Overview of ATLAS Exotics Group Analyses and Interpretive Models

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16 June 2016

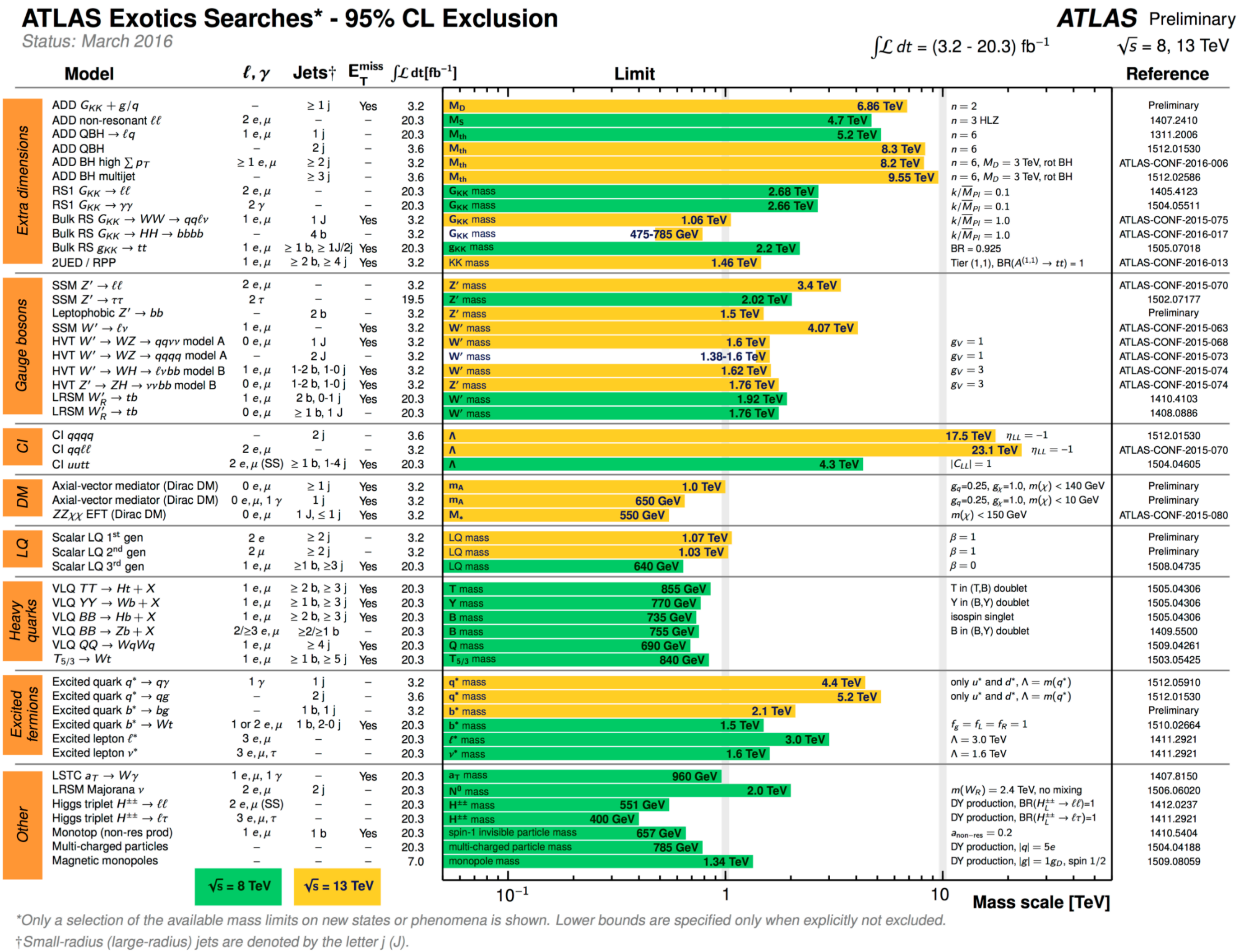
Overview

- Overview of ATLAS Exotics group structure & analyses
  – Group organization aligned by signature-based search strategies

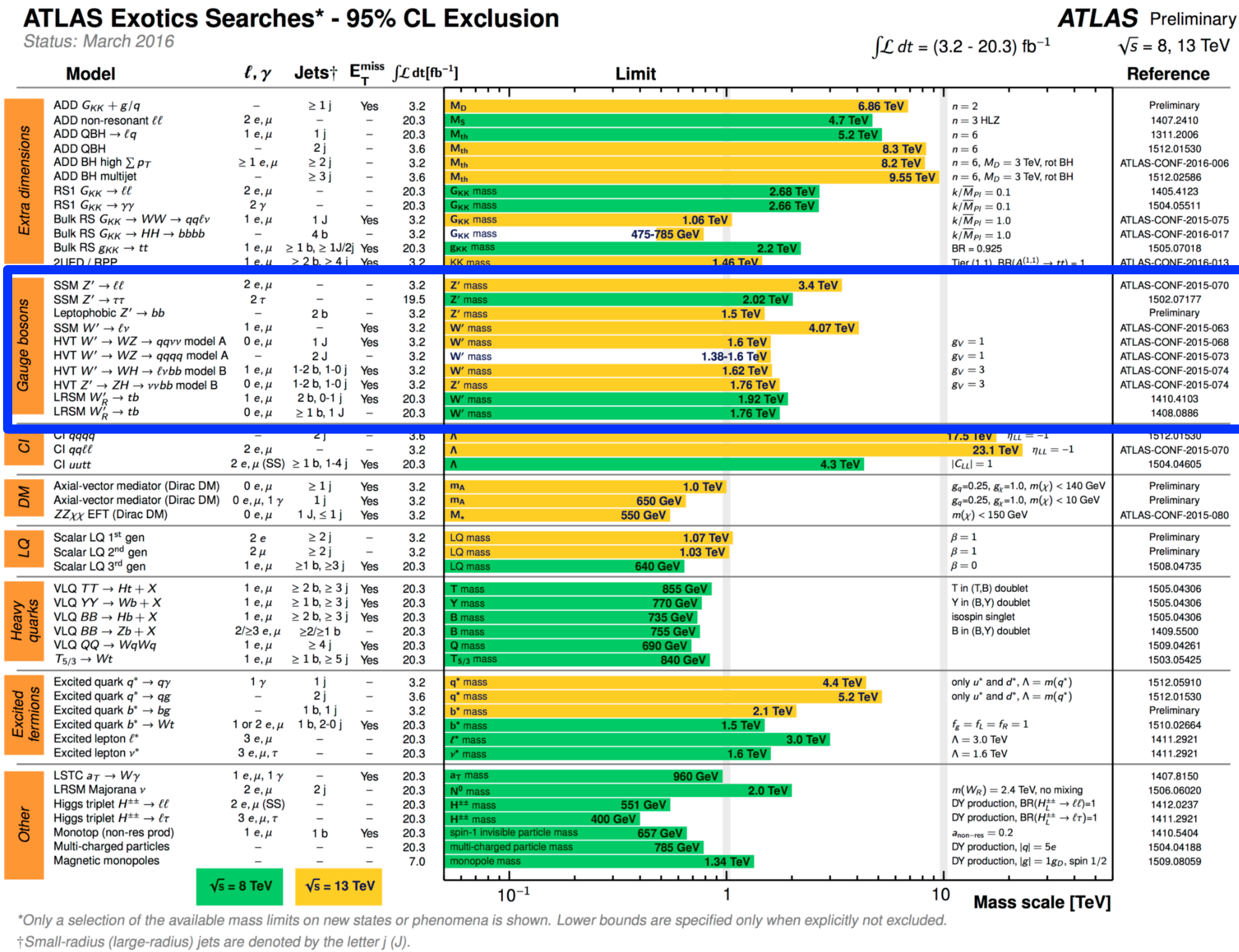
- Organization of generic interpretations
  – Spanning signature-based efforts

- Summary of interpretive paradigms and results
  – Heavy Gauge Bosons
  – Extra Dimensions
  – Heavy Quarks
  – Excited Fermions
  – Contact Interactions
  – And more

ATLAS Exotics Results



Example: Heavy Gauge Bosons



Extra Dimension Interpretations

Extra Dimension Interpretations

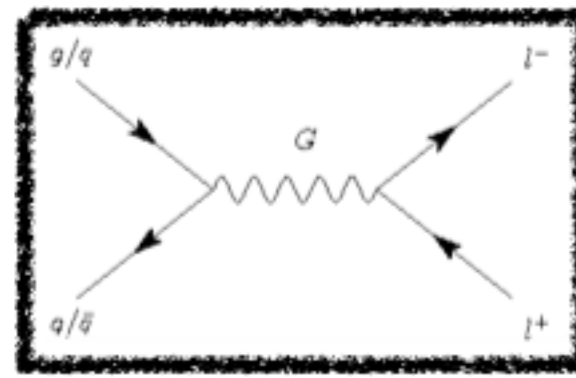
- Extra Dimensions (ED) are proposed in many BSM theories to help explain the apparent weakness of Gravity, invoking a Spin-2 Tensor Boson (G*).

- Two models broadly used in ATLAS searches are Randall-Sundrum (RS1 & RS2), and Arkani, Dimopoulos, Dvali (ADD):

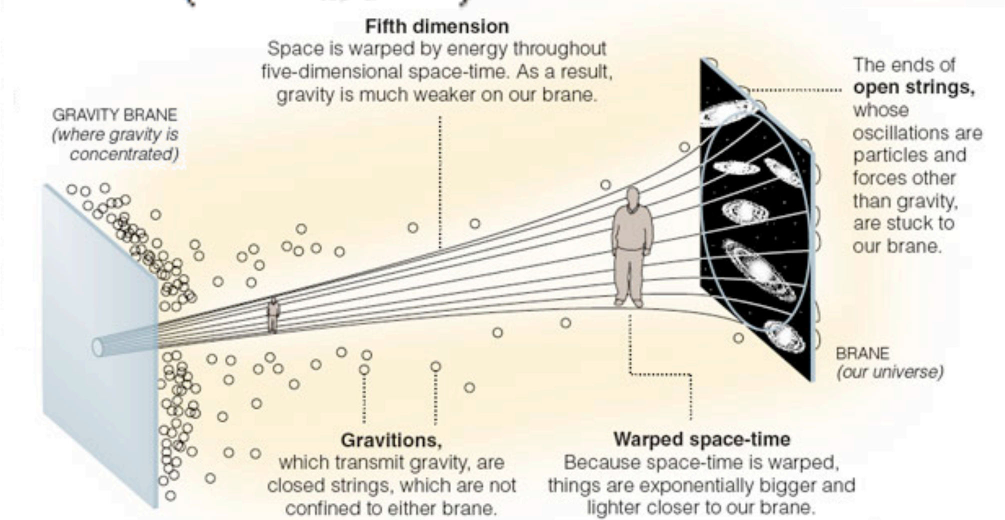
<u>RS Graviton</u>

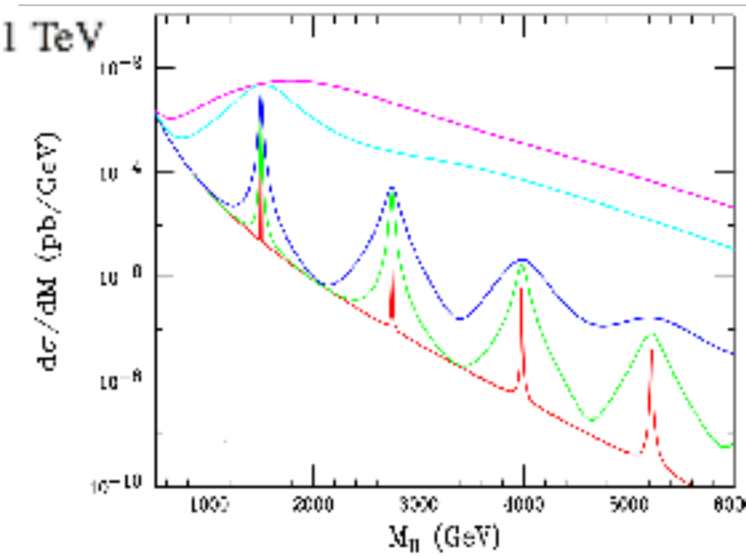
- Warped ED allow access to physics at the Planck Scale from the TeV Scale.

