* Beyond-the-Standard Model Higgs Physics using the ATLAS Experiment

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On behalf of the ATLAS Collaboration

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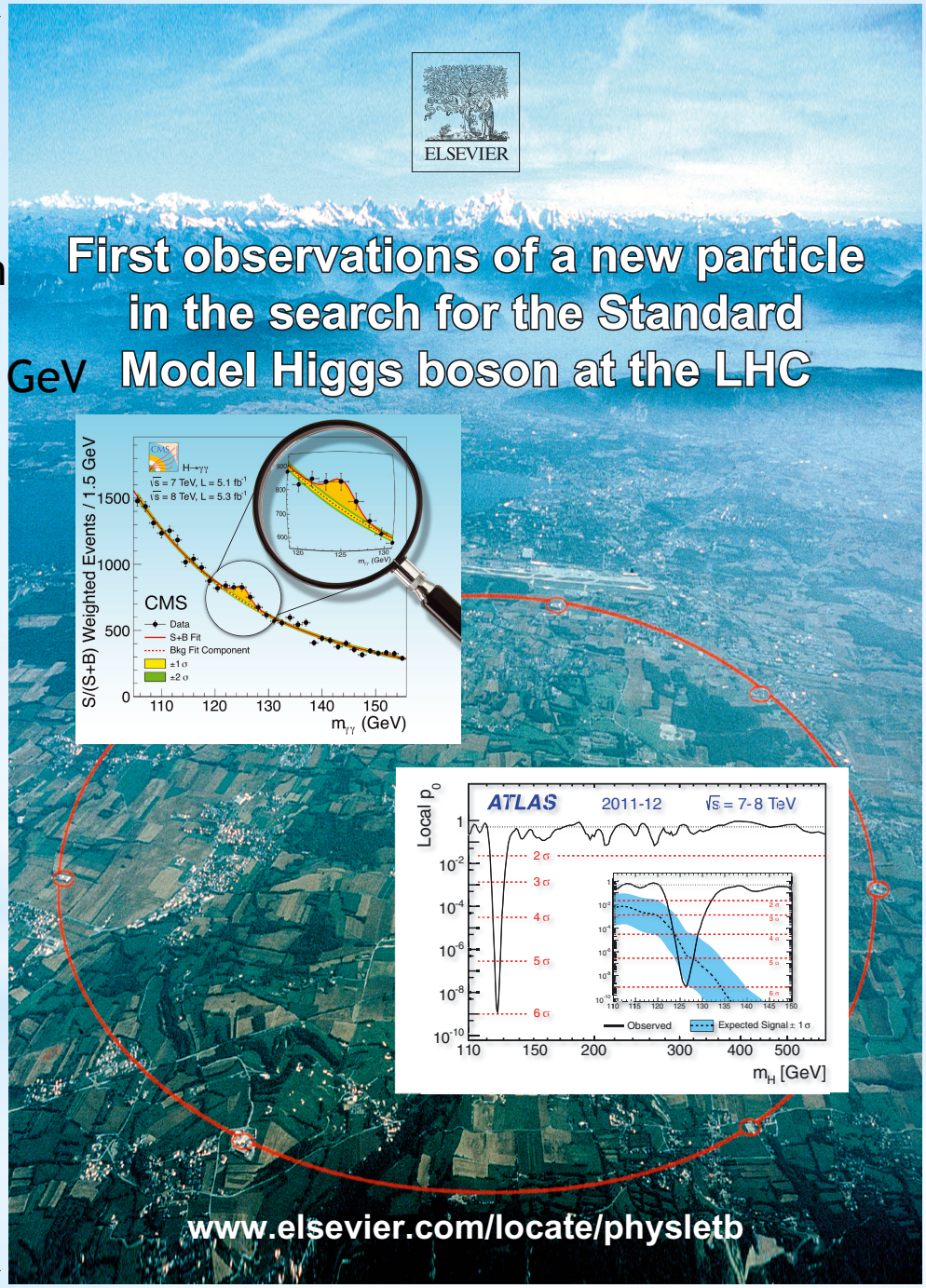
Discovery of a Higgs-like boson last year with a mass about 125 GeV



Is this particle part of a much larger and more complex Higgs sector than the one of the SM?

* BSM Higgs searches

* Models:

- ✓ 125 GeV Higgs + Electro weak singlet model
- ✓ Two-Higgs Doublet Models (2HDM)
- ✓ MSSM and NMSSM Higgs

* Searches based on:

- ✓ Another SM-like Higgs boson with different mass
- ✓ Another Neutral Higgs boson with different mass and with non-SM properties
- ✓ Charged Higgs Boson

* BSM Higgs searches : models

~125 GeV Higgs Boson + EW singlet model

* ~125 GeV Higgs h mixes with a singlet field H
* The allowed values of H couplings depend on the measured production and decay rates of h.
* H can have non-SM decays (BR_{new})
* The relevant observables in the search for H are its x-section (σ'), total width Γ' and the branching ratio BR'. They depend on k' and BR_{new}
* If BR_{new} = 0, narrow width is favoured by current h (125 GeV) measured couplings. Modelled by Narrow width Approximation (NWA)

2HDM

* Addition of a second complex Higgs doublet
* 5 Higgs Bosons: two CP-even scalar fields h and H, one pseudoscalar CP-odd field A, two charged fields $H^{\pm}$
* Parameters:

m_h, m_H, m_A, $m_{H\pm}$

α:rotation angle that diagonalizes the mass-squared matrices of the CP-even scalars.

tan β: ratio of vacuum expectation values of the scalar fields

* Different type models:

type-I all quarks couples to one Higgs doublet

type-II right-handed up quarks couple to Higgs doublet and right-handed down quarks couple to the other doublet

* SM Higgs-like boson with heavier mass

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* Search for a heavy Higgs boson:

- Using 20.7 fb^{-1} of proton-proton collision data at centre-of-mass-energy of 8 TeV
- mass range 260 GeV ≤ m_H ≤ 1 TeV
- channel: H -> WW -> lν lν (l=e,μ)
- Only different lepton-flavour final state considered.
- Analysis take into account two largely different assumptions on the width of the Higgs boson:

  SM width (Higgs Boson) lineshape

  A narrow width lineshape (NWA)

* SM Higgs-like boson with heavier mass

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* Event selection

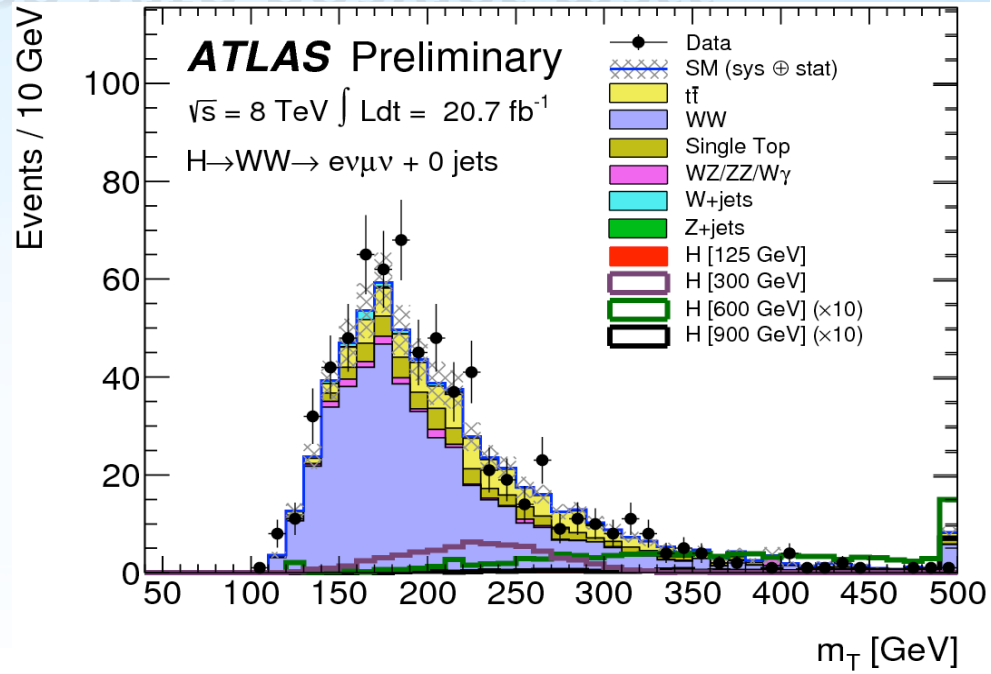
Category	0-jet	1-jet	>=2-jet
Preselection	An isolated electron and an isolated muon, with opposite charge, each with $p_T > 40$ GeV, $m_{\ell\ell} > 10$ GeV		
Missing transverse momentum	$E_{T,rel}^{miss} > 25$ GeV	$E_{T,rel}^{miss} > 25$ GeV	$E_T^{miss} > 20$ GeV
General selection	- $\Delta\phi_{\ell\ell,E_T^{miss}} > \pi/2$ $p_T^{\ell\ell} > 30$ GeV	$N_{b\text{-jet}} = 0$ - $Z/\gamma^* \to \tau\tau$ veto	$N_{b\text{-jet}} = 0$ $p_T^{tot} < 45$ GeV $Z/\gamma^* \to \tau\tau$ veto
VBF topology	- - - -	- - - -	$m_{jj} > 500$ GeV $\lvert \Delta y_{jj} \rvert > 2.8$ No jets ($p_T > 20$ GeV) in the rapidity gap; require both ℓ in the rapidity gap
$H \to WW \to \ell\nu\ell\nu$ topology	$m_{\ell\ell} > 50$ GeV $\Delta\eta_{\ell\ell} < 1.0$	$m_{\ell\ell} > 50$ GeV $\Delta\eta_{\ell\ell} < 1.0$	$m_{\ell\ell} > 50$ GeV $\Delta\eta_{\ell\ell} < 1.0$

