PHOTON-JET CORRELATIONS IN 5.02 TEV *pp* & Pb+Pb COLLISIONS WITH ATLAS AT THE LHC

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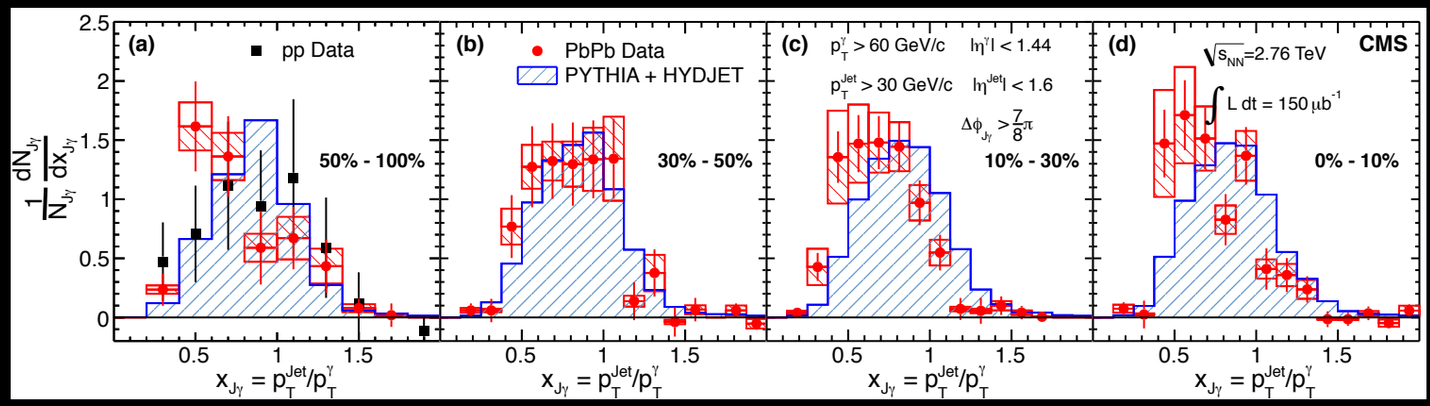
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

ATLAS-CONF-2016-110

γ+JET MEASUREMENTS @ LHC

Photons and W/Z do not interact with the medium, and (to lowest order) balance with the pT of the scattered parton: **direct access** to hard process

Phys. Lett. B 718 (2013) 773



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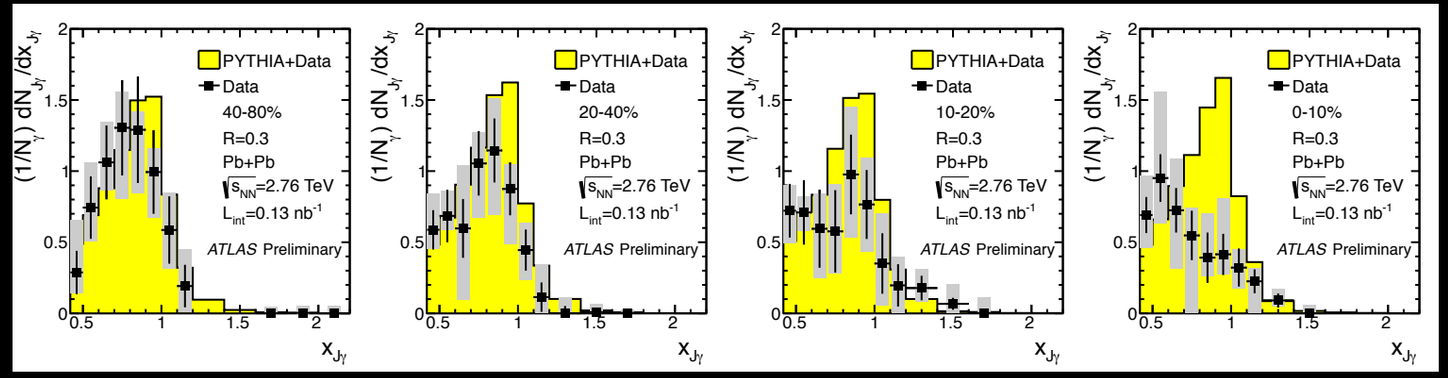


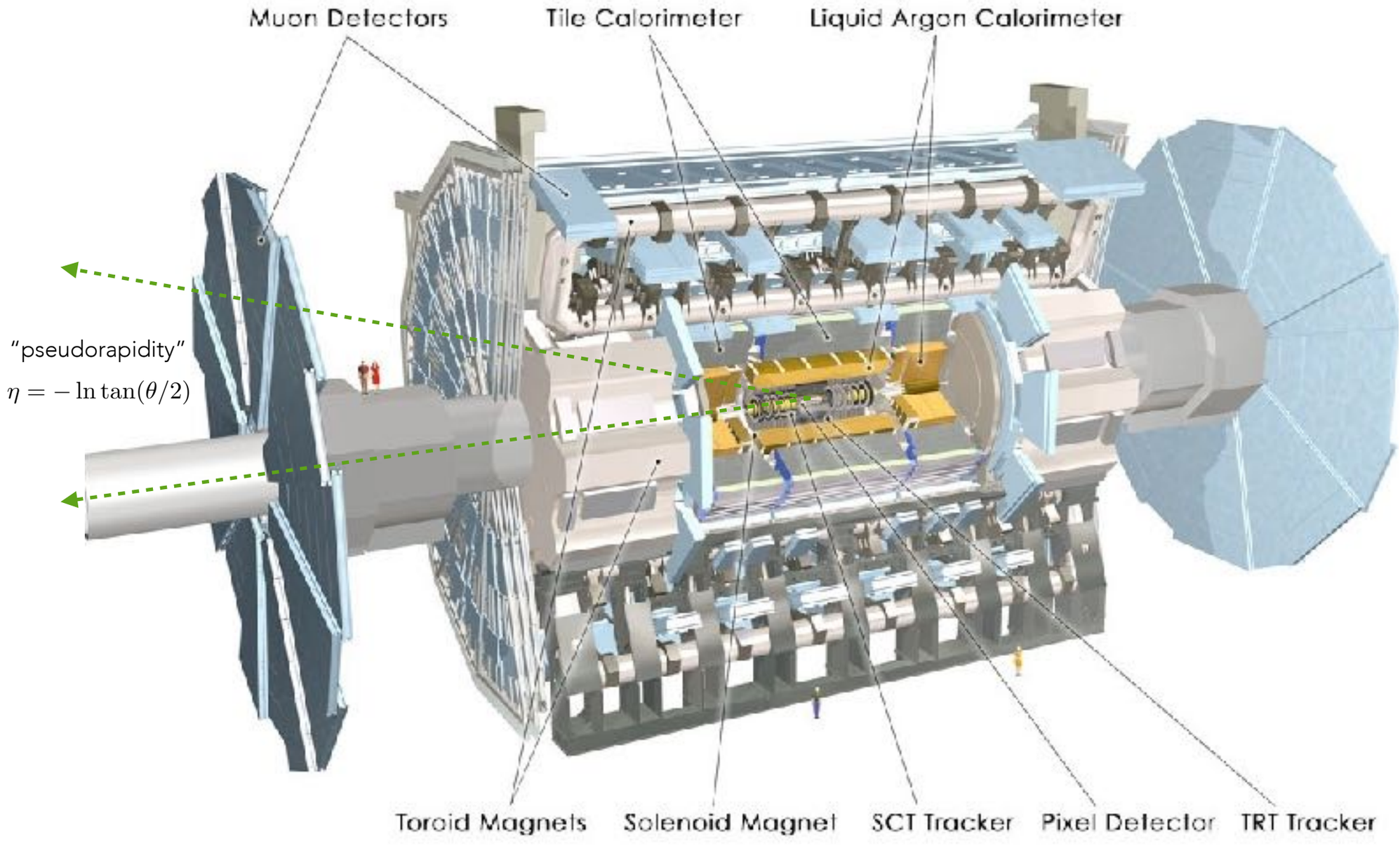
Compared with dijet events, photons in the final state are typically associated with outgoing quark jets: insight into **flavor dependence** of energy loss

CMS (inclusive analysis) and ATLAS (leading jet analysis) observed clear systematic shift of $x_{J\gamma}$ distributions to lower values (w/ a reduction in correlation strength)

