Hadron Collider Physics Symposium
Evian, France, November 2009

Photon Commissioning in ATLAS

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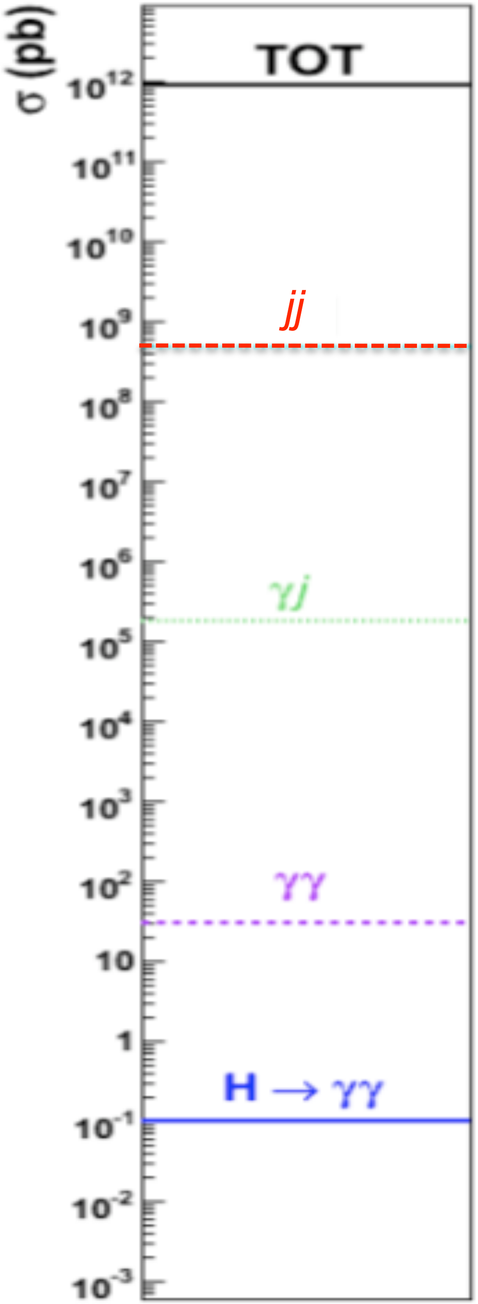
(on behalf of the ATLAS Collaboration)

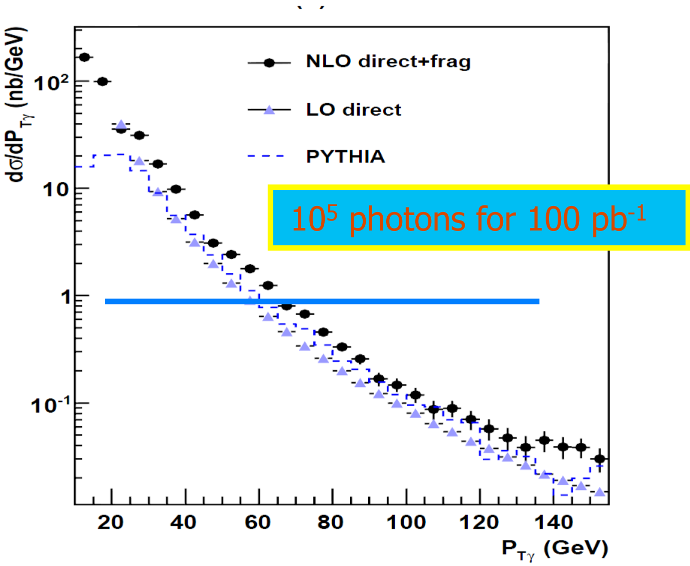
Photons at the LHC

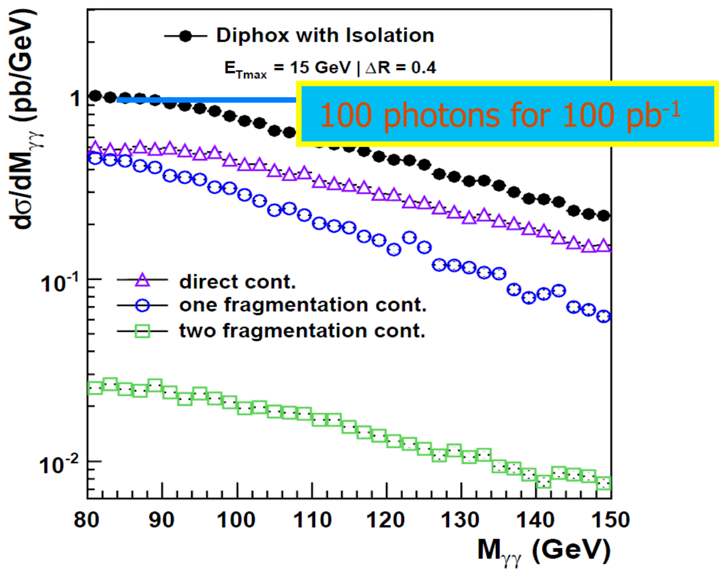


- Main sources of high p_T isolated γ at the LHC: QCD processes.
- Main background: jets

The search for new phenomena with photons requires:

- efficient photon reconstruction
- accurate photon energy and direction measurement
- particle identification: jets rejection

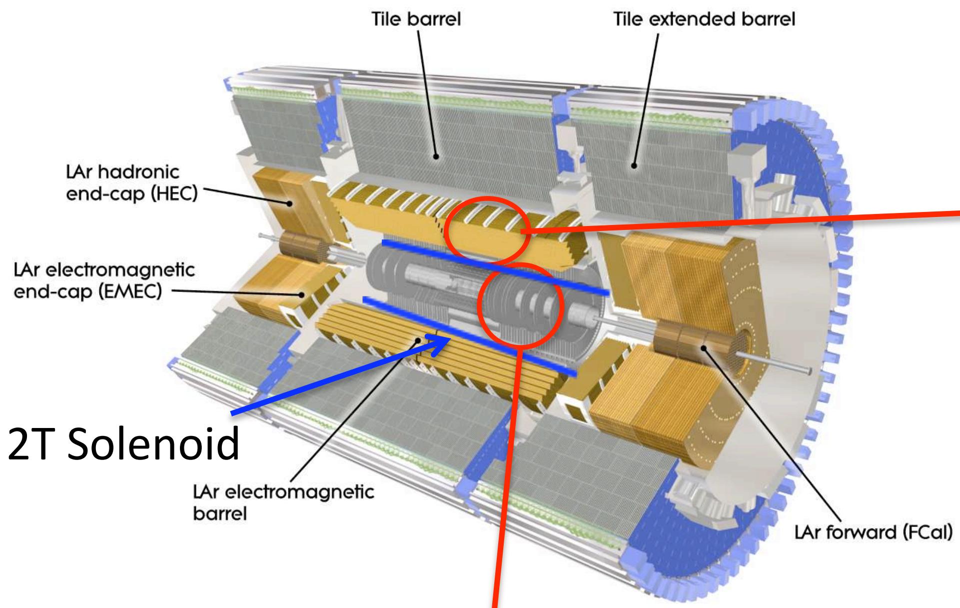


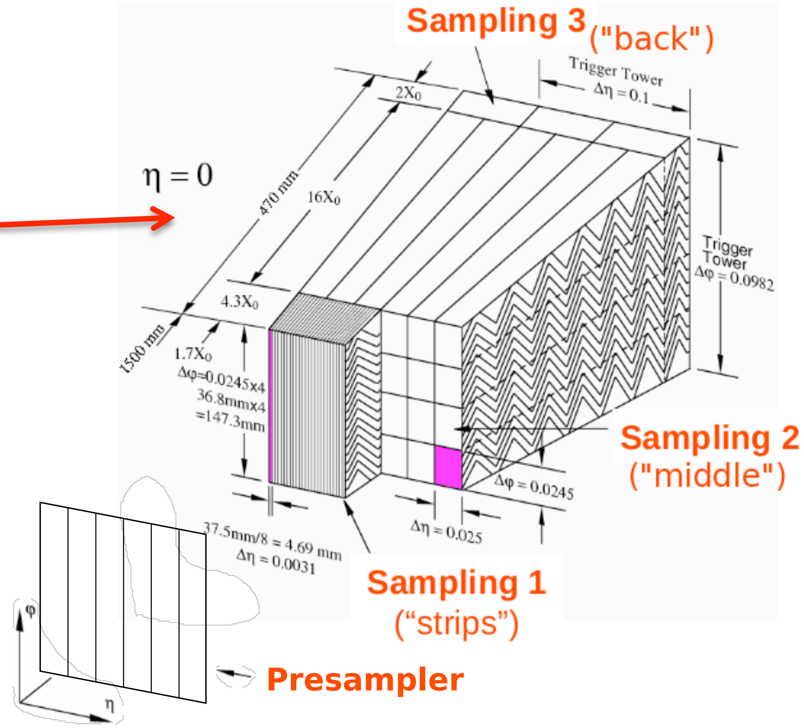


Prompt photon statistics not a problem at the LHC:

- Hundreds of thousands of single prompt photons
- Thousands of di-photons

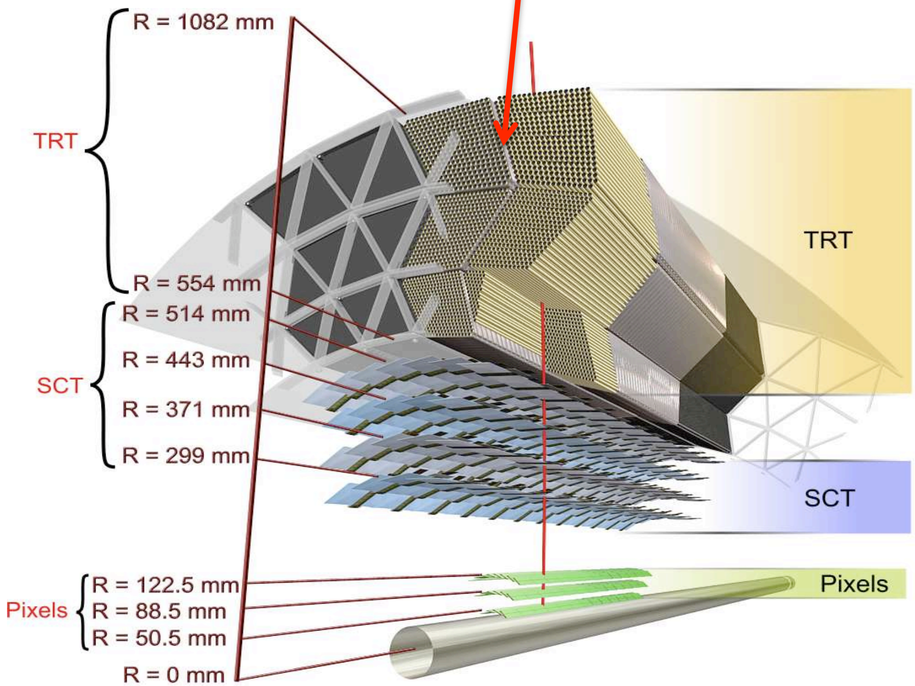
ATLAS sub-detectors used for photon reconstruction





