Searching for the Standard Model Higgs boson at the LHC

$H \rightarrow \gamma\gamma$ in ATLAS with 4.9/fb

"Spåtind" (a.k.a Skeikampen),
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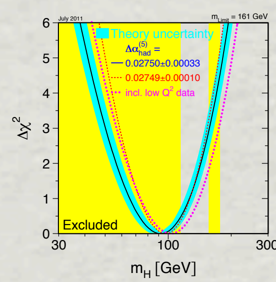
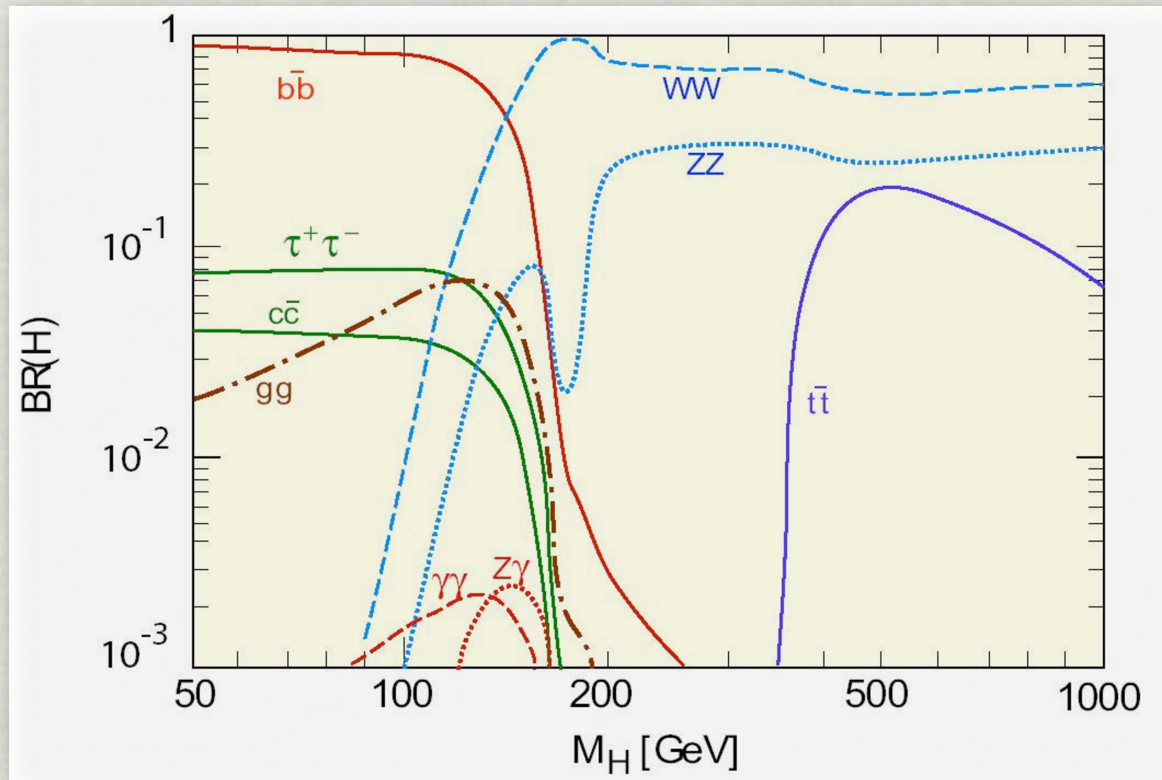
Hunting for the Higgs

To obtain masses for elementary particles is not so straight forward; we have introduced the Higgs mechanism to get there

Despite it's rarity (BR ~0.2%), looking for the diphoton decay of the Higgs boson is useful:

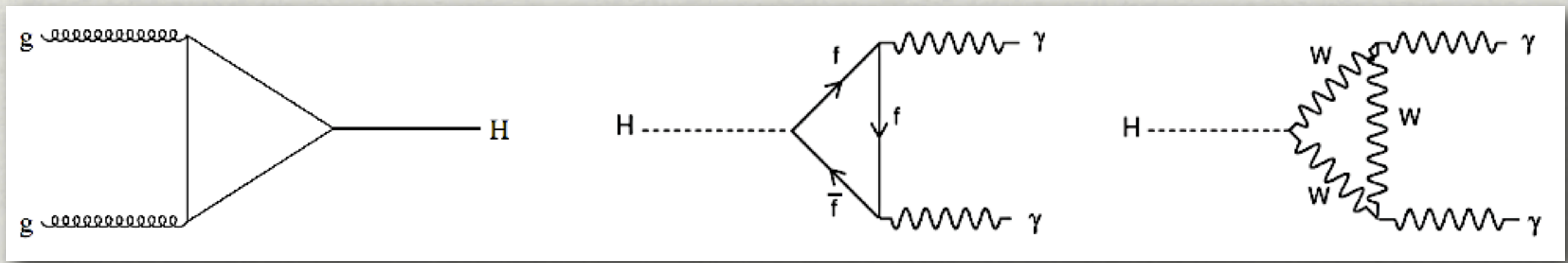
- a low-mass Higgs is favored 

- photons are relatively easy to see in the detector
- if you see it in this channel, you are guaranteed it is not a spin-1 particle (Yang's theorem)

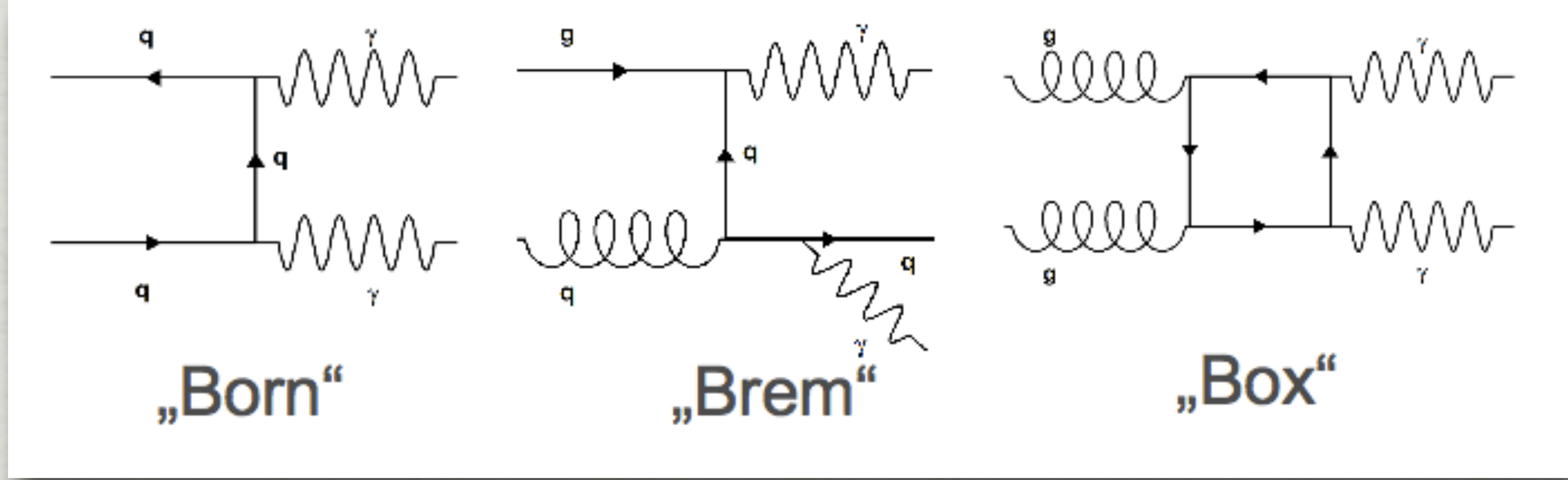


The H → $\gamma\gamma$ signal and background

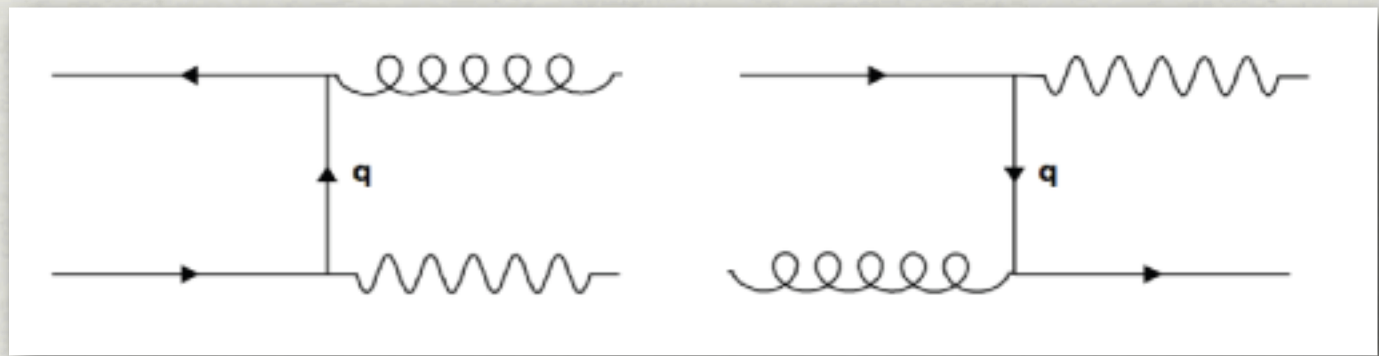
Signal processes



Irreducible background



Reducible background



+ jet-jet and Drell-Yan

Event display of a candidate diphoton event where both photon candidates are unconverted.

