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

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Motivation

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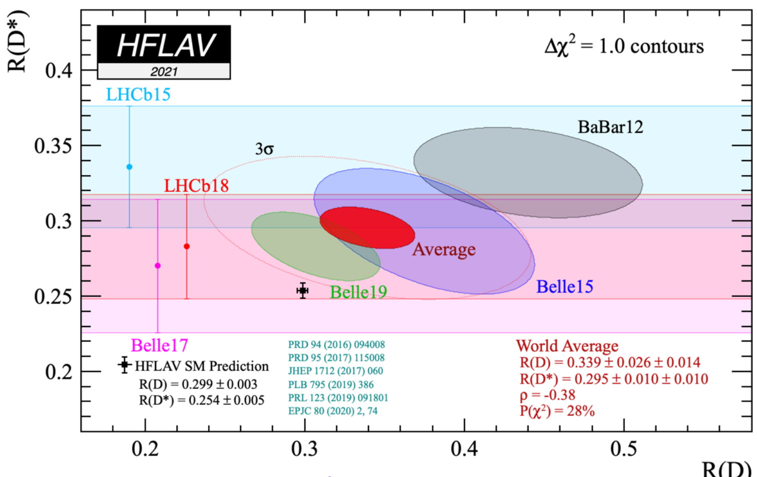
- Test of lepton flavor universality: one important part of physics program at B factories, such as $R(K^{(*)})$ and $R(D^{(*)})$.
- Recently, deviations of these decay rates from the SM reported by BaBar, Belle and LHCb.



Heavy Flavor Averaging Group

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

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

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

https://arxiv.org/abs/2103.11769

Motivation

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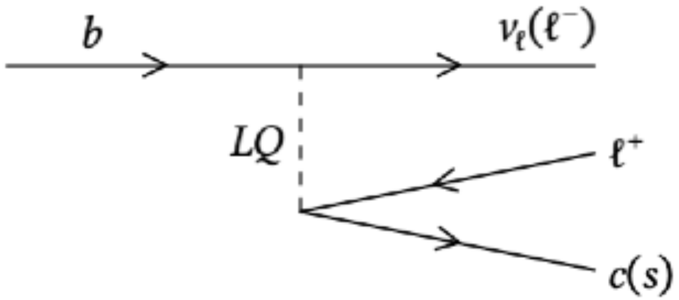
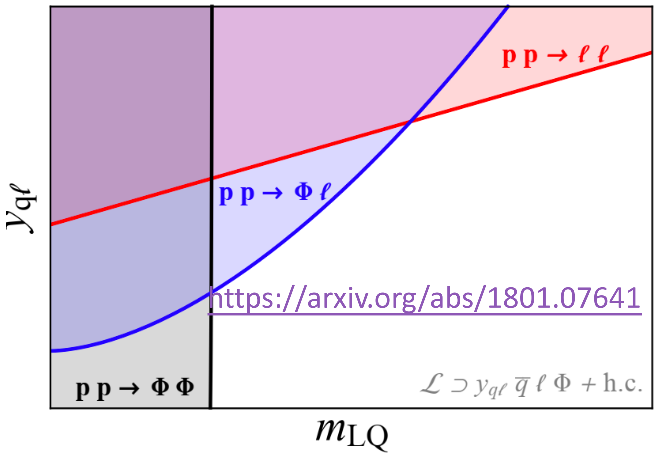
- Leptoquarks(LQs) can explain deviations on lepton flavor universality(LFU) from SM in B physics.
  - Decay to lepton-quark pairs.
  - Carry color charge, fractional electric charge and non-zero baryon and lepton number.
- Cross section of singly-produced LQ not only depends on mass of LQ but also depends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





