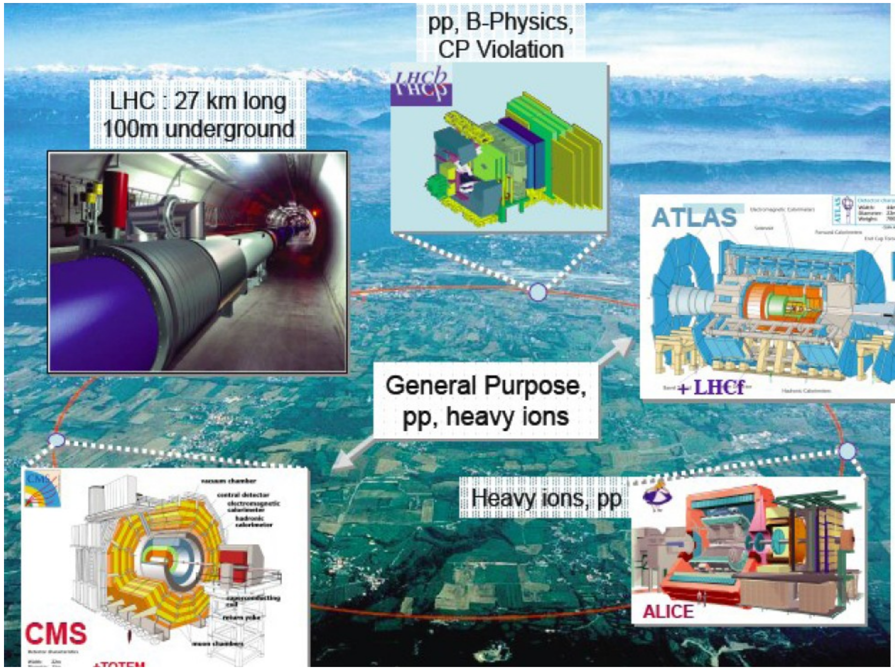
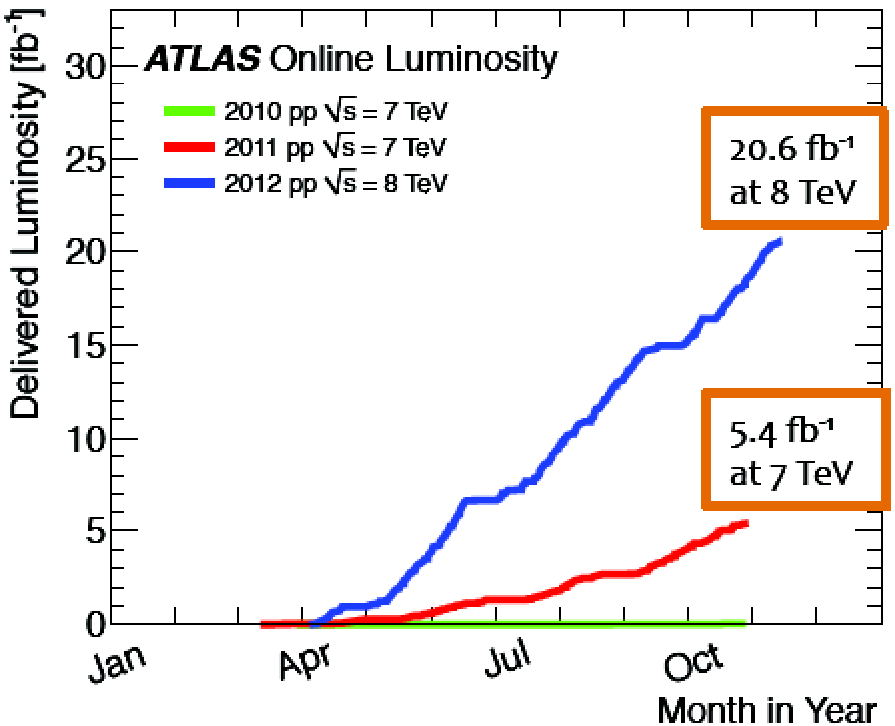
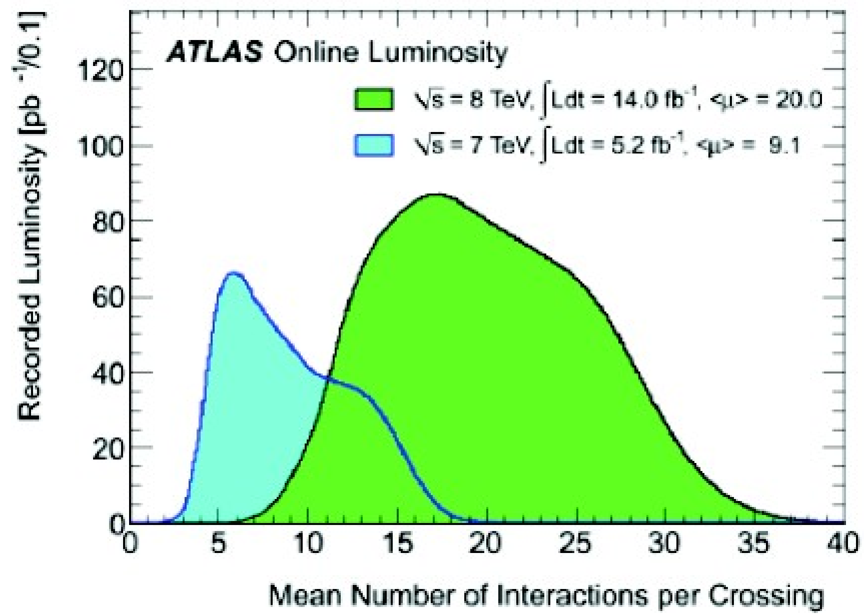
Najnowsze wyniki eksperymentu ATLAS (CERN, LHC) dla 15 fb^{-1}

Living in incredibly exciting time for fundamental partcile physics!

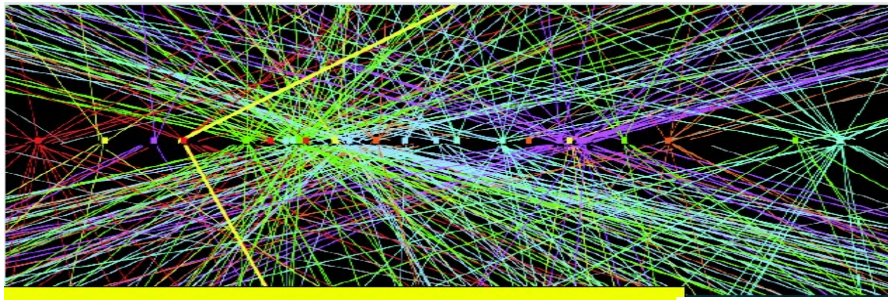


The sucess story so far





Overall Data Taking Efficiency = 93.6%
(recorded vs delivered luminosity during stable beam operation)



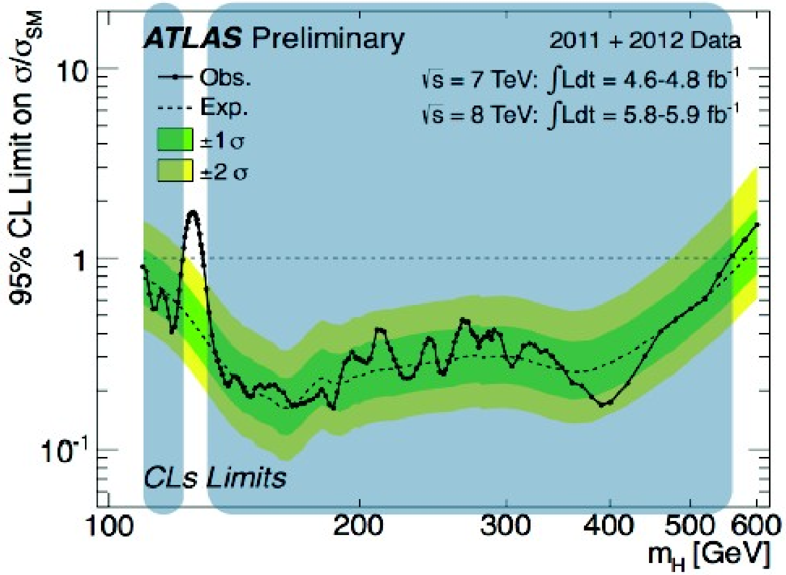
Z→ μμ with 25 reconstructed vertices

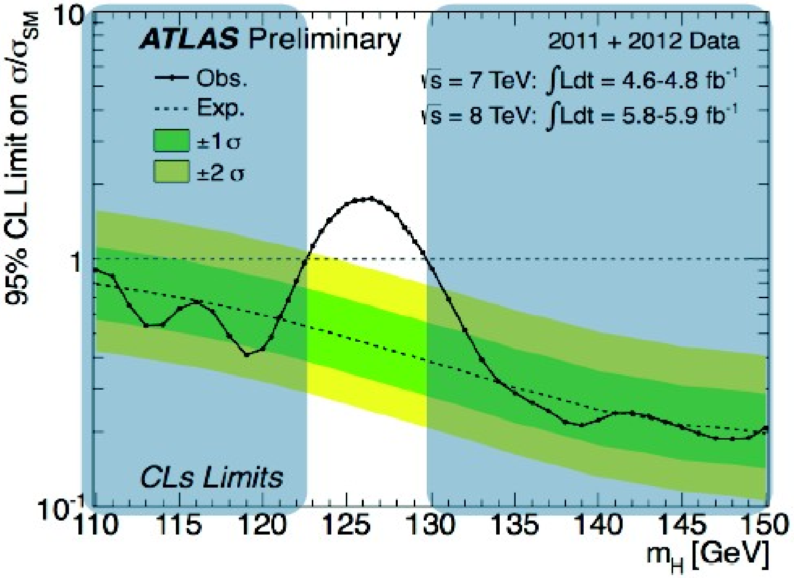
Higgs-like particle: 4-th July

We are living a privileged moment in the history of HEP.

OUR FIRST FUNDAMENTAL SCALAR (?)

The discovery came at half of the design energy, much more several pile-up and one-third of integrated luminosity than was originally judged as necessary.





Definitions:

Global signal strength factor μ:

Scale factor on the total number of events predicted by the SM for the Higgs boson signal:

μ=0 - bgd only hypothesis

μ=1 - SM signal in addition to the bgd

Hypothesised values of μ tested with statistics based on profile likelihood ratio.

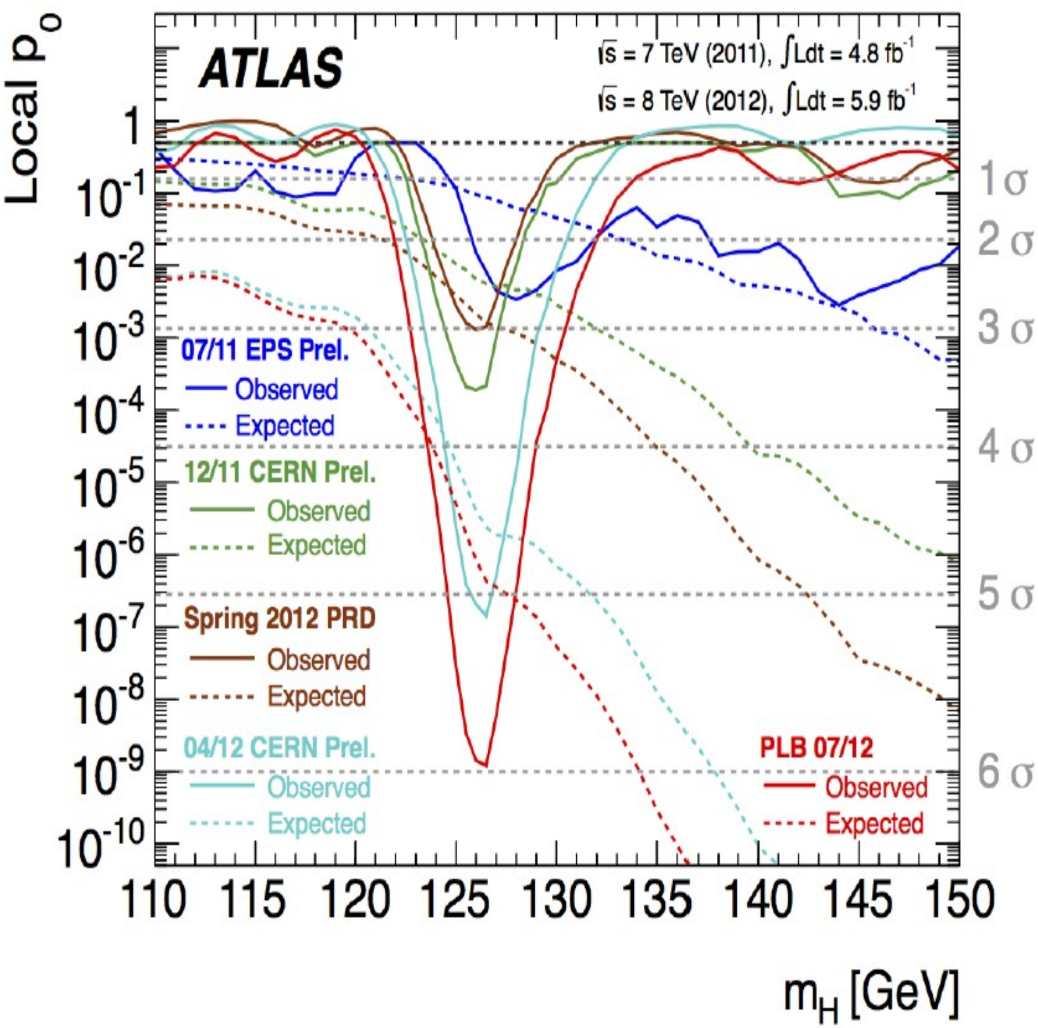
Local p_0:

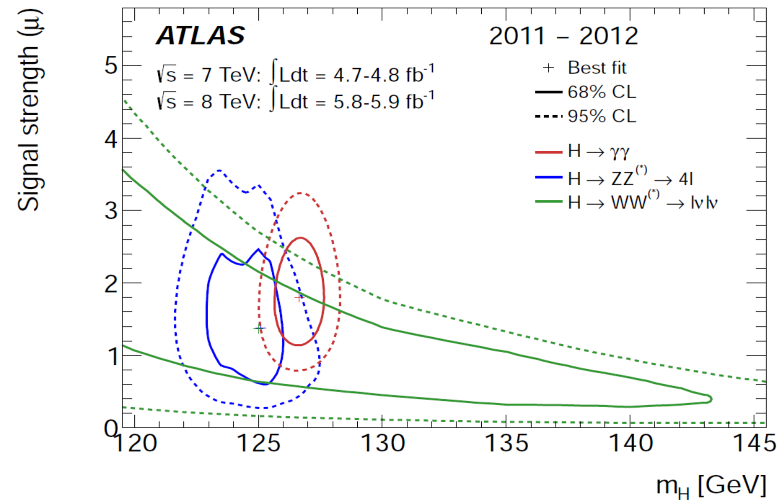
Probability that the background can produce a fluctuation greater than or equal to the excess observed in data. Equivalent in terms of number of standard deviations is called local significance.

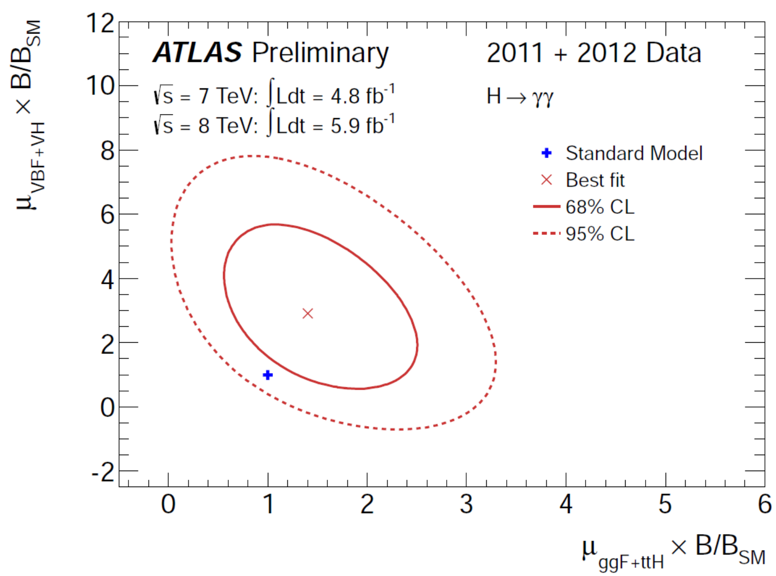
95% CLs exclusion:

Value of μ is regarded as excluded at 95%CL when CLs is less than 5%. A SM Higgs boson with mass m_H is conisdered excluded at 95%CL when μ=1 is exluded at that mass.

Standard Model Higgs







Hadron Collider Physics: 12-16 November

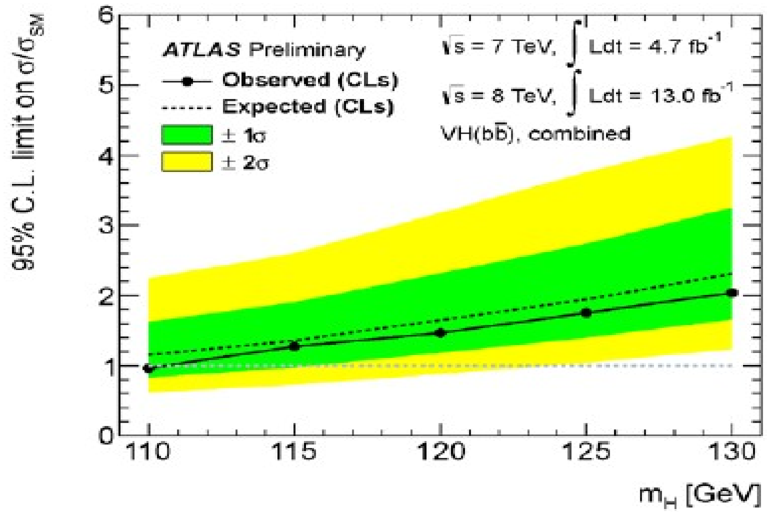
Great collections of new results from LHC and Tevatron exp.

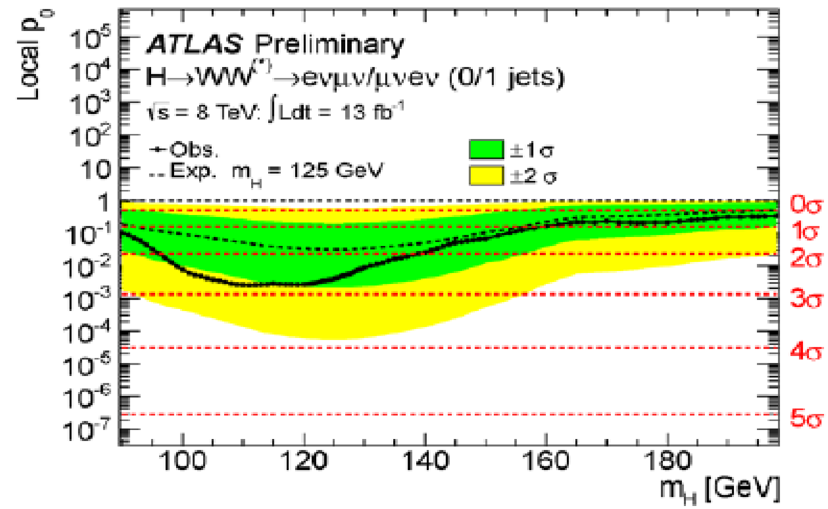
->Updates on direct New Phys. searches.

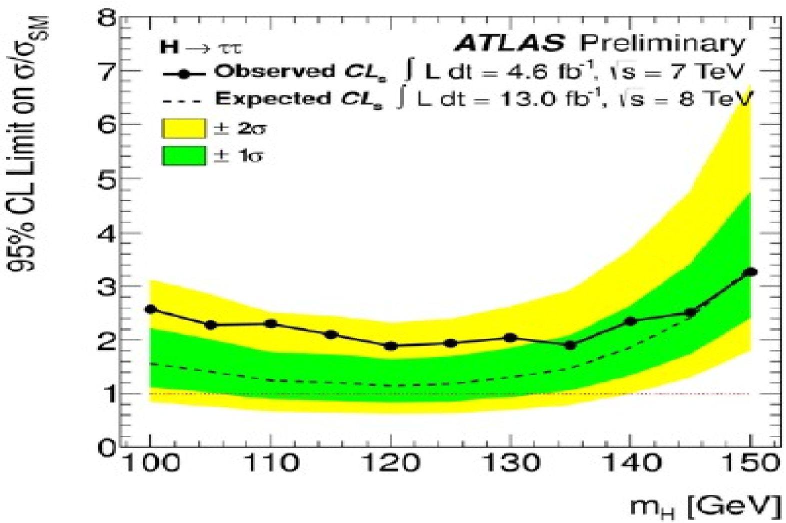
->Precision measurements QCD, W/Z bosons, top physics- indirect New Phys. searches

For the SM Higgs we are entering measurement-based phase.

ATLAS: update on sensitivity with 13fb^{-1}







The **H->ττ and H->bb channels** approaching SM sensitivity, but still compatible with either bgd-only or SM hypothesis.
For **H->WW channel** sensitivity confirmed, significance **~2.6σ**

H->bb: Diboson production

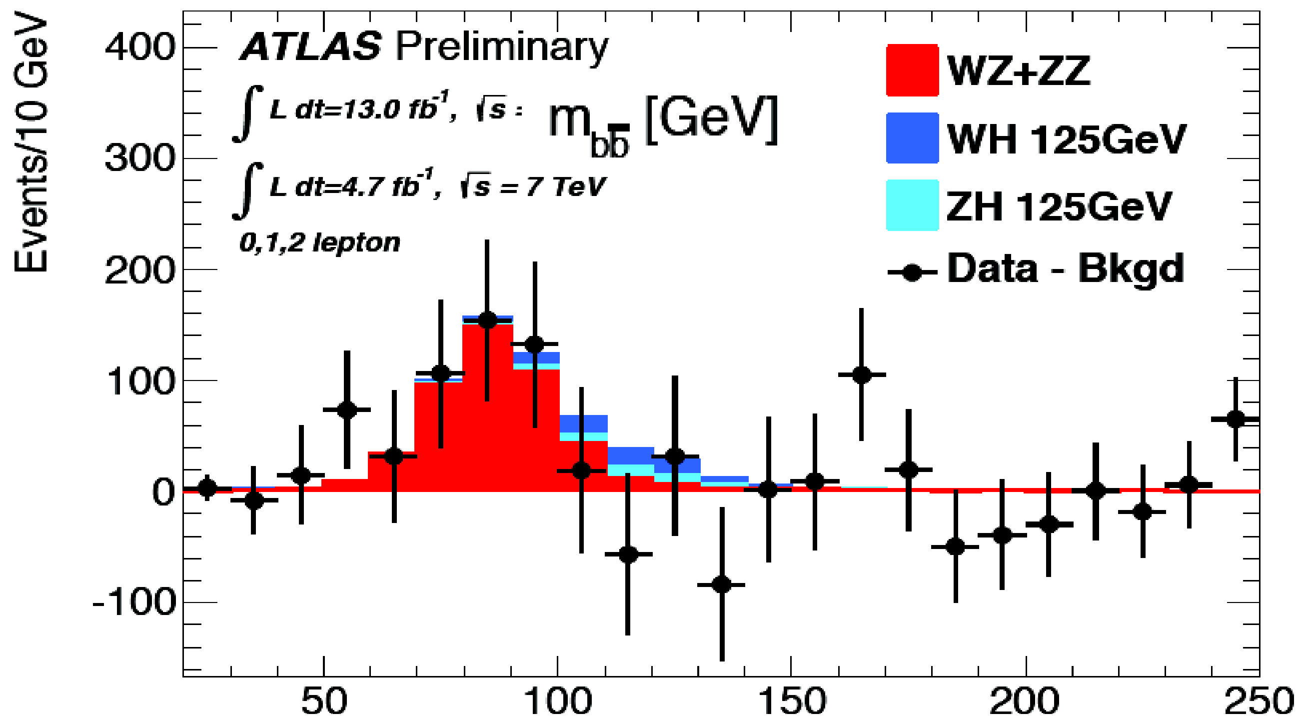
WZ & ZZ production with $Z \rightarrow b\bar{b}$ similar signature, but 5 times larger cross-section

Perform a separate fit to search for it and to validate the analysis procedure

- Profile likelihood fit performed (with full systematics)
- All backgrounds (except diboson) subtracted
- Uses full $p_T^{W,Z}$ range, done individually for each channel & year (see backup)

Clear excess is observed in data at expected mass (all lepton channels combined)

Results: $\sigma/\sigma_{SM} = \mu_D = 1.09 \pm 0.20$ (stat) ± 0.22 (syst). The significance is 4.0σ



ATLAS: update on combination

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\, dt$ [fb^{-1}]
		2011 $\sqrt{s}$ =7 TeV	
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	4.8
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	4.8
$H \to \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet, boosted}, VH\}$	4.7
	$\tau_{lep}\tau_{had}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet, boosted, 2-jet}\}$	4.7
	$\tau_{had}\tau_{had}$	$\{\text{boosted, 2-jet}\}$	4.7
$VH \to Vbb$	$Z \to \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200\text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	4.7

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\, dt$ [fb^{-1}]
		2012 $\sqrt{s}$ =8 TeV	
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	5.8
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	5.9
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{\text{0-jet, 1-jet}\}$	13
$H \to \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{\ell\ell\} \otimes \{\text{1-jet, 2-jet, boosted}, VH\}$	13
	$\tau_{lep}\tau_{had}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet, boosted, 2-jet}\}$	13
	$\tau_{had}\tau_{had}$	$\{\text{boosted, 2-jet}\}$	13
$VH \to Vbb$	$Z \to \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200\text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	13
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	13
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-150, 150-200, \geq 200\text{ GeV}\}$	13

Channels entering HCP combination

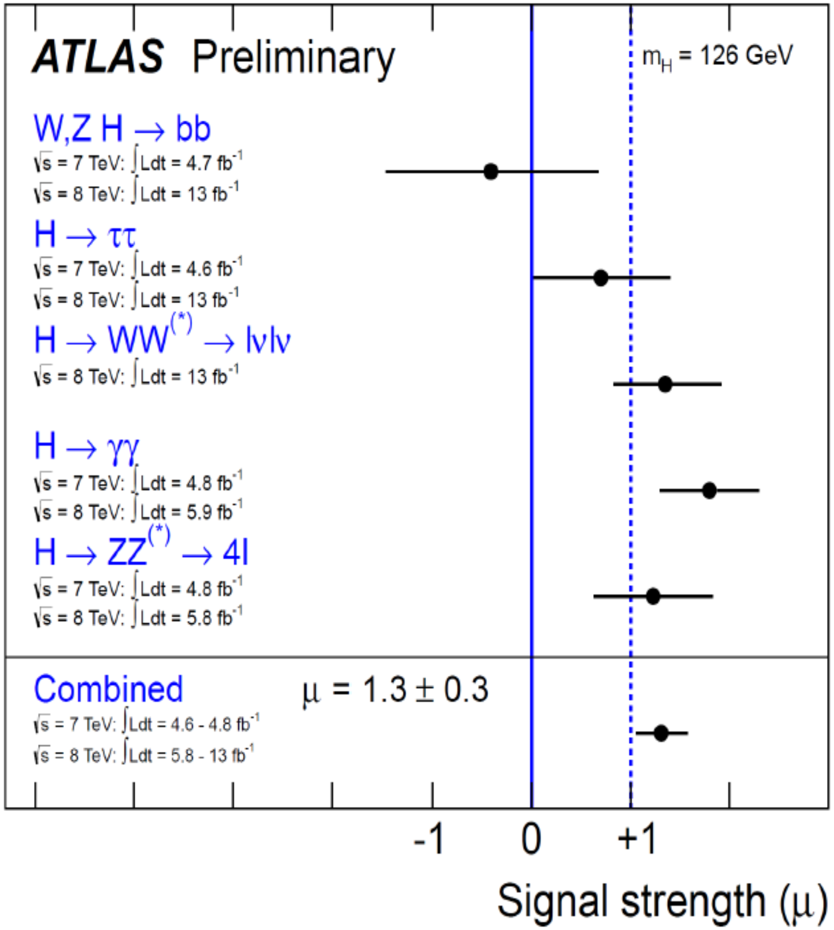
Best–fit Higgs mass m_H :

126.0 ± 0.4 (stat) ± 0.4 (syst) GeV

Best-fit signal strength:

$\mu = 1.3 \pm 0.3$

Couplings measurement not updated for HCP: uncertainies of 20-30%



Higgs couplings workshop

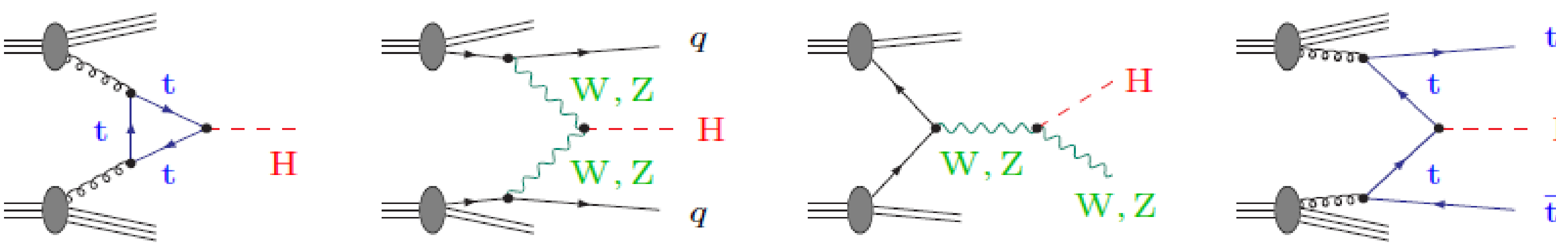
- mass
- spin and parity (J^P)
- CP (even, odd, or admixture?)
- couplings to vector bosons: is this boson related to EWSB, and how much does it contribute to restoring unitarity in $W_L W_L$ scattering
- couplings to fermions
  - is Yukawa interaction at work?
  - contribution to restoring unitarity?
- couplings proportional to mass ?
- is there only one such state, or more?
- elementary or composite?
- self-interaction

Higgs production and decay at LHC

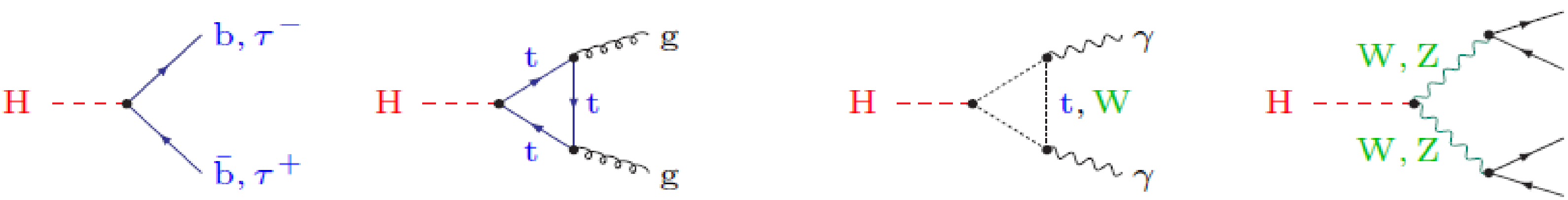
Higgs bosons couple proportional to particle masses:

⇒ Higgs production via couplings to W/Z bosons or top-quarks

Production at hadron colliders ($p\bar{p}/pp$):

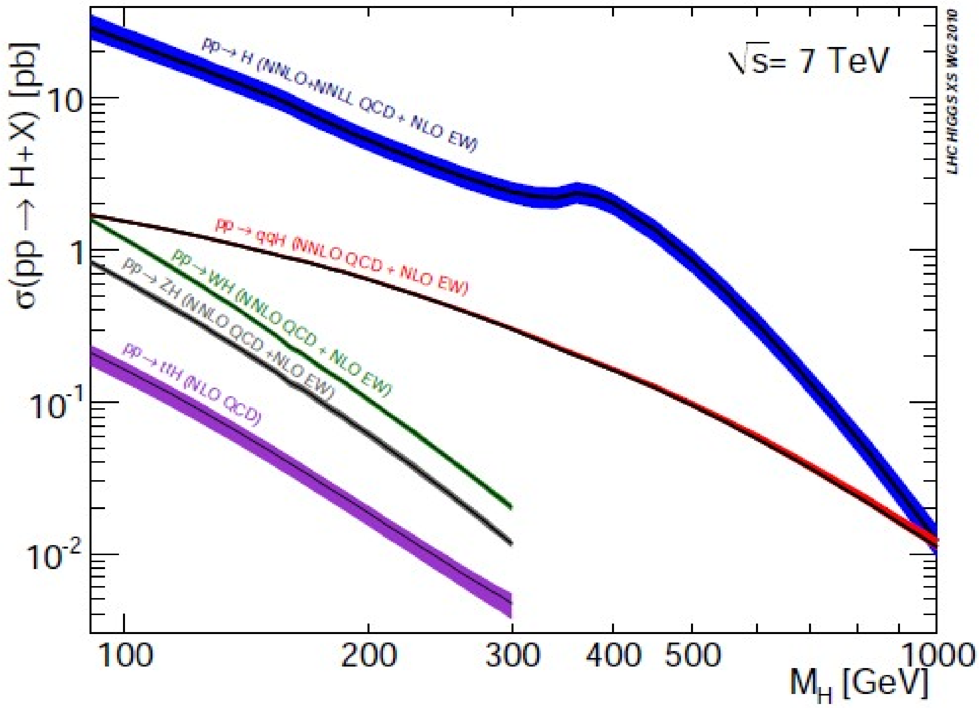


Decay channels for Higgs bosons of moderate mass ($M_H \lesssim 300\,\mathrm{GeV}$):



Higgs production and decay at LHC

SM Higgs XS predictions
for the LHC at $\sqrt{s} = 7\,\mathrm{TeV}$
LHC Higgs XS WG 2010



Rough numbers:

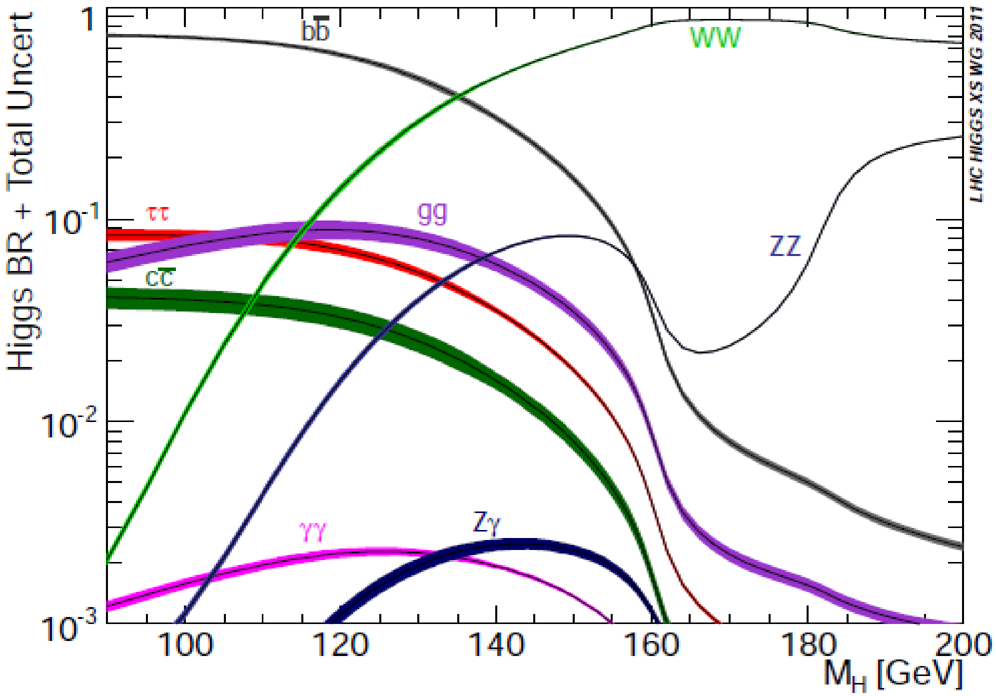
	M_{H}	Uncertainties scale	Uncertainties PDF4LHC	NLO/NNLO/NNLO+ QCD	EW
ggF	$< 500\,\mathrm{GeV}$	6–10%	8–10%	>100%	5%
VBF	$< 500\,\mathrm{GeV}$	1%	2–7%	5%	5%
WH	$< 200\,\mathrm{GeV}$	1%	3–4%	30%	5–10%
ZH	$< 200\,\mathrm{GeV}$	1–2%	3–4%	40%	5%
ttH	$< 200\,\mathrm{GeV}$	10%	9%	5%	?

