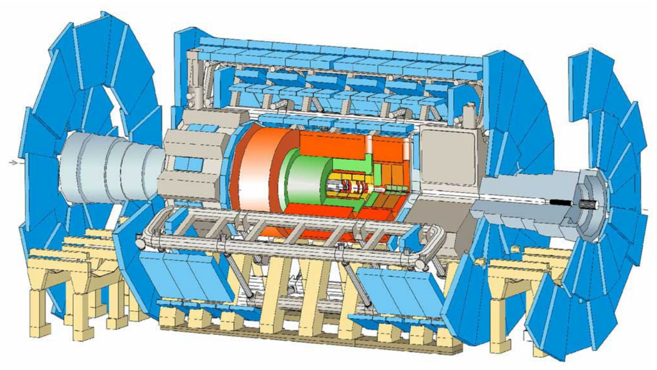
10th International Workshop on Tau Lepton Physics
TAU 2008

Search of the Higgs boson decaying into tau-leptons at ATLAS



Francesca Sarri, Universita' di Pisa and INFN
on behalf of the ATLAS collaboration

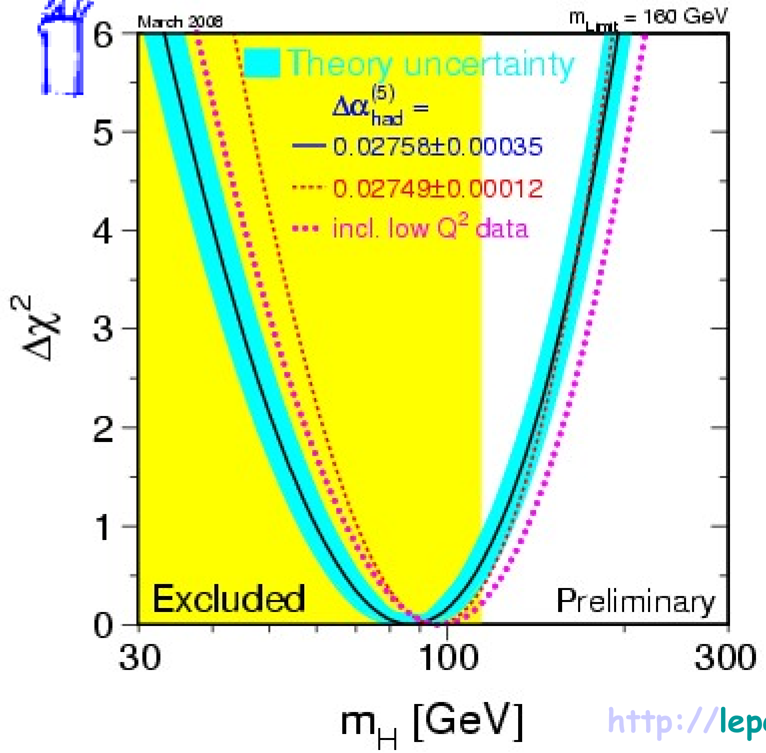
OUTLINE

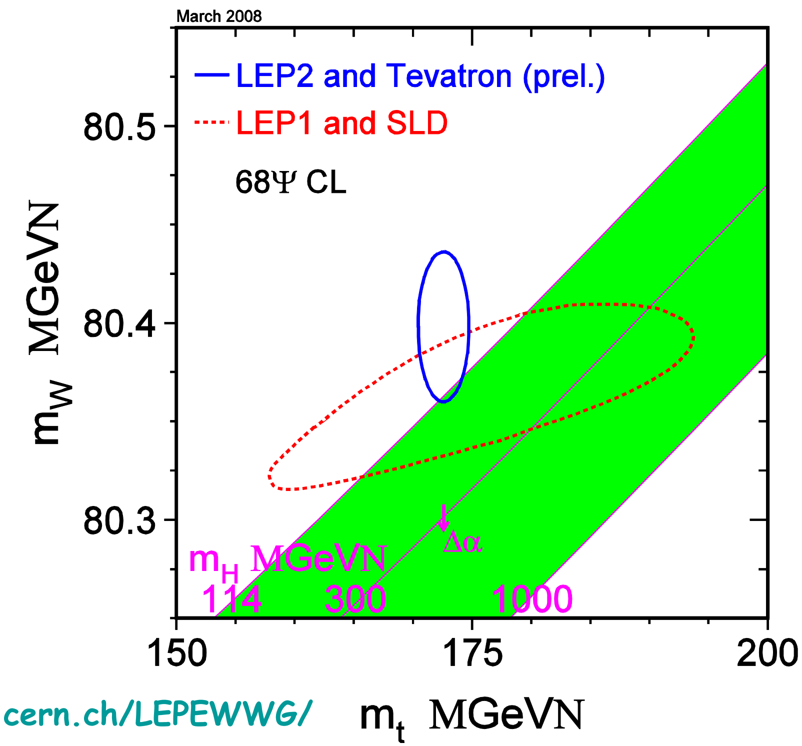
The search for Higgs boson(s) is crucial to the LHC accelerator.

The τ lepton will be essential for Higgs(es) discovery at the LHC.
In fact both in the Standard Model (SM) and in the Minimal Supersymmetric Standard Model (MSSM) the Higgs boson(s) decaying into tau-pairs is one of the favorite discovery channels, especially at low masses.

The detector has to be as efficient (and "robust") as possible to detect any possible tau decay channel, hadronic and leptonic, including a good resolution in the measurement of missing energy. (see Arthur's talk)

REMINDER : EXPERIMENTAL DATA



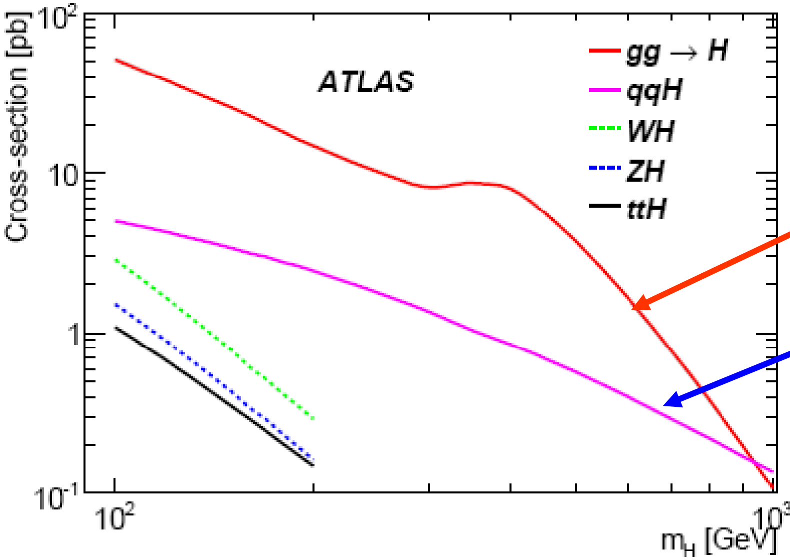


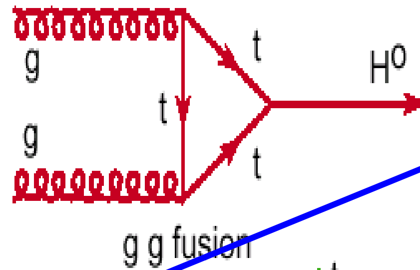
http://lepewwg.web.cern.ch/LEPEWWG/

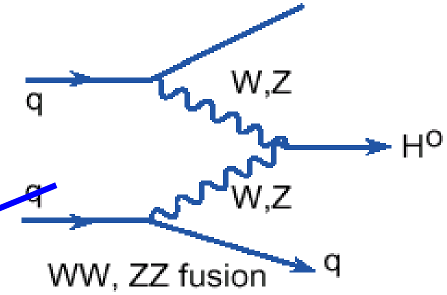
Experimental data prefers a light (SM) Higgs

- Higgs particle is the only particle predicted in SM but not found yet experimentally.
- LEP direct search excludes Higgs below 114 GeV
- With recent Tevatron results, SM electroweak fit prefers Higgs with a mass lower than 190 GeV (@95% C.L.).

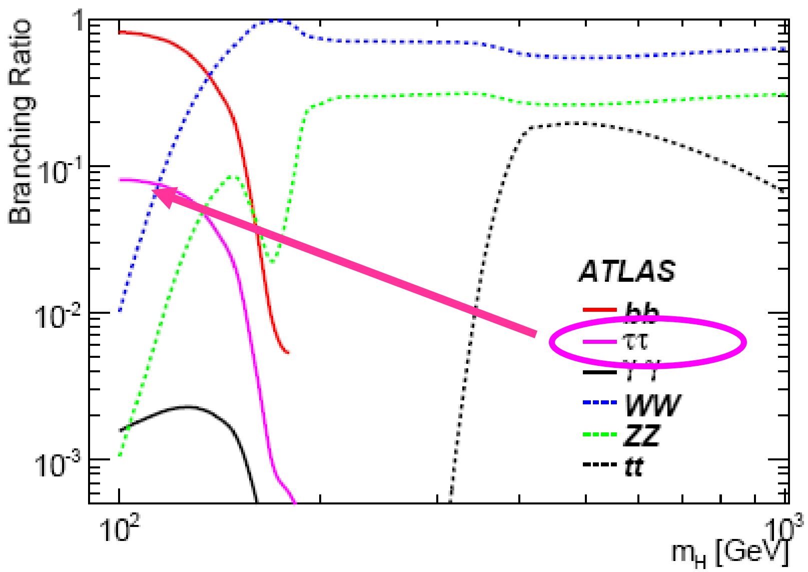
SM HIGGS PRODUCTION AT LHC AND DECAY MODES





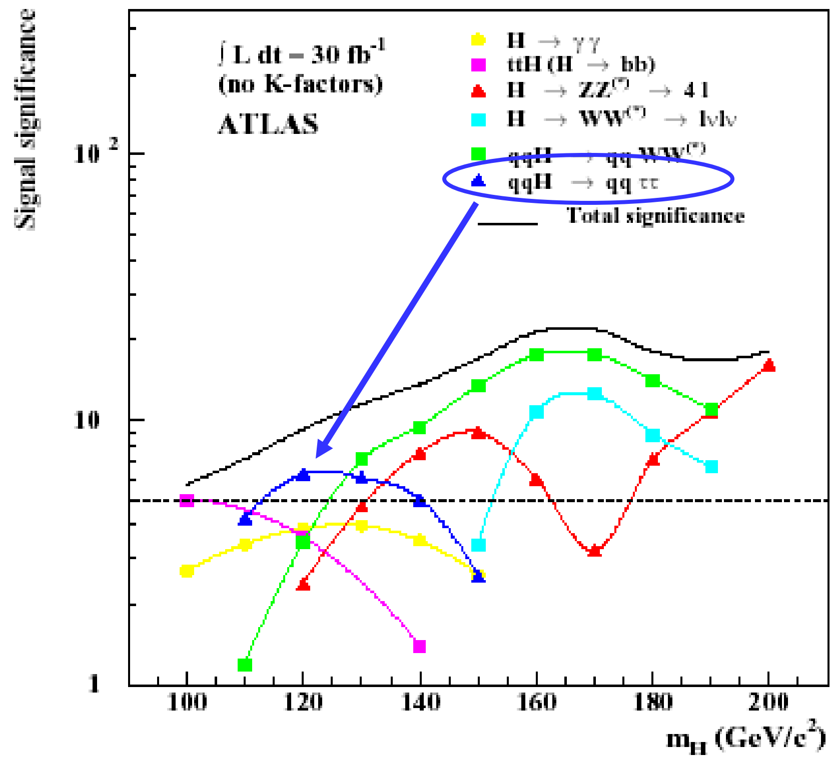


- **gluon fusion:** dominant process;
- **vector boson fusion (VBF):** factor ~10 below gluon fusion, but clear signature in the detector due to the presence of two high p_T jets in the forward region.



- **$H \to bb$** : Dominant decay mode at low mass, difficult final state (large QCD background);
- **$H \to \tau\tau$** : discovery channel, important in VBF for masses above LEP limit (~120 GeV).

