Search for A/H/Z'$\rightarrow\tau\tau$ at 13TeV with 36.5fb^{-1}

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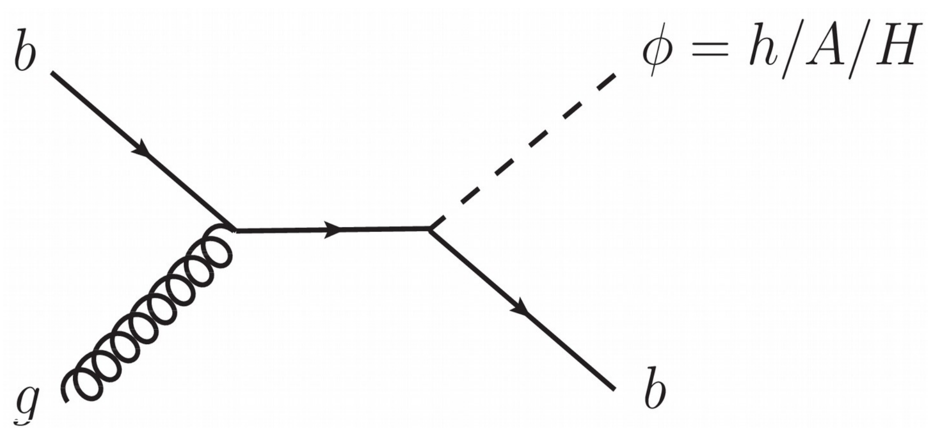
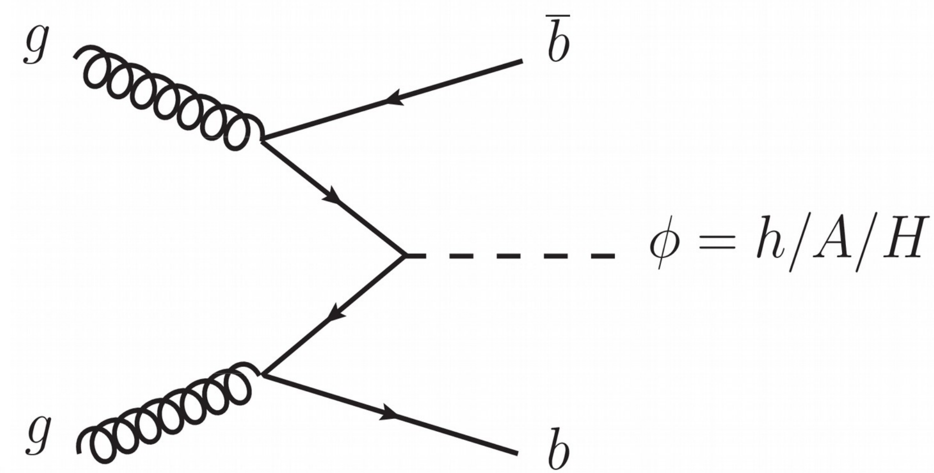
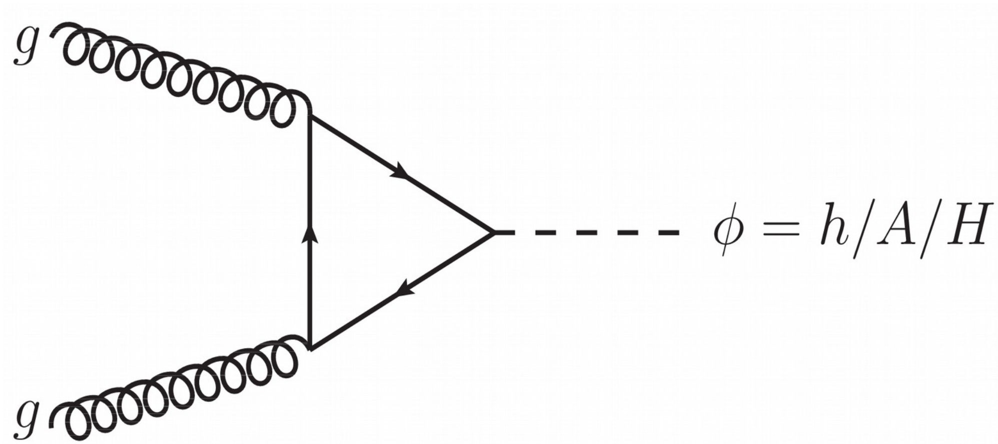
11/27/17

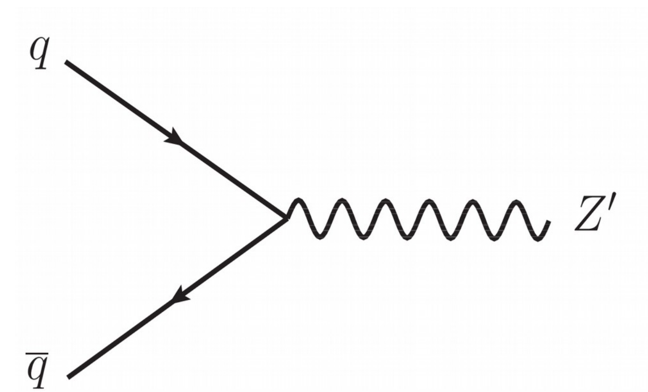
Introduction

- Search for heavy neutral resonances decaying into a pair of taus
- Interpretation in various models of MSSM Higgs and Z' bosons



