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Search for pair- and singly-produced leptoquarks in the final states top tau nu b and top tau nu

T.Yu (IHEP) on behalf of CMS

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Motivation

Several BSM ideas foresee new bosons that carry both lepton and baryon number

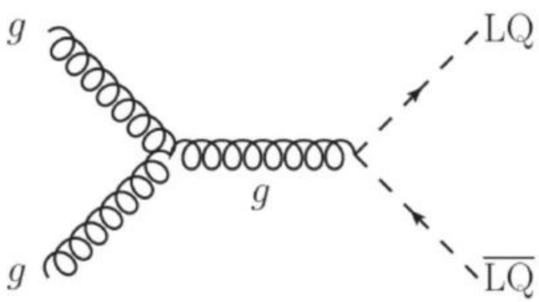
Can SU(3)xSU(2)xU(1) originate from a larger symmetry group? $\rightarrow$ Grand Unified Theory	$\rightarrow$	Quarks and leptons unified in a fermionic multiplet with lepton-quark interaction mediated by new gauge bosons
Can fermions be made of more fundamental objects? $\rightarrow$ Compositeness	$\rightarrow$	Bound states of fundamental constituents may decay to a quark and a lepton
Can a symmetry exist between fermions and bosons? $\rightarrow$ Supersymmetry	$\rightarrow$	Possible decay of sparticles to a quark and a lepton (see e.g. R-parity violation scenario)

- Searches for leptoquarks (LQ) are well-motivated at the LHC
- Recent enhanced interest for LQ as a possible candidate to explain some anomalies in B-physics precision measurements

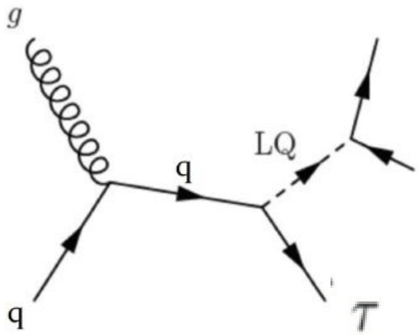
LQ relevant experimental features

- 2 production mechanisms considered(you can find them in paper here and here):

Pair



Single



- Parameters determining the cross section(you can find paper here and here):

	Pair	Single
Scalar: LQ_s	LQ mass	**Lambda (λ)** (coupling of SM lepton-quark to LQ)
Vector: LQ_v	**k** dimensionless coupling k=0 minimal coupling k=1 Yang-Mills	**Lambda (λ)** , k

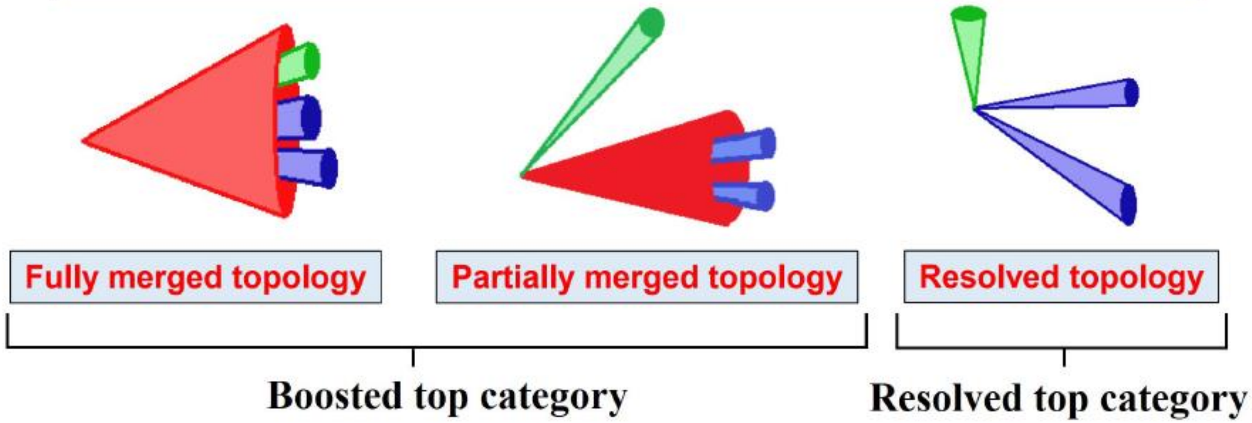
- Decay channel (you can find paper here and here):

LQs->top tau or LQs->bottom nu LQv->bottom tau or LQv->top nu

Analysis strategy

- Final states top tau nu bottom (pair LQ) and top tau nu (single LQ) → 2 categories of events >= 2 b or = 1 b
- Fully hadronic decay of the top quark and tau lepton
- Top reconstruction

- **Three reconstruction algorithms** to have good sensitivity in all mass range
  - ✓ **Fully merged topology**: top candidate is a top-jet
  - ✓ **Partially merged topology**: top candidate given by one W-jet and one ak4 jet
  - ✓ **Resolved topology**: top candidate given by three ak4 jets



