Search for Vector-like Quarks at CMS

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Vector-like Quarks

- Promising playground for new physics searches
- Potential candidate to solve the mass hierarchy problem
- Appear in beyond the SM theories: Little Higgs, Extra dimension or composite Higgs models, and also in non-minimal SUSY extensions
- Vector-like Quarks are hypothetical spin 1/2 particles
  - Similar representation of the left, and right handed Chirality
- VLQs normally appear as SU(2) color singlet, doublet or triplet

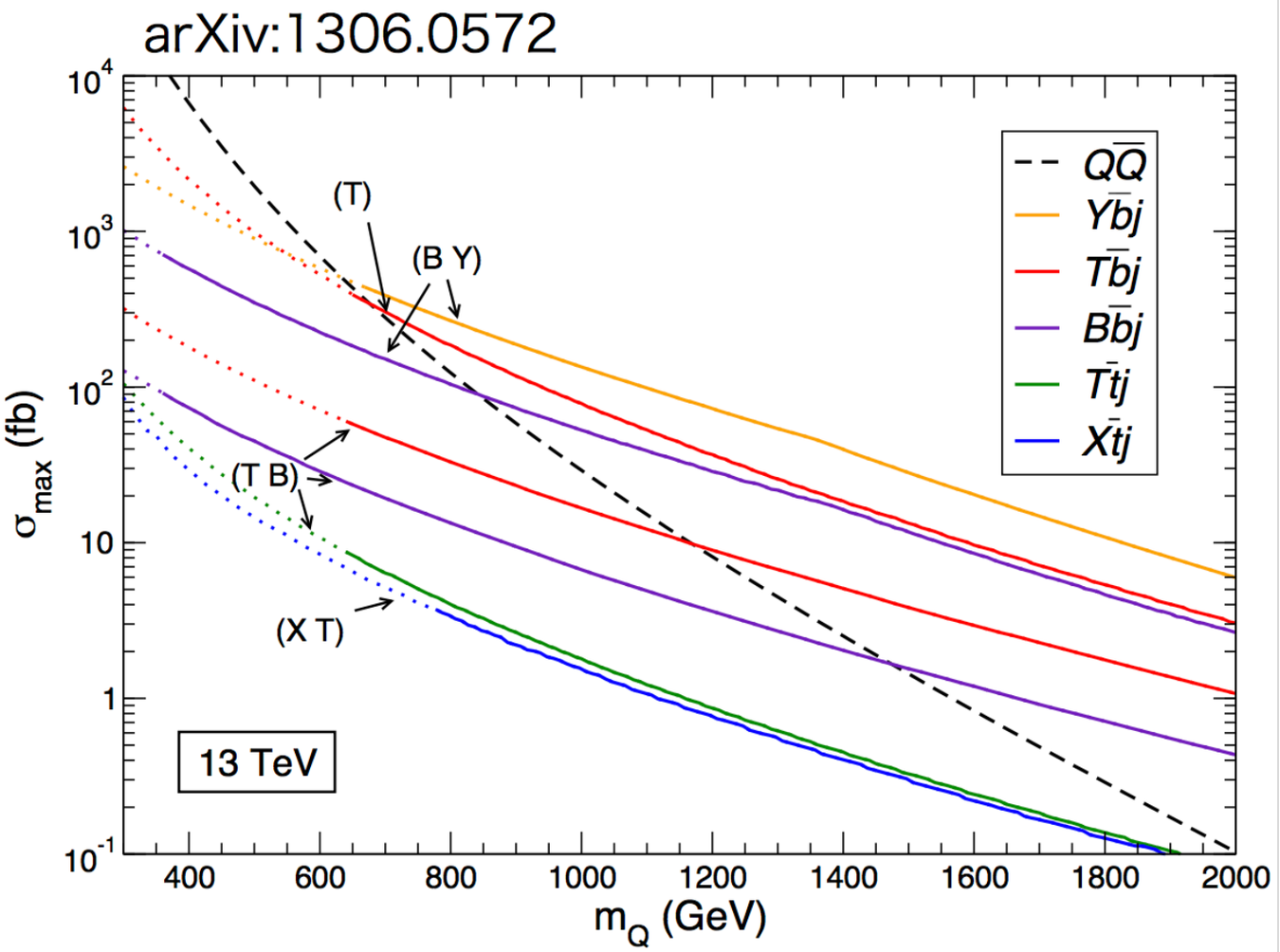
		SM	SU(2) Singlet	SU(2) Doublet	SU(2) Triplet
EM charge	5/3			$\begin{pmatrix} X \\ T \end{pmatrix}$	$\begin{pmatrix} X \\ T \\ B \end{pmatrix}$
	2/3	$\begin{pmatrix} u \\ d \end{pmatrix}\begin{pmatrix} c \\ s \end{pmatrix}\begin{pmatrix} t \\ b \end{pmatrix}$	(T)	$\begin{pmatrix} T \\ B \end{pmatrix}$	
	-1/3		(B)	$\begin{pmatrix} B \\ Y \end{pmatrix}$	$\begin{pmatrix} T \\ B \\ Y \end{pmatrix}$
	-4/3				

Production and Decay at LHC

Rich phenomenology to explore at the LHC

Production Type:

- **Pair:**
  - Dominant in lower mass range
  - Produced in strong interaction
  - Model independent
- **Single:**
  - Produced in electro-weak interaction
  - Model dependent: along with mass, production rate depends on mixing angle, charge etc



Decay Modes:

VLQs with exotic charges: $X_{5/3}$ -> Wt, $Y_{-4/3}$ -> Wb

VLQs with charge 2/3 and -1/3:

$$T \to W^+ b, \quad T \to Zt, \quad T \to Ht,$$
$$B \to W^- t, \quad B \to Zb, \quad B \to Hb.$$

VLQ Searches at CMS

- CMS has a robust program towards exploring every possible corner of the rich VLQ phenomenology
- Many results have already been published setting stronger limits than ever.

