Massachusetts Institute of Technology

Measurement of isolated-photon+jet correlations in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with CMS

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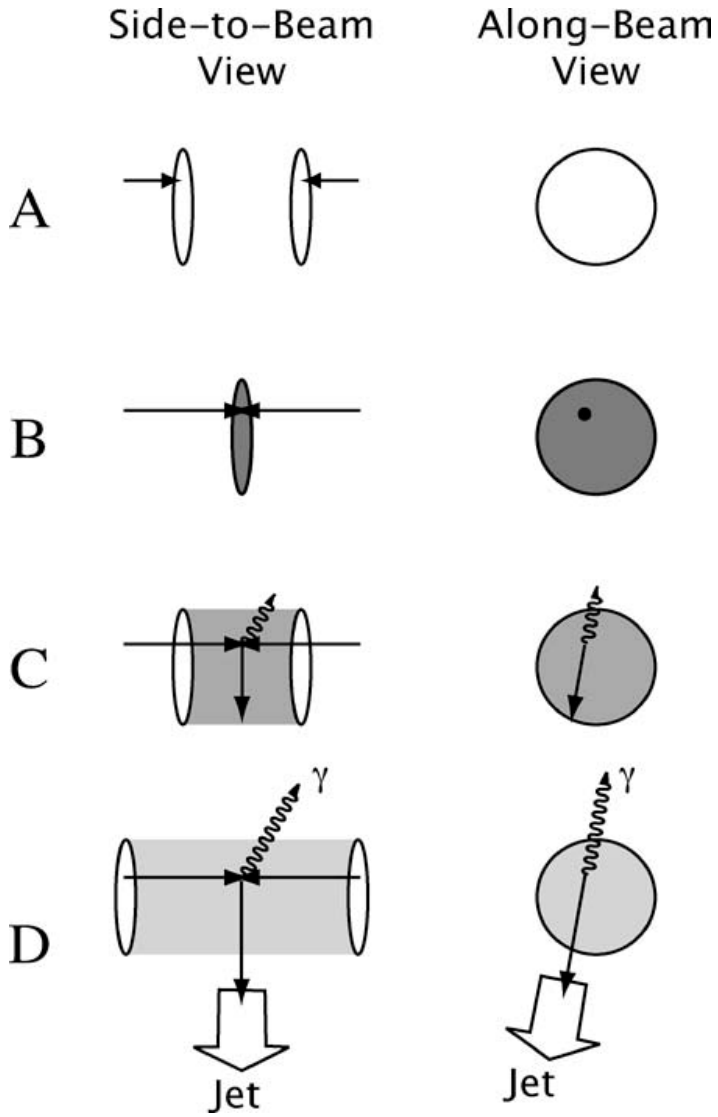
MIT LNS

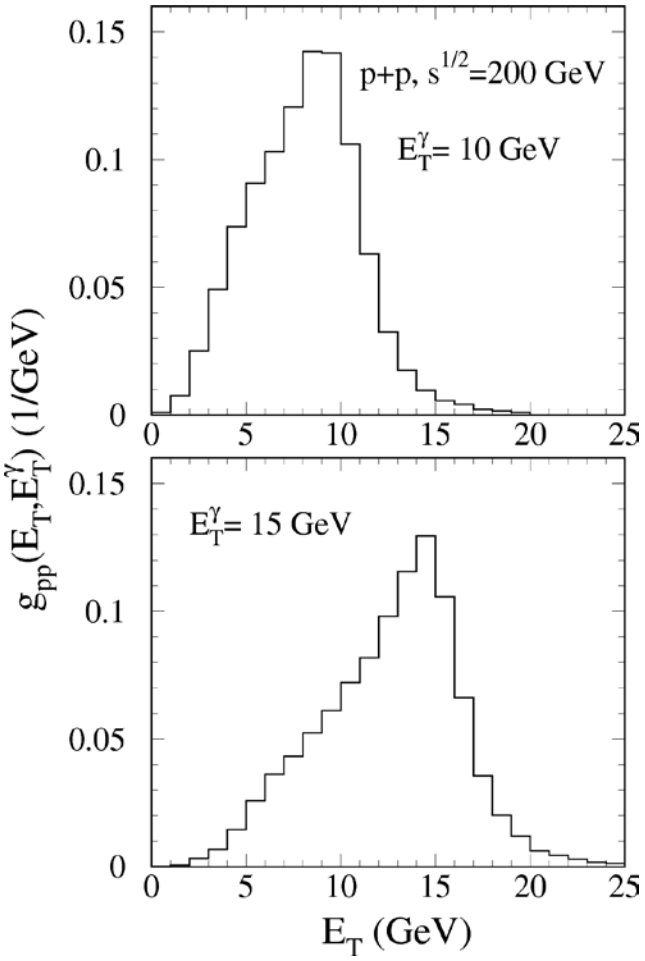
Motivation

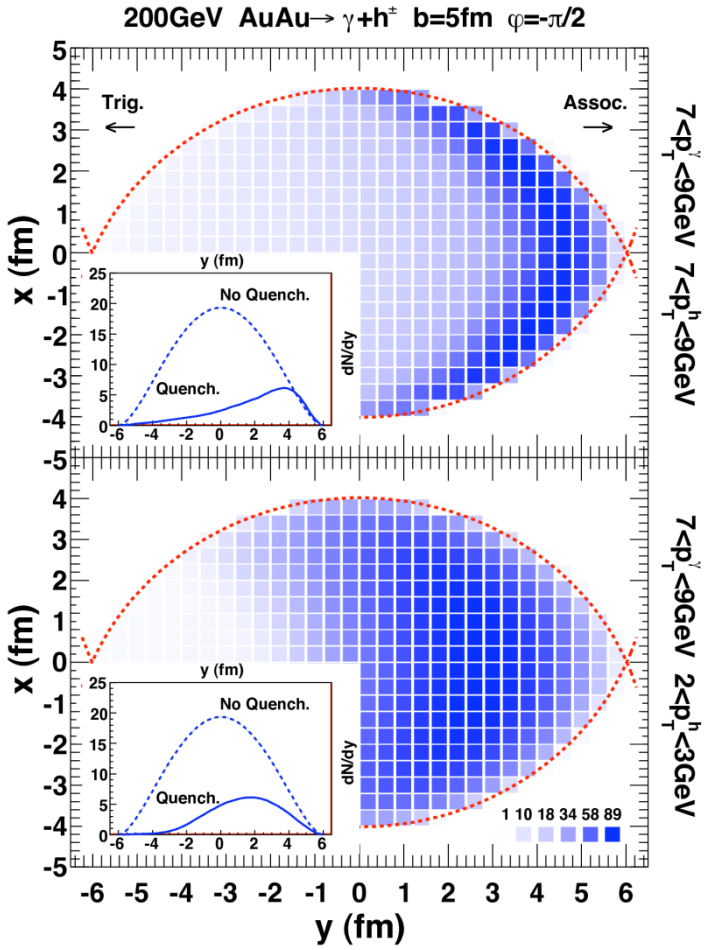
- Direct measurement of the parton energy loss in the QGP with photon–jet events.
- Isolated photons are unmodified
- Remove the "surface bias" which dijet events suffer
- Access to the initial parton energy via isolated photon
- Access to the final parton energy via jet reconstruction



P. Stankus, Ann. Rev. Nucl. Part. Sci. 55, 517 (2005)

15 Years of Photon–Jet Theory



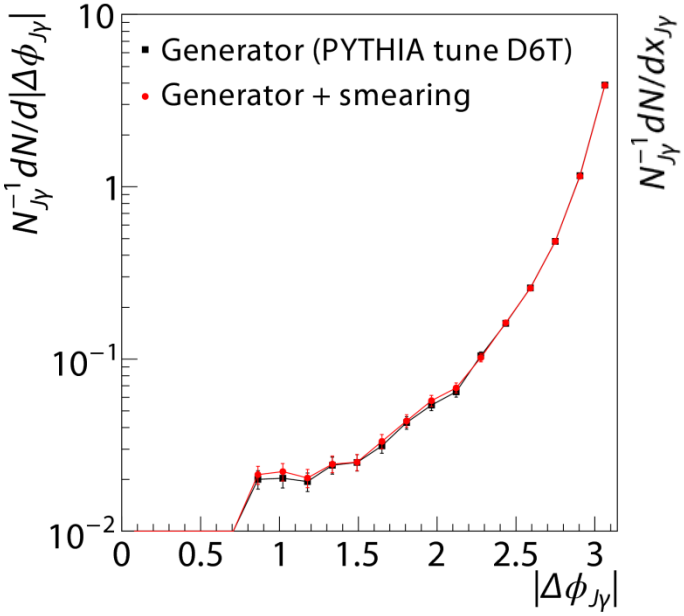


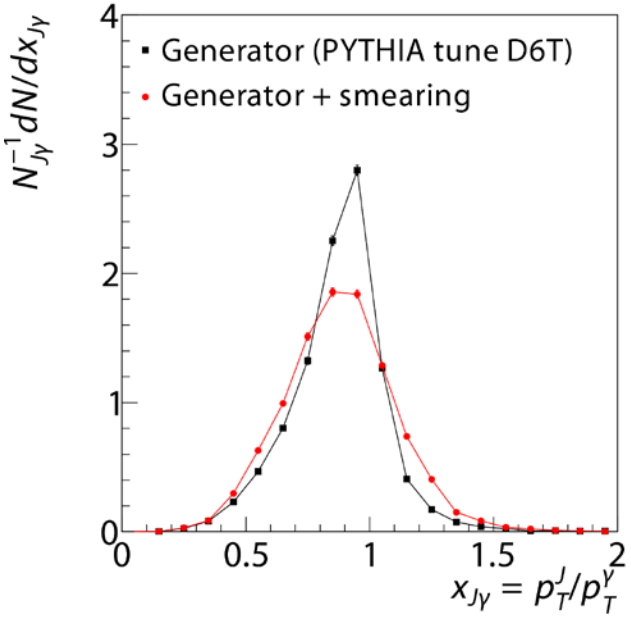
X.-n. Wang (LBNL), Z. Huang, Phys.Rev.C55:3047-3061,1997

