Twin Higgs and Neutrino

- Looking for the shy partner at the LHC

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HSG and C. Krenke (work in progress)

(Little) Hierarchy Problem

EW symmetry breaking in standard model

$$V = -m^2 H^\dagger H + \lambda (H^\dagger H)^2$$

Higgs mass is UV sensitive

$$m^2 \sim m_B^2 + O(\frac{\Lambda^2}{16\pi^2})$$

Cancellation between m_B^2 and Λ^2 is needed. Fine tuning ~ 2%

(With cut off ~ 5 TeV)

~ 10^{-26}

(With cut off ~ M_{Gut})

Not a real problem but unnatural !

and we want to know why

We are just a “little” lucky !

may be for the 1 %

Anthropic principle !

Symmetry ??

Back to old fashion

No Higgs !

No problem

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can we ever find out the nature of the EW symmetry breaking ?

We now have a 14 TeV machine (hopefully). We can search for new particle up to a couple TeV.

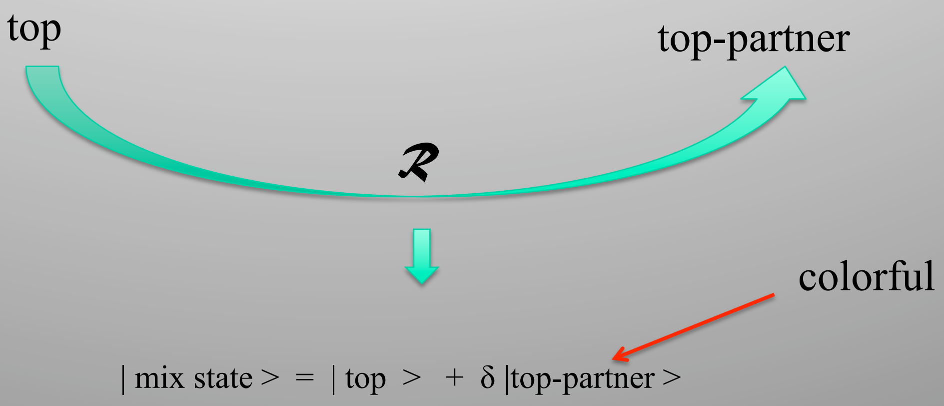
Beyond the cut off of 5 TeV (grant hierarchy “problem”),
it can be anthropic OR new symmetry OR new dynamic.
no direct probe BUT it might be possible to tell indirectly
(It is a different talk)

Below the cut off of 5 TeV (little hierarch “problem”), still
It can be anthropic OR new symmetry OR new dynamic OR we are just a little bit too lucky
But we may have a direct probe.

It is believe that the new particles can be found if the little hierarchy problem
is solved by symmetry
(i.e. MSSM, little Higgs, …)

The reason is quite simple.

The symmetry $\mathcal{R}$ that protect the Higgs and stabilize the electroweak scale is a continuous symmetry that commute with $SU(3)_{\text{color}}$.



top

top-partner

$\mathcal{R}$

colorful

$|\,\text{mix state} > \; = \; |\,\text{top} > \; + \; \delta\, |\text{top-partner} >$

Colored particles is abundant at the hadron collider

We are hopeful that the nature of EW symmetry breaking will be revealed when LHC is turned on

If only Higgs is found at the LHC

Can we conclude that our universe is finely tuned !!?

Not quite

There are a class of model that stabilize the electroweak scale and remain hidden from LHC

(one way or another)

Twin Higgs is one of them

- Twin Mechanism – and why it might be hidden
- Left-right Twin Higgs model – and why it might be too shy at the collider
- TeV seesaw in LR twin - A “natural” way to implement neutrino mass
- Collider study - finding the top-partner using the right handed neutrino
- Conclusion

Twin Higgs mechanism

[Chacko,HSG and Harnik]

$$SU(2) \times SU(2) \quad \subset \quad SU(4)_{Global}$$

Higgs :

$$\begin{tikzcd} (H_{sm}, \langle H_{sm'} \rangle) \arrow[r] \arrow[d] & \langle H \rangle \arrow[d] \\ SU(2)_{EW} & SU(3)_{Global} \end{tikzcd}$$

