



Search for scalar leptoquarks in $b\tau\tau$ in pp collisions at $\sqrt{s} = 13$ TeV with ATLAS detector

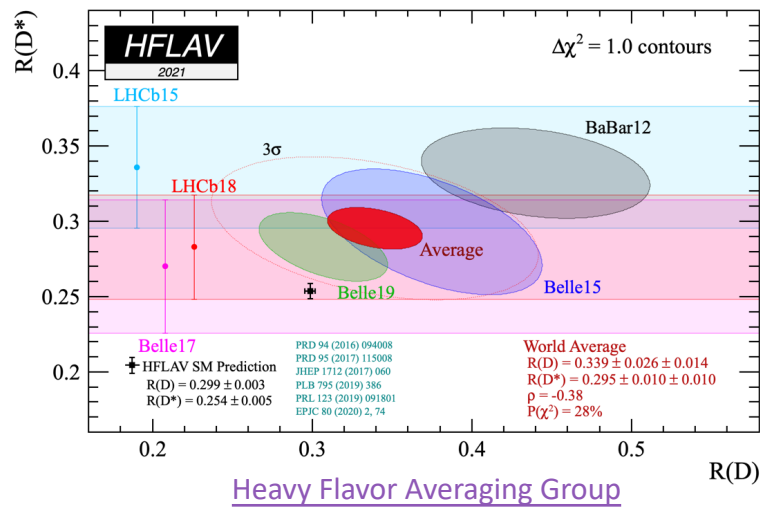
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- Test of lepton flavor universality: one important part of physics program at B factories, such as $R(K^{(*)})$ and $R(D^{(*)})$.
- Recently, deviations of these decay rates from the SM reported by BaBar, Belle and LHCb.



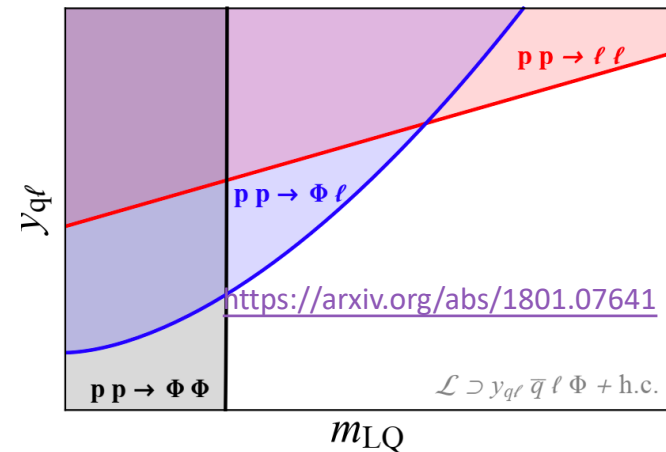
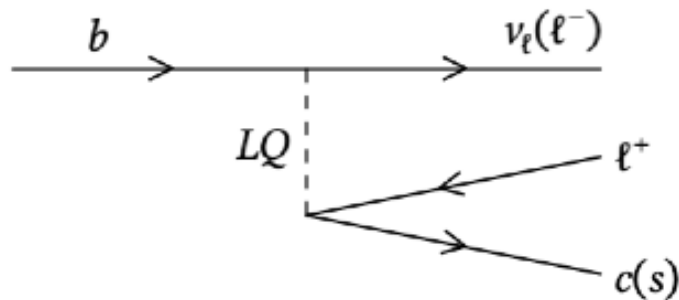
$$R_{D^{(*)}} = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau\nu)}{\mathcal{B}(B \rightarrow D^{(*)}\ell\nu)}$$