Liquid Argon e.m. calorimeter

Coverage $|\eta| < 3.2$ (precision < 2.5)
Total thickness: $>24X_0$
170k channels



ATLAS Tracker

Coverage $|\eta| < 2.5$
- 3 pixel layers
- 8 strip layers (4 space points)

~36 measurements on track straw detector
- electron PID capability

Photon Reconstruction in ATLAS

Clustering algorithm for photons:

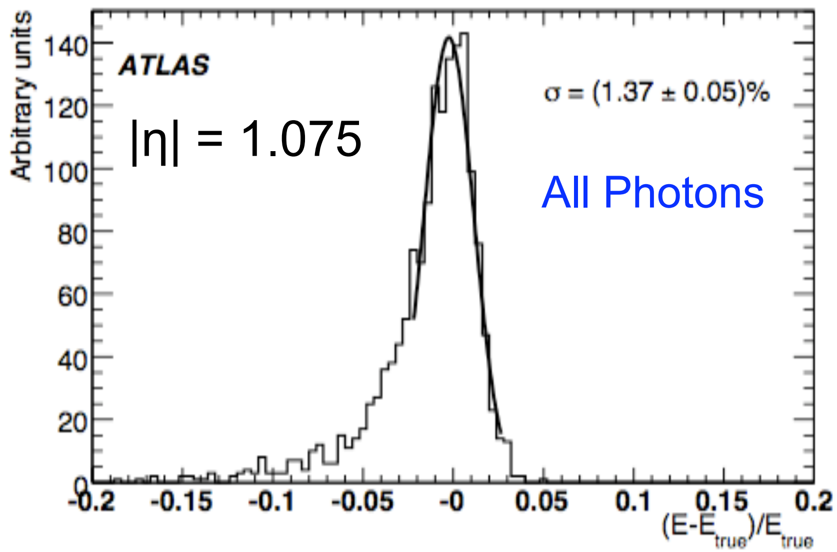
- slide a window ΔηxΔφ = 5x5 in a calorimeter tower (over 4 samplings); find local max
- track/vertex matching distinguishes electrons from unconverted and converted photons
- re-build the cluster: ΔηxΔφ = 3x5 cells for unconverted photons
  ΔηxΔφ = 3x7 cells for converted photons (wider phi to account for B-field opening)

Energy and position reconstruction:

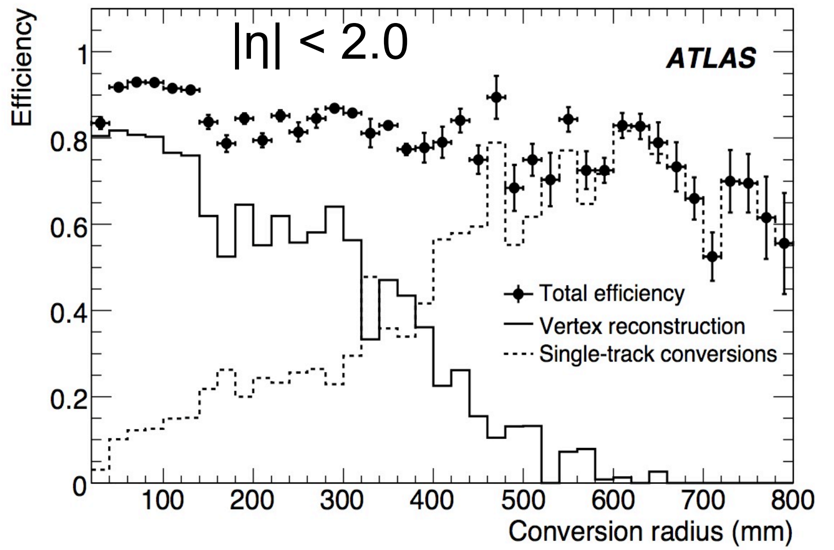
- cells in the clusters are summed
- position dependent energy corrections are applied.

Photon energy resolution

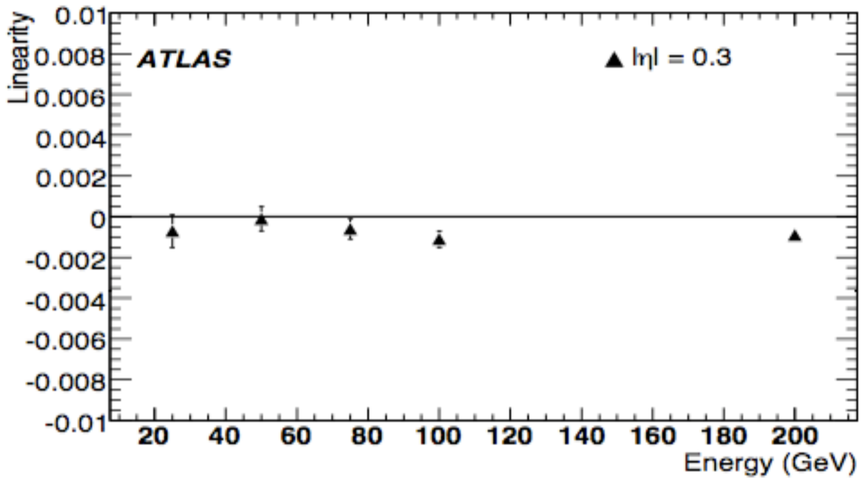
E =100 GeV single photons MC



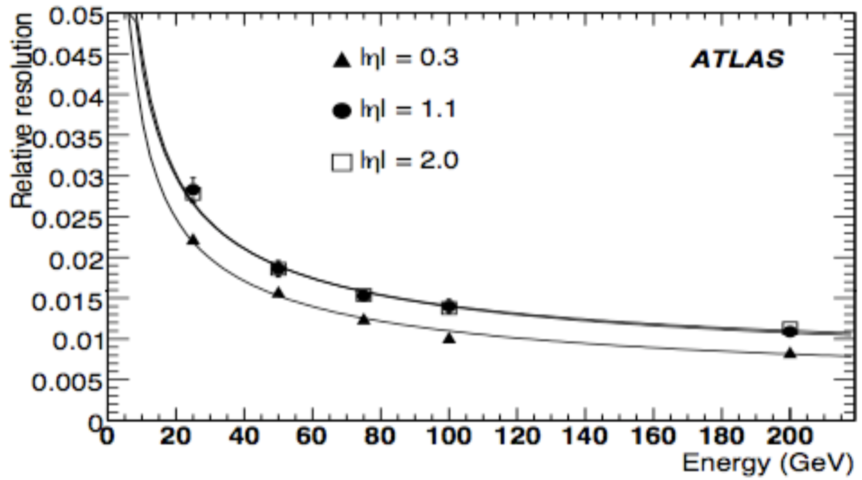
H(120GeV)->γγ, converted photons



Photon Reconstruction in ATLAS II

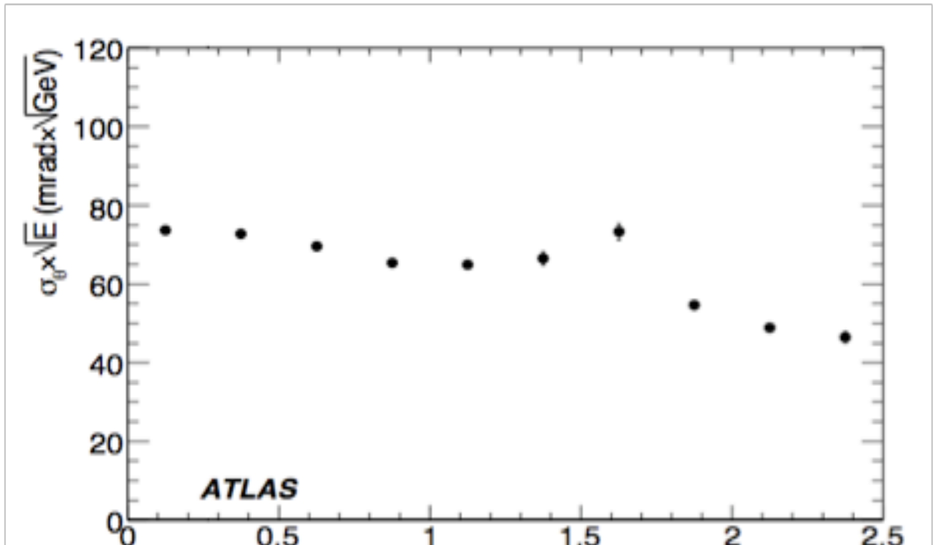


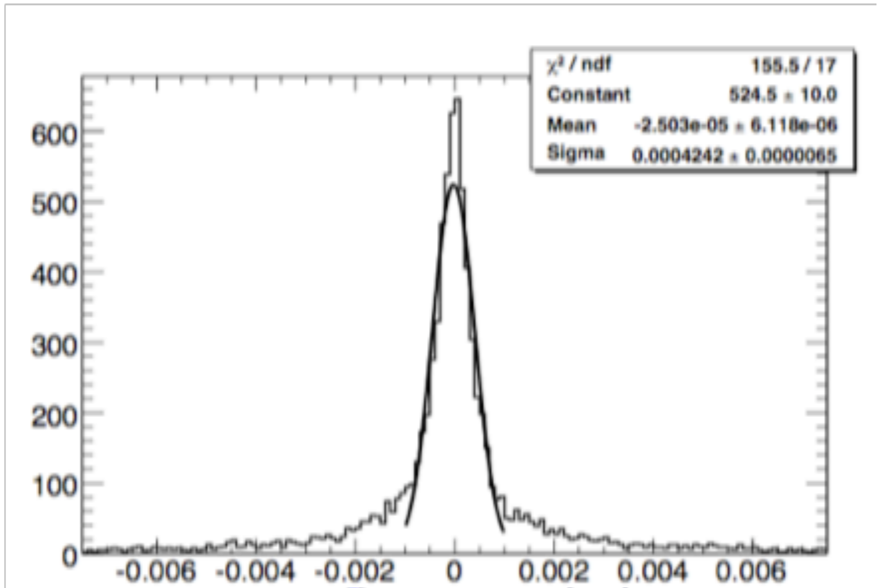
(c) Photon energy linearity.



(d) Photon energy resolution.

Shower direction resolution





Unconverted photons

(45 ÷ 75) mrad/$\sqrt{E}$

Converted photons

width 0.42 mrad

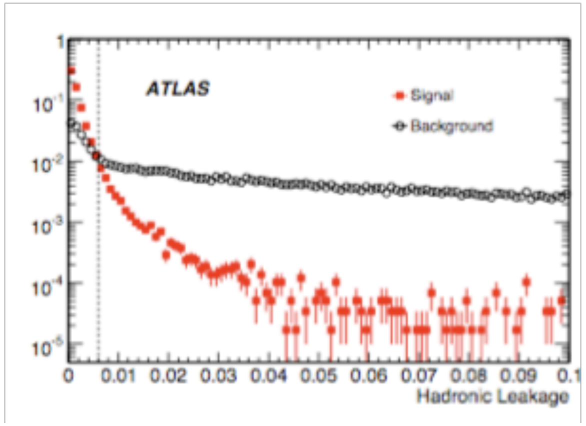
Photon Identification in ATLAS

Photon/Jets discrimination based on their characteristics features:

Photons narrow objects, contained in the e.m. calorimeter.

