

VLQ (Vector-Like Quarks)

ATLAS & CMS

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on behalf of the ATLAS & CMS Collaborations



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1

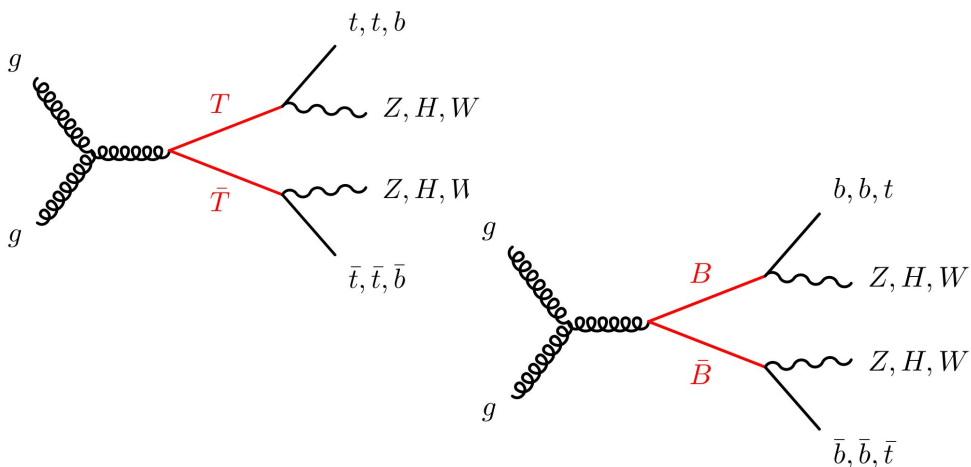
Vector-Like Quarks

Vector-Like Quarks

- Spin 1/2.
- Left and right-handed chiralities transform in the same way under the SM gauge group.
- Decay to qZ , qW or qH where $q = \{t, b\}$

Pair production

- Model Independent production cross section

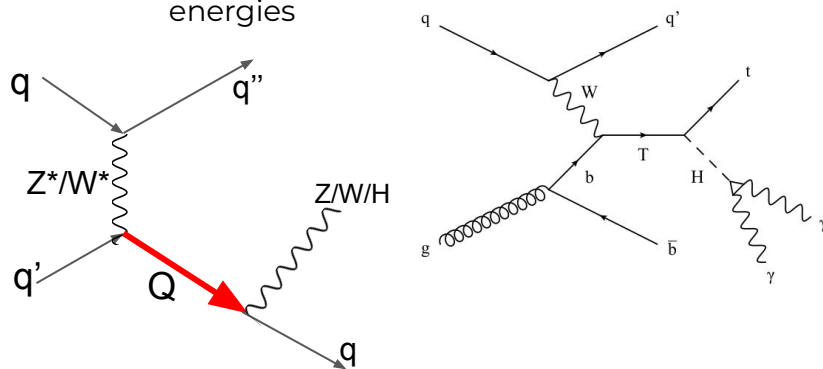


Vector-Like Quarks X, Y, T & B



Single production

- Dependent on qQ coupling (constraints from flavor physics and EW precision tests)
- Becomes dominant at high energies



2

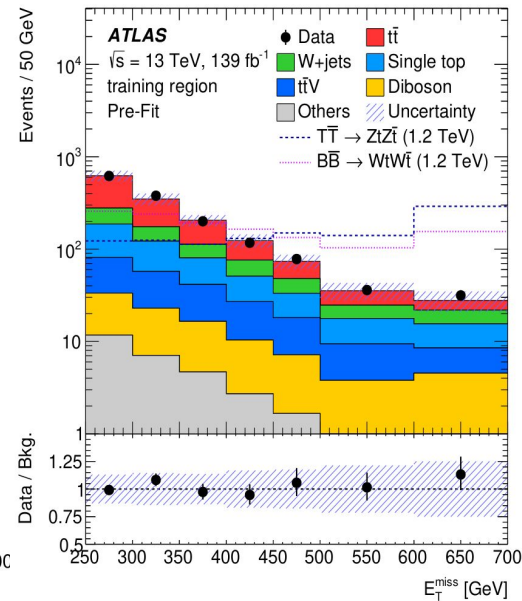
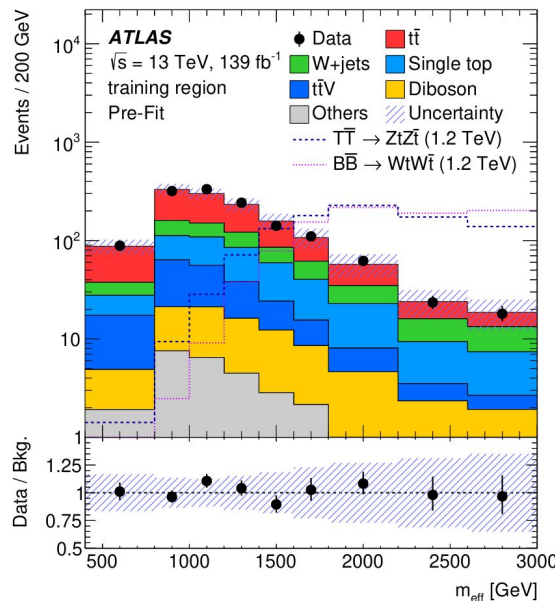
Pair Production

$T\bar{T}$ & $B\bar{B}$ production

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- For masses of the VLQs above 800 GeV
- Branching Ratios \mathcal{B} :
 - T: $\mathcal{B}(Zt, Ht, Wb) \approx (0.25, 0.25, 0.5)$
 - B: $\mathcal{B}(Zb, Hb, Wt) \approx (0.25, 0.25, 0.5)$
- Final state signature:
 - High missing transverse momentum
 $E_T^{\text{miss}} > 250$ GeV
 - One lepton ℓ (e or μ) (veto for a second lepton)
 - At least 4 jets including a b-tagged jet
- Dominant Bkg: $t\bar{t}$ and W+jets
 - "Others": $t\bar{t}H$, tWZ and Z +jets
- Neural Networks (NN) covering sections of the \mathcal{B} plane
 - For $T\bar{T}$ 4 NN: (0.8, 0.1, 0.1), (0.2, 0.4, 0.4), (0.4, 0.1, 0.5), (0.4, 0.5, 0.1).
 - For $B\bar{B}$ 3 NN: (0.1, 0.1, 0.8), (0.4, 0.1, 0.5), and (0.1, 0.4, 0.5).

more sensitive to $T' \rightarrow Zt$, $B' \rightarrow Wt$



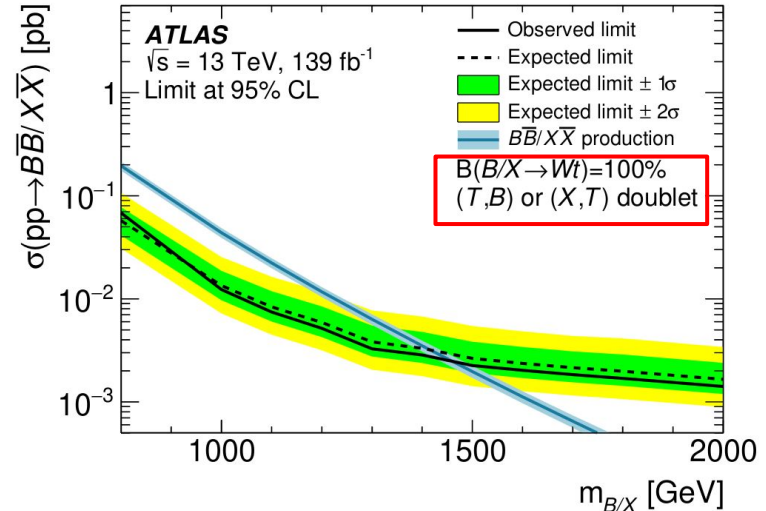
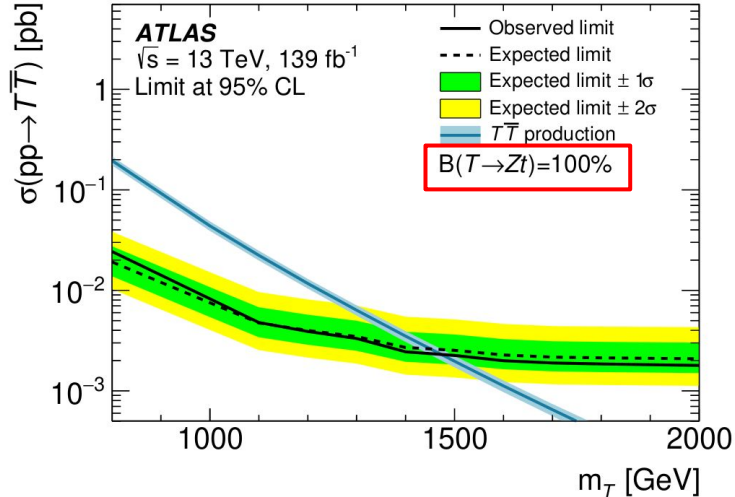
Systematic Uncertainties

Resolution and scale of:

- $t\bar{t}$ bkg
- Jet mass
- Efficiency of lepton identification, isolation, reconstruction and energy.

