# Evidence for Prompt Photon Production in *pp* Collisions at $\sqrt{s} = 7$ TeV with the ATLAS Detector

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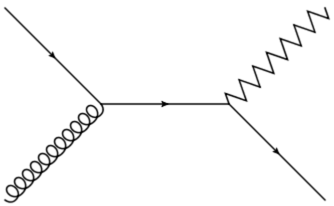
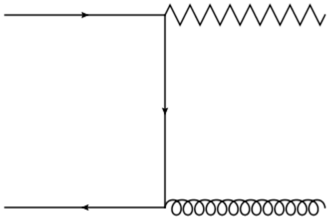
# Prompt Photons at Hadron Colliders

- Importance of prompt photon production at Hadron colliders
  - **A testing ground of perturbative Quantum Chromodynamics (pQCD)**



gluon Compton



$q\bar{q}$ annihilation

  - **Constraint of gluon parton distribution function (PDF)**
  - **High $p_T$ photon identification : important signals for many search physics**, e.g. :

    Higgs boson : $H \rightarrow \gamma\gamma$

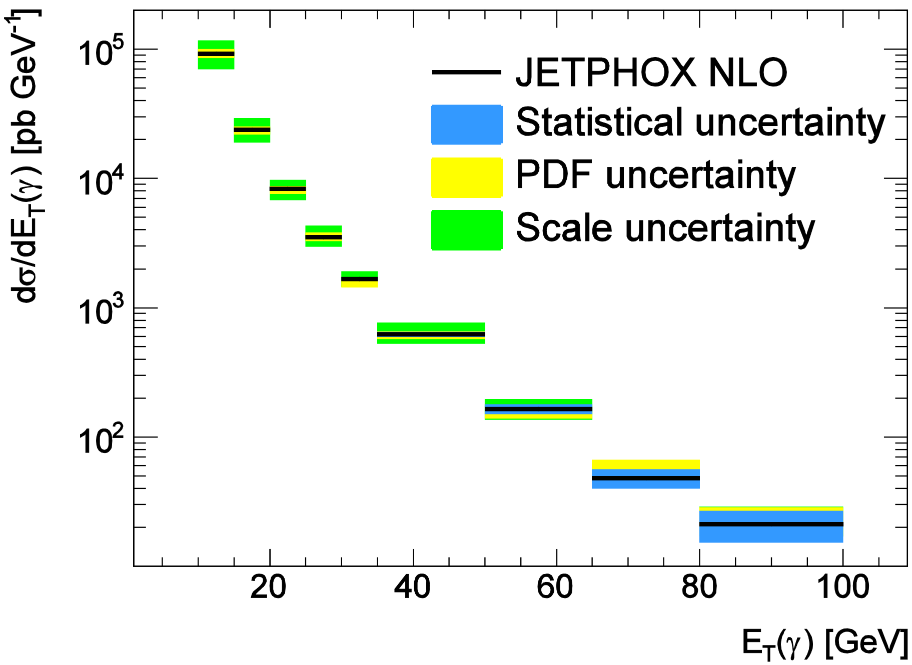
    SUSY : $\tilde{\chi}_0^1 \rightarrow \tilde{G}\,\gamma$ in Gauge-mediated SUSY breaking model

    Exotics : $G \rightarrow \gamma\gamma$ (graviton decay), $f^* \rightarrow f\gamma$ (excited fermion decay)

- Difficulty in extraction of prompt photons
  - Backgrounds of photons from hadron decays (dominated by $\pi^0$ and $\eta$), which fake prompt photons
  - Isolation of photons helps extracting signals.
- Prompt photons can be studied with a modest integrated luminosity, since cross section at $\sqrt{s} = 7$ TeV is of $O(\mu b)$.

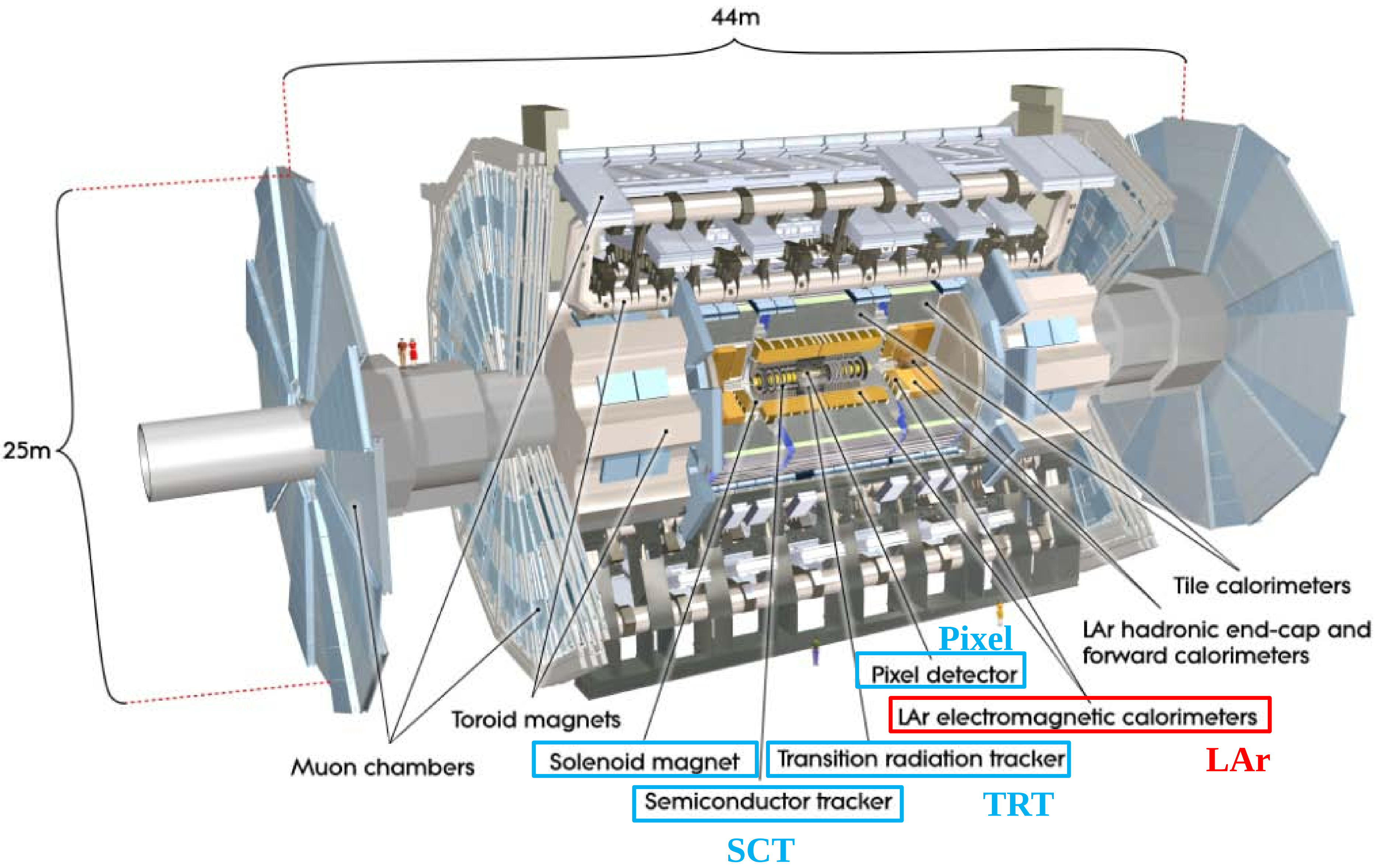
# Theoretical Calculation of Prompt Photon Cross Section

