Centrality, Rapidity and p_T dependence of isolated prompt photon production in Pb+Pb collisions with the ATLAS detector at the LHC

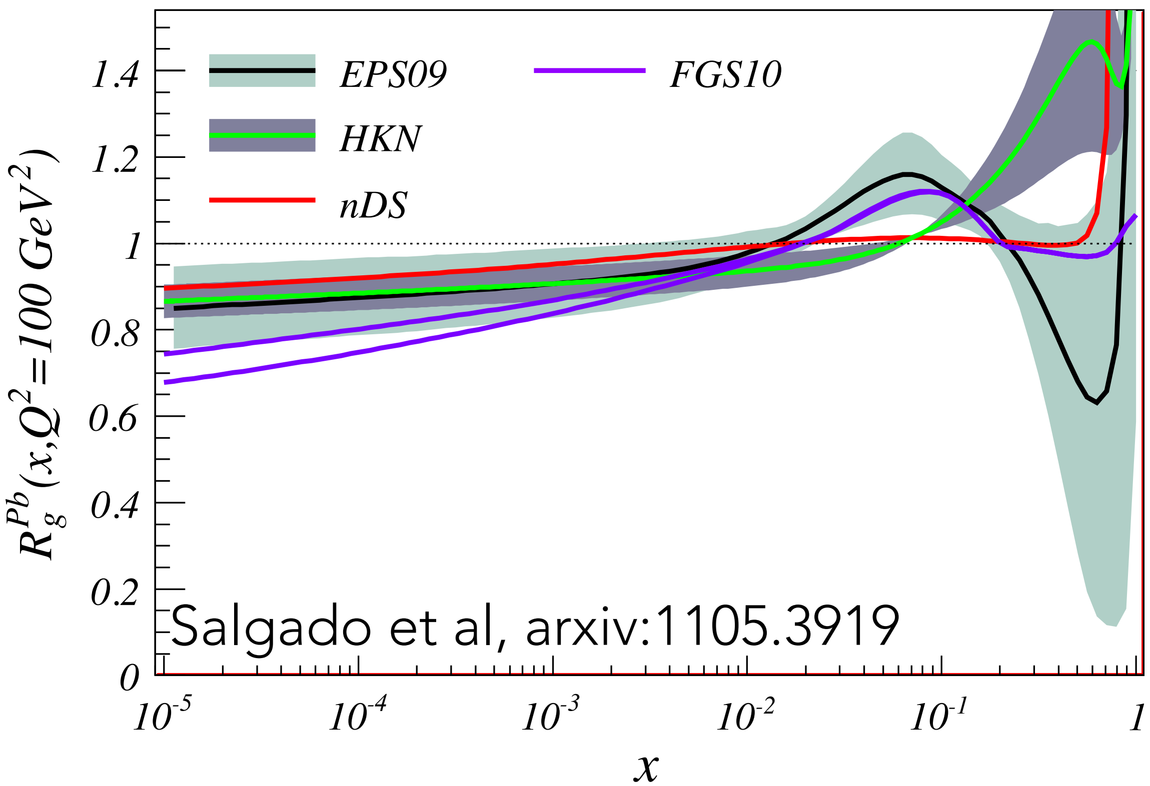
PETER STEINBERG, BROOKHAVEN NATIONAL LABORATORY

QUARK MATTER 2014

MAY 19, 2014

Motivation for inclusive photons

- Photons are a penetrating probe of the hot dense medium
  - Do not interact strongly, so are sensitive to the initial state of the nucleus-nucleus collision
- Important test of our understanding of initial state
  - Should scale with nuclear thickness (initial parton flux)
  - Sensitive to nPDF effects (EPS09, nDS, HKN, FGS)



- Potential sensitivity to jet-medium effects
  - In principle jets could convert to photons in-medium (Gale et al)

Scope of measurement

- This result covers a wide range of nuclear geometry and wide phase space.
  - 4 centrality regions (40-80%, 20-40%, 10-20%, 0-10%)
  - 2 pseudorapidity regions (**central** $|\eta|<1.37$ and **forward** $1.52<|\eta|<2.37$)
  - 11 p_T regions (logarithmic from 22.1-280 GeV)
- Also measure ratio of yields between forward and central η interval
  - Useful to cancel various effects
- Yields scaled by the nuclear thickness function T_{AA} and compared to JETPHOX 1.3.0 NLO pQCD

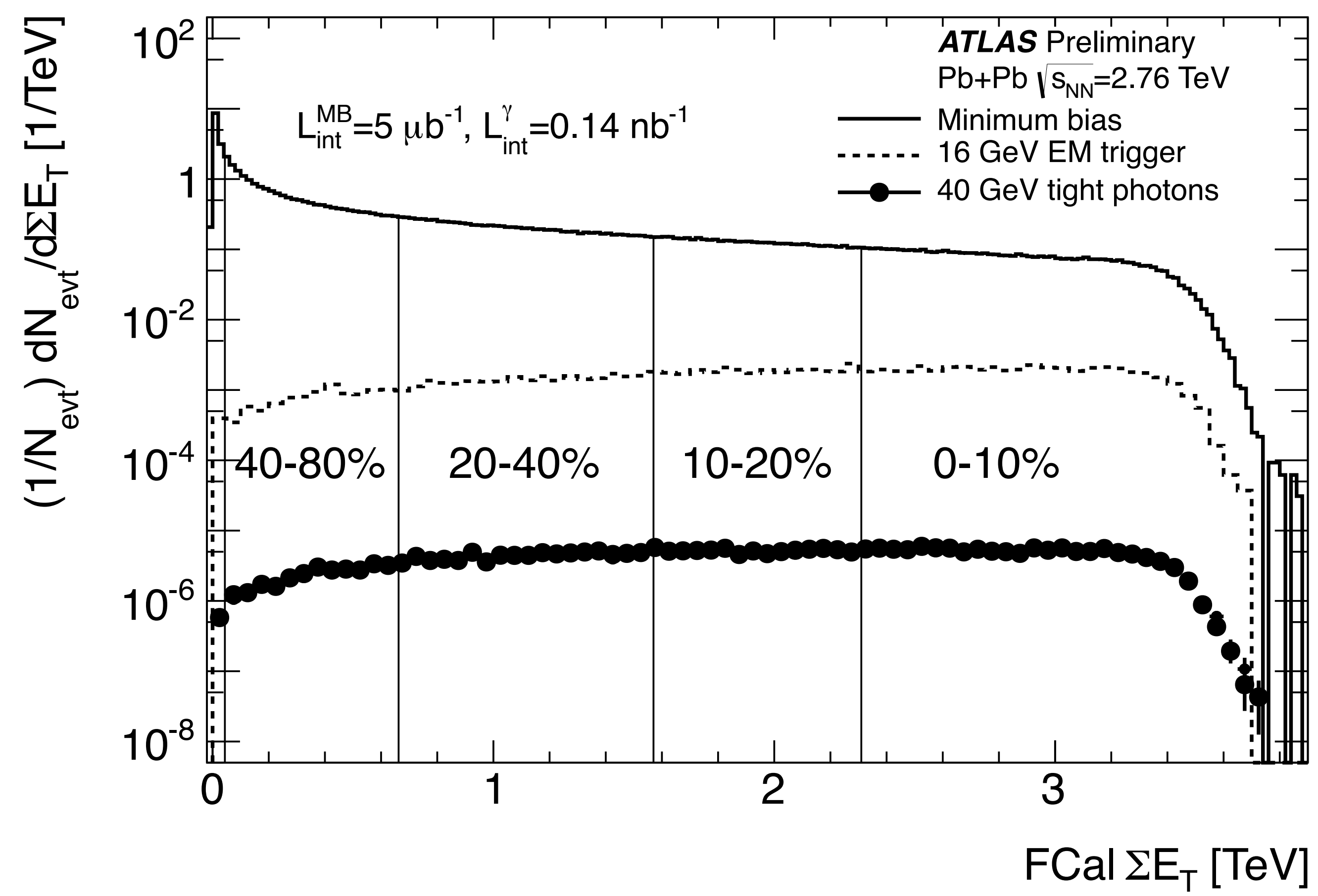
Simulation data samples

- In order to simulate both contributions to the photon cross section — direct and fragmentation — two simulated datasets were run
  - MC11 PYTHIA 6.4 direct photon (17-280 GeV)
  - MC11 PYTHIA 6.4 dijets (17-560 GeV) with hard photon filter
    - O(3 billion) events needed to get 3 million photons

- Simulated pp events are merged with real minimum bias data events, and reconstructed as if they were real data
  - "Data overlay" - perfect description of underlying event.