4 massless GBs
~ 1 Higgs doublet

3 massive gauge bosons

7 Goldstone bosons

$$\alpha \Lambda^2 H_L^\dagger H_L + \cancel{\beta} \Lambda^2 H_R^\dagger H_R = \alpha \Lambda^2 H^\dagger H$$

Z_2 (Twin parity)

Higgs remain massless

As the crucial symmetry is discrete Z_2 The state that can be generated form |top> is |top-partner >
(no mix term is required)

↓

Top partner is not colored, and even neutral under the full SM gauge group

Mirror twin

$$\begin{array}{cc} SU(2)_{SM} & \left(\begin{array}{c} H_{SM} \\ \\ H_{mirror} \end{array} \right. \\ SU(2)_{mirror} & \left. \right) \end{array}$$

Left-Right Models

[Chacko,HSG,Harnik. hep-ph/0512088]

- Twin parity can be realized by left-right symmetry.

$$\mathrm{L} \xleftrightarrow{\text{Twin}} \mathrm{R}$$

$$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \longleftrightarrow \begin{pmatrix} u_R \\ d_R \end{pmatrix} = Q_R$$

$$H^i_L \longleftrightarrow H^i_R \quad \Rightarrow \quad H^i = \begin{pmatrix} H^i_L \\ H^i_R \end{pmatrix}$$

Traditional LR model contains Higgs in triplet and bi-doublet.

Twin mechanism seems to work only for fundamental representation.

Gauge Sector

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

$$\Big\downarrow \langle H_i \rangle = f_i$$

$$U(1)_Y$$

left-right symmetry → $g_L = g_R = g_2$

Massive gauge bosons : W_H and Z_H with masses

$$m_{ZH}^2 \sim m_{WH}^2 \sim \tfrac{1}{2} g^2 (f_1^2 + f_2^2)$$

Z' searches → $f_2 > 2$ TeV , $f_1 \sim 800$ GeV

Top Sector

In addition to Q_L and Q_R for each family,
There are one vector-like pair of quarks T_L and T_R in the top sector
With these extra particles, we can write

$$y(\overline{Q}_R H_R^\dagger) T_L + y(\overline{Q}_L H_L^\dagger) T_R + M \overline{T}_L T_R \qquad m_{TH}^2 \sim M^2 + y^2 f_1^2$$

Preserve L-R symmetry
M can be arbitrarily small

Phenomenology -LR model

[HSG and Su]

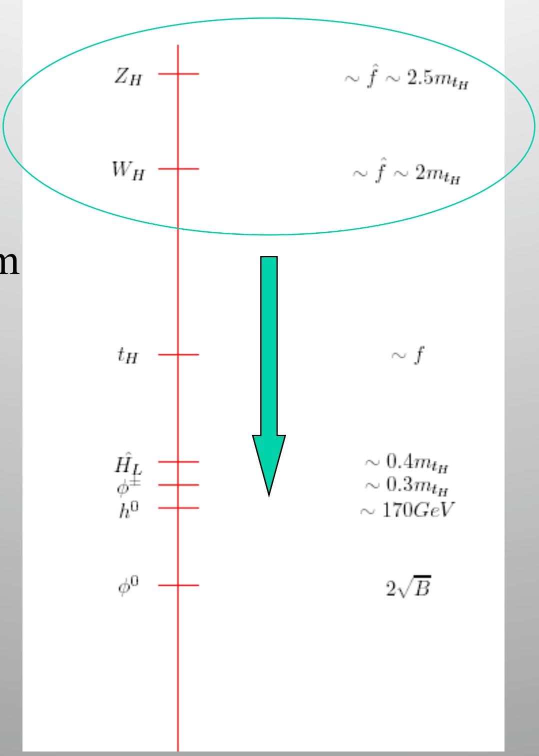
New parameters : $f, \hat{f}, y, M$ (very few)