- NLO pQCD calculation with JETPHOX program
- S. Catani *et. al.*, JHEP05, 028 (2002).
- http://lappweb.in2p3.fr/lapth/PHOX_FAMILY/jetphox_soon.html
  - PDF : CTEQ6.1
  - Systematic uncertainties
    - PDF, Renormalization and factorization scale
- "Prompt" photons include photons from :
  - Hard scattering sub-processes
  - QED radiation off quarks
  - Quark/gluon fragmentation




- Cuts applied in JETPHOX calculation
  - $E_T$ > 10 GeV
  - $|\eta| < 1.37$, $1.52 < |\eta| < 2.37$ (Better photon identification performance in EM calorimeter)
  - Isolation : $E_T$(parton, $\Delta R < 0.4$) < 5 GeV

# The ATLAS Detector



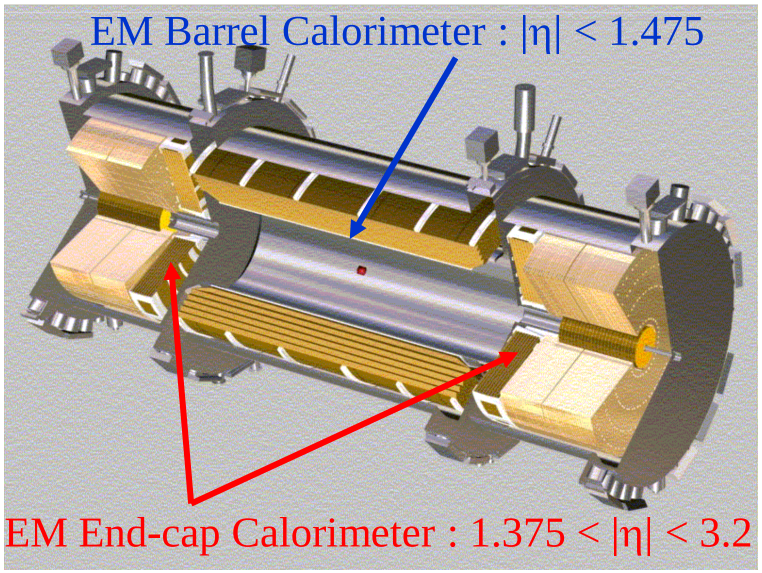
# The ATLAS Detector

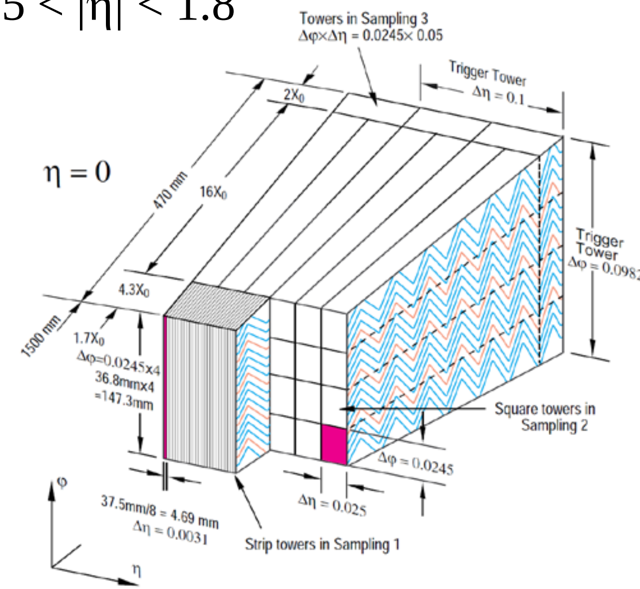
**LAr/Pb sampling calorimeter w/ accordion geometry**

- 3 longitudinal layers with cell of

$\Delta\eta \times \Delta\phi$ : **(0.003-0.006) × 0.1 (1st layer)**, 0.025 × 0.025 (2nd layer), 0.050 × 0.025 (3rd layer)

- Presampler w/ cell $\Delta\eta \times \Delta\phi \sim 0.025 \times 0.1$ in $|\eta| < 1.52$, $1.5 < |\eta| < 1.8$
- $\sigma(E)/E = (10\text{-}17\%)(\eta) / \sqrt{E\,(\text{GeV})} \oplus 0.7\,\%$



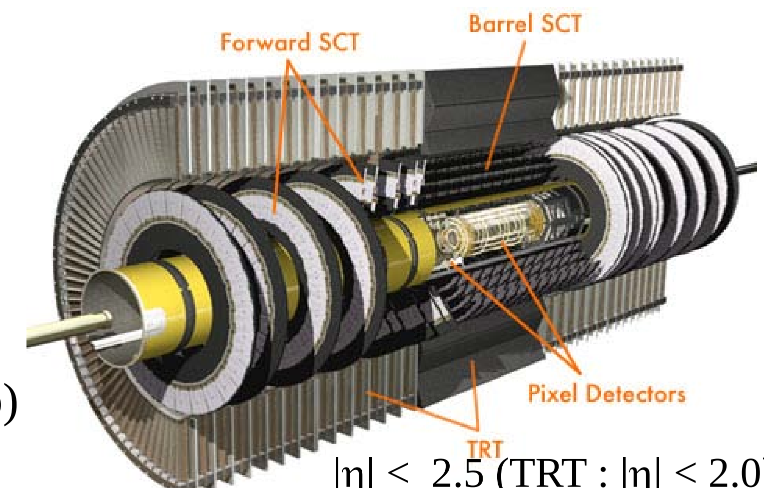

**Inner Detector (ID) in 2 T solenoidal B-field**

- Pixel : 3 barrels + 2 x 3 disks

  $\sigma_{r\phi} \sim 10\ \mu m$, $\sigma_z \sim 115\ \mu m$
- SCT: 4 barrels + 2 x 9 disks

  $\sigma_{r\phi} \sim 17\ \mu m$, $\sigma_z \sim 580\ \mu m$
- TRT: 73 layers (barrel) + 2 x 160 layers (endcap)

  $\sigma_{r\phi} \sim 130\ \mu m$ (barrel)




$|\eta| < 2.5$ (TRT : $|\eta| < 2.0$)

# Data and MC Samples

## Data

- Trigger : L1 calorimeter trigger
  - Granularity : $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ separately for EM and hadronic compartment
  - EM cluster in $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ window
  - $E_T > 5$ GeV on $\Delta\eta \times \Delta\phi = 0.1 \times 0.2$ or $0.2 \times 0.1$
- Primary vertex requirement
  - Primary vertex consistent with the beam spot position
  - At least 3 tracks, associated to the primary vertex
- Integrated luminosity :

  $15.8 \pm 1.7\ \mathrm{nb}^{-1}$
- Total number of events :

