Phenomenology of Twin Higgs Model

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Work in progress

Outline

- **Twin Higgs Model**

Goh's talk

- **Twin Higgs mechanism**
- **Left-right Twin Higgs model**

  Chacko, Goh, Harnik, hep-ph/0512088
- **New particles and model parameters**

- **Collider phenomenology**

  - **Heavy top quark**
  - **Heavy gauge bosons**
  - **Higgses**

Left-right Twin Higgs model

- U(4) × U(4), with gauged $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ + LR symmetry

Couple to gauge boson only

$$H = \begin{pmatrix} H_L \\ H_R \end{pmatrix}$$

SM Higgs doublet

↓ **EWSB**

SM neutral Higgs: H

$SU(2)_L$ Higgs doublet

$H_1^{\pm}$, H_2^0

$$\hat{H} = \begin{pmatrix} \hat{H}_L \\ \hat{H}_R \end{pmatrix}$$

3 eaten by heavy gauge bosons

Left 3 Higgses:

neutral Higgs ϕ^0, charged Higgs $\phi^{\pm}$

$$\langle H \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ f_1 \end{pmatrix}$$

7 GB

U(4) × U(4) → U(3) × U(3)

$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \rightarrow SU(2)_L \times U(1)_Y$

$$\langle \hat{H} \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ f_2 \end{pmatrix}$$

7 GB

$f_2 > f_1$

Left-right Twin Higgs model

Fermion sector:

$$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} = [2,1,1/2]\,, \quad L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} = [2,1,-1]\,,$$

$$Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix} = [1,2,1/3]\,, \quad L_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix} = [1,2,-1]\,,$$

Top quark mass:

$$T_L = [1,1,4/3]\,, \quad T_R = [1,1,4/3]\,,$$

$$yH_R^\dagger Q_R T_L + yH_L^\dagger Q_L T_R + M T_L T_R + h.c.$$

Top quark mass eigenstates: SM top and t_H

New particles

- **Heavy gauge bosons:** W_H, Z_H — $m^2_{WH,ZH} \sim g^2(f_1^2+f_2^2)$
- **Heavy top:** t_H — $m^2_{TH} \sim M^2+y^2f_1^2$
- **Other $SU(2)_R$ Higgses:** $\phi^{\pm}$ — $m^2_{\phi\pm} \sim g^4/(16\pi^2)f_2^2 \log(\Lambda/gf_2)$

  ϕ^0 — $m^2_{\phi 0} \sim B\,(f_2/f_1)$

  B: small, (50-100 GeV)^2
- **Other $SU(2)_L$ Higgs** $H_1^{\pm}$ — $m^2_{H1\pm,\ H20} \sim \mu$

  H_2^0 — **μ: soft symmetry breaking, $O(f_1)$**

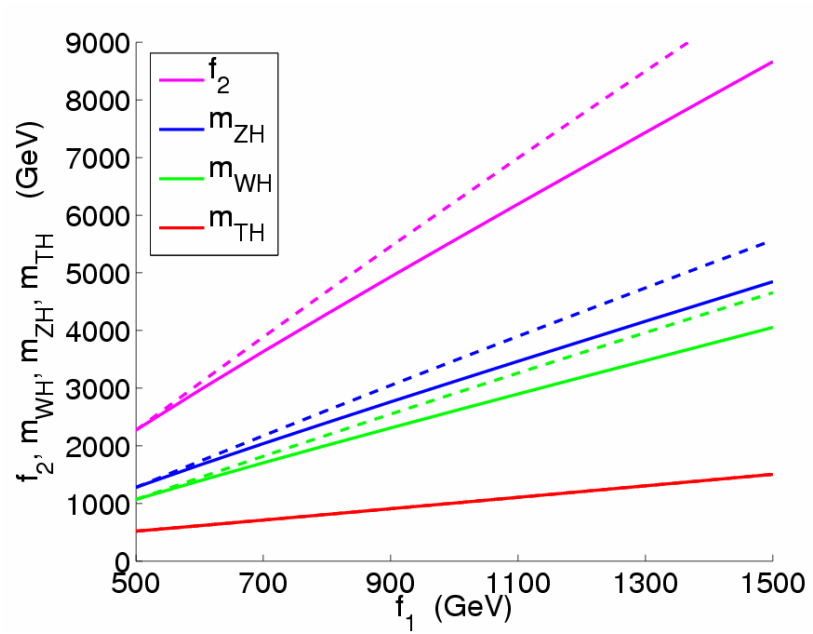
Model parameters

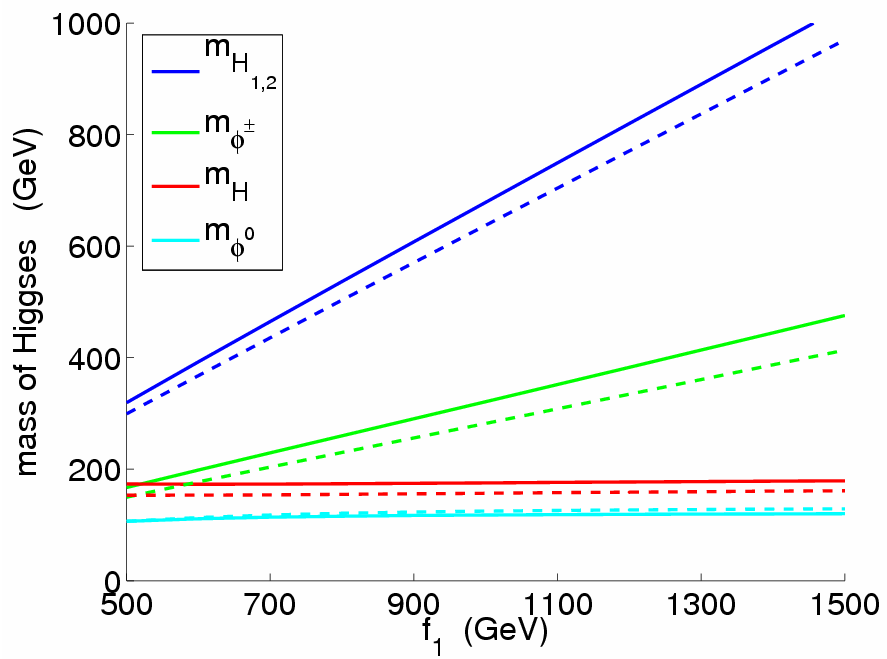
- **Model parameters: f_1, (f_2, y), Λ, M, $\sqrt{B}$, μ**

  fixed by Higgs VEV — **fixed by top quark mass**

- **Determine particle masses and interactions**

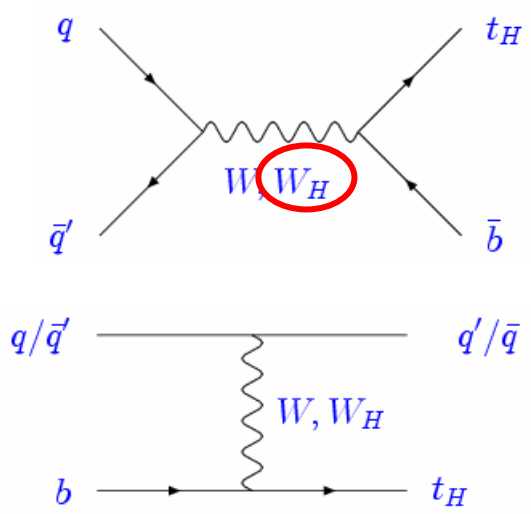
$\Lambda = 4\pi f_1$ or $2\pi f_1$
M=150 GeV
$\sqrt{B}$=50 GeV
$\mu = f_1/2$