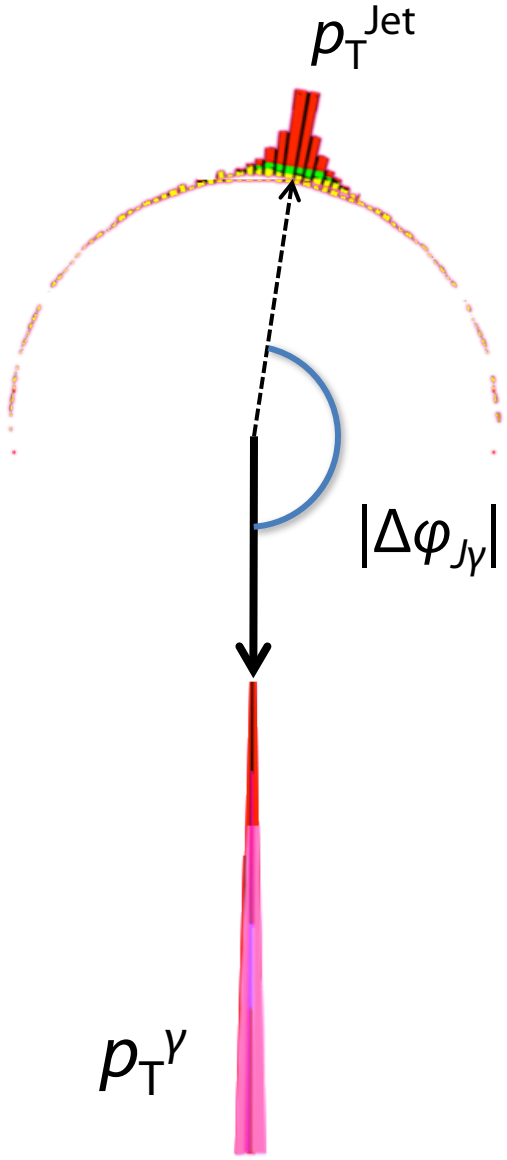
H.-z. Zhang et al., Phys. Rev. Lett. 103, 032302 (2009)

Observables

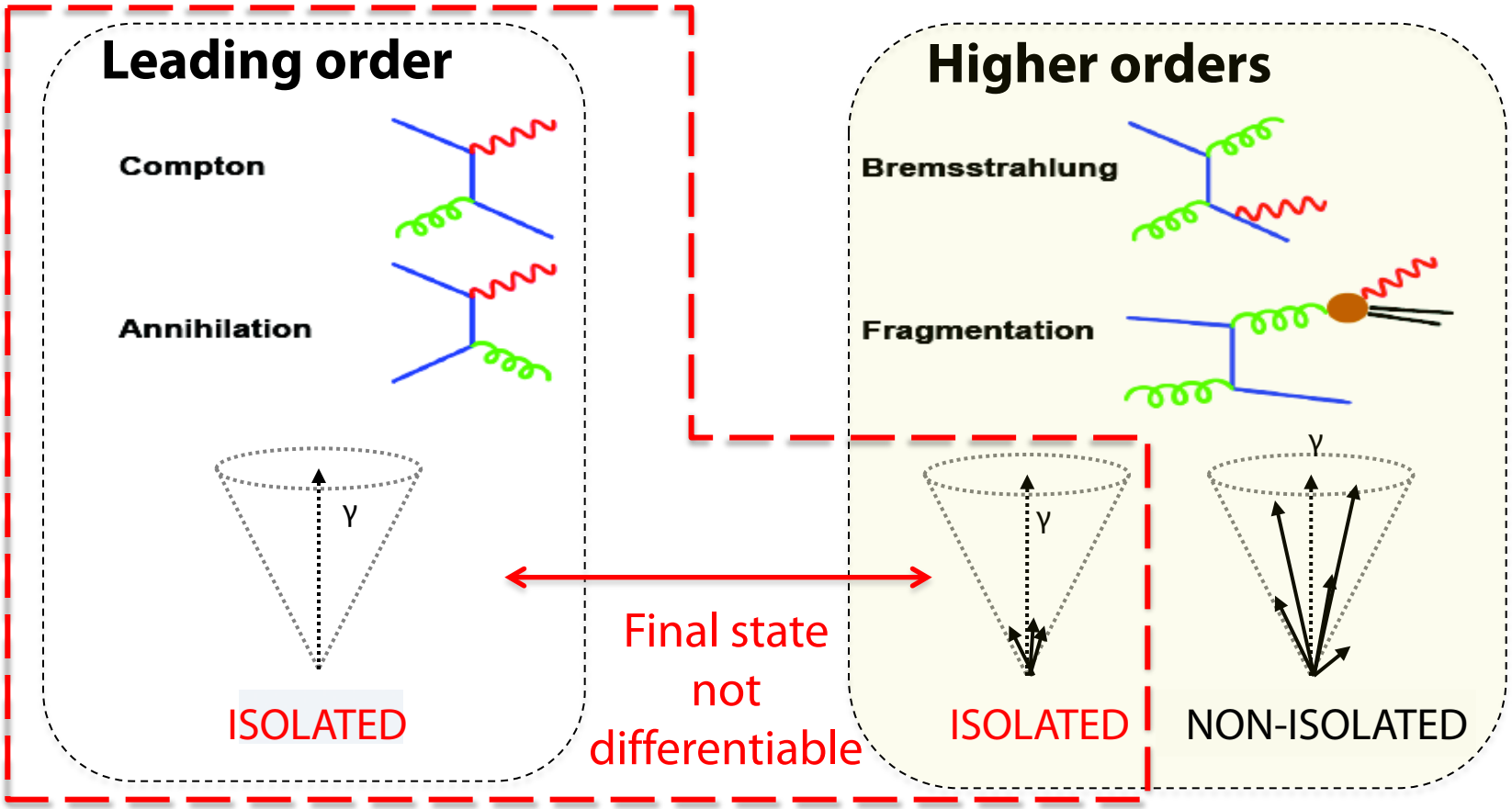
- Azimuthal decorrelation:
  $|\Delta\varphi_{J\gamma}|$, and its parametrized width $\sigma(|\Delta\varphi_{J\gamma}|)$
- Transverse momentum ratio:
  $x_{J\gamma} = p_T^{Jet}/p_T^{\gamma}$, and its mean $\langle x_{J\gamma}\rangle$
- Fraction of photons with associated jets: $R_{J\gamma}$
- $p_T^{\gamma} > 60$ GeV/c (to have sufficient $x_{J\gamma}$ phase space)
- $p_T^{Jet} > 30$ GeV/c (constrained by efficiency)