ATLAS @ THE LHC

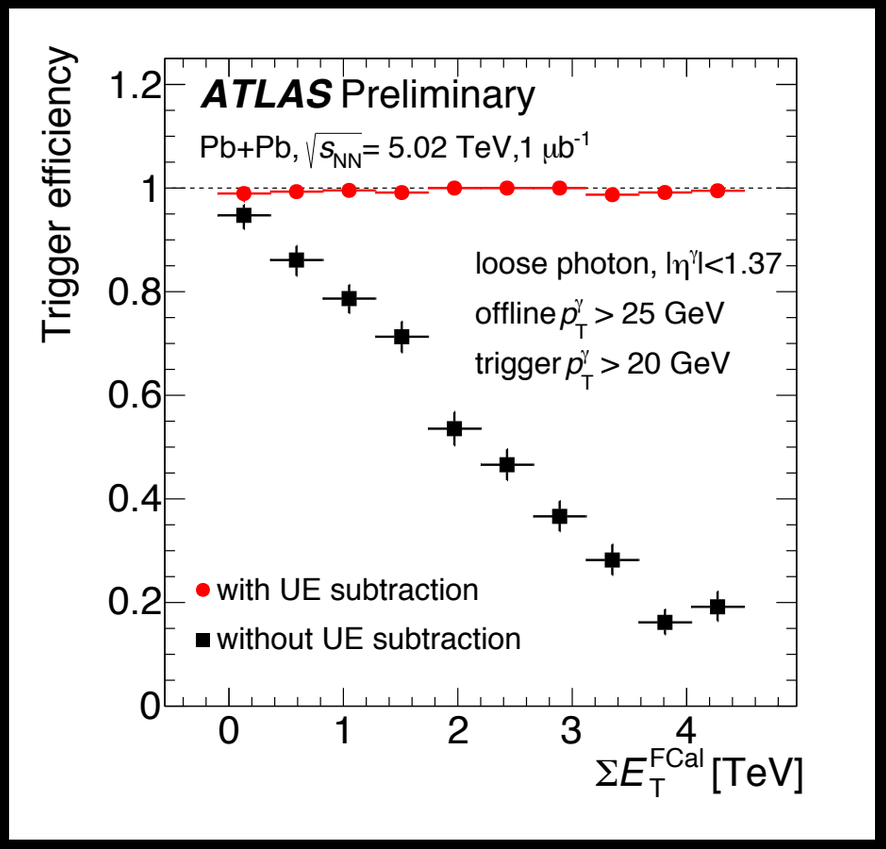
3. Precise μ tracking in |η|<2.7

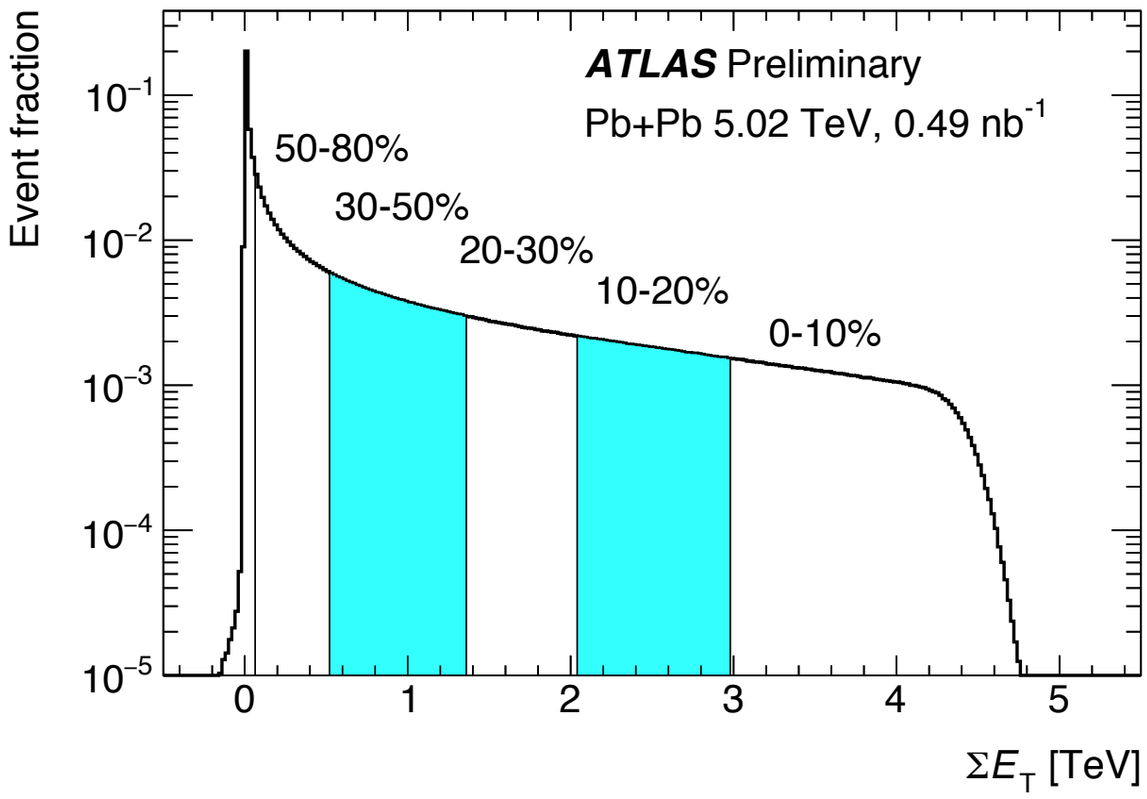
2. Hadronic & EM calorimetry in |η|<4.9



1. Precise charged-particle tracking in |η|<2.5

2015 DATA SET





2015 Pb+Pb run @ 5.02 TeV

p+p run @ 5.02 TeV

0.49 nb^{-1} Pb+Pb taken w/ p_T>20 GeV trigger

26 pb^{-1} p+p with p_T>30 GeV trigger

Tight, isolated candidates

after correction for underlying event (UE)

11k total, ~1500 with p_T>100 GeV

Two-component model (similar to Run 1) used to fit data above ΣE_T>40 GeV, and extract efficiency of 85±1% relative to Glauber expectations.

No scaling by T_{AB} in this correlation analysis.

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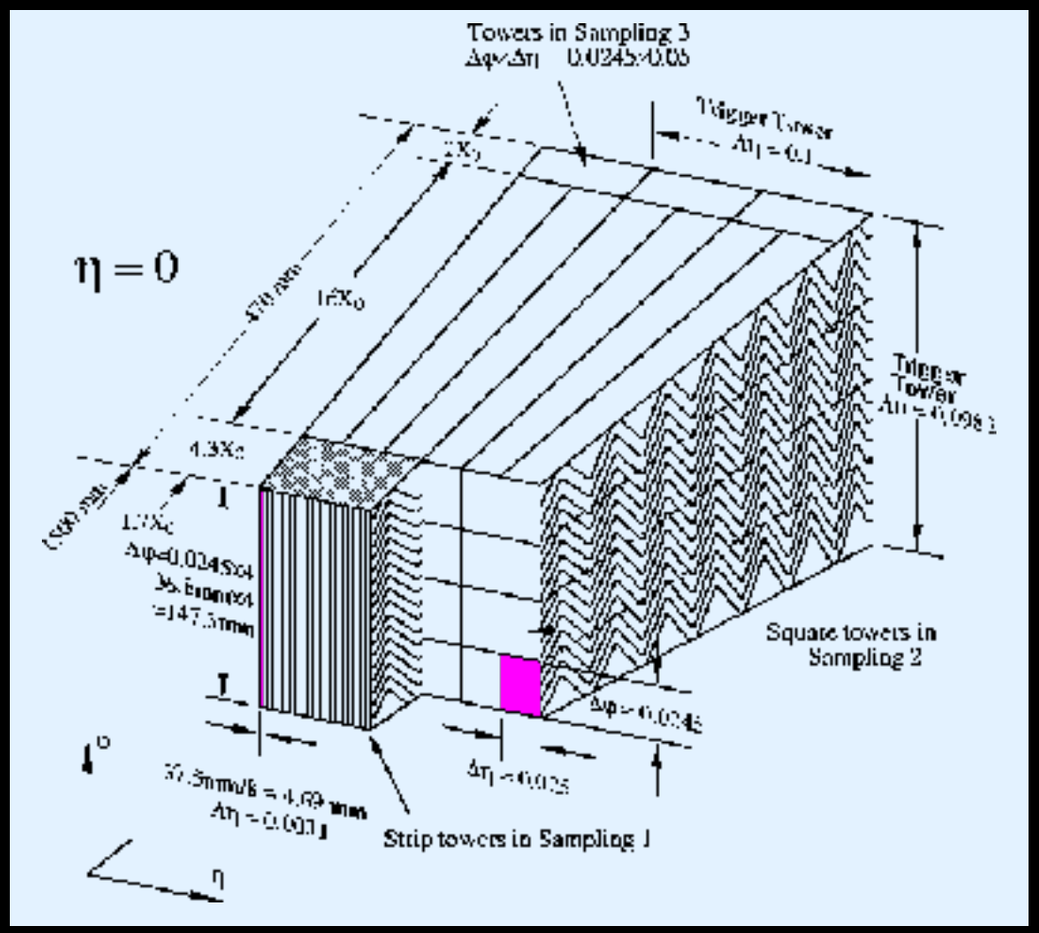
PHOTON ID IN ATLAS

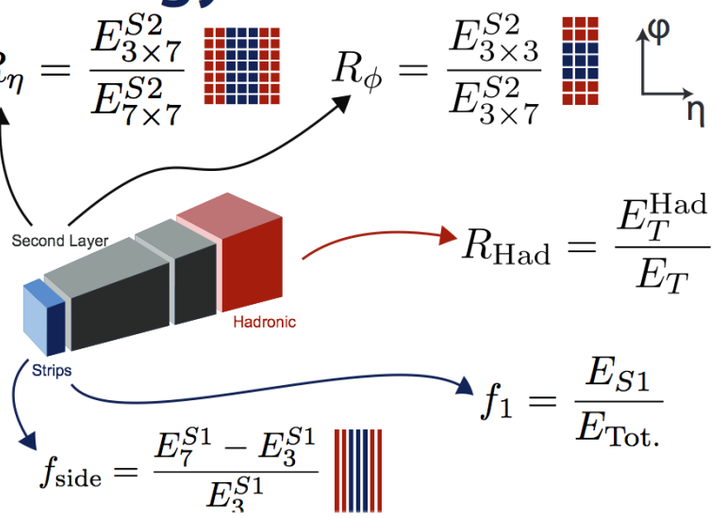


Variables and Position

	Strips	2nd	Had.
Ratios	f_1, f_{side}	R_η*, R_ϕ	$R_{Had.}$*
Widths	$w_{s,3}$, $w_{s,tot}$	$w_{\eta,2}$*	-
Shapes	ΔE, E_{ratio}	* Used in PhotonLoose.	

Energy Ratios

$$R_\eta = \frac{E^{S2}_{3\times7}}{E^{S2}_{7\times7}} \qquad R_\phi = \frac{E^{S2}_{3\times3}}{E^{S2}_{3\times7}}$$



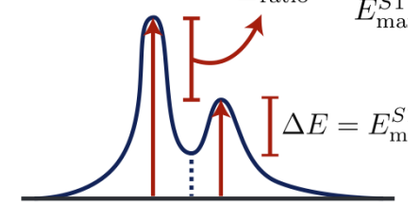
$$R_{\rm Had} = \frac{E^{\rm Had}_T}{E_T}$$

$$f_1 = \frac{E_{S1}}{E_{\rm Tot.}}$$

$$f_{\rm side} = \frac{E^{S1}_7 - E^{S1}_3}{E^{S1}_3}$$

Shower Shapes

$$E_{\rm ratio} = \frac{E^{S1}_{\rm max,1} - E^{S1}_{\rm max,2}}{E^{S1}_{\rm max,1} + E^{S1}_{\rm max,2}}$$

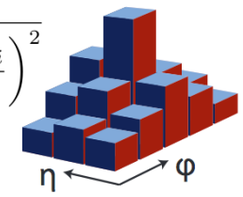


$$\Delta E = E^{S1}_{\rm max,2} - E^{S1}_{\rm min}$$

Widths

$$w_{\eta,2} = \sqrt{\frac{\sum E_i \eta_i^2}{\sum E_i} - \left(\frac{\sum E_i \eta_i}{\sum E_i}\right)^2}$$

Width in a 3×5 (Δη×Δφ) region of cells in the second layer.



$$w_s = \sqrt{\frac{\sum E_i (i - i_{\rm max})^2}{\sum E_i}}$$

ws3 = w_1 uses 3 strips in η; wstot is defined similarly, but uses 20 strips.

