

Searches for Leptoquarks

In scenarios of LFU anomalies

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on behalf of the ATLAS and CMS collaborations

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**Universität
Zürich^{UZH}**

Flavor Anomalies

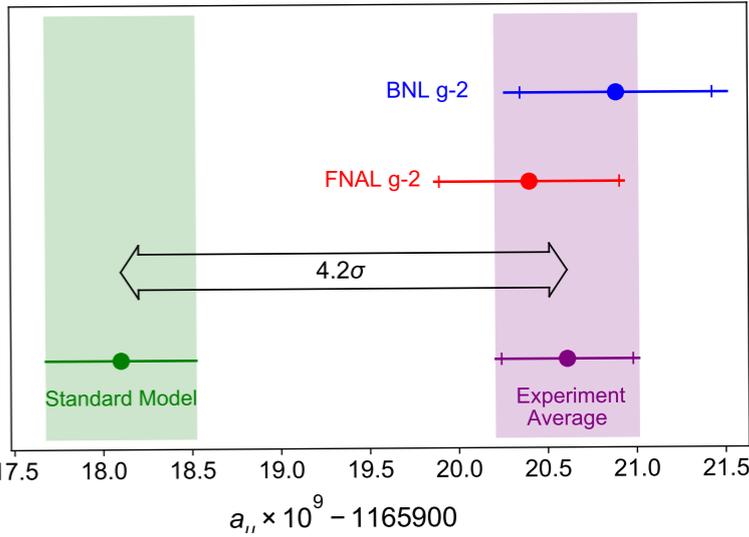
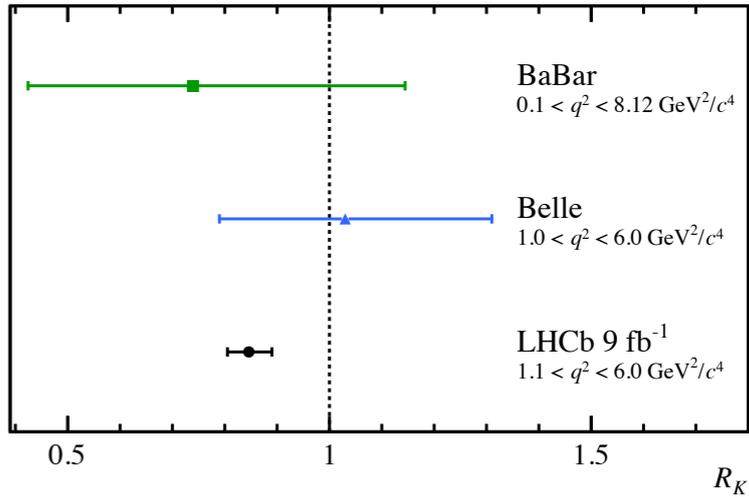
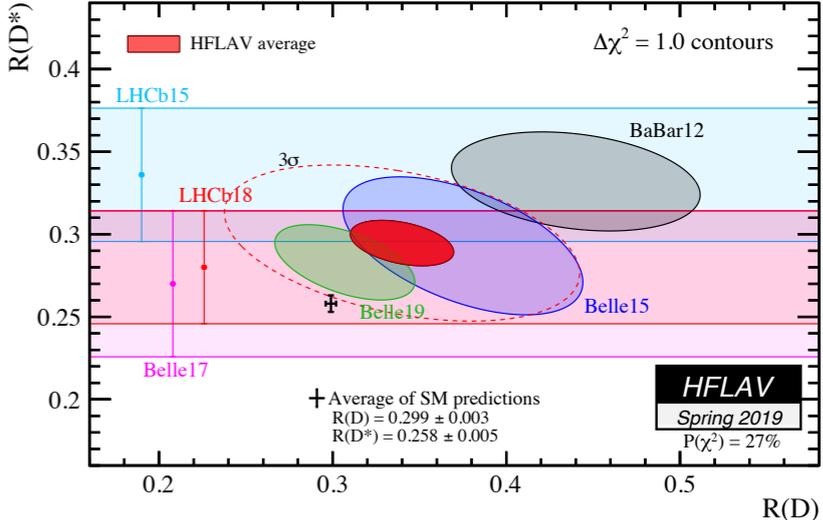
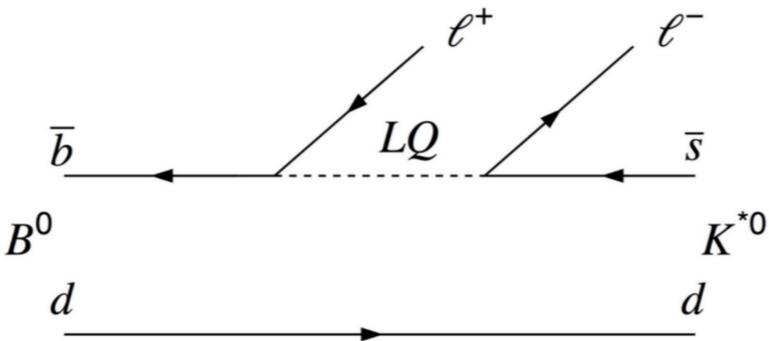
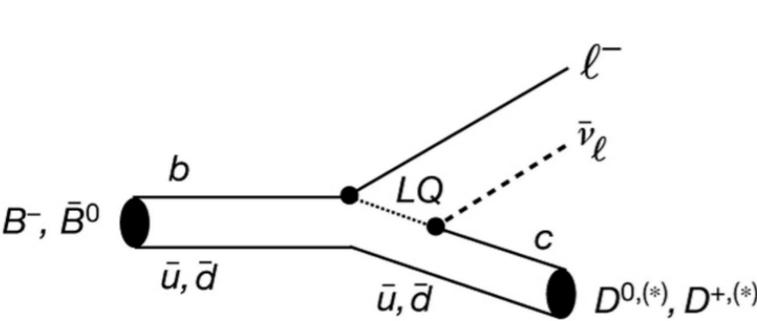
HFLAV: R(D)-R(D*)
 LHCb: arXiv:2103.11769
 Muon g-2: PRL 126, 141801 (2021)

- Recent hints for LFU violation

- $b \rightarrow c\ell\nu$ transitions (3.1σ)
- $b \rightarrow s\ell\ell$ transitions (3.1σ)
- $(g-2)_\mu$ (4.2σ)
- Even more

- Leptoquarks possible solution

- Mass at TeV scale
- Preferential couplings to 2nd/3rd generation
 - Weaker indirect bounds



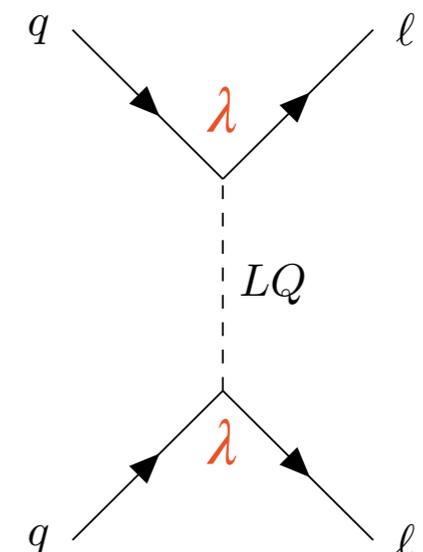
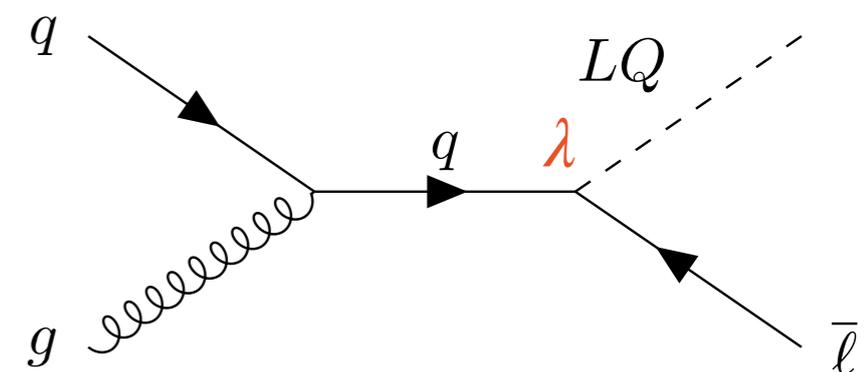
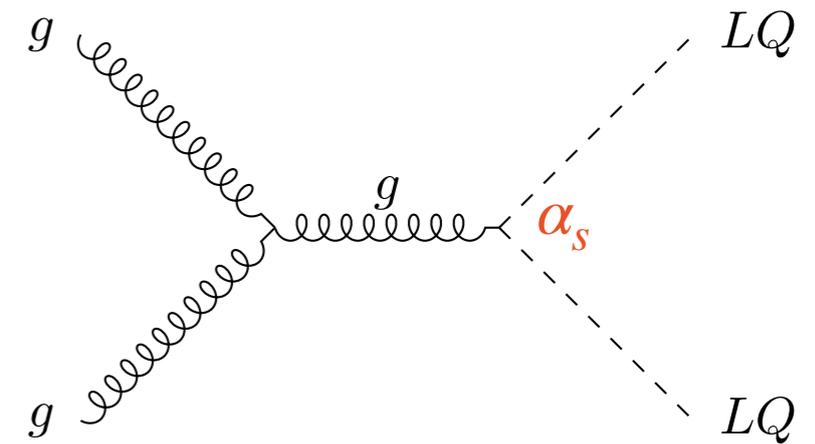
Leptoquarks

Properties

- New scalar or vector bosons
 - ▶ Need 1 vector or 2 scalar LQs to explain anomalies
- Simultaneous coupling to quark and lepton
- $\mathcal{B} = \text{BR}(\text{LQ} \rightarrow q\ell) = 1 - \text{BR}(\text{LQ} \rightarrow q\nu)$ free parameter

Production at the LHC

- Pair production via QCD
 - ▶ Depends only on M_{LQ}
- Single production
 - ▶ Depends on M_{LQ} and LQ $\rightarrow q\ell$ coupling λ
- Non-resonant processes
 - ▶ t-channel LQ
 - ▶ Also depend on M_{LQ} and λ



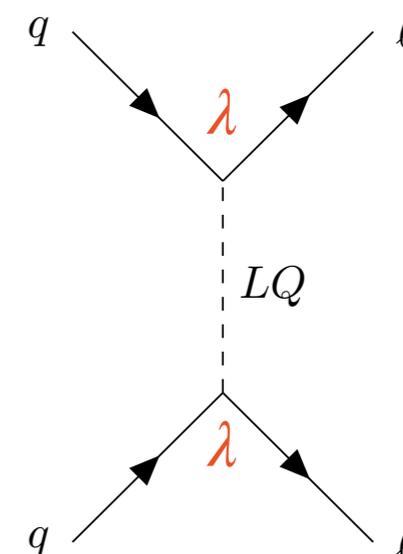
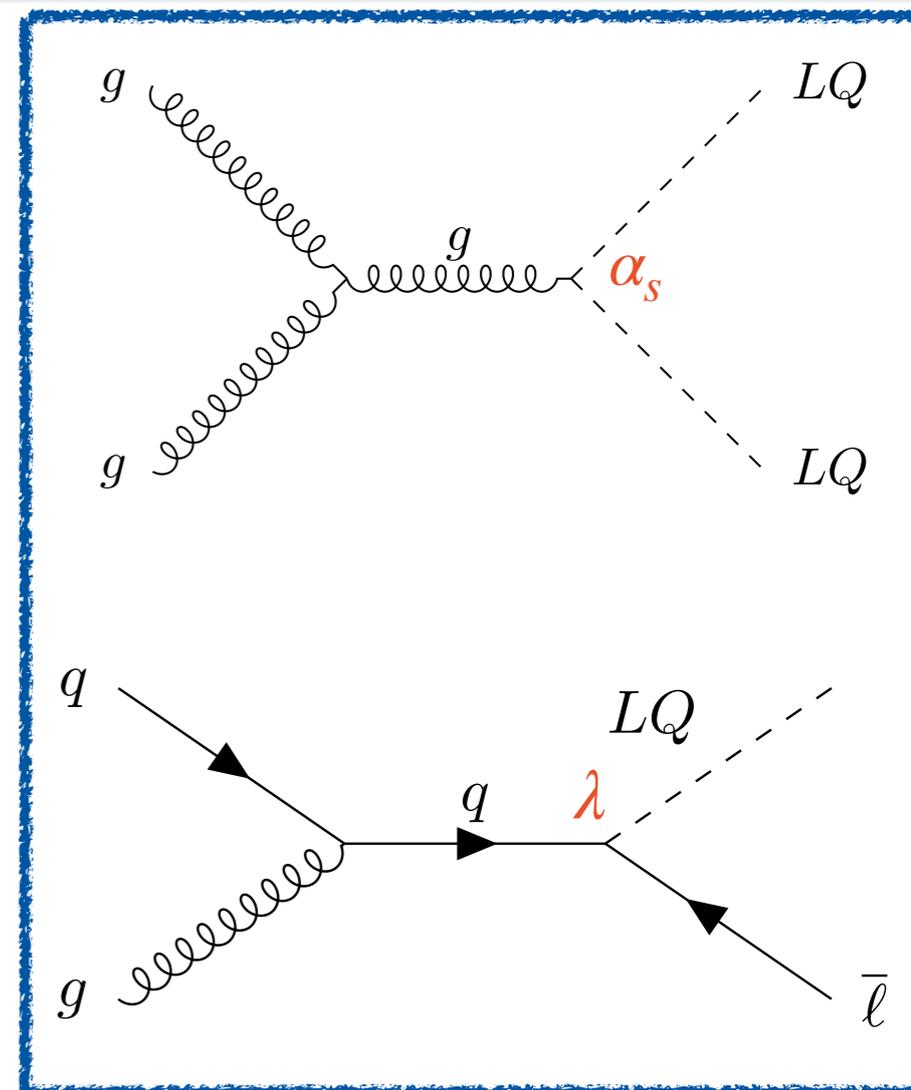
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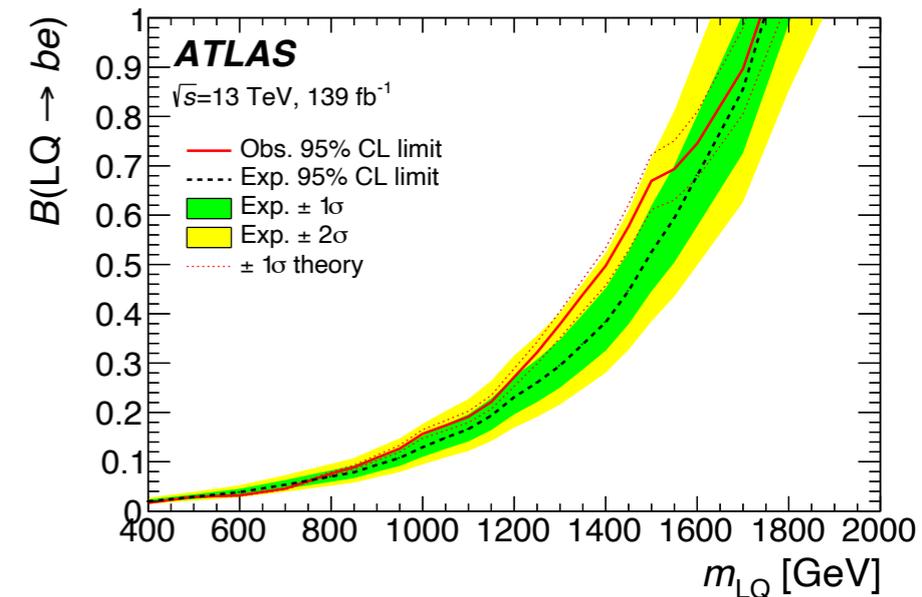
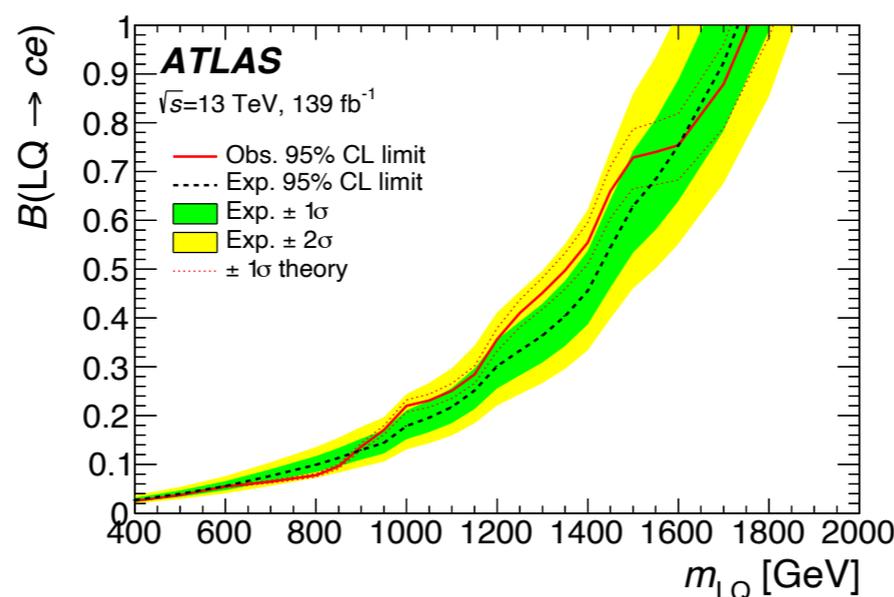
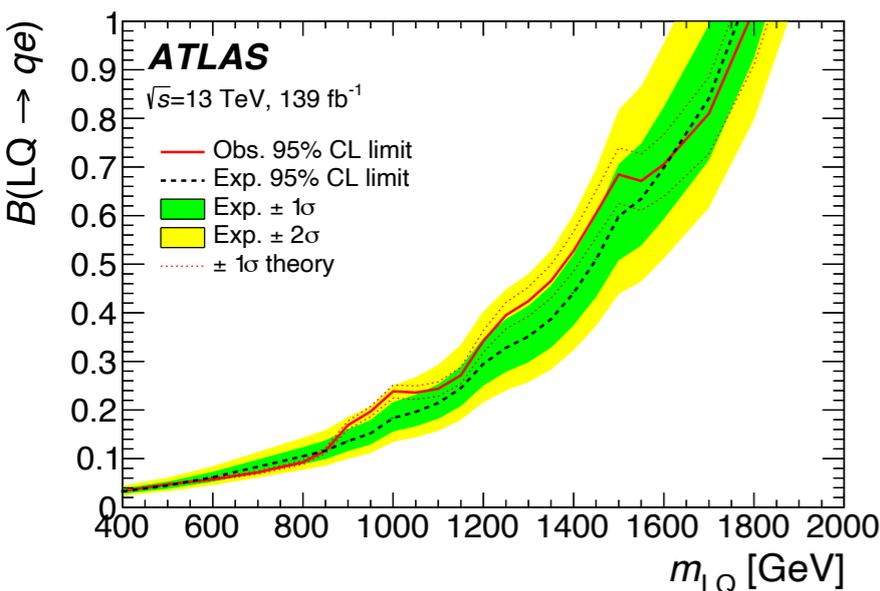
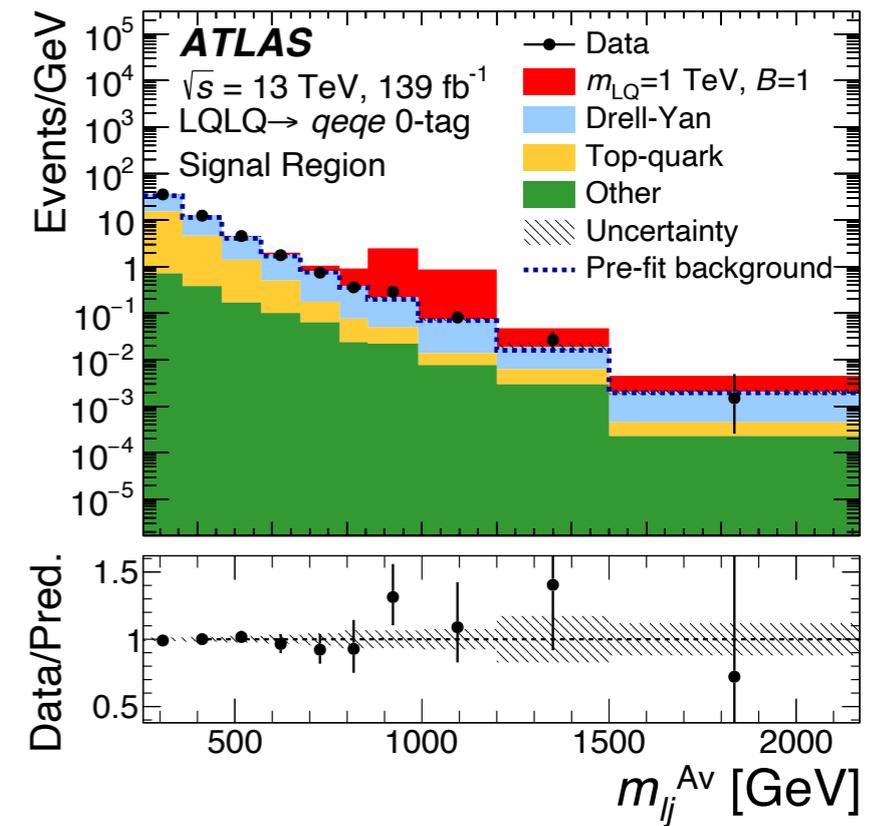
Coupling Overview

