Physics at TeV Energy Scale

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I. Why TeV Scale Is Specially Important?

- SM is $SU(3)_c \times SU(2) \times U(1)$ gauge theory.

  $M_g,\ M_\gamma = 0,$

  $M_W = 80.403 \pm 0.029$ GeV, $\quad M_Z = 91.1876 \pm 0.0021$ GeV.

- Renormalizability of the EW gauge theory requires the Lagrangian to be exactly $SU(2) \times U(1)$ symmetric, while all mass terms

$$-M_W^2 W^i_\mu W^{i\mu}, \qquad -m_f(\bar{\psi}_L \psi_R + \bar{\psi}_R \psi_L)$$

  break the $SU(2) \times U(1)$ symmetry, so that they cannot occur in the Lagrangian.

  In the Lagrangian (equations of motion), all particles are massless.

  Where do the observed nonvanishing particle masses come from?

- In quantum field theory,

$$F_{obs} = \langle phys.\ state | F_{op} | phys.\ state \rangle$$

$$\uparrow \qquad\qquad\qquad \uparrow \qquad \uparrow$$

$$\textbf{asymm.} \qquad\qquad \textbf{symm.} \quad \textbf{asymm.}$$

$$| phys.\ state \rangle = a^{\dagger} \cdots\cdots b^{\dagger} \cdots\cdots | 0 \rangle$$

$$\uparrow \qquad\qquad\qquad \uparrow \qquad\qquad\qquad \uparrow$$

$$\textbf{asymm.} \qquad\qquad \textbf{symm.} \qquad\qquad \textbf{asymm.}$$

Observed particle masses can be nozero if the physical ground state is asymmetric.

$$\textbf{symmetric Lagrangian} \Longrightarrow \textbf{asymmetric vacuum}$$

spontaneous symmetry breaking (SSB).

- SM introduces elementary Higgs field ϕ and Higgs potential

$$V(\phi) = -\mu^2|\phi|^2 + \lambda|\phi|^4|, \qquad \lambda > 0$$

to obtain $\langle\phi\rangle^2 = v^2 \equiv \frac{\mu^2}{\lambda} \neq 0$.

$$v = 246 \text{ GeV}$$

can give the measured values of M_W and M_Z.

Higgs boson H ($\phi = v + H$) is the signal. So far H is not found.

LEP direct search bound:

$$m_H > 114.4 \text{ GeV}.$$

With $m_t = 170.9$ GeV, LEP precision data

$$\Downarrow$$

$$m_H \not> 182 \text{ GeV}, \quad 95\% \text{ CL}.$$

- In SM, Yukawa coupling $y_f \bar{\psi}\phi\psi \Longrightarrow m_f = y_f \frac{v}{\sqrt{2}}$ is put in by hand.

  Fermion masses are free parameters in SM.

- The origin of particle masses:

Newton:

$$m_0 \frac{d^2\vec{x}}{d\,t^2} = \vec{f}$$

Einstein:

$$E = mc^2 = \frac{m_0 c^2}{\sqrt{1 - \frac{\mathrm{v}^2}{c^2}}} \approx m_0 c^2 + \frac{1}{2} m_0 \mathrm{v}^2 + \cdots$$

Static energy: $E_0 = m_0 c^2$

$$m_0 = ?$$

$$v = 246\ \mathrm{GeV}$$

$$v = 246\ \mathrm{GeV}$$

•

$$m_0 c^2 = E_0 \propto v$$

- SM Higgs sector is not a self-consistent theory.

⋆ Triviality:

Suppose SM is valid when $E \leq E_{max}$. Summing up all leading logrithm corrections: $\lambda \xrightarrow{E_{max}\to\infty} 0.$ $\quad$ inconsistent !

There must be a scale of new physics Λ so that $E_{max} \not> \Lambda$.

⋆ Unnaturalness: $\quad m_H^2 = m_{H0}^2 + \delta m_H^2$

$$\textbf{SM:} \Longrightarrow \delta m_H^2 = A\Lambda^2, \;\; m_{H0}^2 = B\Lambda^2 \;\; [A, \; B = O(1)]$$

$$m_H^2 = (A+B)\Lambda^2$$

Possible new physics scale is $\Lambda \sim M_P \sim 1.22 \times 10^{19}\ \mathrm{GeV}$.

