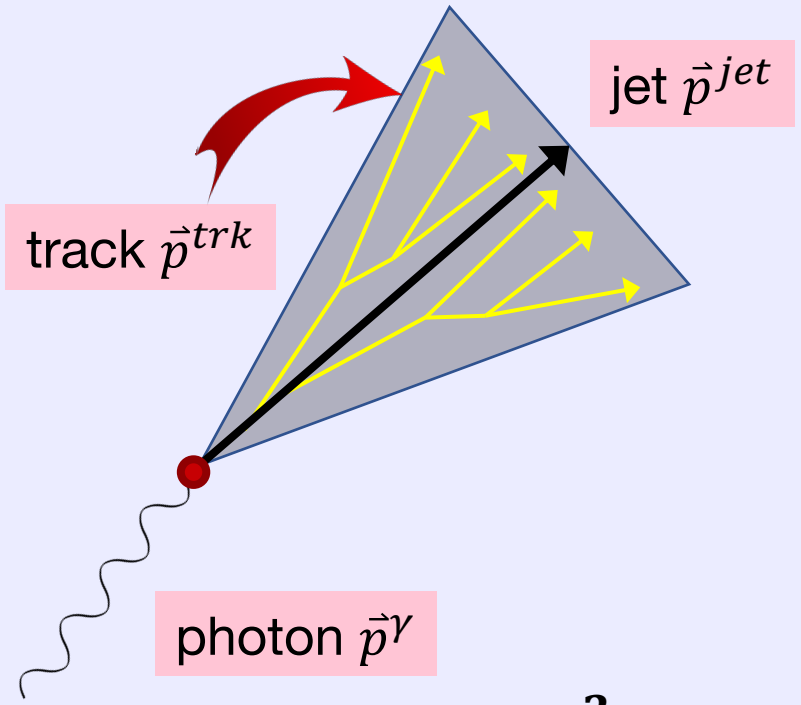

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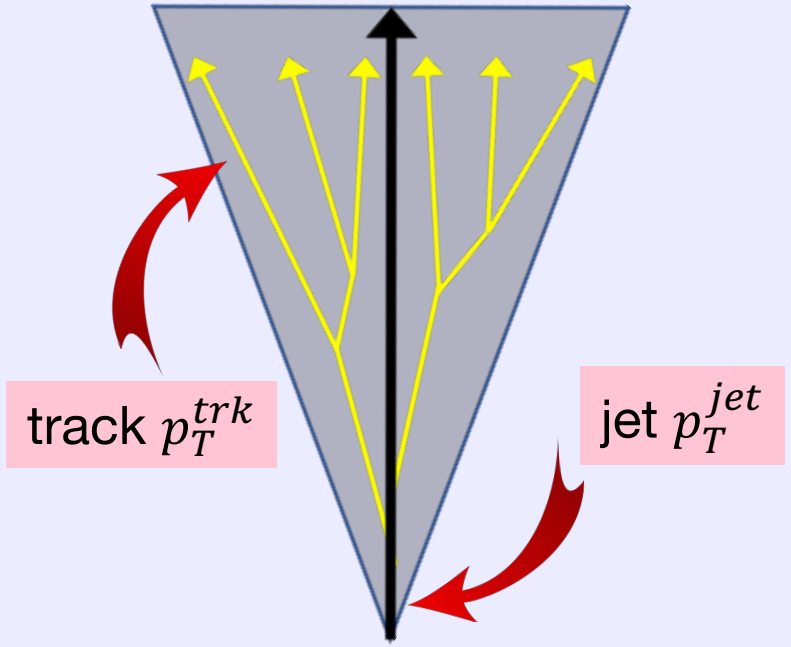

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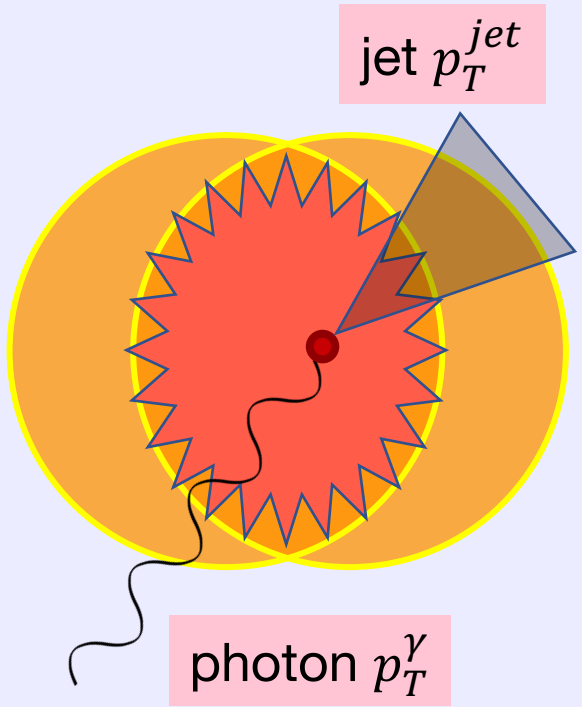

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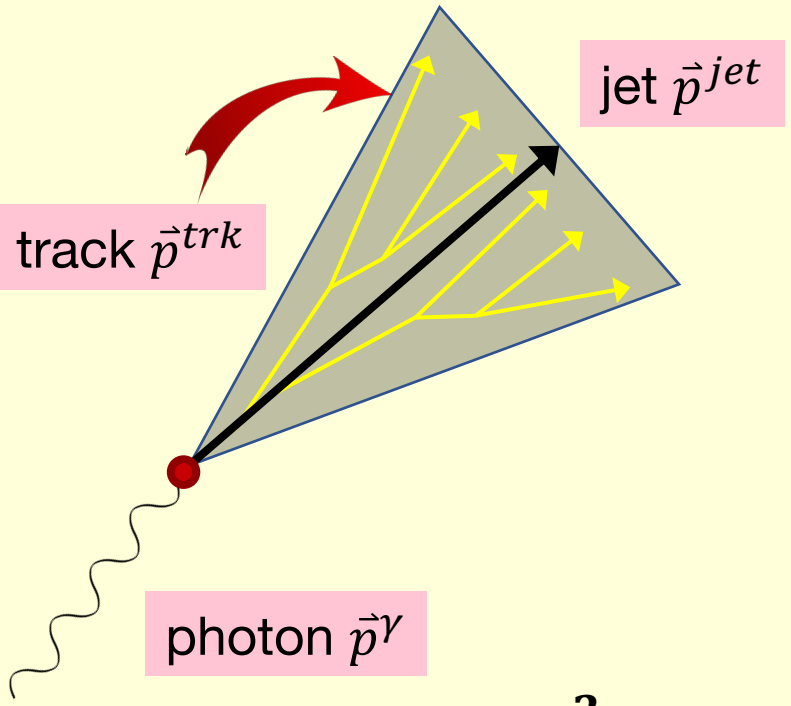

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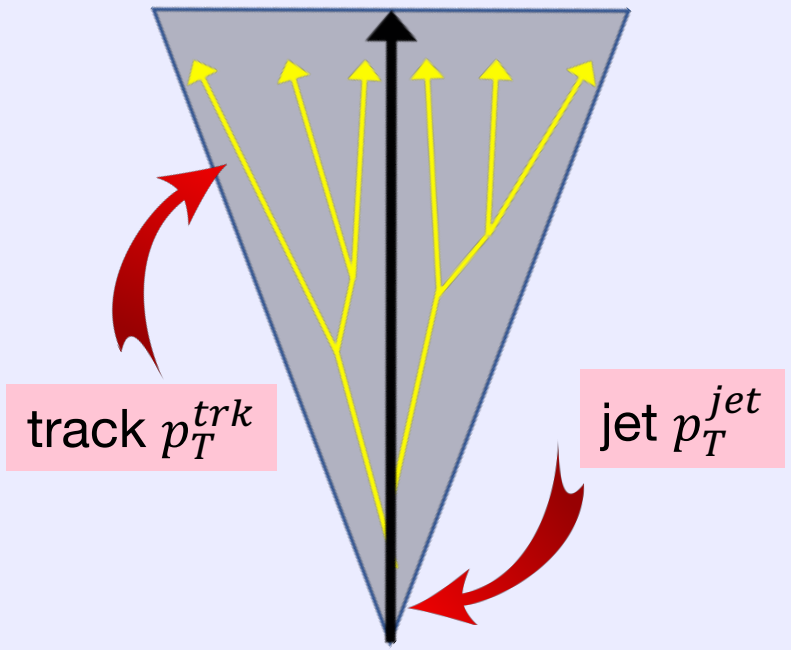
projection of track momentum

Jet Shape



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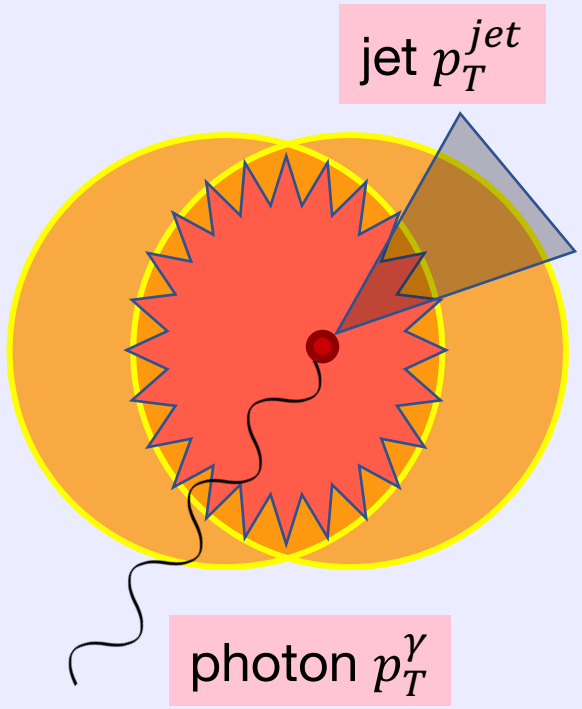