SM HIGGS DISCOVERY POTENTIAL AT ATLAS

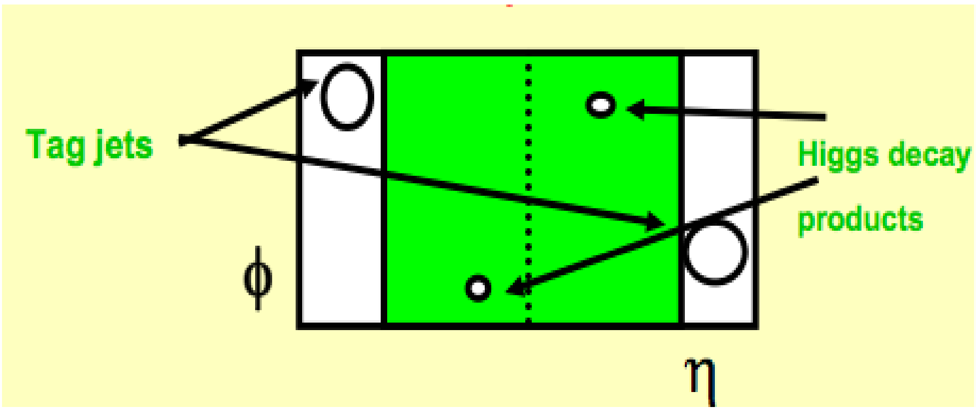


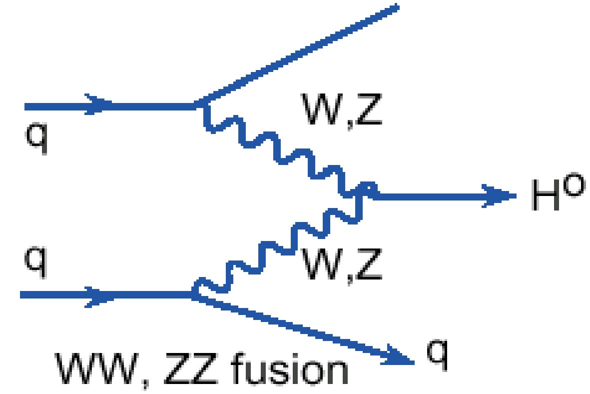
SN-ATLAS-2003-024

ATLAS has performed new studies (2008) using:

- Improved Monte Carlo generators
  (MC@NLO, ALPGEN, HERWIG, PYTHIA, ...)
- Detailed GEANT4-based simulation of the ATLAS detector
- Detailed simulation of trigger response.

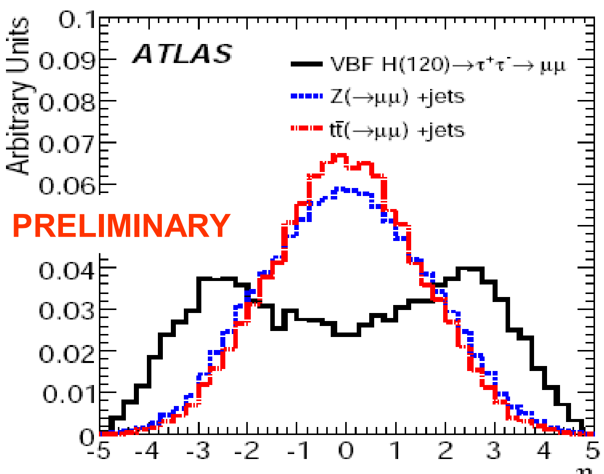
VBF SIGNATURE qqH

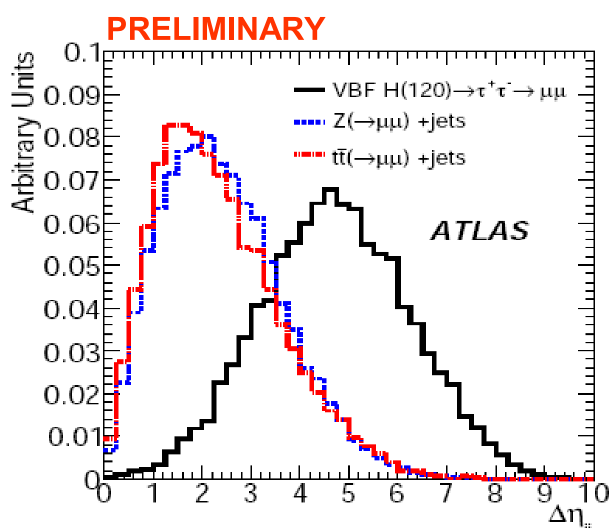


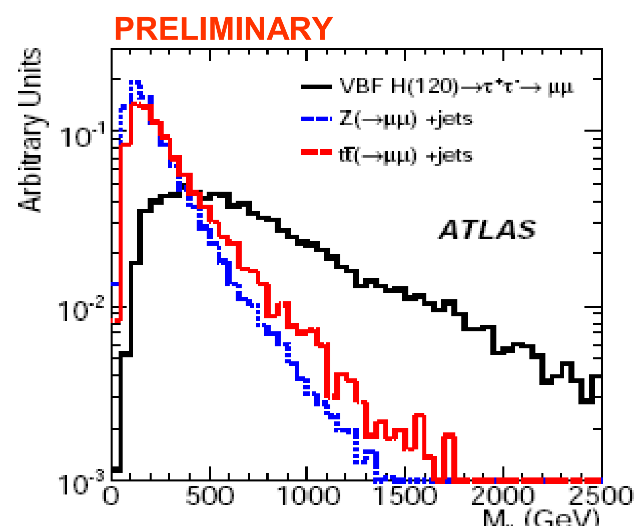


Signatures for VBF:

1. Two forward "tag" jets (large η separation with high p_T) with large Mjj
2. No jet activity in the central region (no color flow between tag jets) : jet veto.

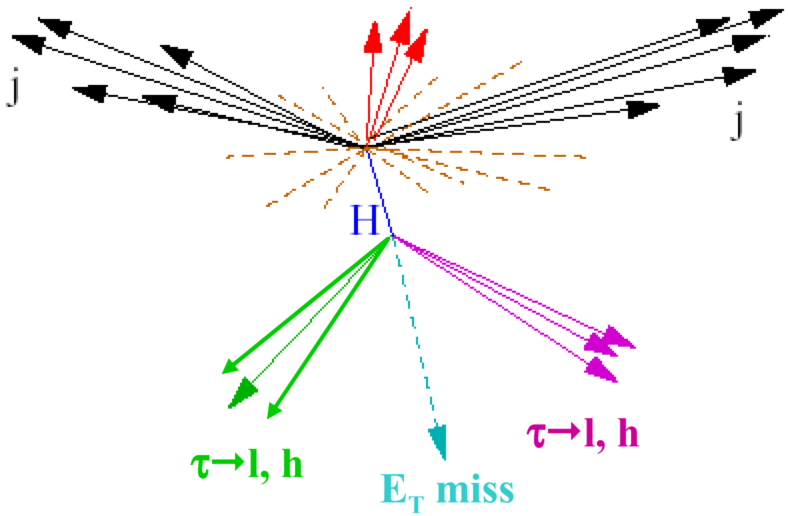






3. In ττ final state also missing transverse energy caused by υ's from τ decays.

VBF qqH ($H \to \tau\tau$)



Three channels :

lepton-lepton, lepton-hadron, hadron-hadron.

Trigger for hadron-hadron channel proved to be feasible using tau + E_T^{miss} trigger; single lepton triggers for other channels.

Background: $Z \to \tau\tau$+jets, $Z \to ll$+jets, W+jets, ttbar, multijet QCD (reliable estimate of the QCD jets background eventually can only be provided with data themselves)

Data-driven control samples are being explored for many backgrounds.

Experimental issues:

- Good efficiency for the reconstruction of forward jets.
- very good τ jet identification to have a low rate of fake τ from jets.
- Good E_T^{miss} measurement for mass resolution of tau-pairs.

VBF qqH (H→ ττ)

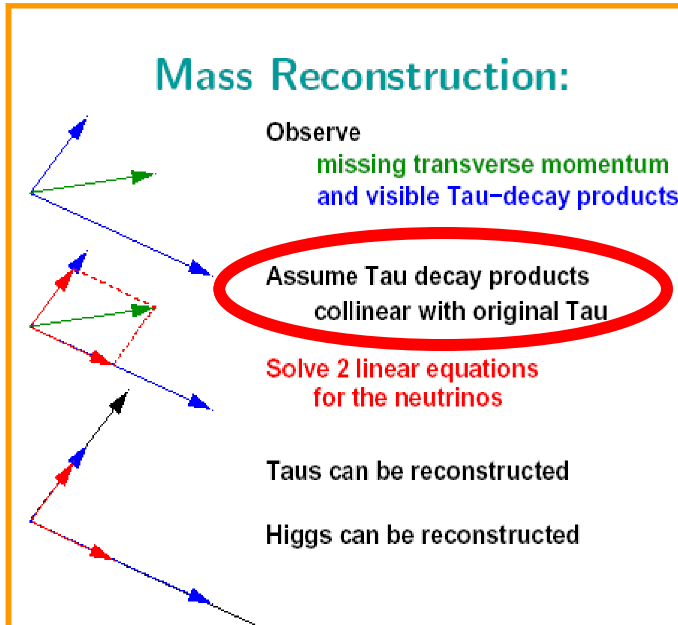
Analysis

- Besides the VBF and E_T^{miss} cuts, thresholds for e/μ/ τ identification are optimized for identification efficiency and fake rejection.

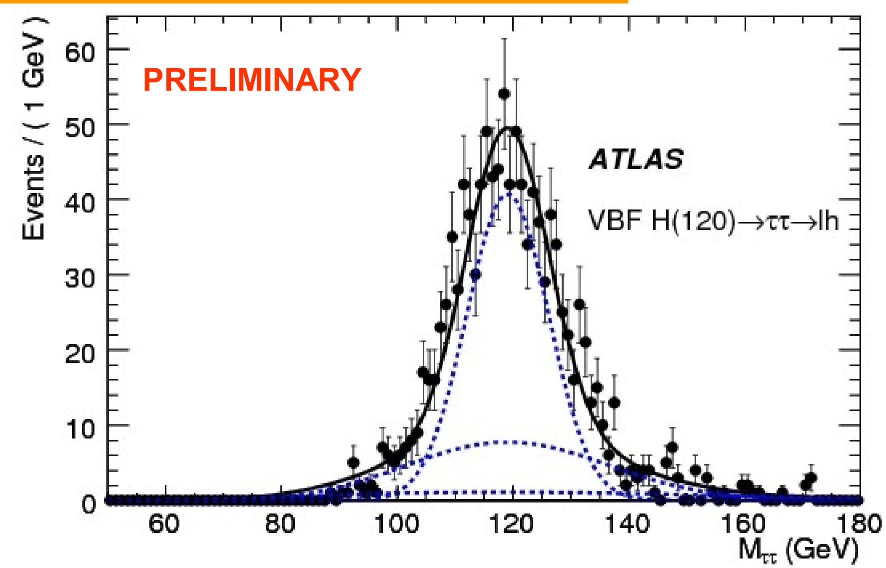
- Low $M_T(l\text{-}E_T^{miss})$ to reduce the W+jet background.

- jet veto (uncertainty on the robustness of the jet veto with respect to radiation in the underlying event and to the presence of pile-up: so far VBF channels studied at low luminosity only).

