A search for high-mass resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

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Introduction

- Heavy Z' gauge bosons appear in many extensions of the Standard Model (SM)
- Grand unified theories often give rise to Z' bosons
- Lepton universality is not necessarily preserved
  - Searches in di-electron and di-muon channels do not apply
  - Preferred couplings to third generation fermions in some models like non-universal G(221)
- Three different tau decay channels are analyzed: $\tau_{had}\tau_{had}$ (BR=42%), $\tau_{\mu}\tau_{had}$ (BR=23%), $\tau_{e}\tau_{had}$ (BR=23%)

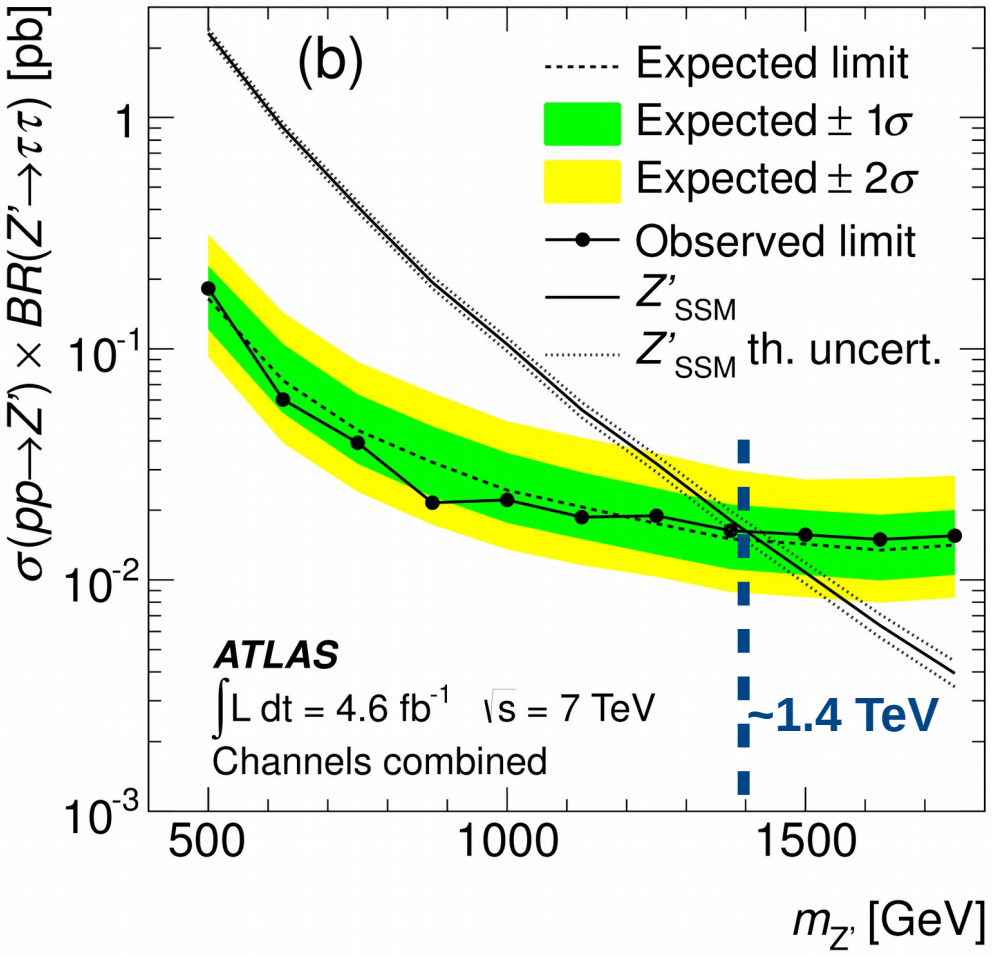
Signal Models

- Sequential Standard Model (SSM) is used as a benchmark scenario
  - Couplings are the same as for SM Z boson
- Variations to purely left/right handed fermion couplings
- Variations to wider and narrower decay widths
- Non-universal G(221) model

$$SU(2)_l \times SU(2)_h \times U(1)_Y \xrightarrow{u} SU(2)_{l+h} \times U(1)_Y \xrightarrow{v} U(1)_{em}$$

Recent Publications

7 TeV Z' → ττ



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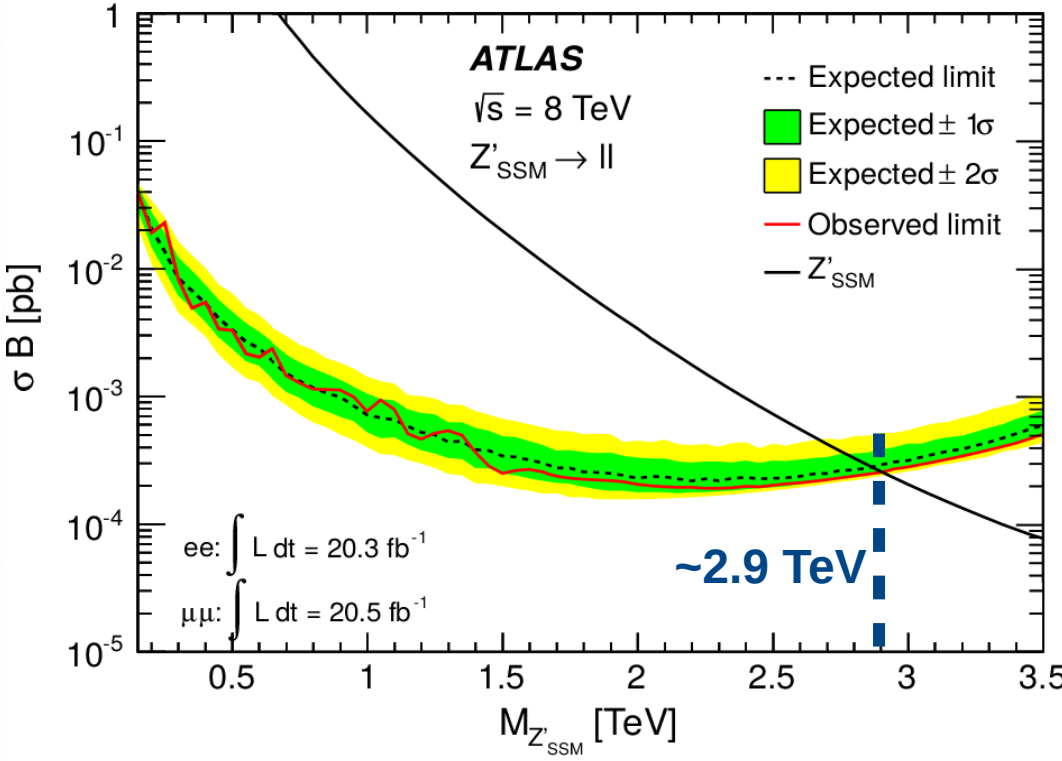
Volume 719, Issues 4–5

8 TeV Z' → leplep



Phys. Rev. D 90, 052005

Analysis strategy

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

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

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

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

	Hadronic tau decays	Muons	Electrons
$\tau_{had}\tau_{had}$	**2**	**0**	**0**
$\tau_{\mu}\tau_{had}$	**1**	**1**	**0**
$\tau_{e}\tau_{had}$	**1**	**0**	**1**

- Count events passing high transverse mass threshold

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

Channel Selections

	$\tau_{had}\tau_{had}$	$\tau_{\mu}\tau_{had}$	$\tau_{e}\tau_{had}$
Trigger	single tau	single muon	single electron
Kinematic Cuts	$p_T(\tau_1) > 150$ GeV $p_T(\tau_2) > 50$ GeV	$p_T(\mu) > 30$ GeV $p_T(\tau) > 30$ GeV	$p_T(e) > 30$ GeV $p_T(\tau) > 30$ GeV
ID Cuts	Loose for both	Medium + muon veto	Medium + medium e-veto
Opposite Charge	$q(\tau_1) \times q(\tau_2) = -1$	$q(\mu) \times q(\tau) = -1$	$q(e) \times q(\tau) = -1$
Back-to-Back Topology	$\Delta\varphi(\tau_1,\tau_2) > 2.7$ rad	$\Delta\varphi(\mu,\tau) > 2.7$ rad	$\Delta\varphi(e,\tau) > 2.7$ rad

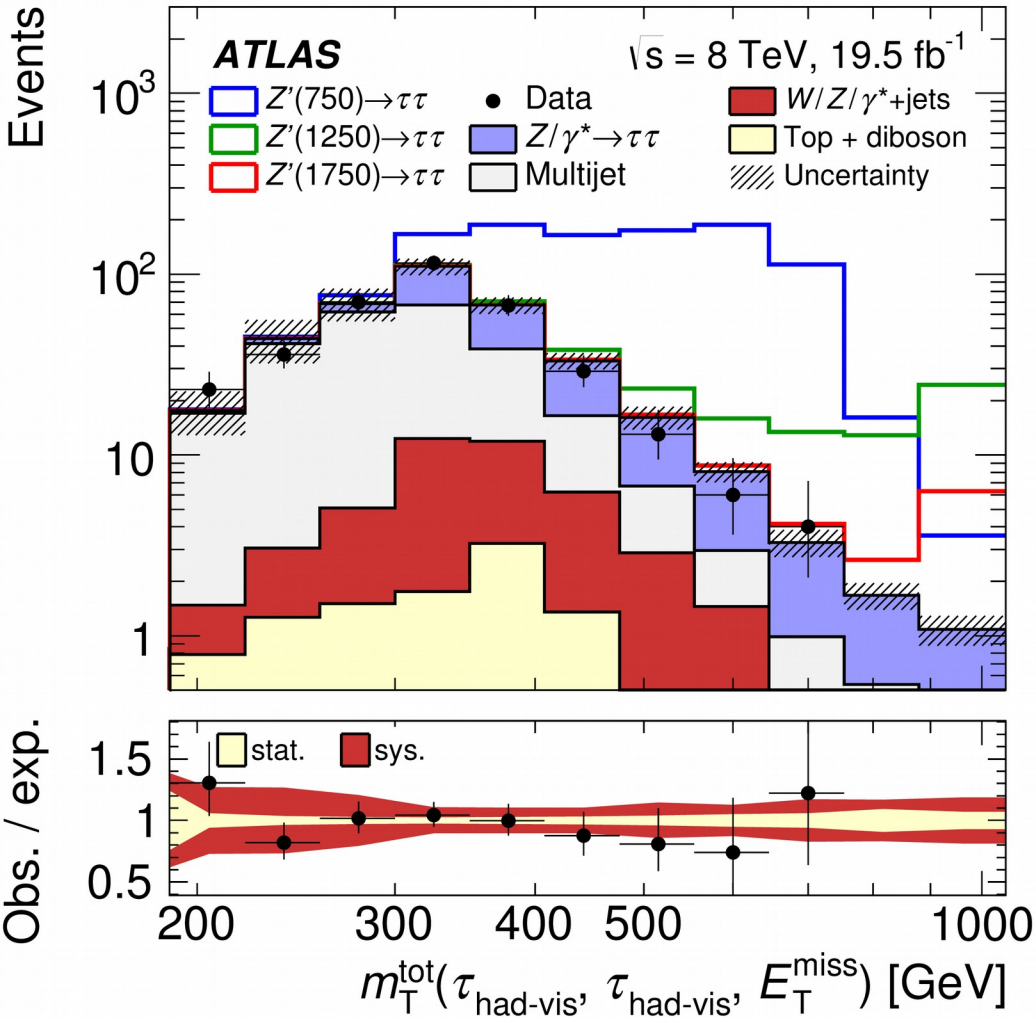
Uncertainties

Uncertainty [%]	Signal			Background		
	$\tau_{\text{had}}\tau_{\text{had}}$	$\tau_{\mu}\tau_{\text{had}}$	$\tau_{e}\tau_{\text{had}}$	$\tau_{\text{had}}\tau_{\text{had}}$	$\tau_{\mu}\tau_{\text{had}}$	$\tau_{e}\tau_{\text{had}}$
Statistical uncertainty	2.4	4	4	6	21	21
Efficiency	16	8	8	12	5	4
Energy scale and resolution	2.9	5	5	10	11	9
Theory cross section	–	–	–	6	6	6
Luminosity	2.8	2.8	2.8	2.5	2.2	1.9
Data-driven methods	0.2	–	–	2.7	8	12
Total	17	11	10	18	27	28