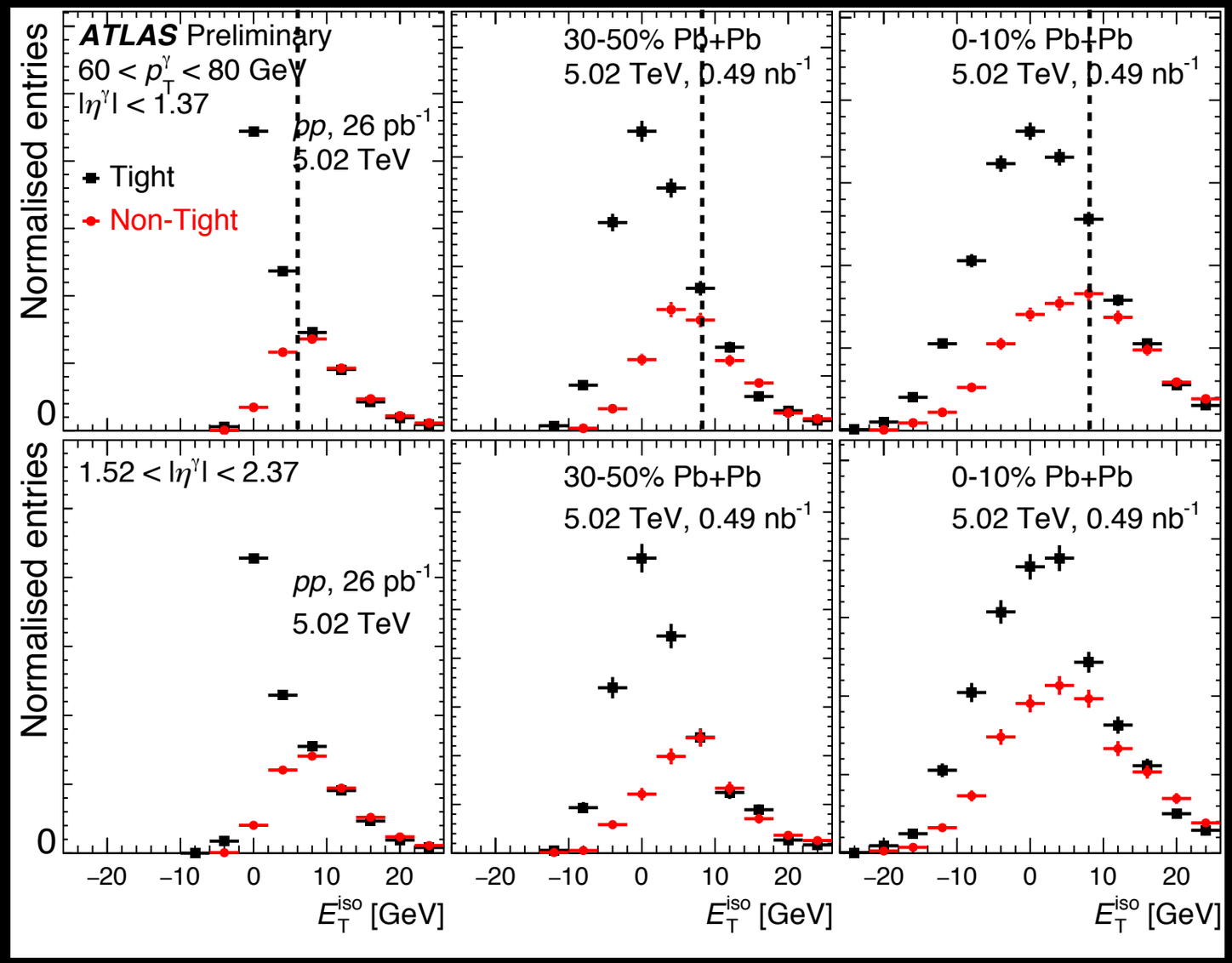
ATL-COM-PHYS-2013-600

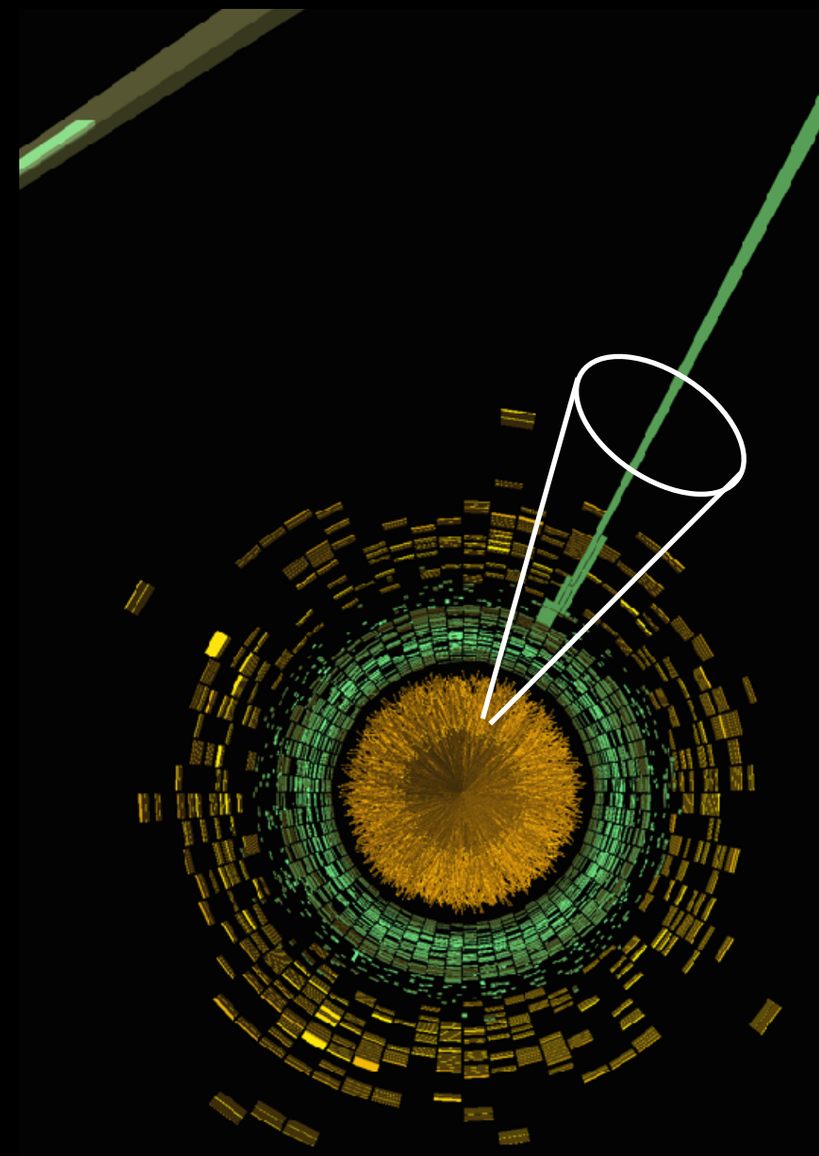
ATLAS "tight" photon ID uses full capabilities of calorimeter:

1. Narrow cluster in EM cal. 2nd layer (most of energy)
2. No energy leakage behind EM section
3. Shower shape inconsistent with diphoton hadron decay

Calorimeter cells corrected for UE in Pb+Pb, including v_2 using algorithm similar to what is used for ATLAS jets

PHOTON ISOLATION DISTRIBUTIONS





Isolation criterion based on E_T of cells in R=0.3 cone,
after subtracting core region, and shower leakage correction.
Signal: E_T<3 GeV in pp, E_T<8 GeV in Pb+Pb
(approx 1-sigma, due to larger fluctuations in HI UE)

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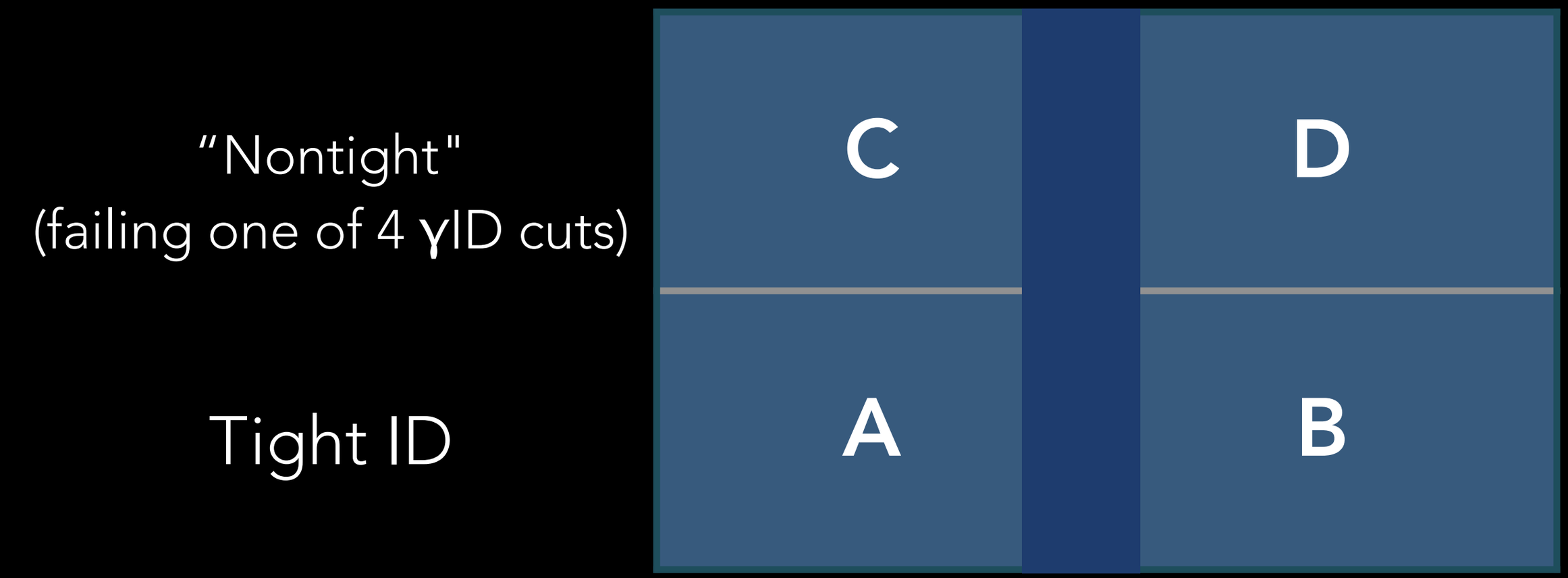
PHOTON PURITY ESTIMATE ("ABCD")



$$A = \frac{BC}{D}$$

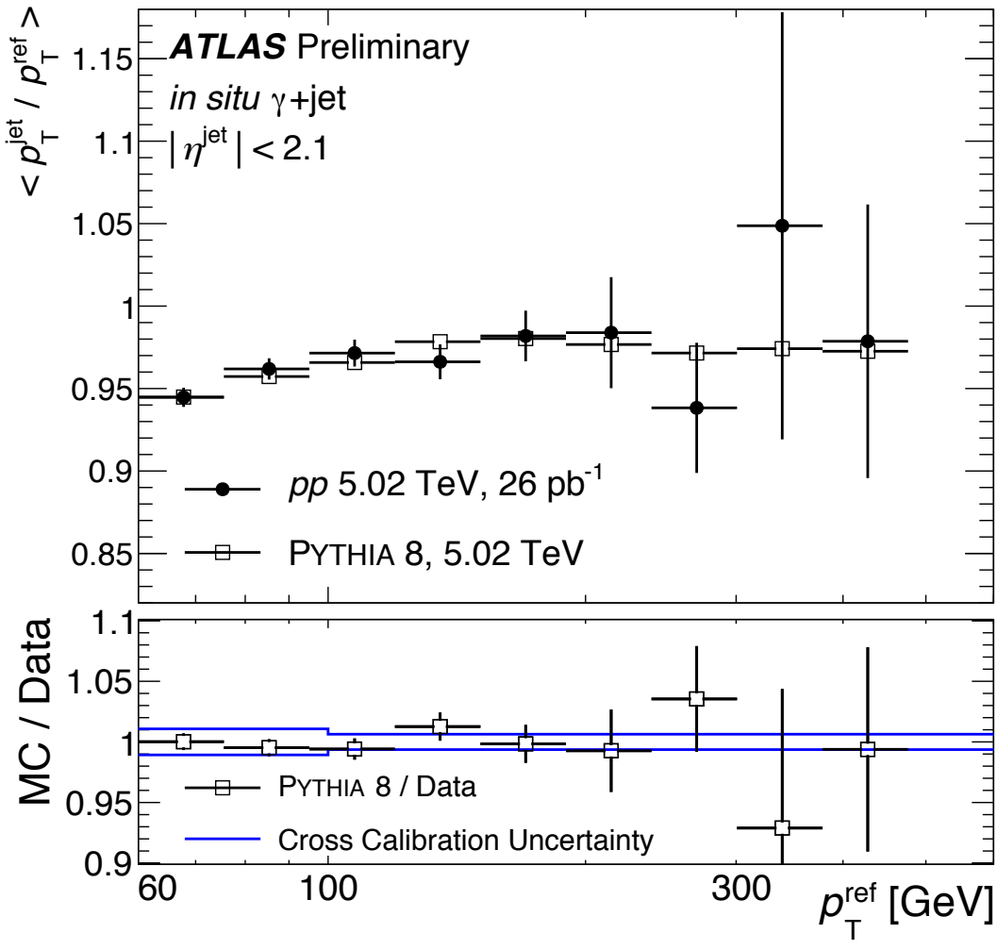
Assumes axes are uncorrelated for background candidates