  2.27M events

## MC

- PYTHIA with "ATLAS MC09 tune"
- Full simulation with GEANT4
- Full emulation of the trigger and the same L1 trigger requirement as data
- Signal
  - Sub-process : $qg \rightarrow \gamma q + q\bar{q} \rightarrow \gamma g$
  - $p_T > 7$ GeV/$c$ in hard scattering
- Backgrounds
  - Non-diffractive minimum bias (MB)
  - All relevant QCD sub-processes (QCD)
    - Including signal sub-processes
    - $p_T > 15$ GeV/$c$ in hard scattering
  - A filter mimicking L1 calorimeter trigger in event generation :

  $E_T(\Delta\eta \times \Delta\phi < 0.18 \times 0.18) > E_T(\mathrm{threshold})$
    - $E_T(\mathrm{threshold}) = 6$ GeV for MB
    - $E_T(\mathrm{threshold}) = 17$ GeV for QCD

# Photon Identification

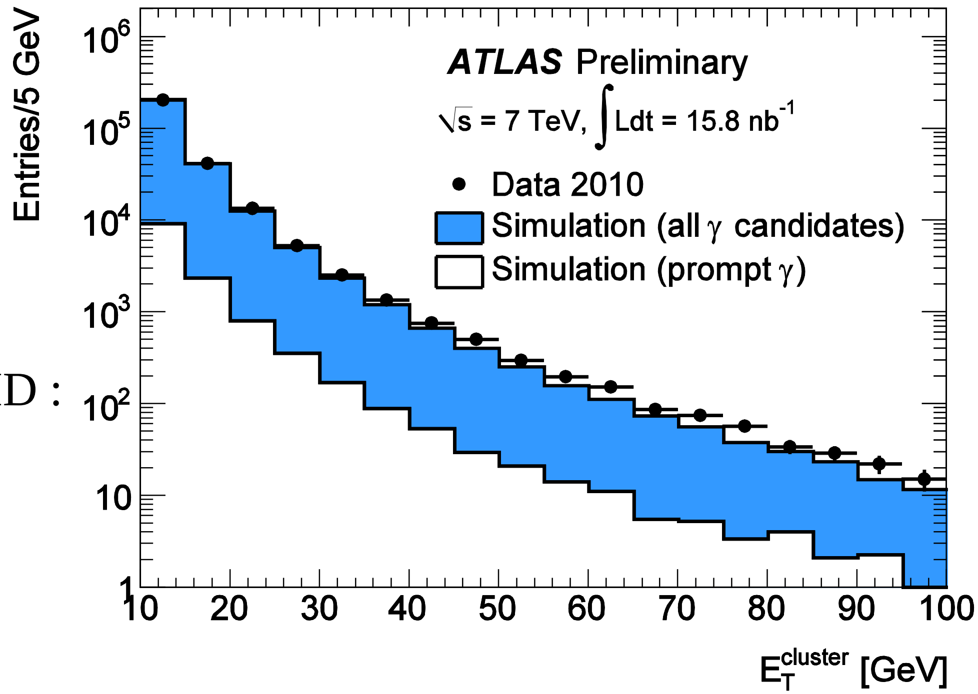
- Seed by a cluster in EM calorimeter with 3 × 5 cells in 2nd layer
- Track-cluster matching

→ No matched track : unconverted $\gamma$

→ Matched to track(s) from γ conversion in ID : converted $\gamma$

- Energy : determined with EM calorimeter
- Energy calibration : unconverted/converted $\gamma$ separately
- Pre-selection for better $\gamma$ identification
  - $|\eta| < 1.37$, $1.52 < |\eta| < 2.37$
  - Non-overlap with non-working cells

→ <u>268,992 $\gamma$ candidates in $E_T$ > 10 GeV</u>

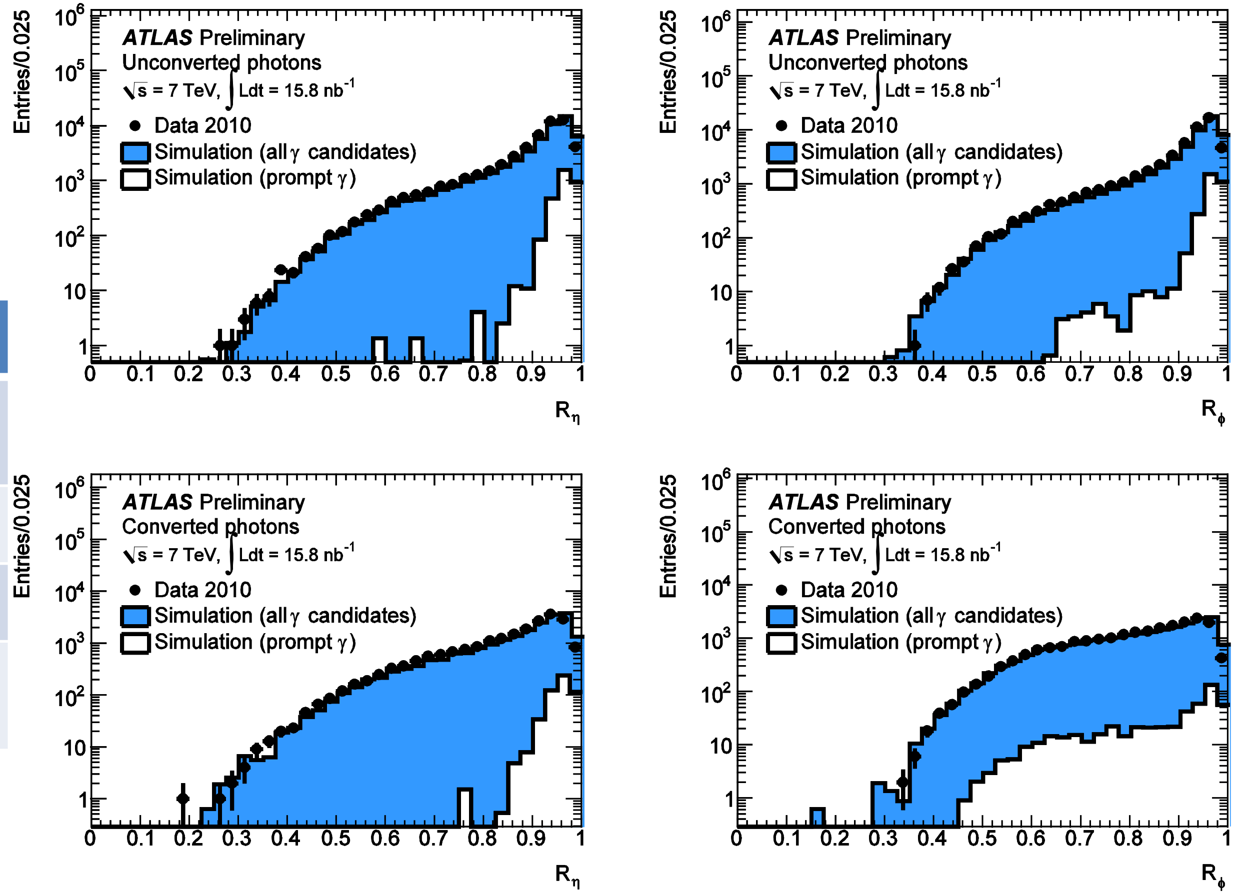



- Data/MC comparison before photon identification using shower shapes
  - Dominated by fake photons
  - BG scaled to match data yield – expected signal.

