Search for the Top Partner at the LHC using Multi-b-jet channel

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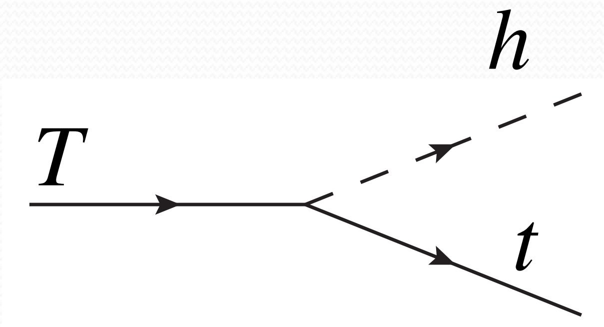
Abstract

Consider the vector-like quark T which mixes with top quark

(Top partner)

Decay mode



is possible

Using multi-b channel, how is the LHC's sensitivity

Contents

1. Models including top partner
2. Current status of the top partner search
3. LHC prospect with multi-b-jet channel

1. Models including top partener

Little Higgs model

Arkani-Hamed, Cohen, Georgi (2001)

MSSM+extra matter

Endo-san

Okada, Moroi (1992)
Kurosawa, Maru, Yanagida (2001)

Little Higgs model

Arkani-Hamed, Cohen, Georgi (2001)

Why the EWSB scale << Mpl ?

How about introducing a dynamical SSB mechanism?   Higgs is pNGB!

Effective theory with cut-off at scale Λ

Generally, any operators should be generated

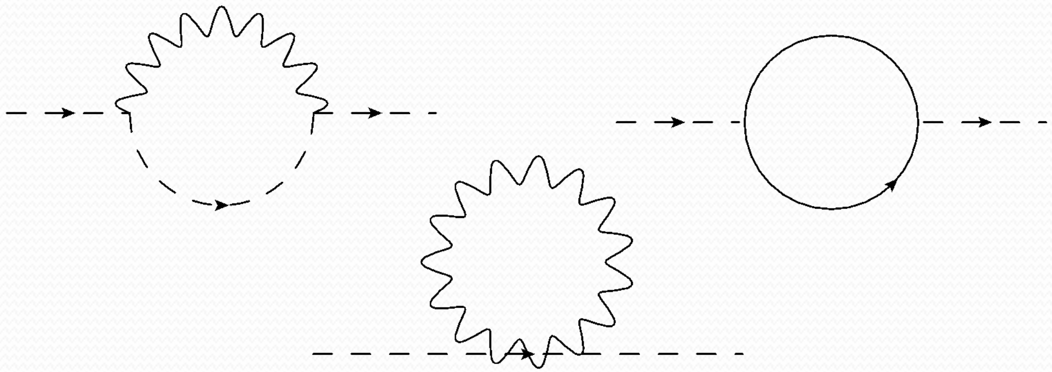
Note : operators like $\frac{1}{\Lambda^2}|H^\dagger D_\mu H|^2 \quad \frac{1}{\Lambda^2}(H^\dagger \sigma^i H)W^i_{\mu\nu}B^{\mu\nu}$

conflict with the electroweak precise measurement

$$\rightarrow \qquad \Lambda > 9\, TeV$$

Han, Skiba (2007)

Little hierarchy



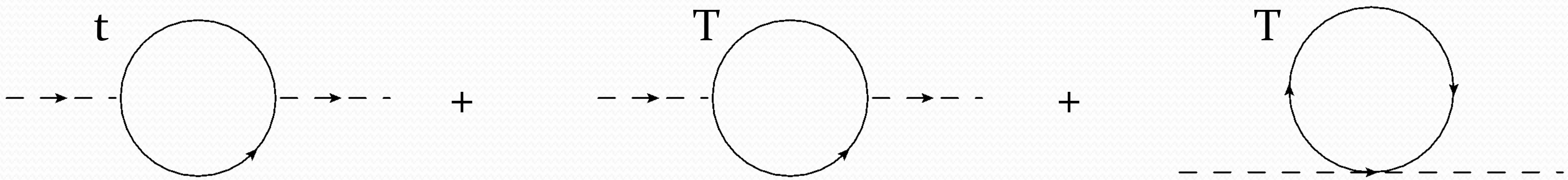
$$\propto \frac{\Lambda^2}{16\pi^2}$$

To avoid fine-tuning, $\Lambda \sim 4\pi m_Z \sim \text{TeV}$

But $\Lambda > 9\, TeV$ Little Hierarchy problem

Solution: symmetry

Due to some symmetry, (depends on model)



$$= 0 \times \Lambda^2 + c_1 \times m_T^2 ln(\frac{\Lambda^2}{m_T^2})$$

(So do gauge sector)

MSSM+extra matter

Endo-san

Okada, Moroi (1992)
Kurosawa, Maru, Yanagida (2001)

MSSM

Super symmetric extension of 2HD Standard model

(later discovered) problem : Higgs is heavier than we thought!

$$m_{h^0} > 114.4 \text{ GeV} > m_Z \quad \text{(LEP)}$$

Quantum correction can raise higgs mass.

Raise SUSY breaking scale?

cf. $m_h = 125 \text{ GeV}$

Possible solution: extra matter

Some models contains
extra vector-like matter at low energy $U(3,2,\frac{1}{6}), Q(\bar{3},1,-\frac{2}{3}),\cdots$

$$W \supset yUQH_u$$

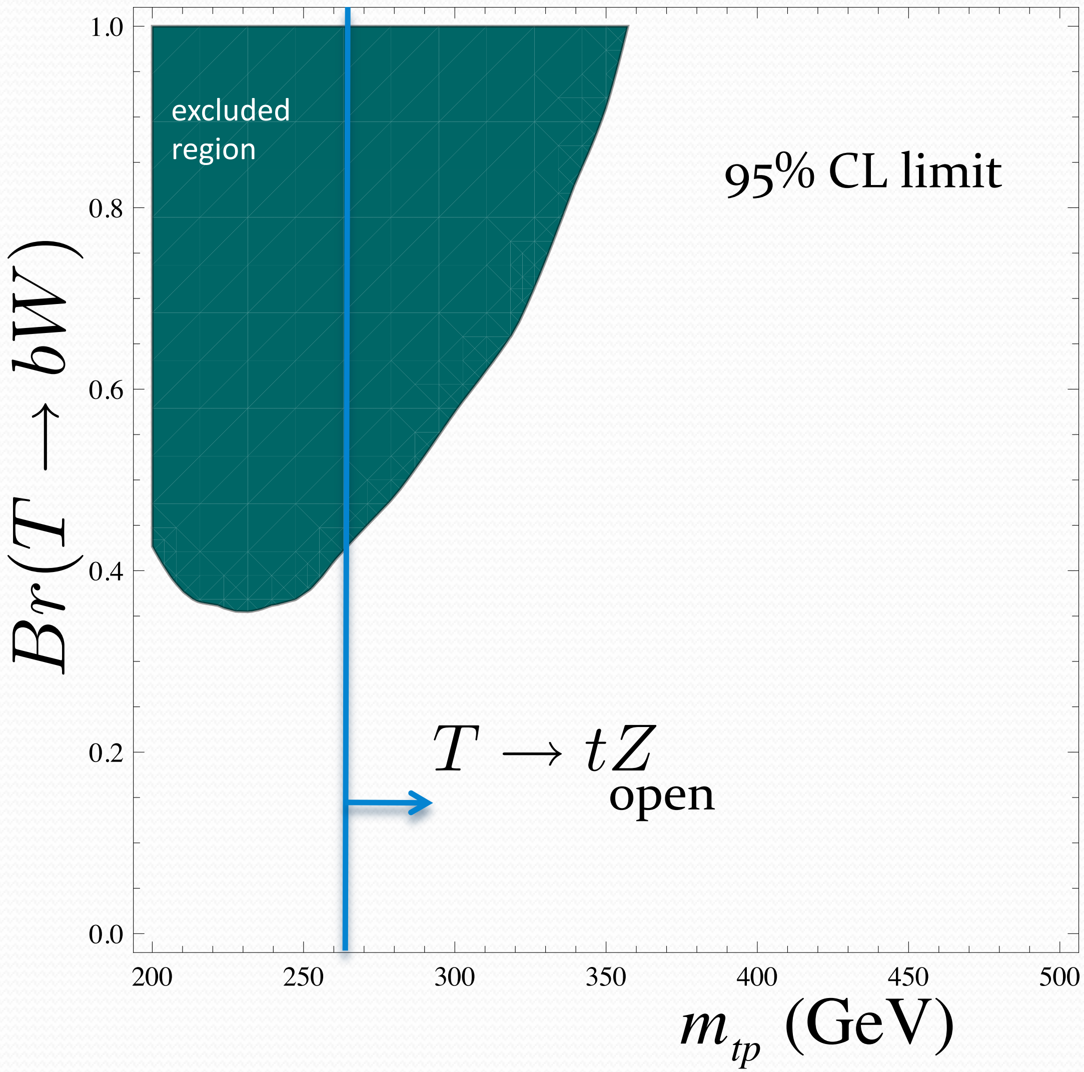
⇒ Enhance Higgs mass!