Expected and observed upper limits on the signal cross-section

VLQ	Scenario	Exp. limit [TeV]	Obs. limit [TeV]
T	$\mathcal{B}(T \rightarrow Zt) = 100\%$	1.45	1.47
T	singlet	1.33	1.26
T	(T, B) or (X, T) doublet	1.41	1.41
B	singlet	1.30	1.33
B/X	$\mathcal{B}(B/X \rightarrow Wt) = 100\%$ or $(T, B)/(X, T)$ doublet	1.42	1.46
$T/B/X$	(T, B) or (X, T) doublet, mass degenerate	1.56	1.59



Expected and observed mass limits as a function of the T' and B' branching ratios

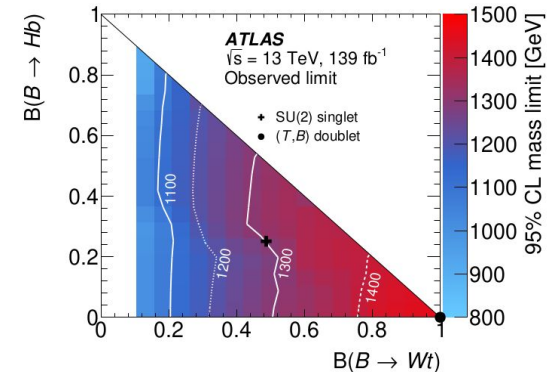
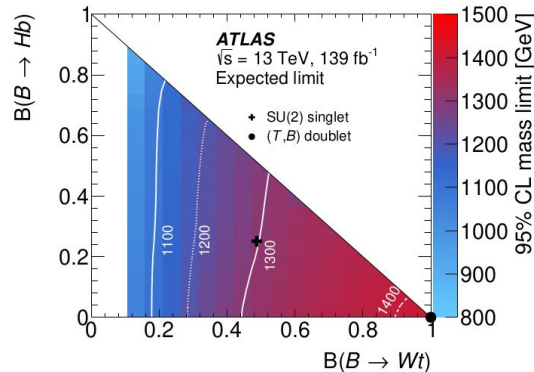
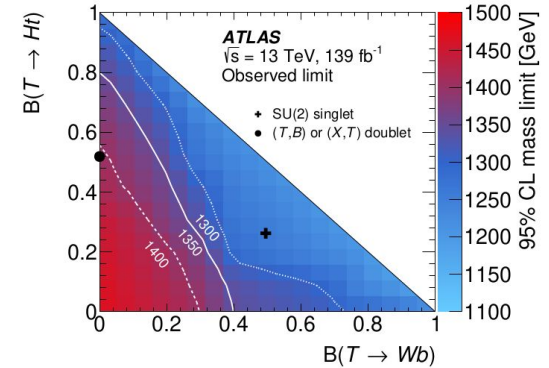
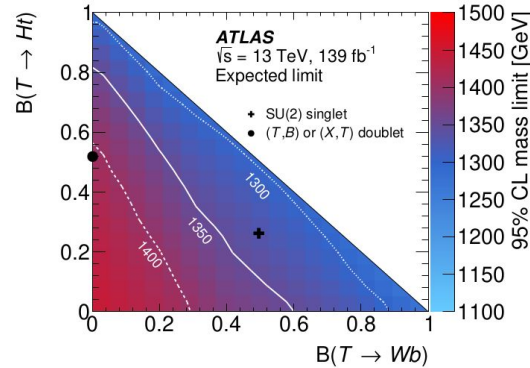
The highest sensitivity is found in the regions near

- $\mathcal{B}(T' \rightarrow Zt) = 100\%$
- $\mathcal{B}(B' \rightarrow Wt) = 100\%$

The strongest lower limits on the masses are 1.59 TeV corresponding to the weak-isospin doublet model

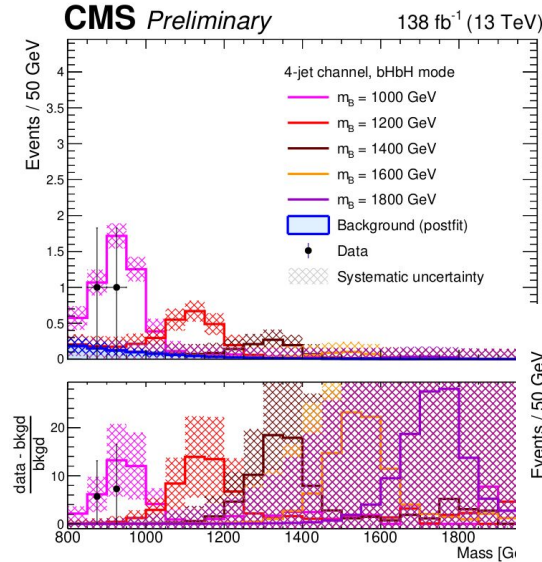
1.47 TeV (1.46 TeV) for exclusive $T \rightarrow Zt$ ($B/X \rightarrow Wt$) decays

Lower limits on the T and B quark masses are derived for all possible branching ratios.

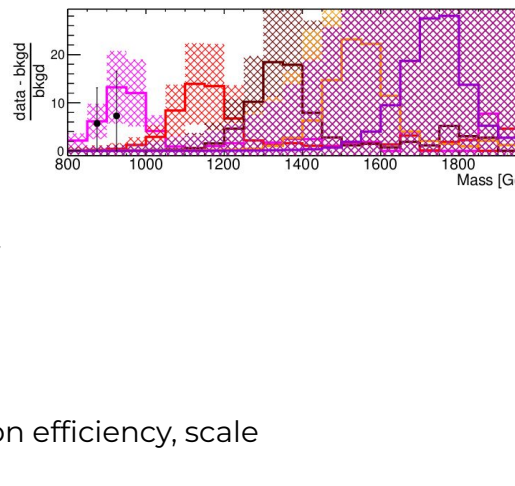


$B \bar{B}$ production (full hadronic and leptonic)

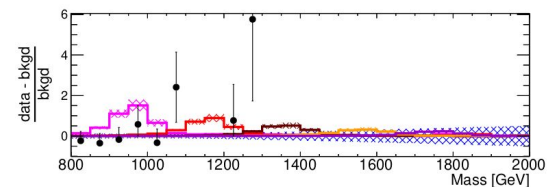
- For masses of the VLQs from 1000 to 1800 GeV
- Branching Ratios \mathcal{B} :
 - Leptonic: $\mathcal{B}(Zb, Hb, Wt)$
 - Hadronic: $\mathcal{B}(Zb, Hb)$
- Fully hadronic category:
 - At least 4 (≤ 6) AK4 jets $P_T > 50$ GeV $|\eta| < 2.4$, $H_T > 1350$ GeV
 - No isolated ℓ or μ $P_T > 50$ GeV
 - Bkg: SM jets produced through the strong interaction (QCD multijet events).
- Leptonic category:
 - At least 3 (≤ 5) AK4 jets $P_T > 50$ GeV and $|\eta| < 2.4$
 - At least one pair of leptons $80 < m_{\ell\ell} < 102$ GeV
 - Bkg: Drell-Yan dilepton production in association with jets
- Systematic uncertainties:
 - Integrated luminosity, trigger, dilepton Z boson efficiency, scale factors...



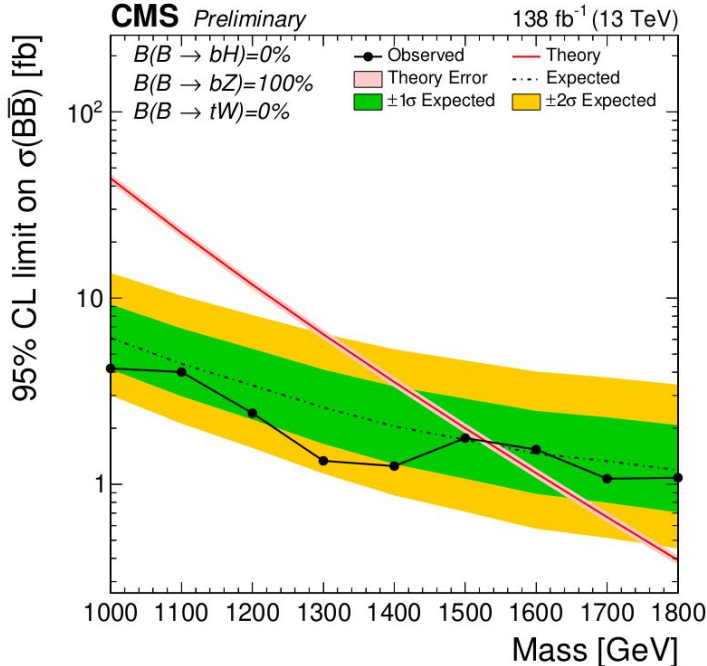
Hadronic category



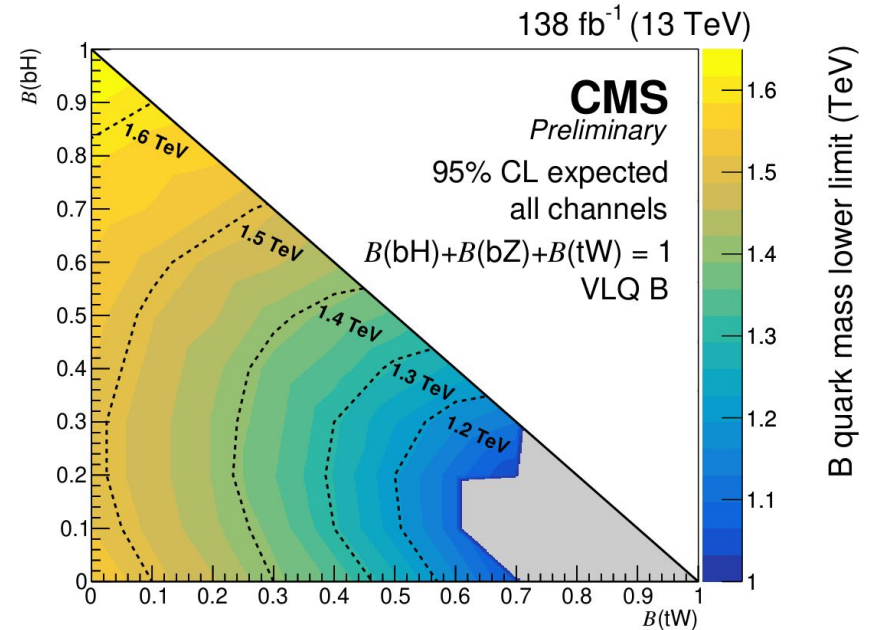
Leptonic category



- Expected and observed limits on the cross section at 95% CL



- Expected exclusion limits on the VLQ mass at 95% CL as a function of the branching fractions



- The limits on the VLQ mass have been increased from 1390 to 1540 GeV in the 100% B->bZ doublet case. These represent the current world best limits on B VLQs in pair production.

