Photons in LHC data @ 7 TeV
Results from ATLAS and CMS

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On behalf of the ATLAS and CMS Collaborations

Higgs Hunting : Discussions on Tevatron and first LHC results

29-31 July 2010
Orsay, France

I - Introduction

- Physics with photons at the LHC
- ATLAS and CMS : trackers and calorimeters

II - Using photons in performance studies

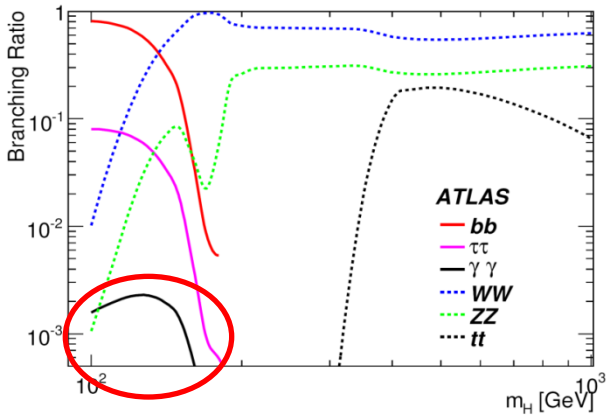
- Photons from π^0 decays [CMS/ATLAS]
- Conversions and Dalitz [CMS/ATLAS]

III - Prompt photons results

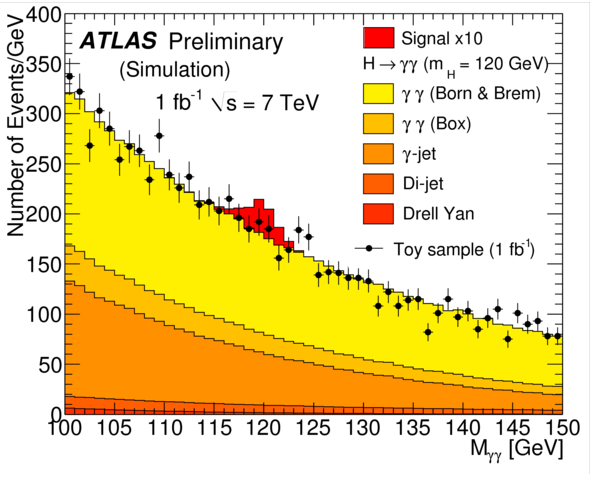
- Photon identification [CMS/ATLAS]
- Photon conversions [CMS/ATLAS]
- Beam-halo background [CMS]
- Prompt isolated photon signal and purity [ATLAS]

I- Introduction

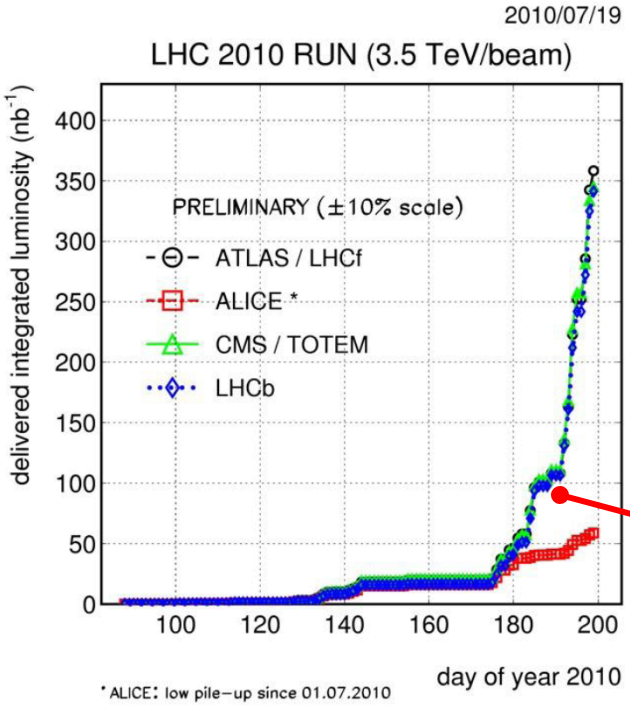
Perspective for $H \rightarrow \gamma\gamma$ searches in CMS and ATLAS

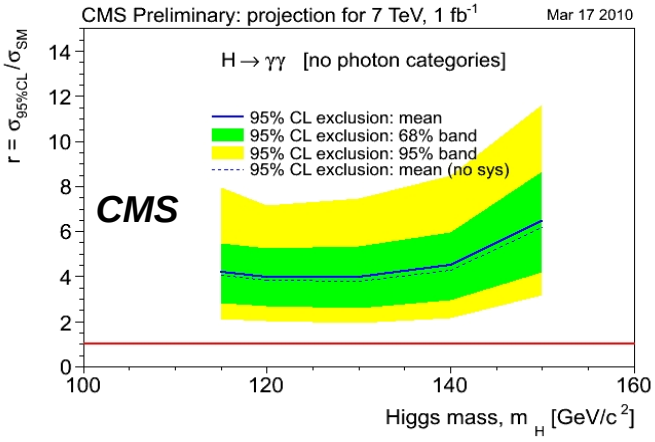


For m_H = 120 GeV => BR ~ 0.2%

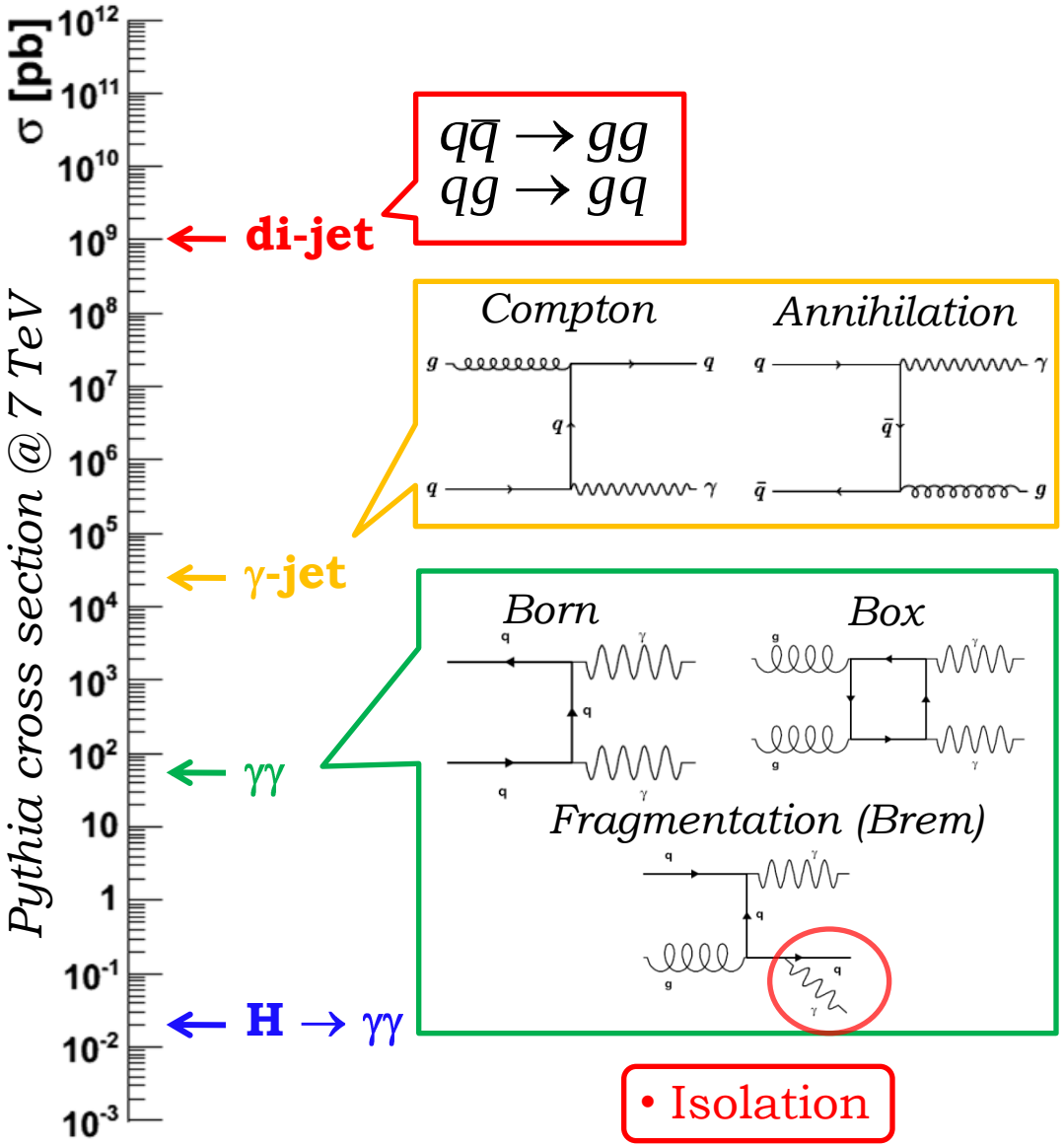


- Clean signature (2 high-E_T isolated photons)
- Huge background from QCD photons and jets





What can we extract from the first 10-100 nb^{-1} ?



In today's data

- **Among reconstructed photons :**
  → Jets with high-pT π^0 misidentified as photons
  → Prompt photons (from ME and fragmentation)

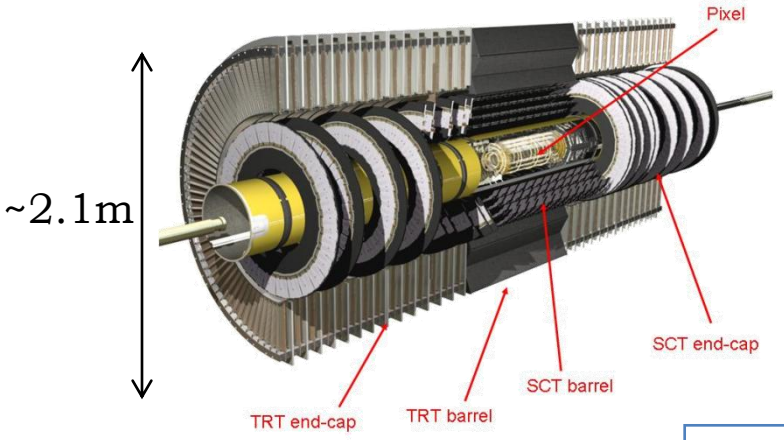
- γ/π^0 separation

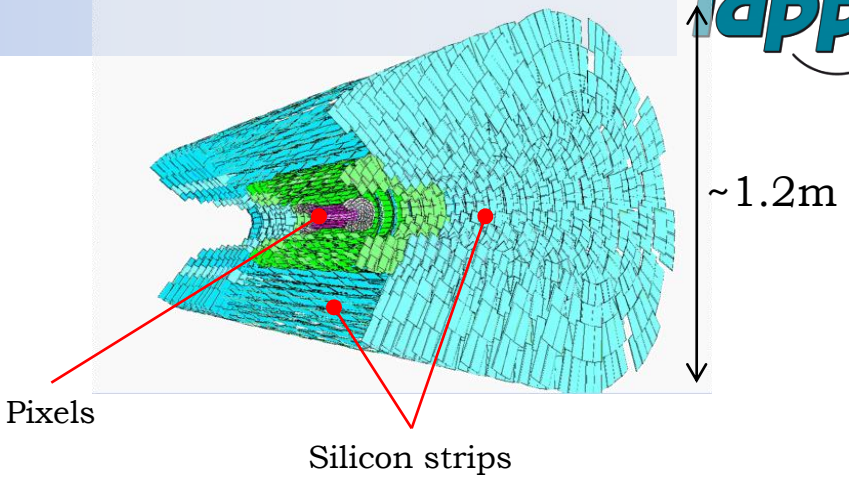
- Energy + angular resolution
- Conversion recovery

