Search for heavy neutral Higgs bosons in $\tau\tau$ final states

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On behalf of the analysis team

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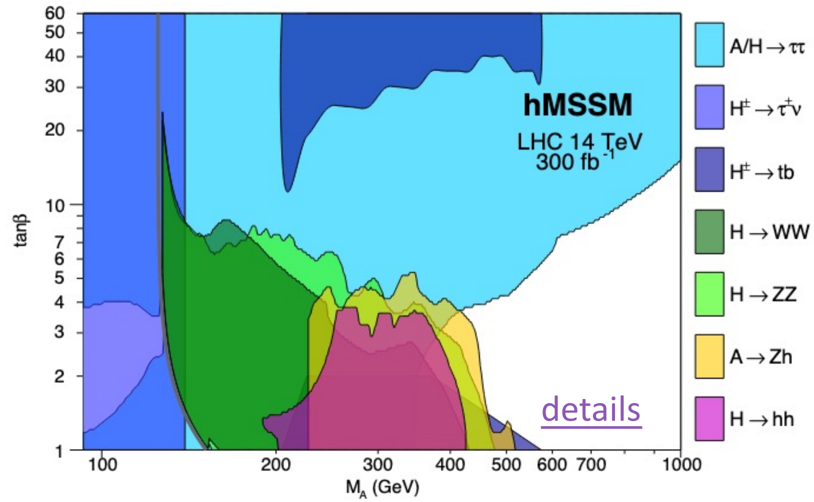
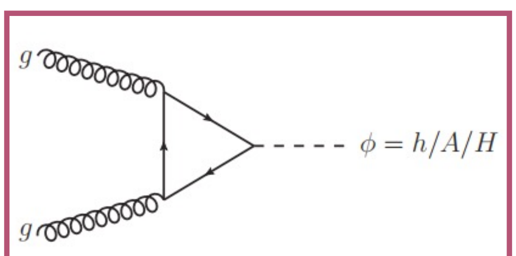
Introduction

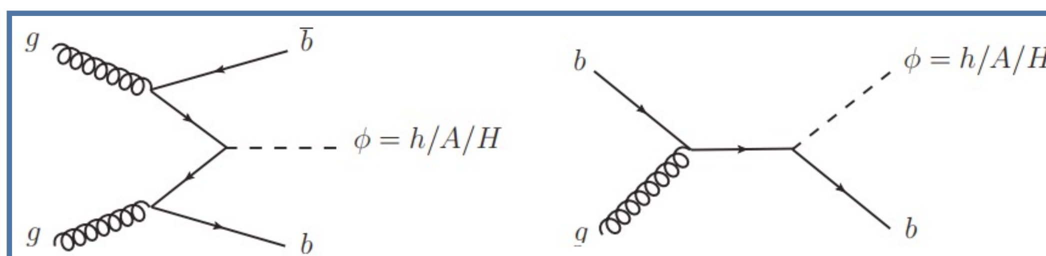
PRL 125, 051801

- 2HDMs extend the Higgs sector of the SM and predict additional neutral and charged Higgs bosons:
  - h, H, A, $H^{\pm}$
  - MSSM is a concrete realization of 2HDM.
- At tree level, described by
  - m_A and $\tan\beta$
  - At large $\tan\beta$, coupling to τ enhanced.
- Search for H/A in $\tau\tau$ final states.
  - Dominant sensitivity at the most of the parameter space.
  - Gluon-gluon fusion and b-associated production.



Run2 @ 13 TeV
$\mathcal{L} = 139$ fb^{-1}





Analysis methodology

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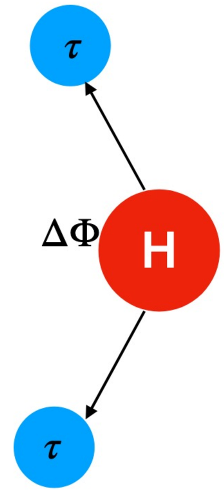
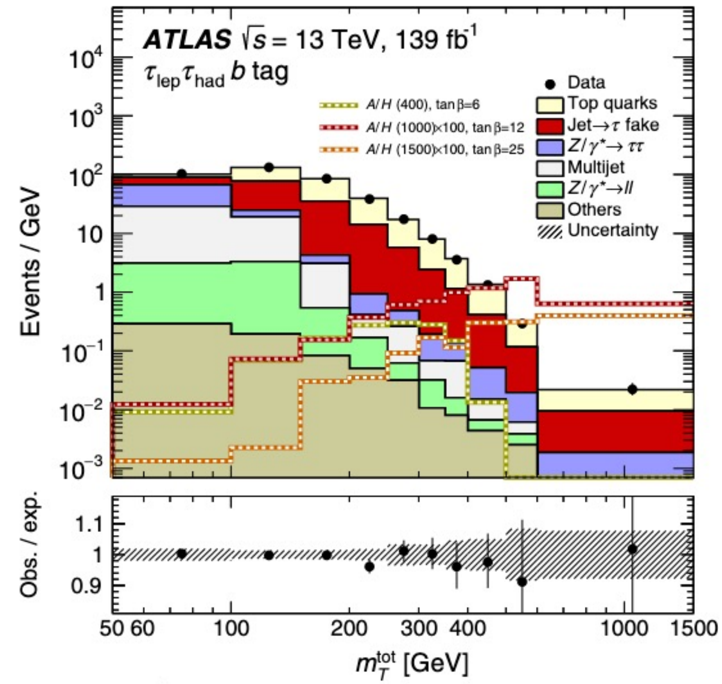


