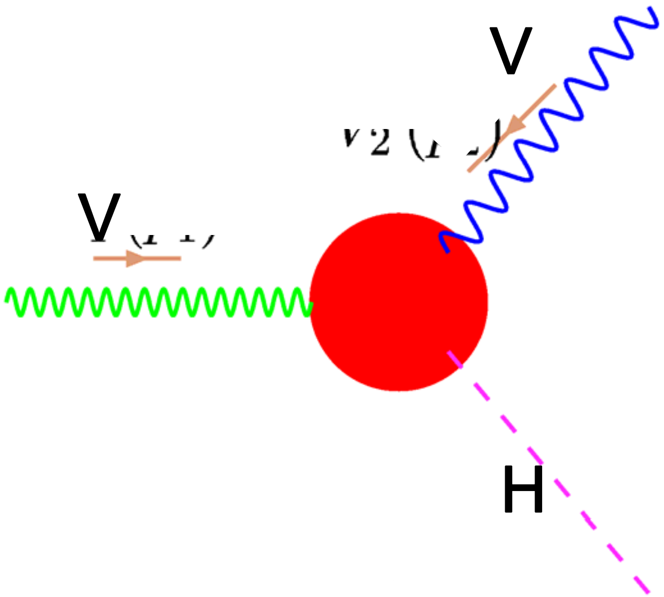
# Presice measurement of the Higgs-boson electroweak couplings at Linear Collider and its physics impacts

Yu Matsumoto (KEK) 2008,11,18 @LCWS08




Contents



In collaboration with K.Hagiwara (KEK) and S.Dutta (Univ. of Delhi)

# 1-1. Motivation

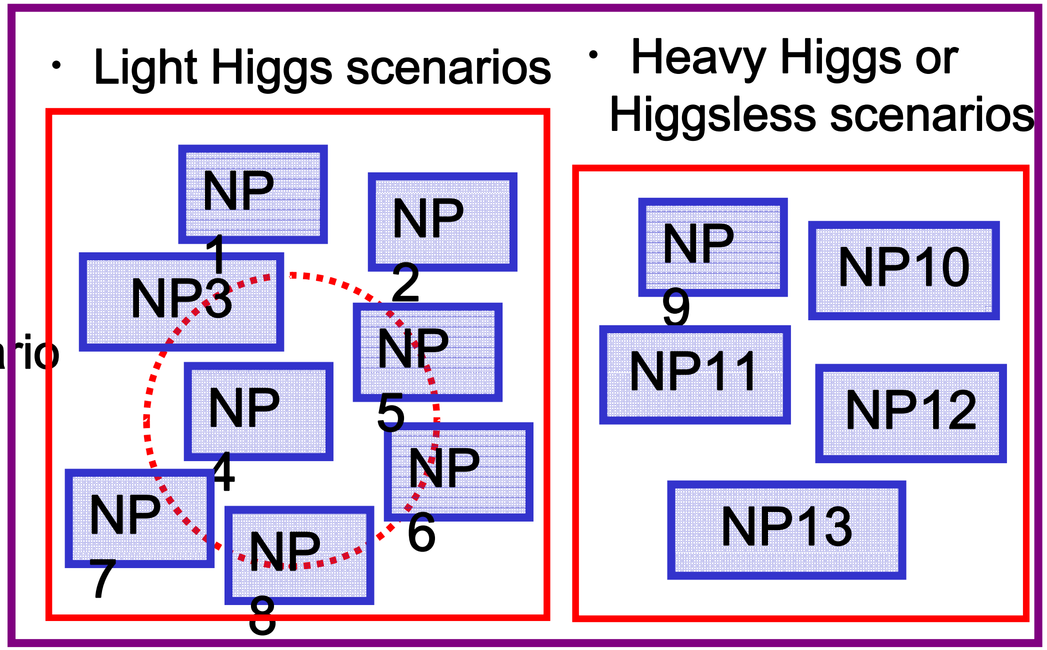
Tevatron LEP → SM

- W, Z-boson discovery
- top-quark discovery
- W,Z boson precision measurements

LHC LC →

- LHC can probe light Higgs scenario
- precision measurements of the Higgs-boson properties