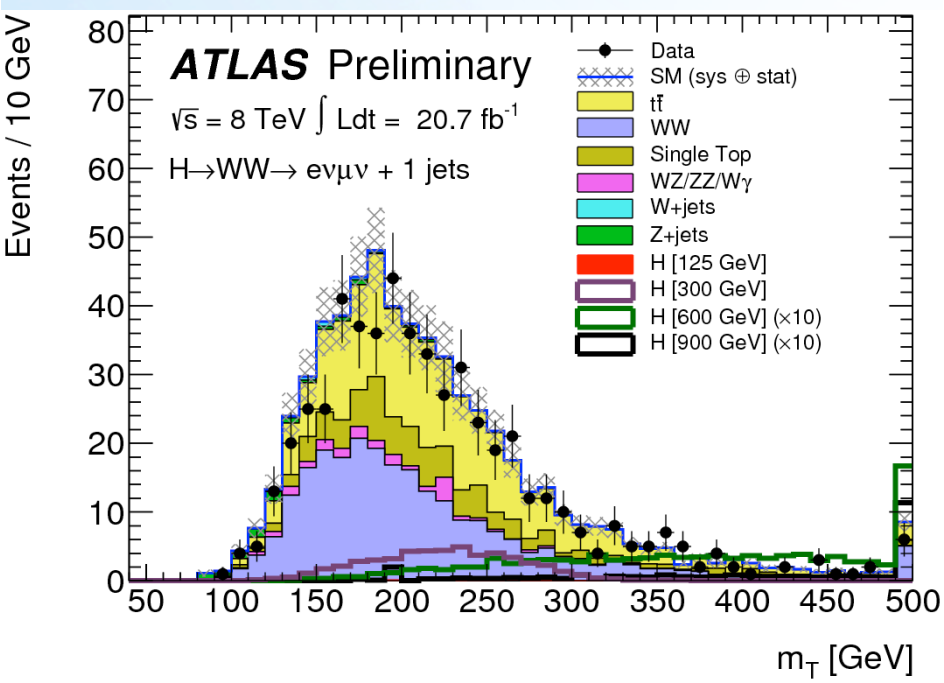
* SM Higgs-like boson with heavier mass

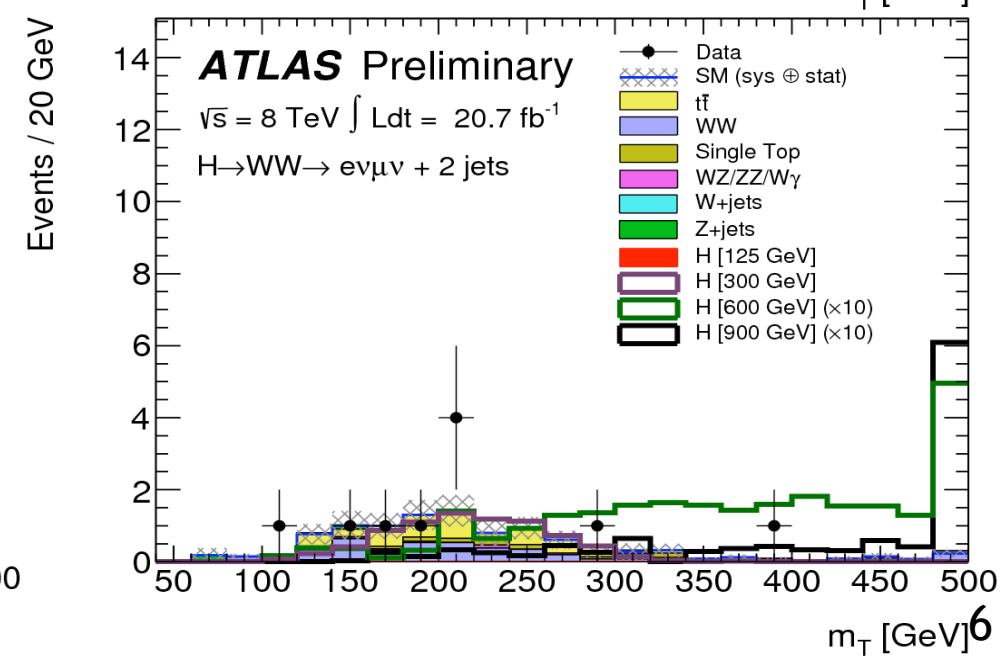
* Transverse mass distributions for the 0-jet, 1-jet and >=2 jets final states

$$m_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 - |\mathbf{p}_T^{ll} + \mathbf{E}_T^{miss}|^2}$$

$$E_T^{ll} = \sqrt{|\mathbf{p}_T^{||}|^2 + m_{ll}^2}$$







* SM Higgs-like boson with heavier mass

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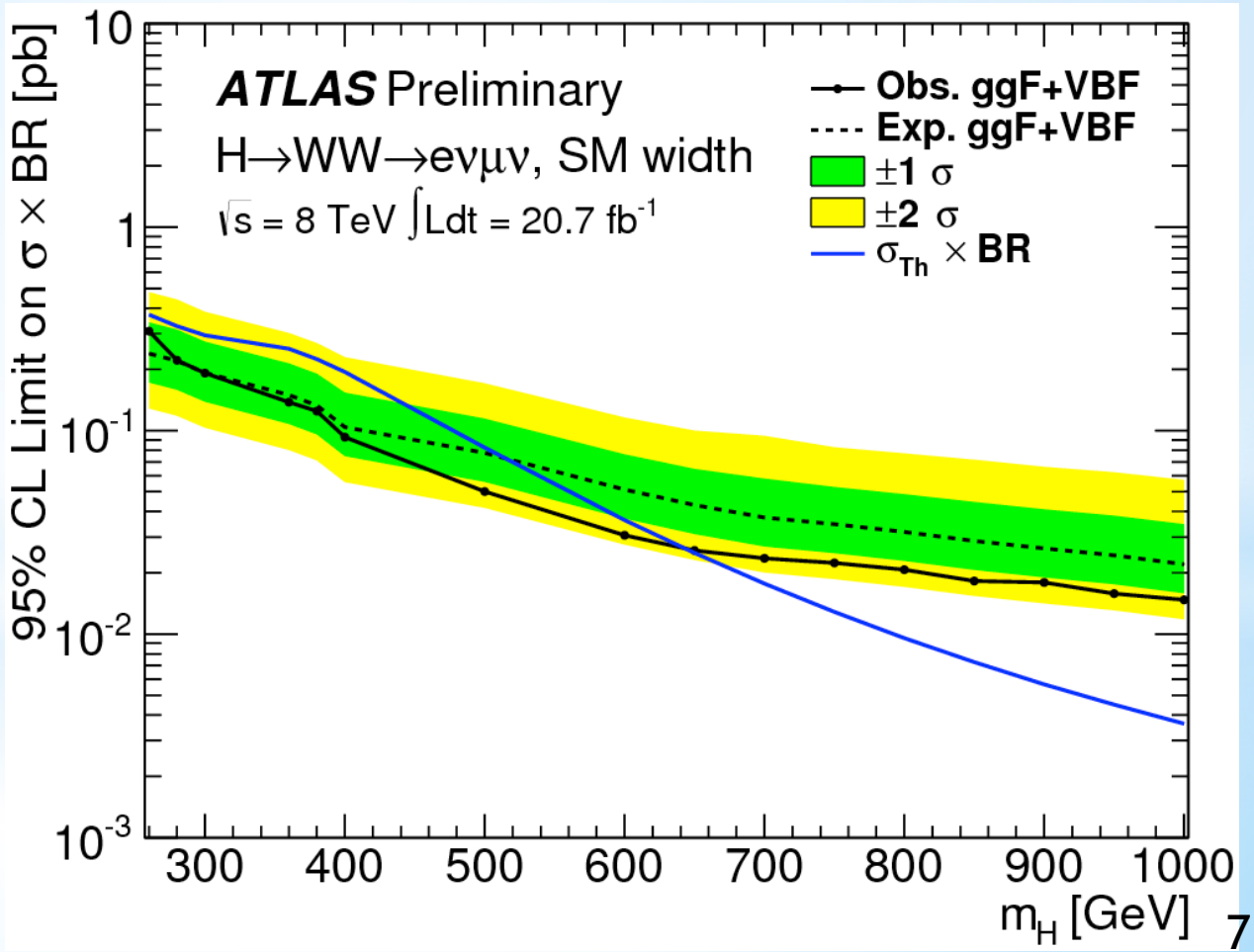
* 95% CL upper limits on the Higgs boson production cross section times branching ratio for H->WW->lvlv for a Higgs boson with a SM-like lineshape