3

Single Production

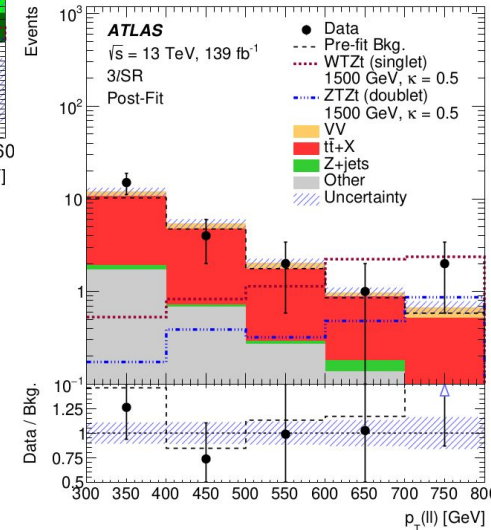
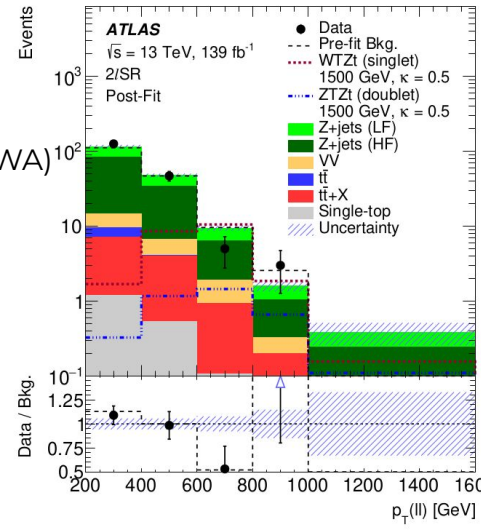
$T' \rightarrow Zt$ (multileptonic)

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- For masses of the VLQs from 1 TeV to 2 TeV
- Relative strength coupling ξ
 - ξ : $(\xi_W, \xi_Z, \xi_H) \approx (0.5, 0.25, 0.25)$
 - Signal samples normalized to NLO cross-section (NWA)
- Final state signature 2ℓ
 - Z boson: $|m_{(\ell\ell)} - m_Z| < 10$ GeV
 - $P_{T(\ell\ell)} > 200$ GeV
 - $H_T > 300$ GeV
 - $H_T + E_T^{\text{miss}} < m_{\ell\ell J}$
 - 1 FWD jet; at least 1 b-jet & 1 top-tagged jet
- Final state signature 3ℓ
 - 3 leptons passing the preselection
 - At least 1 FWD jet, 1 b-tagged jet
 - Z boson candidate $P_{T(\ell\ell)} > 300$ GeV
 - Leading lepton $P_{T(\ell)} > 200$ GeV
 - $H_T \cdot n(\text{jets}) < 6$ TeV

Main Backgrounds:

- 2ℓ : Z+jets, minor contributions from VV and tt processes
- 3ℓ : Diboson processes and $tt+Z$ and other small contributions from $tt+W$ and $tttt$



$T' \rightarrow Zt$ (multileptonic)

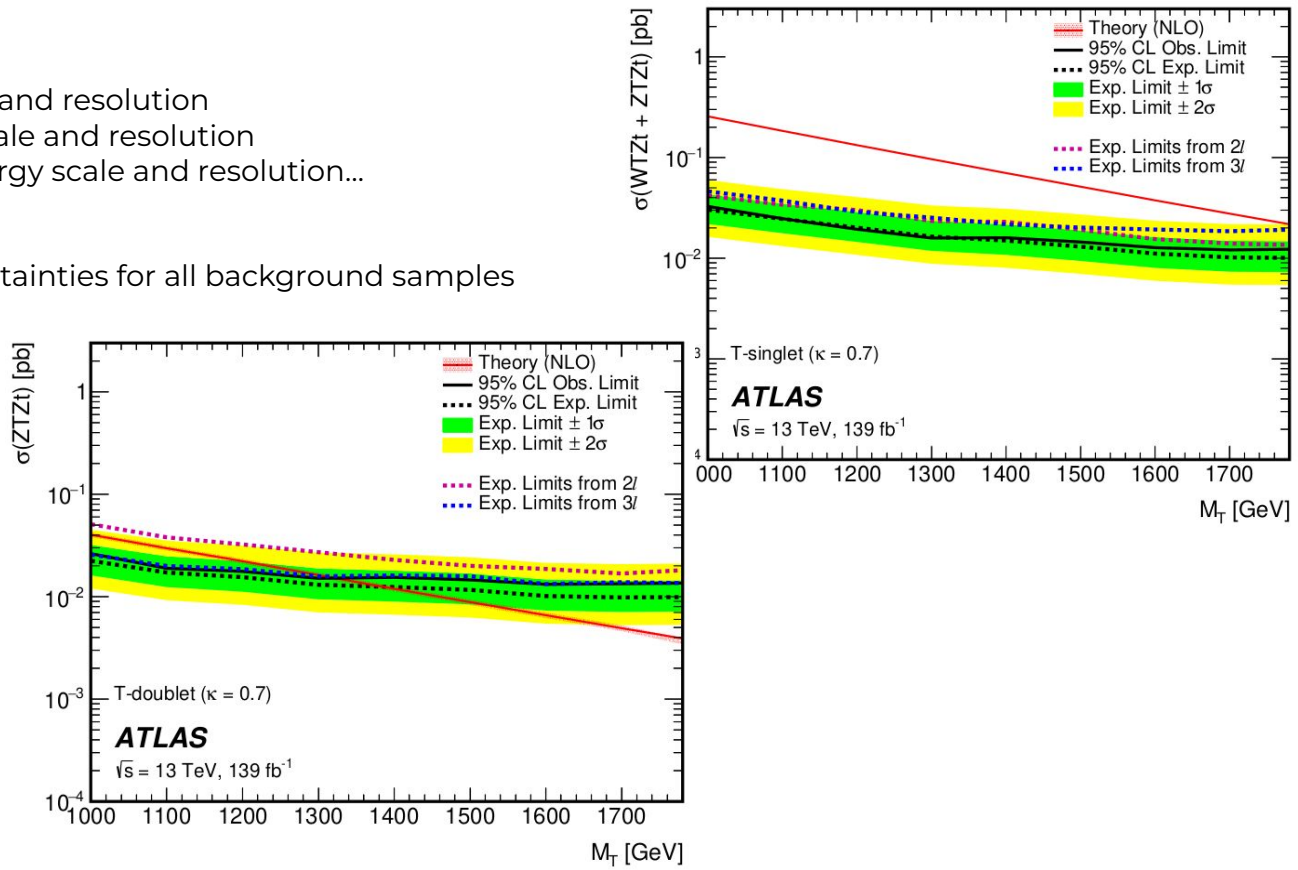
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Systematic uncertainties

- Experimental sources:
 - electron energy scale and resolution
 - muon momentum scale and resolution
 - flavor tagging, jet energy scale and resolution...
- Theoretical sources:
 - cross section
 - other modeling uncertainties for all background samples
- Jets misidentified as leptons