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

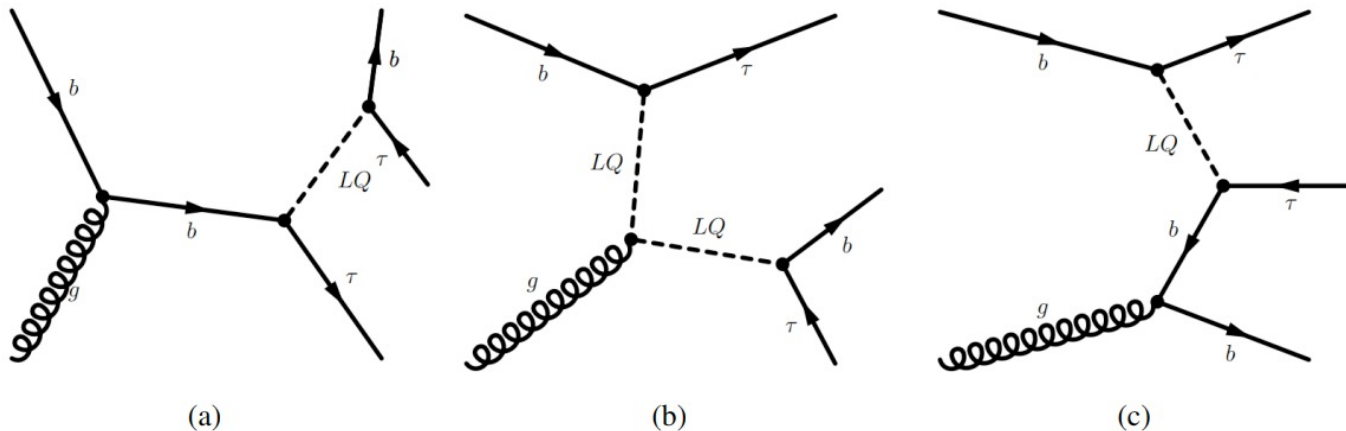
3.1sigma w.r.t SM for $R(K)$ from LHCb.

<https://arxiv.org/abs/2103.11769>

- Leptoquarks(LQs) can explain deviations on lepton flavor universality(LFU) from SM in B physics.
 - Decay to lepton-quark pairs.
 - Carry color charge, fractional electric charge and non-zero baryon and lepton number.
- Cross section of singly-produced LQ not only depends on mass of LQ but also depends on Yukawa coupling(λ) of LQ-lepton-quark.



