Deciphering importance of every measurement in SMEFT

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the 61st general meeting of ILC Physics Subgroup,
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outline

still work-in-progress

mysteries from last general meeting solved

new understanding about role of beam polarization

framework for Higgs coupling determination at e+e-: SMEFT

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \Delta\mathcal{L}$$

$$= \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^{d_i-4}} O_i$$

Barklow, et al, arXiv:1708.08912;
Durieux, et al, arXiv:1704.02333

known: $$Y_i = \sum_j x_{ij} c_j$$

Yi: EWPO (9) + TGCs (3) + LHC Higgs (3) + ILC Higgs (12 x 2)

not known: how important is every measurement (Yi)?

what are the limiting factoring for determining certain EFT operator / Higgs coupling?

framework for Higgs coupling determination at e+e-: SMEFT

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \Delta\mathcal{L}$$

$$= \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^{d_i-4}} O_i$$

not known: how important is every measurement (Yi)?

what are the limiting factoring for determining certain EFT operator / Higgs coupling?

solution: $$c_i = \sum_j y_{ij} Y_j$$

ci: including both EFT coefficients and Higgs couplings

solutions: validations

comparing uncertainties between global fit and my analytic calculation

$\delta = \Delta X / X$, in unit 10^{-4}

pars.	g	g'	v	g_W	g_L	g_R	g_Z
δ (global fitting)	11.0	3.37	5.34	0.622	7.64	9.18	7.09
δ (my formula)	11.1	3.41	5.34	0.622	7.64	9.18	7.09

$\sqrt{s}$ = 250 GeV; 2000 fb^{-1}; P(e-,e+)=(0.,0.)

solutions: validations

mysteries from last meeting

comparing uncertainties between global fit and my analytic calculation

$\Delta = \Delta X$, in unit 10^{-4}

pars.	c_T	$8c_{WW}$	$8c_{WB}$	$8c_{BB}$	c_{HL}	c_{HL}'	c_{HE}	c_H
Δ (global fitting)	5.21	21.3	9.30	21.4	4.39	5.34	8.56	198
Δ (my formula)	5.21	21.6	9.30	21.6	4.39	5.34	2.65	150

$\sqrt{s}$ = 250 GeV; 2000 fb^{-1}; P(e-,e+)=(0.,0.)

myteries solved

inconsistencies in two para. are caused by two bugs in global fit

my analytic calculation was correct

bug 1

Barklow, Fujii, Jung, Peskin, JT, 1708.09079

Equation (83)

$$\delta g_R = -c_w^2 \delta g + (1 + c_w^2)\delta g' - \frac{1}{2s_w^2} c_{HE} - \frac{1}{2} c_w^2 (8c_{WW}) + c_w^2 (8c_{WB}) + \frac{1}{2}\frac{s_w^2}{c_w^2}(1 + c_w^2)(8c_{BB})$$

"-" sign was missed in the code of fitting program

bug found by S.Jung & J.Lee (Seoul National U.)

ILC Higgs precisions become better,
e.g. g(hZZ) @ ILC250, 0.67% -> 0.56%

bug 2

Barklow, Fujii, Jung, Peskin, JT, 1708.09079

Equation (88)

$$b_L = \frac{1}{(1-2s_w^2)}\Big\{c_w^2(1-2s_w^2\frac{m_Z^2}{s})(8c_{WW}) + 2s_w^2(1-2s_w^2)\frac{m_Z^2}{s}(8c_{WB}) - \frac{1}{c_w^2}(1-2c_w^2\frac{m_Z^2}{s})(8c_{BB})\Big\}$$

a factor of $\sin^4\theta_W$ was missed for c_{BB} term in the formula

bug found by myself

ILC Higgs precisions remain almost unchanged; but circular ones become considerably better mysteries solved

solutions: validations

comparing uncertainties between global fit and my analytic calculation

$\Delta = \Delta X$, in unit 10^{-4}

pars.	c_T	$8c_{WW}$	$8c_{WB}$	$8c_{BB}$	c_{HL}	c_{HL}'	c_{HE}	c_H
Δ (global fitting)	5.21	15.5	9.30	15.6	4.39	5.34	2.65	146
Δ (my formula)	5.21	15.6	9.30	15.7	4.39	5.34	2.65	147