Observed and Expected limits at 95% on total cross-section

- $k=0.7$
- Singlet representation
- Doublet representation



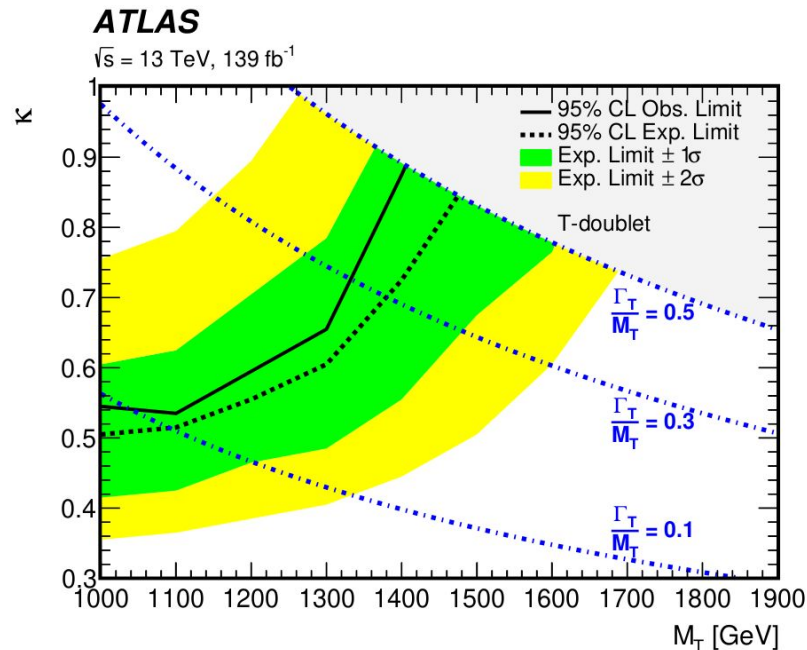
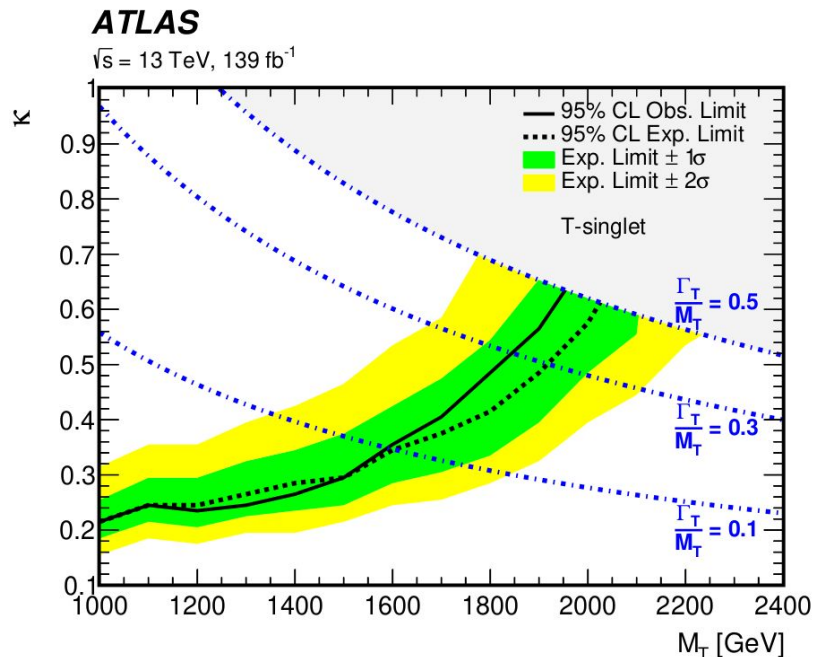
$T' \rightarrow Zt$ (multileptonic)

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[1-lepton channel](#)

[B->bH \(bb\)](#)

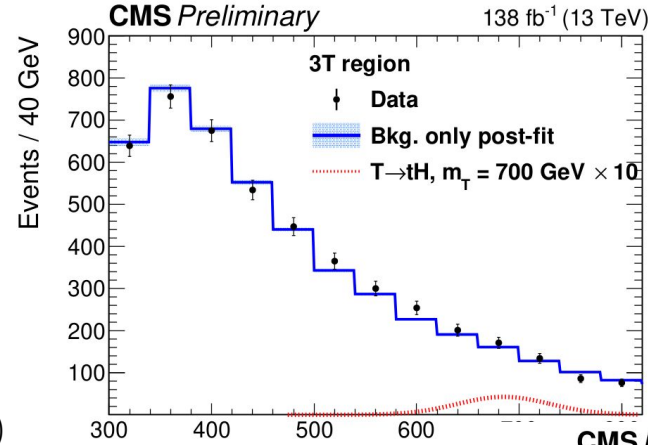
Observed and expected limits at 95% CL on the top partner coupling as a function of the T mass



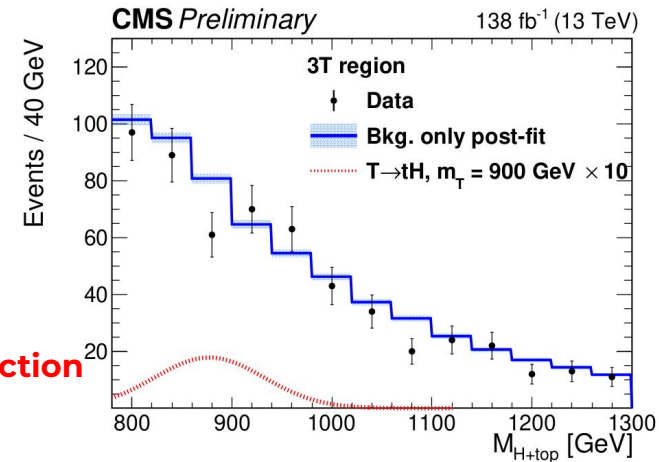
The strongest exclusion is observed for singlet representation with ξ_{WV} approx 0.5 where masses up to 1975 GeV are excluded at relative decay width of $\Gamma_T/M_T=0.5$ for the top partner.

$T' \rightarrow Ht / Zt$

- For masses of the VLQs from 600 - 1200 GeV
- Branching Ratios \mathcal{B} :
 - T' : $\mathcal{B}(Zt, Ht, Wb) \approx (0.25, 0.25, 0.5)$
- Final state signature:
 - 5 jets, single production 2 additional jets
3 of them b-jets
 - $P_T > 400$ GeV (2016)
 - $P_T > 300$ GeV (2017 & 2018)
 - m_T up to 700 GeV (low-mass selection)
 - m_T above 800 GeV (high-mass selection)
- Main Bkg process:
 - multijet
 - tt+ jets
- Systematic Uncertainties
 - Trigger efficiency
 - Jet energy and resolution uncertainties
 - b tagging efficiency scale factor for jets
- Invariant mass reconstructed from 5 jets is used as the main discriminating variable

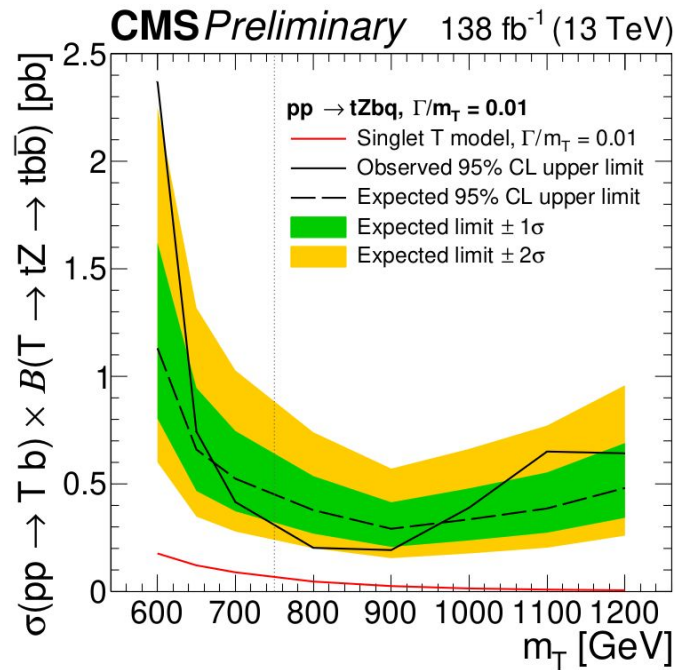
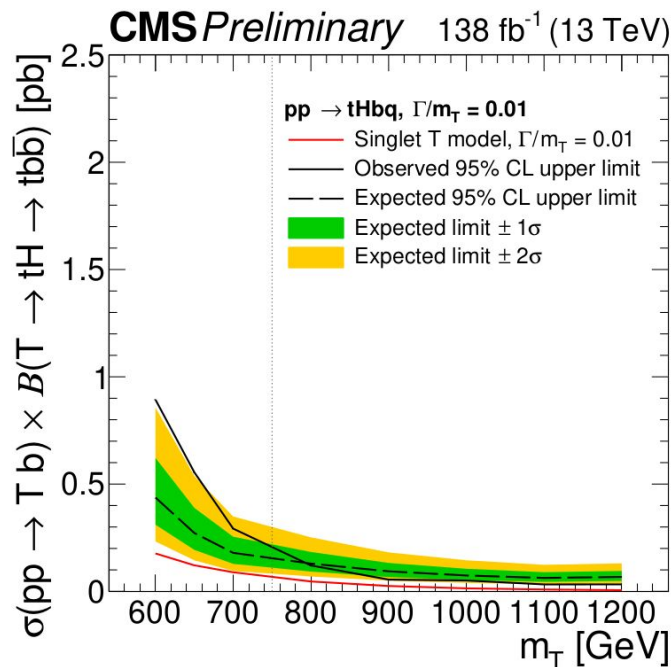


Low-Mass selection
designed to avoid distorting the 5-jet invariant mass distribution and producing artificial peaks (see backup).



High-Mass selection

- Expected and Observed 95% CL upper limits on the cross-section for associated production with a b for final states tHbq and tZbq, for T masses from 600 - 1200 GeV.



- Excess in the tH final state found in [\[1909.04721\]](#), is not observed with a larger dataset. The limits are stronger than those in the previous search by at least a factor of three.

4 Conclusions

Conclusions

- Several studies were performed by ATLAS and CMS
- No significant deviations from the SM predictions are observed
Mass ranges have been excluded at 95% CL.
- Many more searches in other decay channels are in progress
- The search of VLQs conducted by ATLAS & CMS continues to explore, improve and innovate for all the possible decay channels
- This is just the tip of the iceberg. Both ATLAS and CMS have huge programs on searches of VLQs.

Conclusions

- Several studies were performed by ATLAS and CMS
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- Many more searches in other decay channels
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- This is just the tip of the iceberg. Both ATLAS and CMS have huge programs on searches of VLQs.

