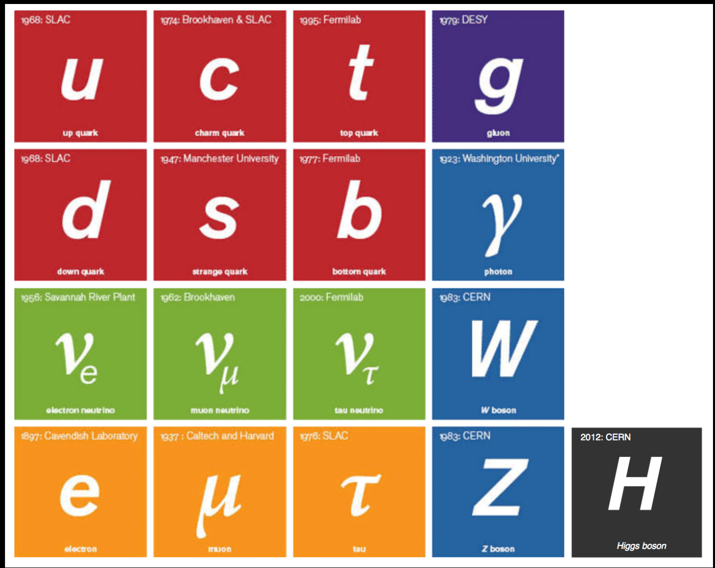
SEARCHES FOR ADDITIONAL HIGGS BOSONS WITH THE ATLAS DETECTOR

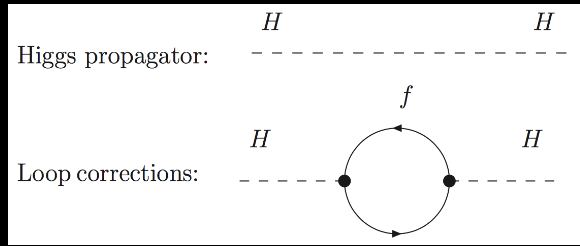
PUJA SAHA
LLWI2017, 20TH FEBRUARY 2017
NORTHERN ILLINOIS UNIVERSITY, USA
ON BEHALF OF THE ATLAS COLLABORATION

MOTIVATION



Standard Model particles

- Standard Model (SM) can not explain:
  - Hierarchy problem of Higgs sector.



Higher order loop correction, unstable Higgs mass

$\delta m_H^2 \sim \lambda^2$, where $\lambda \sim M_{GUT} \sim 10^{16}$ GeV.

  - Existence of Dark Matter particles.
  - Neutrino masses and mixing of neutrinos.

BEYOND STANDARD MODEL (BSM)

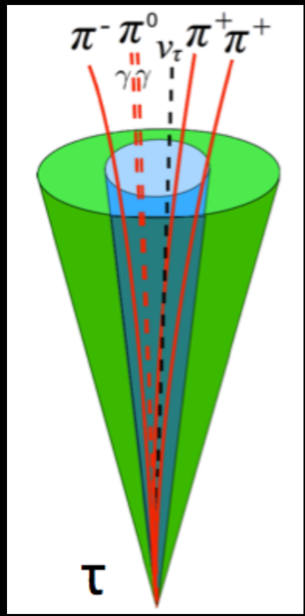
- The Minimal Supersymmetric Standard Model (MSSM) is one of the possible extensions of the SM that includes supersymmetry.
- It needs two Higgs doublets, after EWSB five physical Higgs particles h^0, H^0, $H^\pm$, A^0 appear.

This talk presents a search for BSM H/A, H^+ in different final states, using 13.3 fb^{-1} and 14.7 fb^{-1} data recorded by the ATLAS detector.

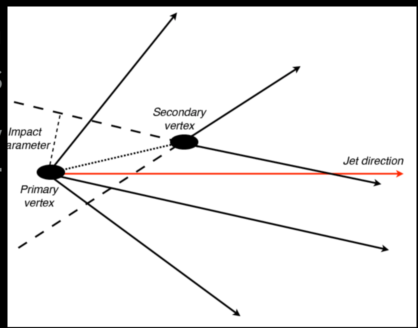
HADRONIC TAU AND B-JET RECONSTRUCTION

Hadronic tau reconstruction:

- $\tau_{\text{had-vis}}$ is reconstructed using electromagnetic and hadronic clusters and seeded by anti-k_t jet finding algorithm with distance parameter of R=0.4 and $p_T >$ 10 GeV, $|\eta| < 2.5$.
- A barycenter is formed using sum of the four vectors of the constituent topological clusters, assuming that each component has zero mass. The τ_{had} detector axis is measured by using clusters within $\Delta R < 0.2$ around the barycenter.
- Tracks of p_T >1GeV in $\Delta R < 0.2$ from barycenter are associated with $\tau_{\text{had-vis}}$ candidate and the electric charge is calculated from sum of the charge of tracks.
- Jets are wider than hadronic τ decay for a given momentum value. Different discriminating variables are combined in a boosted decision tree (BDT), which is trained separately for one-prong and three-prong decays of τ_{had} candidate.
- " loose" and "medium" ID $\tau_{\text{had-vis}}$ of about 60%(50%) and 55%(40%) measured in $Z \to \tau\tau$ sample for one-track (three-track) separately.