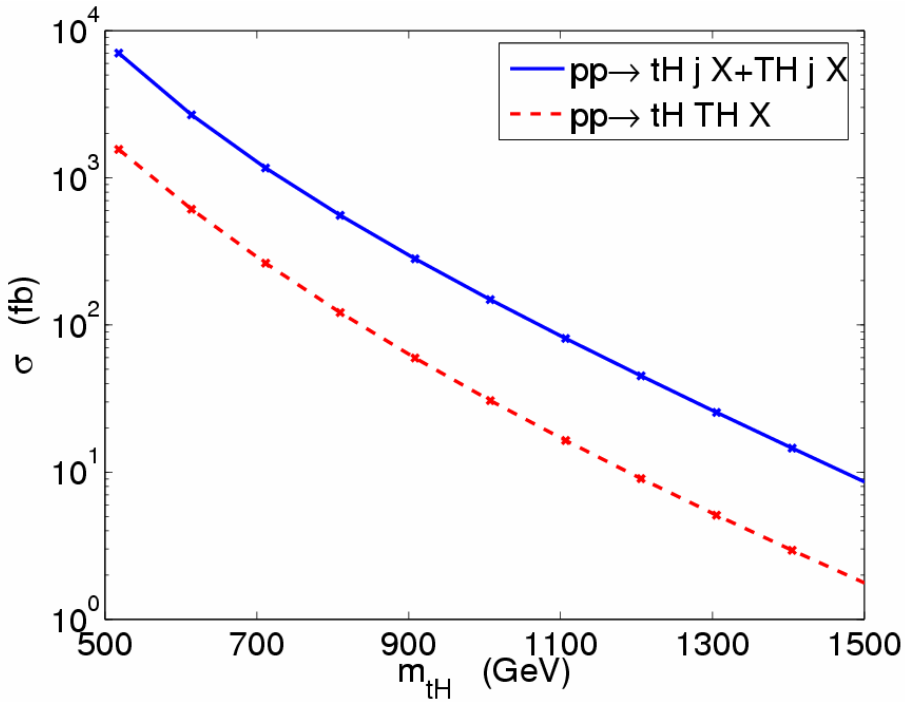
Heavy top t_H production

- **single heavy top production**

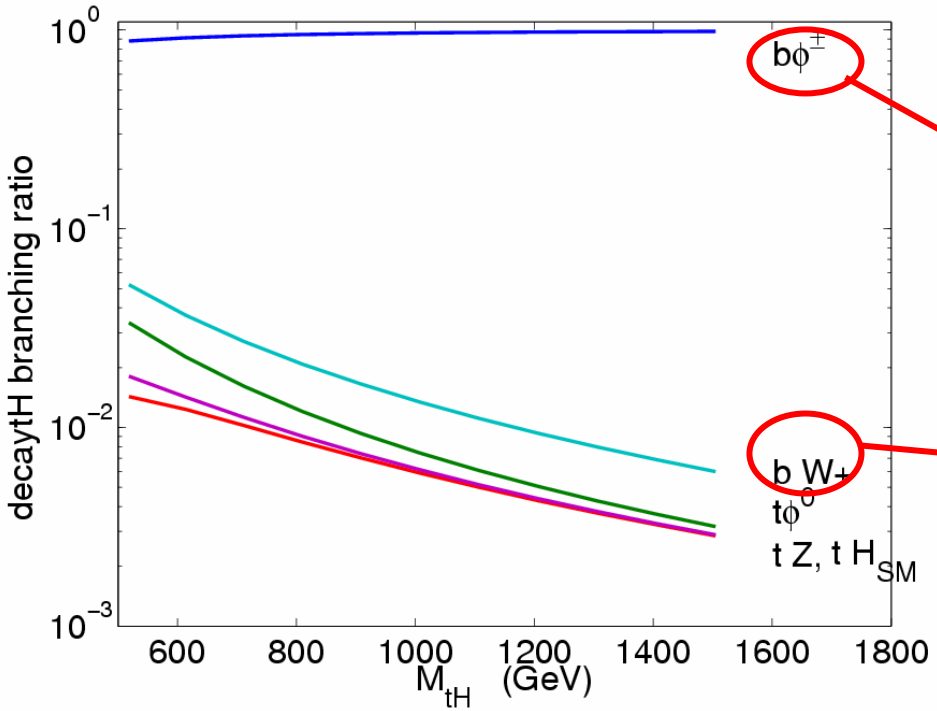


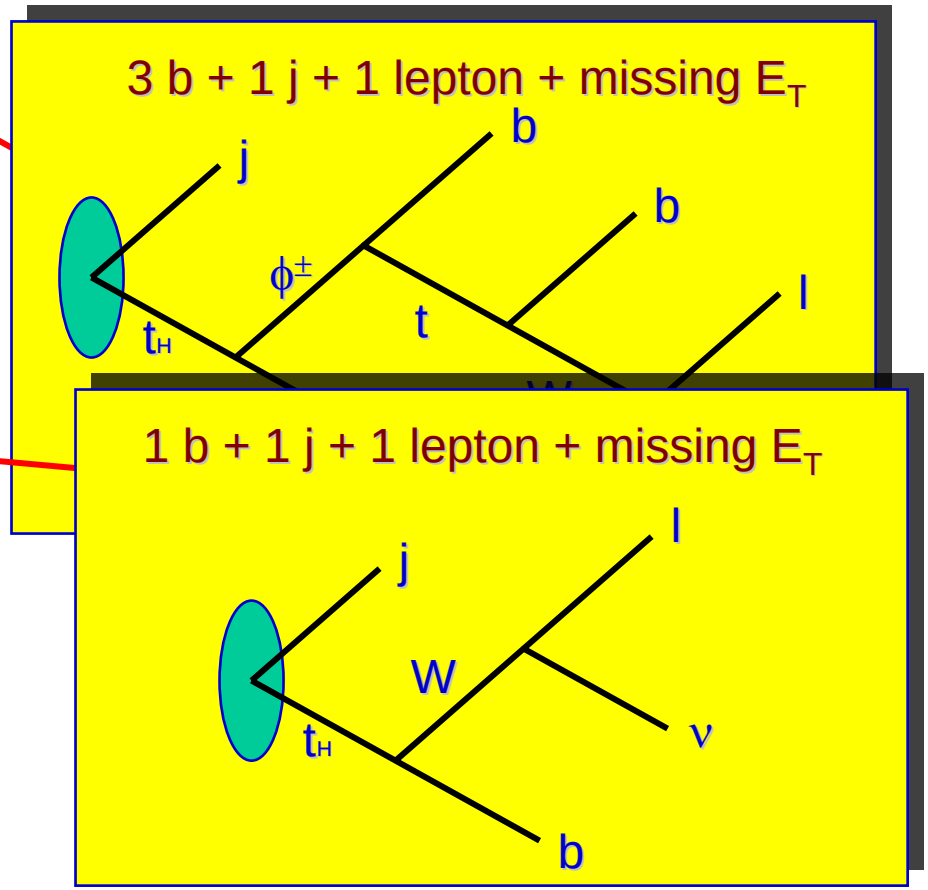
- **heavy top pair production**

$$gg, q\bar{q} \longrightarrow t_H \bar{t}_H$$



Heavy top t_H decay

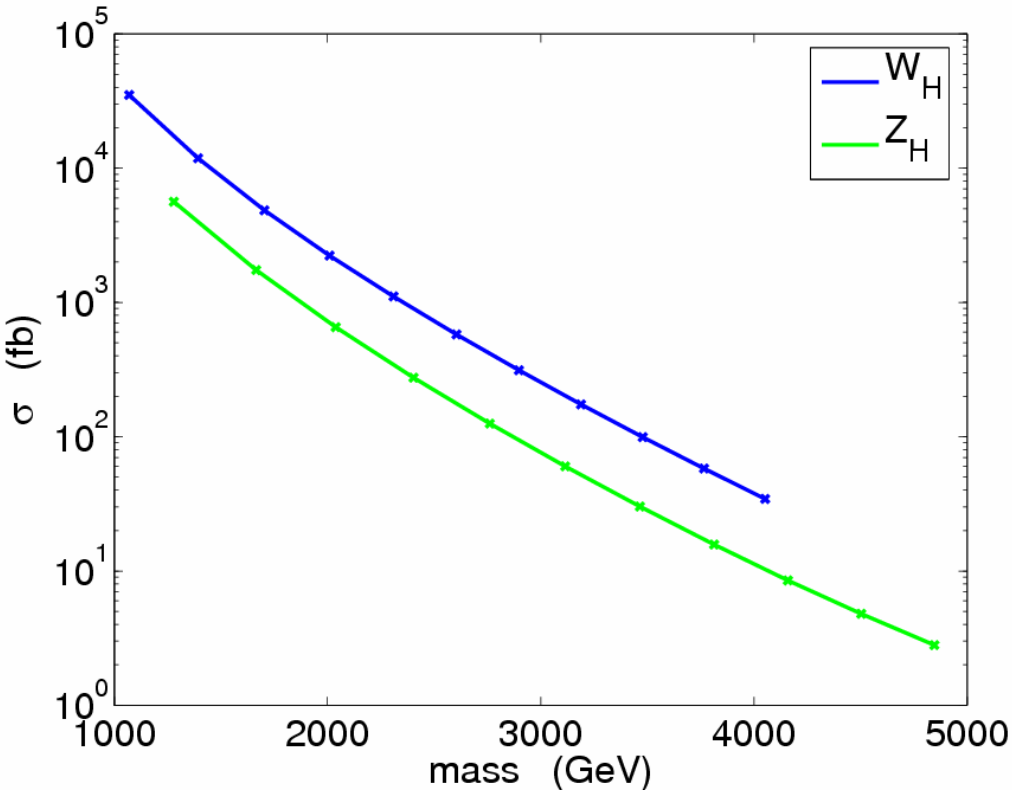




Heavy gauge boson production

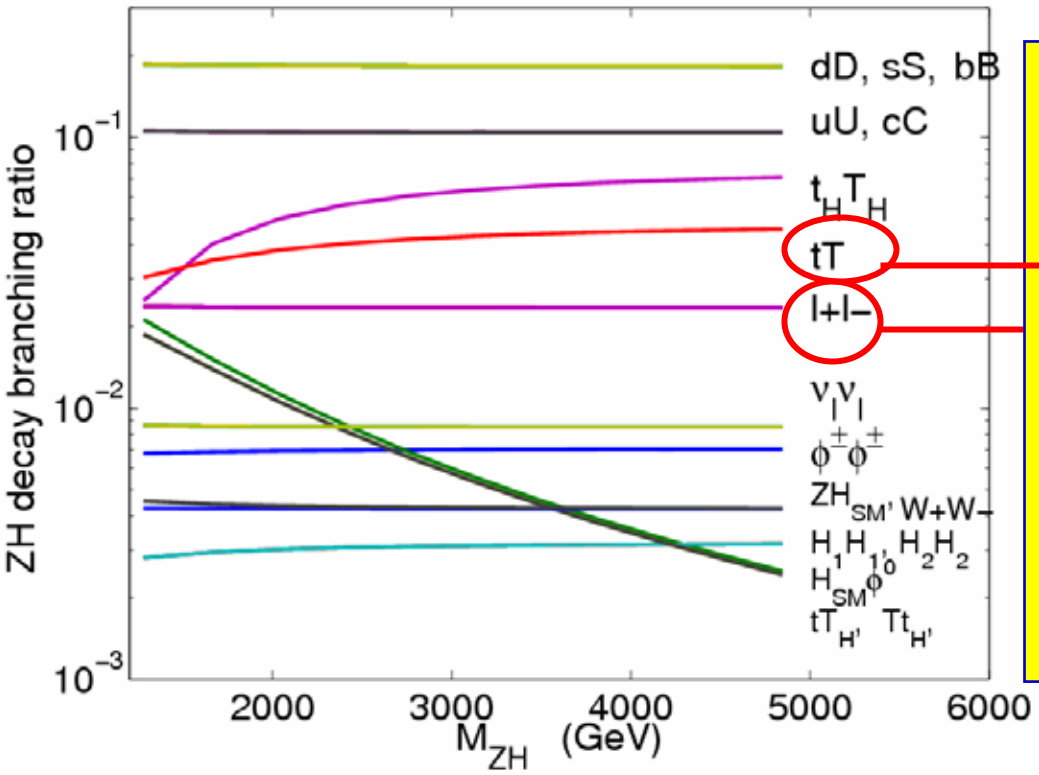
- **Drell-Yan process**

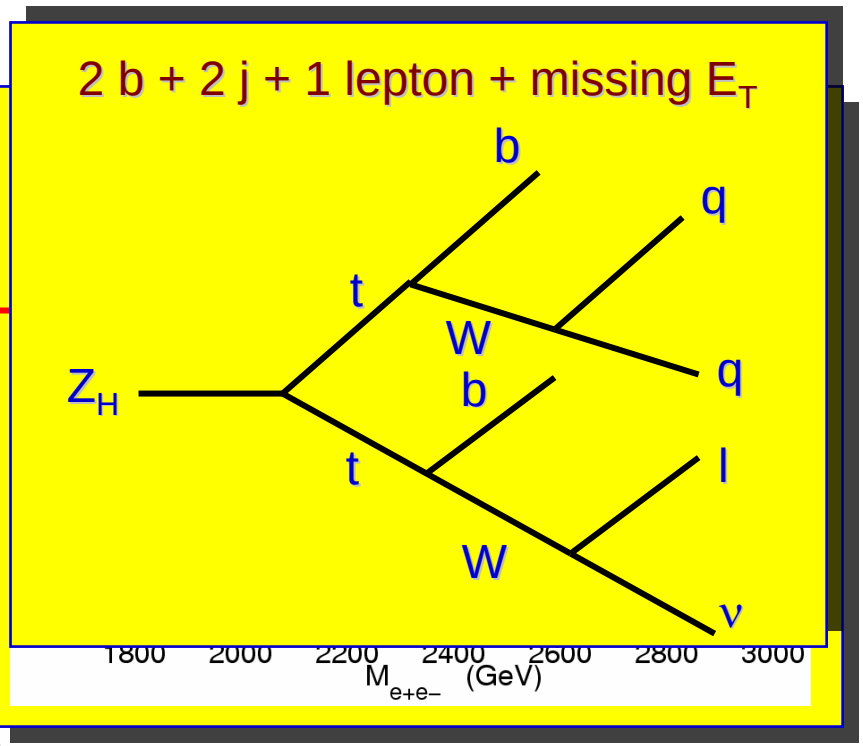