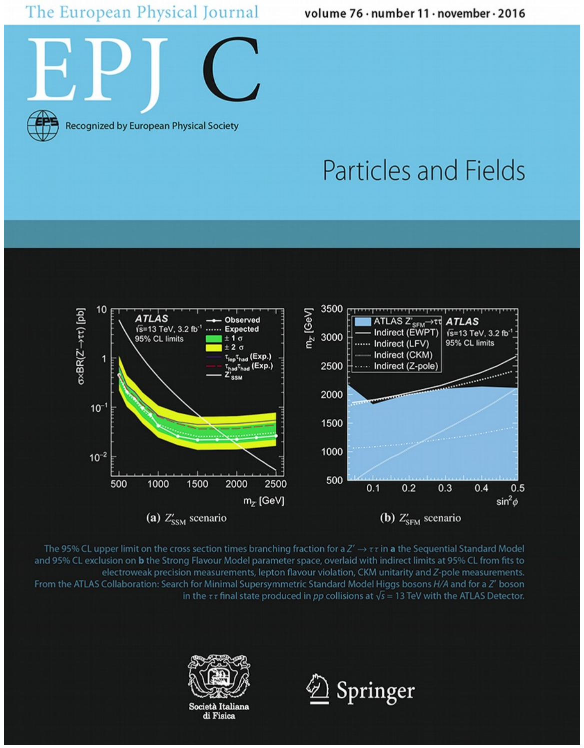




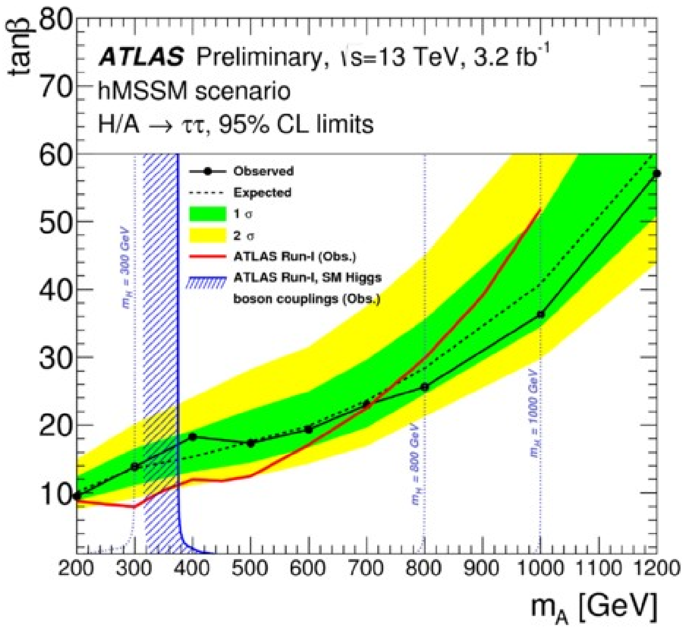


Run 2 Results

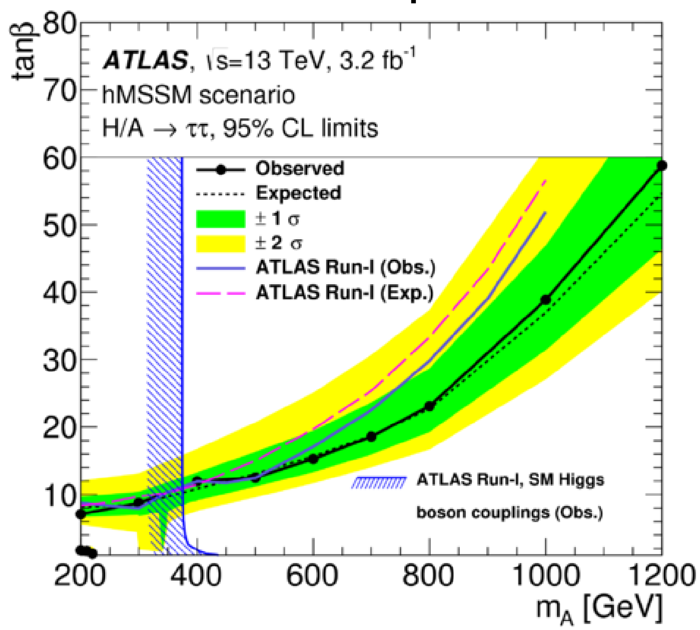
- 2015 EOYE CONF based $3.2fb^{-1}$ 2015 data ATLAS-CONF-2015-061
- Paper based on $3.2fb^{-1}$ 2015 data: ATLAS-HIGG-2015-08
- ICHEP16 CONF based on $13.3fb^{-1}$ 2015+2016 data ATLAS-HIGG-2015-08
- Paper based on full $36.1fb^{-1}$ 2015+2016 data HIGG-2016-12



