IFAE 2014 - Incontri di Fisica delle Alte Energie

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Europe/Rome timezone

BSM Higgs searches at High Mass

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Outlines

- Introduction
- Theoretical interpretation
- Experimental analysis
- Conclusions

Introduction

- Discovery of the Higgs Boson at 125 GeV
- Theory does not exclude the existence of additional singlets or duplets of Higgs boson
- Important to continue searching for Heavy Higgs Bosons
- Focus on two BSM models:
  - 2 Higgs Doublet Model (2HDM)
  - Additional EW singlet

h(125) + Real EW Singlet Model

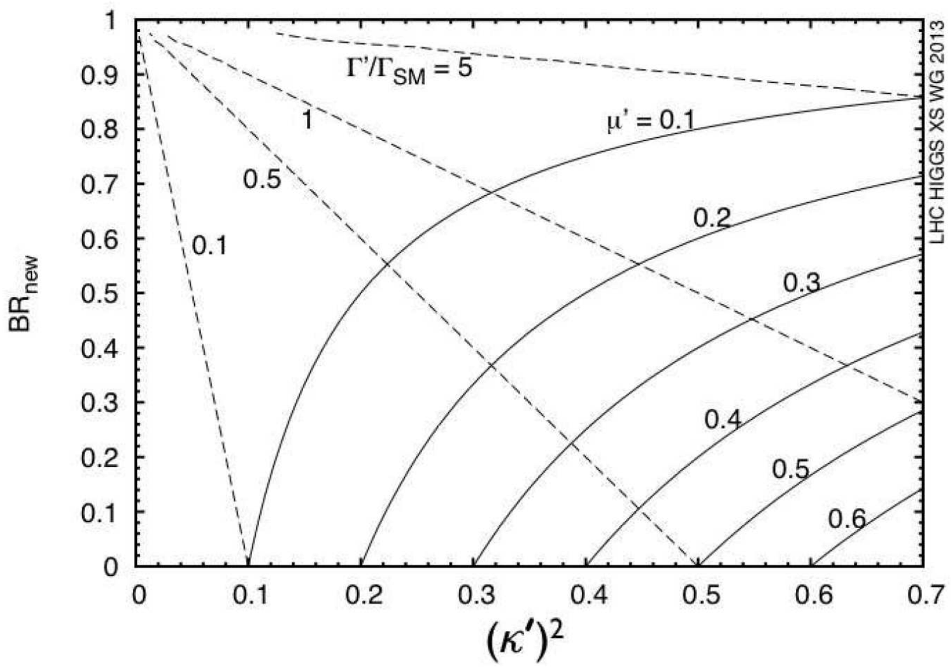
- Heavy real singlet with couplings rescaled from SM signal
- Scan in **two parameters** for each m_H and set upper limit on $\boldsymbol{\sigma}$ x BR
  - H_{new} couplings: **k'** (constrained by $(k')^2 + k^2 = 1$)
  - **BR_{new}**: new decay modes, e.g. to additional Higgses

$$\mu' = \frac{\sigma' \times \mathrm{BR}'}{\sigma_{\mathrm{SM}} \times \mathrm{BR}_{\mathrm{SM}}} = \kappa'^2(1 - \mathrm{BR}_{\mathrm{new}})$$

$$\sigma' = \kappa'^2 \sigma_{\mathrm{SM}}$$

$$\Gamma' = \frac{\kappa'^2}{1 - \mathrm{BR}_{\mathrm{new}}} \Gamma_{\mathrm{SM}}$$

$$\mathrm{BR}' = (1 - \mathrm{BR}_{\mathrm{new}})\mathrm{BR}_{\mathrm{SM}}$$



- Some constraints already from experimental measurement of signal strength μ of the discovered Higgs boson h(125)

2HDM

- Two identical complex scalar field SU(2)
- 5 different physical bosons: **h** (the 125 GeV boson), **H** (heavy higgs), **A** (pseudoscalar) and **H⁺/H⁻** (charged higgs)

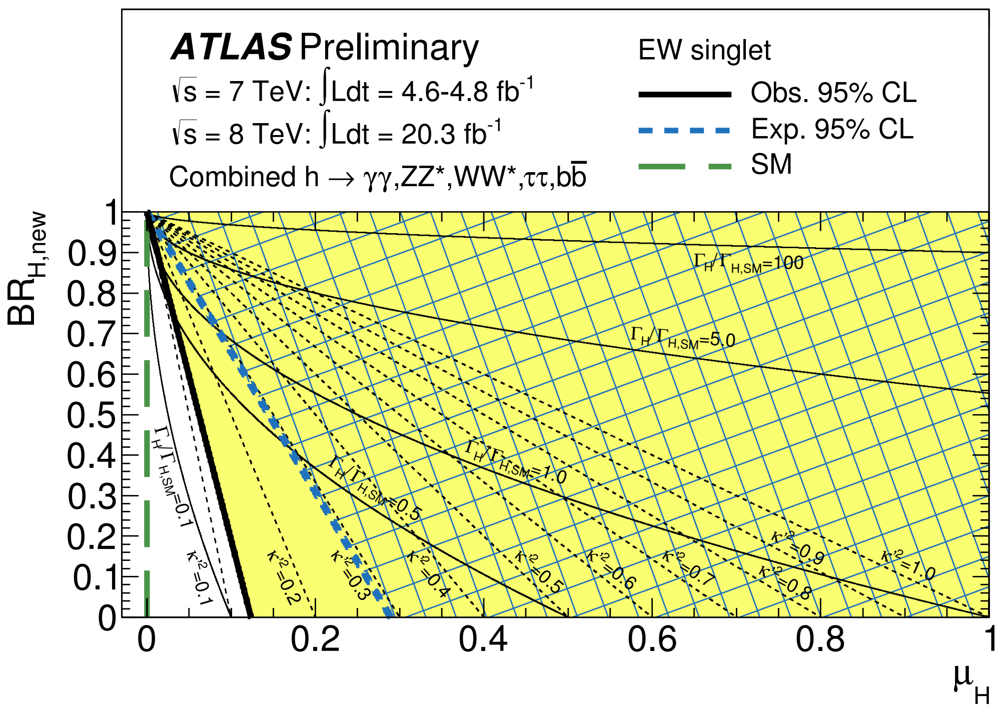
$$V(\Phi_1,\Phi_2) = m_1^2\Phi_1^\dagger\Phi_1 + m_2^2\Phi_2^\dagger\Phi_2 + (m_{12}^2\Phi_1^\dagger\Phi_2 + \mathrm{h.c}) + \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \frac{1}{2}\lambda_5[(\Phi_1^\dagger\Phi_2)^2 + \mathrm{h.c}]$$

