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Searches for new phenomena in final states involving leptons and jets using the ATLAS detector

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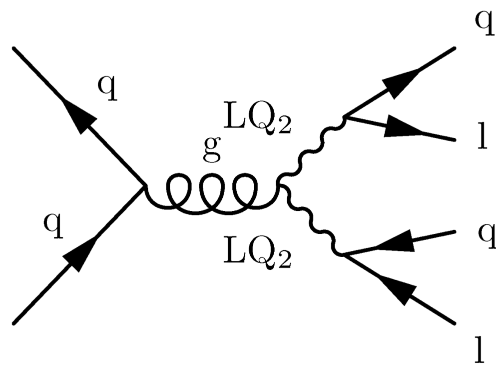
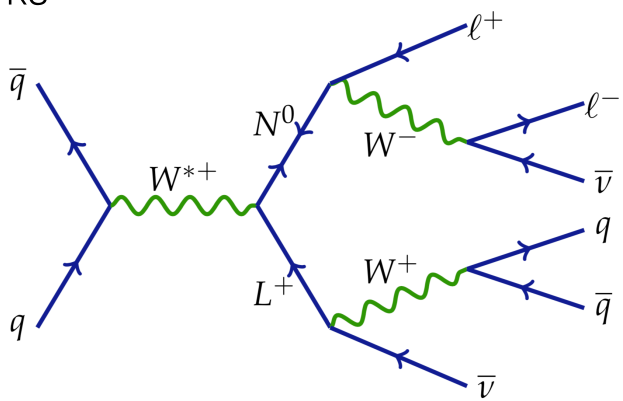
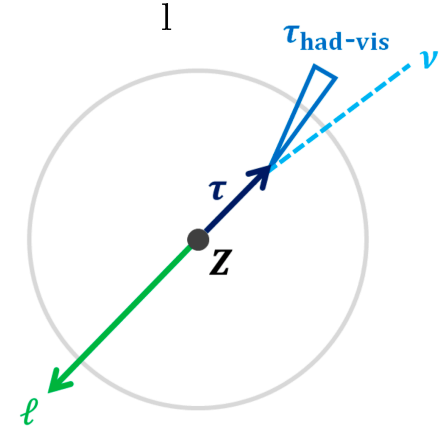
Investigated Topology

★ Reconstructed final states with both **leptons** and **jets** — probes for a wide variety of new physics predictions

- ★ Leptoquarks
- ★ See-saw mechanism
- ★ Lepton flavour violation
- ★ SUSY
- ★ Vector like quarks
- ★ Dark matter
- ★ …







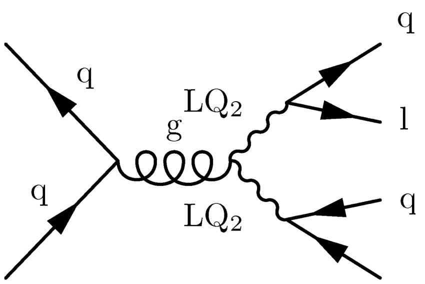
★ In this talk I will concentrate on recently updated searches that cover full Run 2 dataset

- ★ Production of pairs of Scalar **Leptoquarks** (LQ)
- ★ **Lepton Flavour Violation** (LFV) in $Z \to \ell\tau$
- ★ **Type III See-saw** Heavy Leptons

(13TeV, $139\ \text{fb}^{-1}$)

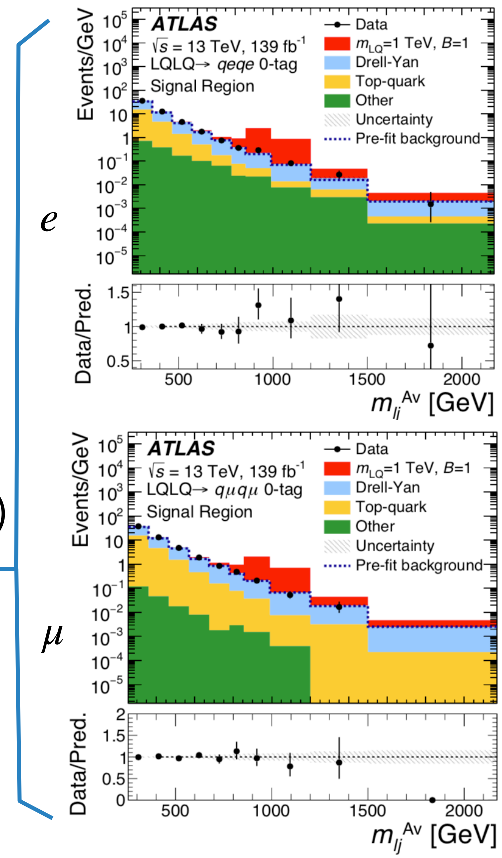
Leptoquarks (LQ)

- ★ Hypothetical particles that couple to leptons and quarks
  - ★ Motivated by the **symmetry** in lepton and quark spectra
- ★ Predicted by many GUT models
- ★ Experimental motivation
  - ★ Flavour anomalies in B decays
  - ★ Anomalous magnetic moment of muon



- ★ Search of **LQs** in **ATLAS**
  - ★ Focus on **scalar LQ pair production**
  - ★ Different final states, including cross-generation

