Leptoquark Searches at the LHC

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Physics 290E

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Theoretical Motivation

- Originally seen in Pati-Salam SU(4) color model. Famously also seen in SU(5) and SO(10) GUTs.
- Include a term in the Lagrangian that provides a coupling to a quark and a lepton.
- This phenomenologically manifests itself as a leptoquark that can turn a quark into a lepton and vice versa.
- Since it also carries charge and color, it must interact with photons and gluons.
- If generation mixing is allowed, an additional 4 fermion vertex must exist.

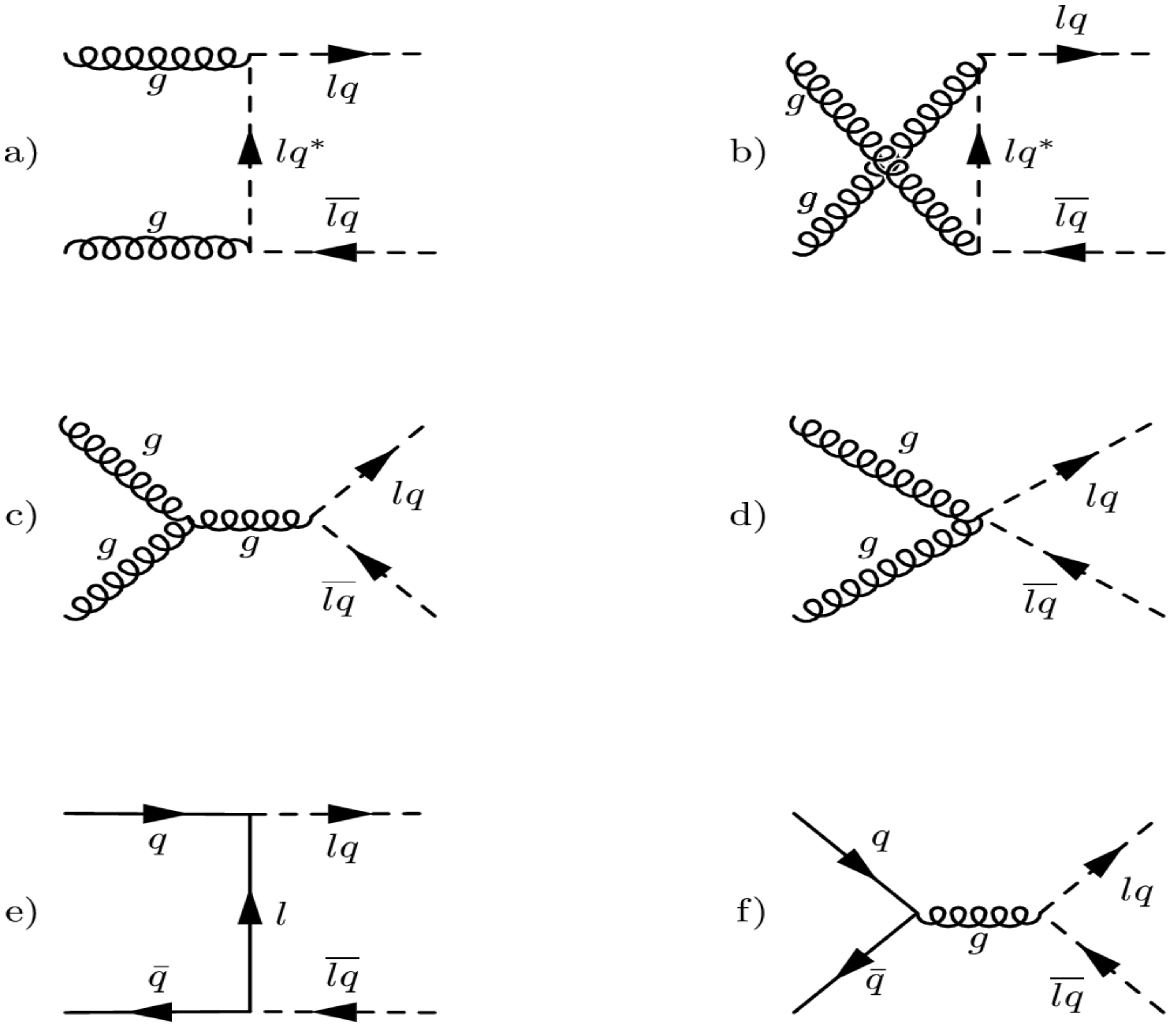
Theory (cont.)

- Can help explain the baryon asymmetry in the universe.
- Would provide a BSM contribution to muon EDM.
- If included in R-parity violating SUSY theories, provides a bound on RPV processes.
- SM discrepancies found in B decays.

