EWPOs using radiative return

- motivation
- A_{LR} (electron)
- A_f (f=b/c/μ/τ)
- R_f
- g_L & g_R

Junping Tian (U. Tokyo)

The 62nd General Meeting of ILC Physics Subgroup, KEK

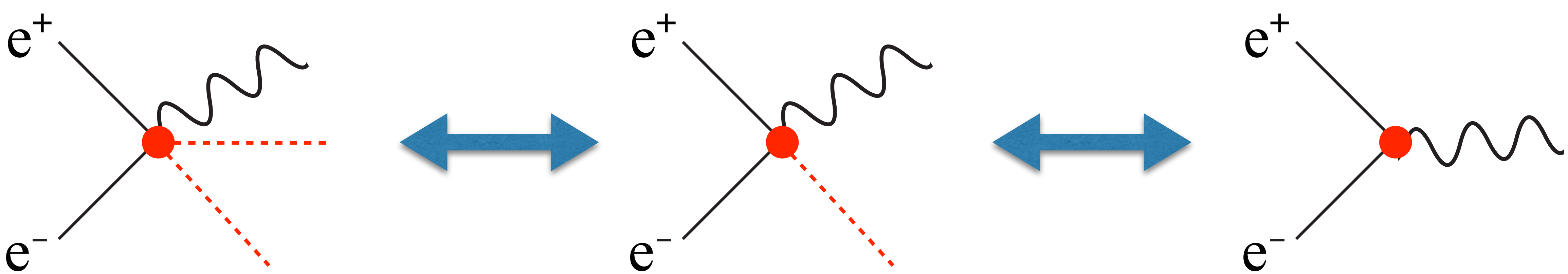
task force: K.Fujii, D.Jeans, M.Kurata, T.Suehara, J.Tian, H.Yamamoto

recap 1: Higgs couplings are related to EW couplings (EWPOs)

$$i\frac{c_{HL}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu \Phi)(\overline{L}\gamma_\mu L)$$

$$4i\frac{c'_{HL}}{v^2}(\Phi^\dagger t^a \overleftrightarrow{D}^\mu \Phi)(\overline{L}\gamma_\mu t^a L)$$

$$i\frac{c_{HE}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu \Phi)(\overline{e}\gamma_\mu e)$$



