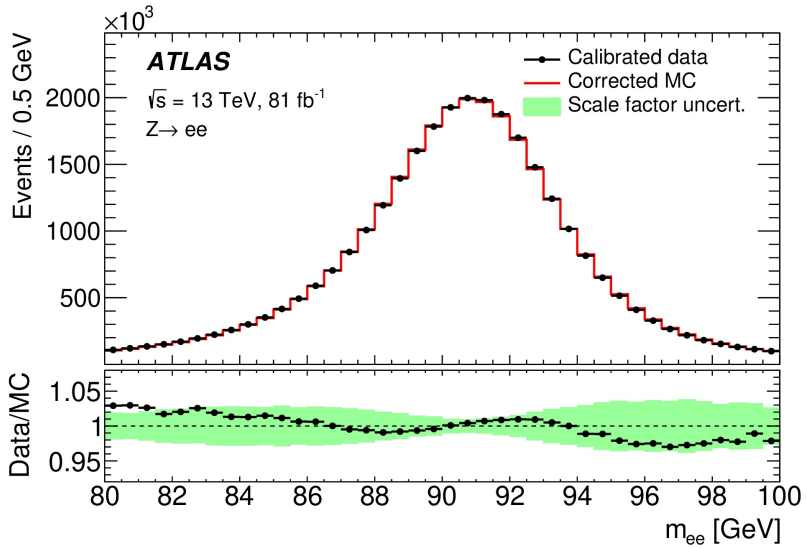
# Searches for new physics with leptons using the ATLAS detector

Monika Wielers (STFC – Rutherford Appleton Laboratory)

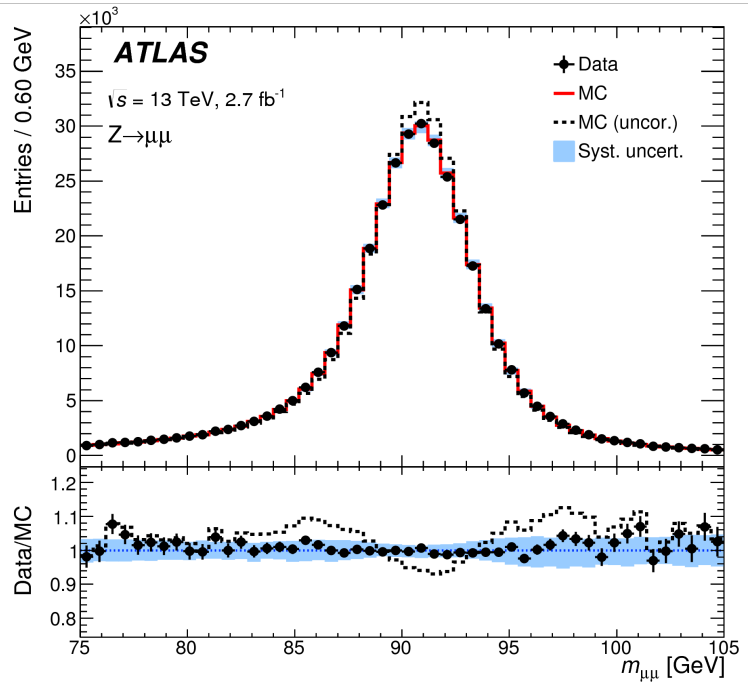
On behalf of the ATLAS collaboration


# Why we like leptons

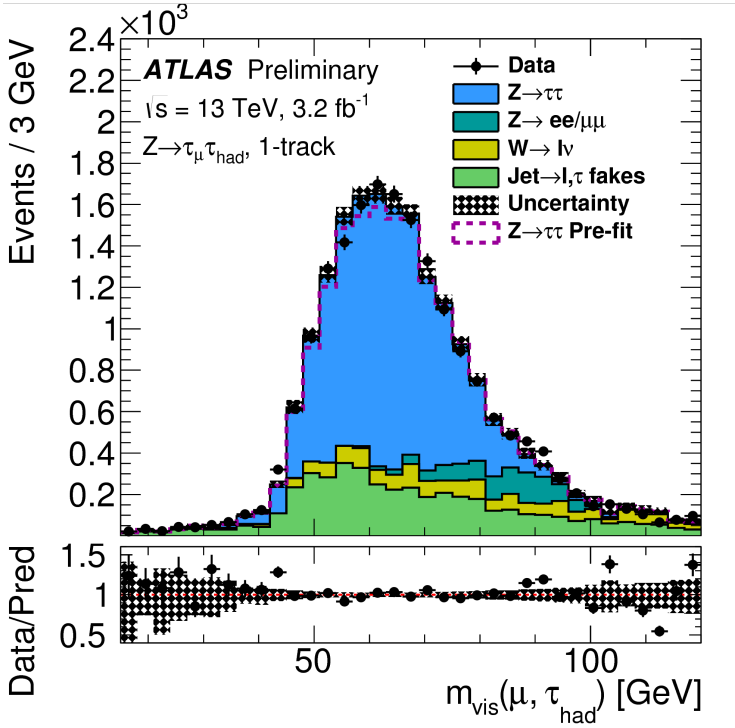
- 'Easy' to identify objects with very good detector resolution




