VV Measurements & Higgs Searches

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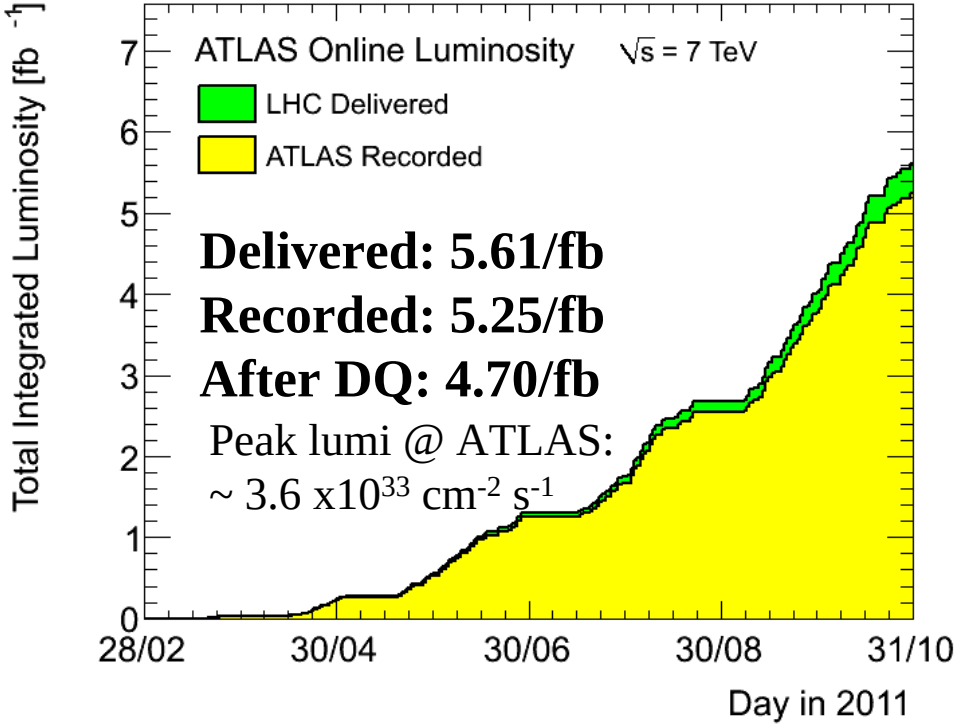
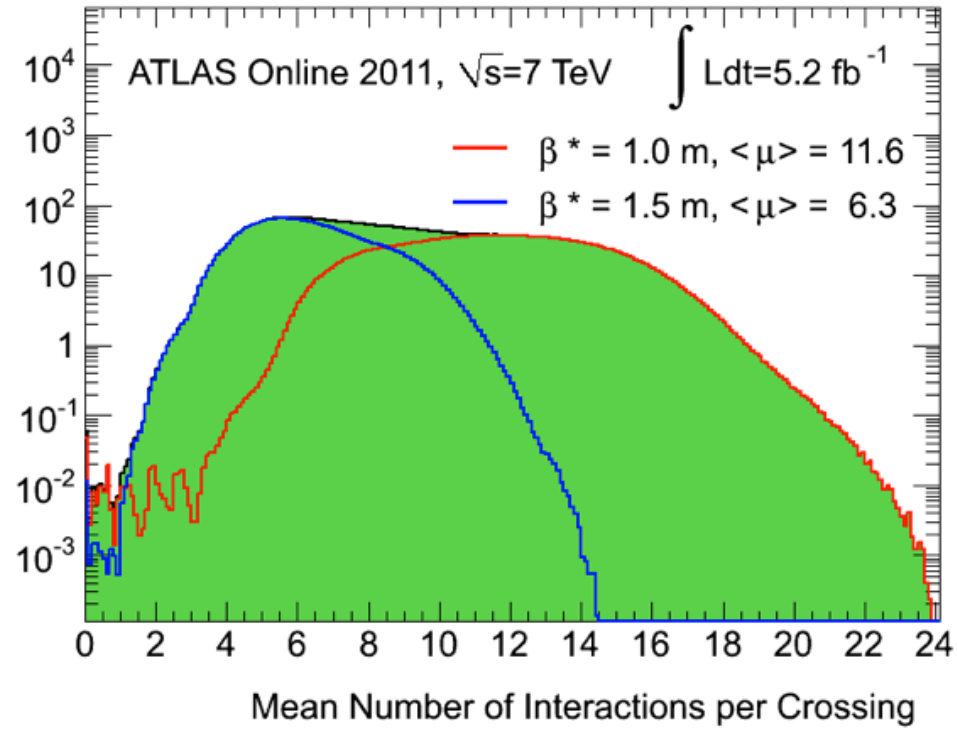
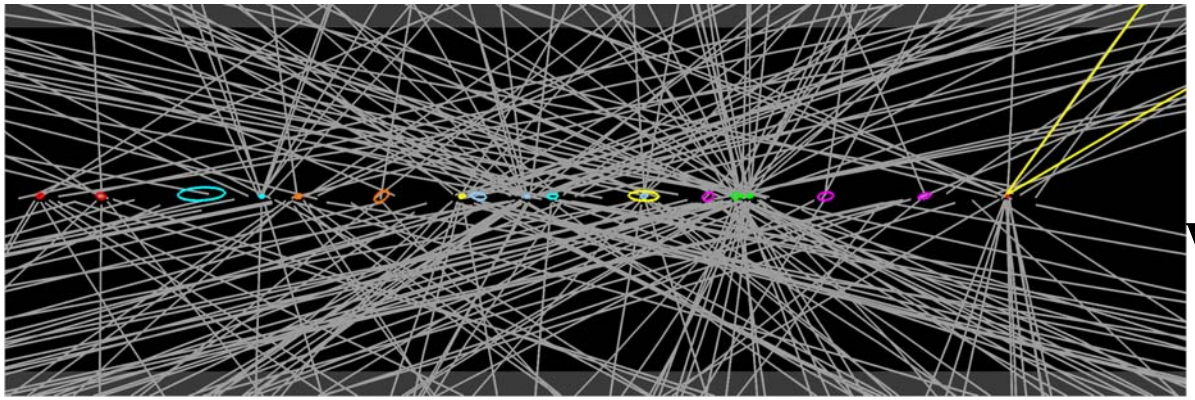
BROOKHAVEN NATIONAL LABORATORY