*A Higgs boson with SM-like Production cross section and couplings Is excluded at 95% CL in the range 260 GeV ≤ *mH* ≤ 642 GeV



* Neutral Higgs Boson with non-SM properties

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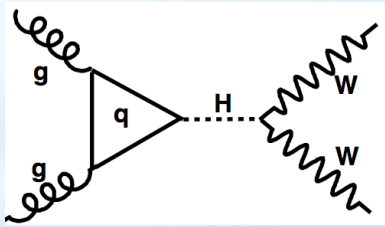
* Boson observed by ATLAS and CMS is part of a 2HDM -> low mass Higgs h of the 2HDM.

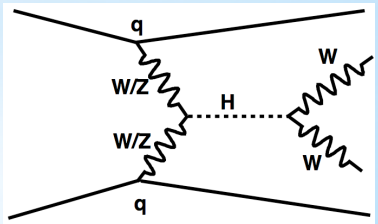
* Analysis searches for additional signal contributions by higher mass CP-even boson H of the model.

* Both bosons are reconstructed in the h/H -> WW* -> lν lν (l= e, μ) decay channel

ggF



VBF



* Considered ggF and VBF Higgs production modes

ggF: two charged leptons + large MET required.

VBF: two high pt jets required in addition.

* mass range : 135 GeV < m_H < 300 GeV

* Neutral Higgs Boson with non-SM properties

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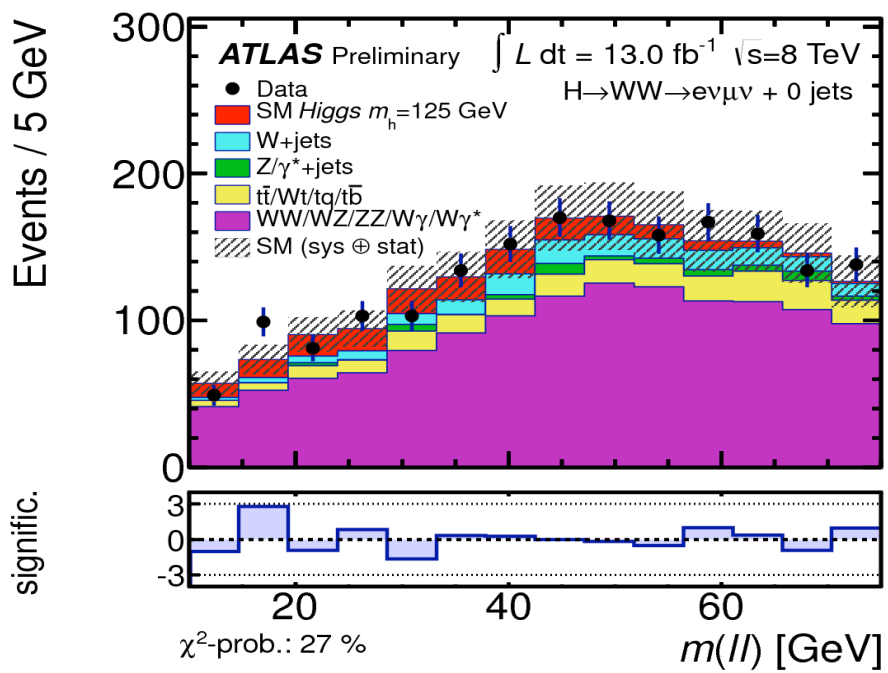
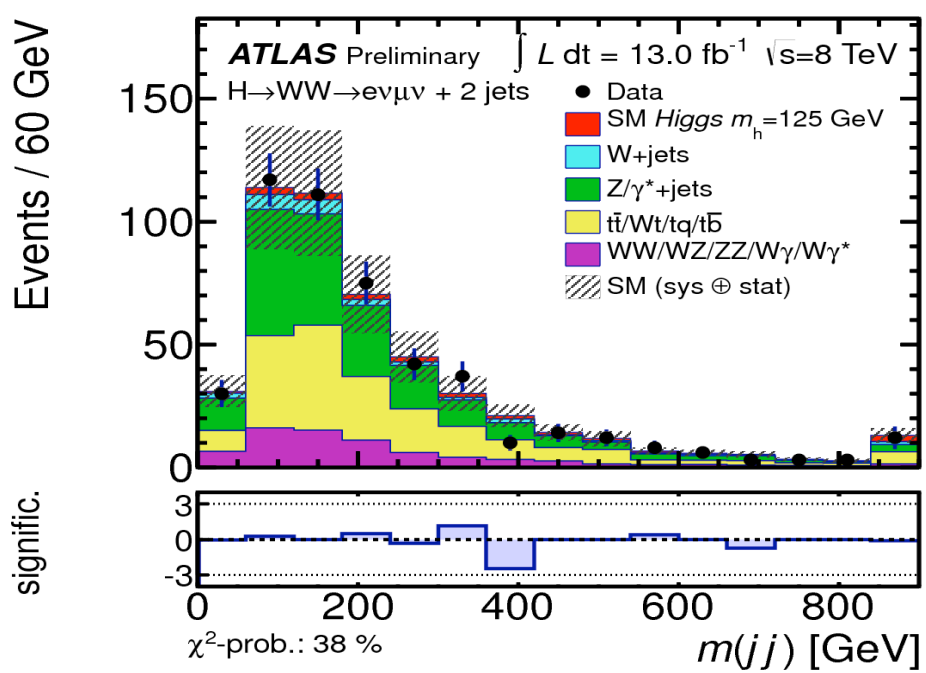
To separate 2HDM signal from background in the WW* channel, several kinematic variables are combined to one discriminant by employing artificial neural networks NN