JINST 14 (2019) P12006




Eur. Phys. J. C 76 (2016) 292




ATLAS-CONF-2012-006

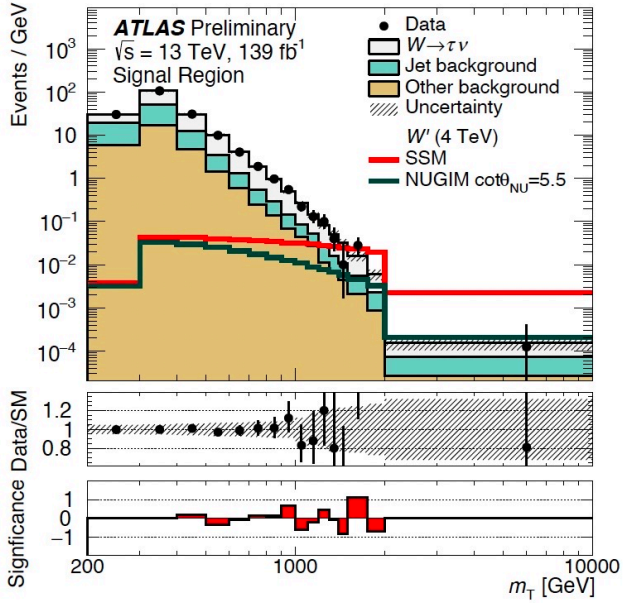
# Overview

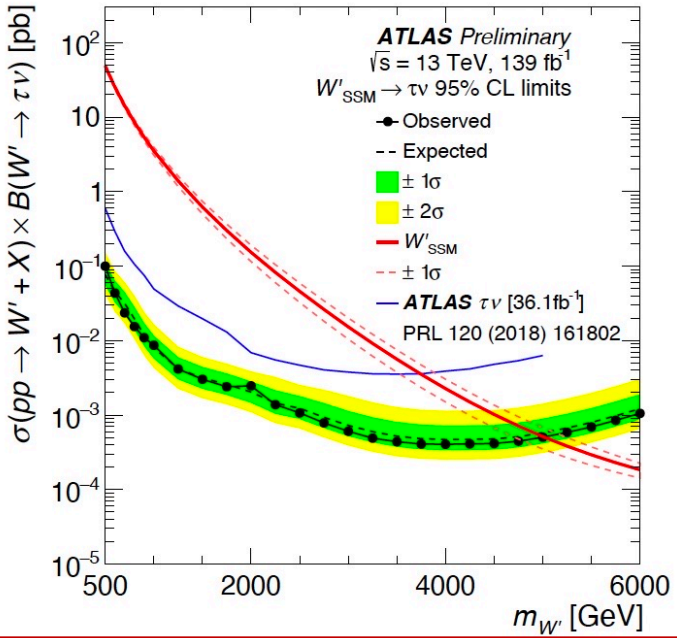
- Selection of more recent exotics searches with leptons in the final state
  - Direct searches
    - W' search
    - Type III SeeSaw heavy leptons
  - Indirect searches
    - Multilepton general
    - Lepton flavour violation in Z decays
    - bs$\ell\ell$ contact interactions
- Searches reported in other talks
  - Vector Like Quarks – Angela Burger
  - Searches for leptoquarks with the ATLAS detector – Tamara Vasquez-Schroeder
- More papers and conference notes to be found in ATLAS exotics results page

# Searches for W' bosons

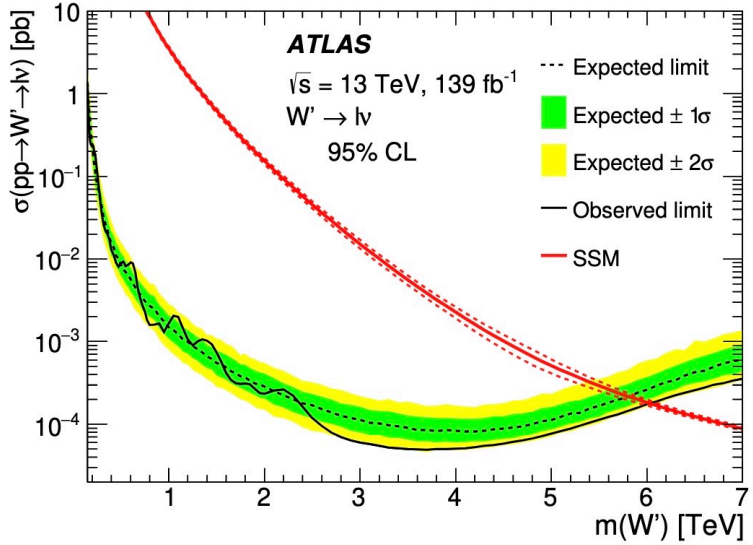
ATLAS-CONF-2021-025
Phys. Rev. D 100 (2019) 052013

