SEARCHES FOR LEPTOQUARKS WITH THE ATLAS DETECTOR

Merve Nazlim Agaras
on behalf of the ATLAS Collaboration

ICHEP 2022 Conference

9.07.2022

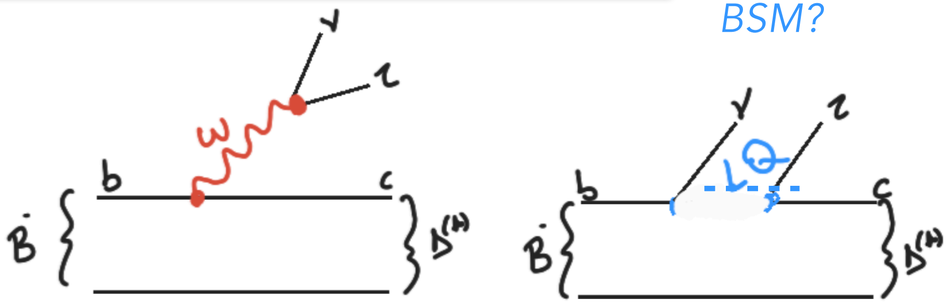
Introduction

* Despite all its phenomenological successes, the SM has some unsolved problems (hierarchy problem, **flavor problem…**)
  - Is SM only an EFT? Is there a UV theory whose low energy limit is SM?

* Searching for violation of **accidental symmetries** is a very powerful way to understand the **New Physics** properties
  - **L**epton **F**lavor **U**niversality - anomalies on **charged** and **neutral** current processes in B-physics
  - Anomalous magnetic dipole moment of muon possibly connected to LFU violation (chirality-changing observable)

* **Leptoquarks** are a good candidate as a BSM mediator to explain such anomalies
  - Predicted by many grand unified theories (GUT SU(5), Pati-Salam SU(4), RPV SUSY)
  - Connection between the quark and lepton sectors (coupling via a Yukawa interaction), carrying both lepton and baryon number
  - Can mediate flavour-changing-neutral-currents and enable violation of **LFU**
    - **Two scalar** or a single **vector** LQ -> the most optimal explanation for the B-anomalies

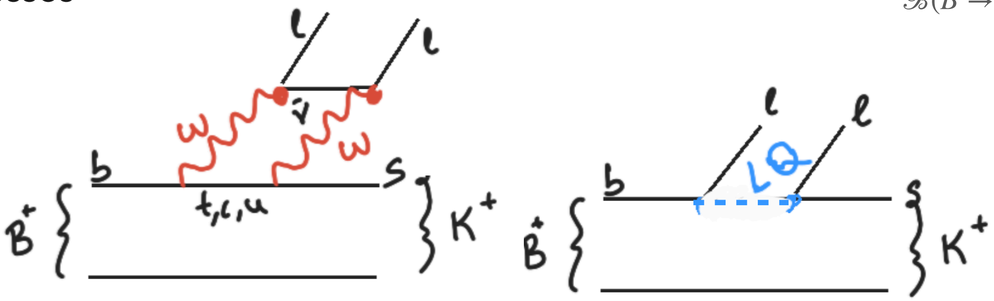
BSM?



arXiv:1909.12524

3.1σ excess in R_D and R_{D^*} combination

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{*}\tau\nu_\tau)}{\mathcal{B}(B \to D^{*}\ell\nu_\ell)} \quad \ell = e, \mu$$

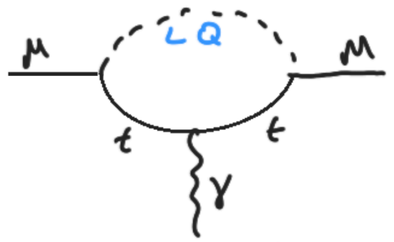


arXiv:2104.05631

3.9σ global significance of NP in b→sμμ

$$R(K^{(*)}) = \frac{\mathcal{B}(B \to K^{*}\mu^{+}\mu^{-})}{\mathcal{B}(B \to K^{*}e^{+}e^{-})}$$

Phys. Rev. Lett. 126, 141801 (2021)

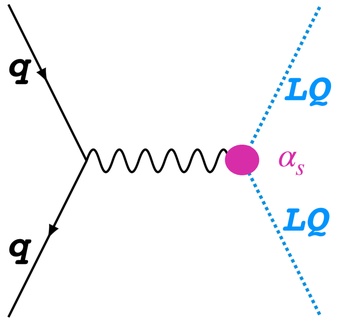


4.2σ deviation from SM

Leptoquarks

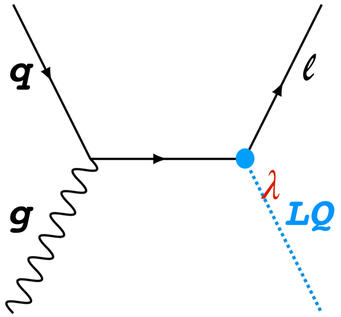
* Many degrees of freedom
  - Mass, electrical charge, scalar/vector type, Yukawa couplings (λ)
  - Can be produced in pairs, singly, off-shell, s/t-channel …
  - β parameter: Determines the branching fraction of LQ into charge lepton (β=1) or neutrino (β=0)

* In ATLAS, broad program of searches for **pair-production** and growing program of **single LQ** searches and interpretations in the context of **vector LQ**
  - Assume only one specific leptoquark
  - **Grid**: LQ mass vs β or λ
  - **Scalar LQ**: up-type (2/3e) and down-type (-1/3e) charge
    - Decays into flavour-diagonal or cross-generational (a.k.a "*mix*")
  - **Vector LQ**
    - Stronger model dependence - needs UV completion
    - Nominal coupling to color (κ = 0) Yang Mills (YM)
    - Minimal coupling (κ = 1): coupling to gluon only via covariant derivative



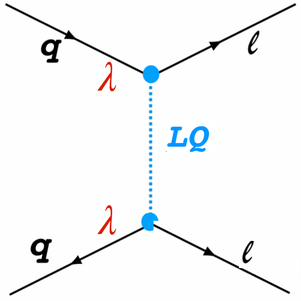
Pair production

QCD driven process
cross section depends on the mass



Single production

cross section ∝ λ^2
sensitive to higher m_{LQ} for sufficiently high λ



Off-shell production

cross section ∝ λ^4
non-resonant
sensitive to very high masses
possible interference with SM

Today's presentation

1. $\tau LQ_s \rightarrow b\tau_{had}\tau_{had}/b\tau_{lep}\tau_{had}$ - **NEW**
2. $LQ^{d(u)}_{mix}\ LQ^{d(u)}_{mix} \rightarrow t\nu b\ell/t\ell b\nu$ - Mar 22
3. $LQ^{d}_{mix}\ LQ^{d}_{mix} \rightarrow t\ell t\ell$ - multilepton **NEW**

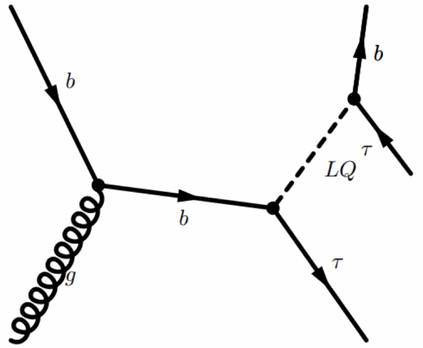
$\tau LQ_s \rightarrow b\tau_{had}\tau_{had}/b\tau_{lep}\tau_{had}$: Analysis strategy

ATLAS-CONF-2022-037

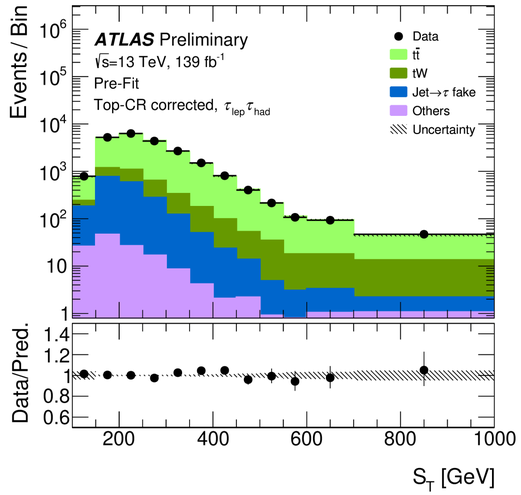
NEW

- Singly-produced **scalar** LQ decays into a τ *lepton* and a *b-hadron in* $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ final states with **non-resonant** LQ production
  - $\lambda = 0.5 - 2.5, \beta = 1, \tilde{S}_1$ scalar LQ
  - Interpretation for $LQ + LQLQ$
- Event selection
  - Single lepton (tau) trigger in $\tau_{lep}\tau_{had}$ ($\tau_{had}\tau_{had}$)
  - Opposite sign leptons
  - ≥ 2 jets, ≥ 1 b-jets, $\Delta\phi(\ell, E_T^{miss}) < 1.5$, $m_{vis}^{\tau\tau} > 100\ GeV$
  - High $p_{T,lead\ bjet} > 200\ GeV$ to avoid SM interferences from non-resonance
- Main backgrounds
  - $t\bar{t}$, single top (**reweighting** as a function of S_T)
  - Fake τ (**scale factors** as a function of $p_{T,\tau_{had}}$ and # of charged tracks)
- Fit to signal regions
  - $S_T > 300\ GeV$
  - S_T as discriminating variable

