Searches for new phenomena with tau leptons in the final state using the ATLAS detector

Masahiro Kuze
Tokyo Institute of Technology

TAU2018 Amsterdam
25/Sep/2018

The Large Hadron Collider

- Completed in 2008, CERN, Geneva
- Physics runs in 2010 - 2012 (Run 1)
  and 2015 - 2018 (Run 2)

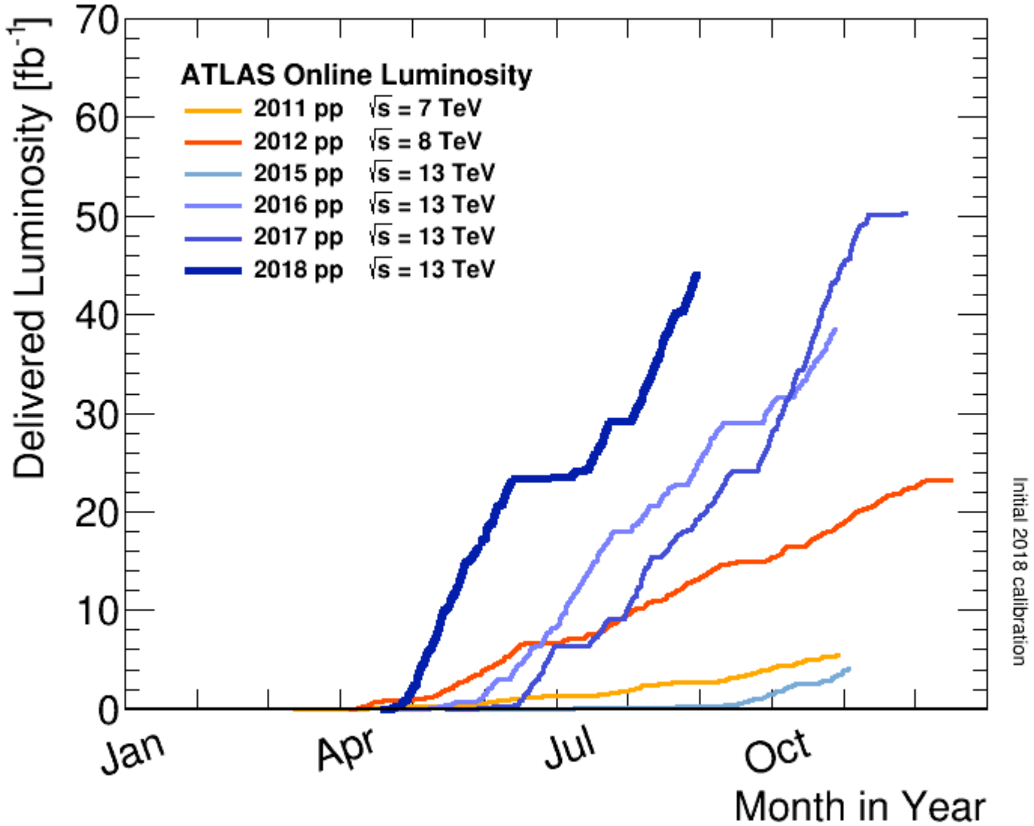
- pp collisions at
  $\sqrt{s}$ = 7 TeV (3.5 + 3.5) for 2010-11
  $\sqrt{s}$ = 8 TeV (4 + 4) for 2012
- also Pb+Pb, p+Pb (not covered here)
- Long Shutdown (LS1) 2013-2014

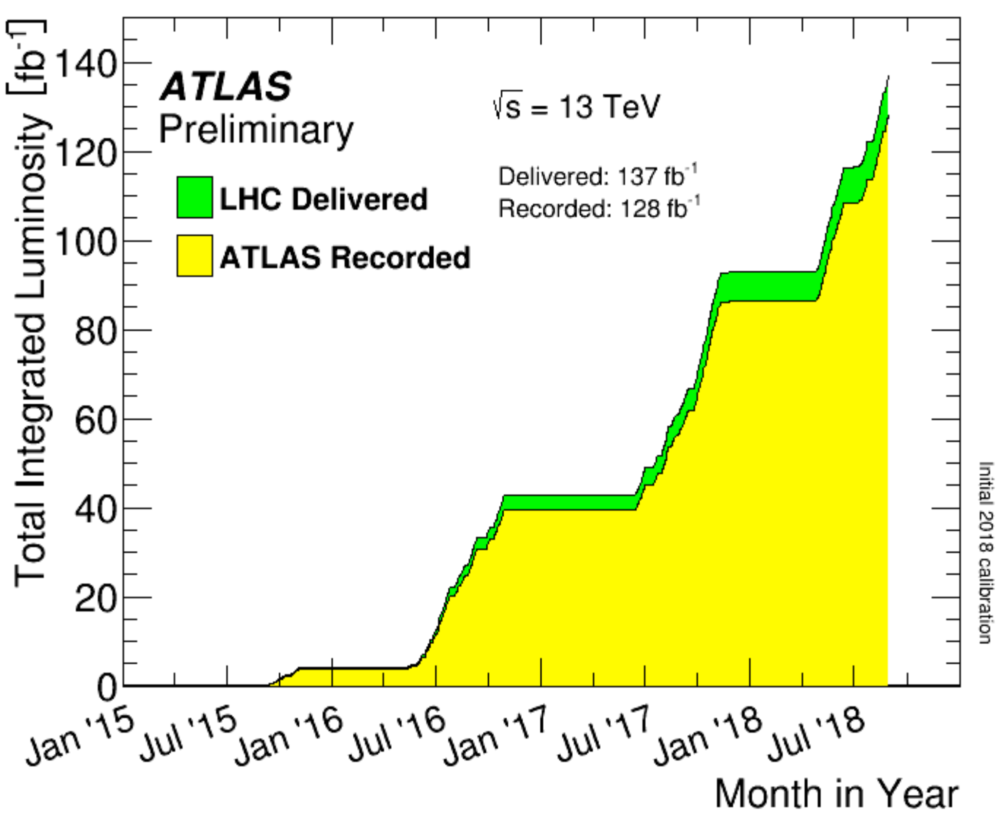
- Run 2 from 2015
  running @ $\sqrt{s}$ = 13 TeV
  (design value = 14 TeV)
- LS2 planned 2019-2020
- Run 3 till 2023