- Two channels:
  - $\tau_{lep}\tau_{had}$ (46%)
  - $\tau_{had}\tau_{had}$ (42%)
- Two categories: b-tag ($N_{bjets} \geq 1$) and b-veto ($N_{bjets} = 0$).
- Range of m_{ϕ}: from 200 GeV to 2500 GeV.
- Signal topology: two back-to-back and opposite-charged τ-leptons.
- Main backgrounds:
  - True τ events: modeled by MC simulation.
  - Fake τ events: estimated by the data-driven method.
- Discriminant variable: total transverse mass.



$$m_{\mathrm{T}}^{\mathrm{TOT}} = \sqrt{m_{\mathrm{T}}^2(\tau_1, E_{\mathrm{T}}^{\mathrm{miss}}) + m_{\mathrm{T}}^2(\tau_2, E_{\mathrm{T}}^{\mathrm{miss}}) + m_{\mathrm{T}}^2(\tau_1, \tau_2)}$$

Event selections

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$\tau_{lep}\tau_{had}$

- Single lepton trigger
- $p_T^l > 30$ GeV, $p_T^\tau > 25$ GeV
- At least one isolated lepton, and medium BDT-based Tau ID WP.
- Opposite sign between l and τ.
- $\Delta\phi(l,\tau) > 2.4$
- Suppress W+jets: $m_T\left(l, E_T^{miss}\right) <$ 40 GeV.
- Suppress $Z \rightarrow ee$: visible mass not in [80,100] GeV.

$\tau_{had}\tau_{had}$

- Single τ_{had} trigger
- $p_T^{\tau_1} > 85/130/185$ GeV, $p_T^{\tau_2} > 65$ GeV
- Medium (for τ_1) and loose (for τ_2) BDT-based Tau ID WP.
- Opposite sign between $\tau_1$and τ_2.
- $\Delta\phi(\tau_1,\tau_2) > 2.7$
- Veto leptons

Overview of background estimation

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Type I: real τ_h or lepton faking τ_h

$Z/\gamma* \to \tau\tau$ (b-veto) $t/t\bar{t}$ (b-tag) Diboson	real τ_h	MC simulation with data driven corr.
$Z/\gamma* \to l^+l^-(\tau_{\text{lep}}\tau_{\text{had}})$	lepton faking τ_h	

Type II: one jet faking τ_h

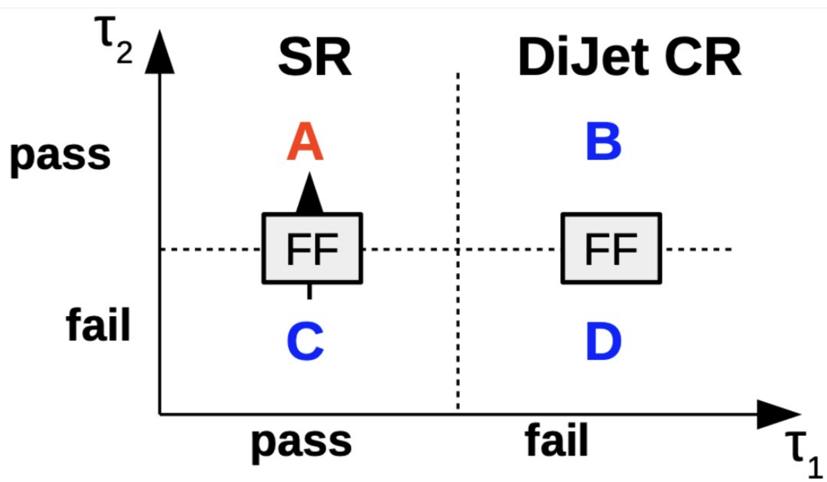
W+jets (b-veto) $t/t\bar{t}$ (b-tag)	jet faking τ_h	Data driven method (FF/FR)

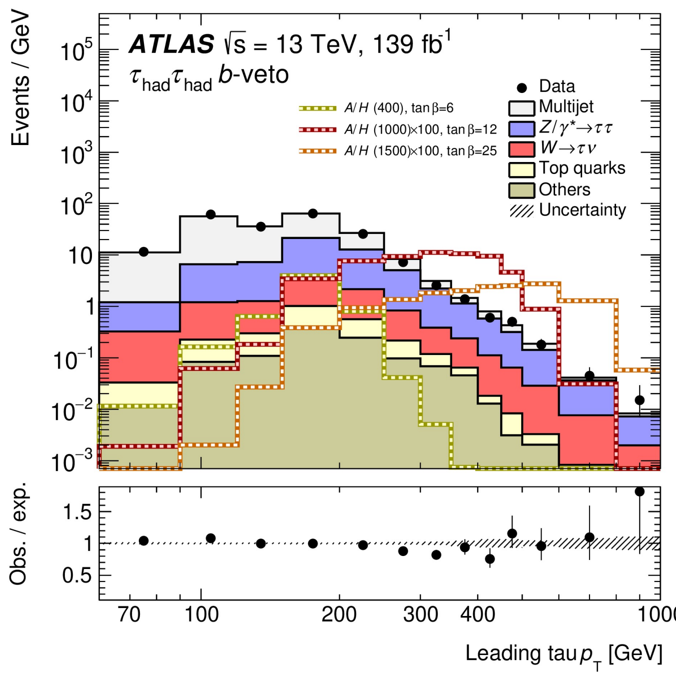
Type III: two jets faking l/τ_h

Multijet	jet faking l and τ_h	Data driven method (FF)

