Search for Vector-like T quarks in the single lepton and multi-lepton channels

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Introduction

- Many extensions of physics beyond the standard model propose the existence of fermionic partners (top-partners) of the top quark.
- Vector-like quarks appear in models such as the Little Higgs, Extra Dimensions and MSSM.
- Vector like T quark (of charge 2/3) search includes T decaying to bW, tZ and tH. The newly discovered Higgs boson is used as a probe for new physics.
- Leads to busy final states with multiple bosons and b-tagged jets.
- The branching ratio of T to bW, tZ and tH is varied from 0 to1, hence scanning the entire parameter space.

Search for vector-like top partners, CMS-B2G-12-015

- T is pair produced and decays to bW, tH and tZ.
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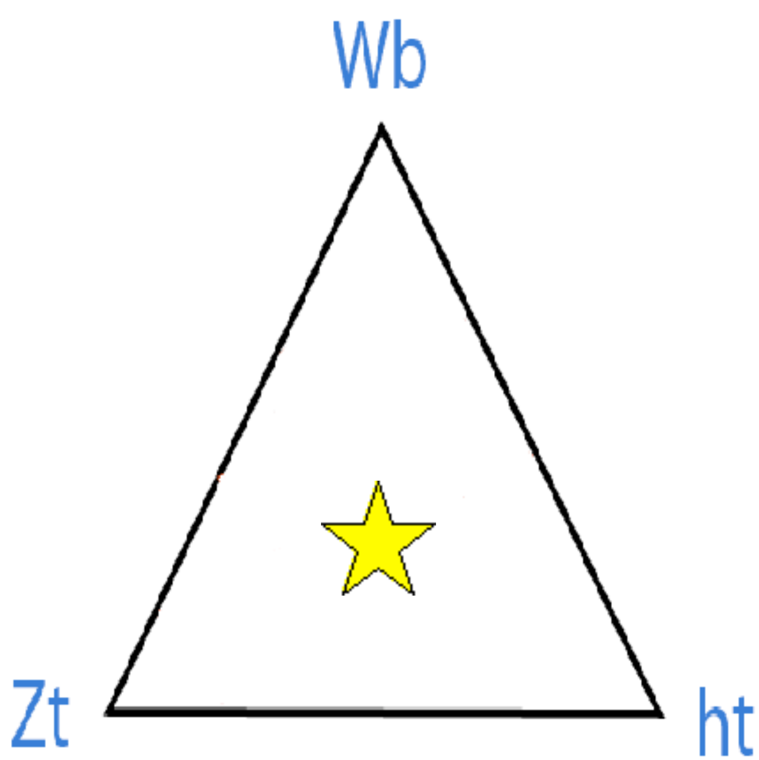
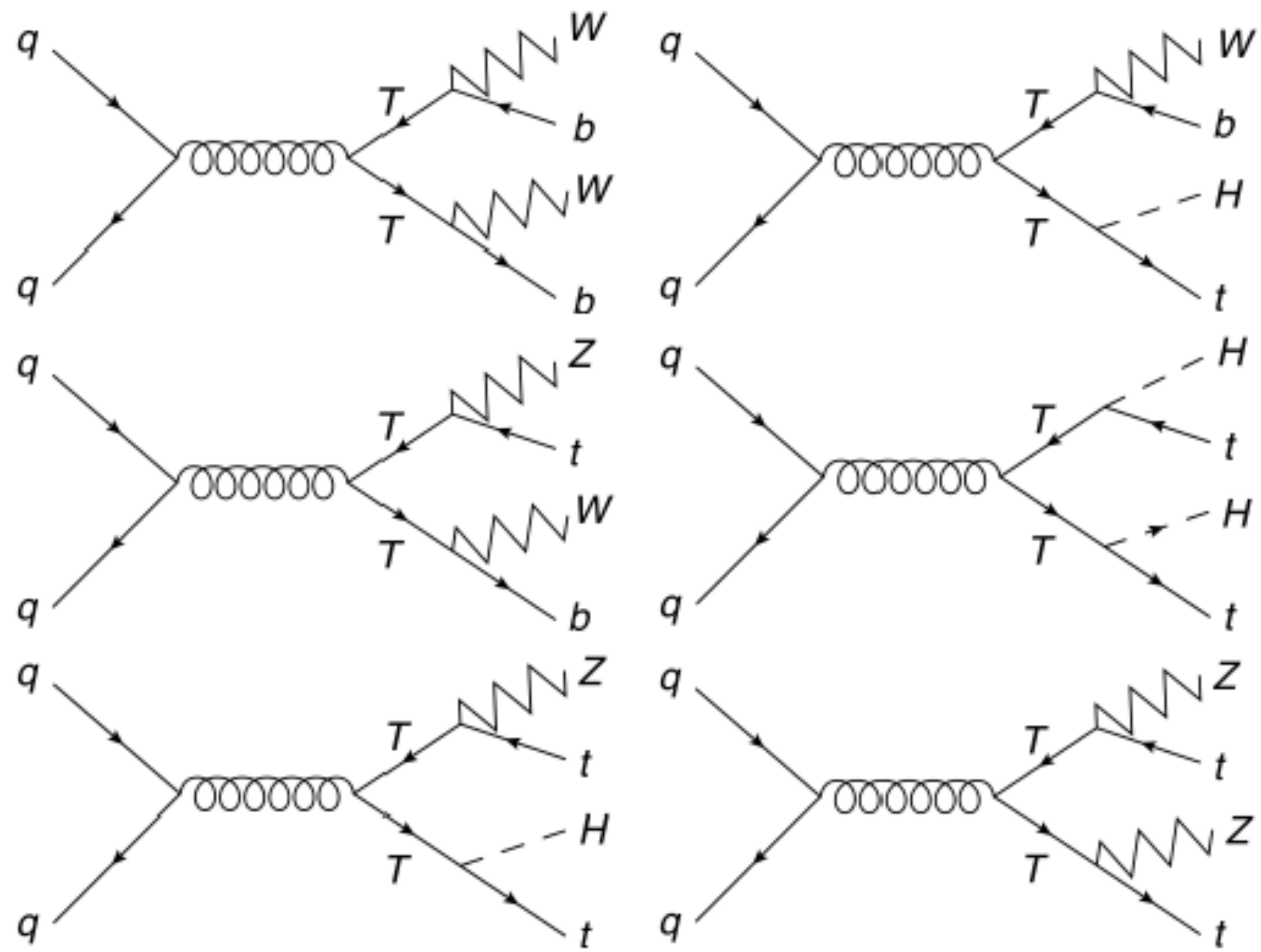
BR(bW) = 1/2 , BR(tH) = 1/4, BR(tZ) = 1/4





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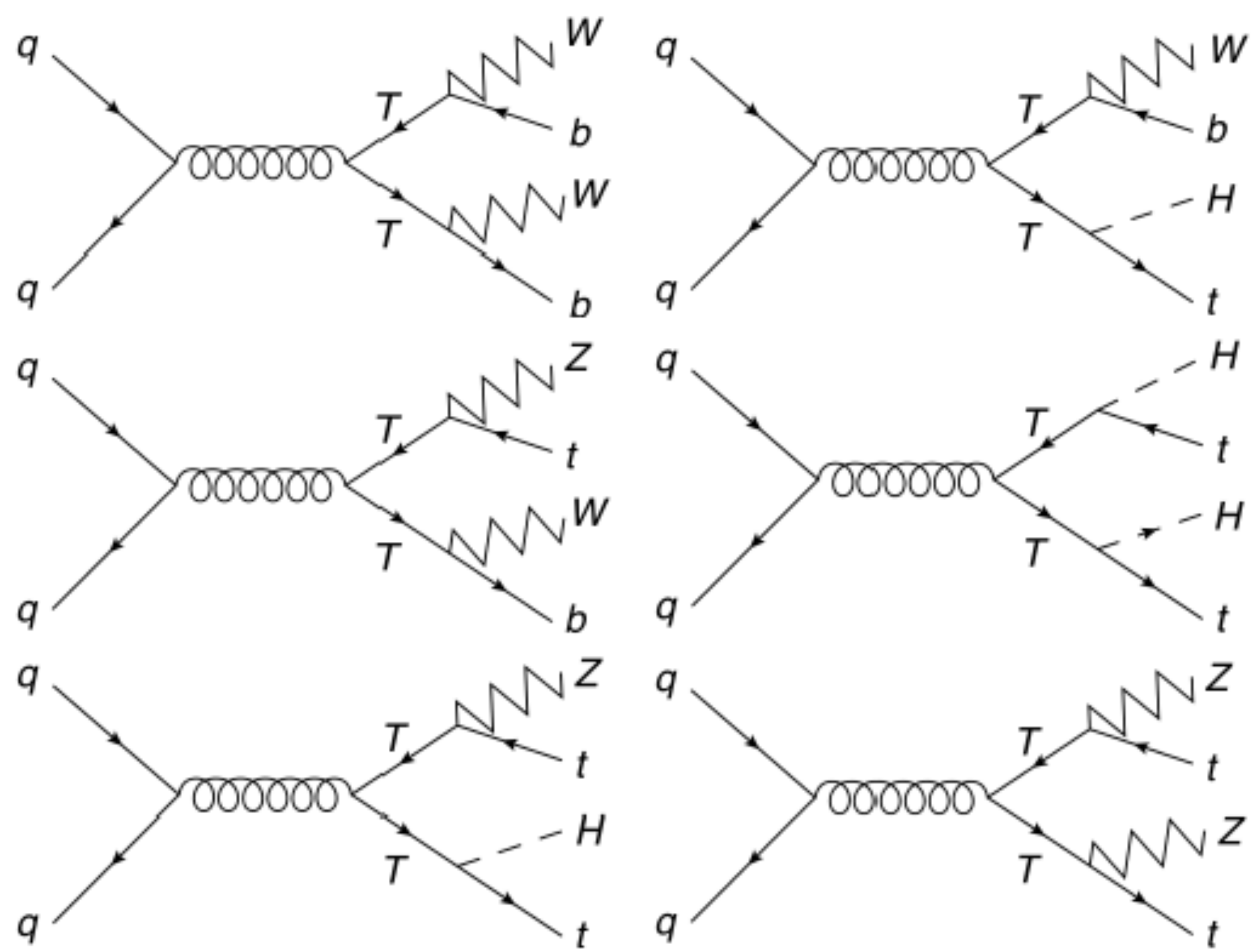

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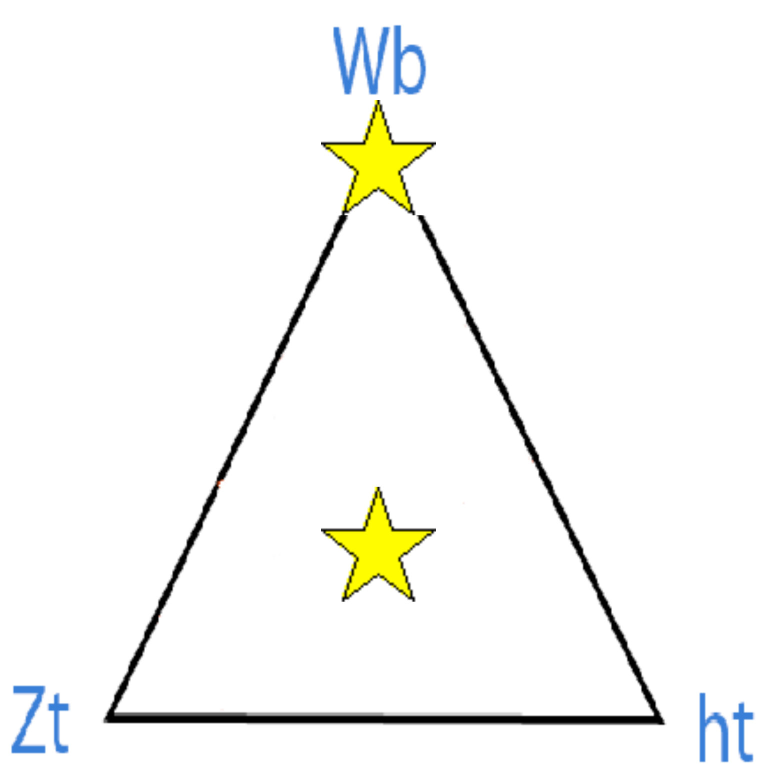

