Inclusive photon studies at ATLAS

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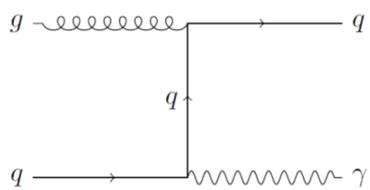
Content

- Role of photons at hadron colliders, physics motivations and challenges
- Brief overview of the most relevant ATLAS detectors in measuring photons
- Observation of an inclusive photon signal in first data
  - Event selection
  - Photon reconstruction and identification
  - Photon isolation
  - Photon purity measurement
- Towards a photon cross section measurement
- Conclusions

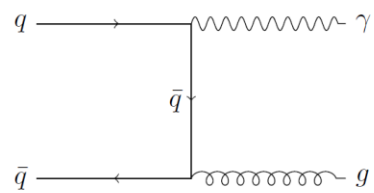
Prompt photons at Hadron Colliders

QCD is the dominant prompt photon production mechanism :

Single photon production

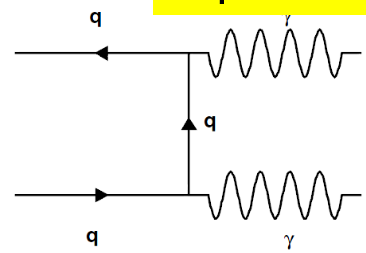


Compton scattering

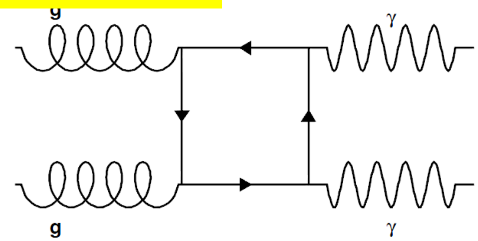


Annihilation

Diphoton production



Born



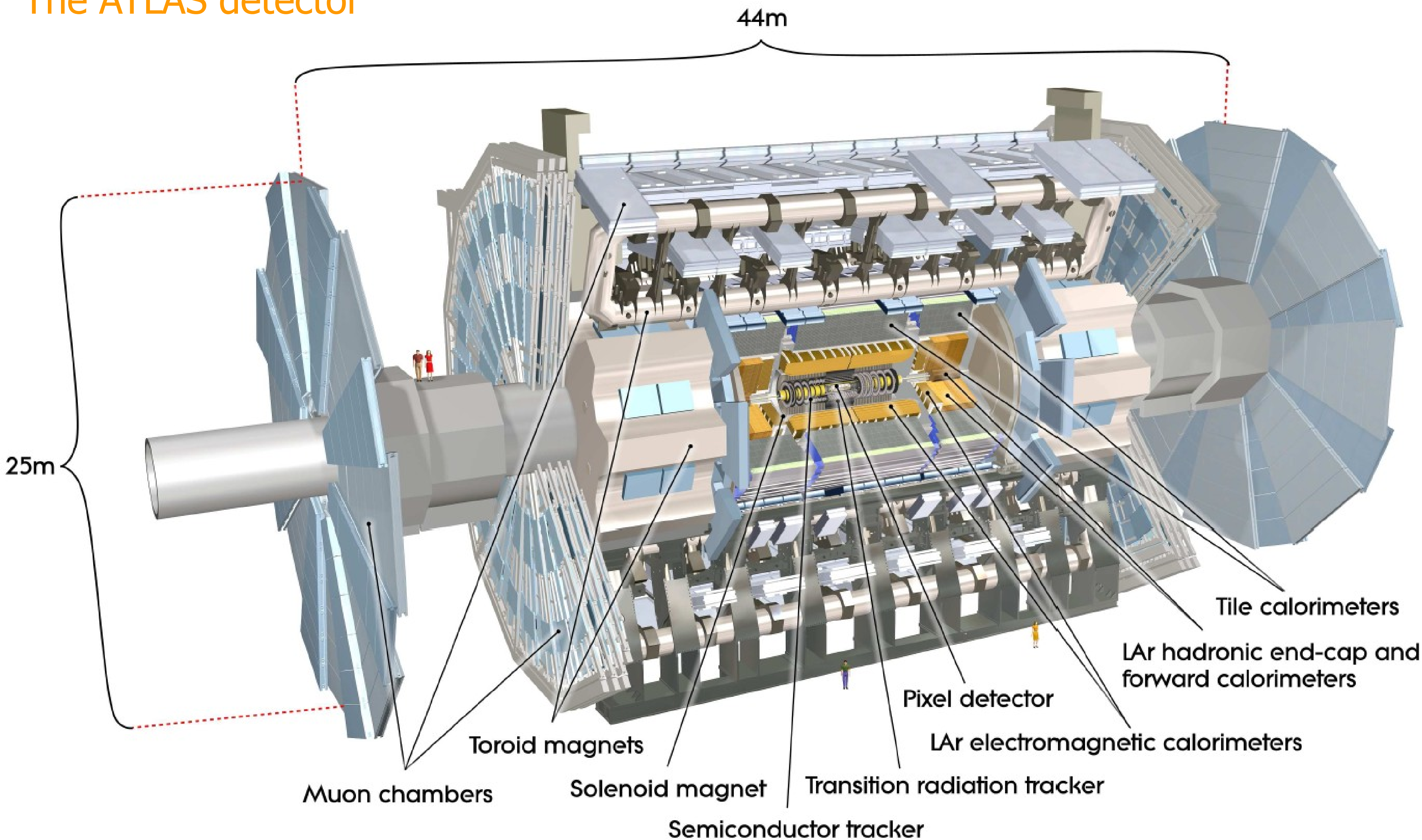
Box

- ❑ Single photon measurements provide a test of the pQCD predictions without jets. Cross section ~ O (0.3 μb) above 15 GeV : already accessible with < 1pb^{-1}
  - ❑ qg ('Compton') dominant contribution : probe the gluon content of the proton.
  - ❑ A photon is a 'nice' object for jet/MET calibration purpose
- ❑ Diphoton : test of perturbative QCD in various ranges of $M_{\gamma\gamma}$ $P_{T\gamma\gamma}$ and $\Delta\phi$ sensitive to the various contributions of the different amplitudes. Cross section ~O (0.1 nb) above 13 GeV : already accessible with 2010 statistic (~50 pb^{-1}).
- ❑ Higgs, new physics might be hidden in the (di)photon channels (inclusive or exclusive):
  - ❑ $H \rightarrow \gamma\gamma$, observe or exclude gravitons decaying into a 2 photons pair? UED ?
  - ❑ Exclude decays of neutralinos?