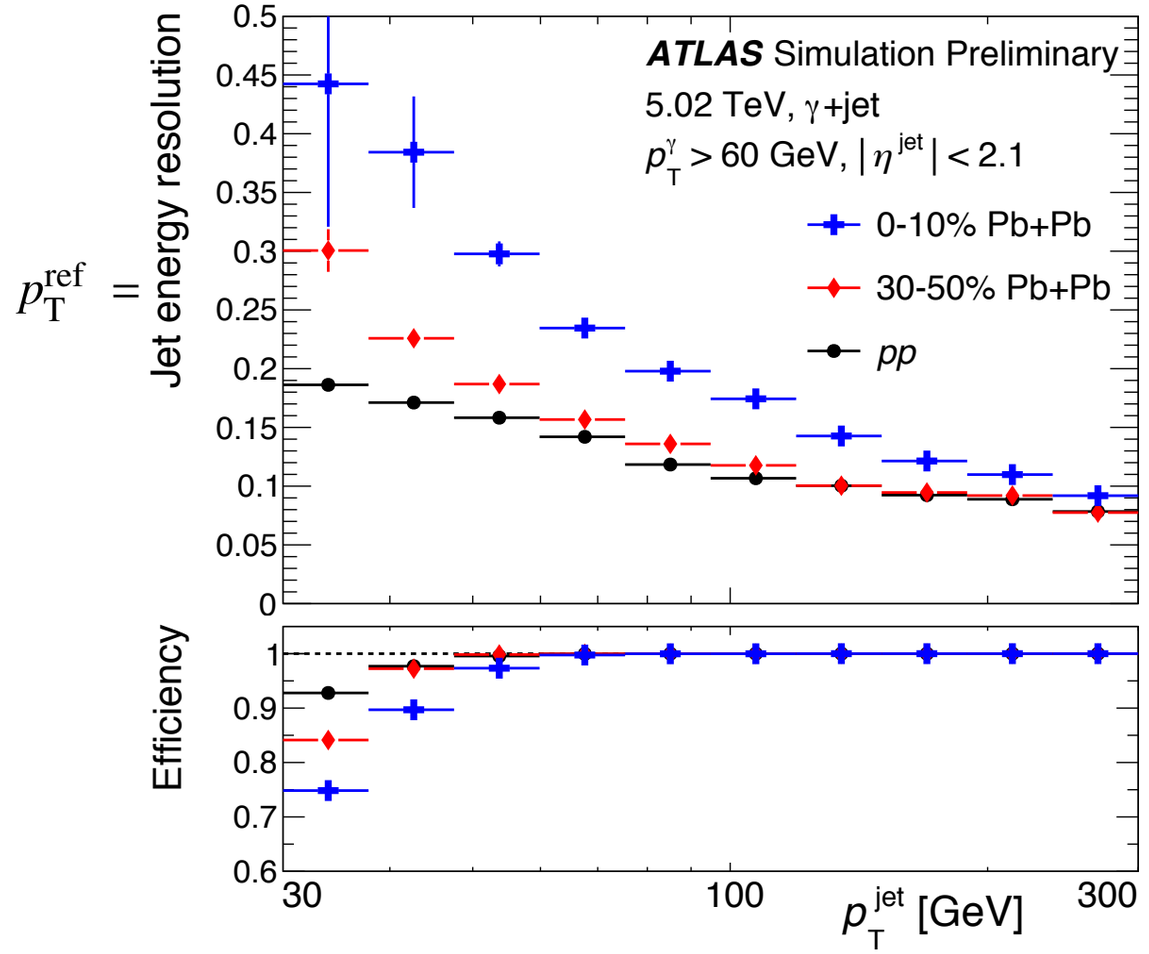
$$N_{\mathrm{sig}} = N_{\mathrm{A}} - R_{\mathrm{bkg}} \frac{(N_{\mathrm{B}} - c_{\mathrm{B}} N_{\mathrm{sig}})(N_{\mathrm{C}} - c_{\mathrm{C}} N_{\mathrm{sig}})}{N_{\mathrm{D}} - c_{\mathrm{D}} N_{\mathrm{sig}}}$$

$$P = 1 - \frac{N_{\mathrm{sig}}}{N_{\mathrm{A}}}$$

>95% @ p_T=100 GeV for pp
>80-85% for Pb+Pb

JET ENERGY SCALE & RESOLUTION





- Jets calibrated using POWHEG+PYTHIA 8
- "In situ" corrections from 13 TeV pp data
- Cross calibration transfer & uncertainty from pp to HI jets
- Corrected for flavor mix (qg vs. gg)

- Resolution determined using PYTHIA 8 photon-jet overlaid onto data ("**data overlay**")

PHOTON-JET MEASUREMENT

Photons selected with "tight" ID & isolation criteria
within $|\eta|<2.37$ (excluding $1.37<|\eta|<1.52$),
presented in 4 p_T intervals:
60-80 GeV, 80-100 GeV, 100-150 GeV, 150-200 GeV

Jets reconstructed based on calorimeter "towers"
(cells summed over $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$) using anti-kt with R=0.4
Background estimated using iterative procedure,
and jets are corrected for UE contributions.

$$|\eta_{\mathrm{jet}}| < 2.1, p_{\mathrm{T,jet}} > 30\mathrm{GeV}$$

PHOTON-JET MEASUREMENT

All photon-jet pairs calculated for each event (no selection of “leading” jets)

Two primary kinematic variables:

1. photon-jet acoplanarity

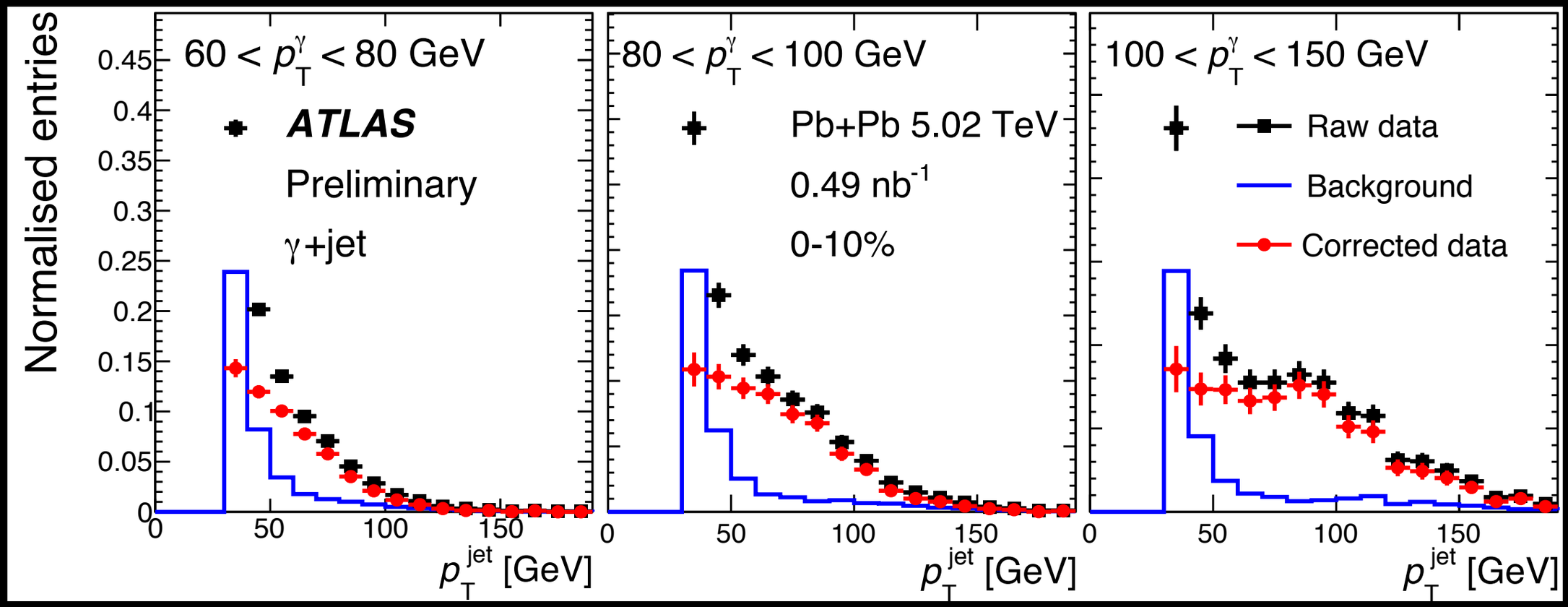
$$\Delta\phi = |\phi_\gamma - \phi_{\mathrm{jet}}|$$

2. photon-jet transverse momentum balance

$$x_{J\gamma} = \frac{p_{\mathrm{T,jet}}}{p_{\mathrm{T},\gamma}} \quad \text{for} \quad \Delta\phi > 7\pi/8$$

(suppresses multi-jet contributions)

BACKGROUND SUBTRACTION



Combinatoric - estimated from embedding PYTHIA8 photon+jet events into minimum bias Pb+Pb events (**data overlay**)

Dijet - Per-photon distributions in ($\Delta\phi$, $p_{T,jet}$, $x_{J\gamma}$) subtracted using regions C+D, after scaling to the purity measured using ABCD method

Sum of two contributions shown:

combinatoric important at low p_T, dijet important at higher p_T

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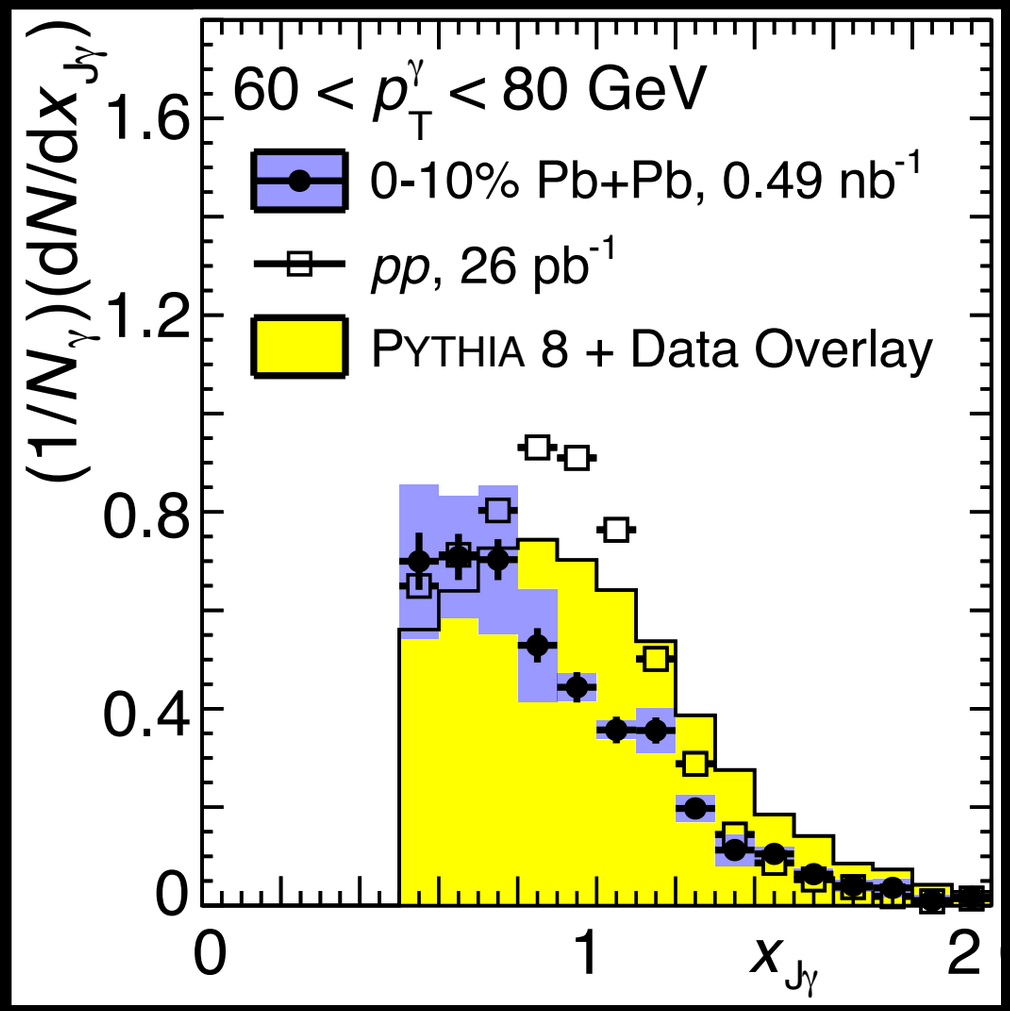
TOTAL SYSTEMATIC UNCERTAINTY