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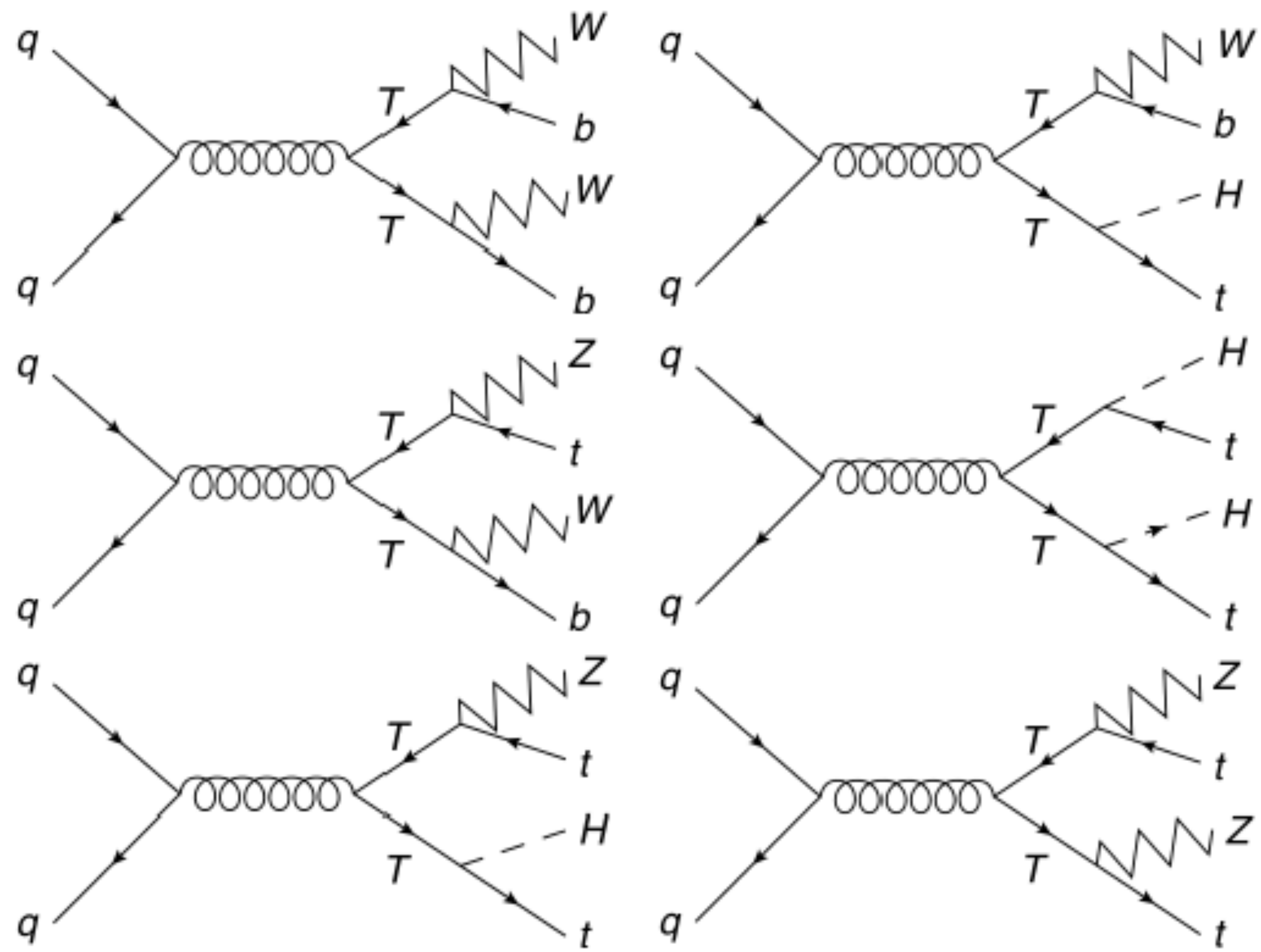

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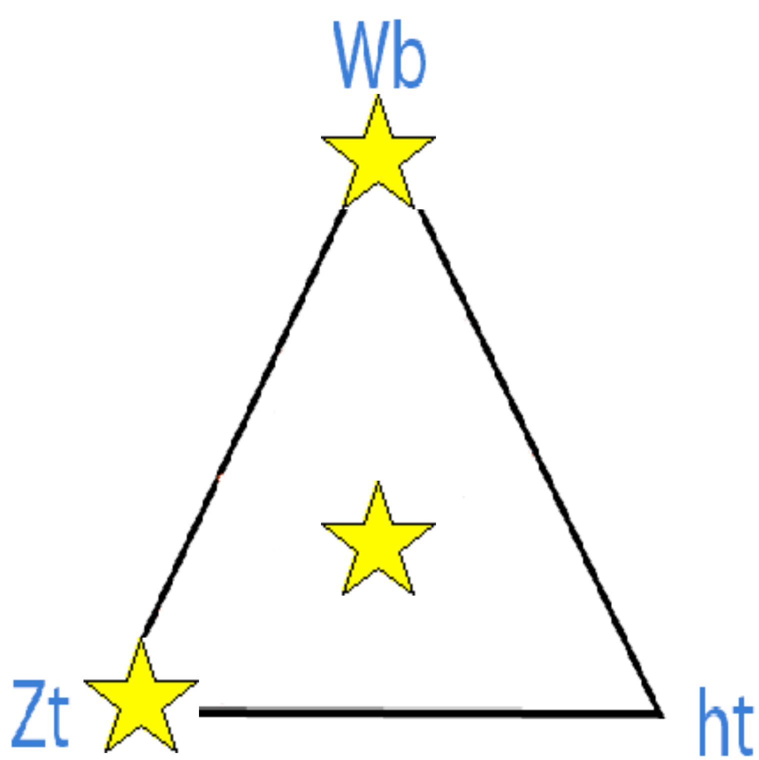

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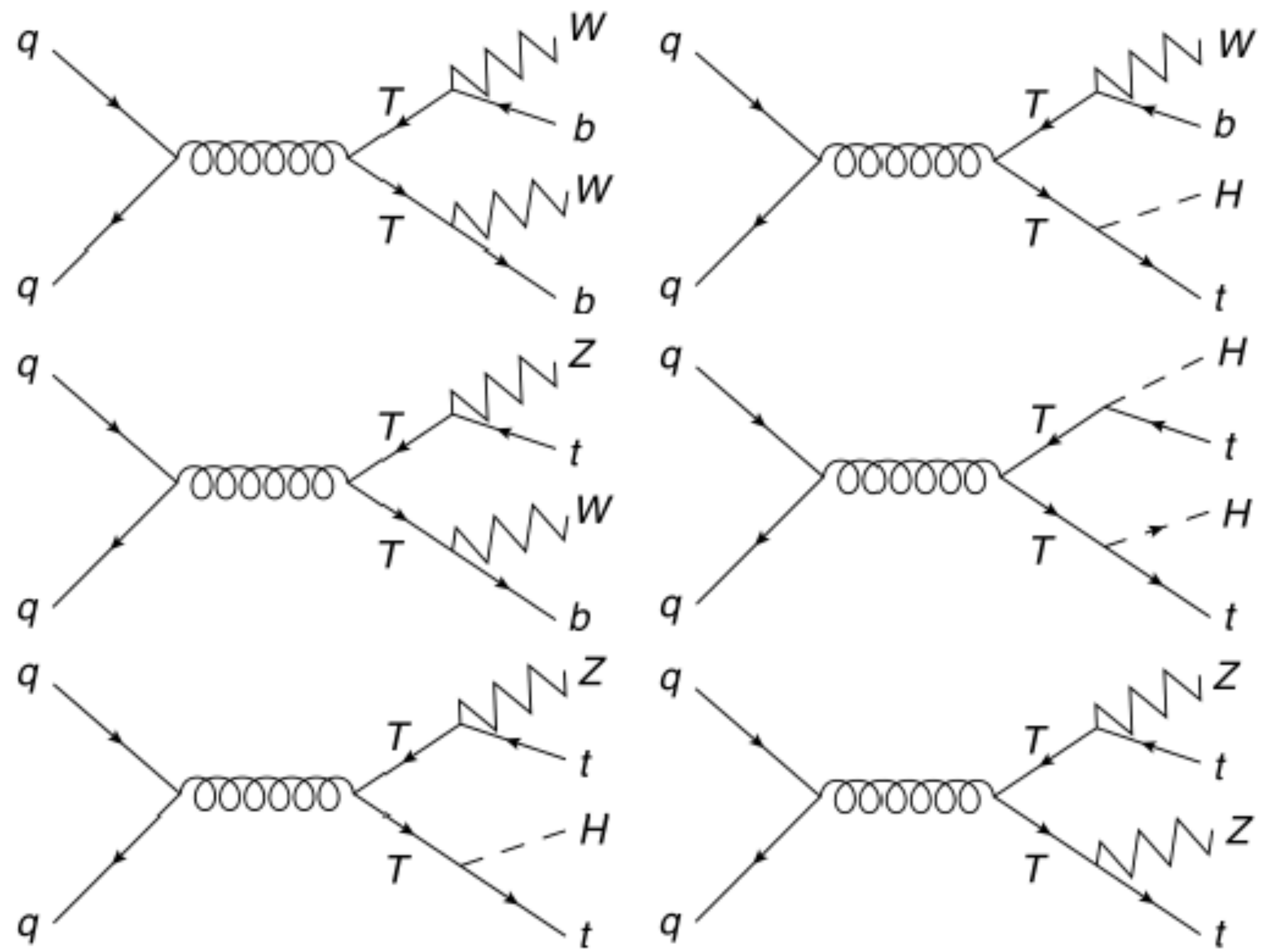

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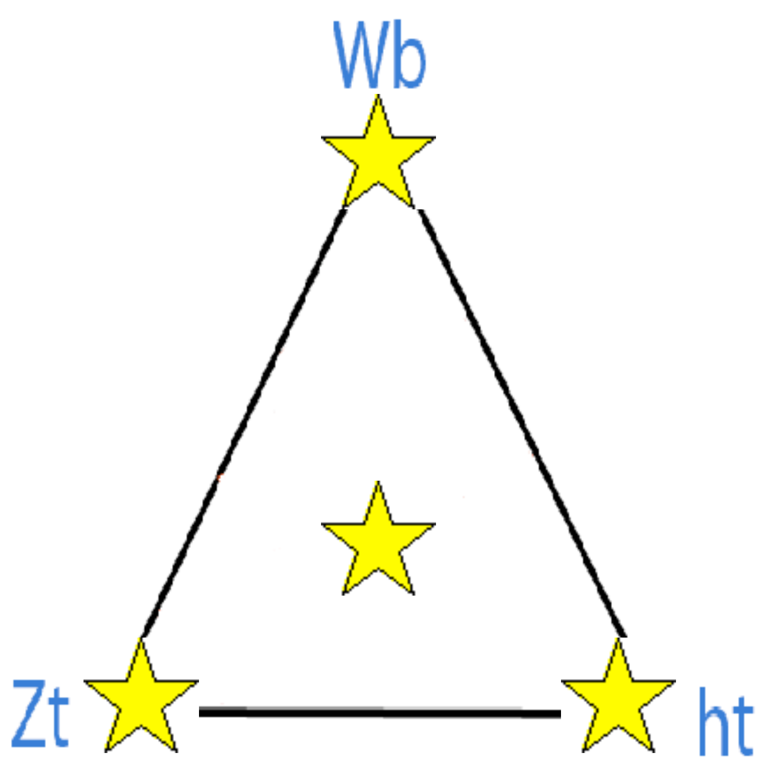
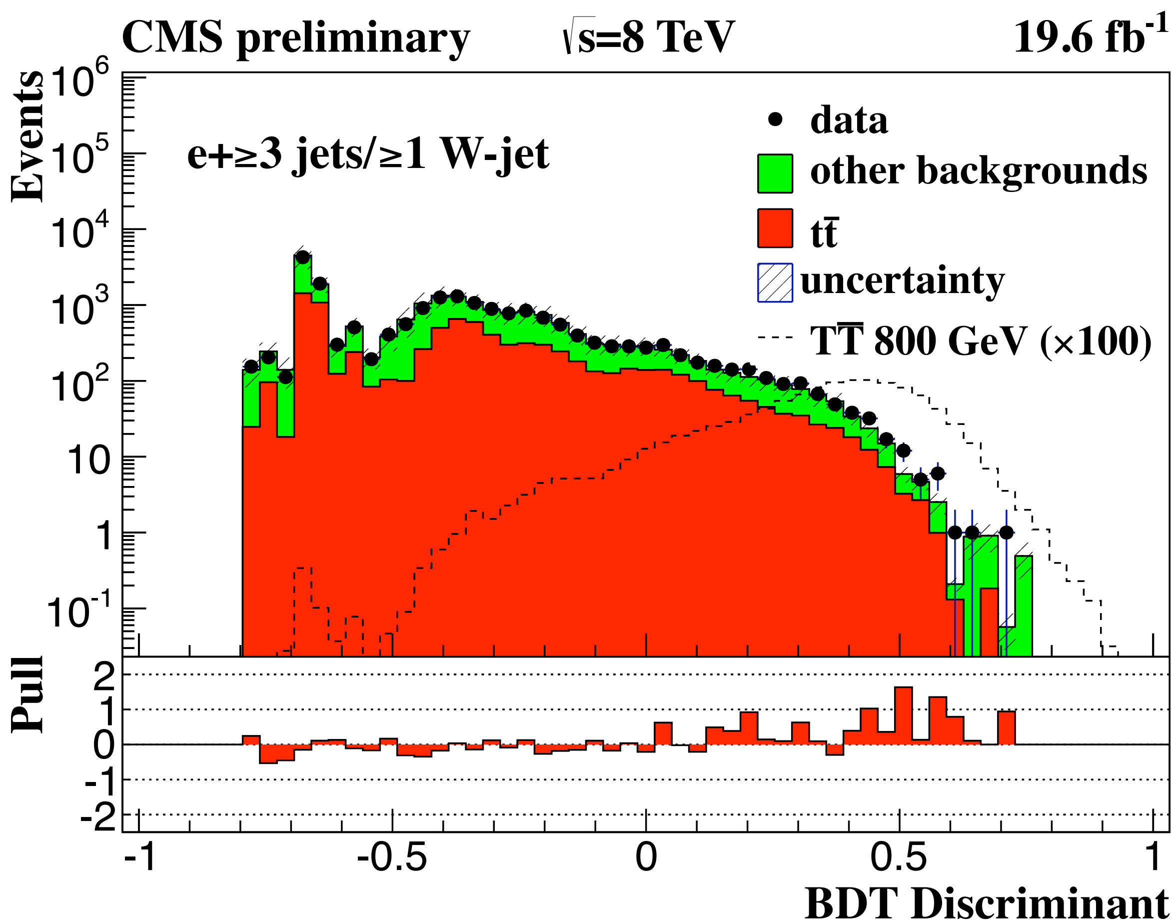