- Search for resonances, where the width and cross-section depends on the warping factor, *k*.



$$\mathcal{L} = -\left(\frac{G_0^{\mu\nu}}{\overline{M}_{Pl}} + \sum_{n>0}\frac{G_n^{\mu\nu}}{\Lambda_\pi}\right)T_{\mu\nu}\text{, where }\Lambda_\pi = \overline{M}_{Pl}e^{-\pi kR} \sim 1\text{ TeV}$$





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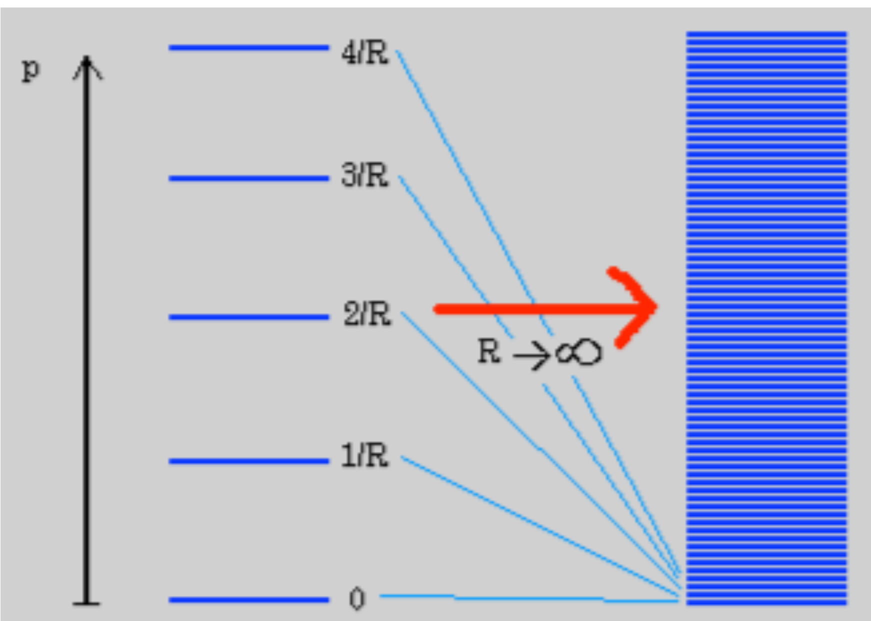
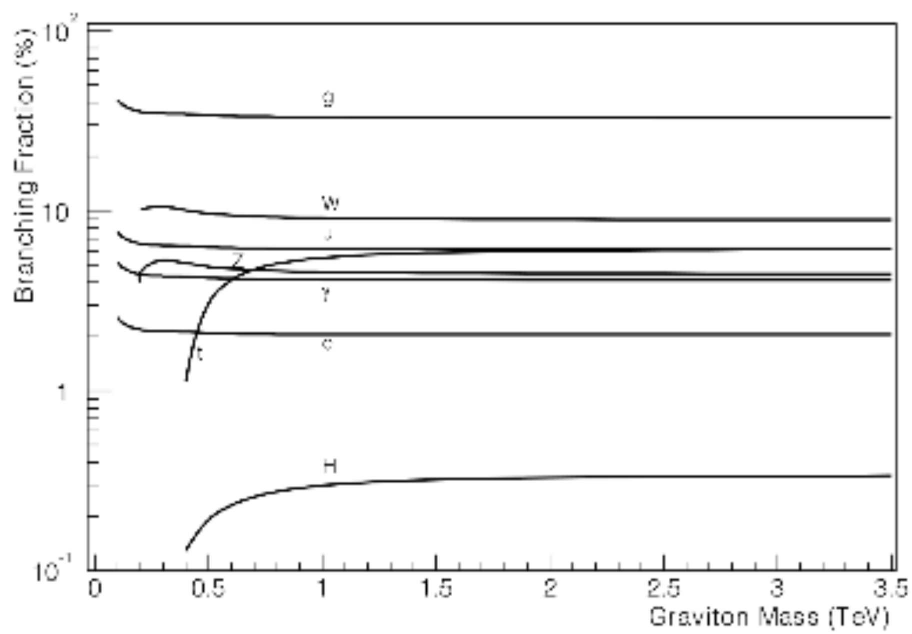
<u>ADD Graviton</u>

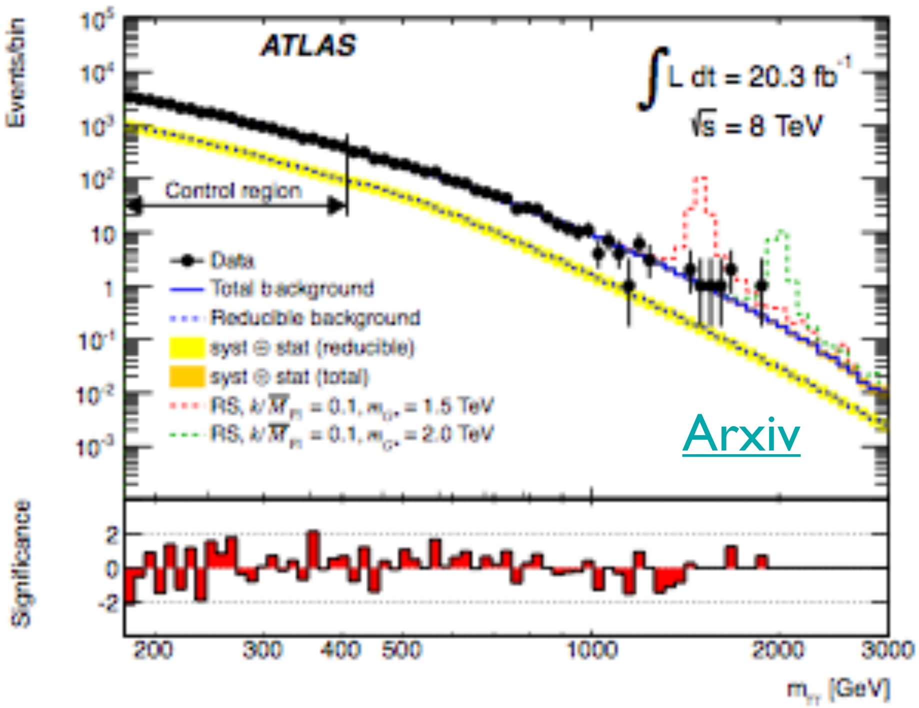
- If the ED were large (> µm) and flat, the spacing between the Kaluza-Klein towers is reduced, and eventually the resonances become a non-resonant excess.

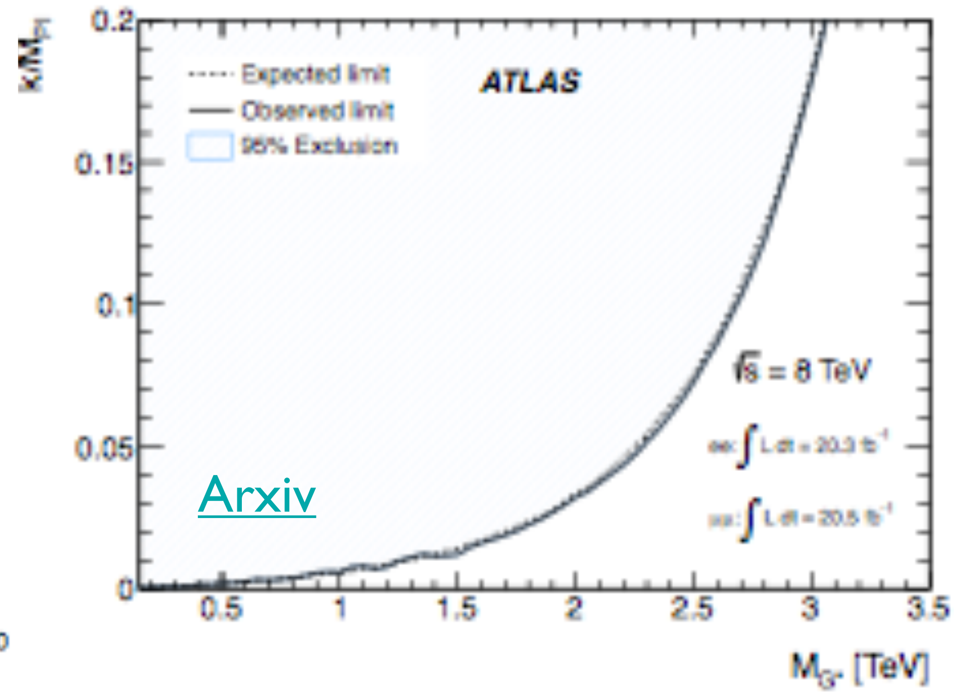




Extra Dimension Interpretations

- These models are searches for in many channels at ATLAS, such as:
- Dilepton: 7, 8 TeV, planned again for 13 TeV. RS1 and ADD Models.
- Diphoton: 7, 8, and 13 TeV (combined with dilepton at 8 TeV!).
- Dibosons [WW, ZZ]: 7, 8, and 13 TeV. RS2 model (SM fields in Bulk).
- Clean signatures with relatively small, well understood backgrounds.

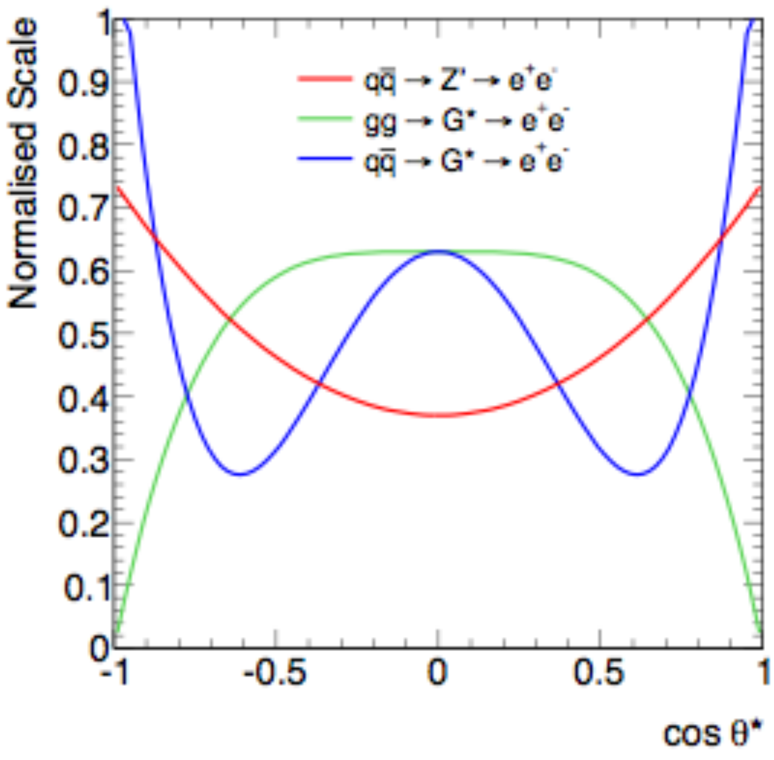


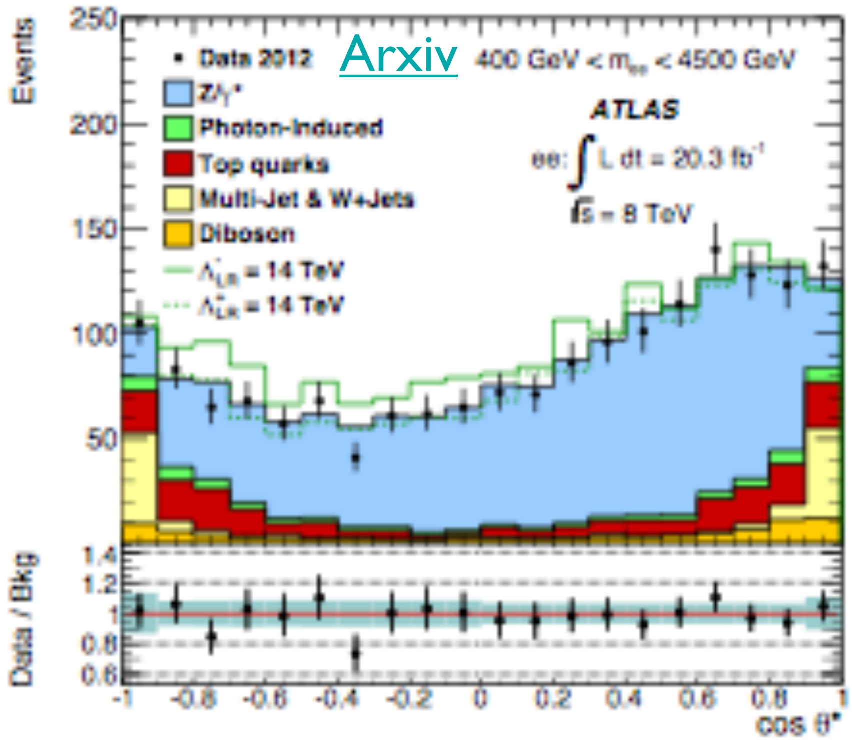


Extra Dimension Interpretations

- What handles do we have to probe new physics?
- What do analyses provide to help theorists (and others) interpret the results?

