H→γγ in the VBF production mode and trigger photon studies using the ATLAS detector at the LHC

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Introduction

- In the Standard Model, Higgs is responsible for the ElectroWeak Symmetry Breaking (EWSB), allowing the W,Z bosons to have masses

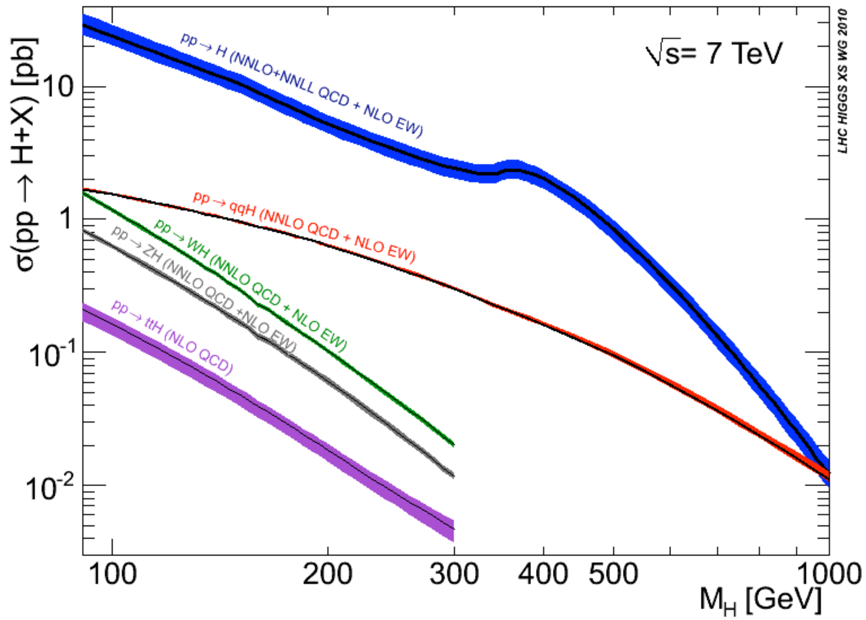
- Experimental background

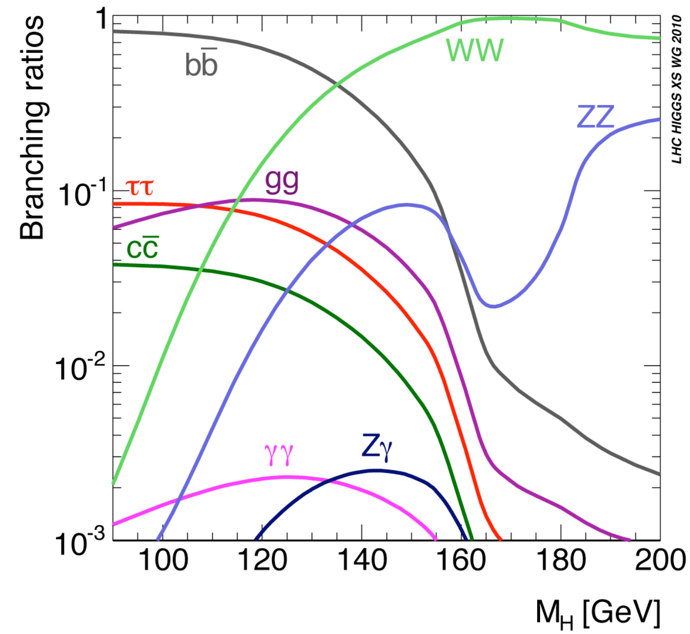
  - As I speak, the Higgs boson is **excluded** at 95% Confidence Level in the following mass regions:
    - Below 114 GeV/c^2 (LEP limit)
    - Between 148 and 181 GeV/c^2 (TeVatron limit)
    - Between 141 and ~ 500 GeV/c^2 (LHC limit obtained by combining ATLAS + CMS)

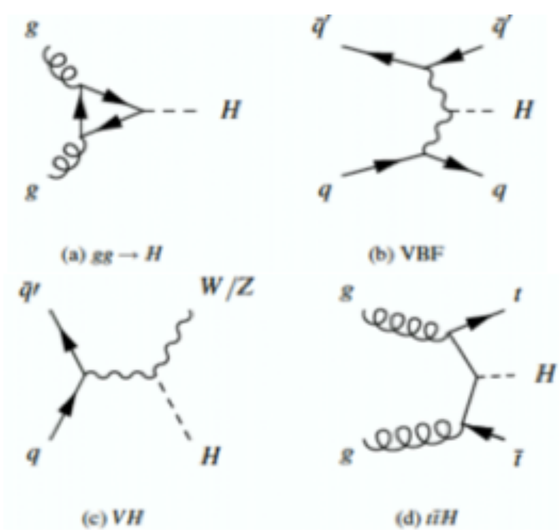
→ **The space allowed by experiments for the Higgs is now really narrow**

(Most likely) $114 < M_{Higgs} < 141$ GeV/c^2

Production – decay modes







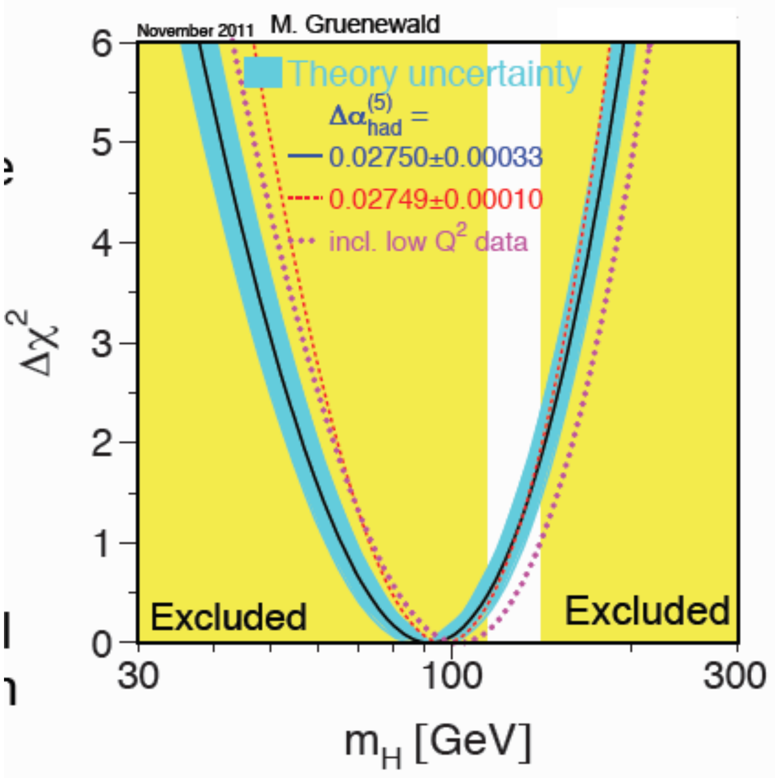
In the mass range M_H=[100,160] GeV/c^2, the total cross-section for Higgs production is of ~10 pb

- → ~85% of gluon fusion
- → ~10% of vector boson fusion
- → <5% of associated VH/tt production

In the case of γγ, this production cross section to be multiplied by the branching ratio O(10^{-3}) to obtain the H→γγ cross section: ~ 100 fb

