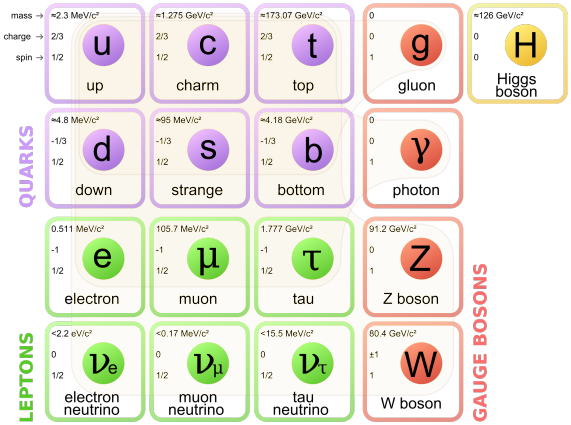
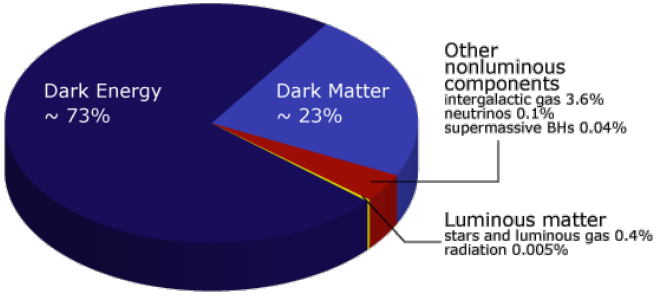
Based on results in
CERN-EP-2017-199 (arXiv:1709.07242)

Search for MSSM Higgs and Z' decaying to ττ at ATLAS



Lei Zhang



CLHCP in Nanjing, 22-24 Dec. 2017

Extended Higgs sector

Two-Higgs Doublets Model (2HDM)

- Minimum extension of Higgs sector
- Requested by MSSM, satisfies experimental constraints

MSSM as bench mark model

$$\phi_u = \begin{pmatrix} \phi_u^+ \\ \phi_u^0 \end{pmatrix}, \qquad v_u : \mathrm{VEV}_u$$

$$\phi_d = \begin{pmatrix} \phi_d^0 \\ \phi_d^- \end{pmatrix}, \qquad v_d : \mathrm{VEV}_d$$

$W^{+/-}$, Z

$$\mathbf{N_{dof} = 8 - 3 = 5}$$

5 Higgs bosons: $H^{+/-}$, A, H, h

- Two free parameters at tree level: m_A, $\tan\beta = v_u/v_d$

$$m_{H^\pm}^2 = m_A^2 + m_W^2$$

$$m_{H,\,h}^2 = \frac{1}{2}\left(m_A^2 + m_Z^2 \pm \sqrt{\left(m_A^2 + m_Z^2\right)^2 - 4 m_A^2 m_Z^2 \cos^2 2\beta}\right)$$

30% of m_h due to higher order corrections

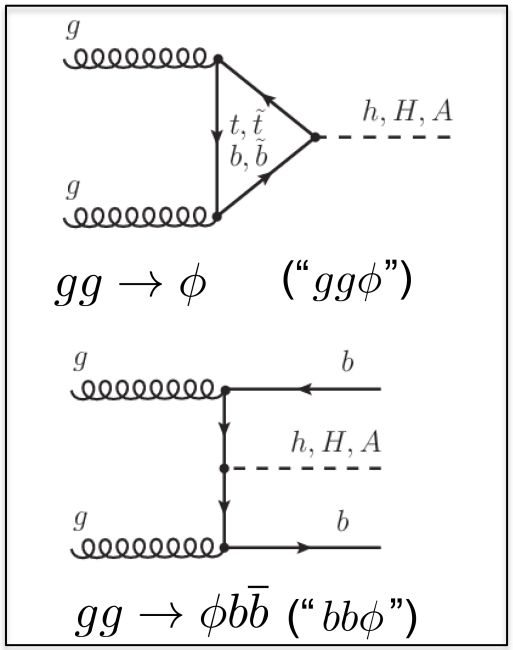
Neutral heavy Higgs bosons

Coupling strength:

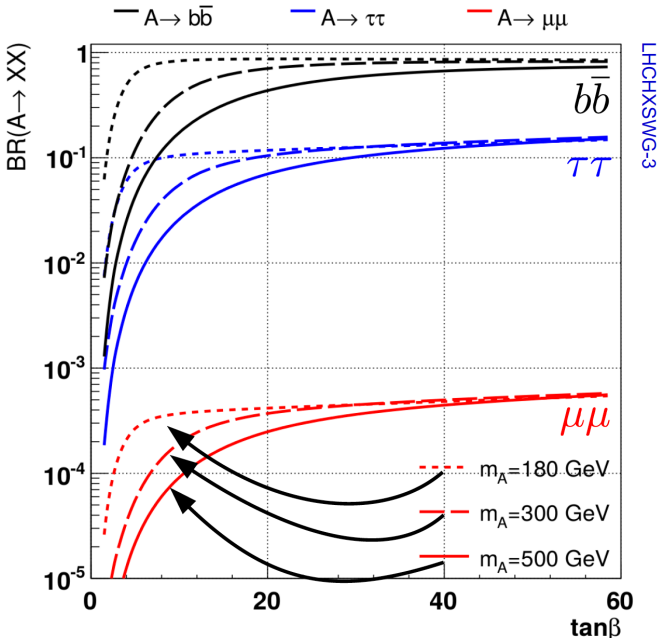
	g_{VV}/g_{VV}^{SM}	g_{uu}/g_{uu}^{SM}	g_{dd}/g_{dd}^{SM}
A	$-$	$\gamma_5 \cot\beta$	$\gamma_5 \tan\beta$
H	$\cos(\beta-\alpha) \to 0$	$\sin\alpha/\sin\beta \to \cot\beta$	$\cos\alpha/\cos\beta \to \tan\beta$
h	$\sin(\beta-\alpha) \to 1$	$\cos\alpha/\sin\beta \to 1$	$-\sin\alpha/\cos\beta \to 1$

For $m_A \gg m_Z$: $\alpha \to \beta - \pi/2$ (coupling to down-type fermions enhanced by $\tan\beta$).

Production modes:



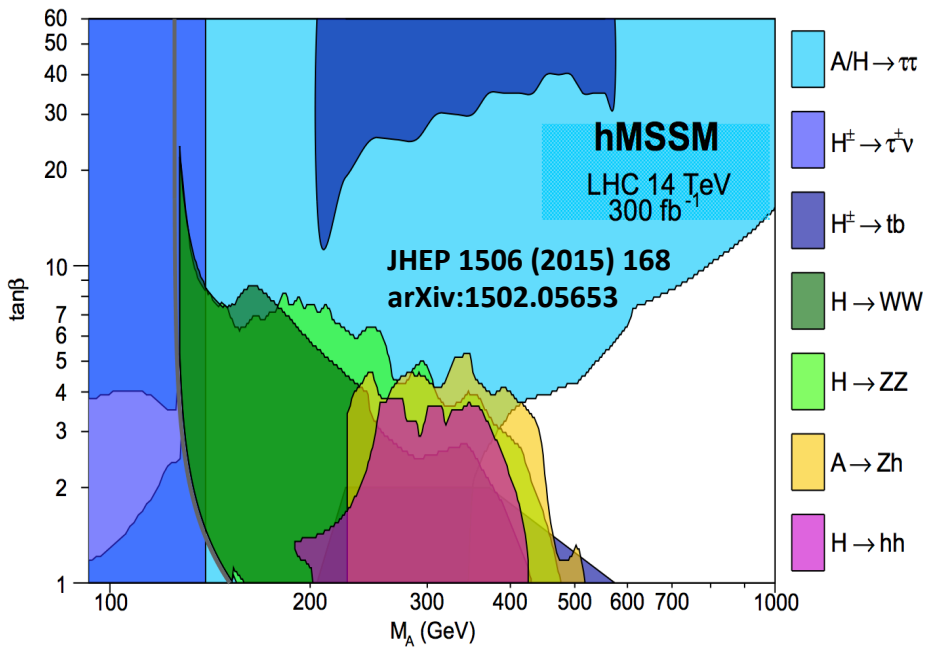
Decay channels:



Importance of the di-τ final state

Why τ is important

- Down-type, 3rd generation fermion and heaviest lepton
- Better experimental accessibility w.r.t. b quark
- Anomalies in B-factories, e.g. $B \to D^{(*)}\tau\upsilon$



Prospect study

- ττ has dominant sensitivity at most of parameter space

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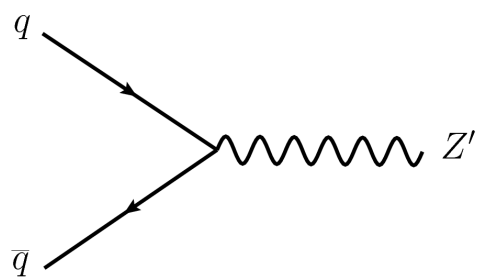

Extra gauge boson Z'

- Introduced in many BSM models with extended symmetry or extra dimension
- Benchmark model: Sequential SM (SSM) → Extra SM-like Z' boson
- $Z' \to \tau\tau$ is sensitive to scenarios, e.g. non-universal G(221) model, which favors the 3rd generation