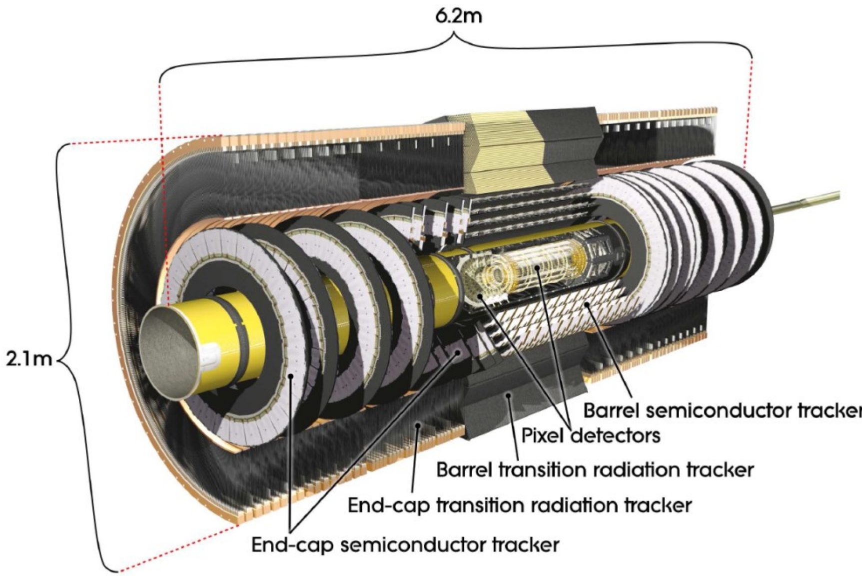
The challenges in photon physics :

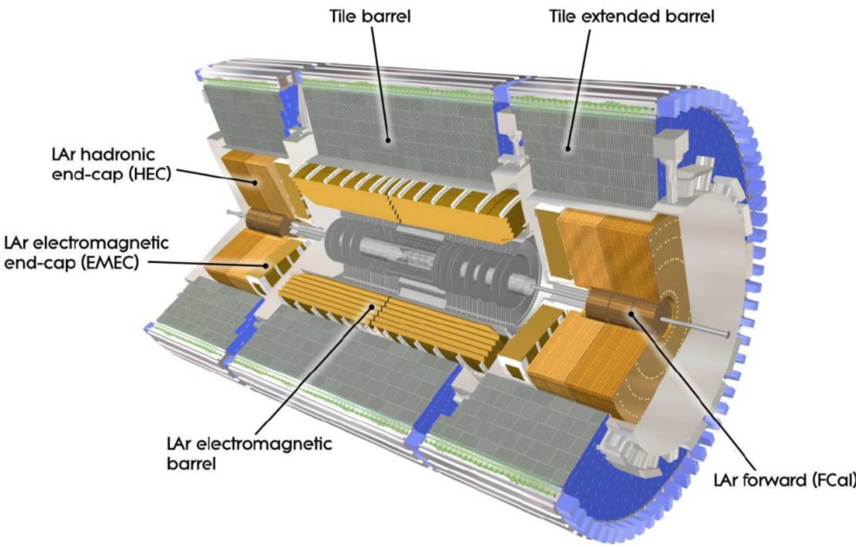
- QCD dijet production cross section is order of magnitudes larger than the signal : excellent jet rejection ($\sim 10^3$-10^4) capability of the detector is required to extract the signal over the background
- In general don't want to trust too much on the MC information and try (as much as possible) data driven techniques to estimate the photon yields
- No clean source of photons (no decays like $Z \rightarrow ee$ unfortunately) to be used to check photon efficiency using some tag and probe technique

The ATLAS detector



Main subsystems





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

- ❑ Pixel: 3 layers(b)+2x3 disks(e) $\sigma_{r\varphi}$~10μm,σ_z~115μm
- ❑ SCT: 4 layers(b)+2x9 disks(e) $\sigma_{r\varphi}$~ 17μm,σ_z~580 μm
- ❑ TRT: 73 layers (b) + 2 x 160 layers (e) $\sigma_{r\varphi}$~ 130 μm (b)

Liquid Argon - Lead sampling calorimeter with an ‘accordion’ geometry :

❑ 3 longitudinal layers with cell of ΔηxΔφ:

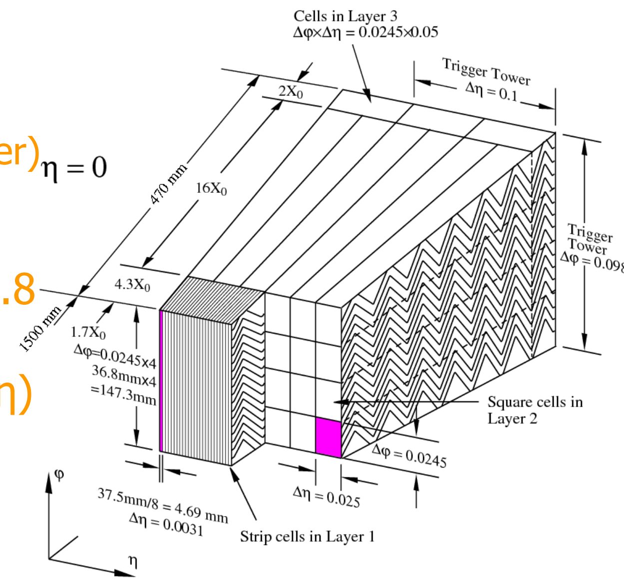
❑(0.003-0.006)x0.1 (1st layer)

❑ 0.025x0.025 (2nd layer),

❑ 0.050x0.025 (3rd layer)

❑ Presampler for |η|<1.8 ΔηxΔφ~0.025x0.1

❑ $\sigma(E)/E = (10\text{-}17\%)\ (\eta) / \sqrt{E\ (\text{GeV})} \oplus 0.7\ \%$