- Previous search for W'→eν or W'→μν complemented now with W'→τν using complete Run 2 dataset
- Look at 1 hadronic τ + $E_T^{miss}$ final state
- Main backgrounds: W→τν, QCD jets
- Results




- For comparison



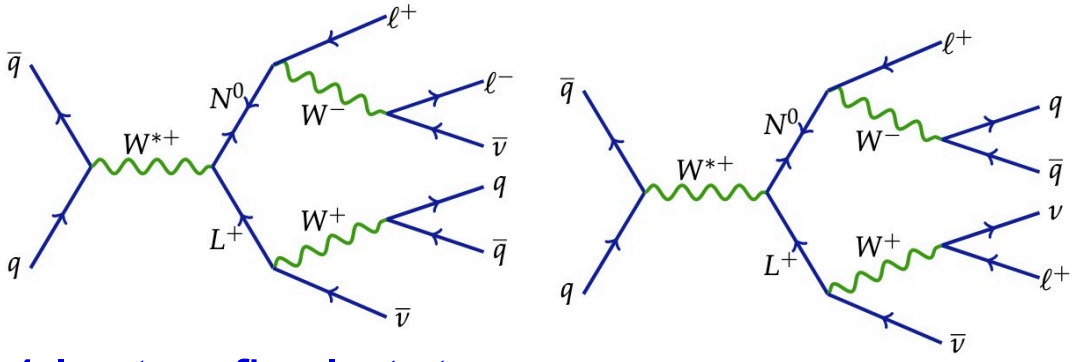

- SSM W' masses excluded up to 6.0 (5.8) TeV observed (excluded) in e and μ channels combined

At 95% CL SSM W' masses excluded up to 5 (4.9) TeV observed (excluded) in τ channel

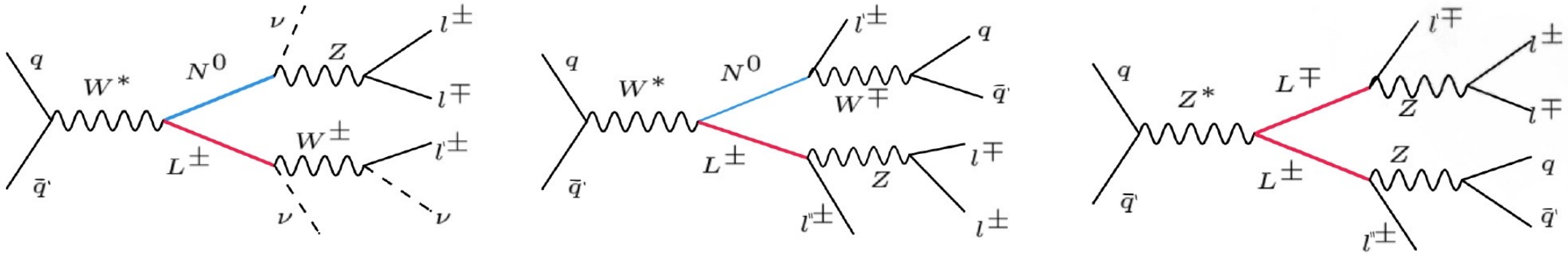
# Type III SeeSaw Heavy Leptons

ATLAS-CONF-2021-023
Eur. Phys. J. C 81 (2021) 218

- Charged and neutral heavy leptons predicted by Type-III SeeSaw models
- Heavy leptons decay in leptons (ν, e/μ) + W, Z or H bosons
- 2 leptons in final state