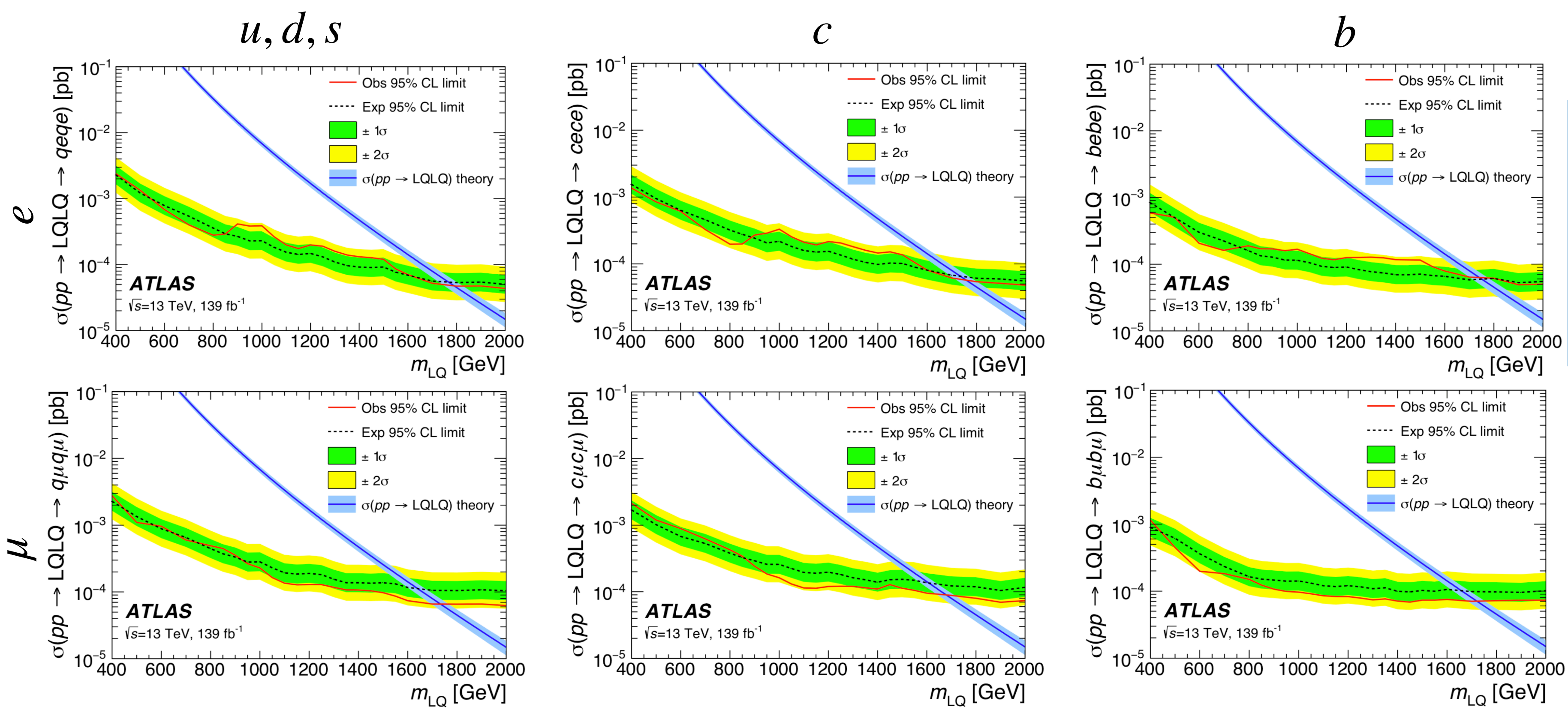
- ★ Will focus on searches extended to Run 2 dataset $(139\ \mathrm{fb}^{-1})$
  - ★ $LQ \rightarrow e/\mu + qq$ arXiv:2006.05872
  - ★ $LQ \rightarrow \tau + t$ ATLAS-CONF-2020-029
  - ★ $LQ \rightarrow e/\mu + t$ ATLAS-CONF-2020-033



$LQ \rightarrow e/\mu + qq$

Accepted by JHEP

- Event selection:
  - 2 oppositely charged, same-flavour leptons, ≥ 2 jets (light jets, *c* and *b* jets) , low E_T^{miss}
- All 6 LQ hypotheses (same and cross gen.) are tested independently — **no excess** observed
- LQ excluded up to **1.8 (1.7) TeV** in **electron (muon)** channel for $Br(LQ \rightarrow lq) = 1$



arXiv:2006.05872

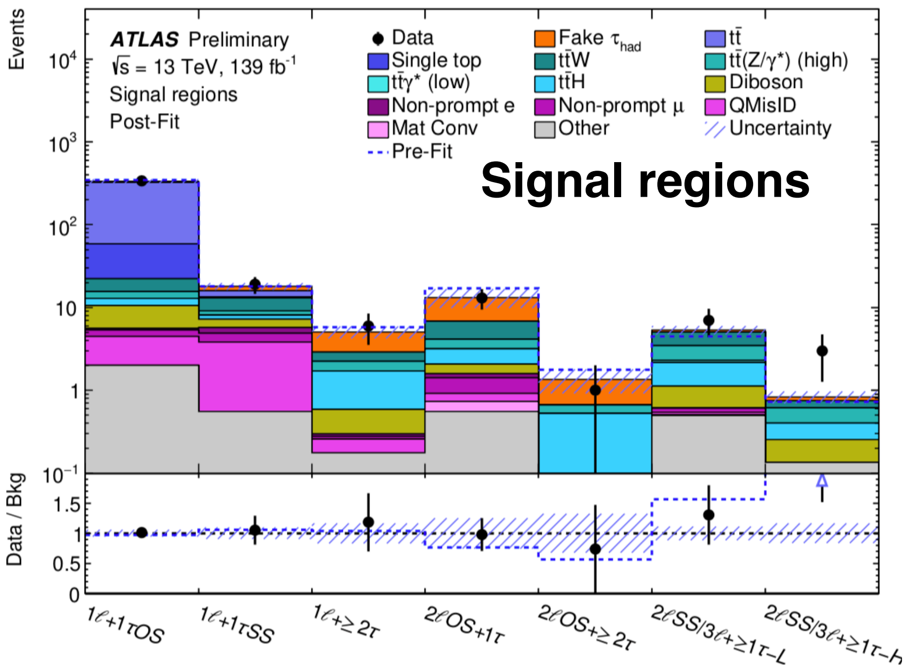
$LQ \to \tau + t$

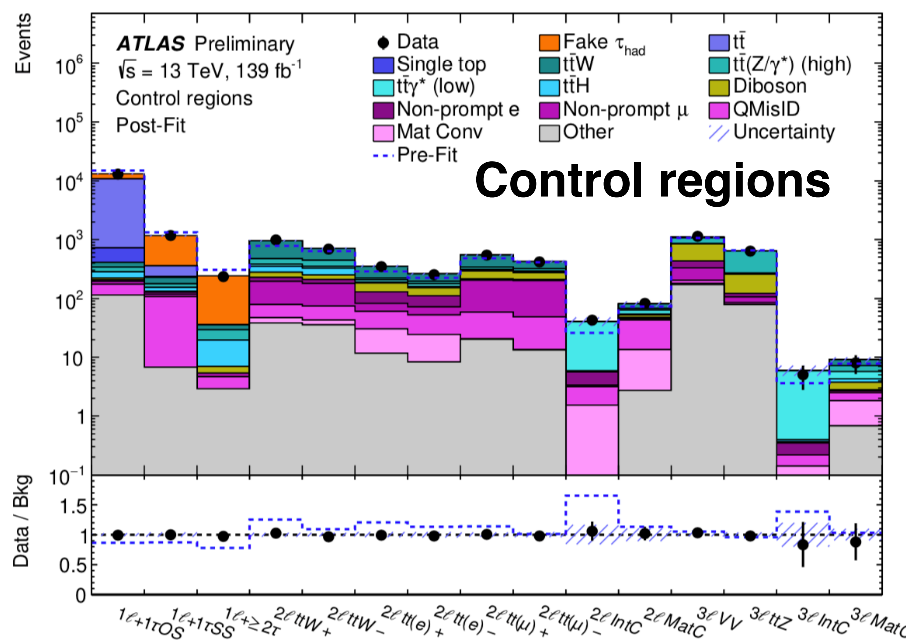
ATLAS EXPERIMENT

- Pair production $LQ_3^d LQ_3^d \to \tau t \tau t$
- Events cathegorised based on number of light leptons and τ decaying hadronically to cover the complex multi-lepton final states
  - NN-based technique for τ_{had} identification
- Simultaneous fit to **7 SRs** and **15 CRs**

- $t\bar{t}$ kinematic reweighing derived by binning in N_{jet} and $$m_{eff} = \sum_{e,\mu,\tau,jet} p_T + E_T^{miss}$$
- data-driven correction in the modelling of fake τ_{had}
- data-driven normalisation of fake l and ttW BGs