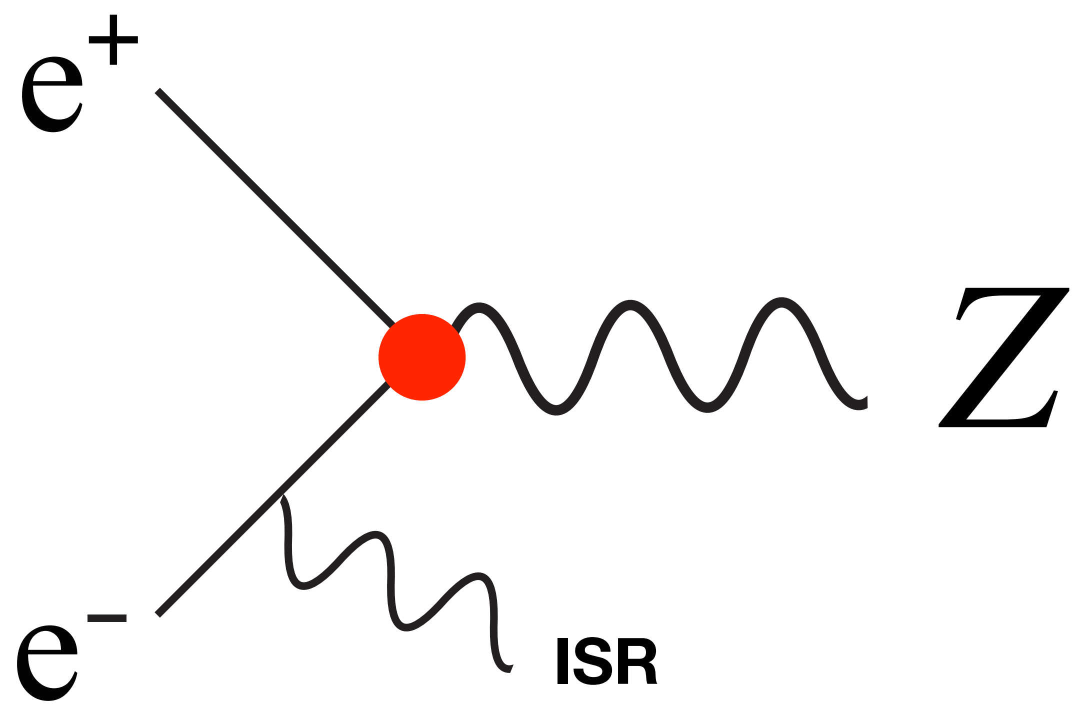
e^+e^- ->Zhh

e^+e^- ->Zh

Z-pole

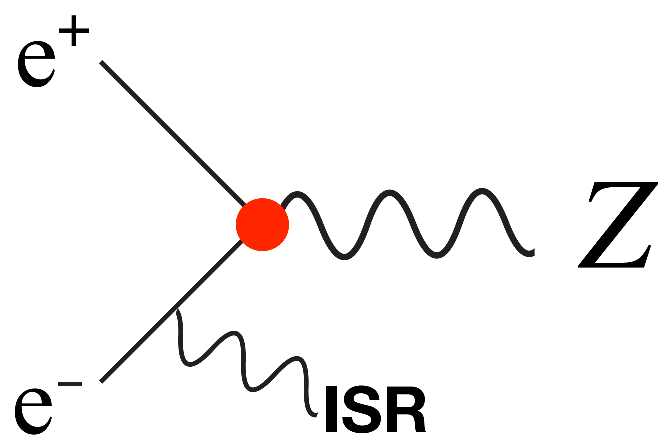
- contact interactions from c_{HL}/c_{HL}'/c_{HE} in Higgs processes can be constrained by EWPOs at Z-pole: $\boldsymbol{A_{LR}}$, $\boldsymbol{\Gamma_l}$

a gift from ISR: radiative return @ ILC250



- ISR is mostly collinear
- asymmetric collision at Z-pole
- ISR (QED) retains initial e-/e+ chirality

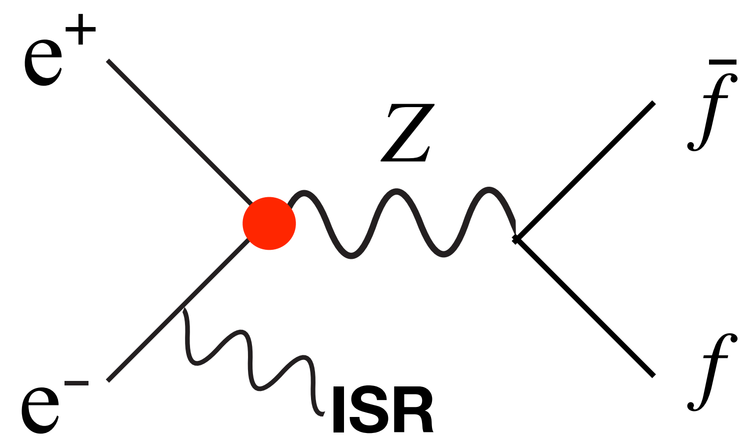
of radiative return events @ ILC250



ILC250	(-0.8,+0.3)	(+0.8,-0.3)
hadronic	46M	31M
leptonic	7.2M	4.9M
combined	54M	36M

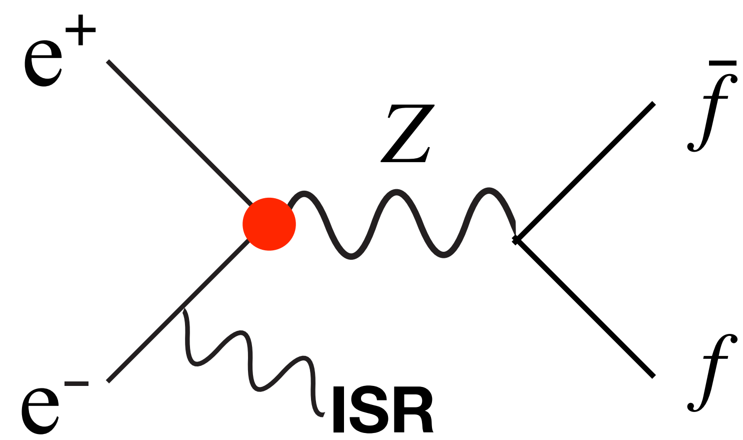
- ~10^8 events at ILC250 with 2 ab^{-1}
- > 5 (100) times than all Z at LEP (SLC)
- and now all with beam polarizations
- potentially much better $\boldsymbol{A_f}$ and $\boldsymbol{R_f}$ measurements

