Study Twin Higgs with Comphep

a model

a tool

My experience in learning/using Comphep

Twin Higgs Experts:

Chacko
Harnik
...

Shufang Su
University of Arizona

Comphep Experts:

Pukhov
Matchev
Belyaev
Hubisz
...

Shufang Su and Hock-Seng Goh
Work in progress

Outline

- Twin Higgs model (Type II)
  - New particles
  - Model parameters
- Study Twin Higgs with Comphep
  - create model
  - particle decay
  - production cross section
  - distinguish signal from background

Twin Higgs Model

Higgs as pseudo-Goldstone boson of a global symmetry

its mass is protected against radiative corrections

- Little Higgs mechanism: collective symmetry breaking
- Twin Higgs mechanism: discrete symmetry

Quote from Chacko:

"Key ingredient of the Twin Higgs mechanism:

the dimensionful terms in the Lagrangian have a larger global symmetry when you impose a discrete symmetry.
Simplest discrete symmetry is Z_2 identified with parity."

Mirror symmetry

Type IA TH: Chacko, Goh, Harnik, hep-ph/0506256
Type IB TH: Chacko, Nomura, Papucci, Perez, hep-ph/0510273

→ Left-right symmetry:

Type II TH: Chacko, Goh and Harnik, hep-ph/0512088

Type II Twin Higgs Model

- Global U(4) , with subgroup $SU(2)_L$ X $SU(2)_R$ X $U(1)_{B-L}$ gauged
- Left-right symmetry: $g_L=g_R$, ($y_L=y_R$)

A linear realization:

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

SM Higgs doublet

↓ EWSB

SM neutral Higgs: H

3 eaten by heavy gauge bosons

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

7 GB

$U(4) \rightarrow U(3)$

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

Twin Higgs Mechanism

Quadratic divergence forbidden by left-right symmetry

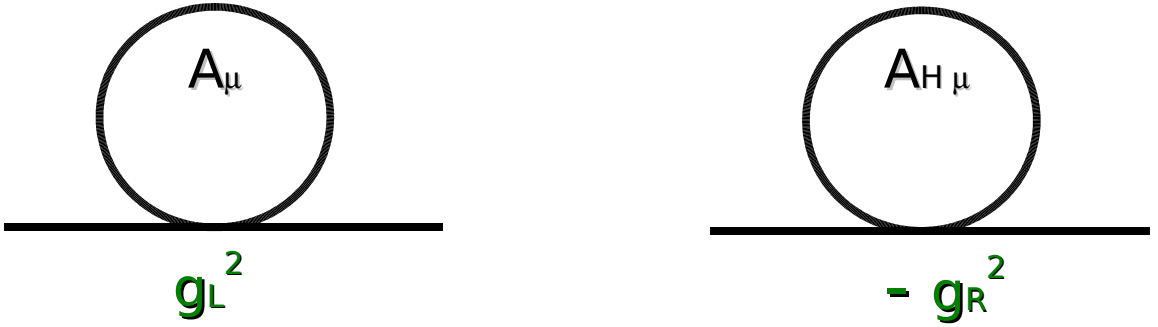
$$\Delta V = (9\, g_L^2 \Lambda^2)/(64\, \pi^2) H_L^\dagger H_L + (9\, g_R^2 \Lambda^2)/(64\, \pi^2) H_R^\dagger H_R$$

$$\downarrow \quad g_L = g_R = g$$

$$\Delta V = (9\, g^2 \Lambda^2)/(64\, \pi^2)(H_L^\dagger H_L + H_R^\dagger H_R) = (9\, g^2 \Lambda^2)/(64\, \pi^2) H^\dagger H$$

U(4) invariant, does not contribute to the mass of GB

non-linear realization



Log contribution:

$$\Delta V \sim g^4/(16\, \pi^2)\, \log(\Lambda/g\, f)(|H_L|^4 + |H_R|^4)$$

$m_H \sim g^2 f/(4\, \pi)$, natural for $f \sim$ TeV

Type II Twin Higgs Model

Fermion sector:

$Q_L=(u,d)_L=[2,1,1/2]$, $L_L=(\nu,e)_L=[2,1,-1]$

$Q_R=(u,d)_R=[1,2,1/3]$, $L_R=(\nu,e)_R=[1,2,-1]$

Top quark mass

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

$y\, Q_R\, H_R^\dagger\, T_L + y\, Q_L\, H_L^\dagger\, T_R + M\, T_L\, T_R + h.c.$

EW precision constraints on $SU(2)_R$ gauge boson $f > 2$ TeV

Introduce another Higgs field that only couples to gauge sector

which has a larger VEV.

Type II Twin Higgs Model

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

couple to gauge boson only

SM Higgs doublet

↓ EWSB

SM neutral Higgs: H

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

$SU(2)_L$ Higgs doublet:

$\hat{H}_1^{\pm}$, $\hat{H}_2^0$

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

3 eaten by heavy gauge boson

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

$U(4) \rightarrow U(3)$

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

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

7 GB

$f_2 > f_1$

Type II TH: New Particles

Heavy gauge boson: W_H, Z_H — $m^2_{W_H,Z_H} \sim g^2 (f_1^2 + f_2^2)$

Heavy Top: T_H — $m^2_{t_H} \sim M^2 + y^2 f_1^2$

Other visible Higgses:

$\phi^{\pm}$ — $m^2_{\phi^{\pm}} \sim g^4/(16\pi^2)\, f_2^2 \log(\Lambda/g f_2)$

ϕ^0 — $m_{\phi^0} \sim \sqrt{B}\,\sqrt{(f_2/f_1)}$

$\sqrt{B}$: small, 50-100 GeV

Other (collider-wise) invisible Higges:

$\hat{H}_1^{\pm}$ — $m_{\hat{H}_{1\pm},\hat{H}_{10}} \sim \hat{\mu}$

$\hat{H}_2^0$ — $\hat{\mu}$: soft symmetry breaking, $O(f_1)$

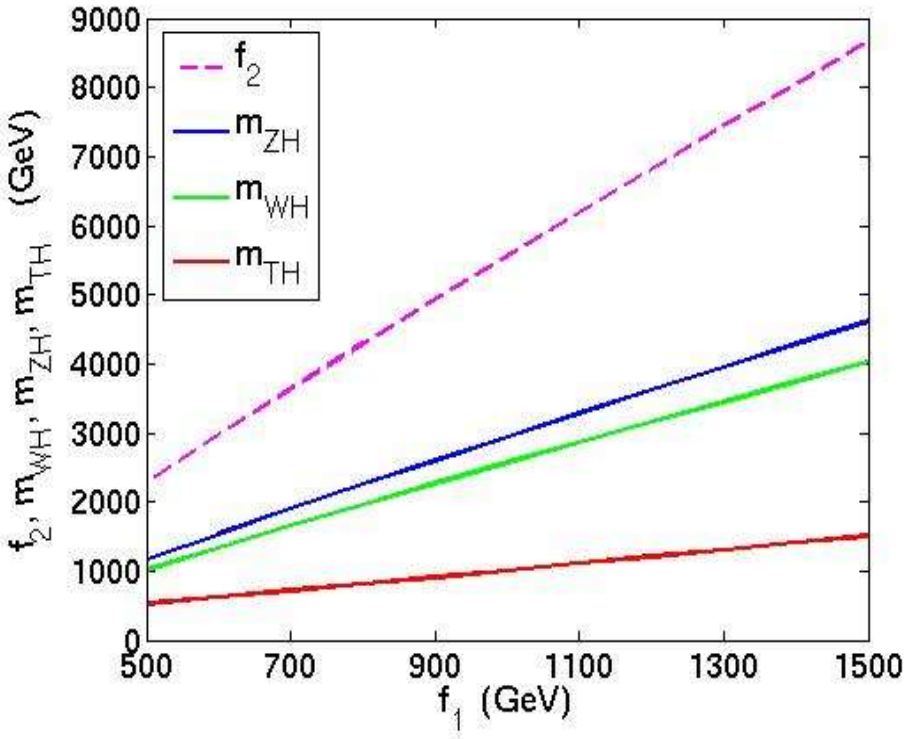
Type II TH: Model Parameters

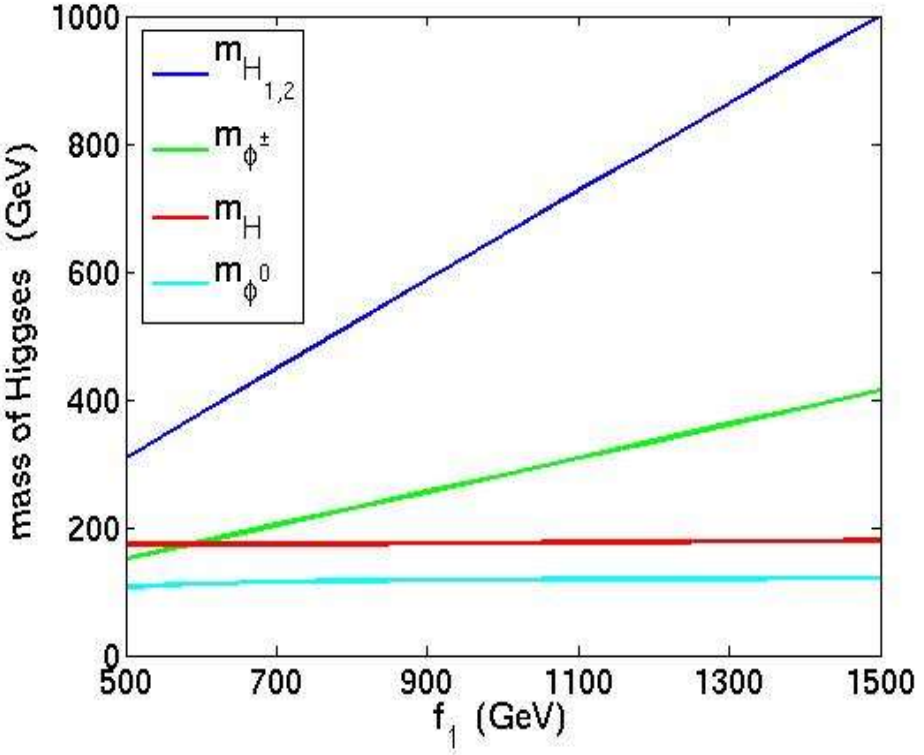
- Model parameters: f_1, (f_2, y), Λ, M, $\hat{\mu}$, $\sqrt{B}$

  fixed by Higgs VEV fixed by top mass

- Determine particle masses and interactions

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





Type II TH with Comphep

- create model:
  - variables
  - constraints
  - particles
  - Lagrangian

Type II TH: Decay

f_1=700 GeV
$\Lambda = 4\pi f_1$
M=150 GeV
$\hat{\mu} = f_1/2$
$\sqrt{B}$ = 50 GeV

Non-SUSY like signals!

Γ_{tH}=8.2 GeV

tH decay	Br
b ϕ+	73.00%
b W+	16.00%
t Z	6.80%
t ϕ0	3.20%
t H	1.10%

Γ_{WH}=53.5 GeV

uD, cS	25%*2
tH B	18.00%
ν l+	8.7%*3
ϕ0 $\phi\pm$	2.10%
uS, cD	1.30%
tB	1.20%
H $\phi\pm$	0.12%

Γ_{ZH}=51.5 GeV

ZH decay	Br
dD, sS, bB	14%*3
uU, cC	8.2%*2
$\nu\nu$	8.1%*3
tHTH	3.10%
tT	3.00%
l+l-	1.9%*3
ZH	0.88%
tTH, TtH	0.8%*2
$\phi+\phi-$	0.55%
ZH	0.33%
W+W-	0.29%
h1H1, h2H2	0.23%*2

