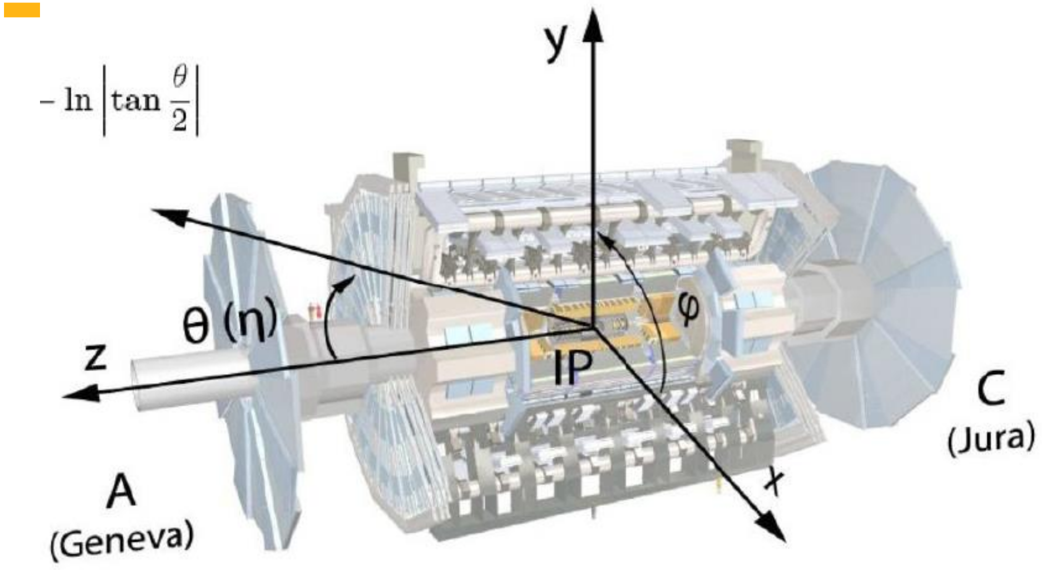
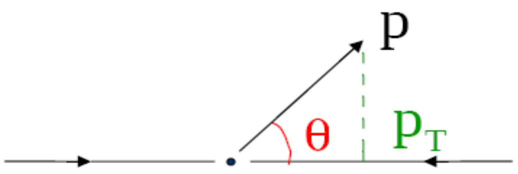
ATLAS Detector



THE ATLAS DETECTOR IS REALLY BIG!

- Length : ~ 46 m
- Radius : ~ 12 m
- Weight : ~ 7000 tons
- ~ 10^8 electronic channels
- 3000 km of cables



Transverse momentum

(in the plane perpendicular to the beam)

$$p_T = p \sin\theta$$

Rapidity: $\eta = -\log\left(\mathrm{tg}\,\frac{\theta}{2}\right)$

$\theta = 90^\circ \rightarrow \eta = 0$

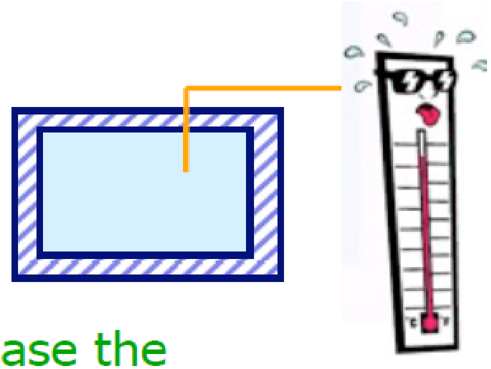
$\theta = 10^\circ \rightarrow \eta \cong 2.4$

$\theta = 170^\circ \rightarrow \eta \cong -2.4$

What is calorimeter

Concept comes from thermo-dynamics:

A leak-proof closed box containing a substance which temperature is to be measured.



Temperature scale:

1 calorie (4.185J) is the necessary energy to increase the temperature of 1 g of water at 15°C by one degre

At hadron colliders we measure GeV (0.1 - 1000)

1 GeV = 10^9 eV ≈ 10^9 * 10-^{19}J = 10^{-10} J = 2.4 10^{-9} cal

1 TeV = 1000 GeV : kinetic energy of a flying mosquito

Required sensitivity for our calorimeters is
~ a thousand million time larger than
to measure the increase of temperature by 1°C of 1 g of water

Why calorimeters

First calorimeters appeared in the 70's:

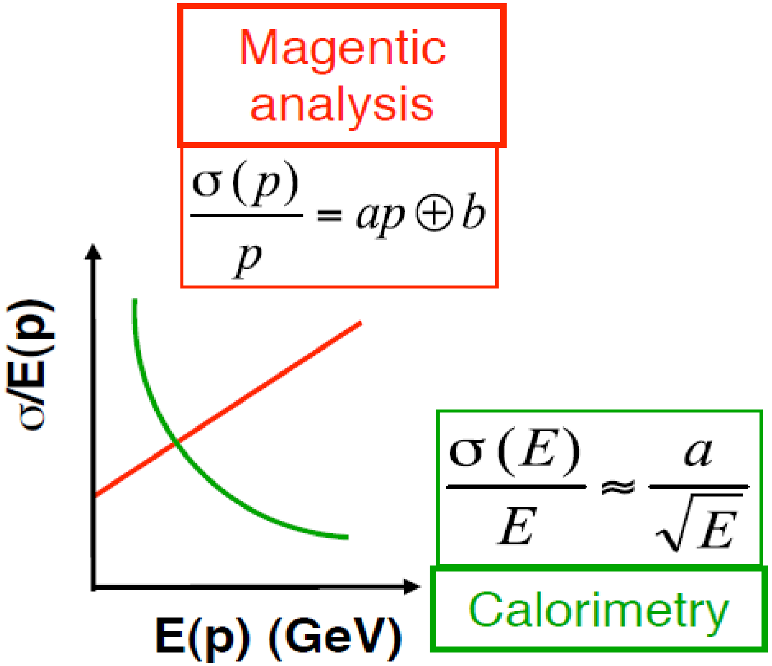
need to measure the energy of all particles, charged and neutral.

Until then, only the momentum of charged particles was measured using magnetic analysis.

The measurement with a calorimeter is destructive e.g.

