Leptoquarks searches at ATLAS and CMS

On behalf of the ATLAS and CMS Collaborations

CKM 2021 University of Melbourne, Australia

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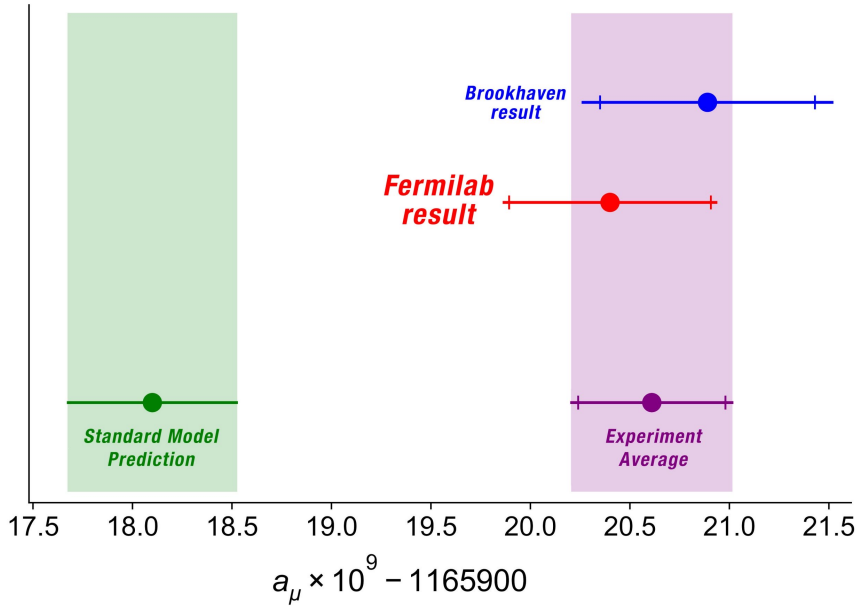
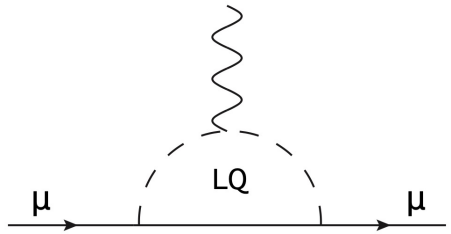
Motivation: B anomalies and recent muon g-2

- Mainly experimental puzzle R_K: Flavor anomalies in B decays PRL 125, 011802 (2020)
- The combined results from Fermilab and Brookhaven show a difference with theory at a significance of 4.2 sigma, a little shy of the 5 sigma. The chance that the results are a statistical fluctuation is about 1 in 40,000.





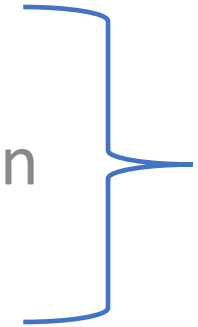
Can LQ help us to solve the puzzle?

BSM explanations ?

New heavy mediators

Lepton flavor universality violation

New left-handed currents



Leptoquarks !

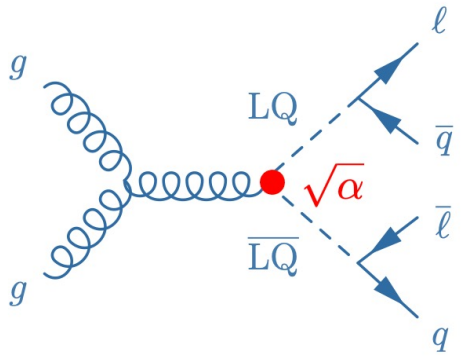
Leptoquarks

- Leptoquarks are hypothetical particles carrying both baryon number (B) and lepton number (L).
- The possible quantum numbers of leptoquark states can be restricted by assuming that their direct interactions with the ordinary standard model (SM) fermions are dimensionless and invariant under the SM gauge group.

Searches for Leptoquarks CMS & ATLAS

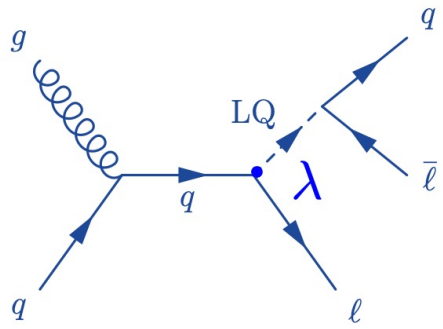
- Pair-production is the dominant process
- Expected signals are characterized by their Yukawa coupling to the lepton-quark λ, or the relative couplings β that control the branching fraction to LQ → ql or LQ → qν
- Look for events with high p_T objects in the final state including a pair of jets and a pair of leptons. In the case of decays to a top quark and a lepton, one could also expect additional leptons and/or b-jets from the top quark decay.

pair



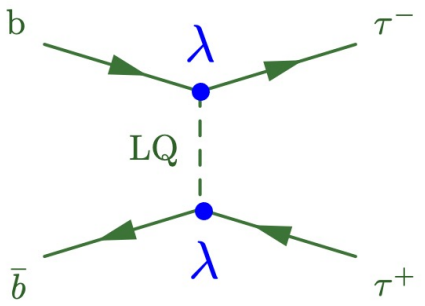
Large QCD production
Model independent
Resonant

single



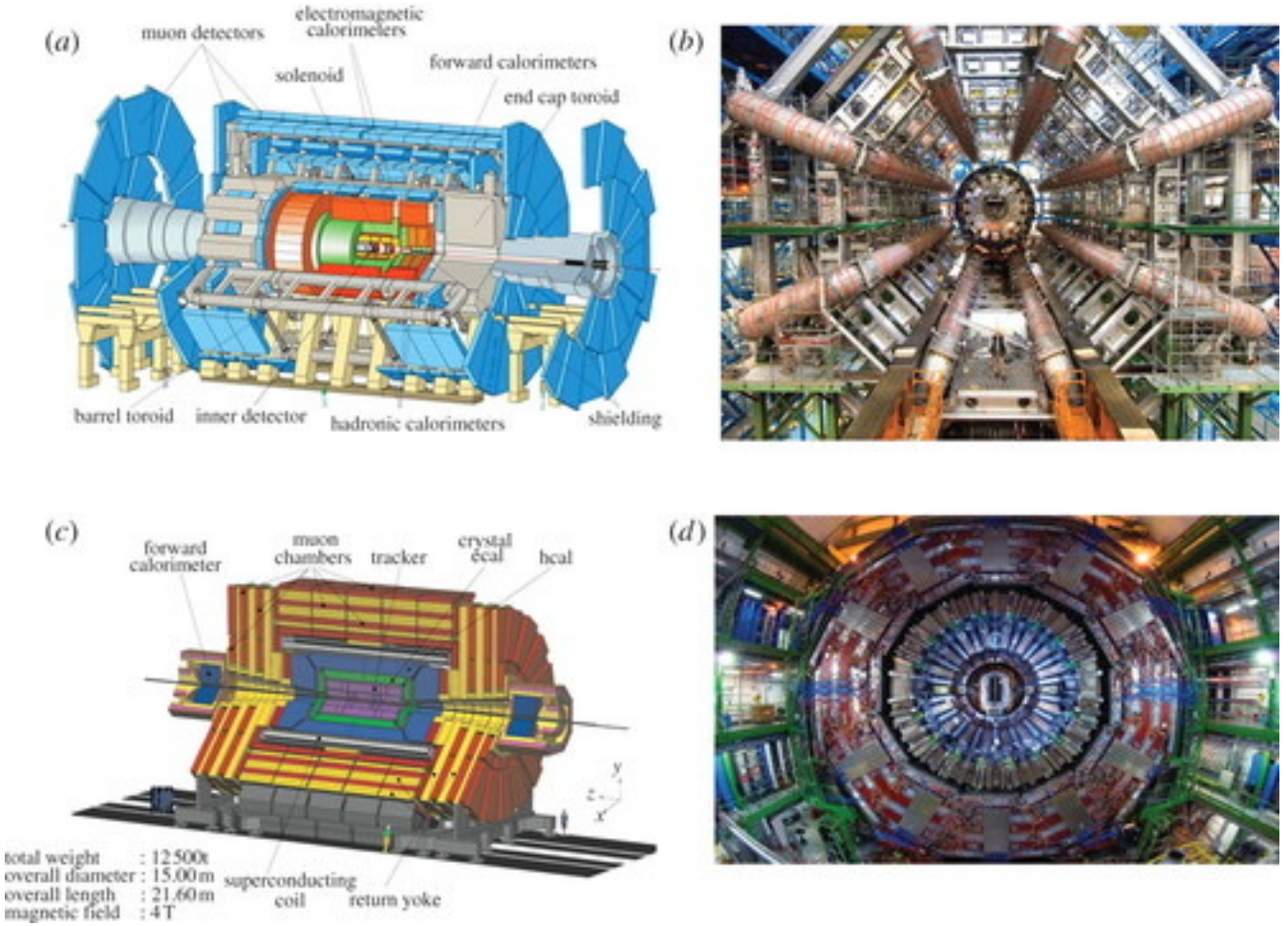
$\sigma \propto \lambda^2$
PDF suppression
Wide-resonance at high λ

