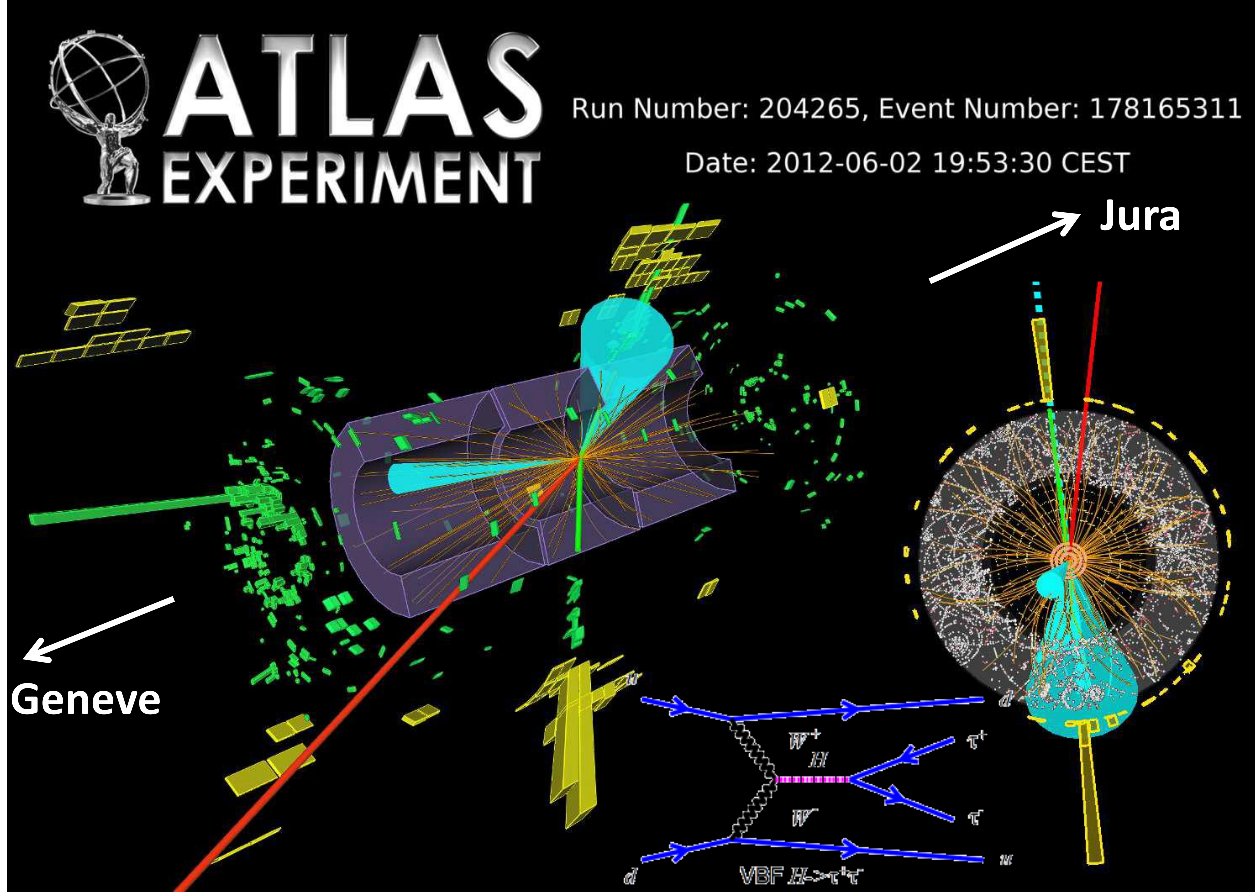


Latest Results on the Standard Model Higgs in ATLAS

Koji Nakamura (KEK)
on behalf of ATLAS collaboration

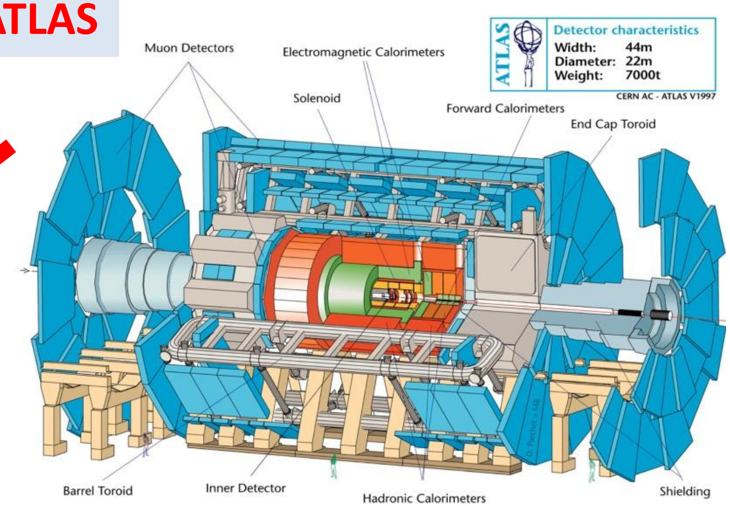
We had fruitful discussions in Japan

http://www.icepp.s.u-tokyo.ac.jp/hcp2012/

http://www.icepp.s.u-tokyo.ac.jp/hc2012/

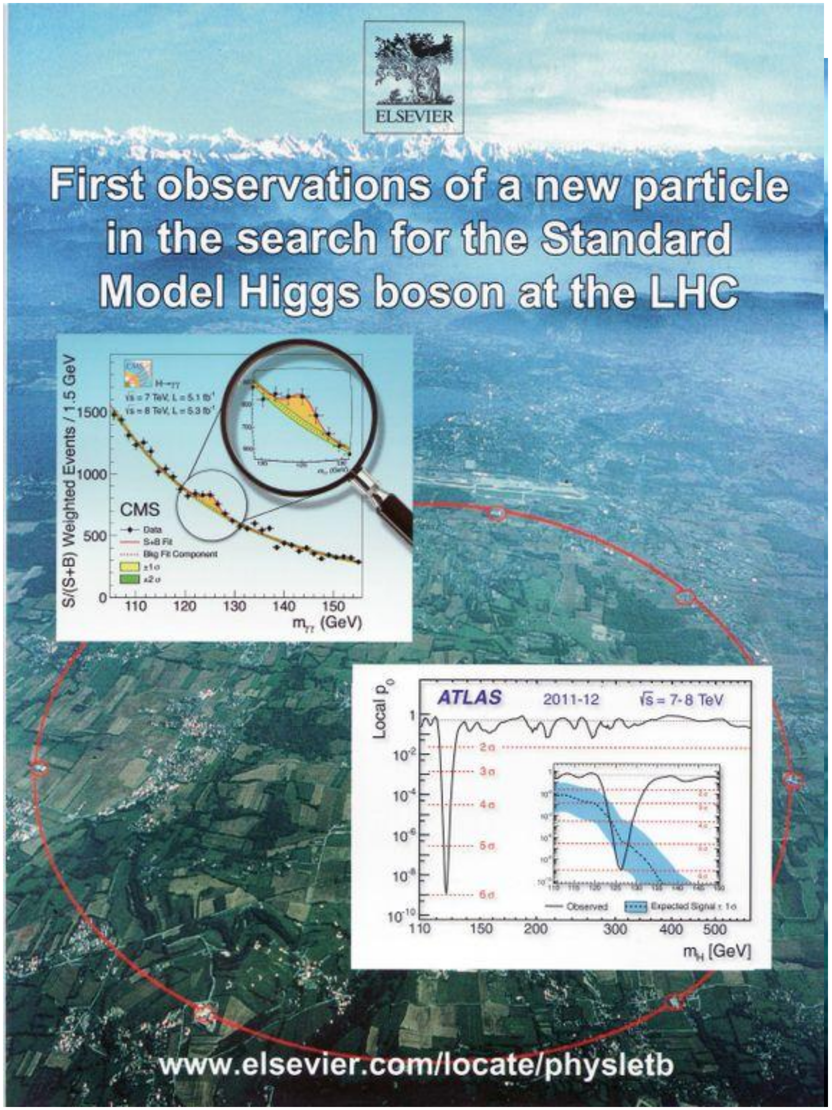
LHC and ATLAS experiment

ATLAS



- 7TeV collisions are Started in March 2010.
- Upgraded CM energy to 8TeV in 2012.
- Extremely successful operation for these 2.5 years.

Historical observation

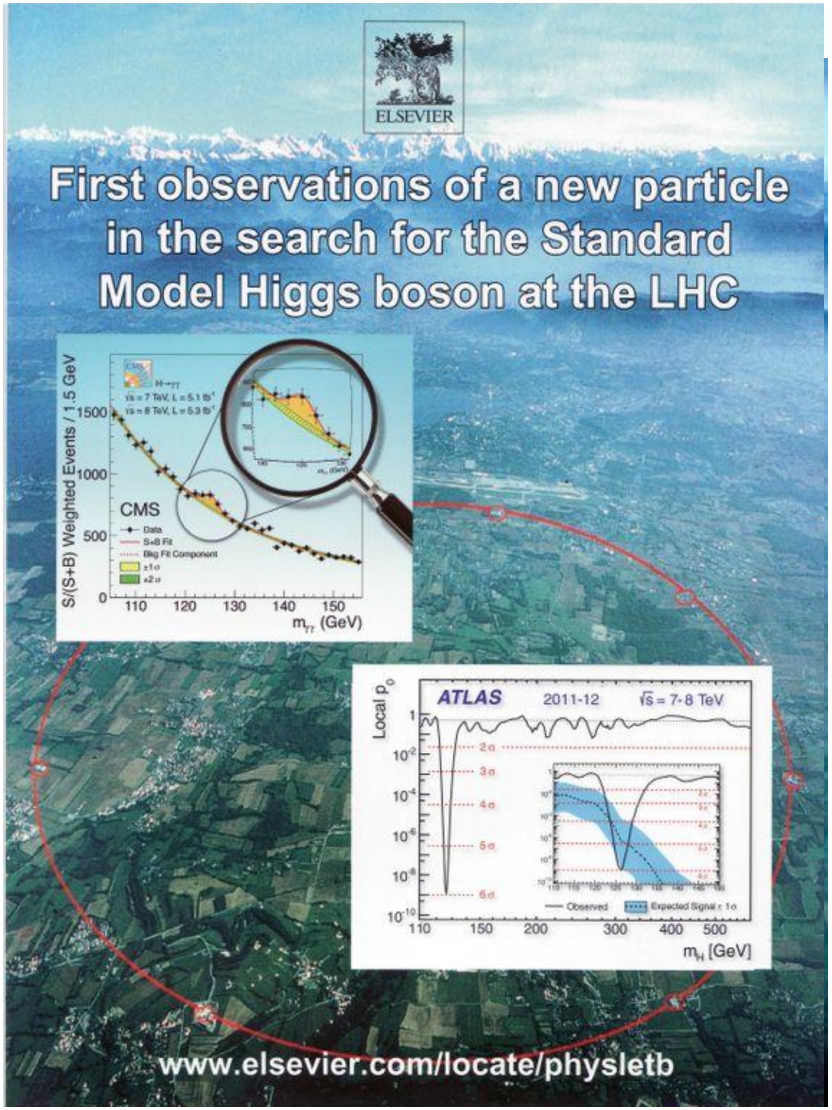


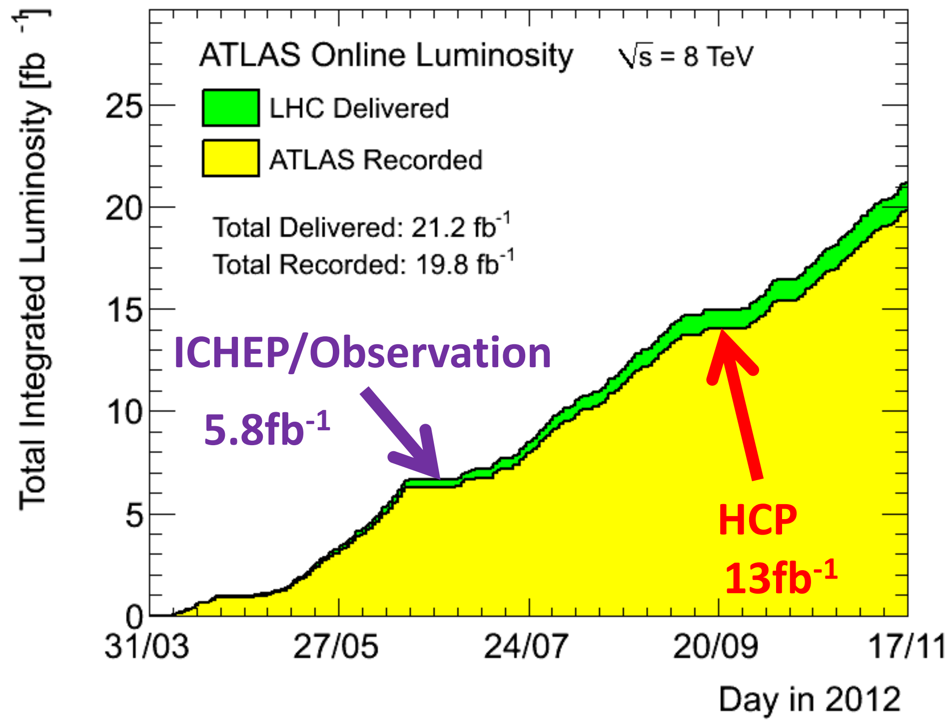
Phys.Lett. B716 (2012) 1-29

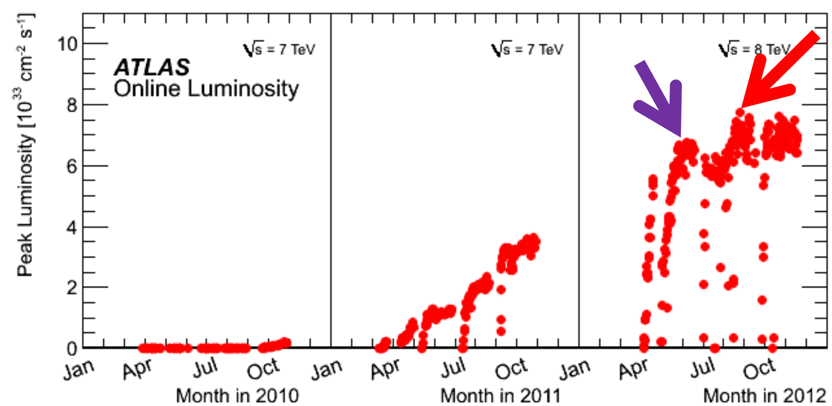
"These results provide conclusive evidence for the discovery of a new particle with mass 126.0±0.4 *(stat)*±0.4 *(sys)* GeV. "

But what's the new particle?

Post Observation





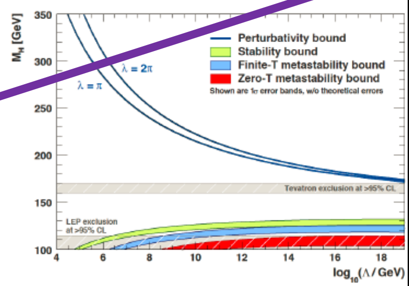


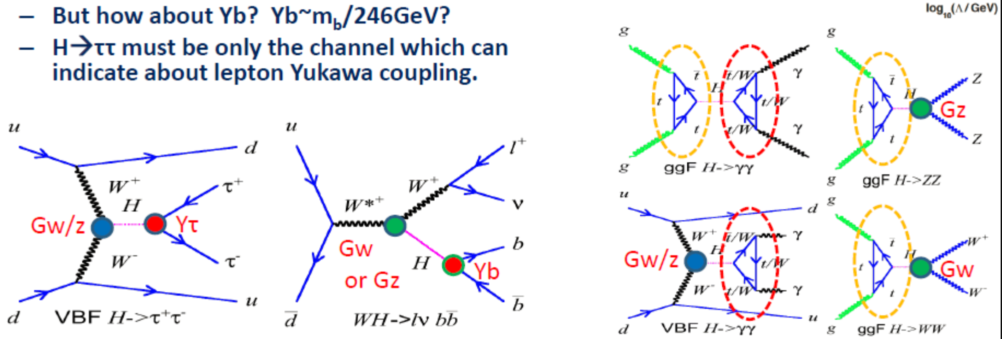
Post Observation

12th July, 2012 KEK seminar

What should we do next?