Very heavy fermions

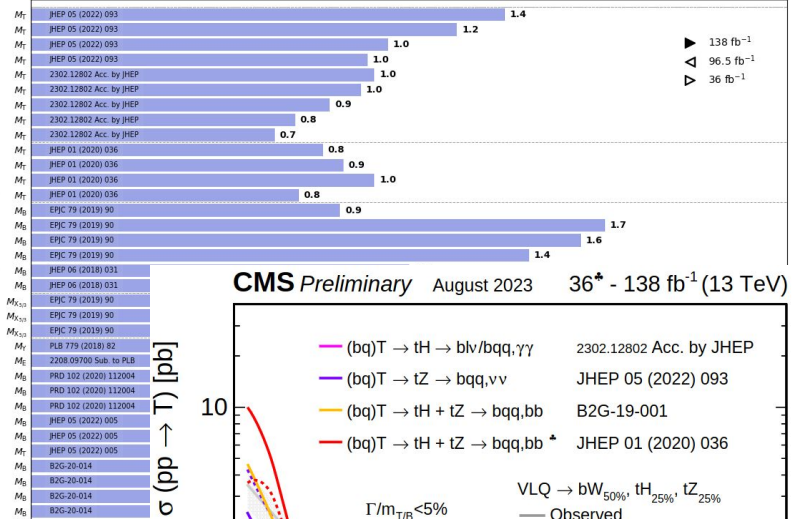
Decay Channel	Model
(qb)T	$b Z t (Z \rightarrow \nu\nu)$ ($\Gamma/\Gamma_{\text{SM}}=0.3$, Singlet)
	$b Z t (Z \rightarrow \nu\nu)$ ($\Gamma/\Gamma_{\text{SM}}=0.2$, Singlet)
	$b Z t (Z \rightarrow \nu\nu)$ ($\Gamma/\Gamma_{\text{SM}}=0.1$, Singlet)
	$b t H (H \rightarrow \gamma\gamma)$ ($\Gamma/\Gamma_{\text{SM}}=0.05$, Singlet)
	$b t H (H \rightarrow \gamma\gamma)$ ($\Gamma/\Gamma_{\text{SM}}=0.04$, Singlet)
	$b t H (H \rightarrow \gamma\gamma)$ ($\Gamma/\Gamma_{\text{SM}}=0.03$, Singlet)
	$b t H (H \rightarrow \gamma\gamma)$ ($\Gamma/\Gamma_{\text{SM}}=0.02$, Singlet)
	$b t H (H \rightarrow \gamma\gamma)$ ($\Gamma/\Gamma_{\text{SM}}=0.01$, Singlet)
	$t t H (H \rightarrow b\bar{b})$ ($\Gamma/\Gamma_{\text{SM}}=0.3$, Doublet)
	$t t H (H \rightarrow b\bar{b})$ ($\Gamma/\Gamma_{\text{SM}}=0.1$, Singlet)
	$t t H (H \rightarrow b\bar{b})$ ($\Gamma/\Gamma_{\text{SM}}=0.05$, Singlet)
	$t t W \rightarrow \text{lep} + \text{jets}$ ($\Gamma/\Gamma_{\text{SM}}=0.1$, LH)
(qb)T/qbIB	$b W \rightarrow \text{lep} + \text{jets}$ ($\Gamma/\Gamma_{\text{SM}}=0.3$, LH)
	$b W \rightarrow \text{lep} + \text{jets}$ ($\Gamma/\Gamma_{\text{SM}}=0.2$, LH)
	$b W \rightarrow \text{lep} + \text{jets}$ ($\Gamma/\Gamma_{\text{SM}}=0.1$, LH)
	$b H b (H \rightarrow b\bar{b})$ ($\Gamma/\Gamma_{\text{SM}}=0.3$, Doublet)
	$b H b (H \rightarrow b\bar{b})$ ($\Gamma/\Gamma_{\text{SM}}=0.2$, Doublet)
	$t W t \rightarrow \text{lep} + \text{jets}$ ($\Gamma/\Gamma_{\text{SM}}=0.3$, LH)
(qb)X	$t W t \rightarrow \text{lep} + \text{jets}$ ($\Gamma/\Gamma_{\text{SM}}=0.2$, LH)
	$t W t \rightarrow \text{lep} + \text{jets}$ ($\Gamma/\Gamma_{\text{SM}}=0.1$, LH)
	$Y_{43} Y_{43} \rightarrow b W b W \rightarrow f \nu q \bar{q} q \bar{q}$
Pair prod.	$\rightarrow Y_{43} Y_{43} \rightarrow 4b \tau \tau \nu \nu \nu$
	$\rightarrow BB \rightarrow b \bar{q} q b \bar{q} (B(tZ) = 1)$
	$\rightarrow BB \rightarrow b \bar{q} q b \bar{q} (B(tH) = 1)$
	$\rightarrow BB \rightarrow b \bar{q} q b \bar{q}$ (Singlet)
	$\rightarrow BB \rightarrow \text{lep} + \text{jets}$ (Doublet)
	$\rightarrow BB \rightarrow \text{lep} + \text{jets}$ (Singlet)
	$\rightarrow TT \rightarrow \text{lep} + \text{jets}$ (Singlet and Doublet)
	$\rightarrow BB \rightarrow \text{lep} + \text{jets} (B(tH) = 1)$
	$\rightarrow BB \rightarrow \text{lep} + \text{jets} (B(tZ) = 1)$
	$\rightarrow BB \rightarrow \text{lep} + \text{jets}$ (Doublet)

Overview of CMS B2G Results

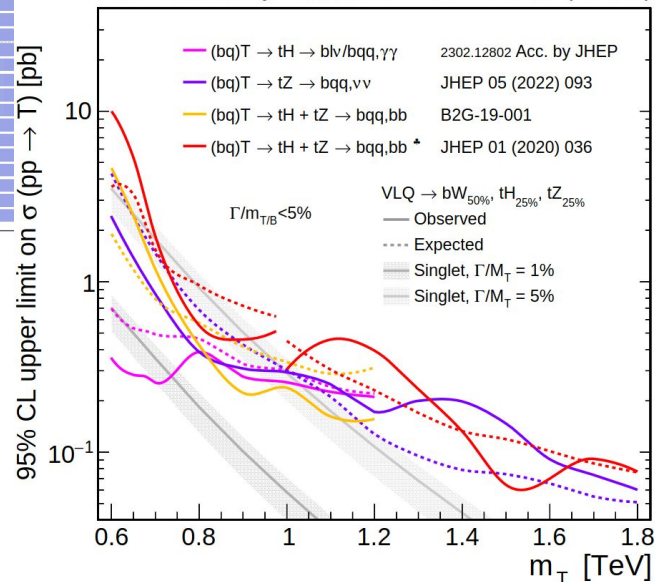
August 2023

CMS Preliminary

36 – 138 fb⁻¹ (13 TeV)



CMS Preliminary August 2023 36* - 138 fb⁻¹ (13 TeV)



https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsB2G/comblimits_VLQ_Tb_narrow_Journalsquare.pdf

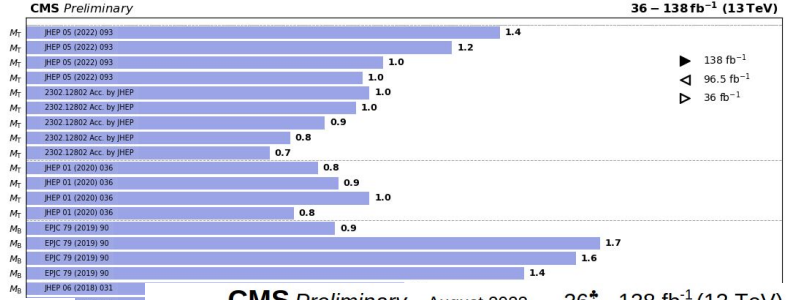
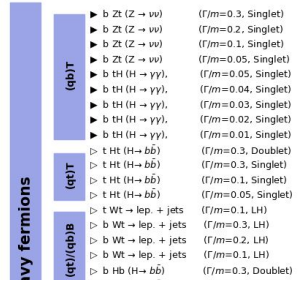
Conclusions

Overview of CMS B2G Results

August 2023

36 - 138 fb⁻¹ (13 TeV)

- Several studies were performed by ATLAS and CMS
- No significant deviations from the SM prediction were observed
- Mass ranges have been excluded at 95% CL.
- Many more searches are ongoing



ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2023

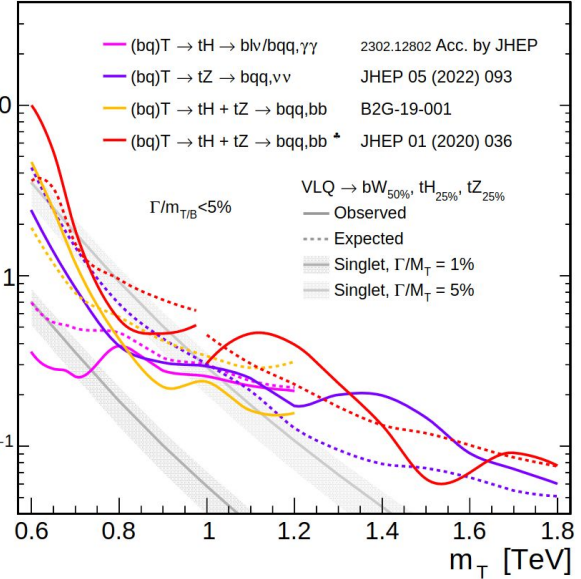
Model	ℓ, γ	Jets ^b	E_{min}^{jet}	$\mathcal{L} dt = \int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$	Limit	Reference
Extra dimen.	ADD $G_{\mu} + \delta G$	1-4j	Yes	139	8.6 TeV	$\mu = 2$
ADD nonrenorm ZZ	2j	-	Yes	36.7	8.6 TeV	$n = 3$ HLZ NLO
ADD BH multilet	2j	-	Yes	139	8.6 TeV	$n = 6$
ADD BH multilet	2j	-	Yes	3.6	8.6 TeV	$n = 6, M_{\text{pl}} = 3 \text{ TeV}$ not BH
RT $G_{\mu} + \delta y$	2j	-	Yes	139	8.6 TeV	$k_{\text{eff}} = 0.1$
BuK RS $G_{\mu} + WW/Z$	multi-channel	-	Yes	38.1	8.6 TeV	$\Gamma_{\text{max}} = 15\%$
BuK RS $G_{\mu} + t$	1 μ, τ	$\geq 1b, \geq 1b, \geq 1b$	Yes	38.1	8.6 TeV	$\text{TeV} \leq \mu, \tau \leq 10^4 \text{ TeV}$
ZUED $\delta g_{\mu\mu}$	1 μ, τ	$\geq 1b, \geq 1b$	Yes	36.1	1.8 TeV	
Change bosons	SSM $Z' \rightarrow \ell\ell$	2 μ, τ	-	139	Z' mass	
SSM $Z' \rightarrow \nu\nu$	2 ν	-	Yes	36.1	2.0 TeV	
Leptophobic $Z' \rightarrow bb$	2 b	-	Yes	139	2.1 TeV	
Leptophobic $Z' \rightarrow tt$	2 t	-	Yes	139	4.1 TeV	$\Gamma_{\text{max}} = 12\%$
SSM $W' \rightarrow \ell\nu$	1 ℓ	-	Yes	139	4.4 TeV	
SSM $W' \rightarrow \nu\nu$	1 ν	-	Yes	139	5.0 TeV	
SSM $W' \rightarrow bb$	2 b	-	Yes	139	4.4 TeV	
HVT $W' \rightarrow WZ$ model B	0, 2 μ, τ	2j/1j	Yes	139	4.0 TeV	
HVT $W' \rightarrow WZ$ model C	0, 2 μ, τ	2j/1j	Yes	139	4.0 TeV	
HVT $W' \rightarrow WZ$ model B	1 μ, τ	2j/1j	Yes	139	3.0 TeV	340 GeV
LRSM $W' \rightarrow \mu\nu$	2 μ	1, 2	Yes	80	5.0 TeV	
CI	CI $qqqq$	2j	-	37.0	2.8 TeV	
CI $\ell\ell qq$	2 μ, τ	1b	-	139	3.8 TeV	
CI $qqbb$	2 b	1b	-	139	1.8 TeV	
CI $qqbb$	2 b	1b	-	139	2.0 TeV	
CI $tttt$	$\geq 1 \mu, \tau$	$\geq 1b, \geq 1b$	-	139	5.0 TeV	
DM	Axial-vector med. (Dirac DM)	-	-	21	139	$\mu = 0.25, g_{\mu\mu} = 1, m_{\text{pl}} \geq 10 \text{ TeV}$
Pseudo-scalar med. (Dirac DM)	0, 2 μ, τ, γ	1-4j	Yes	139	378 GeV	$g_{\mu\mu} = 1, m_{\text{pl}} \geq 10 \text{ GeV}$
Vector med. Z' -DM (Dirac DM)	0, 2 μ, τ, γ	2b	Yes	139	378 GeV	$g_{\mu\mu} = 1, m_{\text{pl}} \geq 100 \text{ GeV}$
Pseudo-scalar med. 2HDM a_1	multi-channel	-	Yes	139	800 GeV	$\tan\beta \geq 1, g_{\mu\mu} = 1, m_{\text{pl}} \geq 10 \text{ GeV}$
LO	Scalar LO 1 st gen	2 μ, τ	$\geq 2j$	Yes	139	1.0 TeV
Scalar LO 2 nd gen	2 μ, τ	$\geq 2j$	Yes	139	1.0 TeV	
Scalar LO 3 rd gen	1 μ, τ	2b	Yes	139	1.0 TeV	
Scalar LO 3 rd gen	0, 2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.0 TeV	
Scalar LO 3 rd gen	0, 2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.0 TeV	
Scalar LO 3 rd gen	0, 2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.0 TeV	
Vector LO mix gen	2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	2.0 TeV	
Vector LO 3 rd gen	2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	2.0 TeV	
Vector-like fermions	VD $T \rightarrow Z + X$	2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.6 TeV
VD $B \rightarrow W + X$	2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.3 TeV	
VD $T \rightarrow W + X$	2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.7 TeV	
VD $T \rightarrow H + Z$	1 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.8 TeV	
VD $T \rightarrow W + X$	1 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.8 TeV	
VD $B \rightarrow H + X$	0, 2 μ, τ	$\geq 1b, \geq 1b$	Yes	139	2.0 TeV	
VD $T \rightarrow Z + H$	1 μ, τ	$\geq 1b, \geq 1b$	Yes	139	2.0 TeV	
Exotic ferm.	Exotic quark $q' \rightarrow q\gamma$	1 γ	1j	Yes	139	8.7 TeV
Exotic quark $q' \rightarrow q\gamma$	1 γ	1j	Yes	36.7	5.3 TeV	
Exotic quark $q' \rightarrow q\gamma$	1 γ	1j	Yes	139	1.8 TeV	
Exotic lepton ℓ'	2 ν	$\geq 2j$	-	139	4.6 TeV	
Other	Type III Seesaw	2, 3, 4 μ, τ	$\geq 2j$	Yes	139	$M_{\text{pl}} \text{ mass}$
LRSM Majorana	2 μ, τ	2j	Yes	139	910 GeV	$m(W_2) = 4.1 \text{ TeV}, g_{\mu\mu} = 0$
Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$	2, 3, 4 μ, τ (SS)	various	Yes	139	350 GeV	UV production
Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2, 3, 4 μ, τ (SS)	various	Yes	139	350 GeV	UV production
Multi-charged particles	1 μ, τ	$\geq 1b, \geq 1b$	Yes	139	1.0 TeV	UV production, $g_{\mu\mu} = 5e$
Magnetic monopoles	-	-	-	34.4	1.9 TeV	UV production, $g_{\mu\mu} = 5e, \text{spin } 3/2$

* Only a selection of the available mass limits on new states or phenomena is shown.
^a Small-radius (large-radius) jets are denoted by the letter (j) (\bar{j}).
^b Small-radius (large-radius) jets are denoted by the letter (j) (\bar{j}).

ATLAS Preliminary $\sqrt{s} = 13 \text{ TeV}$

- The search of VL explore, improve channels
- This is just the tip of huge programs

CMS Preliminary August 2023 36* - 138 fb⁻¹ (13 TeV)

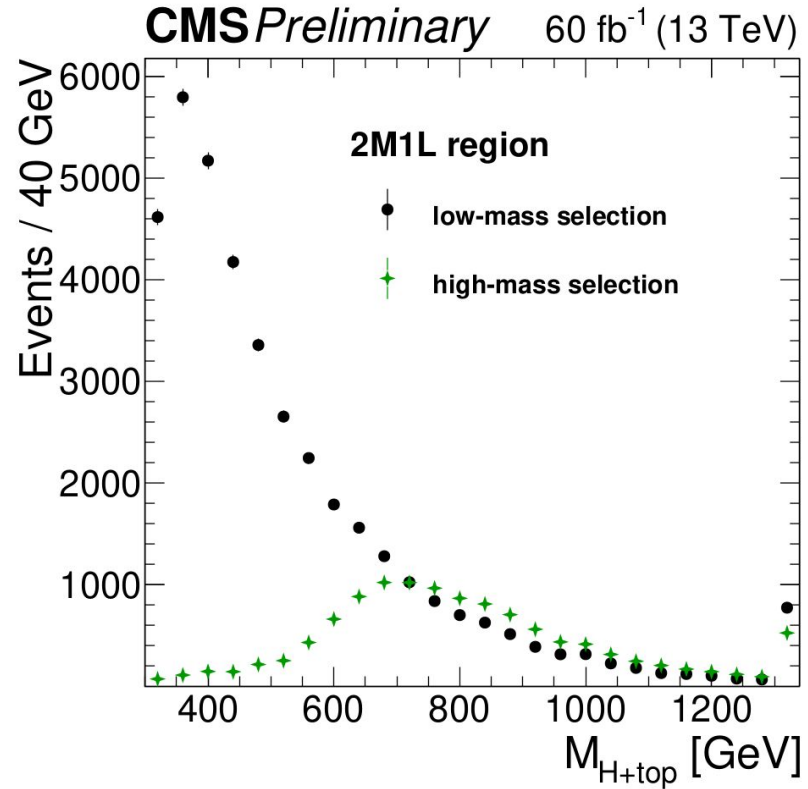




Thank
You

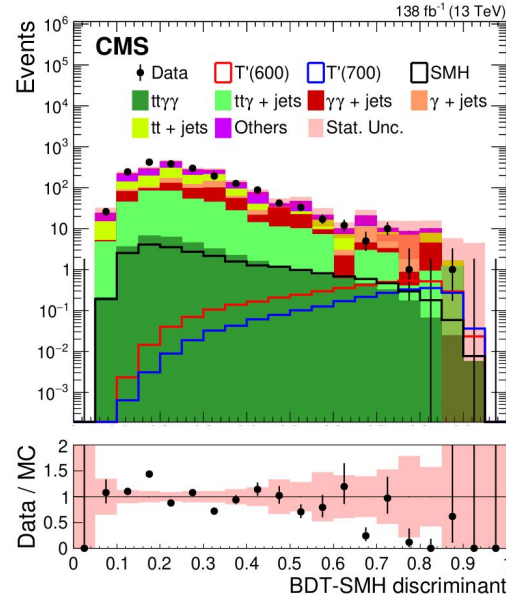


- Low mass requirements are chosen to avoid distorting the five-jet invariant mass distribution and producing artificial peaks.
- The five-jet invariant mass distribution in the 2M1L region after the high-mass and low-mass selections in 2018 dataset.
- The low-mass selection results in a mass distribution that is smoothly falling, unlike the high-mass selection.