- The H mass can be reconstructed using the collinear approximation (Δm ≈ 8-10 GeV)

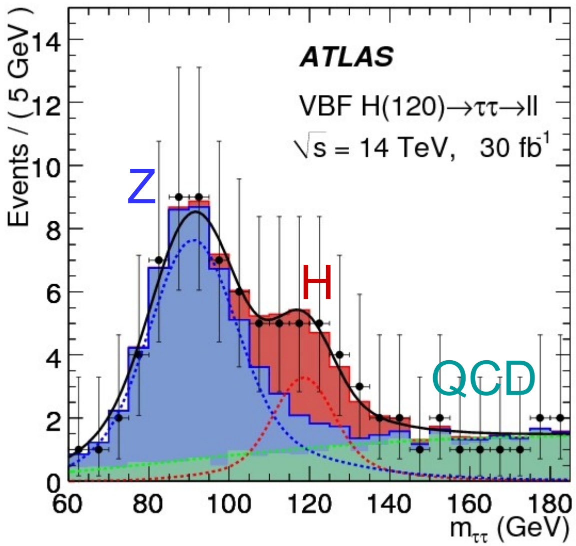


$$M_{\tau\tau} = \sqrt{2(E_h + E_{\nu h})(E_l + E_{\nu l})(1 - \cos\theta_{\tau\tau})}$$



VBF qqH (H→ ττ)

PRELIMINARY



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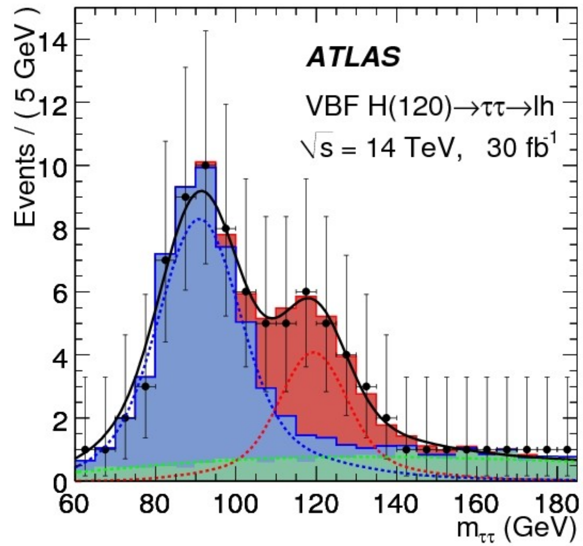

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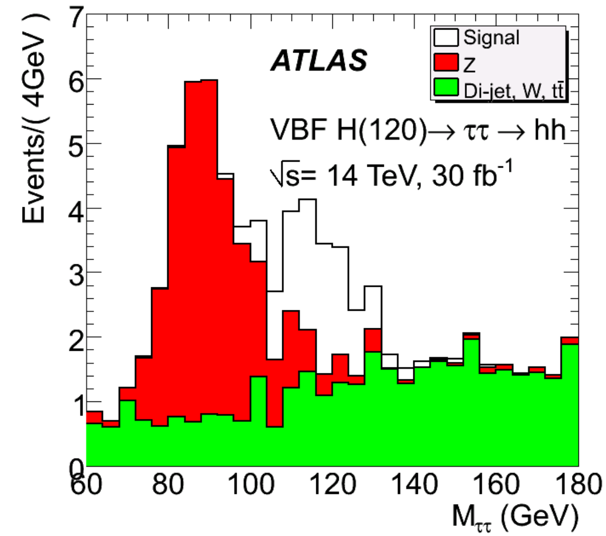
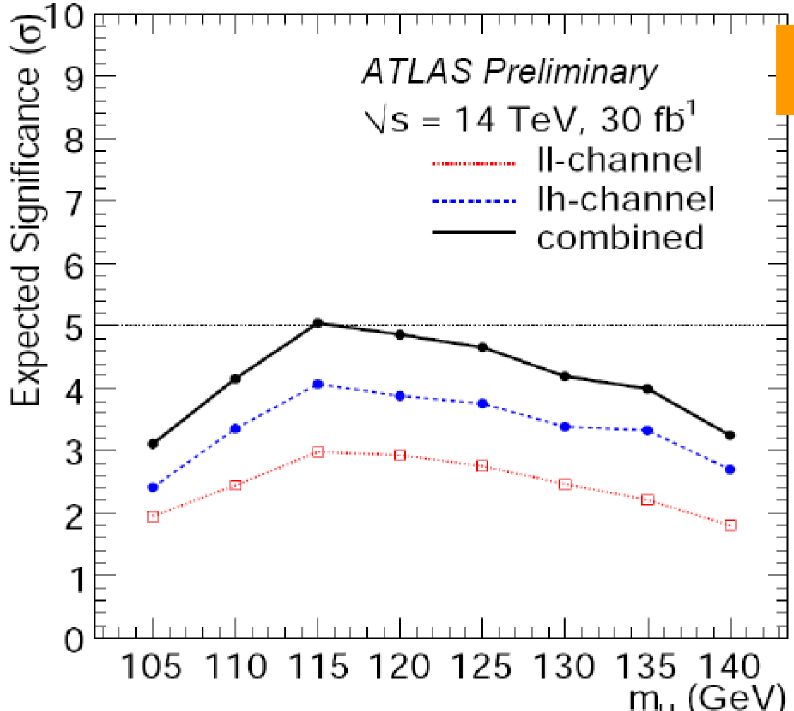




Signal significance in 30 fb^{-1} (no pile-up)

hh channel not included in the significance calculation:
the mass resolution and backgrounds (Z+jets, W+jets, ttbar) similar to ll and lh channel
but large uncertainty on multijet QCD background estimation.

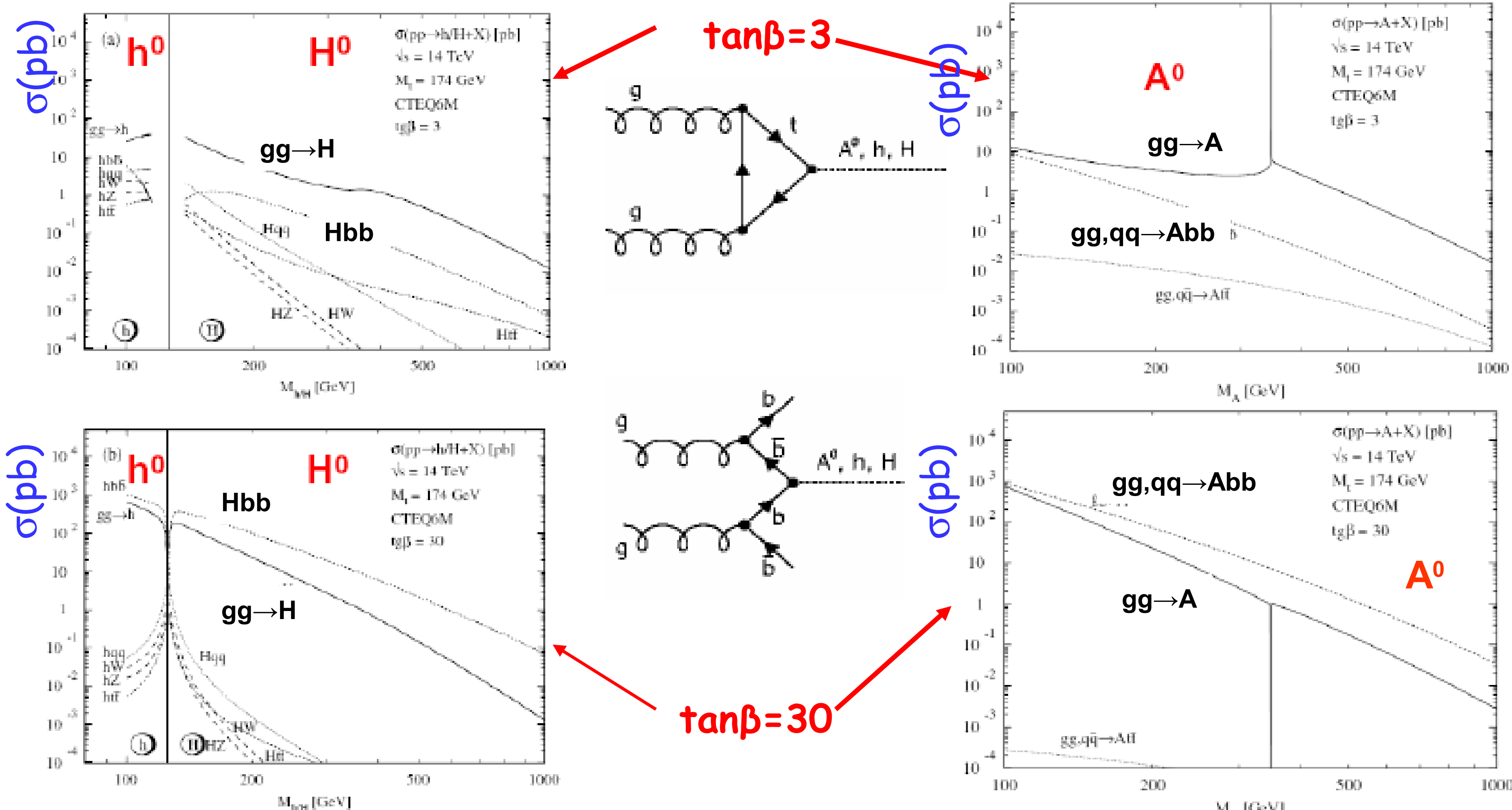
MSSM HIGGS

In the Minimal Supersymmetric extension of the Standard Model (MSSM), two Higgs doublets are required, resulting in **5 physical states**, **h** (neutral lighter scalar), **H** (neutral heavier scalar), ***A*** (neutral pseudoscalar) and the charged Higgs **H^+/H^-**.

With Supersymmetry more than 100 extra parameters are introduced. For practical applications the model has to be constrained, like it is in the constrained Minimal Supersymmetric model which is the minimal supersymmetric extension of the SM with 7 free parameters. Usually 5 of them are kept fixed : each choice provides a different benchmark scenario.

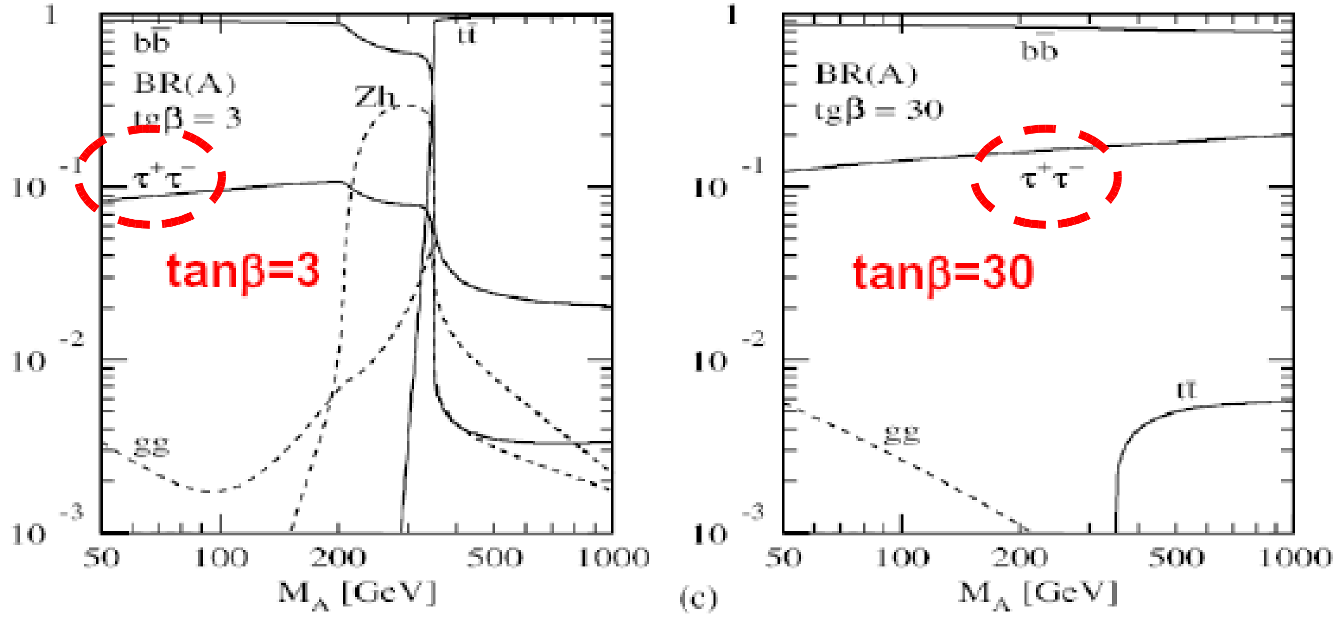
At tree level, Higgs boson masses and couplings can be computed in terms of two parameters, typically m_A (the mass of the pseudoscalar Higgs) and tanβ (the ratio of the vacuum expectation values of the two doublets).

NEUTRAL MSSM HIGGS PRODUCTION



- gluon fusion dominant for low & moderate tanβ.
- for large tanβ bbh/H/A dominant due to enhanced bottom couplings.

NEUTRAL MSSM HIGGS DECAY MODES



- bb decay channel difficult without a distinguishing signature.
- Observation of a neutral boson decaying into two taus accompanied by 2 b-jets is an important signature of a MSSM Higgs sector (results shown) ; inclusive analysis is ongoing.
- $m_{\tau\tau}$ reconstruction is possible with collinear approximation; the visible mass can be used to recover events rejected with the collinear approximation cut.
- Basic backgrounds Z/γ*+jets,tt, bbZ/γ*, W+jet,Wt.
- Recent **full simulation** study **performed in l-l final state**; l-h and h-h studies ongoing. For these two last channels studies have been done in the past for the TDR or in fast simulation only.

bb h/H/A→bb2l4ν EXCLUSIVE ANALYSIS

TRIGGER: lepton trigger.

