Low mass Higgs and Higgs properties at the LHC

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Outline

- Introduction
- Higgs search
  - H->$\gamma\gamma$
  - VBF H->$\tau\tau$
  - ttH, H->bb
  - ttH/WH, H->WW
- Higgs property measurement
  - Mass
  - Coupling
- Summary

Introduction

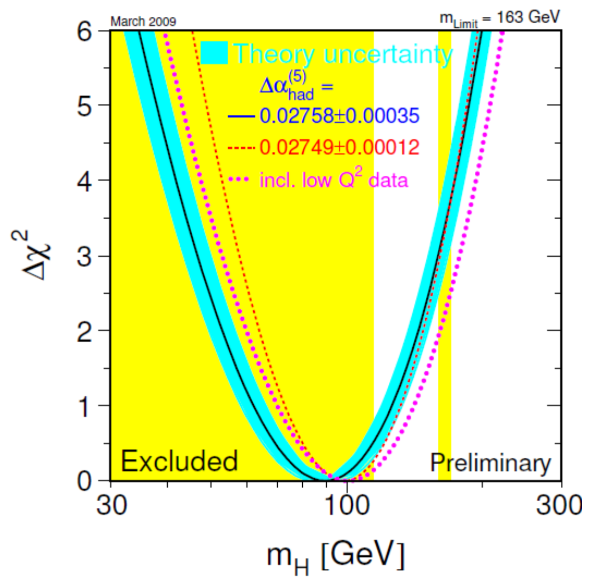
- The discovery of the Higgs boson is a crucial goal of LHC.
- Tevatron has excluded a region of 160-170GeV.
- According to LEP EW working group,

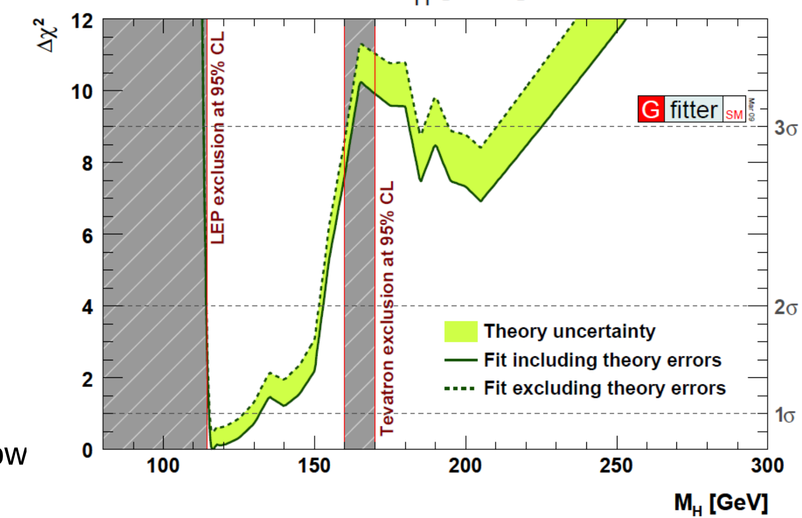
  m_H=90(+36-27)GeV
  m_H < 163 GeV/c^2 @95% C.L.

  is preferred. (see the right plot)
- Search of low mass Higgs is very interesting.
  - SUSY usually needs a Higgs Boson below 135GeV.
- Today, we show results based on the latest simulation with 14TeV center of mass energy (except for coupling);
  - H->$\gamma\gamma$
  - VBF H->$\tau\tau$
  - ttH, H->bb
  - ttH/WH, H->WW

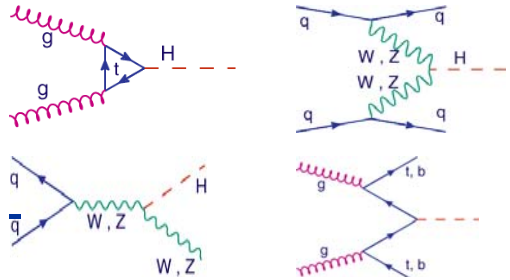
  gg->H->WW, H->ZZ->4l and combined discovery potential results will be shown by Cristina.

(LEP direct search m_H>114GeV)



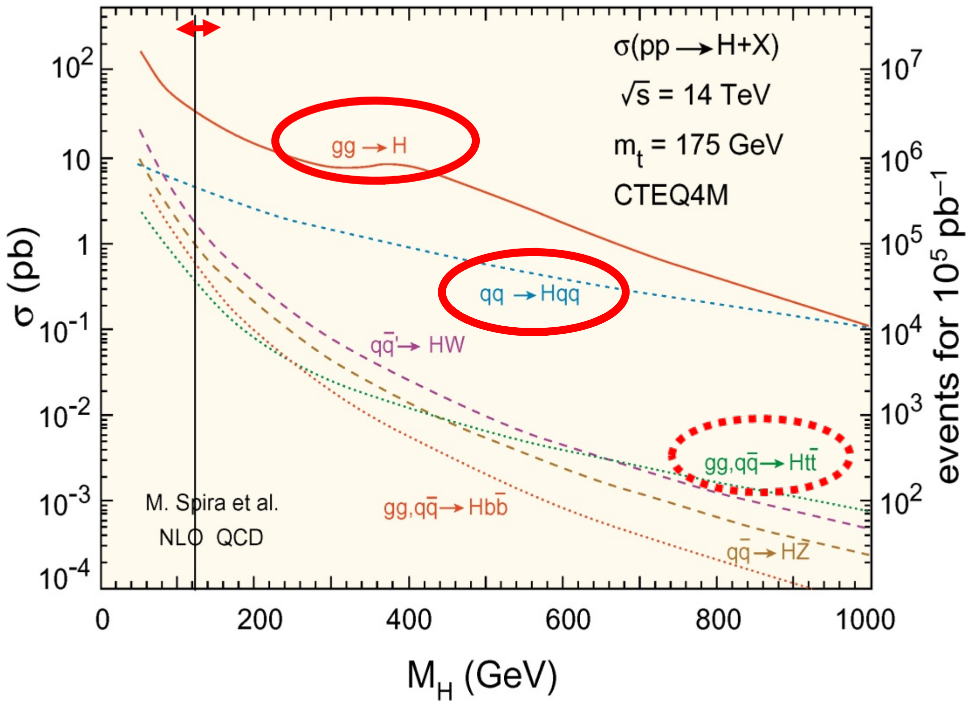


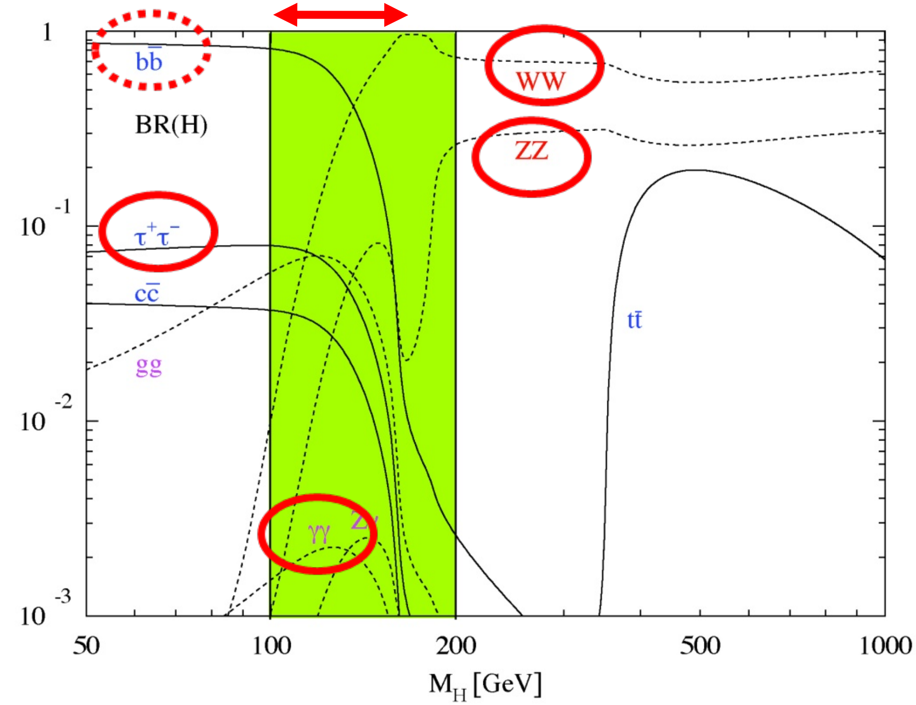
SM Higgs Production and Decay at LHC



m_H=90(+36-27)GeV
m_H < 163 GeV/c^2 @95% C.L.