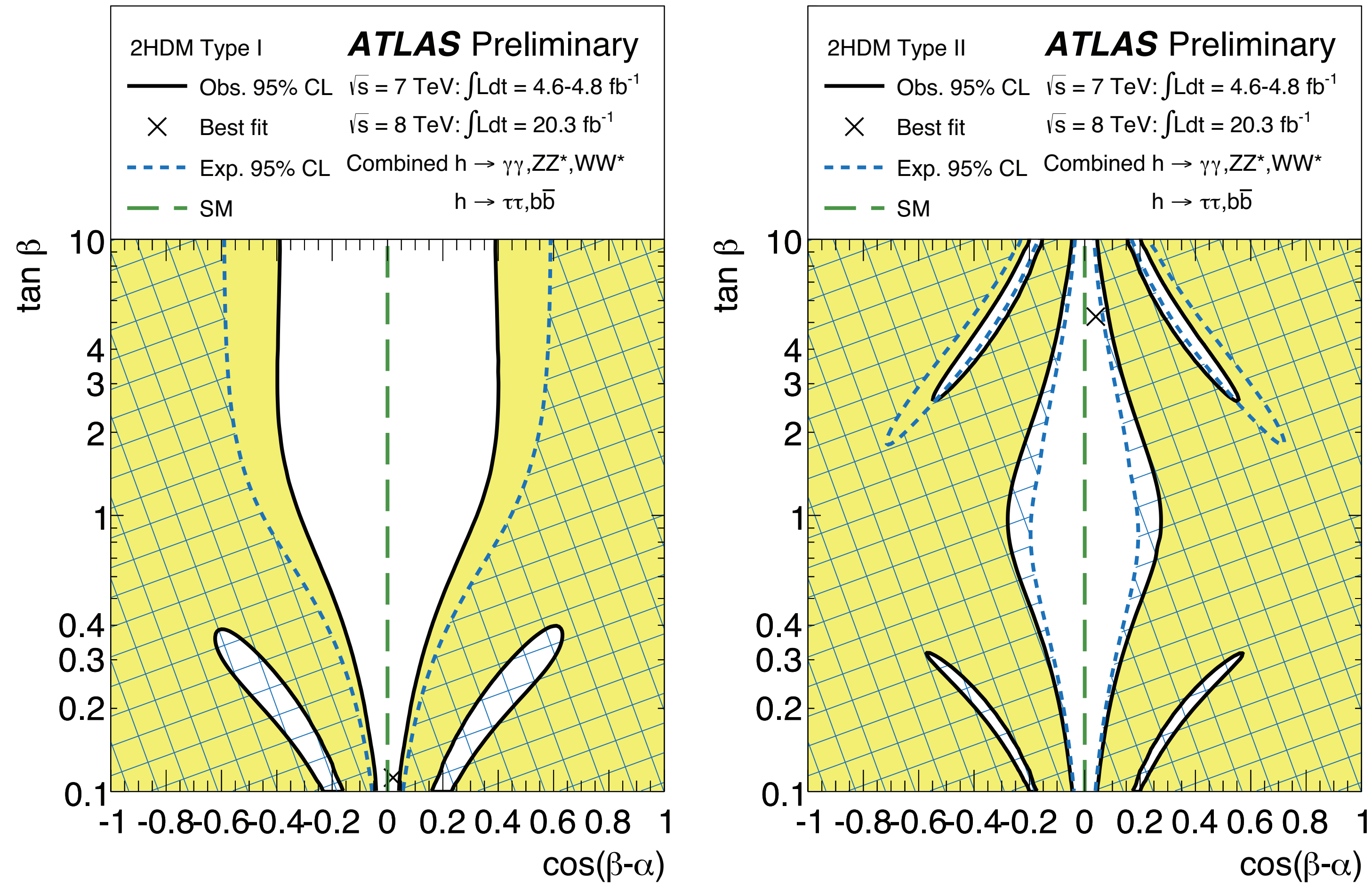
Coupling	Type I	Type II
ξ_h^V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
ξ_h^u	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
ξ_h^d	$\cos\alpha/\sin\beta$	$-\sin\alpha/\sin\beta$
ξ_H^V	$\cos(\beta-\alpha)$	$\cos(\beta-\alpha)$
ξ_H^u	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
ξ_H^d	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$

- Interested in the CP-conserving case with parameters:
  - 3 masses: $\mathbf{m_h, m_H, m_{H+-}, m_A}$
  - 2 angles: $\boldsymbol{\alpha}$ ([h, H] mixing angle) and $\boldsymbol{\beta}$ ($\tan\beta = v_2/v_1$)
  - 1 potential parameter: $(m_{12})^2$
- Each parameter set gives specific prediction on xsec and BR for h/H

