Searches for the SM Higgs boson in the tau-tau decay channel at ATLAS

Higgs Hunting 2012

Orsay-France

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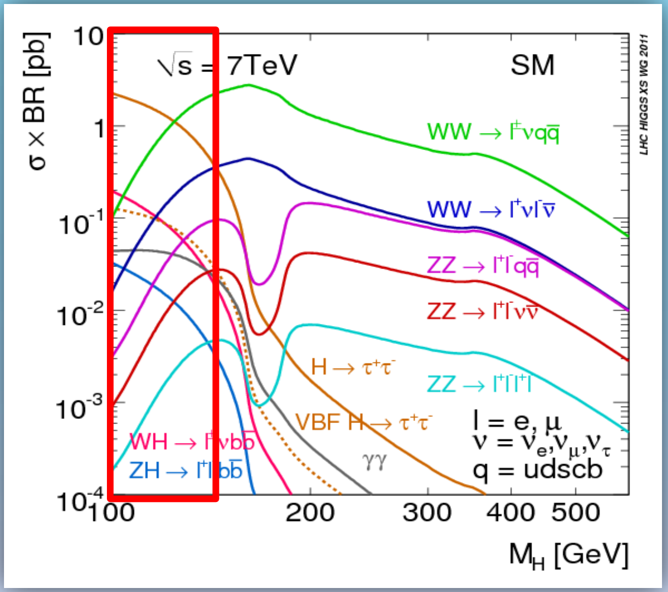
On behalf of the ATLAS collaboration

Introduction of H→ττ analysis



Motivation

1. Large branching ratio in 110<mH<150 GeV.
2. ττ mode is one of the important channels to measure the Higgs coupling with each fermion.

Analysis channel

- There are 3 final states based on the decay of τ.

Channel	Br.	Characteristics
H→ττ→lepton + lepton + 4v	12.4%	Clean but small stat.
H→ττ→hadronic τ + hadronic τ+ 2v	42.0%	Large Br.
H→ττ→lepton + hadronic τ + 3v	45.6%	Large Br. and clean

Focus on

Datasets

- 4.7 fb^{-1} of pp collisions collected in 2011 at a CM energy of 7 TeV.

Analysis strategy: Categorization

- Events are split into 7 categories according to the number of reconstructed jets and their topologies to maximize sensitivity.

Categories

•Vector boson fusion(VBF) category

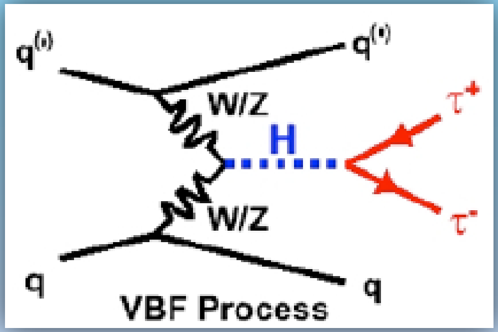
- 2^{nd} largest production cross section.
- Most sensitive category due to unique topology: 2 jets w/ high pt, large $\Delta\eta_{jj}$.

• >=1jet category

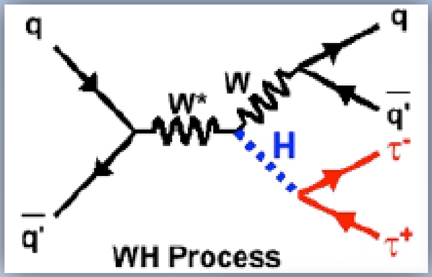
- For ggH and WH/VH process.

•0jet category

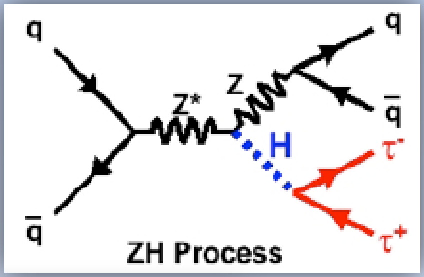
- To cover the bulk of ggH.



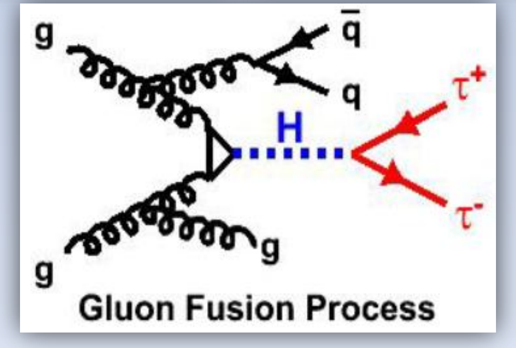
VBF Process



WH Process



ZH Process

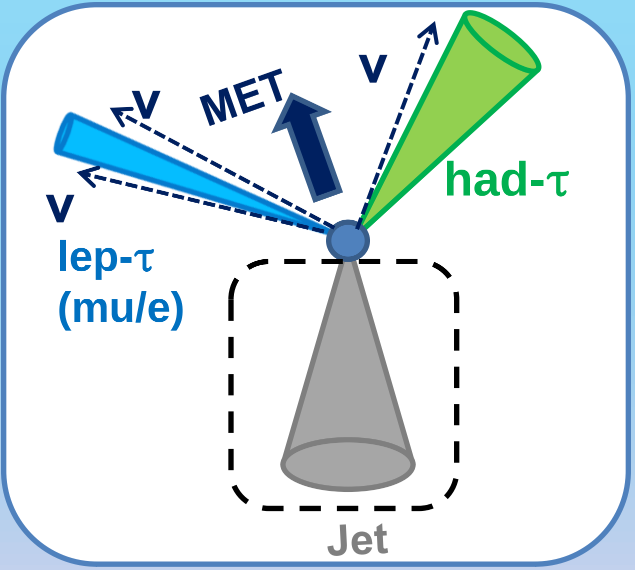


Gluon Fusion Process

Event selection

Preselection

- Topology: One lepton(e/μ) and hadronic tau.
  1. Trigger : Single lepton trigger.
  2. Exactly one lepton and tau with opposite sign.
  3. Missing Et(MET)>20 GeV except for 0jet.
  4. mT(lepton, MET)<30GeV to reduce W+jets contribution.