Excluded by LEP





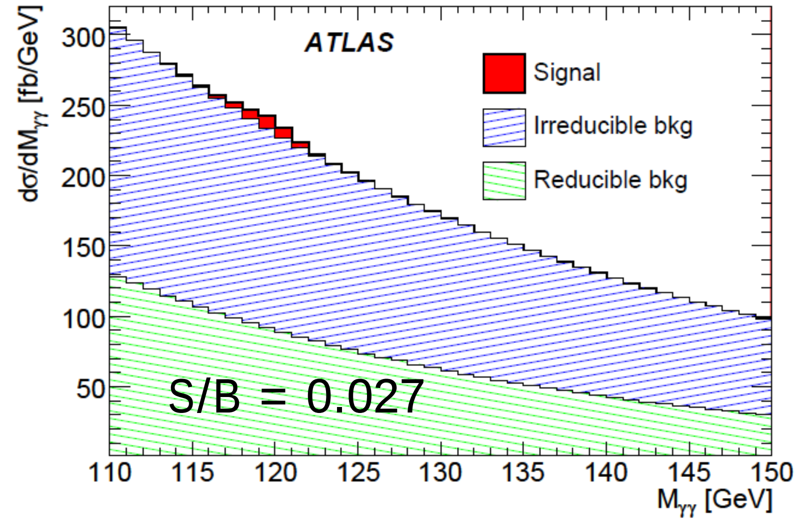
bb, ττ, γγ, WW, ZZ can be observed in the low mass region.

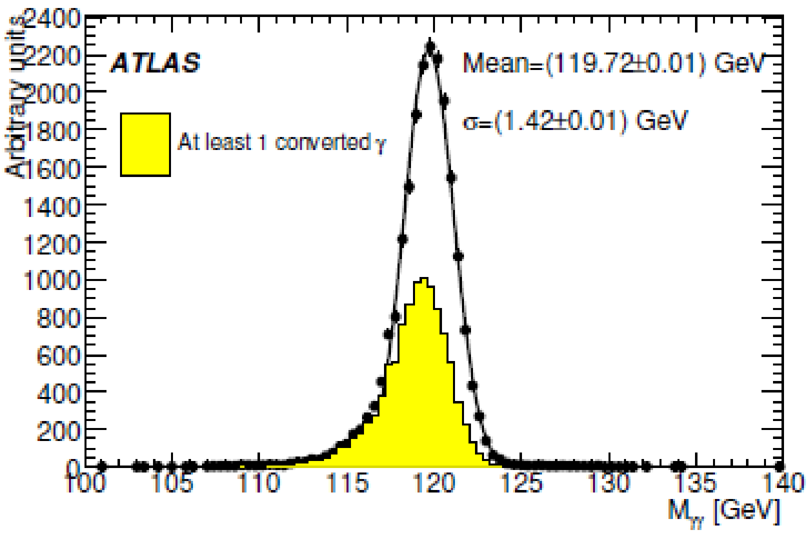
Observation of Higgs by multi modes → **Extract coupling information**

H->γγ

- Small BR (~0.2%) but a narrow mass peak can be observed on a smooth (but quite large) background.
  - Key to mass resolution is
    - Photon energy calibration
    - Precise determination of photon direction

    Mass resolution of 120GeV Higgs = 1.4 GeV (ATLAS)



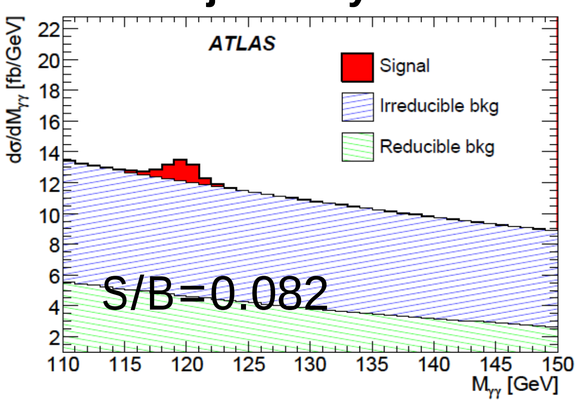


- Conversion rate is high in ATLAS and CMS.
  - ~60% of H->γγ events has at least one conversion.
  - Understanding of material in front of EM calorimeter is important.
  - Conversion identification
    - Energy resolution
    - Primary vertex
    - Material estimation

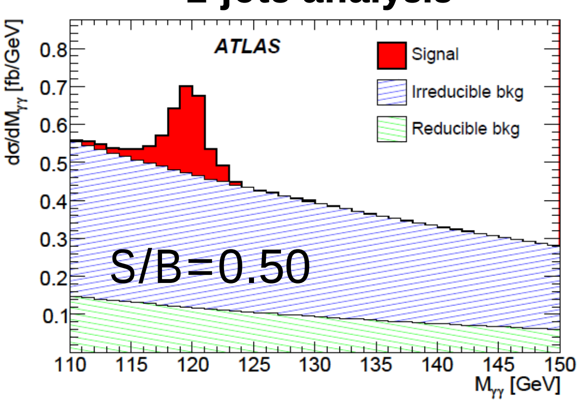
H->γγ

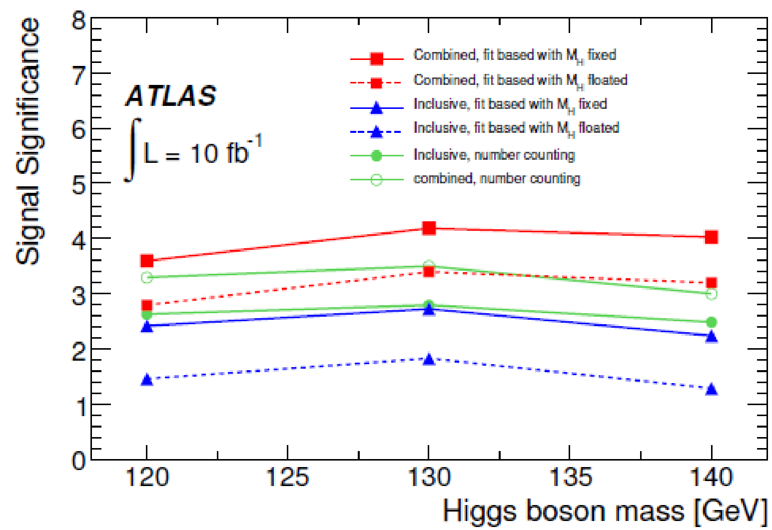
- To improve S/B, additional jets (VBF characteristic) are required.
  - +1 and +2 jets analysis have been studied (ATLAS).
    - The motivation of +1 jet analysis is
      - Additional jet in GF process
      - Recovery of VBF process (one forward jet is out of acceptance etc.)
  - In case of 2 jets analysis, 3rd jet veto (central jet veto) is also applied.