Loopfest XI, 10.05.2012

The 2011 (ATLAS) Data



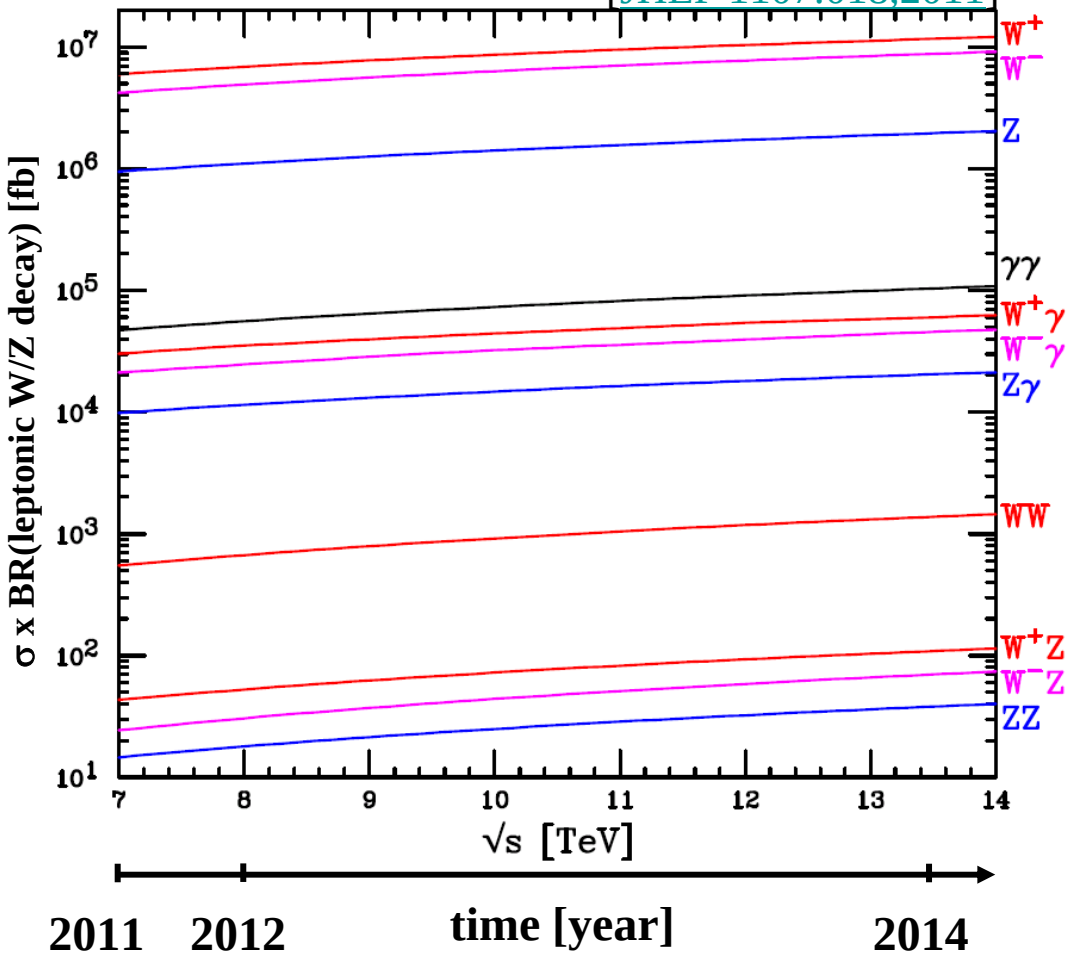


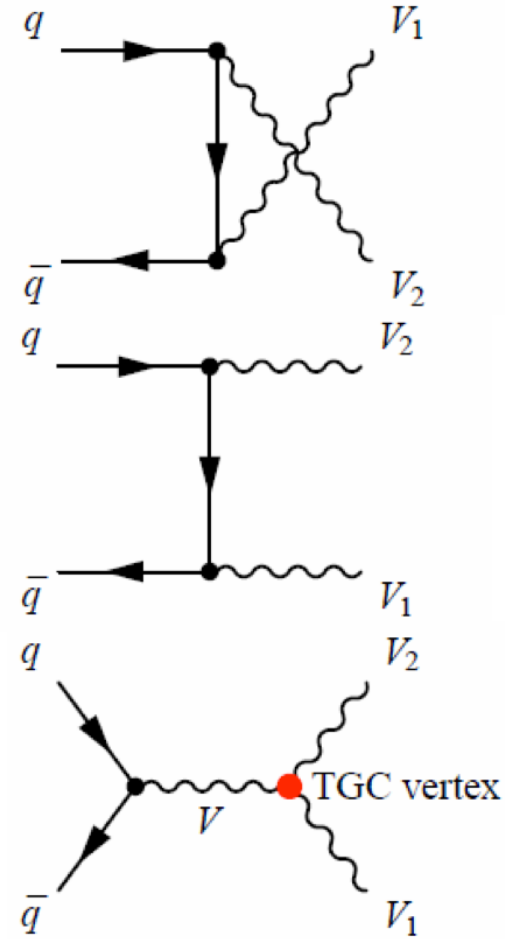


Z→ μμ candidate event, w/ 20 reconstructed vertices.

DiBoson Production

[JHEP 1107:018,2011]





Test SM predictions, probe new phenomena/aTGCs, background to Higgs

$WW \rightarrow \ell\nu\ell\nu$

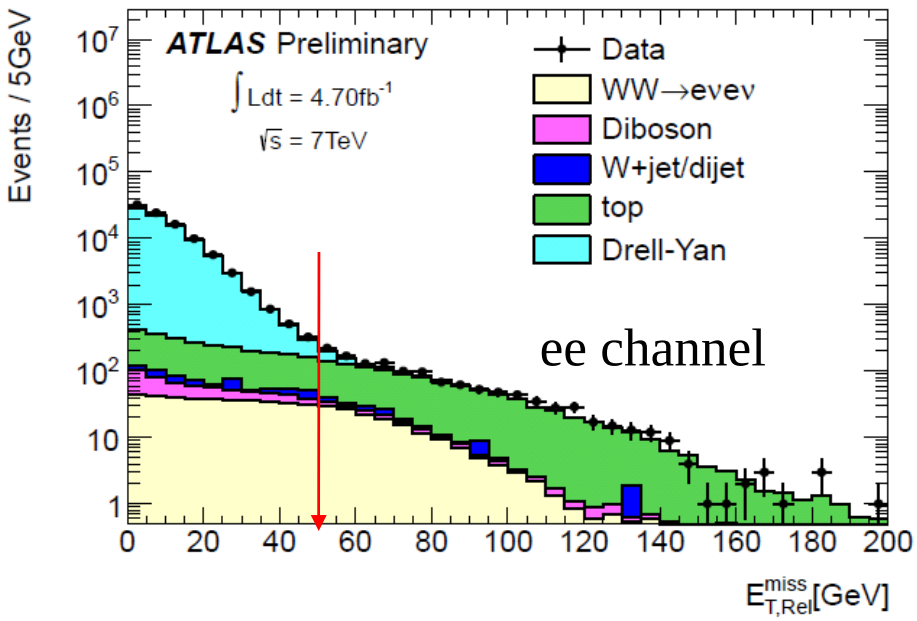
<u>ee, eμ, μμ channels used (includes W→ τ +X → e/μ + X):</u>

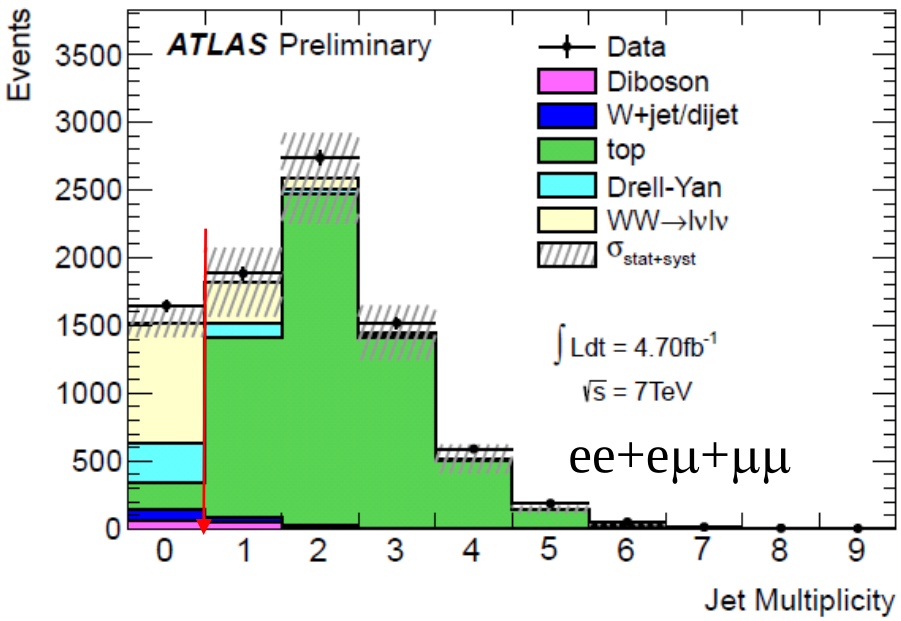
- $p_T(\ell)$ > 25/20 GeV (e/e, e/μ, μ/μ)
- $m_{\ell\ell}$ > 15/15/10 GeV (ee, μμ, eμ), Z mass veto for ee, μμ
- $E^{miss}_{T,Rel}$ > 50/55/25 GeV (ee, μμ, eμ)
- No jets with p_T > 25 GeV, |η| < 4.5, no b-jets with p_T > 20 GeV, |η| < 2.5

$$E^{miss}_{T,Rel} = \begin{cases} E^{miss}_T & \Delta\phi \geq \pi/2 \\ E^{miss}_T \sin\Delta\phi & \Delta\phi < \pi/2 \end{cases}$$

$$\Delta\phi = \min\left\{\Delta\phi\left(\vec{E}^{miss}_T, \ell/\text{jets}\right)\right\}$$

<u>Major backgrounds:</u> Z/γ*+jets, Top, W+jets, VV





$WW \rightarrow \ell\nu\ell\nu$

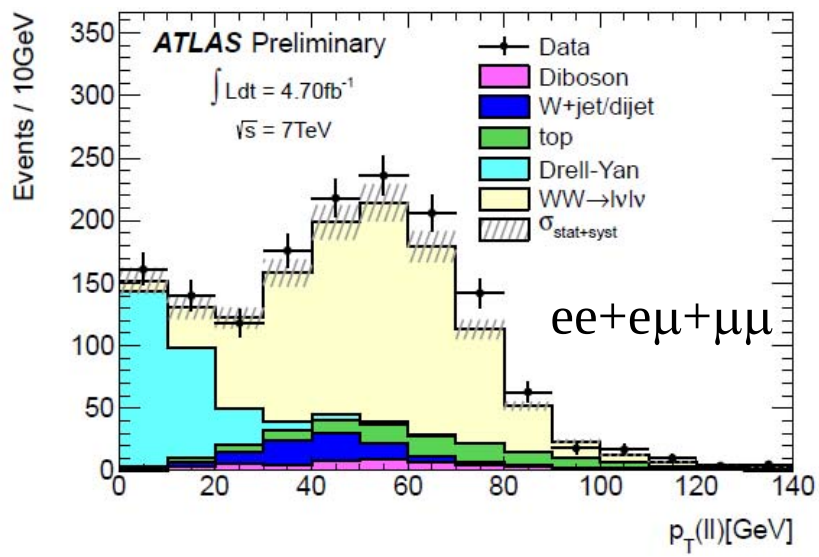
Combined Yields: [ATLAS-CONF-2012-025]

