Associated Production Z/W H $\rightarrow \gamma\gamma$ with ATLAS detector

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on behalf of the ATLAS collaboration

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No results will be given
since work is still in progress

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Introduction

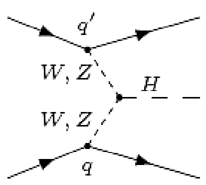
- A Standard Higgs boson up to ~ TeV can be discovered with less than 20 fb^{-1} with the ATLAS experiment.
- Seeing surplus of events in one of the Higgs channels is not sufficient to prove the existence of the Higgs boson :
  - The spin and CP-eigenvalue have to be determine
  - The expected couplings to known SM particles have to be verified :
    - Due to the mechanism of the electroweak symmetry breaking, the couplings of the Higgs to the W and Z bosons are :

$$g_W = \frac{2 m_W^2}{v} \qquad g_Z = \frac{2 m_Z^2}{v}$$

where $v \approx 246$ GeV is the vacuum expectation value of the Higgs field.

Measurement of the Higgs Boson couplings to the W/Z bosons

- Consistency of Standard Model: cross-sections and couplings are predicted for a given mass (ATL-PHYS-2003-030, Michael Dührssen).

Production		Decay	Mass range
	WBF: Weak Boson Fusion $(qq\,H)$	$H \to ZZ^{(*)} \to 4l$	110 GeV - 200 GeV
		$H \to WW^{(*)} \to l\nu\, l\nu$	110 GeV - 190 GeV
		$H \to \tau\tau \to l\nu\nu\, l\nu\nu$	110 GeV - 150 GeV
		$H \to \tau\tau \to l\nu\nu\,\mathrm{had}\nu$	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	WH	$H \to WW^{(*)} \to l\nu\, l\nu\, (l\nu)$	150 GeV - 190 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	ZH	$H \to \gamma\gamma$	110 GeV - 120 GeV

- Associated Production and Vector Boson Fusion are the main processes sensitive to the Higgs couplings to the Z and W bosons.

- These couplings are more difficult to measure for the low Higgs mass : it is important to include all signals. The Higgs decay to photons depends on the couplings via the top and W loop.

Measurement of the Higgs Boson couplings to the W/Z bosons

- The Higgs boson production cross-sections can be expressed by the couplings in the following way :

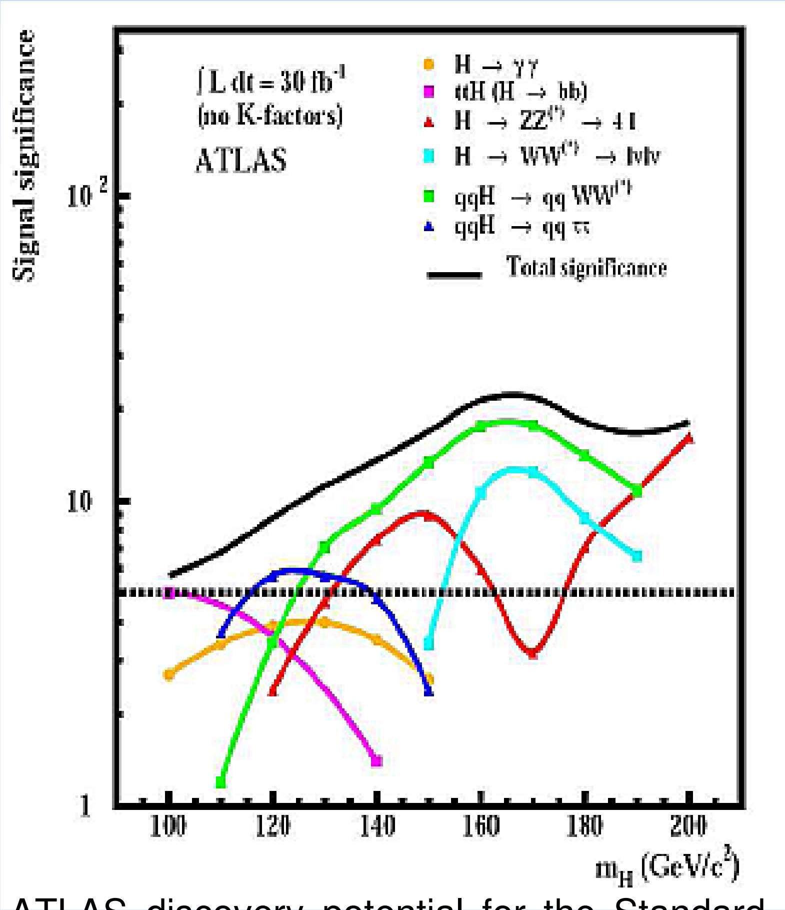
$$
\begin{aligned}
\sigma_{ggH} &= \alpha_{ggH} \cdot g_t^2 \\
\sigma_{\mathrm{WBF}} &= \alpha_{\mathrm{WF}} \cdot g_W^2 + \alpha_{\mathrm{ZF}} \cdot g_Z^2 \\
\sigma_{t\bar{t}H} &= \alpha_{t\bar{t}H} \cdot g_t^2 \\
\sigma_{WH} &= \alpha_{WH} \cdot g_W^2 \\
\sigma_{ZH} &= \alpha_{ZH} \cdot g_Z^2 \quad .
\end{aligned}
$$