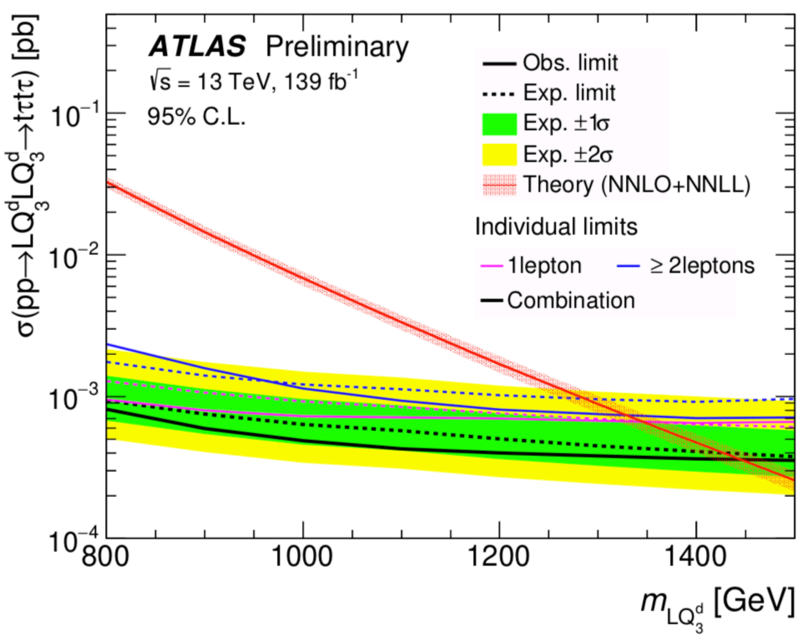
ATLAS-CONF-2020-029

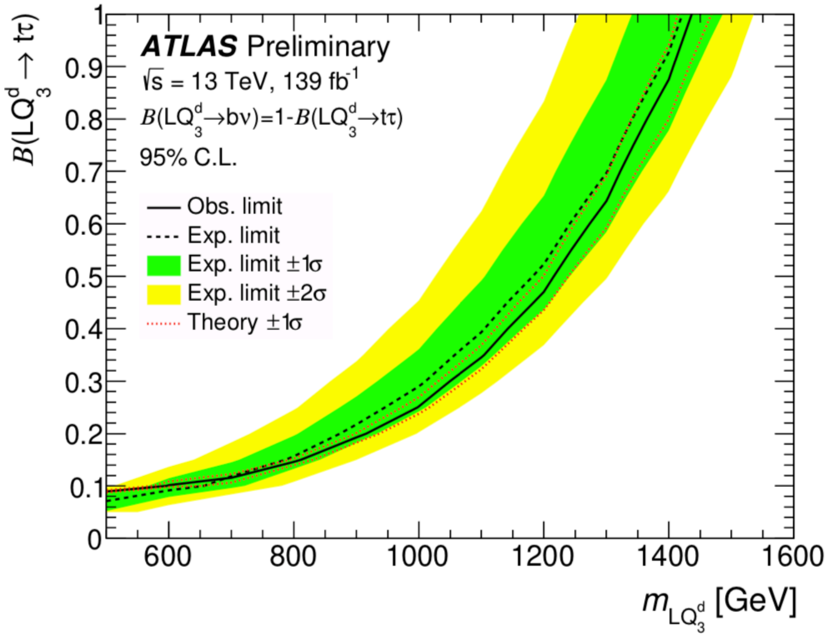




$LQ \rightarrow \tau + t$

- ★ No sig. excess observed after profile-likelihood fit to m_{eff}
- ★ LQ masses excluded @ 95% CL up to **1.4 TeV / 1.2 TeV** for $Br(LQ \rightarrow t\tau) = 1/0.5$

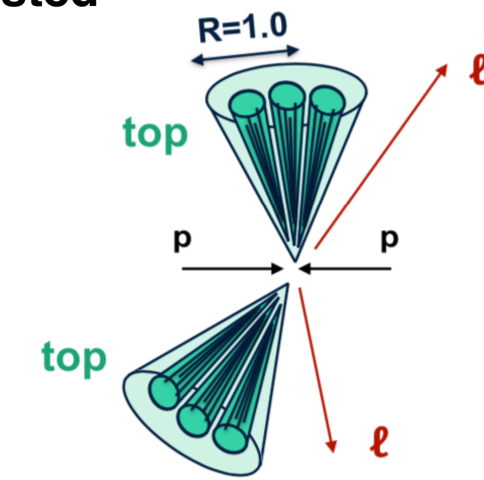


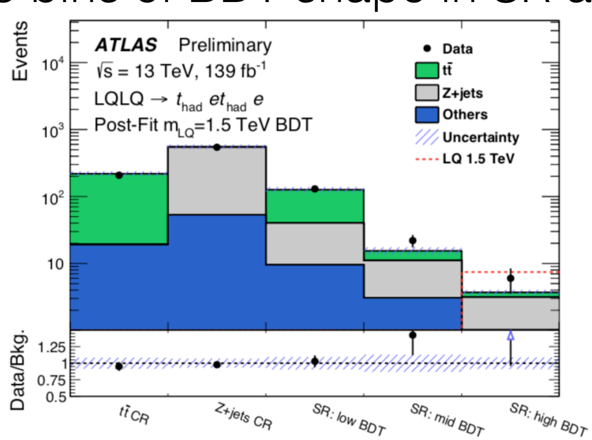


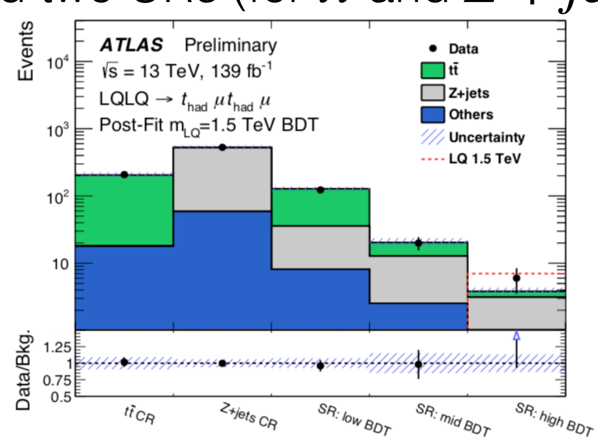
ATLAS-CONF-2020-029

$LQ \rightarrow e/\mu + t$

- Cross-generation LQ decay
- Targeting high mass region, where both top quarks are **boosted**
  - Resulting in **large R (1.0) jets**
- Event selection
  - 2 oppositely charged, same-flavour leptons
  - ≥ 2 **large R jets** (top)
  - $m(\ell\ell) > 120\ GeV$ (to reduce BG from SM production)
- Dominant background $Z + jets$ and $t\bar{t}$
- XGBoost framework: BDT classifier used to distinguish signal from $Z + jets$ and $t\bar{t}$ background
- Simultaneous fit to 3 bins of BDT shape in SR and two CRs (for $t\bar{t}$ and $Z + jets$ backgrounds)