- Mass measurement → can be done by γγ/ZZ
  - To prove the scale of breaking?
  - But 0.5GeV precision is really necessary?
- Spin measurement → spin 0 or 2? WW/ZZ ?
  - Spin 0 is necessary, if this is Higgs.
- **Coupling measurement**
  - **Almost sure the quark Yukawa does exist (by ggF discovery) and may be via top Yukawa coupling.**
  - **But how about Yb? Yb~m_b/246GeV?**
  - **H→ττ must be only the channel which can indicate about lepton Yukawa coupling.**





July 12th, 2011 KEK seminar 37

We had progress on this.

Today's topic

How coupling measurements are started?

What are H→ττ and bb going on?

Post ICHEP results

- Coupling measurements in Sep 2012 :

  ATLAS-CONF-2012-127

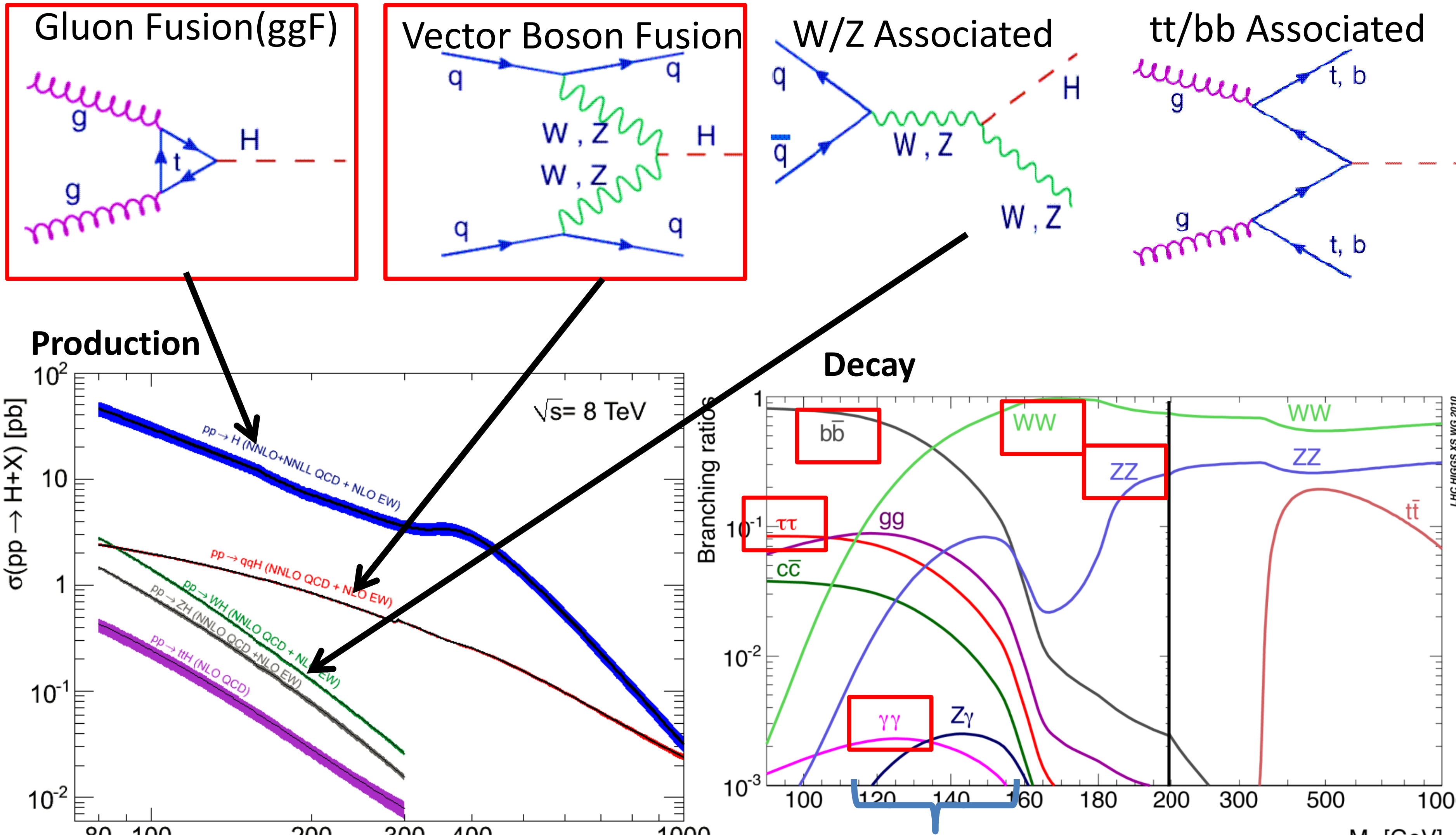
- Updated searches for each channels in Nov 2012 :
  - (H→WW)
  - H→ ττ
  - H→ bb
  - (combination)

  $4.6fb^{-1}$(7TeV)+$13fb^{-1}$(8TeV)

Will be updated to :
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

Coupling measurement

Higgs production and decay @ LHC

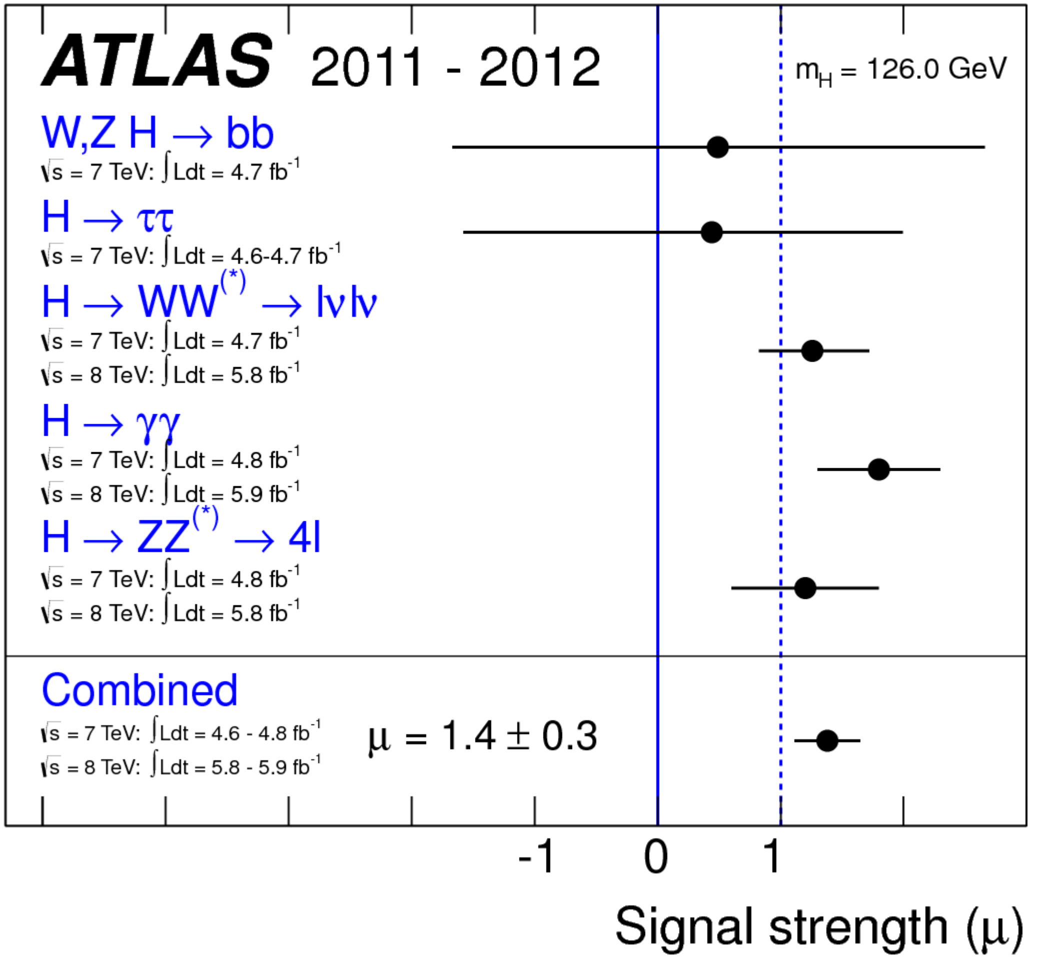


All of bb, WW, ττ, γγ, ZZ can be observed!!

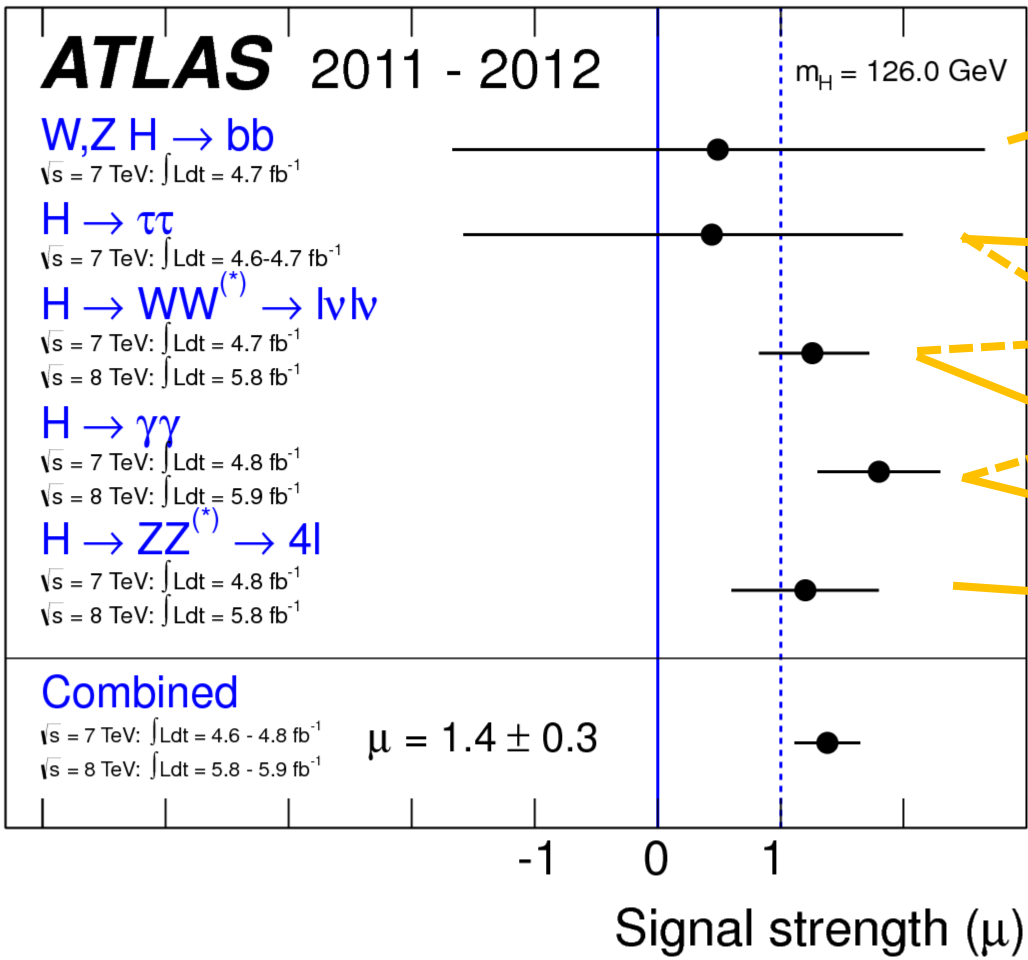
Channels included in the measurement

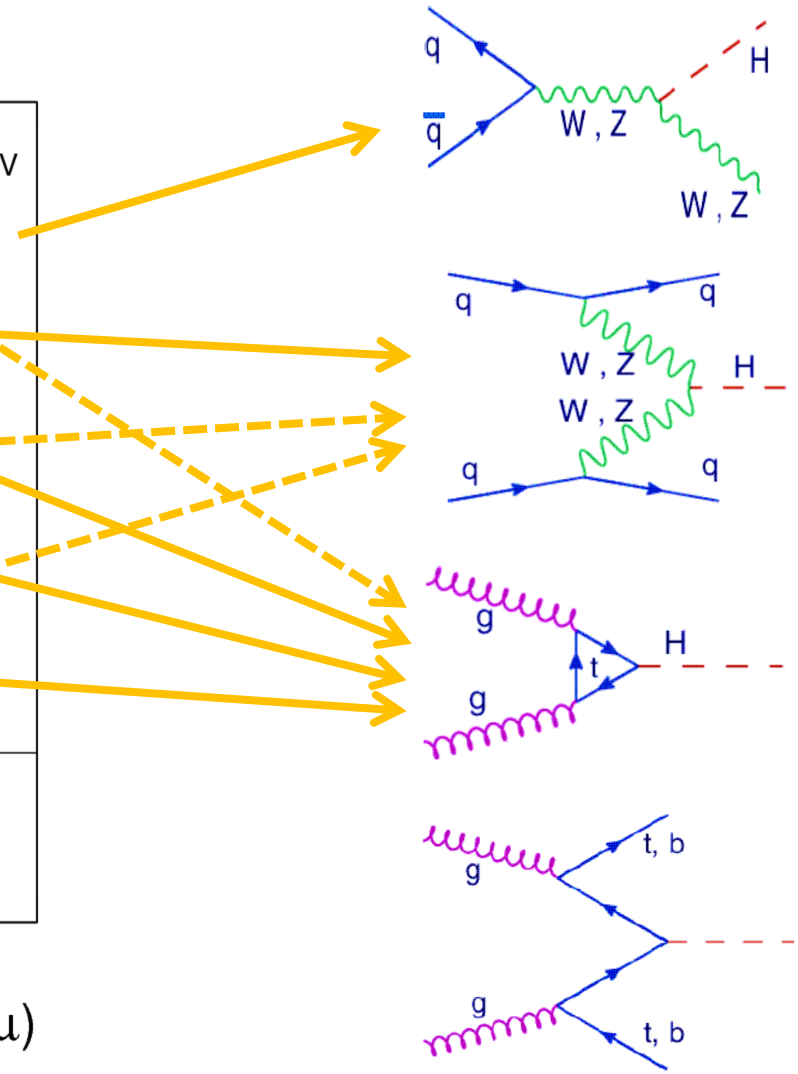
Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	4.8	[10]
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	4.8	[11]
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes \{\text{0-jet, 1-jet, 2-jet}\} \otimes \{\text{low, high pile-up}\}$	4.7	[12]
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet}, VH\}$	4.7	[13]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{\text{0-jet}\} \otimes \{E_{\mathrm{T}}^{\mathrm{miss}} < 20\ \text{GeV}, E_{\mathrm{T}}^{\mathrm{miss}} \geq 20\ \text{GeV}\}$ $\oplus \{e, \mu\} \otimes \{\text{1-jet}\} \oplus \{\ell\} \otimes \{\text{2-jet}\}$	4.7	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{\text{1-jet}\}$	4.7	
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\ \text{GeV}\}$	4.6	[14]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-200, \geq 200\ \text{GeV}\}$	4.7	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-200, \geq 200\ \text{GeV}\}$	4.7	
		2012 $\sqrt{s}$ =8 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	5.8	[10]
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	5.9	[11]
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{\text{0-jet, 1-jet, 2-jet}\}$	5.8	[15]

Signal strength for each channel

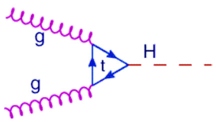


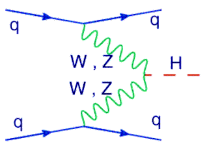
Signal strength for each channel

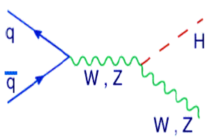


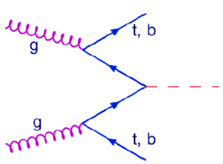


Coupling measurement : Notation









Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ggH}}} = \begin{cases} \kappa^2_{\mathrm{g}}(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, m_H) \\ \kappa^2_{\mathrm{g}} \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{\mathrm{SM}}_{\mathrm{VBF}}} = \kappa^2_{\mathrm{VBF}}(\kappa_{\mathrm{W}}, \kappa_{\mathrm{Z}}, m_H)$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma^{\mathrm{SM}}_{\mathrm{WH}}} = \kappa^2_{\mathrm{W}}$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ZH}}} = \kappa^2_{\mathrm{Z}}$$

$$\frac{\sigma_{\mathrm{t\bar{t}H}}}{\sigma^{\mathrm{SM}}_{\mathrm{t\bar{t}H}}} = \kappa^2_{\mathrm{t}}$$

Total width

$$\frac{\Gamma_{\mathrm{H}}}{\Gamma^{\mathrm{SM}}_{\mathrm{H}}} = \begin{cases} \kappa^2_{\mathrm{H}}(\kappa_i, m_H) \\ \kappa^2_{\mathrm{H}} \end{cases}$$

Detectable decay modes

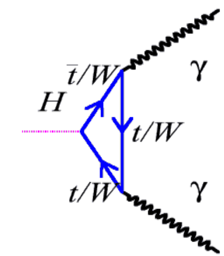
$$\frac{\Gamma_{\mathrm{WW}^{(*)}}}{\Gamma^{\mathrm{SM}}_{\mathrm{WW}^{(*)}}} = \kappa^2_{\mathrm{W}}$$

$$\frac{\Gamma_{\mathrm{ZZ}^{(*)}}}{\Gamma^{\mathrm{SM}}_{\mathrm{ZZ}^{(*)}}} = \kappa^2_{\mathrm{Z}}$$

$$\frac{\Gamma_{\mathrm{b\bar{b}}}}{\Gamma^{\mathrm{SM}}_{\mathrm{b\bar{b}}}} = \kappa^2_{\mathrm{b}}$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{\mathrm{SM}}_{\tau^-\tau^+}} = \kappa^2_{\tau}$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}} = \begin{cases} \kappa^2_{\gamma}(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_H) \\ \kappa^2_{\gamma} \end{cases}$$



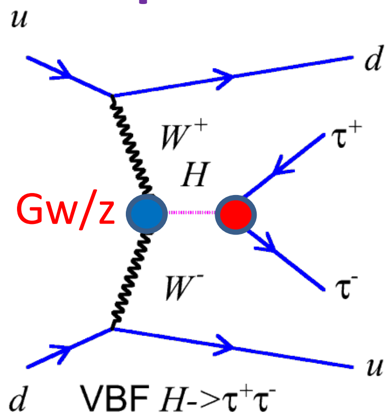
H->γγ

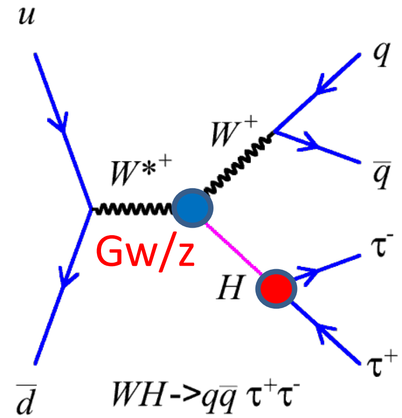
All measurements assume mH=126GeV

Production process dependent μ

We can measure the ratio of Boson and Fermion coupling using different production processes with the same decay mode.