- The coefficient α are the proportionality constants between the couplings squared and the cross-sections : they are predicted from theory. Due to the finite precision of the calculations, the systematic uncertainties of these coefficients are [1] :

$$\alpha_{ggH} \approx 20\%\ ,\ \alpha_{ttH} \approx 15\%\ ,\ \alpha_{ZH/WH} \approx 7\%$$

Motivations for the ZH/WH $\rightarrow \gamma\gamma$ channel

- The Standard Model predicts a light Higgs boson. The LEP experiments excluded a Higgs mass below 115 GeV : in the low mass region, the diphoton decay is one of the most important channels :
  - main advantage : the electromagnetic calorimeter of the ATLAS detector allows us to have a very good mass resolution (~ 1.3 %).
  - main disadvantage : the branching ratio $H \rightarrow \gamma\gamma$ is low (~ 0,2 %) : we have to consider all the possible channels : we can use the associated production to increase the significance of the Higgs boson discovery.



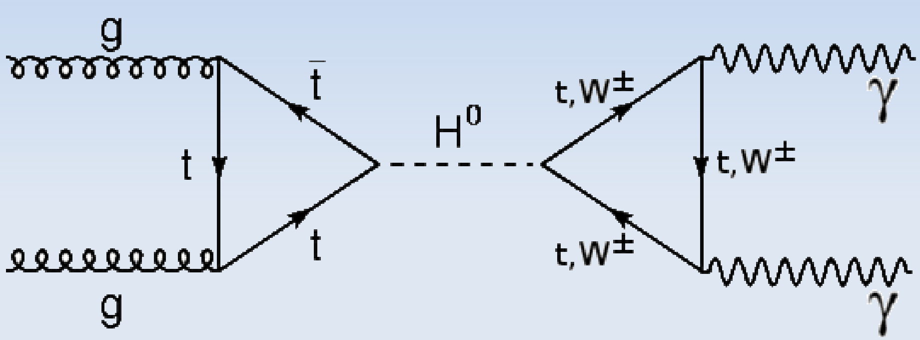
ATLAS discovery potential for the Standard Model Higgs boson searches [3].

Processes in the H → γγ channel

NLO cross sections (14 TeV pp colisions) for m_H = 120 GeV including the branching ratio $H^{(120\ GeV)} \rightarrow \gamma\gamma$:

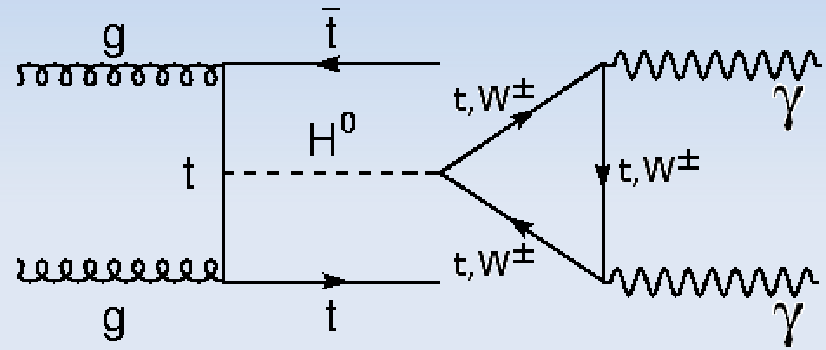
- gluon-gluon fusion :