(BR(h->γZ) @ HL-LHC updated)

$\sqrt{s}$ = 250 GeV; 2000 fb^{-1}; P(e-,e+)=(0.,0.)

wrapping up

Deciphering Importance of Every Measurement in the SMEFT at e^+e^-

CONTENTS

pars	G_F	e	m_W	m_Z	m_h	Γ_l	A_l	$g_{Z,eff}$	$\kappa_{A,eff}$	$\Gamma(h \to \gamma\gamma)$	$\Gamma(h \to \gamma Z)$	σ_{Zh}
g	0.5	1.23	1	0.38	0	-0.38	0.026	0.77	-0.5	-0.00095	-0.0031	0
g'	-0.15	0.93	-0.30	-0.12	0	0.12	-0.0078	-0.23	0.15	-0.00095	0.00095	0
v	-1	-0.23	-1	-0.38	0	0.38	0.014	-0.77	0	0	0	0
g_W	0.5	0	1	0	0	0	0	0	0	0	0	0
g_L	0	0	0	-0.5	0	0.5	0.064	0	0	0	0	0
g_R	0	0	0	-0.5	0	0.5	-0.086	0	0	0	0	0
g_Z	1.3	0	2.6	0.5	0	-0.5	-0.019	1	0	0	0	0
c_T	0	-0.74	2	-2.2	0	0.23	-0.040	-0.46	0.60	0	0	0
$8c_{WW}$	1	-2	2	0	0	0	-0.081	0	1	0.0019	0.0063	0
$8c_{WB}$	1	-2	2	0	0	0	-0.081	0	1	0	0	0
$8c_{BB}$	1	-2	2	0	0	0	-0.081	0	1	0.0063	-0.0063	0
c_{HL}	-0.5	0.092	-1	-0.38	0	0.38	0.014	-0.23	0.30	0	0	0
c'_{HL}	-0.5	-0.23	-1	-0.38	0	0.38	0.014	-0.77	0	0	0	0
c_{HE}	0	-0.28	0	0	0	0	0	-0.46	0.60	0	0	0
c_H	-2.4	-11	-13	-2.3	-2.3	9.7	-0.18	-4.4	3.2	0.011	0.027	-1
$g(hZZ)$	4.5	7.6	7.9	0.066	8.9	-6.4	0.098	5.3	-2.4	-0.0059	-0.015	0.5

TABLE I. analytic formula for EFT operators and Higgs couplings.

solutions: examples

P(e-,e+)=(0.,0.)

$$\delta g_{hZZ} = 4.5\delta G_F + 7.6\delta e - 7.9\delta m_W + 0.066\delta m_Z + 8.9\delta m_h - 6.4\delta\Gamma_l$$
$$-0.098\delta A_l + 5.3\delta g_{Z,eff} - 2.4\delta\kappa_{A,eff} - 0.0059\delta\Gamma_{\gamma\gamma}$$
$$-0.015\delta\Gamma_{\gamma Z} + 0.5\delta\sigma_{Zh}$$

solutions: examples to see importances

P(e-,e+)=(-0.0,+0.0)

$$\delta g_{hZZ} = 11 \oplus 66 \oplus 8.7 \oplus 23 \oplus 14 \oplus 30 \oplus 41 \oplus .. \qquad \times 10^{-4}$$

Γ_l

σ_{Zh}

g_{Zeff}

h->γZ

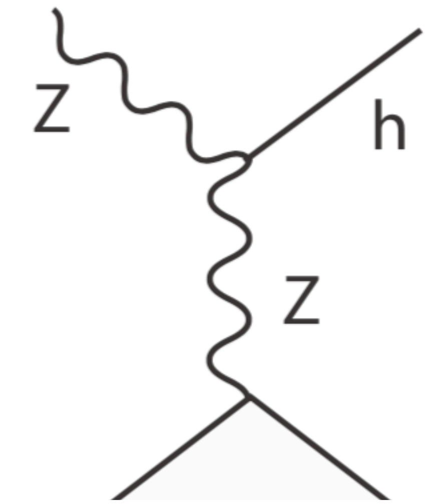
m_h

A_l

κ_{Aeff}

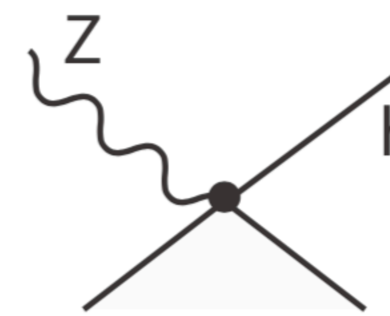
redundancy (iii): impact of beam polarizations