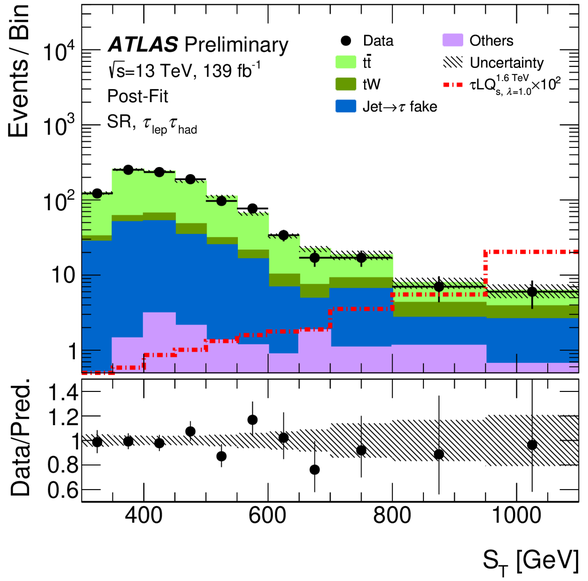
$$S_T = \sum_{bjet,\ell,\tau} p_T$$



Top control region after the correction scale factor



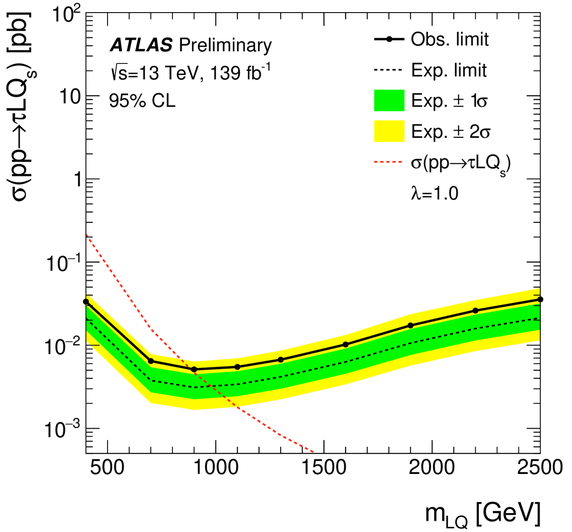
Signal populates the high S_T tails

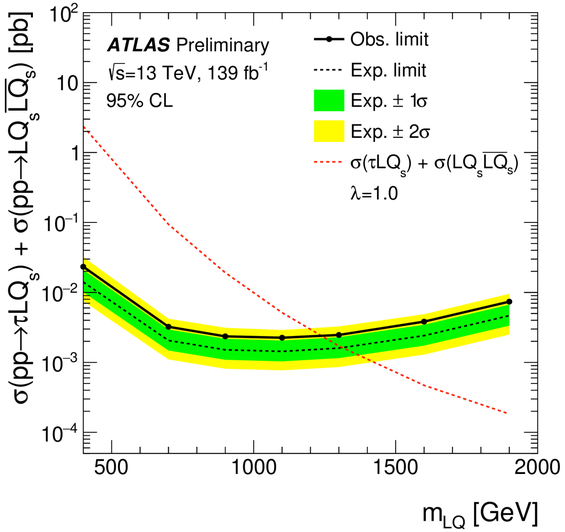


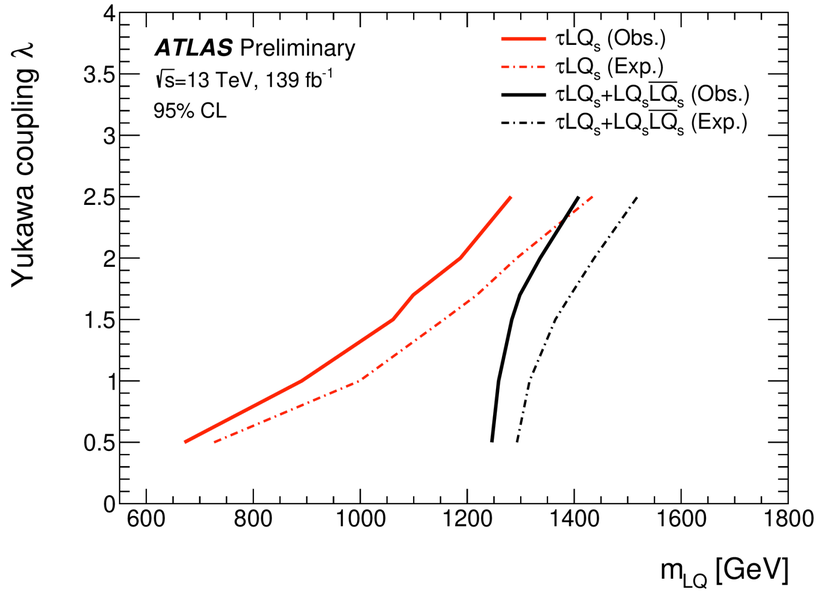
$\tau LQ_s \rightarrow \tau_{had}\tau_{had}/\tau_{lep}\tau_{had}$: Results

ATLAS-CONF-2022-037

- The first ATLAS result for LQ in the $b\tau\tau$ final state!
- Dominating **systematic uncertainties**: top related background modelling but highly statistically dominated in high masses
- 95% C.L. upper limits set on **both scalar LQ and LQ+LQLQ production** scenarios
  - No significant deviations between the data and the expected SM background are observed
- Observed exclusions for **single LQ** production:
  - $m_{LQ} < 0.89\ TeV,\ \lambda = 1.0$
  - $m_{LQ} < 1.28\ TeV,\ \lambda = 2.5$
- The most stringent limits are obtained with **LQ+LQLQ** combination
  - $m_{LQ} < 1.25\ TeV,\ \lambda = 0.5$
  - $m_{LQ} < 1.41\ TeV,\ \lambda = 2.5$
- Updated limits wrt $36\ fb^{-1}\ LQ\ LQ \rightarrow b\tau b\tau$ analysis





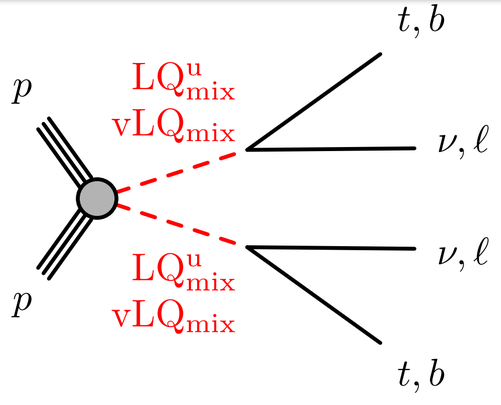


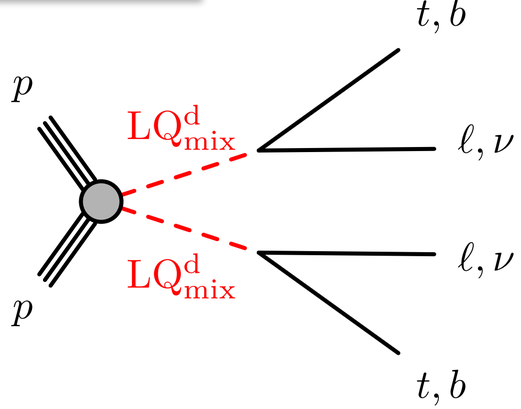
2D exclusion limits in $m_{LQ} - \lambda$ plane

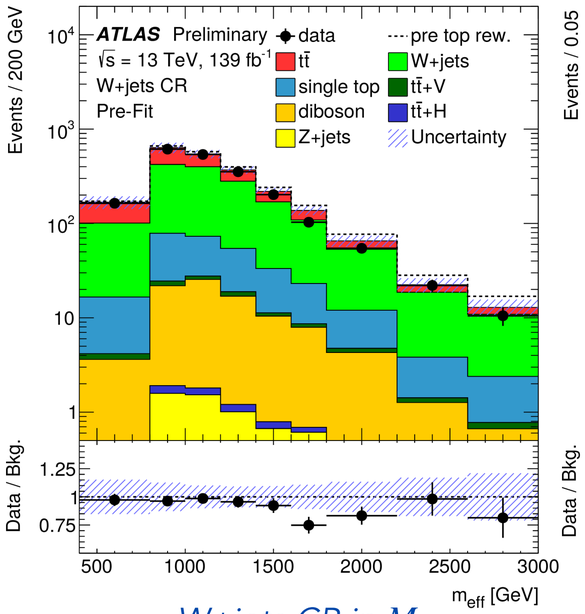
$LQ^{d(u)}_{mix}\ LQ^{d(u)}_{mix} \rightarrow t\nu b\ell / t\ell b\nu$: Analysis strategy

ATLAS-CONF-2022-009

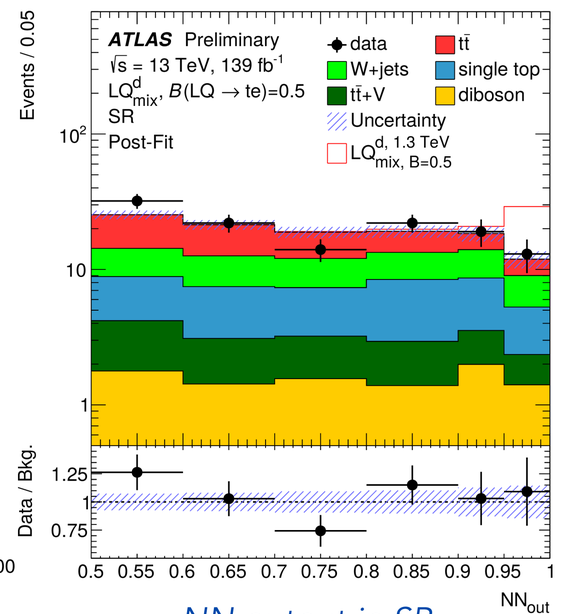
- Search for pair-produced scalar and vector LQs decaying into third-generation quarks and first- or second-generation leptons in **single lepton** final states
  - optimised for $\beta = 0.5$
- Pair produced **scalar** $LQ^{u}_{mix} \rightarrow t\nu,\ b\ell$ or $LQ^{d}_{mix} \rightarrow t\ell,\ b\nu$
- Pair produced **vector** $LQ \rightarrow t\nu,\ b\ell$ with minimal or Yang-Mills coupling
- Event selection
  - **MET trigger,** ≥4jets,≥1b-jet
- Main backgrounds
  - W+jets, single top (dedicated **CRs**), $t\bar{t}$ (**rewighting** as a function of M_{eff})
  - **Free-floated** $t\bar{t}$, single top and the *W*+jets normalisations
- Neural network **(NN)** is trained for different signal hypothesis
  - NN_{out}<0.5 CR (single bin), NN_{out} >0.5 SR (multibin)
- Simultaneous fit to all signal and control regions







