

Vector-like quark (VLQ) searches at LHC

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On behalf of ATLAS and CMS collaborations
LHCP 2017, Shanghai



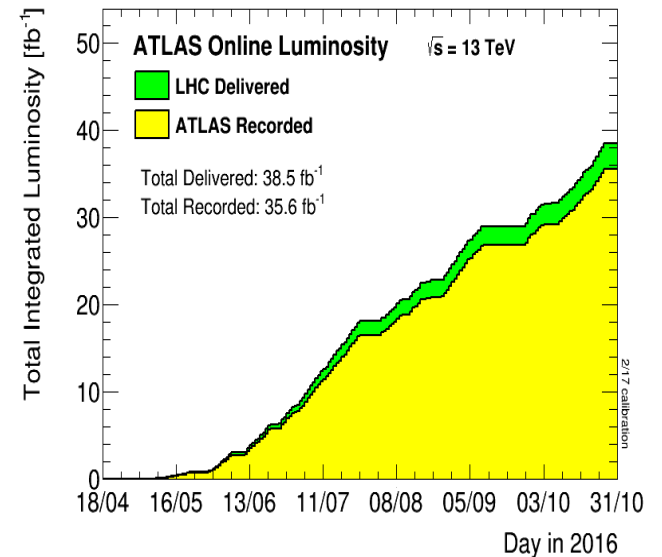
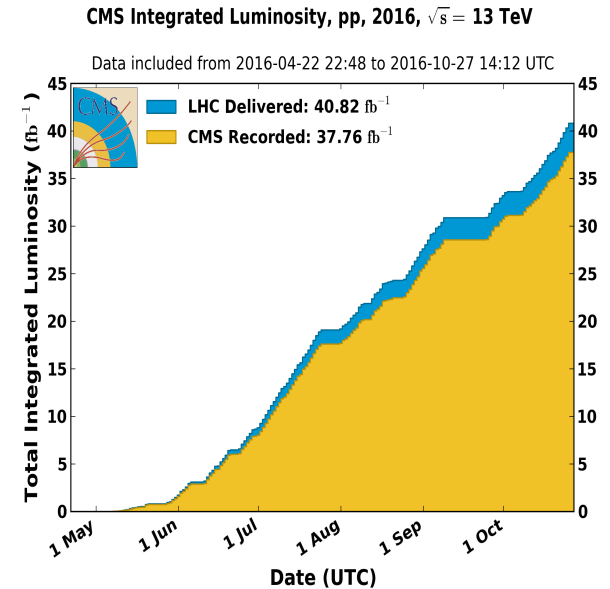
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Content

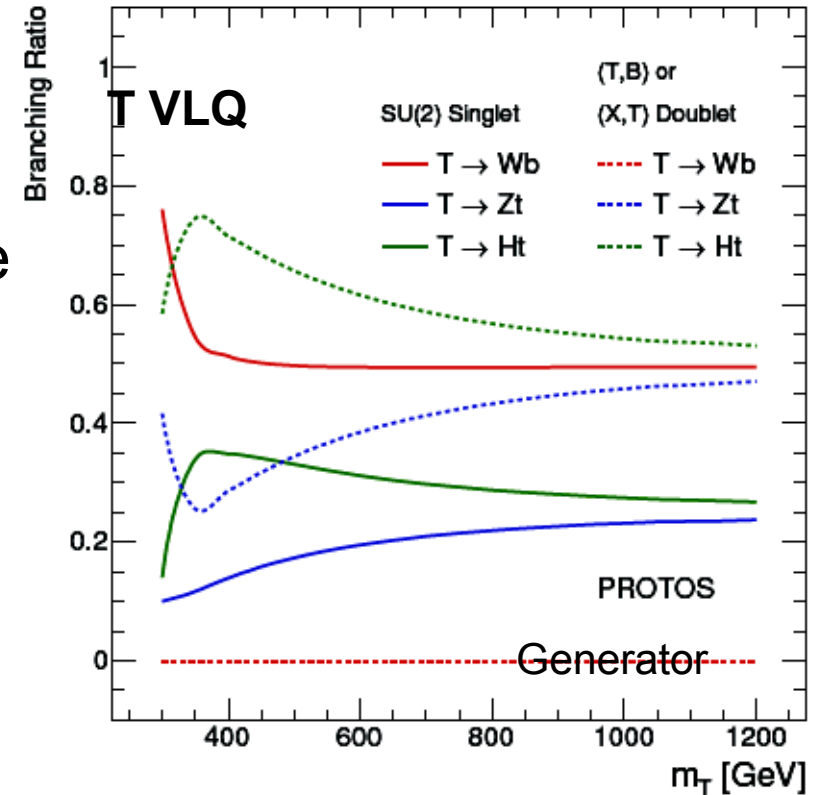
- Introduction
- T VLQ pair production:
 - $tZ(\nu\nu)+X$ (1ℓ) [ATLAS-CONF-2017-015]
 - $Wb+X$ (1ℓ) [ATLAS-EXOT-2016-14]
 - $WbWb$ (1ℓ) [CMS-B2G-17-003]
 - $tH(bb)+X$ ($0\ell, 1\ell$) [ATLAS-CONF-2016-104]
- T VLQ single production: $tZ(\ell\ell)+X$ [CMS-B2G-17-007]
- Other top Partners:
 - X5/3 (same-sign $\ell\ell$) [CMS-B2G-16-019]
 - X5/3 (1ℓ) [CMS-B2G-17-008]
- Conclusions



Results shown are with half/full 2015+2016 dataset.

Introduction

- In the SM, unnatural cancellation between large radiative corrections and bare mass of Higgs \square high-levels of fine tuning.
- Theoretical guiding principle: avoid fine tuning \implies Physics Beyond SM which solves hierarchy problem
- Many BSM theories introduce VLQs - little higgs, composite higgs, extra dimensions,
- VLQ predominantly decaying via bosons and 3rd gen quarks [arXiv:1306.4432]



VLQ:

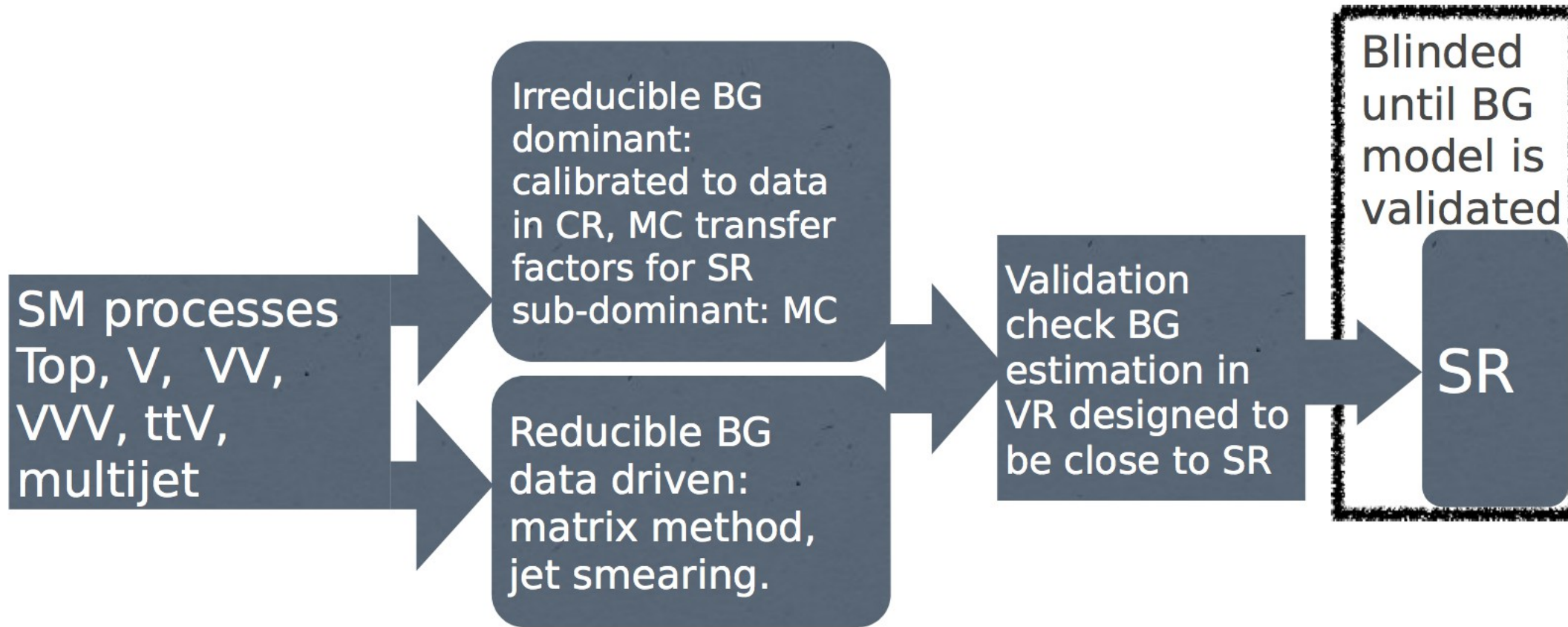
X: charge $+5/3$

T: charge $+2/3$

B: charge $-1/3$

Y: charge $-4/3$

SM BG ESTIMATION



BSM signal “small” compared to SM processes,
in tails of SM distributions => good control is needed.