New physics theories



# 1-2. Effective Lagrangian with a Higgs doublet

New physics can be represented by higher mass dimension operators

$$L_{eff} = L_{SM} + L^{\dim 5} + L^{\dim 6} + L^{\dim 7} + L^{\dim 8} + \cdots,$$

contribute to majonara neutrino mass

contribute to

- four fermion coupling (Proton decay, etc)
- purely gauge term (Triple gauge coupling, etc)
- Higgs electroweak couplings

We focused on this physics

We can write the effective Lagrangian including Higgs doublet as

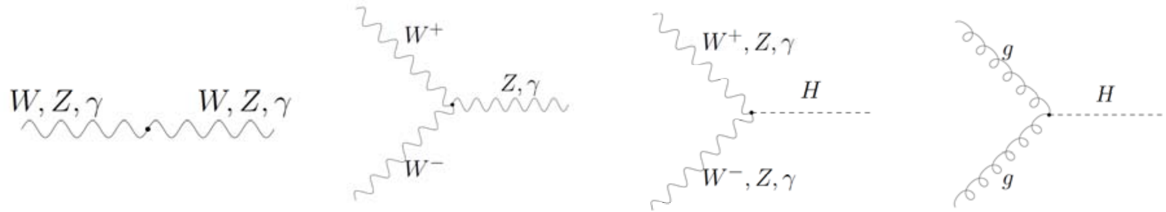
$$L_{eff} = L_{SM} + \underline{\sum_i \frac{f_i}{\Lambda^2} \mathrm{O}_i^{(6)}}$$

New physics effects. Here we consider only dimension 6

and the operators are …

# 1-3. dimension 6 operators including Higgs

2 point function, TGC, vertices include Higgs boson




Precision measurement
(SLC, LEP, Tevatron)

Triple gauge couplings
(LEP2,Tevatron)

LHC

LC

Dimension 6 operators

| $\mathcal{O}$ | $WW$ | $ZZ$ | $Z\gamma$ | $\gamma\gamma$ | $WW\gamma$ | $WWZ$ | $HWW$ | $HZZ$ | $HZ\gamma$ | $H\gamma\gamma$ | $Hgg$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\mathcal{O}_{\phi,1} = \left[(D_\mu\Phi)^\dagger\Phi\right]\left[\Phi^\dagger(D^\mu\Phi)\right]$ | | √ | | | | | √ | √ | | | |
| $\mathcal{O}_{BW} = \Phi^\dagger\hat{B}^{\mu\nu}\hat{W}_{\mu\nu}\Phi$ | | √ | √ | √ | √ | √ | √ | √ | √ | √ | |
| $\mathcal{O}_W = (D^\mu\Phi)^\dagger\hat{W}_{\mu\nu}(D^\nu\Phi)$ | | | | | √ | √ | √ | √ | √ | | |
| $\mathcal{O}_B = (D^\mu\Phi)^\dagger\hat{B}_{\mu\nu}(D^\nu\Phi)$ | | | | | √ | √ | | √ | √ | | |
| $\mathcal{O}_{WW} = \Phi^\dagger\hat{W}^{\mu\nu}\hat{W}_{\mu\nu}\Phi$ | – | – | – | – | – | – | √ | √ | √ | √ | |
| $\mathcal{O}_{BB} = \Phi^\dagger\hat{B}^{\mu\nu}\hat{B}_{\mu\nu}\Phi$ | | – | – | – | | | | √ | √ | √ | |
| $\mathcal{O}_{\phi,4} = (\Phi^\dagger\Phi)(D_\mu\Phi)^\dagger(D^\mu\Phi)$ | – | – | | | | | √ | √ | | | |
| $\mathcal{O}_{\phi,2} = \frac{1}{2}\partial_\mu(\Phi^\dagger\Phi)\partial^\mu(\Phi^\dagger\Phi)$ | | | | | | | √ | √ | | | |
| $\mathcal{O}_{gg} = \Phi^\dagger\hat{G}^{\mu\nu}\hat{G}_{\mu\nu}\Phi$ | | | | | | | | | | | √ |