Constraints from SM Higgs coupling measurements

[ATLAS-CONF-2014-010]





(a) Type I

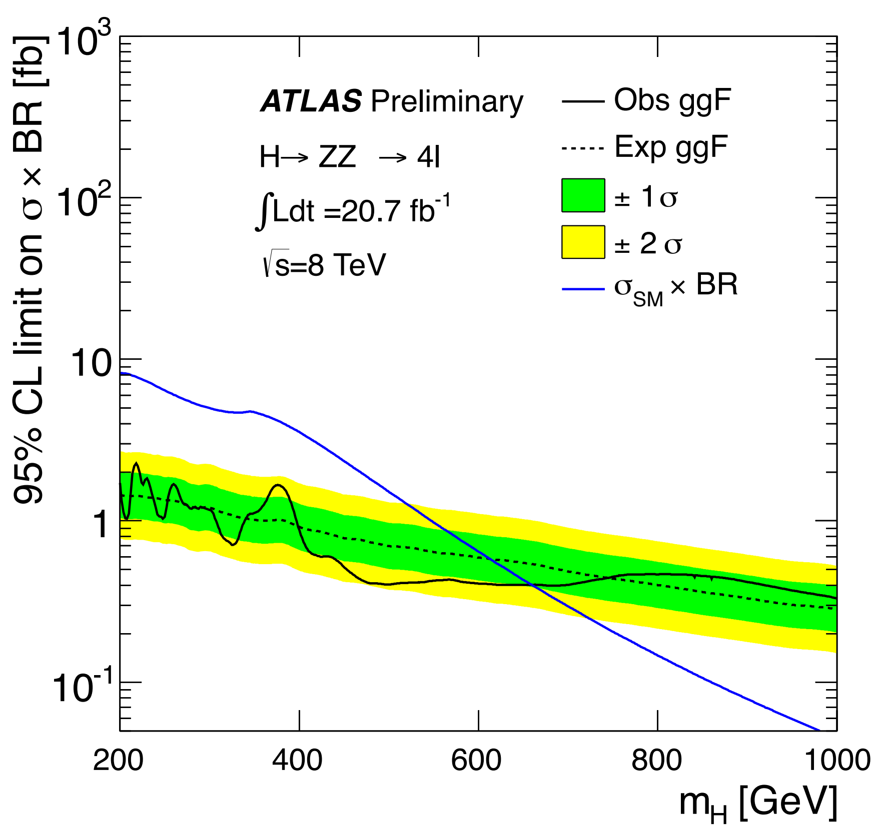
(b) Type II

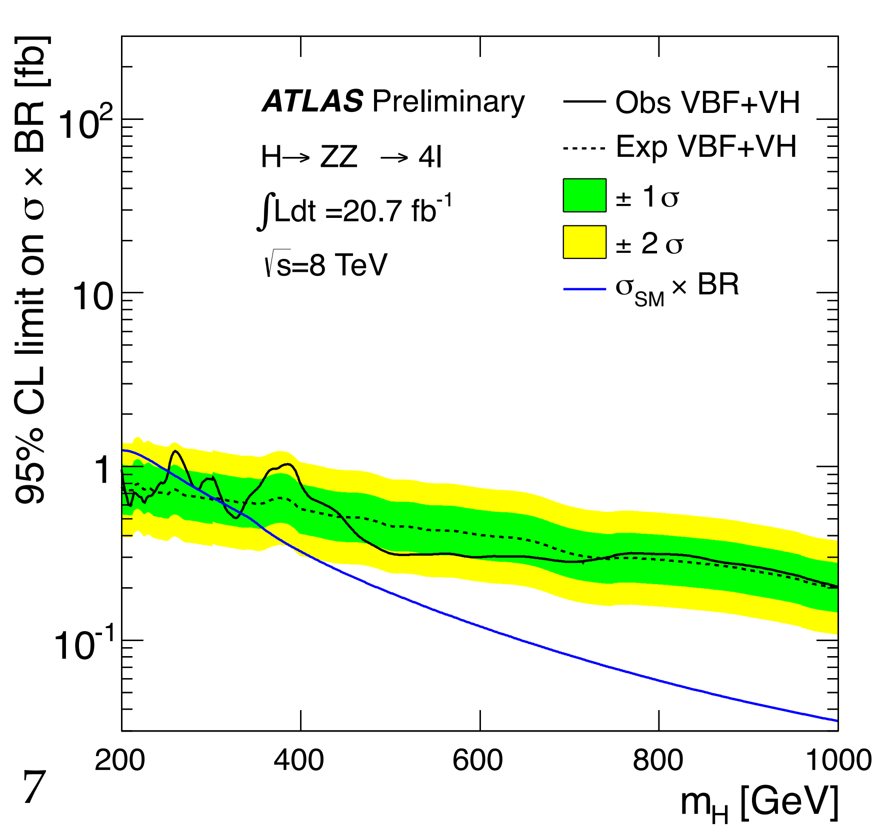
- Constraints from:
  - decay rates of the h(125) in the $h \to \gamma\gamma$, $h \to ZZ^* \to 4l$, $h \to WW^* \to l\nu l\nu$, $h \to \tau\tau$, $h \to bb$ channels
  - measured mass in the $h \to \gamma\gamma$, $h \to ZZ^* \to 4l$ decay channels
- Integrated luminosity: 4.7 fb^{-1} @ 7 TeV and 20.8 fb^{-1} @ 8 TeV

