BSM searches in top-quark sector by ATLAS and CMS

Suman Chatterjee
for the ATLAS and CMS Collaborations

HEPHY Vienna

17/05/2022

LHCP Conference 2022
~~Taipei, Taiwan~~ Online

Top quark as window to new physics

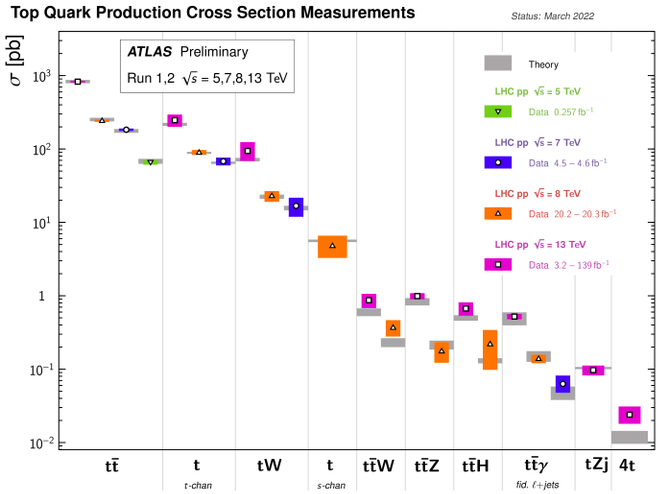
HEPHY
INSTITUT FÜR HOCHENERGIEPHYSIK

Top quark mass close to electroweak (EW) scale → Important role in EWSB

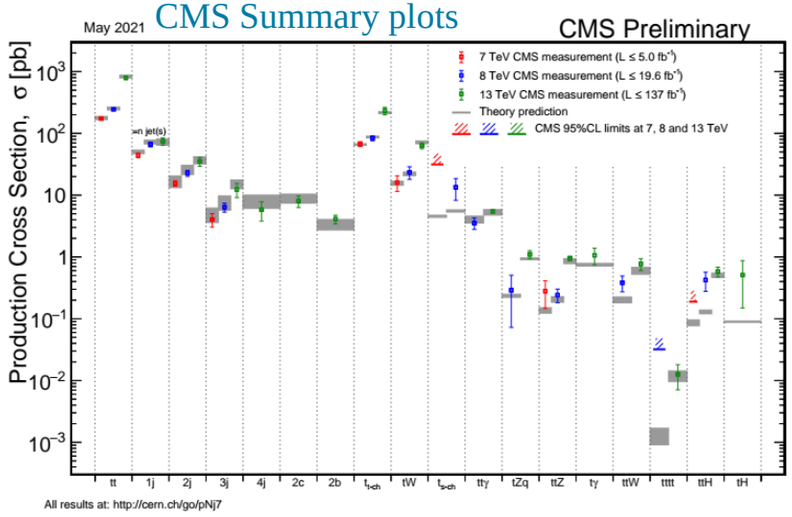
Many new physics models predict enhanced couplings to top quarks

Plethora of results on top quark precision measurements from ATLAS & CMS

ATL-PHYS-PUB-2021-014



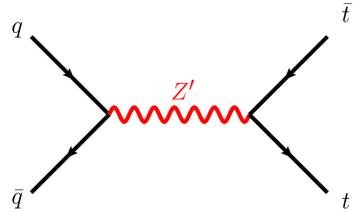
CMS Summary plots



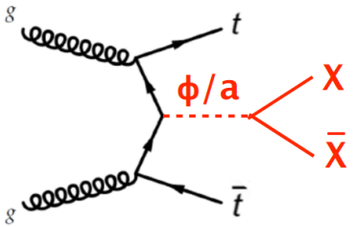
Possible signatures

Resonances decaying top quark final states

Also see talks by Z. Zheng, S. Ghosh



Dark matter production

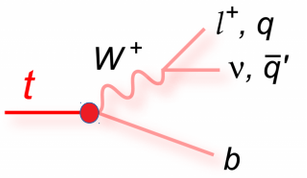


Anomalous couplings modifying Wtb vertex

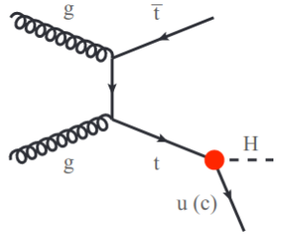
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\left(g_L P_L + g_R P_R\right) t W_{\mu}^{-} + \text{h.c.},$$

V_{tb} in SM (≈1)

Anomalous couplings

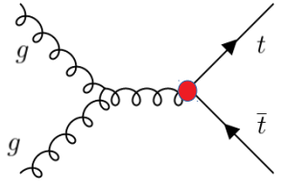


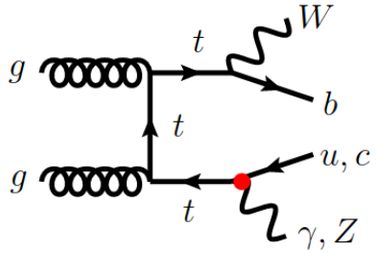
Also see talk by B. Bruers



Flavor changing neutral currents

Covered in talk by X. Chen





EFT operators modifying top quark production & decay + predicting new interactions (@ tree level)

Covered in talks by R. Lysak, J. Wilson

+ Many others

Outline of results to be discussed

Topic	ID & Link to results	Released on
CP violation in $t\bar{t}$	CMS-TOP-20-005	4 May, 2022
VLQ pair production	CMS-B2G-20-011	16 May, 2022
Singly produced VLQ → t H	ATLAS-EXOT-2019-07	18 January, 2022
Singly produced VLQ → t Z	CMS-B2G-19-004	6 January, 2022
W' → VLQ q	CMS-B2G-19-002	13 September, 2021
W' → t b all-hadronic	ATLAS-CONF-2021-043 CMS-B2G-20-005	24 July, 2021 11 April, 2021
$t\bar{t}$ H/A → $t\bar{t}$ $t\bar{t}$ in 2HDM	ATLAS-CONF-2022-008	11 March, 2022
Dark matter in association with t W	ATLAS-CONF-2022-0012	13 March, 2022
LQ pair production	ATLAS-CONF-2022-009	11 March, 2022

If time permits

arXiv:2205.02314

Search for CP violation in $t\bar{t}$

Observables: Combinations of 3-vectors odd under time reversal

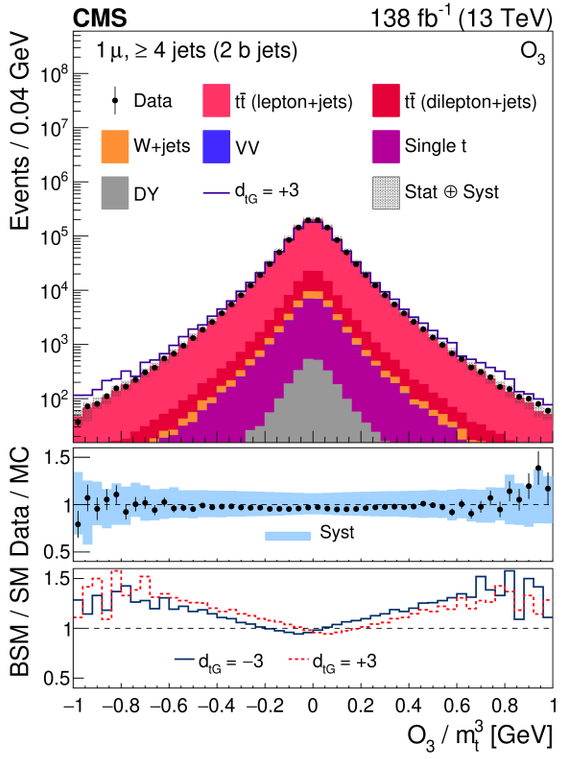
$$O_3 = Q_\ell \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell \vec{p}^{\,*}_b \cdot (\vec{p}^{\,*}_\ell \times \vec{p}^{\,*}_{j_1}),$$
$$O_6 = Q_\ell \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}),$$
$$O_{12} = q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z \cdot (\vec{p}_b \times \vec{p}_{\bar{b}})_z,$$
$$O_{14} = \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j_1}) \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}).$$