LHC luminosity

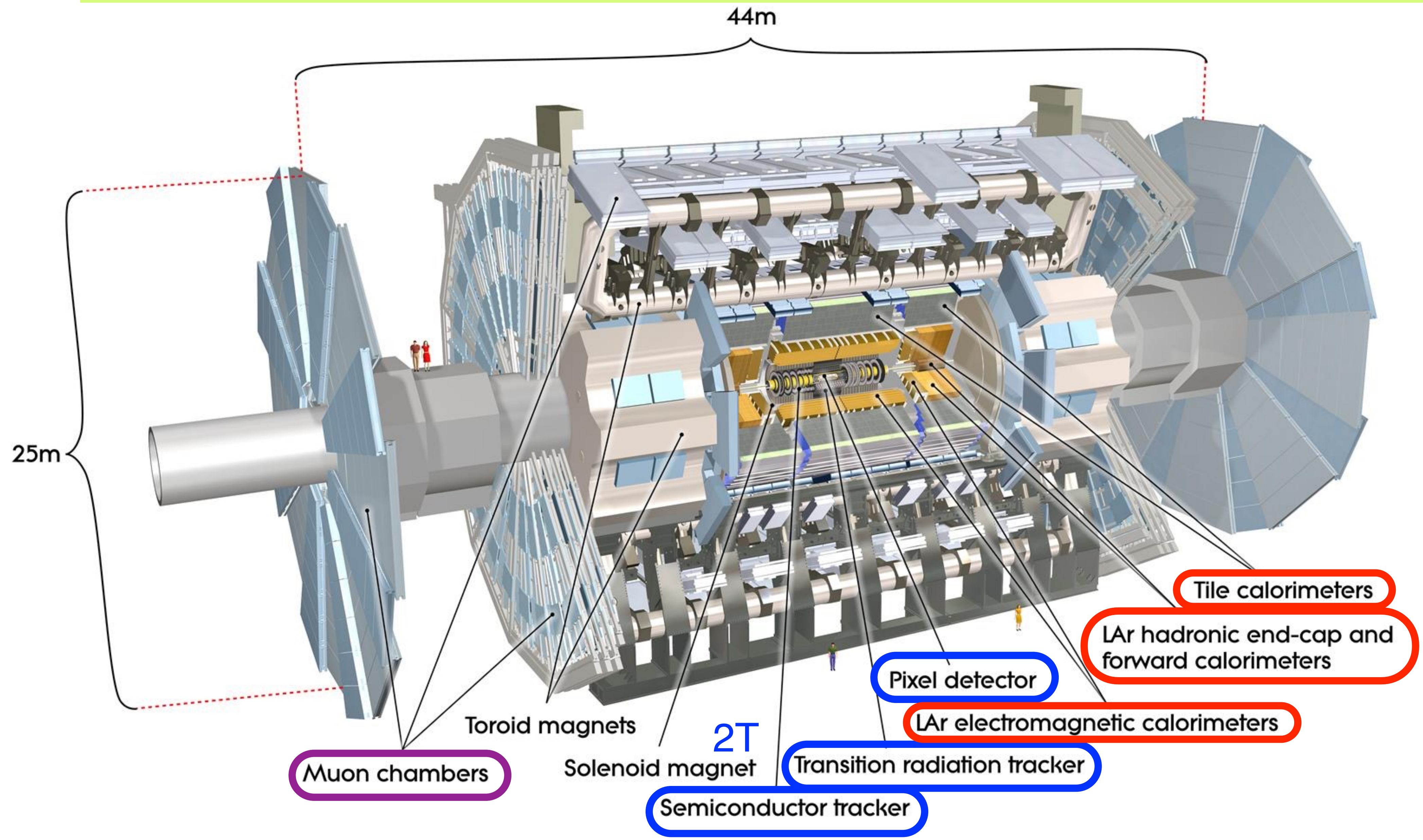
- Run 1
  - 2011, ~5 fb^{-1} @ 7TeV
  - 2012, ~20 fb^{-1} @ 8TeV
- Peak lumi in Run 1 0.75×10^{34} $cm^{-2}\,s^{-1}$

- Run2: peak lumi 2×10^{34} (2018) @ 13TeV (design: 1×10^{34})
- 2015-16: 36.1 fb^{-1}
  2015-17: ~80 fb^{-1}





The ATLAS detector



- Inner Detector tracking (Pixel, SCT, TRT) $|\eta|<2.5$
- EM (LAr) and hadron (Tile+LAr) calorimeters $|\eta|<4.9$
- Muon Spectrometer with toroid magnets $|\eta|<2.7$

Search for BSM with τ's

- 3rd generation (heaviest) lepton may be a unique clue of BSM signatures, e.g.
  - stau in SUSY often considered to be lightest slepton
  - strongest leptonic coupling to Higgs
- Experimentally more complicated than e/μ
  - largest BR to hadrons: separation from jets
  - leptonic decays hard to distinguish from e/μ
  - includes at least one ν (missing E_T)
- Sophisticated identification methods
  - Refer to talk by A.-C. Le Bihan

τ ID in ATLAS (in short)

- 1-track and 3-track $\tau_{\text{had-vis}}$ candidates, seeded from anti-k_t jets with R=0.4
- Identification using Boosted Decision Tree using calorimeter- and track-related variables
- loose, medium and tight working points
  - e.g. in $W' \to \tau\nu$ search, loose criteria are used
  - Efficiency ~ 60% @ p_T=100 GeV, 30% @ 2 TeV

References:

Run 1 paper: EPJC75(2015)303 1412.7086

Run 2 update: ATL-PHYS-PUB-2015-045

Run 2 performance: ATLAS-CONF-2017-029

Searches covered in this talk

- τ b resonance (3rd gen. scalar leptoquark)
  - Lepton-quark unification: bosons with both B and L
  - 7 TeV result
- Multi (>=3) lepton production (excited l/ν, $H^{\pm\pm}$)
  - Compositeness: excited states of fermions
  - 7 TeV and 8 TeV results
- di-τ resonance search (Z'$\rightarrow\tau\tau$, H$\rightarrow\tau\tau$)
  - Extension of gauge sectors: heavier states of Z/W
  - 7 TeV, 8 TeV and 13 TeV results
- τ and missing momentum (W'$\rightarrow\tau\nu$)
  - 13 TeV result

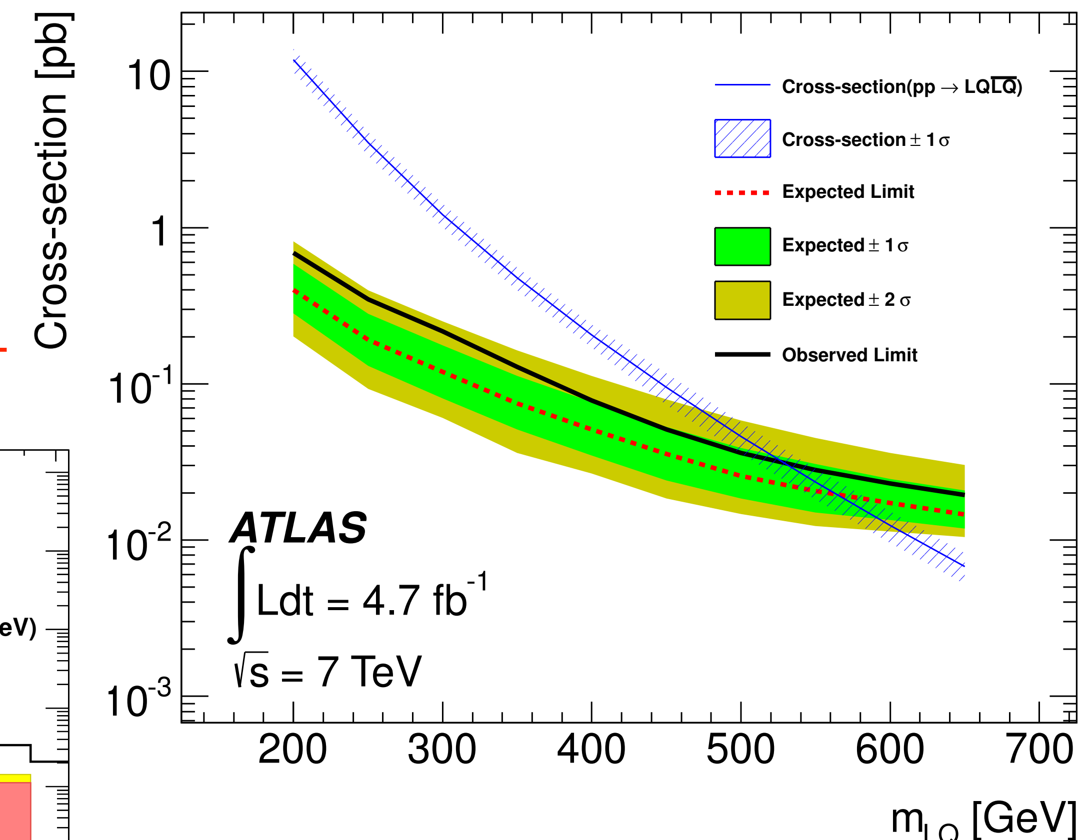
Searches NOT covered here

- For SUSY searches, refer to F. Lyu's talk
- For di-Higgs and BSM Higgs searches, refer to talks by P. Bokan and C. Caputo
- For LFV signatures, refer to B. Le's talk
- For H→leptons (incl. $\tau\tau$), refer to L. Schildgen's
- And, B. Winter's talk on τ polarization in $Z\to\tau\tau$