https://arxiv.org/abs/1801.07641

Signal model

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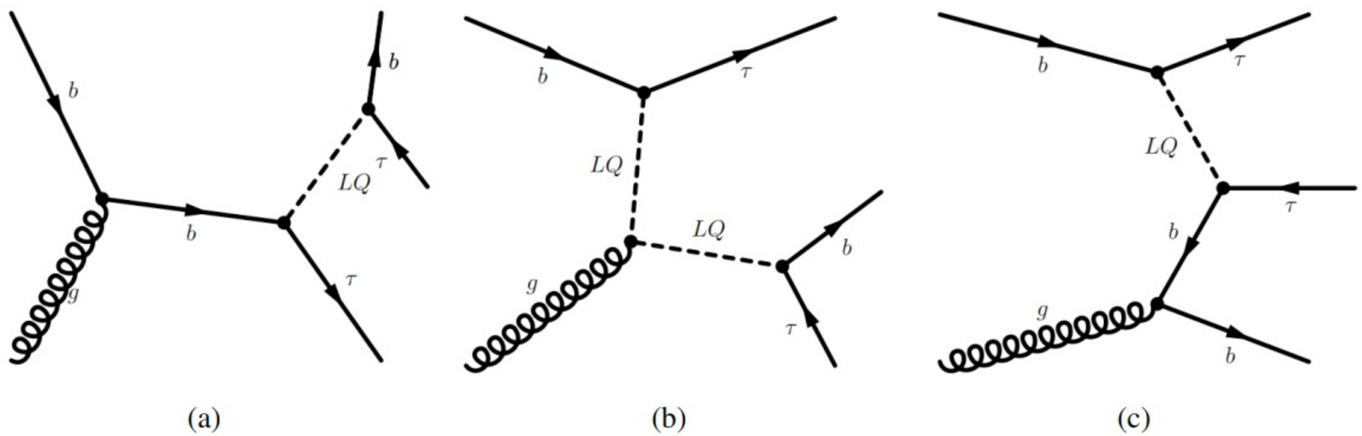
- Focus on singly-produced scalar LQ:
  - Predicted by $\widetilde{S_1}$ model, with 4/3e and $3B + L = -2$.
  - Produced by quark-gluon fusion and scattering.
- Include pair production of scalar LQ since similar final states.
- Search over several mass and coupling points.
- Branching fraction of LQ decaying to bτ is assumed to be 100%.
- Consider two channels: $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$.



Event selections in $\tau_{lep}\tau_{had}$

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- Events required to pass single lepton(electron/muon) triggers
  - Opposite-sign charge between l and τ
  - $\Delta\phi(l, E_T^{miss}) < 1.5$
  - $p_T(bjet) > 200$ GeV, $m_{vis}(l,\tau) > 100$ GeV, $S_T > 300$ GeV