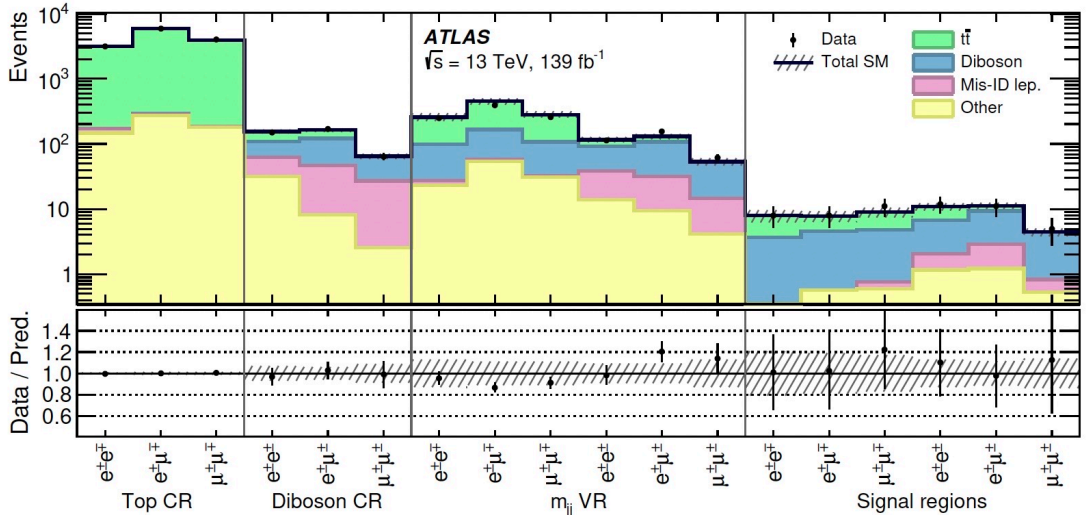

- 3 or 4 lepton final state



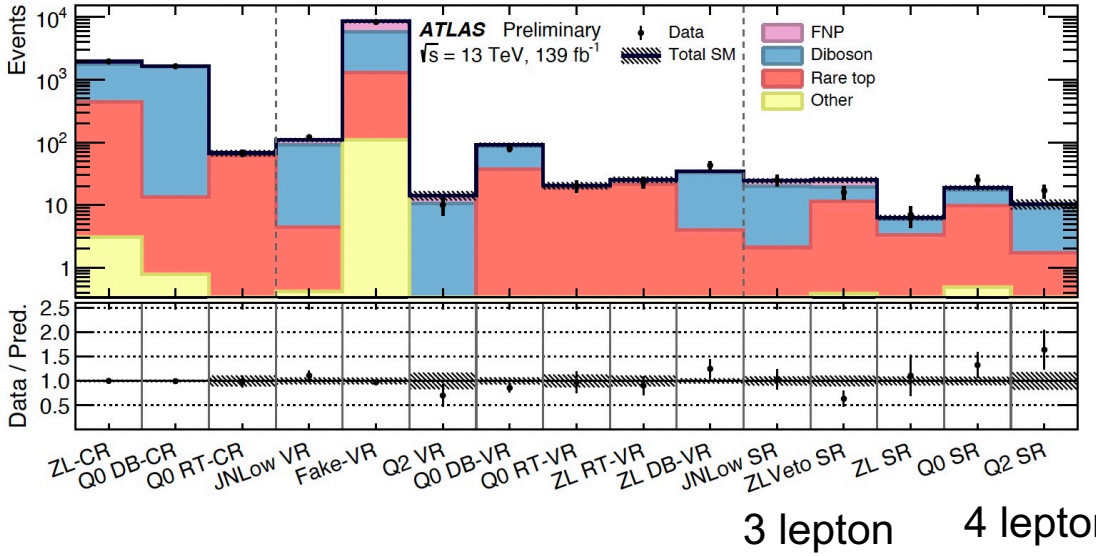
# Type III SeeSaw Heavy Leptons

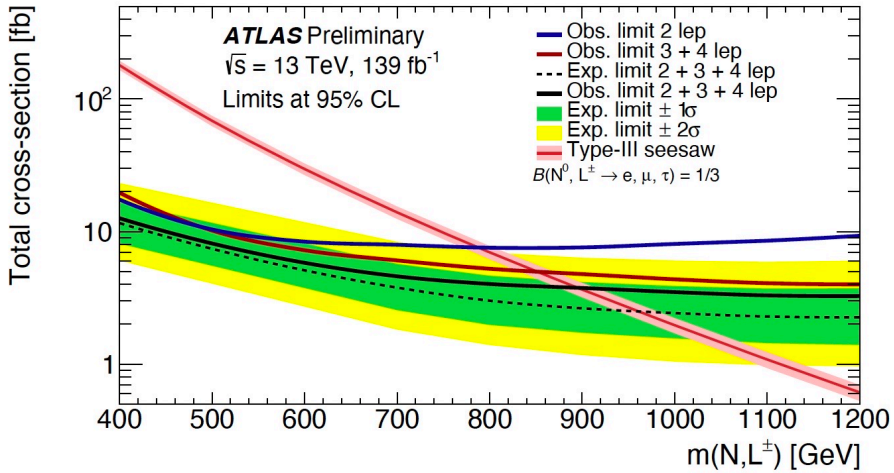
ATLAS-CONF-2021-023
Eur. Phys. J. C 81 (2021) 218

- 2 leptons
  - Classification in OS and SS ee, μμ, eμ
  - Main backgrounds: VV, $t\bar{t}$




- 3 or 4 leptons
  - Classification in 3 or 4 lepton final states
  - Main backgrounds: VV, rare top