# 2. Conclusions

- The most accurately measured combinations of dim-6 operators are sensitive to the quantum corrections

$$\begin{cases} .987\ f_{\phi 1} - \ .16\ f_{BW} = -\ 0.032\ \pm\ 0.015, \\ .16\ f_{\phi 1} + \ .987\ f_{BW} = -\ 0.10\ \pm\ 0.14. \end{cases}$$

(EWPM )

$$\begin{cases} .95 f_W \ -.29 f_B = \pm .012 \\ .48 f_{BW} \ +.66 f_{WW} \ +.54 f_{BB} = \pm .016 \\ +.36 f_{BW} \ +.84 f_B = \pm .025 \end{cases}$$

(ILC our result)

- ILC experiment can constrain completely different combinations of dim-6 operators from EWPM

  We can select new physics by multi-dimensional operator space

- These accuracy of the combinations are not affected from systematic errors ex) luminosity uncertainty
- $e^-$ beam polarization plays an important role to obtain high accuracy
- High energy experiments( $\sqrt{s} > 500 GeV$ ) are important for the measurements of $HZ\gamma$ couplings

# 3-1. Optimal observable method

The differential cross section can be expressed by using non-SM couplings

$$\frac{d\sigma}{d\Omega} = \Sigma_{SM} + \sum_i c_i \Sigma_i(\Omega)$$

$c_i = (c_{iZZ}, c_{2Z\gamma}, c_{3Z\gamma}, c_{2\gamma\gamma}, c_{iWW}), i = 1,2,3$

$\Omega$ is 3-body phase space

$$\begin{cases} N^k_{EXP} \approx L\Sigma_{SM}\Delta\Omega_k, \\ N^k_{TH} = L\Sigma_{SM}\Delta\Omega_k + L\sum_i c_i\Sigma_i(\Omega)\Delta\Omega_k \end{cases}$$

number of event in the k-th bin for experiment and theory

$\chi^2$ can be expressed in terms of non-SM couplings

$$\chi^2(c_1,\cdots,c_n) = \sum_k \left( \frac{N^k_{EXP} - N^k_{TH}(c_i)}{\sqrt{N^k_{EXP}}} \right)^2 + \chi^2_{\min} = \sum_k \left( \frac{L\sum_i c_i \Sigma_i(\Omega_k)\Delta\Omega_k}{\sqrt{L\Sigma_{SM}\Delta\Omega_k}} \right)^2 + \chi^2_{\min}$$

$$= \sum_{i,j} c_i c_j L \sum_k \frac{\Sigma_i(\Omega_k)\Sigma_j(\Omega_k)}{\Sigma_{SM}(\Omega_k)} \Delta\Omega_k + \chi^2_{\min} \equiv \sum_{i,j} c_i (V^{-1})_{ij} c_j + \chi^2_{\min}$$

if $V^{-1}$ is given, we can calculate $\Delta c_i$

$$\mathbf{\Delta c_i} = \sqrt{\mathbf{V_{ii}}}$$

The large discrepancy between $\Sigma_{SM}$ and $\Sigma_i(\Omega)$ makes $V^{-1}$ larger ⇨ errors become small

# 3-2. Operators and Vertices, Form Factors

We exchange the operators into HVV interaction vertices as the experimental observables

$$L_{eff} = L_{SM} + \sum_i \frac{f_i}{\Lambda^2} \mathrm{O}_i^{(6)} = (1 + c_{1ZZ}) \frac{g_Z m_Z}{2} HZ_\mu Z^\mu + (1 + c_{1WW}) g m_W HW_\mu^+ W^{-\mu}$$

$$+ \frac{g_Z}{m_Z} \sum_{V=\gamma,Z} [c_{2ZV} HZ_{\mu\nu} V^{\mu\nu} + c_{3ZV}((\partial_\mu H) Z_\nu - (\partial_\nu H) Z_\mu) V^{\mu\nu}]$$

$$+ \frac{g_Z}{m_Z} [c_{2WW} HW_{\mu\nu}^+ W^{-\mu\nu} + \frac{c_{3WW}}{2}(((\partial_\mu H) W_\nu^- - (\partial_\nu H) W_\mu^-) W^{+\mu\nu} + h.c.)] + \cdots$$