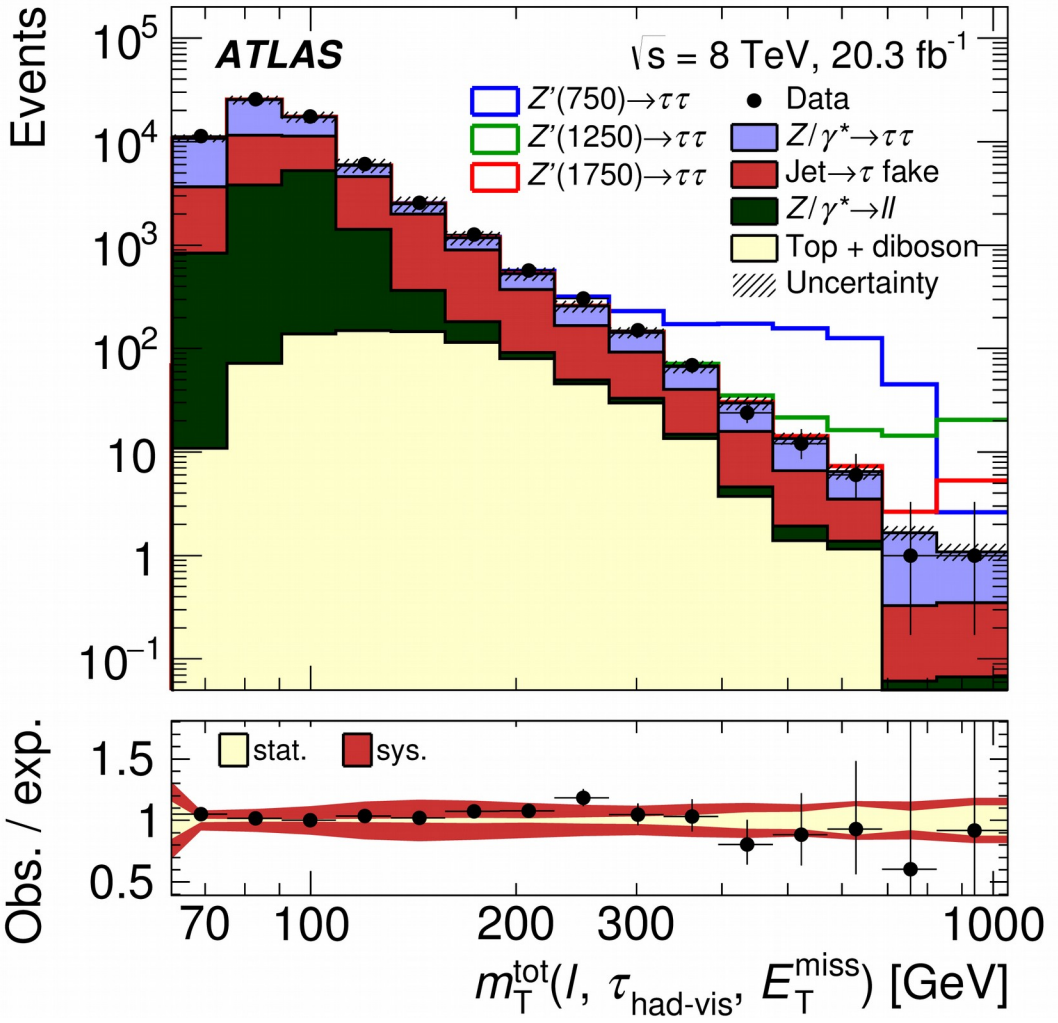
Results – Total Transverse Mass

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

$\tau_{had}\tau_{had}$ – channel



$\tau_{\mu}\tau_{had}$ and $\tau_{e}\tau_{had}$ channels combined

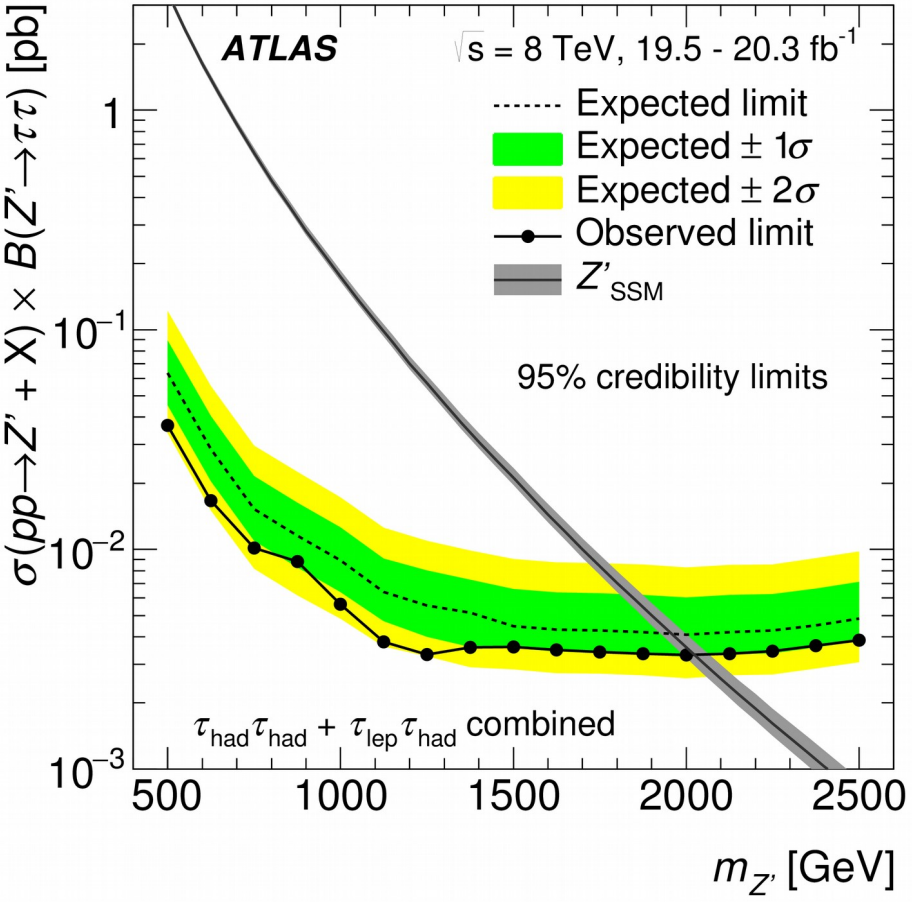


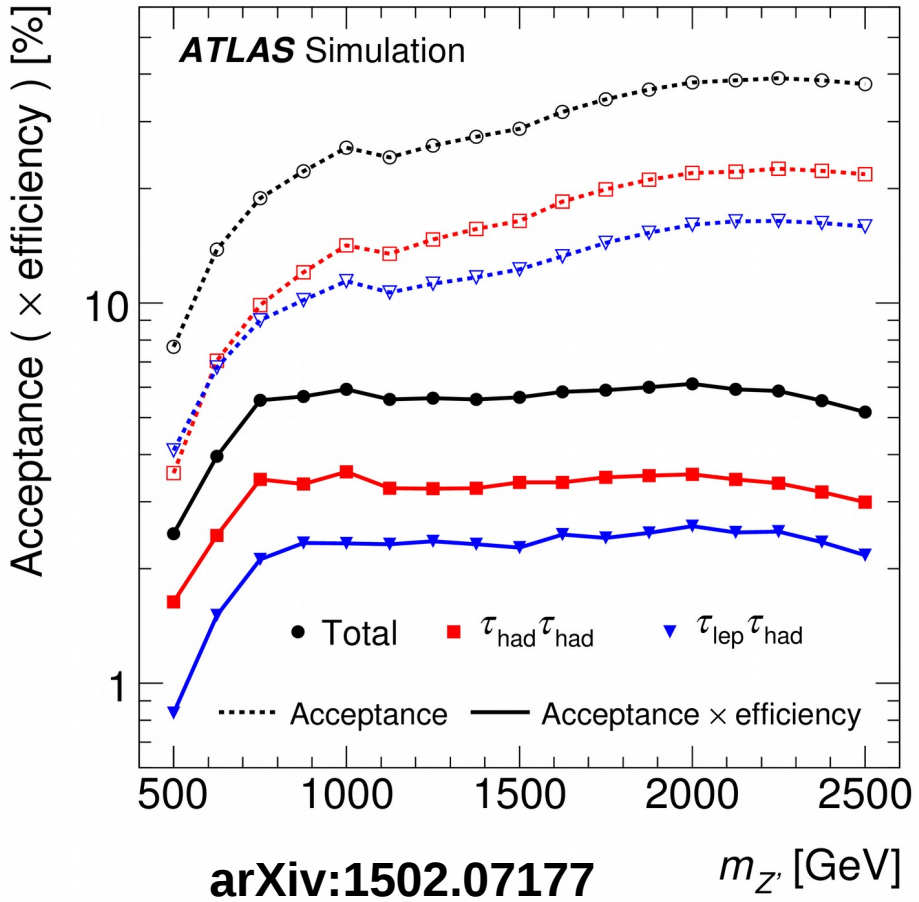
arXiv:1502.07177

Results – Z'_{SSM}

- Set 95% credibility lower limits on Z'_{SSM} mass
- Measured acceptance (x efficiency)

	observed	expected
$\tau_{had}\tau_{had}$	1.88 TeV	1.79 TeV
$\tau_{\mu}\tau_{had}$	1.59 TeV	1.58 TeV
$\tau_{e}\tau_{had}$	1.55 TeV	1.64 TeV
combination	2.02 TeV	1.94 TeV