- ST = tauh p_T + top p_T + p_T^{miss} used for the signal extraction

Signal region

- (top tau nu bottom) + (top tau nu) selection

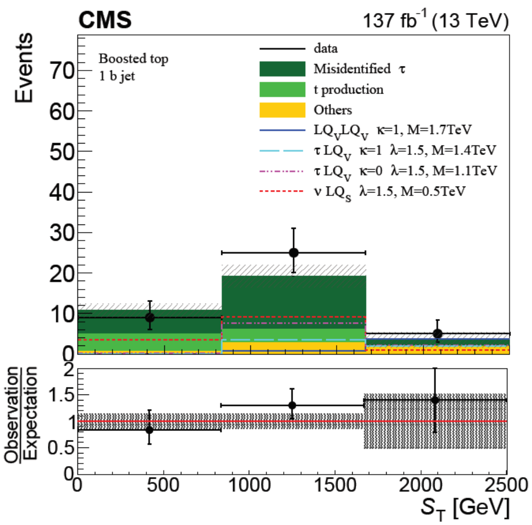
- P_T^{miss}>=200GeV, H_T^{miss}>=200GeV(= magnitude of the sum of pT of the AK4 jet)
- H_T>=300GeV ((H_T = scalar sum of the pT of all AK4 jets)
- 0 electron and muon
- 1 tauh
- massT(tau,P_T^{miss})>=300GeV
- >= 1 top candidate
  - Fully merged topology(1 merged top quark)
  - Partially merged topology(1 merged W boson + 1 b-jet)
  - Resolved topology(2 AK4 jets + 1 b-jet)

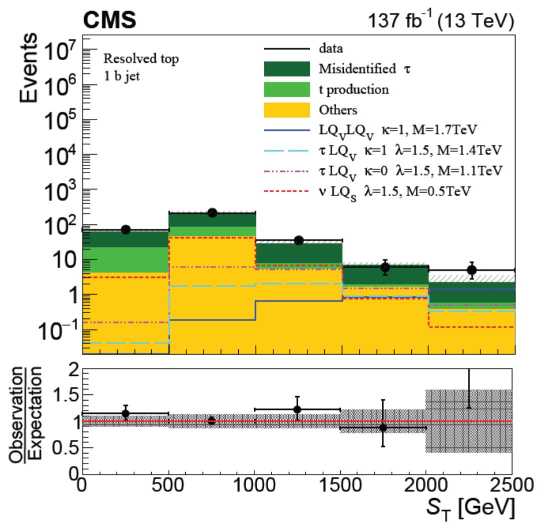
AK4 jet: anti-kt jet with radius = 0.4

➢ 4 categories in total

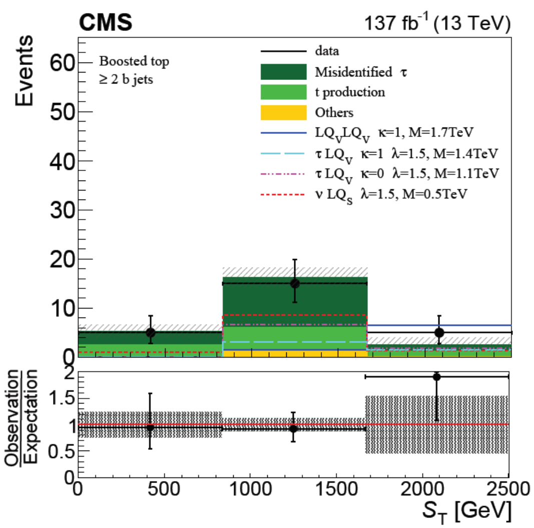
>=2b or = 1b, boosted or resolved

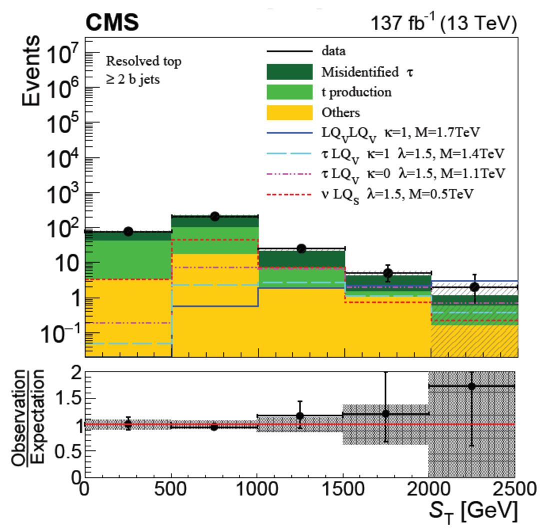
Data vs SM expectation in the signal region





Category	Boosted		Resolved	
	$N_{\text{b-jet}} = 1$	$N_{\text{b-jet}} \geq 2$	$N_{\text{b-jet}} = 1$	$N_{\text{b-jet}} \geq 2$
Misidentified τ	20.5 ± 2.1	14.4 ± 1.8	199 ± 13	170 ± 12
t production	7.8 ± 2.1	8.2 ± 1.9	59 ± 5	127 ± 9
Others	5.3 ± 2.0	1.6 ± 0.8	56 ± 25	23 ± 11
Total bkg	34 ± 4	24.2 ± 2.7	314 ± 29	320 ± 19
Data	39	25	332	316
$LQ_V\ LQ_V$ k=1, M=1.7 TeV	4.6 ± 0.7	8.0 ± 1.2	3.1 ± 0.3	7.7 ± 0.7
τLQ_V k=1 λ=1.5, M=1.4 TeV	5.5 ± 0.4	4.8 ± 0.4	5.03 ± 0.22	6.6 ± 0.3
τLQ_V k=0 λ=1.5, M=1.1 TeV	10.1 ± 0.7	8.6 ± 0.7	13.4 ± 0.6	16.4 ± 0.8
νLQ_S λ=1.5, M=0.5 TeV	13.5 ± 0.8	11.0 ± 0.8	52.7 ± 2.7	58 ± 3





