Sensitivity to the Single and Double Production of Vector-Like Quarks

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LPC meeting on future 100 TeV proton collider, 31st January 2014

Outline

- ***Introduction***
- ***Single T Production***
- ***Double T Production***
- ***Summary***

Introduction

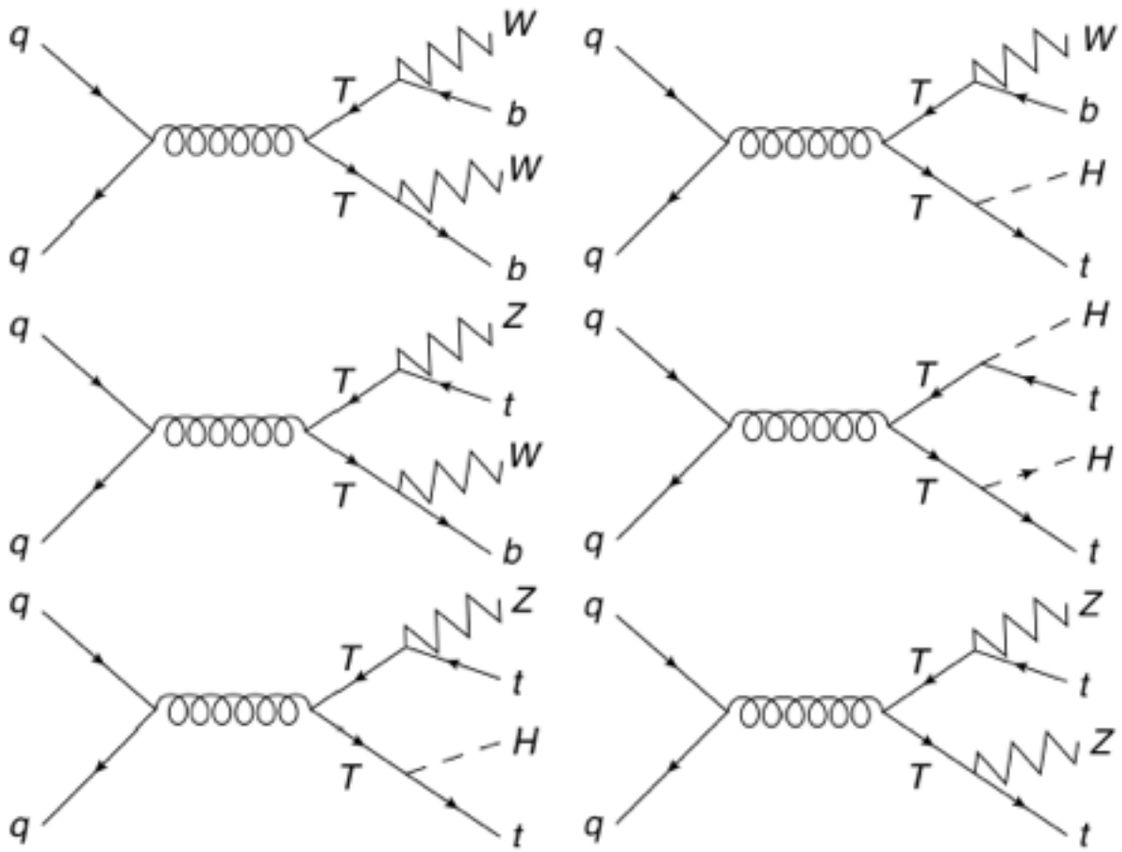
- Many extensions of physics beyond the standard model propose the existence of heavy partners of the top quark.
- Vector like T quarks (charge- 2/3) searches include T decaying to bW, tZ and tH.
- The newly discovered Higgs boson is used as a probe for new physics.
- Nominal BR's considered: bW = 50%, tZ = 25% & tH = 25%.
- Leads to busy final states with bosons and b-tagged jets.
- Massive particles in final state. Decay to boosted tops, Higgs. Thus, have to rely on jet sub-structure tools as final states not resolvable.
- Used Delphes parametrized detector simulation - LHC like detector.

Production

Can be produced singly or in pairs

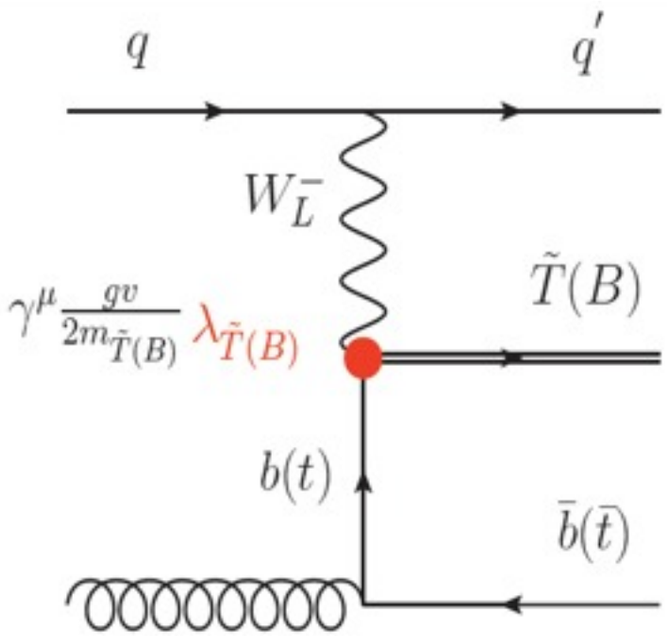
Pair Production

(like heavy $t\bar{t}$)



Single Production

(depends on charge, coupling)



