Heavy Quarks

Meenakshi Narain

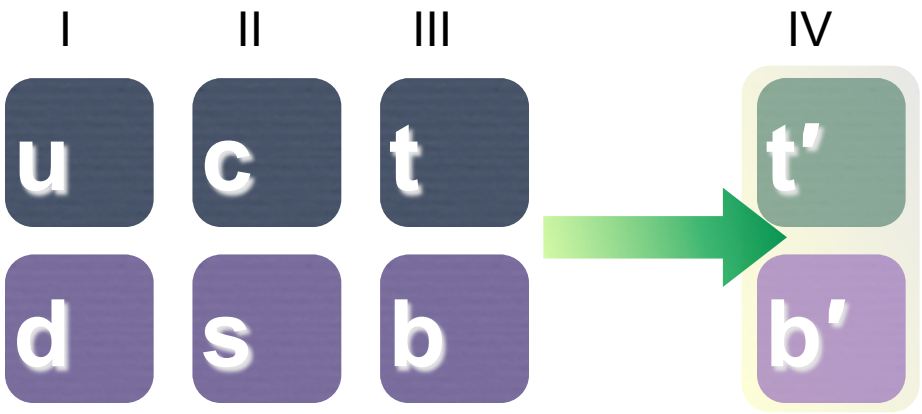
summary of work by

A. Avetisyan, T. Andeen, C. Bernard, S. Bhattacharya, K. Black, T. Childers, U. Heintz, M. Narain, T. Speer, C. Su, E. Varnes

June 30-July 3, 2013

Snowmass meeting, Seattle

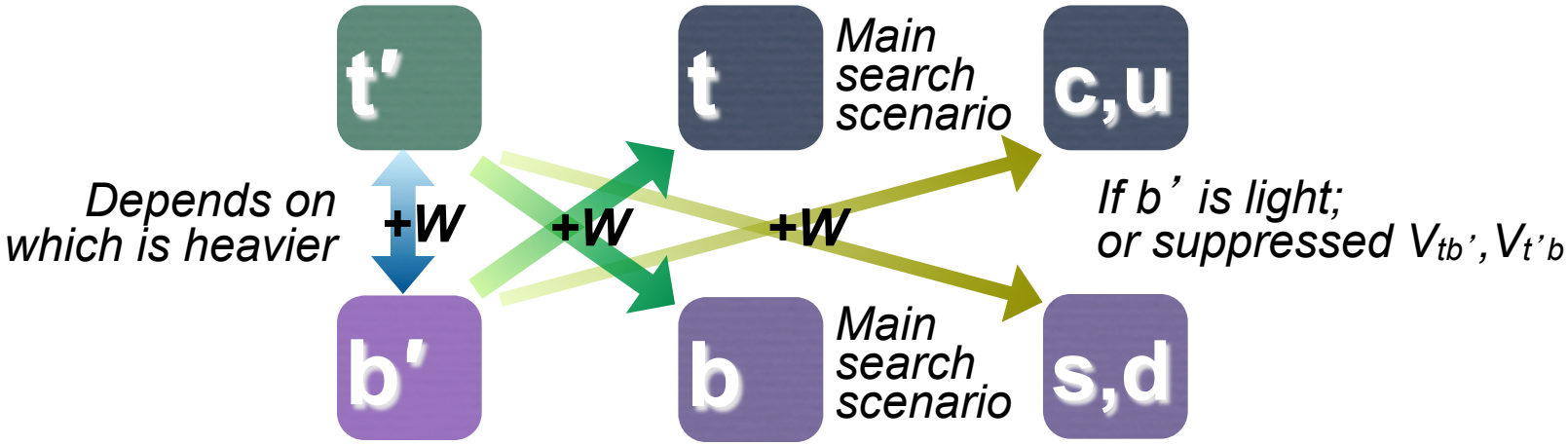
I: Chiral sequential 4G ?



Adding few more heavy quarks to the SM?

- An obvious extension to the SM.
- Disfavoured scenario:
  - EWK precision tests and the observation of a Higgs-like particle @125 GeV with approximately standard-model rate.
  - Would enhance gluon-fusion production rate by a factor of 9!
- However, these searches remain useful to constrain theories which give rise to similar final states.

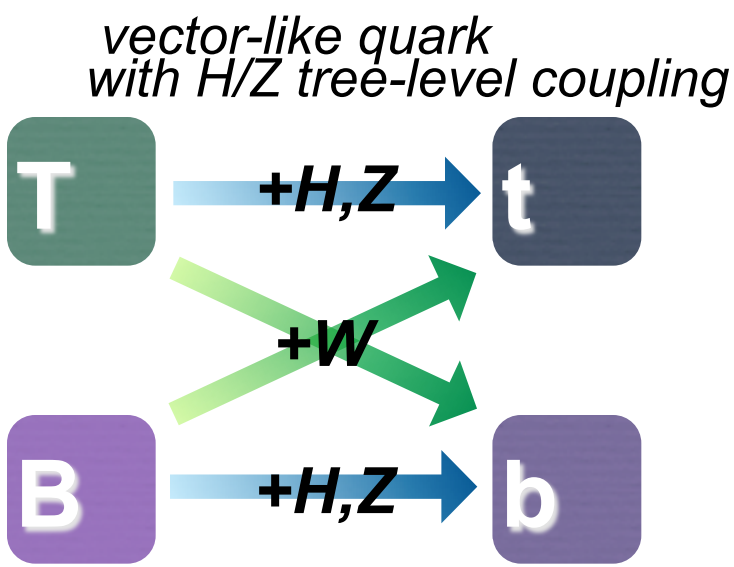
Search Signatures of New Heavy Quarks

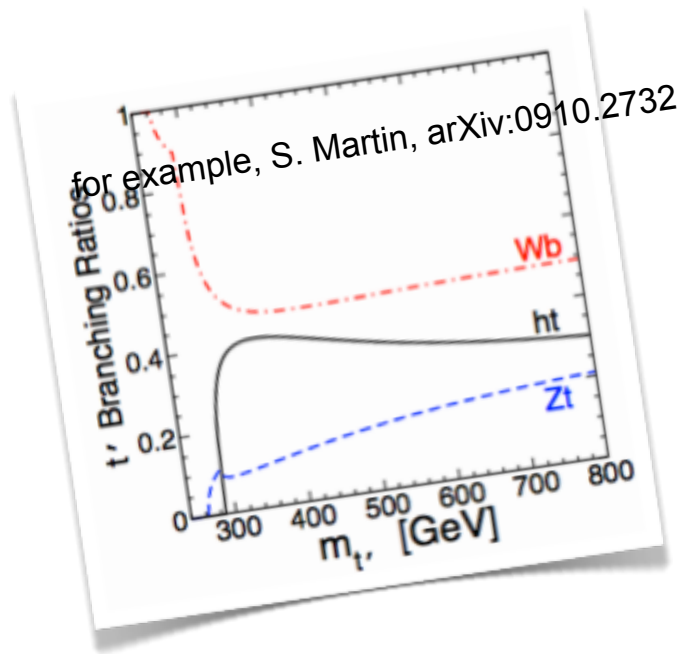


Main decay signatures for direct searches:

- **t' → bW**, **t' → qW** : not really different from a heavy top.
- **b' → tW(→ bWW)** : complex signature, **b' → qW** : heavy top.
- **t' → b' W & b' → t' W** : should be seen after the above two.

II: Vector-like quarks



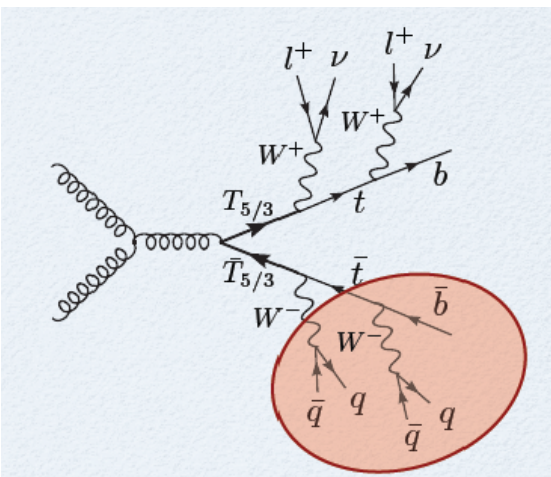


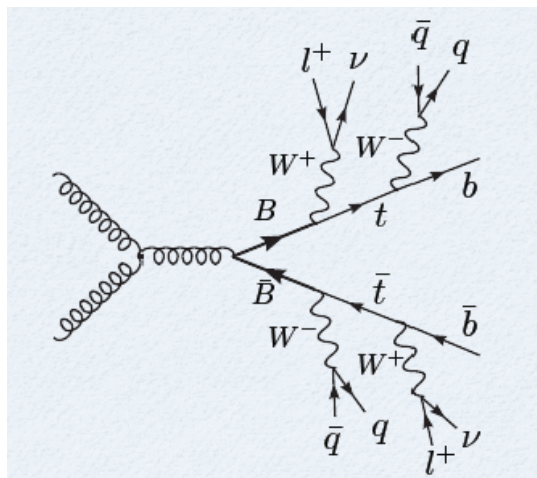
Decay signatures for direct searches:

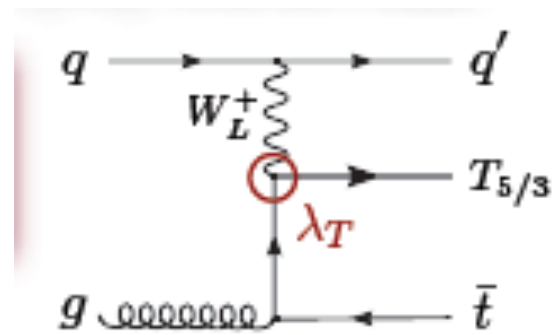
- **T/B → bW, tW** :
  not really different from the sequential 4G quark searches.
- **T → tH, tZ / B → bH, bZ** : vector-like quark with enhanced branching fractions.