study of e+e- -> γZ @ ILC250



- reconstruction method from LEP 2: Z mass can be determined by only directions of two fermions
- shortly after our SMEFT studies in 2017, I proposed to use this process at ILC250 for improving A_{LR} (T.Barklow@AWLC17)
- SiD performed a fast simulation (T.Ueno@LCWS18)
- ILD full simulation ongoing (T.Mizuno)
- following are some expectations

study of e+e- -> γZ @ ILC250



method not working

$$\begin{pmatrix} p_1 \\ p_2 \end{pmatrix} = \frac{p_t}{\sin\phi} \begin{pmatrix} \frac{\sin(\phi-\phi_2)}{\sin\theta_1} \\ \frac{\sin(\phi_1-\phi)}{\sin\theta_2} \end{pmatrix}$$

$$\phi = \phi_1 - \phi_2 \qquad p_t = \sqrt{p_x^2 + p_y^2}$$

proper method

$$|\beta| = \frac{|\sin(\theta_1+\theta_2)|}{\sin\theta_1 + \sin\theta_2}$$

for signal:

$$\beta = \frac{s - m_{12}^2}{s + m_{12}^2}$$

$$m_{12} = \sqrt{\frac{1-\beta}{1+\beta}s}$$

inputs and assumptions for A_f and R_f

	efficiency	systematics
Z->hadrons	73%[1]	0
Z->μμ/ee	88%[2]	0
Z->τ τ (Rf)	80%[3]	0.1%
Z->τ τ (Af)	80%[3]	0
Z->bb (Rf)	73% x 80%[4]	0.1%
Z->bb (Af)	73% x 40%[4]	0
Z-> cc (Rf)	73% x 30%[4]	0.5%
Z-> cc (Af)	73% x 10%[4]	0

[1] Takayuki Ueno, Master Thesis

[2] T.Suehara et al; [3] D.Jeans; [4] R.Poeschl et al

result: A_{LR} using e+e- -> γZ (A_e)

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = A_e \qquad \Delta A_e = \frac{1}{\sqrt{N}}\sqrt{K^2 - A_e^2}$$

$$K = \frac{1 + |P_{e^-}P_{e^+}|}{|P_{e^-}| + |P_{e^+}|}$$

N: # of sig. events

- to measure: cross sections for (-0.8,+0.3) and (+0.8,-0.3), using all hadronic and leptonic channels

ILC250	N_L	N_R	ΔA_{LR}
hadronic	46M	31M	0.00015
leptonic	7.2M	4.9M	0.00035
combined	54M	36M	0.00014

- main systematics would be uncertainty of K factor (effective polarization), which would be determined using WW data -> c.f. R.Karl's thesis, and further study would be needed

result: A_{LR} using e+e- -> γZ (A_f, f=μ/τ/b/c)

$$A_{LRFB} = \frac{\sigma_{LF} - \sigma_{LB} - \sigma_{RF} + \sigma_{RB}}{\sigma_{LF} + \sigma_{LB} + \sigma_{RF} + \sigma_{RB}} = \frac{3}{4} A_f \qquad \Delta A_f = \frac{1}{\sqrt{N}} \sqrt{\frac{16}{9} K^2 - A_f^2}$$