Motivation

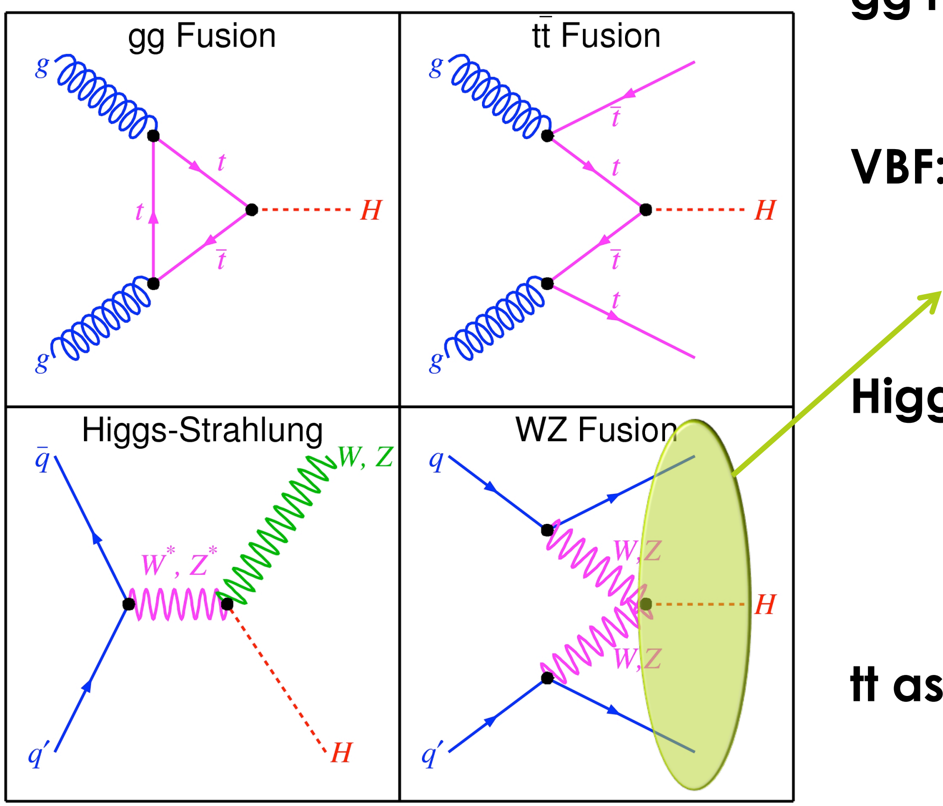
- Why search the H→γγ?
  - The fit of the ElectroWeak sector parameters favorizes a light Higgs
    → Light Higgs decay to γγ with an interesting S/B ratio
  - The background is low w.r.t. to a jet final state
    → This channel is interesting despite low branching fraction
  - The diphoton mass can be fully reconstructed (look for a « narrow » peak)



H→γγ: most sensitive channel at low masses!

$$M_{\gamma_1\gamma_2} = \sqrt{2 p_T^{\gamma_1} p_T^{\gamma_2} \left[\cosh(\eta_{\gamma_1} - \eta_{\gamma_2}) - \cos(\phi_{\gamma_1} - \phi_{\gamma_2})\right]}$$

Signal topologies



gg fusion:

- H produced *at rest*
- *No* Hard Process jets

VBF:

- H produced *at rest*
- ***Two forward jets***

Higgsstrahlung:

- *Boosted* H
- *Hard jets/leptons* coming from on-shell vector boson W or Z

tt associate production:

- Marginal cross-section

One goal can be to take advantage of the VBF specific topology, which distinguishes from background

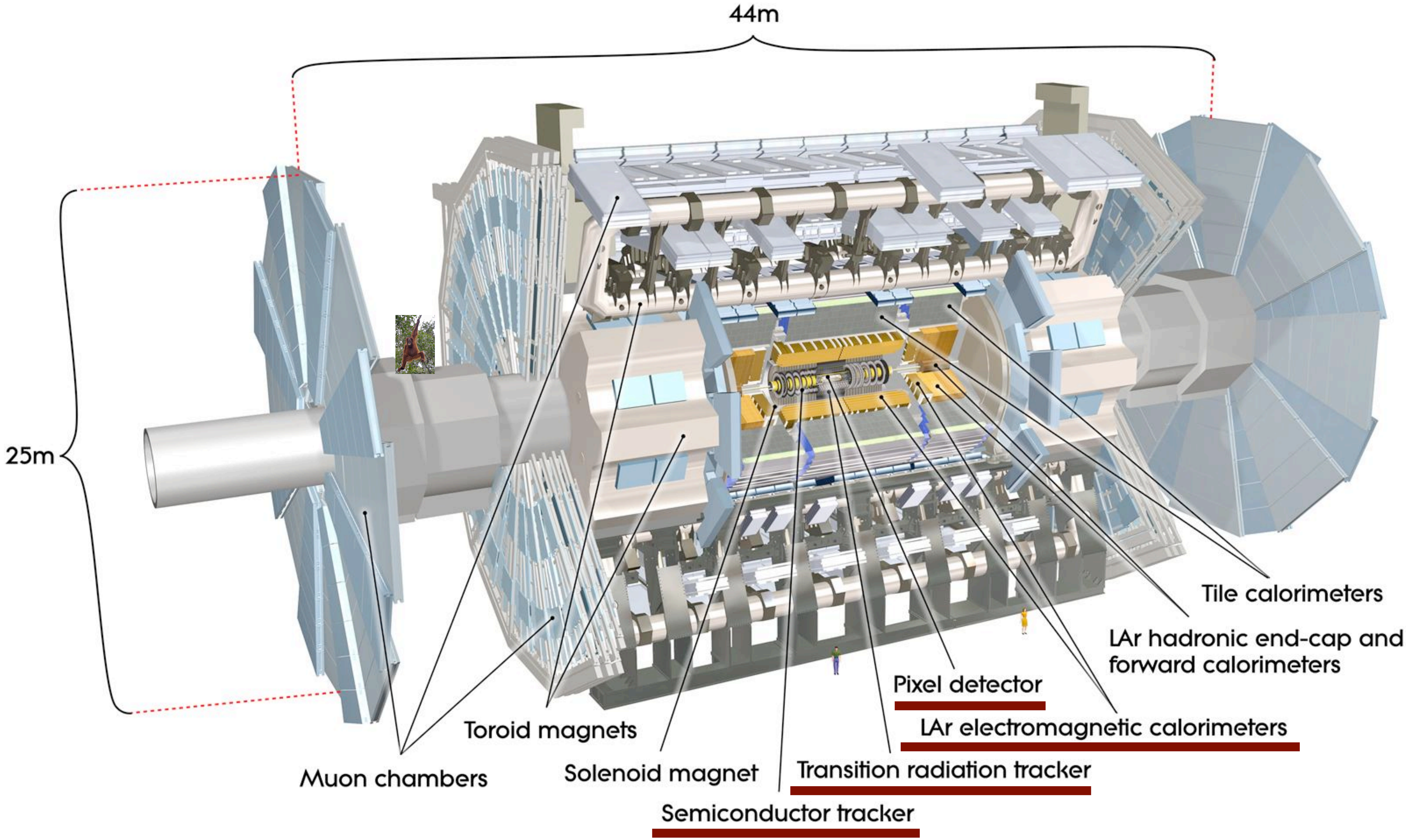
Backgrounds

- **Two main backgrounds (=event with the same final state as signal):**

Irreducible background (true diphoton from SM processes)