Systematics & Combined fit

Detector systematics:

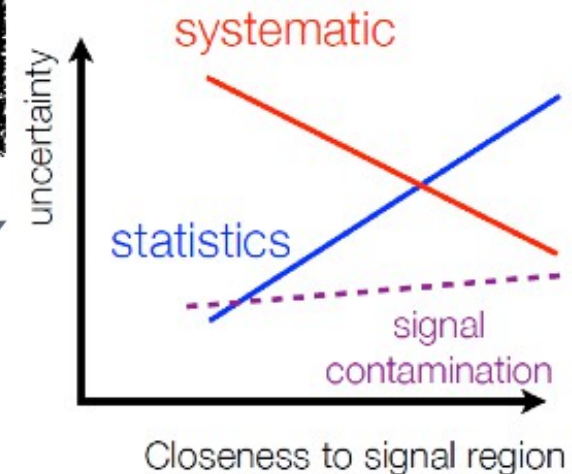
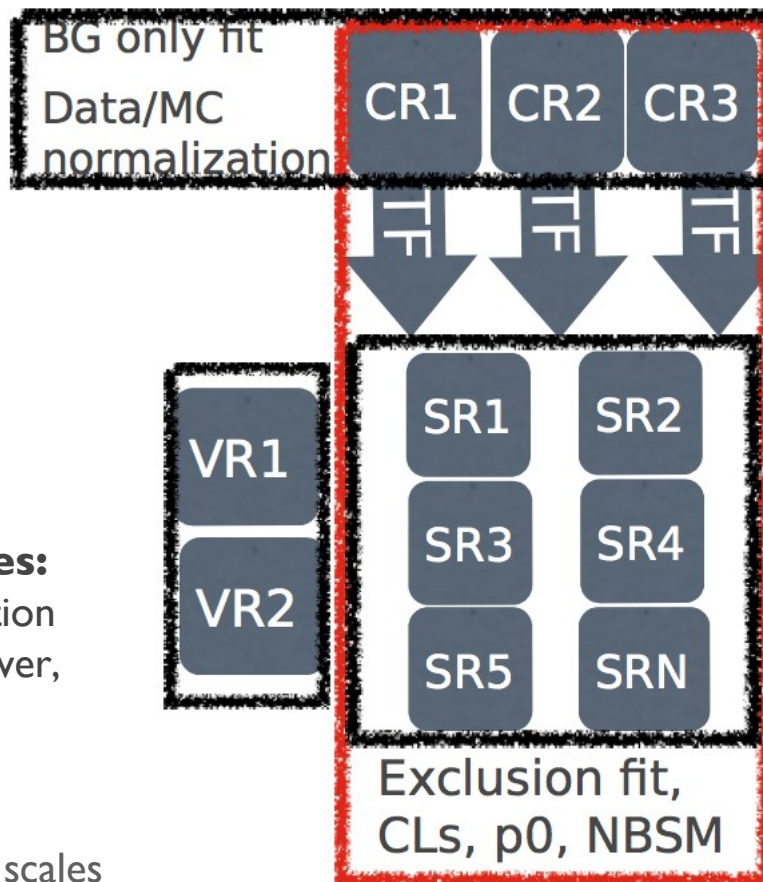
- Jet Energy Scale (JES)
- Jet Energy Resolution (JER)
- b-tagging uncertainties
- Missing Transverse Energy soft component
- ...

BG MC modeling uncertainties:

generator choice, PDF, renormalisation and factorization scales, parton shower, ISR/FSR.

Signal systematics:

ISR/FSR, parton shower, PDF, renormalisation and factorization scales and strong coupling (α_s) uncertainty.

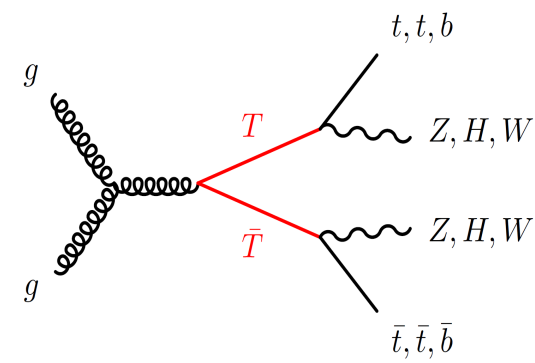


1. if SRs overlap use one with best expected sensitivity,
2. if SRs are orthogonal do statistical combination.

Notations: Standard Model - SM, Background - BG, Monte Carlo - MC, Control Region - CR, Validation Region -VR, Signal Region - SR, Transfer Factor - TF.

ATLAS: VLQ Pair production

“tZ+X”, ATLAS-CONF-2017-015

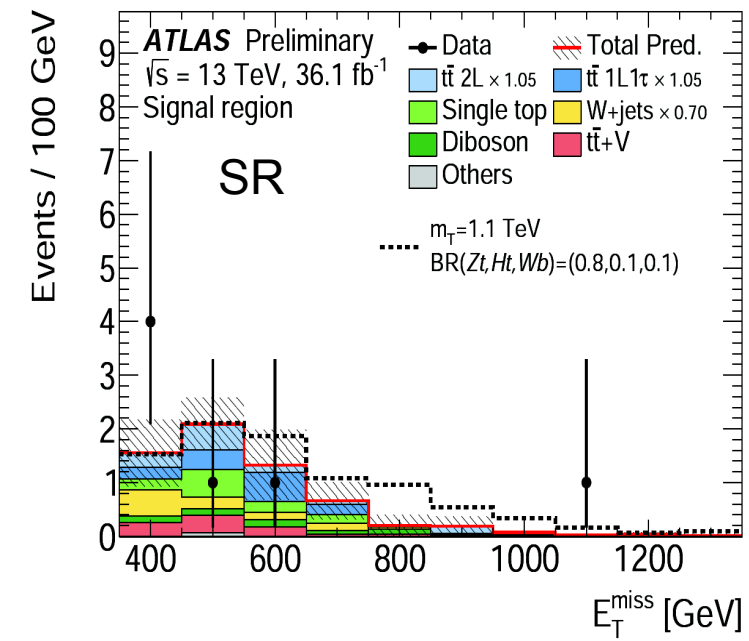
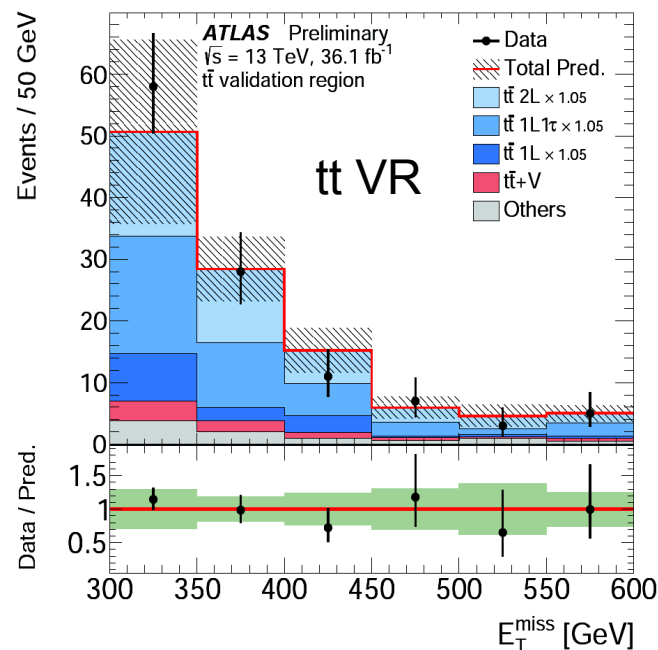
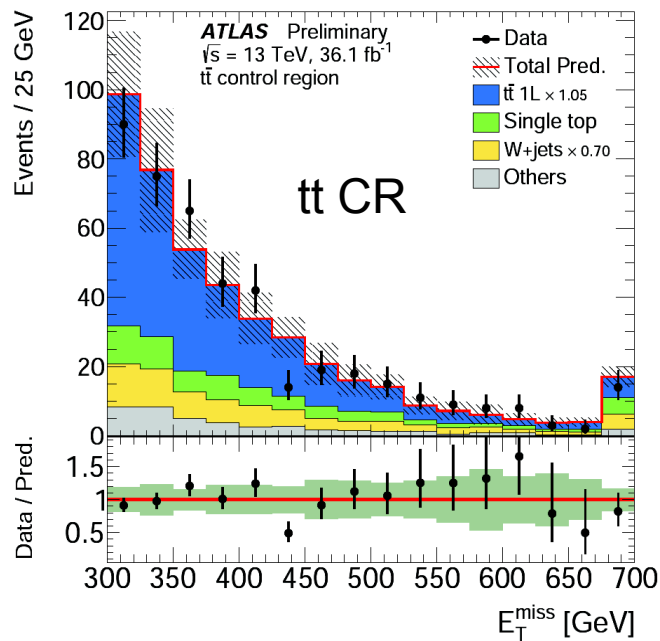


Signal event topology: 1ℓ +jets (≥ 1 b-jet) + very large missing transverse momentum (MET) due to the invisibly decaying Z,

Analysis technique: boosted Top and V (2 large-R jets),

Dominant background: top production, W + jets – estimated in control regions (CRs), and checked in Validation regions (VRs).