$\Gamma_{\phi\pm}$=0.02 GeV

$\phi\pm$ decay	Br
b T	100.00%

$\Gamma_{\phi 0}$=0.0003 GeV

ϕ0 decay	Br
bB	100.00%

$\hat{H}_1^{\pm}$, $\hat{H}_2^0$: small mass splitting
$\hat{H}_2^0$ appears as missing energy
could be dark matter candidate (coannihilation)
work in progress

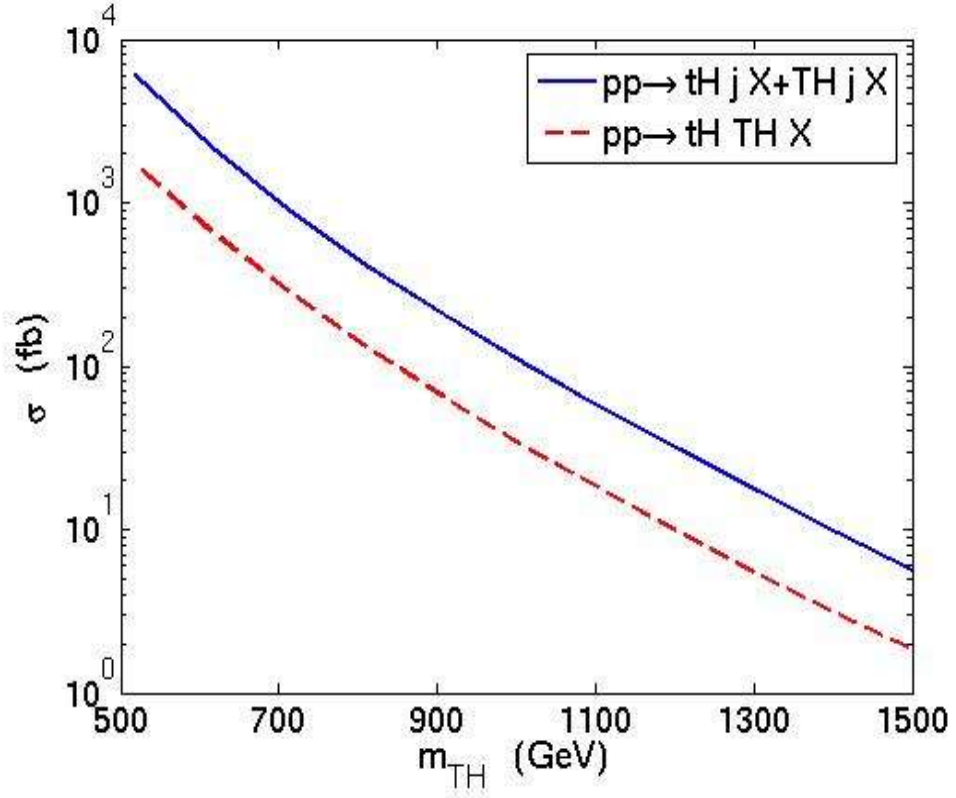
Type II TH: Production

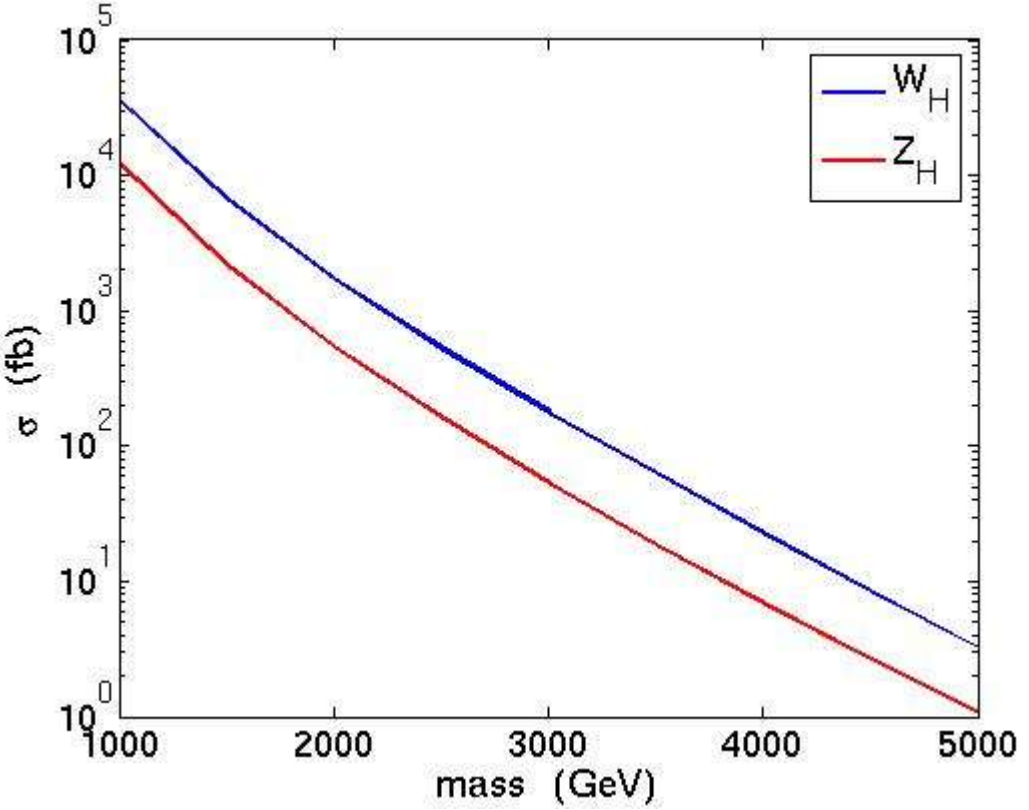
W_H, Z_H: drell-yan process

$$\sigma(uU \to Z_H \to e^+ e^-) = \sigma(uU \to Z_H)\, \Gamma(Z_H \to e^+ e^-) / \Gamma_{total}$$

