Higgs Searches at ATLAS
(Biased Towards $H \longrightarrow \gamma\gamma$)

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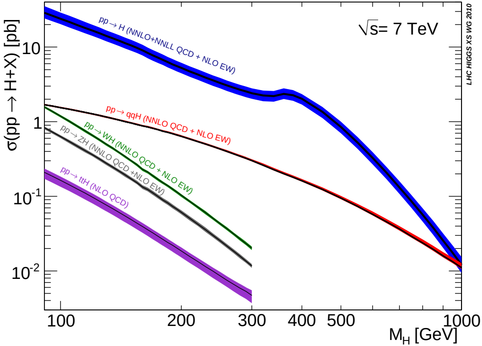
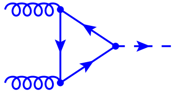
DESY

LHC Physics Discussion – May 23, 2011 – Hamburg

Higgs Boson Production at the LHC

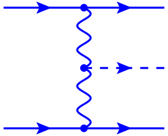


Dominant process: Gluon fusion



Vector boson fusion (VBF)

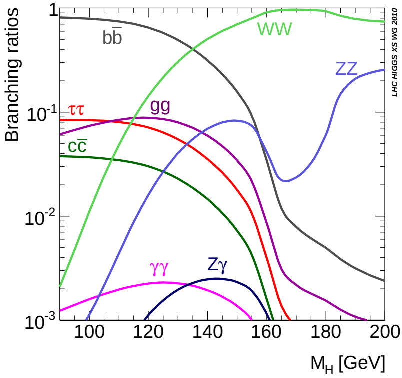
Smaller xsection, but distinct topology with two forward jets



Theoretical uncertainties

- Gluon fusion known at NNLO
  $\sigma_{\textbf{theo}} \sim \mathcal{O}(15\%)$
- VBF known almost at NNLO
  $\sigma_{\textbf{theo}} \sim \mathcal{O}(5\%)$

SM Higgs Decay Channels



Small m_H ($m_H <\approx 140\,\mathrm{GeV}$)

$H \to b\bar{b}$

- Dominant decay mode at small m_H, but needs distinct features at production/decay to beat down backgrounds

$H \to \tau\tau$

- Typically in VBF, enhanced in MSSM

$H \to \gamma\gamma$

- Small BF, but good signal yield and distinct signal

Intermediate m_H ($m_H >\approx 130\,\mathrm{GeV}$)

$H \to WW \to \ell\nu\ell\nu$, $H \to ZZ \to 4\ell$

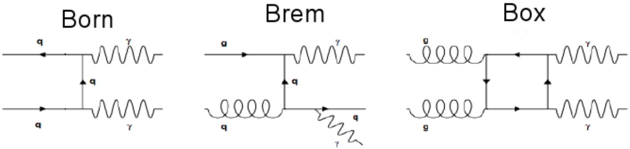
- Small leptonic BFs take their toll

Large m_H ($m_H >\approx 200\,\mathrm{GeV}$)

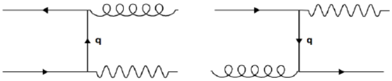
$H \to WW \to \ell\nu q\bar{q}$, $H \to ZZ \to \ell\ell\nu\nu, \ell\ell q\bar{q}$

$H \longrightarrow \gamma\gamma$: Analysis

- Comparably large signal yield despite tiny branching fraction on top of $\sim$ exponentially falling background
- Main background: SM diphotons:

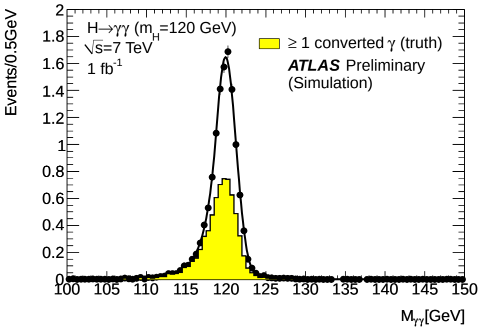


- Hadronic backgrounds: jet with leading π^0 misidentified as γ, e.g.