Big bonus : possible solution to muon $g-2$ even for $m_{h^0}=125$ GeV

Endo, Hamaguchi, Iwamoto, Yokozaki (2011)

2. Current status of the top partner search

Constraints from CDF result



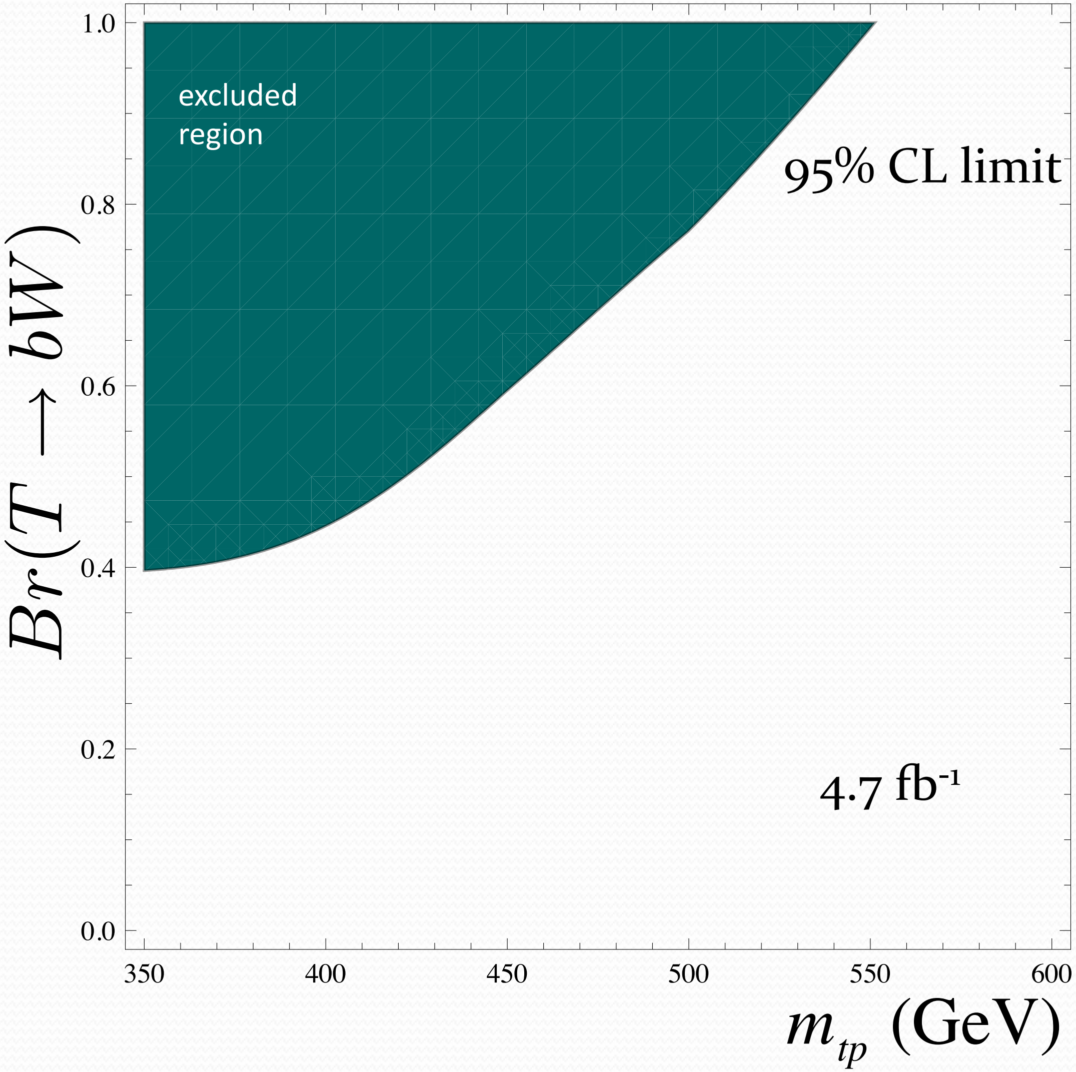
Assuming pair creation and

$$T \to bW$$

1-lepton, b-jet search

Picture: KH, Matsumoto, Nojiri, Tobioka(2012)

Constraints from CMS result



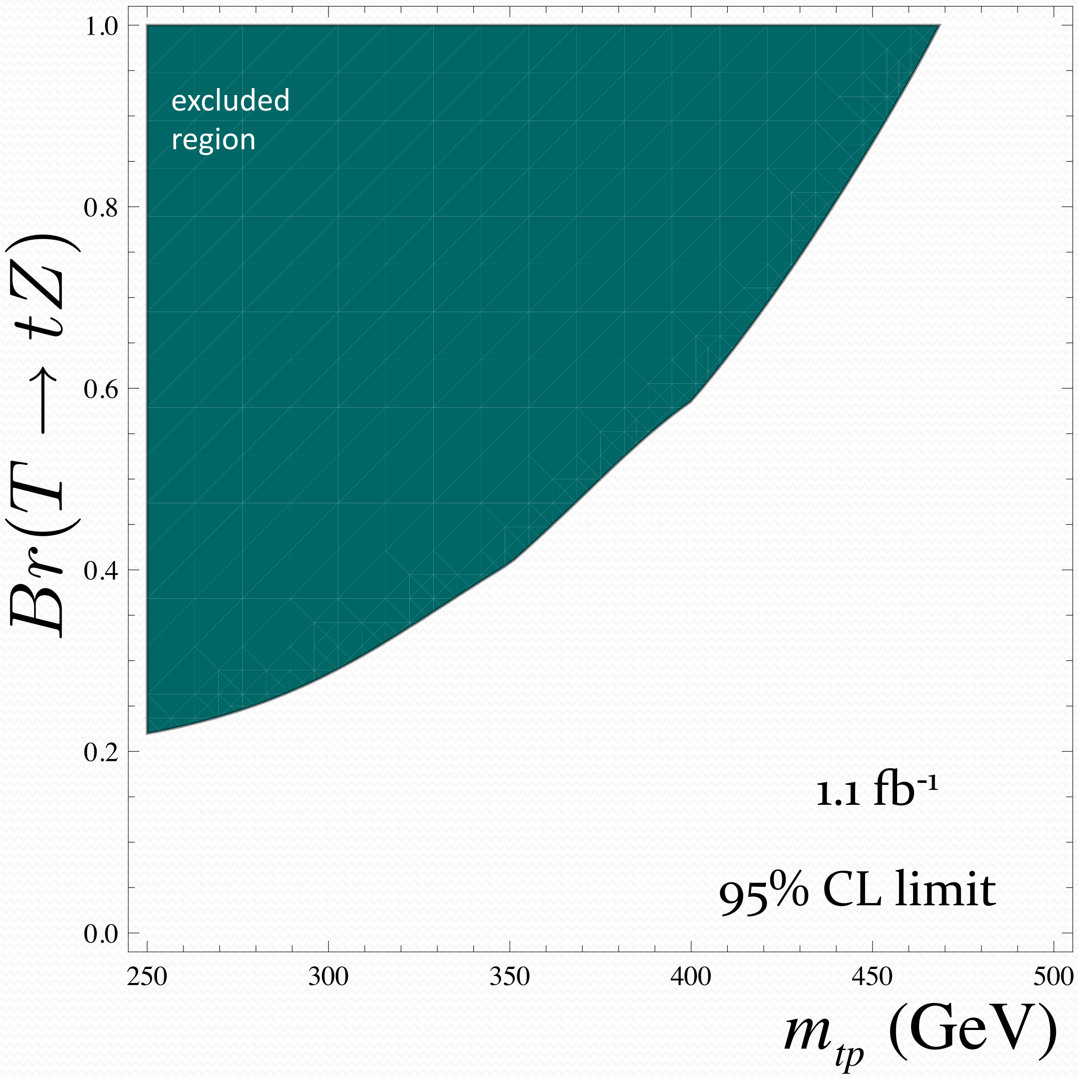
Assuming pair creation and

$$T \to bW$$

di-lepton

Picture: KH, Matsumoto, Nojiri, Tobioka(2012)

Constraints from CMS result



Assuming pair creation and

$$T \to tZ$$

$Z \to l^+ l^-$,

1 isolated lepton

Picture: KH, Matsumoto, Nojiri, Tobioka(2012)

3. LHC prospect with multi-b-jet channel

Concentrate on $bW, \ th$

Tools and assumptions

- Madgraph5
- Pythia
- Delphes
- ATLAS's object reconstruction method
- $m_h = 120$ GeV, $\sqrt{s} = 8$ TeV

For b-tagging,
SVO50 method
b-tag efficiency ~ 0.6
mis-tag rate ~ 0.01
at high-pt

1-lepton + 1,2 b-jet

Imitating and modifying CMS's search

- Aim at $T\overline{T} \rightarrow bW^{+}\overline{b}W^{-}$
- Expect very hard b-jet
- W decay -> lepton, missing, jets
- Try to reconstruct the mass $M_{bl\nu}$

Event selection

- Exactly 1 isolated lepton with pt > 30 GeV
- $\not{E}_T > 20$ GeV
- $\geqq$ 4 isolated jets and 1 or 2 of them are b-jets
- The jets have pt > 80, 50, 30 GeV
- The leading b-jet has pt > 260 GeV
- $M_{bl\nu} > 400$ GeV
- $M_{eff} > 1000$ GeV

Cut flow

15 fb^{-1} data, $m_{tp} = 500$ GeV, ← pt-jet > 70, 40 GeV, leptonic decay

	$t\bar{t}$ +jets	W + jets	$t_p \bar{t}_p \to bWbW$	$t_p \bar{t}_p \to bWth$	$t_p \bar{t}_p \to thth$
generated	6163292	809561	60000	60000	60000
normalized	3060000	4800000	7650	7650	7650
lepton, missing, 4jets, b-jets	282861	16756	1336	1652	1693
jet pt	133099	6392	1160	1555	1654
b-jet pt	1872	415	405	374	215
invariant mass	1025	320	351	287	125
effective mass	387	160	237	164	75
acceptance	0.00013	0.000033	0.031	0.021	0.0099

KH, Matsumoto, Nojiri, Tobioka(2012)