$$q\bar{q}' \rightarrow W_H, Z_H$$



Z_H decay

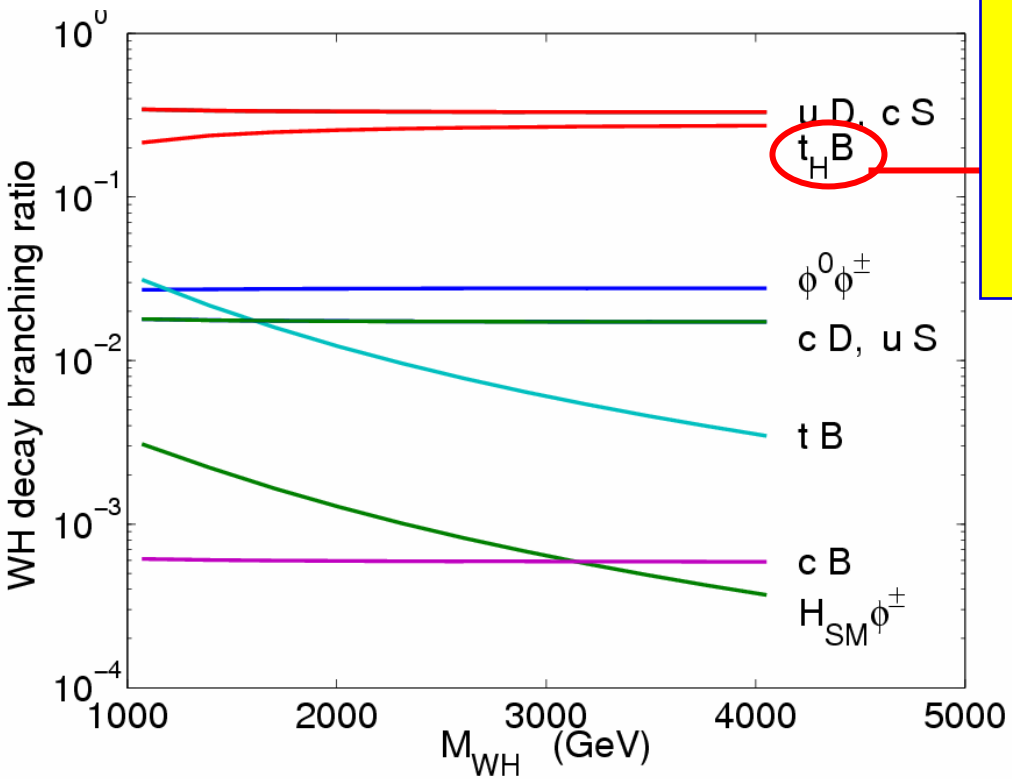
- Z_H


ZH decay branching ratio
10^{-1}
10^{-2}
10^{-3}
2000
3000
4000
5000
6000
M_{ZH} (GeV)
dD, sS, bB
uU, cC
$t_H T_H$
tT
l+l−
$\nu_l \nu_l$
$\phi^{\pm}\phi^{\pm}$
ZH_{SM}, W+W−
$H_1 H_{1'}$, $H_2 H_2$
$H_{SM}\phi^0$
$tT_{H'}$, $Tt_{H'}$


2 b + 2 j + 1 lepton + missing E_T
Z_H
t
b
W
q
q
t
b
W
l
ν
1800
2000
2200
2400
2600
2800
3000
M_{e+e-} (GeV)

W_H decay

- W_H



$t_H \rightarrow b\phi^\pm$: 4b + 1 lepton + missing E_T