$H \rightarrow ZZ \rightarrow 4l$

[ATLAS-CONF-2013-013]

- Sensitive across a wide range of m_H
- High S/B and very sharp resolution
- Statistical limitation due to small branching ratio
- The goal is to perform searches of multiple Higgs bosons using the analysis used to measure the properties of 125 GeV Higgs
- The observed σ/σ_{SM} value is ~ 0.3 for ggF and ~ 1.5 for VBF+VH @ 500 GeV



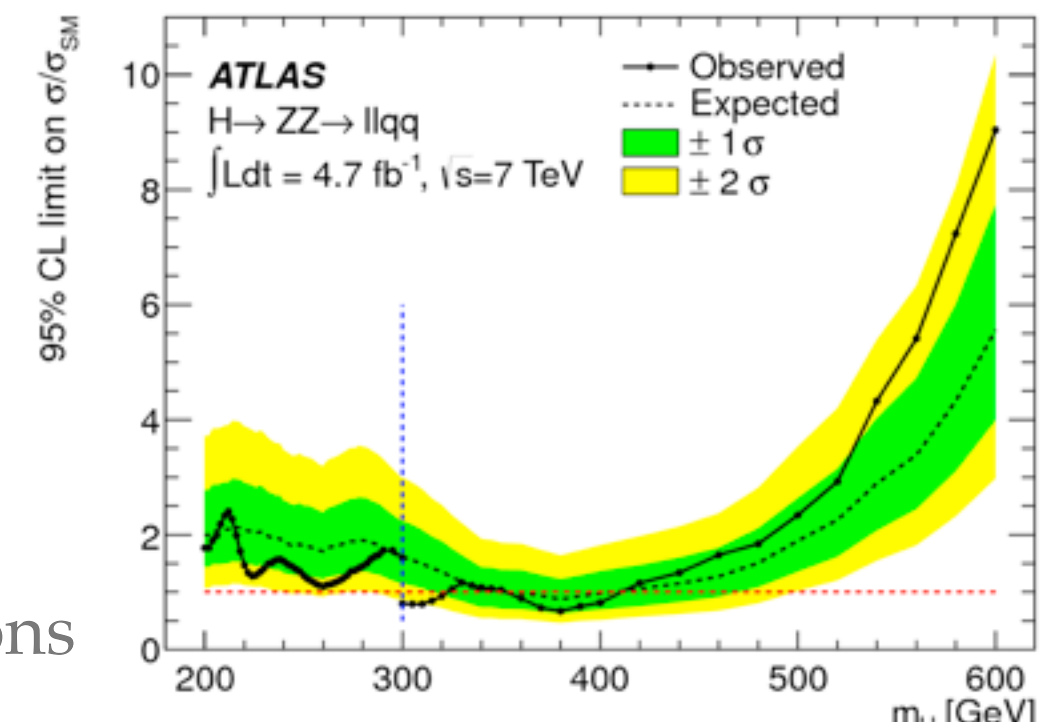


$H \rightarrow ZZ \rightarrow llqq$

- Favored w.r.t. the 4l channel by the **higher branching ratio**
- Very difficult: **huge** irreducible **background** (mostly Z+jets and Top)
- Many improvements w.r.t. published 2011 results (4.7 fb^{-1} @ 7 TeV)

[ATLAS-CONF-2012-017]

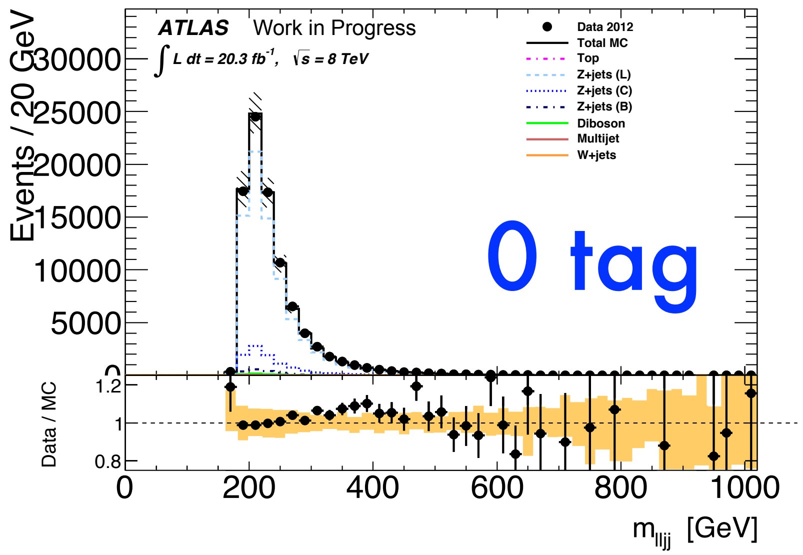
- **Event selection**:
  - Two high-p_T, isolated, opposite charge leptons
  - At least two high-p_T jets
  - Exclusive event categories: 0/1/2 b-tags
  - Z+jets background normalized to control regions