LHC's sensitivity

Expected 95 % CL excluded region if no excess

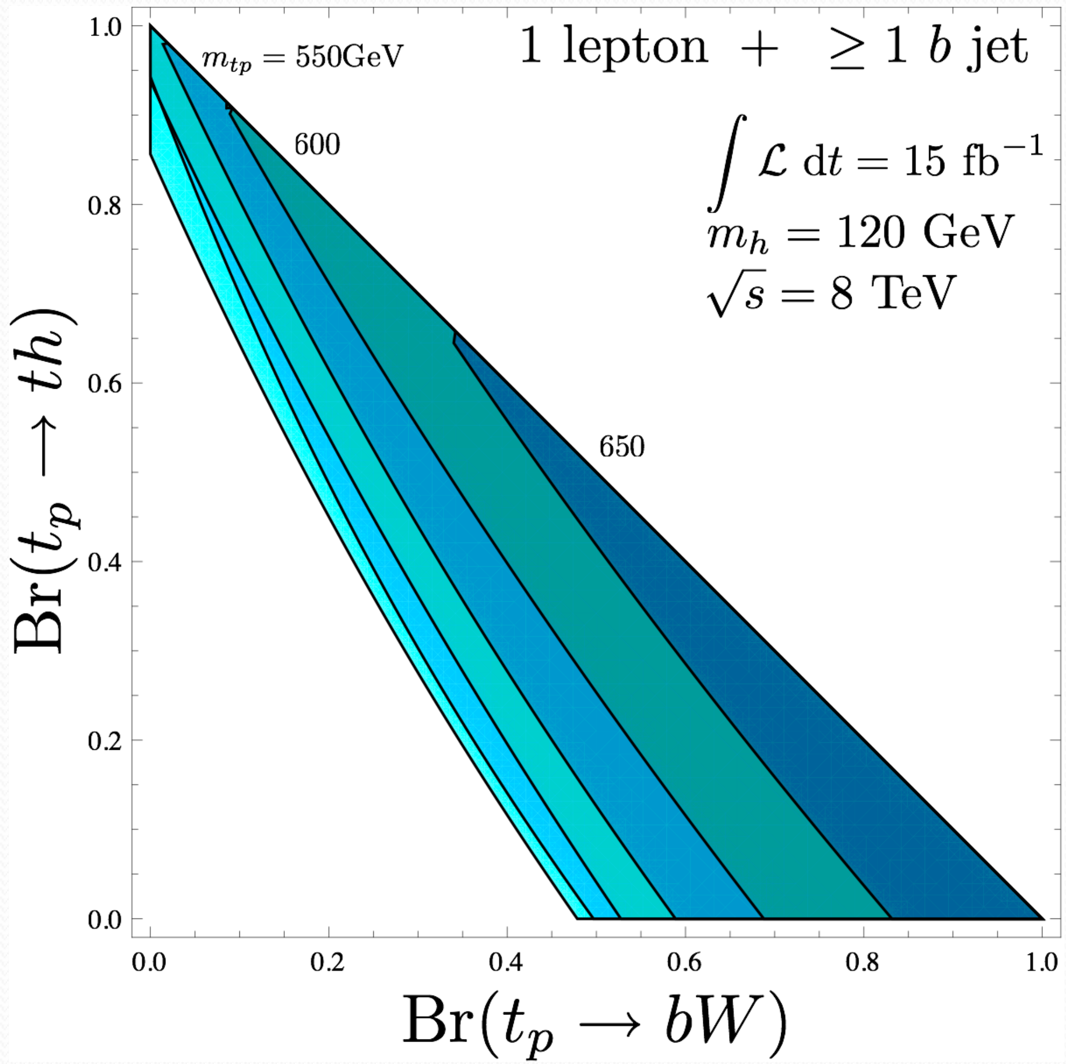
(cross section)

×

(acceptance)

> 4.4 fb

Assuming 20 % uncertainty in
The background estimation



1-lepton + ≧3 b-jet

- Aim at $T\overline{T} \rightarrow bWth$ or $thth$
- Expect many hard b-jet
- W decay -> lepton, missing, jets

Event selection

- Exactly 1 isolated lepton with pt > 30 GeV
- $\not{E}_T > 20$ GeV
- ≧5 isolated jets and more than 2 of them are b-jets
- The b-jets have pt > 140, 80, 80 GeV
- $M_{bl\nu} > 250$ GeV
- $M_{eff} > 1200$ GeV

Cut flow

15 fb^{-1} data, $m_{tp} = 500$ GeV,

ptb-jet > 20GeV

	$t\bar{t}$ +jets	$t\bar{t}b\bar{b}$	$t_p\bar{t}_p \to bWbW$	$t_p\bar{t}_p \to bWth$	$t_p\bar{t}_p \to thth$
generated	6163292	90000	60000	60000	60000
normalized	3060000	24000	7650	7650	7650
lepton, missing, 5jets, b-jets	5328	558	63	380	686
b-jets pt	123	26	19	99	170
invariant mass	78	18	17	86	135
effective mass	15	4	11	40	45
acceptance	0.000050	0.00016	0.0014	0.0052	0.0059

W +jets, $Wb\bar{b}$ +jets : negligible

KH, Matsumoto, Nojiri, Tobioka(2012)

LHC's sensitivity

Expected 95 % CL excluded region if no excess

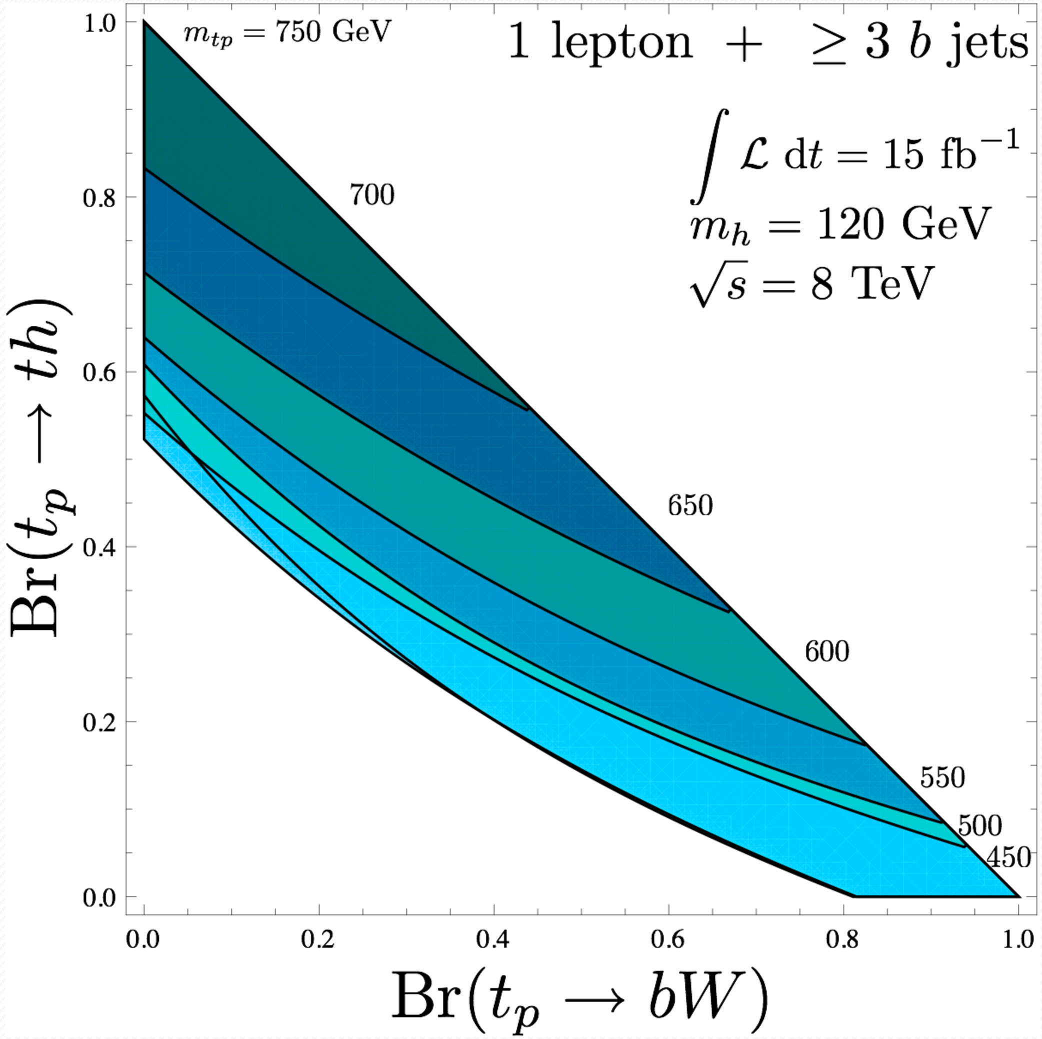
(cross section)

×

(acceptance)