- Misidentified tau main background
  →estimated from data
- top production relevant
  →estimated normalizing MC to data
- Others not dominant
  →taken from simulation

Background estimation method

➢jet->tau misidentification background estimation method

- **Tight-to-loose ratio** used to estimate **fake tau events** (QCD, ttbar, Wjets, etc, without genuine taus)
- FR is the probability that a VLoose tau has to pass the Medium ID

  $FR = {}^{N_{Medium}}/_{N_{VLoose}}$, measured in a control region
- From number of events passing VLoose but not the Medium ID, $N_{VL,!M}$, estimate number of predicted events in the signal region with fake tau:

$$N^{SR}_{fake\ tau} = \sum_{pt,eta} N_{VL,!M}(pt,eta) \cdot \frac{FR(pt,eta)}{[1 - FR(pt,eta)]}$$

➢Top background

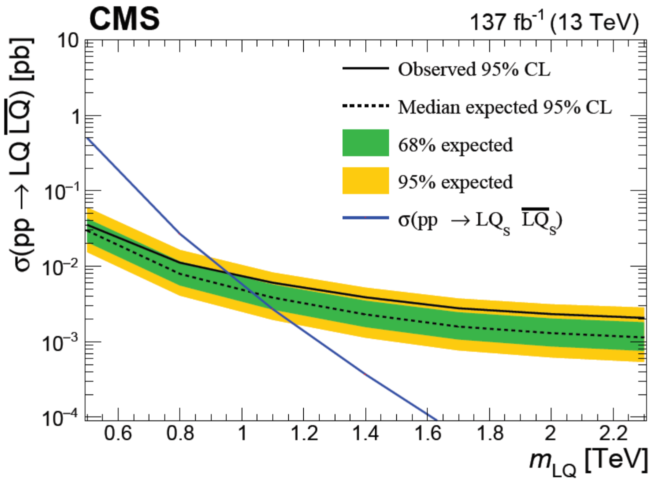
- Normalize MC to data in signal-free region
  - massT(tauh,p_T^{miss}) < 80 GeV
  - N b-jet >= 2
- MC Scaled by 10%

Systematic uncertainties

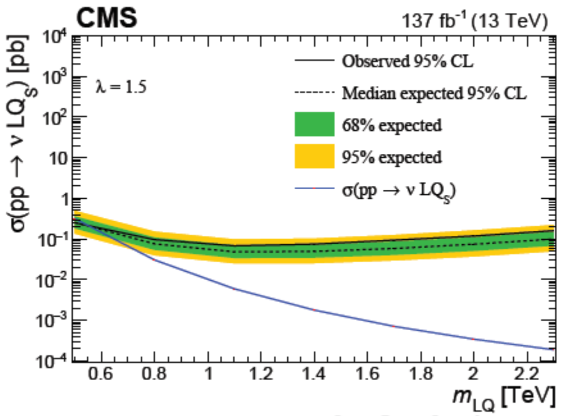
Uncertainty	Background	Signal
Pileup	1-6%	1%
PDF	-	5%
Trigger	1-2%	1-2%
JES/JER	1-35%	2.5%
b-tag	3-10%	8-23%
Tauh scale	1-5%	1%
Tauh ID	5-13%	13-20%
W jet tag	2-11%	1-4%
top jet tag	3-15%	7-14%
Misidentified taus bkg	9-56%	-
Misidentified tau closure	12%	-
Luminosity	2.3-2.5%	2.3-2.5%
Background cross-section	5-30%	-