SELECTION

- Trigger, $n_j < 3$, at least one b-jet
- P_T of leading b-jet
- Dilepton mass below Z mass
- tau visible energy fraction
- E_T^{miss}
- P_T of ll system
- Angle between the 2 leptons
- P_T of leading lepton

PRELIMINARY

Cut	$H \to \tau\tau$	$t\bar{t}$	$Z \to \tau\tau$	$Z \to ee$	$Z \to \mu\mu$	W+Jets
Precuts	115.7 ± 5.1	1096.2 ± 34.6	440.6 ± 16.2	3223.4 ± 122.5	2848.4 ± 107.9	122.4 ± 40.2
p_T leading b-jet (15-66) GeV	90 ± 4.5	443.3 ± 22	337.3 ± 14.2	2755.8 ± 113.3	2481.2 ± 100.7	91.1 ± 34.6
$m_{\ell\ell}$ (27-70, 0-70) GeV	72.6 ± 4.1	137.6 ± 12.3	326 ± 14	133.5 ± 24.9	91.5 ± 19.3	59.6 ± 28
$x_1 \cdot x_2$ (0.04-0.4, 0-0.5)	64.1 ± 3.8	108.1 ± 10.9	251.4 ± 12.3	47.1 ± 14.8	35.8 ± 12.1	40.3 ± 23
p_T^{miss} (20-∞, 15-∞) GeV	52.2 ± 3.5	101.5 ± 10.5	170.8 ± 10.1	4.3 ± 4.5	5.1 ± 4.6	33.3 ± 20.9
p_T^H (-, 0-70) GeV	47.7 ± 3.3	57.9 ± 7.9	159.4 ± 9.8	4.3 ± 4.5	4.6 ± 4.3	28 ± 19.2
$p_{T,\ell\ell}$ (0-45, 0-60) GeV	46.5 ± 3.3	38.2 ± 6.5	155.8 ± 9.6	3.9 ± 4.3	2.5 ± 3.2	22.8 ± 17.3
$\Delta\Phi_{\ell\ell}$ (2.24-3, 2-3)	43.3 ± 3.1	32.8 ± 6	107.5 ± 8	3.6 ± 4.1	3.8 ± 4	21 ± 16.6
p_T leading lepton (10-80) GeV	43.3 ± 3.1	32.8 ± 6	107.5 ± 8	3.6 ± 4.1	3.8 ± 4	21 ± 16.6
Mass window (111 - 198) GeV	28.4 ± 2.6	19.7 ± 4.6	22.1 ± 3.6	1.8 ± 2.9	2 ± 2.8	12.3 ± 12.7
Mass window* (111 - 198) GeV	28.4 ± 2.6	19.7 ± 4.6	22.1 ± 3.6	1.8 ± 2.9	2 ± 2.8	12.3 ± 12.7

(Cross Section (in pb) for m_A = 130GeV and tanβ= 20)

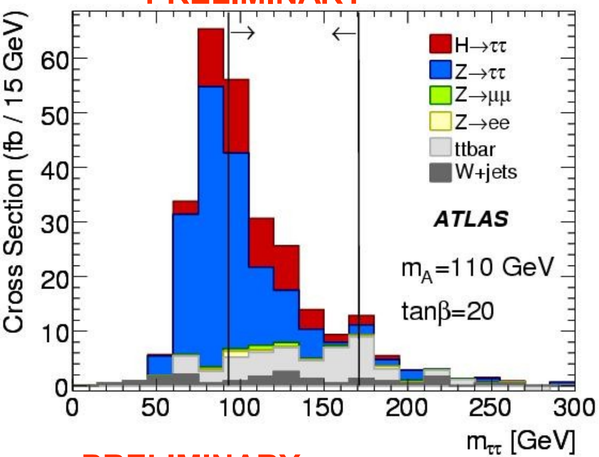
Dominant Systematic Uncertainties:
Jet Energy Scale/Resolution,
b Tagging Efficiency.

Low m_A : $Z \to \tau\tau$ dominant background.
High m_A : $t\bar{t}$ dominant background.

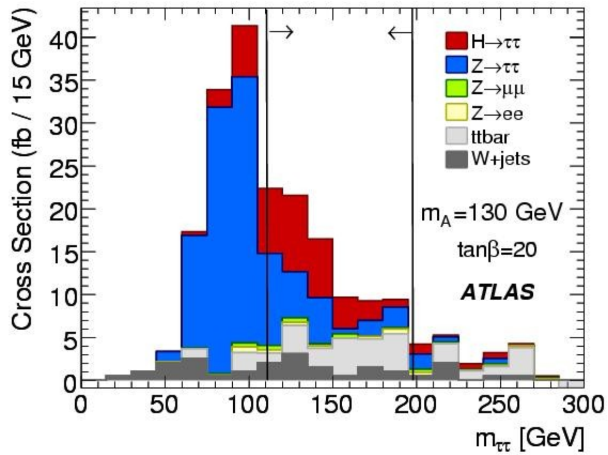
$Z \to \tau\tau$ background shape and normalization can be estimated from data

bb h/H/A→bb2l4υ EXCLUSIVE RESULTS

PRELIMINARY



PRELIMINARY



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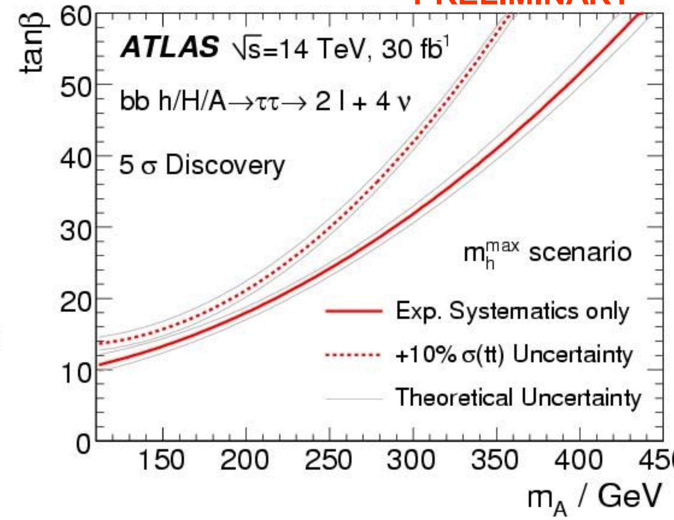

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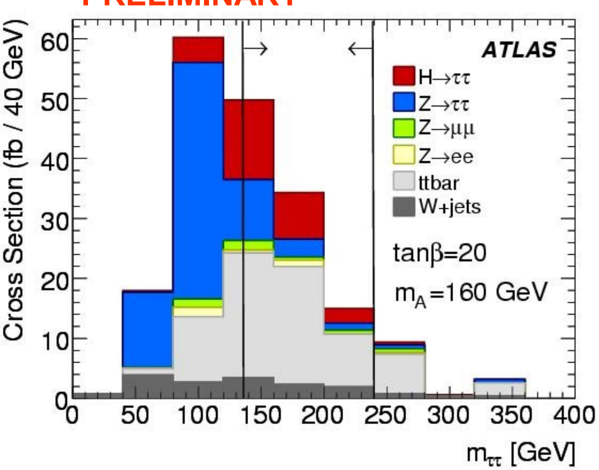

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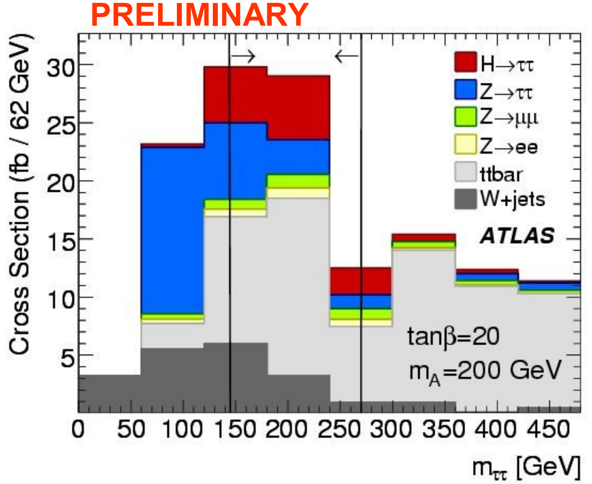

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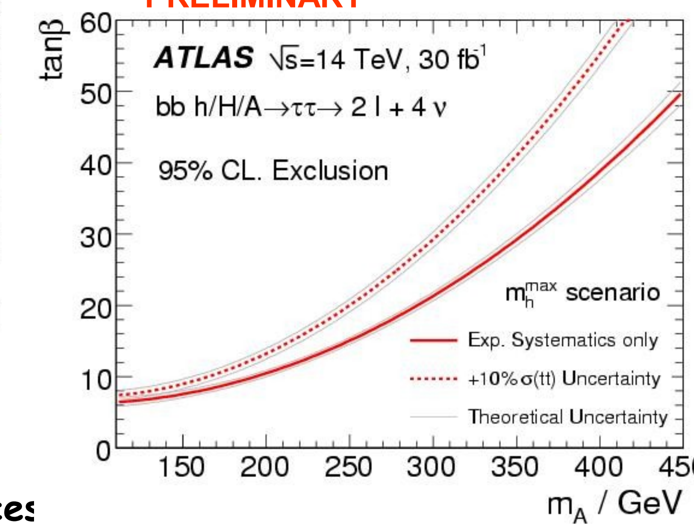
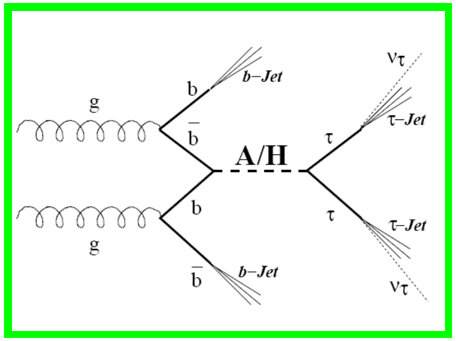


Systematic and statistical uncertainties have been considered.

bb h/H/A (h/A/H→ τ τ →hνhν) ANALYSIS



Possible triggers: Jet+ETmiss, tau+ETmiss, 3 jets. (impact of Level-1 trigger on signal offline selections evaluated).

ATL-PHYS-2003-003 (J. Thomas)

BACKGROUNDS: W+jets, ttbar, QCD jets, Z+jets at LO.

Signal mass range : 450 GeV - 800 GeV.

SELECTION

- 2 tau candidates, no lepton; less that 5 jets, one b-jet;
- E_T^{miss} > 65 GeV; $\Delta\varphi_{\tau\tau}$ = 145-175°, $M_T(\tau,p_T^{miss})$ < 50 GeV;
- Mass window at 1.5 σ

Evaluation of systematic uncertainties influence on significance in 30 fb^{-1}

	$m_{A/H}$	$\tan\beta$	Signal	Background	Significance
Standard analysis	600	30	20.4	7.4	5.8 σ
	800	45	19.6	6.8	5.8 σ
Detector resolution	600	30	20.4	9.4	5.2 σ
	800	45	19.6	8.3	5.3 σ
τ identification and b-tagging	600	30	14.9	7.5	4.3 σ
	800	45	13.8	5.7	4.4 σ
jet energy scale	600	30	18.6	8.6	5.0 σ
	800	45	16.7	7.3	4.8 σ

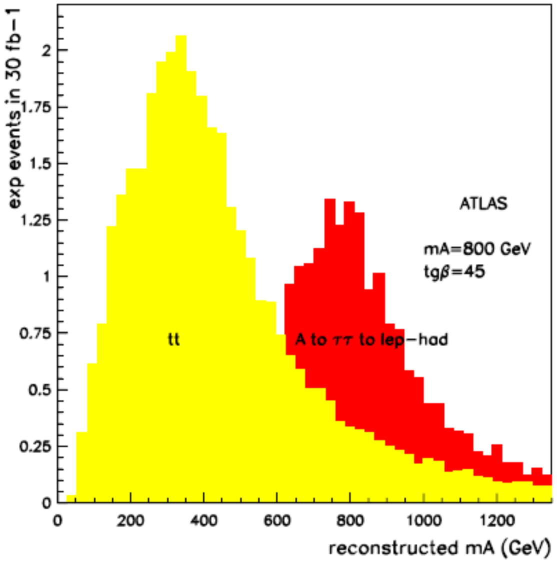
ε_τ from 55% to 40%
ε_b from 70% to 60%

25% reduction

Table 10: Study of the influence of systematic uncertainties of the significance of the channel $(b\bar{b})A/H \to (b\bar{b})\,\tau\,(had)\,\tau\,(had)$.

bb h/H/A (h/H/A→ τ τ →lυυhυ) ANALYSIS

Possible triggers: single lepton trigger.
BACKGROUNDS: W+jets, ttbar, Z+jets
Signal mass range : 150 GeV - 800 GeV
Also direct production included to improve signal significance:
main difference in the analysis is the request of b-jets (0 b-jet in direct production, ≥ 1 b-jet in the associated production).