Jet uncertainties: scale, resolution, cross-calibration, flavor, centrality
Photon uncertainties: purity, isolation, nontight, Rbkg, energy scale

Each variation is performed separately, and differences from nominal results are added in quadrature to determine total systematic uncertainty (bluish bands)

For $x_{J\gamma}<1$, total uncertainties typically 10-15% For lowest values of $x_{J\gamma}$, error rises to 30-40%
For large values $x_{J\gamma}>1$, relative error rises steeply, but low yield overall



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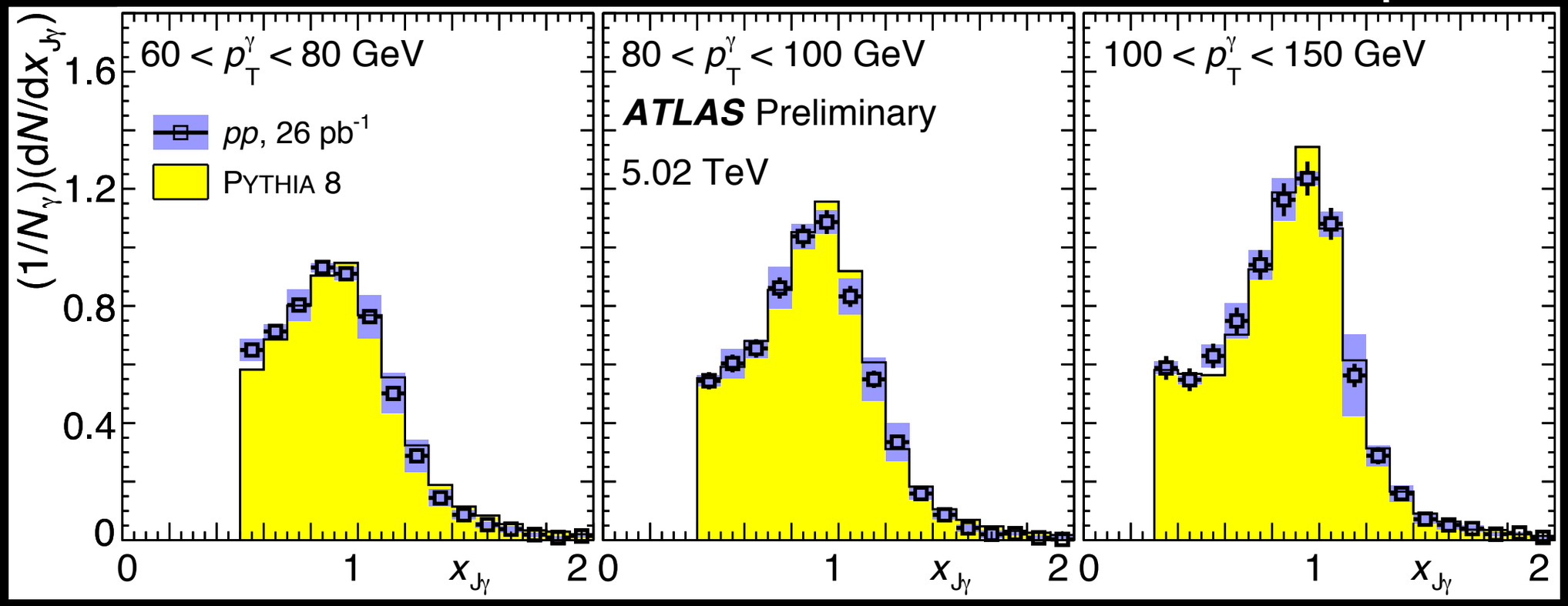
RESULTS: PROTON-PROTON

$\Delta\phi > 7\pi/8$



per-photon $x_{J\gamma}$ distributions, for 5.02 TeV pp collisions compared to simulated PYTHIA8 (A14 tune, NNPDF23LO PDF):
Clear peak structure near $x_{J\gamma}$=1, but quite broad.
Includes calorimeter resolution effects,
additional radiation, and inclusive pair selection

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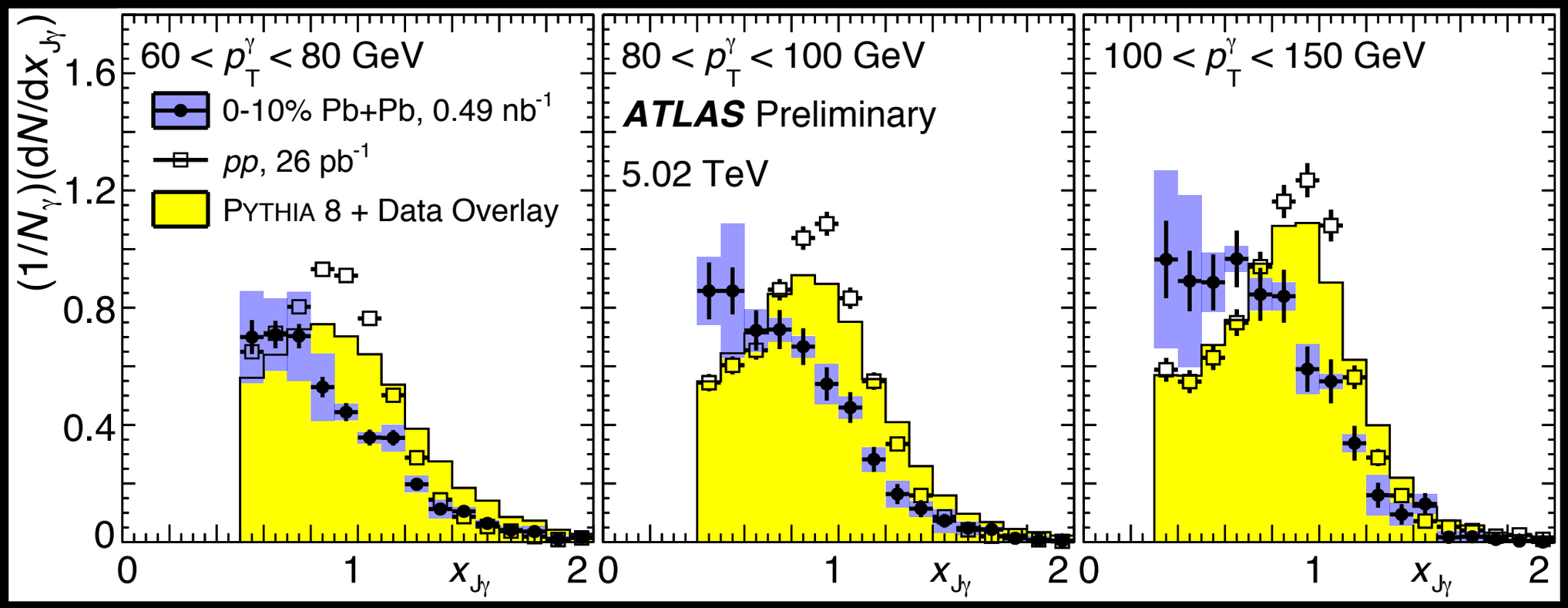
RESULTS: PB+PB



per-photon $x_{J\gamma}$ distribution, for 5.02 TeV Pb+Pb collisions.

No longer any structure near $x_{J\gamma}$=1.

Clear shift of the distribution to lower $x_{J\gamma}$,
as might be expected by parton energy loss.
Impact of increased jet resolution is seen
in comparison of pp to PYTHIA8 + data overlay

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CENTRALITY DEPENDENCE AT FIXED PHOTON PT

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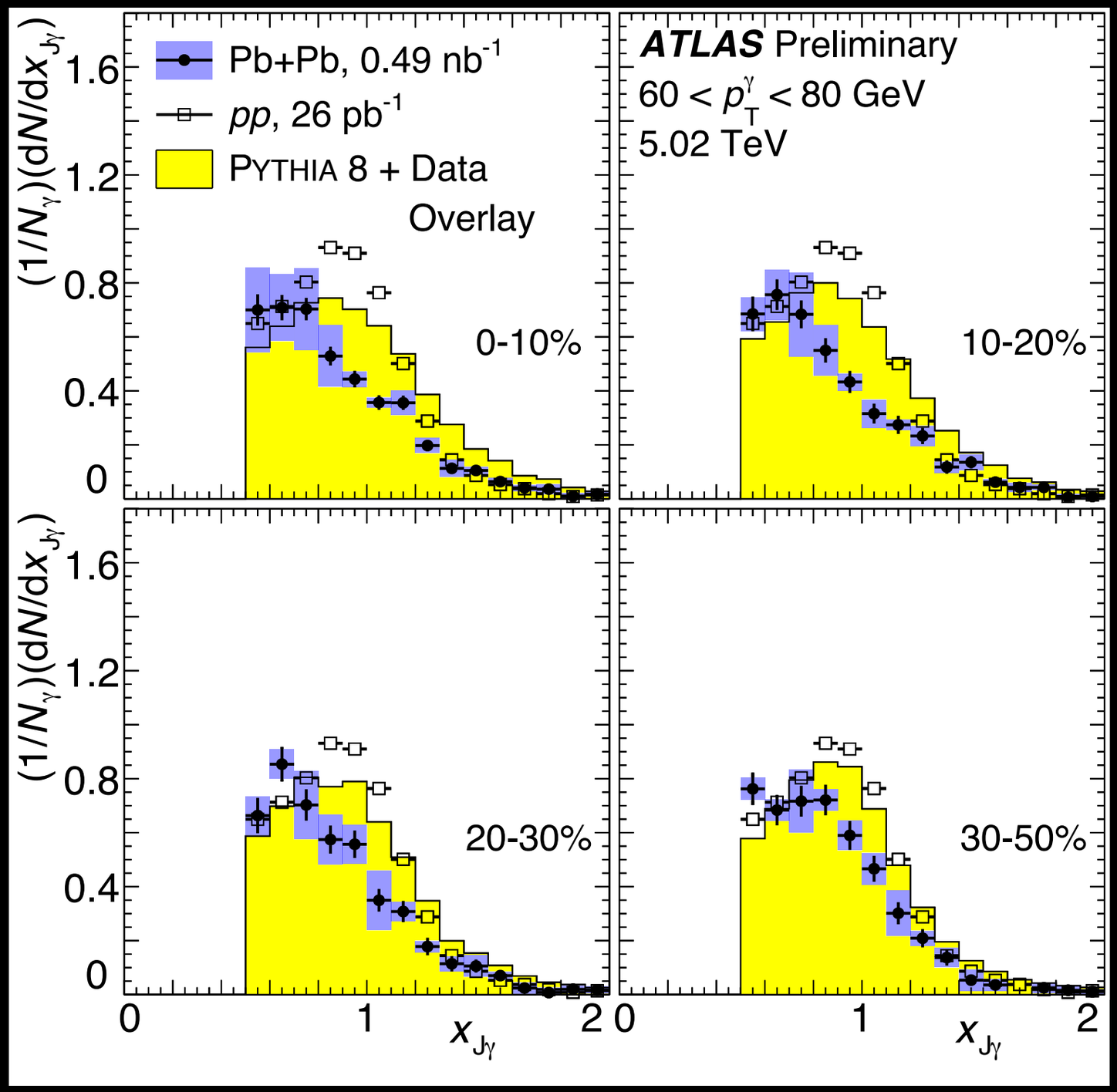