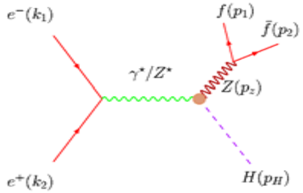
※ $c_i = (c_{iZZ}, c_{2Z\gamma}, c_{3Z\gamma}, c_{2\gamma\gamma}, c_{iWW})$ are the linear function of $f_i$

$$\begin{aligned}
c_{1ZZ} &= \frac{v^2}{4\Lambda^2}(3f_{\phi 1} + 3f_{\phi 4} - 2f_{\phi 2}),\\
c_{2ZZ} &= \frac{m_Z^2}{\Lambda^2}(-s_W{}^4 f_{BB} - s_W^2 c_W^2 \boxed{f_{BW}} - c_W{}^4 f_{WW}),\\
c_{2Z\gamma} &= \frac{m_Z^2}{\Lambda^2}(s_W^2 f_{BB} + \frac{1}{2}(c_W^2 - s_W^2)\boxed{f_{BW}} - c_W^2 f_{WW}) s_W c_W,\\
c_{3ZZ} &= \frac{m_Z^2}{2\Lambda^2}(-s_W^2 \boxed{f_B} - c_W^2 \boxed{f_W}),\\
c_{3Z\gamma} &= \frac{m_Z^2}{4\Lambda^2}(\boxed{f_B - f_W}) s_W c_W,\\
c_{2\gamma\gamma} &= \frac{m_Z^2}{\Lambda^2}(-f_{BB} + \boxed{f_{BW}} - f_{WW}) c_W^2 s_W^2,
\end{aligned}$$

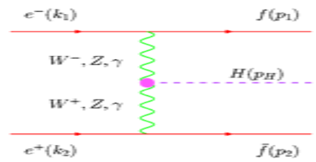
$$\begin{aligned}
c_{1WW} &= \frac{v^2}{4\Lambda^2}(-f_{\phi 1} + 3f_{\phi 4} - 2f_{\phi 2}),\\
c_{2WW} &= \frac{m_Z^2 c_W^2}{\Lambda^2}(-f_{WW}),\\
c_{3WW} &= \frac{m_Z^2 c_W^2}{2\Lambda^2}(\boxed{-f_W})
\end{aligned}$$