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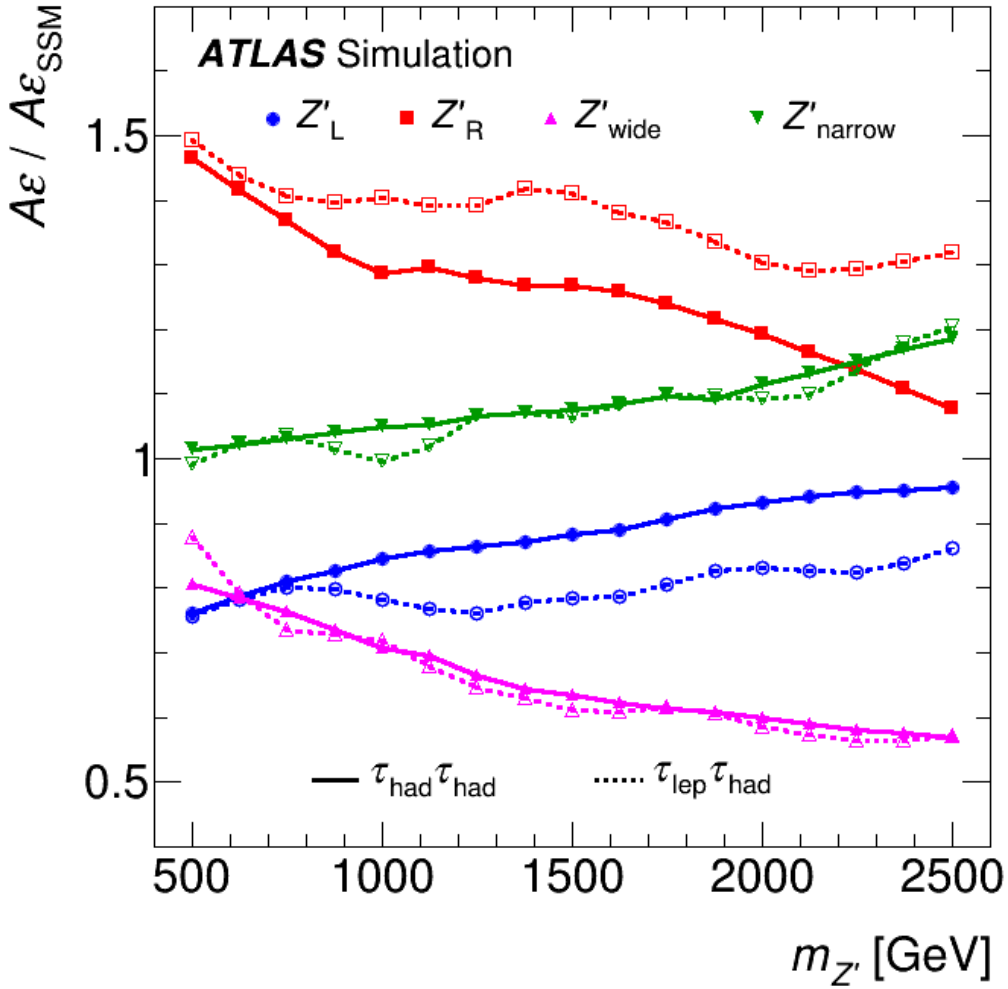
Impact of model variations on Z' acceptance

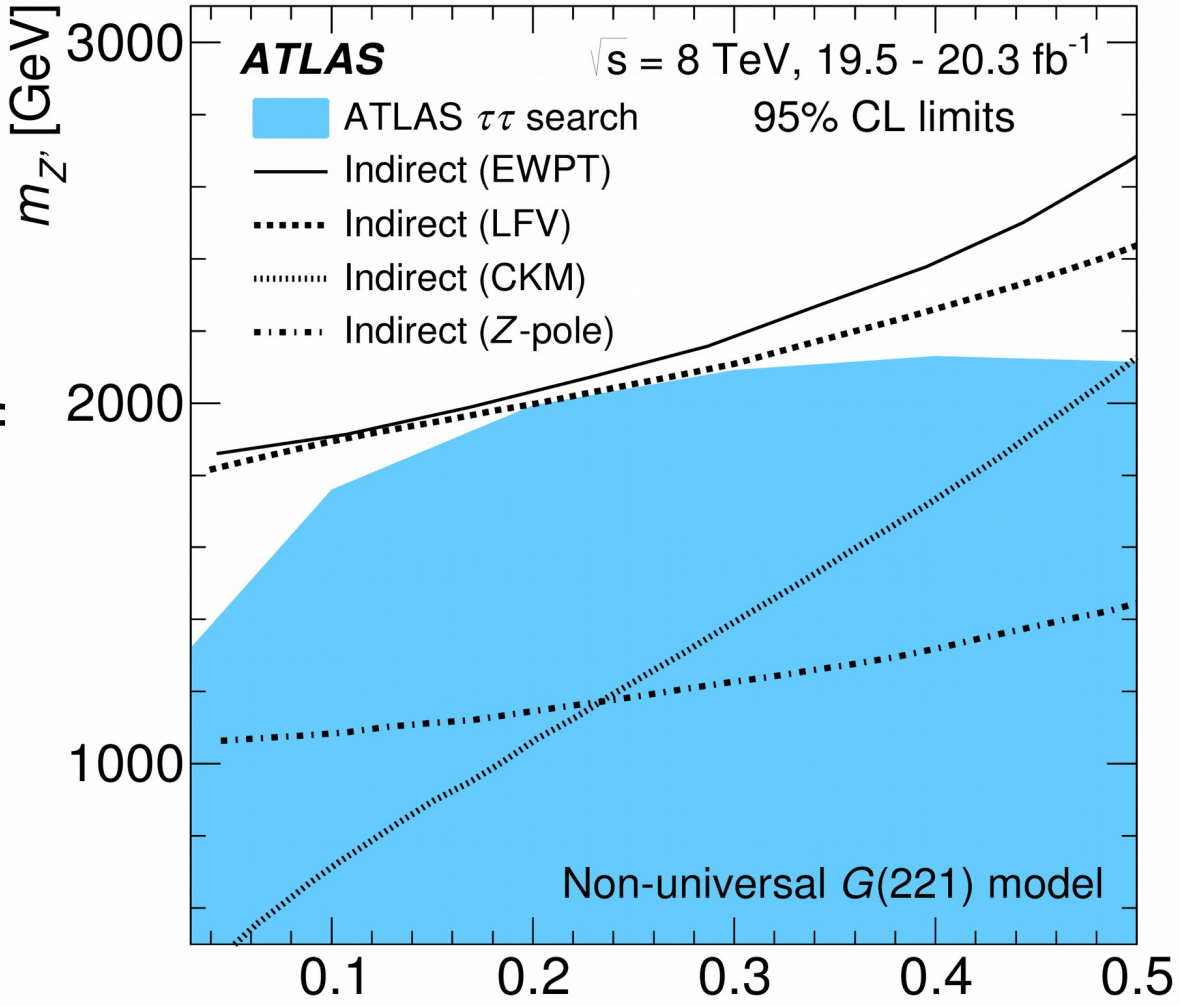
- Variations of couplings to left/right handed fermions
- Variations to wider/narrower decay width



arXiv:1502.07177

Results – NU G(221)

- First direct limits parametrized in $\sin^2\varphi$ (mixing between $SU(2)_h$ and $SU(2)_l$)
- Competitive with indirect searches
- Lower mass limit of 1.3 TeV for small values of $\sin^2\varphi$



arXiv:1502.07177

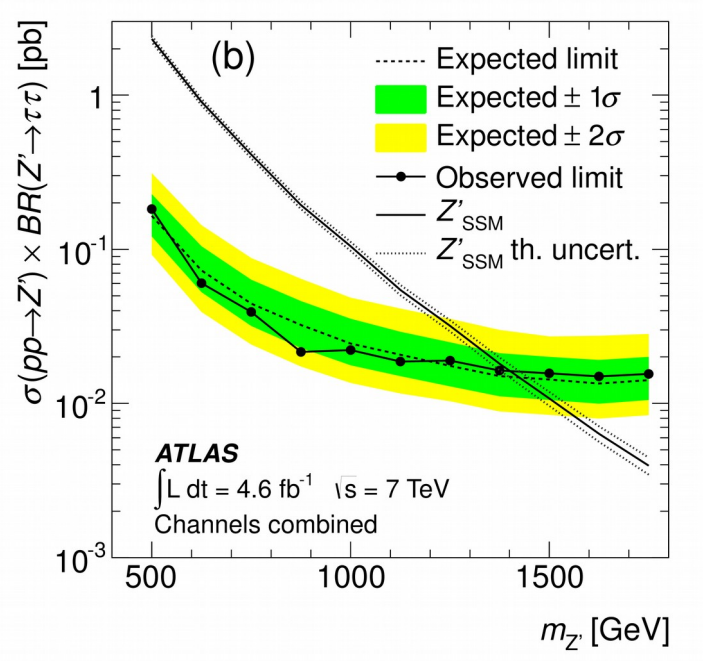
Summary

- Observation is consistent with Standard Model expectation
- Limits set on σ x BR for Z'_{SSM}:
  - observed 2.02 TeV
  - expected 1.94 TeV
- Investigated impact of coupling and decay variations on acceptance
- First direct limits on non-universal G(221) model

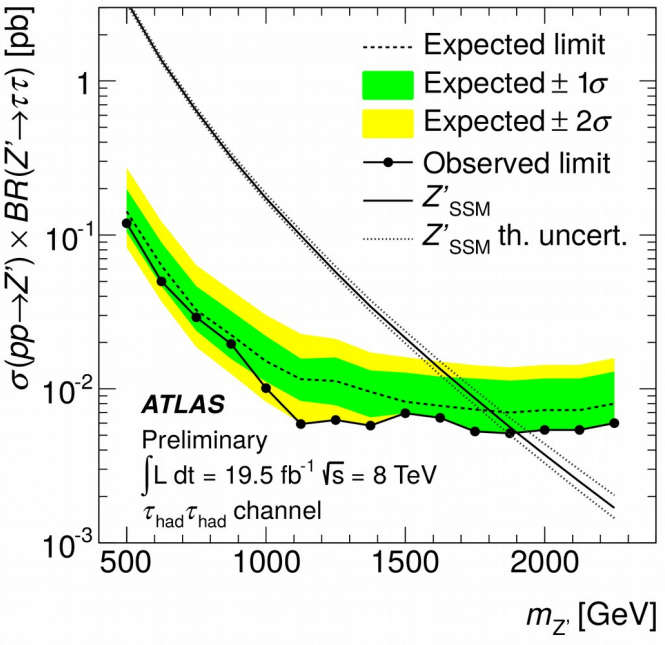
BACKUP

Recent Publications

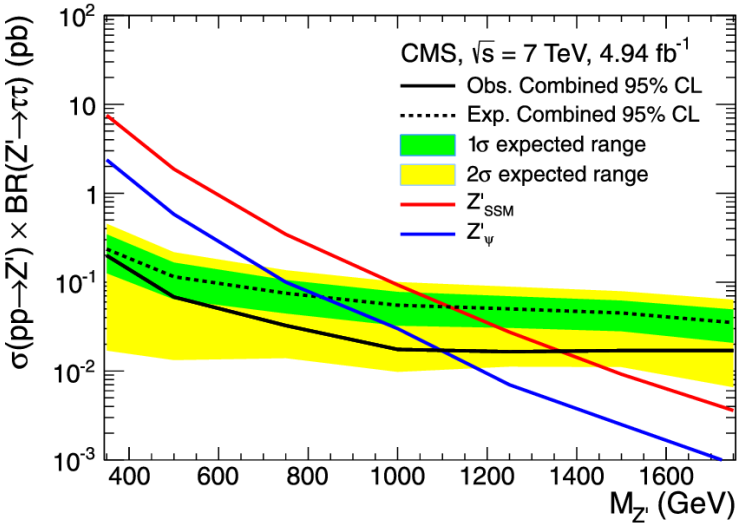
7 TeV Z' → ττ



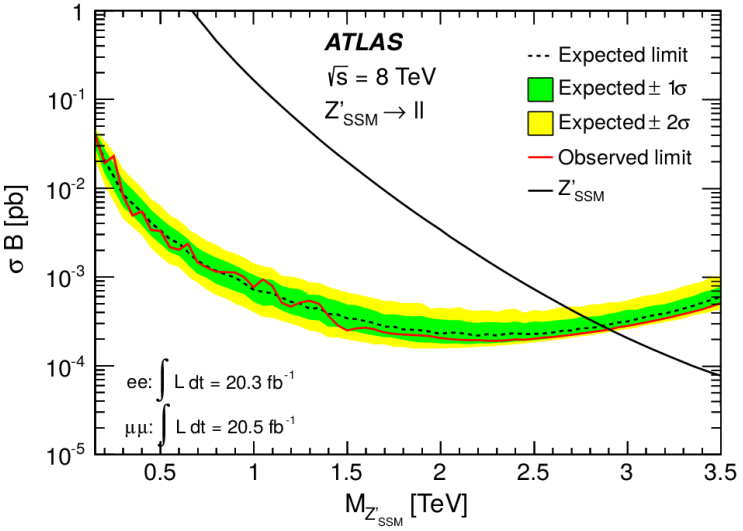
8 TeV Z' → ττ (had had only)