Pb+Pb data is approaching reference, in more peripheral events

CENTRALITY DEPENDENCE AT FIXED PHOTON PT

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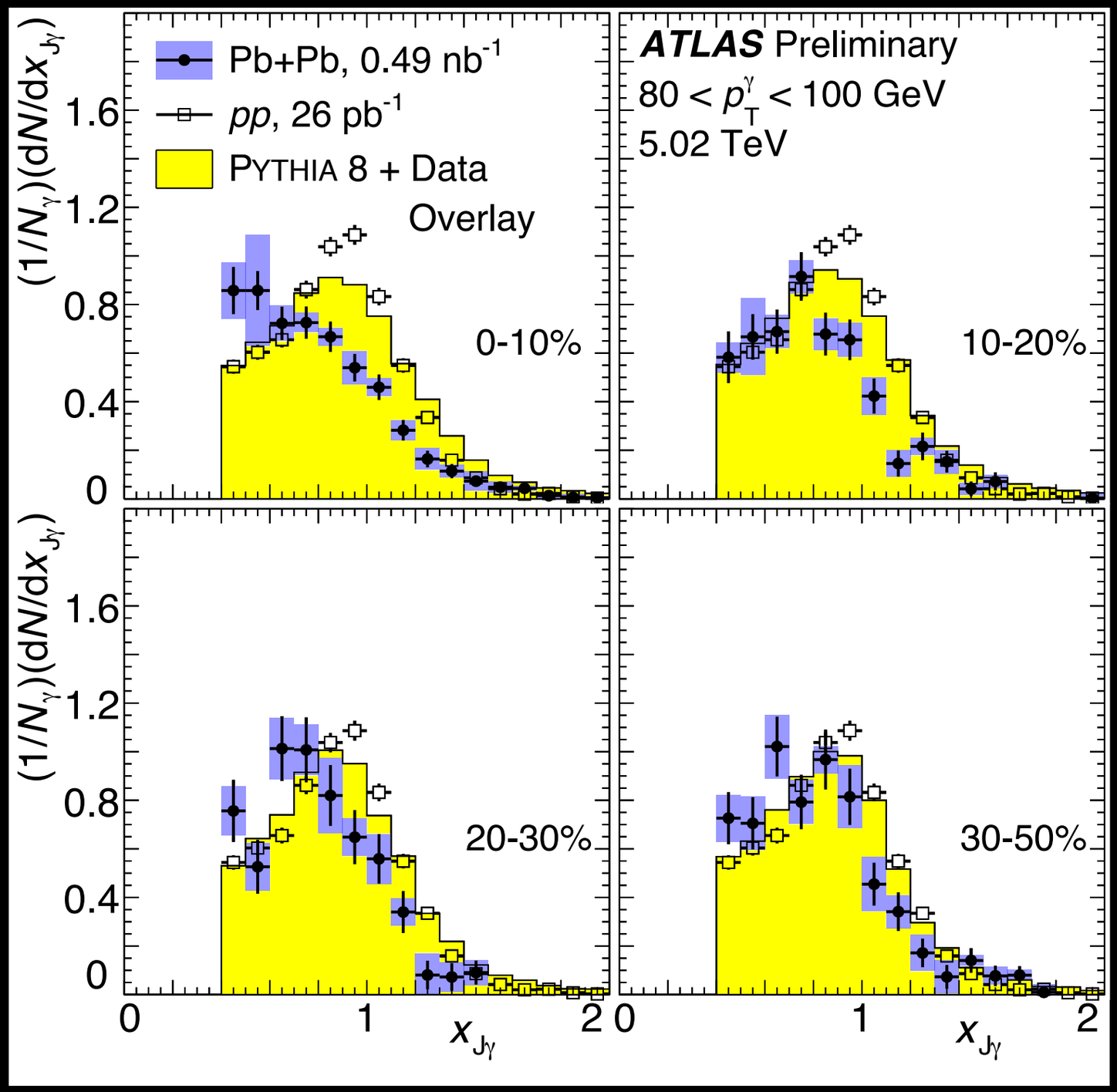

Modifications tend to be reduced with higher $p_{T\gamma}$

CENTRALITY DEPENDENCE AT FIXED PHOTON PT

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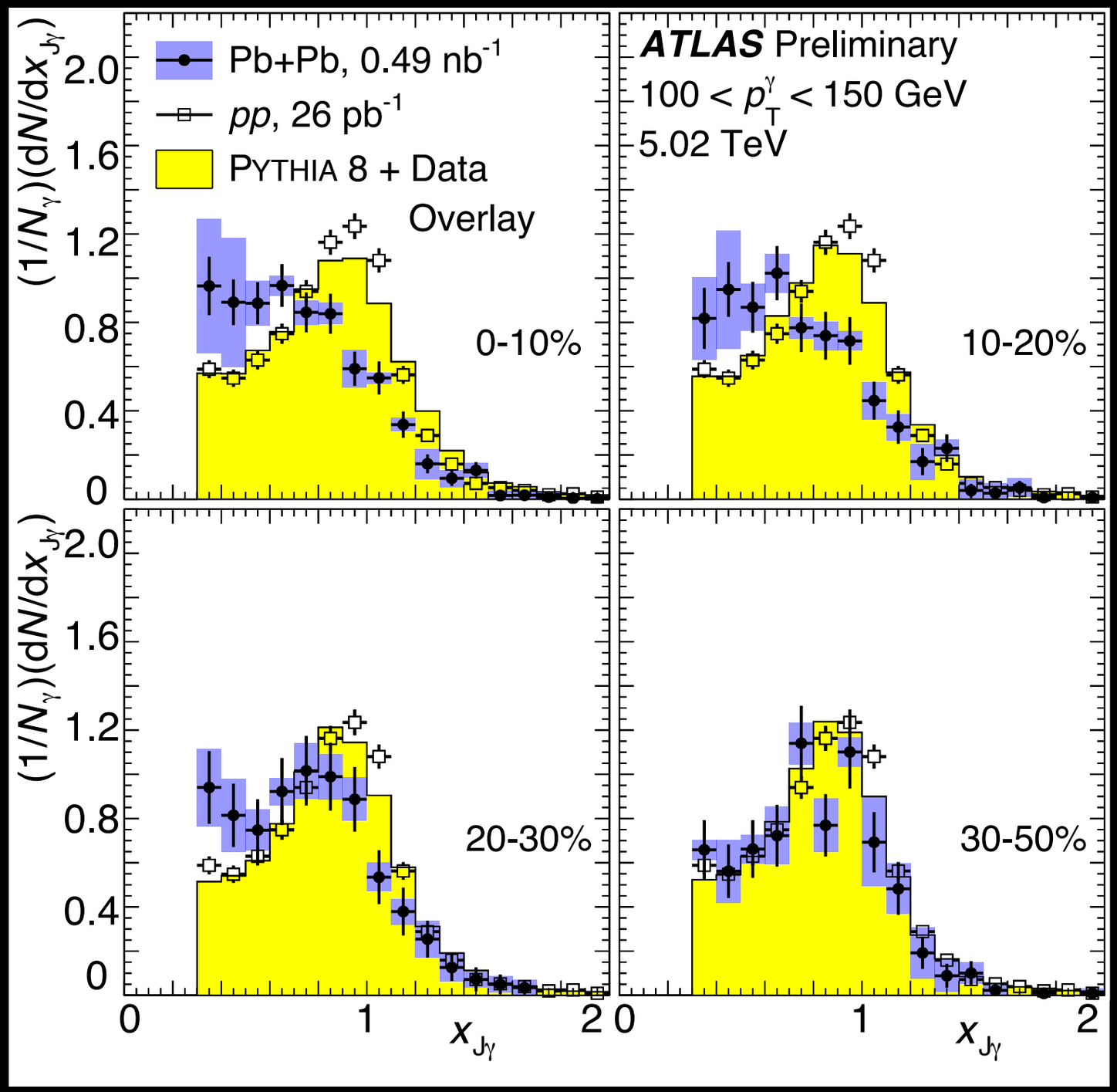

Modifications tend to be reduced with higher $p_{T\gamma}$

GAMMA-JET ACOPLANARITY

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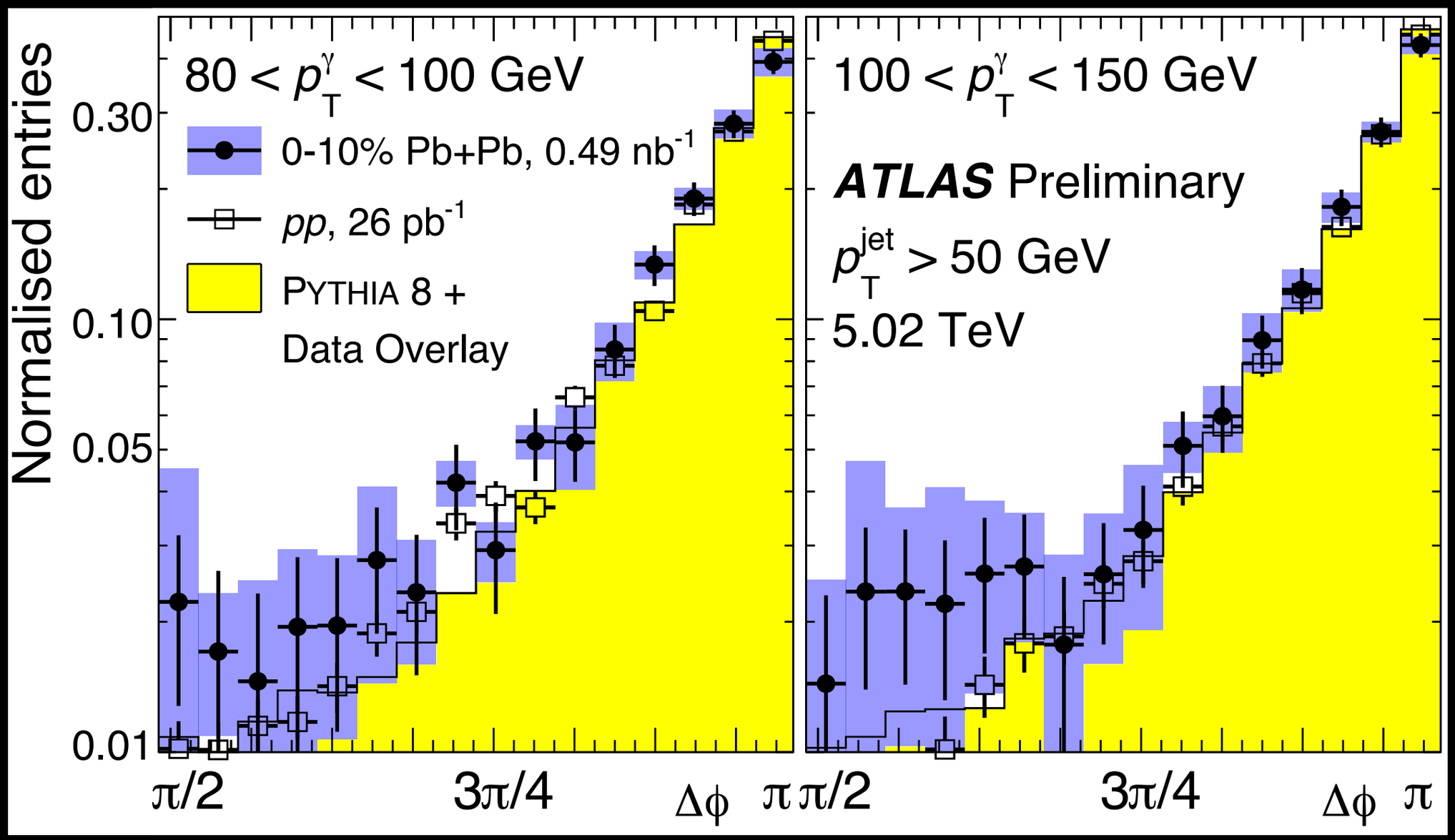
Normalized for $\Delta\phi > 7\pi/8$



Large errors at lower $\Delta\phi$ from jet energy scale and background subtraction.