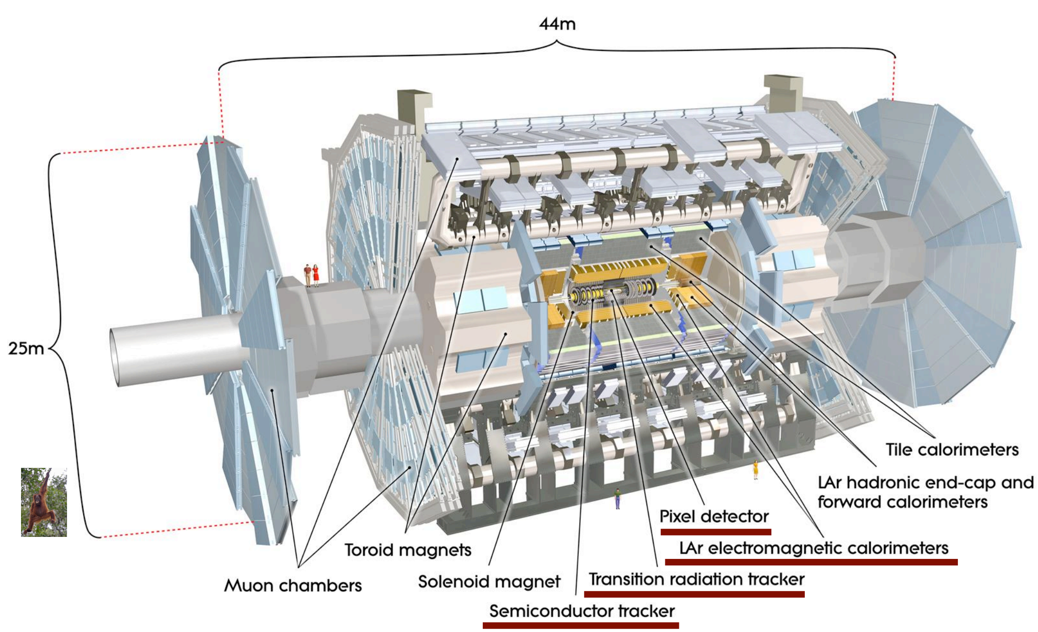
Reducible background (with jets mis-identified as photons)

→ See Heberth Torres' talk for more details


44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

Event selection

- The event selection relies mainly of 4 sub-detectors:



Pixel detector
Semiconductor tracker
Transition Radiation Tracker
Liquid Argon EM calorimeter

1) Look for events triggered by a loose diphoton trigger
2) Photons have to be in the detector acceptance
3) Check for good detector conditions

4) Kinematic cut: photons' transverse momenta
5) Isolation cut (energy around a photon candidate shower): reject events which have an isolation > 5 GeV
6) Identification cut: tight cut on shower shape
7) Mass cut: $100 < M_{\gamma\gamma} < 150$ GeV/c^2

Trigger efficiency (1)

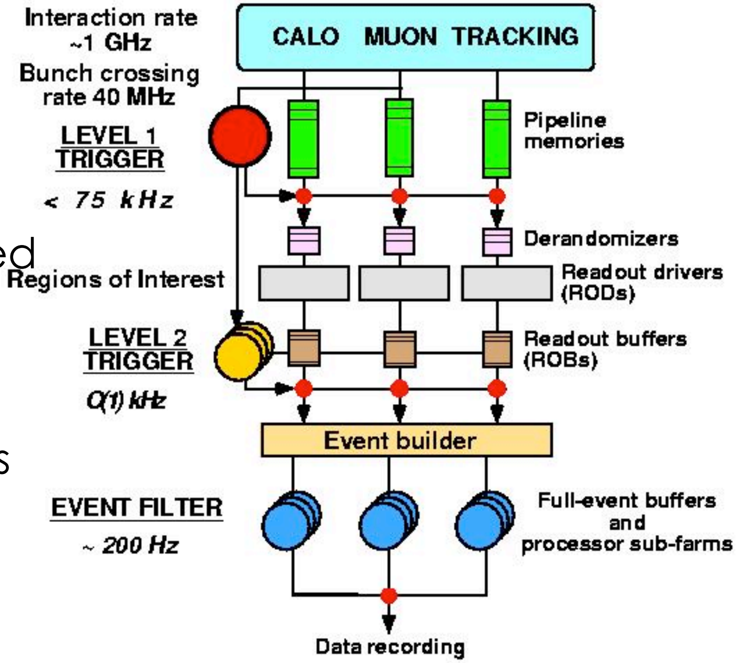
- **The trigger (event selection at the ATLAS detector level) is an important system**
  - If it does not select the signal events correctly, you are losing some important Higgs events
  - → Its efficiency therefore needs to be carefully monitored
  - → There is a limited rate achievable
  - → Efficiency can be dependent to pileup

- There are three trigger levels in ATLAS:

  - **Level 1: from 1 Ghz to 100 kHz**
    Based on hardware quick measure of the deposited energy

  - **Level 2: from 100 Mhz to 1 kHz**
    Based on software study of shower shape variables

  - **Event Filter: from 1 kHz to 100 Hz**
    Based on refined measure of energy and shower shape



Trigger efficiency (2)

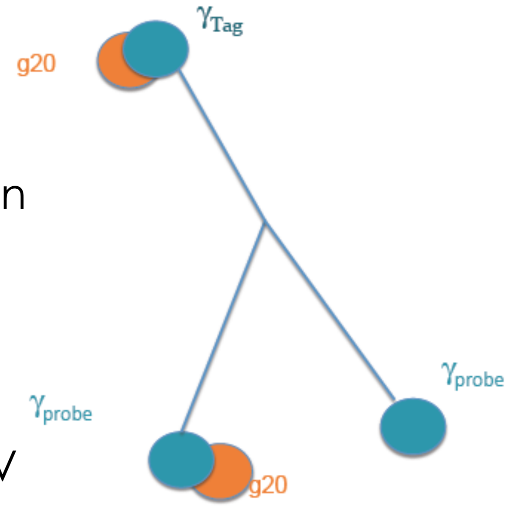
- The are three techniques used in ATLAS that are performed on unbiased samples (selected by a ~ unbiased trigger = very low E_T threshold trigger). We then test one higher E_T threshold trigger. The efficiency of a trigger is defined as the efficiency to select one interesting event.

1) **Bootstrap**: simple N^{pass}/N^{tot} technique on single photon events
   - Select events with at least one "good" photon (tight and isolated, for example=interesting);
   - Count the events for which the photon with a low E_T threshold trigger object = Ntot;
   - Count the events that pass the higher ET threshold trigger for which the photon is matched to the trigger object =Npass;
   - The efficiency is then Npass/Ntot.