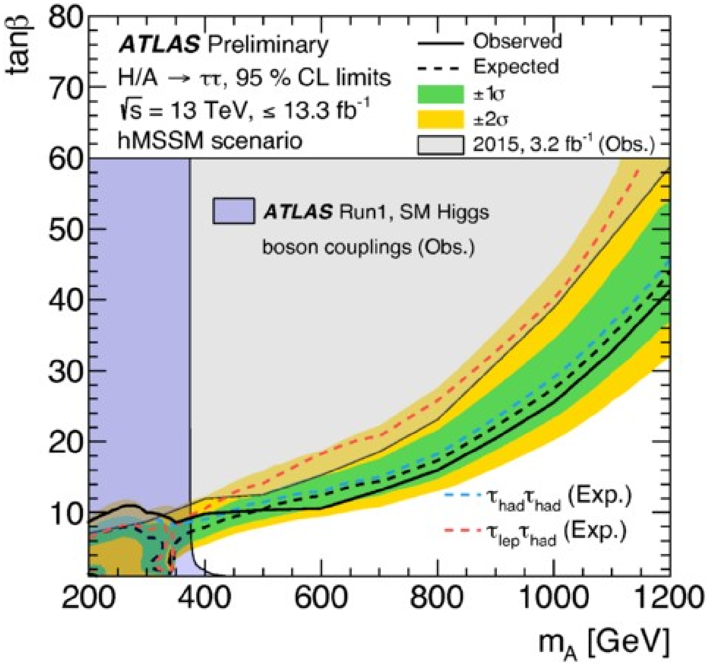
2015 EOYE CONF



2015 Paper



ICHEP 2016 CONF



Analysis strategy

- Not many changes compared to ICHEP CONF

$h^+ + \nu \leftarrow \tau^+ \leftarrow$ A/H/Z' $\rightarrow \tau^- \rightarrow h^- + \nu$

$e^+/\mu^+ + \nu\nu$ $\qquad$ $e^-/\mu^- + \nu\nu$

- Select two back-to-back tau decays of opposite charge
- Channels are complementary

	Muons	Electrons
$\tau_{had}\tau_{had}$	**0**	**0**
$\tau_{\mu}\tau_{had}$	**1**	**0**
$\tau_{e}\tau_{had}$	**0**	**1**

- Reconstructing total transverse mass:

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

Object Preselection

Electrons:

- p_T>15GeV, $|\eta|$<2.47, not in crack region
- "loose" likelihood working point

Muons:

- p_T>7GeV and $|\eta| < 2.5$
- Loose quality

Taus:

- p_T>20GeV, $|\eta| < 2.5$, not in crack region
- 1 or 3 tracks, $|q| == 1$
- Dedicated electron OLR

Jets:

- AntiKt4 jets
- Only enter analysis through missing E_T

Overlap removal:

- preference:
  muons, electrons, taus, jets

Event Selection

$\tau_{had}\tau_{had}$ channel:

- 2 taus, no leptons
- Single tau trigger (tau80, tau125, tau160)
- Leading tau:
  - Matches trigger
  - Thresholds per trigger p_T>85/130/165GeV
  - Jet BDT medium
- Subleading tau:
  - p_T>65GeV
  - Jet BDT loose
- $\Delta\phi(\tau_1,\tau_2) > 2.7$
- Opposite charge

$\tau_{lep}\tau_{had}$ channel:

- 1 tau, 1 lepton
- Single lepton trigger
- Lepton p_T>30GeV
- Tau p_T>25GeV
- $\Delta\phi(\tau_{lep},\tau_{had}) > 2.4$
- Opposite charge
- E-had channel, reject events with: $80<m(e,\tau_{had})<110$GeV
- Suppression of W+jets

$m_T(\ell, E_T^{miss}) < 40$ GeV, where

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

Categories

- **B-tag**
  - At least one preselected b-tagged jet
  - b-tagging efficiency at 70%
  - Most sensitivity at high mass and b-associated production
- **B-veto**
  - No preselected b-tagged jet
  - Dominant at low mass
- **Inclusive category**
  - This region is only used for Z' interpretation and has no further selection
  - Very similar to the b-veto category, but without b-tagging uncertainties

Background Estimation

–

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

Overview

- Main backgrounds:
  - B-tag: QCD and top
  - B-veto + inclusive: QCD and $Z \rightarrow \tau\tau$
- All backgrounds with true hadronic taus decays are directly estimated from simulation
- QCD: purely estimated from data using a **fake factor** technique
- Other backgrounds with jets faking taus ($W \rightarrow l\nu$+jets and single top/ttbar) are estimated from simulation but with data driven **fake rate** correction measured in $\mu\nu$+jets events