The event number is 86694500 and it was recorded during run 191426.

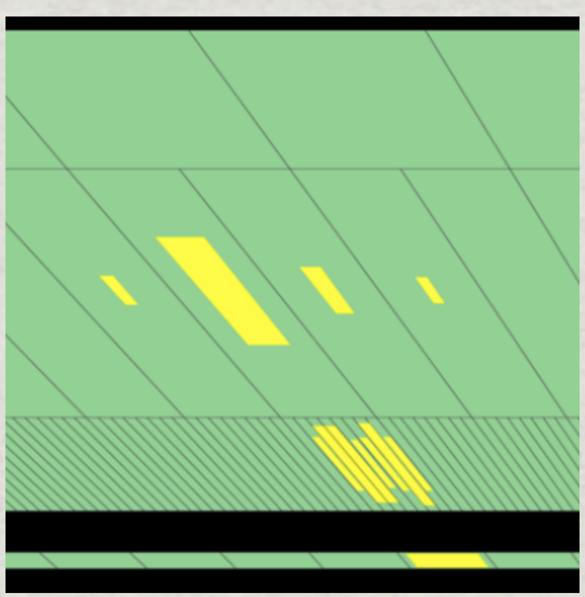
The leading photon has ET=64.2 GeV and eta=-0.34.
The subleading photon has ET=61.4 GeV and eta=-0.61.

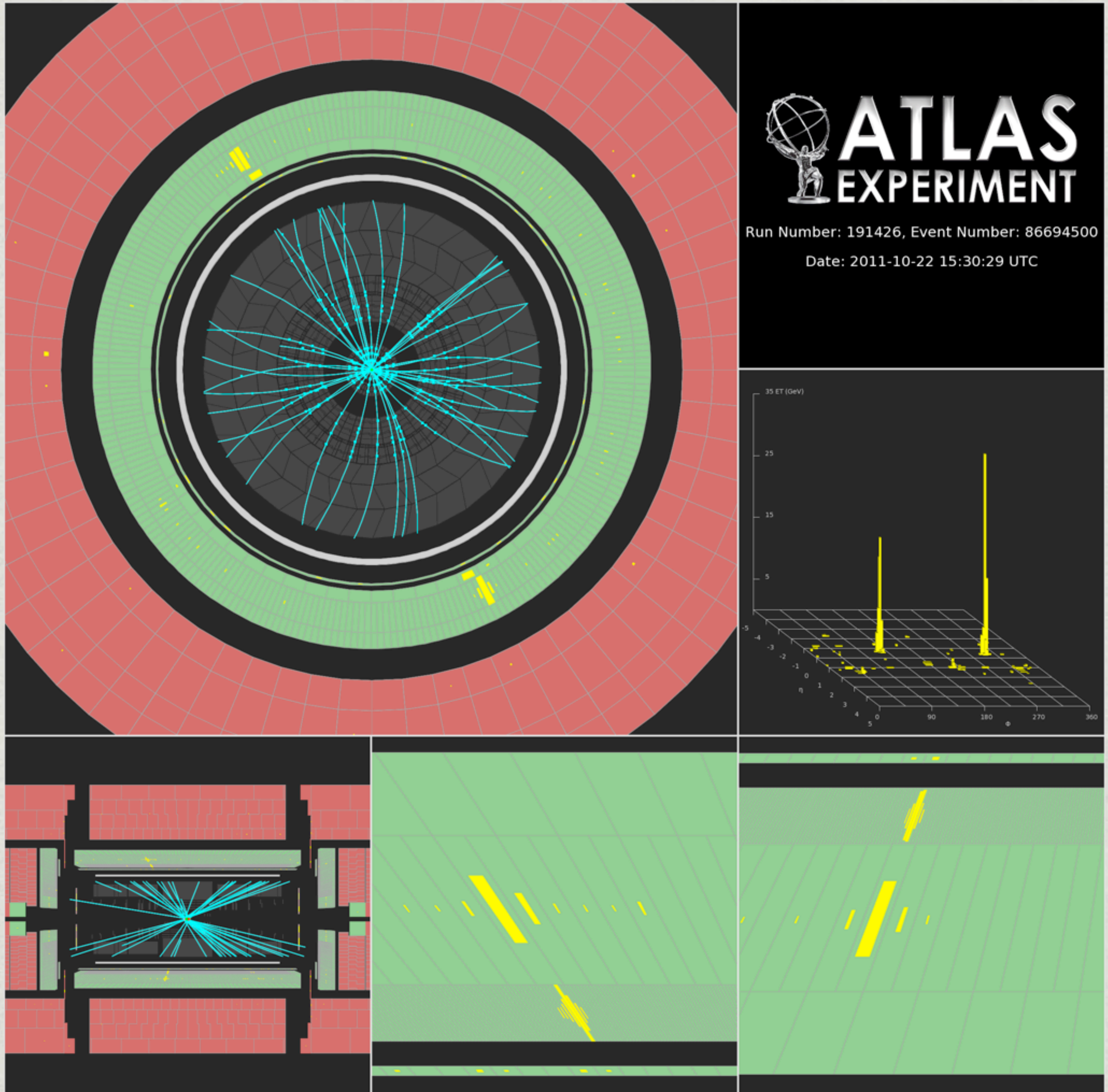
The measured diphoton mass is 126.6 GeV.

The pT and pTt of the diphoton are 6.1 GeV and 5.4 GeV, respectively.

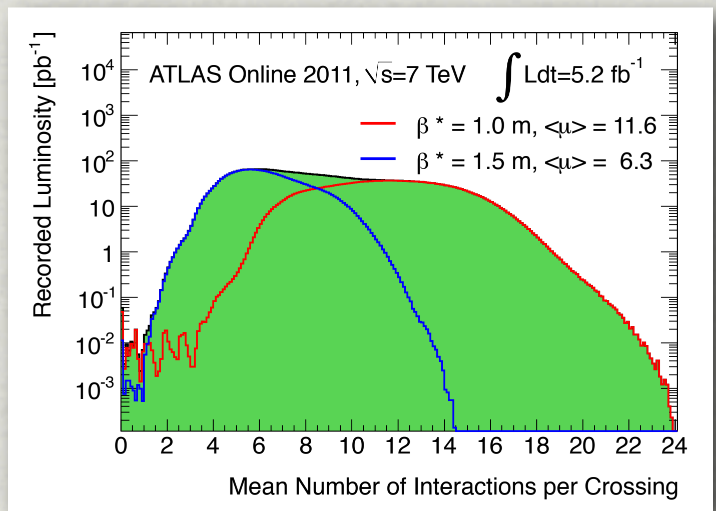
Only reconstructed tracks with pT>1 GeV, hits in the pixel and SCT layers and TRT hits with a high threshold are shown.