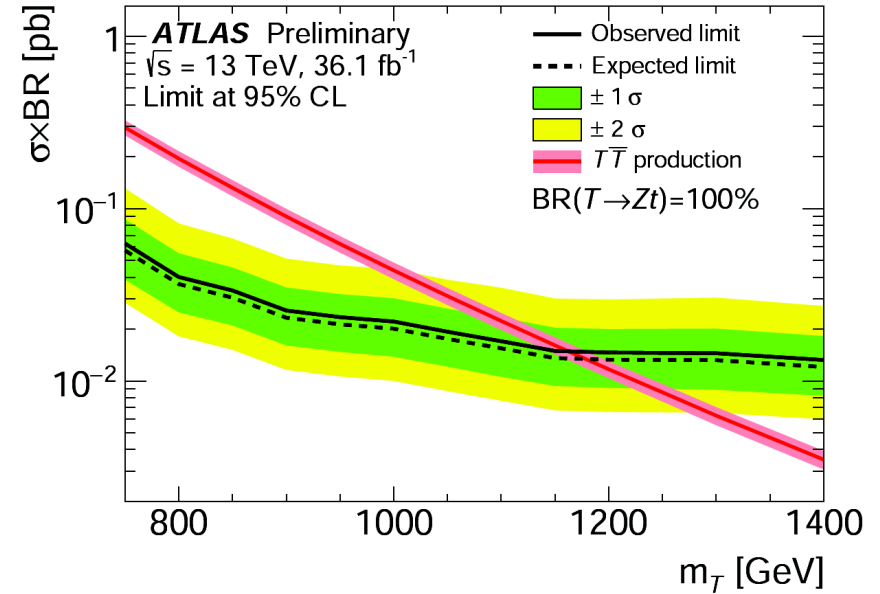
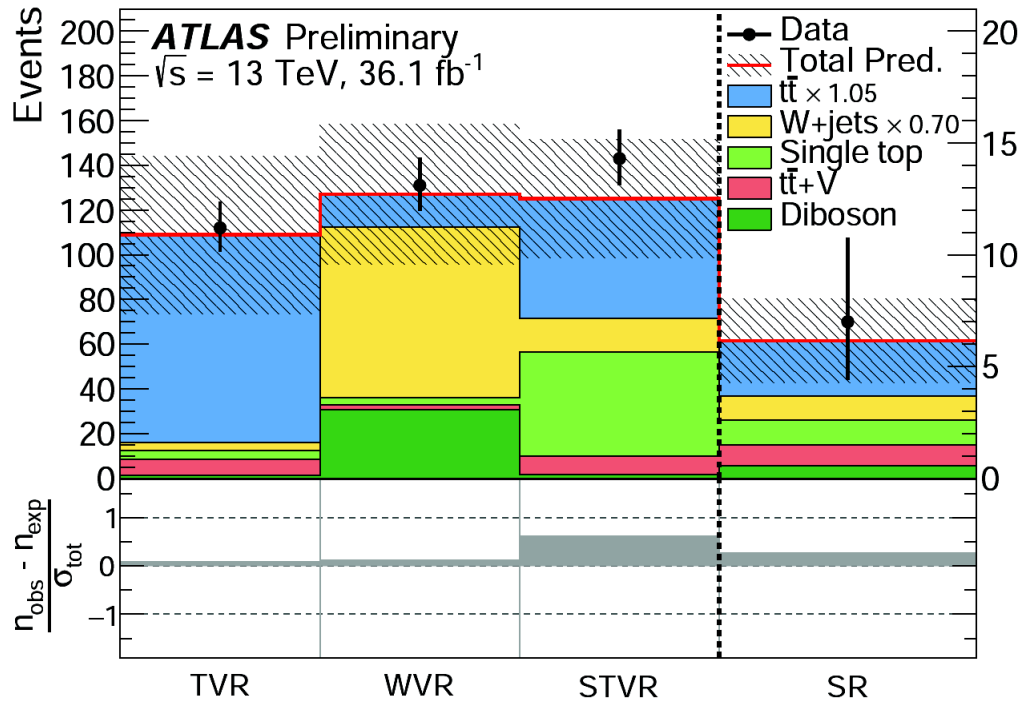
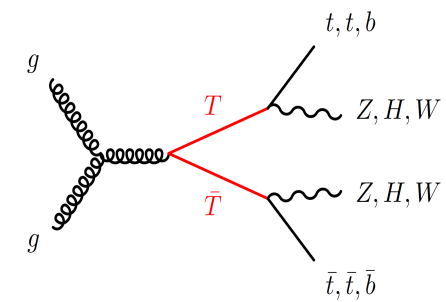
Dominant uncertainty: Statistical error in SR



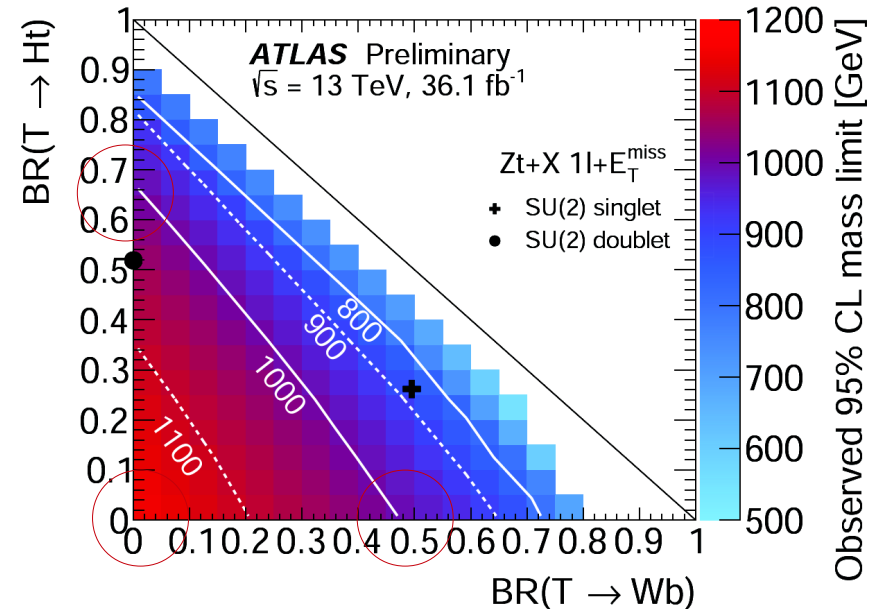
ATLAS: VLQ Pair production

“tZ+X”, ATLAS-CONF-2017-015

New

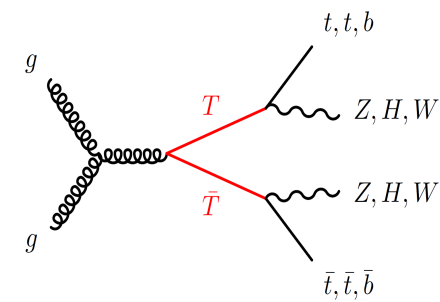


- * Excluded large space of BR (50-60%) combinations with $m_T < 1.0 \text{ TeV}$
- * Exclude $m_T < 1.17 \text{ TeV}$ for pure Zt decay.