- Isolation

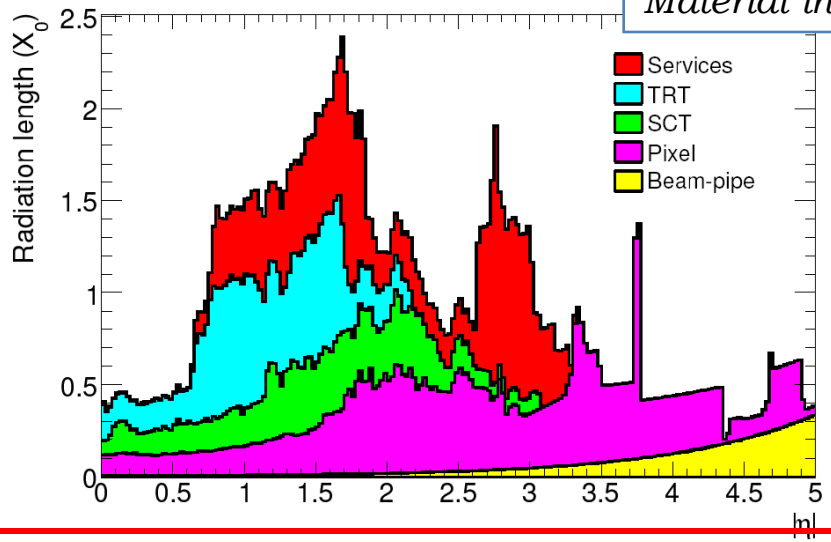
- **Prompt photon measurements :**
  → Background to H → γγ, …
  → Perturbative QCD tests

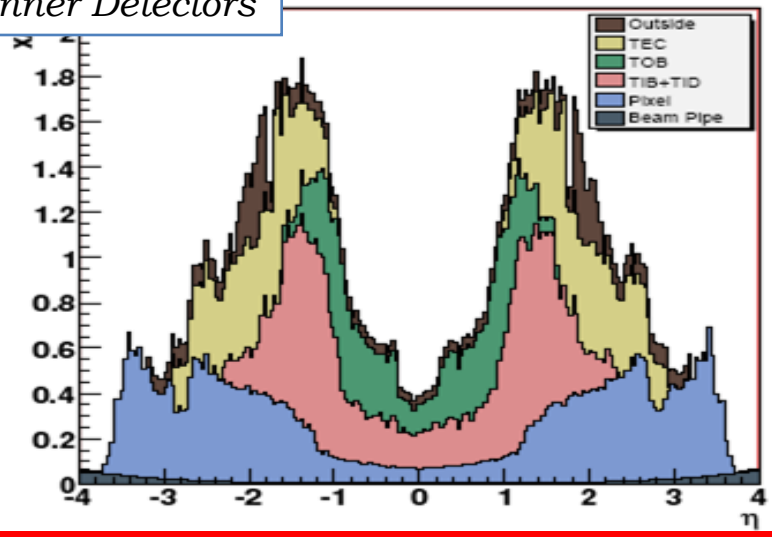
ATLAS and CMS : Trackers



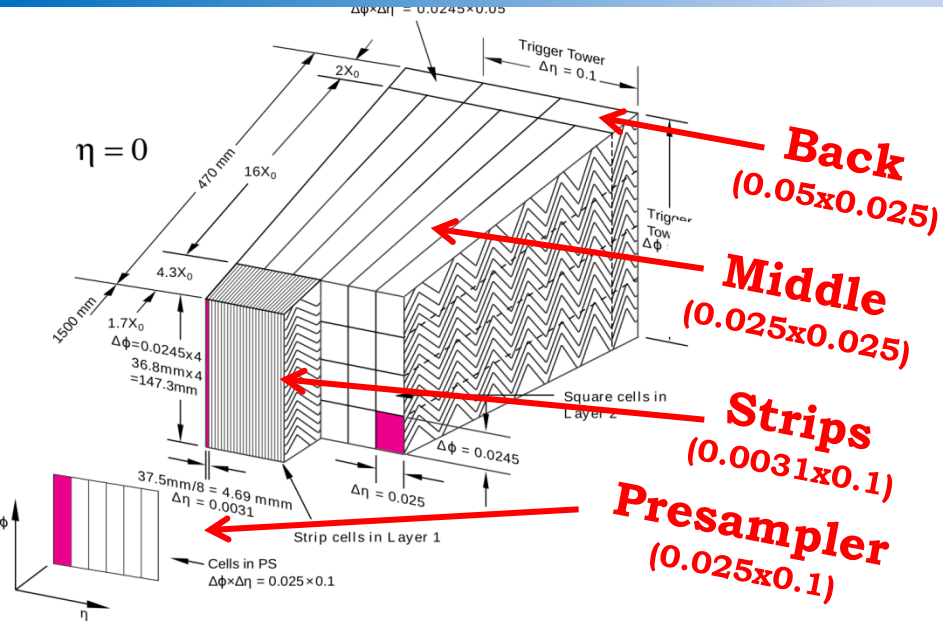


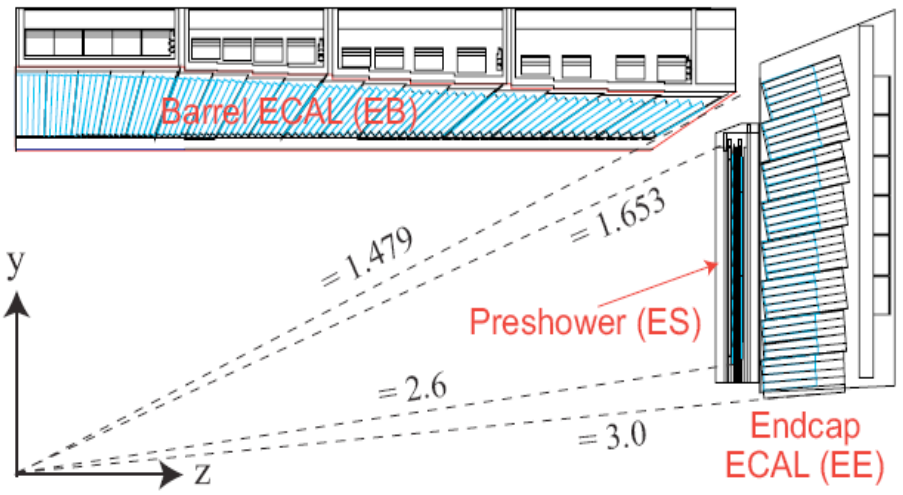
Material in the Inner Detectors





- Material => non-negligible fraction of photon conversions (up to 50% in Si)
  → Consequences on photon ID, energy resolution, etc.
  → Use of conversions as a tool for material mapping
- ATLAS : add $O(2X_0)$ before EM Calo (solenoid coil, cryostat)





- Pb + LAr sampling calorimeter
- 3 radial layers + pre-shower
- Design energy resolution :

$$\frac{\Delta E}{E} = \frac{10\%}{\sqrt{E}} \oplus \frac{300\,\mathrm{MeV}}{\mathrm{E}} \oplus 0.7\%$$

- Outside solenoid coil

- $PbWO_4$ scintillating crystals
- Preshower in front of EE
- Design energy resolution :

$$\frac{\Delta E}{E} = \frac{2.9\%}{\sqrt{E}} \oplus \frac{125\,\mathrm{MeV}}{\mathrm{E}} \oplus 0.3\%$$

- Inside solenoid coil

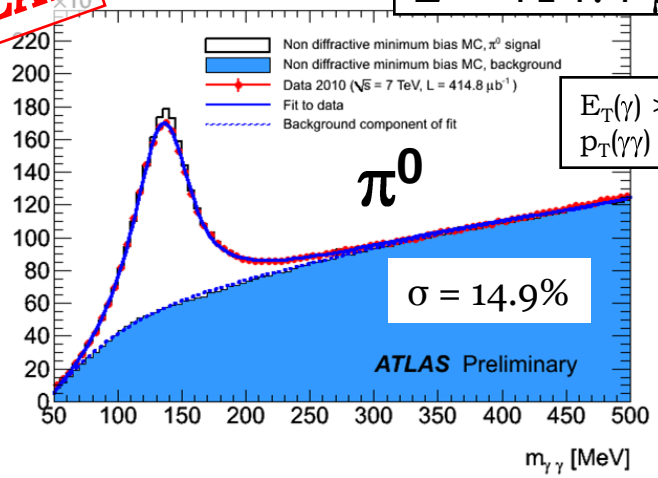
II – Photons in performance studies

- Reconstruction of π^0 peaks
- Material mapping with photon conversions and Dalitz in ATLAS