$t_H \rightarrow bW$: 2b + 1 lepton + missing E_T

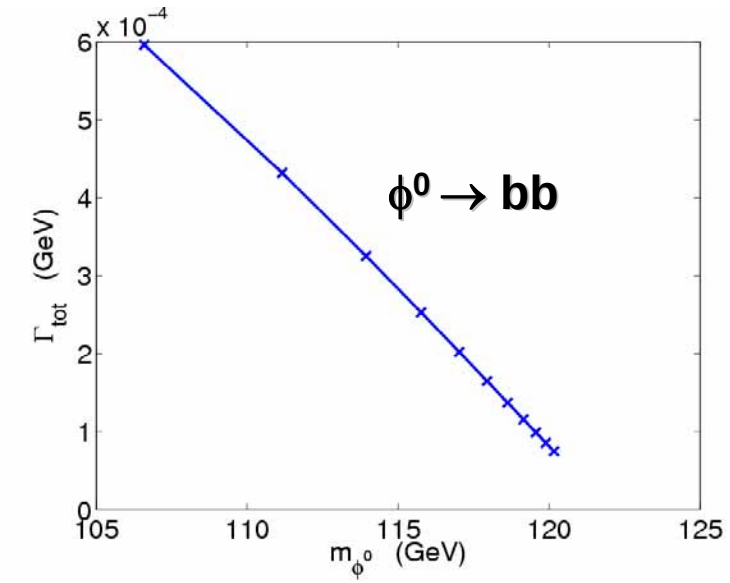
$t_H \rightarrow tZ$: 2b + 3 lepton + missing E_T

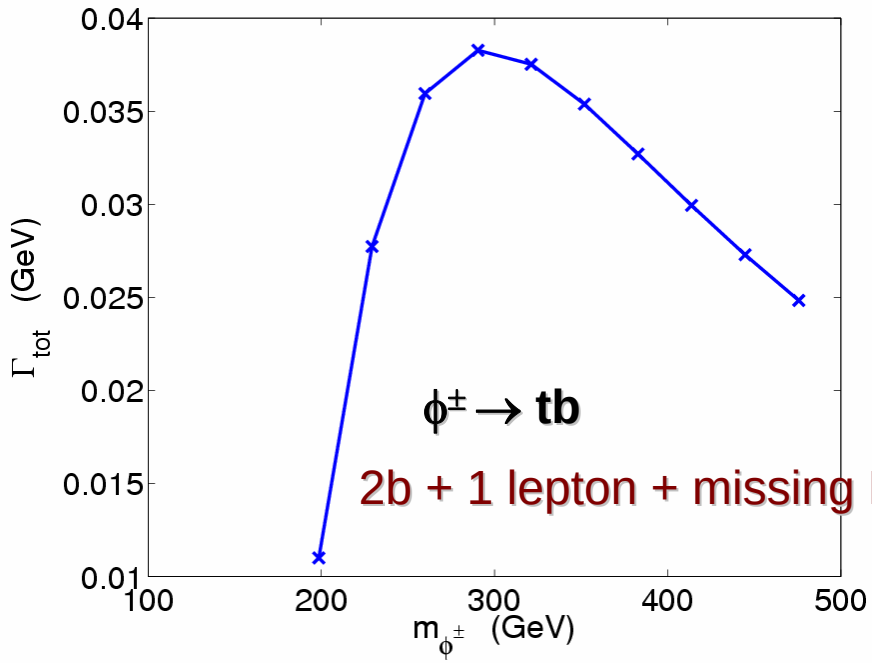
Higgses

SM Higgs

- $m_H \sim 150\text{-}170$ GeV, depending on f_1, Λ and M
- Higgs searches:
  1. $gg \rightarrow H \rightarrow ZZ^* \rightarrow llll$
  2. $gg \rightarrow H \rightarrow WW^* \rightarrow l\nu l\nu$
  3. $WBF \rightarrow qqH \rightarrow qqWW^* \rightarrow qql\nu l\nu$