	q	b	t
ν			
e			
μ			
τ			

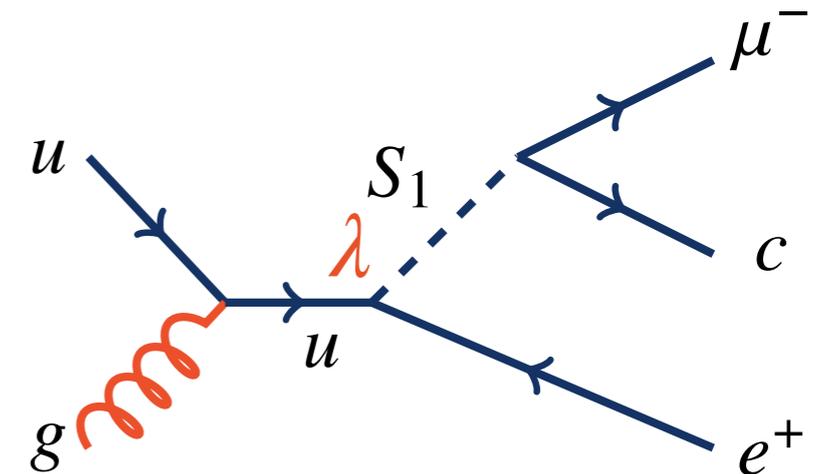
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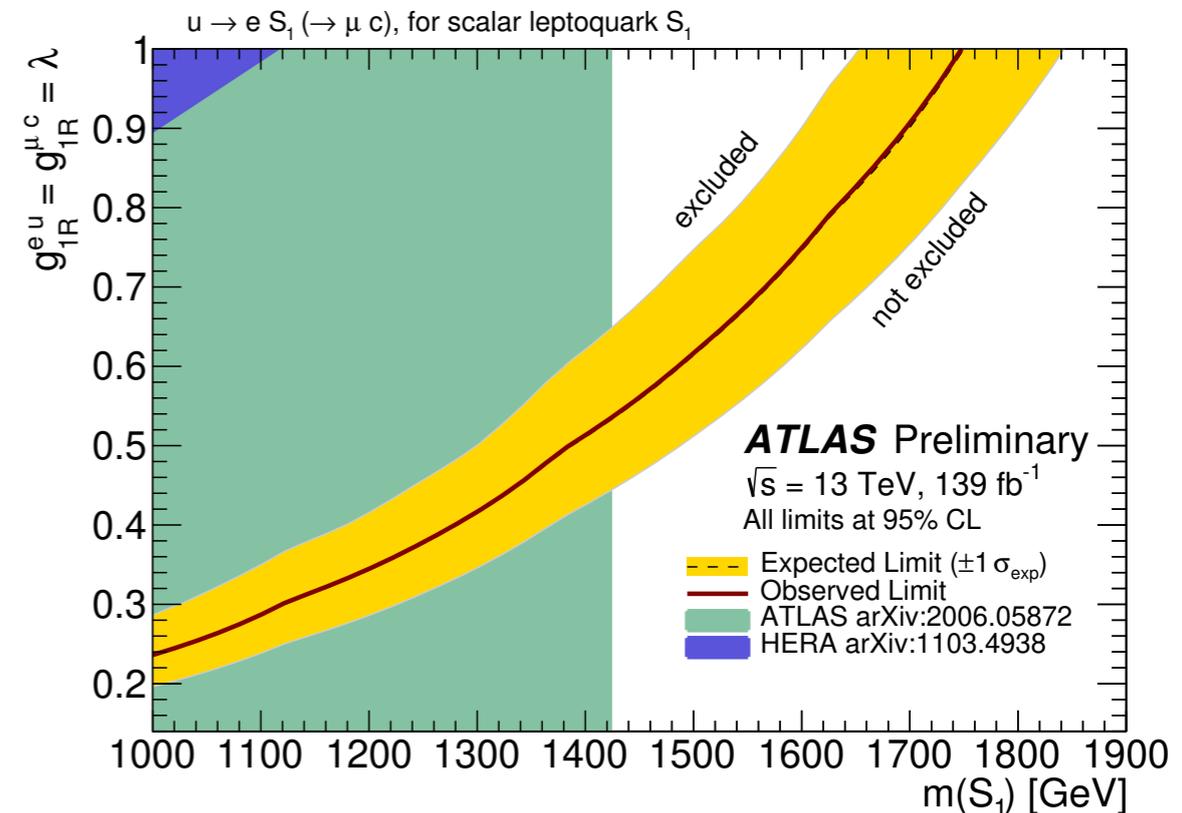
- ATLAS search using 2 e/μ and 2 jets
- Average ℓj invariant mass sensitive variable
- Categorisation using b- and c-tagging
- First time: optimised sensitivity to $b\ell$ and $c\ell$ couplings
- Scalar LQs below $M_{LQ} = 1.7$ TeV excluded in all channels ($\mathcal{B} = 1$) for $q\ell$ and $b\ell$
- Also consider varying \mathcal{B}
 - ▶ Exclude $M_{LQ} < 0.8$ TeV down to $\mathcal{B} = 0.1$



- ATLAS search for $e^+\mu^-$ and $e^-\mu^+$ asymmetry
- In SM pp collisions: $e^-\mu^+$ slightly favored
 - ▶ Single LQ with $q\ell$ couplings: enhances $e^+\mu^-$
- First single LQ result from ATLAS



- Single LQ production
 - ▶ Sensitive to LQ $\rightarrow q\ell$ coupling $\lambda \neq \mathcal{B}$
 - ▶ Exclusion limits depend on λ
 - ▶ Pair-production reach exceeded for $\lambda \geq 0.6$
 - ▶ $M_{LQ} < 1.74$ TeV excluded at $\lambda = 1$ (scalar)



Coupling Overview

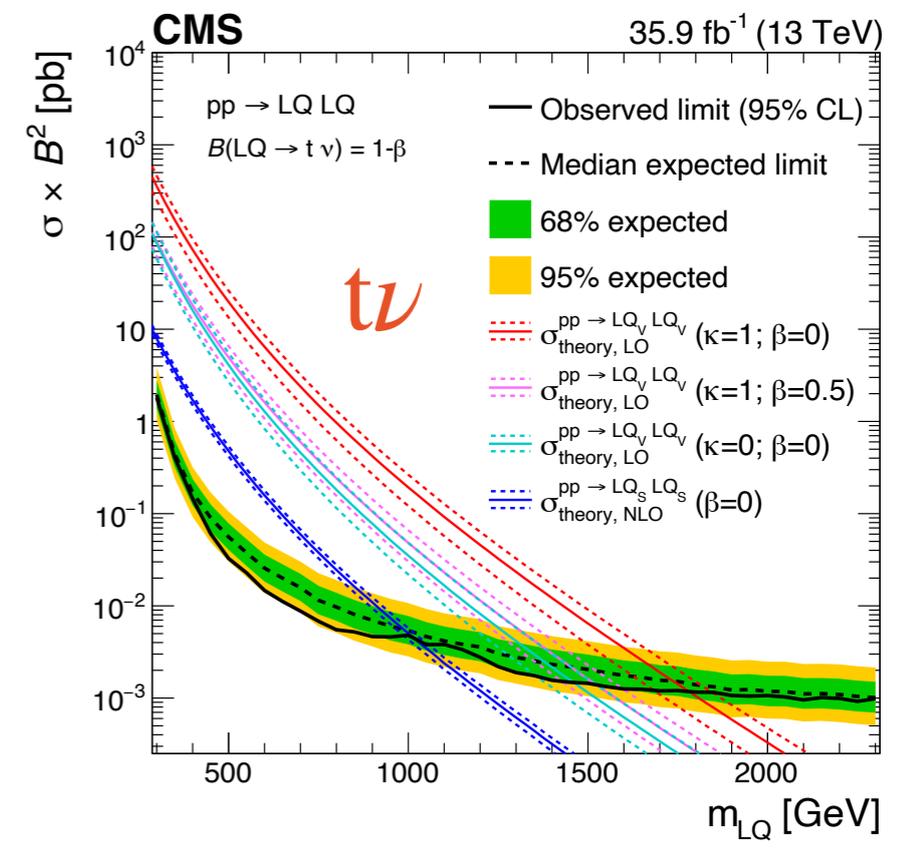
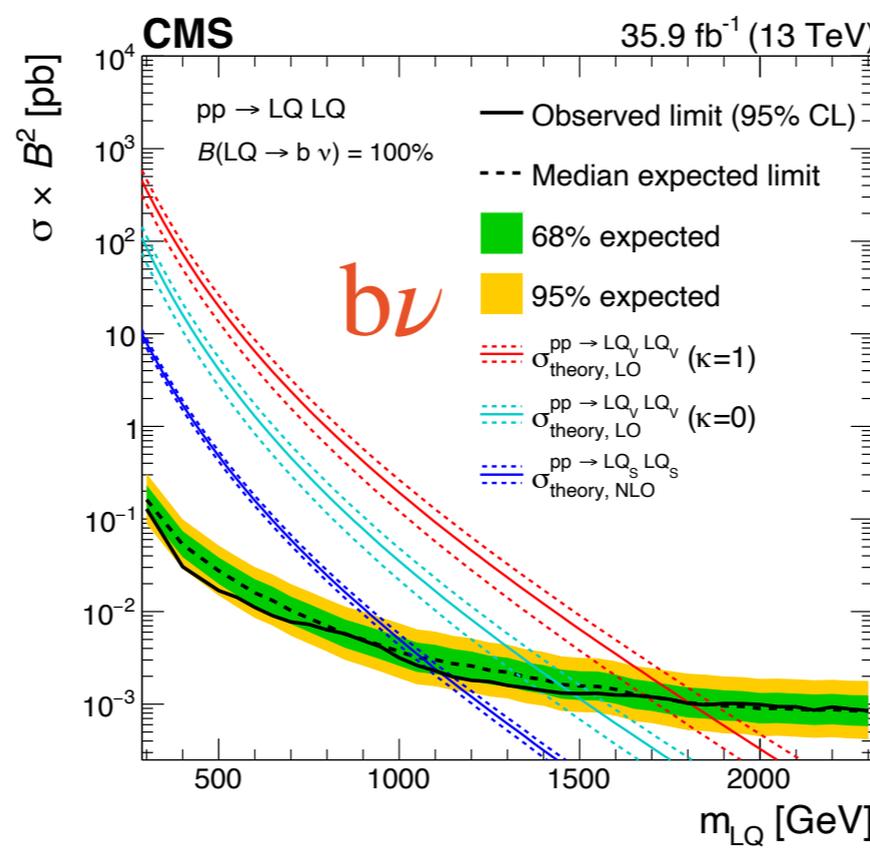
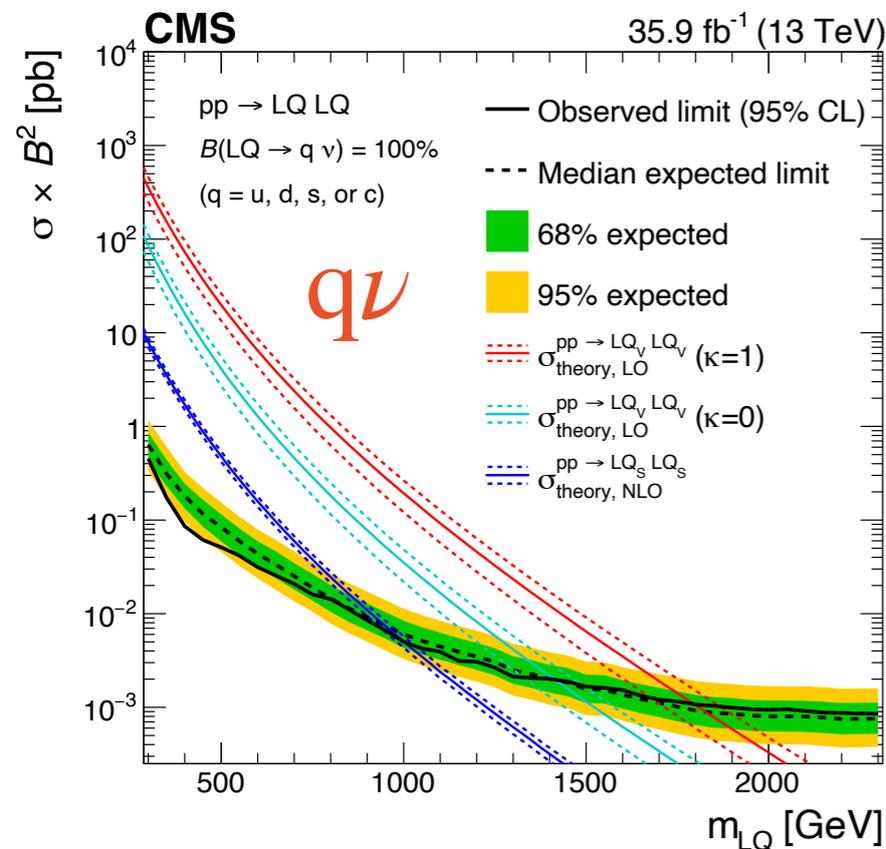
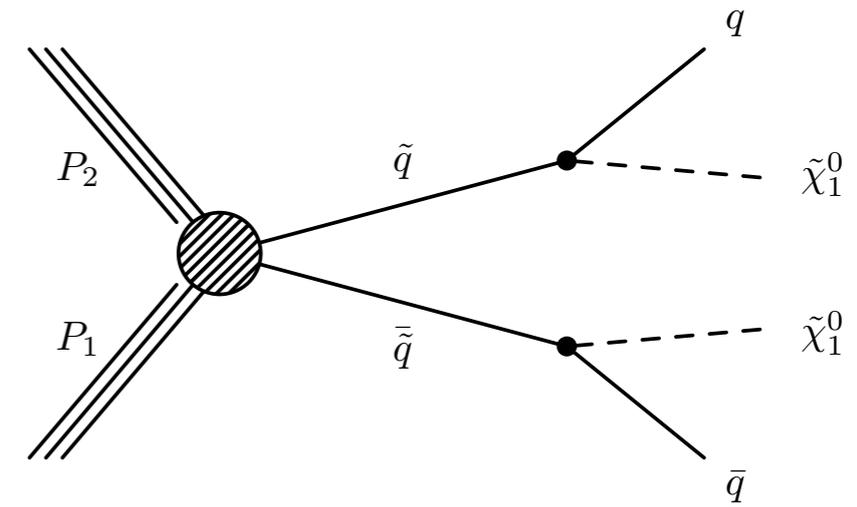
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ν			
e	✓	✓	
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LQ pair — $q\nu$ / $b\nu$ / $t\nu$