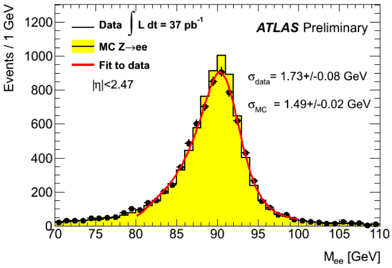
- $2\ \gamma$ candidates with $p_T > 40\,\mathrm{GeV}$ and $p_T > 25\,\mathrm{GeV}$
  - ⋆ Identified using shower shape cuts (in particular using lateral shower shapes in first sampling of LAr calorimeter)
  - ⋆ Calo isolation $E_T^{\mathrm{cone40}} < 3\,\mathrm{GeV}$ ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$)

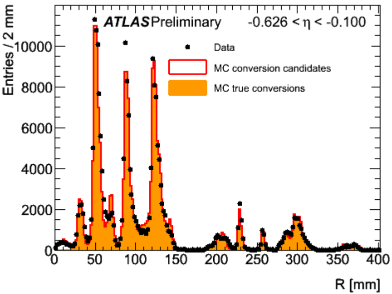
$H \to \gamma\gamma$: Resolution



- Need good resolution for narrow signal peak
- Significant contribution from converted photons
  - ⋆ $\sim 60\%$ signal with at least one converted photon due to large material budget of the Inner Detector
  - ⋆ Worse resolution due to electron bremsstrahlung
- Photon direction determined from first sampling of calorimeter, conversion vertex (if applicable) and primary vertex
  - ⋆ Primary vertex identified by largest $\sum p_T^2$
  - ⋆ Average number of pile-up vertices is 2.3 (in 2010)
- $m_{\gamma\gamma}$ resolution estimated to be $1.9\,\mathrm{GeV}$

Digression: Improving the Calorimeter Resolution

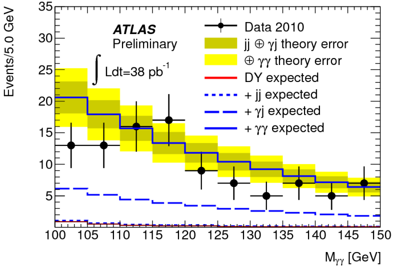


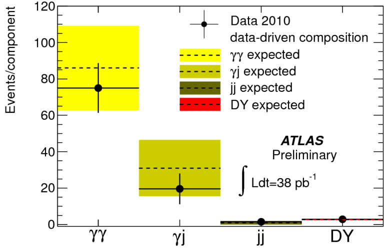


- Calorimeter calibration based on simulation
  - ⋆ Thoroughly tested in test beam
- Additional energy scale corrections derived from $Z \to e^+e^-$
  - ⋆ Will improve further with higher statistics $Z \to e^+e^-$ samples
- Goodness of calibration dependend on understanding of upstream material

→ Major effort to verify and continously improve the material description in the simulation e.g. studying hadronic interactions and photon conversions in ID material

$H \to \gamma\gamma$: Backgrounds





- Reasonable agreement between data and background estimates from simulation
  - ⋆ Simulation predictions from DiPhox and ResBos
- Data using control regions with loosened identification and isolation requirements for background cross checks
- Drell-Yan background estimated from extracted the electron-fake probability with help of $Z \to e^+e^-$

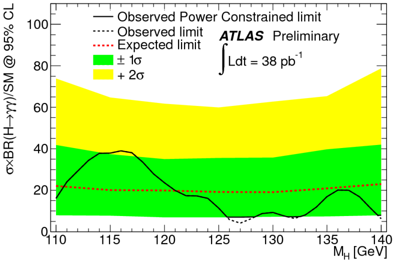
$H \longrightarrow \gamma\gamma$: Systematics

	Source	Uncertainty
	Luminosity	$\pm 3.4\%$
Theory	Cross-section (scales)	$^{+20}_{-15}\%$
Efficiency	Photon identification	$\pm 11\%$
	Photon isolation	$\pm 10\%$
	Trigger	$^{+1.1}_{-3.7}\%$
Resolution	Calibration	
	$e \rightarrow \gamma$ extrapolation	$\pm 13\%$
	Pile-up	

