Search for Leptoquarks with the ATLAS Detector

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On behalf of the ATLAS collaboration

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Motivation

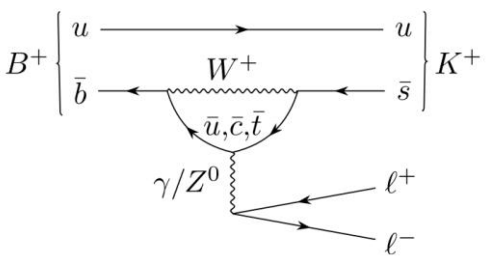
- **Leptoquarks (LQ) are predicted by many extensions of the SM**

- **Hints of Lepton Flavour Universality (LFU) violation in rare B-meson decays**
  - $b \to s\ell\ell$ $(R_{k(*)})$
  - $b \to c\ell\nu$ $(R_{D(*)})$

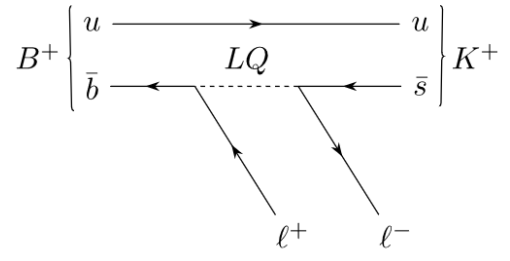
- **Muon g-2 anomaly, possibly connected to the LFU anomaly**

- **The existence of TeV-scale Leptoquarks is a possible solution to the anomalies!**

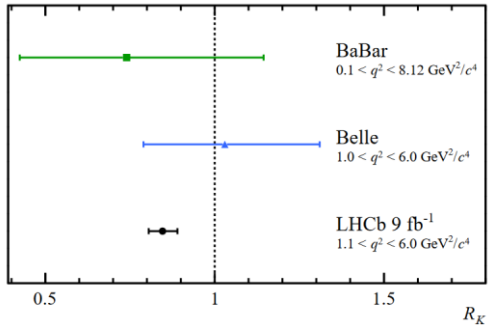
SM scenario



LQ interaction

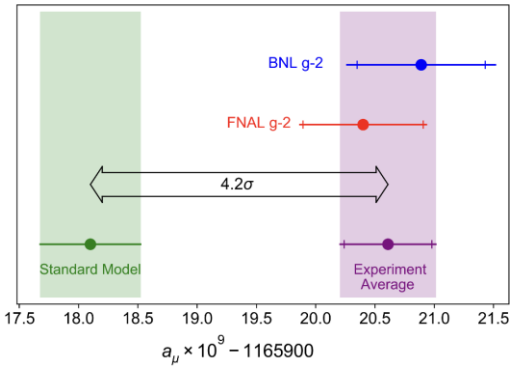


arXiv:2103.11769 R_K anomaly in B-meson decays



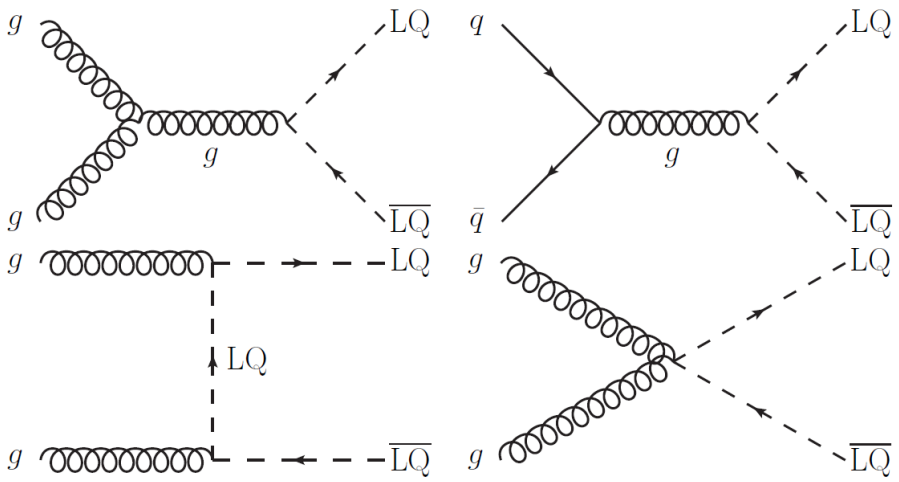
$$R_{k(*)} = \frac{BR(B \to K(*)\mu^+\mu^-)}{BR(B \to K(*)e^+e^-)}$$