Fake estimation in $\tau_{had}\tau_{had}$

- Multi-jet fakes in SR (region A) is estimated from region C by applying a transfer factor, named as fake factor (FF).
- Defined as: $$f_{\tau-\mathrm{ID}}(p_{\mathrm{T}}, N_{\mathrm{track}}) \equiv \left.\frac{N^{\mathrm{pass}\ \tau-\mathrm{ID}}(p_{\mathrm{T}}, N_{\mathrm{track}})}{N^{\mathrm{fail}\ \tau-\mathrm{ID}}(p_{\mathrm{T}}, N_{\mathrm{track}})}\right|_{\mathrm{di-jet}}$$
- Calculated in a background-enriched region (DiJet CR).
- a cut of 0.03 on BDT score is applied to make DiJet CR similar to SR.





Fake estimation in $\tau_{had}\tau_{had}$

- The processes with largest contribution of jet faking τ are W+jet ($t\bar{t}/t$) events.
- Fake rate method is used to estimate these fake τ backgrounds.
- A control region is defined to measure fake rates:
  - Tag lepton: single muon trigger, $p_T(\mu) > 55$ GeV, pass medium lepton ID, isolated
  - Probe τ: only $p_T(\tau) > 50$ GeV
  - $\Delta\varphi(\mu, \tau\ ) > 2.4$
- Fake rates are binned in τ_{had} p_T, the number of associated tracks of τ_{had} and the charge product of μ and τ_{had}.

$$FR_{\tau\text{-ID}}(p_\mathrm{T}, N_\mathrm{track}) \equiv \left.\frac{N^{\mathrm{pass}\ \tau\text{-ID}}(p_\mathrm{T}, N_\mathrm{track})}{N^{\mathrm{fail}\ \tau\text{-ID}}(p_\mathrm{T}, N_\mathrm{track}) + N^{\mathrm{pass}\ \tau\text{-ID}}(p_\mathrm{T}, N_\mathrm{track})}\right|_{\mathrm{W}(\to\mu\nu)+\mathrm{jets\ Top}}$$

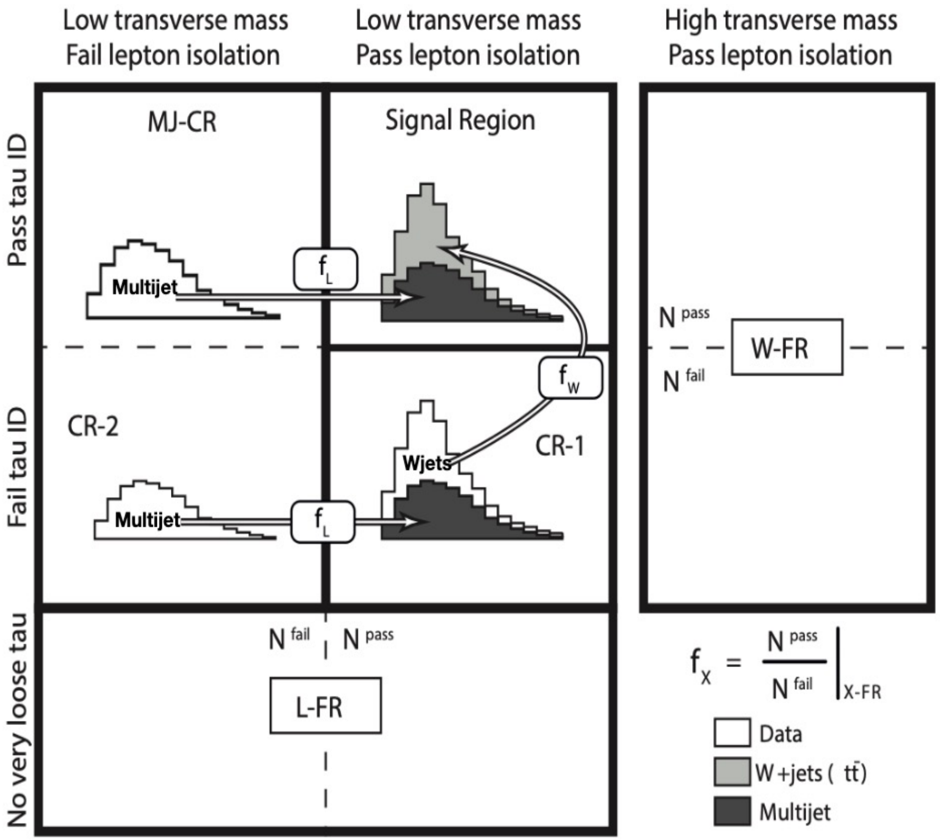
  - Determined by applying the ID requirement on probe τ candidates with Medium ID + Trigger or Loose ID WPs