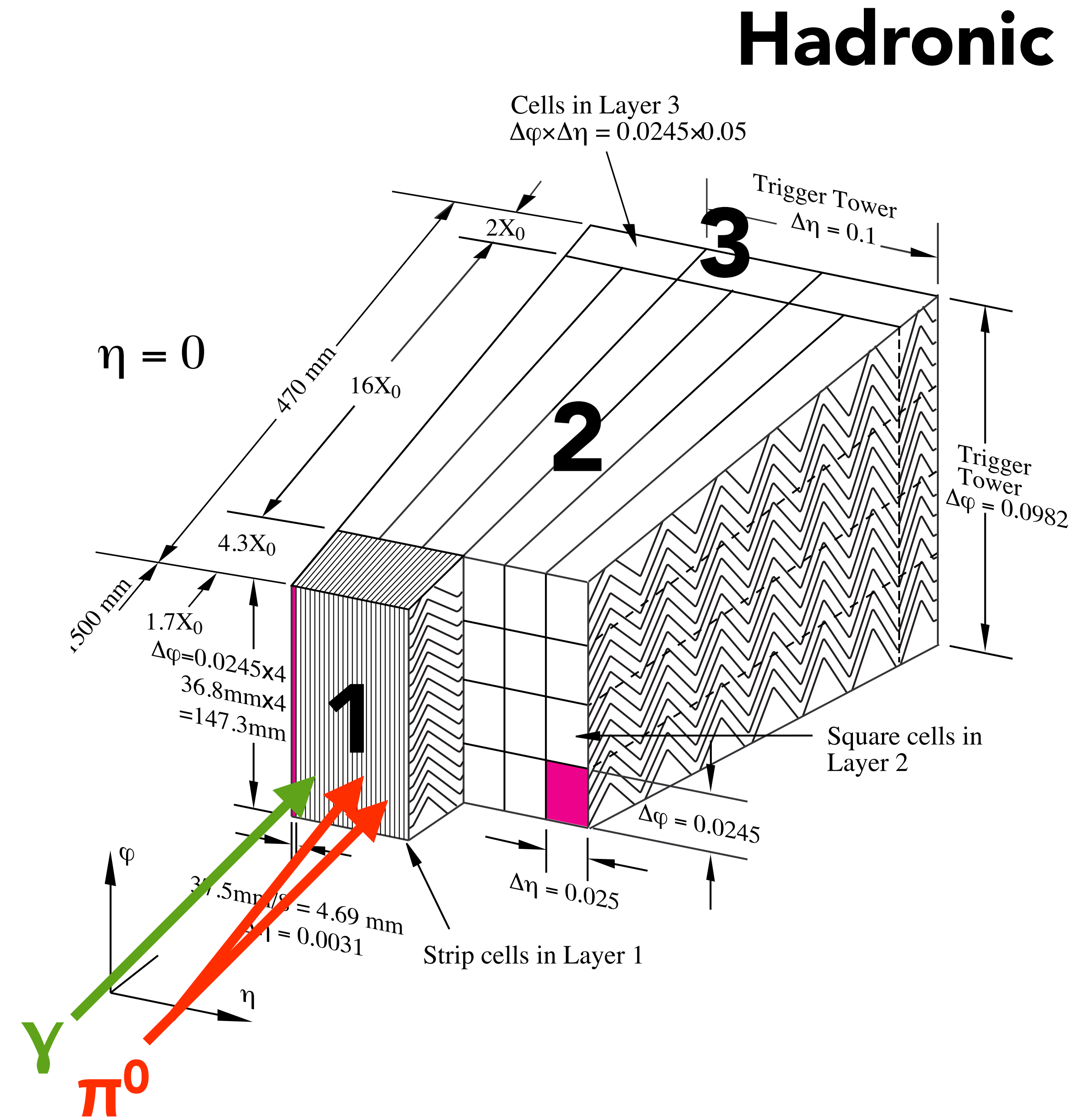
Data selection

- Events from 2011 Pb+Pb dataset, trigged on a 16 GeV electromagnetic deposition within 0.2x0.1 area in $\Delta\eta \times \Delta\phi$
  - Integrated luminosity 0.14 nb^{-1}
- Minimum-bias event selections used to clean events
  - ZDC coincidence, $\Delta t_{MBTS} < 5$ ns, reconstructed vertex
- Centrality selection performed using ATLAS forward calorimeter ($3.2<|\eta|<4.9$)