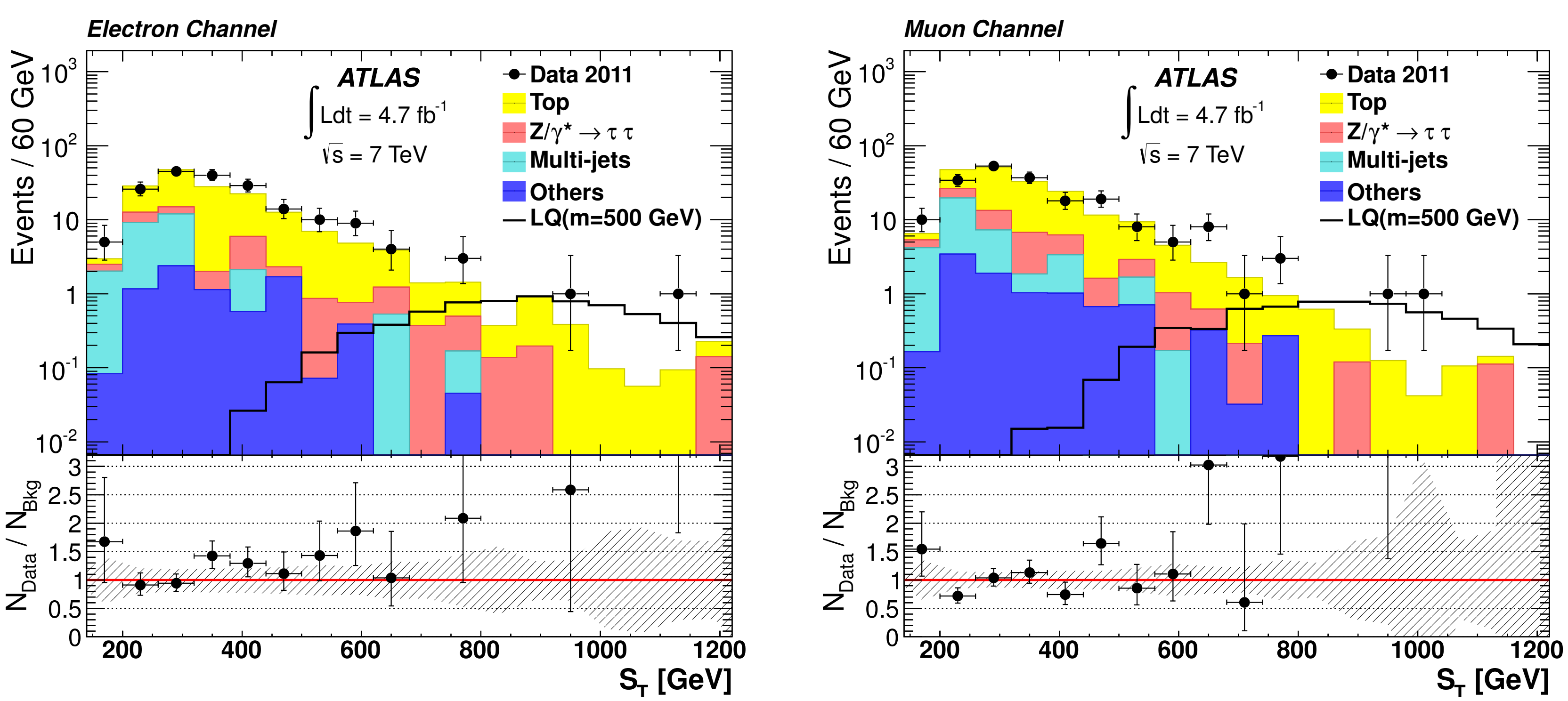
3rd gen. scalar leptoquarks

JHEP06(2013)033 1303.0526

- $LQ_3 LQ_3 \rightarrow \tau b \tau b$ (100% BR assumed)
- $e\tau_{\text{had-vis}} bb+3\nu$ and $\mu\tau_{\text{had-vis}} bb+3\nu$ channels
- m(LQ_3) > 534 GeV