Fake estimation in $\tau_{lep}\tau_{had}$

- Multi-jet events are estimated by lepton fake factors (LFFs).
- LFFs: derived from lepton fake regions (LFRs).

$$FF = \frac{N(\text{pass "gradient" lepton isolation})}{N(\text{fail "gradient" lepton isolation})}$$

- Fake τ events are estimated by τ fake factors.
- τ fake factors: derived from W fake regions (WFRs).



$$\mathrm{FF}^{W+\text{jets}} = \frac{N(\text{pass "medium" tau ID})}{N(\text{fail "medium" tau ID and jet BDT score} > 0.01)}$$

Systematic uncertainties

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Source	ggF (400 GeV)	ggF (1 TeV)	bbH (400 GeV)	bbH (1 TeV)
Tau id. efficiency	0.14	0.16	0.12	0.08
Tau energy scale	0.33	0.09	0.22	0.03
Z+jets bkg. modeling	0.27	0.19	0.08	0.04
Mis-id. $\tau_{\text{had-vis}}$ bkg.	0.22	0.01	0.14	0.03
Others	0.09	0.04	0.11	0.02
Total	0.54	0.28	0.45	0.13

- Low mass:
  - ggF: dominant backgrounds are Z+jets and fakes.
  - bbH: dominant backgrounds are $t\bar{t}$ and fakes.
- High mass:
  - ggF: some contribution from Z+jets, signal efficiency becomes more important.
  - bbH: almost background-free, signal efficiency is the most important.

Upper limits

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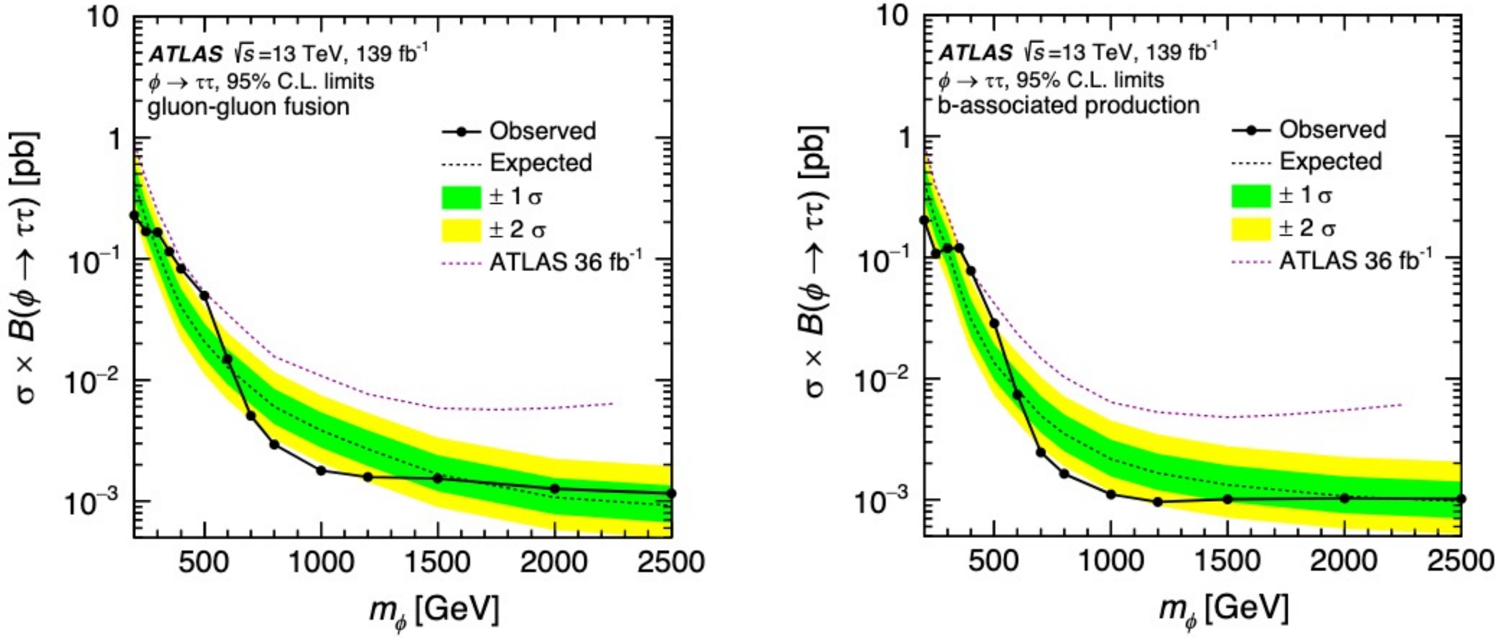

- No significant excess in data is seen.
- Compared to the previous results, upper limits are improved by a factor of 4-5 in the mass range of 700-2500 GeV.