W+jets CR in M_{eff}



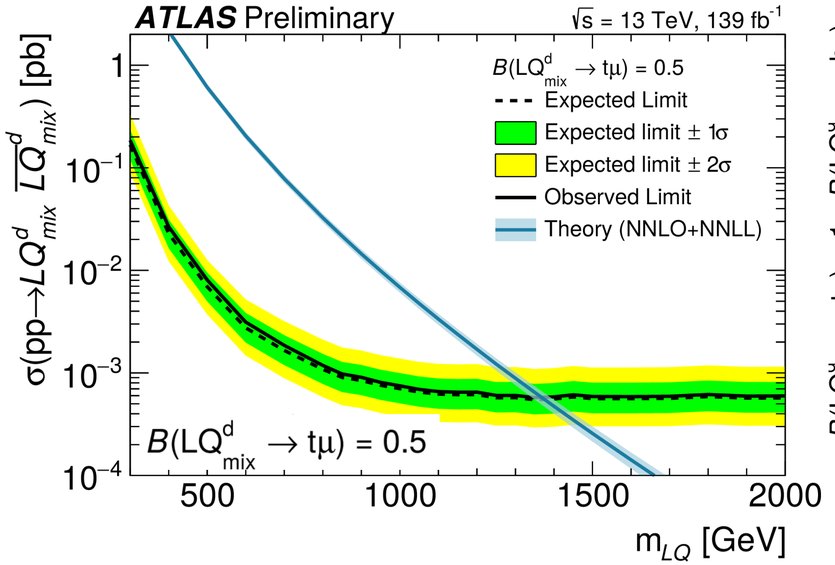
NN output in SR

$$M_{eff} = \sum_{jet,e,\mu} p_T + MET$$

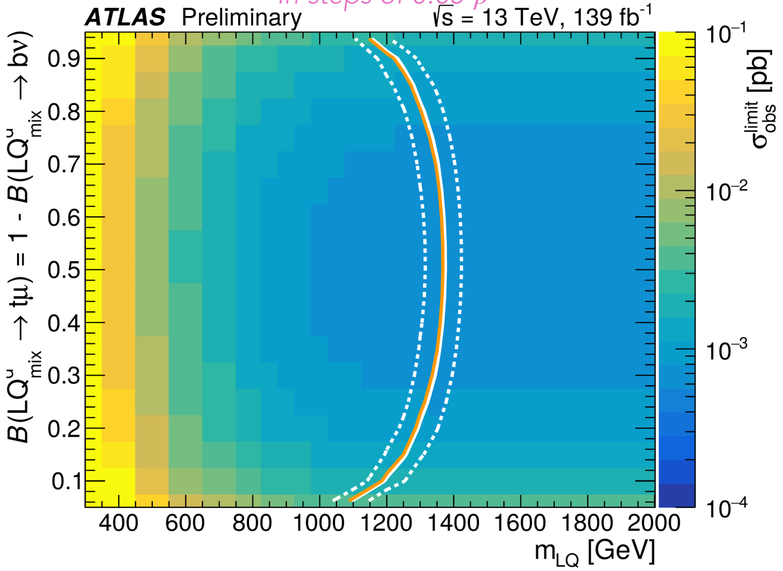
$LQ^{d(u)}_{mix}\ LQ^{d(u)}_{mix} \rightarrow t\nu b\ell / t\ell b\nu$: Results

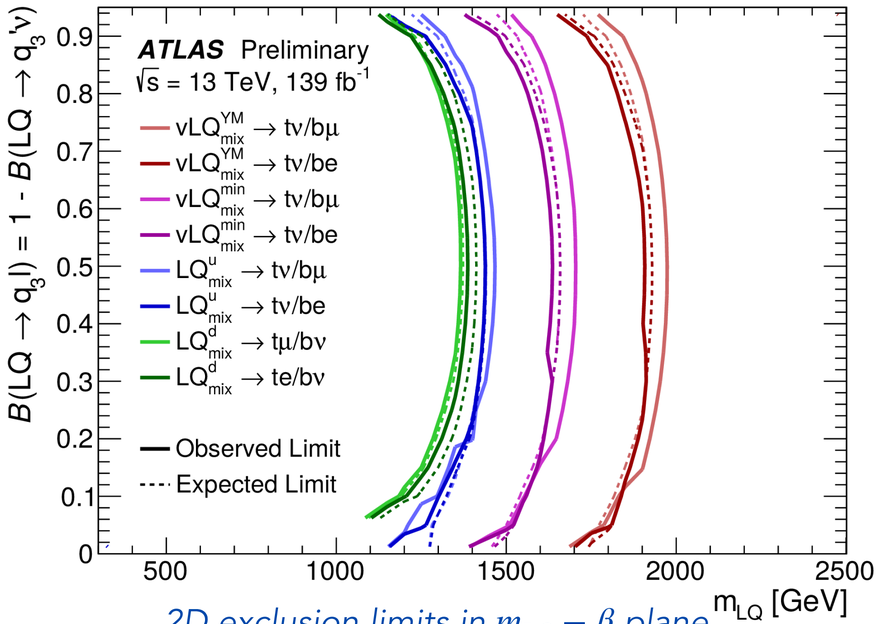
ATLAS-CONF-2022-009

- Dominating **systematic uncertainties**: top related background modelling and Jet Energy Scale (JES) uncertainties but highly statistically dominated in high masses
- 95% C.L. upper limits set on **eight** LQ model
  - No significant deviations between the data and the expected SM background are observed
- Observed exclusions:
  - $m_{LQ^{u}_{mix}\rightarrow e(\mu)} < 1.44\ TeV\ (1.47\ TeV)$ for $\beta = 0.5$
  - $m_{LQ^{d}_{mix}\rightarrow e(\mu)} < 1.39\ TeV\ (1.37\ TeV)$ for $\beta = 0.5$



In steps of 0.05 β





2D exclusion limits in $m_{LQ} - \beta$ plane

$LQ^d_{mix}\ LQ^d_{mix} \rightarrow t\ell t\ell$: Analysis strategy

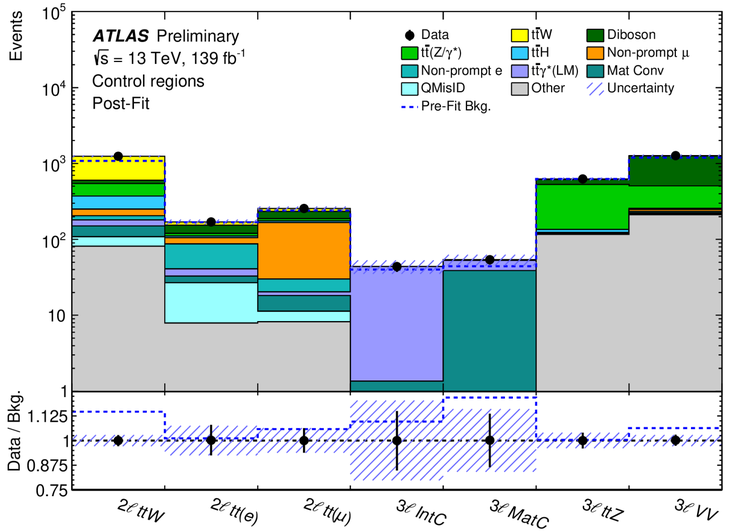
ATLAS-CONF-2022-052

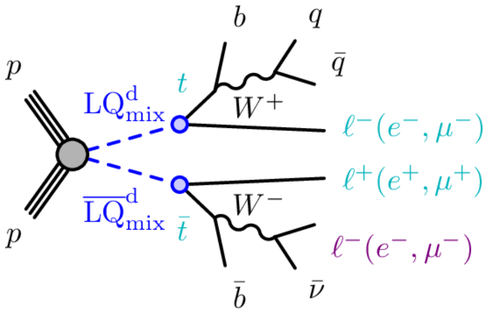
NEW

- Search for pair production of LQs decaying into a top quark pair and a pair of electrons or muons, in multi-lepton final states (2ℓSS, 3ℓ and 4ℓ)
- Pair produced **scalar** $LQ^d_{mix}\ LQ^d_{mix} \rightarrow t\ell t\ell$, $\ell(=e,\mu)$, $\beta = 1.0$
- Pair produced **vector** LQ $\tilde{U}_1$
- Event selection
  - Single and dilepton triggers, ≥ 2 jets, ≥ 1 b-jets
- Main backgrounds (dedicated CRs + free-floated)
  - $t\bar{t}W$, $t\bar{t}Z$, $VV\ (V = Z, W)$, non-prompt ℓ
  - Additional VRs to validate the modelling
- Signal regions
  - $M_{eff} > 500\ GeV$, $m^{min}_{\ell\ell} > 200\ (100)\ GeV$ for **3**ℓ **(4**ℓ**)**
  - M_{eff} as discriminating variable
- Simultaneous fit to all SRs and CRs