EW corrections
$\sim \mathcal{O}$(uncertainties)

Higgs production and decay at LHC

BRs of the SM Higgs boson

LHC Higgs XS WG 2011



Parametric + theoretical uncertainty:

M_H[GeV] H $\to$	$b\bar{b}$	$\tau^+\tau^-$	$c\bar{c}$	gg	$\gamma\gamma$	WW	ZZ
120	3%	6%	12%	10%	5%	5%	5%
150	4%	3%	10%	8%	2%	1%	1%
200	5%	3%	10%	8%	2%	< 0.1%	< 0.1%

$\leftarrow$ driven by δm_b via $\Gamma_{H\to b\bar{b}}$

EW corrections significant in predictions for $\Gamma_{H\to X}$ and $BR_{H\to X}$

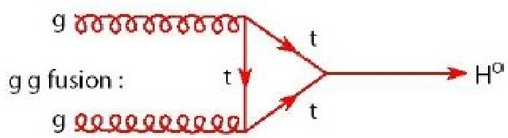
Higgs production and decay at LHC

For each coupling g_i, measure strength in "units" of SM value: $\kappa_i = g_i/g_{i,SM}$

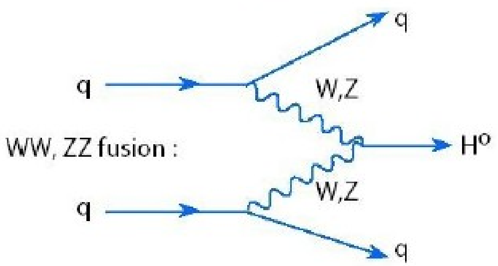
- Defined in analogy to signal strength $\mu = \sigma/\sigma_{SM}$

Production rate is proportional to squared coupling, g^2

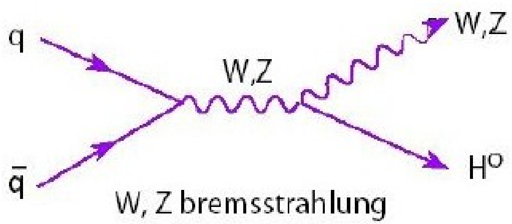
- Scaled each production mode *i* by factor κ_i^2



$\sim \kappa_g^2 \sim \kappa_t^2$ (loop coupling for gluons)



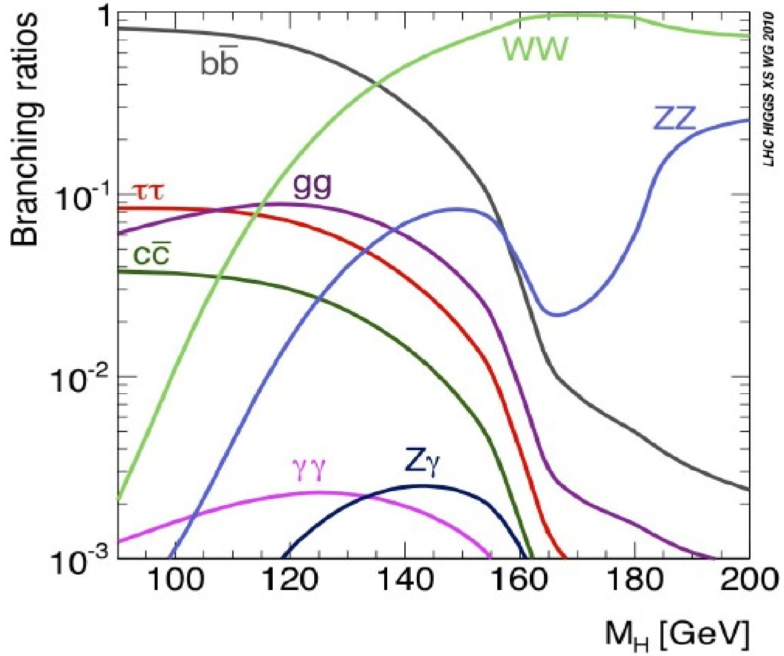
$\sim \kappa_{W,Z}^2$ (tree-level couplings)

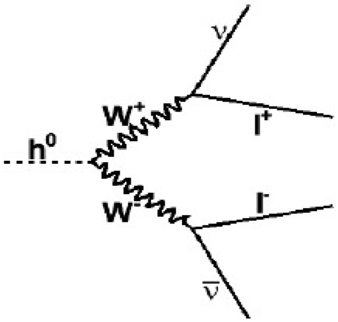


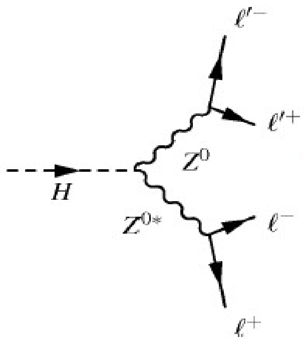
$\sim \kappa_{W,Z}^2$

Higgs production and decay at LHC

- Scaled each decay mode *j* by factor $\kappa_j^2 = g_j^2/g_{j,SM}^2$

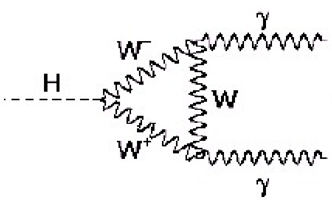


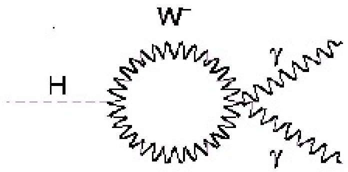


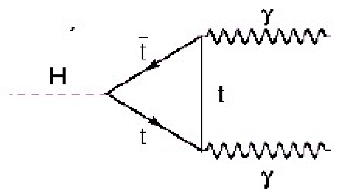


$\sim \kappa_{W,Z}^2$

(tree-level couplings)







$\sim \kappa_\gamma^2 = |1.28\ \kappa_W - 0.28\ \kappa_t|^2$

(loop coupling for photons)

- Example:

$$(\sigma \cdot BR)(gg \to H \to \gamma\gamma) = \sigma_{SM}(gg \to H) \cdot BR_{SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

HIGGS landscape

Higgs-landscape: asking the right questions takes as much skill as giving the right answers

Probing up-type and down-type fermion symmetry assuming no invisible or undetectable widths

Free parameters: $\kappa_V (= \kappa_Z = \kappa_W)$, $\lambda_{du} (= \kappa_d / \kappa_u)$, $\kappa_u (= \kappa_t)$.

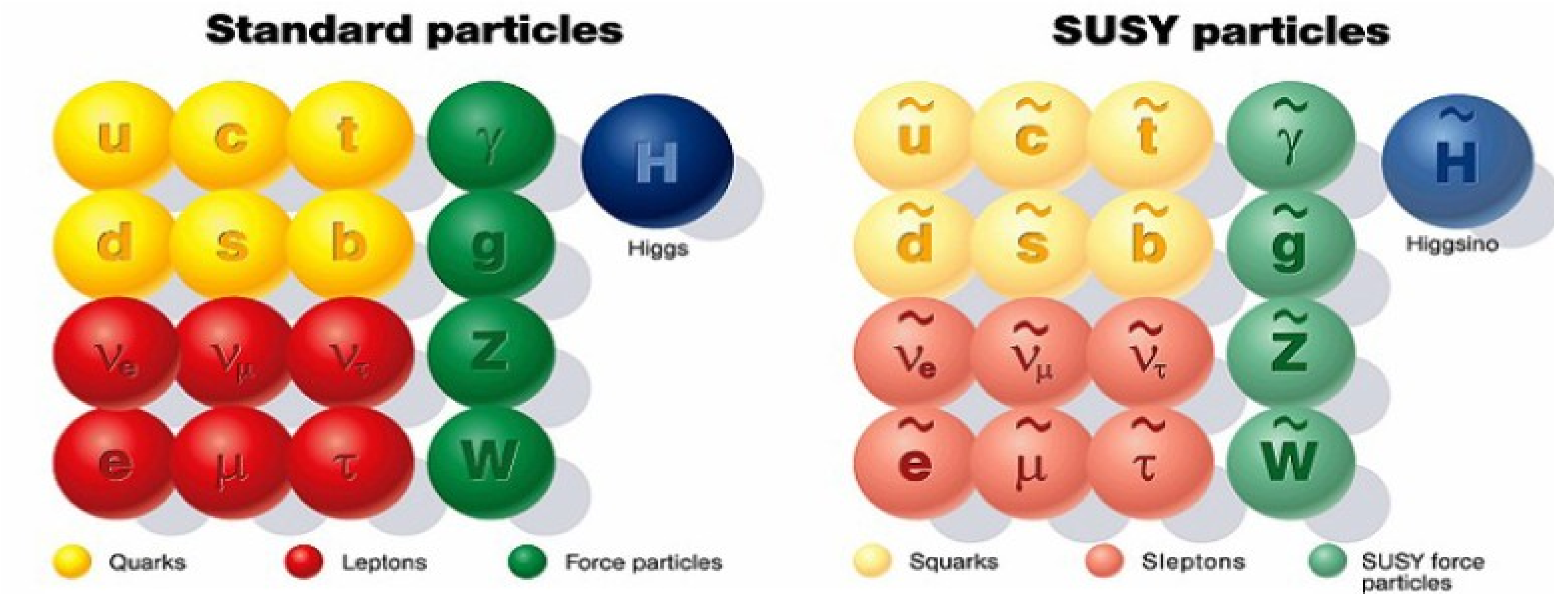
	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH	$\frac{\kappa_g^2(\kappa_u\lambda_{du}, \kappa_u) \cdot \kappa_\gamma^2(\kappa_u\lambda_{du}, \kappa_u, \kappa_u\lambda_{du}, \kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_g^2(\kappa_u\lambda_{du}, \kappa_u) \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_g^2(\kappa_u\lambda_{du}, \kappa_u) \cdot (\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	
$t\bar{t}H$	$\frac{\kappa_u^2 \cdot \kappa_\gamma^2(\kappa_u\lambda_{du}, \kappa_u, \kappa_u\lambda_{du}, \kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_u^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_u^2 \cdot (\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_\gamma^2(\kappa_u\lambda_{du}, \kappa_u, \kappa_u\lambda_{du}, \kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2 \cdot (\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	

Probing up-type and down-type fermion symmetry without assumptions on the total width

Free parameters: $\kappa_{uu} (= \kappa_u \cdot \kappa_u / \kappa_H)$, $\lambda_{du} (= \kappa_d / \kappa_u)$, $\lambda_{Vu} (= \kappa_V / \kappa_u)$.

	$H \to \gamma\gamma$	$H \to ZZ^{(*)}$	$H \to WW^{(*)}$	$H \to b\bar{b}$	$H \to \tau^-\tau^+$
ggH	$\kappa_{uu}^2 \kappa_g^2(\lambda_{du}, 1) \cdot \kappa_\gamma^2(\lambda_{du}, 1, \lambda_{du}, \lambda_{Vu})$	$\kappa_{uu}^2 \kappa_g^2(\lambda_{du}, 1) \cdot \lambda_{Vu}^2$		$\kappa_{uu}^2 \kappa_g^2(\lambda_{du}, 1) \cdot \lambda_{du}^2$	
$t\bar{t}H$	$\kappa_{uu}^2 \cdot \kappa_\gamma^2(\lambda_{du}, 1, \lambda_{du}, \lambda_{Vu})$	$\kappa_{uu}^2 \cdot \lambda_{Vu}^2$		$\kappa_{uu}^2 \cdot \lambda_{du}^2$	
VBF WH ZH	$\kappa_{uu}^2 \lambda_{Vu}^2 \cdot \kappa_\gamma^2(\lambda_{du}, 1, \lambda_{du}, \lambda_{Vu})$	$\kappa_{uu}^2 \lambda_{Vu}^2 \cdot \lambda_{Vu}^2$		$\kappa_{uu}^2 \lambda_{Vu}^2 \cdot \lambda_{du}^2$	

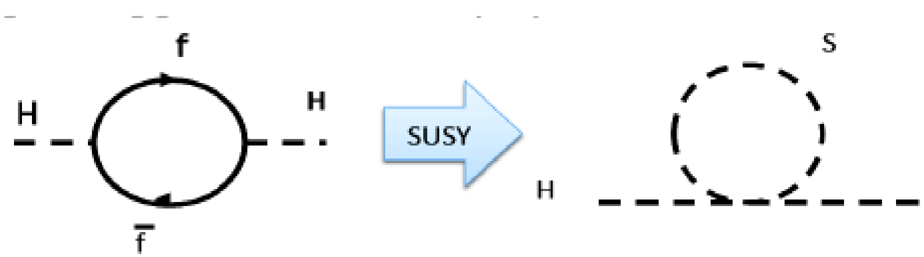
SUSY



Supersymmetry common in many SM extensions

Strong motivation for TeV-scale SUSY:

- Stabilize a light Higgs mass
- Dark-matter candidate
- Gauge coupling unification

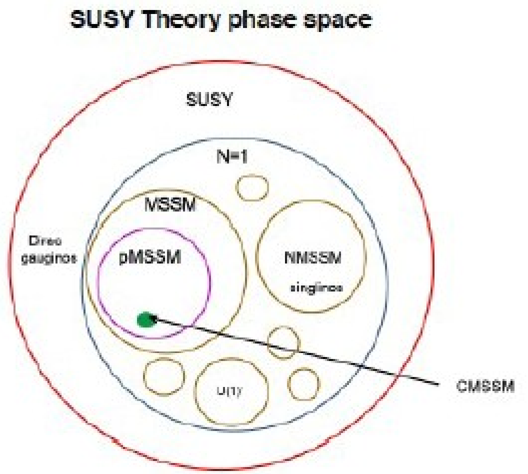


SUSY

SUSY is not just one model

Many possible variations

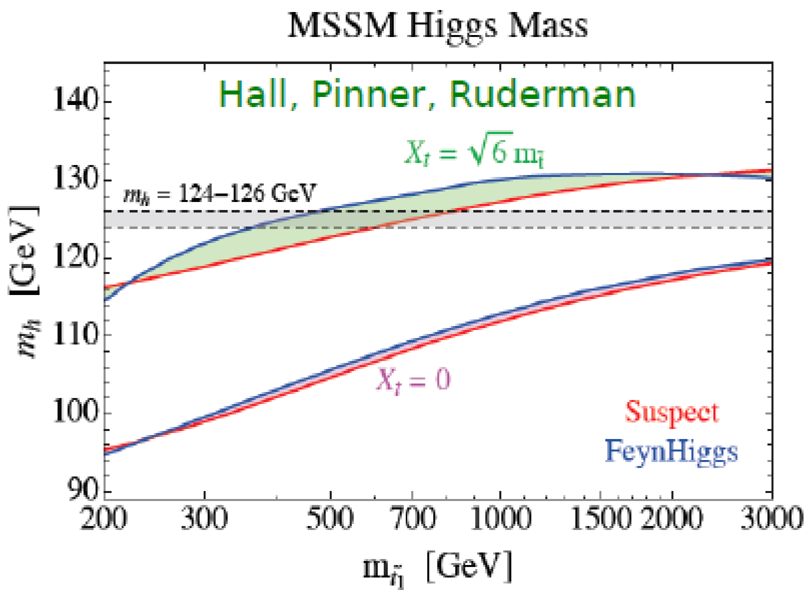
- SUSY breaking mechanism
  gravity-, gauge-, anomaly-mediated, …
- Beyond MSSM
- R-parity = $(-1)^{2S}(-1)^{3B+L}$ conserved?
  If not, lifetime of lightest sparticle



No signs of SUSY yet

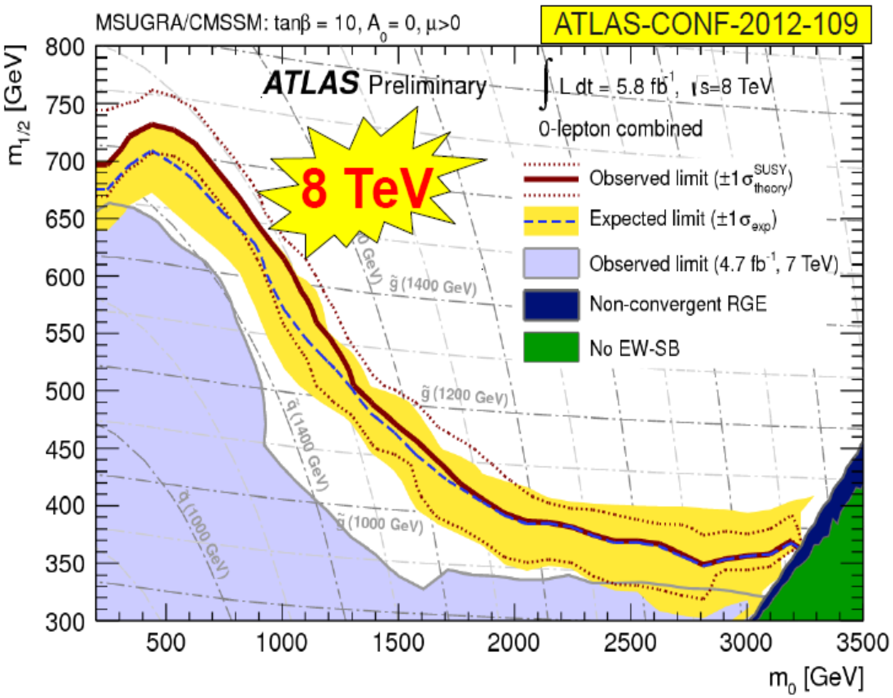
Allowed phase space is getting squeezed

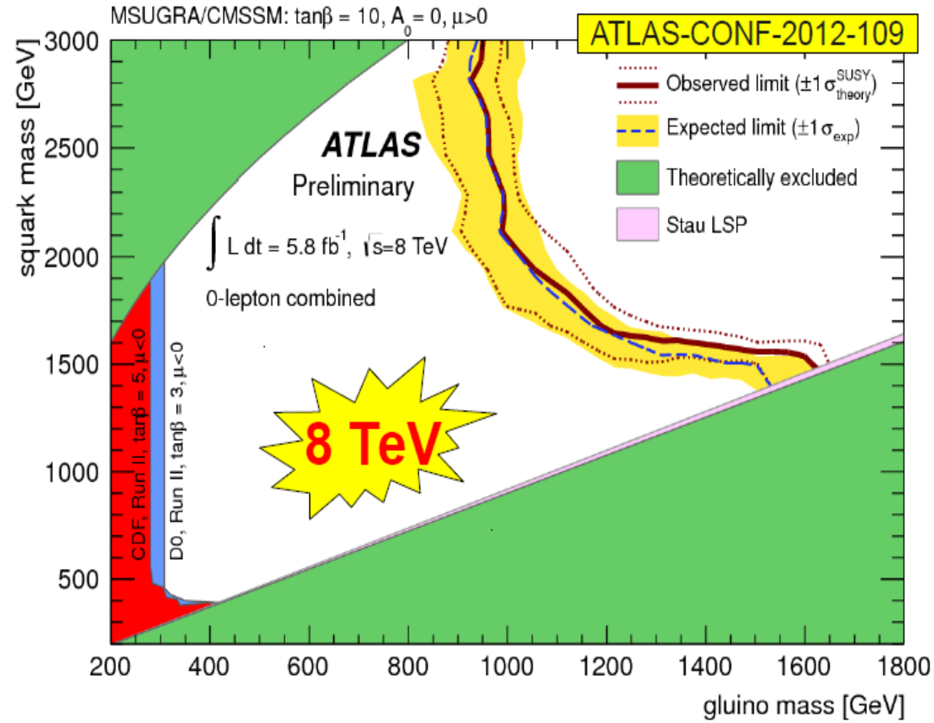
- Flavor physics remains in good agreement with SM
- Light Higgs-like boson discovered,
  but at high end of (MSSM) preference



- Either large stop mixing
- Very heavy squarks
- Or beyond MSSM

SUSY





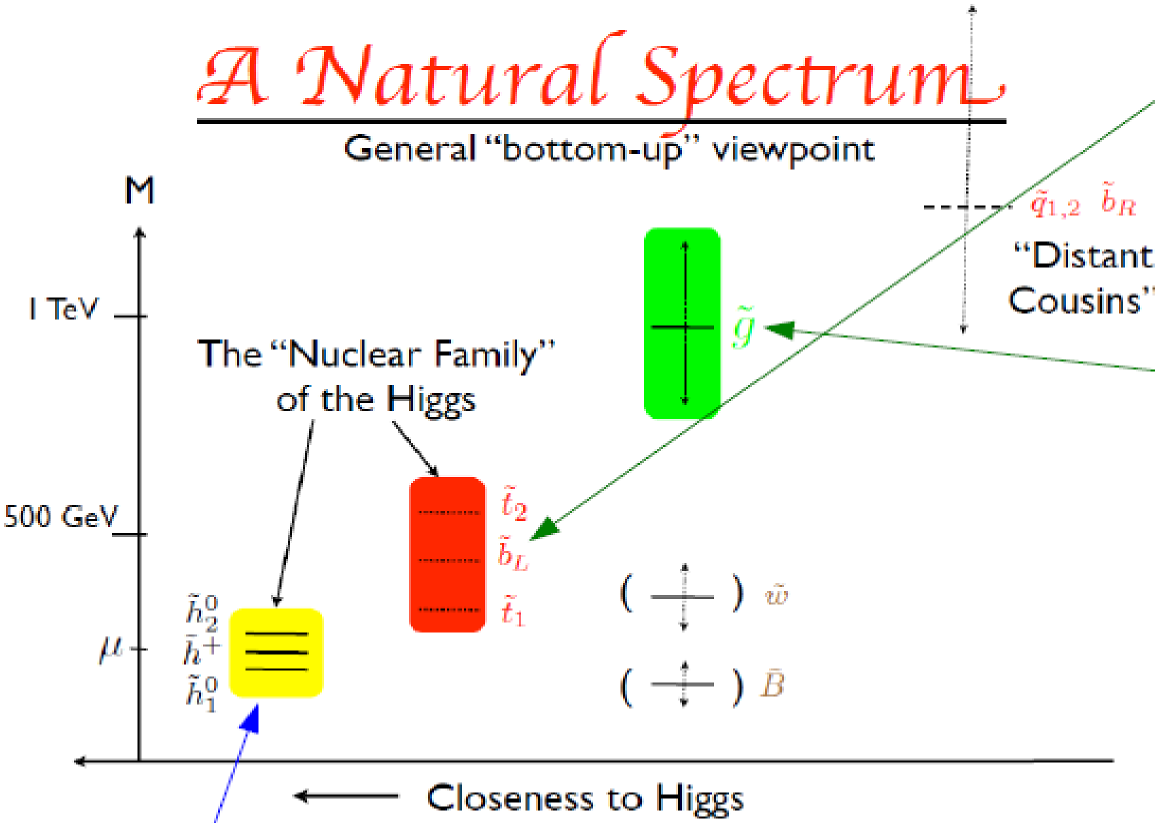
$m_{\tilde{q}} \gtrsim 1400$ TeV,

$m_{\tilde{g}} \gtrsim 900$ TeV OR

$m_{\tilde{q}} \sim m_{\tilde{g}} \gtrsim 1400$ TeV

SUSY

Inclusive searches constrain 1st/2nd generation squarks and gluinos to be $\gtrsim$ TeV, unless χ^0_1 is heavy



Only light stop needed to regularize light Higgs boson

The gluino should not be too heavy either

Light as μ~m_Z at tree level

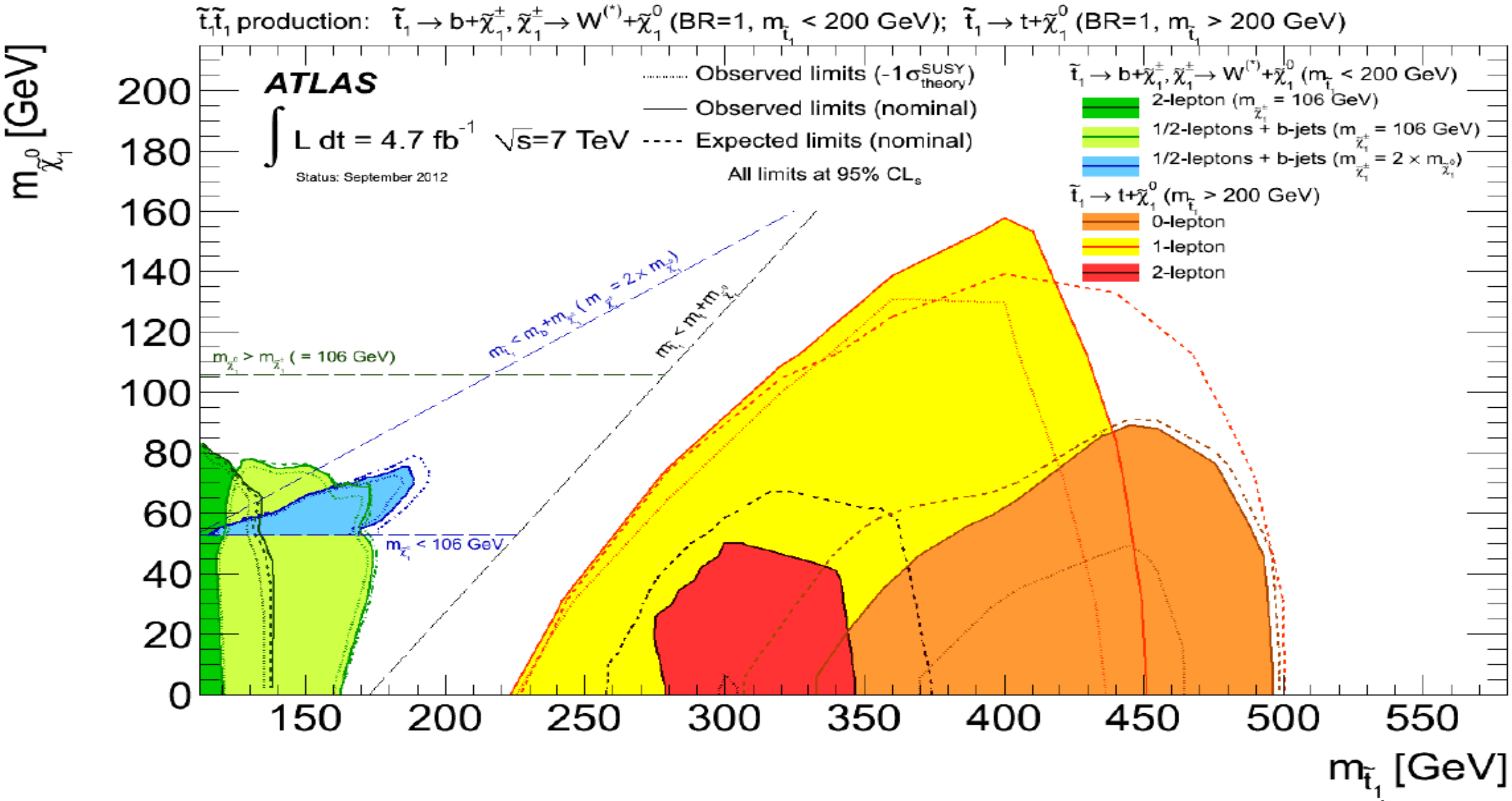
New search frontier

- Search for stop and sbottom
- Direct production or through gluino pairs

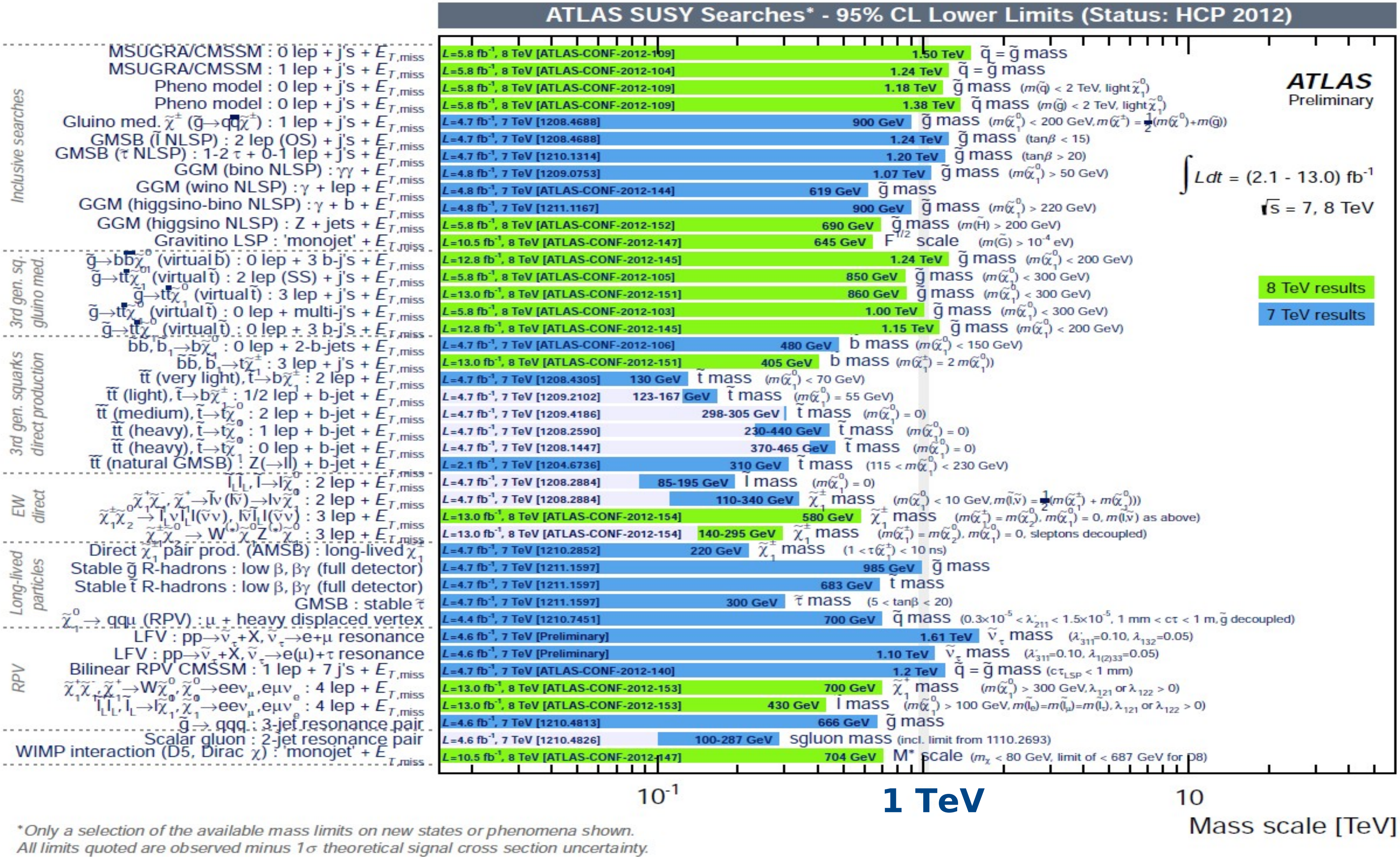
SUSY

Multiple dedicated searches
Target different stop mass & decay

- High stop mass, $\tilde{t}_1 \to t\tilde{\chi}^0_1$
- $m(\tilde{t}_1) \sim m(t)$
- Light stop, $\tilde{t}_1 \to b\tilde{\chi}^\pm_1$