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

- 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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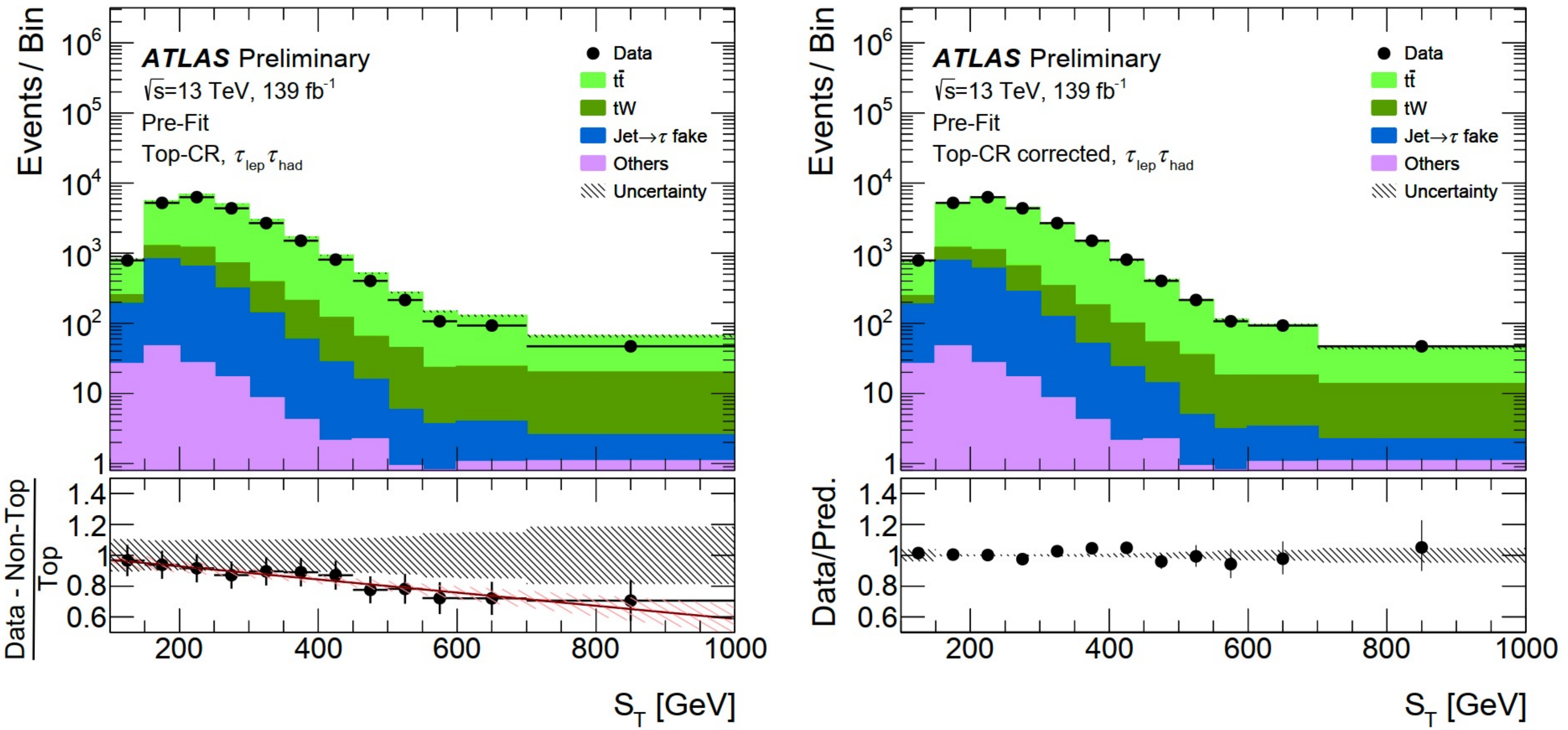

- Large mis-modelling for Top backgrounds in Top-CR.
- Correction parameterized as function of S_T, fitted by linear function.