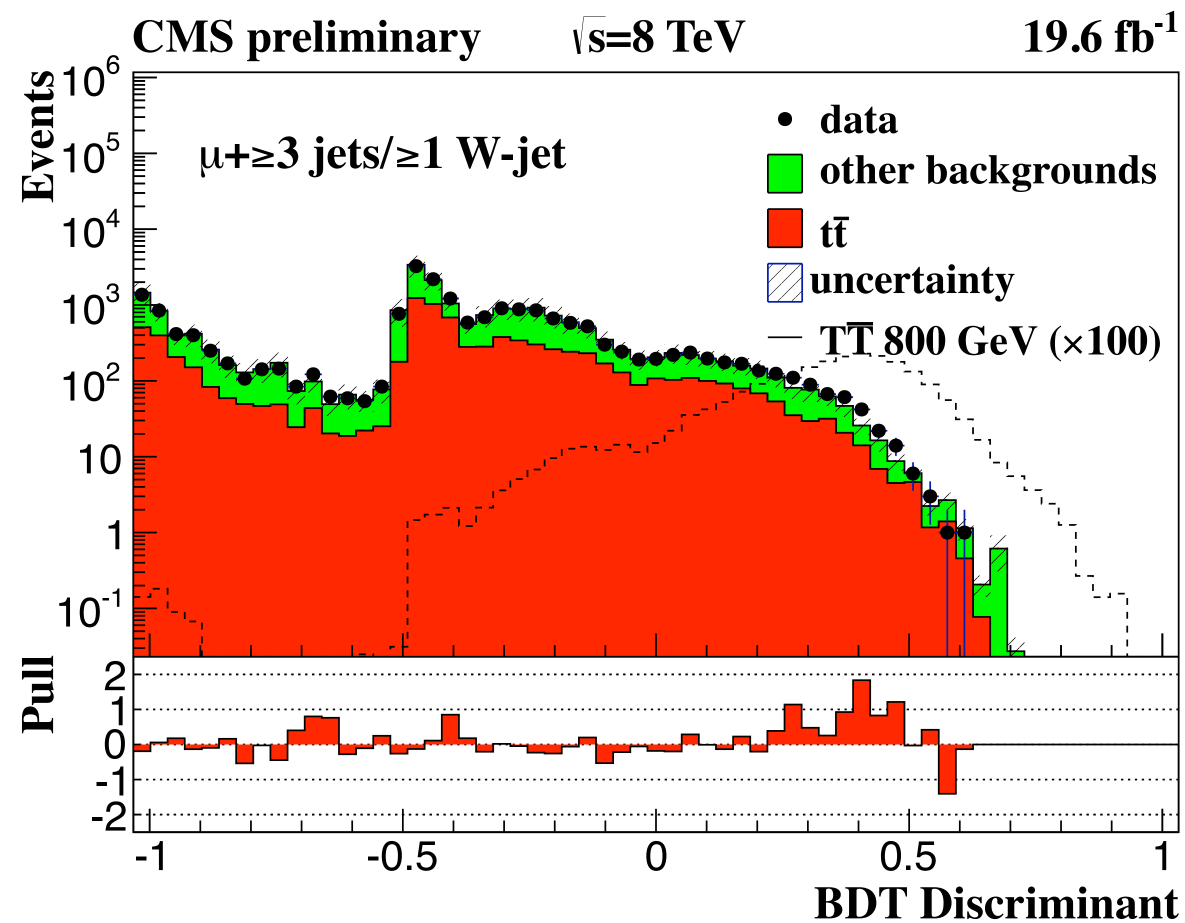
Single lepton channel

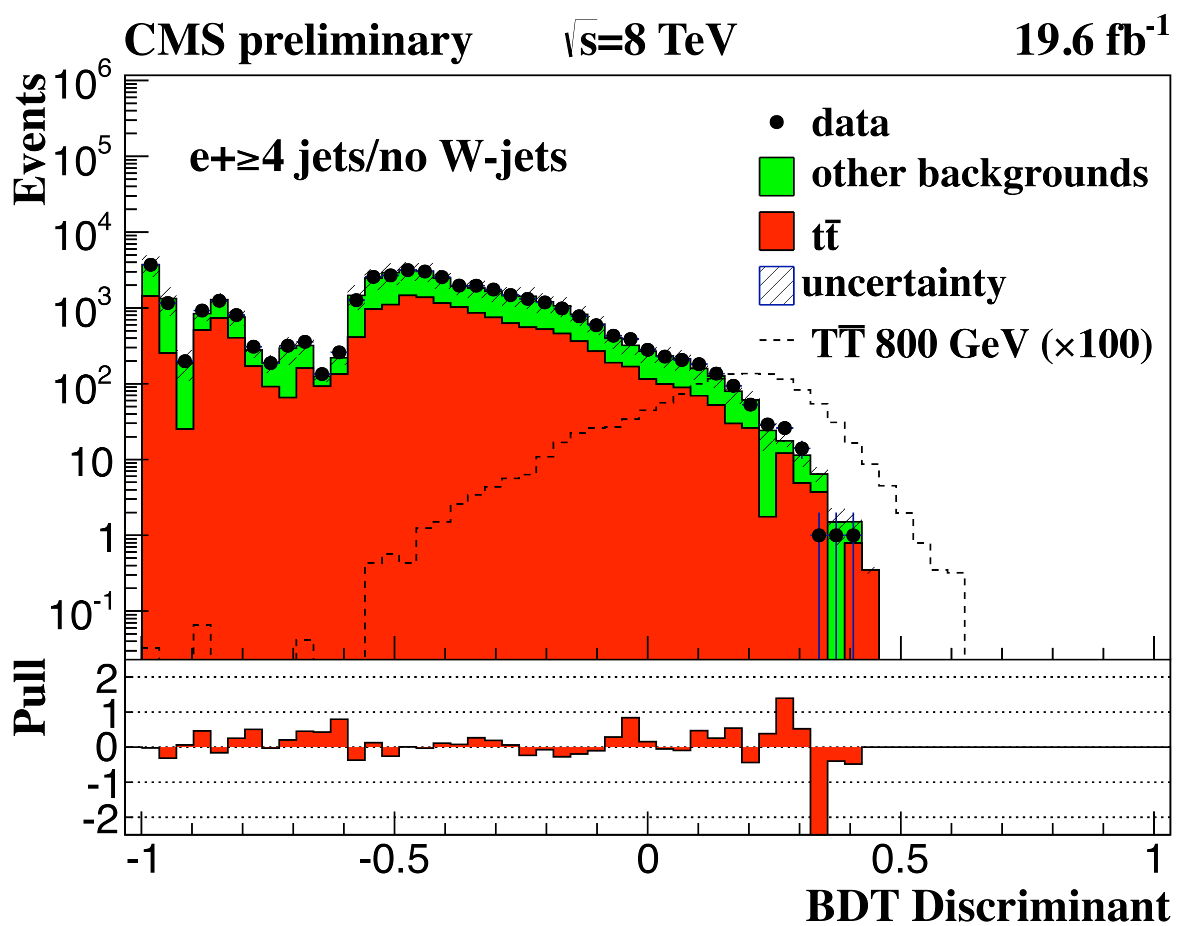
- Tools used:
  - Jet substructure variables used to tag "top" and "W" jets.
  - W tagging uses a jet-pruning algorithm which takes Cambridge-Aachen (CA) jets of distance parameter, R, of 0.8 as inputs.
  - Jets from highly boosted top quarks are merged into one jet using a top-tagging algorithm.
- Analysis strategy:
  - A boosted decision tree (BDT) is used to separate signal from standard model (SM) background (96% of which originates from ttbar, W and Z boson production processes).
  - Two separate event categories constructed based on the presence of a W tagged jet.
  - The input variables to the BDT are: jet multiplicity, b-tag multiplicity, sum of the transverse momenta of the selected jets (H_T), missing E_T, lepton p_T, p_T of the 3rd and the 4th jet.
  - W tagged events also utilize the p_T of the W-jets and the number of top tagged jets.

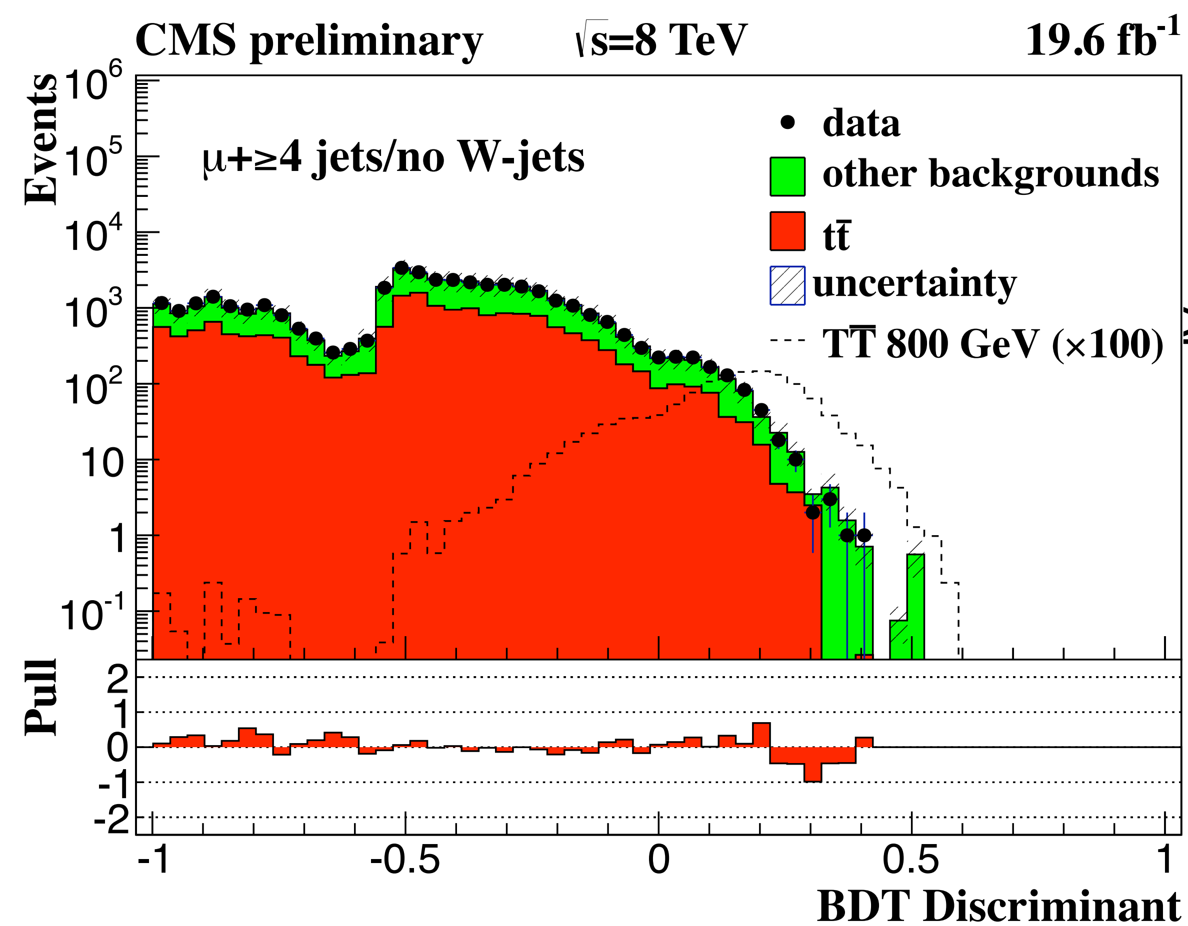
BDT distributions

with W-jet, ≥3 jets







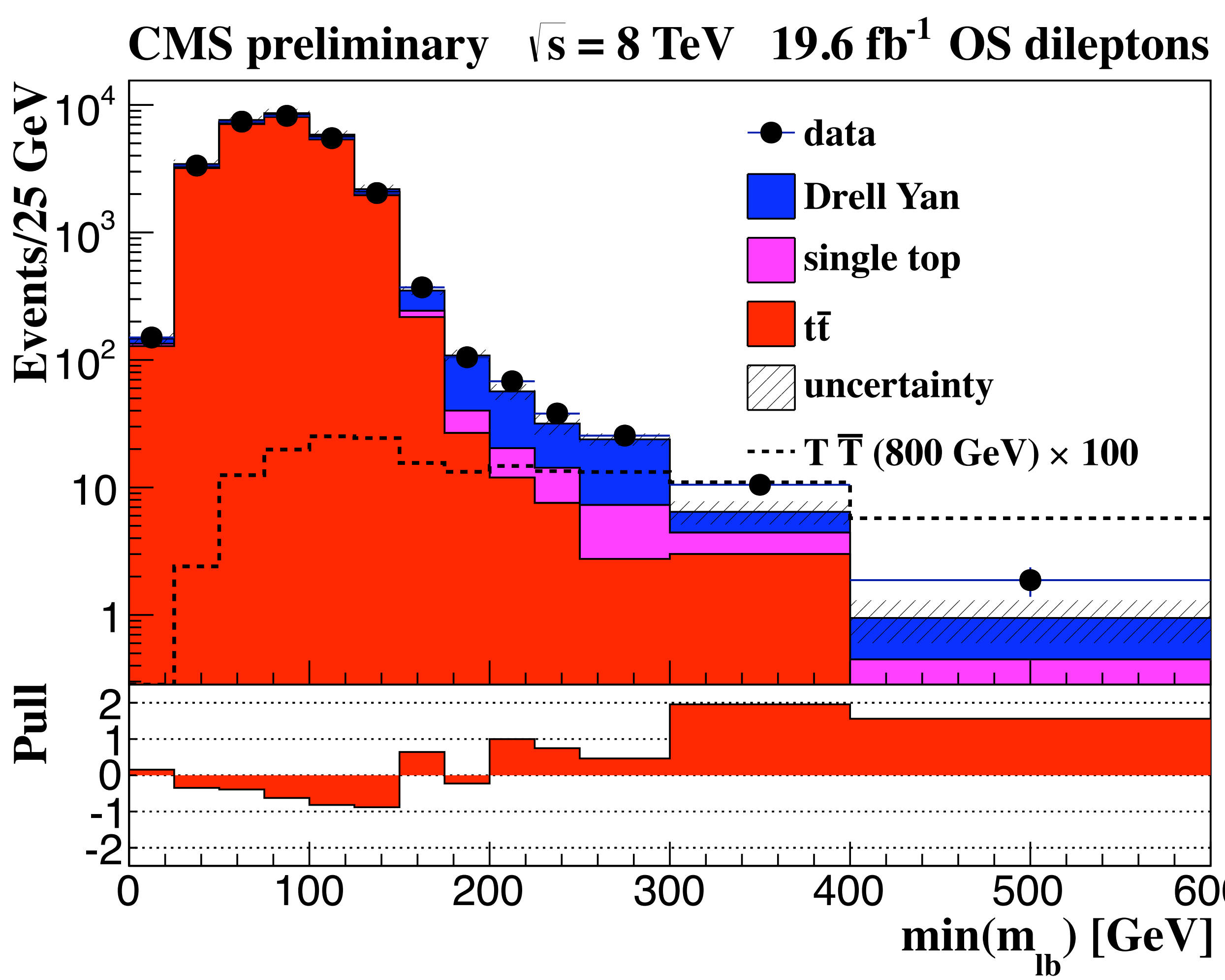


no W-jet, ≥4 jets

Multi-lepton channel (≥ 2 leptons)

Construct various categories:

- Opposite sign lepton final state: main backgrounds are ttbar and ZJets.
  - OS1: Constructed to be sensitive to the bWbW mode.
    - Require 2 or 3 jets, a Z-veto, 1 b-tagged jet, missing E_T > 30 GeV, H_T > 300 GeV, S_T (sum of the p_Ts of all the selected jets, sum of the p_Ts of all the selected leptons and MET) > 900 GeV and min(M_{lb}) > 170 GeV.
  - OS2: Sensitive to modes with tH and tZ.
    - Require at least 5 jets, 2 b-tagged jets, missing E_T > 30 GeV, H_T > 500 GeV and S_T > 1000 GeV.