- $\hat{f}$ is fixed by f to get m_W
- y is fixed by m_t
- M is arbitrary. It can even be zero

New particles

- W_H, Z_H
- T_H
- 14-6=8 : $h^o, \widehat{H}_L, \phi^\pm$ and ϕ^0

General spectrum

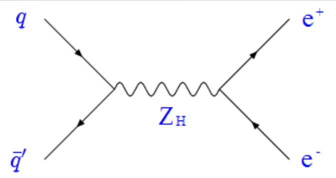


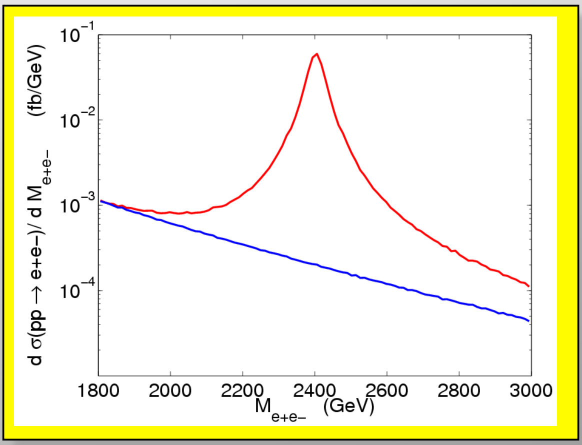
Drell-Yan

Z_H and W_H are produced by Drell-Yan process

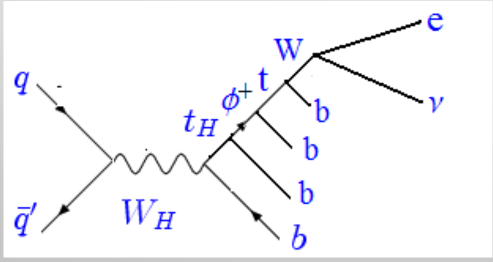
Z_H mass

Can be measure through

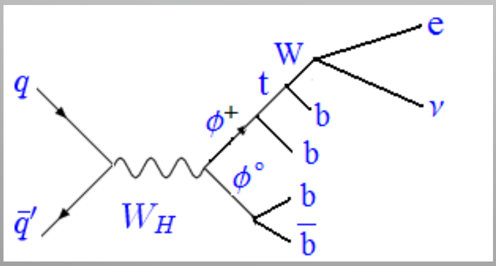




Two W_H decay chain (for M = 150 GeV)



- have nice leptonic final state
- particle in the chain are on shell
- reconstruct TH, WH, charged sclar
- with help from tagging b and cuts, BG can be largely reduced



We can definitely see these particles at the LHC

However,

The colored heavy top T_H can appear

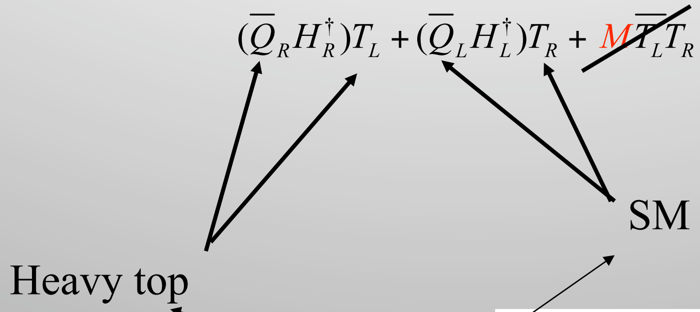
Dark

In the bright QCD environment

In the special case $M = 0$

[HSG and Krenke]