Hadronic τ Reconstruction

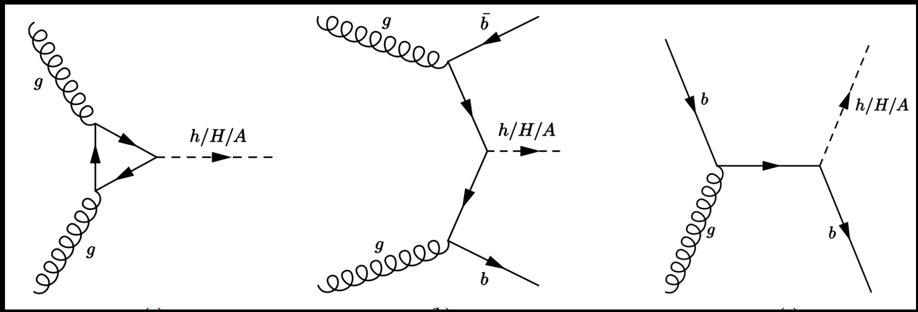


b-jet reconstruction

b-jet reconstruction:

- **Life-time based tagging:** relatively large mean lifetime ~1.5 ps, at least on vertex displaced from the primary vertex (PV).
- Tracks from the *b* quark decay are separated from the tracks originating from PV by the transverse and longitudinal impact parameters.
- **Vertex based tagging:** algorithm selects all tracks which are displaced from PV and associated with jets, and forms vertex candidate for track pairs. Vertices compatible with long lived particle and material interaction are rejected. Invariant mass is used to reject vertices from other processes.

SEARCH FOR MSSM NEUTRAL HIGGS IN $\tau\tau$ FINAL STATE AT 13 TEV



MSSM Higgs production modes

- We consider the neutral Higgs decays in $\tau\tau$ final state, where at least one τ should decay in hadronic final state.
- The MSSM heavy Higgs couplings to down type fermions are enhanced with respect to SM at larger tanβ.
- Neutral Higgs production via gluon-gluon fusion and in association with *b* quark.

EVENT SELECTION (LEP-HAD)

- Events are triggered either by single lepton trigger or E_T^{miss} trigger, depending on event category.
- Single-*e* trigger has p_T >24 GeV or 26 GeV, 60 GeV and 120 GeV or 140GeV, single-μ trigger of p_T > 50 GeV.
- Events must have at least one $\tau_{had\text{-}vis}$ ("medium") of $p_T > 25$ GeV and either one e or μ.
- For $\tau_e \tau_{had}$ channels, events are vetoed if $80 < m_{vis}(e, \tau_{had\text{-}vis}) < 110$ GeV.
- $m_T(l, E_T^{miss}) \equiv \sqrt{(2p_T(l)E_T^{miss}(1 - \cos\Delta\varphi(l, E_T^{miss}))} < 40$ GeV.
- $\Delta\Phi(\tau_{had\text{-}vis}, l) > 2.4$.
- High E_T^{miss} category: $\tau_e \tau_{had}$ channel $E_T^{miss} > 150$ GeV, $\tau_\mu\tau_{had}$ channel $|\bar{E}_T^{miss} + \bar{p}_T(\mu)| > 150$ GeV.
- Events which fail high E_T^{miss} are categorised in b-veto and b-tag region.

LEP-HAD CHANNEL BACKGROUND

Background Modelling:

$$\mathrm{FF(Pr)} = \frac{N(\text{nominal } \tau_{\text{had-vis}} \text{ ID, Pr})}{N(\text{anti-}\tau_{\text{had-vis}} \text{ ID, Pr})}$$

Fake factor (FF): It is a data driven method for modelling background from particle misidentification, defined as the ratio of number of $\tau_{\text{had-vis}}$ candidates with "medium" ID to the number of anti-$\tau_{\text{had-vis}}$ candidates which are not "medium" but "loose".

Main backgrounds arise from misidentified $\tau_{\text{had-vis}}$, $Z \rightarrow \tau\tau$ in *b*-veto, $t\bar{t}$ and multi-jet in *b*-tag. Background processes where τ_{had} or both lepton and τ_{had} arise from misidentified jets are dominated by $t\bar{t}$, multi-jet, *W*+jets.

- FF (*W*+jets/ $t\bar{t}$): calculated from data in control region having same selections as the signal region except $m_T(l, E_T^{miss}) > 70(60)$ for $\tau_e \tau_{had}$ ($\tau_\mu \tau_{had}$). FF obtained in *b*-tag, *b*-veto, high E_T^{miss} regions.

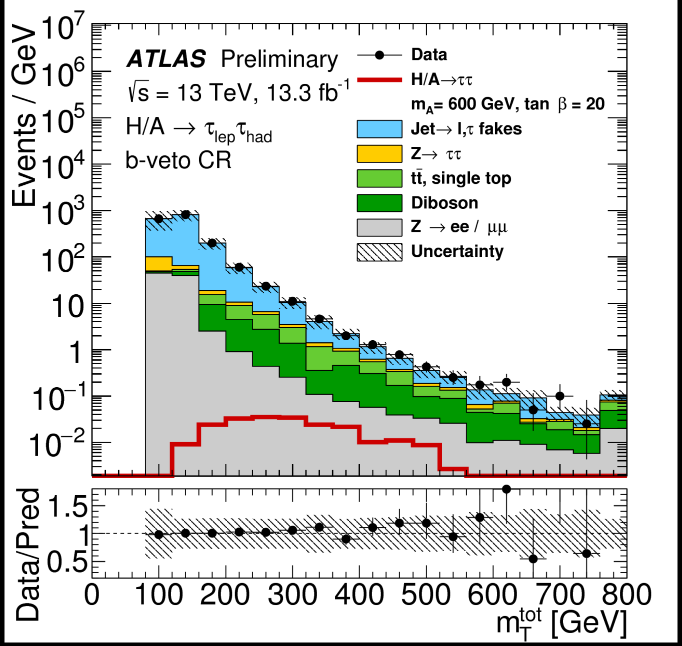
- FF (multi-jet): measured from data in the multi-jet control region have same requirements as the signal regions with the exception that the isolation requirement on the *e* or μ is inverted.