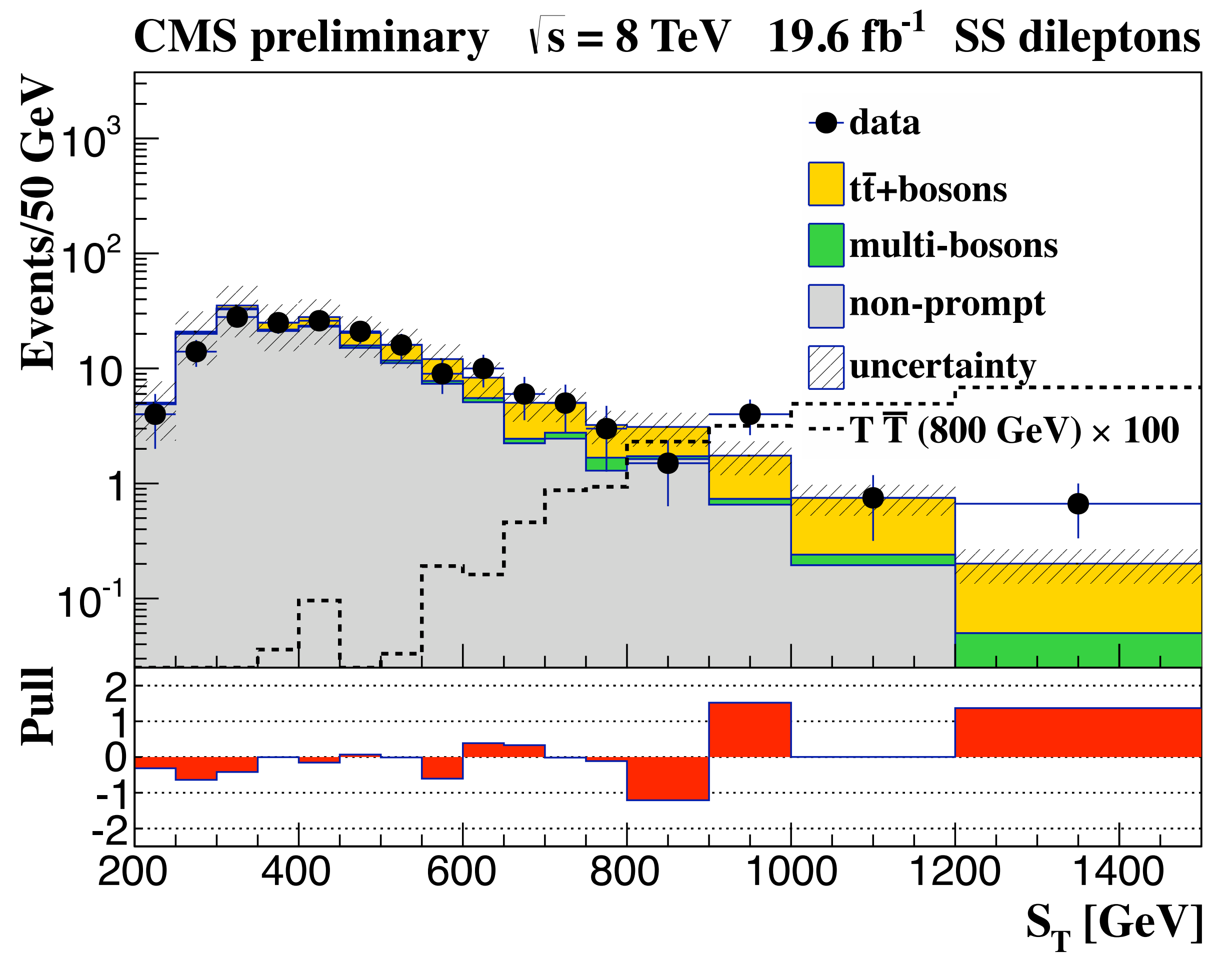


- min(M_{lb}) = smallest mass of lepton-b-jet pairs. Sensitive to mass of the T.
- min(M_{lb}) > 170 GeV.

Multi-lepton channel (≥ 2 leptons)

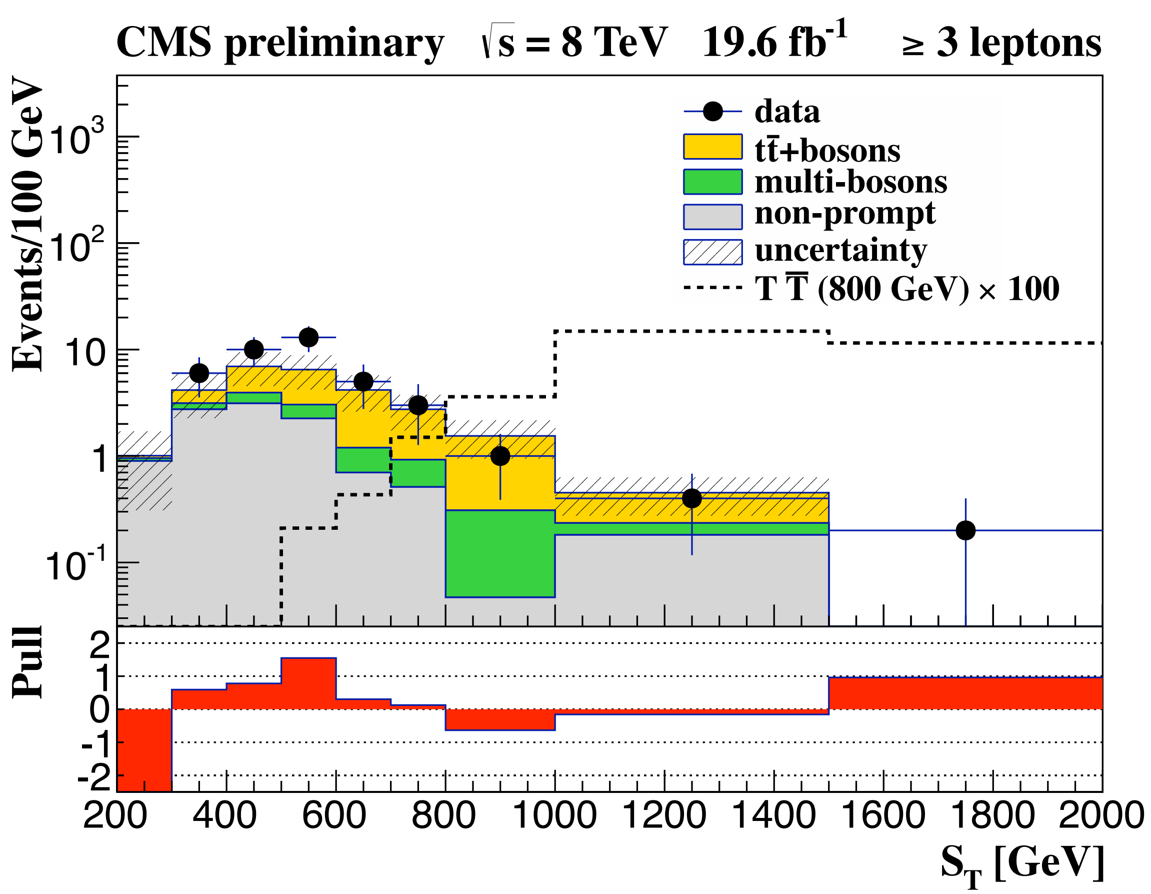
•Same sign leptonic final state (SS): Backgrounds are from SM processes with diboson and triboson decays and instrumental backgrounds from jets misidentified as leptons.

- •Require ≥ 3 jets, 1 b-tagged jet, missing E_T > 30 GeV, H_T > 500 GeV and S_T > 700 GeV.



•Multi-lepton/trilepton final state (≥ 3 leptons): Background processes include diboson and triboson decays and instrumental backgrounds from misidentified leptons.

- •Require ≥ 3 jets, 1 b-tagged jet, missing E_T > 30 GeV, H_T > 500 GeV and S_T > 700 GeV.



- Fake rate computed in a control region. Applied to the multi-lepton selection.
- Instrumental backgrounds or the non-prompt contribution determined directly from data.

Yields for single lepton and multi-lepton channels

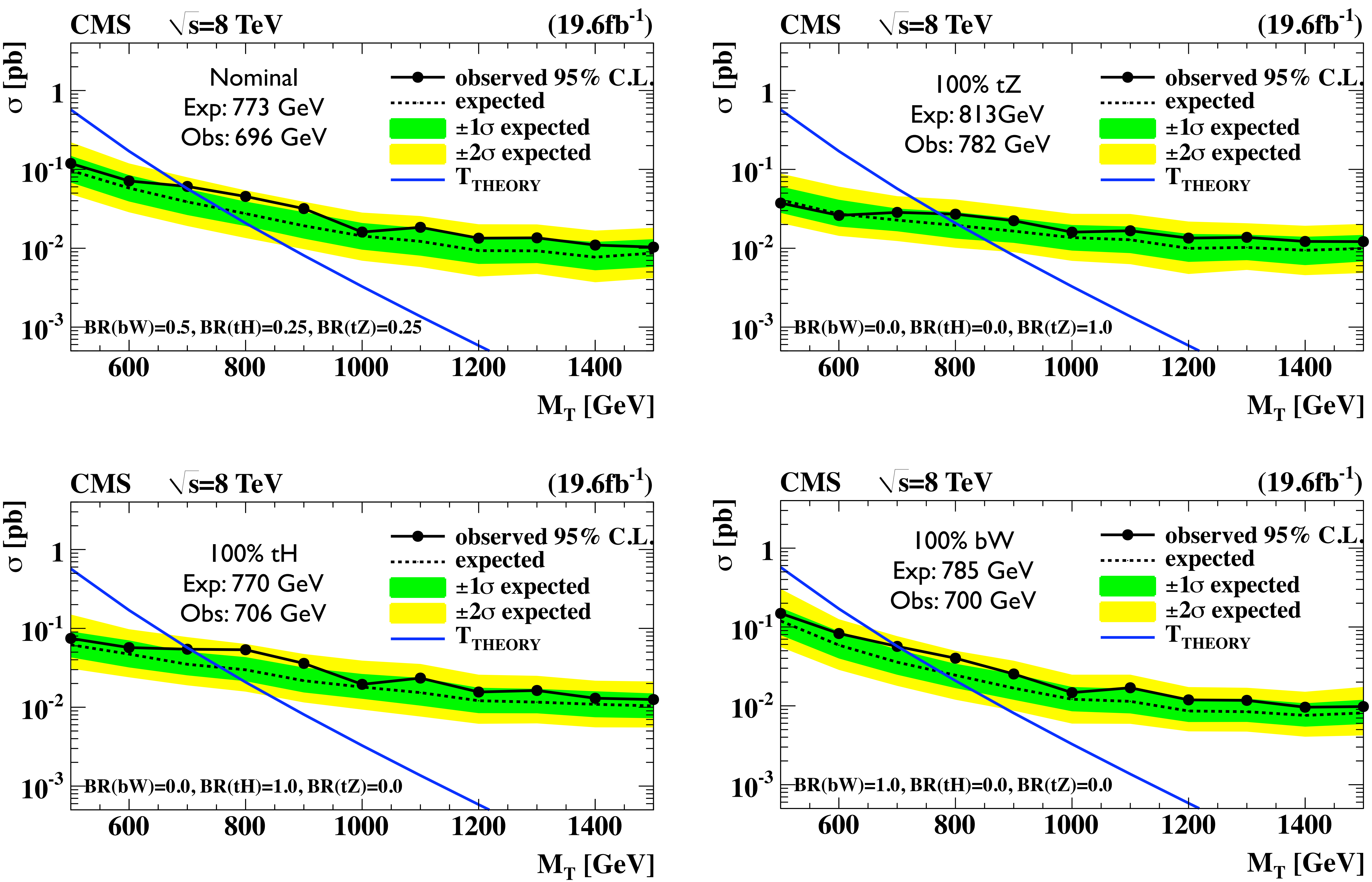
lepton flavor	muon	electron
$t\bar{t}$	36700±5500	35900±5400
single top	2190±1101	2100±1000
W	19200±9700	18200±9200
Z	2170±1100	2000±1000
multijets	0	1680±620
$t\bar{t}$ W	144±72	137±68
$t\bar{t}$ Z	109±54	108±54
$t\bar{t}$ H	570±280	570±285
WW/WZ/ZZ	410±205	400±200
total background	61500±13700	61100±13500
data	58478	57743

Single lepton channel: likelihood computed using BDT distributions.

Multi-lepton channel: use predicted and expected number of events in 12 bins to compute likelihood.

