Generalized Interpretation of Searches of Singly Produced Vector-like Quarks at the LHC

(A summary of the results from arxiv:2003.00640)

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Vector-like Quarks

- Identical SU(2) quantum numbers for left and right chiralities
- 4 possible particles, multiple EWK representations
- Interactions represented by a model-independent parameterization
- Nature and strength of interaction with SM particles depend on representation and coupling strengths

$$X_{+\frac{5}{3}} \quad B_{-\frac{1}{3}}$$
$$T_{+\frac{2}{3}} \quad Y_{-\frac{4}{3}}$$

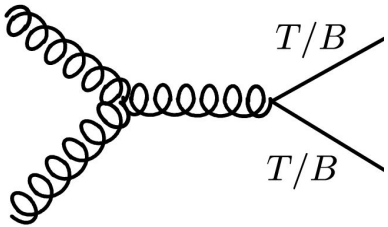
Singlets	$(T), (B)$
Doublets	$(X,T), (T,B), (B,Y)$
Triplets	$(X,T,B), (T,B,Y)$

$$\mathcal{L} = \sum_{\zeta,q,Q} \left[\frac{g_w}{2} \sum_V c^{Qq}_{\zeta,V} \bar{Q}_\zeta \gamma_\mu V^\mu q_\zeta + c^{Qq}_{\zeta,H} H \bar{Q}_{\zeta'} q_\zeta \right] + \text{h.c.}$$

Production and Decay of VLQs

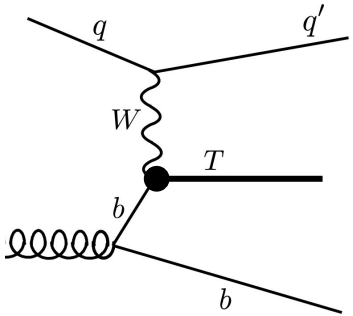
Pair Production (PP):

Strong force-mediated, model-independent production

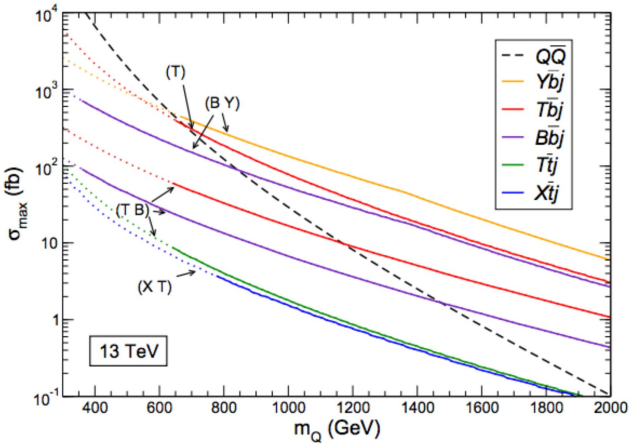


Single Production (SP):

Weak force-mediated, model-dependent production



PhysRevD.88.094010



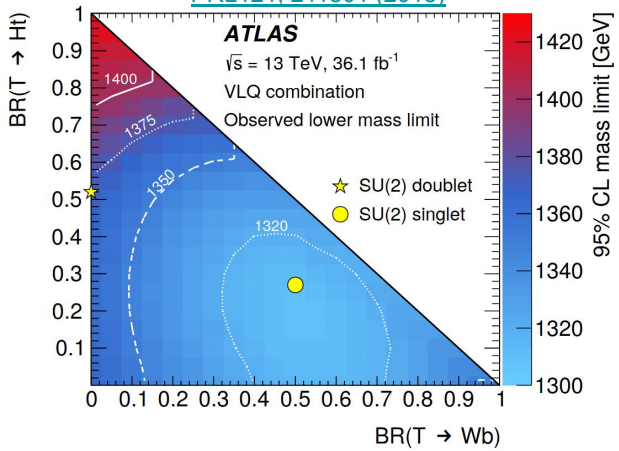
- At larger masses, SP may dominate
- VLQ searches focused on PP in LHC Run-1
- SP is getting more popular in LHC Run-2

Interpretation of VLQ Searches

- Represent the search results in terms of parameters in VLQ Lagrangian
- A model-independent approach allows results to be interpreted in context of multiple models
- Thanks to the strong force-mediated production and narrow width approximation, PP of VLQs utilize a simple interpretation strategy

$$\sigma^{\mathrm{NW}}_{\mathrm{prod},\, Q\bar{Q}}\,(M_Q) \geq \sigma^{\mathrm{NW}}_{\mathrm{lim},\, Q\bar{Q}}\,(M_Q, \mathrm{BR}_W, \mathrm{BR}_H)$$