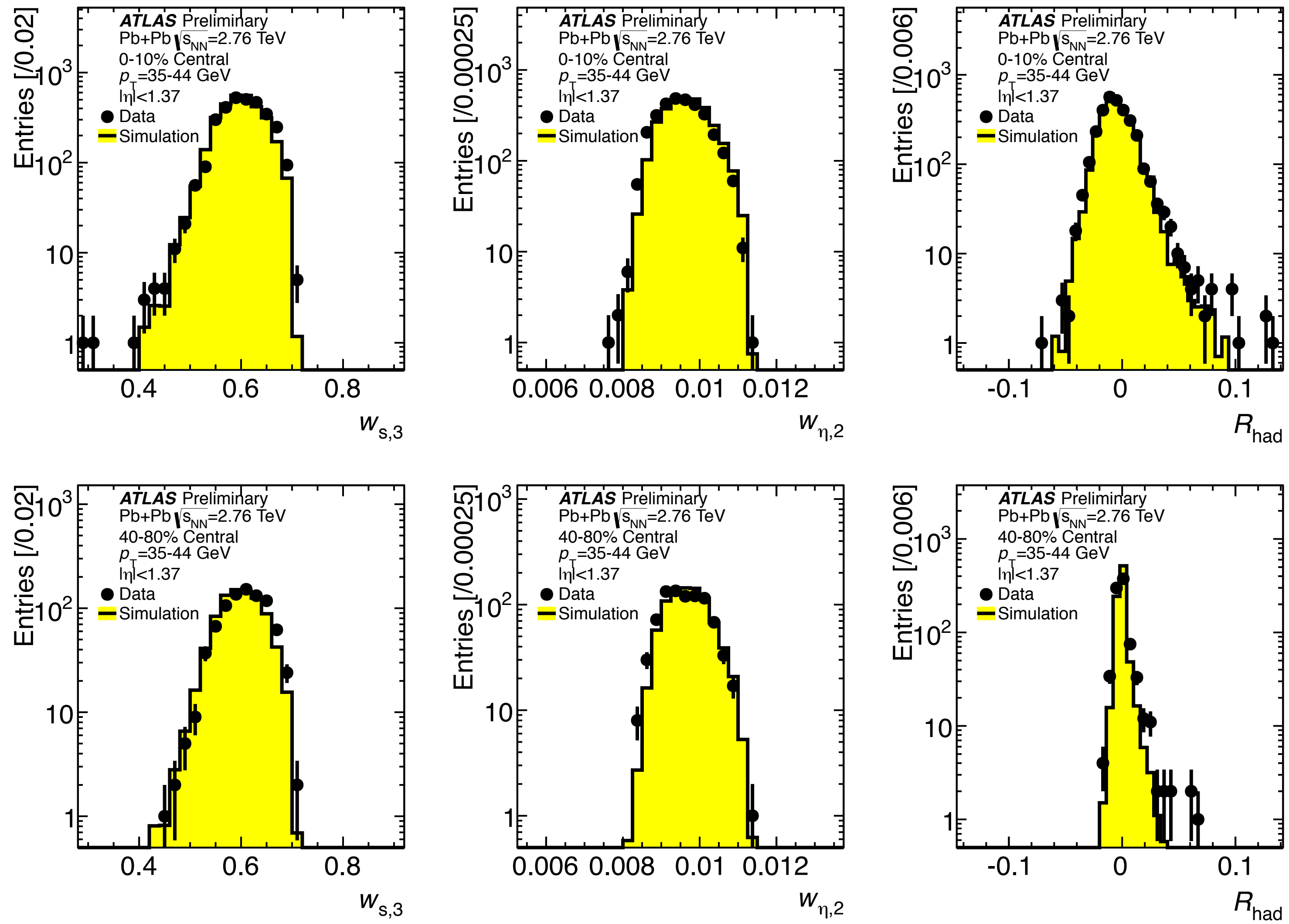


Photon reconstruction & shower shape variables

- Underlying event removed in $\Delta\eta$=0.1 regions from HI jet reconstruction
- Photon clusters seeded using sliding window in 2nd calorimeter layer.
- Photon identification is based on 9 shower shape variables
  - **Second layer variables**:
    - Containment and width of showers
  - **Hadronic leakage variables**:
    - Fraction of cluster E_T in hadronic section
  - **First layer variables**:
    - Rejects candidates with two showers



Selecting photons with shower shape variables



small shower-shape corrections applied to account for observed data vs. MC differences

Width in three strips

η width in 2nd layer

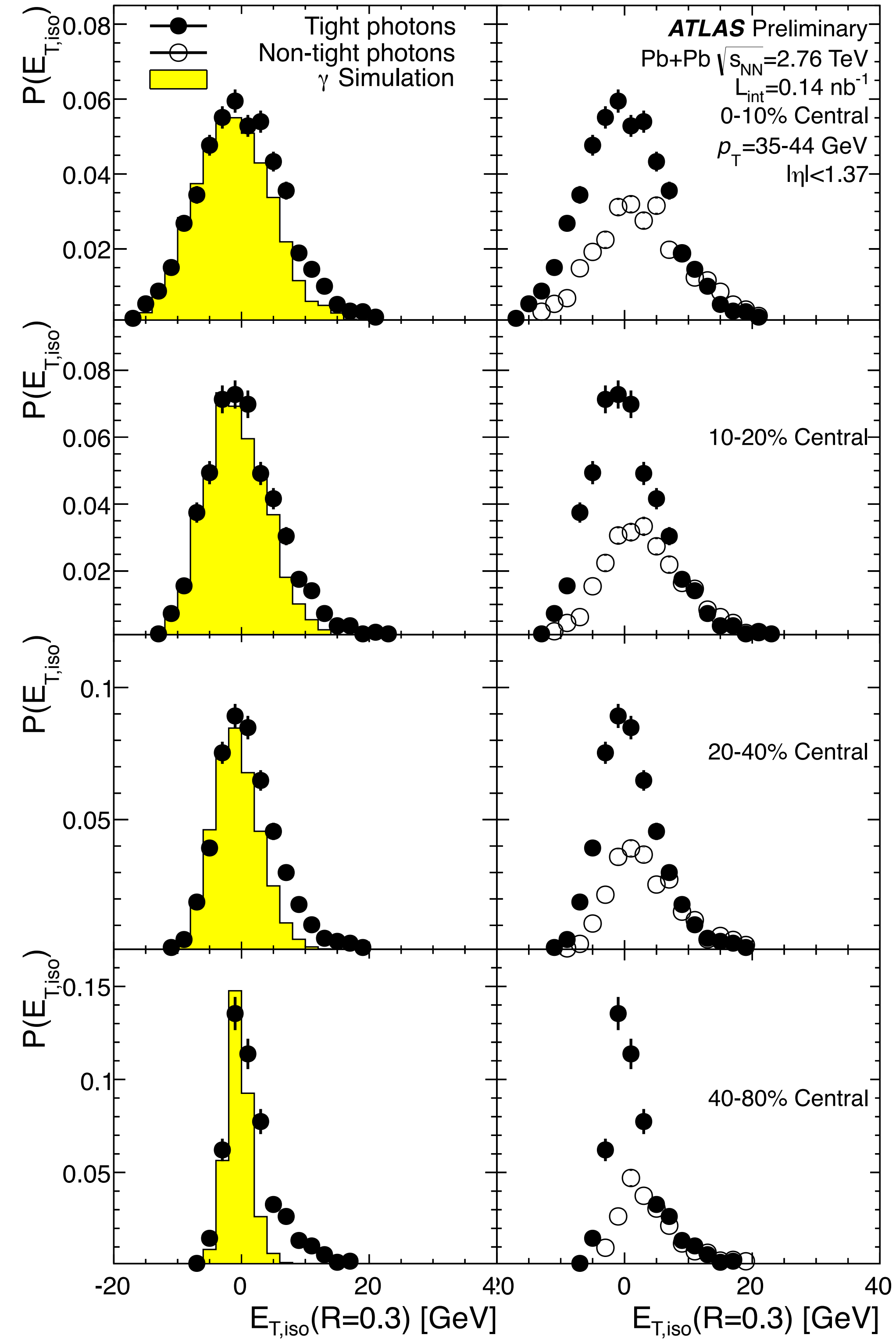
Hadronic leakage fraction

"Tight" selection - satisfies 9 shower shape selections per photon, tuned on photons in HI events

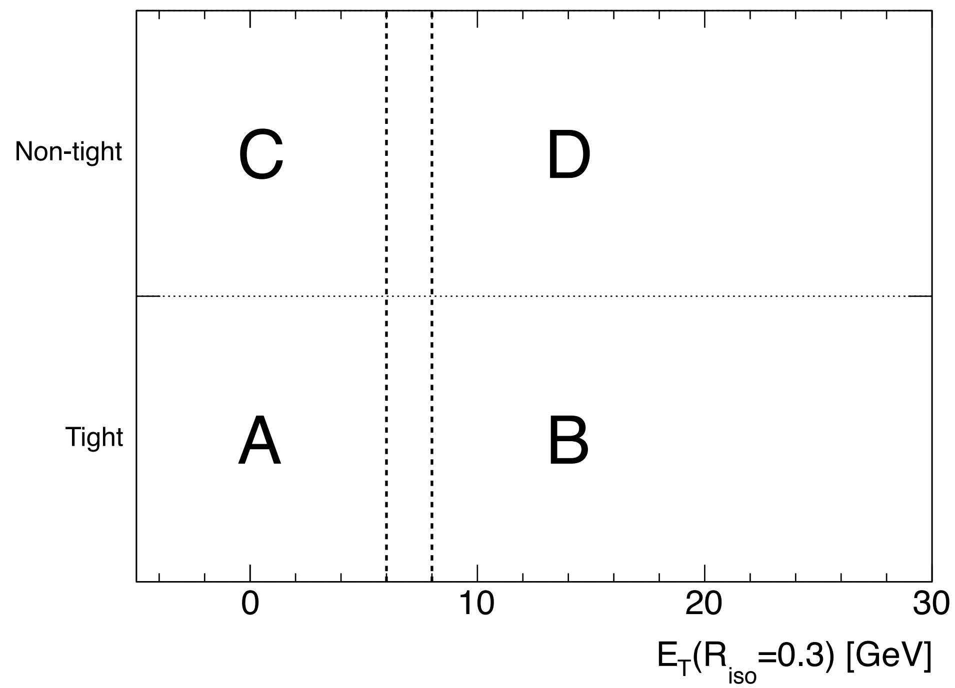
"Non-tight" selection - Background enhanced by selecting clusters that fail selections which usually reject having two distinct showers, or two merged showers