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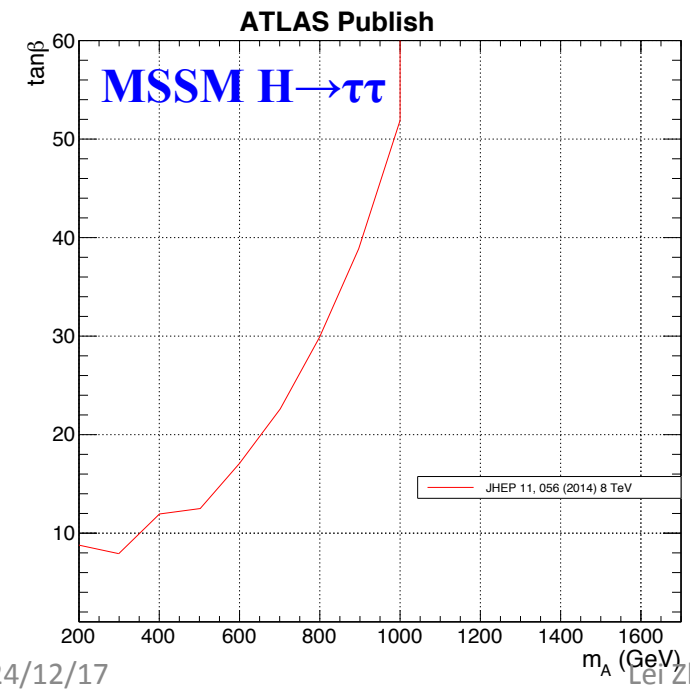
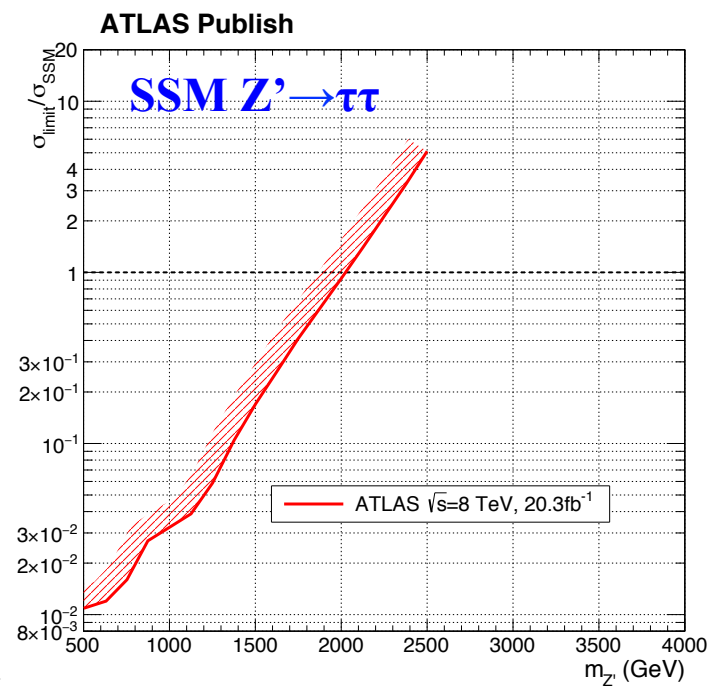
History of di-τ analyses @ ATLAS





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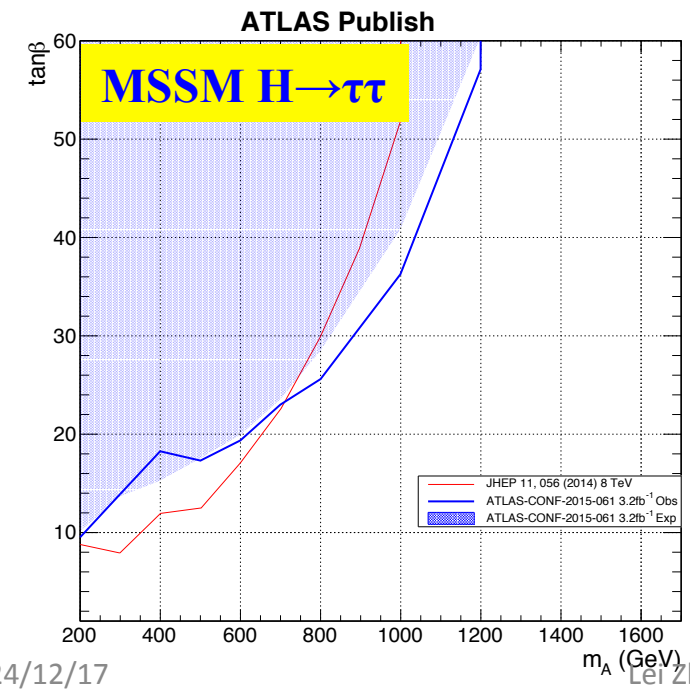

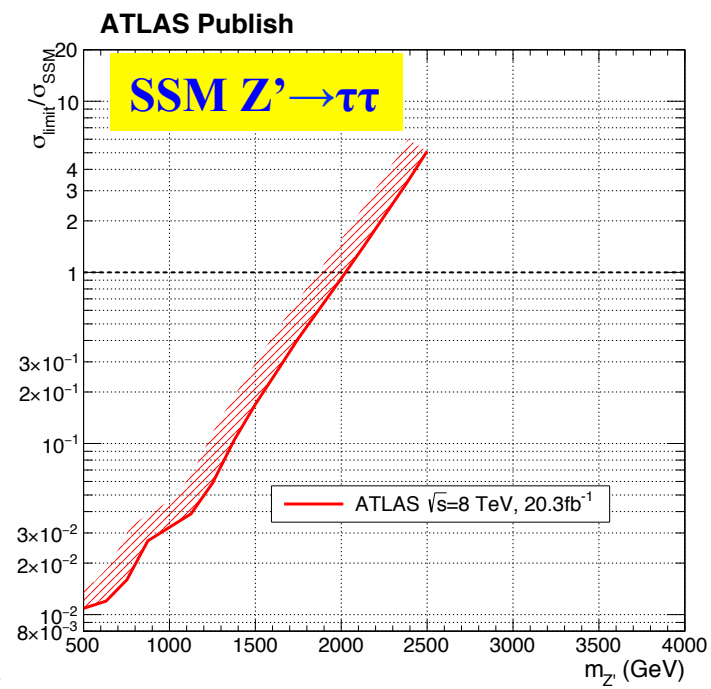

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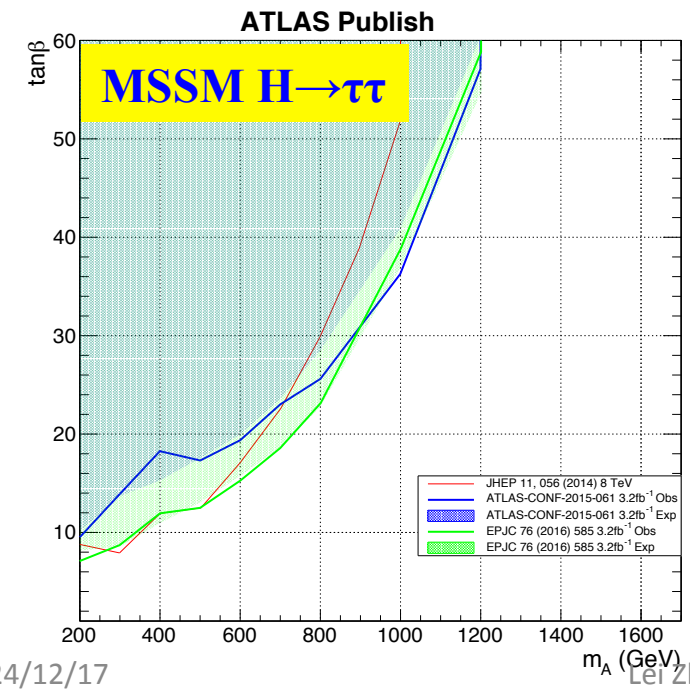