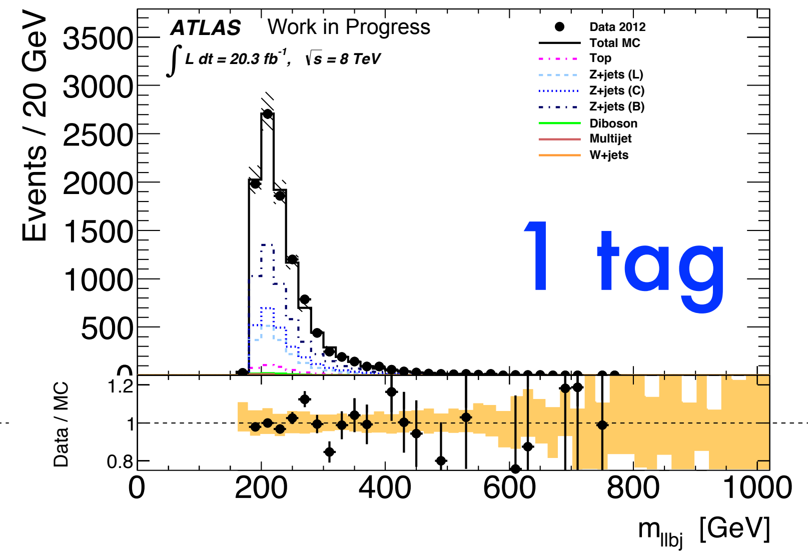


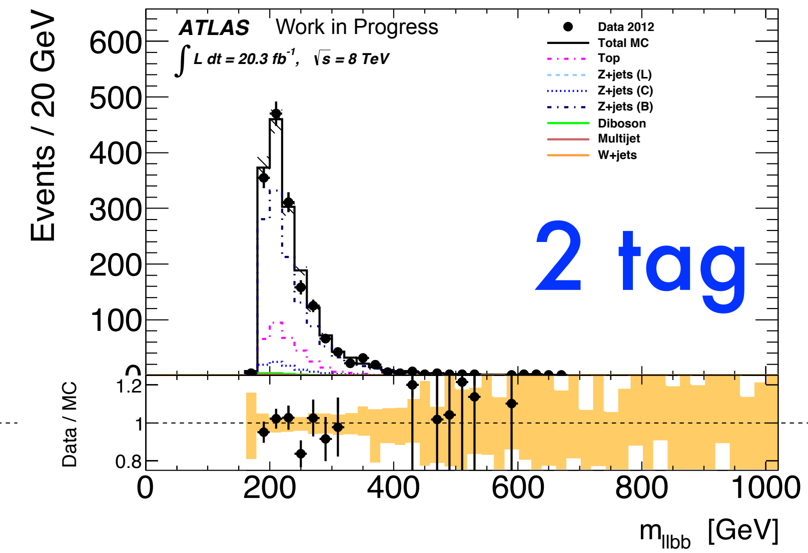
observed σ/σ_{SM} ~2.5 @ 500 GeV

Z+jets and Top CRs

- **Z+jets CR:** m_{jj} SBs (50 < m_{jj} < 70 GeV or 105 < m_{jj} < 150 GeV)