CMS 7 TeV Z' → ττ



8 TeV Z' → leplep



Signal Models

- TauSpinner is used to reweight Z/γ* → ττ to produce Z' signals
- Models:
  - Sequential Standard Model (SSM) is used as a benchmark scenario
    - Couplings are the same as for SM Z boson
  - Variations to purely left/right handed fermion couplings
  - variations to wider and narrower decay widths
  - Non-universal G(221) model

$$SU(2)_l \times SU(2)_h \times U(1)_Y \xrightarrow{u} SU(2)_{l+h} \times U(1)_Y \xrightarrow{v} U(1)_{em}$$

- 17 mass points from 500 GeV up to 2.5 TeV in steps of 125 GeV

Event Samples

- Data:
  - Only data taken with pp collisions in stable beam conditions and with all ATLAS subsystems operational
  - Analyzed 19.5-20.3fb^{-1} for $\tau_{had}\tau_{had}$ and $\tau_{lep}\tau_{had}$ channels
- Backgrounds:
  - Main backgrounds: $Z/\gamma^{*} \rightarrow \tau\tau$, Multijets, W+jets
  - Minor backgrounds: Z+jets, $Z \rightarrow ll$, diboson, single top, $t\bar{t}$

Common Preselection

- **Hadronic Taus:**
  - p_T>20GeV
  - 0<|η|<1.37 or 1.52<|η|<2.47
  - 1 or 3 tracks
  - |Charge| = 1
  - Loose BDT electron veto

- **Muons:**
  - p_T>10GeV
  - |η|<2.5
  - Loose + ID quality
- **Electrons:**
  - p_T>15GeV
  - 0<|η|<1.37 or 1.52<|η|<2.47
  - LoosePP
  - Object Quality
  - B-Layer hit if expected

- **Jets:** Only enter analysis through missing ET

- **Overlap removal:** within ΔR<0.2 with preference: muons, electrons, taus, jets

- **Missing transverse energy:** RefFinal STVF

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

- No electrons, no muons, 2 tau candidates
- Trigger: EF_tau125_medium1, 19.5fb^{-1} (w/o period A)
- τ_1: p_T>150 GeV, matched to trigger
- τ_2: p_T>50 GeV
- Both taus pass tau ID BDT loose
- $q(\tau_1) \times q(\tau_2) = -1$
- $\Delta\varphi(\tau_1,\tau_2) > 2.7$ rad

$\tau_{had}\tau_{had}$ Channel – Multijet Background

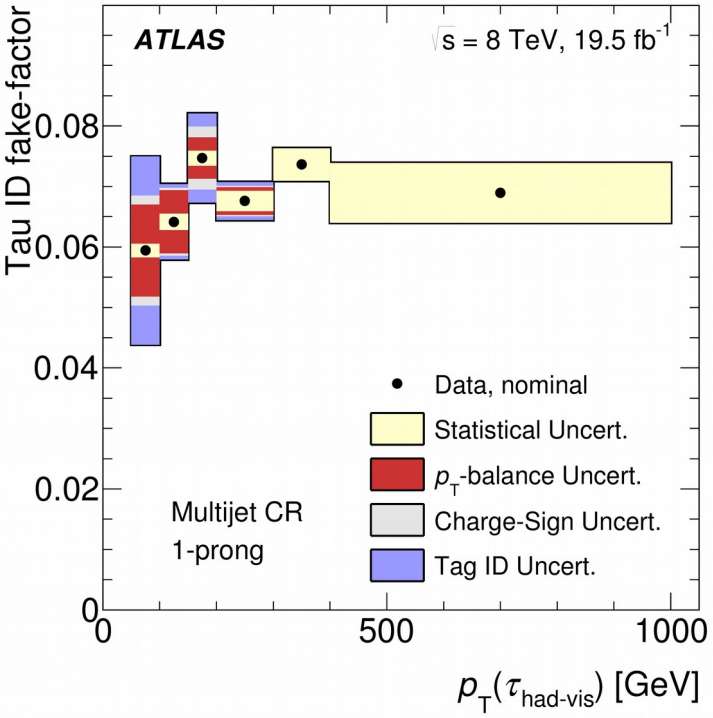
- Modeling from MC inadequate
  ➡ estimation from data
- Fake factors measured in multijet control region
  - Similar to signal region with small variations
    ➡ high multijet purity

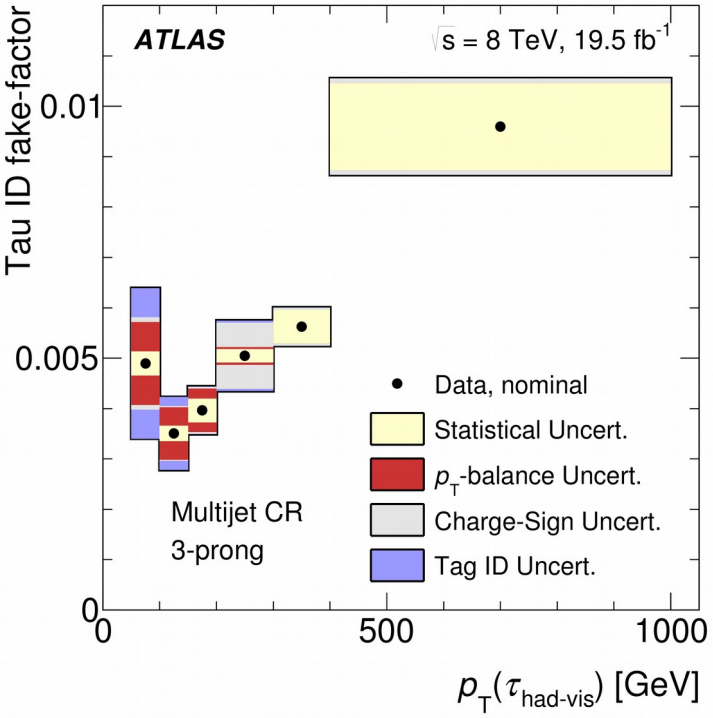
$$f_{\text{tau-ID}}(p_{\text{T}}, N_{\text{track}}) \equiv \left. \frac{N^{\text{pass tau-ID}}(p_{\text{T}}, N_{\text{track}})}{N^{\text{fail tau-ID}}(p_{\text{T}}, N_{\text{track}})} \right|_{\text{multijet}}$$

- Fake factors applied on events where τ_2 fails BDT loose

$$N_{\text{multijet}}(p_{\text{T}}, N_{\text{track}}, x) = f_{\text{tau-ID}}(p_{\text{T}}, N_{\text{track}}) \times N_{\text{data}}^{\text{fail tau-ID}}(p_{\text{T}}, N_{\text{track}}, x)$$

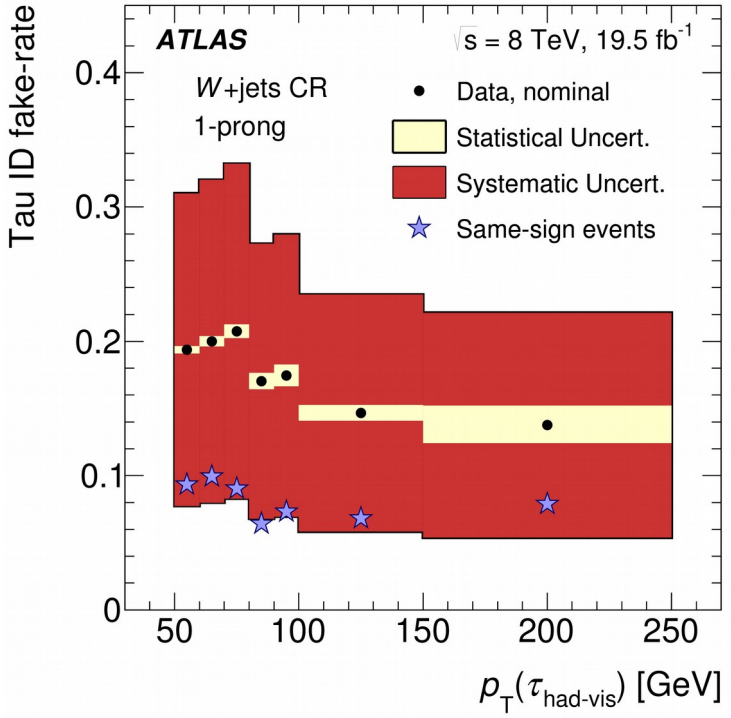
- Uncertainties account for:
  - Statistical uncertainty
  - Variations made for multijet control region

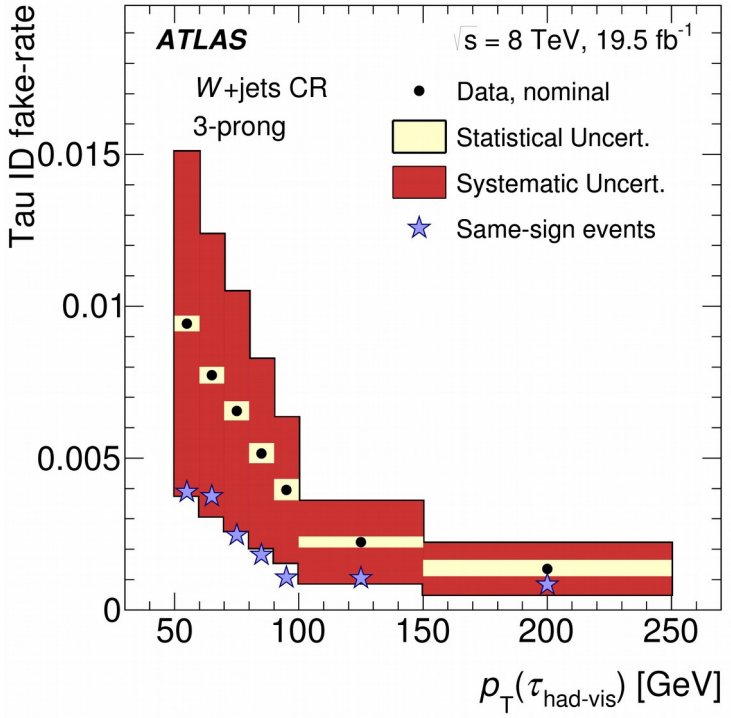




$\tau_{had}\tau_{had}$ Channel – Other Jet Background

- Jet-to-tau fake rate mis-modeled in MC
- Fake rates measured in W+jets control region in data
- BDT loose requirement dropped for simulated quark- and gluon-initiated jets
- Instead apply fake rates
- Uncertainties account for:
  - Statistical uncertainty
  - 60% composition uncertainty





$\tau_\mu\tau_{had}$ and $\tau_e\tau_{had}$ Channel

- $\tau_\mu\tau_{had}$
  - Trigger: EF_mu24i_tight or EF_mu36_tight
  - **Exactly one STACO muon: combined, isolated, $p_T > 30$ GeV**
  - One tau: BDT medium, $p_T > 30$ GeV, **pass muon veto**
  - No additional muons/electrons
  - q(**μ**) x q(**τ**) = -1, **Δφ**(**μ**,**τ**) > 2.7 rad
- $\tau_e\tau_{had}$
  - Trigger: EF_e24vhi_medium1 or EF_e60_medium1
  - **Exactly one electron: tight++, isolated, $p_T > 30$ GeV**
  - One tau: BDT medium, $p_T > 30$ GeV, **pass medium electron veto**
  - No additional muons/electrons
  - q(e) x q(**τ**) = -1, **Δφ**(e,**τ**) > 2.7 rad