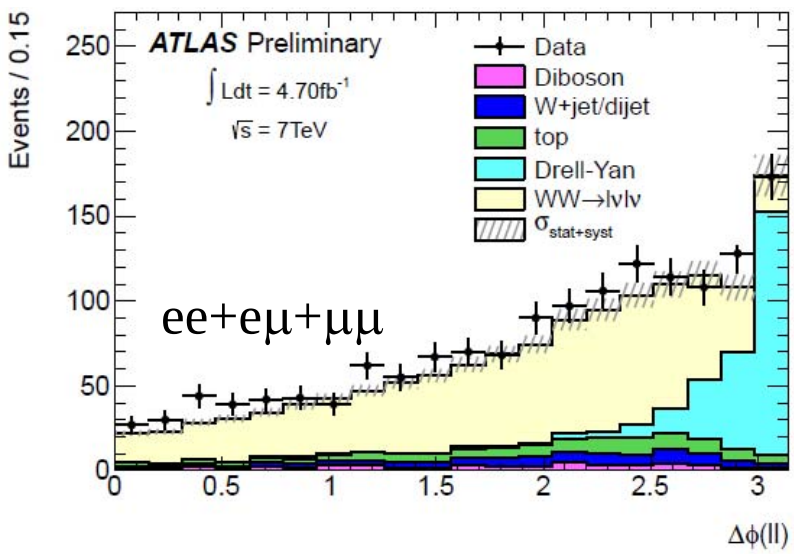
Observed Events	1524
Total expected events (S+B)	1370.1±14.3±96.5
MC WW Signal	839.0±4.2±83.3
Background estimations	
Top(data-driven)	110.0±6.2±22.4
W+jets (data-driven)	79.0±1.4±39.0
Drell-Yan (MC/data-driven)	284.2±11.7±17.2
Other dibosons (MC)	57.6±3.2±7.4
Total background	531.1±13.7±48.7

σ_{WW} = 53.4±2.1(stat)±4.5(syst)±2.1(lumi)pb

SM: σ_{WW} (NLO) = 45.1±2.8 pb

(cross sections in fid. volume provided as well)





$ZZ \rightarrow \ell\ell\nu\nu$

- 2 same flavour leptons of $p_T > 20$ GeV
- $|m_{\ell\ell} - m_Z| < 15$ GeV
- Axial- $E_T^{miss} > 80$ GeV (projection along $\vec{p}_T^{\,Z}$)
- No jets with $p_T > 25$ GeV, $|\eta| < 4.5$
- $\left|E_T^{miss} - p_T^Z\right| / p_T^Z < 0.6$

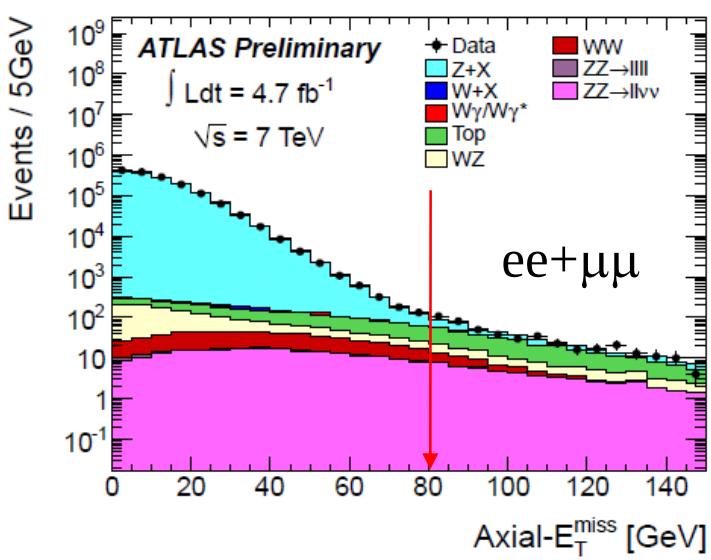
$$\sigma_{ZZ} = 5.4^{+1.3}_{-1.2}(\text{stat})^{+1.4}_{-1.0}(\text{syst}) \pm 0.2(\text{lumi})\text{pb}$$

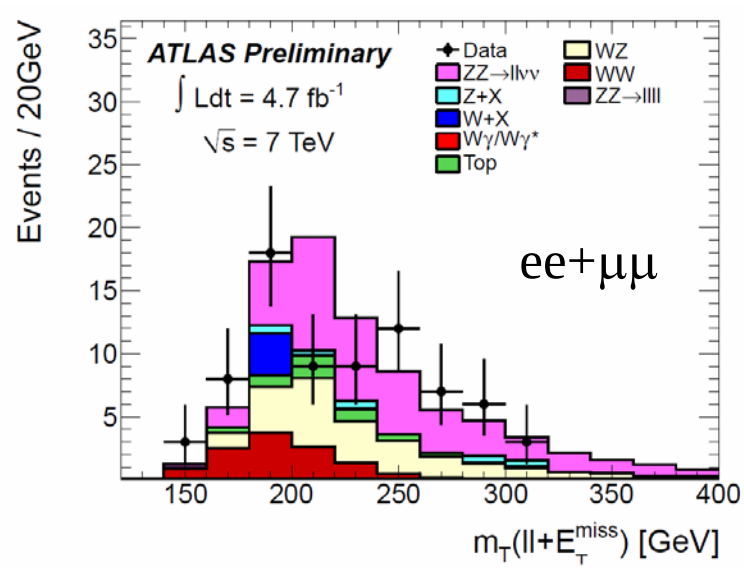
SM: σ_{ZZ} (NLO) = $6.5^{+0.3}_{-0.2}$ pb

(cross section in fid. volume provided as well)

Combined Yields: [ATLAS-CONF-2012-027]

Observed	78
Expected ZZ	$42.3 \pm 0.8 \pm 1.8$
Background estimations:	
$W^{\pm}Z$ (MC)	$22.7 \pm 0.8 \pm 3.5$
$W^{\pm}+\gamma$ (MC)	$0.29 \pm 0.12 \pm 0.01$
$t\bar{t}$, $W^{\pm}t$, W^+W^- and $Z \rightarrow \tau\tau$ (data-driven)	$14.7 \pm 4.1 \pm 0.6$
Z+jets (data-driven)	$1.7 \pm 0.5 \pm 0.8$
$W^{\pm}$+jets (data-driven)	$1.3 \pm 0.4 \pm 0.3$
Total Background	$40.7 \pm 4.3 \pm 3.7$





$ZZ \rightarrow \ell\ell\ell\ell$

- four leptons with $p_T > 7$ GeV,
- leading lepton > 25/20 GeV (e/μ)
- two opposite-sign same-flavour $\ell\ell$ pairs
- 66 GeV < $m_{\ell\ell}$ < 116 GeV each

Very *clean* signature. Backgrounds: V+X, top, VV

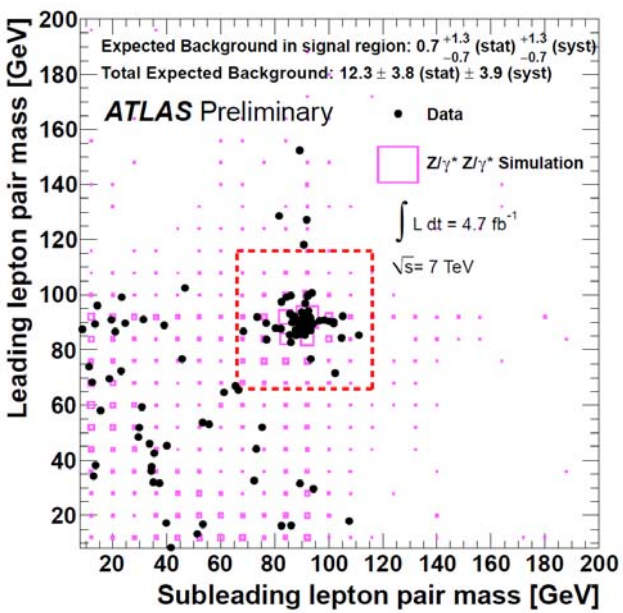
$$\sigma_{ZZ} = 7.2^{+1.1}_{-0.9}(\text{stat})^{+0.4}_{-0.3}(\text{syst}) \pm 0.3(\text{lumi})\text{pb}$$

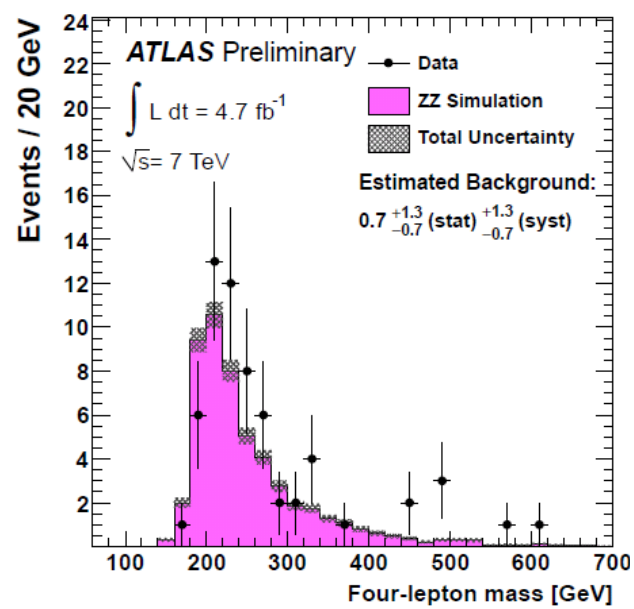
SM: σ_{ZZ} (NLO) = $6.5^{+0.3}_{-0.2}$ pb

(cross section in fid. volume provided as well)