# Photon Identification with Shower Shapes

- "Loose" photon selection
  - Leakage to Hadronic calorimeter
  - **Shower shapes in 2nd layer of EM calorimeter**

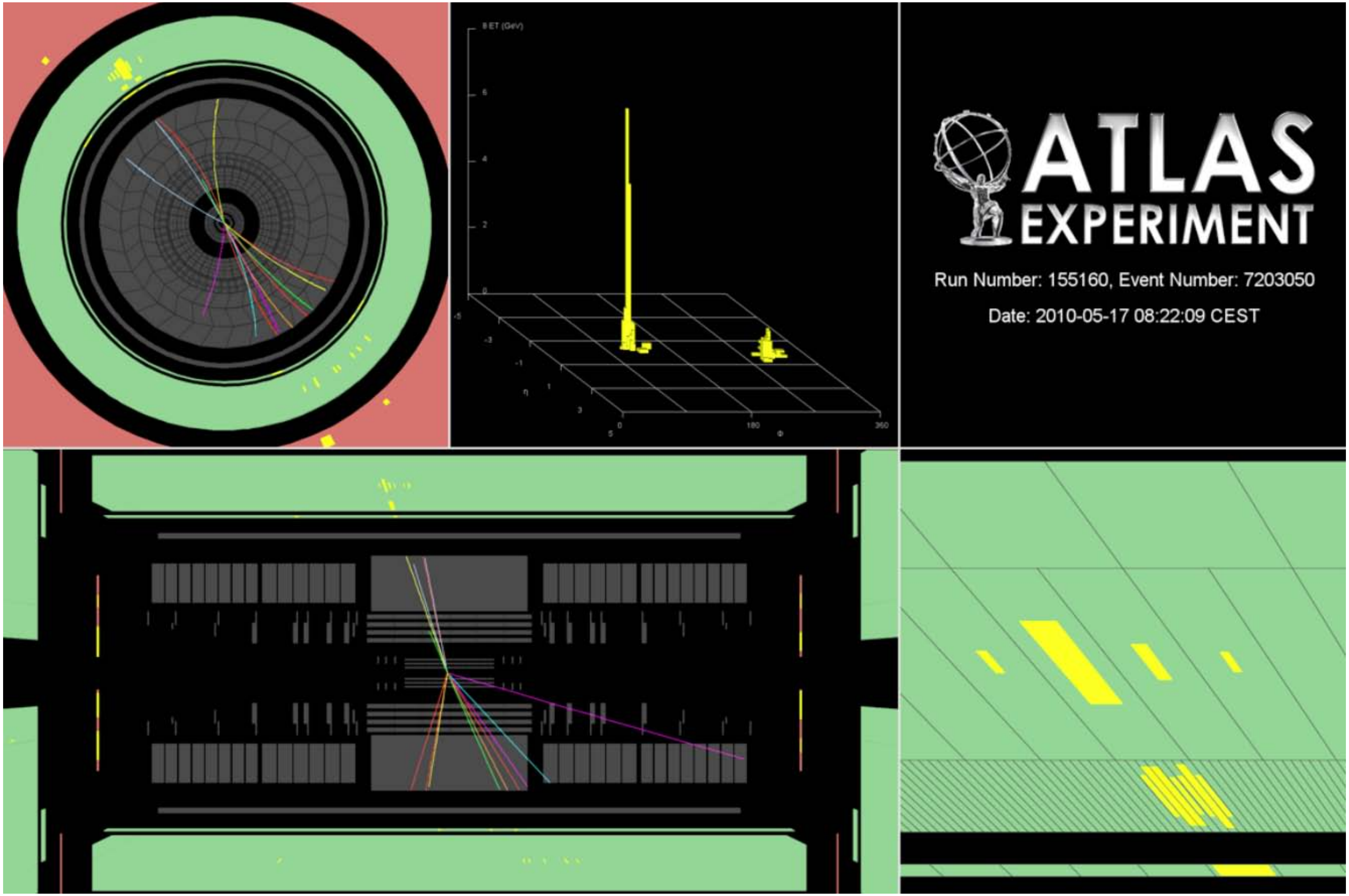
| Variable | Definition |
|---|---|
| $E_T^{had} / E_T$ | Ratio of $E_T$ in hadronic calorimeter to $E_T$ in cluster |
| $R_\eta$ | $E_{3\times7} / E_{7\times7}$ |
| $R_\phi$ | $E_{3\times3} / E_{3\times7}$ |
| $w_{\eta 2}$ | RMS width of energy distribution in $\eta$ |




- Data/MC comparison
  - Without loose selection (after pre-selection)
  - BG scaled to match data yield – expected signal.

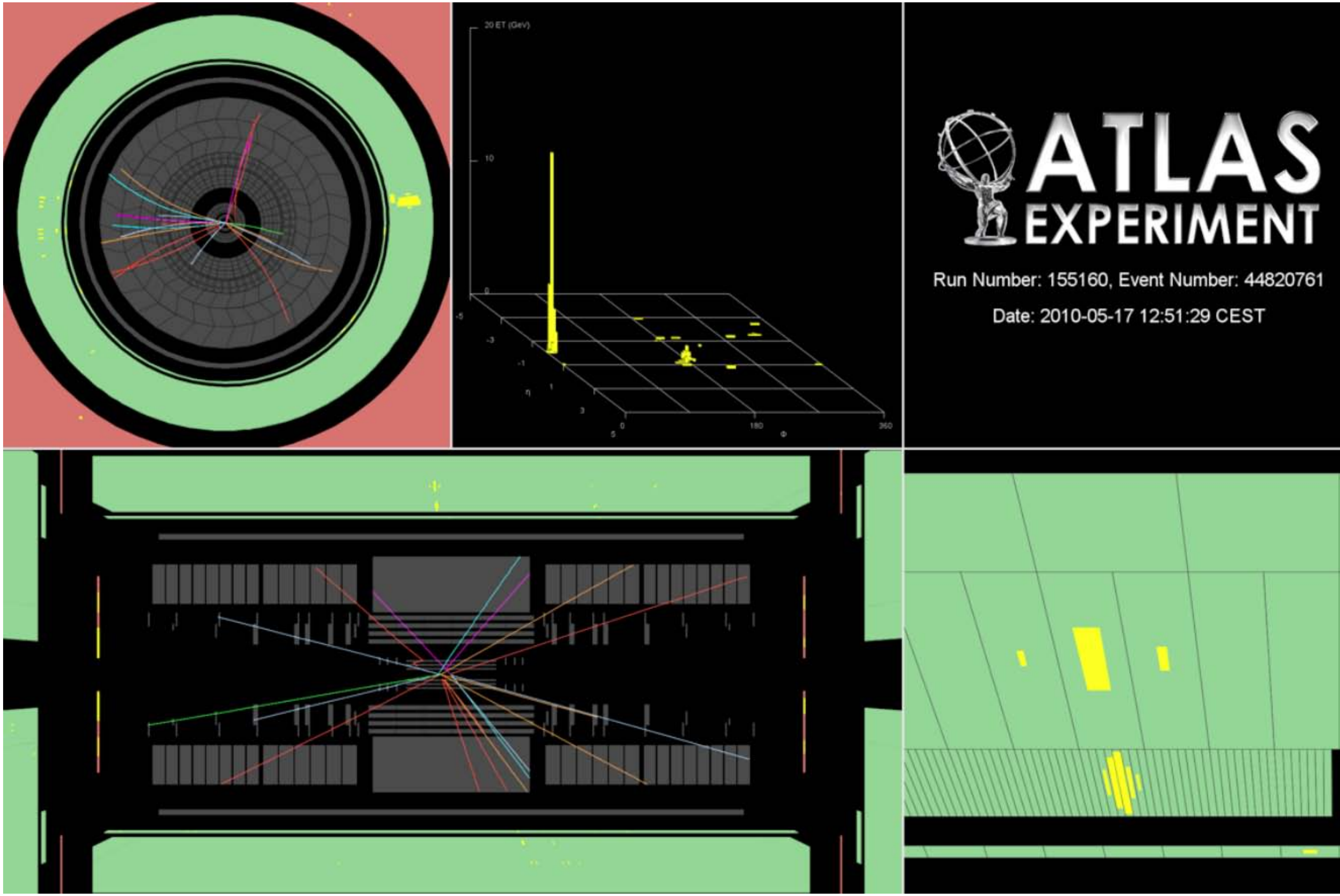
# Photon Identification with Shower Shapes