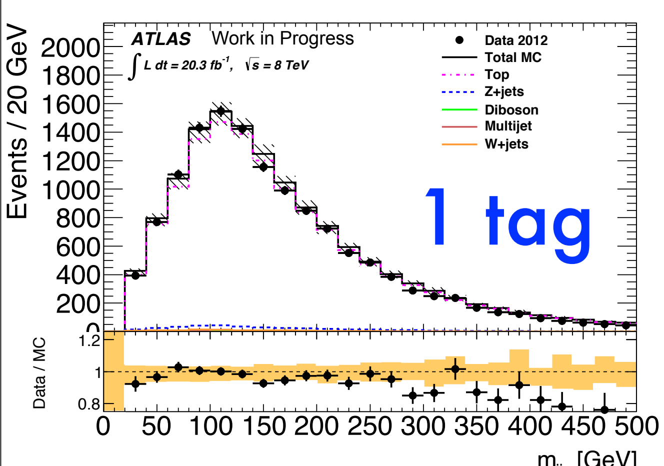


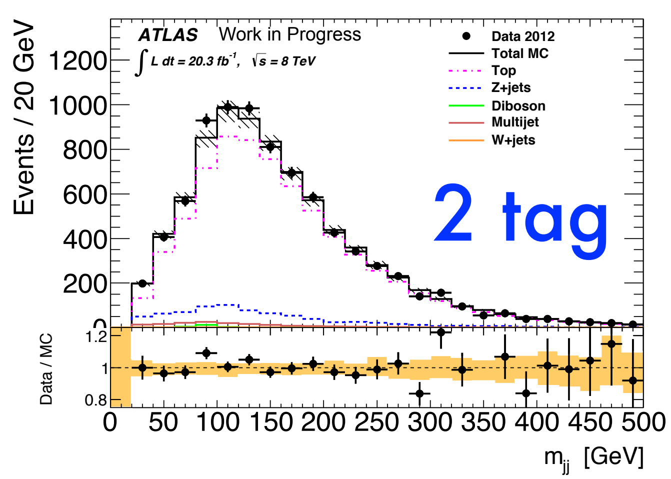




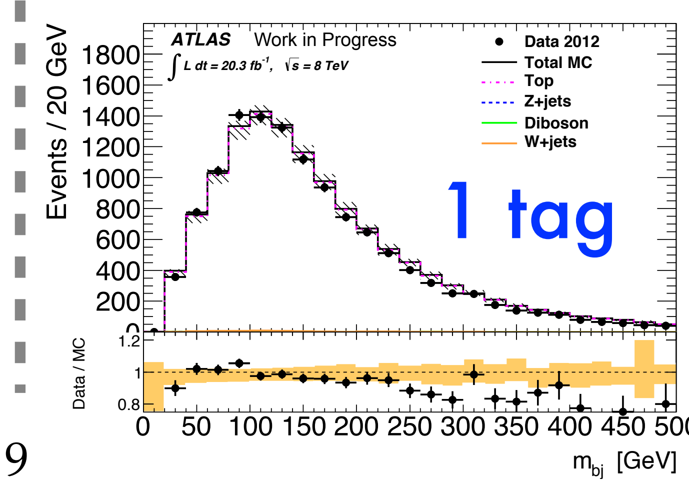
- **2 Top CRs:**

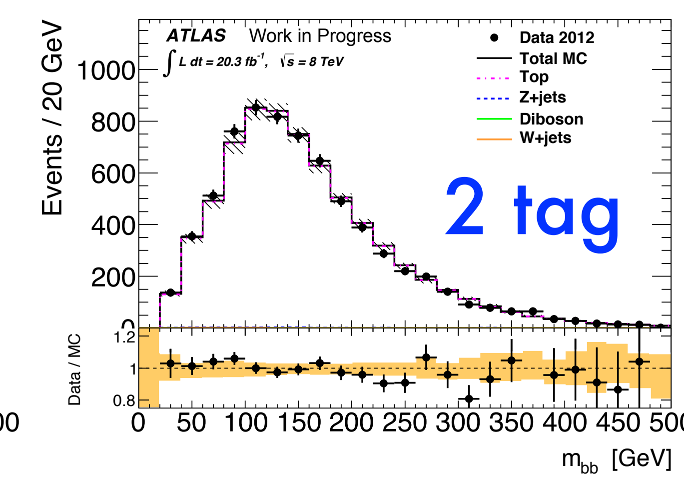
  - **m_{ll} SBs** (40 < m_{ll} < 76 GeV or m_{ll} > 106 GeV; E_T^{miss} > 60 GeV for 1 b-tag)





  - **eμ CRs** (opposite charge only; E_T^{miss} > 60 GeV for 1 b-tag)