T_H: $pp \to T_H\, j\, X$ on shell W_H decay

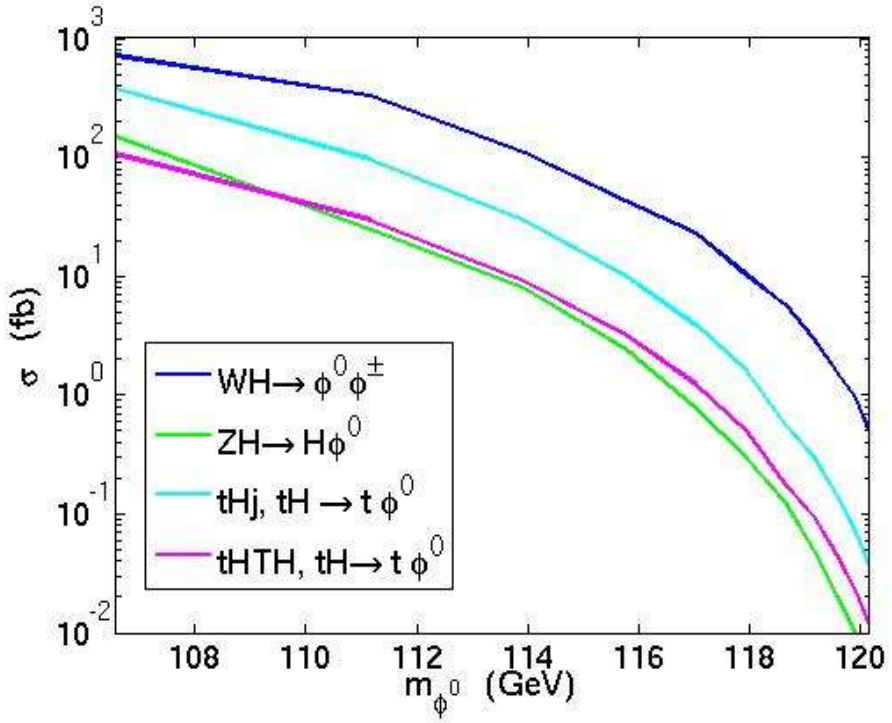
$pp \to T_H\, T_H\, X$ via gluon

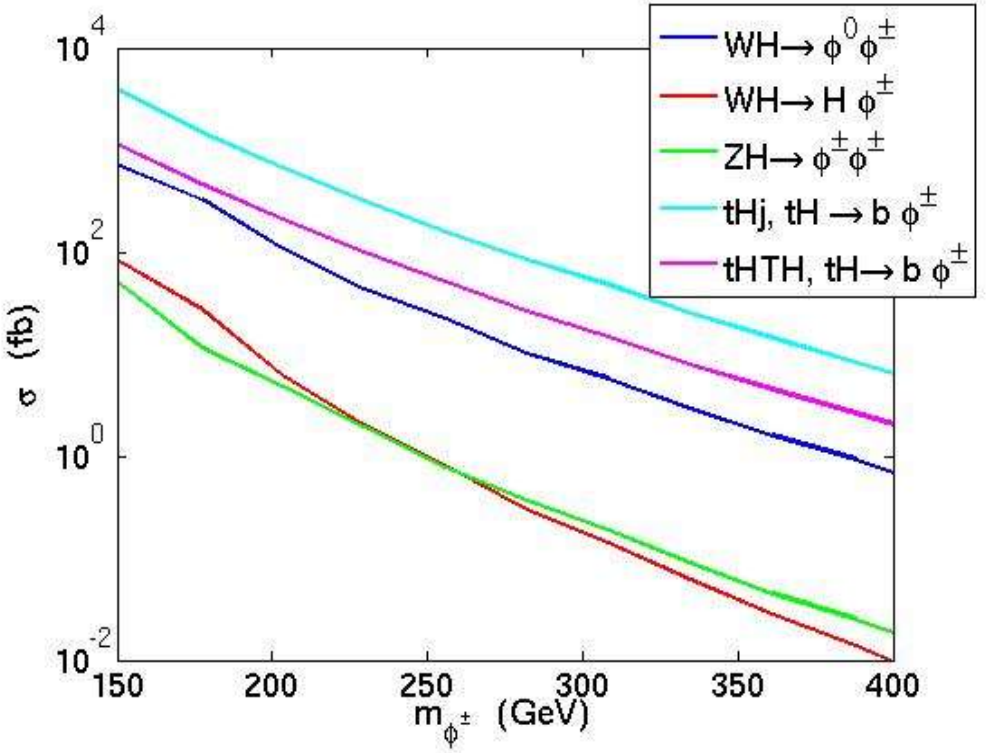




Type II TH: Production

$\phi^{\pm}$, ϕ^0: via T_H, W_H, Z_H decay, or $bB\phi^0$, $tB\phi^-$

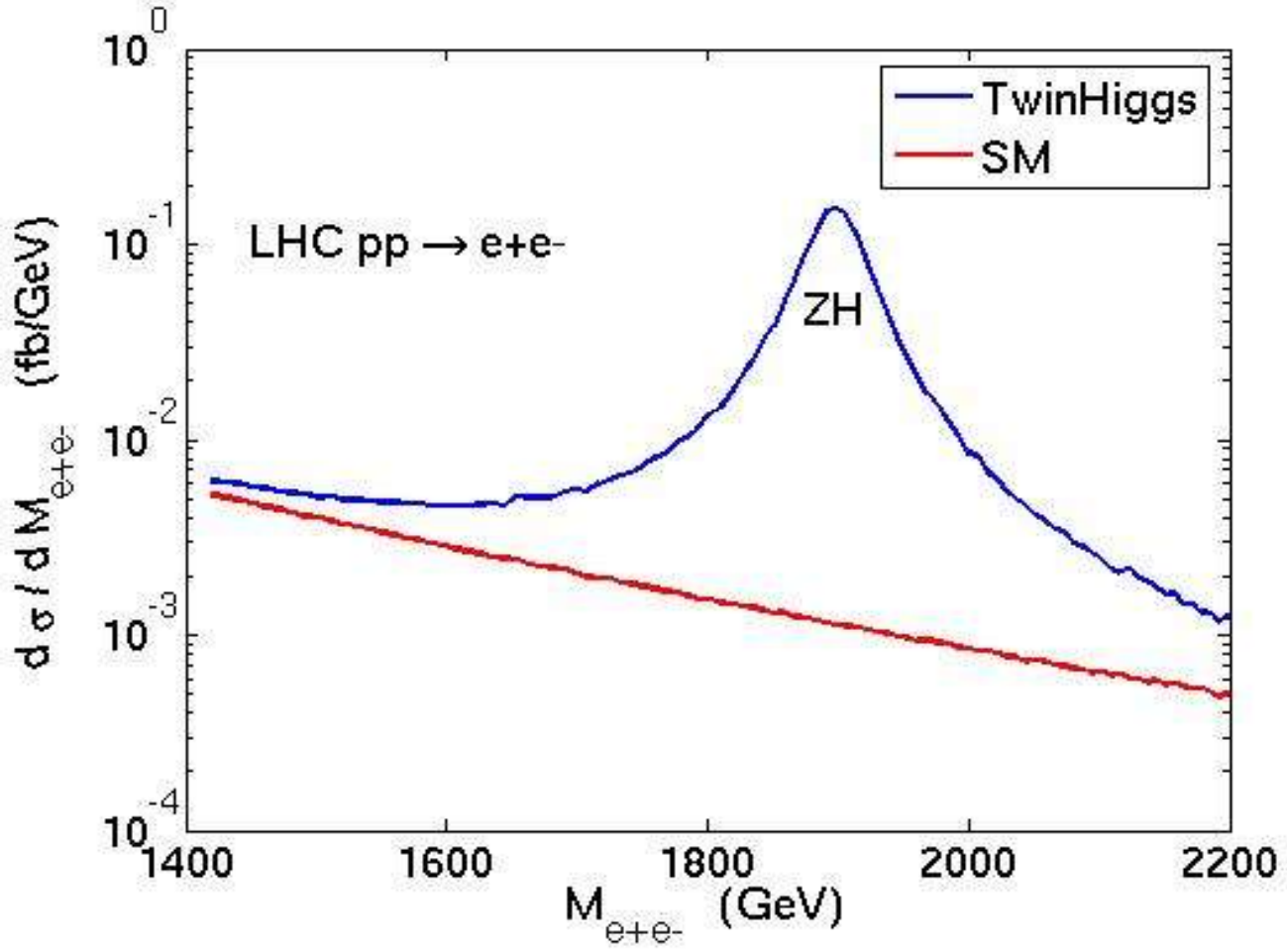




prelimenary

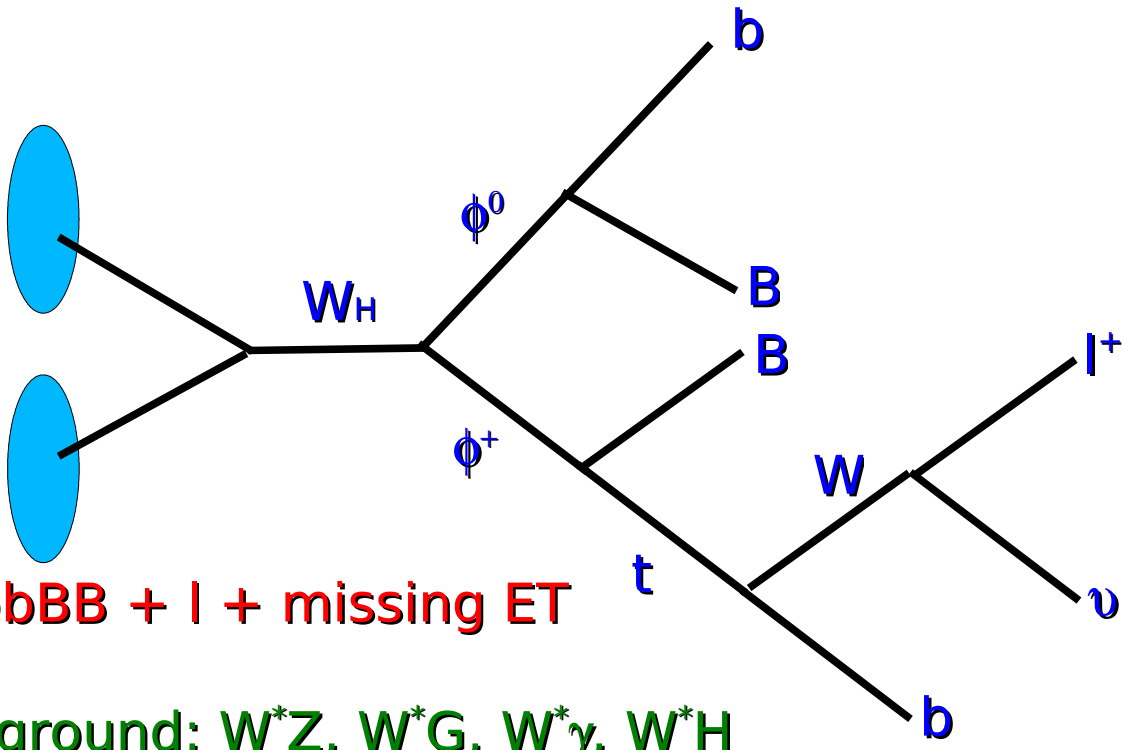
Type II TH: signal/background

distinguish signal from background