$$\Delta\mathcal{L} = \frac{m_Z^2}{v}(1+a)\,h\,Z_\mu Z^\mu + \frac{1}{2}\frac{b}{v}\,h\,Z_{\mu\nu}Z^{\mu\nu}$$



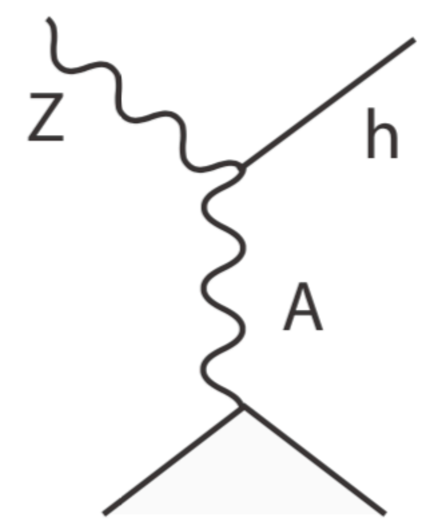
$$a_L = \delta g_L + 2\delta m_Z - \delta v + \eta_Z + \frac{(s-m_Z^2)}{2m_Z^2(1/2-s_w^2)}(c_{HL}+c'_{HL}) + k_Z\delta m_Z + k_h\delta m_h$$

$$a_R = \delta g_R + 2\delta m_Z - \delta v + \eta_Z - \frac{(s-m_Z^2)}{2m_Z^2(s_w^2)}c_{HE} + k_Z\delta m_Z + k_h\delta m_h$$