$SU(2)_R$ Higgs: ϕ^0, $\phi^\pm$

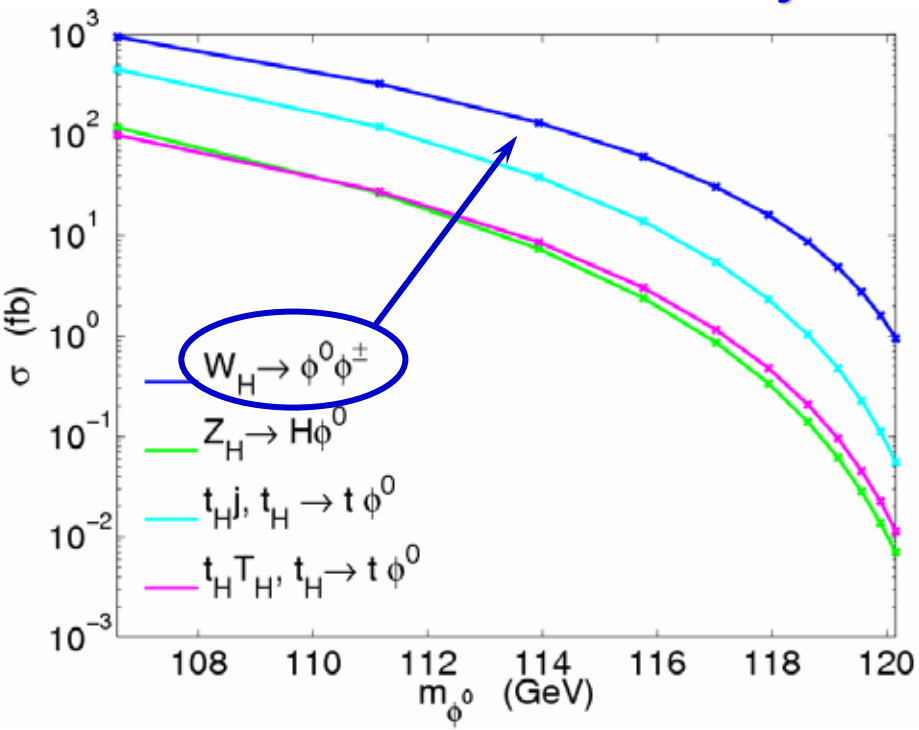


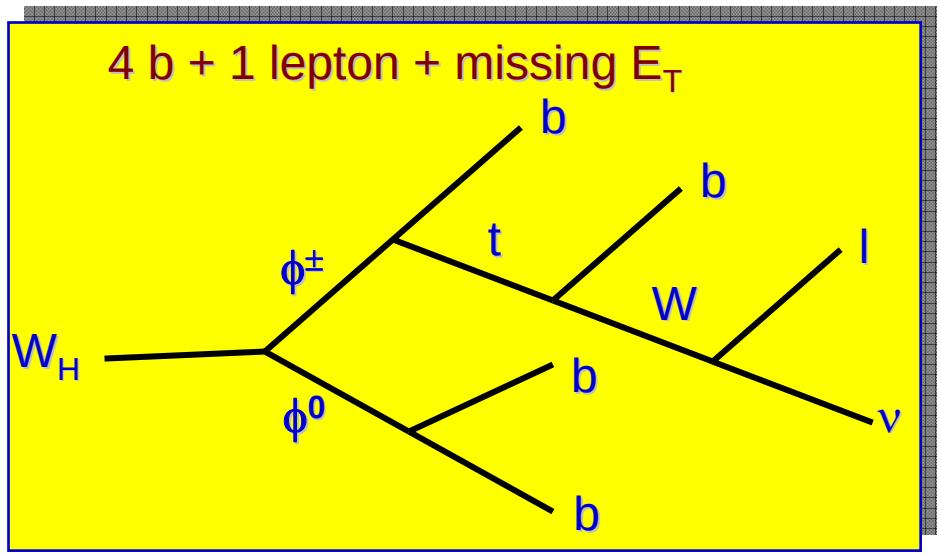


ϕ^0

Neutral Higgs ϕ^0

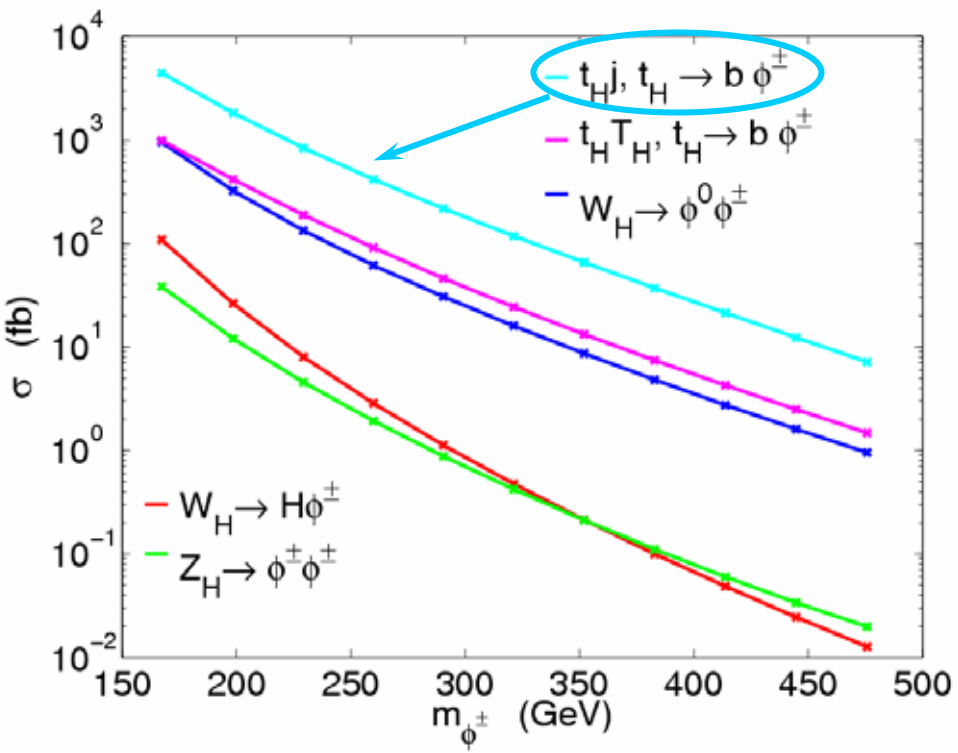
- $gg \rightarrow \phi^0 \rightarrow bb$, QCD background overwhelming
- no $W\phi^0$, $Z\phi^0$ associated production (no such coupling)
- $bb\phi^0$, $tb\phi^0$, $tt\phi^0$ cross section small
- Produced via the decay of heavy particles

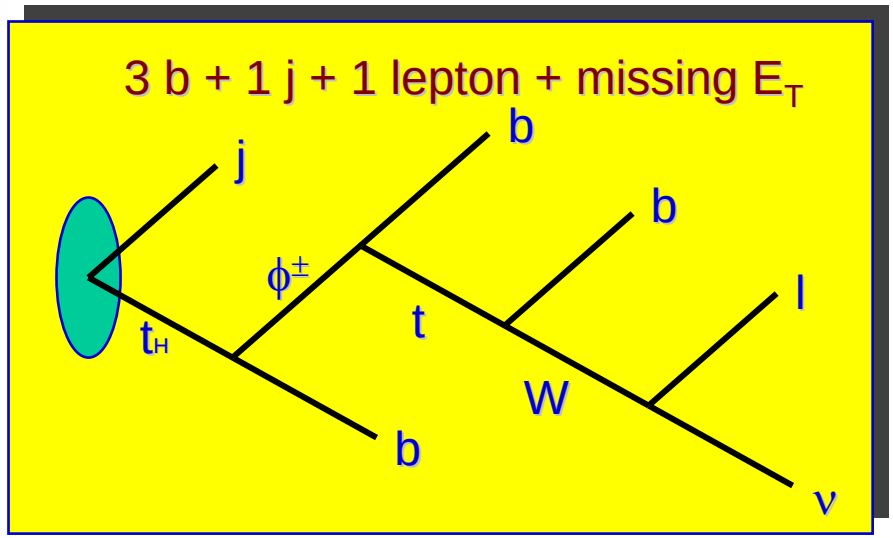




Neutral Higgs $\phi^{\pm}$

- no $W\phi^{\pm}$, $Z\phi^{\pm}$ associated production (no such coupling)
- $bb\phi^{\pm}$, $tb\phi^{\pm}$, $tt\phi^{\pm}$ cross section small
- Produced via the decay of heavy particles