$$\pi^- + p \rightarrow \pi^0 + n$$

$$\hookrightarrow \gamma\ \gamma$$



Magentic analysis

$$\frac{\sigma(p)}{p} = ap \oplus b$$

$$\frac{\sigma(E)}{E} \approx \frac{a}{\sqrt{E}}$$

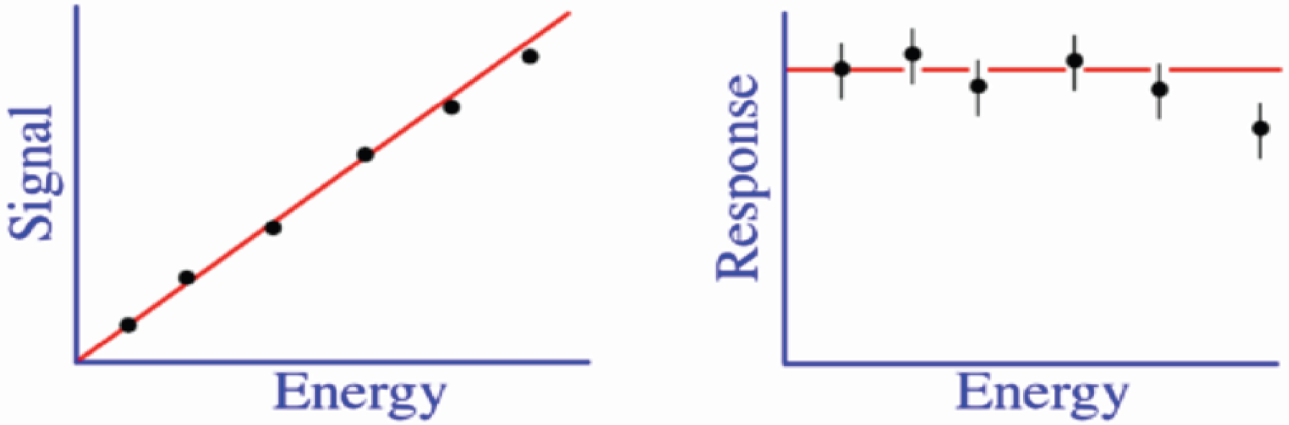
Calorimetry

Particles do not come out alive of a calorimeter

Important characteristic: linearity

Response: mean signal per unit of deposited energy
e.g. # of photons electrons/GeV, pC/MeV, μA/GeV

→A linear calorimeter has a constant response

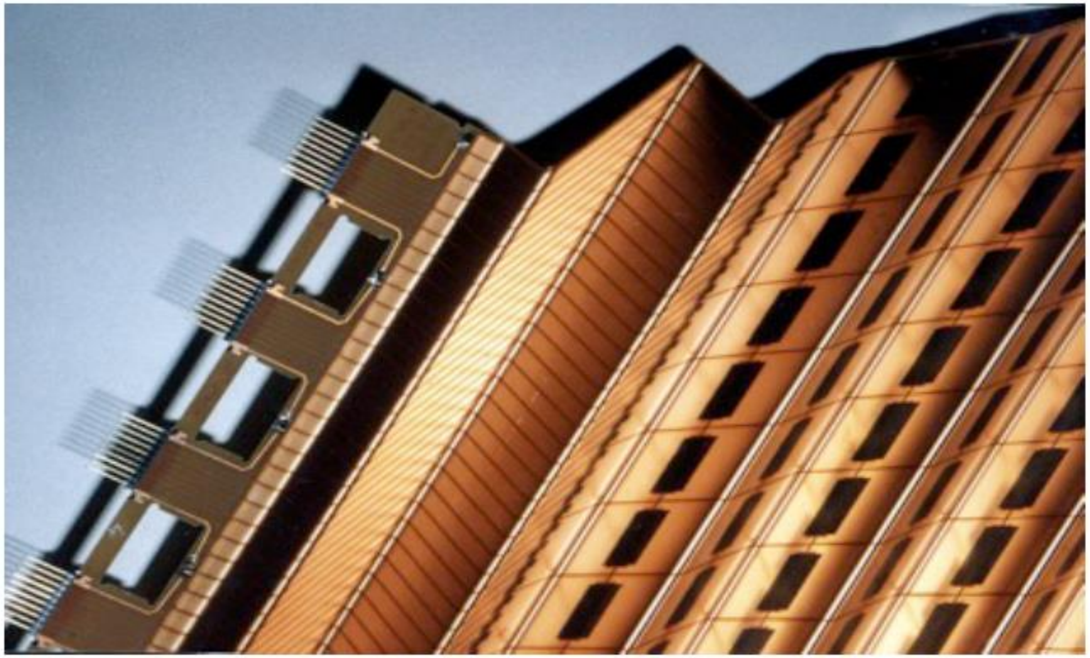


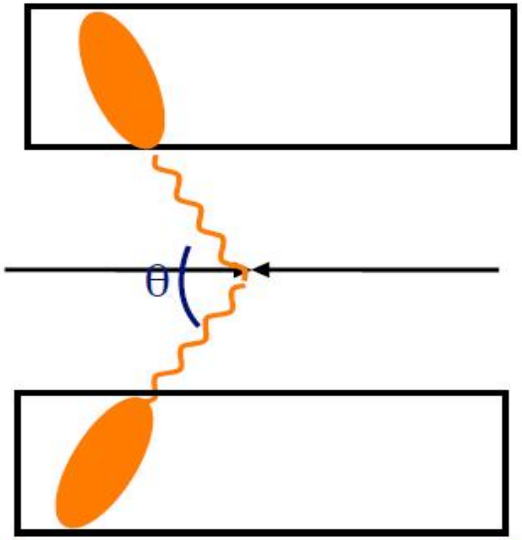
Electromagnetic calorimeters are in general linear.
All energies are deposited via ionisation/excitation of the absorber.

Important characteristic: position resolution

Higgs Boson search in ATLAS

- if MH ~ 120 GeV search in channel $H \rightarrow \gamma\gamma$
- $\sigma(M_H) / M_H = \frac{1}{2} [\sigma(E_{\gamma 1})/E_{\gamma 1} \oplus \sigma(E_{\gamma 2})/E_{\gamma 2} \oplus \cot(\theta/2)\, \sigma(\theta)]$





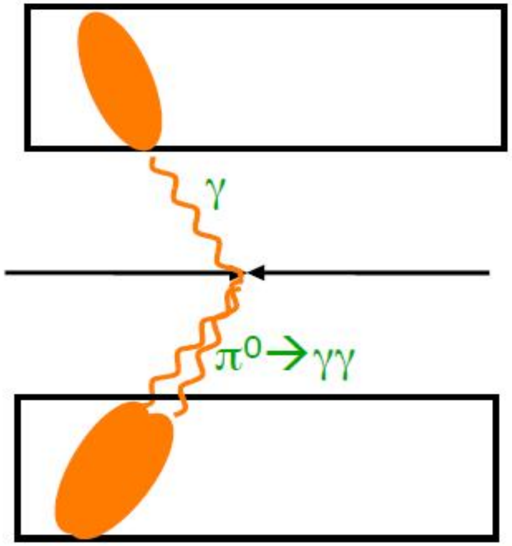
$pp \rightarrow H + x \rightarrow \gamma\gamma + x$

Important characteristic: particle identification

Higgs boson search in ATLAS

- if $M_H \sim 120$ GeV search in channel $H \rightarrow \gamma\gamma$
- Background: π^0 looking like a γ


γ/π^0 rejection



$pp \rightarrow \gamma\text{-jet} \rightarrow \gamma + \pi^0 + x$

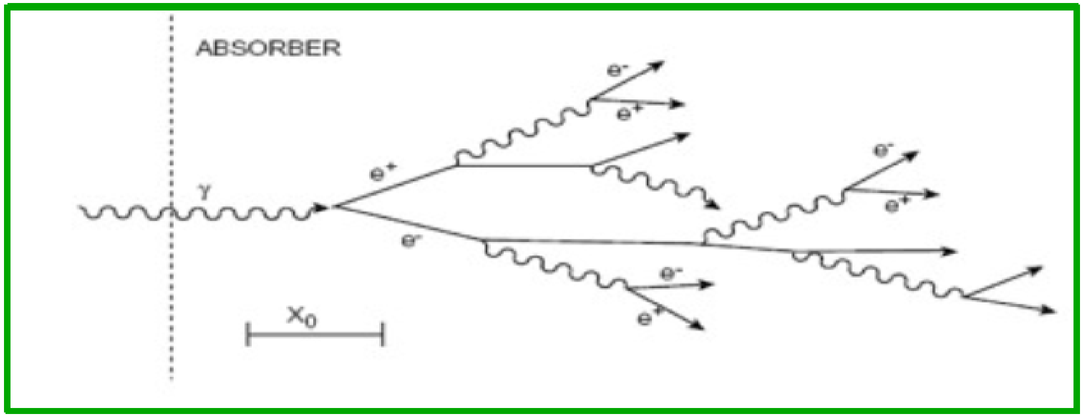
General characteristic

Calorimeters have the following properties:

- Sensitive to charged and neutral particles
- Precision improves with Energy (opposite to magnetic measurements)
- No need of magnetic field
- Containment varies as ln(E): compact
- Segmentation: position measurement and identification
- Fast response
- Triggering capabilities

Electromagnetic shower

Electromagnetic showers result from electrons and photons undergoing bremsstrahlung and pair creation

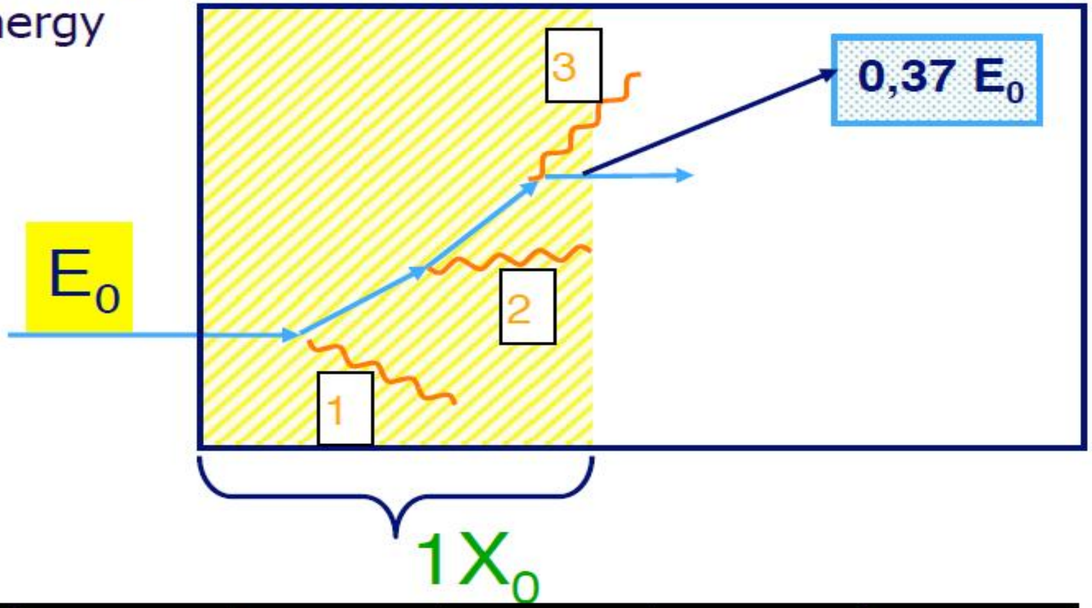


For high energy (GeV scale) electrons bremsstrahlung is the dominant energy loss mechanism
For high energy photons pair creation is the dominant absorption mechanism
Shower development is governed by these processes

Radiation length

The radiation length is a "universal" distance, very useful to describe electromagnetic showers (electrons & photons)

X_0 is the distance after which the incident electron has radiated (1-1/e) 63% of its incident energy



	Air	Eau	Al	LAr	Fe	Pb	$PbWO_4$
Z	-	-	13	18	26	82	-
X_0 (cm)	30420	36	8,9	14	1,76	0.56	0.89

Development of EM shower

The shower develops as a cascade by energy transfer from the incident particle to a multitude of particles ($e^{\pm}$ and γ).

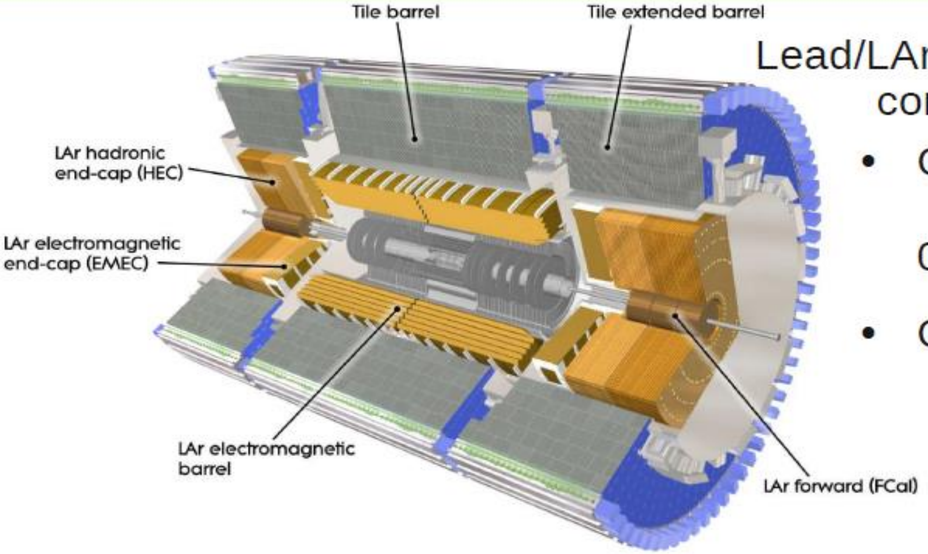
The number of cascade particles is proportional to the energy deposited by the incident particle

The role of the calorimeter is to count these cascade particles

The relative occurrence of the various processes briefly described is a function of the material (Z)

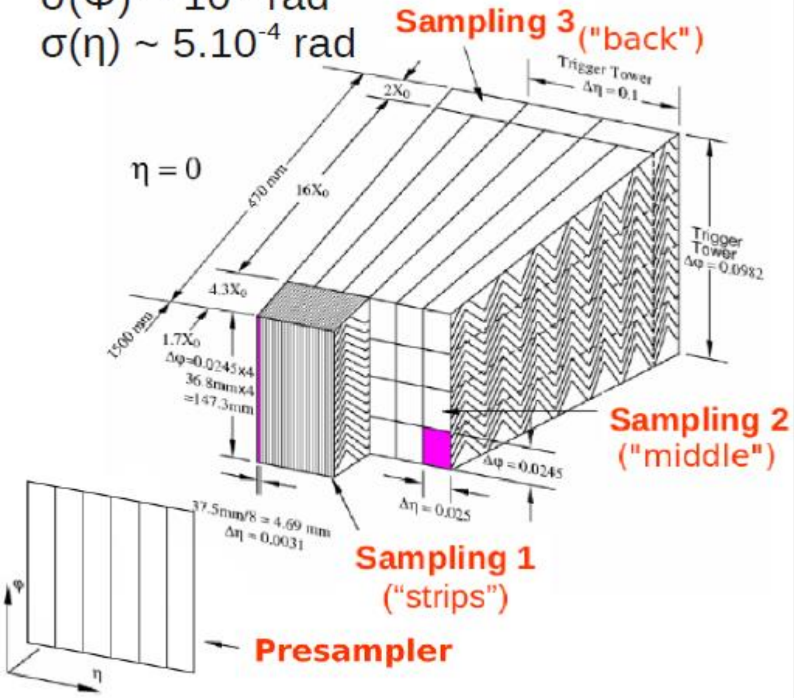
The radiation length (X_0) allows to universally describe the shower development