Cross-Sections

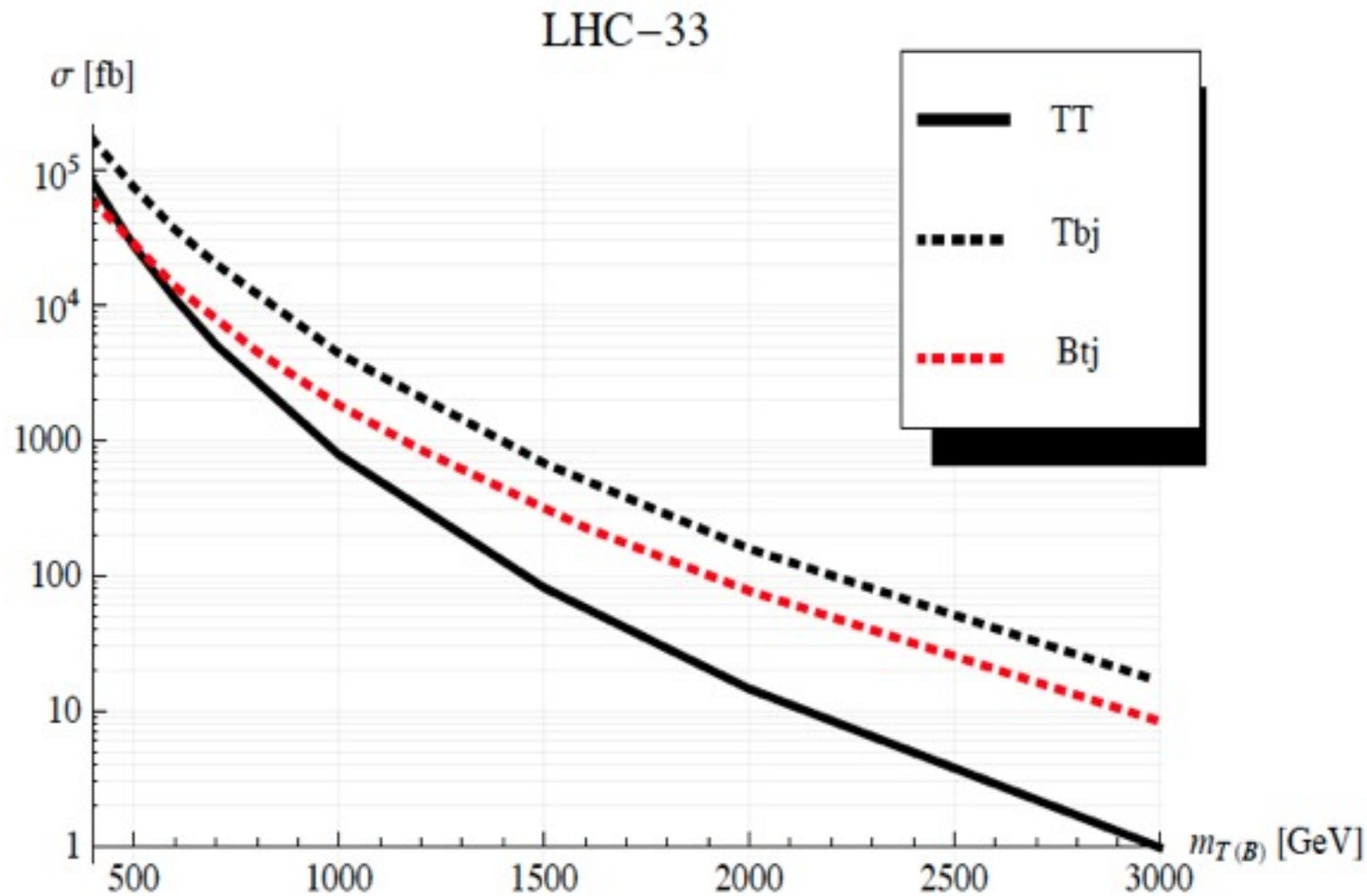
Natascia Vignaroli (MSU)@LO

Preliminary cross-sections for single and pair produced Vector-quarks

- pair production (pure QCD)
- single production depends on EW properties (more model dependent)

Pair production ~ 20% higher @NLO

S. Bhattacharya (Brown)



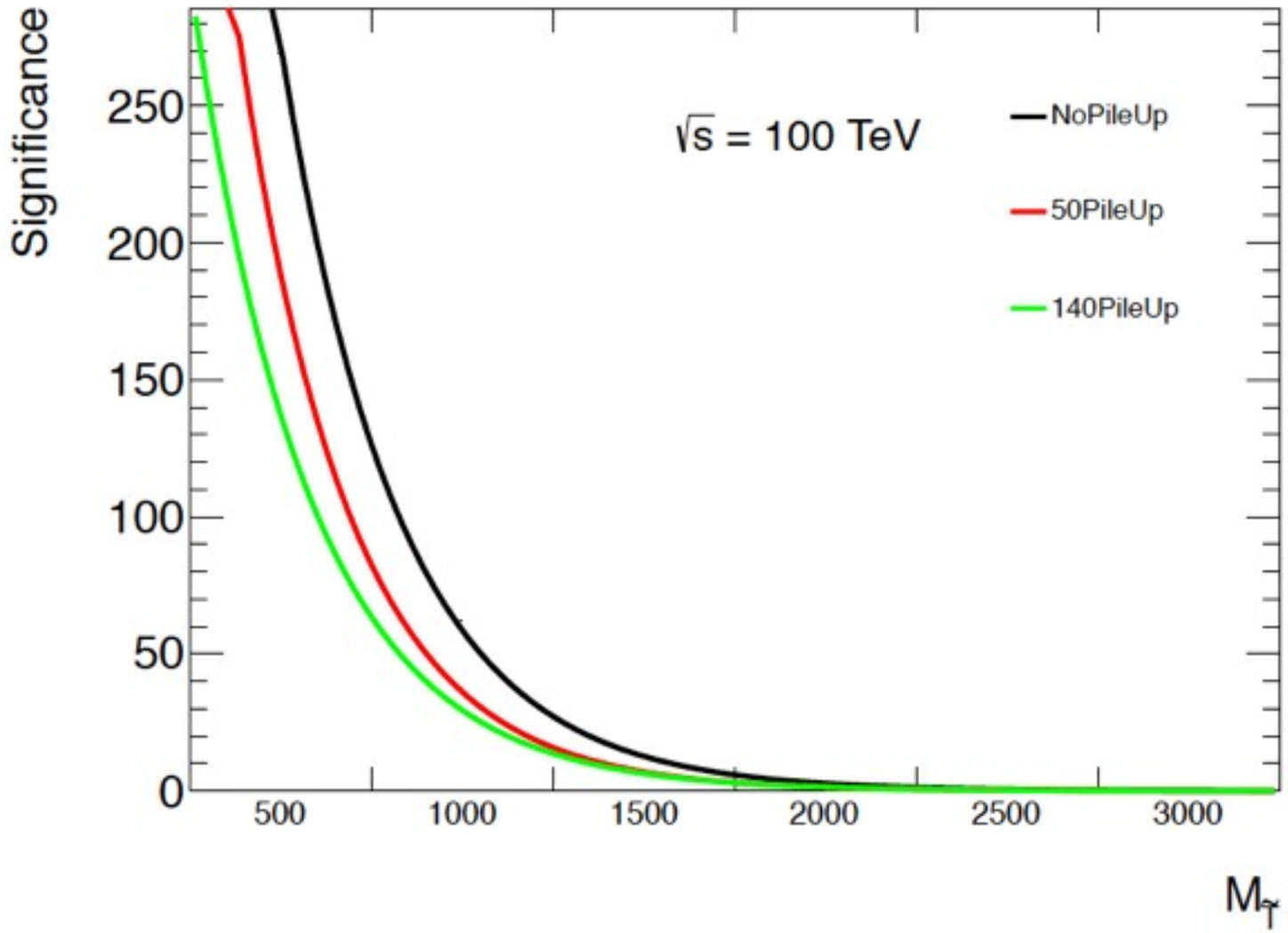
Single production of VLQ

$T \rightarrow tZ$

- Studied various decay channels. Due to large backgrounds to the **single production**, we found this was the most promising channel after including an estimate of systematics
- Require:
  - ✓ 3 leptons with pT > 20 GeV, $|\eta| < 2.5$
  - ✓ 2 b-jet pT > 30 GeV, $|\eta| < 2.5$
  - ✓ MET > 30 GeV
  - ✓ 1 light jet with $|\eta| > 2.5$
- Reconstruct Z from invariant mass, W from MET and remaining lepton (standard method), top as W+b closet to top mass and finally T as top + Z

Sensitivity

- Significance for 5 sigma discovery around 1700 GeV
- Assume 3000 fb^{-1}
- Main limitation is huge backgrounds at 100 TeV and large width in this model at large masses



Double production of VLQ

TTbar

- Search carried out in lepton+jets channel. Considered all decay modes (TT→ tHtH, tZtZ, WbWb, tHtZ, tHWb, tZWb).
- Sensitivity studies at a VLHC for $\sqrt{s}$ = 100 TeV, $\int L$ = 1000 fb^{-1} & simulated Pile-up = 40.
- Signal: Generated using MadGraph & hadronization taken care of using PYTHIA. Eight mass points between 2 and 15 TeV.
- Background: HT binned MadGraph samples. ttbar, W+jets, Z+jets, single top quark, and diboson.