Diphoton invariant mass spectrum

ATLAS

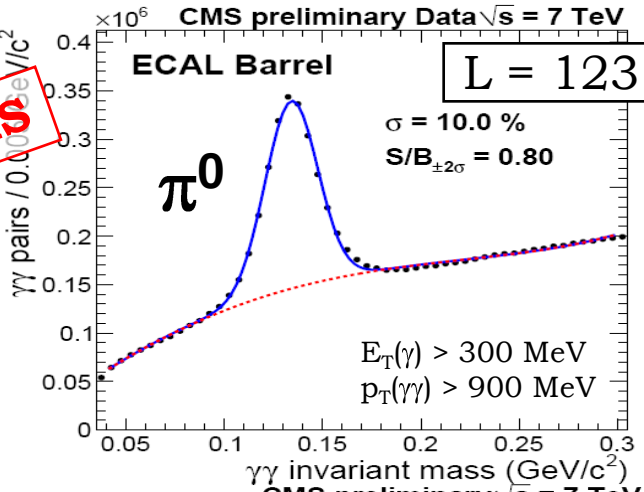
$L = 414.4\ \mu b^{-1}$

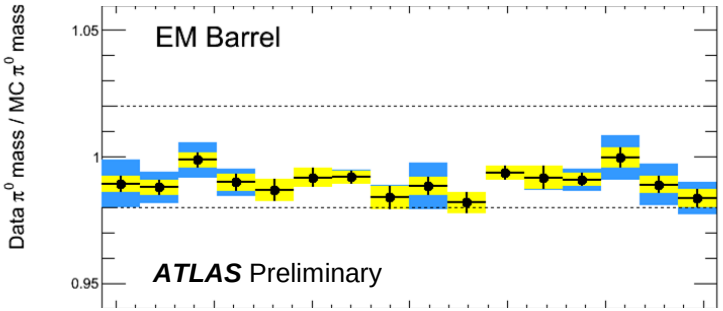


$E_T(\gamma) > 400$ MeV
$p_T(\gamma\gamma) > 900$ MeV

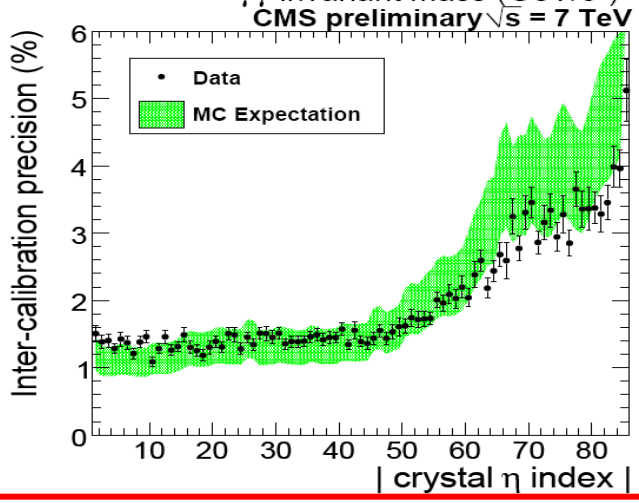
CMS

$L = 123\ nb^{-1}$





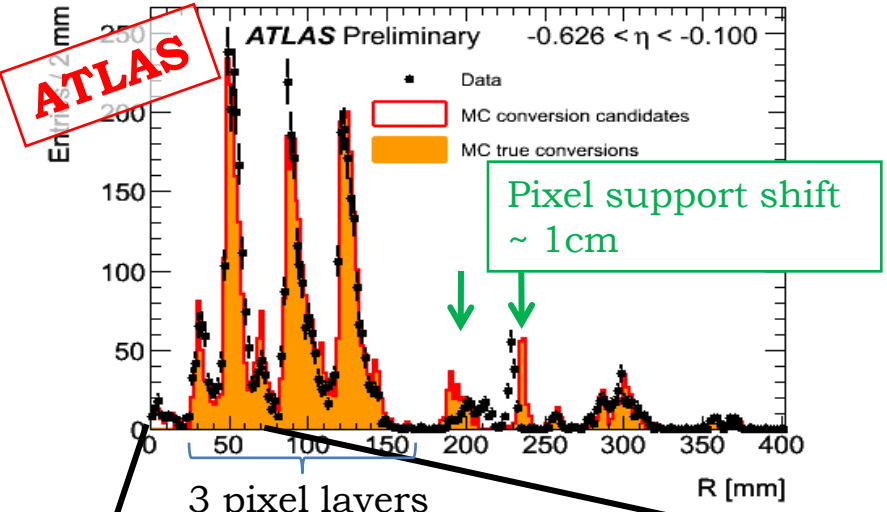
Uniformity in ϕ

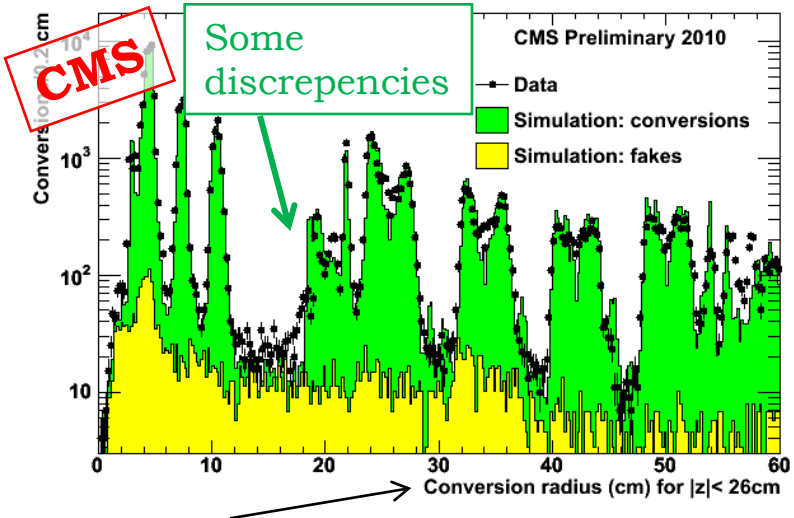


- Uniformity along ϕ : < 0.7% in EM Calorimeter ($|\eta| < 2.37$)
- Agreement data/MC in energy scale along η ~ 1 – 2 %

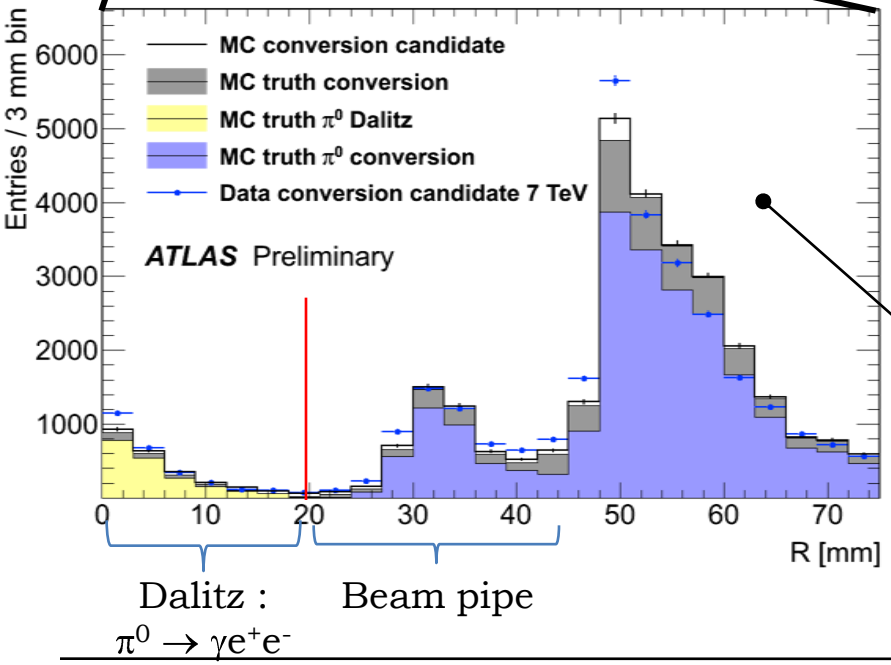
- Channel-by-channel *in-situ* intercalibration precision :
  1.2% for $|\eta| < 0.8$ (π^0, ϕ symmetry)
- Agreement data/MC in energy scale ~ 1 – 3 % (Barrel – Endcap)

Converted photons in ATLAS and CMS





Corrected from overall shift between tracker and reference frame



- **Conversions :**
  → Track-based conversion finding

- **Dalitz decays ($\pi^0 \rightarrow \gamma e^+ e^-$)**
  → Used to constrain material in the Beam pipe
  → Beam pipe = reference for material estimate

III – Prompt photons results

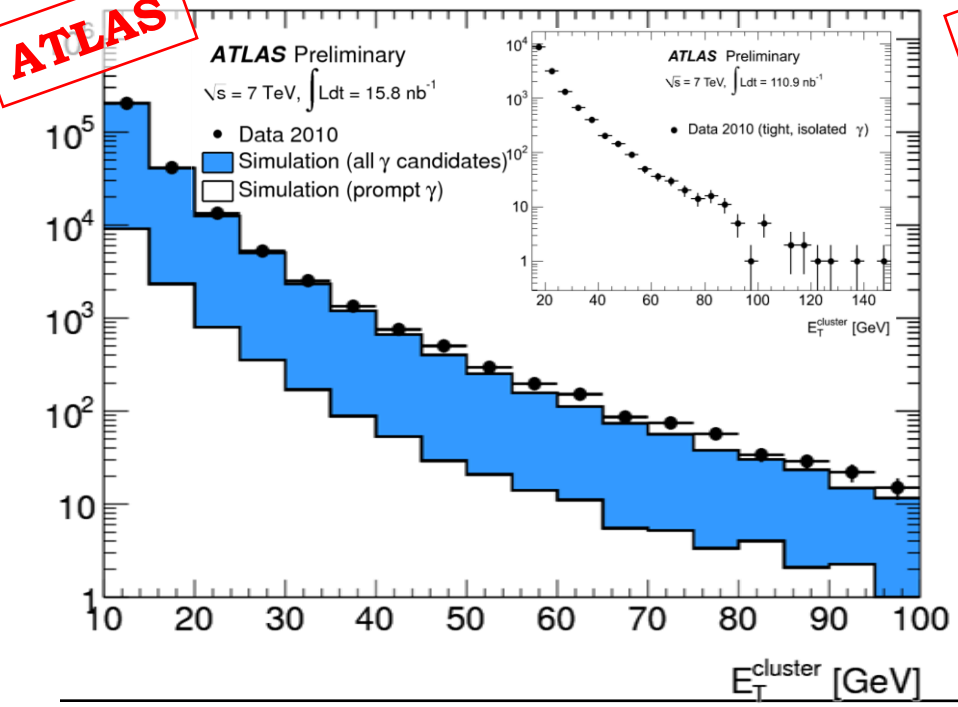
- Photon identification
- Photon conversions
- Non-collision backgrounds
- Extraction of isolated photon signal and purity

In the next plots

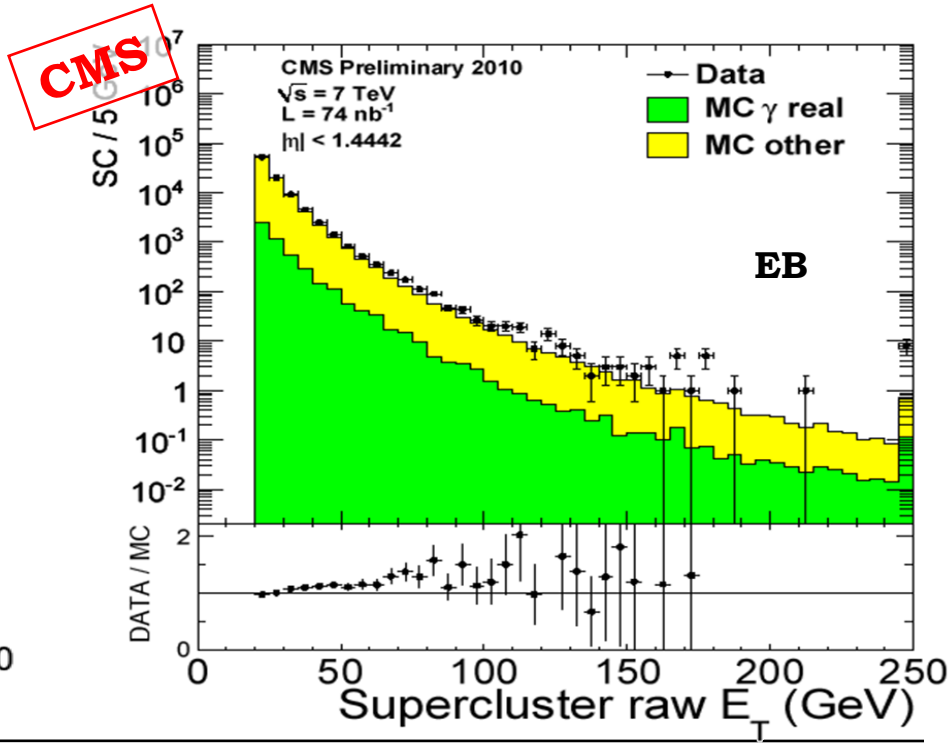
- **Integrated luminosity**
  - → ATLAS : L = 15.8 nb^{-1}
  - → CMS : L = 74 nb^{-1}
  - (53.6 nb^{-1} for beam bkg study)
- **Event selection**
  - → L1 trigger : E_{EM} > 5 GeV
  - → ≥ 1 vertex with ≥ 3 tracks

- **(Super)Clusters**
  - → ATLAS : E_{Cl} > 10 GeV
  - → CMS : E_{SC} > 20 GeV
  - → $|\eta|$ < 2.37 / 2.5, out of crack
  - → Remove problematic regions / anomalous signals
  - → ATLAS : 2.3 10^5 photon cand.
  - → CMS : 1.3 10^5 events