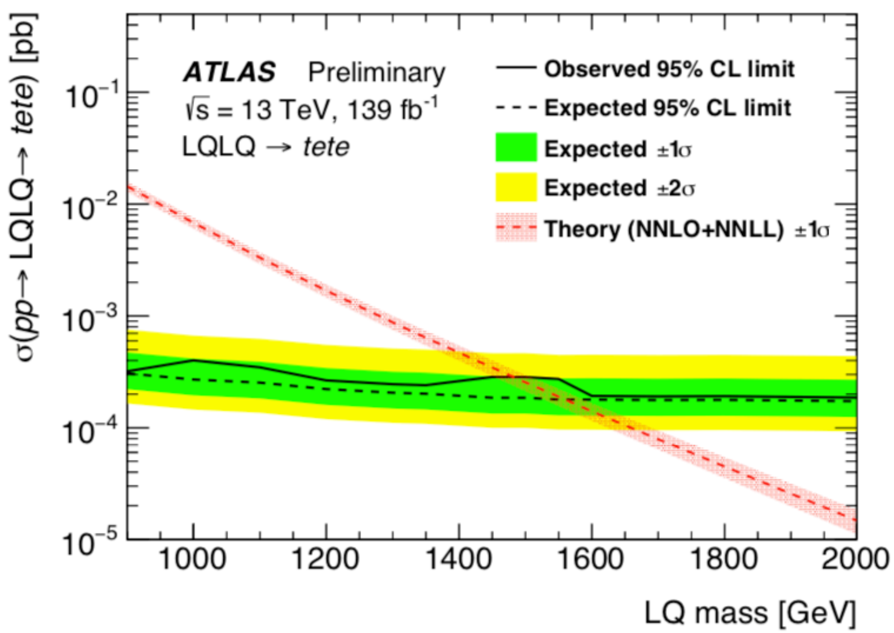


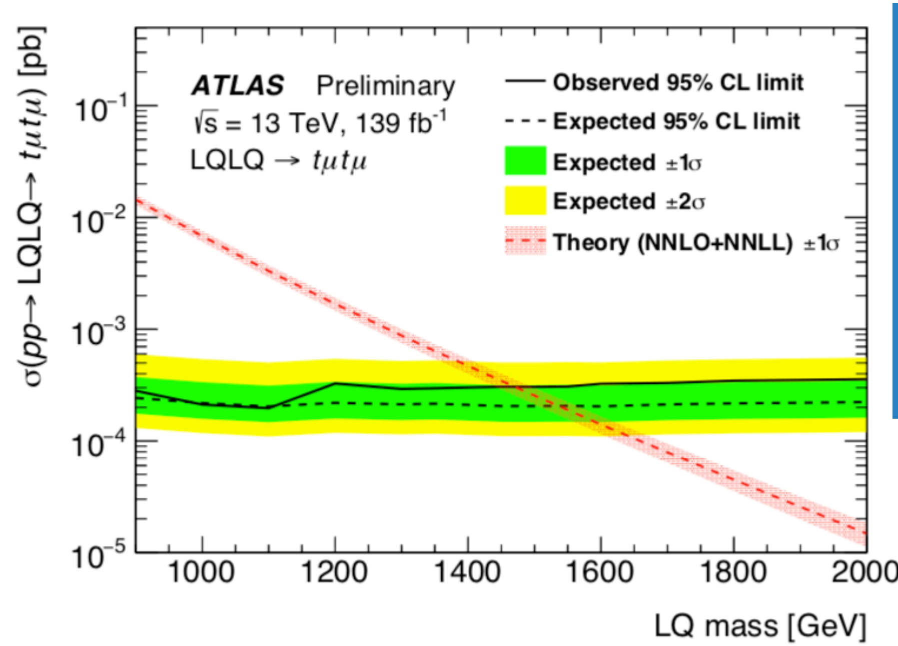


ATLAS-CONF-2020-033

$LQ \to e/\mu + t$

- ★ Data compatible with SM / no significant excess observed
- ★ Lower limit on LQ masses @ 95% CL:
    - ★ **1.48 TeV** / **1.47 TeV** for **electron** / **muon**

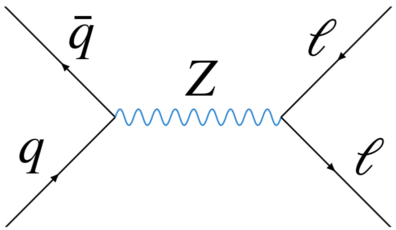




ATLAS-CONF-2020-033

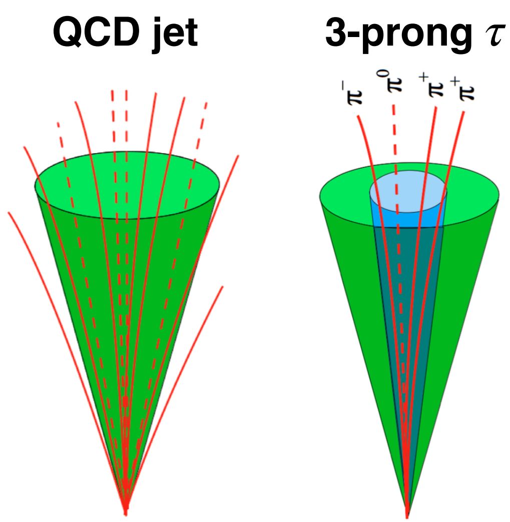
Lepton flavour violation ($Z \to \ell\ \tau$)

- From **neutrino mixing** — prediction: Br($Z \to \ell\tau$) $\leq$ O(10^{-54})
  - see e.g. arXiv:hep-ph/0001273



- Analysis focuses on **hadronic** τ decays
  - Typically **one** or **three** charged tracks (1-prong, 3-prong)