- to measure: + cross sections in the forward/backward regions

	ΔAb	ΔAc	ΔAμ	ΔAτ
ILC250	0.00053	0.0014	0.00080	0.00083

- systematics: + uncertainties from charge identification, momentum directions -> c.f. study by Adrain for bb/cc, need further study here due to the boost of Z (more forward jets); also need to study tau channel the about the momentum directions

result: BR(Z->ff) using e+e- -> γZ (R_f, f=μ/τ/b/c)

$$R_{b/c} = \frac{\Gamma(Z \to b\bar{b}/c\bar{c})}{\sum_q \Gamma(Z \to q\bar{q})} \qquad R_{\mu/\tau} = \frac{\sum_q \Gamma(Z \to q\bar{q})}{\Gamma(Z \to \mu^+\mu^-/\tau^+\tau^-)}$$

- to measure: σxBR, relative simple

	ΔRb	ΔRc	ΔRμ	ΔRτ	ΔRe
ILC250	0.00023	0.00087	0.011	0.024	0.024

- systematics: uncertainty on various efficiencies

result: Zff couplings (gL/gR) using e+e- -> γZ

$$\delta g_L = \frac{A_f}{2(A_f+1)}\delta A_f \;\oplus \frac{1}{2}\delta R_f \;\oplus \frac{1}{2}\delta\Gamma_{had}$$

$$\delta g_R = \frac{A_f}{2(A_f-1)}\delta A_f \;\oplus \frac{1}{2}\delta R_f \;\oplus \frac{1}{2}\delta\Gamma_{had}$$

↑

note the large factor for b_R coupling

result: EWPOs from e+e- -> γZ

Quantity	Value	current	GigaZ		250 GeV	
		$\delta[10^{-4}]$	$\delta_{stat}[10^{-4}]$	$\delta_{sys}[10^{-4}]$	$\delta_{stat}[10^{-4}]$	$\delta_{sys}[10^{-4}]$
boson properties						
m_W	80.379	1.5	-	-		0.3 °
m_Z	91.1876	0.23	-	-	-	-
Γ_Z	2.4952	9.4		3.2	-	-
$\Gamma_Z(had)$	1.7444	11.5		3.2	-	-
Z-e couplings						
$1/R_e$	0.0482	24.	2.	4 †	5.5	10 +
A_e	0.1515	139.	0.1	5 *	9.5	3 *
g_L^e	-0.632	16.	1.	2.5	2.8	7.6
g_R^e	0.551	18.	1.	2.5	2.9	7.6
Z-ℓ couplings						
$1/R_\mu$	0.0482	16.	2.	2. †	5.5	10 +
$1/R_\tau$	0.0482	22.	2.	4. †	5.7	10 +
A_μ	0.1515	991.	2.	5 *	54.	3 *
A_τ	0.1515	271.	2.	5 *	57.	3 *
g_L^μ	-0.632	66.	1.	1.8	4.5	7.6
g_R^μ	0.551	89.	1.	1.9	5.5	7.6
g_L^τ	-0.632	22.	1.	2.5	4.7	7.6
g_R^τ	0.551	27.	1.	2.5	5.8	7.6
Z-b couplings						
R_b	0.2163	31.	0.4	7. #	3.5	10 +
A_b	0.935	214.	1.	5. *	5.7	3 *
g_L^b	-0.999	54.	0.31	4.0	2.2	7.6
g_R^b	0.184	1540	7.2	36.	41.	23.
Z-c couplings						
R_c	0.1721	174.	2.	30 #,+	5.8	50 +
A_c	0.668	404.	3.	6. *	21.	3 *
g_L^c	0.816	119.	1.2	15.	5.1	26.
g_R^c	-0.367	415.	3.1	16.	21.	26.