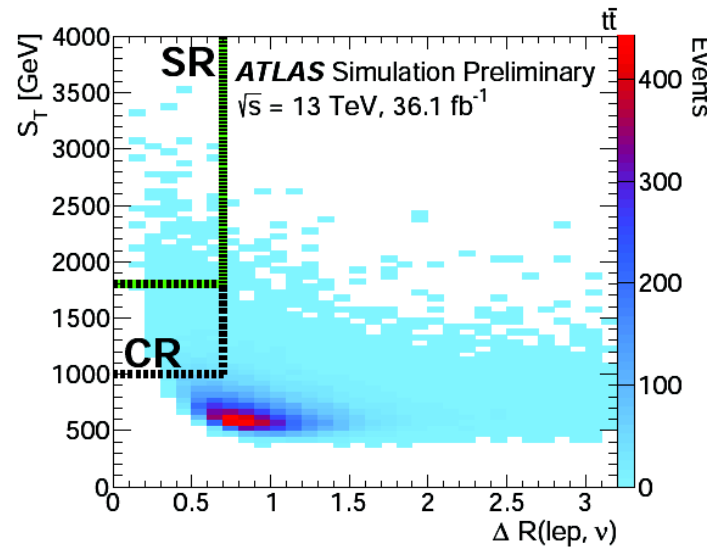
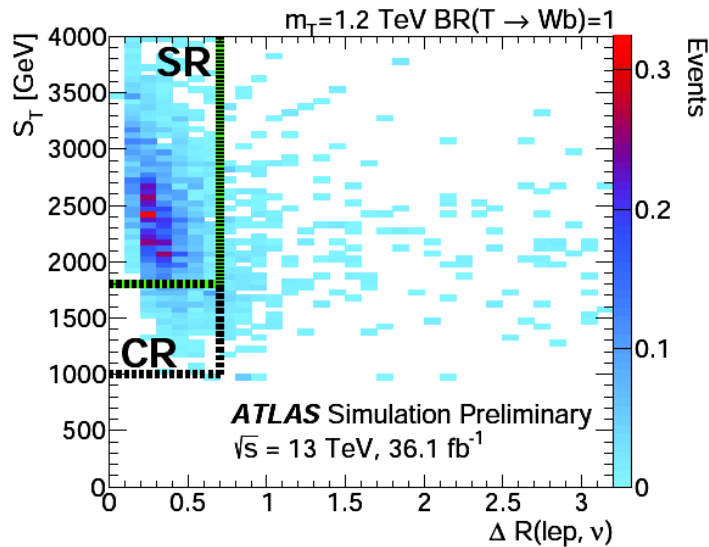
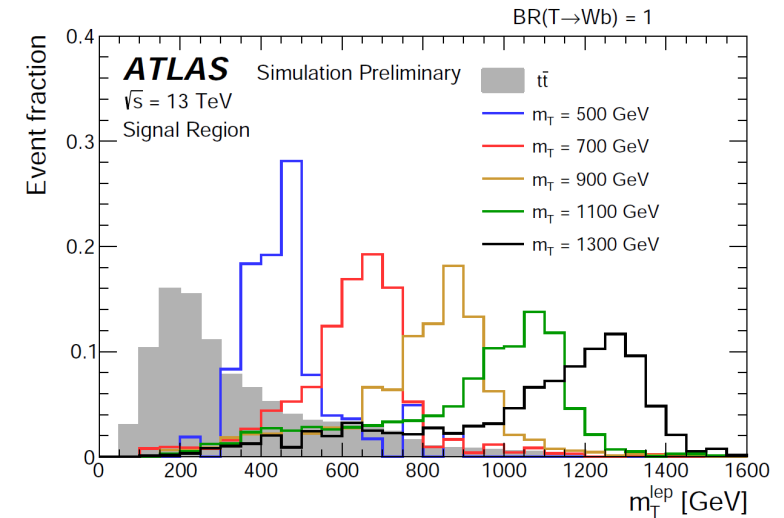


ATLAS: VLQ Pair production

$Wb/t+X$ (1 ℓ) ATLAS-EXOT-2016-14



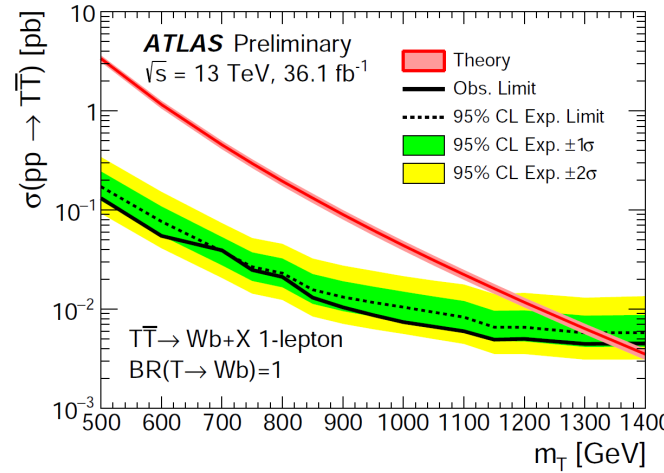
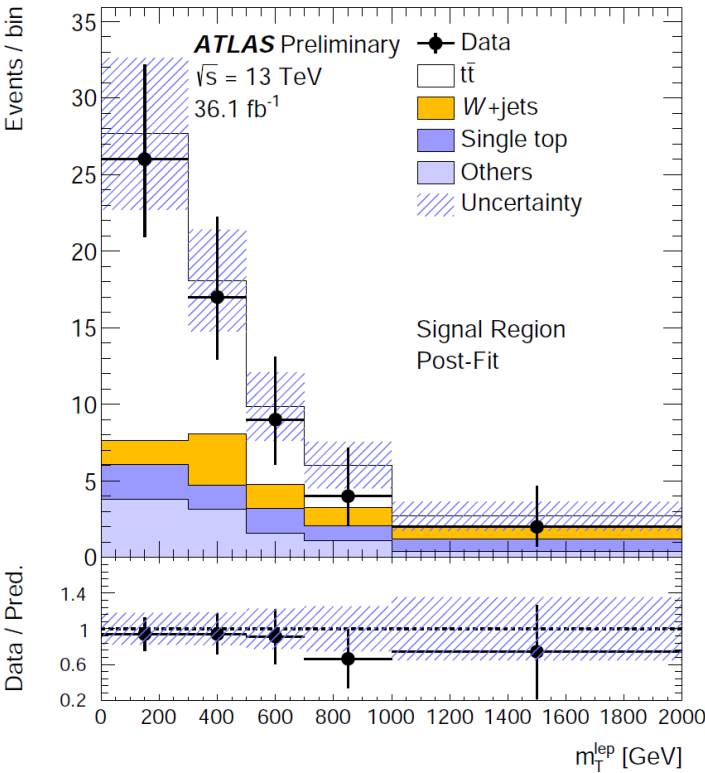
- **Event Topology:** 1 +jets+MET, 1b + $ST > 1.8\text{TeV}$
- **Dominant Background:** $t\bar{t}$ - calibrated from CR
- **Analysis technique:** Tagged W/top-jets, full TT reconstruction
- **Signal region categorization:** boosted topology,
- **Dominant uncertainty:** single top/ $t\bar{t}$ interference, top modeling, b tagging and large R jets.



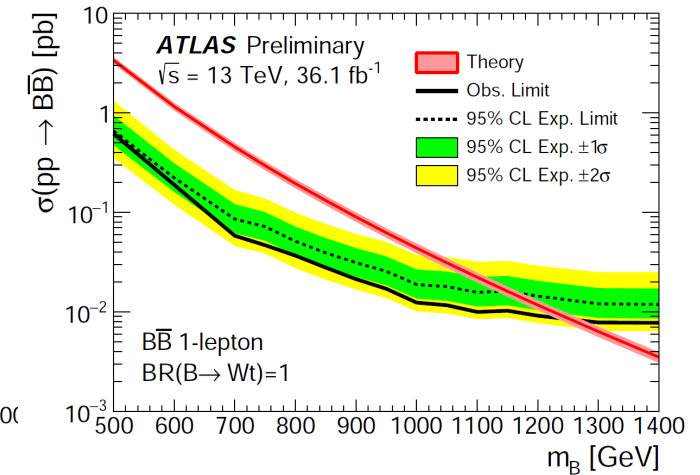
Reconstructed mass of the leptonically decaying VLQ

ATLAS: VLQ Pair production Wb/t+X (1ℓ)

New

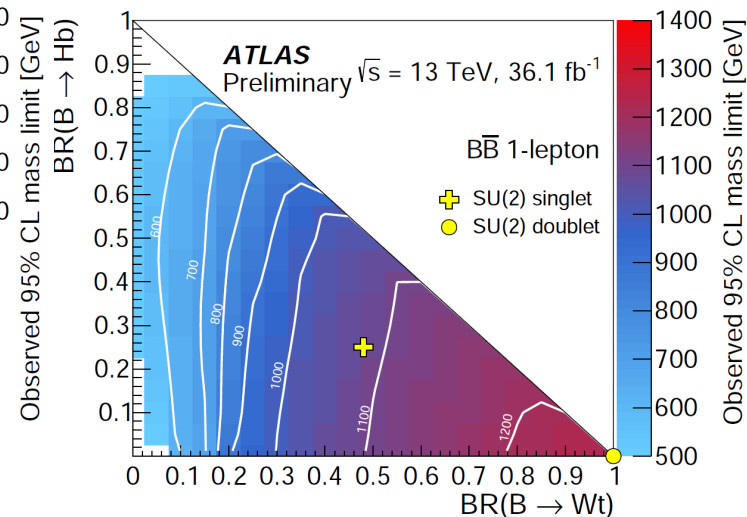
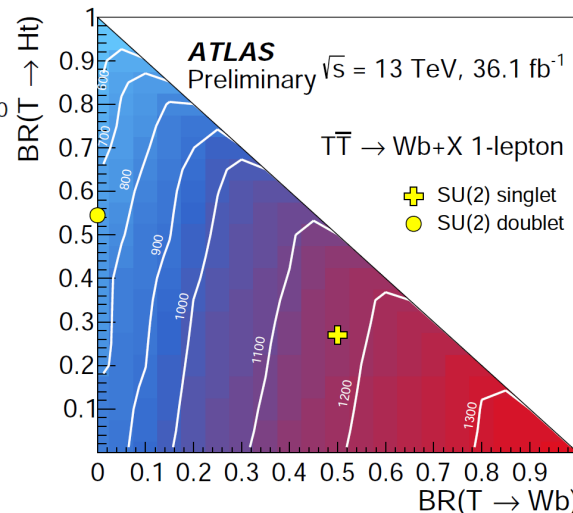


No dedicated optimization for B but analysis found to be sensitive.