III: Exotic Partners

- Heavy T with Q_e = 5/3 and B with Q_e = -1/3
  - decays to tW
  - B generally heavier than T



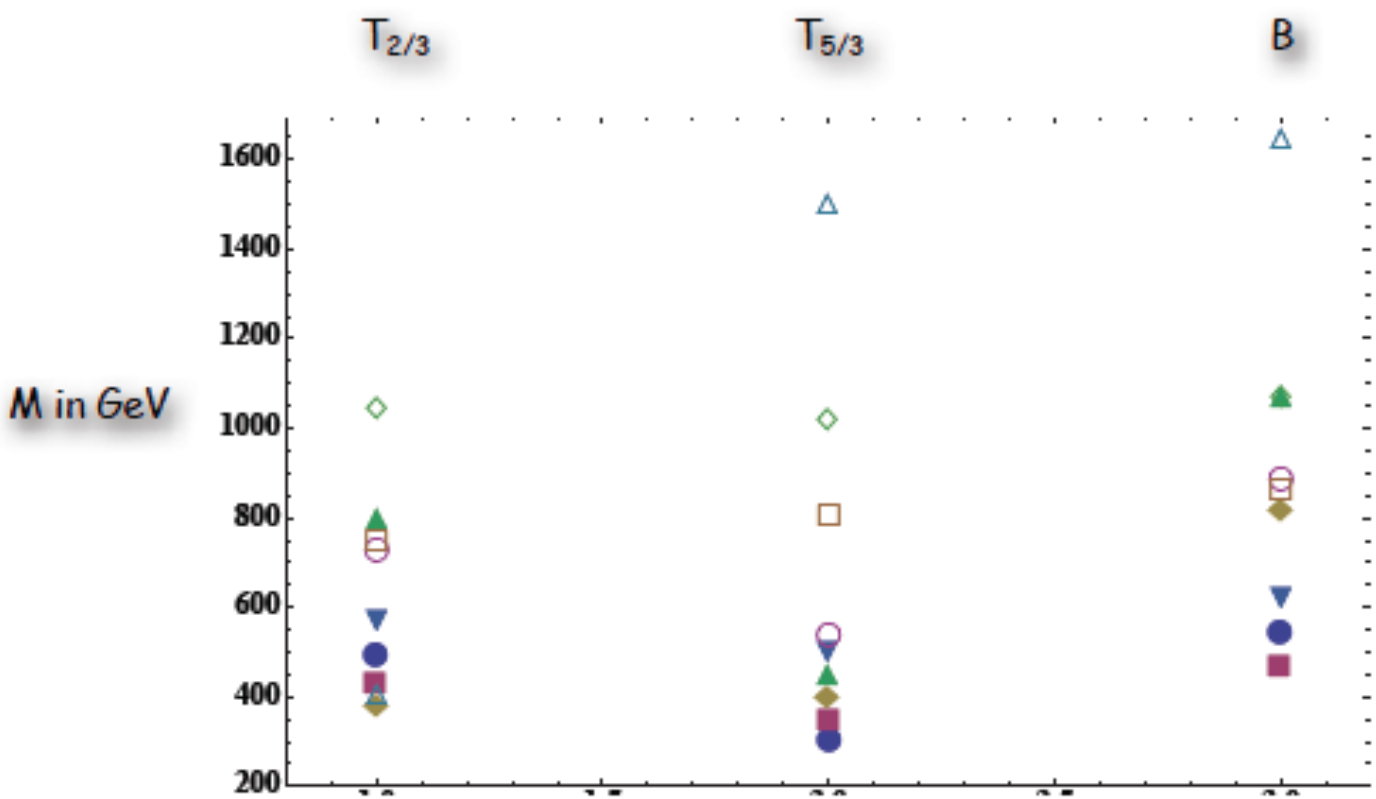




Contino and Servant; Mrazek & Wulzer

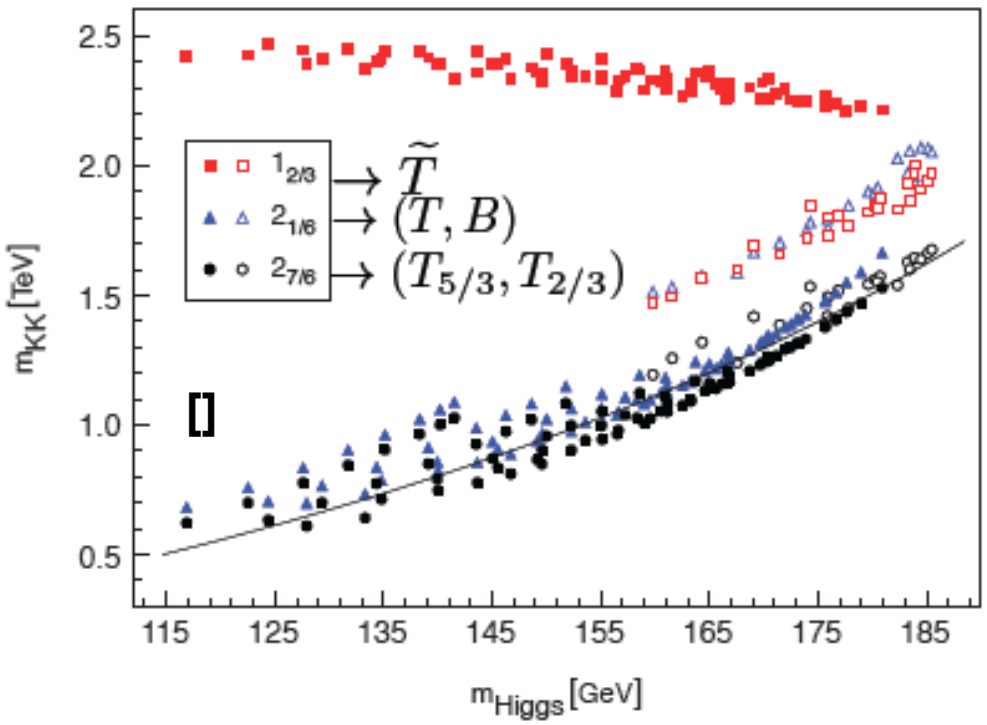
Shrihari Gopalakrishna, on bottom partners: http://arxiv.org/abs/arXiv:1107.4306

Examples of mass spectra
for different sets of parameters (y_*, $\sin\varphi_L$, $\sin\varphi_R$)



Agashe, Contino & Pomarol '05
Kaplan, ' 80s
[slide from Servant, Anjou' 12]

Naturalness: light top partners



- At least one top partner below 1 TeV

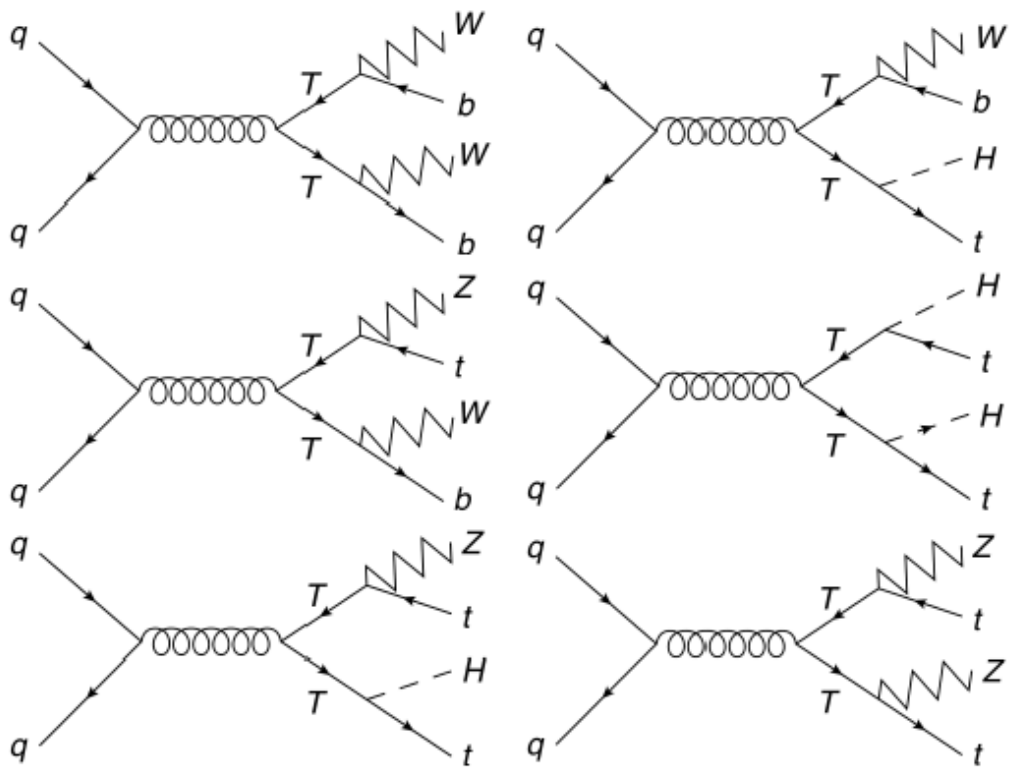
Pomarol & Rivam 1206.6424
Contino, Da Rold, Pomarol' 06
[material from Servant, Anjou' 12]

Vector Like quarks

- have pure vector couplings to W boson
- different from 4th generation quarks
  - not chiral
  - not excluded by observed Higgs cross section
- predicted in many models:
  - top see-saw, KK partner, GUT, SUSY, holographic Higgs, little Higgs
- help solve hierarchy problem:

T Pair Production Processes

S. Bhattacharya, U. Heintz, M. Narain, T. Speer



Signal cross-sections at $\sqrt{s}$=14 TeV(HATHOR)

t' Mass (GeV)	σ (in pb)
500	4.10091
600	1.44649
700	0.57883
800	0.25400
900	0.11961
1000	0.05948
1100	0.03089
1200	0.01662
1300	0.00920
1400	0.00521
1500	0.00301
1600	0.00177
1700	0.00105
1800	0.00063
1900	0.00038
2000	0.00024