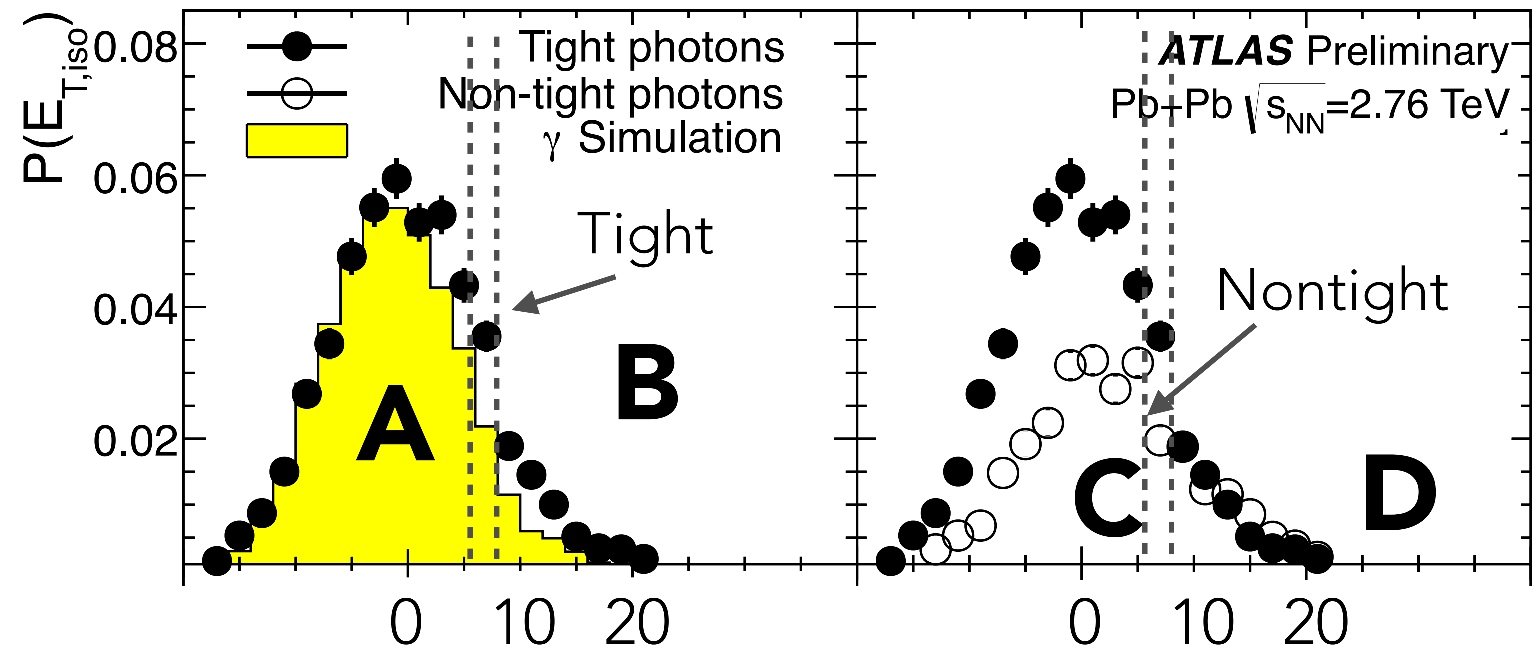
Isolation selection

- $E_{T,iso}$ is the transverse energy in the full depth of the calorimeter in a ring of R=0.3 around the photon direction, with photon removed
  - "Isolated": $E_{T,iso}$(R=0.3) < 6 GeV
- Simulated isolation distribution, normalized to data for $E_{T,iso}$<0, showing increasing fluctuations in central events
- Non-tight photons from data, normalized for $E_{T,iso}$>8 GeV, showing how jets fill the tails in the isolation distributions