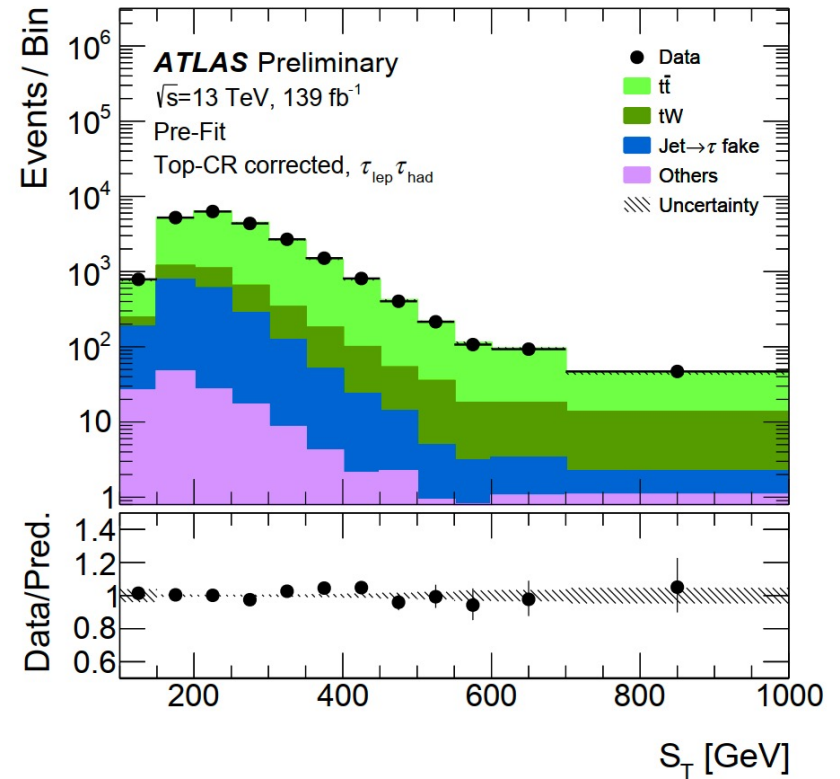
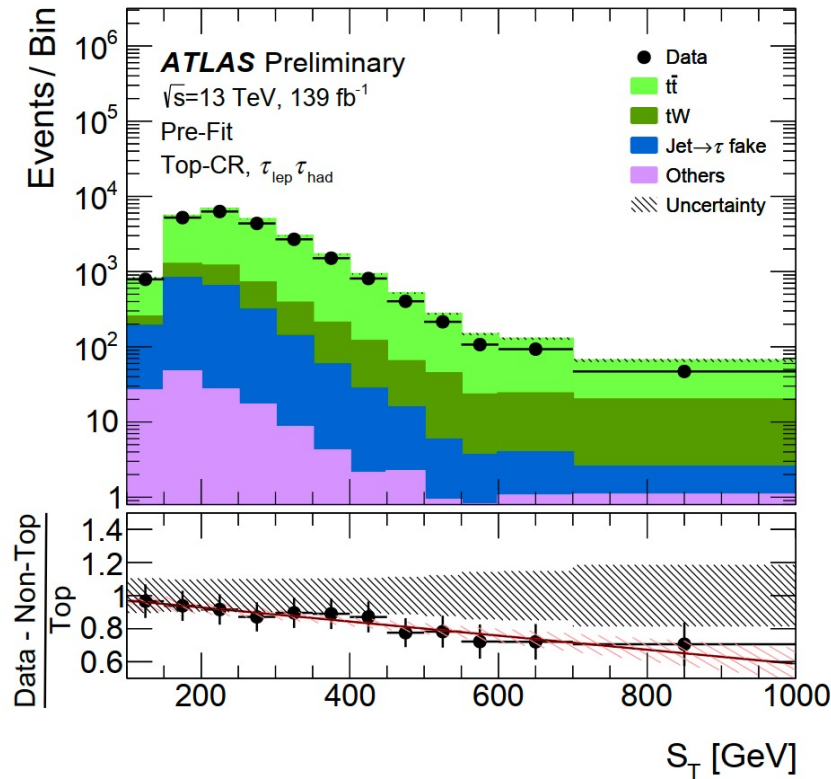
- Focus on singly-produced scalar LQ:
 - Predicted by \tilde{S}_1 model, with $4/3e$ and $3B + L = -2$.
 - Produced by quark-gluon fusion and scattering.
- Include pair production of scalar LQ since similar final states.
- Search over several mass and coupling points.
- Branching fraction of LQ decaying to $b\tau$ is assumed to be 100%.
- Consider two channels: $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$.