Data and MC samples

Data

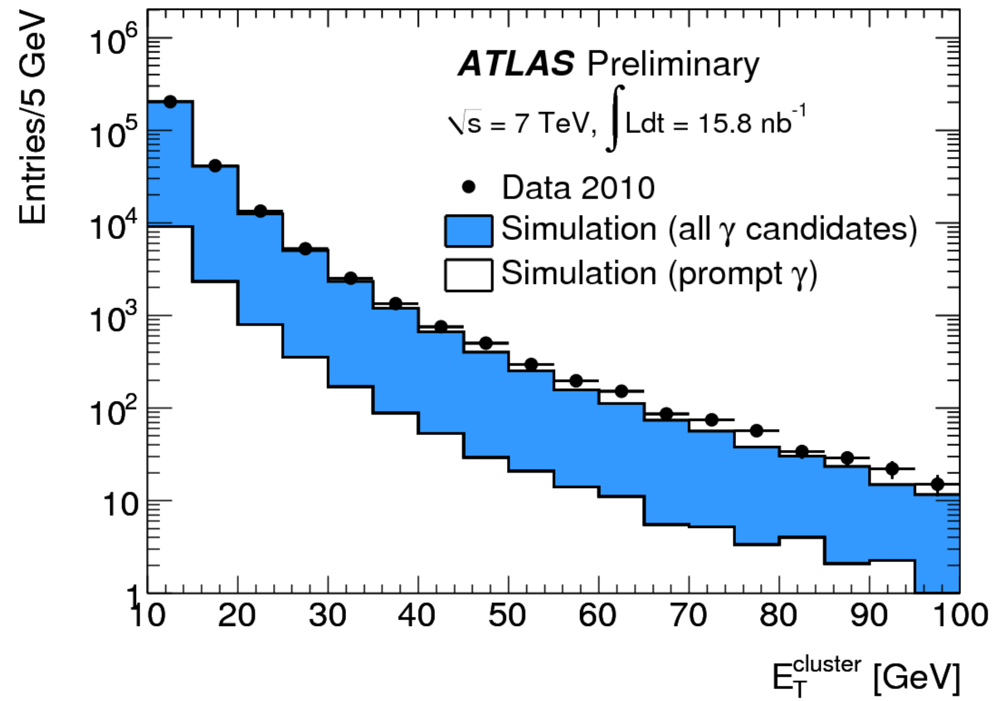
- Integrated luminosity : 15.8 +/- 1.7 nb^{-1}
- Trigger : L1 Calorimeter (hardware). Look for energy deposition E_T> 5 GeV in a $\Delta\eta x \Delta\phi$= 0.2x0.2 window (trigger granularity : $\Delta\eta x \Delta\phi$ = 0.1x0.1)
- Data only from luminosity blocks with inner detector and EM calorimeter fully operational
- Primary vertex: require primary vertex consistent with the beam spot position
  - At least 3 tracks, associated to the primary vertex
- Total number of events : 2.27M events

Montecarlo

- PYTHIA (Herwig) with "ATLAS MC09 tune"
- Full simulation with GEANT4
- Full emulation of the trigger and the same L1 trigger requirement as data
- Signal sub-process: 'direct' part, qg$\rightarrow$ γq and qq(bar)$\rightarrow\gamma$g, p_T>7 GeV ckin hard scatt.
- Background processes :
  - non-diffractive minimum bias (MB)
  - All relevant QCD 2->2 sub-processes (QCD) pT> 15 GeV ckin hard scattering
  - A filter mimicking L1 calorimeter trigger in event generation : ET($\Delta\eta x \Delta\varphi$< 0.18x0.18) > ET(threshold)
  - ET(threshold) = 6 GeV for MB, 17 GeV for QCD

Photon reconstruction and preselection

- Seed by a cluster in EM calorimeter with 3x5 cells in 2^{nd} layer exceeding 2.5 GeV
- Track-cluster matching :
  - No matched track : unconverted γ
  - Matched to track(s) from γ conversion in ID : converted γ. Single track conversions are also retained
  - Different cluster sizes for converted (3x7) and unconverted (3x5) photons
- Energy : determined with EM calorimeter
  - Energy calibration is optimized separately for converted and uncoverted photons on Geant4 based detailed full detector simulations



Preselection :

- Require calibrated cluster E_T > 10 GeV
- Require pseudorapidity range covered by strips : $|\eta| < 1.37$, $1.52 < |\eta| < 2.37$
- Require no overlap with non working cells/zones (5.5% inefficiency)
- 268992 γ candidates in E_T> 10 GeV

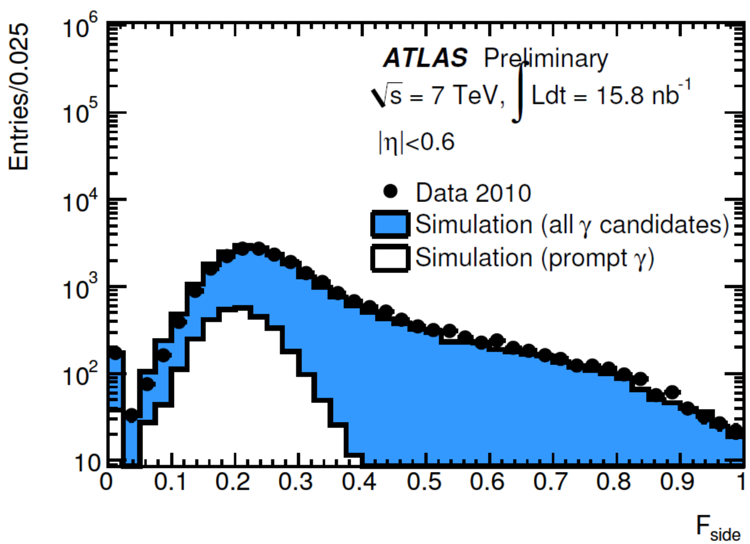
Data/MC comparison before photon identification using shower shapes :

- dominated by fake photons at this stage
- signal normalized to the data luminosity using Pythia LO cross section
- background scaled to match data - expected signal yield (~0.45 factor on absolute MC normalization)