non-resonant



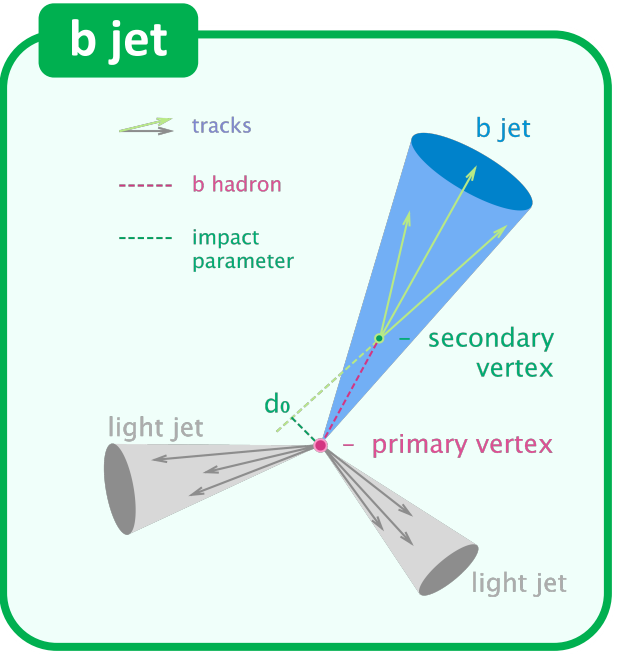
$\sigma \propto \lambda^4$
PDF suppression ^ 2
No resonance

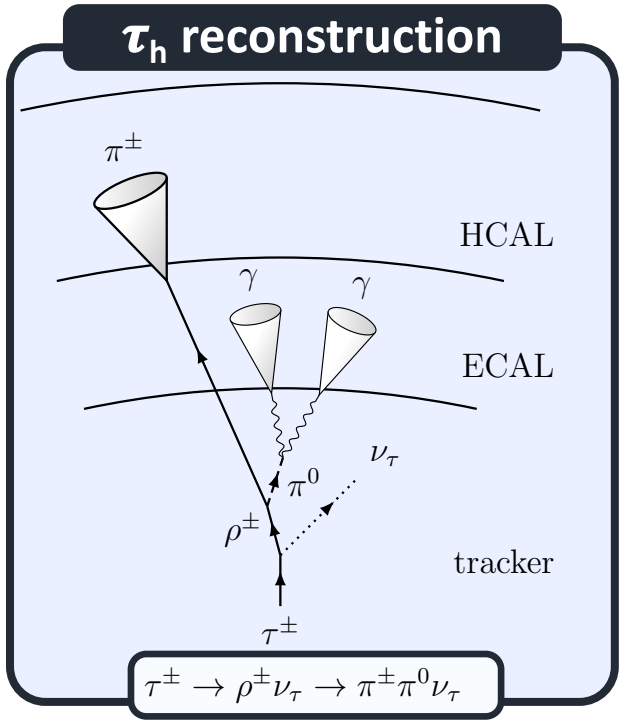
Showing a selection of the latest LQ results from CMS & ATLAS Collaborations

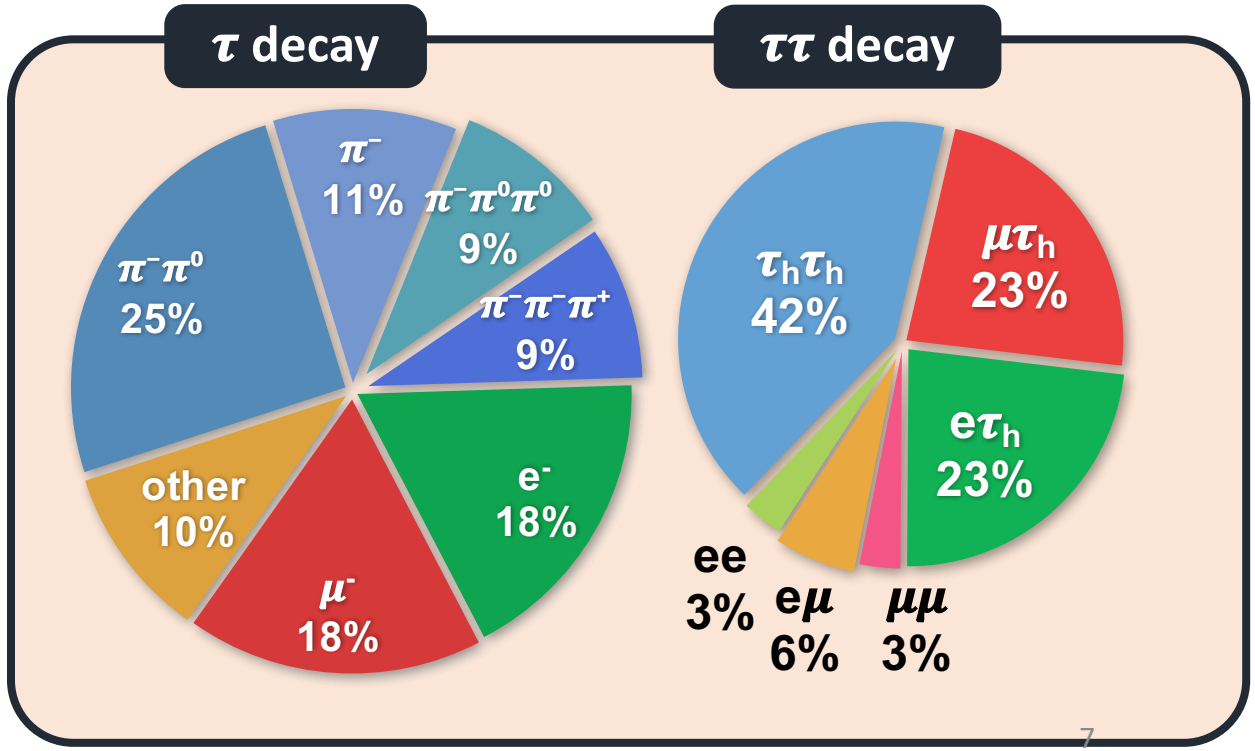


LQ reconstruction: Typical reconstruction

- Improve electron and muon reconstruction and better object identification
- b-jet and hadronic taus in CMS and ATLAS (see below)