$\tau_\mu\tau_{had}$ and $\tau_e\tau_{had}$ Channel – Jet Background

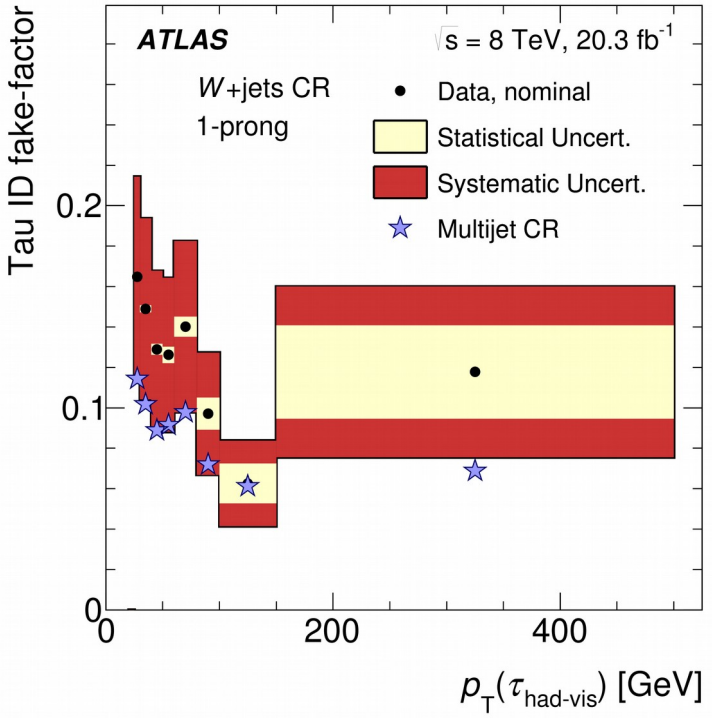
- Fake factor measured in W+jets control region in data

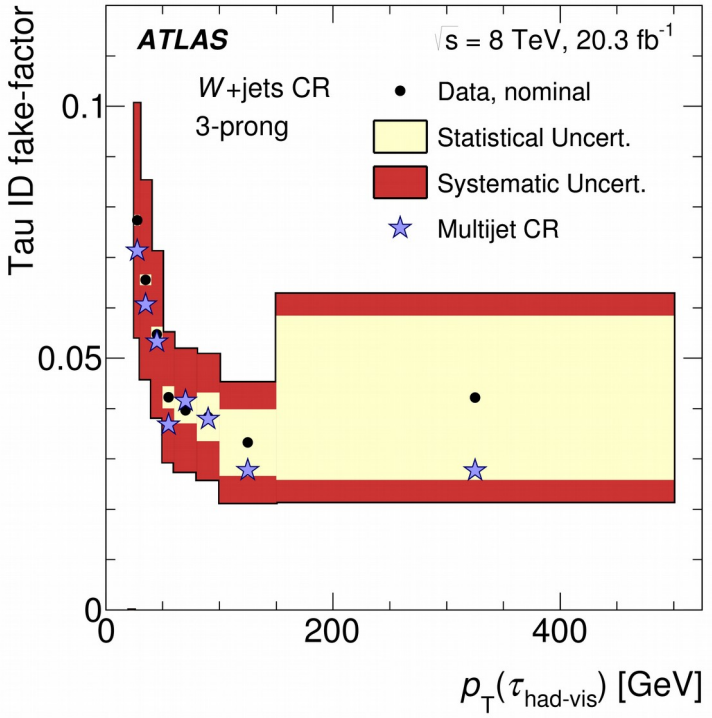
$$f_\tau(p_T,\eta) \equiv \left.\frac{N^{\text{pass }\tau\text{–ID}}(p_T,\eta)}{N^{\text{fail }\tau\text{–ID}}(p_T,\eta)}\right|_{\text{W–CR}}$$

- MC contributions subtracted for fake factor measurement and application

$$N_{W+\text{jet}}(p_T,\eta,x) = f_\tau(p_T,\eta)\cdot\left(N_{\text{data}}^{\text{fail }\tau\text{–ID}}(p_T,\eta,x) - N_{\text{MC}}^{\text{fail }\tau\text{–ID}}(p_T,\eta,x)\right)$$

- Uncertainties account for:
  - Statistical uncertainty
  - 25% uncertainty derived from deviation to multijet control region





Results – Z'_{SSM}

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- Measured acceptance (x efficiency)

	observed	expected
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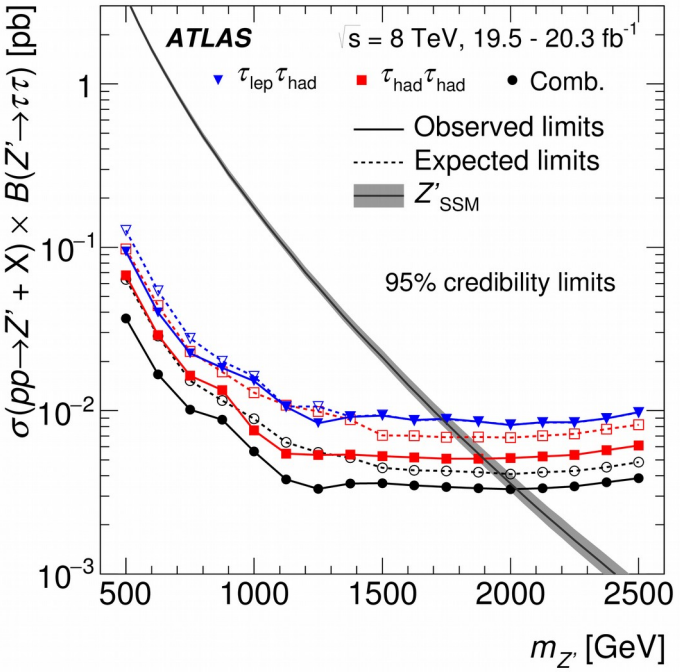

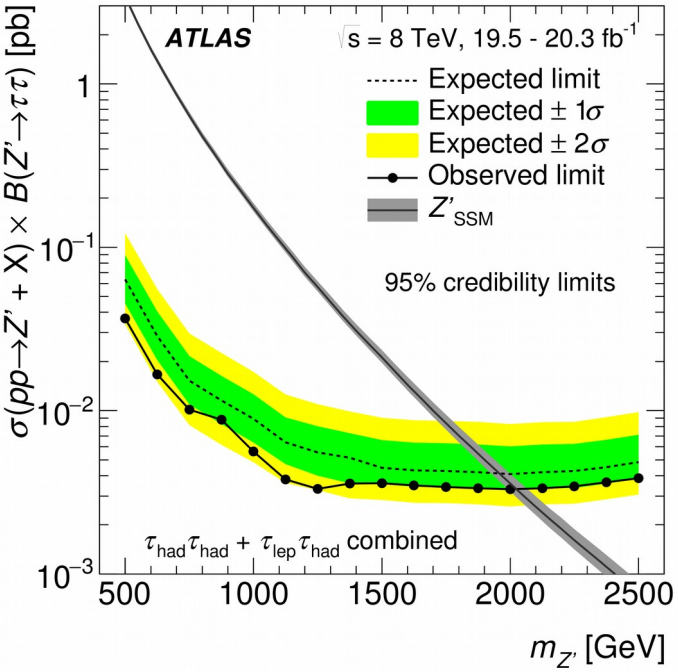

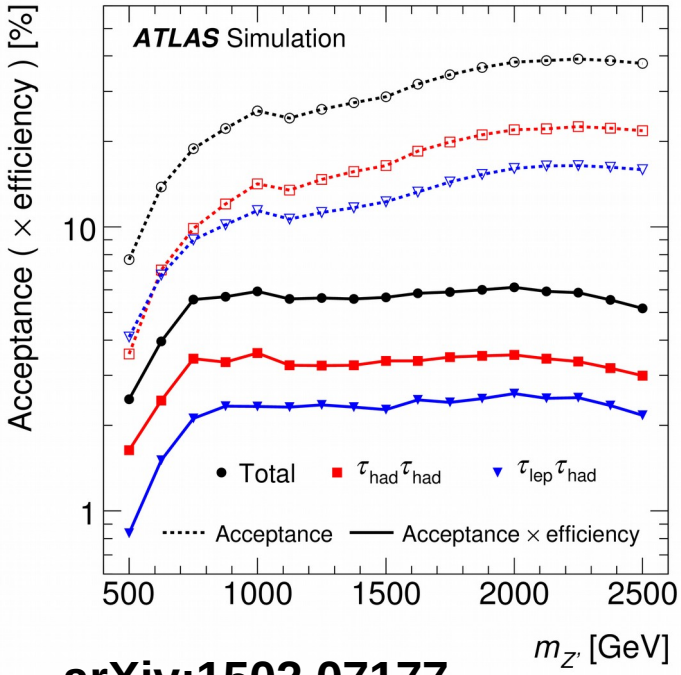

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Results – NU G(221)