VVH coupling in production

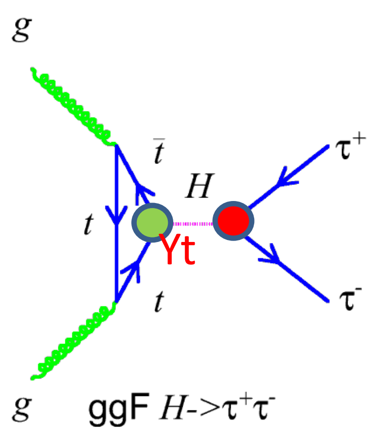


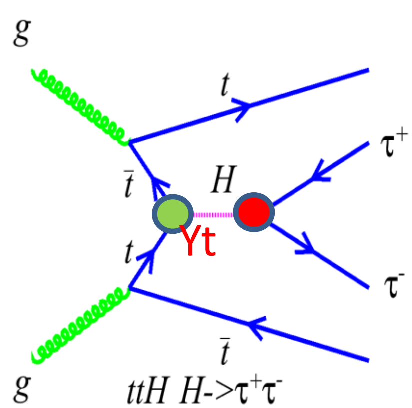


$$\frac{\sigma_{VBF}}{\sigma^{SM}_{VBF}} = \frac{\sigma_{WH}}{\sigma^{SM}_{WH}} = \frac{\sigma_{ZH}}{\sigma^{SM}_{ZH}}$$

$= \mu_{VBF+VH}$

qqH coupling in production

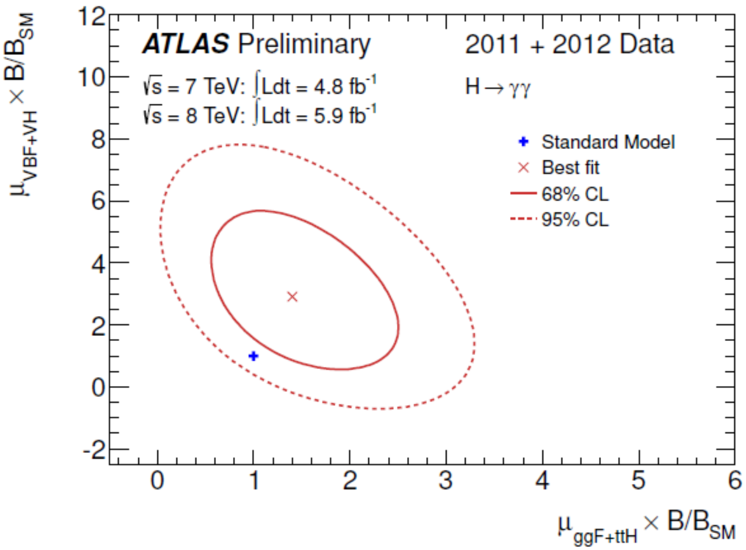




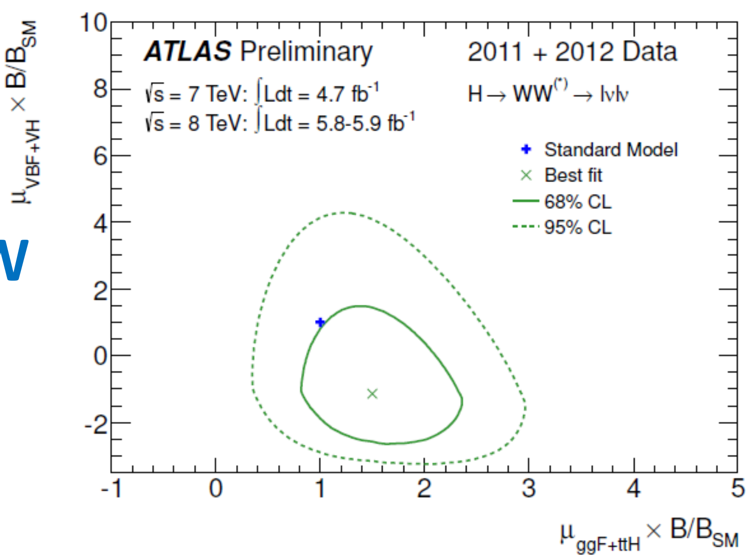
$$\frac{\sigma_{ggH}}{\sigma^{SM}_{ggH}} = \frac{\sigma_{t\bar{t}H}}{\sigma^{SM}_{t\bar{t}H}} = \mu_{ggF+ttH}$$

Production process dependent μ

H→γγ



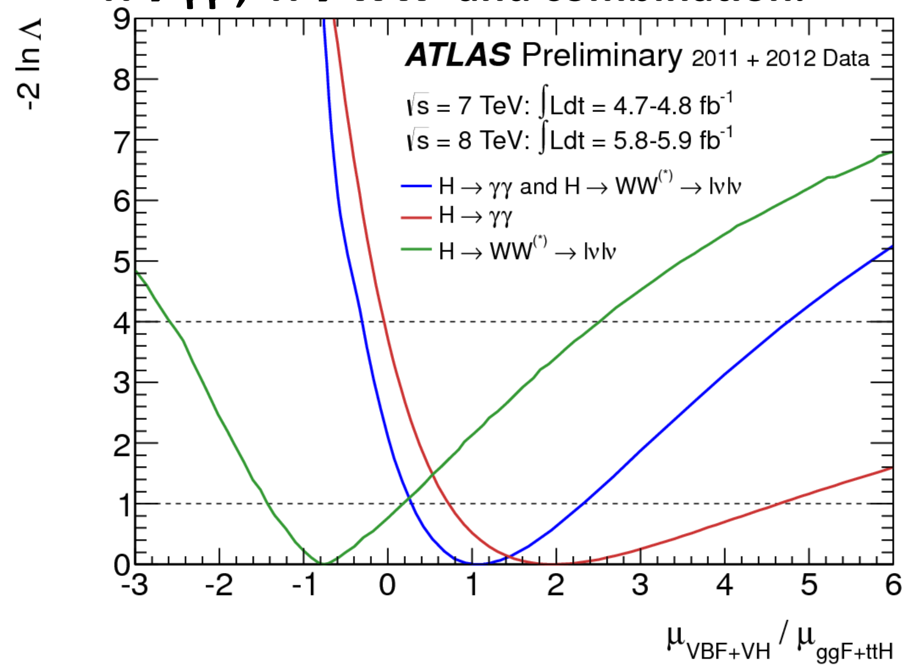
H→WW



Take a ratio to avoid BR effect :

$$\mu_{VBF+VH} / \mu_{ggF+ttH}$$

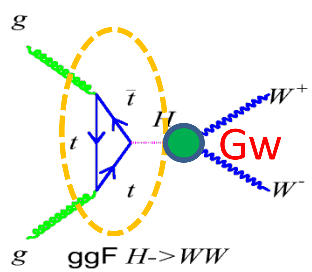
H→γγ , H→WW and combination.



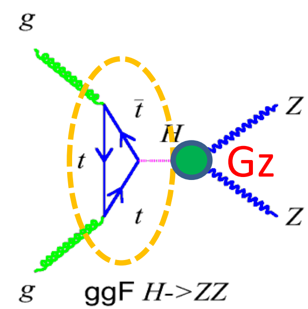
Coupling with Gauge boson

We saw clear excess on the both WW and ZZ decay channels so meaningful HVV measurement could be presented

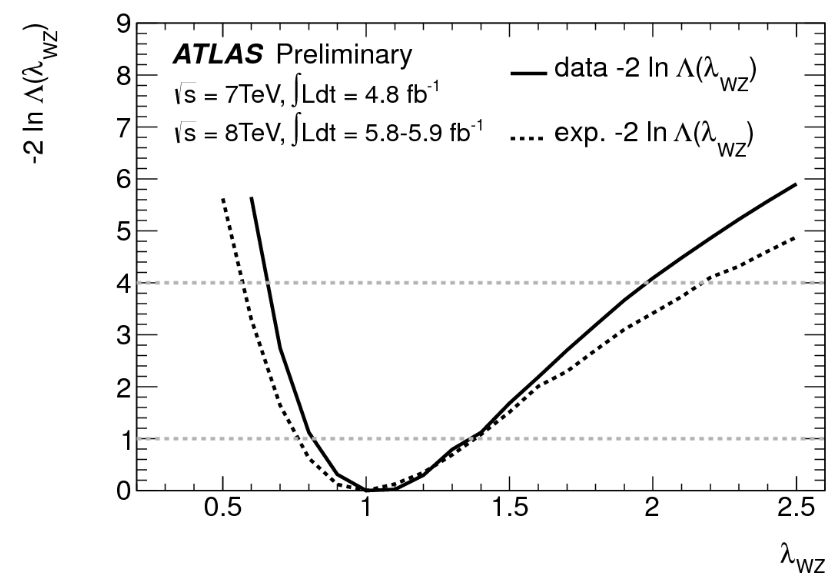
$\lambda_{WZ} = \kappa_W / \kappa_Z =$



/



Observed : $\boxed{\lambda_{WZ} = 1.07^{+0.35}_{-0.27}}$

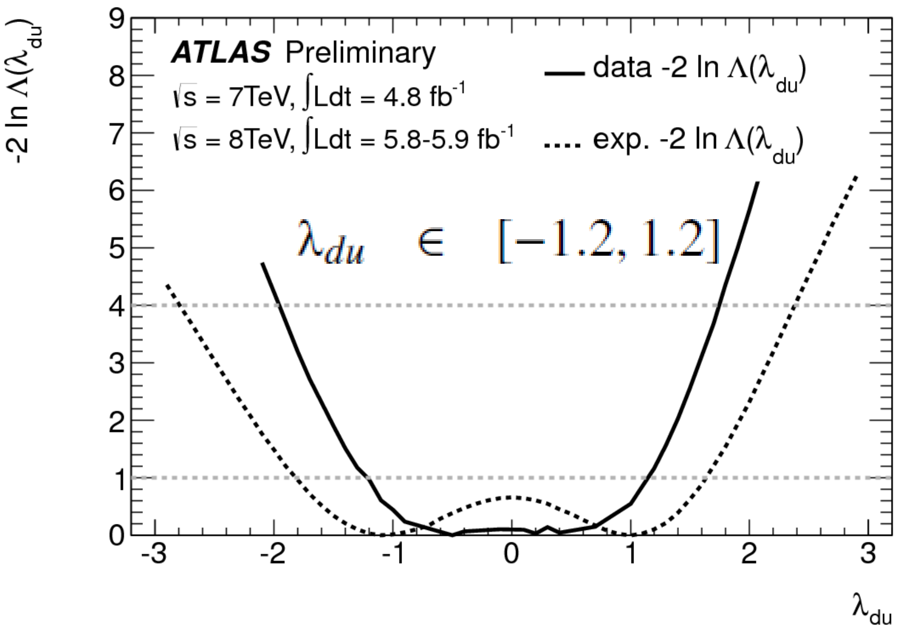


Coupling with Fermion

May be this is too early to discuss since not yet observed bb and ττ

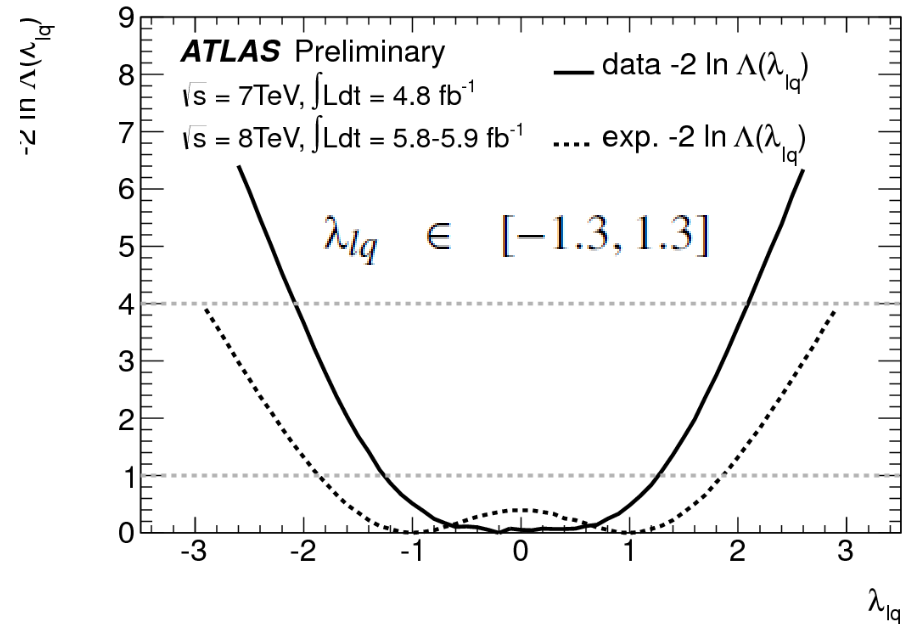
Up type v.s. down type

$$\kappa_d = \kappa_b = \kappa_\tau$$
$$\kappa_u = \kappa_t$$
$$\lambda_{du} = \kappa_d / \kappa_u$$



Lepton v.s. quark

$$\kappa_l = \kappa_\tau$$
$$\kappa_q = \kappa_b = \kappa_t$$
$$\lambda_{lq} = \kappa_l / \kappa_q$$