work in progress

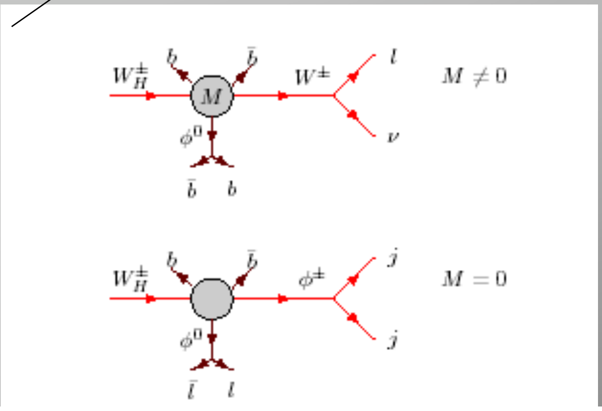


$$(\overline{Q}_R H_R^\dagger)T_L + (\overline{Q}_L H_L^\dagger)T_R + \cancel{M\overline{T}_L T_R}$$

SM top

Heavy top

decouple



Either

- Final states are hadronic
- Suppress by small Yukawa

Only easy signal is $Z_H \longrightarrow ee$

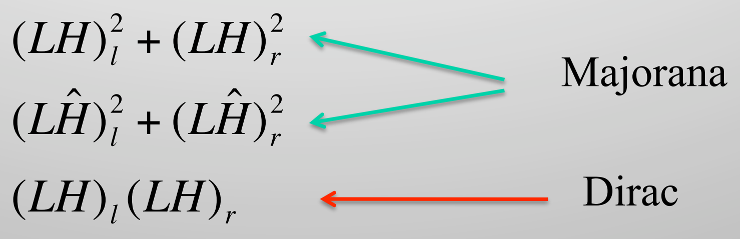
Other way to look for the SM twin ?

Right handed neutrino is lighter than W_R may be our last hope.

What is the neutrino mass in this model ?

Neutrino mass

- No GUT scale Majorana mass, TeV seesaw



$$(LH)_l^2 + (LH)_r^2$$

$$(L\hat{H})_l^2 + (L\hat{H})_r^2$$

Majorana

$$(LH)_l (LH)_r$$

Dirac

- Due to the fact that $\langle \hat{H}_l \rangle = 0$

  only the 2nd term gives a TeV scale Majorana mass to ν_R and leave ν_l massless

- $m_{\nu R} = y_N \hat{f}^2 / \Lambda \approx 1.6\ TeV$

$y_N \approx 1; \quad \hat{f} = 4\ TeV; \Lambda = 10\ TeV$

$m_{WR} = 1.9\,TeV$

Constraint from 0νββ decay

$$\frac{m_{\nu R} p^2}{p^2 - m_{\nu R}^2} \prod_{i=1,2} \frac{V_{iq} V_{il}}{g_2^2} \frac{m_w^2}{m_{\chi i}^2} < eV$$

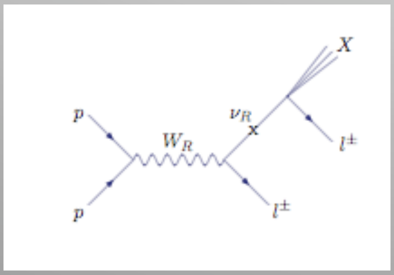
⇓

$$m_{\nu R} m_{WR}^4 > 0.4\ TeV^5$$

Collider phenomenology

We consider the spectrum

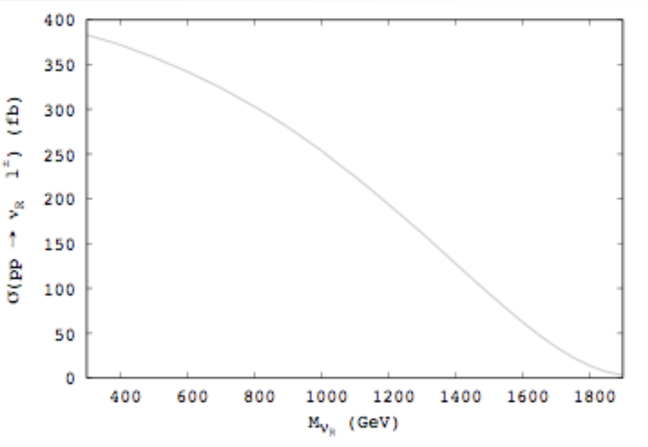
m_{TH} = 800 GeV
$m_{\nu R}$ = 1.5 TeV
m_{WR} = 1.9 TeV