arXiv:2104.03281 $g-2$ anomaly



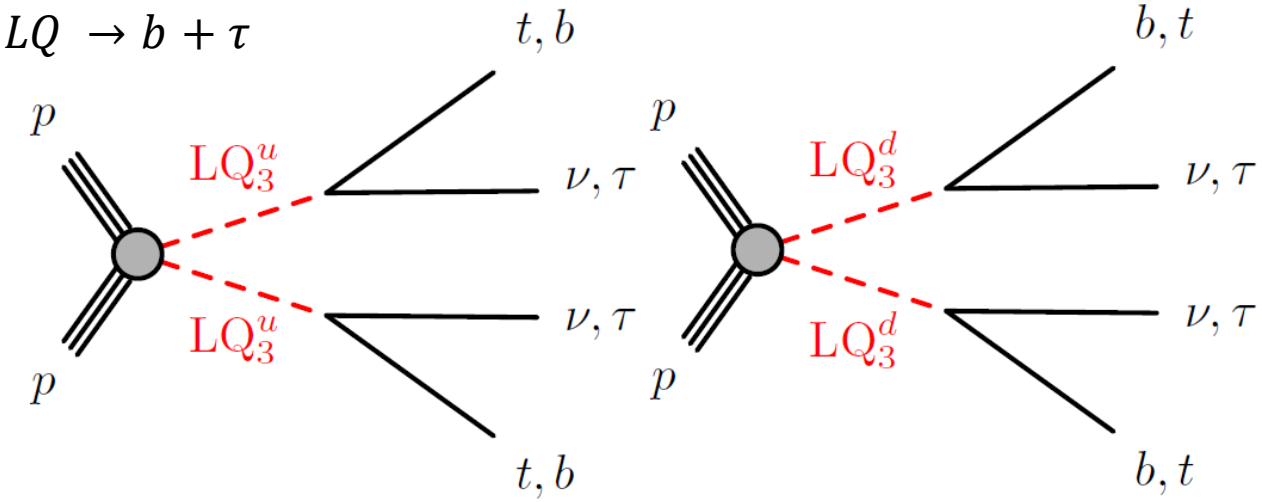
LQ Searches at the LHC

- **Dominant production $gg \rightarrow LQ + \overline{LQ}$**



- **Model parameters:**
  - LQ mass (M_{LQ})
  - $\beta(LQ \rightarrow XY)$

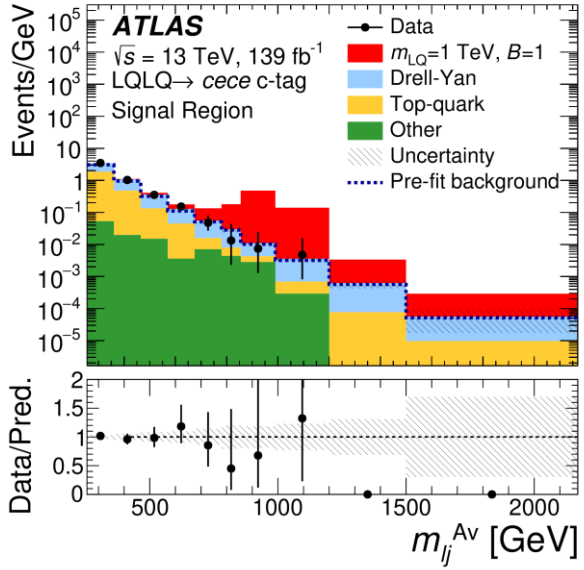
- **Analysis vary by the LQ type and decay channel**
  - $LQ \rightarrow q/c/b + e/\mu$
  - $LQ \rightarrow t + e/\mu$
  - $LQ \rightarrow t + \tau$
  - $LQ \rightarrow t + \nu$
  - $LQ \rightarrow b + \nu$
  - $LQ \rightarrow b + \tau$

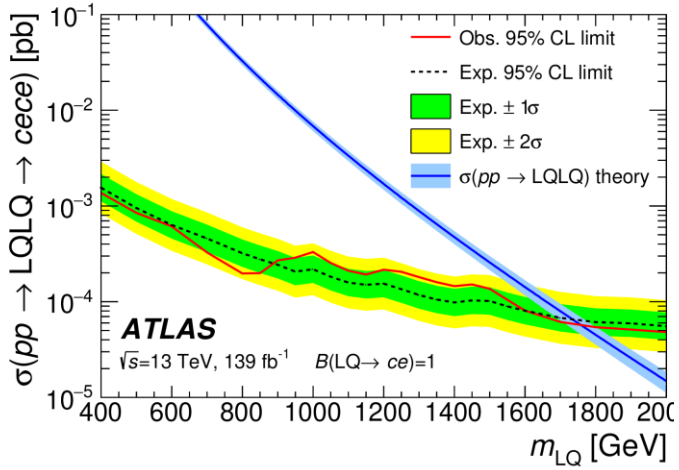


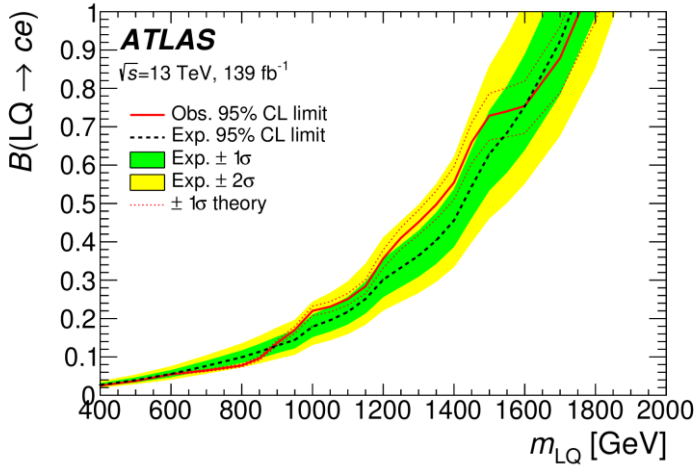
Scalar $LQ \rightarrow q/c/b + e/\mu$

- **First dedicated ATLAS search for cross-generational LQs**
- **First use of c-tagging in LQ searches**
- **SR defined by mass asymmetry:** $m_{asym} = \frac{M_{\ell j}^{max} - M_{\ell j}^{min}}{M_{\ell j}^{max} + M_{\ell j}^{min}} < 0.2$
- **Result presented in:** $m_{\ell j}^{Av} = \frac{M_{\ell j}^{max} - M_{\ell j}^{min}}{2}$
- **Main backgrounds:**
  - $t\bar{t}$, Drell-Yan, di-boson, W + jets, Z + jets, normalised from data