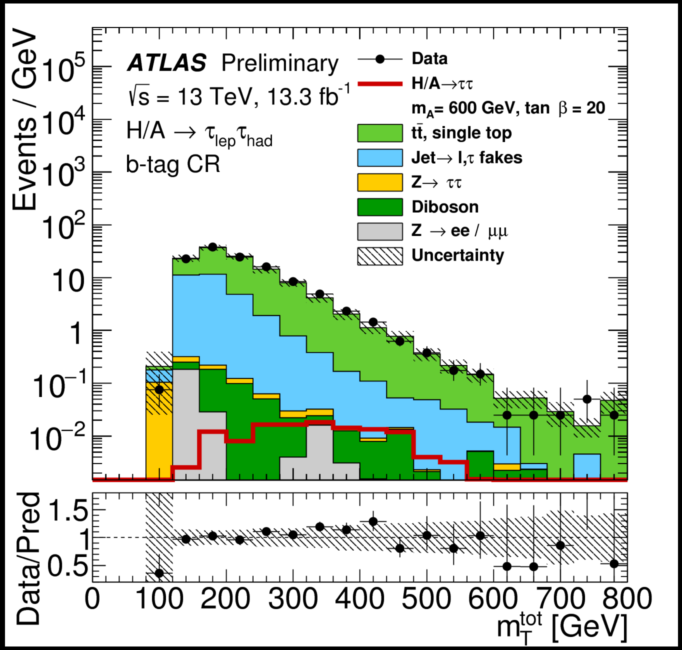
- Combined FF: the calculated FFs are then combined and weighted by the predicted contribution of each background process to the anti-τ_{had} region.

$$\mathrm{FF(comb)} = \mathrm{FF}(W\text{+jets}) \times r_{W/t\bar{t}} + \mathrm{FF(MJ)} \times r_{MJ}$$

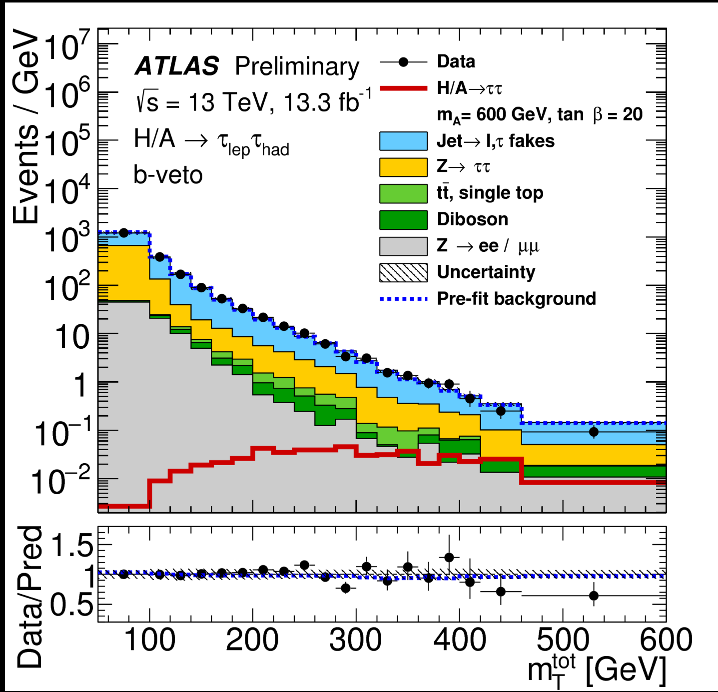
r_{MJ} denotes the fraction of multi-jet events in the anti-τ region and $r_{W/t\bar{t}} = 1 - r_{MJ}$.

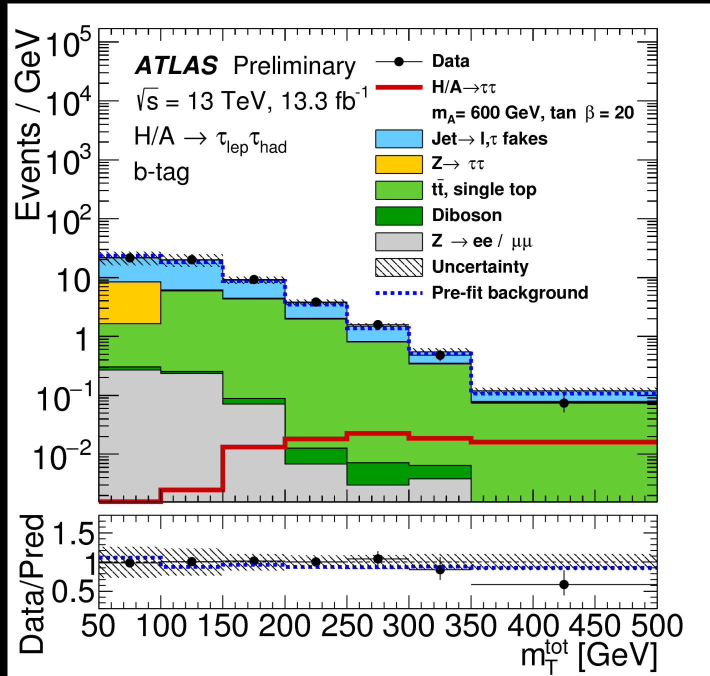
- Backgrounds where *e*/μ is identified as $\tau_{\text{had-vis}}$, estimated from simulation. Correction for misidentification rate is derived from data in $Z \rightarrow ee$ enriched region and applied to the simulation.