- Events required to pass single lepton(electron/muon) triggers
 - Opposite-sign charge between l and τ
 - $\Delta\phi(l, E_T^{miss}) < 1.5$
 - $p_T(bjet) > 200 \text{ GeV}$, $m_{vis}(l, \tau) > 100 \text{ GeV}$, $S_T > 300 \text{ GeV}$
- Dominant backgrounds:
 - Top (ttbar and single top): MC simulation with correction derived in Top-CR
- Other backgrounds:
 - Mis-identified τ : MC simulation with correction
 - Multi-jet: data-driven method
 - Diboson, V+jets: MC simulation

Top background correction

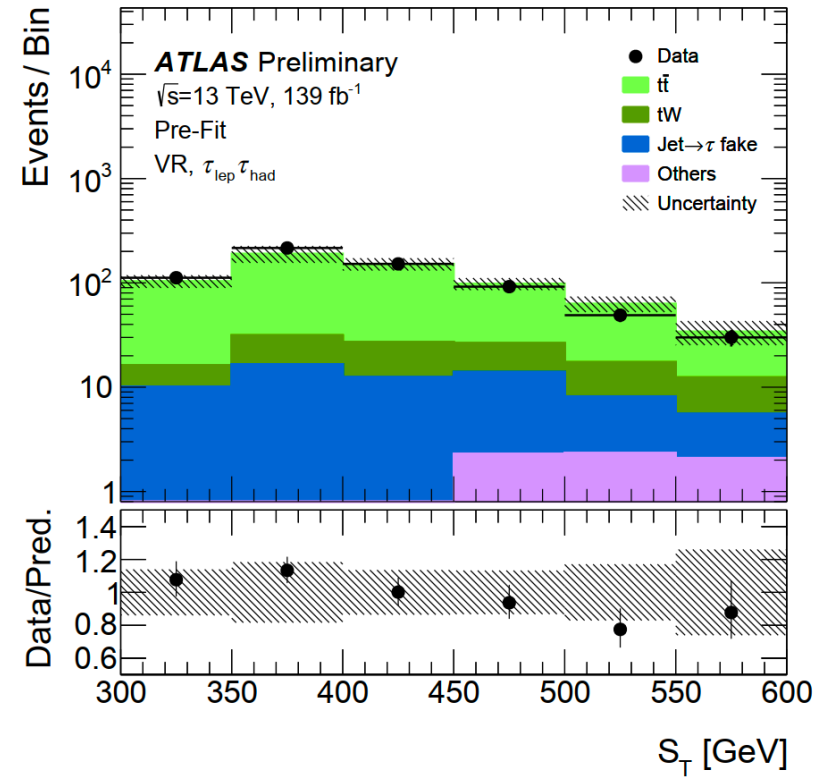
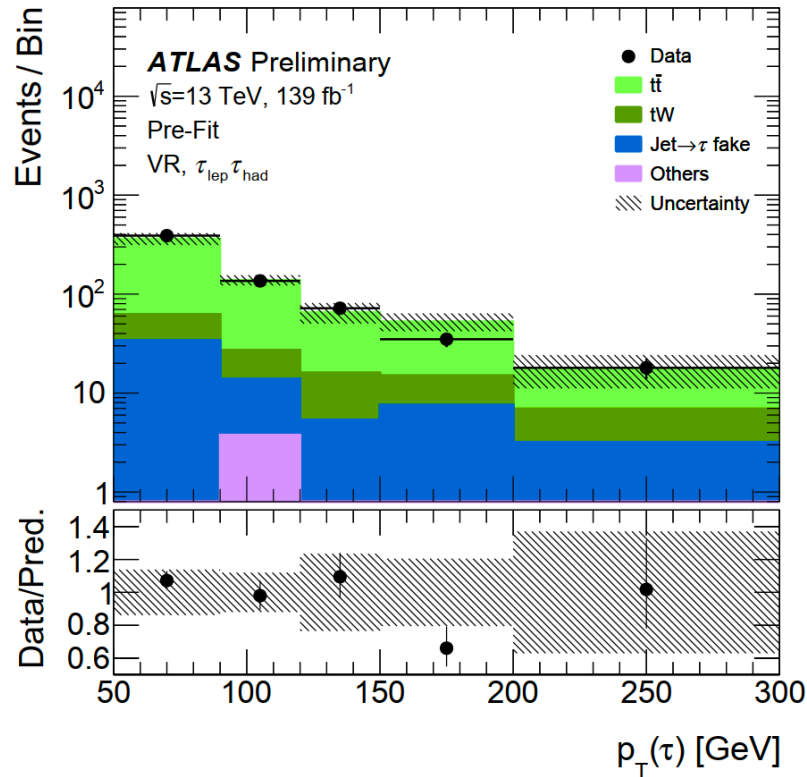
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- Large mis-modelling for Top backgrounds in Top-CR.
- Correction parameterized as function of S_T , fitted by linear function.