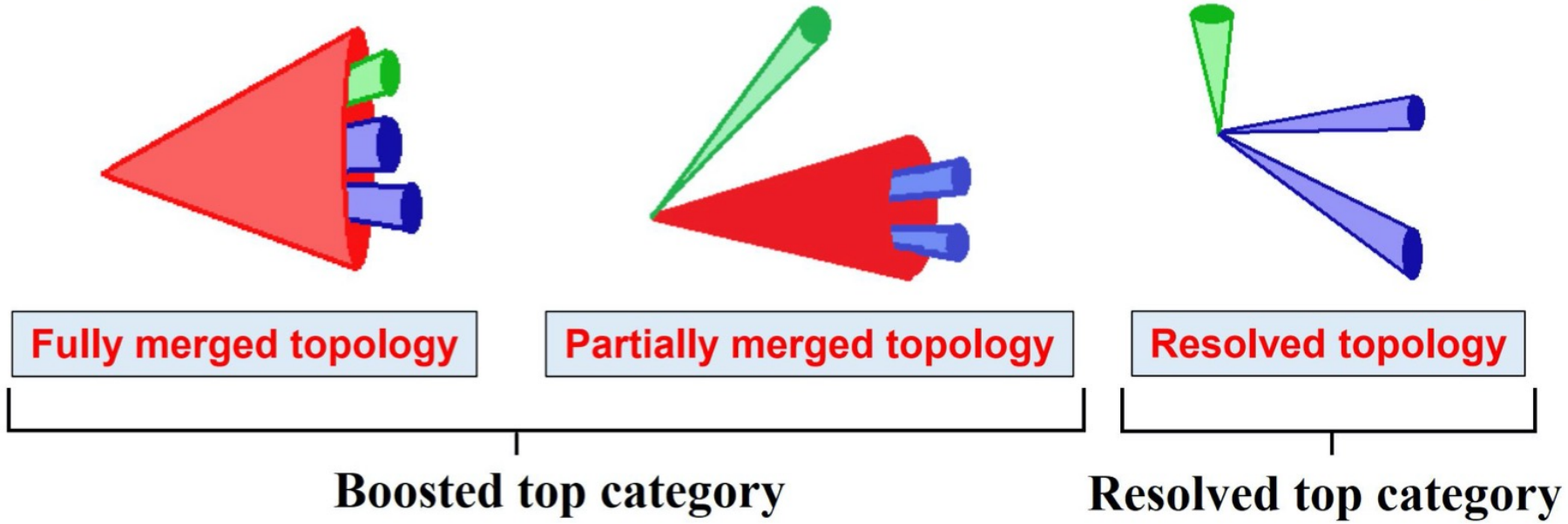






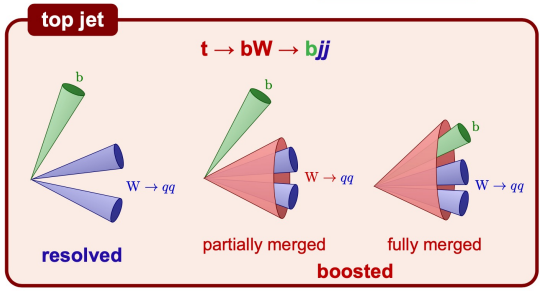
Top reconstruction

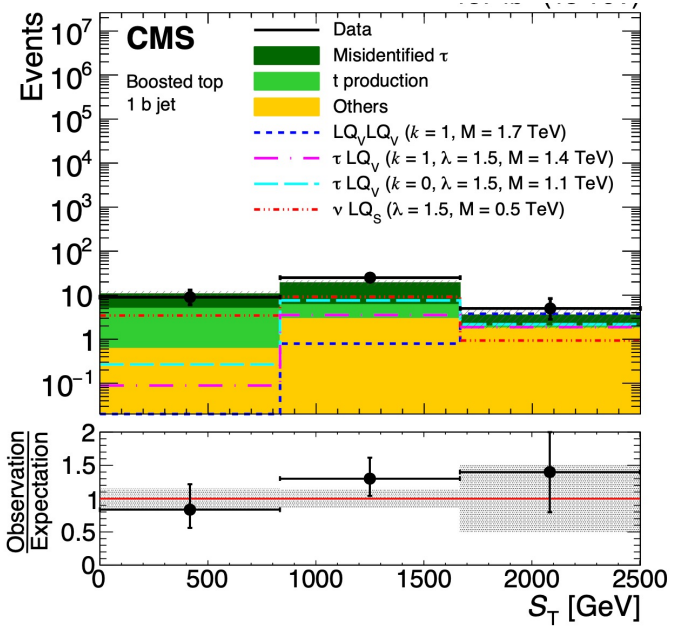
- **Three reconstruction algorithms** to have good sensitivity in all mass range
  - ✓ **Fully merged topology**: top candidate is a top-jet
  - ✓ **Partially merged topology**: top candidate given by one W-jet and one ak4 jet
  - ✓ **Resolved topology**: top candidate given by three ak4 jets

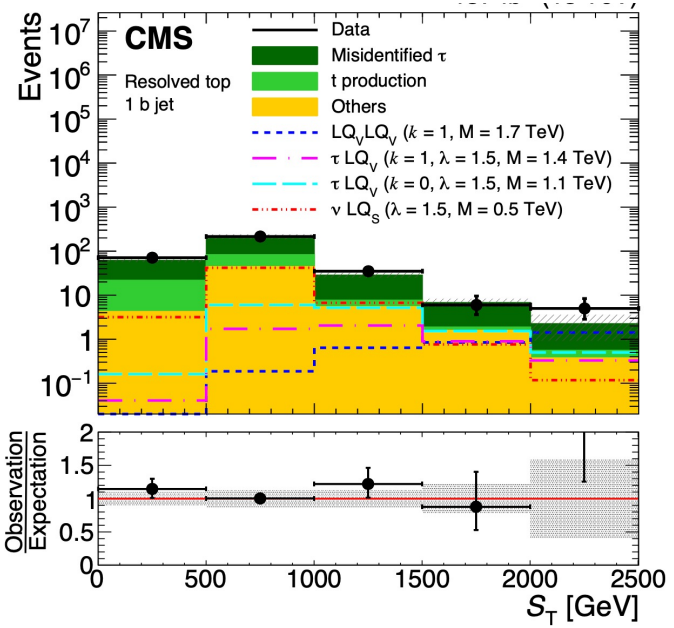


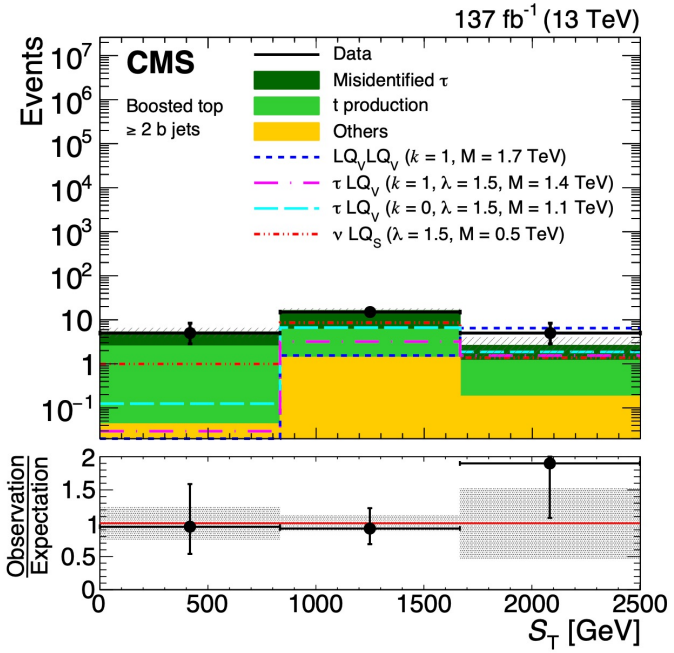
CMS Search for 3rd generations

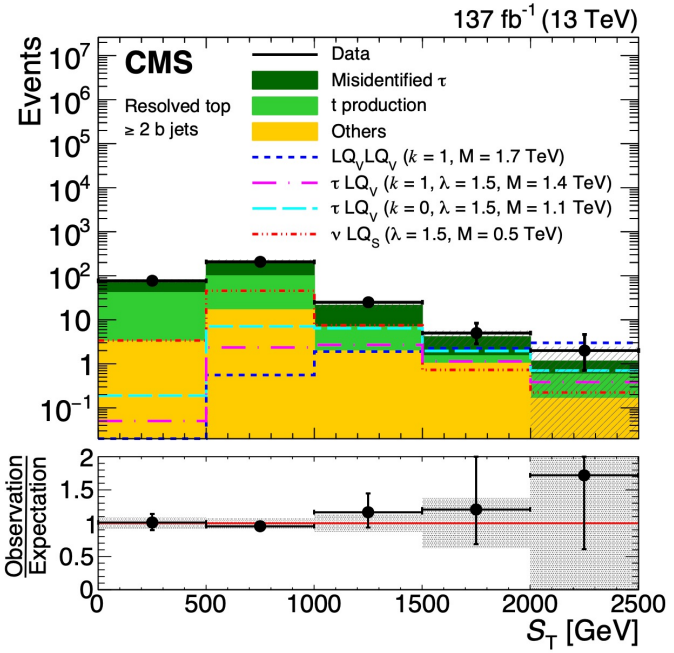
- Use 137 fb^{-1} Full Run 2 Single and Pair produced scalar or vector LQs searched simultaneously arXiv:2012.04178 with expected signals $\boldsymbol{\tau t \nu}$ & $\boldsymbol{\tau b t \nu}$
- Search done as a function of the LQ mass and in a fully hadronic signature including *boosted* top topologies
- Employ discriminating variable $\boldsymbol{S_T}$ corresponding to the scalar p_T sum of *the top candidate*, *taus* and the p_T^{miss} in the final state
- Main background comes from misidentified tau leptons, and is estimated using data driven methods
- The best limits are found for scalar LQ masses combining single and pair production