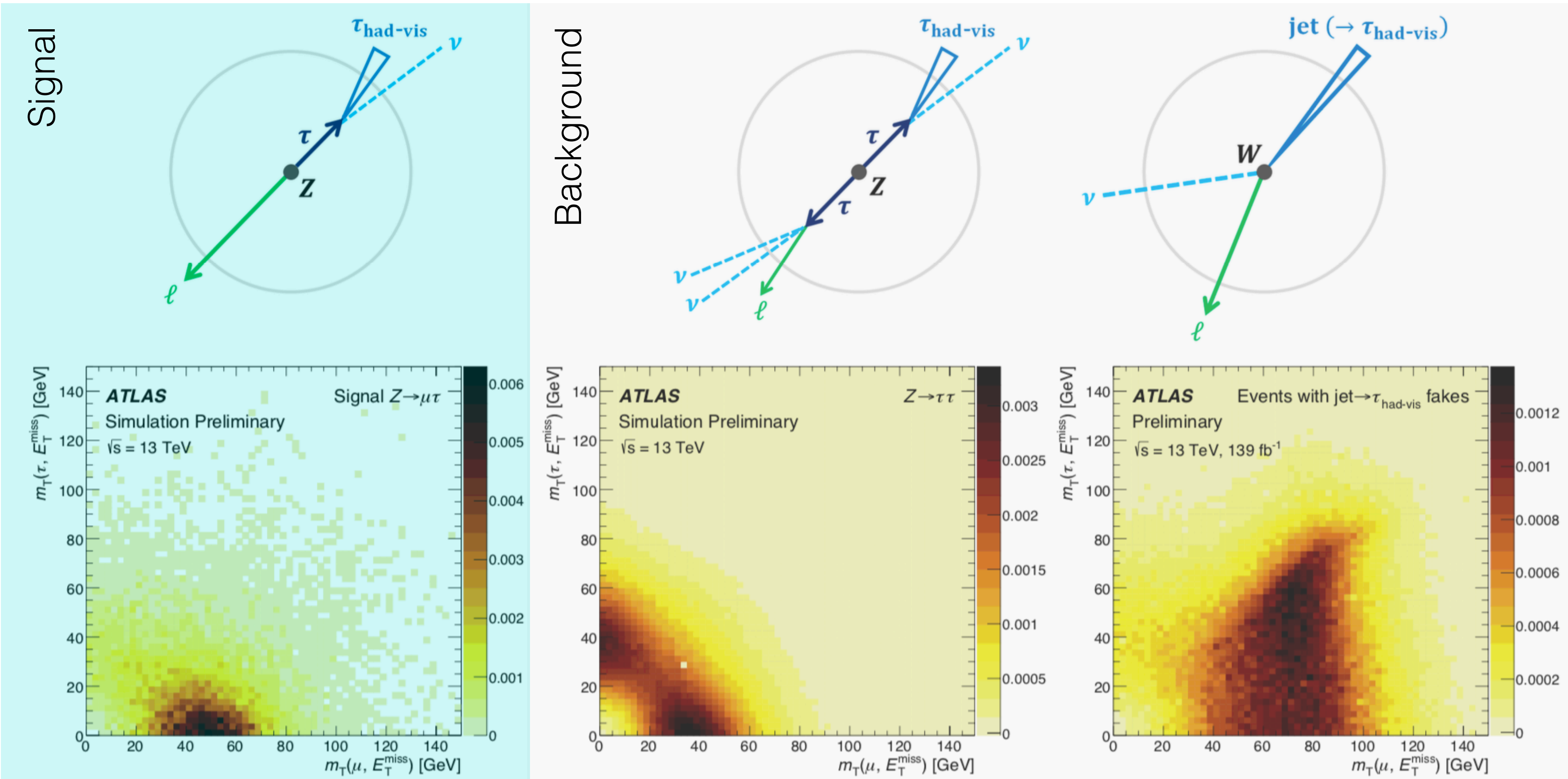
- Selection criteria:
  - At least **one hadronic** τ candidate and exactly **one light lepton** (e or μ) of opposite charge
  - $m_T(\tau_{had-vis}, E_T^{miss}) < 35\ GeV$ to **reject** $Z \to \tau\tau$ and $W + jets$
  - $m_{vis}(\ell, \tau_{had-vis}) > 60\ GeV$ to **reject lepton pairs incompatible with** $Z \to \tau\ell$
  - **NN-based** τ identification



ATLAS-CONF-2020-035

LFV — topology

★ Signal events — $Z \to \ell\tau$, main background events $Z \to \tau\tau$ and $W \to \ell\nu\ jet$



★ Event topologies of signal and two main BGs show that the angular relations of the decay products is different between the three processes.

★ Consequently, transverse mass using μ vs τ candidate is a good discriminating distribution

ATLAS-CONF-2020-035

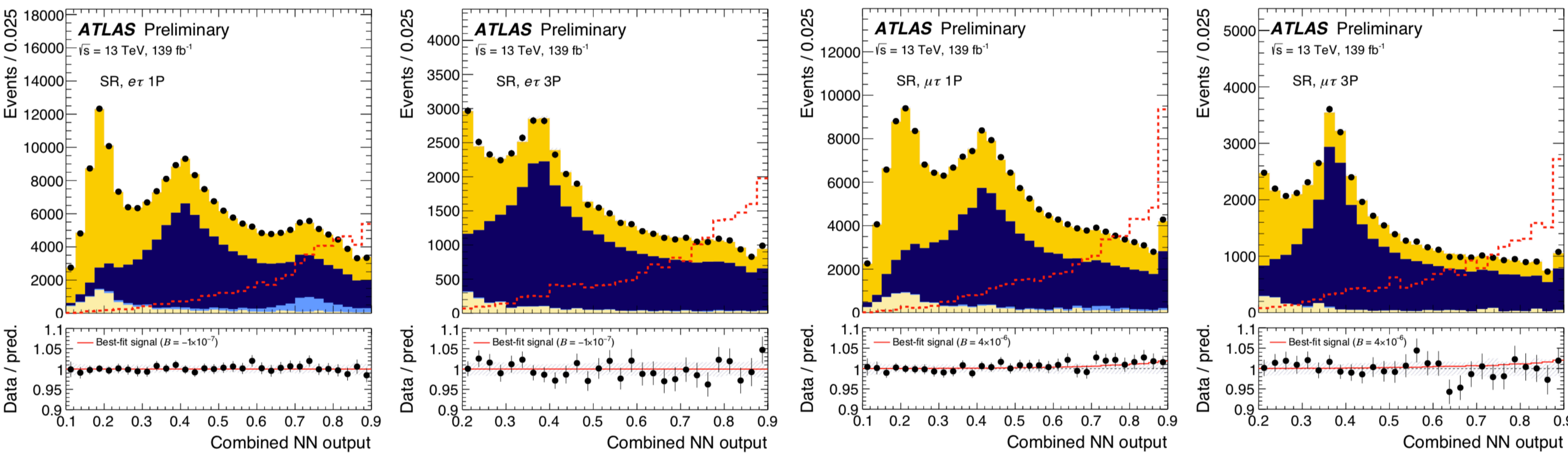
LFV ($Z \to \ell\ \tau$) — upper limit on Br

★ Main backgrounds:

- ★ **q or g-initiated jets** are misidentified as $\tau_{had-vis}$ (W(→ lν)+jets, QCD multijet, Z+jets, $t\bar{t}$)
  - ★ Estimated using the data-driven fake factor method
- ★ $Z \to \tau\tau$
  - ★ MC with data driven p_T-based corrections, derived in regions with negligible signal

★ Best-fit performed on NN score for $e\tau$ and $\mu\tau$

- ● Data
- jet→$\tau_{\text{had-vis}}$ fakes
- Z→ττ
- Z→ll
- Others
- Total uncertainty
- Z→eτ (B = 5×10^{-4})