> 0.92 fb

Assuming 20 % uncertainty in
The background estimation



LHC's discovery potential

Expected 5 σ discovered region

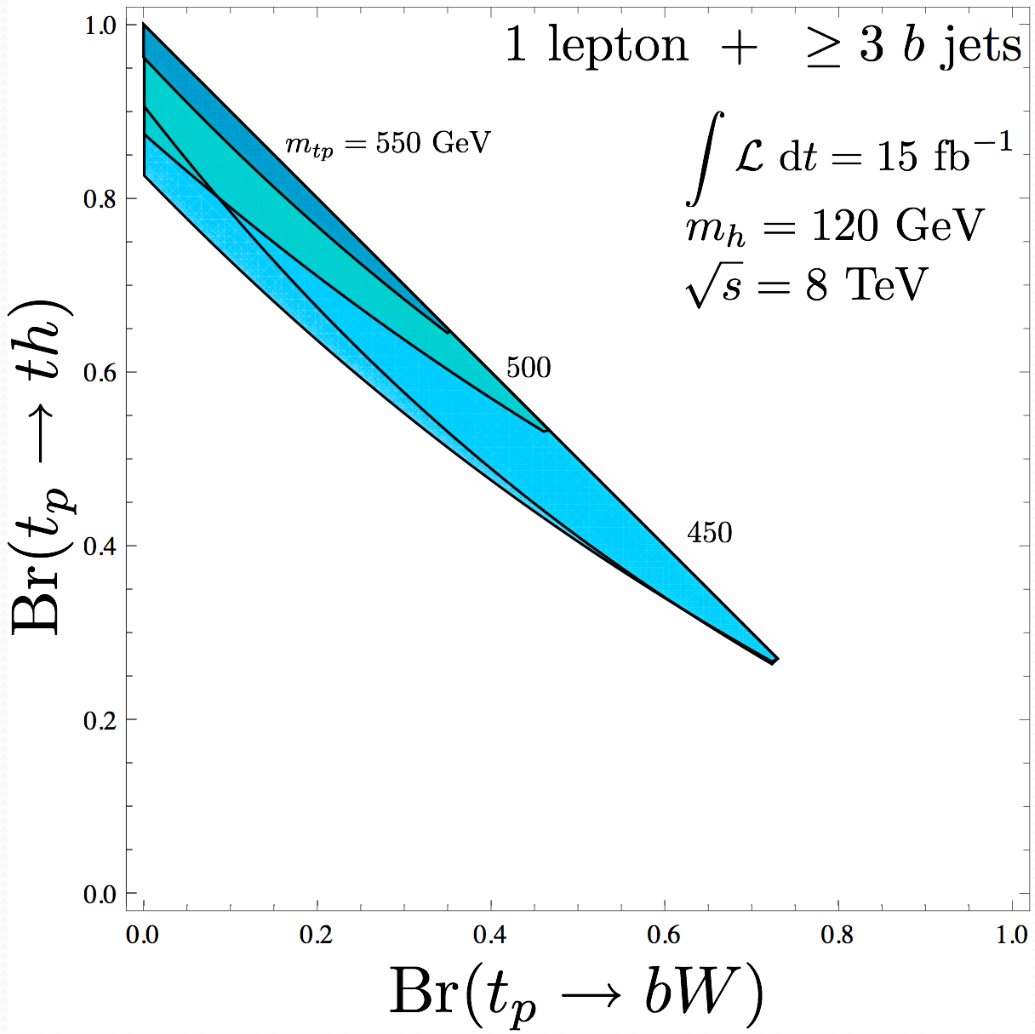
(cross section)

×

(acceptance)

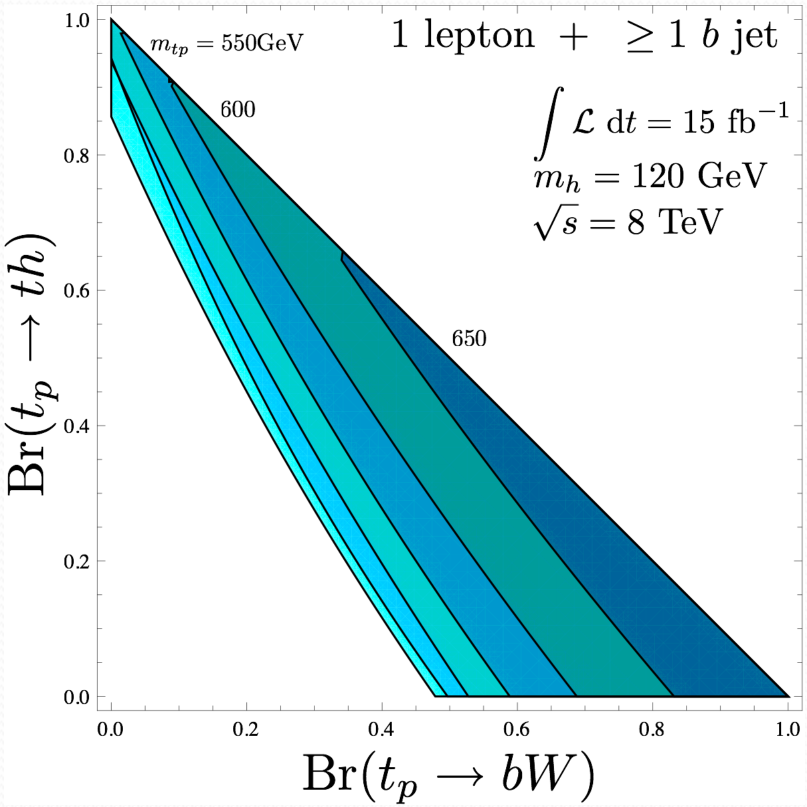
> 2.3 fb

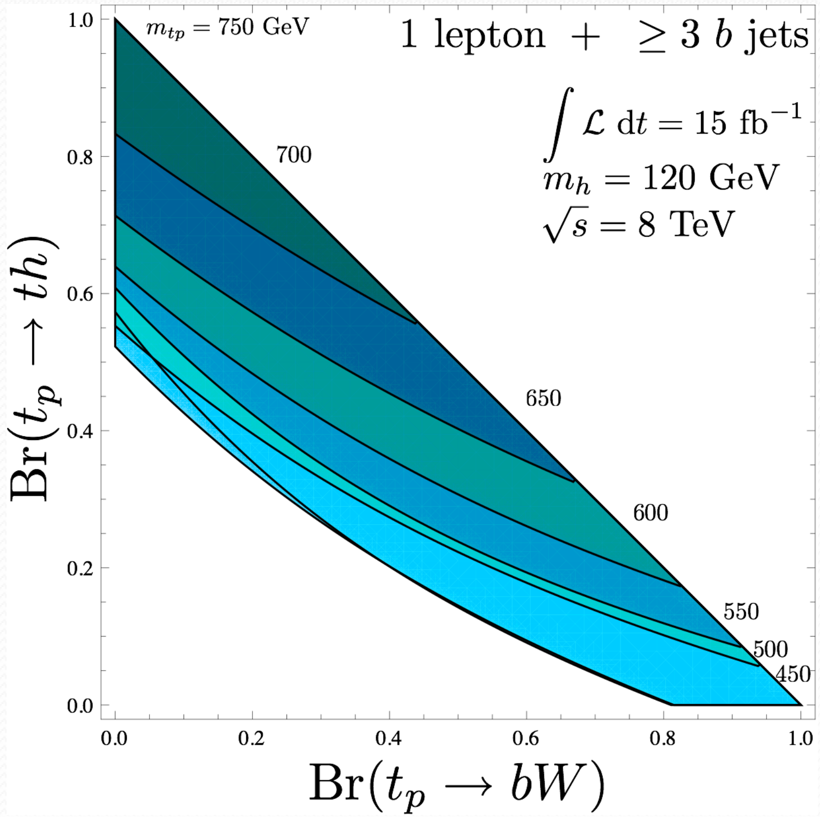
Assuming 20 % uncertainty in
The background estimation



Summary

- Some models contain vector-like quark which mixes with top quark (top partner)
- Multi b- jet channel have grate sensitivity to the top partner, especially for decay into top and higgs





Electro weak observables

parameter	value
α^{-1}	137.035999679(94)
G_F (GeV^{-2})	1.16637(1)$\times10^{-5}$
m_Z (GeV)	91.1876(21)
$\Delta\alpha_{lep}(m_Z^2)$	0.03150
$\Delta\alpha_h(m_Z^2)$	0.027626(138)
$\Delta\alpha_{top}(m_Z^2)$	-0.00007
m_W (GeV)	80.399(23)
m_t (GeV)	173.2(9)
$\bar{s}_l^2$	0.23153(16)
$\Gamma_{Z\to l^+l^-}$ (MeV)	83.984(86)
$\alpha_s(m_Z^2)$	0.1184(7)

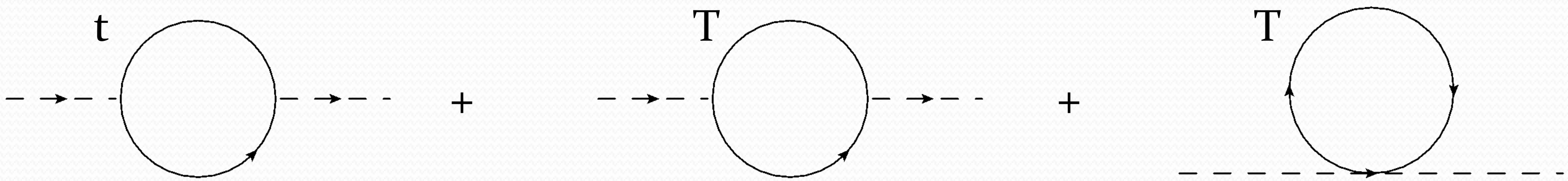
Little Higgs model

Suppose EWSB is generated by some mechanism

⇒ Cutoff $\Lambda > 10\ \mathrm{TeV}$ Han, Skiba (2007)

$$\frac{1}{\Lambda^2}(H^\dagger \sigma^i H) W^i_{\mu\nu} B^{\mu\nu}$$

Even if Higgs were pNGB, to avoid little hierarchy,



$$= 0 \times \Lambda^2 + c_1 \times m_T^2 ln(\frac{\Lambda^2}{m_T^2})$$

due to some symmetry. (depends on model)

Top see saw

Chivukula, Dobrescu, Georgi, Hill (1999)

Top quark condensate

$H \Leftrightarrow t_L^\dagger t_R$: same quantum number

How about top quark condensation like BCS theory?