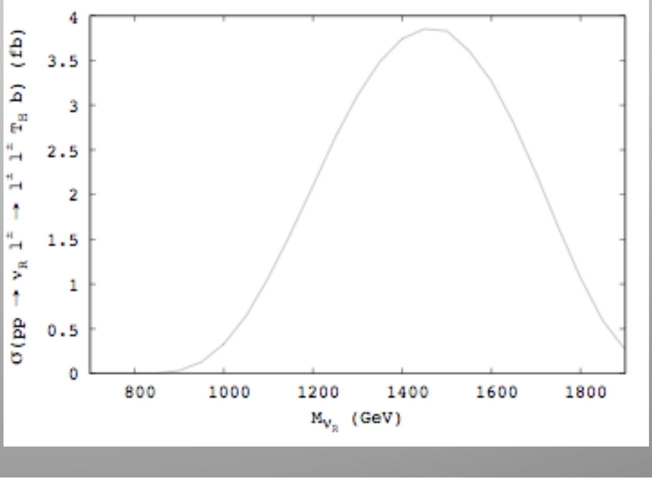
X = j j (Br ~ 0.95)
search for W_R

X = T_H b (Br ~ 0.05)
search for the top partner

σ (pp – ν_R+l) = 100 fb (50 fb has same sign dilepton)



$\sigma = 50$ fb,
before cuts



$\sigma = 3$ fb,
before cuts

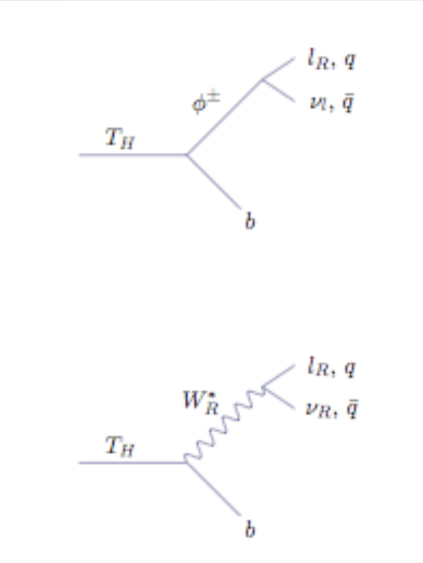
Signal violate lepton number by 2
(no SM background)

However, the following can fake the signal

- mis-measuring the charge of a lepton
  - ○ $Zjj \to l^+ l^- j j$ ⟹ 0.04 fb
  - ○ $t\,t \to W^+ W^- b\,b \to l^+ l^- \nu\nu\, b\,b$ ⟹ 0.05 fb
- missing neutrino
  - ○ $W^+ W^+ j\,j \to l^+ l^+ \nu\nu\, j\,j$ ⟹ 0.14 fb
  - ○ $t\,t \to W^+ W^- b\,b \to W^+ W^- W^{+*} b\,c \to$ ⟹ 0.017 fb + ??
- jet faking lepton
  - ○ $jjjj \to l^+ l^+\, jj$ ⟹ 10^{-3} fb
- hybrid
  - ○ $Wjjj \to l^+ \nu\, l^+ (j)\, j\,j$ ⟹ 10^{-2} fb

(MadGraph) Background(lljj/lljjjj) ⟹ 0.25 fb/0.017 fb + ??
(CalcHEP) Signal (lljj/llbbjj) after cuts ⟹ 17.0 /0.63 fb

When the RH neutrino get too light (< TH)



Br = 10^{-5} (too small)

Conclusion

- LEP paradox is solved by Twin Mechanism which

Predict

- Extra gauge bosons W_H and Z_H with mass ~ few TeV
- Extra top quarks of mass ~ f ~ 800 GeV
- These particles may be searched for in different way
  - For the decoupling case, it depends on the TeV scale neutrino mass
  - They may also be too shy to show. Careful with what what you don't see.