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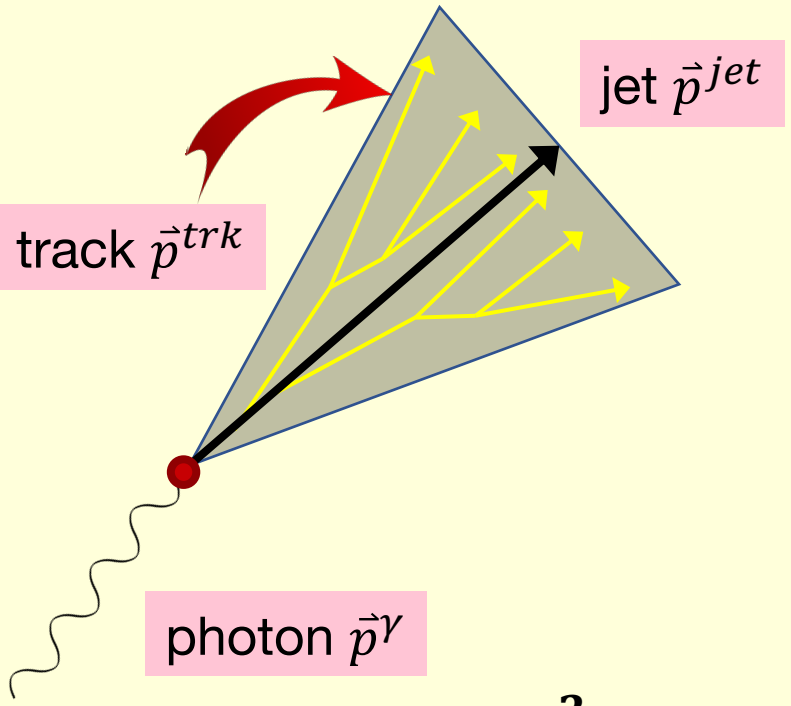
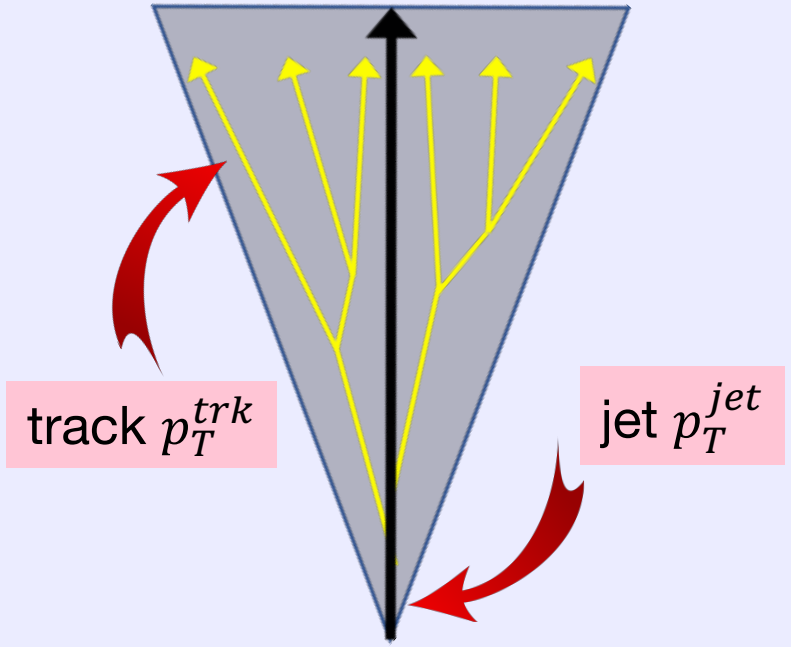


$$\xi_T^{\gamma} = \ln \frac{-\left|\vec{p}_T^{\gamma}\right|^2}{\vec{p}_T^{trk} \cdot \vec{p}_T^{\gamma}}$$

projection of track momentum

Jet Shape



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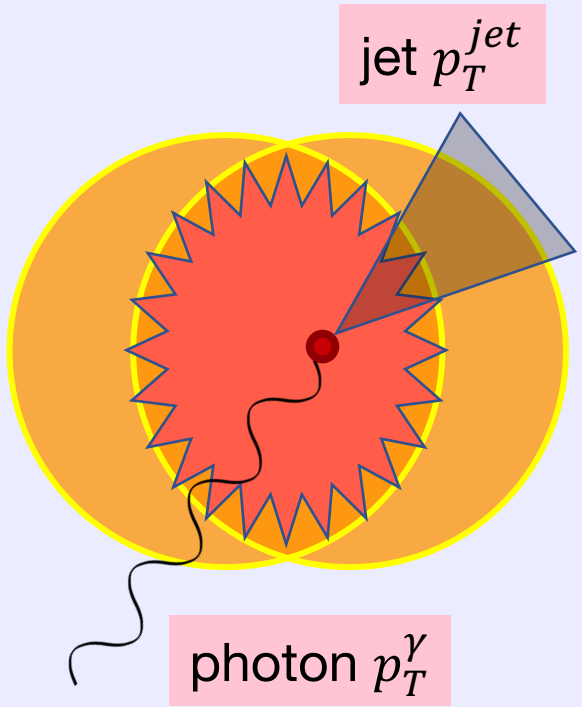

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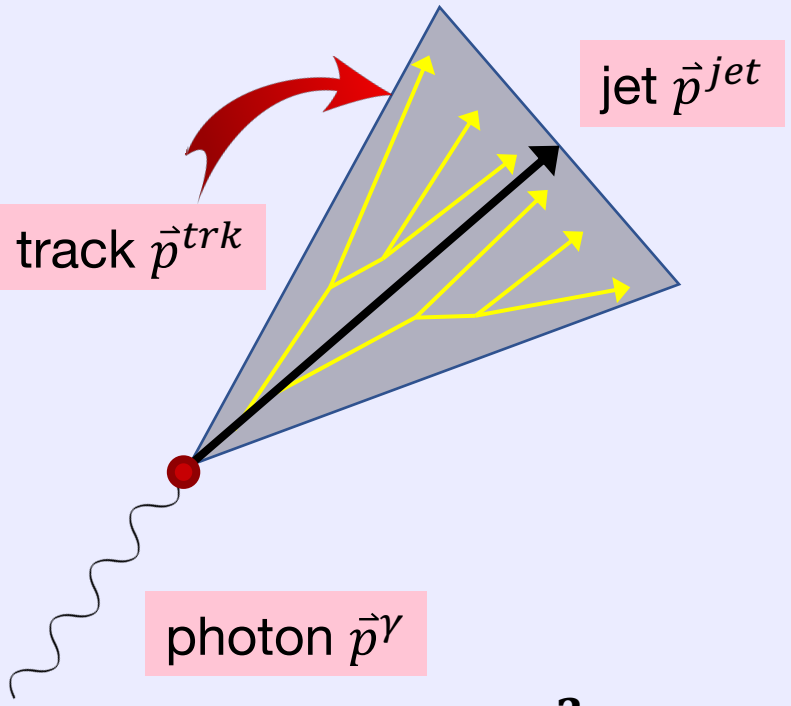

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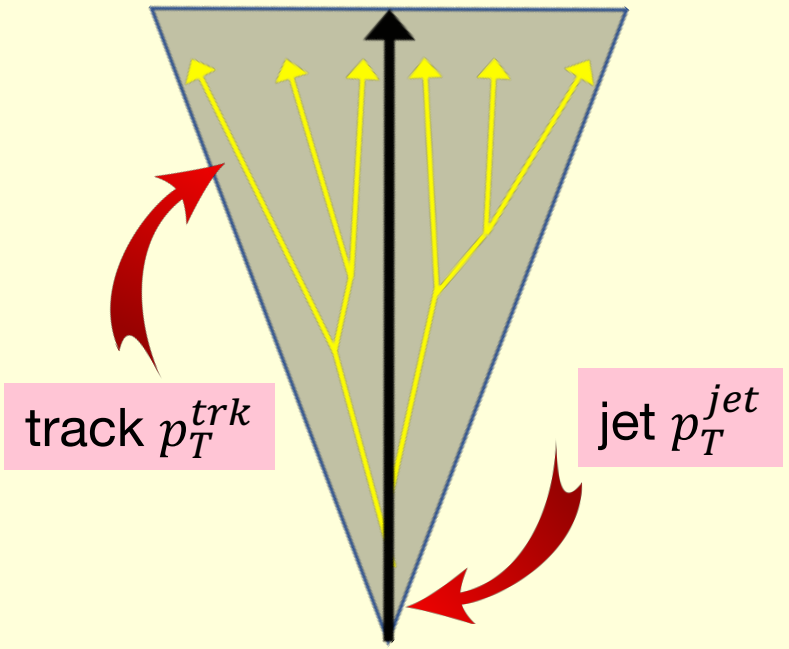

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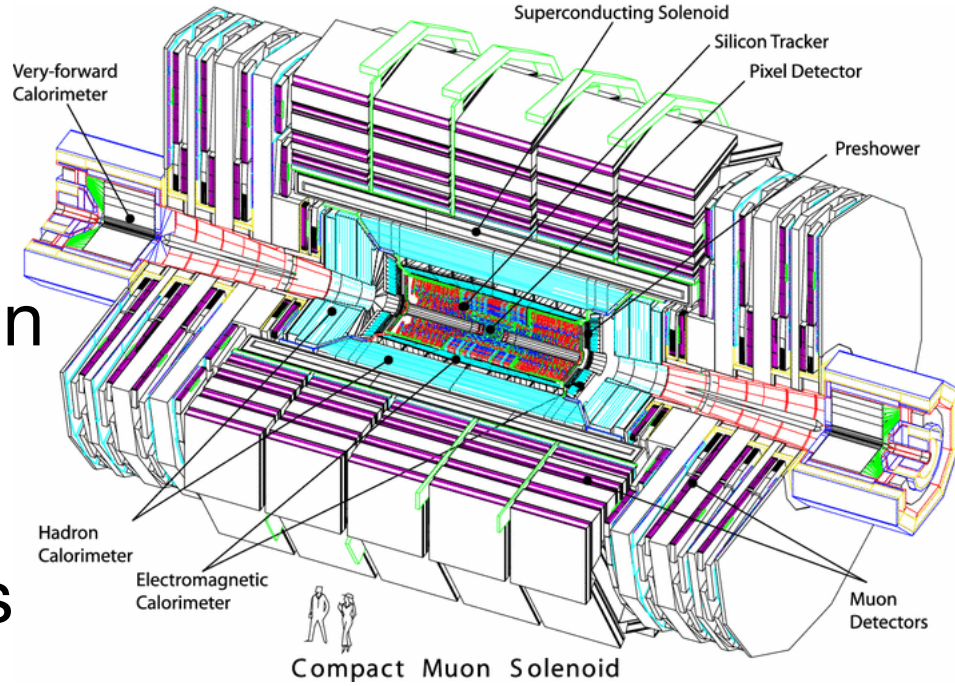
track transverse distribution

Analysis strategy

- Trigger on events with $p_T^\gamma > 40$ GeV/c, $|\eta^\gamma| < 1.44$
- Cluster anti-k_T R = 0.3 jets with FASTJET
- Subtract underlying event for PbPb colllisions
- Find isolated photons, reject if close to electron
- Remove decay & fragmentation photons
- Pair photons and jets to find photon-jet events
- Subtract combinatorial background