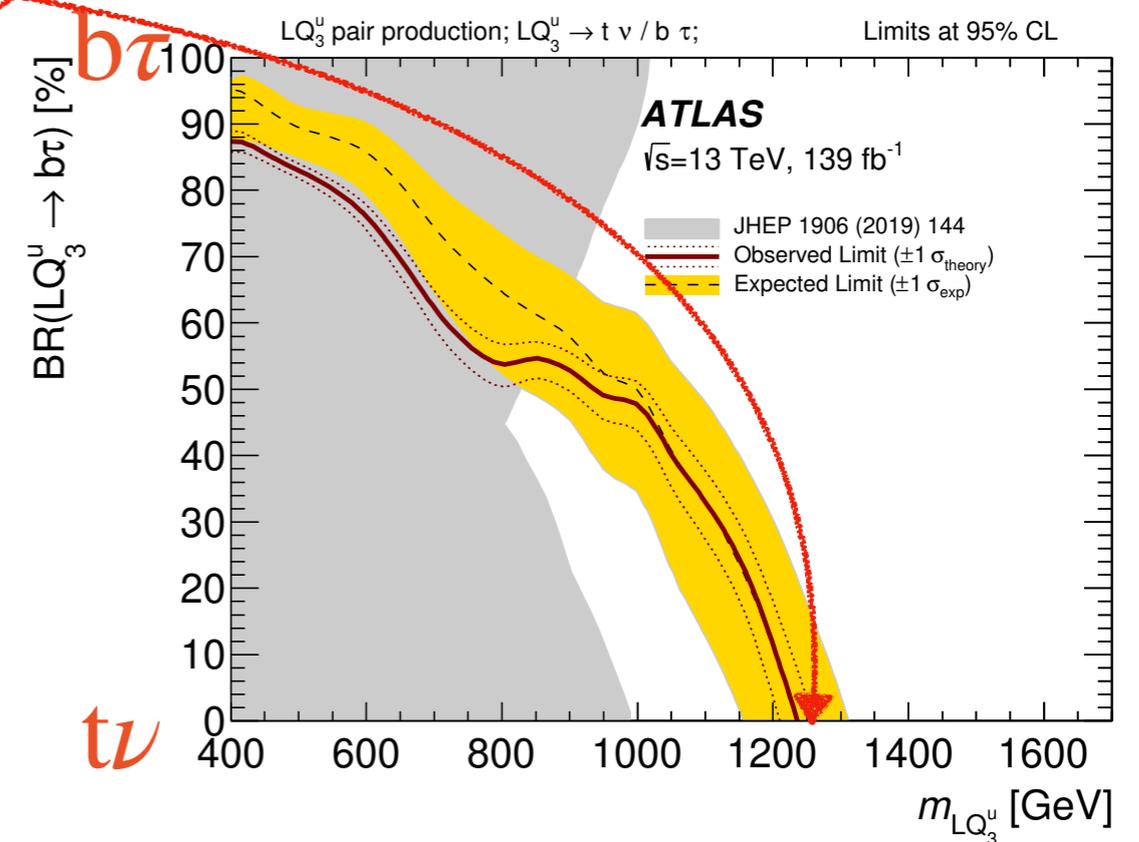
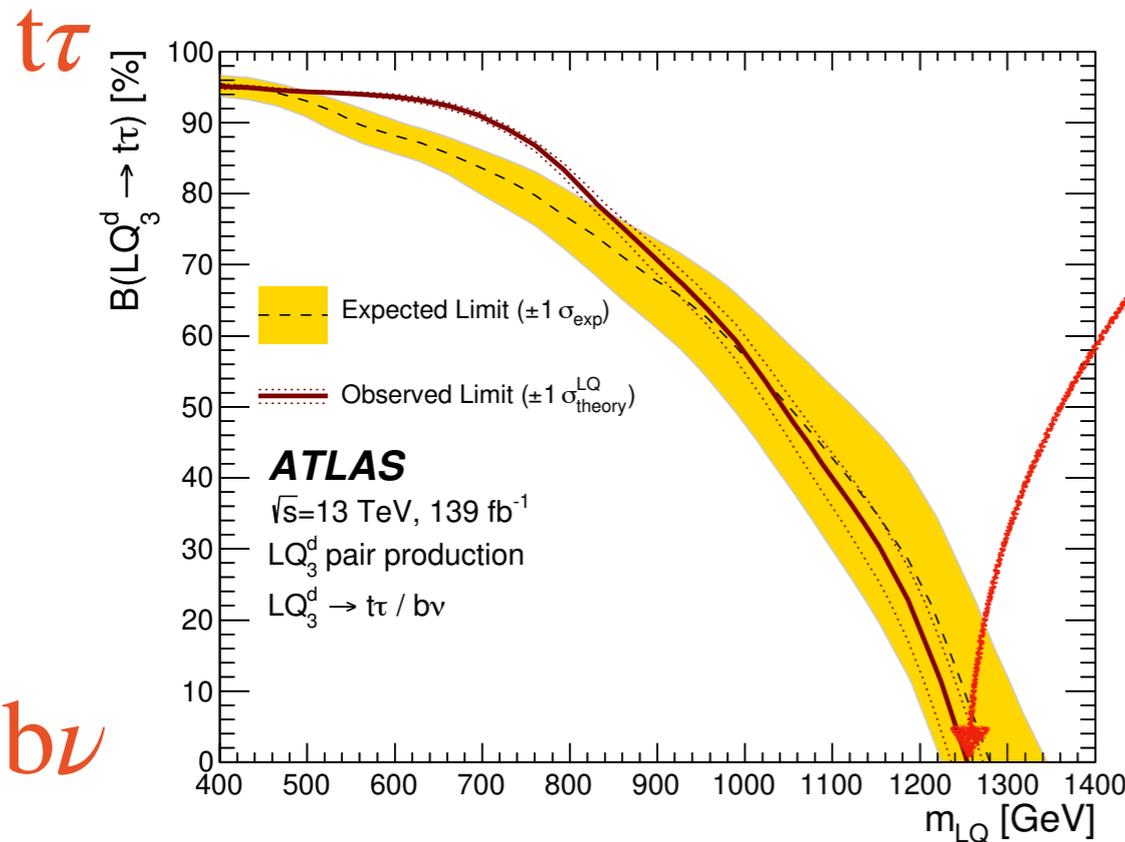
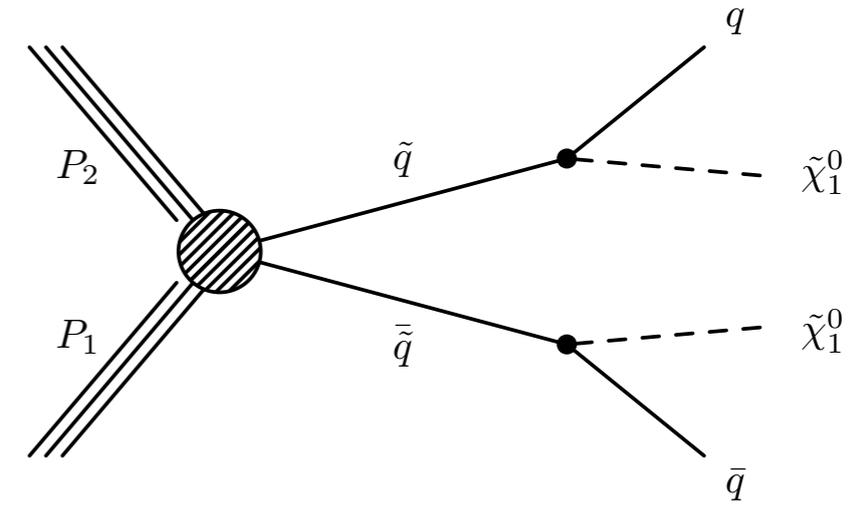
- SUSY searches for pair-produced squarks: $\tilde{q} \rightarrow q\tilde{\chi}$
 - ▶ For $M(\tilde{\chi}) \rightarrow 0$: Same final state as $LQ \rightarrow q\nu$
- Reinterpretation in LQ models
 - ▶ Signal acceptance similar
- CMS: Interpretation in scalar and vector scenarios
 - ▶ Excludes $M_{LQ} \lesssim 1$ TeV (scalar) and up to 1.8 TeV (vector) (35.9 fb^{-1})



LQ pair — $q\nu / b\nu / t\nu$

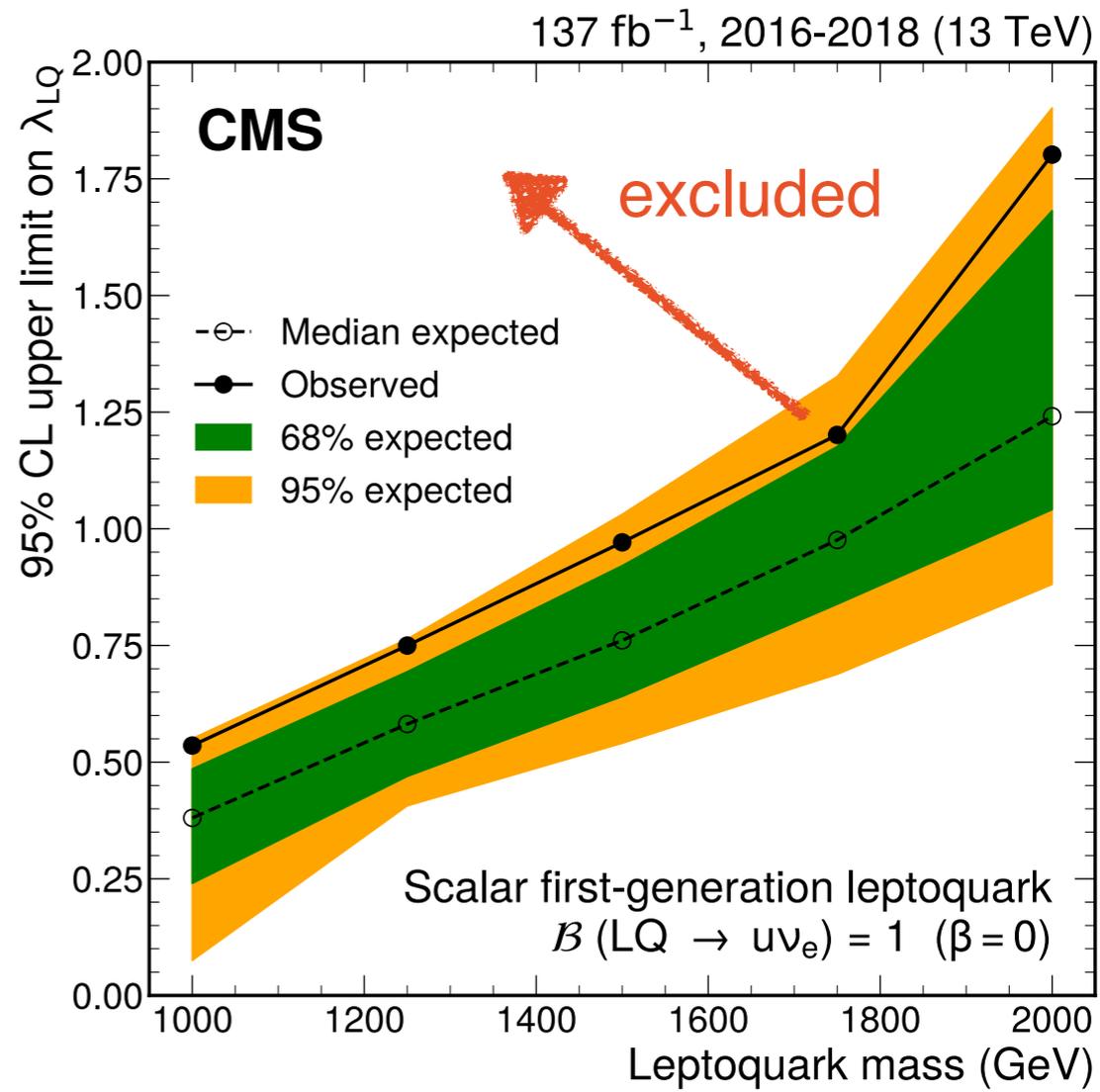
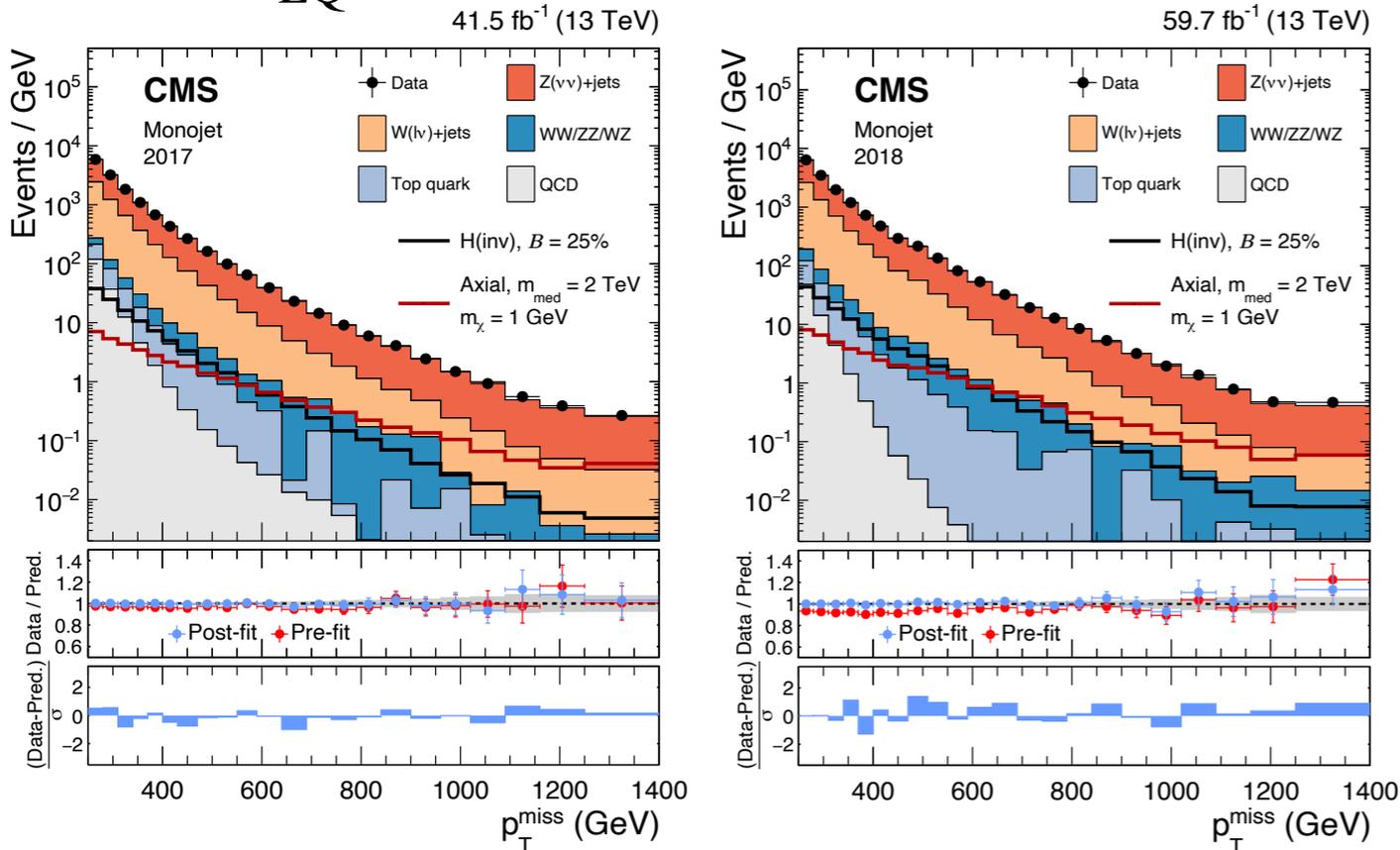
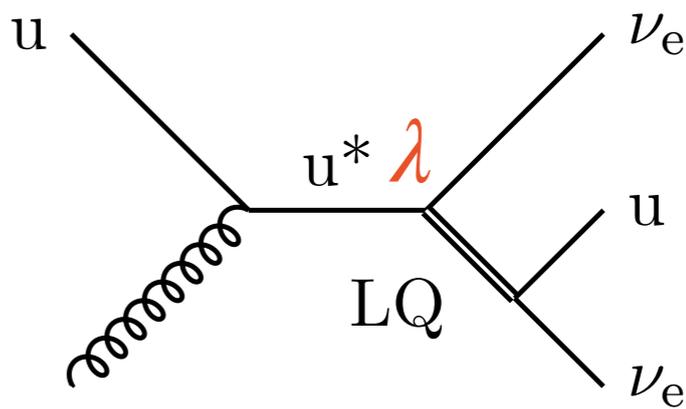
CMS: Phys. Rev. D 98, 032005 (2018)
 ATLAS: Eur. Phys. J. C 80 (2020) 737
 ATLAS: JHEP 05 (2021) 093