S_T: scalar sum of p_T of e/μ, τ, 2 jets and missing E_T



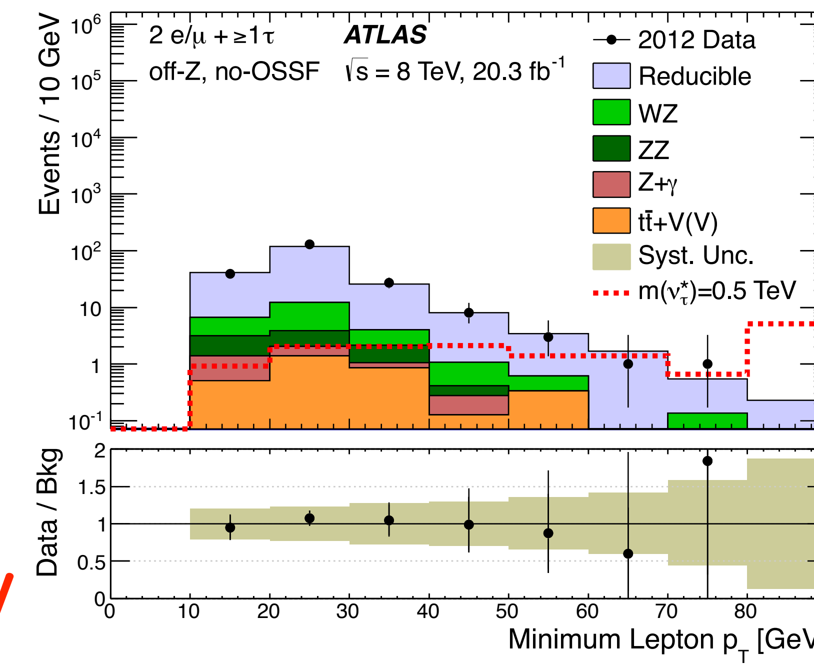
(a) Electron Channel (b) Muon Channel

Generic multi-lepton search

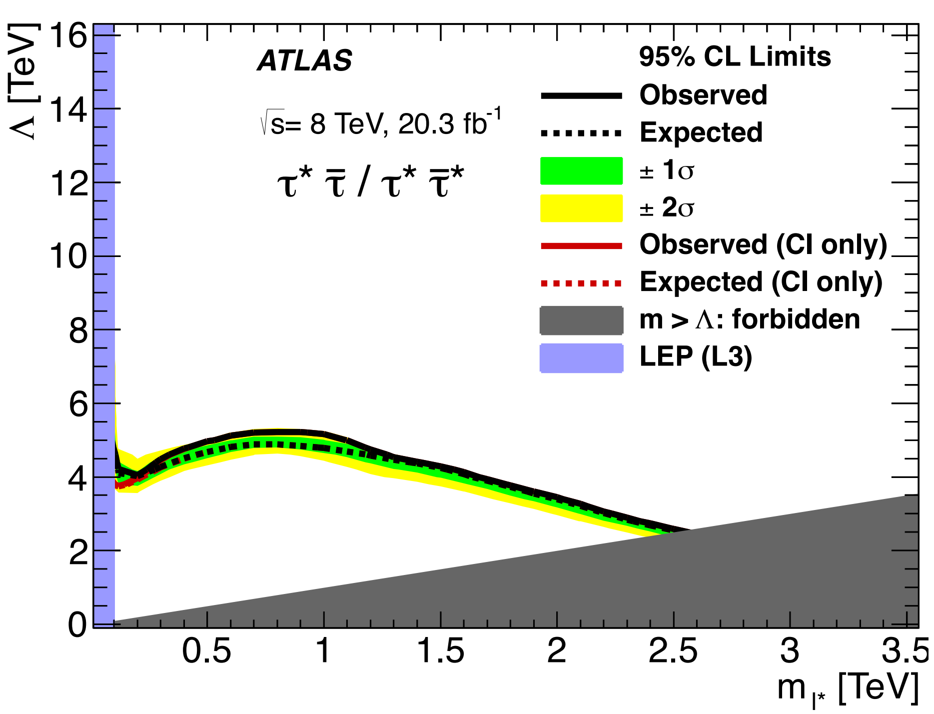
JHEP08(2015)138 1411.2921 (7TeV: PRD87(2013)052002 1211.6312)

- ≧3e/μ, 2e/μ + ≧1τ_{had}, on-Z and off-Z
- Model-independent σ_{vis} limit interpreted as $H^{\pm\pm}\rightarrow e^{\pm}\tau^{\pm}/\mu^{\pm}\tau^{\pm}$ and excited leptons
- $\tau^{*}\rightarrow\tau Z$, $\nu_{\tau}^{*}\rightarrow\tau W$, etc.
- For m(l*)=Λ, m(τ*)>2.5 TeV, m(ν*)>1.6 TeV

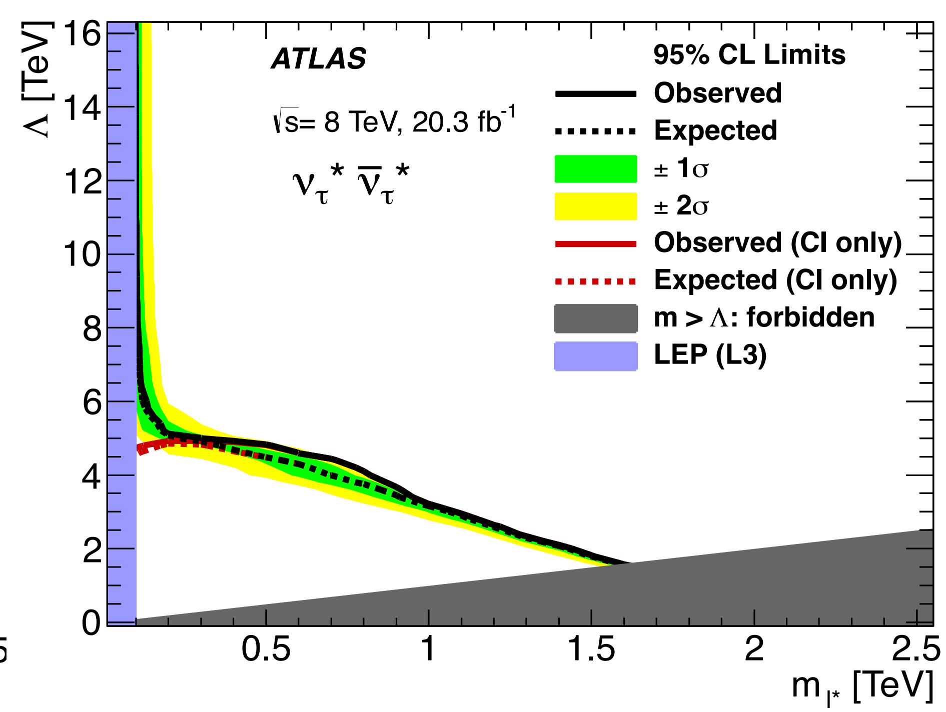
Λ: compositeness scale



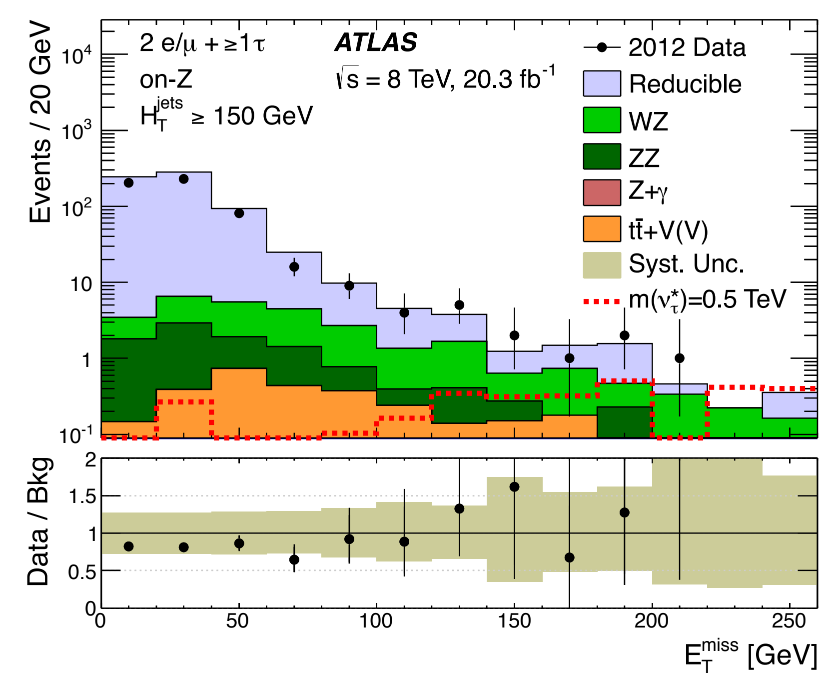
(b) $2e/\mu+\geq 1\tau_{\rm had}$, off-$Z$, no-OSSF