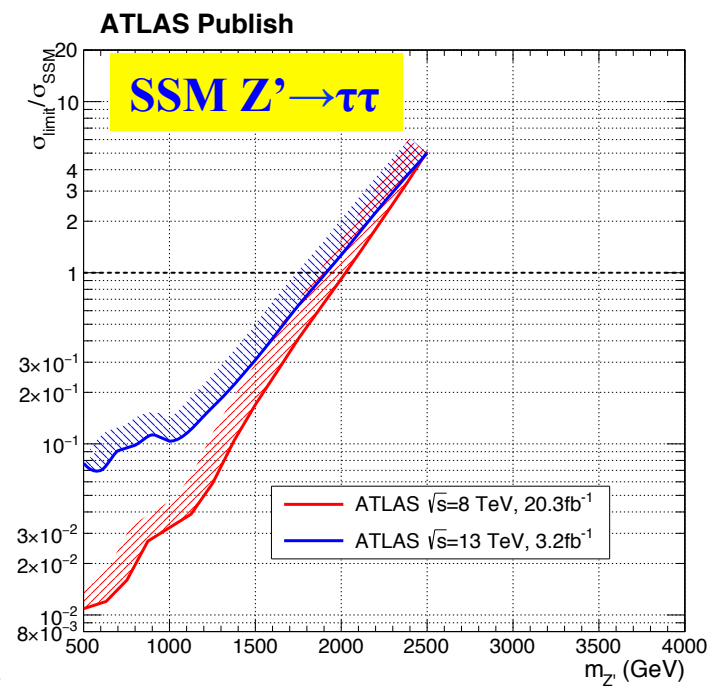

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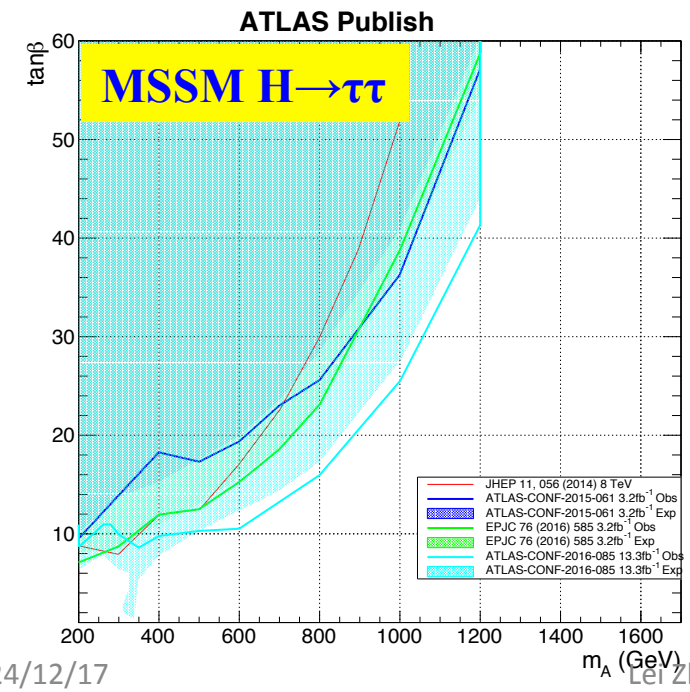

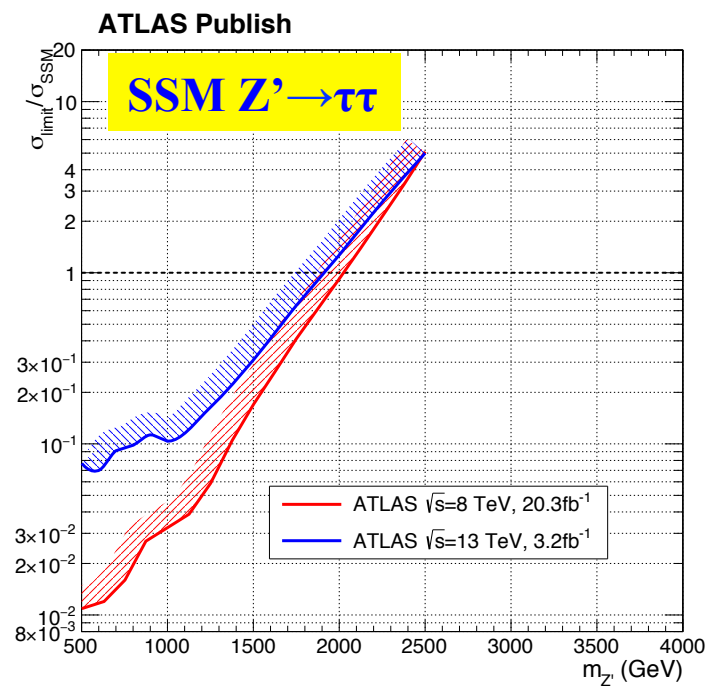

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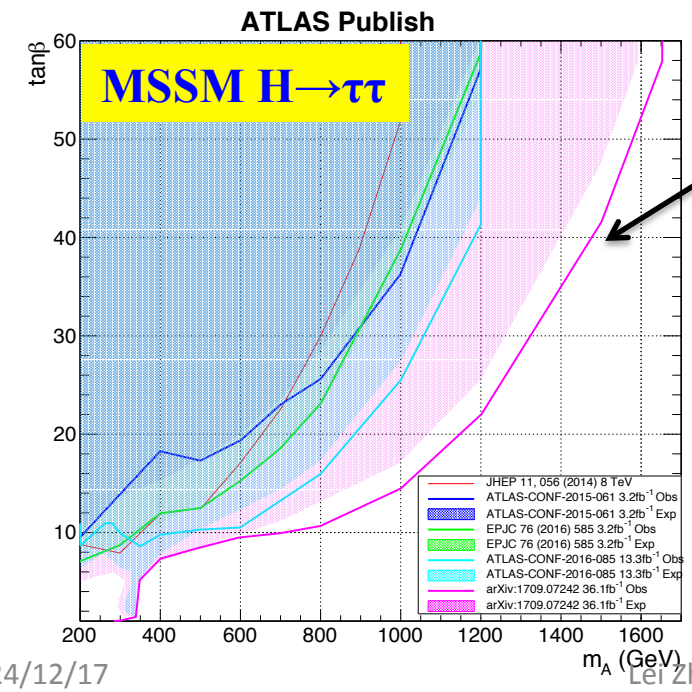
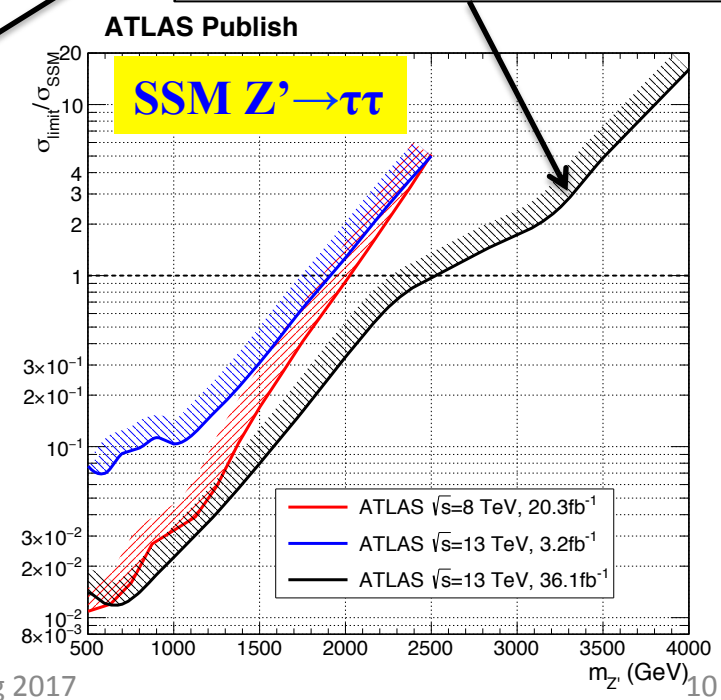
History of di-τ analyses @ ATLAS

Latest ATLAS result
(based on 36/fb@13TeV)

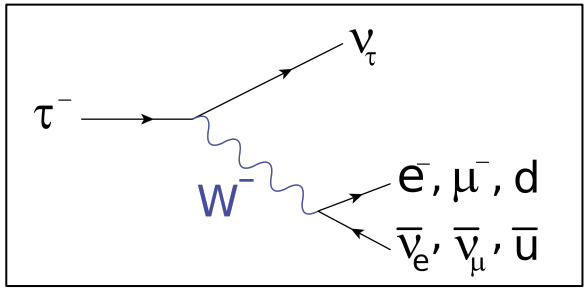




Analysis strategy overview

Selections

$\tau \rightarrow$hadrons (65%) or lepton(35%)



- $\tau_{had}\tau_{had}$ (42%): single tau trigger, $p_T(\tau_1)$>85/130/165 GeV, $p_T(\tau_2)$>65 GeV
- $\tau_{lep}\tau_{had}$ (46%): single e or μ trigger, $p_T(l/\tau_{had})$>30/25 GeV, $M_T(l, E_T^{miss})$<40 GeV
- Futher selection: opposite charge sign, $\Delta\Phi(l/\tau_{had}, \tau_{had})$>2.4/2.7
- Categorization: b-veto (b-tag) with 0 (≥1) b-tagged jet @ 70% eff.

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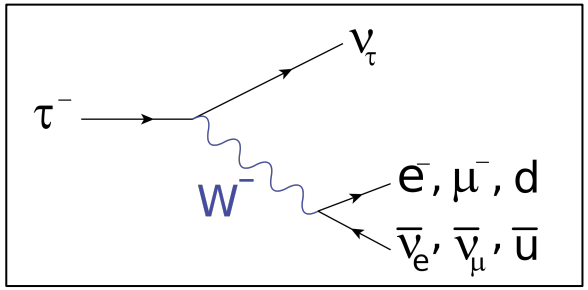