Angular Distributions

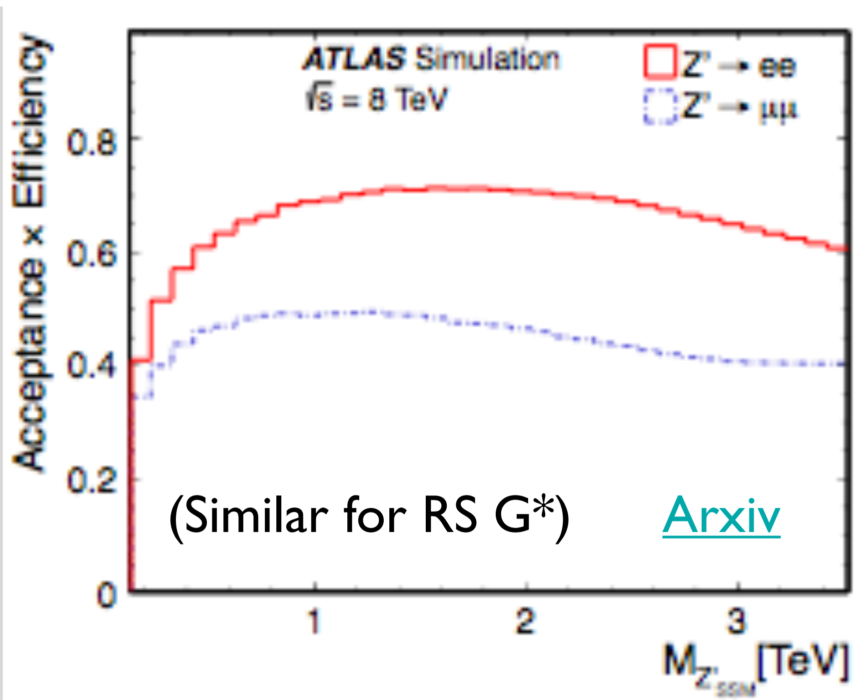




Extra Dimension Interpretations

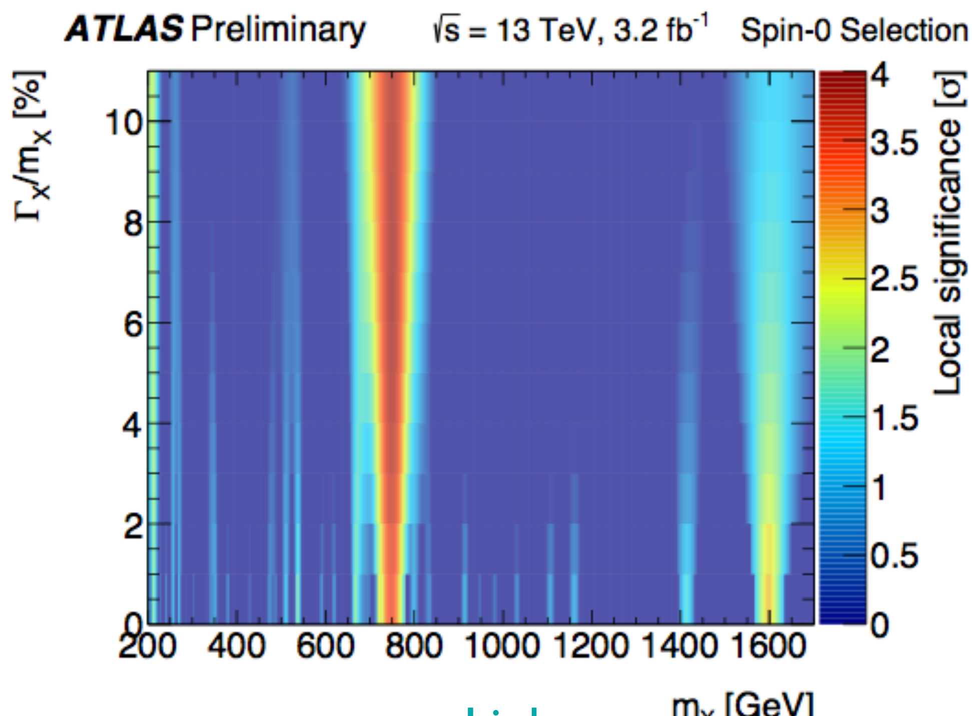
- What handles do we have to probe new physics?
- What do analyses provide to help theorists (and others) interpret the results?

<u>Acceptance x Efficiency</u>



(Similar for RS G*) Arxiv

<u>Width Scans</u>



Link

Heavy Gauge Boson Interpretations

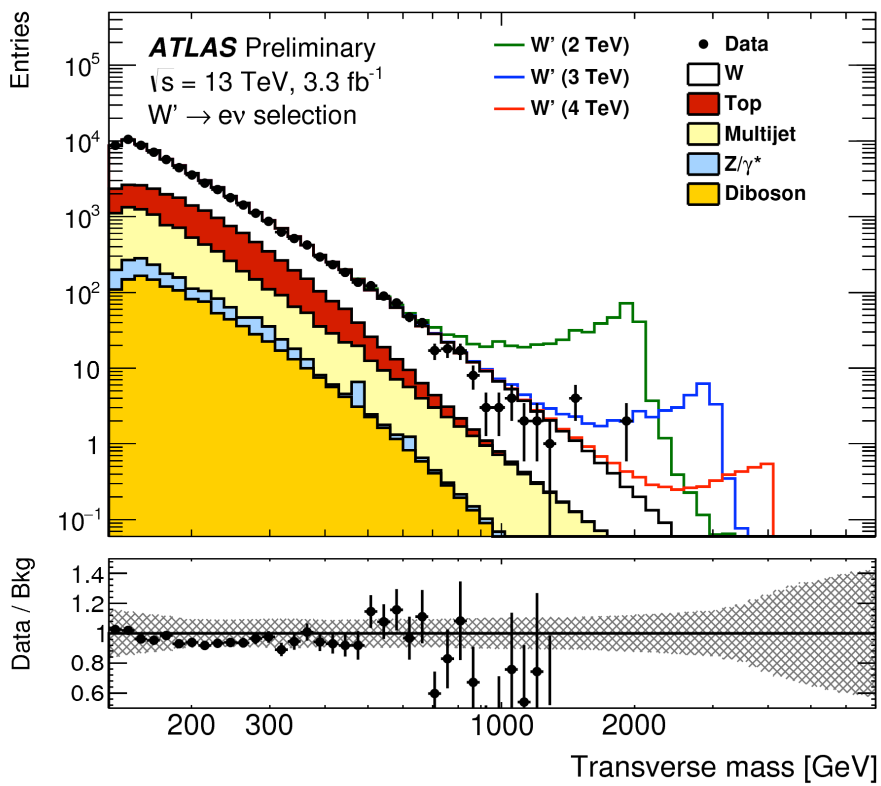
Heavy Gauge Boson Interpretations

- Several BSM models predict heavy gauge bosons:
  - Extended Gauge Models (EGM)
  - Technicolour
  - Composite Higgs models
  - Little Higgs
  - Theories with universal extra dimensions (e.g. Kaluza-Klein)
  - Sequential Standard Model (SSM)
  - Randall-Sundrum (RS) Graviton model
  - Heavy Vector Triplet (HVT).

W’ and Z’ to leptons

- Relatively “clean” background
- Benchmark model : W’ (SSM), Z’ (SSM and E_6).

ATLAS-CONF-2015-063



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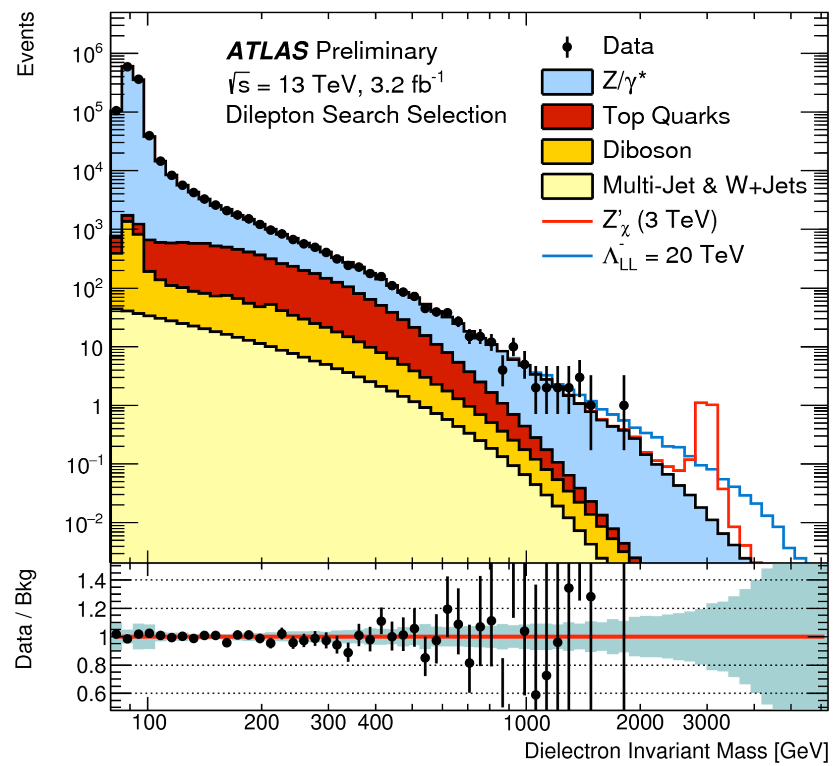
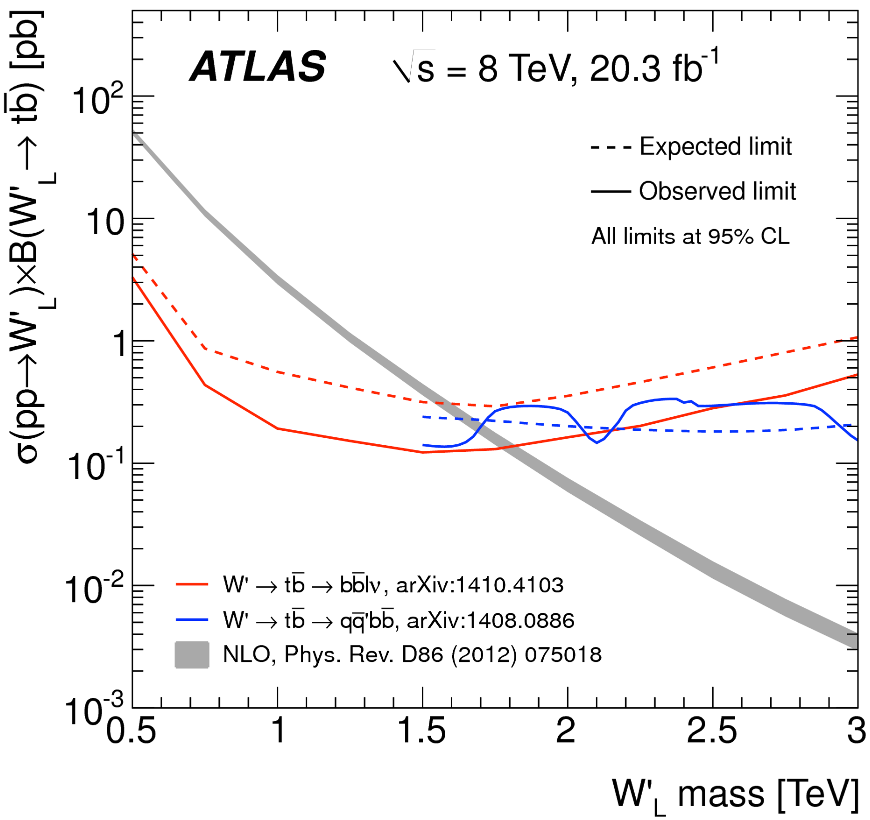
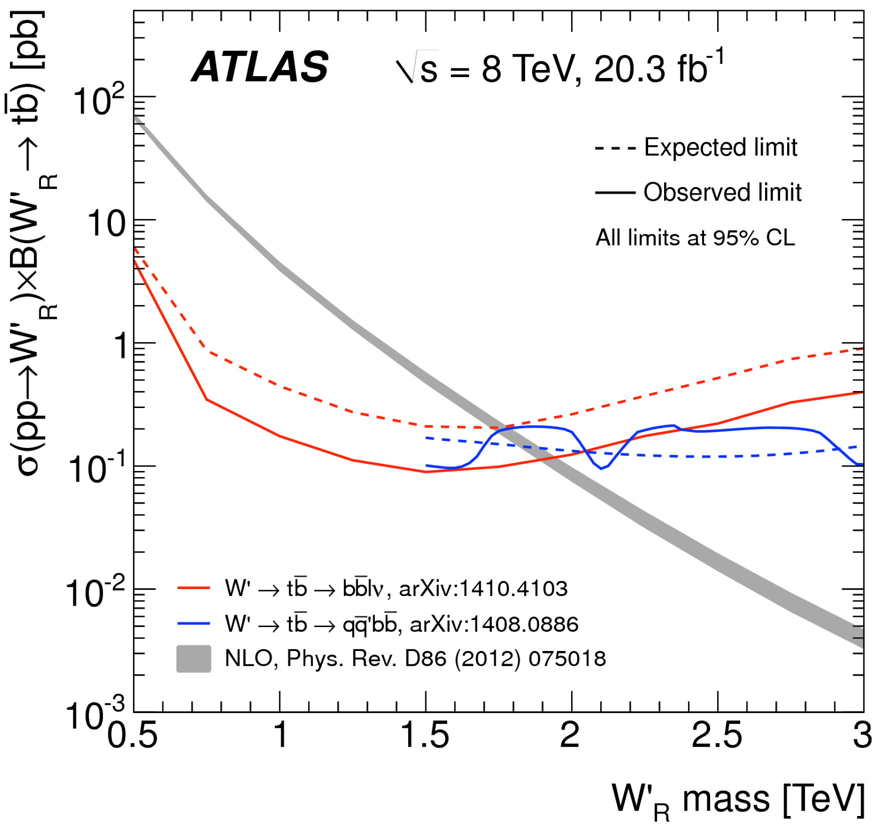