$\pi^0$ candidate passing "loose", failing "tight" selection



# Photon Identification with Shower Shapes

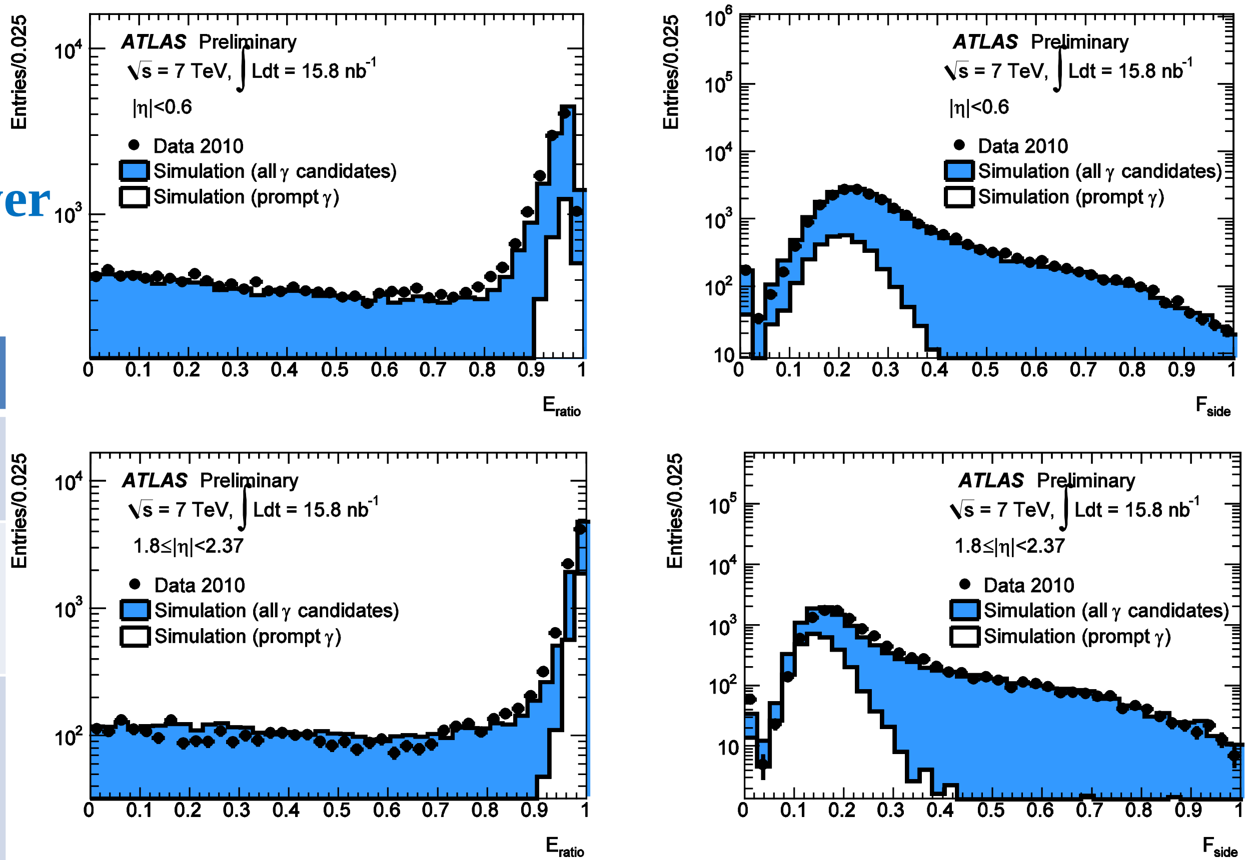
Photon candidate passing “tight” selection



# Photon Identification with Shower Shapes

- “Tight” photon selection
- Applied in addition to “loose” selection
- **Shower shapes in 1st layer of EM calorimeter**

| Variable | Definition |
| --- | --- |
| $w_{stot}$ | RMS width of energy distribution in η |
| $E_{ratio}$ | Asymmetry between 1st and 2nd maxima in η energy profile |
| ΔE | Energy difference between 2nd maximum and the minimum between the two maxima |
| $F_{side}$ | Fraction of energy in 7 cells centered around 1st maximum and outside 3 core cells |
| $w_{s3}$ | RMS width of energy distribution in 3 core cells |




- Data/MC comparison
  - After loose selection
  - BG scaled to match data yield – expected signal.

# Isolation

- **Prompt photon signal is expected to be more isolated from hadronic activity than fake background.**
- In cone of R = 0.4 in η–ϕ space :