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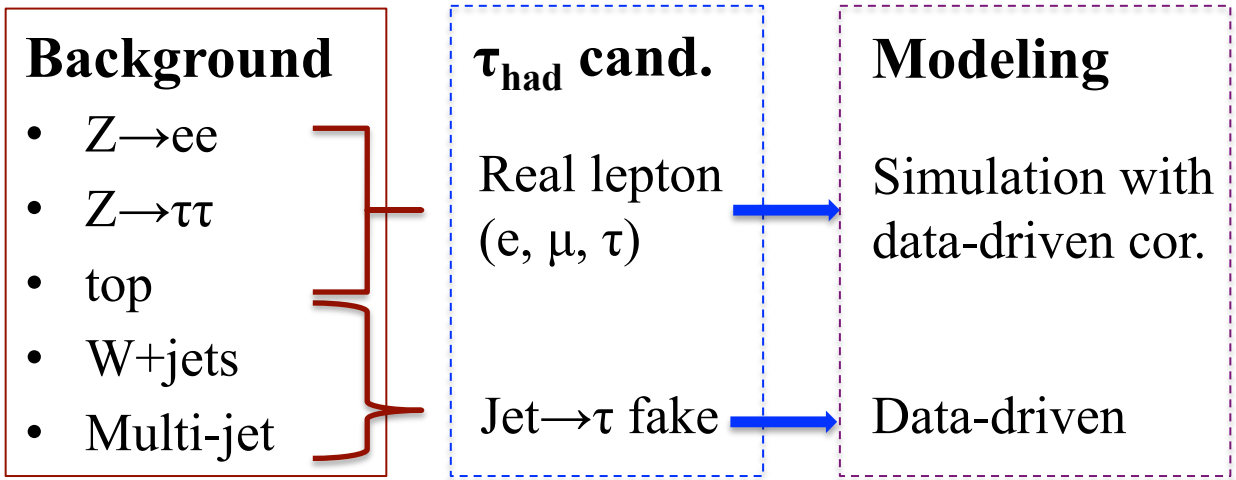
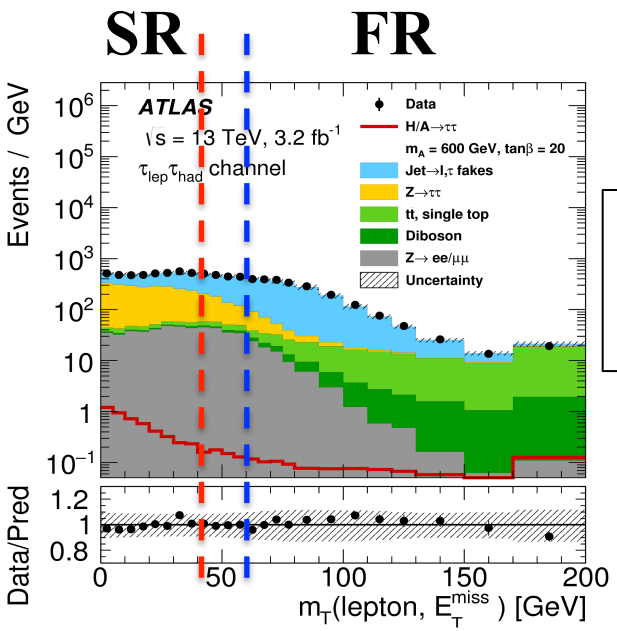
Background modeling



Jet fake τ_{had} estimation

- Simulation not suitable: modeling and sample size
- Fake Factor: $\mathbf{FF(n_{track}, p_T) = N_{pass}/N_{fail}}$
  - Measured in top, W+jets, Multi-jet enriched regions

FF Region (FR) definition



btag $\rightarrow$ $\mathbf{FR_{Top}}$

bveto $\rightarrow$ $\mathbf{FR_{W+jets}}$

$\mathbf{FR_{MJ}}$

- $\boldsymbol{\tau_{lep}\tau_{had}}$ **:** lepton fail isolation
- $\boldsymbol{\tau_{lep}\tau_{had}}$ **:** leading tau fail identification

EPJC 76 (2016) 585

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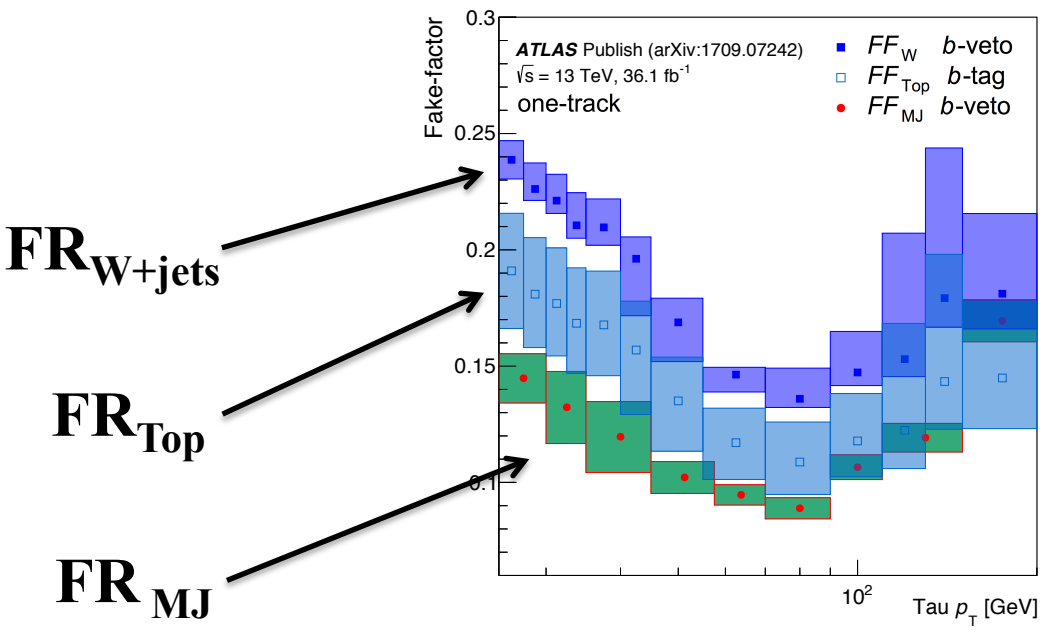

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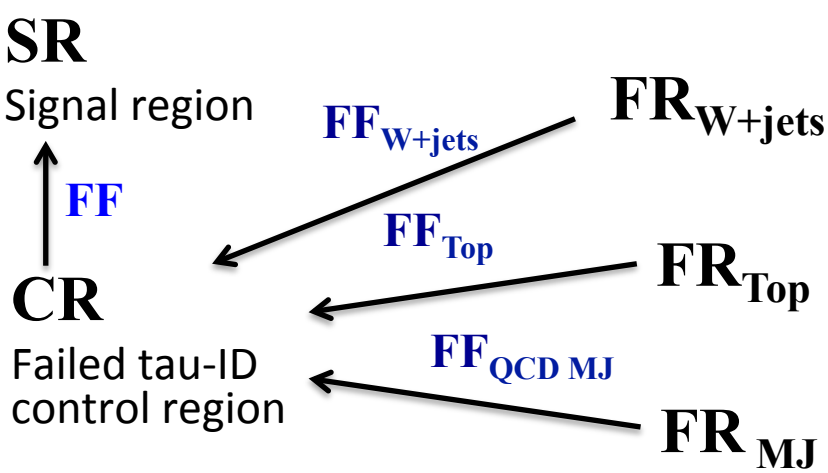
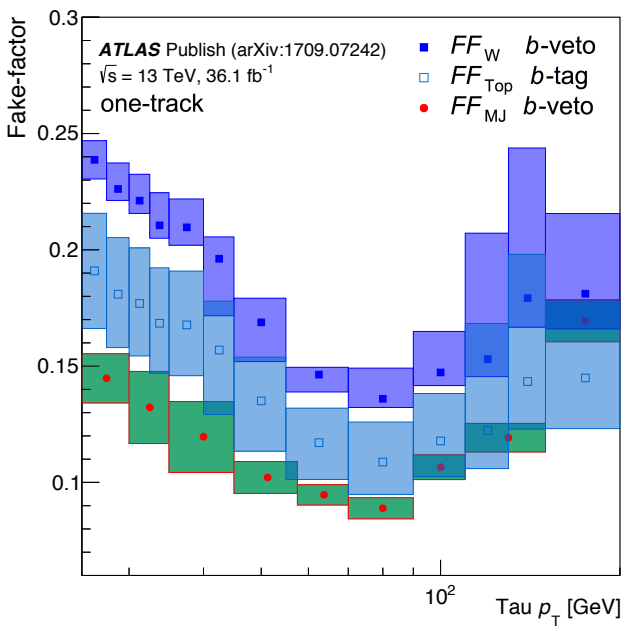
- Fake Factor: $\mathbf{FF(n_{track}, p_T) = N_{pass}/N_{fail}}$
  - Measured in top, W+jets, Multi-jet enriched regions
  - Application: $\mathbf{N_{bkg} = CR_{fail\text{-}ID} \times FF}$; composition estimated by simulation ($\tau_{had}\tau_{had}$) or data-driven ($\tau_{lep}\tau_{had}$)

$$\mathrm{FF} = \sum_i w_i \cdot \mathrm{FF}_i \qquad i\text{: W+jets, MJ, Top}$$



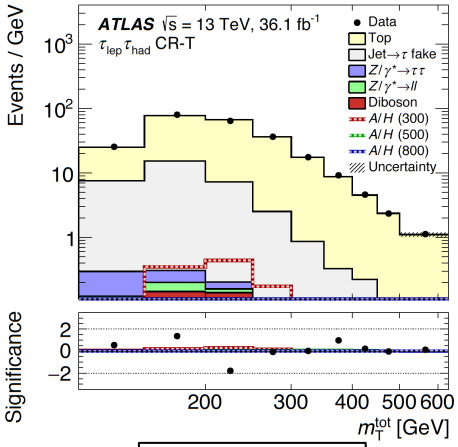


Final discriminant

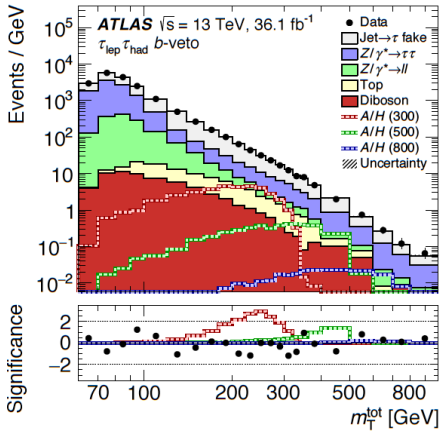
- Total transverse mass

$$m_{\mathrm{T}}^{\mathrm{tot}} \equiv \sqrt{(p_{\mathrm{T}}^{\tau_1} + p_{\mathrm{T}}^{\tau_2} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{p}_{\mathrm{T}}^{\tau_1} + \mathbf{p}_{\mathrm{T}}^{\tau_2} + \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