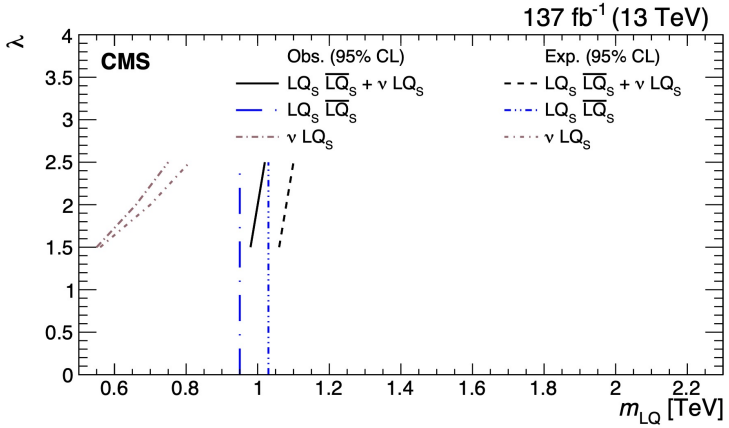




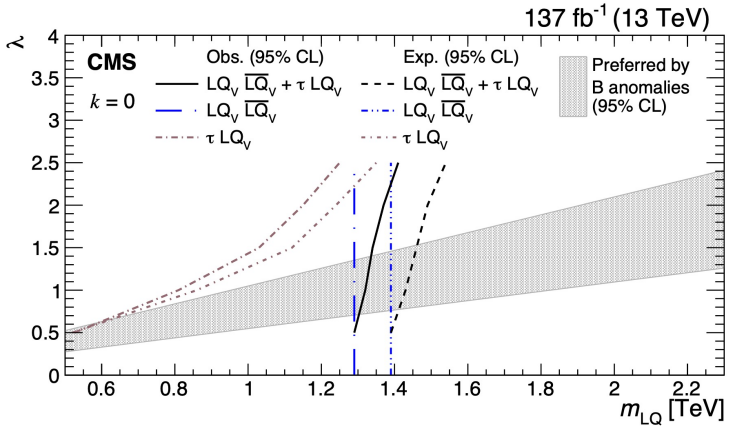
Thanks to Izaak Neutelings

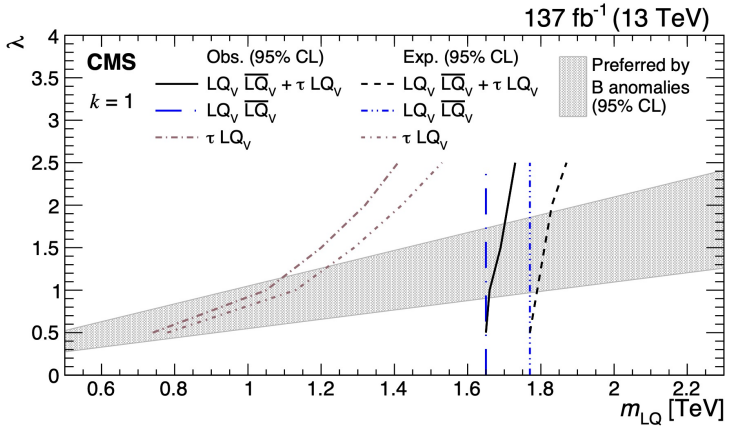
CMS 3rd gen

arXiv:2012.04178



Scalar



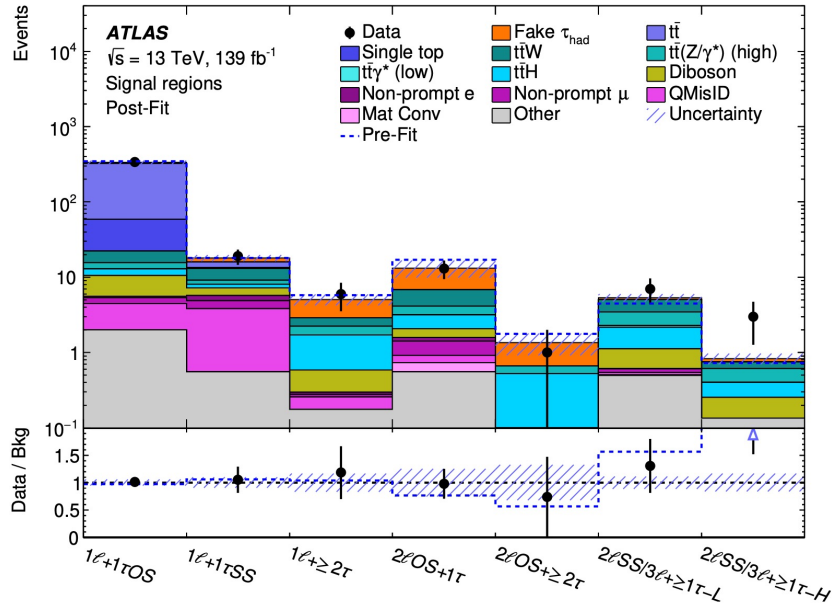


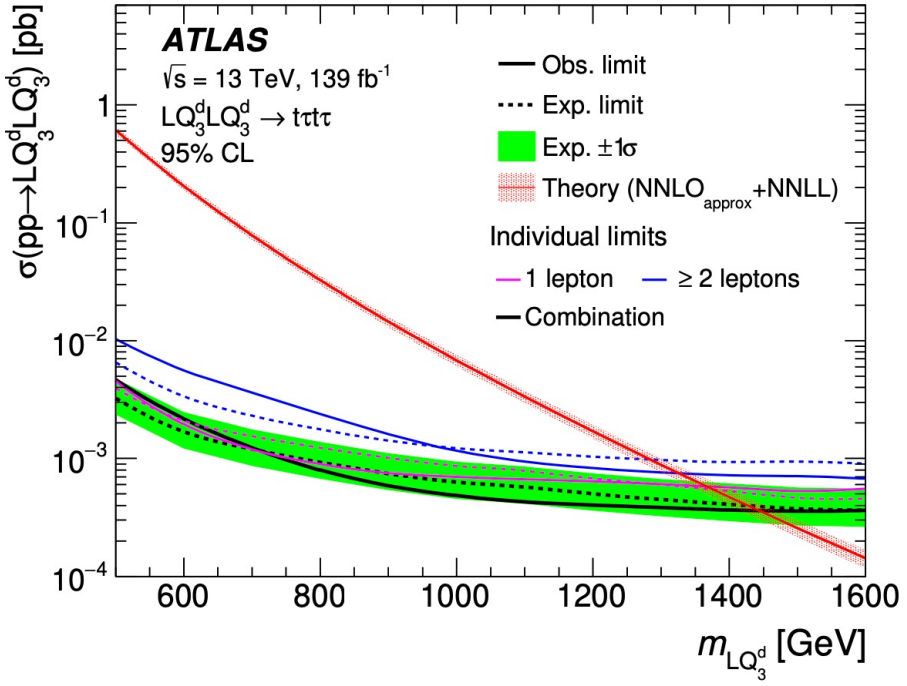
Vector

	LQ_S (TeV)		LQ_V $k = 0$ (TeV)		LQ_V $k = 1$ (TeV)	
Pair	0.95 (1.03)		1.29 (1.39)		1.65 (1.77)	
	$\lambda = 1.5$	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)