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- ATLAS considers varying \mathcal{B} : Excludes $M_{LQ} \lesssim 1.2$ TeV (scalar) at $\mathcal{B} = 0$ (139 fb^{-1})



Single + Pair LQ — $q\nu$

- CMS Mono-jet search
 - ▶ Signature of single LQ $\rightarrow q\nu$
 - ▶ Analysis also sensitive to LQ pair production
 - ▶ Search in p_T^{miss} spectrum
- Single LQ production
 - ▶ Sensitive to LQ $\rightarrow q\ell$ coupling $\lambda \neq \mathcal{B}$
 - ▶ $M_{\text{LQ}} \lesssim 1.50 \text{ TeV}$ excluded at $\lambda = 1$



Coupling Overview

	q	b	t
ν	✓	✓	✓
e	✓	✓	
μ	✓	✓	
τ			

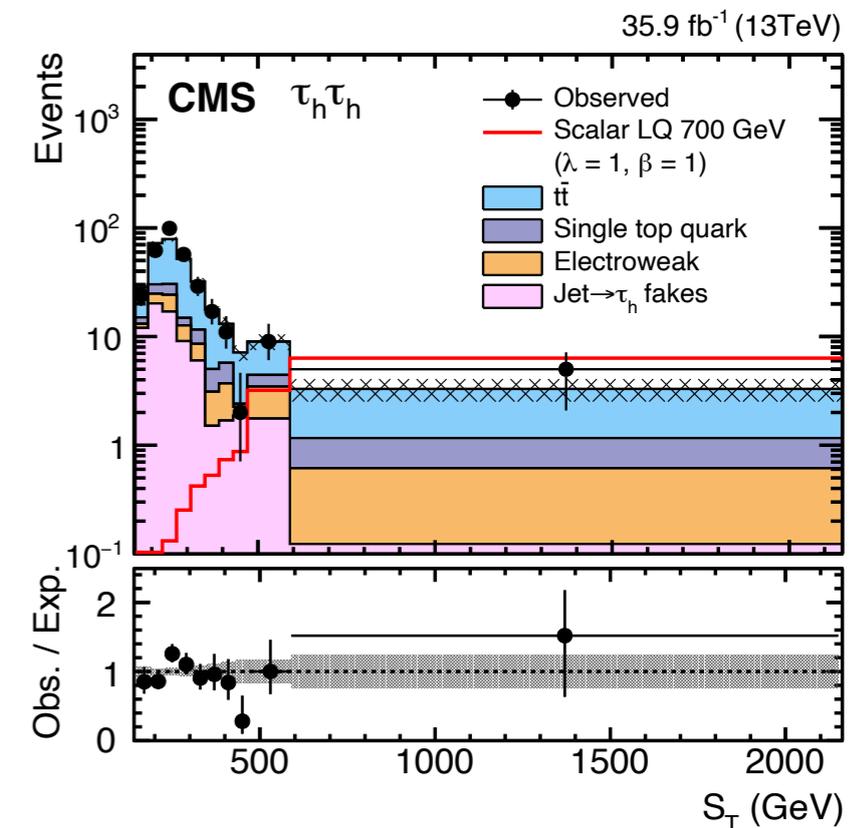
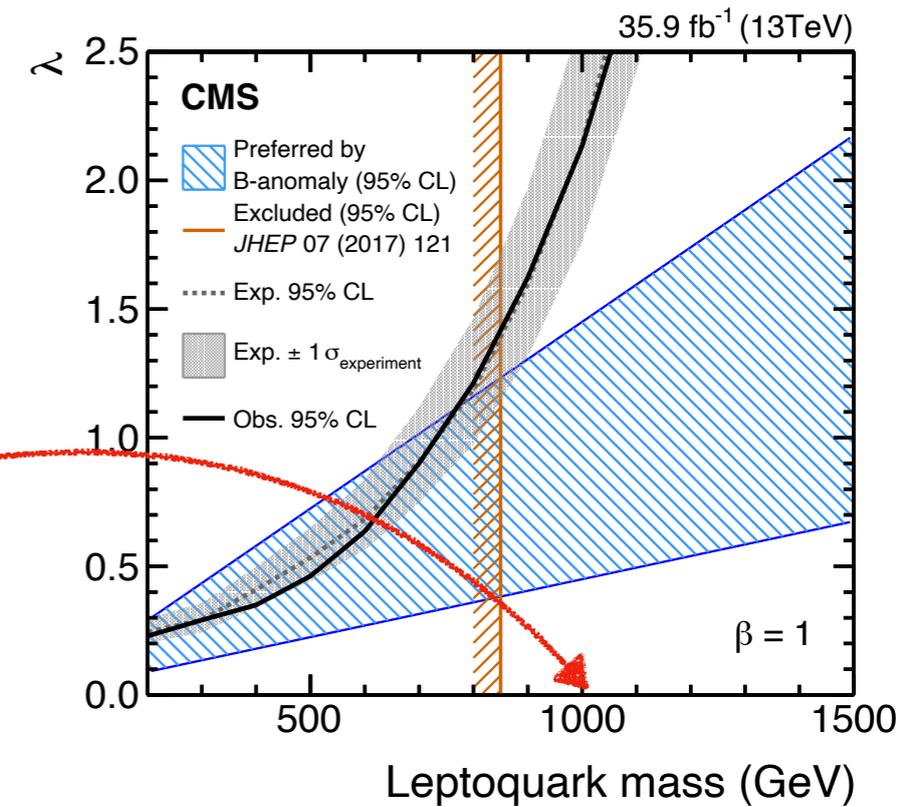
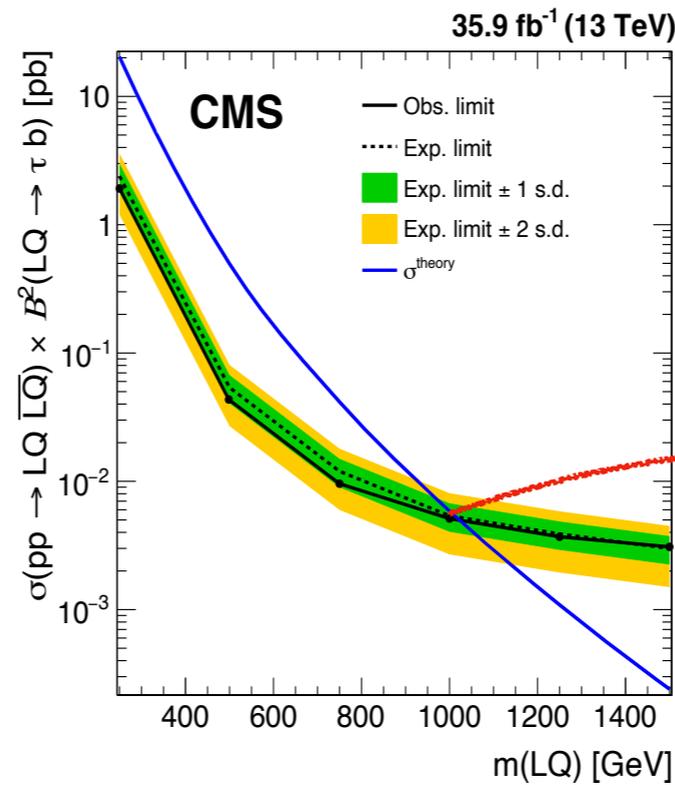
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LQ couplings to $b\tau \leftrightarrow t\nu$

- $LQ \rightarrow b\tau$ ($\mathcal{B} = 1$)

- ▶ CMS excludes $M_{LQ} \lesssim 1$ TeV (scalar LQ pair)
- ▶ CMS probes highest λ (scalar single LQ)



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CMS: JHEP 03 (2019) 170
 CMS: JHEP 07 (2018) 115
 CMS: Phys. Lett. B 819 (2021) 136446

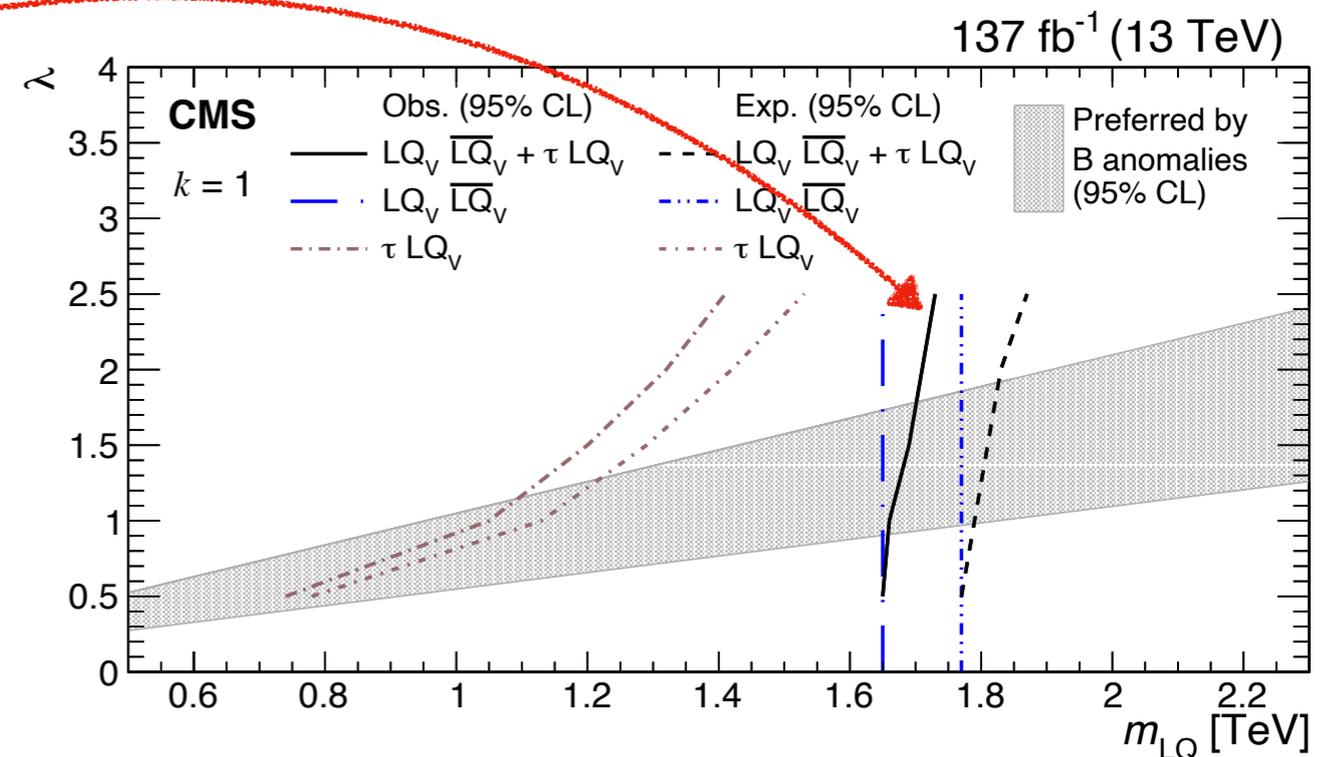
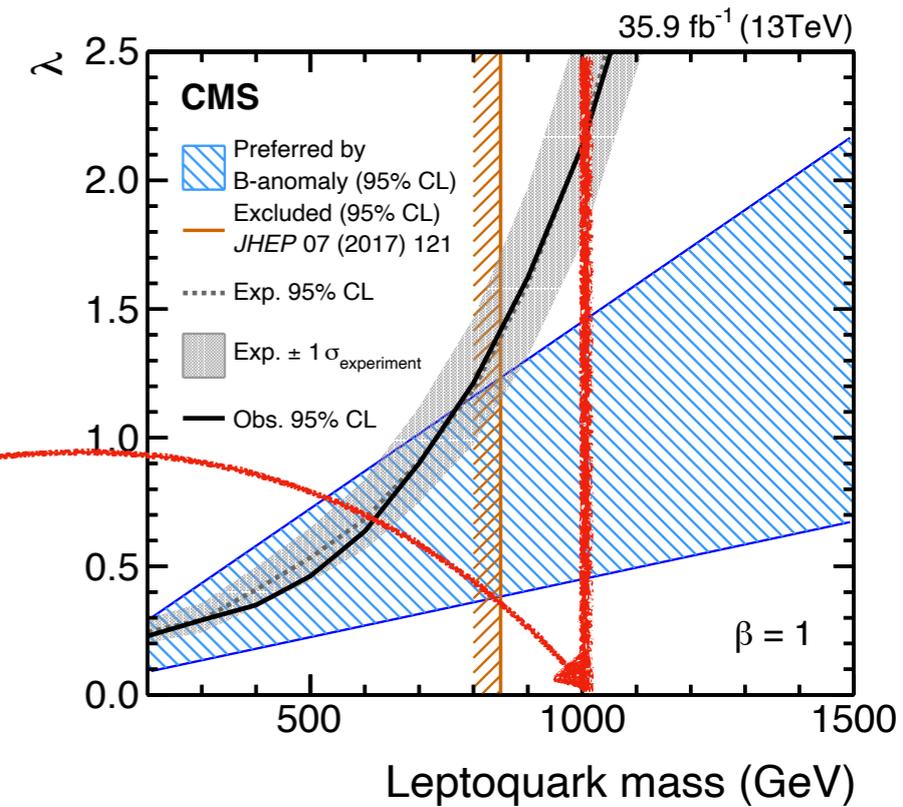
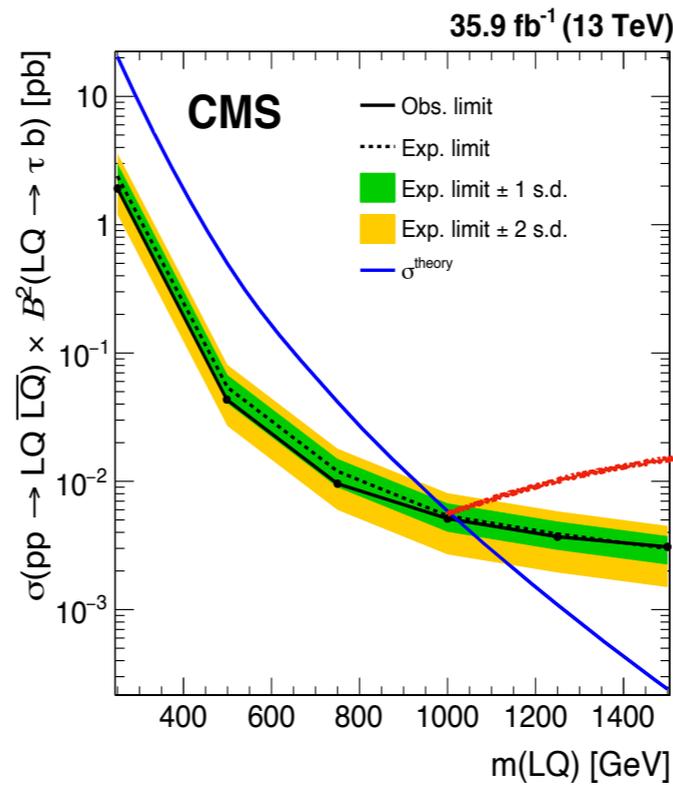
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- $LQ \rightarrow t\nu / b\tau$ ($\mathcal{B} = 0.5$)