$$M_{eff} = \sum_{jet,e,\mu} p_T + MET$$

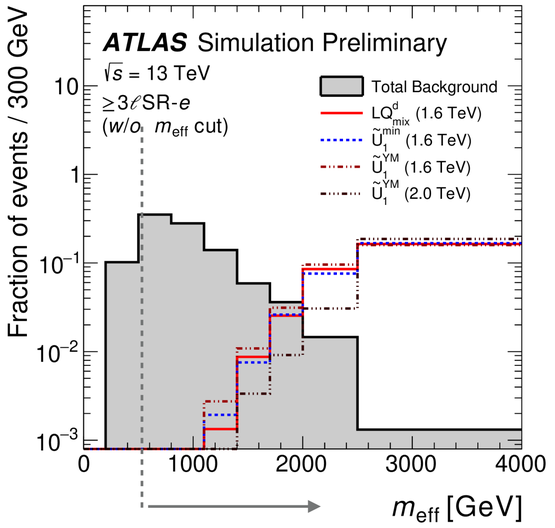
Summary of CRs

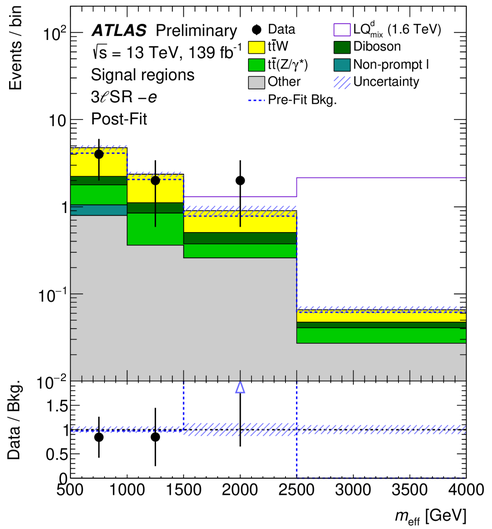




3ℓ

Signal populates the high tails of M_{eff}

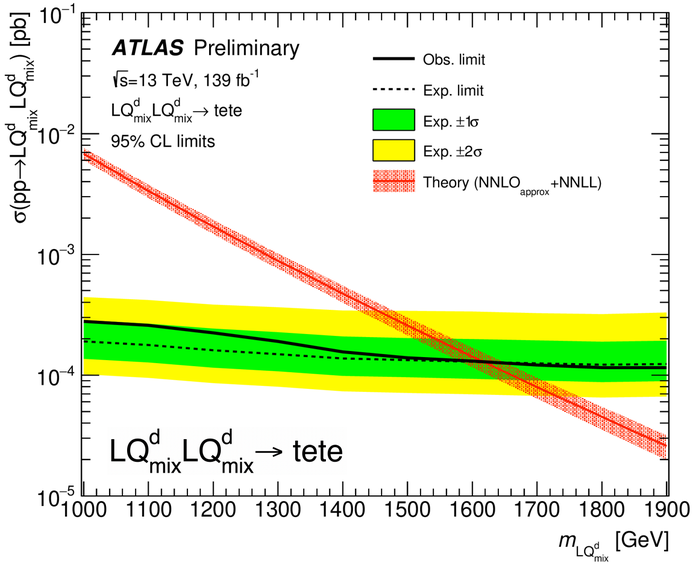


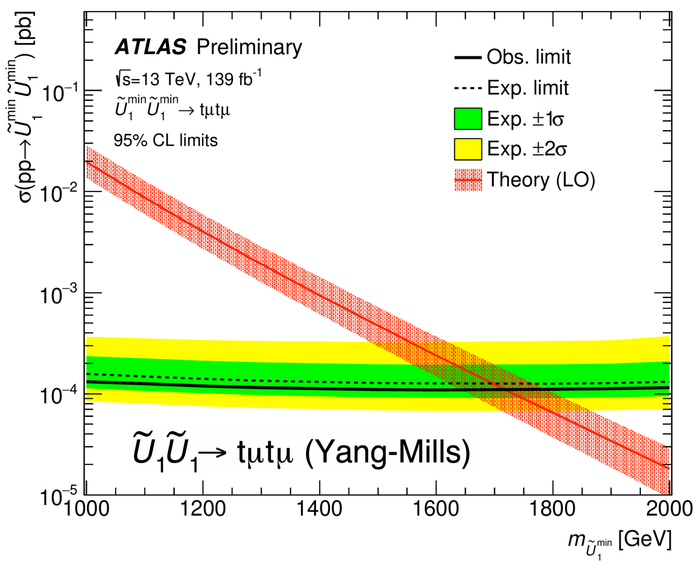


$LQ^d_{mix}\ LQ^d_{mix} \to t\ell t\ell$: Results

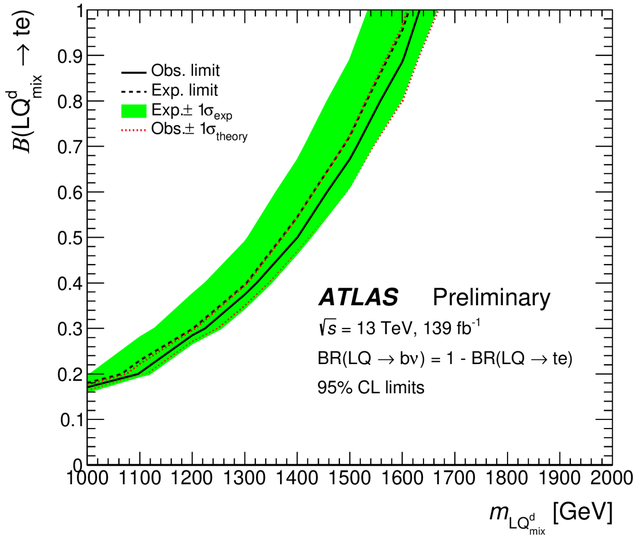
ATLAS-CONF-2022-052

- Main systematic uncertainty from lepton identification, but analysis is statistically limited
- 95% C.L. upper limits set on **both scalar and vector** LQ model
  - No significant deviations between the data and the expected SM background are observed
- Observed exclusions ($LQ \to te\ (t\mu)$):
  - Scalar $m_{LQ^d_{mix}} < 1.64\ TeV,\ (1.61\ TeV)$
  - Yang-Mills vector $m_{LQ_{\tilde{U}}} < 1.71\ TeV,\ (1.73\ TeV)$
  - Minimal coupling vector $m_{LQ_{\tilde{U}}} < 2.0\ TeV,\ (2.0\ TeV)$
- The most stringent limits up-to-date!

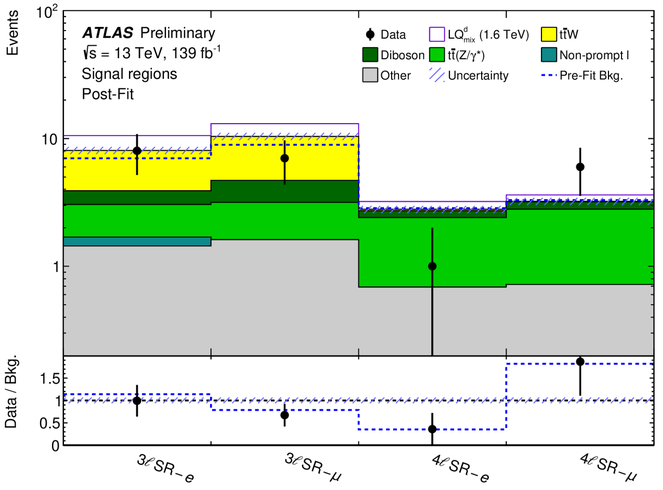




In steps of 0.1 β



2D exclusion limits in $m_{LQ} - \beta$ plane

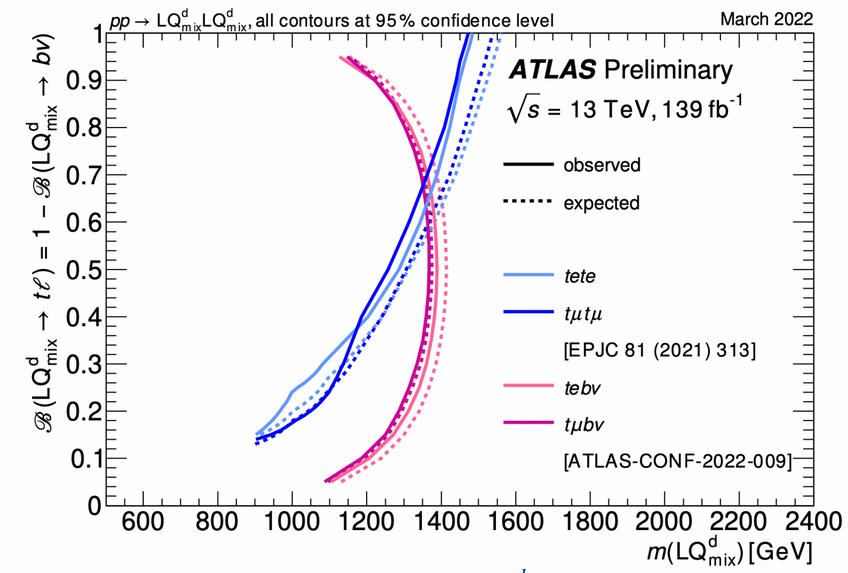


Summary of SRs

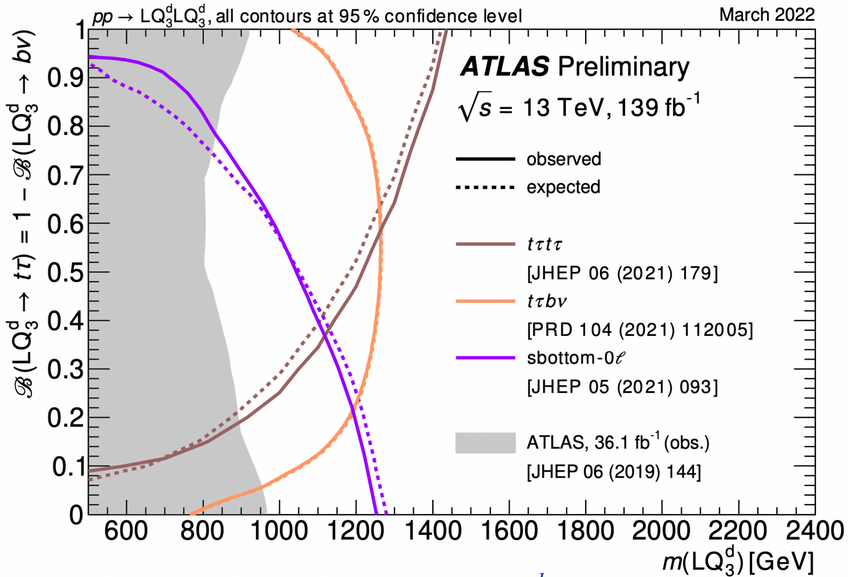
Towards combination

ATL-PHYS-PUB-2022-012

* **Overlays** of exclusion contours of pair produced scalar leptoquark models
  - Third-Generation ($LQ_3^u \to t\nu b\tau$, $LQ_3^u \to t\nu t\nu$ and $LQ_3^d \to t\tau t\tau$, $LQ_3^d \to b\nu b\nu$ analyses)
  - Mixed-Generation ($LQ_{mix}^d \to b\nu/t\ell$, $LQ_{mix}^u \to t\nu/b\ell$)
  - More summary plots are available online!