+1 jet analysis



+2 jets analysis



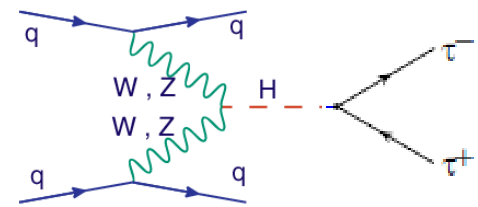


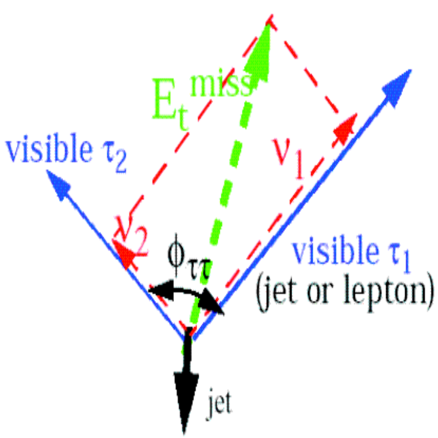
- Significance (counting method, green)
  - ~2.6 sigma (only inclusive)
  - ~3.3 sigma (combined)

  with 10 fb^{-1} data (14TeV).

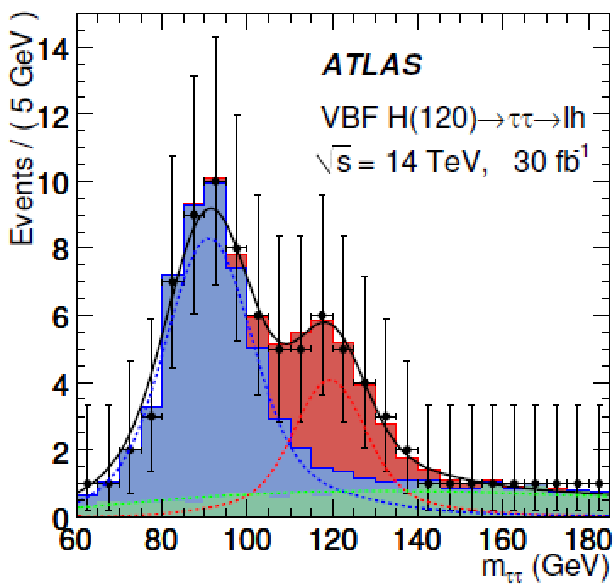
VBF H->ττ

- VBF process has two important characteristics, which are very useful to suppress background.
  - Two forward jets (opposite hemisphere)
  - No color exchange in the central region -> small jet activity in the central (central jet veto)
- We can reconstruct M(ττ), which corresponds to Higgs mass, using missing Et with the collinear assumption.
  -> A Higgs mass peak on the right side of Z peak can be observed.