Jets broader profile and have significant energy deposition in the hadronic calorimeter

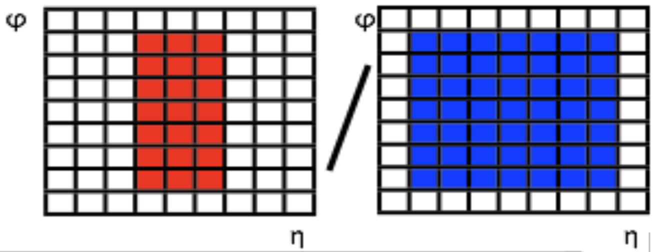
- Hadronic leakage

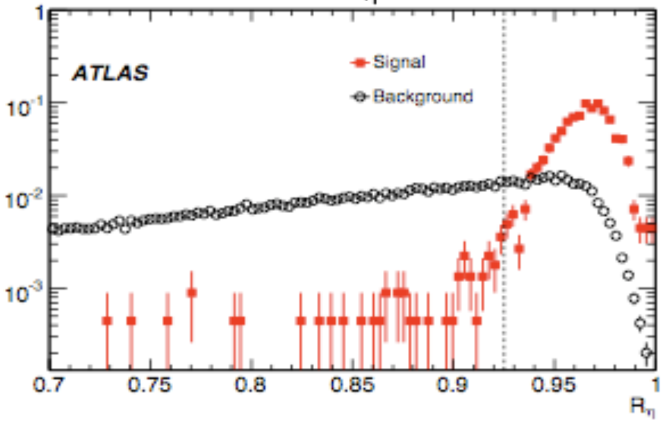


Plots shown for:
$|\eta|<0.7$ $20<E_T<30$GeV

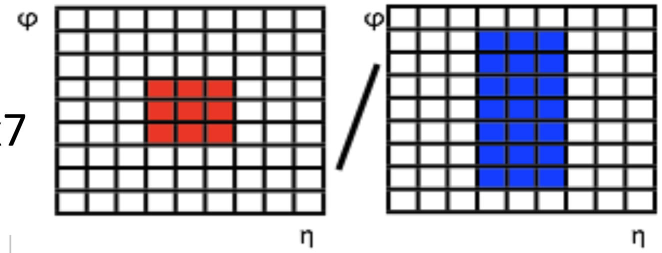
- Shower shapes in the middle layer of the electromagnetic calorimeter:

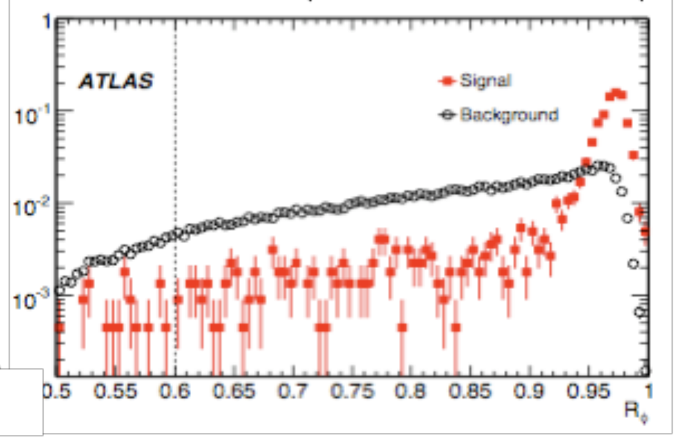
R_η = 3x7 / 7x7





R_ϕ = 3x3 / 3x7

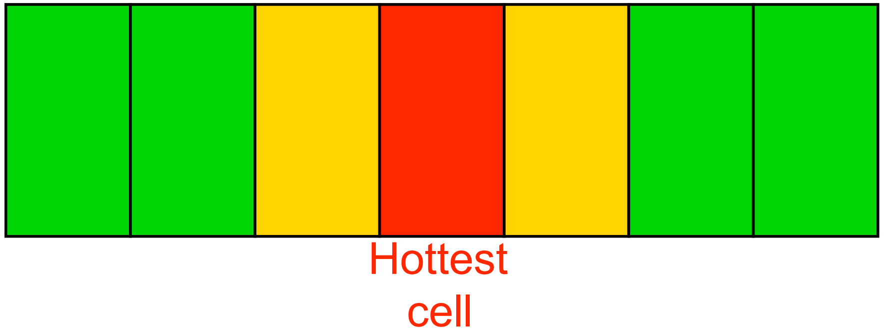


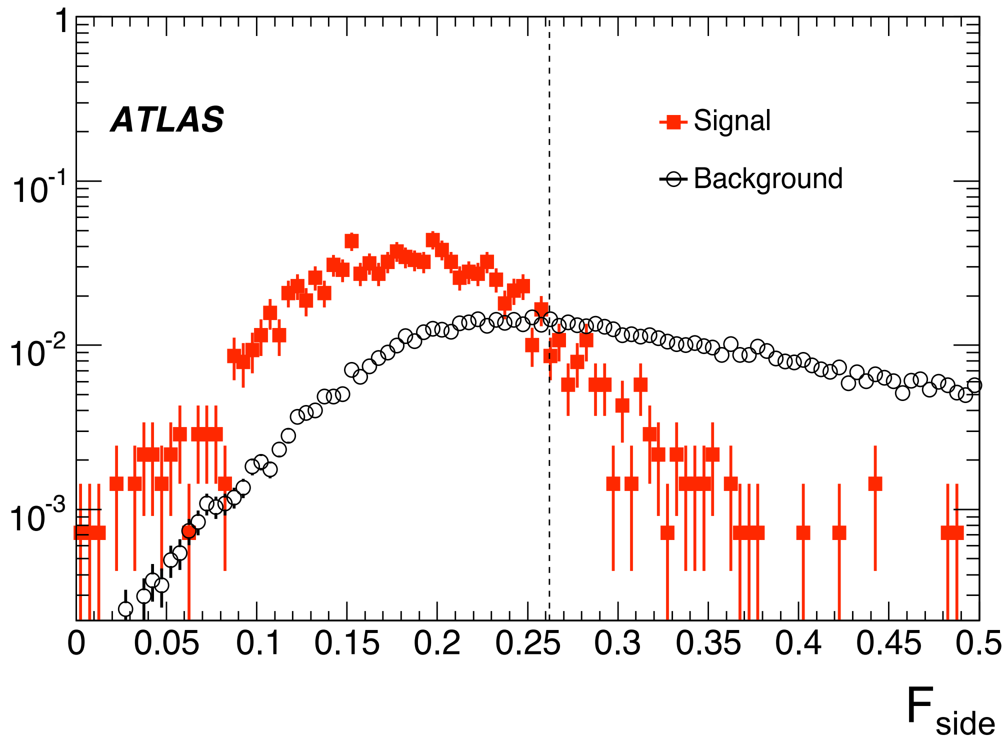


Photon Identification in ATLAS II

Ratio of energy outside core of 3 strips but within 7 strips

$F_{side} = (E_{\pm 3} - E_{\pm 1})/E_{\pm 1}$



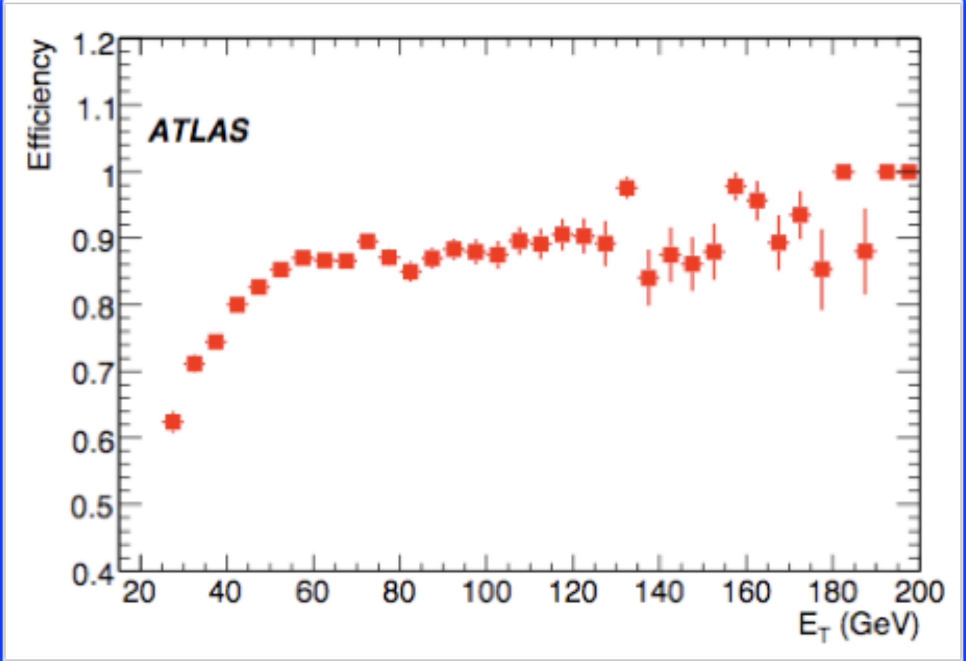


Photon Reconstruction Performance

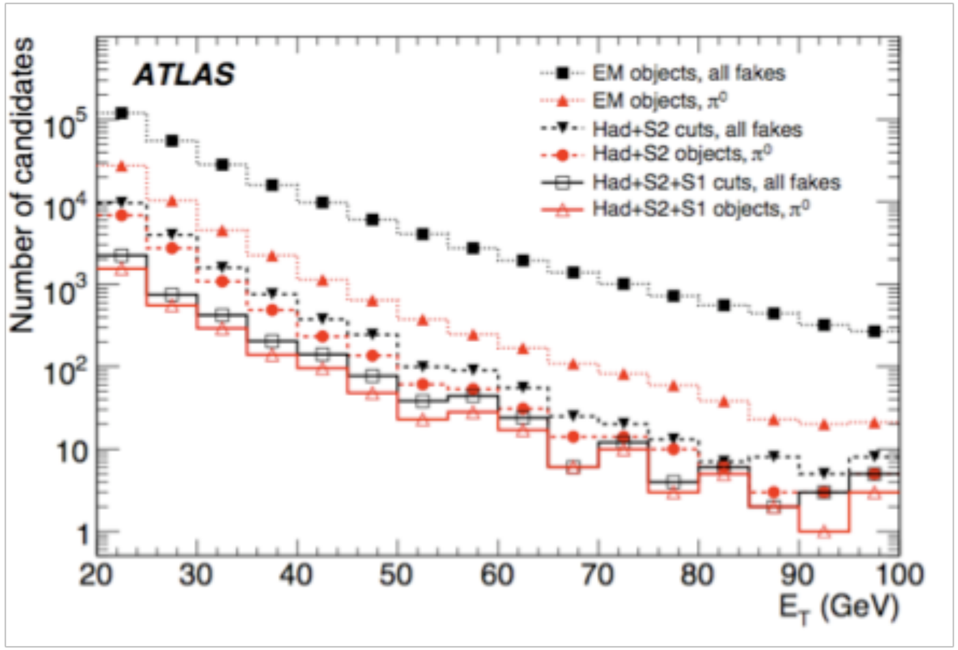
Example: photons E_T > 25 GeV from H→γγ

Main background from tight jets faking photon showers.
A rejection factor of ~10^3-10^4 for quark/gluon jets respectively, is achieved.