Combined Yields: [ATLAS-CONF-2012-026]

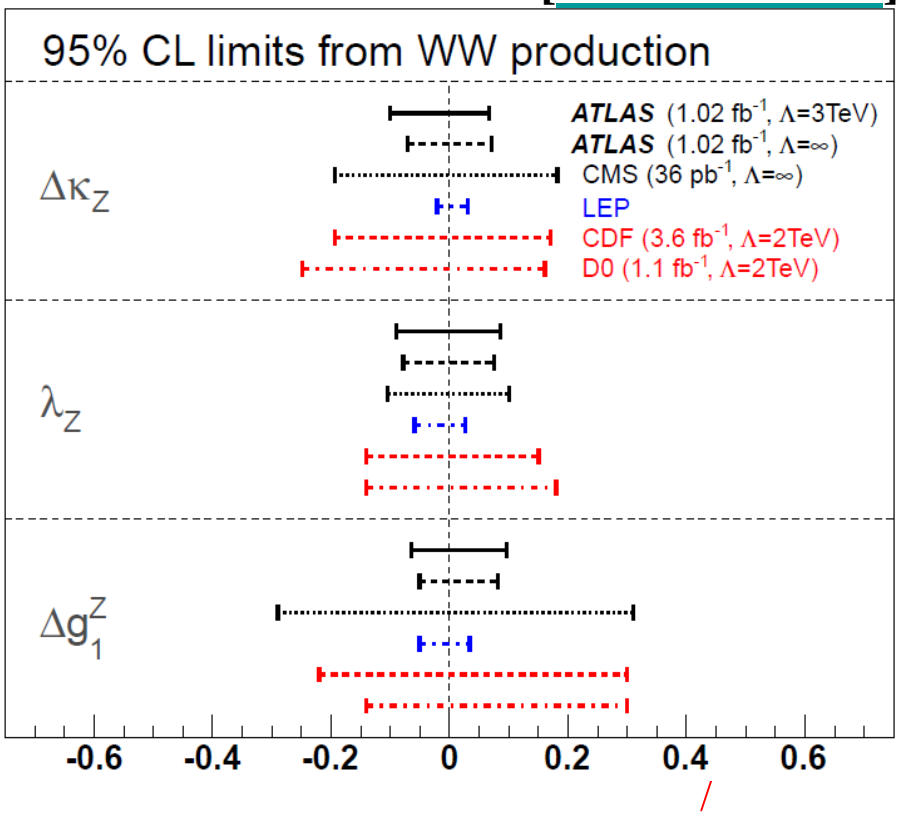
Final state	combined ($\ell\ell\ell\ell$)
Observed	62
Signal(MC)	$53.2 \pm 1.1 \pm 1.9$
Bkg(d.d.)	$0.7^{+1.3+1.3}_{-0.7-0.7}$
Bkg(MC)	1.0 ± 0.6





aTGC Extraction: WW → ℓνℓν

[arxiv:1203.6232]



Leading lepton p_T sensitive to aTGCs:

$$\mathcal{L}_{WWV}/g_{WWV} = ig_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + ik_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{i\lambda_V}{m_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu V^{\nu\lambda},$$

Anomalous parameters: Δg_1^Z, $\Delta\kappa_z$, λ_z, $\Delta\kappa_\gamma$, λ_γ

- LEP scenario (3 free pars):

$$\Delta\kappa_\gamma = (\cos^2\theta_W/\sin^2\theta_W)(\Delta g_1^Z - \Delta\kappa_Z), \quad \lambda_Z = \lambda_\gamma$$

- HISZ scenario (2 free pars) = LEP +

$$\Delta g_1^Z = \Delta k_\gamma/(2\cos^2\theta_W)$$

- Equal couplings scenario (2 free pars):

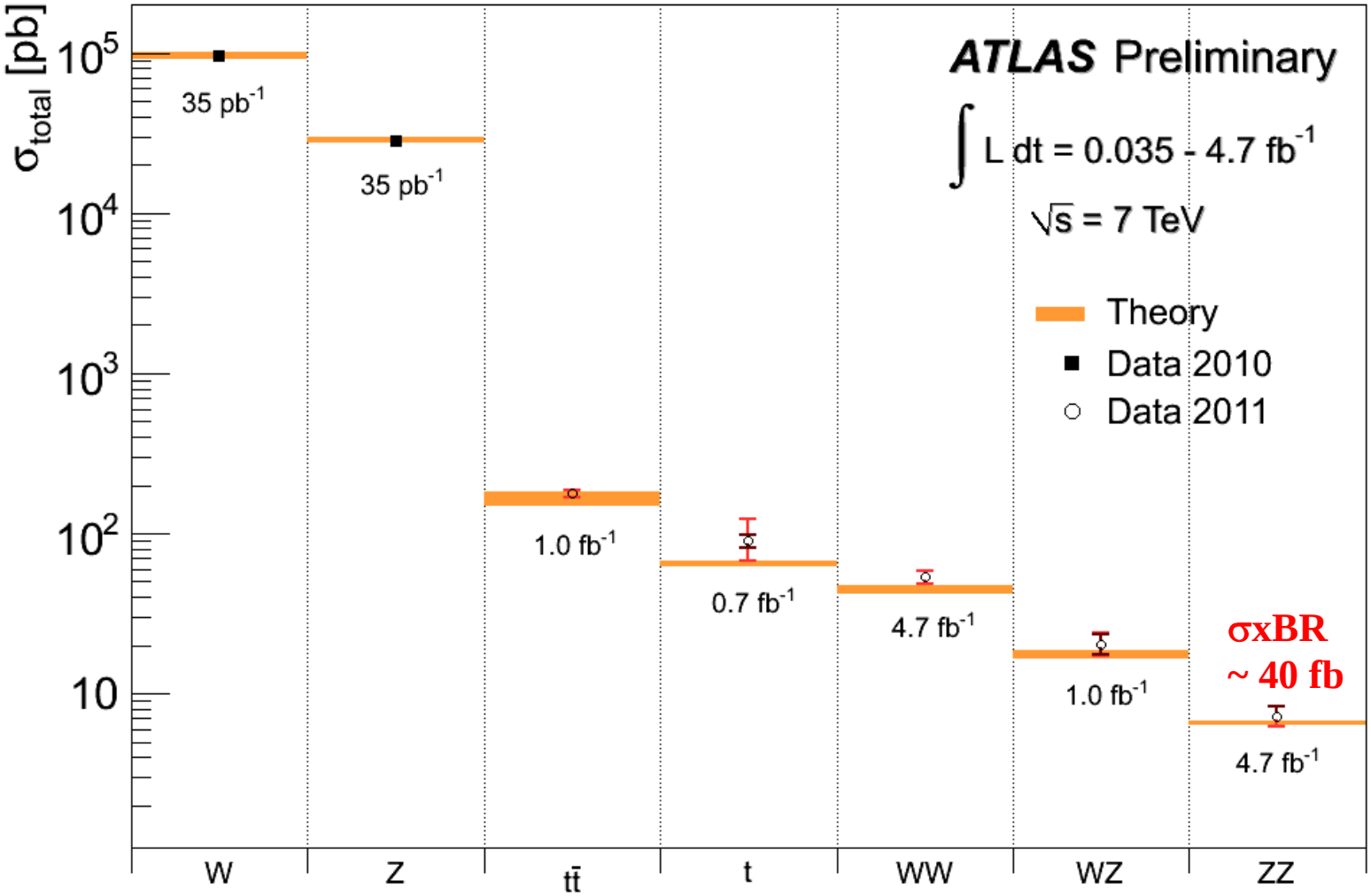
$$\Delta\kappa_Z = \Delta\kappa_\gamma, \quad \lambda_Z = \lambda_\gamma \quad \Delta g_1^Z = 0.$$

Modelling anomalous couplings: reweight MC@NLO to BHO at ME level.