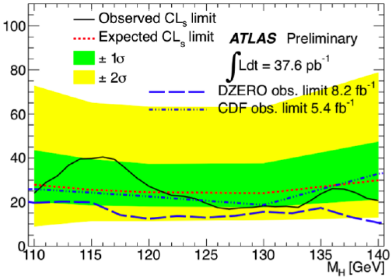
- Systematics treated in limit setting as nuisance parameters using penalty Pdfs

$H \longrightarrow \gamma\gamma$: Results

Power-Constrained Limit (PCL)



CL_s

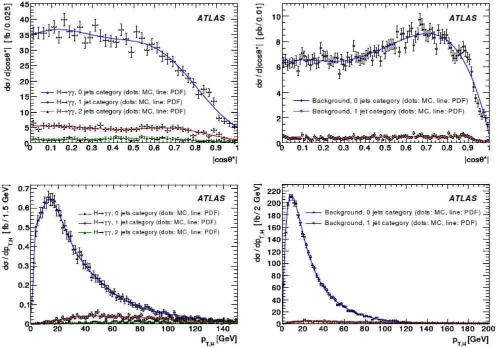


- Limits already competitive with Tevatron results
- Expected limits ~ 20 SM
- PCL (CL_{s+b} with power constraint) less conservative than CL_s

$H \rightarrow \gamma\gamma$: Future Improvements

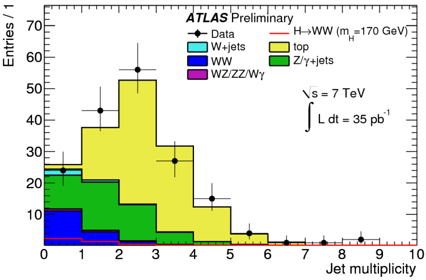
Possible improvements to the analysis studied in detail on simulation

- Need better identification of primary vertex with increasing pile-up
  - ⋆ Add calorimeter pointing to primary vertex selection
- Categorize γs according to being (un)converted and according to their η
  - ⋆ Separates classes of events according to their $m_{\gamma\gamma}$ resolution
- Use additional discriminating variables: $\cos\theta^*$ (Higgs decay angle) and $P_{T,\gamma\gamma}$
- Classify events according to their jet content
  - ⋆ Different categories have different mix of production modes
  - ⋆ Different categories rather different in S/B