- ▶ CMS excludes $M_{LQ} \lesssim 1.65$ TeV (vector LQ pair + single)

- Limits vs. λ improve by combination with single LQ



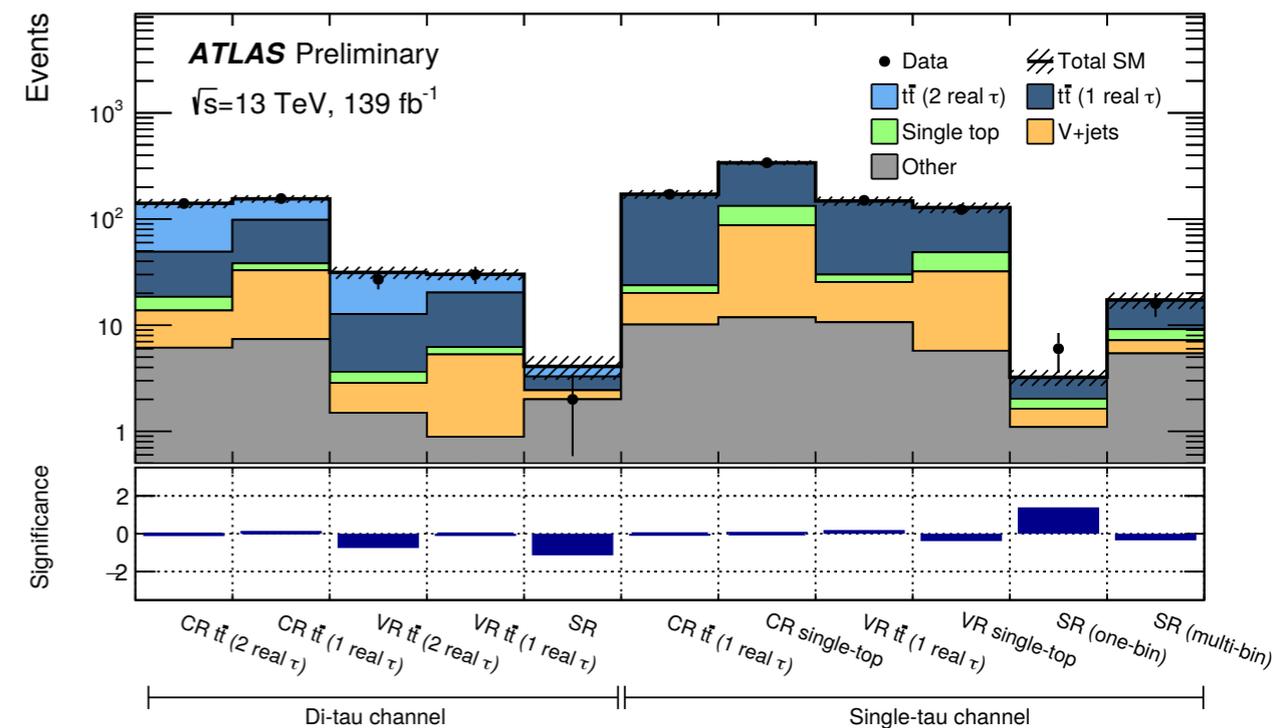
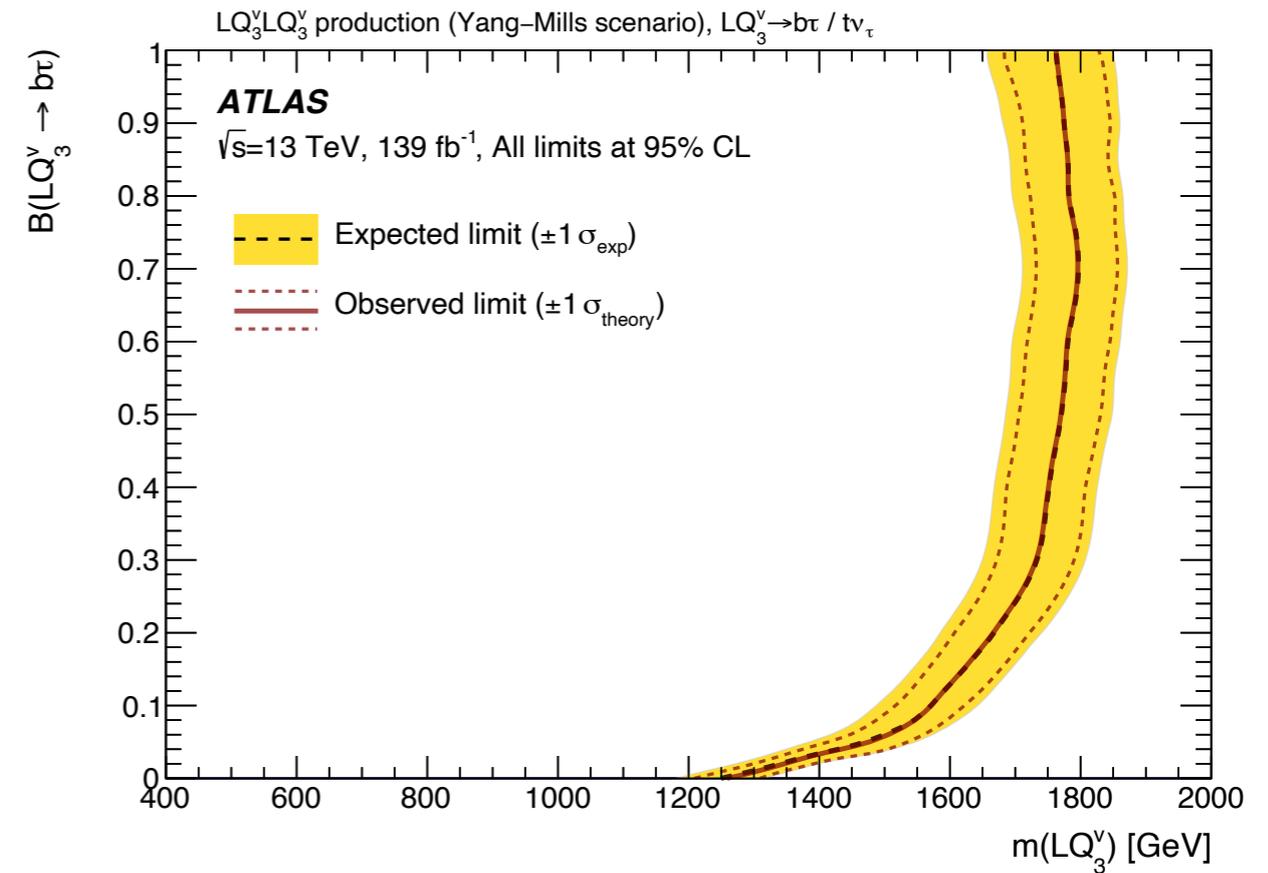
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- ▶ CMS excludes $M_{LQ} \lesssim 1.65$ TeV (vector LQ pair + single)
 - Limits vs. λ improve by combination with single LQ
- ▶ ATLAS excludes $M_{LQ} \lesssim 1.25 - 1.8$ TeV (scalar + vector LQ pair)



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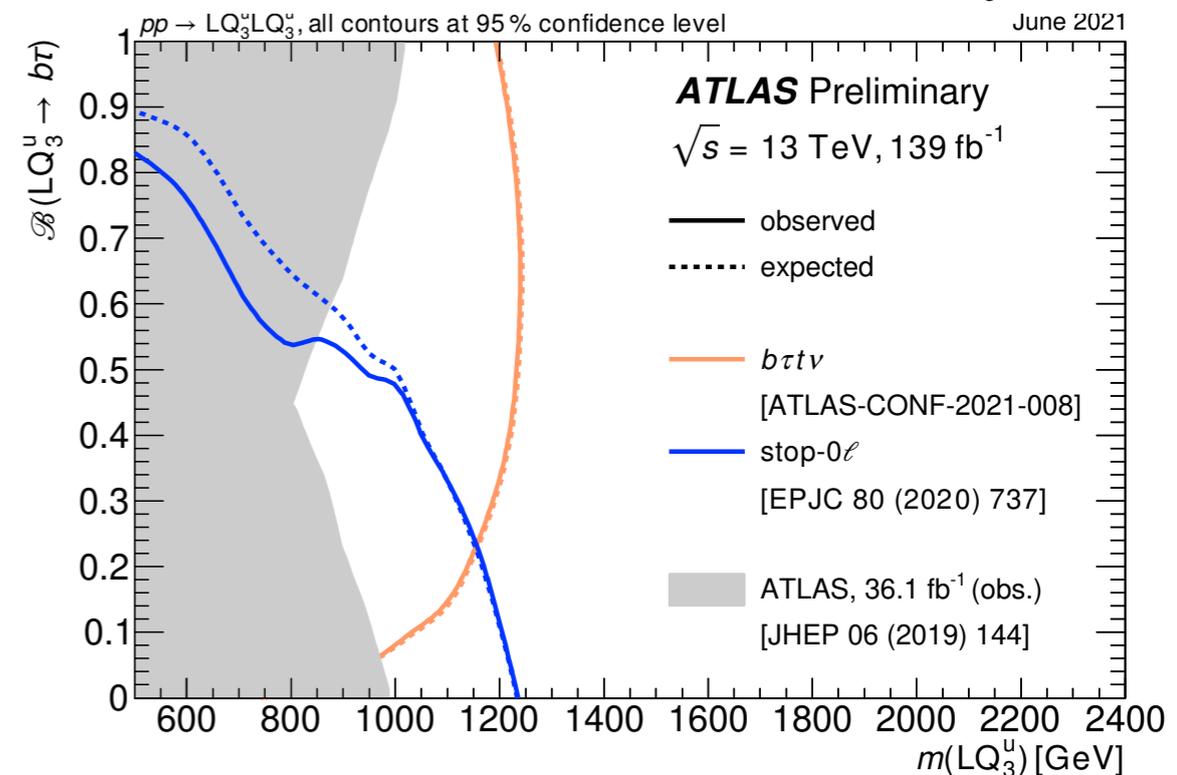
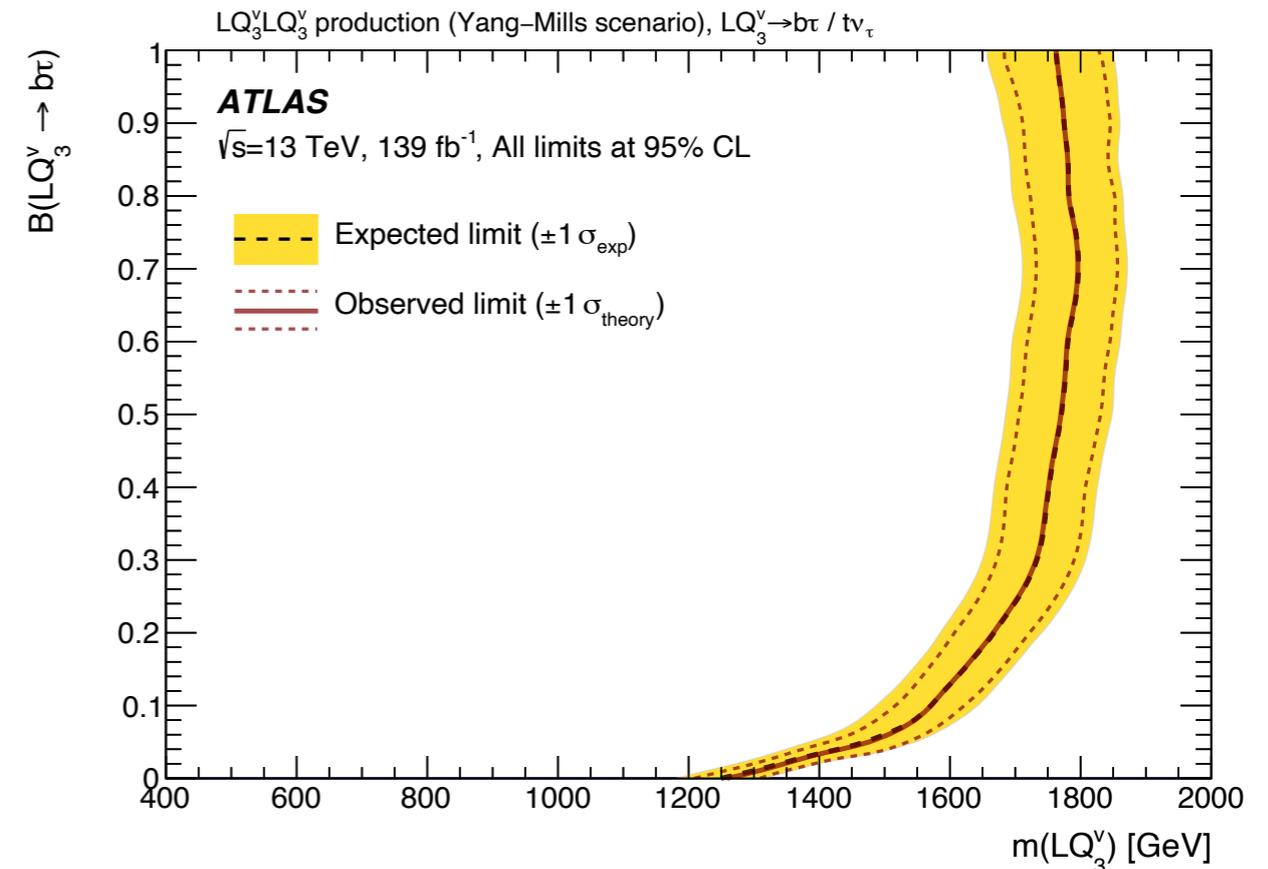
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- Combination with $LQ \rightarrow t\nu$ ($\mathcal{B} = 0$)