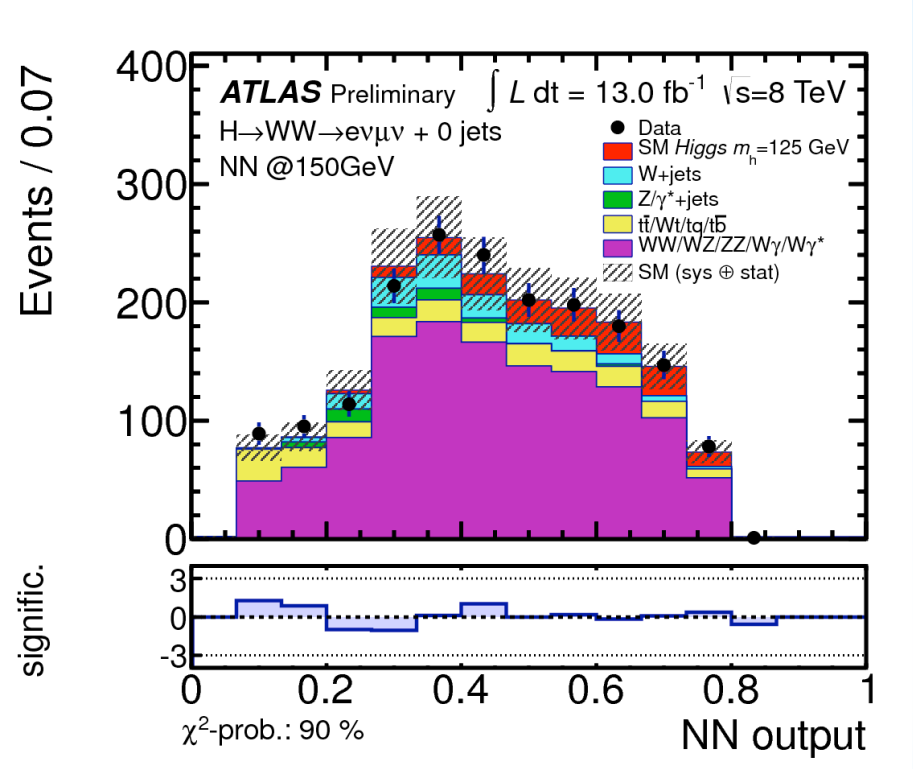
NNs are trained at 3 Higgs mass points: 150 GeV, 180 GeV and 240 GeV.



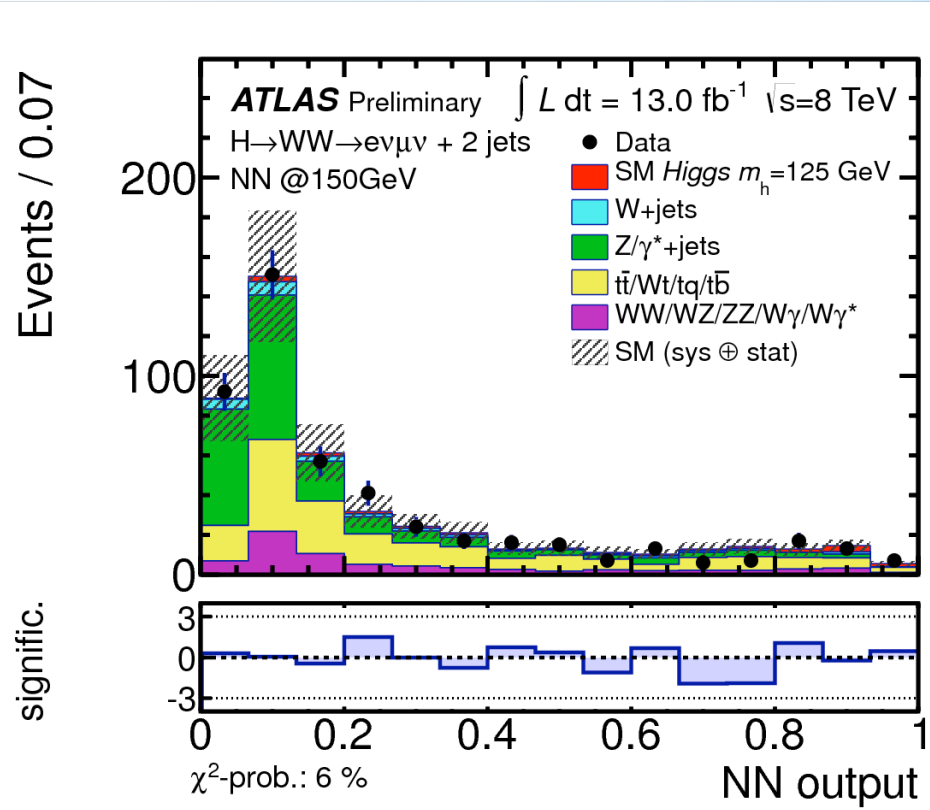


Distribution of the highest-ranking input variable of the NN optimised for m_H=150 GeV in the signal region of the 0-jet and 2-jet channel respectively

* Neutral Higgs Boson with non-SM properties



Discriminant distribution obtained with the NN optimised for m_H=150 GeV in the 0-jet channel and 2-jet channel



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* Neutral Higgs Boson with non-SM properties

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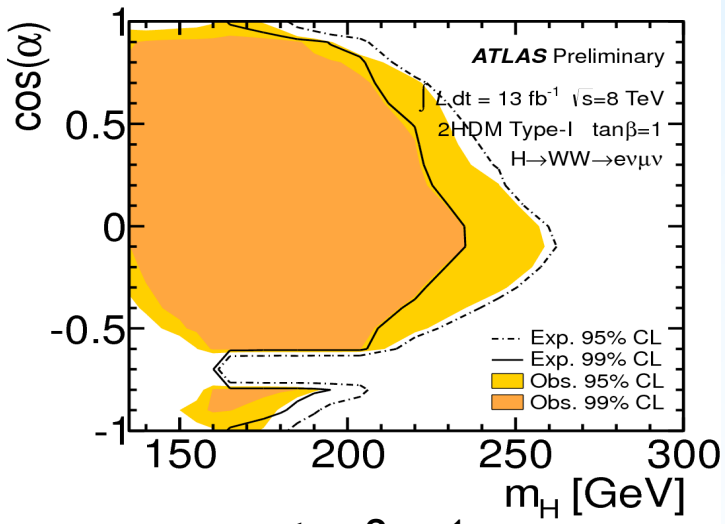
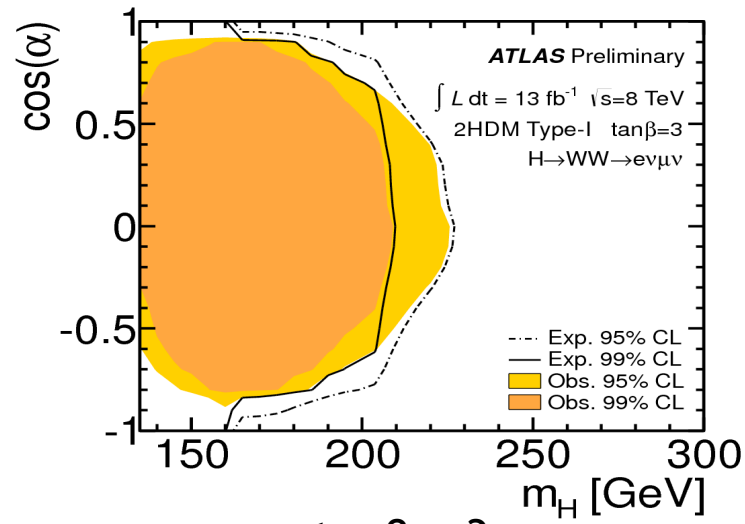
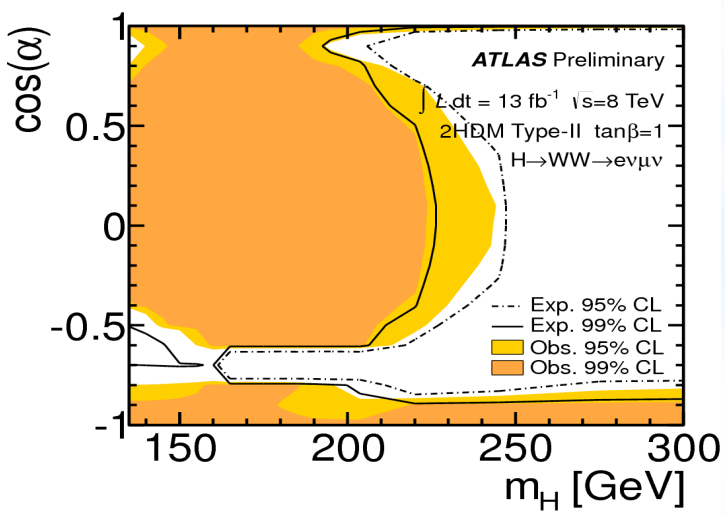