Interpretation

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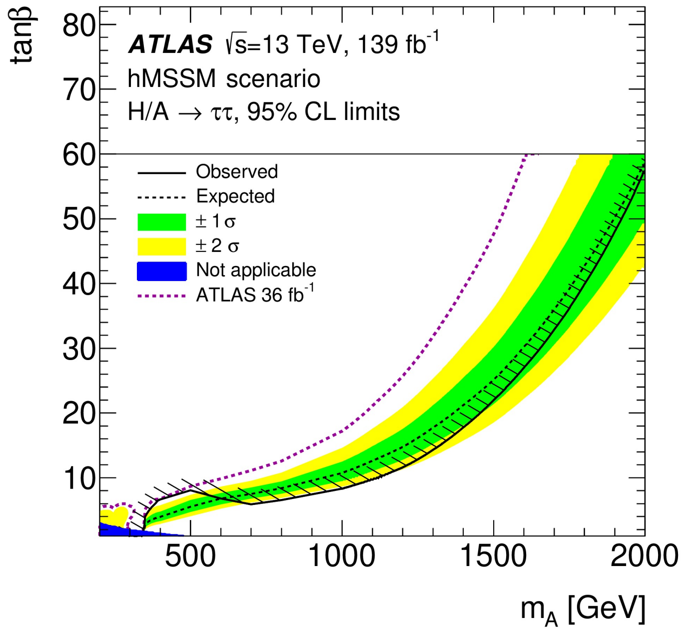
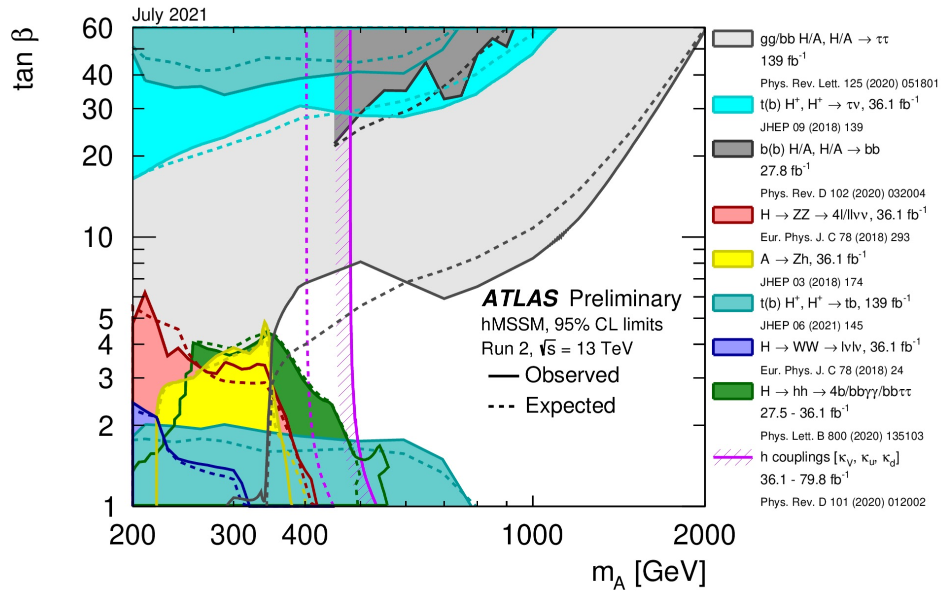




- Results are interpreted in different scenarios, e.g. hMSSM.
- Dominant contribution at high m_A and $\tan\beta$.