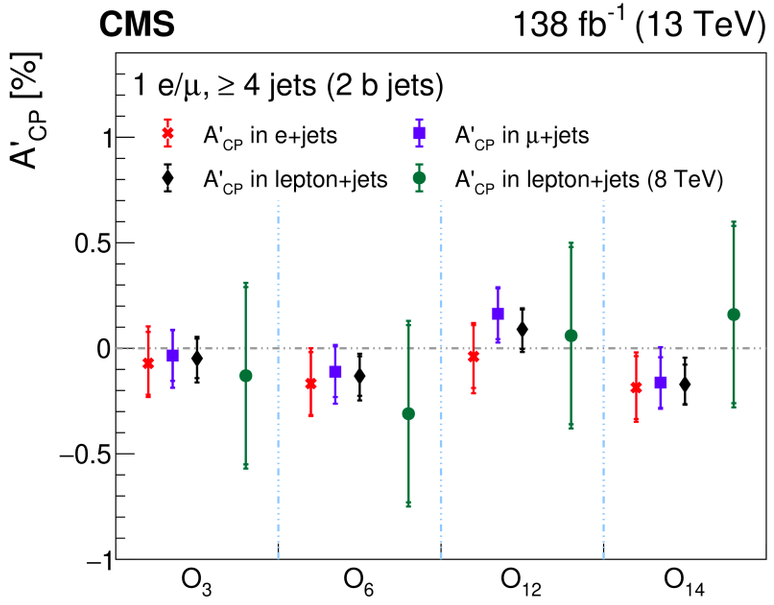
Define asymmetry:

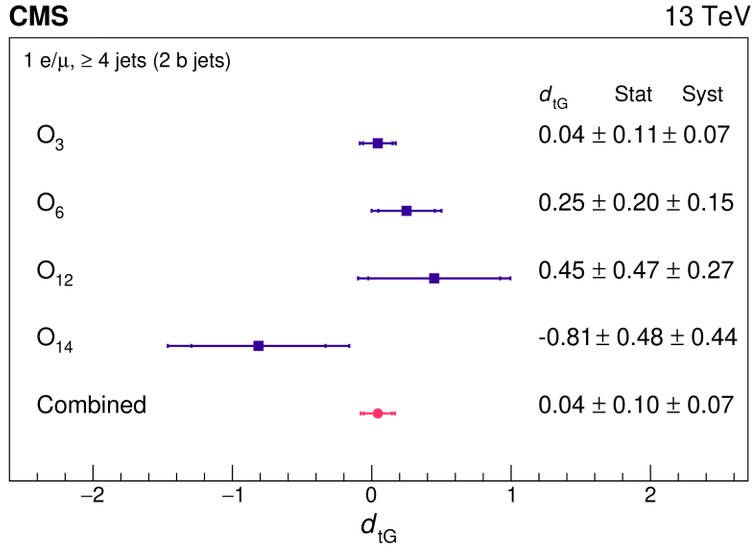
$$A_{CP}(O_i) = \frac{N_{events}(O_i > 0) - N_{events}(O_i < 0)}{N_{events}(O_i > 0) + N_{events}(O_i < 0)}, \quad i = 3, 6, 12, 14.$$

A possible source of CPV:
Chromoelectric dipole moment (CEDM) of top quark

$$\mathcal{L} = \frac{g_s}{2} \bar{t} T^a \sigma^{\mu\nu} (a_t^g + i\gamma_5 d_t^g) t G^a_{\mu\nu}, \longrightarrow d_t^g = \frac{\sqrt{2}v}{\Lambda^2} \mathrm{Im}(d_{tG})$$



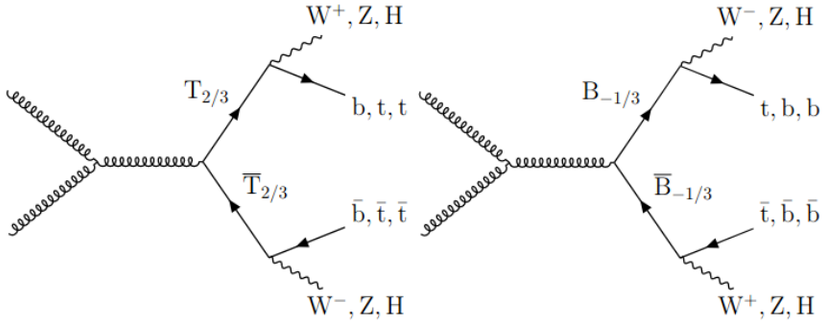




Asymmetry measured < 0.2%

CMS-PAS-B2G-20-011

Search for VLQ pair production in lepton final state



Final states considered:

Single-lepton & Same-sign di-lepton & >=3 leptons

New @ LHCP

+ 3 AK8 jets (W-/Z-/H-/ t-tagged)

+ >= 4 AK4 jets

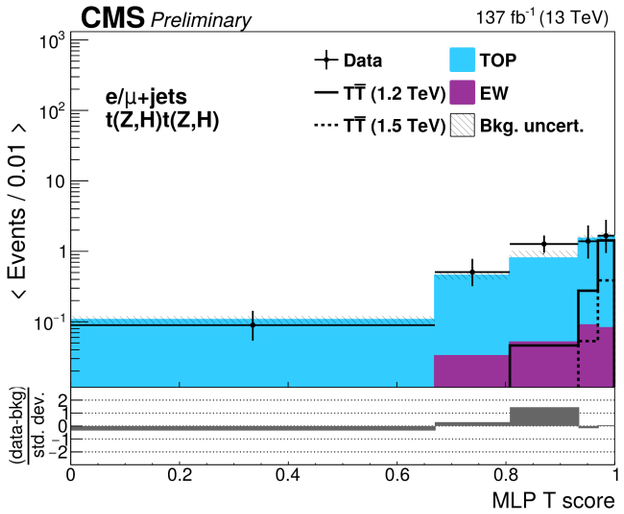
+ >= 3 AK4 jets + >=1 b jet

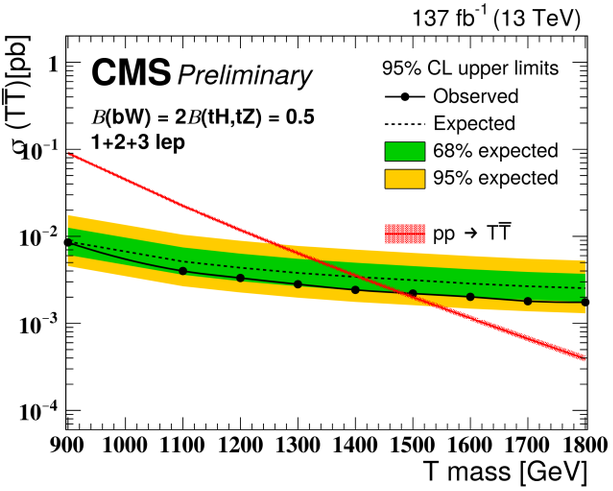
Signal separation:

Multilayer perceptron in single-lepton channel

$H_T^{lep} = \sum p_T^{lep} + p_T^{jet}$ in di-lepton channel

$S_T = H_T^{lep} + MET$ in tri-lepton channel





Exclusion region:

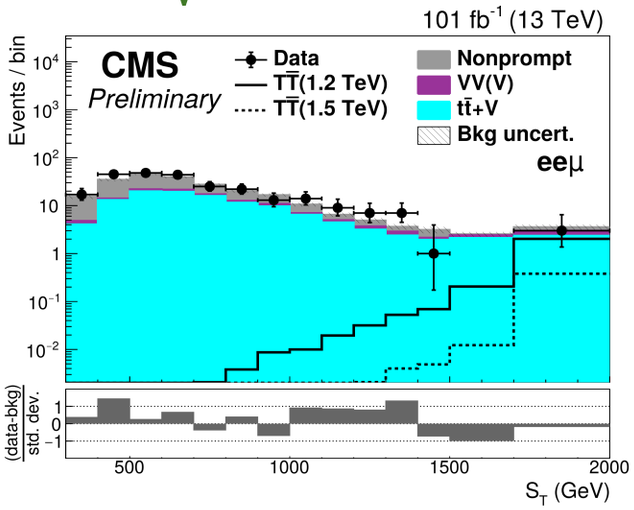
$m_{T,B} < 1.5$ TeV

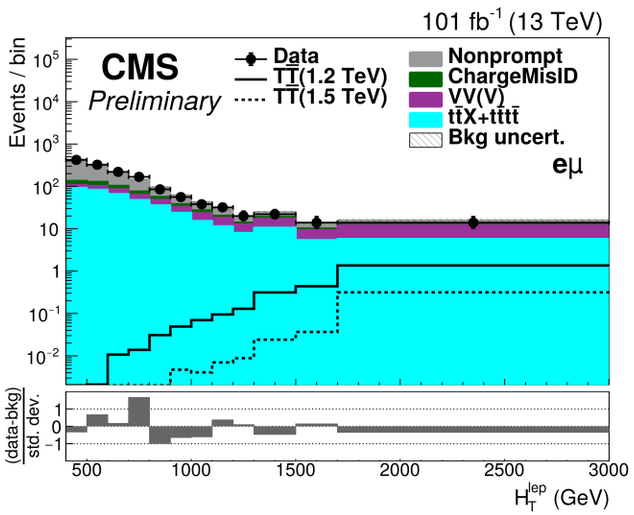
Strongest limits on

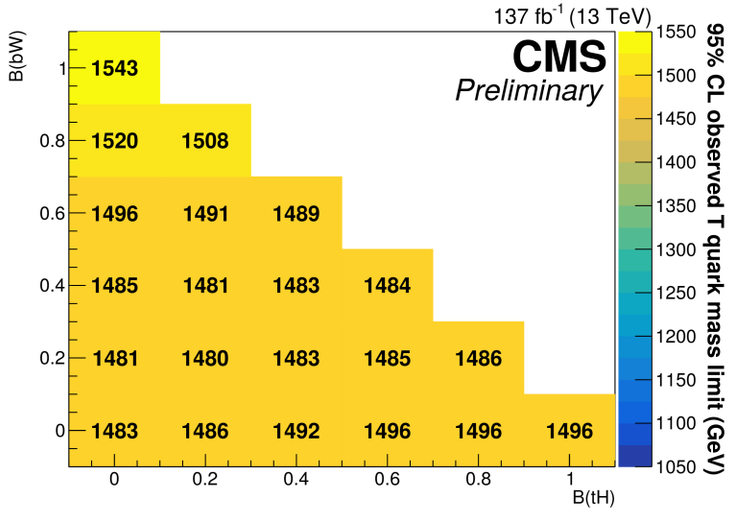
TT→ tHtH,

TT→ bWbW, &

BB̄→ tWtW!