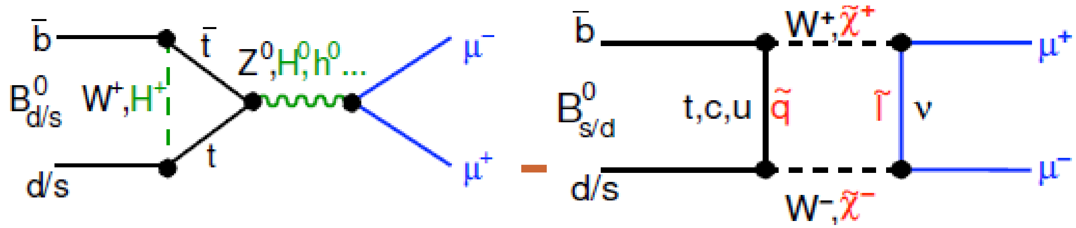


SUSY



ATLAS SUSY Searches* - 95% CL Lower Limits (Status: HCP 2012)
ATLAS
Preliminary
8 TeV results
7 TeV results
1 TeV
Mass scale [TeV]
Inclusive searches
3rd gen. sq. gluino med.
3rd gen. squarks direct production
EW direct
Long-lived particles
RPV
*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Rare decays



First observation of $B_s^0 \to \mu^+\mu^-$ LHCb-PAPER-2012-043

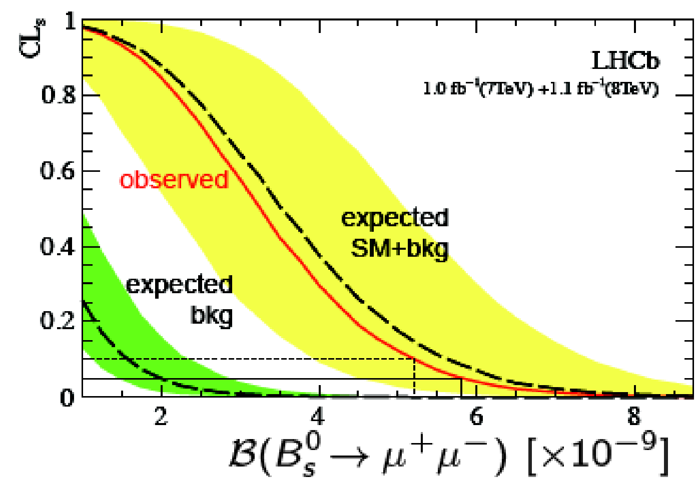
- In $1\,\text{fb}^{-1}$ ($\sqrt{s} = 7\,\text{TeV}$) + $1.1\,\text{fb}^{-1}$ ($\sqrt{s} = 8\,\text{TeV}$) of data, LHCb observes a signal for $B_s^0 \to \mu^+\mu^-$ that is **incompatible with the background only hypothesis at 3.5 σ.** With:

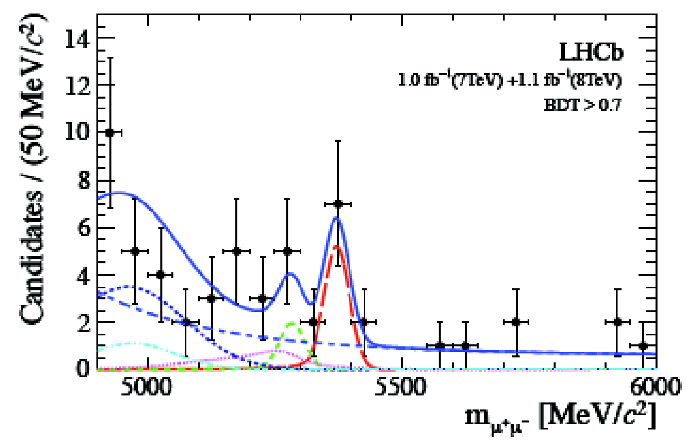
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 3.2\,^{+1.5}_{-1.2} \times 10^{-9}$$

c.f. a time integrated SM expectation of:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.54 \pm 0.30) \times 10^{-9}$$

[arXiv:1208.0934], [arXiv:1204.1735]





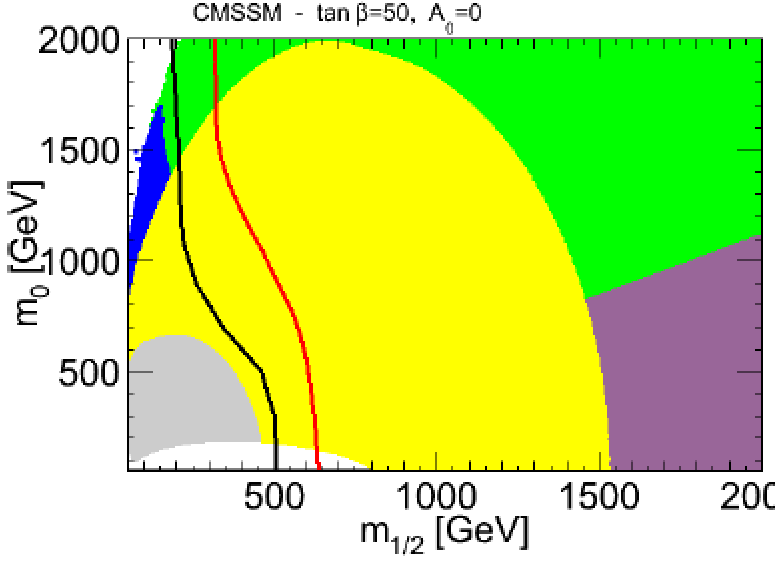
Constraints in CMSSM model

In general a SM-like $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ rules out CMSSM points with large $\tan\beta$.

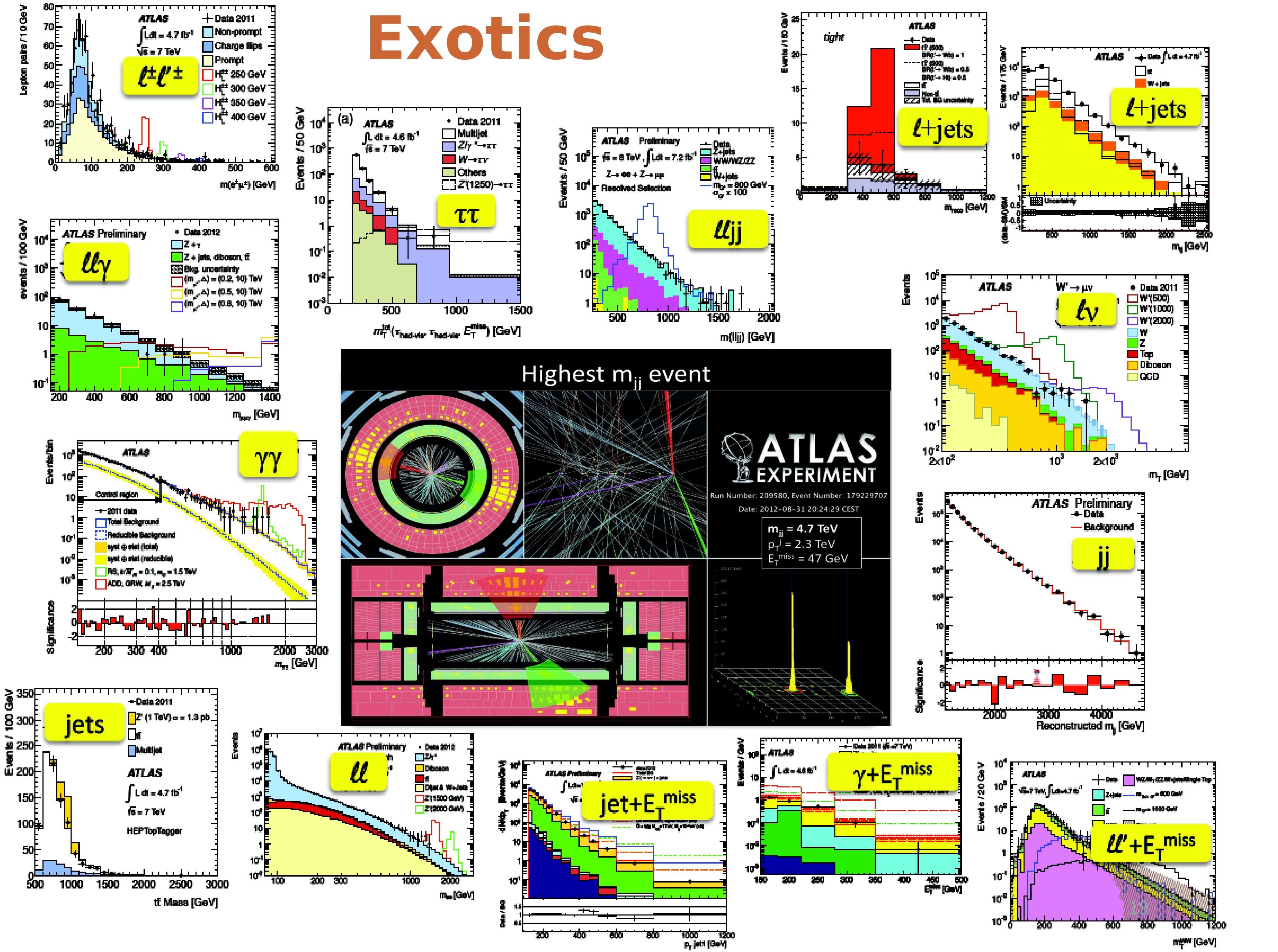
Direct search results (CMS $5\,\mathrm{fb}^{-1}$), Charged LSP, $B \to \tau\nu$, $B_s^0 \to \mu^+\mu^-$, Allowed region.

At lower tanβ the relative importance of direct searches increases.

F. Mahmoudi et. al. [arXiv:1205.1845]

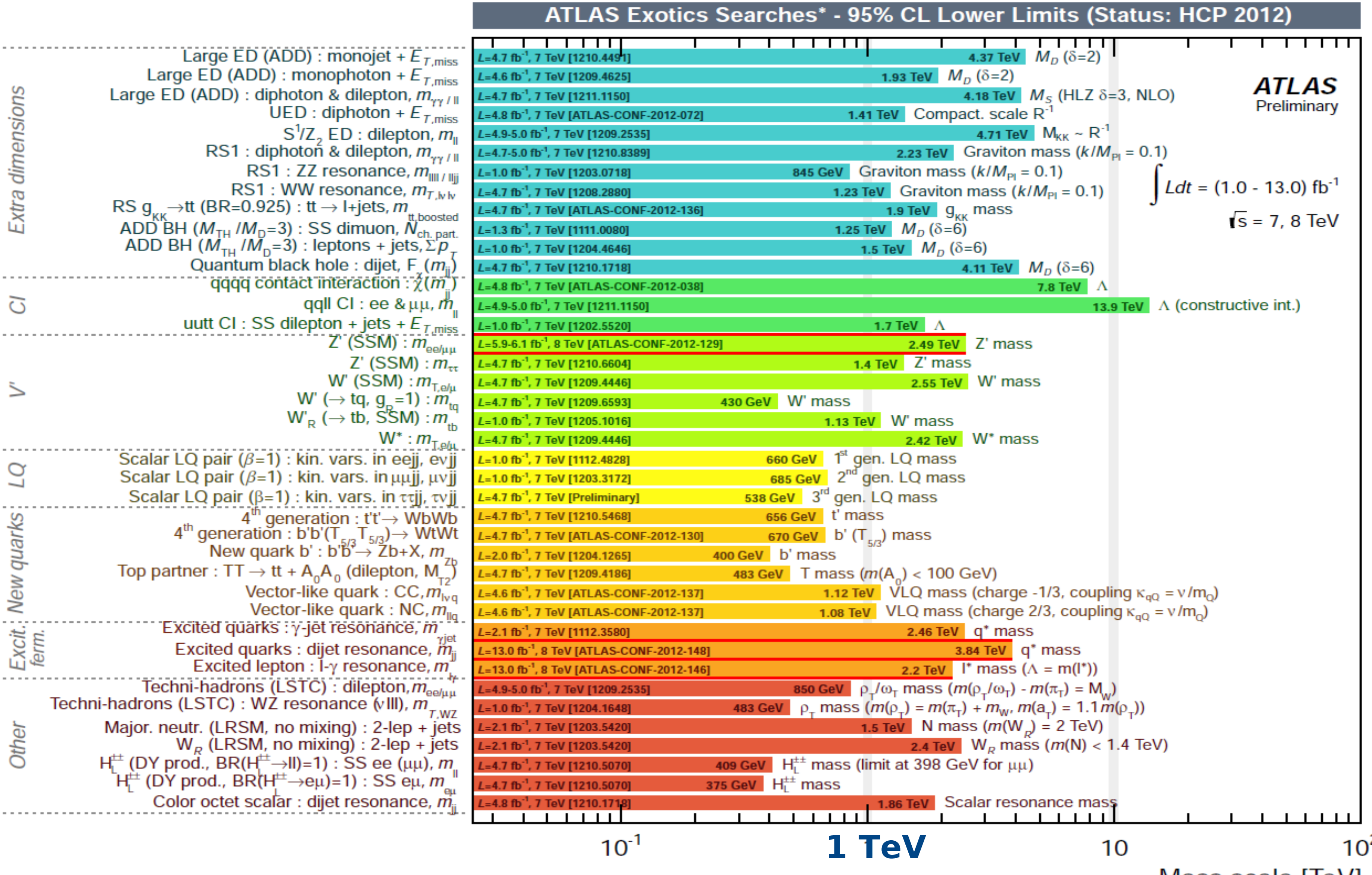


Exotics



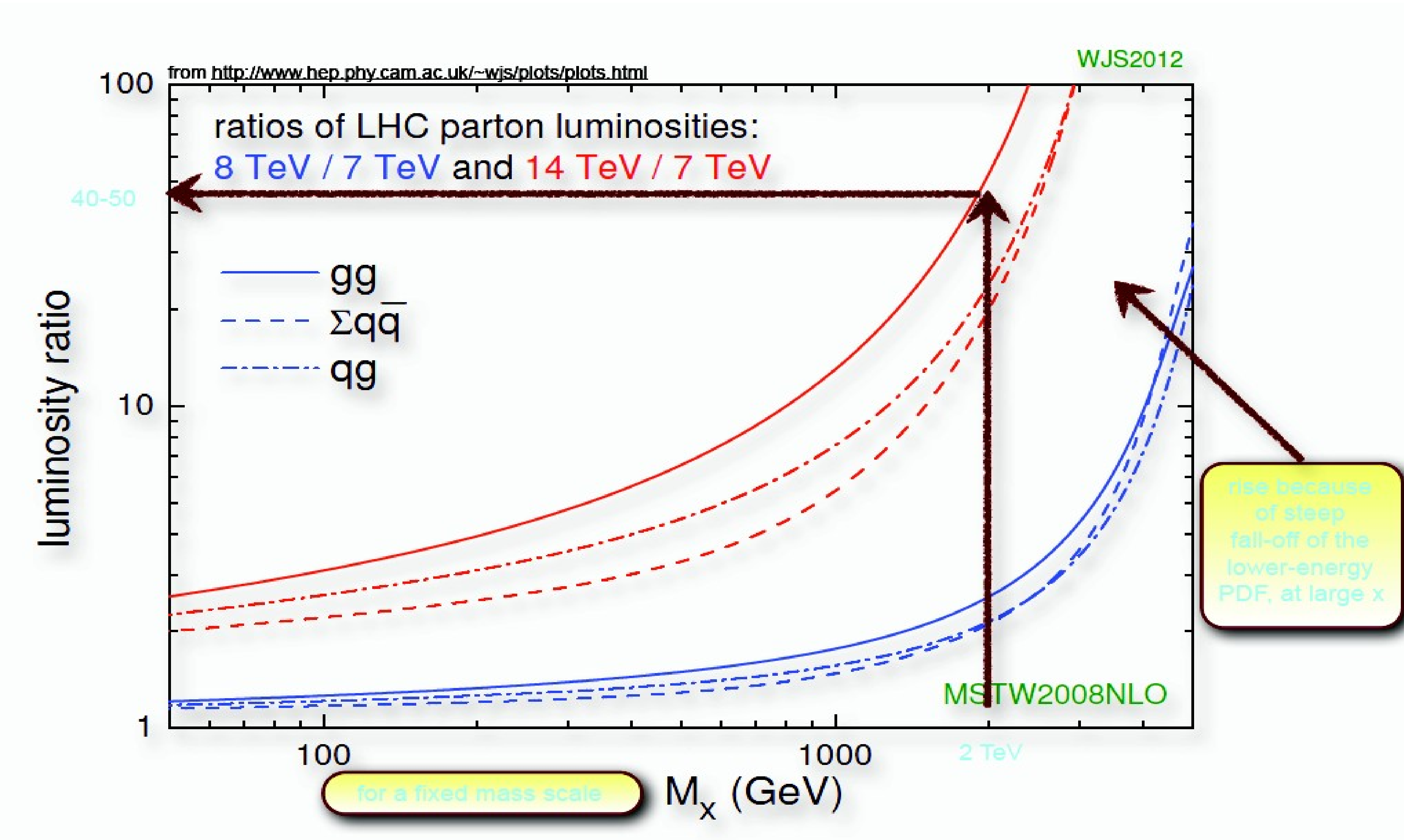
ℓ±ℓ'±
ττ
ℓℓjj
ℓ+jets
ℓ+jets
ℓℓγ
ℓν
γγ
Highest m_{jj} event
ATLAS EXPERIMENT
Run Number: 209580, Event Number: 179229707
Date: 2012-08-31 20:24:29 CEST
m_{jj} = 4.7 TeV
p_T^j = 2.3 TeV
E_T^{miss} = 47 GeV
jj
jets
ℓℓ
jet+E_T^{miss}
γ+E_T^{miss}
ℓℓ'+E_T^{miss}

Exotics

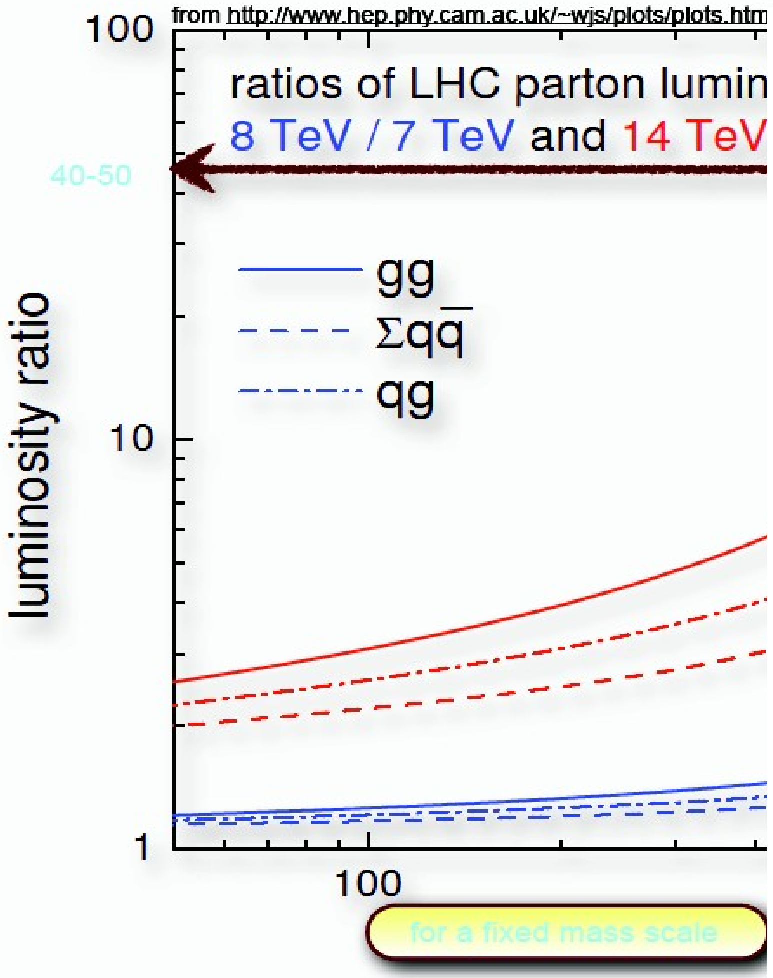


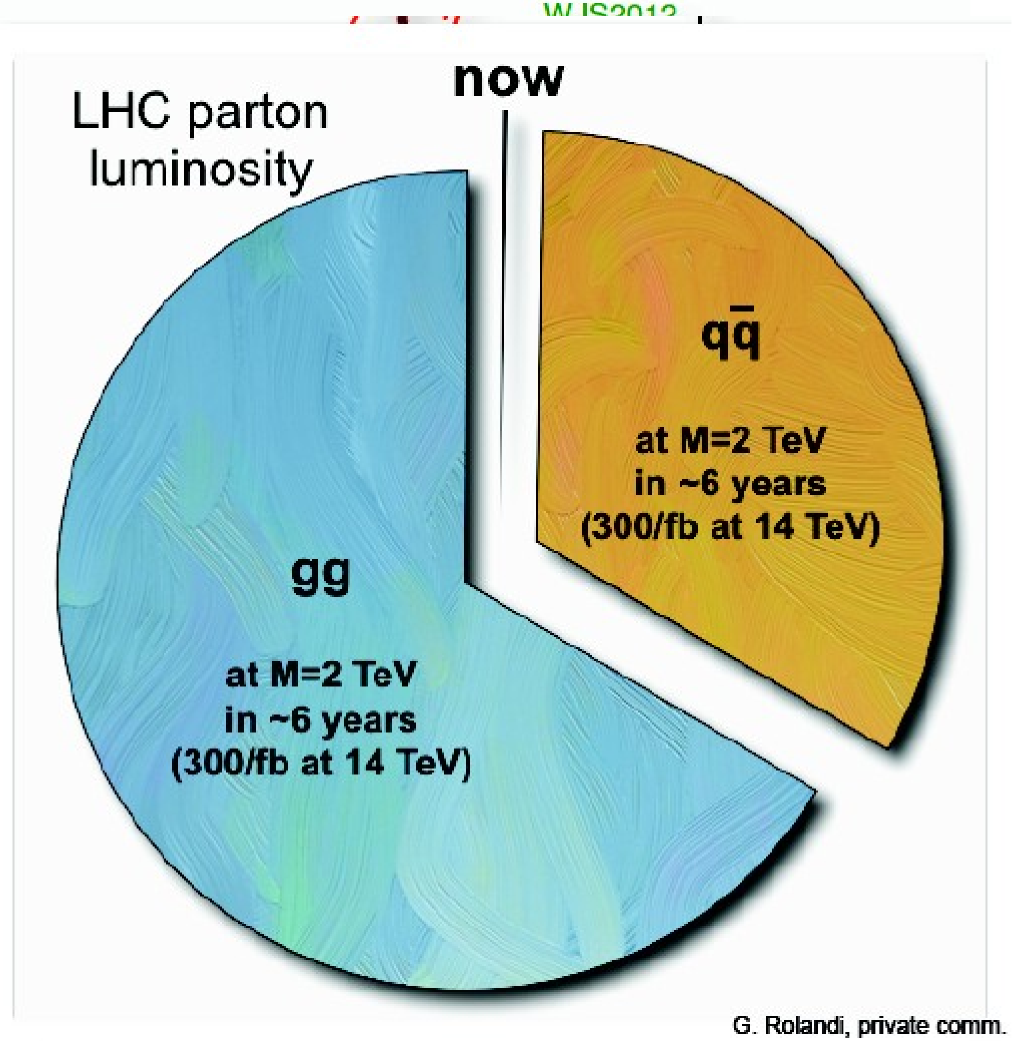
*Only a selection of the available mass limits on new states or phenomena shown