$$b_L = \zeta_Z + \frac{s_w c_w}{(1/2-s_w^2)}\frac{(s-m_Z^2)}{s}\zeta_{AZ}$$

$$b_R = \zeta_Z - \frac{c_w}{s_w}\frac{(s-m_Z^2)}{s}\zeta_{AZ}$$



$\sigma(e^+e^- \to Zh) / \sigma_{SM} = 1 + 2a + 5.7b$

backup

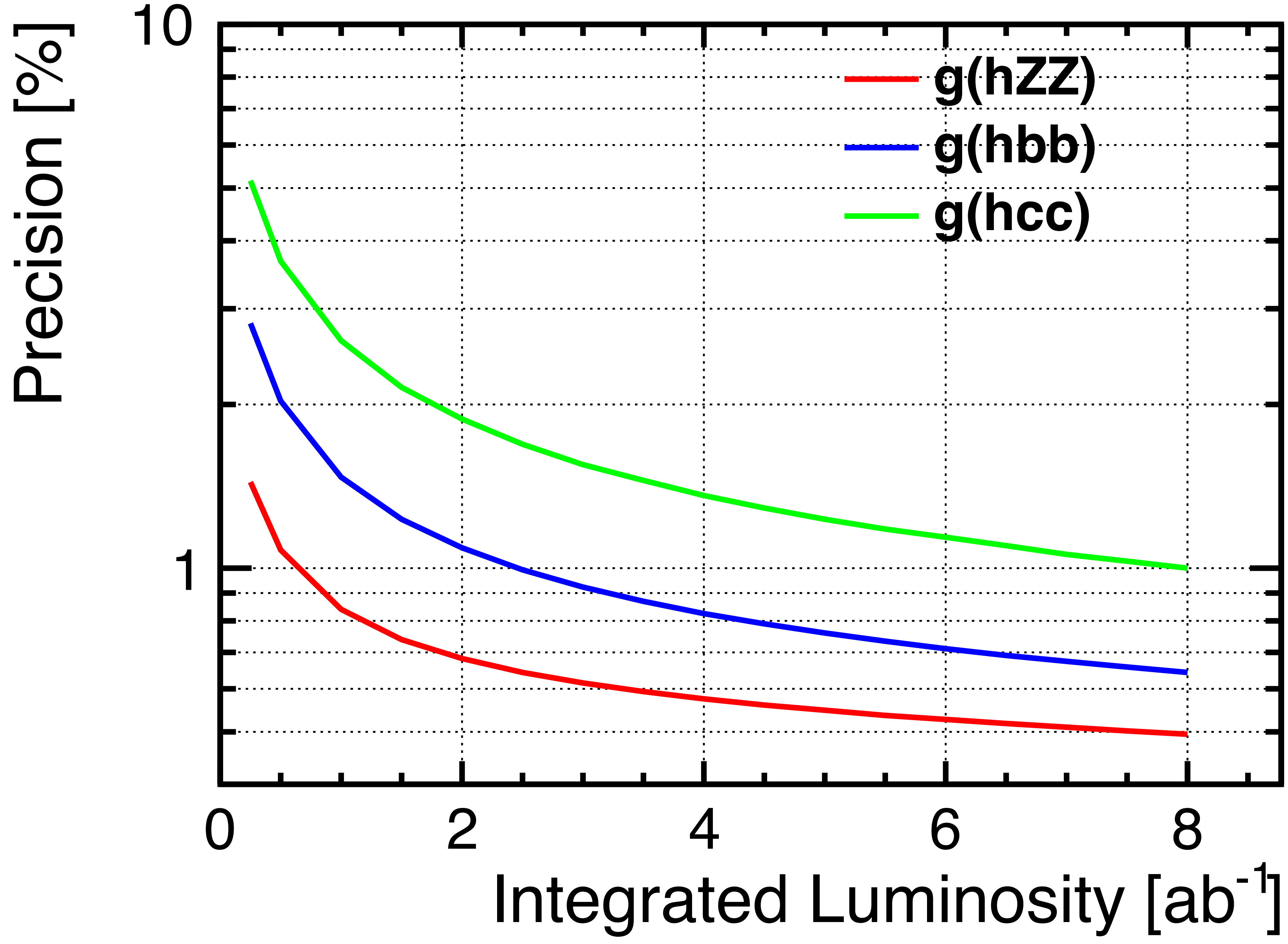
examples

why?