In this talk:

- Pair Production: $\mathbf{X_{5/3}X_{5/3}}$ in single lepton, and di-lepton final state and **TT/YY** with 13 TeV data
- Single Production: **B -> Hb**, **T -> tZ**, **T/Y -> bW** with 13 TeV data

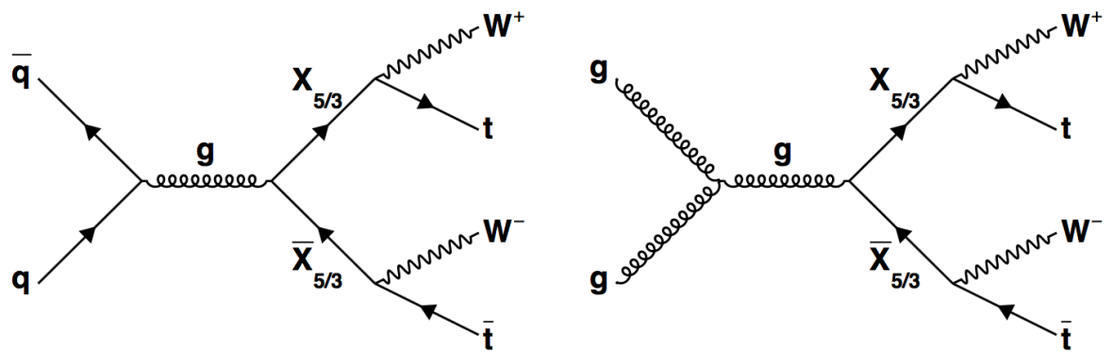
Pair Production

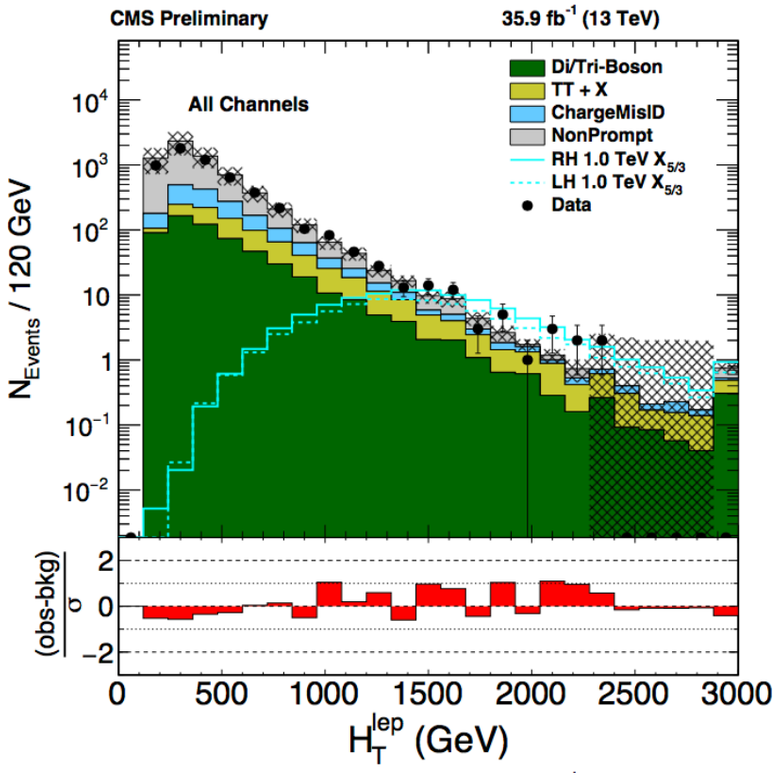
CMS-PAS-B2G-16-019

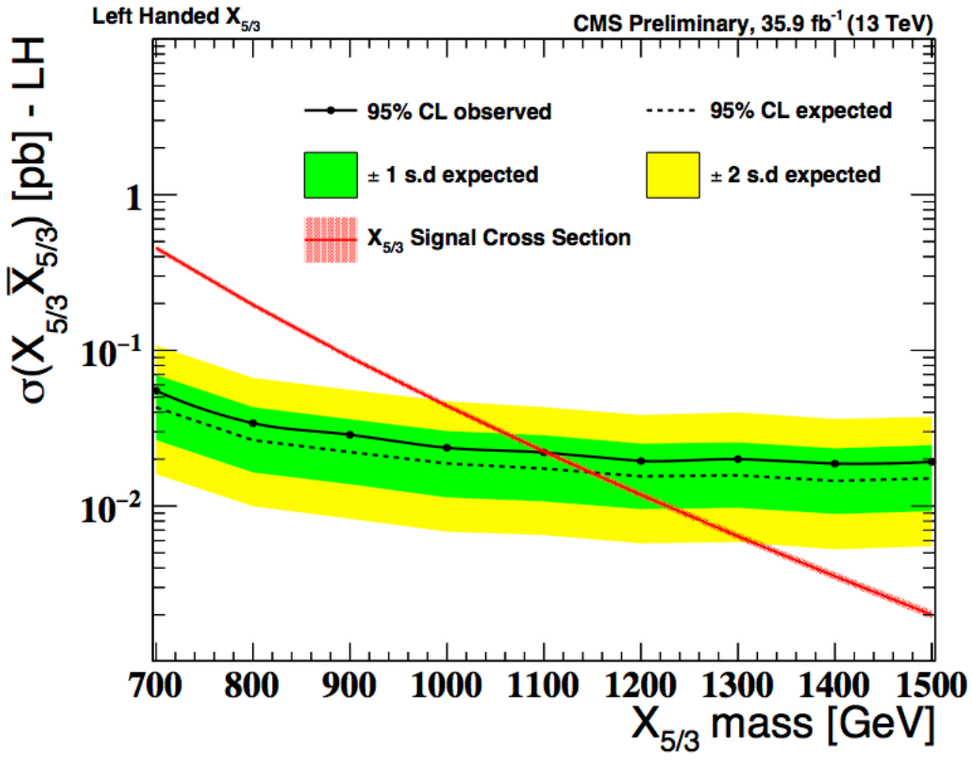
Pair: $X_{5/3}$ → Wt, Same Sign di-lepton

Full 2016, 13 TeV Data

- **Signal Signature:** Two same sign charged leptons + jets
- Same-sign non-prompt background from data driven fake rate technique
- Opposite sign prompt background from charge mis-identification rate from Z-> ee







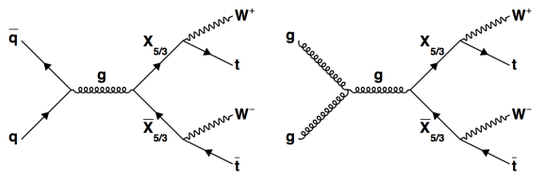
LH M_x > 1.15 TeV, RH M_x > 1.2 TeV @ 95% CL
Br(X -> tW) = 100%

