Searches for new physics in top quark final states with the ATLAS experiment

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Recent results

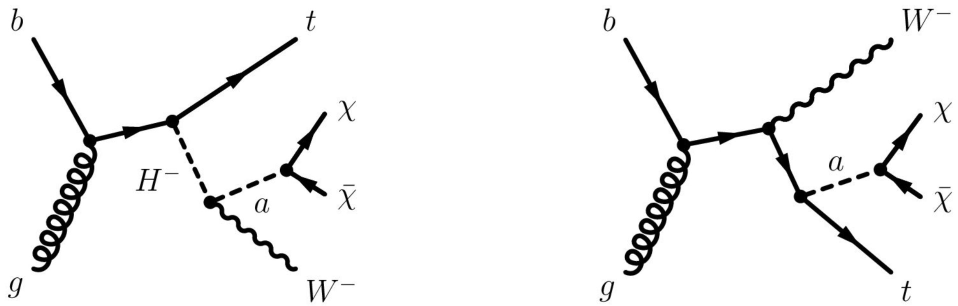
- Dark matter search in the tW+MET final state: ATLAS-CONF-2022-012
- Search for pair-produced scalar and vector LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons: ATLAS-CONF-2022-009
- Search for ttH/A→4-top production in multilepton final states: ATLAS-CONF-2022-008
- Heavy Higgs boson from g2HDM in multilepton plus b-jets final states, ATLAS-CONF-2022-039

Search for dark matter produced in association with a single top quark and an energetic W boson in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector

ATLAS-CONF-2022-012

Dark matter search in the tW+MET final state

- Dark matter search in a single-top final state
- Benchmark model 2HDM+a (JHEP05(2017)138 and 1712.03874)

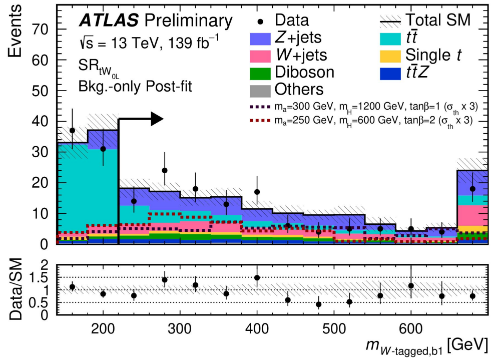


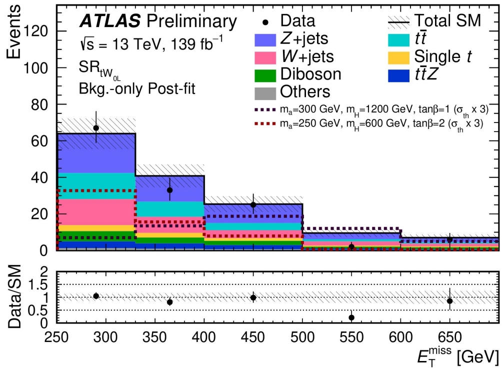
- Final state
  - 0 leptons (0L) or 1 lepton (1L) final states (2L covered by Eur. Phys. J. C 81 (2021) 860)
  - Jets from top and W decays
  - Large missing transverse energy (E_T^{miss}) due to dark-matter particles

Dark matter search in the tW+MET final state

0L final state strategy

- High E_T^{miss} from dark matter
- All-hadronic decays of t and W
- Expected boosted W for wide range of model parameters → W tagging
- At least one b jet from top decay
- Discriminating variable (binned in 5 bins of E_T^{miss}): $m_{W\text{-tagged,b1}}$





Dark matter search in the tW+MET final state

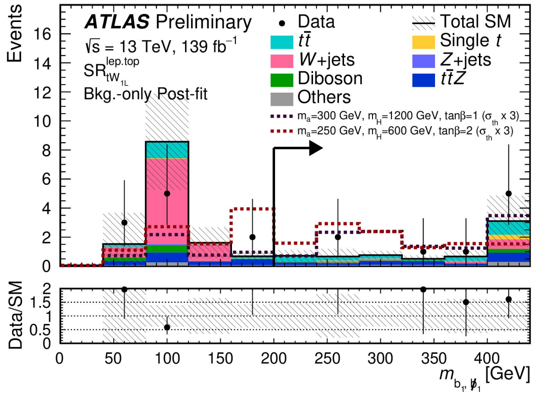
1L final state strategy

- Leptonic top: $m(b_1,j_1) > 200$ GeV
  - W(qq) expected boosted → using W-tagger to reconstruct W
  - Inclusive SR

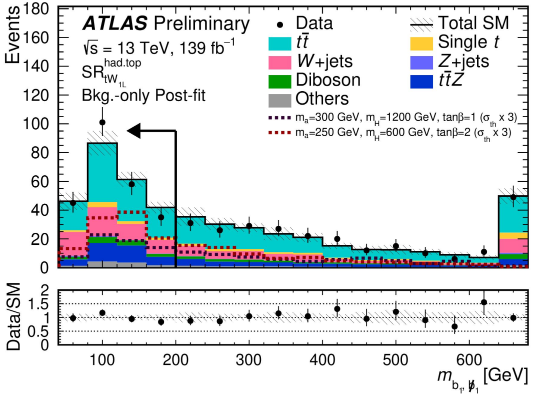
- Hadronic top: $m(b_1,j_1) < 200$ GeV
  - W from to less boosted
  - SR binned in MET (same as 0L)