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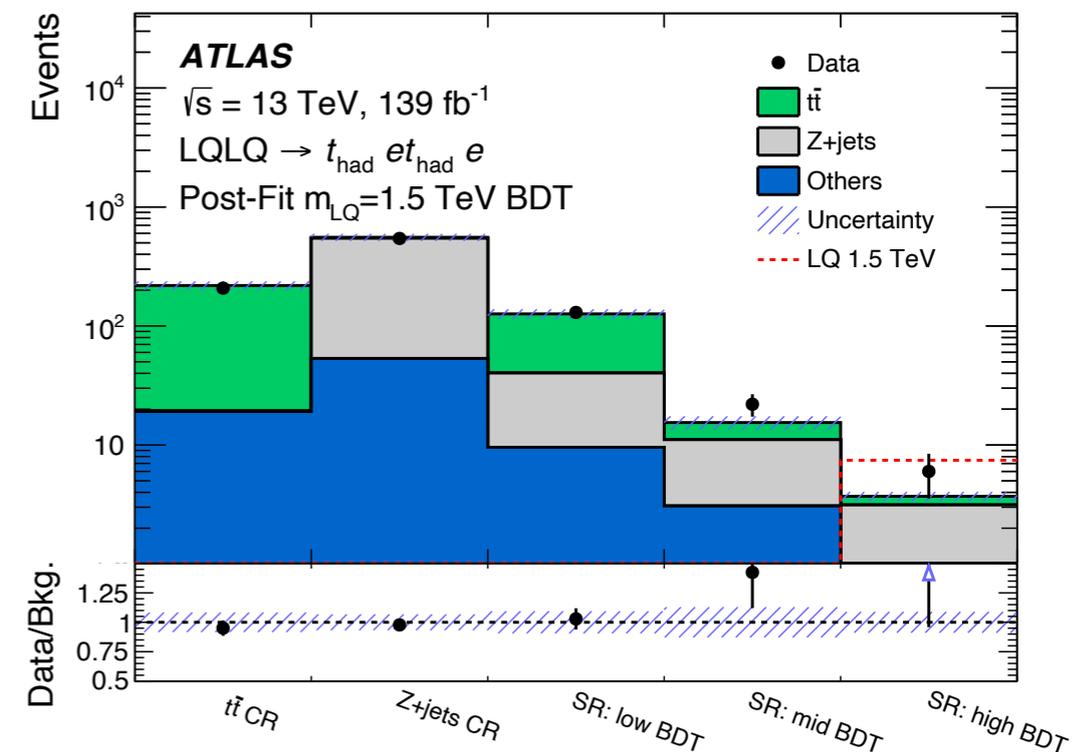
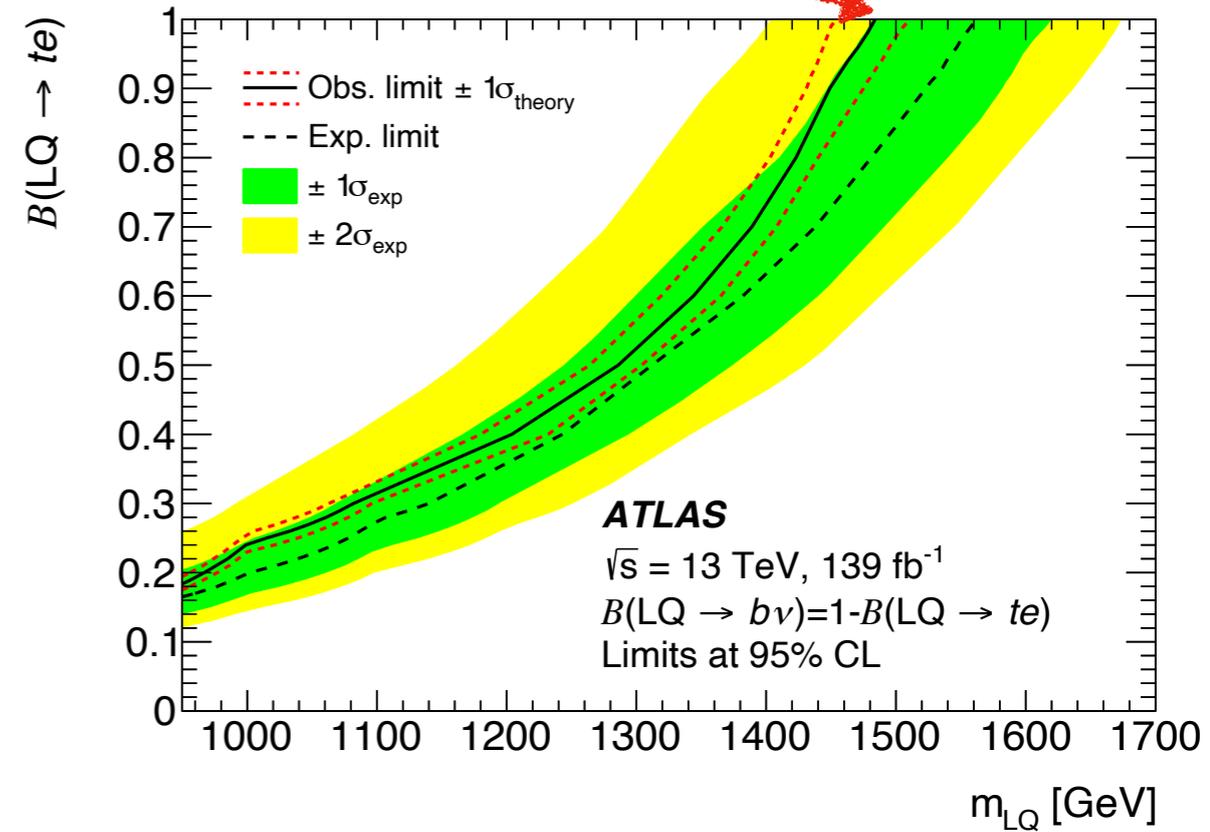
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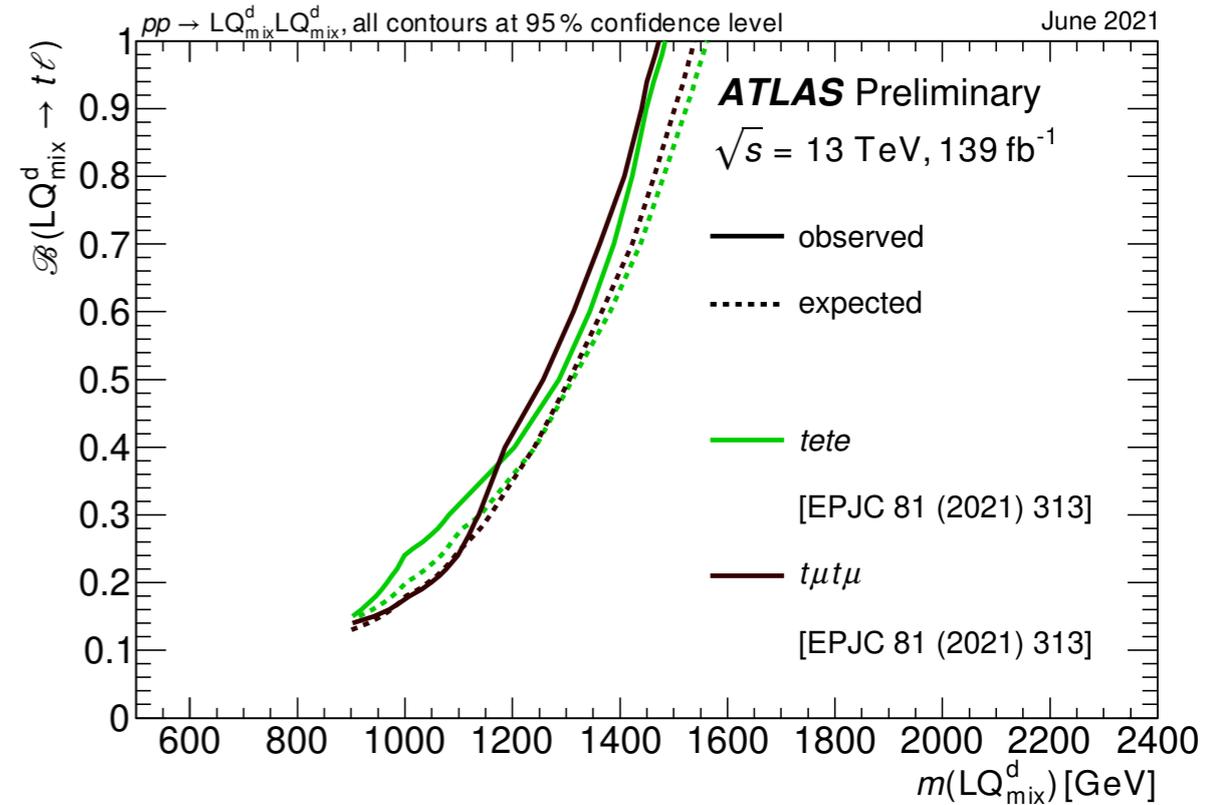
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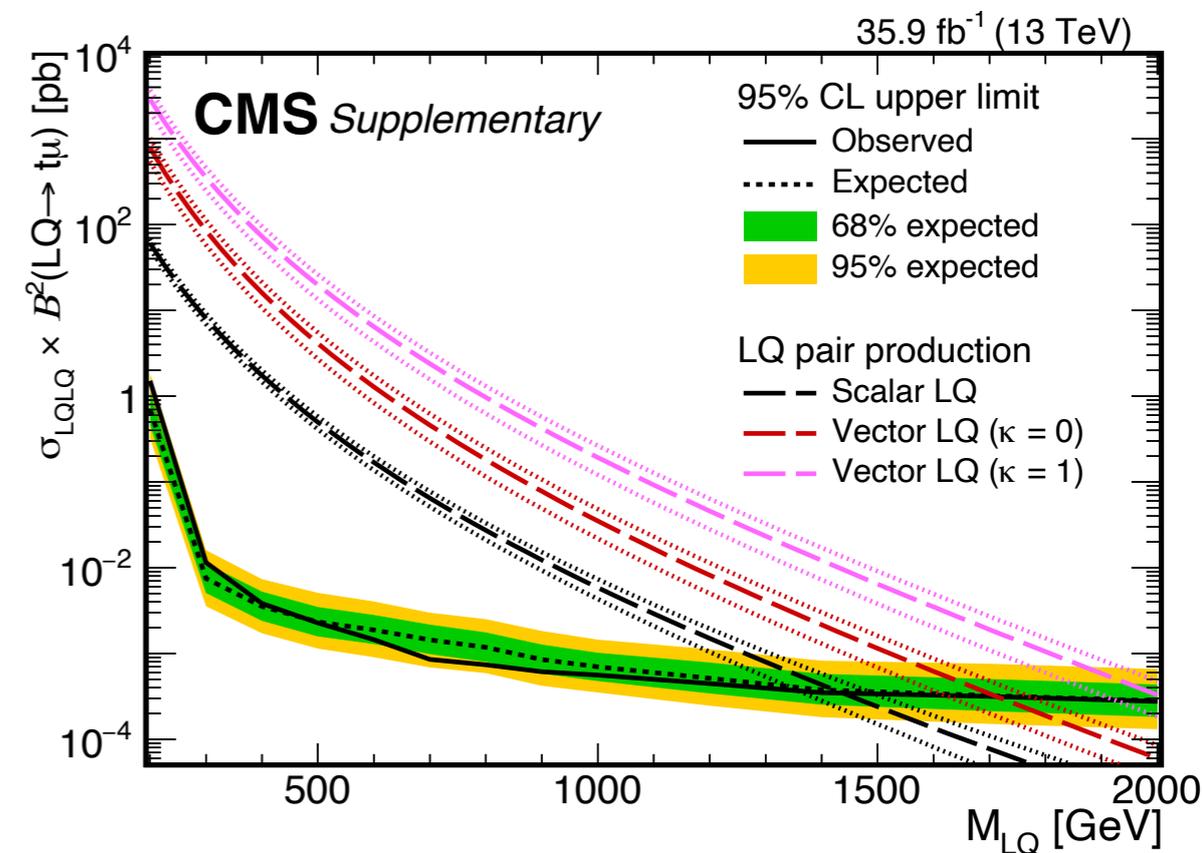
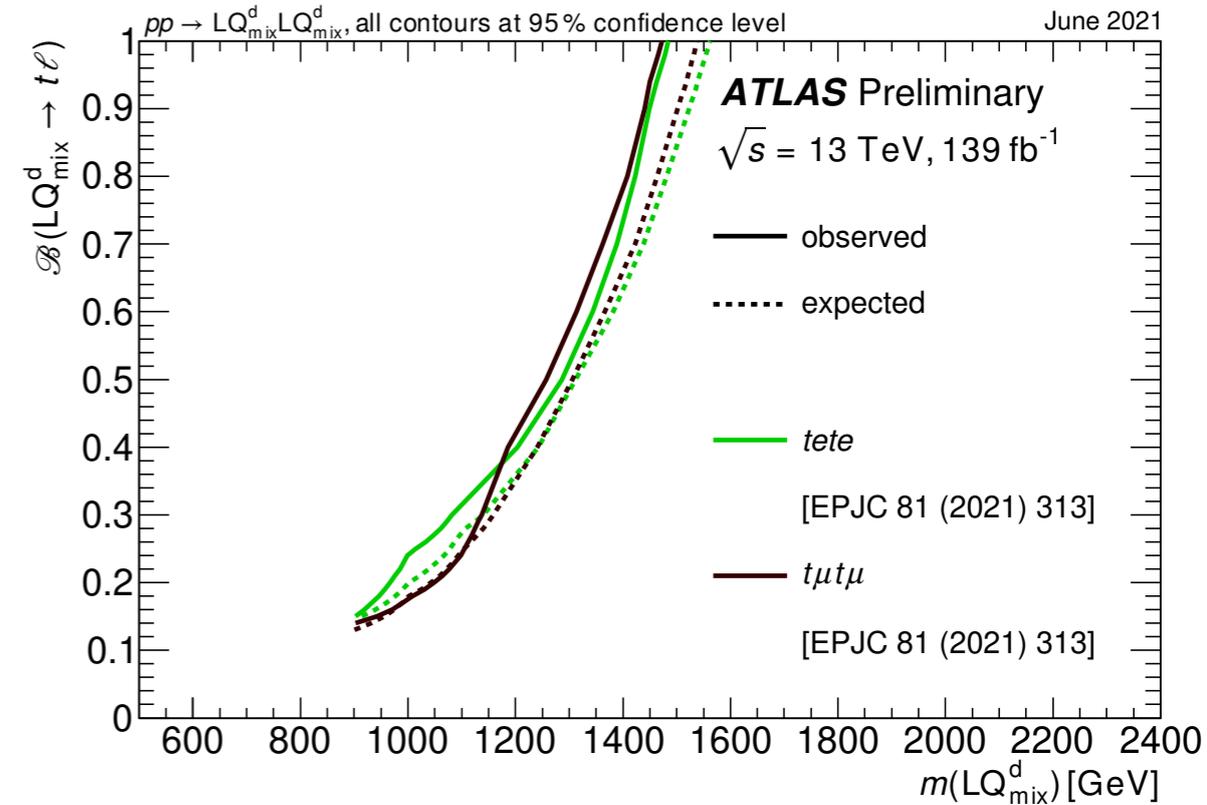
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ATLAS: Eur. Phys. J. C 81 (2021) 313

ATLAS: Summary

CMS: PRL 121, 241802 (2018)