Fake Factor Measurement

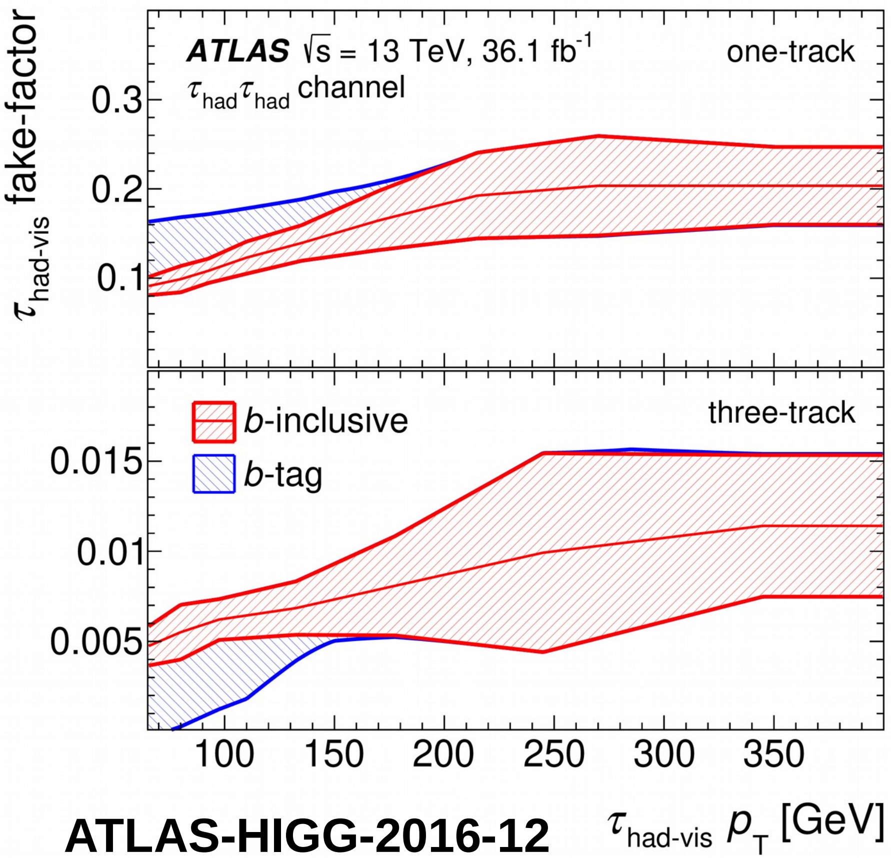
- Measured in dijet control region
- Fake factors definition:

$$f_{\tau-\mathrm{ID}}(p_\mathrm{T}, N_\mathrm{track}) \equiv \left.\frac{N^{\mathrm{pass}\ \tau-\mathrm{ID}}(p_\mathrm{T}, N_\mathrm{track})}{N^{\mathrm{fail}\ \tau-\mathrm{ID}}(p_\mathrm{T}, N_\mathrm{track})}\right|_{\mathrm{di-jet}}$$

- The shape and normalization of the multijet contribution is estimated by:

$$N_\mathrm{multijet}(p_\mathrm{T}, N_\mathrm{track}, x) = f_{\tau-\mathrm{ID}}(p_\mathrm{T}, N_\mathrm{track}) \times \left(N^{\mathrm{fail}\ \tau-\mathrm{ID}}{}_\mathrm{data}(p_\mathrm{T}, N_\mathrm{track}, x)\right)$$

- MC contributions are subtracted
- Interpolation between measurement bins
- Uncertainty bands include
  - Statistical data uncertainty
  - Statistical MC uncertainty
  - Systematic variations on MC background
  - Difference of *b*-inclusive fake factors to *b*-tag (only for *b*-tagged region)
- QCD estimation validated in same sign region



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Fake Rate Measurement

- μ+jet control region
  - *W*: No *b*-tagged jets
  - top: at least one *b*-tagged jet
- Fake rates are defined by the number of taus passing a given ID requirement over the total number of taus
- Separate measurement for loose BDT ID and trigger ID
- Fake rates parametrized in number of tracks and p_T
- They are applied where leading/subleading taus fail these ID requirements

Signal Region – $\tau_{had}\tau_{had}$ channel

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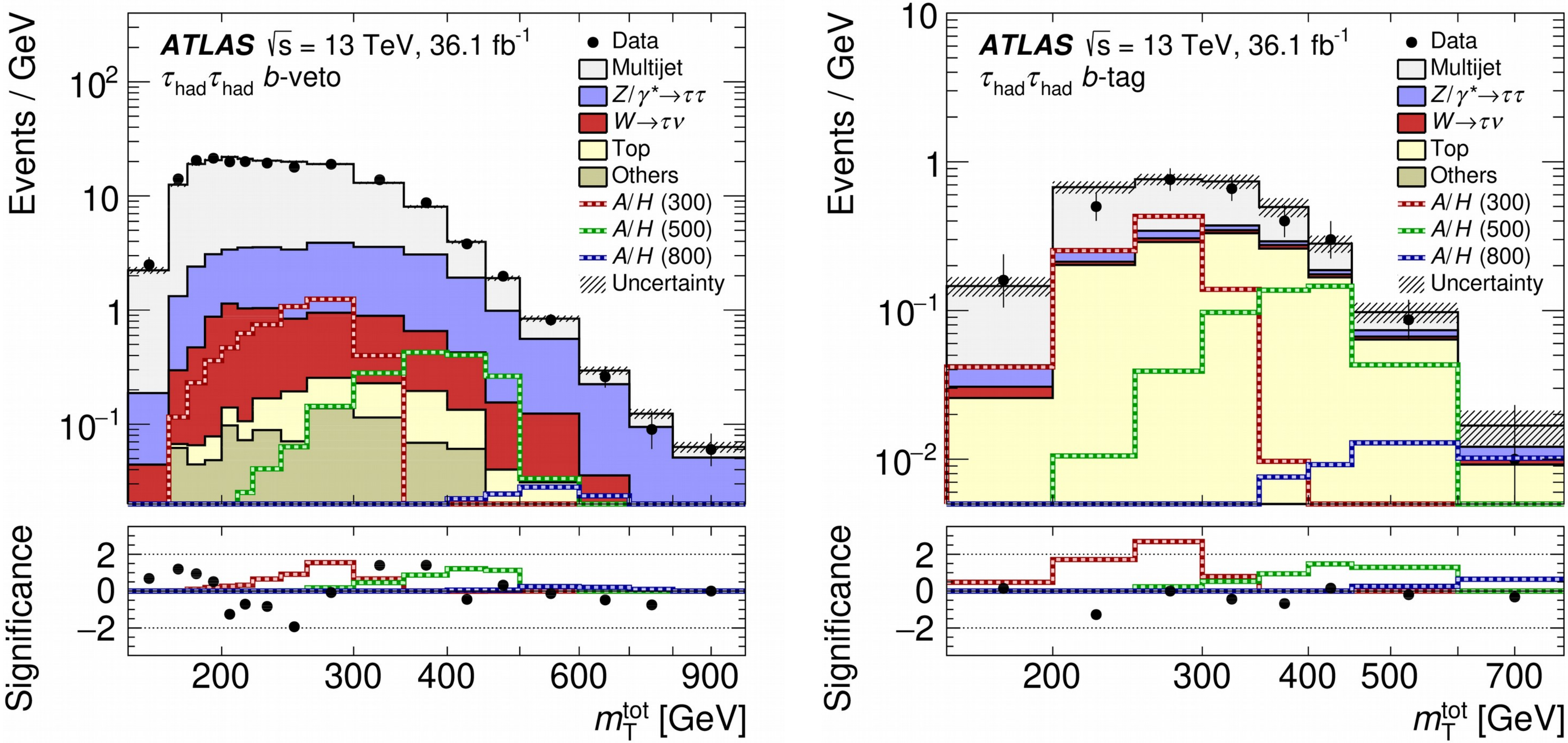