Intrinsic energy scale provide dynamical scale
top quark Yukawa coupling is naturally large

Problem: top quark should be heavier

$$m_t \approx \frac{4\pi v}{\sqrt{N_c \ln \frac{\Lambda}{v}}}$$

Λ : cut off (=intrinsic energy scale)

N_c : Number of color

Solution: seesaw mechanism

Introduce vector-like quark T

$$m_t \approx \frac{4\pi v}{\sqrt{N_c \ln \frac{\Lambda}{v}}} \sin\theta$$

Suppressed by mixing angle

MSSM+extra matter

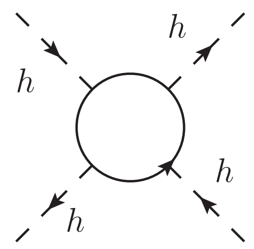
$$m_{h^0} > 114.4\ \text{GeV} > m_Z \quad \text{(LEP)}$$

Raise stop mass and allow little hierarchy?

Possible solution : utilize vector-like extra matter $U(3,2,\frac{1}{6}), Q(\bar{3},1,-\frac{2}{3}),\cdots$

$$W \supset yUQH_u$$

⇒ Enhance Higgs mass!

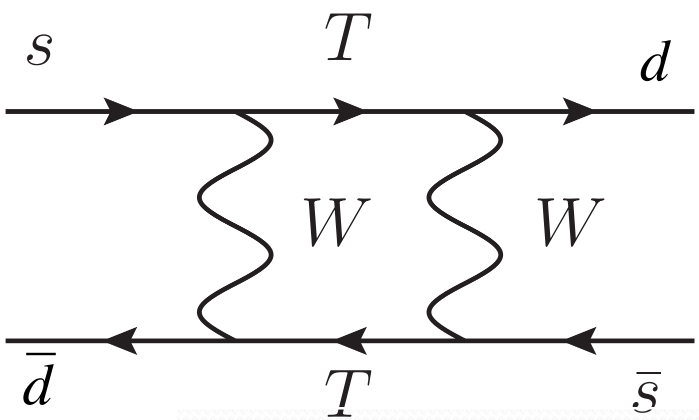


…

cf. $m_h = 124 - 126\text{GeV}$?

Coupling with 1st, 2nd generations

ex.) $K\bar{K}$



$$\theta_{L1,2} \leq 10^{-3}$$

Systematic errors

- $t\bar{t}$ cross section: 166 ± 11 pb (CMS,2011)
- Integrated luminosity: 3.7% (ATLAS, 2011)
- b-tag efficiency and mis-tag rate

  : not accurately included

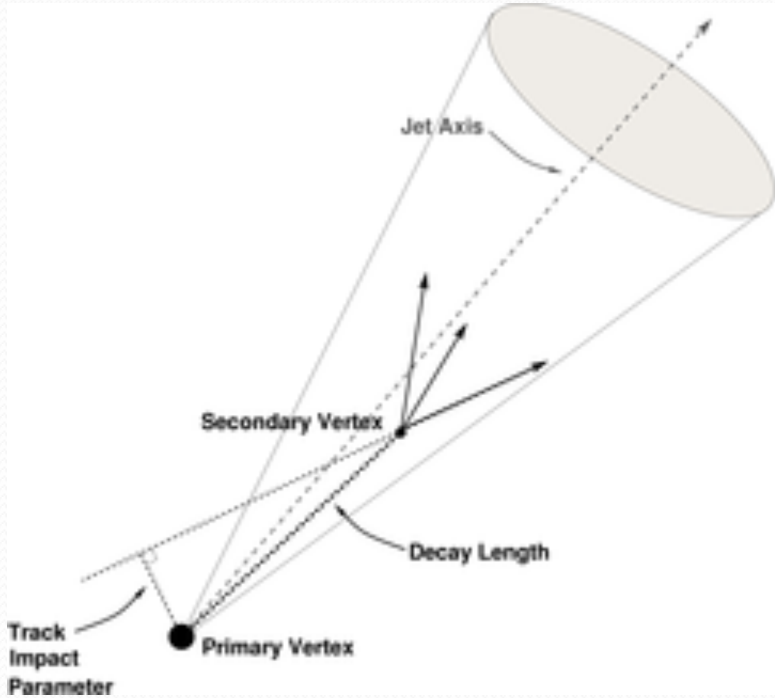
  (results with taking into the effect with rough estimate are also shown)

Uncertainties in b-tagging

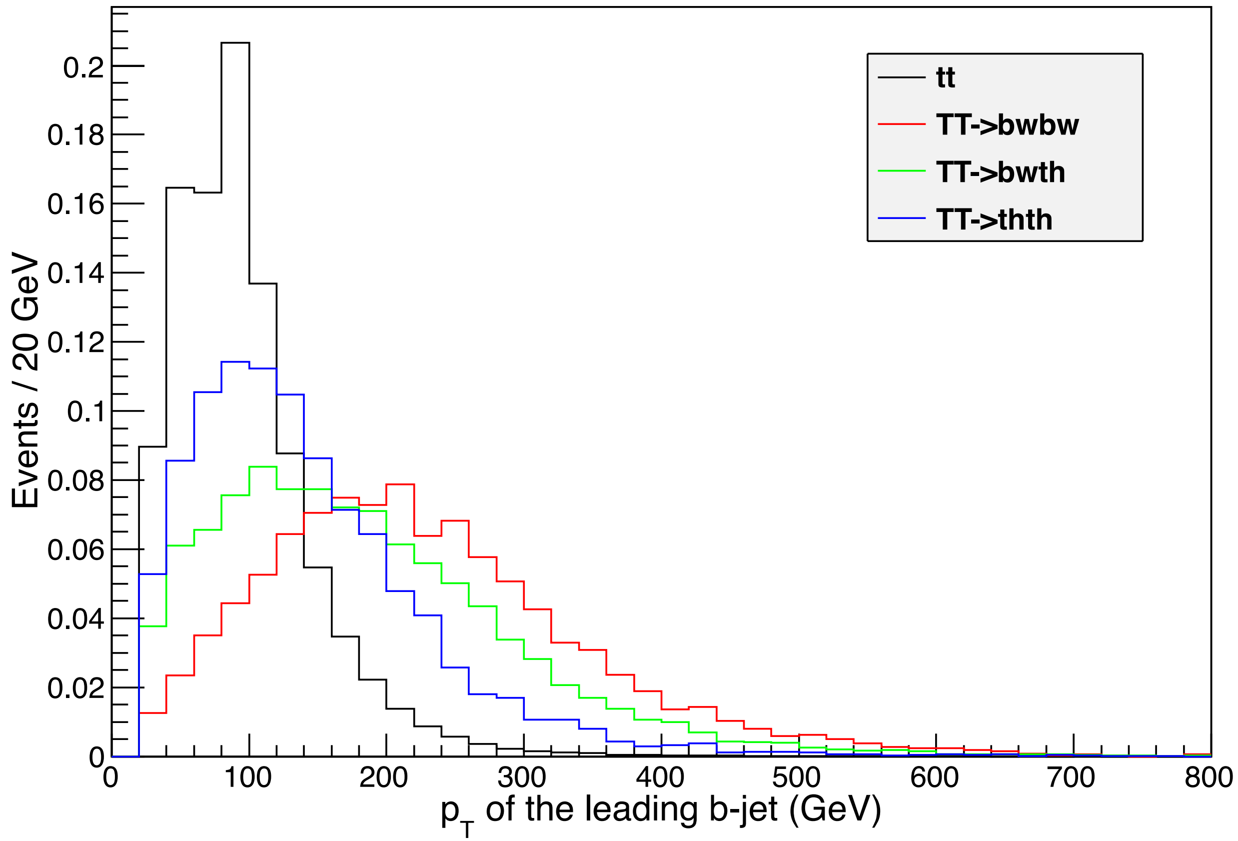
With 35 pb^{-1} data, for SVO50 method,

(ATLAS-CONF-2011-089)

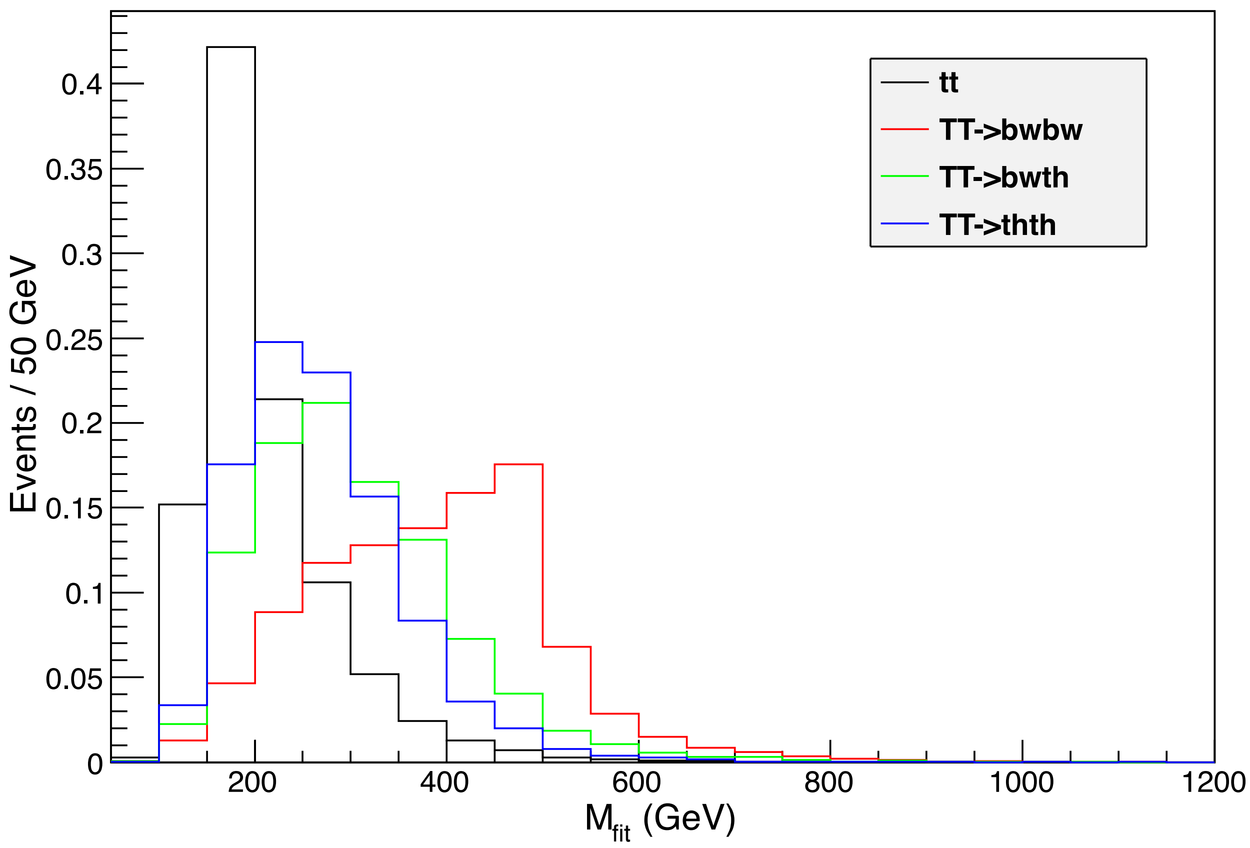
- b- tagging efficiency : ~ 5% (sys) 10% (stat)
- mis-tag rate for light jets : ~10% (stat)
- mis-tag rate for c-jets : not calibrated. ~0.14 (ATLAS TDR)