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

$$SF_t(S_\mathrm{T}) = \frac{N_\mathrm{data} - N_{\mathrm{non}-t}}{N_t}$$

Background modelling validation

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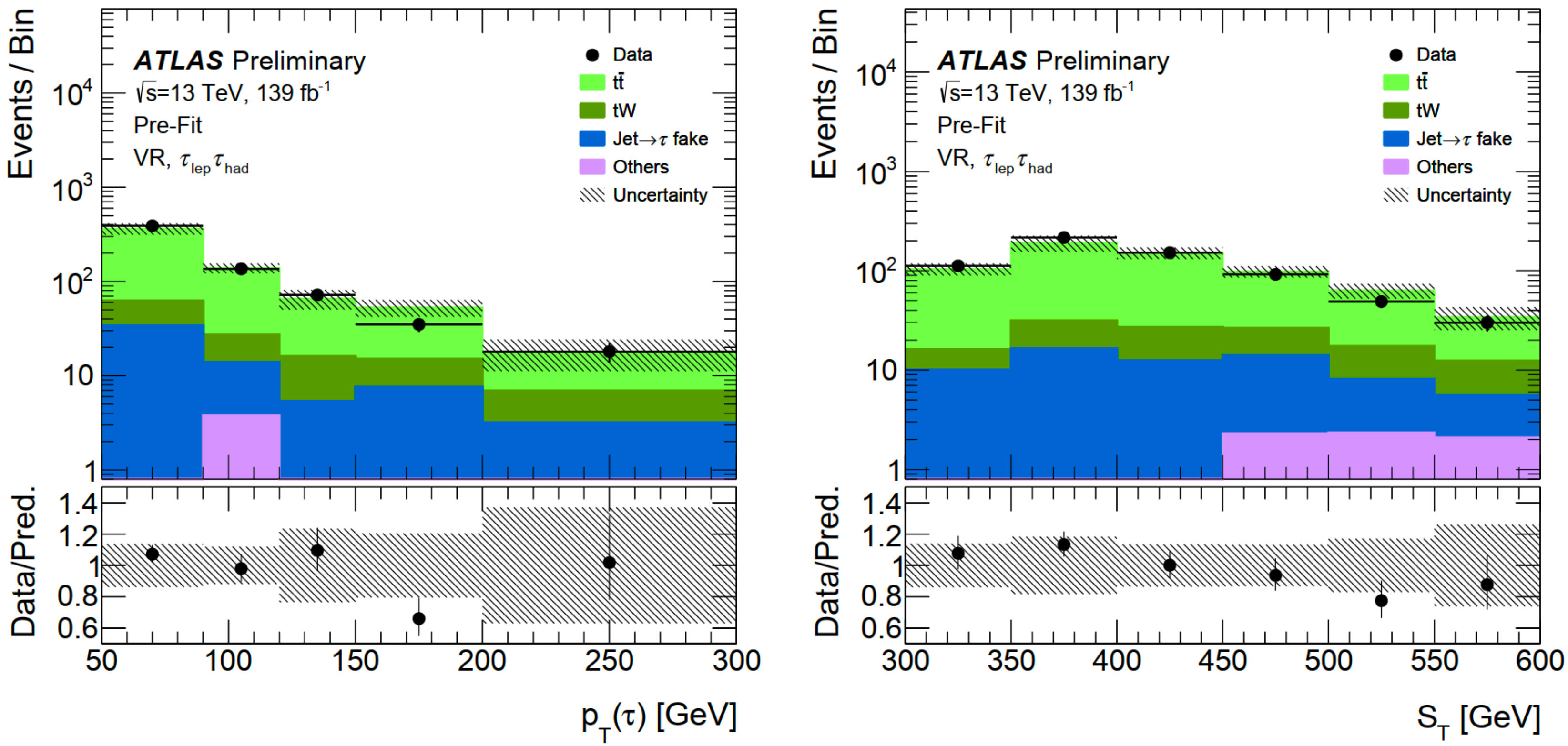

- Background modelling validated in VR.
- Modelling looks good within pre-fit uncertainties.

Event selections in $\tau_{had}\tau_{had}$

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- 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

Statistical model and fit strategy

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- 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