Then $$A + B = \frac{m_H^2}{M_P^2} \sim 10^{-34},$$

requiring A, B to be of the precision of 34 digits. $\quad$ Unnatural !.

Naturalness requires $\quad \Lambda \sim \mathrm{TeV}$.

- If there are only presently discovered particles, the cross section of $WW \to WW$ will increase with the c.m. energy E. When $E \geq 1.2\ \mathrm{TeV}$, the cross section will be so large that it violates the conservation of probability (unitarity of S-matrix). So there must be yet undiscovered particle(s) below 1.2 TeV– **(unitarity bound)** !

- We see that, in EW theory, all masses come from the VEV $v \neq 0$ breaking $SU(2) \times U(1)$. EWSBM is not clear yet. Probing EWSBM concerns the understanding of the original of all particle masses.
- We also see that TeV scale is the scale of discovering new particle(s) or going beyond the SM.
- Building high energy colliders covering the TeV scale will be able to explore the mechanism of mass generation and/or find out new physics beyond the SM.

II. TeV Colliders

- **LHC**:

14 TeV pp collider, designed luminosity: $\int_{yr} \mathcal{L} dt = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μrad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ^* (μm, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	$6\times10^{30}-10^{32}$	$10^{32}-10^{33}$	$(1-2)\times10^{33}$	10^{34}
Year (?)	2008	2009	2009-2010	> 2010

⋆ Advantage: parton colliding energy up to a couple of TeV

⋆ Sortcoming: large hadronic bkgd

LHC: discovery machine

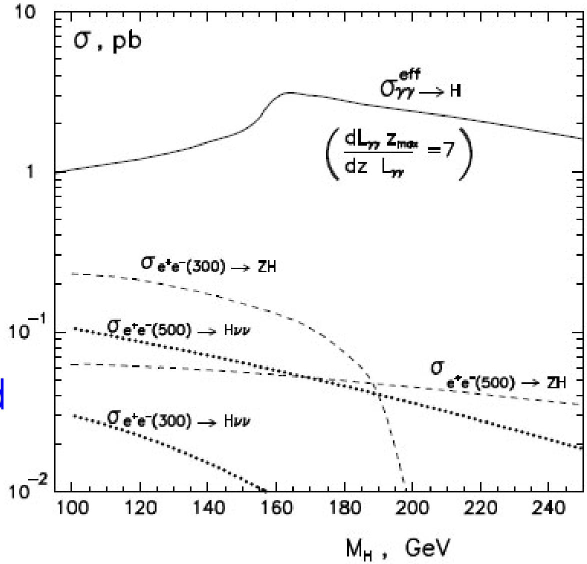
- **ILC**:

  e^+e^- collider (in R&D)

  Phase I: $\mathbf{200\ GeV \le \boldsymbol{E} \le 500\ GeV}$ (adjustable)

  Phase II: $\boldsymbol{E} \sim \mathbf{1\ TeV}$

  Photon collider can be made by means of laser back-scattering. Good for studying Higgs boson.



  ⋆ Advantage: small hadronic bkgd

  ⋆ Sortcoming: expensive for increasing energy

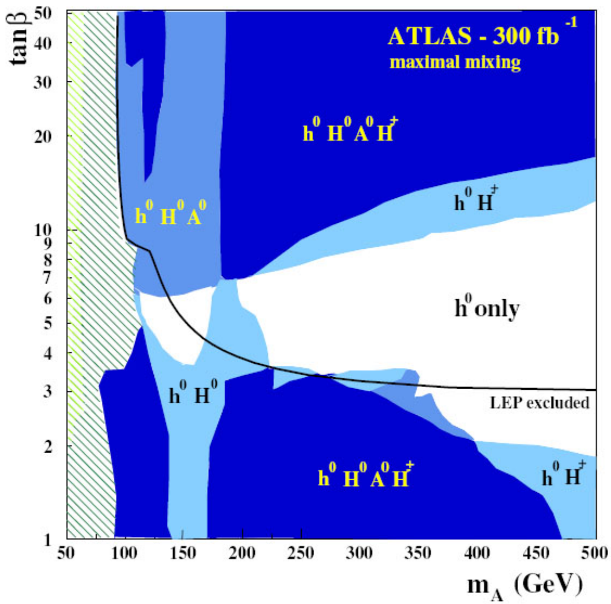
ILC: discovery and precision measurement machine

- More higher energy colliders are under consideration.