Parton luminosity



Parton luminosity



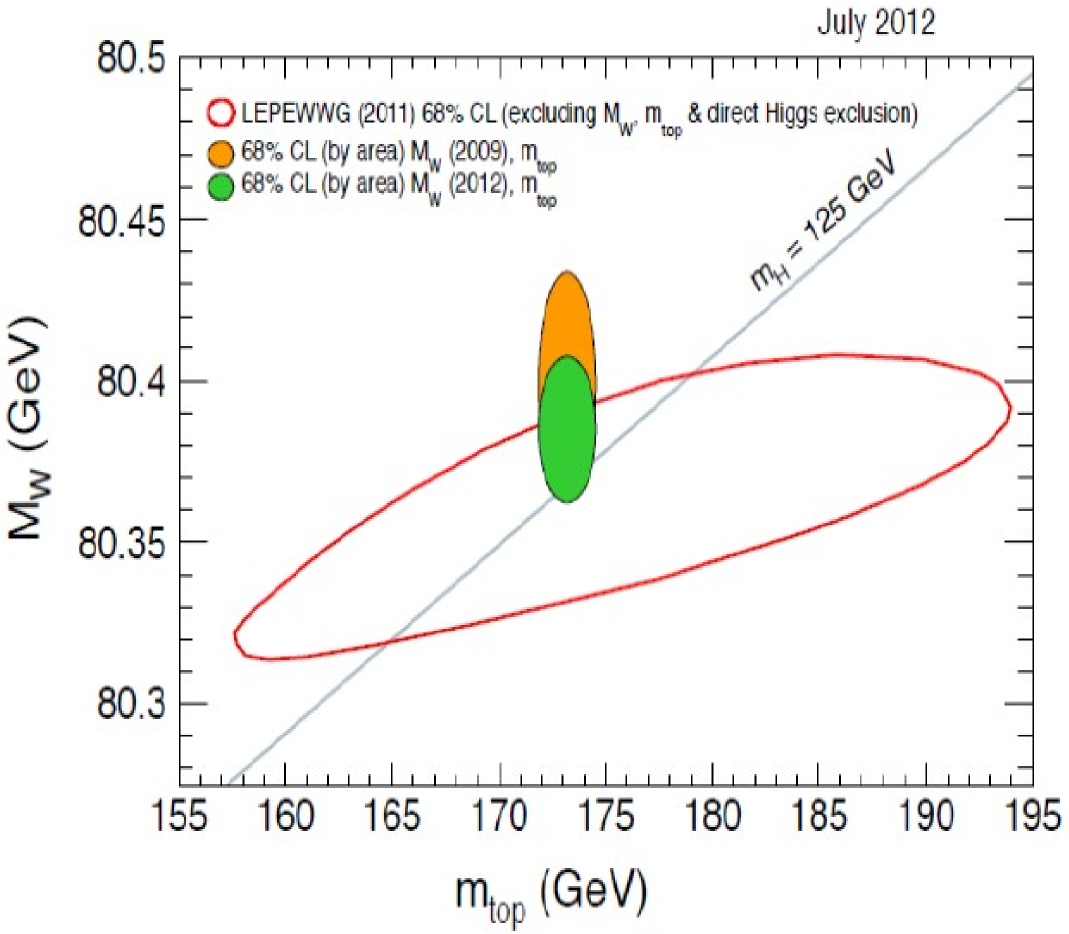


Global fit to the Standard Model

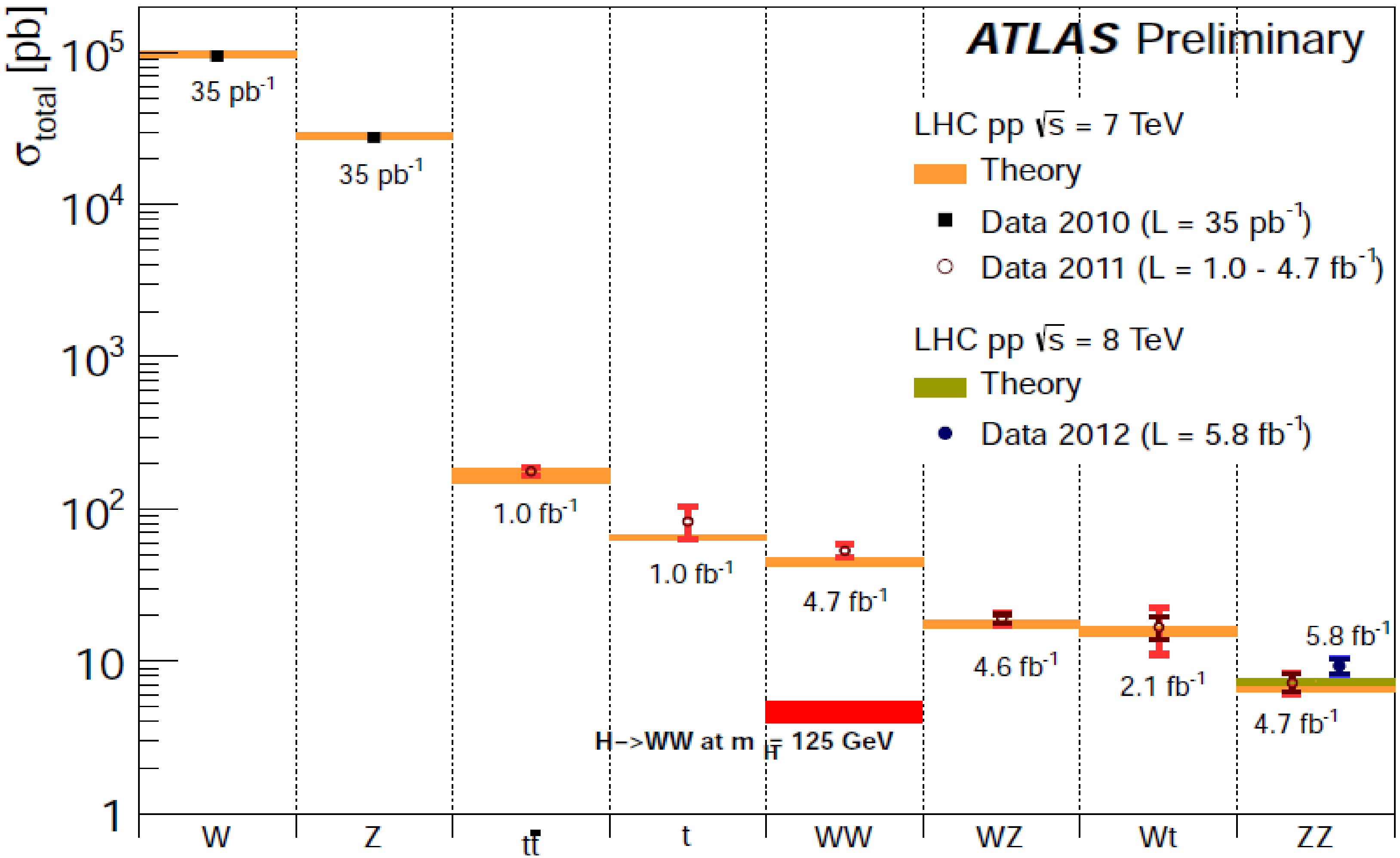
With M_W = 80385±15 MeV

$M_H = 94^{+29}_{-24}$ GeV
$M_H < 152$ GeV @95% CL

LEPEWWG/ZFitter



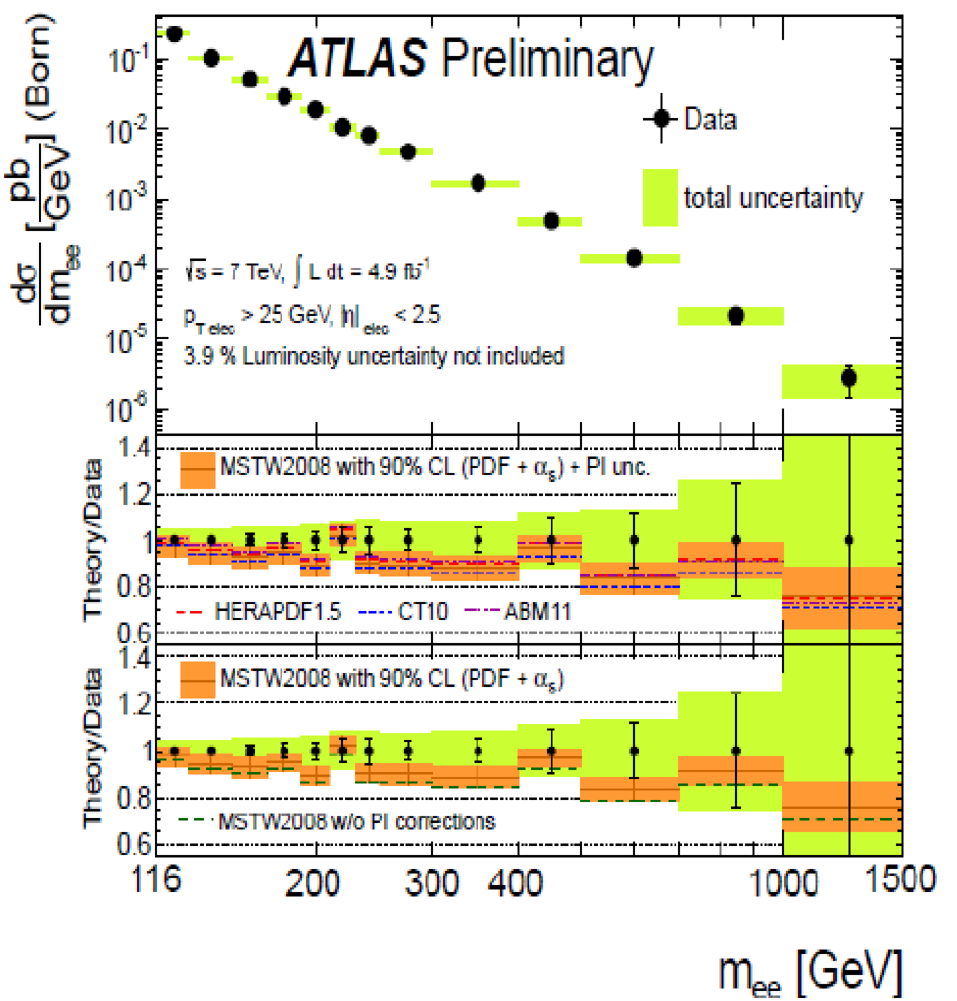
W and Z boson physics



Drell-Yan production at high masses

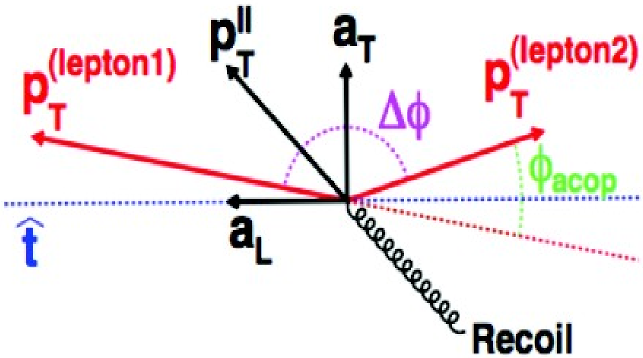
Starting to challenge NNLO predictions

- Measurement of absolute differential cross-section in range [116-1500] GeV
- Compared to pQCD at NNLO from FEWZ 3.1 which includes NLO EWK corrections such as photon induced background $\gamma\gamma$->ee process (of the same size as syst. from PDFs and α_s uncertainties)



Z/γ* transverse momenta

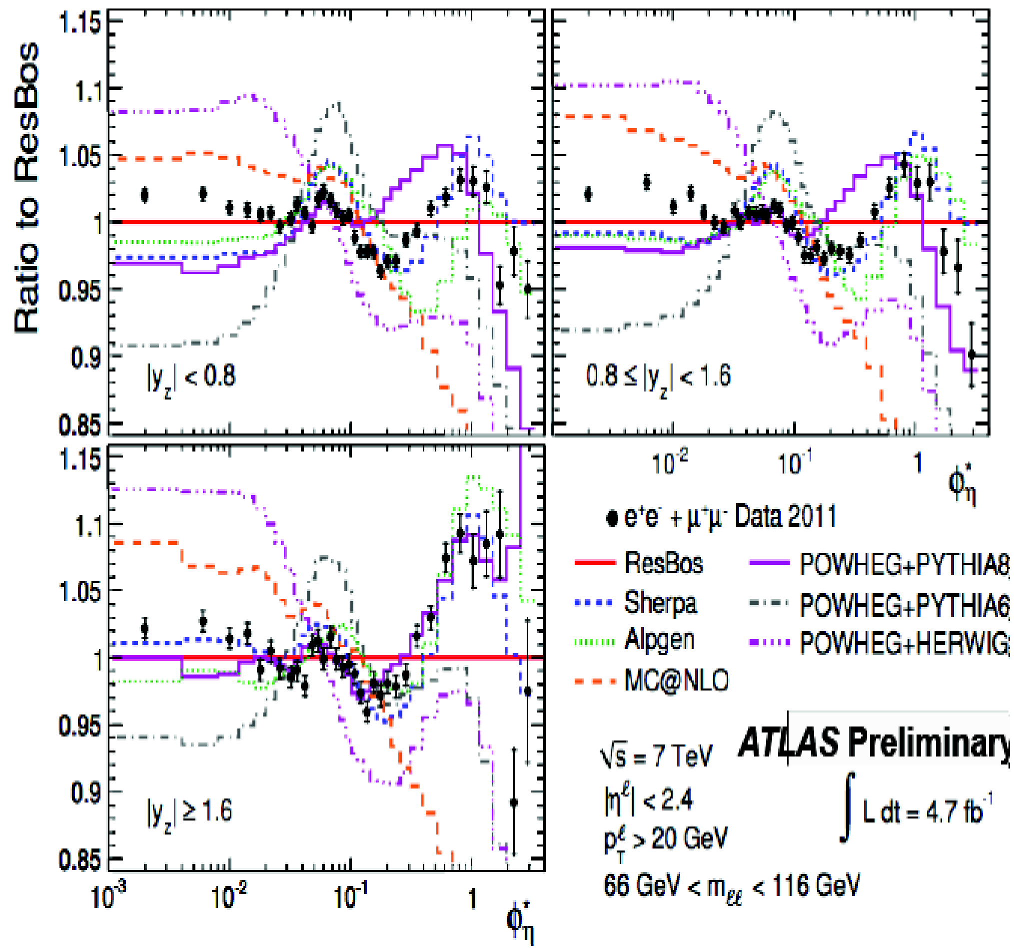
ϕ^*_η depends exclusively on the angles of the two leptons which are better measured than their momenta



$$\phi^*_\eta = \tan\left(\phi_{\mathrm{acop}}/2\right)\sin(\theta^*_\eta)$$

$$\cos(\theta^*_\eta) = \tanh\left[\left(\eta^- - \eta^+\right)/2\right]$$

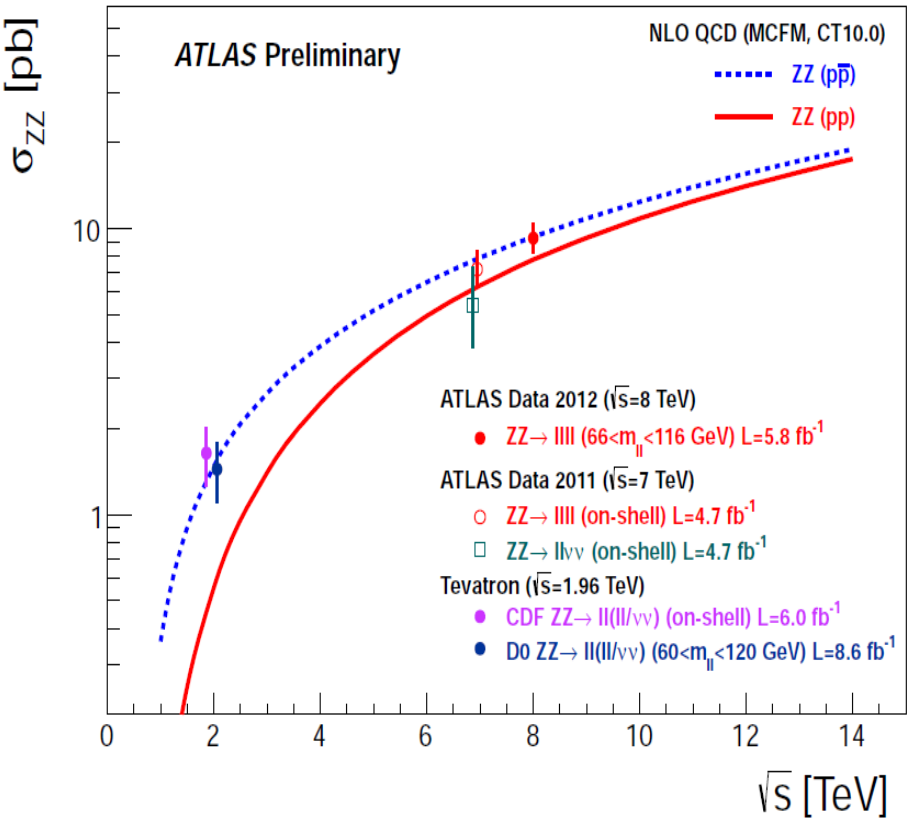
Good description of ATLAS data by RESBOS at the ~4% level



EW physics: Dibosons

Measurements crucial to check the gauge structure of the Standard Model

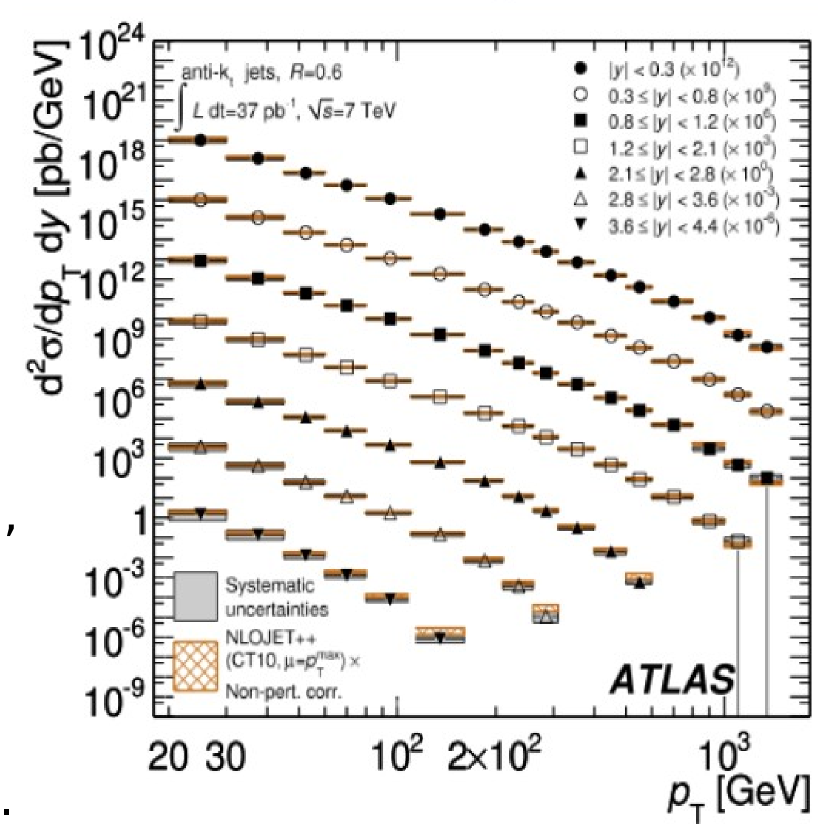
- Cross-section measurements performed in WW, WZ, Wγ, Zγ and ZZ channels. Results in agreement with SM predictions. Typical precision comparable with size of NLO corrections.
- Sensitivity to new physics in most channels: imposing contraints by setting limits on aTGC (anomalous couplings)



QCD : jet physics

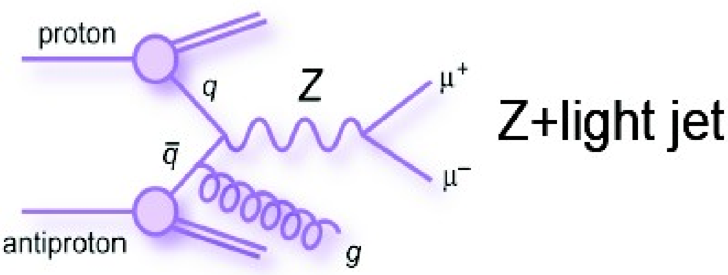
Rates span 10 orders of magnitude

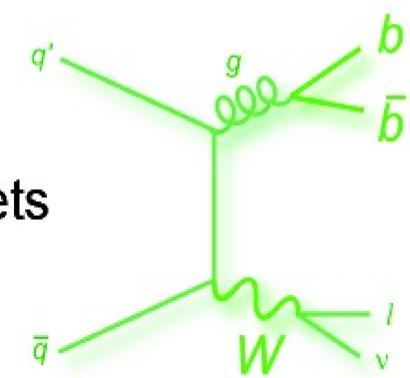
- Absolute NLO theory prediction for both shape and normalisation, agreement to **within 20%**
- Residual discrepancy consistent with PDF's and perturbative NLO uncertainties
- **Jet properties**: fragmentation function, jet shapes, <Nch>, angular decorelations,... data more precise than theory predictions.
- Starting to explore also **ratios of 8 TeV/7 TeV** which reduces syst. errors.
- Should be able to probe **Njet ~ 11-12** (pT>60 GeV) by end of 2012
- New ideas: **subjets within jets**

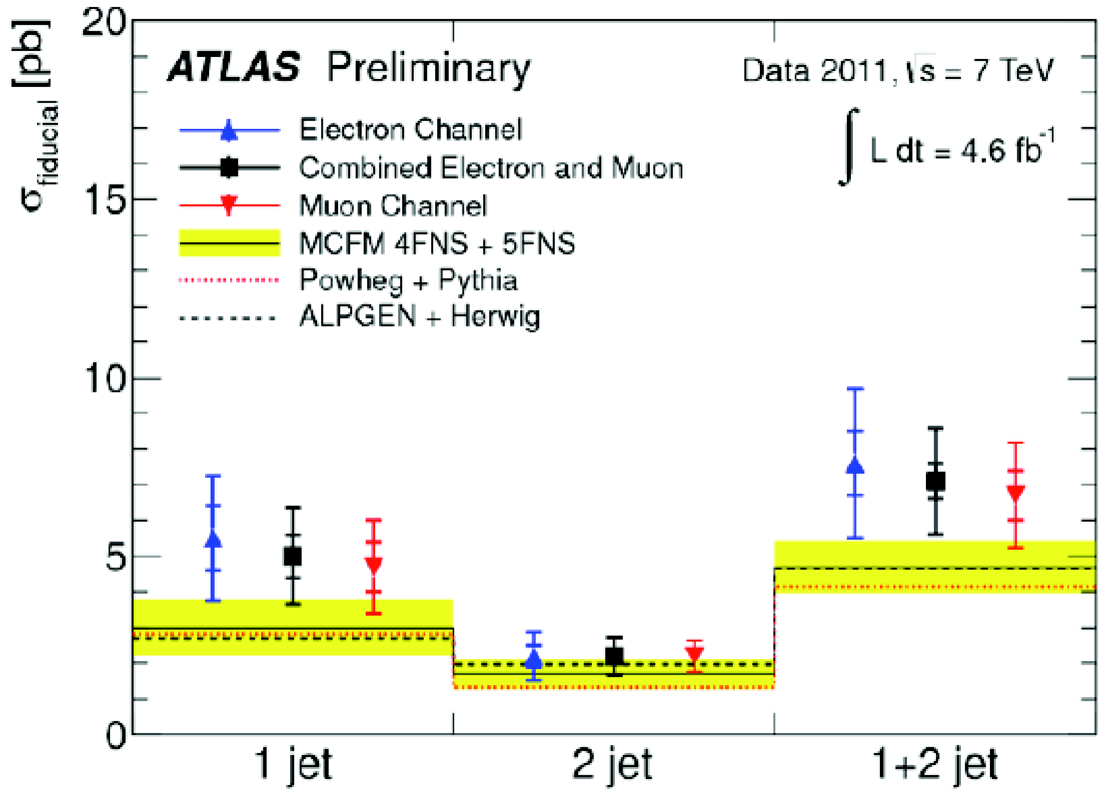


QCD: V+jets (b-jets)

- W+b-jet: exactly 1 b-jet required (+ light jet)



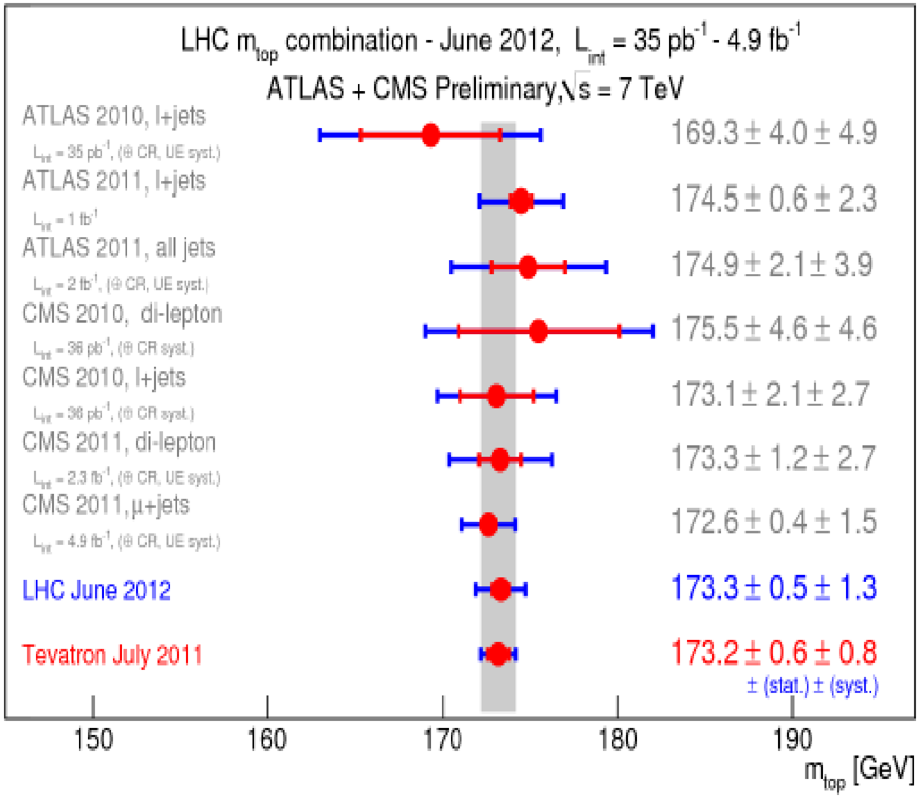




Theory (NLO) consistent within 1.5σ

Top physics: mass

Top mass measurements from different experiments and different techniques agree well within each other.



Which mass are we measuring?

- Pole mass (unphysical): based on the concept of the top being free parton
- $\overline{MS}$ ("running") mass: related to the top mass via RGE

Top physics: cross-section

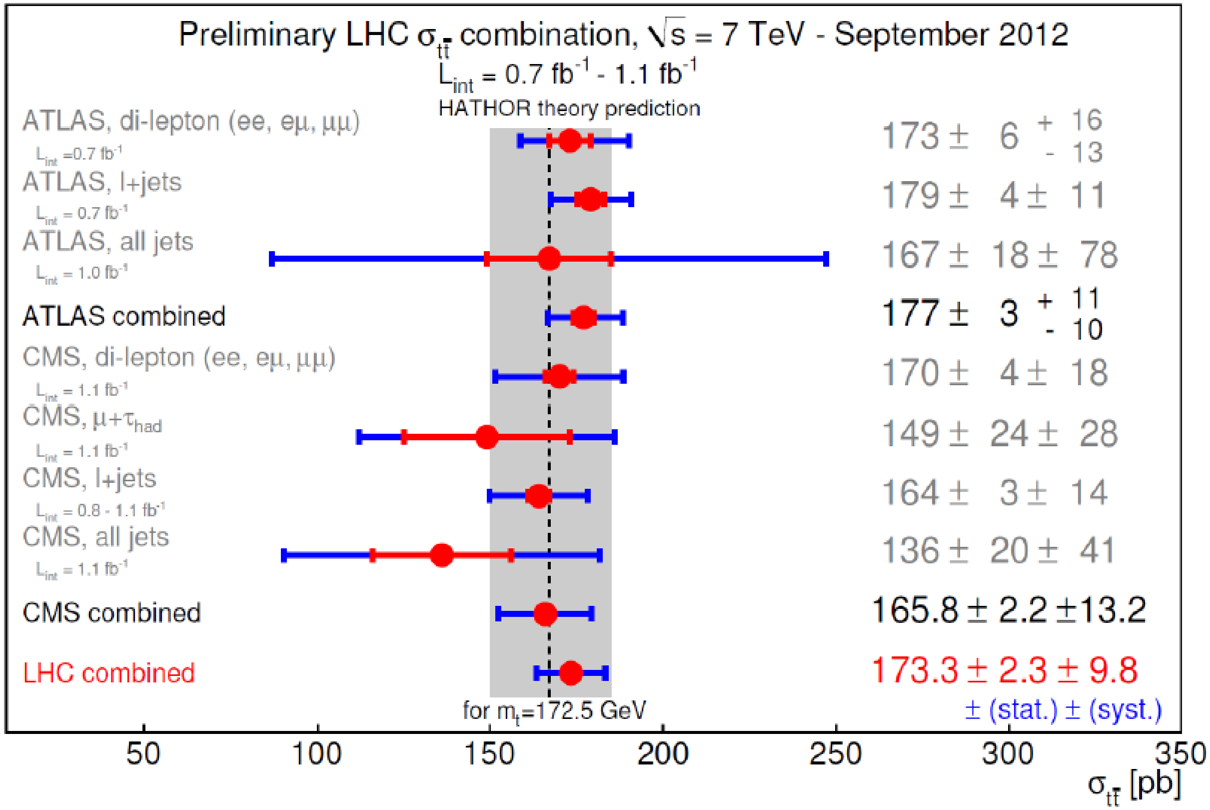
NEW September 2012

Use individual ATLAS, CMS combinations as input

Use BLUE method

Weights: ATLAS 67%, CMS 33%

Uncertainty 5.8%



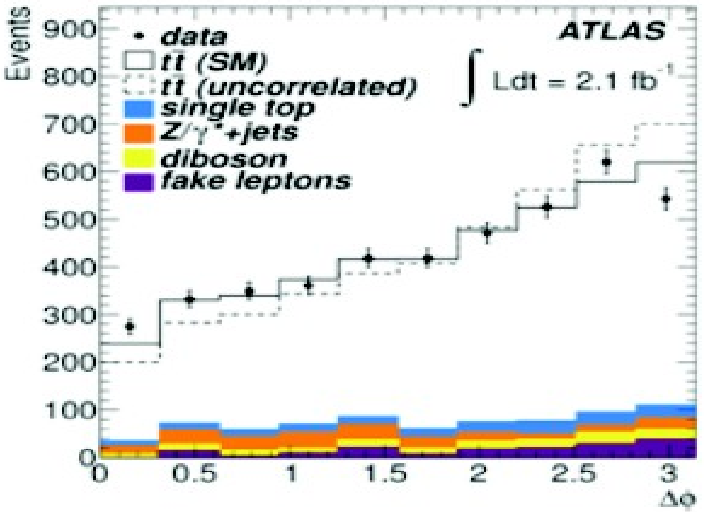
The era of precision top quark physics, started at the TEVATRON, is continuing at LHC

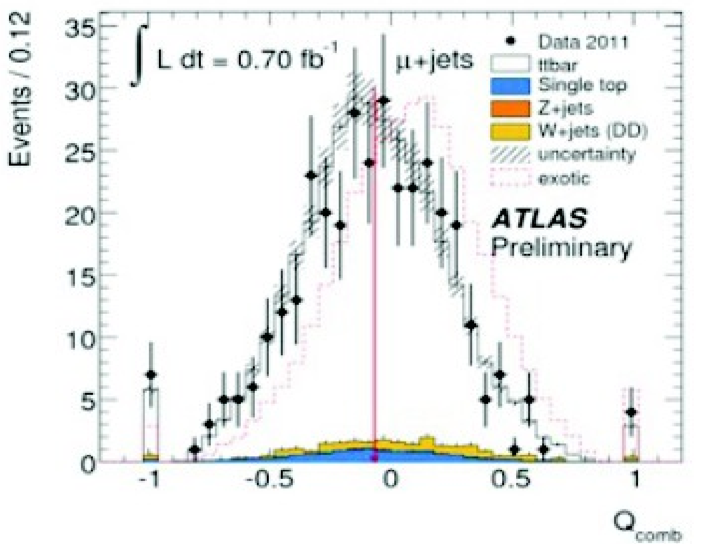
- 5% precision on total cross section (CMS dilepton), competing with theory uncertainty
- First round of differential cross section measurements
- Measurements of tt+X, where X=(b-)jets, γ, W, Z

Top physics: properties

Statistics available at LHC allowed for new and more precise measurements

- Spin correlations in to pair production observed
- First measurements of top quark polarisation
- Precise measurements of \ helicity allowed to set stringent limits on the anomalous W_{tb} couplings
- Exotic top-quark charge excluded



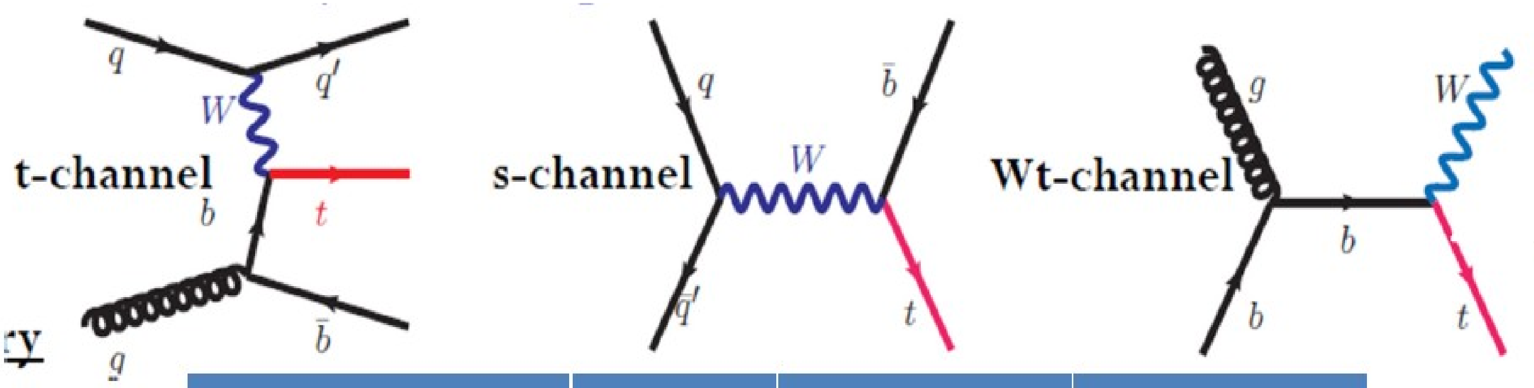


Electroweak production of top quark

For the first time evidence at Tevatron in 2010 (s+t channel)

It is challenging even for LHC, in particular s-channel observation is a long shot (background)