Photon identification

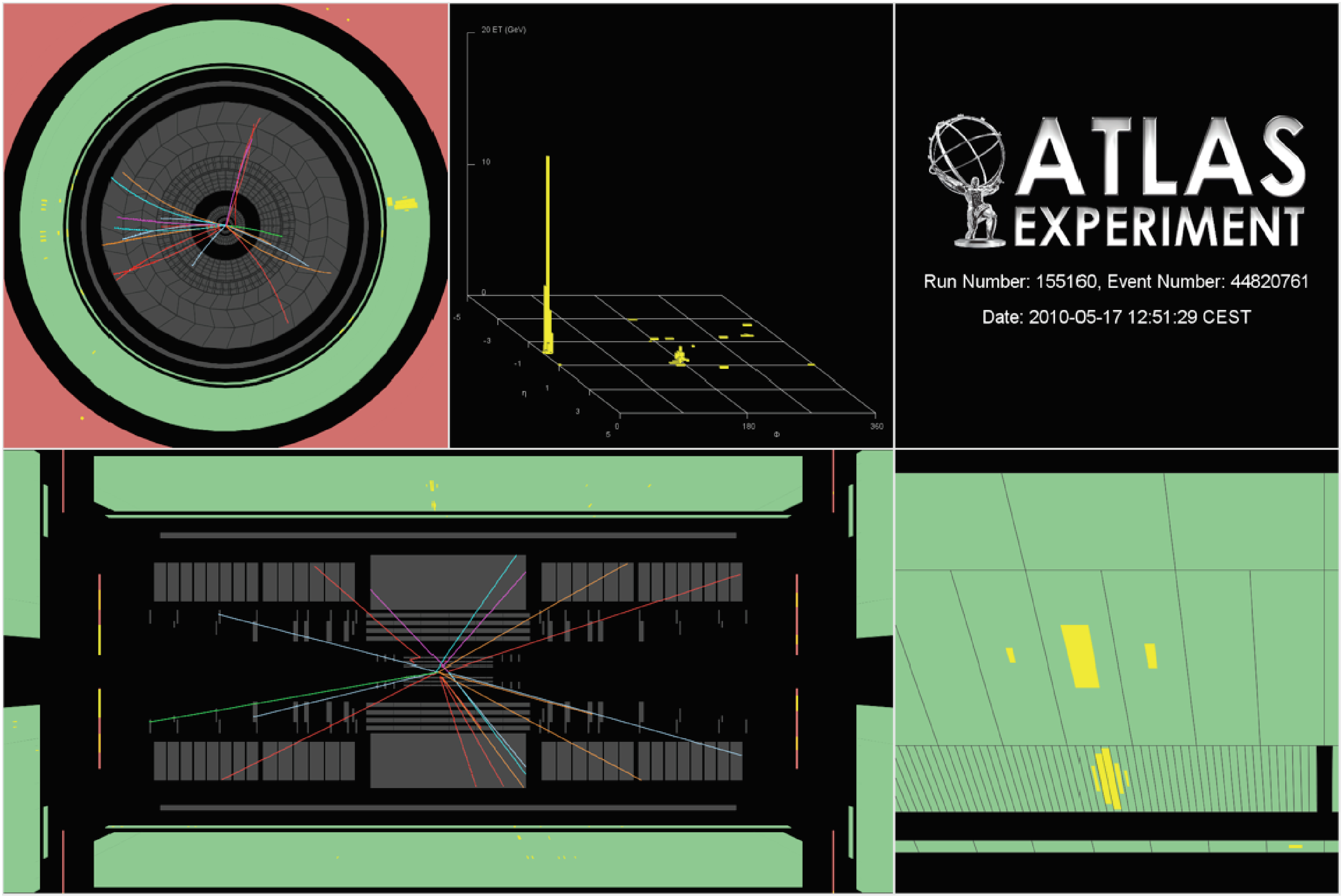
Simple cuts on shower shape variables (isEM) : 2 levels of quality are defined

- "loose" photon definition:
  - leakage in the hadronic calorimeter
  - second EM calorimeter sampling shower shapes
- "tight" photon definition :
  - tighter cuts on the "loose" photon variables
  - $R\phi$ from 2nd sampling added
  - Shower shapes cuts in the first sampling
  - Different cuts for converted and unconverted photons