$$S_T = p_T^\tau + p_T^\tau + p_T^{bjet}$$

$$SF_t(S_T) = \frac{N_{\text{data}} - N_{\text{non-}t}}{N_t}$$



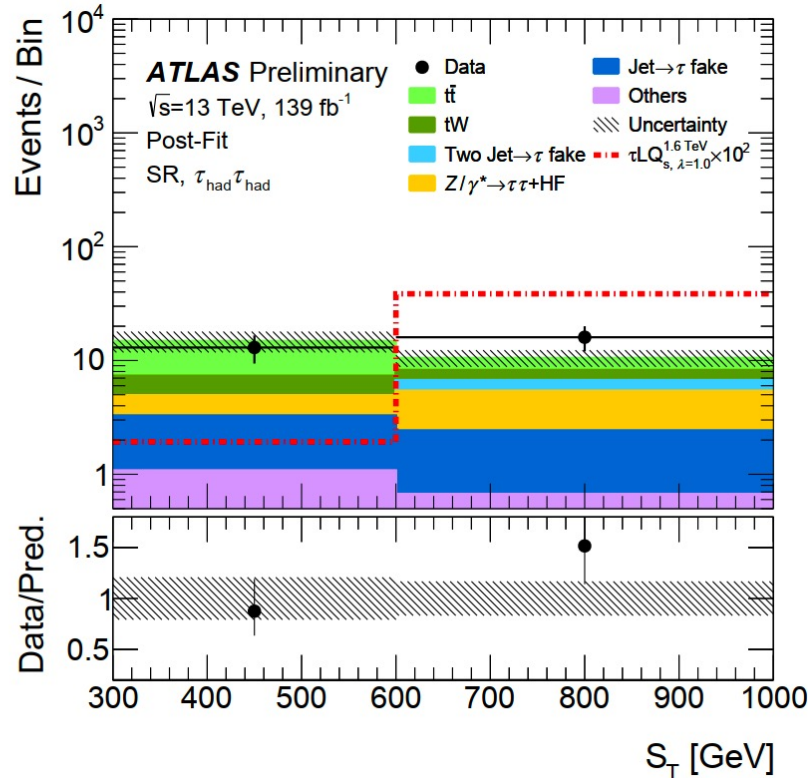
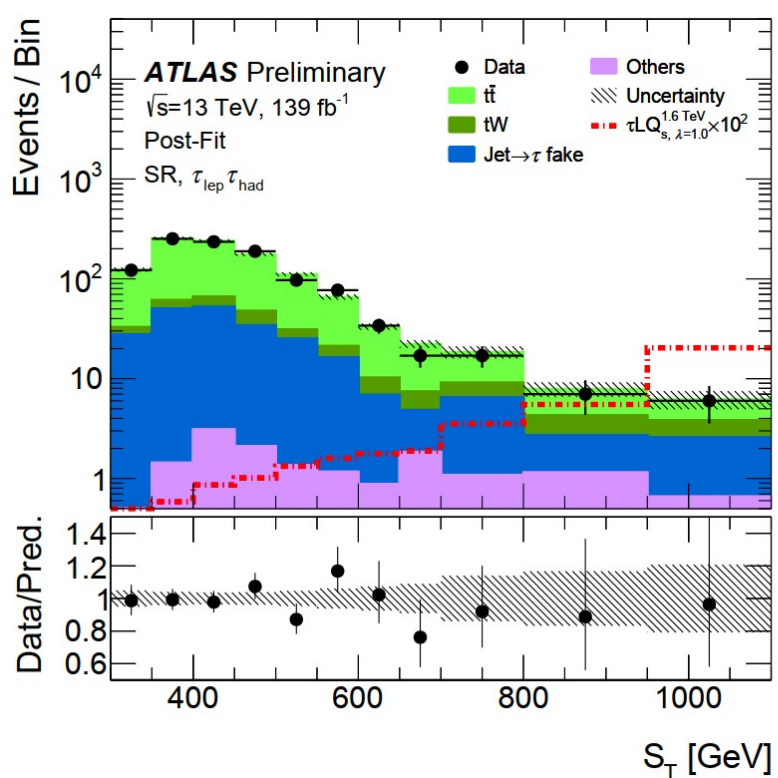
- Background modelling validated in VR.
- Modelling looks good within pre-fit uncertainties.

- Events required to pass single τ triggers.
 - Opposite-sign charge between τ and τ
 - Veto electrons or muons
 - $p_T(bjet) > 200$ GeV, $m_{vis}(\tau, \tau) > 100$ GeV, $S_T > 300$ GeV
- Main backgrounds:
 - Top (ttbar and single top): MC simulation with correction derived in $\tau_{lep}\tau_{had}$ Top-CR.
 - Multi-jet: data-driven method
 - Z+HF jets: MC simulation with normalization correction
- Negligible backgrounds:
 - Diboson, W+jets, Z+LF jets: MC simulation

- Binned likelihood function in bins of S_T :