Note: measurement statistics limited

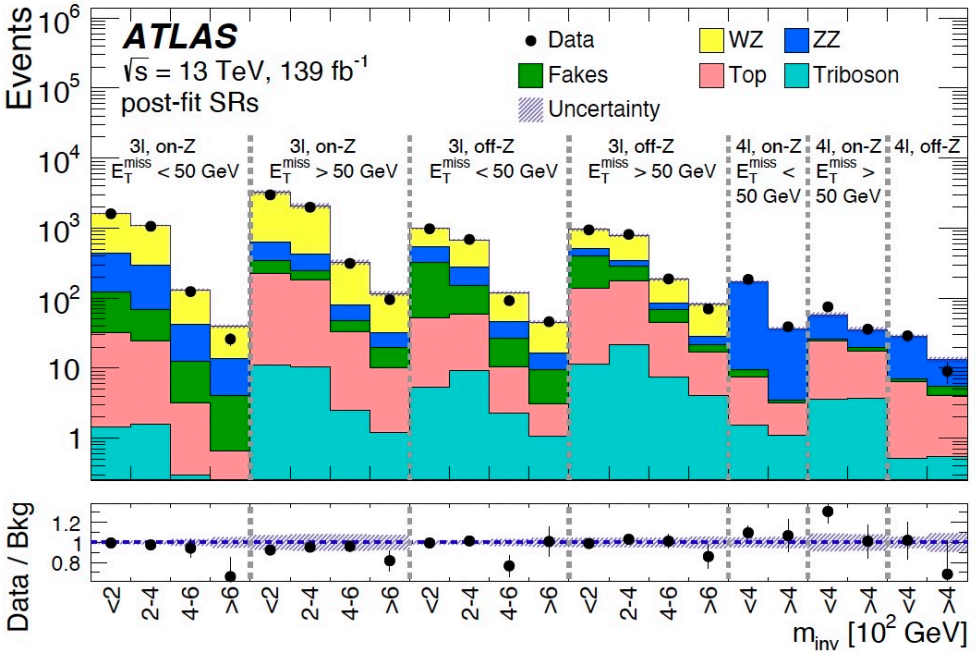
Observed (expected) exclusion limits at 95% CL
m(L,N) > 910 ($960^{+90}_{-80}$) GeV

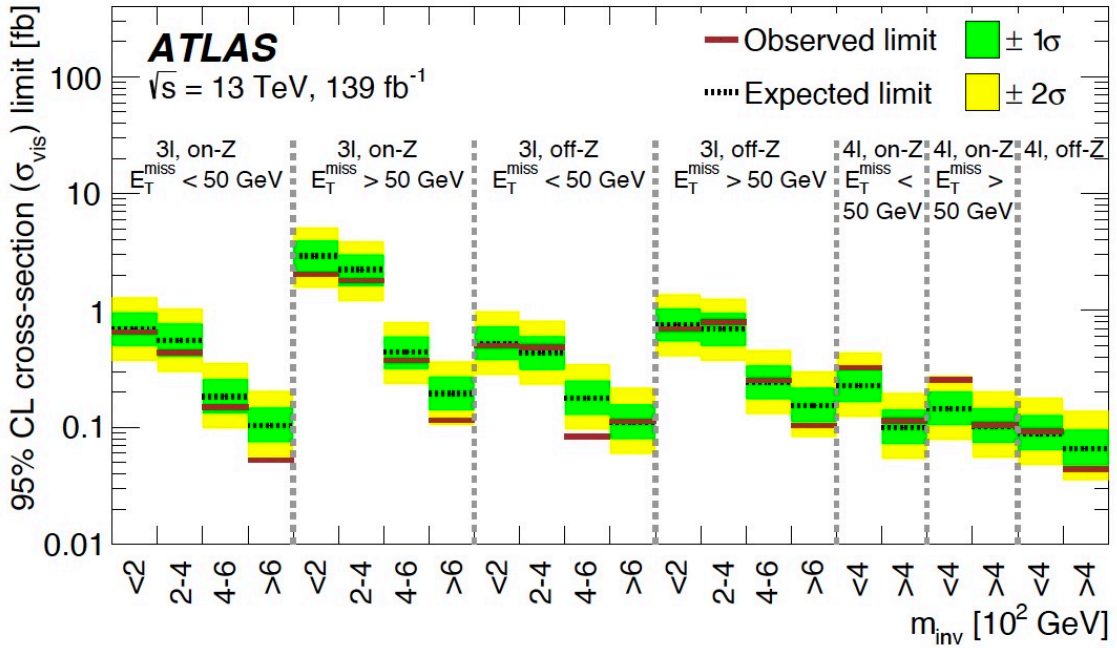
arXiv:2107.00404

# General multilepton search

- Model-independent search for BSM in 3 or 4 lepton (e or μ) events
  - Wide range of scenarios where BSM might be hidden
- Signal regions classified according to # leptons, lepton pairs compatible with Z boson, $E_T^{miss}$
- Main backgrounds: VV and VVV, top, QCD