ATLAS



CMS



Identification of photons in ATLAS

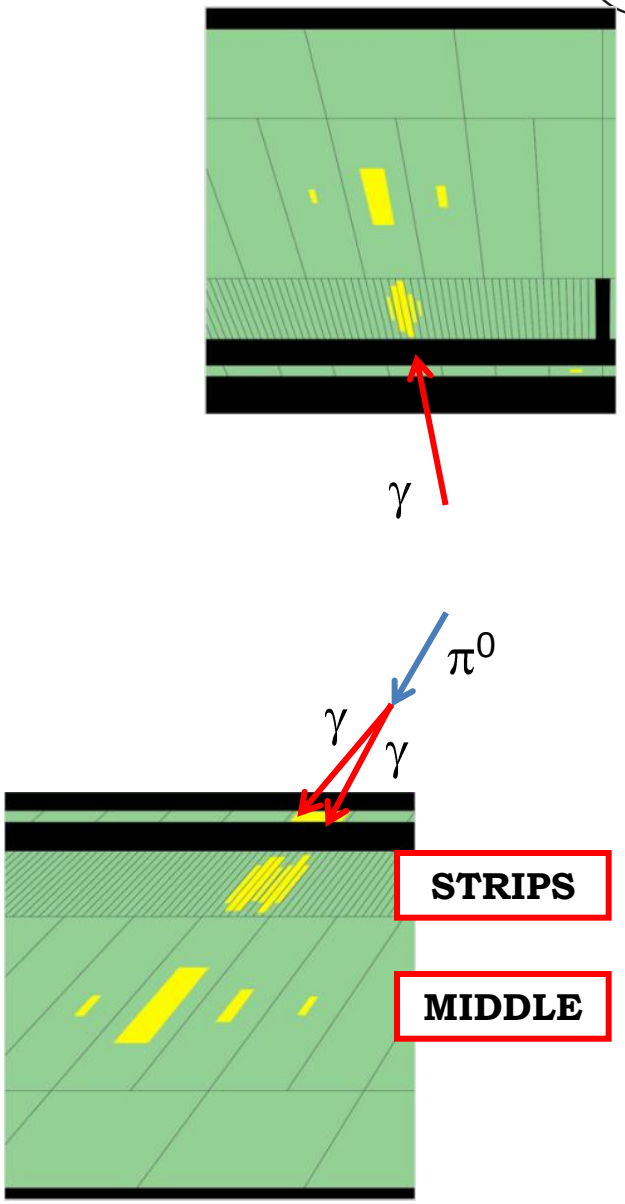
ATLAS

	Variable	Definition
MIDDLE	Hadronic leakage	$E_T(Had)/E_T$
MIDDLE	R_η	E_{3x7}/E_{7x7}
MIDDLE	$w_{\eta 2}$	RMS of energy in η in middle layer
STRIPS	R_ϕ	E_{3x3}/E_{3x7}
STRIPS	w_{stot}	RMS of energy in η in strips
STRIPS	E_{ratio}	Asymetry between 1st and 2nd max
STRIPS	ΔE	Difference between 2nd max and min (between the 2 max)
STRIPS	F_{side}	Fraction of energy in 7 cells outside the core of 3 cells
STRIPS	w_{s3}	RMS of energy in η in the core of 3 cells

Loose selection
→ Had. Leakage + Middle variables

Tight selection
→ Loose + Strips variables

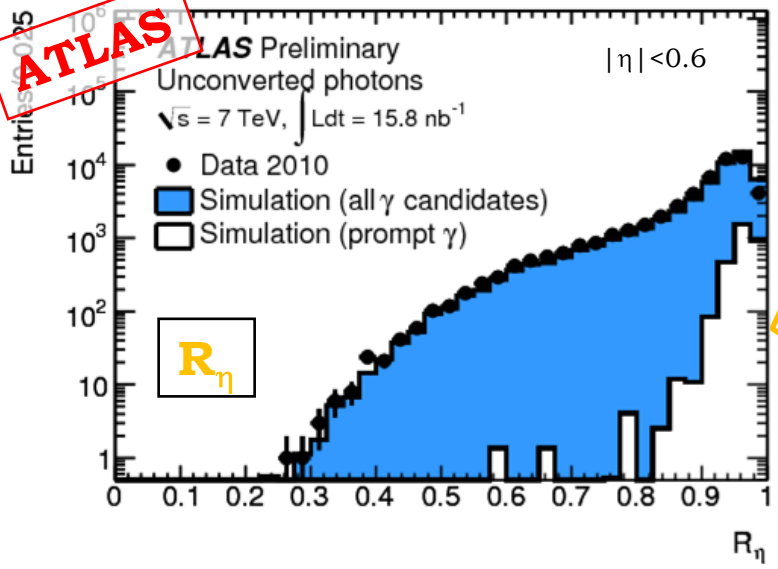
(different cuts for converted and unconverted photons)

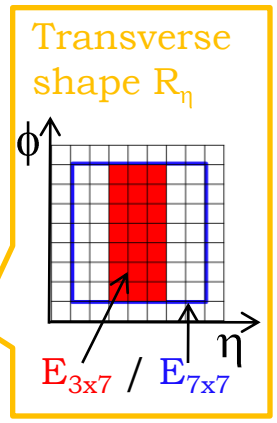


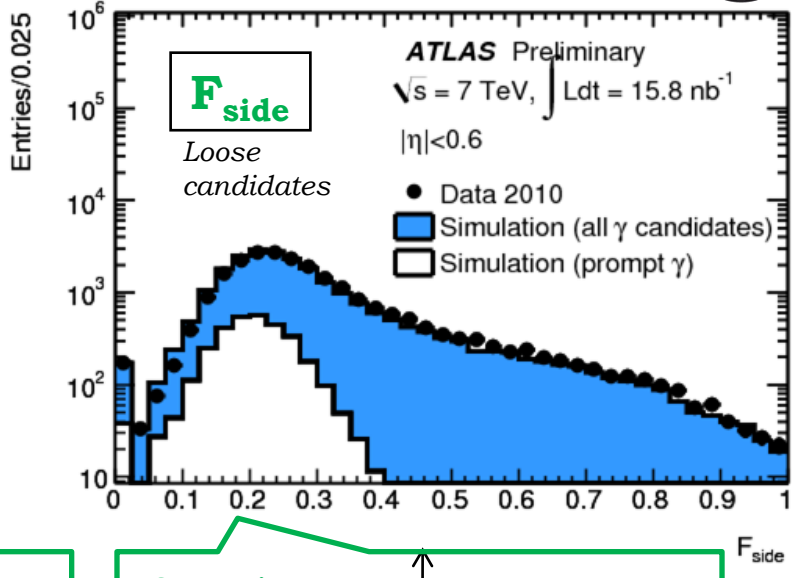
- **Isolation**

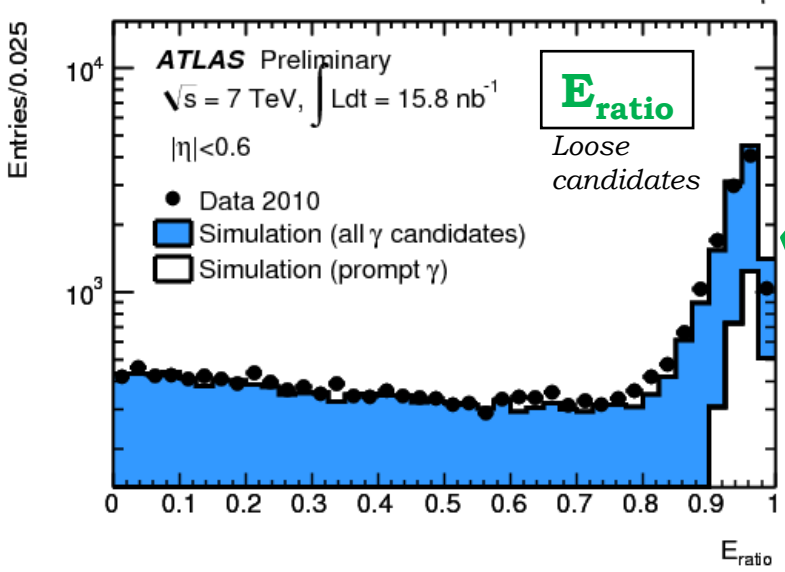
→ Treated separately *(see after)*

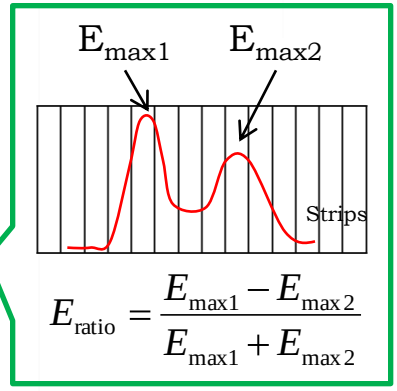
Shower shapes in the ATLAS EM Calorimeter

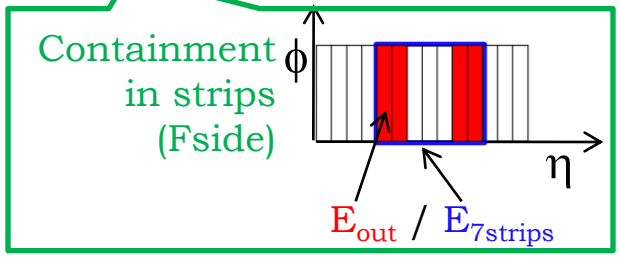












Good agreement between Data and MC after loose ID cut

Efficiencies computed from H → γγ MC

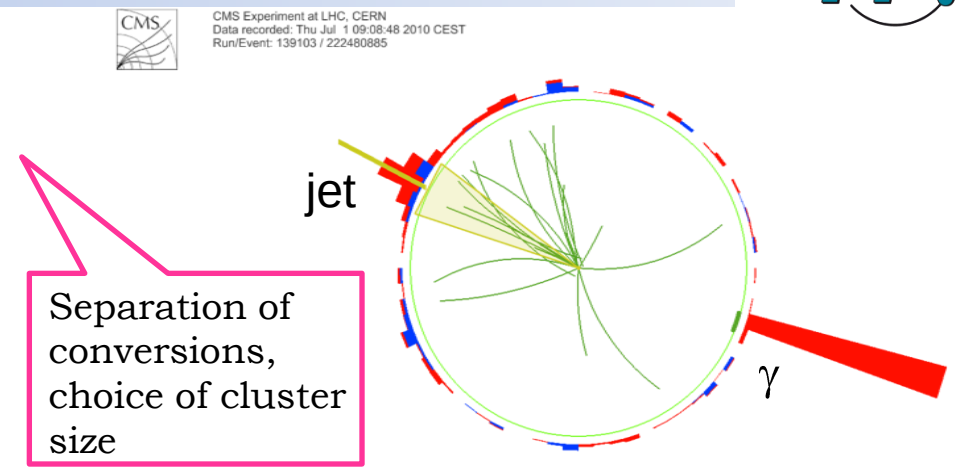
(E_T > 20 GeV) :