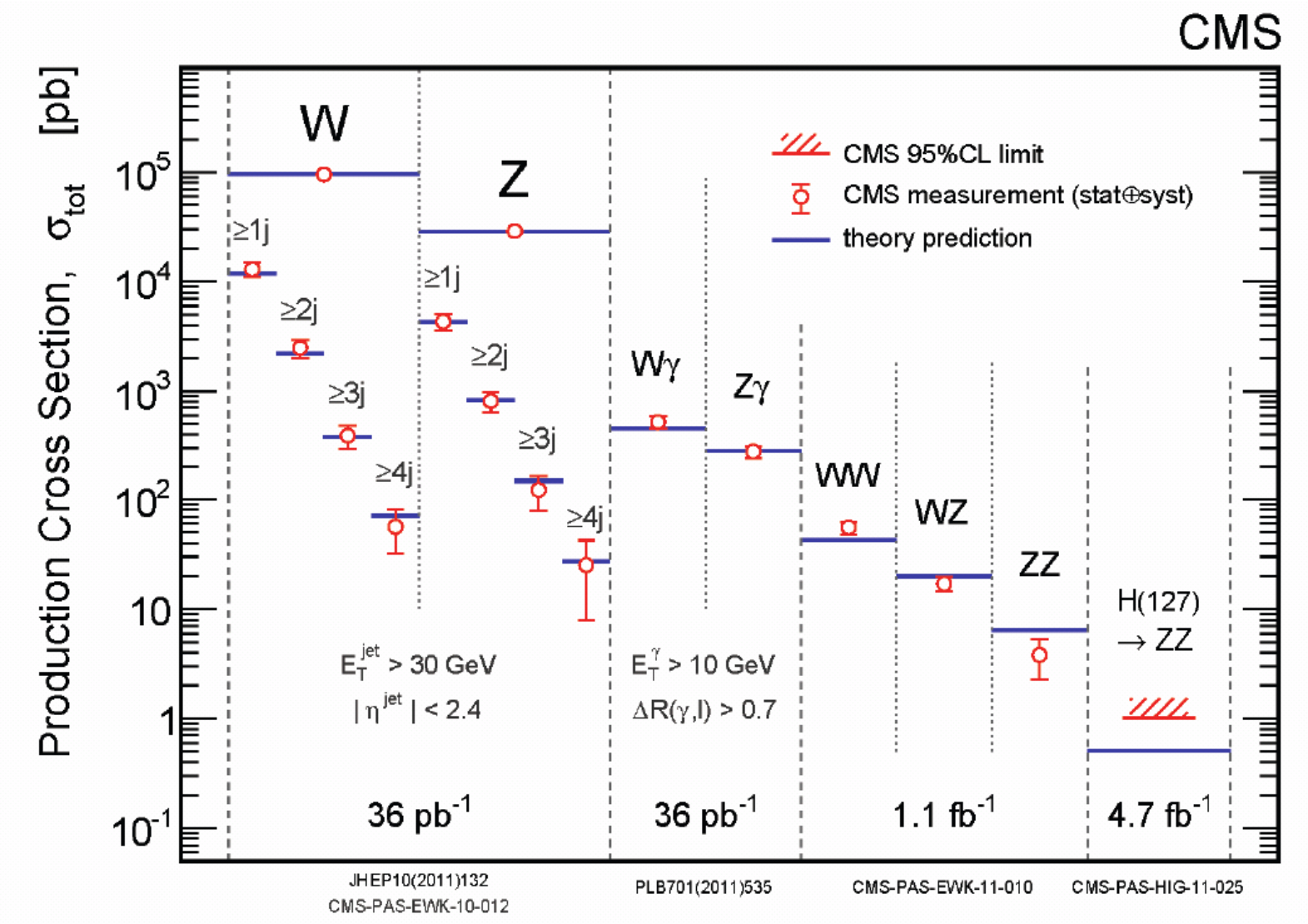
- p_T > 120 GeV: max sensitivity
- Low p_T excess: negligible impact on aTGC limits
- Measured fiducial xsec in last bin (SM expecation = 12.2 ± 1.0 fb):

$$\sigma_{\rm fid}(p_T > 120\,{\rm GeV}) = 5.6^{+5.4}_{-4.4}\,({\rm stat.}) \pm 2.9\,({\rm syst.}) \pm 0.2\,({\rm lumi.})\,{\rm fb}$$

SM total production cross section measurements @ ATLAS…

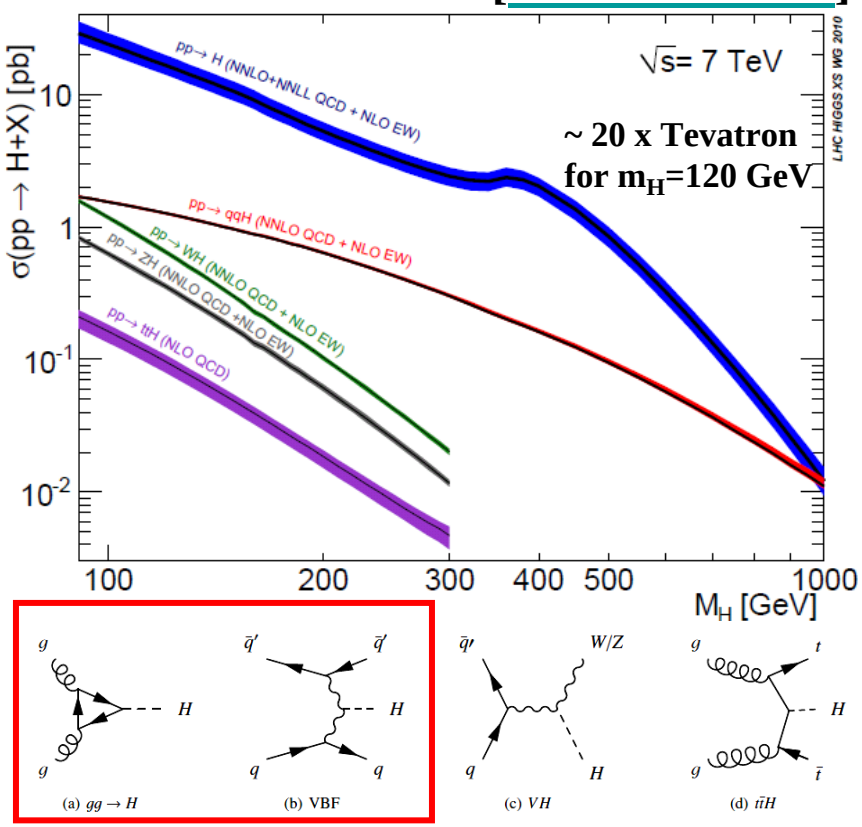


…and @ CMS

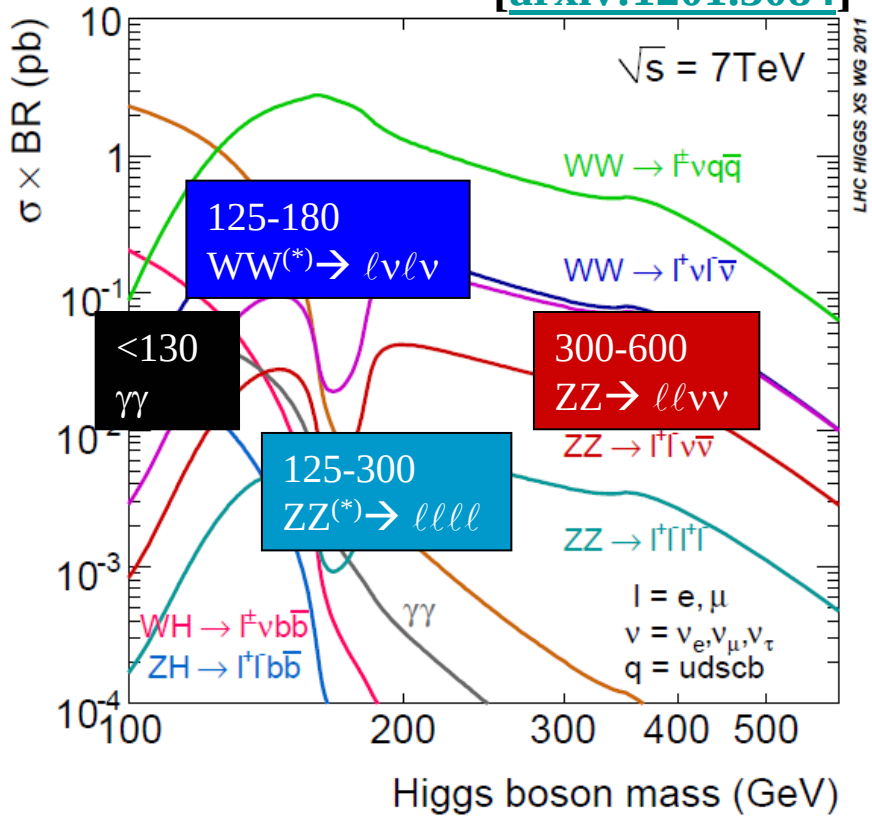

CMS
Production Cross Section, σ_{tot} [pb]
10^5
10^4
10^3
10^2
10
1
10^{-1}
W
Z
≥1j
≥2j
≥3j
≥4j
≥1j
≥2j
≥3j
≥4j
Wγ
Zγ
WW
WZ
ZZ
H(127) → ZZ
CMS 95%CL limit
CMS measurement (stat⊕syst)
theory prediction
E_T^{jet} > 30 GeV
$|\eta^{jet}|$ < 2.4
E_T^{γ} > 10 GeV
$\Delta R(\gamma,l)$ > 0.7
36 pb^{-1}
36 pb^{-1}
1.1 fb^{-1}
4.7 fb^{-1}
JHEP10(2011)132
CMS-PAS-EWK-10-012
PLB701(2011)535
CMS-PAS-EWK-11-010
CMS-PAS-HIG-11-025

Higgs Production & Decay

[arxiv:1101.0593]



