Higgs searches with ATLAS using b- and τ-signatures

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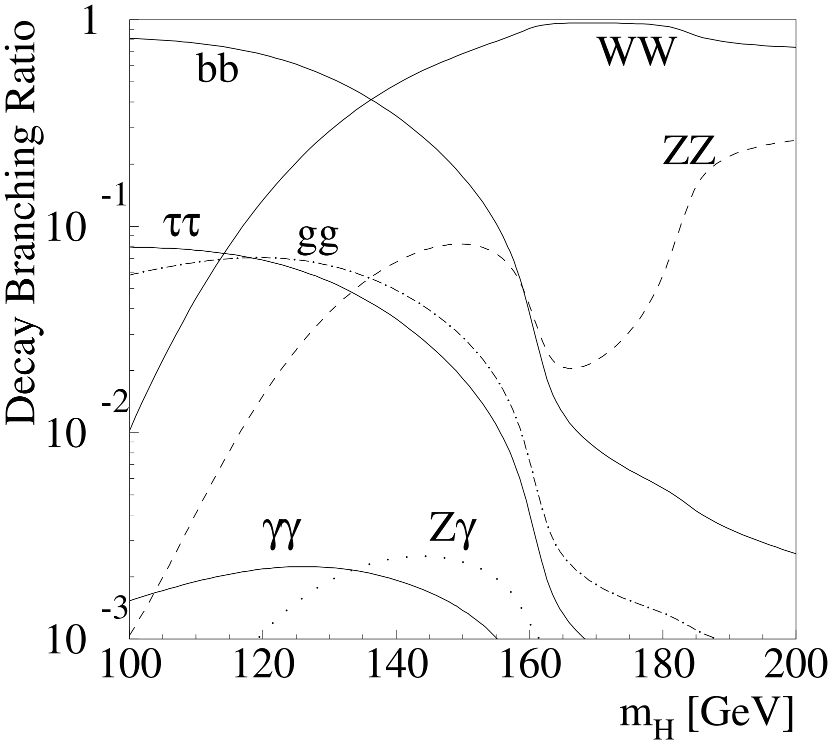
WORKSHOP ON b/τ PHYSICS AT THE LHC

Higgs boson with b/τ decays

- SM Higgs and/or the lightest MSSM Higgs boson is/are expected to be relatively light (≤ 130 GeV).
- For such light Higgs bosons, compared to the higher m_{H} region where decays to vector bosons are very effective for Higgs boson searches, it is rather difficult to improve signal significance with small integrated luminosity (ex.≤ 30 fb^{-1}).
- In this mass region, b and τ decay channels dominate its decay branching ratios.
- High production cross section, but high background rate.
  - Decays to b-quarks is difficult to be tagged among high QCD activities. Better to have other signals in the final state.
  - Leptonic and hadronic τ decays can be tagged more easily than b decay case.
- Heavy Higgs boson in the MSSSM also can be explored by τ decay channel.
  - $\mathrm{H}/\mathrm{A} \rightarrow \tau\tau$
  - $\mathrm{H}^{\pm} \rightarrow \tau\nu$

Higgs and b/τ Decays

Decay branching ratios (%)