Double sideband method: ideal



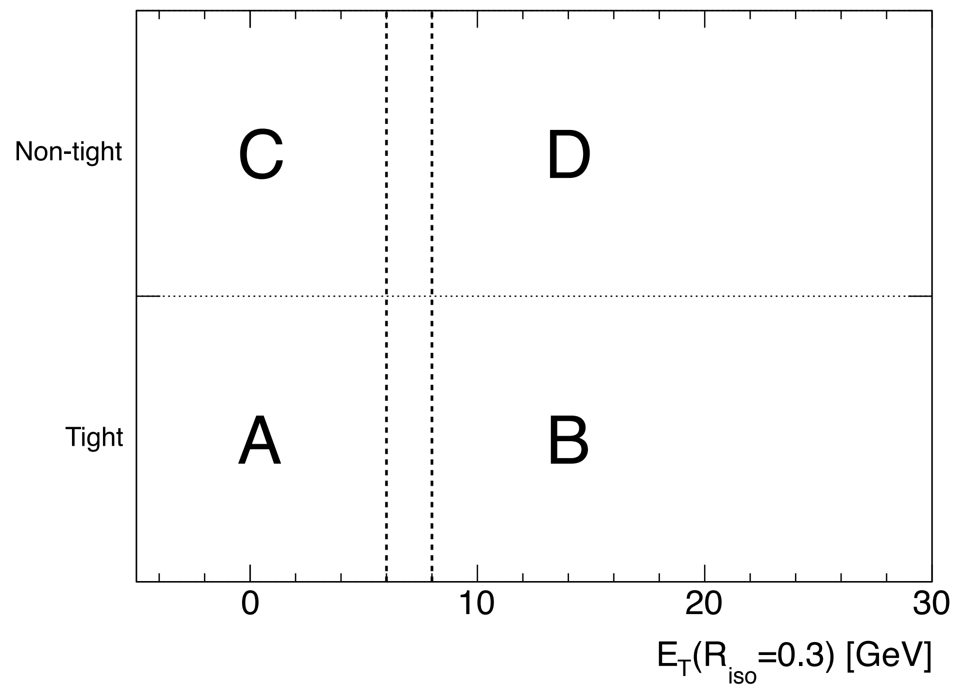


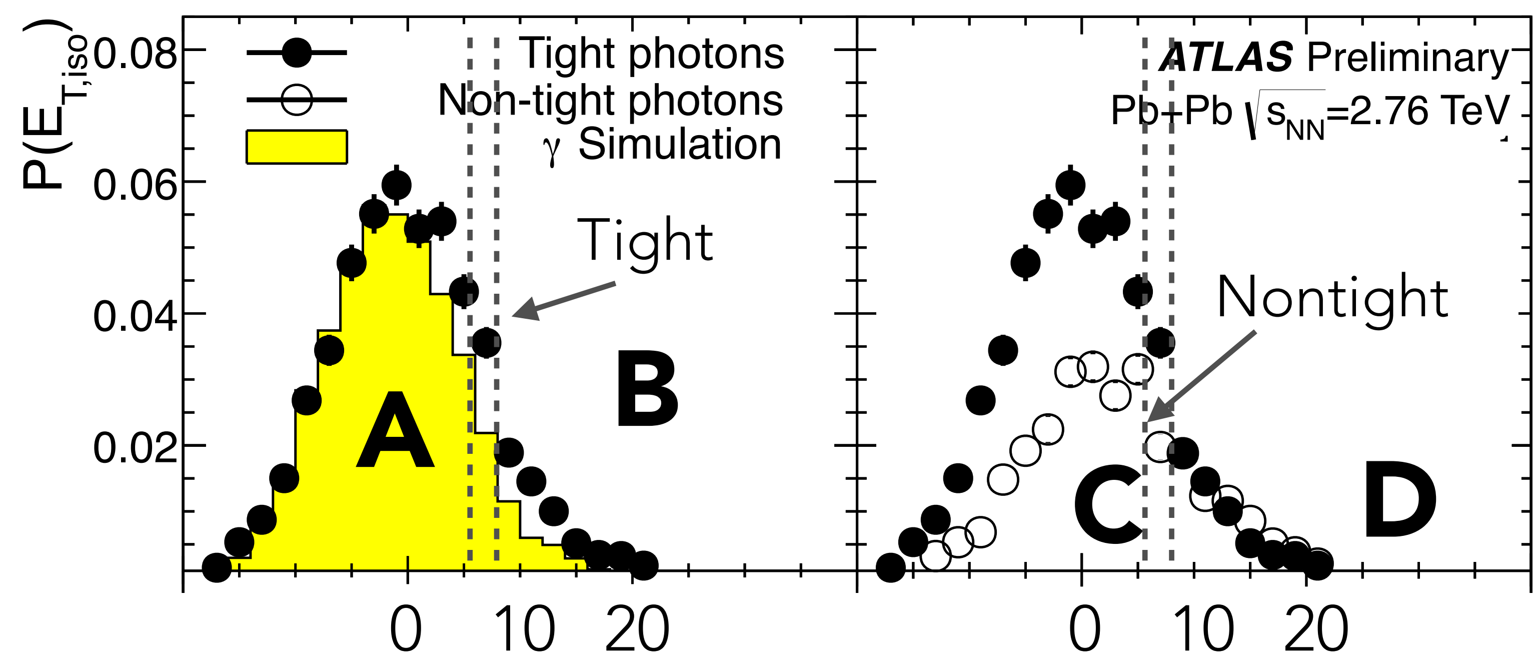
Basic principle is straightforward: use non-tight photons to extrapolate non-isolated/non-tight photons into the signal (tight, isolated region):

Yield = A - B (C/D) = A - C (B/D)

(If A/B = C/D, then yield =0)

Double sideband method: actual





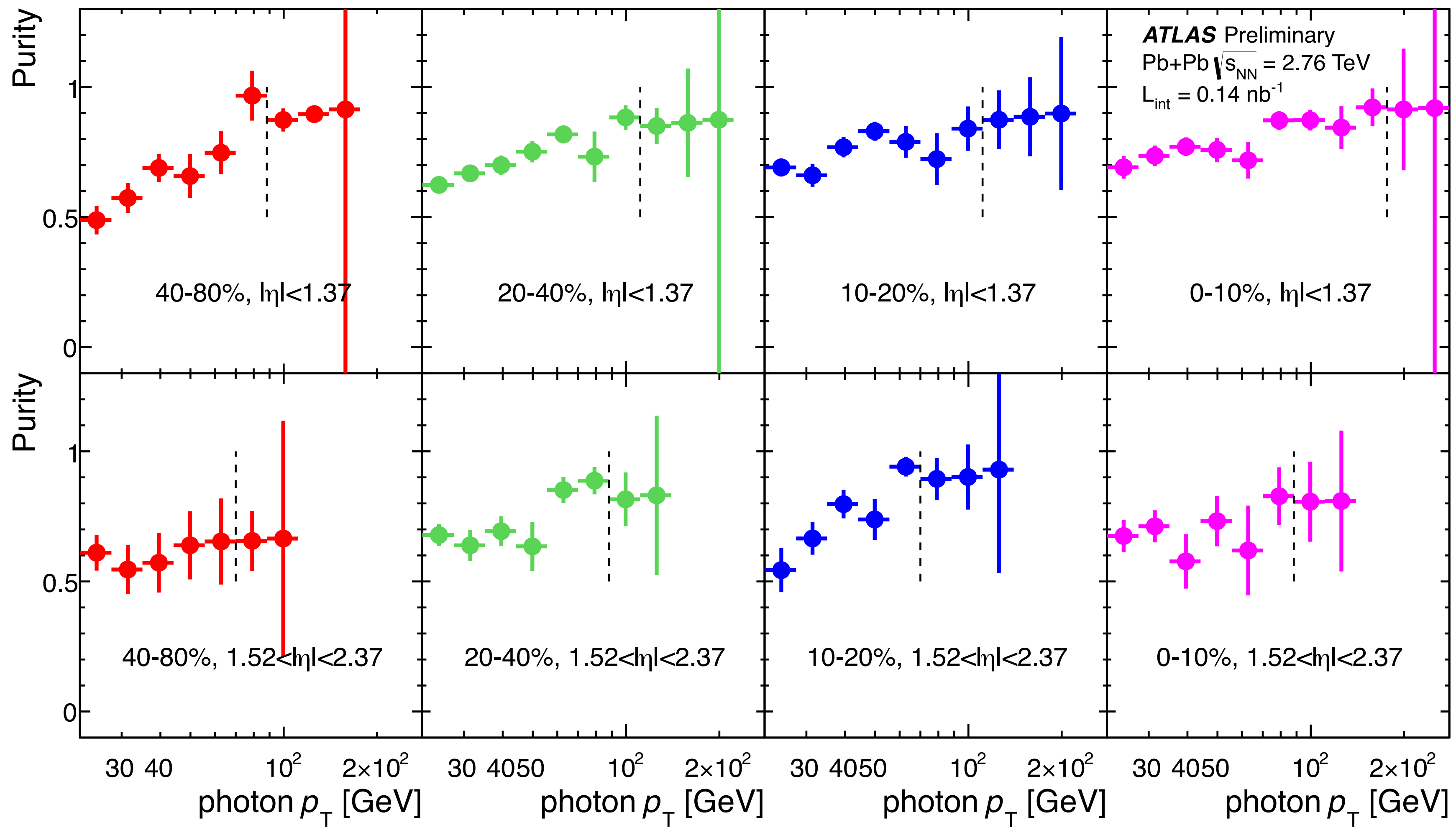
In reality, signal photons can "leak" into the sidebands:
use simulations to estimate leakage factors using signal-only: $c_X = N_X/N_A$

$$N_A^{\rm sig} = N_A^{\rm obs} - \left(N_B^{\rm obs} - c_B N_A^{\rm sig}\right) \frac{\left(N_C^{\rm obs} - c_C N_A^{\rm sig}\right)}{\left(N_D^{\rm obs} - c_D N_A^{\rm sig}\right)}$$

obs=Data
sig=signal

Solved for $N^{sig}{}_A$ with quadratic formula, and
only one root is physical (the one that is zero when AD=BC)