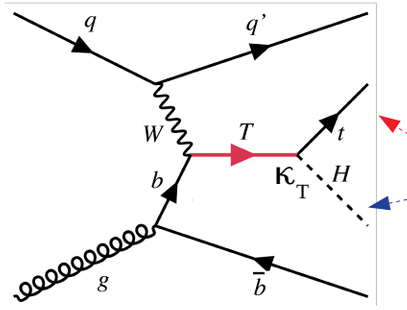






arXiv: 2201.07045

Search for VLQ T → t H in fully hadronic final state



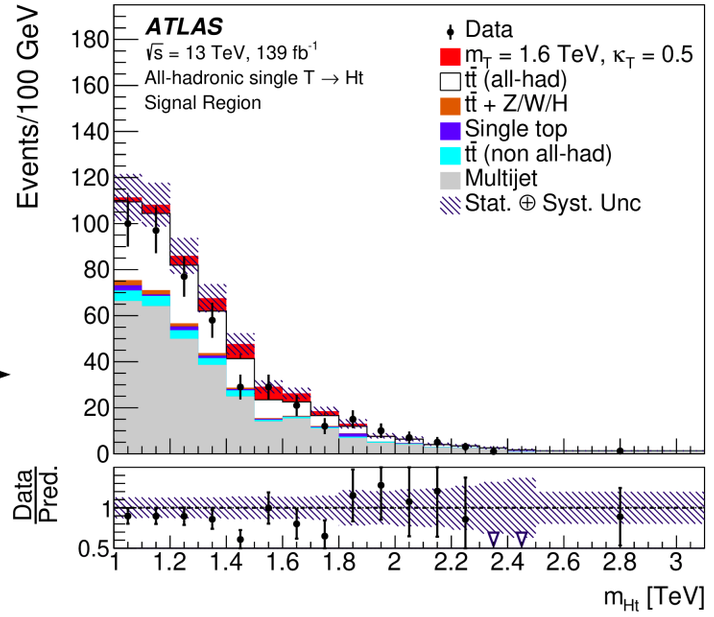
Targeted signal:

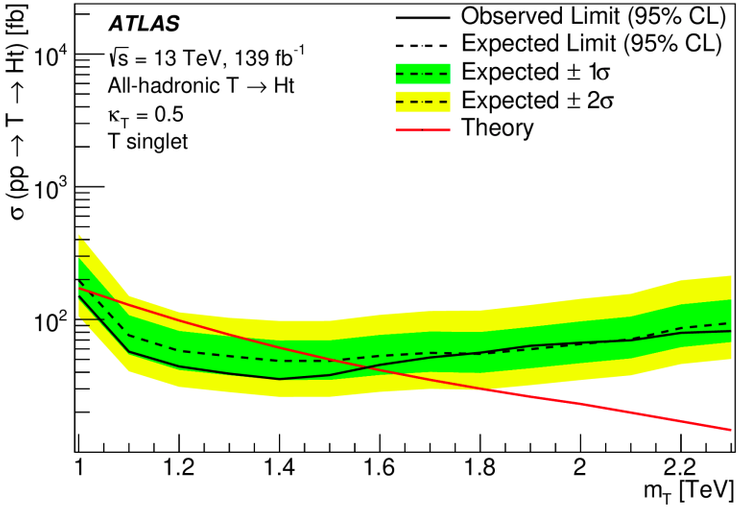
Singlet VLQ production in electroweak interaction

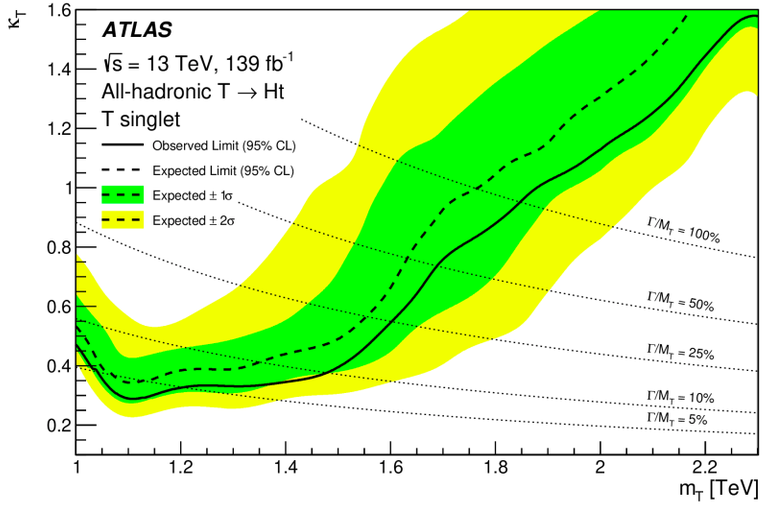
Higgs ($\rightarrow b\bar{b}$) jet identification using mass + τ_{21}

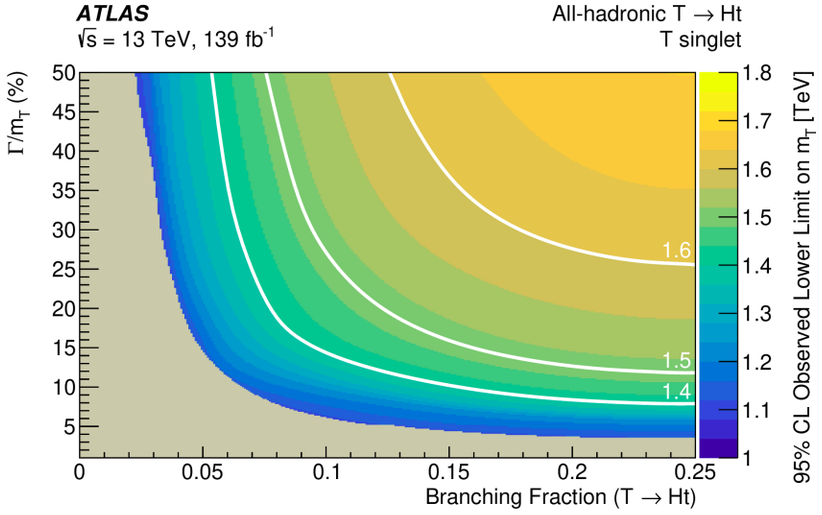
Hadronic top & b jet identification using DNN

Bump hunt in 1-D mass spectrum





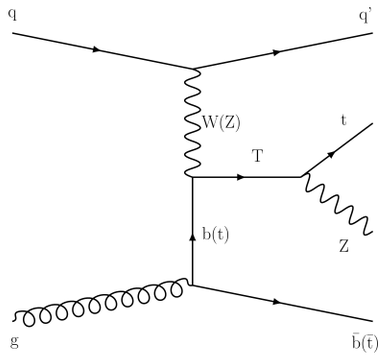




Lower limit on m_T @ 95% CL increases for higher couplings & decay widths

arXiv: 2201.02227

Search for VLQ T → t Z with jets + missing energy



t→ b q q'

Z→ ν ν̄

Targeted signal:

Singlet VLQ production in electroweak interaction

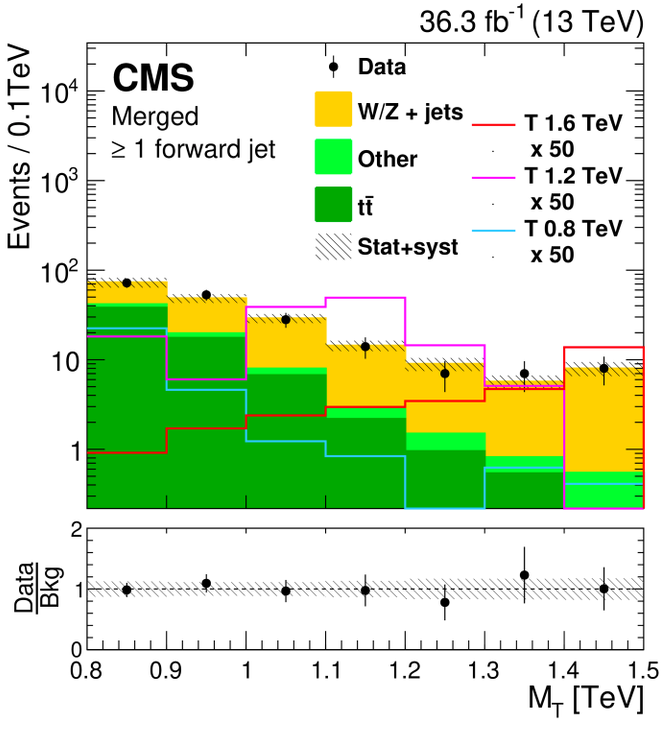
Analysis performed separately for different kinematic topologies of top decay:

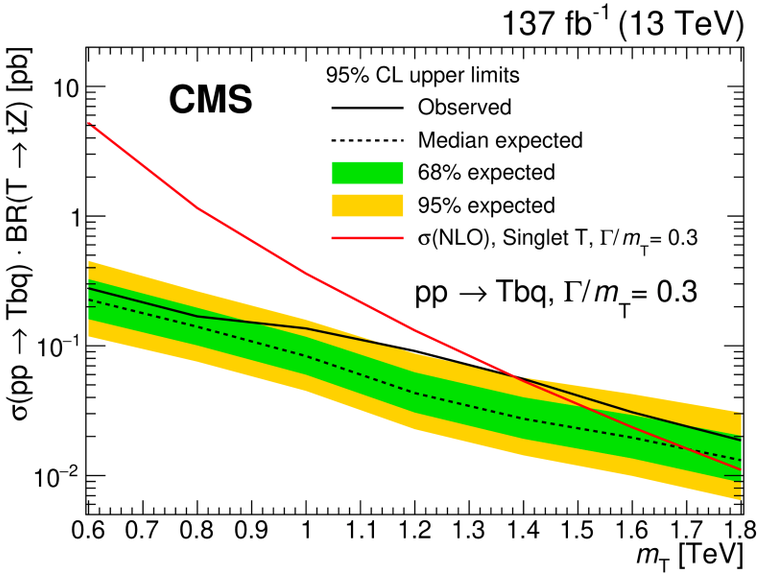
- Resolved → 3 AK4 jets
- Partially merged → 1 b-tagged AK4 jet + 1 W-tagged AK8 jet
- Fully merged → 1 t-tagged AK8 jet

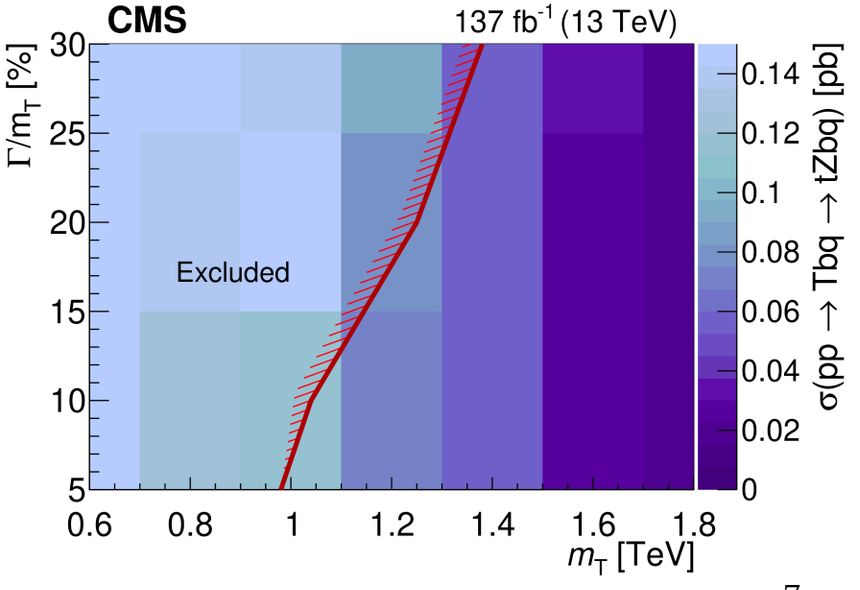
\+ 0 / >=1 forward jets (2.4<= |η| <4.0)

Signal extraction:

Using $m_T = \sqrt{2 p_T^t p_T^{miss} \left(1 - \cos \Delta\phi_{t,\vec{p}_T^{miss}}\right)}$ distribution



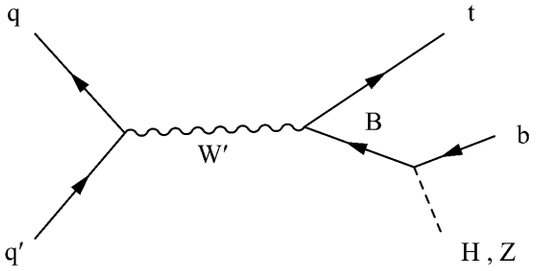


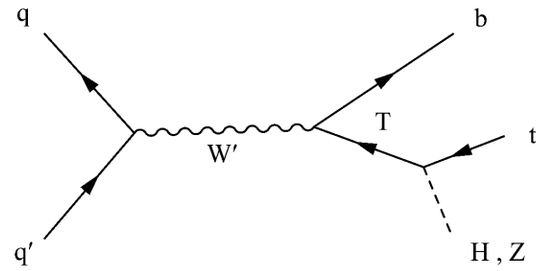


Exclusion region: m_T < 0.98-1.4 TeV for Γ/m_T = 5-30%

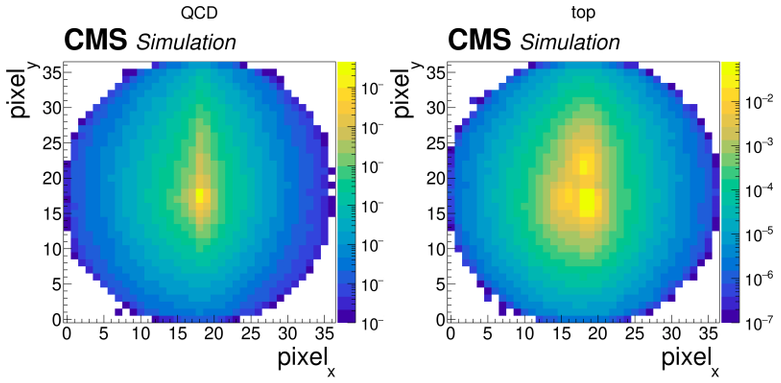
arXiv: 2202.12988

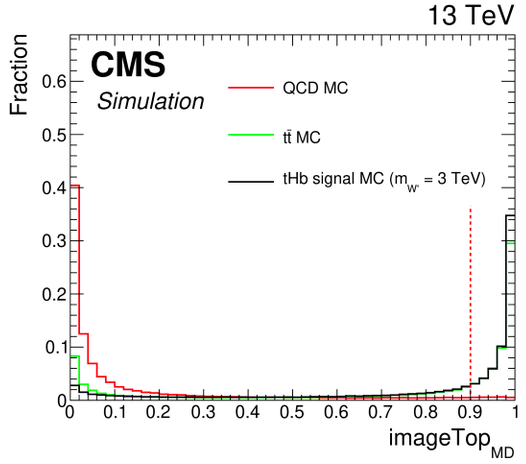
Search for W'→Tb/tB in fully hadronic final state