CMS-PAS-B2G-17-008

Pair: $X_{5/3}$ → Wt, single lepton

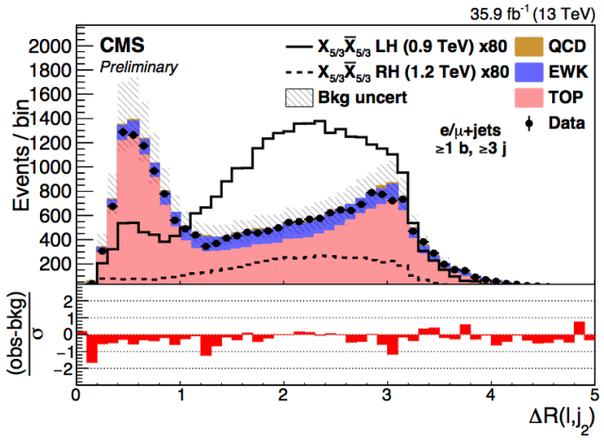
Full 2016, 13 TeV Data

- Single lepton + jets final state
- Significant amount of jet activity in final state

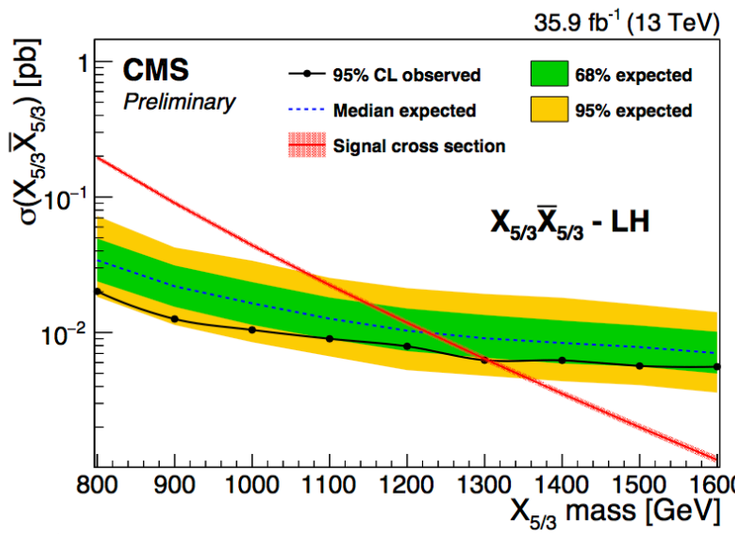


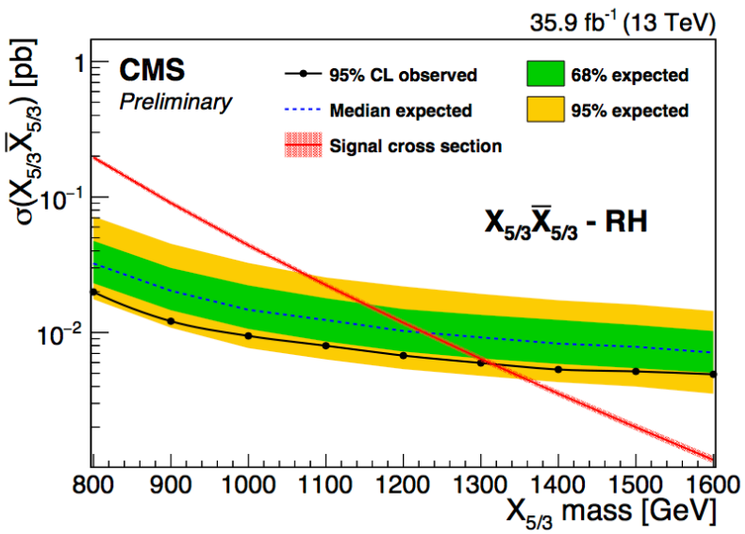
Signal Signature:

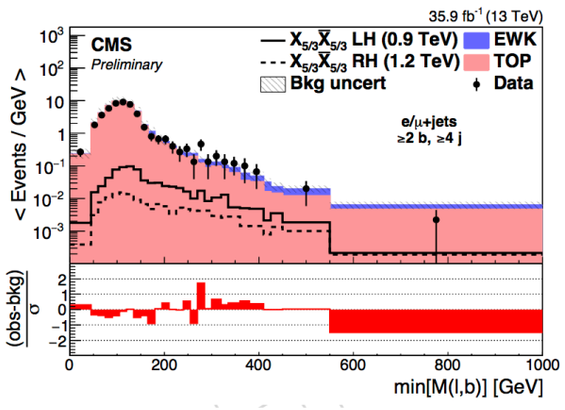
- 1 x W(lnu), 3 x W(jj), 2 x b-jet
- Template likelihood fit to data: discriminating variable M(l, b)