(e) τ^*



(f) ν_τ^*



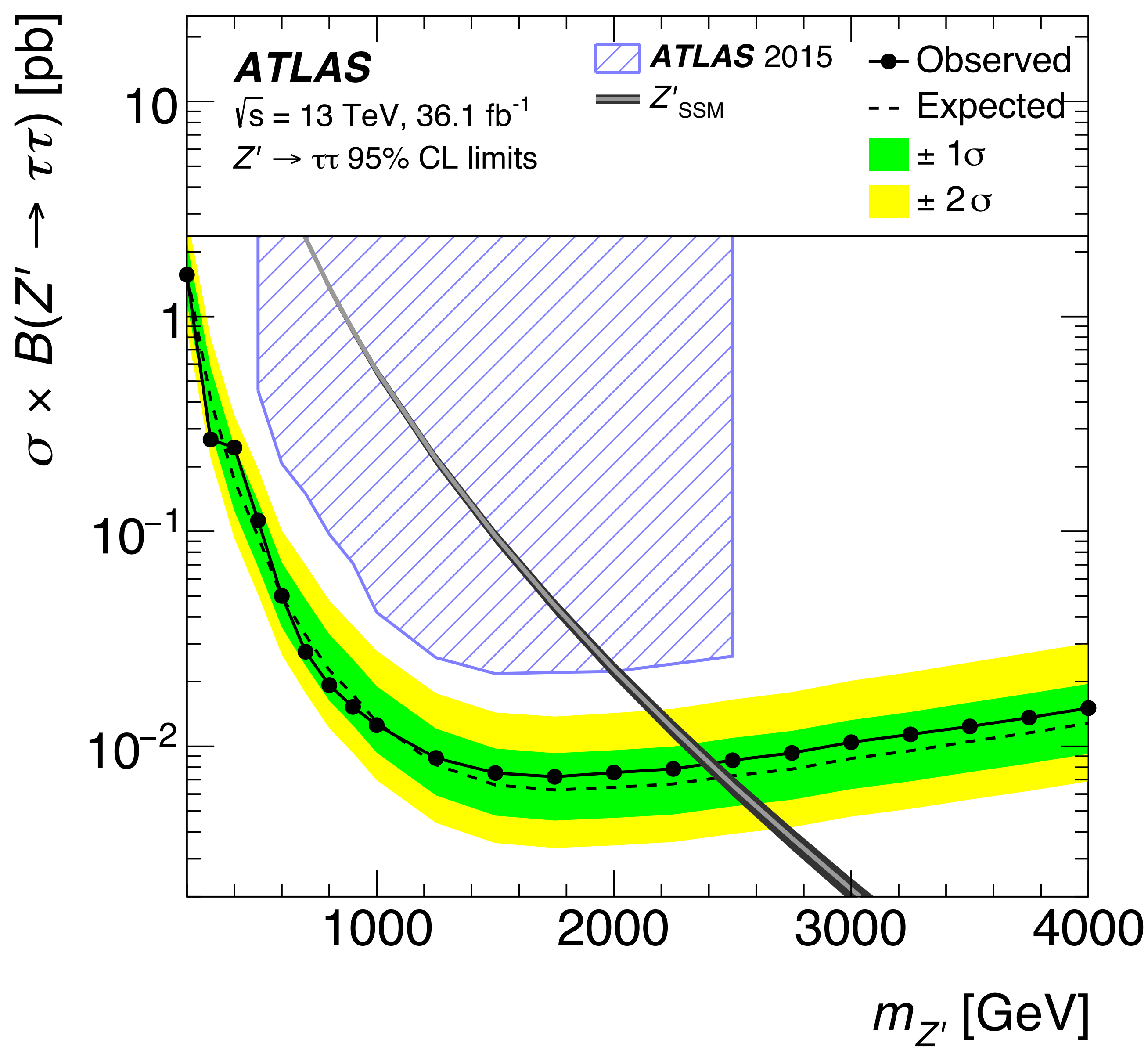
(f) $2e/\mu+\geq 1\tau_{\rm had}$, on-$Z$

Di-τ resonance search

JHEP01(2018)055 1709.07242

(8TeV: JHEP07(2015)157 1502.07177)
(7TeV: PLB719(2013)242 1210.6604)

- Analysis results for BSM H search (see C. Caputo's talk) interpreted for $Z' \to \tau\tau$ limits
- $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ channels (b-veto and b-tag selections in H search were merged)
- m(Z'$_{SSM}$) < 2.42 TeV excluded for Sequential Standard Model
- Results also interpreted in G(221) model (shown later)



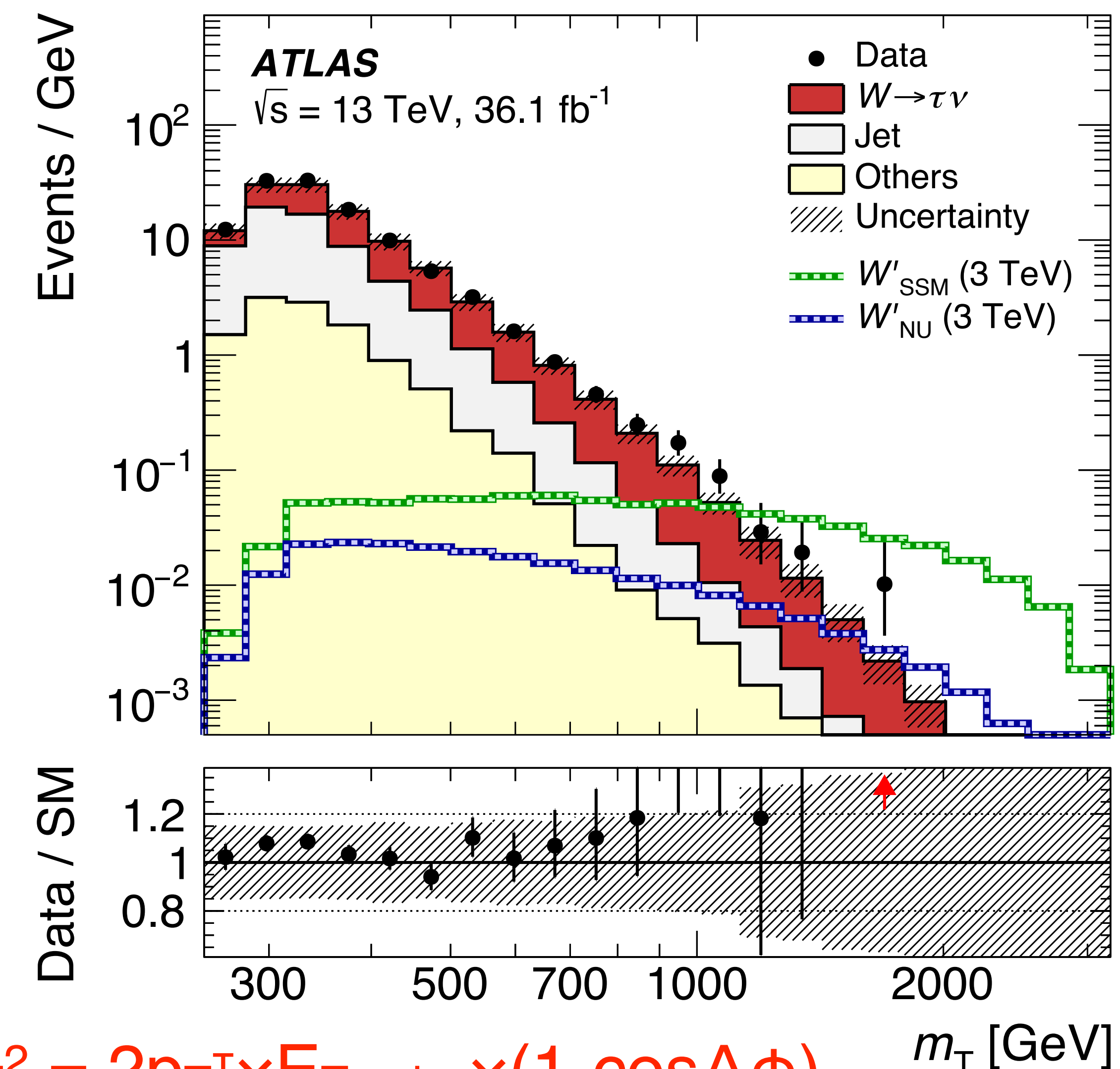
τ +MET resonance search

PRL120(2018)161802 1801.06992

cf. CMS 8TeV: PLB755(2016)196

13TeV: 1807.11421

- First search on this channel by ATLAS
- $\tau_{\text{had-vis}}$ with $p_T > 50$ GeV, $E_{T\_miss} > 150$ GeV
- $0.7 < p_T/E_{T\_miss} < 1.3$, $\Delta\phi > 2.4$
- Main background (BG) from $W \to \tau\nu$ (from MC)
- Jet($\to \tau_{\text{had}}$) BG from W/Z+jets, multi-jets (estimated data-driven)
- Other BG: W/Z/γ*, pair/single-top, diboson (from MC)