$H_1^{\pm}$, H_2^0

Higgs that couple to gauge boson only: $H_1^{\pm}$, H_2^0

- $H_1^{\pm}H_2^0$, $H_1^{\pm}H_1^{\pm}$, $H_2^0H_2^0$, associated production (small)
- H_2^0 stable : missing energy
- $H_1^{\pm} \rightarrow H_2^0$ + soft jets/leptons

  if decay fast enough: appears as missing energy

  if decay slow: track !

H_2^0: good dark matter candidates

M=0 case

Top Yukawa:

$$yH_R^\dagger Q_R T_L + yH_L^\dagger Q_L T_R + h.c.$$

f_1 $\qquad$ v

$t_H = (T_L, t_R)$, $m_{tH} = yf_1$ $\qquad$ $t_{SM} = (t_L, T_R)$, $m_t = yv$

Gauge coupling

- ✓ $W - t - b$
- × $W - t_H - b$
- × $W_H - t - b$
- ✓ $W_H - t_H - b$

- ✓ $Z - t - t$
- ✓ $Z - t_H - t_H$
- × $Z - t_H - t$
- ✓ $Z_H - t - t$
- ✓ $Z_H - t_H - t_H$
- × $Z_H - t_H - t$

Yukawa coupling

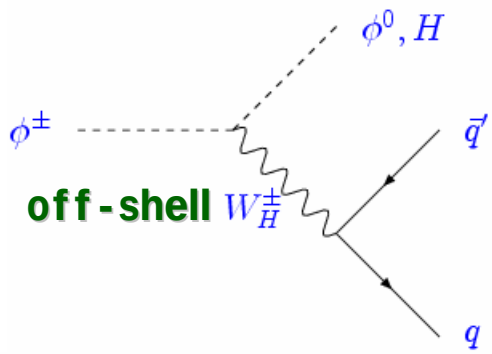
- ✓ $\phi^0 - t_H - t_H$
- × $\phi^0 - t - t$
- × $\phi^0 - t_H - t$

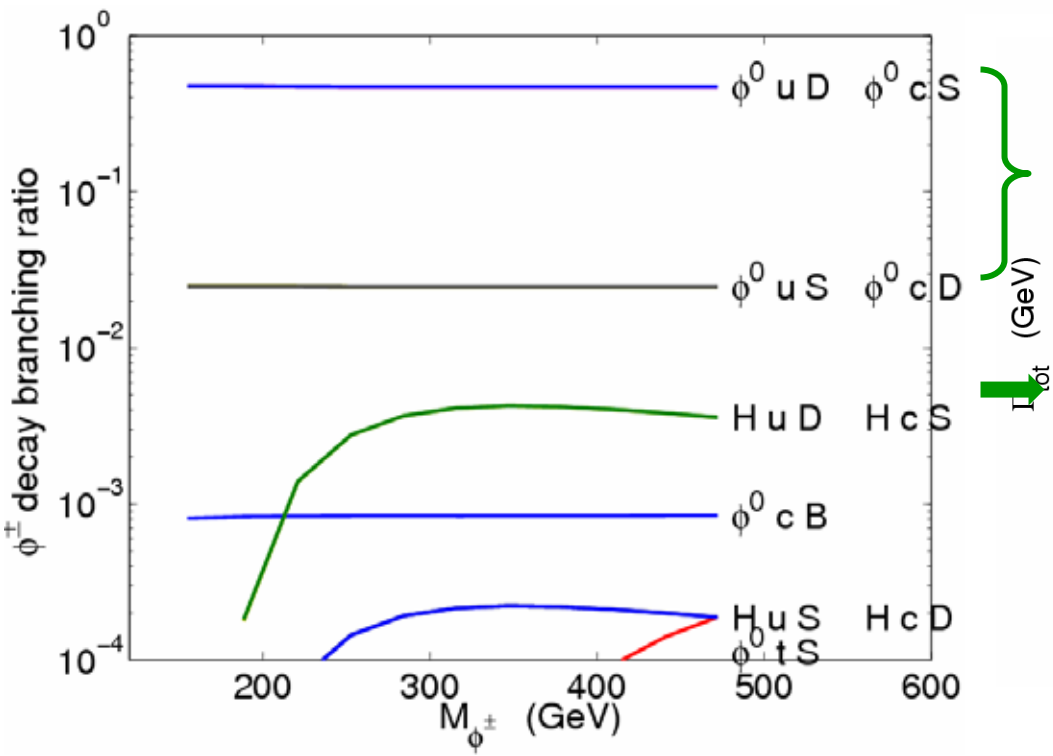
- ✓ $H - t - t$
- ✓ $H - t_H - t_H$ (small)
- × $H - t_H - t$

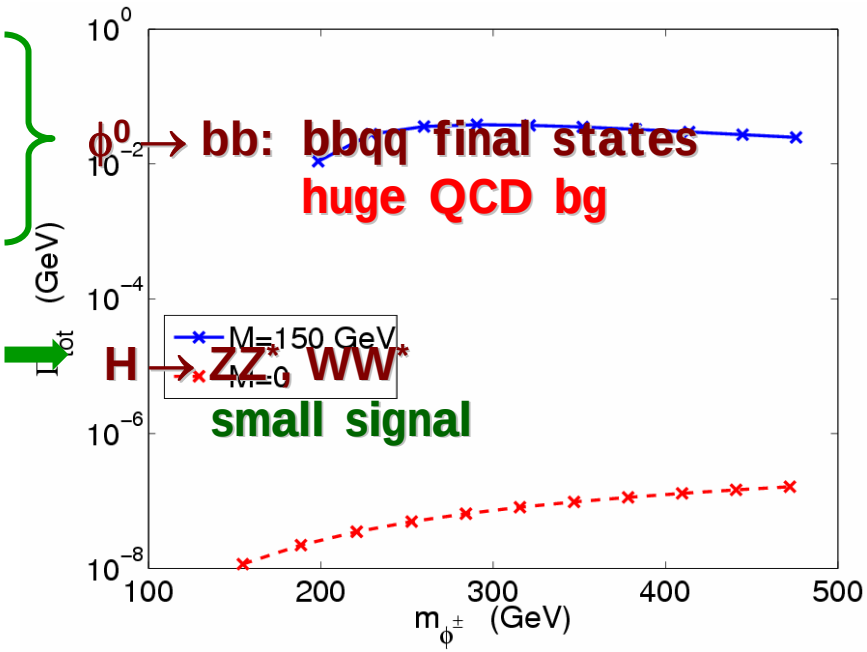
- ✓ $\phi^\pm - t_H - b$
- × $\phi^\pm - t - b$ ⟸ $\phi^\pm \not\to t + b$ (~100%)