Exclusion contours $LQ_{mix}^d \to b\nu/t\ell$ (boosted) as a function of β



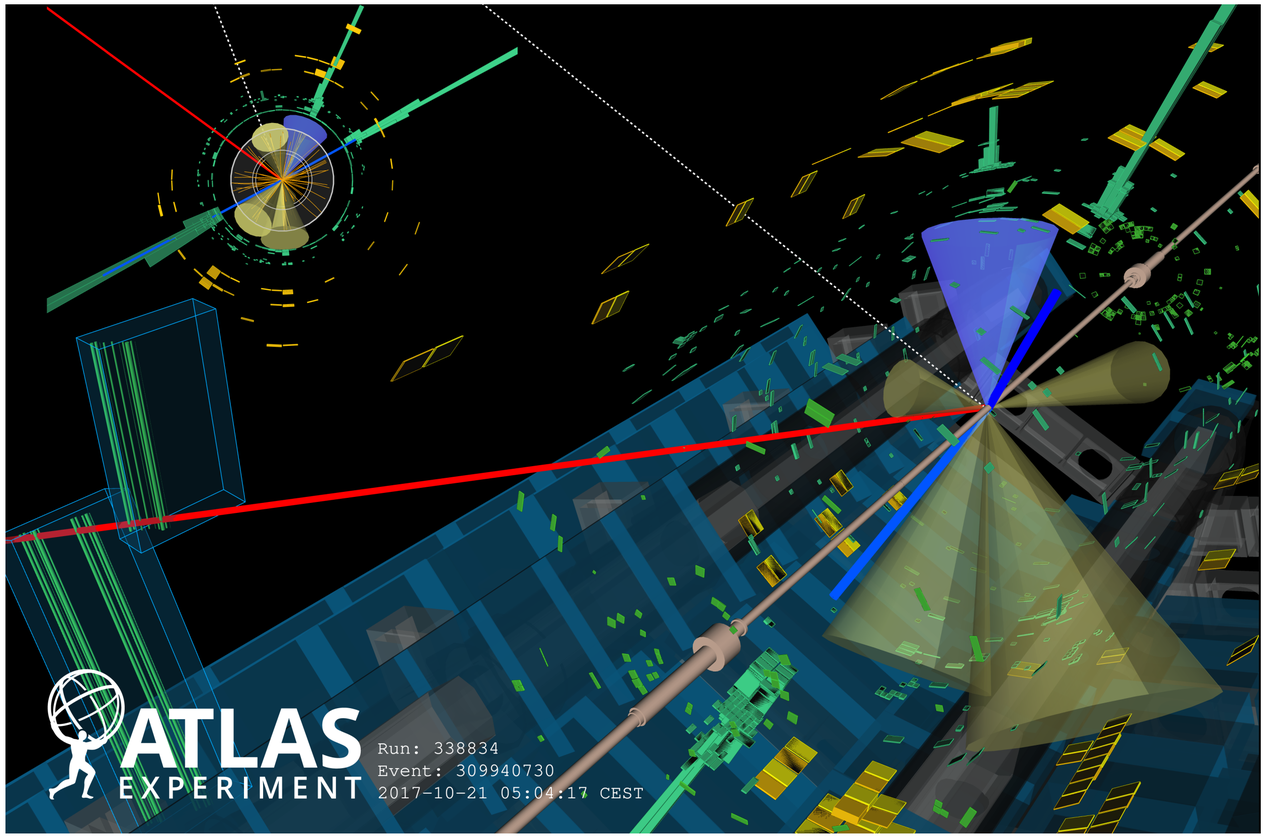
Exclusion contours $LQ_3^d \to b\nu/t\tau$ as a function of β

* **Combination** is ongoing!

Summary

* ATLAS has a broad program of searches for **pair-production** and growing program of **single LQ** searches and interpretations in the context of **vector LQ**
* Presented the latest findings from searches for LQ with the ATLAS experiment
* Stringent limits set on scalar LQs with flavour-diagonal and cross-generational couplings

* More scenarios to cover
  - Vector LQ, single LQ, s-channel and off-shell production
* LHC expected to further improve sensitivity with increasing luminosity!

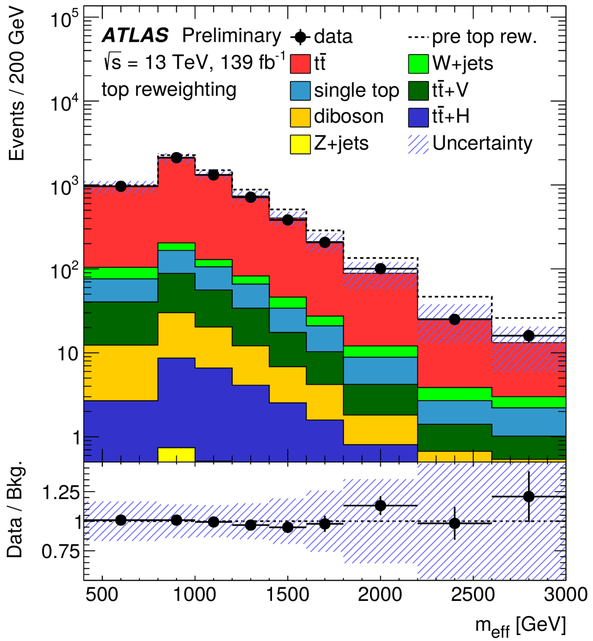


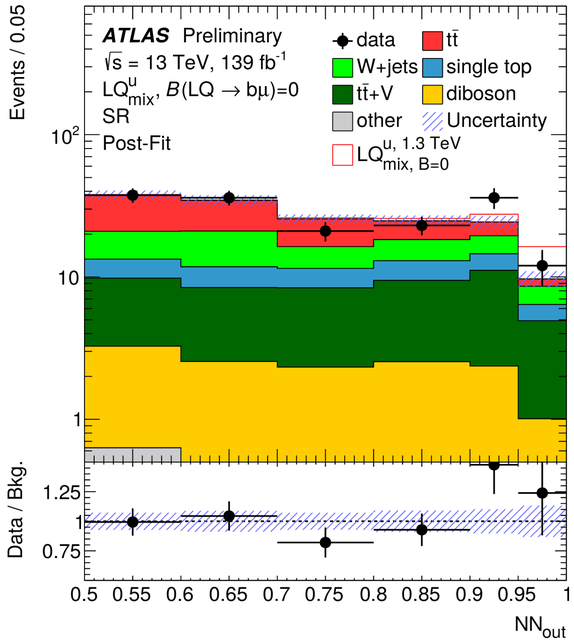
Data event candidate for LQLQ>tete, eeμ channel, M_{eff}= 2.1 TeV

Backup

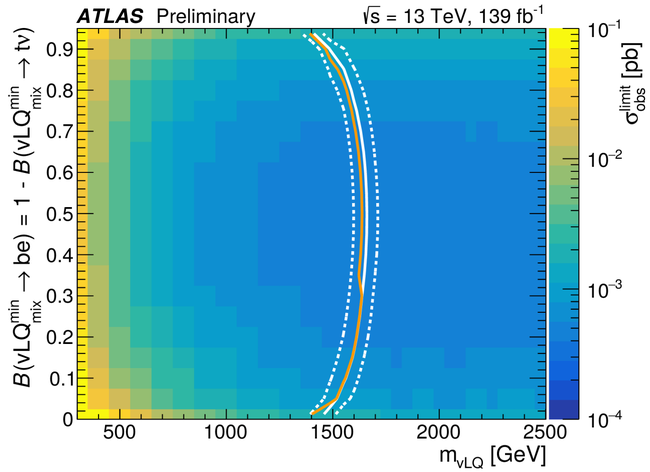
Preselection			
$E_{\mathrm{T}}^{\mathrm{miss}}$ triggers = 1 signal lepton veto on additional baseline leptons $E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$ ≥ 4 small-R jets $\Delta\Phi(E_{\mathrm{T}}^{\mathrm{miss}}, j_{1,2}) > 0.4$			
top reweighting region	W+jets CR	single top CR	training region
$n_b \geq 1$	$n_b = 1$	$n_b = 2$	$n_b \geq 1$
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) \geq 120\,\mathrm{GeV}$	$50\,\mathrm{GeV} \leq m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 120\,\mathrm{GeV}$	$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 120\,\mathrm{GeV}$	$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) \geq 120\,\mathrm{GeV}$
$am_{T2} < 200\,\mathrm{GeV}$	$am_{T2} > 200\,\mathrm{GeV}$	$am_{T2} > 200\,\mathrm{GeV}$	$am_{T2} > 200\,\mathrm{GeV}$
-	t_{had} candidate veto	large-R jet veto	-
-	lepton charge $= +1e$	-	-
-	-	$\Delta R(b_1, b_2) > 1.2$	-