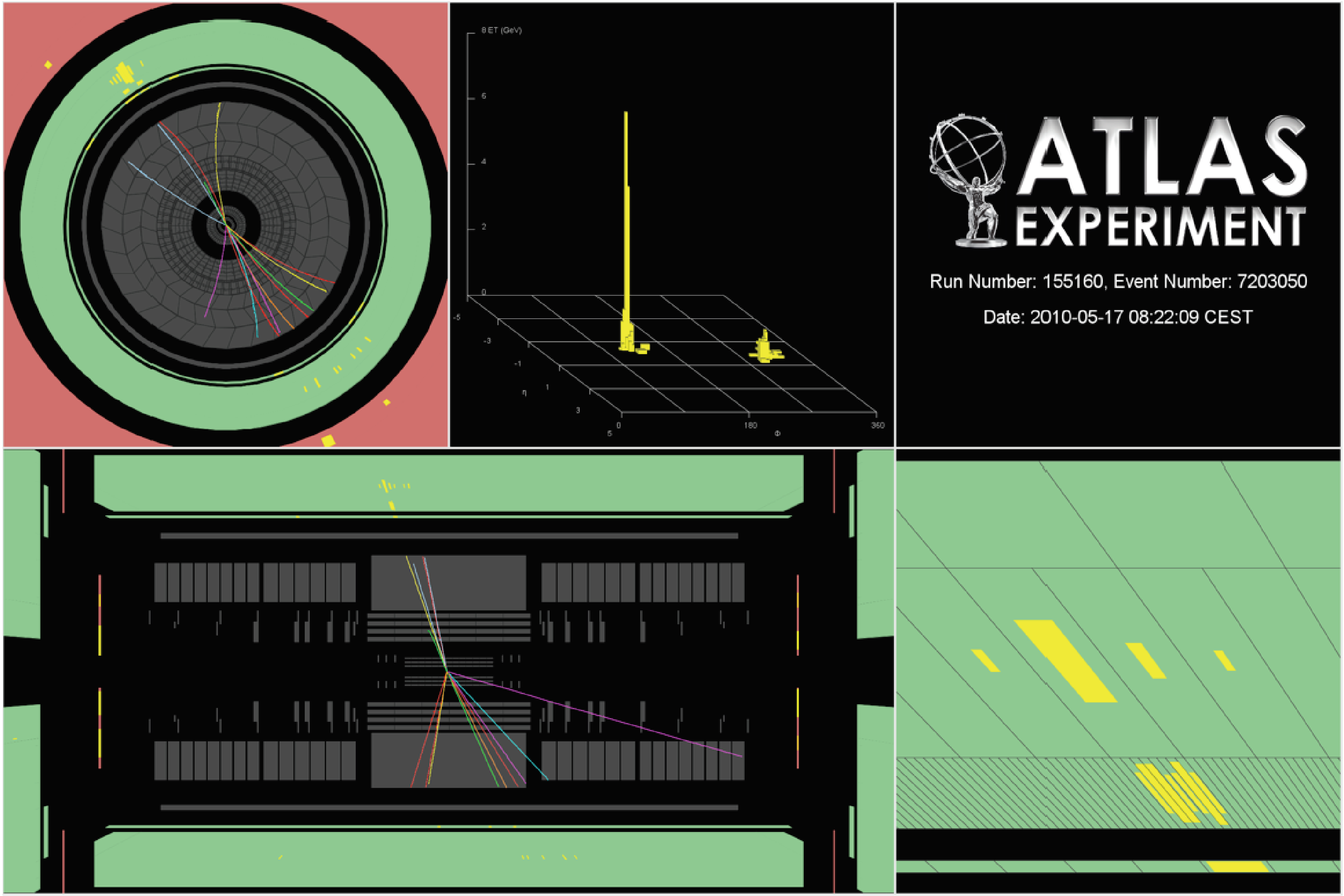


Category	Description	Name	Loose	Tight
Acceptance	$\lvert\eta\rvert < 2.37$, $1.37 < \lvert\eta\rvert < 1.52$ excluded	–		✓
Hadronic leakage	Ratio of E_T in the first sampling of the hadronic calorimeter to E_T of the EM cluster (used over the range $\lvert\eta\rvert < 0.8$ and $\lvert\eta\rvert > 1.37$)	R_{had_1}	✓	✓
	Ratio of E_T in all the hadronic calorimeter to E_T of the EM cluster (used over the range $\lvert\eta\rvert > 0.8$ and $\lvert\eta\rvert < 1.37$)	R_{had}	✓	✓
EM Middle layer	Ratio in η of cell energies in 3×7 versus 7×7 cells	R_η	✓	✓
	Lateral width of the shower	w_2	✓	✓
	Ratio in ϕ of cell energies in 3×3 and 3×7 cells	R_ϕ		✓
EM Strip layer	Shower width for three strips around maximum strip	w_{s3}		✓
	Total lateral shower width	$w_{s\,tot}$		✓
	Fraction of energy outside core of three central strips but within seven strips	F_{side}		✓
	Difference between the energy of the strip with the second largest energy deposit and the energy of the strip with the smallest energy deposit between the two leading strips	ΔE		✓
	Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies	E_{ratio}		✓

A nice photon candidate



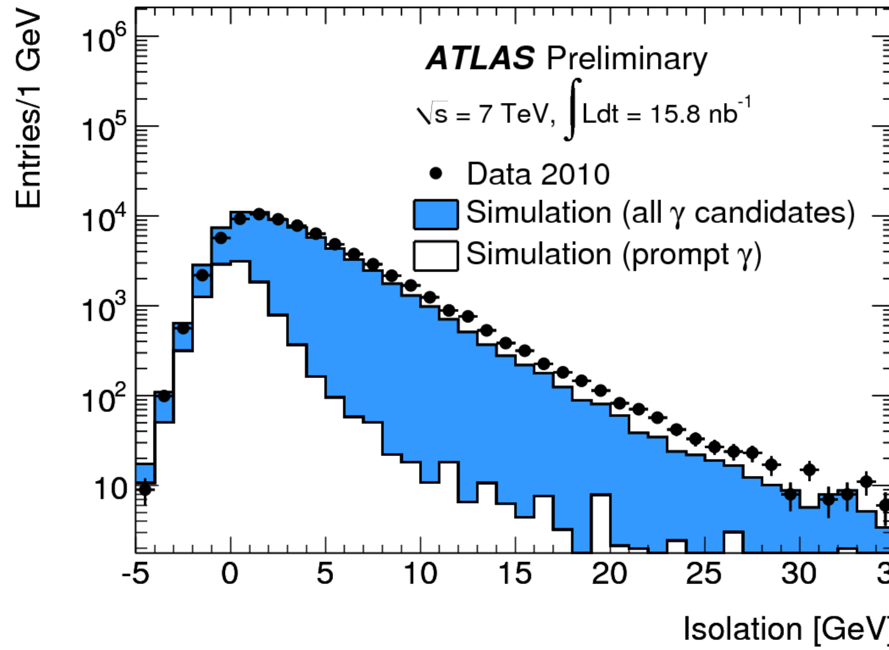
A nice fake photon candidate



Photon isolation

Isolation is necessary to get rid of the jet background and (to some extent) of the fragmentation contribution: the definition of the isolation prescription is a tricky business

- Calorimeter isolation
  - Based on sum of energies in cells in cone R<0.4 in η-φ around the photon, removing the cells in a 5x7 cluster
- Corrections for residual leakage of photon energy, using single photon MC samples
- Corrections for underlying event
  - Using ambient energy density estimated with low-p_T jets, following M. Cacciari, G. P. Salam, S. Sapeta, "On the characterisation of the underlying event", JHEP 04 (2010) 65
- Signal region
  - Require isolation < 3 GeV



Data/MC comparison before photon identification using shower shapes :

- dominated by fake photons
- background scaled to match data yield-expected signal

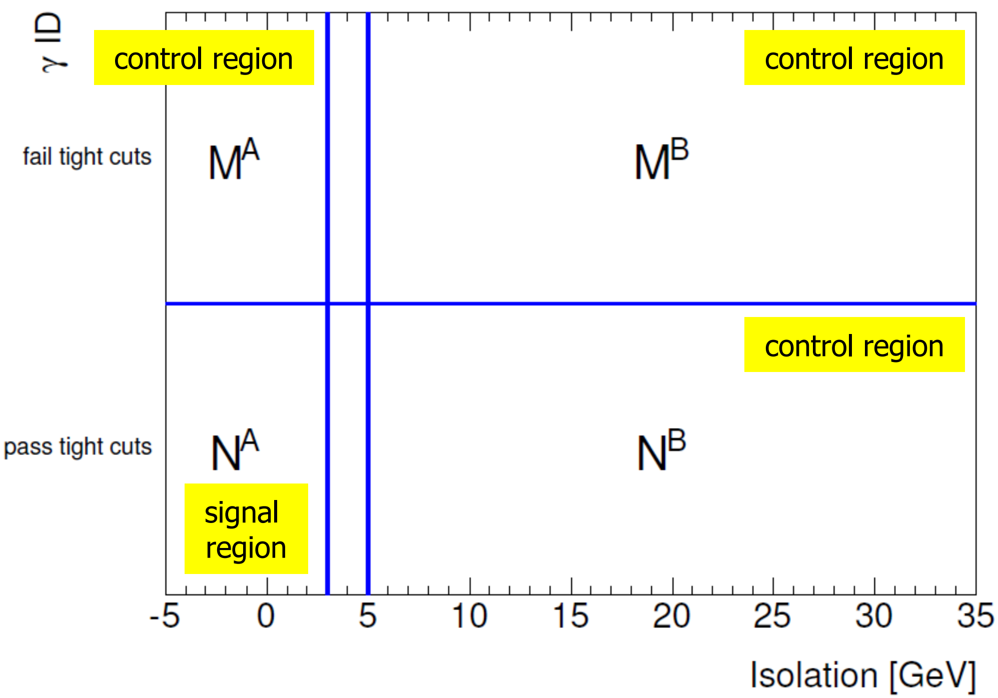
Signal extraction :