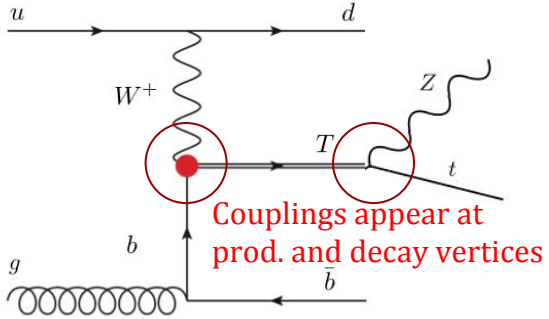
PRL121, 211801 (2018)



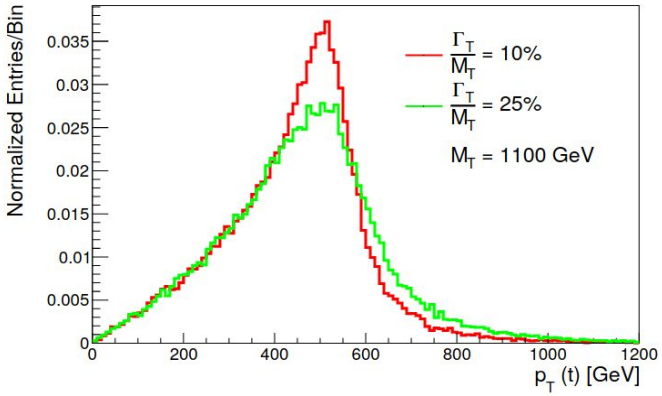
- BR(Wb) + BR(Zt) + BR(Ht) = 1.0
- Narrow-width approximation

Interpretation of ***Single*** VLQ Searches

- Appearance of couplings at both production and decay vertices
- Narrow Width Approximation (NWA) breaks down at larger masses and couplings
- Tails of wide resonances alter the distribution of signal events in the phase space



arxiv:2003.00640



Many Approaches to Interpretation

- Most approaches make model-specific assumptions about group representation or branching ratios
- These diverging approaches are often incompatible for comparison or combination

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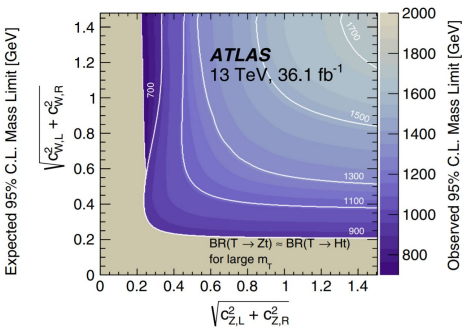
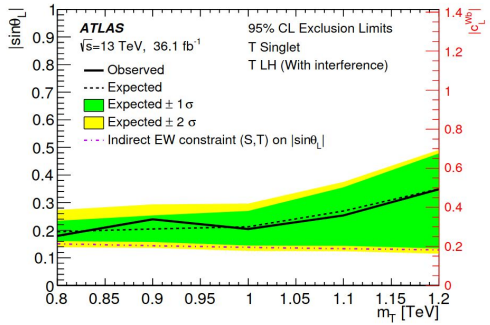
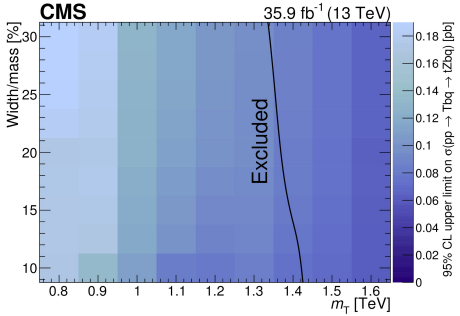


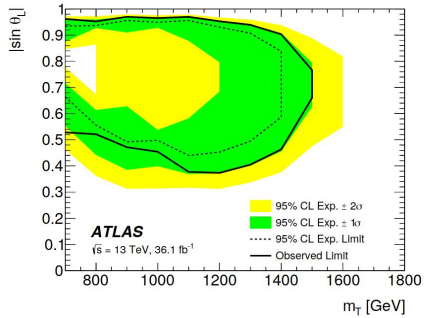
JHEP 164 (2019)