arXiv:1603.04993v3

$(SU(3), SU(2), U(1))$	Spin	Symbol	Type	F
$(\overline{\mathbf{3}}, \mathbf{3}, 1/3)$	0	S_3	$LL\,(S_1^L)$	-2
$(\mathbf{3}, \mathbf{2}, 7/6)$	0	R_2	$RL\,(S_{1/2}^L)$, $LR\,(S_{1/2}^R)$	0
$(\mathbf{3}, \mathbf{2}, 1/6)$	0	$\tilde{R}_2$	$RL\,(\tilde{S}_{1/2}^L)$, $\overline{LR}\,(\tilde{S}_{1/2}^{\overline{L}})$	0
$(\overline{\mathbf{3}}, \mathbf{1}, 4/3)$	0	$\tilde{S}_1$	$RR\,(\tilde{S}_0^R)$	-2
$(\overline{\mathbf{3}}, \mathbf{1}, 1/3)$	0	S_1	$LL\,(S_0^L)$, $RR\,(S_0^R)$, $\overline{RR}\,(S_0^{\overline{R}})$	-2
$(\overline{\mathbf{3}}, \mathbf{1}, -2/3)$	0	$\bar{S}_1$	$\overline{RR}\,(\bar{S}_0^R)$	-2
$(\mathbf{3}, \mathbf{3}, 2/3)$	1	U_3	$LL\,(V_1^L)$	0
$(\overline{\mathbf{3}}, \mathbf{2}, 5/6)$	1	V_2	$RL\,(V_{1/2}^L)$, $LR\,(V_{1/2}^R)$	-2
$(\overline{\mathbf{3}}, \mathbf{2}, -1/6)$	1	$\tilde{V}_2$	$RL\,(\tilde{V}_{1/2}^L)$, $\overline{LR}\,(\tilde{V}_{1/2}^R)$	-2
$(\mathbf{3}, \mathbf{1}, 5/3)$	1	$\tilde{U}_1$	$RR\,(\tilde{V}_0^R)$	0
$(\mathbf{3}, \mathbf{1}, 2/3)$	1	U_1	$LL\,(V_0^L)$, $RR\,(V_0^R)$, $\overline{RR}\,(V_0^{\overline{R}})$	0
$(\mathbf{3}, \mathbf{1}, -1/3)$	1	$\bar{U}_1$	$\overline{RR}\,(\bar{V}_0^R)$	0

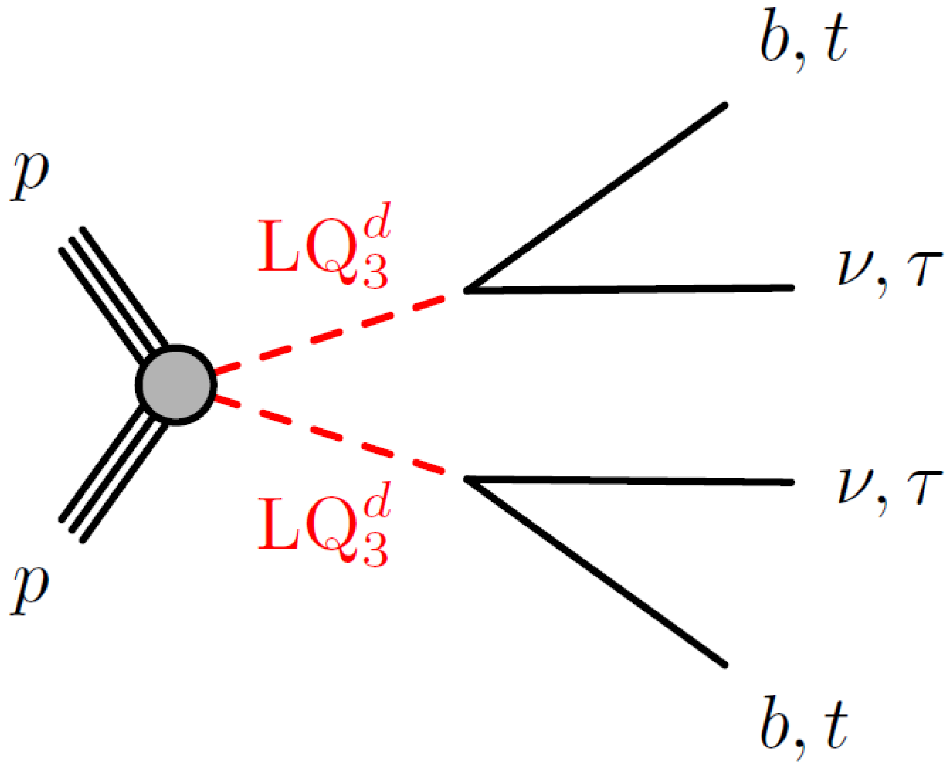
Leptoquark Searches at LHC



arXiv:0910.2215v1

CMS Search for 3rd gen coupling at 13 TeV

- Looking at Scalar LQ PP production.
- Here exclusively looking at ττ final state.
- Main Backgrounds:
  - Ttbar + jets
  - W + jets
- Large BG contribution due to jets mis-ID as τ.



arXiv:1902.08103v1

CMS Event Selection

arXiv:1803.02864v2

	Category A		Category B
	OS $\ell\tau_h$ + jets	SS $\ell\tau_h$ + jets	OS $\ell\tau_h\tau_h$ + jets
Jet selection	$\geq$4 jets	$\geq$3 jets	$\geq$3 jets
p_T^{miss} selection	$p_T^{miss} > 100$ GeV	$p_T^{miss} > 50$ GeV	$p_T^{miss} > 50$ GeV
τ_h selection	$p_T > 100$ GeV		$p_T^{\tau 1} > 65$ GeV, $p_T^{\tau 2} > 35$ GeV
b tagging	$\geq$1 b tag		—
S_T selection	—		$S_T > 350$ GeV
Fit variable	p_T^t in two S_T bins		number of events