W'→tb

- Complementarity :
  - Theories with extension of fundamental symmetries of the SM predict W'_R
  - Not always seen by other channels. No decay to charged lepton and ν_R if $m_\nu > m_{W'}$

arXiv:1410.4103

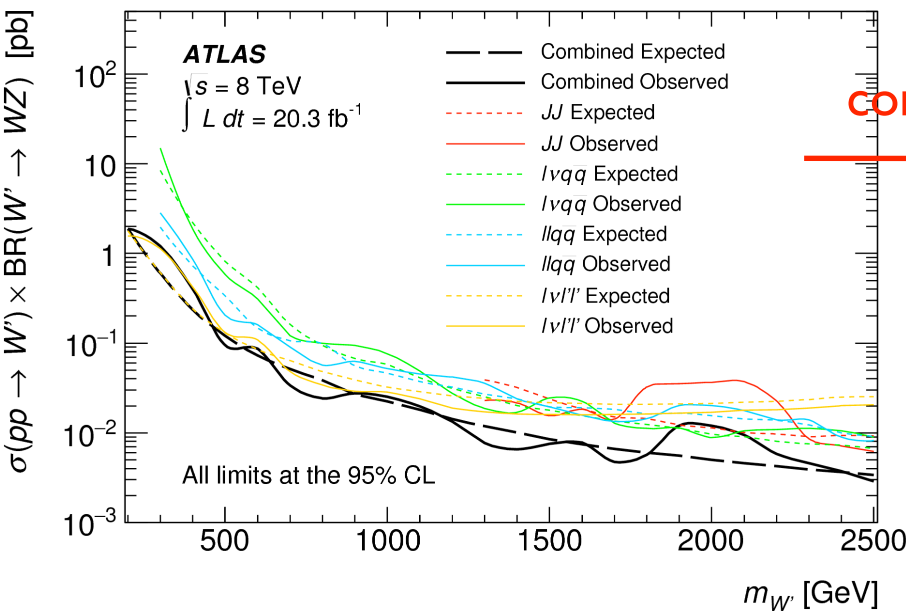




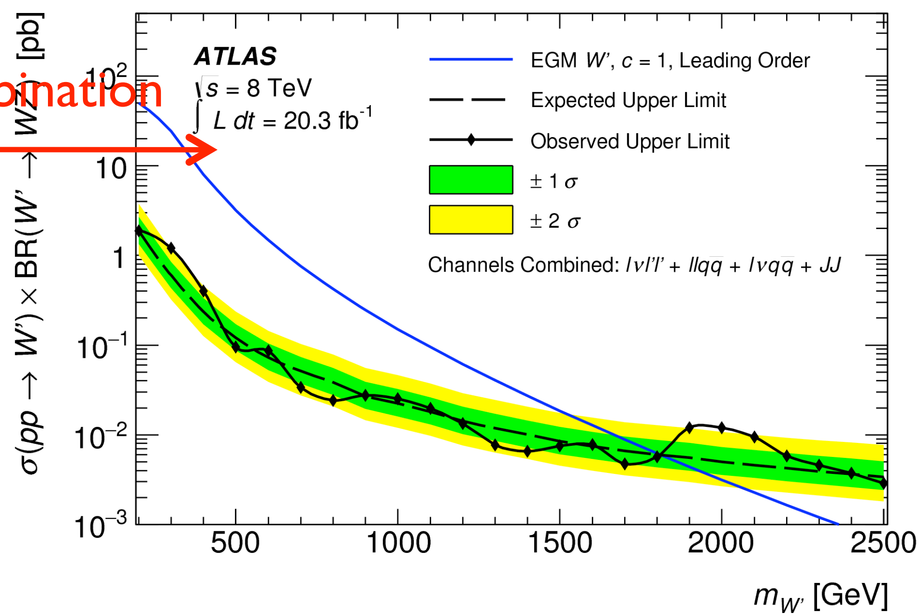
W' and Z' to VV

- Benchmark models:
  - Extended Gauge Model
  - Randall-Sundrum (RS) gravitation model
- EGM vs SSM → check of W'WZ coupling

arXiv:1512.05099



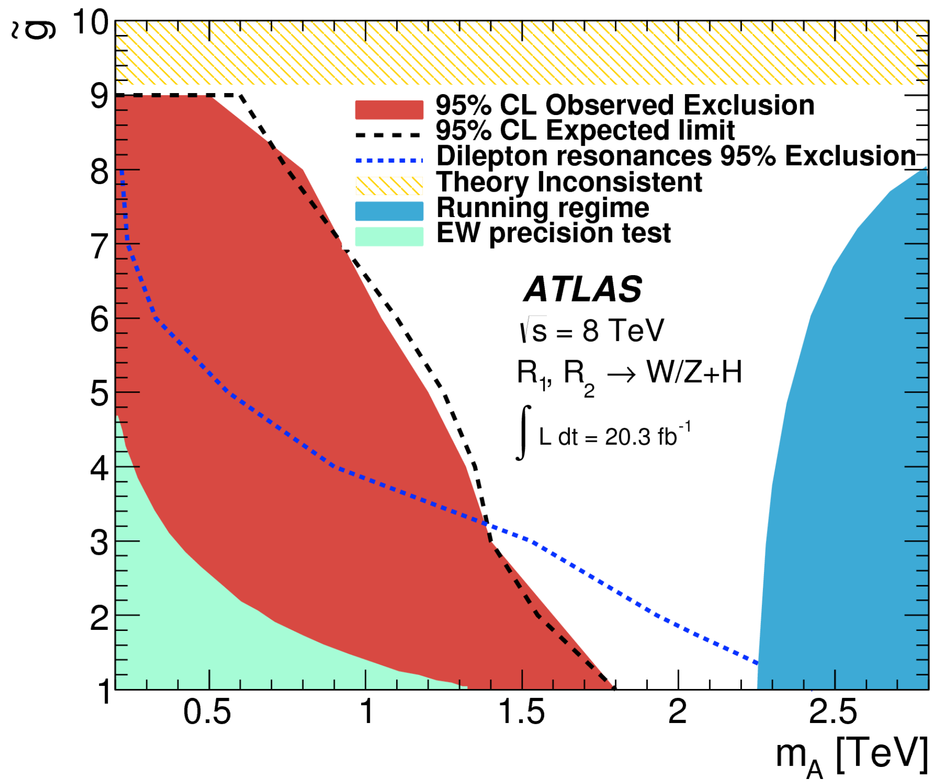
combination

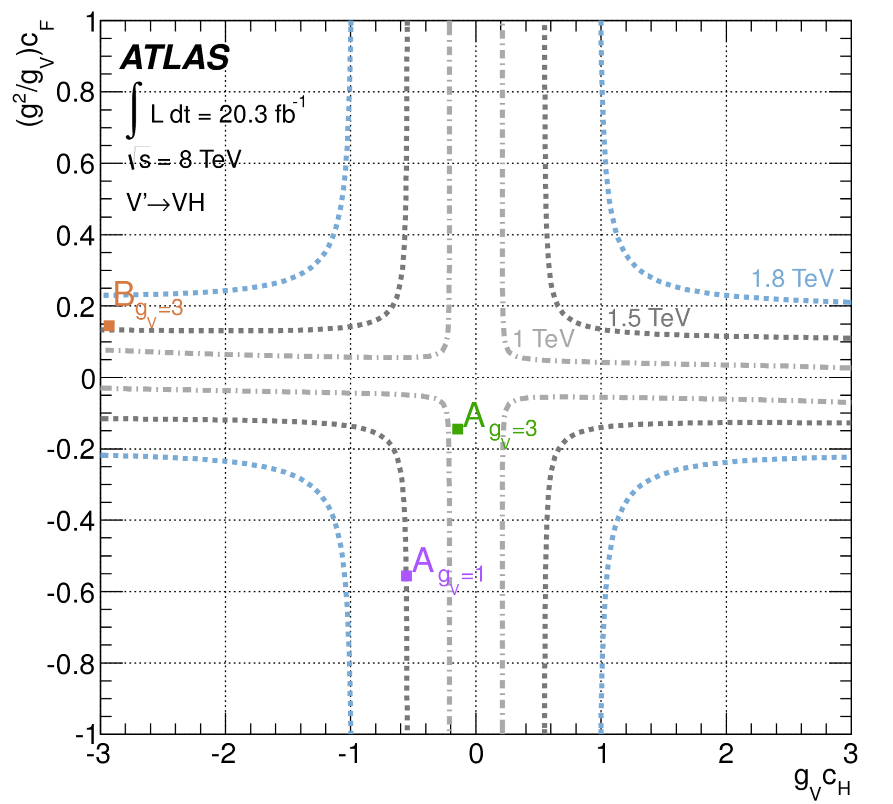


W' and Z' to VH

- Similar search for V'->VH interpreted in Heavy Vector Triplet model and Minimal Walking Technicolor.

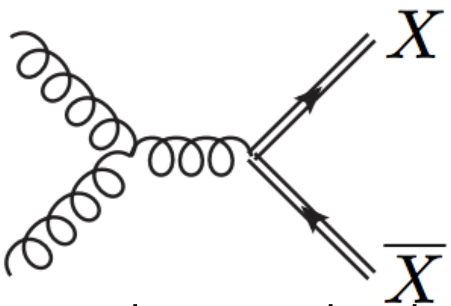
arXiv:1503.08089



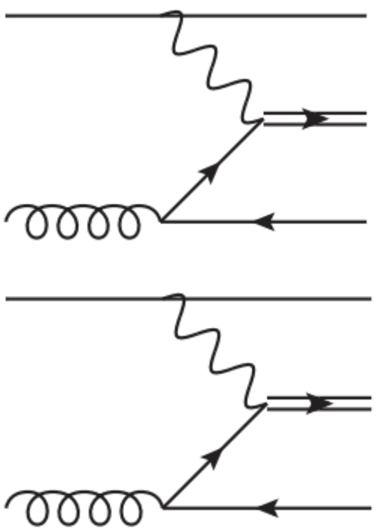


Vector-Like Quark Interpretations

Vector-Like Quark Pair Searches

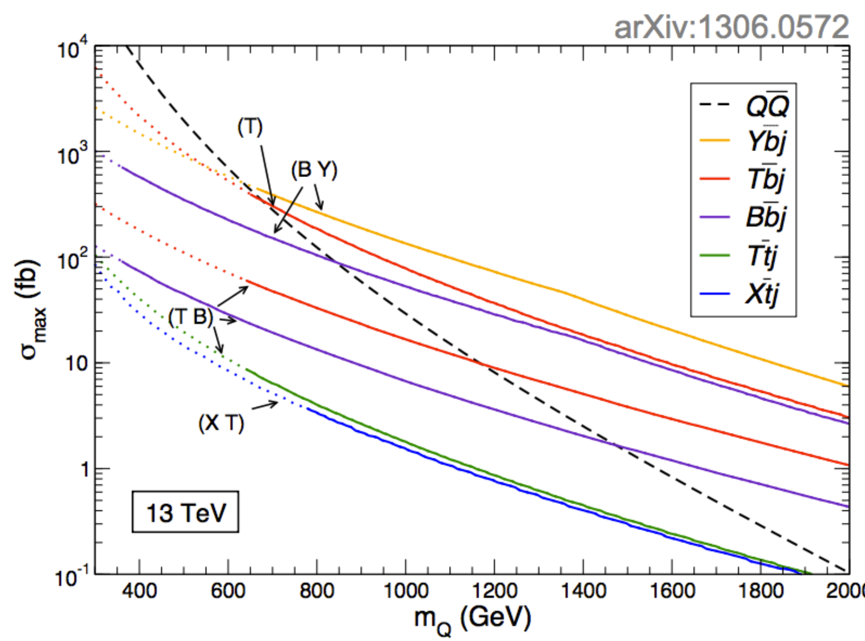


Pair production mediated via strong interactions



Single production mediated via EW interactions: associated top or b

- Present in many BSM models (eg. Composite Higgs), contain useful top-partner
- Search strategies are generally designed by production mode
  - Pair production dominates at lower masses, mostly model independent
  - Single production pdf-favored at high mass, sensitive to mixing with SM quarks (generally taken to be 3rd gen only)



Vector-Like Quark Pair Searches

- Models can be built in increasing steps of phenomenological complexity
  - Mixing with SM quarks can modify couplings to V/H bosons and lead to FCNCs
  - Leads to a potentially complex overlap of production/decay modes in experimental searches. Complicates interpretation to some degree.