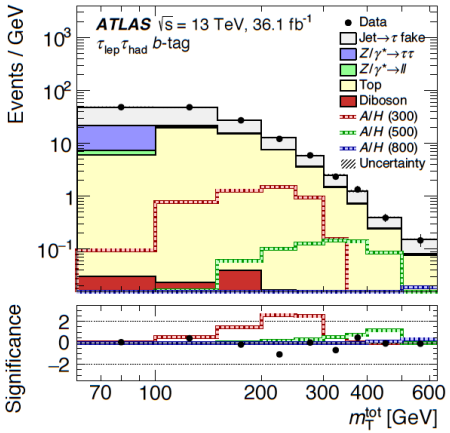
- Final fit model
  - $(\tau_e\tau_{had} + \tau_\mu\tau_{had} + \tau_{had}\tau_{had}) \times$ (btag+bveto)
  - Top control region



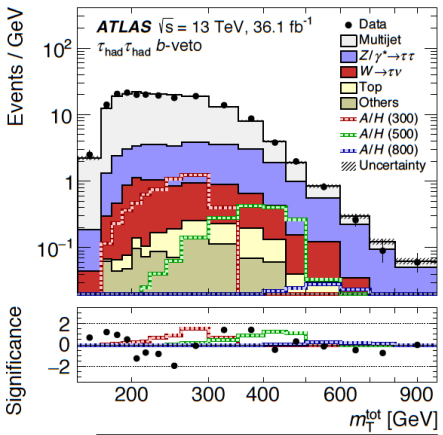
Top CR



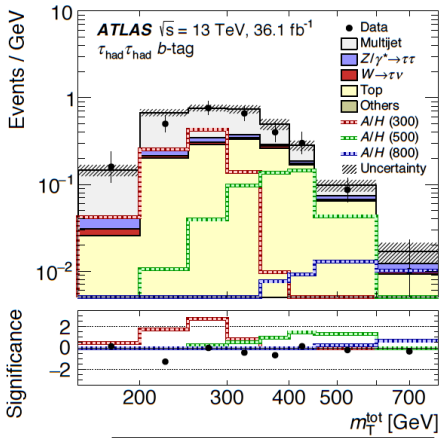
$\tau_{e/\mu}\tau_{had}$, bveto



$\tau_{e/\mu}\tau_{had}$, btag



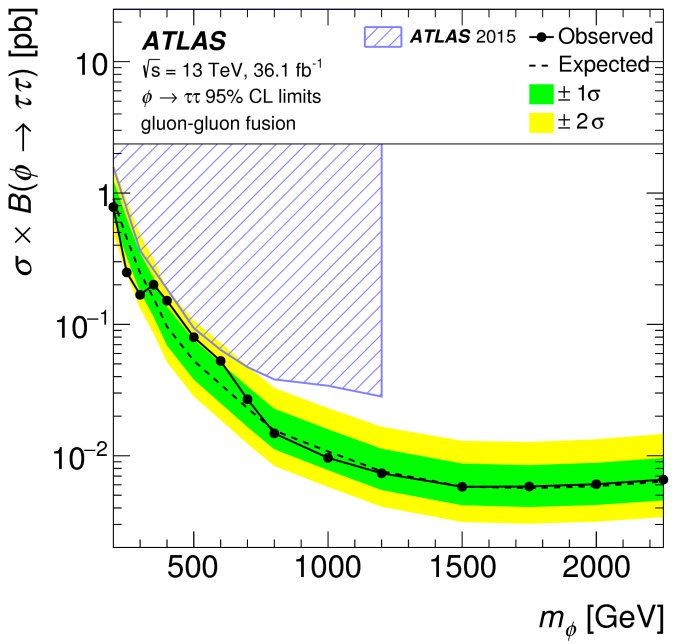
$\tau_{had}\tau_{had}$, bveto

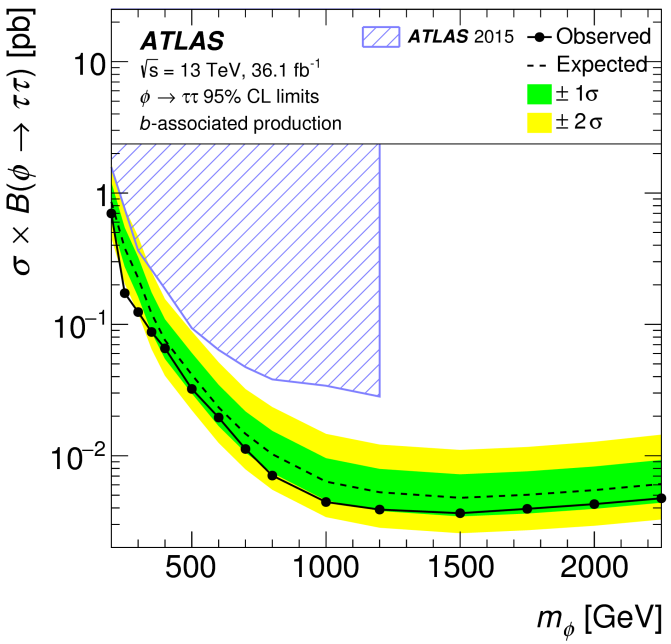


$\tau_{had}\tau_{had}$, btag

Model independent limit

- Narrow width approximation: ggH, bbH

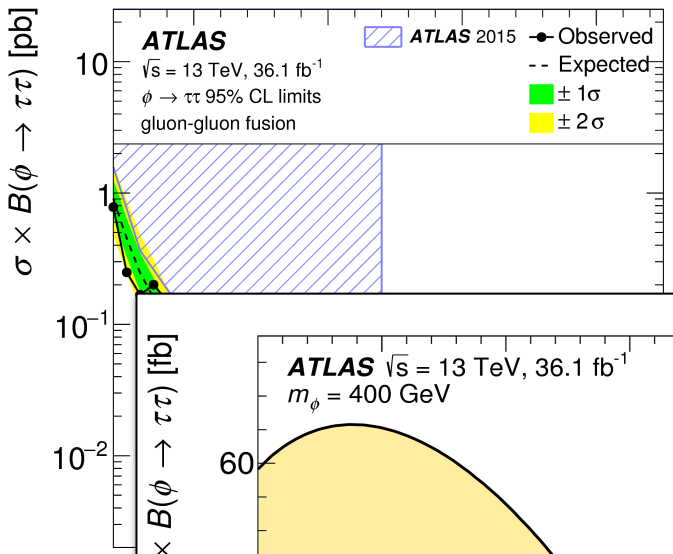


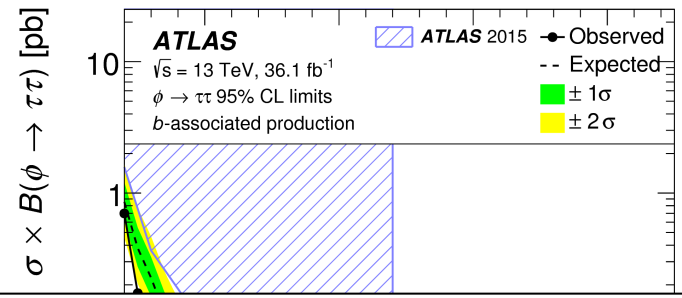


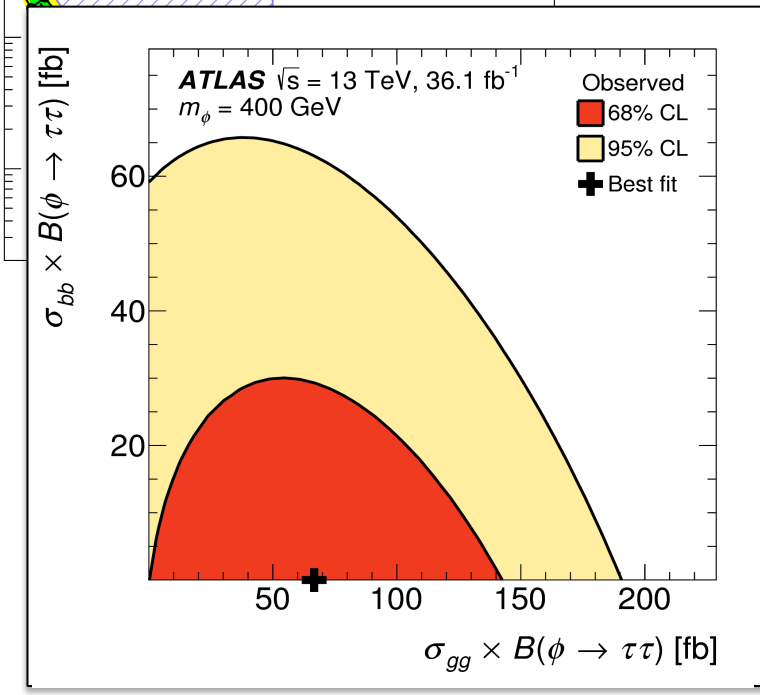
- No deviation beyond 2 σ found

Model independent limit

- Narrow width approximation: ggH, bbH

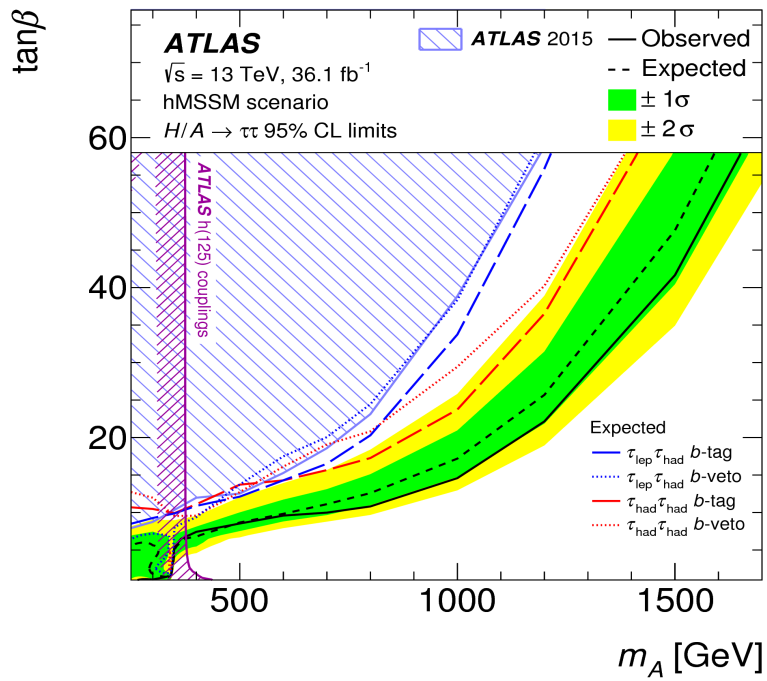


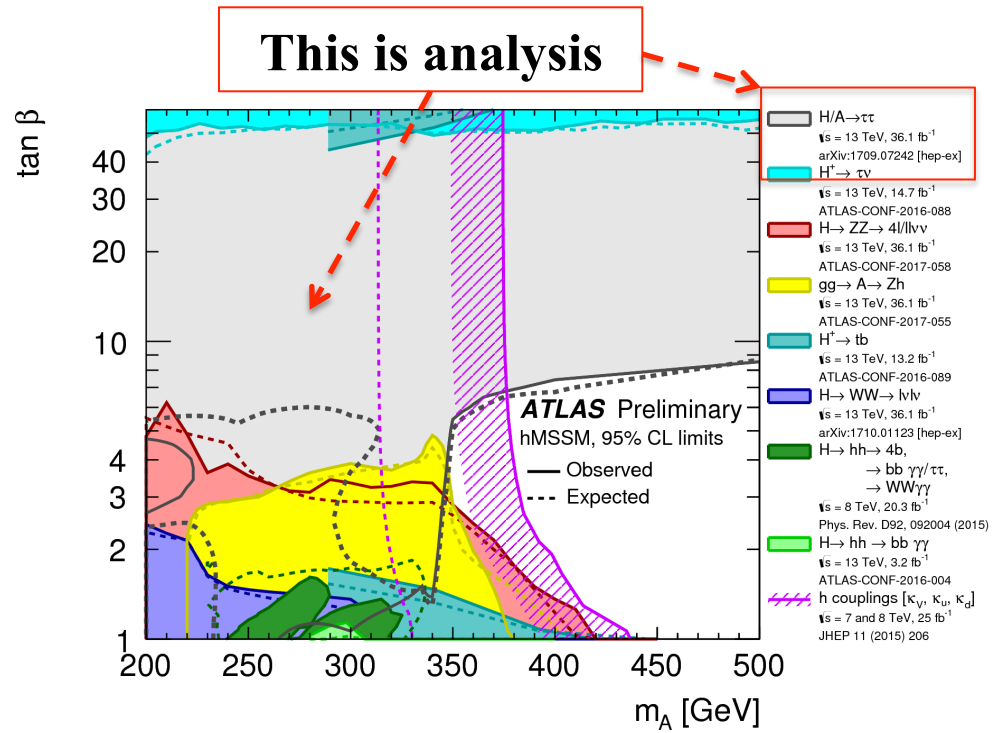




- Provide 3D likelihood scan (×15 masses)
- Allows more sophisticated re-interpretation in alternative models (e.g. arXiv:1507.06706)

Model dependent exclusion

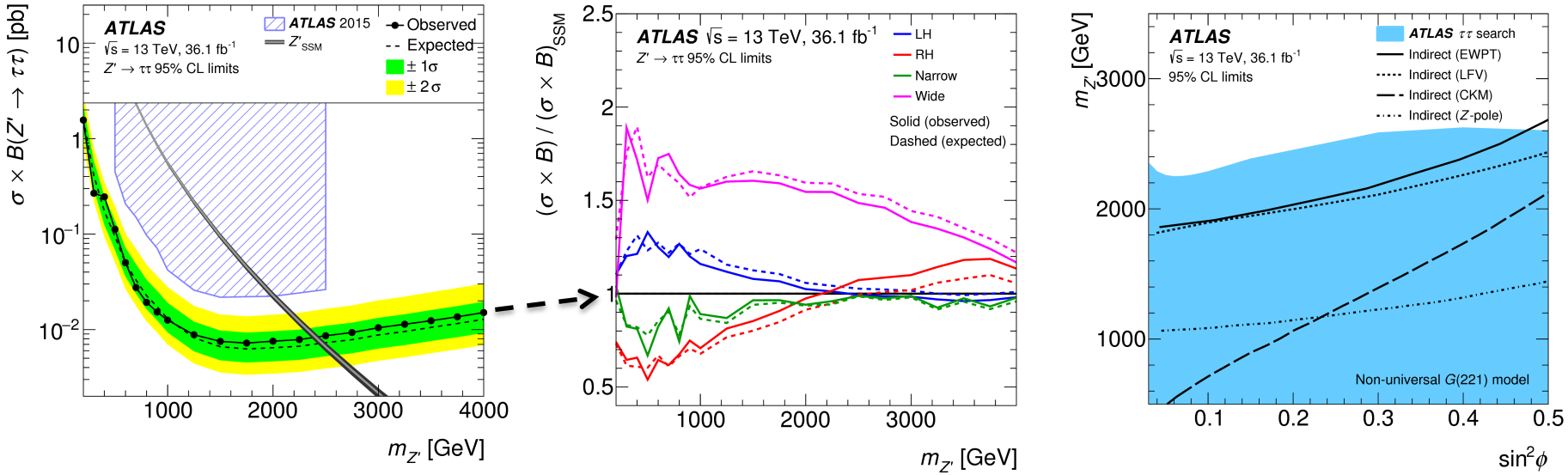




- Exclusion contours in benchmark model: hMSSM
- Search range extended up to 1.7 TeV and tanβ≳1 excluded for $m_A \lesssim 350$ GeV