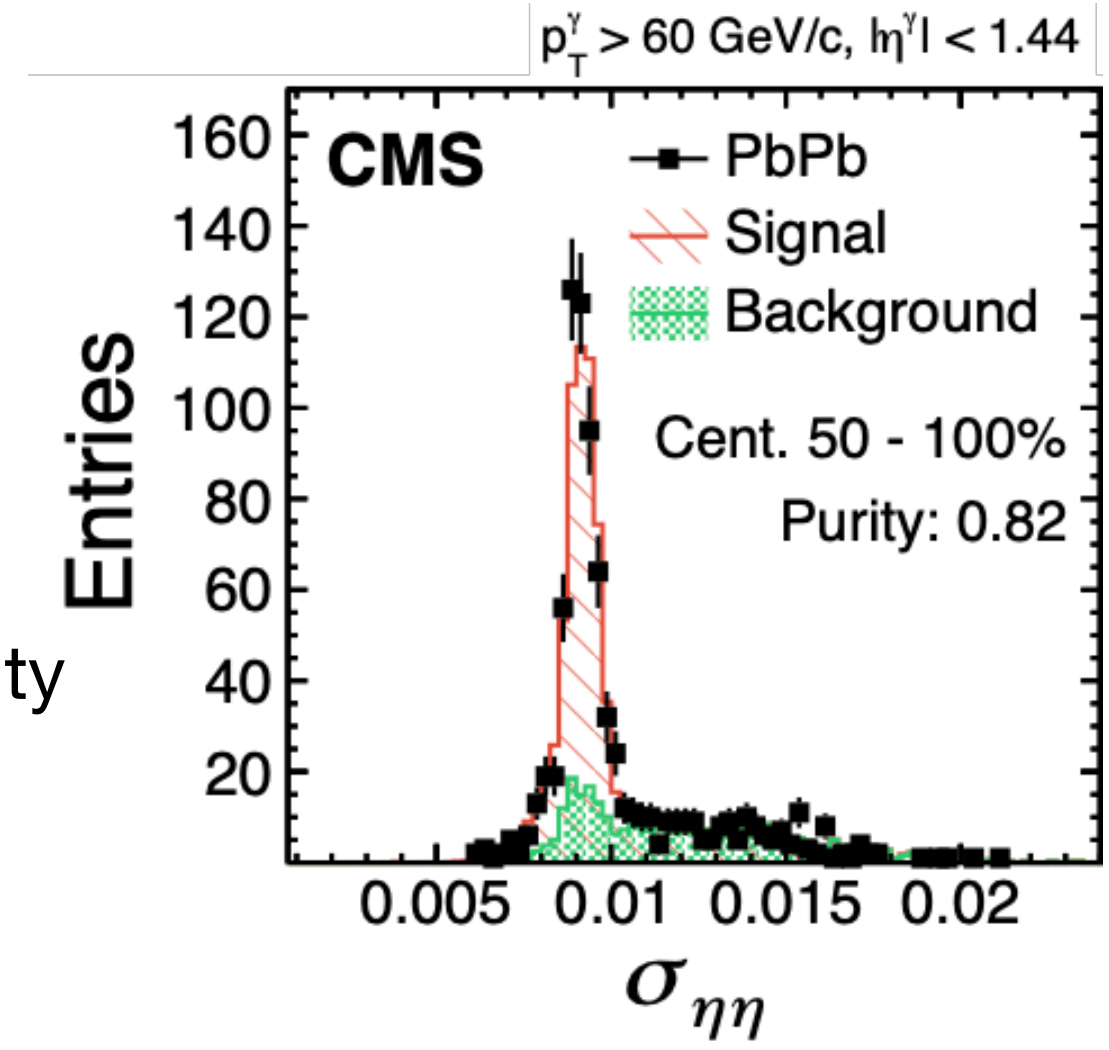


Photon isolation and cluster shape

- Discard photons candidates close to electrons tracks with $p_T^e > 10$ GeV/c
- SumIso = UE-sub energy sum in R = 0.4 cone around photon
- Require SumIso < 1 GeV
- Reject hadron showers
- Do template fit for $\sigma_{\eta\eta}$ to find photon purity

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

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



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Mixed-event background subtraction

- Consider correlations between photon and all jets in event
- Subtract contributions from uncorrelated background jets and tracks
  - Statistically identical to jets in MB events, also uncorrelated
- Estimate background by embedding photon in MB events

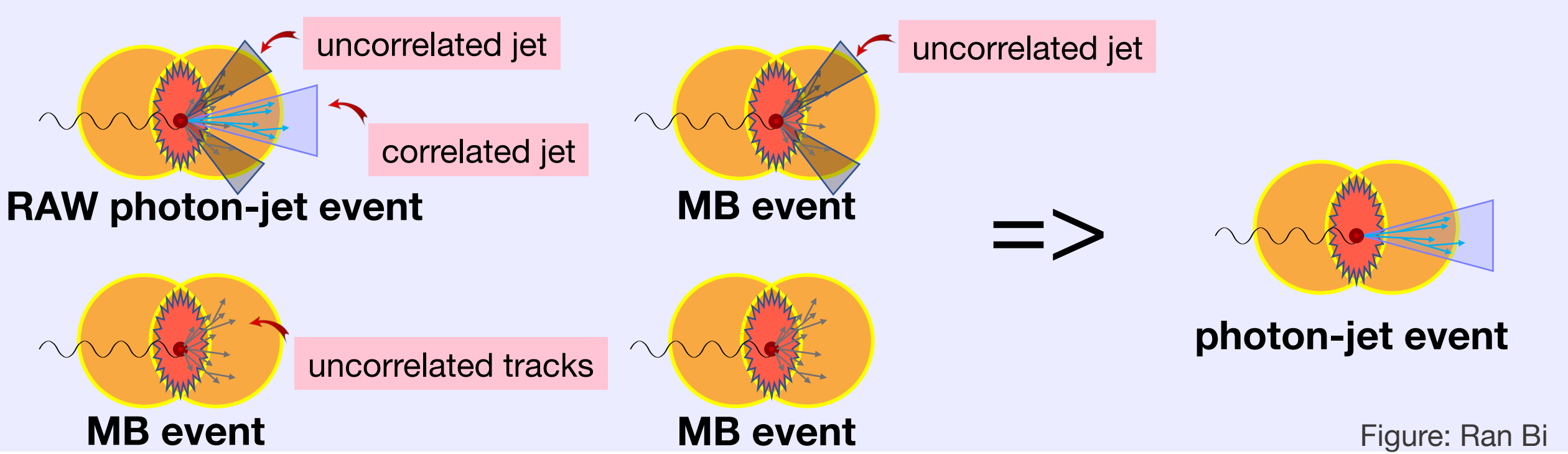
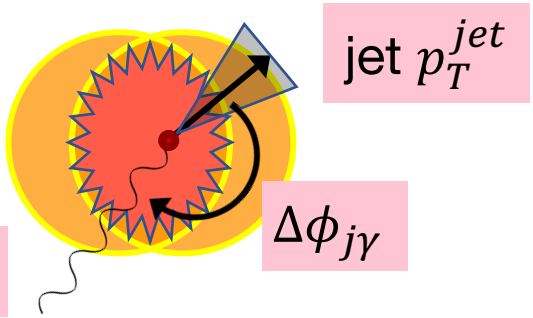
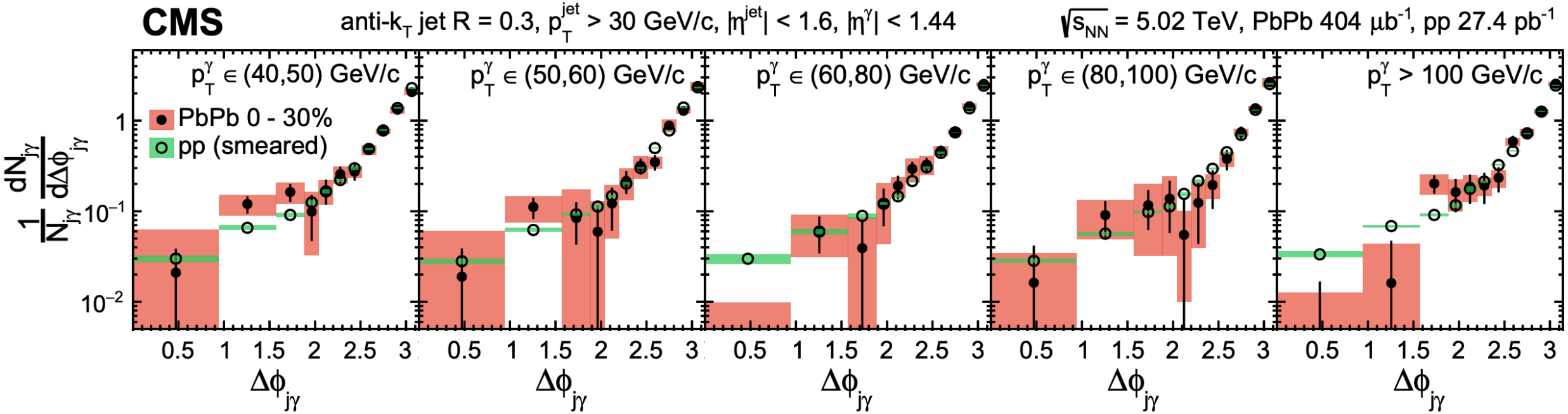


Figure: Ran Bi

Photon-tagged jet azimuthal correlations

- Look at alignment of photon and recoiling jet
- PbPb result consistent with smeared pp data
- No significant large angle enhancement