Double sideband method: purity

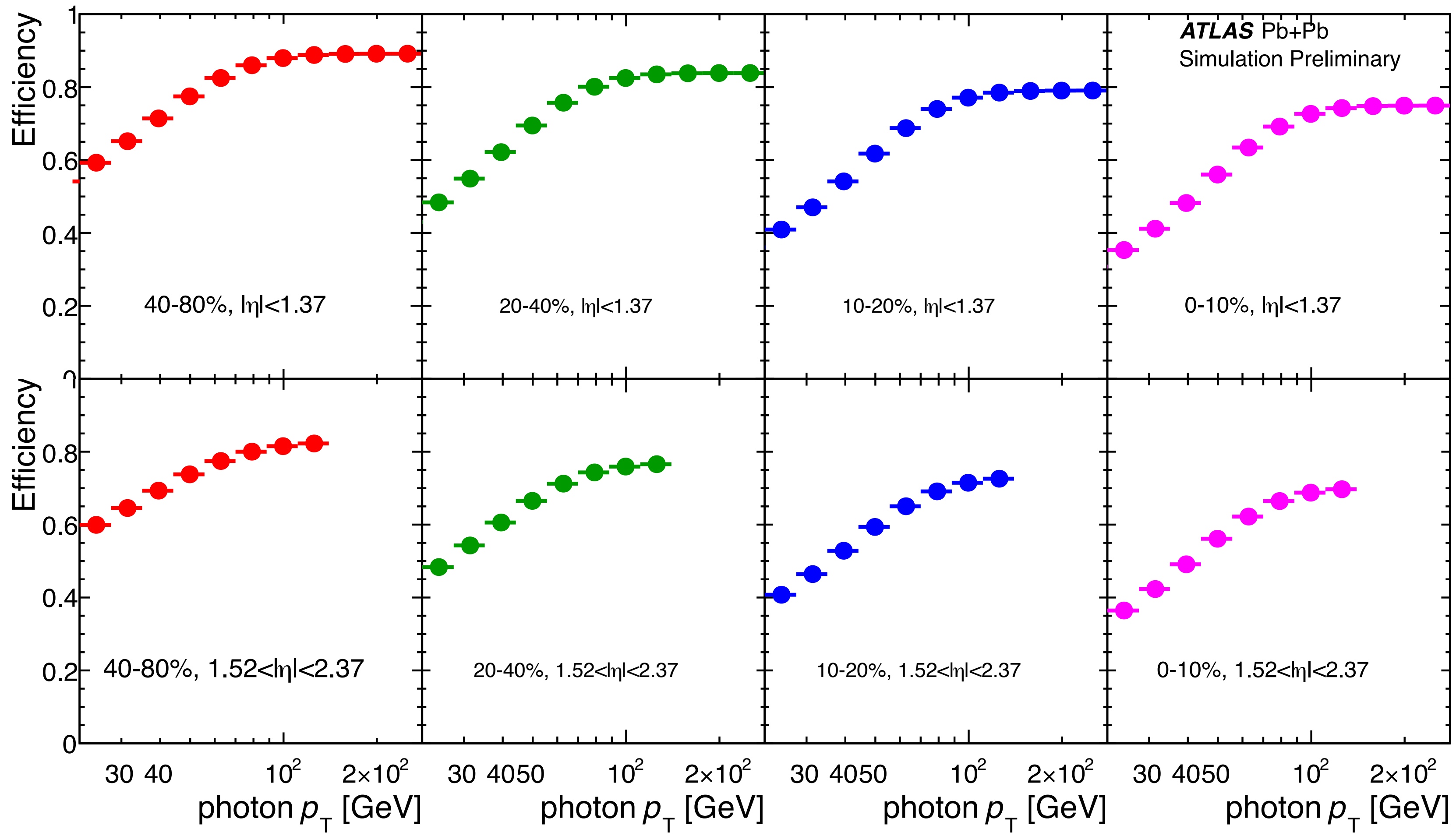


$$P = \frac{N^A_{\rm sig}}{N^A_{\rm obs}}$$

Statistical error assuming A,B,C,D follow multinomial statistics

- The purity extracted from the double sideband method is defined as fraction of the tight isolated candidates left after removing backgrounds
- Beyond dotted lines, statistics in sideband D are small; data extrapolated to sideband regions, and statistical errors reflect fit errors

Efficiency in centrality & eta bins



Relative to PYTHIA photons with $E_{T\,iso}$<6 GeV at parton level.

Includes contributions from <u>reconstruction</u> (**η** dependence), <u>identification</u> (p_T dependence), and <u>isolation</u> (centrality dependence)

No systematic uncertainties shown, since effect of cut variations affect both efficiency and purity. Net effect represented in systematics on yield.

Systematic uncertainties

- Variations applied to various parts of the analysis simultaneously in data and MC, to probe data/MC differences
  - Photon selection cuts (shower shape, isolation)
  - Effect of leakage correction
  - Shower shape corrections removed
  - Energy scale & resolution uncertainties
  - Removed fragmentation photons from MC
- Evaluated in two regions 22-44.1 GeV, 44.1-111.1 GeV
  - Largest of each variation selected and applied symmetrically
- Total uncertainties vary from 10% to 38%, with larger values in most peripheral events (lower data statistics), forward region (lower statistics), and central events (larger UE fluctuations).

Corrected per-event yield

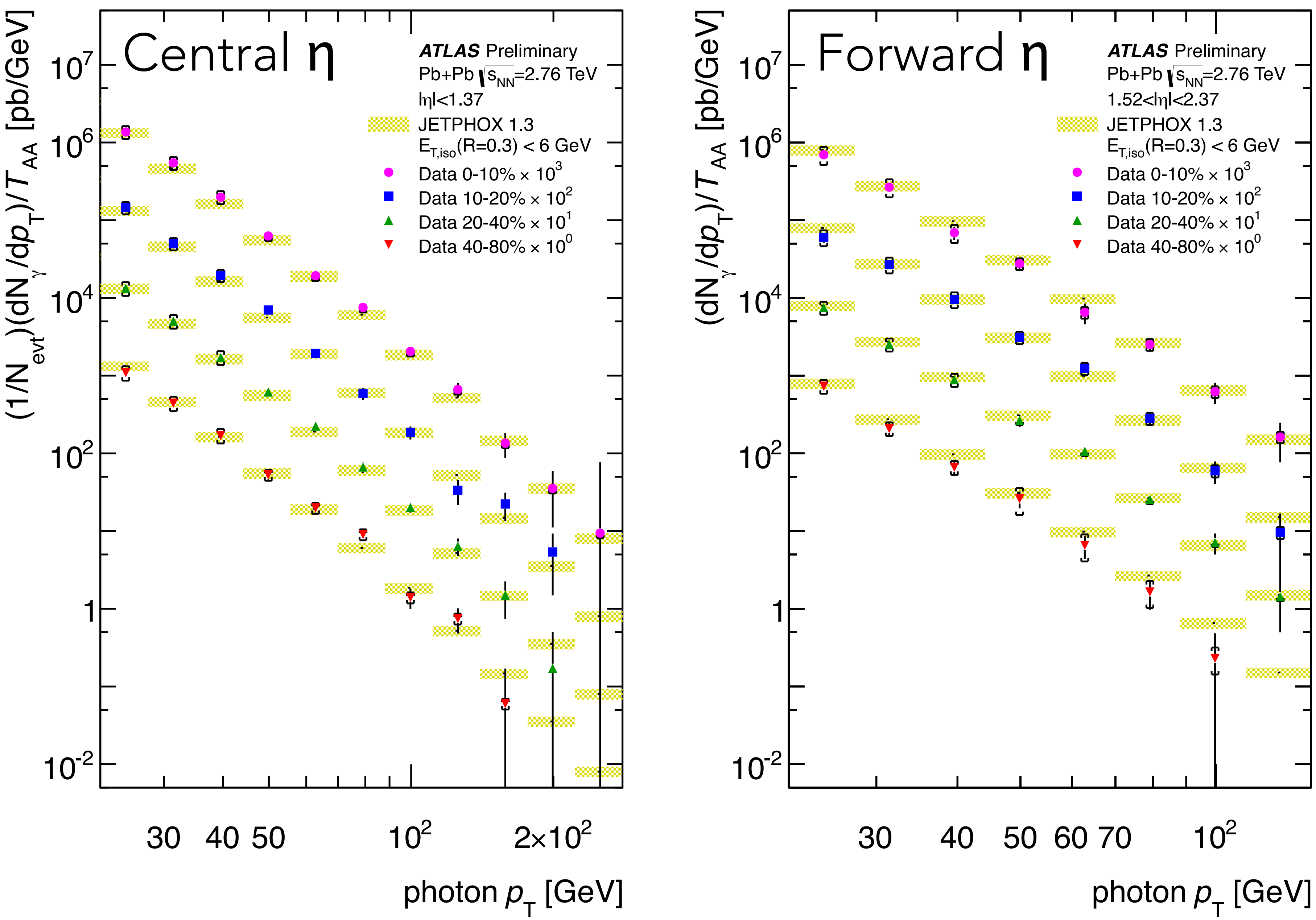
$$\frac{1}{N_{\rm evt}(C)}\frac{dN_\gamma}{dp_T}(p_{\rm T},\eta,C) = \frac{N_A^{\rm sig}\mathcal{U}(p_{\rm T},\eta,C)}{N_{\rm evt}(C)\epsilon_{\rm tot}(p_{\rm T},\eta,C)\Delta p_{\rm T}}$$