CMS Results

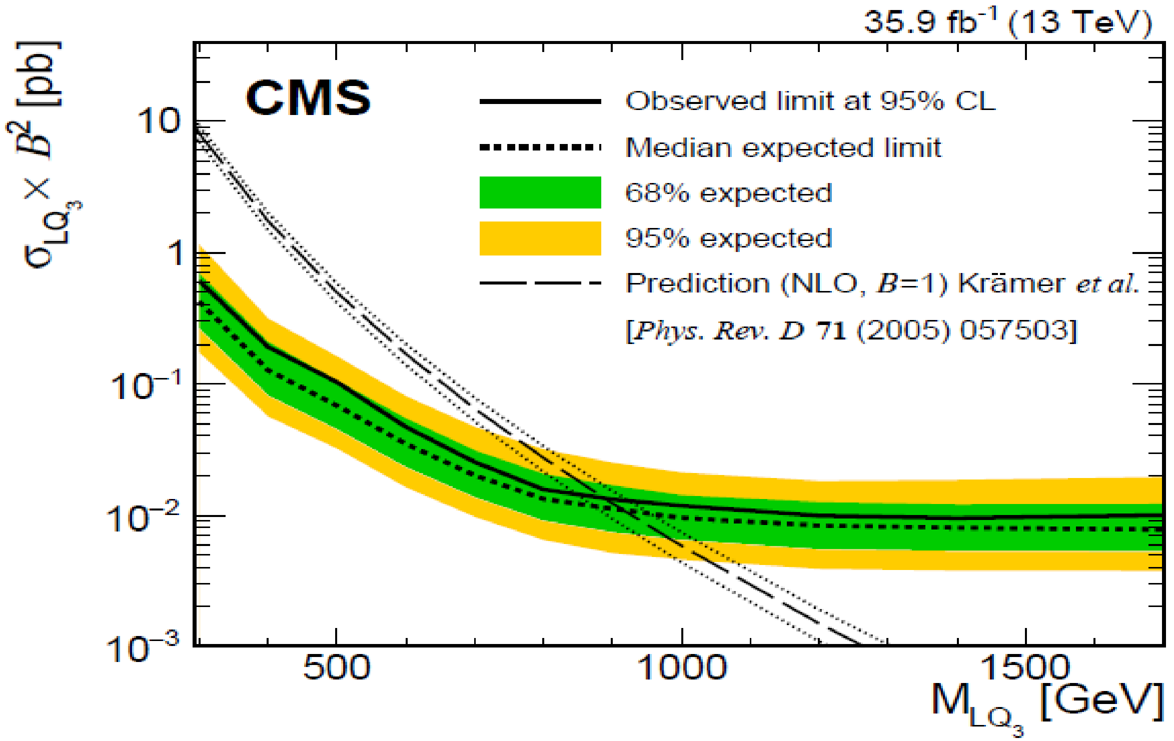
Process	$e\tau_h\tau_h$ + jets	$\mu\tau_h\tau_h$ + jets
LQ_3 (300 GeV)	97^{+25}_{-24}	167^{+36}_{-37}
LQ_3 (400 GeV)	73^{+14}_{-13}	98^{+19}_{-17}
LQ_3 (500 GeV)	$34.1^{+6.6}_{-6.2}$	$44.9^{+8.5}_{-7.9}$
LQ_3 (600 GeV)	$14.1^{+2.8}_{-2.7}$	$21.1^{+4.1}_{-3.8}$
LQ_3 (700 GeV)	$7.3^{+1.5}_{-1.4}$	$7.1^{+1.5}_{-1.4}$
LQ_3 (800 GeV)	$3.2^{+0.7}_{-0.7}$	$4.4^{+1.0}_{-0.9}$
LQ_3 (900 GeV)	$1.5^{+0.4}_{-0.3}$	$1.9^{+0.4}_{-0.4}$
LQ_3 (1000 GeV)	$0.8^{+0.2}_{-0.2}$	$0.9^{+0.2}_{-0.2}$
$t\bar{t}_f$	$2.5^{+0.8}_{-1.2}$	$3.2^{+1.5}_{-1.2}$
$t\bar{t}_{p+f}$	$1.5^{+0.8}_{-0.8}$	$2.0^{+0.8}_{-0.9}$
Single t	$0.3^{+0.3}_{-0.3}$	$0.0^{+0.2}_{-0.0}$
W+jets	$0.5^{+1.2}_{-0.5}$	$0.4^{+0.7}_{-0.4}$
Z+jets	$1.4^{+0.5}_{-0.5}$	$1.0^{+0.4}_{-0.4}$
Diboson	$1.6^{+1.7}_{-1.6}$	$1.7^{+1.8}_{-1.7}$
Total background	$7.9^{+2.4}_{-2.5}$	$8.4^{+2.6}_{-2.3}$
Data	9	11