Signal cross-sections at $\sqrt{s}$=33 TeV(HATHOR)

t' Mass (GeV)	σ (in pb)
500	44.4263
600	18.1717
700	8.35889
800	4.19501
900	2.25365
1000	1.27784
1100	0.75733
1200	0.46586
1300	0.29547
1400	0.19250
1500	0.12836
1600	0.08733
1700	0.06046
1800	0.04253
1900	0.03032
2000	0.02189
2100	0.01598
2200	0.01178
2300	0.00876
2400	0.00657
2500	0.00497
2600	0.00378
2700	0.00290
2800	0.00223
2900	0.00173
3000	0.00134

signatures

H->bb

Channel	Multi-leptons	Lepton+jets
tHWb	$2l$(OS)+MET+$4b$	l+ MET+$2j$+$4b$
tH tZ ($Z \to jj(bb)$)	$2l$+MET+$2j$+$4b$	l+MET+ $4j$+$4b$
tH tZ ($Z \to \nu\nu$)	$2l$+MET+$4b$	l+ $2j$+MET+$4b$
tH tZ ($Z \to ll$)	$4l$+MET+$4b$ or $3l$+MET+$2j$+$4b$	
tZ tZ (Z$Z \to jj(bb)$)	$2l$(OS)+MET+$2j$+$2b$	l+MET+ $4j$+$2b$z
tZ tZ (Z$Z \to \nu\nu$)	$2l$(OS)+MET+$2b$	l+$2j$+MET+$2b$
tZ tZ (Z$Z \to ll$)	$4l$+MET+ $2b$ or $3l$+$2j$+MET+$2b$	
tHtH ($H \to bb$)	$2l$(OS)+MET+ $6b$	l+MET+$2j$ + $6b$
WbWb	$2l$(OS)+MET+$2b$	l+MET+$2j$+$2b$
WbtZ ($Z \to jj(bb)$)	$2l$+MET+$2j$+$2b$	l+MET+$4j$+$2b$
WbtZ ($Z \to \nu\nu$)	$2l$+MET+$2b$	l+MET+$2j$+$2b$
WbtZ ($Z \to ll$)	$4l$+MET+$2b$ or $3l$+MET+$2j$+$2b$	

signatures

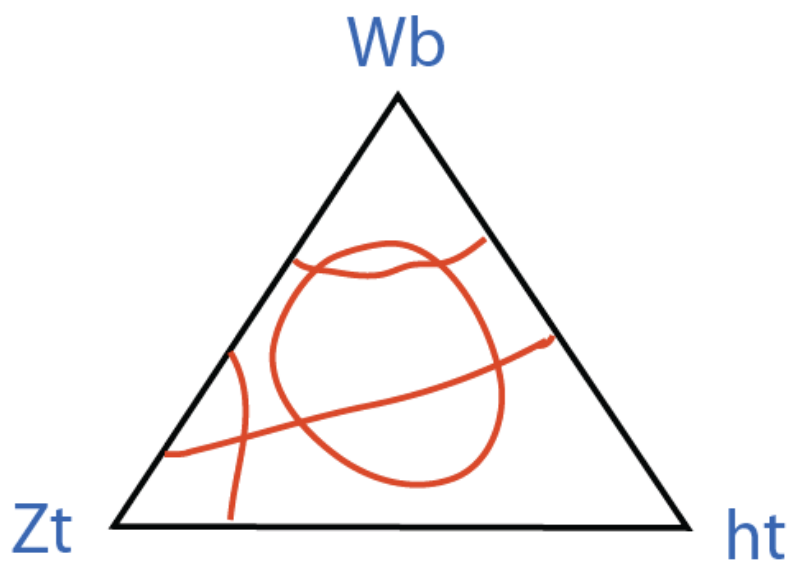
H->WW

-

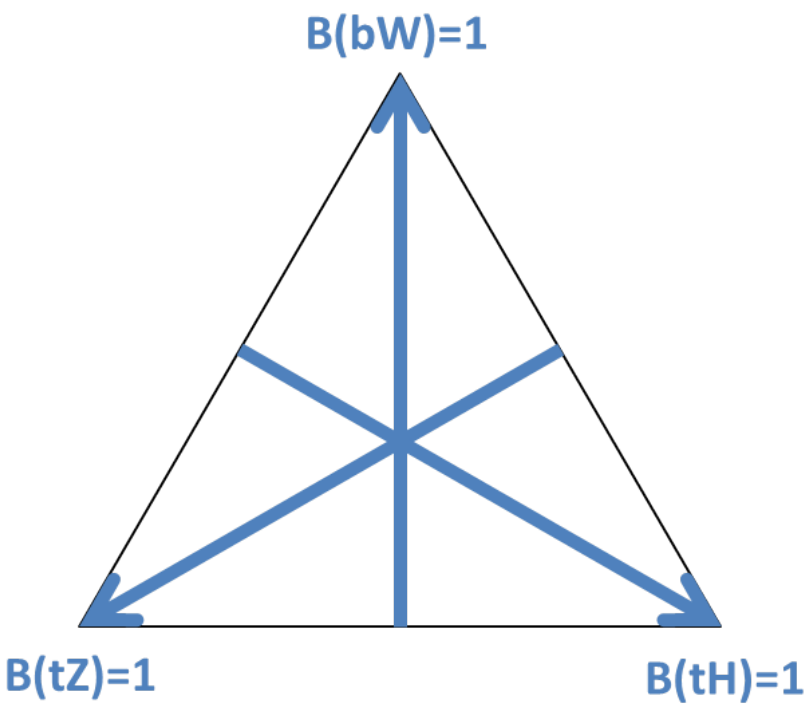
Channel	Multi-leptons	Lepton+jets
tHWb	$4l$+MET+$2b$ or $2l$(SS)+MET+$4j$+$2b$	l+MET+$6j$+$2b$
tH tZ ($Z \to jj(bb)$)	$4l$+MET+$2j$+$2b$ or $2l$(SS)+MET+$6j$+$2b$	l+MET+$8j$+$2b$
tH tZ ($Z \to \nu\nu$)	$4l$+MET+$2b$ or $2l$(SS)+MET+$4j$+$2b$	l+MET+$6j$+$2b$
tH tZ ($Z \to ll$)	$6l$+MET+$2b$ or $3l$+MET+$6j$+$2b$	
tHtH ($H \to W^+W^-$)	$6l$+MET+ $2b$ or $3l$+MET+$6j$+$2b$	l+MET+$10j$ + $2b$
tHtH ($H \to W^+W^-, b\bar{b}$)	$4l$+MET+ $4b$ or $2l$(SS)+MET+$4j$ + $4b$	l+MET+$6j$ + $4b$

Vector Like Quarks: Peskin @ SEARCH

2. Exclude Triangles not Points



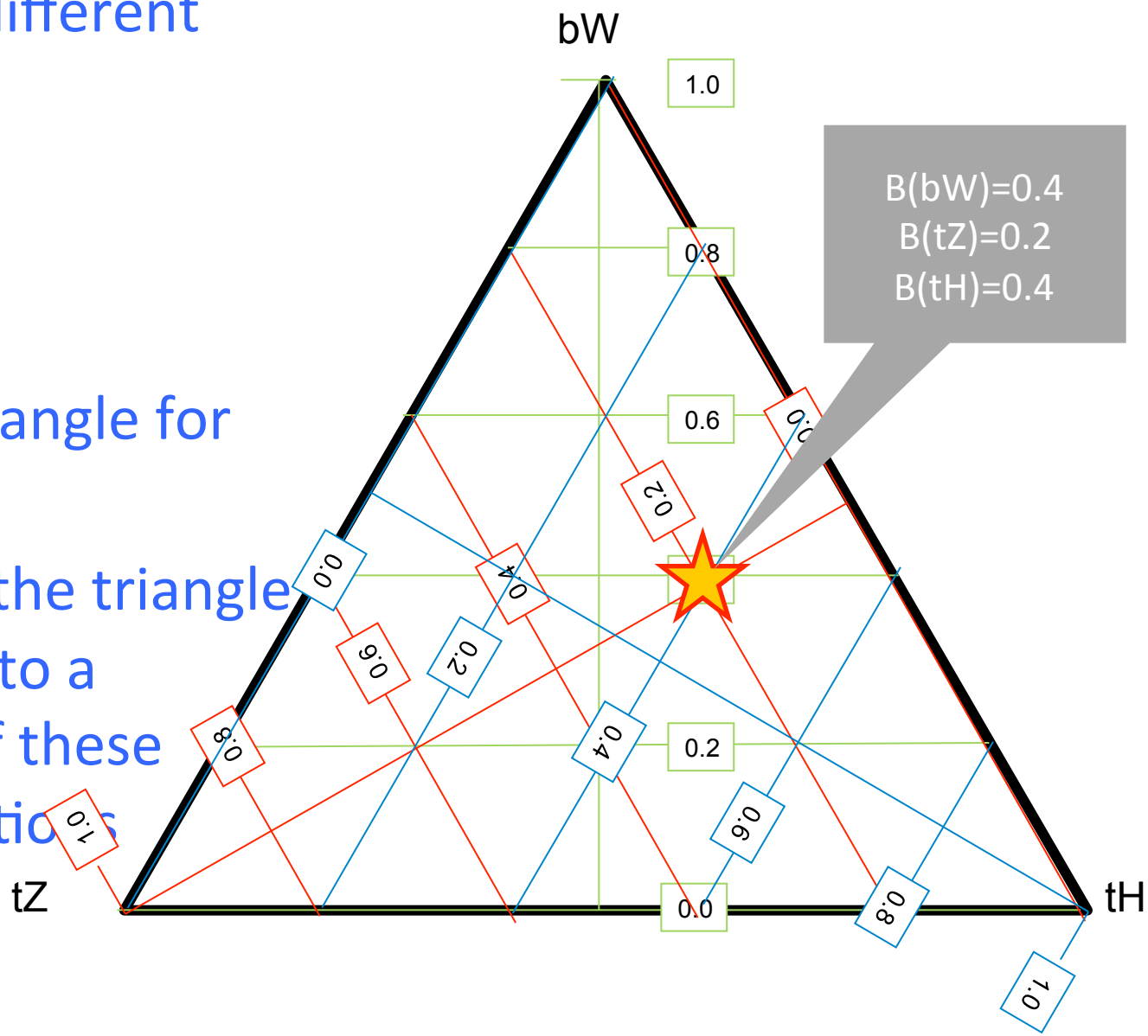
Basic Analysis Plan



- Look for pair produced T-quark (dominant production at low T masses)
- Look at events with at least one isolated lepton
- We scan across the entire BR phase space of final states -- model independent