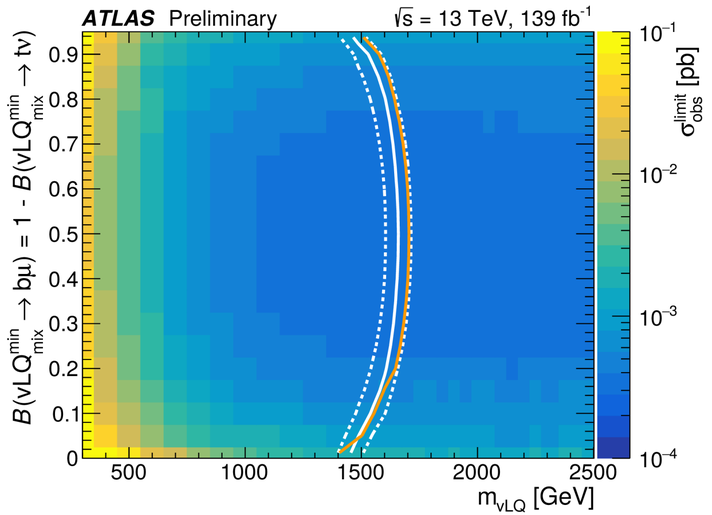
Backup





Variable	Description
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}})$	transverse mass of lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$
m_{eff}	scalar sum of the transverse momenta of leptons, jets, and $E_{\mathrm{T}}^{\mathrm{miss}}$
lepton flavour	flavour of the signal lepton
$p_{\mathrm{T}}(\ell)$	transverse momentum of the lepton
$m_{\mathrm{inv}}(b_1, \ell)$	invariant mass of leading-p_{T} b-jet and lepton
n_{lj}	reclustered large-R jet multiplicity
am_{T2}	asymmetric transverse mass
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	measure for the compatibility of the observed $E_{\mathrm{T}}^{\mathrm{miss}}$ with zero, taking resolutions of reconstructed objects into account
$m_T(b_1, E_{\mathrm{T}}^{\mathrm{miss}})$	transverse mass of leading-p_{T} b-jet and $E_{\mathrm{T}}^{\mathrm{miss}}$
$p_{\mathrm{T}}(t_{\mathrm{had}})$	transverse momentum of t_{had}
$\Delta\Phi(E_{\mathrm{T}}^{\mathrm{miss}}, b_2)$	azimuthal angle separation between $E_{\mathrm{T}}^{\mathrm{miss}}$ and subleading-p_{T} b-jet
$m_{\mathrm{inv}}(b_2, \ell)$	invariant mass of subleading-p_{T} b-jet and lepton
$\Delta\Phi(E_{\mathrm{T}}^{\mathrm{miss}}, b_1)$	azimuthal angle separation between $E_{\mathrm{T}}^{\mathrm{miss}}$ and leading-p_{T} b-jet
$\Delta\Phi(t_{\mathrm{had}}, \ell)$	azimuthal angle separation between t_{had} and lepton
$p_{\mathrm{T}}(b_1)$	transverse momentum of leading-p_{T} b-jet





	Exp. limit [GeV]	Obs. limit [GeV]
$\mathrm{LQ}^{\mathrm{u}}_{\mathrm{mix}} \to t\nu/b\mu$	1440^{+60}_{-60}	1460
$\mathrm{LQ}^{\mathrm{u}}_{\mathrm{mix}} \to t\nu/be$	1440^{+60}_{-60}	1440
$\mathrm{LQ}^{\mathrm{d}}_{\mathrm{mix}} \to t\mu/b\nu$	1380^{+50}_{-60}	1370
$\mathrm{LQ}^{\mathrm{d}}_{\mathrm{mix}} \to te/b\nu$	1410^{+60}_{-60}	1390
$\mathrm{vLQ}^{\mathrm{YM}}_{\mathrm{mix}} \to t\nu/b\mu$	1930^{+50}_{-60}	1980
$\mathrm{vLQ}^{\mathrm{YM}}_{\mathrm{mix}} \to t\nu/be$	1930^{+50}_{-70}	1900
$\mathrm{vLQ}^{\mathrm{min}}_{\mathrm{mix}} \to t\nu/b\mu$	1660^{+50}_{-50}	1710
$\mathrm{vLQ}^{\mathrm{min}}_{\mathrm{mix}} \to t\nu/be$	1650^{+50}_{-60}	1620

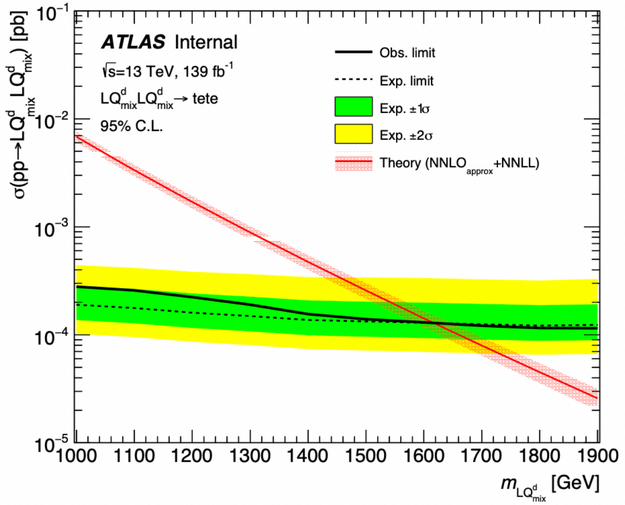
Backup

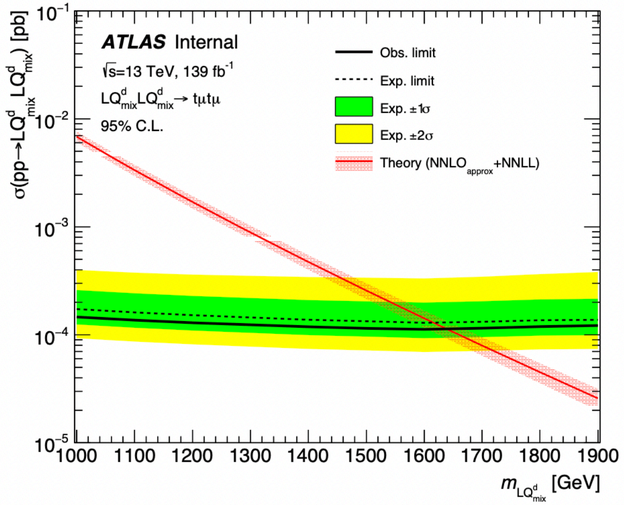
	3ℓ						
	CR				VR	SR	
	3ℓVV	3ℓttZ	3ℓIntC	3ℓMatC	3ℓVR	3ℓSR-e	3ℓSR-μ
e/μ selection	M (SS pair), L other						
e/μ combination	$3e$ / $2e1\mu$ / $1e2\mu$ / 3μ				$3e$ / $2e1\mu$ / $1e2\mu$ / 3μ	$3e$ / $ee\mu$	3μ / $\mu\mu e$
Total charge	±1		$-$		±1		
e internal conversion veto	Yes	Yes	Inverted (ℓ_1 or ℓ_2)	Yes (ℓ_1 and ℓ_2)	Yes		
e material conversion veto	Yes	Yes	Yes (ℓ_1 and ℓ_2)	Inverted (ℓ_1 or ℓ_2)	Yes		
Number of jets	≥ 2		≥ 0		≥ 2		
Number of b-jets	≥ 1	≥ 2	≥ 0		≥ 1		
p_{T}^{ℓ} [GeV]	> 20 (SS pair), > 10 other				> 20		
$m_{\ell^+\ell^-}^{OS-SF}$ [GeV]	> 12						
$\lvert m_{\ell^+\ell^-}^{OS-SF} - m_Z\rvert$ [GeV]	< 10		> 10		< 10		
$\lvert m_{\ell\ell\ell} - m_Z\rvert$ [GeV]	$-$		< 10		$-$		
$m_{\ell\ell}^{\mathrm{min}}$ [GeV]	$-$				< 200	≥ 200	
m_{eff} [GeV]	$-$				$-$	≥ 500	

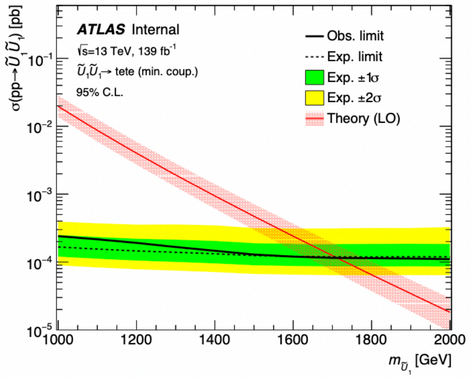
	4ℓ		
	VR	SR	
	4ℓVR	4ℓSR-e	4ℓSR-μ
e/μ selection	L		
e/μ combination	$4e$ / $3e1\mu$ / $2e2\mu$ / 4μ	$4e$ / $3e1\mu$ / $2e2\mu$ (lead e)	4μ / $3\mu1e$ / $2\mu2e$ (lead μ)
Total charge	0		
Number of jets	≥ 2		
Number of b-jets	≥ 1		
p_{T}^{ℓ} [GeV]	> 10		
$m_{\ell^+\ell^-}^{OS-SF}$ [GeV]	> 12		
$\lvert m_{\ell^+\ell^-}^{OS-SF} - m_Z\rvert$ [GeV]	< 10		
$m_{\ell\ell}^{\mathrm{min}}$ [GeV]	< 100	≥ 100	
m_{eff} [GeV]	$-$	≥ 500	

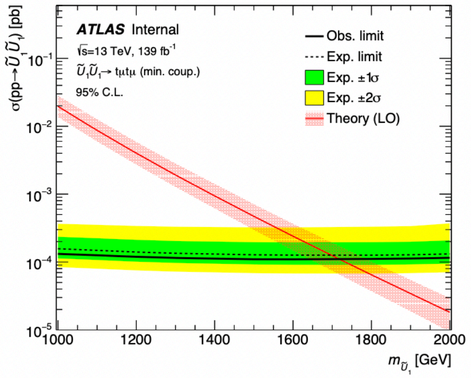
	2ℓSS CRs		
	2ℓtt(e)	2ℓtt(μ)	2ℓttW
e/μ selection	TM_{ex} || $M_{ex}T$ || $M_{ex}M_{ex}$		TT
e/μ combination	$ee/\mu e$	$\mu\mu/e\mu$	$ee/\mu\mu/e\mu/\mu e$
$\ell\ell$ charge	++ or $--$		
e internal conversion veto	Yes		
e material conversion veto	Yes		
Number of jets	≥ 2		
Number of b-jets	≥ 1		≥ 2
p_{T}^{ℓ} [GeV]	> 20		
$m_{\mathrm{T}}(\ell_0, E_{\mathrm{T}}^{\mathrm{miss}})$ [GeV]	< 250		$-$