Photons



Fakes



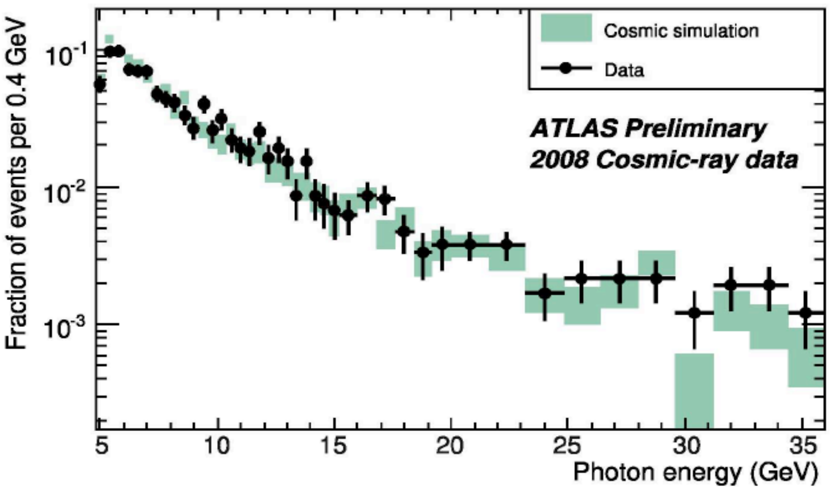
After all cuts 70% of the remaining fake photons are high momentum π^0

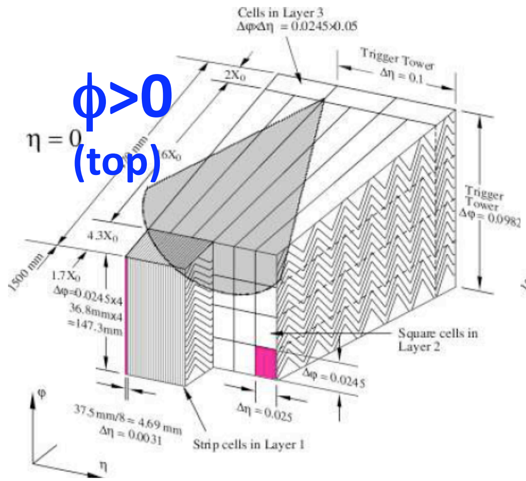
Validation of Photon Identification with Cosmic Events

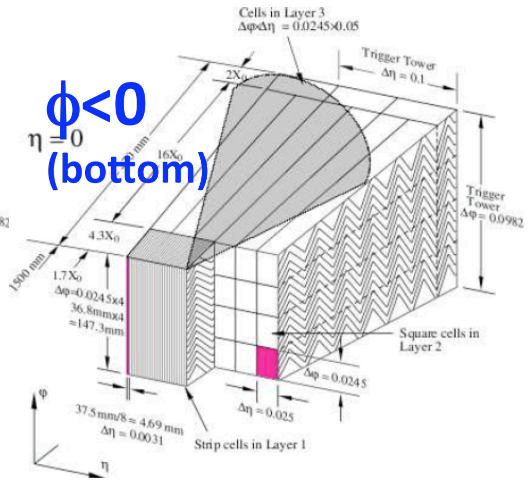
- Would like to validate as much as possible the γ identification before collision data using cosmic events:
  - Confirm robustness of γ initial selection by comparing shower shapes to MC expectations

Limitations of cosmics validation

- Average energy of EM objects in cosmics fairly low
- Most cosmic events are not projective!
- Shower shapes mostly not like what we will see in ATLAS due to cosmics direction
- In the barrel:
  - $\phi>0$ (coming in through the top of the detector) have showers starting in the back of the calorimeter (or before)
  - $\phi<0$ is more like what we expect to see in ATLAS
- Important to compare cosmics data with cosmics MC



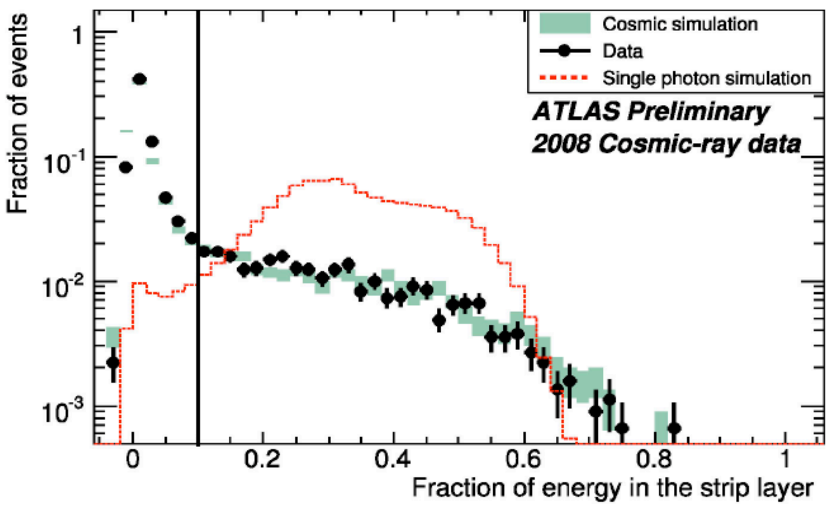




Data Sets and Event Selection

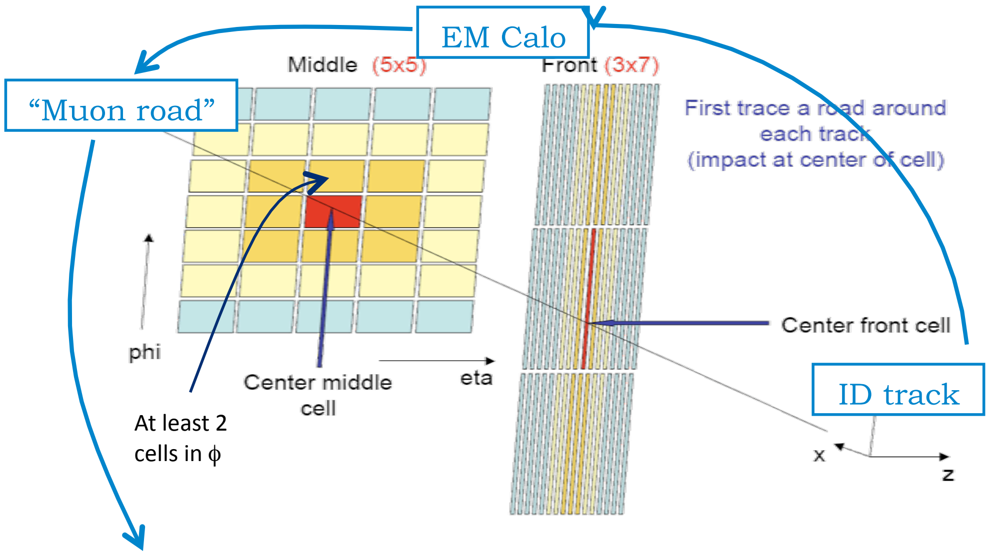
EM shower-shape studies with photons

- **Cosmic dataset:**
  - Barrel: 3.5M events with high-level trigger (L2) track candidate reconstructed in barrel inner detector (IDCosmics trigger stream)
  - Endcap: 270k events, at least one sliding-window cluster in EM (L1CaloEM trigger stream)
- **Cosmic simulation:**
  - 11.7M cosmic-muons required to go through the ID geometrical volume
- **Barrel event selection:**
  - $E_{cluster}$>5GeV (sliding-window cluster)
  - Loose projectivity: at least one Si track $|d_0|$ < 220 mm and p_T > 5 GeV
  - "collision-like" photon candidates: E_{strips} /$E_{cluster}$ > 0.1
  - 1200 candidates for the data and 2161 for simulation

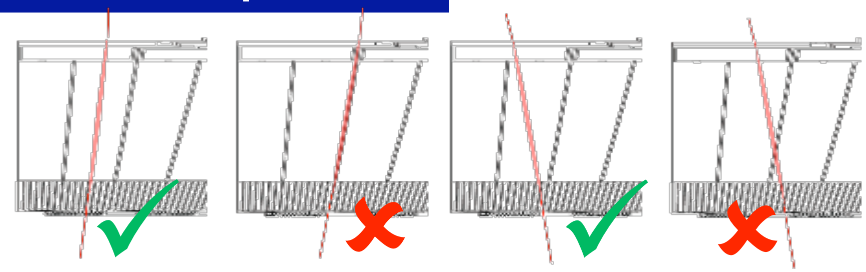


Work in progress for the endcaps

Measured Calorimeter Response



Middle : 1x3
Front : 2x1

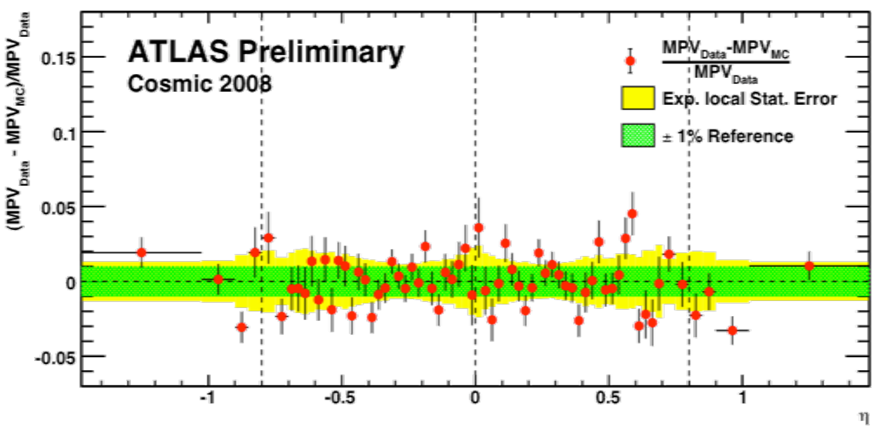


Projectivity and centrality of muons are not trivial => tight selection

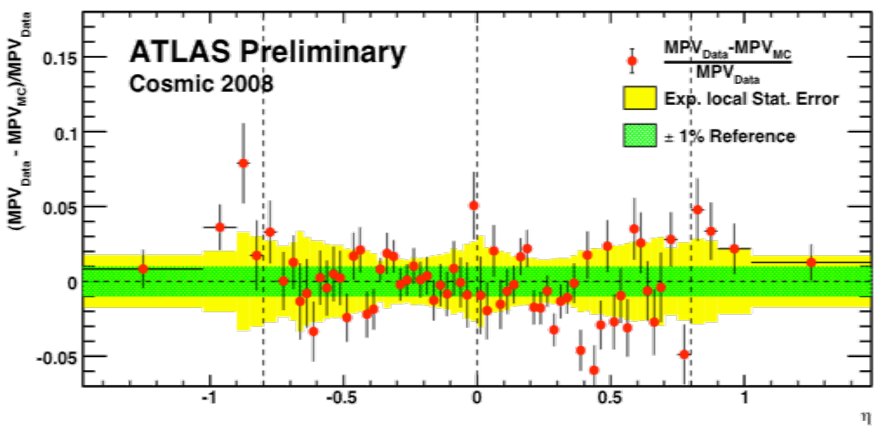
Event selection:

- From DPD stream : Projective ID track (1 hit in Si, |z0|,|d0| < 300 mm)
- Addional cut based on geometry of LAr cells
  - No effect of misalignments !
  - Cuts effects of leakage
- After cuts, about 75 000 events left

Middle layer



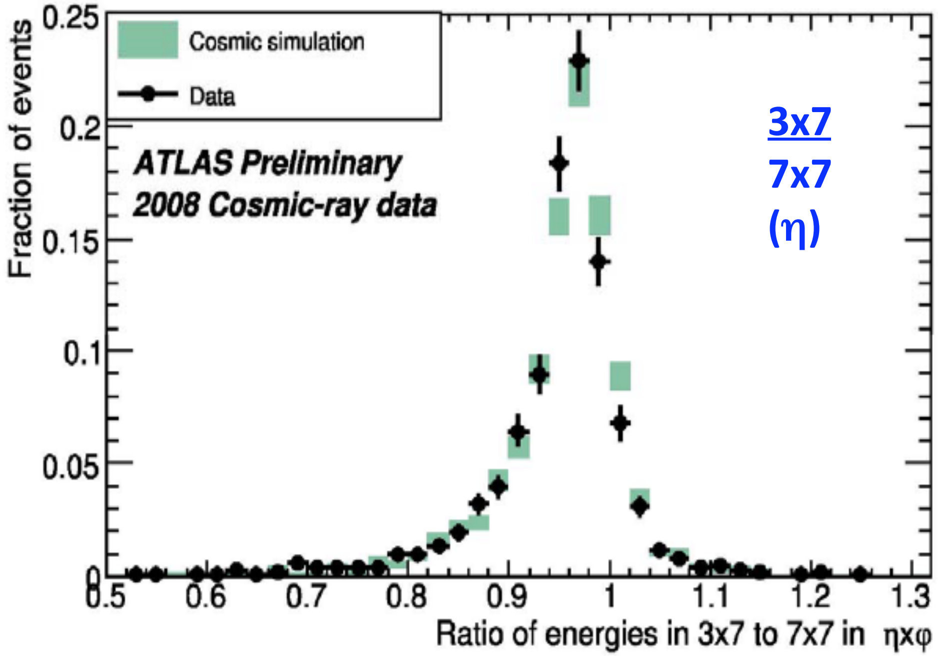
Front layer



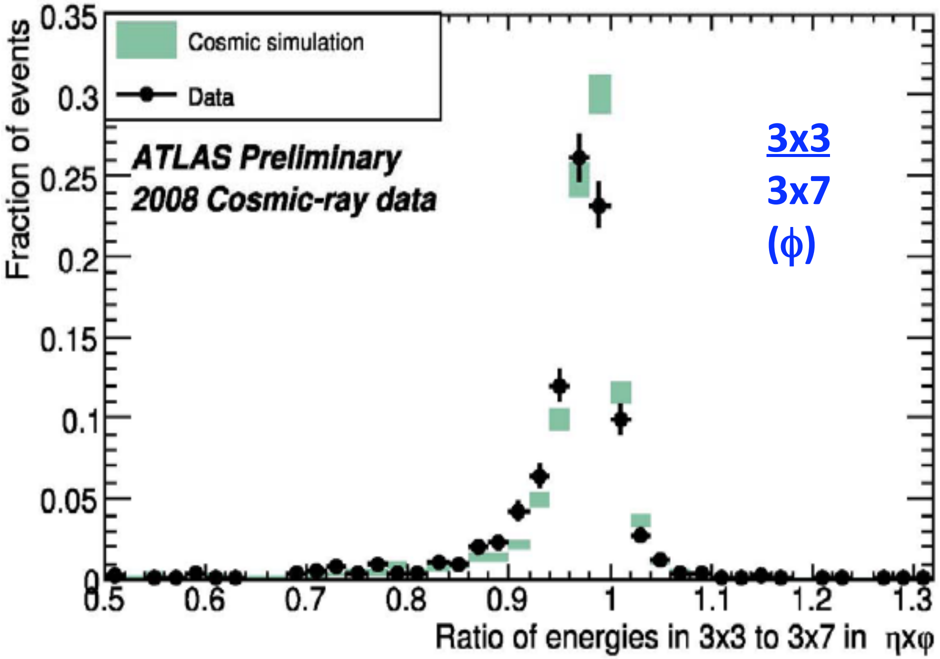
Middle Layer Calorimeter Variables

At the heart of electron/photon identification!

- The lateral shower containment in the middle layer ($\Delta\eta x\Delta\phi \cong 0.025x0.025$)
  - Along η : Ratio of energy in a $\Delta\eta x\Delta\phi$ =3x7 cells cluster size with respect to a 7x7 cells cluster size
  - Along Φ : Ratio of energy in a $\Delta\eta x\Delta\phi$ =3x3 cells cluster size with respect to a 3x7 cells cluster size
- Agreement between cosmics data and simulation gives confidence that these are reasonably robust variables to use with early data.



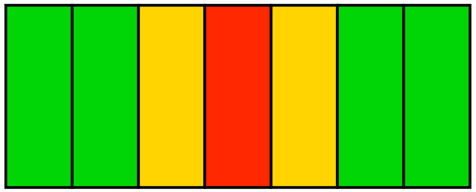
3x7
7x7
(η)



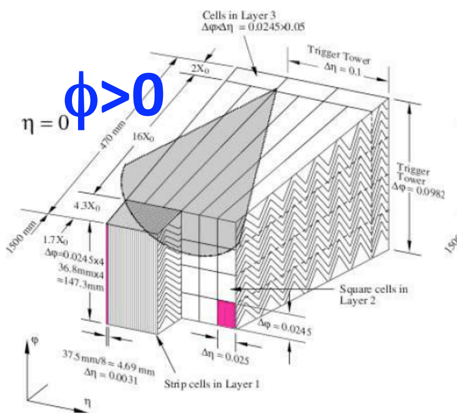
3x3
3x7
(ϕ)

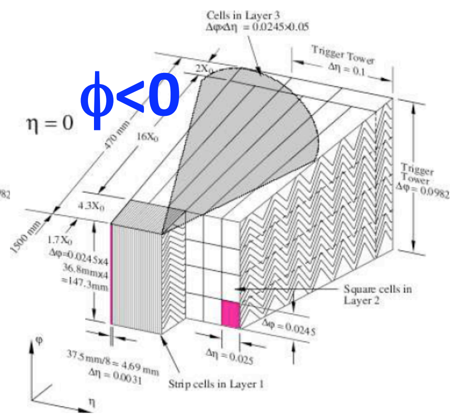
First Layer (strips) Calorimeter Variables

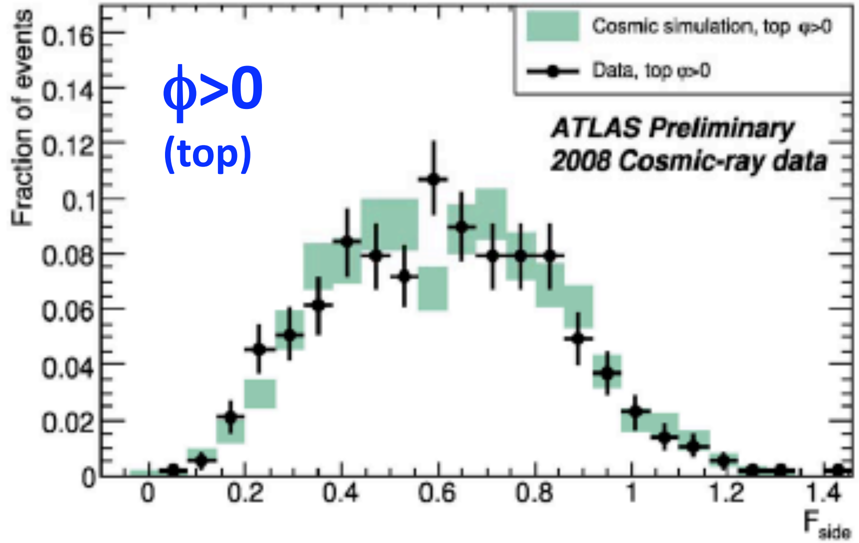
- The lateral shower containment in strip layer
  - Ratio of energy outside core of 3 strips but within 7 strips
    - $F_{side} = (E_{\pm 3} - E_{\pm 1})/E_{\pm 1}$

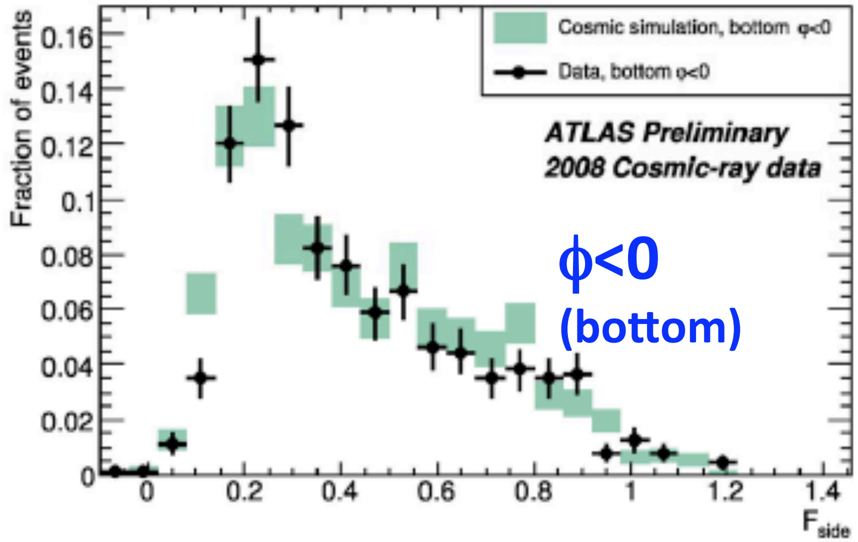


- **ϕ>0 (top):** shower profile is wider
  - more likely to be initiated in middle or back calorimeter layers
- **ϕ<0 (bottom):** shower profile is narrower
  - showers initiated in ID or cryostat wall