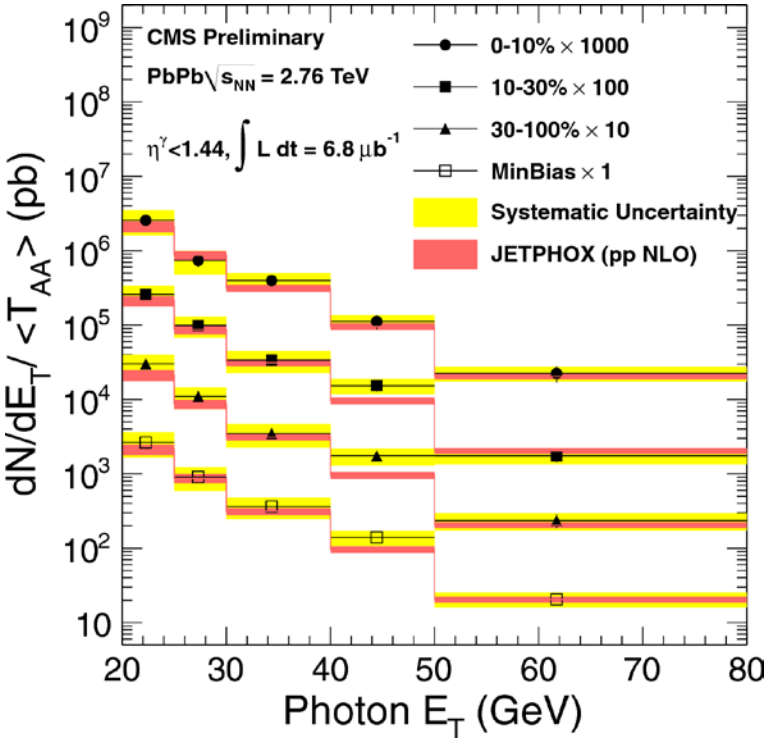


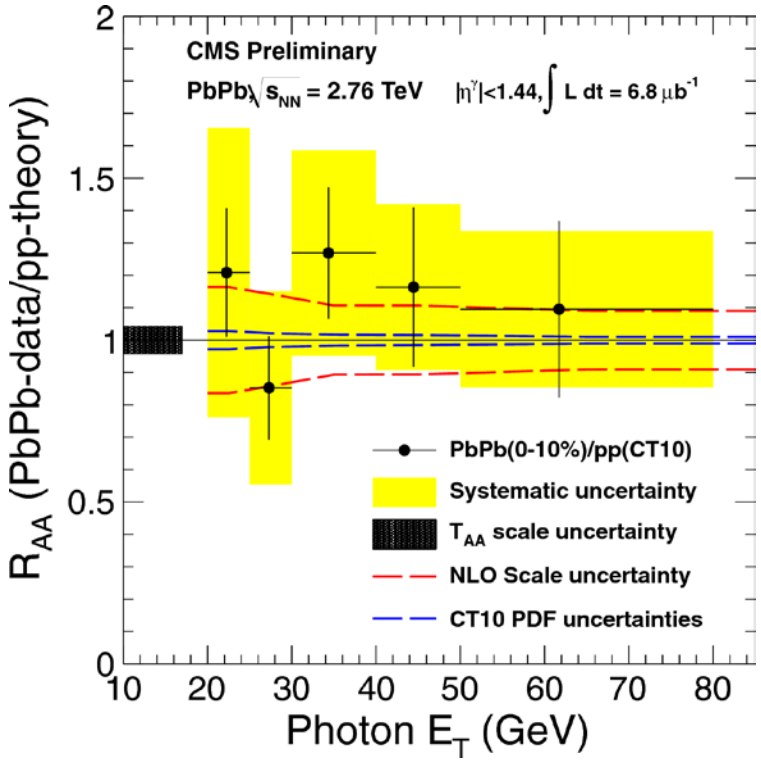
Signal Definition



- SumIso = uncorrected Track + ECAL + HCAL E_T in $R < 0.4$
- GenIso = generator level particle energy in $R < 0.4$
- Isolated prompt (non-decay) photons with SumIso < 1 GeV
- Comparison to MC definition GenIso < 5 GeV
- SumIso ≠ GenIso due to PbPb underlying event fluctuation

Isolated Prompt Photons in CMS



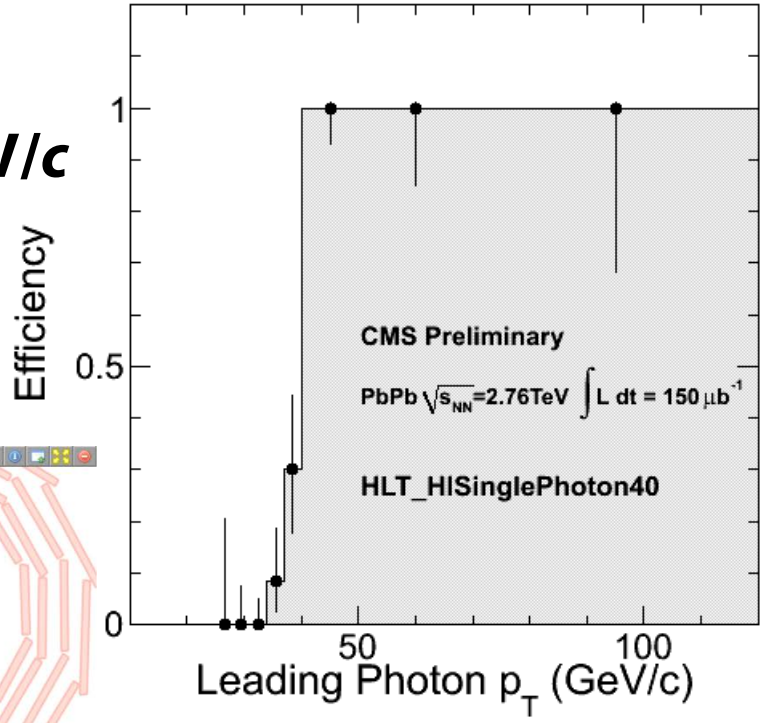


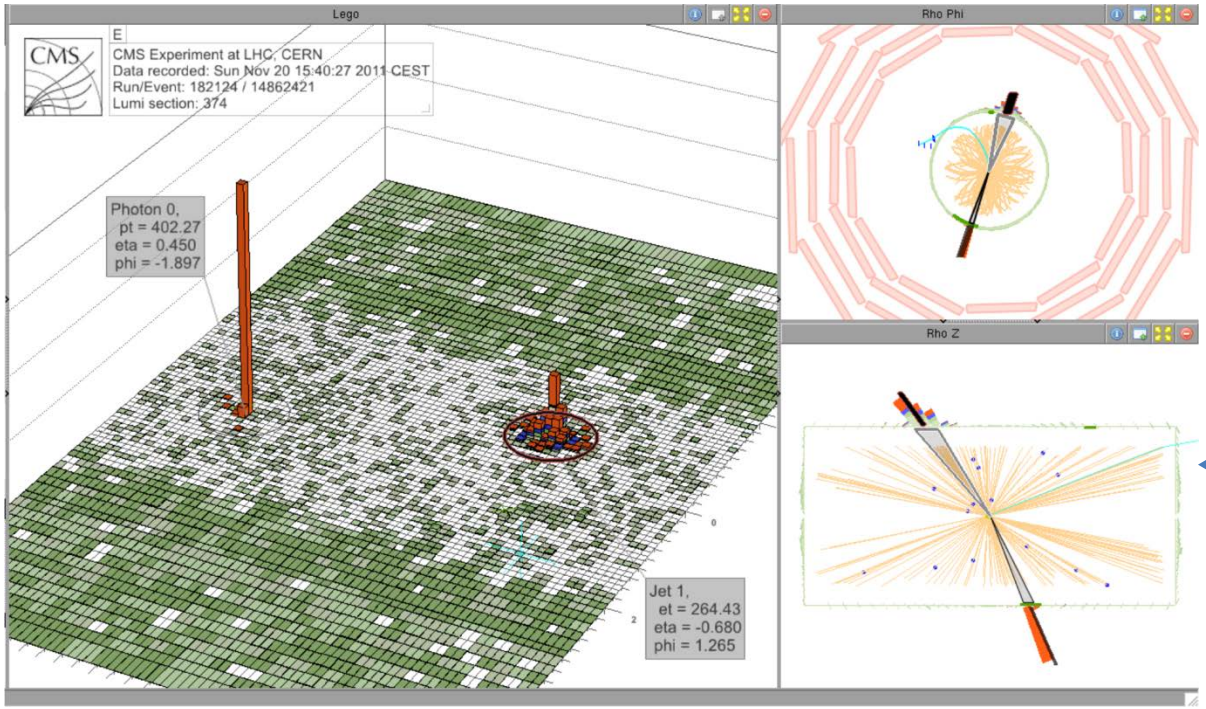
- Isolated prompt photons in 2010 PbPb Data
- Yield matches pp NLO × $\langle T_{AA} \rangle$

Photon–Jet in 2011 CMS PbPb

HLT photon trigger

Fully efficient for $p_T^{\gamma} > 40$ GeV/c



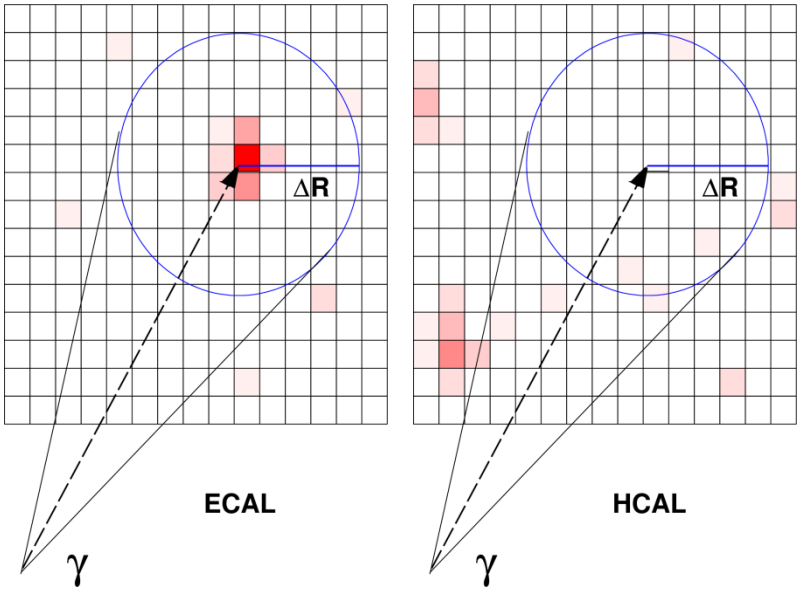


Event with:

p_T^{γ} = 400 GeV/c

p_T^{Jet} = 260 GeV/c

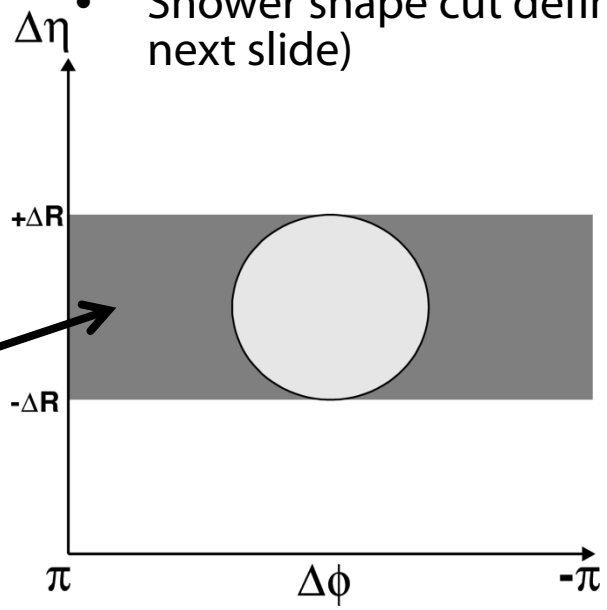
Signal Selection: Photon Isolation



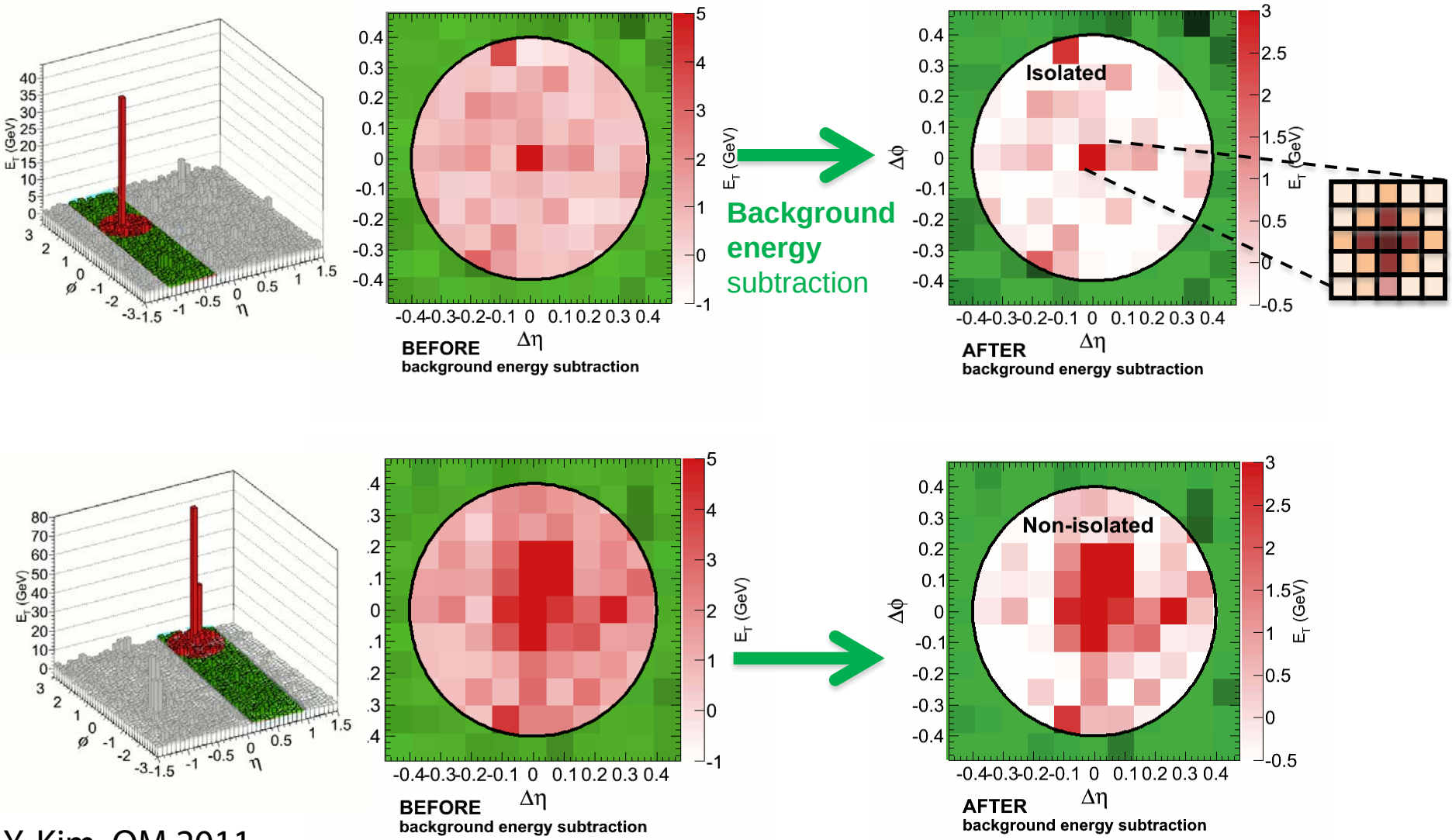
- $\mathrm{Iso}_4^{\mathrm{ECAL}} = -p_T^{\mathrm{cand}} + \sum_{\Delta R < 0.4} p_T^j$
- $\mathrm{Iso}_4^{\mathrm{UE\text{-}sub,ECAL}} = \mathrm{Iso}_4^{\mathrm{ECAL}} - \langle p_T^{\mathrm{Background,ECAL}} \rangle$
- Analogously for track, HCAL (without $-p_T^{\mathrm{cand}}$)

Photon Selection Cuts

- $|z_{\mathrm{vertex}}| < 15$ cm
- $(1 - E_4/E_1) < 0.9$
  (Index 1: highest crystal, 4: 4 adjacent crystals)
- Seed supercluster $|\Delta t| < 3$ ns
- $H/E < 0.1$
- No electron candidate
- SumIso < 1 GeV
- Shower shape cut defined next slide)

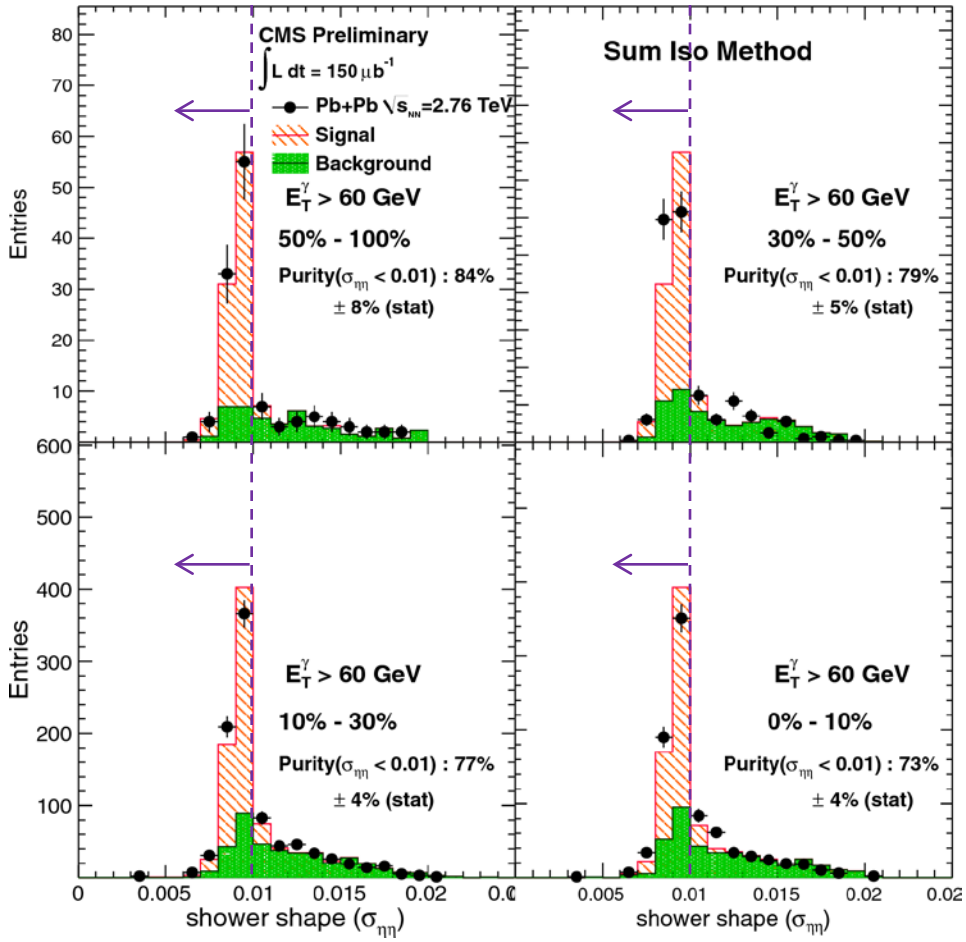


Isolation in Data



Y. Kim, QM 2011

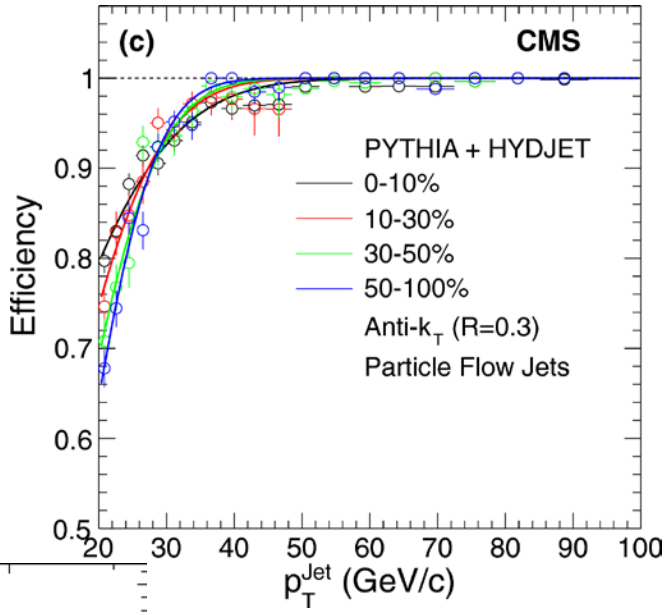
Signal Selection: Stat. Subtr. of Decay Photons