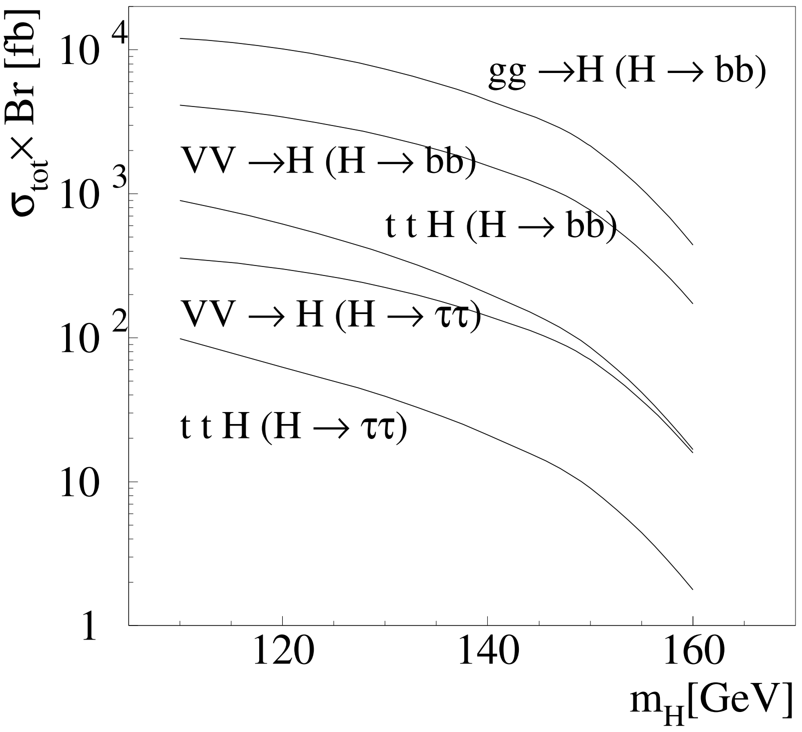


m_{H}	110	120	130	140	150	160
$\mathrm{b}\overline{\mathrm{b}}$	77.0	67.8	52.5	34.2	17.4	3.83
$\tau^+\tau^-$	7.7	6.9	5.4	3.6	1.83	0.41

- $\mathrm{H} \to \mathrm{b}\overline{\mathrm{b}}$ and $\to \tau^+\tau^-$ are two major decay channel of the SM light Higgs boson.
- Branching ratios rapidly decrease as m_{H} becomes higher.

SM Higgs Production

Production cross sections × branching ratios

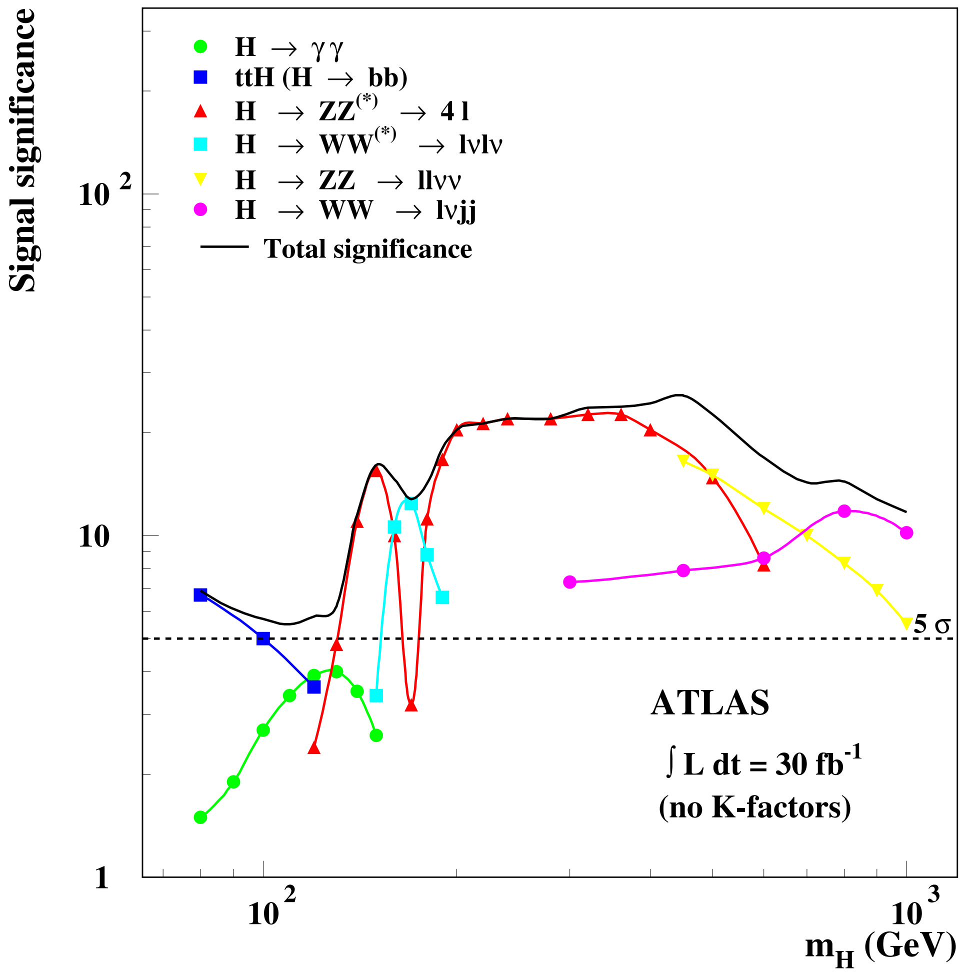


Production and decays (τ and b channels)

Production	g-fusion	ttH	VV-fusion
$\mathrm{b\bar{b}}$	High BG	◯	High BG
$\tau^+\tau^-$	High BG	Low Rate	◯

- g-fusion processes have no distinctive signals in their final states $\rightarrow$ QCD background is high
- ttH process has very complex final states.
- Forward jets tagging can improve S/$\sqrt{\mathrm{B}}$ in VV fusion processes