Loose : ε ~ 95%

Tight : ε ~ 88 %

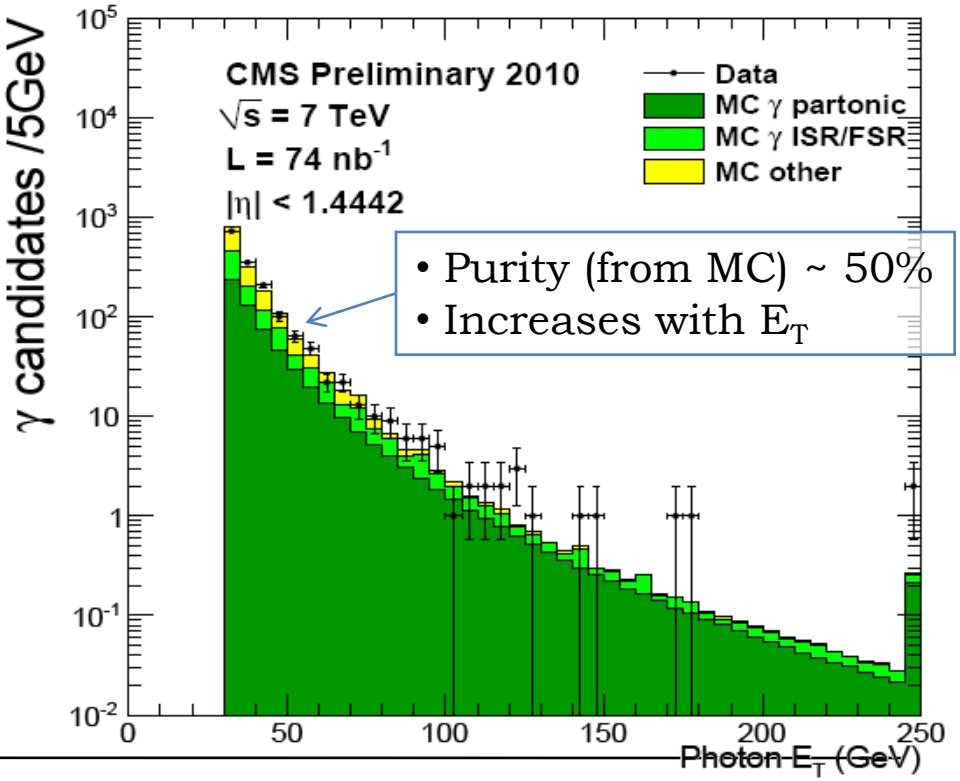
Identification of photons in CMS

Variable	Definition
R_9	E_{3x3}/E_{SC}
Pixel seed	Match with track in pixels
Tracker Iso.	Sum(p_T) in a ring between R = 0.04 and R = 0.4
ECAL Iso.	Sum(E_T(EM)) in a ring between R = 0.06 and R = 0.4
HCAL Iso.	Sum(E_T(HCAL)) in a ring between R = 0.15 and R = 0.4
$\sigma_{i\eta-i\eta}$	Width in η of the SC
Hadronic fraction	H/E = E_T(Had)/E_T

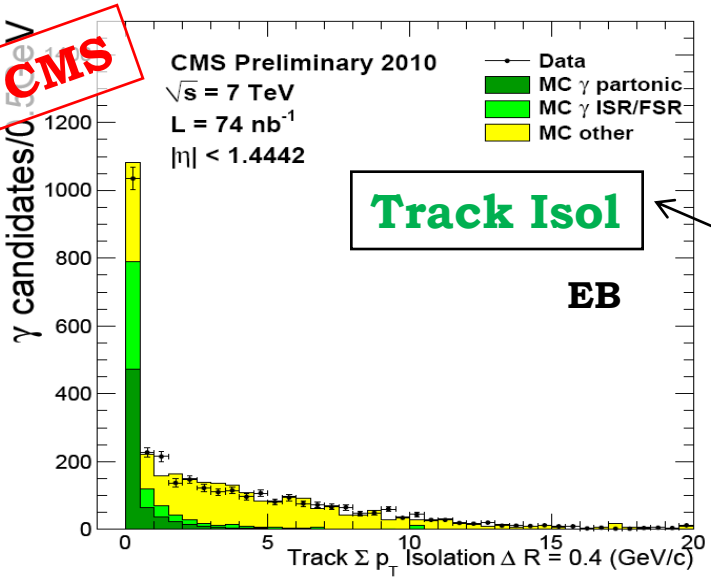


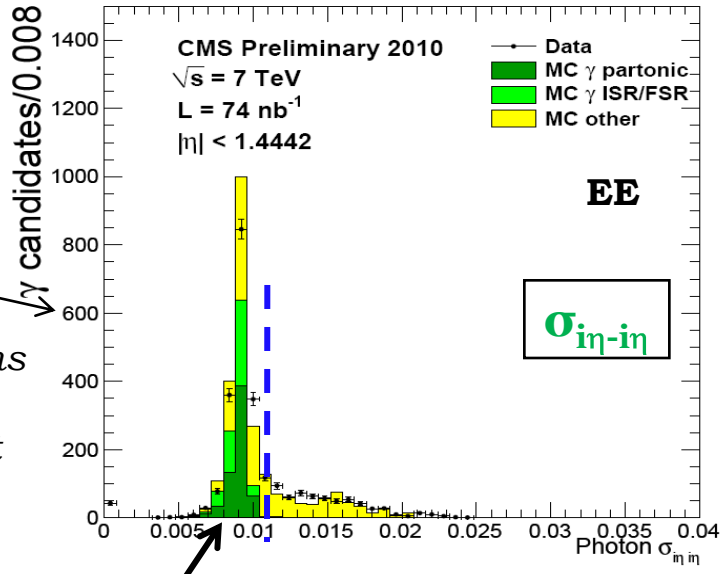
Additional cut : E_T > 30 GeV

- **Efficiencies computed on MC isolated photons :**
  - → EB : ε ≈ 90%
  - → EE : ε ≈ 80%



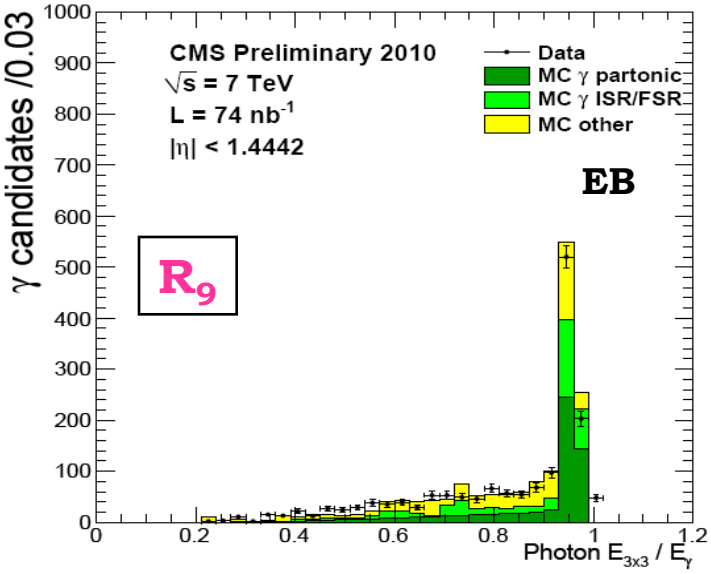
Identification variables in the CMS ECAL





N – 1 distributions (apply all cuts except the one plotted)

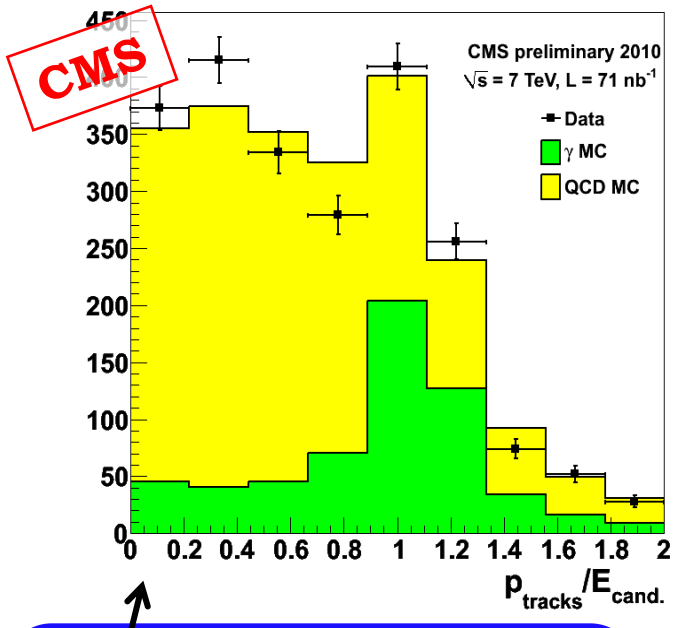
Signal contribution

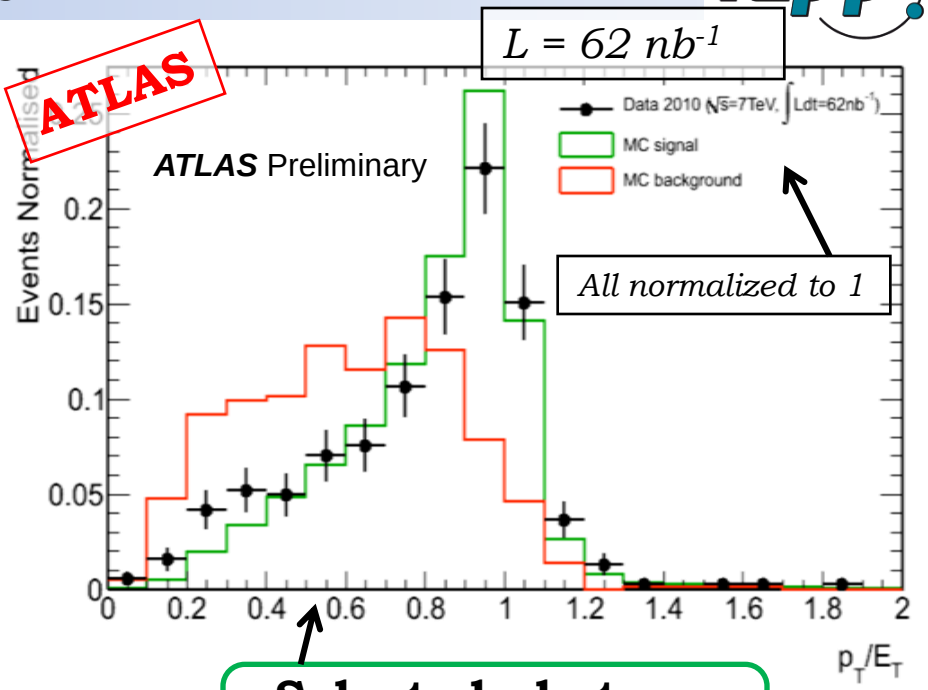


On selected photons

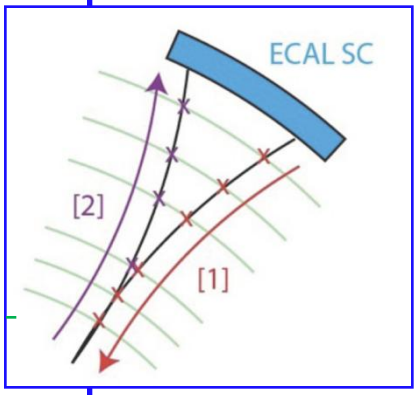
- Good agreement between Data and MC
- Signal contribution visible

Photon conversions in CMS and ATLAS





- **Selected photons :**
  - → No pixel seed
  - → E_T > 30 GeV
  - → Track Iso < 2 GeV
  - → ECAL Iso. < 4.2 GeV
  - → HCAL Iso. < 2.2 GeV
  - → H/E < 0.05
  - → $\sigma_{i\eta\text{-}i\eta}$ < 0.01 (0.03)
  - → $|\Delta\phi|$ < 0.2
  - → $|\Delta\cot\theta|$ < 0.3
  - →P(vertex) > 5.10-4