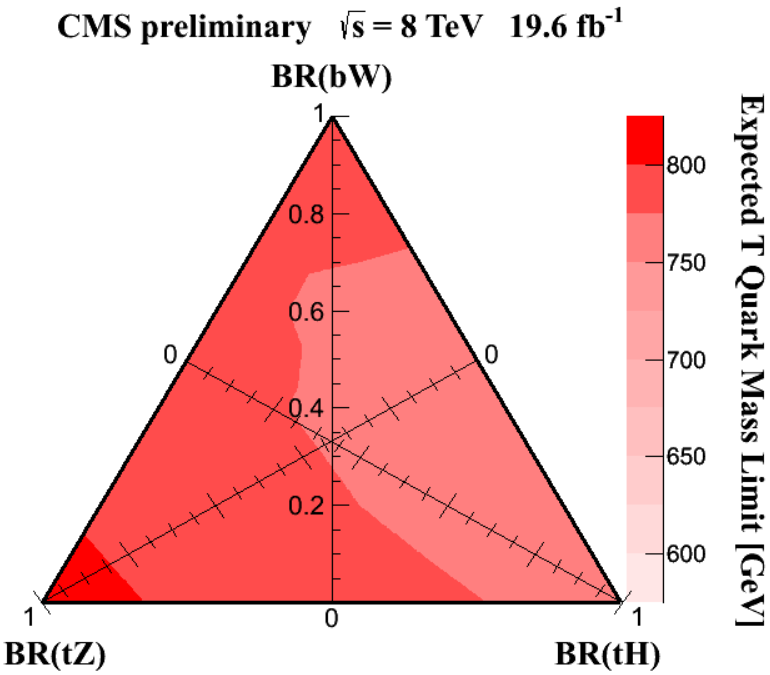
Recasting to a Triangle

- T decays into different final states
  - T→bW
  - T→tZ
  - T→tH
- there is one triangle for every T mass
- every point in the triangle corresponds to a different set of these branching fractions

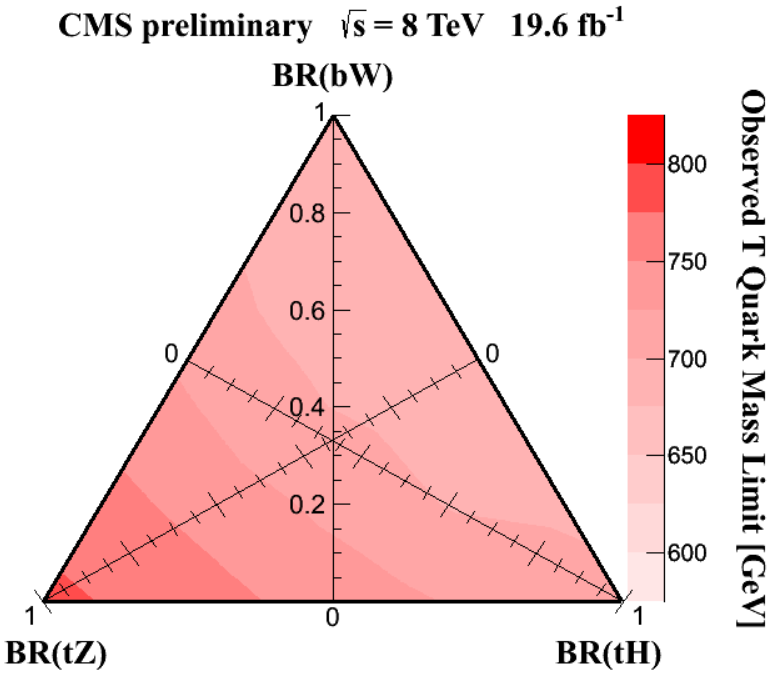


Combined limits

CMS PAS B2G-12-015

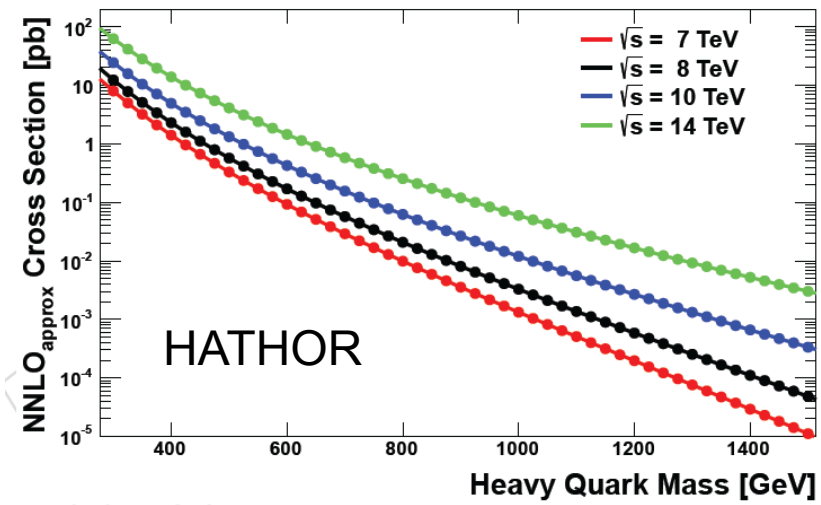


Expected Limit



Observed Limit

extrapolation to 14 TeV (CMS)

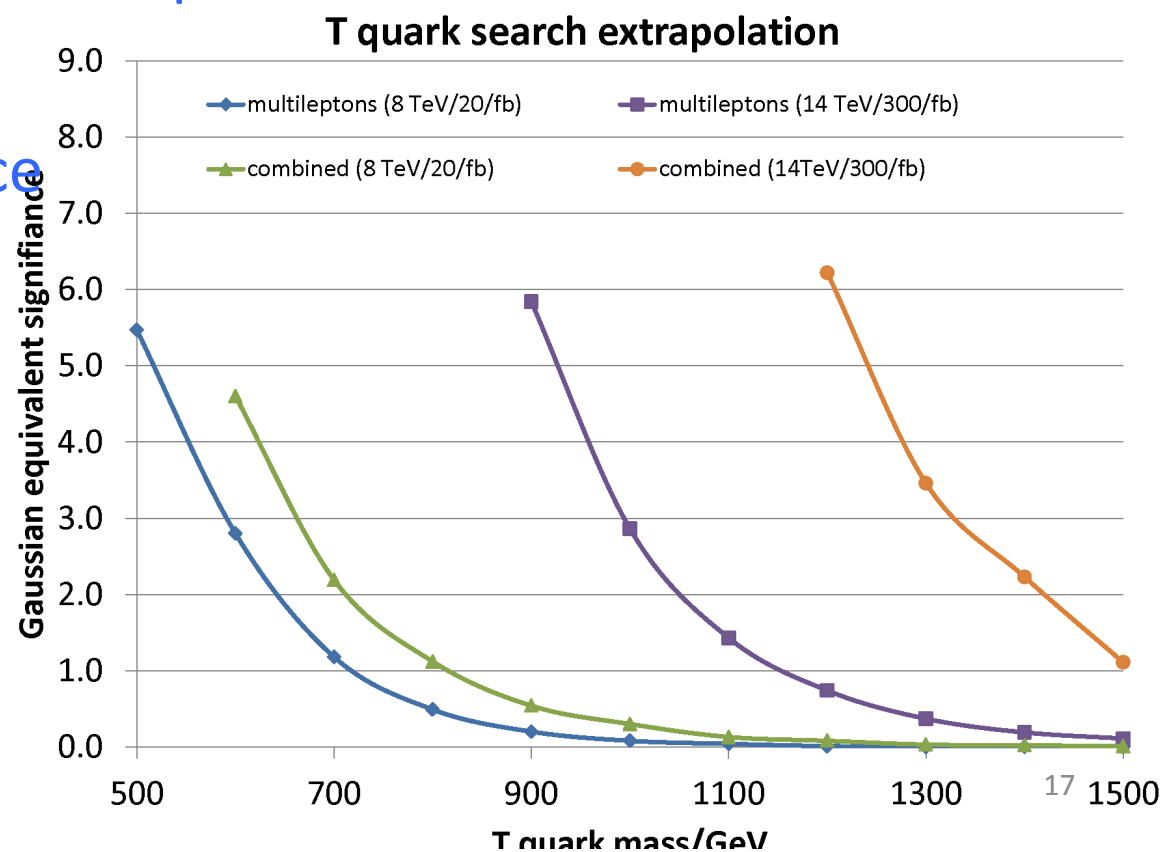


process	8 TeV	14 TeV	ratio
W+jets			1.8
ttbar	249 pb	966 pb	3.9
ttW	0.23 pb	0.77 pb	3.3
ttZ	0.21 pb	1.00 pb	4.8
all others			3

- scale all yields
- multileptons
  - assume efficiencies stay the same as at 8 TeV
  - can be improved by optimizing cuts
- lepton+jets
  - choose cut on BDT discriminant to optimize significance in each channel

extrapolating to 14 TeV (CMS)