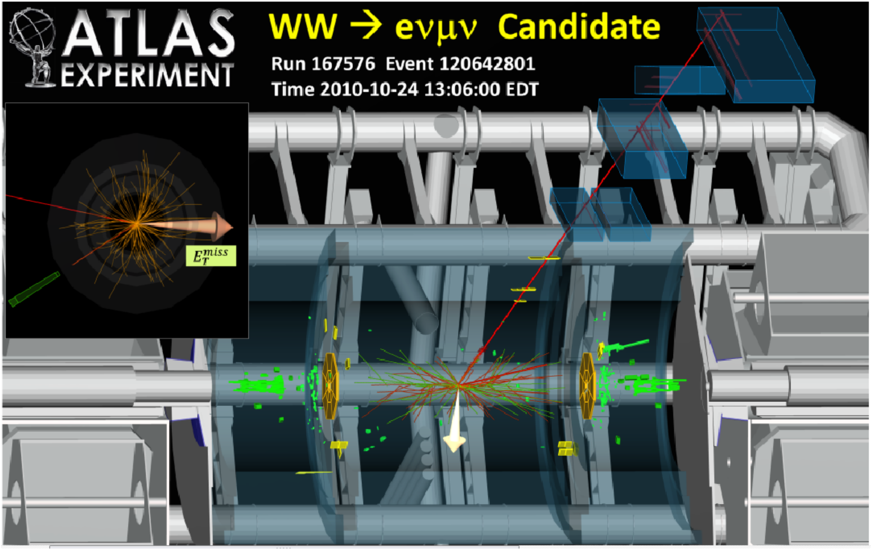
$H \to WW \to \ell\nu\ell\nu$: Analysis

- Essentially no mass resolution
- Comparably large yield with rather low backgrounds
- Events separated according to jet multiplicity
- Common preselection for the different jet channels
  - ⋆ 2ℓ with $p_T > 15/20\,\mathrm{GeV}$, isolated and identified
    - ▶ e shower shapes and tracking
    - ▶ μ muon spectrometer
  - ⋆ $m_{\ell\ell} > 15\,\mathrm{GeV}$, $|m_{ee,\mu\mu} - m_Z| > 10\,\mathrm{GeV}$
  - ⋆ $E_T^{\mathrm{miss}} > 30\,\mathrm{GeV}$
  - ⋆ $\Delta\phi_{\ell\ell} < 1.3(1.5)$ for $m_{\ell\ell} < (>)170\,\mathrm{GeV}$

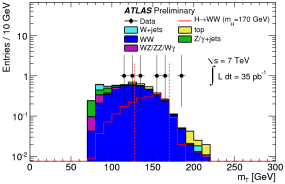


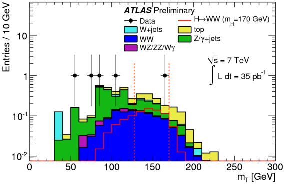
- Dominant backgrounds estimated in control regions and extrapolated into signal region
  - ⋆ WW $\ell\ell$ sidebands
  - ⋆ top reverse b-veto
  - ⋆ W+jets loosen id on 2nd ℓ
  - ⋆ Z+jets $m_{\ell\ell}$-E_T^{miss} plane

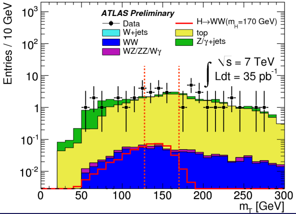
A $WW \to e\nu\mu\nu$ Candidate



$H \to WW \to \ell\nu\ell\nu$: Exclusive Jet Channels







Transverse mass

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 + (\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,\text{miss}})^2}$$

0-jet Dominant bkgd: WW

Data	3
BG	1.8±0.1
Higgs	1.26±0.02

1-jet Dominant bkgd: top (WW, Z+jets)

Data	1
BG	1.2±0.1
Higgs	0.6±0.01

2-jet Dominant bkgd: top, WW

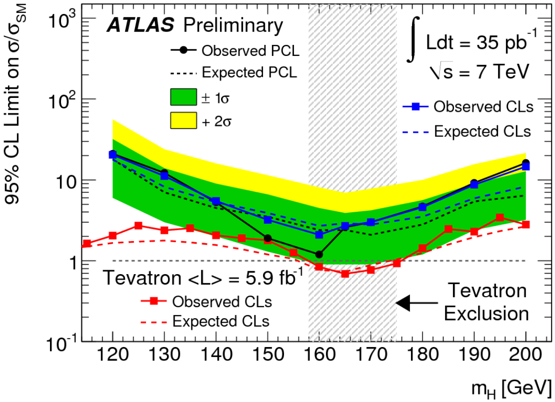
Data	0
BG	0.02±0.01
Higgs	0.06±0.01

(Numbers for analysis point at $m_H = 170\,\text{GeV}$)

$H \to WW \to \ell\nu\ell\nu$: Systematics

Source of Uncertainty	Treatment in analysis
Jet Energy Resolution (JER)	$\sim$ 14%, see Ref. [56]
Jet Energy Scale (JES)	$< 10\%$ for $p_T > 15$ GeV and $\|\eta\| < 4.5$, see Ref. [53].
Electron Selection Efficiency	$6 - 16\%$ as a function of p_T
Electron Energy Scale	1% for $\|\eta\| < 1.4$, 3% for $1.4 < \|\eta\| < 2.5$
Electron Energy Resolution	Sampling term 20%, a small constant term has a large variation with η
Muon Selection Efficiency	1.2% for $p_T < 20$ GeV and 0.4% for $p_T > 20$ GeV
Muon Momentum Scale	η dependent scale offset in p_T, up to $\sim$ 3.5%
Muon Momentum Resolution	p_T and η dependent resolution smearing functions, $\leq 10\%$
b-tagging Efficiency	p_T dependent scale factor uncertainties, 10-12%, see Ref. [54]
b-tagging Mis-tag Rate	up to 26%
Missing Transverse Energy	Add/subtract object uncertainties into the E_T^{miss}, up to 20%
Luminosity	11%