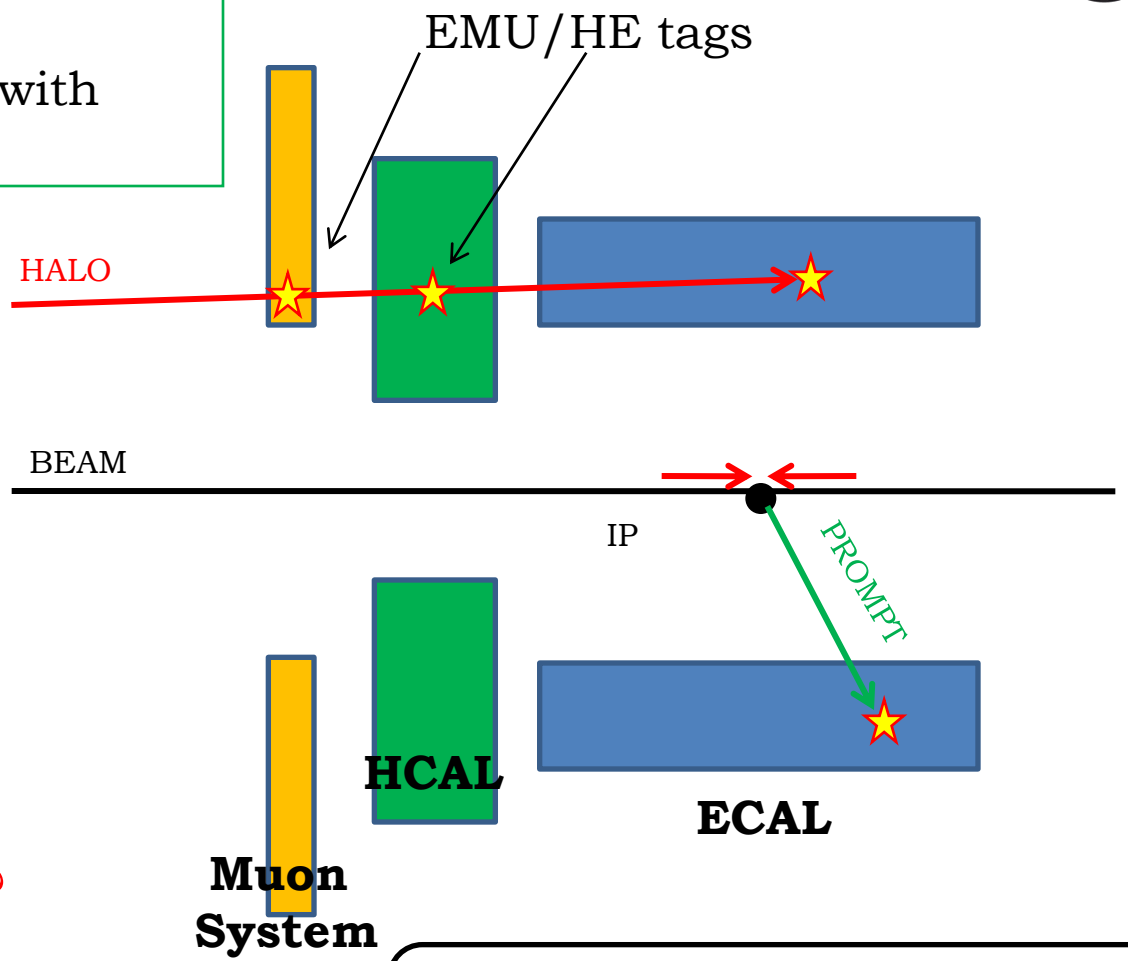


- **Selected photons :**
  - → Tight selection
  - → E_T > 20 GeV
  - → Isolation < 3 GeV

Distributions compatible with isolated converted photons

CMS

Non-collision events = background to studies with photons or MET



- **HALO :**
  → No reco track
  → MET > 25 GeV
  → tagged in Had Endcap (HE) or Muon System Endcap (EMU)

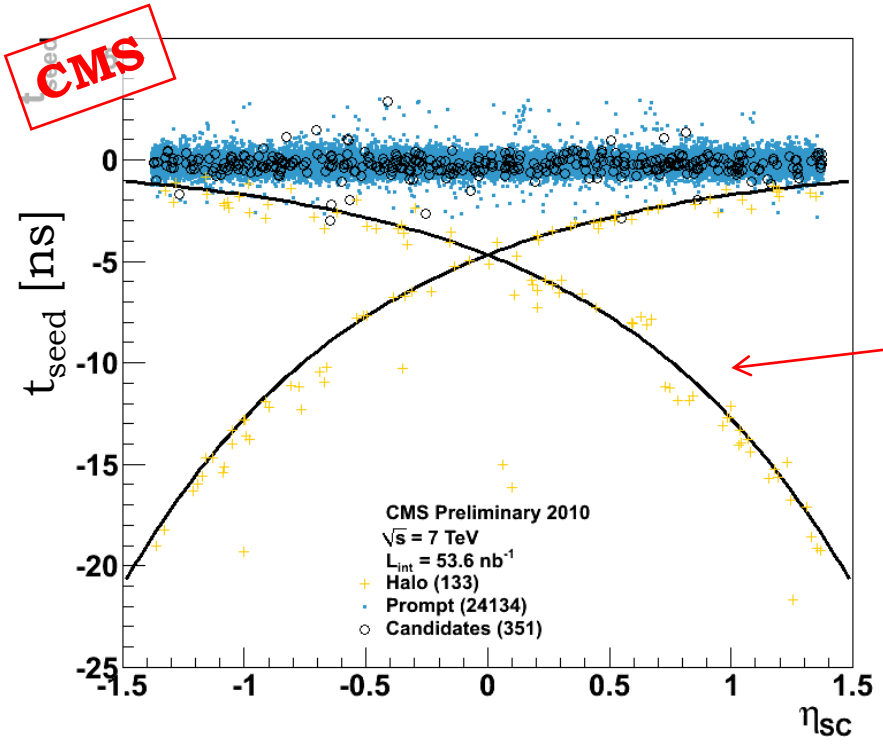
- **PROMPT :**
  → > 3 reco tracks
  → MET < 15 GeV
  → $|t_{seed}| < 3$ ns
  → no tag

Contamination ?

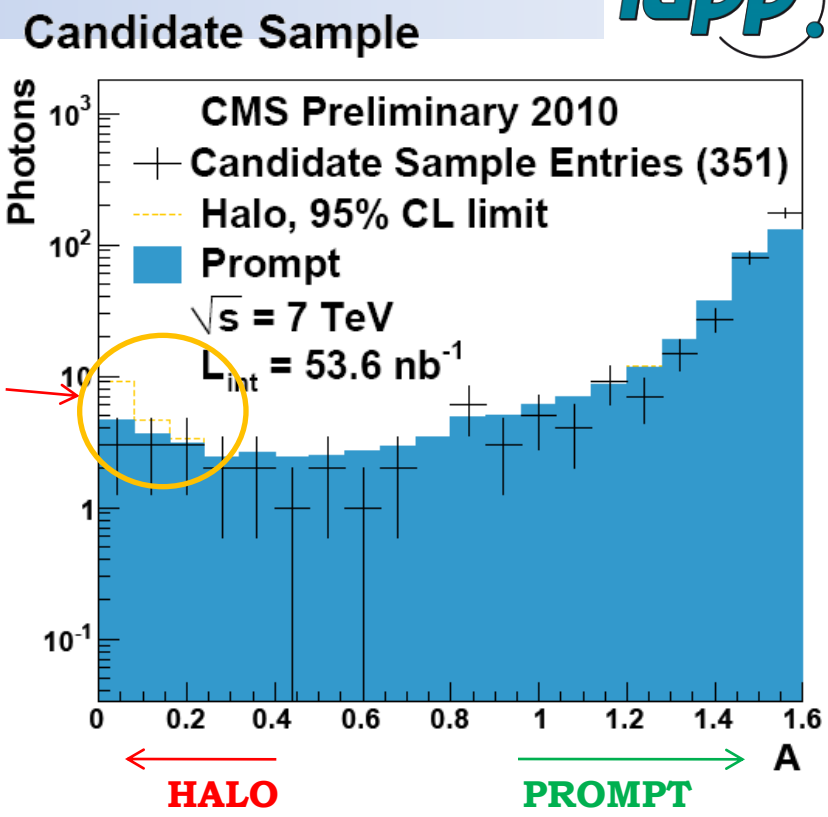
- **CANDIDATE :**
  → > 3 reco tracks
  → MET > 25 GeV
  → photon with ET > 30 GeV
  → $|t_{seed}| < 3$ns
  → no tag

⇒ Time of seed in ECAL : t_{seed}
⇒ Angle of shower in η-ϕ plane w.r.t beam axis : A

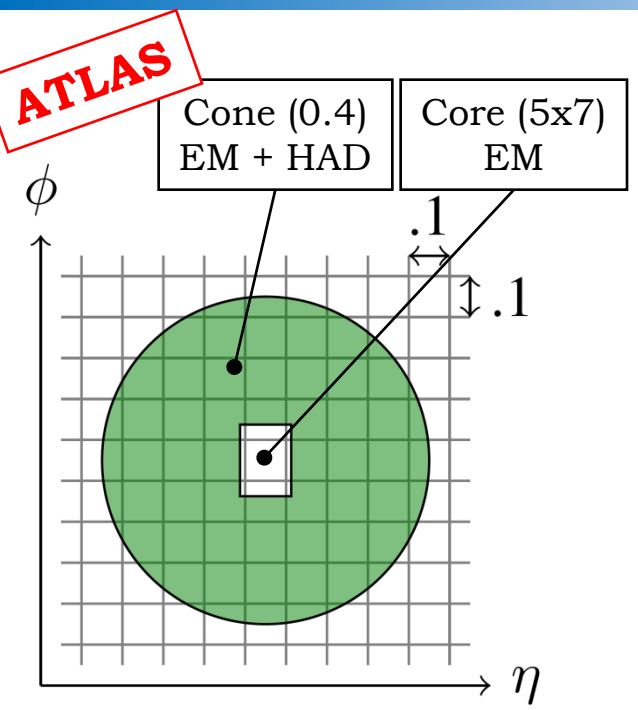
Non-collision background (II)



HALO



- Data driven method to estimate candidate contamination
- Estimate < 5.9 halo events in "candidate" sample (351 candidates) with MET > 25 GeV