Observed limits

T mass < 1350 GeV are excluded for 100% BR to W b.
 B mass < 1250 GeV are excluded for 100% BR to Wt.

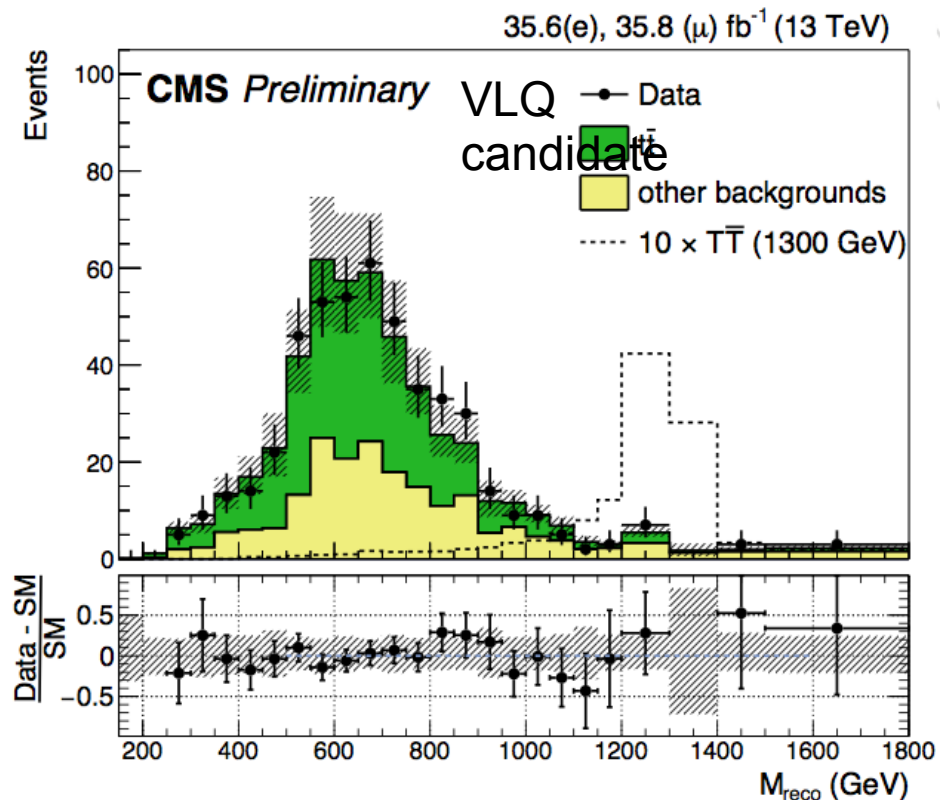
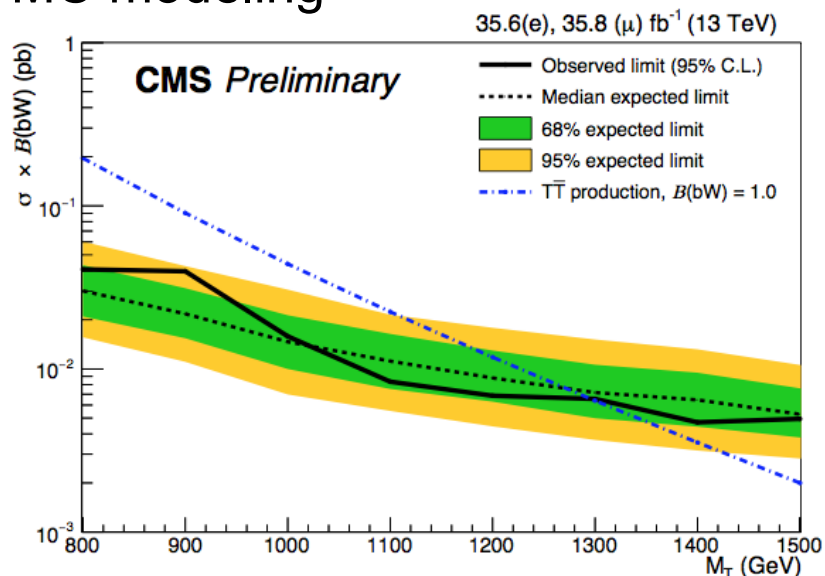


CMS: Pair production of $TT(YY) \square WbWb (1\ell)$

New

CMS-B2G-17-003

- **Event Topology:** $1\ell + \geq 4/3$ jets with 1 fat jet (W-tagged) + $ST > 1$ TeV ($ST = \ell + MET + JETs$)
- **Analysis technique:** Kinematic fit: 2 M_w , 2 $M_{\nu lq}$, using b-jet and ST info,
- **Dominant BG:** top production, W+JETs – estimated using MC, BG estimation is cross checked in CR
- **Dominant uncertainty:** Jet energy scale, MC modeling



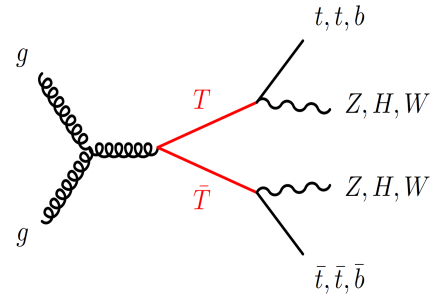
kinematic reconstruction of bWbW final state

Observed limits
 T/Y mass $< 1295/1275$ GeV

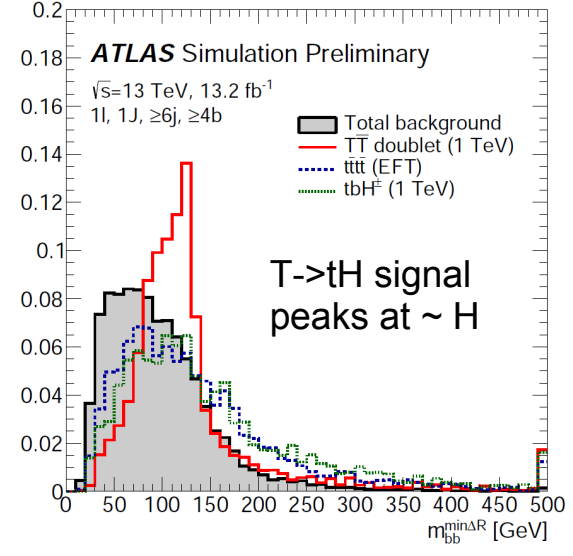
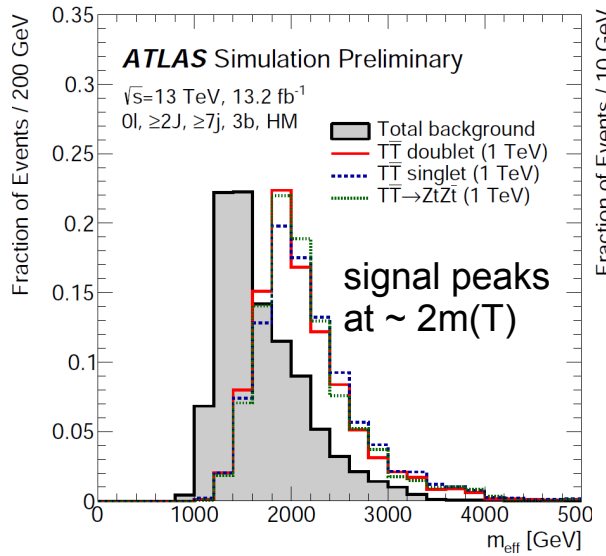
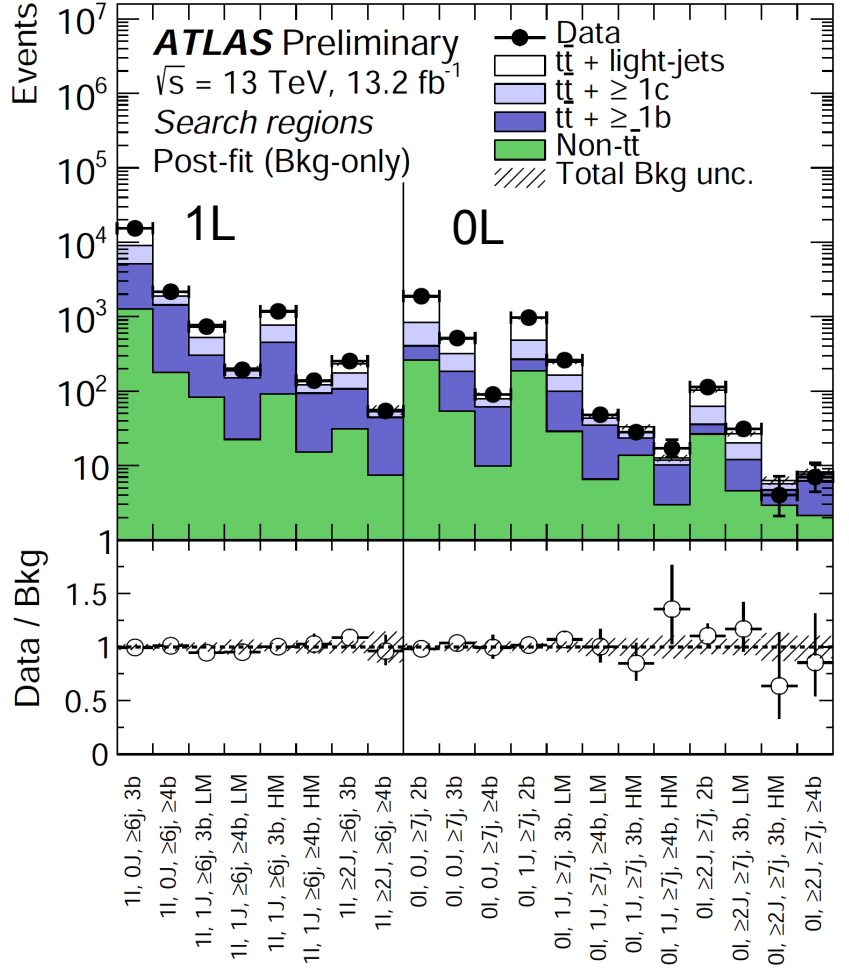
ATLAS: VLQ Pair production