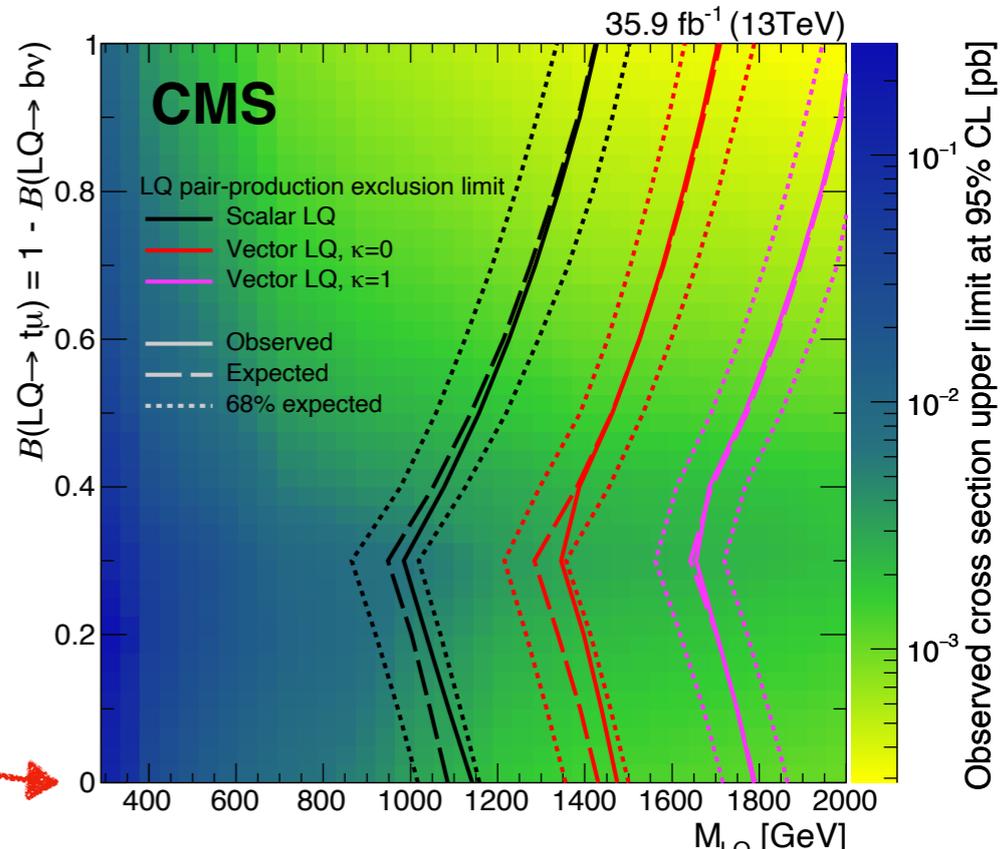
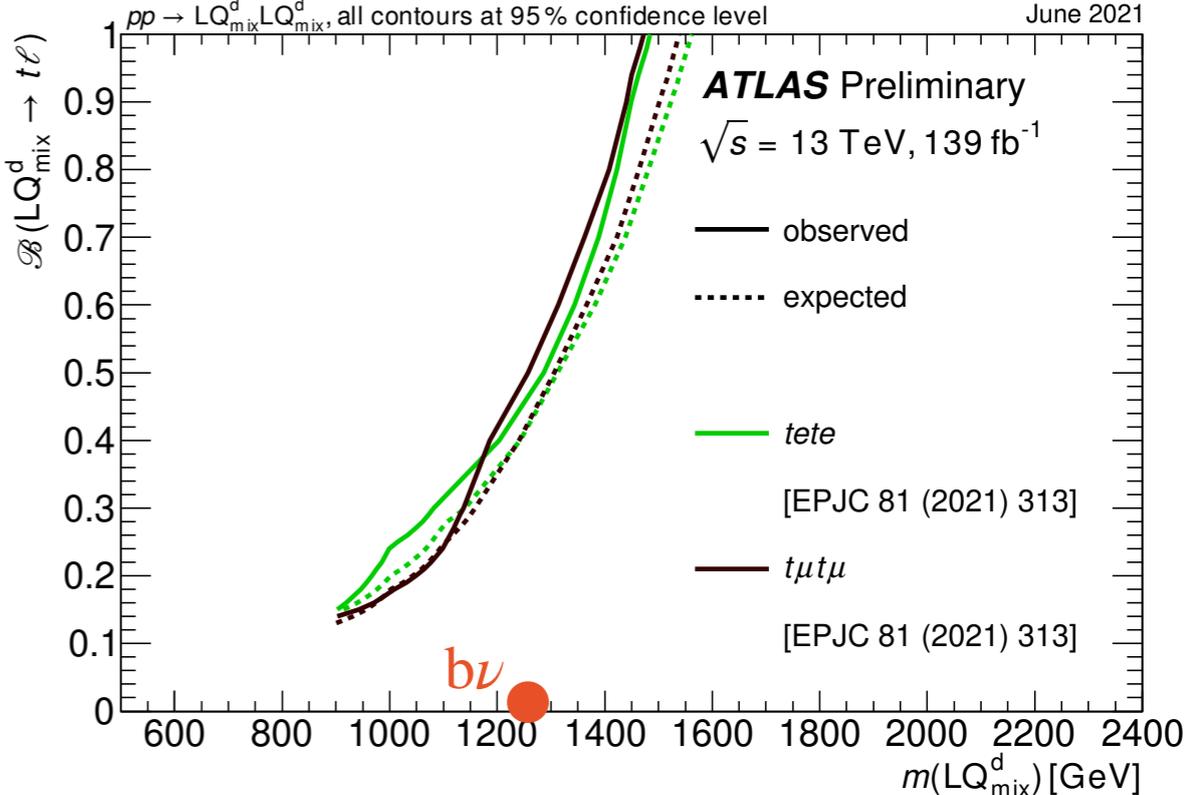
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- Combination of $LQ \rightarrow t\mu$ with $LQ \rightarrow b\nu$
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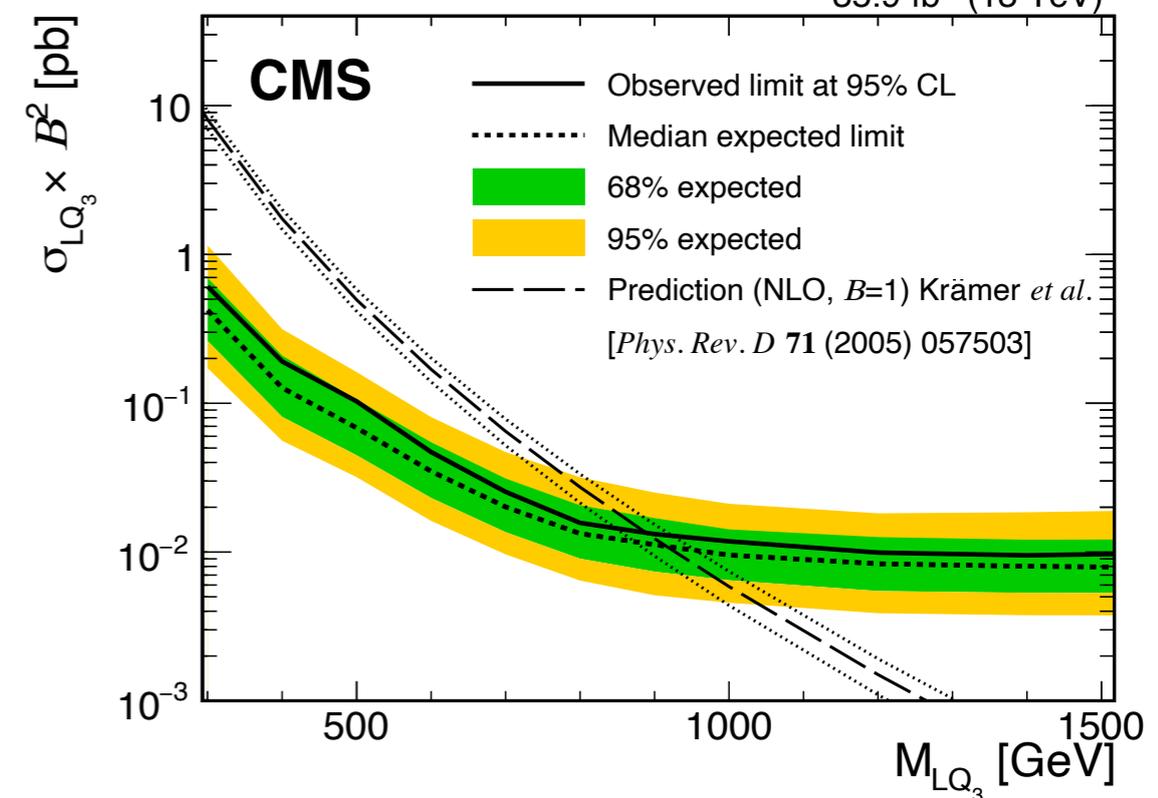
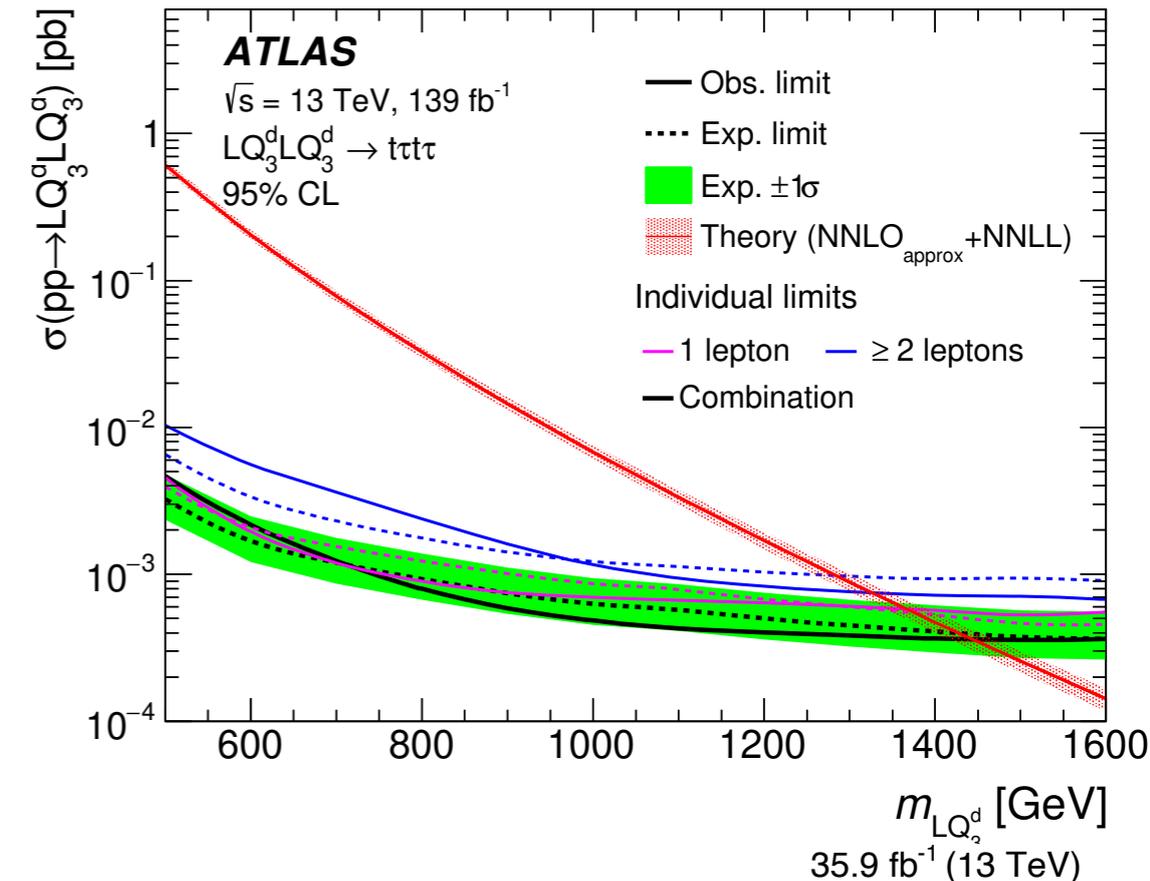
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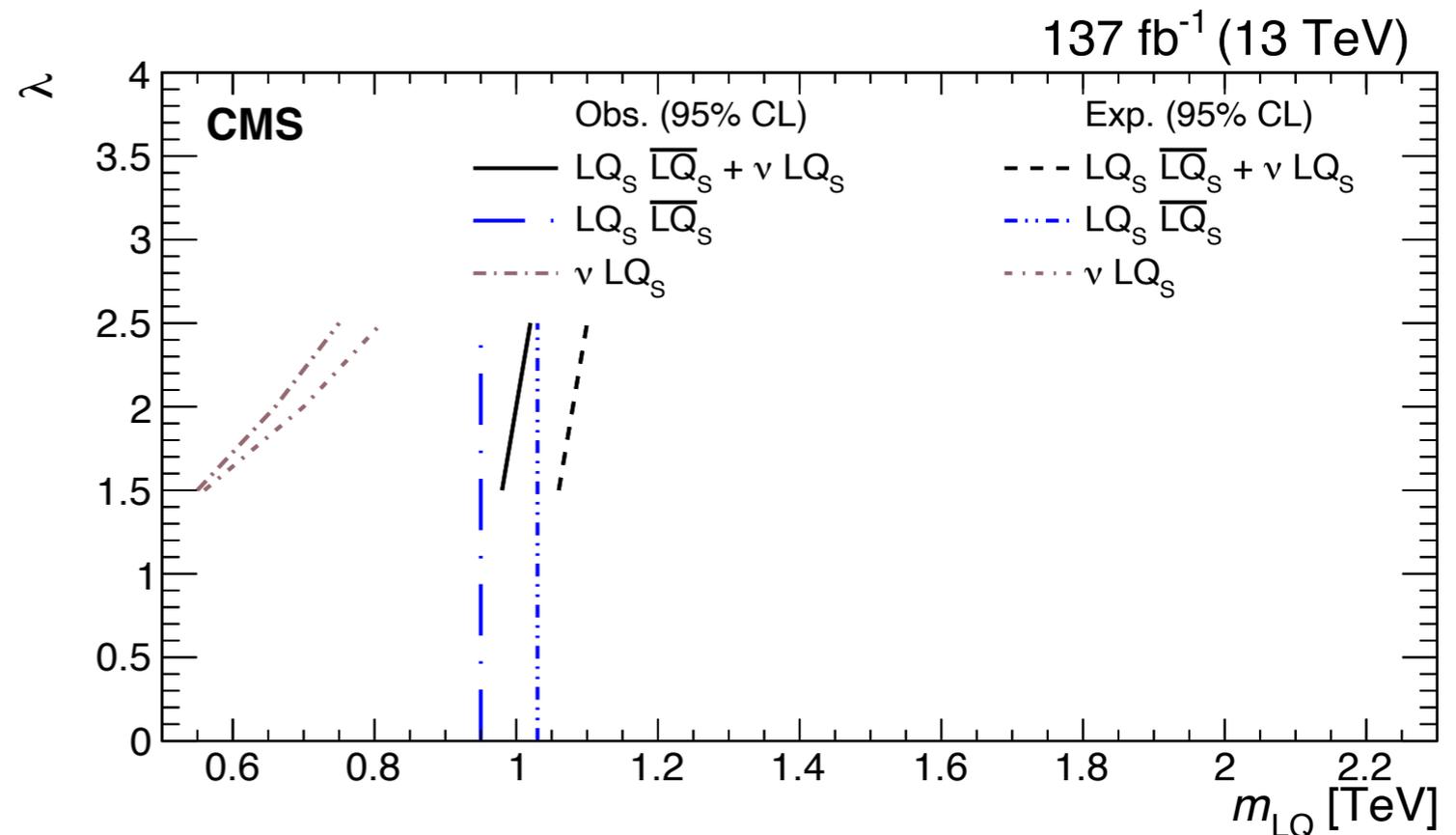
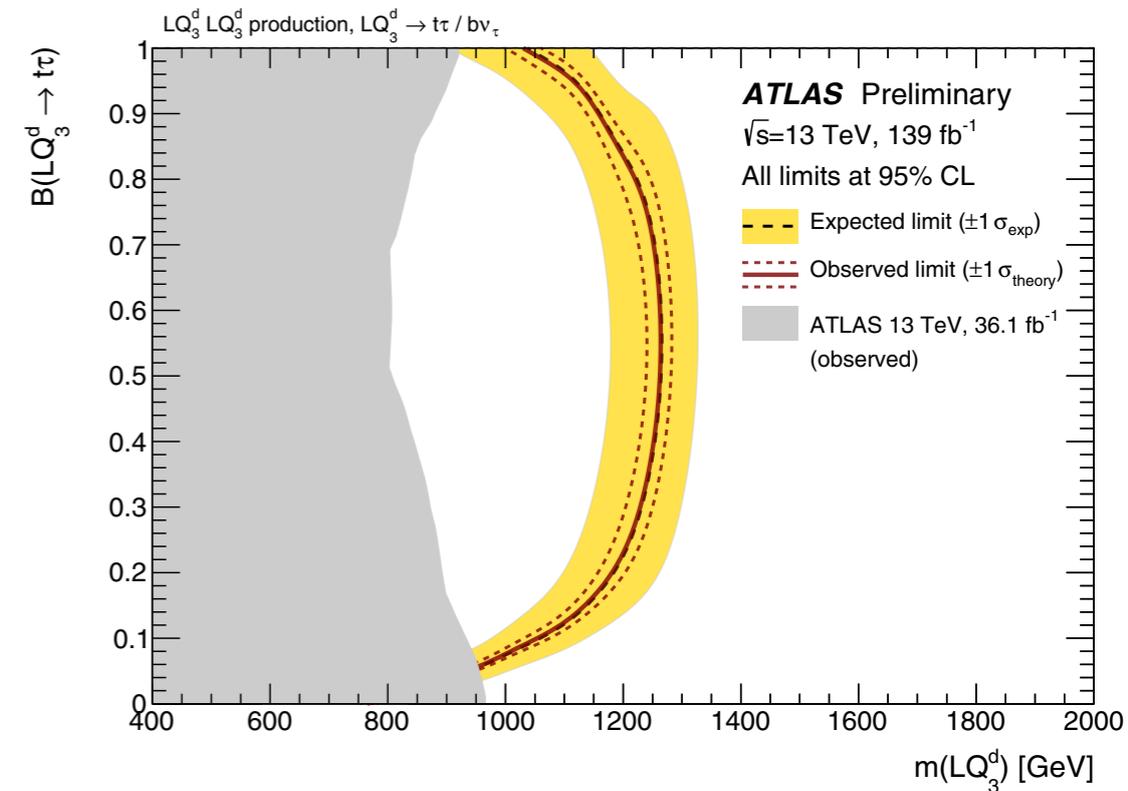
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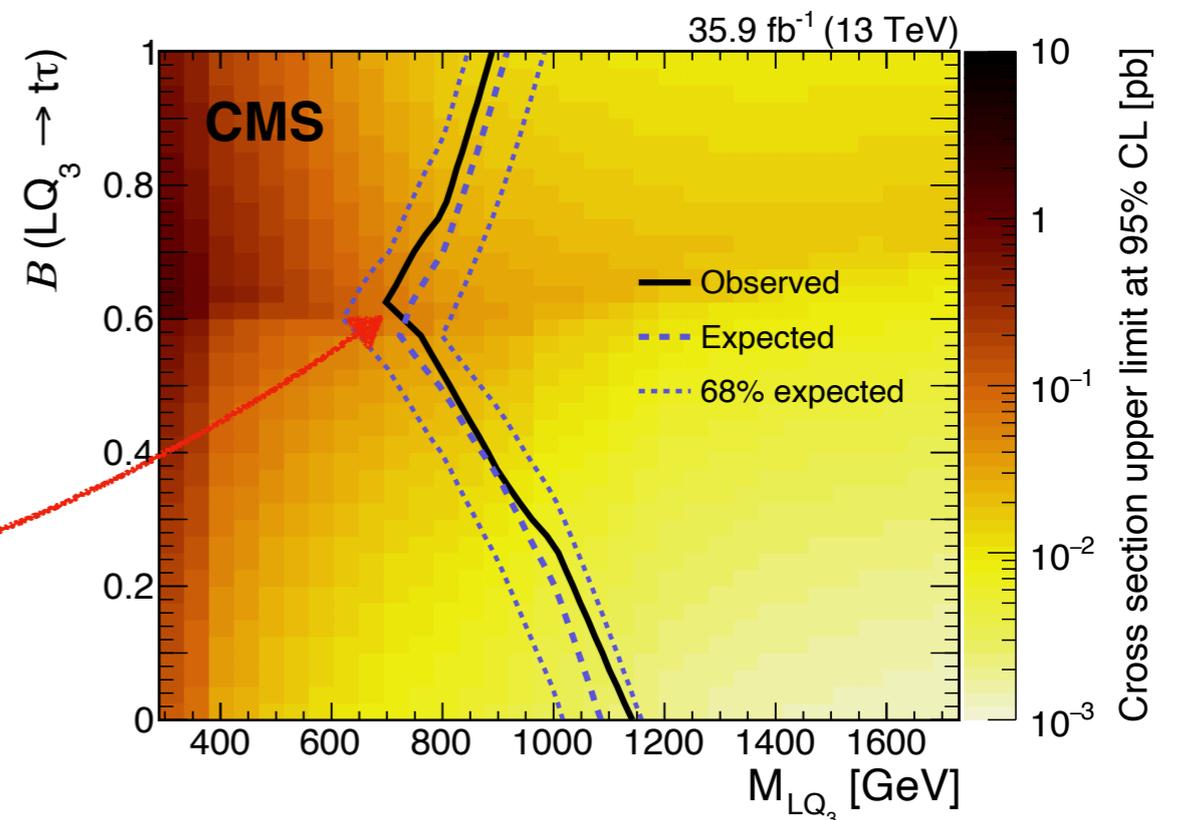
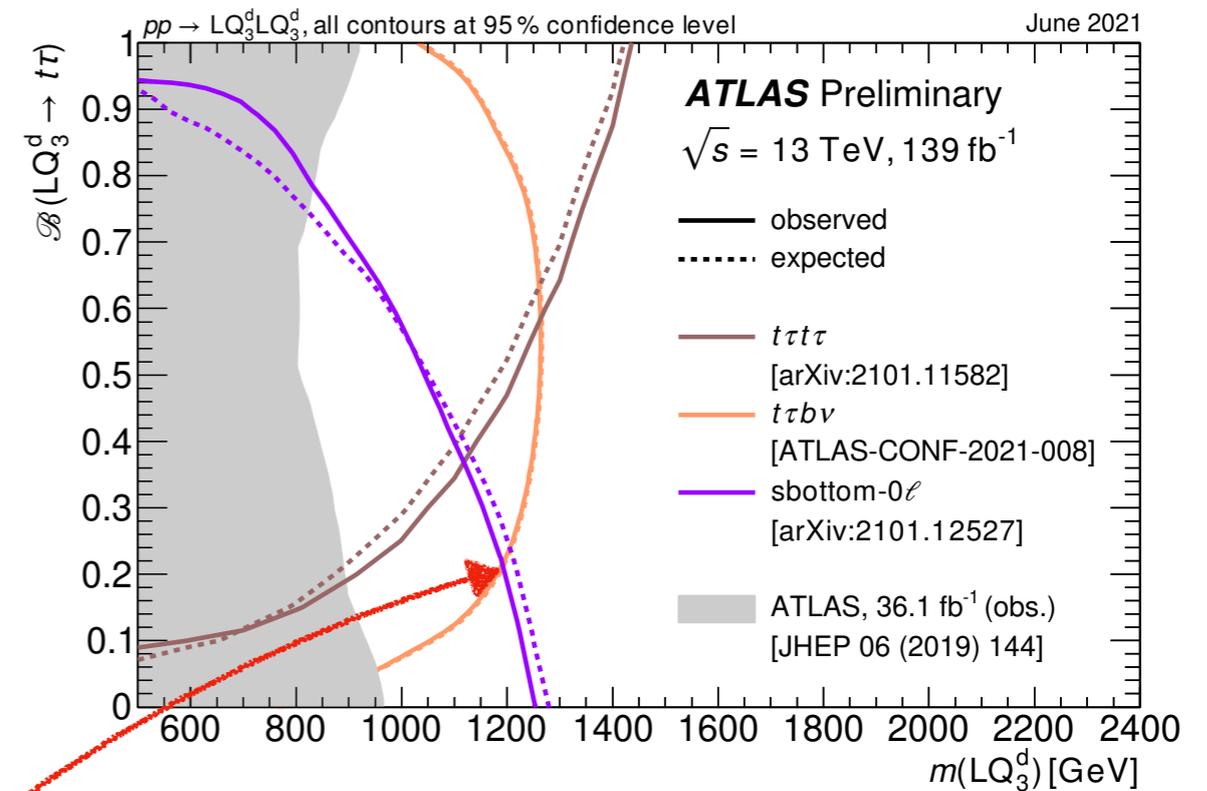
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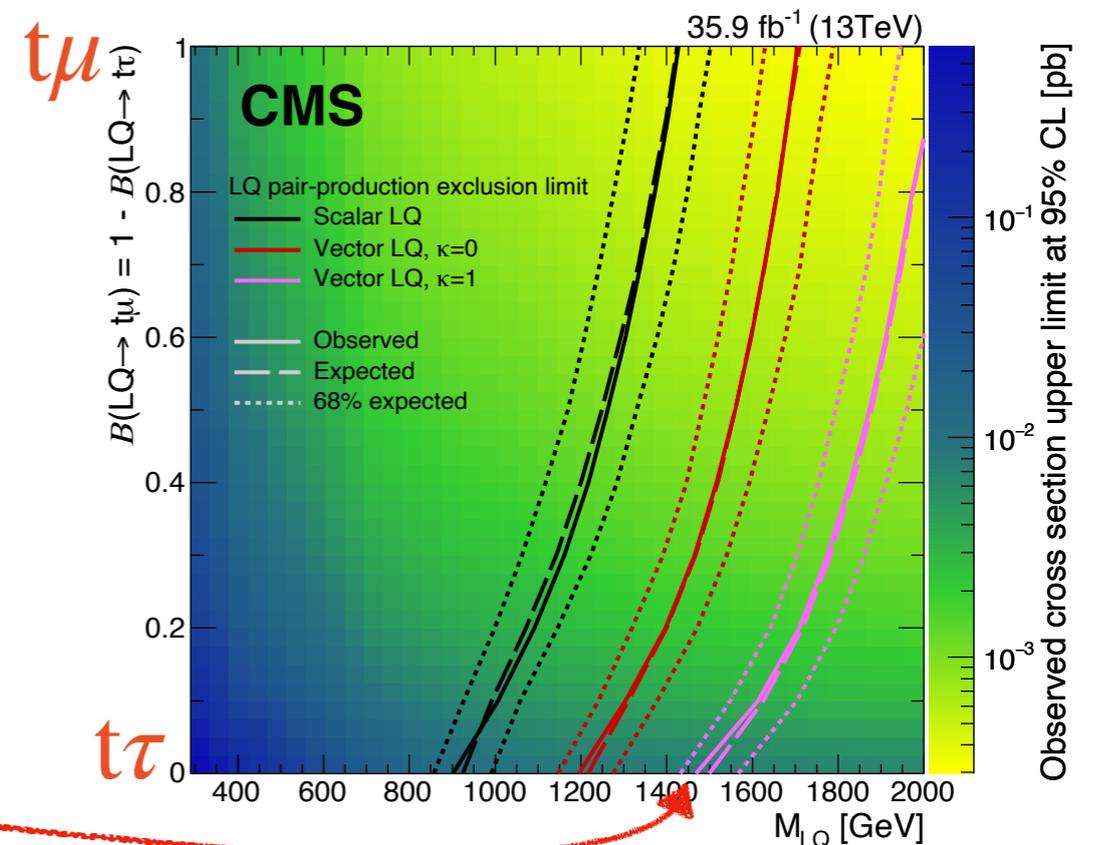
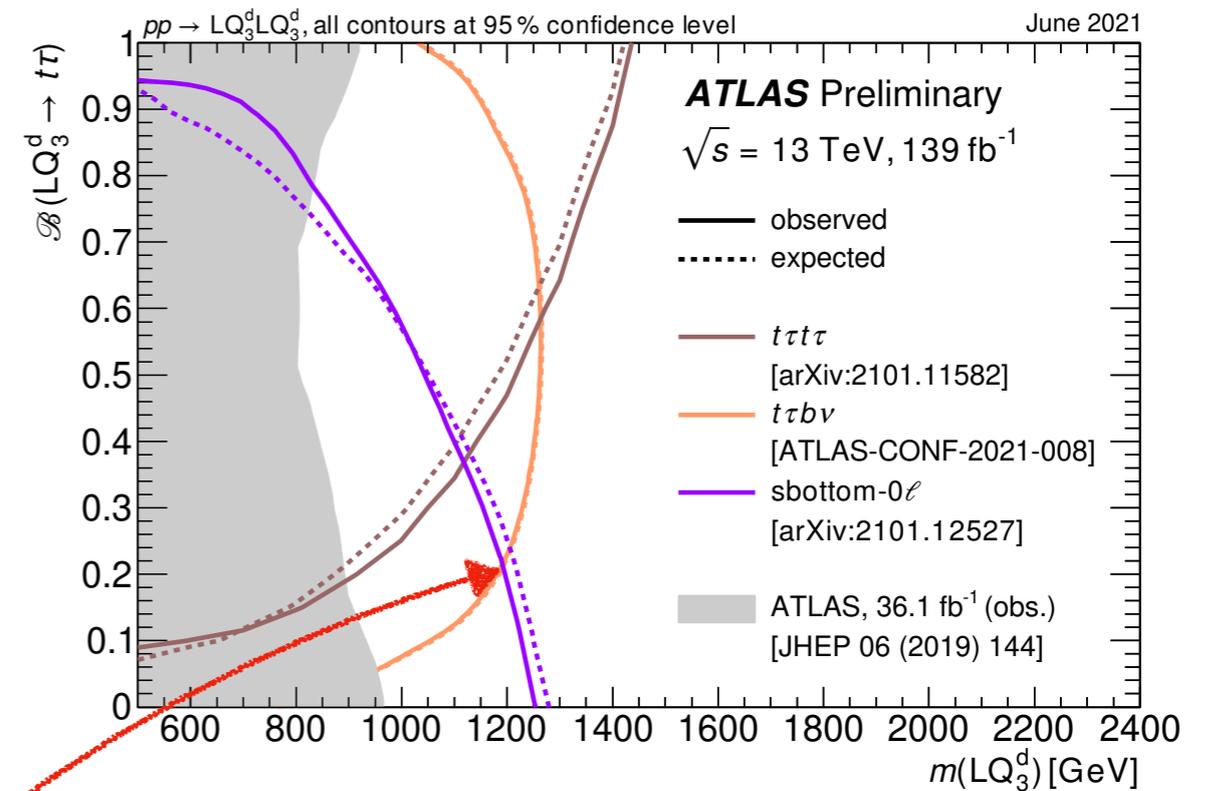