ATLAS electromagnetic calorimeter



Lead/LAr EM calorimeter divided in 3 longitudinal compartments + Pre-sampler in front

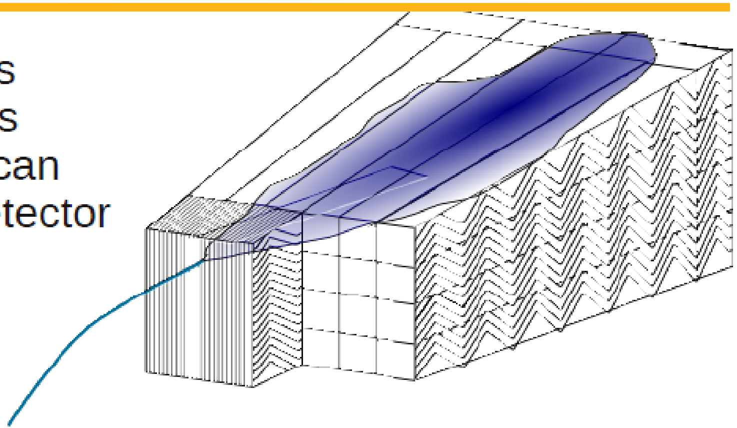
- Good energy resolution :
  $\sigma(E)/E = a/E \oplus b/\sqrt{E} \oplus c$ (with a ~ 0.3 GeV, b ~ 10%, c ~ 0.7%)
- Good angular resolution :
  $\sigma(\Phi) \sim 10^{-3}$ rad
  $\sigma(\eta) \sim 5.10^{-4}$ rad



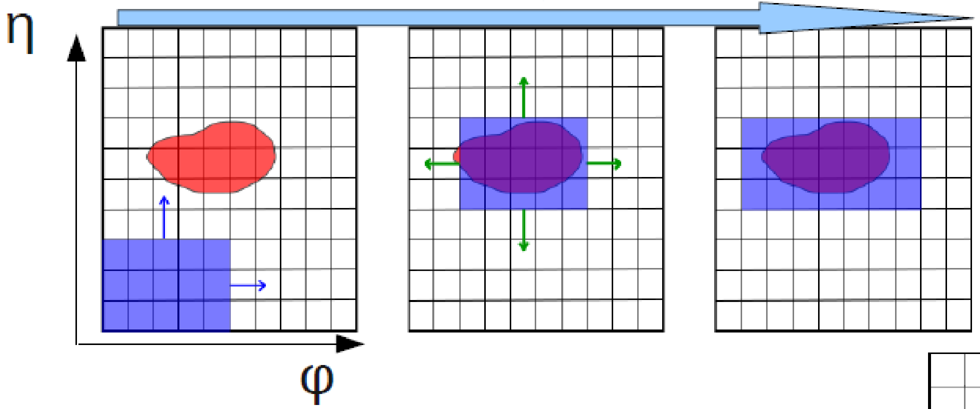
Layer	Granularity $\Delta\eta \times \Delta\varphi$	Radiation length
Pre-sampler	0.025 x 0.1	
Strips	0.003 x 0.1	4.3 X_0
Middle	0.025 x 0.025	16 X_0
Back	0.05 x 0.025	2 X_0

ATLAS electromagnetic object

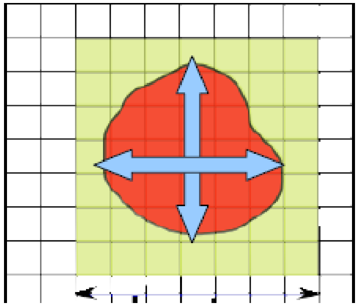
- In ATLAS an electron or a photon candidate is defined as a cluster of cells in the calorimeters representing the energy deposit to which we can associate tracks reconstructed in the inner detector



- Sliding window algorithm to reconstruct the energy deposits :

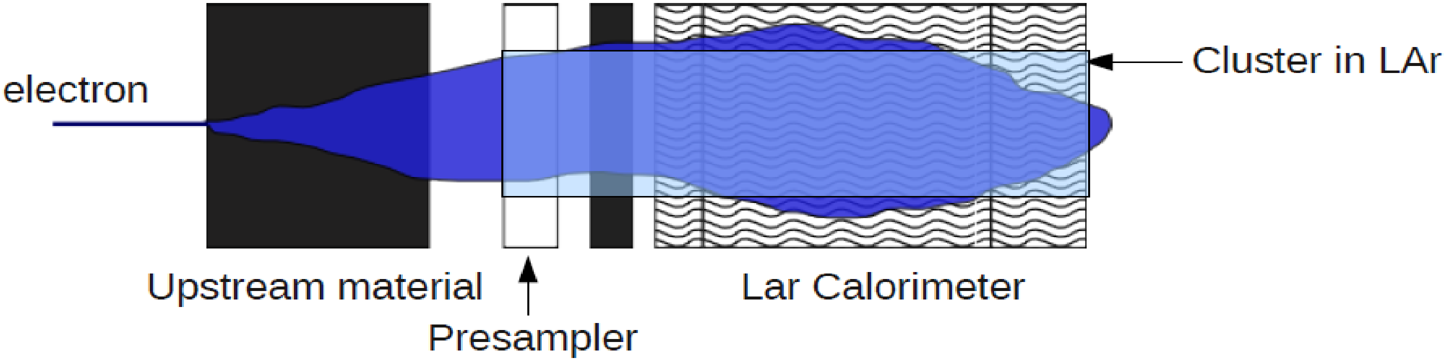


- The identification of such objects is then based on :
  - The shower shape in the calorimeter
  - Track quality (number of hits, direction wrt the cluster,...)
  - Transition radiation (TRT “high threshold hits”)



Energy calibration

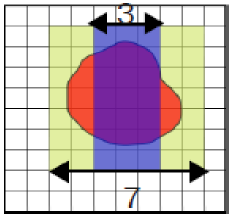
- One reason why the simulation is sensitive to the knowledge of material is the energy calibration scheme
- As the initial energy does not fully deposit within the electron/photon cluster, it is important to correct the cells energy sum to improve the energy scale and resolution
- Our calibration procedure is based on calibration hits
  - Store all GEANT4 energy deposits (in active, inactive material or escaping)
  - Parametrize the energy leaks (ouside the cluster, in the dead material,...) in function of the position, the energy and the shower depth using this simulation



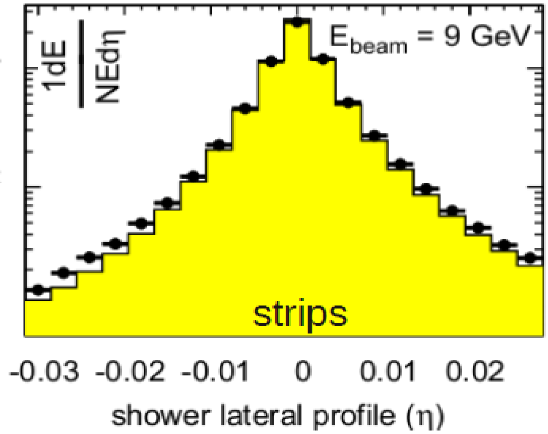
- Of course this calibration is strongly dependent on the knowledge of the upstream material, this is why we need to map it