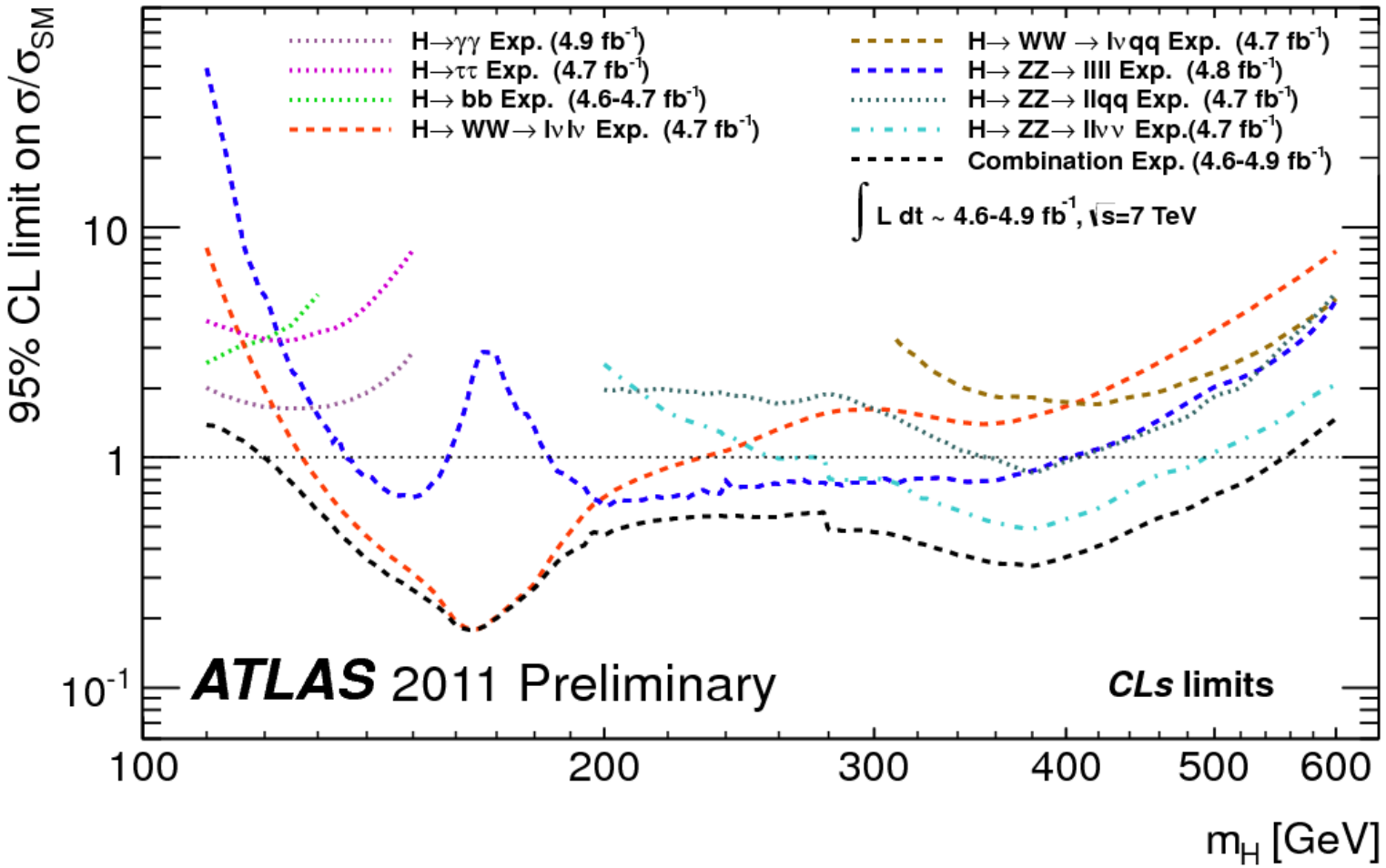
[arxiv:1201.3084]



- Mostly NNLO Cross-sections ⇒ theory uncertainties < 20%
- Progress in theoretical predictions of numerous and complex backgrounds
- Working group for high-mass Higgs (>600 GeV) started

Channel Sensitivities

[ATLAS-CONF-2012-019]



H→ WW → $\ell\nu\ell\nu$ has the best sensitivity between 125 GeV and ~200 GeV

$H \rightarrow WW \rightarrow \ell\nu\ell\nu$

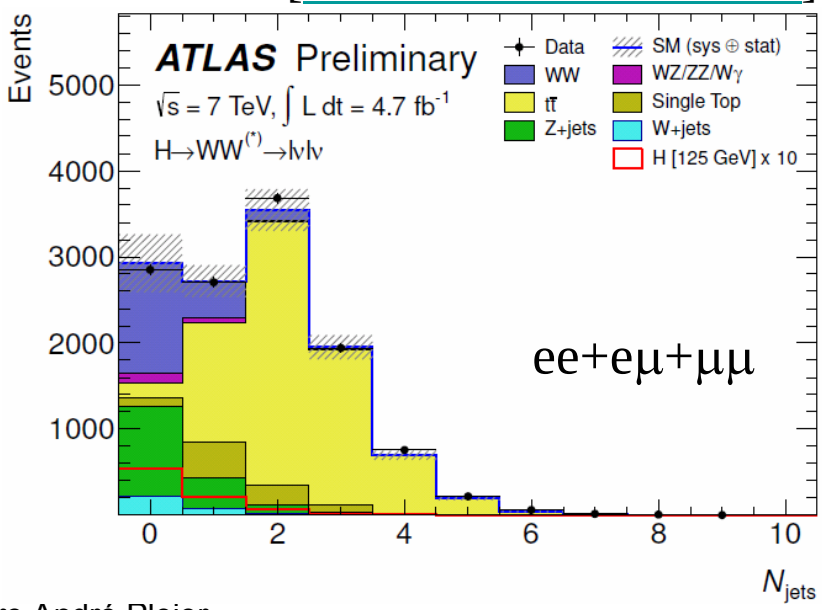
signal contributions considered: ggF, VBF

- $p_T(\ell_1,\ell_2) > 25$, 15 GeV, $|\eta| < 2.5$
- $m_{\ell\ell} > 12/12/10$ GeV (ee, μμ, eμ),
- Z mass veto for ee, μμ
- $E_{T,Rel}^{miss} > 45/45/25$ GeV (ee, μμ, eμ)
- Jets $p_T > 25$ GeV, $|\eta| < 4.5$

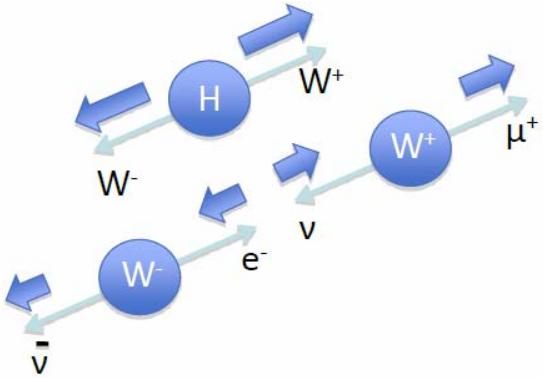
Major backgrounds: WW, V+jets, Top, …

=> study 9 channels: (ee, μμ, eμ) x (0, 1, 2 jets), m_H dependent selections (110-200, 200-300, 300-600 GeV)

[ATLAS-CONF-2012-012]



Utilize scalar Higgs decay kinematics:

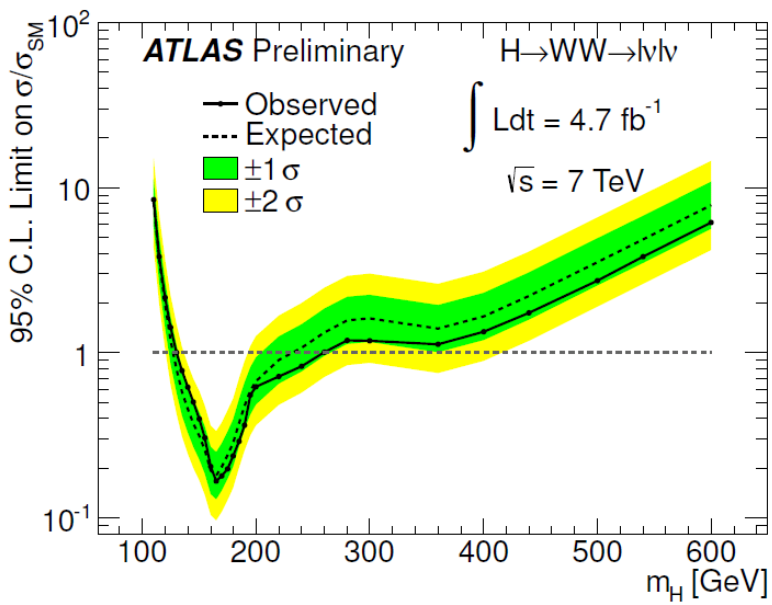


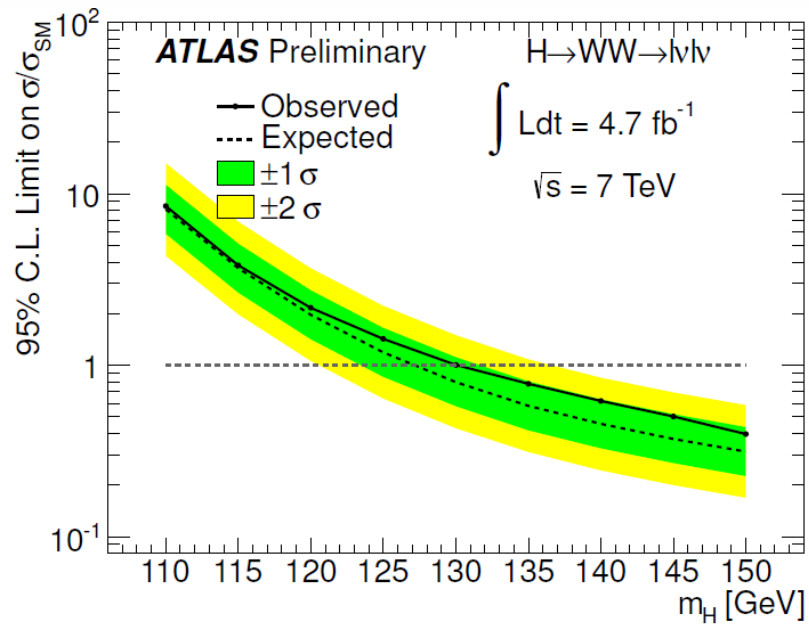
Spin correlation => a smaller average opening angle between the two leptons.