Backup

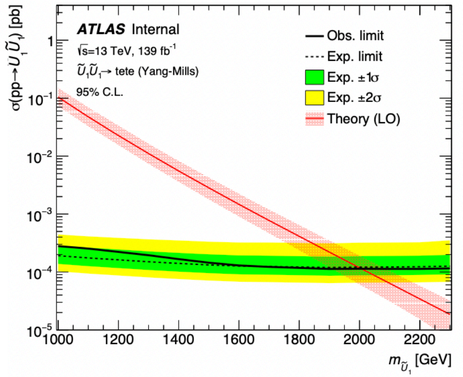

ATLAS Internal
√s=13 TeV, 139 fb-1
LQdmixLQdmix→ tete
95% C.L.
Obs. limit
Exp. limit
Exp. ±1σ
Exp. ±2σ
Theory (NNLOapprox+NNLL)
σ(pp→LQdmixLQdmix) [pb]
mLQdmix [GeV]

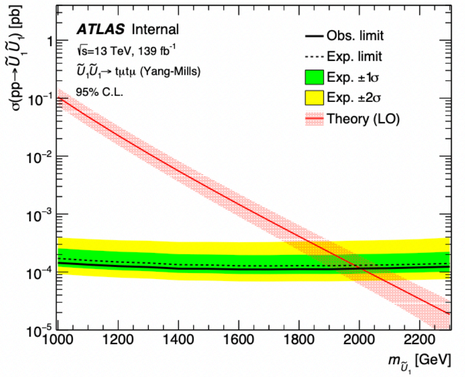

ATLAS Internal
√s=13 TeV, 139 fb-1
LQdmixLQdmix→ tμtμ
95% C.L.
Obs. limit
Exp. limit
Exp. ±1σ
Exp. ±2σ
Theory (NNLOapprox+NNLL)
σ(pp→LQdmixLQdmix) [pb]
mLQdmix [GeV]

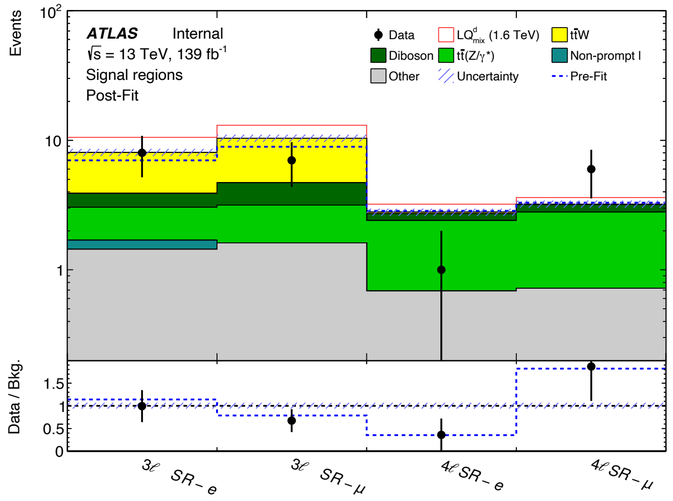

ATLAS Internal
√s=13 TeV, 139 fb-1
U1U1→ tete (min. coup.)
95% C.L.
Obs. limit
Exp. limit
Exp. ±1σ
Exp. ±2σ
Theory (LO)
σ(pp→U1U1) [pb]
mU1 [GeV]

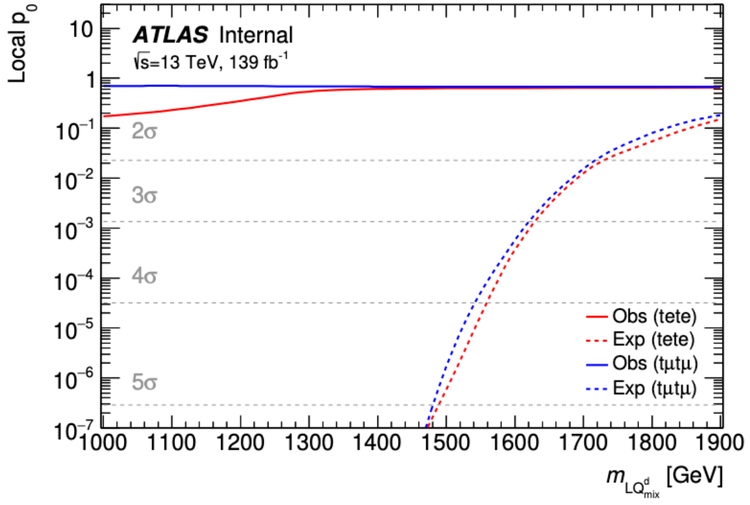

ATLAS Internal
√s=13 TeV, 139 fb-1
U1U1→ tμtμ (min. coup.)
95% C.L.
Obs. limit
Exp. limit
Exp. ±1σ
Exp. ±2σ
Theory (LO)
σ(pp→U1U1) [pb]
mU1 [GeV]

(a) (b)

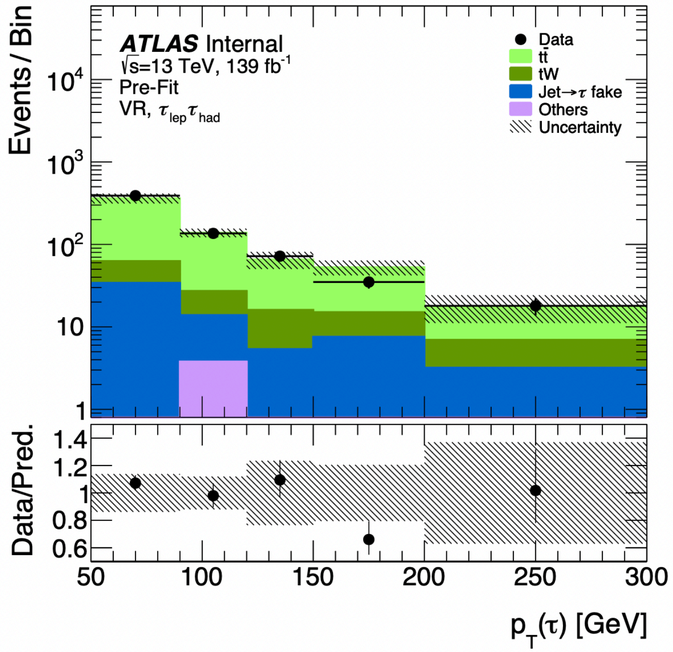

ATLAS Internal
√s=13 TeV, 139 fb-1
U1U1→ tete (Yang-Mills)
95% C.L.
Obs. limit
Exp. limit
Exp. ±1σ
Exp. ±2σ
Theory (LO)
σ(pp→U1U1) [pb]
mU1 [GeV]

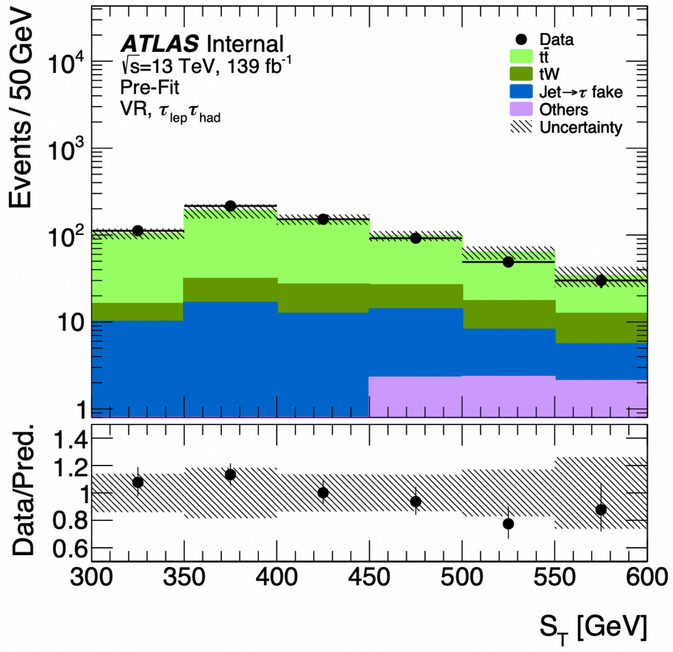

ATLAS Internal
√s=13 TeV, 139 fb-1
U1U1→ tμtμ (Yang-Mills)
95% C.L.
Obs. limit
Exp. limit
Exp. ±1σ
Exp. ±2σ
Theory (LO)
σ(pp→U1U1) [pb]
mU1 [GeV]

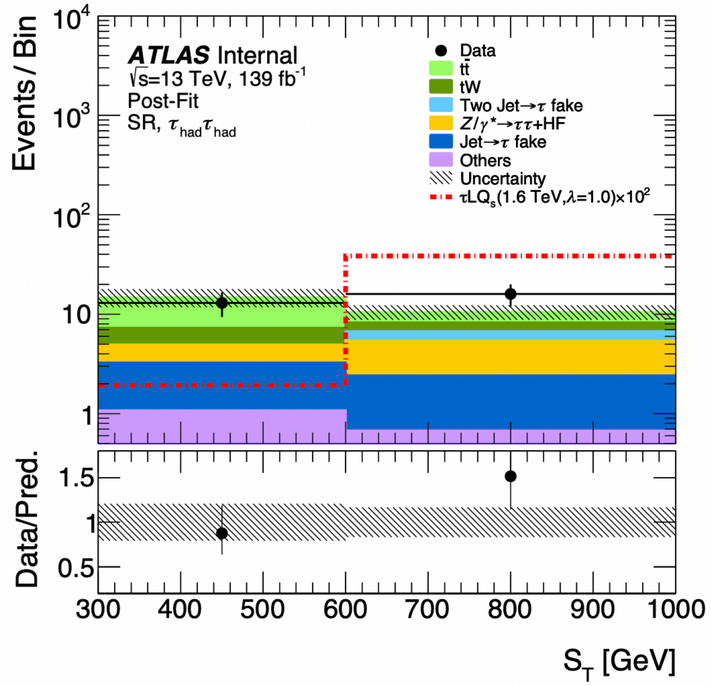

ATLAS Internal
√s = 13 TeV, 139 fb-1
Signal regions
Post-Fit
Data
Diboson
Other
LQdmix (1.6 TeV)
tt̄(Z/γ*)
Uncertainty
tt̄W
Non-prompt l
Pre-Fit
Events
Data / Bkg.
3ℓ SR−e
3ℓ SR−μ
4ℓ SR−e
4ℓ SR−μ