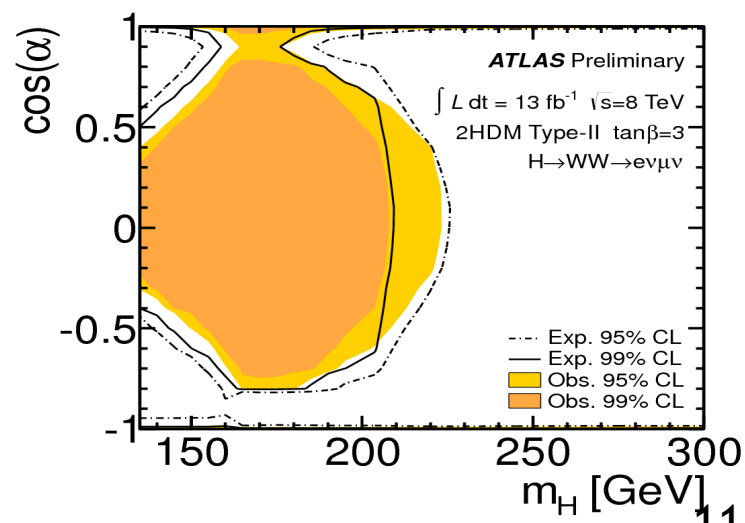
tanβ = 1



tanβ = 3

Exclusion contour in the cosα-m_H plane for different values of tanβ of the type-I (up) and type-II (down) 2HDM.





* Neutral Higgs Boson of the MSSM

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* In the MSSM model two higgs doublets are necessary (at tree level MSSM is a type-II 2HDM).

* In the MSSM, the Higgs boson couplings to τ leptons and b-quarks are strongly enhanced for a large part of the parameter space (large tan β values)

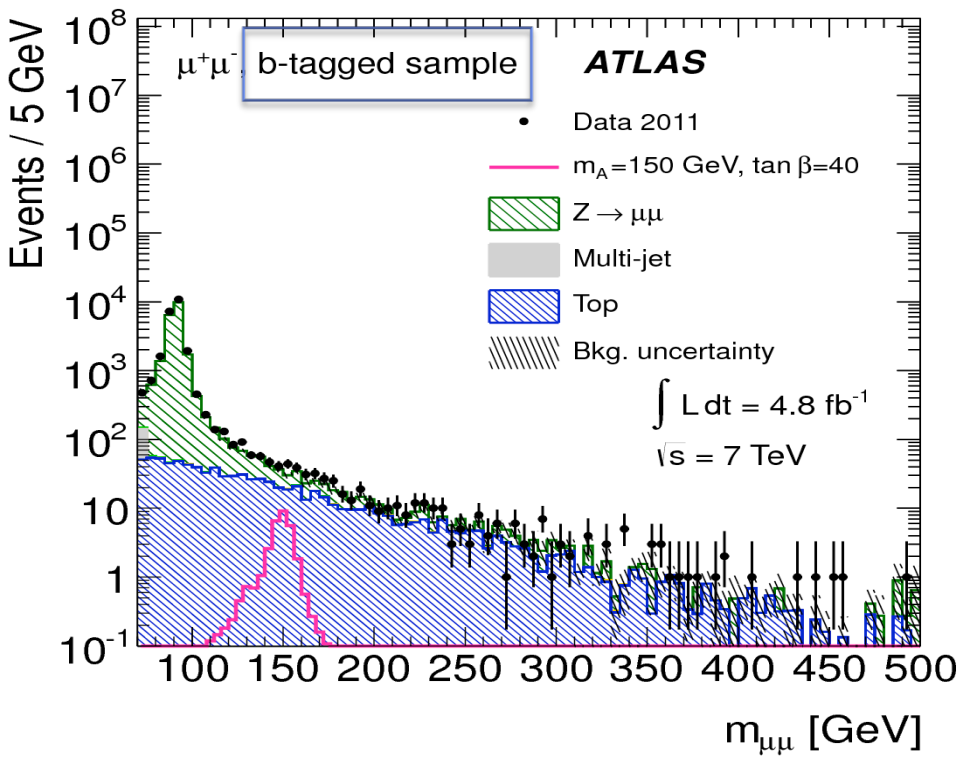
* Search in the dimuon and ditau decay modes

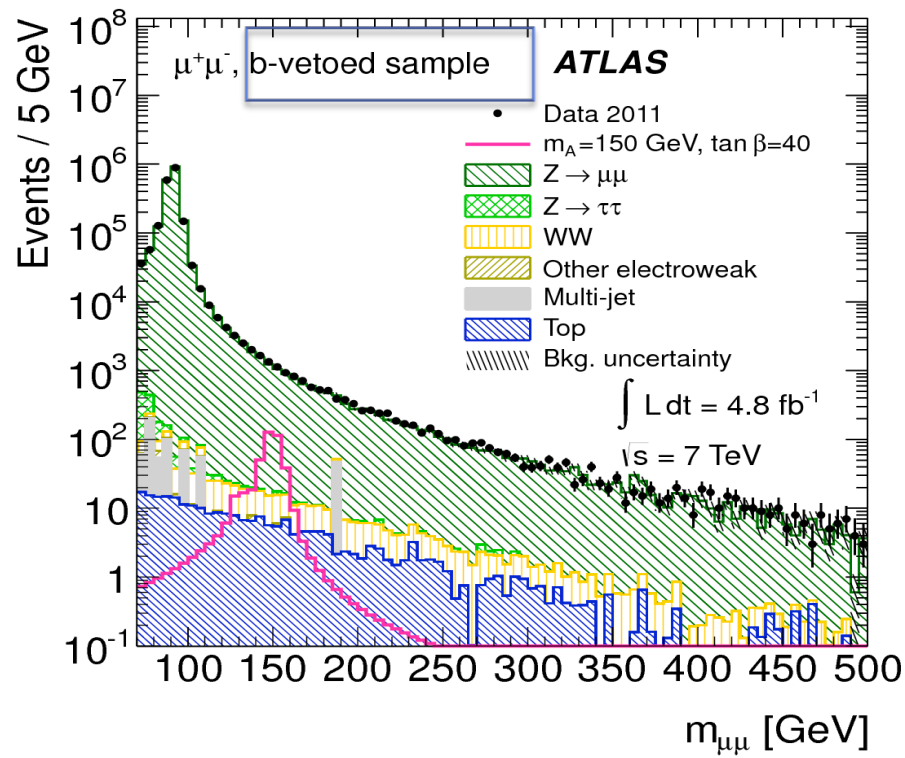
* Events from each channel are classified according to the presence or the absence of an identified b-jet

* Neutral Higgs Boson of the MSSM

Pair of isolated muons with high p_T and opposite charge.

Complicated channel because of the small BR and the considerable background rates





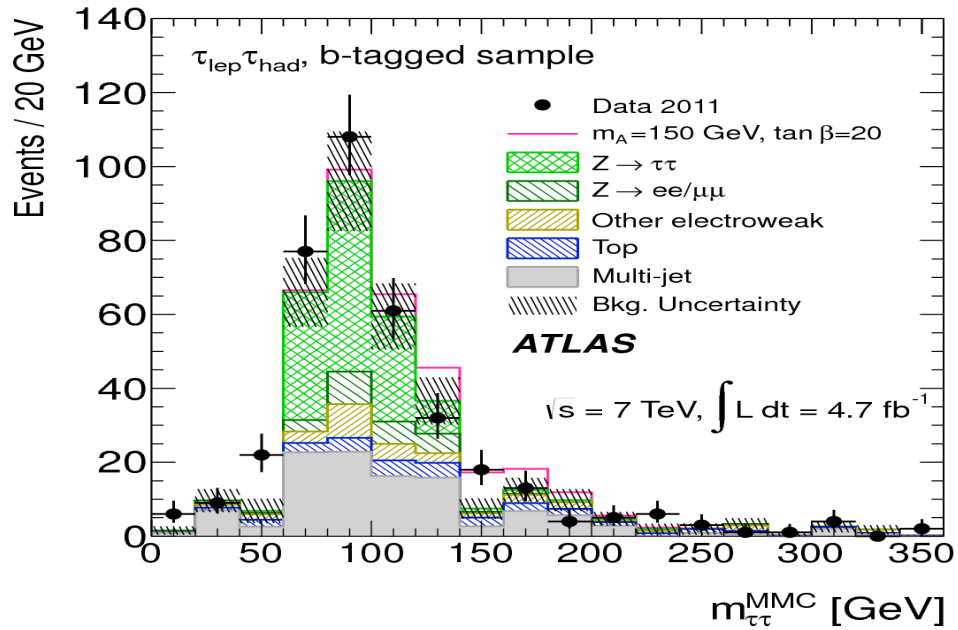
Invariant mass distribution of the two muons of the h/H/A->μμ search