Discriminant variable distributions

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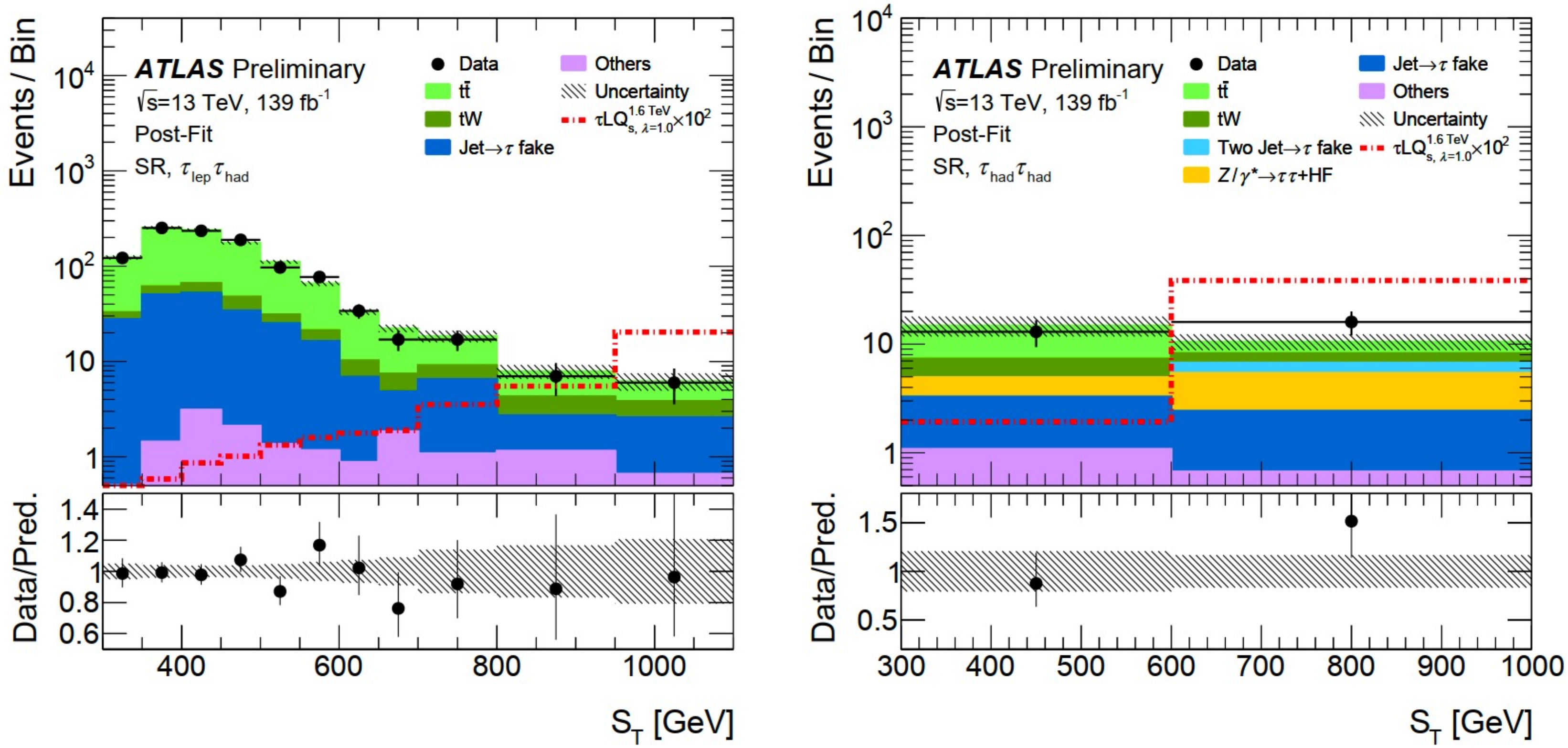

- Data in good agreement with SM predictions.
- No significant excess observed in data.

Upper limits on singly-produced LQ

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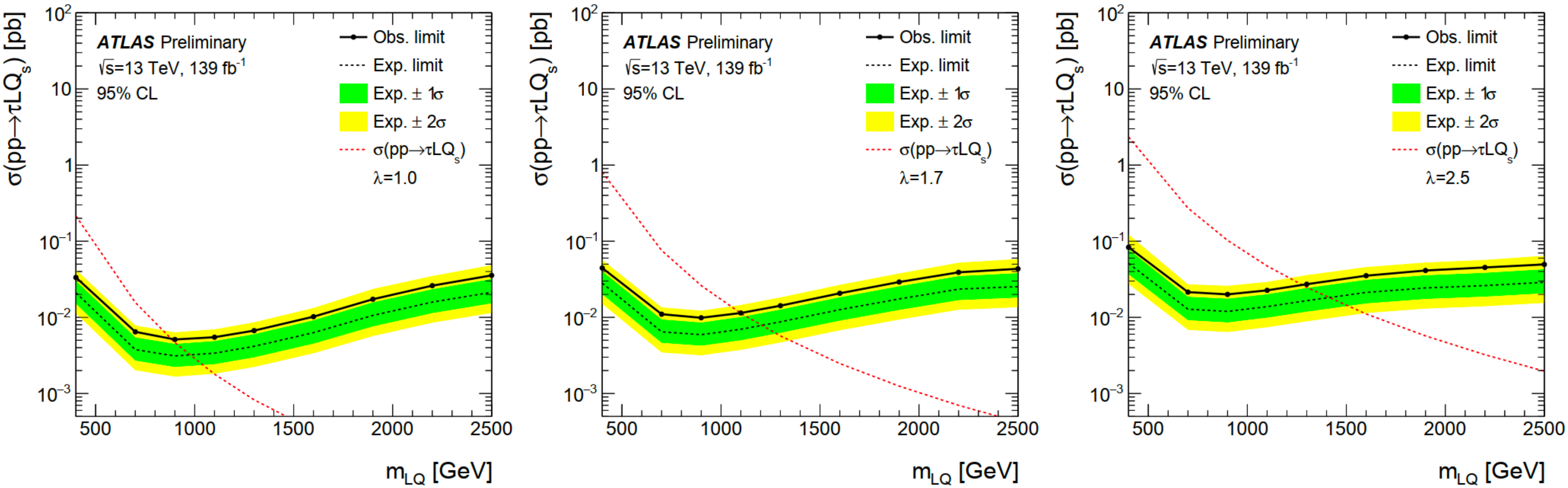