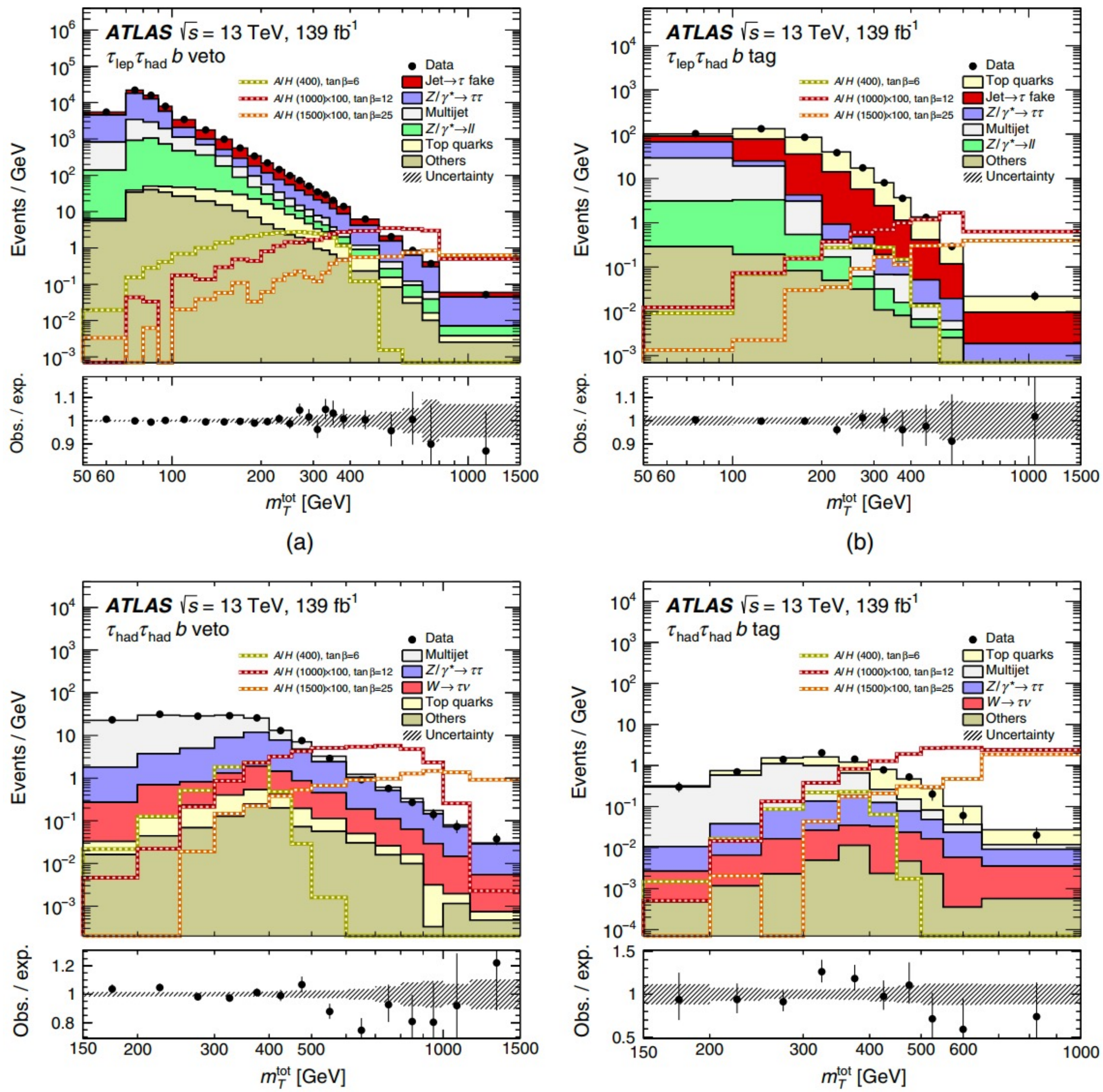
Summary

- This talk summarizes the latest search for heavy neutral Higgs bosons in $\tau\tau$ final states.
- No significant excess in data is seen.
  - Compared to the previous results, upper limits are improved by a factor of 4-5 at the high mass range.
- Results are also interpreted in different scenarios, like hMSSM.
- Significant update of constraints on BSMs.

Thanks for listening!