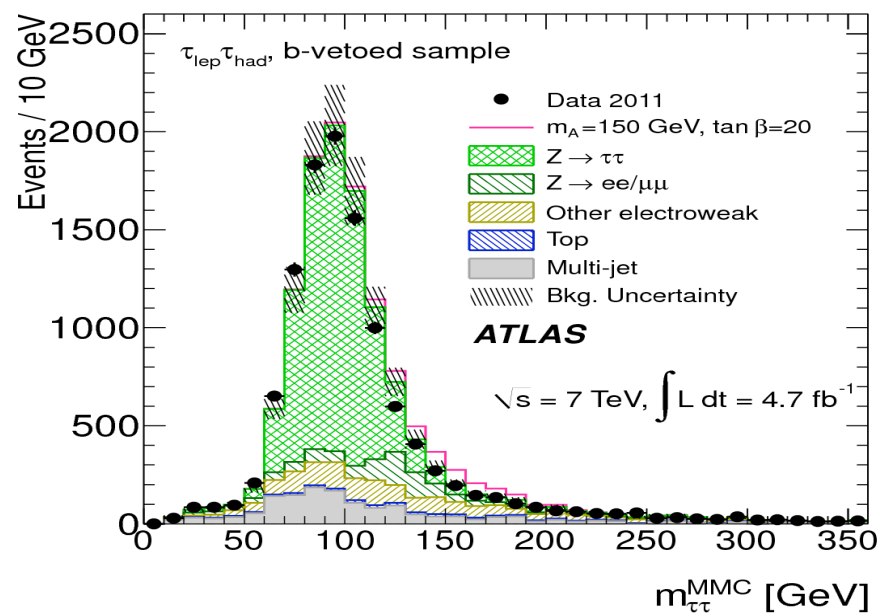
* Neutral Higgs Boson of the MSSM

* The $\tau^+ \tau^-$ decay channel is analysed in several categories:

$$\tau_e\tau_\mu \ , \ \tau_e \ \tau_{had}, \ \tau_\mu \ \tau_{had} \ , \ \tau_{had} \ \tau_{had}$$

* Invariant mass of ττ system cannot be reconstructed directly due to the presence of the neutrinos from the τ lepton decays.
* To reconstruct the Higgs Boson candidate mass: use of the Missing Mass calculator (MMC).





Invariant mass distribution of the two taus of the h/H/A>ττ search (leptonic Hadronic)

* Neutral Higgs Boson of the MSSM

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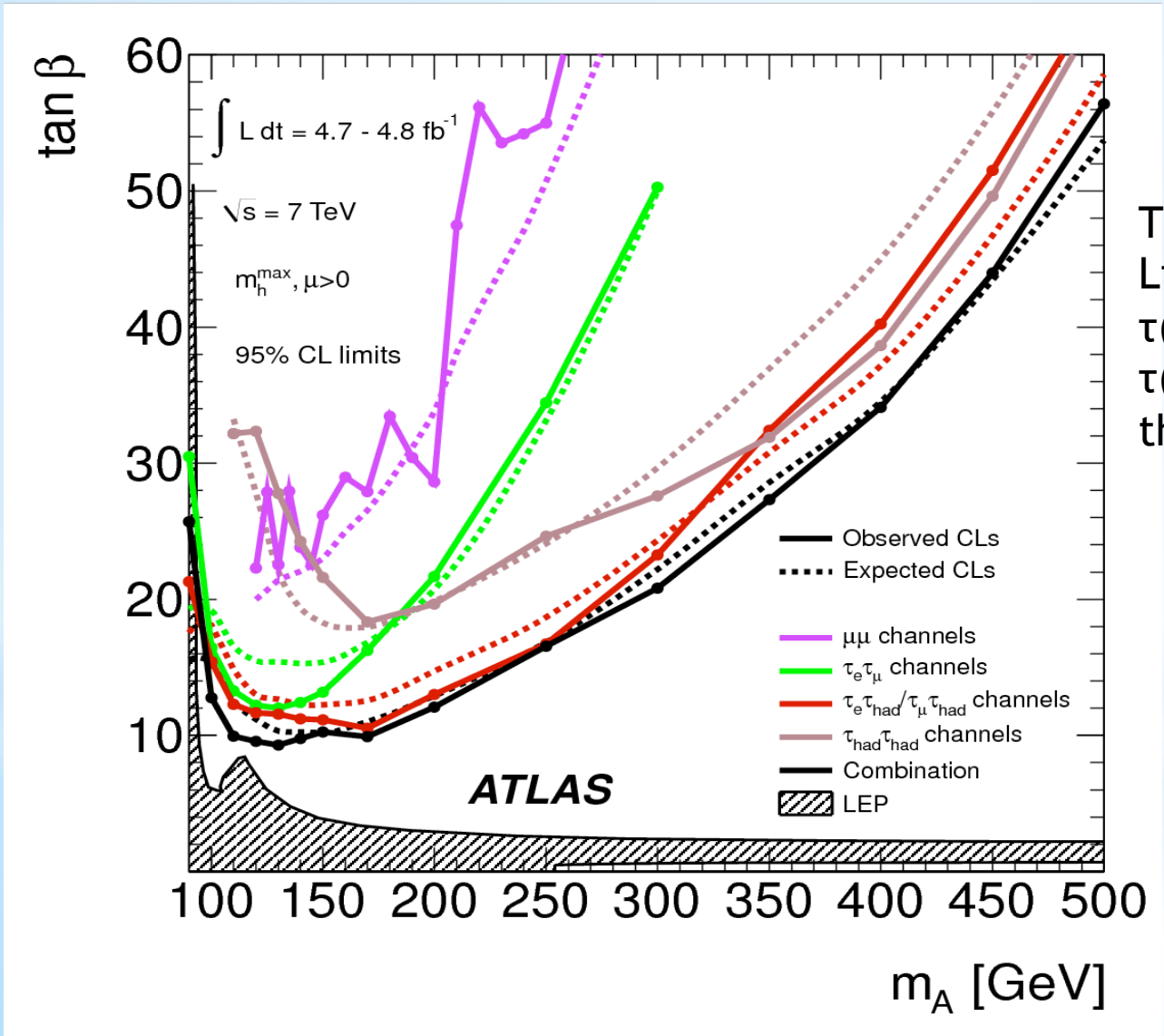

The 95% confidence level CLs Limits for each of the μμ, τ(e)τ(μ), τ(lep)τ(had) and τ(had)τ(had) channels and their statistical combination

* Charged Higgs searches

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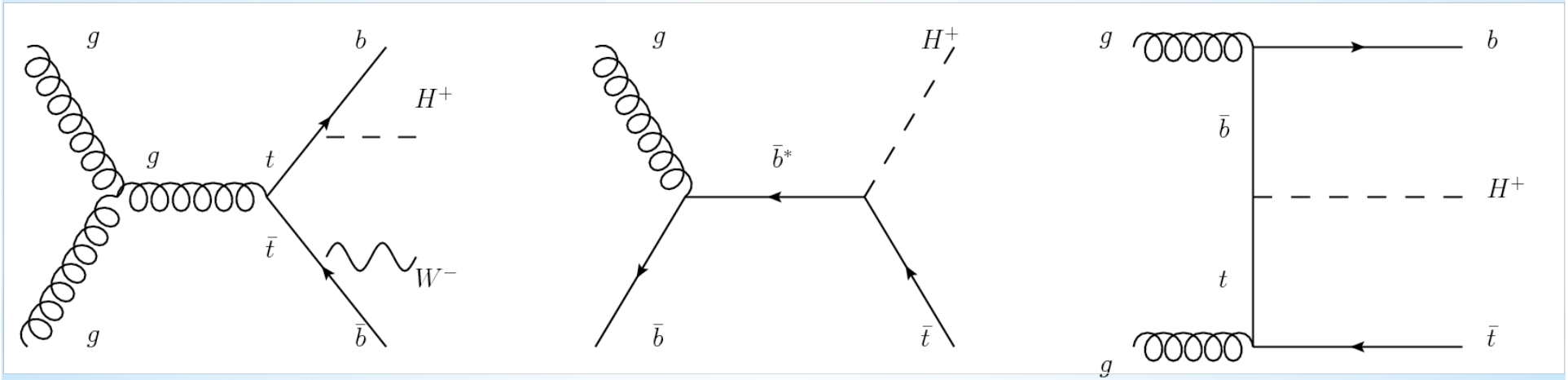
* Charged Higgs H^+ and H^- are predicted in several BSM models, with Higgs triplets and 2HDM.