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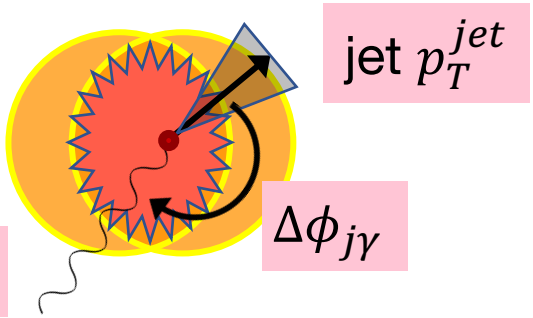
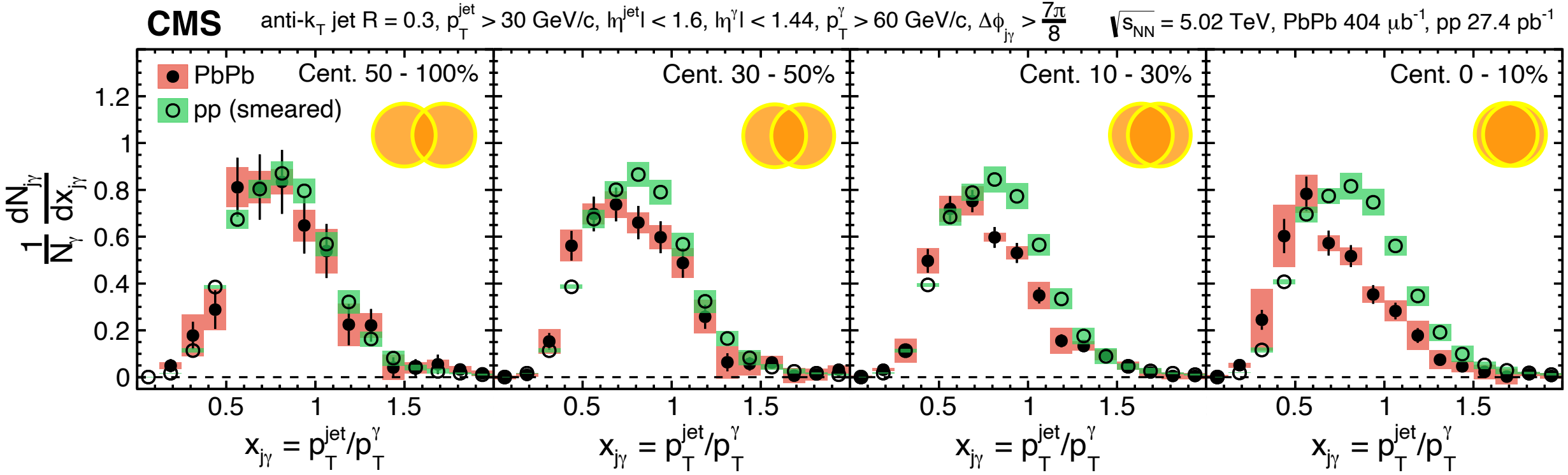
Photon-tagged jet momentum imbalance

- Select $\Delta\phi_{j\gamma} > 7\pi/8$
- Quantify imbalance from parton energy loss
- Mean and yield shift to lower values





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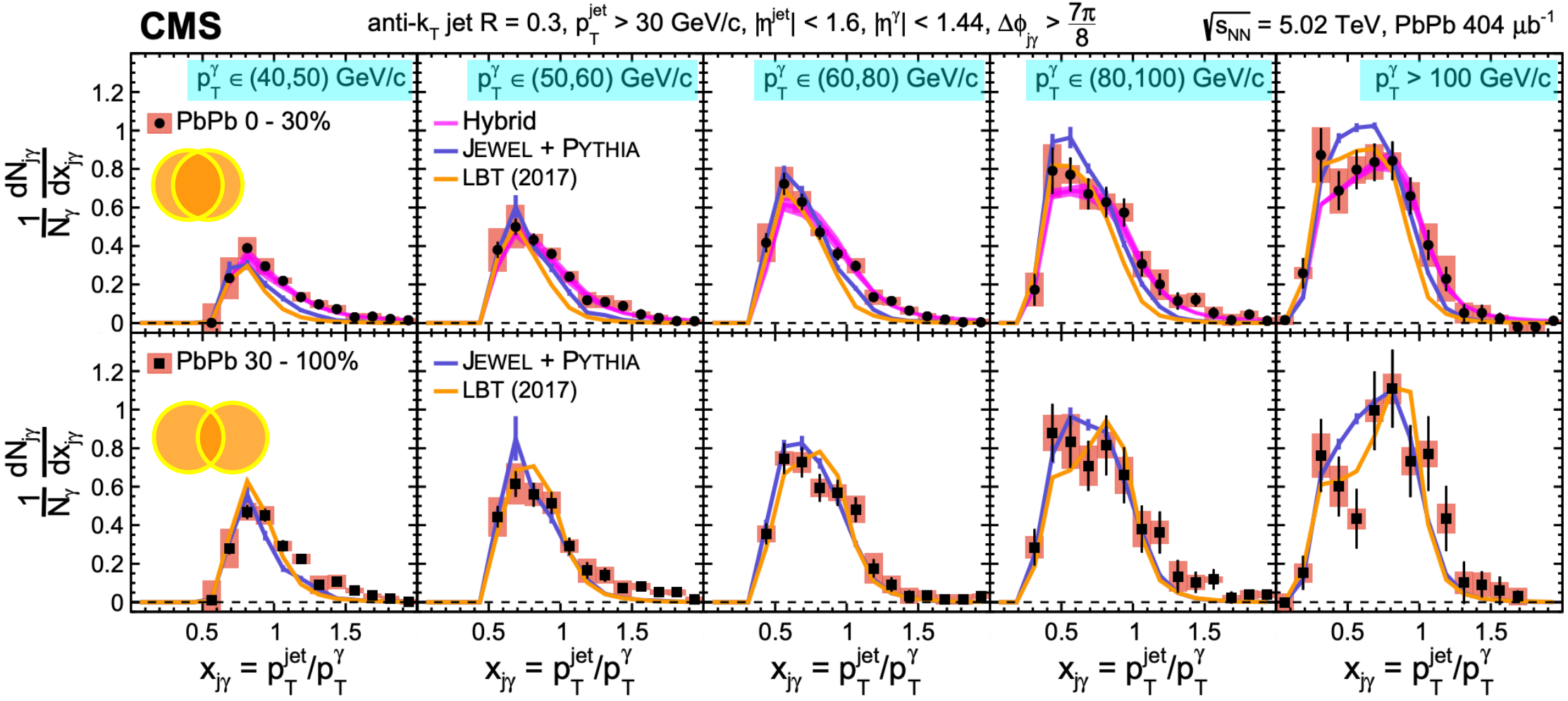
Momentum imbalance theory comparison



Data is well described by JEWEL, Hybrid, and LBT models

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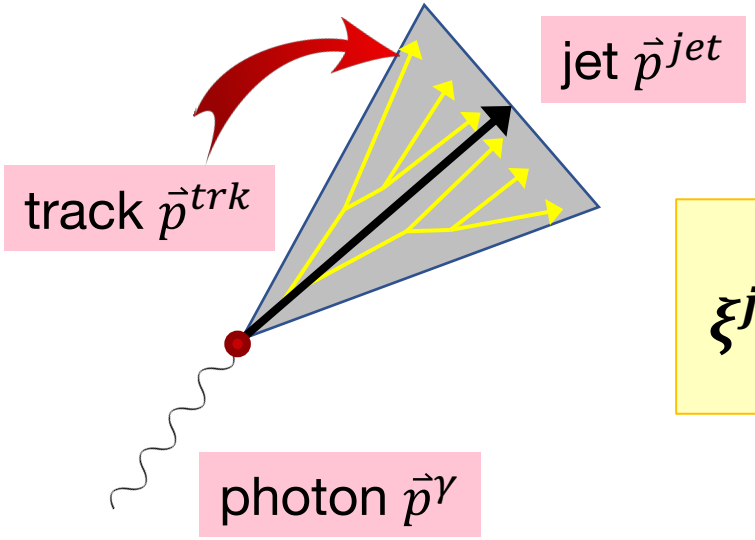
Photon-tagged jet fragmentation function

- Small excess of low p_T particles
- Depletion of high p_T particles
- Direct evidence of jet quenching
- Peripheral events consistent with pp data



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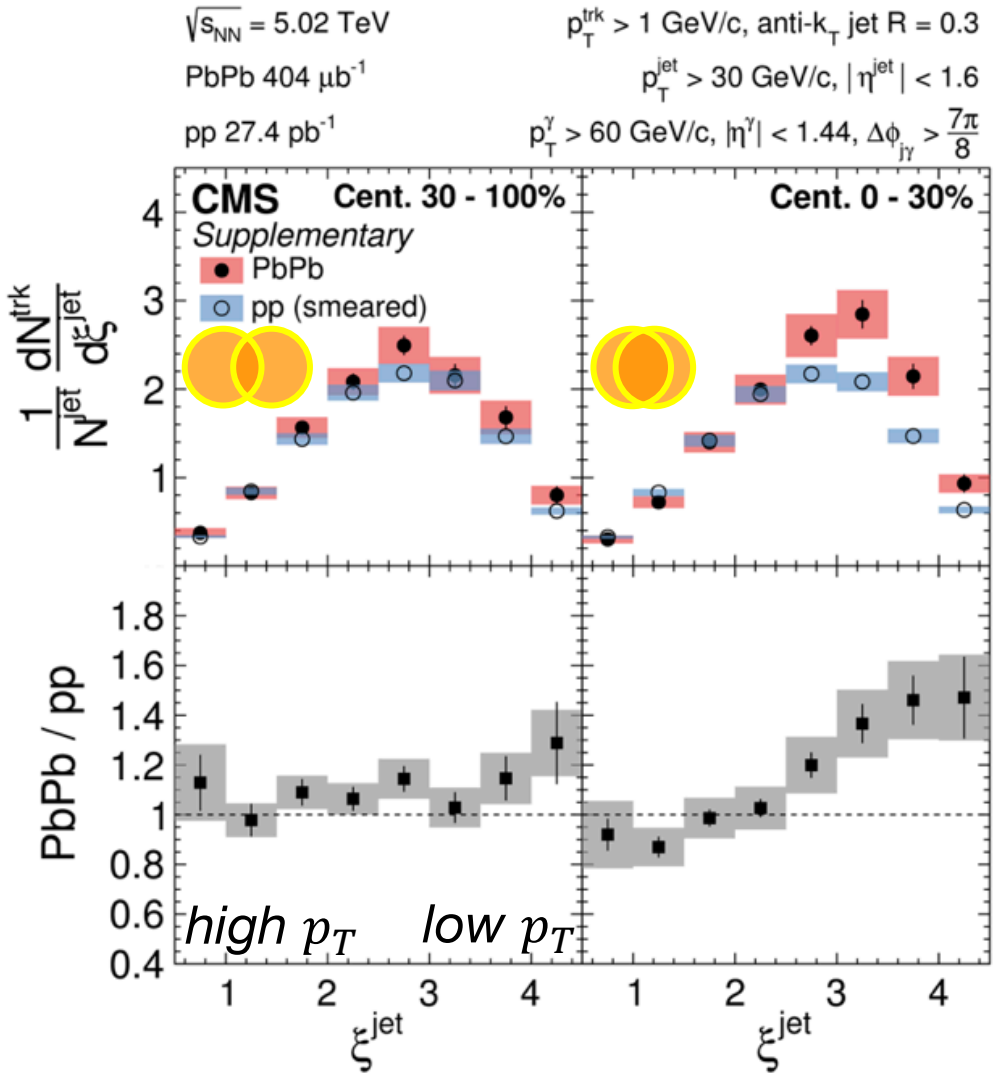