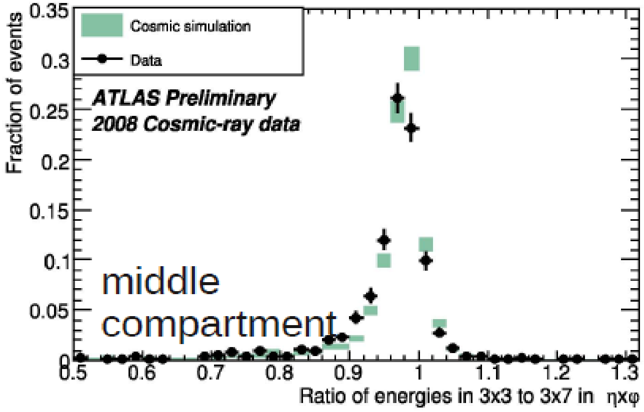
Shower shape variables

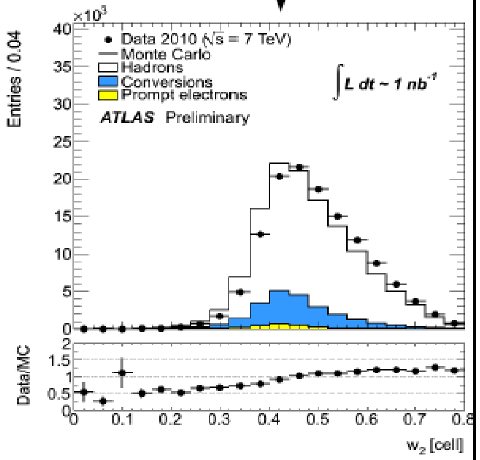
- The shower shape in the calorimeter allows for the rejection of a large fraction of background (O(1000))

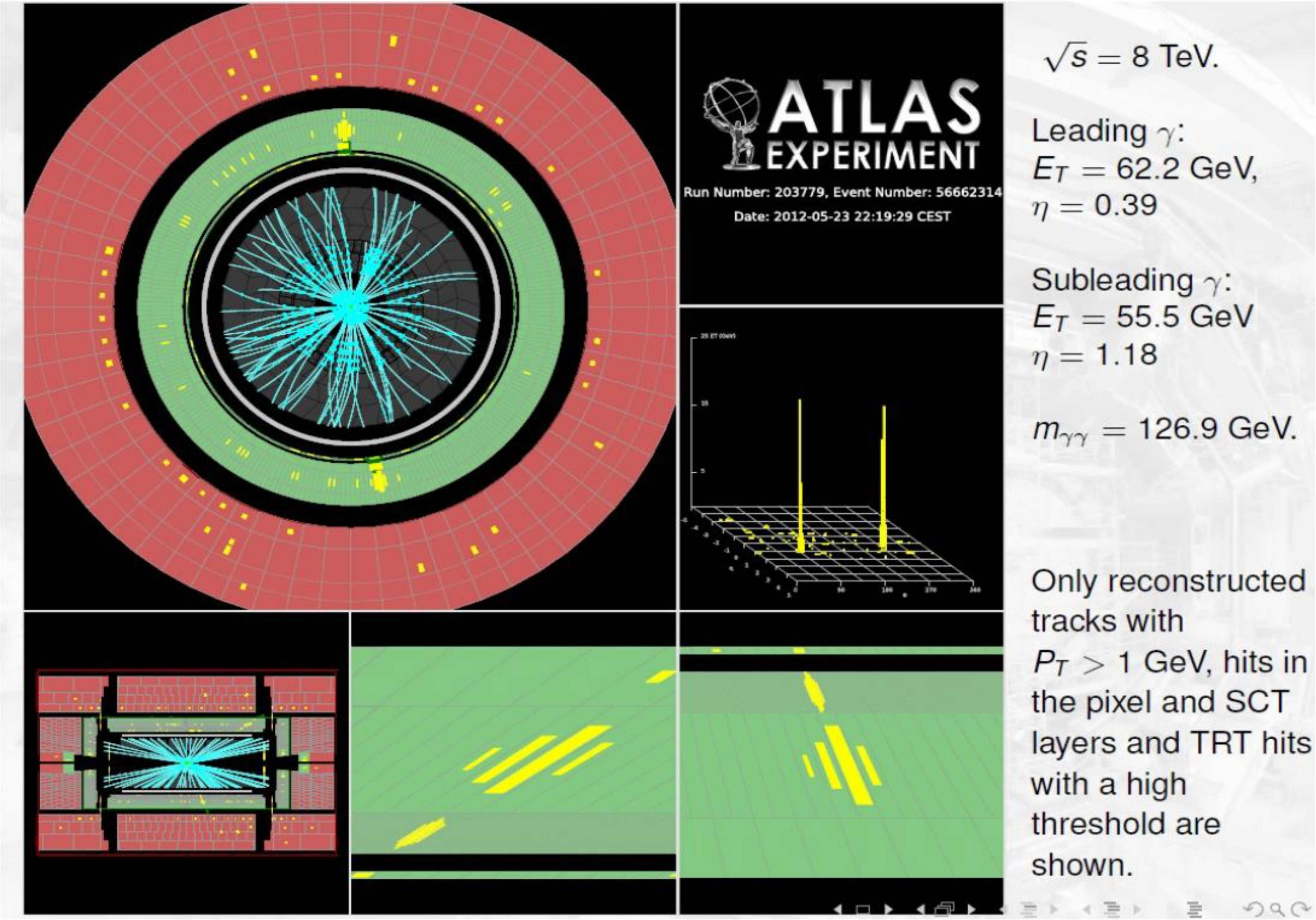


- Benefiting from the thin granularity and the segmentation of the calorimeter, ATLAS defined a few variables illustrating the shower width in eta/phi and its longitudinal extension
- Even if the agreement is fairly good, the simulation does not perfectly predict the key distributions for the lateral development
- This has been observed during the test beam, the cosmics, and the collisions data-taking









$\sqrt{s} = 8$ TeV.

Leading γ:
$E_T = 62.2$ GeV,
$\eta = 0.39$

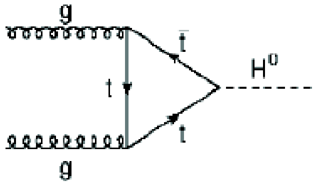
Subleading γ:
$E_T = 55.5$ GeV
$\eta = 1.18$

$m_{\gamma\gamma} = 126.9$ GeV.

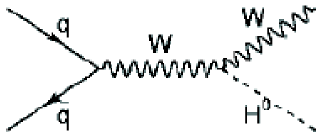
Only reconstructed tracks with $P_T > 1$ GeV, hits in the pixel and SCT layers and TRT hits with a high threshold are shown.