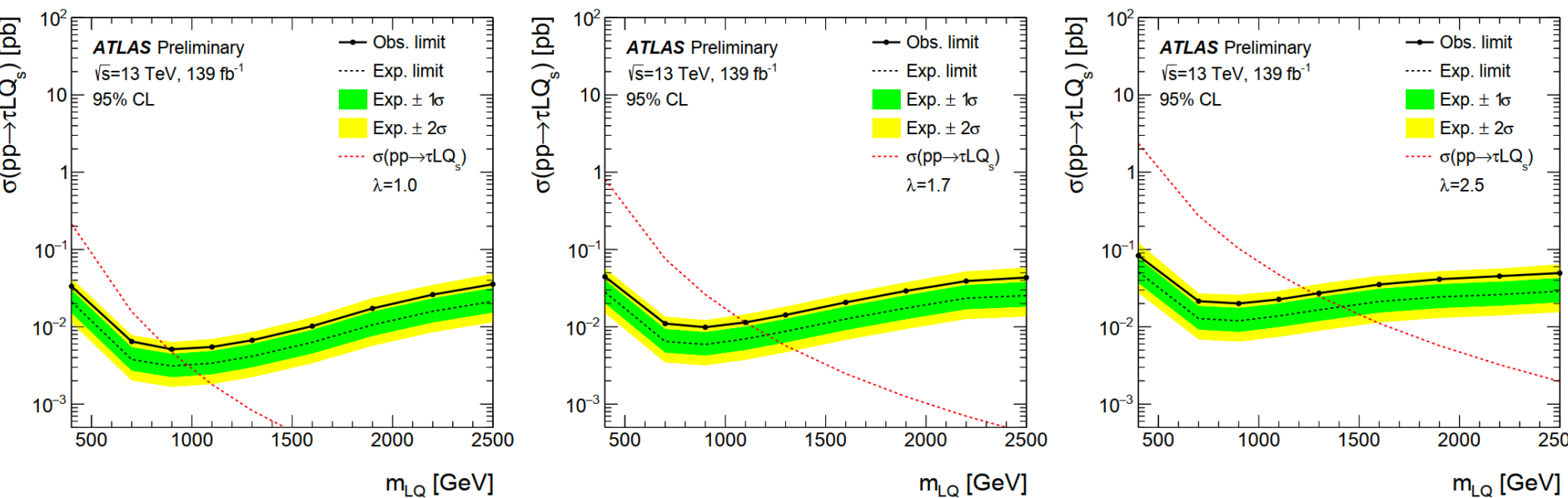
$$\mathcal{L}(\mu, \vec{\theta}) = \prod_{i=1} e^{-(\mu s_i + b_i)} \frac{(\mu s_i + b_i)^{n_i}}{n_i!} \cdot \prod_{j=1} G(\theta_j)$$

- Binning optimized
 - Make sure at least 10 background events at last bin of S_T .
- Simultaneous fit by combining $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ SRs
- Two kinds of fit performed:
 - Background-only fit on real data
 - Signal-plus-background fit on real data



- Data in good agreement with SM predictions.
- No significant excess observed in data.

Upper limits on singly-produced LQ

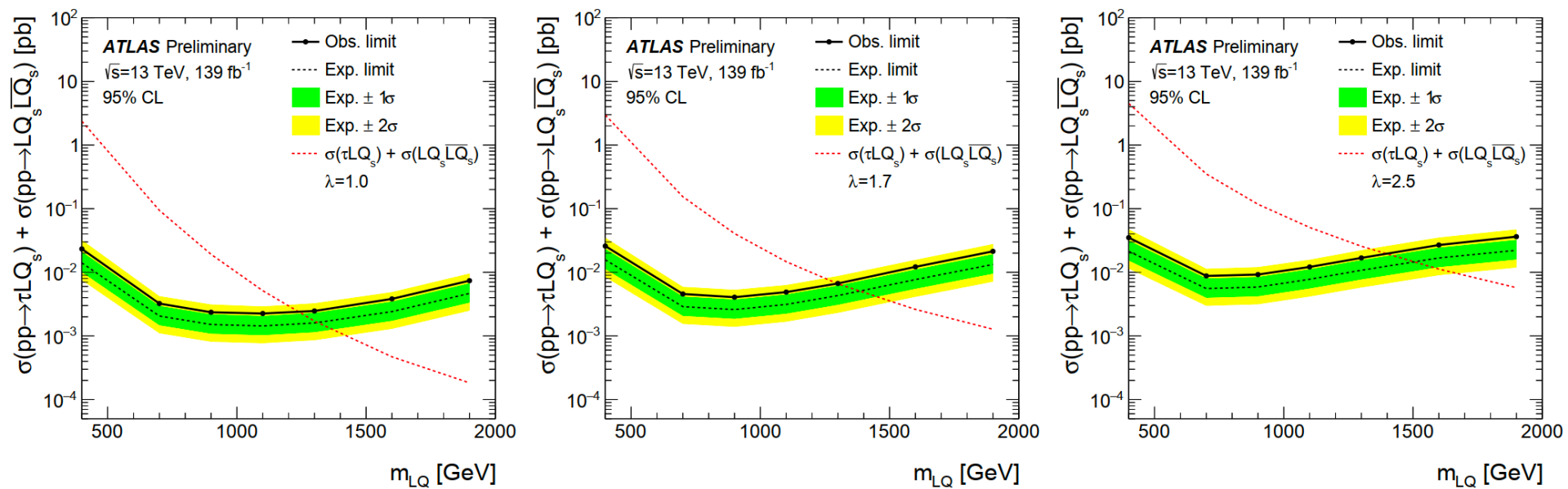


- Observed limits are higher than expected limits due to high S_T in $\tau_{had}\tau_{had}$.
- First ATLAS results for searching singly-produced LQ in $b\tau\tau$ final states.