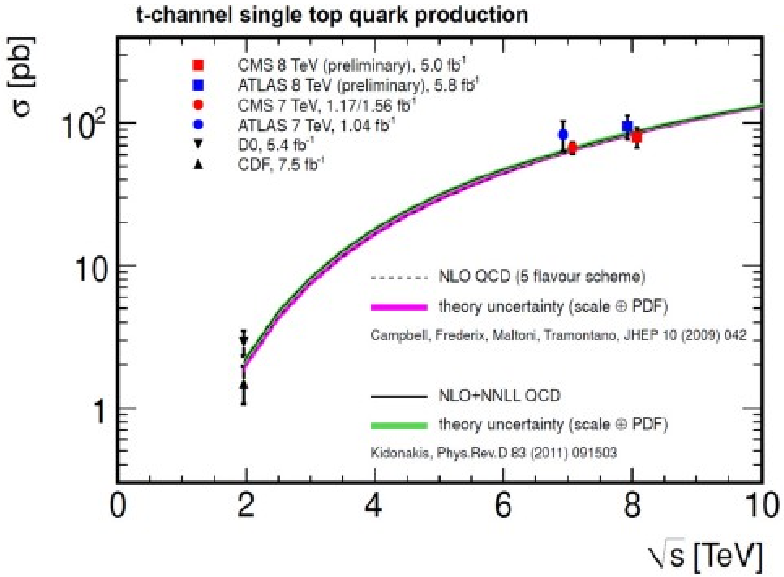
All diagrams have V_{tb} vertex

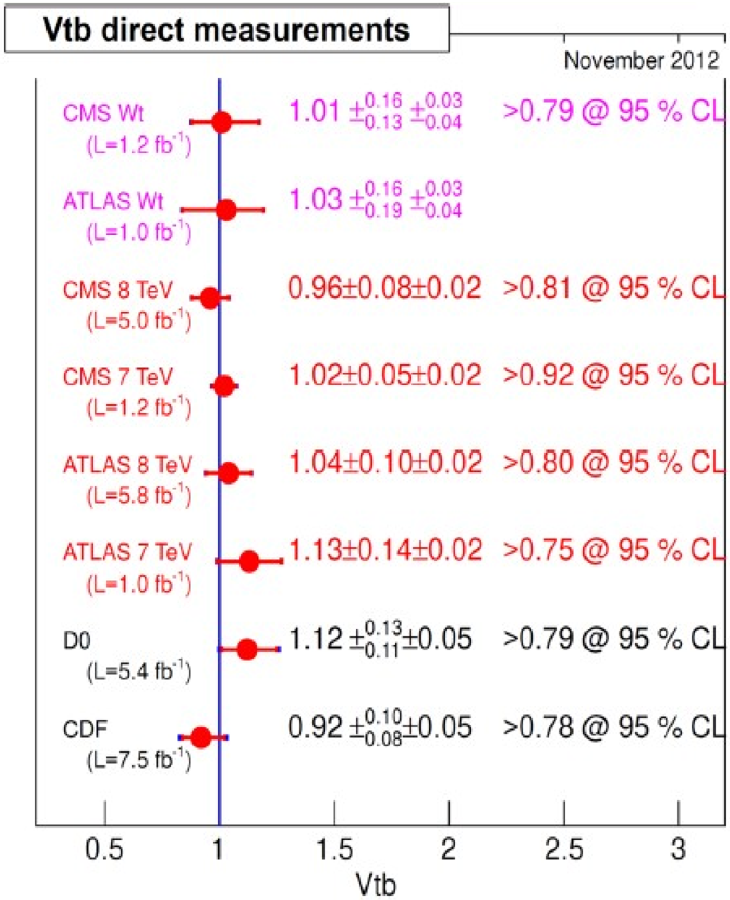


	t channel	s channel	Wt
Tevatron (1.96 T eV)	2.26±0.2	1.04±0.1	0.3±0.06
LHC (7 TeV)	64.2±2.4	4.6±0.2	15.7±1.1
LHC (8 TeV)	87.8±3.4	5.6±0.3	22.4±1.5

x-sec in pb

Electroweak production of top quark





s channel (Tevatron only)

CDF=$1.81^{+0.63}_{-0.58}$ pb

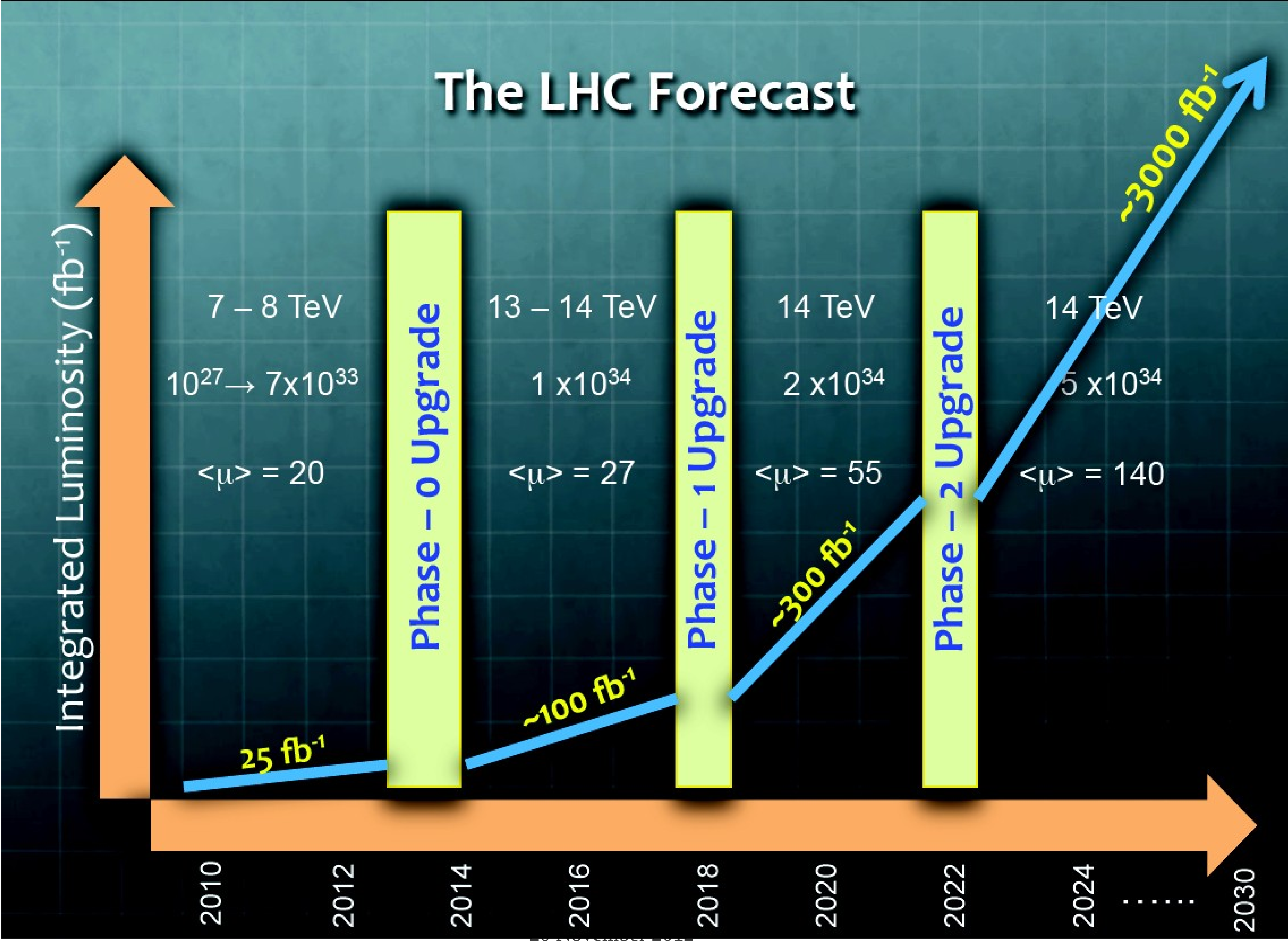
D0=0.98±0.63 pb

Wt (LHC only, 7 TeV)

ATLAS 16.8±5.7 pb

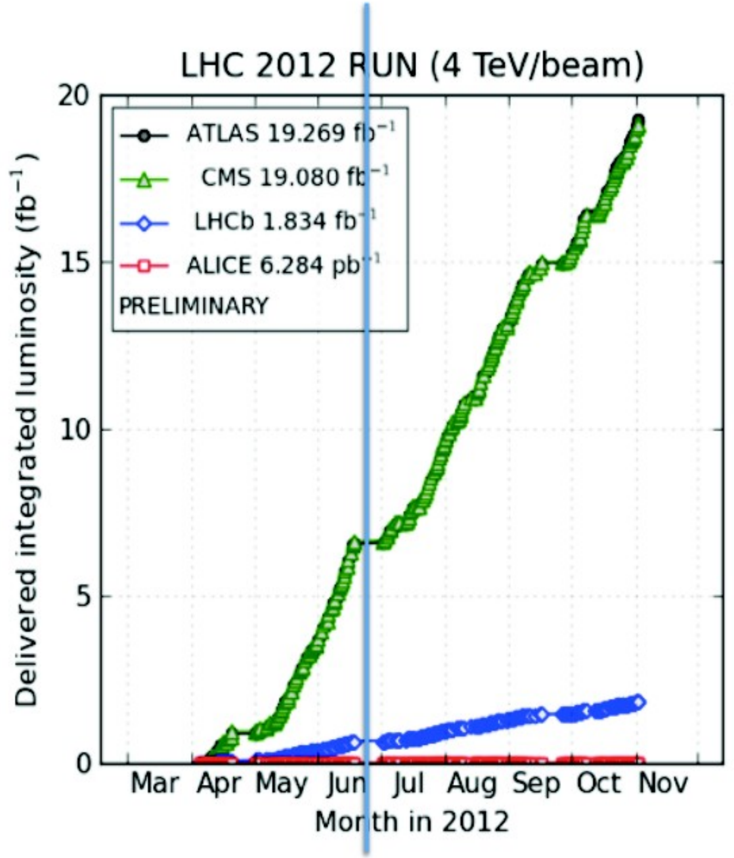
CMS 16^{+5}_{-4} pb

V_{tb} might stay at 10% precision for some time


The LHC Forecast
Integrated Luminosity (fb-1)
7 – 8 TeV
10^27 → 7x10^33
<μ> = 20
25 fb-1
Phase – 0 Upgrade
13 – 14 TeV
1 x10^34
<μ> = 27
~100 fb-1
Phase – 1 Upgrade
14 TeV
2 x10^34
<μ> = 55
~300 fb-1
Phase – 2 Upgrade
14 TeV
5 x10^34
<μ> = 140
~3000 fb-1
2010
2012
2014
2016
2018
2020
2022
2024
......
2030

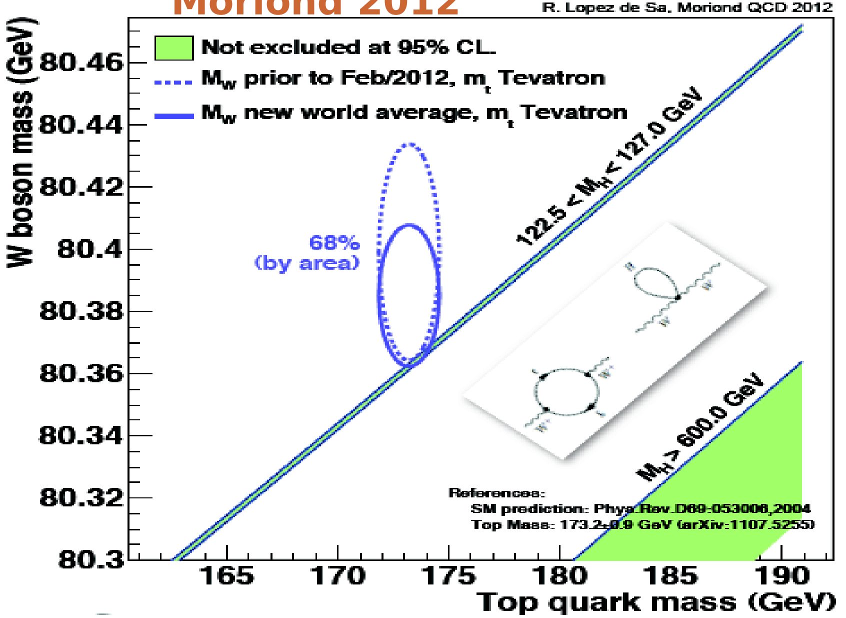
Luminosity colected up to date

- Almost 4 x more data with 8 TeV pp available for analysis today: **about 20fb^{-1} recorded**
- Some channels updated with 12-13fb^{-1}, **presented at HCP conference**
- Next major updates planned for Moriond 2013 ...
- However still not excluded that new intermediate results will be released for December CERN Counsil week.



Standard Model: global fit

Moriond 2012



With M_W = 80385±15 MeV

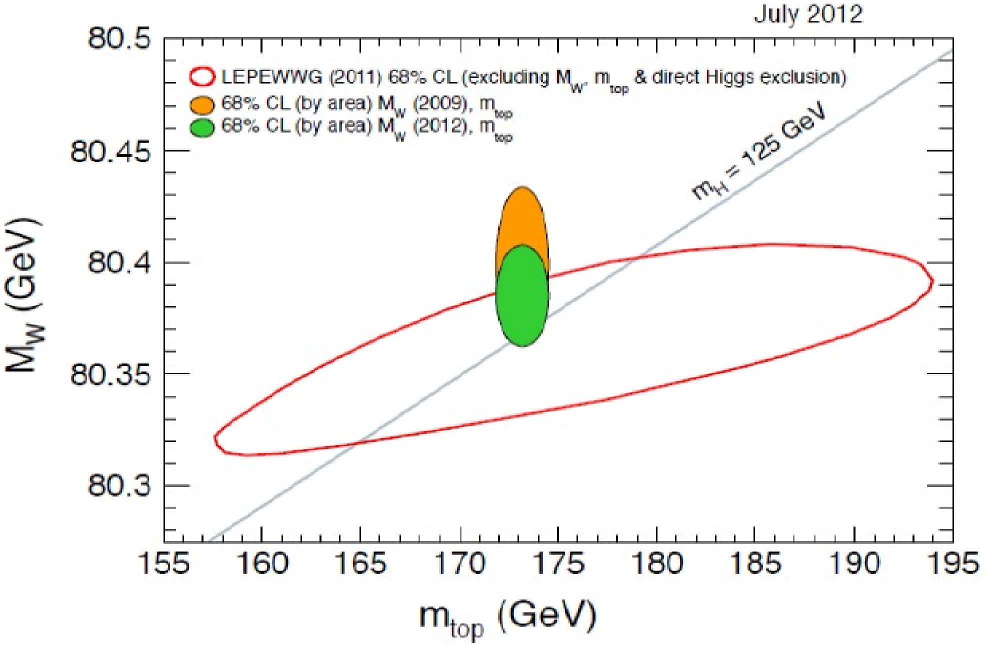
$M_H = 94^{+29}_{-24}$ GeV
M_H < 152 GeV @95% CL

LEPEWWG/ZFitter

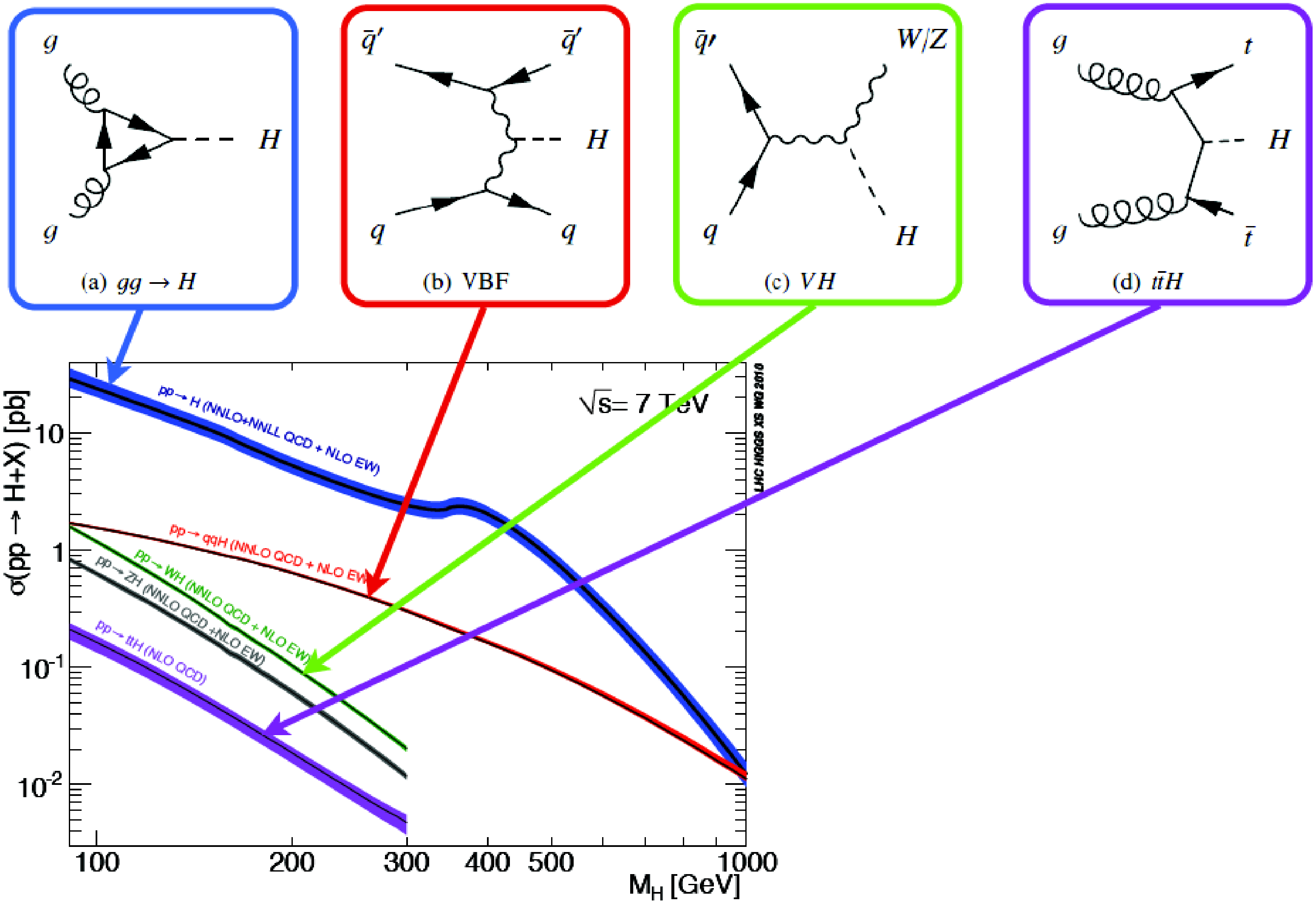
Since then:

→ **New mW measurement**

→ **Higgs-like particle discovery**



SM Higgs production at the LHC



SM Higgs decays

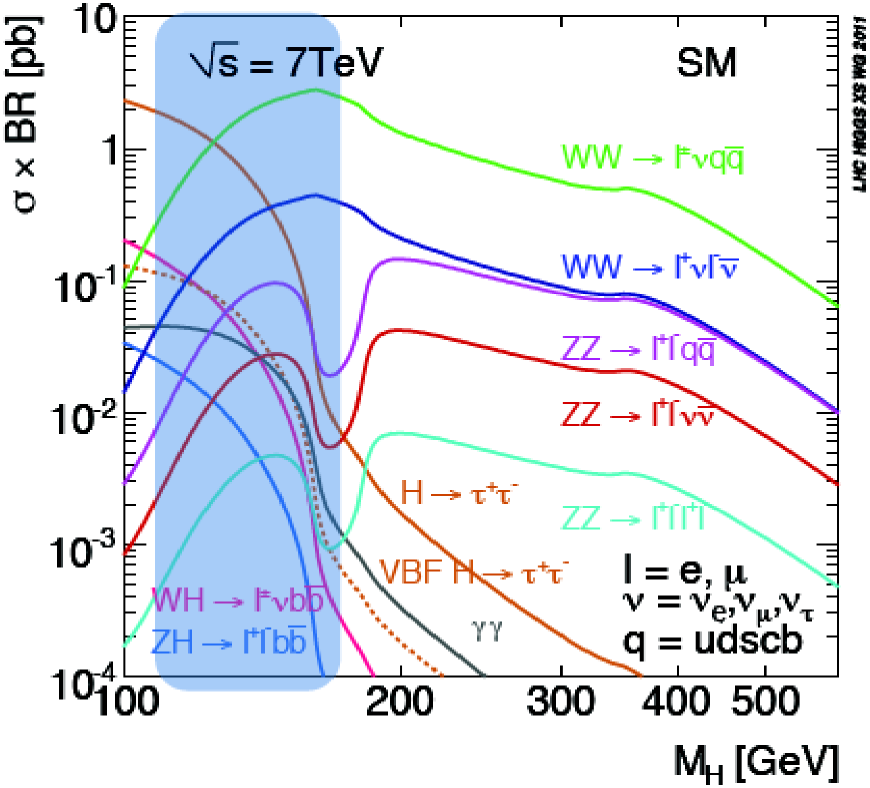
$H \rightarrow \gamma\gamma$

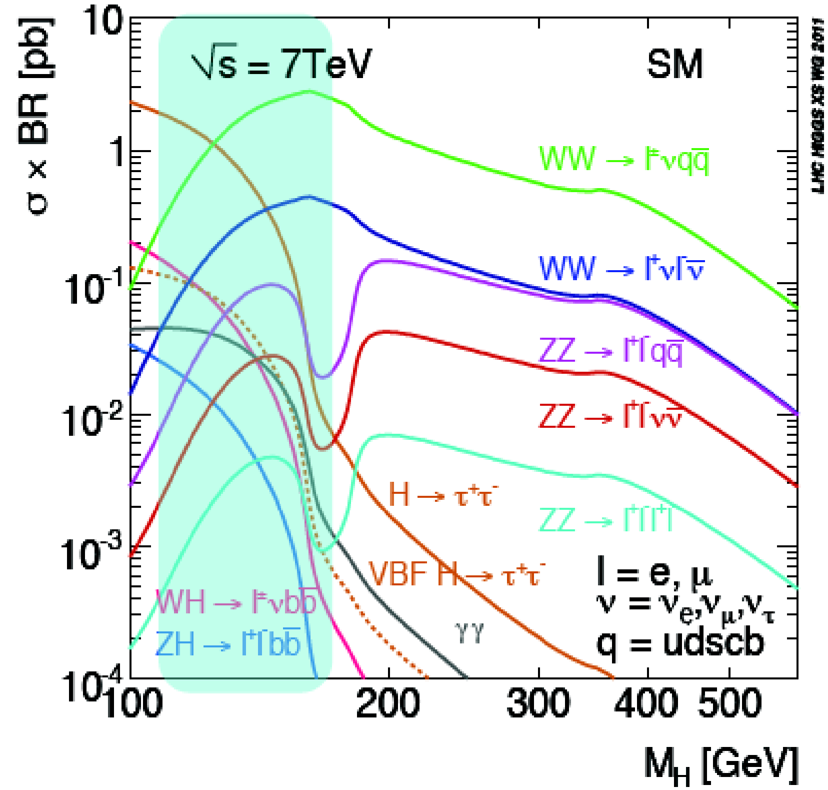
$H \rightarrow ZZ \rightarrow llll$

$H \rightarrow WW \rightarrow l\nu l\nu$

$VH \rightarrow bb$

$H \rightarrow \tau\tau$





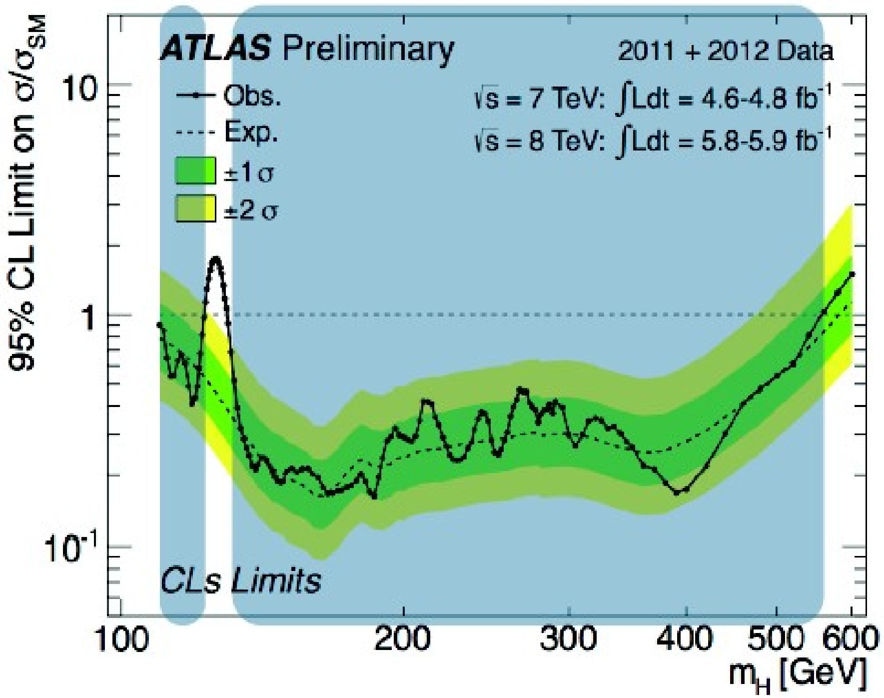
ATLAS results of 4-th July

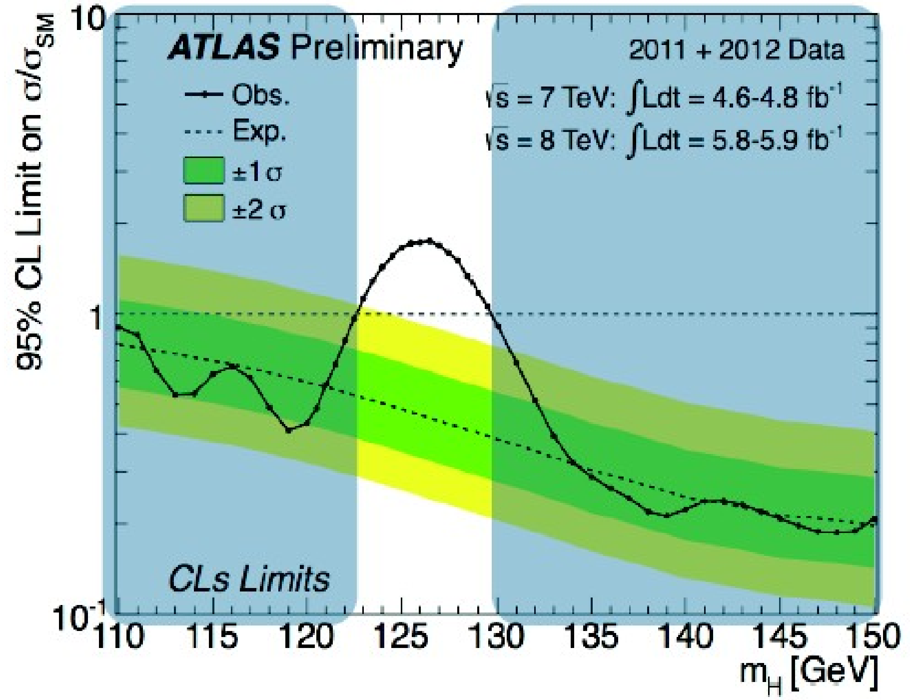
- Searches performed in 12 channels in the range 110 GeV < m_H < 600 GeV

Updated with 2012 data

Higgs decay	Subsequent decay	Mass range [GeV]	L [fb^{-1}]	Publication (arXiv)
$H \to \gamma\gamma$		110-150	4.8 + 5.9	1202.1414
$H \to ZZ$	$lll'l'$	110-600	4.8 + 5.8	1202.1415
	$ll\nu\nu$	200-600	4.7	1205.6744
	$llqq$	200-600	4.7	1206.2443
$H \to WW$	$l\nu qq$	300-600	4.7	1206.6074
	$l\nu l\nu$	110-600	4.7	1206.0756
$H \to \tau\tau$	$ll4\nu$	110-150	4.7	1206.5971
	$l\tau_{had}3\nu$		4.7	
	$\tau_{had}\tau_{had}2\nu$		4.7	
$VH \to bb$	$l\nu bb$	110-130	4.7	1207.0210
	$llbb$		4.7	
	$\nu\nu bb$		4.6	

ATLAS results of 4-th July



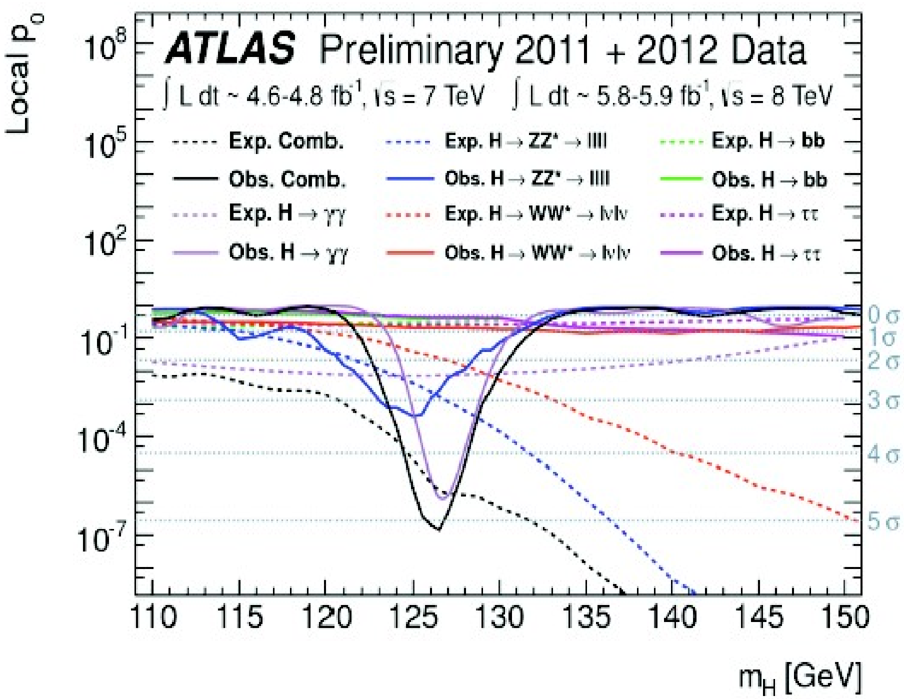


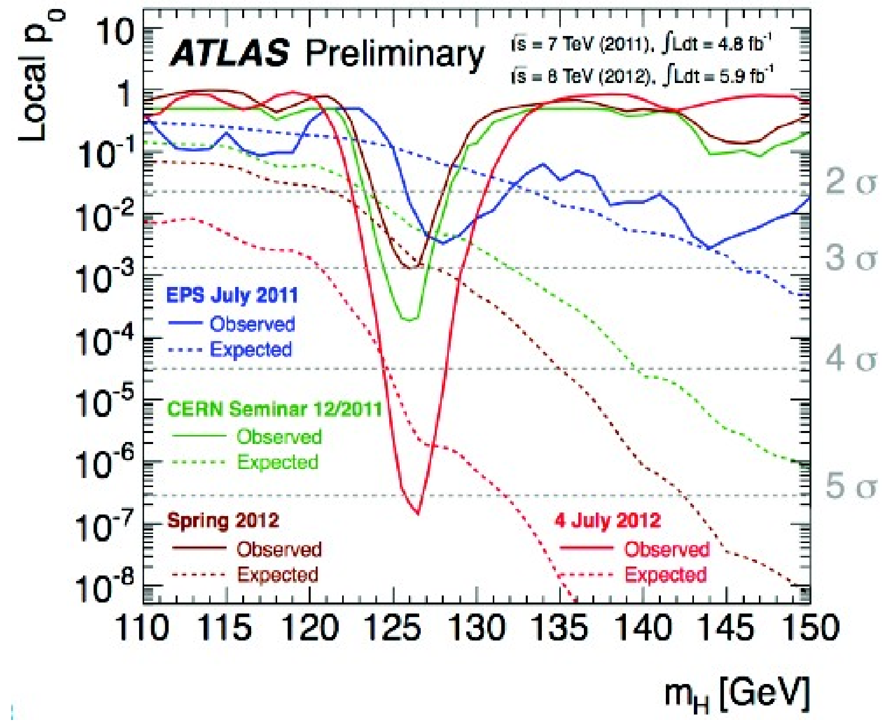
Excluded at 95% CL: 110-122.6 GeV, 129.7-558 GeV

Excluded at 99% CL: 111.7-121.7 GeV, 130.7-523 GeV

Expected exclusion at 95% CL (no signal): 110-582 GeV

ATLAS results of 4-th July

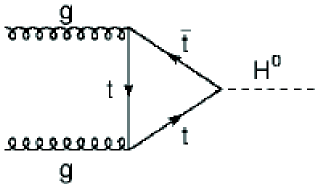




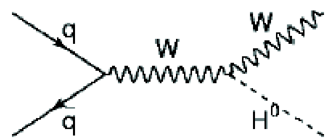
Excess consistent with
H->γγ and H->ZZ*->4l decays

SM predictions for H->γγ

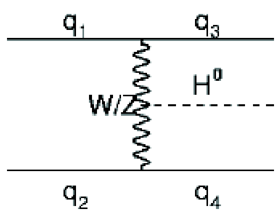
- **SM Higgs production channels**



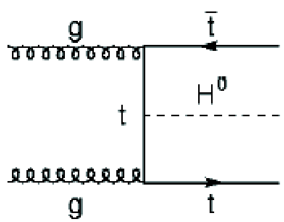
Gluon-gluon fusion (~87%)