Categorization

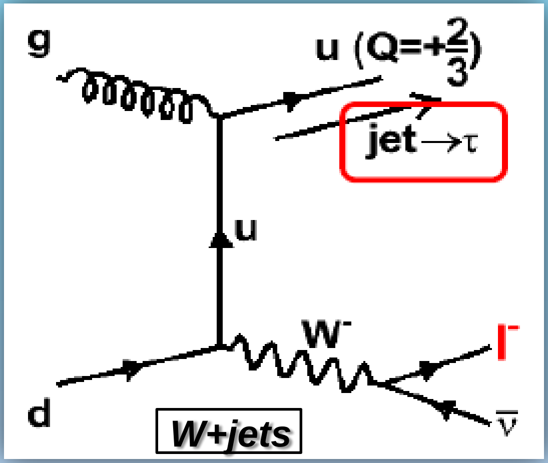
0jet	>=1jet	VBF
•No jet with pT>25GeV •4 categories - e/mu separated - Low/High MET (Low: MET<20 GeV) (High: MET>20GeV)	•>=1jet with pT>25GeV •Not VBF category •2 categories - e/mu separated	•Opposite hemispheres ($\eta_{j1} \times \eta_{j2} < 0$) •$\mid \eta_{j1} - \eta_{j2} \mid > 3.0$ •Leptons between jets: $\eta_{j1} < \eta_l, \eta_\tau < \eta_{j2}$ (or j1↔j2) •M(j1,j2) > 300 GeV

Missing Mass Calculator(MMC) :Our final discriminant variable.

Backgrounds

1.Reducible background
- Sources : QCD multi-jets, W+jets and so on.
- Estimation: Data-driven(described later.)

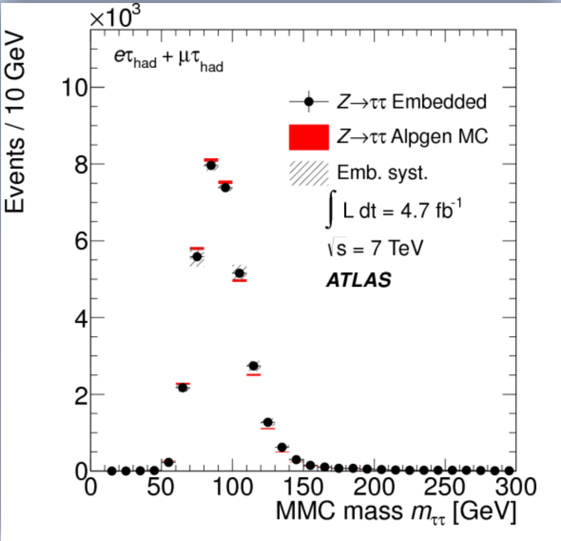
2.Irreducible background
- Sources: Z→ττ, ttbar and diboson….
- Estimation: Embedded sample for shape and MC(theory) for normalization.



τ-embedded Z→μμ data(Embedded sample)

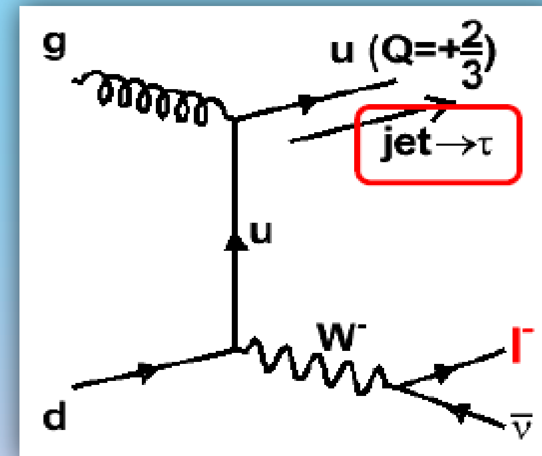
- Shape estimation from Z→μμ data:
  1. Remove mu tracks and calorimeter cells.
  2. Replace with tau from full-simulated Z→ττ decays.

- Event content from data, except tau decay products. (Jets/MET/pile-up/UE/etc are from the data)



Background estimation for fake tau

- Assumption that QCD events are the same in the opposite sign(OS) and same sign (SS) region.(~10% uncertainty)



$$n_{\mathrm{OS}}^{\mathrm{bkg}} = n_{\mathrm{SS}}^{\mathrm{all}} + n_{\mathrm{OS-SS}}^{W+\mathrm{jets}} + n_{\mathrm{OS-SS}}^{Z\to\tau\tau} + n_{\mathrm{OS-SS}}^{\mathrm{other}}$$

SS events in data.

Additional W+jets component.(AddOn)

Other EWK processes (SS subtracted) .

AddOn:

- Asymmetry in W+jets events due to charge correlation between W and outgoing quark.
- Typically $N_{OS} > N_{SS}$
  →Need to know N of OS-SS event and add extra contribution to OS.

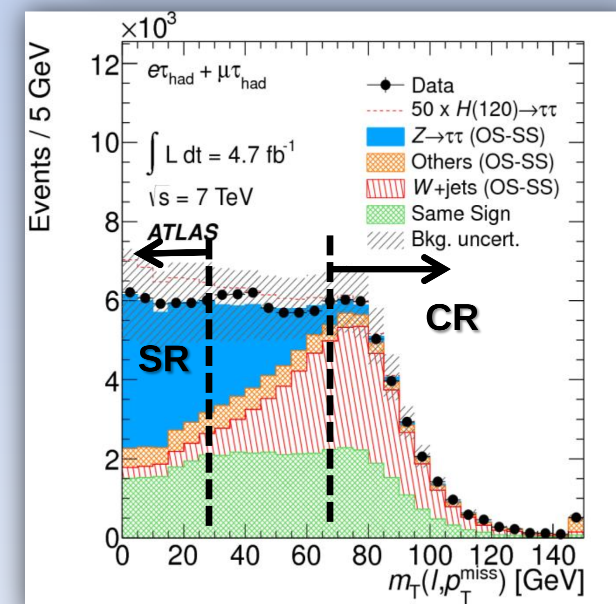
SS events in CR

$$k_{W+\mathrm{jets}} \times \left(n_{\mathrm{SS,data}}^{\mathrm{high}\ m_T} - n_{\mathrm{SS,MC}}^{\mathrm{other,high}\ m_T} \right) \times \frac{n_{\mathrm{SS,MC}}^{W+\mathrm{jets,all\ selection\ req.}}}{n_{\mathrm{SS,MC}}^{W+\mathrm{jets,high}\ m_T}}$$