Both 0L and 1L categories have CR to control ttbar, Z+jets and W+jets

Lep-top

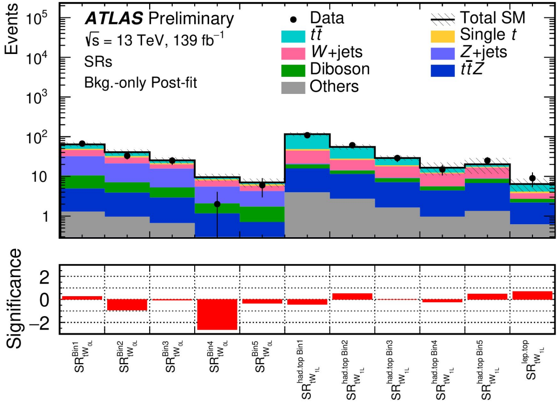


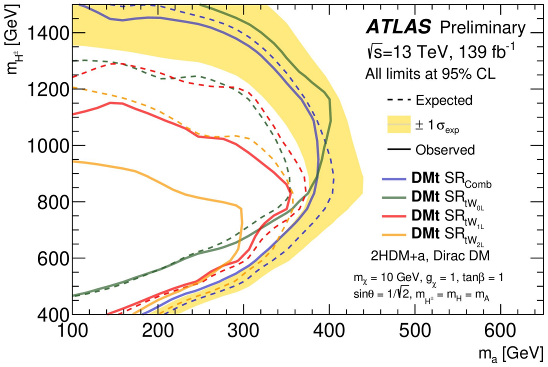
Had-top

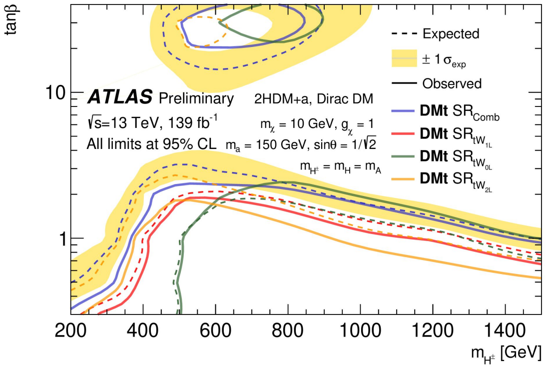


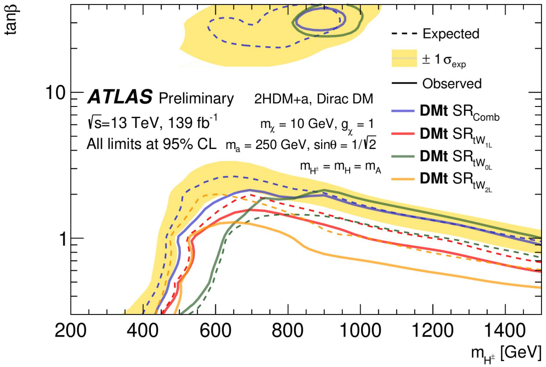
Dark matter search in the tW+MET final state

- Background-only fit: upper limits on the BSM number of events and the BSM fiducial cross-section
- Exclusion limits: combination of 0L+1L (this analysis) + 2L (EPJ C 81 (2021) 860)
  - Limit up to m_H = 1.5 TeV and m_a = 100 GeV if tanβ=1
    - m_a=150 GeV: m_H-tanβ scan → Exclusion at high tanβ > 20
    - m_a=250 GeV: m_H-tanβ scan → Exclusion at tanβ=30, m_H = 900







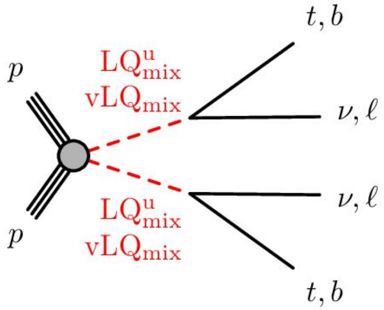


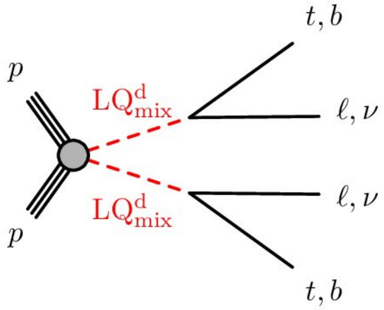
Search for pair-produced scalar and vector leptoquarks decaying into third-generation quarks and first- or second-generation leptons in pp collisions with the ATLAS detector

ATLAS-CONF-2022-009

LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons

- search for pair-produced cross-generational leptoquarks (LQ)
- benchmark models:
  - scalar up-type and down-type LQs
  - vector up-type LQs in Yang-Mills or minimal coupling scenario
  - couplings to t/b and l/v characterised by B(LQ → ql)
- motivated by flavour anomalies, measurements of anomalous magnetic moment of muons
- Focus on single lepton final state with at least 4 jets and hight E_T^{miss}

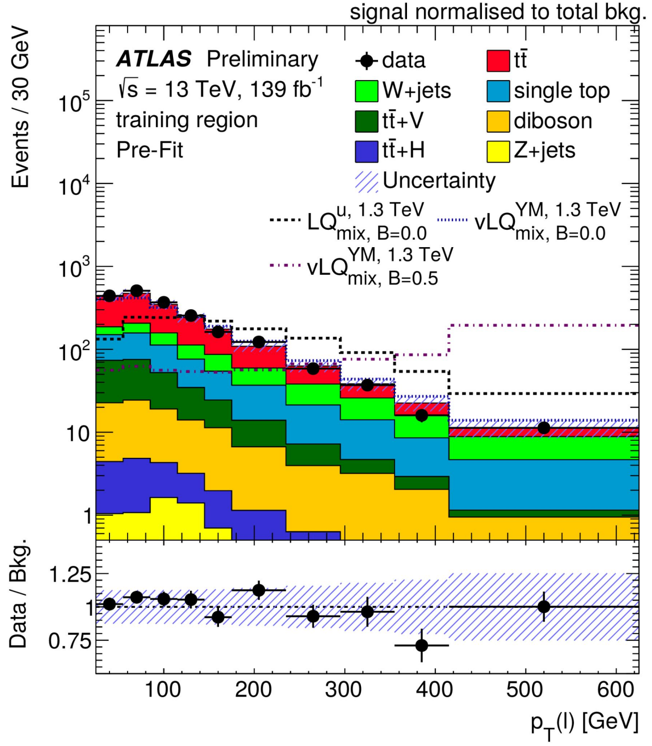




LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons

Analysis strategy:

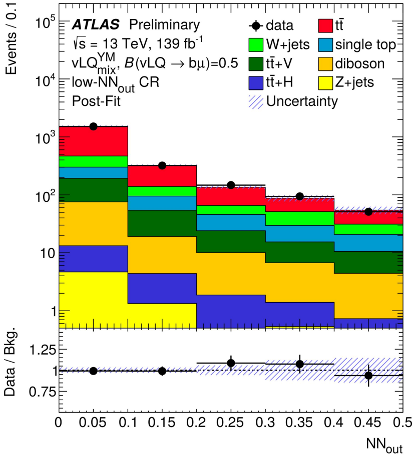
- Using NN output as discriminating variable
  - Dedicated training region enriched with signal
  - Neural networks for various signal hypotheses
  - In each training combined multiple mass hypotheses
- NN output defines SR and CR:
  - NNout > 0.5: SR (5 bins)
  - NNout < 0.5: CR (mostly ttbar events)
- Additional 2 CR:
  - W+jets CR
  - Single-top CR