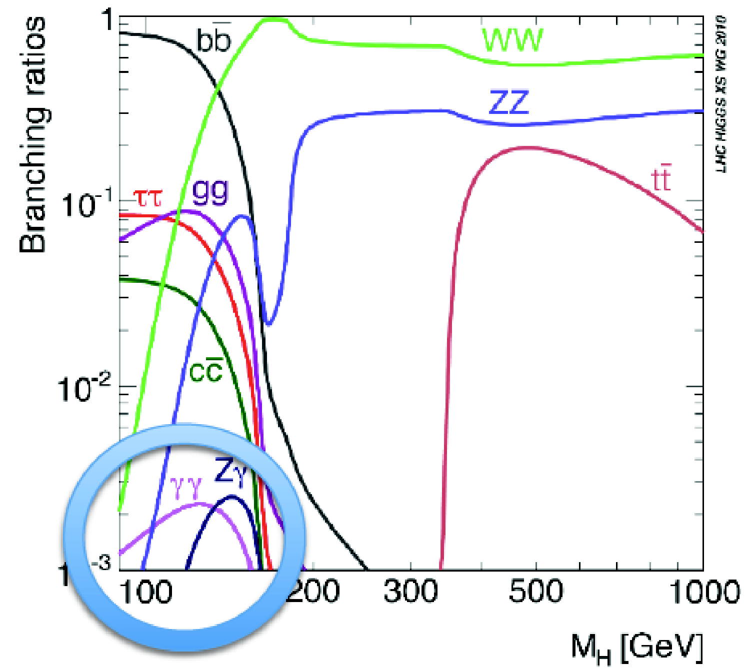
Associated Higgs (< 5%)



Vector-Boson Fusion (~7%)

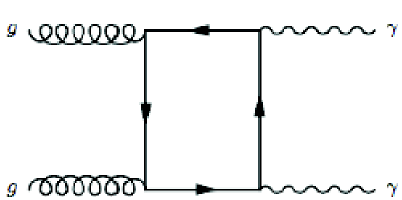


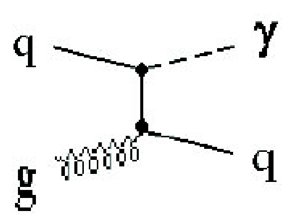
ttH (< 5%)

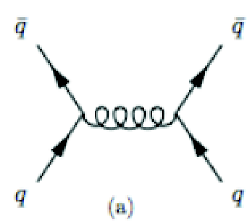


- **Branching fraction small** but simple signature (two high p_T photons in final state)

Main backgrounds to H→ γγ are SM diphoton, jet-γ and jet-jet events

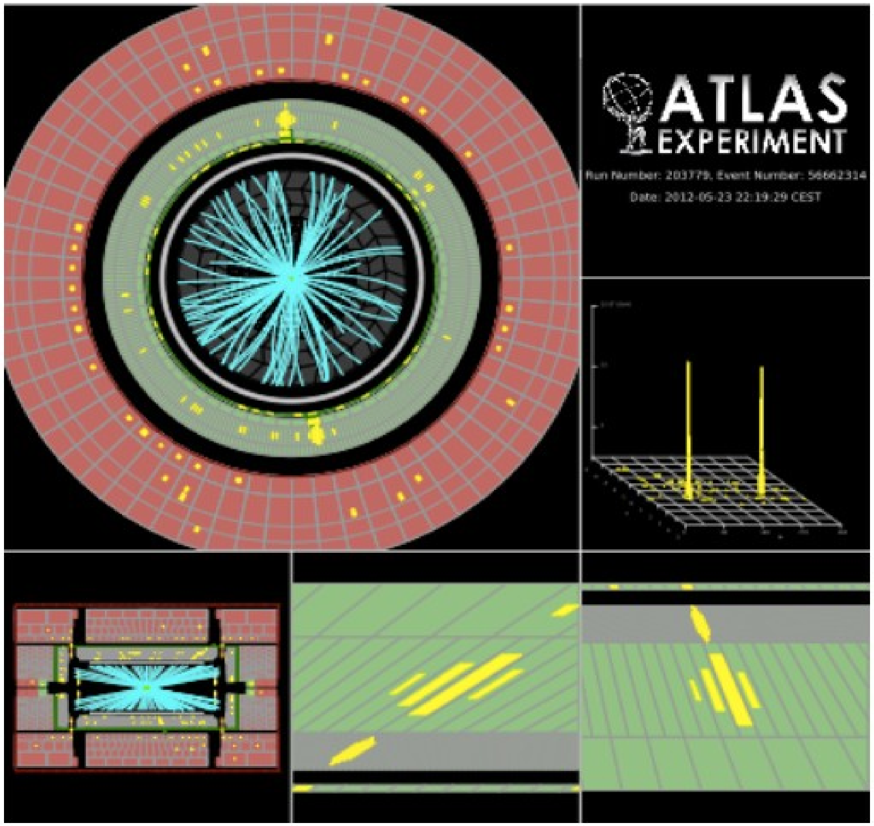






- Signal expected as **narrow resonance over smooth decaying background**

H->γγ event signature



Simple event signature

❑ Two high pT photons
$pT_1 > 40$ GeV and $pT_2 > 30$ GeV

❑ High trigger efficiency
~99%

❑ High event selection efficiency despite high jet-jet & γ-jet production
~40%

❑ High signal over background
~3-10 % (depending on sub-category)

Invariant mass reconstruction $m_{\gamma\gamma}^2 = 2 * E_1 E_2 (1 - \cos \alpha)$

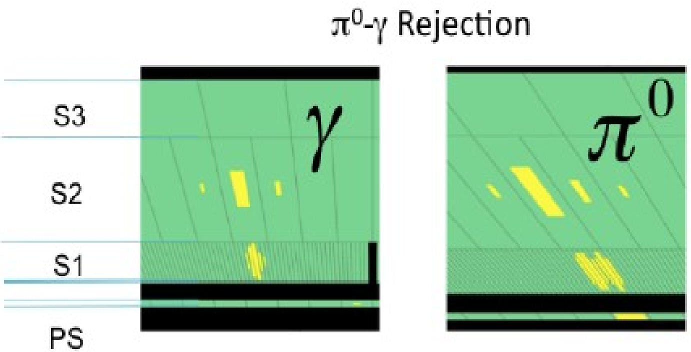
❑ Good energy calibration

❑ Robust primary vertex reconstruction

→ Excellent invariant mass resolution ~1.6 GeV with 90% of events within ±2σ

Shower shapes and vertex reconstr.

Photon ID 2 – Photon shower shapes and background rejection



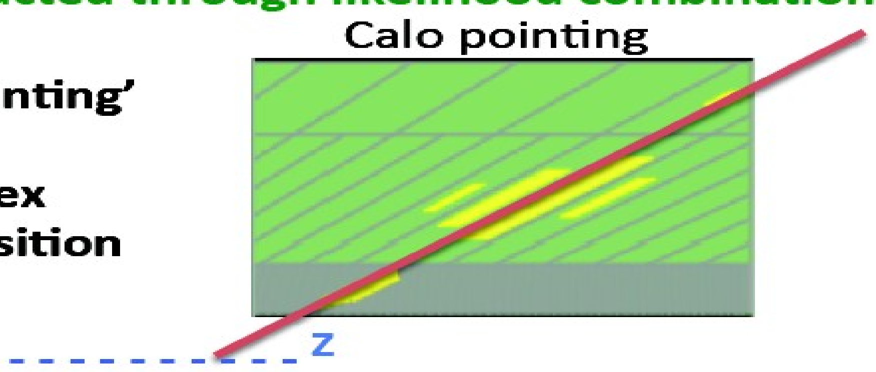
- Photons shower shape distributions in LAr sampling layers - different for signal and background (π^0)

Vertex Reconstruction

$$m_{\gamma\gamma}^2 = 2*E_1E_2(1 - \cos\alpha)$$

- Vertex reconstructed through likelihood combination

- Calorimeter 'pointing'
- Σ tracks pT^2
- Conversion vertex
- Mean vertex position



Event categorization

Event categories based on eta, pTt, and conversion

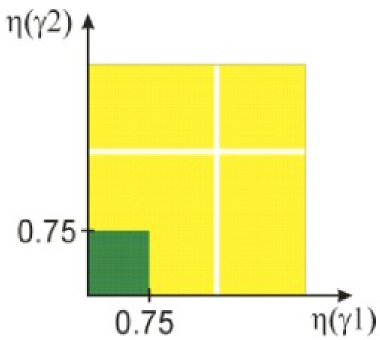
Both unconverted:

- Central
- Rest

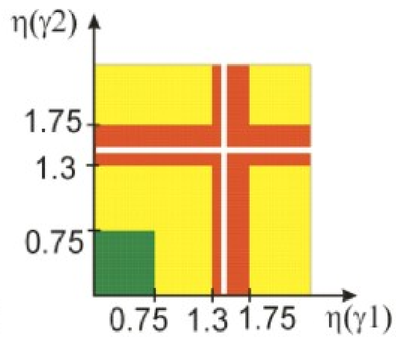
At least one converted:

- Central
- Transition
- Rest

2 unconverted:

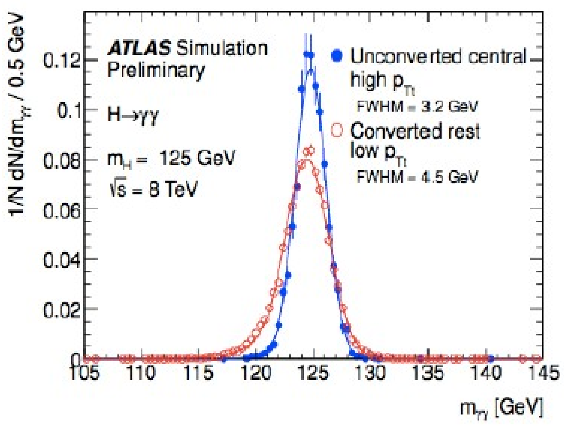


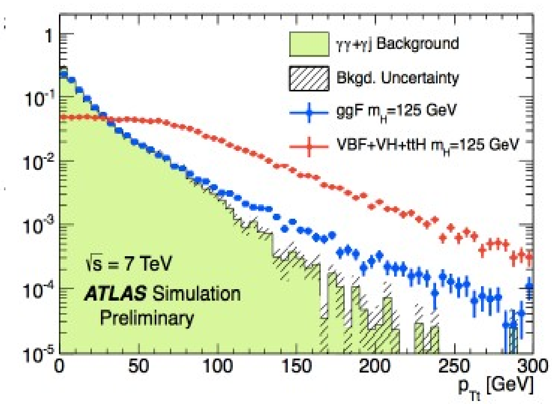
>=1 converted:



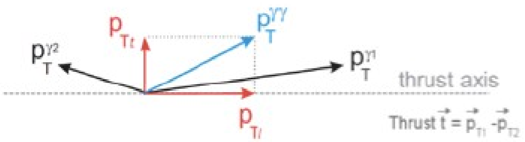
Resolution:

Good
Medium
Poor





Central and Rest divided into $p_{Tt} < 60$ GeV and $p_{Tt} > 60$ GeV



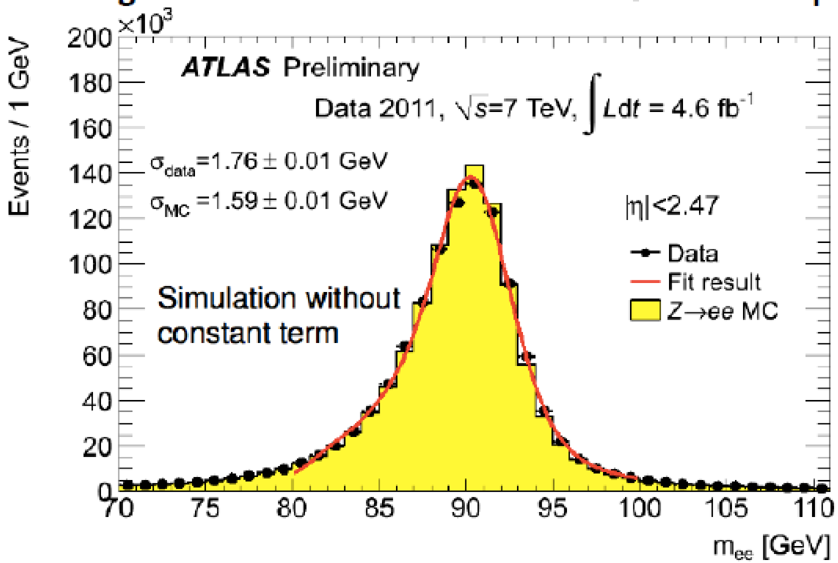
Energy calibration and resolution

$$m_{\gamma\gamma}^2 = 2 * E_1 E_2 (1 - \cos\alpha)$$

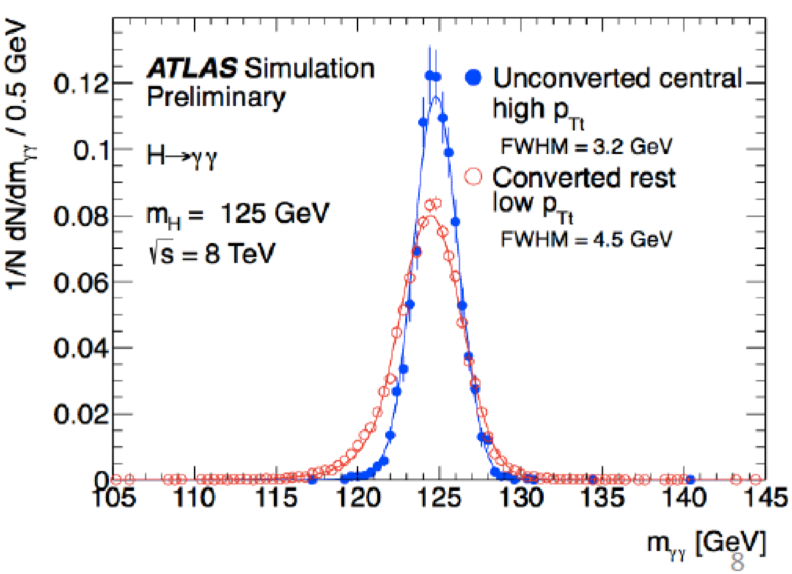
- MC based calibration improved with energy scale and resolution corrections based on in-situ analysis of Z→ee, W→eν and J/ψ → ee

- Energy scale at m_Z known to 0.3%, uniformity (constant term) 1% in barrel, 1.2 – 2.1% in endcap

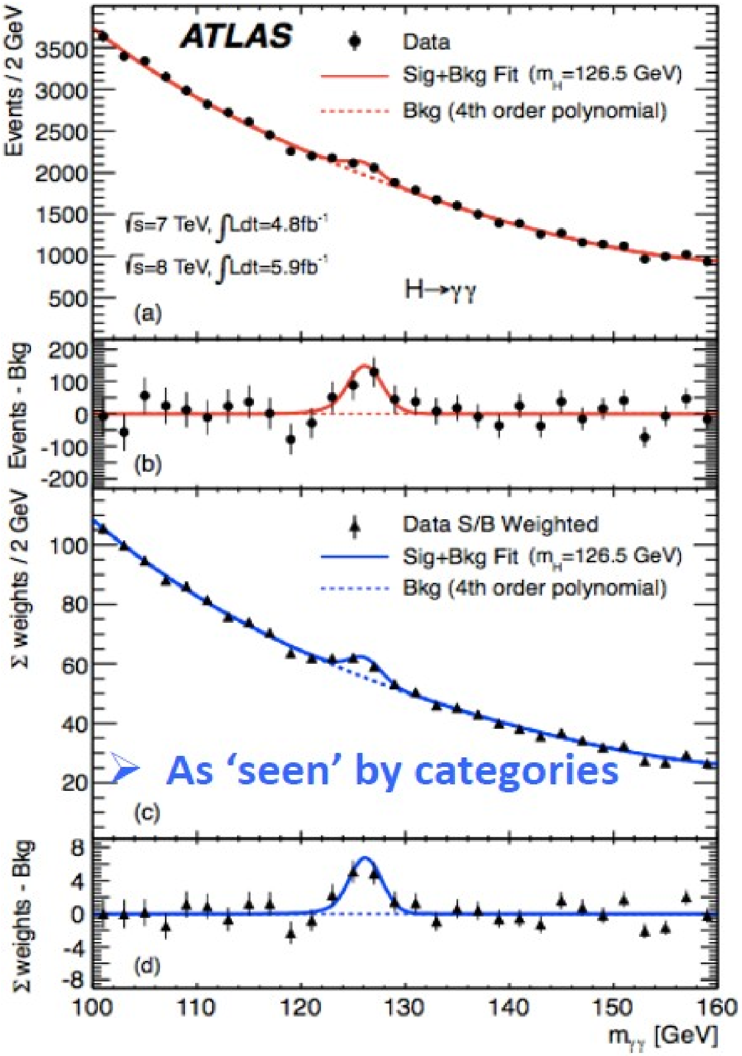
Agreement between data & MC Z→ee lineshape



Expected resolution of Higgs signal



Invariant mass distribution



- ❑ Photon ID efficiency ~10%
- ❑ Energy resolution ~14% and mass scale ~0.6%
- ❑ Isolation < 1%
- ❑ Pileup 4%
- ❑ Lumi 1-3.6 % (2011-2012)
- ❑ Theory cross section
  - ~ up to 25% (for VBF contribution)
  - ~ up to 12% (in other ggF)
  - (underlying event ~5% and PTt dist up to 12% at hight PTt)

- ❑ Bkg Param (evts) 0.2-4.6 (0.3-6.8) for 2011(2012)

In VBF category

- ❑ Jet E-scale 9-10%
- ❑ Underl. Evt. 6-30%
- ❑ Higgs p_T up to 12.5%

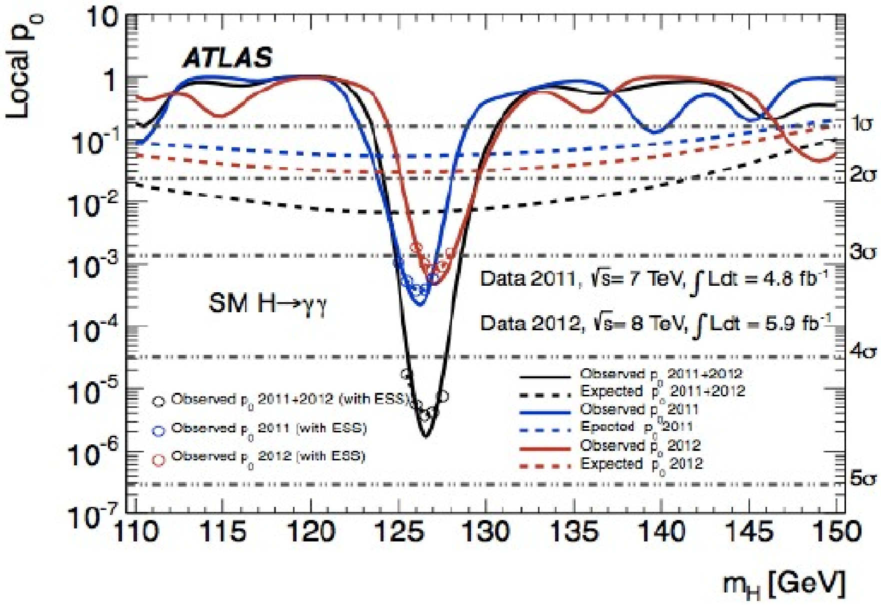
23788 events (7 TeV) and 35251 events (8 TeV)

Background+signal fit, signal fixed at 126.5 GeV

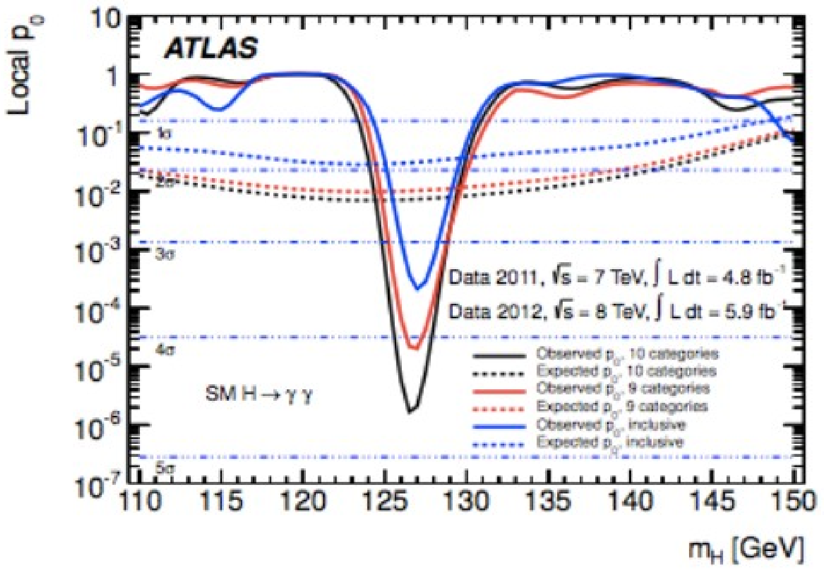
Quantifying the excess

- Maximum deviation from background only expectation at $m_{\gamma\gamma}$ 126.5 GeV
→ Local significance 4.5σ *(expected from SM Higgs 2.4σ)*

Effect of combination of 2011 & 2012



Effect of adding VBF category



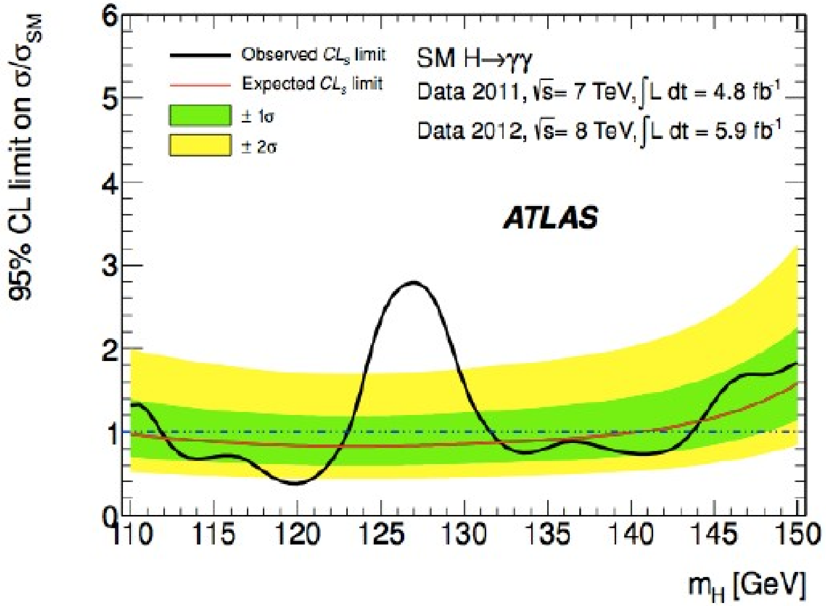
- *Results consistent between 2011 and 2012 and improved by VBF category*
- *Results consistent between inclusive analysis (no categories) and with categories*

Signal strenght

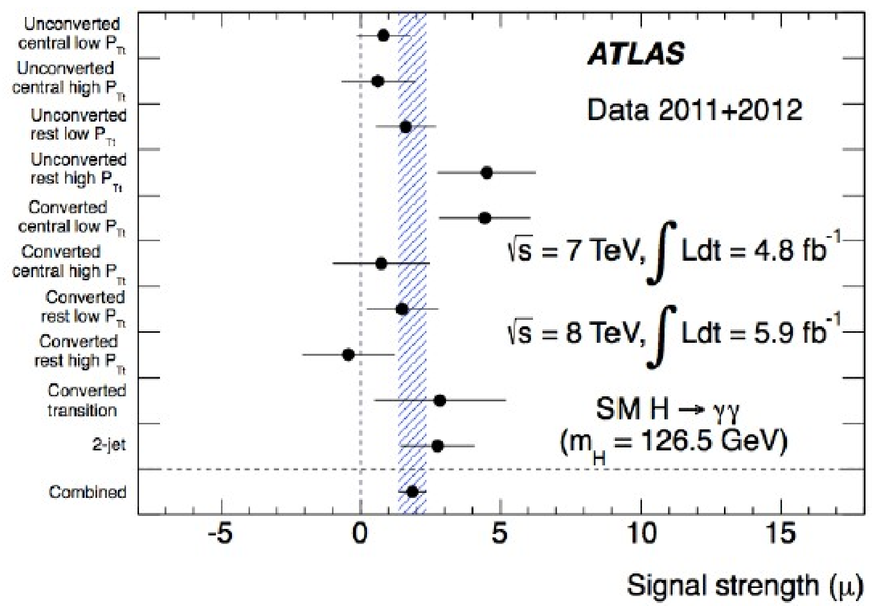
- SM hHggs excluded in the regions of **112 – 122.5 GeV and 132 – 143 GeV**
- Best fitted signal strength (wrt SM) for $m_{\gamma\gamma}$ = 126 of **μ = 1.8 ± 0.5**

- *Consistent results from different categories*

CL limit on σ/σ_{SM}

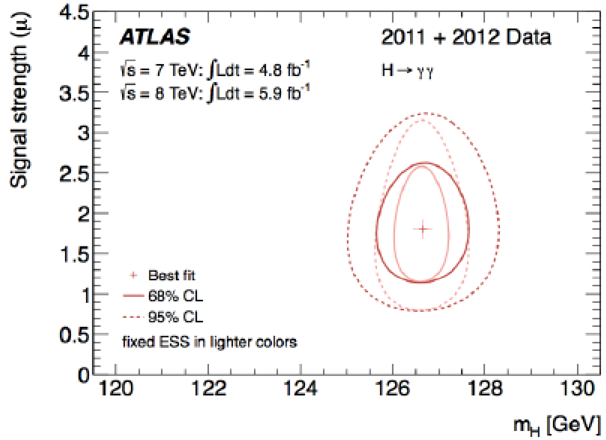


Signal Strength per Category



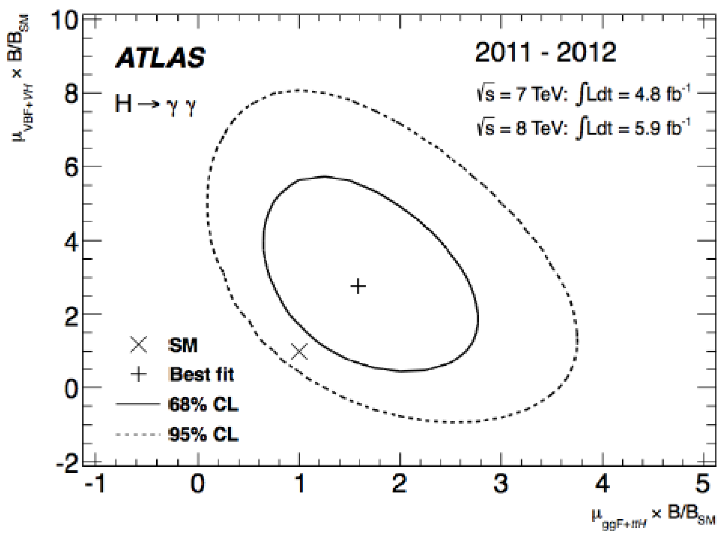
Properties of new resonance

- **Mass**
  → Likelihood contours in the (μ, mH) plane. Uncertainty on fit comparable for statistical and systematic uncertainty



- **With and without ES uncertainty**

- **Couplings**
  → Constraints in the plane of μ (ggF+$t\bar{t}$ *H* ×B/B_{SM}) and μ (VBF+*V H* × B/B_{SM}), where *B* is the branching ratio for *H*→γγ, can be obtained
  → The data are compatible with the SM at the 1.5 σ level
- **Production modes merged due to similar couplings and small stats (with current data-set)**



Since then........ (4-th July)

ATLAS

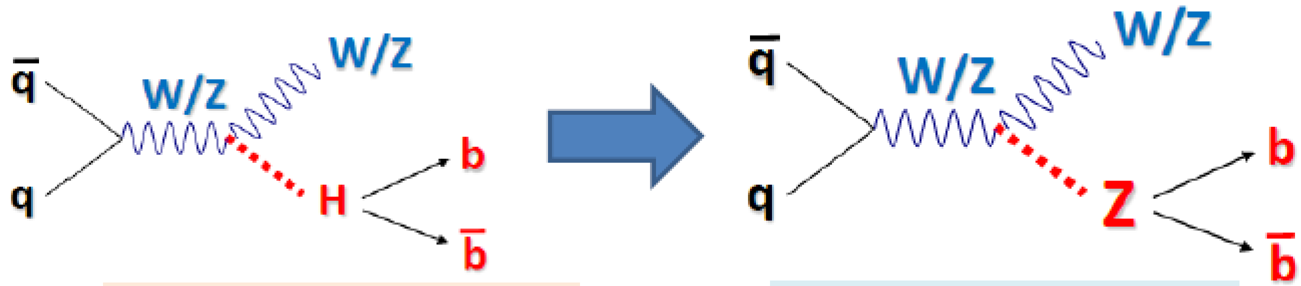
- The WW channel completed with 5.8fb^{-1} and released end of July, included in the SM Higgs published paper.
- Low mass channels with decay to WW, bb, $\tau\tau$ updated with ~13fb^{-1} (2012) and released for HCP conference.
- Update on combination for signal strength.

CMS

- Updated ZZ, WW, bb, $\tau\tau$ with ~12 fb^{-1} (2012).
- Updated combination, couplings and spin.

- **Tevatron**
- Update on H->bb analysis with 10fb^{-1}.

The TEVATRON update

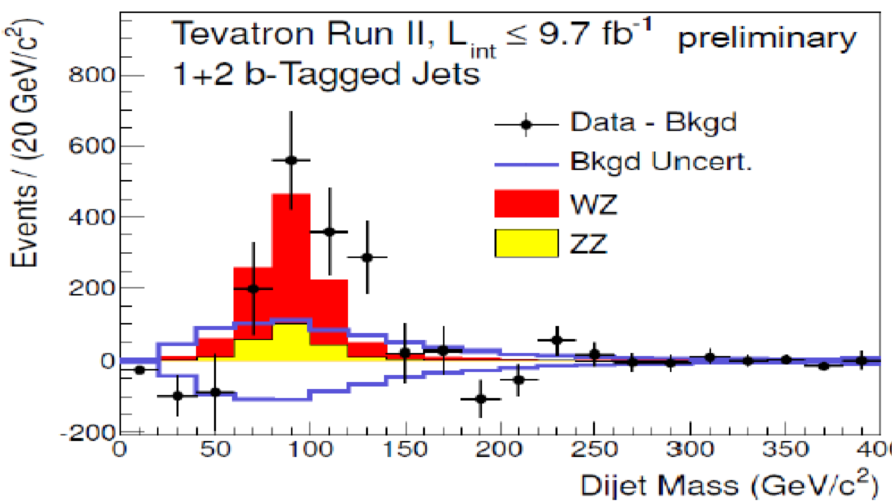


For m_H=115 GeV
Total VH: σ = 46 fb

Replace Z with H
Total VZ: σ = 213 fb

Z→bb yields is 5 times larger, but more W+jets at lower mass, also there is **BG from WW**.

Measure diboson cross section with **exactly the same** analysis procedure.