Extra gauge boson Z'

No b-tag categorization in Z' search



- SSM Z'<2.5 TeV excluded
- Left(Right)-Handed only coupling, Narrow(Wide) width scenarios presented w-r-t SSM
- Non-universal G(221) model: $m_{Z'} \lesssim 2.25$-2.6 TeV excluded in $0.03 < \sin^2\phi < 0.5$.

Summary

- Latest result for MSSM Higgs and $Z' \rightarrow \tau\tau$ search with 36.1 fb^{-1} data presented (arXiv:1709.07242, submitted to JHEP)
  - Significantly extend the excluded parameter space
  - All information available
    - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2016-12/
- Flagship analysis of ATLAS in the BSM Higgs program
  - Set many standards for ATLAS analyses (τ_{had} identification, background and signal modeling, statistical inference, …)
- By the end of Run 2, data size will increase by a factor of 3. More exciting results ahead, stay tuned!

Make NJU-HEP Greater!

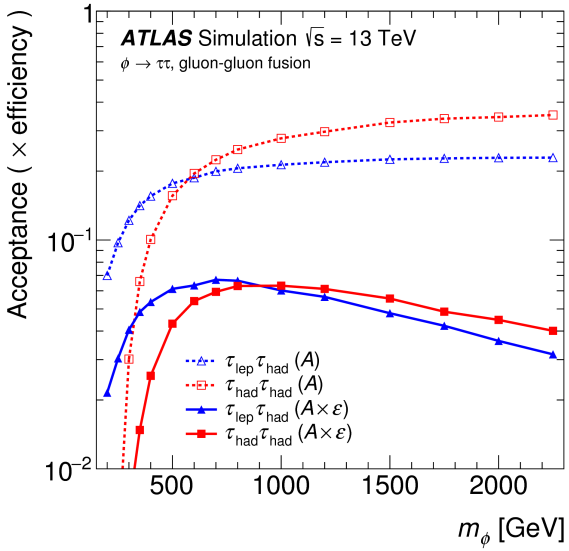
- Joined Nanjing University HEP group
  - Main focus: BSM search and Higgs precision measurement
- HEP group has great support from NJU and many open positions
  - Postdoc positions: https://inspirehep.net/record/1636919