ATLAS Discovery potentials



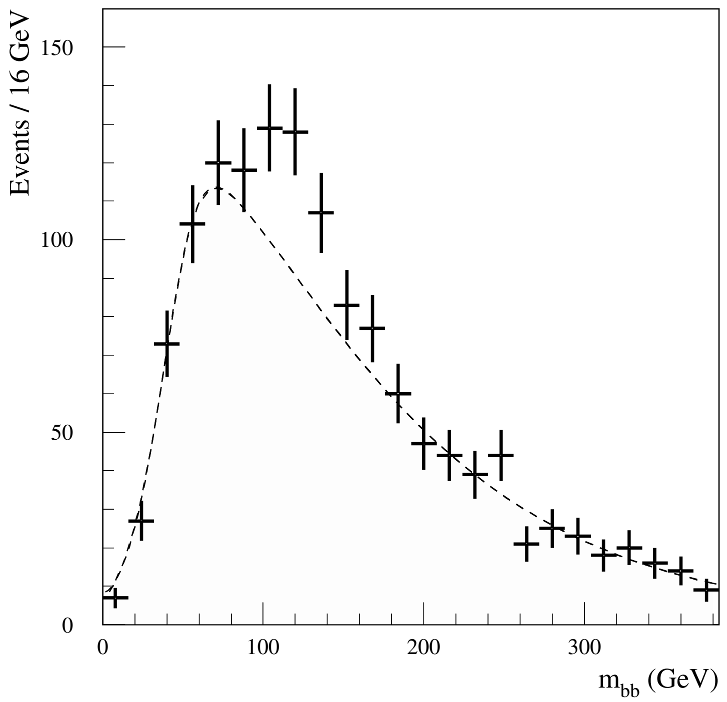
- Only $\mathrm{gg} \to \mathrm{H} \to \gamma\gamma$ and $\mathrm{t\bar{t}H(H \to b\bar{b})}$ have been two major discovery channels for the low mass Higgs bosons
- With 30 fb^{-1} luminosity data, it is necessary to combine both two channels for 5σ discovery.

$\mathrm{t\bar{t}H \to t\bar{t}b\bar{b}}$

- $\sigma \times$ BR ~ 380 fb ($m_{\mathrm{H}} = 130$ GeV)
- Very complex final states (two W bosons and two b-jets $\rightarrow$ four b-jets in the final state) $\rightarrow$ considerable large combinatorial background in the signal events themselves
- Both top quarks are reconstructed with the help of $p_{\mathrm{T}}^{\mathrm{m}iss}$

$$
\begin{aligned}
\mathrm{t\bar{t}H} &\rightarrow \mathrm{t\bar{t}b\bar{b}} \\
&\rightarrow (\mathrm{bW})(\mathrm{bW})\mathrm{b\bar{b}} \\
&\rightarrow (\mathrm{b}\ell\nu)(\mathrm{b}\,j\,j)\mathrm{b\bar{b}}
\end{aligned}
$$

For $\int \mathcal{L}\, dt$=100 fb^{-1} and m_{H}=120 GeV



- Results

$$\text{S} = 62 \text{ events}$$
$$\text{B} = 257 \text{ events}$$
$$\text{S}/\text{B} \sim 0.24$$
$$\text{S}/\sqrt{\text{B}} = 3.9$$

- Major background comes from QCD $\mathrm{t\bar{t}}\,j\,j$ (~ 242 events)
- Crucial for the b-tagging efficiency ($\times\epsilon_{\mathrm{b}}^{4}$)
- Shape of background should be well known

Characteristics of Vector Boson Fusion (VBF)

- Vector Boson Fusion
  - Another promising production process with relatively high cross section
  - Can observe some decay channels in the same production process
    $\rightarrow$ Very effective for the measurement of Higgs boson couplings to these decay products
- $\mathrm{H} \rightarrow \mathrm{b\overline{b}}$
  - Large production cross section:
    - 2.5pb ($m_{\mathrm{H}} = 130$ GeV)
    - $\sigma(\mathrm{VBF}) \approx \frac{1}{3} \times (\mathrm{g-fusion})$
  - Two forward jets with high p_{T} ($\sim \frac{1}{2} \cdot M_{\mathrm{W}}$)
  - Higgs mass can be reconstructed from invariant mass of two b-jets
  - Suffers from large QCD background
- $\mathrm{H} \rightarrow \tau^+\tau^-$
  - Require leptons in the final state to trigger events
  - $\tau^+\tau^- \rightarrow \ell\nu\nu\ell\nu\nu$ and $\ell\nu\nu + \mathrm{hadrons}$ channels are analyzed
  - Though ν's carry away some energy, m_{H} can be reconstructed via $p_{\mathrm{T}}^{\mathrm{m}iss}$ information.