Background Estimation
–
$\tau_{lep}\tau_{had}$

Overview

- Main backgrounds:
  - B-tag: jet fakes and top
  - B-veto + inclusive: jet fakes and $Z \rightarrow \tau\tau$
- All backgrounds with a true lepton and a true hadronic tau decay are directly estimated from simulation
- Background estimation of events with fakes is estimated with fake factor teqnique

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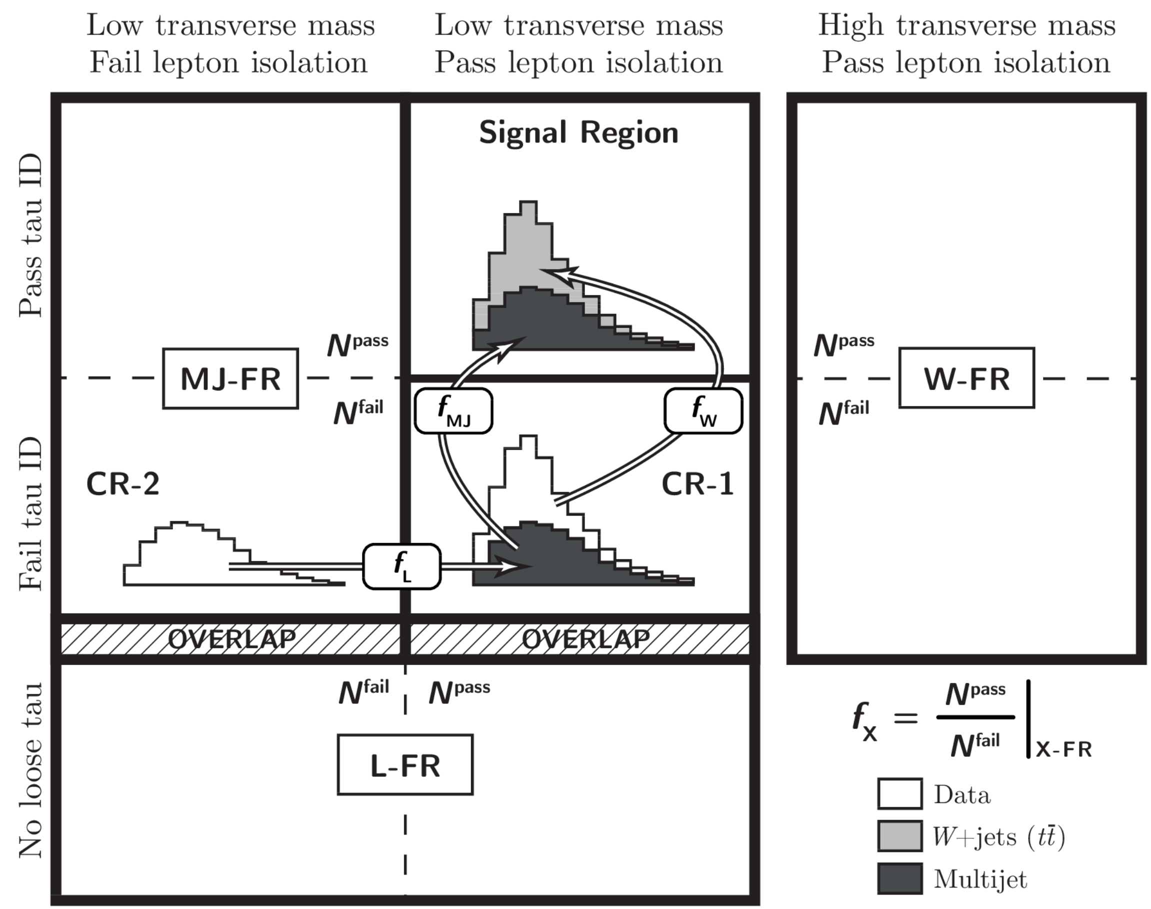