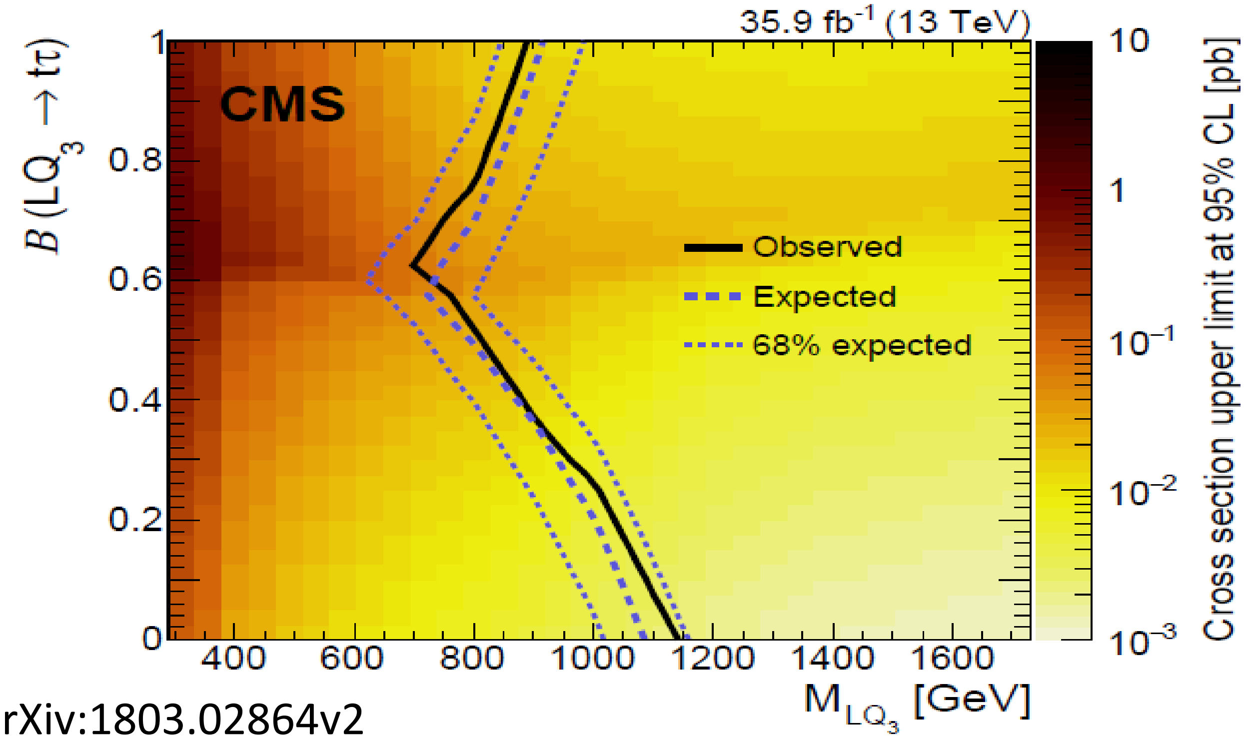
- Different number of events are calculated for the different masses of the LQ.
- Here is shown how many events are expected for a given mass at a center of mass energy of 13 TeV.
- No significant excess found.

arXiv:1803.02864v2

CMS Results (cont.)

- Overall, LQ masses can be excluded at the 95% CL for M < 900 GeV for B = 1 and M < 700 GeV for a full range of B.

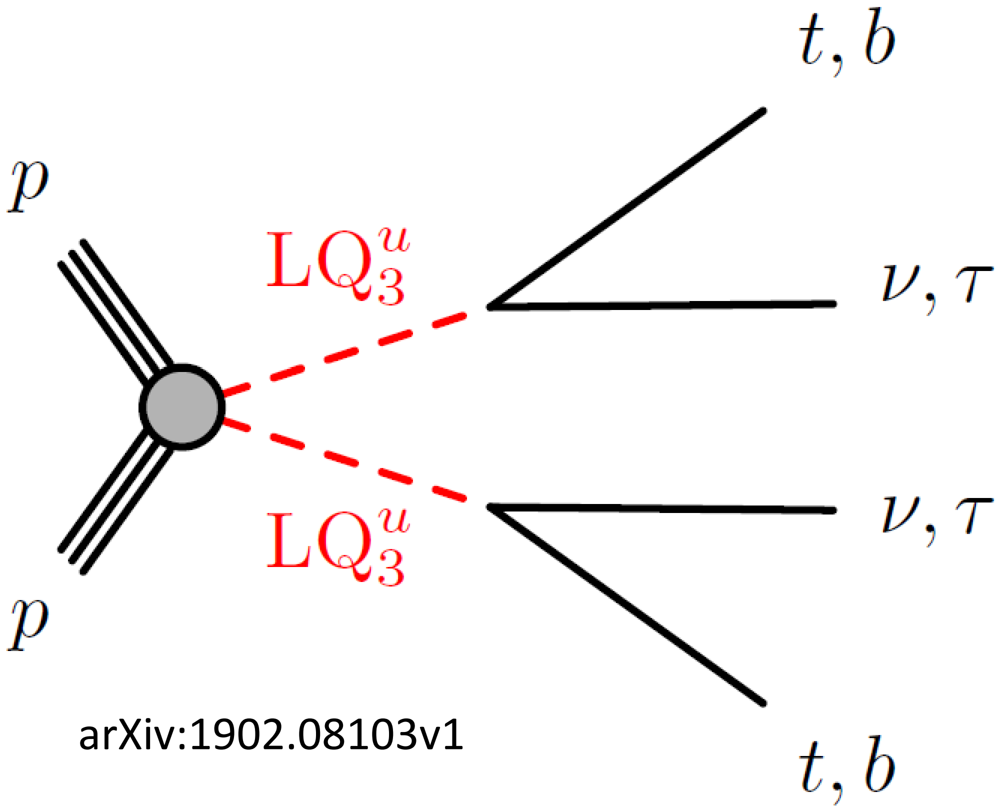




arXiv:1803.02864v2

ATLAS Search for 3rd gen coupling at 13 TeV

- Focus on scalar LQ pair production
- Decay channels:
  - tν/bτ
  - bν/tτ
- We'll only look at tτ
- Main Backgrounds:
  - ttbar + jets
  - W + jets



arXiv:1902.08103v1

ATLAS Event Selection

Category	**tN_med**	**tN_high**
Sensitivity	600 GeV	1 TeV
Lepton	1i	1i
Jet Selection	≥ 4	≥ 4
b-tagging	> 1	> 1
E_T^{miss}	$> 250\ GeV$	-
Bin	E_T^{miss}	1-bin cut-and-count