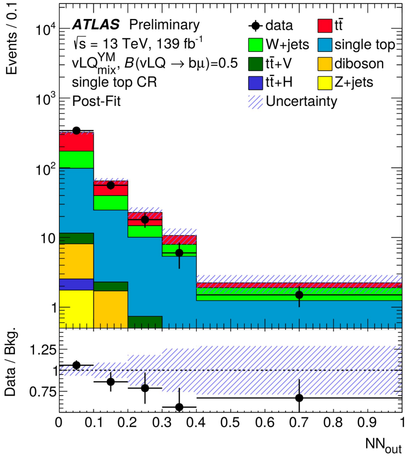


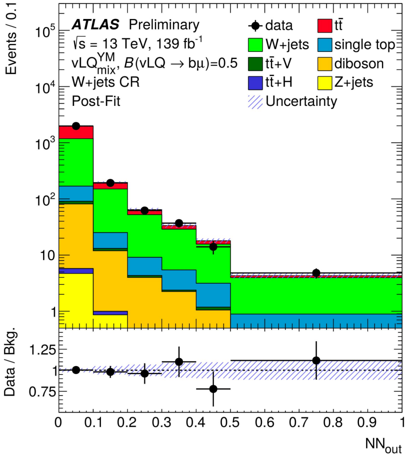
LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons

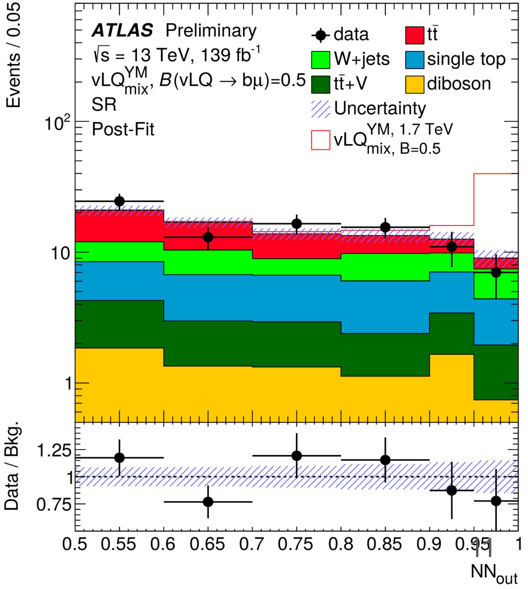
Fit results:

- simultaneous fit to the CR + low NN + single-top + Wjets CRs
- largest uncertainty from top modelling
- Example for vLQ DY with B=0.5



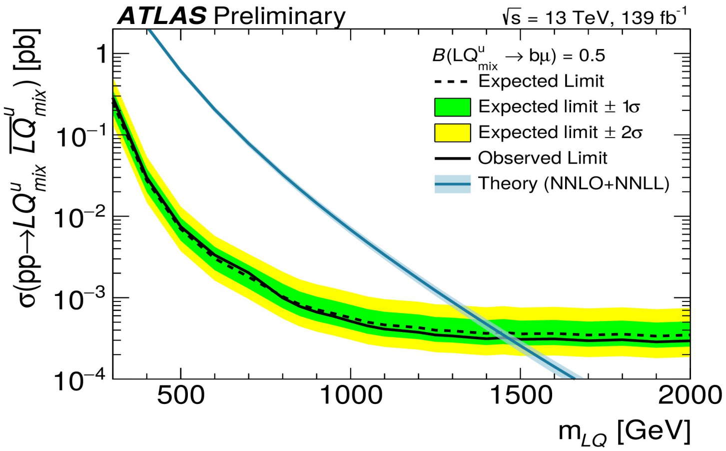


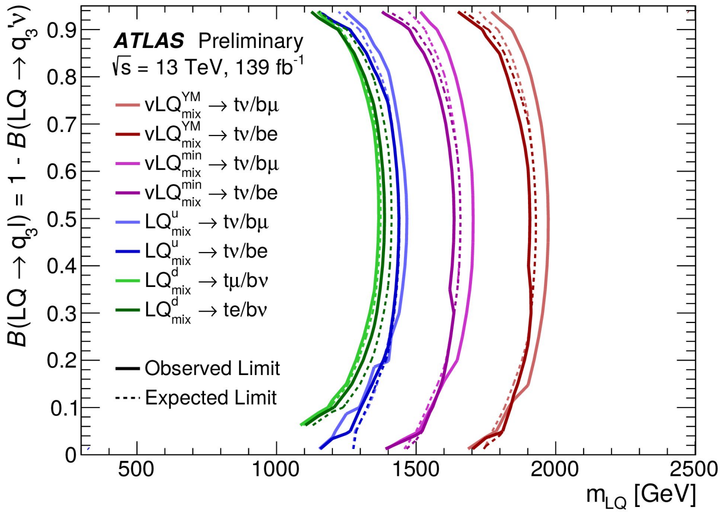




LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons

- limits reach up to 1980 GeV for vector LQs
- limits reach around 1400 GeV for scalar LQs
- Strictest limits for B = 0.5



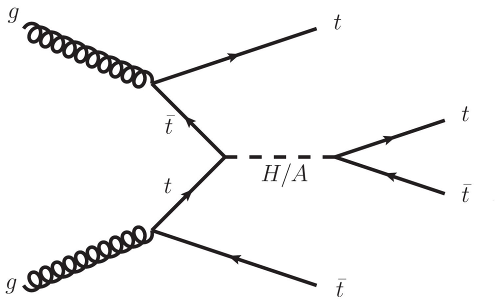


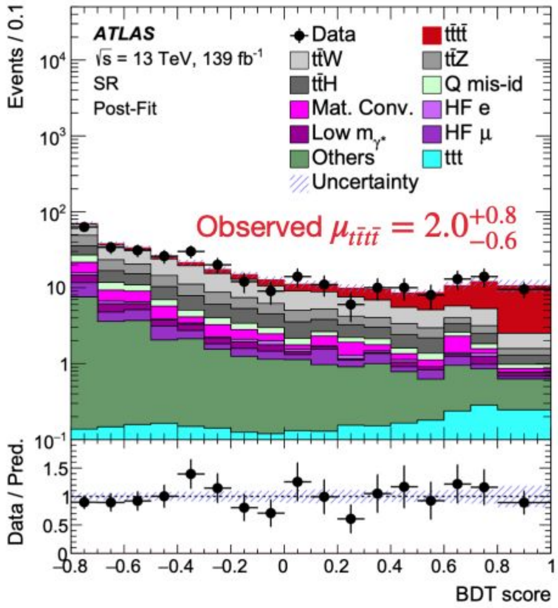
Search for $t\bar{t}H/A \rightarrow t\bar{t}t\bar{t}$ production in the multilepton final state in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