★ Constraints supersede the so-far most stringent limits by LEP experiments

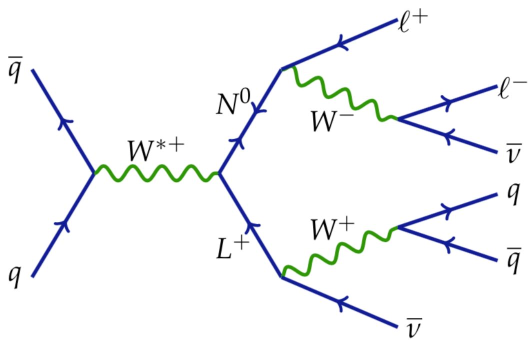
Experiment, polarisation assumption	Observed (expected) upper limit on $\mathcal{B}(Z \to \ell\tau)$ [$\times 10^{-6}$] $e\tau$	$\mu\tau$
ATLAS Run 2, unpolarised τ	8.1 (8.1)	9.9 (6.3)
ATLAS Run 2, left-handed τ	8.2 (8.6)	9.5 (6.7)
ATLAS Run 2, right-handed τ	7.8 (7.6)	10 (5.8)

ATLAS-CONF-2020-035

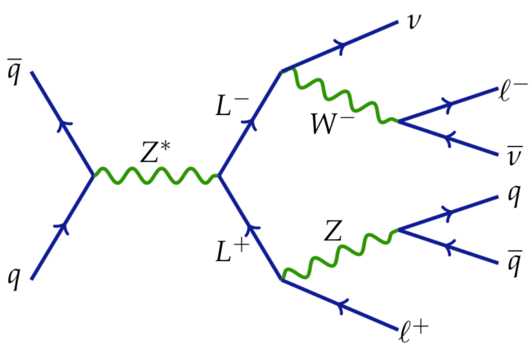
Type III Seesaw

- SM neutrinos are only **left-handed** — thus no standard mass term
- **Neutrino oscillations** observed → at least two neutrinos have $m \neq 0$
- With **Seesaw mechanism** relative small neutrino mass can be explained by introducing new heavy right handed “neutrinos” (neutrino like particles)

- We focus on **Type III Seesaw** where a new fermion triplet is introduced (N^0, L^+, L^-)
  - $N^0 \to \nu h$ / νZ / $\ell^{\pm} W^{\mp}$
  - $L^{\pm} \to \ell^{\pm} h$ / $\ell^{\pm} Z$ / $\nu W^{\pm}$



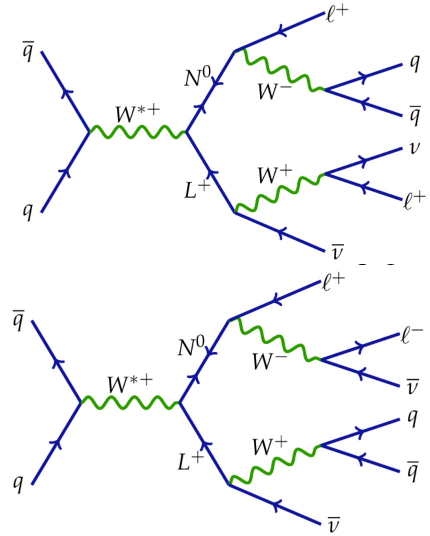
- Search for pair production:
  - $pp \to N^0\, L^{\pm}$
  - $pp \to L^{\pm}\, L^{\mp}$



arXiv:2008.07949

Type III Seesaw — analysis

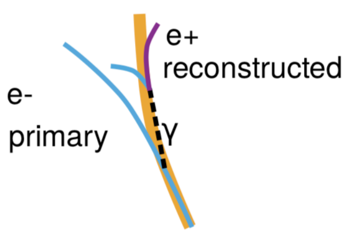
- ATLAS analysis focuses on the following signature:
  - **2 lepton** final state:
    - opposite **sign** (OS) or same **sign** (SS)
    - same **flavour** ($ee, \mu\mu$) or opposite **flavour** ($e\mu$)
  - **2 jets** from quark hadronisation
  - Large **missing energy** (E_T^{miss}) due to neutrinos
- Events split into 3 sets of 6 regions:
  - 6x signal (**SR**), 6x control (**CR**) and 6x validation (**VR**)



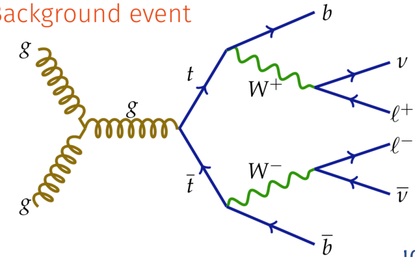
SS

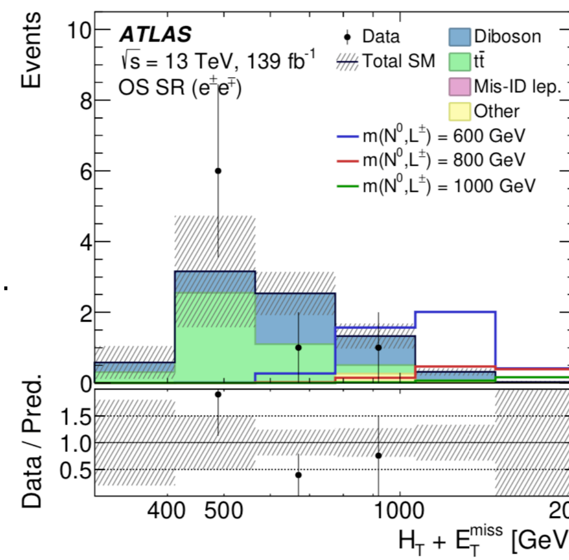
arXiv:2008.07949

- Backgrounds:
  - **Prompt leptons** (based on detailed MC)
    - $t\bar{t}$ pairs, diboson production
  - **Non-prompt or “fake" leptons** (data driven methods)
    - conversions, jets, semileptonic c/b, charge misID,…