ATLAS Results

Observed events	8
Total SM	3.8 ± 1.0
$m(LQ_3^u)$ = 800 GeV	11.9 ± 1.8
$m(LQ_3^u)$ = 900 GeV	9.5 ± 1.2
$m(LQ_3^u)$ = 1000 GeV	6.7 ± 0.7
$m(LQ_3^u)$ = 1100 GeV	3.7 ± 0.3

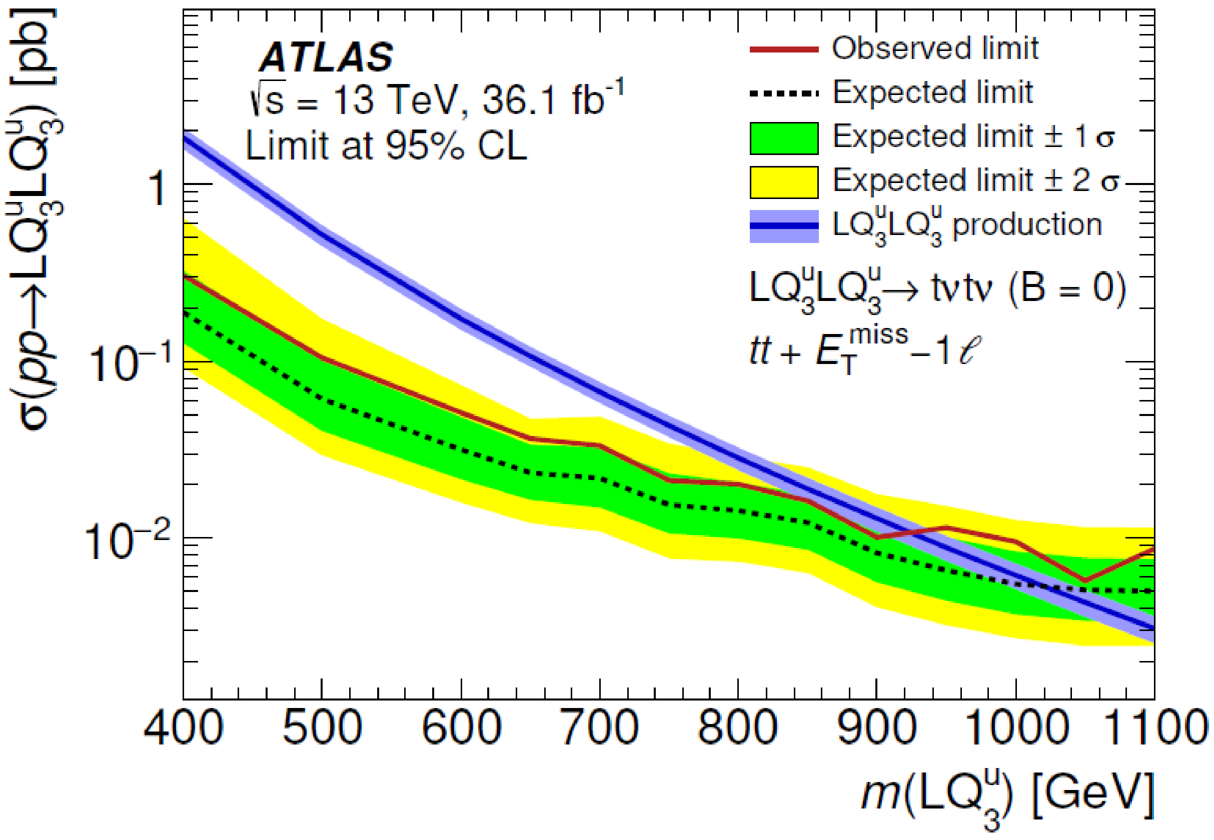
arXiv:1902.08103v1

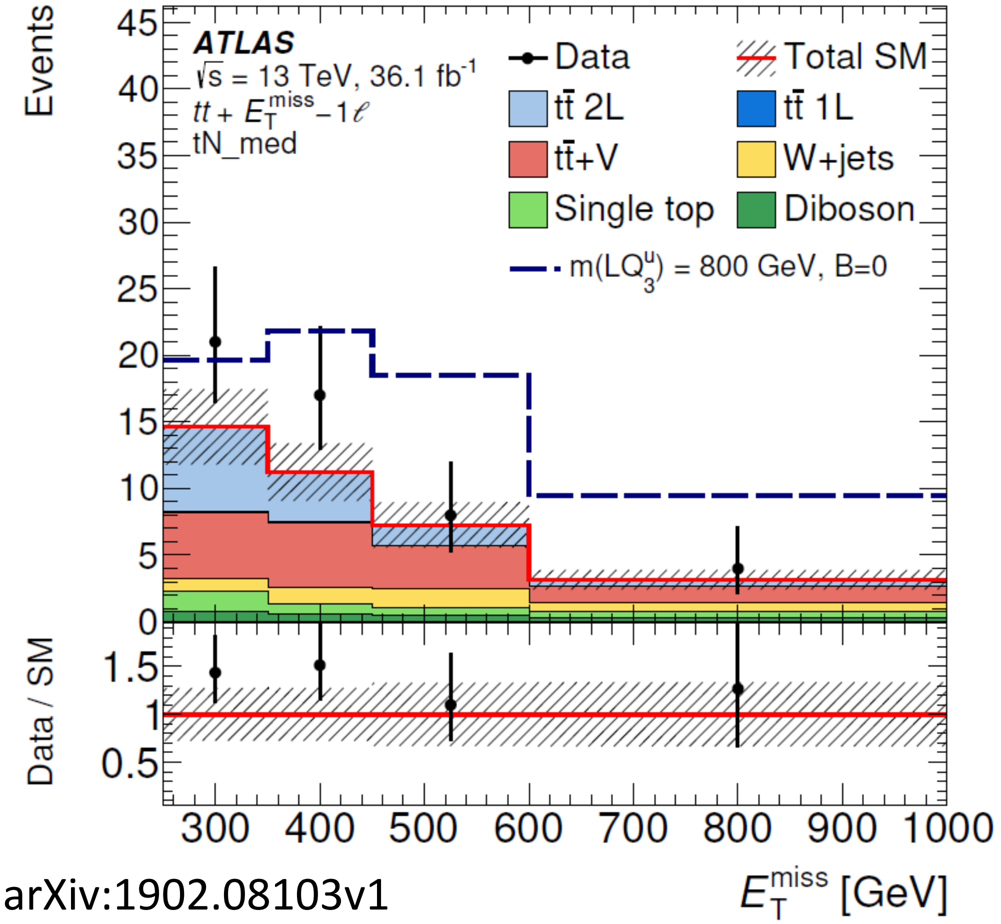
- Different number of events are calculated for the different masses of the LQ.
- Here is shown how many events are expected for a given mass at a center of mass energy of 13 TeV.
- No significant excess found.