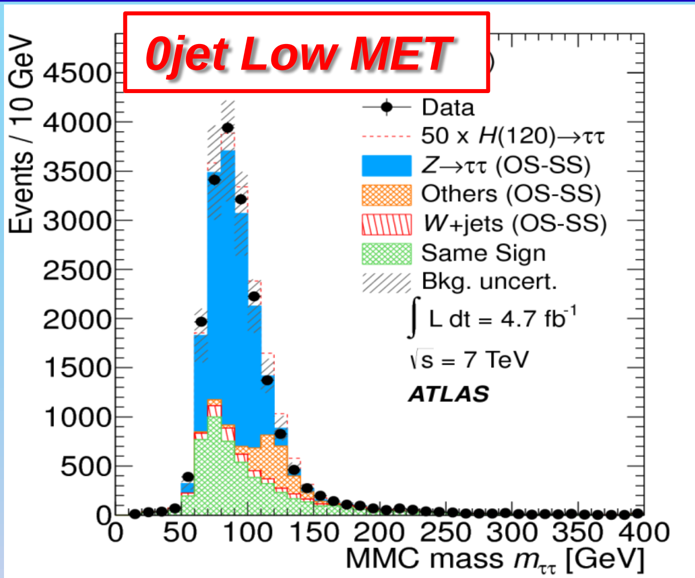
Acceptance CR to SR

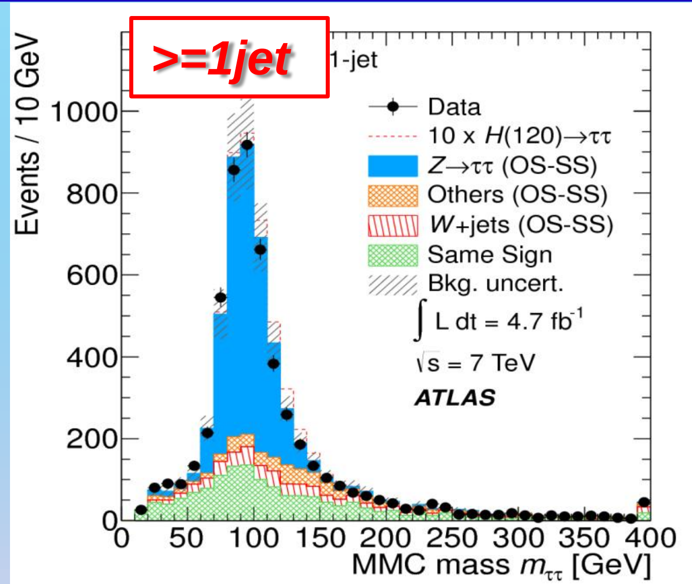
$$k_{W+\mathrm{jets}} = \frac{n_{\mathrm{OS,data}}^{\mathrm{high}\ m_T} - n_{\mathrm{OS,MC}}^{\mathrm{other,high}\ m_T}}{n_{\mathrm{SS,data}}^{\mathrm{high}\ m_T} - n_{\mathrm{SS,MC}}^{\mathrm{other,high}\ m_T}} - 1$$

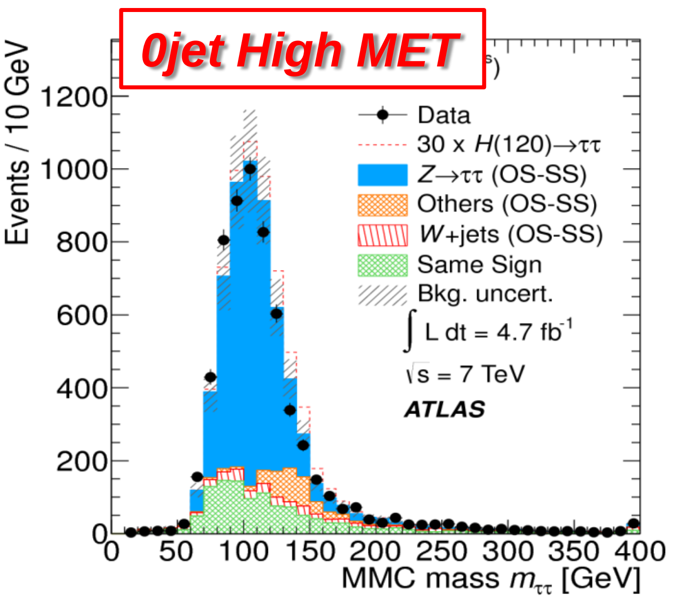
:Ratio OS to SS events.