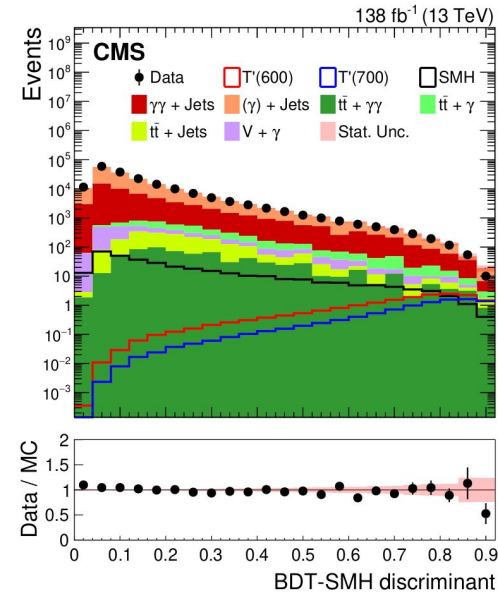


$T' \rightarrow Ht \quad (H \rightarrow \gamma\gamma)$

- For masses of the VLQs from 600 - 1200 GeV
- Branching Ratios \mathcal{B} :
 - T' : $\mathcal{B}(Zt, Ht, Wb) \approx (0.25, 0.25, 0.5)$
- Final state signature:
 - At least 2 γ :
 - $P_T(\gamma_1) > 30 \text{ GeV}$; $P_T(\gamma_2) > 18$ or $>22 \text{ GeV}$
 - $m_{\gamma\gamma} > 90 \text{ GeV}$
 - Jet candidates $P_T > 25 \text{ GeV}$ and $|\eta| < 4.5$
 - Photons and leptons well separated
- Leptonic Category:
 - 2 photons
 - 1 lepton at least
 - 1 b-tagged jet
 - Bkg: QCD, γ +jets and $\gamma\gamma$ +jets 25% of the bkg yield
- Hadronic Category:
 - 3 jets
 - 1 b-tagged jet
 - Bkg: $t\bar{t}H$ with $H \rightarrow \gamma\gamma$



Boosted Decision Trees (BDT) used to separate signal from the SM Higgs boson backgrounds



$T' \rightarrow Ht \quad (H \rightarrow \gamma\gamma)$

[2302.12802](https://cds.cern.ch/record/230212802)

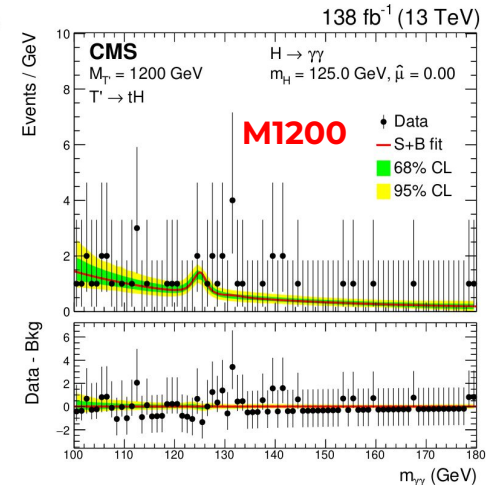
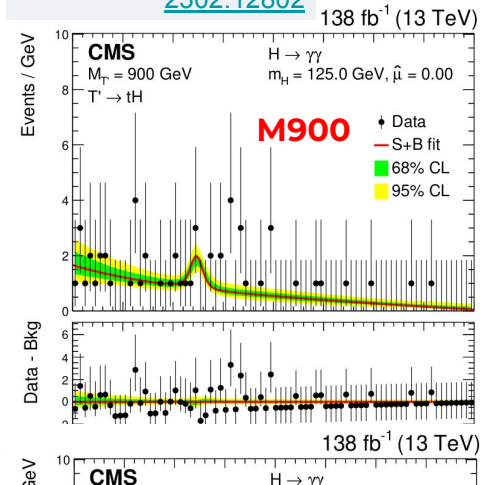
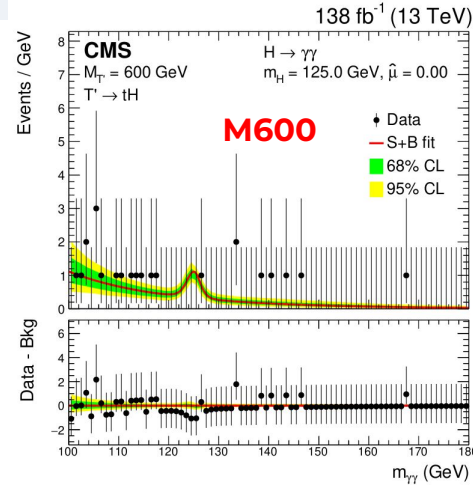
Uncertainties associated are less than 5% on the final parameter of interest

Data distributions and the corresponding signal+bkg model fits to $m_{\gamma\gamma}$

$M_{T'} = 600 \text{ GeV}$

$M_{T'} = 900 \text{ GeV}$

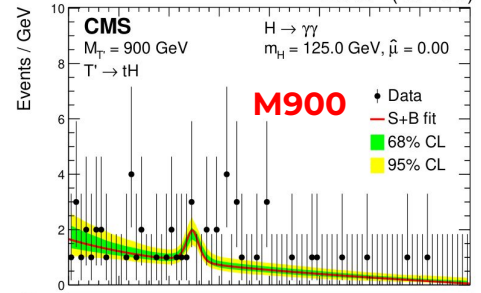
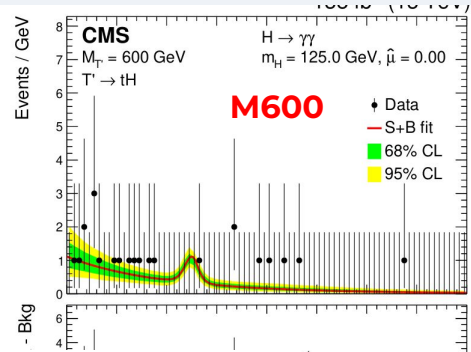
$M_{T'} = 1200 \text{ GeV}$



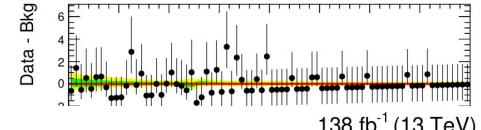
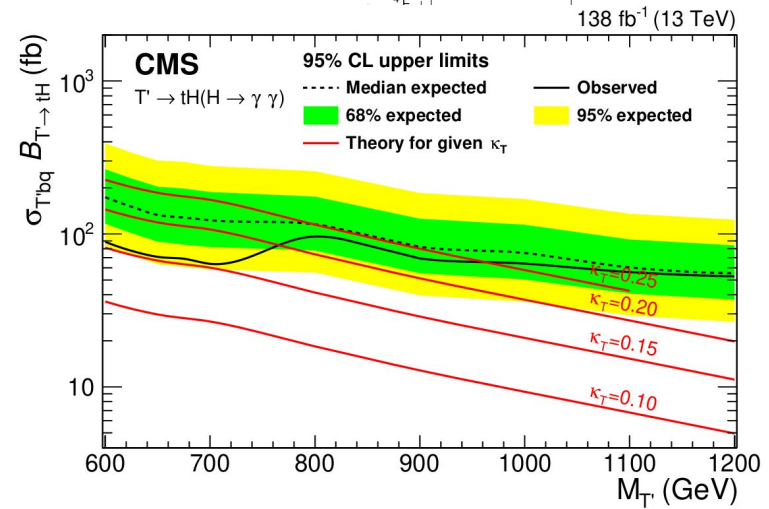
$T' \rightarrow Ht \quad (H \rightarrow \gamma\gamma)$

2302.12802 138 fb⁻¹ (13 TeV)

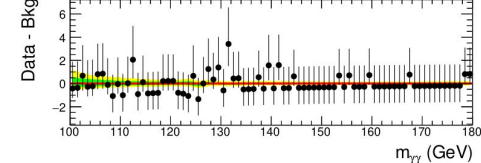
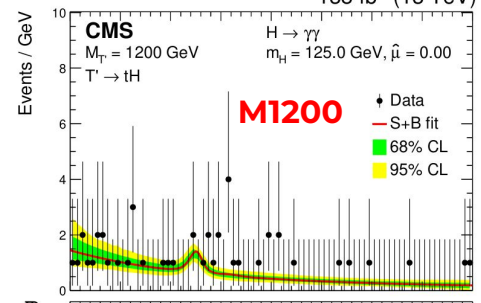
- Uncertainties associated are less than 5% on the final parameter of interest
- Data distributions and the corresponding signal+bkg model fits to $m_{\gamma\gamma}$
 - $M_{T'} = 600$ GeV
 - $M_{T'} = 900$ GeV
 - $M_{T'} = 1200$ GeV



- Combined upper limits 95% CL on $\sigma_{T'bq} \mathcal{B}_{T' \rightarrow tH}$ as a function of $M_{T'}$.