E_T^{miss}	[250, 350] GeV	[350, 450] GeV	[450, 600] GeV	>600 GeV
Observed events	21	17	8	4
Total SM	14.6 ± 2.8	11.2 ± 2.2	7.3 ± 1.7	3.16 ± 0.74
$m(LQ_3^u)$ = 400 GeV	166 ± 44	58 ± 32	11 ± 11	5.7 ± 5.7
$m(LQ_3^u)$ = 600 GeV	21.0 ± 5.6	49.6 ± 8.8	31.8 ± 5.5	1.4 ± 2.1
$m(LQ_3^u)$ = 800 GeV	5.0 ± 1.5	10.6 ± 1.7	11.2 ± 2.0	6.3 ± 1.4
$m(LQ_3^u)$ = 1000 GeV	0.46 ± 0.14	1.18 ± 0.24	2.92 ± 0.49	4.61 ± 0.64

ATLAS Results (cont.)

- Overall, M < 930 GeV can be excluded at the 95% CL for pair produced scalar LQ masses coupled to 3rd gen quarks decaying to $t\nu\bar{t}\bar{\nu}$.





arXiv:1902.08103v1

Conclusion

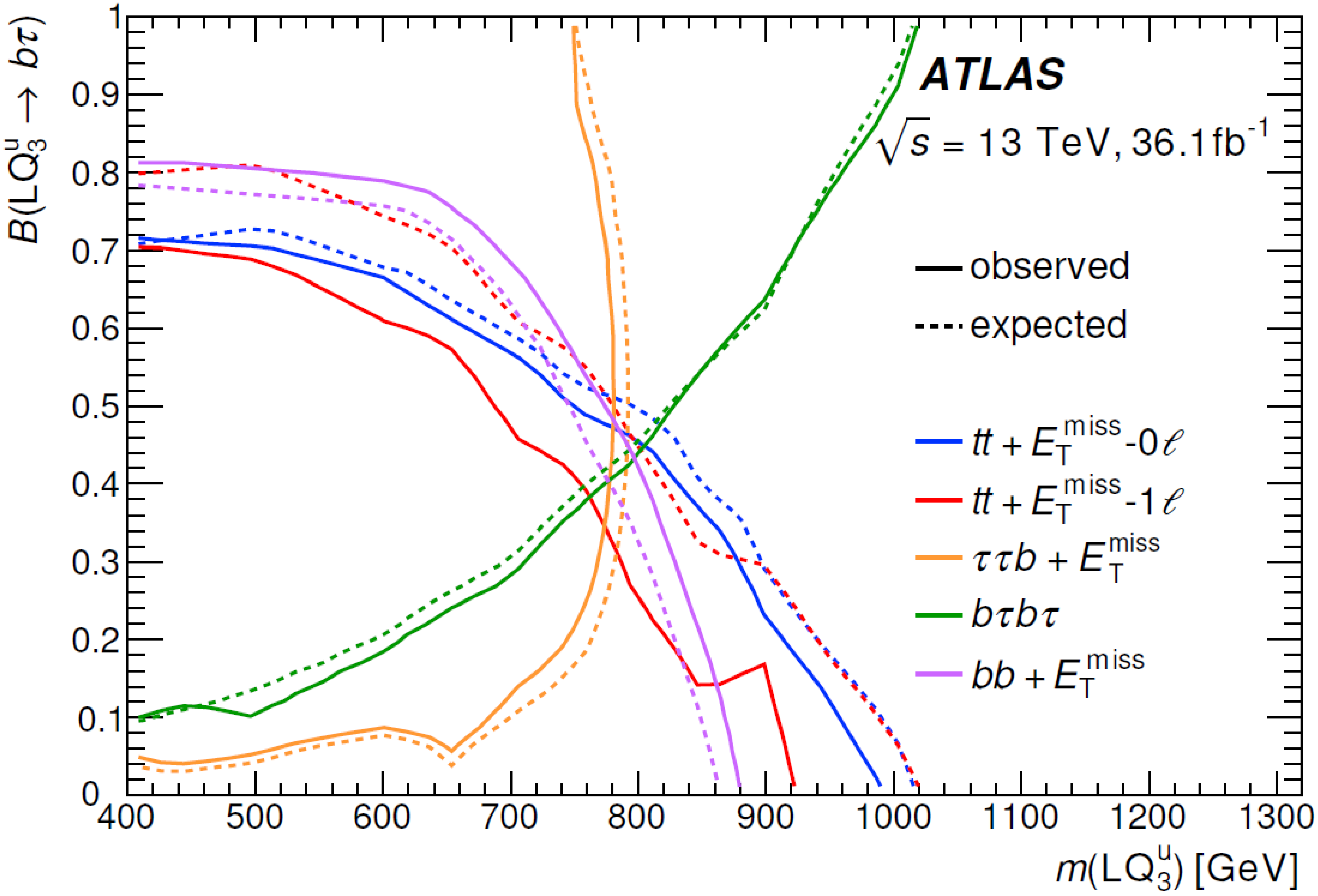
- BaBar, Belle and LHCb experiments have shown anomalies in $\bar{B} \to D\tau\bar{\nu}$ and $\bar{B} \to D^{*}\tau\bar{\nu}$ decay processes.
- These discrepancies can be explained by the Leptoquark model.
- Leptoquarks can also explain why there is more matter than anti-matter in the universe.
- Experiments like ATLAS and CMS have found no excesses but have set limits.
- Higher COM Energies will push these limits further up.