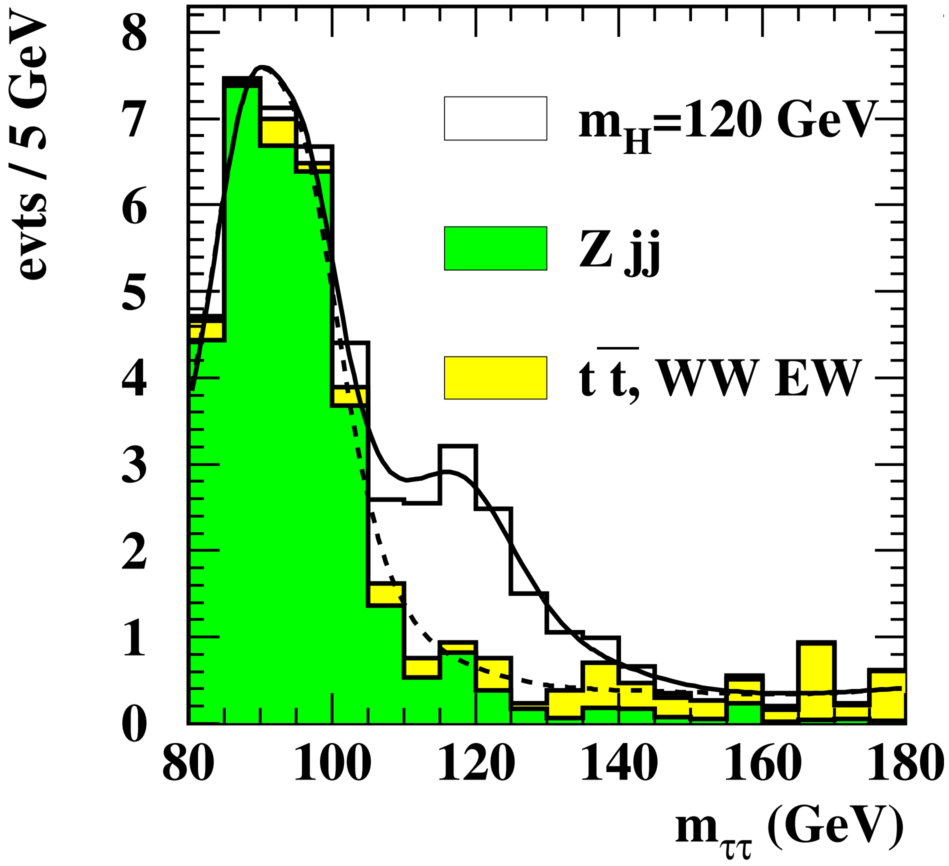
$\mathrm{VV} \rightarrow \mathrm{H} \rightarrow \tau^+\tau^-$

- Two decay channels are considered:

$$\mathrm{H} \rightarrow \tau\tau \rightarrow \ell^+\ell^- p_{\mathrm{T}}^{\mathrm{m}iss}$$
$$\rightarrow \ell^\pm \mathrm{h}\, p_{\mathrm{T}}^{\mathrm{m}iss}$$

- Selection flow:
  - τ tagging via lepton and hadronic τ-jet identification
  - Two tagged jets in the forward region
  - Small transverse mass between lepton and $p_{\mathrm{T}}^{\mathrm{m}iss}$
    - $*$ Reject events with leptons from W decays
  - Reconstruct $m_{\tau\tau}$ via $p_{\mathrm{T}}^{\mathrm{m}iss}$ information.
  - Mass window cut of ± 10 GeV

$m_{\tau\tau}$ distribution for ℓ-ℓ channel
(m_{H}=120 GeV and 30 fb^{-1})