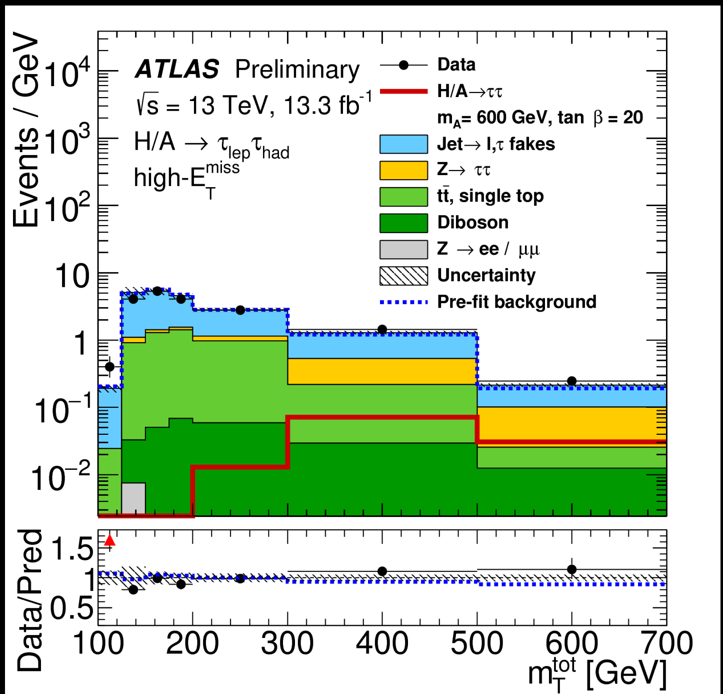




LEP-HAD CHANNEL







Final discriminating variable

$$m_T^{tot} = \sqrt{m_T^2(E_T^{miss}, \tau_1) + m_T^2(E_T^{miss}, \tau_2) + m_T^2(\tau_2, \tau_1)}$$

The total transverse mass is used to achieve best separation between signal and background for $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ channels.

Systematics:

- Systematics uncertainty arising from energy scale of $\tau_{had\text{-}vis}$, electron, muon, *b*-jets.
- Uncertainty in fake factor calculation in *W*+jets/$t\bar{t}$ and multi-jet fake factors.

HAD-HAD CHANNEL

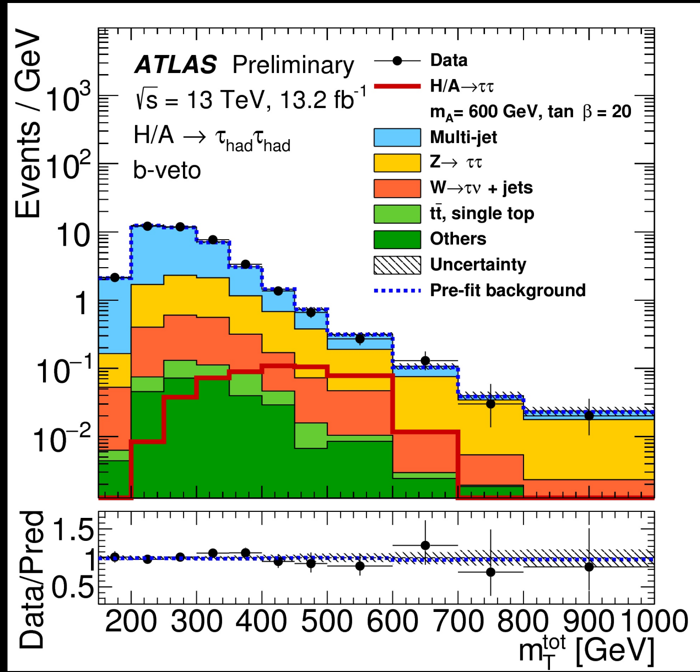
Event Selection:

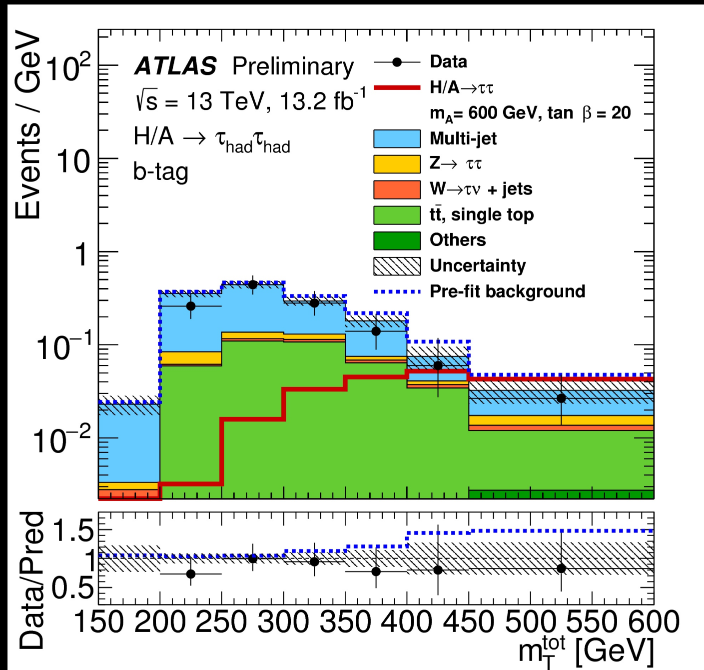
- Trigger requires $\tau_{\text{had-vis}}$ of "medium" ID, p_T > 80 to 125 GeV.
- Leading $\tau_{\text{had-vis}}$ p_T > 110 or 140 GeV, sub-leading $\tau_{\text{had-vis}}$ p_T > 55 GeV.
- The leading $\tau_{\text{had-vis}}$ should be "medium" and sub-leading $\tau_{\text{had-vis}}$ has "loose" ID and opposite charge.
- $\Delta\varphi(\tau_{\text{had-vis},1}, \tau_{\text{had-vis},2})$ > 2.7, back to back.
- Further categorised in *b*-tag and *b*-veto region. In b-tag category the sub-leading τ p_T > 65 GeV to reduce the multi-jet background.

Background Modelling:

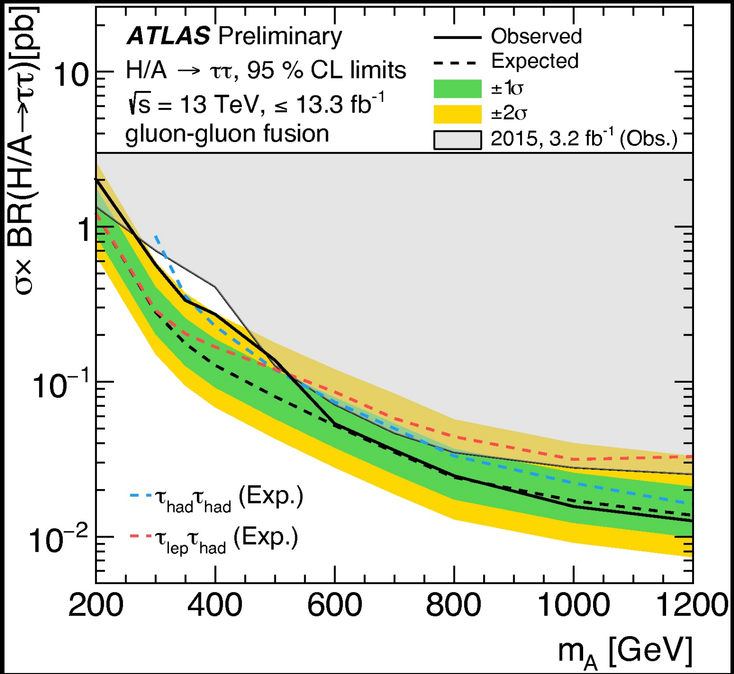
Multi-jet, $t\bar{t}$ are the main backgrounds of the had-had channel.

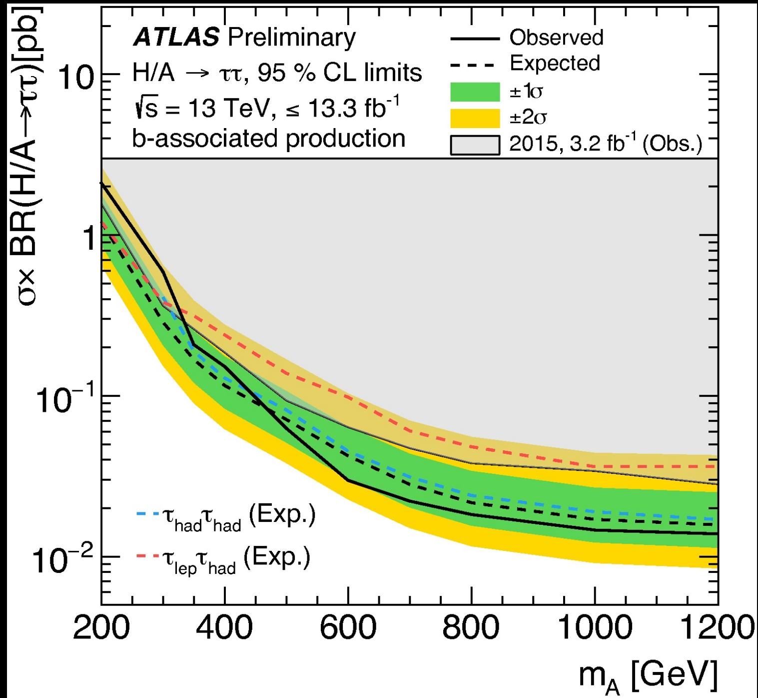
- FF is parameterised as a function of p_T ratio of two τs and n-tracks of sub-leading τ in multi-jet control region to estimate fake $\tau_{\text{had-vis}}$. Control region is defined with leading $\tau_{\text{had-vis}}$ p_T > 100 GeV and fails "medium" ID. Requirements on n_{tracks} = 1,3, p_T ratio > 0.3.
- In $t\bar{t}$ and *W*+jets, probability of jet being misidentified as $\tau_{\text{had-vis}}$ modelled in fake rate control region for *b*-tag and *b*-veto category separately. This b-tag category fake factor is applied in $t\bar{t}$ simulated events and *b*-veto category to the other process.
- Same sign region is enriched with events where at least one jet is misidentified as $\tau_{\textit{had-vis}}$ and both τs have same sign.