Trigger efficiency (3)

2) **Pseudo Tag & Probe**: performed on diphoton events, where the first photon passing the selection is a tag, and the trigger selection is tested on the second photon (probe)

- Select events passing your high E_T threshold trigger;
- Require one "good" photon to be matched to a high E_T threshold trigger object. This photon is considered to be the **tag** photon;
- The other photons in the events are called the **probes**;
- Compute the efficiency as the ratio between the **number of probe photons matching** with high ET threshold trigger objects and **the total number of probe photons;**

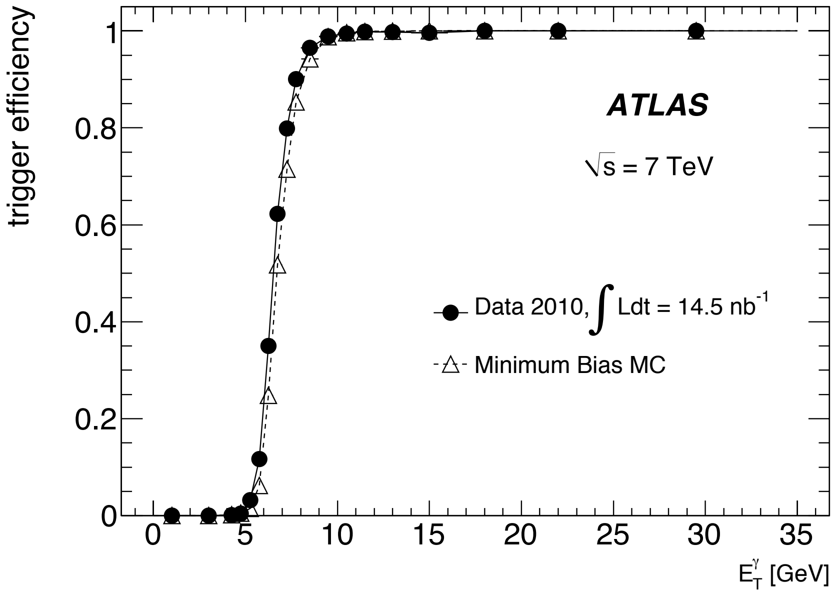


3) **Tag & Probe**: performed on the Z→ee peak, using the same procedure as Pseudo Tag & Probe:

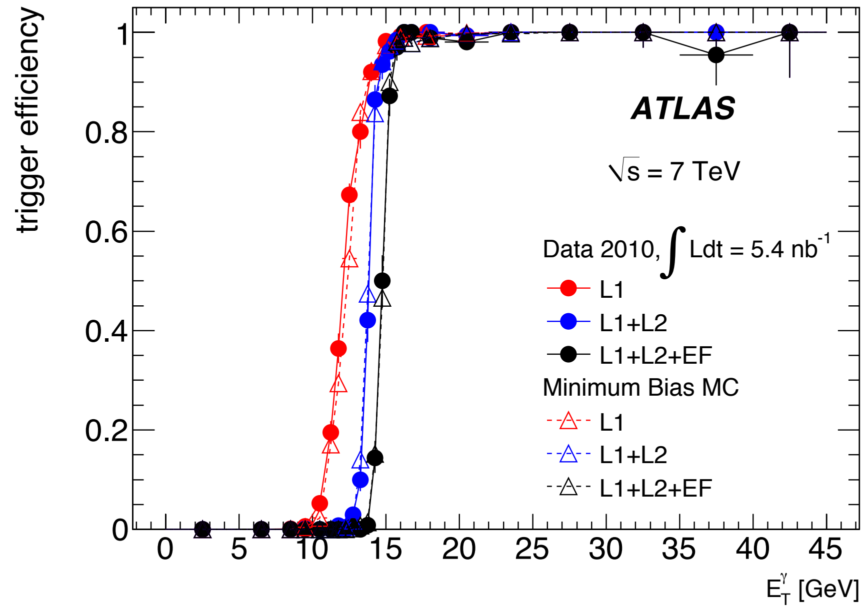
- Exploiting the fact that electrons showers look like photon showers
- You may need a function to extrapolate the electron shape to your photon shape to take the small differences into account
- The purity in electrons and their high energy (tens of GeV usually) makes this method very interesting

Trigger efficiency (4)

- **The efficiency is build in p_T-bins. We then check the trigger efficiency at each level (L1/L2/EF) and see a turn-on curve (convolution of a step function and the trigger energy measurement resolution).**



L1_EM5 efficiency w.r.t. a MinBias trigger selection



g15_loose efficiency w.r.t. a L1_EM5 trigger selection

- **A symmetric threshold diphoton trigger (e.g. 2g15_loose) efficiency can be calculated from the single photon efficiency (with same E_T cut) by the formula:**

$$\varepsilon_{\text{diphoton trigger}} = 1-(1-\varepsilon_{\text{photon trigger}})^2$$

Categories

- Generally speaking, categories are defined to benifit from the different Signal/Background ratio in the different categories

→ **Definition of 5 eta-conversion categories**

both unconverted :

-Unconverted central : $|\eta_{1,2}|<0.75$

-Unconverted rest : $|\eta_{1 \text{ or},2}|>0.75$

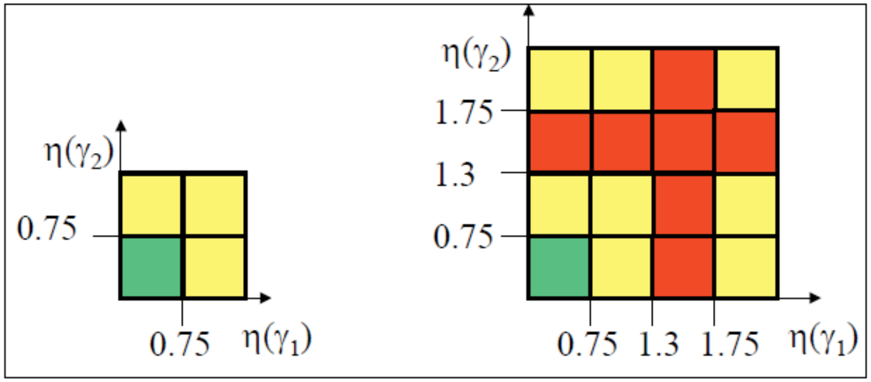
≥1 converted :

-Converted (≥1) central : $|\eta_{1,2}|<0.75$

-Converted (≥1) rest : $|\eta_{1,2}|<1.3$ or $|\eta_{1,2}|<1.75$ but ≥1 $|\eta_{1,2}|>0.75$