$\sigma(WZ+ZZ) = 3.0 \pm 0.9$ pb

(Fit performed with MVA output without Higgs signal)

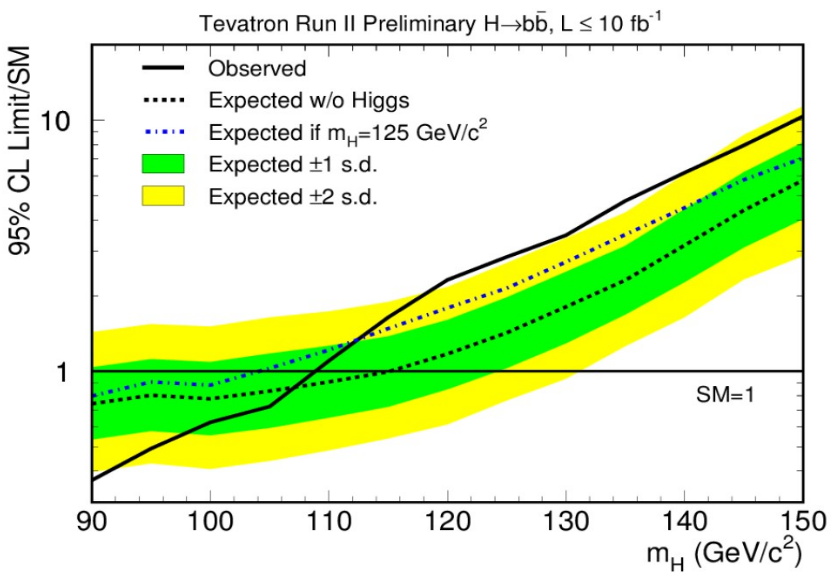
$\sigma(VZ)^{NLO}_{SM} = 4.4 \pm 0.3$ pb

The TEVATRON update

$\sigma(WH+ZH) \times Br(H \to b\bar{b})$

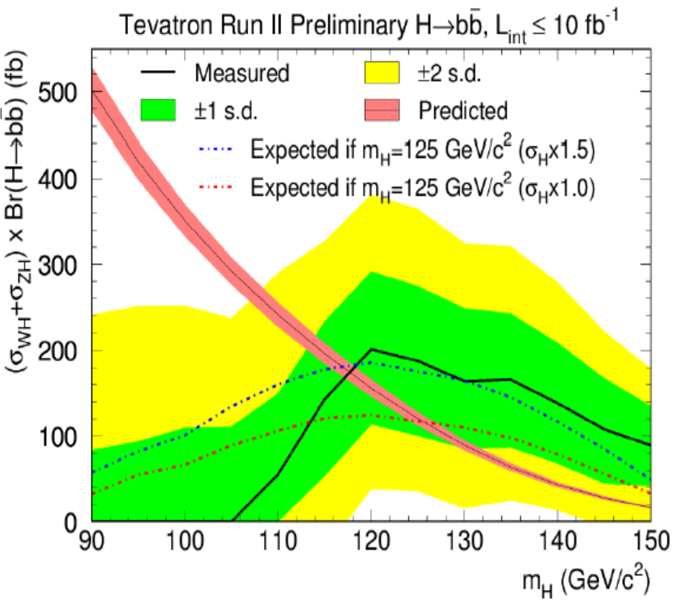
$= 0.19 \pm 0.09$ (stat+syst) pb

$\to \mu = 1.56 \pm^{0.72}_{0.73}$ @M_H=125GeV



95% CL SM Higgs limit ratio @M_H = 125 GeV

Exp : 1.4 Obs : 2.9



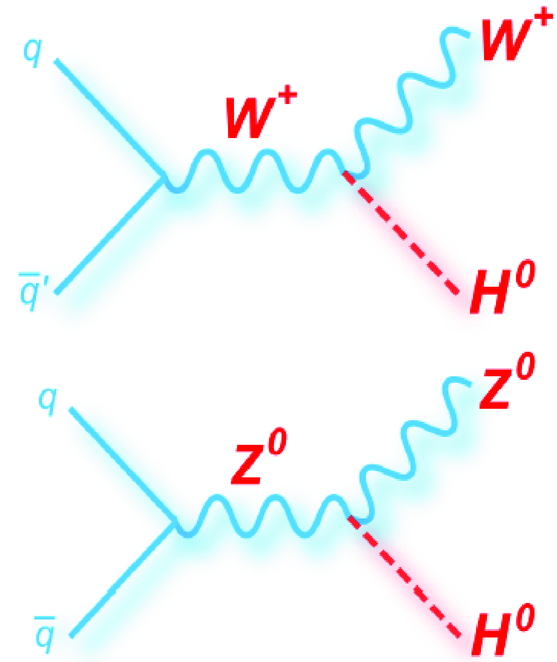
$\mu = 1.56 \pm^{0.72}_{0.73}$

$(\sigma_{WH} + \sigma_{ZH}) \times \mathcal{B}(H \to b\bar{b}) = 0.19 \pm 0.09$ (stat + syst) pb

SM expectation : 0.12 ± 0.01 pb

SM Higgs @ 125 GeV

ATLAS H->bb: analysis strategy



Search for Higgs decaying to pair of b-quarks

- Associated production to reduce backgrounds

The analysis is divided into three channels

- Two (llbb), one (lνbb) or zero (ννbb),) (l=e,μ)

Cuts common to all channels

- Two or three jets: 1st jet $p_T > 45$ GeV
  other jets $p_T > 20$ GeV
- Two b-tags: 70% efficiency per tag (mistag ~1%)

Two lepton

ZH → llbb
- No additional leptons
- $E_t^{miss} < 60$ GeV
- $83 < m_Z < 99$ GeV
- Single & di-lepton trigger

One lepton

WH → lνbb
- No additional leptons
- $E_t^{miss} > 25$ GeV
- $40 < M_T^W < 120$ GeV
- Single lepton trigger

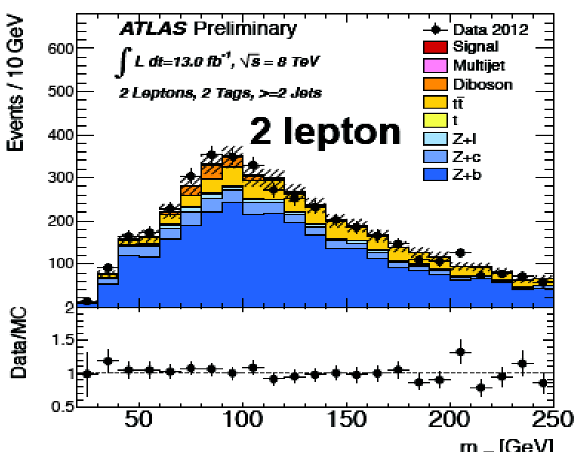
Zero lepton

ZH → ννbb
- No leptons
- $E_t^{miss} > 120$ GeV
- E_t^{miss} trigger

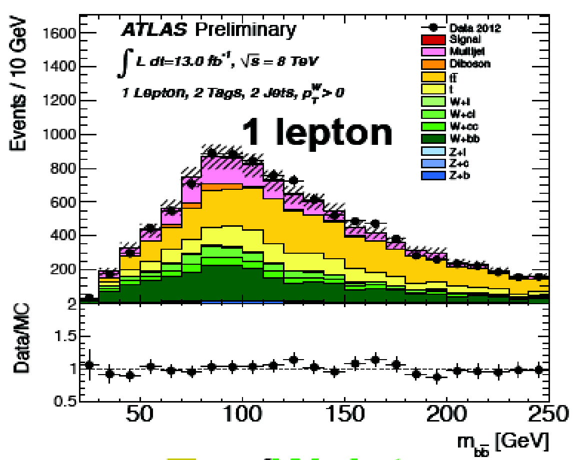
H->bb: backgrounds

Signal:	WH/ZH Pythia8
Diboson	WW/WZ/ZZ Herwig
Multijet:	Data driven
Ttbar:	MC@NLO
Single Top	Acer/MC@NLO
W+b	Powheg
W+c/light-jets	Alpgen
Z+ b/c/light-jets	Alpgen/Sherpa

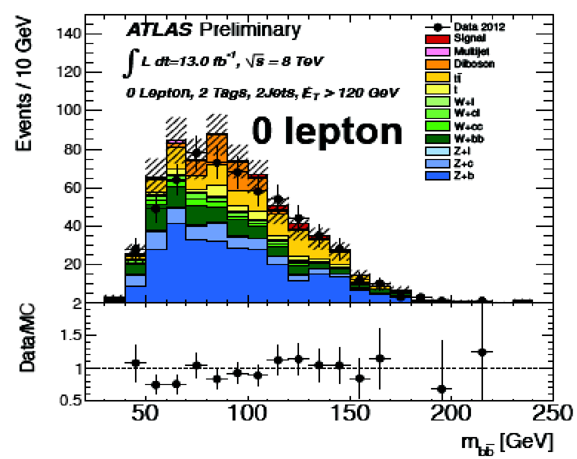
- Background shapes from simulation and normalised using data (flavour & signal fit)
- Multi-jet bkg determined by data-driven techniques
- WZ(Z→bb) & ZZ(Z→bb) resonant bkg normalisation and shape from simulation



Z+jets

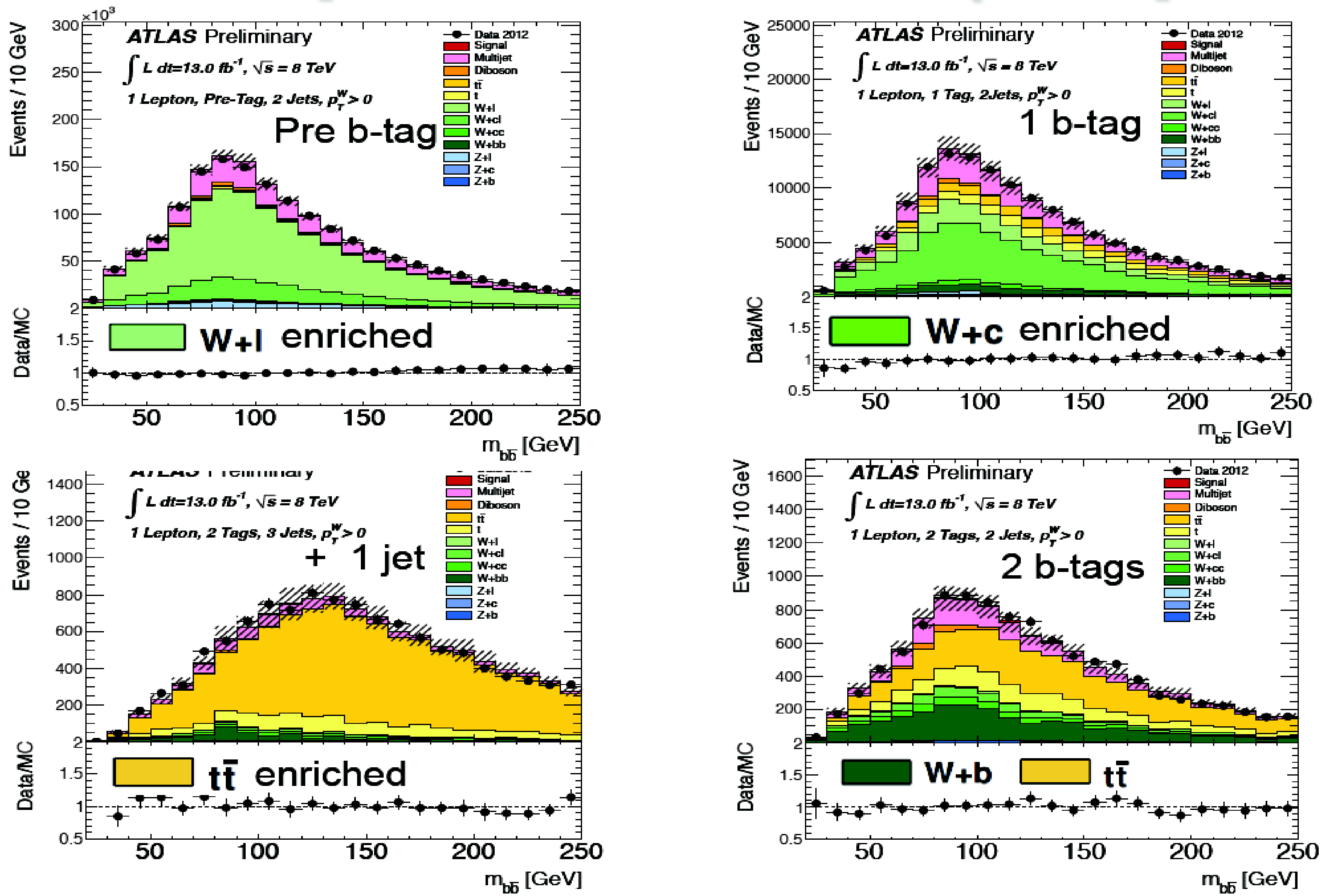


Top/W+jets



Z+jets/W+jets/Top

H->bb: example flavour fit



H->bb: systematic uncertainties

Main experimental uncertainties

b-tagging and **jet energy** dominate

- Jets: components (7 JES, 1 p_T^{Reco}, resol.)
- E_T^{miss} – scale and resolution
- bTagging – light, c & 6 p_T efficiency bins
- Top, W, Z background modelling
- Lepton/ Multijet / diboson / Luminosity
- MC statistics

Main theoretical uncertainties

- W/Z+jet m_{bb} and V pT
- BR(H→bb) @ mH=125 GeV
- Signal cross-sections include pT-dependent electroweak correction factors
- Single top/top normalisation
- W+c, Z+c

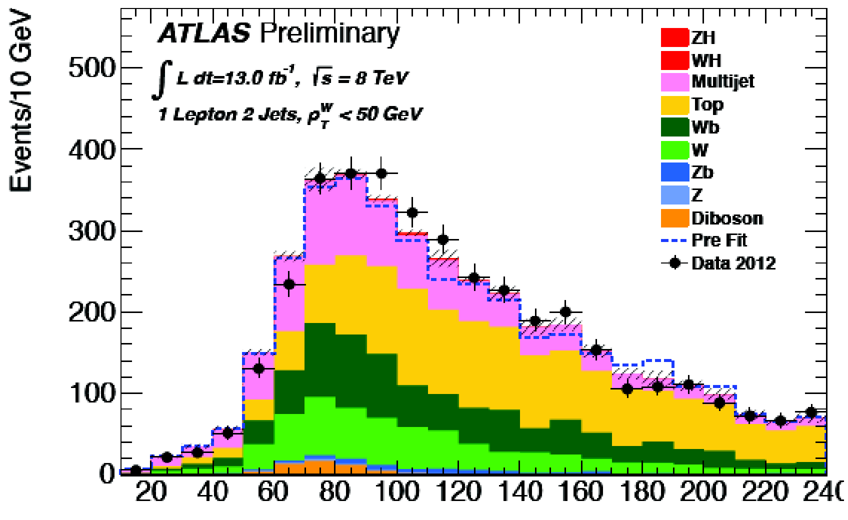
Uncertainty [%]	0 lepton	1 lepton	2 leptons
b-tagging	6.5	6.0	6.9
c-tagging	7.3	6.4	3.6
light tagging	2.1	2.2	2.8
Jet/Pile-up/E_T^{miss}	20	7.0	5.4
Lepton	0.0	2.1	1.8
Top modelling	2.7	4.1	0.5
W modelling	1.8	5.4	0.0
Z modelling	2.8	0.1	4.7
Diboson	0.8	0.3	0.5
Multijet	0.6	2.6	0.0
Luminosity	3.6	3.6	3.6
Statistical	8.3	3.6	6.6
Total	25	15	14

Background systematics (after cuts)

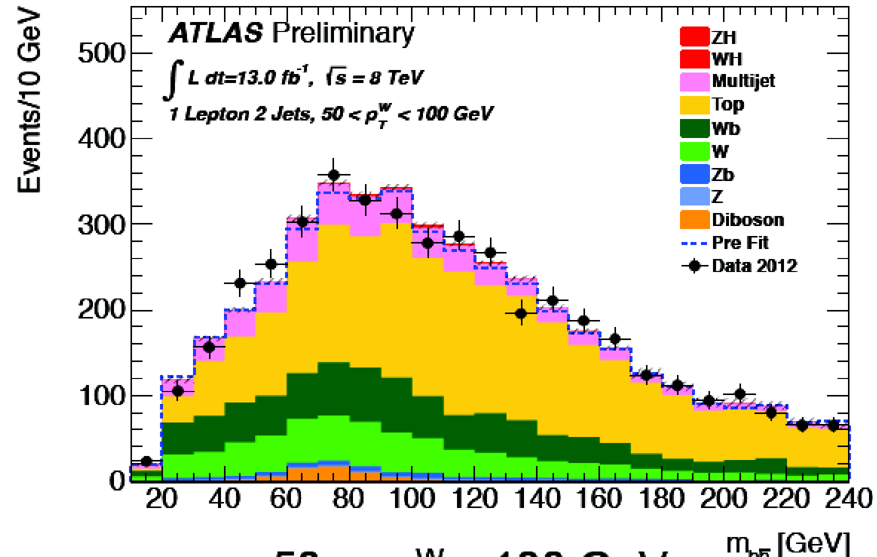
Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	*WH*	*WH*	*ZH*
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \to bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

Signal systematics (after cuts)

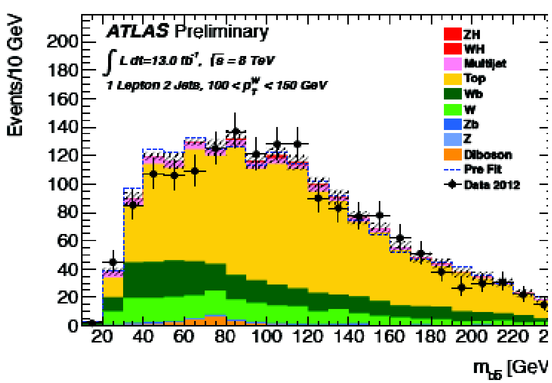
H->bb: m_{bb} distribution (1 lepton)



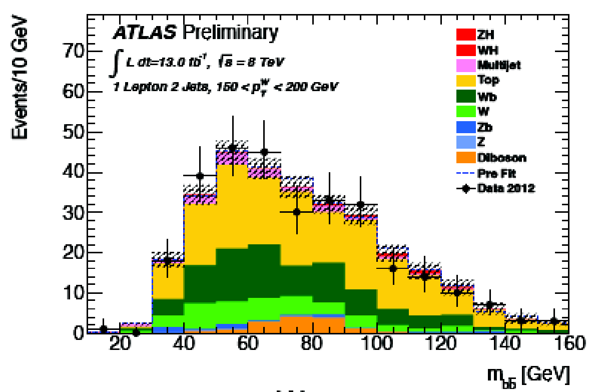
$p_T^W < 50$ GeV



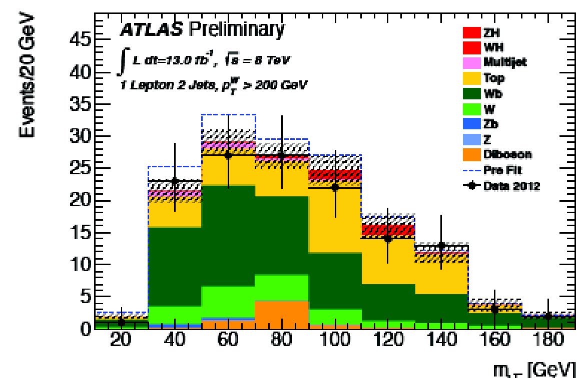
$50 < p_T^W < 100$ GeV



$100 < p_T^W < 100$ GeV



$150 < p_T^W < 200$ GeV



$p_T^W > 200$ GeV

H->bb: Diboson production

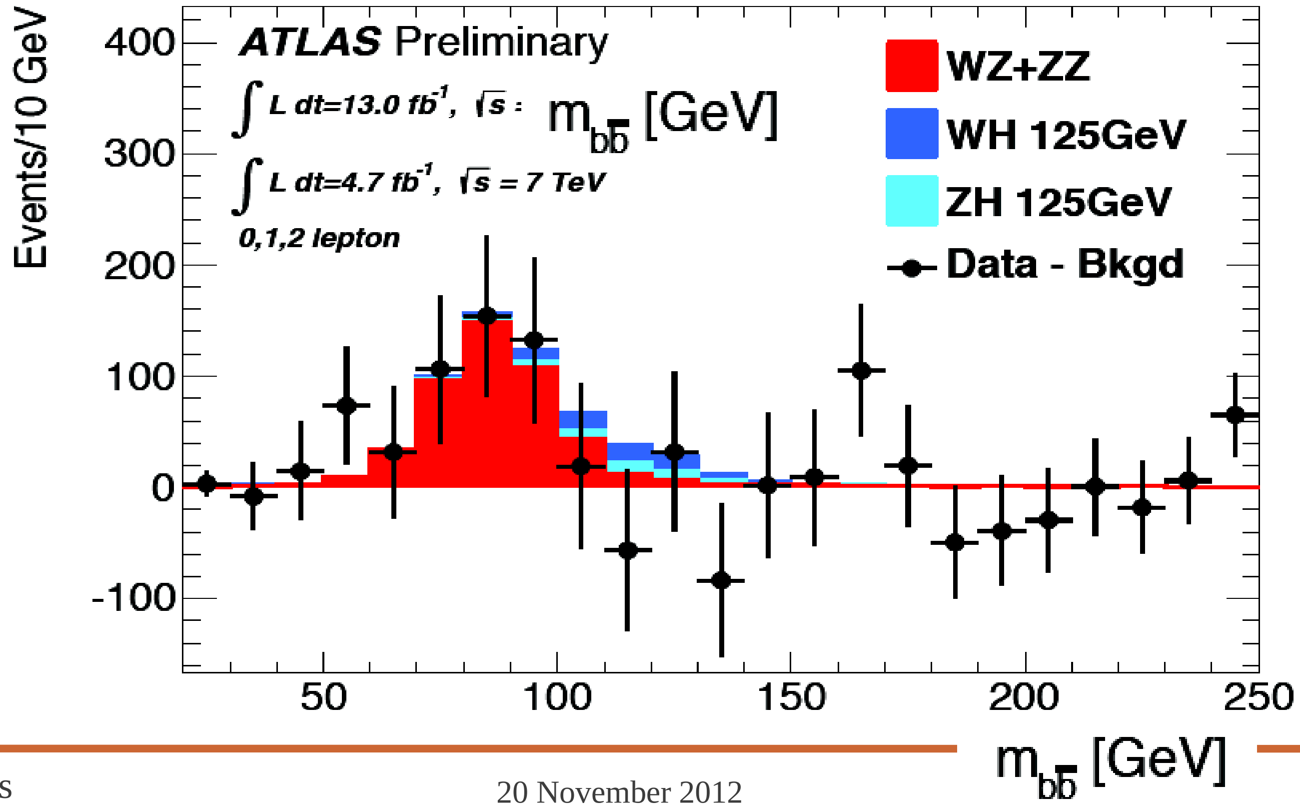
WZ & ZZ production with $Z\rightarrow b\bar{b}$ similar signature, but 5 times larger cross-section

Perform a separate fit to search for it and to validate the analysis procedure

- Profile likelihood fit performed (with full systematics)
- All backgrounds (except diboson) subtracted
- Uses full $p_T^{W,Z}$ range, done individually for each channel & year (see backup)

Clear excess is observed in data at expected mass (all lepton channels combined)

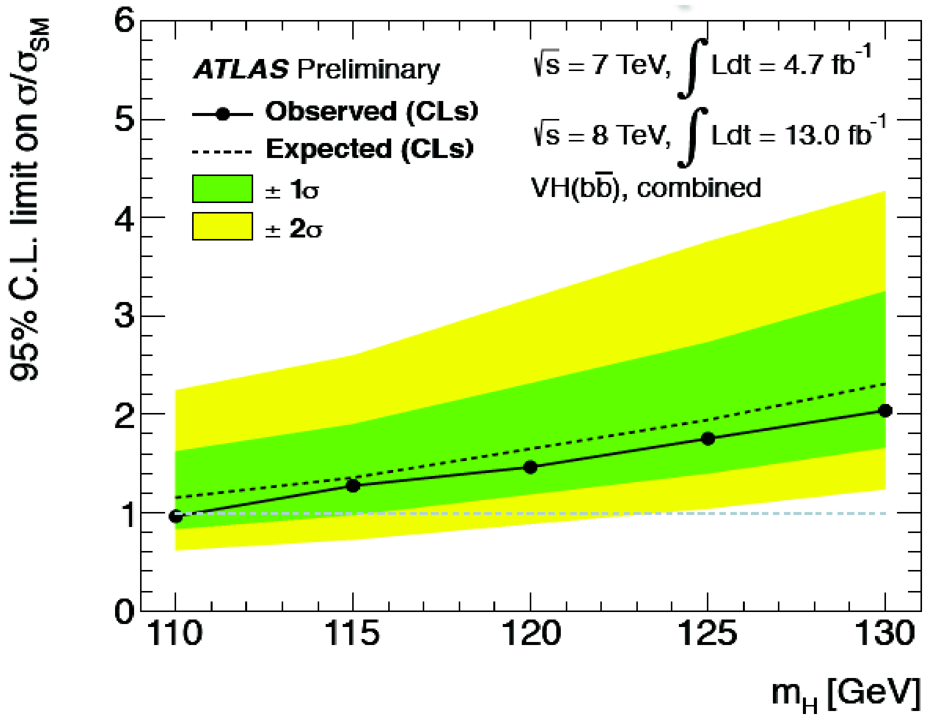
Results: $\sigma/\sigma_{SM} = \mu_D = 1.09 \pm 0.20$ (stat) ± 0.22 (syst). The significance is 4.0σ

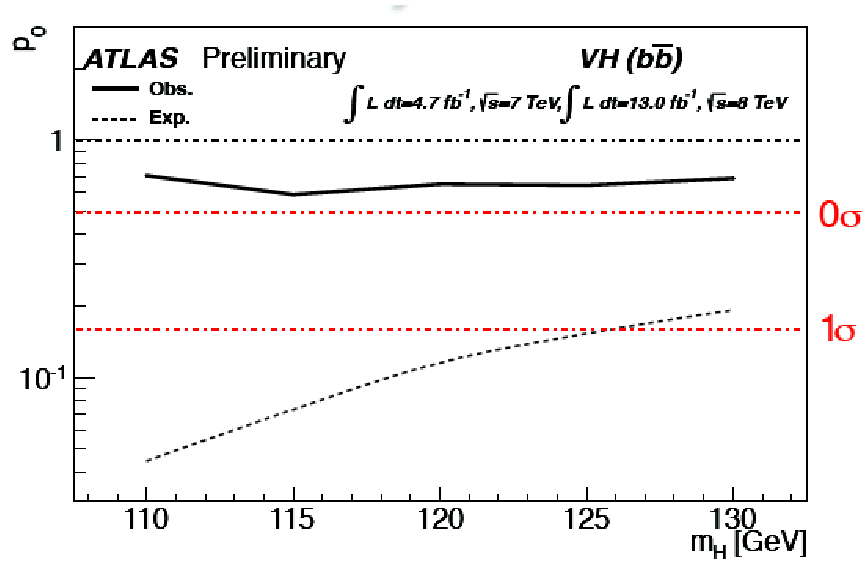


H->bb: Expected and observed events

	0-lepton, 2 jet			0-lepton, 3 jet			1-lepton					2-lepton				
Bin	E_T^{miss} [GeV]						p_T^W [GeV]					p_T^Z [GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
WH	0.8	0.4	0.4	0.2	0.2	0.2	10.6	12.9	7.5	3.6	3.6	0.0	0.0	0.0	0.0	0.0
Top	89	25	8	92	25	10	1440	2276	1120	147	43	230	310	84	3	0
$W+c$,light	30	10	5	9	3	2	580	585	209	36	17	0	0	0	0	0
$W+b$	35	13	13	8	3	2	770	778	288	77	64	0	0	0	0	0
$Z+c$,light	35	14	14	8	5	8	17	17	4	1	0	201	230	91	12	15
$Z+b$	144	51	43	41	22	16	50	63	13	5	1	1010	1180	469	75	51
Diboson	23	11	10	4	4	3	53	59	23	13	7	37	39	16	6	4
Multijet	3	1	1	1	1	0	890	522	68	14	3	12	3	0	0	0
Total Bkg.	361	127	98	164	63	42	3810	4310	1730	297	138	1500	1770	665	97	72
	± 29	± 11	± 12	± 13	± 8	± 5	± 150	± 86	± 90	± 27	± 14	± 90	± 110	± 47	± 12	± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

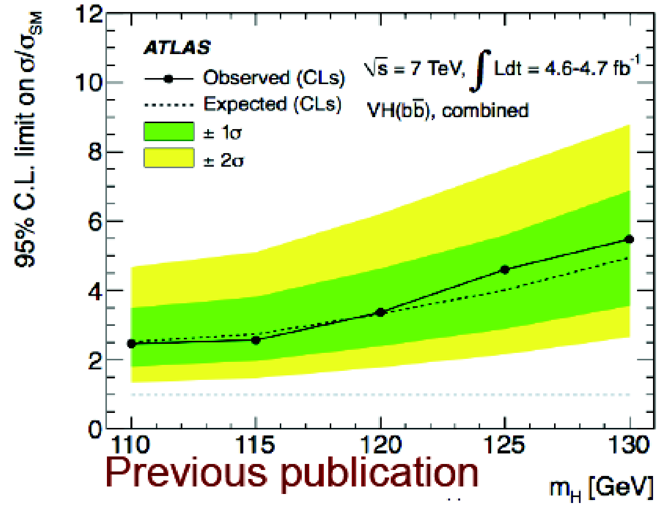
H->bb: Expected and observed events





- Observed (expected) limit at m_H =125 GeV
  - 1.8 (1.9) x SM prediction
  - $\sigma/\sigma_{SM} = \mu = -0.4 \pm 0.7(\text{stat.}) \pm 0.8(\text{syst.})$
- Observed (expected) p_0 value: 0.64 (0.15)
- Exclusion at m_H ~ 110 GeV

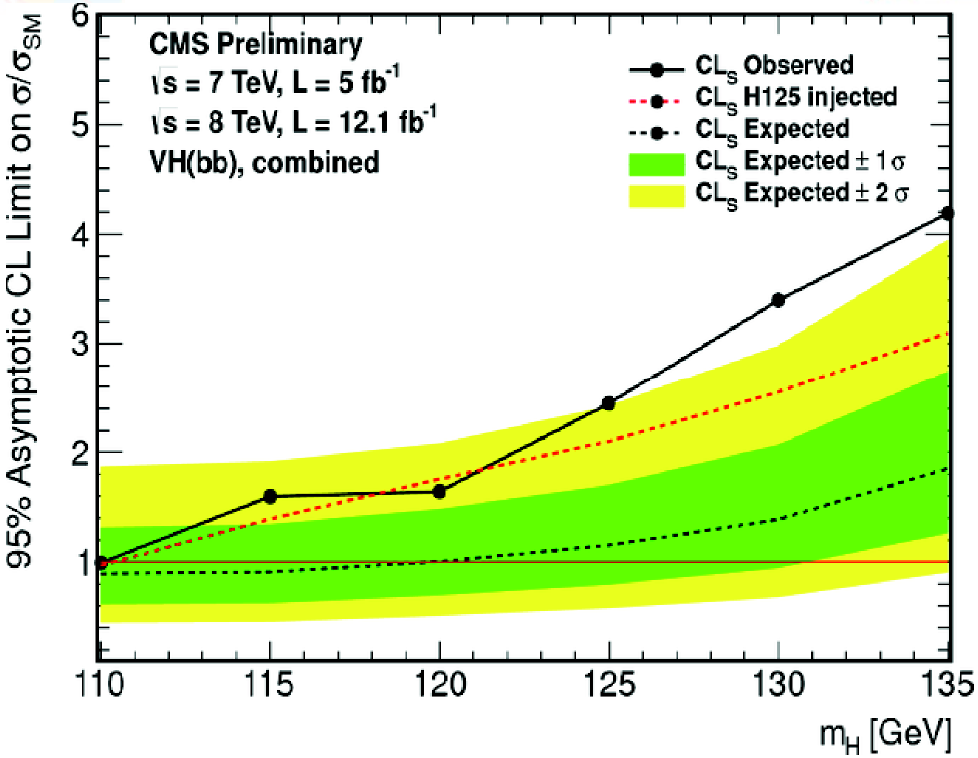
More than doubled the analysis sensitivity ➡