	SM	Singlets	Doublets	Triplets
	$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$	$(T)_{L,R}$ $(B)_{L,R}$	$(X, T)_{L,R}$ $(T, B)_{L,R}$ $(B, Y)_{L,R}$	$(X, T, B)_{L,R}$ $(T, B, Y)_{L,R}$
$SU(2)_L$	2 and 1	1	2	3
$U(1)_Y$	$q_L = 1/6$ $u_R = 2/3$ $d_R = -1/3$	2/3 -1/3	7/6 1/6 -5/6	2/3 -1/3
$\mathcal{L}_Y$	$-\frac{y_u^i v}{\sqrt{2}} \bar{u}_L^i u_R^i$ $-\frac{y_d^i v}{\sqrt{2}} \bar{d}_L^i V_{CKM}^{i,j} d_R^j$	$-\frac{\lambda_u^i v}{\sqrt{2}} \bar{u}_L^i U_R$ $-\frac{\lambda_d^i v}{\sqrt{2}} \bar{d}_L^i D_R$	$-\frac{\lambda_u^i v}{\sqrt{2}} U_L u_R^i$ $-\frac{\lambda_d^i v}{\sqrt{2}} D_L d_R^i$	$-\frac{\lambda_i v}{\sqrt{2}} \bar{u}_L^i U_R$ $-\lambda_i v \bar{d}_L^i D_R$

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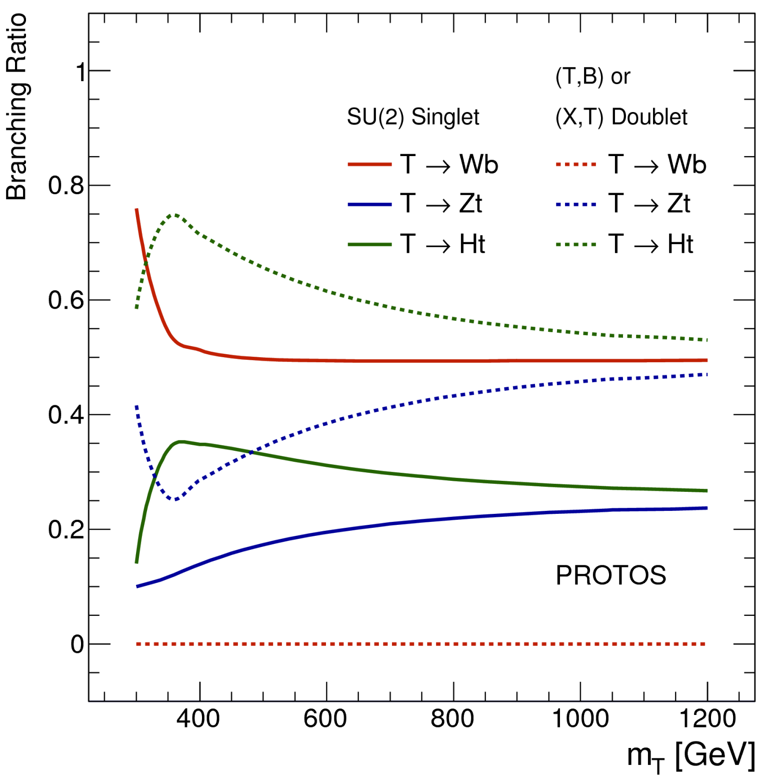
	charge	decay modes
T singlet	+2/3	T→Wb, Ht, Zt
B singlet	-1/3	B→Wt, Hb, Zb
(T,B) doublet	(+2/3,-1/3)	T→Wb, Ht, Zt B→Wt, Hb, Zb
(X,T) doublet	(+5/3,+2/3)	X→Wt T→Ht, Zt
(B,Y) doublet	(-1/3,-4/3)	B→Hb, Zb Y→Wt



Vector-Like Quark Pair Searches

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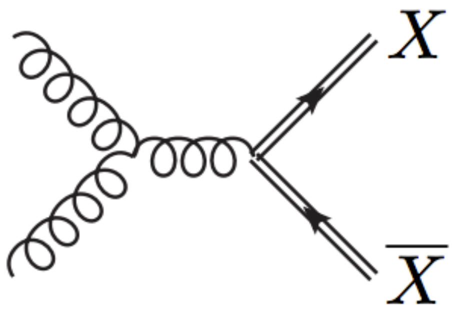
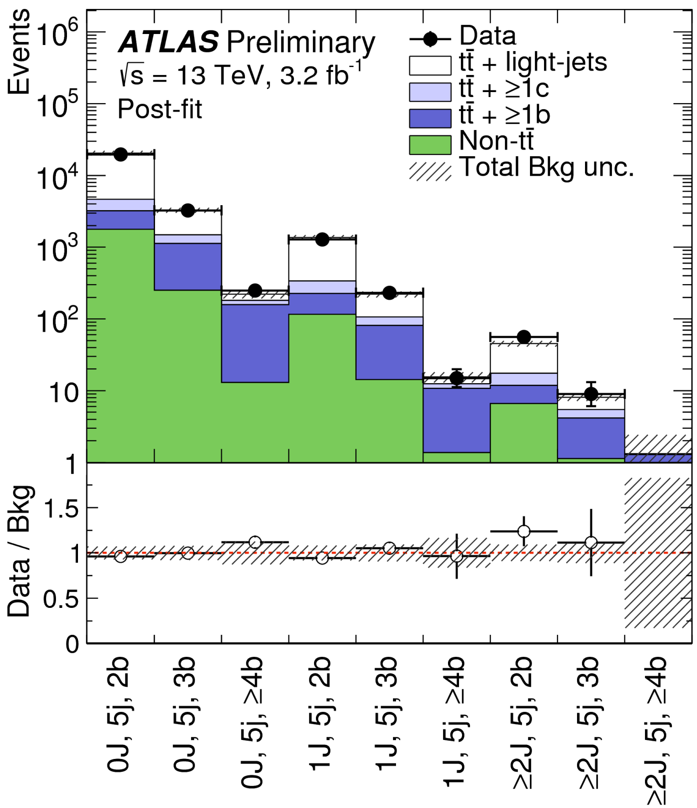
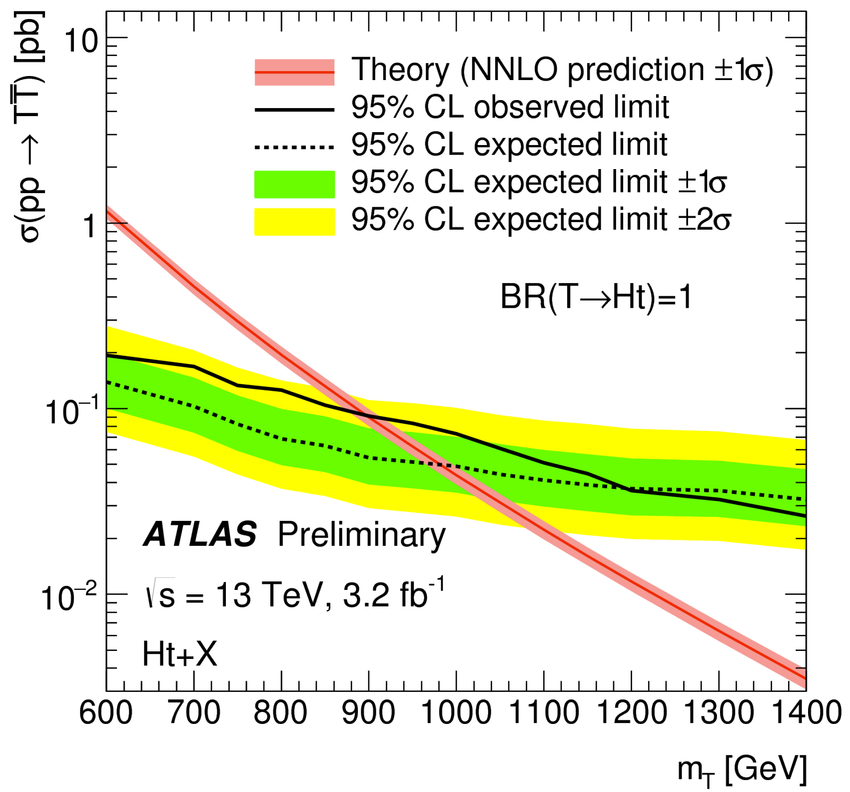
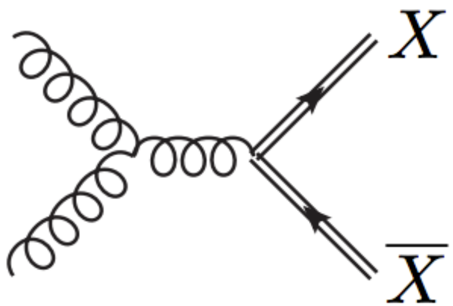


- Vector-like top pair production search
  - Divided by identified jets (small-R and large-R) and b-tags
  - Limits on total rate compared yield mass exclusions at O(1 TeV) for BR(T→Ht)=1





Vector-Like Quark Pair Searches



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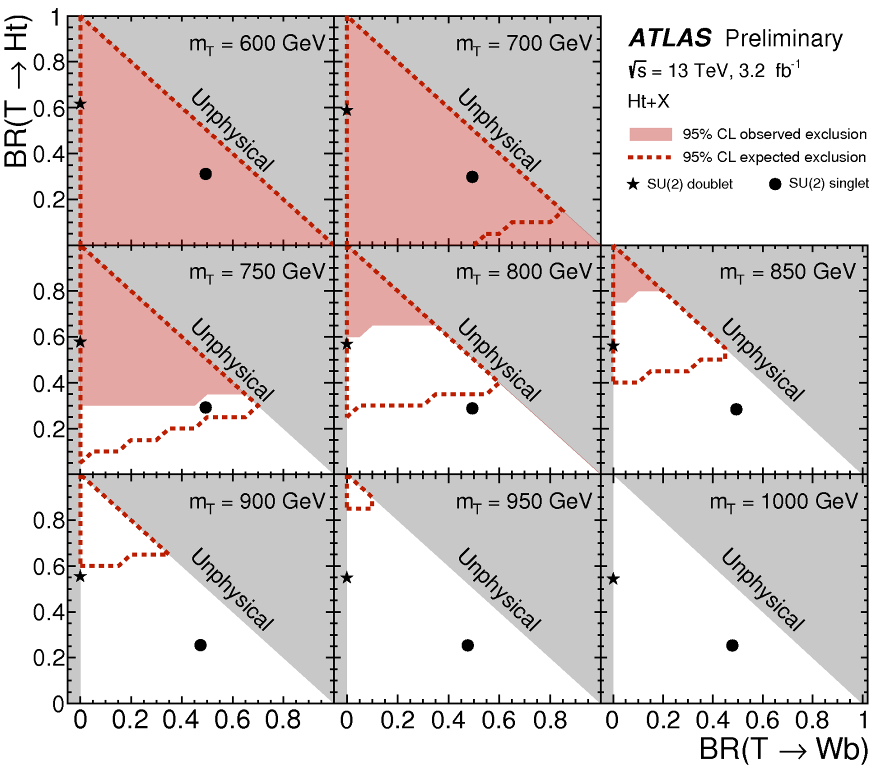
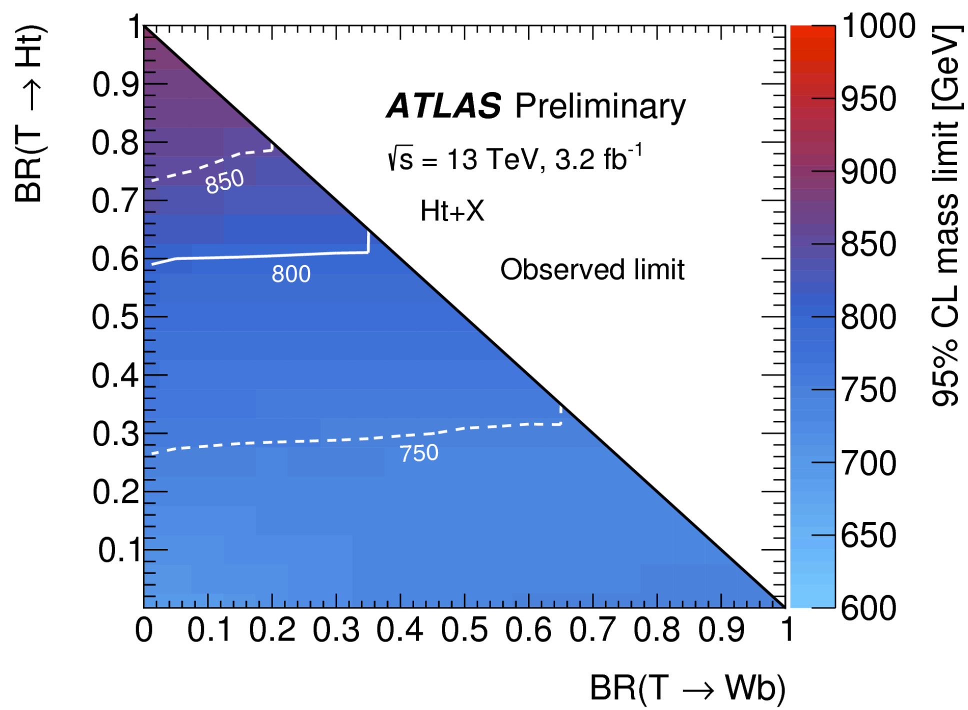
- Mass limits weaken as BR(T→Ht) decreases
  – Limits for fixed mass predictions can be mapped to the 2D BR plane for vector-like tops