π^0 in the ECAL:

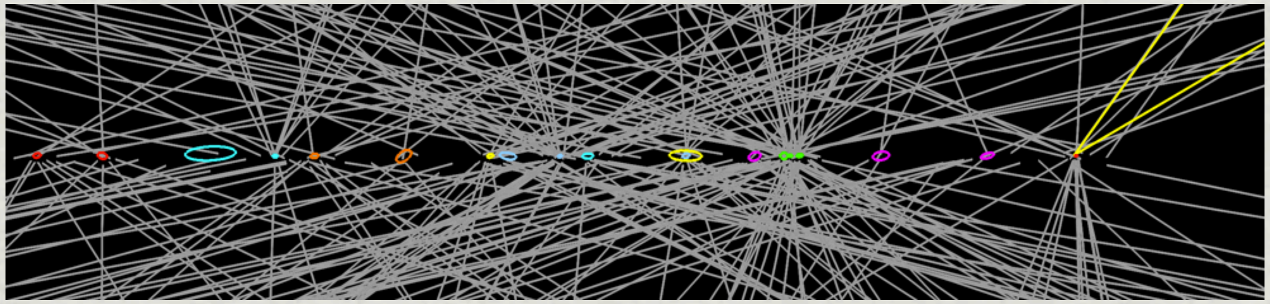




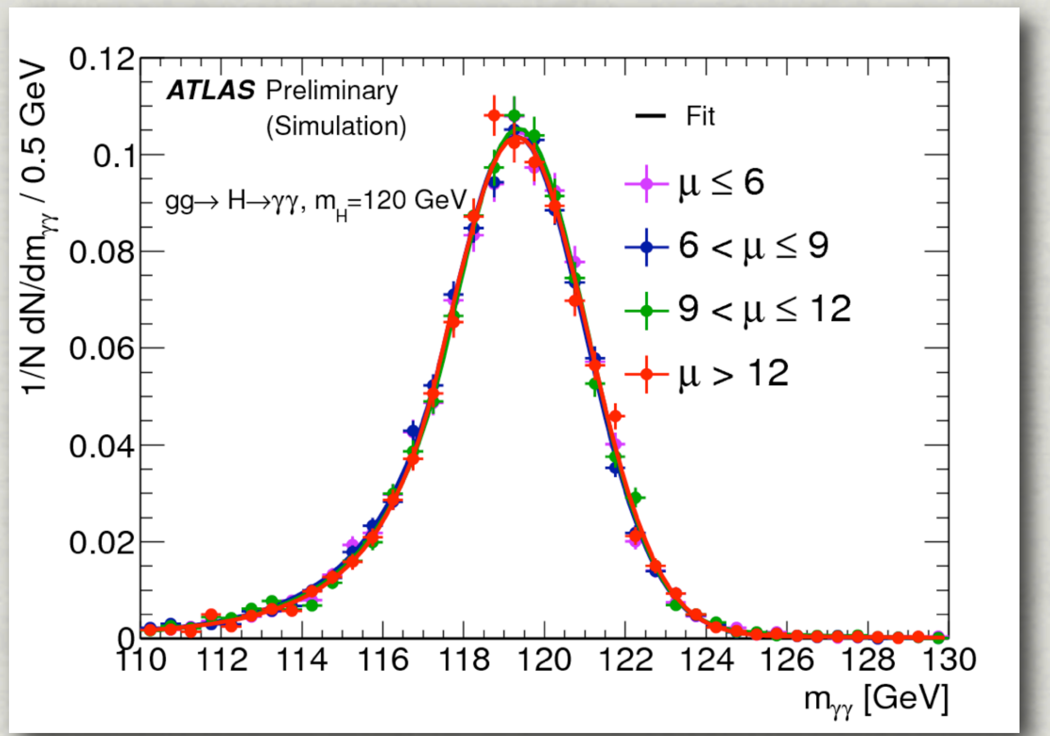
The challenge of pile-up

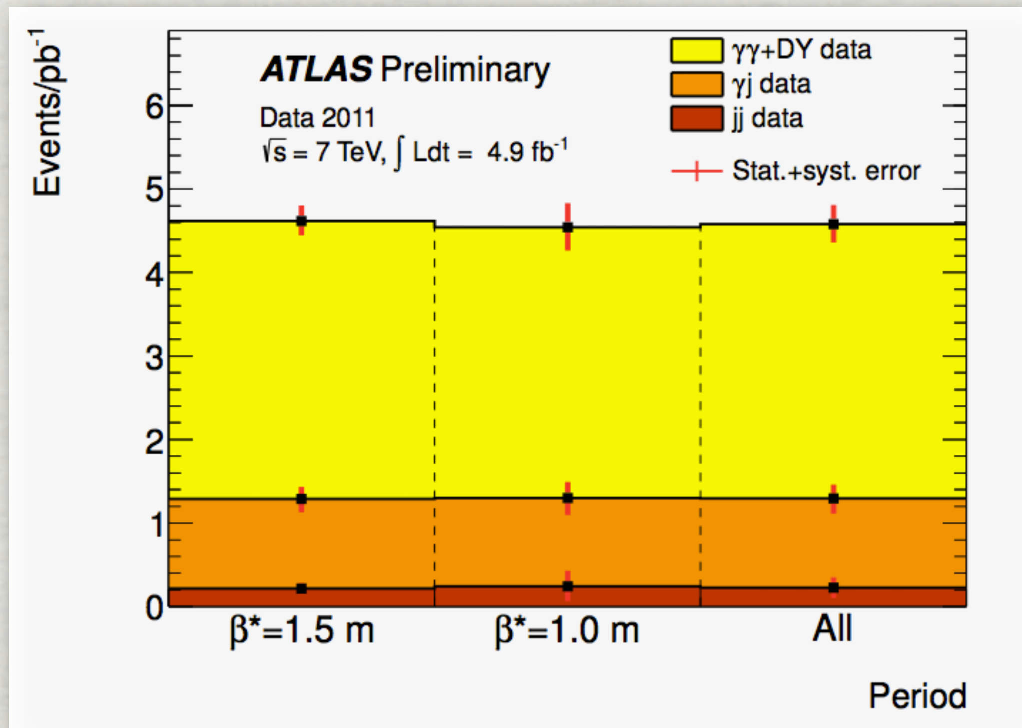


In September 2011, the beam parameters of the LHC got changed



Good news: $M_{\gamma\gamma}$ is not too sensitive to pile-up





The selection

- diphoton trigger with $E_T > 20$ GeV (99 % efficient)
- Events must pass data quality requirements, must contain at least one good PV (>=3 tracks)
- Fiducial cuts: $|\eta_{s2}| < 2.37$, excluding the crack $1.37 < |\eta_{s2}| < 1.52$
- Photons must be isolated: $E_{Tcorrected} < 5$ GeV (cone size $\Delta R = \sqrt{(\Delta\varphi^2 + \Delta\eta^2)} = 0.4$)
- Photons required to pass tight ID based on cuts on shower shape variables
- pT cuts: 40 GeV (leading photon), 25 GeV (subleading photon)
- Converted photons are rejected if a track passes through a faulty element in the pixel B-layer
- Invariant diphoton mass must be in the range 100-160 GeV