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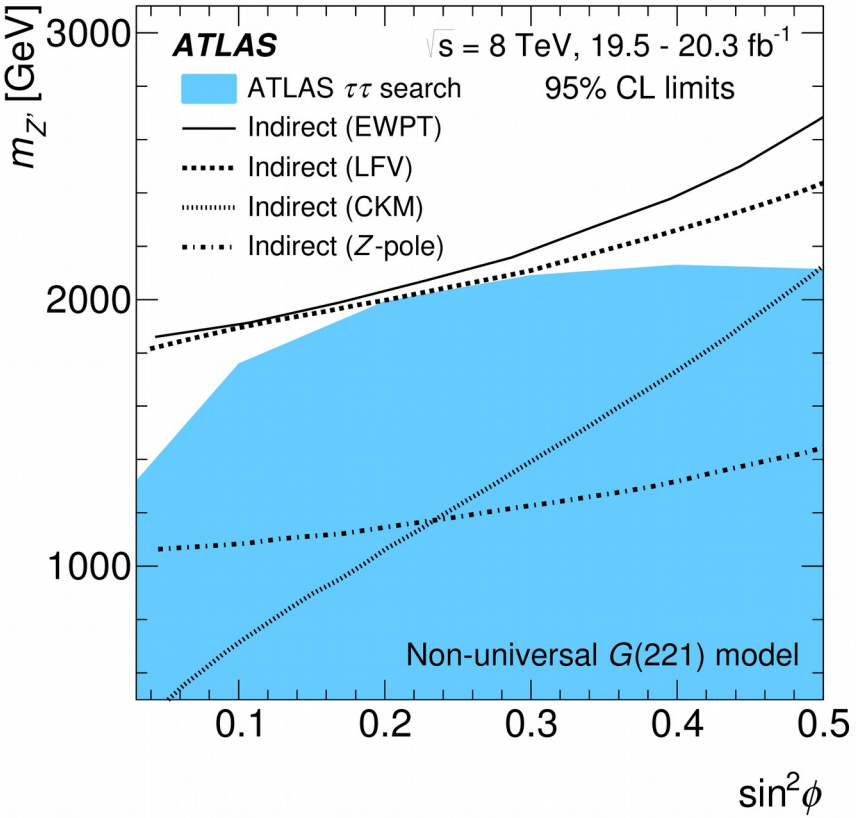
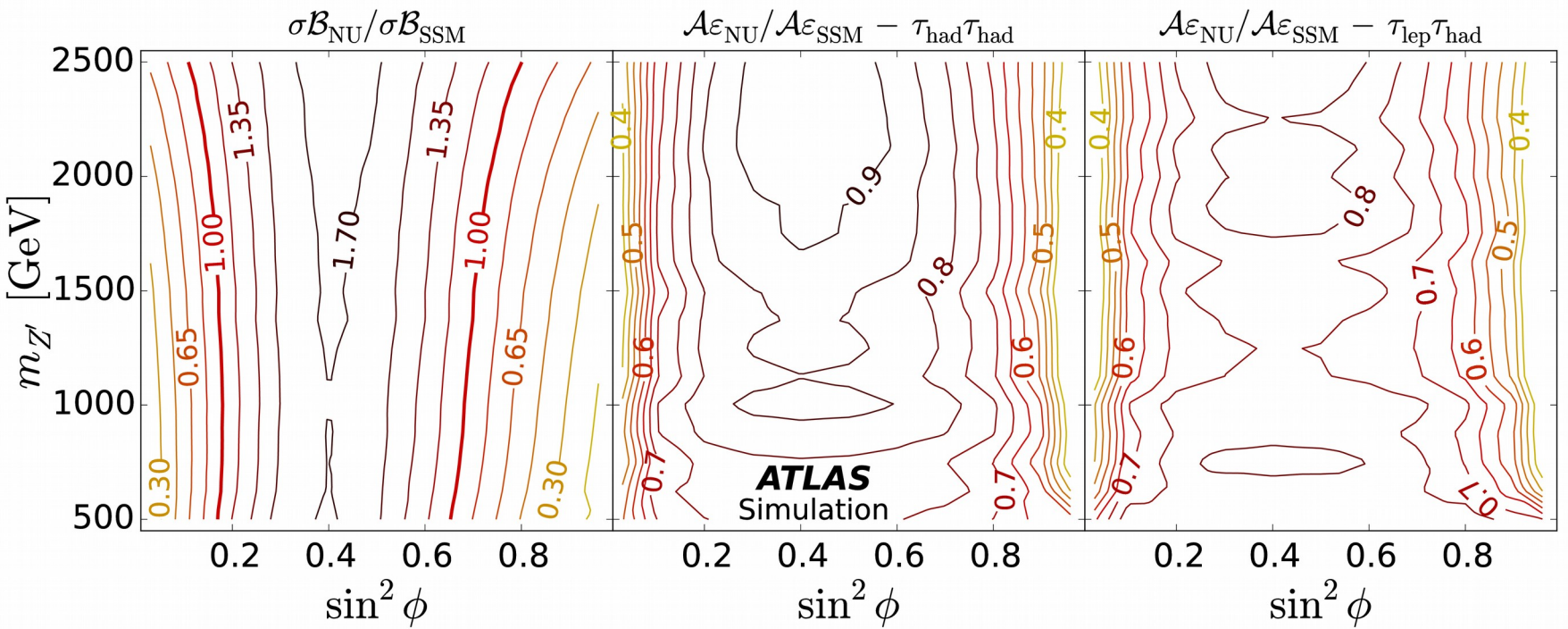
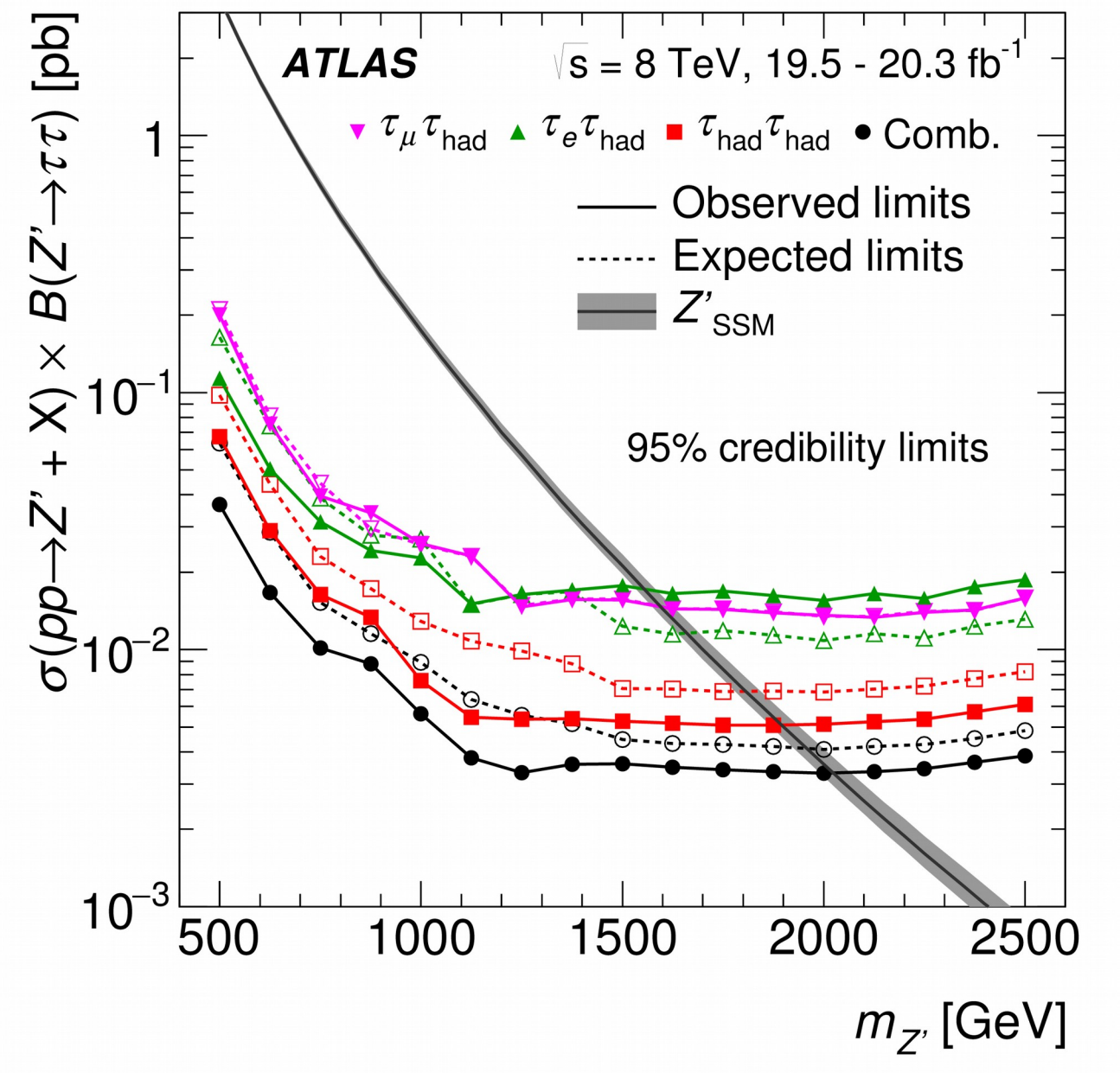
- First direct limits
  - Competitive with indirect searches
  - Lower mass limit of 1.3TeV for small values of $\sin^2\varphi$