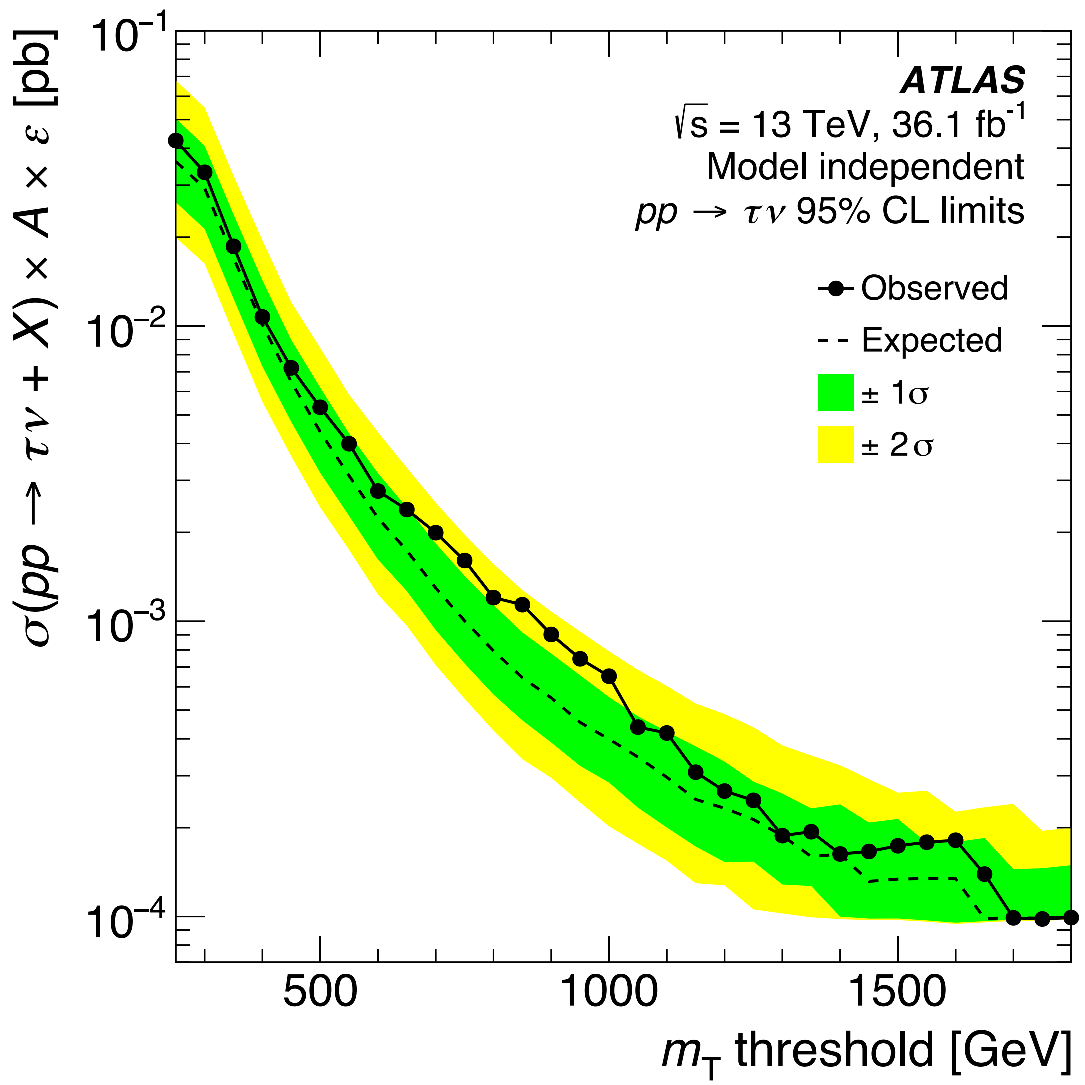


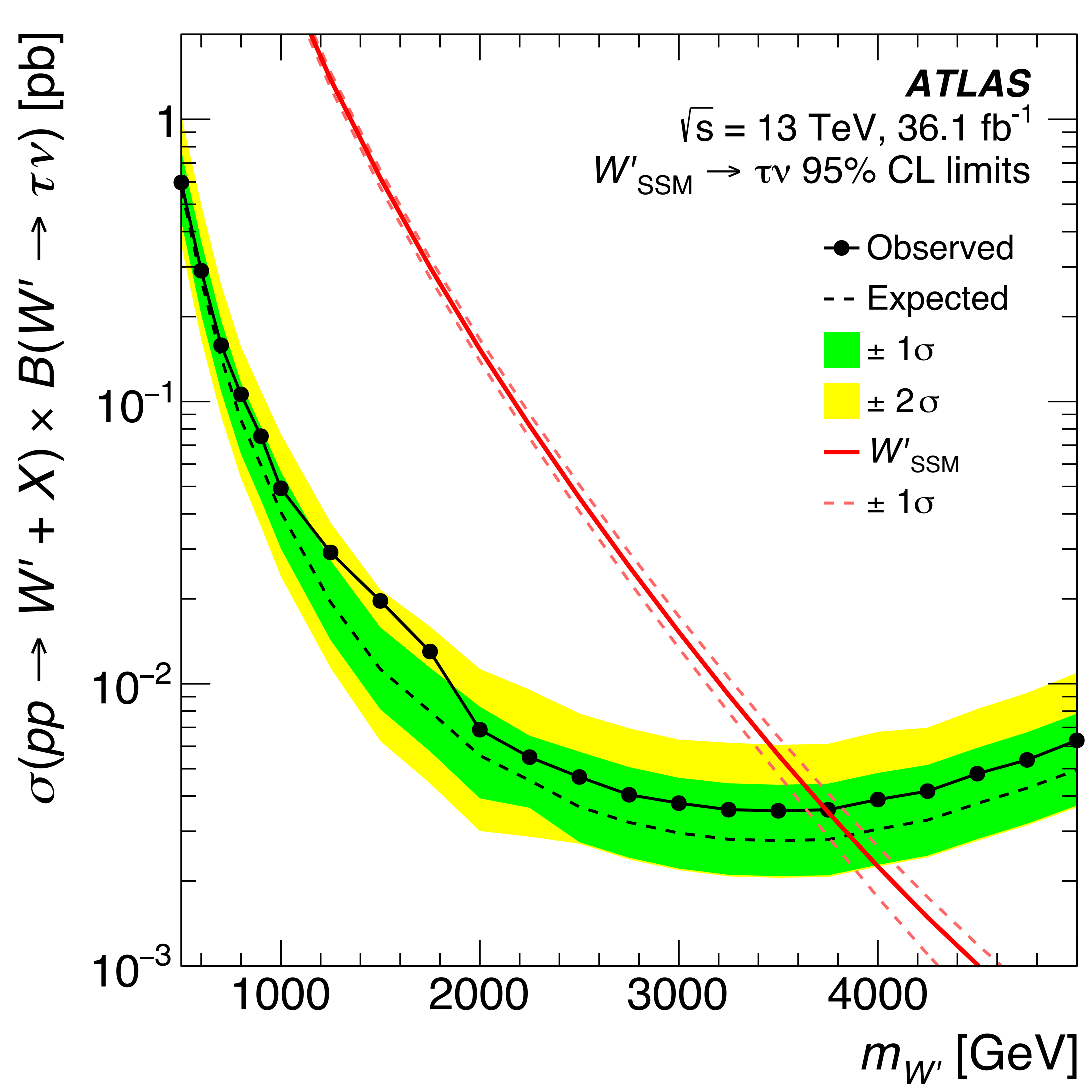
$m_T^2 = 2p_T^{\tau} \times E_{T\_miss} \times (1-\cos\Delta\phi)$