III. Examples of New Physics Models

- **SUSY (MSSM)**
  - ⋆ SUSY partners: $\tilde{W}^{\pm}\ldots,\ \tilde{g},\ \tilde{q},\ \tilde{l}^{\pm}\ldots$. Can solve the triviality and fine-tuning problems.
  - ⋆ Can accommodate SUSY GUT $M_{GUT} \sim 5 \times 10^{16}$ GeV, and radiative EWSB.
  - ⋆ Two Higgs doublets $\Longrightarrow h^0,\ H^0, A^0,\ H^{\pm}$.

    Two loop $\Longrightarrow m_h \not> 135$ GeV.
  - ⋆ LHC coverage:

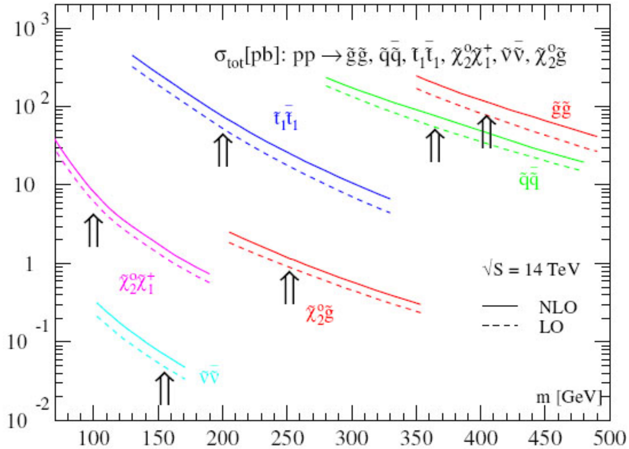


⋆ sparticles not found $\Longrightarrow$ SUSY is broken, SUSY breaking mechanism not clear (general description: 105 free parameters).

⋆ $$\Delta m_H^2 \sim (M_{SUSY}^2 - M_{SM}^2)\frac{\lambda_f^2}{16\pi^2}\ln\left(\frac{\Lambda}{M_{SUSY}}\right).$$

To avoid fine-tuning, $M_{SUSY} \not> \mathrm{TeV}$ (low energy SUSY).

⋆ LHC, ILC: can find sparticles.



⋆ ILC: can make precision measurement of sparticle masses:

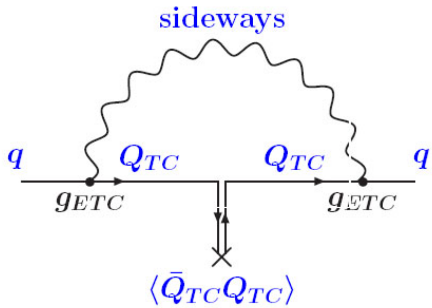
$$\delta m_{\tilde{t},\tilde{b}} = 1\ \mathrm{GeV},$$
$$\delta m_{\chi^{\pm,0}} = 0.1 - 1\ \mathrm{GeV},$$
$$\delta m_{\tilde{l},\tilde{\nu}} = 0.05 - 0.3\ \mathrm{GeV},$$
$$\delta m_{\tilde{\tau},\tilde{\nu}_\tau} = 0.6\ \mathrm{GeV}.$$

can test SUSY breaking mechanism.

- **Technicolor (TC)**

⋆ Abandon ϕ to avoid triviality and fine-tuning. Introduce new strong interactions TC and new fermions to develop

$$\langle\bar{\psi}\psi\rangle \neq 0 \Longrightarrow v \neq 0.$$



⋆ Yukawa interaction is dynamically induced

⋆ Original QCD-like TC model is ruled out by LEP precision data S paramter too large).

⋆ Improved models associated with Topcolor (TC2) [Hill (1995);Lane, Eichten (1995), etc]. Consistent with LEP data [Chivukula, Terning (1996); Yue, Kuang, Wang, Li (2000)]

⋆ Signals: ρ_{TC}, π_{TC}, π_t, $\cdots$.