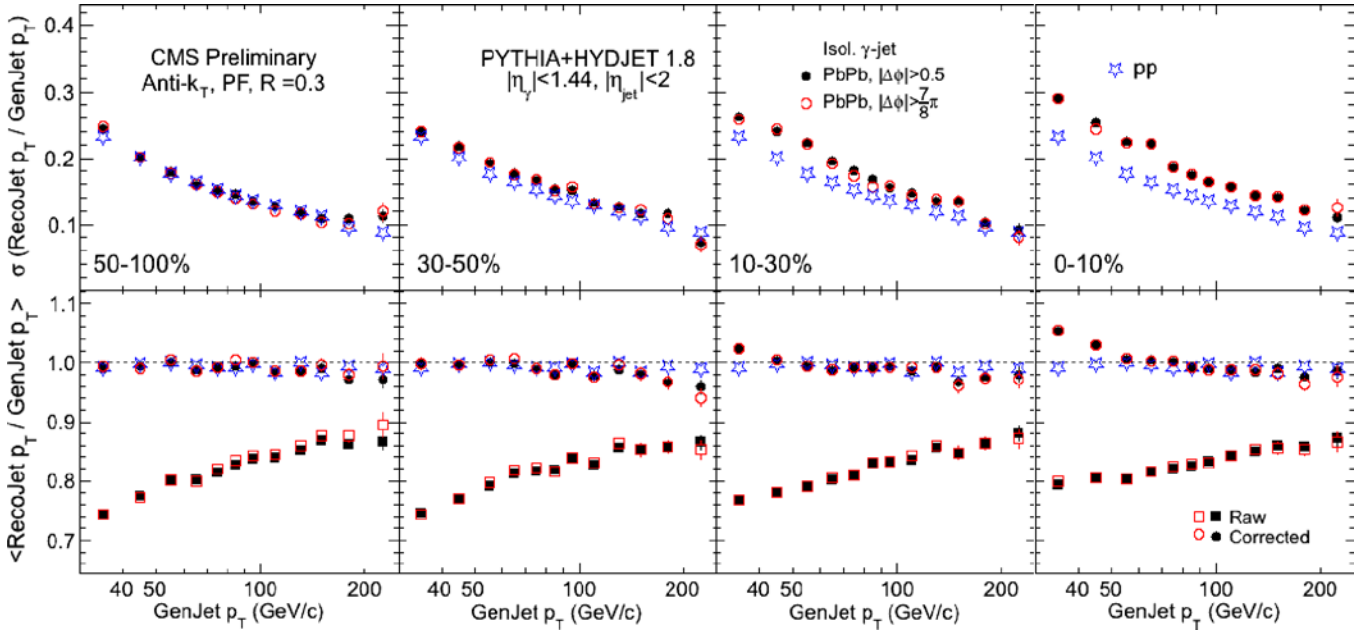


- Shower shape
  $\sigma_{\eta\eta} = \sum_i^{5\times5} w_i(\eta_i - \eta_{5\times5})^2 / \sum_i^{5\times5} w_i$
  $w_i = \max(0, c + \ln E_i/E_{5\times5})$
- Decay photons largely removed by cutting on $\sigma_{\eta\eta} < 0.01$
- Remaining contribution of decay photons removed using predicted $\sigma_{\eta\eta}$ distribution
- Shape of background $\sigma_{\eta\eta}$ found **data driven** using photons failing the SumIso cuts

Signal Selection: Jet

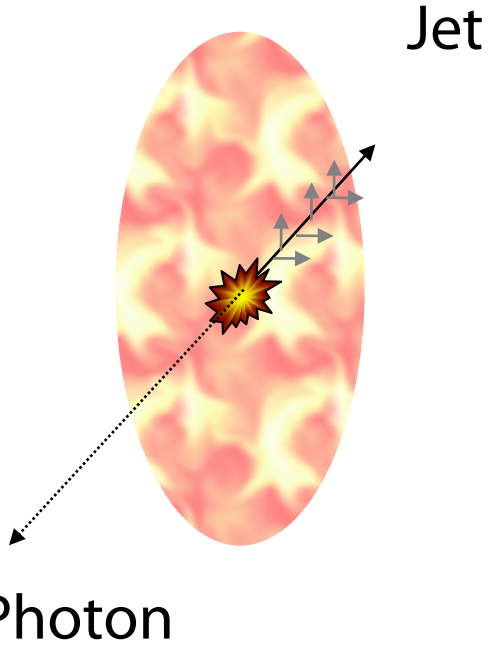
- Anti-k_T particle flow jets, $R = 0.3$
- UE estimation/subtraction using φ-rings in η, excluding jet candidates (two iterations)
- Reconstruction > 90% efficient for $p_T^{Jet} > 30$ GeV/c in PbPb