1. Signal events from sideband analysis
2. Energy scale/resolution corrections *U* (10% from 22-28.1 GeV, then less than 4% for full $p_{\rm T}$ and η range)
3. $N_{\rm evt}$ from full counting of minimum bias events
4. Efficiency from simulations
5. $\Delta p_{\rm T}$ bin width (no scaling by $\Delta\eta$ or $\Delta\phi$)

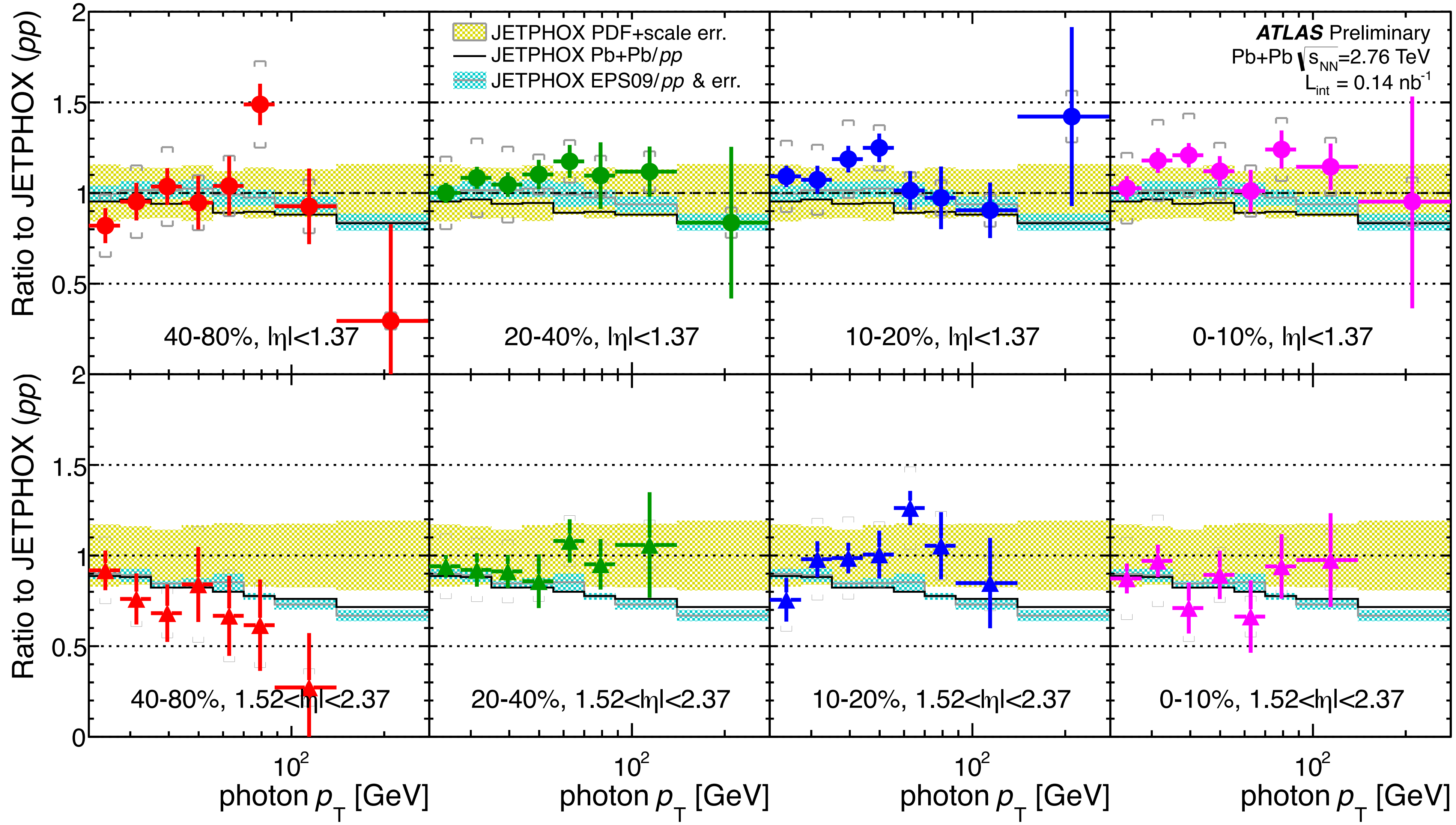
Contamination from electrons from W estimated to be only appreciable in 2 bins around 40 GeV: 3.5% correction in central η, 5% at forward η

Corrected per-event yield vs. JETPHOX

$$\frac{1}{N_{\mathrm{evt}}(C)}\frac{dN_\gamma}{dp_T}(p_{\mathrm{T}},\eta,C) = \frac{N_A^{\mathrm{sig}}\mathcal{U}(p_{\mathrm{T}},\eta,C)}{N_{\mathrm{evt}}(C)\epsilon_{\mathrm{tot}}(p_{\mathrm{T}},\eta,C)\Delta p_{\mathrm{T}}}$$