Channel	M_{LQ} Limits [TeV]
electron	>1.8
muon	>1.7







Scalar $LQ_3^d \rightarrow t\tau$

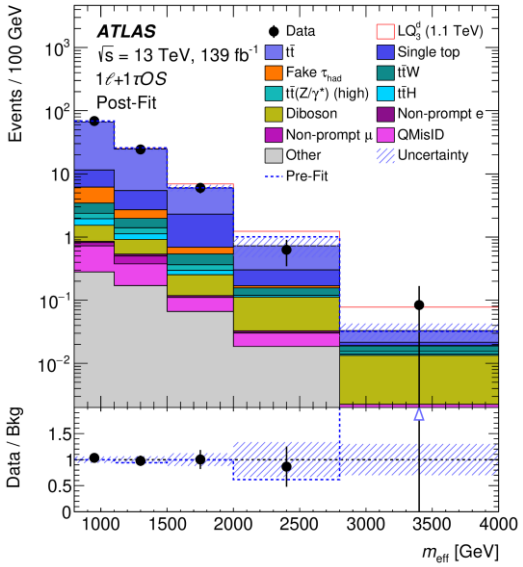
- **First dedicated ATLAS analysis for $LQ_3^d LQ_3^d \rightarrow t\tau t\tau$.**

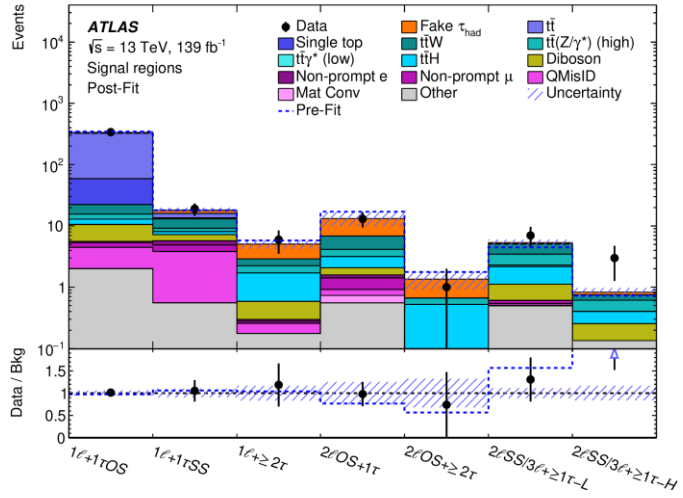
- **Require final states with:**
  - At least one light lepton ($\ell, e/\mu$), and at least one hadronic τ, or
  - At least two light leptons

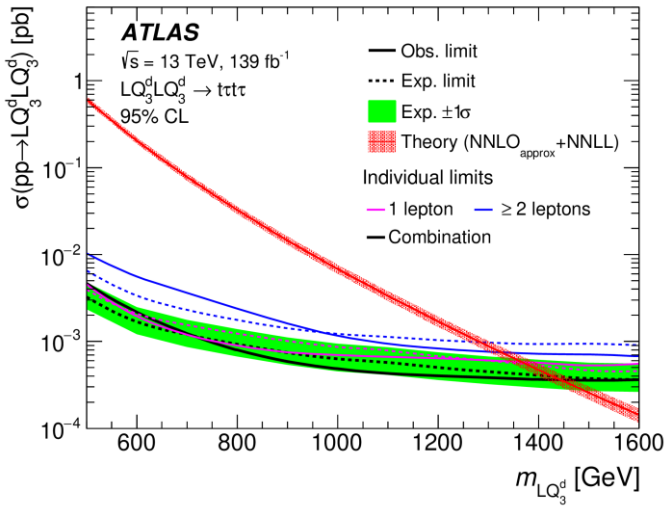
- **Main discriminating variable:**
  - $m_{eff} = \sum_{j,e,\mu,\tau} pT + E_T^{miss}$
- **Main backgrounds:**
  - $t\bar{t}$, $t\bar{t} + V/H$, diboson, Fake τ_{had}

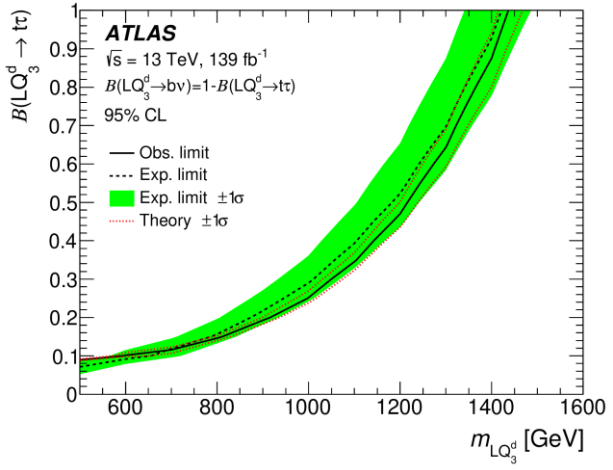
- **7 SRs categorised by number of ℓ, τ, charge of ℓ and τ**
  - SR optimised by m_{eff} and other kinematics: charge configuration, multiplicity, etc.