Backup

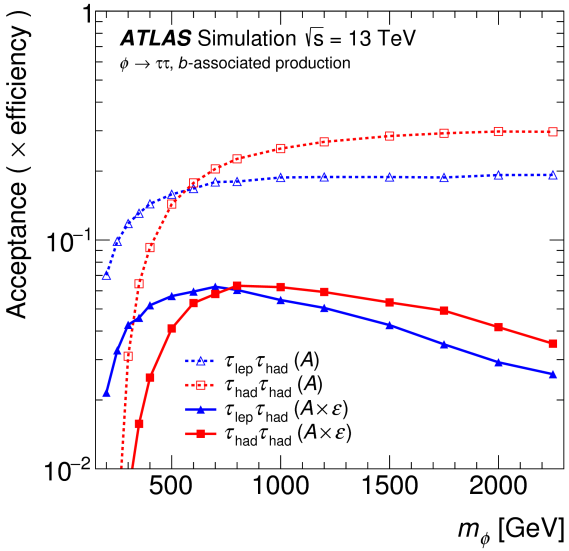
Acceptance and efficiency

- Acceptance calculated with respect to all ditau final states

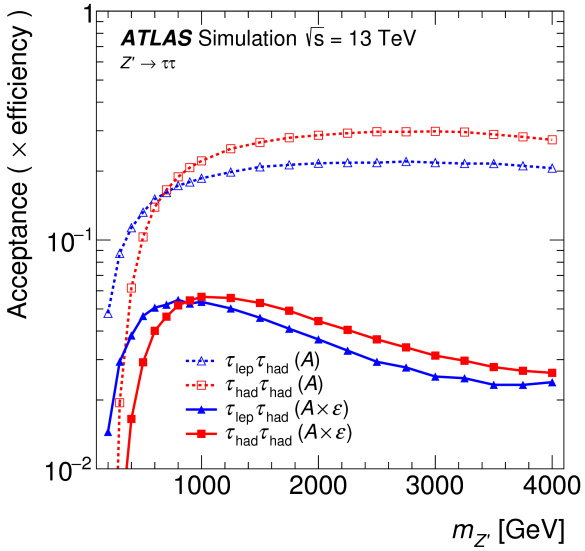
ggH



bbH

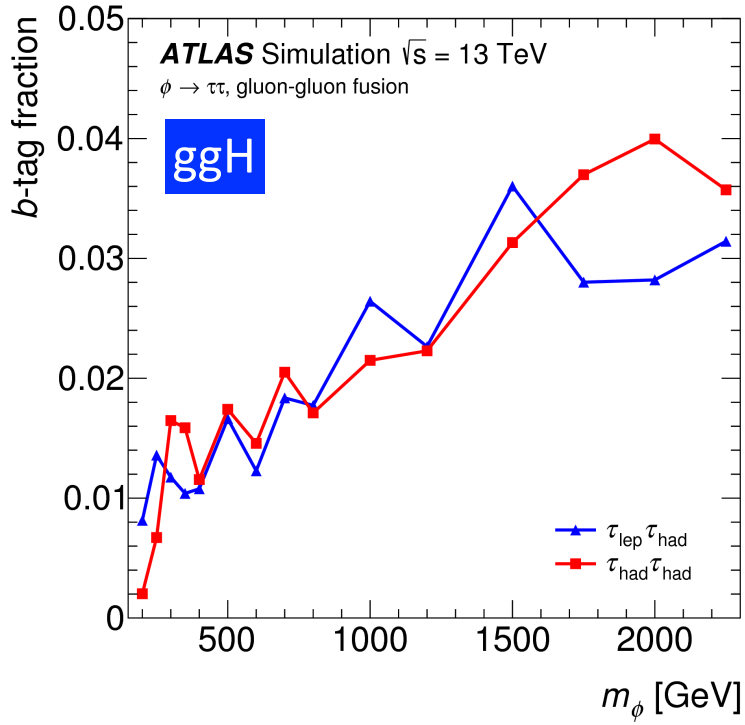


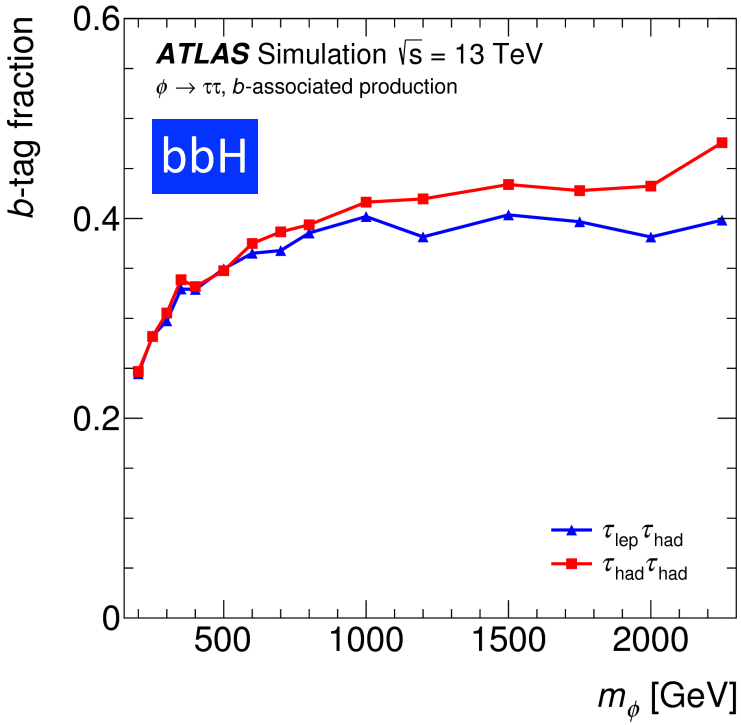
Z'



Fraction of events in b-tag category

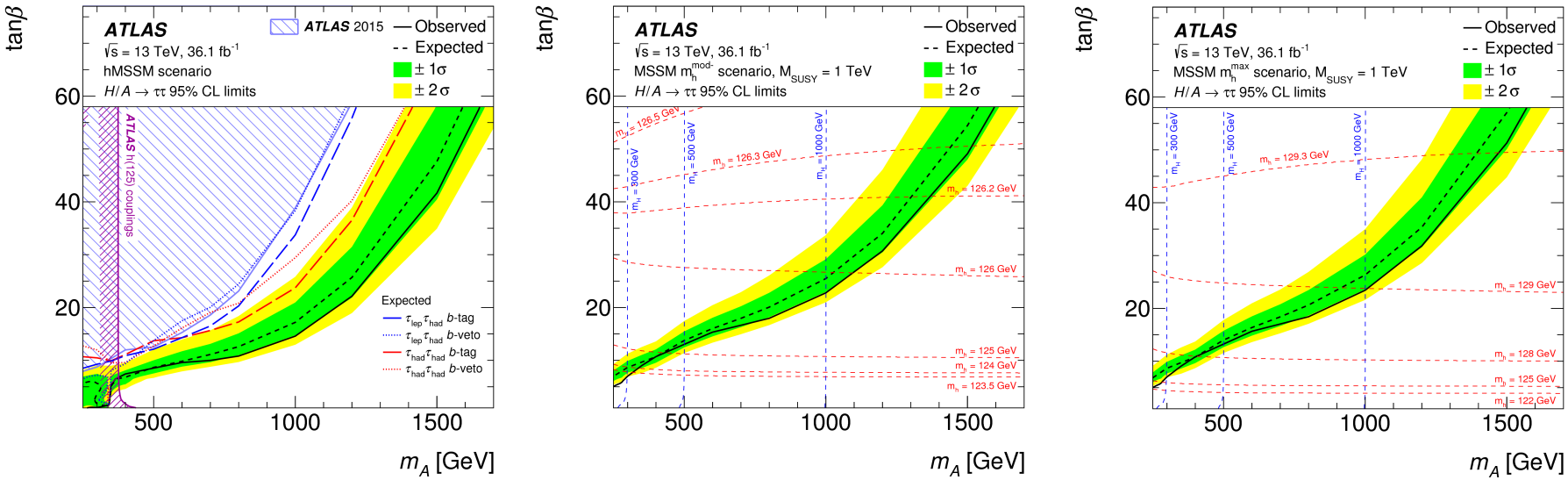
- Fraction of events entering b-tag category for a scalar boson