Light charged Higgs
$m_H < m_{top}$
$t \to H^+ b$

Heavy charged Higgs
$m_H > m_{top}$
Production via top quark association



* In MSSM for tanβ > 3, light charged Higgs boson decay mainly via

$$H^+ \to \tau \nu$$

* Charged Higgs searches

In this search

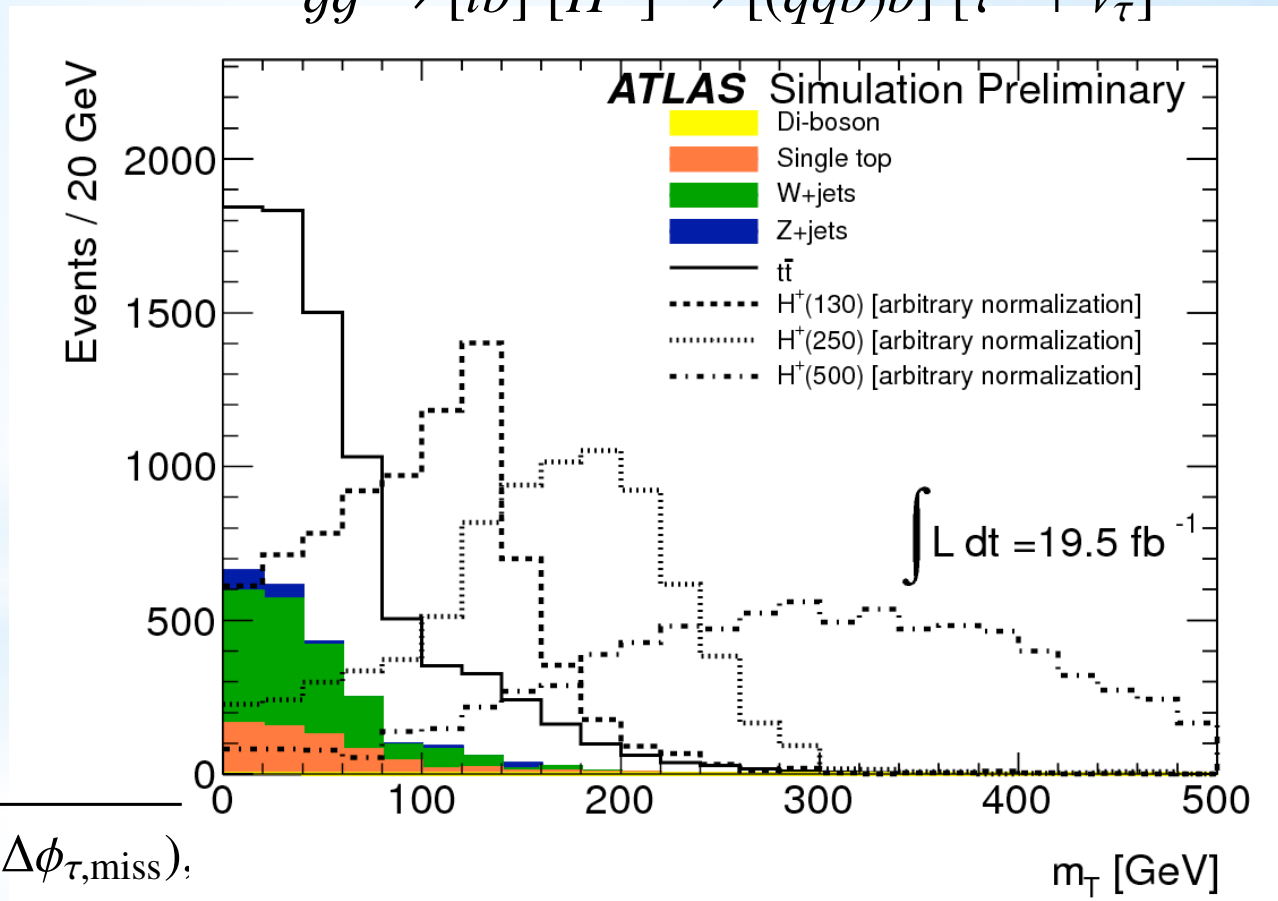
$$t\bar{t} \to [H^+ b]\,[W^- \bar{b}] \to [(\tau^+ + \nu_\tau)b]\,[q\bar{q}\bar{b}]$$

Production and decay of the H^+ :

$$g\bar{b} \to [\bar{t}]\,[H^+] \to [q\bar{q}\bar{b}]\,[\tau^+ + \nu_\tau]$$

$$gg \to [\bar{t}b]\,[H^+] \to [(q\bar{q}\bar{b})b]\,[\tau^+ + \nu_\tau]$$

Only consider τ decaying hadronically



Transverse mass m_T distribution for events passing the heavy H^+ signal selection.

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\tau} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi_{\tau,\mathrm{miss}})},$$

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* Charged Higgs searches

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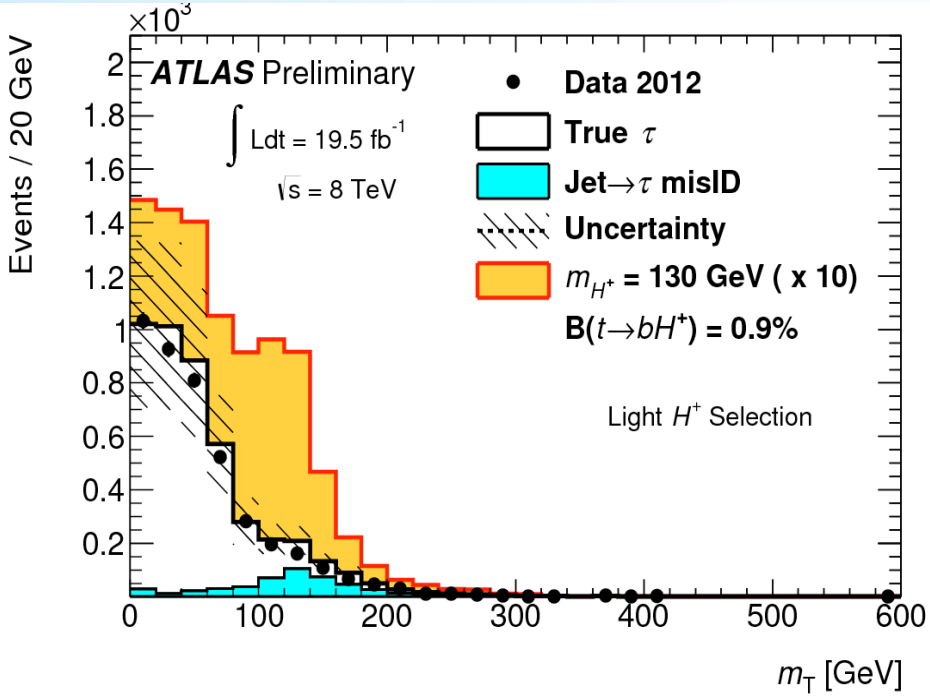
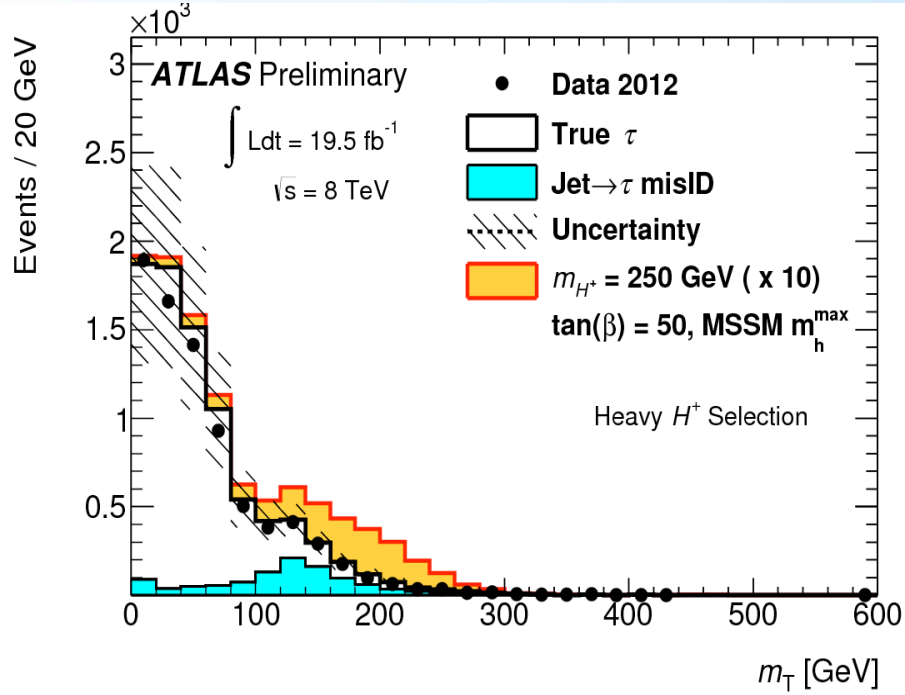
Data and background predictions after applying the nominal selection for the light and heavy charged Higgs boson search