-Converted (≥1) transition : ≥1 w/ $1.3<|\eta|<1.75$

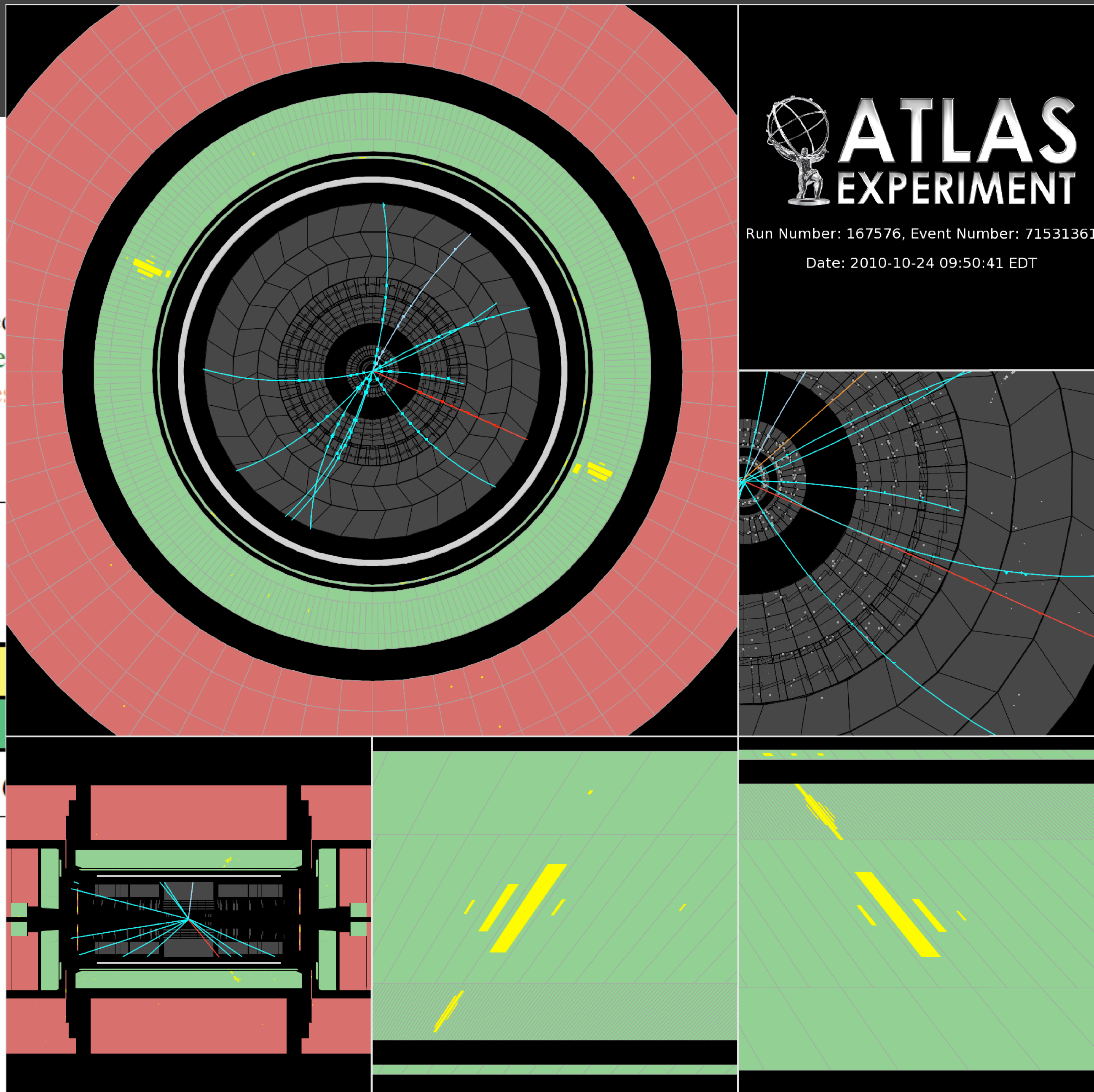
inclusive



Fractions of candidates in $1.08\ fb^{-1}$ of data

Category	Fraction
Unconverted central	8%
Unconverted rest	28%
Converted central	7%
Converted rest	41%
Converted transition	16%

~15% improvement w.r.t. an inclusive analysis



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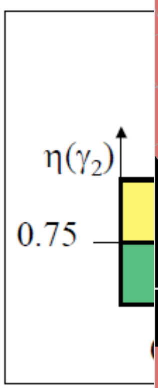
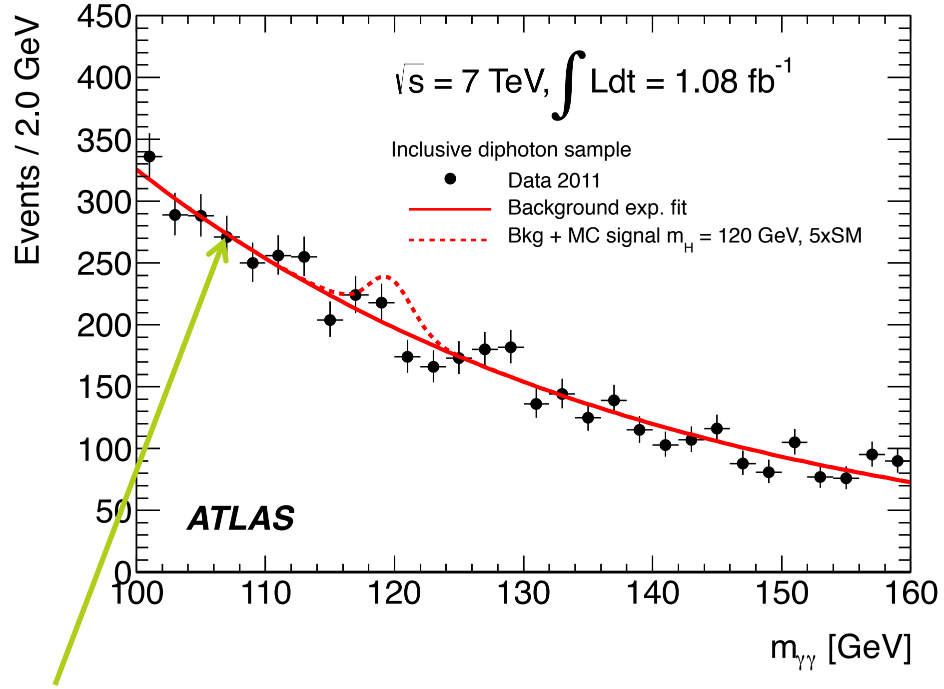


Fraction
8%
28%
7%
41%
16%

First look at data

- In data, we are looking for a peak on top of a falling background



- **For background, we take the data and its model is chosen to be a falling exponential**
- What should the signal look like → **no other choice but to take a look at MC**

Monte-Carlo signals

- Our Monte-Carlo (MC) simulators generate pure events of signal
- We can study them in order to determine:
  - The yields of accepted signal
  - The Higgs signals shape expectation
  - The specific topologies of events
- The MC has been generated and corrected to follow the pileup conditions seen in 2011 data

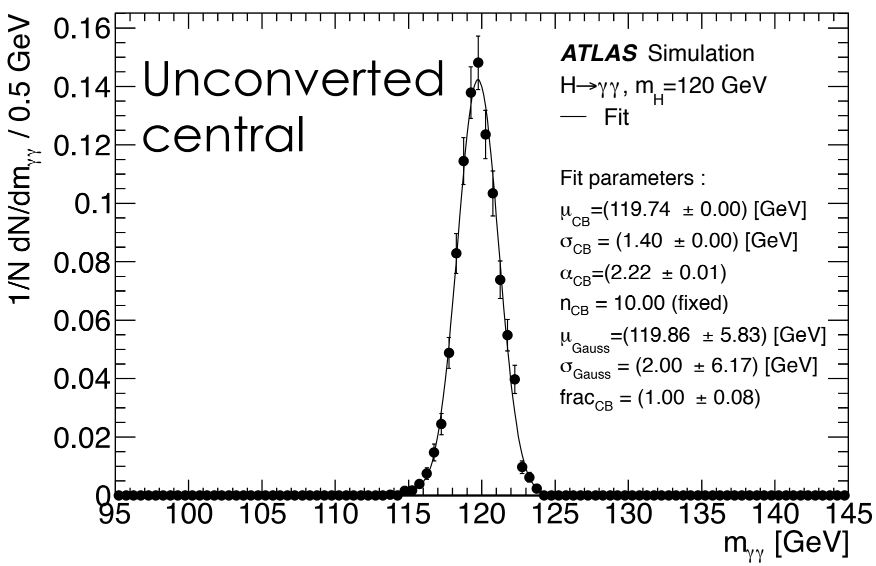
Yields of accepted signal (expection for 1.08 fb^{-1})