22 489 events pass these requirements

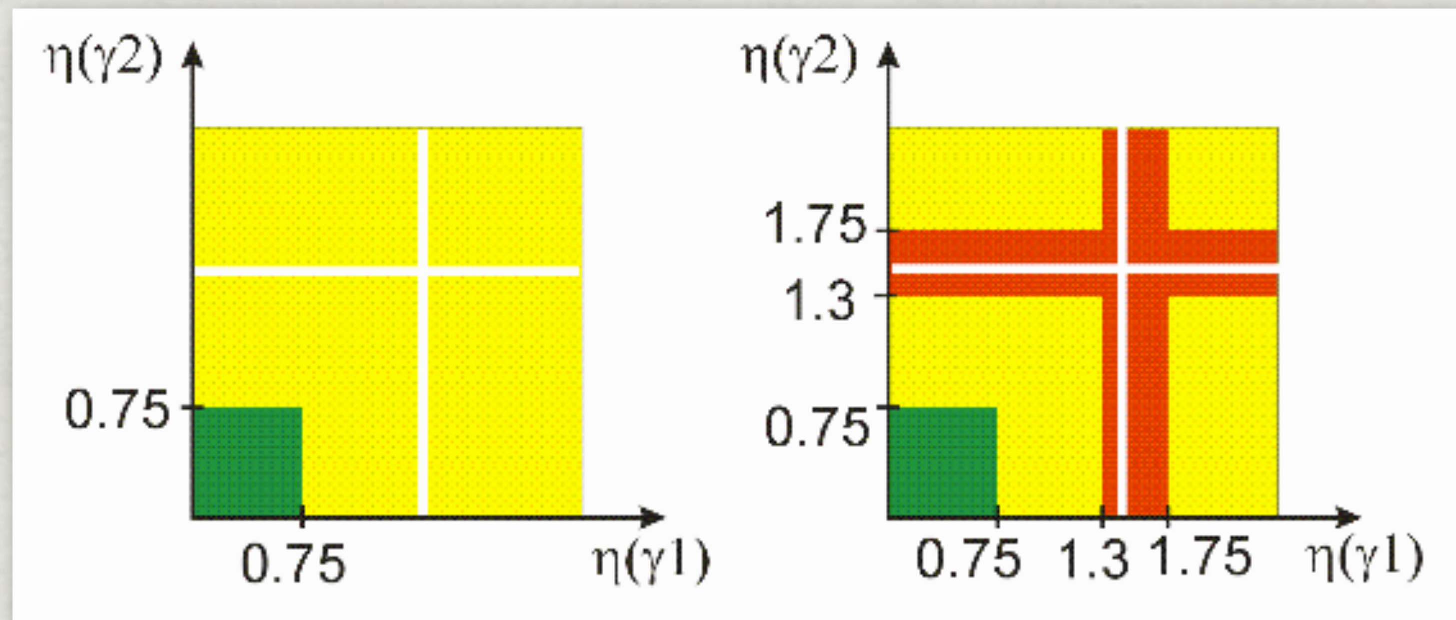
Categorization of the events

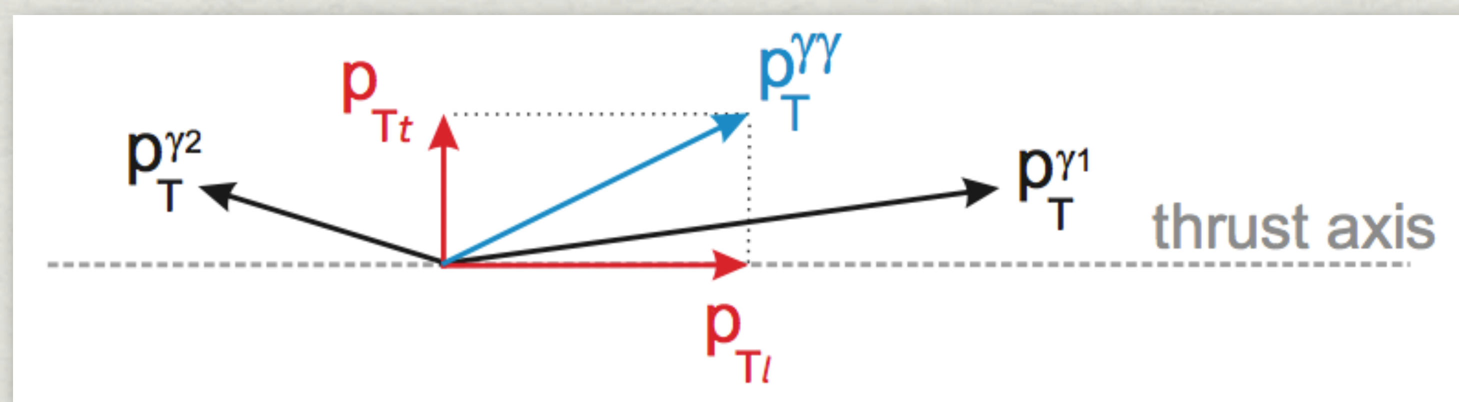
To obtain better sensitivity, we use 9 categories, depending on position in the detector, conversion status and p_{Tt}:

1. uconv - **central** - p_{Tt} low
2. uconv - **central** - p_{Tt} high
3. uconv - **rest** - p_{Tt} low
4. uconv - **rest** - p_{Tt} high
5. conv - **central** - p_{Tt} low
6. conv - **central** - p_{Tt} high
7. conv - **rest** - p_{Tt} low
8. conv - **rest** - p_{Tt} high
9. conv - **transition**

conversion: $\gamma \to e^+e^-$

Both unconverted　　At least one converted



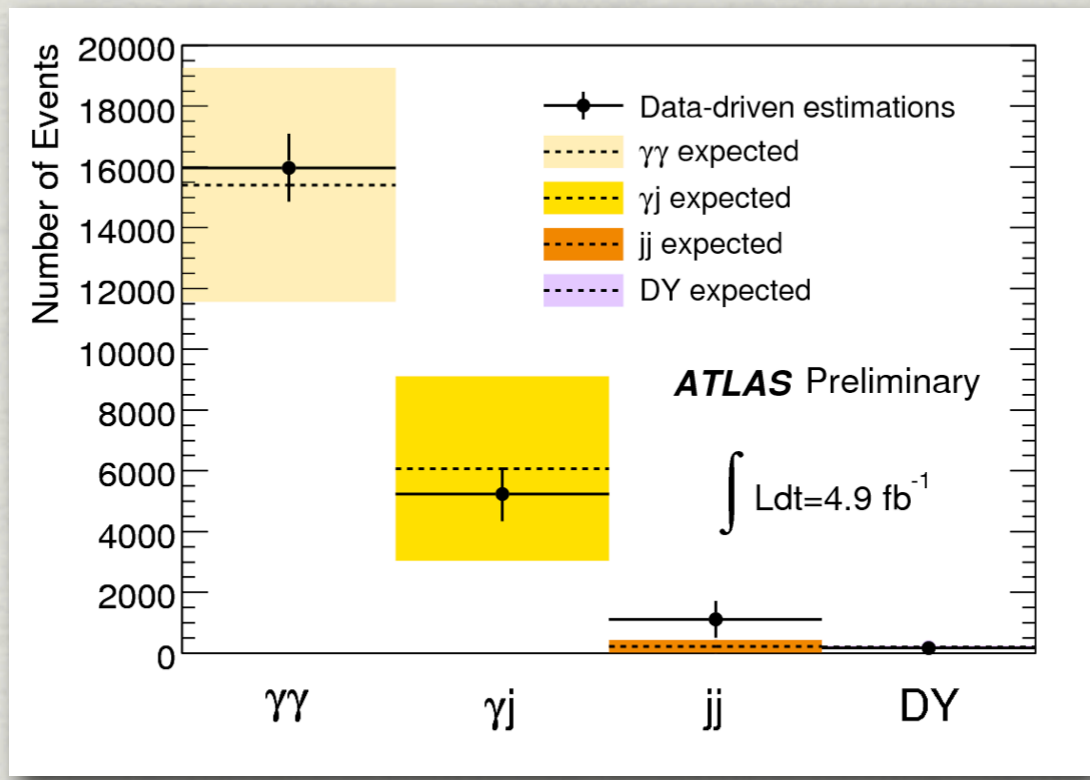


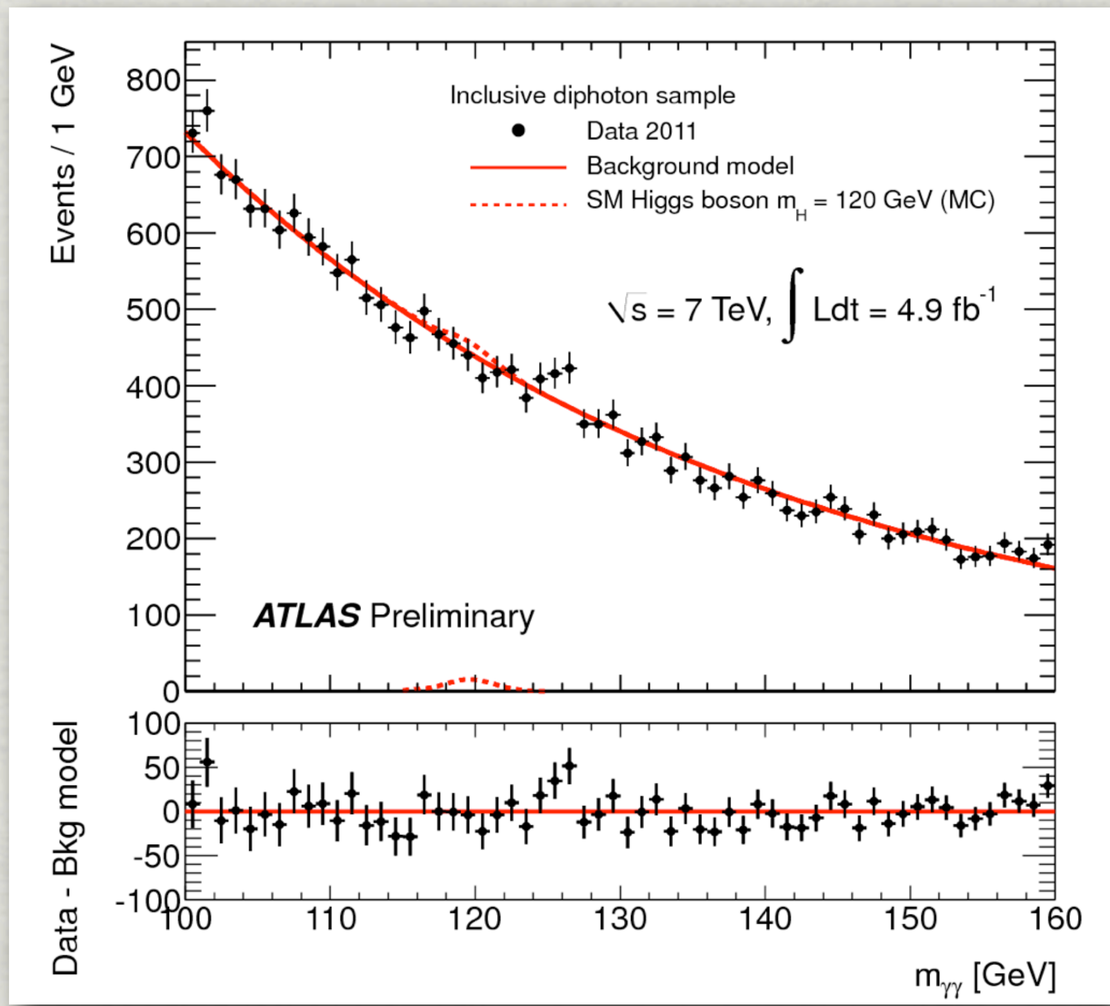
$p_{Tt} \leq 40$ GeV (low)　　$p_{Tt} > 40$ GeV (high)