Event Selection (lepton+jets)

- Pre-selections: (cuts optimized based on $S/\sqrt{B}$)

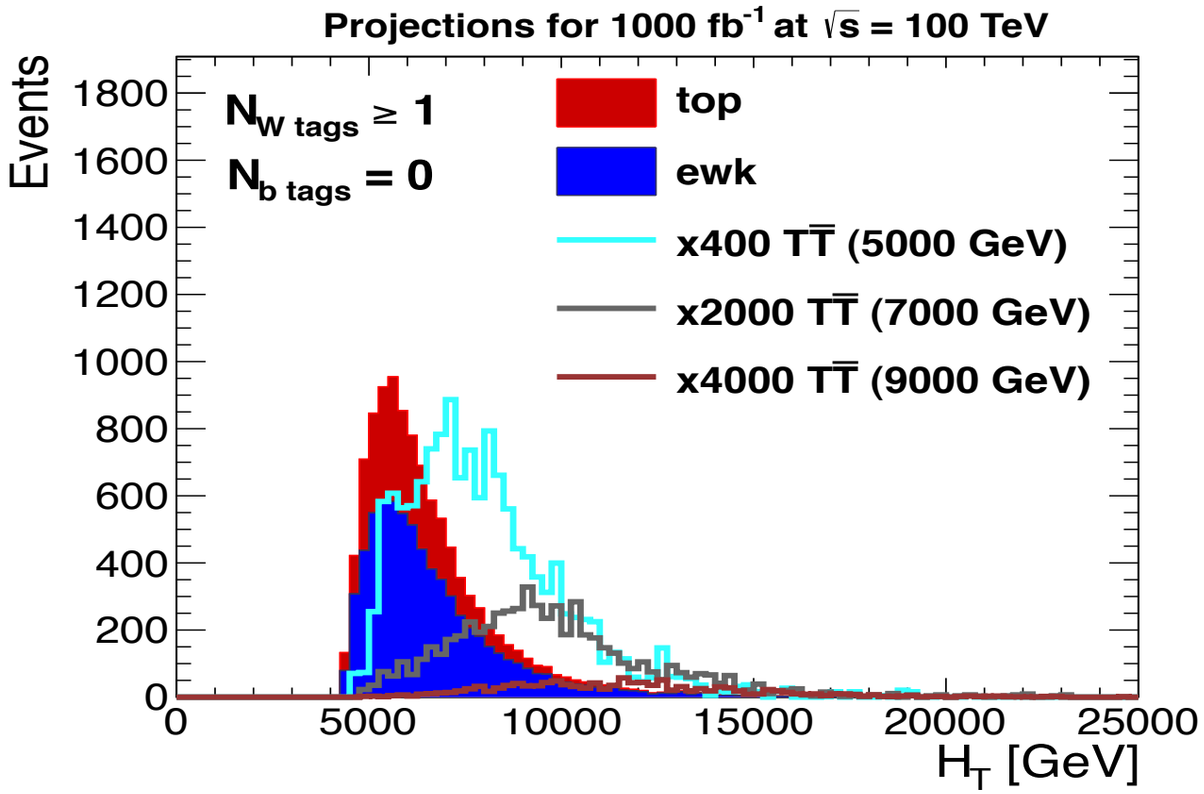
  - ✓ exactly one charged lepton (electron or muon) with pT > 30 GeV
  - ✓ MET > 150 GeV,
  - ✓ at least three jets with pT > 2000, 1300, 700 GeV and $|\eta| < 2.5$
  - ✓ Leading b-jet pT > 1500 GeV.
  - ✓ w-jets pT > 200 GeV

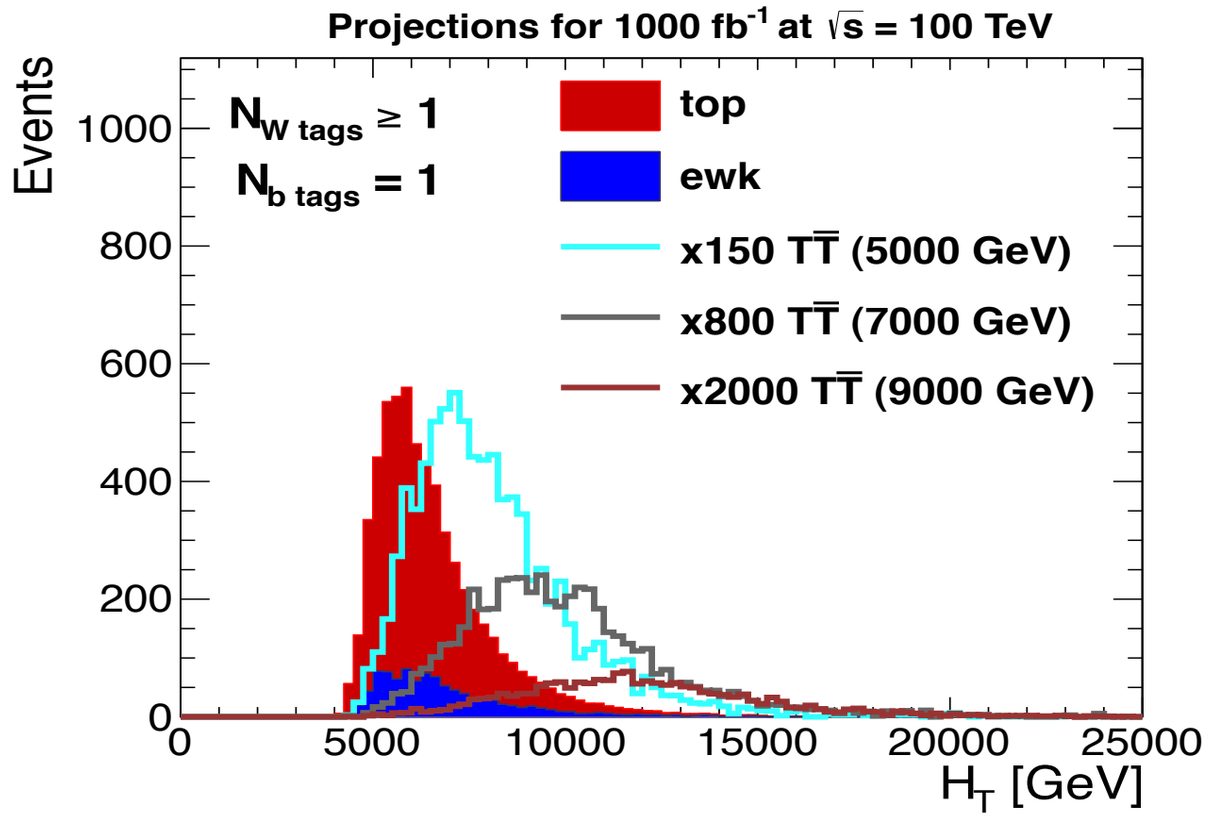
- Event Categories: divided into eight categories based on jet multiplicities.