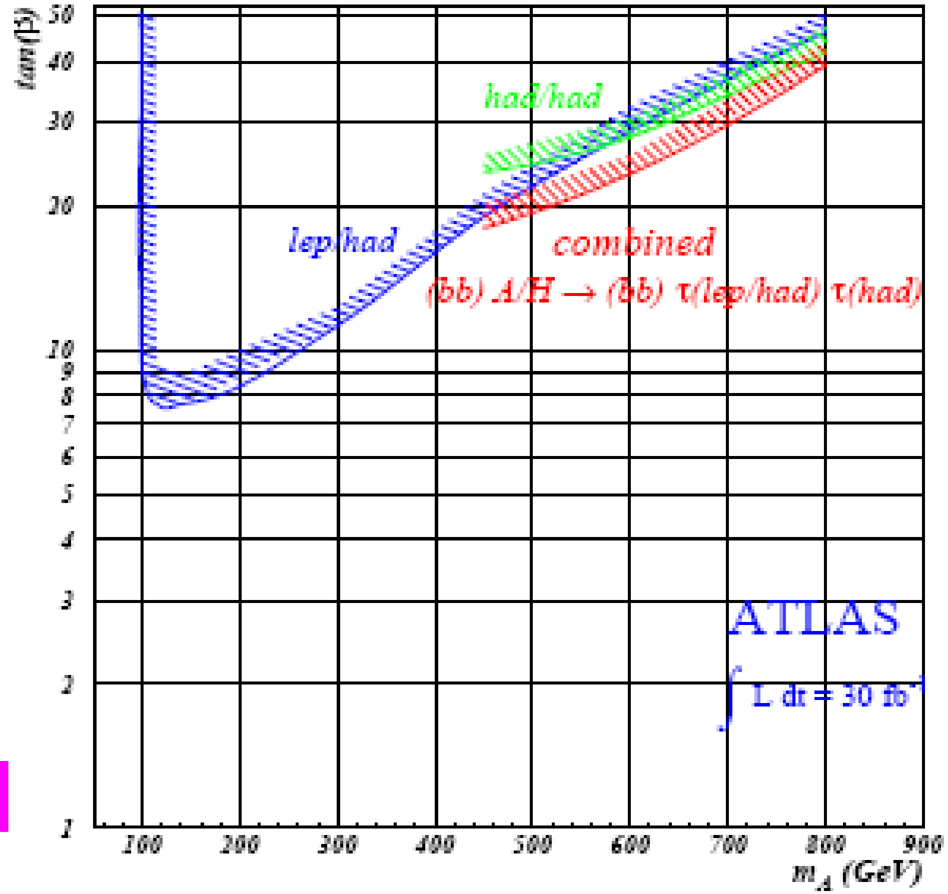
Cut	Sig ass	$t\bar{t}$	W	Z	$b\bar{b}$
	1093	4788720	901778368	29693	3.25668024E+10
lepton+isolation	761	2114442	8252015	9073	1576261
m_T(lepton-p_T^{miss})	448	245750	2347276	5030	1121589
p_T^{miss}	399	123710	584140	2332	134794
τ-jets	174	356	131	233	367
$m_{\tau\tau}$ in window, $\geq$ 1b-jet, $<$ 3 non-b-jets	14.6	4.3	0.4	0.3	0.5

ATL-PHYS-2003-009 (Cavalli, Negri)

The number of events expected for 30 fb^{-1} are given for A/H →ττ with m_A=800 GeV and for all the backgrounds.

bb h/H/A→ τ τ (lh,hh) RESULTS

5-σ discovery contour
(fast simulation)

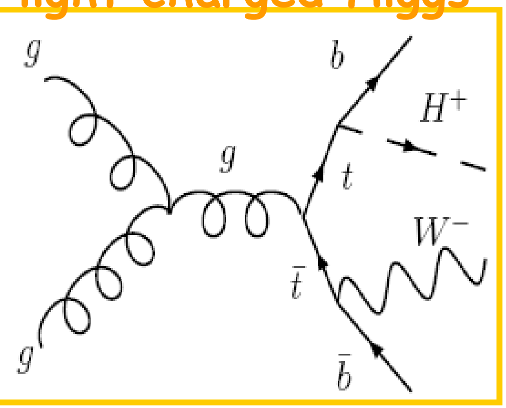


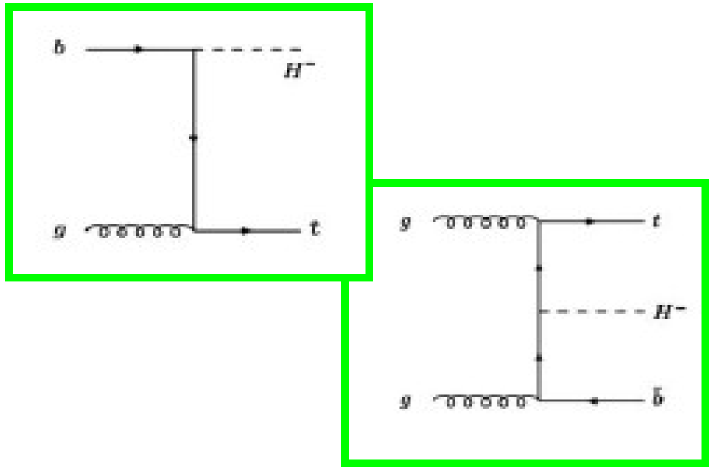
ATL-PHYS-2003-009 (Cavalli, Negri)

Full simulation analysis will be redone

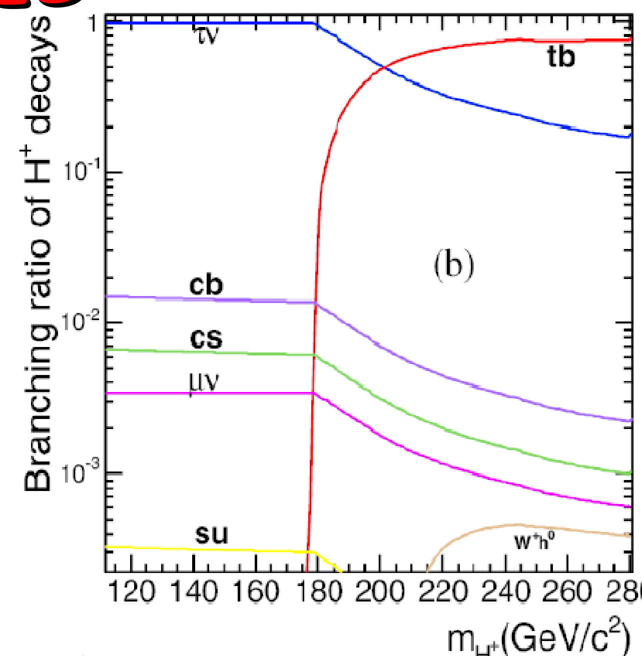
CHARGED MSSM HIGGS PRODUCTION AND DECAY MODES

light charged Higgs





heavy charged Higgs



➢For the *light* charged Higgs boson ($m_{H+} < m_{top}$) :
dominant production mode is from top decay $t \to bH^+$ and the dominant decay is $H \to \tau\nu$. $BR(t \to bH^+)$ depends on both $\tan\beta$ and m_{H+}

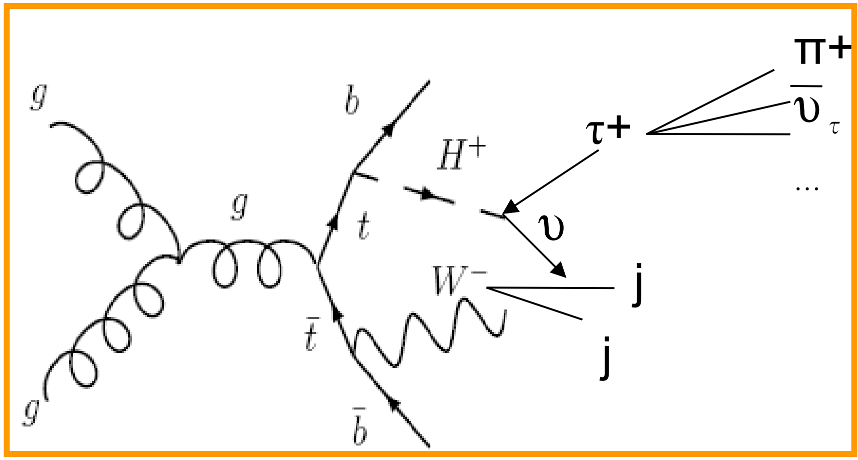
➢For the *heavy* charged Higgs boson ($m_{H+} > m_{top}$):
dominant production modes are $gg \to tbH+$ and $gb \to tH+$ and dominant decays are $H \to tb$ and $H \to \tau\nu$ (cleaner signature).

Several final states have been studied with **full detector simulation** in different scenarios. Reported results from:
$tt \to bH^+bW \to b\tau(had)\upsilon bqq$ (light) and $gg/gb \to t[b]H^+ \to bqq[b]\tau(had)\upsilon$ (heavy).

LIGHT CHARGED MSSM HIGGS ANALYSIS

Signature:

- E_T^{miss}
- 4 jets and 2 b-tags
- W and top reconstructed masses consistent with measured values.
- one hadronic τ-jet.



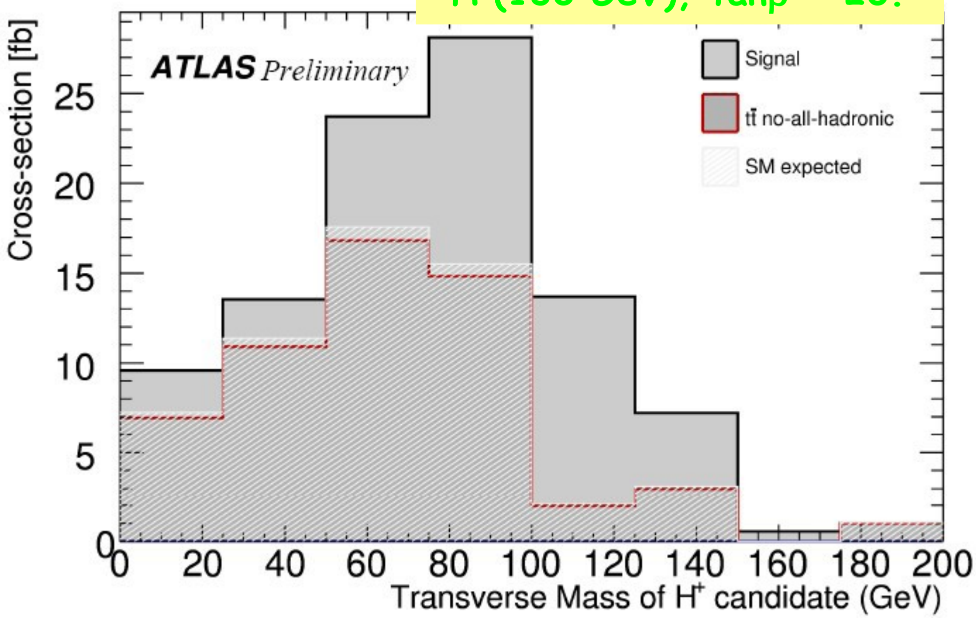
Main background : ttbar.
W+jets, single top, QCD dijet found to be negligible after cuts.

TRIGGER: E_T^{miss} + tau, E_T^{miss}+tau+3jet (thresholds depend on luminosity).