Hadronic top jet identification using jet images



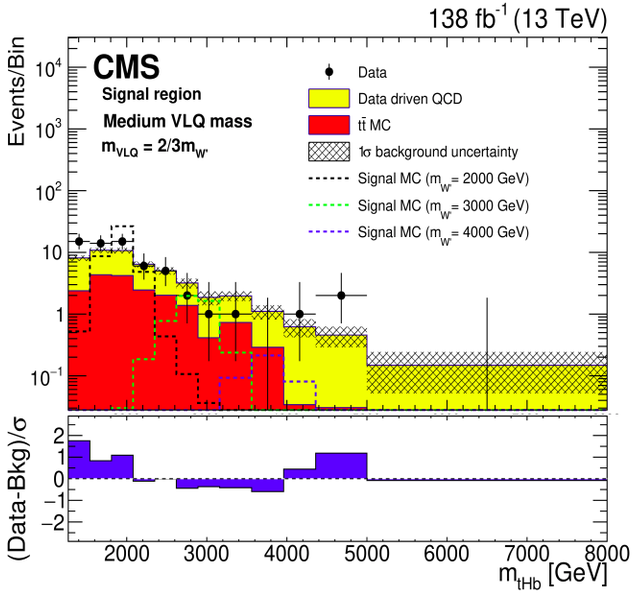


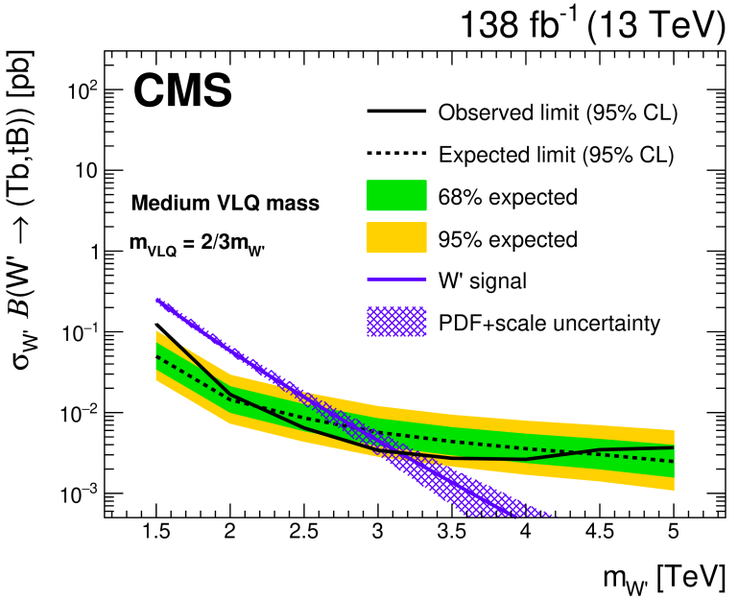
JINST 15 (2020) P06005

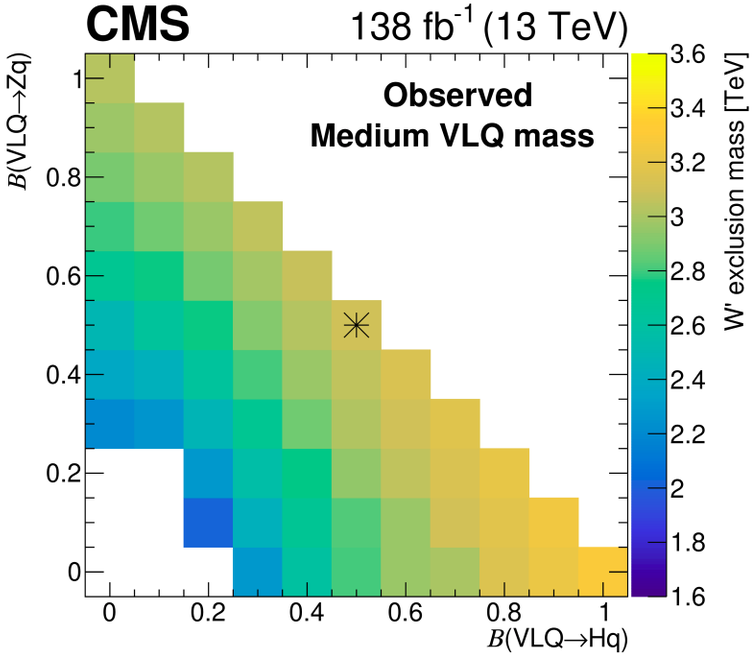
Final states considered: $t(\rightarrow b\,q\,q') + b + H(\rightarrow b\,b) / Z(\rightarrow q\,\bar{q})$

Boosted topology

Search for an excess in invariant mass spectrum



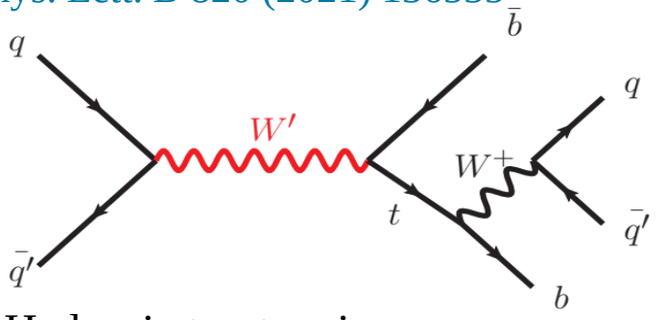




Exclusion region: $m_{W'} < 3.1$ TeV for $\mathrm{BR}(VLQ \rightarrow Hq) = \mathrm{BR}(VLQ \rightarrow Zq) = 0.5$

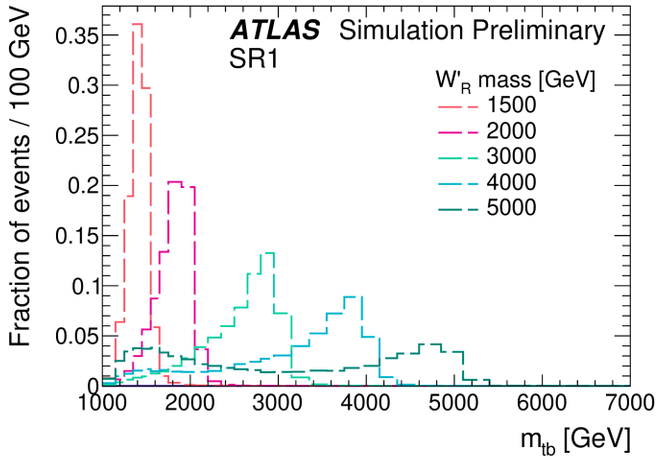
ATLAS-CONF-2021-043
Phys. Lett. B 820 (2021) 136535

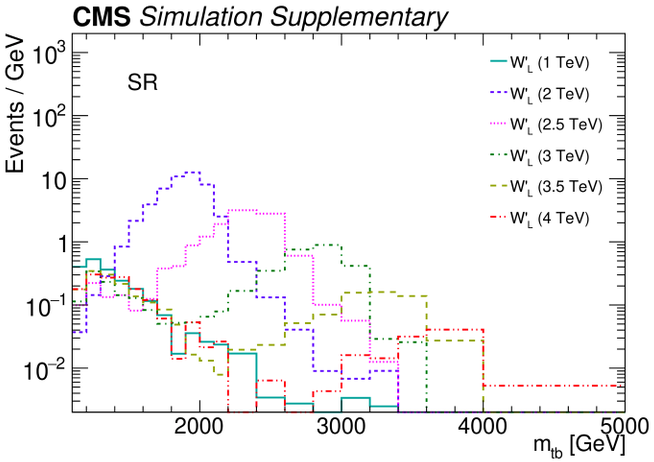
Search for W'→ t b in fully hadronic final state