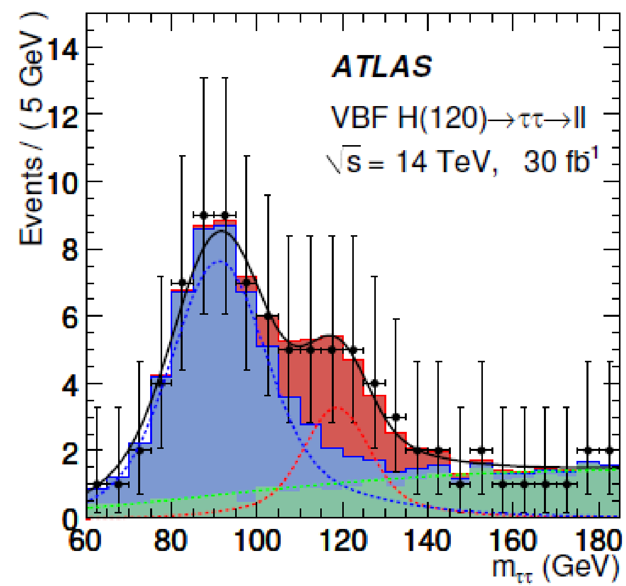




$$\tau^+\tau^- \to h\nu_\tau \ell \nu_\tau \nu_\ell$$

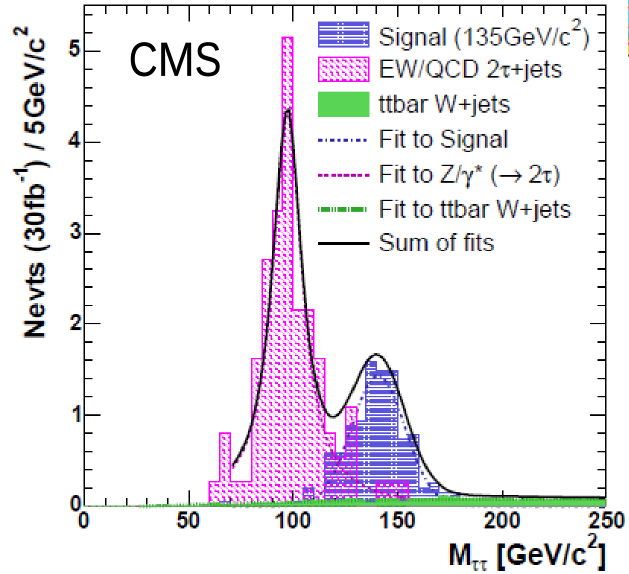


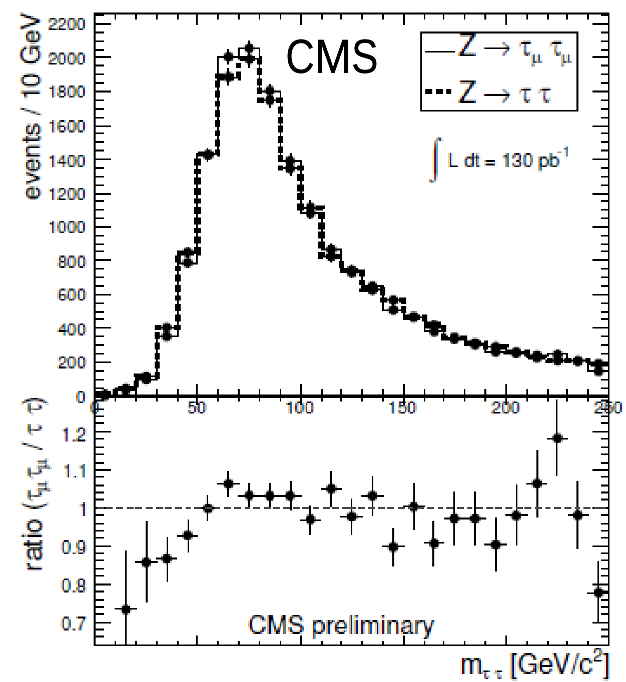
$$\tau^+\tau^- \to \ell\ell 4\nu$$



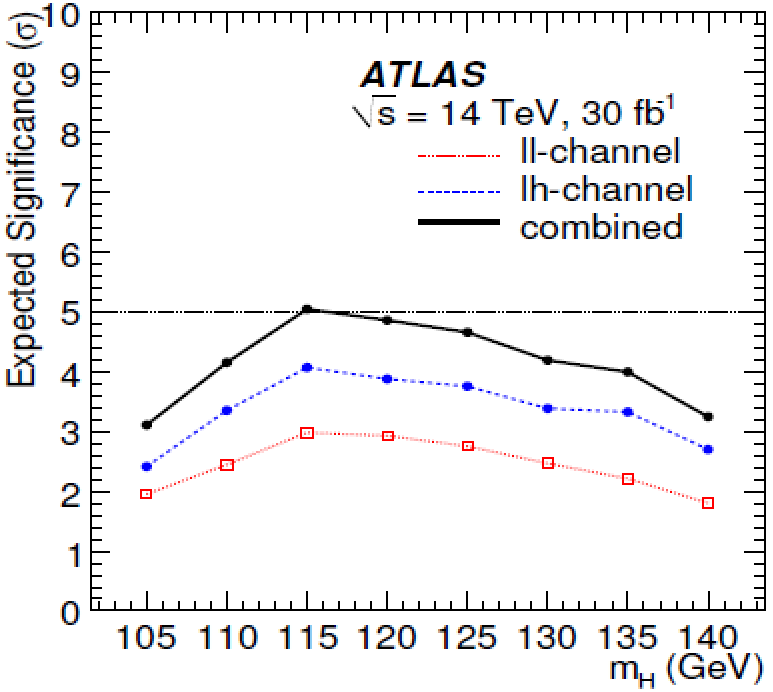
VBF H->$\tau\tau$

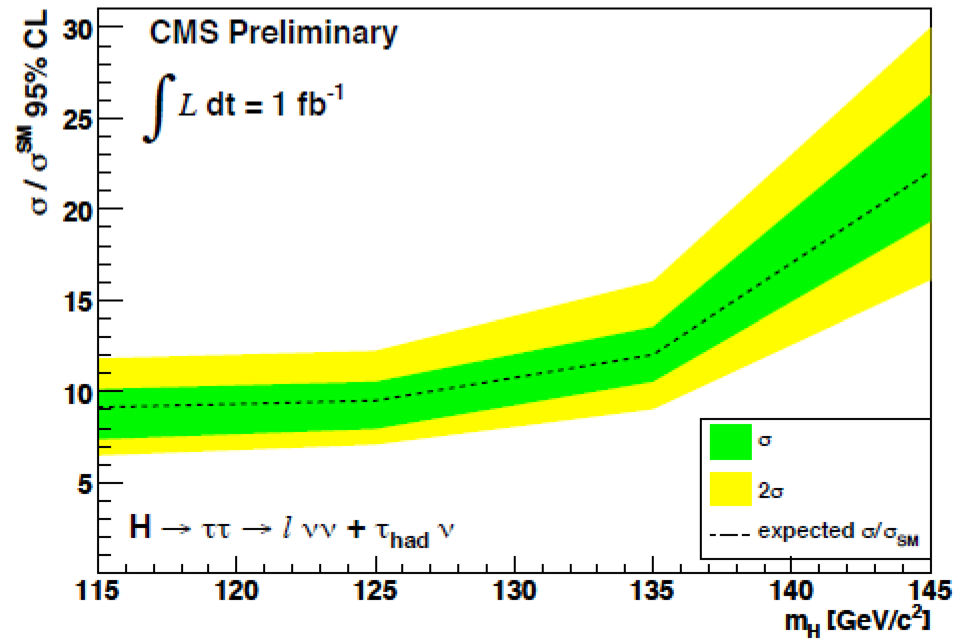
- Tau identification
  - Reject QCD and W+jets backgrounds and keep signal events
- Mass reconstruction
  - Reconstruction and Resolution of Missing Et
  - -> Understanding of a long tail of DY is very important to claim the discovery. (related to Z->$\tau\tau$ BG estimation)
- Background estimation using real data
  - Z->$\tau\tau$ shape can be estimated from Z->$\mu\mu$ by replacing μ to τ. (embedding method)
  - QCD and W+jets can be estimated by SS method.
  - ttbar under investigation, 4 jet bin, SumEt or b-tag...
- Study of 3rd jet for the central jet veto cut
  - Rapidity gap is a crucial signature of VBF.
  - Understand this uncertainty using several generators.
  - Can we estimate its probability from data?
- Pileup affect on all the above items.





VBF H->ττ

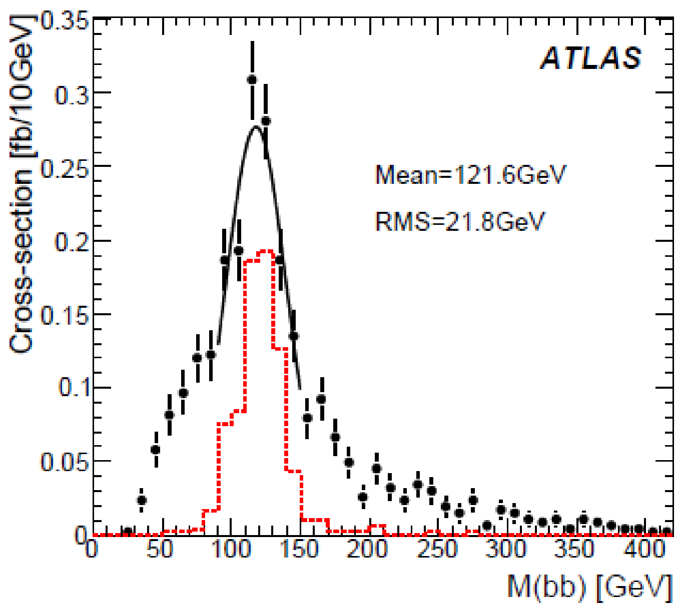


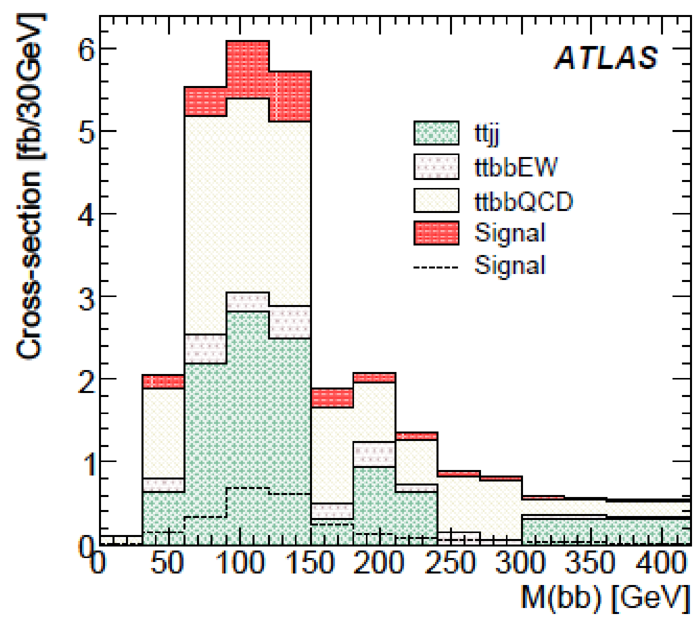


- ATLAS : Significance ~ 5 sigma with 30fb^{-1} data (14TeV)
  - hh-channel is under investigation. -> QCD BG estimation from data is critical.
- CMS : σ/σ_{SM}~9 with 1fb^{-1} data (14TeV)

ttH, H->bb

- This process was one of discovery channels for low mass Higgs.
- With more realistic Monte Carlo studies, we found that
  - The combinatorial background from the signal degrades the mass resolution badly.
  - Difficulty of estimation of both background shape and normalization by using real data. -> difficult to separate signal from background.
- Now this is not a discovery channel but important for bottom Yukawa coupling measurement.





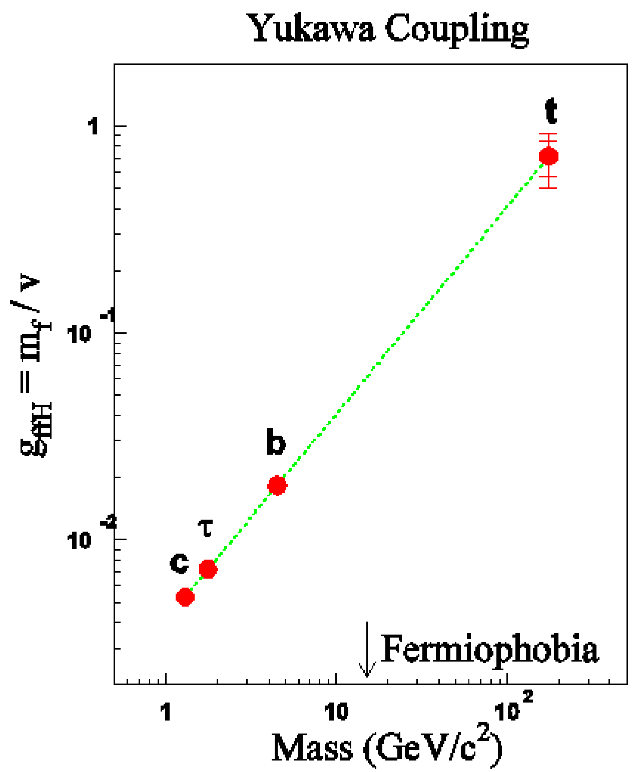
ttH/WH, H->WW

- Three different channels have been studied with the latest full simulation at ATLAS.
  - Two same charged leptons are required in ttH, H(160GeV)->WW.
    - Signal = 1.9 fb, background = 10 fb
  - Three leptons are required in ttH, H(160GeV)->WW.
    - Signal = 0.8 fb, background = 3.4 fb
  - Three leptons are required in WH, H(160GeV)->WW.
    - Signal = 0.3 fb, background = 0.4 fb
- Since we cannot reconstruct Higgs mass peak in H->WW (not full had), it is difficult to separate signal from background.
  - Development of background estimation from real data is necessary. (on going)
- These processes are important to measure couplings, particularly, a ratio to ttH, H->bb.
  - H->$\tau\tau$ channel is also useful in low mass region.