Jet Fake Factor Measurement

- Fake factors depend on p_T and number of tracks
- Correlation between tau ID and TES/E_T^{MISS}
- Applying correction for systematic shift in $\Delta\phi(\text{tau}/E_T^{MISS})$
- Reasonable top modeling, top CR is used in the fit

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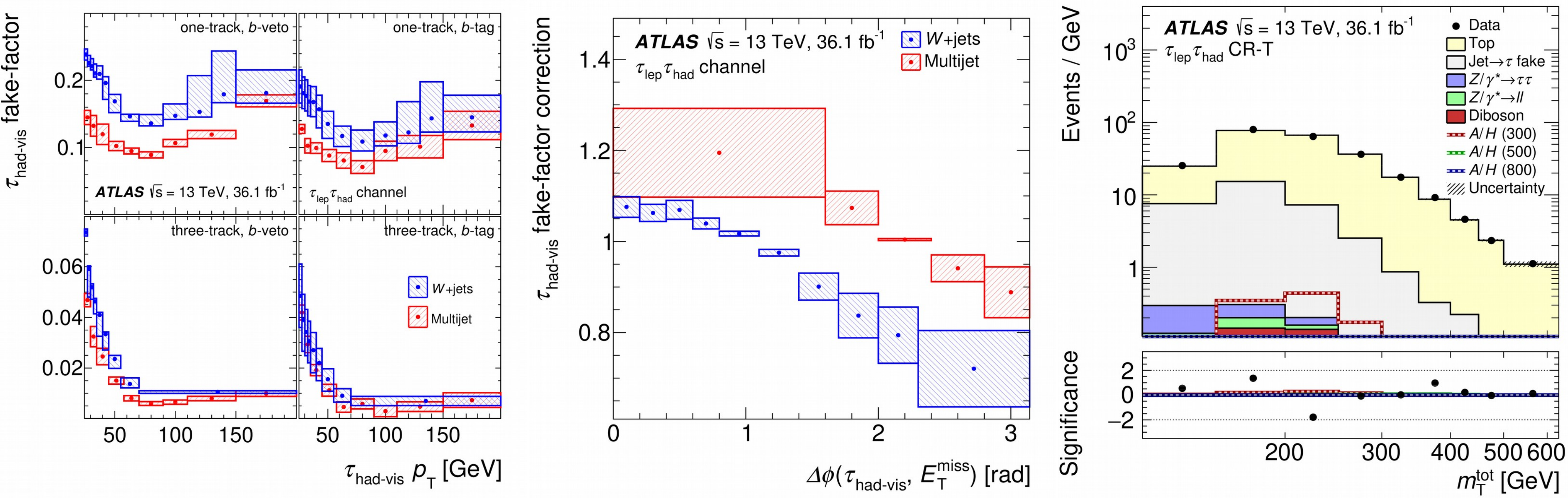

Signal Region – $\tau_{lep}\tau_{had}$ channel

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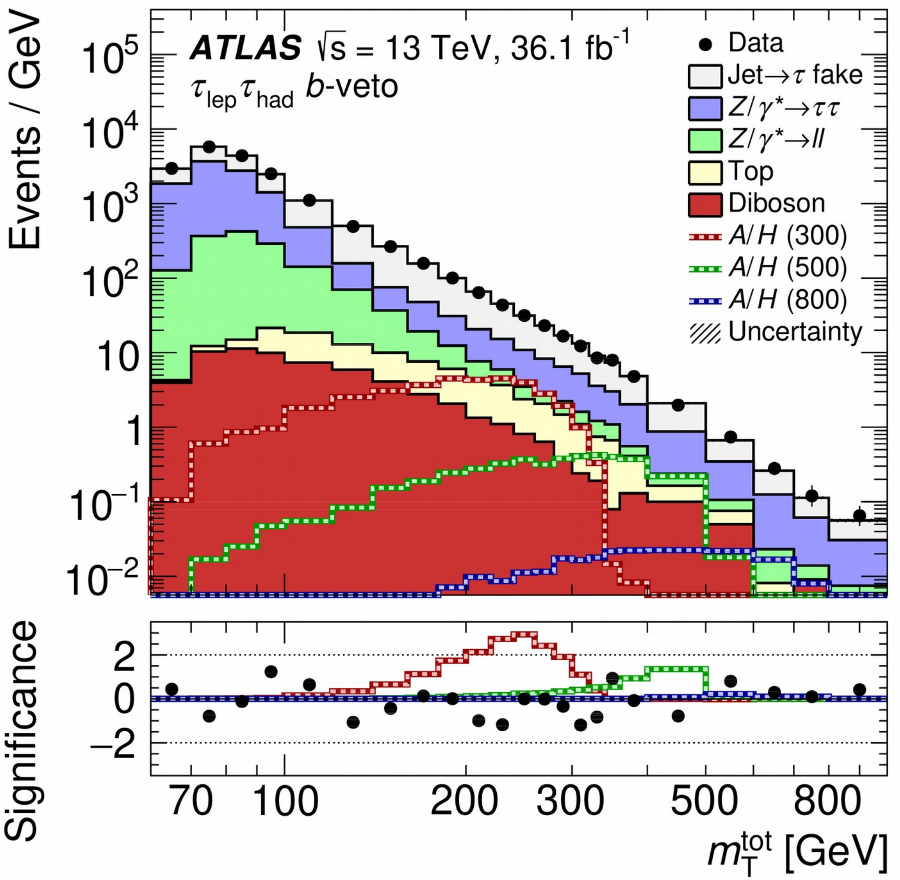