	m_{LQ} Obs (Exp) lim at 95% CL
$\lambda = 1$	0.89 (1.0) TeV
$\lambda = 1.7$	1.01 (1.22) TeV
$\lambda = 2.5$	1.28 (1.43) TeV

Upper limits on singly+pair produced LQ

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- More stringent limits compared to standalone singly-produced LQ limits
- Masses below 1.25 TeV are excluded for all λ values above 0.5

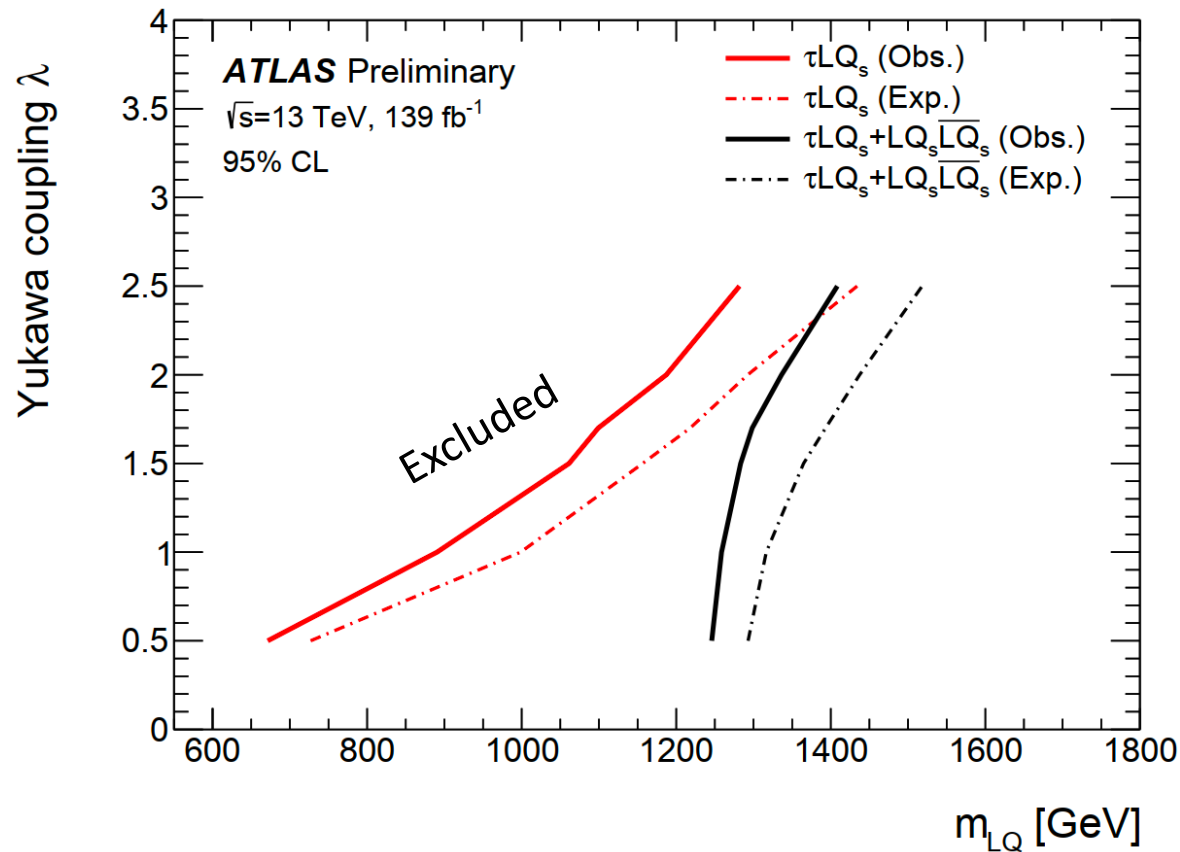
	m_{LQ} Obs (Exp) lim at 95% CL
$\lambda = 1$	1.26 (1.32) TeV
$\lambda = 1.7$	1.30 (1.40) TeV
$\lambda = 2.5$	1.41 (1.52) TeV

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 modelling	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

- Impact denoted by relative increase on expected limits relative to statistical-only expected limits
 - Correlation between each group of uncertainties not considered.
- Largest impact:
 - Top background modelling: initial/final state radiation, parton shower and matrix element uncertainties.