ANALYSIS summary:

- Exactly one τ-jet and 2 b-jets
- At least 2 non-tagged jets
- Isolated lepton veto
- E_T^{miss} > 30 GeV
- W and t mass constraint
- Likelihood cut
- Transverse H+ mass distribution cut

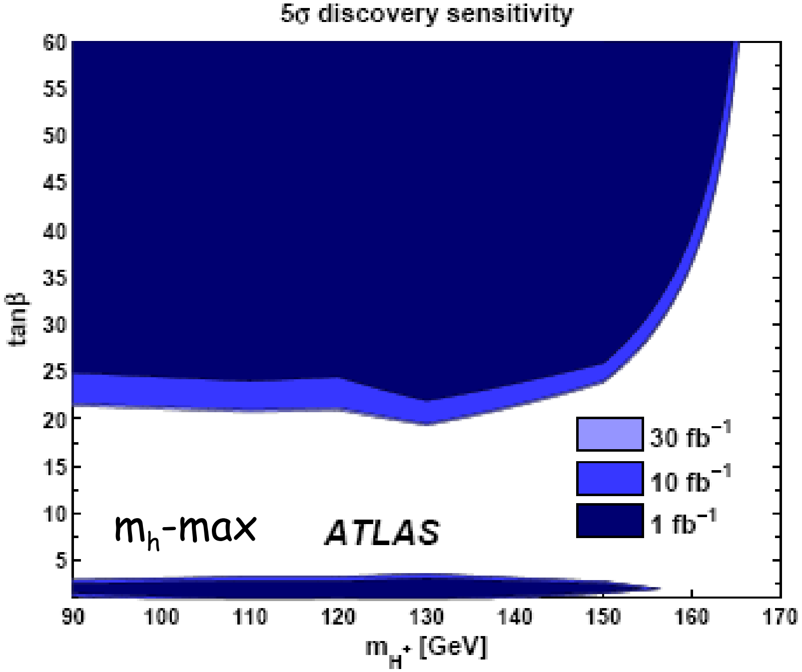
H^+(130 GeV), tanβ = 20.



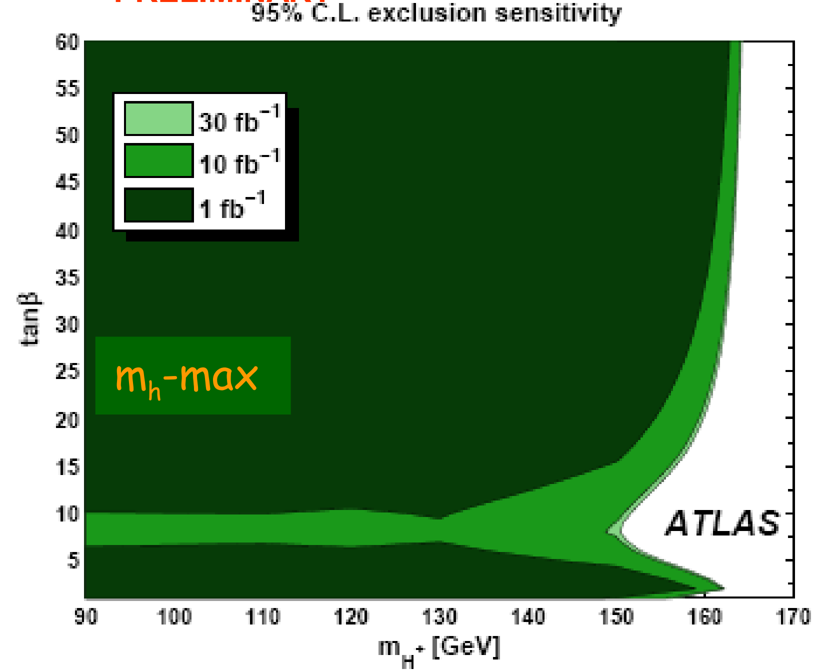
LIGHT CHARGED MSSM HIGGS RESULTS

Study has been performed in a mass range between 90 and 150 GeV.
Systematic and statistical uncertainties have been considered.

PRELIMINARY



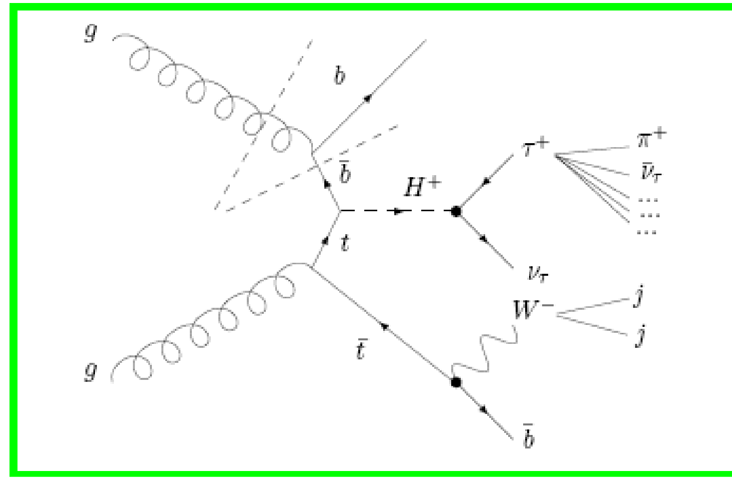
PRELIMINARY



HEAVY CHARGED MSSM HIGGS ANALYSIS

Signature:

- one τ-jet
- 3 or 4 jets (1 or 2 b-jet)
- E_T^{miss}
- W and top reconstructed masses consistent with measured values



Main background : ttbar.
W+jets, single top, QCD dijet found to be negligible after cuts.

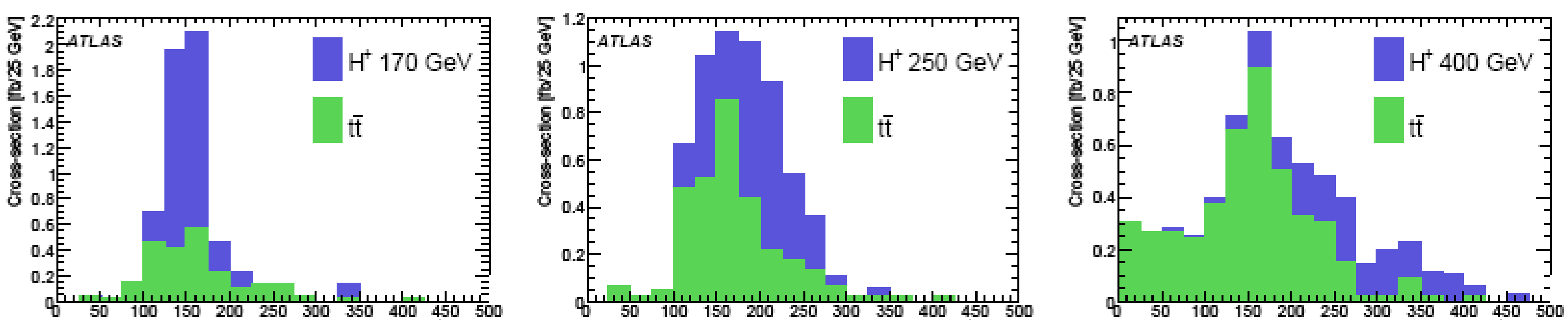
TRIGGER: E_T^{miss} + tau, E_T^{miss}+tau+3jet (thresholds depend on luminosity).

ANALYSIS summary:

Exactly one τ-tagged jet (high quality cut); at least 3 jets, with exactly one b-tagged jets.

E_T^{miss} > 40 GeV, lepton veto, W and top mass constraint.

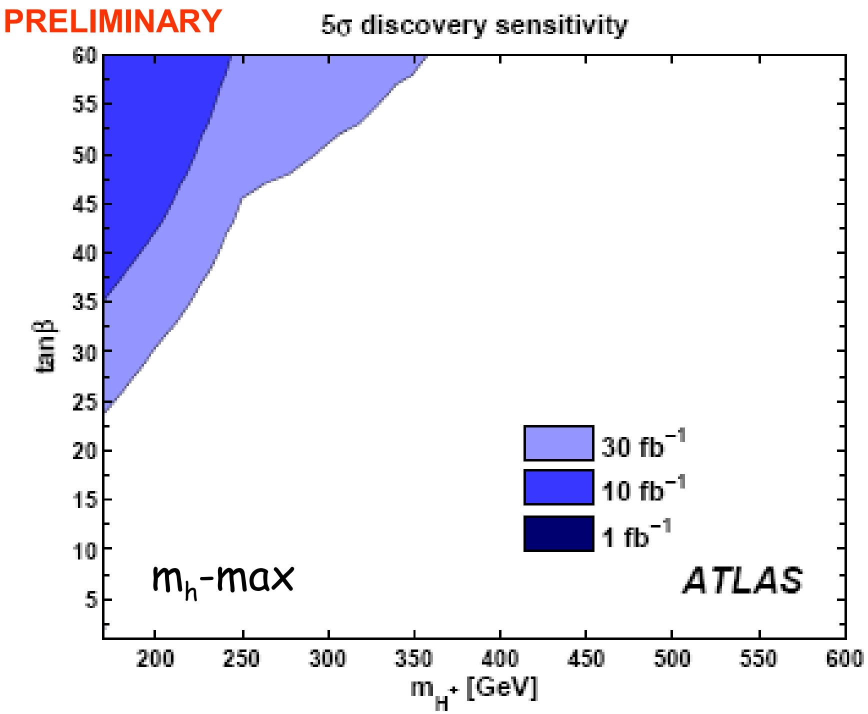
Likelihood discriminant cut, transverse H+ mass distribution cut.

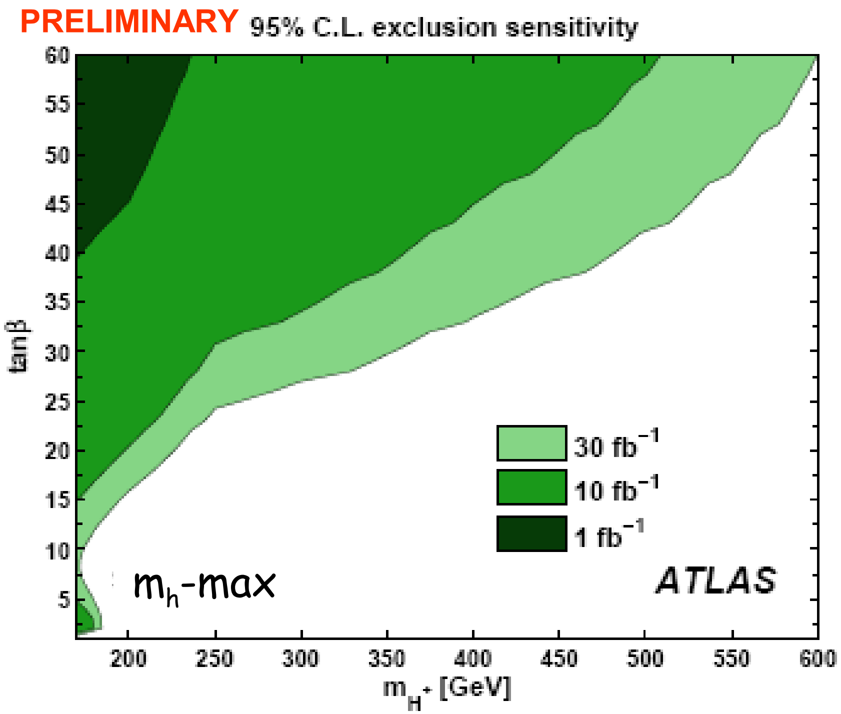


PRELIMINARY

HEAVY CHARGED MSSM HIGGS RESULTS

Study has been performed in a mass range up to 600 GeV.
Systematic and statistical uncertainties have been considered.





The discovery and exclusion potential for both light and heavy H^+ depends critically on the H+→τ(had)υ channel.
The H+→τ(had)υ channel in the current analysis depends on the tau+E_T^{miss}+3jet and tau+E_T^{miss} triggers.

CONCLUSIONS

Tau lepton measurement is fundamental for many searches for Higgs bosons both in SM and in MSSM at LHC.

SM VBF $H \rightarrow \tau\tau$ has been studied with detailed detector simulation and latest theoretical developments in the three possible final states lepton-lepton, lepton-hadron, hadron-hadron: in 30 fb^{-1}

Higgs can be discovered with a 5σ significance in the interval 115-120 GeV

MSSM Higgs, neutral and charged, can be discovered in a significant m_A-$\tan\beta$ interval with 30fb^{-1} of integrated luminosity.

Next year we shall see the first collisions at LHC. In one year or so Higgs could be at hand thanks to the **tau lepton** measurement.