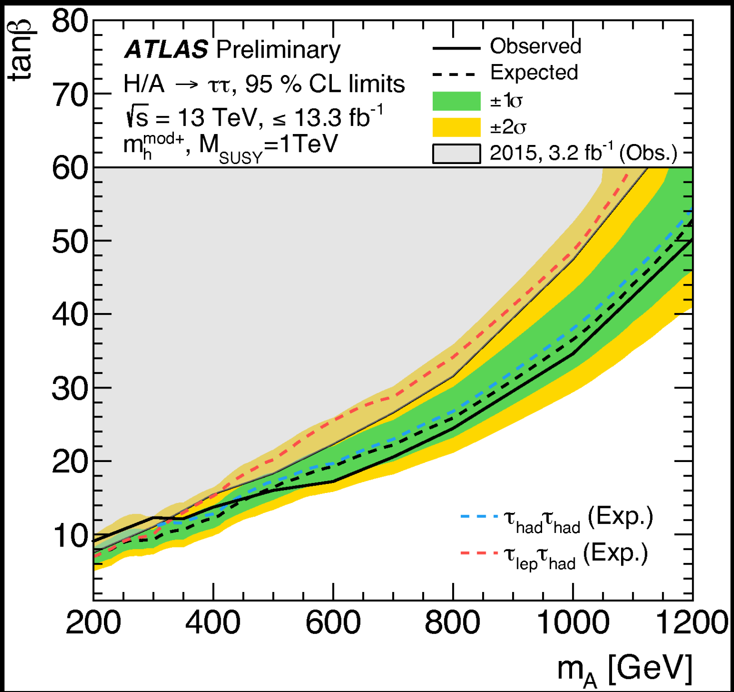




LIMITS ON MSSM NEUTRAL HIGGS PRODUCTION



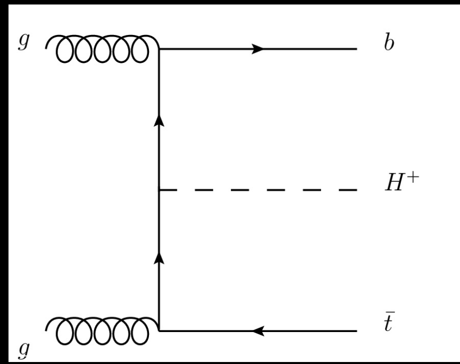


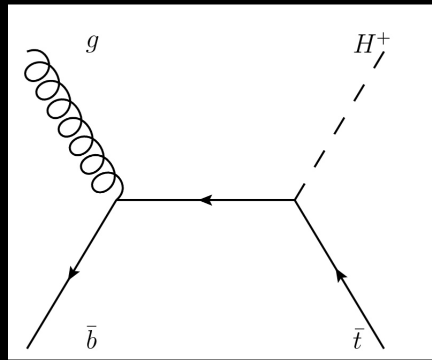


- The lowest excluded cross section × BR values are 2 pb at 200 GeV and .013 pb at 1200 GeV in ggF.
- The lowest excluded cross section × BR values are 2.1 pb at 200 GeV and .014 pb at 1200 GeV *b* associated production mode.
- Limits are interpreted in different MSSM scenario i.e m_h^{mod+}.

SEARCH FOR CHARGED HIGGS BOSON IN $H^+ \longrightarrow \tau\nu$ FINAL STATE AT 13TEV

- In MSSM , production of charged Higgs and its decay depend on the parameters tanβ and mass of charged Higgs m_H^+ .
- Branching fraction of $H^+ \rightarrow \tau\nu$ can reach 10-15% at large tanβ value.
- For $m_H^+ > m_t$, the main production of H^+ at the LHC is expected to be in association with top quark.
- This analysis considers hadronic decay of τ arising from H^+ , hadronic decay of top quark, as well as absence of high-transverse-momentum of e or μ.





Charged Higgs Production

$pp \rightarrow [b]tH^+ \rightarrow [b](jjb)(\tau_{had}\nu)$

EVENT SELECTION

- Events are selected by E_T^{miss} > 70 (90) GeV for 2015(2016) data.
- One $\tau_{\text{had-vis}}$ candidate with $p_T > 40$ GeV.
- Three or more jets $p_T > 25$ GeV, at least one b-tag jet.
- No e (μ) of E_T (p_T) > 20 GeV.
- $E_T^{miss} > 150$ GeV.
- Discriminating variable:

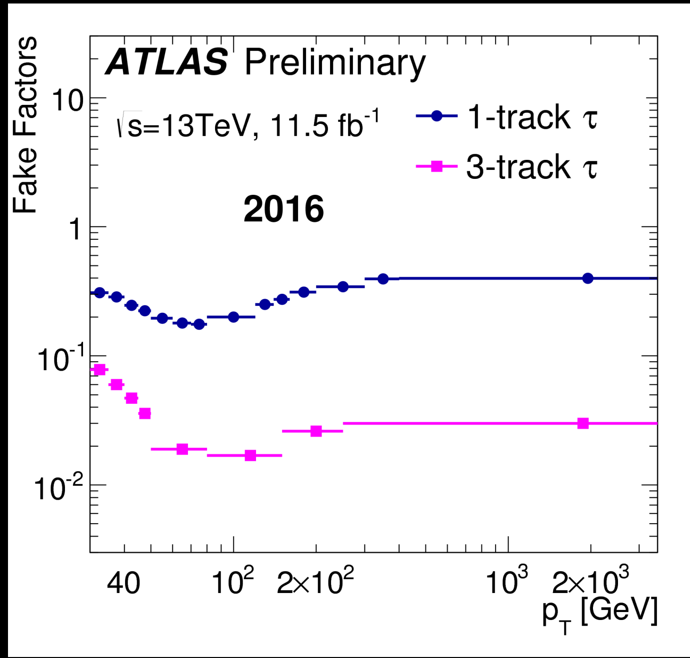
$$m_T(\tau, E_T^{miss}) \equiv \sqrt{2p_T(\tau)E_T^{miss}\,(1 - \cos\Delta\varphi(\tau, E_T^{miss}))}$$