| Region | Particles | $E_{\mathrm{T}}^{\mathrm{miss}}$ | $Z$-pairs | Other |
|---|---|---|---|---|
| | | **Signal regions** | | |
| $3\ell$ | $3\ell$ | < 50 GeV | 1 | **veto** event if $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 80$ GeV for off-$Z$ $\ell$ |
| | $3\ell$ | > 50 GeV | 1 | **veto** event if $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 80$ GeV for off-$Z$ $\ell$ |
| | $3\ell$ | < 50 GeV | 0 | **veto** event if $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 40$ GeV for off-flavour $\ell$ |
| | $3\ell$ | > 50 GeV | 0 | **veto** event if $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 40$ GeV for off-flavour $\ell$ |
| | *$3\ell$ SRs are divided into $m_{\mathrm{inv}}$ ranges of* 0–200, 200–400, 400–600 *and* >600 GeV. | | | |
| $4\ell$ | $4\ell$ | < 50 GeV | 1 | - |
| | $4\ell$ | > 50 GeV | 1 | - |
| | $4\ell$ | - | 0 | - |
| | *$4\ell$ SRs are divided in $m_{\mathrm{inv}}$ ranges of* 0-400 *and* >400 GeV. | | | |



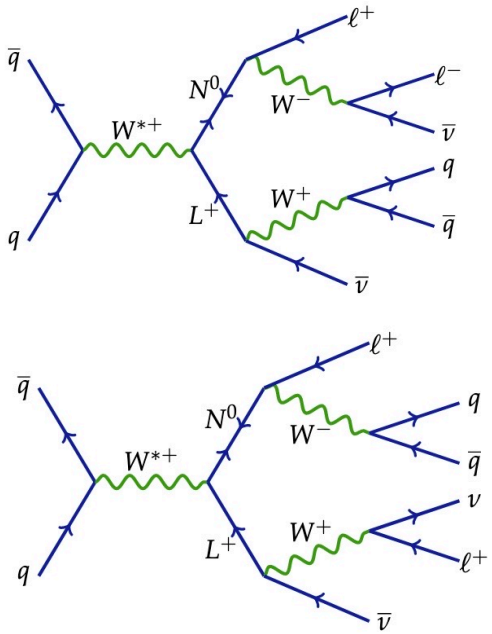
arXiv:2107.00404

# General multilepton search

- Can use results to interpret $H^{\pm\pm}$ production and Type III SeeSaw

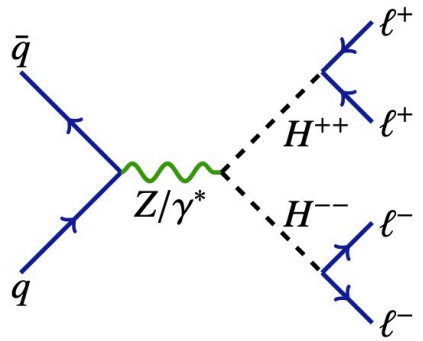
- Type-III SeeSaw
  - Expected 95% CL cross-section upper limit (for 3l final state) is 41 (12) fb for $m_L$ = 400 (700) GeV
  - Only a bit weaker than dedicated Run 2 analysis using dilepton final state ($\sigma$ upper limit of $22^{+8.5}_{-6.4}$ ($7.5^{+3.1}_{-1.8}$) fb for $m_L$=400 (700) GeV)

Eur. Phys. J. C 81 (2021) 218




- $H^{\pm\pm}$
  - expected 95% CL cross-section upper limit $0.16^{+0.14}_{-0.07}$ fb for m(H) = 300 GeV and $0.14^{+0.13}_{-0.07}$ fb for m(H)= 500 GeV
  - Comparable to results from dedicated search using 2015+2016 data

Eur. Phys. J. C 78 (2018) 199




- General search provides similar sensitivity as exclusive searches published previously