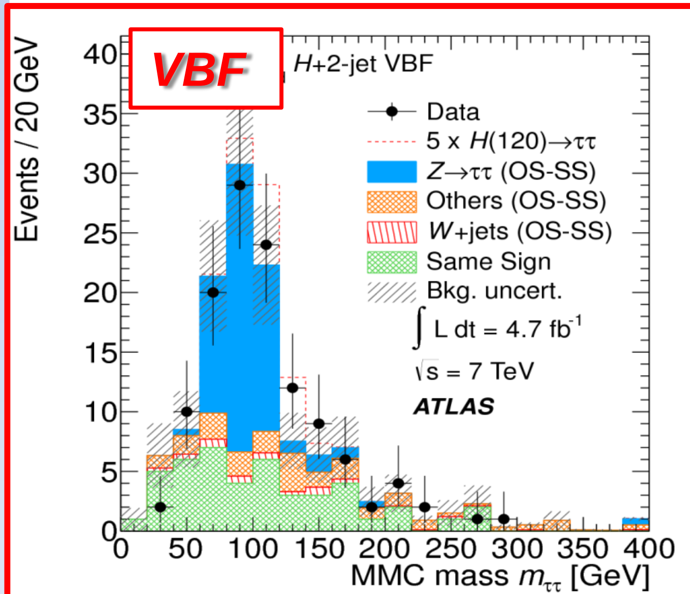


Result: MMC distributions





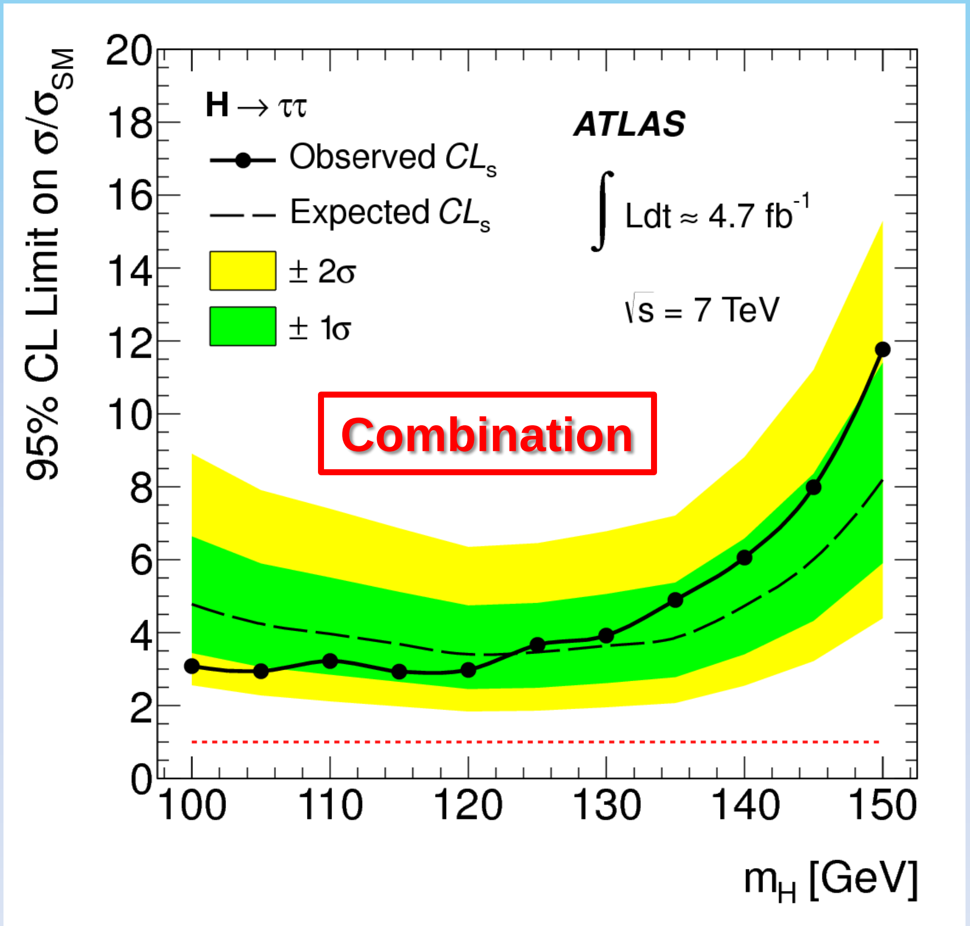




- Most sensitive
- Signal composition (ggF:VBF:VH) =29:70:1

Exclusion limit

- No excess is observed.
- Set limit.



Systematic sources (lh)	
Energy scale	~11%
QCD	~13%
W+jets AddOn	~15%

mH [GeV]	Observed	Expected
115	2.9(5.0)	3.7(5.8)
120	3.0(5.4)	3.4(5.5)
125	3.7(6.2)	3.5(5.9)
130	3.9(6.6)	3.6(6.1)

*Numbers in parentheses are for lepton-hadron channel only.

Summary

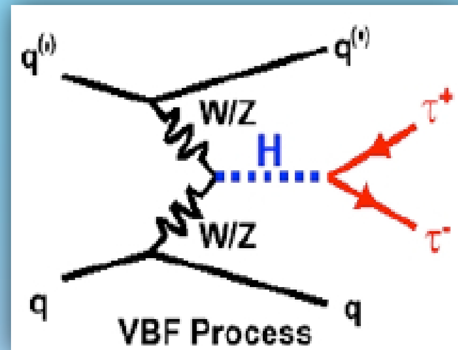
- Search for SM Higgs Boson decaying into tau pairs performed with the ATLAS detector is presented, mainly on lepton-hadron channel.
- Full 2011 data sample of 4.7fb-1 collected at 7TeV.
- Categorized based on presence of jets and their kinematics and Missing Et.
- Most sensitive channel is VBF category in this channel.
- Observed exclusion limit is $3.7 \times \sigma_{SM}$ at m_H=125GeV ($6.2 \times \sigma_{SM}$ from lepton-hadron channel only).

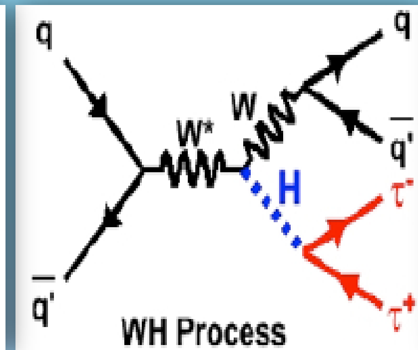
→Paper submitted to JHEP: arXiv:1206.5971

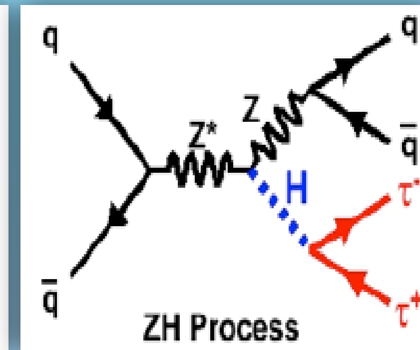
- Include 8 TeV data taken in 2012.
- The analysis is being further improved.

Back up

Summary of categorization





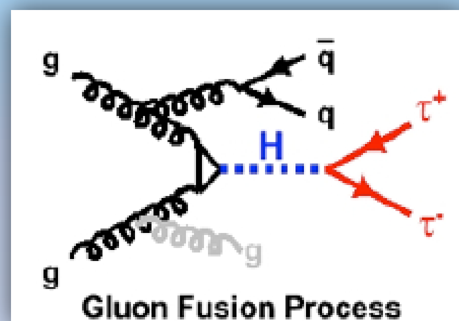


ll channel:

- H+2jets VBF
- H+2jets VH
- H+1jet
- H+0jet

hh channel:

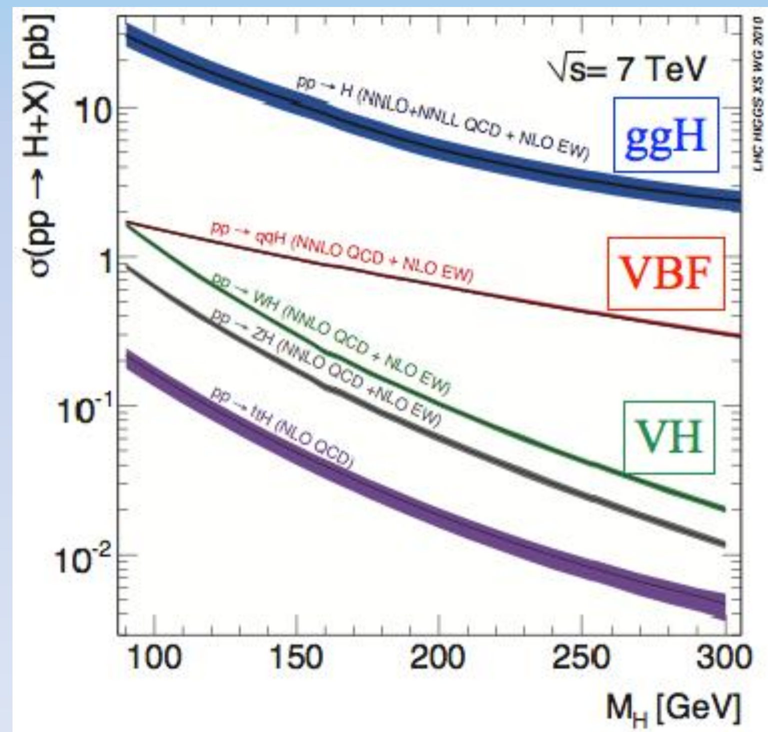
- H+1jet



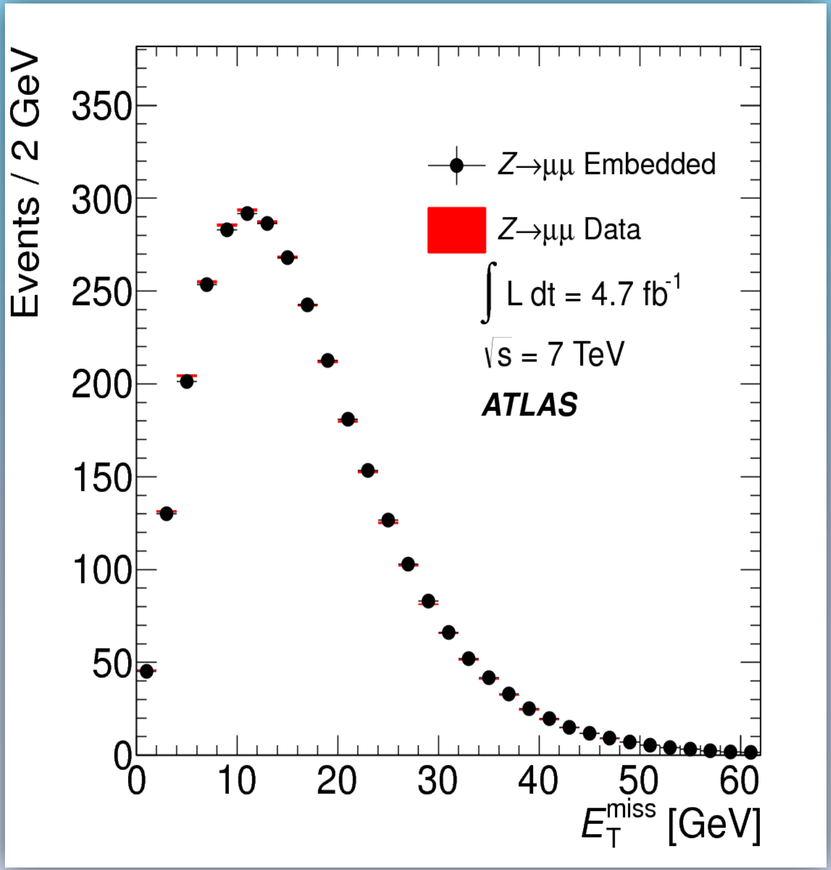
lh channel:

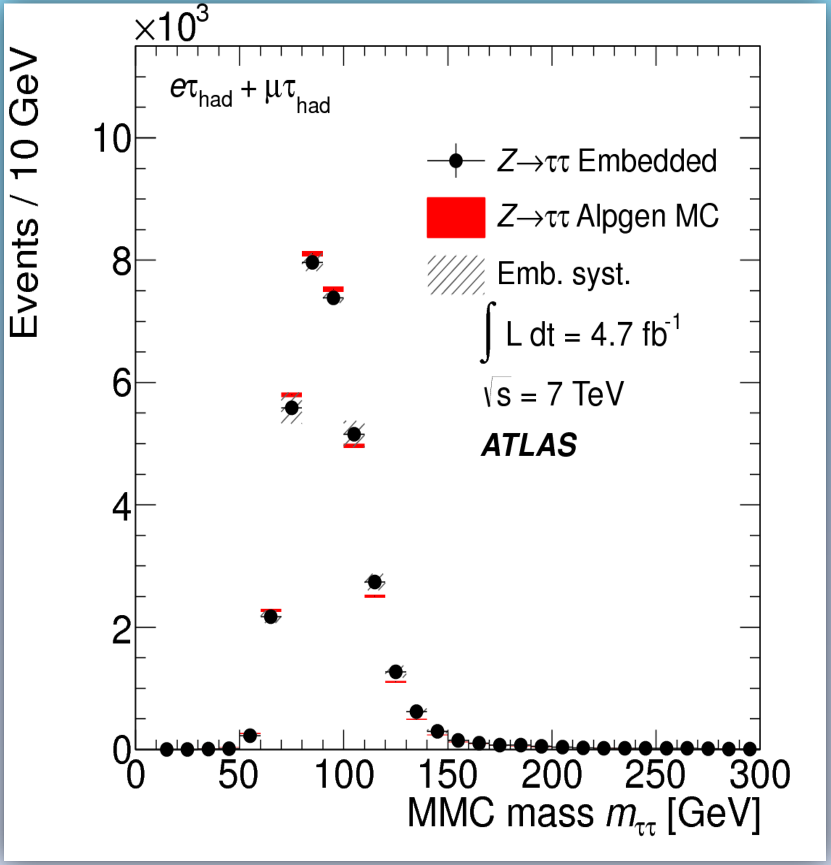
- H+2jets VBF
- H+1jets
- H+0jet in low MET
- H+0jet in high MET

(for the last three:) each channel. (e/mu)



Embedded validation





E_T^{miss} comparison from the selected Z→μμ events before and after this embedded.

→No bias introduced by this method.

Comparison of MMC distribution from the embedded and simulated Z→ττ.