- Observed limits are higher than expected limits due to high S_T in $\tau_{had}\tau_{had}$.
- First ATLAS results for searching singly-produced LQ in $b\tau\tau$ final states.

	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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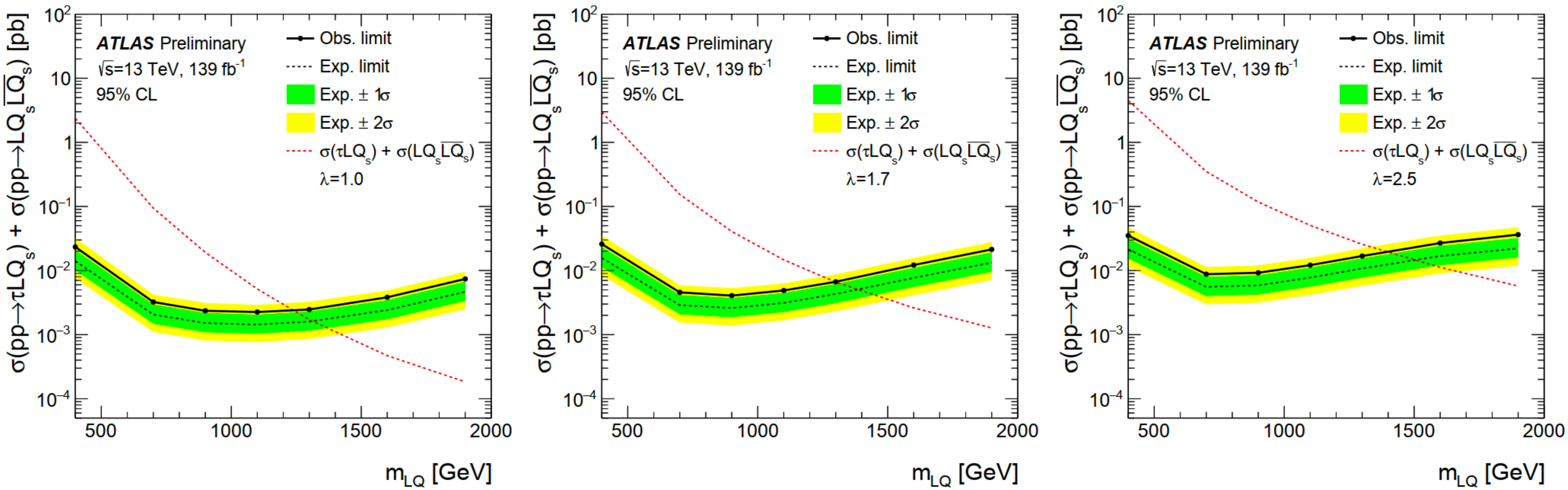

- More stringent limits compared to standalone singly-produced LQ limits
- Masses below 1.25 TeV are excluded for all λ values above 0.5

	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

Systematic uncertainty impact

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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}-λ plane