ATLAS: 3rd Gen Scalar LQ

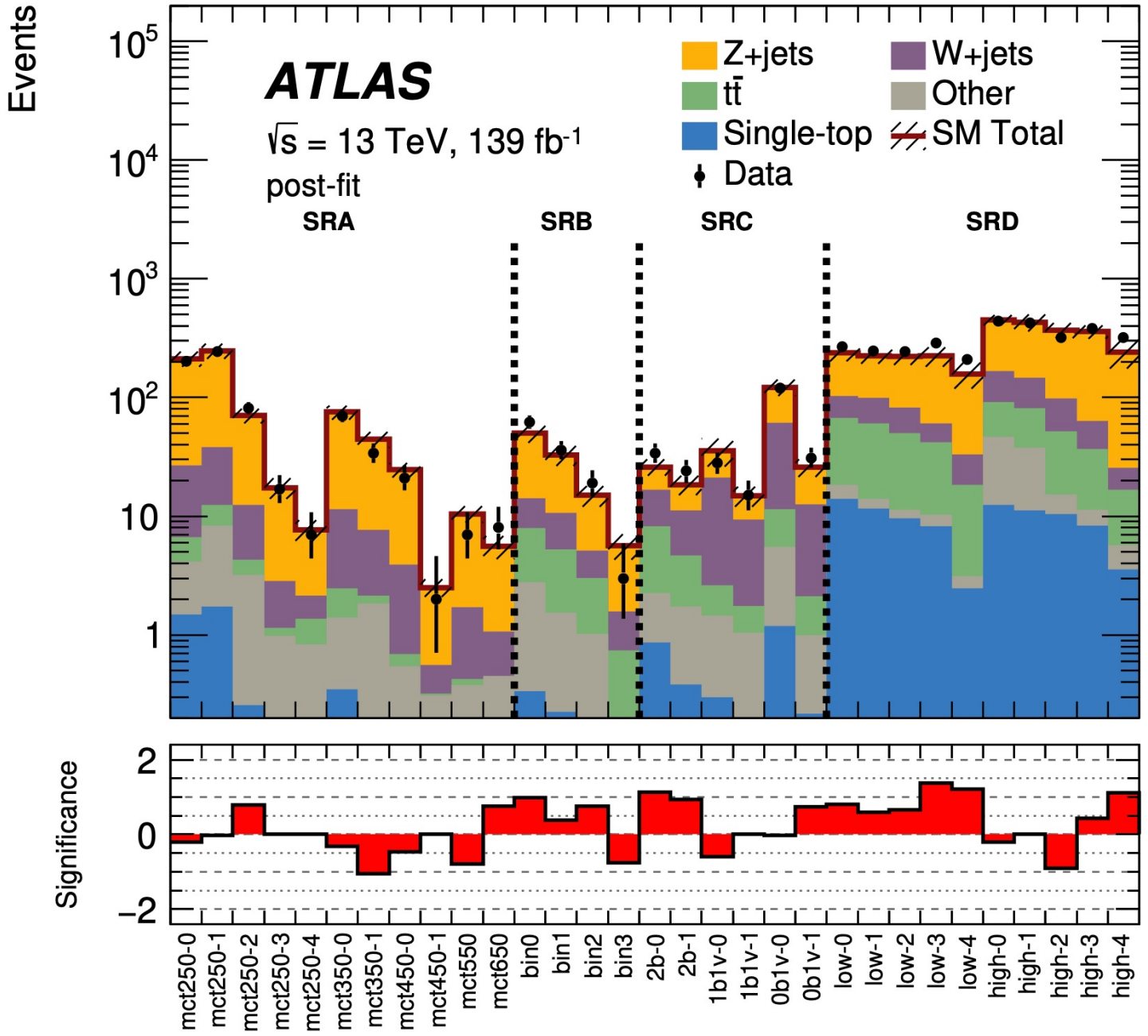
- Full Run 2 targeting down-type leptoquarks in the $t\tau$ decay channel
- Results: arXiv:2101.11582 & JHEP 06 (2021) 179
- Search 6 different final states corresponding to 7 SR are considered in the search, in addition 15 CR and 6 VR are used to estimate and validate the different backgrounds respectively
- Background sources vary significantly depending on the signature considered but main contributions come in general from $t\bar{t}$ + X
- Scalar leptoquarks decaying exclusively into $t\tau$ are excluded up to masses of 1.43 TeV



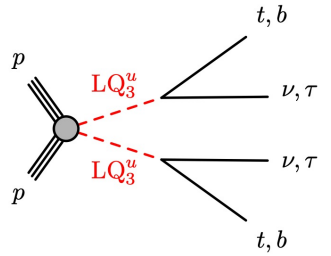


ATLAS 3rd generation scalar LQ searches

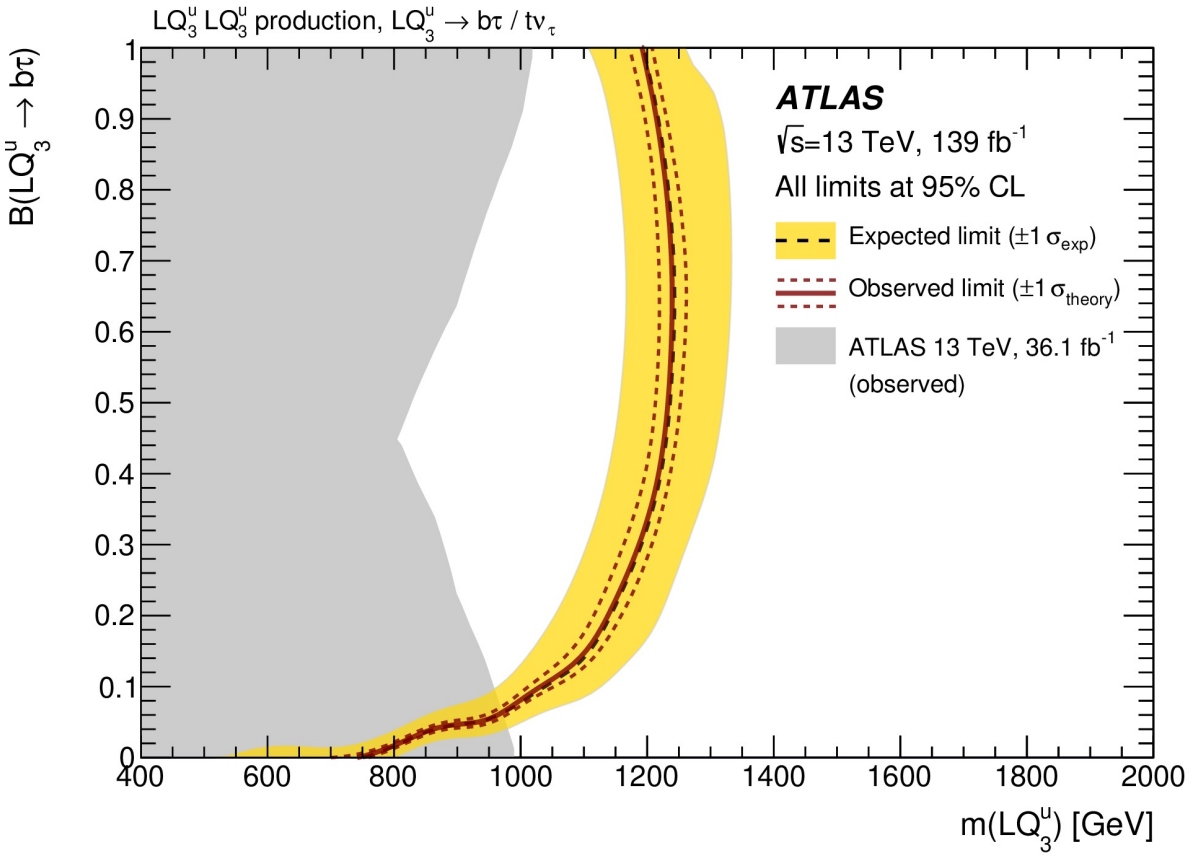
- Search for pair-produced ***b-squarks*** decaying into bb + E_T^{miss} in terms of LQs using Full Run 2 analysis described in **arXiv:2101.12527**
- Signal regions A & B requiring E_T^{miss}> 250 *GeV* are combined for the LQ analysis
- The main background come from ***Z+jets*** *and* ***W+jets*** production
- Limits on the LQ mass are set depending on B($LQ_3^d \rightarrow t\tau$) ranging from 400 GeV to 1.26 TeV