Within the large errors Pb+Pb is consistent with pp and data overlay

CONCLUSIONS

ATLAS has measured **photon-jet correlations** using the 2015 LHC **pp & Pb+Pb** data at **5.02 TeV**

While the **back-to-back correlations** are clearly seen, the **p_T balance of the jet is clearly modified** in more central heavy ion collisions, relative to MC expectations which describe the pp data well: indicative of **jet energy loss in the hot, dense medium**

Upcoming results will perform a fuller set of corrections, in particular to unfold for the detector response. Also looking more specifically at the tracking information to study modifications of fragmentation functions: complementary to existing dijet studies

ATLAS
EXPERIMENT

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

"SMALL MULTIPLE" REPRESENTATION

pp | 50-80% | 30-50% | 20-30% | 10-20% | 0-10%

$60<p_T<80$ GeV

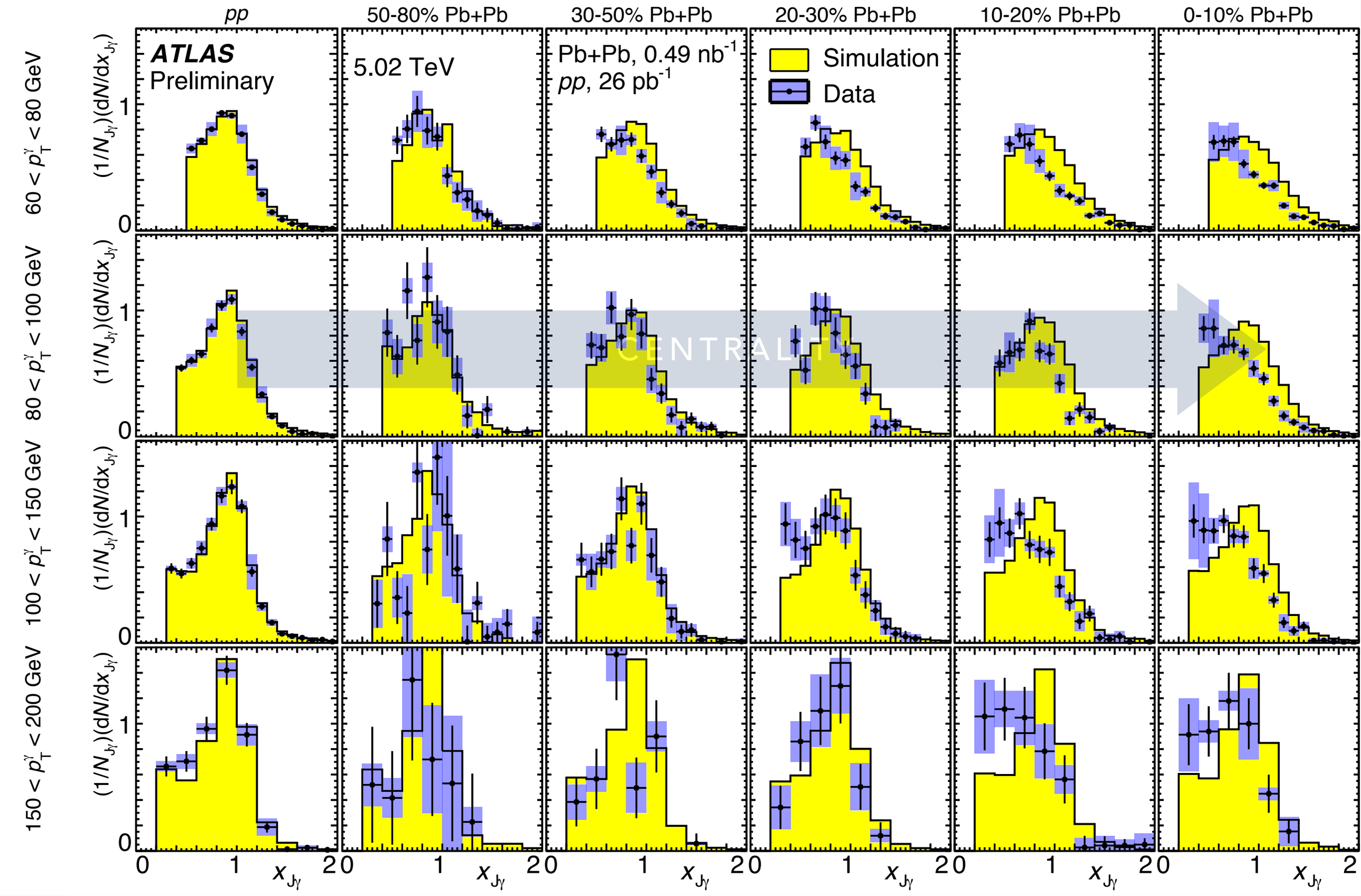
$80<p_T<100$ GeV

$100<p_T<150$ GeV

$150<p_T<200$ GeV

CENTRALITY

PHOTON p_T



The entire $x_{J\gamma}$ dataset, in one slide

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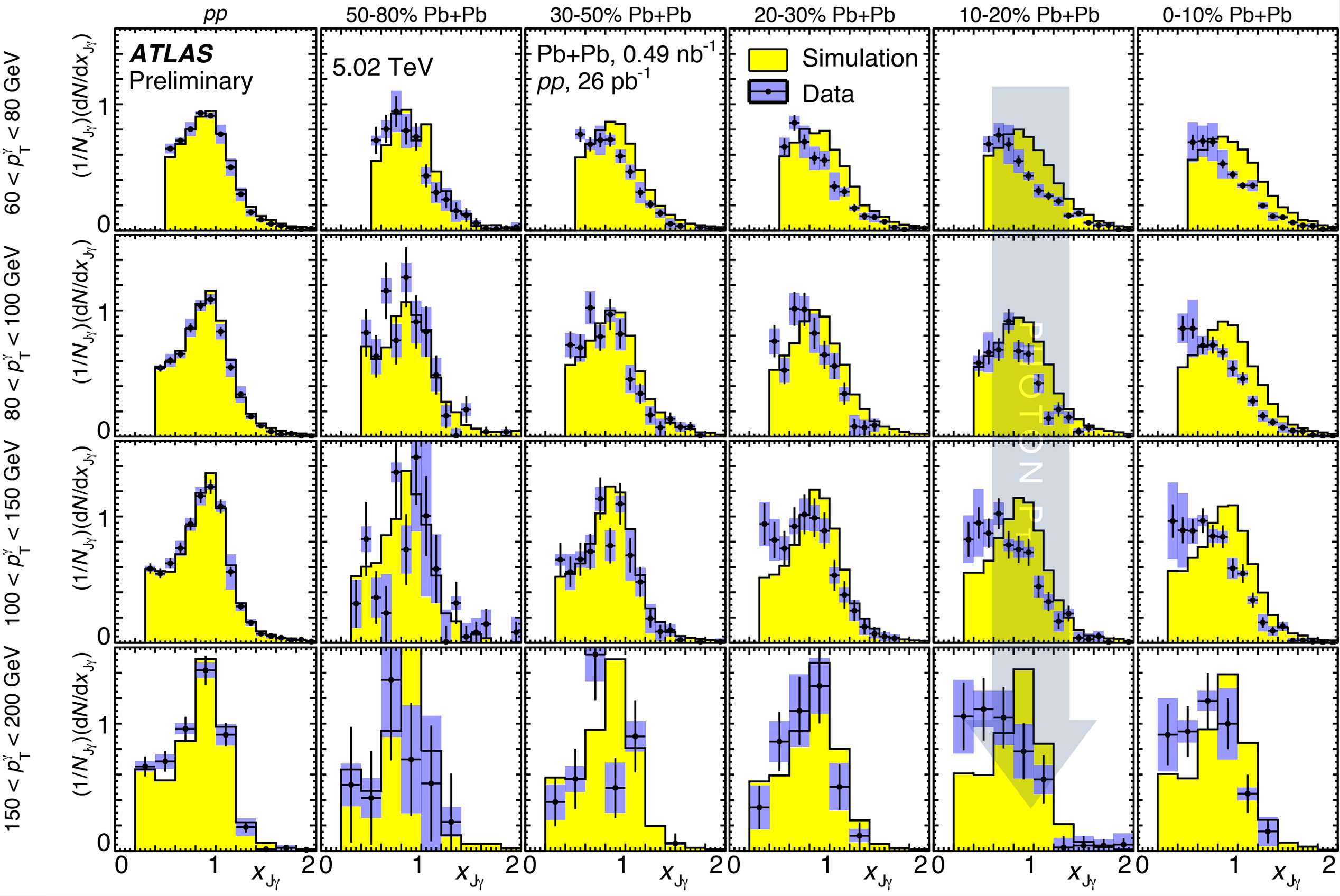
The entire $x_{J\gamma}$ dataset, in one slide