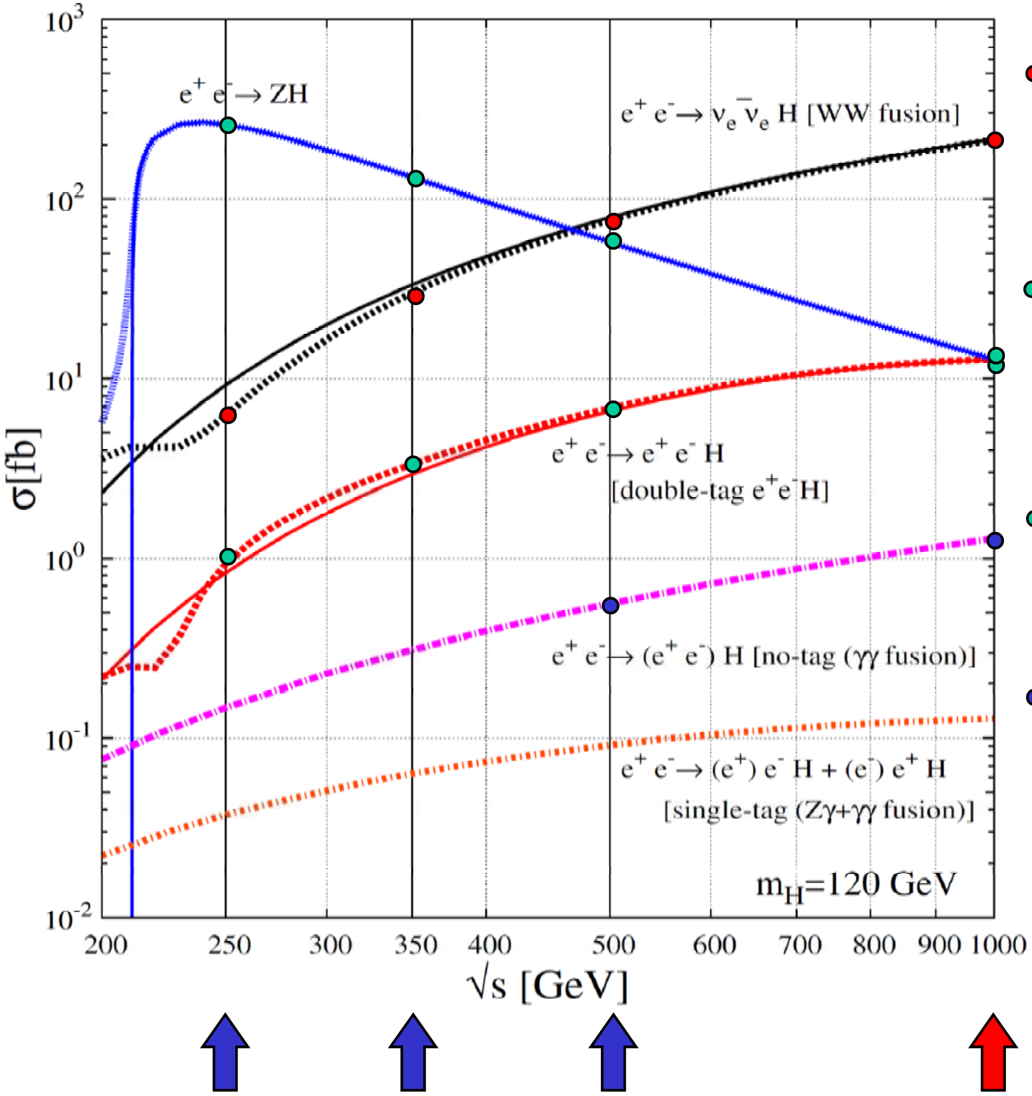
: EW precision, S and T parameter

: Triple Gauge Couplings



# 3-3. Cross section






~ ILC phase I

phase II

- WW-fusion $c_{iWW}$ $\left\{ f_{\phi 1}, f_{\phi 2}, f_{\phi 4};\ f_W;\ f_{WW} \right.$
- double-tag eeH, ZH production $c_{iZZ}$ $\left\{ f_{\phi 1}, f_{\phi 2}, f_{\phi 4};\ f_W, f_B;\ f_{WW}, f_{BB}, f_{BW} \right.$
- double-tag eeH, single-tag eeH, ZH production $c_{iZ\gamma}$ $\left\{ f_W, f_B;\ f_{WW}, f_{BB}, f_{BW} \right.$
- no-tag (ee)H $c_{2\gamma\gamma}$ $\left\{ f_{WW}, f_{BB}, f_{BW} \right.$