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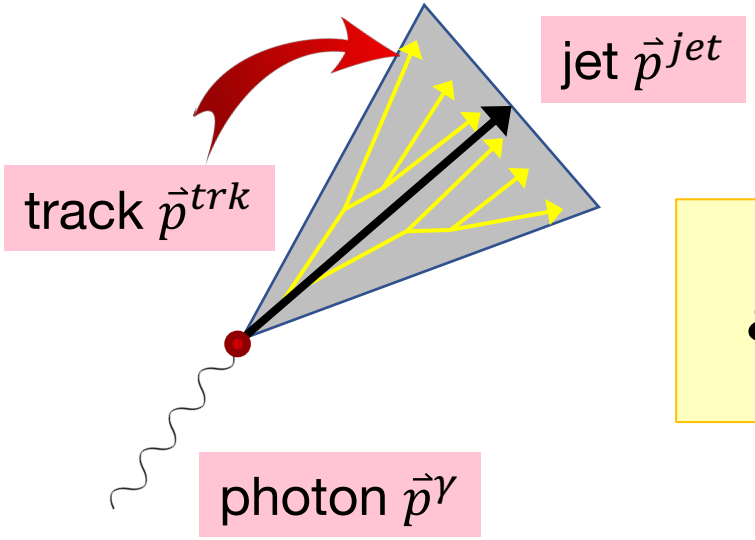
Photon-tagged jet fragmentation function

- Small excess of low p_T particles
- Depletion of high p_T particles
- Direct evidence of jet quenching
- More strongly modified than ξ_{jet}



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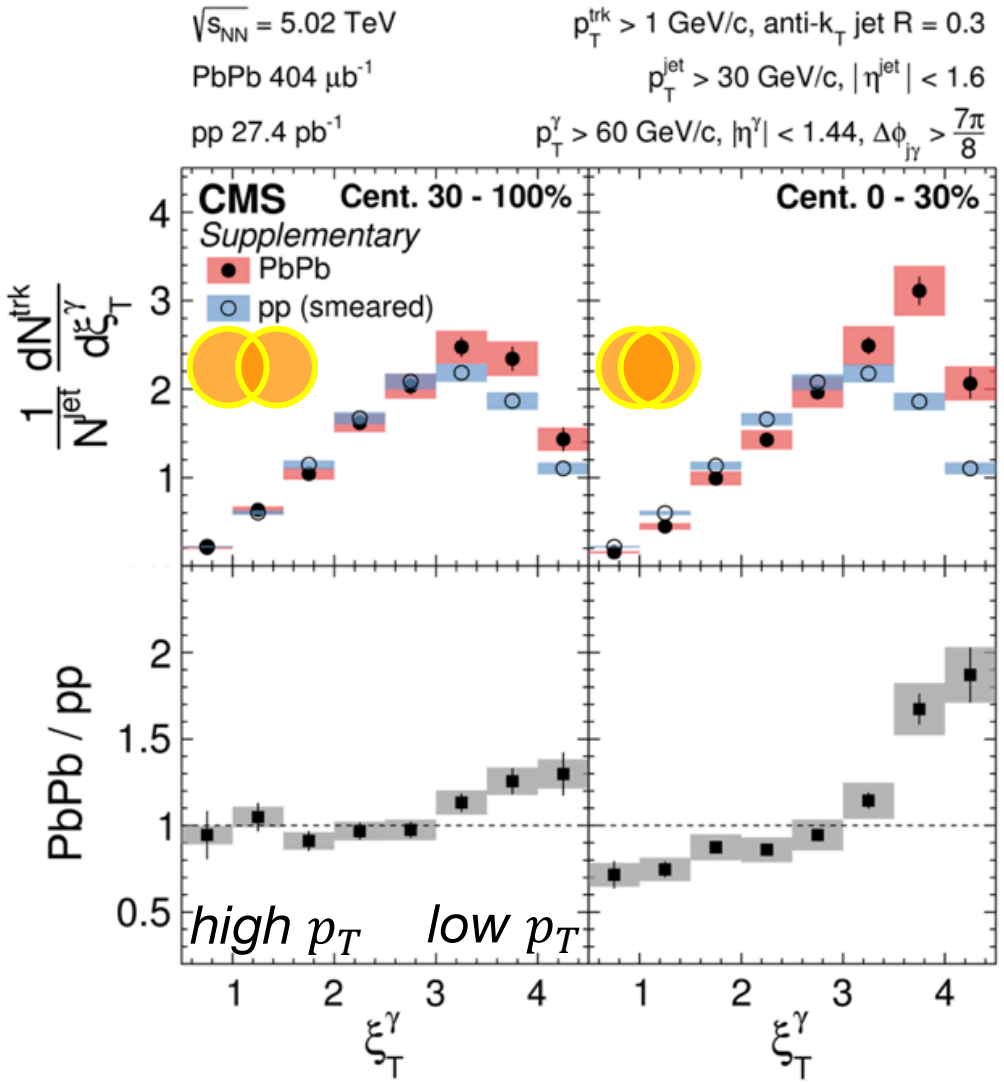
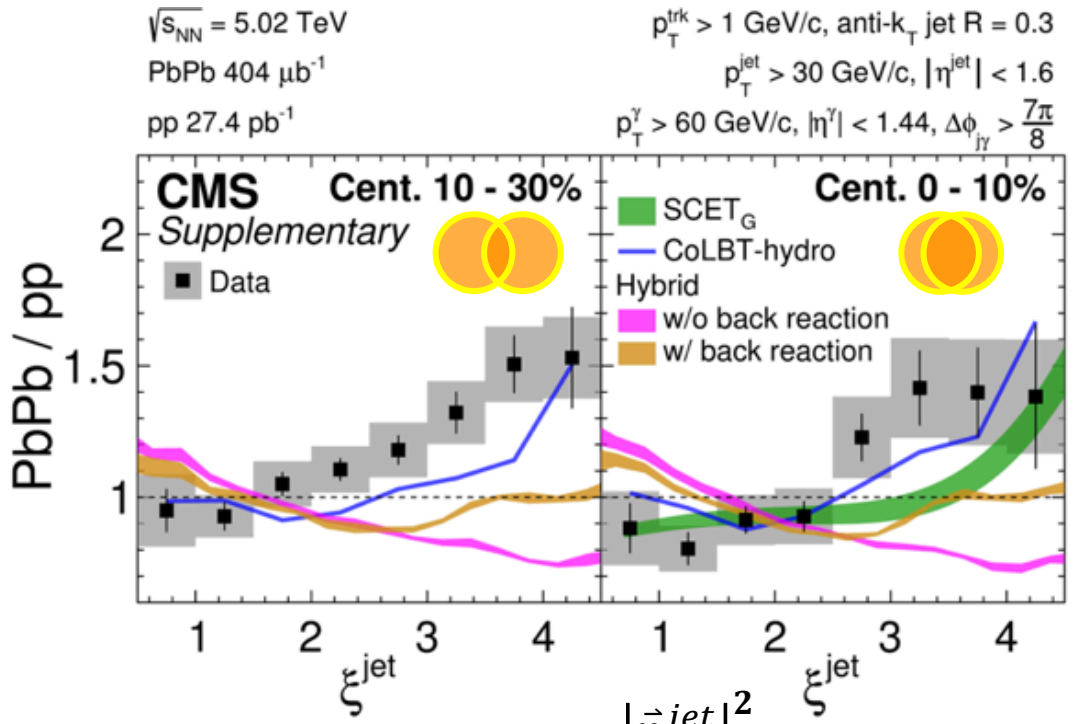


PRL 121 (2018) 242301

Photon-tagged jet fragmentation function

- Photon trigger => initial parton spectra are the same for PbPb and pp
- $SCET_G$ and CoLBT-hydro describe trend
- Back reaction improves agreement of Hybrid with data



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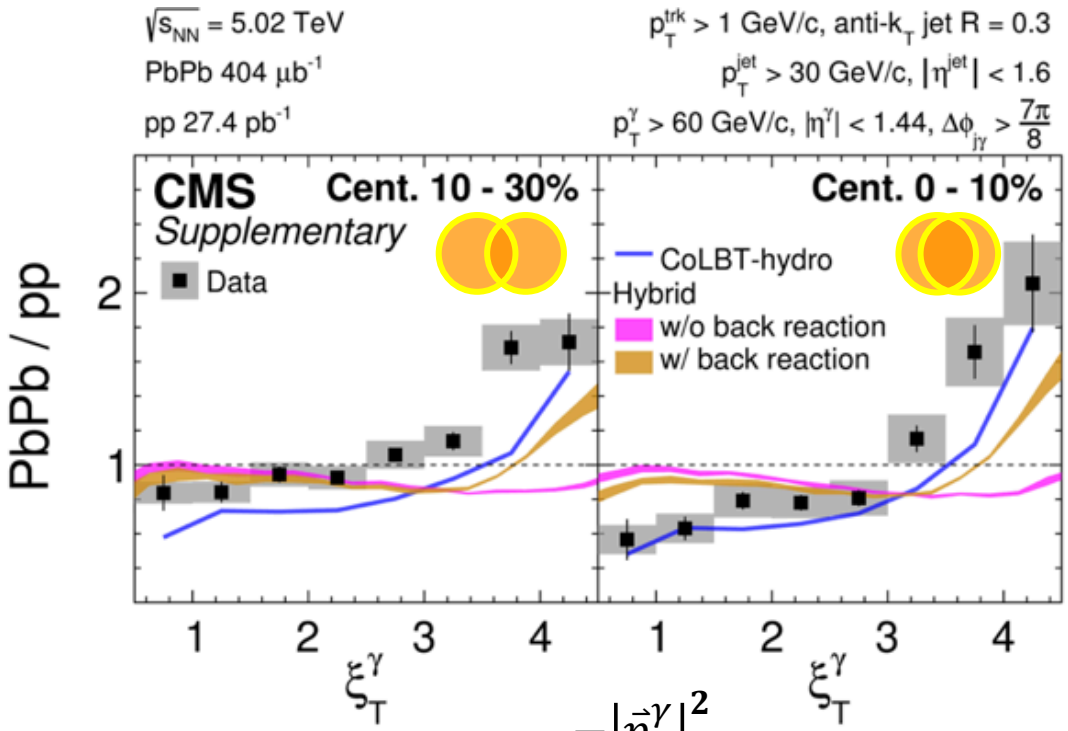

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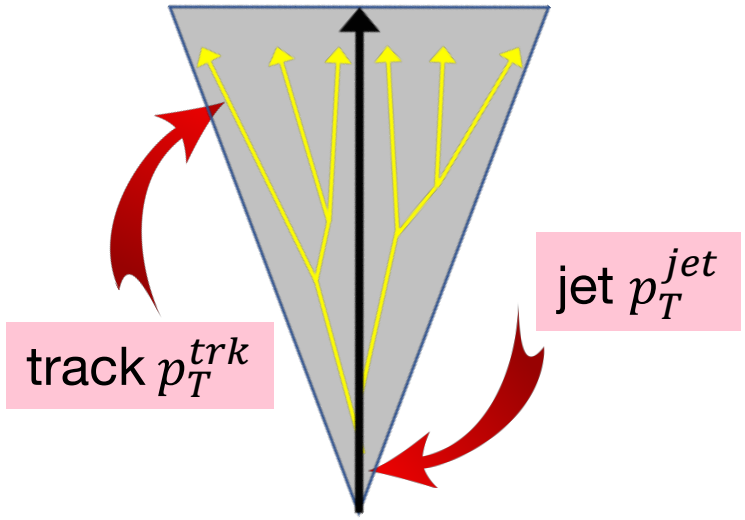
Photon-tagged jet shape