References

- Leptoquarks PDG Review, http://pdg.lbl.gov/2017/reviews/rpp2017-rev-leptoquark-quantum-numbers.pdf
- I. Dorsner et. Al., "Physics of leptoquarks in precision experiments and at particle colliders", arXiv:1603.04993v3
- ATLAS Collaboration, "Searches for third-generation scalar leptoquarks in $\sqrt{s} = 13\ TeV\ pp$ collisions with the ATLAS detector", arXiv:1902.08103v1
- CMS Collaboration, "Search for third-generation scalar leptoquarks decaying to a top quark and a τ lepton at $\sqrt{s} = 13\ TeV$", arXiv:1803.02864v2
- V. Bansal, "ATLAS Sensitivity to Leptoquarks, W_R and Heavy Majorana Neutrinos in Final States with High-p_T Dileptons and Jets with Early LHC Data at 14 TeV proton-proton collisions", arXiv:0910.2215v1 ""
- P. Bandyopadhyay and R. Mandal, "Revisiting Scalar Leptoquarks at the LHC" Eur. Phys. J. C (2018) 78:491

BACKUP

ATLAS Overall Results



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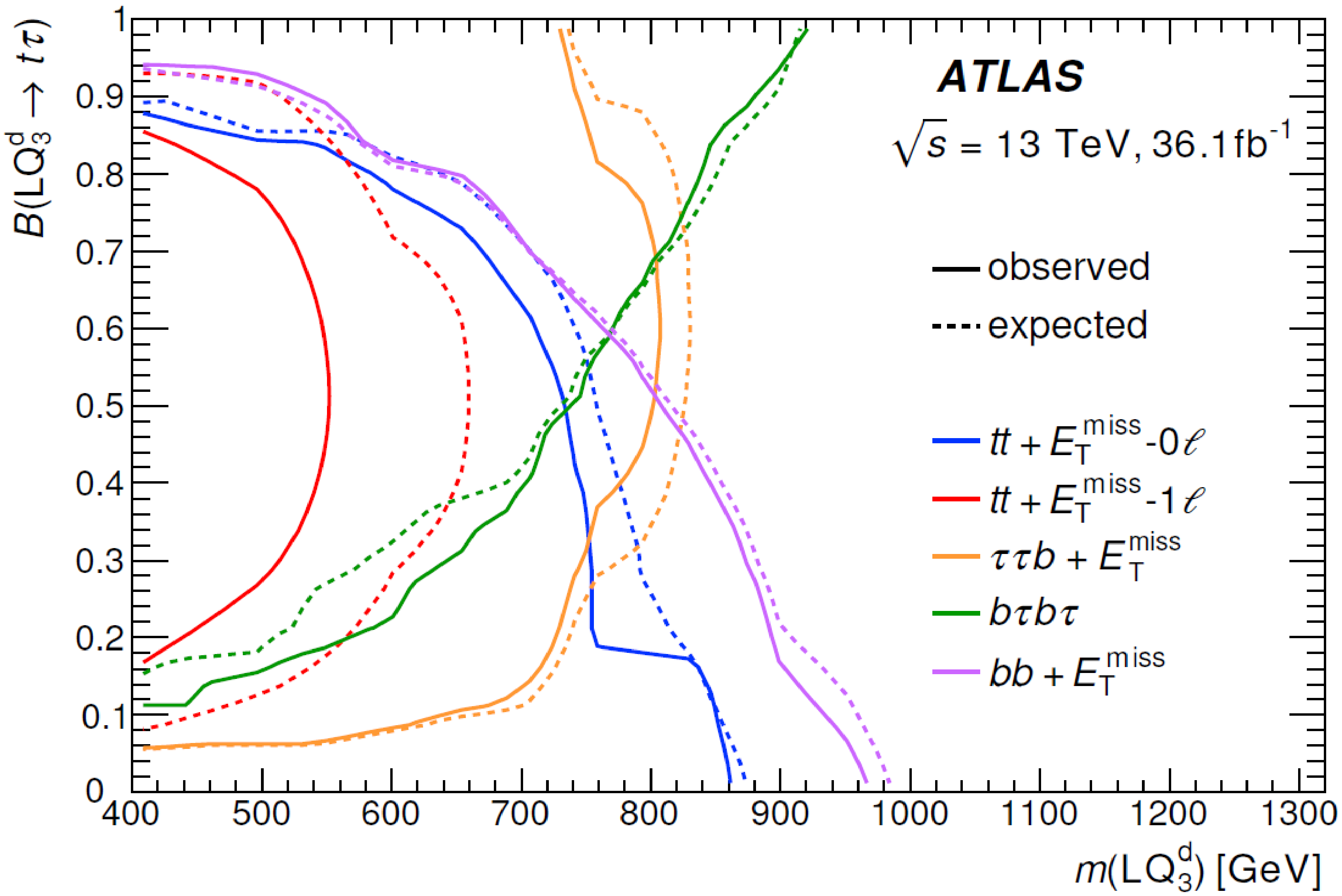
ATLAS Overall Results