ATLAS 3rd generation scalar LQ searches

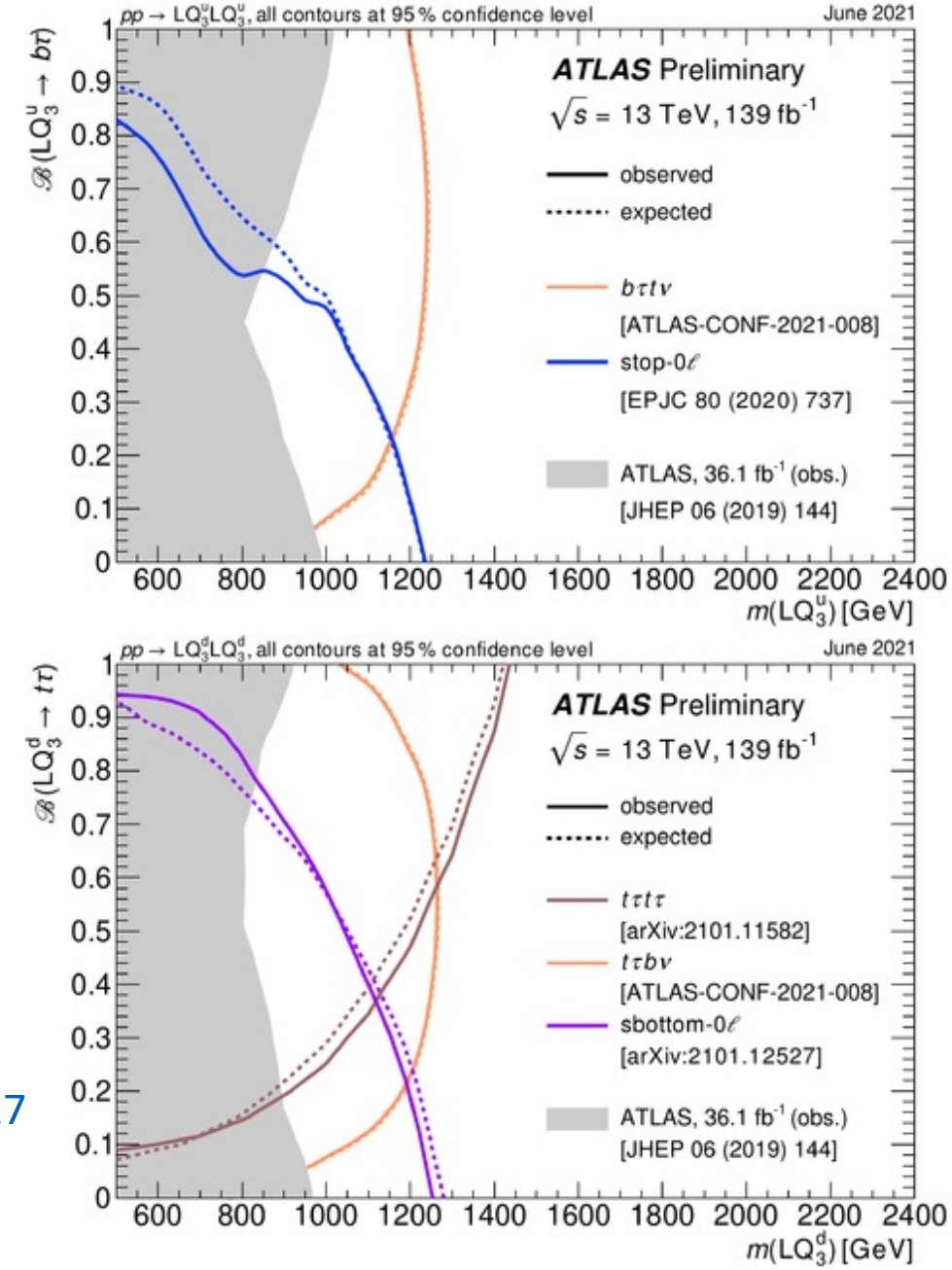


- **LQ benchmark** model and **top-squarks** comprising final states with b-jets, τ and missing momentum using the Full Run 2 result arXiv:2108.07665
- Single τ signal region targeting LQ search in the $b\tau t\upsilon$ final state, with the tau decaying to hadrons only
- Improving Limits on $\boldsymbol{B(LQ_3^d \rightarrow t\tau)}$ and $\boldsymbol{B(LQ_3^u \rightarrow b\tau)}$ as a function of m_{LQ}, with $\lambda = 0.3$
- Set limits on LQ_v



ATLAS Summary Plot

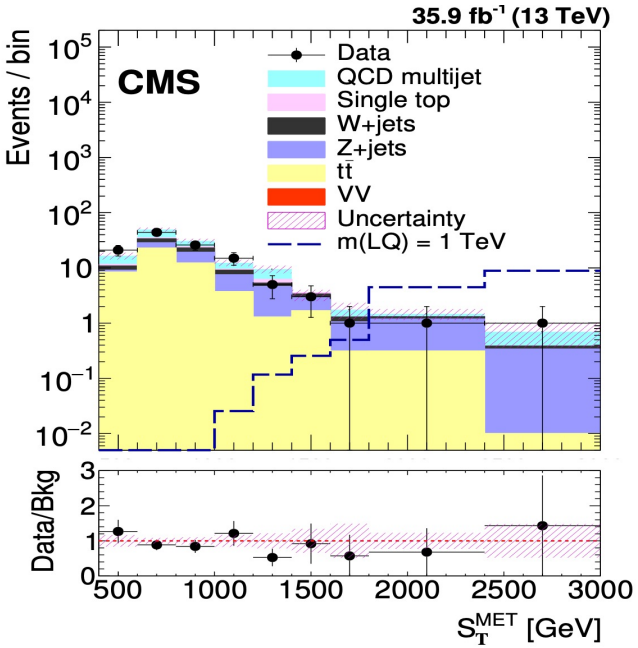
- Full Run 2 Limits on the branching ratio of a third generation leptoquark are shown as a function of its mass. For up and down-type
- New analyses greatly improve the exclusion limits of those using the partial Run 2 dataset
- $\boldsymbol{b\tau t\nu}$ analysis arXiv:2108.07665 sensitive to both leptoquark types

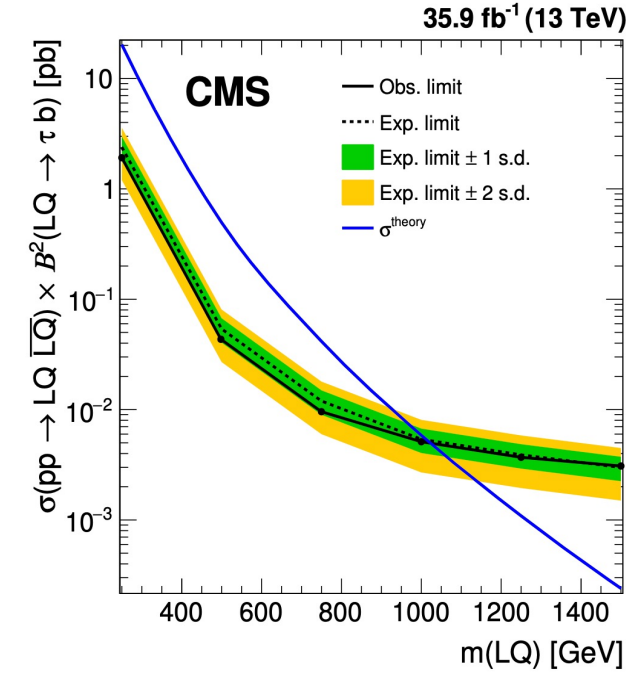


ATL-PHYS-PUB-2021-017

3rd generation scalar LQ searches (CMS)