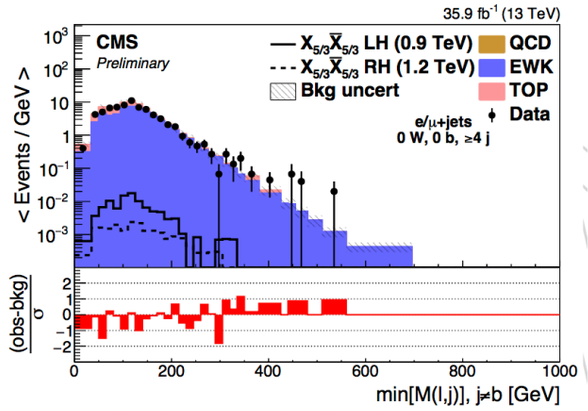


Background Modeling









RH Mx > 1.32 TeV
and
LH Mx > 1.30 TeV
@95% CL

CMS-PAS-B2G-17-003, arXiv:1710.01539

Submitted to PLB

Pair Production: TT(YY) → bWbW

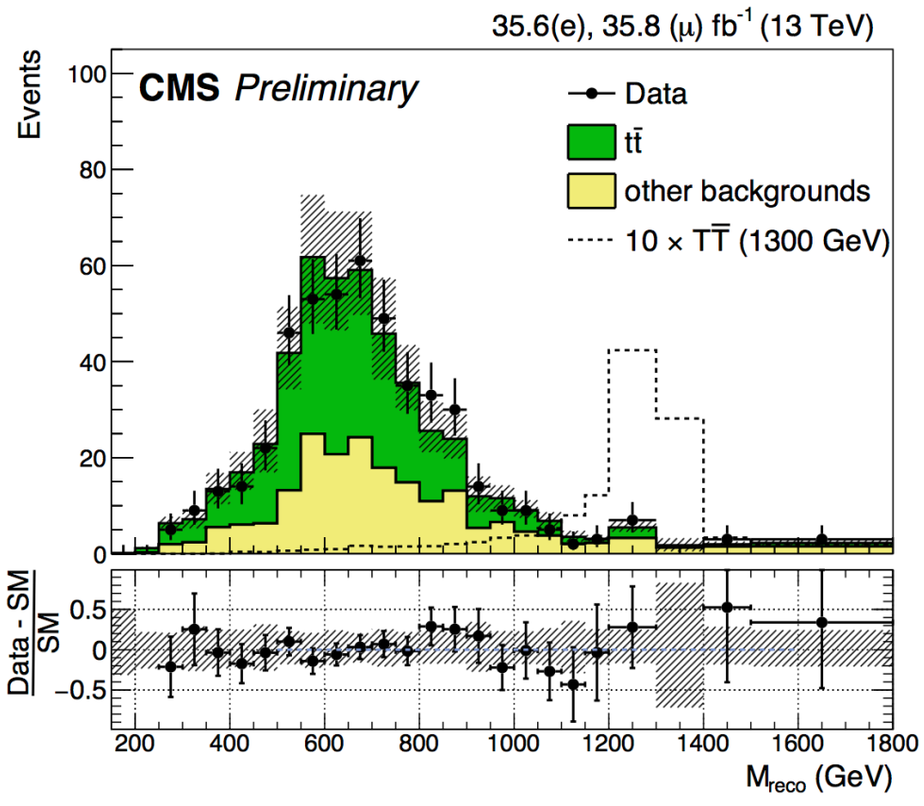
Full 2016, 13 TeV Data

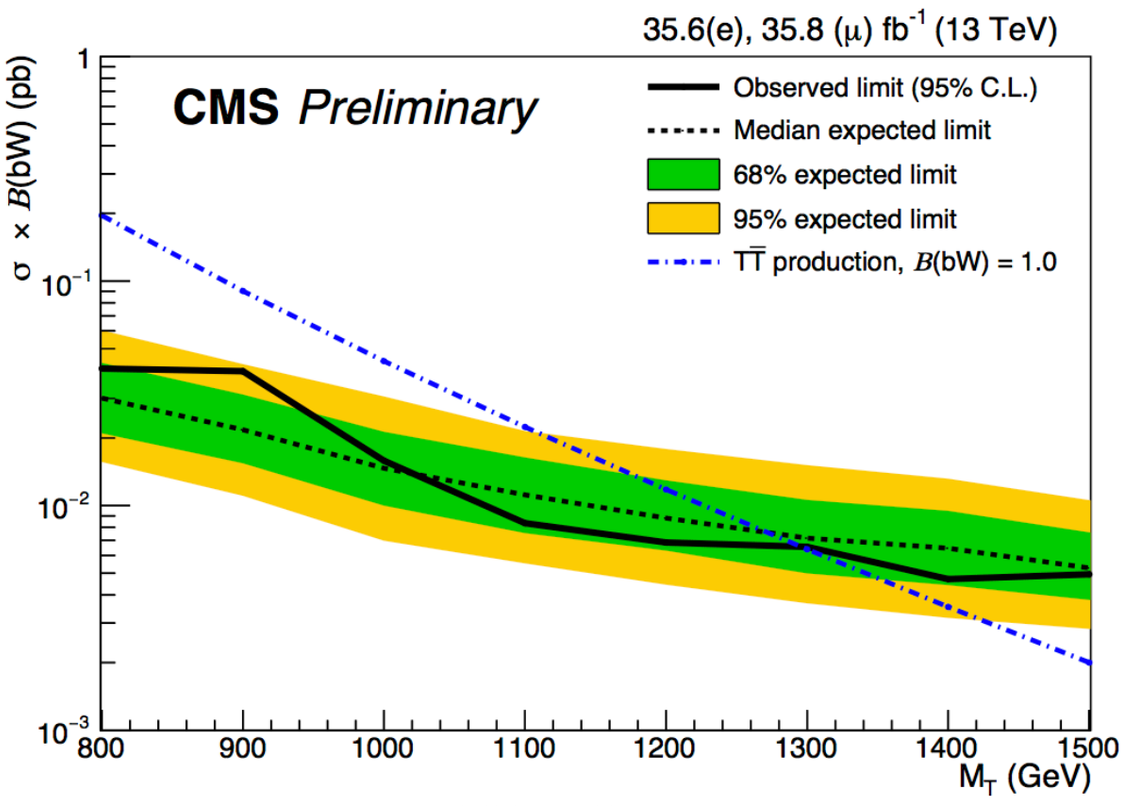
- T(Y) quarks are exclusively assumed to decay to a W-boson and a b-quark
- Analysis performed in lepton + jets final state

$$T\bar{T}(Y\bar{Y}) \rightarrow bW\bar{b}W \rightarrow b\ell\nu\bar{b}q\bar{q}'$$

Event Signature:

- Only one charged lepton (electron or muon)
- At least 4 reconstructed jets or 3 jets + 1 W-jet
- Kinematic fit to the mass hypothesis to find the resonance