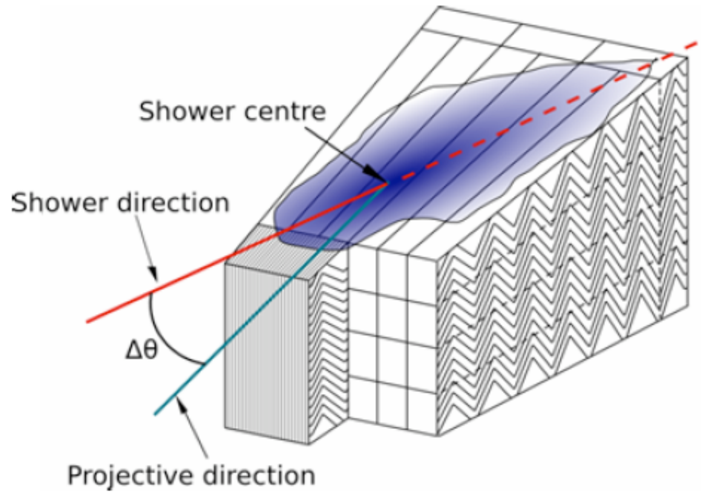




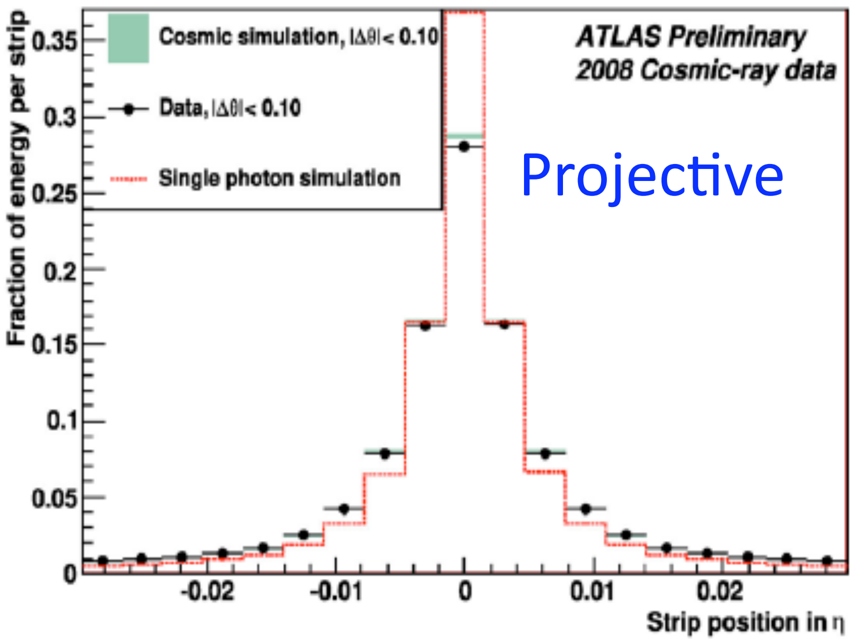


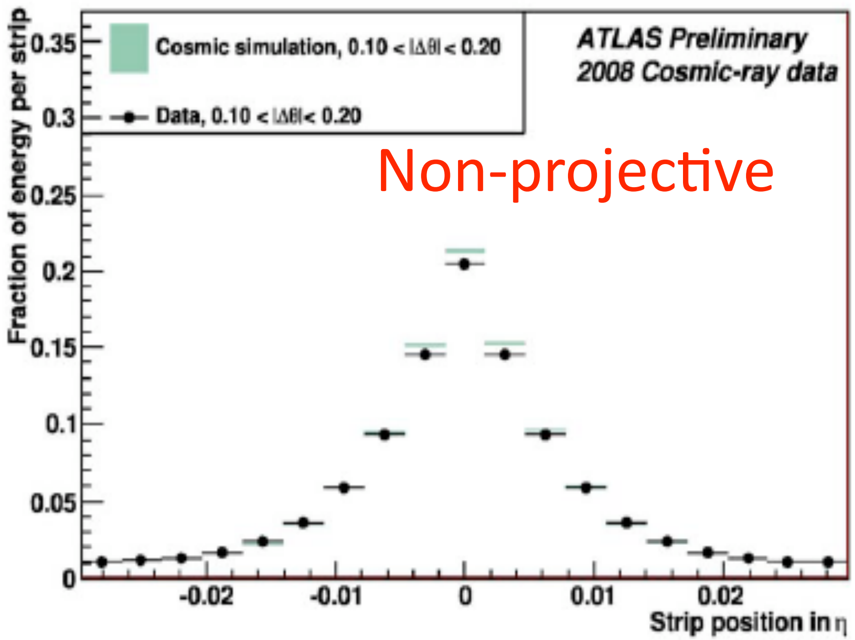


Calorimeter Strip Variable Dependence on Projectivity



- Δθ = shower direction – direction from centre of detector to centre of cluster
- Plots of average lateral profiles in the strips
  - Data, simulated cosmic-rays, simulated projective single photon showers (E_T=5GeV)
- projective (|Δθ| <0.10) and non-projective (0.10<|Δθ| <0.20) showers
  - widening of the showers as they become less projective



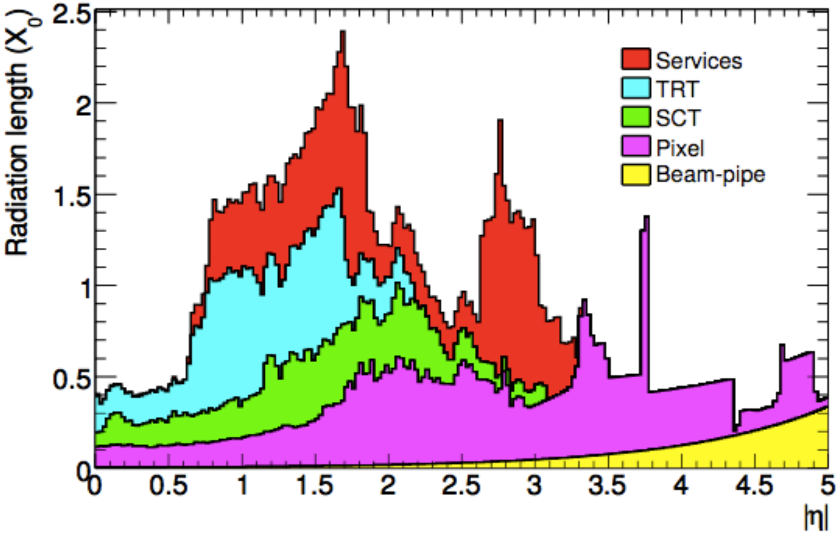


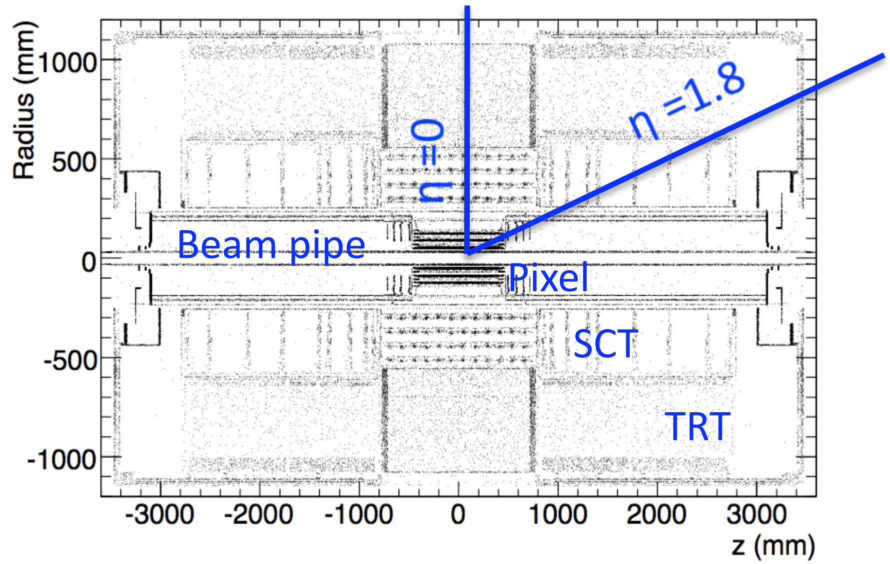
Material Mapping with Converted Photons I

LHC trackers: heavier than any previous one (LEP, TeVatron):

ATLAS Inner Detector ~ 4.5 ton

Large amount of material in front of the EM calorimeter means:
- large energy losses of electrons through bremsstrahlung
- high photon conversion probability
- a complex calibration procedure for the EM calorimeter





The conversion probability ranges from 40 % (η =0) up to 80% (η =1.8)

Knowing the exact amount and position of the upstream material is of paramount importance !

Use conversions as a tool to reconstruct the 3D material map of the detector

Radial resolution (3mm) with low p_T photons.

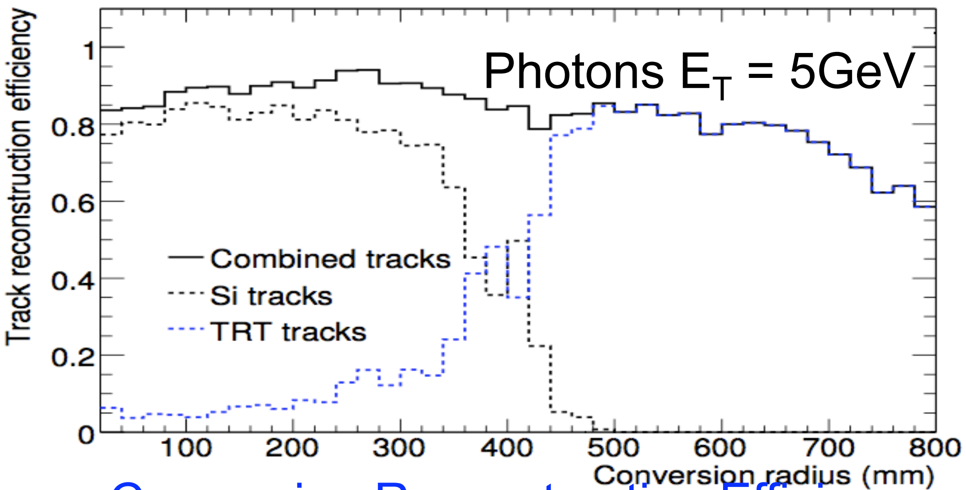
Material Mapping with Converted Photons II

Precise 3D mapping of the material with low-energy conversions from minimum bias data

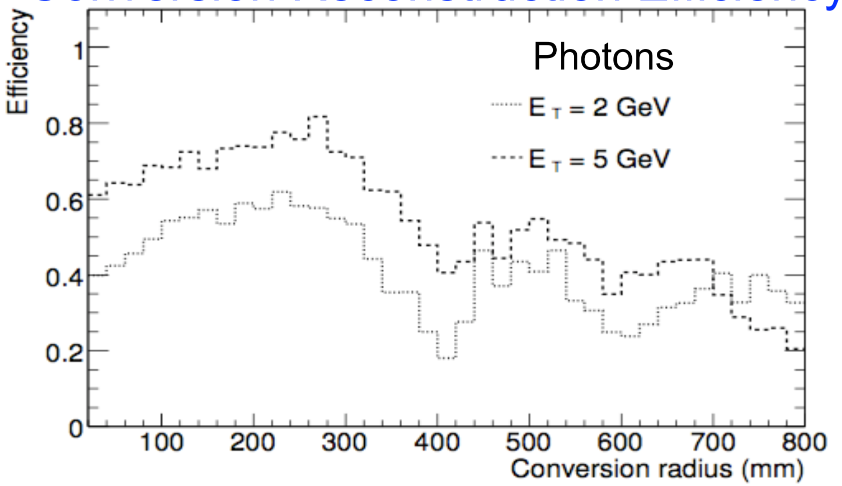
Enough statistics for a 1% material map in a few months of data taking