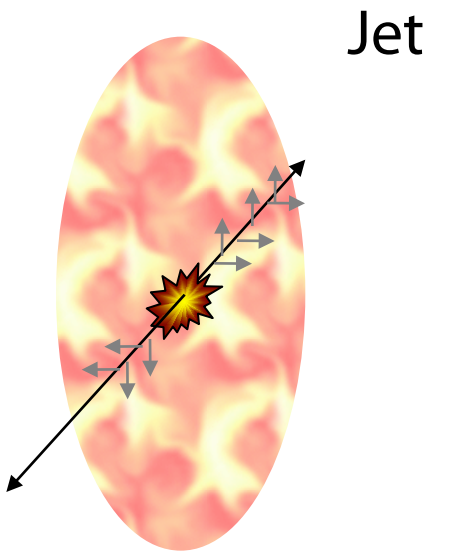


Background processes

Signal photon-jet



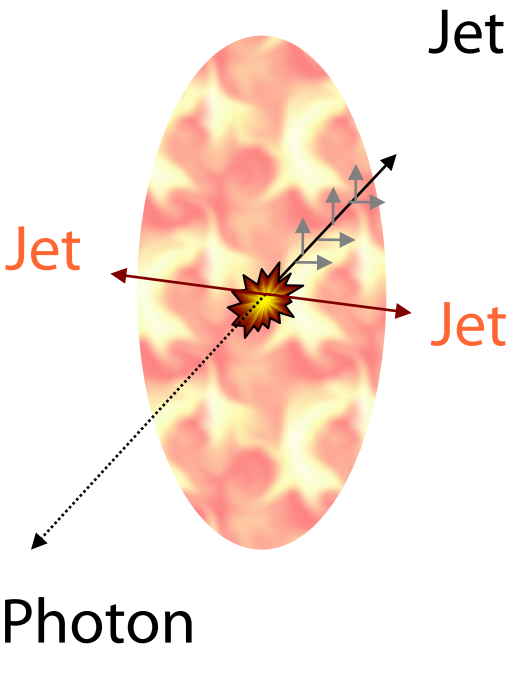
Background from dijet



Background photon from jet

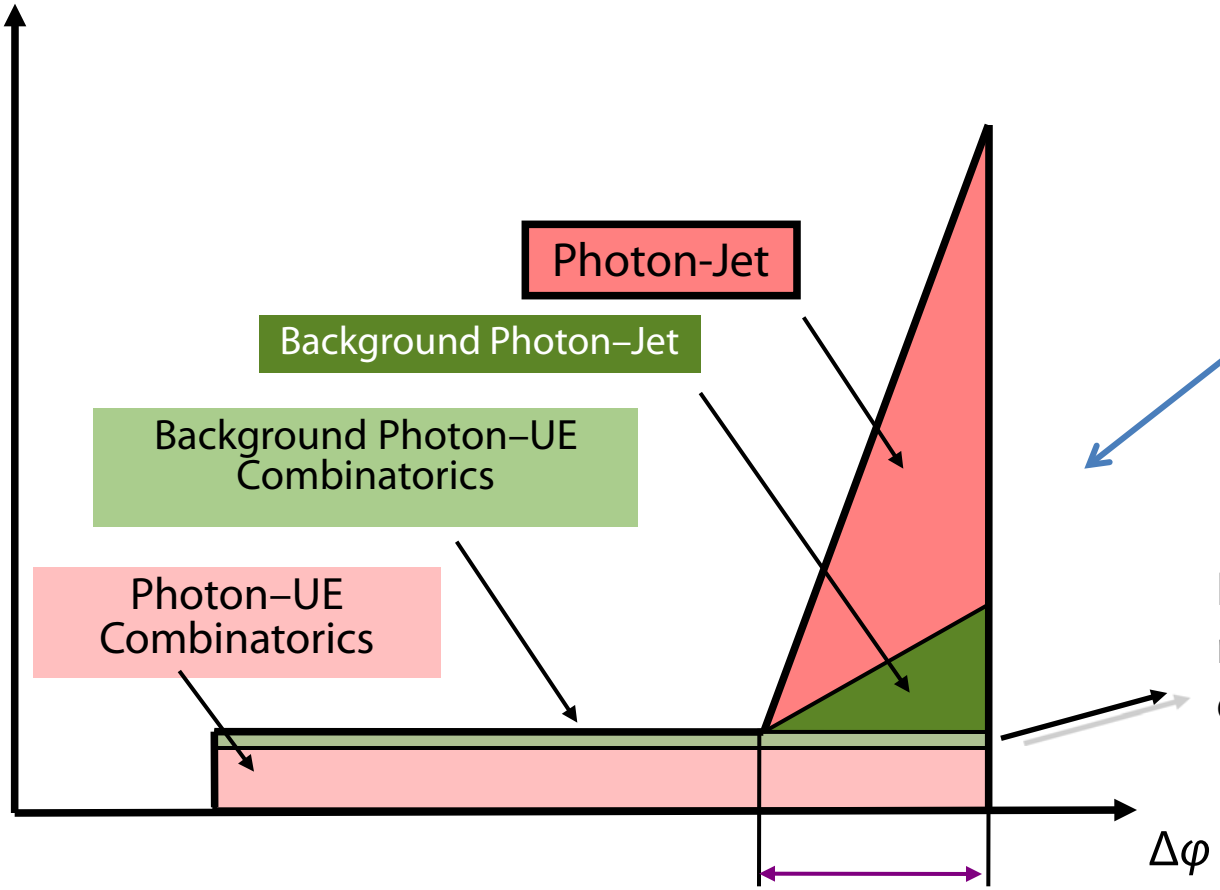
Remove data-driven by shower shape

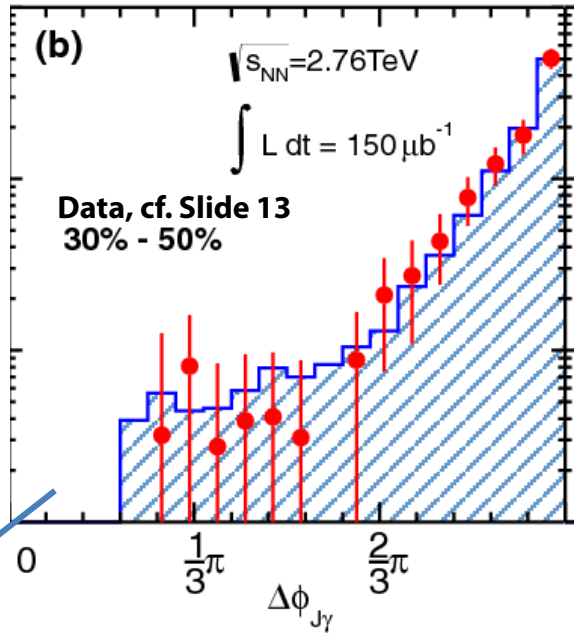
Contribution from uncorrelated multiple interaction/fake