⋆ Attempt to account for CKM matrix and CP violation [Martin, Lane (2005)].

- **Top Quark Seesaw**

  [Dobrescu,Hill (1998); Chivukula,Dobrescu, Georgi, Hill (1999)]

  ⋆ Introduce topcolor group: $G_{tc} = SU(3)_1 \times SU(3)_2$ and new strong interaction group G breaking $G_{tc} \to SU(3)_{QCD}$.

  ⋆ introduce $SU2)_W$-singlet quark χ with proper $U(1)_Y$ quantum number. Topcolor causes the bound state scalar

$$\varphi = \begin{pmatrix} \overline{\chi_R}\, t_L \\ \overline{\chi_R}\, b_L \end{pmatrix}$$

  φ behaves like a Higgs doublet. $\langle\varphi\rangle = v$ breaks EW symmetry.

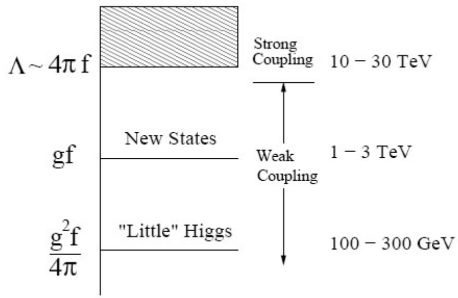
  ⋆ Dynamics leads to

$$m_t \approx m_{t\chi} \frac{\mu_{\chi t}}{\mu_{\chi\chi}} \sim 174 \text{ GeV}$$

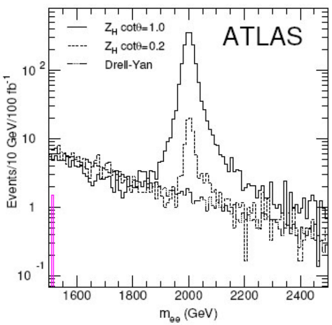
  ⋆ $m_H \sim 1$ TeV [He, Hill, Tait (2002)].

● Little Higgs

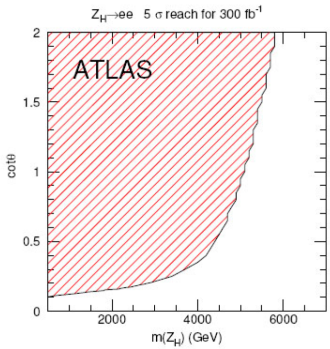
[Arkani-Hamed, Cohen, Georgi, Gregoire, Schmaltz, Wacker, Walker (2001−2005)]



- ⋆ Strong interaction at $\mathbf{\Lambda \approx 10 \sim 30\ TeV}$ pseodo Goldstone bosons (PGBs).
- ⋆ Heavy states at $\boldsymbol{gf \approx 1 \sim 3}$ $\mathbf{TeV}$
- ⋆ Same spin particles cancel quardratic divergences to keep one or two PGBs light, ($\mathbf{100{-}300\ GeV}$), as light Higgs boson(s) ϕ, $\langle\phi\rangle = v$ breaks $\boldsymbol{SU(2) \times U(1)}$
- ⋆ Phenomenology of $\boldsymbol{SU(5)/SO(5)}$ model [Han, Logan,McElrath, Wang (2003); Burdman, Perelstein, Pierce (2002)]



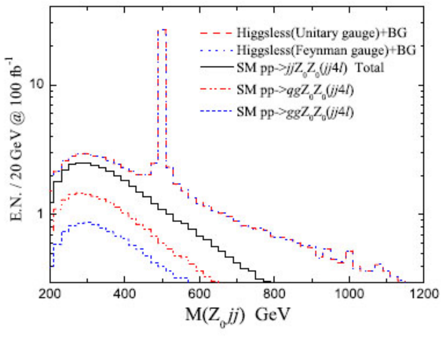
(a)