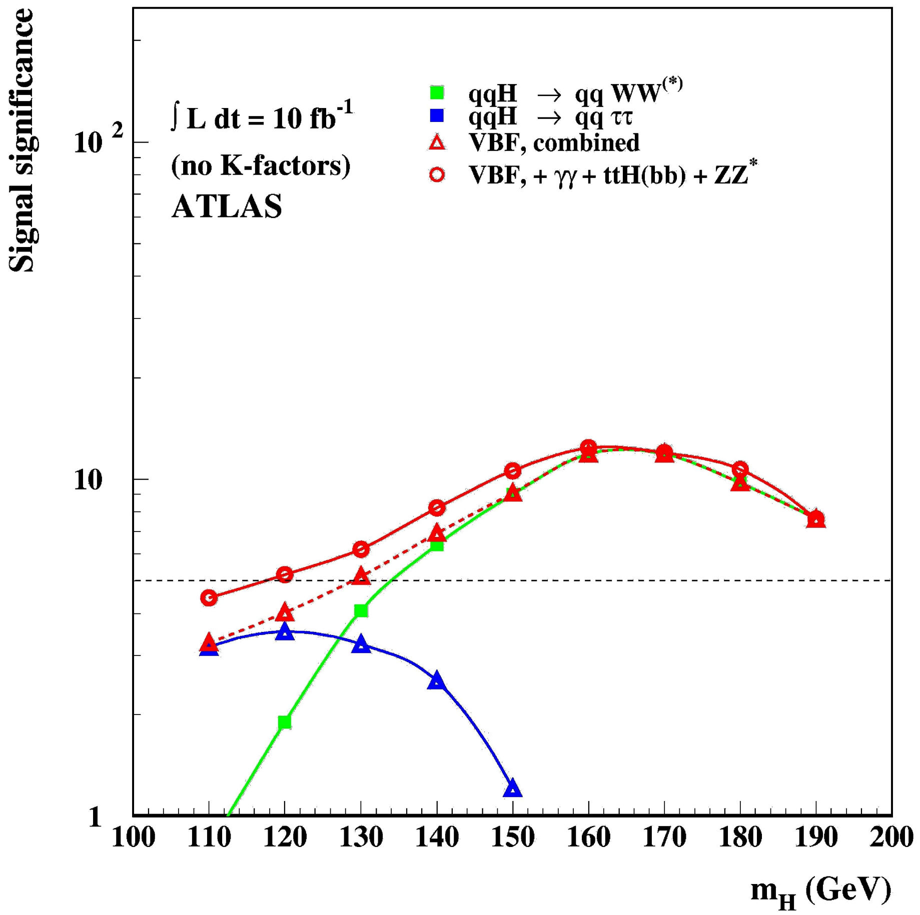


Combined signal significance

m_{H}	110	120	130	140	150
Combined	5.1	6.1	5.5	4.5	2.6

Combined significance of VBF channels

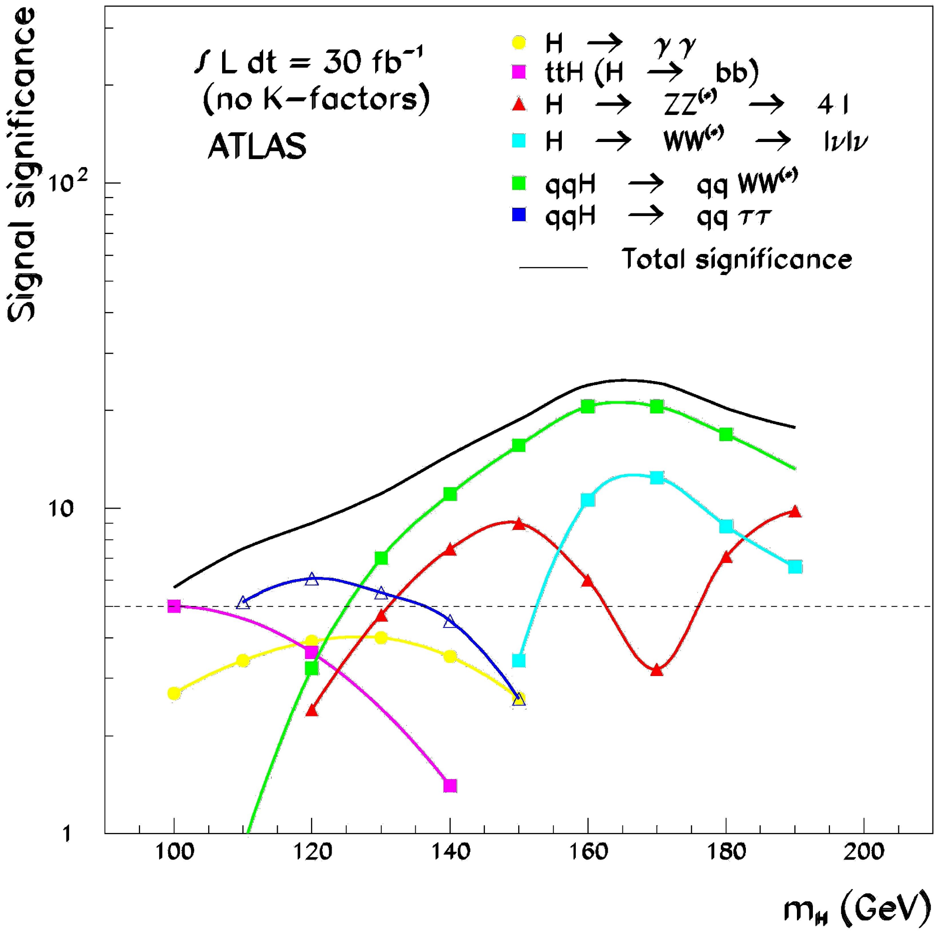
Signal significance for 10 fb^{-1}



- Including results of VBF analyses, we can improve our discovery potential especially for light Higgs bosons.
- After combining results of the standard channels, we can obtain 5σ Higgs signal in the mass region between $120 \leq m_{\mathrm{H}} \leq 190$ GeV only with 10 fb^{-1} in ATLAS.
- Contribution of τ decay channel is significant in the region of $m_{\mathrm{H}} < 130$ GeV.

ATLAS Higgs discovery potential for 30 fb^{-1}

Combine signal significance for 30 fb^{-1}



- For 30 fb^{-1}, with the help of VBF channels, full mass range can be covered by the ATLAS results.
- Overlaps between several decay channels for a mass contribute to the measurement of Higgs properties significantly.

MSSM Higgs search

Higgs members in the MSSM:

- Three neutral: h, H, A
- Two charged: $\mathrm{H}^{\pm}$

Complex mass spectra and decay branching ratios depending on m_{A} and $\tan\beta$

- The same analysis as SM:
  - $\mathrm{h} \to \gamma\gamma$