- **Energy in ring includes :**

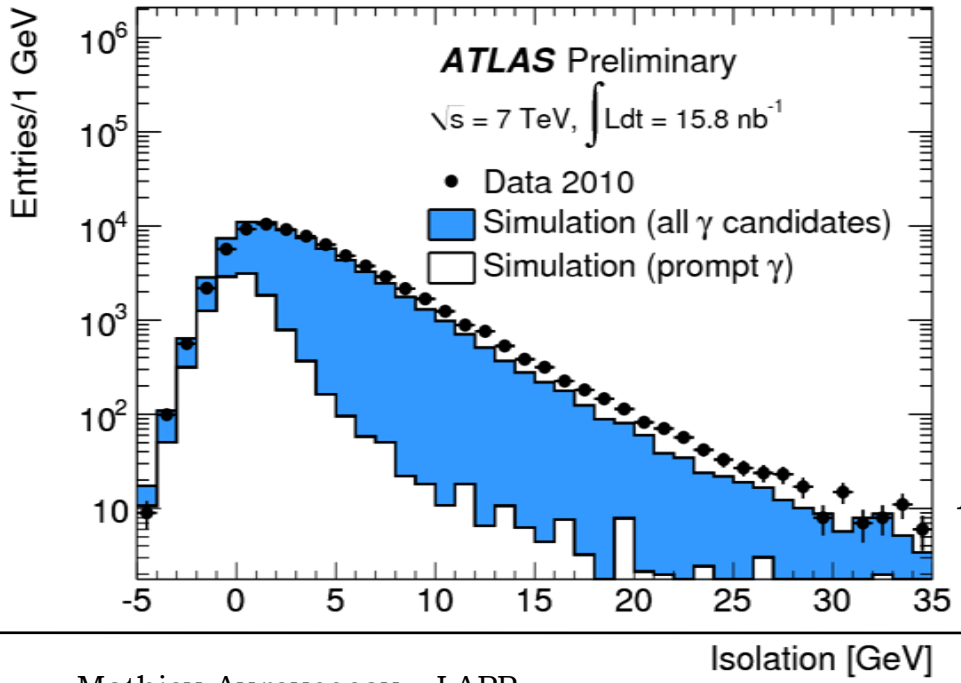
→Photon leakage out of the core

- Depends on photon pT
- Subtracted from the ring energy

→ Pile-up / Underlying Event effects

- Ambient energy density from low E jets
- Subtracted from the ring energy

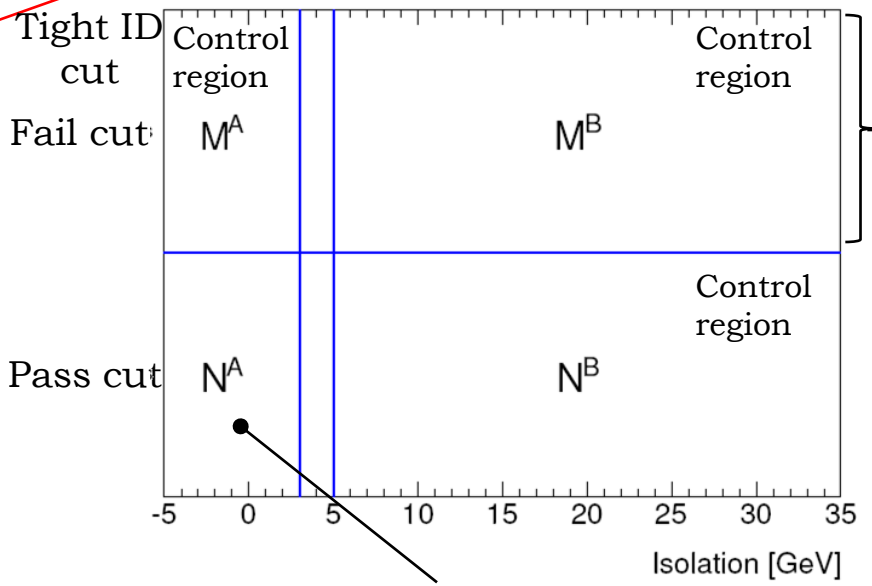
→ Nearby hadronic activity → Isolation energy



Candidates already passing the loose ID cut

This definition of isolation is closer to theoretical parton-level isolation

ATLAS



Isolated signal region

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

Two corrections :

- **Correlation between ID and isolation cuts**

→ Reverse only a *subset* (E_{ratio}, ΔE, F_{side}, W_{s3}) of the strips shower shape variables to minimize correlation

- **Signal contamination in control regions**

→ Use fraction of signal in the control regions from MC (c_1, c_2, c_3)

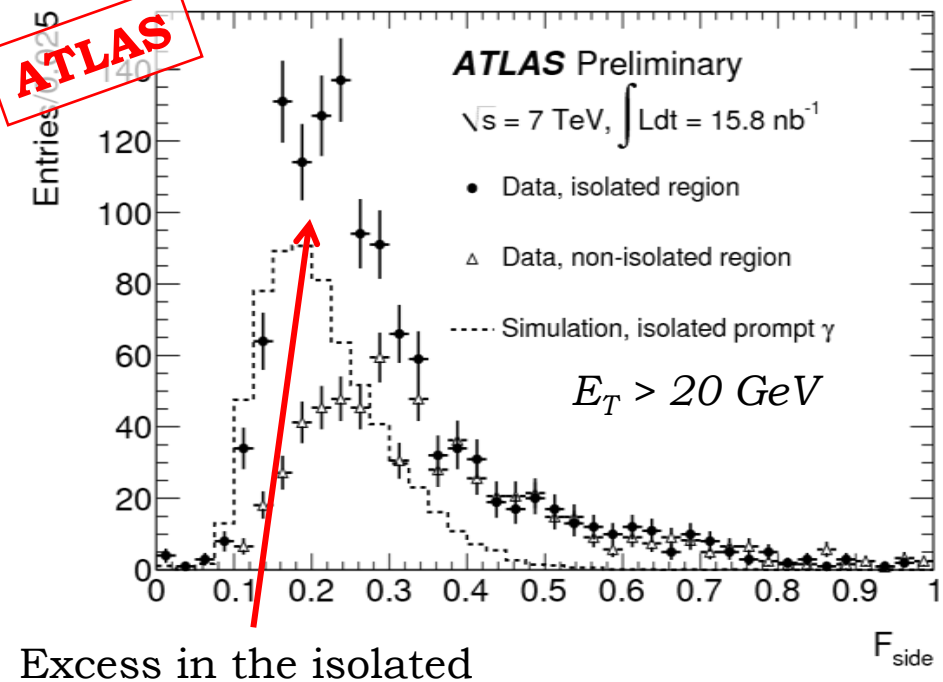
Signal contamination Correlation

Corrected formula :

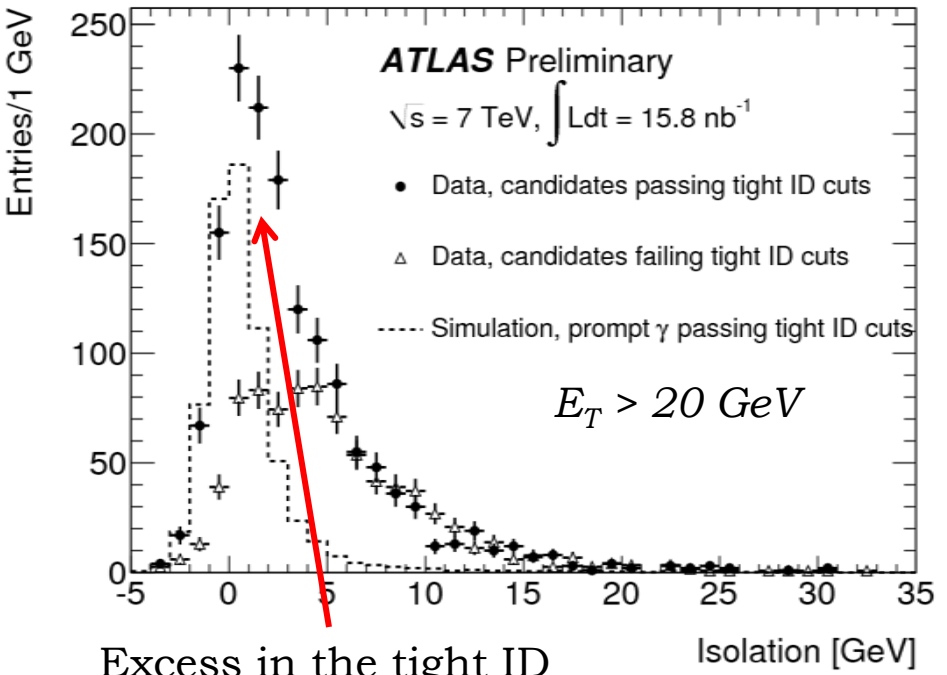
$$N^A_{sig} = N^A - \left[(N^B - c_1 N^A_{sig}) \frac{M^A - c_2 N^A_{sig}}{M^B - c_3 N^A_{sig}} \right] \left(\frac{N^A_{bkg}}{N^B_{bkg}} \frac{M^B_{bkg}}{M^A_{bkg}} \right)$$

→ *Data driven* extraction of number of isolated signal

Signal extraction (II)



Excess in the isolated region (→ signal)



Excess in the tight ID cut region (→ signal)

Signal yield with 15.8 nb^{-1} of data

ET interval	Estimated signal yield (+/- stat. +/- syst.)
10 – 15 GeV	$1289 \pm 297 \pm 1362$
15 – 20 GeV	$706 \pm 69 \pm 86$
> 20 GeV	$618 \pm 42 \pm 59$

Systematics dominated by choice of first layer ID cuts, isolation cut and correlations.

Signal extraction (III) : Photon purity

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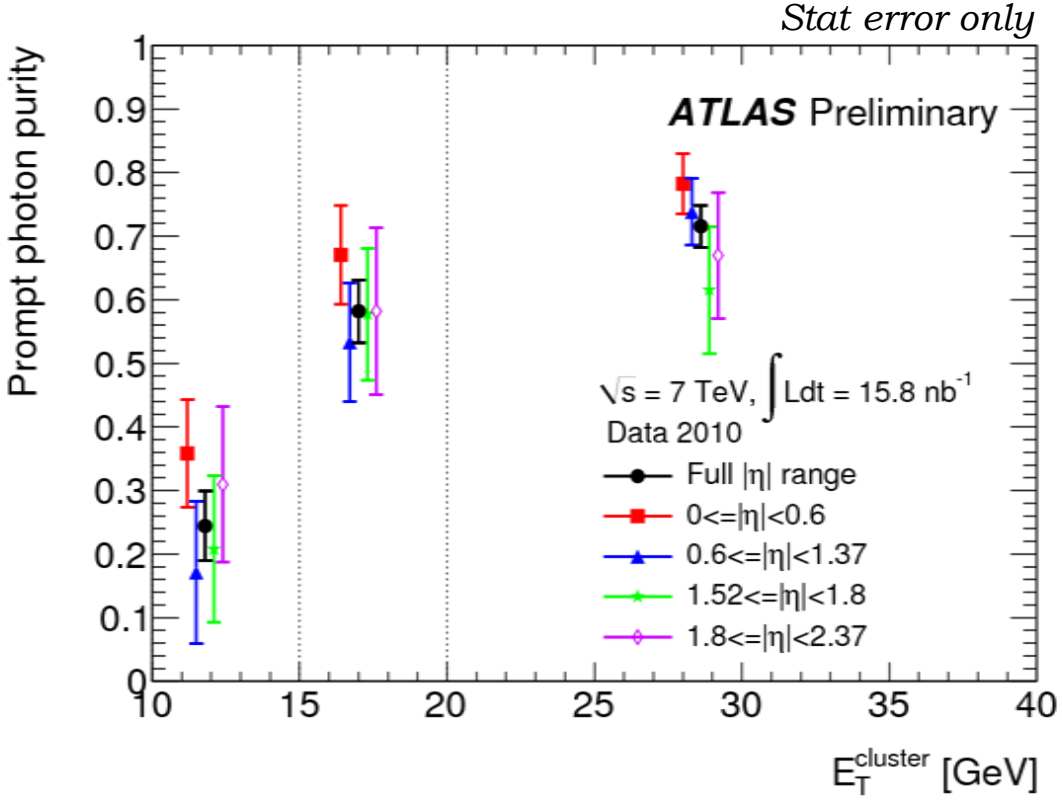
$$P = \frac{N_{\mathrm{sig}}^{A}}{N^{A}}$$



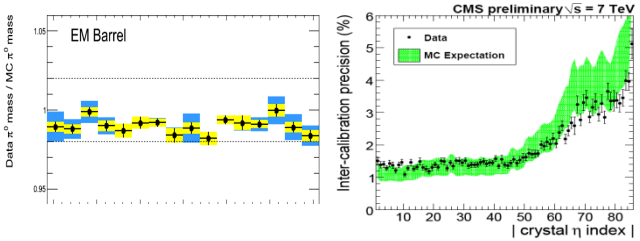
Estimated purity with 15.8 nb^{-1} of data

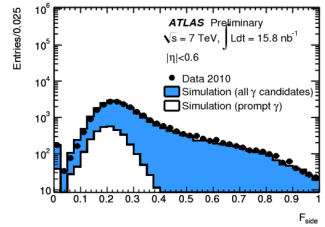
ET interval	Estimated purity in % (+/- stat. +/- syst.)
10 – 15 GeV	$24 \pm 5 \pm 24$
15 – 20 GeV	$58 \pm 5 \pm 8$
> 20 GeV	$72 \pm 3 \pm 6$

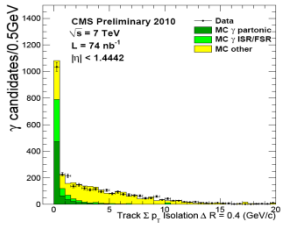
Systematics dominated by choice of first layer ID cuts, isolation cut and correlations.