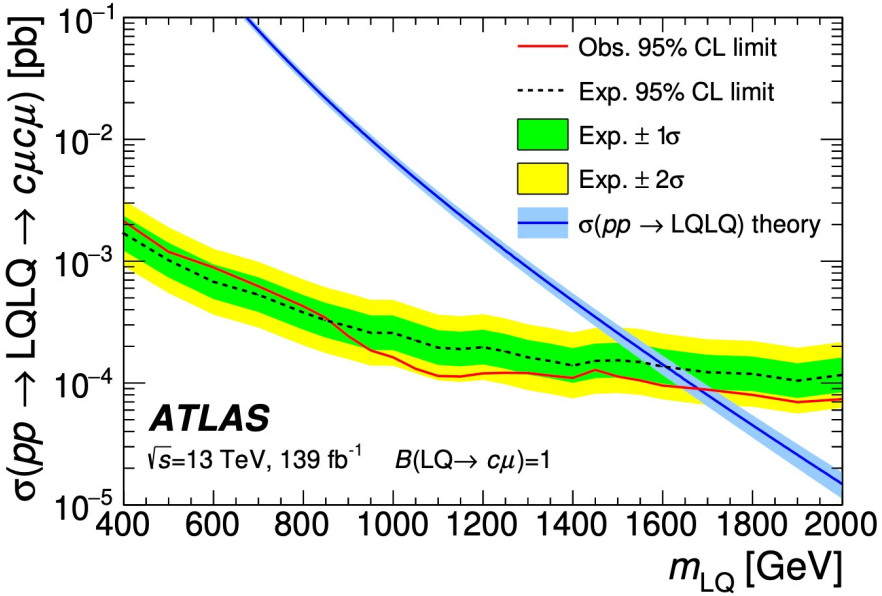
- Partial Run 2 results using 35.9 fb^{-1} of data JHEP03(2019)170
- The search was performed in the fully hadronic final state with **two b-jets** are used to obtain $t\bar{t}$-**enriched** CR for the estimation of the background rate in the SR
- A variable $\boldsymbol{S_T^{MET}}$ equal to the scalar sum of the p_T's of the two hardest jets, the taus and the missing p_T is used as a discriminating variable

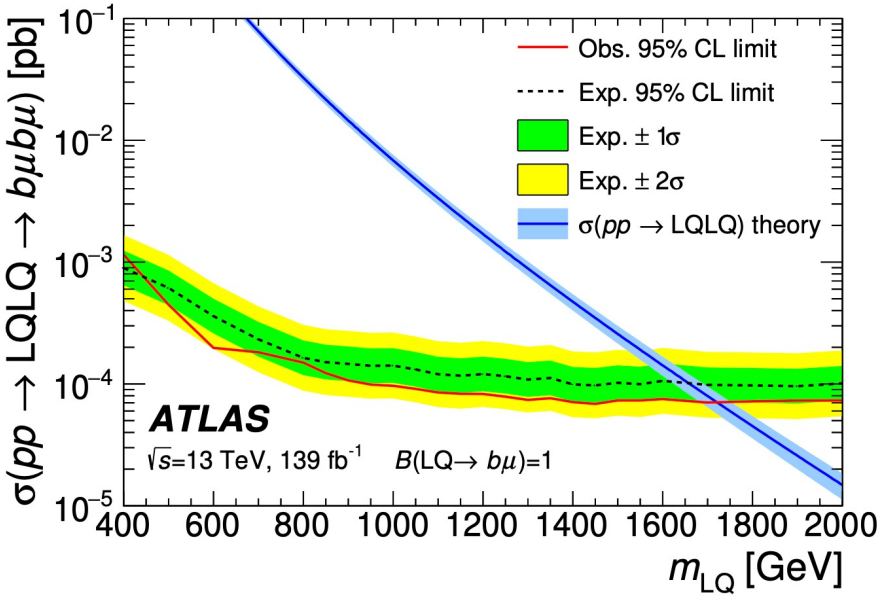




Search for LQ coupled to different generations (ATLAS)

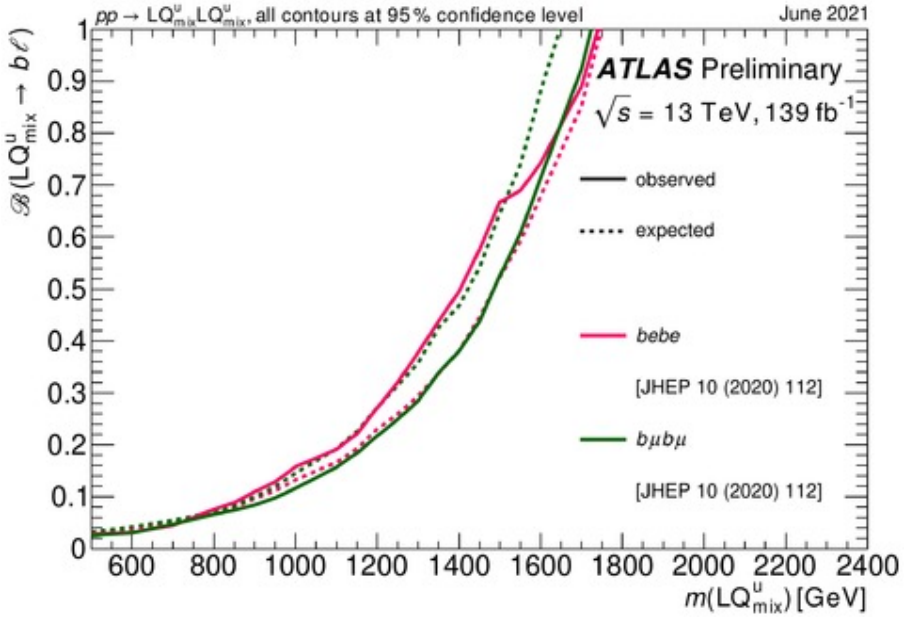
- Searches for leptoquarks in final states of the form $lQlQ$ with $Q = udcsb$ were performed in **JHEP (2020) 112**
- This analysis considers LQs that can mix quarks from different generations with e & μ
- Three signal regions are used: b, c (tag) and untag (for c-jets) and 2,1 and 0-tags for b-jets.
- Leptoquarks with masses below 1.8 TeV and 1.7 TeV are excluded in the electron and muon channels.