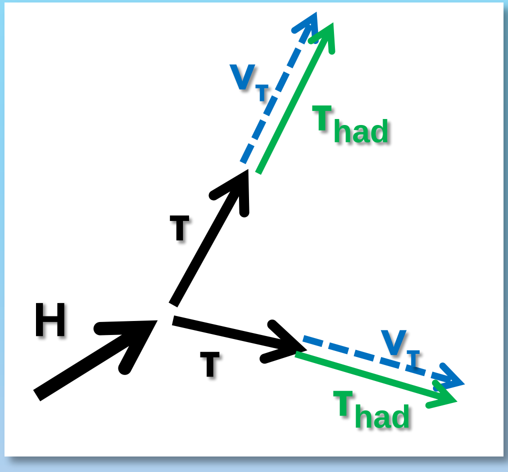
→Good agreement is found.

Di-tau mass reconstruction

1.Collinear approximation

- Assumption:
  - τ decay products are collinear.
  - All the MET comes from ν_τ s.
- It doesn't work when τ's are back-to-back.
- x_1, x_2 calculated in the function of MET and $p_{x,y}$ of τ_{had}.

$$m_{coll} = \frac{m_{vis}^{\tau\tau}}{\sqrt{x_1 x_2}}$$



2.Missing mass calculator(MMC)

- Algorithm based on Nucl. Inst. Meth. A 654 (2011) 481
- Δθ(ν-τ) is very small but non zero.
- Create grid point[Δφ(τ1,ν's), Δφ(τ2,ν's)].
- Solve 4 equations for P(ν1) and P(ν2) for each point.

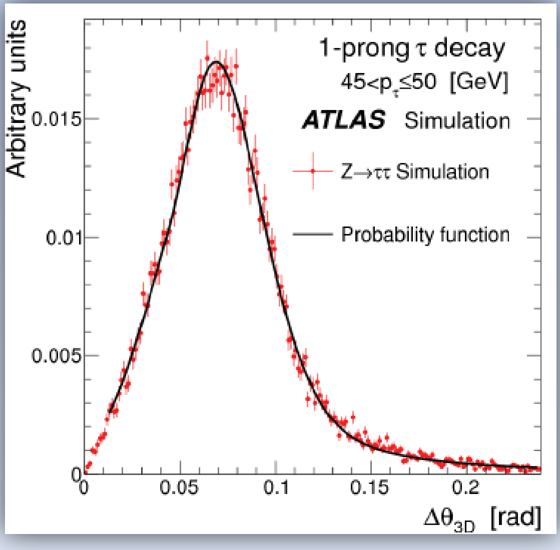
→Select more likely solution.

$$\not{E}_{T_x} = p_{\text{mis}_1} \sin\theta_{\text{mis}_1} \cos\phi_{\text{mis}_1} + p_{\text{mis}_2} \sin\theta_{\text{mis}_2} \cos\phi_{\text{mis}_2}$$

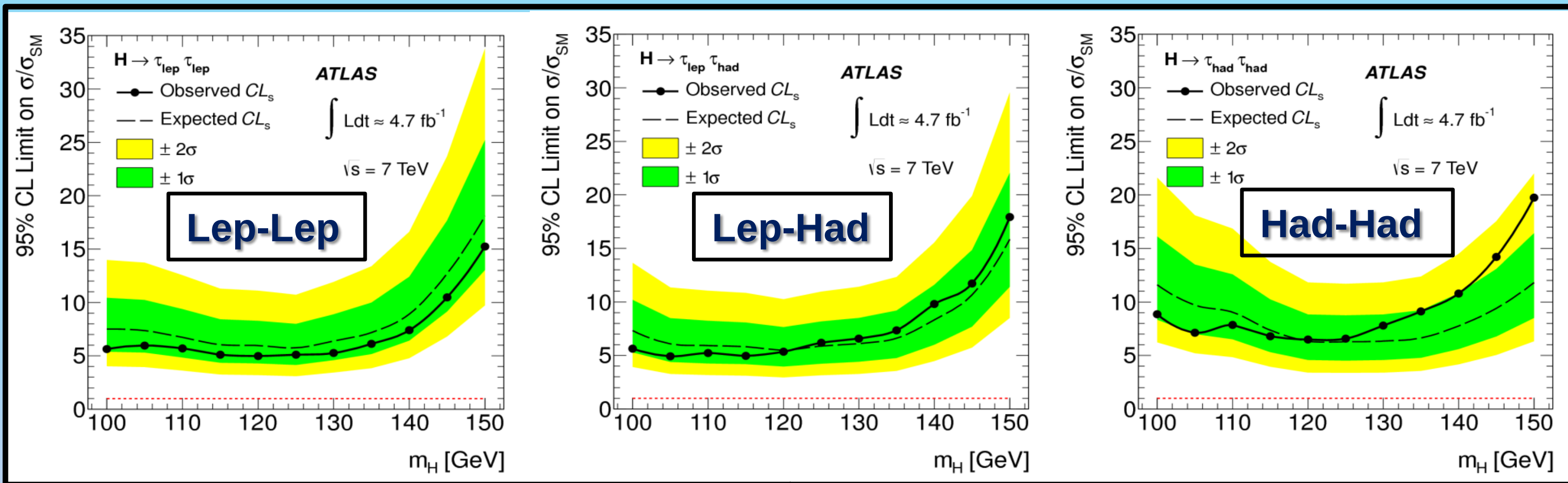
$$\not{E}_{T_y} = p_{\text{mis}_1} \sin\theta_{\text{mis}_1} \sin\phi_{\text{mis}_1} + p_{\text{mis}_2} \sin\theta_{\text{mis}_2} \sin\phi_{\text{mis}_2}$$

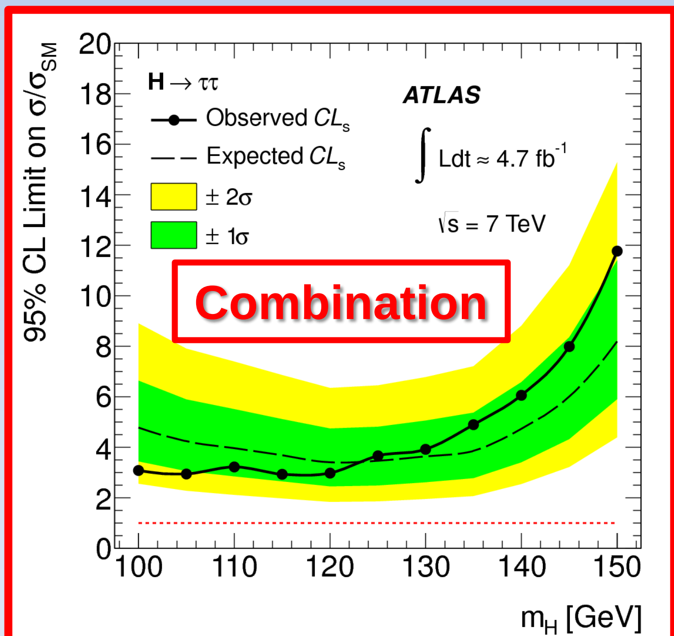
$$M_{\tau_1}^2 = m_{\text{mis}_1}^2 + m_{\text{vis}_1}^2 + 2\sqrt{p_{\text{vis}_1}^2 + m_{\text{vis}_1}^2}\sqrt{p_{\text{mis}_1}^2 + m_{\text{mis}_1}^2} - 2p_{\text{vis}_1} p_{\text{mis}_1} \cos\Delta\theta_{vm_1}$$