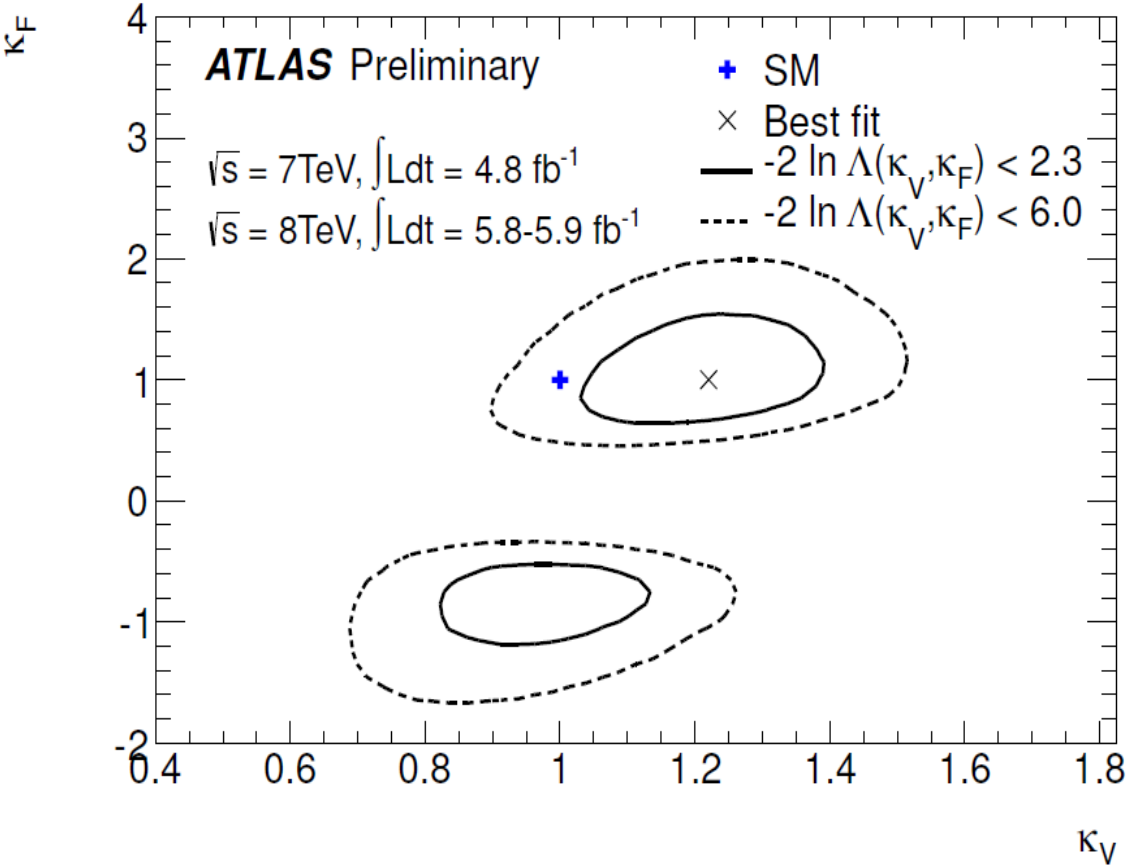


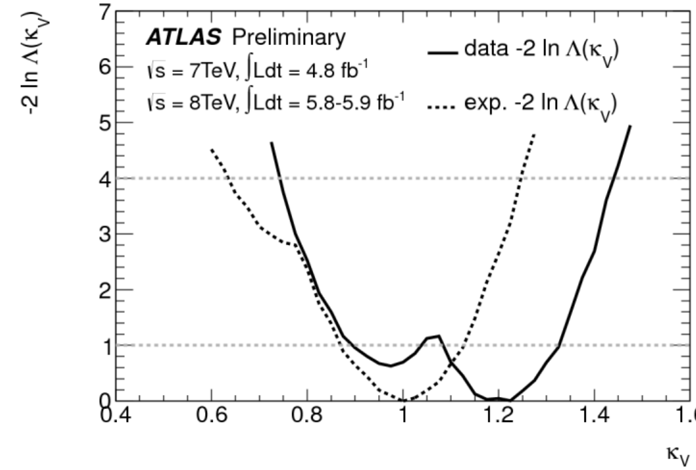
More global view

$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$$

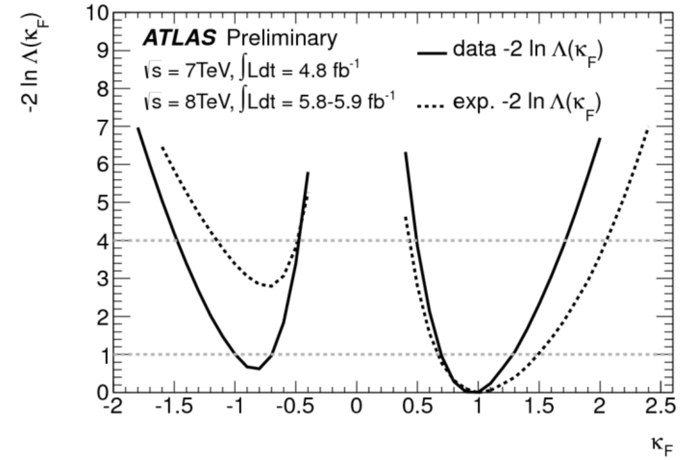
$$\kappa_V = \kappa_W = \kappa_Z$$

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





$$\kappa_V \in [0.9, 1.0] \cup [1.1, 1.3]$$

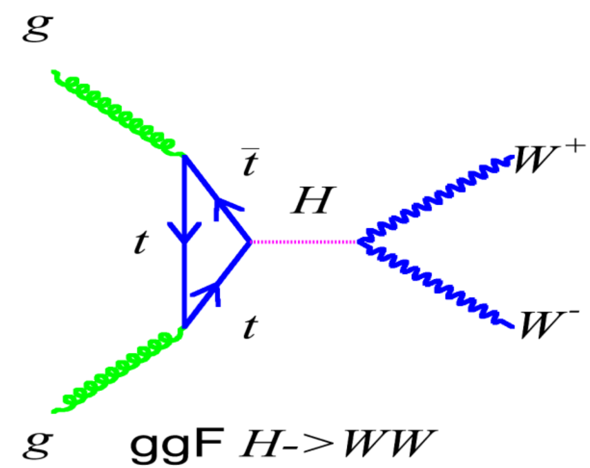


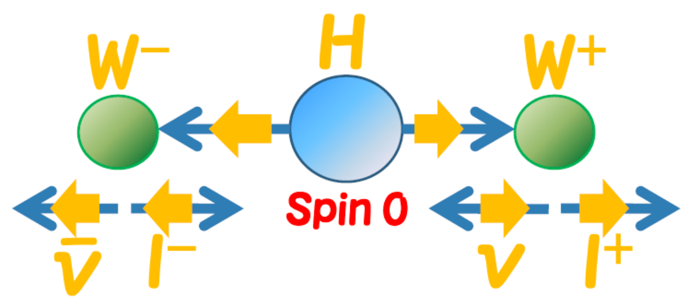
$$\kappa_F \in [-1.0, -0.7] \cup [0.7, 1.3]$$

New results for each channel

H→W(lν)W(lν) channel in ATLAS

- One of the highest sensitivity channel.
- Contributed to the observation a lot.
- May probe production mechanism dependence
  - VBF H→qqWW
  - VH→VWW
  - ttH→ttWW
- Analysis is assuming/using spin 0, this means that it's quite sensitive to the spin measurement.





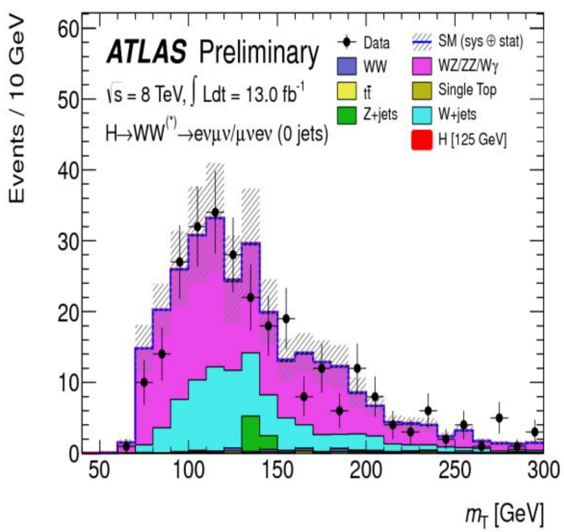
For HCP, only different flavor leptons channels with 0/1jet are updated.

Event selection & background estimation

- two leptons + Missing ET
- ggF : 0,1 jet

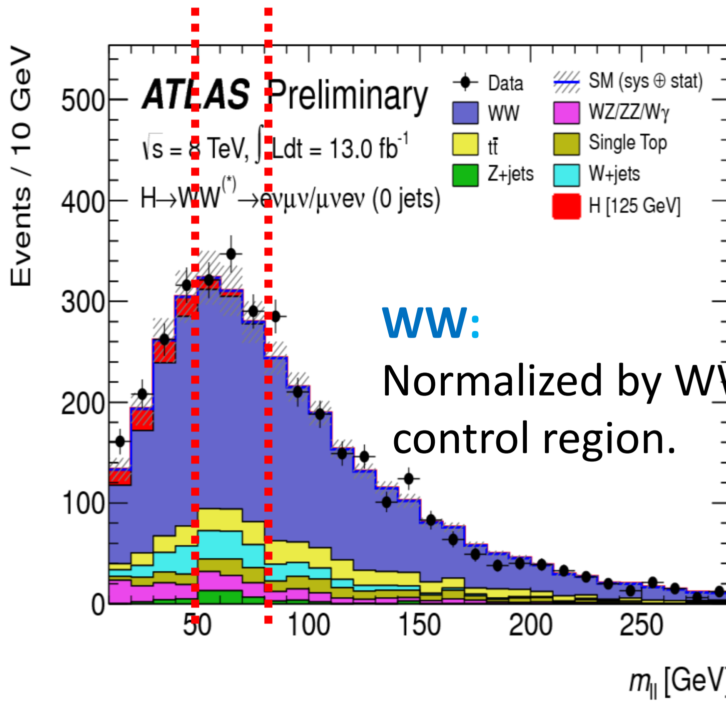
W+jets/Wγ* :

Fake lepton background.
Prepare Loose lepton CR
And multiplied by Fake rate.



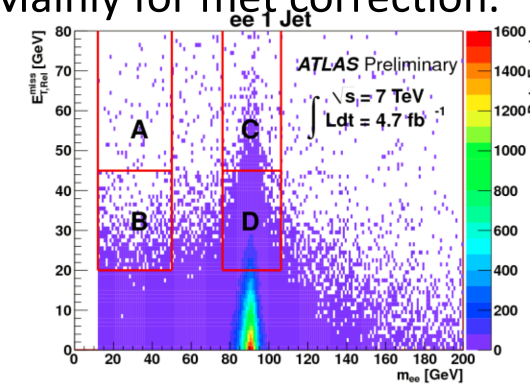
Signal region

WW control region

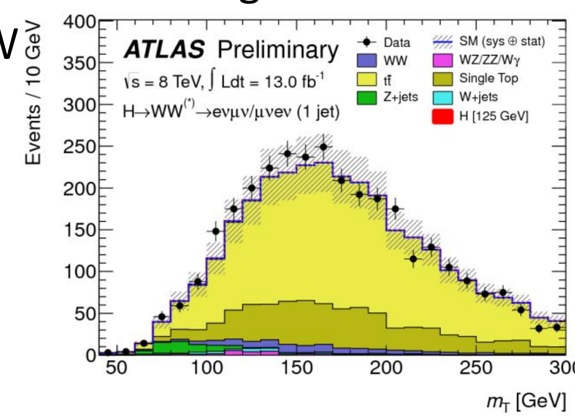


WW:
Normalized by WW control region.

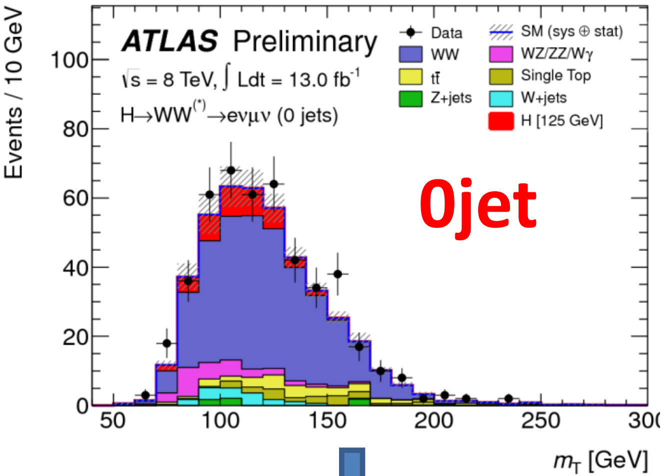
Z+jets :
MET vs mll
Mainly for met correction.



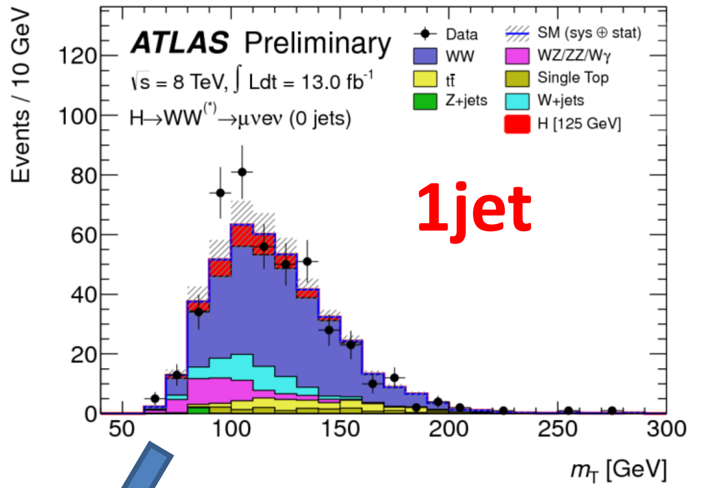
Top :
Apply b-tagging to enhance ttbar background.



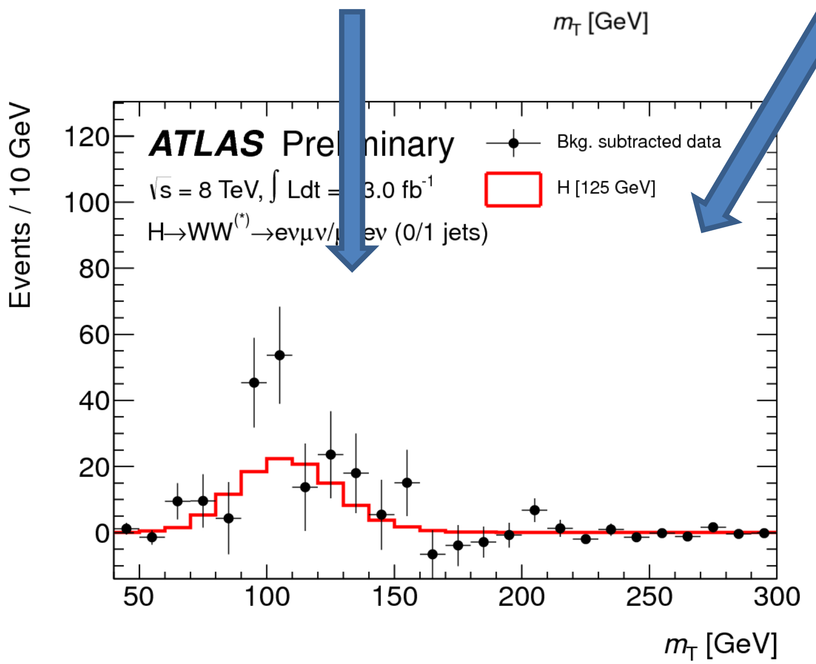
H→WW results.