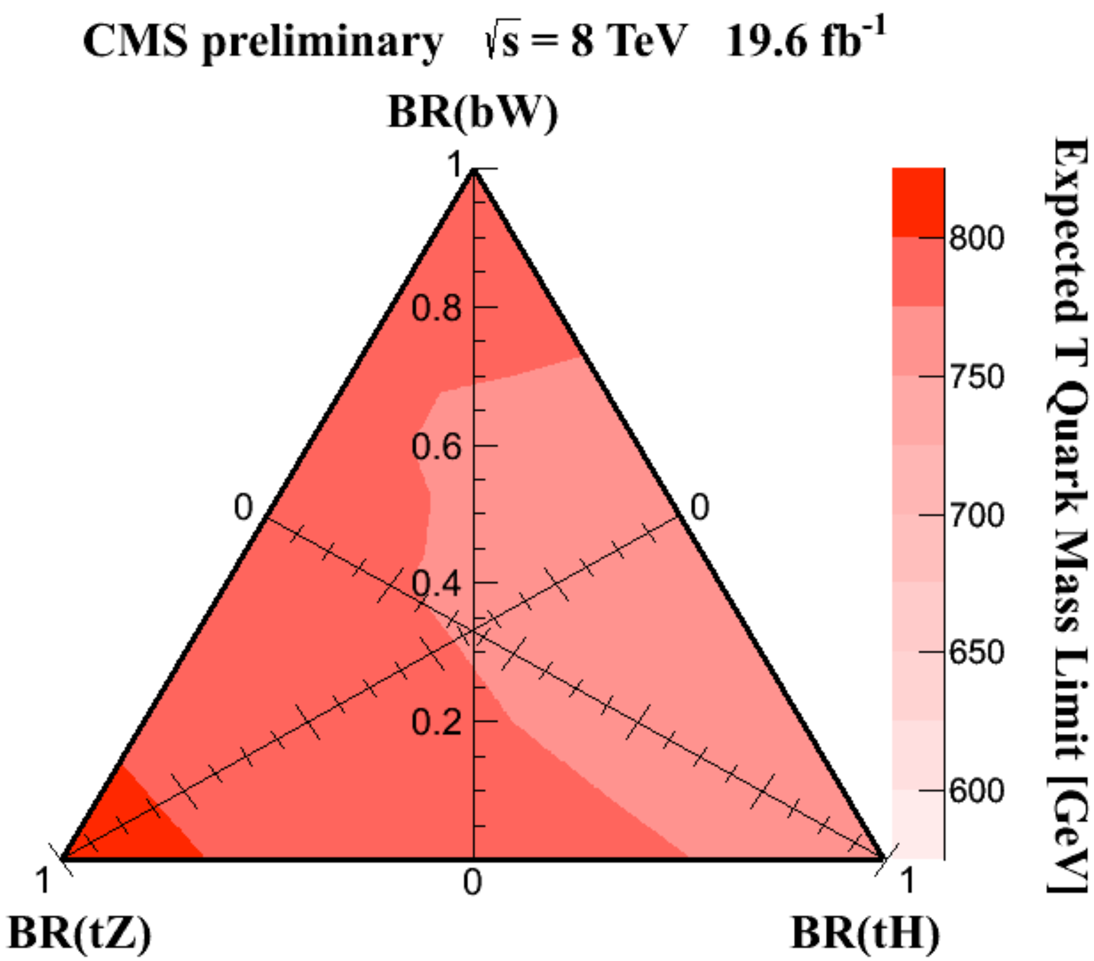
channel	OS1	OS2	SS	trileptons
$t\bar{t}$	5.2±1.9	80 ±12	-	-
single top	2.5±1.3	2.0±1.0	-	-
Z	9.7±2.9	2.5±1.9	-	-
$t\bar{t}W$	-	-	5.8 ±1.9	0.25±0.11
$t\bar{t}Z$	-	-	1.83±0.93	1.84±0.94
WW	-	-	0.53±0.29	-
WZ	-	-	0.34±0.08	0.40±0.21
ZZ	-	-	0.03±0.00	0.07±0.01
WWW/WWZ/ZZZ/WZZ	-	-	0.13±0.07	0.08±0.04
$t\bar{t}WW$	-	-	-	0.05±0.03
charge mis-ID	-	-	0.01±0.00	-
non-prompt	-	-	7.9 ±4.3	0.99±0.90
total background	17.4±3.7	84 ±12	16.5 ±4.8	3.7 ±1.3
data	20	86	18	2

Combined limit

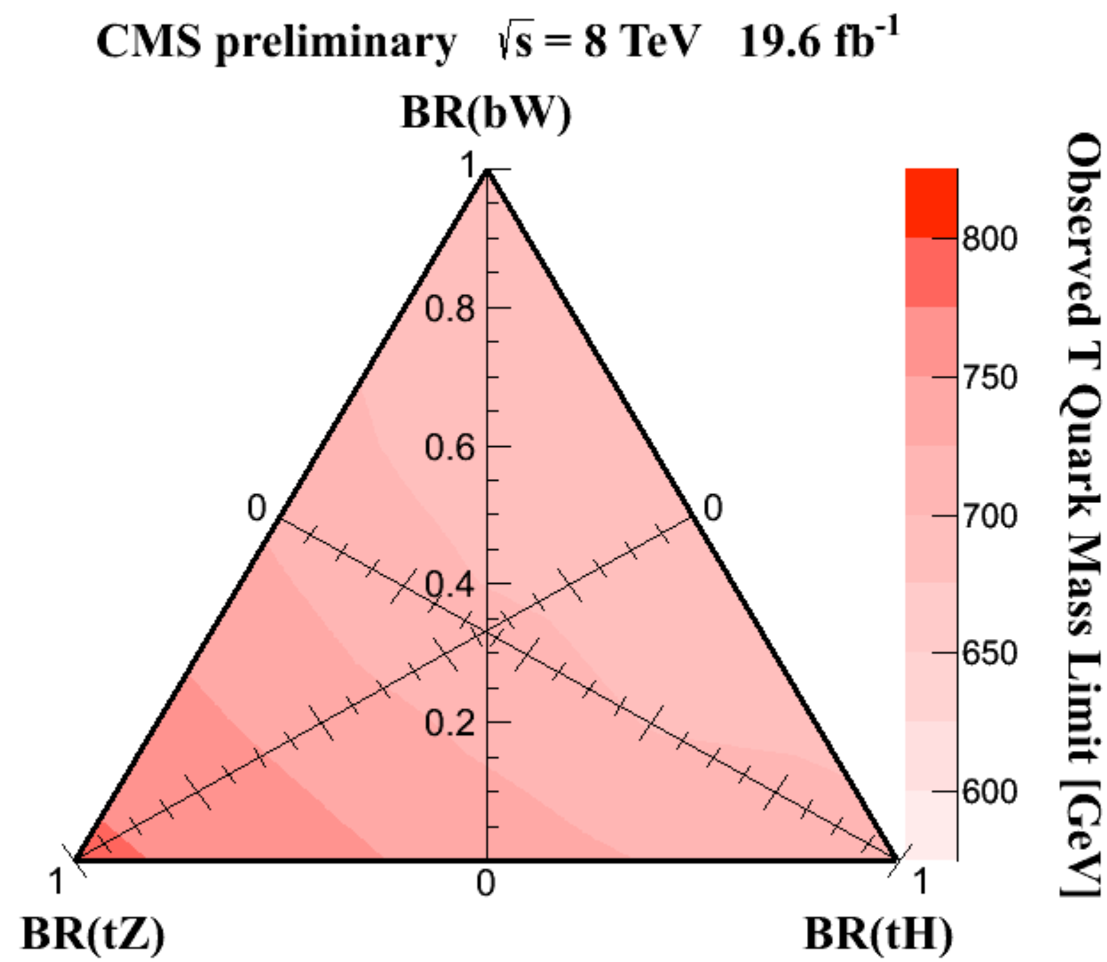


Combined limit

Scanning 22 branching fraction scenarios



Expected Limit



Observed Limit

Conclusion

Branching fraction scenario	Expected Limit	Observed limit
TT -> 50% bW, 25% tH, 25% tZ	773 GeV	696 GeV
TT ->100% bW	785 GeV	700 GeV
TT ->100% tH	770 GeV	706 GeV
TT ->100% tZ	813 GeV	782 GeV

- We have performed an inclusive search for the vector-like quark T in the single-lepton and multi-lepton channels.
- We see good agreement between data and Monte Carlo.
- We set exclusion limits on the mass of the new heavy vector-like quark, scanning across the entire range of branching ratios:
  - Expected limit: 770-813 GeV.
  - Observed limit: 696-782 GeV.
- Most stringent limit set on the mass of a vector-like quark of charge 2/3

http://cds.cern.ch/record/1557571?ln=en

Back up Slides

Same-signed (SS) and trilepton ($\geq$ 3 leptons) Category

Fake Rate Estimation

Control region constructed:

- At least one jet with p_T > 40 GeV and ΔR > 1.0 relative to the lepton ("away-jet").
- MET < 25 GeV.
- m_T < 25 GeV.
- Apply a Z-veto.
- pT range of leptons restricted between 20 - 35 GeV.

DataSet	Fake Rate
Raw Fake Rates:	
DoubleMuon 2012 ABCD	0.195 ± 0.098
DoubleElectron 2012 ABCD	0.171 ± 0.085
Fake Rates after Subtracting the $t\bar{t}$ and Drell-Yan contributions:	
Muon	0.188 ± 0.098
Electron	0.157 ± 0.079

The errors quoted include systematic and statistical errors.

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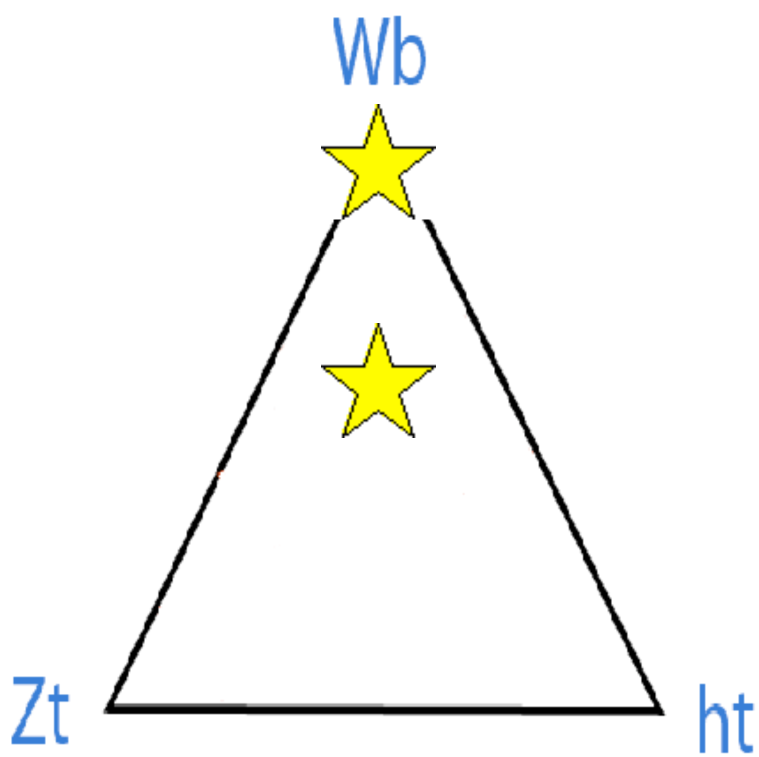