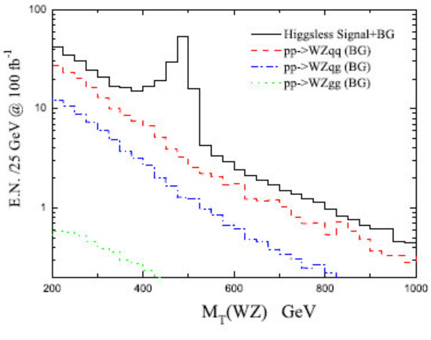


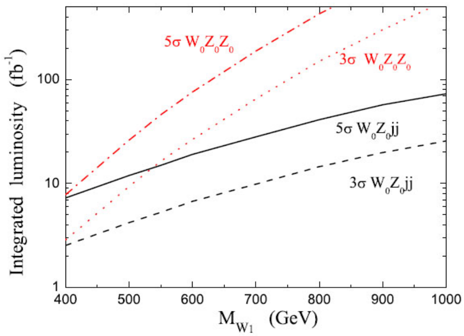
(b)

- **Higgsless Model Based on Extra Dimension**
  - ⋆ Higgsless model in 5-dim with broken $SU(2) \times U(1)$ built by imposing boundary conditions in the 5th-dim [Csaki *et al.* (2004)]
  - ⋆ By means of dimension deconstruction Higgsless model can be constructed in 4-dim gauge theories with $SU(2) \times U(1)$ broken spontaiously by strong dynamics, and boundary condition in the 5th-dim can be induced by diagonalizing the mass matrix. Minimal model contains extra W_1 and Z_1 with $400\ \mathrm{GeV} \leq M_{W_1} \leq 1\ \mathrm{TeV}$. Can make $S, T, U \approx 0$ [He (2004); Chivukula *et al.* (2005)].
  - ⋆ LHC signals: [Tsinghua-MSU (2007)]

$$pp \to W_1^* Z_0 \to W_0 W_0 Z_0, \qquad pp \to W_1^* jj \to W_0 Z_0 jj$$







IV. Perspectives of LHC and ILC Expts

- **General No-Lose Probe of New Physics Effects**

MSSM	TC	top seesaw	extra dim.	little Higgs	⋯
(light Higgs)	(no Higgs)	(heavy Higgs)	(no Higgs)	(light Higgs)	
↘	↘	↓	↙	↙	

Nature=?

No hint that nature can be described by one of the known models.

General no-lose probe is needed.

effective Lagrangian | heavy particles in new physics ——— E

Λ

Effective couplings of known particles reflect the effect of new physics.

How to measure effective couplings at LHC and ILC?

- **What If Only a Light Higgs Resonance Is Found?**

Is it a SM Higgs or a Higgs in new physics?

Need to test Higgs couplings.

⋆ **Testing gauge couplings of the Higgs boson**

$$\mathcal{L}_{eff}^{HVV} = g_{H\gamma\gamma} H A_{\mu\nu} A^{\mu\nu} + g^{(1)}_{HZ\gamma} A_{\mu\nu} Z^{\mu} \partial^{\nu} H + g^{(2)}_{HZ\gamma} H A_{\mu\nu} Z^{\mu\nu}$$
$$+ g^{(1)}_{HZZ} Z_{\mu\nu} Z^{\mu} \partial^{\nu} H + g^{(2)}_{HZZ} H Z_{\mu\nu} Z^{\mu\nu}$$
$$+ g^{(1)}_{HWW} (W^{+}_{\mu\nu} W^{\mu}_{-} \partial^{\nu} H + h.c.) + g^{(2)}_{HWW} H W^{+}_{\mu\nu} W^{\mu\nu}_{-}$$

SM: $g^{(i)}_{HVV} = 0$.

⋆ **LHC**

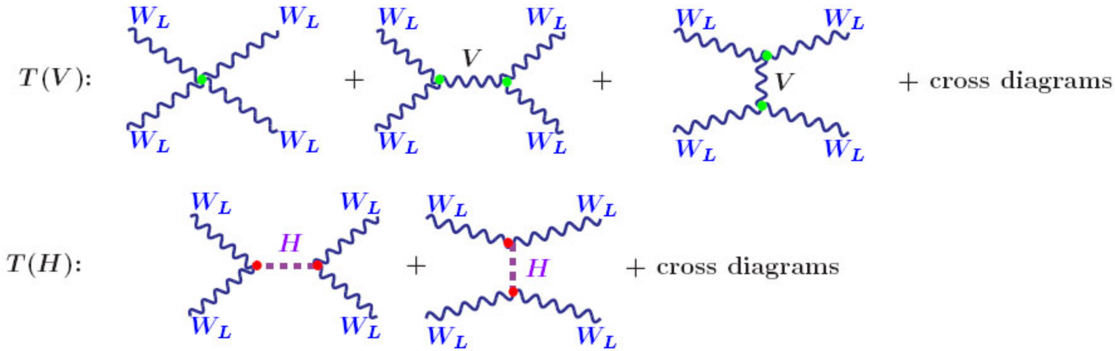
○ [Plehn, Rainwater, Zeppenfeld (2003)] WW fusion at the LHC:

$$pp \to qq'H,\ H \to \gamma\gamma,\ \tau^{+}\tau^{-}:$$

$$1\sigma\ \text{(stat.)}: \quad |g^{(2)}_{HWW}| \geq 0.1\ \text{TeV}^{-1}.$$

- [Zhang, Kuang, He, Yuan (2003)]

$$W^+W^+ \to W^+W^+ \to l^+\nu_l l^+\nu_l$$



$$3\sigma \text{ (stat.)}: \quad |g^{(1)}_{HWW}| \geq 0.075 \text{ TeV}^{-1}, \quad |g^{(2)}_{HWW}| \geq 0.15 \text{ TeV}^{-1},$$

$$|g^{(1)}_{HZZ}| \geq 0.075 \text{ TeV}^{-1}, \quad |g^{(2)}_{HZZ}| \geq 0.058 \text{ TeV}^{-1},$$

$$|g^{(1)}_{HZ\gamma}| \geq 0.041 \text{ TeV}^{-1}, \quad |g^{(2)}_{HZ\gamma}| \geq 0.032 \text{ TeV}^{-1},$$

$$|g_{H\gamma\gamma}| \geq 0.035 \text{ TeV}^{-1}.$$

⋆ **ILC**:

- [Hagiwara, Ishihara, Kamoshita, Kniel (2000)] ILC:

$$e^+e^- \to HZ, \quad H \to b\bar{b}, \;\; Z \to f\bar{f}:$$

$$2\sigma \text{ (stat.)}: \qquad |g^{(i)}_{HZZ}|, \; |g^{(i)}_{HZ\gamma}| \geq 10^{-3} - 10^{-2}\ \text{TeV}^{-1}.$$

- [Han, Kuang, Zhang (2005)] $\gamma\gamma$ colliders:

$$\gamma\gamma \to ZZ \to 4\, jets$$

3σ (stat.) :

500 GeV ILC $\quad |g_{H\gamma\gamma}| \geq 0.023\ \text{TeV}^{-1}$,

1 TeV ILC $\quad |g_{H\gamma\gamma}| \geq 0.010\ \text{TeV}^{-1}$,

3 TeV CLIC $\quad |g_{H\gamma\gamma}| \geq 0.0018\ \text{TeV}^{-1}$.

- **What If Not Even a Light Resonance Is Found?**

Definitely new physics. Unitarity$\Longrightarrow$ new particle(s) [probably wide resonance(s)] below **1.2 TeV**.

EW chiral Lagrangian [Appelquist, Wu (1995)]

$$\mathcal{L}_{eff}(W,Z,\varphi)=\sum_{i=0}^{14}\mathcal{L}^{(i)}=\sum_{i=0}^{14}\alpha_i\mathcal{O}(W,Z,\varphi)$$

$$(\varphi^{\pm}\sim W_L^{\pm},\ \varphi^0\sim Z_L^0).$$

SM: $\alpha_i=0$.

⋆ Measuring α_i can obtain information about nature.

⋆ A theoretical analysis of the sensitivity of measuring α_i [He, Kuang, Yuan (1996)]:

Collider(s)	$\mathcal{L}^{(2)\prime}$	$\mathcal{L}_{1,13}$	$\mathcal{L}_2$	$\mathcal{L}_3$	$\mathcal{L}_{4,5}$	$\mathcal{L}_{6,7}$	$\mathcal{L}_{8,14}$	$\mathcal{L}_9$	$\mathcal{L}_{10}$	$\mathcal{L}_{11,12}$	$T_1 \ \Vert\ B$	Processes
LEP-I (S,T,U)	$\perp$	$\perp$ †					$\perp$ †				$g^4 \frac{f_\pi^2}{\Lambda^2}$	$e^-e^+ \to Z \to f\bar{f}$
LEP-II	$\perp$	$\perp$	$\perp$	$\perp$			$\perp$	$\perp$		$\perp$	$g^4 \frac{f_\pi^2}{\Lambda^2}$	$e^-e^+ \to W^-W^+$
LC(0.5)/LHC(14)			$\surd$	$\surd$				$\surd$			$g^2 \frac{E^2}{\Lambda^2} \Vert g^2 \frac{M_W^2}{E^2}$	$f\bar{f} \to W^-W^+/(LL)$
		$\triangle$	$\triangle$	$\triangle$			$\triangle$	$\triangle$		$\triangle$	$g^3 \frac{E f_\pi}{\Lambda^2} \Vert g^2 \frac{M_W}{E}$	$f\bar{f} \to W^-W^+/(LT)$
LC(1.5)/LHC(14)				$\surd$	$\surd$	$\surd$		$\surd$		$\surd$	$g^2 \frac{1}{f_\pi} \frac{E^2}{\Lambda^2} \Vert g^3 \frac{M_W}{E^2}$	$f\bar{f} \to W^-W^+Z/(LLL)$
		$\triangle$	$\triangle$	$\triangle$	$\triangle$	$\triangle$	$\triangle$	$\triangle$		$\triangle$	$g^3 \frac{E}{\Lambda^2} \Vert g^3 \frac{M_W^2}{E^3}$	$f\bar{f} \to W^-W^+Z/(LLT)$
				$\surd$	$\surd$	$\surd$			$\surd$		$g^2 \frac{1}{f_\pi} \frac{E^2}{\Lambda^2} \Vert g^3 \frac{M_W}{\Lambda^2}$	$f\bar{f} \to ZZZ/(LLL)$
					$\triangle$	$\triangle$			$\triangle$		$g^3 \frac{E}{\Lambda^2} \Vert g^3 \frac{f_\pi}{\Lambda^2} \frac{M_W}{E}$	$f\bar{f} \to ZZZ/(LLT)$
					$\surd$						$\frac{E^2}{f_\pi^2} \frac{E^2}{\Lambda^2} \Vert g^2$	$\boldsymbol{W^-W^\pm \to W^-W^\pm/(LLLL)}$ ‡
				$\triangle$	$\triangle$			$\triangle$		$\triangle$	$g \frac{E}{f_\pi} \frac{E^2}{\Lambda^2} \Vert g^2 \frac{M_W}{E}$	$W^-W^\pm \to W^-W^\pm/(LLLT)$ ‡
					$\surd$	$\surd$					$\frac{E^2}{f_\pi^2} \frac{E^2}{\Lambda^2} \Vert g^2$	$\boldsymbol{W^-W^+ \to ZZ}$ **& perm.** $\boldsymbol{/(LLLL)}$
			$\triangle$	$\triangle$	$\triangle$	$\triangle$		$\triangle$		$\triangle$	$g \frac{E}{f_\pi} \frac{E^2}{\Lambda^2} \Vert g^2 \frac{M_W}{E}$	$W^-W^+ \to ZZ$ & perm.$/(LLLT)$
					$\surd$	$\surd$			$\surd$		$\frac{E^2}{f_\pi^2} \frac{E^2}{\Lambda^2} \Vert g^2 \frac{E^2}{\Lambda^2}$	$\boldsymbol{ZZ \to ZZ/(LLLL)}$
				$\triangle$	$\triangle$	$\triangle$			$\triangle$		$g \frac{E}{f_\pi} \frac{E^2}{\Lambda^2} \Vert g^2 \frac{M_W E}{\Lambda^2}$	$ZZ \to ZZ/(LLLT)$
LHC(14)				$\surd$						$\surd$	$g^2 \frac{E^2}{\Lambda^2} \Vert g^2 \frac{M_W^2}{E^2}$	$q\bar{q}' \to W^\pm Z/(LL)$
		$\triangle$	$\triangle$	$\triangle$			$\triangle$	$\triangle$		$\triangle$	$g^3 \frac{E f_\pi}{\Lambda^2} \Vert g^2 \frac{M_W}{E}$	$q\bar{q}' \to W^\pm Z/(LT)$
				$\surd$	$\surd$			$\surd$		$\surd$	$g^2 \frac{1}{f_\pi} \frac{E^2}{\Lambda^2} \Vert g^3 \frac{M_W}{E^2}$	$q\bar{q}' \to W^-W^+W^\pm/(LLL)$
			$\triangle$	$\triangle$	$\triangle$		$\triangle$	$\triangle$		$\triangle$	$g^3 \frac{E}{\Lambda^2} \Vert g^3 \frac{M_W^2}{E^3}$	$q\bar{q}' \to W^-W^+W^\pm/(LLT)$
				$\surd$	$\surd$	$\surd$				$\surd$	$g^2 \frac{1}{f_\pi} \frac{E^2}{\Lambda^2} \Vert g^3 \frac{M_W}{E^2}$	$q\bar{q}' \to W^\pm ZZ/(LLL)$
		$\triangle$	$\triangle$	$\triangle$	$\triangle$	$\triangle$	$\triangle$	$\triangle$		$\triangle$	$g^3 \frac{E}{\Lambda^2} \Vert g^3 \frac{M_W^2}{E^3}$	$q\bar{q}' \to W^\pm ZZ/(LLT)$
LC($e^-\gamma$)		$\surd$	$\surd$	$\surd$			$\surd$	$\surd$		$\surd$	$eg^2 \frac{E}{\Lambda^2} \Vert eg^2 \frac{M_W^2}{E^3}$	$e^-\gamma \to \nu_e W^-Z, e^-WW/(LL)$
LC($\gamma\gamma$)		$\surd$	$\surd$	$\surd$			$\surd$	$\surd$			$e^2 \frac{E^2}{\Lambda^2} \Vert e^2 \frac{M_W^2}{E^2}$	$\gamma\gamma \to W^-W^+/(LL)$
		$\triangle$	$\triangle$	$\triangle$			$\triangle$	$\triangle$			$e^2 g \frac{E f_\pi}{\Lambda^2} \Vert e^2 \frac{M_W}{E}$	$\gamma\gamma \to W^-W^+/(LT)$