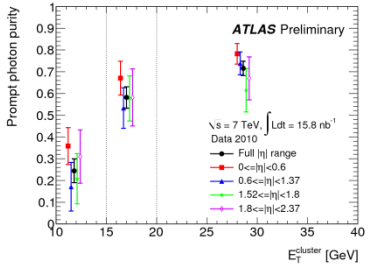
Conclusions

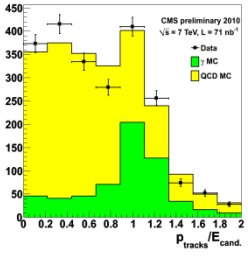
Conclusions











- Performance with photons
- Check of photon ID variables
- Signal of prompt photons (incl. conversions)
- Good agreement between data and MC in general
  - Though some discrepancies to understand

Experiments are ready for next steps : (differential) cross section measurements, prompt di-photon signal, …

- Backup

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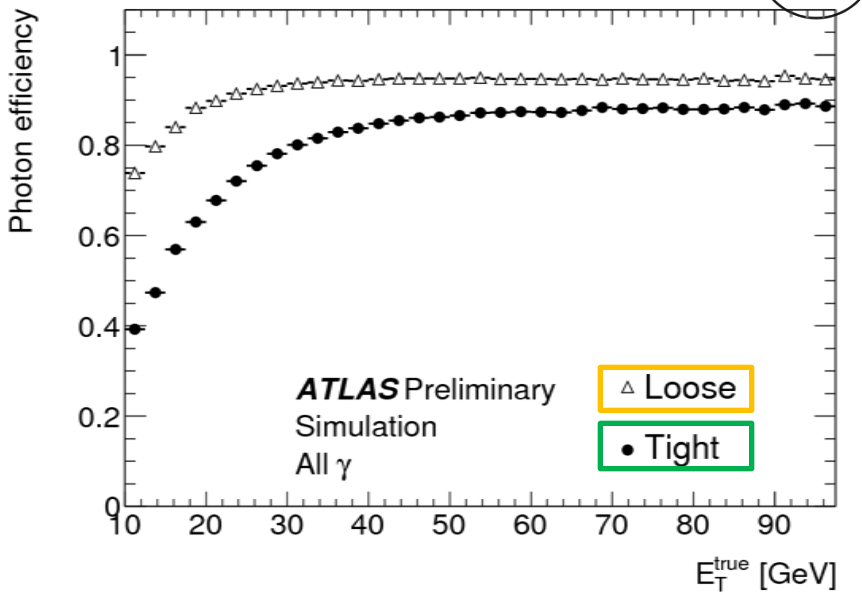
- **Photon identification efficiency**

→ Estimated from MC

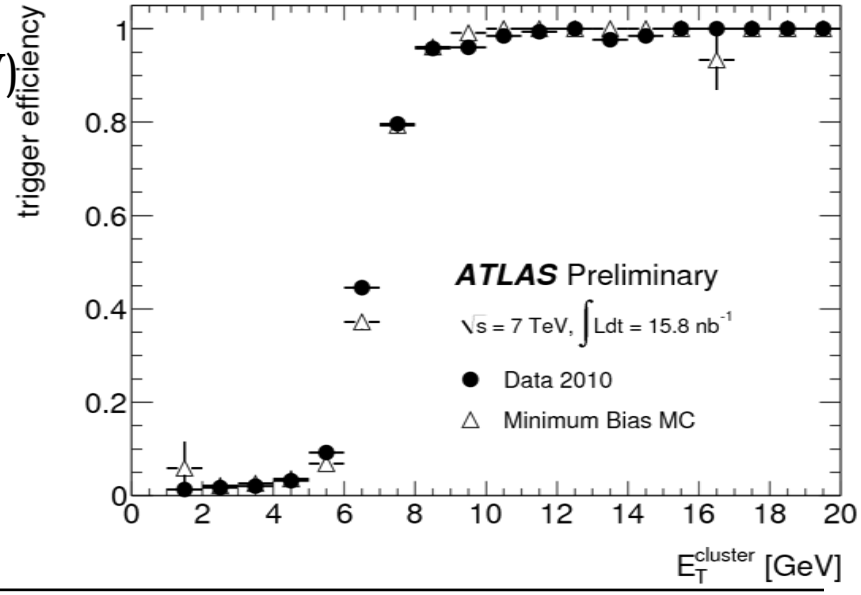
→ Systematic uncertainties :
  - Material description
  - Cross-talk
  - Classification of conversions



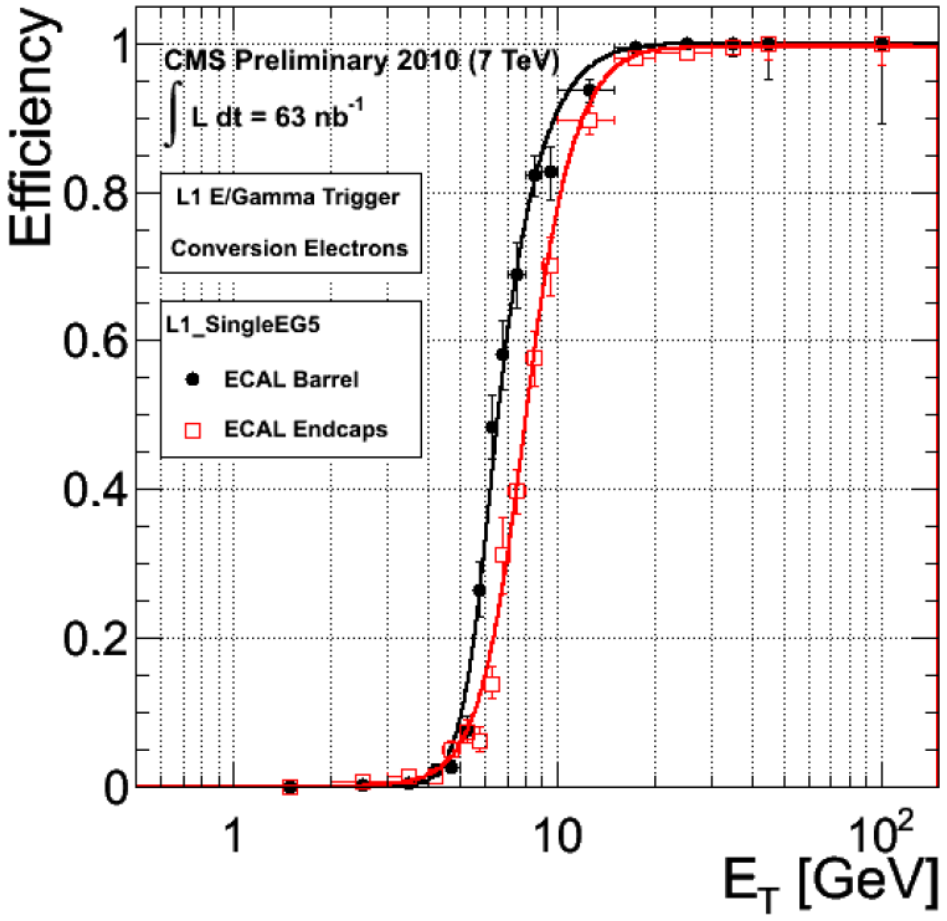
- **Photon trigger efficiency** (L1 Calo 5 GeV)

→ Estimated from Data (bootstrap)
  - Sample of Min Bias triggered events
  - Lower threshold L1Calo trigger (2 GeV)

→ Systematic uncertainty :
  - < 0.3% , estimated from signal/background differences, from MC



CMS L1 electron/photon trigger efficiency



CMS

• **Had. Endcap (HE) tag :**
→ E_{HE} > 1 GeV
→ 115 cm < R_{HE} < 130 cm
→ $\Delta\phi_{ph\text{-}HE}$ < 0.2

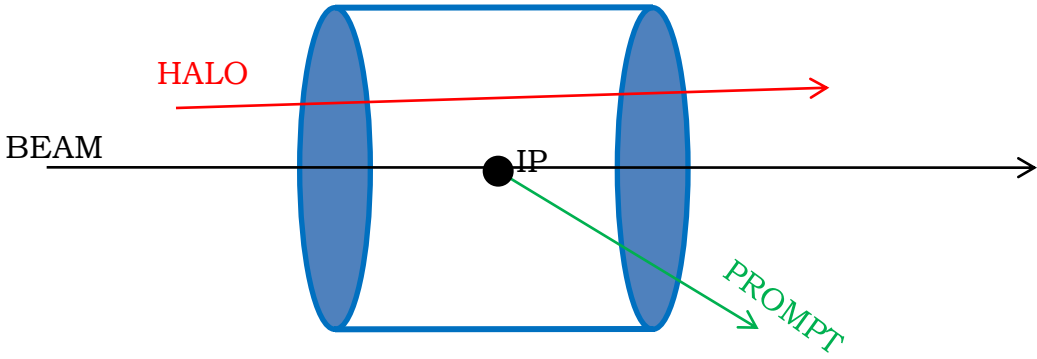
• **Muon System Endcap (EMU) tag :**
→ 115 cm < R_{EMU} < 170 cm
→ $\Delta\phi_{ph\text{-}EMU}$ < 0.2

• **HALO :**
→ No reco track
→ MET > 25 GeV
→ HE or EMU tag

• **PROMPT :**
→ > 3 reco tracks
→ MET < 15 GeV
→ |tseed| < 3 ns
→ no tag

• **CANDIDATE :**
→ > 3 reco tracks
→ MET > 25 GeV
→ photon with ET > 30 GeV
→ |tseed| < 3ns
→ no tag

• **Selected photons :**
→ No pixel seed
→ ET > 30 GeV
→Track Iso < 2 GeV
→ ECAL Iso. < 4.2 GeV
→ HCAL Iso. < 2.2 GeV
→ H/E < 0.05
→ **E_2/E_{5x5} < 0.95**



⇒ Time of seed in ECAL
⇒ Angle w.r.t beam axis