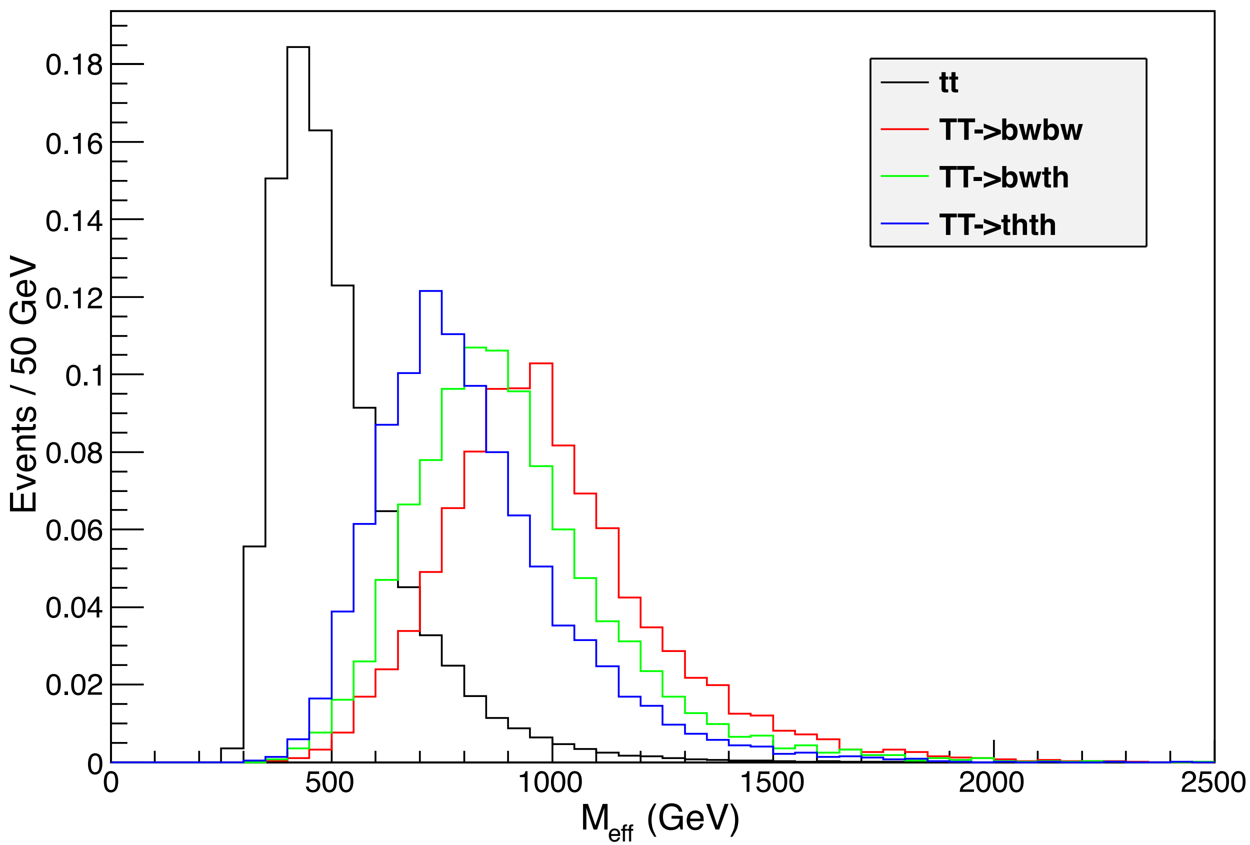
1 lepton + 1,2b-jets



1 lepton + 1,2b-jets



1 lepton + 1,2b-jets

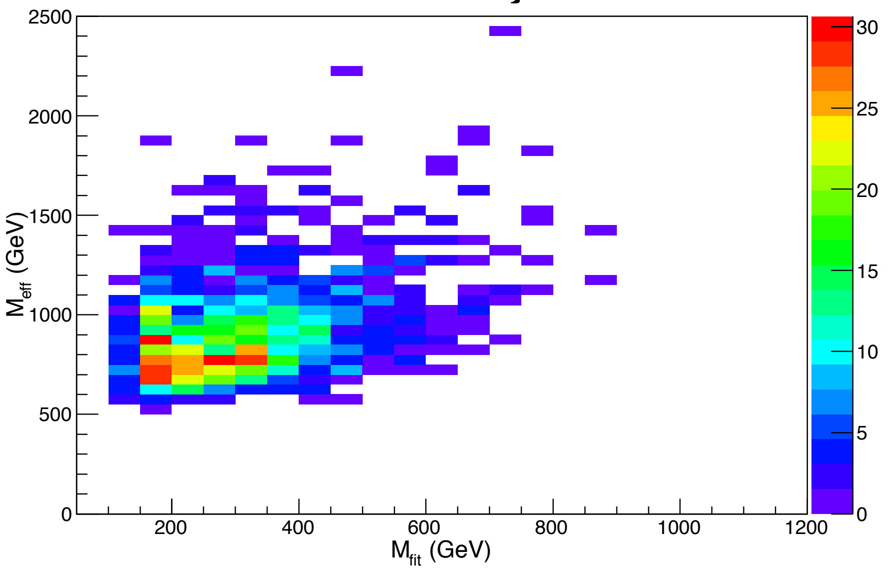


1 lepton + 1,2b-jets

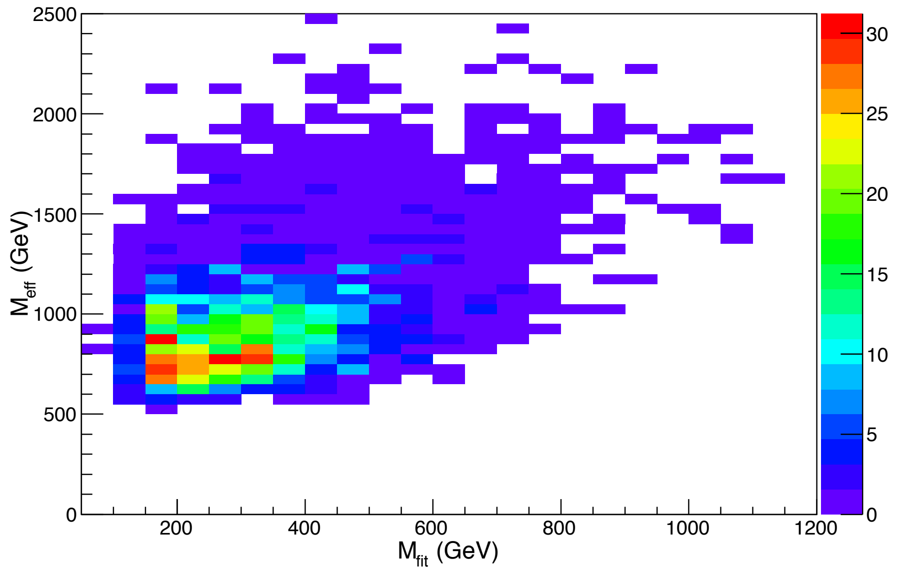
After hard b-jet cut,

$$m_{tp} = 500 \text{ GeV}, \ \sin\theta_L = 0.1, \ \sin\theta_R = 0.03$$

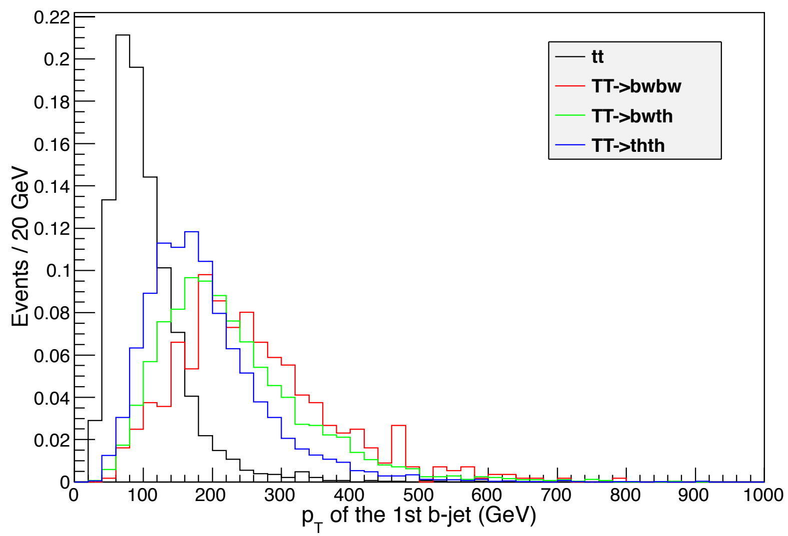
$t\bar{t}$ only

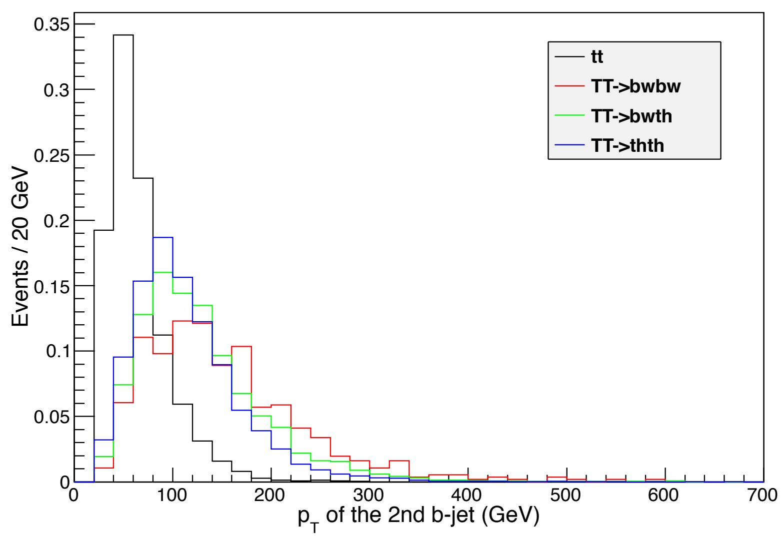


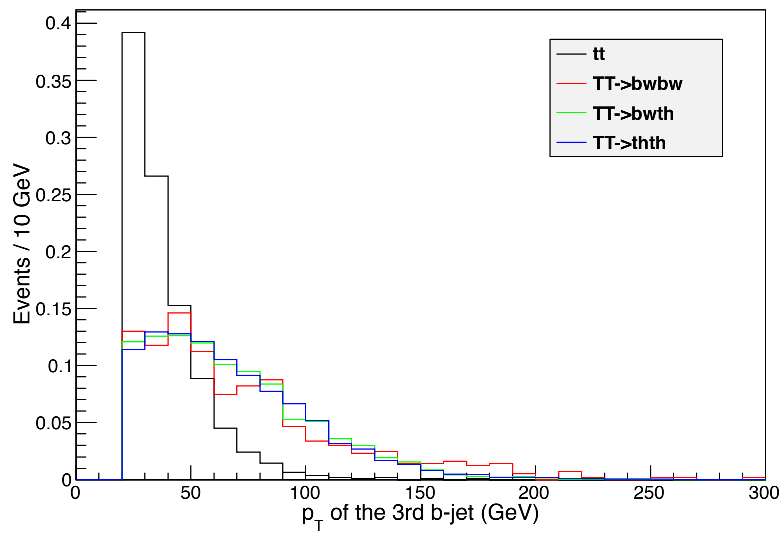
$t\bar{t}$ +signal



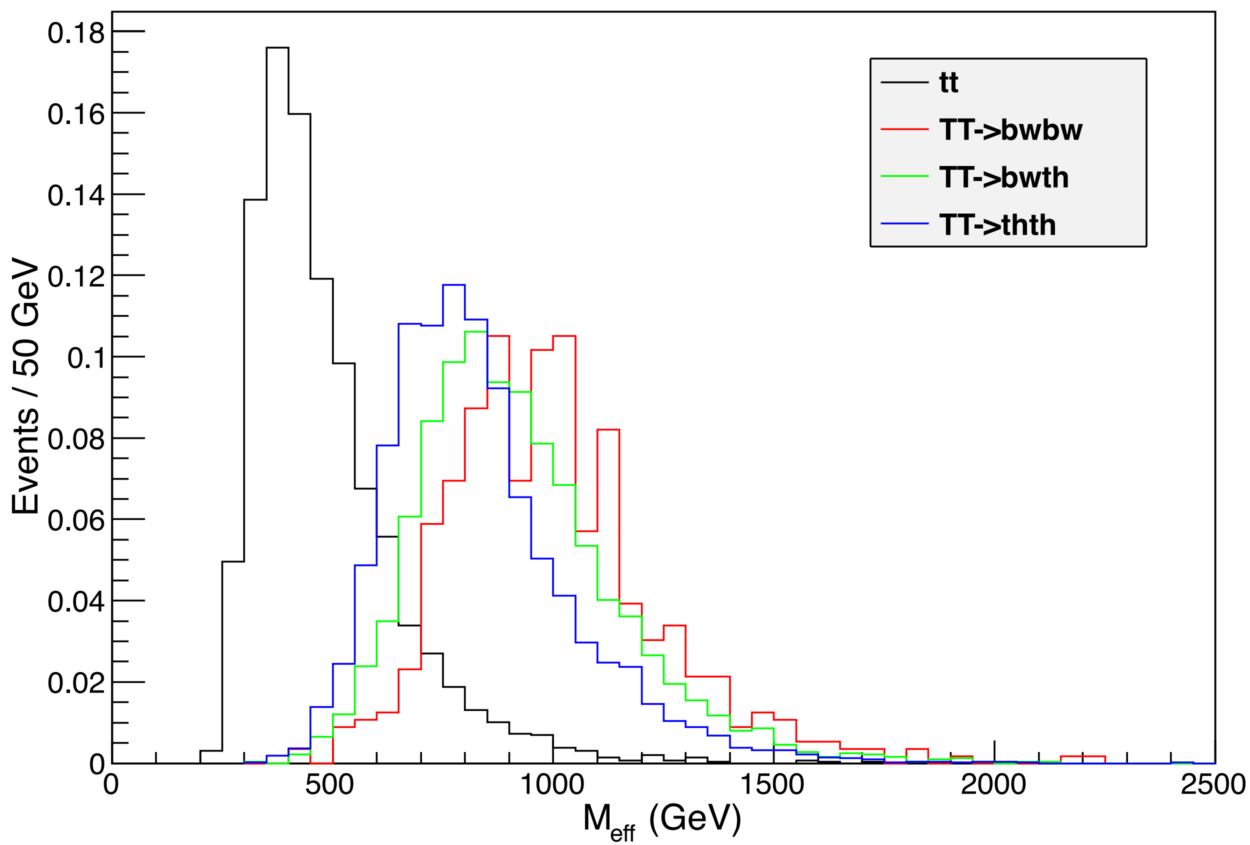
1 lepton + ≧3b-jets







1 lepton + ≧3b-jets