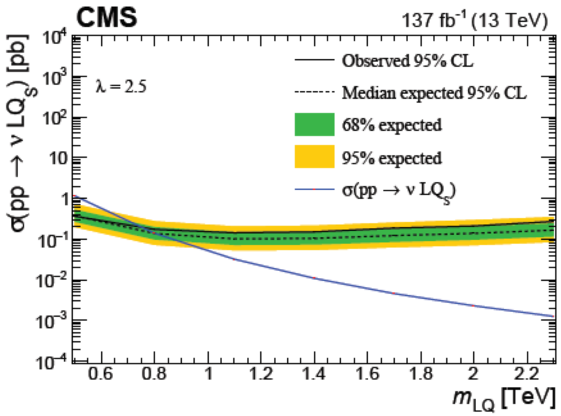
Exclusions for scalar LQ

Pair LQ

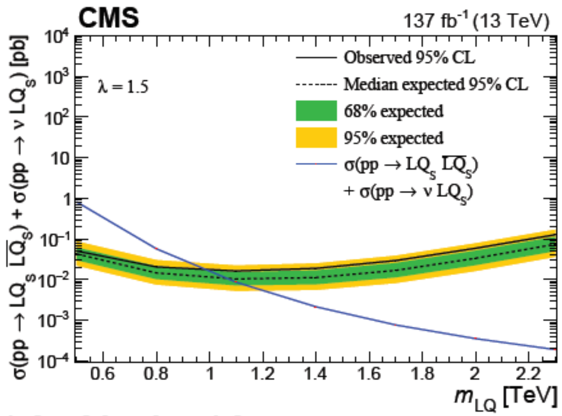


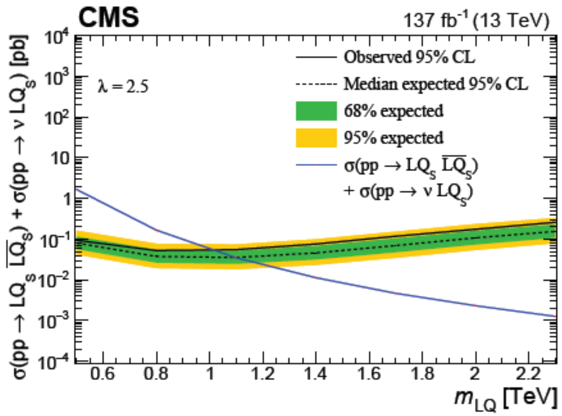
Single LQ





Pair + Single LQ

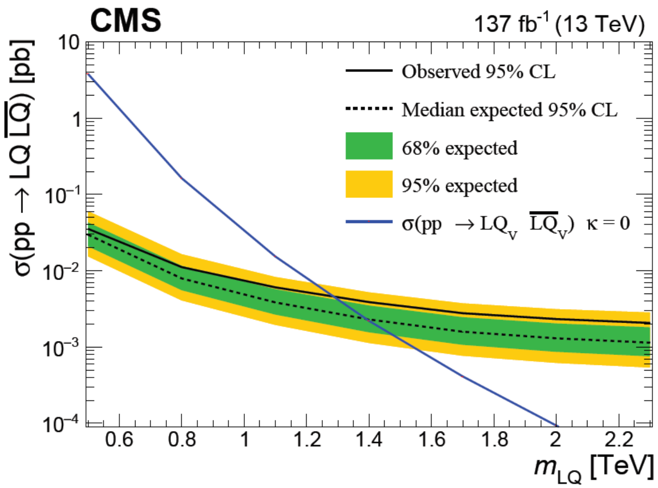




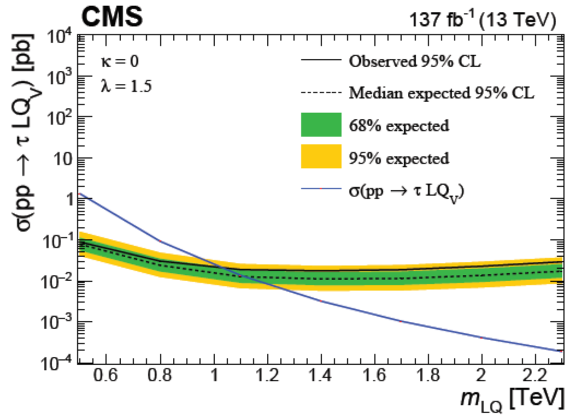
- Scalar Pair LQ production does not depend from λ.
- LQsLQs: LQs masses below 0.95 (1.03) TeV are excluded
- *v*LQs : LQs masses below 0.55 (0.56) TeV and 0.75(0.81) TeV for **λ** of 1.5 and 2.5 are excluded.
- LQsLQs+*v*LQs : LQs masses below 0.98 (1.06) TeV and 1.02 (1.10) TeV for **λ** of 1.5 and 2.5 are excluded.

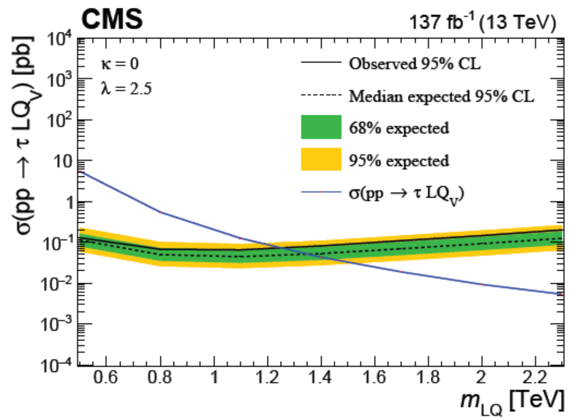
Exclusions for vector LQ(k=0)