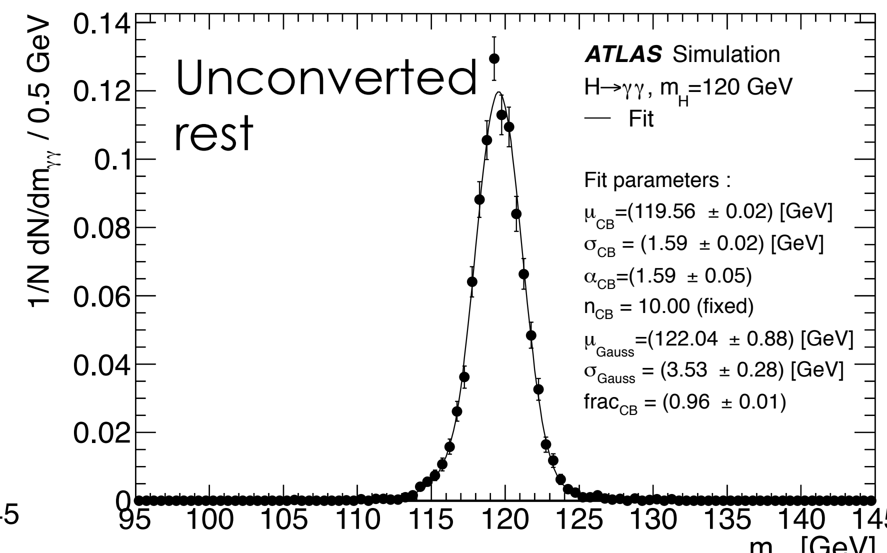
m_H [GeV]	110	120	130	140	150
$\sigma\times$BR [fb]	45	43	37	27	16
Signal yield	17.0	17.6	15.8	12.1	7.7
Unconverted central	2.6	2.6	2.3	1.7	1.1
Unconverted rest	4.6	4.7	4.2	3.4	2.1
Converted central	2.0	2.0	1.7	1.3	0.8
Converted transition	2.3	2.2	2.1	1.5	1.0
Converted rest	5.6	6.0	5.6	4.2	2.7

Signal parametrization (1)

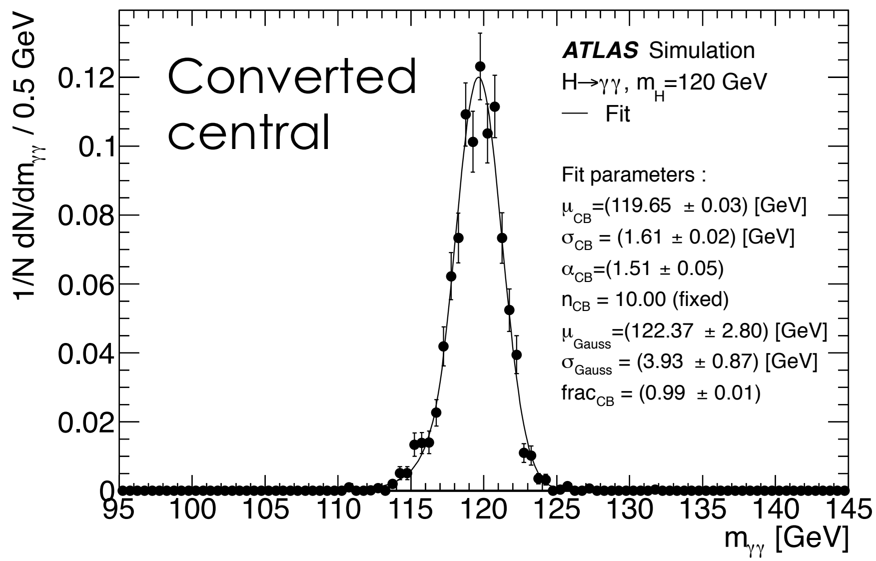
- We want to get the signal resolution because, the narrower the peak, the clearer is the picture
- Higgs natural width depends on its mass: $$\Gamma_H = \frac{3g^2}{128\pi m_W^2} m_H^3 \quad GeV/c^2$$
  - In M_H=[100,160 GeV/c2], Γ_H=O(100) MeV/c^2
  - We are completely dominated by the detector's resolution
- Looking at the MC distribution, we decide to fit the resolution with a Crystal Ball + Gaussian

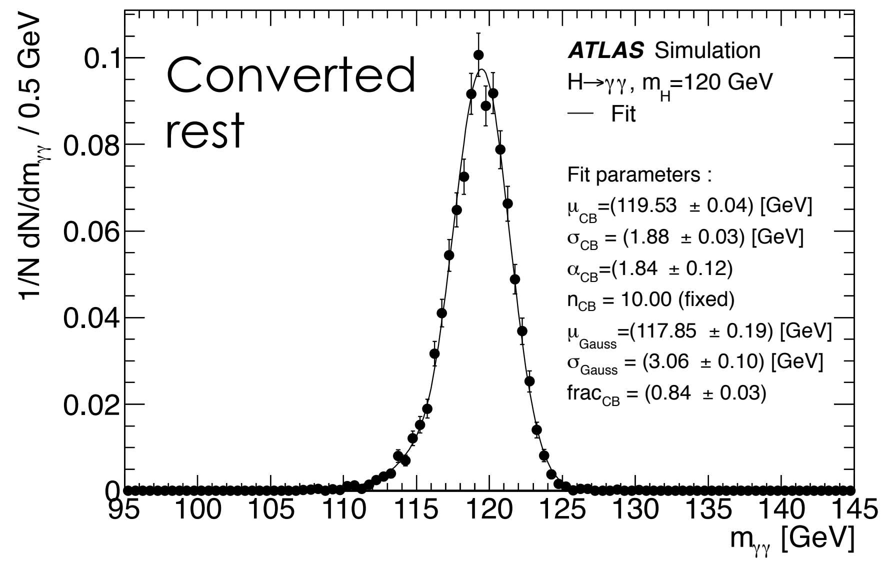
$$N \cdot \begin{cases} e^{-t^2/2} & \text{if } t > -\alpha_{CB} \\ \left(\frac{n_{CB}}{\alpha_{CB}}\right)^{n_{CB}} \cdot e^{-\alpha_{CB}^2/2} \cdot \left(\frac{n_{CB}}{\alpha_{CB}} - \alpha_{CB} - t\right)^{-n_{CB}} & \text{otherwise} \end{cases}$$

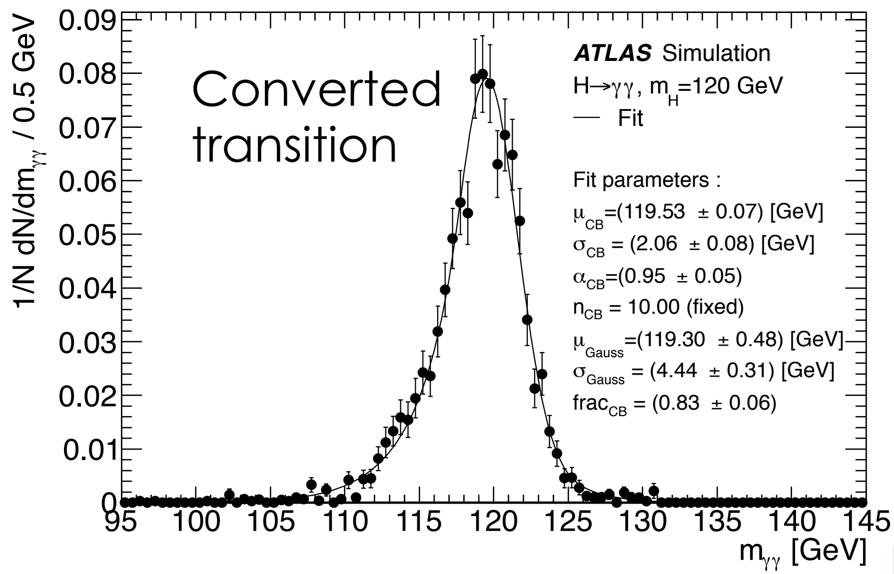




Signal parametrization (2)