SM predictions for H->$\gamma\gamma$

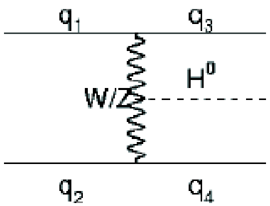
- **SM Higgs production channels**



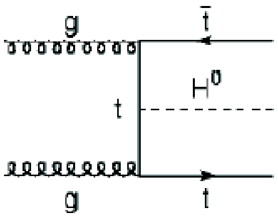
Gluon-gluon fusion (~87%)



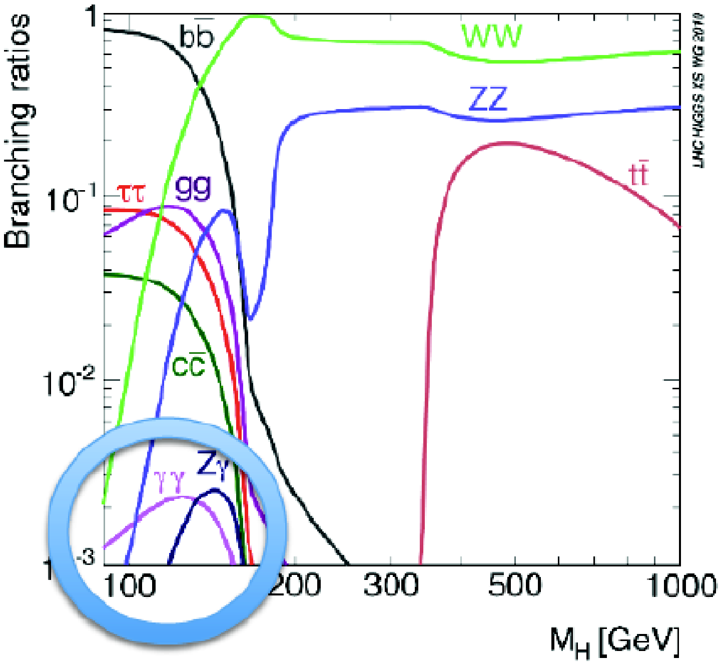
Associated Higgs (< 5%)



Vector-Boson Fusion (~7%)

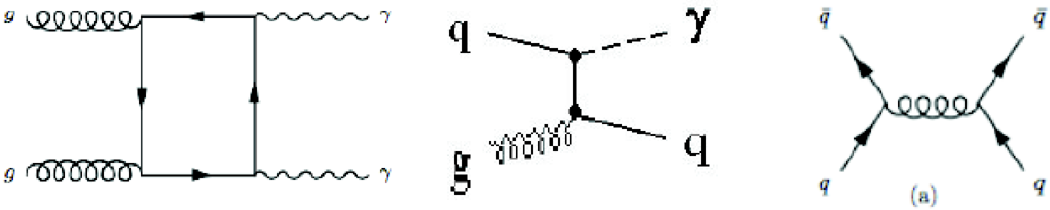


ttH (< 5%)



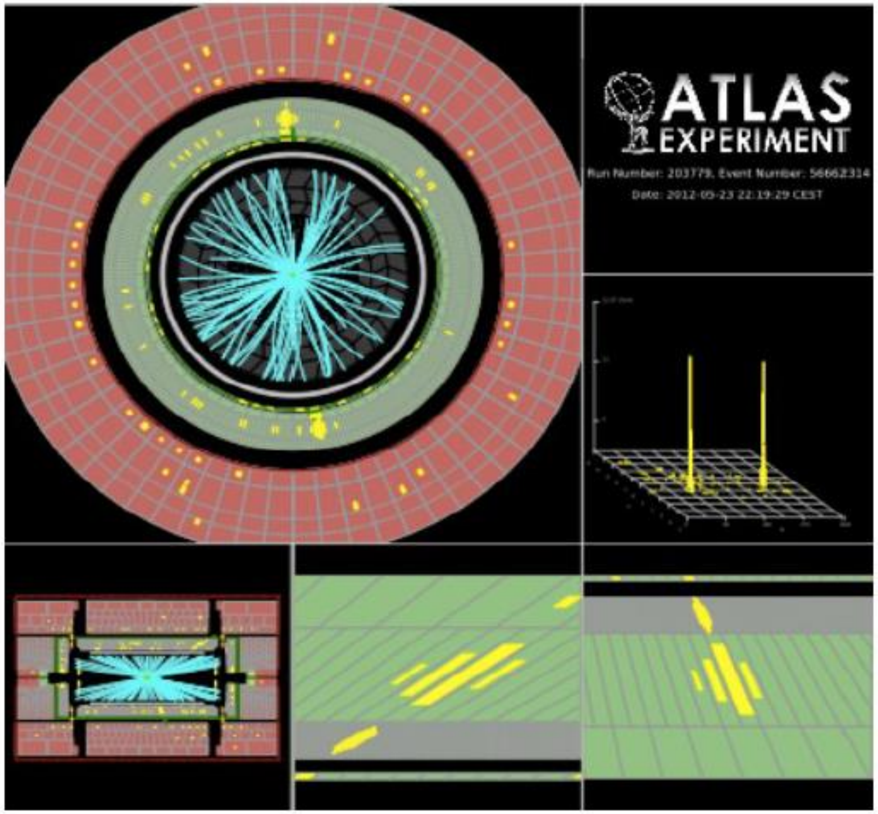
- **Branching fraction small** **but simple signature (two high p_T photons in final state)**

Main backgrounds to H→ γγ are SM diphoton, jet-γ and jet-jet events



- Signal expected as **narrow resonance over smooth decaying background**

H->γγ event signature



Simple event signature

☐ Two high pT photons
$pT_1 > 40$ GeV and $pT_2 > 30$ GeV

☐ High trigger efficiency
~99%

☐ High event selection efficiency despite high jet-jet & γ-jet production
~40%

☐ High signal over background
~3-10 % (depending on sub-category)

Invariant mass reconstruction $m_{\gamma\gamma}^2 = 2*E_1E_2(1-\cos\alpha)$

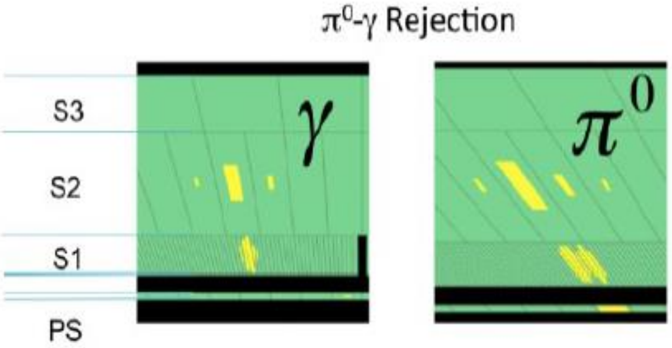
☐ Good energy calibration

☐ Robust primary vertex reconstruction

→ Excellent invariant mass resolution ~1.6 GeV with 90% of events within ±2σ

Shower shapes and vertex reconstr.