Data driven approach using a 2D-sidebands subtraction method: (tight-4 strips) variable on one axis and calorimetric isolation on the other. 2 assumptions

- No correlation between isolation and isEM for the background
- No signal in the control regions

$$N^A_{\rm sig} = N^A - N^B \frac{M^A}{M^B}$$

$$P = 1 - \frac{N^B}{N^A}\frac{M^A}{M^B}$$



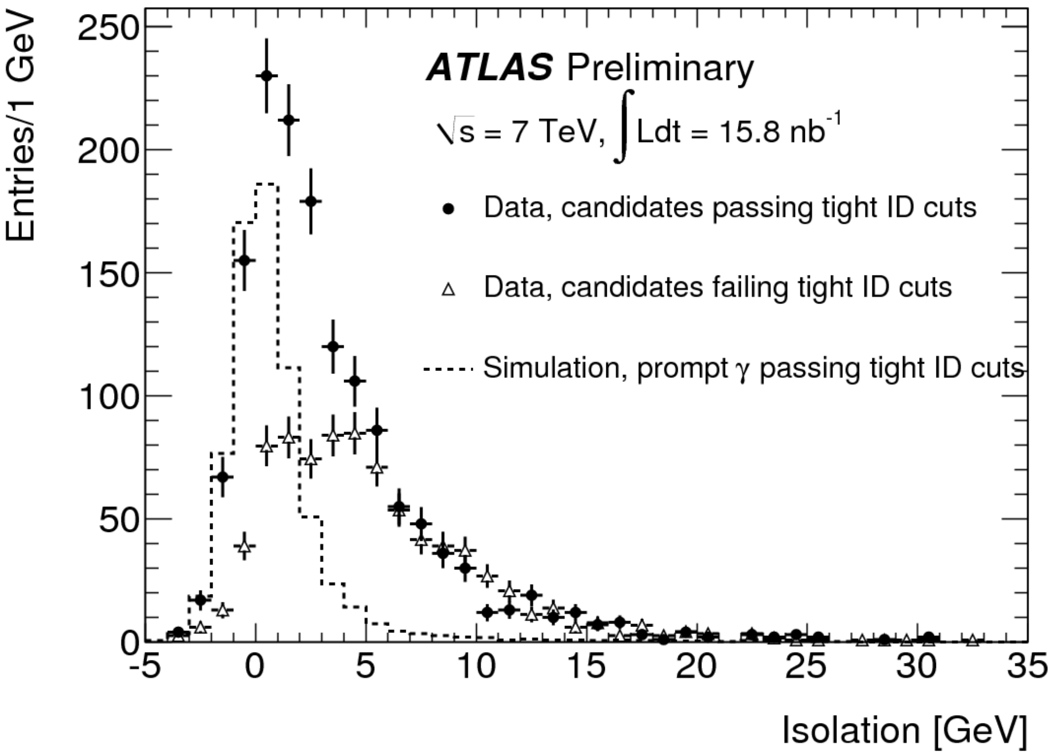
- Signal region (NA):
  - Calo isolation < 3 GeV; pass tight photon selection
- Bkg control regions:
  - non-isolated (NB): Calo isolation >= 5 GeV, pass tight photon selection
  - non-tight-ID (MA): Calo isolation < 3 GeV, fail tight photon selection, pass tight photon selection after relaxing fracm, weta1, DeltaE, Eratio
  - non-isolated and non-tight-ID (MB): Calo isolation >=5 GeV, fail tight photon election, pass tight photon selection after relaxing fracm, weta1, DeltaE, Eratio

Evidence of direct photons in first data

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.

Isolation in tight ID pass/fail region

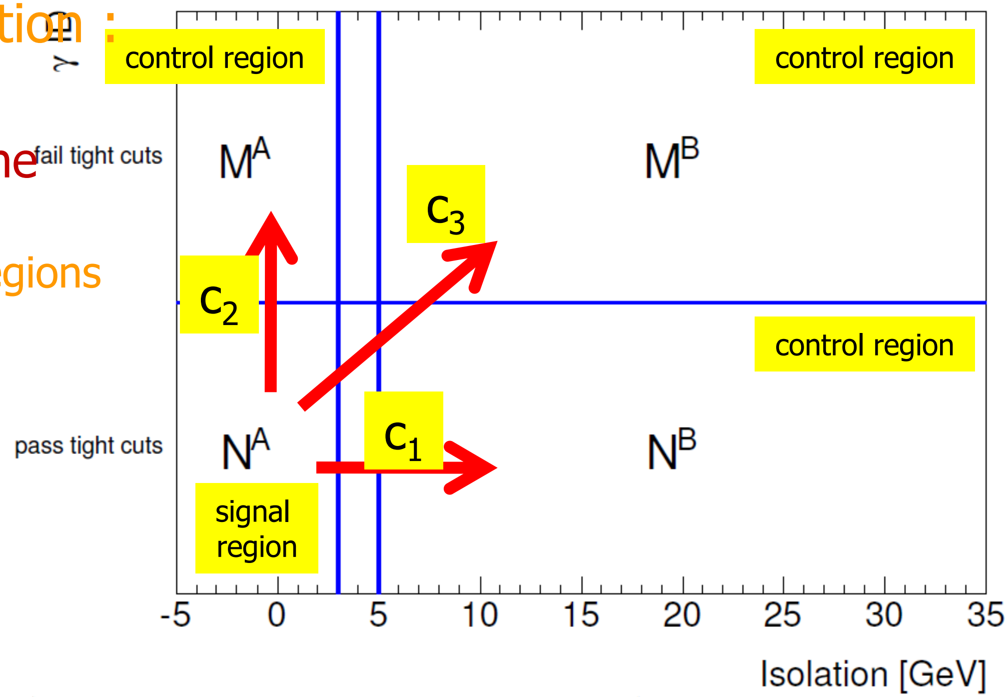


- Data candidates failing the tight ID cuts distribution normalized by the ratio N^B/M^B (same number of events in the non isolated control region)