The spectrum and it's composition

The composition of the background is done in a completely data-driven way (looking at control regions), and cross-checked using three different methods.

~71% of the spectrum is true $\gamma\gamma$.

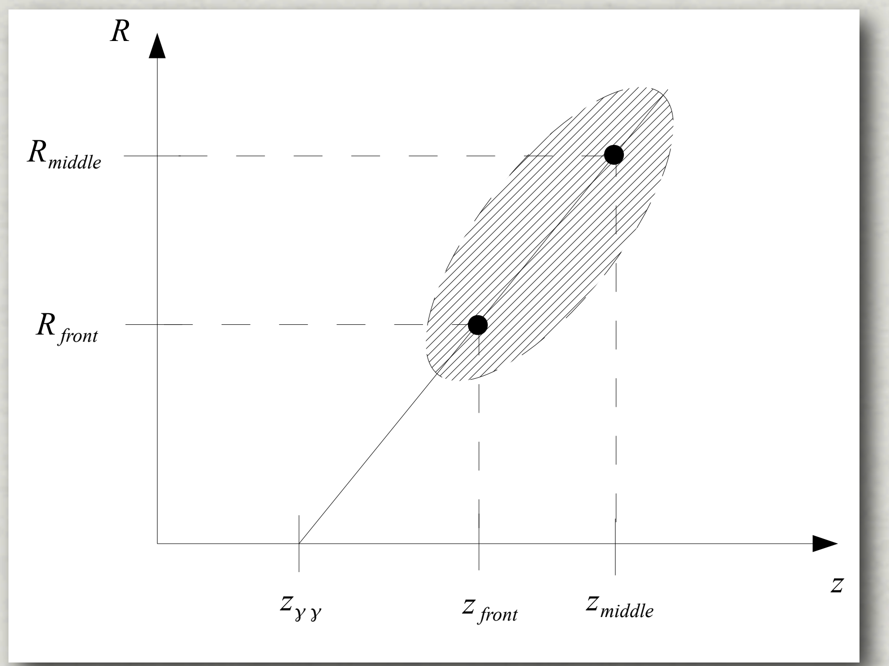


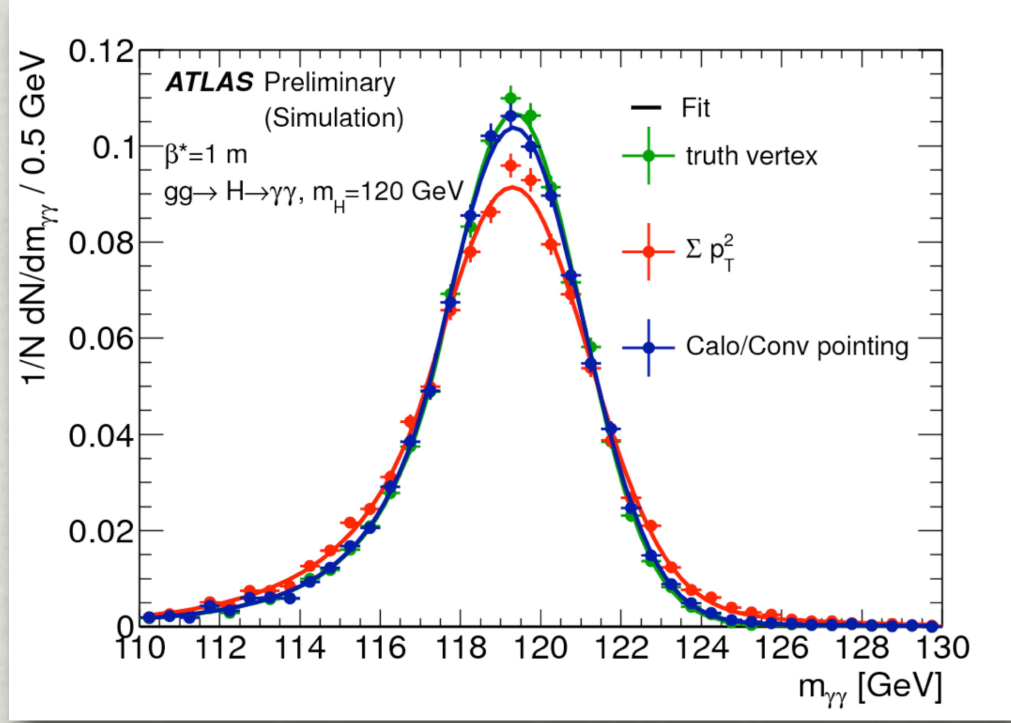


How to decide the position along the beam-line of the vertex;

Calorimeter pointing

- A narrow mass peak on top the smoothly falling background is what is used for the potential discovery of the Higgs boson in the $\gamma\gamma$-channel
- Which vertex you decide your two photons came from is very important for the resolution of the invariant mass (because the position of the vertex influence the angles)
- Using calorimeter-pointing of the diphoton pair is shown to be the best you can do (nearly as good as the truth vertex)





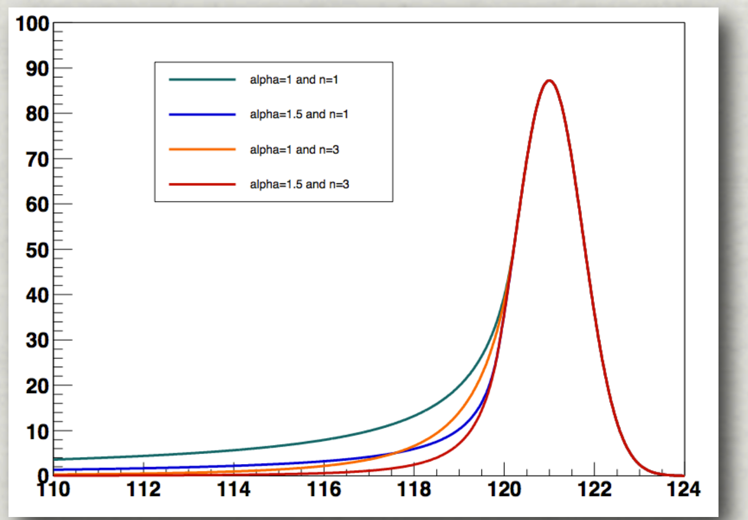
Systematic uncertainties

The systematics can be grouped into three kinds:
on the signal yield, on the invariant mass resolution and
on the migration between the categories.

Type and source	Uncertainty
Event yield	
Photon reconstruction and identification	±11%
Effect of pileup on photon identification	±4%
Isolation cut efficiency	±5%
Trigger efficiency	±1%
Higgs boson cross section	+15%/−11%
Higgs boson p_T modeling	±1%
Luminosity	±3.9%
Mass resolution	
Calorimeter energy resolution	±12%
Photon energy calibration	±6%
Effect of pileup on energy resolution	±3%
Photon angular resolution	±1%
Migration	
Higgs boson p_T modeling	±8%
Conversion reconstruction	±4.5%

Signal description

The signal is described by a Crystal Ball function on top of a wide, small amplitude Gaussian describing the symmetric tails.