LCC Physics WG

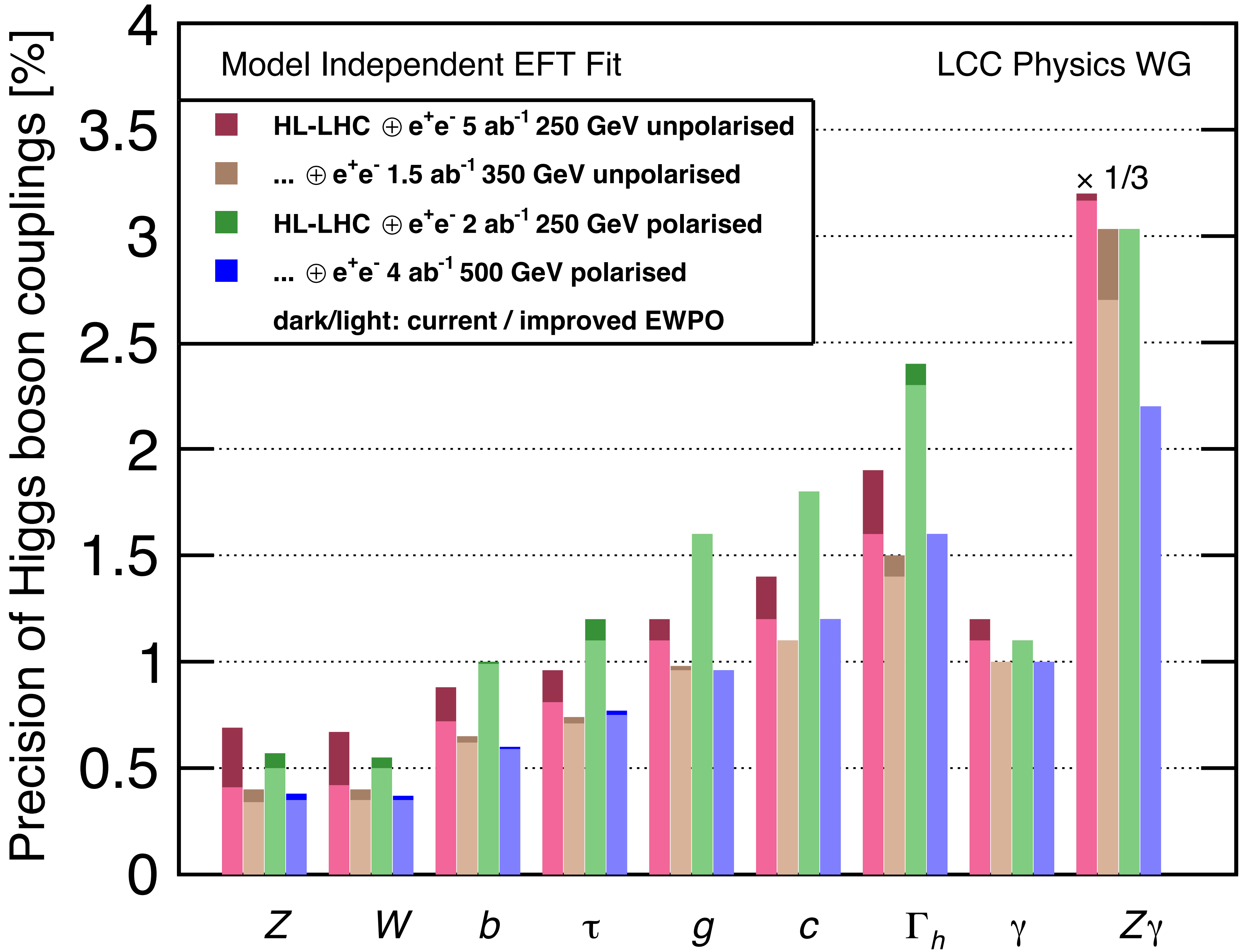
take-home message

if we work hard and be smart

ILC250 = ILC250 + 100xLEP/SLC

appendix

impact of EWPOs



experimental inputs and assumptions for section 1

	efficiency	systematics	cosθ	bin width
μ μ	98%[1]	0.1%	[-0.95,0.95]	0.1
τ τ	90%[2]	0.2%	[-0.95,0.95]	0.1
b b	29%[3]	0.2%	[-0.95,0.95]	0.1
c c	7%[3]	0.5%	[-0.95,0.95]	0.1
e e	97%[1]	0.1%	[-0.95,0.95]	0.1

flat acceptance function within the fiducial volume

b- and c-charge identification efficiency applied

analytic differential cross section, w/o effects from beamstrahlung and ISR

[1] T.Suehara; [2] D.Jeans; [3] R.Poeschl

computation for W and Y oblique parameters

(provided by M. Peskin & M. Perelstein)