- $m_T > 50$ GeV, to reject events where $\tau_{\text{had-vis}}$ is nearly aligned along E_T^{miss} .

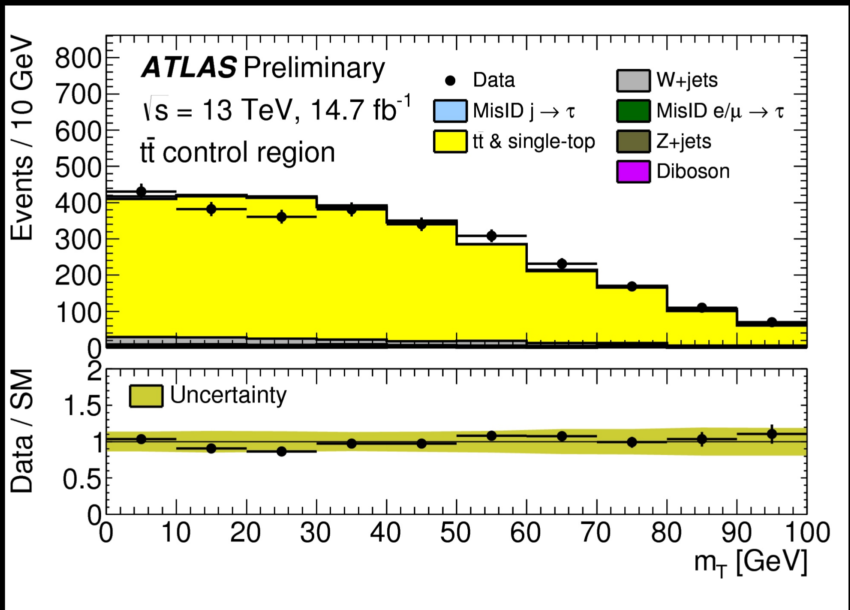
BACKGROUND CONTROL REGION

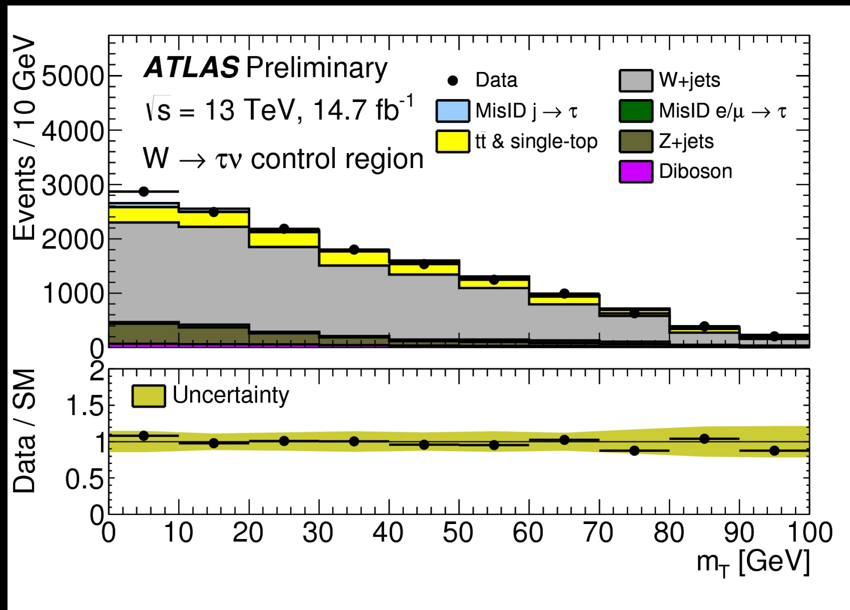
$t\bar{t}$, single t, W+ jets, Z/γ +jets, diboson, multi-jets are main backgrounds.

- jets → $\tau_{\text{had-vis}}$, is estimated from data using fake factor from a control region having selections as the signal region except E_T^{miss} <80 GeV and zero b-tag .
- Fake Factor: $$N_{\text{fakes}}^{\tau_{\text{had-vis}}} = \sum_i N_{\text{anti}-\tau_{\text{had-vis}}}(i) \times \text{FF}(i)$$
- Background arising from μ/e misidentified as $\tau_{\text{had-vis}}$ is estimated from simulation $t\bar{t}$, single top, W/Z+jets, diboson with correction from data.
- Backgrounds having true τ_{had} are dominated by $t\bar{t}$, $W\rightarrow\tau\nu$ process and estimated from simulation and validated in two different control regions. They have same selection like signal region except m_T <100 GeV and divided in b-tag and b-veto region (figures below).