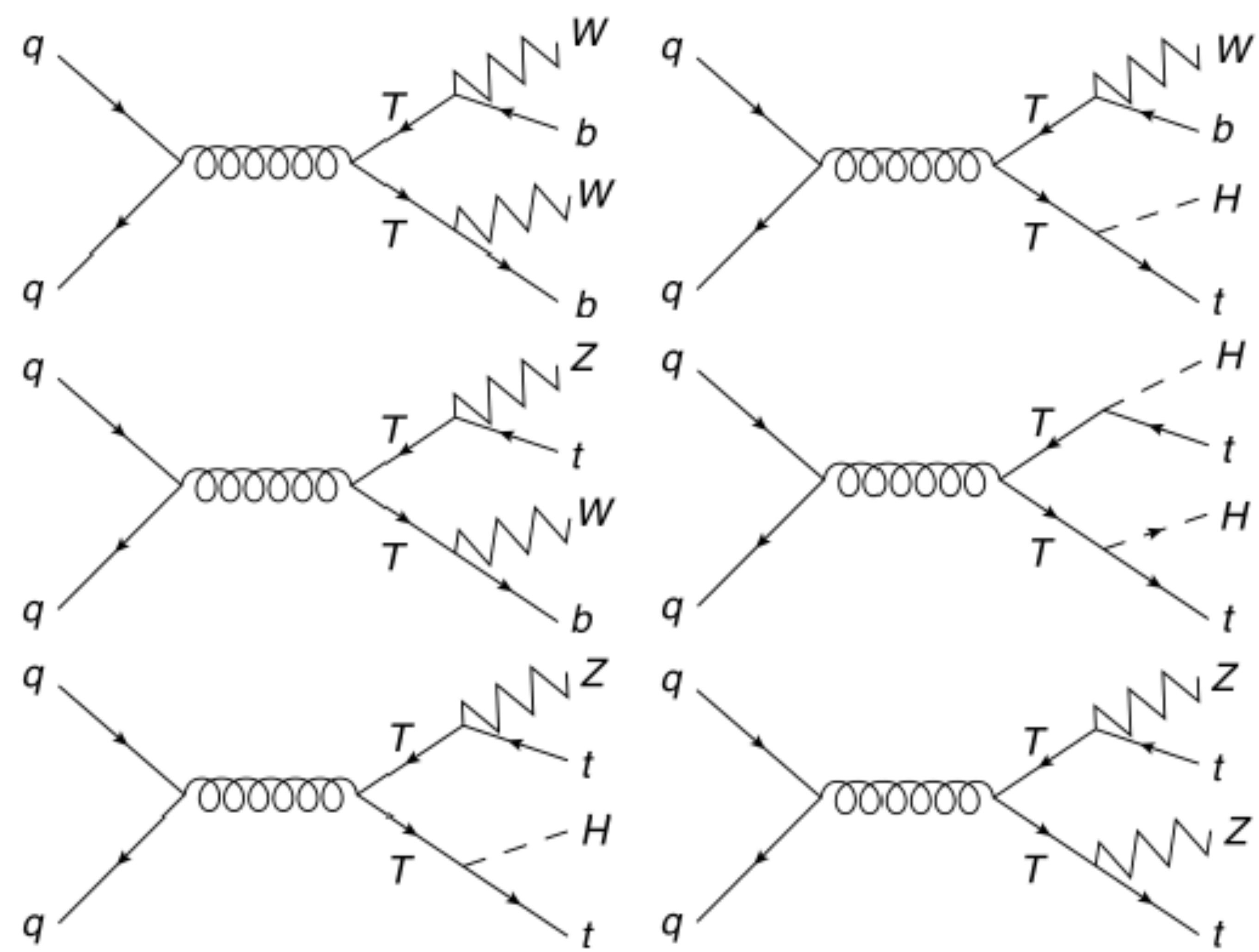

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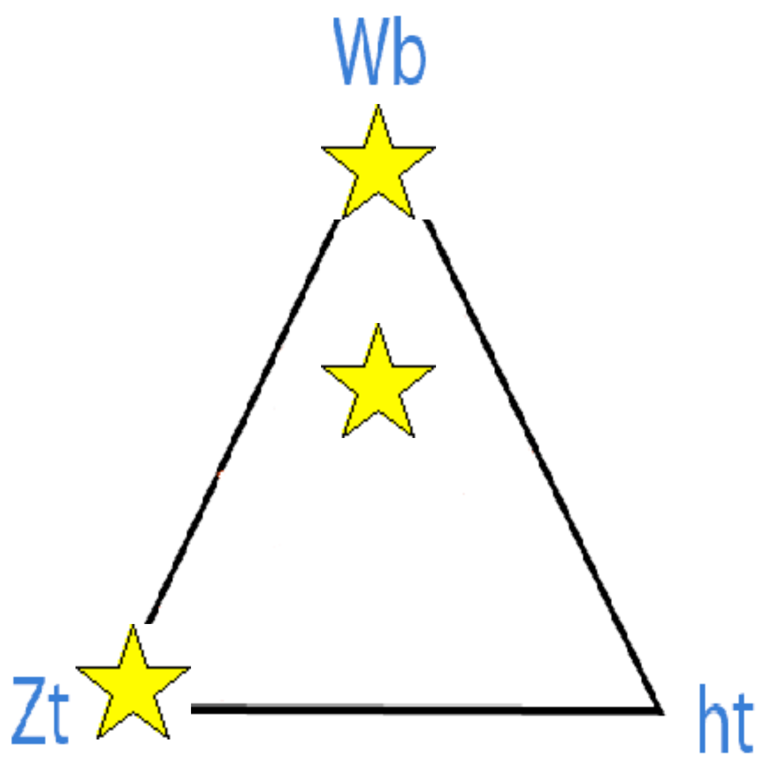

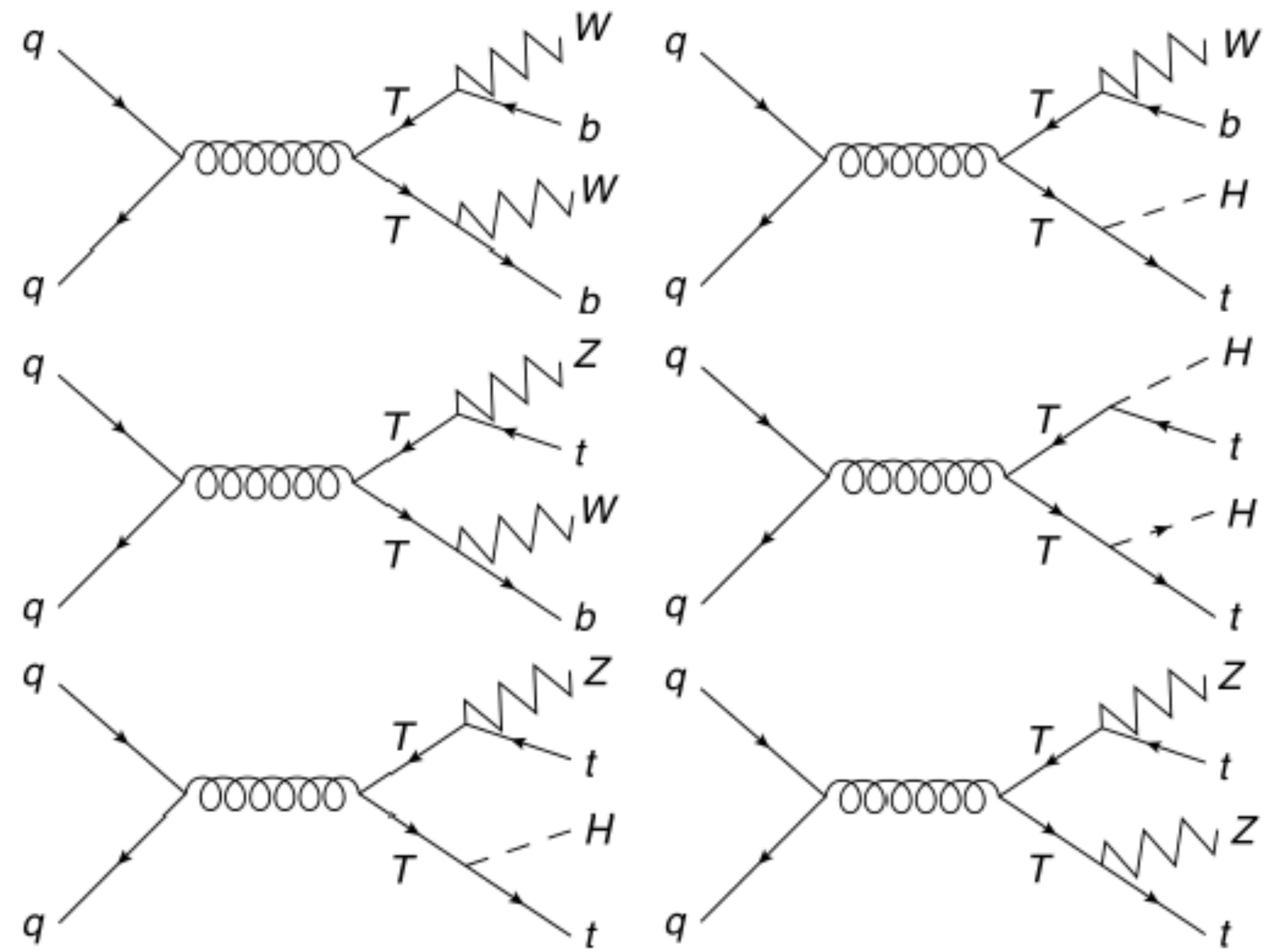

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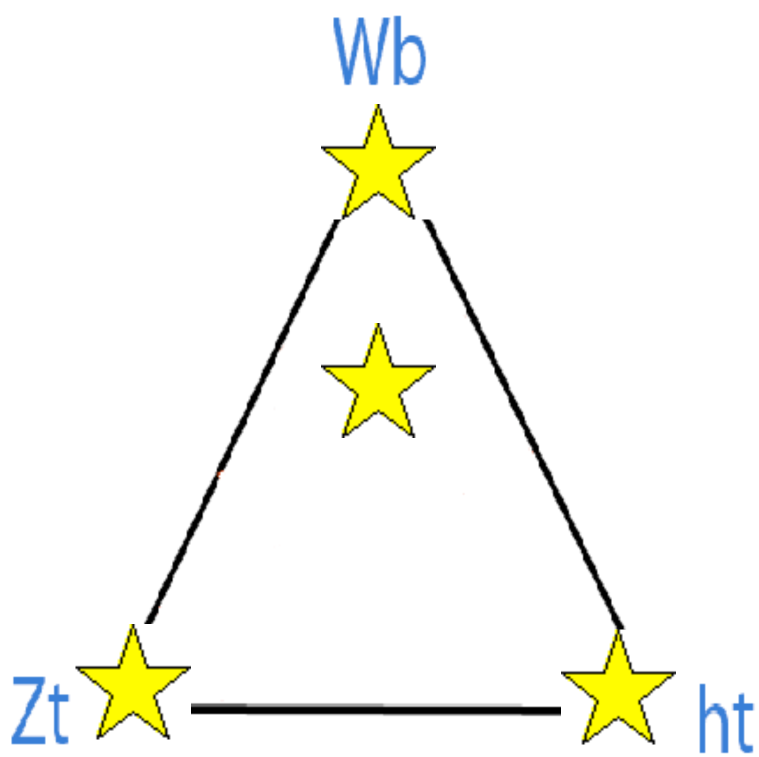