Pair LQ

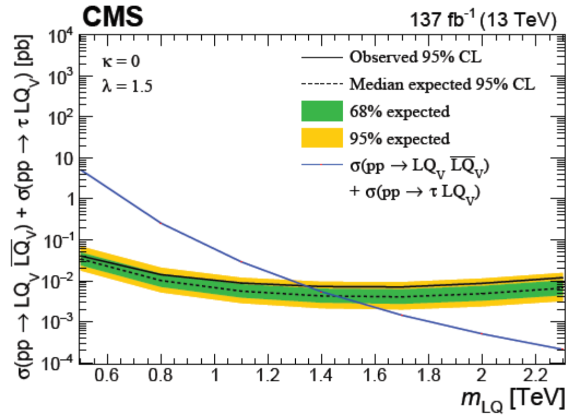


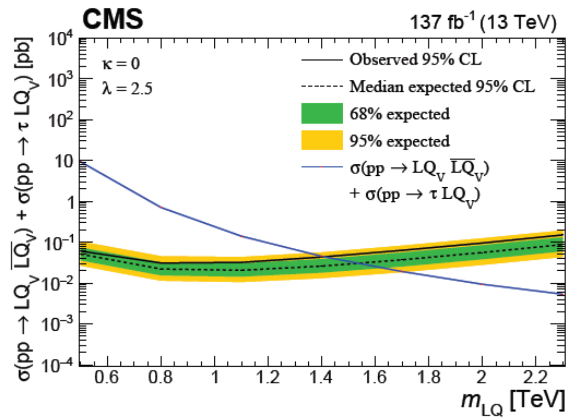
Single LQ





Pair + Single LQ

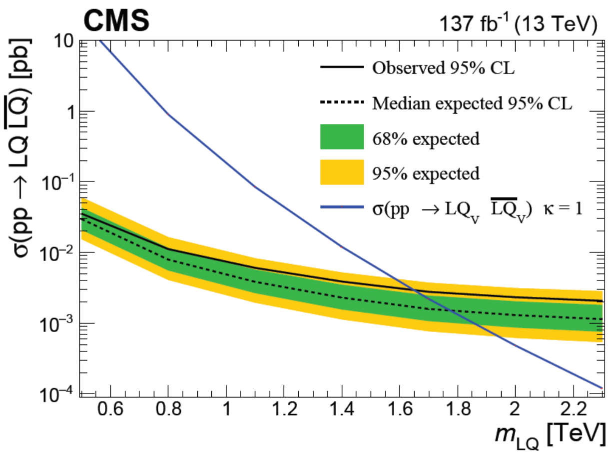




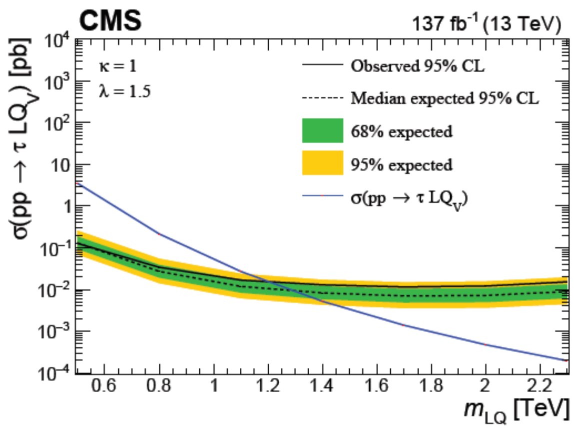
- LQvLQv: LQv masses below 1.29 (1.39) TeV are excluded.
- *τ*LQv : LQv masses below 1.03 (1.12) TeV and 1.25(1.35) TeV for **λ** of 1.5 and 2.5 are excluded.
- LQvLQv+*τ*LQv : LQv masses below 1.34 (1.46) TeV and 1.41 (1.54) TeV for **λ** of 1.5 and 2.5 are excluded.

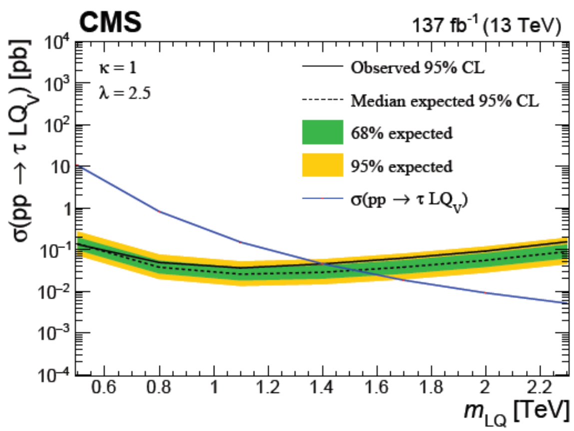
Exclusions for vector LQ(k=1)