- **M_{LQ} limit > 1.4 TeV**



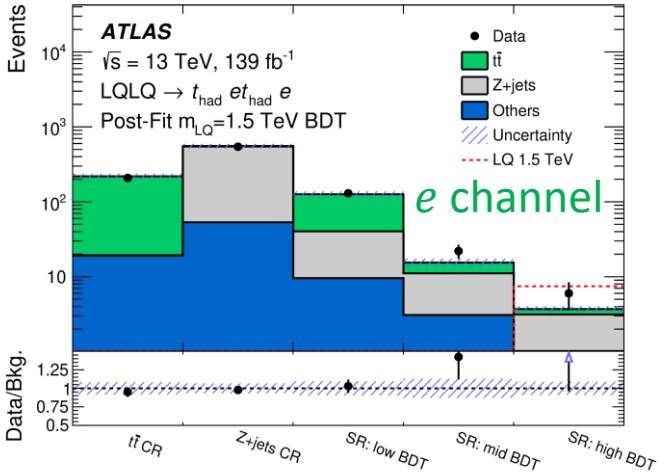






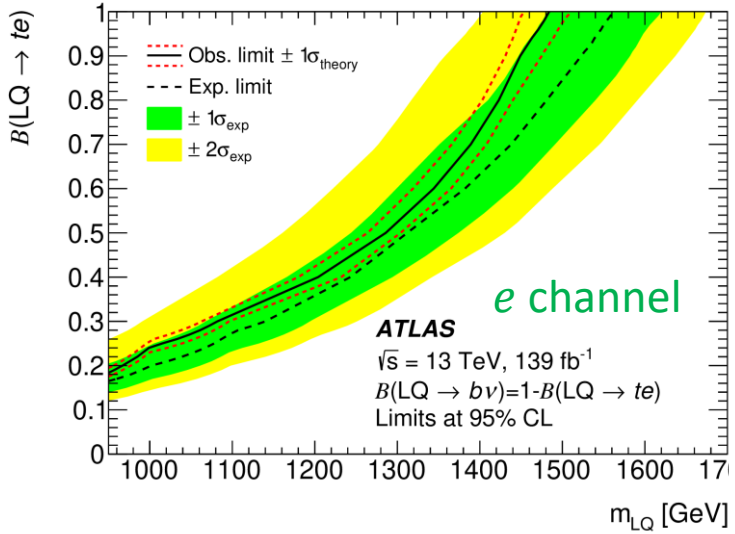
Scalar $LQ \rightarrow t + e/\mu$

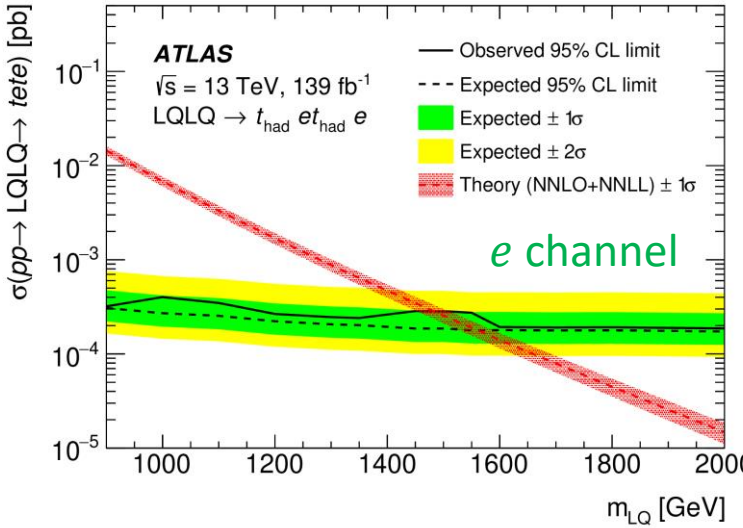
- **First ATLAS search for top-cross-generational LQ couplings.**
- **Boosted Decision Trees (BDT) are used to further separate signals from backgrounds**
  - 29(32) input variables used for $e(\mu)$ channel
- **Main backgrounds:**
  - Z + jets and di-leptonic $t\bar{t}$, normalisation extracted from CR.



	$t\bar{t}$ CR	Z + jets CR	SR
Leptons	$p_{\mathrm{T}}^{\ell} > 100$ GeV, $\lvert\eta_e\rvert < 2.47$, $\lvert\eta_\mu\rvert < 2.5$		
	$N_\ell = 2$; opposite-sign		
Large-R jets	$p_{\mathrm{T}}^{\mathrm{J}} > 200$ GeV, $\lvert\eta_{\mathrm{J}}\rvert < 2.0$, $m_{\mathrm{J}} > 50$ GeV		
	$N_{\mathrm{J}} \geq 2$		
Dilepton invariant mass	$m_{\ell\ell} > 120$ GeV	70 GeV $< m_{\ell\ell} <$ 110 GeV	$m_{\ell\ell} > 120$ GeV
Lepton flavour	$e\mu$	ee or $\mu\mu$	

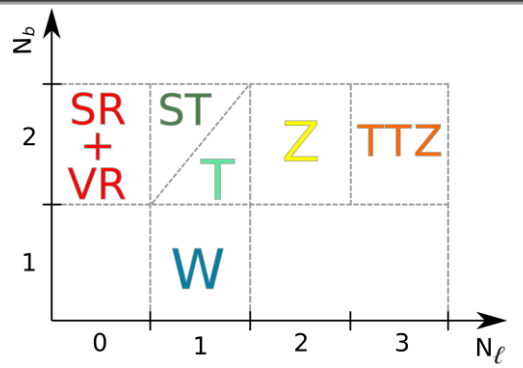
Channel	M_{LQ} Limits [TeV]
electron	>1.5
muon	>1.5