PLB 781.574(2018)



JHEP 41 (2019)



Semi-analytic Framework for Interpretation

Three Assumptions:

- VLQs interact with third generation SM quarks only i.e. with $q,\ q' \epsilon \{\ t,\ b\ \}$

$$\mathrm{BR}(Q \to Hq) + \mathrm{BR}(Q \to Zq) + \mathrm{BR}(Q \to Wq') = 1.0$$

- Heavy VLQs

$$M_Q \gg m_t$$

- Chirality-agnostic:
  Analyses are insensitive to the chiral structure of VLQ couplings or,
  A single chirality always dominates

Semi-analytic Framework for Interpretation

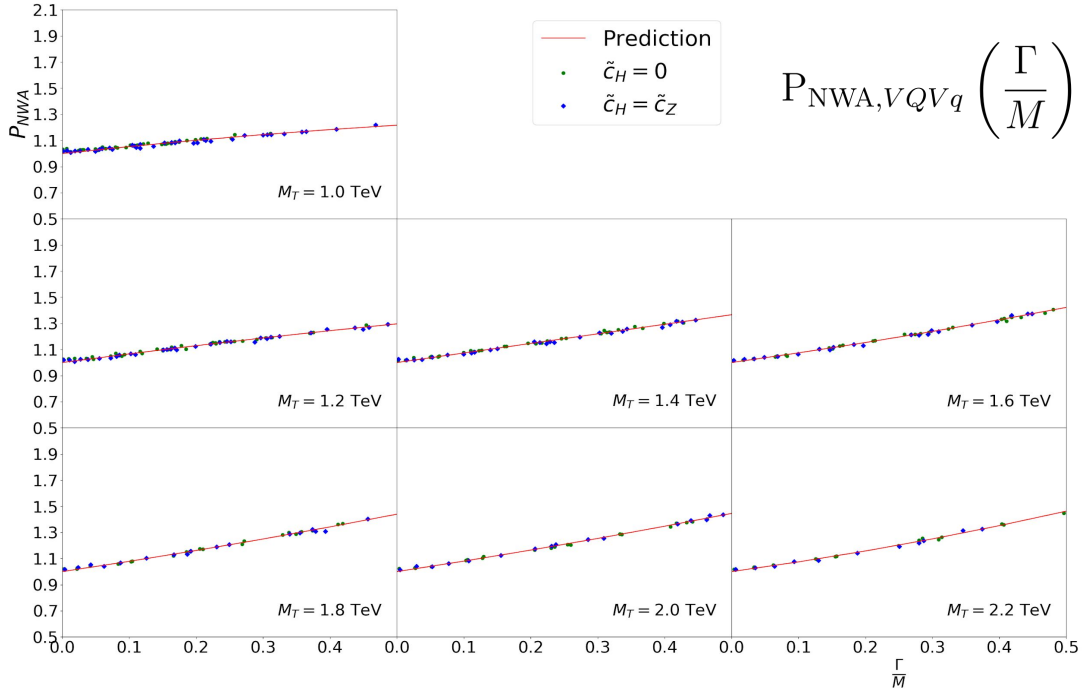
$$\frac{\tilde{c}_V^2 \times \sigma^{\rm NW}_{{\rm prod},\,VQ}\,(M_Q, \tilde{c}_V = 1) \times {\rm BR}(Q \to Aq)}{{\rm P}_{\rm NWA}(M_Q, \vec{c})} \geq \sigma_{{\rm lim},\,VQAq}\,(M_Q, \vec{c})$$

- Theory prediction of process cross-section under NWA
- Correction on cross-section for the NWA
- Statistical Limits on process cross-section, depends of mass/coupling choices

$\rm P_{NWA}$ defines the correction to cross-section calculation for NWA

$$\begin{aligned} {\rm P}_{\rm NWA}(M_Q, \vec{c}) &= \frac{\sigma^{\rm NW}_{{\rm prod},\,VQ} \times {\rm BR}(Q \to Aq)}{\sigma_{VQAq}} \\ &\approx 1 + \sum_n A_n \left(\frac{\Gamma_Q}{M_Q}\right)^n \end{aligned}$$