Light charged Higgs

Heavy charged Higgs

* Charged Higgs searches

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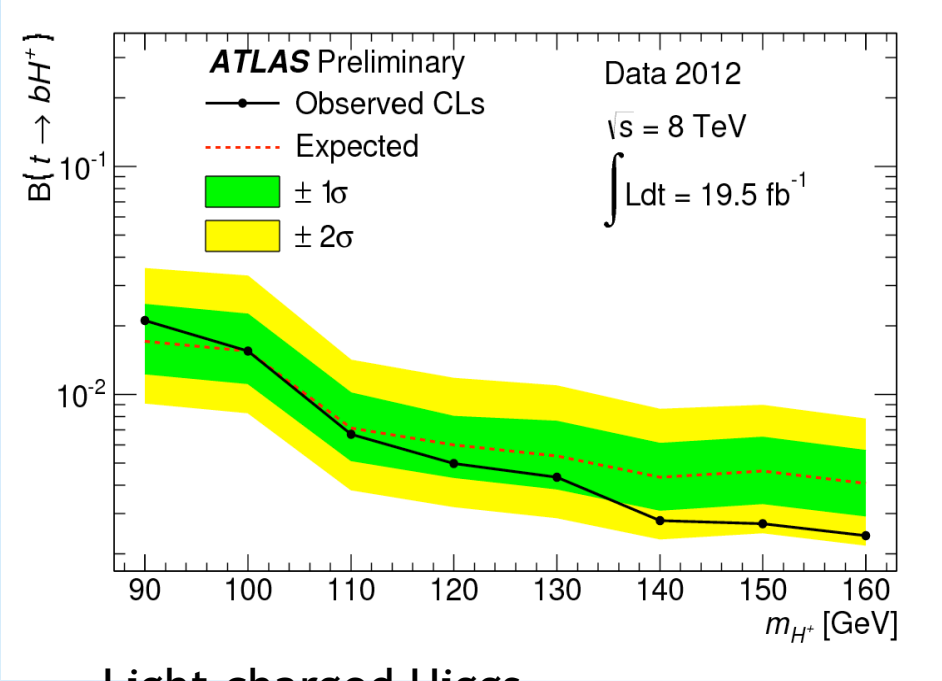
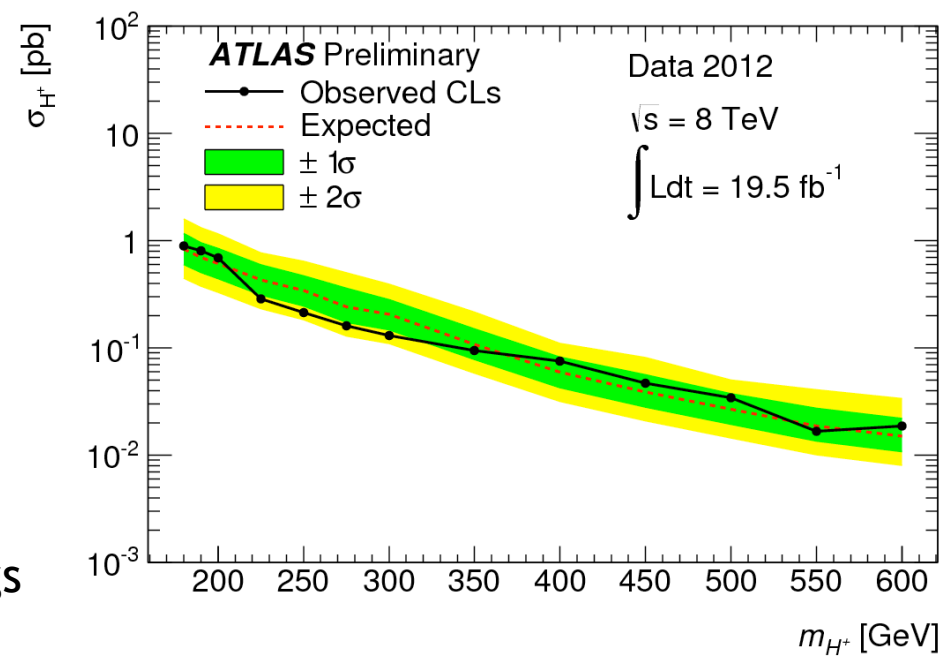


The expected and observed 95% CL upper limits for charged Higgs Boson

Light charged Higgs
BR($H^+ \to \tau\nu$) = 1



Heavy charged Higgs
BR($H^+ \to \tau\nu$) = 1

* Summary

* Different extensions of the SM predict non-SM properties of a 125 GeV Higgs boson and additional Higgs Bosons.

* Different searches have been performed in ATLAS: with different channels, topologies and final states. Different models have been considered.

* No evidence of deviations from the SM have been found. Limits have been set.

* More analysis for other channels are being implemented.

* Looking forward for the next RUN II data.

* BackSlides

NN variables

Table 2: Input variables used for the NNs in the 0-jet and 2-jet channels. The definitions of the variables use the terms *leading lepton* and *leading jet*, defined as the lepton/jet with the highest p_{T}.

Variables used in the 0-jet channel and the 2-jet channel	
$\lvert\eta(\ell_1)\rvert$	The absolute value of the pseudorapidity of the leading lepton.
m_{T}	The transverse mass of the lepton-$E_{\mathrm{T}}^{\mathrm{miss}}$system, as defined in Equation 2.
$m(\ell_1\ell_2)$	The invariant mass of the dilepton system.

Variables used in the 0-jet channel only	
$p_{\mathrm{T}}(\ell_1\ell_2)$	The transverse momentum of the dilepton system.
$E_{\mathrm{T,rel}}^{\mathrm{miss}}$	The projection of the calorimeter-based missing transverse momentum.
$\lvert\Delta Y(\ell_1\ell_2)\rvert$	The absolute value of the rapidity differences of the two charged leptons.

Variables used in the 2-jet channel only	
$p_{\mathrm{T}}(\ell_2)$	The transverse momentum of the second-leading lepton.
$p_{\mathrm{T}}(j_1)$	The transverse momentum of the leading jet.
$m(j_1)$	The mass of the leading jet.
$\cos\theta(\ell_1,\ell_2)$	The cosine of the angle between the two charged leptons.
$m(j_1 j_2)$	The invariant mass of the dijet system.
$p_{\mathrm{T}}^{\mathrm{tot}}$	The total transverse momentum, defined as the magnitude of the vector sum of the transverse momenta of the two jets, the two leptons and the missing transverse momentum: $p_{\mathrm{T}}^{\mathrm{tot}} = \lvert\mathbf{p}_{\mathrm{T}}^{\mathrm{tot}}\rvert = \lvert\mathbf{p}_{\mathrm{T}}^{\ell 1} + \mathbf{p}_{\mathrm{T}}^{\ell 2} + \mathbf{p}_{\mathrm{T}}^{j1} + \mathbf{p}_{\mathrm{T}}^{j2} + \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}\rvert$.