Vector-Like Quark Pair Searches

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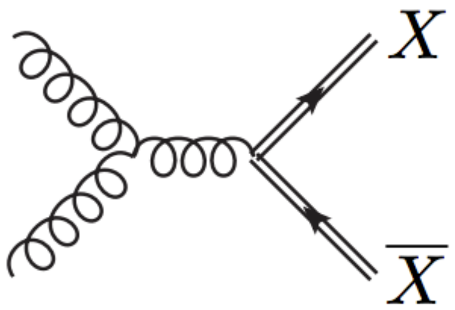
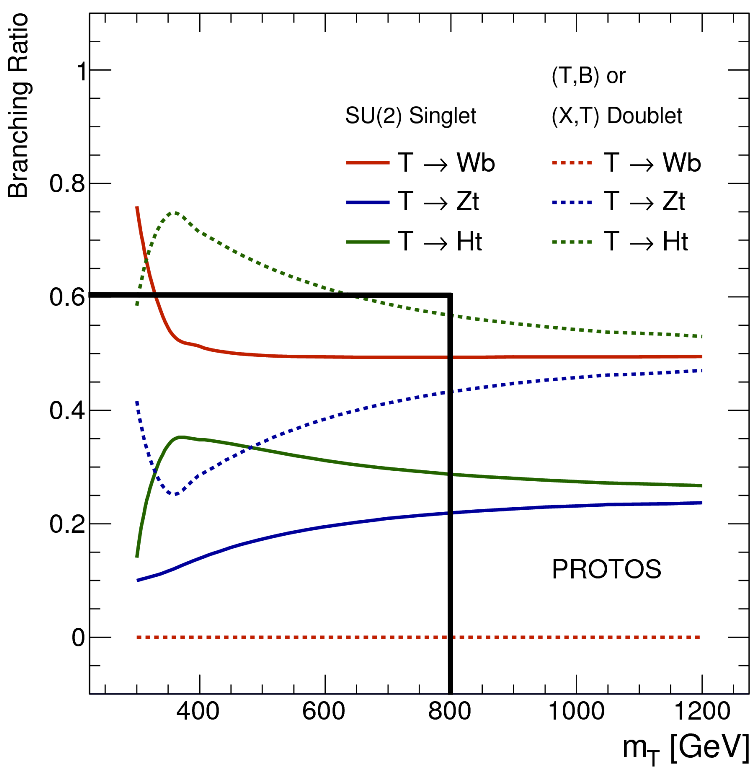
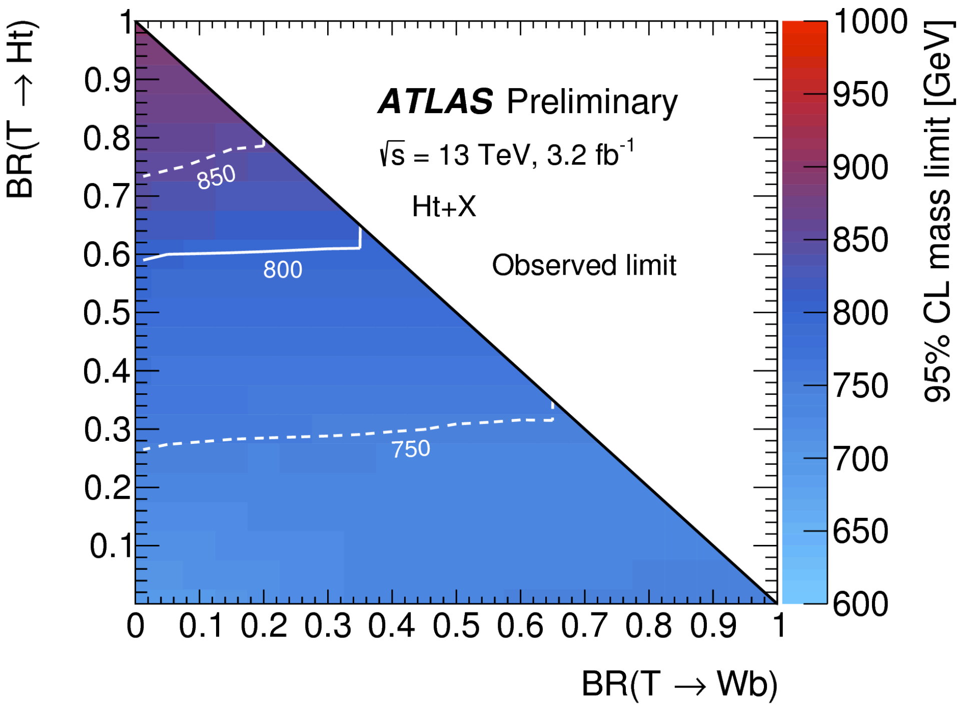


- Mass limits weaken as BR(T→Ht) decreases
  - Limits for fixed mass predictions can be mapped to the 2D BR plane for vector-like tops
  - Limits can be mapped back to BR/M space where the difference between model structure becomes apparent





Vector-Like Quark Pair Searches

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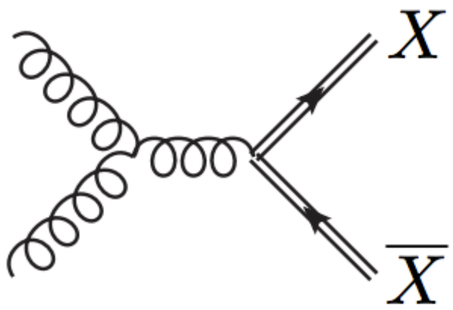
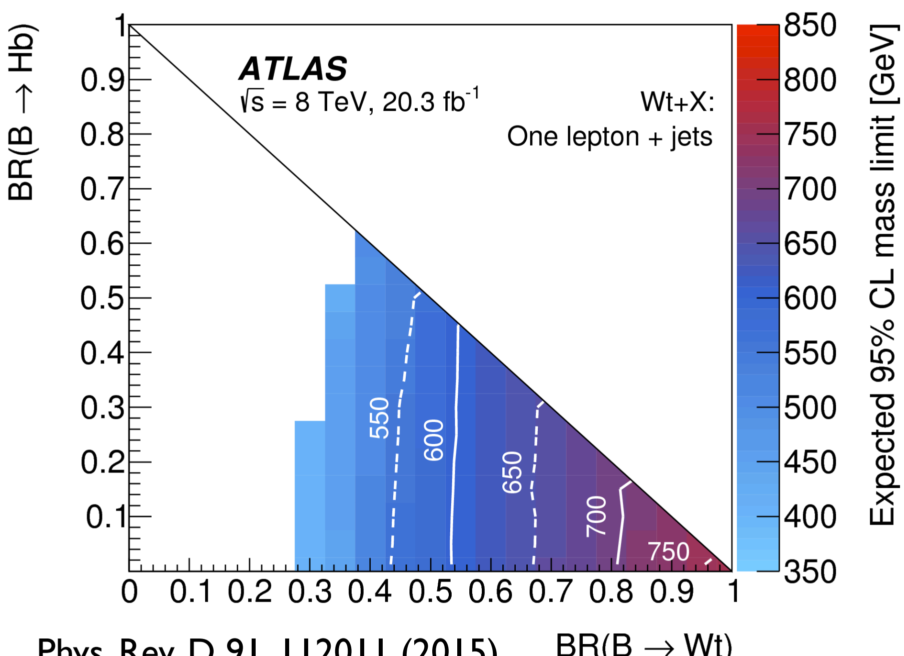
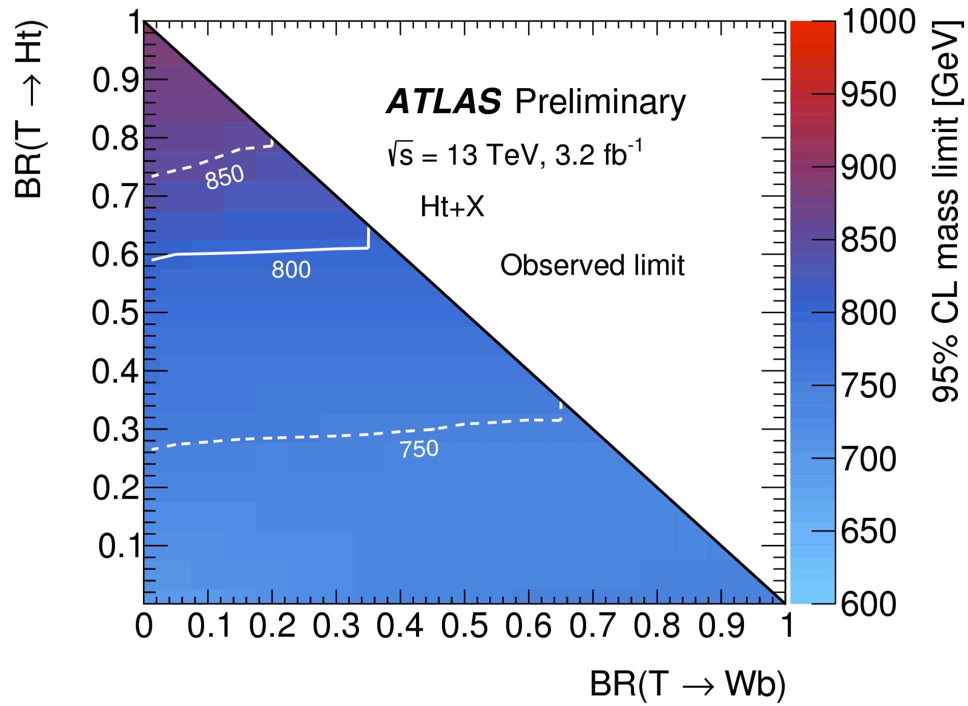


- Mass limits weaken as BR(T→Ht) decreases
  – Limits for fixed mass predictions can be mapped to the 2D BR plane for vector-like tops
  – Limits can be mapped back to BR/M space where the difference between model structure becomes apparent
  – A similar behavior is observed when the search is aimed at B→Wt

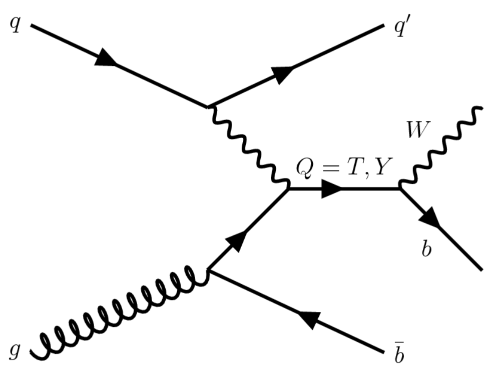


Phys. Rev. D 91, 112011 (2015)