Possible terms

	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
Q^3	3	2	1/6
u^3_R	3	1	2/3
U_L	3	1	2/3
U_R	3	1	2/3
H	1	2	1/2

$$-m_U U_L^\dagger U_R + h.c.$$

$$-y_3 Q^{3\dagger} H^c u_R^3 - y_U Q^{3\dagger} H^c U_R + h.c.$$

$$-\frac{\lambda}{m_U} U_L^\dagger u_{3R} |H|^2 + h.c.$$

Parameterization

To diagonalize mass,

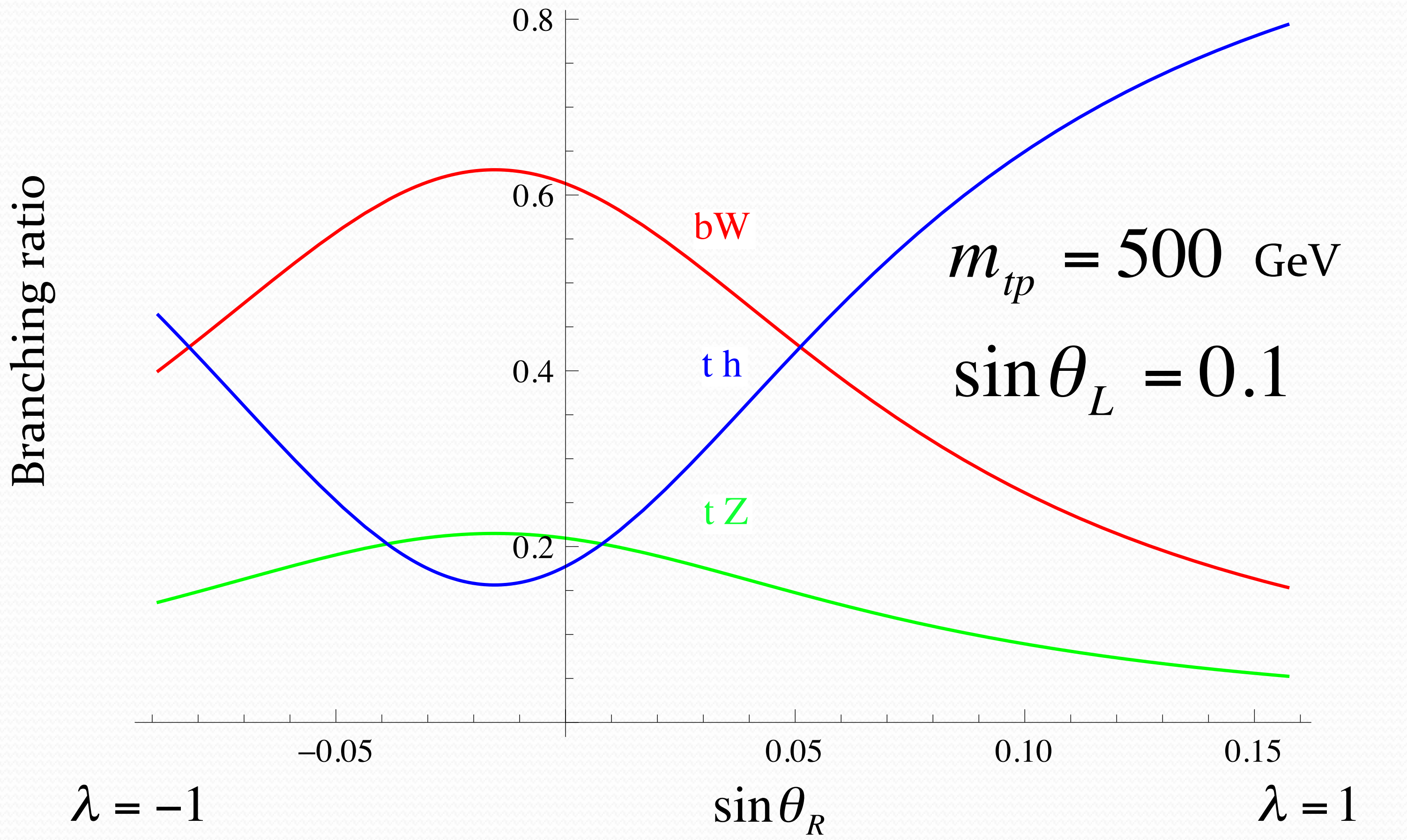
$$\begin{pmatrix} t_L \\ T_L \end{pmatrix} = \begin{pmatrix} \cos\theta_L & -\sin\theta_L \\ \sin\theta_L & \cos\theta_L \end{pmatrix} \begin{pmatrix} u_L^3 \\ U_L \end{pmatrix}$$