- expected significance of T quark search for 300/fb @ 14 TeV
- multilepton channels → event counts in 4 categories
- single lepton channels → optimize cut on BDT discriminant
- combine p-values
- convert to significance

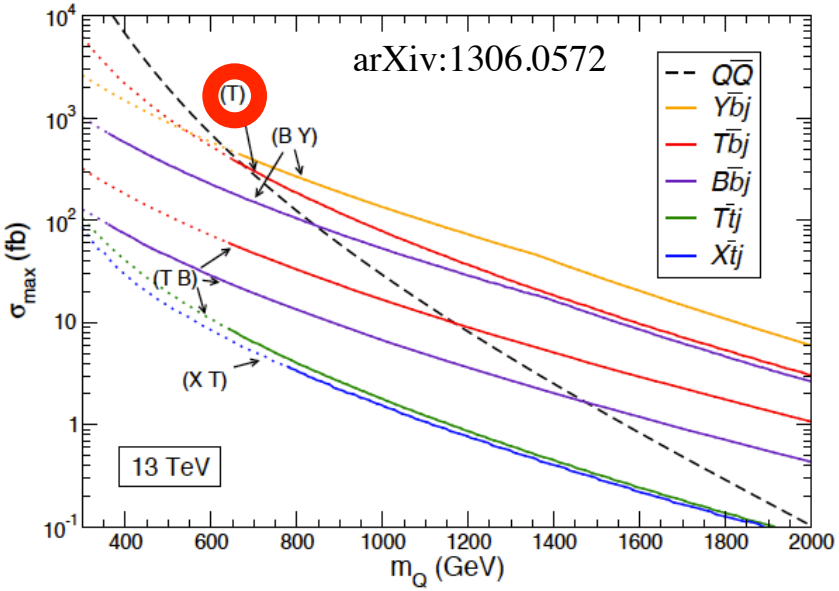


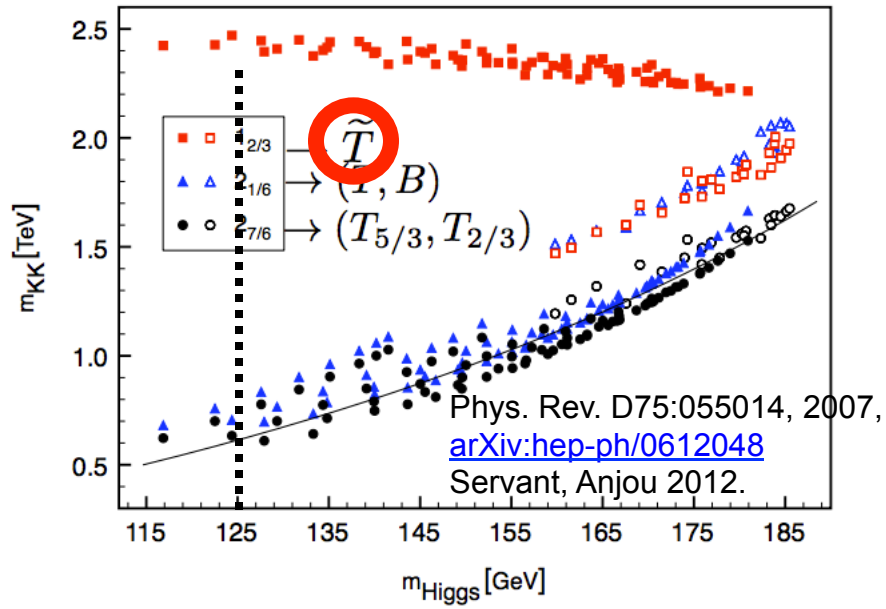
see J. Olsen plenary talk

VLQ Top Partner Single Production

Tim Andeen, Clare Bernard (BU), Clover Su (BU),
Kevin Black (BU), Taylor Childers (CERN)

VLQ Top Partner Single-EW Production





Why VLQ single production?

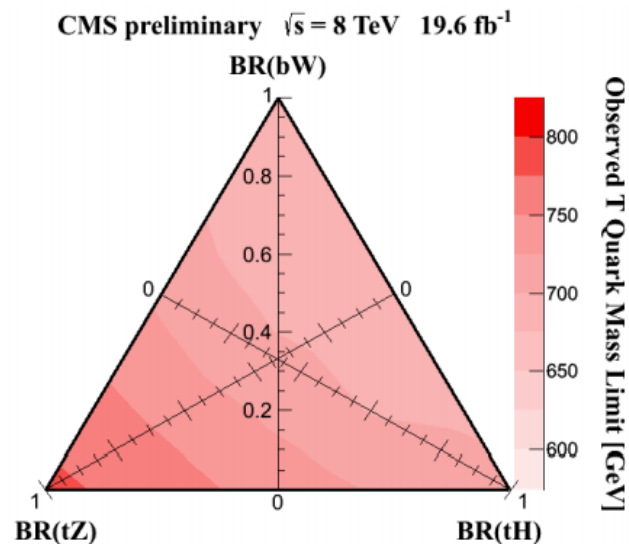
Simplest new colored fermions allowed by experimental data.

Predominant mixing with third generation SM quarks.

Theoretically motivated in composite Higgs and warped ED models.

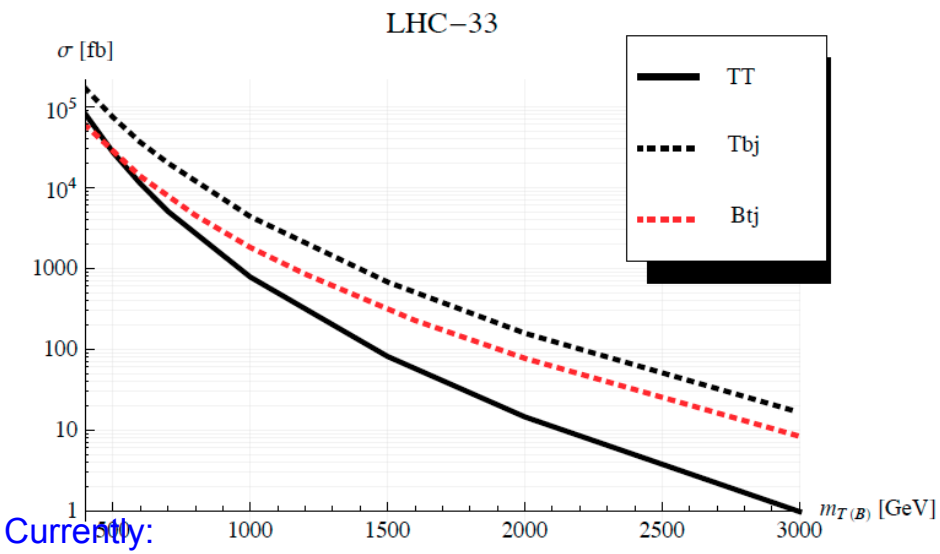
Lightest resonances should be ~TeV.

Single production has a favorable cross section and is sensitive to masses/BRs with the least stringent experimental limits.



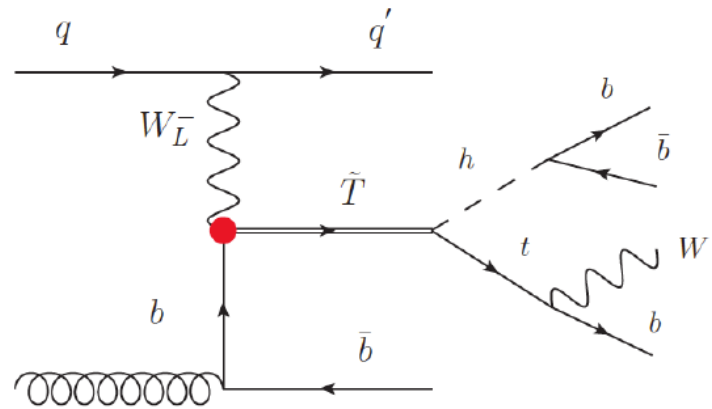
http://cds.cern.ch/record/1557571

VLQ Top Partner Single-EW Production



$$(\tilde{T} \to (h \to bb)t)b + X$$

$$pp \to l^{\pm} + n\,jets + \not{E}_T$$



Currently:

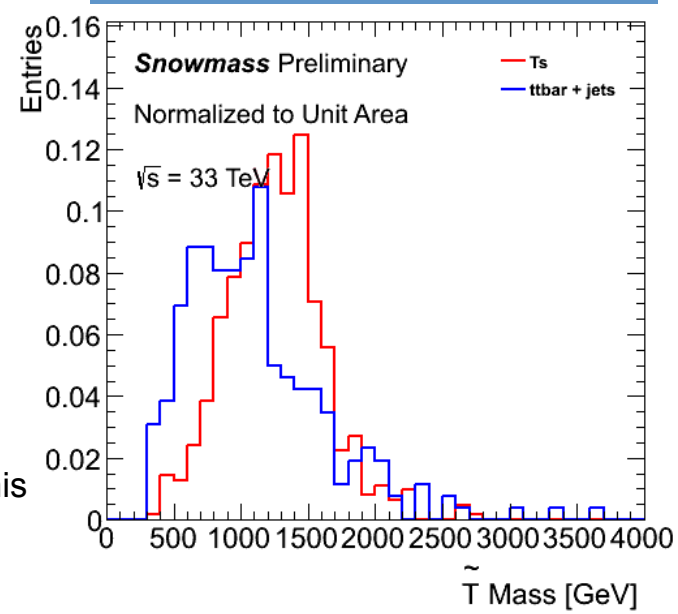
Model based on PRD 86, 075017 (2012), arXiv: 1207.0830 and implemented in MG5 processed through Snowmass detector simulation.

T_s masses 0.5 - 3.0 TeV. Currently using no pileup samples.

Select for single lepton (e/μ) top final state, with h->bb.