tH(bb)+X (0ℓ+jets+MET/1ℓ)

ATLAS-CONF-2016-104

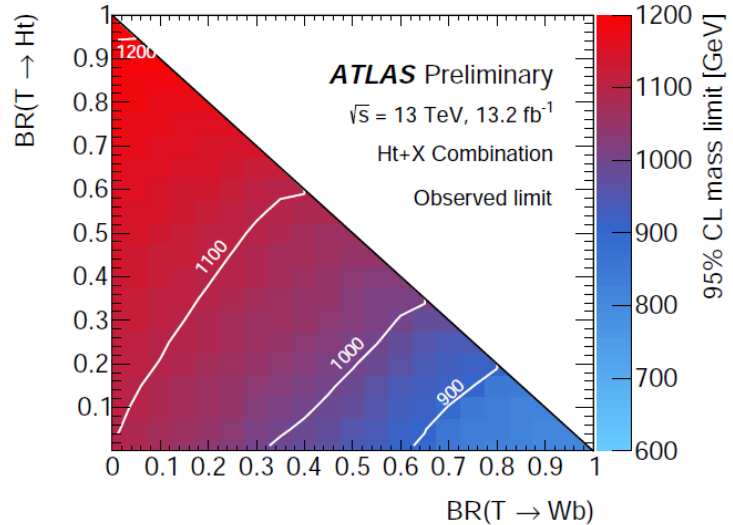
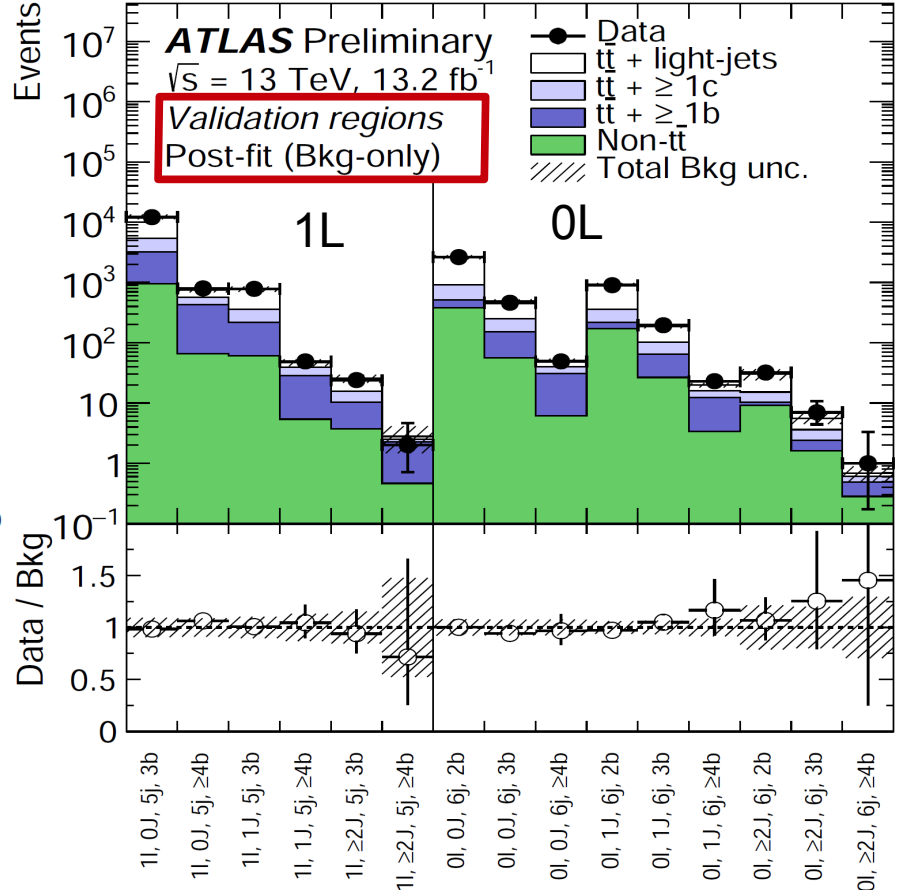
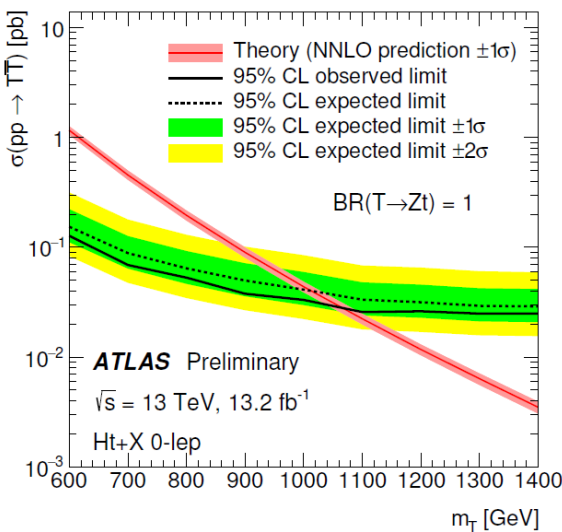
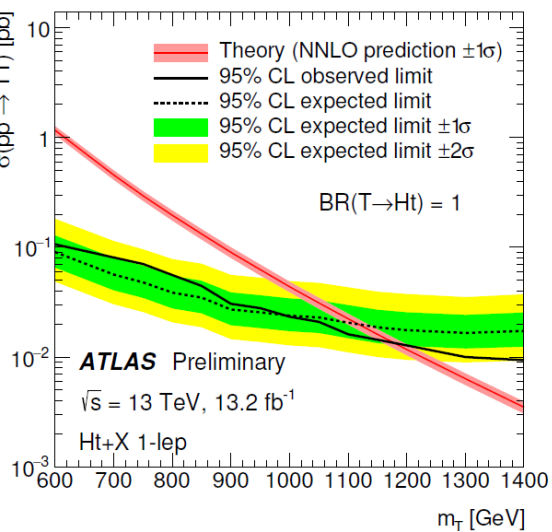
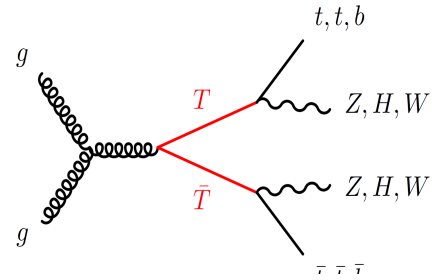


- **Event Topology:** 0 ℓ + jets + MET / 1 (2b-jet)
- **Dominant Background:** tt+jets, Single Top, and V+jets - estimated from CRs
- **Analysis technique:** Tagged H/top-jets with subjets (2),
- **Signal region categorization:** jet/b-jet multiplicities, binning in: m_{bb}, m_{Tb}, m_{eff}
- **Dominant uncertainty:** tt+(heavy flavour) modeling.