ATLAS-CONF-2022-008

ttH/A→4-top production in multilepton final states

- Analysis of 4-top events with 2 same-sign leptons or multiplepton final states
- Previous SM 4top analysis: EPJ C 80 (2020) 1085
  - Excess of data over SM expectation
- This analysis benchmark model:
  - 2HDM type-II ttH → 4top signal and interpretation on low tan(β) region in the alignment limit tan(β-α) → 1
  - all couplings are similar to the SM Higgs boson



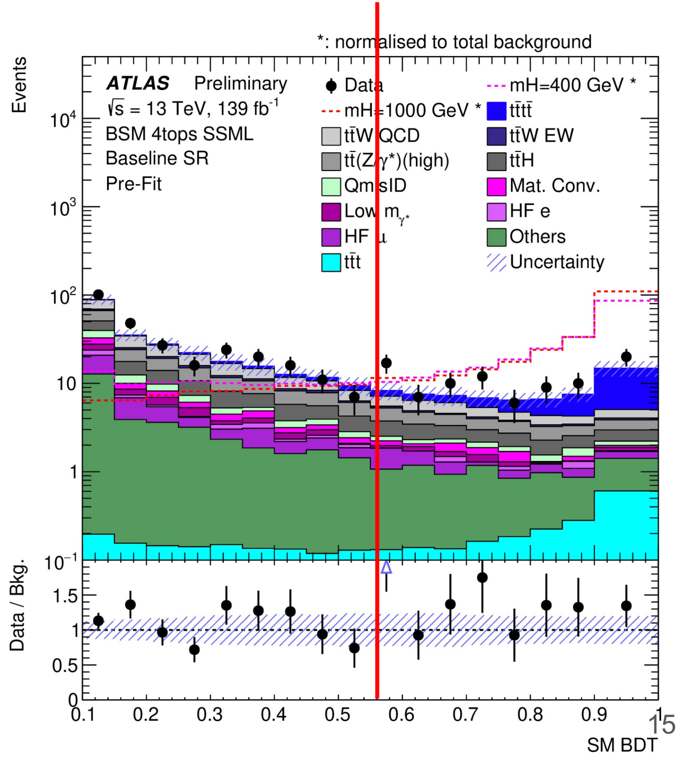


ttH/A→4-top production in multilepton final states

Analysis strategy

- High jet and b-jet multiplicities and high H_T
- Same-sign di-lepton category (SS):
  - same-sign ee, eμ, and μμ events
- Multi-lepton category (ML):
  - >= 3 leptons (e or μ)
  - eee, eeμ, eμμ, μμμ
  - Z-veto (based on the invariant mass)
- Using BDT output as a discriminating variable
  - SM BDT to select 4-top-like events. Used to define SR
  - mass-parametrized BSM BDT (pBDT) to separate BSM 4-top from the rest
- 4 more CRs to control heavy-flavour contribution, ttW contribution, and contribution from gamma conversions

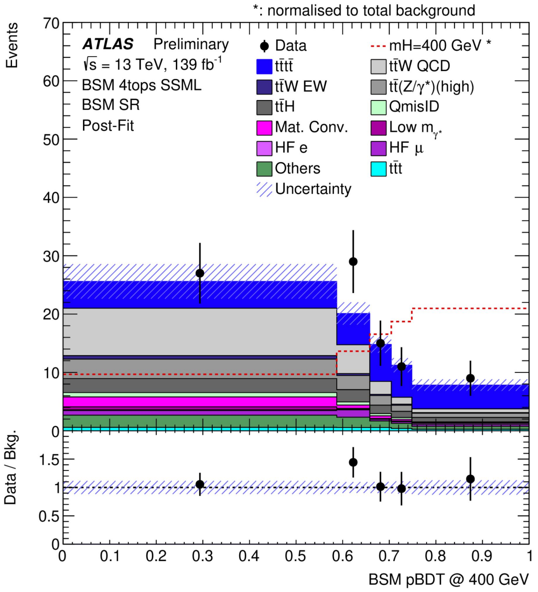
low-BDT CR BSM SR (>0.55)



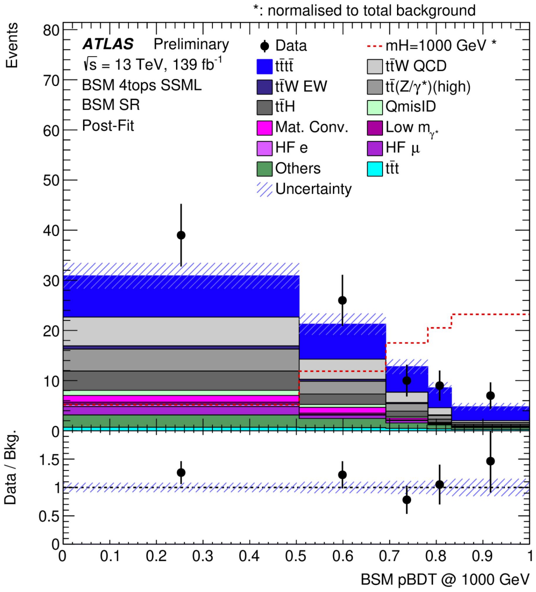
ttH/A→4-top production in multilepton final states

Fit results (background-only fit): no significant excess over SM expectation

m(H/A) = 400 GeV



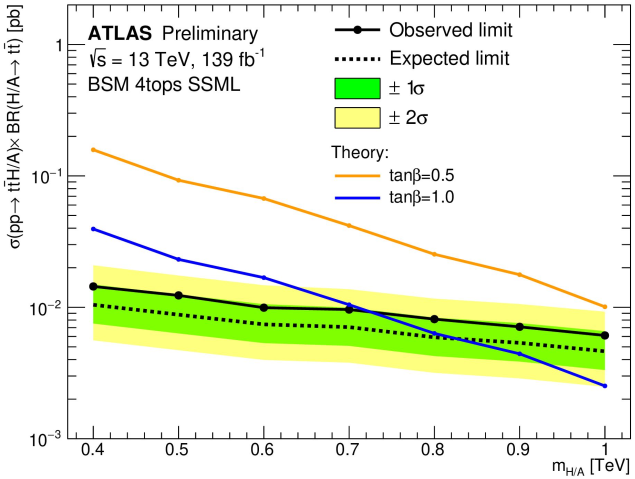
m(H/A) = 1 TeV



ttH/A→4-top production in multilepton final states

Results:

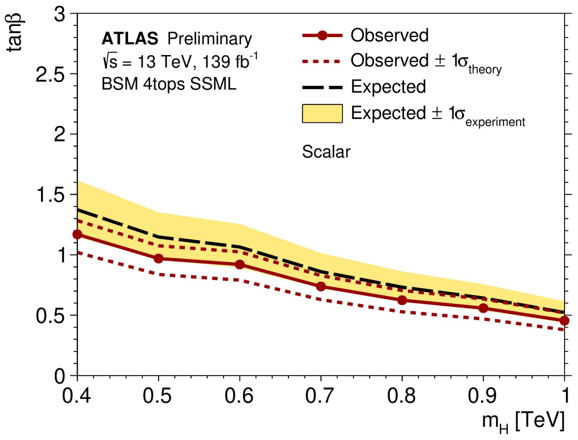
- 95% CL exclusion limits on cross-section of 2HDM type II scalar (H) and pseudo-scalar (A) Higgs boson
- The observed upper limits range between 14 fb and 6 fb for the studied mass range

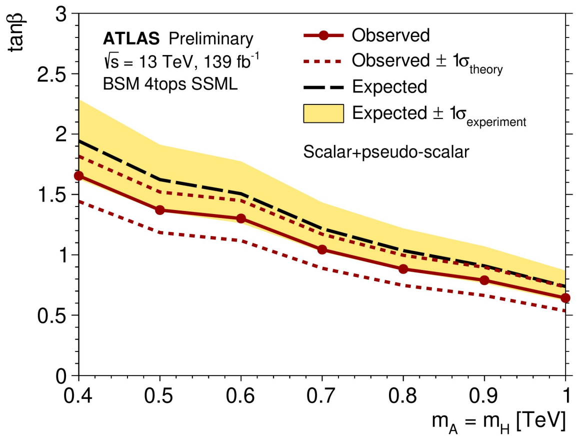


ttH/A→4-top production in multilepton final states

Results:

- Three scenarios of interpretation are considered:
  - Only ttH or only ttA: excluded values of tan(β) range between 0.5 (for large m) to 1.2 (small m)
  - ttH + ttA: excluded values of tan(β) range between 0.6 to 1.6



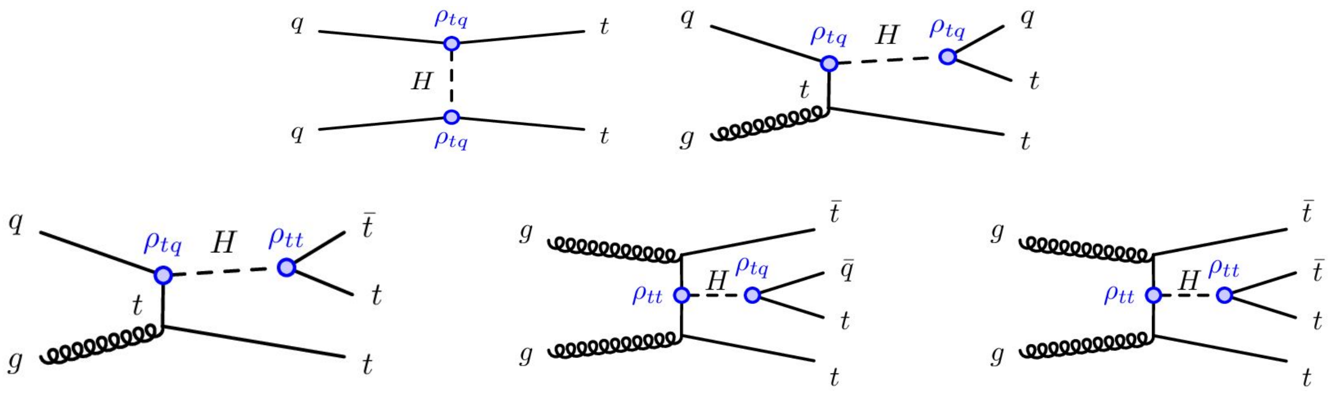


Search for heavy Higgs bosons from a g2HDM in multilepton plus b-jets final states in pp collisions at 13 TeV with the ATLAS detector

ATLAS-CONF-2022-039

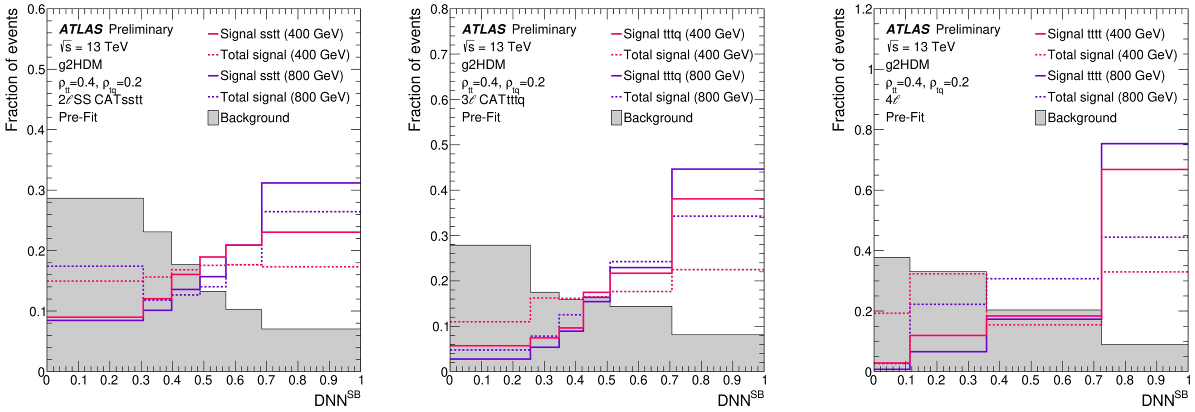
Heavy Higgs boson in multilepton plus b-jets final states

- Analysis of multi-lepton + b-jets final state
- Benchmark model:
  - A general 2HDM including off-diagonal Yukawa couplings for the second doublet
  - Heavy sub-TeV bossons: scalar H and pseudo-scalar A
  - can address several shortcomings of the SM: electroweak baryogenesis, strong CP problem, flavour problem, etc