Pair LQ

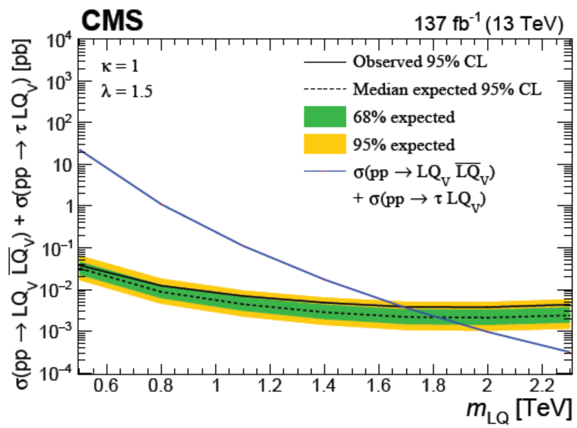


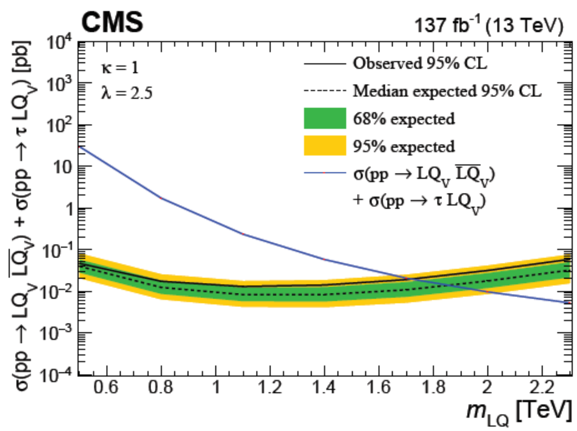
Single LQ





Pair + Single LQ

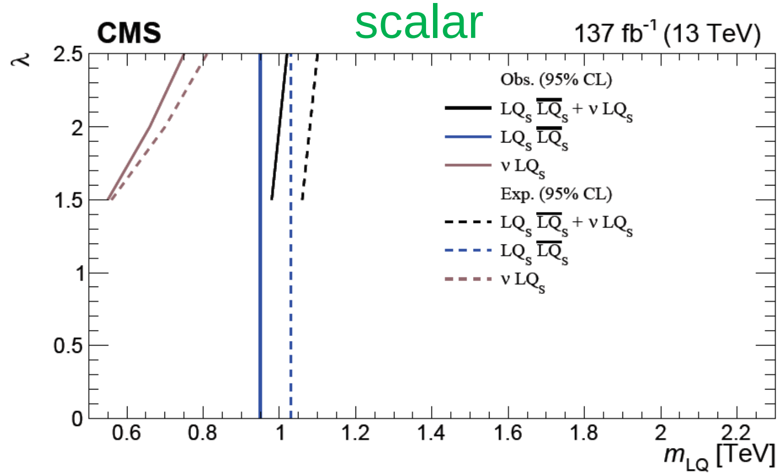




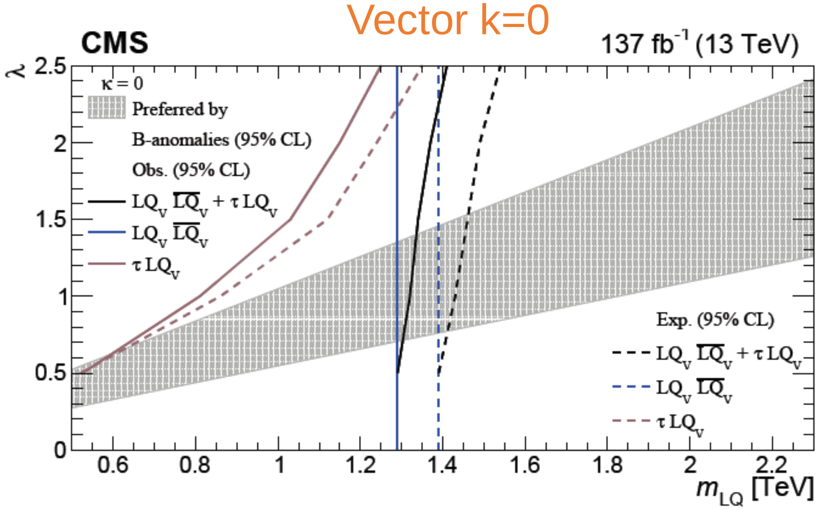
- LQvLQv: LQv masses below 1.65 (1.77) TeV are excluded.
- τLQv : LQv masses below 1.20 (1.29) TeV and 1.41(1.53) TeV for **λ** of 1.5 and 2.5 are excluded.
- LQvLQv+τLQv: LQv masses below 1.69 (1.81) TeV and 1.73 (1.87) TeV for **λ** of 1.5 and 2.5 are excluded.

λ-Mass exclusion

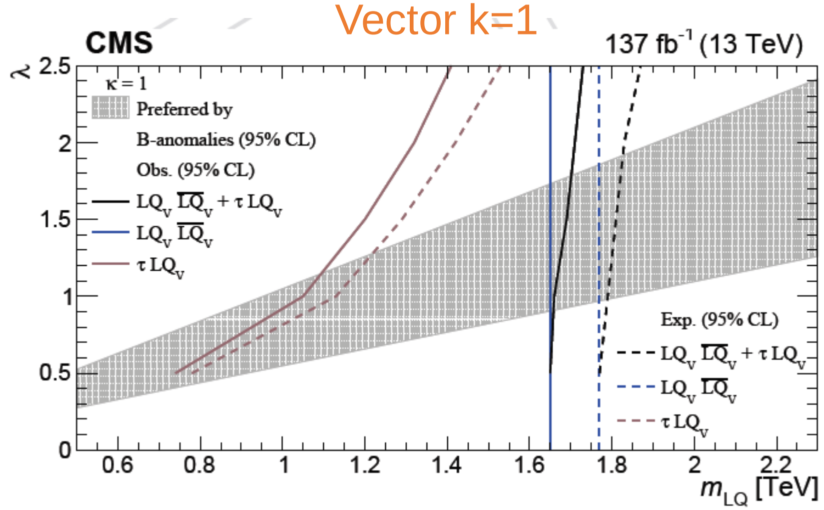
scalar



Vector k=0



Vector k=1



- Values of **λ** up to 2.5 are constrained by electroweak precision measurements
- For LQv, the gray area(get from paper) shows the 95% CL band preferred by the B physics anomalies: **λ =** $\sqrt{\mathbf{0.7 \pm 0.2}} \times \boldsymbol{m_{LQ}}$ TeV . A relevant portion of this parameter space is excluded.