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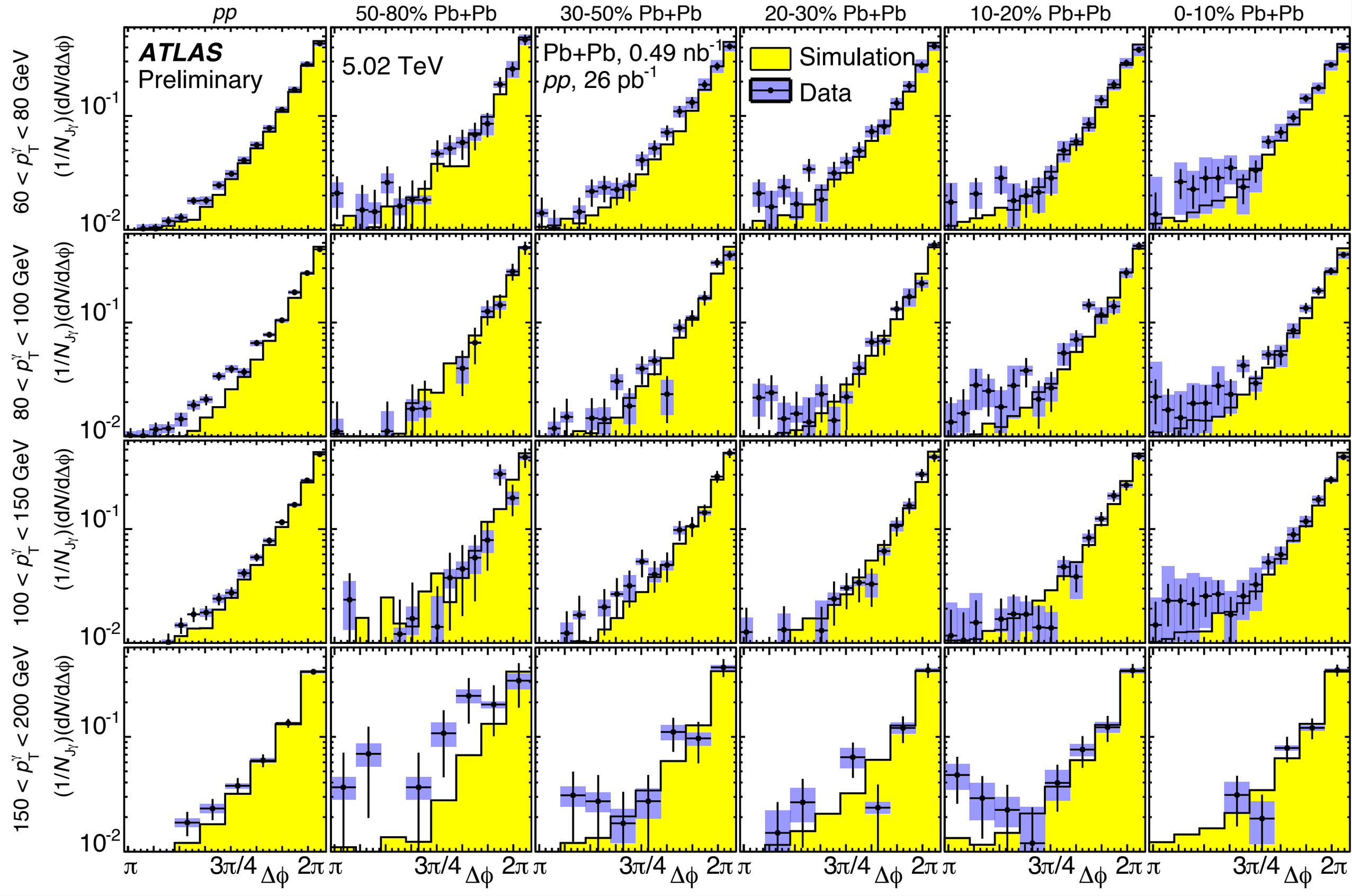

The entire Δϕ dataset, in one slide

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EXTRA SLIDES

JET SYSTEMATIC UNCERTAINTIES

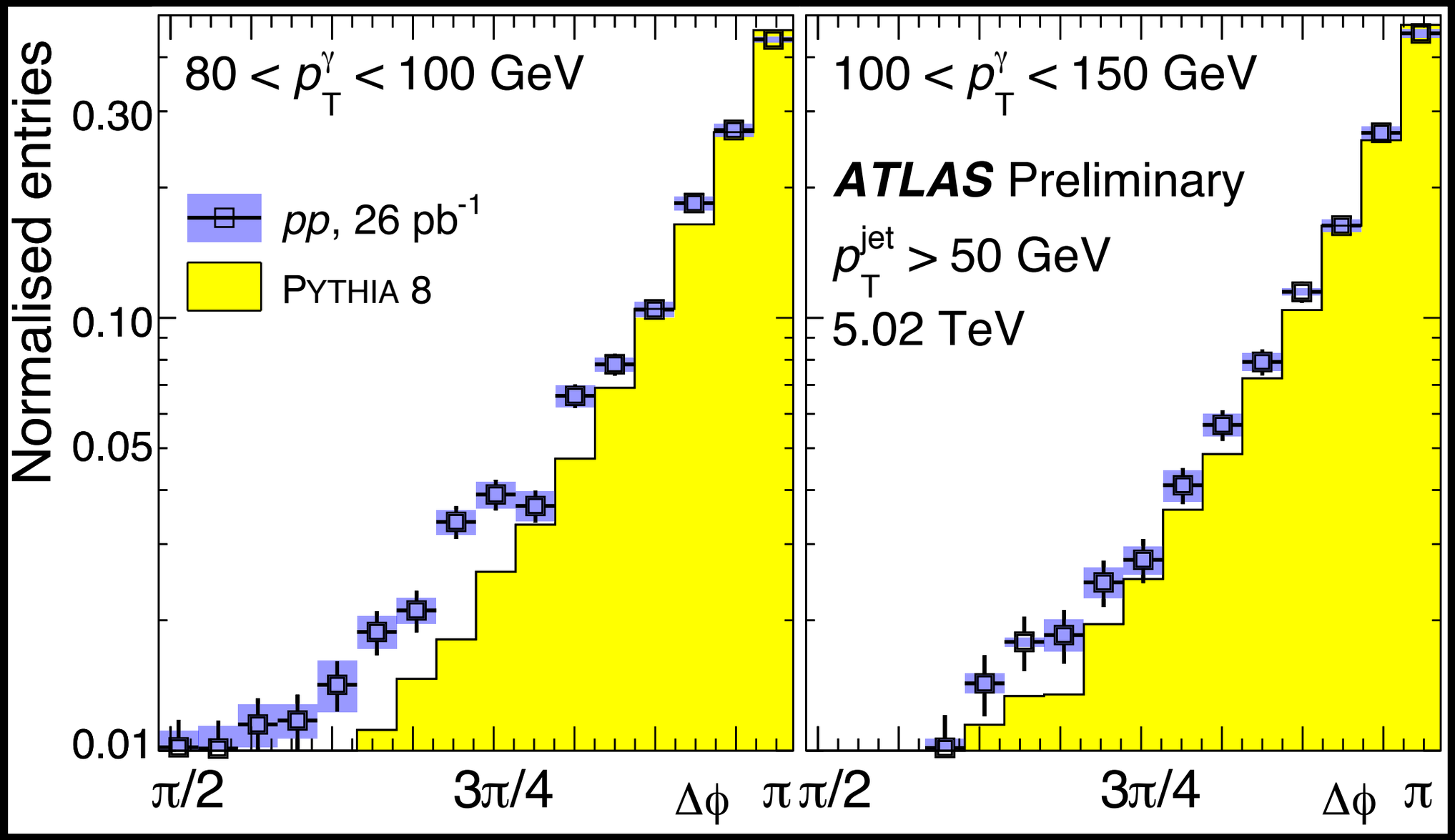
1. Jet energy scale (JES): 5% @ low jet p_T, decreasing with p_T
2. Cross calibration: 1% additional JES uncertainty
3. Jet energy resolution (JER): evaluated by increasing the resolutions measured in pp by a few percent
4. Combined uncertainty on composition of jet flavor, and difference in flavor response: 2% at low p_T, decreasing with p_T
5. Additional Pb+Pb JES uncertainty: 1% for p_T>50 GeV, up to 5-10% for p_T<50 GeV
    1. comparing charged-particle jets and calorimeter jets
    2. studying response of simulated quenched jets
    3. residual non-closure of simulated jets at low p_T

PHOTON SYSTEMATIC UNCERTAINTIES

1. Photon purities varied by their statistical uncertainties, which adjusts contribution of jet background
2. Photon isolation cuts increased by 2 GeV in both pp and Pb+Pb, which increases efficiency but lowers purity
3. Non-tight selection definition varied, which changes sideband occupancies
4. Photon energy uncertainties evaluated for *pp* and are typically less than 1%
5. R_{bkg} varied to assess impact of correlations of background candidates in ABCD

GAMMA-JET ACOPLANARITY

Normalized for $\Delta\phi > 7\pi/8$



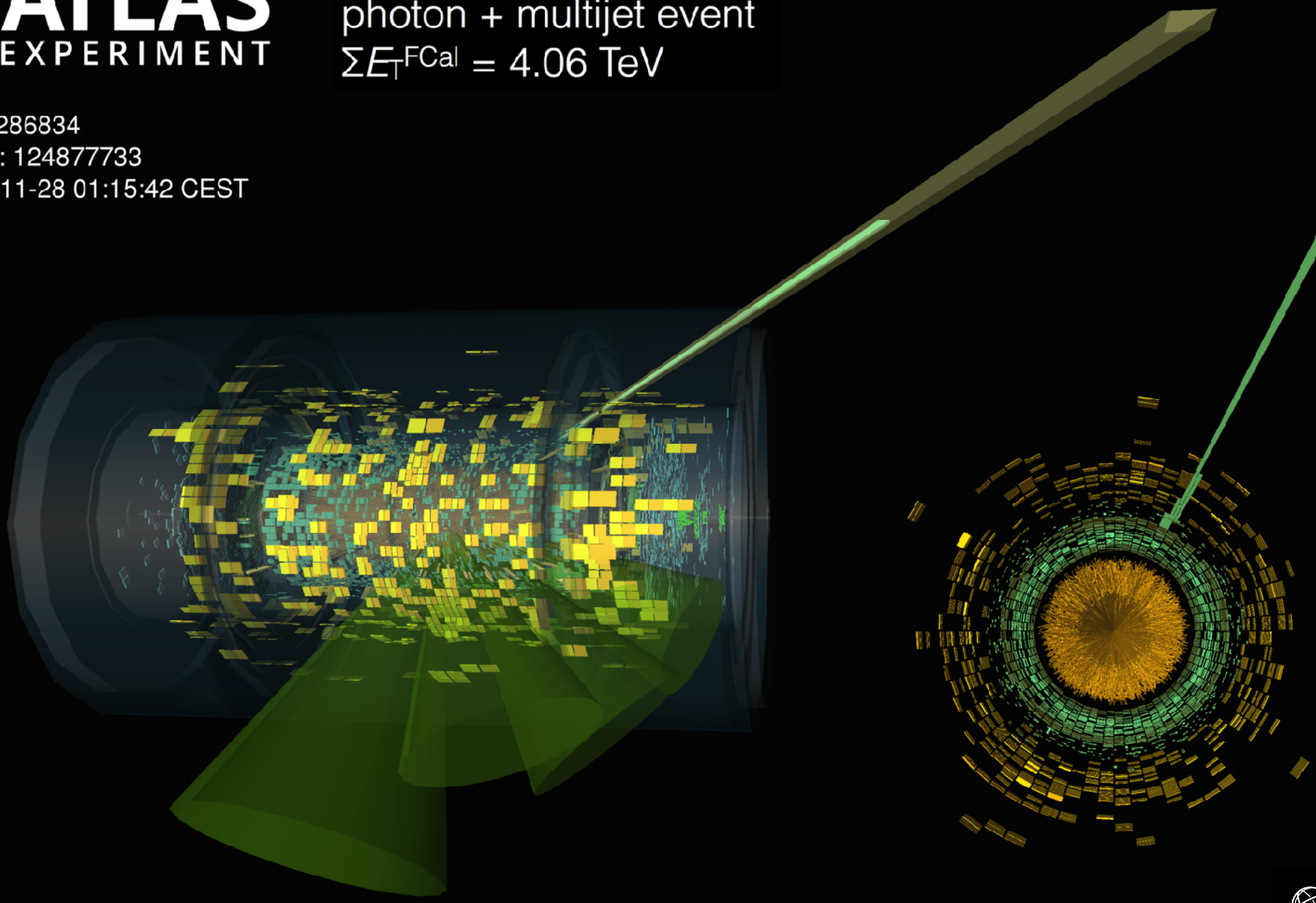
Data/MC mismatch may result from suboptimal mix of direct and fragmentation processes, or from insufficiency of LO+shower process

PHOTON-JET EVENTS

ATLAS EXPERIMENT

Pb+Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
photon + multijet event
ΣE_T^{FCal} = 4.06 TeV

Run: 286834
Event: 124877733
2015-11-28 01:15:42 CEST



ATLAS EXPERIMENT