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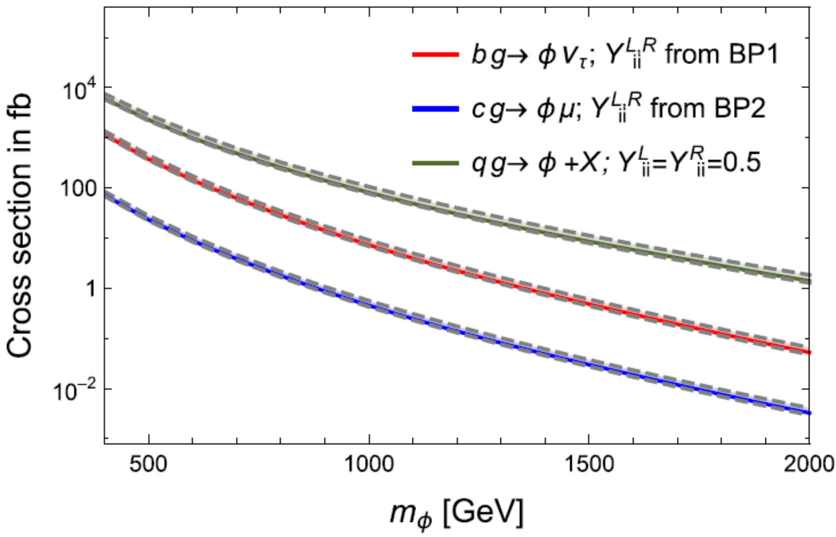
Prospects at 14 TeV



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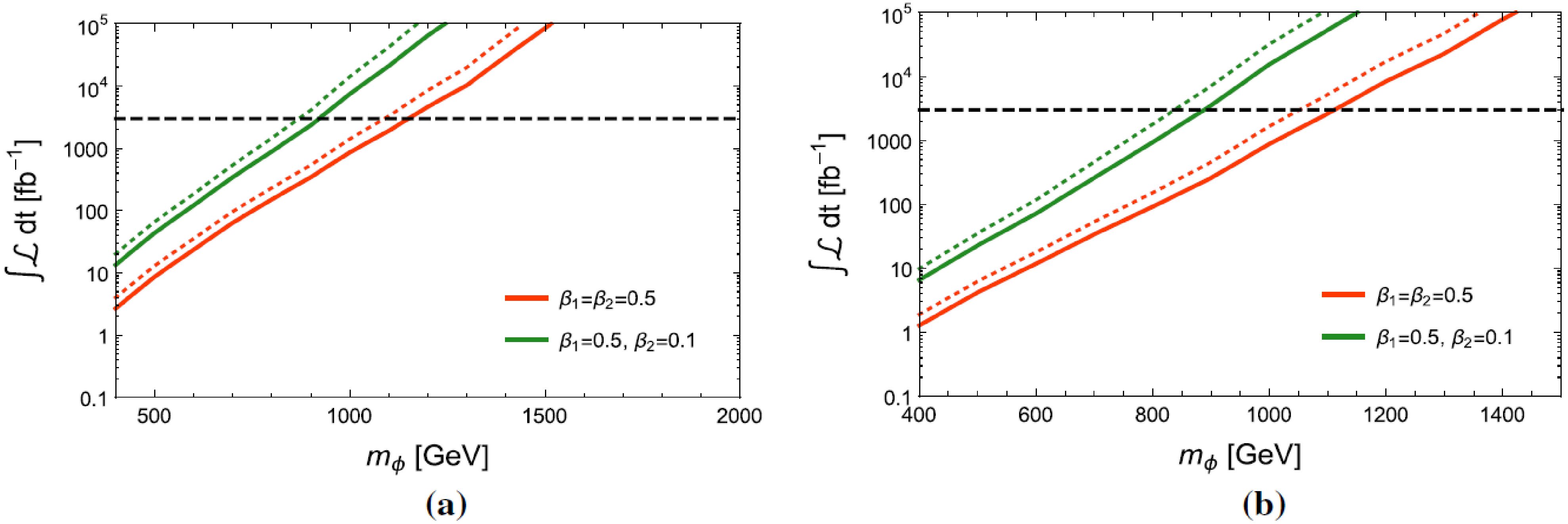

Fig. 9 Required integrated luminosity for 5σ reach at the LHC with 14 TeV of center of mass energy for the final states defined in Table 10 (in panel **a**) and Table 11 (in panel **b**), where β_1 and β_2 are the branching fraction to $t\,\tau$ and $c\,\mu$, respectively