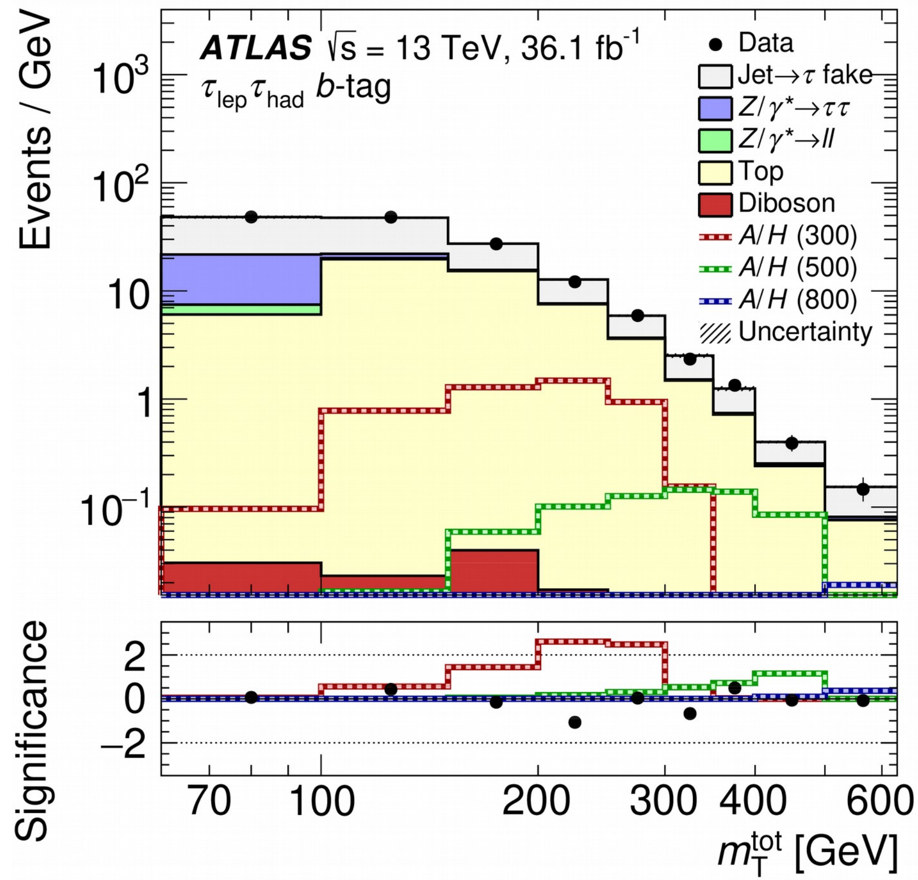

Special thanks goes to the

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BACKUP

Fake factor measurement

- Measured in dijet control region, differences to signal region:
  - jet trigger
  - two jets reconstructed as tau candidates:
    - Leading pT > 100 GeV
    - Subleading pT > 65 GeV
    - Subleading pT must be at least 30% of leading pT
    - No separation in b-tag and b-veto
- Fake factors definition:

$$f_{\tau-\mathrm{ID}}(p_{\mathrm{T}}, N_{\mathrm{track}}) \equiv \left.\frac{N^{\mathrm{pass}\ \tau-\mathrm{ID}}(p_{\mathrm{T}}, N_{\mathrm{track}})}{N^{\mathrm{fail}\ \tau-\mathrm{ID}}(p_{\mathrm{T}}, N_{\mathrm{track}})}\right|_{\mathrm{di-jet}}$$

- The shape and normalization of the multijet contribution is estimated by:

$$N_{\mathrm{multijet}}(p_{\mathrm{T}}, N_{\mathrm{track}}, x) = f_{\tau-\mathrm{ID}}(p_{\mathrm{T}}, N_{\mathrm{track}}) \times \left(N^{\mathrm{fail}\ \tau-\mathrm{ID}}{}_{\mathrm{data}}(p_{\mathrm{T}}, N_{\mathrm{track}}, x)\right)$$