Use jet mass to select higgs decay, study jet mass to veto additional tops.

before analysis selection



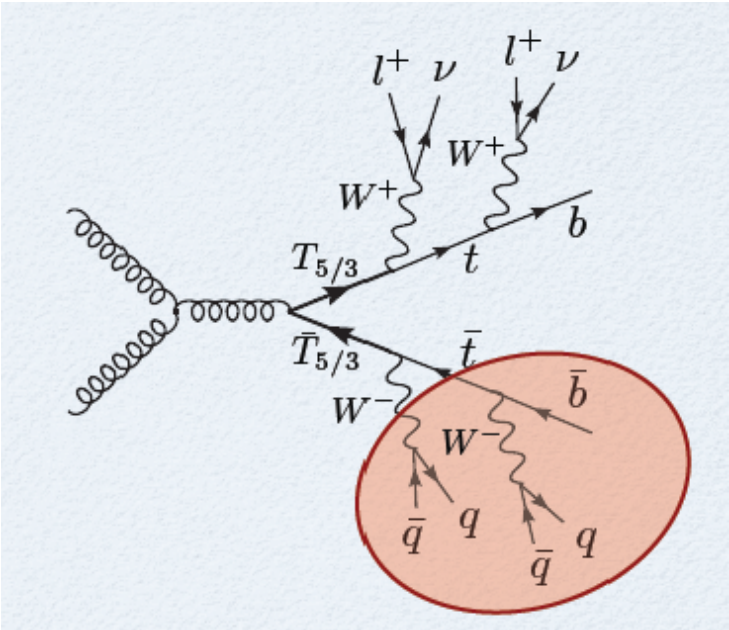
To come:

Waiting for HT-binned 33 TeV sample for additional tuning and limit setting (this week).

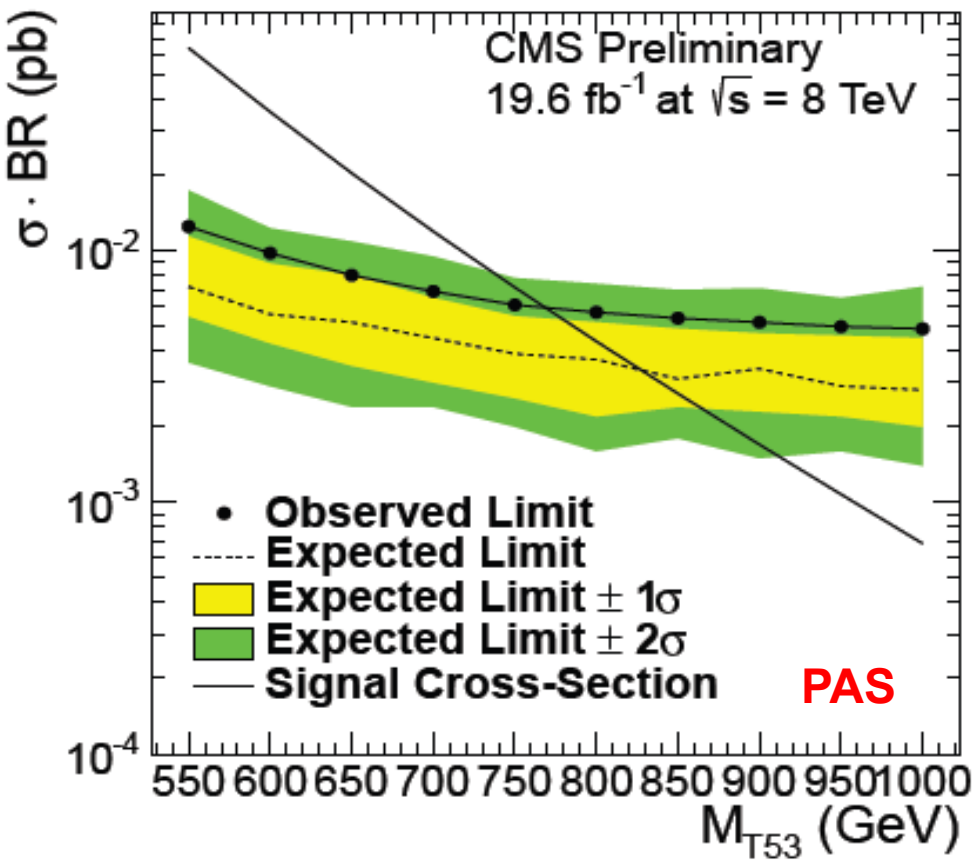
Generate signal samples at 14 TeV, for HL-LHC analysis.

Exotic T with Q_e=5/3

A. Avetisyan (BU)



CMS B2G-12-012

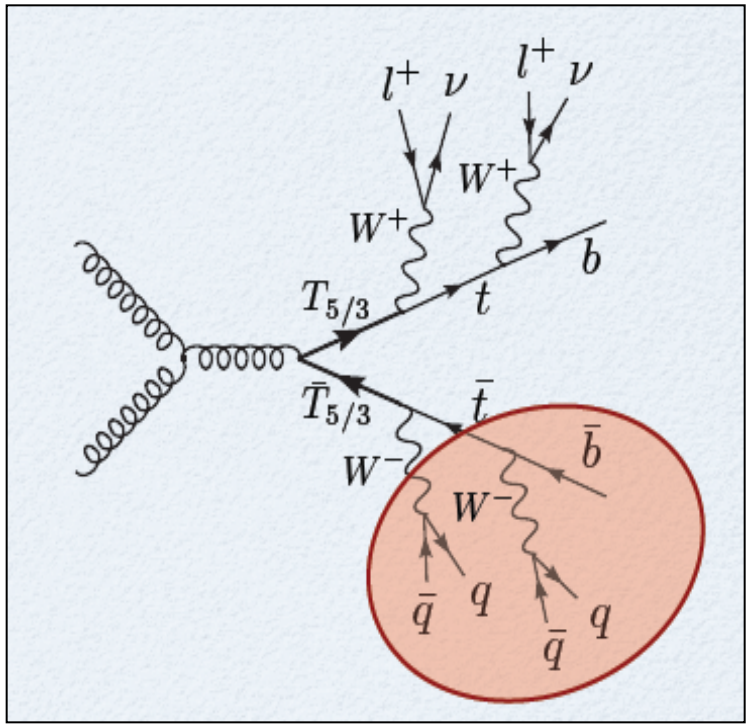


–***Contino & Servant***, JHEP 0806:026 (2008)
–***Mrazek & Wulzer***, Phys. Rev. D 81, 075006 (2010)
– More recently: CERN-PH-TH/2012-323 (arXiv:1211.5663)

Model

- $T_{5/3}$ with Q_e = 5/3 and B with Q_e = -1/3 decay into W and top
  - Per Mrazek & Wulzer, B is typically more massive than $T_{5/3}$
  - Focus on $T_{5/3}$