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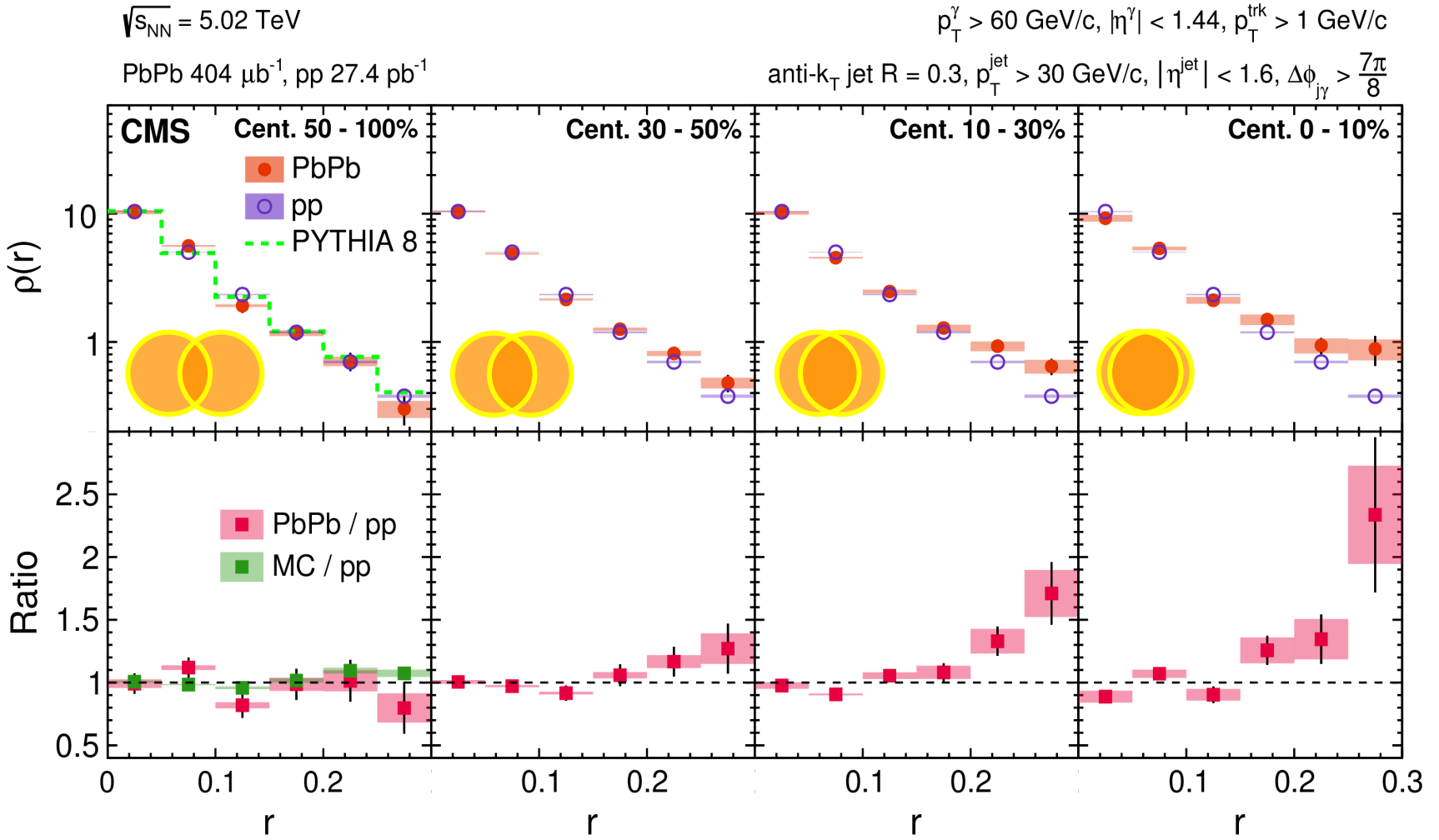
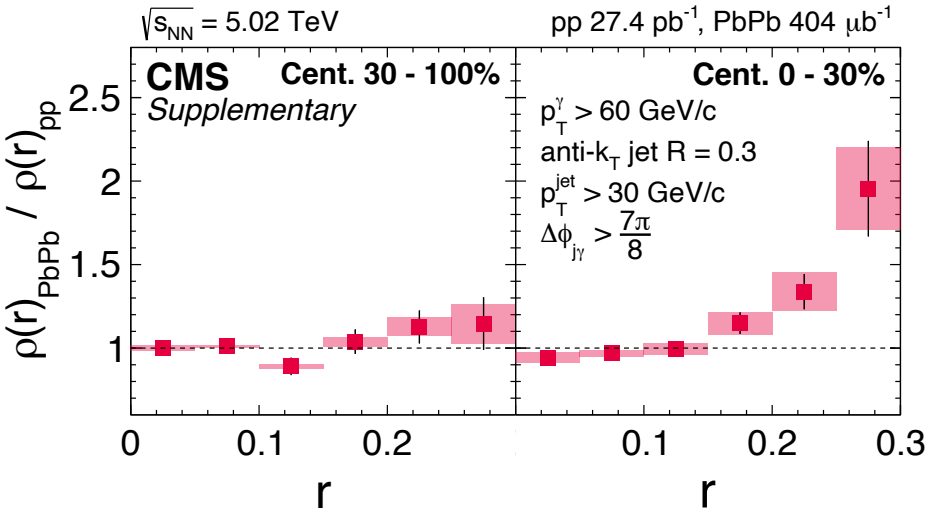


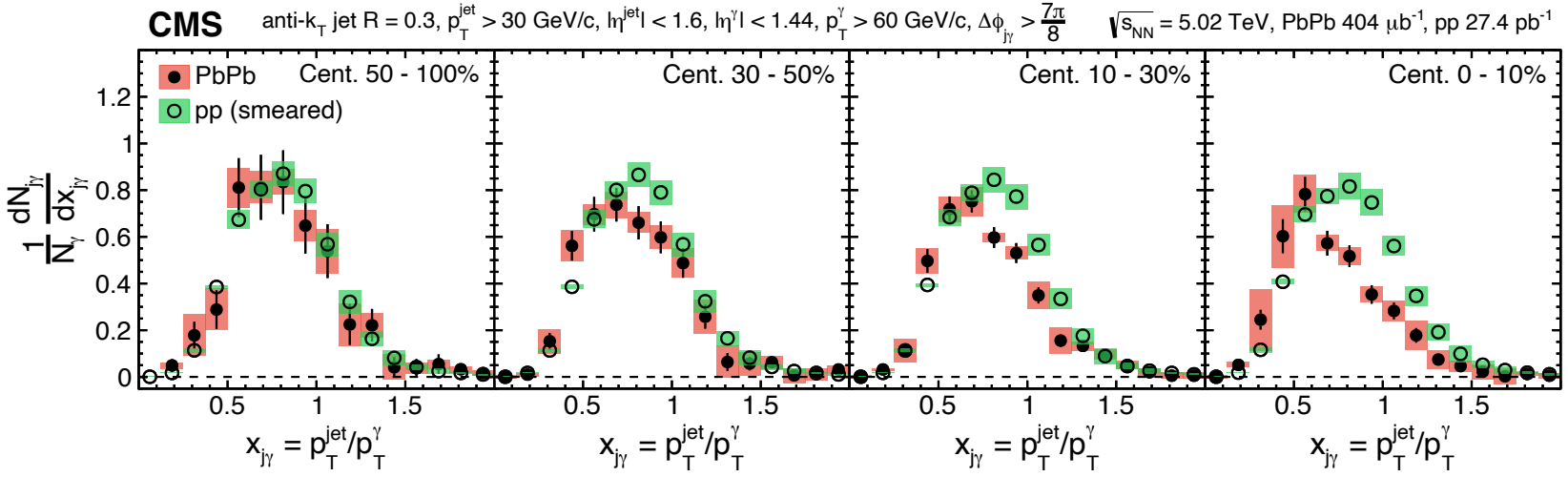
Small relative modification of jet core & enhancement of particles away from jet axis

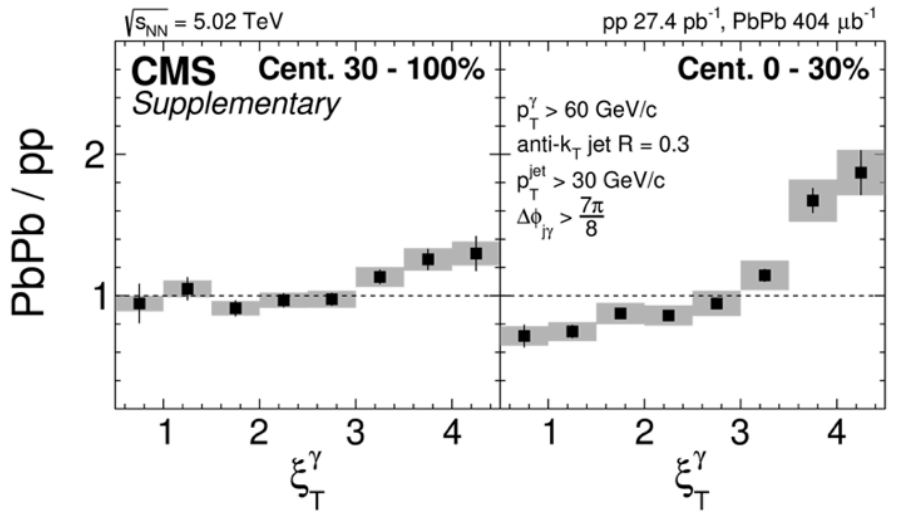
PRL 122 (2019) 152001

Summary

- PbPb data has larger γ-jet asymmetry
  => jet energy loss
- Enhancement of low p_T particles
- Depletion of high p_T particles
- Small relative modification of jet core
- Enhancement of particles away from jet axis