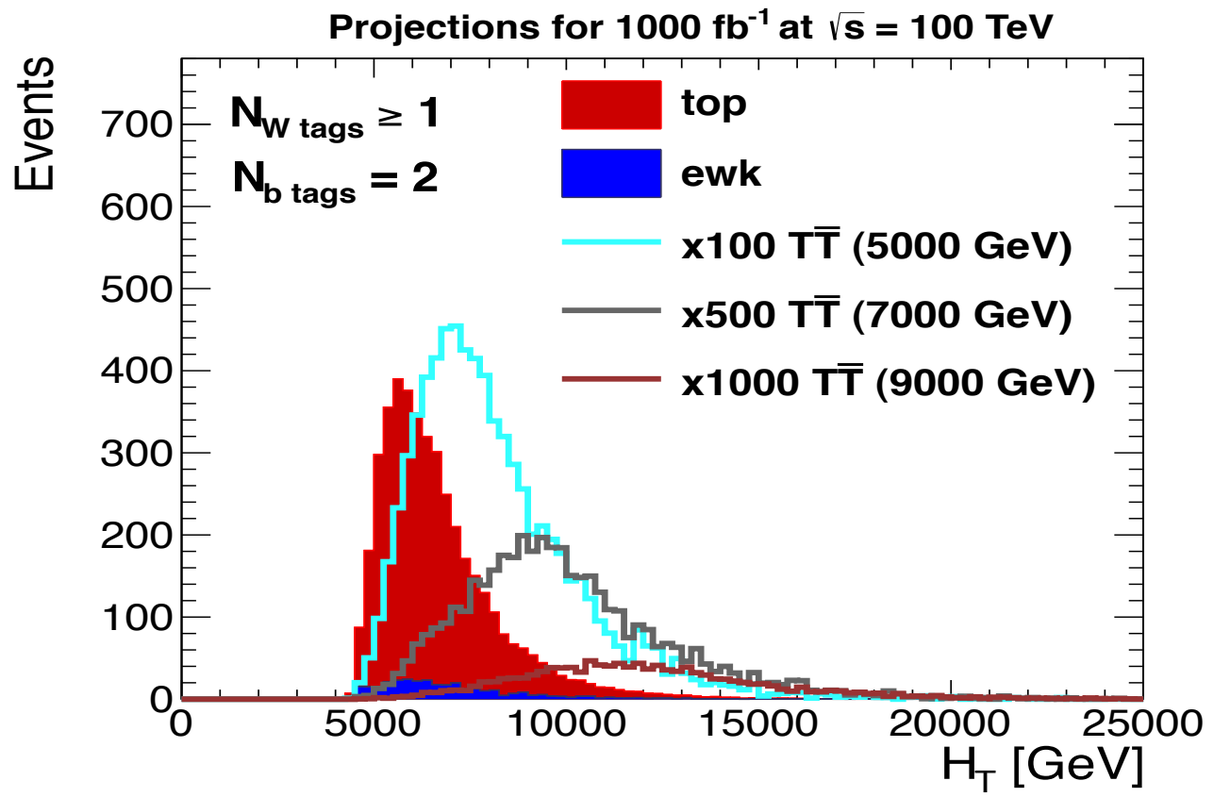
  - Category l3+nb: At least one W-jet + 0....n b-tagged jets (n = 0...3, where n = 3 includes events with at least three b-tagged jets)
  - Category l4+nb: ≥ 4 jets. pT > 2000, 1300, 700 & 150 GeV & no requirement on W-jets

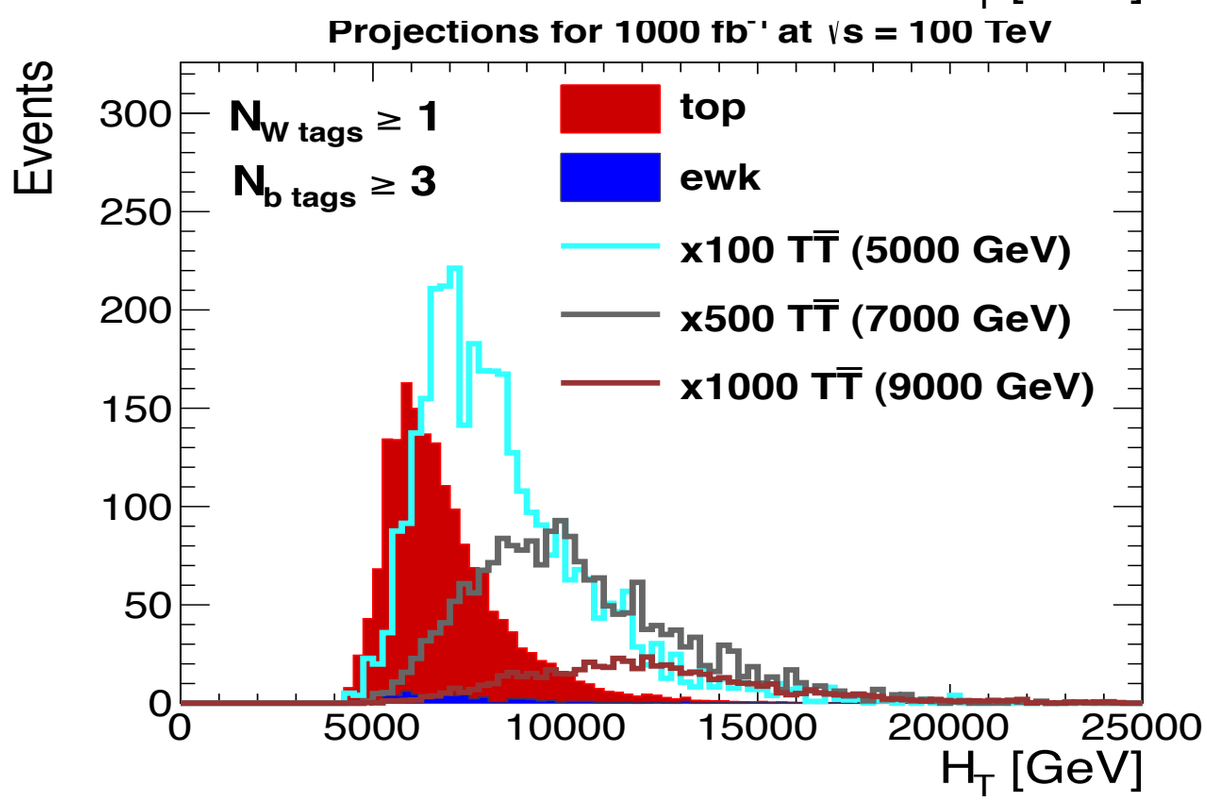
- Signal presence studied using HT distributions