The Crystal Ball (CB) function:

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

N is a normalization parameter, n_{CB} and α_{CB} describes the non-Gaussian tail, $t = (m_{\gamma\gamma} - m_H - \delta_{mH}) / \sigma_{CB}$, δ_{mH} is a category depending offset, σ_{CB} represents the diphoton invariant mass resolution.

- the mean of the Gaussian is constrained to $\delta_{mH} \cdot m_H$ and the width to $\kappa \cdot \sigma_{CB}$
- $\alpha_{CB}, \sigma_{CB}, \delta_{mH}, \kappa$ and the fraction of CB are found with a simultaneous fit to all the $m_{\gamma\gamma}$ distributions when fixing n_{CB} to 10
- $\alpha_{CB}, \sigma_{CB}, \delta_{mH}$ depend linearly on the Higgs mass

Background description

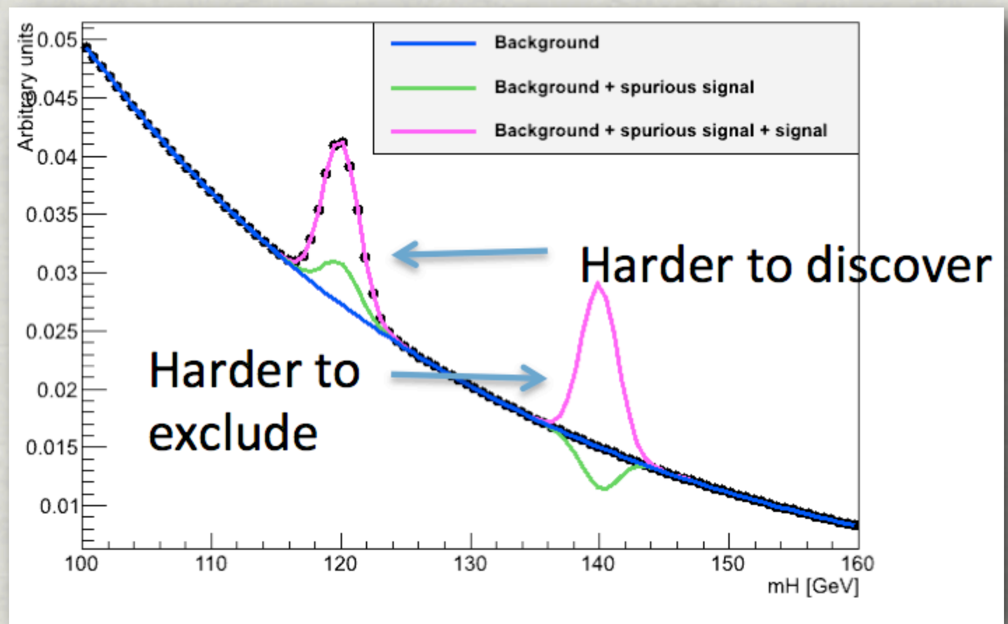
The background model is a single exponential
(double exponential and 2nd order Bernstein polynomial were also tried).

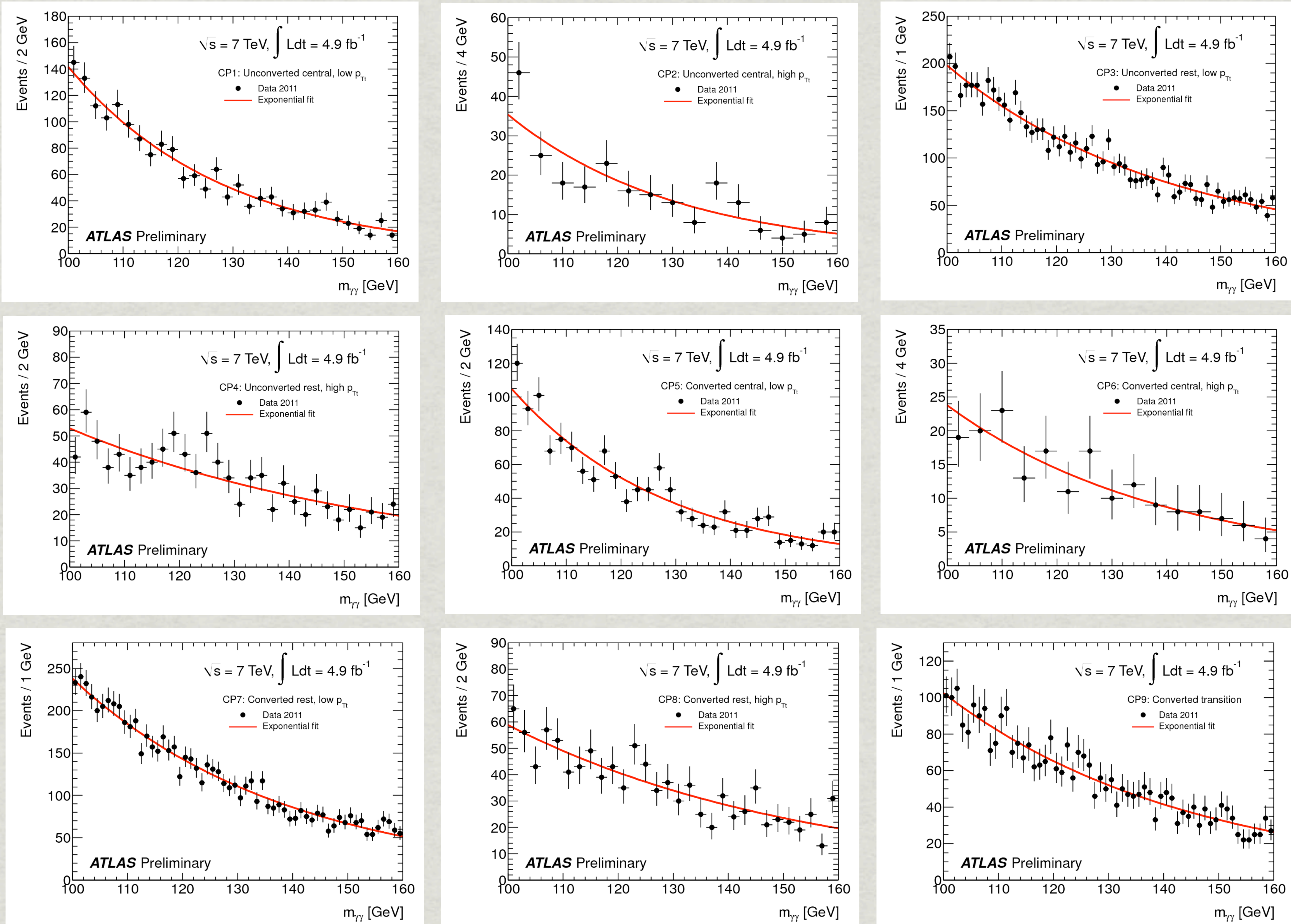
$$B(x) = \sum_{\nu=0}^{n} \beta_\nu b_{\nu,n}(x) \qquad b_{\nu,n}(x) = \binom{n}{\nu} x^\nu (1-x)^{n-\nu}, \quad \nu = 0, \ldots, n.$$

In addition, we have "spurious signal":

the background model is allowed to have a signal shape deviation at the mass we are testing, where the amplitude is constrained by the uncertainty in the table (which is the largest discrepancy of the RESBOS MC simulation from the background fit, when integrating in 4 GeV bins (~FWHM)).