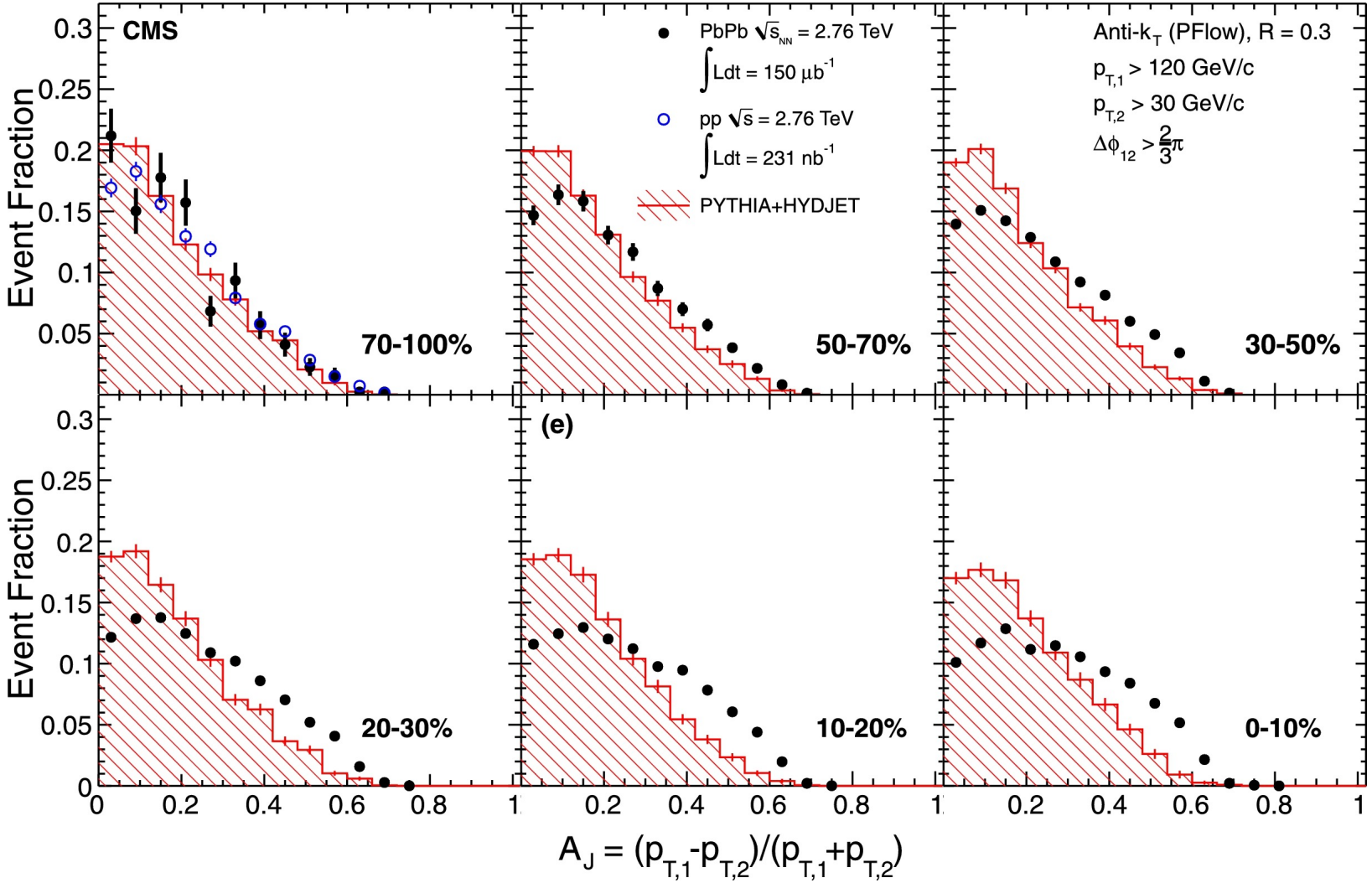






Backup

Dijet asymmetry



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Prompt photon production

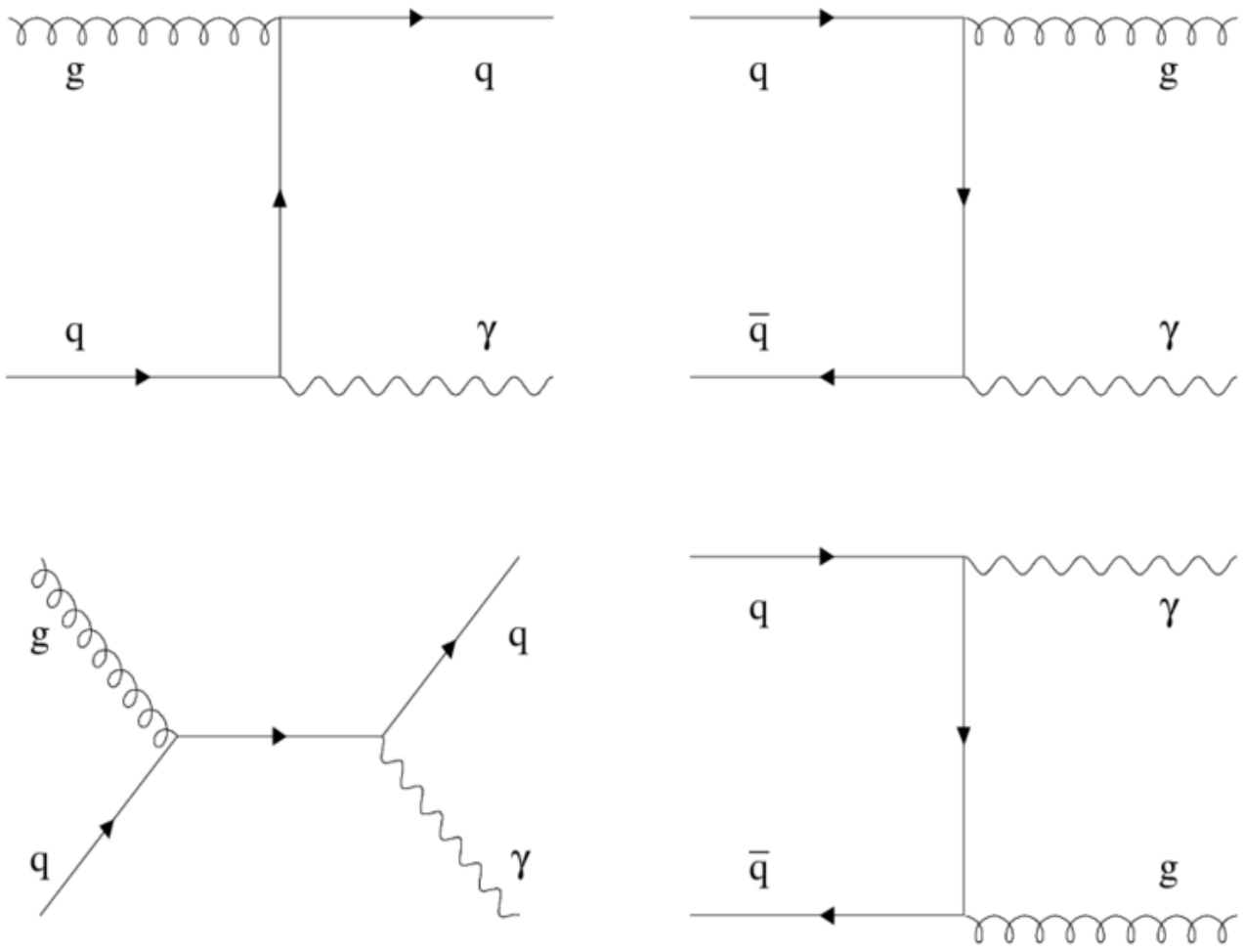
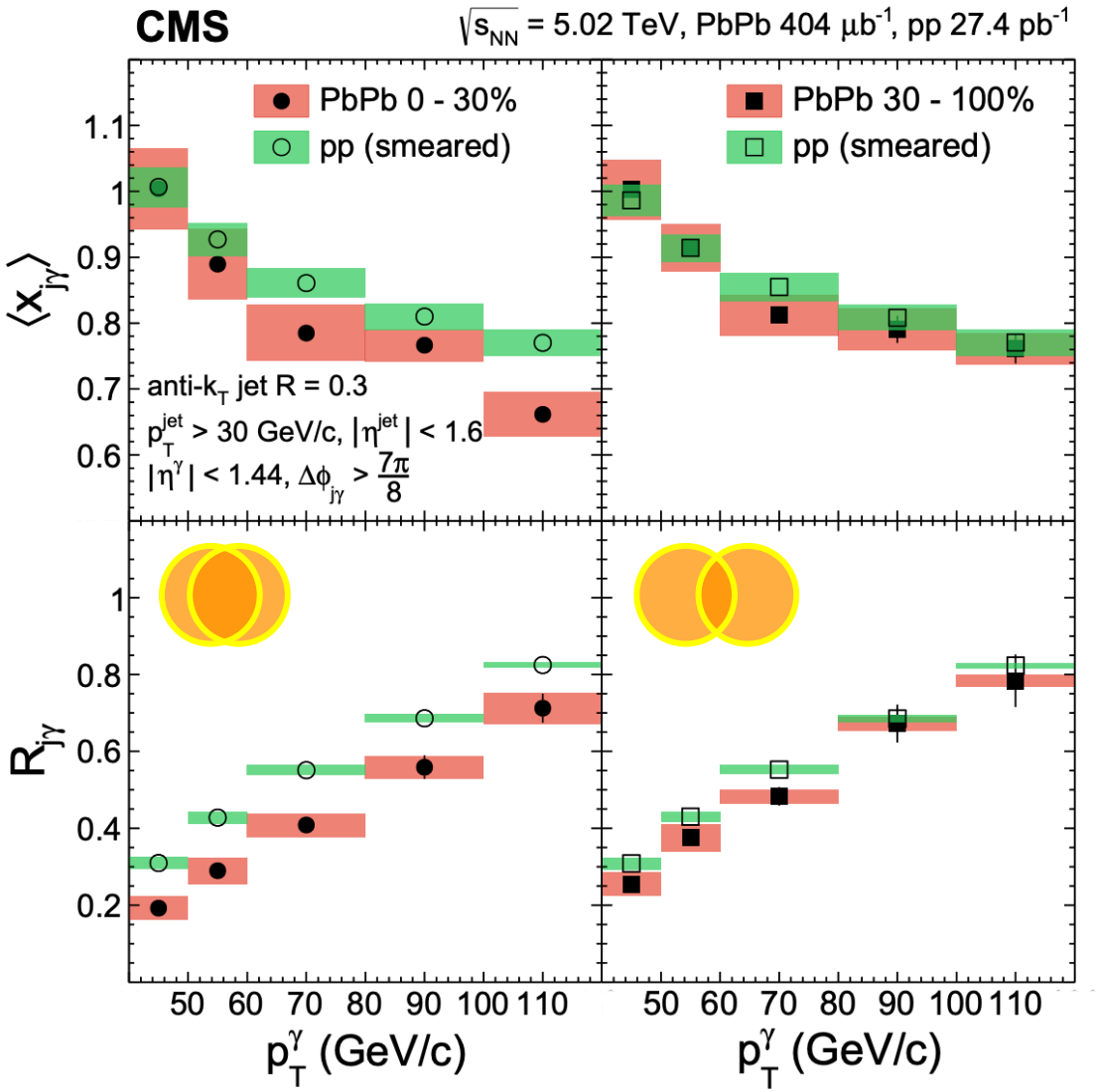