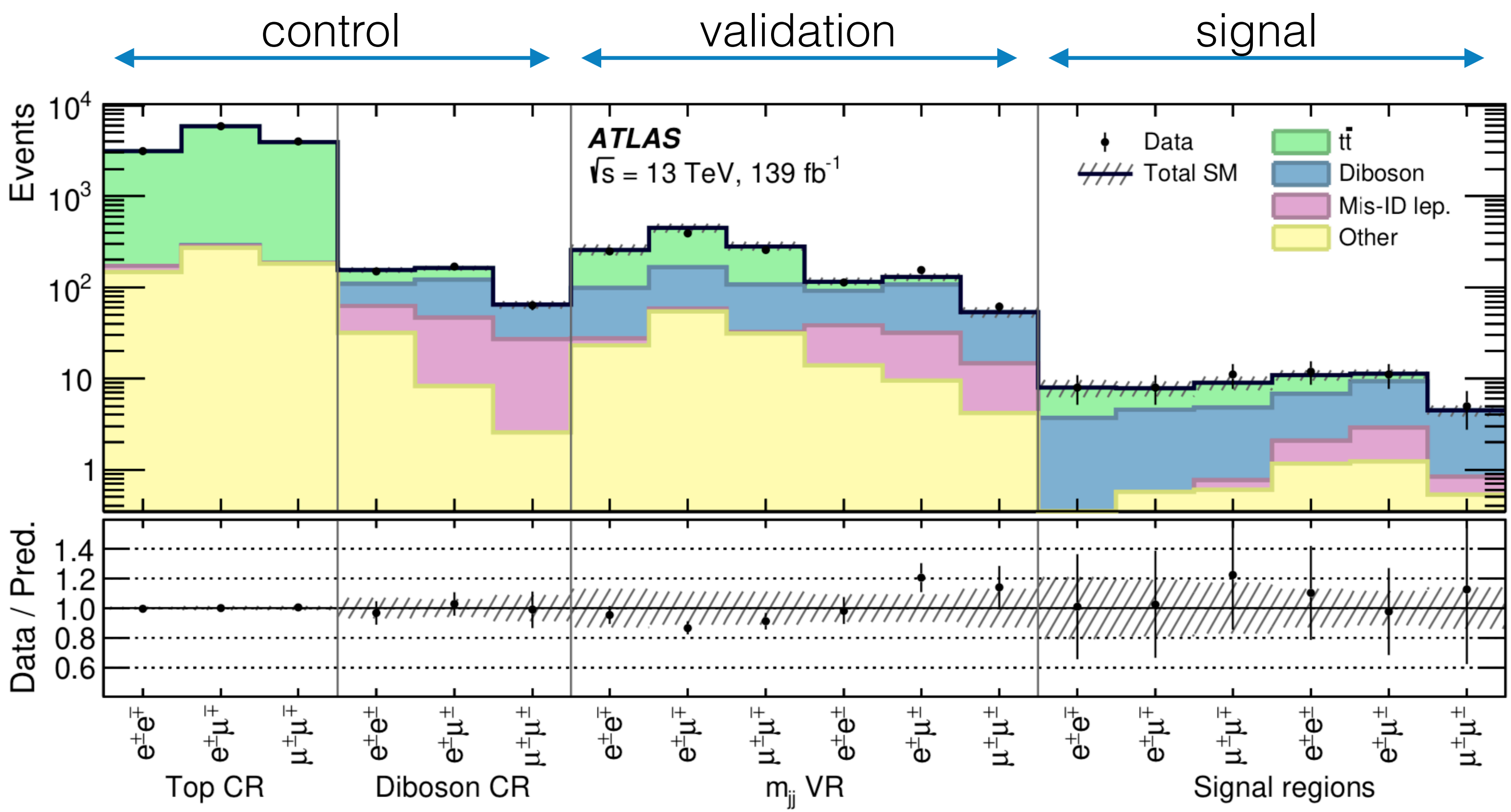
Background event





Type III Seesaw — number of events

- ★ Comparison of number of observed (data) and expected events in
  - ★ Background control and validation and signal regions



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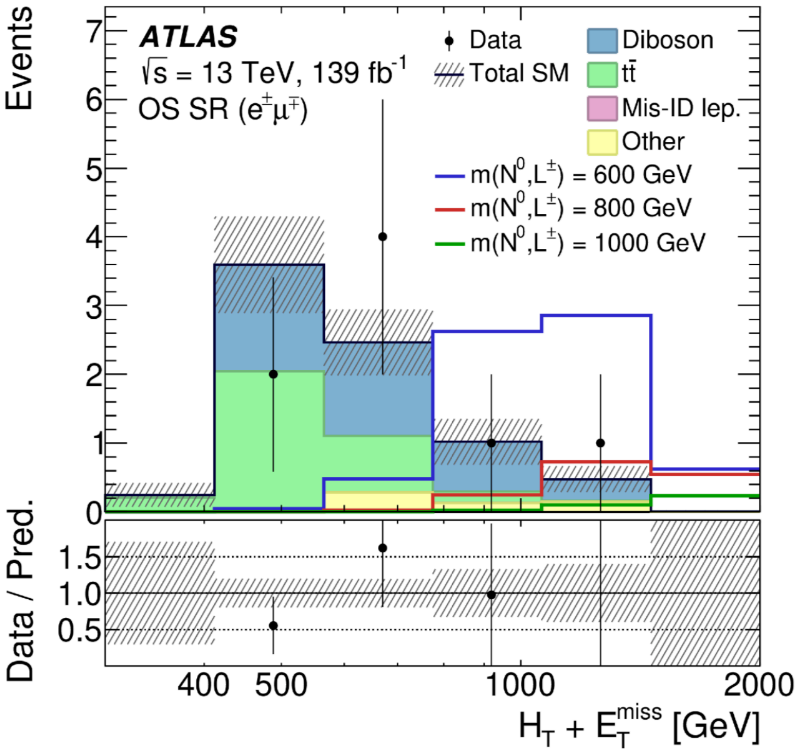
Type III Seesaw — limit

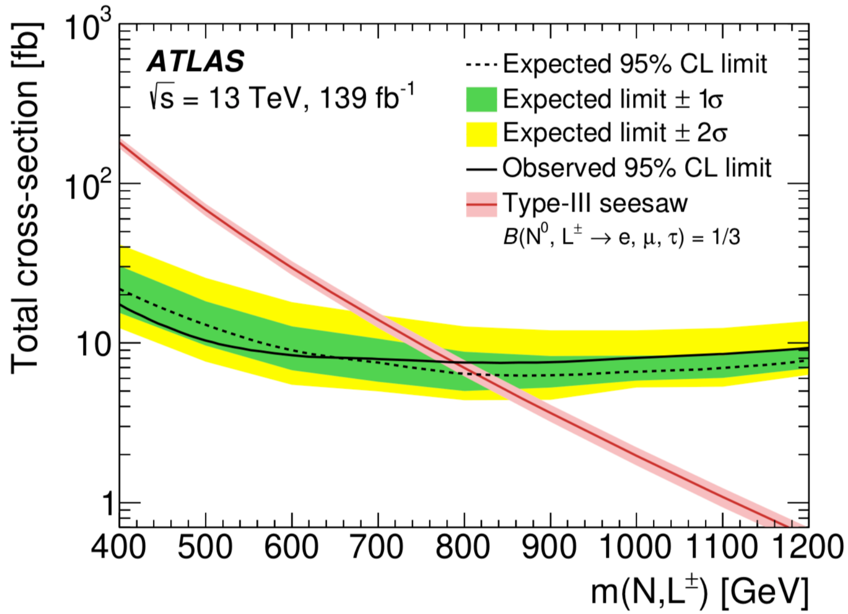
- ★ Lower limits on masses of Type III Seesaw heavy leptons at the 95 % CL
  - ★ Heavy leptons are excluded below masses of **790 GeV** using only final states with two light leptons



Cut-based analysis

expected limit: 820^{+40}_{-60} GeV

observed limit: 790 GeV



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H_T — scalar sum of the transverse momenta of selected leptons and jets

Summary

- Many different processes have signature with two leptons and jets in the final state

- The presentation focuses on recently published results from ATLAS Experiment on the full data set of Run 2 (2015-2018, 13TeV, $139\ \mathrm{fb}^{-1}$)

- **Leptoquarks**
  - $LQ \rightarrow e/\mu + qq\ (c, b\ jets)$ — excluded up to **1.8 (1.7) TeV** in **electron (muon)**
  - $LQ \rightarrow \tau + t$ — excluded up to **1.4 TeV**
  - $LQ \rightarrow e/\mu + t$ — excluded up to **1.48 TeV** / **1.47 TeV** for **electron** / **muon**