HT template distributions

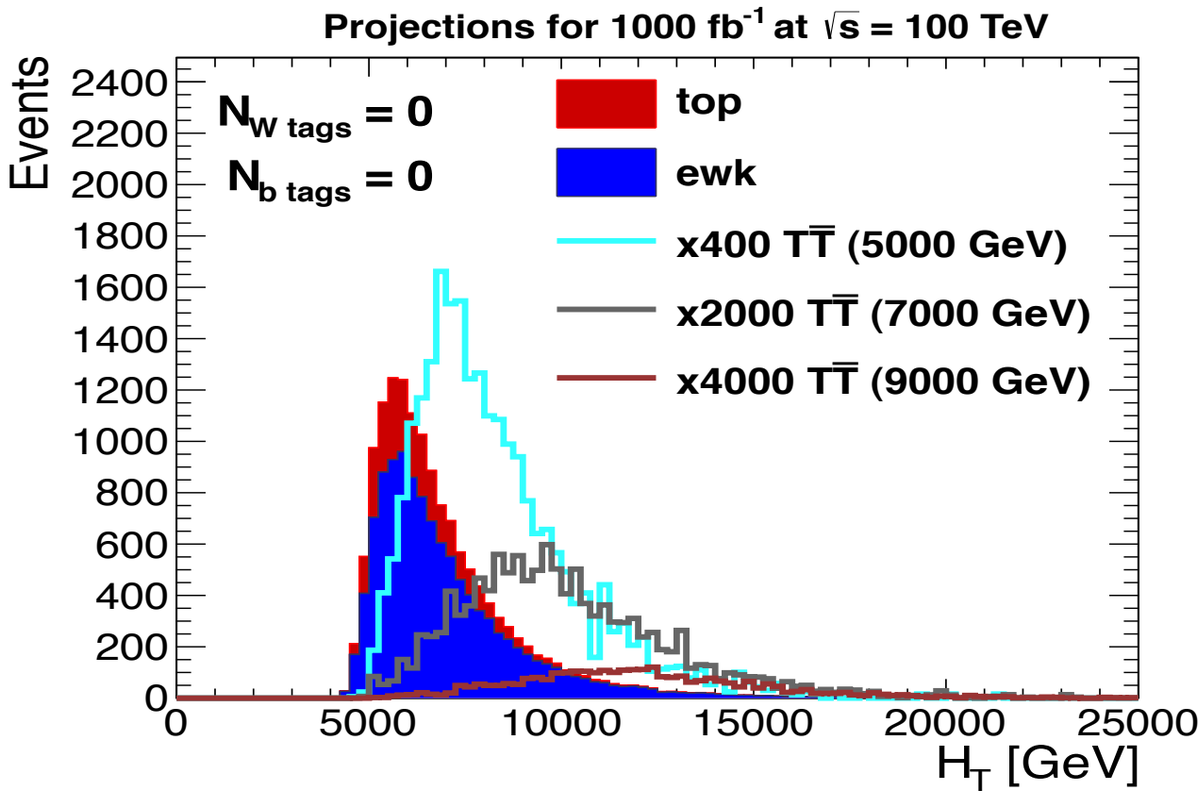


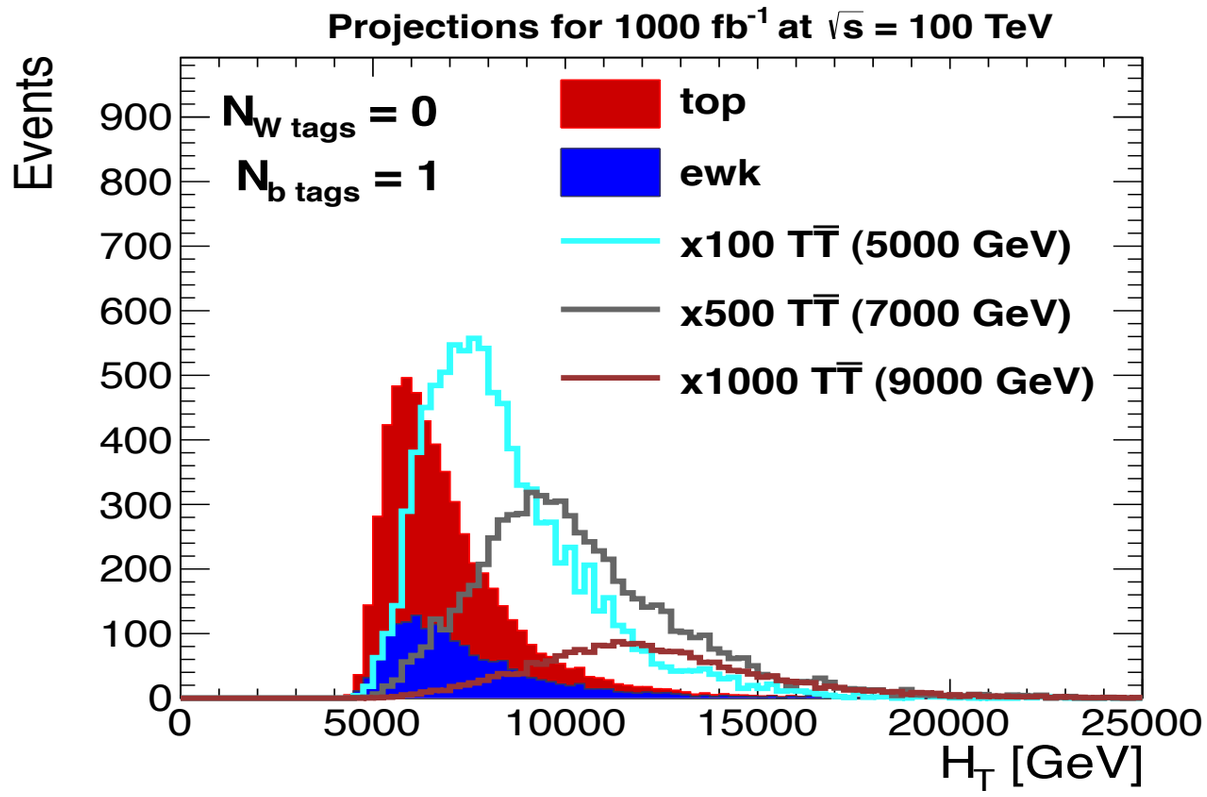


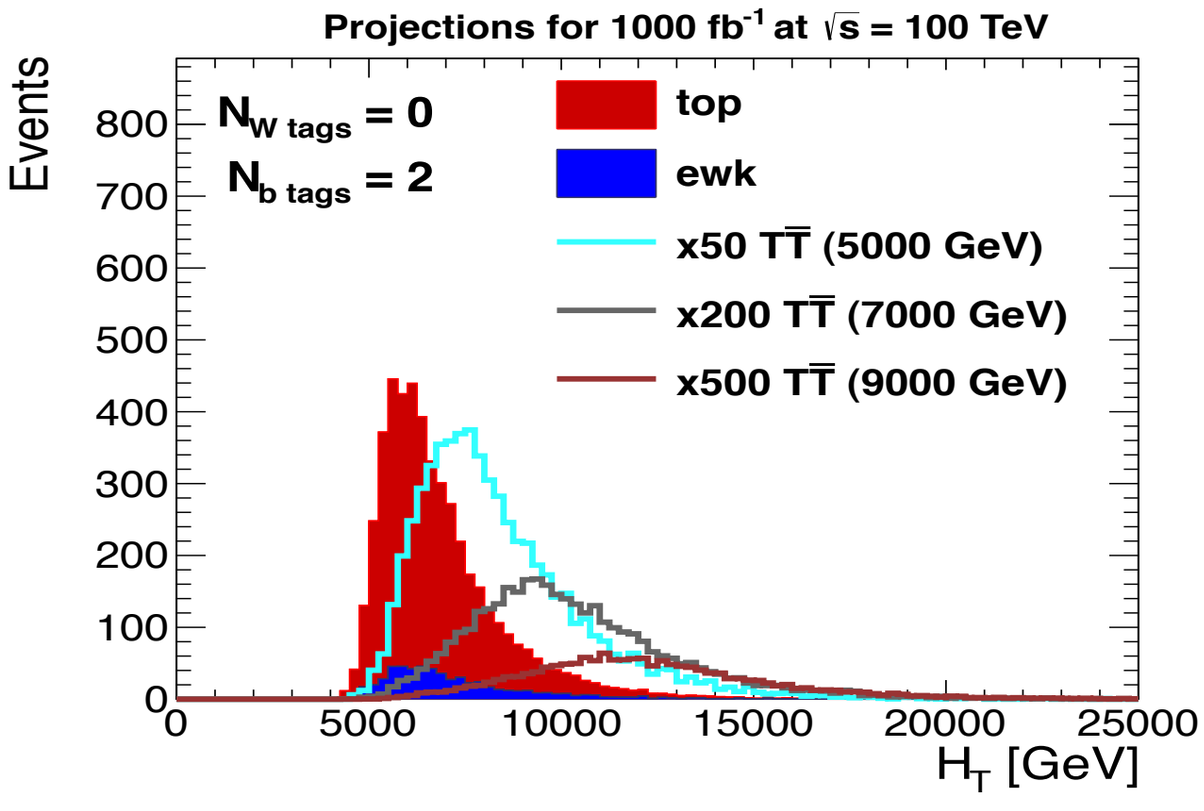


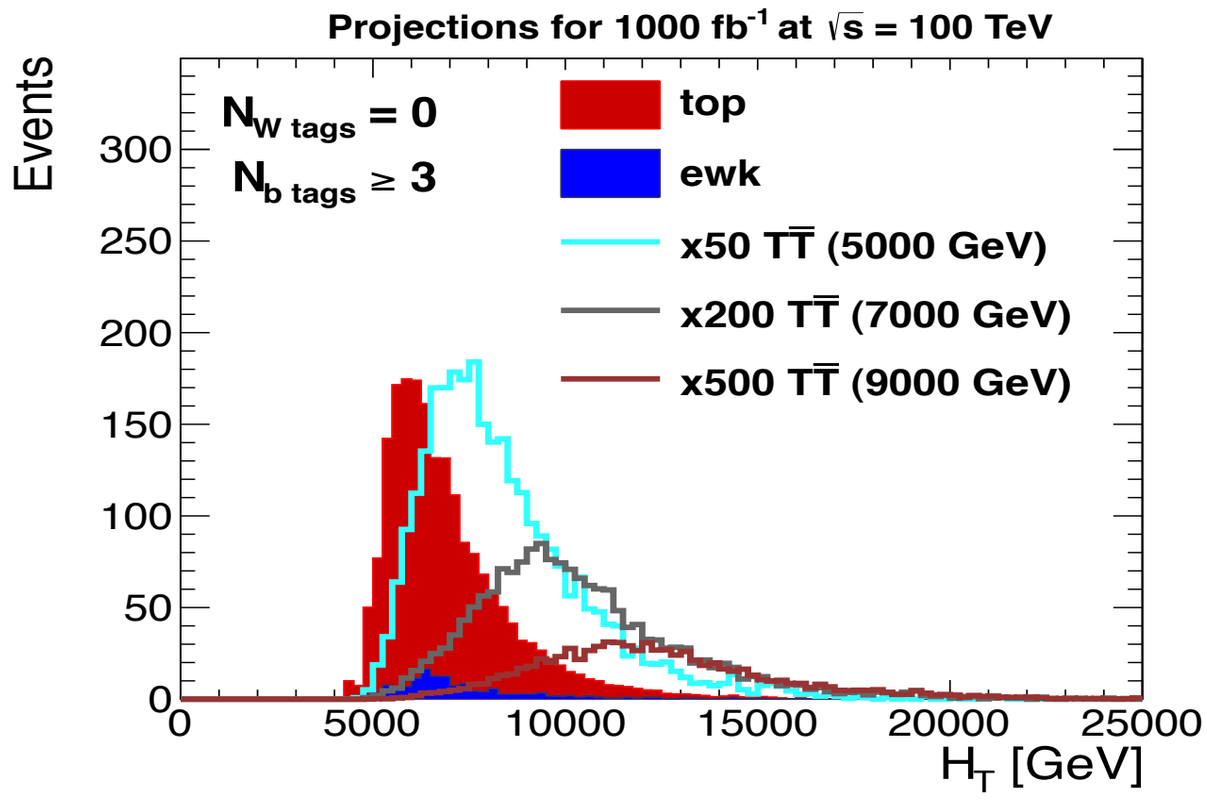


HT template distributions









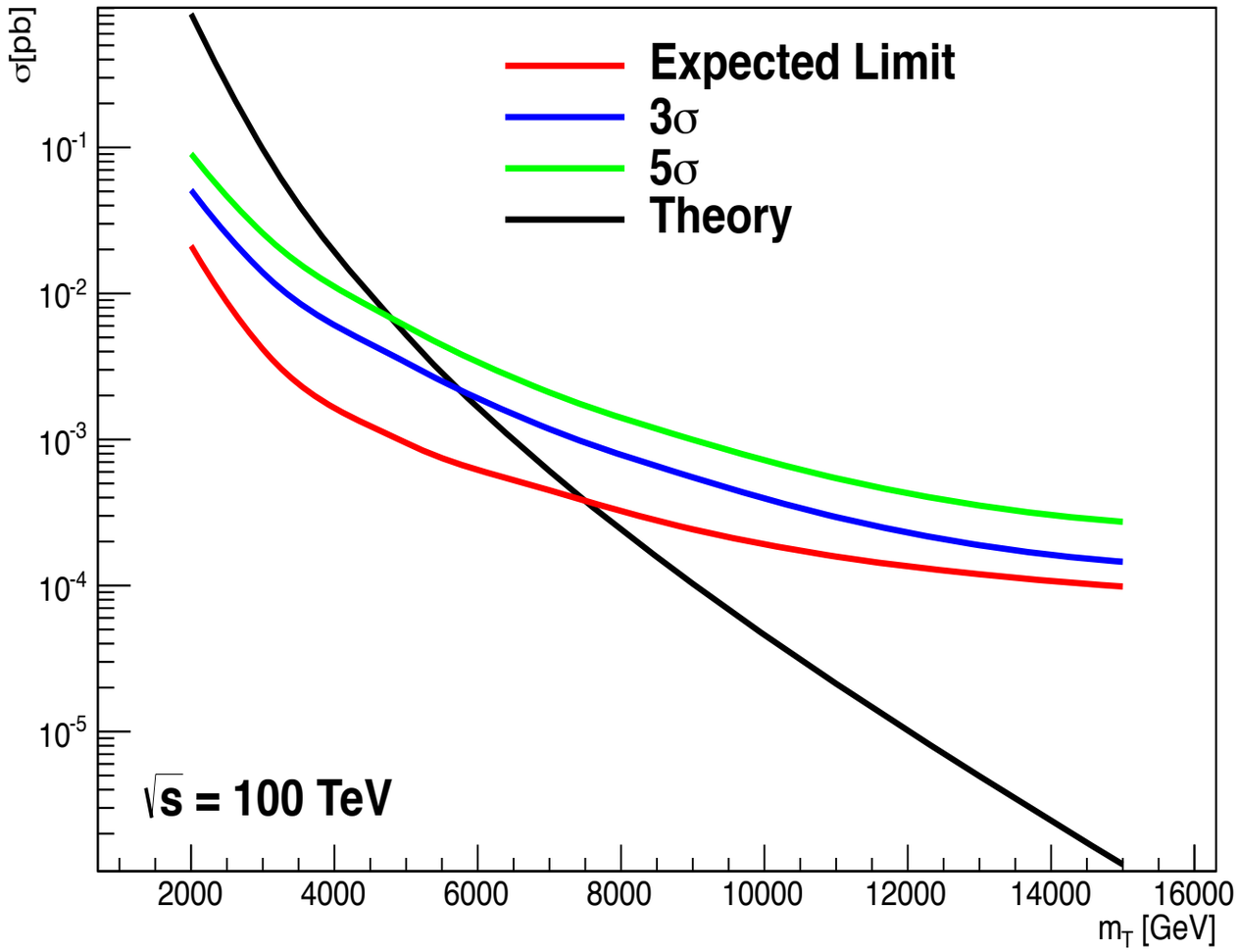
Event Yields

Mass (GeV)	$e3+\mu3,0b$	$e3+\mu3,1b$	$e3+\mu3,2b$	$e3+\mu3,3b$	$e4+\mu4,0b$	$e4+\mu4,1b$	$e4+\mu4,2b$	$e4+\mu4,3b$