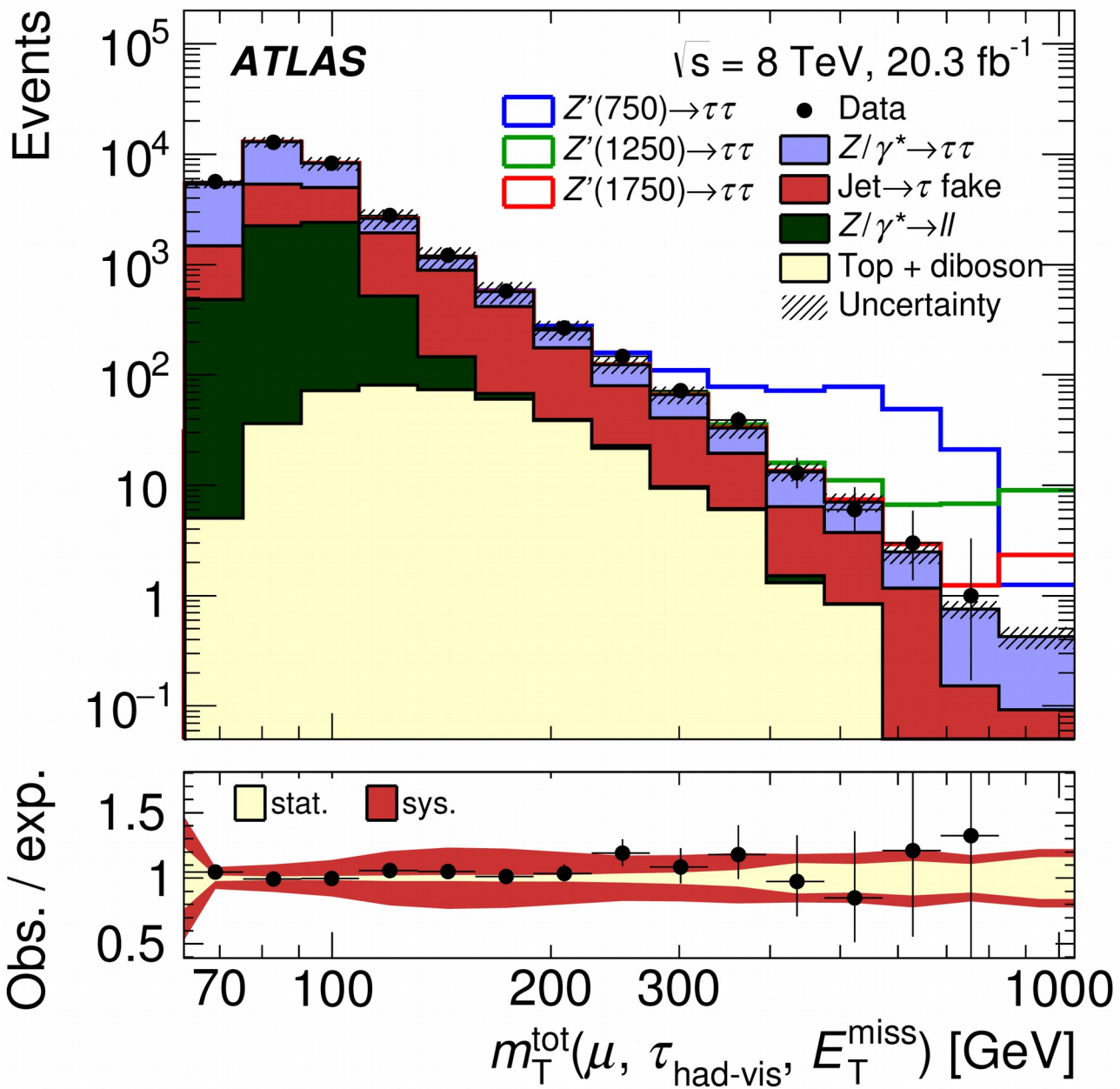




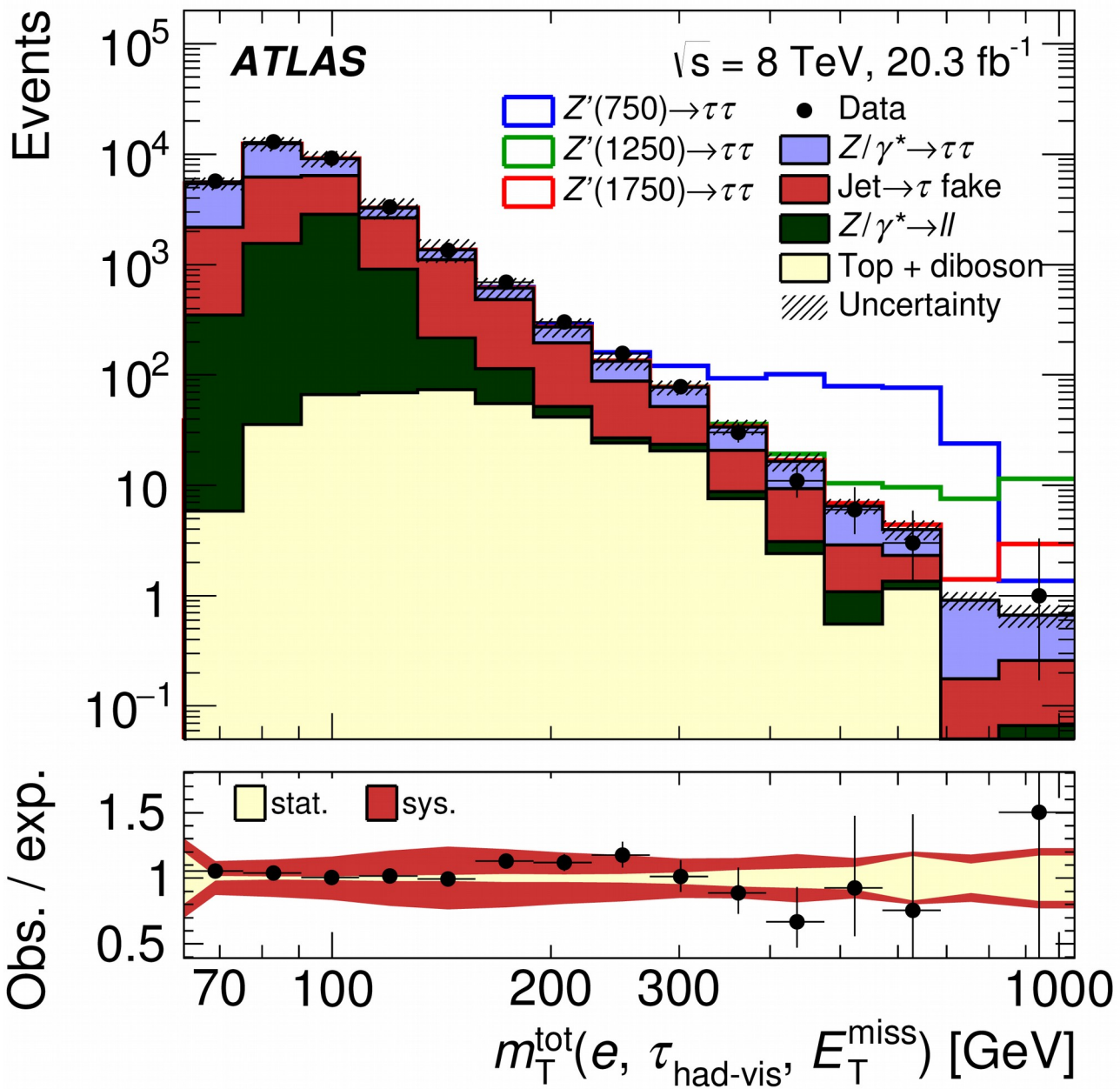
Z' SSM limits with $\tau_e\tau_{had}$ and $\tau_\mu\tau_{had}$ shown separately



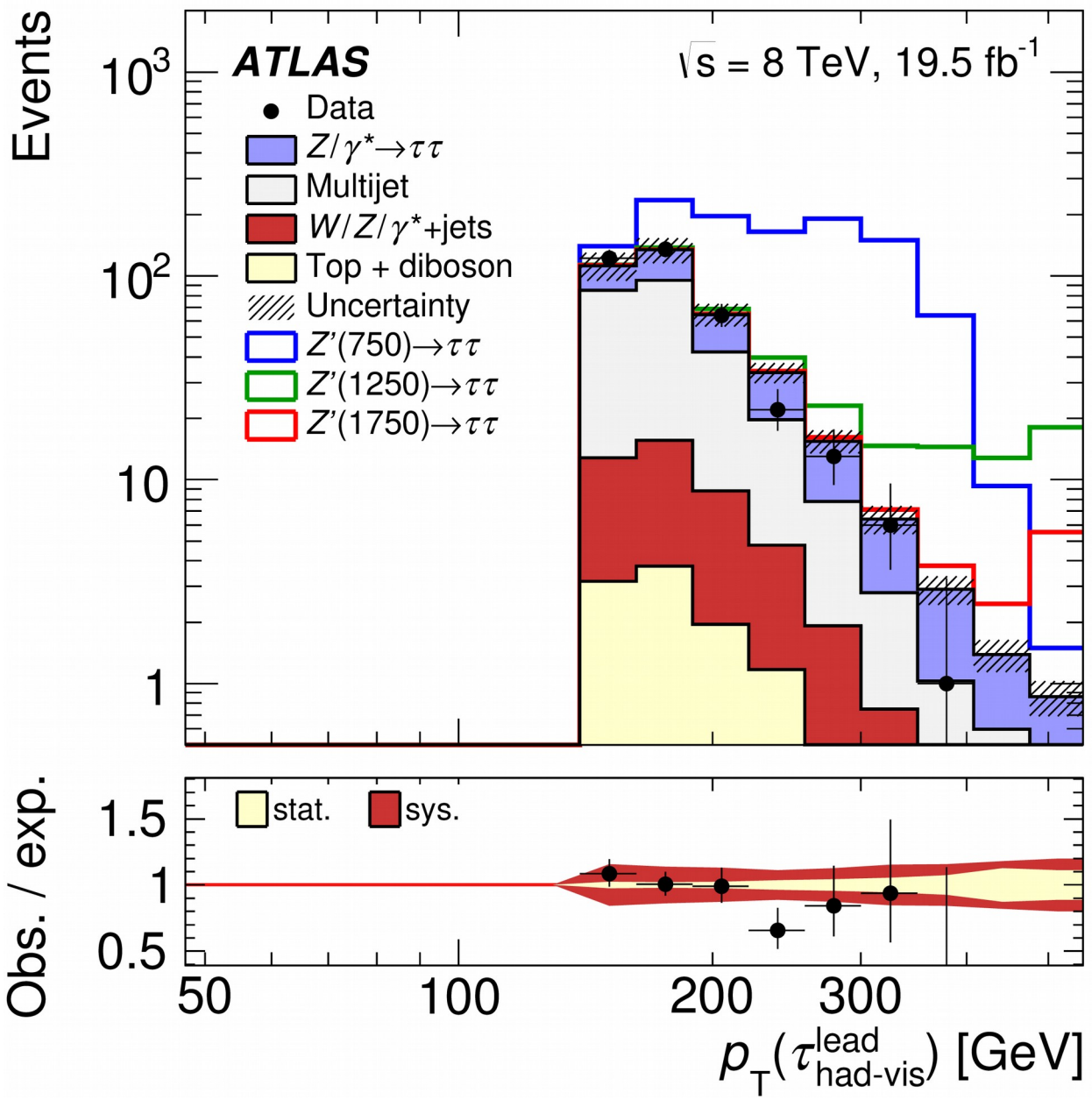
Total transverse mass distribution for $\tau_\mu \tau_{had}$ channel



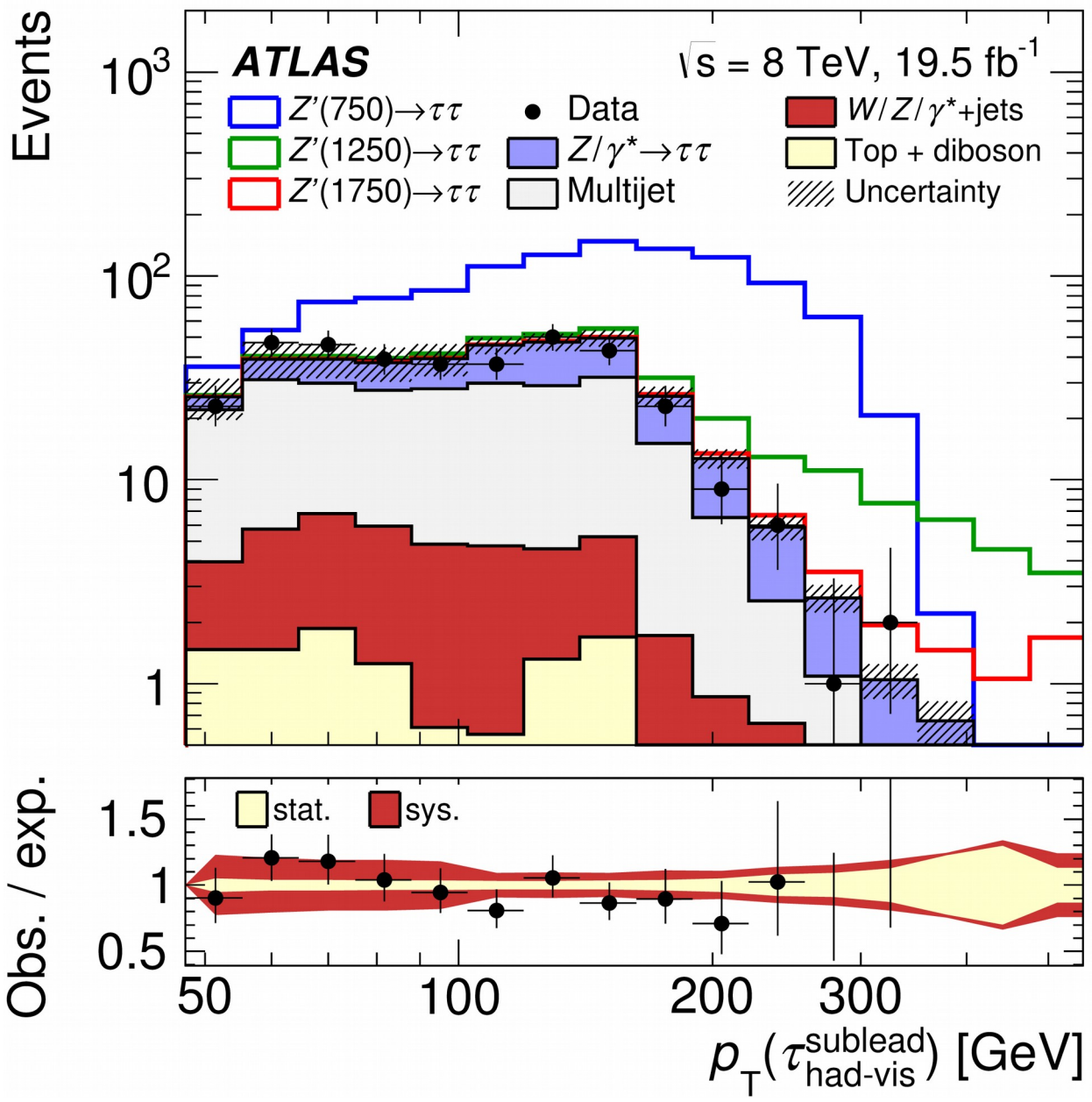
Total transverse mass distribution for $\tau_e\tau_{had}$ channel