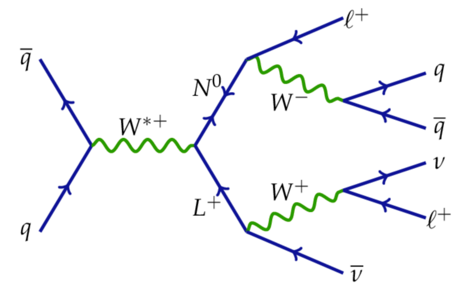
- **Lepton Flavour Violation**
  - $Br(Z \rightarrow e\tau) \leq 8.1 \times 10^{-6}$
  - $Br(Z \rightarrow \mu\tau) \leq 9.5 \times 10^{-6}$

- **Type III Seesaw**
  - Heavy leptons **(N^0, L^+, L^-)** are excluded below masses of **790 GeV**

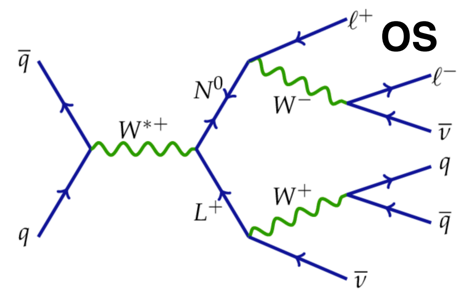
Backup

Type III Seesaw — analysis

- ATLAS analysis focuses on the following signature:
  - **2 lepton** final state:
    - opposite **sign** (OS) or same **sign** (SS)
    - same **flavour** ($ee, \mu\mu$) or opposite **flavour** ($e\mu$)
  - **2 jets** from quark hadronisation
  - Large **missing energy** (E_T^{miss}) due to neutrinos



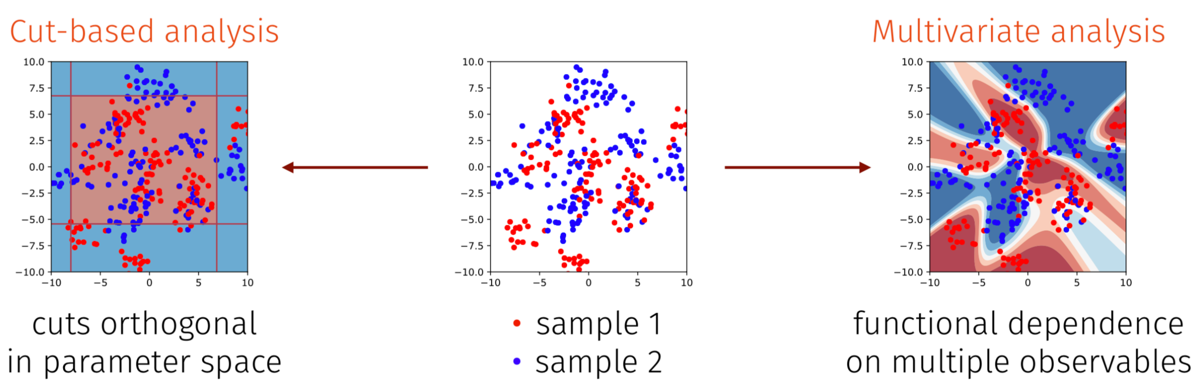
SS



OS

- Events split into 3 sets of 6 regions:
  - 6x signal (**SR**), 6x control (**CR**) and 6x validation (**VR**)

- Two different approaches:
  - **Cut-based** — presented here
  - Multivariate ML approach in preparation



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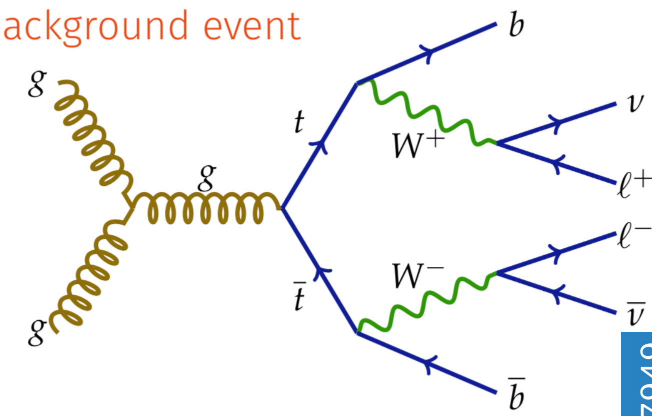
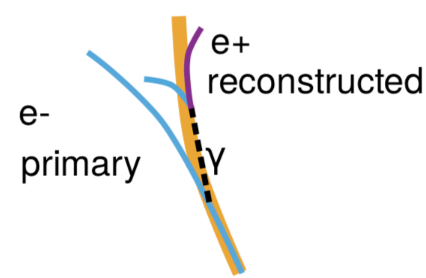
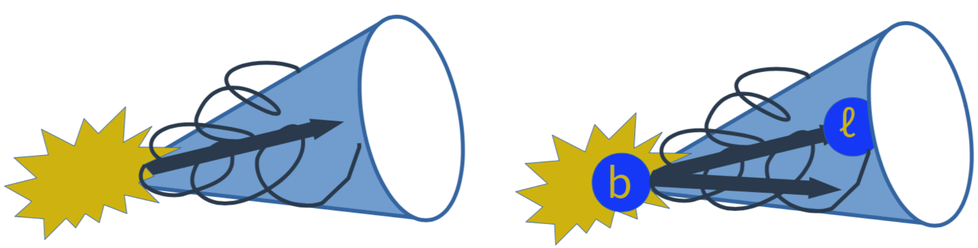
Type III Seesaw — background

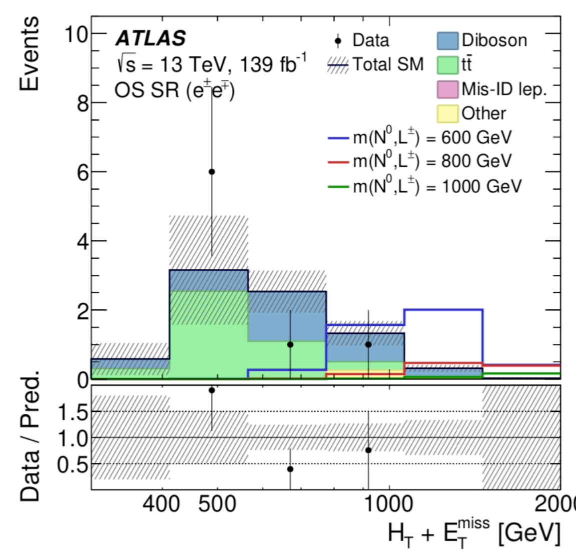
- Many **different sources of background** fit in two categories wrt to origin of reconstructed lepton
  - **Prompt leptons** — estimated based on detailed MC (MadGraph/Sherpa/Pythia + Geant4)
    - Main sources: **top quark** pairs, **diboson** production (WW, WZ, ZZ)
  - **Non-prompt or “fake" leptons** (data driven methods)
    - Photon conversions
    - Semileptonic decays of c/b
    - Jets
    - Punch trough particles
    - Charge misID

Background event









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