$\tau\nu$ resonance search: results

PRL120(2018)161802 1801.06992
cf. CMS 8TeV: PLB755(2016)196
13TeV: 1807.11421

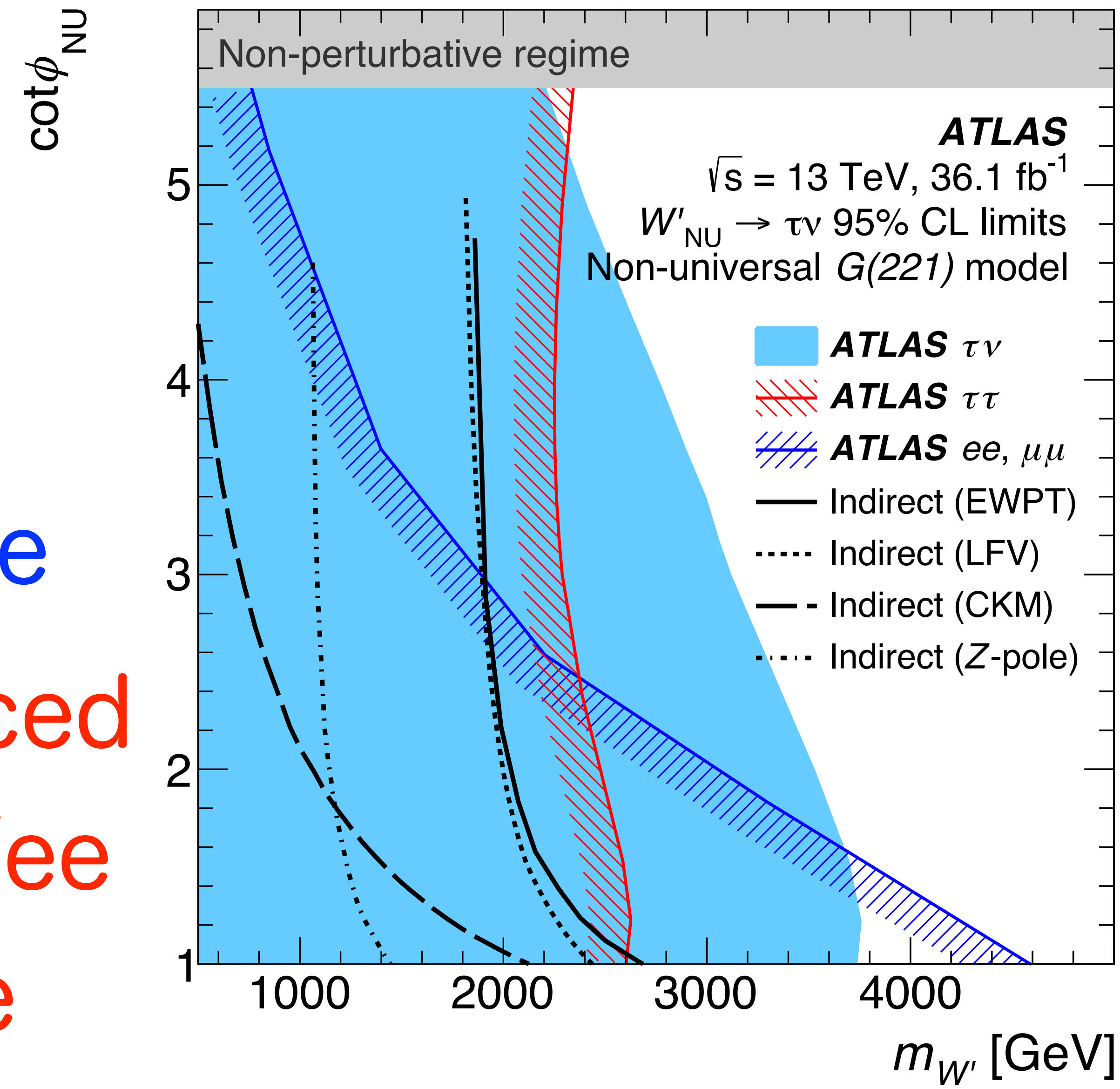
- Model-independent $\sigma\times A\times\varepsilon$ limits with m_T thresholds
  (Acceptance etc. can be found in www.hepdata.net/record/80812)
- Sequential Standard Model: m(W'$_{SSM}$) > 3.7 TeV





Non-universal G(221) model

- Also known as "topflavor"
- $SU(2)_l \times SU(2)_h \times U(1)$ split gauge groups for light(e/μ) and heavy(τ) fermions
- ϕ: mixing of light/heavy
- τ coupling enhanced by $\cot\phi_{NU}$ w.r.t. W'_{SSM}
- W'_{NU} and Z'_{NU} degenerate
- $\tau\nu$ channel gives enhanced sensitivity than $\tau\tau/\mu\mu$/ee for large parameter space



Conclusions

- Final states with τ leptons could be key signatures for Beyond-SM physics

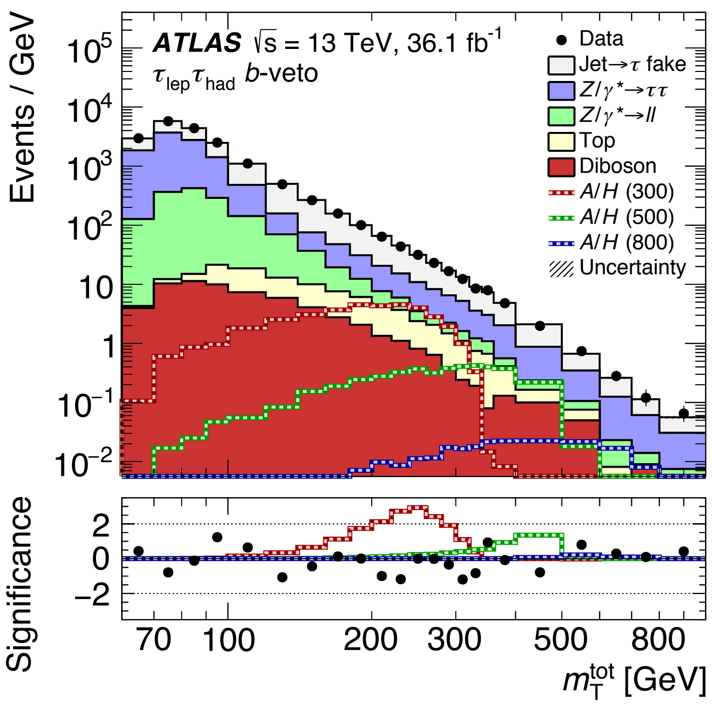
- Search results shown for following topologies, bringing constraints on specific models:
  - τ b resonance (leptoquarks)
  - 3 or more leptons (excited leptons)
  - $\tau^+\tau^-$ resonance (Z'_{SSM} and Z'_{NU})
  - $\tau\,\nu$ resonance (W'_{SSM} and W'_{NU})

- Stay tuned for more 13 TeV results to come!