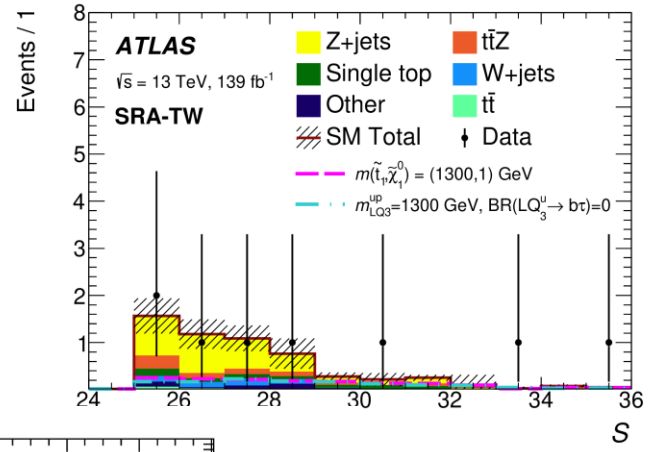


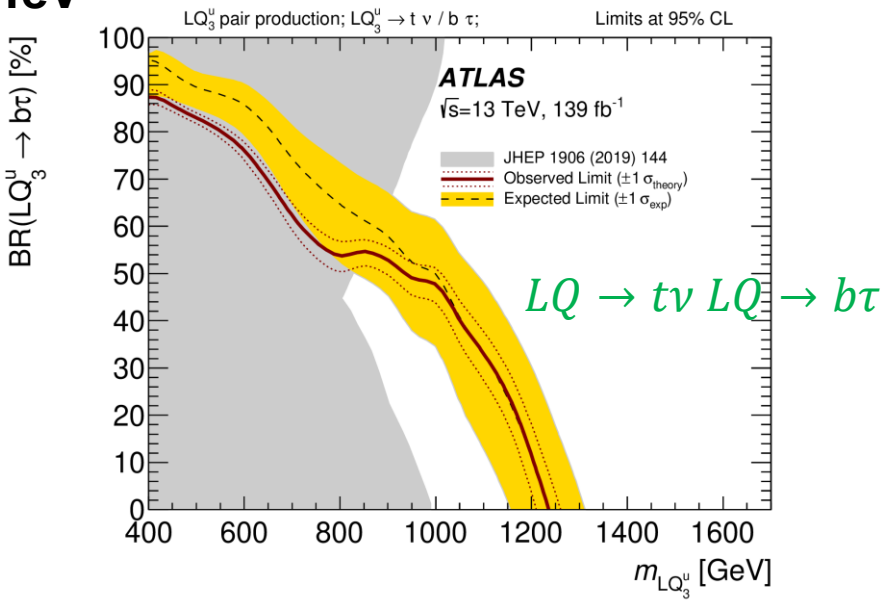


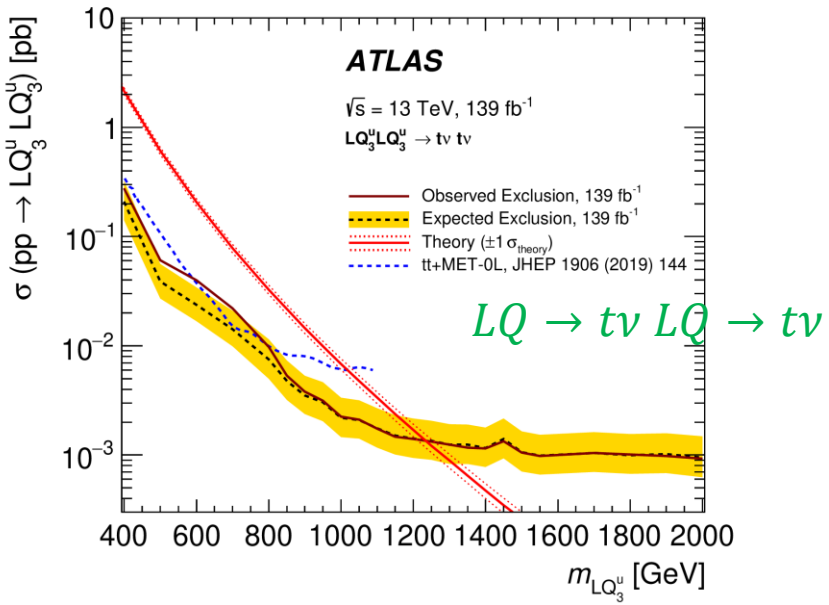
Scalar $LQ_3^u \rightarrow b\tau/t\nu$

- **Search for events with $t\bar{t} + E_T^{miss}$** in all hadronic channel
- **Reclustered jets**
  - with R = 1.2 and R = 0.8 for top and W
- **Main backgrounds**:
  - Z + jets, W + jets, $t\bar{t}$, single top, $t\bar{t} + Z$, all normalised from data
- **M_{LQ} limit > 1.2 TeV**