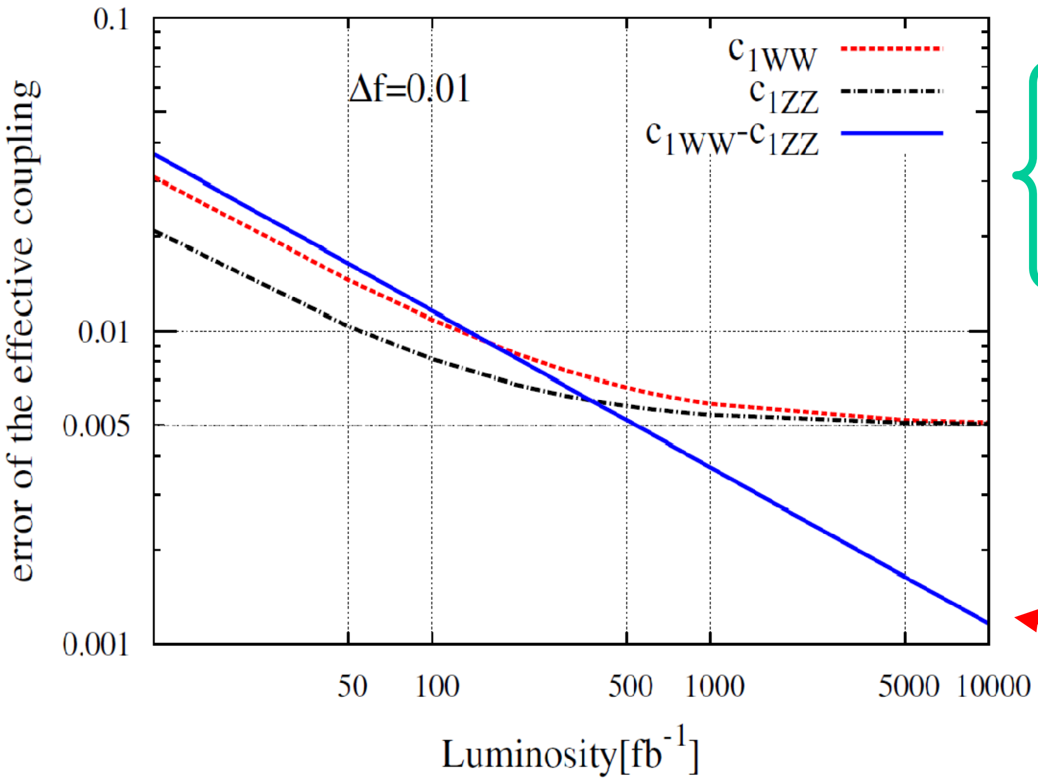
| | **High $\sqrt{s}$ experiment** | **polarization** | **no-tag (ee)H** |
|---|---|---|---|
| $f_{\phi i}$ | ○ | | |
| $f_W$, $f_B$ | ○ | ○ | |
| $f_{VV}$ | ○ | ○ | ○ |

# 3-4. Luminosity uncertainty

Here we set $L = f\,\bar{L}, \qquad f = 1 \pm \Delta f,$ L is true luminosity

$\chi^2$ can be redefined as $\chi^2(c_i) \;\rightarrow\; \bar{L}\sum_{k=1}^{N}\frac{\left[(f-1)\,\Sigma_{\rm SM}(\Phi_k)+\sum_{i=1}^{n} c_i\,\Sigma_i(\Phi_k)\right]^2}{\Sigma_{\rm SM}(\Phi_k)}\Delta + \left(\frac{f-1}{\Delta f}\right)^2,$

Luminosity uncertainty is absorbed into $c_{1ZZ}$ , $c_{1WW}$ errors




$$c_{1WW} = \pm\sqrt{\left(\frac{\Delta f}{2}\right)^2 + (\Delta c_{1WW})^2}, \quad c_{1ZZ} = \pm\sqrt{\left(\frac{\Delta f}{2}\right)^2 + (\Delta c_{1ZZ})^2},$$

$$\rho = \left[\left(1 + 4\,\frac{(\Delta c_{1WW})^2}{(\Delta f)^2}\right)\left(1 + 4\,\frac{(\Delta c_{1ZZ})^2}{(\Delta f)^2}\right)\right]^{-\frac{1}{2}}$$

The correlation between $c_{1ZZ}$ and $c_{1WW}$ is generated through luminosity uncertainty

$$c_{1WW} - c_{1ZZ} \propto f_{\phi 1}$$

The measurement of $f_{\phi 1}$ doesn't depend on $\Delta f$

# 4-1. constraint on dim-6 operators (1)

① EWPM results

$$\begin{cases} .987\, f_{\phi 1} - .16\, f_{BW} = -0.032 \pm 0.015, \\ .16\, f_{\phi 1} + .987\, f_{BW} = -0.10 \pm 0.14. \end{cases}$$

1 dimensional

② ILC-I+ILC-II with $|P_{e-}| = 0.8, |P_{e+}| = 0.0, \Delta f = 0.01, L_{total} = 1200 fb^{-1}$

$\sqrt{s}$ : 250,350,500,1000
$L$ : 100,100,500,500

$$\begin{cases} .95 f_W - .29 f_B = \pm .012 \\ .48 f_{BW} + .66 f_{WW} + .54 f_{BB} = \pm .016 \\ +.36 f_{BW} + .84 f_B = \pm .025 \end{cases}$$