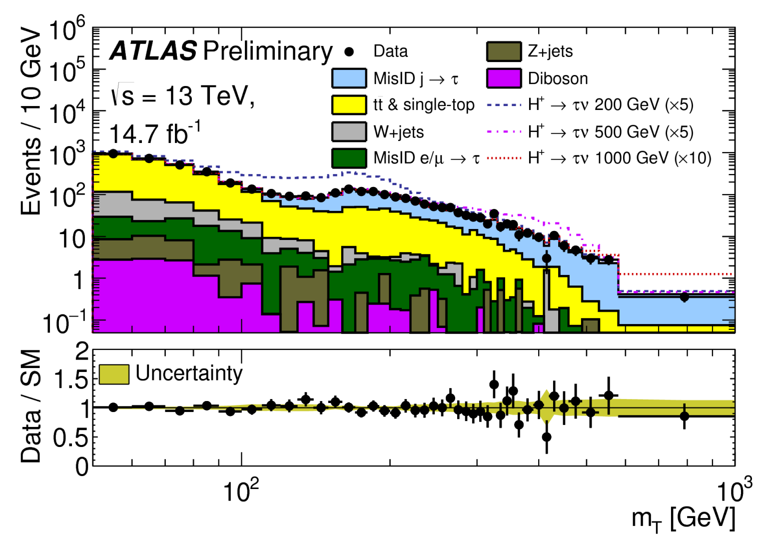


Fake factor as a function of τ p_T

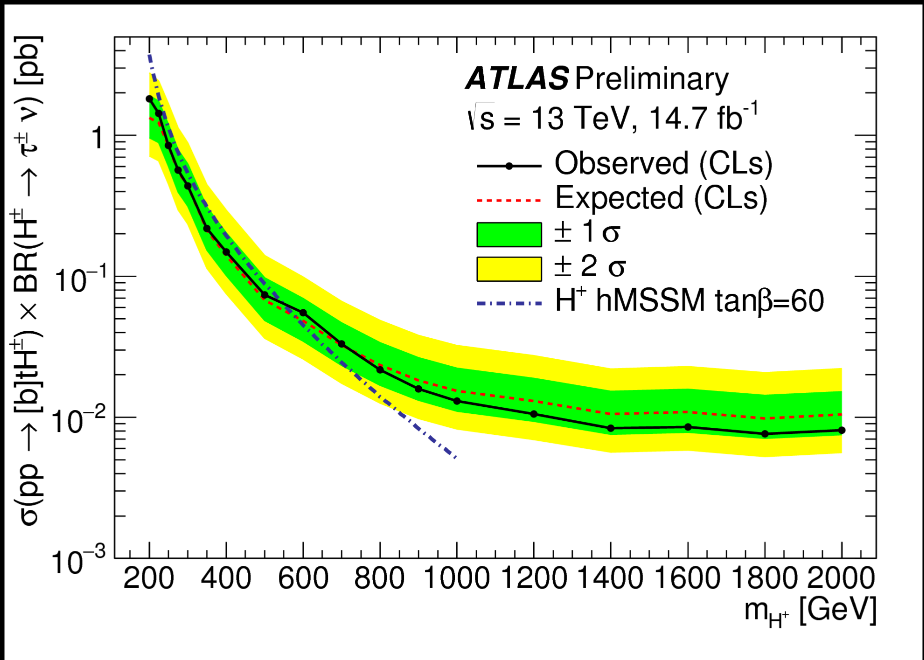


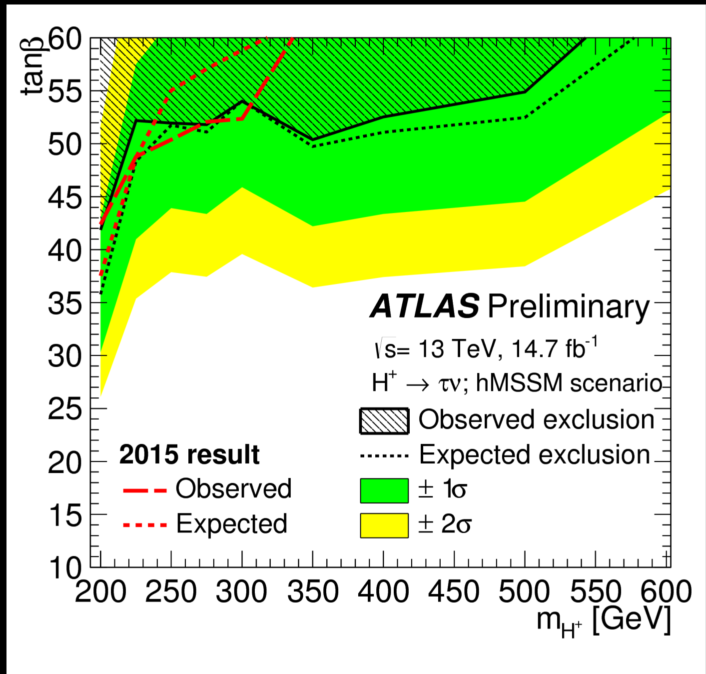


LIMITS ON MSSM CHARGED HIGGS PRODUCTION



Major systematic uncertainties are $\tau_{\text{had-vis}}$ identification and energy scale uncertainty, $t\bar{t}$ background modelling and estimation of background where jets are misidentified as $\tau_{\text{had-vis}}$.





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- Performance of *b*-jet identification in the ATLAS experiment.https://arxiv.org/abs/1512.01094
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