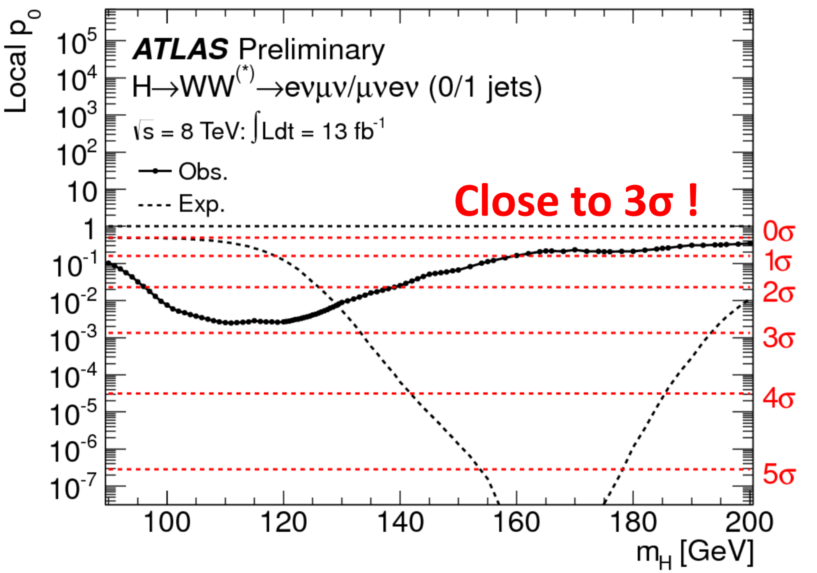
ATLAS Preliminary
√s = 8 TeV, ∫ Ldt = 13.0 fb-1
H→WW(*)→eνμν (0 jets)
Data
WW
tt̄
Z+jets
SM (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [125 GeV]
0jet
Events / 10 GeV
mT [GeV]



ATLAS Preliminary
√s = 8 TeV, ∫ Ldt = 13.0 fb-1
H→WW(*)→μνeν (0 jets)
Data
WW
tt̄
Z+jets
SM (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [125 GeV]
1jet
Events / 10 GeV
mT [GeV]



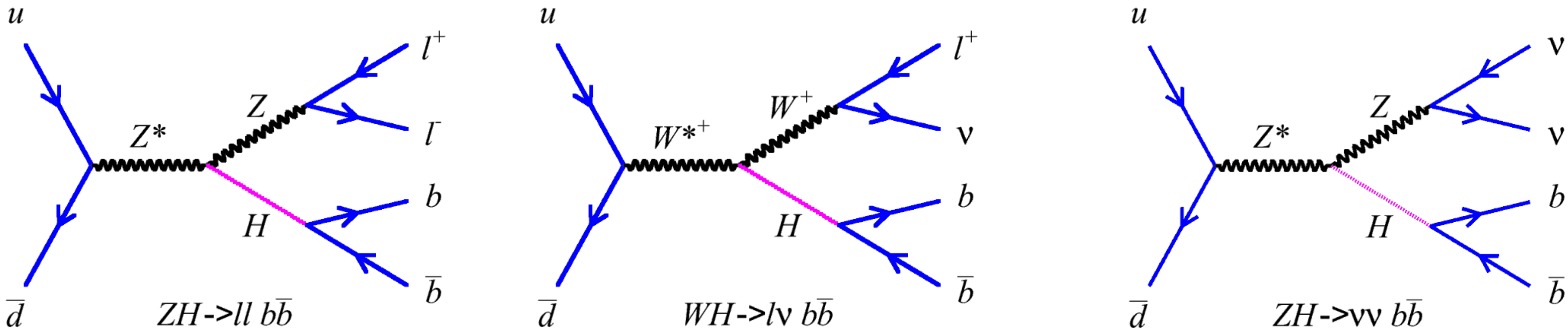
ATLAS Preliminary
Bkg. subtracted data
H [125 GeV]
H→WW(*)→eνμν/μνeν (0/1 jets)
Events / 10 GeV
mT [GeV]



ATLAS Preliminary
H→WW(*)→eνμν/μνeν (0/1 jets)
√s = 8 TeV: ∫Ldt = 13 fb-1
Obs.
Exp.
Close to 3σ !
0σ
1σ
2σ
3σ
4σ
5σ
Local p0
mH [GeV]

H→bb searches in ATLAS

2 lepton　　1 lepton　　0 lepton



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

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

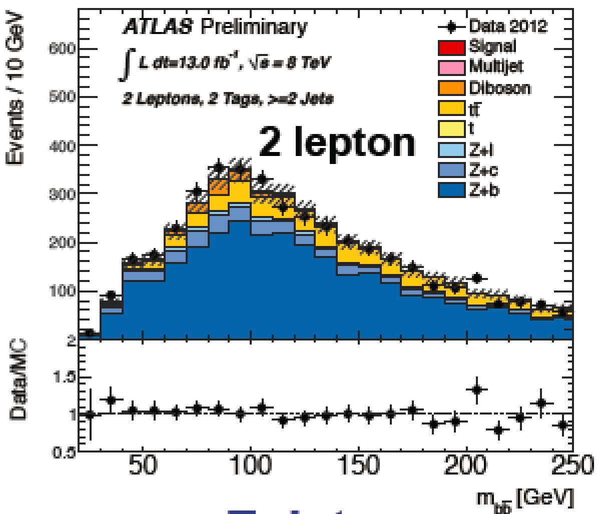
ZH → ννbb
- No leptons
- E_t^{miss} > 120 GeV
- E_t^{miss} trigger

$p_T^{W/Z}$ [0-50],[50,100],[100-150],[150-200] [>200] GeV / E_T^{miss} [120-160] [160-200] [>200] GeV

Show the results with 4.6fb^{-1}(7TeV) and 13fb^{-1} (8TeV) data

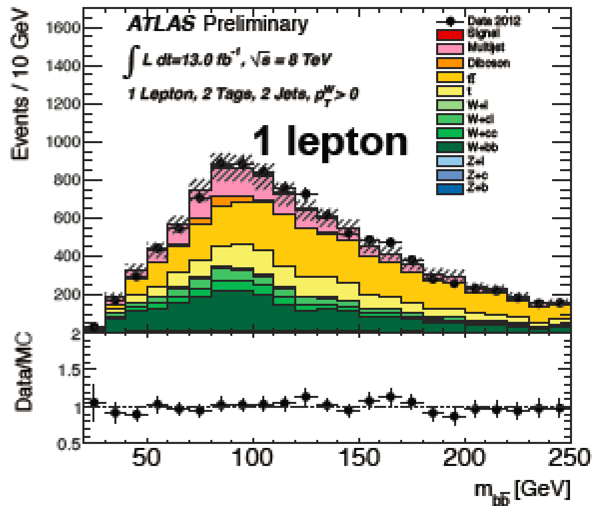
Background and estimation

2 lepton



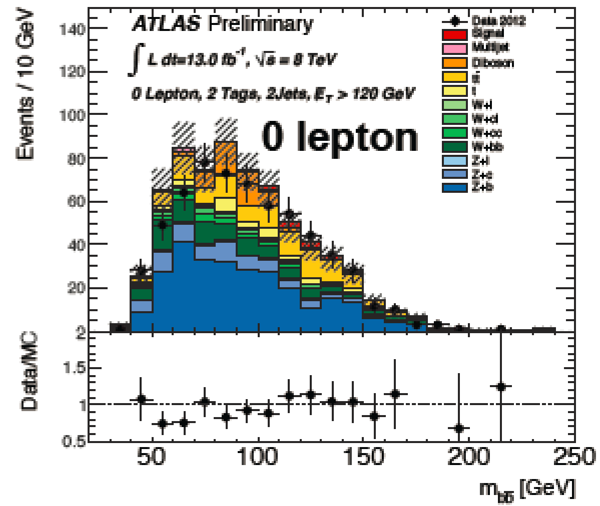
Z+jets

1 lepton



Top/W+jets

0 lepton

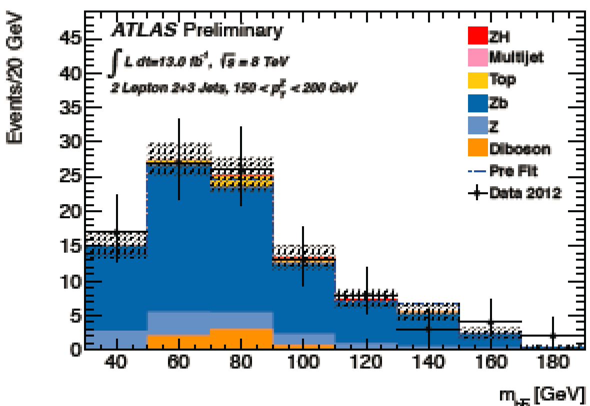


Z+jets/W+jets/Top

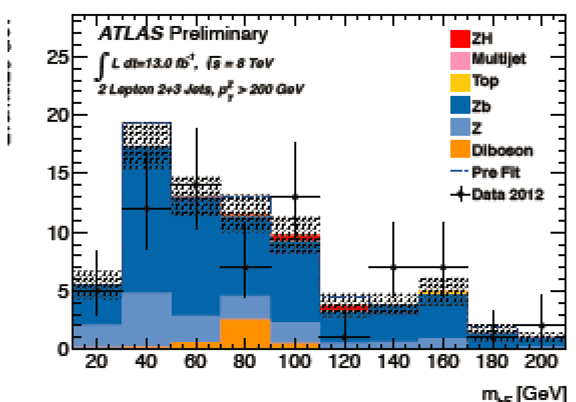
Shapes are obtained by MC and normalized to data by Control region.
Multi-jet background was determined by data-driven way.
WZ/ZZ(Z→bb) resonant backgrounds fully rely on the MC.