  - $\mathrm{t\bar{t}h} \to \mathrm{t\bar{t}b\bar{b}}$
  - $\mathrm{H} \to \mathrm{ZZ}^{(*)} \to 4\ell$
- Specific to MSSM:
  - $\mathrm{H/A} \to \mu\mu$, $\tau\tau$, $\mathrm{t\bar{t}}$
  - $\mathrm{H}^{\pm} \to \tau\nu$, cs, tb
  - $\mathrm{H} \to \mathrm{hh}$, $\mathrm{A} \to \mathrm{Zh}$
- SUSY decays:
  - $\mathrm{H/A} \to \widetilde{\chi}_2^0\widetilde{\chi}_2^0$
  - $\widetilde{\chi}_2^0 \to \mathrm{h}\widetilde{\chi}_1^0$

MSSM Higgs and b/τ Decays

Decay channels with τ:

- $\mathrm{H}^{\pm} \rightarrow \tau\nu$
  - Plays important role in the wide range of $m_{\mathrm{H}^{\pm}}$
- $\mathrm{H}/\mathrm{A} \rightarrow \tau\tau$
  - $\mathrm{b\overline{b}H/A}$ (associated $\mathrm{b\overline{b}}$) production is dominant for high $\tan\beta$

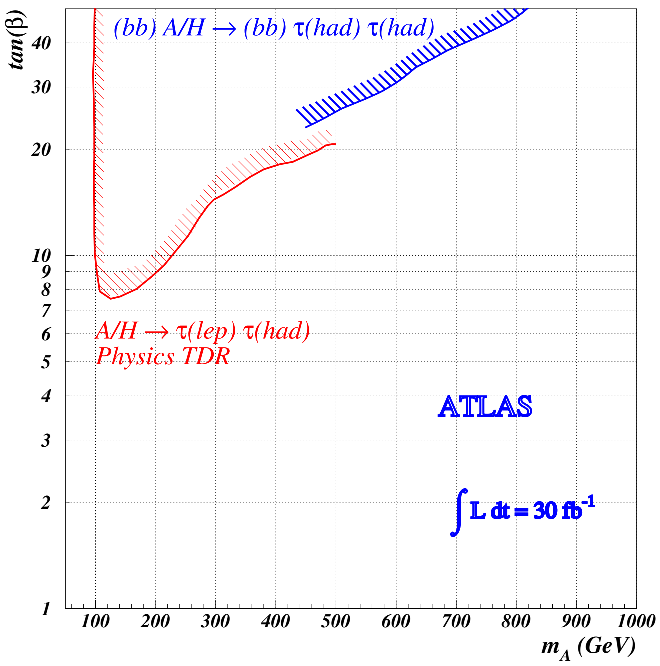
Decay channel with b:

- $\mathrm{t\bar{t}h(h \rightarrow b\overline{b})}$
  - Same analysis as the SM case
  - h behaves as SM Higgs if $m_{\mathrm{A}} > 100$ GeV
- $\mathrm{b\overline{b}h(h \rightarrow b\overline{b})}$
  - If $m_{\mathrm{A}} < 100$ GeV, $\mathrm{t\bar{t}h}$ production is suppressed and $\mathrm{b\overline{b}h}$ production is observable at high $\tan\beta$
  - $4\mathrm{b}$ final states with large QCD background