$M_T > 1295$ GeV at 95% CL

BR (bW) = 100%

Single Production

CMS-PAS-B2G-17-009

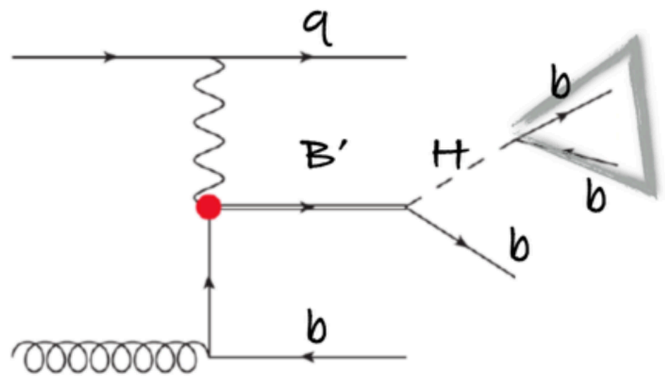
Paper in preparation

Single Production: B → Hb

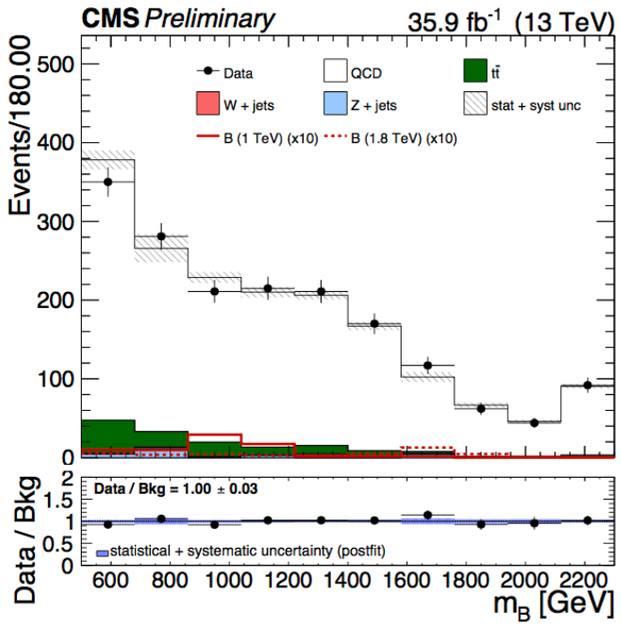
Full 2016, 13 TeV Data

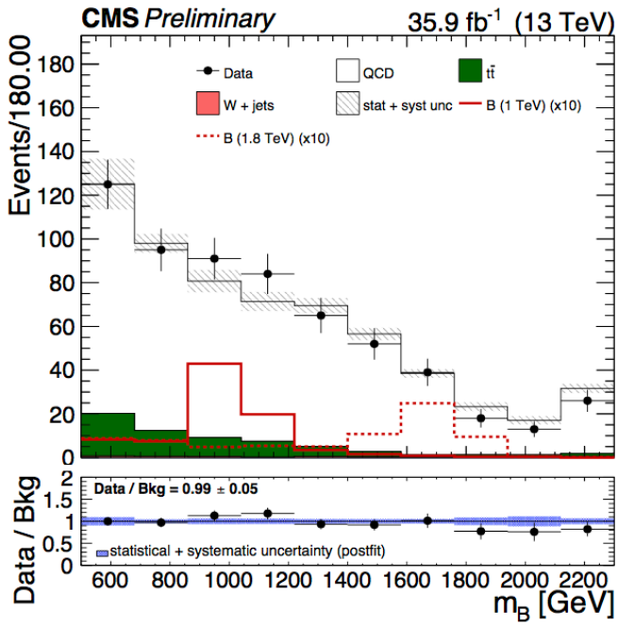
Analysis Strategy:

- Fully hadronic final state
- Boosted Higgs.
  Higgs Tagging: pruned mass, 2 b-tagged sub-jets
- Leading jet b-tagged
- QCD multi-jet background from Data
- Binned likelihood fit to mass for signal extraction

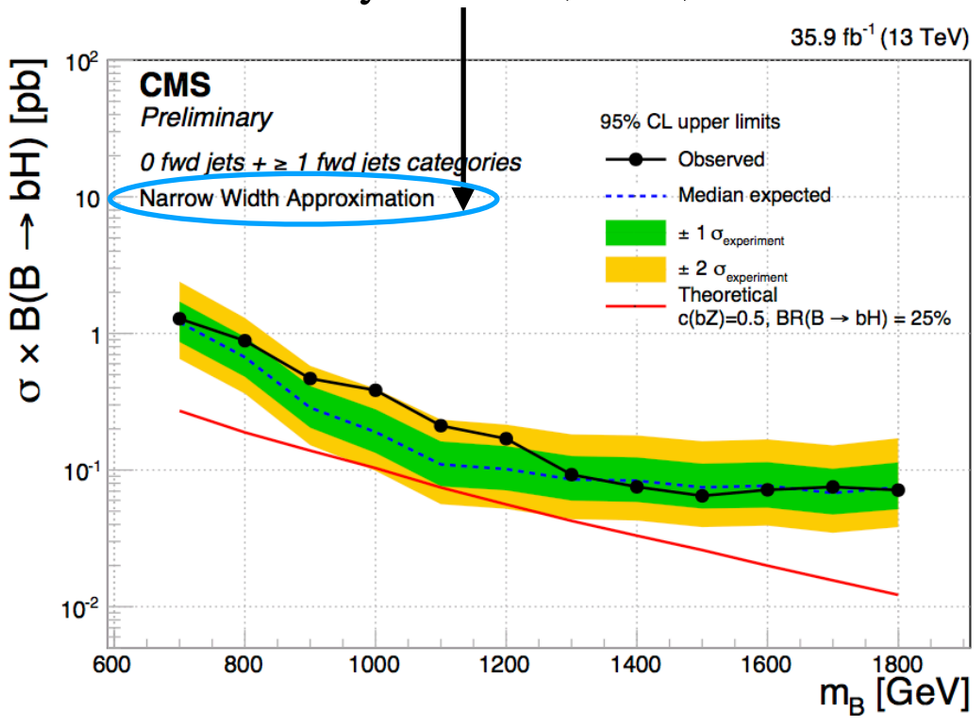


2 Categories: 0 or >= 1 forward jet





Similar sensitivity for 10%, 20%, 30% width/mass



Expected upper limit
0.07 - 1.2 pb
@ 95% CL for the mass range
C(bZ) = 0.5, BR (B->Hb) =25%