  σ = 83,8 fb



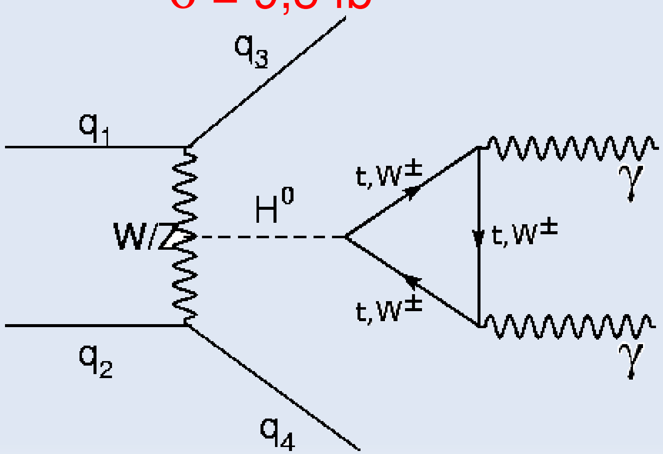
- Associated Production with a top quark pair :

  σ = 1,49 fb



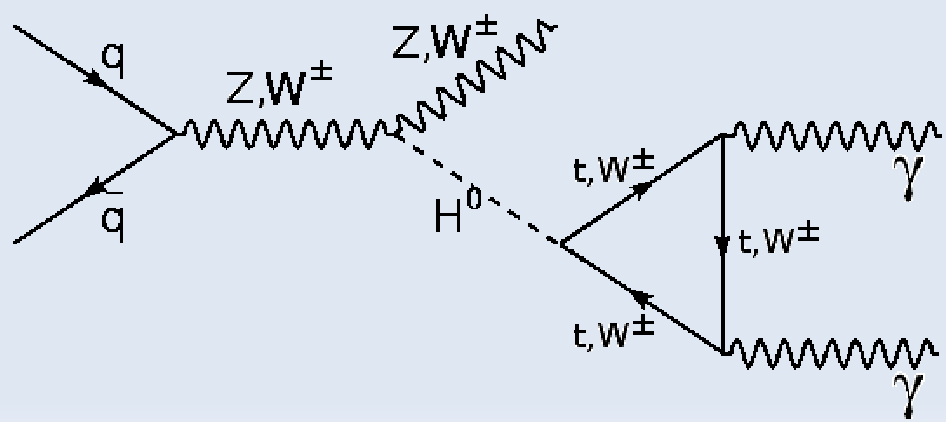
- Vector Boson Fusion :

  σ = 9,5 fb



- Associated Production with a Z/W boson :

  σ_{WH}= 3,66 fb σ_{ZH}= 1,97 fb



Reconstruction of ZH→ $\gamma\gamma$ and WH→ $\gamma\gamma$ events

- To select ZH → $\nu\nu\gamma\gamma$ signal , we look for events containing two photons and missing transverse energy.
- To select WH → $l\nu\gamma\gamma$ signal , we look for events containing two photons, a isolated lepton and missing transverse energy.
- A photon can convert into two electrons in the detector : in this case, we have a energy deposition in the Electromagnetic Calorimeter associated with one or two tracks in the Inner Detector which can correspond to the same signal deposited by an electron. It is difficult to discriminate an electron from a converted photon :
    - The Higgs group developed common tools to reconstruct the conversion vertex.
- we have likelihood methods to discriminate photons from jets.

Reconstruction of ZH$\rightarrow \gamma\gamma$ and WH$\rightarrow \gamma\gamma$ events

- Main background producing the same topology :
  - W/Z + $\gamma\gamma$: $\sigma_{W\gamma\gamma}$ = 6,4 fb $\sigma_{Z\gamma\gamma}$ = 4,8 fb where $90 < M_{\gamma\gamma} < 150$ GeV
    (including the branching ratios of the W and Z decays)
- $W\gamma \rightarrow e\nu$ where the electron is mis-reconstructed as a photon : we have two photons and missing energy (same signature as the ZH$\rightarrow\nu\nu\gamma\gamma$ signal) : $\sigma_{W\gamma \rightarrow e\nu} \approx$ 5900 fb
- $\gamma\gamma$ + n partons : if a jet (parton) is mis-reconstructed, the signature of this event would be two photon and missing energy.
- γ-jet (π^0) : the fine segmentation of the strips in the calorimeter allows a very good γ/π^0 separation