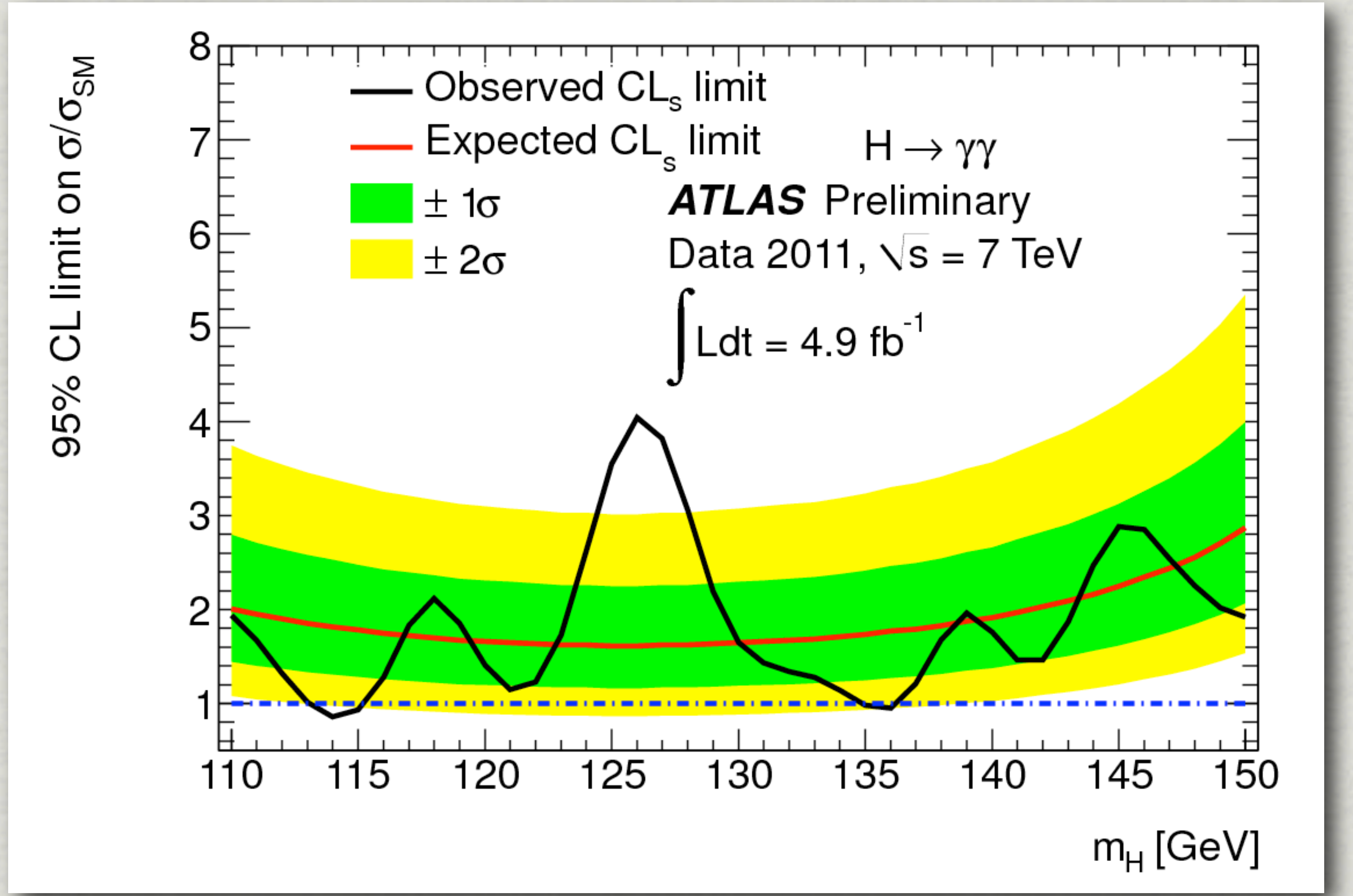
Category	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	CP9
Events	±4.3	±0.2	±3.7	±0.5	±3.2	±0.1	±5.6	±0.6	±2.3



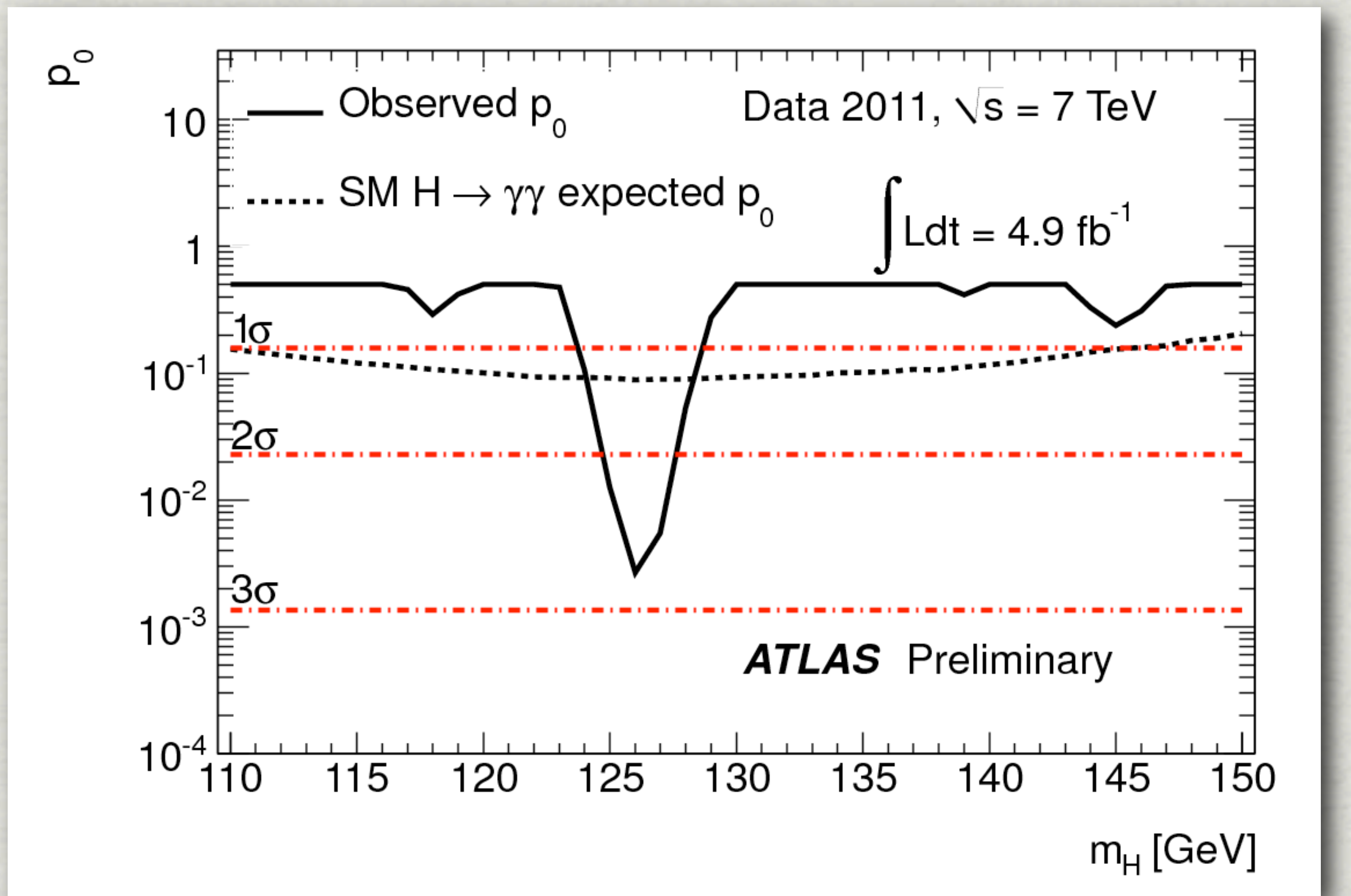

Events / 2 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP1: Unconverted central, low pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 4 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP2: Unconverted central, high pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 1 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP3: Unconverted rest, low pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 2 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP4: Unconverted rest, high pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 2 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP5: Converted central, low pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 4 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP6: Converted central, high pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 1 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP7: Converted rest, low pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 2 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP8: Converted rest, high pTt
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]
Events / 1 GeV
√s = 7 TeV, ∫ Ldt = 4.9 fb-1
CP9: Converted transition
Data 2011
Exponential fit
ATLAS Preliminary
mγγ [GeV]

The Result

A SM Higgs boson in the mass ranges 114 – 115 GeV and 135 – 136 GeV is excluded.



The minimal observed p0-value is 0.27% (2.8 σ) and is found for a mass hypothesis of mH = 126 GeV.



The probability of such an excess appearing anywhere in the mass range investigated due to a background fluctuation is estimated to be approximately 7%.

This reduces the observed significance to 1.5 σ.

What exiting times!