ATLAS Internal
√s=13 TeV, 139 fb-1
Local p0
2σ
3σ
4σ
5σ
Obs (tete)
Exp (tete)
Obs (tμtμ)
Exp (tμtμ)
mLQdmix [GeV]

Backup

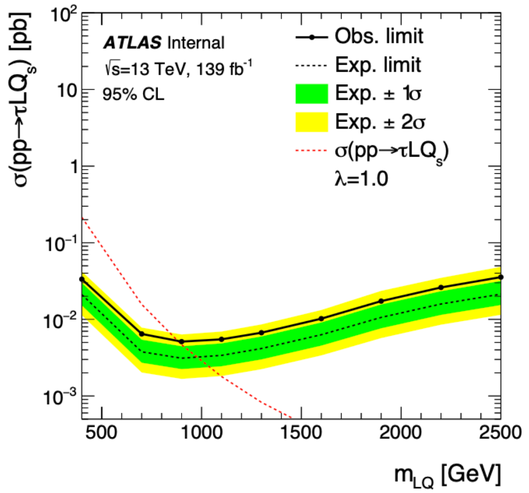


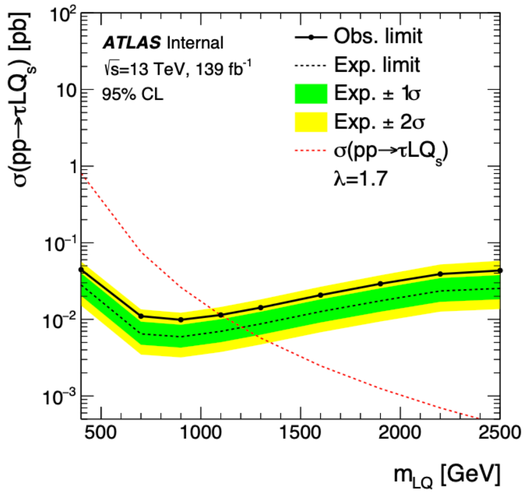


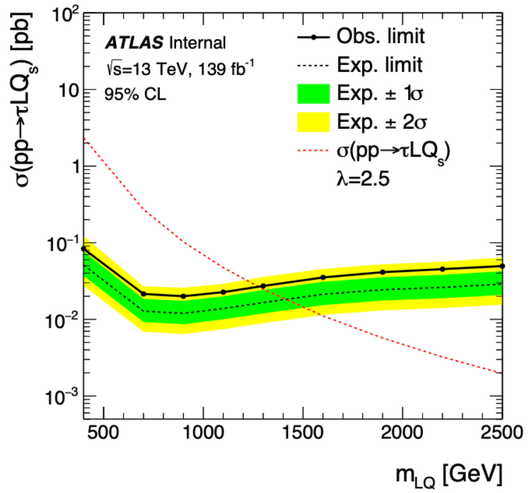


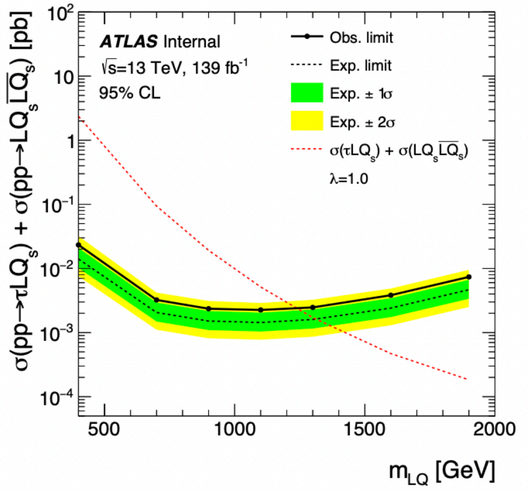
Source / m_{LQ}	$\lambda = 1.0$		$\lambda = 1.7$		$\lambda = 2.5$	
	0.9 TeV	1.6 TeV	0.9 TeV	1.6 TeV	0.9 TeV	1.6 TeV
Top background modeling	0.11	0.05	0.12	0.08	0.13	0.12
Tau reconstruction/identification	0.06	0.05	0.06	0.05	0.06	0.06
Tau energy scale	0.05	0.02	0.05	0.05	0.06	0.05
Flavor tagging	0.02	0.03	0.02	0.03	0.02	0.03
Signal acceptance	0.01	0.03	0.01	0.03	0.04	0.04
Others	0.03	0.02	0.03	0.03	0.04	0.04
Total	0.16	0.11	0.17	0.15	0.22	0.21

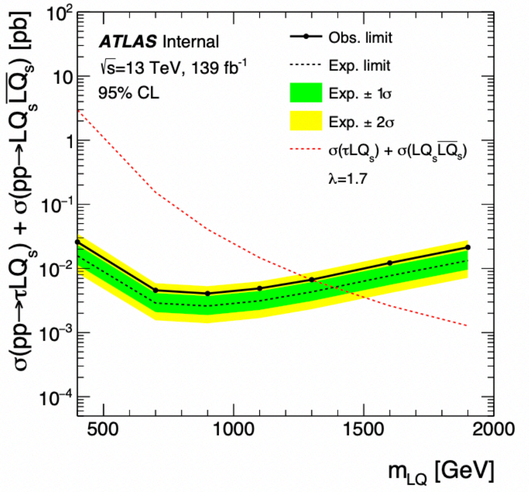
Backup

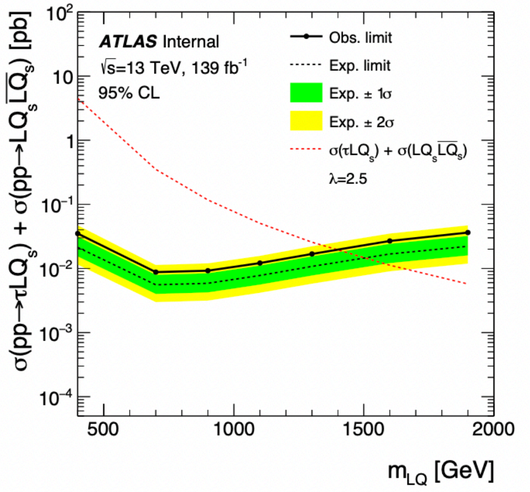

ATLAS Internal
√s=13 TeV, 139 fb-1
95% CL
Obs. limit
Exp. limit
Exp. ± 1σ
Exp. ± 2σ
σ(pp→τLQs)
λ=1.0
σ(pp→τLQs) [pb]
mLQ [GeV]

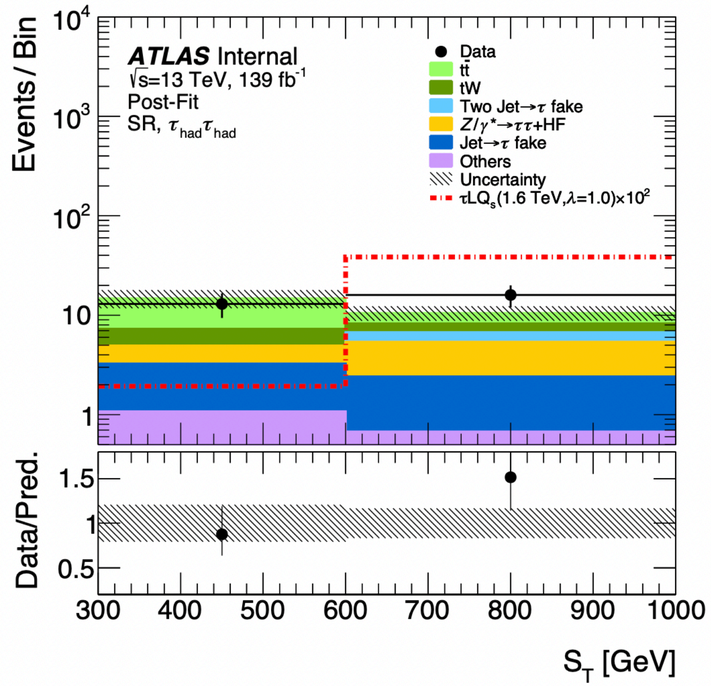

ATLAS Internal
√s=13 TeV, 139 fb-1
95% CL
Obs. limit
Exp. limit
Exp. ± 1σ
Exp. ± 2σ
σ(pp→τLQs)
λ=1.7
σ(pp→τLQs) [pb]
mLQ [GeV]


ATLAS Internal
√s=13 TeV, 139 fb-1
95% CL
Obs. limit
Exp. limit
Exp. ± 1σ
Exp. ± 2σ
σ(pp→τLQs)
λ=2.5
σ(pp→τLQs) [pb]
mLQ [GeV]


ATLAS Internal
√s=13 TeV, 139 fb-1
95% CL
Obs. limit
Exp. limit
Exp. ± 1σ
Exp. ± 2σ
σ(τLQs) + σ(LQsLQs)
λ=1.0
σ(pp→τLQs) + σ(pp→LQsLQs) [pb]
mLQ [GeV]


ATLAS Internal
√s=13 TeV, 139 fb-1
95% CL
Obs. limit
Exp. limit
Exp. ± 1σ
Exp. ± 2σ
σ(τLQs) + σ(LQsLQs)
λ=1.7
σ(pp→τLQs) + σ(pp→LQsLQs) [pb]
mLQ [GeV]


ATLAS Internal
√s=13 TeV, 139 fb-1
95% CL
Obs. limit
Exp. limit
Exp. ± 1σ
Exp. ± 2σ
σ(τLQs) + σ(LQsLQs)
λ=2.5
σ(pp→τLQs) + σ(pp→LQsLQs) [pb]
mLQ [GeV]


ATLAS Internal
√s=13 TeV, 139 fb-1
Post-Fit
SR, τhadτhad
Data
tt
tW
Two Jet→τ fake
Z/γ*→ττ+HF
Jet→τ fake
Others
Uncertainty
τLQs(1.6 TeV,λ=1.0)×10²
Events / Bin
Data/Pred.
ST [GeV]