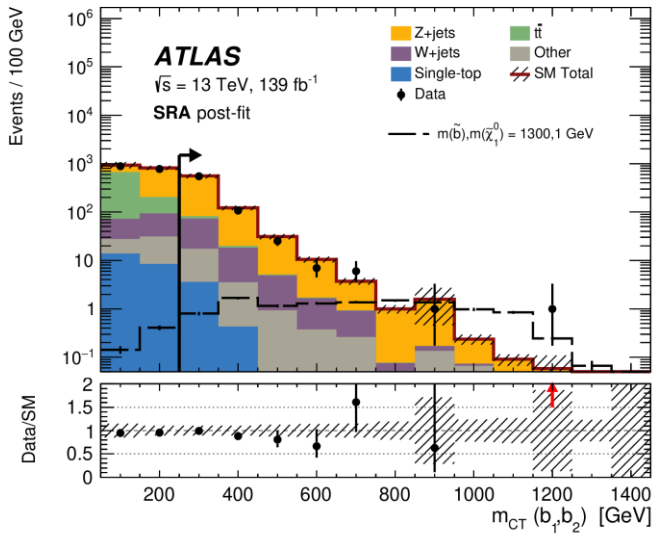


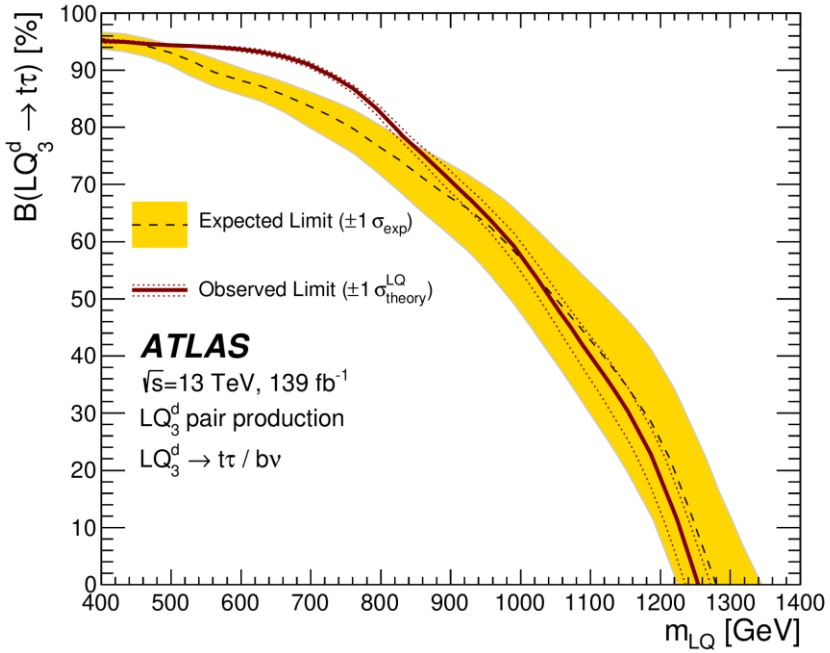




Scalar $LQ_3^d \rightarrow b\nu/t\tau$

- **Search for events with $b\bar{b} + E_T^{miss}$**
- **Most discriminating variables:**
  - $m_{eff} = \sum_j p_T + E_T^{miss}$, $m_{CT}^2(\nu_1, \nu_2) = [E_T(\nu_1) + E_T(\nu_2)]^2 - [p_T(\nu_1) - p_T(\nu_2)]^2$
- **Using BDT score as final discriminant**
- **Main background:**
  - Z + jets, normalised from data
- **M_{LQ} limit > 1.3 TeV**

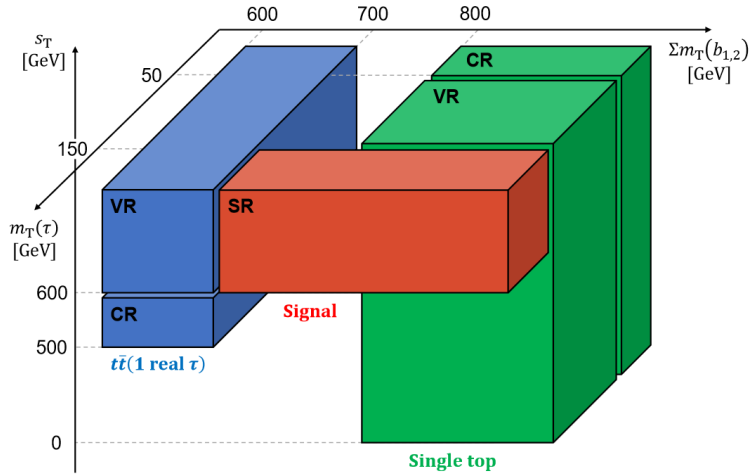


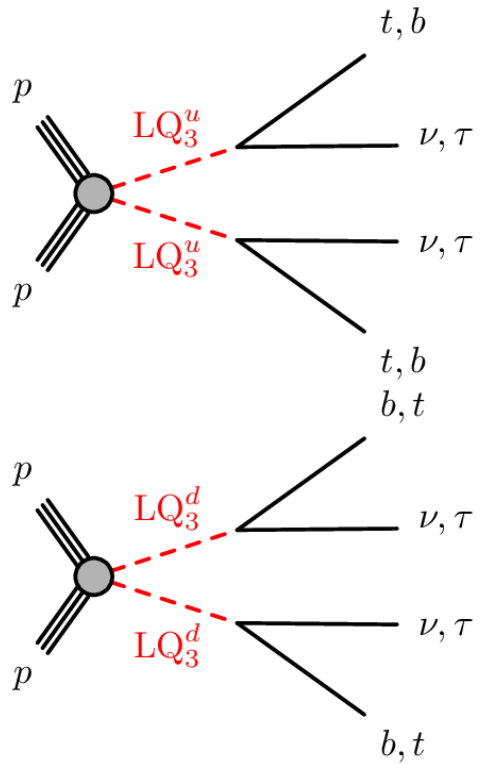


Scalar $LQ_3^u \rightarrow t\nu/b\tau$, $LQ_3^d \rightarrow b\nu/t\tau$, vector LQ_3^v

- **First ATLAS search for vector LQ**
  - Same analysis strategy as scalar LQ: same charge, same decay modes, similar kinematics

Di-tau preselection	Single-tau preselection
$E_{\mathrm{T}}^{\mathrm{miss}}$-trigger fired and $E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$ No light leptons (e/μ) At least two jets At least one b-tagged jet	
At least two hadronic tau leptons	Exactly one hadronic tau lepton At least two b-tagged jets