CMS-PAS-B2G-17-007, arXiv:1708.01062

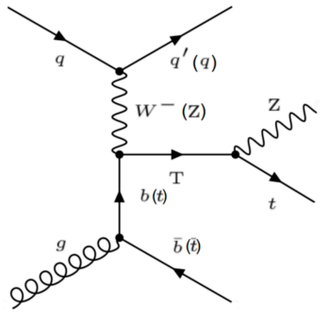
Submitted to PLB

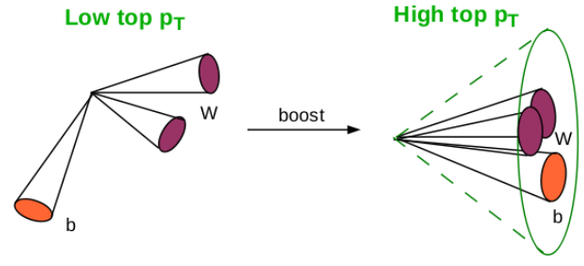
Single Production: T → tZ

Full 2016, 13 TeV Data

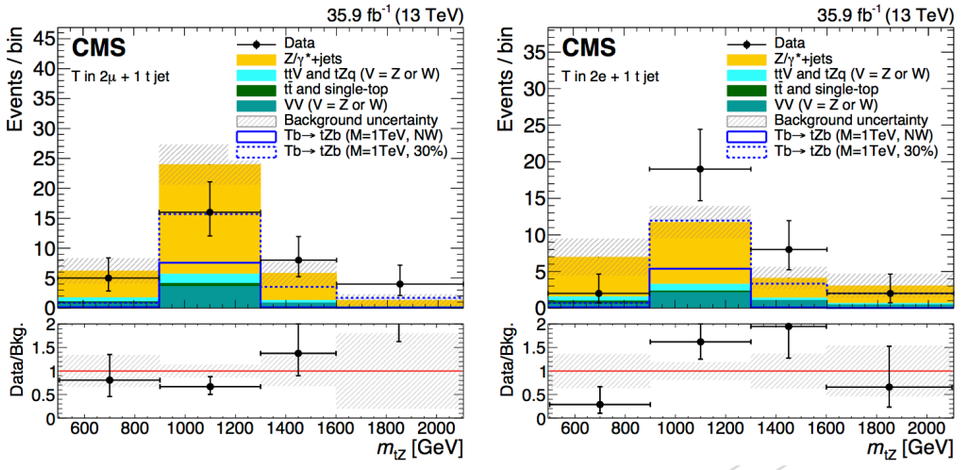
Analysis Strategy:

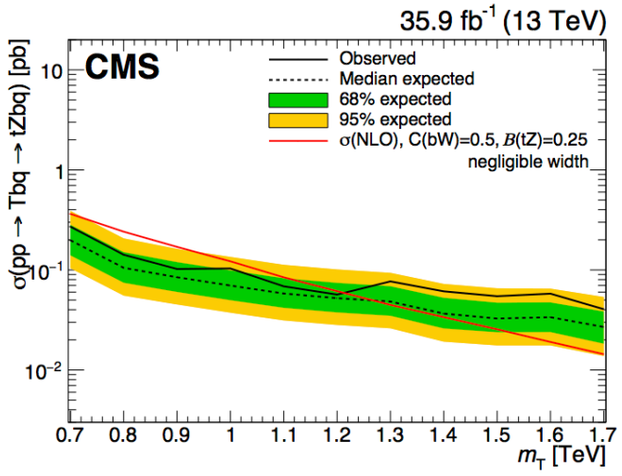
- Leptonic Z decay - electron or muon pair
- Hadronic Top -
  A. Fully Resolved: 3 reconstructed jets
  B. Partially Merged: a W-jet and a b-tagged jet are identified
  C. Fully Merged: Decay products are within one top jet



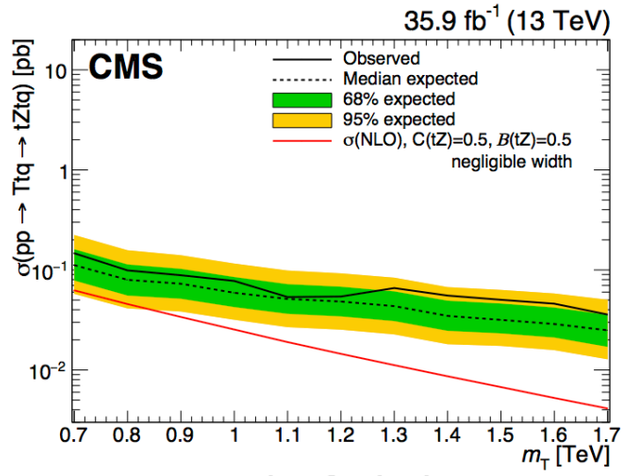


- Several categories depending on Z decay, Hadronic Top reconstruction and number of forward jets
- Search for a bump in the reconstructed T mass (t, Z mass)
- Data driven background estimation





LH M_T > 1.2 TeV
C(bW) = 0.5
@95% CL



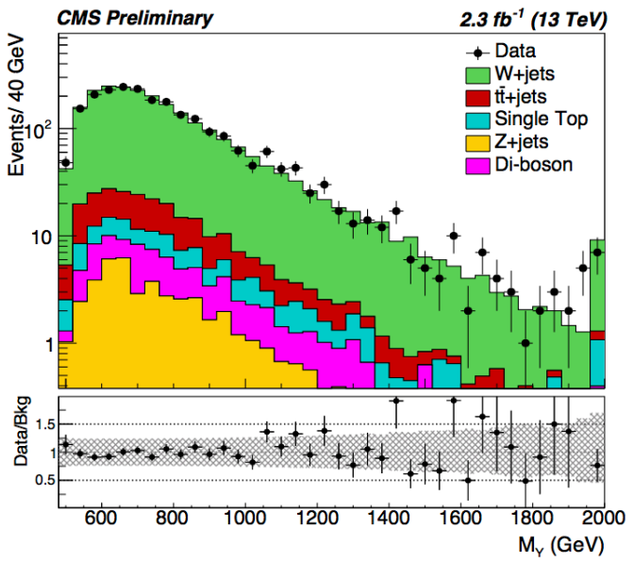
Upper limit on RH T(t)
xsec 0.15-0.04 pb
for mass range,
C(tZ) = 0.5