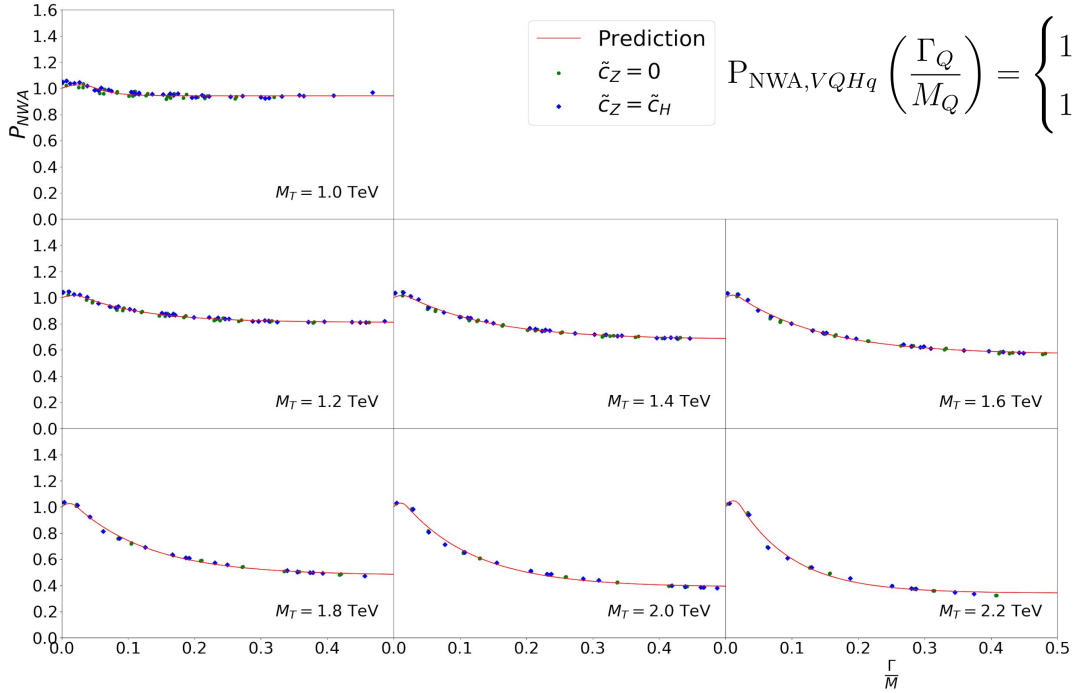
P_{NWA} for VLQ Decays to Vector Bosons



$$\mathrm{P}_{\mathrm{NWA},VQVq}\left(\frac{\Gamma}{M}\right) = 1 + A_1\frac{\Gamma}{M} + A_2\left(\frac{\Gamma}{M}\right)^2$$

$\mathrm{P}_{\mathrm{NWA}}$ for *WTZt* process i.e. *T* produced via *W* and decaying to *Zt*

P_{NWA} for VLQ Decays to Higgs Boson

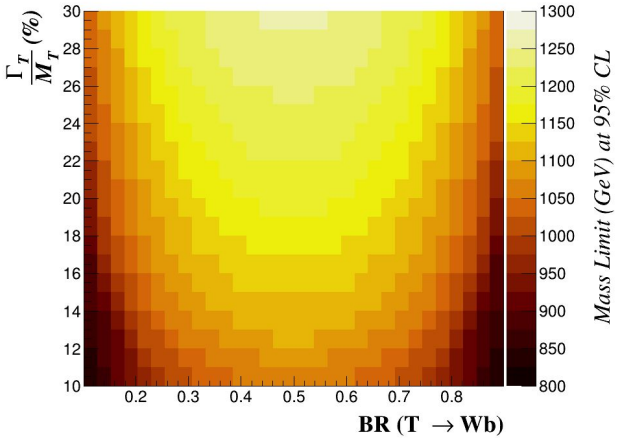


$$P_{\mathrm{NWA},VQHq}\left(\frac{\Gamma_Q}{M_Q}\right) = \begin{cases} 1 + AB\frac{\Gamma_Q}{M_Q} - \left(\frac{AB}{x_0}\right)\left(\frac{\Gamma_Q}{M_Q}\right)^2, & \frac{\Gamma}{M} < x_0 \\ 1 - A\left(1 - \exp\left(-B\frac{\Gamma_Q}{M_Q}\right)\right), & \frac{\Gamma}{M} \geq x_0 \end{cases}.$$