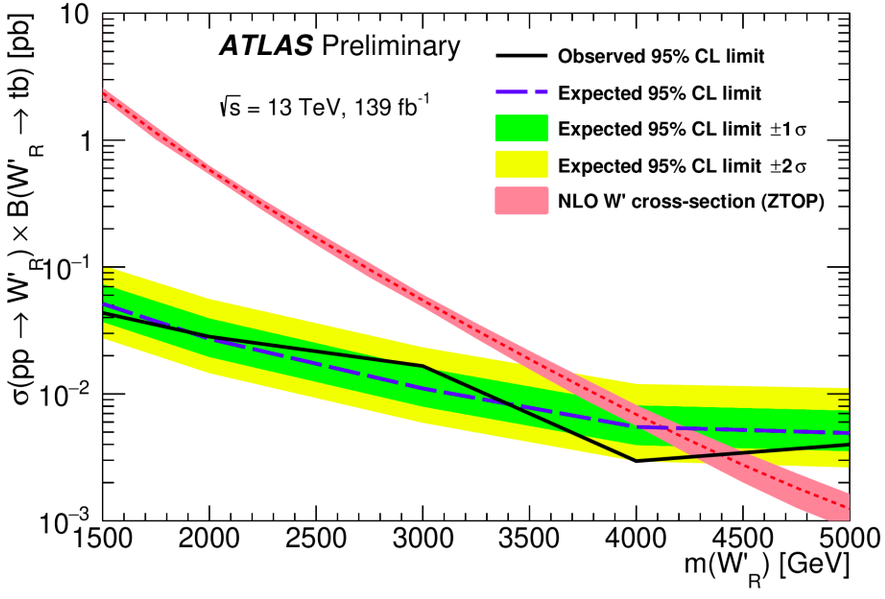


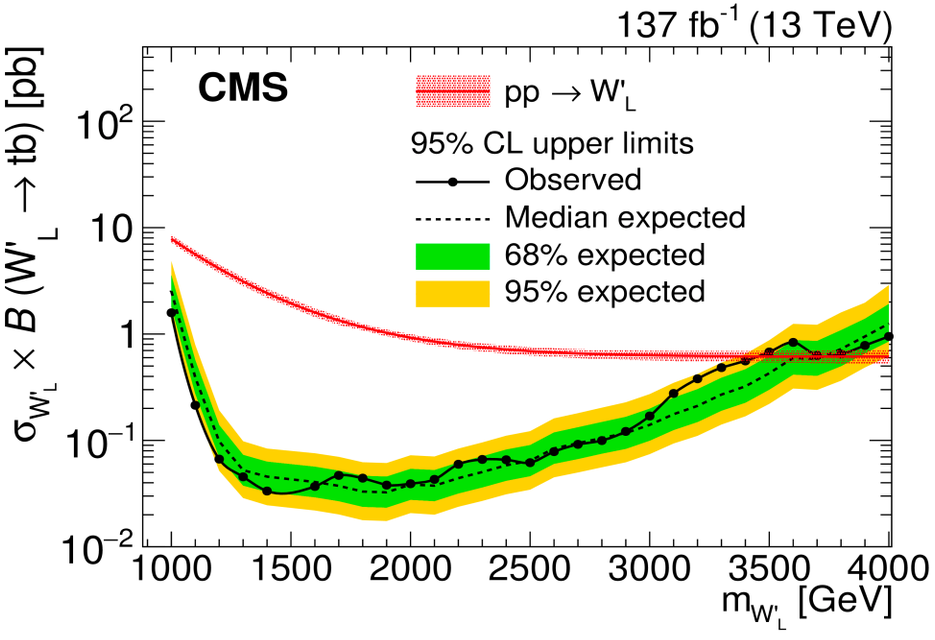
Hadronic top tagging:

ATLAS: DNN on trimmed AK10 jets
CMS: DNN on AK8 jets + soft-drop mass





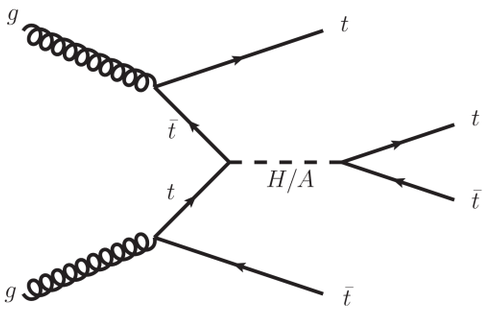




Exclusion region: $m_{W'} < 4.4$ TeV for right-handed W' from ATLAS & < 3.4 TeV for left-handed W' from CMS

ATLAS-CONF-2022-008

Search for $t\bar{t}H/A \rightarrow t\bar{t}t\bar{t}$



Targeted model:

2HDM

Final states considered:

2 same-sign leptons / >= 3 leptons

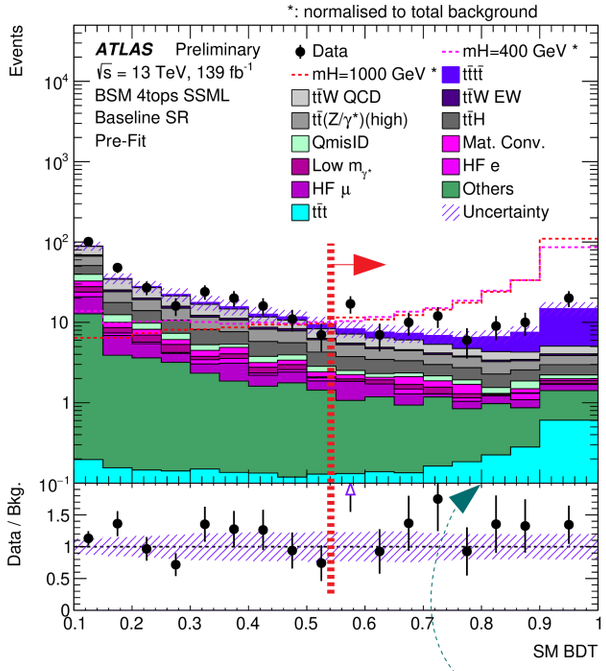
Signal separation:

Using 2 BDTs:

(1)

SM $t\bar{t}t\bar{t}$ vs other SM bkgs

→ Access to 4 top-enriched region

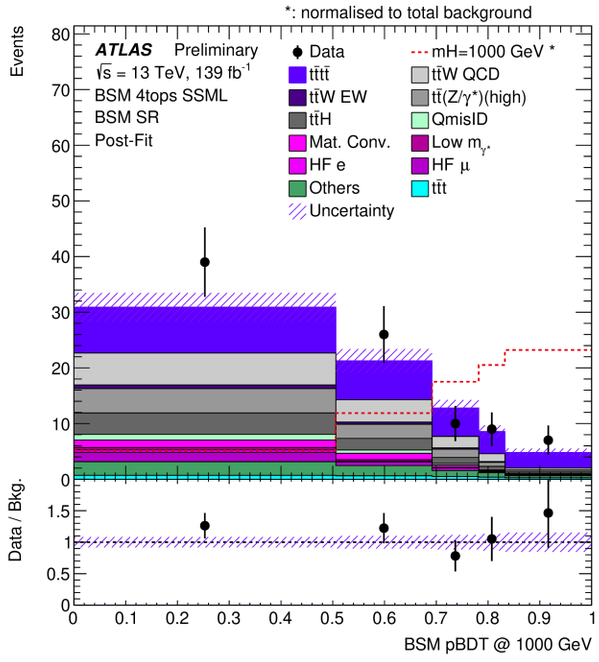


(2)

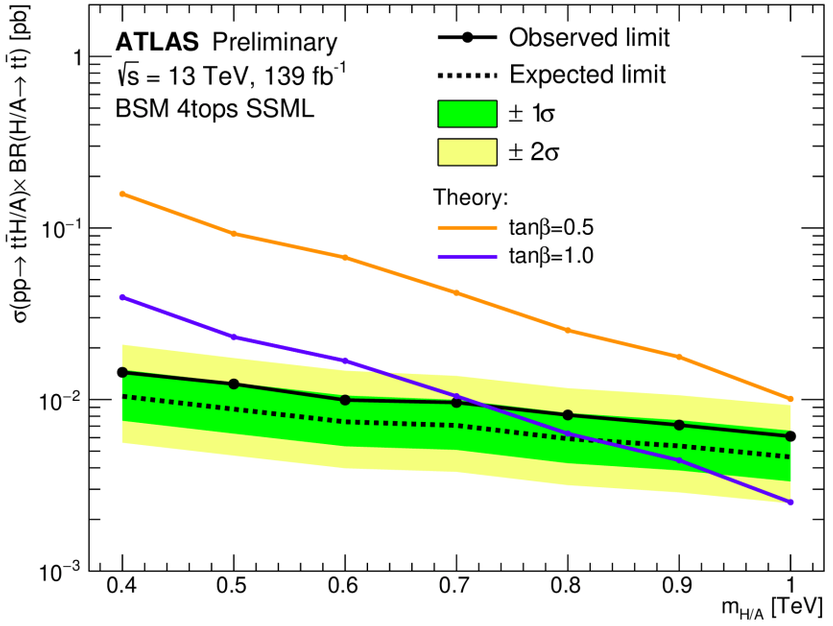
BSM $t\bar{t}t\bar{t}$ vs all SM bkgs

Parameterized in H/A mass

→ Used in final signal extraction



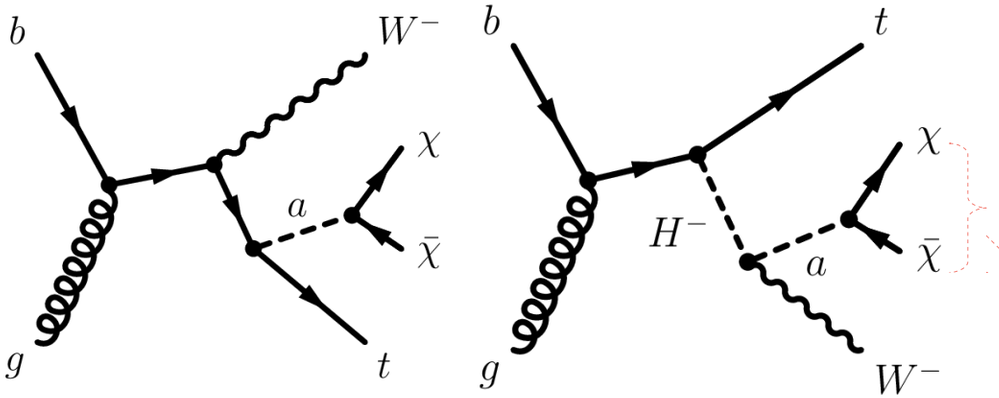
BSM signal region



Stricter constraints for smaller tanβ

Exclusion region: tanβ < [0.6-1.6] for $m_{H/A}$ < 400-1000 GeV

ATLAS-CONF-2022-012 Search for dark matter production with t + W



Targeted signal model:

2HDM + additional pseudo-scalar (a)