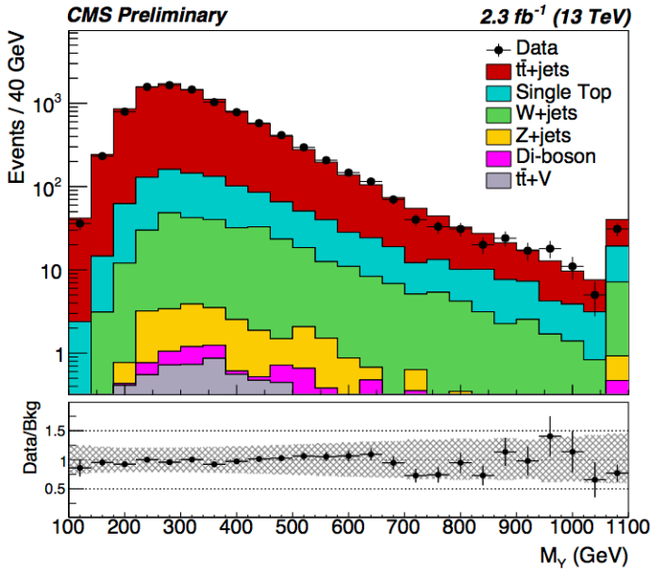
Phys Lett B 772 (2017) 634

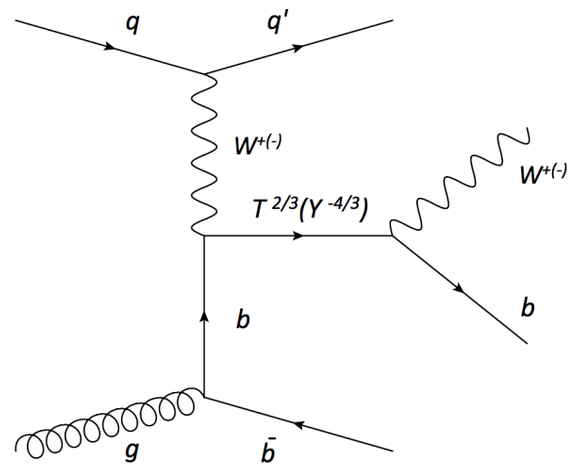
Single Production: T/Y, lepton + jets

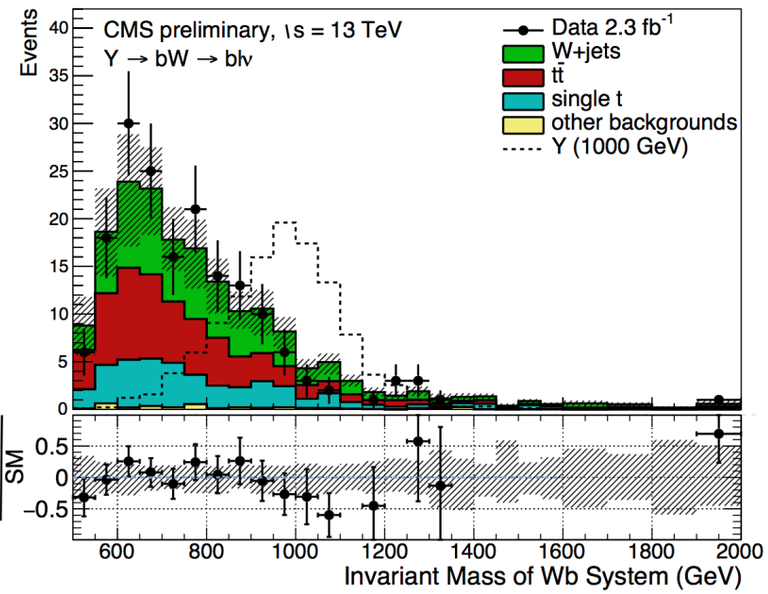
2015, 13 TeV Data

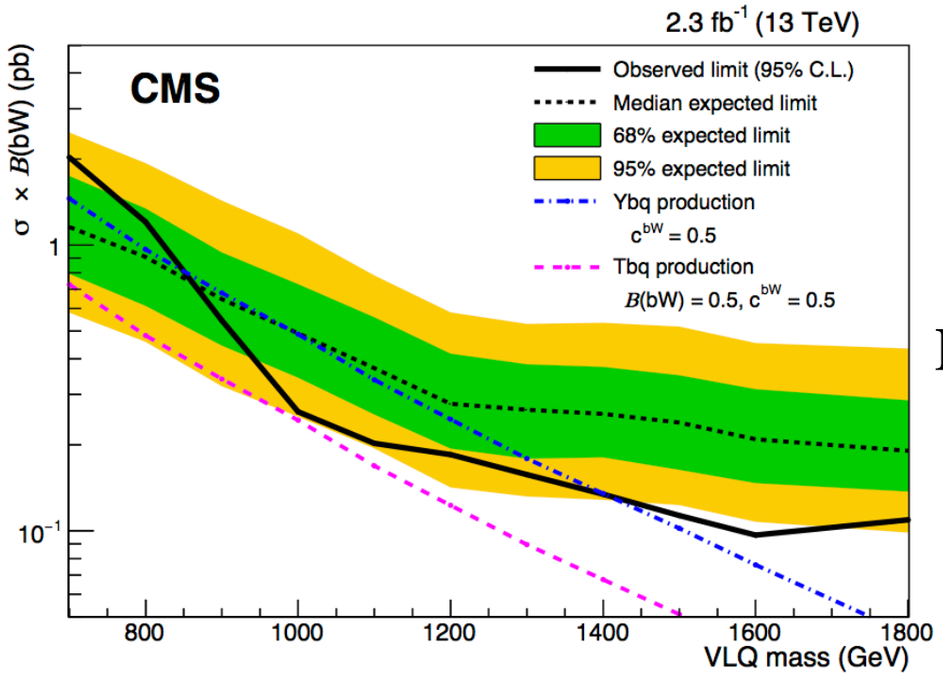
- Signal Signature: One Lepton, >= 1 b-tag, >=1 forward jet
- Reconstruct the quark mass M(W, b)
- Validate MC modeling TTJets and WJets enriched region