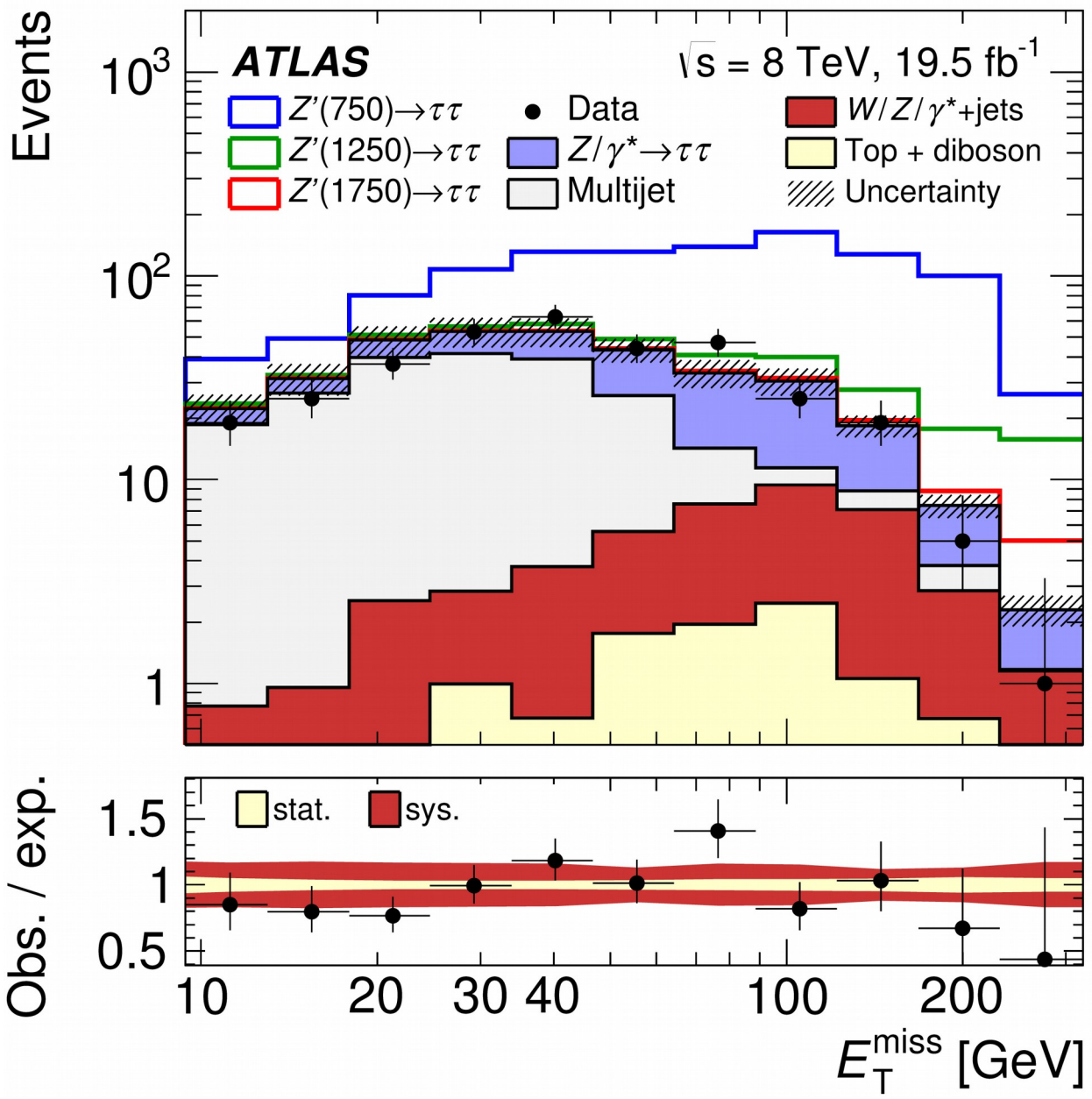
Leading tau transverse momentum in the $\tau_{had}\tau_{had}$ channel



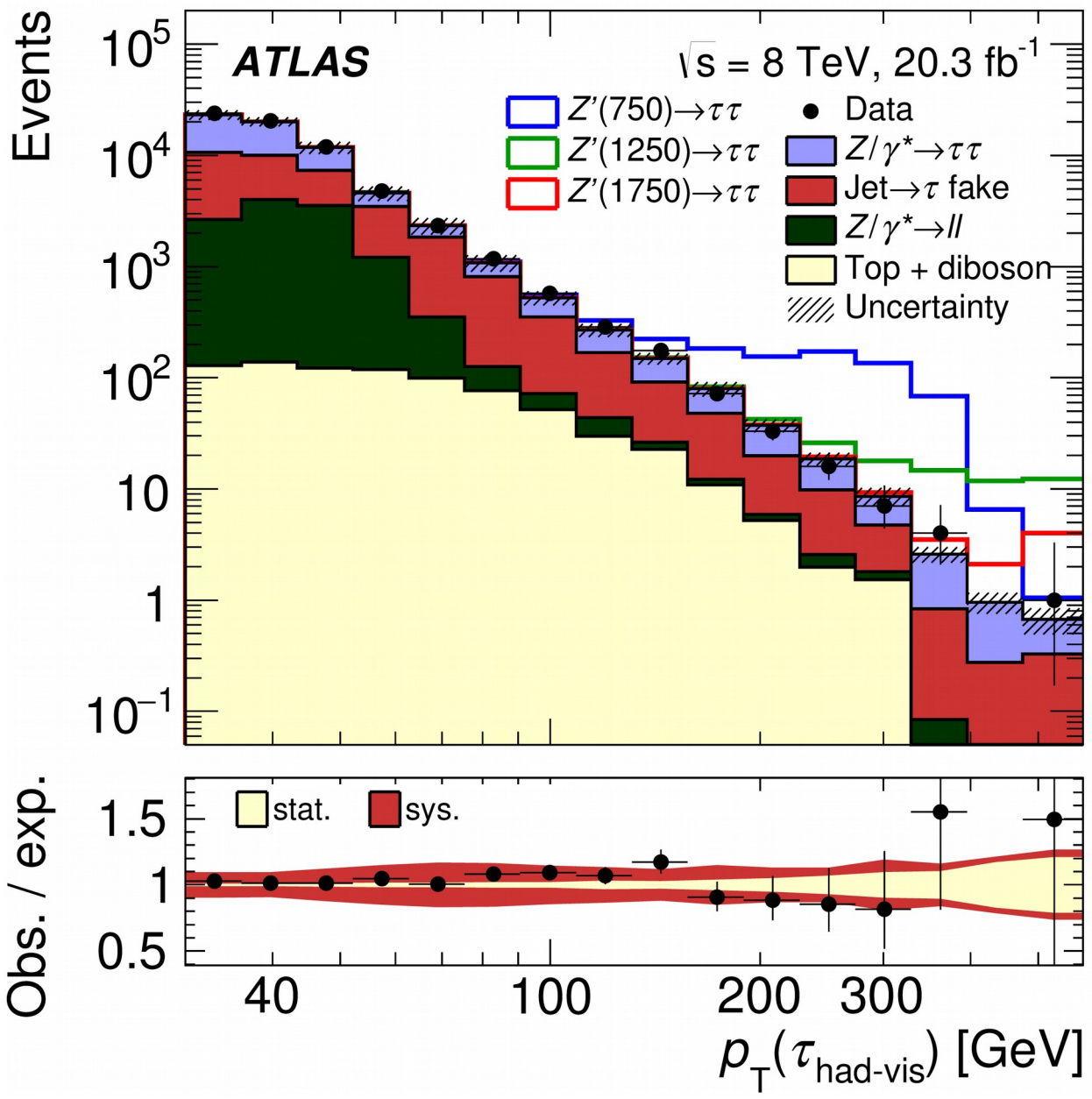
Subleading tau transverse momentum in the $\tau_{had}\tau_{had}$ channel



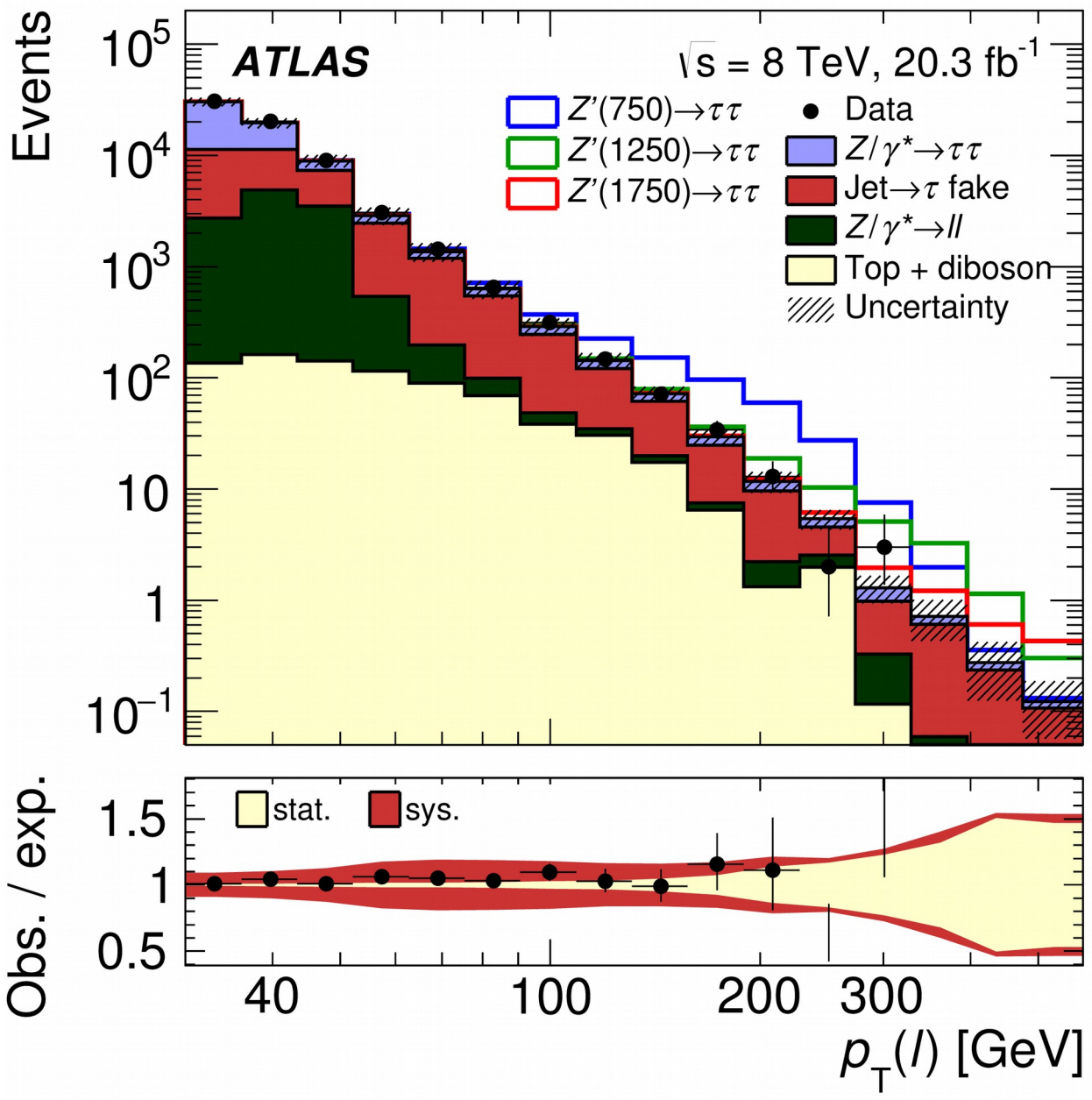
Missing transverse energy in the $\tau_{had}\tau_{had}$ channel



Tau transverse momentum distribution for $\tau_{lep}\tau_{had}$ channel



Lepton transverse momentum distribution for $\tau_{lep}\tau_{had}$ channel



Missing transverse energy in the $\tau_{lep}\tau_{had}$ channel