Remove by data-driven template from event mixing

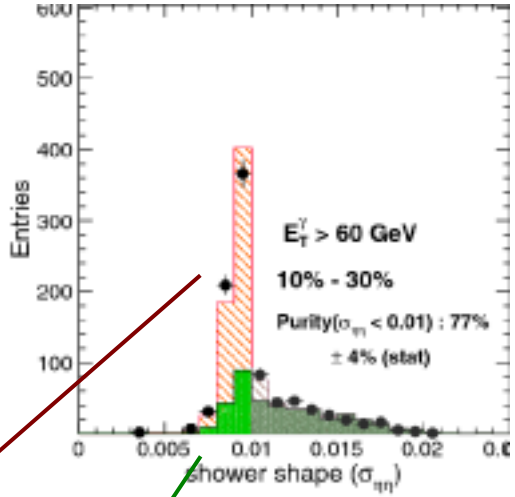
Statistical Subtraction





Estimated from event mixing method using minimum-bias data

Statistical Subtraction



Photon-Jet

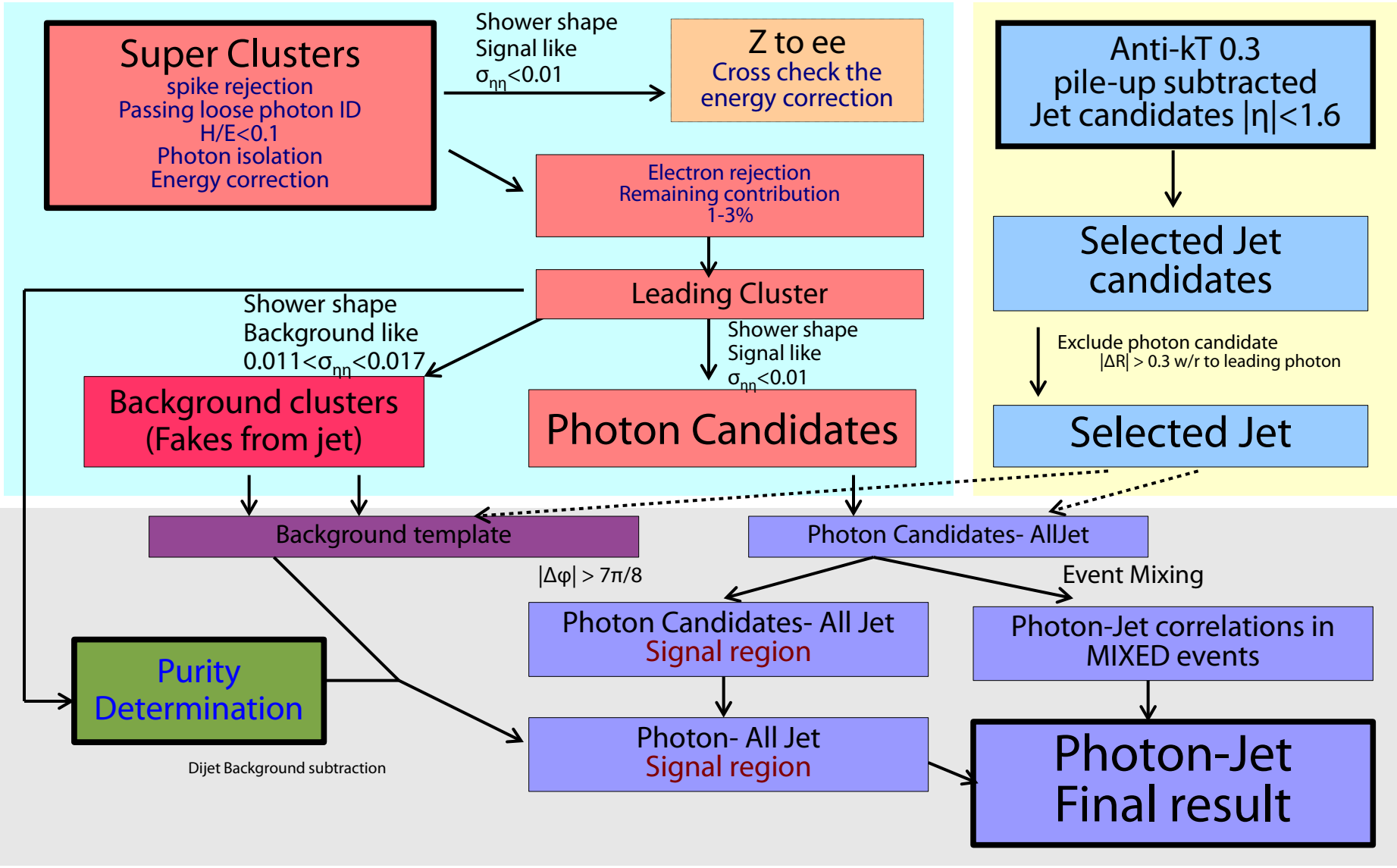
Background Photon–Jet

Estimated from shower shape sideband & purity

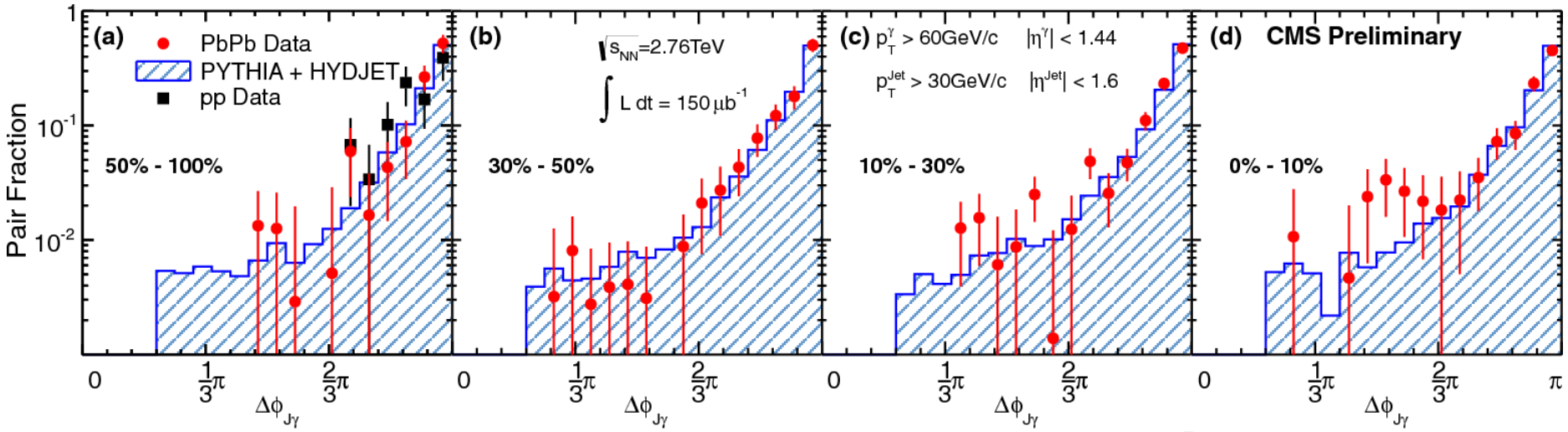
$\Delta\varphi$

Signal region

Analysis Flow Chart

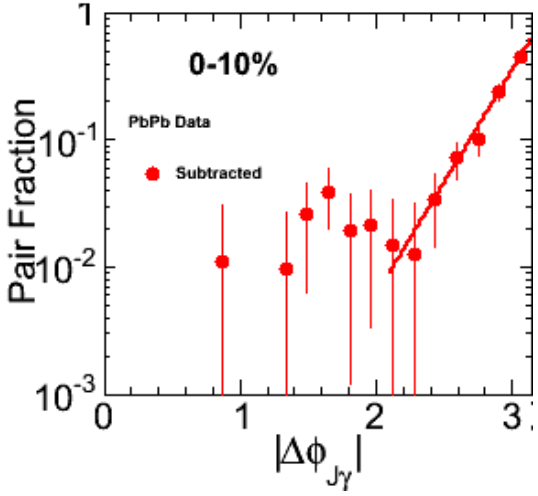


Angular Corrrelation: $N_{J\gamma}^{-1}\, dN/d|\Delta\varphi_{J\gamma}|$

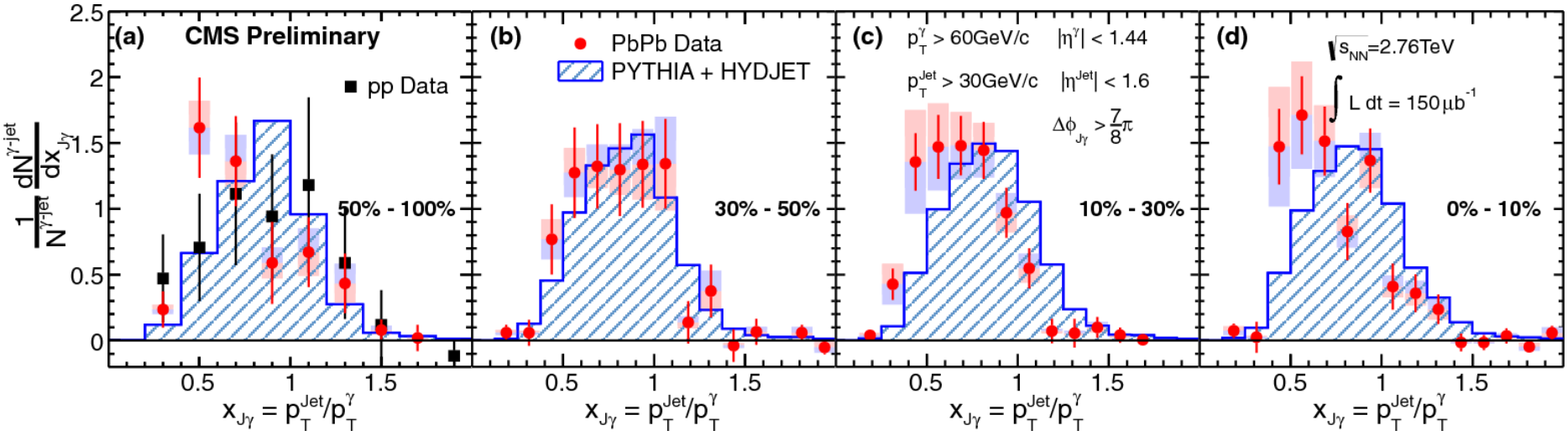


- Distribution is consistent with pp & PYTHIA tune Z2 + Hydjet
- To quantify the centrality dependence, peak region is fit with an empirical formula

$$\frac{1}{N^{\gamma\text{-jet}}}\frac{dN^{\gamma\text{-jet}}}{d\Delta\phi_{J\gamma}} = \frac{e^{(\Delta\phi-\pi)/\sigma}}{(1-e^{-\pi/\sigma})\,\sigma}$$

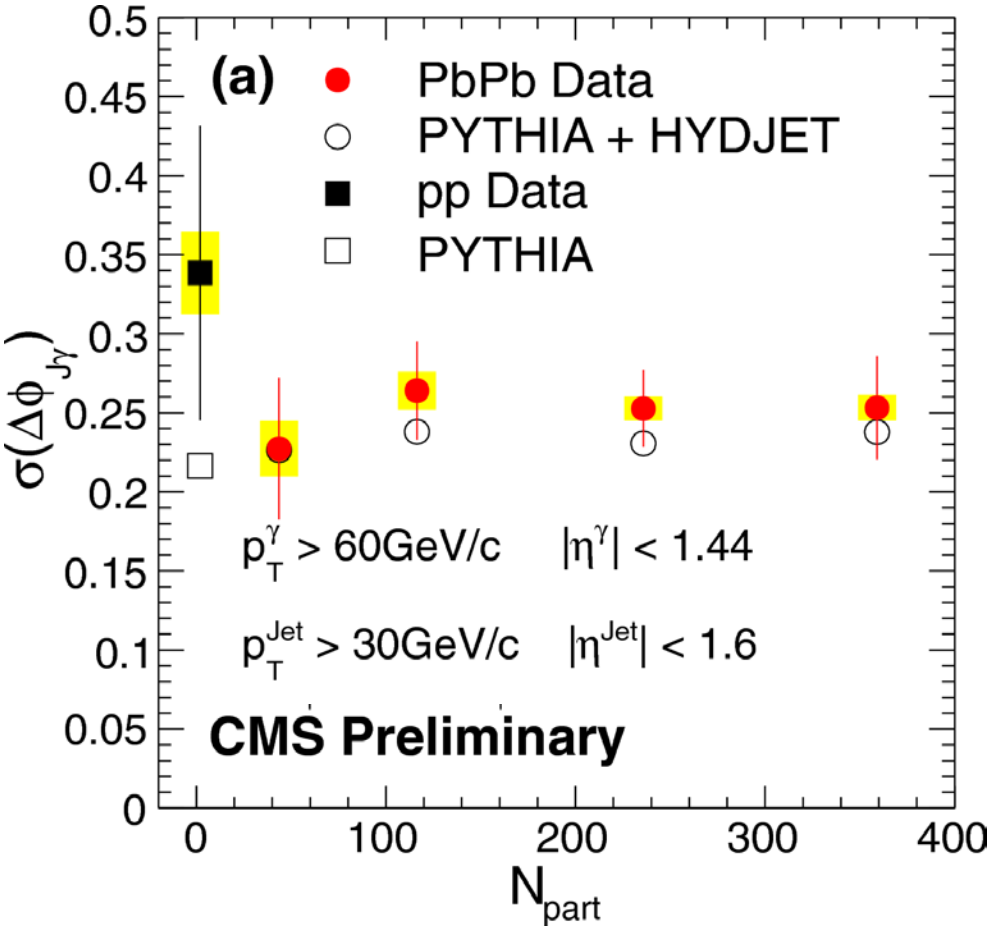


p_T Ratio: $N_{J\gamma}^{-1}\, dN/dx_{J\gamma}$ $x_{J\gamma} = p_T^{Jet}/p_T^{\gamma}$