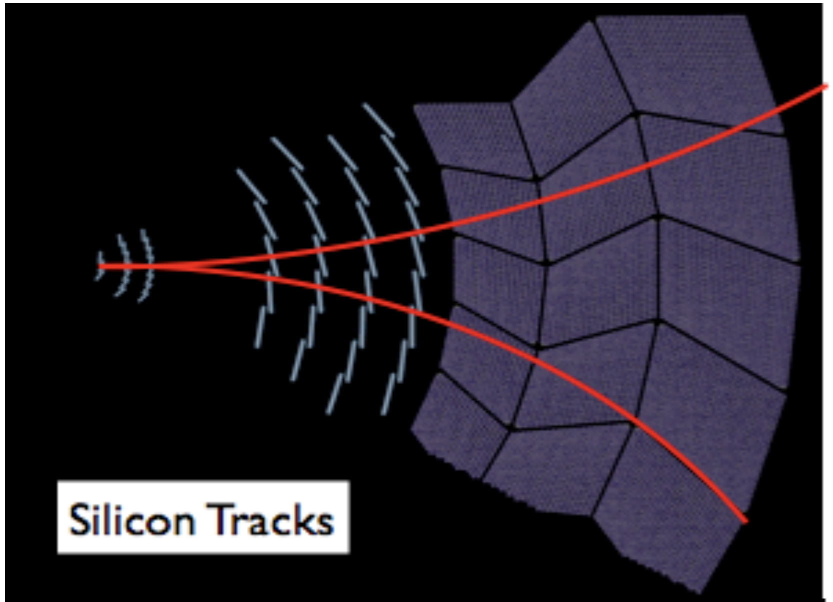
Conversion ingredients: Tracking + Vertexing

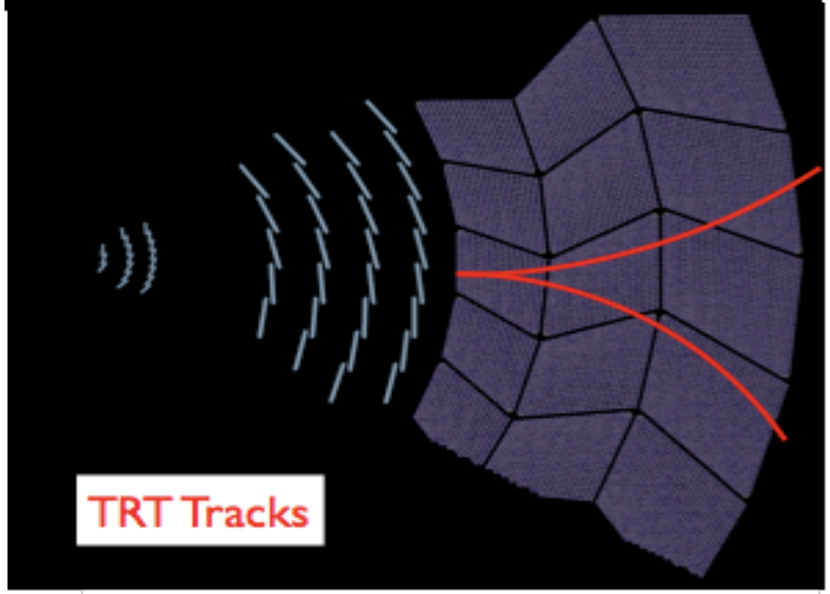
Tracking Efficiency



Conversion Reconstruction Efficiency

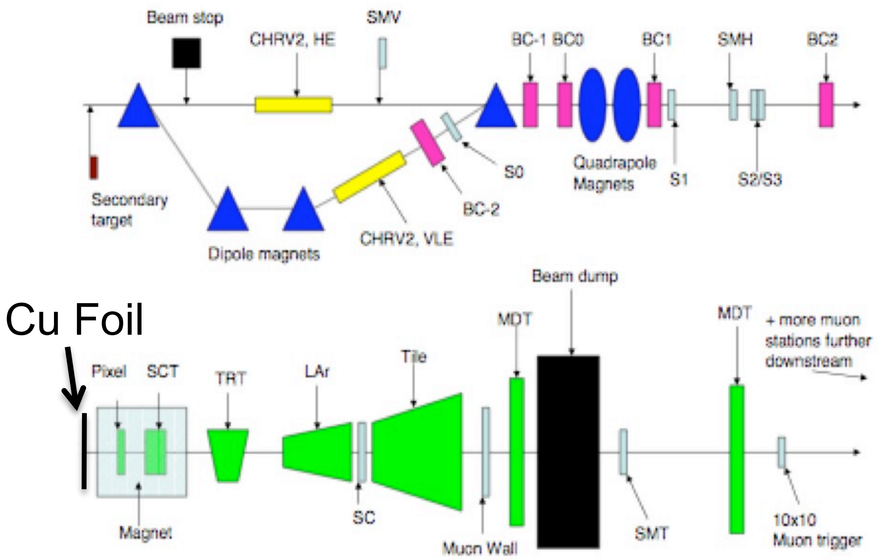


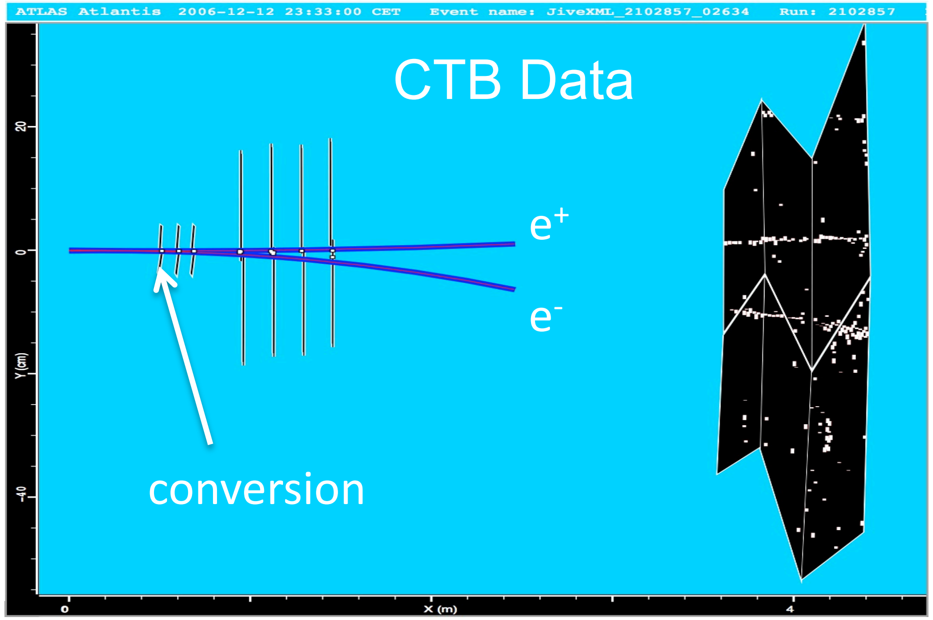




Material Mapping with Converted Photons III

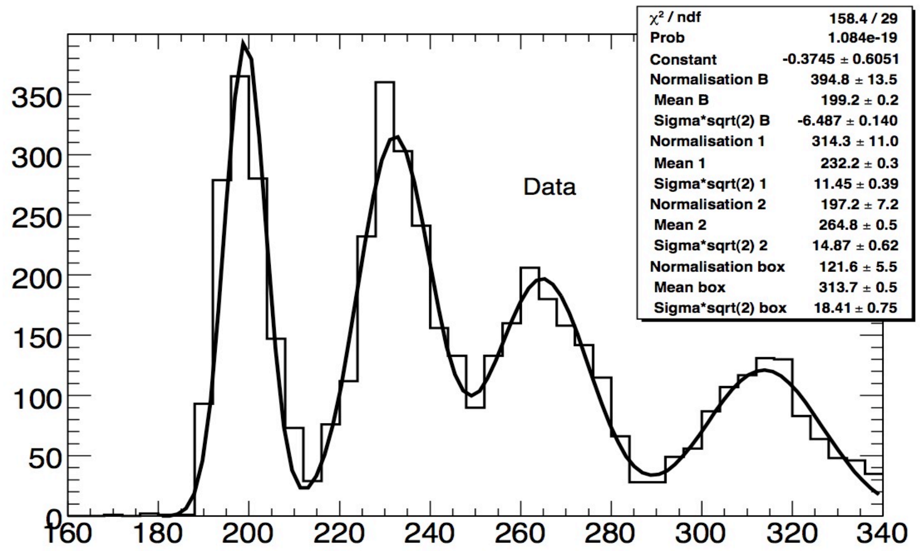
Converted photons already used to map the Inner Detector material in the 2004 Combined Test Beam (CTB)

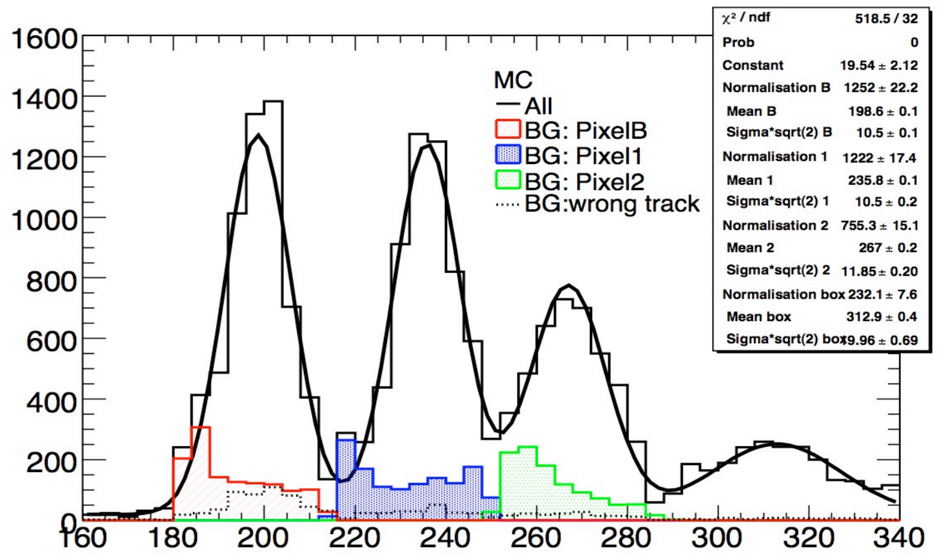




- Events with two TRT track segments pointing back to the Si tracker are selected.
- Concentrate on conversion vertices reconstructed in the pixel tracker.
- Count reconstructed conversions within each pixel layer:
  - Use the simulation to correct for efficiency variations on each layer
- Use the well measured Cu foil in front of the pixel as a material reference.