- MC signal distribution normalized to the estimated yield in data in the signal region (divided by the expected efficiency of the isolation criterium)

- (not used to estimate the purity, just an evidence plot)

Background estimation and signal extraction :



If we take correlation and signal leakage in the control regions into account (both from MC)

- ❑ c_X : signal leakage in the background control regions
- ❑ R_{mc} : background pseudo-correlation factor

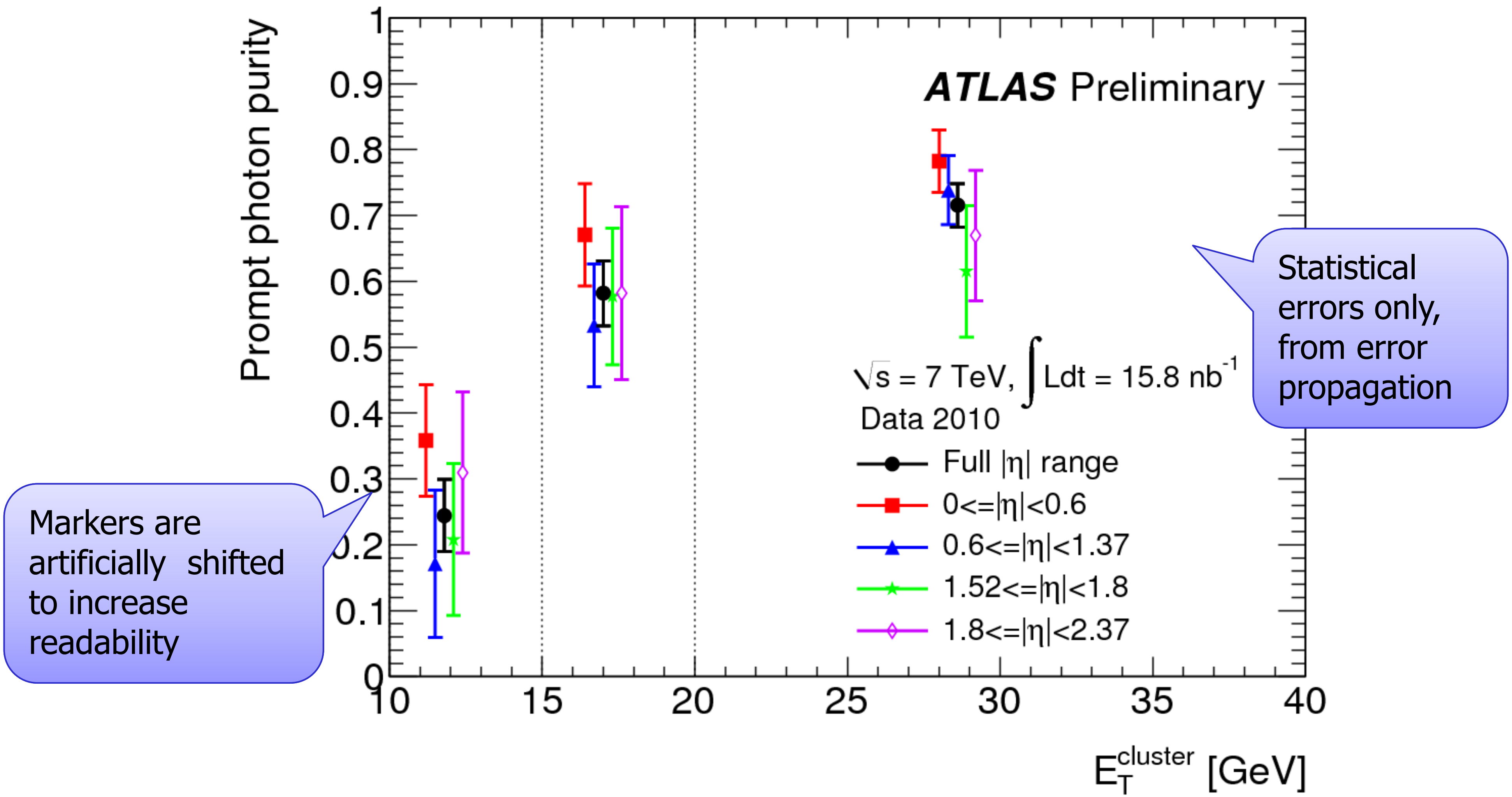
R_{mc}

$$N^A_{\rm sig} = N^A - \left[(N^B - c_1 N^A_{\rm sig}) \frac{M^A - c_2 N^A_{\rm sig}}{M^B - c_3 N^A_{\rm sig}} \right] \left(\frac{N^A_{\rm bkg}}{N^B_{\rm bkg}} \frac{M^B_{\rm bkg}}{M^A_{\rm bkg}} \right)$$

Table 2: Background pseudo-correlation factor $R = \frac{N^A_{\rm bkg} M^B_{\rm bkg}}{N^B_{\rm bkg} N^A_{\rm bkg}}$ and ratios $c_1 = \frac{N^B_{\rm sig}}{N^A_{\rm sig}}$, $c_2 = \frac{M^A_{\rm sig}}{N^A_{\rm sig}}$ and $c_3 = \frac{M^B_{\rm sig}}{N^A_{\rm sig}}$ between the expected signal photons in the three control regions and the expected signal photons in the signal region, in different intervals of the reconstructed photon transverse energy.

E_T interval [GeV]	$10 \le E_T < 15$	$15 \le E_T < 20$	$E_T \ge 20$
R	1.10 ± 0.03	0.91 ± 0.05	1.02 ± 0.02
c_1	$(1.8 \pm 0.2) \times 10^{-2}$	$(3.1 \pm 0.5) \times 10^{-2}$	$(5.3 \pm 0.3) \times 10^{-2}$
c_2	$(18.0 \pm 0.6) \times 10^{-2}$	$(11.3 \pm 0.7) \times 10^{-2}$	$(6.6 \pm 0.2) \times 10^{-2}$
c_3	$(5.3 \pm 1.1) \times 10^{-3}$	$(2.5 \pm 1.3) \times 10^{-3}$	$(6.9 \pm 1.0) \times 10^{-3}$