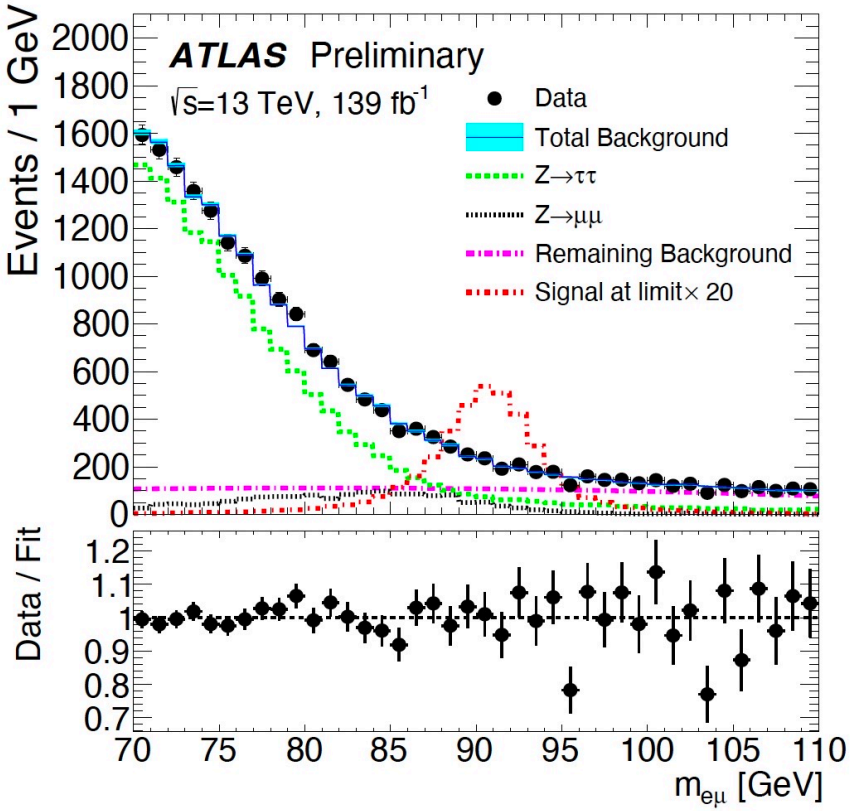
# Lepton Flavour Violation in Z decays

ATLAS-CONF-2021-042
arXiv:2105.12491

- LHC is factory of direct Z boson production and allows to look for LFV during its decay
  - LFV very rare process in SM (neutrino mixing): BR(Z→eμ) < $4 \times 10^{-60}$
  - Deviation would indicate new physics beyond Standard Model (BSM)
  - Analysis done using eμ, eτ and μτ final states
- Search strategy in eμ channel
  - Fit peak in m(ℓℓ') invariant mass distribution
  - Signal optimisation and background rejection using BDT
  - Main backgrounds: Z→ττ, Z →μμ with μ misidentified as electron, top and VV production
  - Measurement precision dominated by statistical uncertainties
- As no deviations are observed

  Observed (expected) limit at 95% CL:
  BR(Z→eμ) < 3.04 (2.75) × $10^{-7}$

  - Limit improved by factor of ~3 w.r.t. ATLAS result from Run 1!

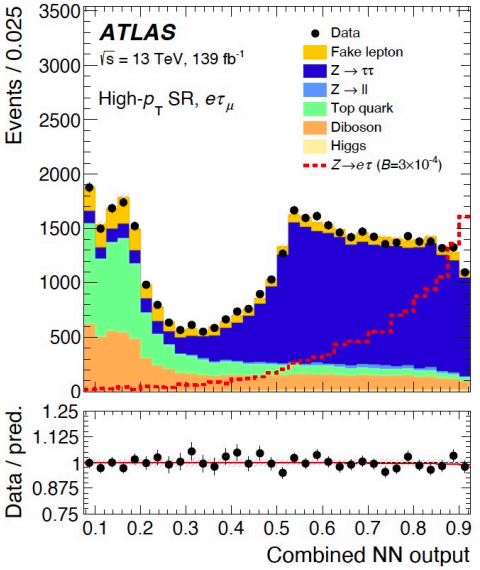


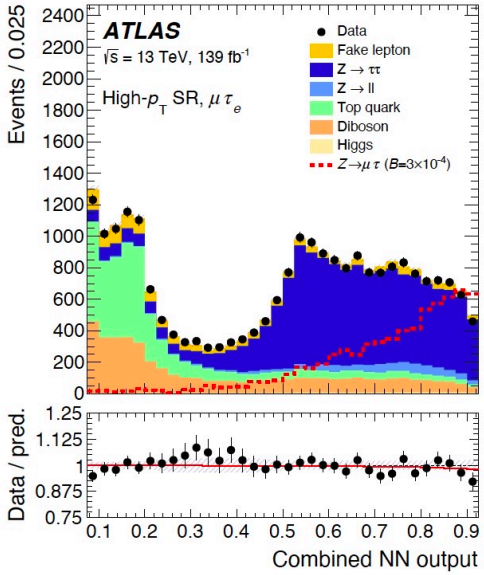
# Lepton Flavour Violation in Z decays

ATLAS-CONF-2021-042
Nature Physics 17 (2021) 819–825

- Search strategy in τe and τμ channels with τ decaying leptonically
  - Signal optimisation and background rejection using deep neural network
    - For better sensitivity, distinguish regions with low and high $p_T$ of subleading lepton
    - NN trained individually on $Z\to\tau\tau$, top-quark pair and diboson background
  - Main background: lepton Z→ττ, smaller background: Z→ ℓℓ (with 1 fake lepton), top, VV and Higgs production
- Observed limit (unpolarised τ's)
  - BR(Z→ eτ) < 7.0 × $10^{-6}$ at 95% CL
  - BR(Z→ μτ) < 7.2 × $10^{-6}$ at 95% CL
- Combination of results with combined Run 1 + Run 2 results using hadronic τ decays (at 95% CL: BR(Z→eτ) < 8.1 × $10^{-6}$, BR(Z→μτ) < 9.5 × $10^{-6}$)