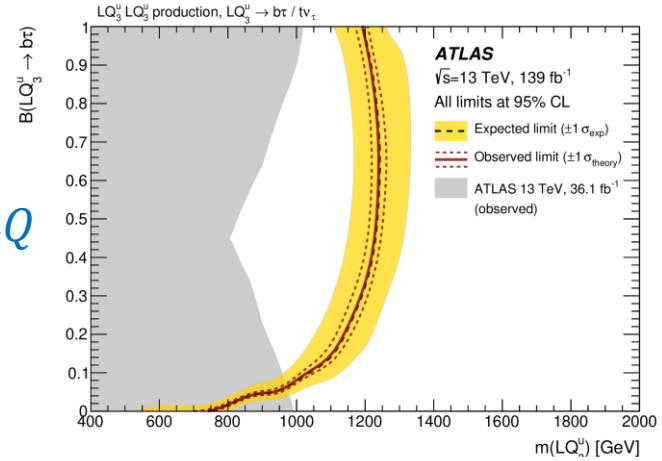


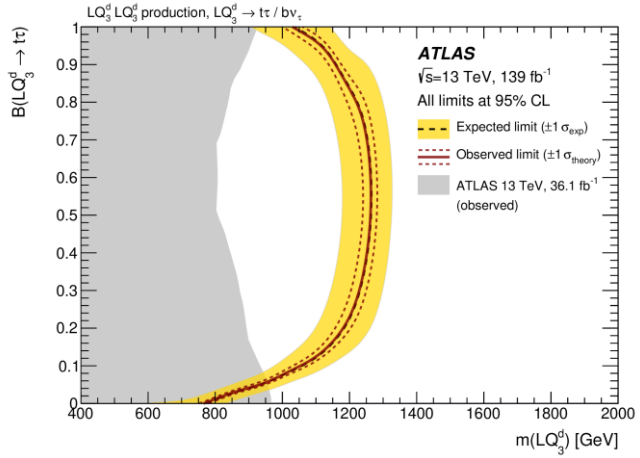
- **Only Single-tau all hadronic channel** is used for LQ searches
  - **Single-tau**: Targeting $B(LQ^{u/d} \rightarrow q\ell) \sim 0.5$, most events have final states: **1τ, 2 b-jets, large E_T^{miss}**
  - **All hadronic**: Leptonic decay leads to extra neutrino washes away sensitivity
  - SR and other regions defined by most discriminating variable: $m_T(\tau), \sum m_T(b_{1,2}), s_T$: defined as the scalar sum of the transverse momenta of the tau lepton and the two leading jets

Scalar $LQ_3^u \rightarrow t\nu/b\tau$, $LQ_3^d \rightarrow b\nu/t\tau$, vector LQ_3^v

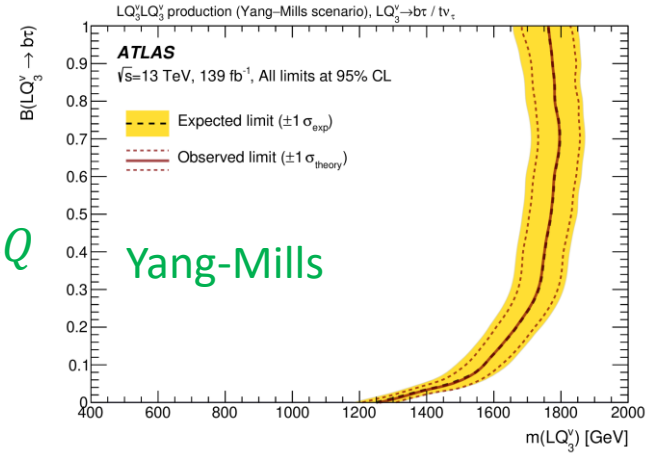
- **Continue…**
- **Main backgrounds: $t\bar{t}$ (1 real τ) and single-top, normalised from data.**