Photon ID 2 – Photon shower shapes and background rejection



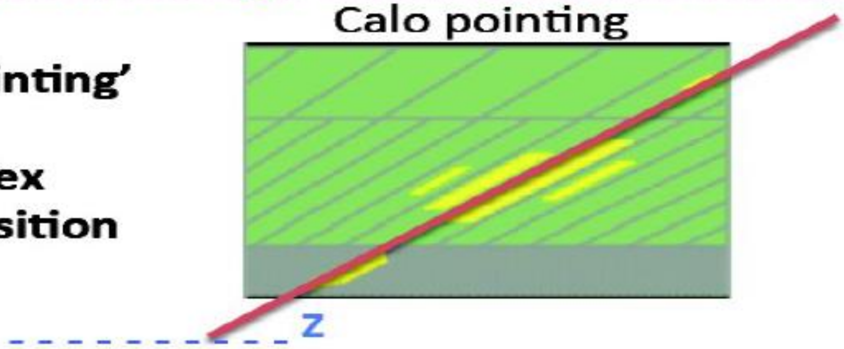
- Photons shower shape distributions in LAr sampling layers - different for signal and background (π^0)

Vertex Reconstruction

$$m_{\gamma\gamma}^2 = 2*E_1E_2(1-\cos\alpha)$$

☐ Vertex reconstructed through likelihood combination

- Calorimeter 'pointing'
- Σ tracks pT^2
- Conversion vertex
- Mean vertex position



Event categorization

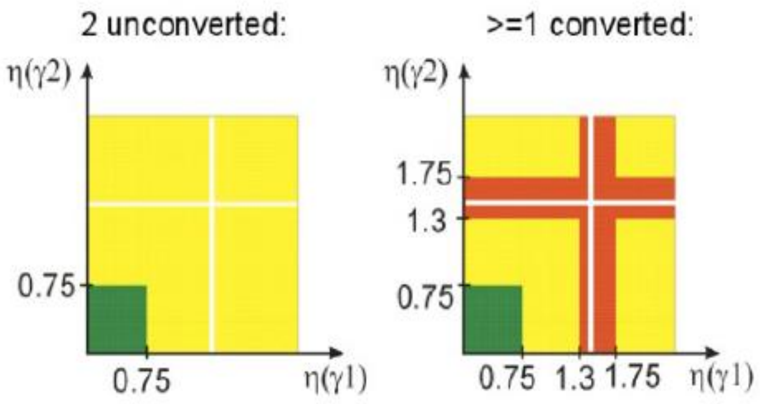
Event categories based on eta, pTt, and conversion

Both unconverted:

- Central
- Rest

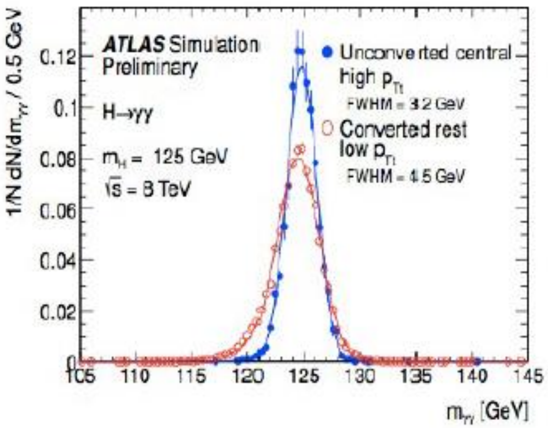
At least one converted:

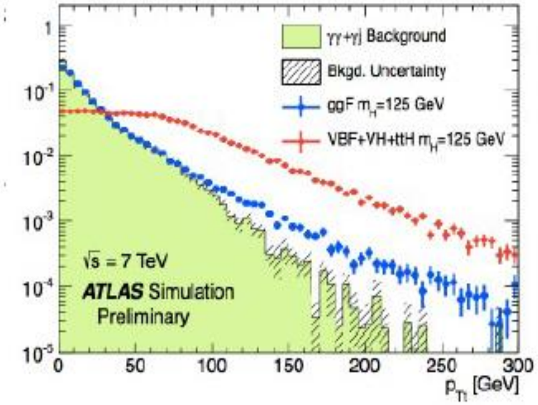
- Central
- Transition
- Rest



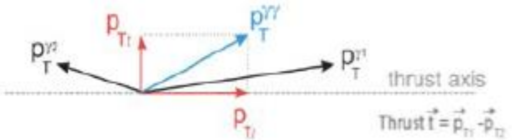
Resolution:

Good
Medium
Poor





Central and Rest divided into $p_{Tt} < 60\ \mathrm{GeV}$ and $p_{Tt} > 60\ \mathrm{GeV}$

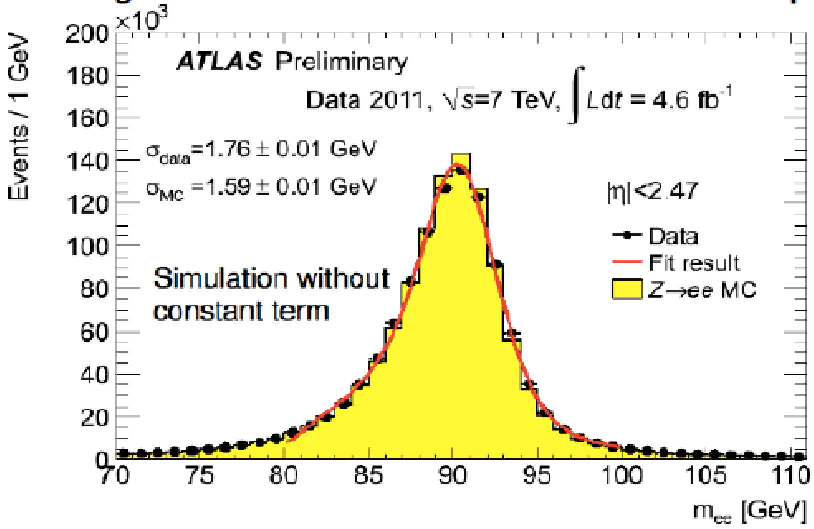


Energy calibration and resolution

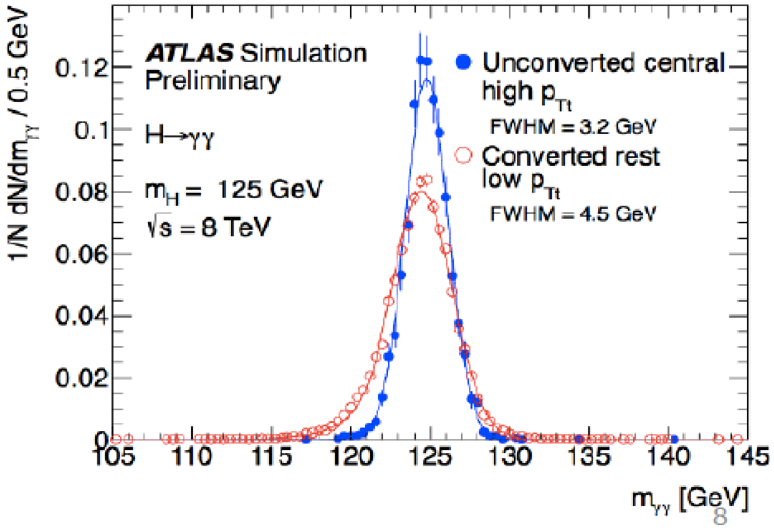
$$m_{\gamma\gamma}^2 = 2 * E_1 E_2 (1 - \cos\alpha)$$

- MC based calibration improved with energy scale and resolution corrections based on in-situ analysis of Z→ee, W→eν and J/ψ → ee

- Energy scale at m_Z known to 0.3%, uniformity (constant term) 1% in barrel, 1.2 – 2.1% in endcap