Measurement

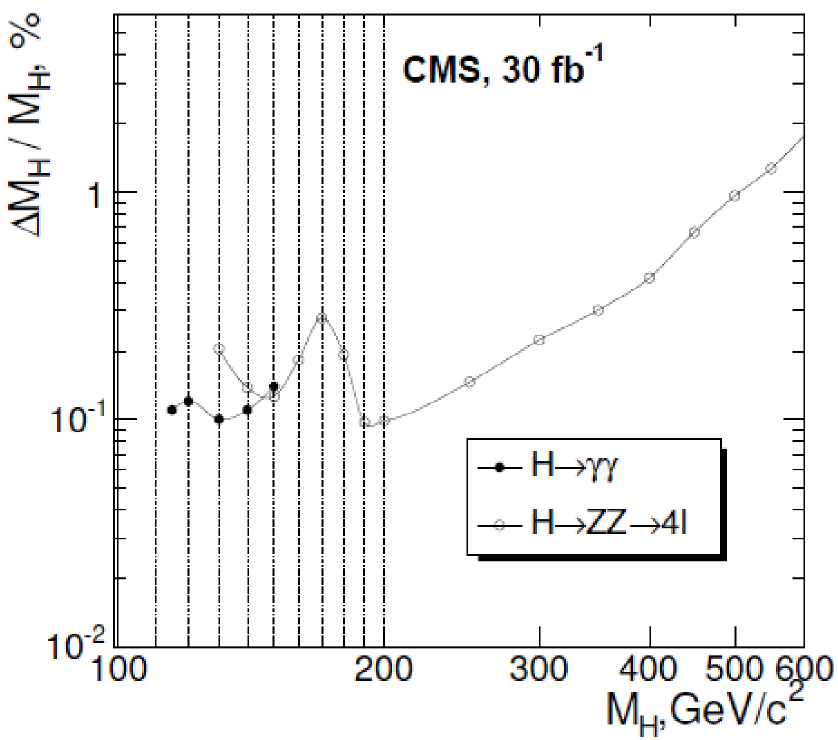
- Once we discover Higgs-like particle, we need to measure its properties, that is, mass, width, spin, CP, couplings and so on.
- Mass ... Next page
- Width ... direct measurement is very difficult for low mass Higgs. (0.1~1% level in m_H>200GeV with H->ZZ->4l, ATLAS TDR)
- Spin and CP (and anomalous coupling)
  - "H->$\gamma\gamma$" -> spin = 0 or 2
  - H->WW $\Delta\phi_{ll}$ correlation -> spin = 0
  - H->ZZ->4l -> Spin and CP
  - Forward jets of VBF process
- Couplings
  - "Origin of mass" should be confirmed.
  - We expect that Yukawa coupling has a linearity with respect to the particle mass. That is the SM prediction.

  -> top, bottom and tau Yukawa coupling measurement can be done at the LHC.



Mass

- ATLAS
  - Resolution with the latest simulation;
    ~1.2% with H->$\gamma\gamma$ and ~1.6-2% with H->ZZ->4l (almost same as ATLAS TDR)
  - Mass determination precision ~ 0.1% (m_H<400GeV) (from ATLAS TDR)
- CMS



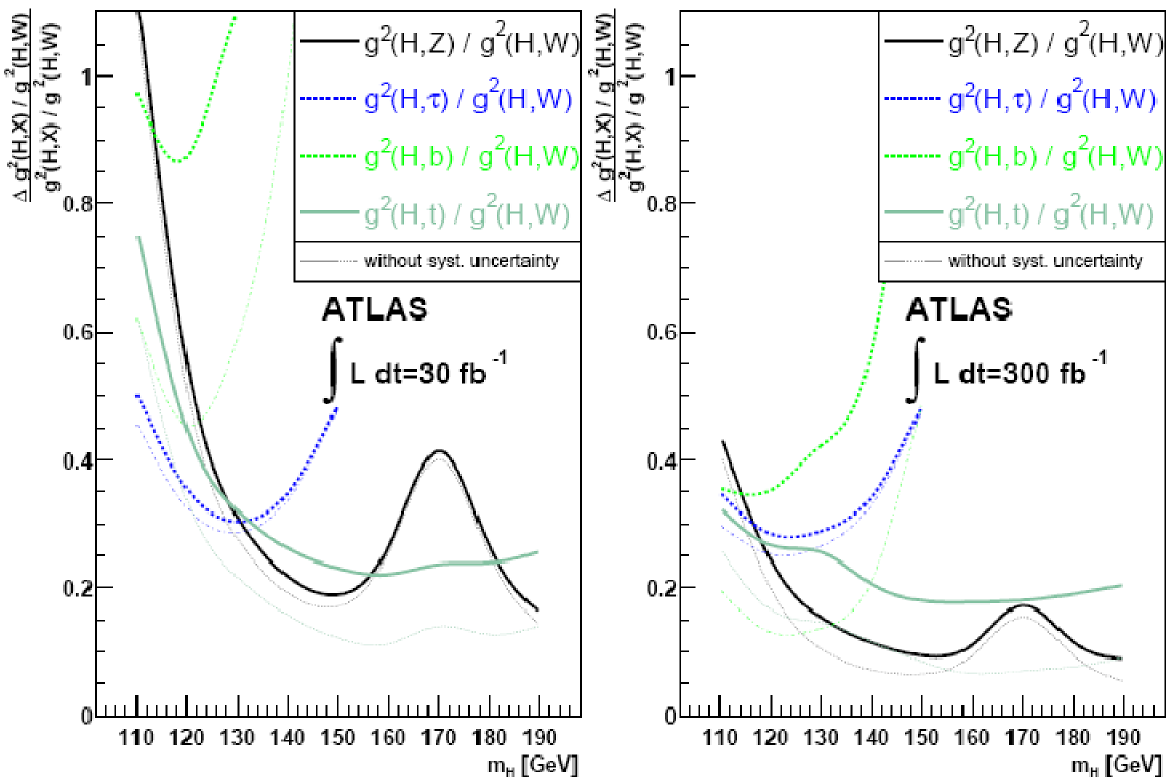
~0.1% can be achieved in low mass region.

Ratio of Couplings

- In the low mass region, we can measure event rates of Higgs with multi modes. So we can extract coupling information, particularly, determination of ratios is possible with a model-independent way.

ATLAS-PHYS-2003-030

Accuracy of measurement of “ratio of coupling constants” wrt $g^2(H,W)$



With $300fb^{-1}$:
- Yukawa
  - g_t^2 : 15-30%
  - g_b^2 : 35-70%
  - g_τ^2 : 25-50%
- Gauge Boson
  - g_z^2 : 10-40%

This is slightly old result. (based on our old results)

Bottom Yukawa can be also measured by using WH/ZH, H->bb (high boosted Higgs). -> new technique, under investigation

Summary

- Discovery of low mass Higgs at the LHC (14TeV) is promising.
  - Covered by several channels!!! H->$\gamma\gamma$, $\tau\tau$, WW and ZZ.
    - Development of BG estimation from data is on-going.

- The existence of low mass Higgs is interesting from a viewpoint of coupling measurement.
  - Top, bottom and tau Yukawa coupling measurement can be done at the LHC.
    - Bottom Yukawa has the largest uncertainty.
      - New analysis technique (high boosted Higgs with WH/ZH, H->bb)
      - ttH, H->bb measurement should be improved more.