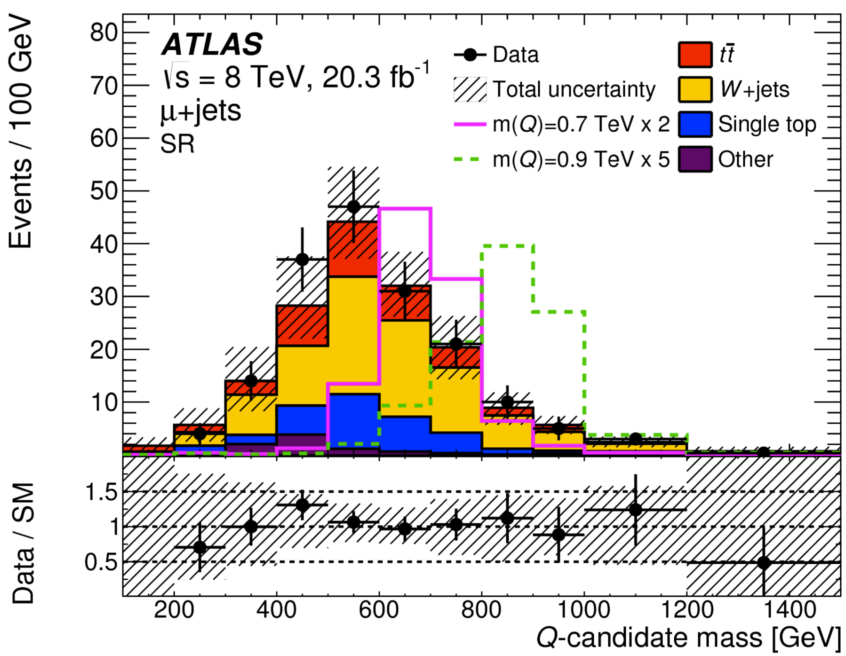


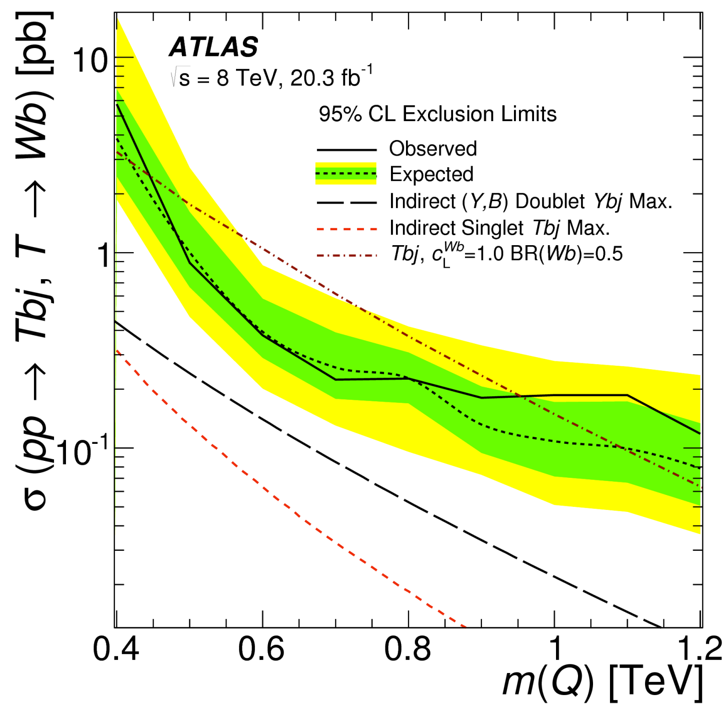
Singly-Produced VLQs

Submitted to EPJC
arxiv:1602.05606



- Search for singly-produced vector-like quarks decaying to Wb
  - Limits on total rate derived from reconstructed VLQ candidate mass and compared to benchmark models





Singly-Produced VLQs

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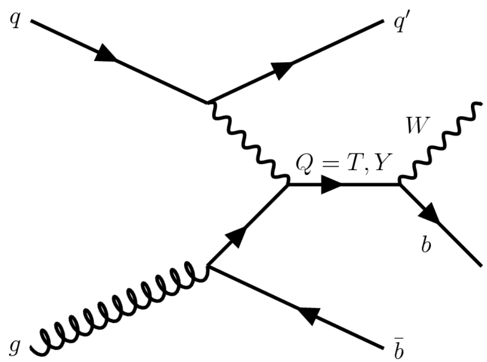
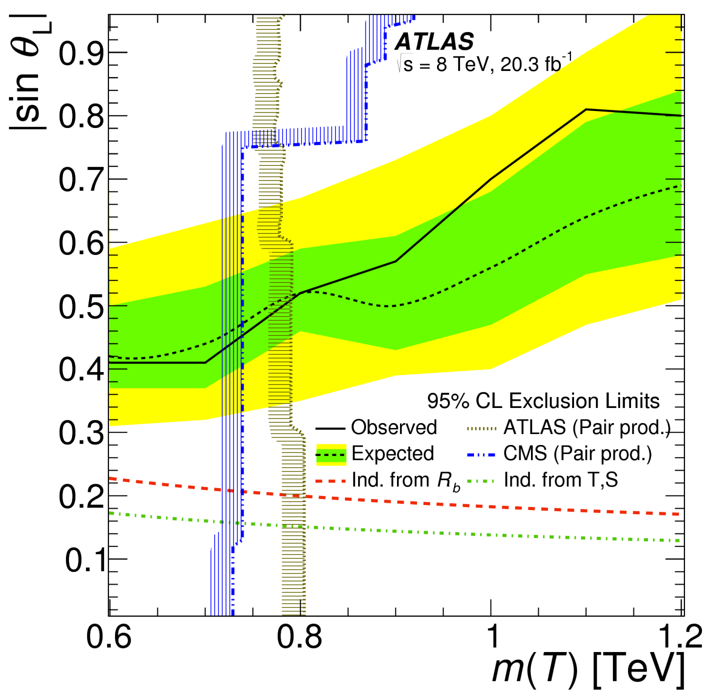
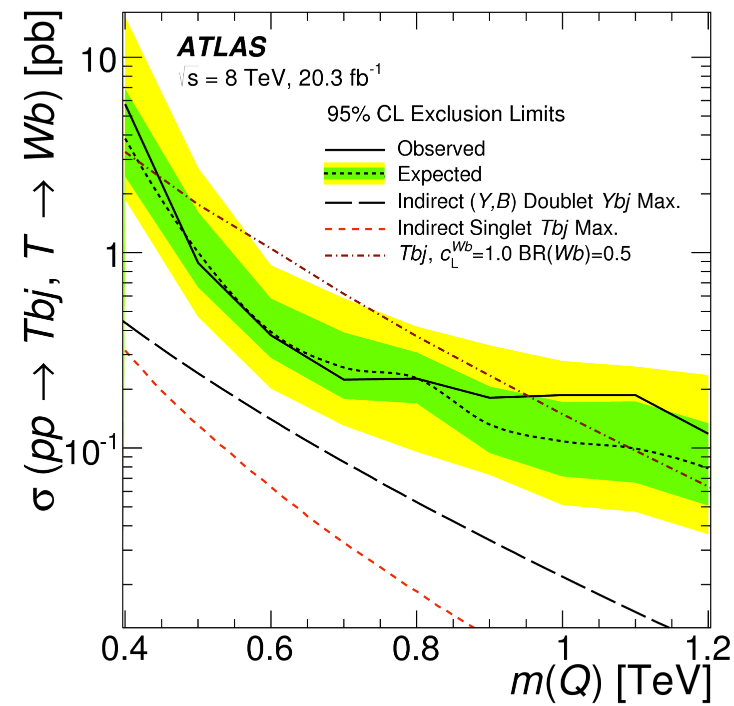


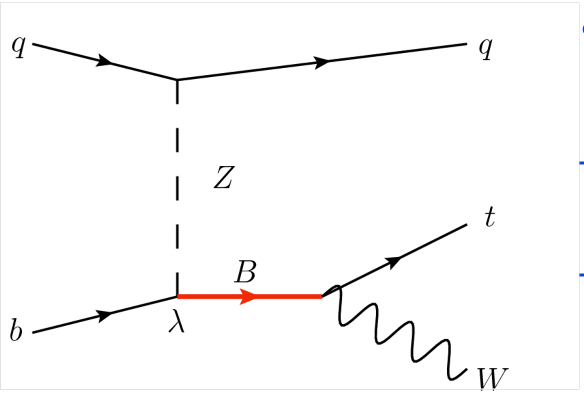
- Search for singly-produced vector-like quarks decaying to Wb
  - Limits on total rate derived from reconstructed VLQ candidate mass and compared to benchmark models
  - Limits on rate can be translated to VLQ/SM mixing angle for a given VLQ flavor. Facilitates comparison with pair prod. searches.



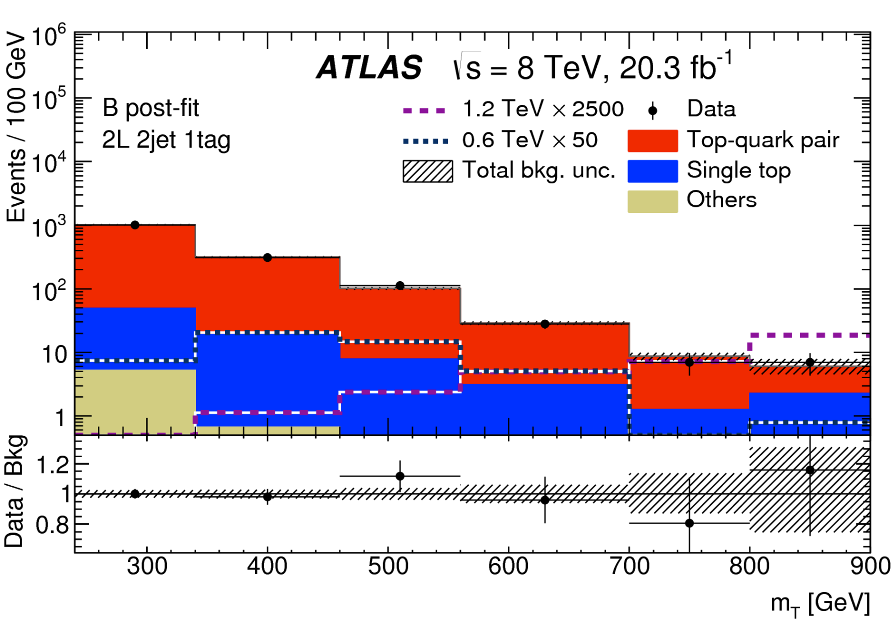


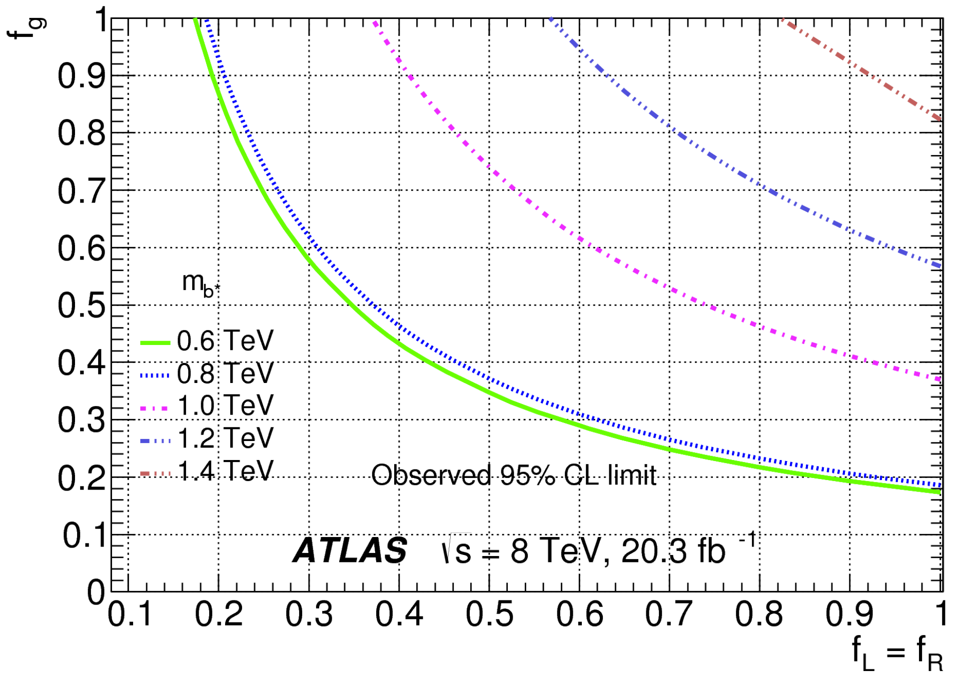
Singly-Produced VLQs

JHEP02(2016)110



- Search for singly-produced vector-like quarks decaying to Wt
  - Limits on total rate derived from reconstructed VLQ candidate transverse mass, similar to Wb search
  - Limits on coupling factors for gluon-b and Wt can be derived as a function of VLQ mass



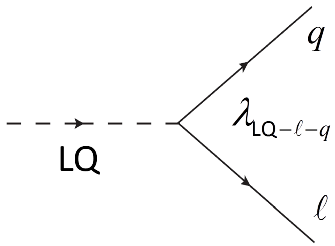


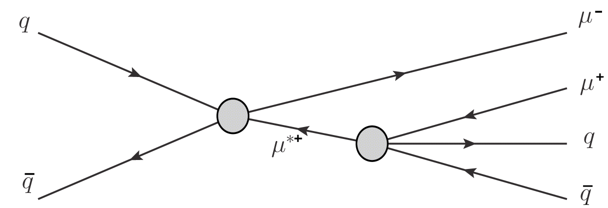
Other Interpretations

- There are many more ATLAS Exotics interpretive efforts that we cannot cover in detail for this talk
  - Contact Interaction Interpretations
  - Lepto-quarks
  - Dark Matter
  - Excited Fermions
  - Higgs triplet
  - LRSM w/ Majorana neutrino
  - Monopoles
  - Multi-charge
  - And more!