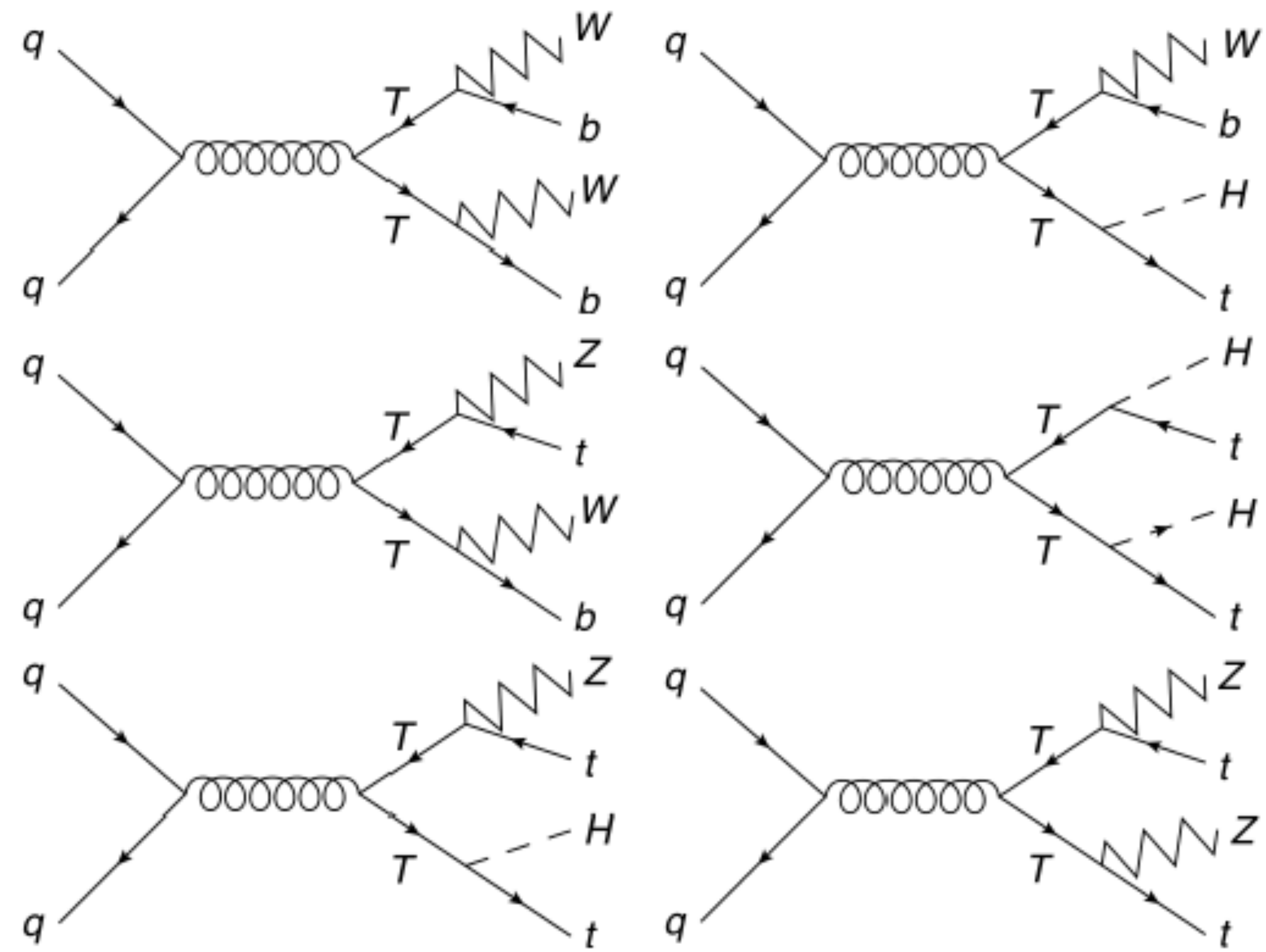

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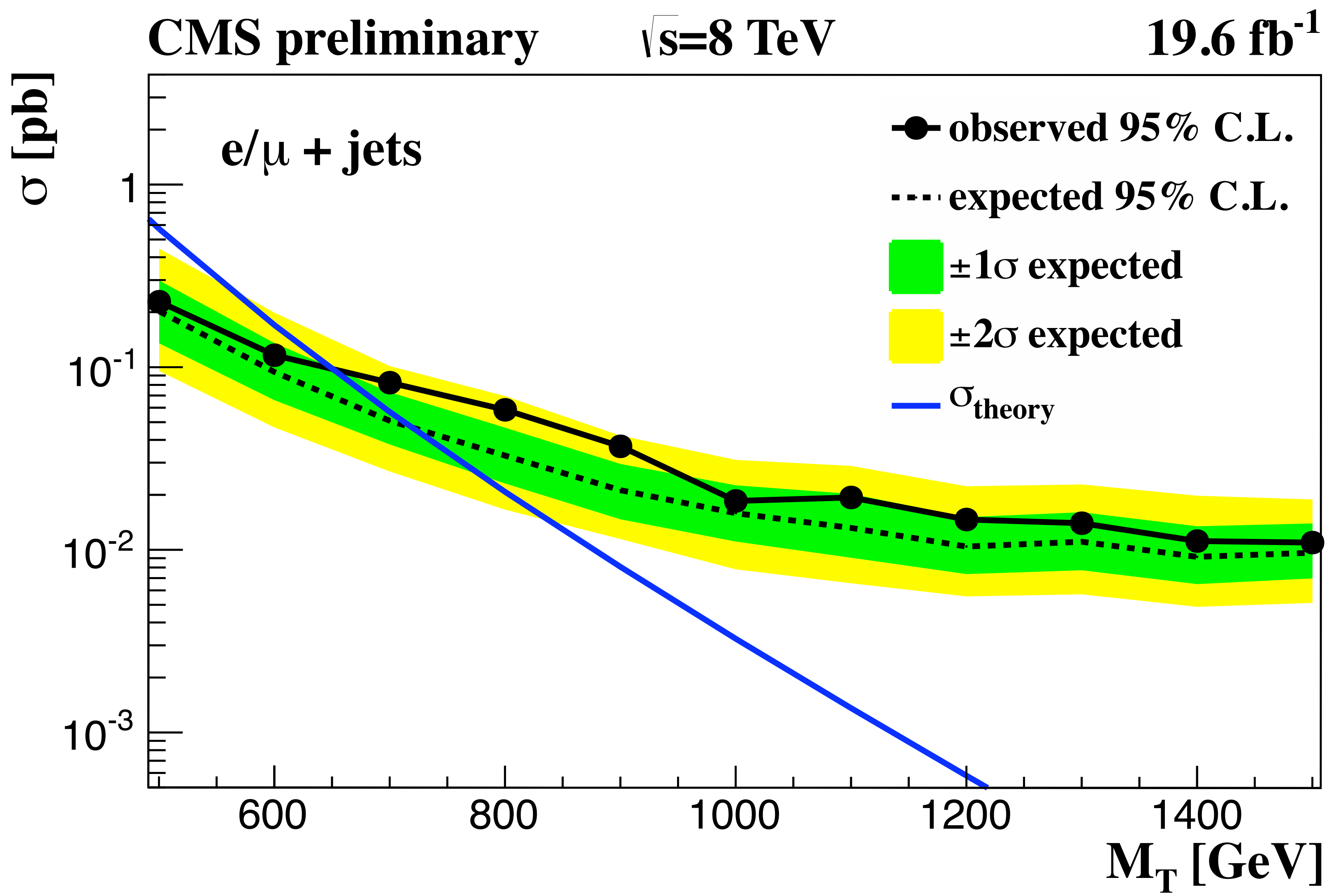
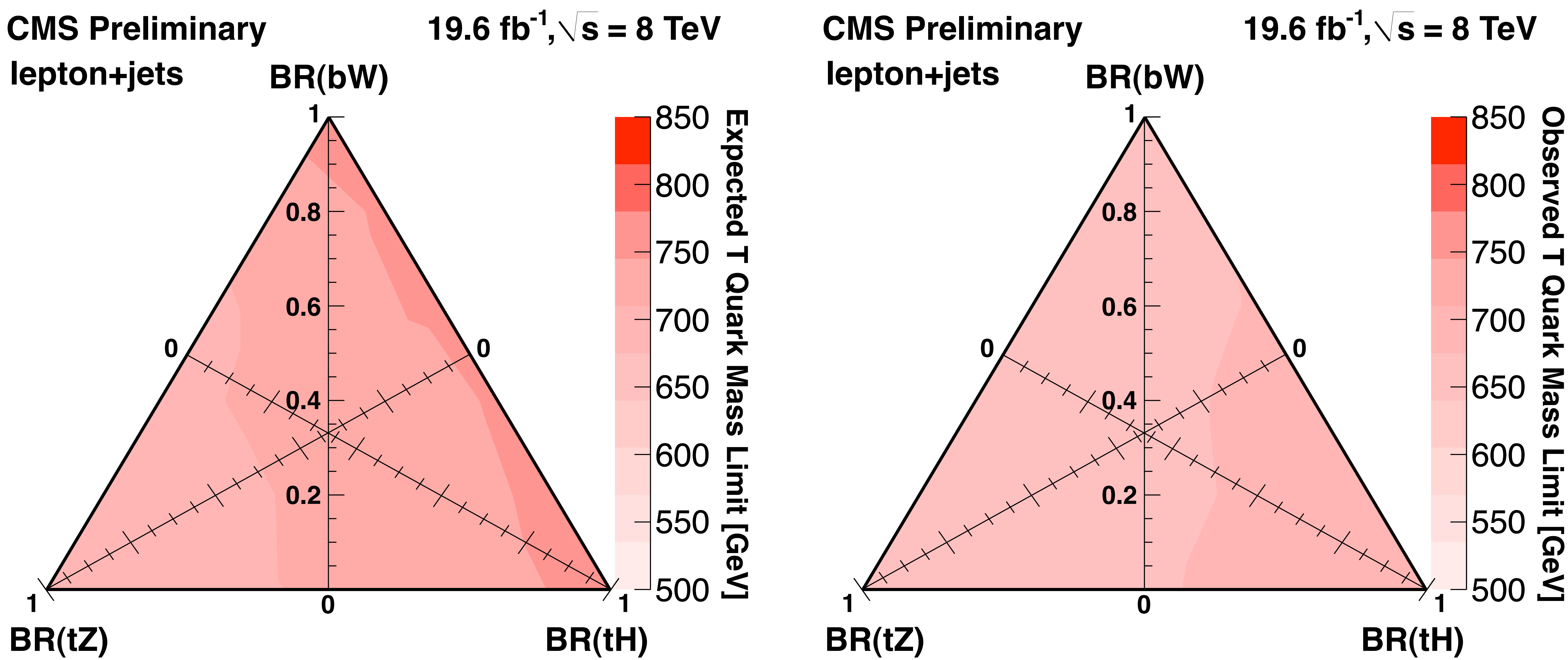
Limit computation: Single lepton channel



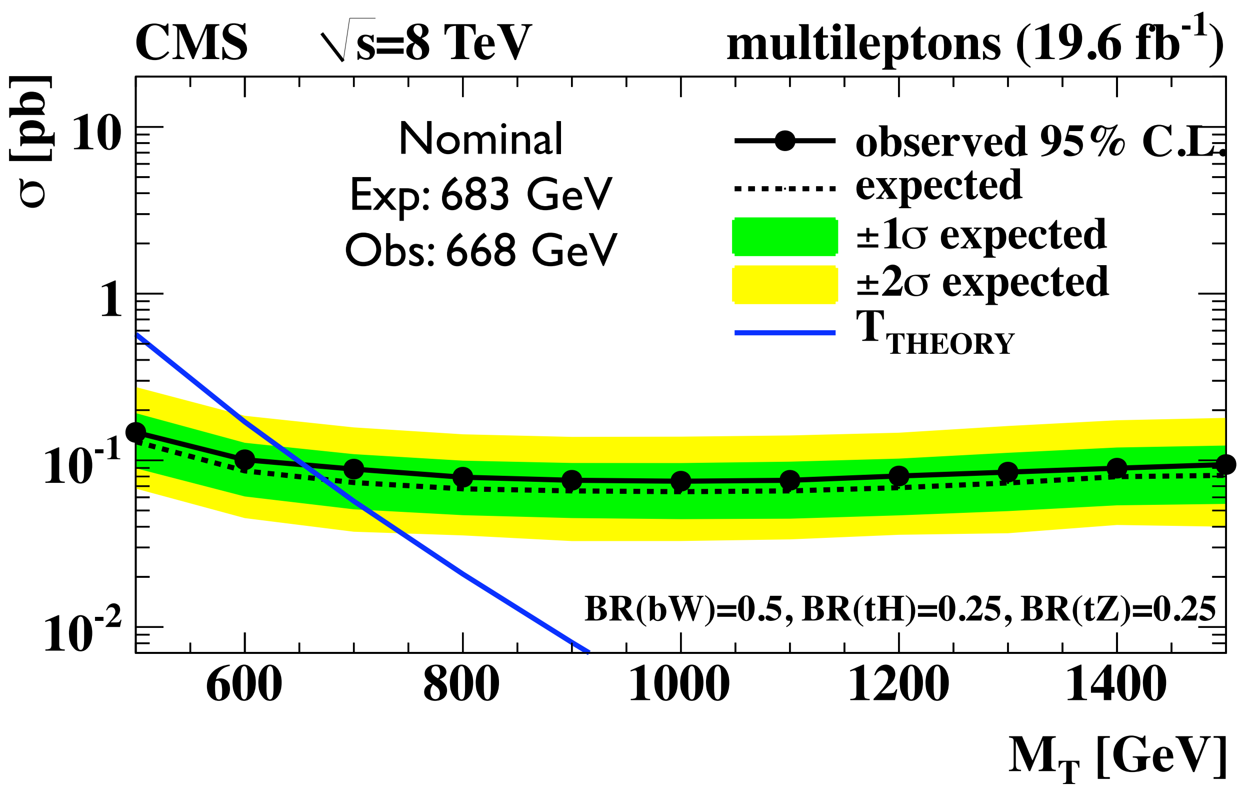
Nominal Branching Ratios

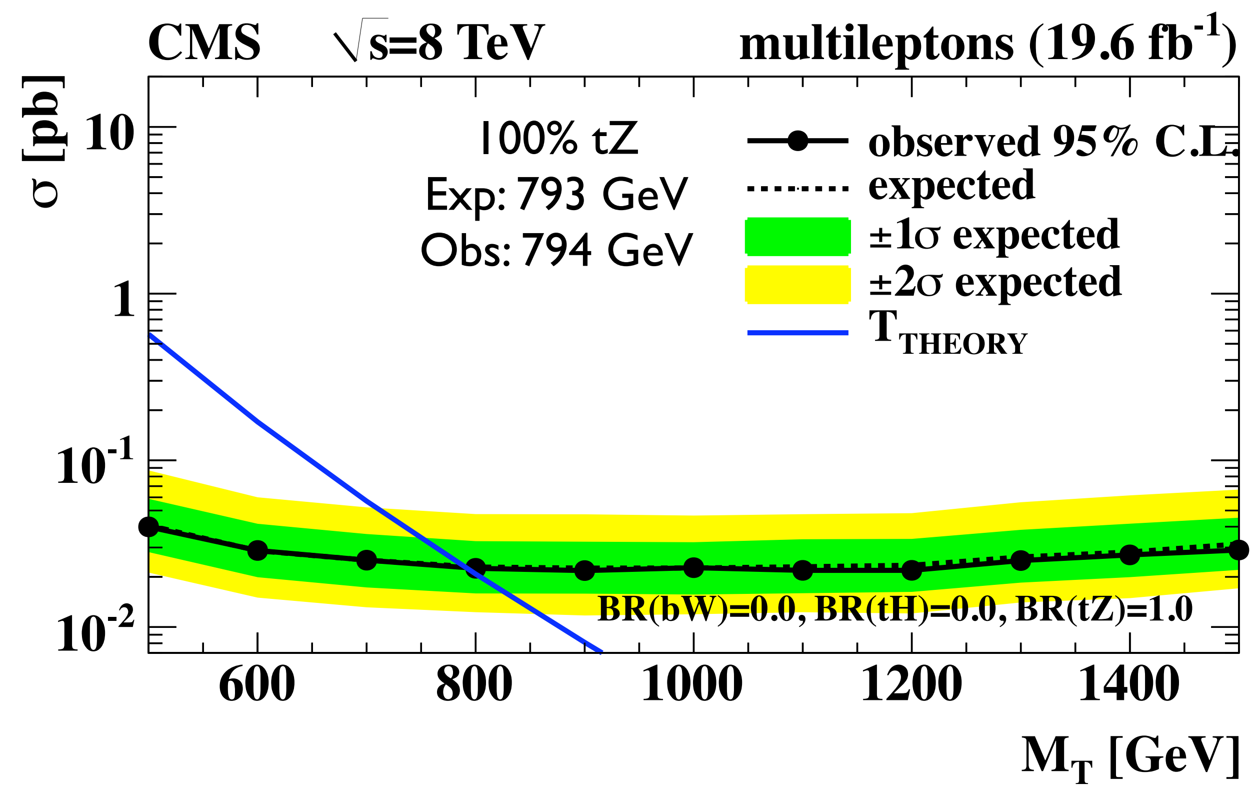
Limit computation: Single lepton channel

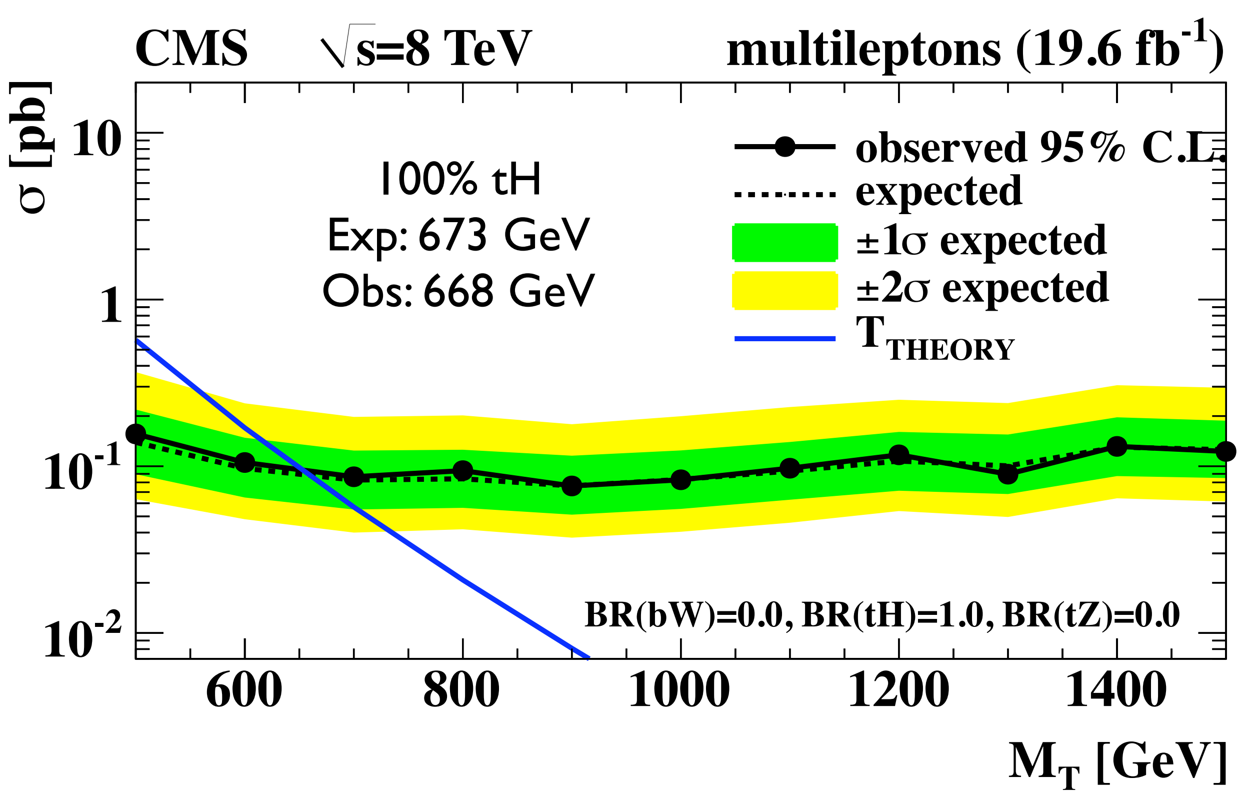
Scanning 22 branching fraction scenarios