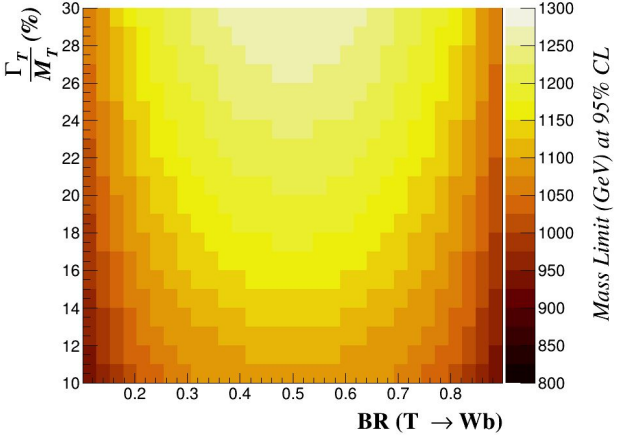
P_{NWA} for *WTHt* process
i.e. *T* produced via *W*
and decaying to *Ht*

Reinterpretation of ATLAS and CMS Analyses

CMS VLQ-OSML

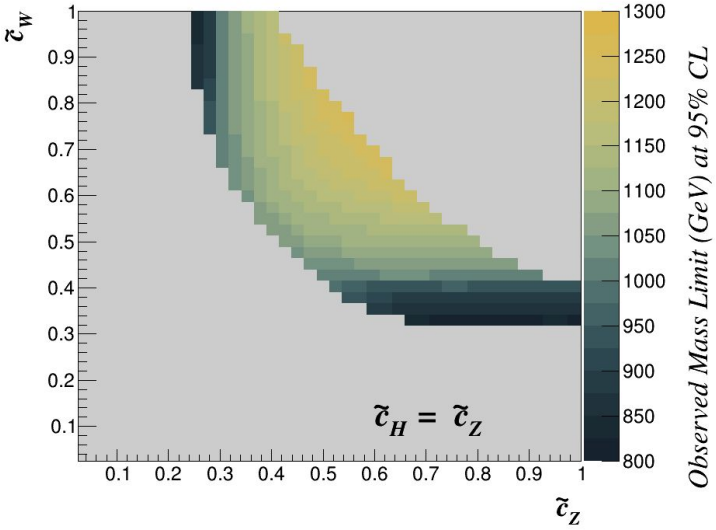


ATLAS VLQ-OSML

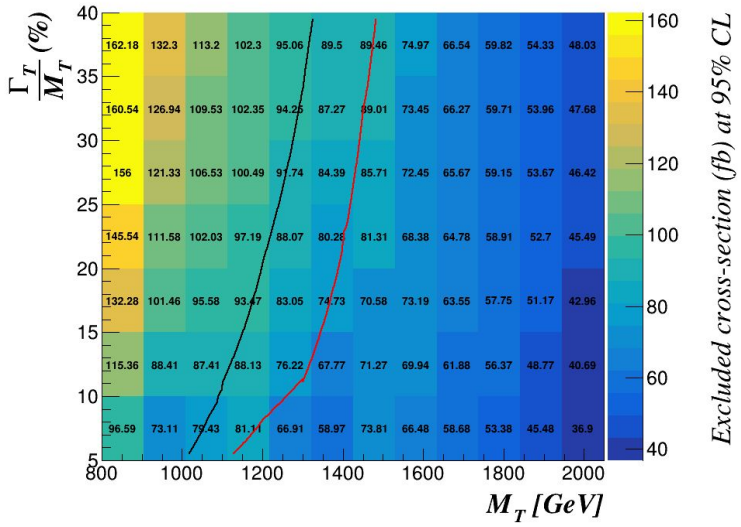


- Results from 2015+2016 Run-2 data
- Search for T → Zt signatures in multi-lepton final states
- Excluded Mass limit reinterpreted as a function of relative decay width and Branching ratio
- Assuming BR(Zt) = BR(Ht) [not necessary, but convenient]

Translating between Limit Representations



Excluded Mass limit from the CMS analysis as a function of couplings (originally proposed in the ATLAS analysis)



Excluded cross-section limit from the ATLAS analysis as a function of relative decay width and mass (originally proposed in the CMS analysis)

Conclusions

- Current work proposes a semi-analytic framework for a uniform and generalized interpretation of single VLQs
- Presents a parameterized correction to NWA for cross-section estimation
- Demonstration of how this framework applies for translating across different representations

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