⋆ Monte Carlo simulations: 1σ sensitivities at LHC and ILC:

[TESLA TDR] 2-parameter fit:

$$\textbf{LHC}\ (\int \mathcal{L}dt = 100\ \text{fb}^{-1}):$$

$$\alpha_4 < -0.0011 \text{ or } \alpha_4 > 0.011, \quad \alpha_5 < -0.0022 \text{ or } \alpha_5 > 0.0076$$

$$\textbf{800 GeV TESLA}\ (\int \mathcal{L}dt = 1000\ \text{fb}^{-1}):$$

$$\alpha_4 < -0.0070 \text{ or } \alpha_4 > 0.0051, \quad \alpha_5 < -0.0025 \text{ or } \alpha_5 > 0.0019$$

[2005 International LC Workshop, Stanford] 5-parameter fit:

$$\textbf{ILC}\ (\int \mathcal{L}dt = 1000\ \text{fb}^{-1}):$$

$$\alpha_4 < -0.017 \text{ or } \alpha_4 > 0.015, \qquad \alpha_5 < -0.016 \text{ or } \alpha_5 > 0.015,$$

$$\alpha_6 < -0.025 \text{ or } \alpha_6 > 0.035, \qquad \alpha_7 < -0.020 \text{ or } \alpha_7 > 0.021,$$

$$\alpha_{10} < -0.035 \text{ or } \alpha_{10} > 0.029.$$

- The measured effective couplings (**sensitivity** is crucial) reflect certain properties of the nature. Checking what model can lead to the measured effective couplings$\Longrightarrow$clue of finding out the right new physics model.

V. SUMMARY

- EWSBM is not clear. New physics$\sim$ **TeV**.
- LHC and LC may explore EWSBM and discover new physics.
- Signals of known new physics models have been intensively studied. More studies needed.
- If LHC and LC only find a light Higgs, testing effective Higgs couplings may help to explore new physics.
- If LHC and LC find not even a light Higgs, studying EW chiral Lagrangian may help to explore new physics.
- After finding new physics, particle physics will be in exciting new era.

Thanks **!**