High sensitivity categories

2 lepton

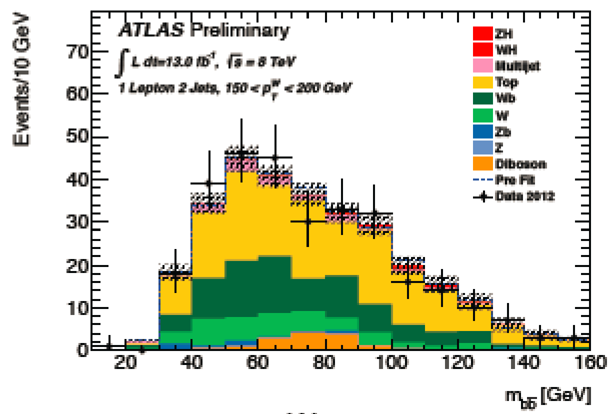


150 < p_T^Z < 200 GeV

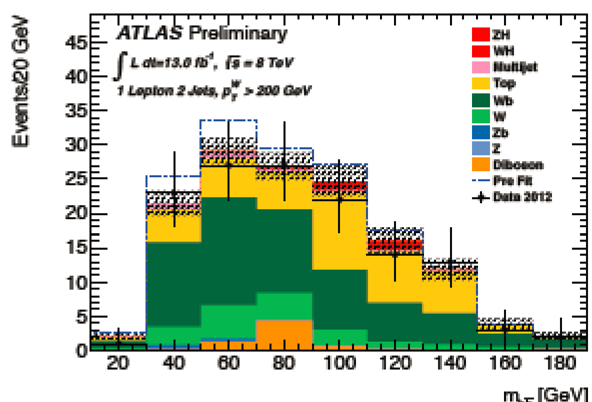


p_T^Z > 200 GeV

1 lepton

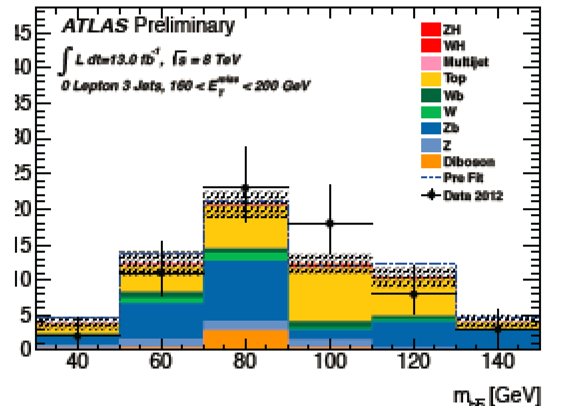


150 < p_T^W < 200 GeV

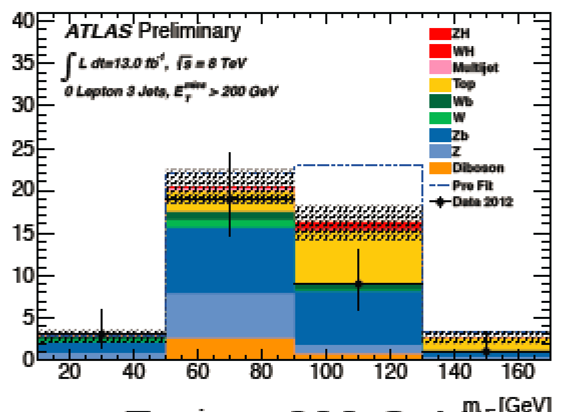


p_T^W > 200 GeV

0 lepton

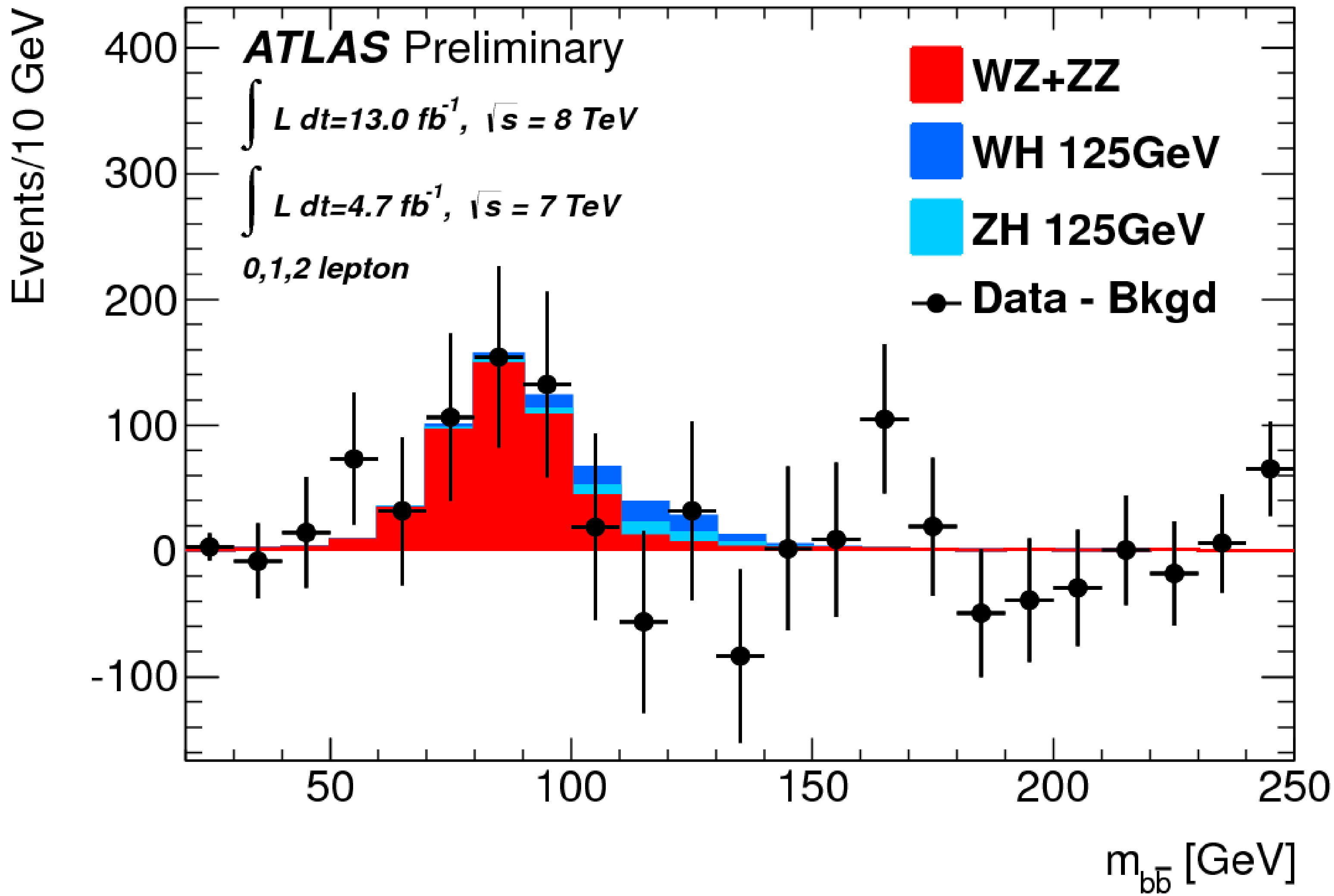


160 < E_T^{miss} < 200 GeV



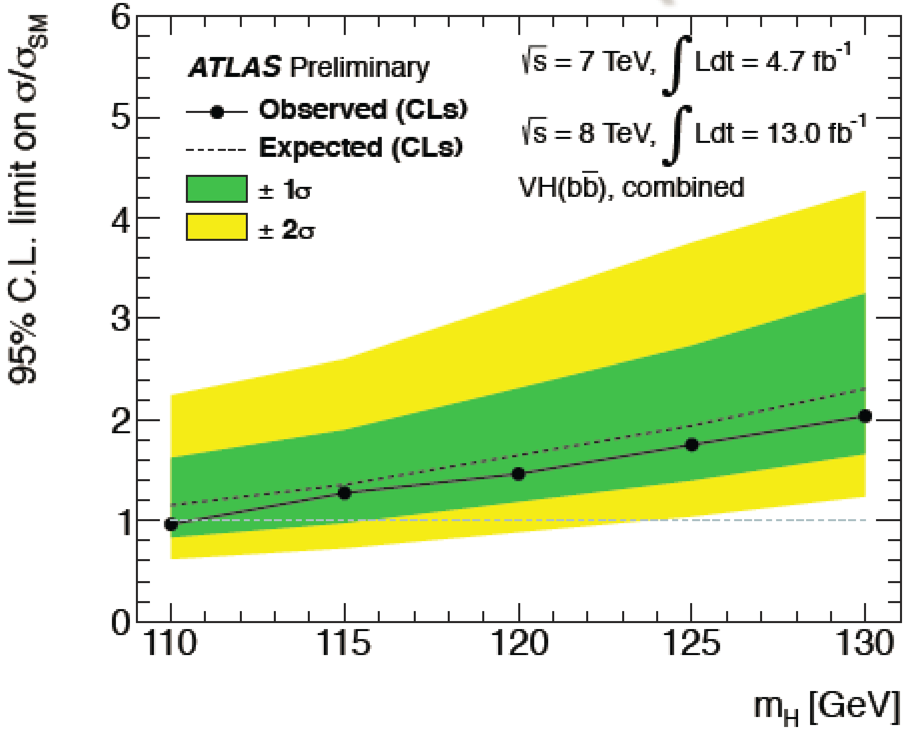
E_T^{miss} > 200 GeV

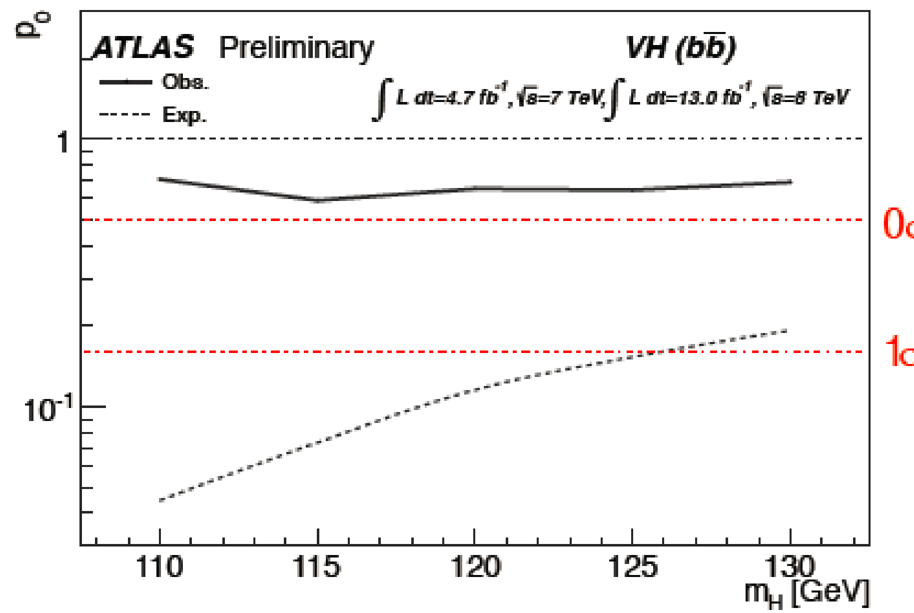
After background subtraction



Results : combined limit and p0

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



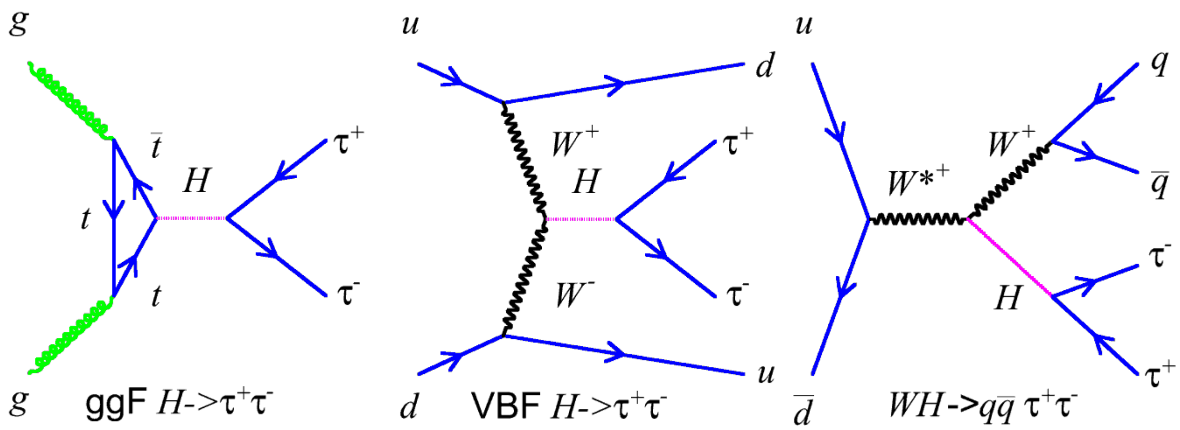


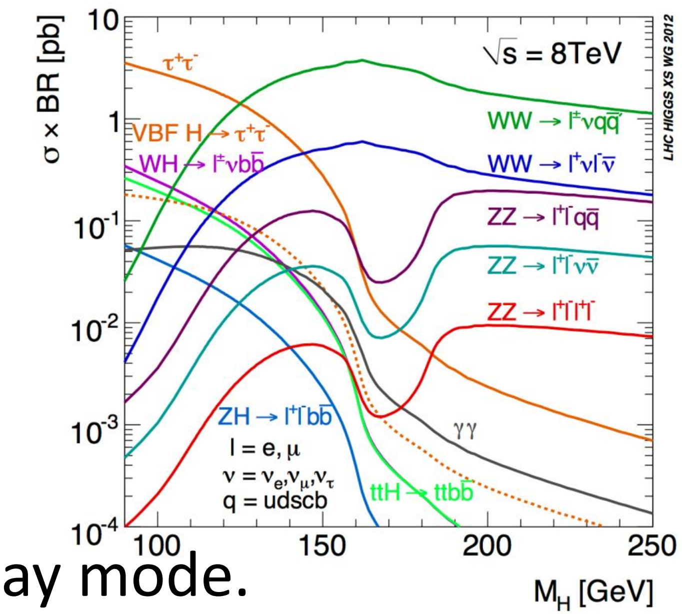
Expected:1.9xSM (μ=0) **Observed:1.8xSM** **Expected:15%** (μ=1) **Observed:64%**

Best fit value of Signal Strength (μ) is -0.4±0.7±0.8

H→ττ searches in ATLAS

- Three Higgs production processes are considered in this analysis.





- Separate analysis for three different ττ decay mode.
  - lep-lep = ll4ν : (ee)+eμ+μμ
  - lep-had = $l\tau_{had}3\nu$: $e\tau_{had}$+ $\mu\tau_{had}$
  - had-had = $\tau_{had}\tau_{had}\nu\nu$: ($\tau_{had}\tau_{had}$)
- Combined all three channels to search for H→ττ signature.

Show the results with 4.6fb^{-1}(7TeV) and 13fb^{-1} (8TeV) data

Di-tau Mass reconstruction

Di-tau invariant mass should be a important discriminating variable from backgrounds. But having 2-4ν in a events.

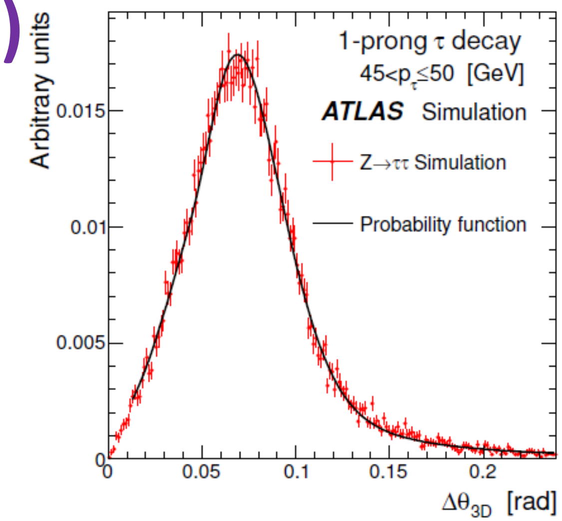
Need…

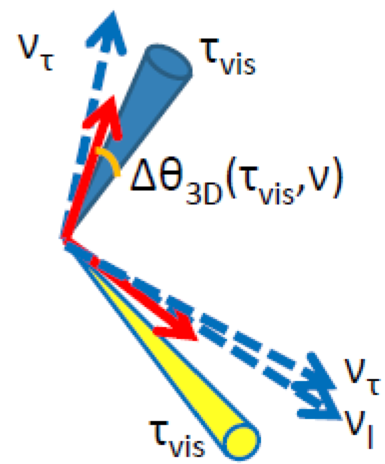
Event by Event estimator of true di-τ mass likelihood.

Full reconstruction of event kinematics.

Missing Mass Calculator(MMC)

- Solve τ, E_T^{miss} in $\Delta\phi(\tau_{vis},\nu)$ parameter space using $\Delta\theta_{3D}(\tau_{vis},\nu)$ template from simulation as PDF.

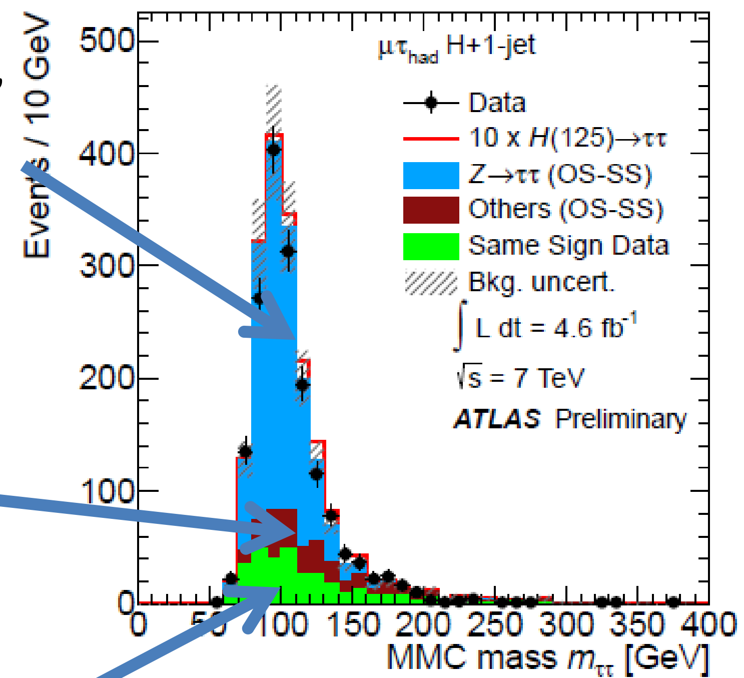




Background and estimation

- Opposite sign tau decay products are required.
- High Missing ET and low MT cuts are added.

Z→ττ estimated by embedding+MC
-- used Z→μμ data and replace μ by full simulated τ, so that all the objects except tau decay product are obtained by real data.
-- Used high statistics MC for VBF channel with correction by data.

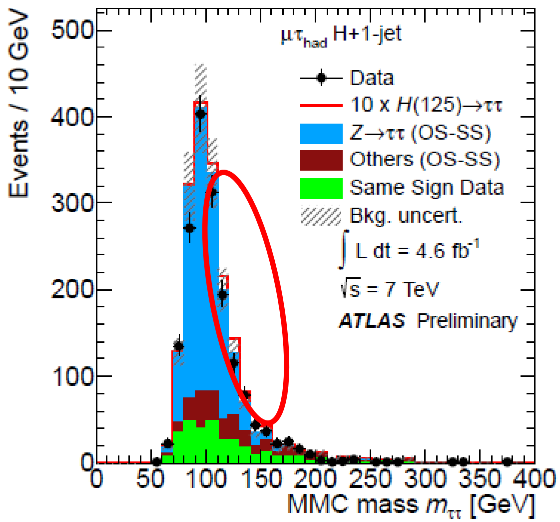


Z→ee/μμ + jets, Top, di-boson Estimated by MC with correction.

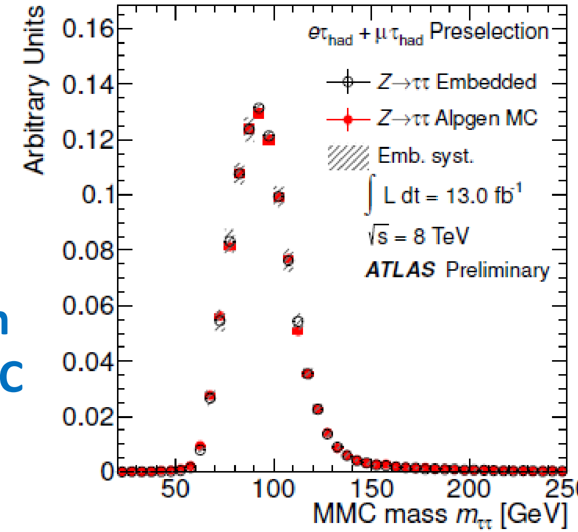
QCD and W+Jets – Estimated from Same Sign events(lephad)
-- Template fit by loose selection (lep-lep,hadhad)

Z(→ττ)+jets modeling validation

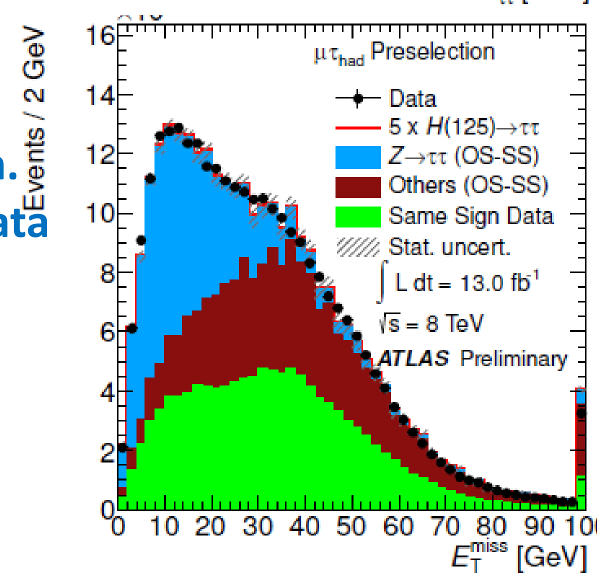
Higgs Signal is on the right hand side tail of Z.
Need carful varidation of the Z→ττ shape.



MMC distribution
embedding vs MC



MET distribution.
estimation vs data



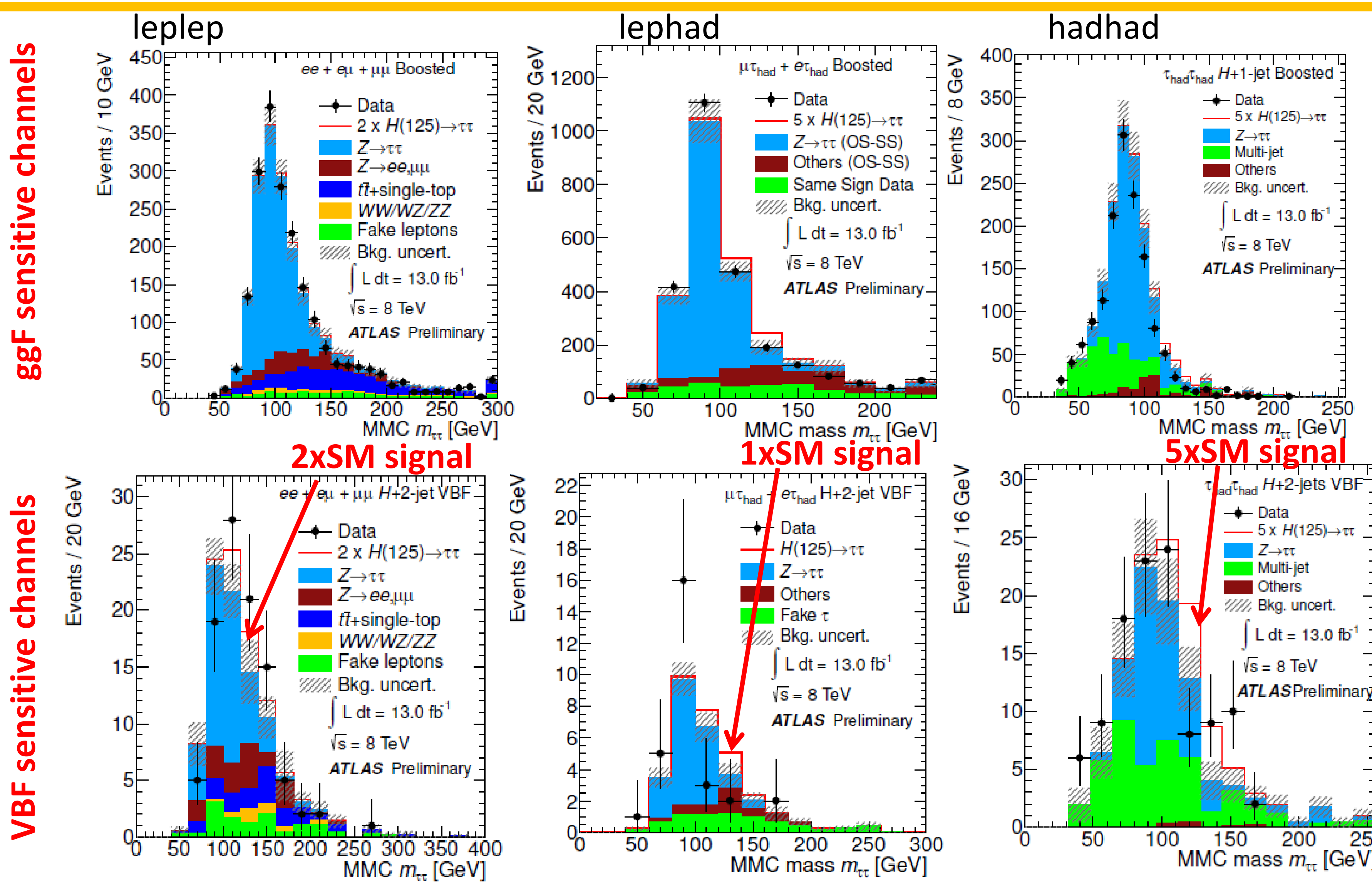
Non-VBF channel : Embedding

- → Checked with MC sample
- → Assigned systematics by varying condition.