Jet Rejection

- To reduce the photon-jet mis-identification, photon identification cuts have been optimized based on the shower shapes in the calorimeter.
  - An efficiency of 84% [4] has been obtained for photons with an energy spectrum as expected from $H \rightarrow \gamma\gamma$ decay with m_H = 120 GeV

Selection cuts	$E_T > 25$ GeV		$E_T > 40$ GeV	
	Quark jets	Gluon jets	Quark jets	Gluon jets
Before isolation	1770 ± 50	15000 ± 700	1610 ± 100	15000 ± 1600
After isolation	2760 ± 100	27500 ± 2000	2900 ± 240	28000 ± 4000

Jet rejections obtained before and after applying track-isolation cuts for photon candidates with E_T> 25 GeV and E_T > 40 GeV and for a photon efficiency of approximately 84%. The rejection values are shown with their statistical errors separately for quark and gluon jets [4].

- The backgrounds have very high cross sections, we have to use very tight cuts to select signal events and decrease the background contribution.

Statistical combination of the different channels

- Idea : fit simultaneously different channels. The Higgs group in ATLAS collaboration is developing a tool (Hfitter) to combine the different categories (depending on the event topology) :
  - 2 photons (the main contribution is gluon-gluon fusion)
  - 2 photons + 1 or 2 jets (main contribution : Vector Boson Fusion)
  - 2 photons + missing energy (main contribution : ZH → $\nu\nu\gamma\gamma$)
  - 2 photons + lepton(s) (main contribution : WH → $l\nu\gamma\gamma$)

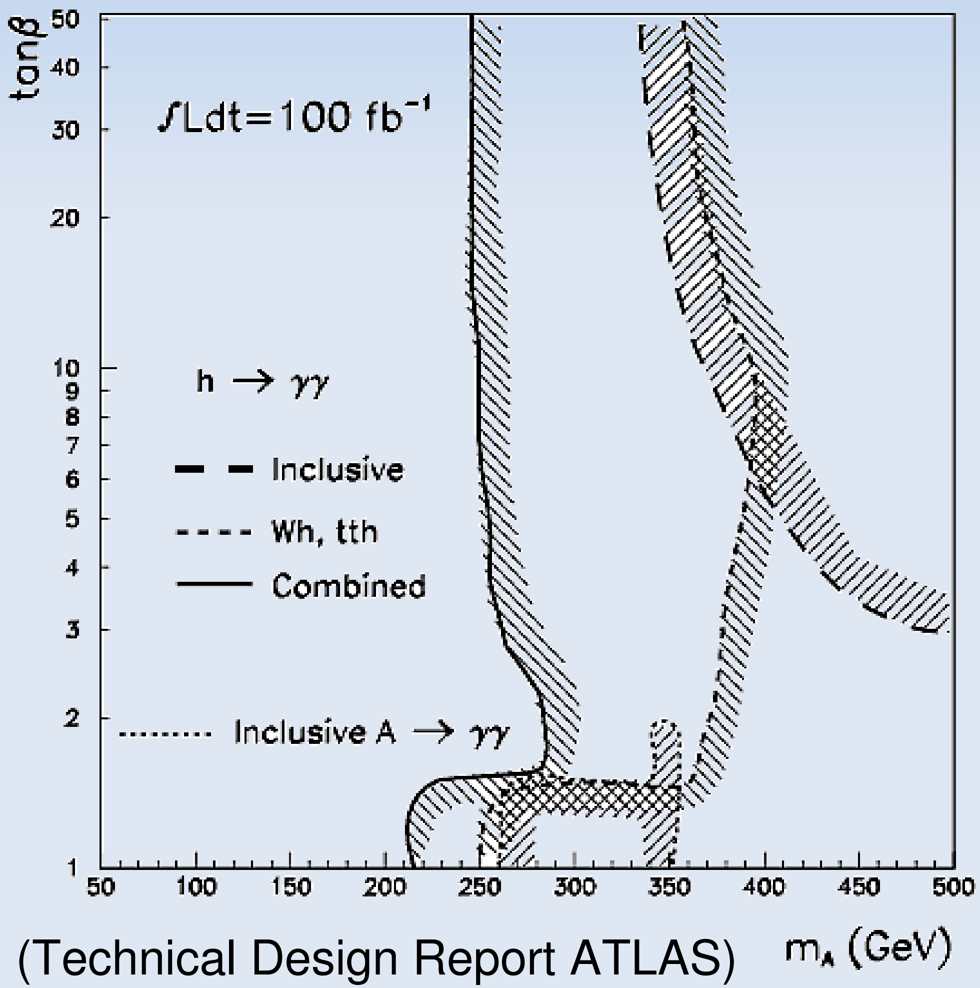
- We have a better significance by combining different channels.