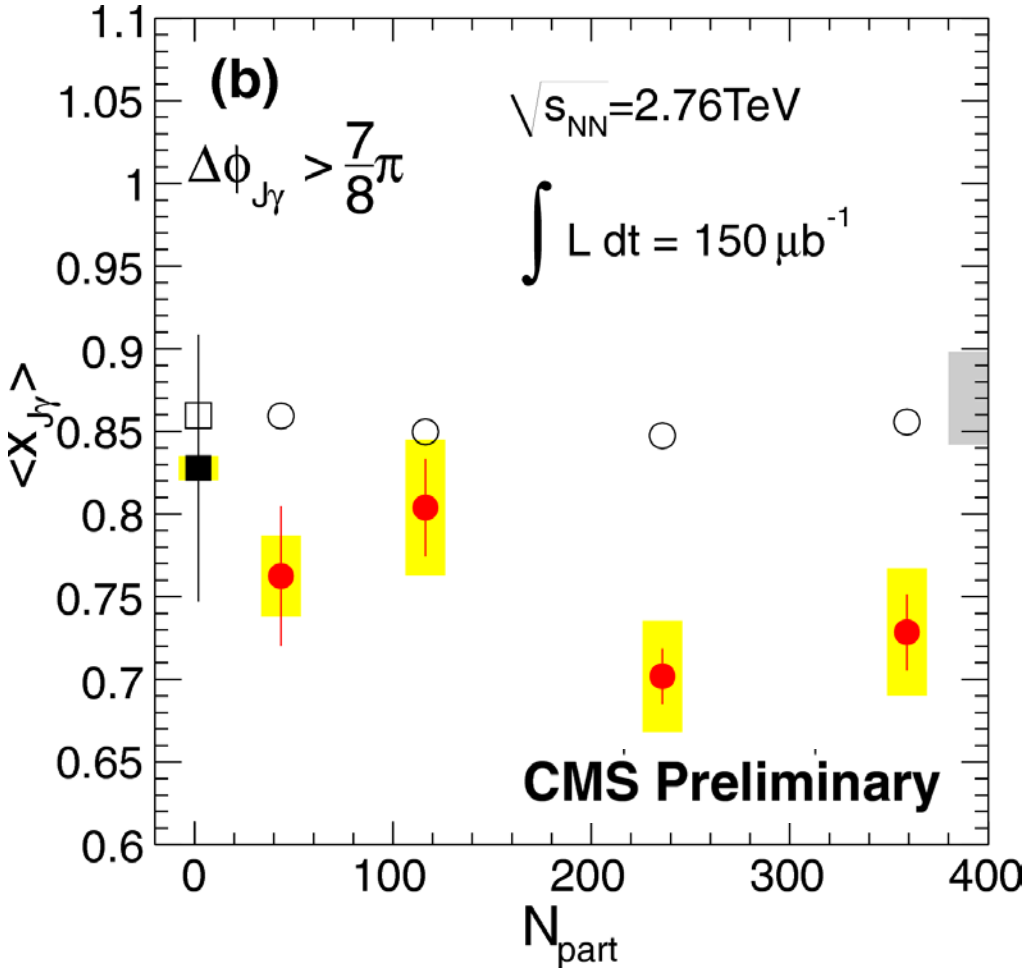
- Momentum ratio shifts/decreases with centrality
- Unitary normalized distribution, points anticorrelated
- Red/blue boxes try to indicate possible, anticorrelated systematic variation

$\sigma(|\Delta\varphi_{J\gamma}|)$



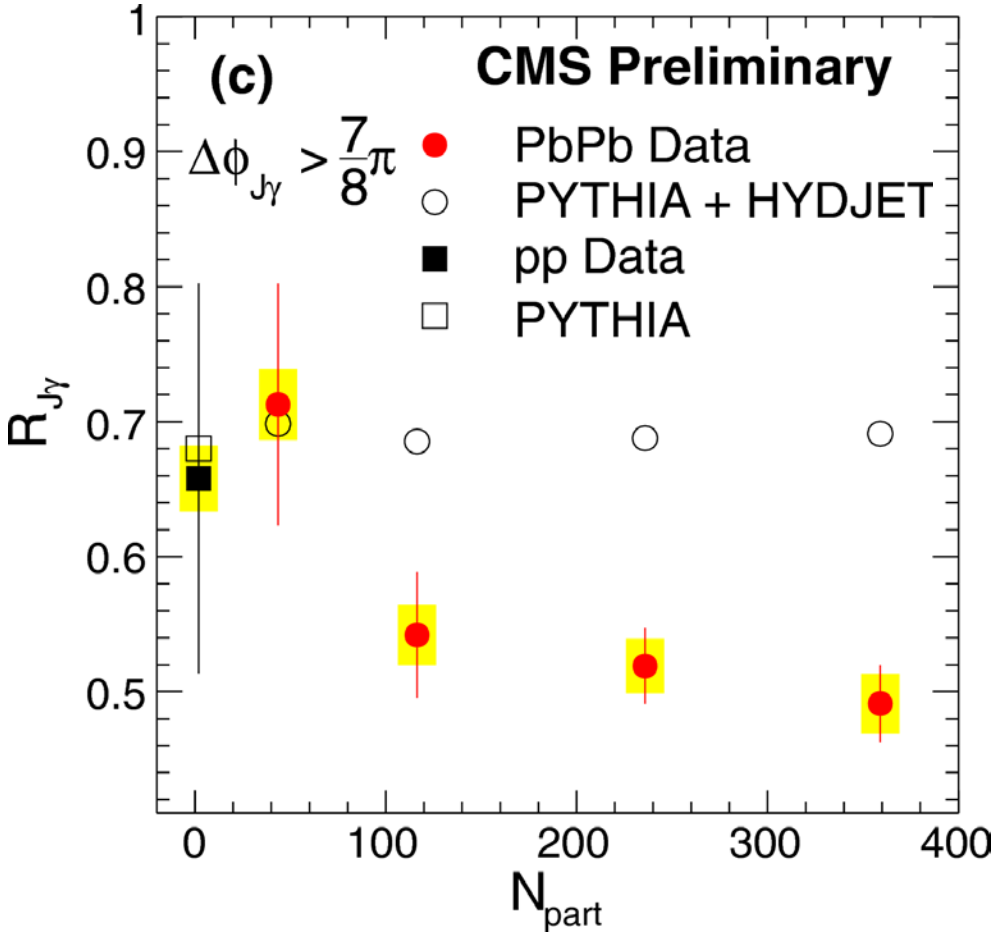
- Angular width $\sigma(|\Delta\varphi_{J\gamma}|)$ is consistent, both PbPb to pp and PbPb to PYTHIA tune Z2 + HYDJET

$\sigma(|\Delta\varphi_{J\gamma}|), \langle x_{J\gamma} \rangle$



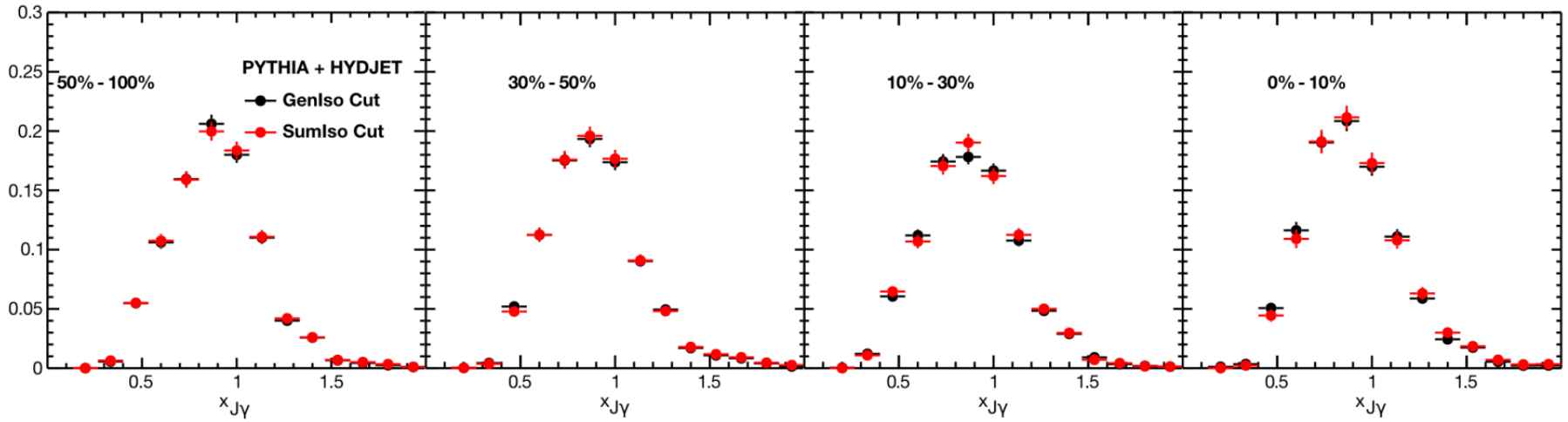
- Angular width $\sigma(|\Delta\varphi_{J\gamma}|)$ is consistent, both PbPb to pp and PbPb to PYTHIA tune Z2 + HYDJET
- Significant deviation of $\langle x_{J\gamma} \rangle$ PbPb compared to PYTHIA tune Z2 + HYDJET, significance of PbPb vs. pp is weaker

$\sigma(|\Delta\varphi_{J\gamma}|), \langle x_{J\gamma}\rangle, R_{J\gamma}$



- Angular width $\sigma(|\Delta\varphi_{J\gamma}|)$ is consistent, both PbPb to pp and PbPb to PYTHIA tune Z2 + HYDJET
- Significant deviation of $\langle x_{J\gamma}\rangle$ PbPb compared to PYTHIA tune Z2 + HYDJET, significance of PbPb vs. pp is weaker
- The centrality dependence is mostly visible in $R_{J\gamma}$ (jet p_T shifting below the 30 GeV threshold)

Isolated Photon Definition (System. Uncert.)



- Comparison of SumIso < 1 GeV reconstructed photon to GenIso < 5 GeV generator photon
- GenIso/SumIso difference quoted as a systematic uncertainty

Summary

- Measurement of isolated prompt photon+jet correlation
- Direct observation of jet energy loss vs. initial parton energy
- Shift of associated jet towards lower p_T with centrality:
  - Significant fraction of jets are shifted to $p_T < 30$ GeV/c
  - Observation of significant shift of jet–photon p_T ratio with respect to MC
    - Shift with respect to pp is less significant due to large pp statistical uncertainties
- No measurable change in $\Delta\varphi_{J\gamma}$, extends to $p_T^{Jet} = 30$ GeV/c