$$M_{\tau_2}^2 = m_{\text{mis}_2}^2 + m_{\text{vis}_2}^2 + 2\sqrt{p_{\text{vis}_2}^2 + m_{\text{vis}_2}^2}\sqrt{p_{\text{mis}_2}^2 + m_{\text{mis}_2}^2} - 2p_{\text{vis}_2} p_{\text{mis}_2} \cos\Delta\theta_{vm_2}$$



Exclusion limit





Combination

The observed(expected)upper limits are between 2.9(3.4) and 11.7(8.2).

m_h [GeV]	Expected $\times \sigma_{SM}$	Observed $\times \sigma_{SM}$
120	3.3	2.8
125	3.2	3.4
130	3.5	3.8

Event yield: Lep-Lep, Had-Had

Lep-Lep channel:

	$ee+\mu\mu+e\mu$ H+2-jet VBF	$ee+\mu\mu+e\mu$ H+2-jet VH	$ee+\mu\mu+e\mu$ H+1-jet	$e\mu$ H+0-jet
$gg \to H$ signal	0.26±0.06±0.10	0.8 ±0.1 ±0.2	3.9 ±0.2 ±1.0	23 ±1 ±3
VBF H signal	1.08±0.03±0.11	0.10±0.01±0.01	1.15±0.03±0.01	0.75±0.03±0.06
VH signal	0.01±0.01±0.01	0.53±0.02±0.07	0.40±0.02±0.03	0.52±0.02±0.04
$Z/\gamma^* \to \tau^+\tau^-$	24 ± 3 ± 2	107 ±12 ± 9	(0.52±0.01±0.04)·10^3	(9.68±0.05±0.07)·10^3
$Z/\gamma^* \to \ell^+\ell^-$ (ℓ=e,μ)	2 ± 1 ± 1	25 ± 4 ± 9	83 ±10 ±30	185 ±11 ±14
$t\bar{t}$+single top	7 ± 1 ± 2	42 ± 2 ± 6	98 ± 3 ±12	169 ± 4 ±14
$WW/WZ/ZZ$	0.9± 0.3± 0.3	6 ± 1 ± 1	21 ± 1 ± 3	221 ± 3 ±18
Fake leptons	1.3± 0.8± 0.6	13 ± 2 ± 5	30 ± 4 ±12	(1.2±0.5)·10^3
Total background	35 ± 3 ± 4	193 ± 7 ±20	(0.75±0.01±0.05)·10^3	(11.4±0.5)·10^3
Observed data	27	185	702	11420

Main bkg.

Most sensitive!

Had-Had channel:

	$H \to \tau_{had}\tau_{had}$ H+1-jet
$gg \to H$ signal	3.1 ± 0.2 ± 0.6
VBF H signal	1.51 ± 0.05 ± 0.18
VH signal	0.61 ± 0.04 ± 0.06
$Z/\gamma^* \to \tau^+\tau^-$	287 ± 23 ± 34
W+jets / Z+jets	6.1 ± 1.3 ± 1.4
$t\bar{t}$+single top	1.9 ± 0.3 ± 0.4
$WW/WZ/ZZ$	2.1 ± 0.4 ± 0.4
Multi-jet	54 ± 21 ± 12
Total background	348 ± 31 ± 36
Observed data	317

Main bkg.