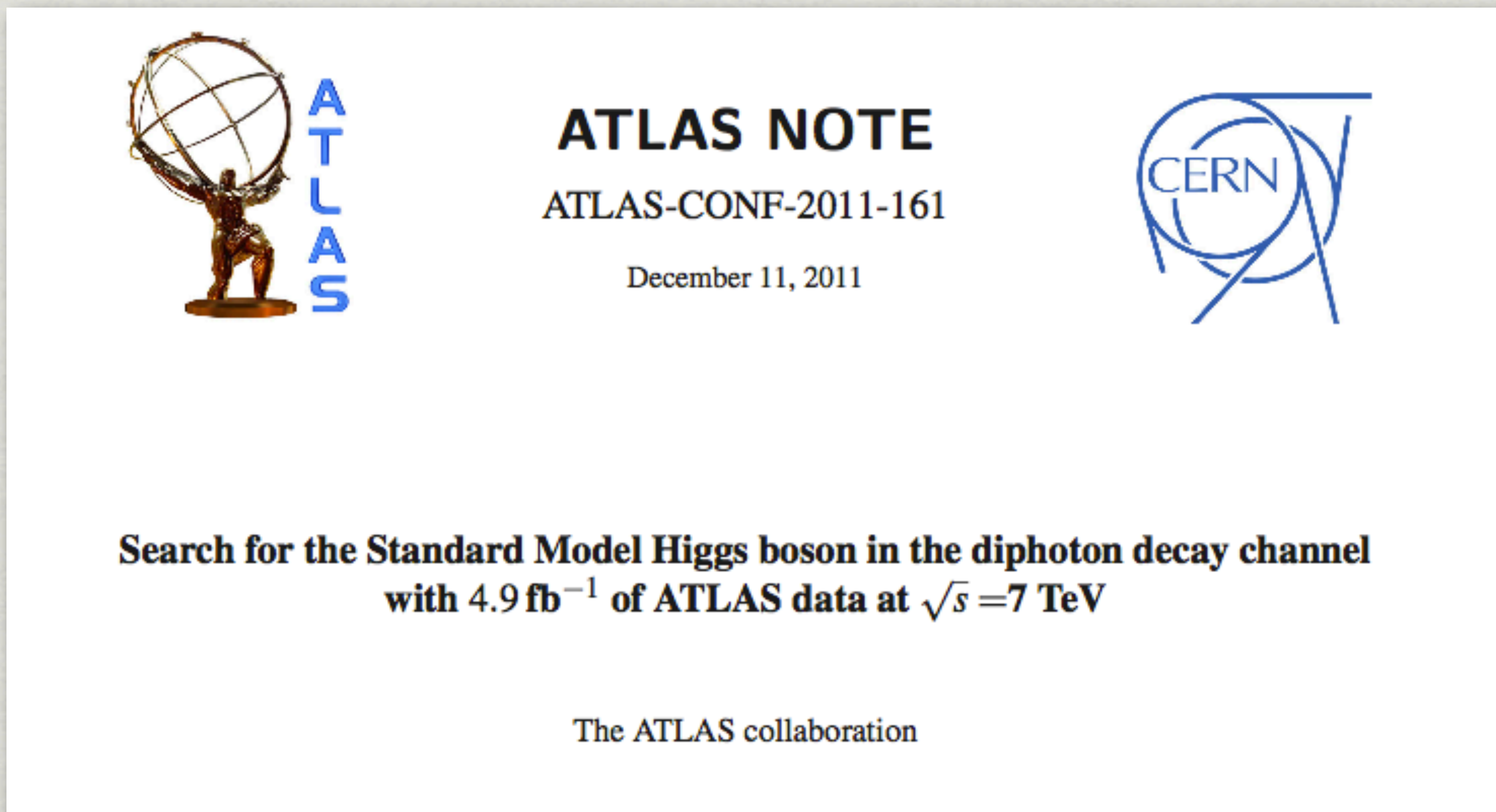
Let's see what next year brings us :)

Thank you!

Back up

Link to the paper
"Search for the Standard Model Higgs boson in the diphoton decay channel with 4.9 fb−1 of ATLAS data at √s =7 TeV"

[HTTPS://CDSWEB.CERN.CH/RECORD/1406356/FILES/ATLAS-CONF-2011-161.PDF](https://cdsweb.cern.ch/record/1406356/files/ATLAS-CONF-2011-161.pdf)



ATLAS NOTE

ATLAS-CONF-2011-161

December 11, 2011

Search for the Standard Model Higgs boson in the diphoton decay channel with 4.9 fb^{-1} of ATLAS data at $\sqrt{s}$ =7 TeV

The ATLAS collaboration

Corrections to MC (for it to resemble data)

- shower shape distributions are shifted and possibly reweighted
- the width of the longitudinal beam-spot is adjusted
- events are reweighted to match the distribution of interactions per bunch
- energy is smeared to match the resolution seen in studies of $Z \rightarrow ee$
- The signal yield is adjusted to fit isolation cut efficiency studies - this reduces the expected signal yield by ~4.4%
- MC gluon fusion processes are adjusted for destructive interference between background continuum $gg \rightarrow \gamma\gamma$ and the $gg \rightarrow H \rightarrow \gamma\gamma$. Correction is in the range 2-5%
- Higgs pT in MC gluon fusion signal processes are adjusted to match the HqT pT-spectrum

Expected signal yield and resolution

In the mass window 100-160 GeV

m_H [GeV]	110	115	120	125	130	135	140	145	150
CP1: Unconverted central, low p_{Tt}	8.9	8.9	8.7	8.2	7.5	6.7	5.7	4.6	3.5
CP2: Unconverted central, high p_{Tt}	2.5	2.6	2.6	2.5	2.3	2.1	1.8	1.5	1.2
CP3: Unconverted rest, low p_{Tt}	16.3	16.7	16.6	16.0	15.0	13.6	11.9	9.8	7.4
CP4: Unconverted rest, high p_{Tt}	4.4	4.6	4.6	4.5	4.3	4.0	3.5	2.9	2.2
CP5: Converted central, low p_{Tt}	5.9	5.9	5.8	5.5	5.1	4.6	4.0	3.3	2.4
CP6: Converted central, high p_{Tt}	1.6	1.7	1.6	1.6	1.6	1.4	1.3	1.1	0.8
CP7: Converted rest, low p_{Tt}	17.5	18.1	17.9	17.1	15.8	14.1	12.0	9.7	7.2
CP8: Converted rest, high p_{Tt}	4.6	4.7	4.7	4.6	4.4	4.1	3.6	2.9	2.2
CP9: Converted transition	8.2	8.4	8.4	8.1	7.6	6.9	6.0	4.9	3.7
Total	69.9	71.5	70.9	68.3	63.7	57.5	49.8	40.8	30.6

Category	σ_{CB} [GeV]	FWHM [GeV]	N_{sig}	N_{BG}	N_{sig}/N_{BG}
CP1: Unconverted central, low p_{Tt}	1.4	3.4	7.3	142	0.051
CP2: Unconverted central, high p_{Tt}	1.4	3.3	2.2	18	0.117
CP3: Unconverted rest, low p_{Tt}	1.7	4.1	13.5	589	0.023
CP4: Unconverted rest, high p_{Tt}	1.6	3.9	3.8	87	0.043
CP5: Converted central, low p_{Tt}	1.7	3.9	4.7	125	0.038
CP6: Converted central, high p_{Tt}	1.6	3.7	1.4	16	0.085
CP7: Converted rest, low p_{Tt}	2.0	4.7	14.0	805	0.017
CP8: Converted rest, high p_{Tt}	1.9	4.5	3.7	110	0.034
CP9: Converted transition	2.3	5.8	5.9	429	0.014

$\pm 1.4\sigma_{CB}$ for $m_H = 120$ GeV

Systematic uncertainties

Three kinds of systematics: on the signal yield, on the invariant mass resolution and on the migration between the categories.

Signal yield uncertainties:

- ± 11% on the photon ID and reconstruction
- ± 4% on the effect of pileup on photon ID and reconstruction
- ± 5% on the isolation cut efficiency
- ± 1% on trigger efficiency
- +15/-11% on signal cross section
- ± 1% on signal acceptance from modeling of Higgs pT
- ± 3.9% on luminosity

Category migration uncertainties:

- ± 8% on high pTt to low pTt category
- ± 4.5% on unconverted to converted category

Resolution uncertainties:

- ± 12% on calorimeter energy resolution
- ± 6% on extrapolation from electron energy resolution to photon energy resolution
- ± 3% on effect of pileup on energy resolution
- ± 1% on photon angle measurement

The selection

- diphoton trigger with $E_T > 20$ GeV (99 % efficient)
- Events must pass data quality requirements, must contain at least one good PV (>=3 tracks)
- Photons seeded by clusters in the ECAL with ET > 2.5 GeV
- In case of converted photons, clusters are matched to tracks in the inner detector
- Energy calibration separately for converted and unconverted photons, a correction applied on top of the calibration obtained from $Z \rightarrow ee$ studies
- Fiducial cuts: $|\eta_{s2}| < 2.37$, excluding the crack $1.37 < |\eta_{s2}| < 1.52$
- Photons must be isolated: $E_{Tcorrected} < 5$ GeV (cone size $\Delta R = \sqrt{(\Delta\varphi^2 + \Delta\eta^2)} = 0.4$)
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