Signal Event Yields								
2000	159	390	609	307	167	399	733	295
3000	85	217	339	146	110	251	443	189
5000	11	32	49	22	19	60	96	46
7000	1	4	6	3	3	10	16	8
9000	0.2	1	1	1	1	2	3	2
11000	0.04	0.16	0.22	0.11	0.11	0.5	1	0.33
13000	0.01	0.03	0.05	0.02	0.03	0.11	0.16	0.1
15000	0.002	0.008	0.012	0.006	0.007	0.027	0.040	0.020
Background Event Yields								
$t\bar{t}$	1751 ± 351	2462 ± 493	1957 ± 392	842 ± 169	1513 ± 304	1997 ± 400	2129 ± 427	915 ± 184
Electroweak	3431 ± 687	495 ± 100	163 ± 33	31 ± 7	5591 ± 1119	840 ± 169	291 ± 59	72 ± 15
Total Background	5181 ± 1037	2957 ± 592	2119 ± 425	873 ± 176	7105 ± 1422	2838 ± 568	2420 ± 485	987 ± 198

Results

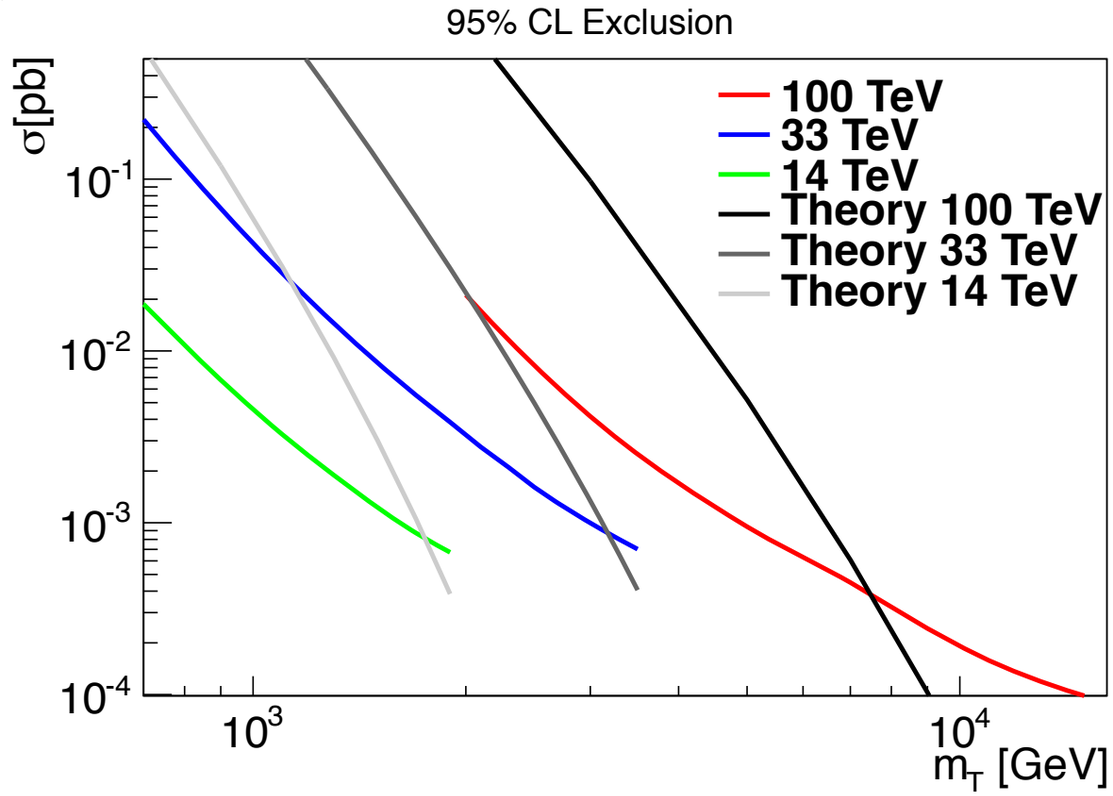
Mass reach for double production of T quark in l+jets channel estimated to be:

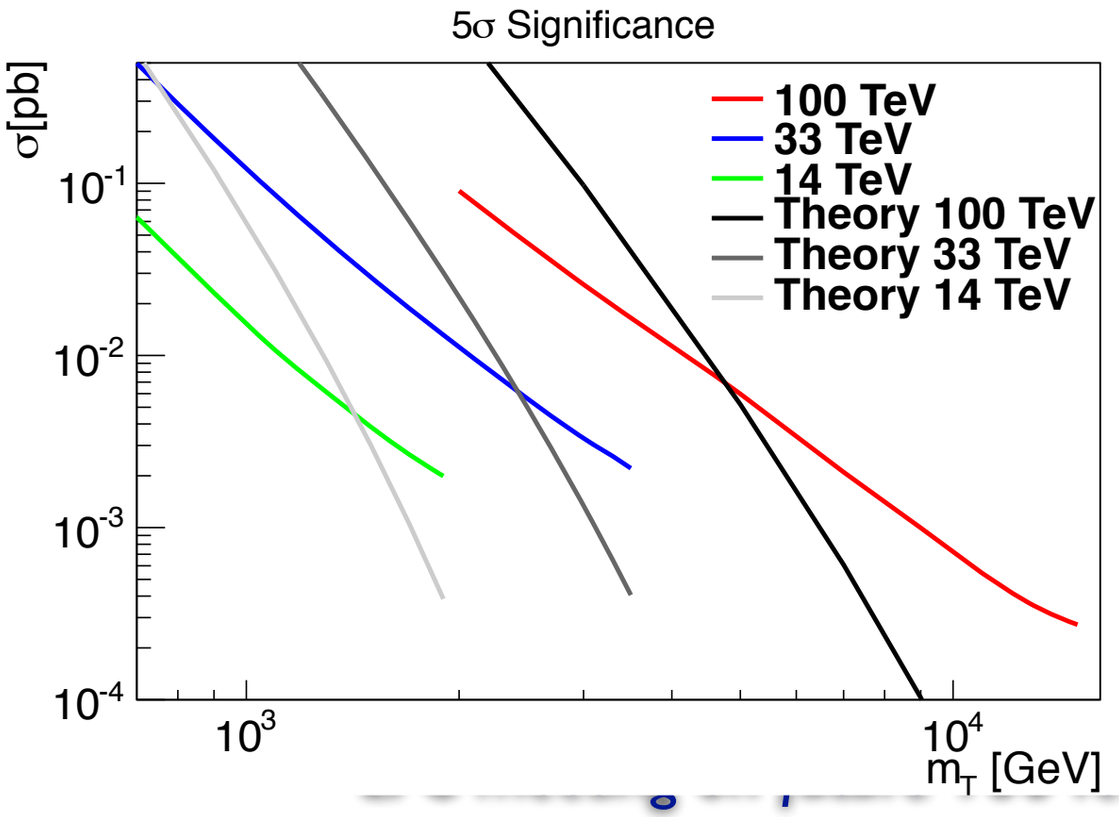
- 95% exclusion limit ~ 7.3 TeV
- 3sigma discovery reach ~ 5.7 TeV
- 5sigma discovery reach ~ 4.8 TeV

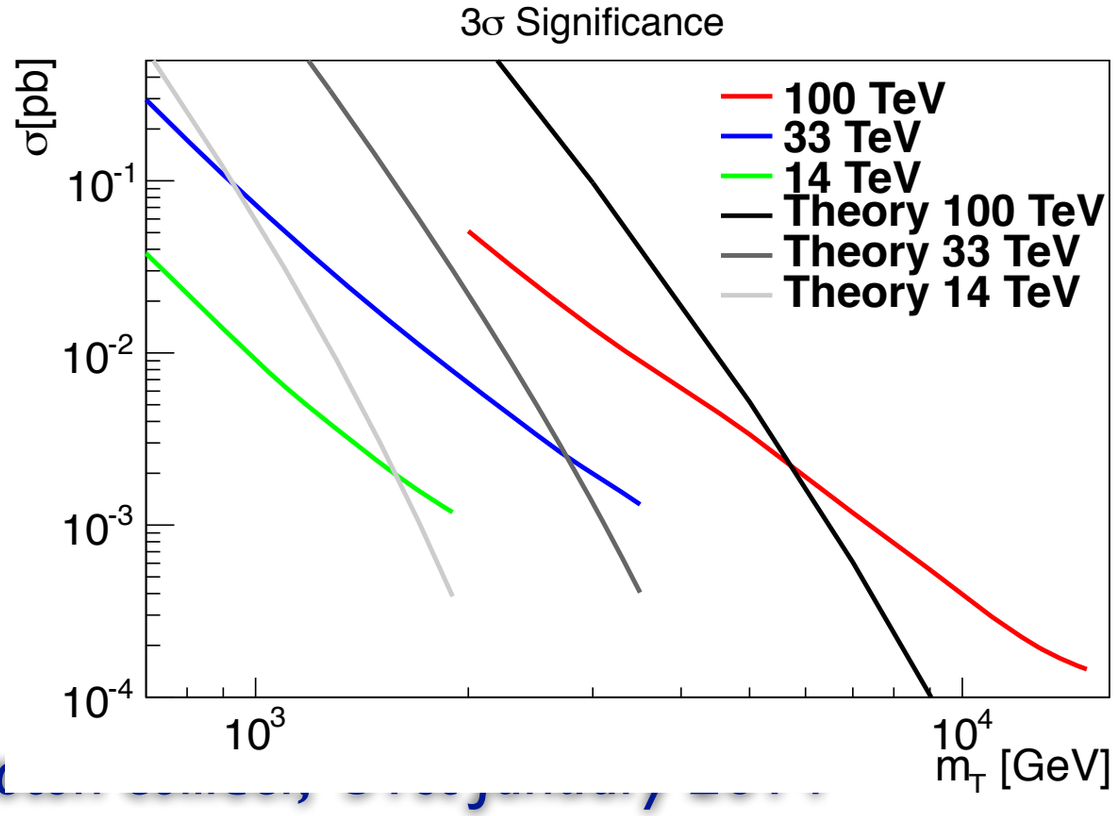


Comparison

Discovery reaches for
100 TeV vs 33 TeV vs 14 TeV
colliders







Summary

- **T quark production & decay provides test for many BSM VLQ models.**
- **Presented sensitivity studies for single & double production of vector like quarks at 100 TeV collider scenarios.**
- **Based on our studies: the 5sigma discovery reach for single production ~ 1.7 TeV, while for double production ~ 4.8 TeV.**
- **Extensively rely on jet-substructure techniques. So would require re-optimization of tools for usage at high energies like 100 TeV.**

BACK-UP

Why are they called vector like

- A SM chiral quark couples only to the left-handed charged current (V-A) interaction

$$J_L^{\mu+} = \bar{u}_L \gamma^\mu d_L = \bar{u} \gamma^\mu (1-\gamma^5) d = V - A$$
$$J_R^{\mu+} = 0$$

- Vector like quarks would couple to both the left handed and right-handed charged current

$$J^{\mu+} = J_L^{\mu+} + J_R^{\mu+} = \bar{u}_L \gamma^\mu d_L + \bar{u}_R \gamma^\mu d_R = \bar{u} \gamma^\mu d = V$$

At 100 TeV

Center of Mass Energy [TeV]	Lambda	Decay	Mass [GeV]	Width [GeV]	Cross Section [pb]
100	3	Zt	500	78.6	117.104966
100	3	Zt	1000	173.6	10.877649
100	3	Zt	1500	264.9	2.237840
100	3	Zt	2000	355.4	0.675062
100	3	Zt	2500	445.4	0.254231
100	3	Zt	3000	535.3	0.110822
100	3	Wb	500	78.6	318.691708
100	3	Wb	1000	173.6	23.474201
100	3	Wb	1500	264.9	4.624145
100	3	Wb	2000	355.4	1.371373
100	3	Wb	2500	445.4	0.513678
100	3	Wb	3000	535.3	0.223635
100	3	ht	500	78.6	107.749943
100	3	ht	1000	173.6	10.286034
100	3	ht	1500	264.9	2.256206
100	3	ht	2000	355.4	0.726233
100	3	ht	2500	445.4	0.290587
100	3	ht	3000	535.3	0.134324