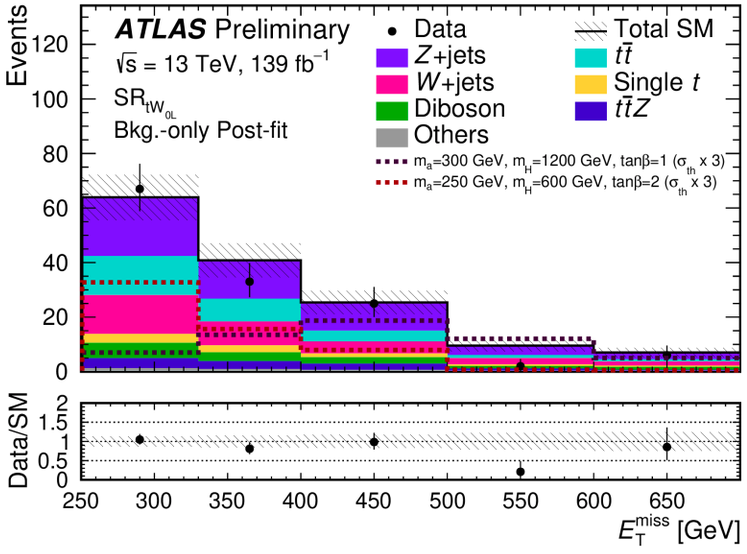
Final states considered:

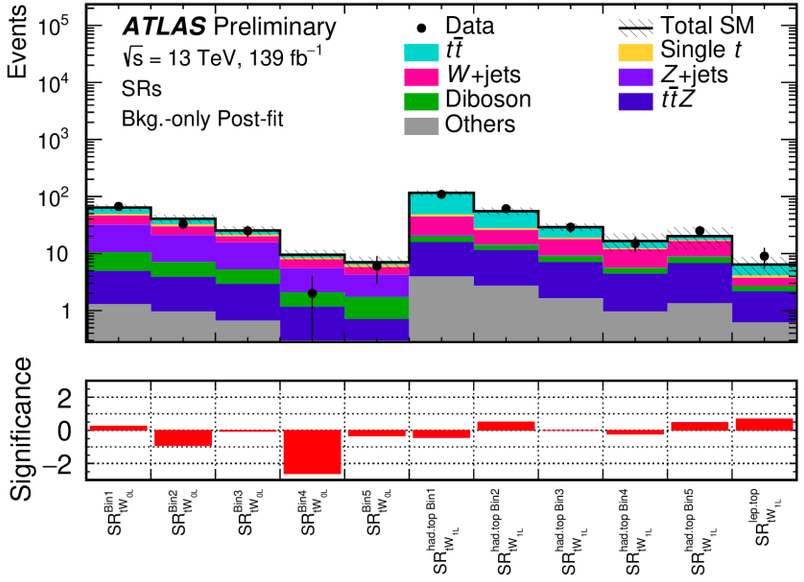
0-lepton / 1-lepton + b jet + >= 1 W-tagged fat jet + large missing energy

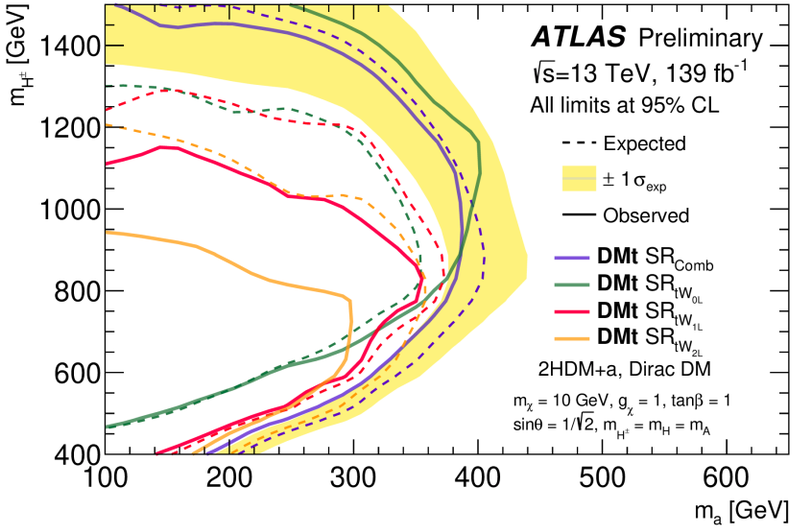
- Jet mass
- \+
- # of tracks
- \+
- D_2: Ratio of 2-&3-point ECFs

JHEP12(2014)009

Results combined with 2-lepton analysis



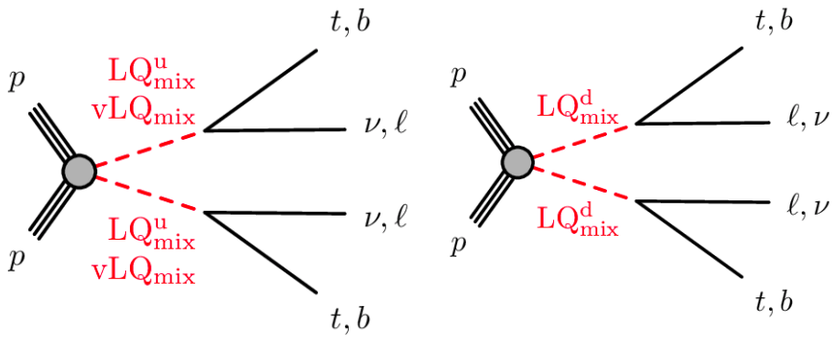




~2.5 σ deviation in MET ϵ [500, 600] GeV

Exclusion region: $m_{H+-} < 1.5$ TeV & $100 < m_a < 350$ GeV (for tanβ = 1)

Search for pair production of leptoquarks



Leptoquarks offer potential solutions to flavor anomalies
(e.g. deviation from LFU in b→sll & b→clν transitions)

Targeted signal:

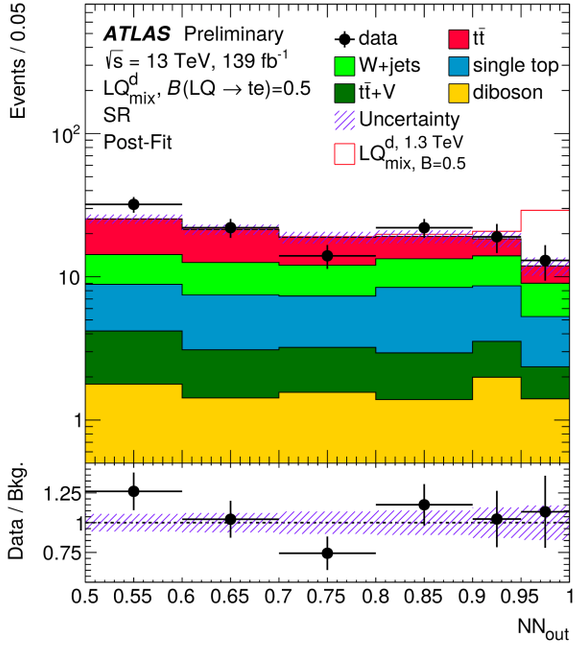
Scalar/vector LQs coupling to 3rd generation quarks + leptons of 1st & 2nd generations

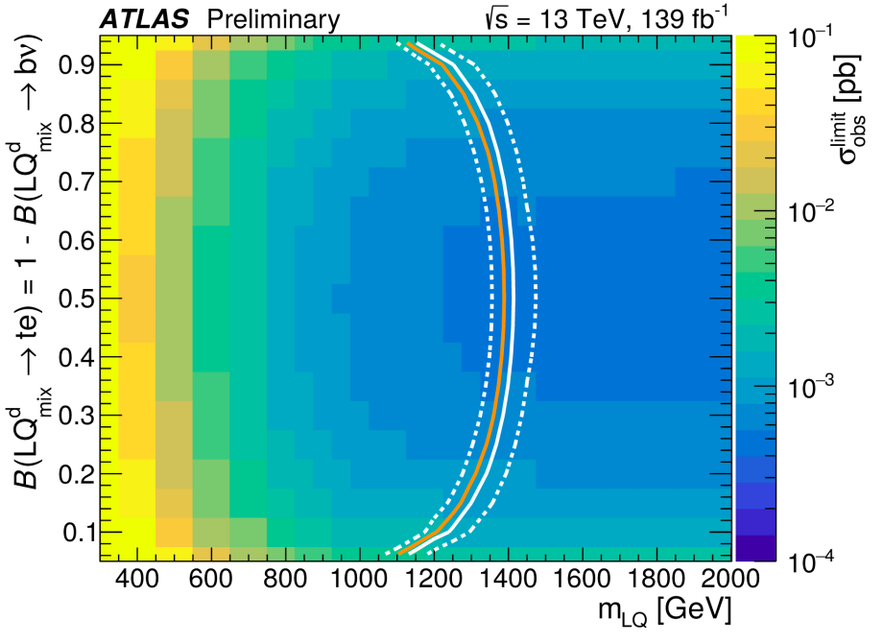
Final states considered:

Exactly 1 electron / 1 muon + jets

Signal extraction:

Using neural networks trained separately for scalar & vector LQ signals





Exclusion region for vector LQ:

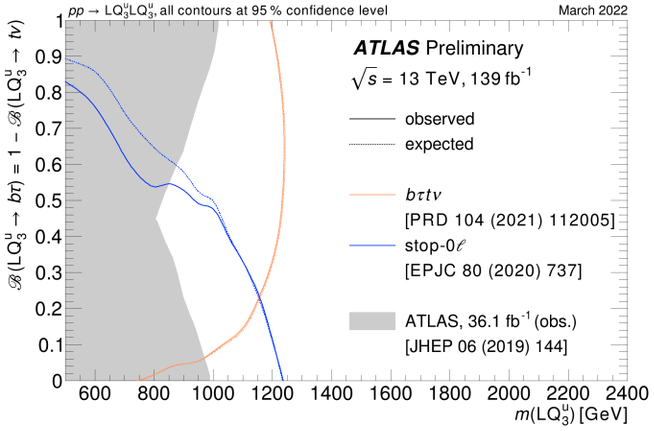
	Electrons:	Muons:
m_{LQ} (Yang-Mills)	< 1.9 TeV	< 2.0 TeV
m_{LQ} (minimal coupling)	< 1.6 TeV	< 1.7 TeV

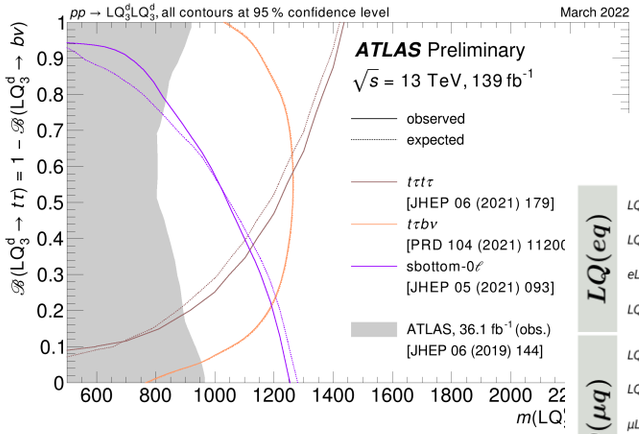
Br(LQ→l+Q = 0.5)

Exclusion region for scalar LQ:

	Electrons:	Muons:
m_{LQ} (up-type)	< 1.4 TeV	< 1.5 TeV
m_{LQ} (down-type)	< 1.4 TeV	< 1.4 TeV

Search for pair production of leptoquarks: Summary





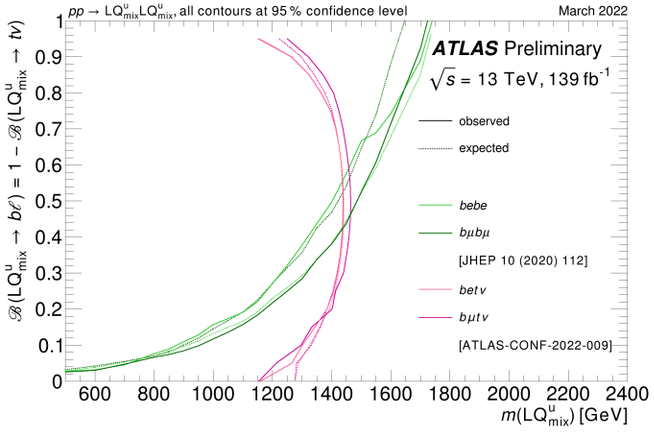
3rd generation lepton from LQ

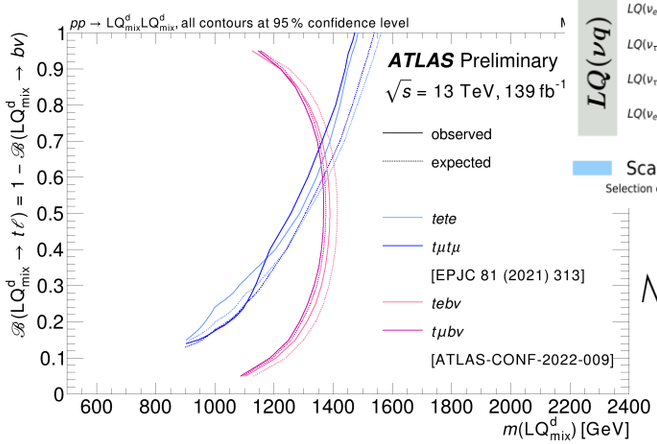
3rd generation models

Scalar LQs only

Mixed generation models

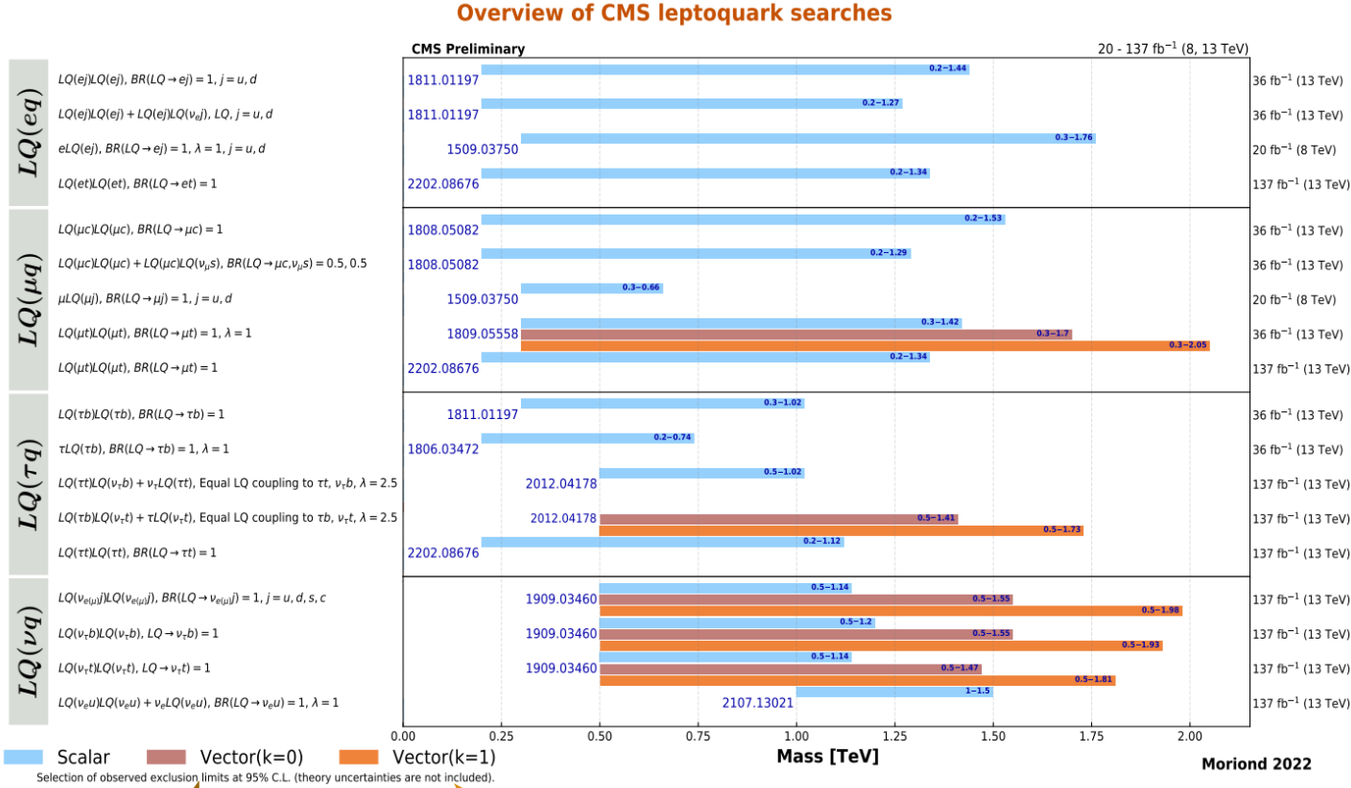
1st & 2nd generation leptons from LQ





ATL-PHYS-PUB-2022-012

Leptoquark summary plot from CMS



Minimal coupling

Yang-Mills coupling

Complementary sensitivity from single-lepton & di-lepton analyses at smaller & larger LQ→ q l branching ratios

Summary & Outlook

- Top quark offers plenty of opportunities to search for new physics at LHC
- Innovations in reconstruction techniques enable to probe different corners of phase space

Top tagging in ATLAS: Eur. Phys. J. C 79 (2019) 375 CMS: JINST 15 (2020) P06005

- Extensive efforts from experiments to look for signatures of new physics using top quark

ATLAS

TOP

Exotica

Full list of public results

CMS

TOP

Exotica

Beyond 2 generations