$$\begin{pmatrix} t_R \\ T_R \end{pmatrix} = \begin{pmatrix} \cos\theta_R & -\sin\theta_R \\ \sin\theta_R & \cos\theta_R \end{pmatrix} \begin{pmatrix} u_R^3 \\ U_R \end{pmatrix}$$

$$m_{tp}, \theta_L, \theta_R$$

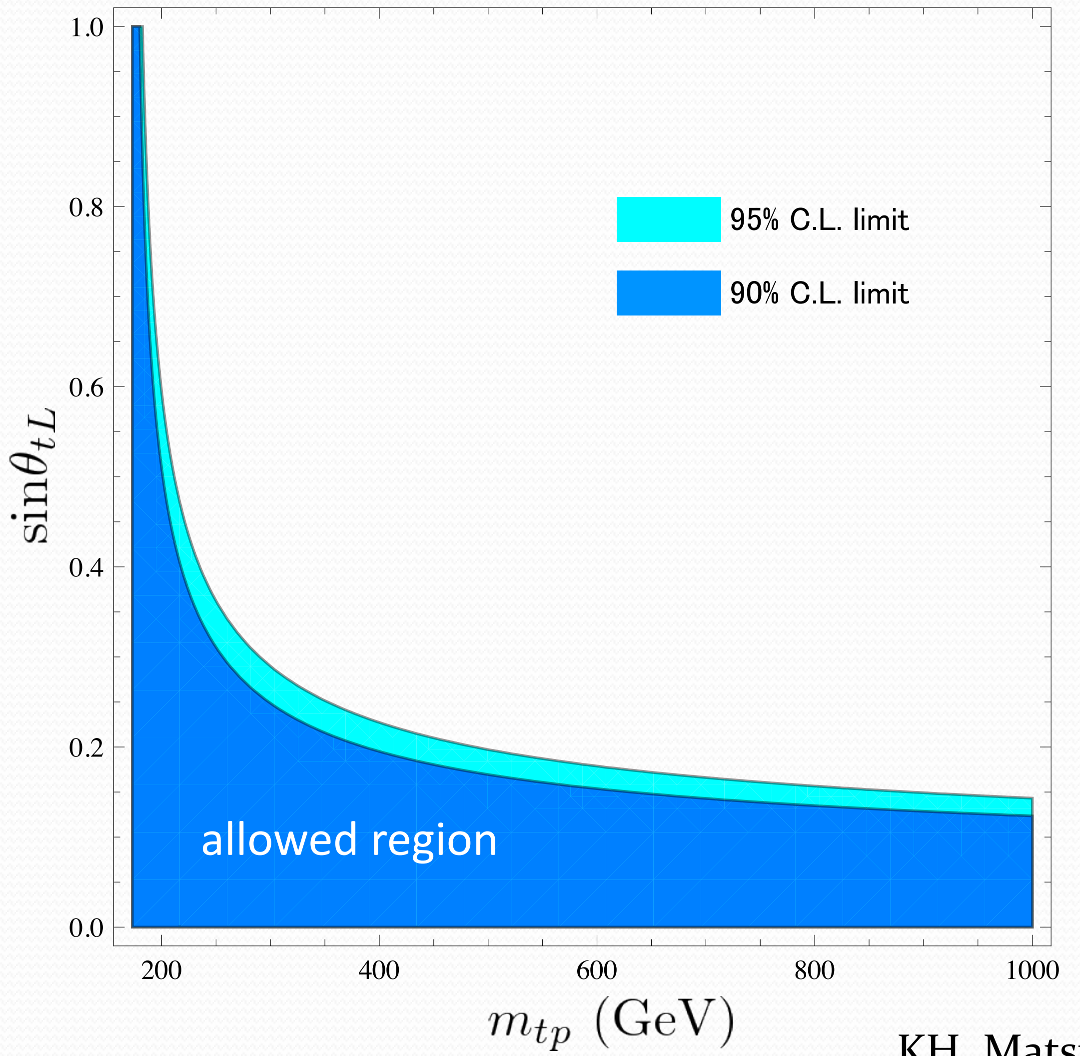
Branching ratio

Let's look at $\sin\theta_R$ dependence



KH (2012)

Constraint from EWPM



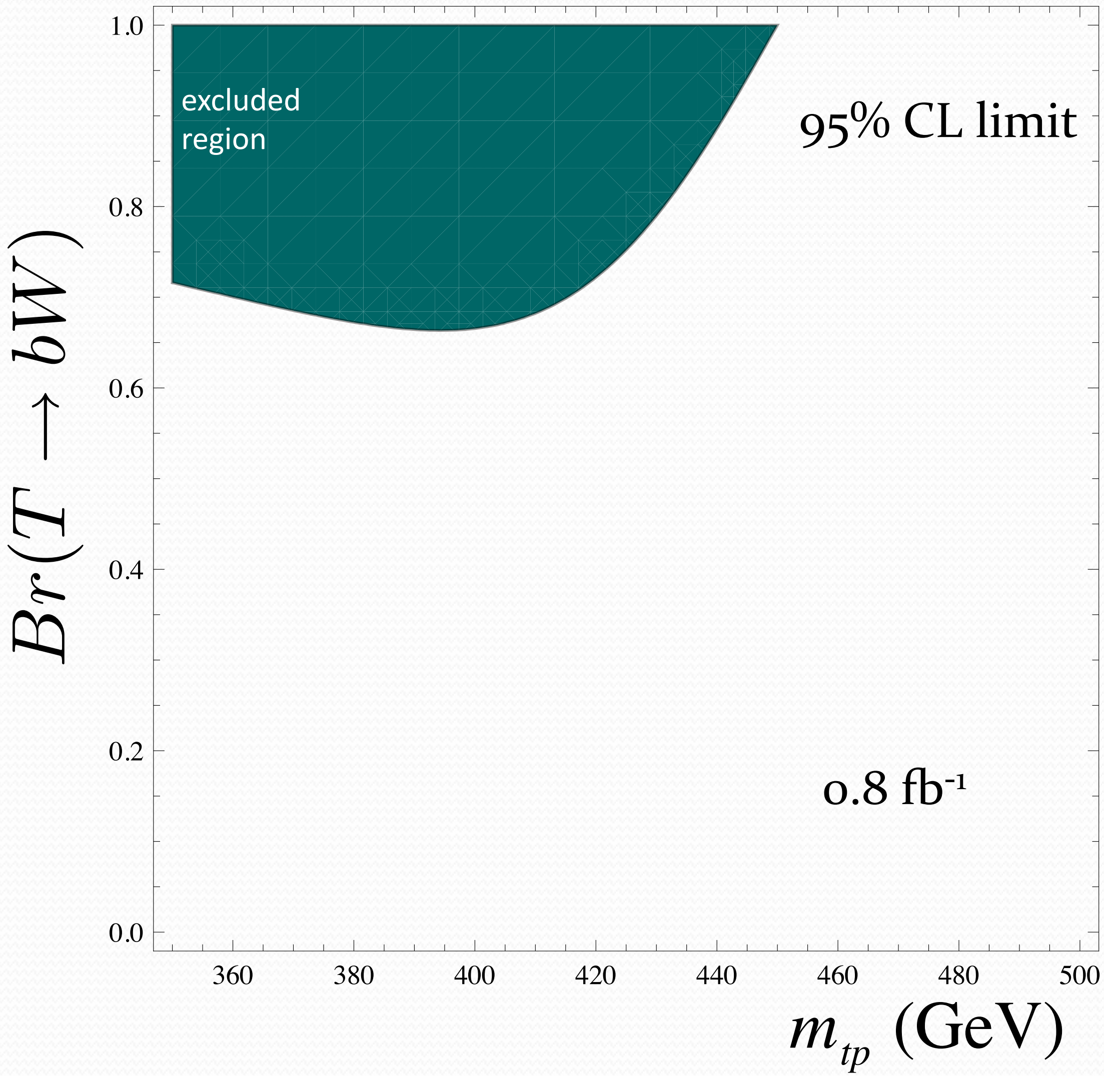
$m_h = 120$ GeV

S, T, U method with

$\sin^2\theta_{eff}^{lep}, \Gamma_{Z\to l^+l^-}, m_W$

KH, Matsumoto, Nojiri, Tobioka(2012)

Constraints from CMS result



Assuming pair creation and

$$T \to bW$$

1-lepton, b-jet search

Picture: KH, Matsumoto, Nojiri, Tobioka(2012)