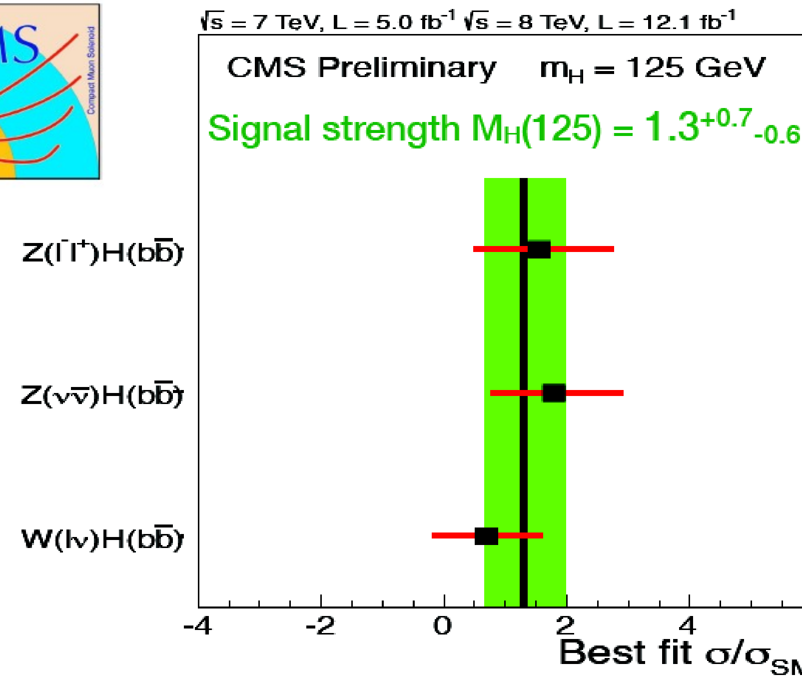


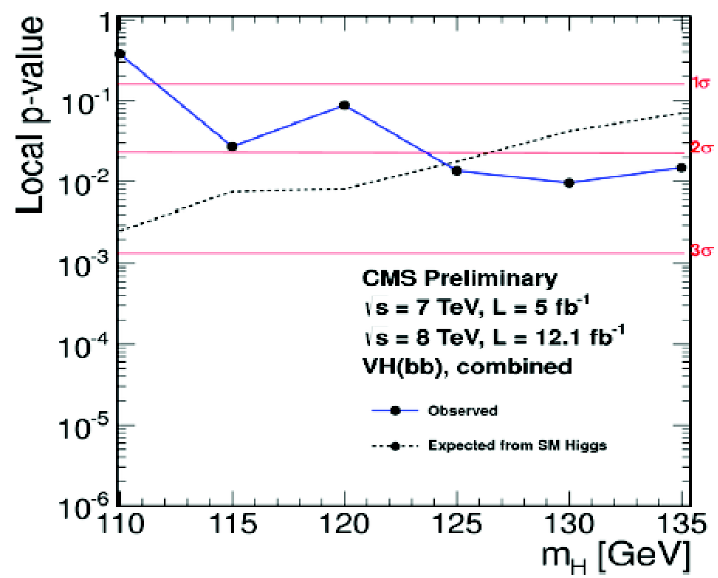
Previous publication

http://arxiv.org/abs/1207.0210

VH, H→bb results





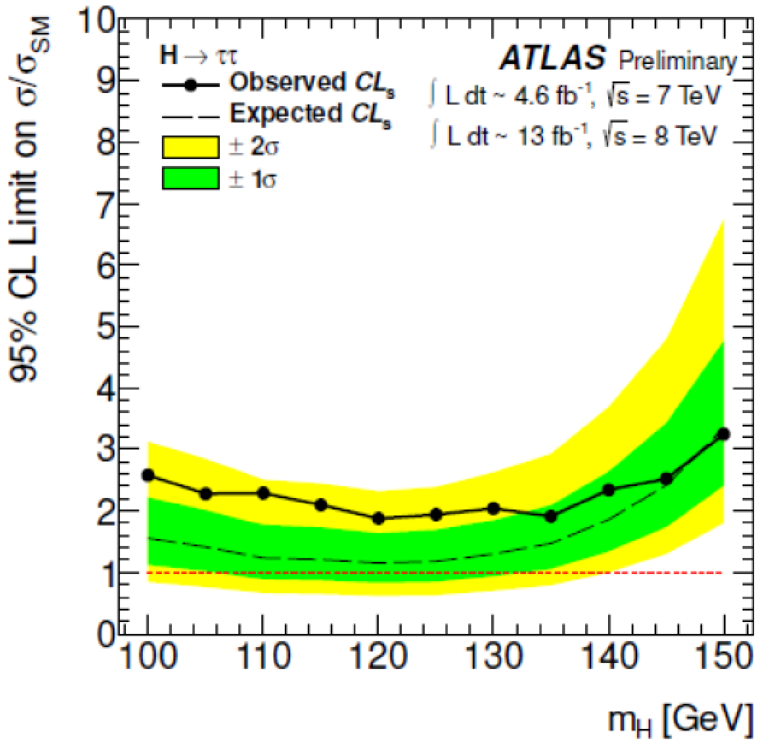


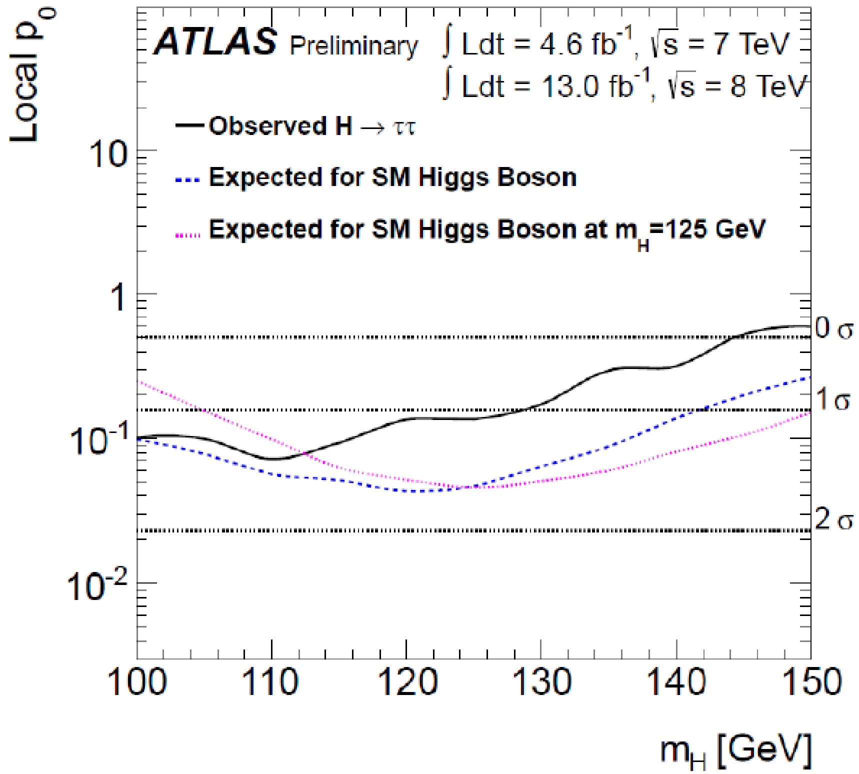
- Obs (exp) excess 2.2σ (2.1σ) @ 125 GeV
  [Tevatron obs (exp) ~2.8σ (1.5σ)]

- Reached SM sensitivity < 120 GeV.

H->ττ: sensitivity not yet reached

- Calculated limit and significance using MMC distribution as the discriminant.
- To extract signal, Profile likelihood was used.



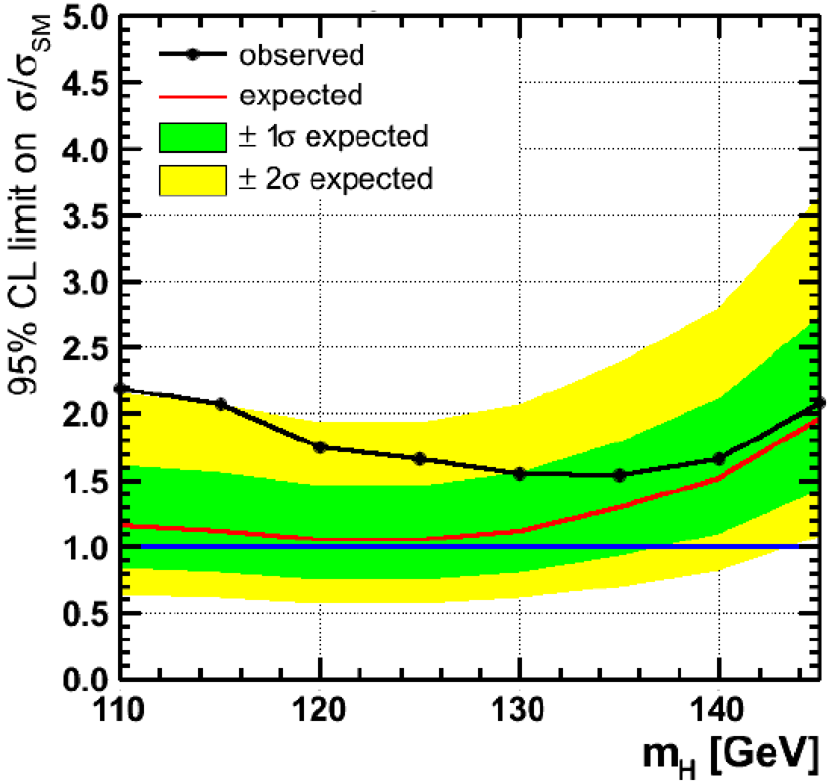


Expected:1.2xSM (μ=0) **Observed:1.9xSM** **Expected:1.7σ** (μ=1) **Observed:1.1σ**

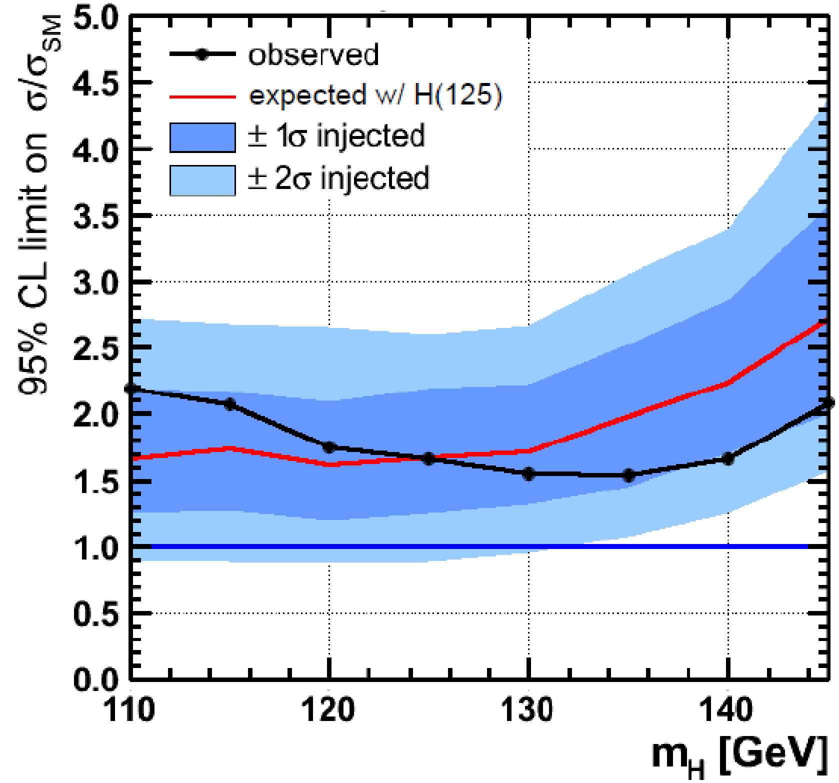
Best fit value of Signal Strength (μ) is 0.7 ±0.7

Observed Limit (inclusive $H\rightarrow\tau\tau$)

Expectation w/o Higgs:



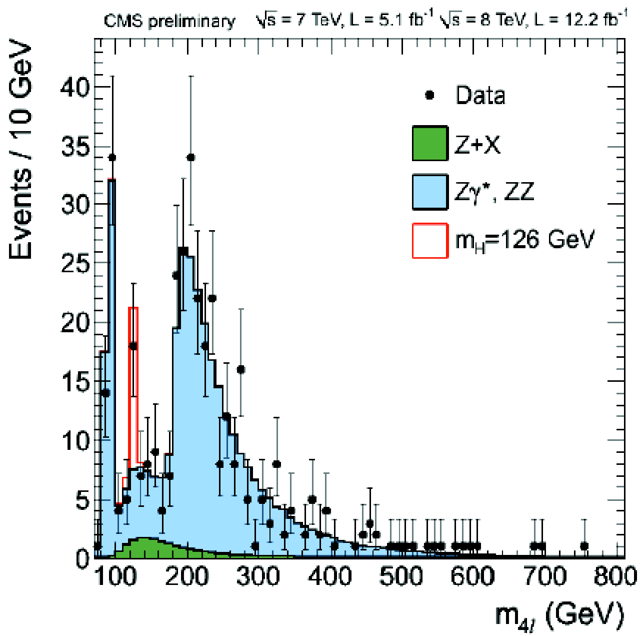
Expectation w/ SM H(125):[1)]

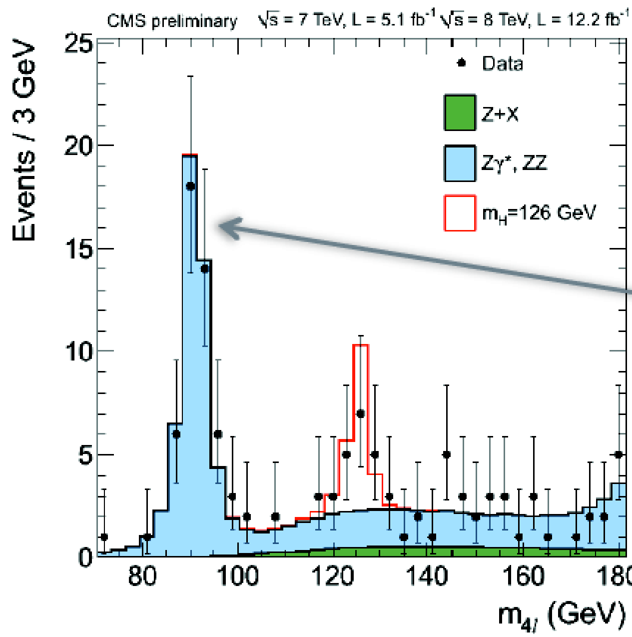


- Sensitivity(125 GeV)=1.05. Observed limit(125 GeV)=1.66.
- Compatible with Higgs boson signal at 125 GeV but also with background only hypothesis.

[1)] no fit to data for expectation

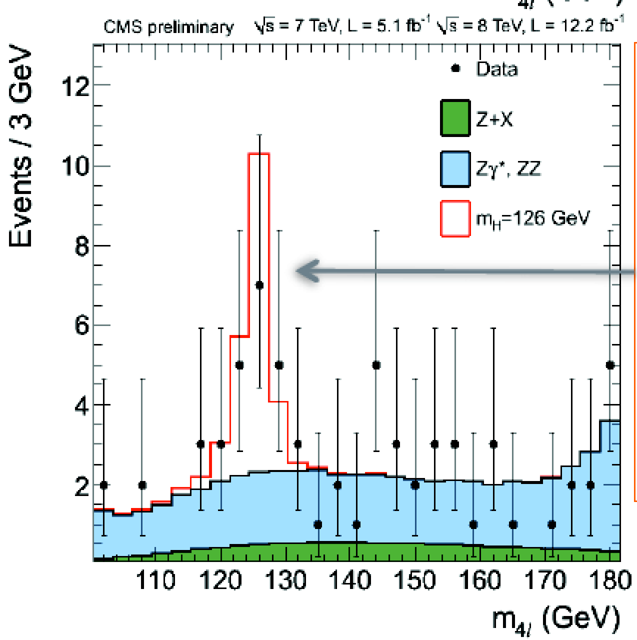
Results





Good agreement between predicted and observed ZZ continuum.

Z→4l peak is in place and in agreement with prediction. Fit of the Z→4l peak shows δm~0.4±0.28 GeV and expected resolution.



X→ZZ→4l peak is there and increasing in statistics corresponding to luminosity and expectation of H→ZZ→4l

For m(4l) = 121.5..130.5 GeV:

- Expected background: 6.5 events
- Expected signal (m_H=126 GeV): 12.5 events
- Signal:Bckg ~ 2:1!
- Observed: 17 events

ATLAS: update on combination

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\, dt$ [fb^{-1}]
		2011 $\sqrt{s}$ =7 TeV	
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	4.8
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	4.8
$H \to \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet, boosted, } VH\}$	4.7
	$\tau_{lep}\tau_{had}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet, boosted, 2-jet}\}$	4.7
	$\tau_{had}\tau_{had}$	$\{\text{boosted, 2-jet}\}$	4.7
$VH \to Vbb$	$Z \to \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200 \text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	4.7
		2012 $\sqrt{s}$ =8 TeV	
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	5.8
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	5.9
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{\text{0-jet, 1-jet}\}$	13
$H \to \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{\ell\ell\} \otimes \{\text{1-jet, 2-jet, boosted, } VH\}$	13
	$\tau_{lep}\tau_{had}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet, boosted, 2-jet}\}$	13
	$\tau_{had}\tau_{had}$	$\{\text{boosted, 2-jet}\}$	13
$VH \to Vbb$	$Z \to \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200 \text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	13
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	13
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	13

Channels entering HCP combination

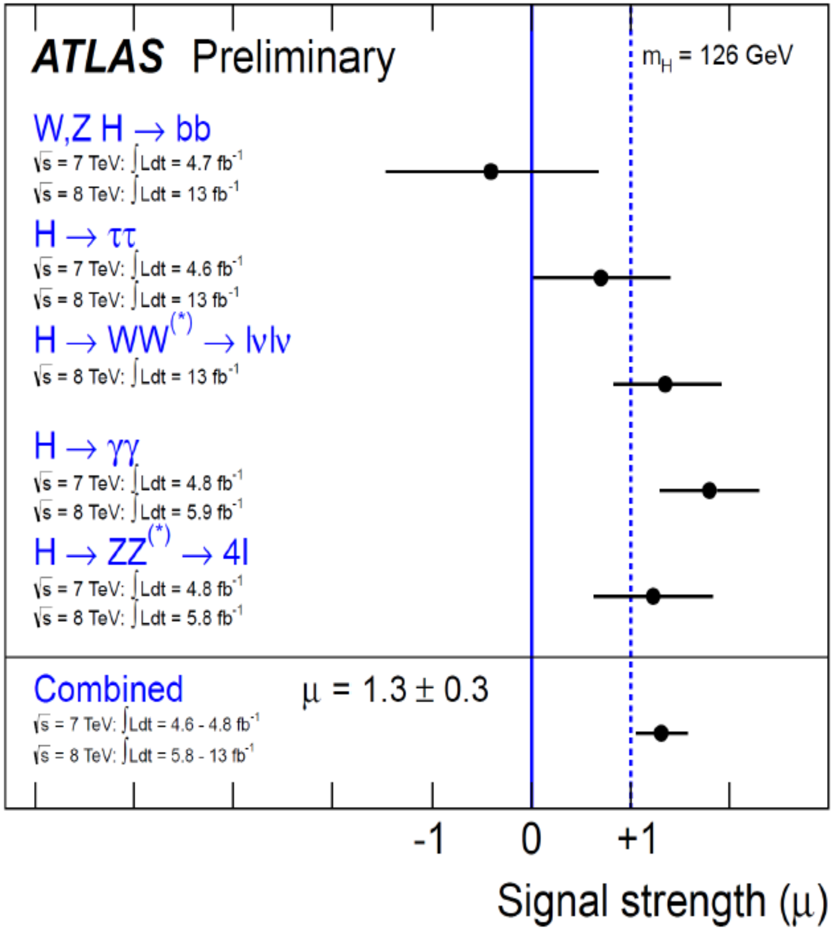
Best–fit Higgs mass m_H :

126.0 ± 0.4 (stat) ± 0.4 (syst) GeV

Best-fit signal strength:

μ = 1.3 ± 0.3

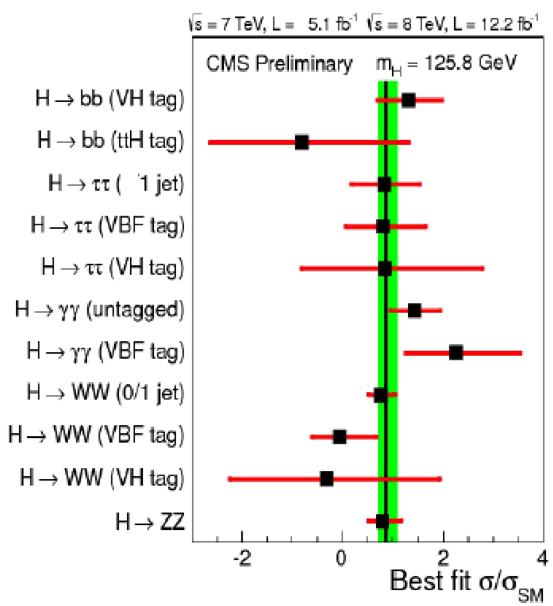
Coupling measurement not updated for HCP: uncertainies of 20-30%

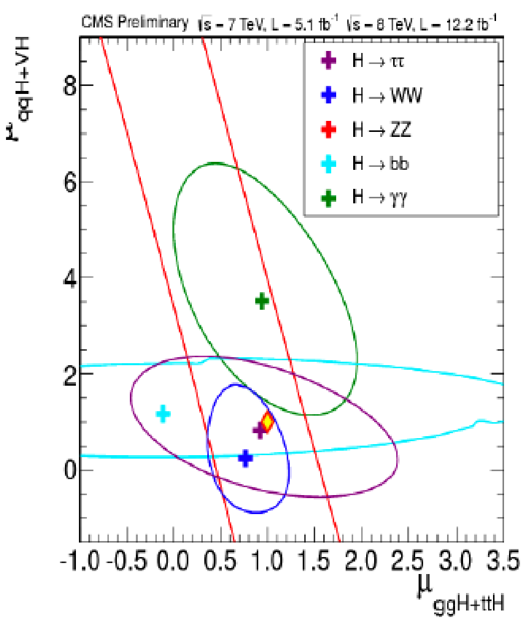


Signal strength

- Combined significance at MH=125.8 GeV: 6.9 σ
- Combined $\sigma/\sigma_{SM}=0.88\pm0.21$
- Overall satisfactory level of compatibility of the individual channels to the SM cross section
  - p-value=0.46 from pseudo experiments
- Break-down production mode shows compatibility within 1σ for each decay channel

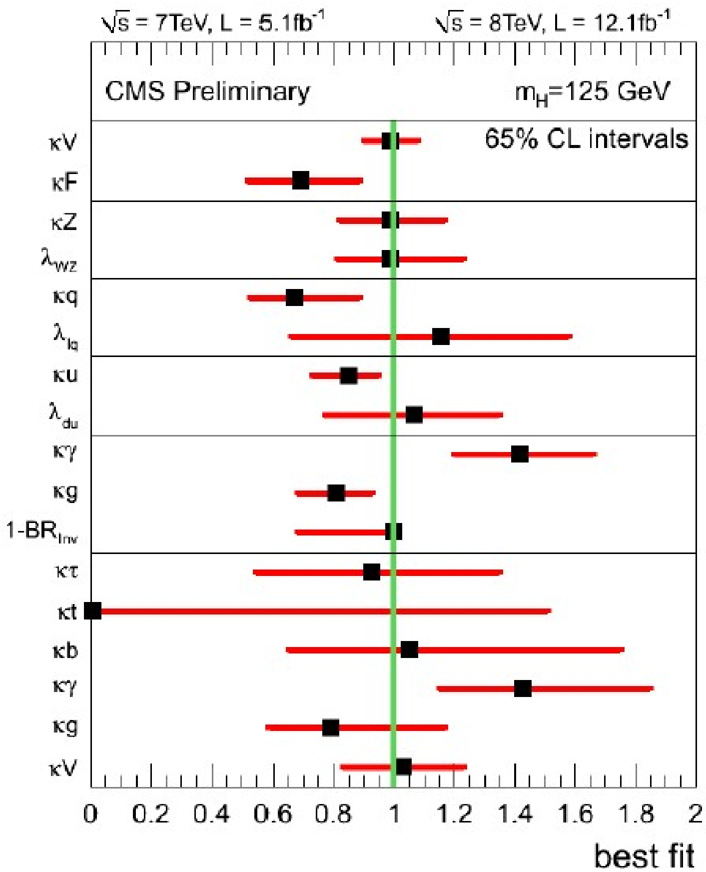
MH=125.8 GeV	Expected (σ)	Observed (σ)
ZZ	5.0	4.4
γγ	2.8	4.0
WW	4.3	3.0
bb	2.2	1.8
ττ	2.5	1.5
Combination	7.8	6.9





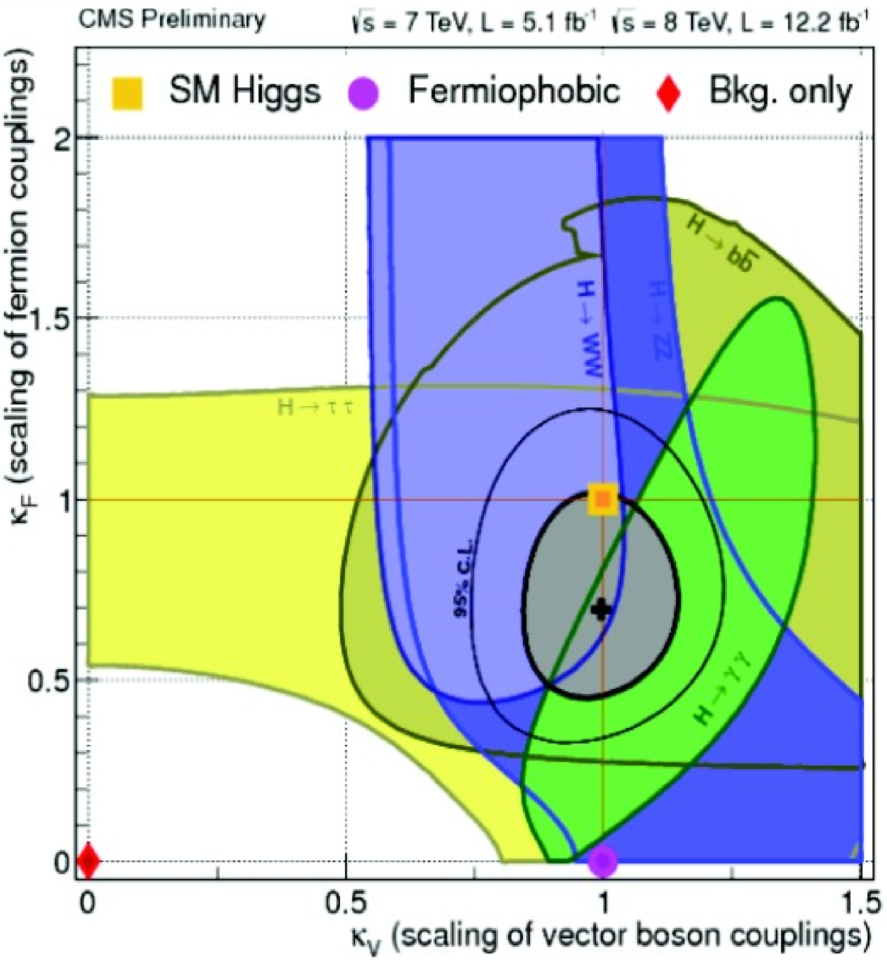
Couplings summary

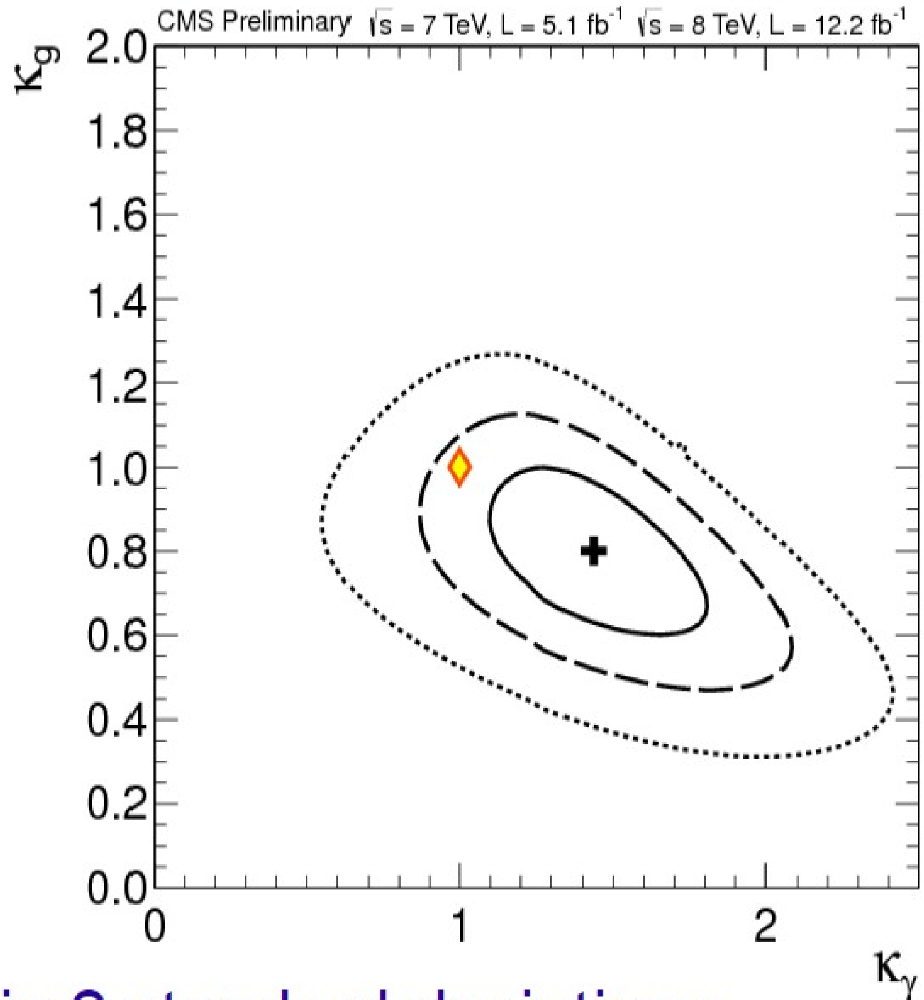
- Overall good compatibility with SM predictions
- Still limited precision



Model parameters	Assessed scaling factors (95% CL intervals)	
λ_{WZ}, κ_Z	λ_{WZ}	[0.57–1.65]
$\lambda_{WZ}, \kappa_Z, \kappa_f$	λ_{WZ}	[0.67–1.55]
κ_V	κ_V	[0.78–1.19]
κ_f	κ_f	[0.40–1.12]
κ_γ, κ_g	κ_γ	[0.98–1.92]
	κ_g	[0.55–1.07]
$\mathcal{B}(H \to BSM), \kappa_\gamma, \kappa_g$	$\mathcal{B}(H \to BSM)$	[0.00–0.62]
$\lambda_{du}, \kappa_V, \kappa_u$	λ_{du}	[0.45–1.66]
$\lambda_{\ell q}, \kappa_V, \kappa_q$	$\lambda_{\ell q}$	[0.00–2.11]
$\kappa_V, \kappa_b, \kappa_\tau, \kappa_t, \kappa_g, \kappa_\gamma$	κ_V	[0.58–1.41]
	κ_b	[not constrained]
	κ_τ	[0.00–1.80]
	κ_t	[not constrained]
	κ_g	[0.43–1.92]
	κ_γ	[0.81–2.27]

Combination of Higgs Results





Couplings look consistent within 2 standard deviations

- Fermions versus vector bosons
- effective gluon versus photon couplings (loops)

Final comments:

For SM Higgs physics we are shifting from a search-based to a **measurement based program**. It presents a challenge.

In particular **final fitting and fit models undergo much deeper scrutinity and optimisation**

→ **Enormous numbers of nuisance parameters** in the likelihoods require deep understanding of their uncertainties and petential correlations

→ **Fitting process itself is very complicated** and time consuming

→ Mixture of fitered Monte Carlo and data-driven techniques makes **understanding of uncertainties particularly challenging**.