Summary

- We have presented a search for for LQ produced singly and in pairs in the final states t tau nu b and top tau nu
- We have use ST = tauh pT + top pT + pTmiss variable for the signal extraction
- The main background, due to jet->tau misidentification, is estimated from data
- Data are found to be in agreement with SM prediction
- We interpret the results considering simultaneously pair and single LQ and setting exclusion limits in the LQ lambda-mass plane

	LQ_S		LQ_V $k = 0$		LQ_V $k = 1$	
Pair	0.95 (1.03)		1.29 (1.39)		1.65 (1.77)	
λ	1.5	2.5	1.5	2.5	1.5	2.5
Single	0.55 (0.56)	0.75 (0.81)	1.03 (1.12)	1.25 (1.35)	1.20 (1.29)	1.41 (1.53)
Pair+Single	0.98 (1.06)	1.02 (1.10)	1.34 (1.46)	1.41 (1.54)	1.69 (1.81)	1.73 (1.87)

backup

Status of B-physics anomalies

Courtesy of Andreas Hoecker
LHCP2020 Experimental highlights

Status of flavour anomalies:

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

Possible new physics in charged current in tree diagram

Tension reduced after 2019 Belle result [1904.08794]
in agreement with SM

Remaining tension (HFLAV): 3.1σ
Corresponding $R_{J/\psi|\tau/\mu}$ ~2σ above SM [LHCb: 1711.05623]

$$R_{K^{(*)}} = \frac{B(B \to K^{(*)}\mu\mu)}{B(B \to K^{(*)}ee)} \overset{\text{[SM]}}{\cong} 1$$

Experiments measure double ratio involving J/ψ

R_K: LHCb most precise, Run-2 ~SM, combination with Run-1: 2.5σ < SM

R_{K^*}: LHCb (most precise) low (2.3~2.5σ) at low q^2

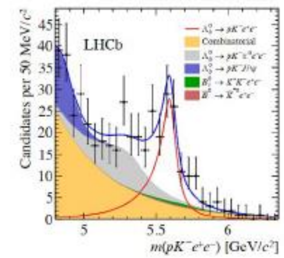
New results by LHCb:

$$R_{pK} = \frac{B(\Lambda_b^0 \to pK^-\mu\mu)}{B(\Lambda_b^0 \to pK^-ee)} \overset{\text{[SM]}}{\cong} 1$$

LHCb measures double ratios to J/ψ

Result: $\boldsymbol{R_{pK} = 0.86^{+0.14}_{-0.11} \pm 0.05}$
in agreement with SM (but also lower)

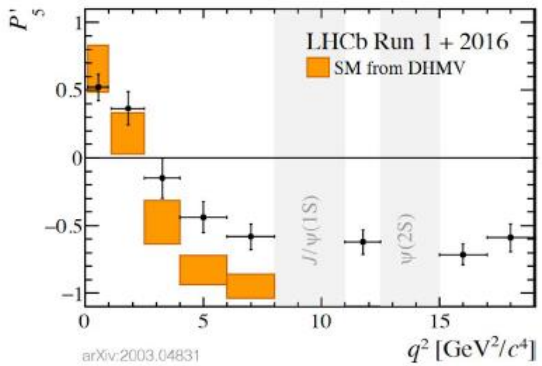
arXiv:1912.08139



Observation > 7σ

$B \to K^*\mu\mu$ angular analysis

New result from LHCb with 4.7 fb^{-1} (Run 1 + 2016 data)



arXiv:2003.04831

Full fit to all angular observables

Global fit by LHCb to SM model varying Re(C_9) only gives 3.3σ discrepancy

- No firm conclusion, need more data!
- Possible to clarify anomalies within timescale of Phase 2((arXiv:1709.10308))

B-physics anomalies and LQ

Standard Model process

+ new physics?

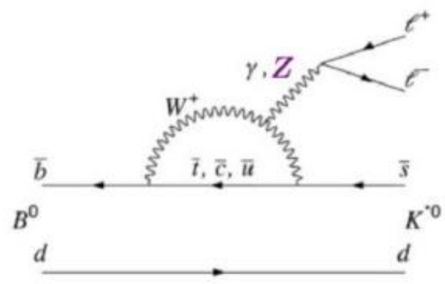
Quark level transition $b \to s\ell\ell$

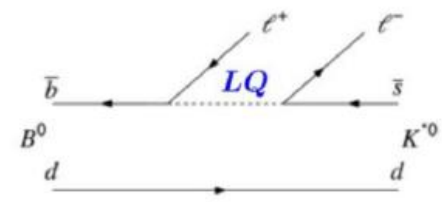
$$R_{K^{(*)}} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}^{(*)}e^+e^-)}$$

R_K, R_{K^*}

$B^0 \to K^{*0}\mu^+\mu-$ angular analysis:

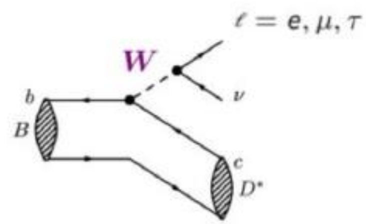
$B^0 \to \phi\mu^+\mu-$

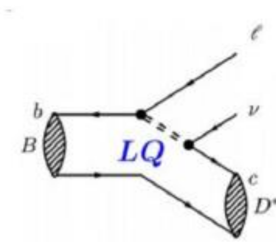




Quark level transition $b \to c\ell\nu$

$$R^{\tau/\ell}_{D^{(*)}} = \frac{\Gamma(\bar{B} \to D^{(*)}\tau\bar{\nu})}{\Gamma(\bar{B} \to D^{(*)}\ell\bar{\nu})}$$



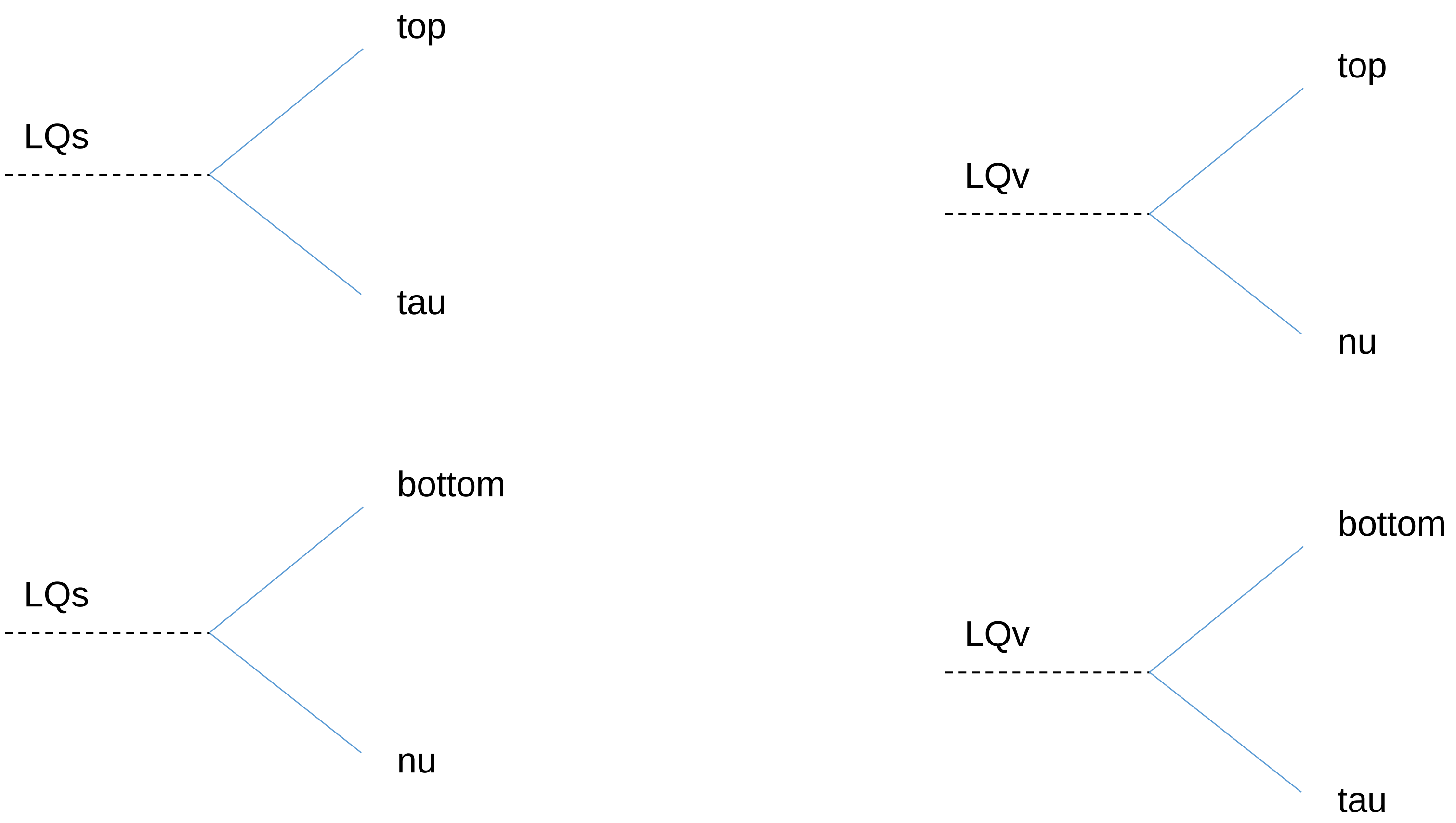


- Upper limit on new physics scale: 9 (80) TeV for b→clv (b→sll) transition (arXiv:1706.01868)
- Couplings to 2nd, 3rd fermion generation favored
- LQ_s (LQ_v) → t tau (t v), b nu (b tau) strong candidate to explain the anomalies

  arXiv:1808.02063 (arXiv:1706.07808)

  Decay BR of 0.5 preferred case to explain the anomalies

  → t tau nu b has x2 BR w.r.t. existing searches ttnunu (SUS-19-005) and bbtautau (EXO-17-016)



- Decay branching ratio of 0.5 to each leptonquark