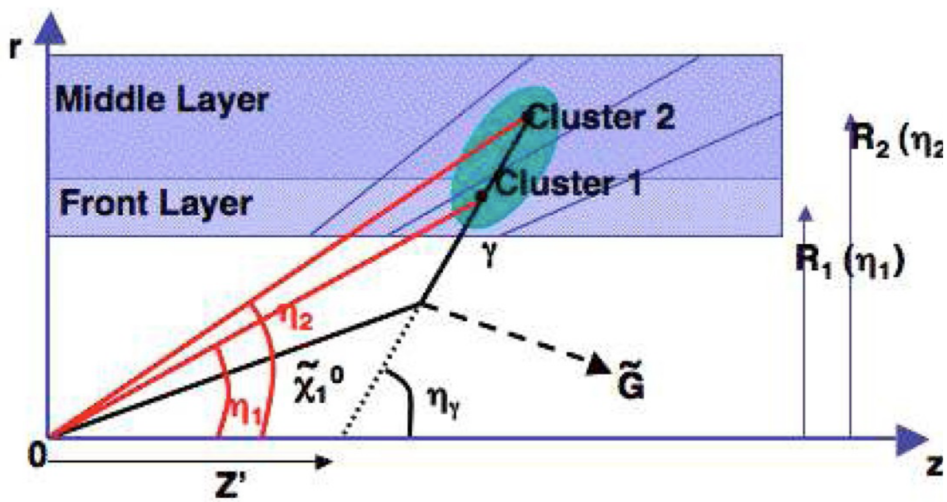


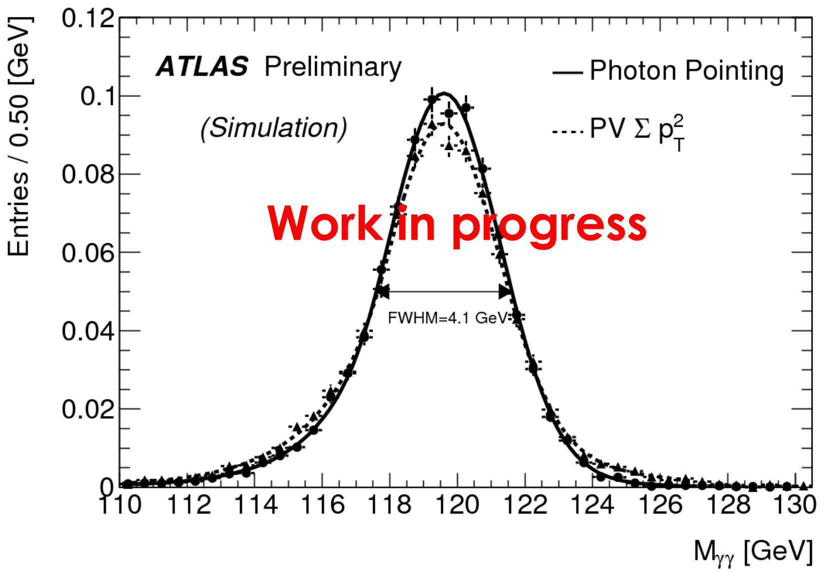
Inclusive resolution: 1.7 GeV/c^2

Vertex pointing

- The resolution of the angle measurement is dominated by the reconstruction of the primary vertex z-position
- To provide a good resolution, we use information coming from the photons' directions in the EM calorimeter

→ Improvement of resolution on diphoton mass





Systematics

- Our signal yield is taken from MC and corrected at Next-to-Next Leading Order
- There are statistical and systematic errors to take into account
- **We can estimate the systematic errors by comparing diphoton data and MC, or with data-driven techniques**

Systematics	Value
Reconstruction and identification efficiency	±11 %
Isolation cut efficiency	±3 %
Trigger efficiency	±1 %
Luminosity	±3.7 %
Effect of MC modeling on efficiency	±1 %
Energy Resolution	±12 %
Energy Calibration	±6 %
Pileup	±3 %
Angle Measurement	±1 %

Prospects

- To increase the sensitivity to a Higgs peak, we can rely on:

1) Better performance of the diphoton reconstruction:

e.g. better resolution → narrower peak → clearer signal

This is detector performance oriented

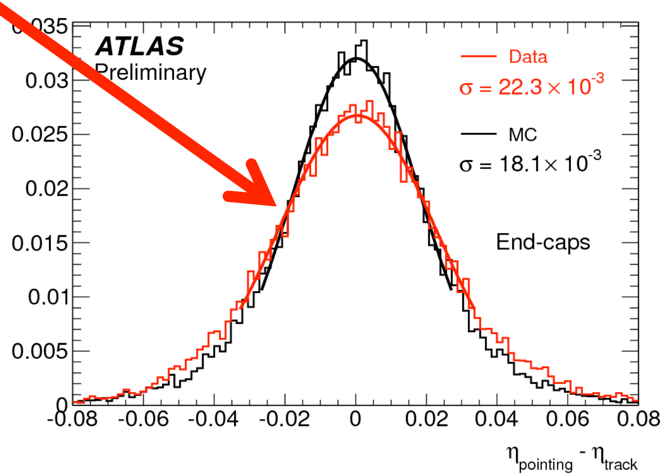
2) Better performance of the analysis:

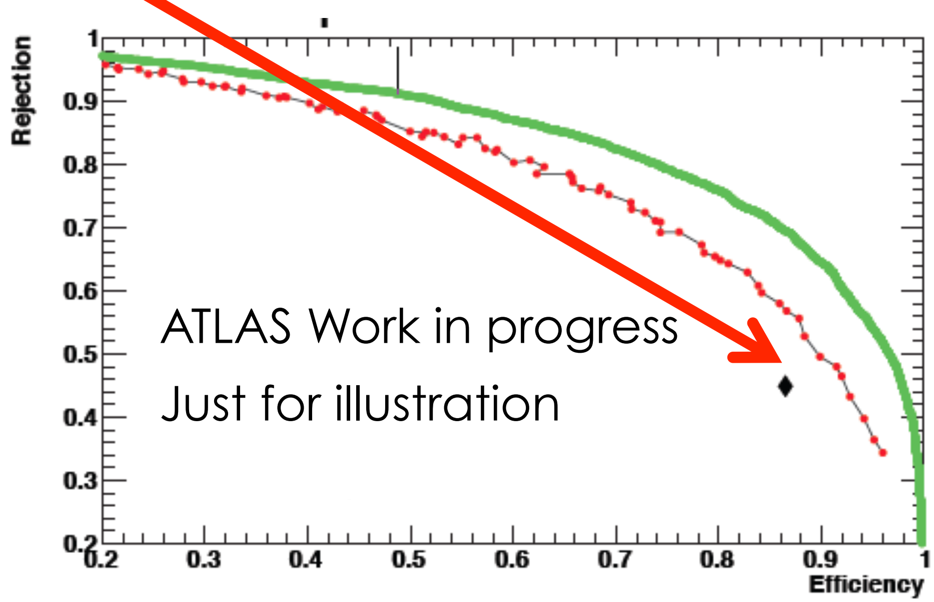
e.g. better signal/background discrimination → better S/B → higher sensitivity

This is analysis oriented

Detector Performance

- The performance of the detector can be improved by:
  - Using more information contained in the shower shapes to distinguish signal from background
  - → This would mean changing our "tight" criteria
  - Better calibration of the energy
  - → Potential gain in resolution width