- This technique leads to an increased sensitivity to T' mass values up to 1 TeV with respect to the previous searches

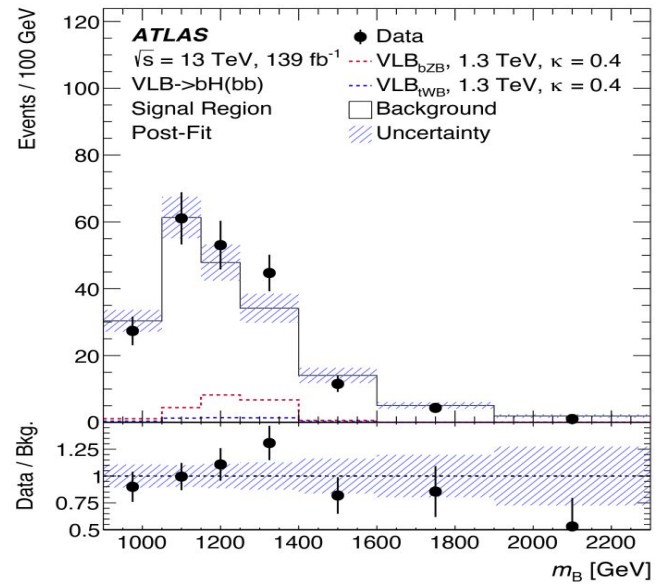


$B' \rightarrow bH (b \bar{b})$

2308.02595

- For masses of the VLQs from 1 TeV to 2 TeV
- Branching Ratios \mathcal{B} :
 - $\mathcal{B}(Zb, Hb, Wt) \approx (0.25, 0.25, 0.5)$
- Final state signature:
 - High P_T Higgs boson decaying into $b b^-$
 $P_T > 480$ GeV, $|\eta| > 2.0$
 - Energetic jet from the b-quark from VLB
 - Softer forward jet from the spectator quark
 - Veto over leptons (e or μ).
- Dominant Bkg: Multijet production
 - "Others": tt^- shows small contributions
- Systematic uncertainties
 - Signal and Bkg uncertainties

	forward Jets	
≥ 1	C	A (SR)
0	D	B
	NO	YES
		b -tagged Small- R jet

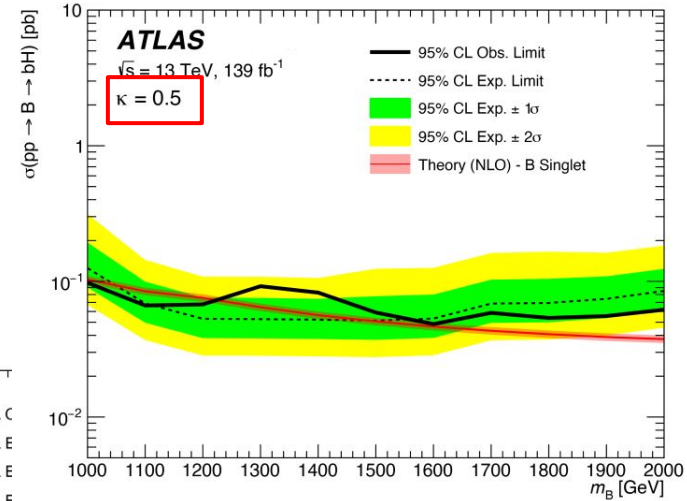
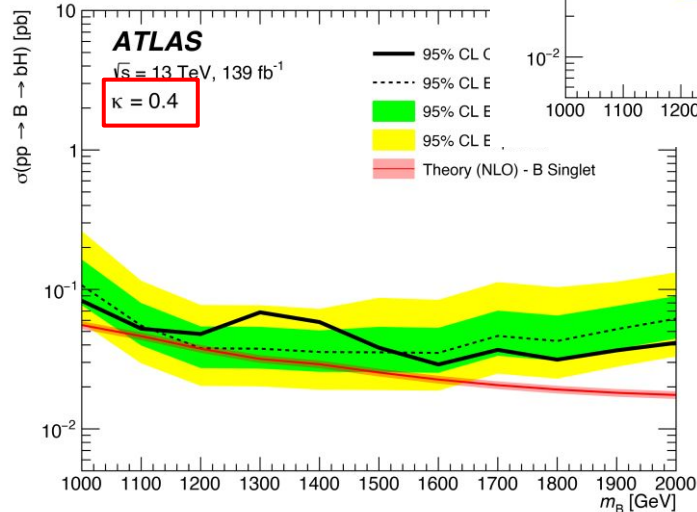
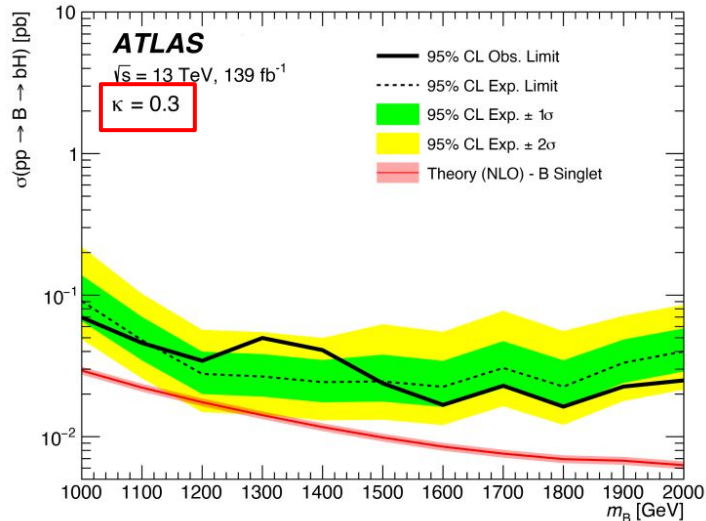


- A:** Events passing the full selection
- B:** Events lacking fwd jet
- C:** Events lacking b-tagged jet
- D:** Events lacking both fwd and b-tagged jets

$B' \rightarrow bH (b \bar{b})$

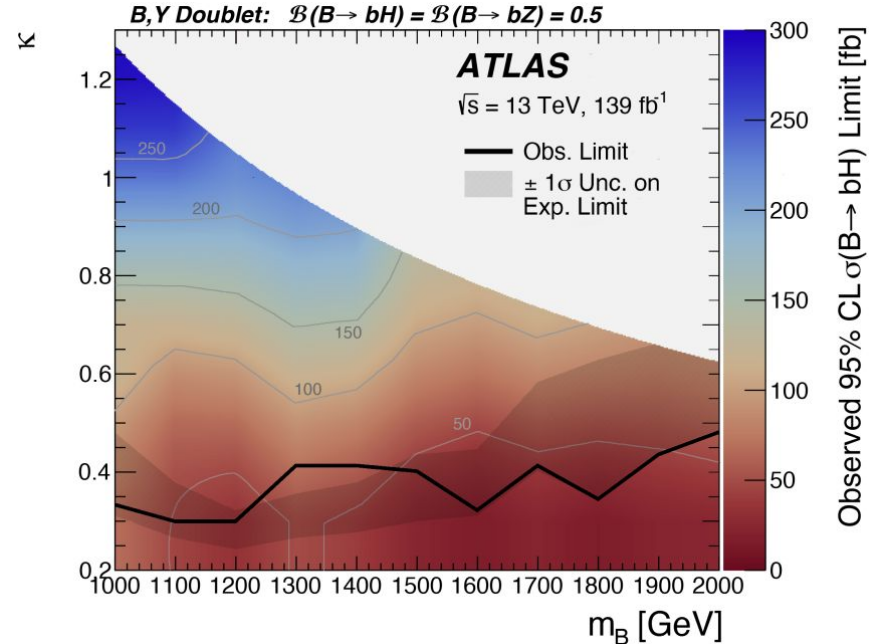
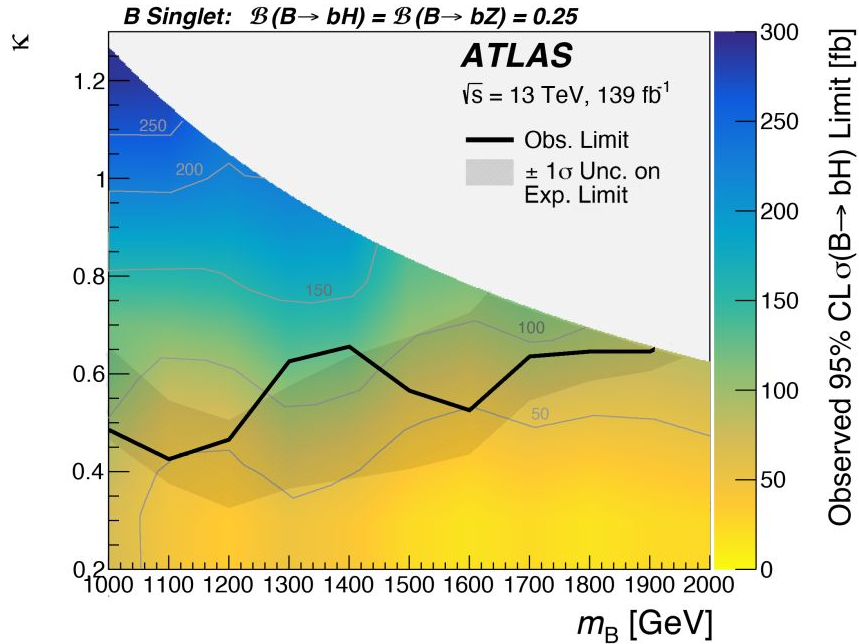
2308.02595

- Expected and Observed 95% CL exclusion limits on the cross-section for single VLB production
- Higgs decay mode in the B' singlet
- Limits presented for three values of the coupling strength κ : 0.3, 0.4 and 0.5



$B' \rightarrow bH \ (b \bar{b})$

Expected and Observed exclusion limits on $\sigma(pp \rightarrow B' \rightarrow bH)$, as a function of the resonance mass and coupling strength k and relative width in the isospin-singlet and doublet scenarios.



Improvement by significantly expanding the region of the VLQ theoretical phase space explored and excluded by collider experiments.