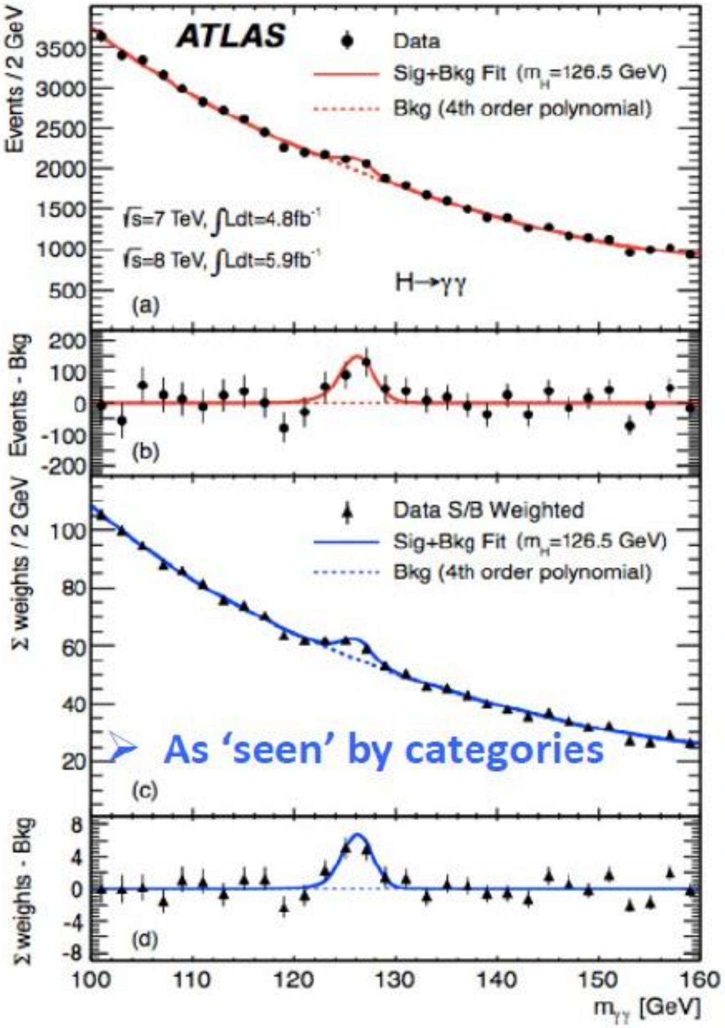


Agreement between data & MC Z→ee lineshape



Expected resolution of Higgs signal

Invariant mass distribution



➢ As ‘seen’ by categories

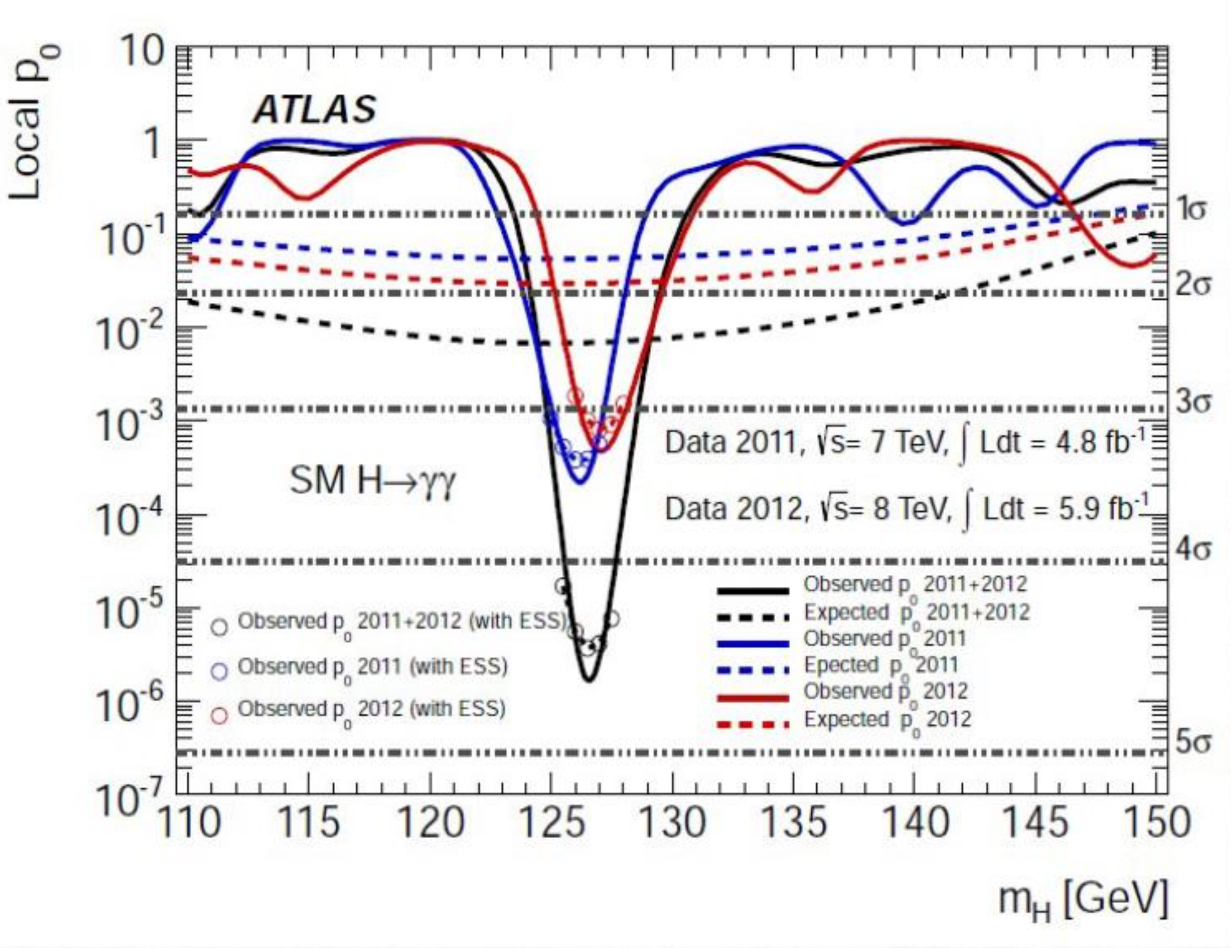
❑ Photon ID efficiency ~10%
❑ Energy resolution ~14% and mass scale ~0.6%
❑ Isolation < 1%
❑ Pileup 4%
❑ Lumi 1-3.6 % (2011-2012)
❑ Theory cross section
~ up to 25% (for VBF contribution)
~ up to 12% (in other ggF)
(underlying event ~5% and PTt dist up to 12% at hight PTt)

❑ Bkg Param (evts) 0.2-4.6 (0.3-6.8) for 2011(2012)

In VBF category
❑ Jet E-scale 9-10%
❑ Underl. Evt. 6-30%
❑ Higgs p_T up to 12.5%

23788 events (7 TeV) and 35251 events (8 TeV)
Background+signal fit, signal fixed at 126.5 GeV

Quantifying the excess p0



- Excess (m_H): 126.5 GeV
- Expected (local-significance): 2.5σ
- Observed (local-significance): 4.5σ
- Fitted signal strength: $\hat{\mu} = 1.8 \pm 0.5$