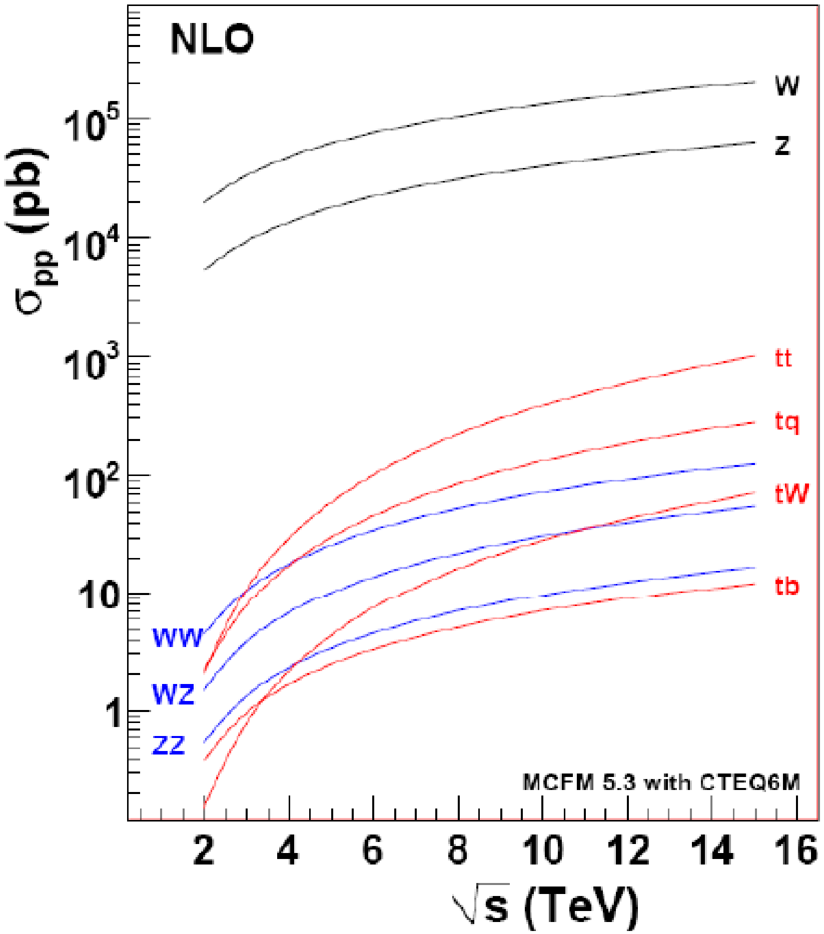
- Even with 10TeV energy, LHC is still the discovery machine of Higgs and BSM.
  - Production x-sec of 10TeV decreases by ~60-70% with respect to 14TeV.

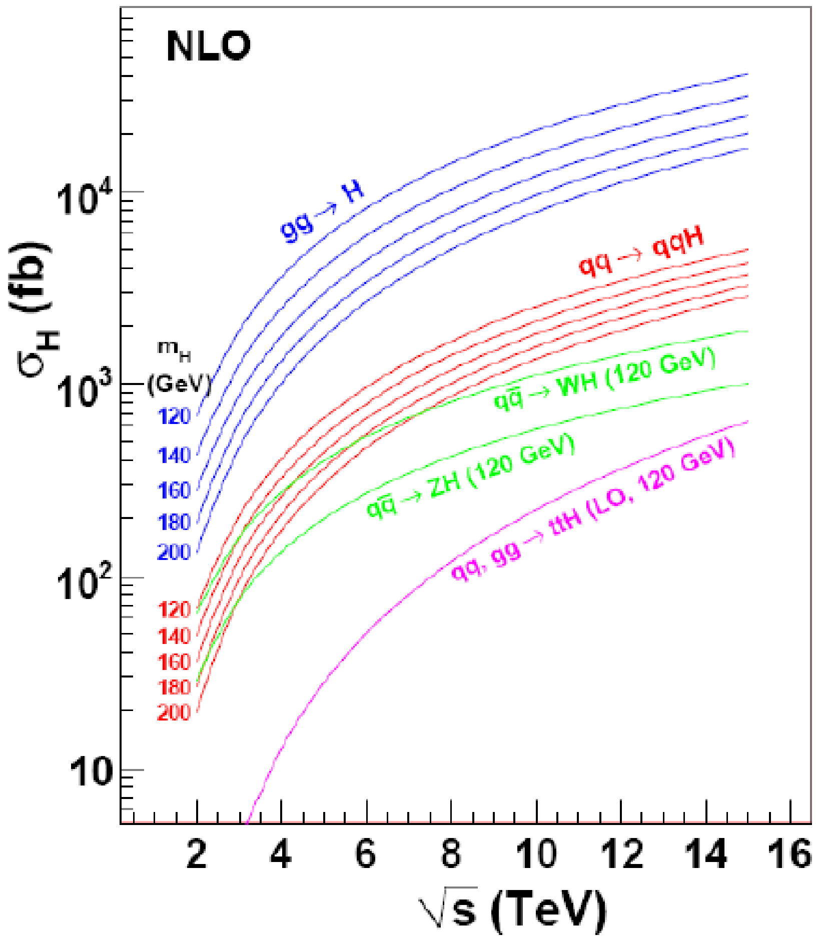
Backup

Reference

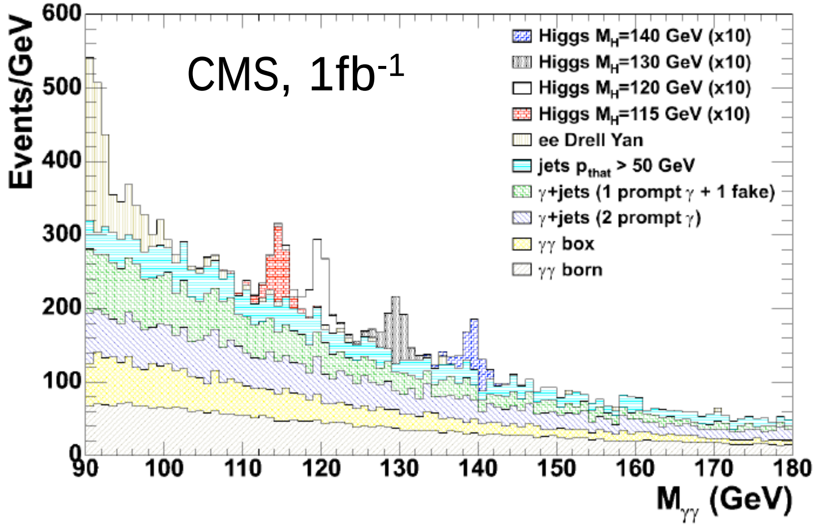
- ATLAS
  - CERN-OPEN-2008-020 ... ATLAS CSC Book
  - ATLAS-PHYS-2003-030
  - CERN/LHCC/99-15 ... ATLAS TDR
- CMS
  - CERN/LHCC 2006-021
  - CMS PAS HIG-08-001, 008