BR(Z→ eτ) < 5.0 × $10^{-6}$ at 95% CL
BR(Z→ μτ) < 6.5 × $10^{-6}$ at 95% CL



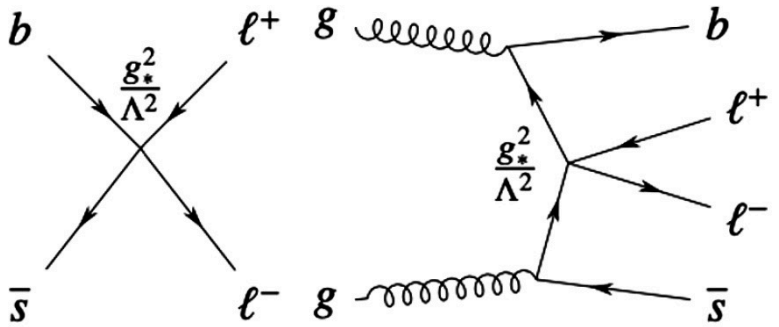



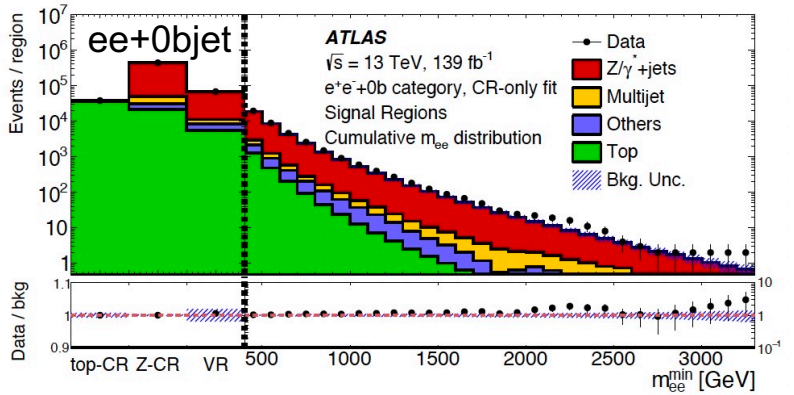
Phys. Rev. Lett. 127 (2021) 141801

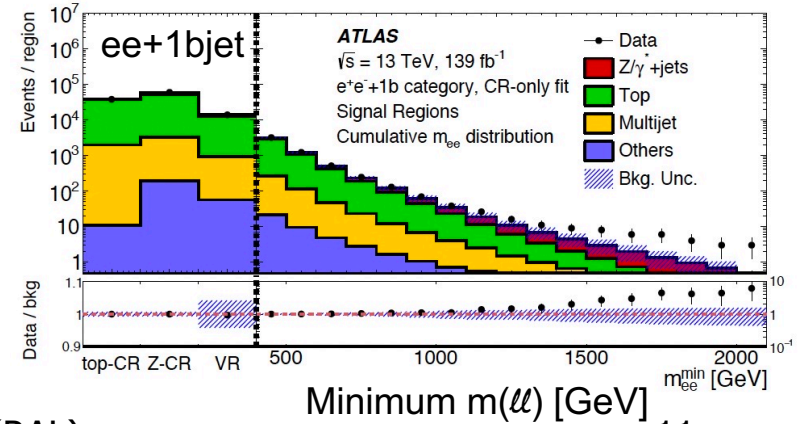
# Search for bs$\ell\ell$ contact interactions

- Search motivated by hints LFU violated in rare B meson decays, BSM could appear between initial b and final state s-quark interactions
  - Search for asymmetry in bsee vs bs$\mu\mu$ as direct probe for new physics
- Look at events with 2 SF OS electrons or muons and 0 or 1 b-jets
- Main backgrounds: Z/$\gamma$+jets, jets, $t\bar{t}$, Vt, $t\bar{t}V$
- Results

Observed limits at 95% CL: $\Lambda/g_* > 2.0$ (2.4) TeV in electron (muon) channel for model independent bs$\ell\ell$ EFT model



# Summary

- No evidence yet for new physics looking at multitude of final states many of which include leptons
- Limits constantly improving thanks to increased statistics and more sophisticated analysis techniques with many Run 2 results still to come
- Run 3 will start this spring with collisions at $\sqrt{s}$ = 13.6 TeV!
  - This will push limits even further and hopefully allows to catch the first glimpse of BSM physics