$$\frac{d\sigma}{d\cos\theta}(e^-_L e^+_R \to f_L \overline{f}_R) = \frac{\pi\alpha^2}{2s}\left|F_{LL}\right|^2 (1+\cos\theta)^2$$
$$\frac{d\sigma}{d\cos\theta}(e^-_L e^+_R \to f_R \overline{f}_L) = \frac{\pi\alpha^2}{2s}\left|F_{LR}\right|^2 (1-\cos\theta)^2$$
$$\frac{d\sigma}{d\cos\theta}(e^-_R e^+_L \to f_L \overline{f}_R) = \frac{\pi\alpha^2}{2s}\left|F_{RL}\right|^2 (1-\cos\theta)^2$$
$$\frac{d\sigma}{d\cos\theta}(e^-_R e^+_L \to f_R \overline{f}_L) = \frac{\pi\alpha^2}{2s}\left|F_{RR}\right|^2 (1+\cos\theta)^2$$

$$F_{LL}(s) = -\left[Q_f + \frac{(\frac{1}{2}-s_w^2)(I_f^3 - s_w^2 Q_f)}{s_w^2 c_w^2}\frac{s}{(s-m_Z^2)} - \frac{\frac{1}{2}\,I_f^3}{s_w^2}\frac{s}{m_W^2}\mathbf{W} - \frac{\frac{1}{2}\,Y_f}{c_w^2}\frac{s}{m_W^2}\mathbf{Y}\right]$$
$$F_{LR}(s) = -\left[Q_f + \frac{(\frac{1}{2}-s_w^2)(-s_w^2 Q_f)}{s_w^2 c_w^2}\frac{s}{(s-m_Z^2)} - \frac{\frac{1}{2}\,Q_f}{c_w^2}\frac{s}{m_W^2}\mathbf{Y}\right]$$
$$F_{RL}(s) = -\left[Q_f + \frac{(-s_w^2)(I_f^3 - s_w^2 Q_f)}{s_w^2 c_w^2}\frac{s}{(s-m_Z^2)} - \frac{Y_f}{c_w^2}\frac{s}{m_W^2}\mathbf{Y}\right]$$
$$F_{RR}(s) = -\left[Q_f + \frac{(-s_w^2)(-s_w^2 Q_f)}{s_w^2 c_w^2}\frac{s}{(s-m_Z^2)} - \frac{Q_f}{c_w^2}\frac{s}{m_W^2}\mathbf{Y}\right]$$

composite models

	η_{LL}	η_{RR}	η_{LR}	η_{RL}
Λ^+_{LL}	1	0	0	0
Λ^-_{LL}	-1	0	0	0
Λ^+_{RR}	0	1	0	0
Λ^-_{RR}	0	-1	0	0
Λ^+_{VV}	1	1	1	1
Λ^-_{VV}	-1	-1	-1	-1
Λ^+_{AA}	1	1	-1	-1
Λ^-_{AA}	-1	-1	1	1
$\Lambda^+_{(V-A)}$	0	0	1	1
$\Lambda^-_{(V-A)}$	0	0	-1	-1

$$\mathcal{L}_{LL} = \frac{g^2_{\text{contact}}}{2\Lambda^2} \sum_{i,j} \eta^{ij}_{LL} (\bar{\psi}^i_L \gamma_\mu \psi^i_L)(\bar{\psi}^j_L \gamma^\mu \psi^j_L),$$

$$\mathcal{L}_{RR} = \frac{g^2_{\text{contact}}}{2\Lambda^2} \sum_{i,j} \eta^{ij}_{RR} (\bar{\psi}^i_R \gamma_\mu \psi^i_R)(\bar{\psi}^j_R \gamma^\mu \psi^j_R),$$

$$\mathcal{L}_{LR} = \frac{g^2_{\text{contact}}}{2\Lambda^2} \sum_{i,j} \eta^{ij}_{LR} (\bar{\psi}^i_L \gamma_\mu \psi^i_L)(\bar{\psi}^j_R \gamma^\mu \psi^j_R),$$

$$\mathcal{L}_{RL} = \frac{g^2_{\text{contact}}}{2\Lambda^2} \sum_{i,j} \eta^{ij}_{RL} (\bar{\psi}^i_R \gamma_\mu \psi^i_R)(\bar{\psi}^j_L \gamma^\mu \psi^j_L),$$

Tanabashi, et al,
PRD 98 (2018) 030001

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