VBF channel : High statistics MC

- → Jet kinematics are validated by Zee/μμ data.
- → Reweighted kinematics for MC mismodeling.

Results: discriminant distributions



Results : combined limit and p0

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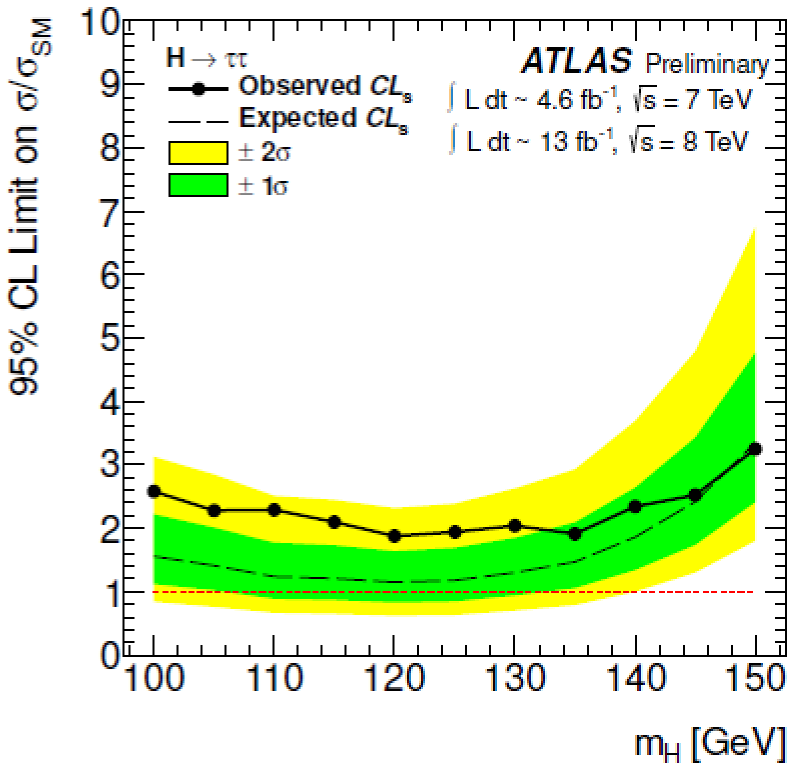
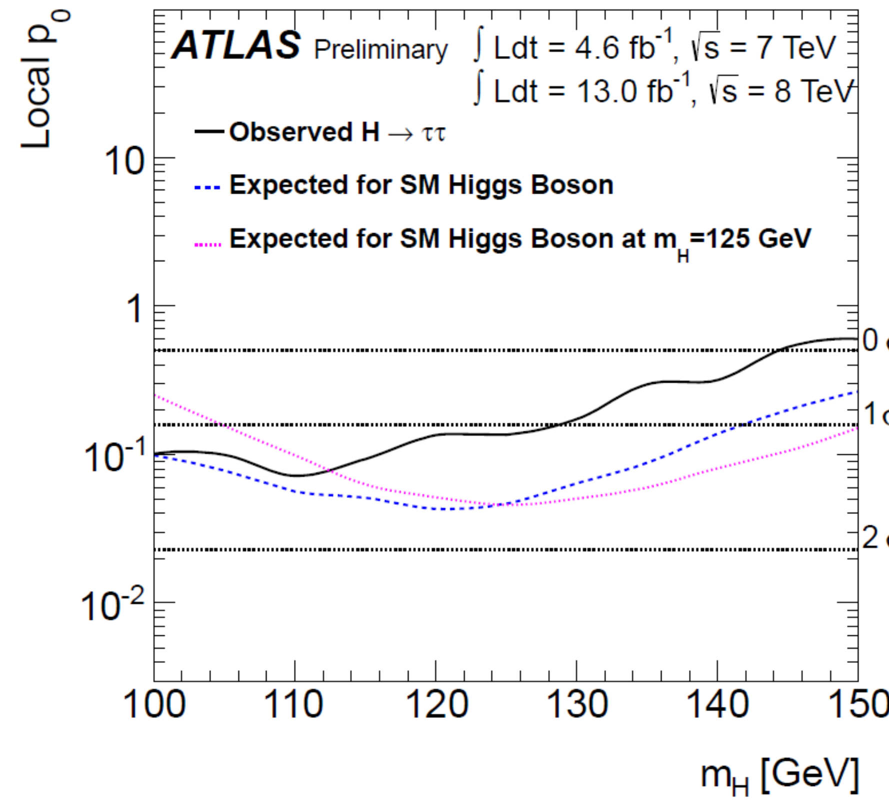
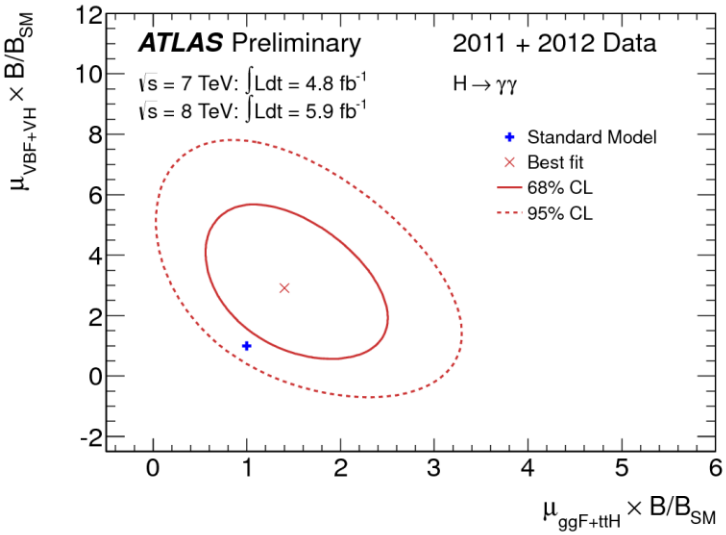


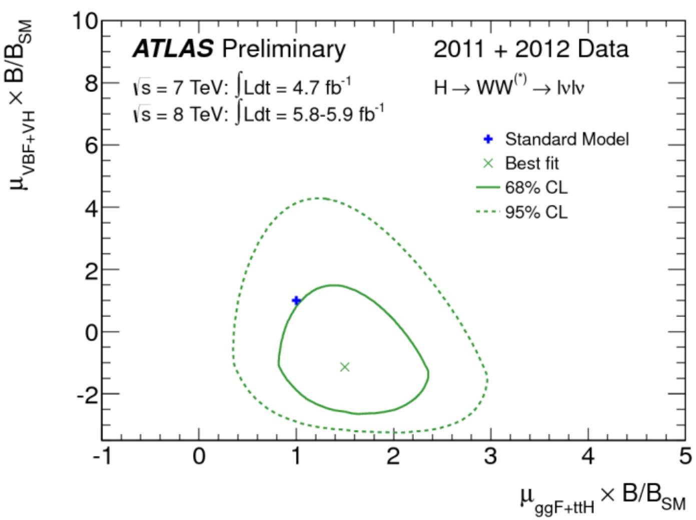


Expected:1.2xSM (μ=0) **Observed:1.9xSM** **Expected:1.7σ** (μ=1) **Observed:1.1σ**

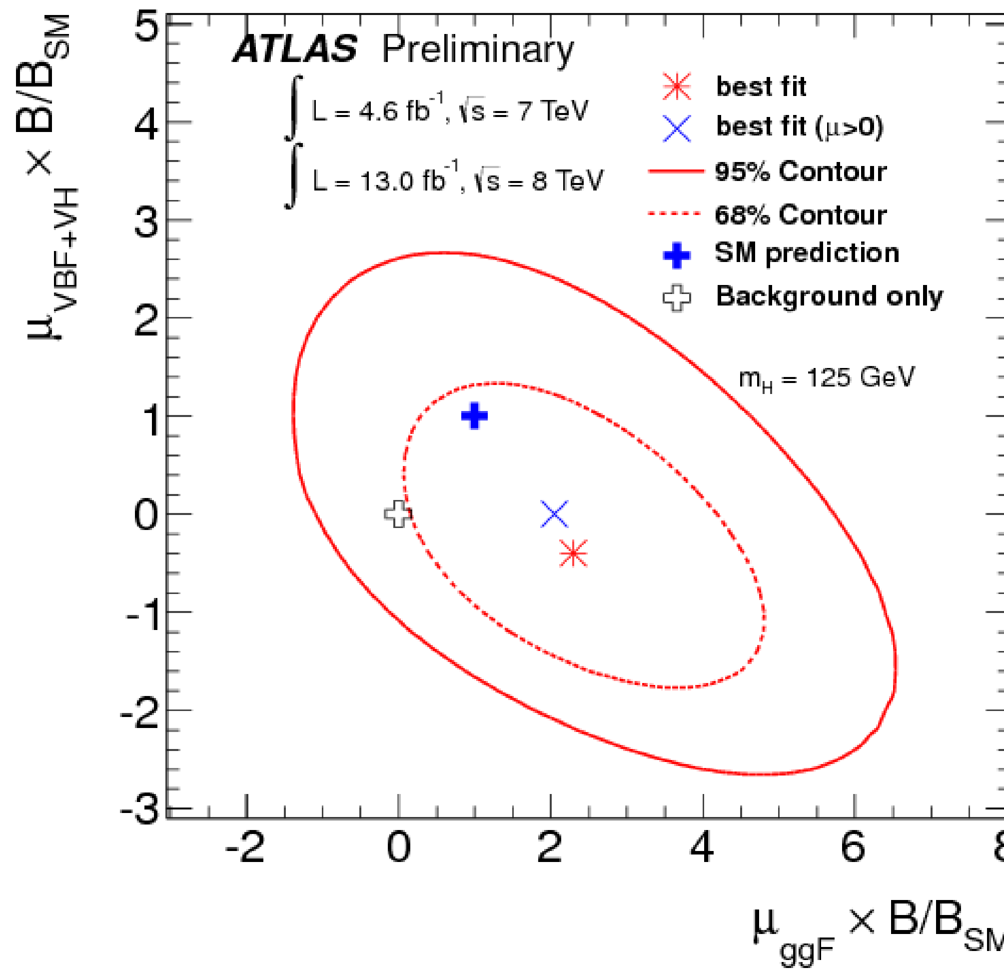
Best fit value of Signal Strength (μ) is 0.7 ±0.7

Summary of production dependence

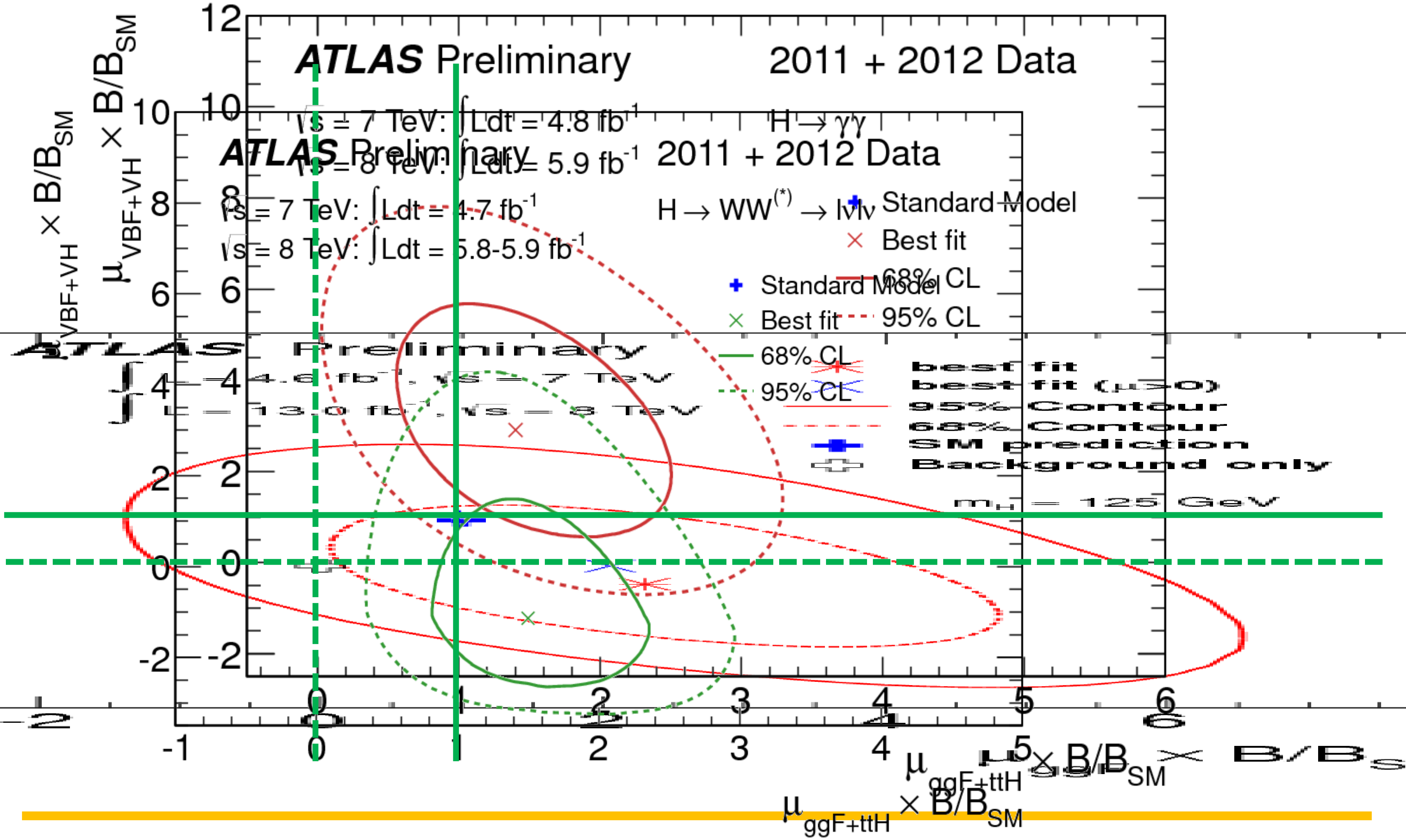




- H→ ττ result.