$\mathrm{H/A} \to \tau\tau$

- Strong enhancement of $\mathrm{b\bar{b}H/A}$ production process
  $\sigma(\mathrm{MSSM})/\sigma(\mathrm{SM}) \approx 5000$ ($\tan\beta$=30, $m_{\mathrm{H/A}}$=300 GeV)
- $\mathrm{H/A} \to \tau\tau$ decay is observable and can cover large part of the parameter space
- All $\tau\tau$ final states are available ($\ell\ell$, $\ell\mathrm{h}$, hh)
  hh channel provides good sensitivity at high m_{A} region
- Mass reconstruction is possible
- Require good τ/jet separation and p_{T}^{miss} resolution

Discovery potential for $\mathrm{H/A} \to \tau\tau$



$\mathrm{H}^{\pm} \to \tau\nu$

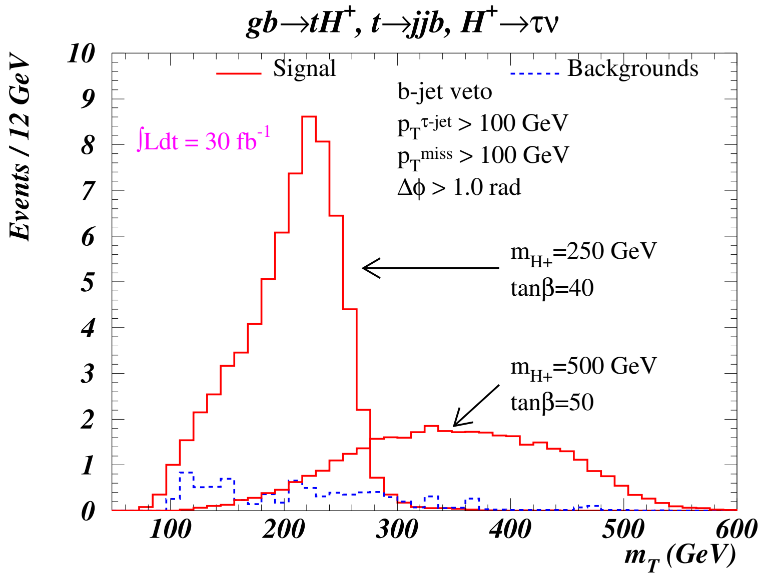
- $m_{\mathrm{H}^{\pm}} < m_{\mathrm{t}}$: $\mathrm{t} \to \mathrm{H}^{\pm}\mathrm{b}(\mathrm{H}^{\pm} \to \tau\nu)$ process appears as an excess of τ leptons

Observability of the $\mathrm{H}^{\pm} \to \tau\nu$ channel
($\tan\beta$=5, 30 fb^{-1})

$m_{\mathrm{H}^{\pm}}$ [GeV]	110	130	150
$\sigma \times$ BR(pb)	23.3	13.1	4.8
Signal	3050	1550	380
Background	7020	7170	9120
Significance	13.1	6.6	1.3

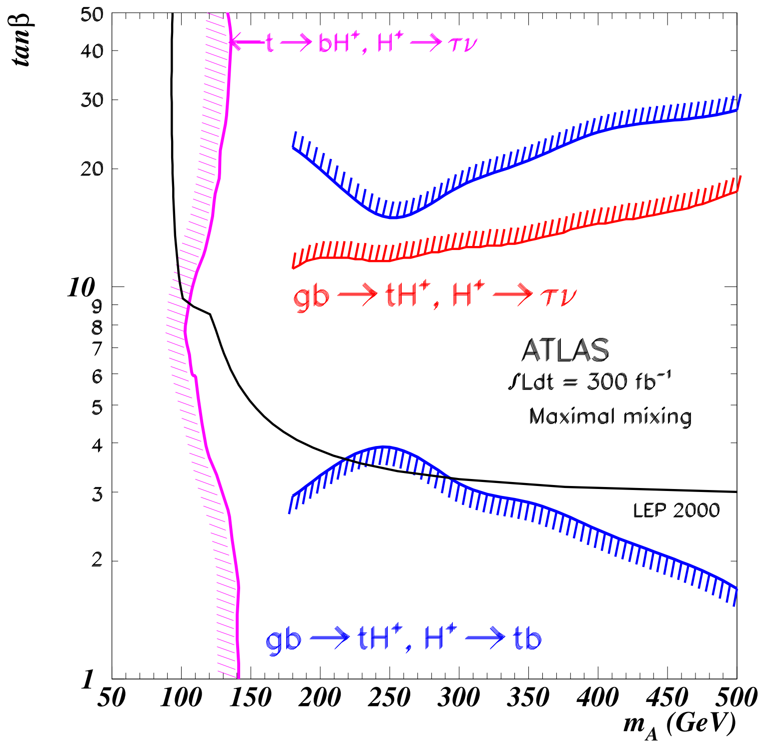
- $m_{\mathrm{H}^{\pm}} > m_{\mathrm{t}}$: $\mathrm{gb} \to \mathrm{H}^{\pm}\mathrm{t}(\mathrm{H}^{\pm} \to \tau\nu)$
Polarization and p_{T} of τ and p_{T}^{miss} are used to suppress background from $\mathrm{t\bar{t}b}$, Wtb, $\mathrm{W+jets}$ and QCD jets.