$$\sigma_{Comb} \sim \sqrt{\sum_i \sigma_i^2}$$

(first approximation, more exact methods of combination are being implemented)

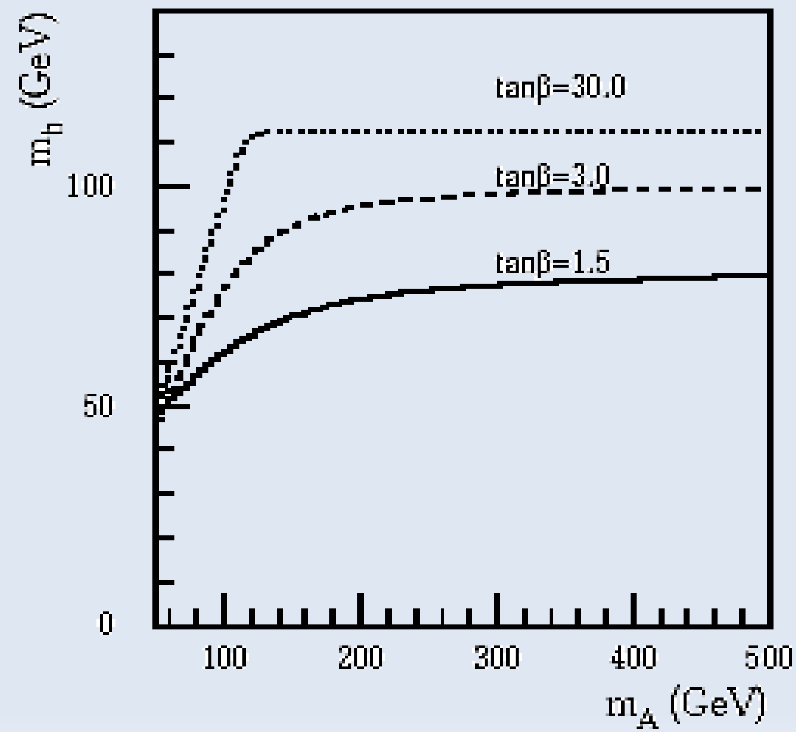
Physics beyond the Standard Model

- Associated production could reveal physics beyond the Standard Model :
  - Supersymmetry (depending on (tan β)) :



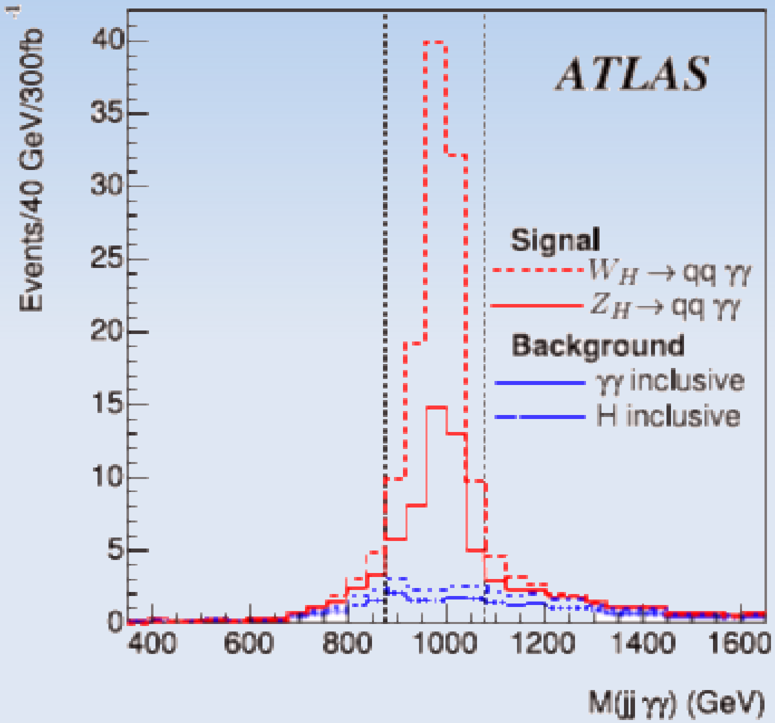
(Technical Design Report ATLAS)

High tan β and high m_A mass region is the most important for low m_h mass.