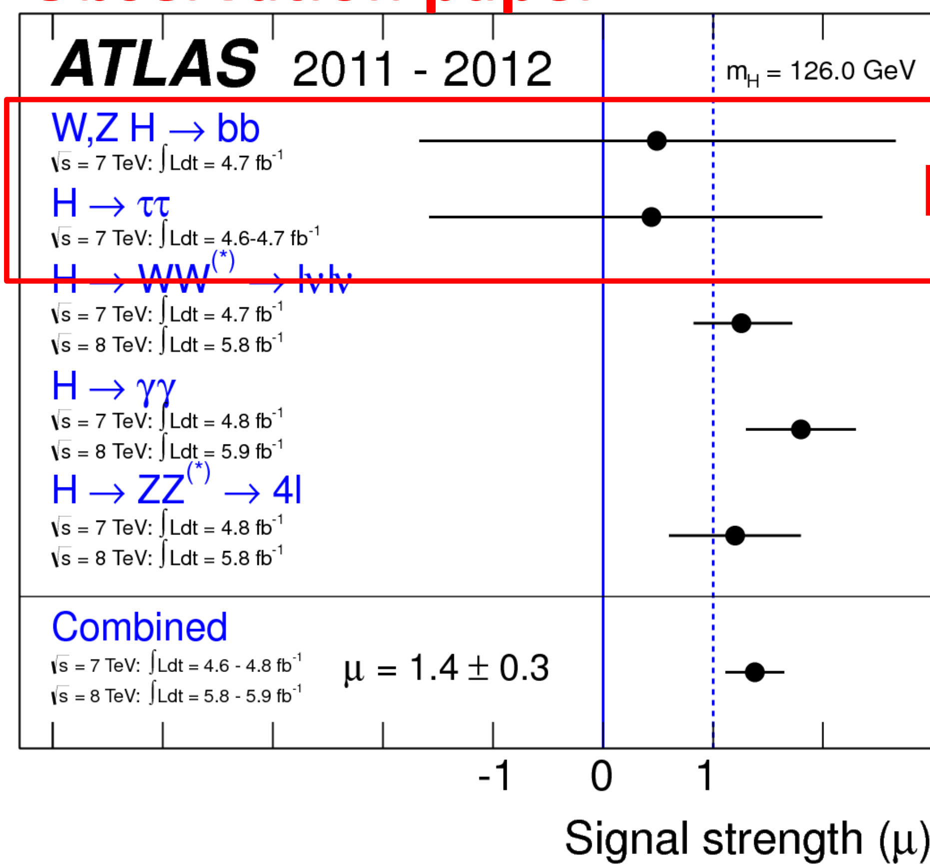


Summary of production dependence

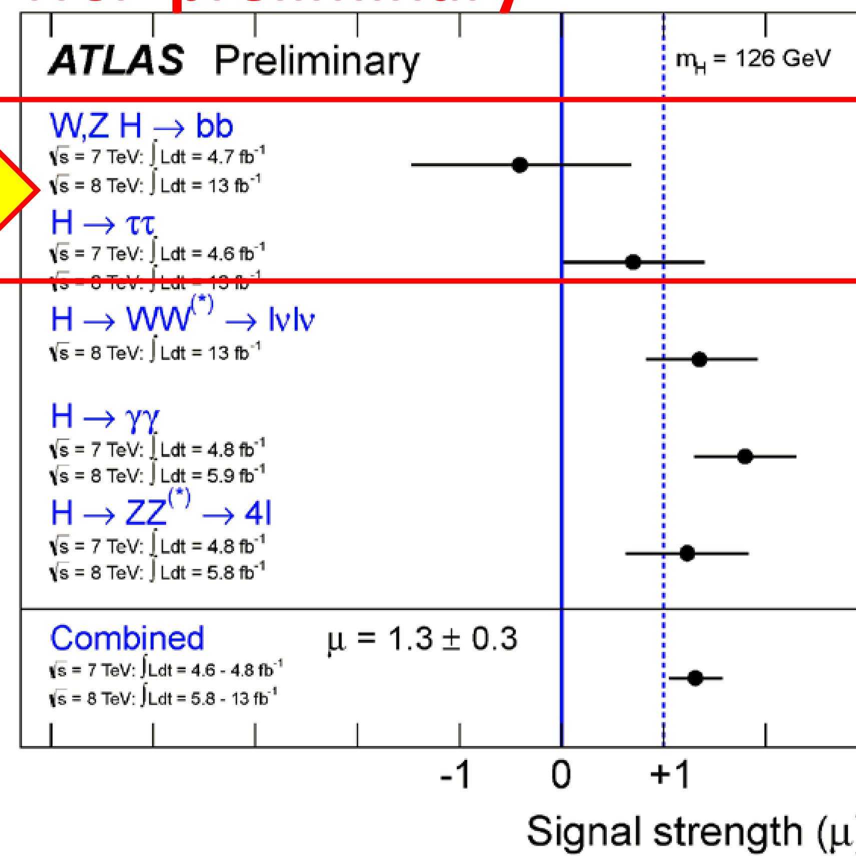


What we achieved post-observation

Observation paper



HCP preliminary



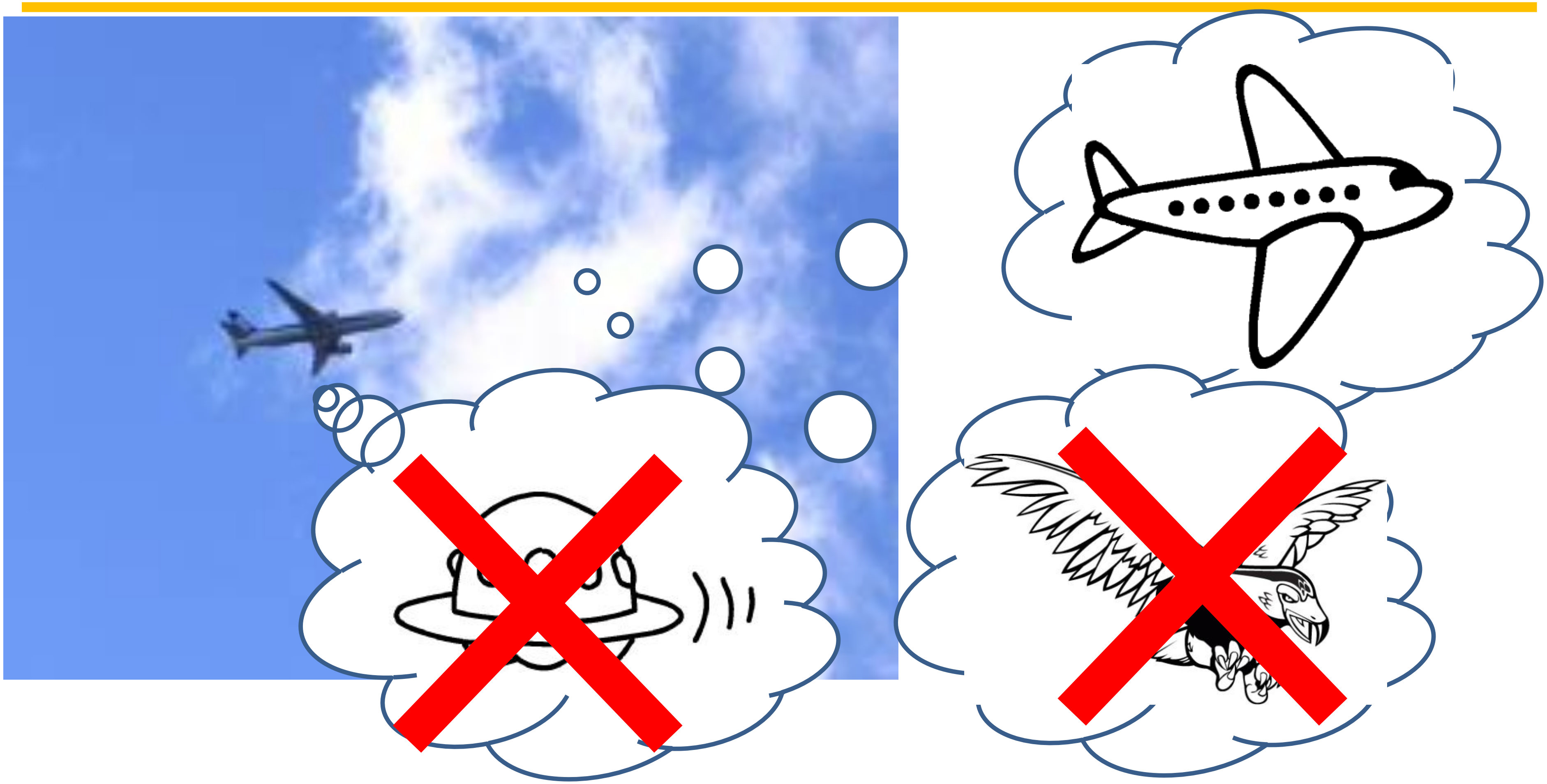
We observed something in July

- **Indeed the observation was clear! (6σ)**

We observed something in July

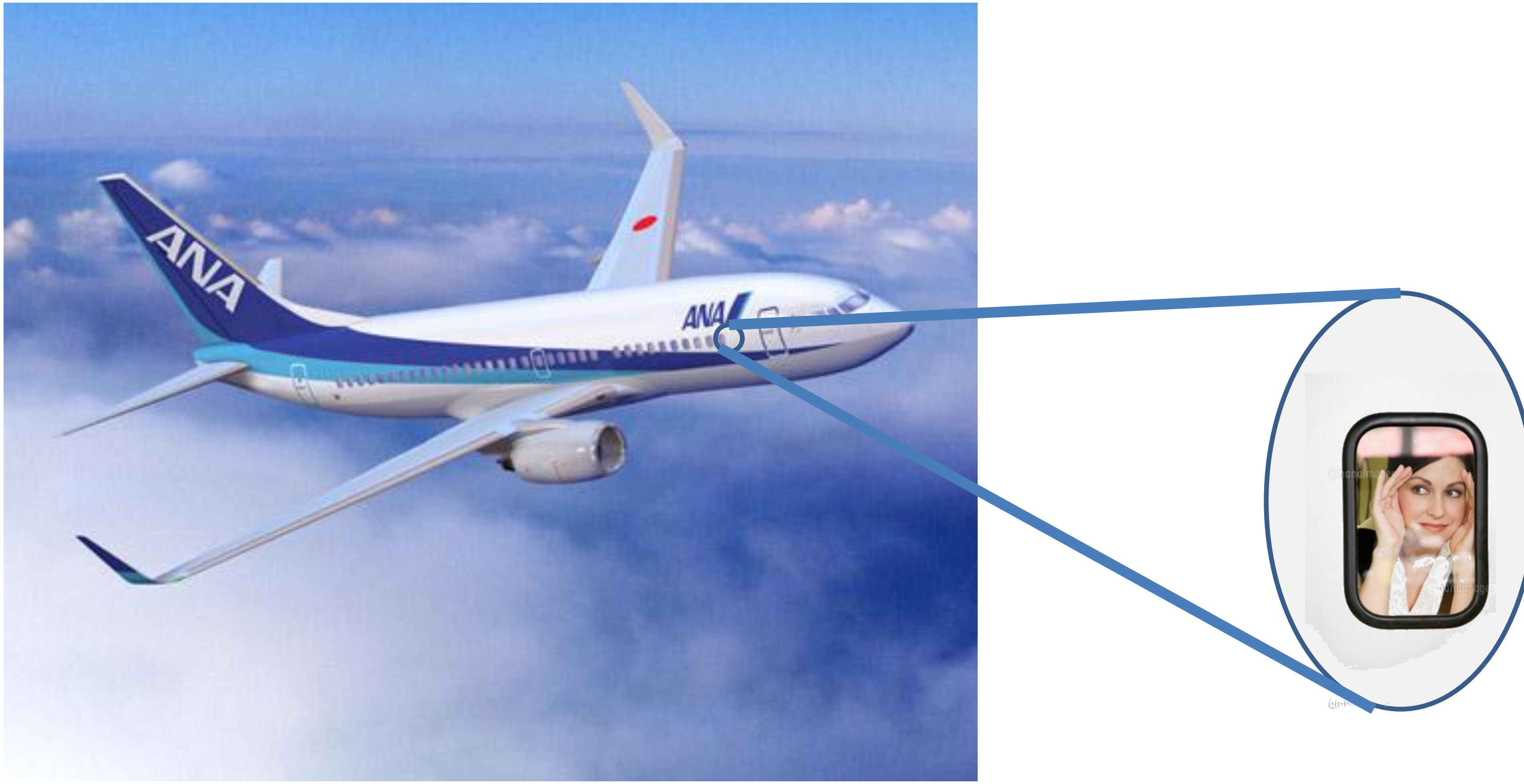
- **Indeed the obs… tion was clear! (**
- **But still not sure what it is.**

With full data in 2012



LHC after 2yr shutdown

Open question : next generation exp.



How easy to see who is sitting on the plane ?
Do we have enough motivation for the cost?

backup

Other measurement

ΓZZ vs Total width

$$\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$$

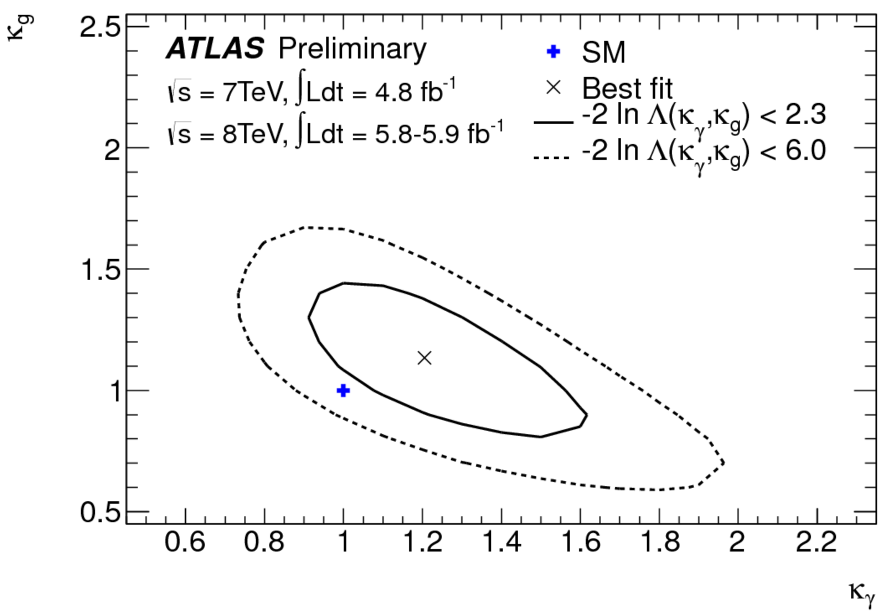
$$\kappa_{ZZ} = 1.3^{+0.9}_{-0.6}$$

ΓZZ vs Fermion

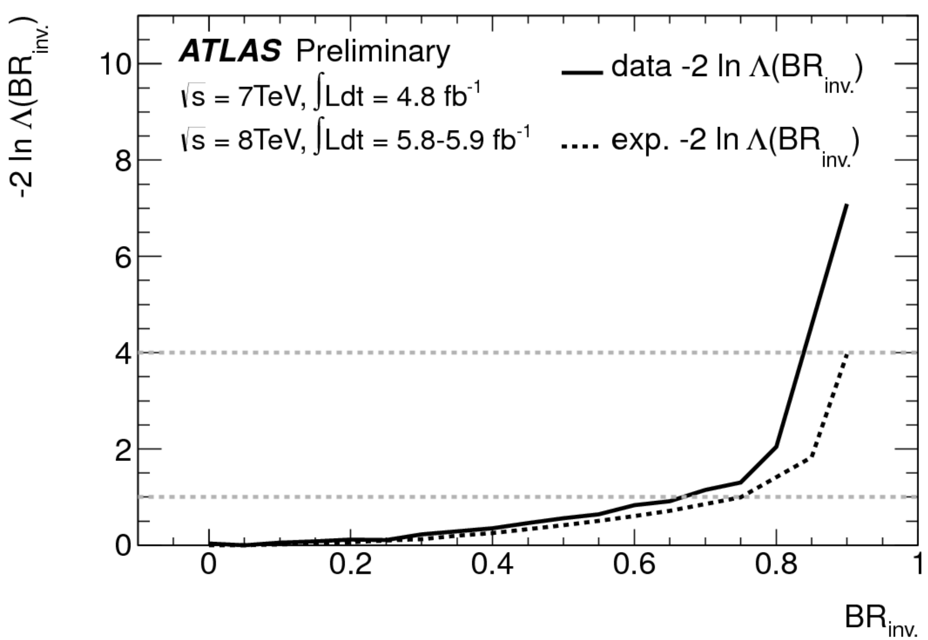
$$\lambda_{FZ} = \kappa_F / \kappa_Z$$

$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$ $\lambda_{FZ} \in [-1.1, -0.5] \cup [0.6, 1.2]$

Loop coupling : photon and gluon



Higgs decaying to invisible particles.



Systematic Uncertainties.

- Systematic uncertainties for Z→ττ background and Signal.
- Dominant systematics are Embedding, Tau Energy Scale and Jet Energy Scale. Both Shape and Normalization variation are taken into account.

Uncertainty	$H \to \tau_{\rm lep}\tau_{\rm lep}$	$H \to \tau_{\rm lep}\tau_{\rm had}$	$H \to \tau_{\rm had}\tau_{\rm had}$
		$Z \to \tau^+\tau^-$	
Embedding	1–4% (S)	2–4% (S)	1–4% (S)
Tau Energy Scale	–	4–15% (S)	3–8% (S)
Tau Identification	–	4–5%	1–2%
Trigger Efficiency	2–4%	2–5%	2–4%
Normalisation	4.7%	4% (non-VBF), 16% (VBF)	9–10%
		Signal	
Jet Energy Scale	1.0–5.0% (S)	3–9% (S)	2–4% (S)
Tau Energy Scale	–	2–9% (S)	4–6% (S)
Tau Identification	–	4–5%	10%
Theory	7.9–28%	18–23%	3–20%
Trigger Efficiency	small	small	5%