Exclusion limits in $m_{LQ}-\lambda$ plane

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- Regions to the left of lines are excluded.

- Search for scalar leptoquarks in $b\tau\tau$ in pp collisions at $\sqrt{s} = 13$ TeV with ATLAS detector.
 - Both singly and pair produced LQs considered.
 - Scan over mass and coupling points.
 - Two channels: $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$
- No significant excess observed in data.
- Upper limits on cross section times branching fraction at 95% CL for singly and singly+pair produced LQs are provided.
- Lower limits on LQ mass at 95% CL are set:
 - For singly-produced LQ, masses below 1 TeV are excluded for all λ values above 1.0
 - For singly+pair produced LQs, masses below 1.25 TeV are excluded for all λ values above 0.5

Thanks for your attention

Backups

MC samples

Process	Generator		PDF set		Tune	Normalisation
	ME	PS	ME	PS		
$LQ \rightarrow b\tau$	MadGraph5_aMC@NLO	PYTHIA 8.244	NNPDF3.0 _{NNLO}	NNPDF2.3 _{LO}	A14	LO
$LQLQ \rightarrow b\tau b\tau$	MadGraph5_aMC@NLO	PYTHIA 8.244	NNPDF3.0 _{NNLO}	NNPDF2.3 _{LO}	A14	NNLO + NNLL
$t\bar{t}$	POWHEG BOX v2	PYTHIA 8	NNPDF3.0 _{NNLO}	NNPDF2.3 _{LO}	A14	NNLO + NNLL
Single top	POWHEG BOX v2	PYTHIA 8	NNPDF3.0 _{NNLO}	NNPDF2.3 _{LO}	A14	NLO
$Z/\gamma^* \rightarrow \tau\tau$	POWHEG BOX v1	PYTHIA 8	CT10 _{NLO}	CTEQ6L1	AZNLO	NLO
W +jets	SHERPA 2.2.1		NNPDF3.0 _{NNLO}		SHERPA	NNLO
Diboson	SHERPA 2.2.1/SHERPA 2.2.2		NNPDF3.0 _{NNLO}		SHERPA	NLO

Post-fit yields

Process	$\tau_{lep} \tau_{had}$	$\tau_{had} \tau_{had}$
Background	Yields (with post-fit uncertainties)	
$t\bar{t}$	765±82	9.9±2.6
Single top	65±35	3.9±1.0
Single Jet→ τ fake	214±79	3.9±1.0
Two Jet→ τ fake	-	1.3±0.3
$Z(\tau\tau)$ +HF	5.5±1.4	4.7±1.1
$Z(\tau\tau)$ +LF	1.6±0.3	0.4±0.1
$Z(ee,\mu\mu)$ +jets	1.0±0.3	-
Others	7.1 ±0.8	1.4±0.3
Total background	1059±51	25.4±4.8
Data	1053	29
Signal	Yields (with pre-fit uncertainties)	
LQ, m_{LQ} =0.9 TeV, $\lambda = 1$	13±1	14±1
LQ, m_{LQ} =1.6 TeV, $\lambda = 1$	0.40±0.05	0.40±0.06
LQ, m_{LQ} =0.9 TeV, $\lambda = 1.7$	42±4	42±4
LQ, m_{LQ} =1.6 TeV, $\lambda = 1.7$	1.7±0.2	1.7±0.2
LQ, m_{LQ} =0.9 TeV, $\lambda = 2.5$	92±11	87±14
LQ, m_{LQ} =1.6 TeV, $\lambda = 2.5$	5.5±1.0	5.1± 0.8
LQLQ, m_{LQ} =0.9 TeV	74±5	93±14
LQLQ, m_{LQ} =1.6 TeV	0.6±0.1	1.0±0.1