5 dimensional

③ ILC-I with $|P_{e-}| = 0.8, |P_{e+}| = 0.0, \Delta f = 0.01, L_{total} = 700 fb^{-1}$

$\sqrt{s}$ : 250,350,500
$L$ : 100,100,500

$$\begin{cases} +.31 f_B + .73 f_{WW} + .47 f_{BB} = \pm .031 \\ -.35 f_{\phi 1} + .84 f_W - .28 f_B = \pm .032 \\ -.49 f_{\phi 1} + .63 f_{BW} + .47 f_B = \pm .045 \end{cases}$$

④ ILC-I (250,350GeV) with $|P_{e-}| = 0.8, |P_{e+}| = 0.0, \Delta f = 0.01, L_{total} = 700 fb^{-1}$

$\sqrt{s}$ : 250,350
$L$ : 350,350

$$\begin{cases} -.79 f_{\phi 1} + .33 f_W + .50 f_{WW} = \pm 0.059 \\ -.53 f_{\phi 1} - .78 f_W - .28 f_{WW} = \pm 0.18 \\ -.31 f_{BW} - .41 f_W + .70 f_{WW} + .42 f_{BB} = \pm 0.46 \end{cases}$$

# 4-2. Constraints on dim6-Operators (2) combining with LEP and future experiments

EWPM will be also improved at ILC experiments

$$\boxed{\begin{aligned} .987\, f_{\phi 1} - .16\, f_{\rm BW} &= -0.032 \pm 0.015, \\ .16\, f_{\phi 1} + .987\, f_{\rm BW} &= -0.10 \pm 0.14. \end{aligned}}$$

@ LEP2,Tevatron (present EWPM)

if

$$\left\{\begin{aligned} m_W\,[\mathrm{GeV}] &= 80.403 \pm 0.010, \\ m_t\,[\mathrm{GeV}] &= 172.50 \pm 0.10, \\ \alpha_s(m_Z)_{\overline{\rm MS}} &= 0.1180 \pm 0.0010, \\ \Delta\alpha^5_{\rm had} &= 0.02768 \pm 0.00010, \end{aligned}\right.$$

@ ILC

+ $\sin^2\theta_W^{\rm eff} = 0.23153 \pm 0.000013.$ @ GigaZ

$$\boxed{\begin{aligned} .98\, f_{\phi 1} - .17\, f_{\rm BW} &= -0.041 \pm 0.0034, \\ .17\, f_{\phi 1} + .98\, f_{\rm BW} &= -0.33 \pm 0.062. \end{aligned}}$$

+

$$\begin{array}{lllll} & .95 f_{\rm W} \; -.29 f_{\rm B} & & & = \pm .012 \\ .48 f_{\rm BW} & & +.66 f_{\rm WW} & +.54 f_{\rm BB} & = \pm .016 \\ +.36 f_{\rm BW} & +.84 f_{\rm B} & & & = \pm .025 \end{array}$$

The results combining our HVV measurements at ILC and EWPM at ILC are

$$\boxed{\begin{array}{lllll} .98 f_{\phi 1} & & & & = \pm .0034 \\ & .95 f_{\rm W} \; -.30 f_{\rm B} & & & = \pm .012 \\ -.50 f_{\rm BW} & & +.65 f_{\rm WW} & +.54 f_{\rm BB} & = \pm .015 \\ .32 f_{\rm BW} & +.88 f_{\rm B} & & & = \pm .023 \end{array}}$$

# 5. Conclusions

- We obtain the sensitivity to the ILC experiment on 8 dim-6 operator space by using Optimal observable method
- The t-channel processes of $e^+e^- \to \nu\bar{\nu}H$ and $e^+e^- \to e^+e^-H$ at high energy experiment are important to measure $HWW, HZ\gamma$ and $H\gamma\gamma$ couplings
- Polarization is important to obtain high accurate measurement on $HZ\gamma$ coupling
- Luminosity uncertainty affects $c_{1ZZ}, c_{1WW}$ measurements, but only one combination of the operators, $3f_{\phi 4} - 2f_{\phi 2}$ is affected
- The expected accuracy of the measurements will be sensitive to quantum corrections as same accuracy as EWPM.
  And its constraints are in the multi dimensional space.