$H \to WW \to \ell\nu\ell\nu$: Results



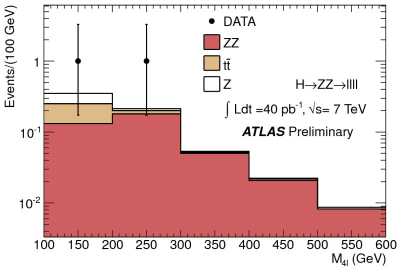
Best sensitivity at $m_H = 170\,\mathrm{GeV}$: exclusion of $2.1\times$ SM

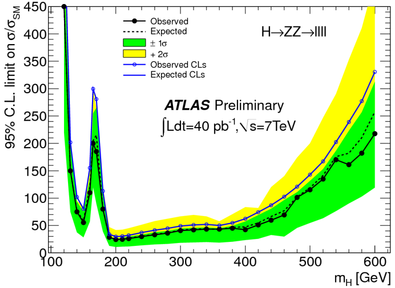
Exclusion of $1.2\times$ SM at $m_H = 160\,\mathrm{GeV}$

$H \to ZZ \to 4\ell$

- Very clean channel with good mass resolution
- Low event yield to due leptonic BF
- Selection of two opposite-sign isolated dileptons with requirements on dilepton masses, $\Delta R(\ell_i, \ell_j)$ and small impact parameter significance

After cuts on dileptons





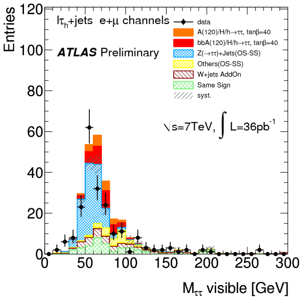
- No events left after full selection
- Background dominated by SM ZZ

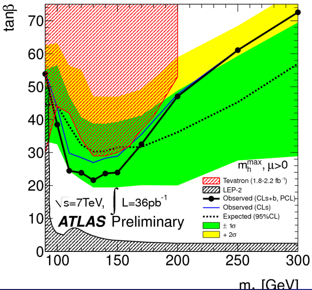
Data	0
BG	0.4
Higgs	0.10±0.02

- ZZ and ZQQ cross checked on data
- Exclusion limit $\sim 25\times$ SM

$H \to \tau\tau$

- MSSM $h/H/A$ produced in gluon fusion and in association with $b\bar{b}$
- Reconstructed in $\tau_{\mathrm{had}}\ell\nu\nu$ (BF$\sim 46\%$) from τ_{had}, ℓ, E_T^{miss} and m_T^{τ}
- W/Z+jets and QCD backgrounds cross checked on data using control regions





- For $m_A = 120\,\mathrm{GeV}$ and $\tan\beta = 40$

Data	206
BG	207 ± 6
Higgs	52 ± 1

- $M_{\tau\tau}(\mathrm{vis})$ shape used in limit determination
- Limits better than Tevatron for much of $\tan\beta$–m_A plane ($m_h^{\max}$ scenario)

Summary

- Higgs searches performed with 2010 data set in many channels, more than have been shown here
  - ⋆ $H \to WW \to \ell\nu q\bar{q}$ for $m_H > 200\,\mathrm{GeV}$
  - ⋆ $H \to ZZ \to \ell\ell q\bar{q}, \ell\ell\nu\nu$ for $m_H > 200\,\mathrm{GeV}$
  - ⋆ Light CP-odd Higgs decaying into $\mu\mu$
  - ⋆ Study for charged Higgs boson search in $t\bar{t}$ events with leptons
  - ⋆ Data-driven bkgd estimation for charged Higgs decays into hadronically decaying τ

- Already competitive (with 2010 data) with Tevatron results in low mass searches ($H \to \gamma\gamma$, MSSM $H \to \tau\tau$)

- Searches will continue on the much larger 2011 data set with new challenges posed by much larger pile-up

Backup

$H \rightarrow \gamma\gamma$: Backgrounds With Higher Statistics