$H \rightarrow WW \rightarrow \ell\nu\ell\nu$

Combined Yields: [ATLAS-CONF-2012-012]

		Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* + \text{jets}$	$W + \text{jets}$	Total Bkg.	Obs.
0-jet	$m_H = 125$ GeV	25 ± 7	110 ± 12	12 ± 3	7 ± 2	5 ± 2	13 ± 8	27 ± 16	173 ± 22	174
	$m_H = 240$ GeV	60 ± 17	432 ± 49	24 ± 3	68 ± 15	39 ± 9	8 ± 2	36 ± 24	607 ± 63	629
1-jet	$m_H = 125$ GeV	6 ± 2	18 ± 3	6 ± 3	7 ± 2	4 ± 2	6 ± 1	5 ± 3	45 ± 7	56
	$m_H = 240$ GeV	23 ± 9	99 ± 22	8 ± 1	73 ± 27	35 ± 19	6 ± 2	7 ± 7	229 ± 55	232
2-jet	$m_H = 125$ GeV	0.4 ± 0.2	0.3 ± 0.2	negl.	0.2 ± 0.1	negl.	0.0 ± 0.1	negl.	0.5 ± 0.2	0
	$m_H = 240$ GeV	2.5 ± 0.6	1.1 ± 0.7	0.1 ± 0.1	2.6 ± 1.3	0.3 ± 0.3	negl.	0.1 ± 0.1	4.2 ± 1.7	2





Observed Exclusion: 130-260 GeV (expected: 127-234 GeV)

Higgs Search Combination

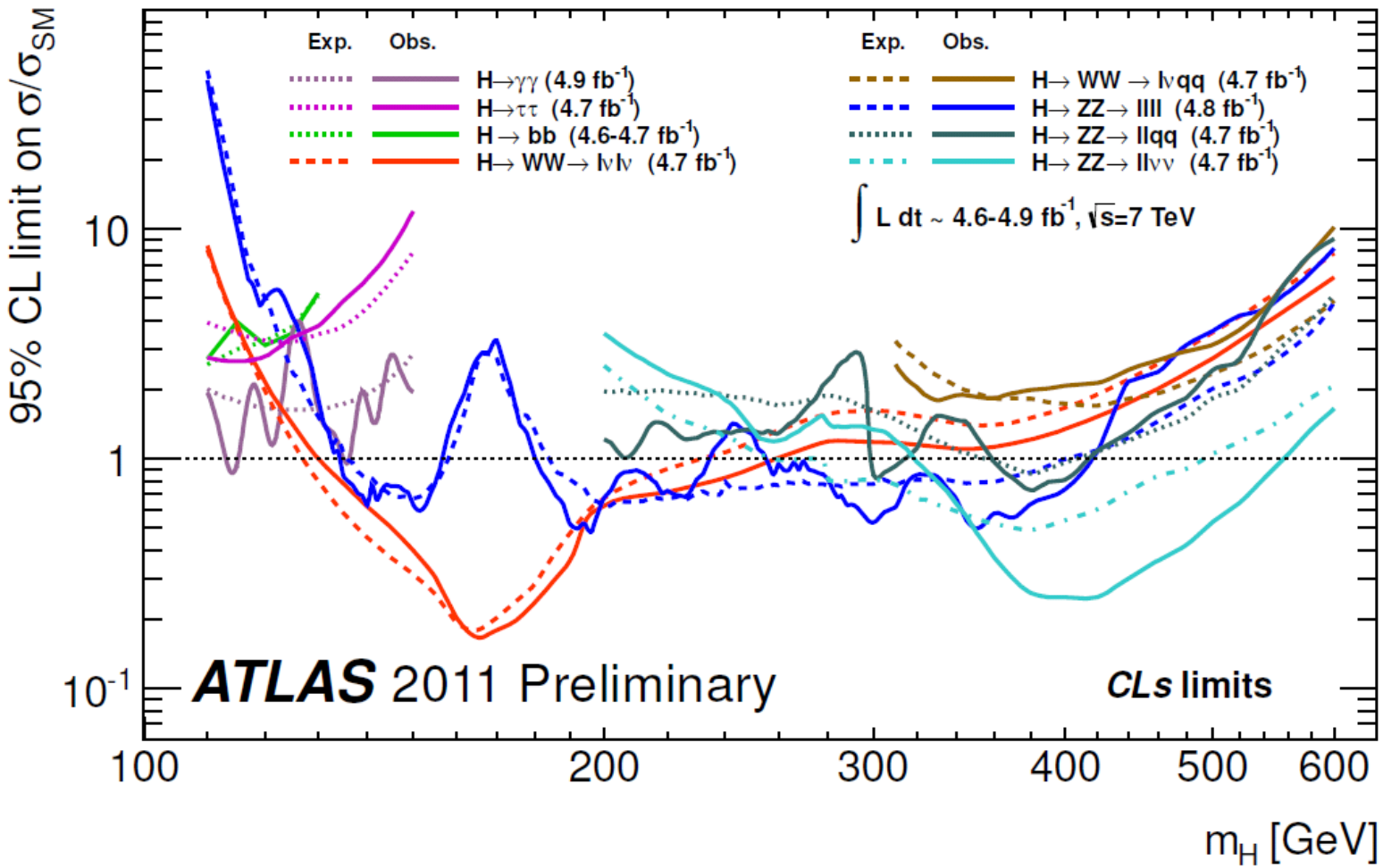
[ATLAS-CONF-2012-019]

Higgs Decay	Subsequent Decay	Additional Sub-Channels	m_H Range	L [fb^{-1}]
$H \to \gamma\gamma$	–	9 sub-channels ($p_{T_t} \otimes \eta_\gamma \otimes$ conversion)	110-150	4.9
$H \to ZZ$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110-600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low pile-up, high pile-up}	200-280-600	4.7
	$\ell\ell q\bar{q}$	{b-tagged, untagged}	200-300-600	4.7
$H \to WW$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes$ {0-jet, 1-jet, VBF}	110-300-600	4.7
	$\ell\nu q\overline{q'}$	$\{e, \mu\} \otimes$ {0-jet, 1-jet}	300-600	4.7
$H \to \tau^+\tau^-$	$\ell\ell 4\nu$	$\{e\mu\} \otimes$ {0-jet} $\oplus$ {1-jet, VBF, VH}	110-150	4.7
	$\ell\tau_{\rm had}3\nu$	$\{e, \mu\} \otimes$ {0-jet} $\otimes$ $\{E_T^{\rm miss} \gtrless 20$ GeV$\}$ $\oplus$ $\{e, \mu\} \otimes$ {1-jet, VBF}	110-150	4.7
	$\tau_{\rm had}\tau_{\rm had}2\nu$	{1-jet}	110-150	4.7
$VH \to b\bar{b}$	$Z \to \nu\bar{\nu}$	$E_T^{\rm miss} \in \{120-160, 160-200, \geq 200$ GeV$\}$	110-130	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7