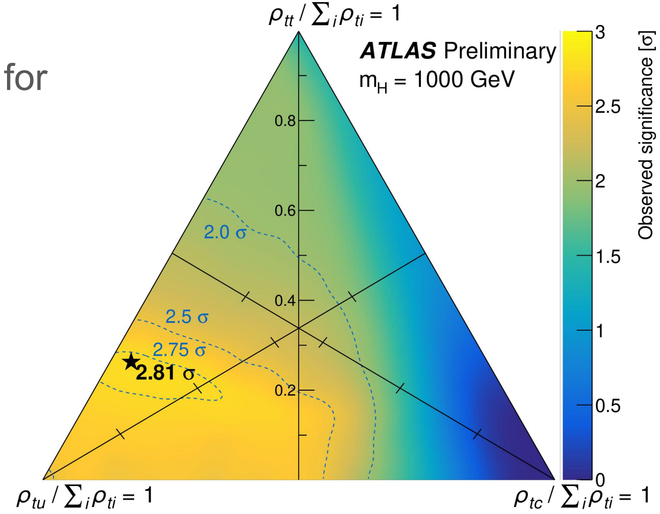
Heavy Higgs boson in multilepton plus b-jets final states

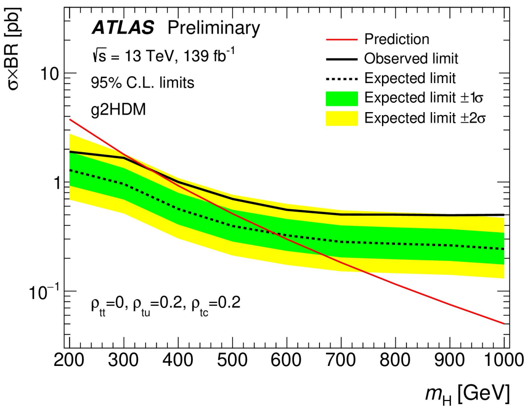
- Analysis strategy
  - Event categorization based on lepton multiplicity and total charge and output of the multi-category deep neural network (2l same-sign, 3l, and 4l combined with NN categories: ss tt, ttq, tttq, and tttt)
  - Multi-output deep neural network (DNN^{cat}) trained to categorize BSM signal
  - Second DNN^{sb} in each category to suppress SM background
  - Control regions to control main backgrounds: WZ, ttZ, conversion lep., and non-promp HF lep.

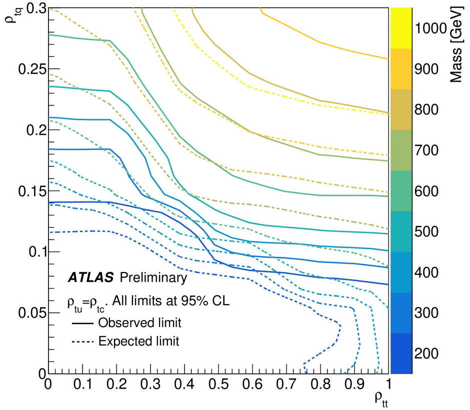


Heavy Higgs boson in multilepton plus b-jets final states

- Results
  - Scan the full 4D planes of couplings vs mass - search for new physics (small excess for m_H = 1 TeV)
  - 95% CL upper limits on the σ x BR for all the 2HDM signals together
  - Excluded masses as a function of two couplings
  - Bonus: SUSY RPV reinterpretation







Conclusions

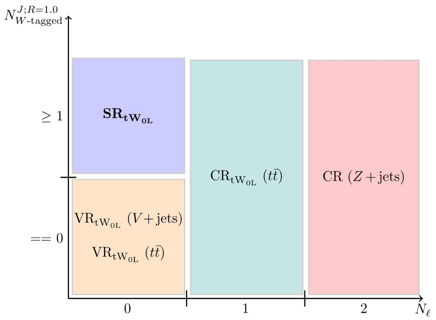
Conclusions

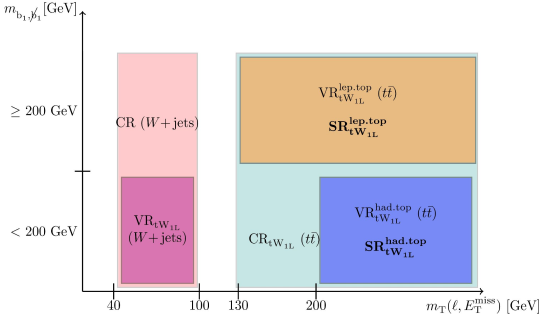
- Four recent BSM searches with top quark in the final state were presented
- The tW+MET final state was probed
  - The reach of the search was extended using the 0-lepton final state and reconstruction of boosted hadronically decaying W bosons
  - The exclusion limits of the 2HDM+a benchmark model were extended using a combination with the previous measurement
- The search for a pair production of the leptoquarks with a subsequent decays into the 3rd generation quarks and light leptons was performed
  - The benchmark models were excluded for LQ masses ranging from 1.4 to 1.9 TeV
- 4-top events were analyzed in the same-sign di-lepton and multi-lepton final states
  - The 2HDM type-II model was used as a benchmark
  - Limits on the BSM signal cross-section was as a function of H/A mass were determined
- Limits on heavy Higgs boson in g2HBM model in multilepton plus b-jets final states were set

Backup slides

Dark matter search in the tW+MET final state

Signal regions definition:

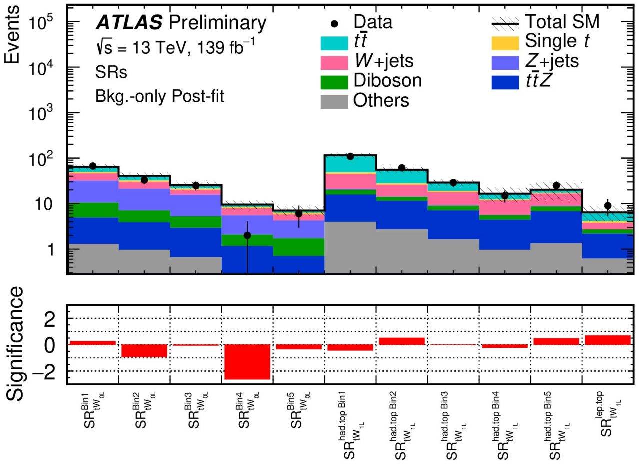




Variable	$\mathrm{SR_{tW_{0L}}}$	$\mathrm{SR^{lep.top}_{tW_{1L}}}$	$\mathrm{SR^{had.top}_{tW_{1L}}}$
Trigger	E_T^{miss}	E_T^{miss}	E_T^{miss}
E_T^{miss} [GeV]	≥ 250	≥ 250	≥ 250
$\mathcal{S}_{E_T^{miss}}$	≥ 14	≥ 15	-
$\min[\Delta\phi(\mathrm{jet}_{1-4}, E_T^{miss})]$	≥ 0.9	≥ 0.5	≥ 0.5
Number of baseline leptons	0	1	1
Number of signal leptons	0	1	1
$p_T^{\ell_1}$ [GeV]	-	≥ 30	≥ 30
Number of signal jets	≥ 4	≥ 2	≥ 3
$p_T^{j_1}$ [GeV]	≥ 100	≥ 50	≥ 50
$p_T^{j_2}$ [GeV]	≥ 60	≥ 30	≥ 30
$p_T^{j_3}$ [GeV]	≥ 60	-	≥ 30
$p_T^{j_4}$ [GeV]	≥ 40	-	-
Number of b-tagged jets	≥ 1	≥ 1	≥ 1
$p_T^{b_1}$ [GeV]	≥ 50	≥ 50	≥ 50
$p_T^{b_2}$ [GeV]	≤ 50	≤ 50	≤ 50
Number of W-tagged jets ($N^{J;R=1.0}_{W\text{-tagged}}$)	≥ 1	≥ 1	-
$p_T^{J;R=1.0}$ [GeV]	≥ 200	≥ 200	-
$\Delta R_{W-\mathrm{tagged},b_1}$	≥ 1.0	-	-
$m_{W-\mathrm{tagged},b_1}$ [GeV]	≥ 220	-	-
$m_T(b_1, E_T^{miss})$ [GeV]	≥ 180	-	-
m_{b_1,b_1} [GeV]	-	≥ 200	≤ 200
$m_T(\ell, E_T^{miss})$ [GeV]	-	≥ 130	≥ 200
am_{T2} [GeV]	-	≥ 180	≥ 180
m_W^{had} [GeV]	-	-	≥ 60

Dark matter search in the tW+MET final state

- Background-only fit: upper limits on the BSM number of events and the BSM fiducial cross-section
- Background uncertainty dominated by W-tagging, jet, and theory uncertainties (V+jets, ttbar and single top)



Region	E_T^{miss} bins
0L SR	[250, 330, 400, 500, 600,inf] GeV
1L leptonic-top SR	Inclusive
1L hadronic-top SR	[250, 300, 350, 400, 450,inf] GeV

Signal channel	Obs.	SM. exp	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B
$\mathrm{SR}_{\mathrm{tW_{0L}}}(E_T^{\mathrm{miss}} \geq 250\ GeV)$	133	147 ± 15	0.27	37.2	$39.4^{+16.9}_{-7.2}$	0.33
$\mathrm{SR}_{\mathrm{tW_{0L}}}(E_T^{\mathrm{miss}} \geq 330\ GeV)$	66	82.8 ± 8.9	0.14	20.1	$25.8^{+8.2}_{-6.0}$	0.17
$\mathrm{SR}_{\mathrm{tW_{0L}}}(E_T^{\mathrm{miss}} \geq 400\ GeV)$	33	42.0 ± 5.6	0.10	13.9	$18.5^{+6.5}_{-5.0}$	0.22
$\mathrm{SR}_{\mathrm{tW_{0L}}}(E_T^{\mathrm{miss}} \geq 500\ GeV)$	8	16.6 ± 2.3	0.04	5.0	$9.9^{+4.1}_{-2.2}$	0.04
$\mathrm{SR}_{\mathrm{tW_{0L}}}(E_T^{\mathrm{miss}} \geq 600\ GeV)$	6	7.0 ± 1.7	0.05	6.6	$7.4^{+2.9}_{-1.5}$	0.38
$\mathrm{SR}^{\mathrm{had.top}}_{\mathrm{tW_{1L}}}(E_T^{\mathrm{miss}} \geq 250\ GeV)$	239	237 ± 25	0.43	59.4	59^{+20}_{-15}	0.51
$\mathrm{SR}^{\mathrm{had.top}}_{\mathrm{tW_{1L}}}(E_T^{\mathrm{miss}} \geq 300\ GeV)$	130	121 ± 17	0.35	48.8	43^{+15}_{-12}	0.65
$\mathrm{SR}^{\mathrm{had.top}}_{\mathrm{tW_{1L}}}(E_T^{\mathrm{miss}} \geq 350\ GeV)$	69	65.8 ± 8.8	0.20	27.9	$25.9^{+9.2}_{-6.7}$	0.59
$\mathrm{SR}^{\mathrm{had.top}}_{\mathrm{tW_{1L}}}(E_T^{\mathrm{miss}} \geq 400\ GeV)$	40	36.7 ± 9.0	0.18	24.6	$23.8^{+9.7}_{-4.3}$	0.59
$\mathrm{SR}^{\mathrm{had.top}}_{\mathrm{tW_{1L}}}(E_T^{\mathrm{miss}} \geq 450\ GeV)$	25	20.2 ± 8.4	0.17	23.0	$19.1^{+7.0}_{-3.8}$	0.72
$\mathrm{SR}^{\mathrm{lep.top}}_{\mathrm{tW_{1L}}}$	9	6.4 ± 2.3	0.08	10.9	$8.7^{+2.6}_{-1.8}$	0.78

Observed number of data events and expected SM contribution from the background-only fit

The 95% CL upper limits on the visible cross section ($\langle\epsilon\sigma\rangle_{obs}^{95}$) and on the number of signal events (S_{obs}^{95}), and the limit on signal events, given the expected number of bkg events (S_{exp}^{95})

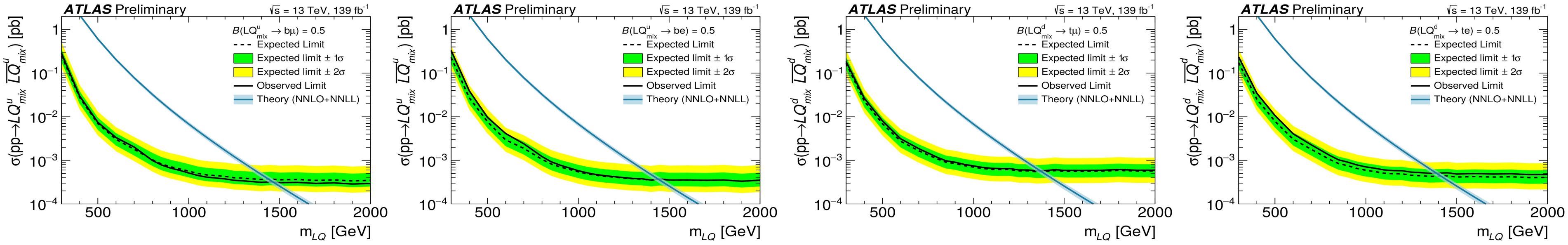
LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons