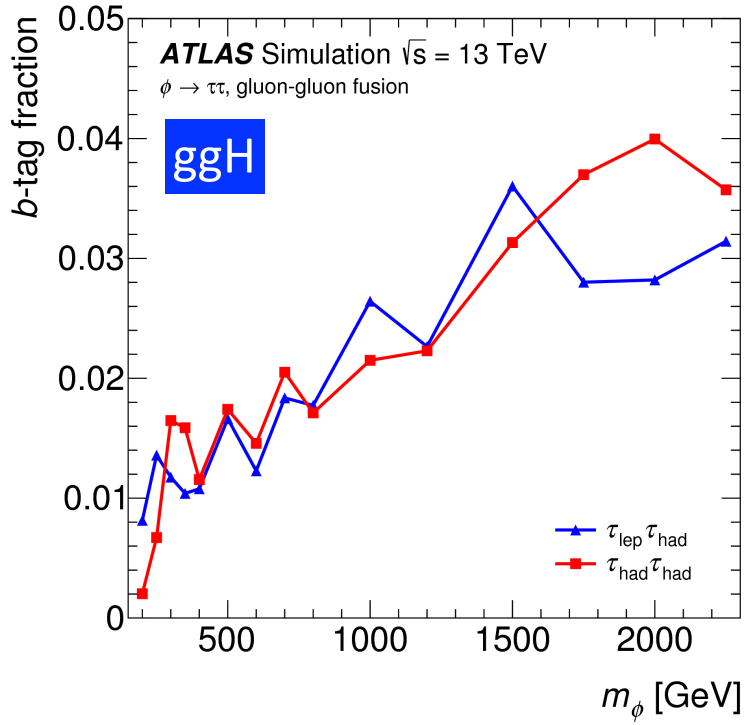
MSSM Higgs sector

- Various scenarios: hMSSM, m_h^{mod}, m_h^{max}

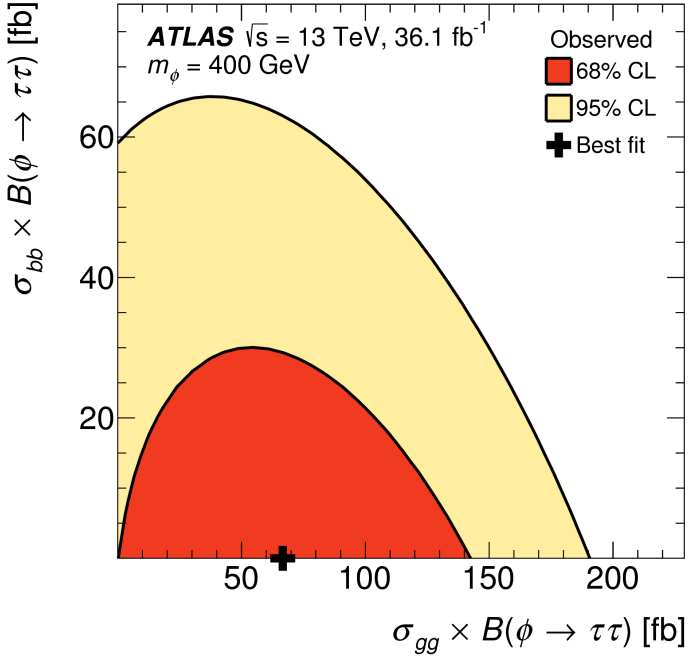


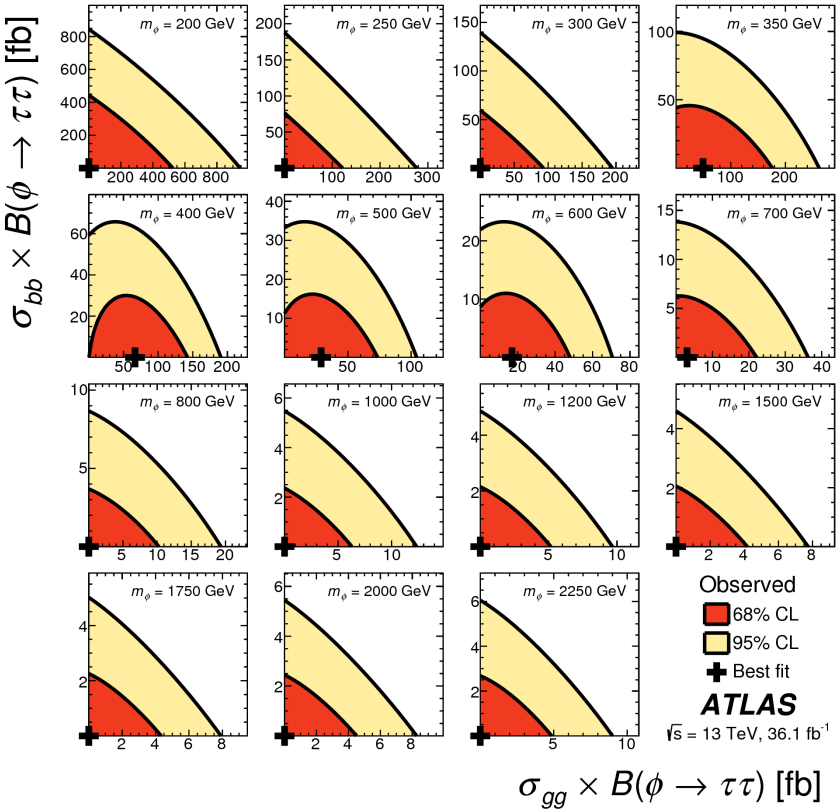
Fraction of events in b-tag category

- Fraction of events entering b-tag category for a scalar boson



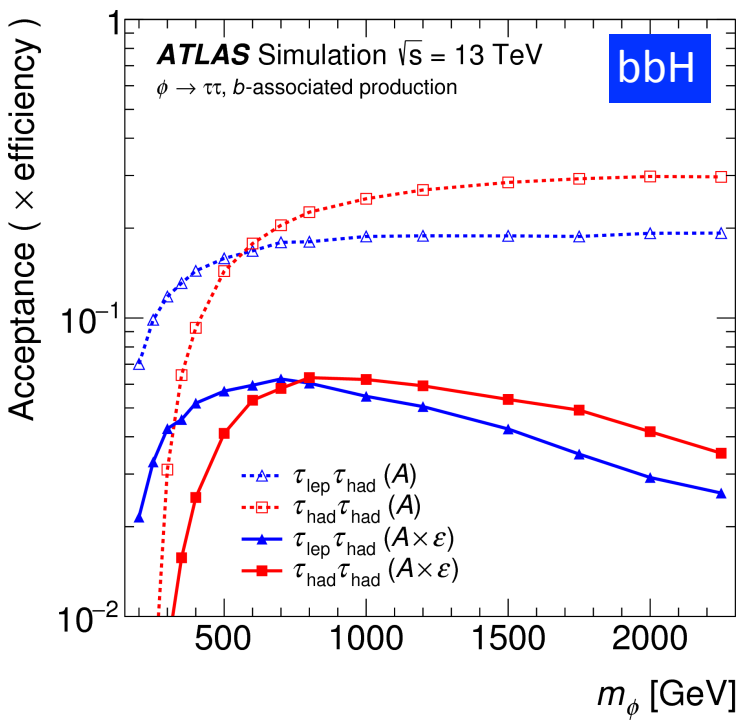
Likelihood scan: ggH VS bbH

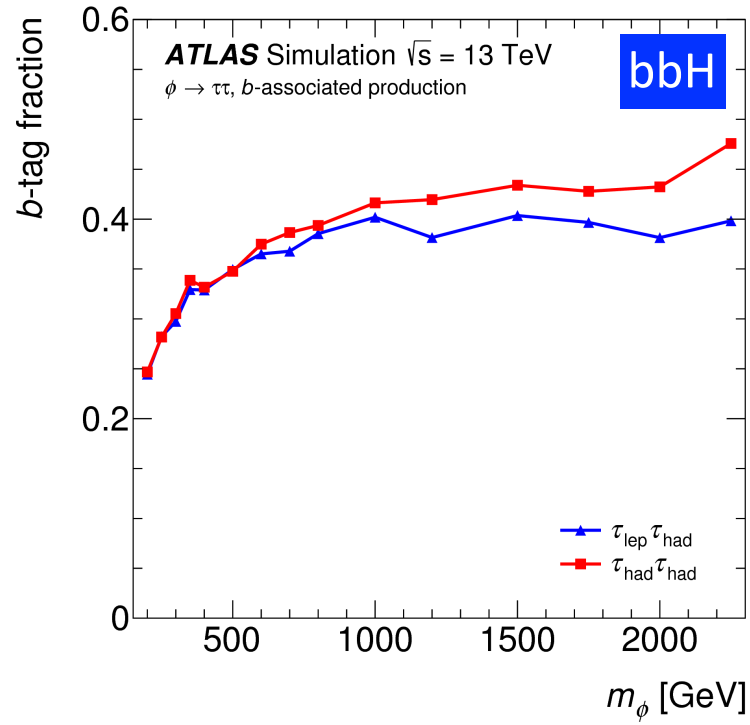




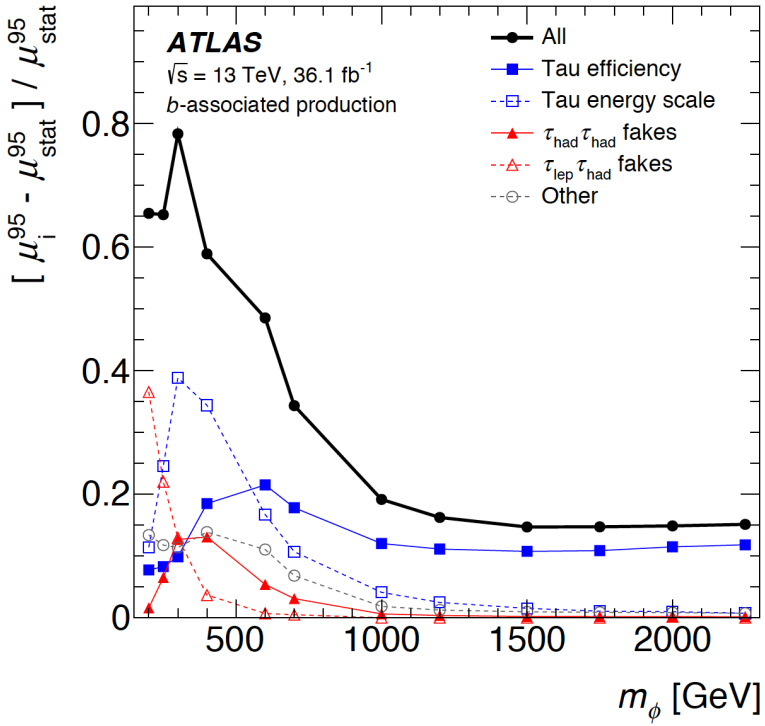
Acceptance and efficiency

- Acceptance calculated with respect to all ditau final states





Systematic uncertainties



- Major Systematics
  - Tau ID, energy scale, jet fake
  - Tau sys. dominant at the high mass regime