$$l^{\pm}l^{\pm} + 2b + 2\mathrm{W}$$

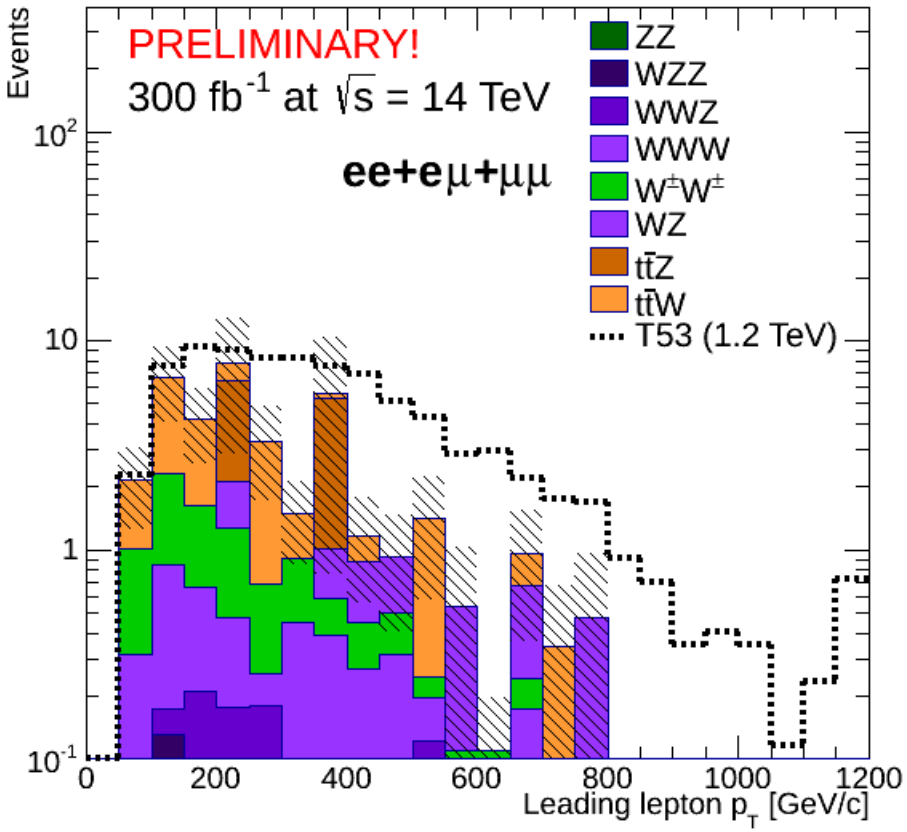


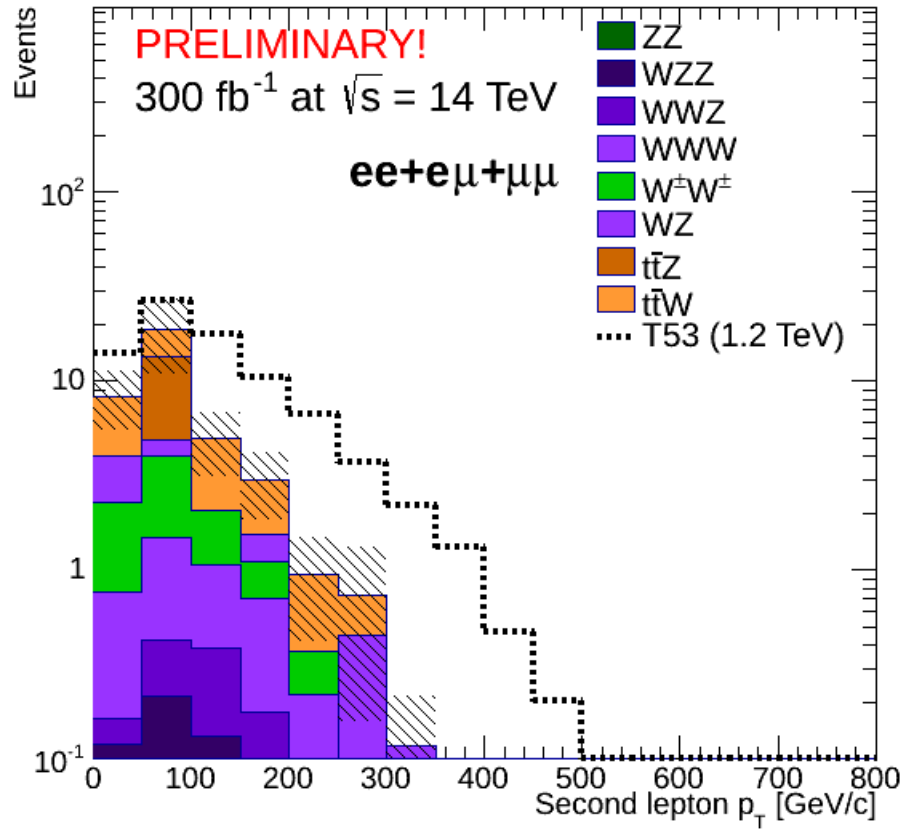
- Most striking signature: same-sign dileptons

$T_{5/3}$ Selection

- Two same-sign leptons:
  - Leading p_T > 80 GeV, the other p_T > 30 GeV
  - Trilepton Z-veto
- Jets:
  - Leading jet p_T > 150 GeV, second p_T > 50 GeV
  - Minimum of 5 constituents
    - Top-tagged jet = 3 constituents
    - W-tagged jet = 2 constituents
    - Jets and leptons (other than the 2 same-sign ones) with p_T > 30 GeV = 1 constituent each
- H_T = Sum of all selected lepton and jet p_T > 1400 GeV
- Missing E_T > 100 GeV
- **PRELIMINARY!**

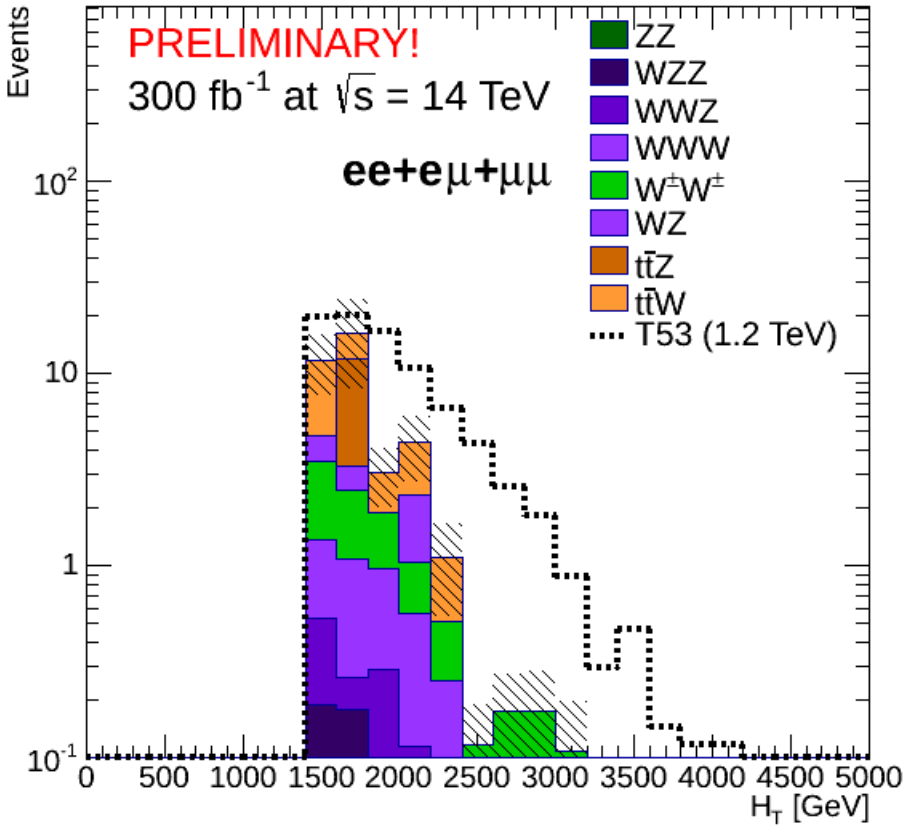
Lepton p_T

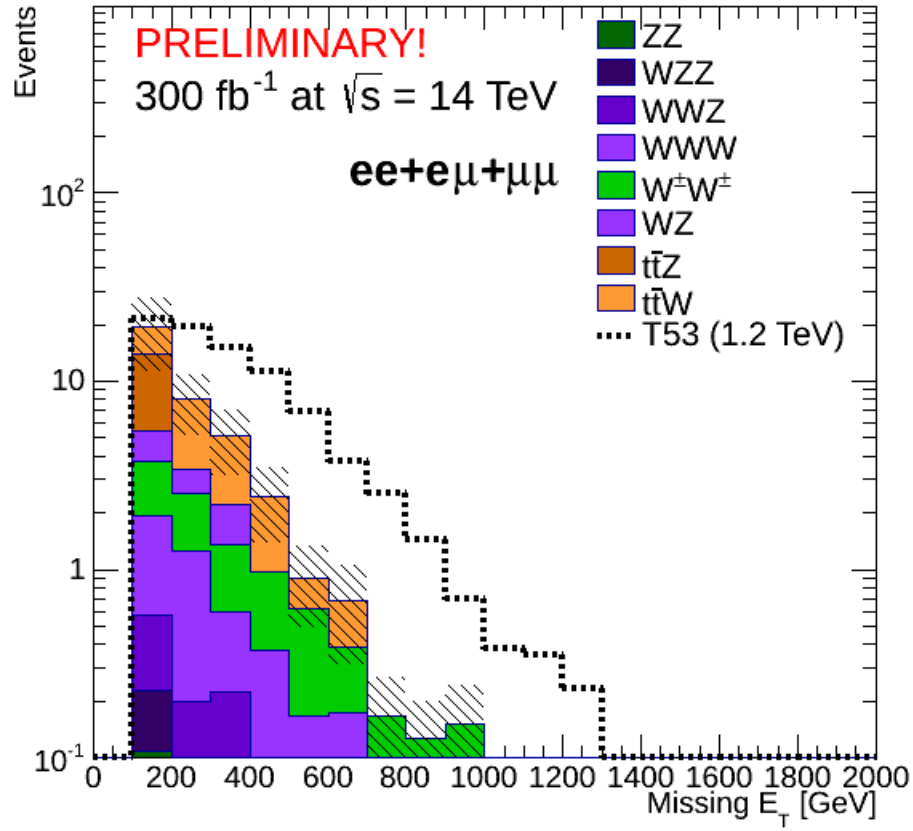




- Note: Backgrounds are 13 TeV inclusive samples with cross-sections scaled to 14 TeV
  - Will switch to binned 14 TeV samples soon

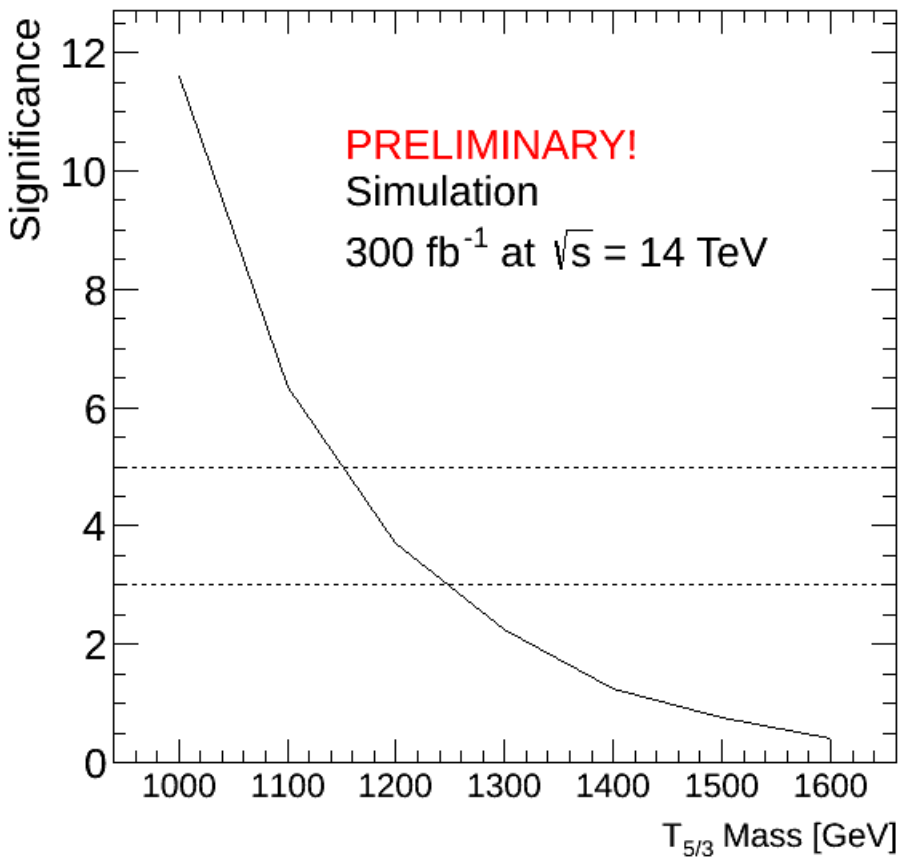
H_T and Missing E_T





- All plots are after the full selection
  - 50 pileup

Significance



- With 300 fb^{-1} at 14 TeV:
  - 5 sigma if $T_{5/3}$ mass is less than ~1.15 TeV
  - 3 sigma if $T_{5/3}$ mass is less than ~1.25 TeV