BACKUP SLIDES

VBF qqH → ττ

Estimating Backgrounds from Real Data

Data-driven Background Estimation

$Z \to \mu\mu$ + jets has identical jet activity as $Z \to \tau\tau$ +jets

→ Procedure:

⇒ select $Z \to \mu\mu$ + jets events

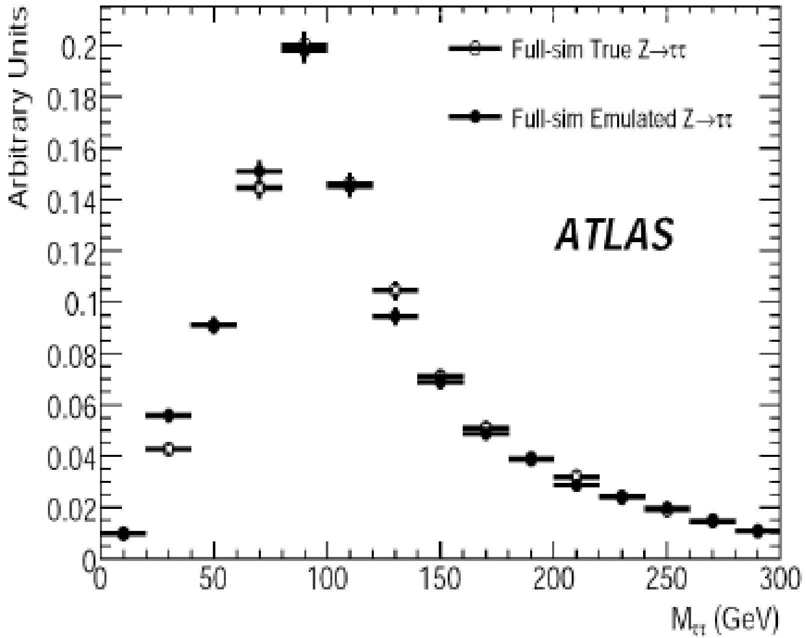
⇒ replace the μ's by the τ's

⇒ carefully treat the decay of the τ

→ Full event selection is then applied to the emulated $Z \to \tau\tau$ + jets control sample

→ Expected uncertainty ~ 10%

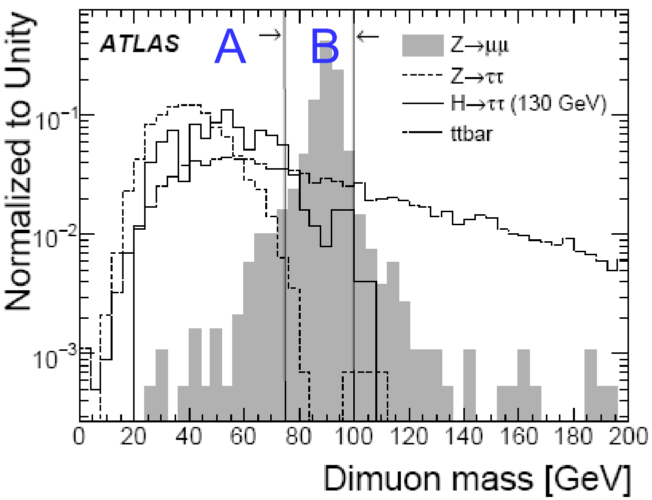
→ Normalization can be directly obtained from data



MSSM H → ττ

Estimation of $Z \to \tau^+\tau^-$ shape from data

2 jets, at least 1 b-jet



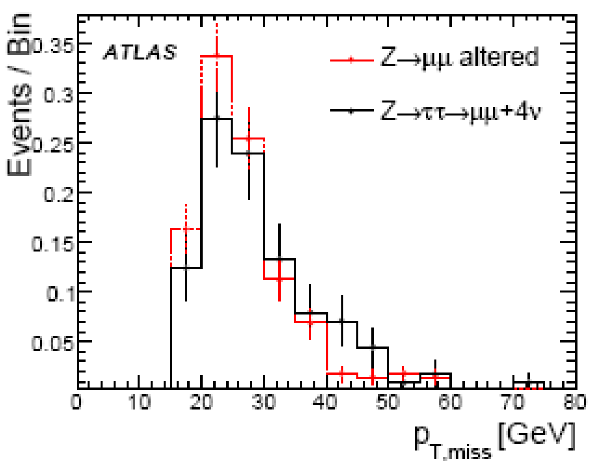
A pure sample of Z→μμ events is selected from a sideband region **B. A** is the signal region.

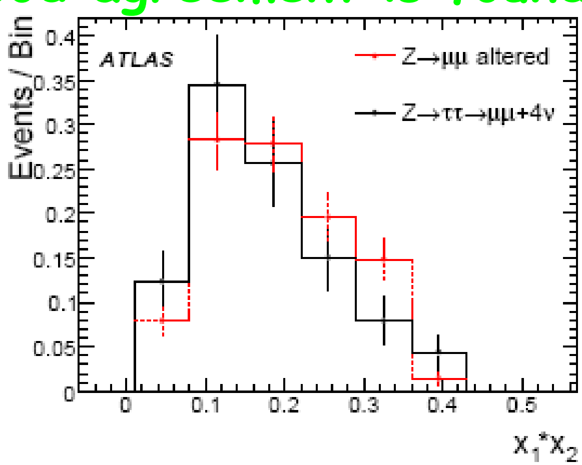
For the calorimeters these events are indistinguishable from Z →ττ →μμ + 4υ events.

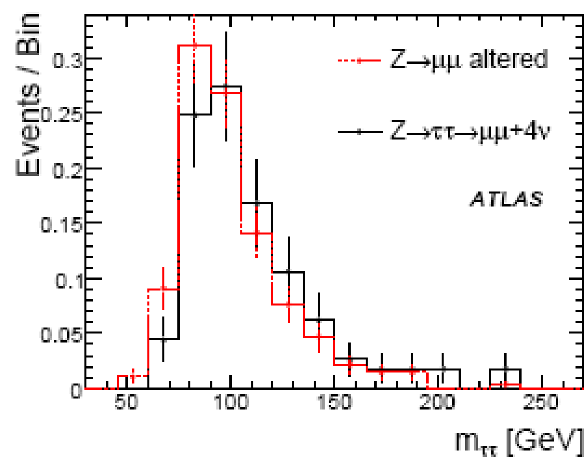
Reference histograms are produced for Z →ττ →μμ + 4υ events in the A region and momentum components for muons coming from Z→μμ events of region B are altered to reproduce reference histograms.

Missing energy is recalculated as well as visible energy fractions and $m_{\tau\tau}$ according to the new momenta.

Good agreement is found

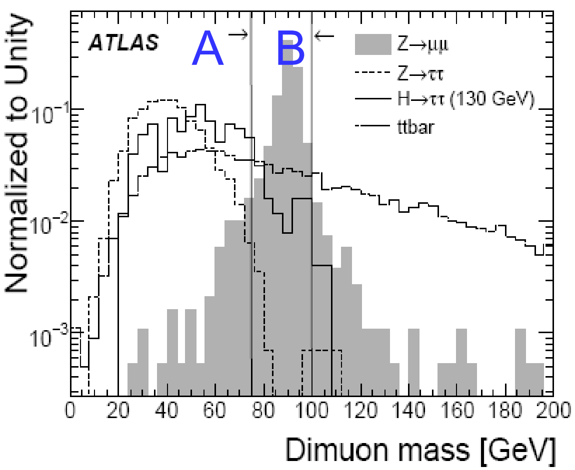






MSSM H → ττ

Estimation of $Z \to \tau^+\tau^-$ normalization from data



The number of $Z \to \tau^+\tau^-$ background events in the signal region A can be obtained by re-weighting the number of events found in data in region B by the predicted ratio of the number of events found in Monte Carlo in region A relative to that found in region B.

$$(Z \to \tau\tau \to \mu\mu + 4\nu)^A_{DATA} = (Z \to \tau\tau \to \mu\mu + 4\nu)^B_{DATA} * \frac{(Z \to \tau\tau \to \mu\mu + 4\nu)^A_{MC}}{(Z \to \tau\tau \to \mu\mu + 4\nu)^B_{MC}}$$

In order for this method to be valid, the following two conditions have to hold:

$$\frac{(Z \to \ell\ell)^B_{\mathrm{Data}}}{(Z \to \ell\ell)^B_{\mathrm{MC}}} = \frac{(Z \to \tau^+\tau^- \to \ell\ell + 4\nu)^B_{\mathrm{Data}}}{(Z \to \tau^+\tau^- \to \ell\ell + 4\nu)^B_{\mathrm{MC}}}$$

$$\frac{(Z \to \ell\ell)^B_{\mathrm{Data}}}{(Z \to \ell\ell)^B_{\mathrm{MC}}} = \frac{(Z \to \tau^+\tau^- \to \ell\ell + 4\nu)^A_{\mathrm{Data}}}{(Z \to \tau^+\tau^- \to \ell\ell + 4\nu)^A_{\mathrm{MC}}},$$

where the first condition means that $Z \to \ell\ell$ events behave like $Z \to \ell\ell + 4\nu$ events, and combined with the second it implies that events in region A and in region B behave identically.

Systematic Errors

Source	Relative uncertainty	Effect on signal efficiency
luminosity	± 3%	± 3%
tau energy scale	± 5%	± 4.9%
tau ID efficiency	± 5%	± 5%
jet energy scale	± 7% ($\|\eta\|<3.2$) ± 15% ($\|\eta\|>3.2$) ± 5% (on Etmiss)	+16% / -20%
...	...	...
total summed in quadrature	-	± 20%

Jet energy/Etmiss scale is the dominant source of systematics

MSSM

- M_h^{max}: maximum allowed mass for h. Replaces the "maximal mixing" scenario used in the past.

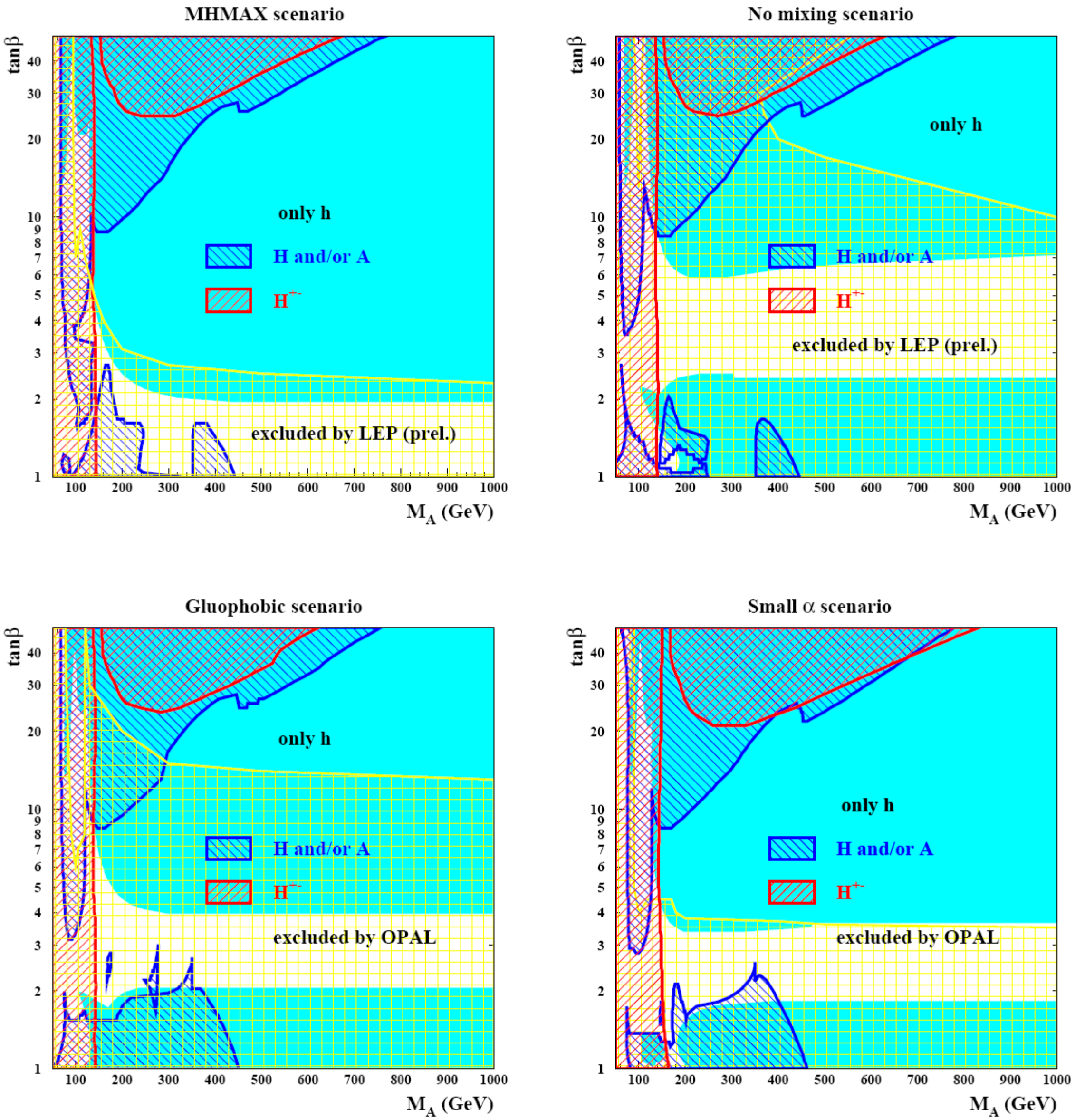
- No-mixing: as above but no mixing in stop sector. Smaller M_h

- Gluophobic H: large mixing suppresses gluon fusion production $gg \to h$ and $h \to \gamma\gamma$, $h \to 4l$

- Small α_{eff}: small mixing angle of the neutral CP-even Higgs boson can suppress $h \to bb$, $\tau\tau$

- CPX: CP eigenstates h, A, H mix to mass eigenstates H H H
Maximal mixing.