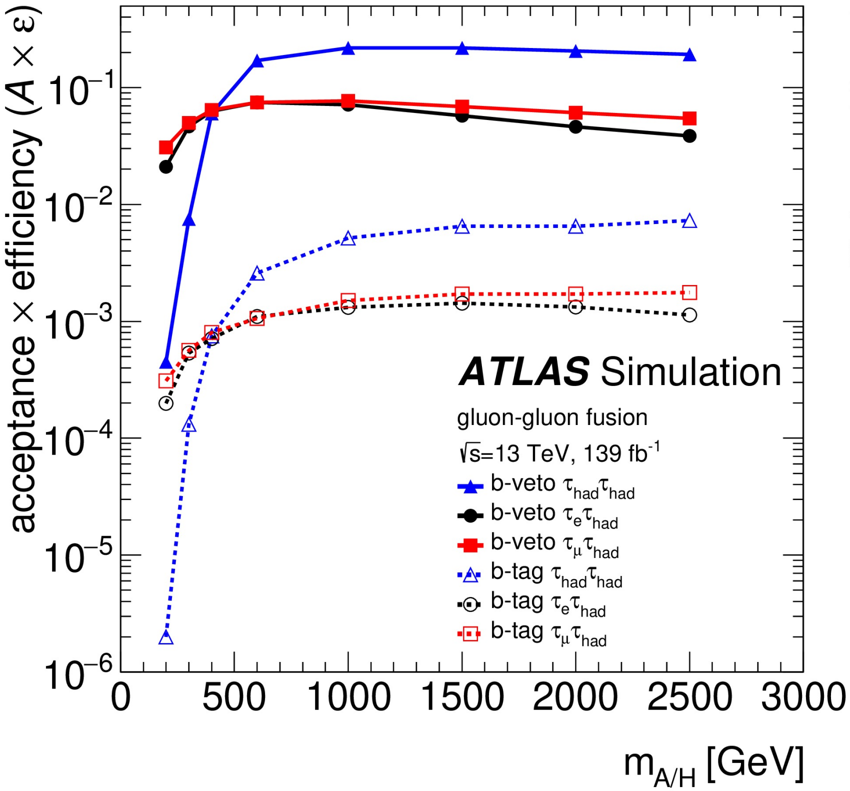
Backups

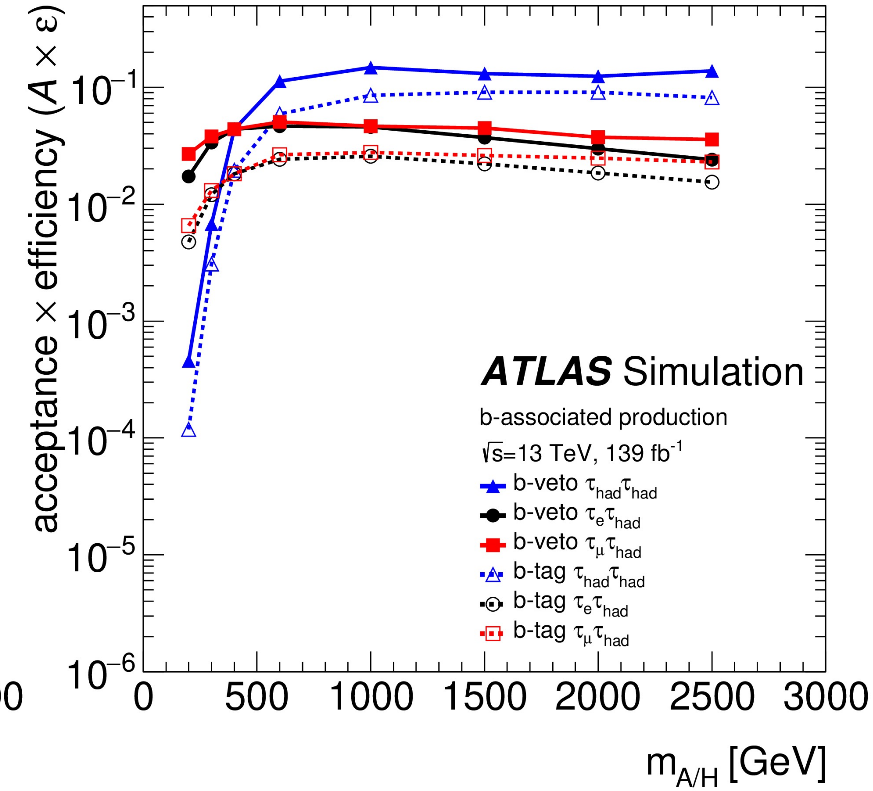
Post-fit plots



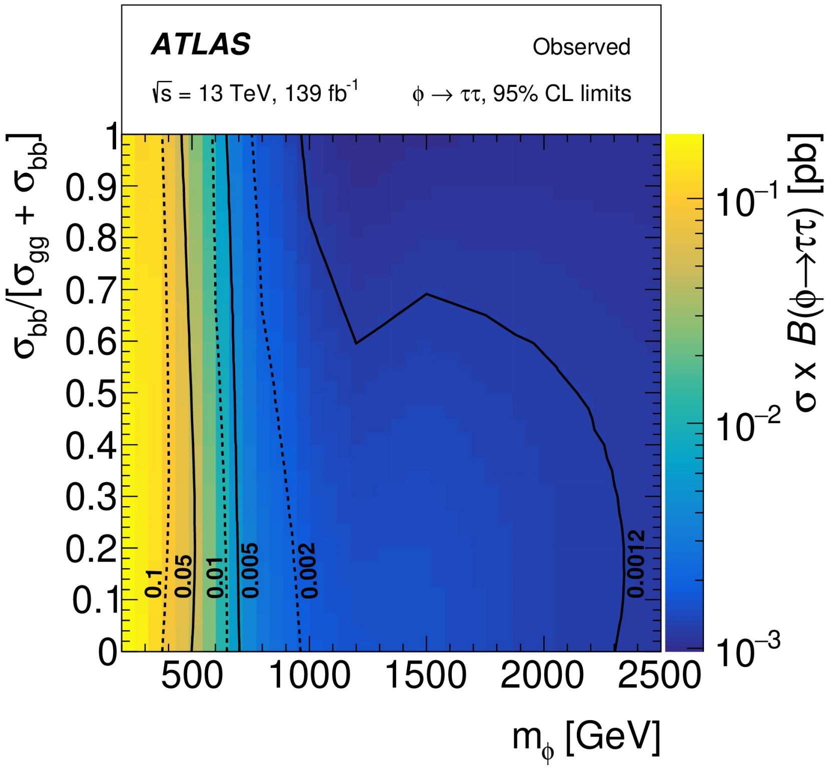
(a) (b) (c) (d)