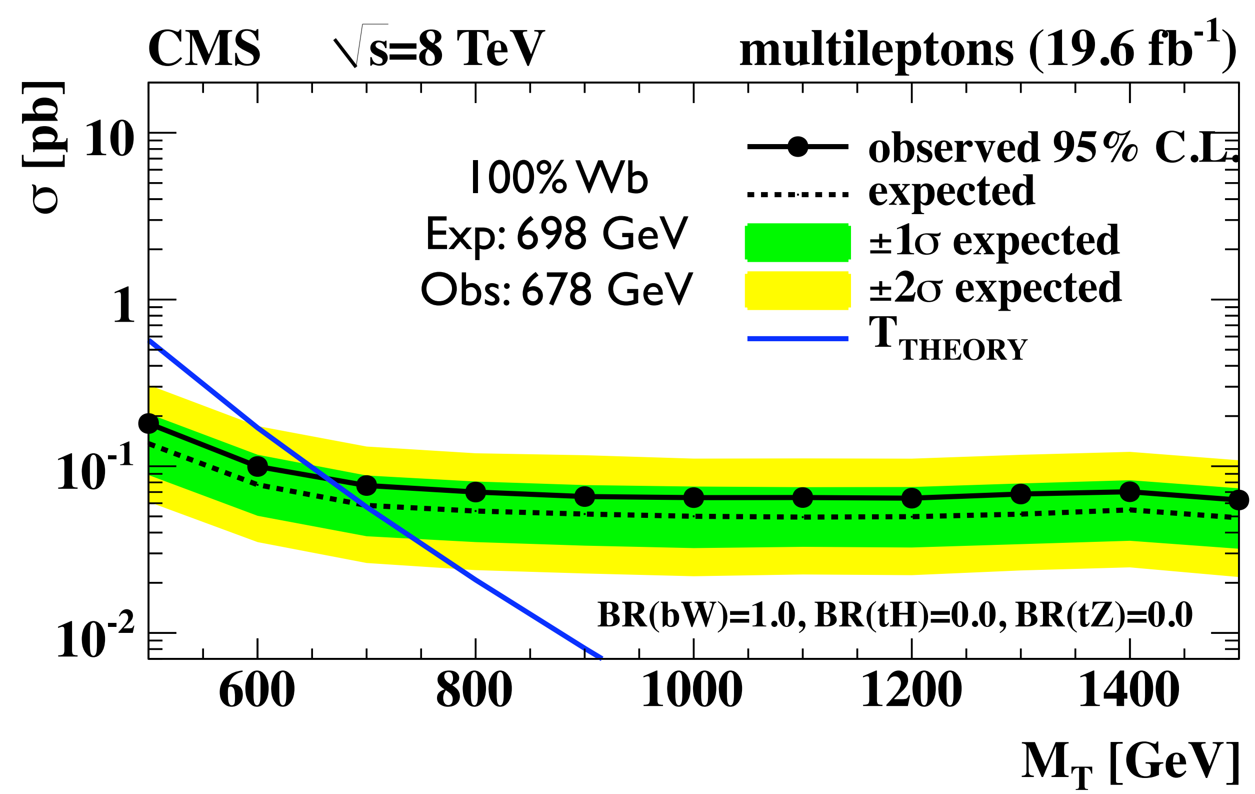


Limit Computation: Multilepton channel (≥ 2 leptons)









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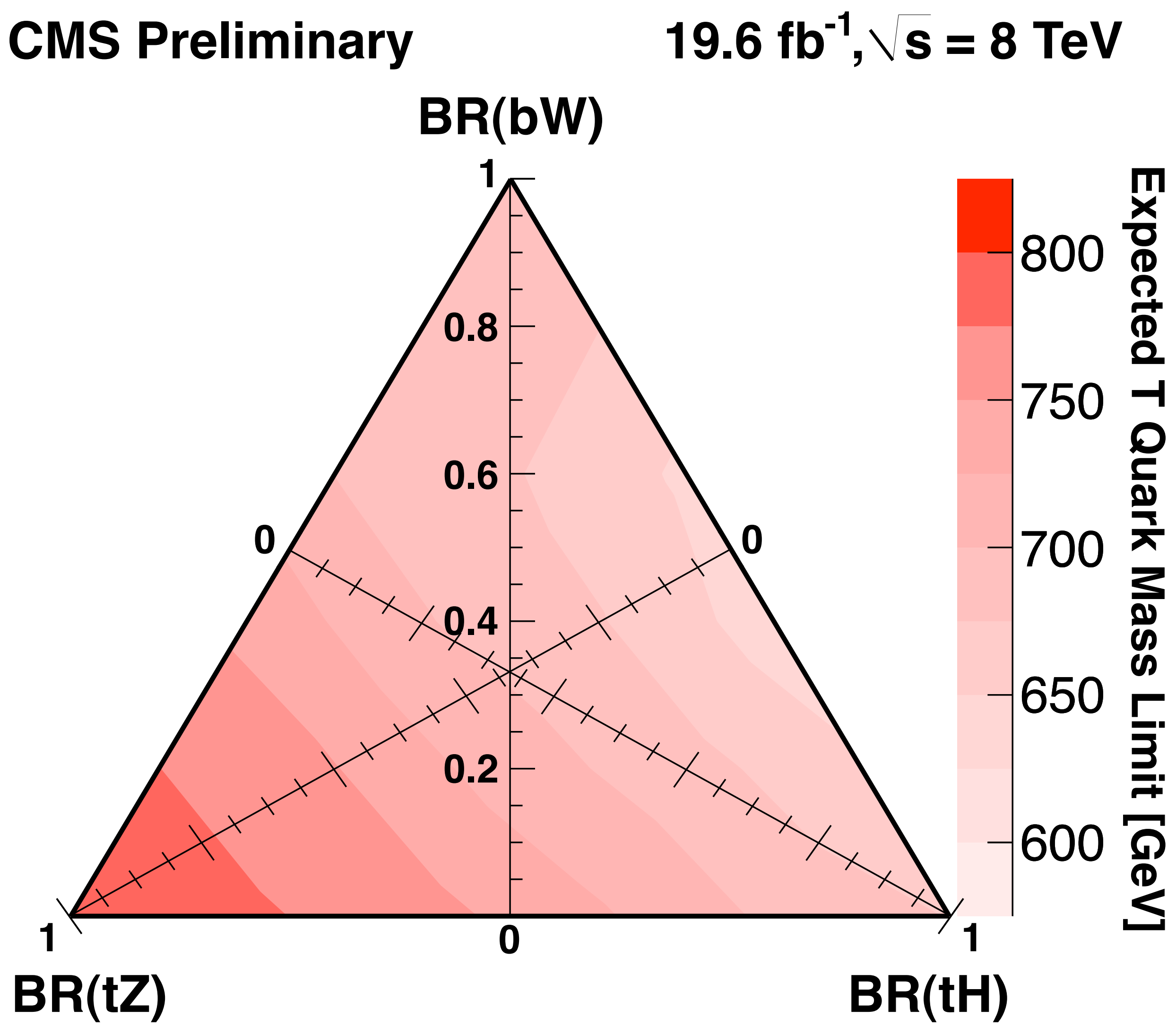

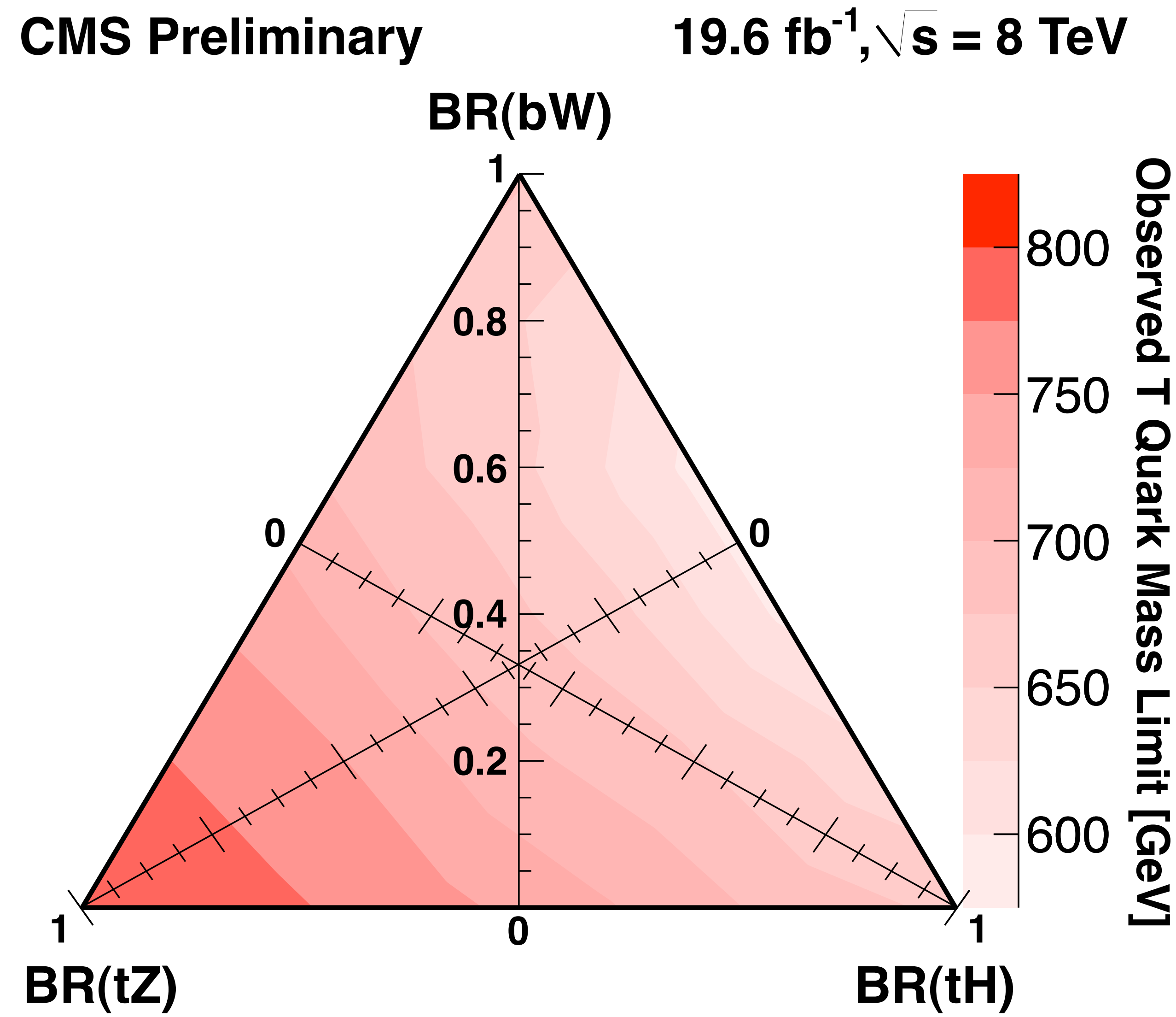

Combined limit: Grand combined of single-lepton and multi-lepton channels

	Scenario	Branching Fractions T→bW	T→tH	T→tZ	expected limit	observed limit
Nominal	**(0)**	**0.5**	**0.25**	**0.25**	**773 GeV**	**696 GeV**
100% tZ	**(1)**	**0.0**	**0.0**	**1.0**	**813 GeV**	**782 GeV**
	(2)	0.0	0.2	0.8	798 GeV	766 GeV
	(3)	0.0	0.4	0.6	790 GeV	747 GeV
	(4)	0.0	0.6	0.4	783 GeV	731 GeV
	(5)	0.0	0.8	0.2	773 GeV	715 GeV
100% tH	**(6)**	**0.0**	**1.0**	**0.0**	**770 GeV**	**706 GeV**
	(7)	0.2	0.0	0.8	794 GeV	758 GeV
	(8)	0.2	0.2	0.6	786 GeV	739 GeV
	(9)	0.2	0.4	0.4	777 GeV	717 GeV
	(10)	0.2	0.6	0.2	767 GeV	698 GeV
	(11)	0.2	0.8	0.0	766 GeV	694 GeV
	(12)	0.4	0.0	0.6	786 GeV	734 GeV
	(13)	0.4	0.2	0.4	776 GeV	705 GeV
	(14)	0.4	0.4	0.2	766 GeV	693 GeV
	(15)	0.4	0.6	0.0	762 GeV	690 GeV
	(16)	0.6	0.0	0.4	779 GeV	703 GeV
	(17)	0.6	0.2	0.2	771 GeV	693 GeV
	(18)	0.6	0.4	0.0	769 GeV	687 GeV
	(19)	0.8	0.0	0.2	779 GeV	695 GeV
	(20)	0.8	0.2	0.0	777 GeV	689 GeV
100% bW	**(21)**	**1.0**	**0.0**	**0.0**	**785 GeV**	**700 GeV**

Systematic Uncertainties

- Jet energy scale
- Jet energy resolution
- B-tagging
- Jet-Parton Matching Scale (ttbar)
- Jet-Parton Factorization Scale (ttbar)
- Trigger Efficiency
- Lepton Efficiency
- Luminosity: 4.4 %
- Normalization uncertainty.
- Non-prompt background uncertainty: 50%
- Charge mis-identification uncertainty: 20%