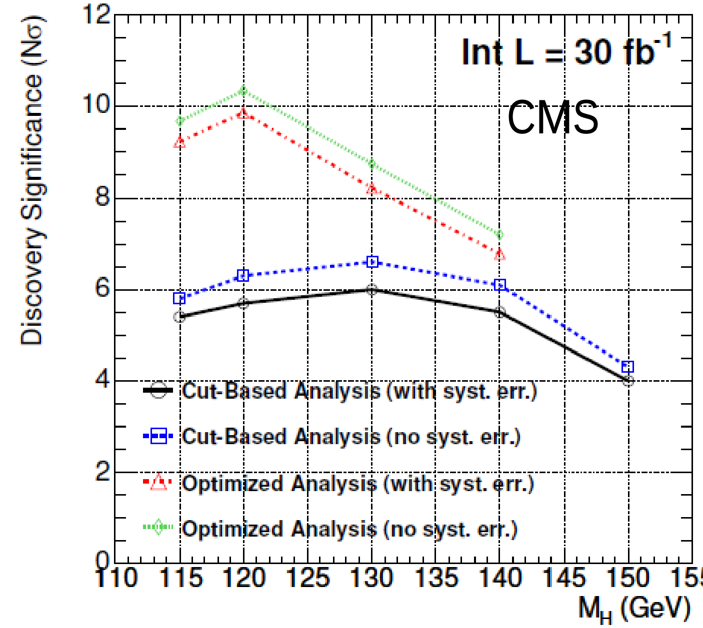
14TeV -> 10TeV



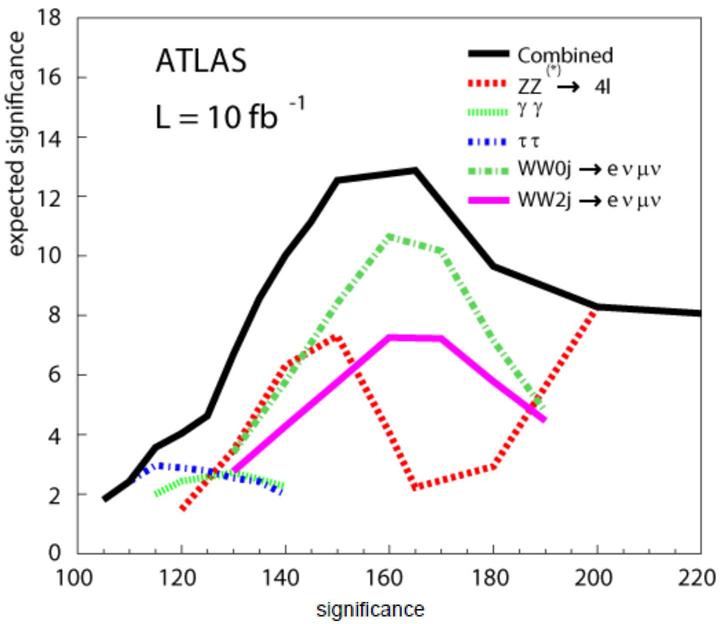


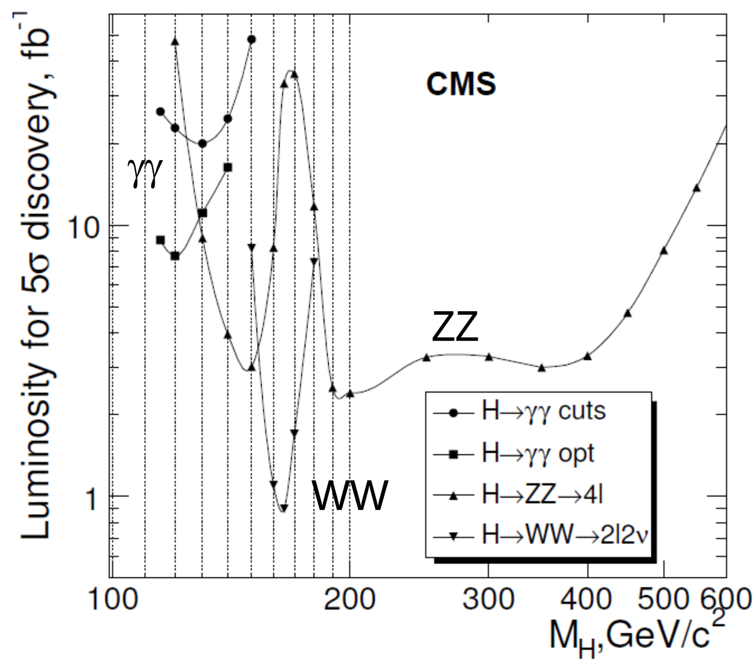
- W^+ : 109nb -> 78nb (72%), W^-: 80nb -> 55nb (69%), Z: 58nb->40nb (69%)
  ttbar: 876pb -> 396pb (45%)
- gg->H(120): 37pb -> 21pb (57%)
- qq->qqH(120): 4.6pb -> 2.6pb (57%)

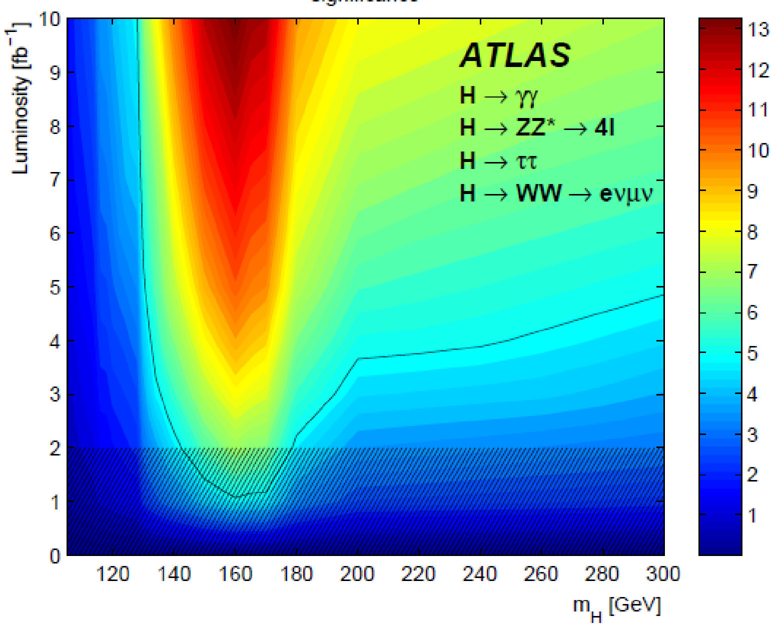

CMS, 1fb-1
Higgs MH=140 GeV (x10)
Higgs MH=130 GeV (x10)
Higgs MH=120 GeV (x10)
Higgs MH=115 GeV (x10)
ee Drell Yan
jets pthat > 50 GeV
γ+jets (1 prompt γ + 1 fake)
γ+jets (2 prompt γ)
γγ box
γγ born
Events/GeV
Mγγ (GeV)

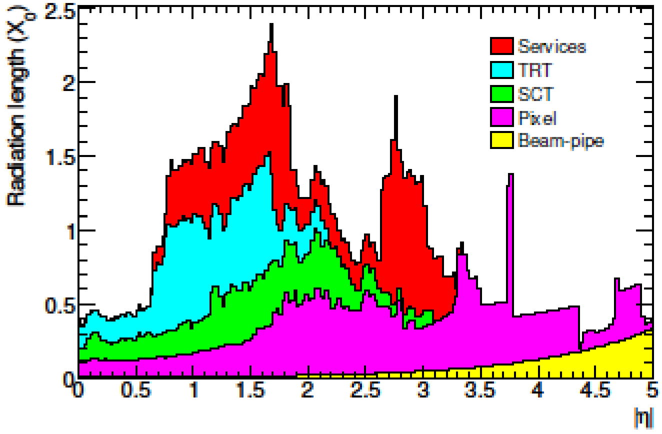

Int L = 30 fb-1
CMS
Cut-Based Analysis (with syst. err.)
Cut-Based Analysis (no syst. err.)
Optimized Analysis (with syst. err.)
Optimized Analysis (no syst. err.)
Discovery Significance (Nσ)
MH (GeV)