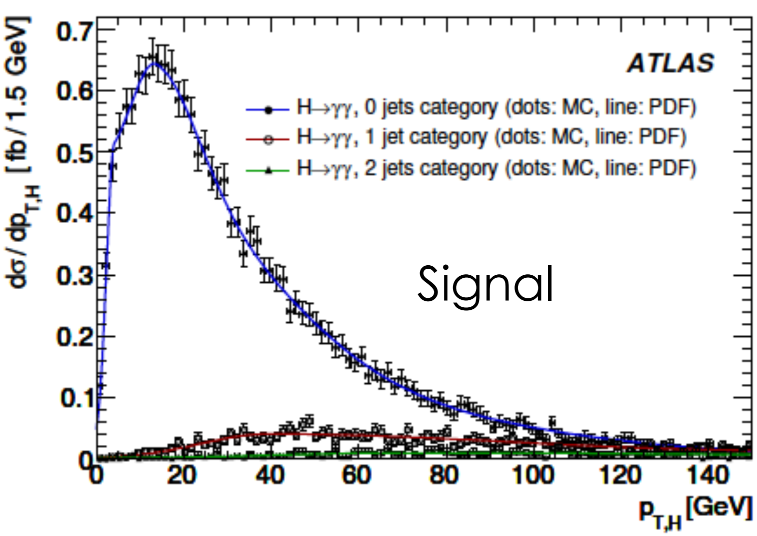
Analysis Performance (1)

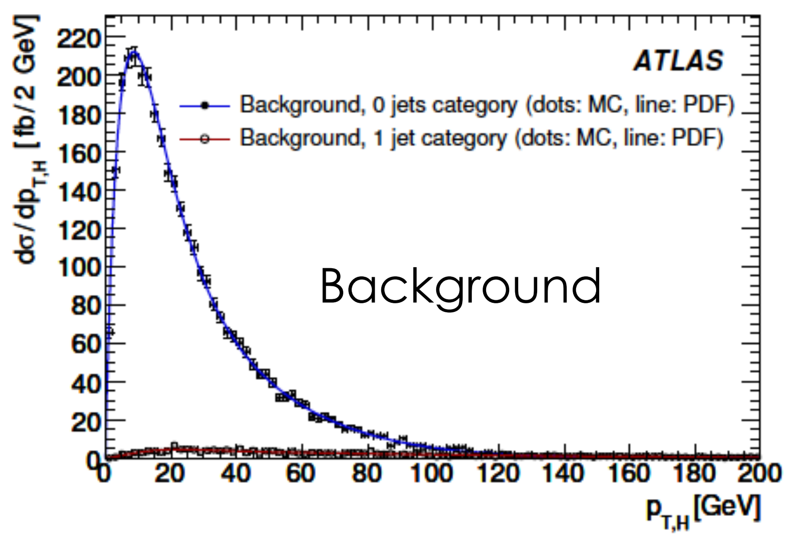
- The performance of the analysis can be improved by using more information contained in an event
- Two strategies are possible:
  - Simple analysis: not biaising the mass distribution, doing a loose cut based analysis, etc.

  → Keep a possible Higgs peak on the distribution
  - Agressive analysis: biasing the mass by using a lot of input variables

  → Improve sensitivity but need better control of backgrounds

P_T of the diphoton is a discrimination variable



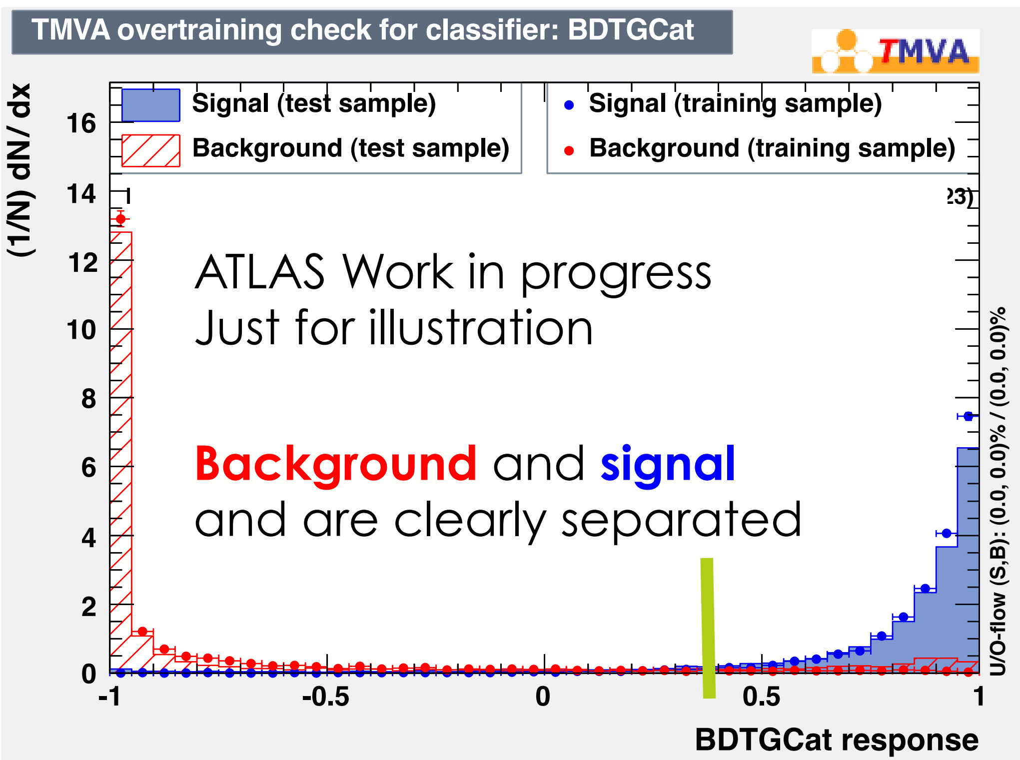


Analysis Performance (2)

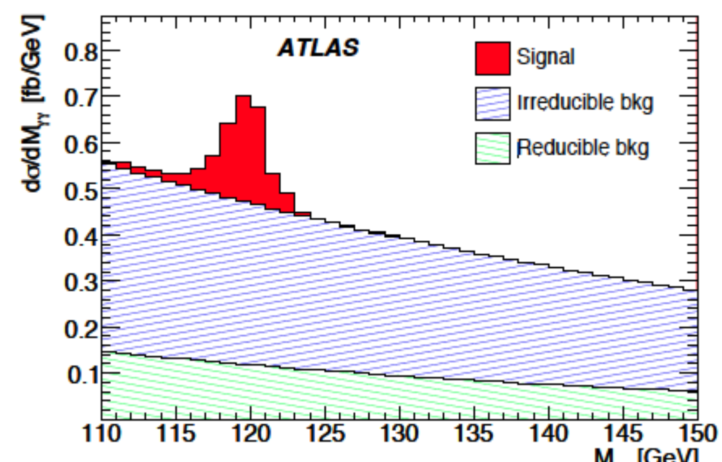
- Using more information:

  VBF topology can easily be distinguished by using the forward jets information

  VBF has no colour flux exchanged in the vertex → low central hadronic activity



Result of such implementation in the events with 2 jets (from MC):



Conclusions

- The search for H→γγ has a strong potential at low masses
- A few detector and analysis improvements could lead to a faster exclusion/discovery of the Higgs
- …or a faster measurement of its mass
- This needs a deep understanding of the detector and of the systematics
- The current results on this analysis will be presented by Heberth
- **Advert: on the 13th of December, there will be a public joint ATLAS+ CMS seminar showing latest/fresh results of the Higgs searches…**