Acceptance times efficiency

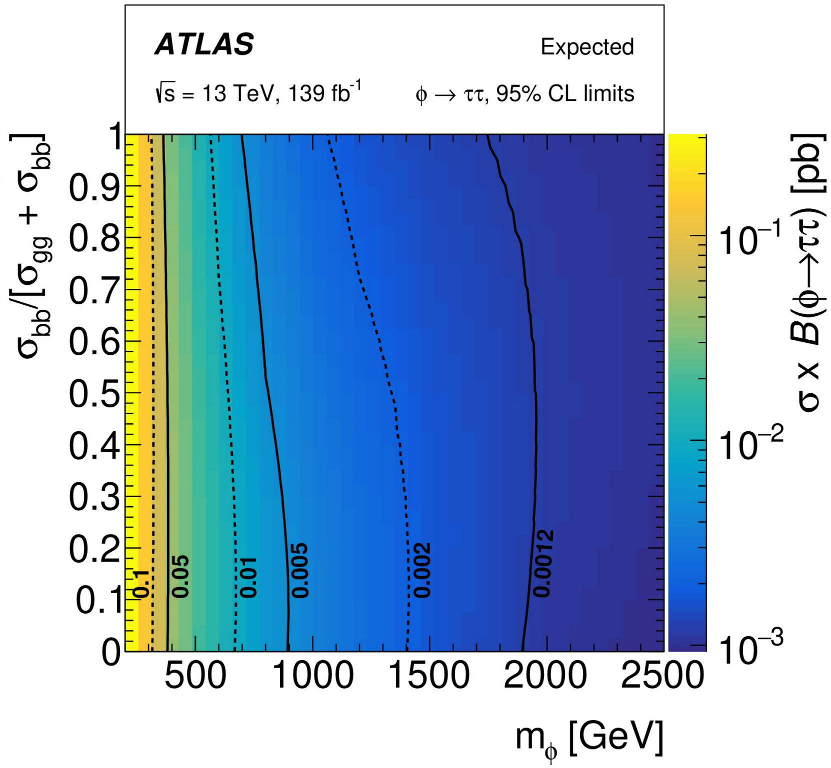




2D limits

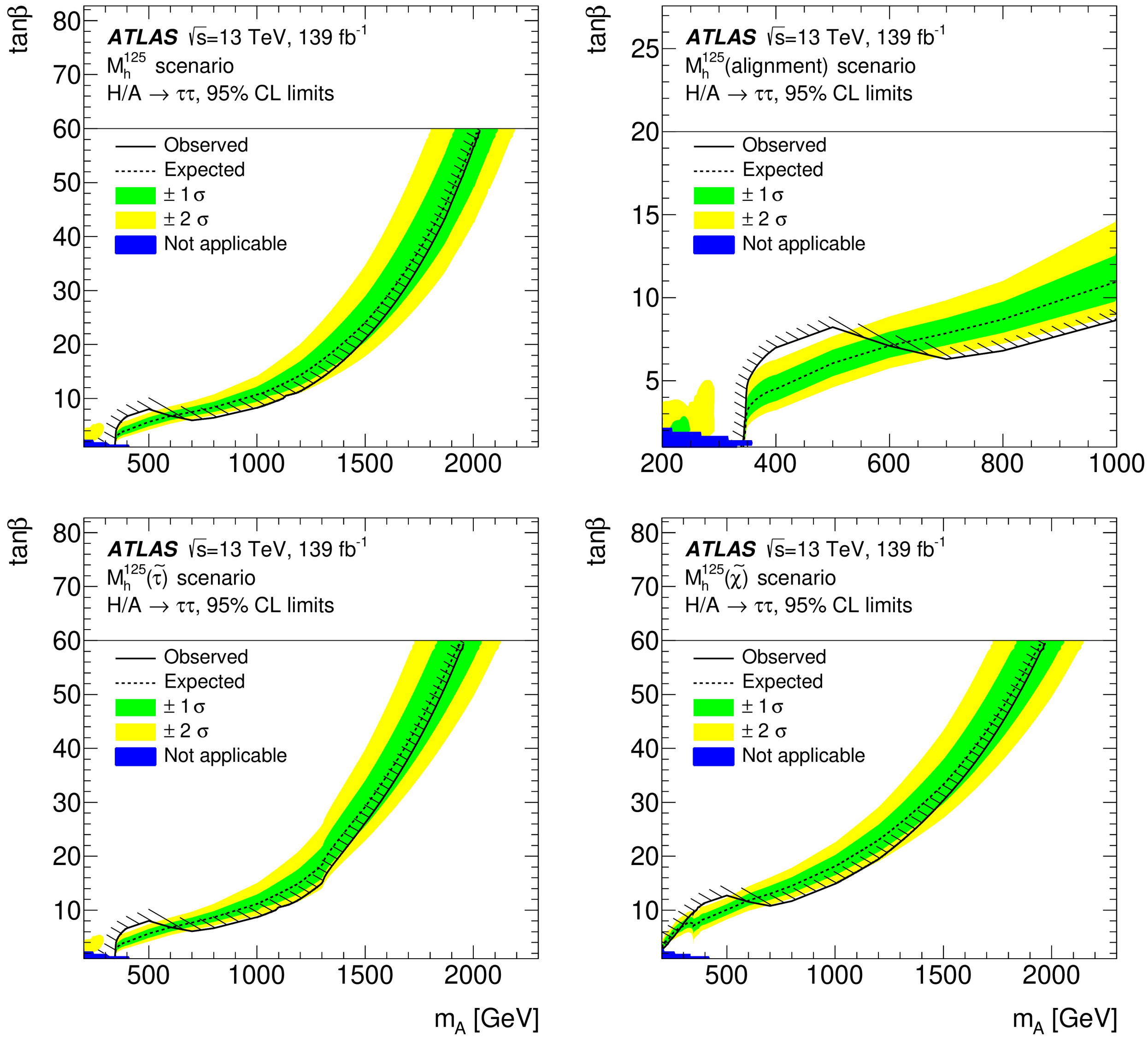


ATLAS
Observed
$\sqrt{s}$ = 13 TeV, 139 fb^{-1}
$\phi \rightarrow \tau\tau$, 95% CL limits
$\sigma_{bb}/[\sigma_{gg} + \sigma_{bb}]$
$\sigma \times B(\phi\rightarrow\tau\tau)$ [pb]
m_ϕ [GeV]
0.1
0.05
0.01
0.005
0.002
0.0012



ATLAS
Expected
$\sqrt{s}$ = 13 TeV, 139 fb^{-1}
$\phi \rightarrow \tau\tau$, 95% CL limits
$\sigma_{bb}/[\sigma_{gg} + \sigma_{bb}]$
$\sigma \times B(\phi\rightarrow\tau\tau)$ [pb]
m_ϕ [GeV]
0.1
0.05
0.01
0.005
0.002
0.0012

Other interpretations



2D NLL Scan

- Observed two dimensional likelihood scans.
- Δ(NLL): the negative-log-likelihood (NLL) of the conditional fit to the observed data with σ_{gg} and σ_{bb} fixed to their values at the point and with the minimum NLL value at any point subtracted.