Region definitions

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Channel	Region	Selection
$\tau_{\rm lep}\tau_{\rm had}$	SR	ℓ (trigger, isolated), τ_1 (medium), $q(\ell) \times q(\tau_1) < 0$, $\lvert\Delta\phi(\mathbf{p}_{\rm T}^{\ell}, \mathbf{p}_{\rm T}^{\tau_1})\rvert > 2.4$, $m_{\rm T}(\mathbf{p}_{\rm T}^{\ell}, \mathbf{E}_{\rm T}^{\rm miss}) < 40\,{\rm GeV}$, veto $80 < m(\mathbf{p}^{\ell}, \mathbf{p}^{\tau_1}) < 110\,{\rm GeV}$ ($\tau_e\tau_{\rm had}$ channel only)
	CR-1	Pass SR except: τ_1 (very-loose, fail medium)
	CR-2	Pass SR except: τ_1 (very-loose, fail medium), ℓ (fail isolation)
	MJ-FR	Pass SR except: τ_1 (very-loose), ℓ (fail isolation)
	W-FR	Pass SR except: $70\,(60) < m_{\rm T}(\mathbf{p}_{\rm T}^{\ell}, \mathbf{E}_{\rm T}^{\rm miss}) < 150\,{\rm GeV}$ in $\tau_e\tau_{\rm had}$ ($\tau_\mu\tau_{\rm had}$) channel
	CR-T	Pass SR except: $m_{\rm T}(\mathbf{p}_{\rm T}^{\ell}, \mathbf{E}_{\rm T}^{\rm miss}) > 110\,(100)\,{\rm GeV}$ in the $\tau_e\tau_{\rm had}$ ($\tau_\mu\tau_{\rm had}$) channel, b-tag category only
	L-FR	ℓ (trigger, selected), jet (selected), no loose $\tau_{\rm had\text{-}vis}$, $m_{\rm T}(\mathbf{p}_{\rm T}^{\ell}, \mathbf{E}_{\rm T}^{\rm miss}) < 30\,{\rm GeV}$
$\tau_{\rm had}\tau_{\rm had}$	SR	τ_1 (trigger, medium), τ_2 (loose), $q(\tau_1) \times q(\tau_2) < 0$, $\lvert\Delta\phi(\mathbf{p}_{\rm T}^{\tau_1}, \mathbf{p}_{\rm T}^{\tau_2})\rvert > 2.7$
	CR-1	Pass SR except: τ_2 (fail loose)
	DJ-FR	jet trigger, τ_1+τ_2 (no identification), $q(\tau_1) \times q(\tau_2) < 0$, $\lvert\Delta\phi(\mathbf{p}_{\rm T}^{\tau_1}, \mathbf{p}_{\rm T}^{\tau_2})\rvert > 2.7$ $p_{\rm T}^{\tau_2}/p_{\rm T}^{\tau_1} > 0.3$
	W-FR	μ (trigger, isolated), τ_1 (no identification), $\lvert\Delta\phi(\mathbf{p}_{\rm T}^{\mu}, \mathbf{p}_{\rm T}^{\tau_1})\rvert > 2.4$ $m_{\rm T}(\mathbf{p}_{\rm T}^{\mu}, \mathbf{E}_{\rm T}^{\rm miss}) > 40\,{\rm GeV}$, b-veto category only
	T-FR	Pass W-FR except: b-tag category only

Event yields

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Channel	Process	b-veto pre-fit	b-veto post-fit	b-tag pre-fit	b-tag post-fit
$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$Z/\gamma^* \to \tau\tau$	$92\,000 \pm 11\,000$	$96\,400 \pm 1600$	670 ± 140	690 ± 70
	Diboson	880 ± 100	920 ± 70	6.3 ± 1.7	6.5 ± 1.4
	$t\bar{t}$ and single top-quark	1050 ± 170	1090 ± 130	2800 ± 400	2680 ± 80
	Jet $\to \tau$ fake	$83\,000 \pm 5000$	$88\,800 \pm 1700$	3000 ± 400	3390 ± 170
	$Z/\gamma^* \to \ell\ell$	$15\,800 \pm 1200$	$16\,200 \pm 700$	86 ± 21	89 ± 16
	SM Total	$193\,000 \pm 13\,000$	$203\,400 \pm 1200$	6500 ± 600	6850 ± 120
	Data	203 365		6843	
	A/H (300)	720 ± 80	–	236 ± 32	–
	A/H (500)	112 ± 11	–	39 ± 5	–
	A/H (800)	10.7 ± 1.1	–	4.8 ± 0.6	–
$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	Multijet	3040 ± 240	3040 ± 90	106 ± 32	85 ± 10
	$Z/\gamma^* \to \tau\tau$	610 ± 230	770 ± 80	7.5 ± 2.9	8.6 ± 1.3
	$W(\to \tau\nu)$+jets	178 ± 31	182 ± 15	4.0 ± 1.0	4.1 ± 0.5
	$t\bar{t}$ and single top-quark	26 ± 9	29 ± 4	60 ± 50	74 ± 15
	Others	25 ± 6	27.4 ± 2.1	1.0 ± 0.5	1.1 ± 0.4
	SM Total	3900 ± 400	4050 ± 70	180 ± 60	173 ± 16
	Data	4059		154	
	A/H (300)	130 ± 50	–	44 ± 19	–
	A/H (500)	80 ± 33	–	28 ± 12	–
	A/H (800)	11 ± 4	–	5.1 ± 2.2	–

Simulated Backgrounds

- Z+jets: Powheg+Pythia8
- W+jets:
  - Sherpa 2.2.0 ($\boldsymbol{\tau_{had}\tau_{had}}$)
  - POWHEG+Pythia8 ($\boldsymbol{\tau_{lep}\tau_{had}}$)
- ttbar + single top: Powheg+Pythia6
- Diboson: Sherpa 2.1.0