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 - ▶ CMS limit: $M_{LQ} \lesssim 0.75$ TeV
- CMS: Combination of $t\tau$ and $t\mu$ channels
 - ▶ Cross-gen. couplings: $M_{LQ} \lesssim 0.9 - 1.5$ TeV



Coupling Overview

	q	b	t
ν	✓	✓	✓
e	✓	✓	✓
μ	✓	✓	✓
τ		✓	✓

Summary

- Leptoquarks potential solution to LFU anomalies
 - ▶ Third-generation couplings preferred
- ATLAS and CMS probe coupling matrix systematically
 - ▶ Focus on pair production so far
- **No deviations from SM: Exclusion limits of 1–2 TeV**

	q	b	t
ν	Scalar: 1.2 TeV Vector: 1.8 TeV	Scalar: 1.2 TeV Vector: 1.8 TeV	Scalar: 1.2 TeV Vector: 1.8 TeV
e	Scalar: 1.8 TeV	Scalar: 1.7 TeV	Scalar: 1.5 TeV
μ	Scalar: 1.8 TeV	Scalar: 1.7 TeV	Scalar: 1.5 TeV Vector: 2.0 TeV
τ		Scalar: 1.2 TeV Vector: 1.8 TeV	Scalar: 1.4 TeV Vector: 1.5 TeV