- We will do a quick fly-by pass of these, but it's not a comprehensive summary

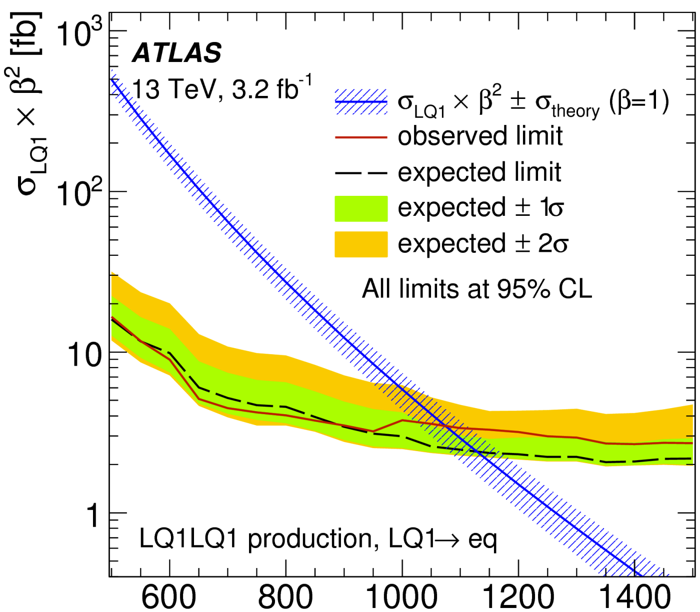
LeptoQuarks and Excited Fermions



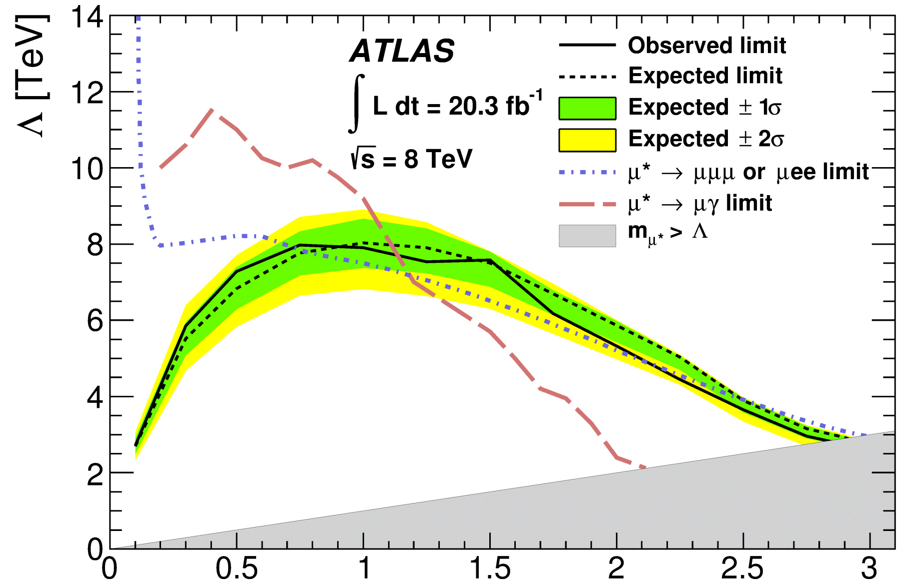


- Search for scalar leptoquarks
  - Production rate depends primarily on LQ mass, decay rate to lepton+quark depends on Yukawa coupling. Leads to relatively model-independent limits.

- Search for excited muons
  - Effective Lagrangian predicts rates that depend on lepton compositeness scale (Λ) and excited fermion mass.



Submitted to NJP arXiv:1605.06035 m_{LQ1} [GeV]



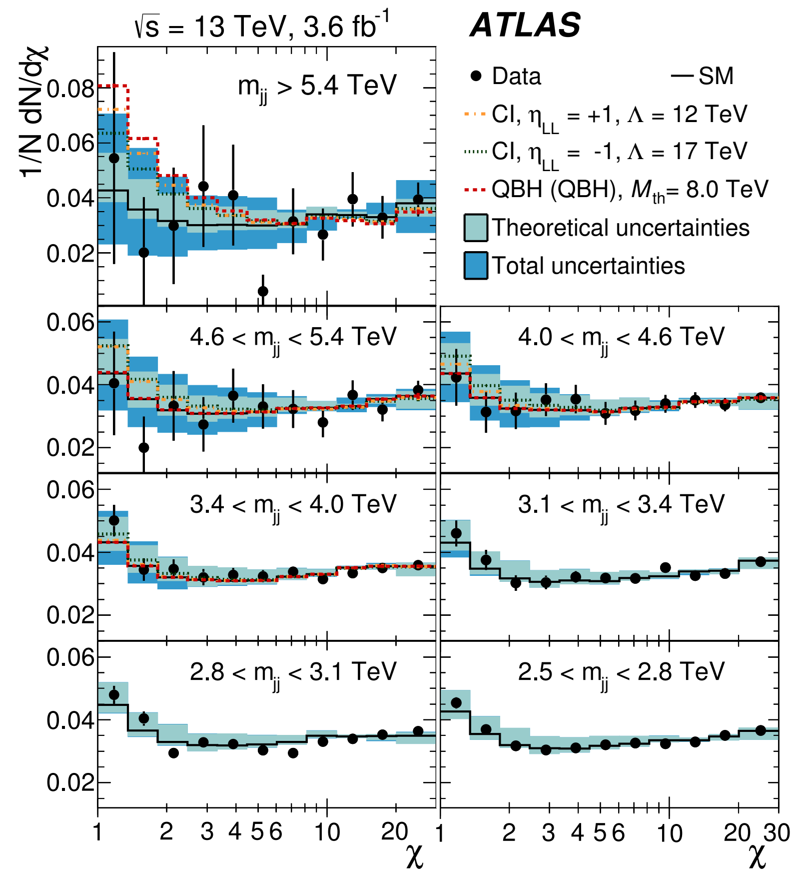
Submitted to PLB arXiv:1601.05627 m_{μ^*} [TeV]

Contact Interactions

$$\mathcal{L} = \frac{g^2}{\Lambda^2}\left[\eta_{LL}\left(\overline{q}_L\gamma_\mu q_L\right)\left(\overline{\ell}_L\gamma^\mu\ell_L\right) + \eta_{RR}\left(\overline{q}_R\gamma_\mu q_R\right)\left(\overline{\ell}_R\gamma^\mu\ell_R\right) + \eta_{LR}\left(\overline{q}_L\gamma_\mu q_L\right)\left(\overline{\ell}_R\gamma^\mu\ell_R\right) + \eta_{RL}\left(\overline{q}_R\gamma_\mu q_R\right)\left(\overline{\ell}_L\gamma^\mu\ell_L\right)\right],$$

$$\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{DY}}{dm_{\ell\ell}} - \eta\frac{F_I}{\Lambda^2} + \frac{F_C}{\Lambda^4}$$

- qqll and qqqq: four-fermion effective field theories considered in ATLAS searches. Compositeness, depending on energy scale, Λ.
- Broad excess over the SM invariant mass spectrum, and forward-backward asymmetry in angular distributions.
- Interaction describes a color and isospin singlet with couplings to L/R-handed fermion states.
- η_{XY} describes whether the interference is constructive (-), or destructive (+), and the couplings i.e. $\eta_{LL} = 1$, $\eta_{RR} = \eta_{LR} = 0$



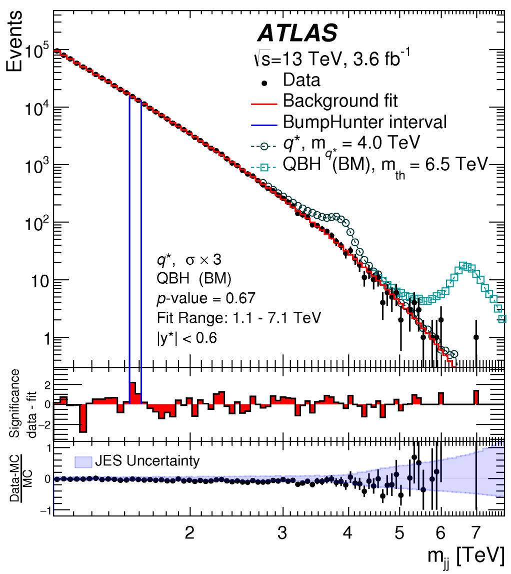
$$\chi = e^{2|y^*|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*},$$

Dijet: arXiv:1512.01530 Dilepton: CONF

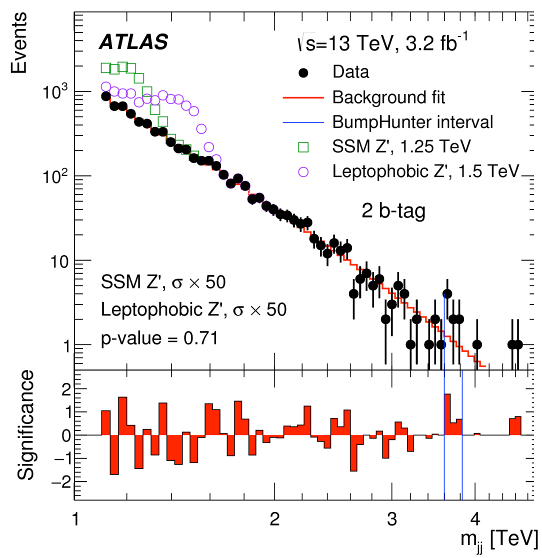
Di-jets, di-b-jets, ttbar

- Dijet resonances → exclude quantum black holes (QBH) in benchmark models : m_{QBH} < 8.3 GeV (excited quarks), m_{QBH} < 8.1 GeV (W' model), and m_{QBH} < 5.3 GeV (Z' model)
- bbbar, bq, bg resonances : Sequential Standard Model (SSM) and Leptophobic Z'
- ttbar : topcolour-assisted-technicolour → Z' boson production

arXiv:1512.01530



arXiv:1603.08791



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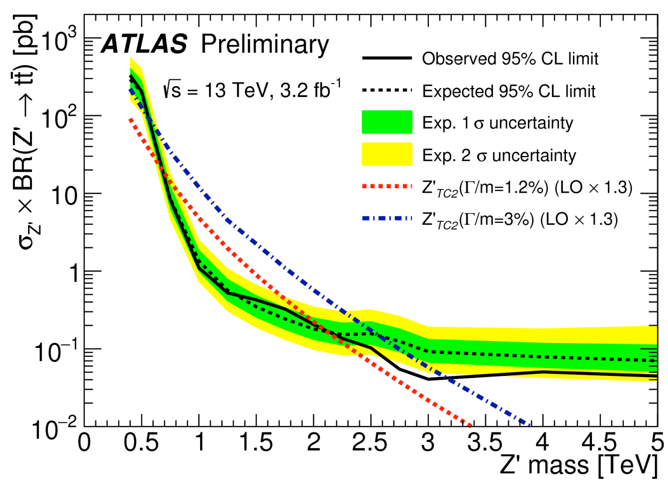

Summary / Conclusions

- ATLAS Exotics group searches cover a broad range of BSM signatures
  - Benchmark interpretations are applied to compare sensitivities for similar searches, but are not always trivial to compare/combine for coherent groups
  - Where possible, try to provide acceptance and efficiency curves, fiducial cross-section limits, etc, to help with theorist re-interpretation. Use of Rivet too.

- Broad classes of interpretive models lead to a loose organization of signature-based searches
  - For example, Composite Higgs models can predict BSM signatures across experimental observables: leptons, jets, MET, etc.

- Potential for expansion of interpretative efforts where useful and/or feasible
  - Though a generic set of models common to many signatures and agreed with CMS helps streamline the experimental effort.