Name	M_{SUSY}	μ	M_2	X_t	$m_{\tilde{g}}$
m_h-max	1000	200	200	2000	800
No mixing	2000	200	200	0	800
Gluophobic	350	300	300	-750	500
Small α	800	2000	500	-1100	500



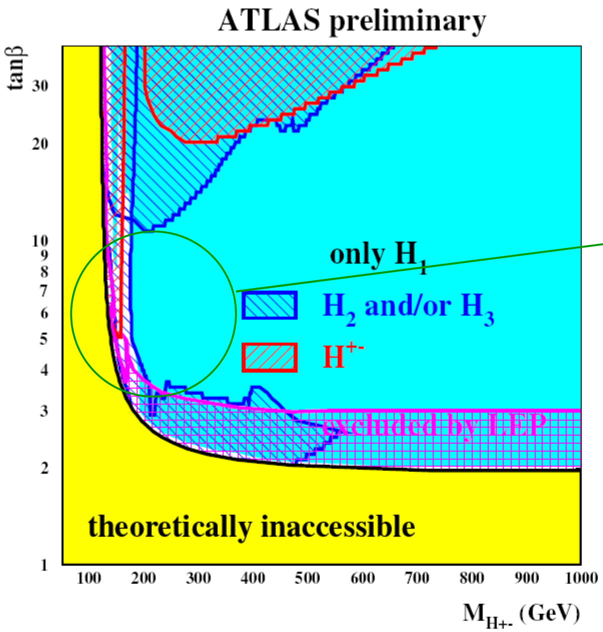
ATLAS, 30 fb^{-1}, 5σ discovery potential in 4 benchmark scenarios

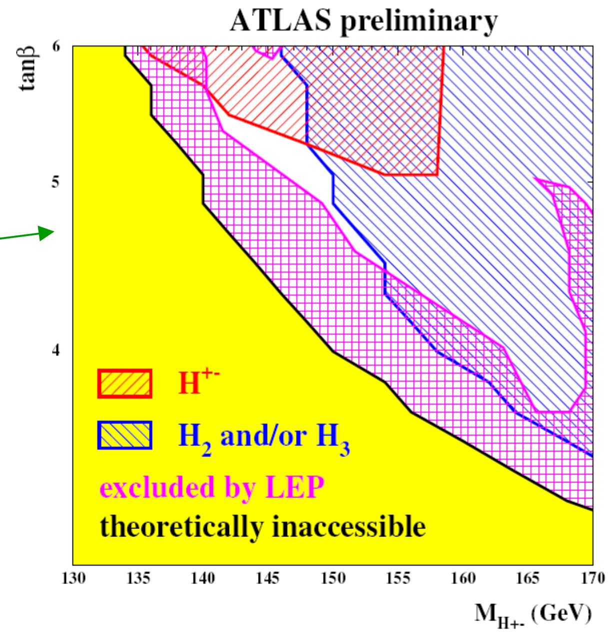
At least one Higgs boson is expected to be found in the allowed parameter space.

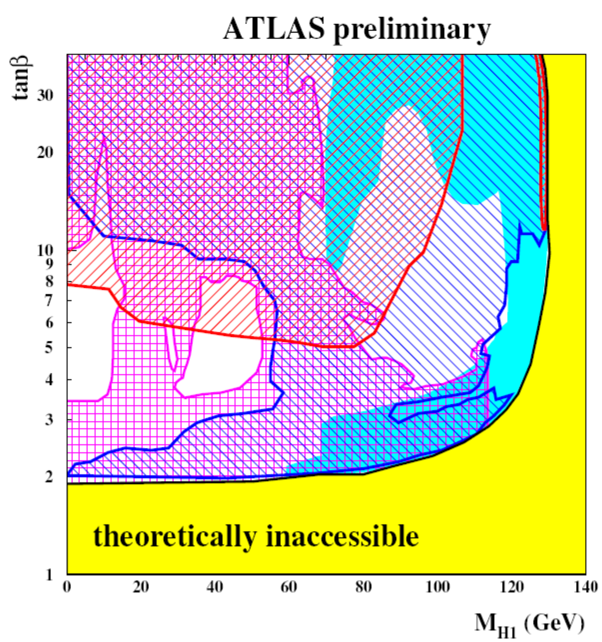
However, in some regions of the parameter space only one Higgs boson (SM like), h, can be observed.

At higher luminosity (300 fb^{-1}) the h boson can be seen in more than one channel in most of the parameter space.

ATLAS preliminary





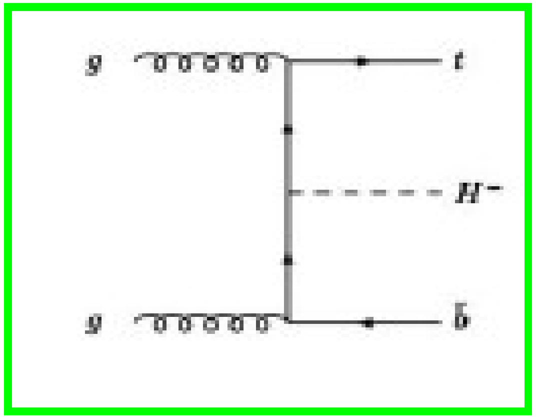


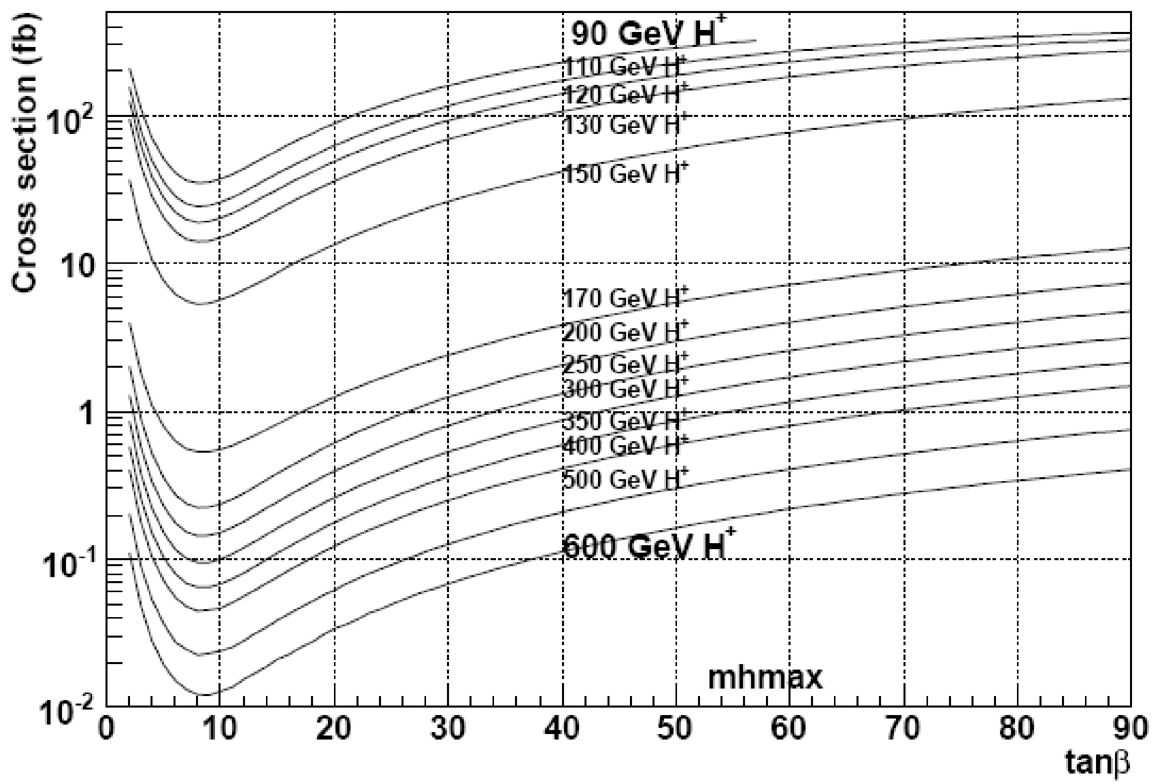
ATLAS, 300 fb^{-1}, 5σ discovery potential in CPX scenario.

Almost all of the parameter space is covered by the observation of at least one Higgs boson (mainly the lightest H_1)

Small region of phase space not covered: corresponds to M_{H1}<50 GeV.

CHARGED MSSM HIGGS CROSS SECTIONS





CHARGED MSSM HIGGS RESULTS

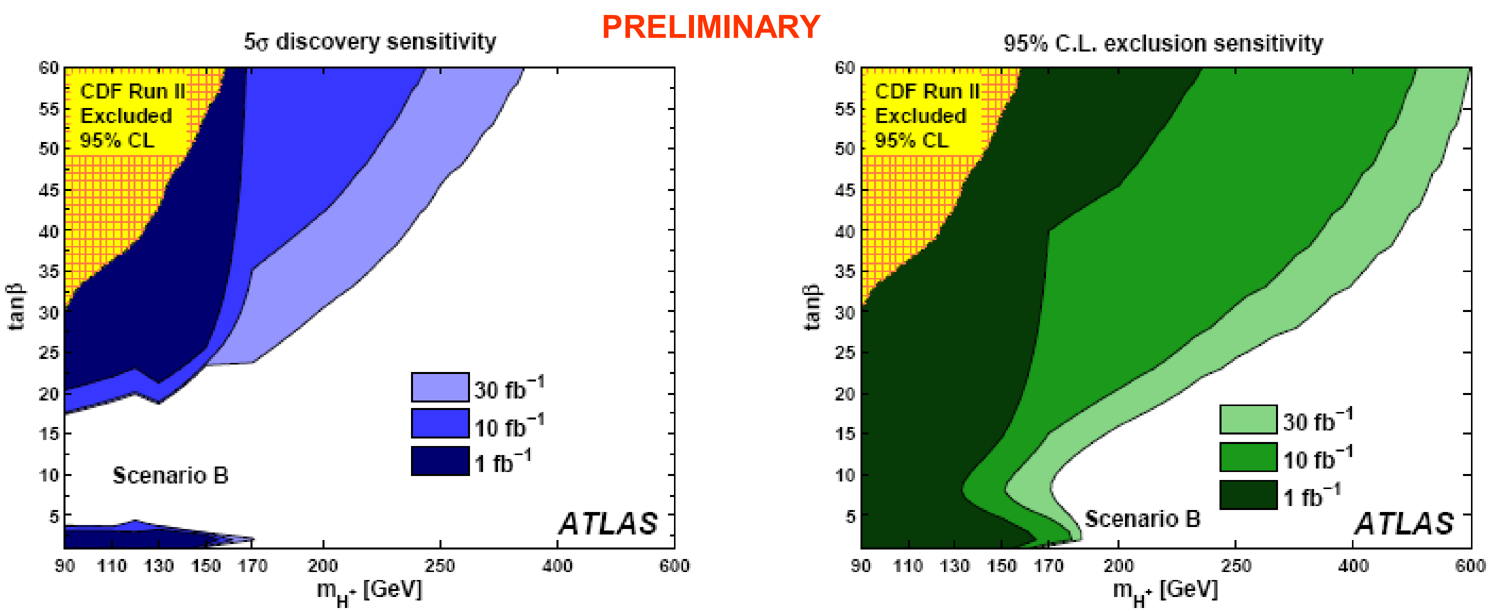


Figure 18: Scenario B (m_h-max): Combined Results. Left: Discovery contour, Right: Exclusion contour. Systematic and statistical uncertainties are included.