Transverse mass distribution of $\mathrm{H}^{\pm}$ signals



ATLAS discovery potential for $\mathrm{H}^{\pm}$

Discovery potential for $\mathrm{H}^{\pm}$

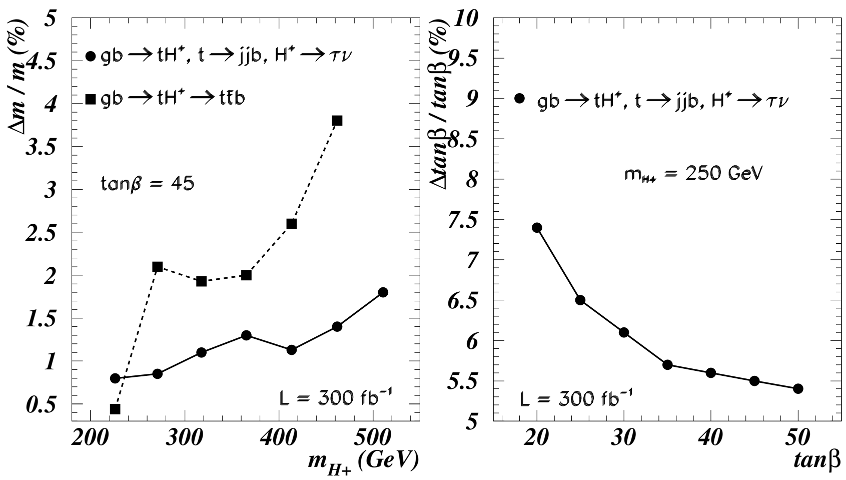


- $\mathrm{H}^{\pm} \to \tau\nu$ channel contributes to extend the reach in $\tan\beta$ and m_{A} plane.
- For high $\tan\beta$ region, the $\mathrm{H}^{\pm} \to \tau\nu$ channel becomes very important.

Determination of $m_{\mathrm{H}^\pm}$ and $\tan\beta$

- $m_{\mathrm{H}^\pm}$ determination
  - Maximum likelihood from transverse mass distributions.
  - Also can be done in $\mathrm{H}^\pm \to \mathrm{tb}$ channel
  - Errors dominated by statistics. $\tau\nu$ channel gives a better result.
- $\tan\beta$ determination
  - Measuring $\sigma \times$ BR
  - Because it is a measurement of the absolute cross section, uncertainty on luminosity measurements limits its precision.
  - Because rate of $\mathrm{H}^\pm \to \tau\nu$ increases as higher $\tan\beta$, precision of $\tan\beta$ improves.

Precision of $m_{\mathrm{H}^\pm}$ and $\tan\beta$ determination



Summary

- τ and b decay channels play a very important role in studying light Higgs bosons.
- Not only $\mathrm{t\bar{t}H(H \to b\bar{b})}$ channel, but also $\mathrm{VV} \to \mathrm{H} \to \tau\tau$ channel, which has been extensively studied recently, contribute to the discovery of light Higgs bosons.
- Combining these new results with the standard channels previously studies, we can obtain 5σ Higgs signal in the mass region between $120 \leq m_{\mathrm{H}} \leq 190$ GeV only with 10 fb^{-1} in ATLAS.
- In the Higgs production through vector boson fusion process, some decay channels can be observed simultaneously. In that case, because systematic effects from production processes can be reduced, better measurements of properties of Higgs bosons become possible.
- For the study of the MSSM Higgs bosons, either neutral or charged, decay channels with τ can extend the reach in the $\tan\beta$ and m_{A} plane.
- Determination of Higgs mass and also $\tan\beta$ are found to be possible through the analysis of these decay channels.