Physics beyond the Standard Model

- Little Higgs models (hep-ph/0402037; SN-ATLAS-2004-038)



These models predict new resonances :

$Z_H \rightarrow ZH$ et $W_H \rightarrow WH$:

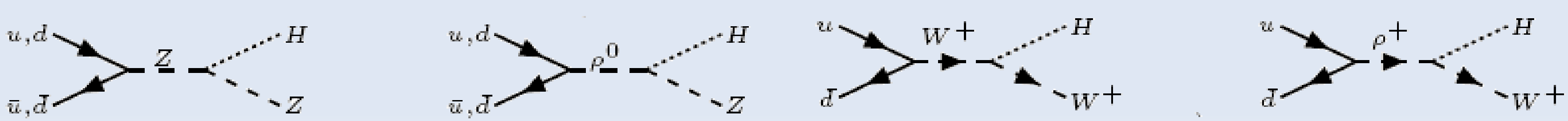
► increase the associated production cross-section of the Higgs with higher energetic particles : the background is easier to reduce.

we need high statistics (a couple of years at high luminosity).

- Left-Right symmetric model : resonance $W_R \rightarrow WH$; $Z_R \rightarrow ZH$

(Physics Letters B, Volume 255, Issue 4, p. 599-604)

- Technicolor ($\rho_T \rightarrow WH$ in the s channel, hep-ph/0512261 A. Zerwekh), ...



Conclusions

- The $H \rightarrow \gamma\gamma$ channel will be used to look for a light SM Higgs boson : the branching ratio is low, it is necessary to keep all the possible channels (Higgs, Higgs + jets, associated production) :
  - By combining the different channels, we can increase the significance : by adding the associated production, the significance of $H^{(120\ GeV)} \rightarrow \gamma\gamma$ increases by approximatively 10% (30 fb^{-1}).
- The associated production channels allow us to measure directly the coupling of the Higgs to the Z and W bosons.
- These channels could eventually (after few years) reveal physics beyond the Standard Model.
- We are currently writing a scientific note (ATLAS CSC notes) showing the discovery potential of a Higgs boson decaying into photons in the mass range $115 < m_H < 140\ GeV.c^{-2}$ using the ATLAS detector.

References

[1] Prospect for the measurement of Higgs Boson coupling parameter in the mass range from 110-190 GeV.

Michael Duhrssen, ATL-PHYS-2003-030

[2] Prospects to measure the Higgs boson properties in ATLAS

A. Dahlhoff, hep-ex/0505022

[3] Technical Design Report of the ATLAS experiment

LHCC 99-14/15

[4] The ATLAS Experiment at the CERN Large Hadron Collider

Atlas Collaboration, ATL-COM-PHYS-2007-102

Back-up slides

Systematic uncertainties

- Sources of systematic uncertainties [1] :
  - Detector :
    - Luminosity measurement : 5 %
    - Detector efficiency : 2%
    - Lepton reconstruction efficiency : 2%
    - Photon reconstruction efficiency : 2%
    - b-tagging efficiency : 3 %
    - τ-tagging efficiency : 3 %
    - WBF tag-jets : 5%
    - Lepton isolation efficiency : 3%

Back-up slides

Systematic uncertainties

- Sources of systematic uncertainties [1] :
  - Background normalization :
    - in the diphoton channel, the two photons final state is observed in a narrow resonance peak on top of a huge flat background. The normalization sample at least 10 times larger than the ±1,4σ mass window of the peak is used.

      systematic uncertainty on the extrapolation ≈ 0,1%
  - Background cross-sections

    ≈ 0,1 % in the diphoton study.
  - QCD / PDF and QED uncertainties for signal processes