Selection

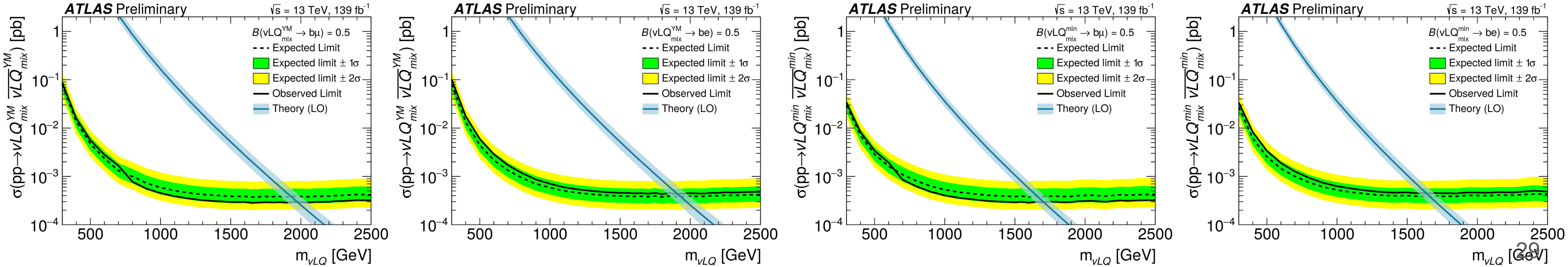
Preselection			
$E_{\mathrm{T}}^{\mathrm{miss}}$ triggers			
= 1 signal lepton			
veto on additional baseline leptons			
$E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$			
≥ 4 small-R jets			
$\Delta\Phi(E_{\mathrm{T}}^{\mathrm{miss}}, j_{1,2}) > 0.4$			
top reweighting region	W+jets CR	single top CR	training region
$n_b \geq 1$	$n_b = 1$	$n_b = 2$	$n_b \geq 1$
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) \geq 120\,\mathrm{GeV}$	$50\,\mathrm{GeV} \leq m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 120\,\mathrm{GeV}$	$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 120\,\mathrm{GeV}$	$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) \geq 120\,\mathrm{GeV}$
$am_{T2} < 200\,\mathrm{GeV}$	$am_{T2} > 200\,\mathrm{GeV}$	$am_{T2} > 200\,\mathrm{GeV}$	$am_{T2} > 200\,\mathrm{GeV}$
-	t_{had} candidate veto	large-R jet veto	-
-	lepton charge = $+1e$	-	-
-	-	$\Delta R(b_1, b_2) > 1.2$	-

LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons

Cross-section limits on scalar LQs for B=0.5



Cross-section limits on vector LQs for B=0.5



LQs decaying to 3rd-gen quarks and 1st/2nd-gen leptons

NN variables

Variable	Description
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}})$	transverse mass of lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$
m_{eff}	scalar sum of the transverse momenta of leptons, jets, and $E_{\mathrm{T}}^{\mathrm{miss}}$
lepton flavour	flavour of the signal lepton
$p_{\mathrm{T}}(\ell)$	transverse momentum of the lepton
$m_{\mathrm{inv}}(b_1, \ell)$	invariant mass of leading-p_{T} b-jet and lepton
n_{lj}	reclustered large-R jet multiplicity
am_{T2}	asymmetric transverse mass
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	measure for the compatibility of the observed $E_{\mathrm{T}}^{\mathrm{miss}}$ with zero, taking resolutions of reconstructed objects into account
$m_T(b_1, E_{\mathrm{T}}^{\mathrm{miss}})$	transverse mass of leading-p_{T} b-jet and $E_{\mathrm{T}}^{\mathrm{miss}}$
$p_{\mathrm{T}}(t_{\mathrm{had}})$	transverse momentum of t_{had}
$\Delta\Phi(E_{\mathrm{T}}^{\mathrm{miss}}, b_2)$	azimuthal angle separation between $E_{\mathrm{T}}^{\mathrm{miss}}$ and subleading-p_{T} b-jet
$m_{\mathrm{inv}}(b_2, \ell)$	invariant mass of subleading-p_{T} b-jet and lepton
$\Delta\Phi(E_{\mathrm{T}}^{\mathrm{miss}}, b_1)$	azimuthal angle separation between $E_{\mathrm{T}}^{\mathrm{miss}}$ and leading-p_{T} b-jet
$\Delta\Phi(t_{\mathrm{had}}, \ell)$	azimuthal angle separation between t_{had} and lepton
$p_{\mathrm{T}}(b_1)$	transverse momentum of leading-p_{T} b-jet

ttH/A→4-top production in multilepton final states

Selection

Region	Channel	N_j	N_b	Other selection cuts	Fitted variable
CR Conv	$e^\pm e^\pm \,\|\|\, e^\pm \mu^\pm$	$4 \leq N_j < 6$	≥ 1	$m_{ee}^{CV} \in [0, 0.1]$ GeV $200 < H_T < 500$ GeV	m_{ee}^{PV}
CR HF e	$eee \,\|\|\, ee\mu$		$= 1$	$100 < H_T < 250$ GeV	Yield
CR HF μ	$e\mu\mu \,\|\|\, \mu\mu\mu$		$= 1$	$100 < H_T < 250$ GeV	Yield
CR $t\bar{t}W$	$e^\pm \mu^\pm \,\|\|\, \mu^\pm \mu^\pm$	≥ 4	≥ 2	$m_{ee}^{CV} \notin [0, 0.1]$ GeV, $\|\eta(e)\| < 1.5$ for $N_b = 2$, $H_T < 500$ GeV or $N_j < 6$; for $N_b \geq 3$, $H_T < 500$ GeV	$\sum p_T^\ell$
CR lowBDT	SS+3L	≥ 6	≥ 2	$H_T > 500$ GeV, SM BDT < 0.55	SM BDT
BSM SR	SS+3L	≥ 6	≥ 2	$H_T > 500$ GeV, SM BDT ≥ 0.55	BSM pBDT