Figure: PLB 317 (1993) 250256

Mean photon jet asymmetry



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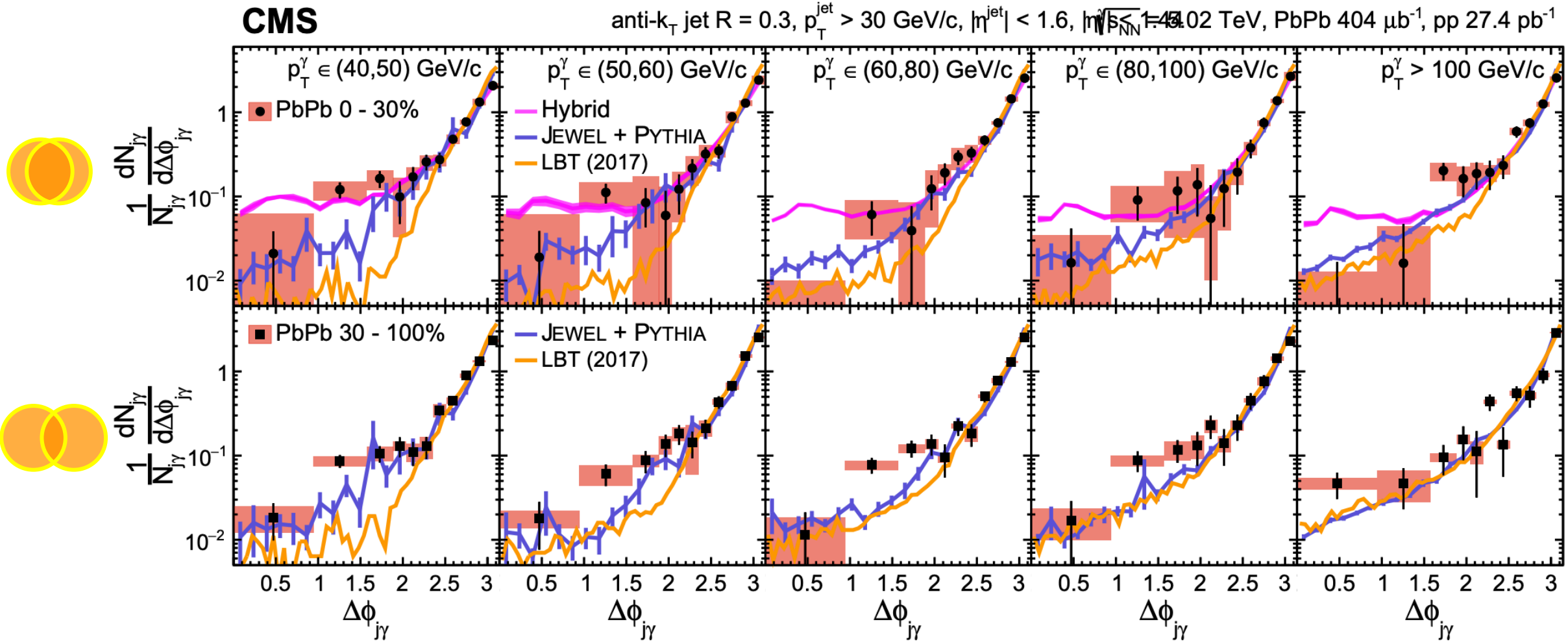
Photon jet azimuthal correlation theory



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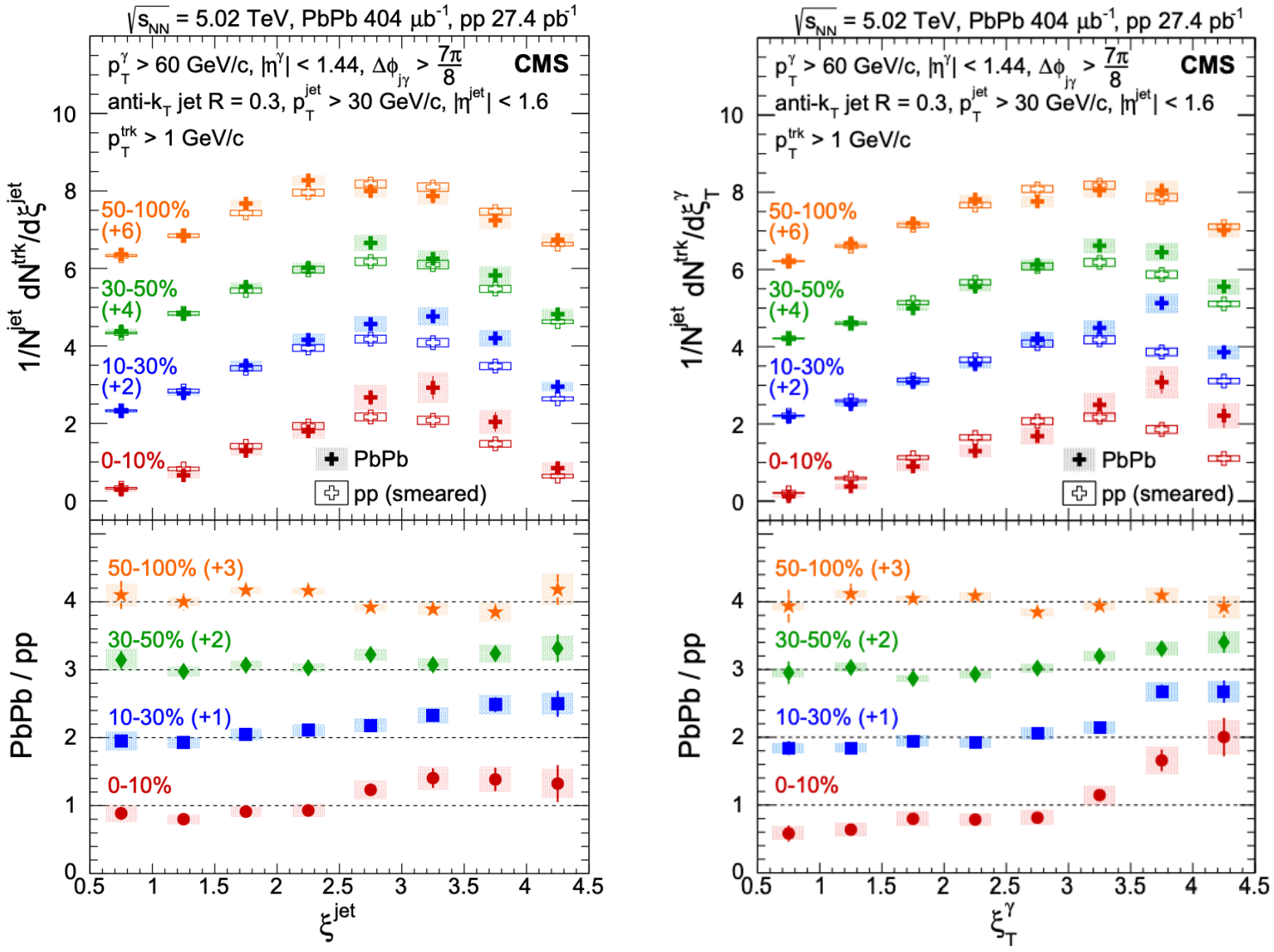
Fragmentation function centrality dependence



$$\xi_{jet} = \ln \frac{\left|\vec{p}^{jet}\right|^2}{\vec{p}^{trk} \cdot \vec{p}^{jet}}$$

$$\xi_\gamma = \ln \frac{-\left|\vec{p}_T^{\gamma}\right|^2}{\vec{p}_T^{trk} \cdot \vec{p}_T^{\gamma}}$$

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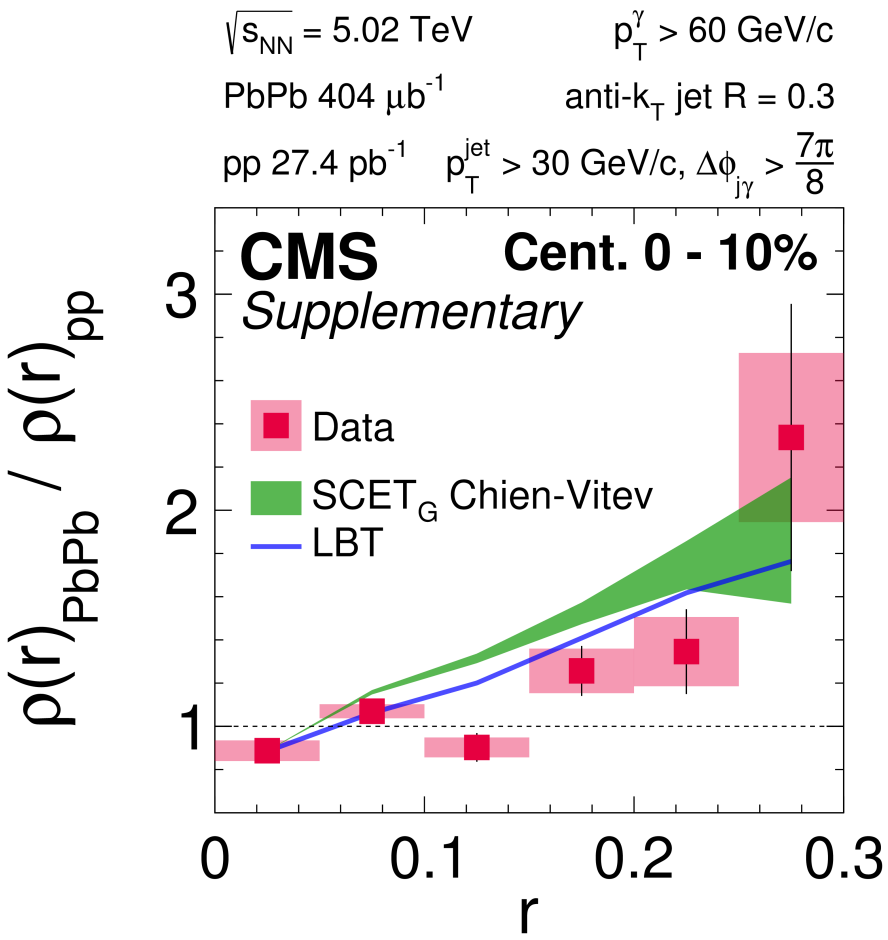
Photon-tagged jet shape theory



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