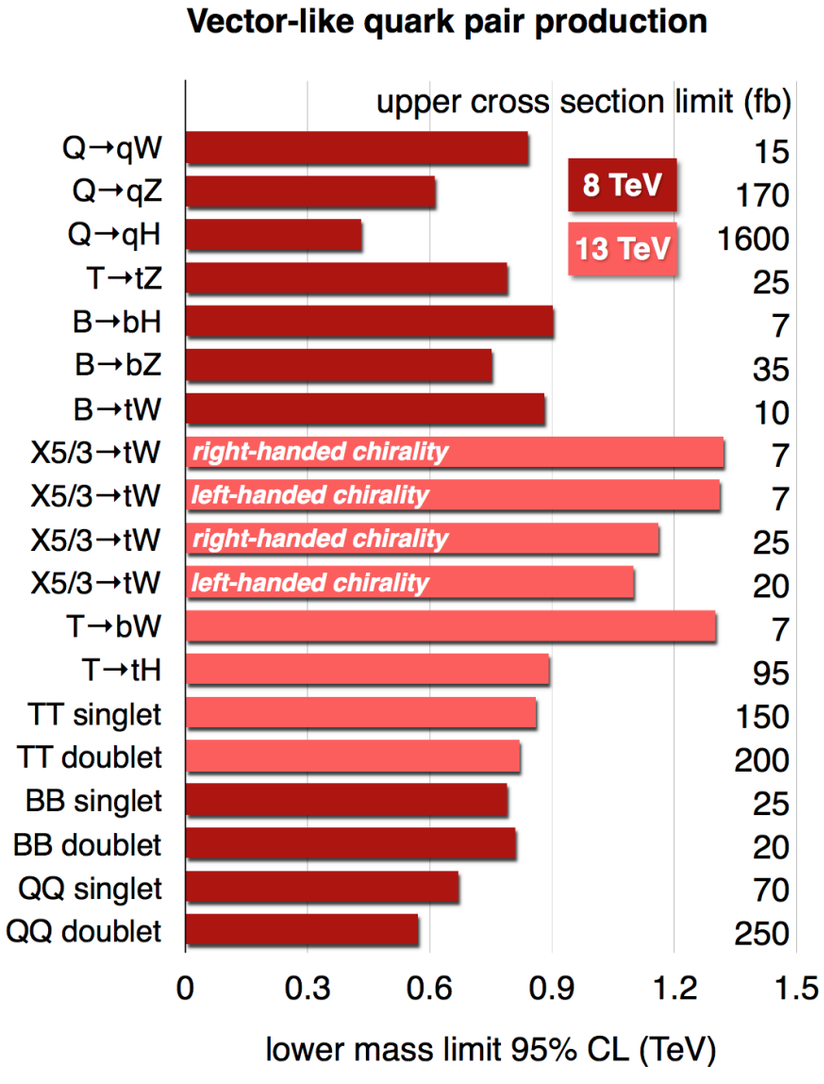


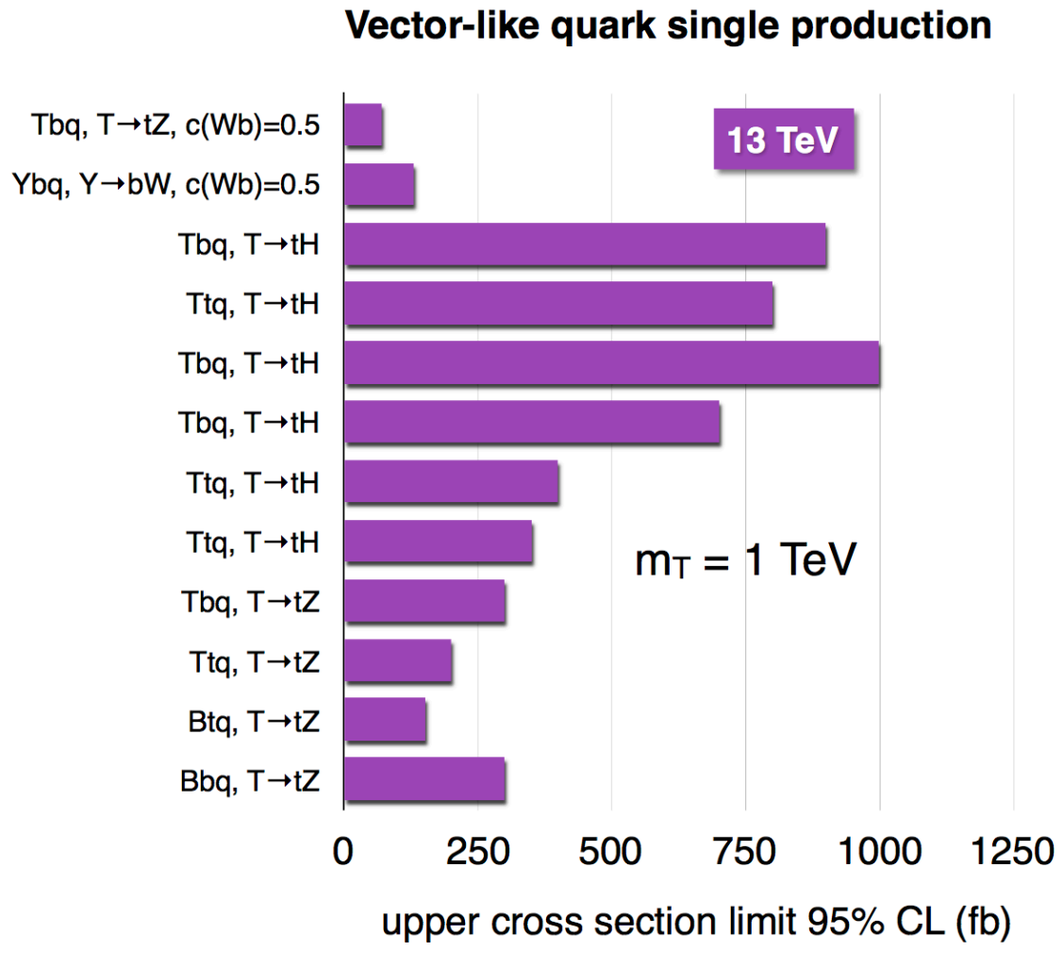


M_Y > 1.4 TeV @ 95% CL
C(bW) = 0.5
BR (Y -> Wb) = 100%

Summary

- Presented the status of VLQ searches in CMS focusing on some of the recent results
- No sign of VLQ yet
- But we are setting stronger limits than ever





- More data is coming in, stay tuned for many interesting results

BackUp

Single Production: B → Hb

Ref: slide 10

Analysis sensitivity for 10%, 20%, 30% width/mass