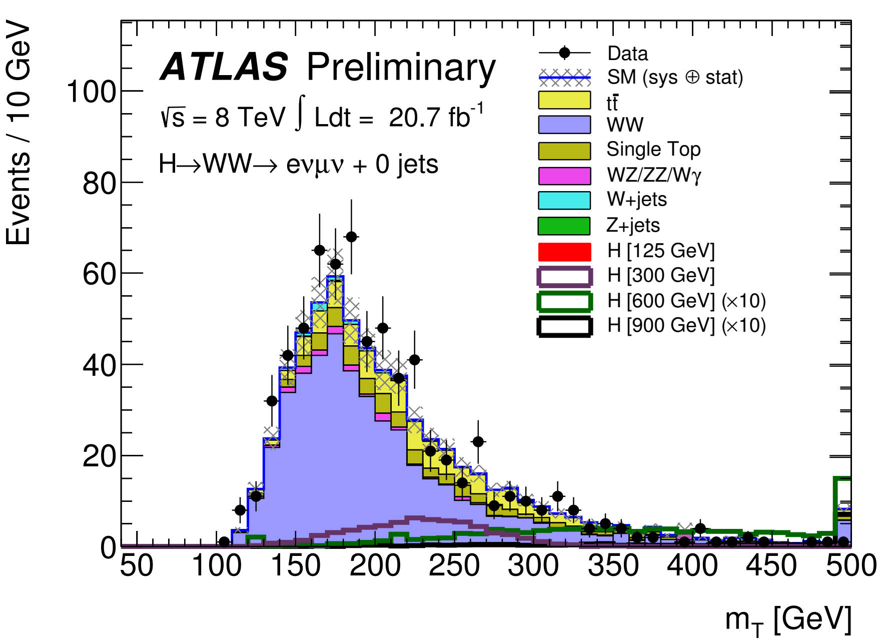


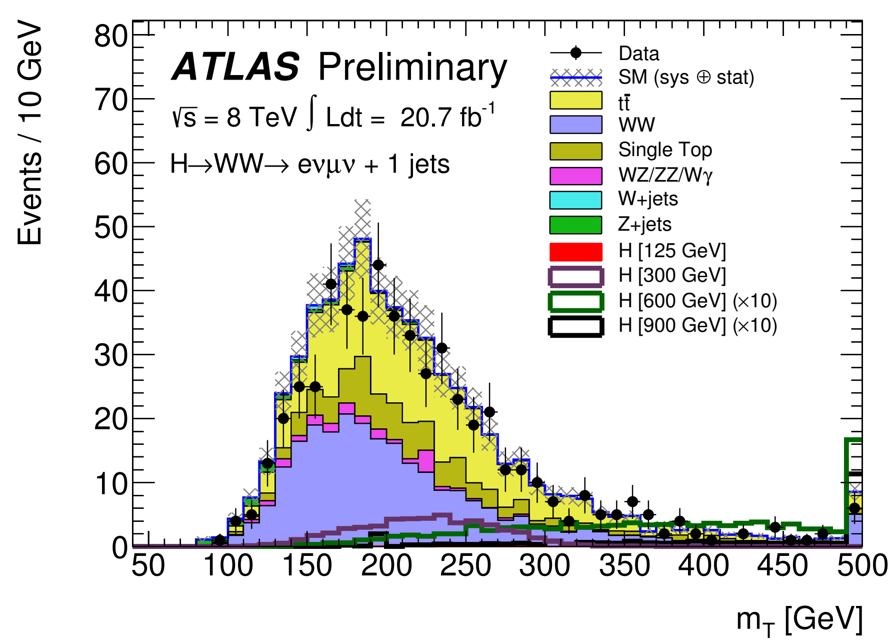


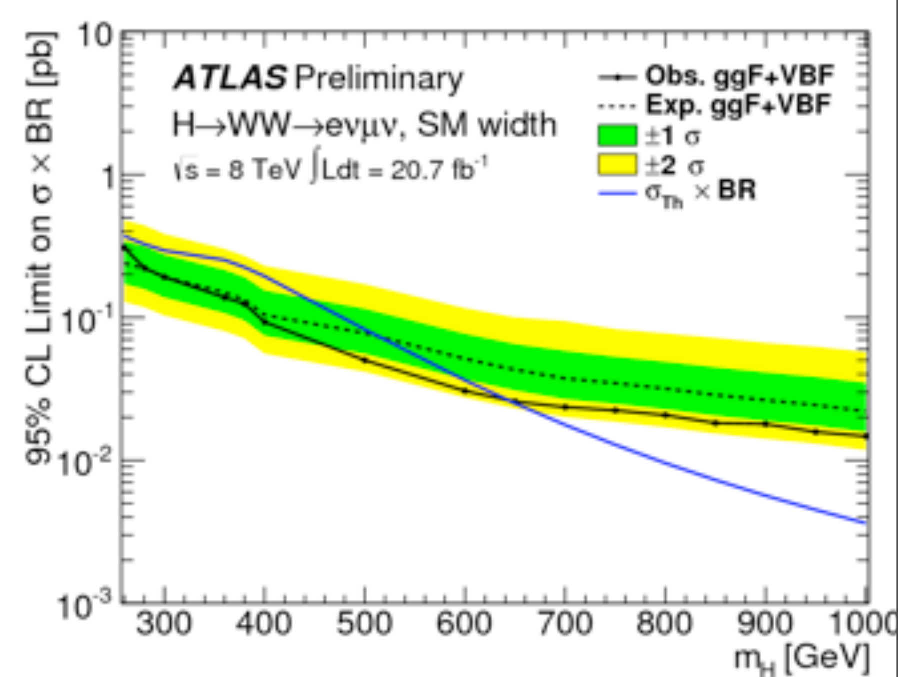
$H \to WW \to l\nu l\nu$

- Two isolated, opposite sign leptons and E_T^{miss}
- Only leptons with different flavor used
- Event categories: 0-jet, 1-jet, ≥ 2-jets (VBF)
- Top and WW backgrounds normalized to control regions
- Selection optimized to be more sensitive to higher m_H values
- The observed σ / σ_{SM} value is ~ 0.7 for ggF @ 500 GeV

[ATLAS-CONF-2013-067]