Summary of B pair production status

Erich Varnes
University of Arizona
June 28, 2013

Introduction

- Though chiral (i.e. SM-like) additional quark generations are disfavored by the measured Higgs cross section, "vector-like" heavy quark models remain viable
  - left- and right-handed "vector-like" quark components transform identically under SU(2)
    - can write gauge-invariant mass term without coupling to Higgs
  - many BSM models that address the hierarchy problem posit the existence of such quarks
- I am investigating sensitivity of future accelerators to pair-production of vector-like B (i.e. charge -1/3) quarks
  - using same-sign dilepton signature
  - two reference mass points (1000 and 1500 GeV)
  - considering all possible branching ratios to *Wt*, *Zb*, and *Hb*

Samples and selection

- For now considering only the SM backgrounds:
  - *ZZ*, *WZ*, *ttW*, same-sign *WW*
- Have generated signal samples using Madgraph 5/ Pythia 8/Delphes 3.0.9
- Preselection:
  - jets, leptons, must have pt > 25 GeV and $|\eta| < 3.0$ (2.5)
  - require one same-sign lepton pair
  - >= 2 jets, >=1 of which has loose b-tag
  - veto leptons pairs in Z mass window
- Optimization
  - scan cuts in # of b-tagged jets, Ht, and MET to optimize significance, defined as

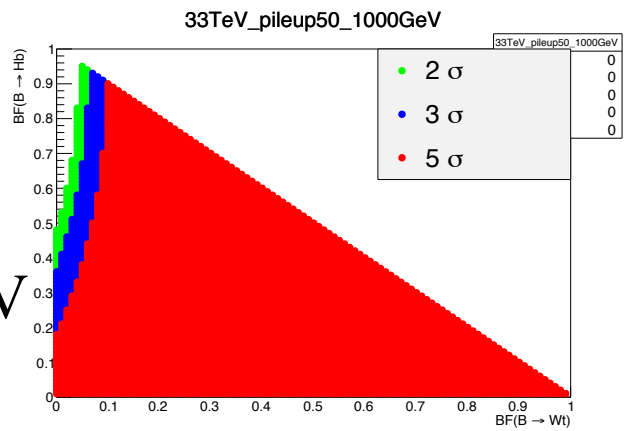
$$\frac{S}{\sqrt{S + B + \sigma^2}}$$

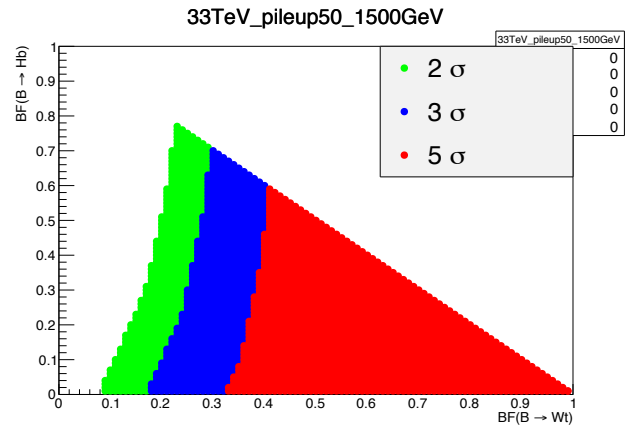
systematic uncertainty

Early results

- Potential for 33 TeV accelerator, 3000 fb^{-1}, 50 pileup
  - *ttW* is most problematic background (relatively large cross section, similar signature to signal)
- stat-only:

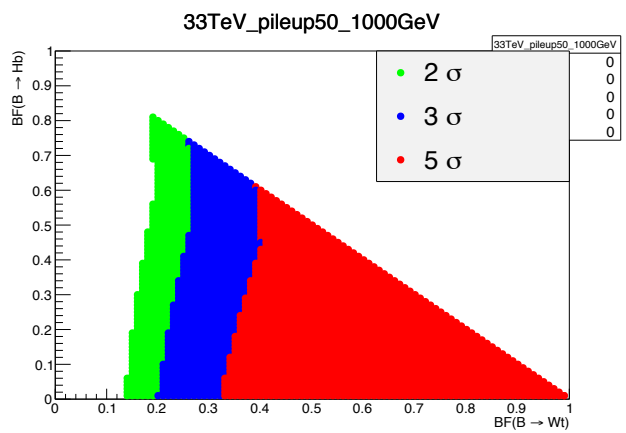
$m_B =$ 1000 GeV

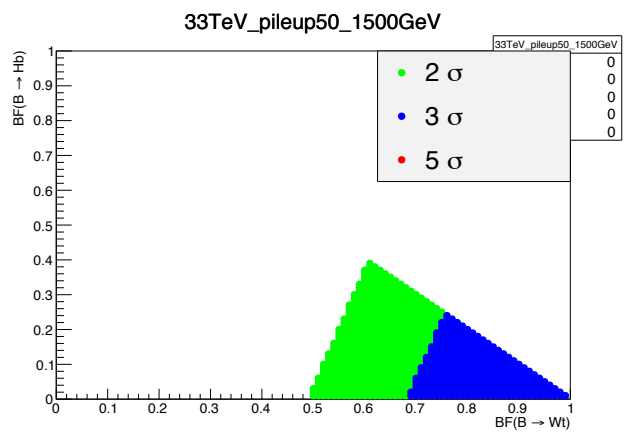




$m_B =$ 1500 GeV

- systematics = 10% of background estimate:

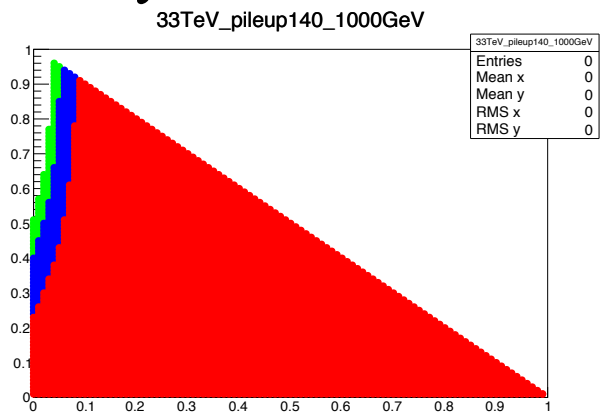


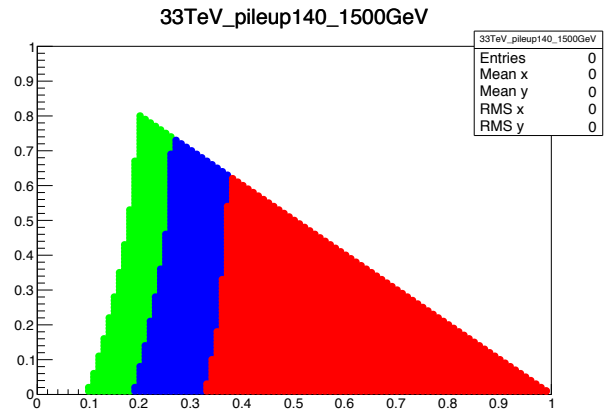


Early results

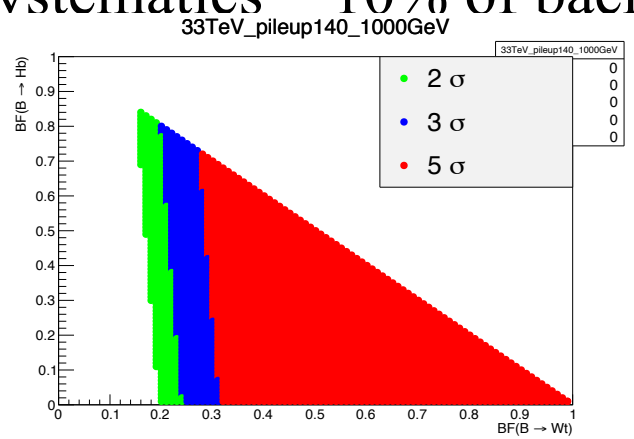
- Potential for 33 TeV accelerator, 3000 fb^{-1}, 140 pileup

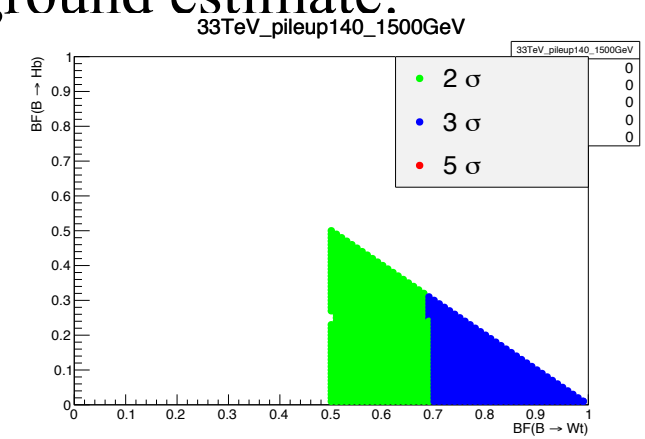
- stat-only:





- systematics = 10% of background estimate:





Conclusion

- Investigate
  - sqrt(s) = 14 and 33 TeV and corresponding PU scenarios and lums.
  - Work has started, and hopefully have the results in a few weeks.
- What if we see something? (need to work on this too!)
  - How could we identify this is heavy quark, not contributions of something else (SUSY, etc...)
  - Mass reconstruction, property (charge, spin, etc?)