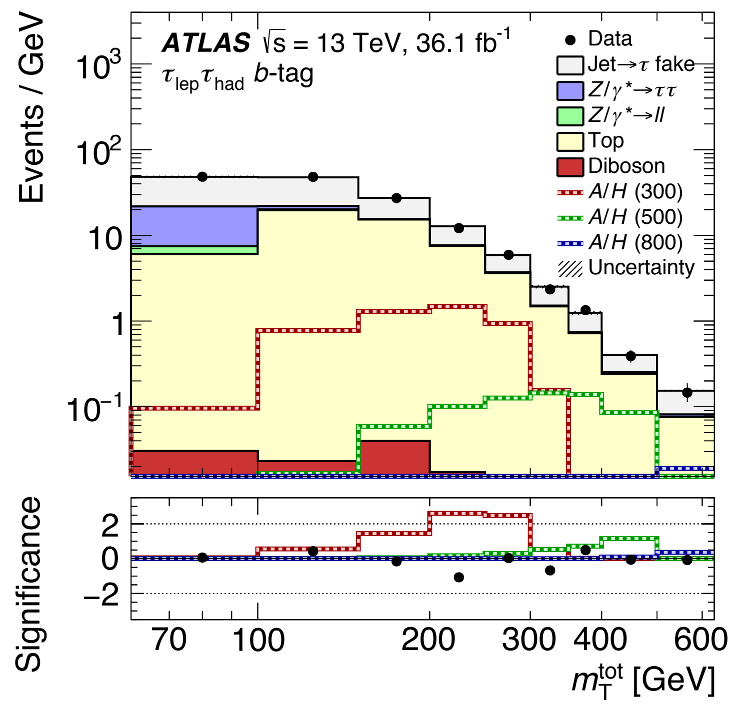
backup (1709.07242)

m_T^{tot} distributions in ττ selection channels

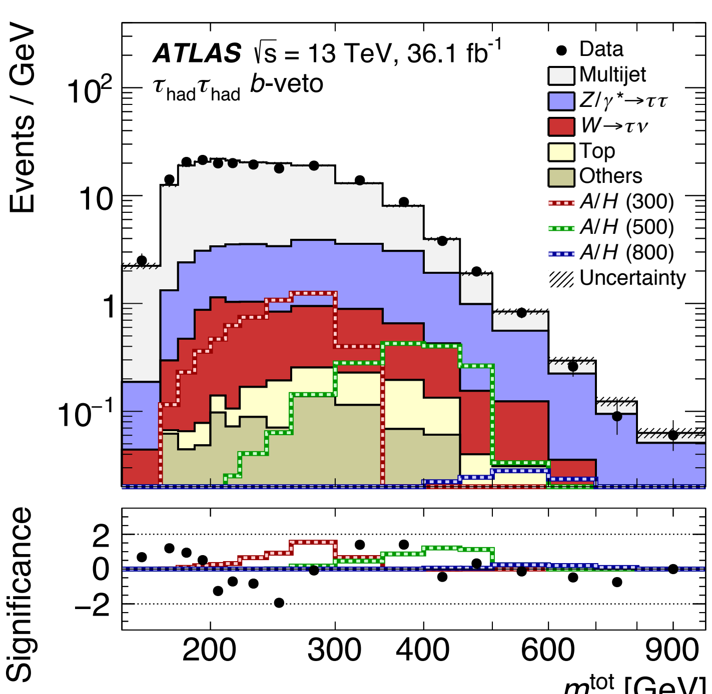
= invariant mass of $p_T(\tau_1)$, $p_T(\tau_2)$, E_T(miss)



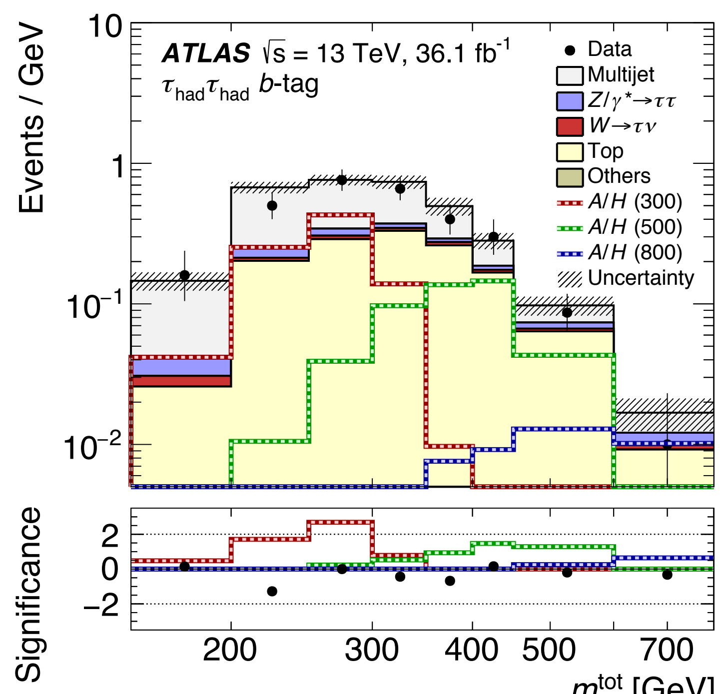
(a) $\tau_{\text{lep}}\tau_{\text{had}}$ *b*-veto category



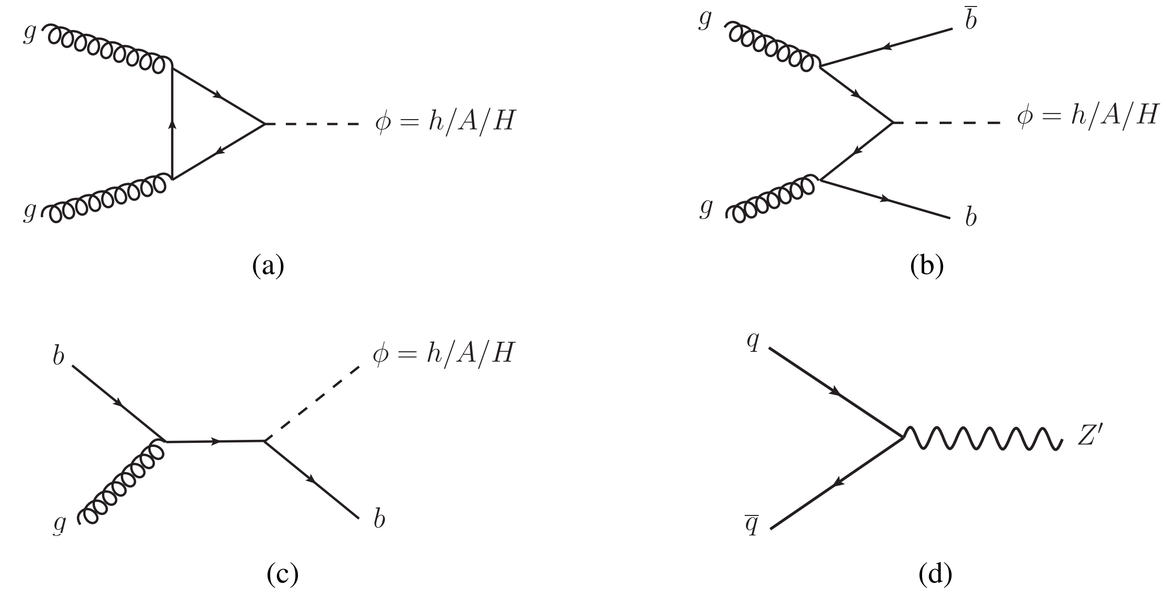
(b) $\tau_{\text{lep}}\tau_{\text{had}}$ *b*-tag category



(c) $\tau_{\text{had}}\tau_{\text{had}}$ *b*-veto category



(d) $\tau_{\text{had}}\tau_{\text{had}}$ *b*-tag category



G(221) constraints in Z'→ττ