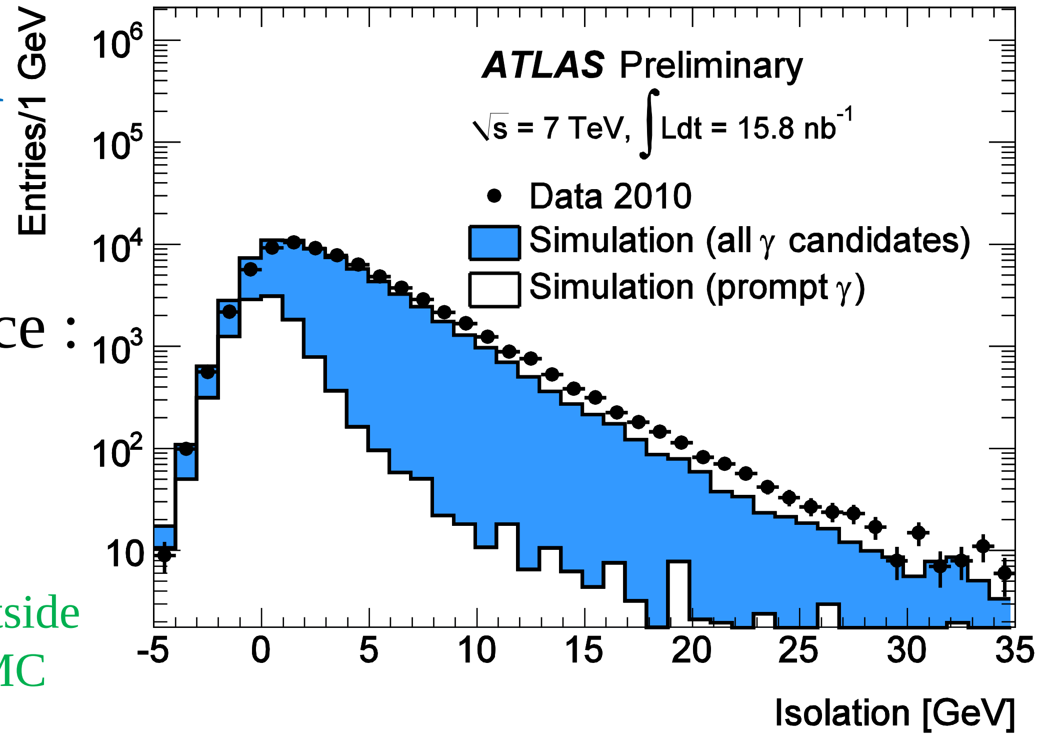
*Isolation = E(R < 0.4; EM and HAD)*

*– E(5 ×7 cells in EM)*

*– E(leak) – E(UE correction)*

  - E(leak) : photon energy leakage outside 5×7 cells in EM, estimated from MC
  - E(UE correction) : activity due to underlying event, estimated from data of low energy jets

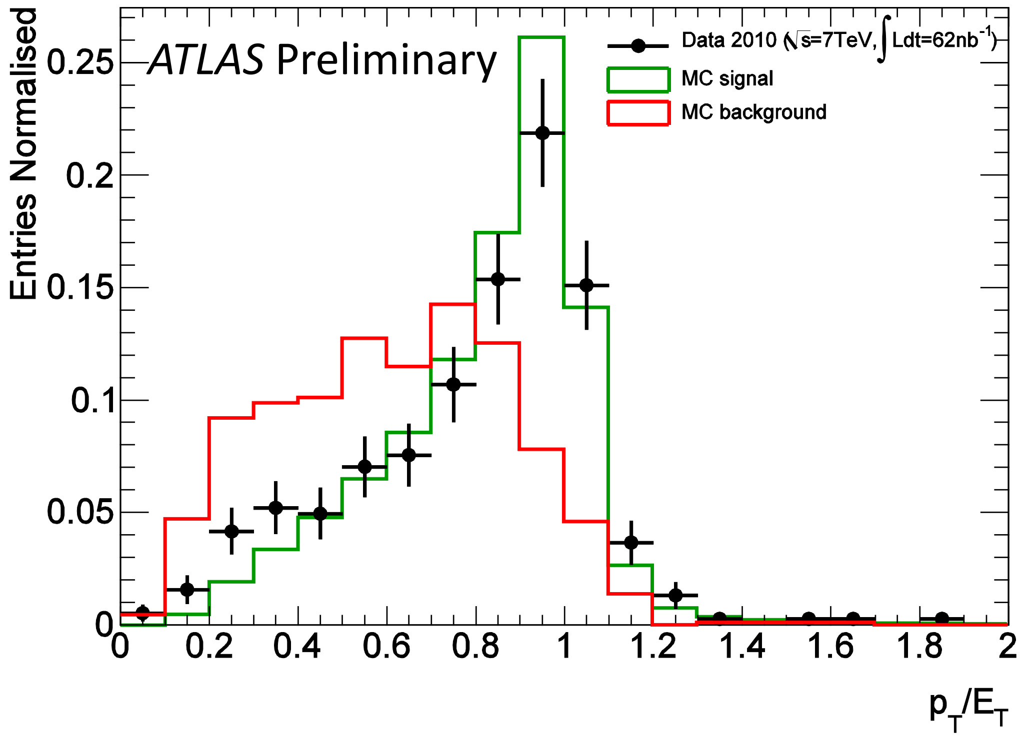
- Discrimination with isolation
  - "Isolated" : Isolation < 3 GeV
  - "Non-isolated" : Isolation > 5 GeV




- Data/MC comparison
  - After loose selection
  - BG scaled to match data yield – expected signal.

# Photon Conversions

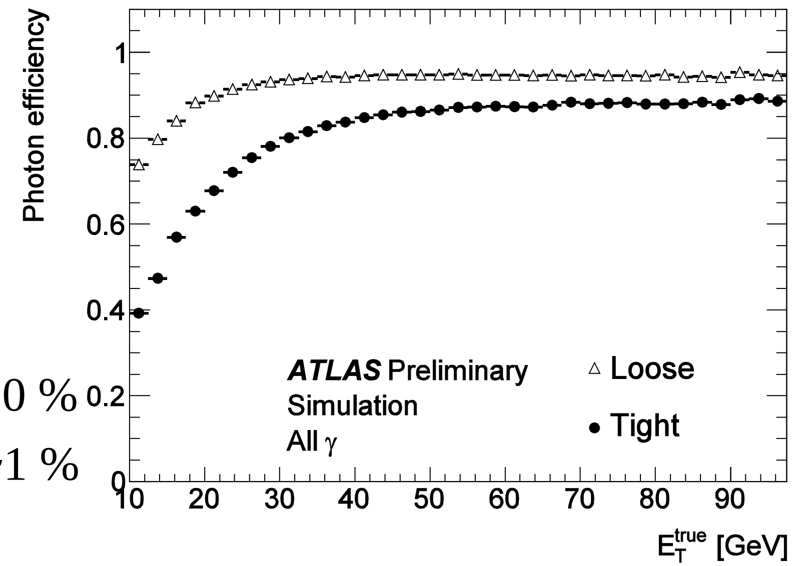
- Performance of photon conversion reconstruction
  - Photon conversions with two reconstructed tracks
  - $p_T$(photon) $\geq$ 20 GeV/$c$
  - Isolation < 3 GeV

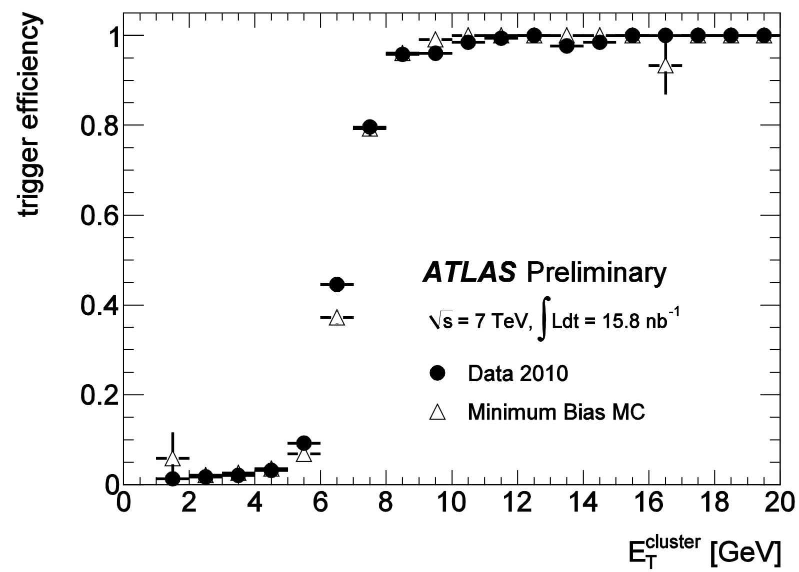



- Data/MC comparison
  - Data and MC are normalized to unity.