ATLAS: VLQ Pair production

tH(bb)+X (0ℓ, 1ℓ) ATLAS-CONF-2016-104

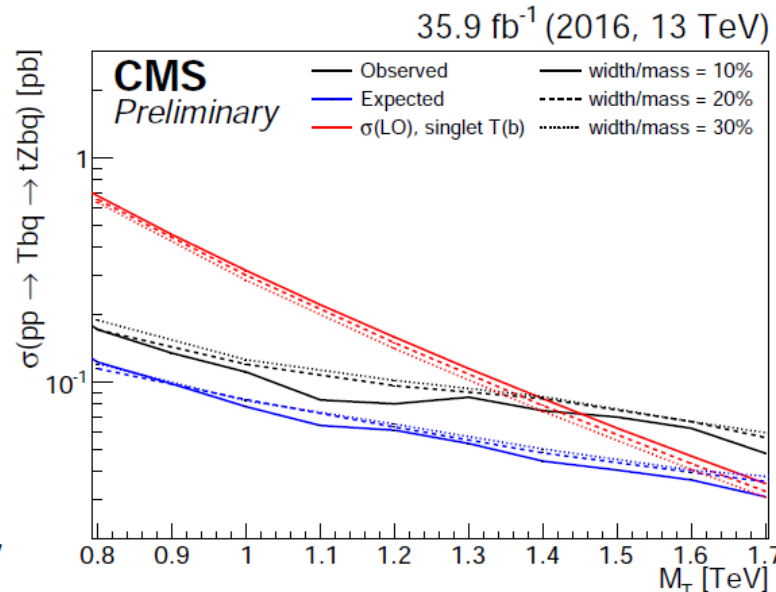
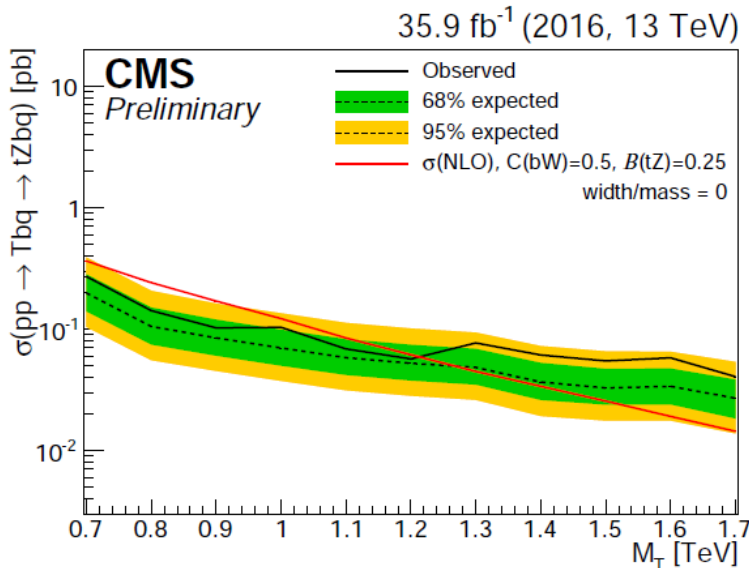
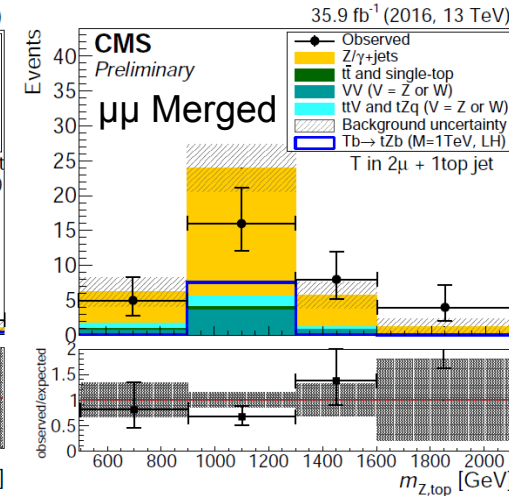
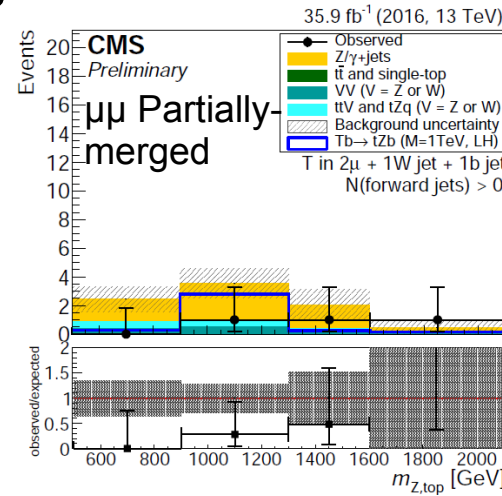
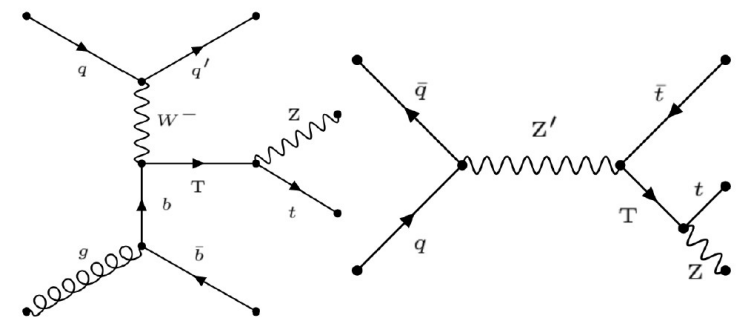


Search	BR(T → Ht) = 1	BR(T → Zt) = 1
1-lepton channel	1180 (1120)	740 (820)
0-lepton channel	1090 (1070)	1060 (1010)
Combination	1200 (1160)	1100 (1040)

CMS: Single VLT production “tZ(l)+X”, CMS-B2G-17-007

New

- **Event Topology:** $\ell\ell$ +jets ($\geq 1b$)
- **Dominant Background:** Z+jets - estimation from a CR with b-jet veto
- **Analysis technique:** Z($\ell\ell$) rec, t- and W-jet tagging
- **Signal region categorization:** number of forward jets, merged/partial-merged and resolved final states (in total 9 cat).
- **Dominant uncertainty:** statistics in CR



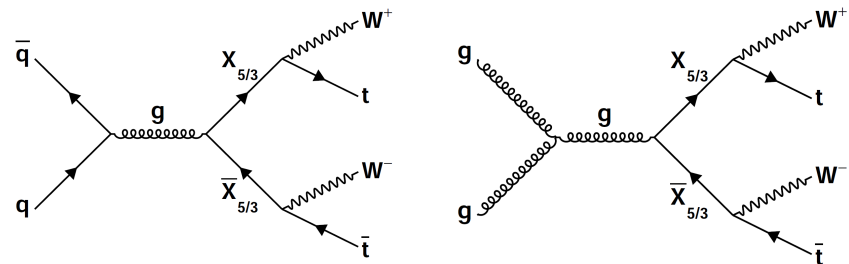
A singlet LH T(b) excluded below 1.35 to 1.45 TeV for the width of 10 - 30%.

A doublet RH T(t) excluded below 0.85 to 0.95 TeV for widths of 10 - 30% (plots not shown here).

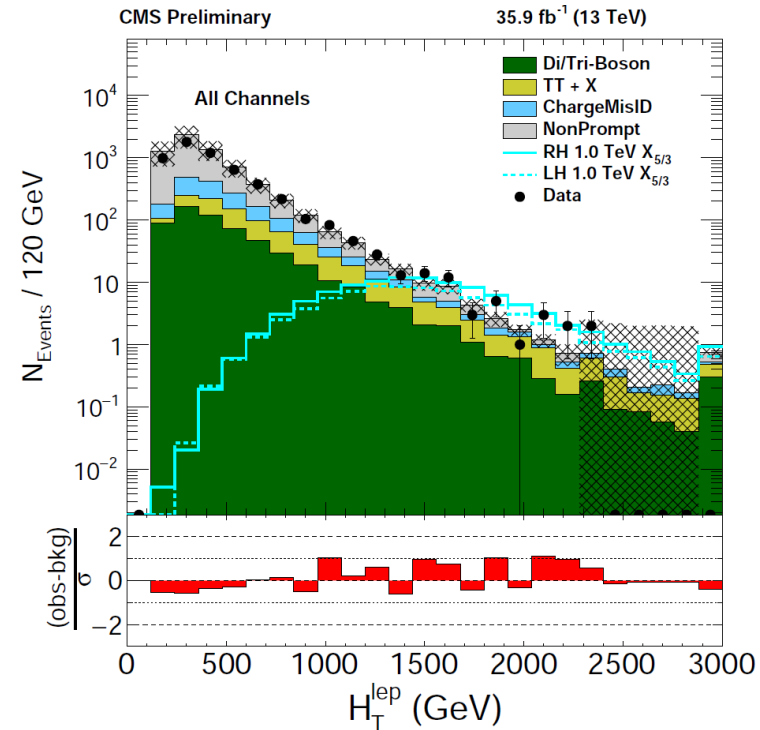
CMS: Pair production of $X_{5/3}$ \square $W+t(bW+)$