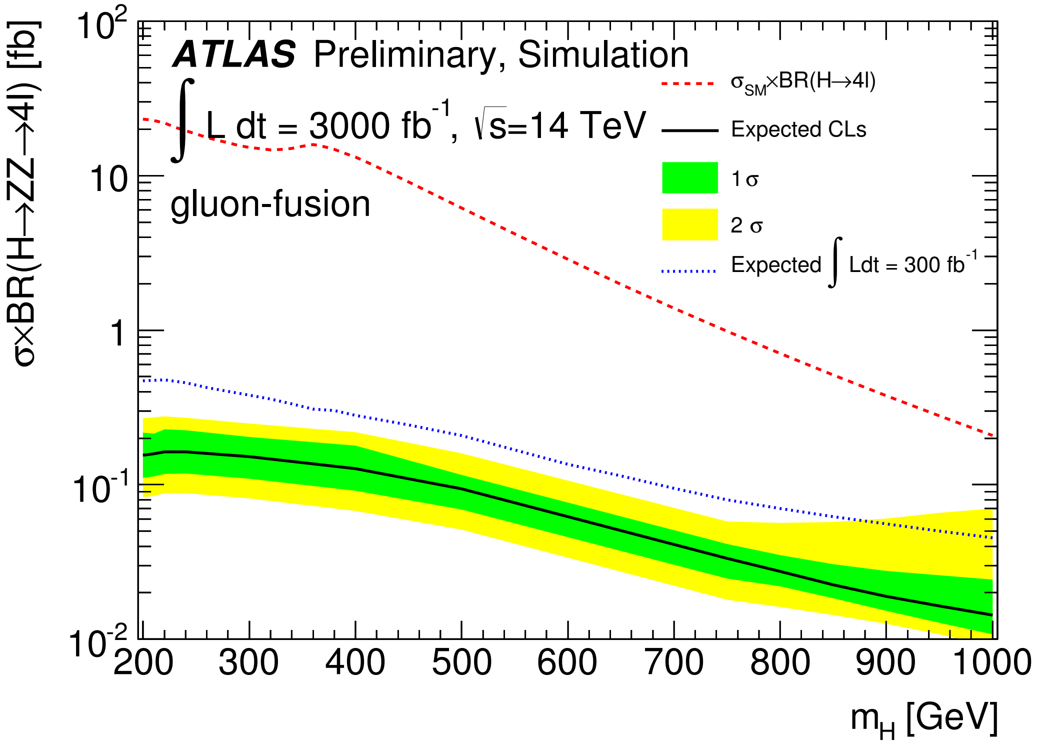


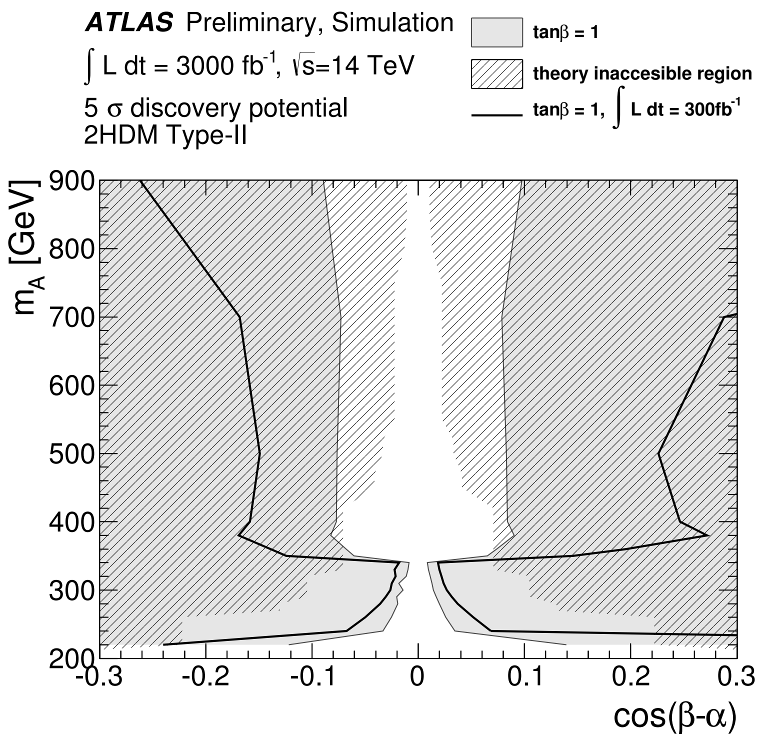


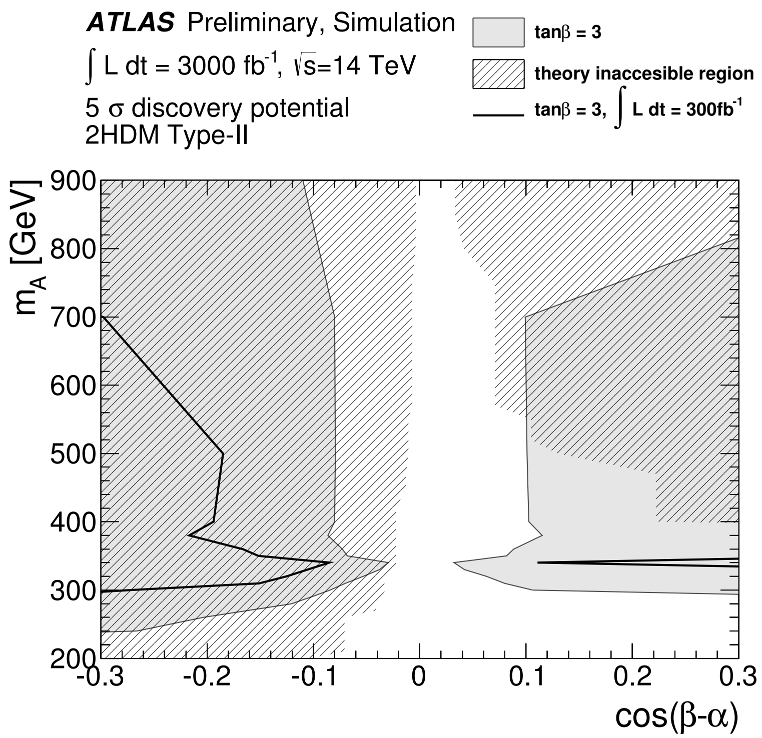
Perspectives for HL-LHC

- Expected exclusion of a SM-like Higgs boson assuming an integrated luminosity of **300 and 3000 fb^{-1} @ 14 TeV** in the 4l channel is about **4 - 40 times @ 300 fb^{-1}** (10 - 150 @ 3000 fb^{-1}) better than that expected for a SM-like Higgs Boson

- Discovery potential with **300 and 3000 fb^{-1} @ 14 TeV** for a type-II 2HDM for values of tanβ = 1 and 3 has been evaluated for the A → Zh production







[ATL-PHYS-PUB-2013-016]

Conclusions

- Heavy Higgs searches are important to explore BSM models (2HDM, EWS)
- The goal is to perform searches of multiple Higgs bosons by scanning over m_H, $\tan\beta$ and $\cos(\beta - \alpha)$ planes
- Run I data analysis still on-going: inclusion of latest analysis developments, inclusion of interference at very high mass values, final interpretations of results
- Aim for a combination paper of $H \to ZZ$ and $H \to WW$ production modes
- Perspectives for Run II show a very good potential for BSM Higgs searches

And thanks for your attention!

Backup

2HDM Benchmark

Strategy compatible with current knowledge on h(125)

- Light Higgs (h) is a 125 GeV CP-even particle
- m_A and m_{H+-} large, equal to m_H
- scan over m_H, $\cos(\beta - \alpha)$ and $\tan\beta$ planes
    - h compatible with SM rates ➙ restrict $\cos(\beta - \alpha) \sim 0$
    - Explore both positive and negative quadrants
- Fix $(m_{12})^2$ parameter
    - $(m_{12})^2 = 0$ (exact Z_2 symmetry)
    - $(m_{12})^2 = f(m_A, \tan\beta)$ (softly broken Z_2 symmetry, e.g. MSSM)
- Apply to both Type I and II (no FCNC)

Datasets

- Muon/Egamma streams: 20.3 fb^{-1} @ 8 TeV
- Signal: Powheg ggF and VBF
  - 200 - 1000 GeV range in 20 (50) GeV steps below (above) 600 GeV
  - Both narrow width approximation (NWA) and complex-pole scheme (CPS)
- Background MC:
  - Z/W + jets : Sherpa (ggF) and Alpgen+Pythia (VBF)
  - ttbar: Powheg
  - single top: Powheg (Wt/s-chan) + Acer (t-chan)
  - Diboson (ZZ/WZ/WW): Herwig
  - QCD multijet from data in the ee channel (negligible in $\mu\mu$):
    - loose++ lepton ID + reversed track isolation