Type II TH: signal/background

distinguish signal from background: use cuts and distributions



Signal: bbBB + l + missing ET

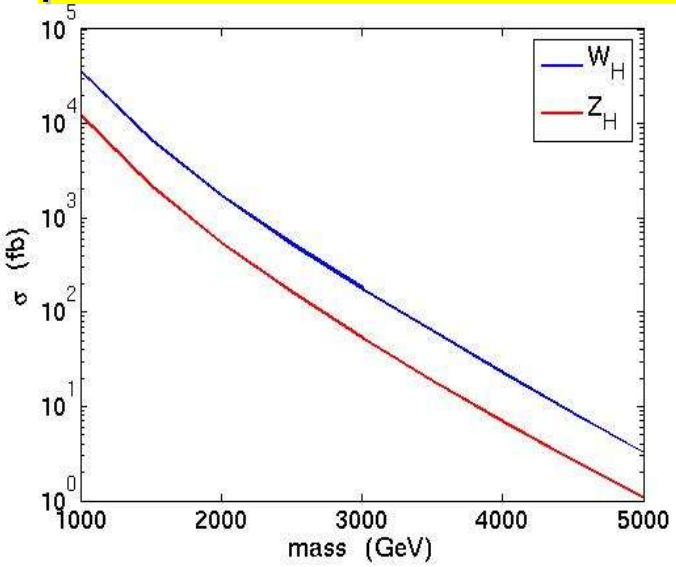
SM Background: W^*Z, W^*G, $W^*\gamma$, W^*H
with $W^* \rightarrow tB$, $Z/G/\gamma/H \rightarrow bB$
(using Madgraph?)

Identify Twin Higgs mechanism: work in progress ...

Conclusion

- Type II 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: t_H
  Other visible Higgses: neutral Higgs ϕ^0, Charged Higgs $\phi^\pm$
  Other (collider) invisible Higgses: $\hat{H}_1^\pm$, $\hat{H}_2^0$ (DM candidate)
- Model parameters: f_1, (f_2, y), Λ, M, μ, $\sqrt{B}$
- Using Comphep
  create model: variables, constraints, particles, Lagrangian

production cross sections



particle decays

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signal/background