CMS-B2G-16-009

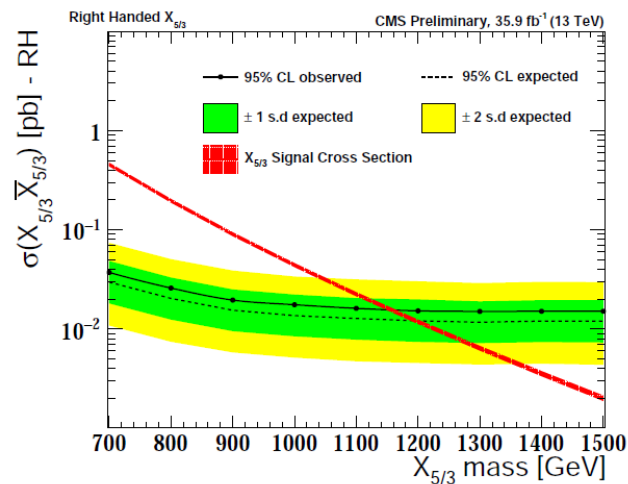
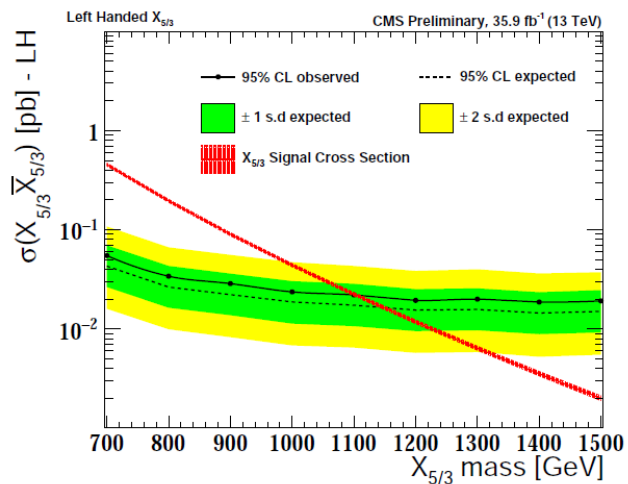
New



- **Event Topology:** SS $\ell\ell + \geq 5$ (jets+other leptons), $HT_{lep} > 1200$ GeV,
- **Dominant Background:** Prompt leptons from MC (VV, VVV, tV, ttVV), charge mis-id leptons and non-prompt/fake leptons fully data driven
- **Dominant uncertainty:** 30% for the charge mis-id and a 50% on the the fake lepton background, MC Modeling.



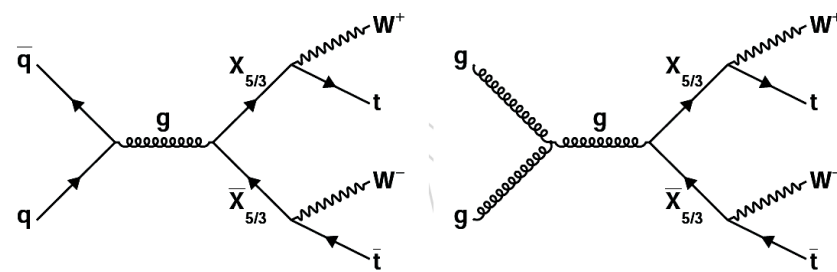
The observed limits are placed on the $X_{5/3}$ mass of 1.16 TeV for a right handed $X_{5/3}$ and 1.10 TeV for a left handed $X_{5/3}$.



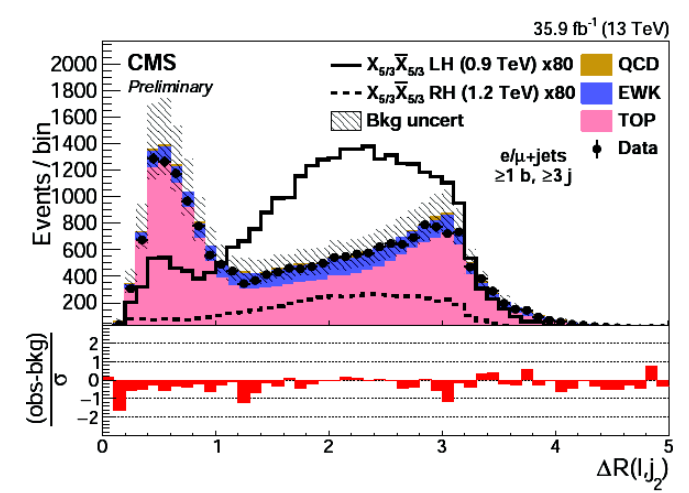
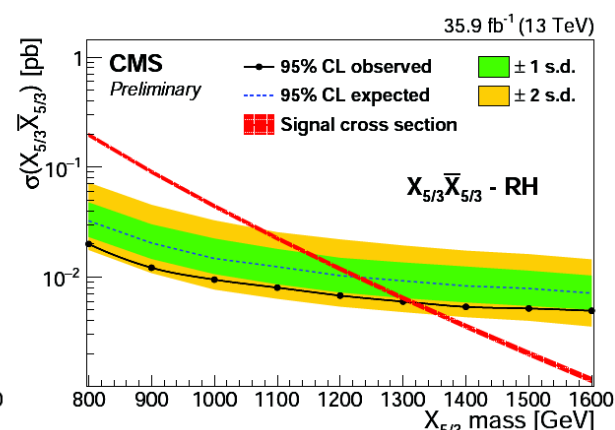
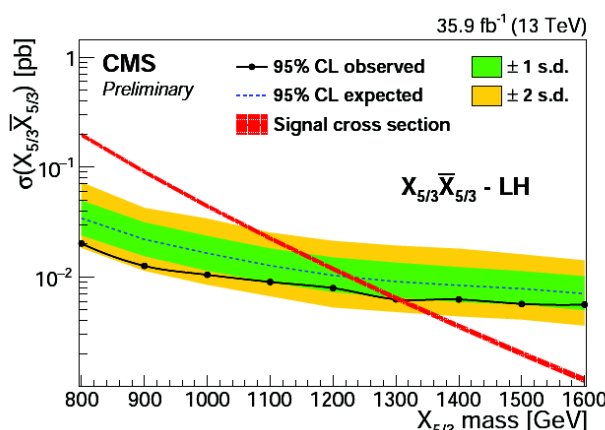
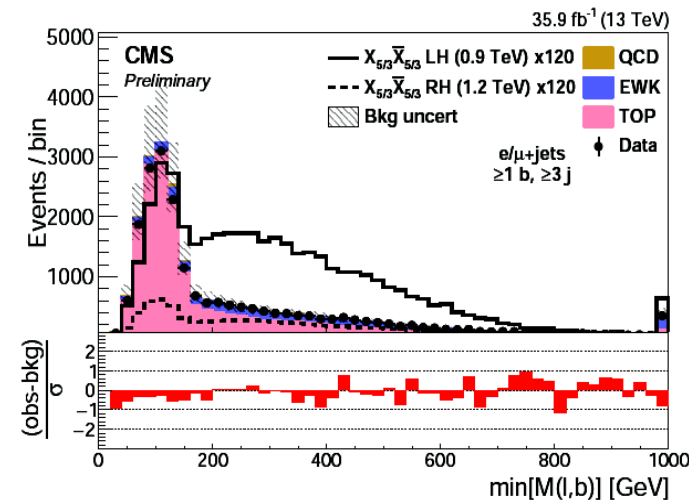
CMS: Pair production of $X_{5/3} \bar{X}_{5/3} W+t (1\ell)$

CMS-B2G-17-008

New



- **Event Topology:** $1\ell + \geq 4\text{jets} (\geq 1 \text{ b-jet}) + \text{MET}$
- **Dominant Background:** $tt, W+\text{JETs}$ – estimated using MC, BG estimation is cross checked in multiple VRs defined with $0.4 < DR(\ell, \text{jet}2) < 1.0$ and binned in b-jet, W tag multiplicities.
- **Signal region categorization:** 16 cat. based on lepton flavor, b-tagged jets (1, 2), **W/t-tagged jets** (0, 1) multiplicities
- **Dominant uncertainty:** Jet energy scale, MC modeling



$X_{5/3}$ masses with right-handed (left-handed) couplings below 1.32 (1.30) TeV are excluded

Conclusions

- Very diverse searches for VLQ and Top partners at LHC: tH , Wb , tZ , tW , ...
- Covering all Top/H/Z/W decays, full hadronic, semi-leptonic, dileptonic
- Background with not fully reconstructed SM events (e.g. objects out of acceptance or wrong ID) and/or with fake/non-prompt objects,
- Most relevant ingredients needed for the searches:
 - good theory modeling in all corners/tails
 - Efficient and robust Top/W/Z/H/ reconstruction for all topologies
 - good and robust b-jet identification

2017 data-taking starts in few days, search for top partners is still preferred new physics!