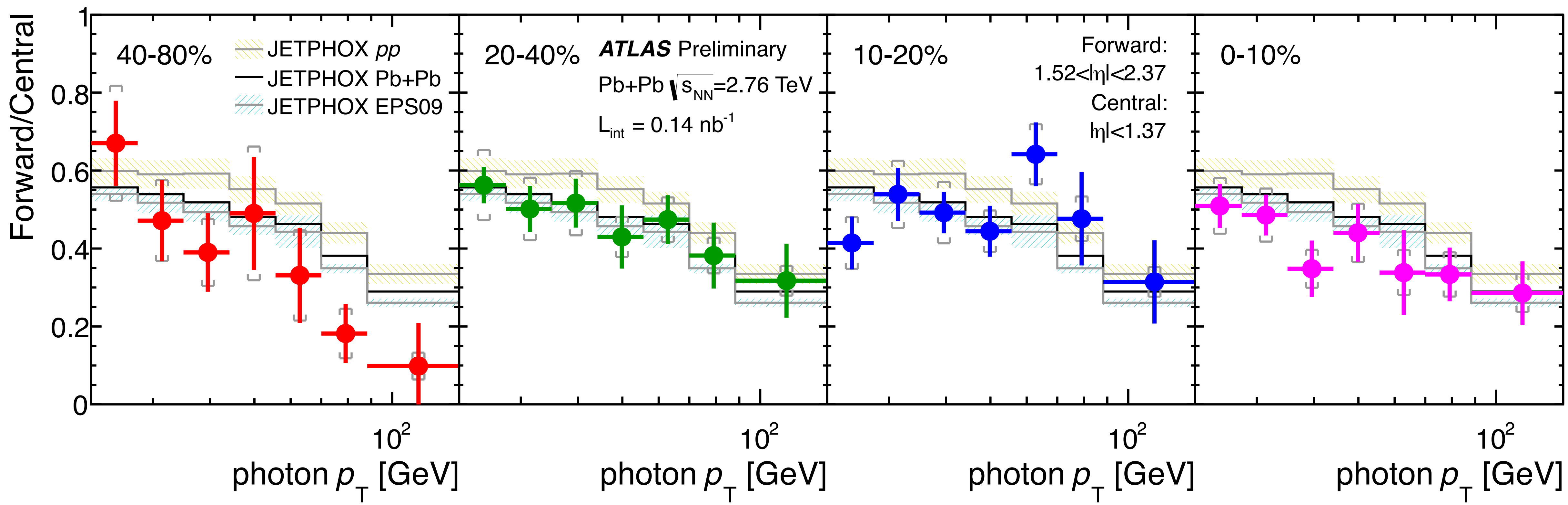


Ratios to JETPHOX



Ratios to JETPHOX NLO pQCD calculations
(CTEQ6.6, BFG II) run with R=0.3/6 GeV isolation.
Three configurations: **pp** (unity), **Pb+Pb/pp** (black line), **EPS09/pp** (blue area).
Yellow shaded region is scale & PDF uncertainties, shared with Pb+Pb.
EPS09 errors represented by blue area.

Forward/Central ratios



Ratios of forward and central yields, compared with pp (yellow), Isospin (black line), and nPDF EPS09 (blue area).

Total uncertainties are large enough to preclude strong statements regarding isospin & nPDF effects.

Conclusions

- Centrality, pseudorapidity and p_T dependence of photon production in Pb+Pb collisions
  - First HI measurements at high p_T forward η region
- Fully corrected yields
  - Background subtracted, efficiency and resolution corrections
- Yields in good agreement with JETPHOX pp
  - Comparisons made to Pb+Pb with and without nPDF effects
  - Errors still too large to distinguish among scenarios
- Forward/central ratios presented for first time
  - Sensitive to isospin and nuclear effects
  - Data systematically lower than pp, but the predictions are close enough that no strong conclusions can be made

Extra slides

Phys.Lett.B 706 (2011) 150–167

JETPHOX vs. ATLAS data

35 pb^{-1} of 7 TEV data show quite good agreement with JETPHOX (with a tighter isolation)

JETPHOX provides a reliable reference over the full phase space in this measurement

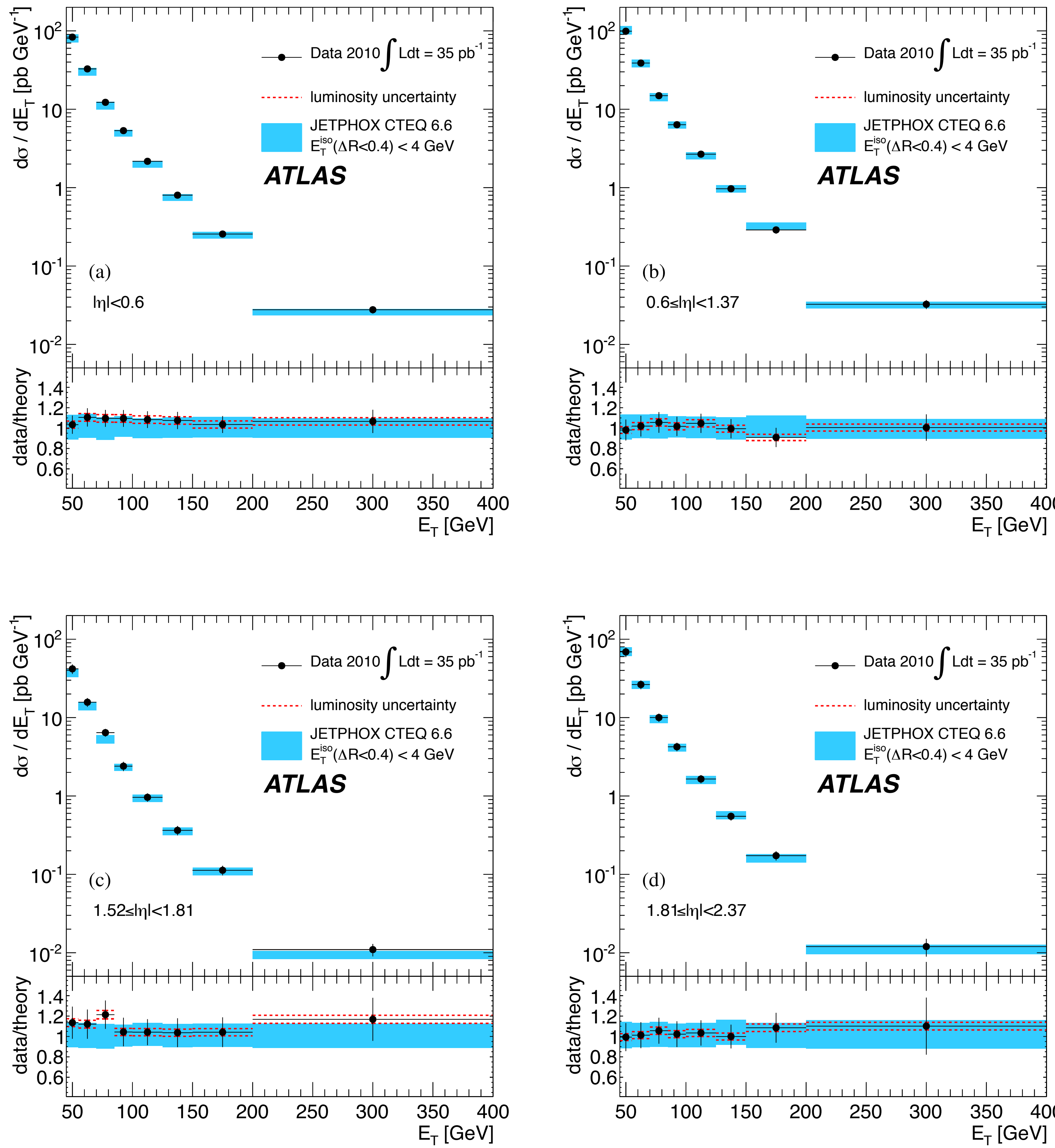


Figure 2: Measured (dots) and expected (shaded area) inclusive prompt photon production cross-sections, and their ratio, as a function of the photon E_T and in the range (a) $|\eta| < 0.6$, (b) $0.6 \leq |\eta| < 1.37$, (c) $1.52 \leq |\eta| < 1.81$ and (d) $1.81 \leq |\eta| < 2.37$. The data error bars combine the statistical and systematic uncertainties, with the luminosity uncertainty shown separately (dotted bands).