$\phi^{\pm}$ decay

- No two body decay
- Leading decay: 3 body



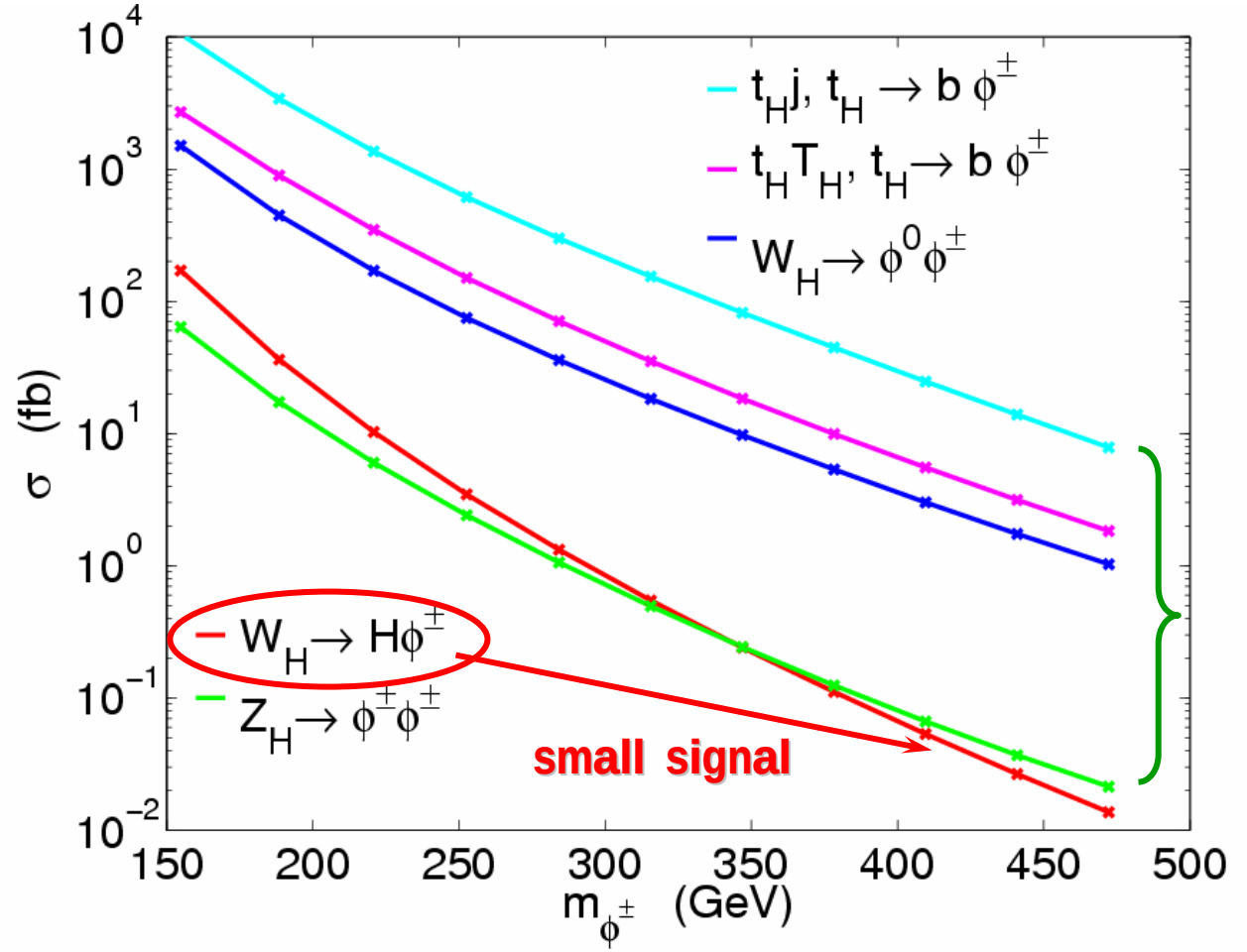




$\phi^0 \rightarrow$ bb: bbqq final states
huge QCD bg

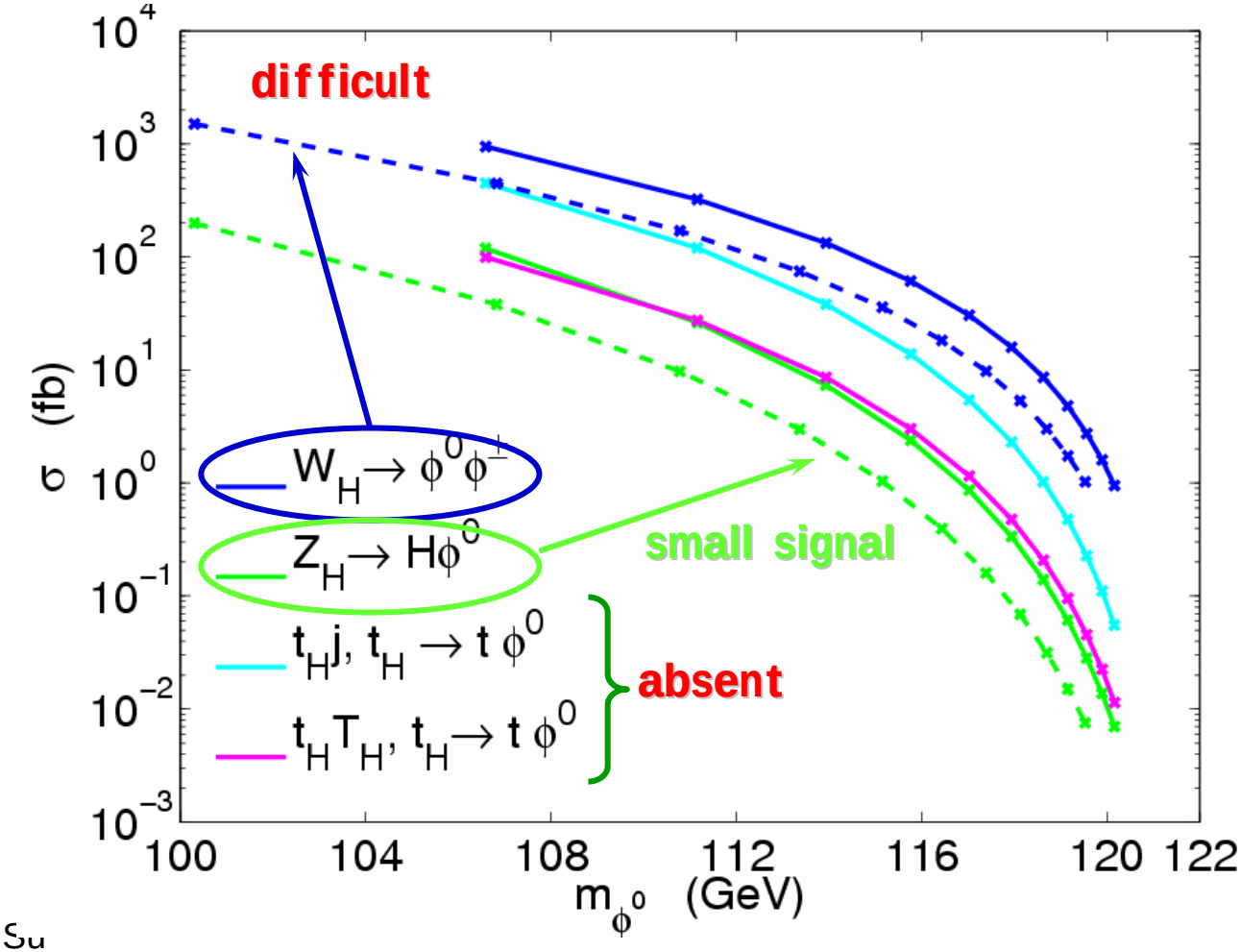
H $\rightarrow$ ZZ*, WW*
small signal

$\phi^{\pm}$ discovery



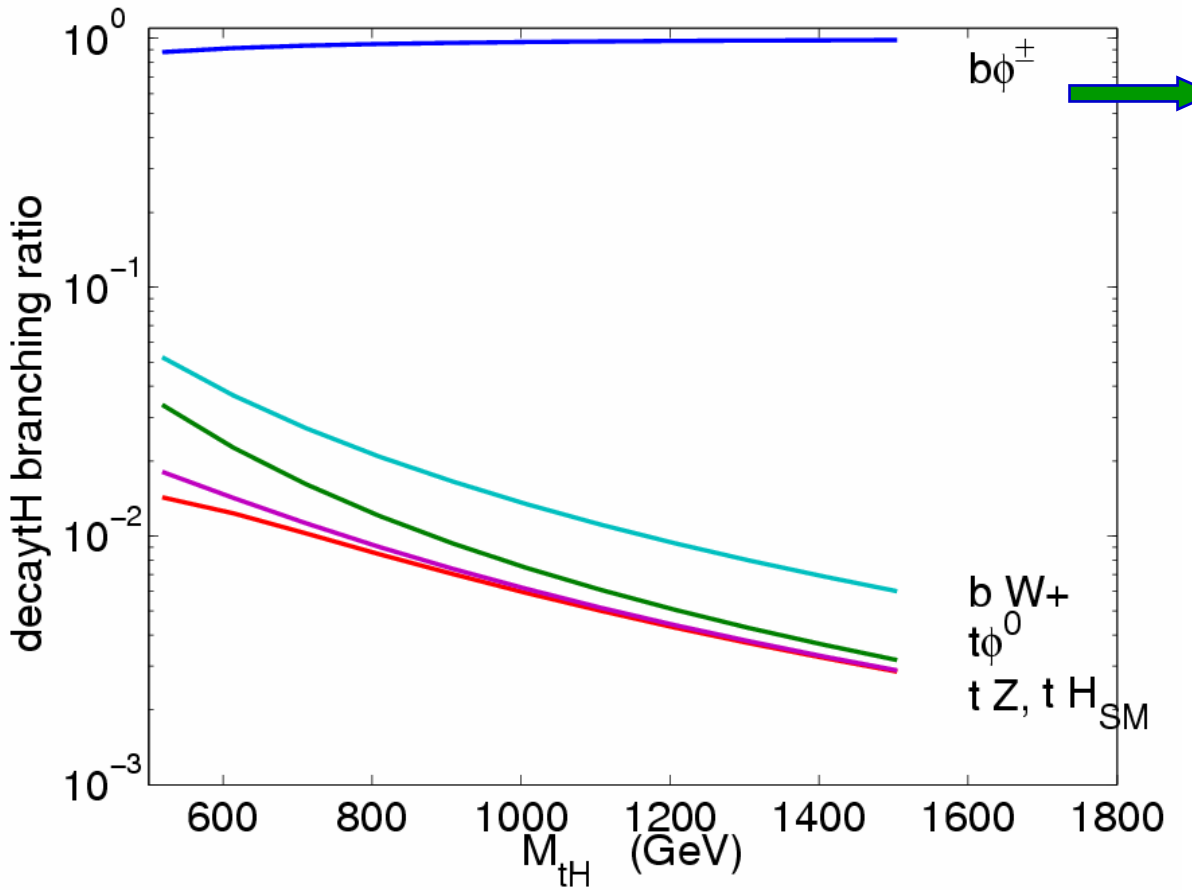
Difficult
Large QCD bg or small signal

ϕ^0 discovery



Heavy top t_H discovery

- single, pair production does not change much.
- decay: only $t_H \rightarrow b\,\phi^{\pm}$ (100%)



100%
either huge QCD bg
Or small signal

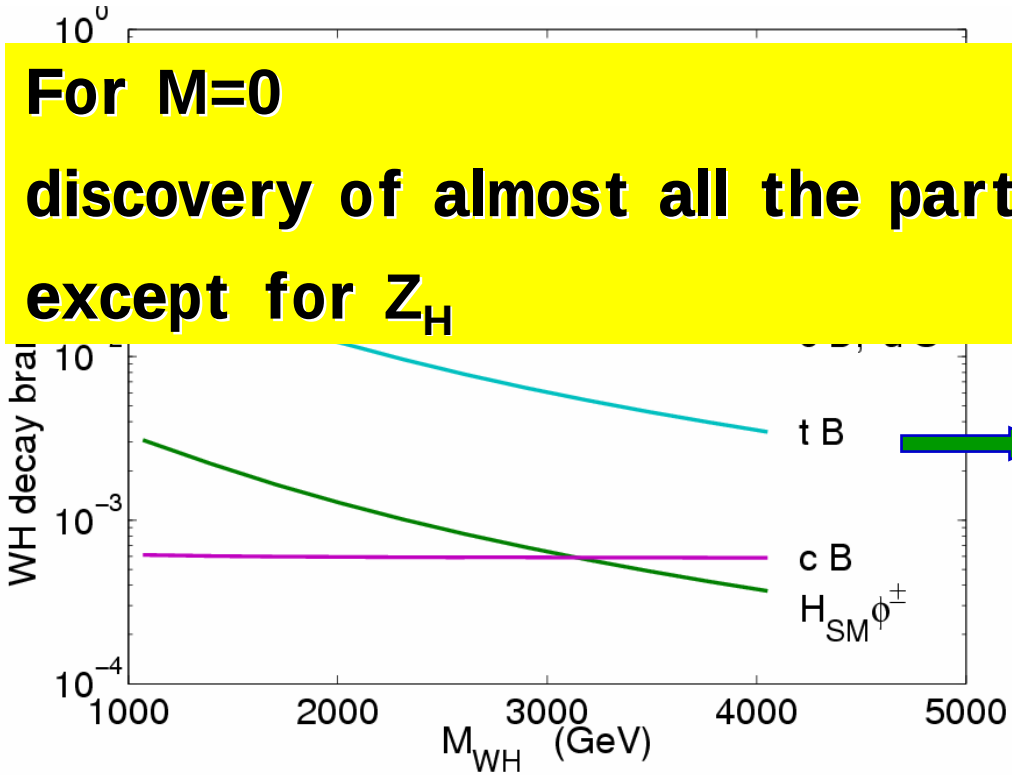
absent

Heavy gauge boson discovery

- Z_H, W_H drell-yan cross section does not change
- Z_H: $Z_H \rightarrow ll$ does not change much ✓
  $Br(Z_H \rightarrow t\, t_H) = 0$
- W_H: difficult

For M=0

discovery of almost all the particle are difficult except for Z_H



absent

Conclusions

- Left-right twin Higgs model: Higgs as pseudo-goldstone boson quadratic divergence forbidden by left-right symmetry
- New particles
  - Heavy gauge boson: W_H, Z_H
  - Heavy top quark t_H
  - New Higgses: ϕ^0, $\phi^{\pm}$, $H_1^{\pm}$, H_2^0 (DM)
- M≠0: rich collider phenomenology
- M=0: difficult except for Z_H
- Future work
  - Pick certain channel for detailed study: background, cuts,…
  - Identify twin Higgs mechanism
  - Dark matter study
  - Comparison with other models, e.g., little higgs