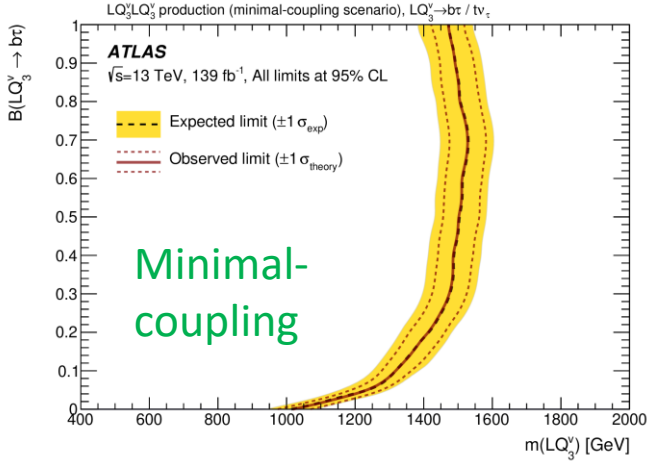
Scalar LQ

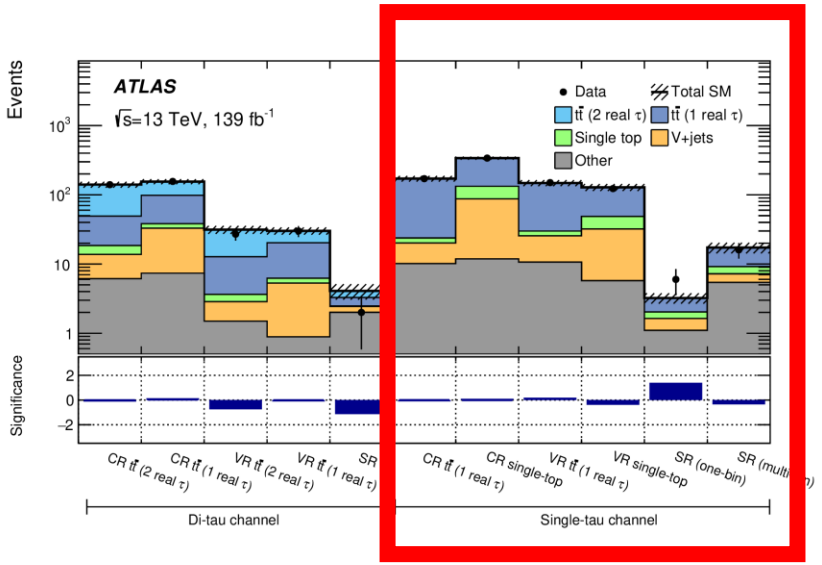




Vector LQ



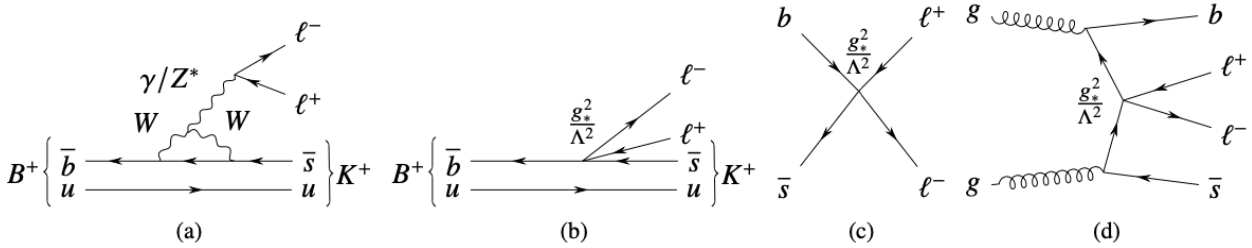




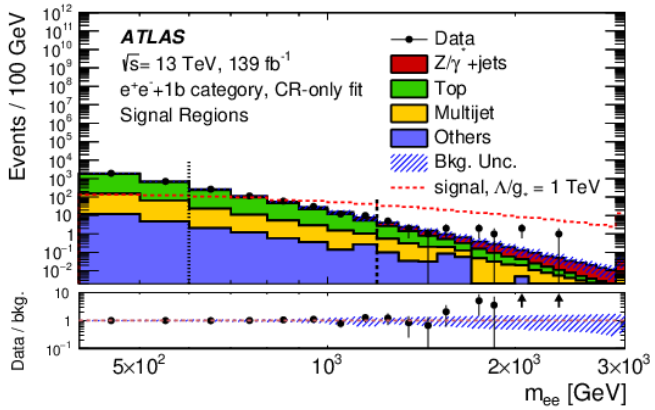
LQ Type	M_{LQ} Limits [TeV]
Scalar	>1.3
Vector, Yang-Mills	>1.8
Vector, minimal-coupling	>1.5

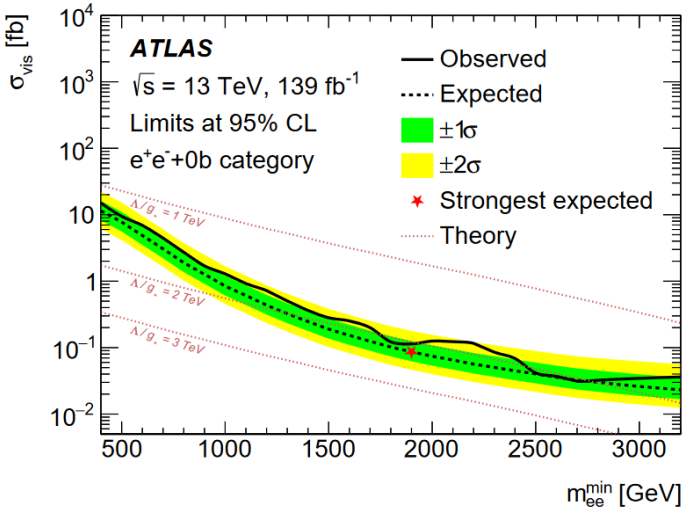
$bs\ell\ell$ Contact Interaction

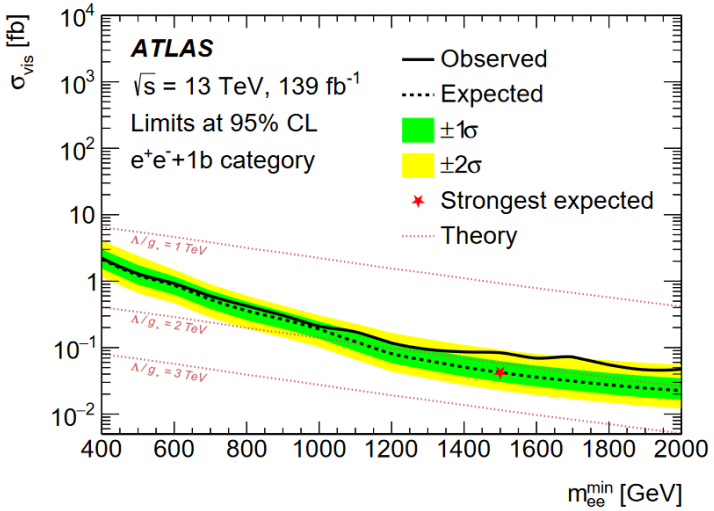
- **Consider $bs\ell\ell$ interaction for:**
  - SM(a), EFT(b) & for production of two leptons & with/without b jet in final state (c,d)



- **Main backgrounds: dileptonic $t\bar{t}$, Z + jets, normalised from data**
- **Result categorised in lepton flavour, number of b jets**







Channel	Limit
electrons	Λ/g^*>2.0
muons	Λ/g^*>2.4

Summary

- **Presented results of various LQ pair production searches, with a few dedicated searches first done in ATLAS**
- **Limits were set, still no sign of TEV scale LQs**

Leptoquarks		
Decay Mechanism	Comments	M_{LQ} Limits [TeV]
LQ → q/c/b + e/μ	electron	>1.8
	muon	>1.7
LQ → t + e/μ	electron	>1.5
	muon	>1.5
LQ → t + τ	-	>1.4
LQ → t + ν	-	>1.2
LQ → b + ν	-	>1.3
LQ →b + τ	Scalar	>1.3
	Vector, Yang-Mills	>1.8
	Vector, minimal-coupling	>1.5
Contact Interaction		
bsℓℓ	electrons	Λ/g^*>2.0
	muons	Λ/g^*>2.4

Summary

- **Continue…**