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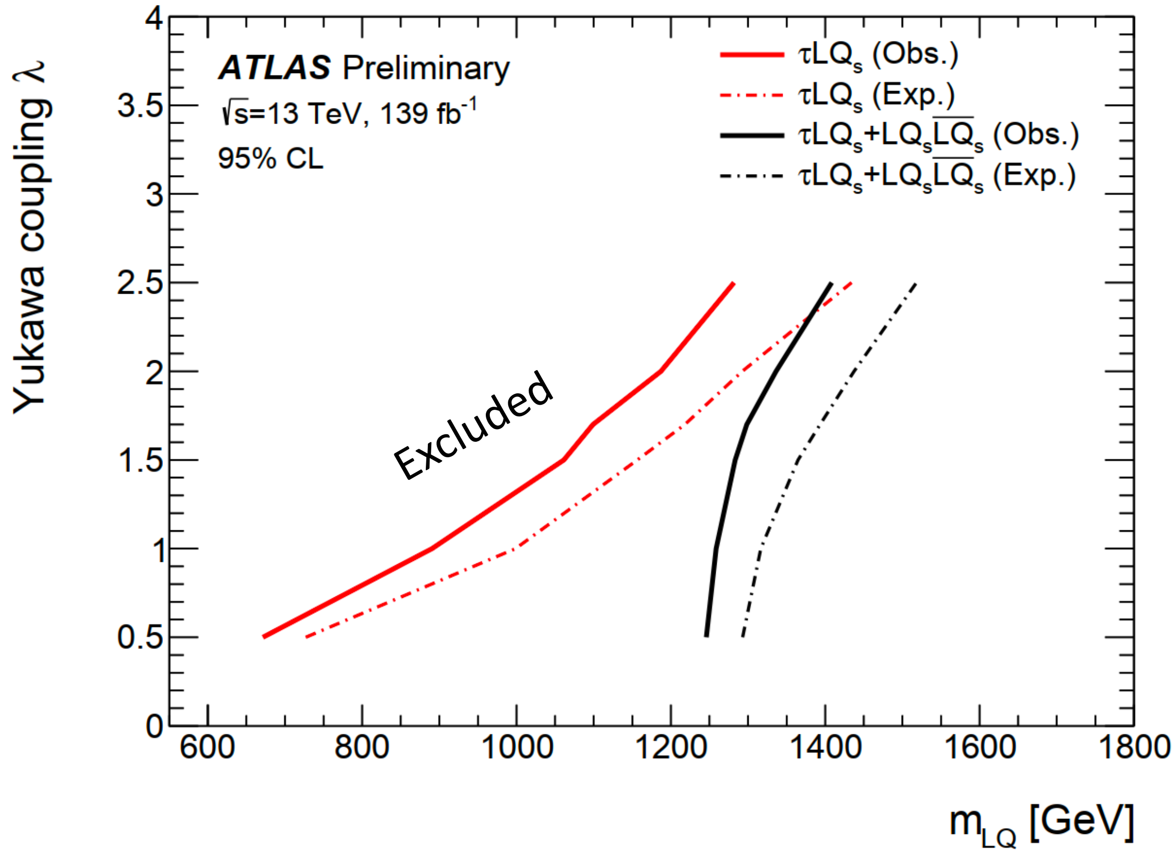

- Regions to the left of lines are excluded.

Summary

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- 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 faction 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	NNPDF3.0nnlo	NNPDF2.3lo	A14	LO
LQLQ$\rightarrow b\tau b\tau$	MadGraph5_aMC@NLO	Pythia 8.244	NNPDF3.0nnlo	NNPDF2.3lo	A14	NNLO + NNLL
$t\bar{t}$	Powheg Box v2	Pythia 8	NNPDF3.0nnlo	NNPDF2.3lo	A14	NNLO + NNLL
Single top	Powheg Box v2	Pythia 8	NNPDF3.0nnlo	NNPDF2.3lo	A14	NLO
$Z/\gamma^* \rightarrow \tau\tau$	Powheg Box v1	Pythia 8	CT10nlo	CTEQ6L1	AZNLO	NLO
W+jets	Sherpa 2.2.1		NNPDF3.0nnlo		Sherpa	NNLO
Diboson	Sherpa 2.2.1/Sherpa 2.2.2		NNPDF3.0nnlo		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$\rightarrow\tau$ fake	214±79	3.9±1.0
Two Jet$\rightarrow\tau$ 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