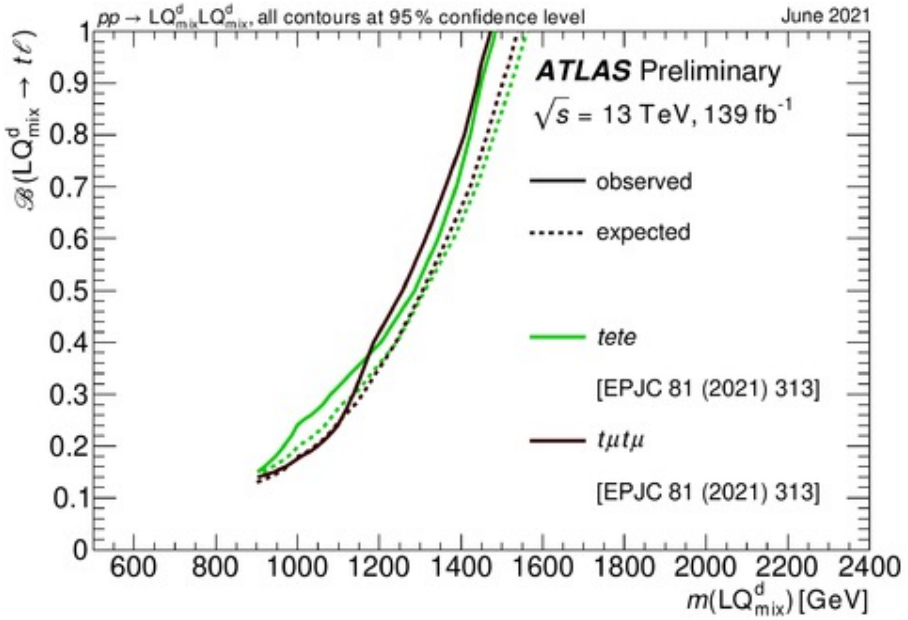




Mixed Generations ATLAS Summary Plots

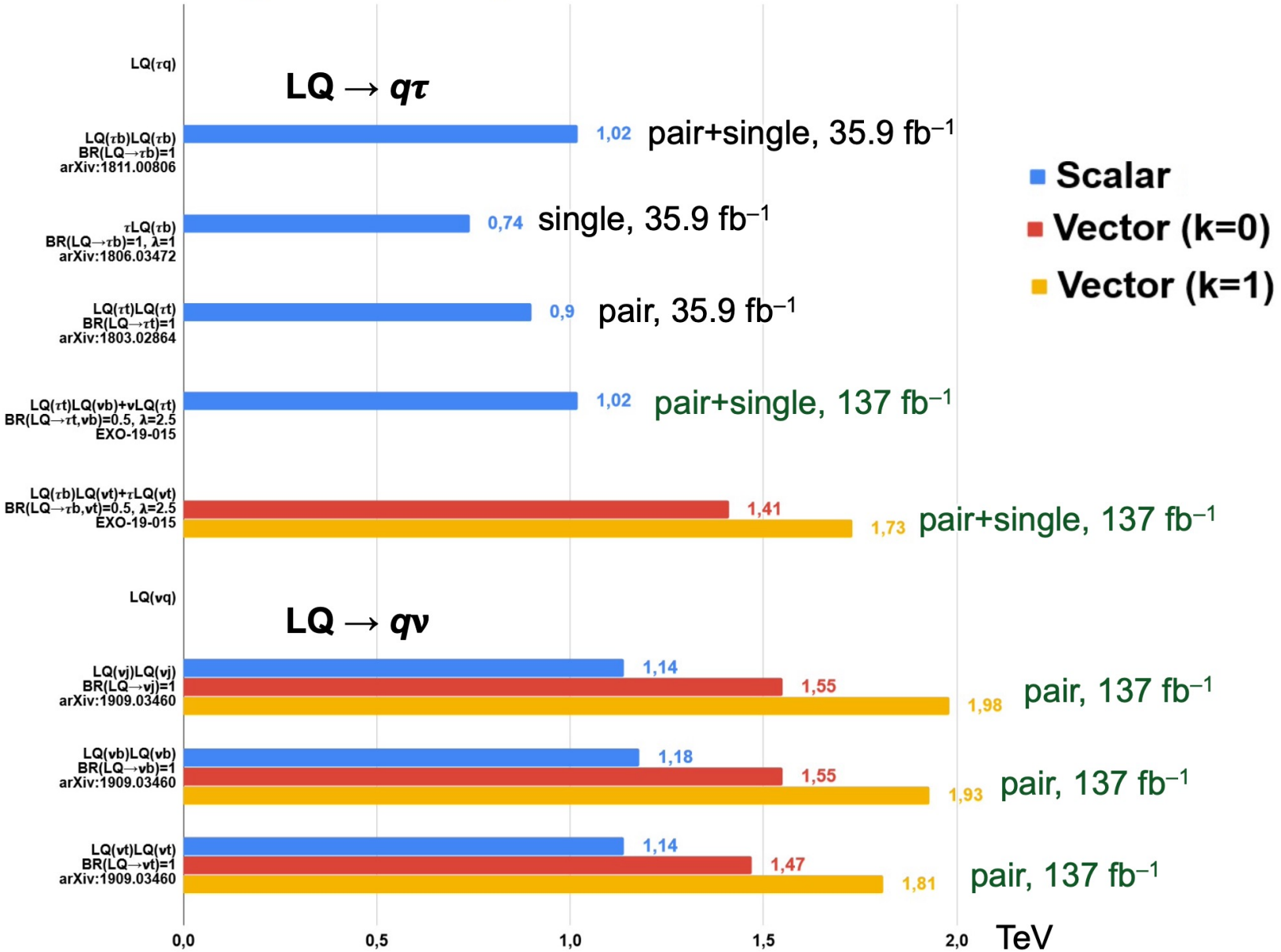
- Limits on the branching ratio of mixed-generation leptoquarks are shown as a function of its mass. For up and down-type
- Limits ranging from ~500 GeV to 1.6 TeV depending on the BR.





Thanks to F. Romeo

CMS LQ_3 summary



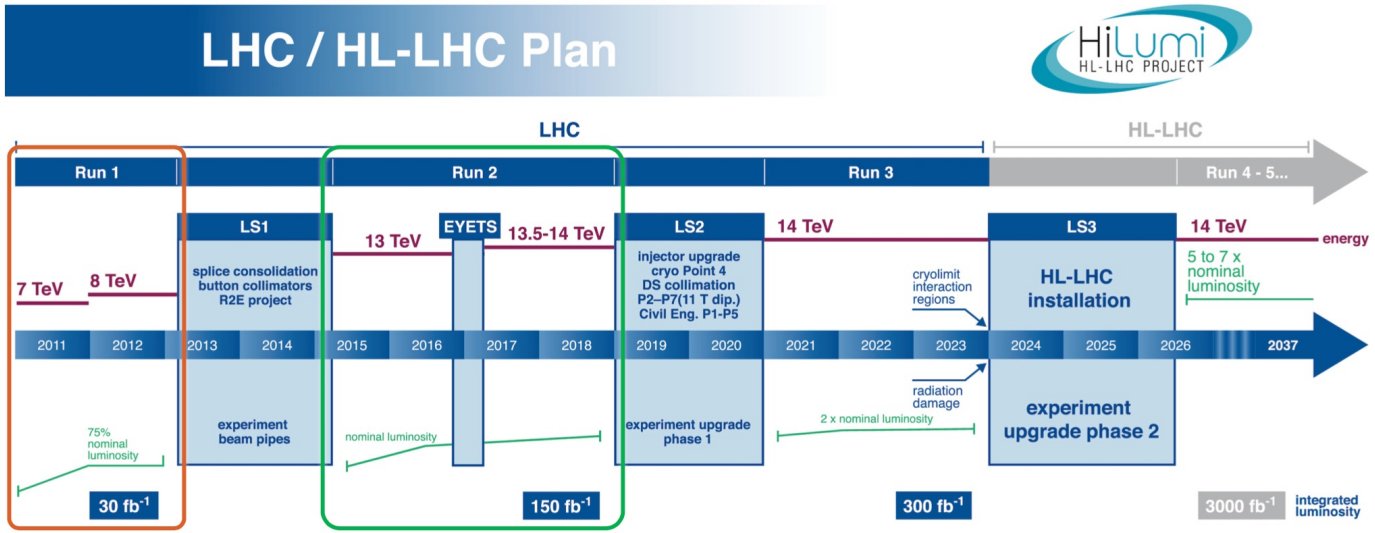
ATLAS LQ Summary

Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Limit		Reference
Scalar LQ 1st gen	2 e	≥2 j	Yes	139	LQ mass	1.8 TeV	$\beta = 1$	2006.05872
Scalar LQ 2nd gen	2 μ	≥2 j	Yes	139	LQ mass	1.7 TeV	$\beta = 1$	2006.05872
Scalar LQ 3rd gen	1 τ	2 b	Yes	139	LQ_3^u mass	1.2 TeV	$\mathcal{B}(LQ_3^u \to b\tau) = 1$	2108.07665
Scalar LQ 3rd gen	0 e, μ	≥2 j, ≥2 b	Yes	139	LQ_3^u mass	1.24 TeV	$\mathcal{B}(LQ_3^u \to t\nu) = 1$	2004.14060
Scalar LQ 3rd gen	≥2 e, μ, ≥1 τ	≥1 j, ≥1 b	–	139	LQ_3^d mass	1.43 TeV	$\mathcal{B}(LQ_3^d \to t\tau) = 1$	2101.11582
Scalar LQ 3rd gen	0 e, μ, ≥1 τ	0 – 2 j, 2 b	Yes	139	LQ_3^d mass	1.26 TeV	$\mathcal{B}(LQ_3^d \to b\nu) = 1$	2101.12527

Ref: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-033/fig_01.png

Summary

- We have presented some results produced by CMS & ATLAS Collaborations using Run 2 Data
- We have improved some limits
- Future studies may involve many more decay modes
- More fun with new incoming Data



References

- *CMS Public Results*
- *ATLAS Public Results*
- *The Leptoquark Hunter's Guide: Pair Production*
  https://arxiv.org/abs/1706.05033
- *The Leptoquark Hunter's Guide: Large Coupling* (single + *t*-channel)
  https://arxiv.org/abs/1810.10017
- *Leptoquark toolbox for precision collider studies*
  https://arxiv.org/abs/1801.07641
- *LQ searches at CMS (Ben Kilminster, ICHEP 2020)*
  https://indico.cern.ch/event/868940/