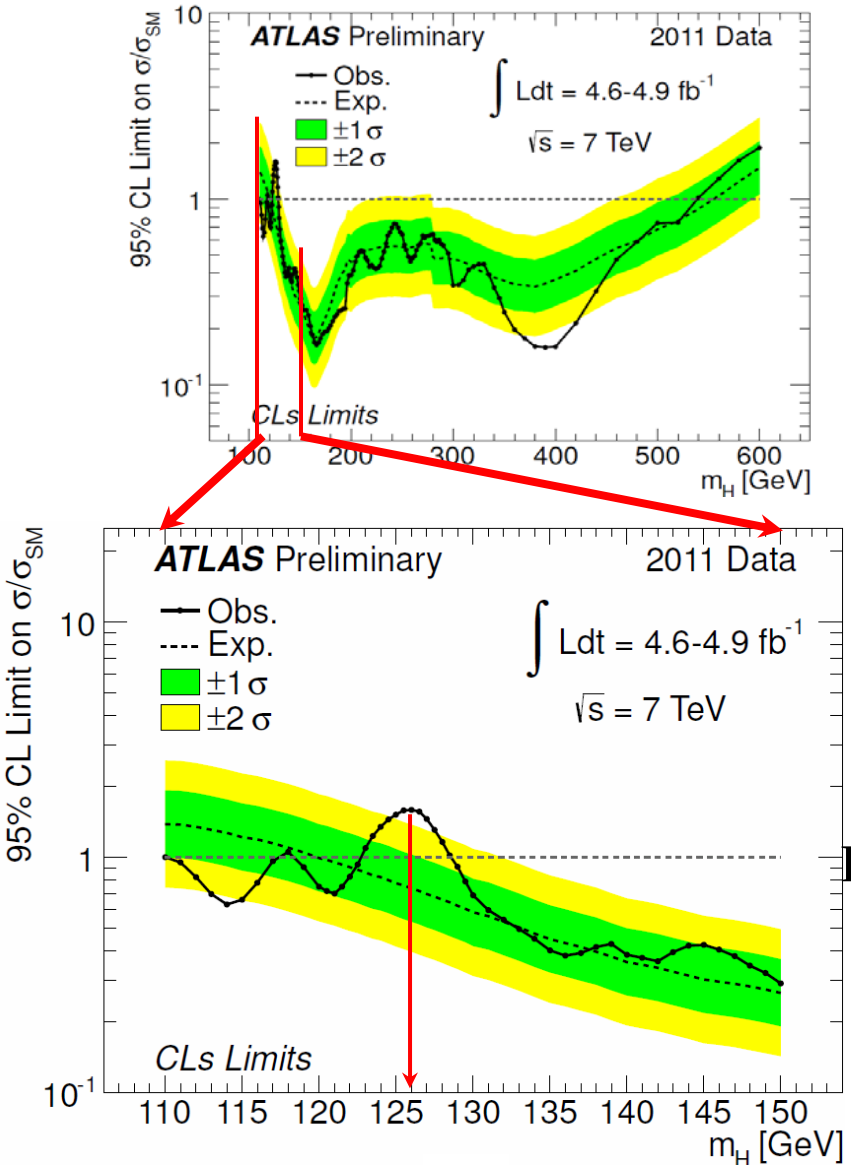
- Covered mass range: 110–600 GeV
- H→γγ and H→ZZ→4ℓ unchanged wrt. last combination [arxiv:1202.1408]
- combined likelihood for m_H < 200 GeV derived from 68 disjoint signal/control regions.

Individual Channel Limits

[ATLAS-CONF-2012-019]



Combination Result



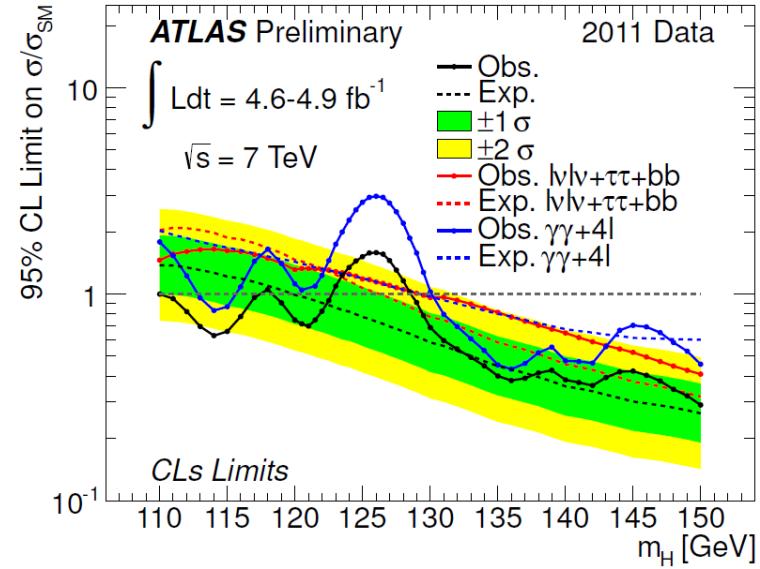
[ATLAS-CONF-2012-019]

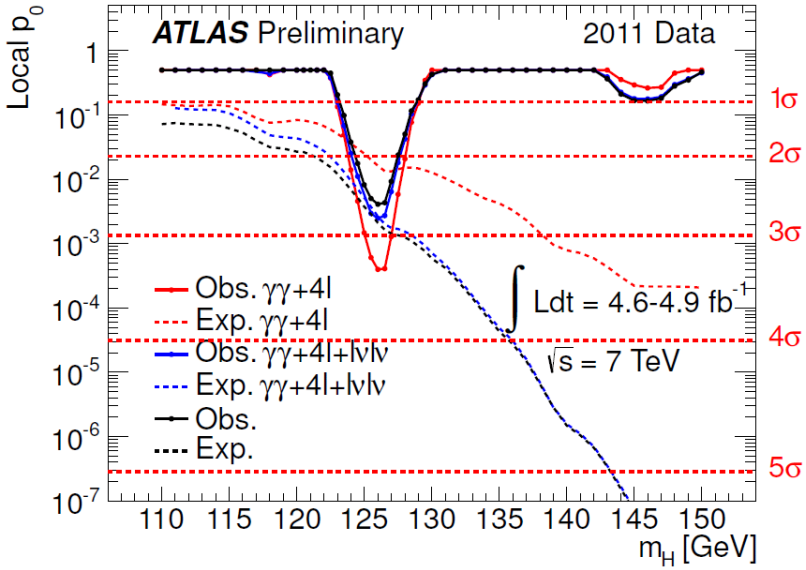
- Expected 95% CL exclusion region:
  - ➢120 GeV < m_H < 555 GeV.
- Observed 95% CL exclusion region:
  - ➢110.0 GeV < m_H < 117.5 GeV,
  - ➢118.5 GeV < m_H < 122.5 GeV,
  - ➢129.0 GeV < m_H < 539.0 GeV.

Largest *excess* observed at m_H = 126 GeV:
2.5 σ **local** significance
(2.9 σ expected for 126 GeV Higgs)

Probability for such an excess from bg fluctuation
anywhere in:
full mass range (110-600 GeV): 30%
99% CL unexcluded (110-146 GeV) range: 10%

Excess Anatomy



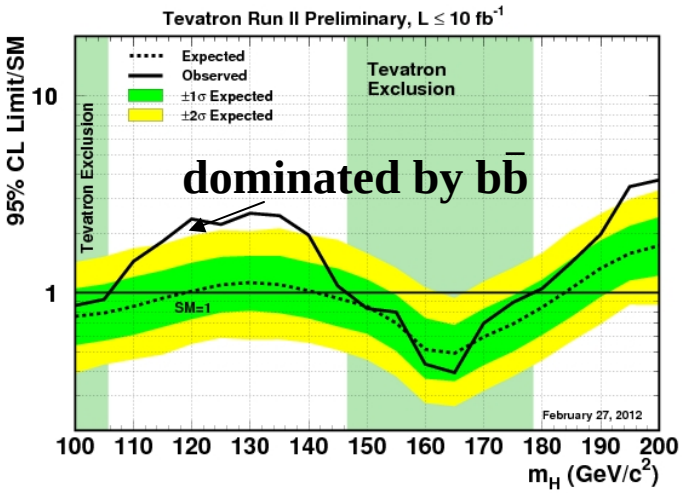


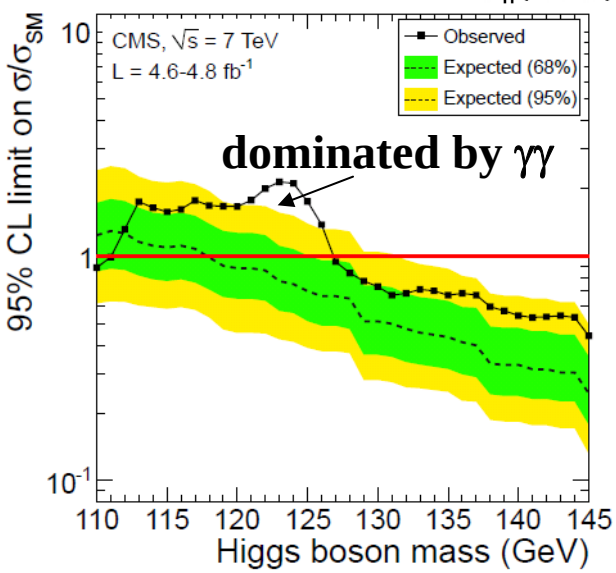
Excess dominated by high mass-resolution channels:
$H\to\gamma\gamma$, $H\to ZZ\to 4\ell$ combined: 3.4 σ local

No significant excess in low-resolution channels:
$H\to\tau\tau$, $H\to b\bar{b}$, $H\to WW\to \ell\nu\ell\nu$,
but: 126 GeV Higgs not excluded by these!

Reduced excess wrt. last December results
mainly due to updated $H\to WW\to \ell\nu\ell\nu$ result
(2/fb analysis showed broad 1.4 σ excess,
combined local significance was 3.6 σ)

More Direct Higgs Searches





- **LEP: m_H > 114.4 GeV (95% CL)**

- **Tevatron [arxiv:1203.3774]:**

Expected exclusion: 100-119 GeV, 141-184 GeV
Observed exclusion: 100-106 GeV, 147-179 GeV
Excess sign. @ 120 GeV: 2.7 σ local, 2.2 σ global

- **CMS [arXiv:1202.1488]:**

Expected exclusion: 118 – 543 GeV
Observed exclusion: 127 – 600 GeV
Excess sign. @ 124 GeV: 3.1 σ local, 1.5 σ global

Conclusions

- **LHC performs superbly**
- **SM continues to prove resilient**
- **Measurement precision catching up with theory**
- **No Higgs found (yet)**