# Efficiency

- Photon identification efficiency
  - Determined from PYTHIA MC for signal
  - Systematic uncertainty
    - Material description in MC : a few %
    - Cross-talk btw calorimeter cells : ~ 2 %
    - Data/MC comparison (shower shape) : 5-10 %
    - Converted/Unconverted $\gamma$ classification : ~1 %
- Trigger efficiency
  - Determined from data, relative to photon reconstruction and offline selection, from samples of :
    - Minimum bias trigger
    - Lower threshold L1 calorimeter trigger
  - Systematic uncertainty < 0.3 %, estimated from MC of signal and/or BG



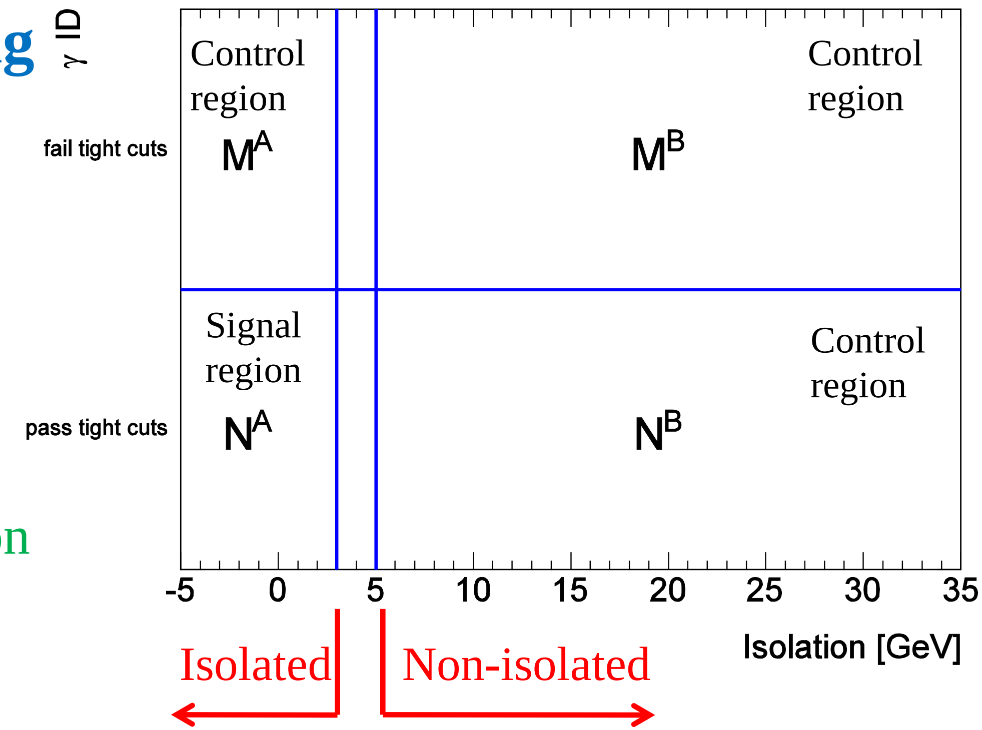
# Background Estimation and Signal Extraction

- BG estimation
  - **Data driven approach using 2D-sideband background subtraction**
    - Isolation
    - $\gamma$ ID = ( $E_{ratio}$, $\Delta E$, $F_{side}$, $w_{s3}$ )
  - Assuming

    1) No correlation between Isolation and $\gamma$ ID

    2) No signal leakage into control regions

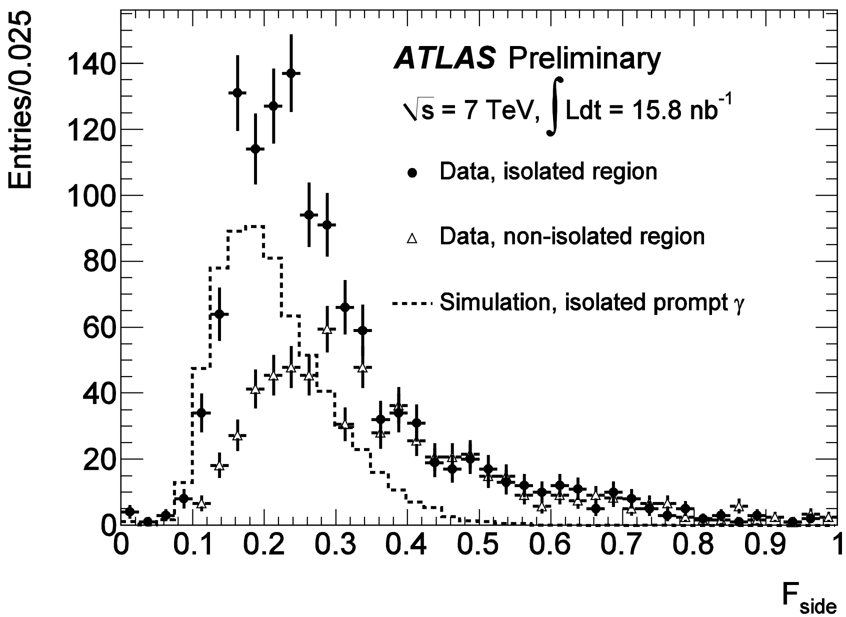
    $$N_{sig}^{A} = N^{A} - N^{B} \times (M^{A}/M^{B})$$
  - Correction factor for 1) and 2) was estimated from MC and was applied to the equation.



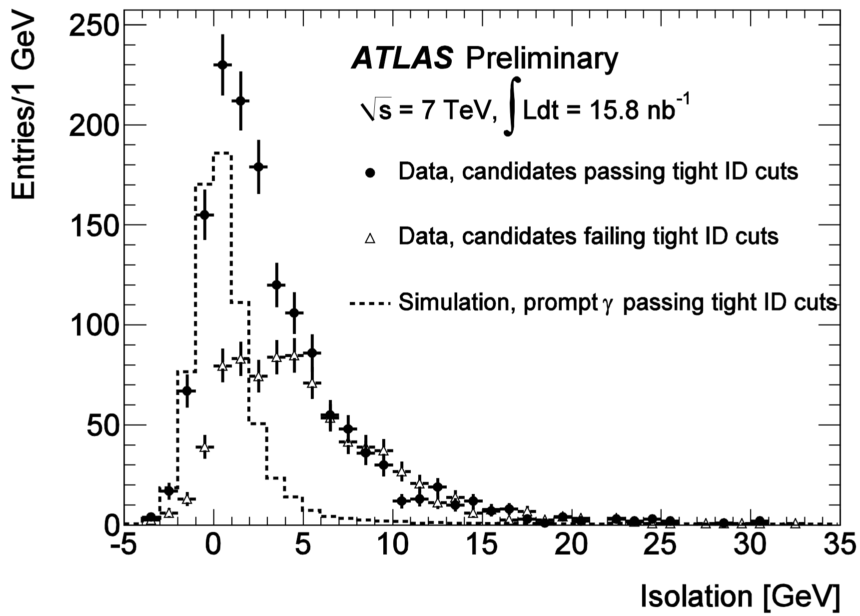
# Background Estimation and Signal Extraction