Material Mapping with Converted Photons IV (Preliminary)





Estimated amount of material per pixel layer with respect to the Cu foil

	Copper	PixelB	Pixel1	Pixel2
X/X_0(%) with stat. error	0.21±0.02±0.04	1.68±0.19±0.35	1.95±0.23±0.40	1.98±0.24±0.41
Ratio	–	8.16±1.28±1.97	9.47±1.51±2.29	9.62±1.56±2.26
X/X_0(%) in MC	0.25	2.6	2.6	2.6
Ratio in MC	–	10.4	10.4	10.4

Good qualitative agreement between data and simulation.
Absolute value restricted by large systematic error on the incoming photon flux.

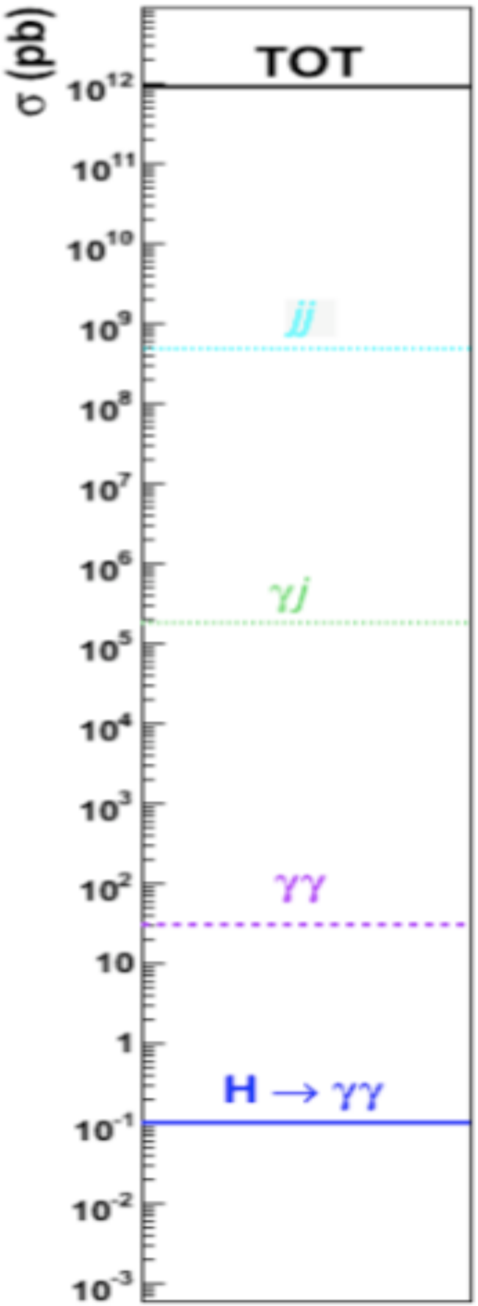
Summary

- Photons constitute an important tool for commissioning the ATLAS detector:
  - Plenty of signal already with early data
- Dedicated software for photon reconstruction already in place
  - Utilization of few simple variables to validate quantities for photon identification
  - Initial performance based on MC data well established
- Cosmics data of great importance for validating the photon reconstruction:
  - Significant amount of available statistics
  - Contain both the tracker and the EM calorimeter inputs
  - Comparison with the cosmics data MC confirms the robustness of the reconstruction
- Converted photons an important tool for accurate detector description
  - Conversions in minimum bias data can be used to determine the tracker material
  - Initial implementation in the Combined Test Beam gave consistent results.
  - Enough statistics within a few months to map the tracker material down to 1% accuracy
  - Initial source of clean electron sample for PID commissioning in the TRT.

Looking forward to see the first photons from collisions into the ATLAS detector!

Backup Slides

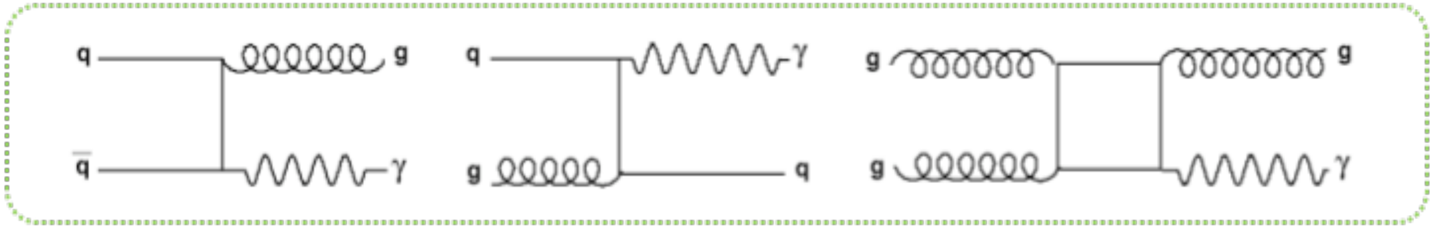
Photons at the LHC

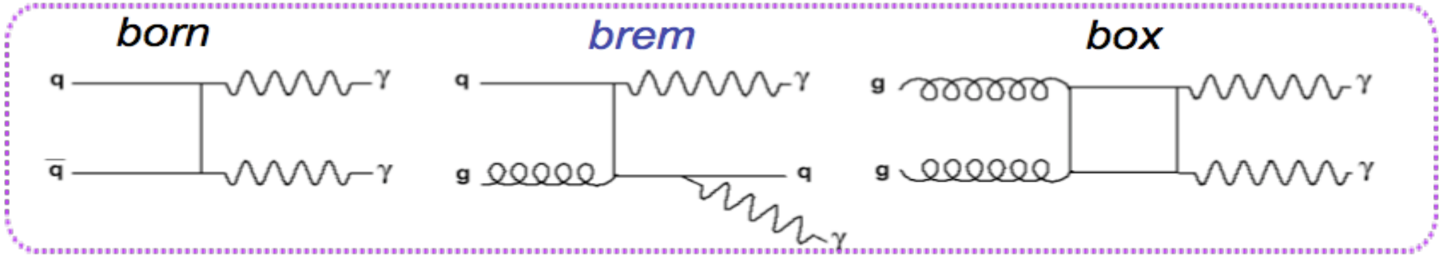


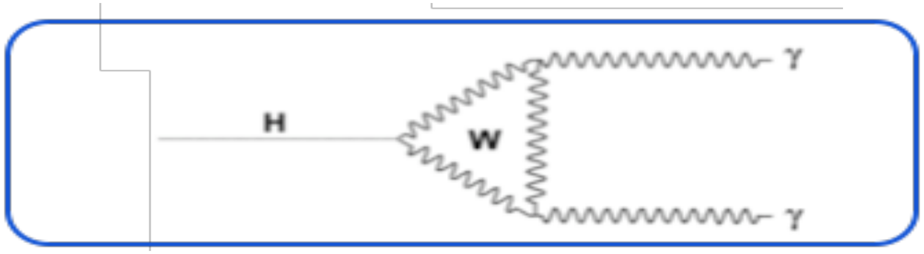
- Main sources of high p_T isolated γ at the LHC: QCD processes.
- Main background: jets

The search for new phenomena with photons requires:

- efficient photon reconstruction
- accurate photon energy and direction measurement
- particle identification: jets rejection

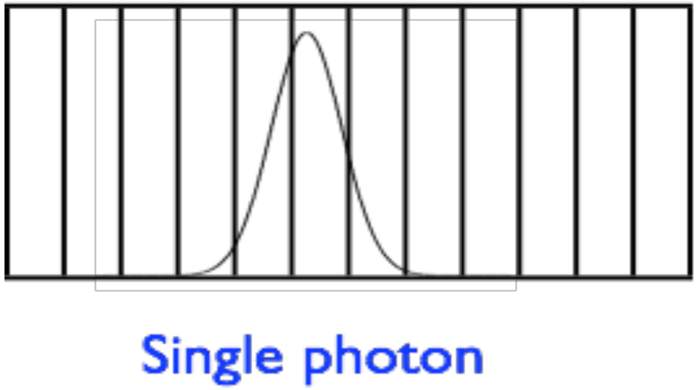


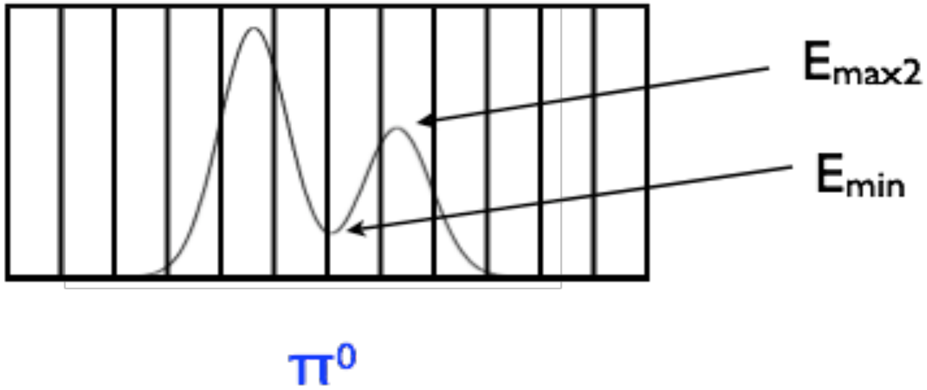


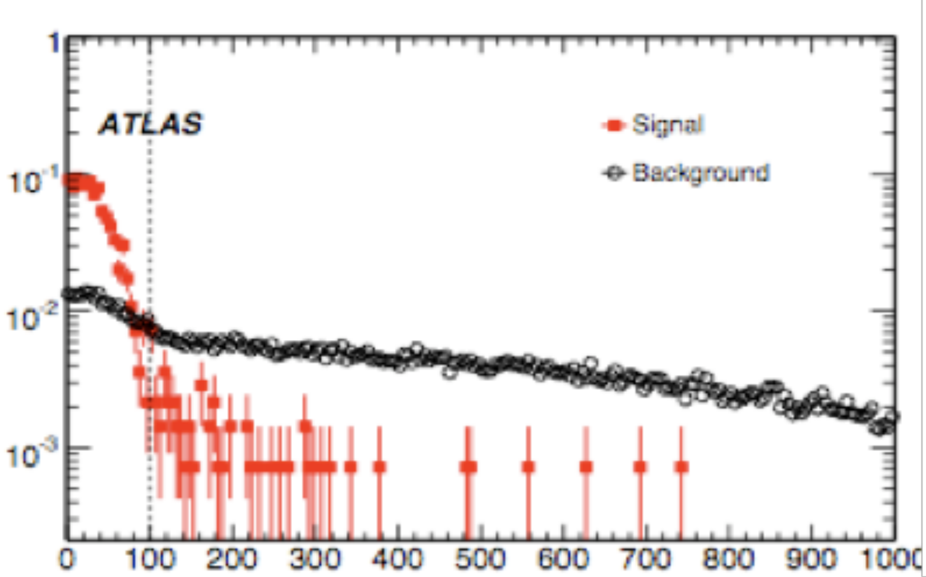


Photon Identification in ATLAS II

Example of a variable built with the strips (first layer) of the electromagnetic calorimeter:







$\Delta E_s = E_{max2} - E_{min}$

Track Isolation

After shower shape cuts the remaining background is dominated by low track multiplicity jets containing a high pT π^0

Track Isolation = sum of the pT of all tracks with pT>1 GeV within $\Delta R<0.3$ (tracks from conversions are excluded)