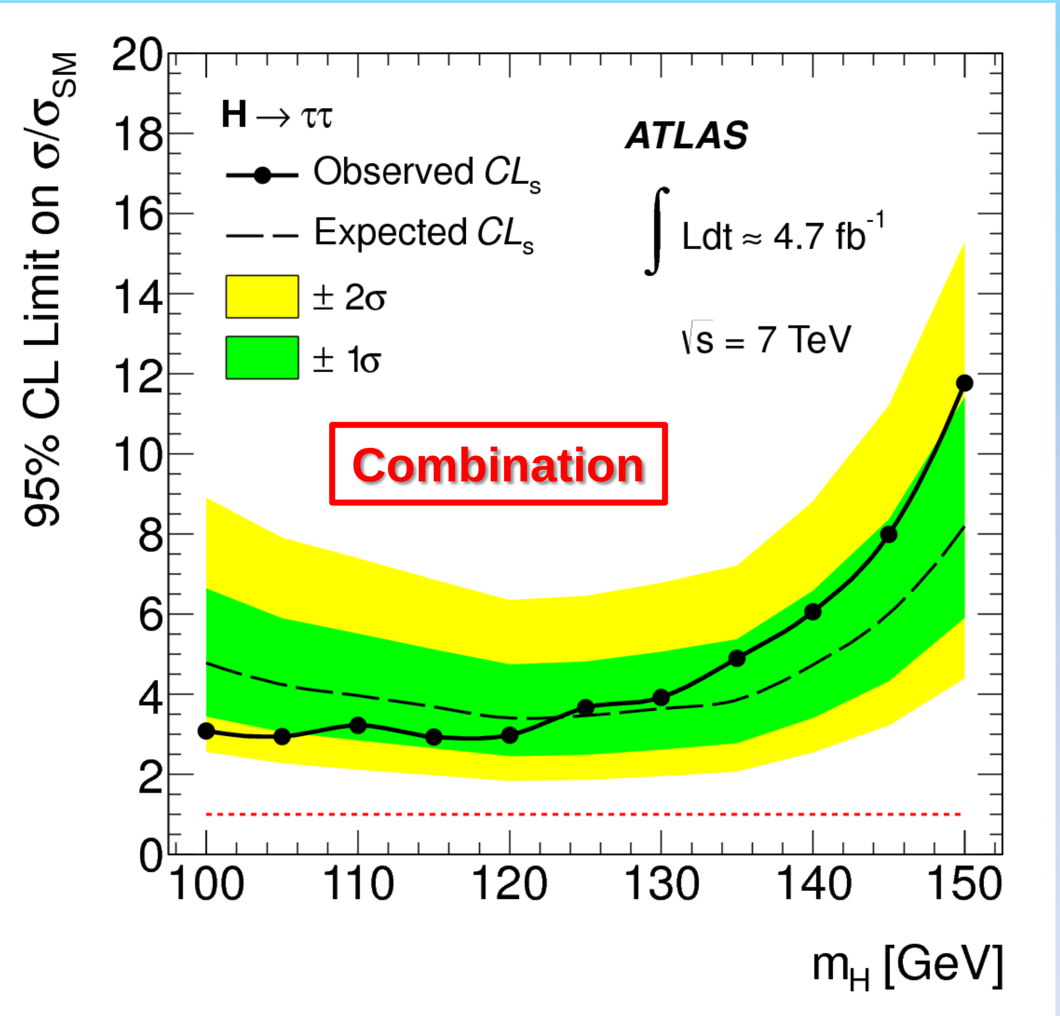
Event yield: Lep-Had

	H +0-jet (low E_T^{miss})		H +0-jet (high E_T^{miss})	
	Electron	Muon	Electron	Muon
ggH signal	$11 \pm 1 \pm 2$	$17 \pm 1 \pm 4$	$7.1 \pm 0.8 \pm 1.5$	$9.8 \pm 0.9 \pm 2.1$
VBF H signal	$0.08 \pm 0.02 \pm 0.12$	$0.11 \pm 0.03 \pm 0.03$	$0.09 \pm 0.02 \pm 0.02$	$0.14 \pm 0.03 \pm 0.03$
VH signal	$0.07 \pm 0.02 \pm 0.05$	$0.10 \pm 0.03 \pm 0.01$	$0.08 \pm 0.0 2 \pm 0.01$	$0.08 \pm 0.02 \pm 0.01$
n_{SS}^{all}	$(3.3 \pm 0.2 \pm 0.7) \cdot 10^3$	$(2.0 \pm 0.1 \pm 0.4) \cdot 10^3$	$(0.69 \pm 0.06 \pm 0.14) \cdot 10^3$	$(0.47 \pm 0.04 \pm 0.09) \cdot 10^3$
n_{OS-SS}^{W+jets}	$(0.33 \pm 0.02 \pm 0.04) \cdot 10^3$	$(0.50 \pm 0.02 \pm 0.07) \cdot 10^3$	$(0.15 \pm 0.01 \pm 0.02) \cdot 10^3$	$(0.18 \pm 0.01 \pm 0.03) \cdot 10^3$
$n_{OS-SS}^{Z\to\tau\tau}$	$(3.70 \pm 0.06 \pm 0.61) \cdot 10^3$	$(7.29 \pm 0.06 \pm 1.21) \cdot 10^3$	$(1.49 \pm 0.04 \pm 0.23) \cdot 10^3$	$(2.80 \pm 0.04 \pm 0.42) \cdot 10^3$
n_{OS-SS}^{other}	$(0.97 \pm 0.04 \pm 0.22) \cdot 10^3$	$(0.59 \pm 0.04 \pm 0.14) \cdot 10^3$	$(0.27 \pm 0.02 \pm 0.08) \cdot 10^3$	$(0.14 \pm 0.02 \pm 0.04) \cdot 10^3$
Total background	$(8.2 \pm 0.2 \pm 0.8) \cdot 10^3$	$(10.4 \pm 0.2 \pm 1.2) \cdot 10^3$	$(2.59 \pm 0.07 \pm 0.26) \cdot 10^3$	$(3.59 \pm 0.06 \pm 0.43) \cdot 10^3$
Observed data	8363	10911	2545	3570
Altern. estimate	$(8.7 \pm 0.1 \pm 0.8) \cdot 10^3$	$(10.7 \pm 0.1 \pm 1.0) \cdot 10^3$	$(2.76 \pm 0.05 \pm 0.33) \cdot 10^3$	$(3.75 \pm 0.05 \pm 0.47) \cdot 10^3$

Most sensitive!

	H +1-jet		H +2-jet VBF
	Electron	Muon	Electron + Muon
ggH signal	$8.1 \pm 0.7 \pm 1.6$	$10.8 \pm 0.8 \pm 2.2$	$0.9 \pm 0.2 \pm 0.3$
VBFH signal	$1.6 \pm 0.1 \pm 0.1$	$1.9 \pm 0.1 \pm 0.1$	$2.2 \pm 0.1 \pm 0.2$
VH signal	$1.1 \pm 0.1 \pm 0.1$	$1.4 \pm 0.1 \pm 0.1$	$0.02 \pm 0.01 \pm 0.01$
n_{SS}^{all}	$(0.93 \pm 0.07 \pm 0.19) \cdot 10^3$	$(0.49 \pm 0.04 \pm 0.10) \cdot 10^3$	$45 \pm 7 \pm 9$
n_{OS-SS}^{W+jets}	$(0.25 \pm 0.01 \pm 0.03) \cdot 10^3$	$(0.26 \pm 0.01 \pm 0.03) \cdot 10^3$	$5 \pm 1 \pm 2$
$n_{OS-SS}^{Z\to\tau\tau}$	$(1.23 \pm 0.03 \pm 0.17) \cdot 10^3$	$(1.76 \pm 0.03 \pm 0.25) \cdot 10^3$	$54 \pm 6 \pm 8$
n_{OS-SS}^{other}	$(0.28 \pm 0.02 \pm 0.04) \cdot 10^3$	$(0.24 \pm 0.01 \pm 0.03) \cdot 10^3$	$20 \pm 3 \pm 5$
Total background	$(2.69 \pm 0.08 \pm 0.26) \cdot 10^3$	$(2.75 \pm 0.05 \pm 0.27) \cdot 10^3$	$124 \pm 10 \pm 13$
Observed data	2610	2711	122
Altern. estimate	$(2.63 \pm 0.05 \pm 0.25) \cdot 10^3$	$(2.72 \pm 0.04 \pm 0.28) \cdot 10^3$	$131 \pm 11 \pm 23$

Combined limit



mH [GeV]	Observed	Expected
100	3.1	4.8
105	2.9	4.2
110	3.2	4.0
115	2.9	3.7
120	3.0	3.4
125	3.7	3.5
130	3.9	3.6
135	4.9	3.9
140	6.1	4.7
145	8.0	6.0
150	11.7	8.2