- Apply 2D-sideband technique to the photons candidates
- **A clear excess can be observed and is consistent with the expected shape for prompt photons from MC.**

$F_{side}$ in isolated/non-isolated region

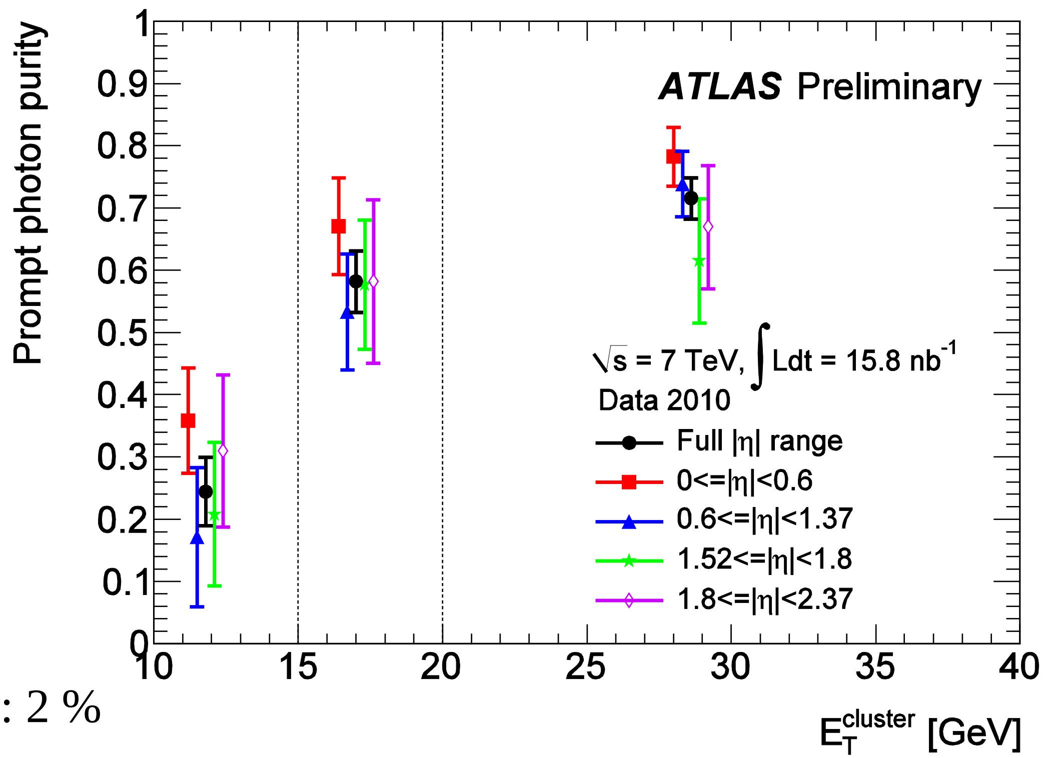



Isolation in tight ID pass/fail region



# Photon Purity and Signal Yield

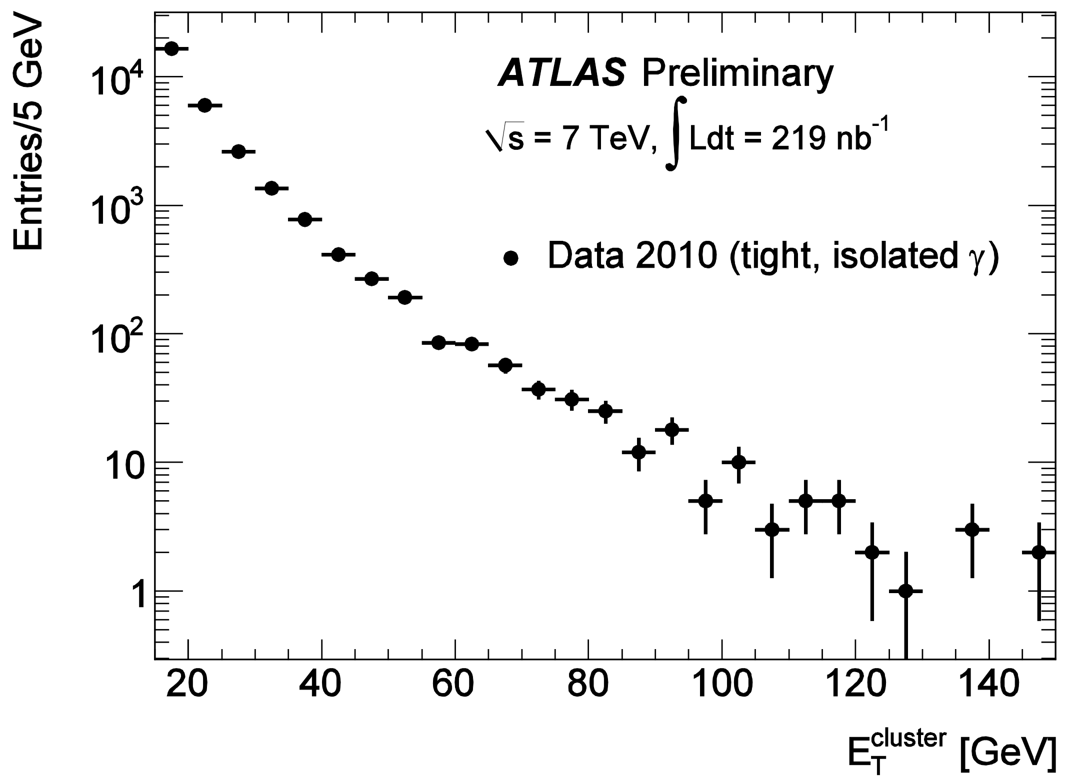
- Photon purity estimated with 2D-sideband technique.
  - **Clear increase with $E_T$ (expected from MC)**
- Systematic uncertainty in Purity for $E_T > 20$ GeV
  - Isolation : 1 %
  - Choice of $\gamma$ ID variables : 3 %
  - Signal inefficiency : 4 %
  - Signal composition : 2%
  - Correlation btw isolation and $\gamma$ ID : 2 %
  - Energy scale : 1 %




| $E_T$ interval [GeV] | $10 \leq E_T < 15$ | $15 \leq E_T < 20$ | $E_T \geq 20$ |
|---|---|---|---|
| Num of candidates | 5271 | 1213 | 864 |
| Purity [%] (±stat±syst) | 24±5±24 | 58±5±8 | 72±3±6 |
| Signal yield (±stat±syst) | 1289±297±1362 | 706±69±86 | 618±42±59 |

# Towards Prompt Photon Cross Section Measurement

- Higher integrated luminosity was made available recently.
- Data analysis towards the cross section measurement has started.
  - Tight selection
  - Isolation < 3 GeV
  - $E_T$ > 15 GeV
- Consistent with the result from the low statistics data sample.



# Conclusion

- From 15.8 $nb^{-1}$ of 7 TeV *pp* collisions collected with the ATLAS detector, we successfully extracted prompt photon signals statistically significant in $E_T > 15$ GeV.

- In $E_T > 20$ GeV, a prompt photon yield was measured to be 618 ± 72 with a purity of 72 ± 7 %.

- A measurement of the prompt photon production cross section will be performed in the next step.

- Physics studies using high $p_T$ photons with the ATLAS detector are promising.

Reference : ATLAS-CONF-2010-077