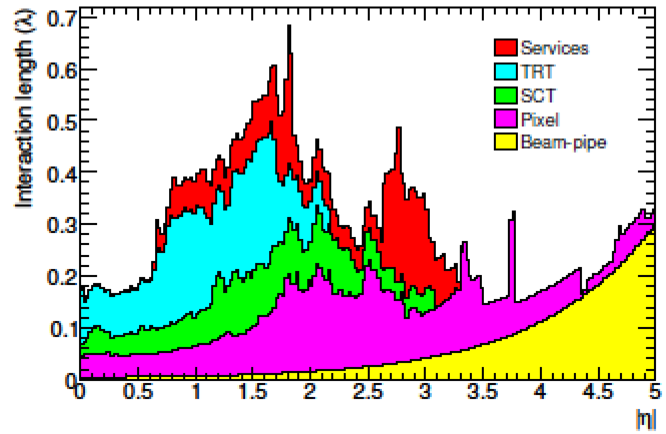
Combined

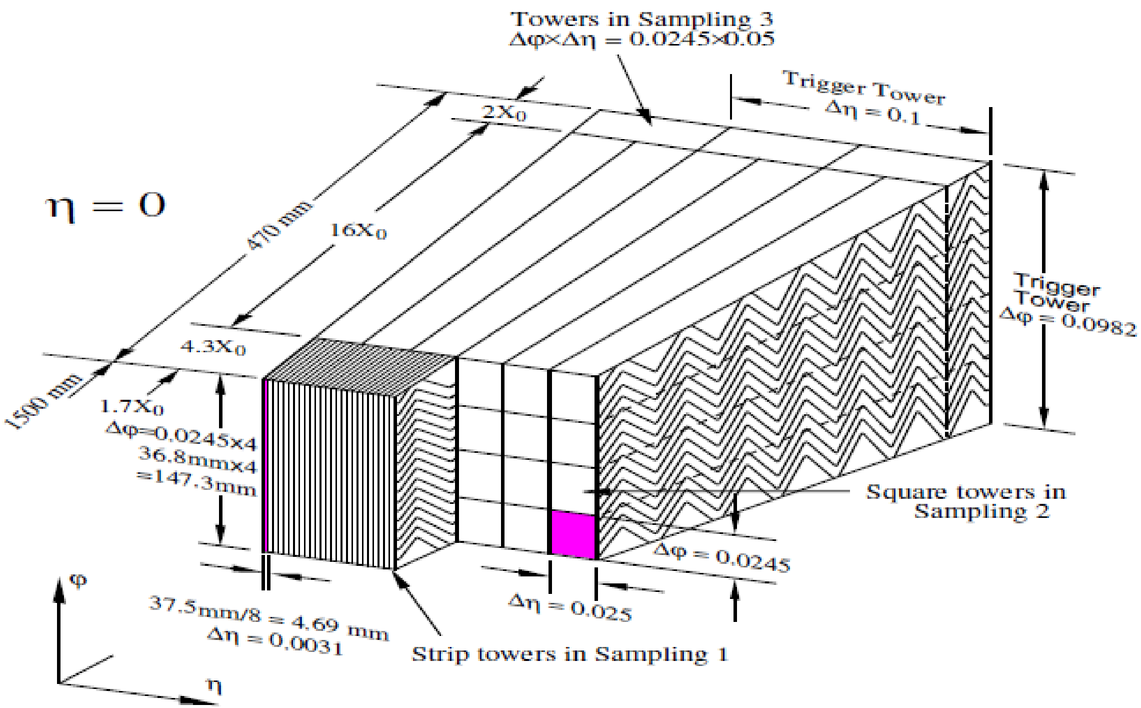

ATLAS
L = 10 fb -1
Combined
ZZ(*) → 4l
γ γ
τ τ
WW0j → e ν μ ν
WW2j → e ν μ ν
expected significance
significance


CMS
γγ
ZZ
WW
H→γγ cuts
H→γγ opt
H→ZZ→4l
H→WW→2l2ν
Luminosity for 5σ discovery, fb-1
MH,GeV/c2

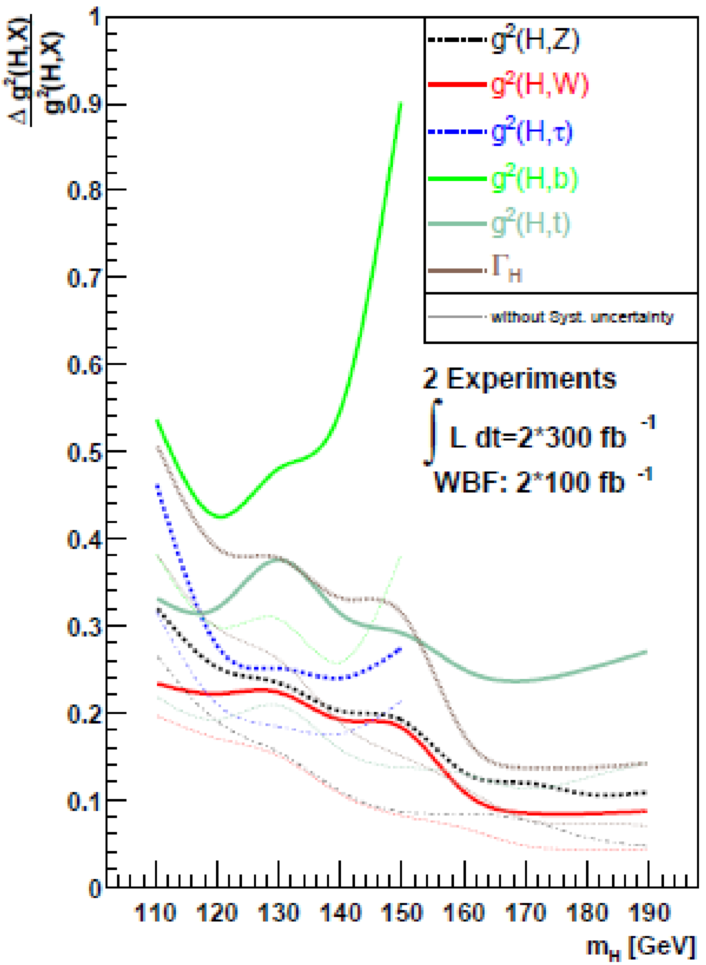

ATLAS
H → γγ
H → ZZ* → 4l
H → ττ
H → WW → eνμν
Luminosity [fb-1]
mH [GeV]


Radiation length (X_0)
Services
TRT
SCT
Pixel
Beam-pipe
|η|


Interaction length (λ)
Services
TRT
SCT
Pixel
Beam-pipe
|η|


Towers in Sampling 3
Δφ×Δη = 0.0245×0.05
Trigger Tower
Δη = 0.1
2X0
η = 0
470 mm
16X0
Trigger
Tower
Δφ = 0.0982
4.3X0
1500 mm
1.7X0
Δφ=0.0245x4
36.8mmx4
=147.3mm
Square towers in
Sampling 2
Δφ = 0.0245
Δη = 0.025
37.5mm/8 = 4.69 mm
Δη = 0.0031
Strip towers in Sampling 1
φ
η

Absolute Coupling Determination



- Need a help of theory to obtain the absolute values of couplings.

Assumption [hep-ph/0407190] :

- HVV (V=W,Z) couplings cannot be larger than the SM case, namely,
  - $g^2(H,W) < g^2_{SM}(H,W)$
  - $g^2(H,Z) < g^2_{SM}(H,Z)$

  This constraint is valid in generic multi-Higgs-doublet models. (eg. MSSM)

With $2 \times 300 fb^{-1}$:
- Yukawa
  - g_t^2 : 25-40%
  - g_b^2 : 45-90%
  - g_τ^2 : 25-50%
- Gauge Boson
  - g_z^2 : 10-30%
  - g_w^2 : 10-25%
- Total Width : 15-50%

Summary of Studies for SM Higgs

Production	Decay	Mass region and purpose	
Gluon Fusion	H -> $\gamma\gamma$	110-140GeV	**Discovery**, Mass
	H -> ZZ-> 4l	140-**800** GeV	**Discovery**, Mass, spin, coupling
	H -> WW	130-170 GeV	**Discovery**
Vector Boson Fusion	H -> $\tau\tau$	110-140GeV	**Discovery**, Mass, coupling
	H -> WW	130-200GeV	**Discovery**, W coupling
	H -> $\gamma\gamma$	110-140GeV	**Discovery**, Mass
	H -> bb	110-140GeV	Yb coupling (need study of trigger)
ttH	H -> bb	110-130GeV	Yt, Yb, Yτ, W coupling
	H -> $\tau\tau$	110-130GeV	
	H -> WW	130-180GeV	
WH/ZH	H -> WW	140-170GeV	W coupling
	H -> bb	110-130GeV	Yb coupling