Photon purity as a function of P_T for different η bins



Systematic uncertainties (errors are absolute)

	pT bin [GeV]		
	[10,15)	[15,20)	[20,inf)
Nominal purity (%)	**24.4**	**58.2**	**71.5**
stat error [%]	**5.4**	**4.9**	**3.3**
neglecting correlations, or taking Herwig-Pythia difference (-6%) [%]	9.5	4.7	1.9
relax 2 strip cuts instead of 4 to define isEM control region [%]	21	2.1	2.9
varying isolated control region [%]	3.2	1.6	1.2
leakage: changing prompt fraction by +-40% [%]	1.1	1.5	2.4
leakage: isEM eff +-5% [%]	3.4	3.2	3.6
total syst. error	**23.5**	**6.4**	**5.7**
total error	**24.2**	**8.1**	**6.6**

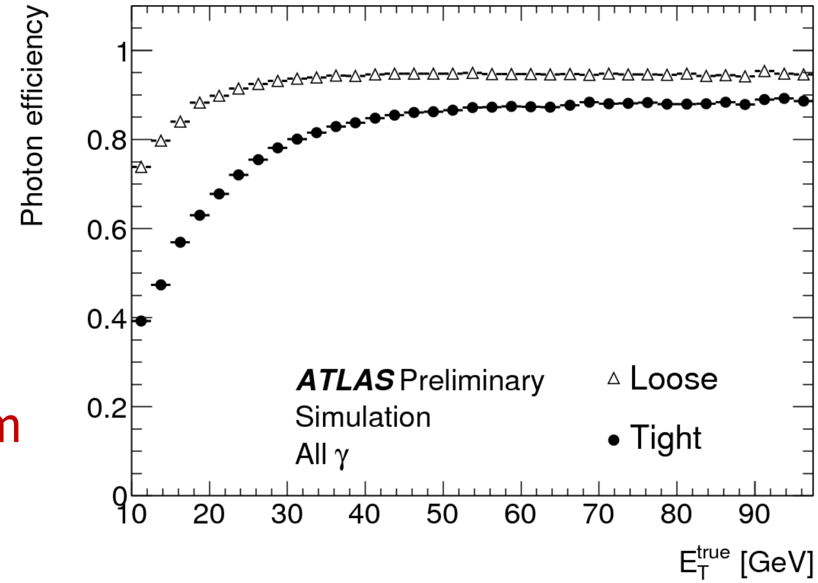
Photon purity and yield

Table 3: Number of candidates in data, estimated signal purity and signal yield in the signal region (photon with isolation energy below 3 GeV and passing tight identification criteria), and corresponding systematic uncertainties, in three intervals of the photon transverse energy.

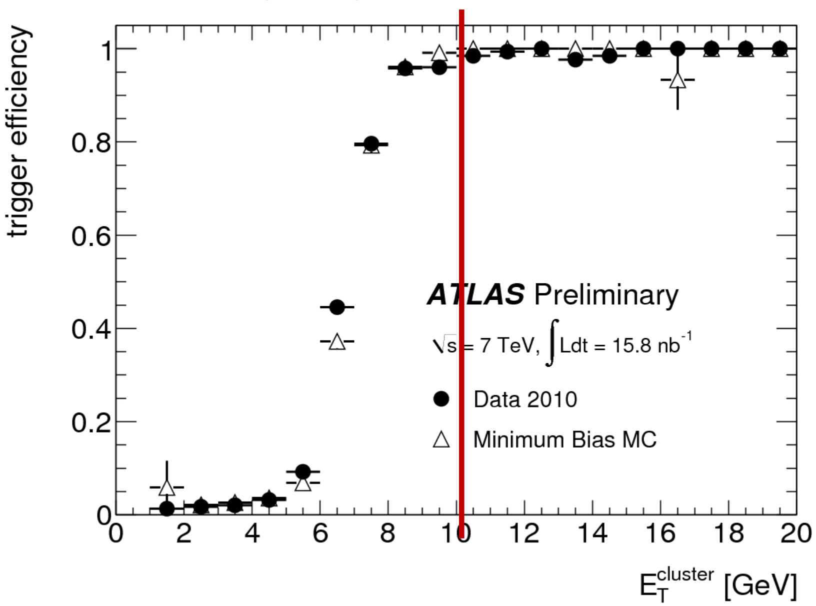
E_T interval [GeV]	$10 \leq E_T < 15$	$15 \leq E_T < 20$	$E_T \geq 20$
Number of candidates	5271	1213	864
Estimated purity P [%]	24 ± 5	58 ± 5	72 ± 3
Systematic uncertainty on P [%]	24	6	6
Estimated signal yield N^A_{sig}	1289 ± 297	706 ± 69	618 ± 42
Systematic uncertainty on N^A_{sig}	1231	77	49

Towards the first cross section measurement : offline and trigger efficiencies

- Photon identification efficiency determined from PYTHIA MC for signal. Main expected systematic uncertainties :
  - Material description in MC : a few %
  - Cross-talk btw calorimeter cells : ~ 2%
  - Data/MC comparison (shower shape) : 5-10 %
  - Converted/Unconverted γ classification : ~1%



- More 'data driven' studies and extrapolation from electrons ongoing



- Trigger efficiency determined from data, relative to photon reconstruction and offline selection, from samples of :
  - Minimum bias trigger
  - Lower threshold L1 calorimeter trigger
- ~100% for E_T>10 GeV. Systematic uncertainty < 0.3 %, estimated from MC of signal and/or BG

Conclusion and next steps

- From 15.8 nb^{-1} of 7 TeV pp collisions collected with the ATLAS detector, we successfully extracted a statistically significant prompt photon signal for 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 %. Reference : ATLAS-CONF-2010-077

- A first inclusive isolated cross section paper is in the pipeline : extended p_T range, additional photon purity estimation techniques, more studies on photon identification

- Evidence of prompt diphoton signal soon public and a first measurement will be ready by spring 2011

Isolation requirements

Isolation is not only an additional ID cuts, it has strict connections with physics:

- Maintain a high efficiency for retaining real photons while removing most of the jet backgrounds and (to some extent) the fragmentation contribution
  - require the isolation energy in a cone surrounding the photon be as small as possible while retaining a high (80-90%) efficiency for real photons reducing the fragmentation contributions
- Be relatively independent of the instantaneous luminosity and UE
  - Need a dynamic definition of isolation, taking into account the instantaneous luminosity and UE contribution for that particular event
- Be relatively independent of the photon energy
  - Isolation energy increase for high p_T photons since there is a leakage outside of the cluster.
- Be “kind” with respect to the theoretical calculation
  - Cone isolation is perfectly fine but the parameters have to be choosen carefully in order to preserve consistency with the theory: cone size not too small (R~0.4/0.5 fine) and energy in the cone not too small (few %?)

And actually we saw diphoton events in first data

… although not exactly the most interesting ones…