	2 ab-1	8 ab-1
g(hZZ)	0.68%	0.50%
g(hbb)	1.1%	0.64%
g(hcc)	1.9%	1.0%

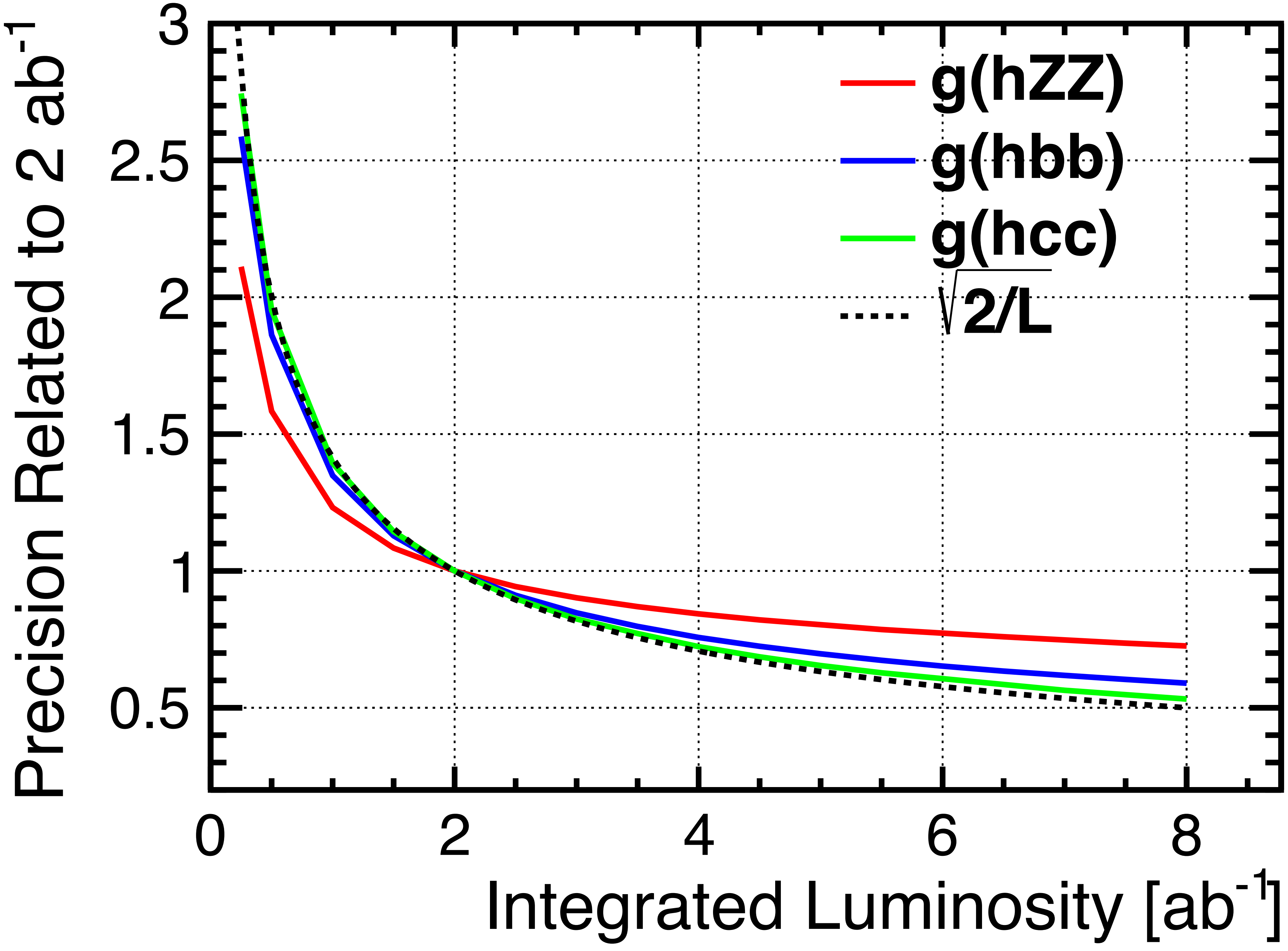
examples

why?



examples

why?



starting point:

full formalism (23 parameters)

$$\Delta\mathcal{L} = \frac{c_H}{2v^2}\partial^\mu(\Phi^\dagger\Phi)\partial_\mu(\Phi^\dagger\Phi) + \frac{c_T}{2v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu \Phi)(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi) - \frac{c_6\lambda}{v^2}(\Phi^\dagger\Phi)^3$$
$$+\frac{g^2 c_{WW}}{m_W^2}\Phi^\dagger\Phi W^a_{\mu\nu}W^{a\mu\nu} + \frac{4gg' c_{WB}}{m_W^2}\Phi^\dagger t^a \Phi W^a_{\mu\nu}B^{\mu\nu}$$
$$+\frac{g'^2 c_{BB}}{m_W^2}\Phi^\dagger\Phi B_{\mu\nu}B^{\mu\nu} + \frac{g^3 c_{3W}}{m_W^2}\epsilon_{abc}W^a_{\mu\nu}W^{b\nu}{}_\rho W^{c\rho\mu}$$
$$+i\frac{c_{HL}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu \Phi)(\overline{L}\gamma_\mu L) + 4i\frac{c'_{HL}}{v^2}(\Phi^\dagger t^a \overleftrightarrow{D}^\mu \Phi)(\overline{L}\gamma_\mu t^a L)$$
$$+i\frac{c_{HE}}{v^2}(\Phi^\dagger \overleftrightarrow{D}^\mu \Phi)(\overline{e}\gamma_\mu e)\ .$$

full formalism
23 parameters

10 operators (h,W,Z,γ): c_H, c_T, c_6, c_{WW}, c_{WB}, c_{BB}, c_{3W}, c_{HL}, c'_{HL}, c_{HE}

+ 4 SM parameters: g, g', v, λ

+ 5 operators modifying h couplings to b, c, τ, μ, g

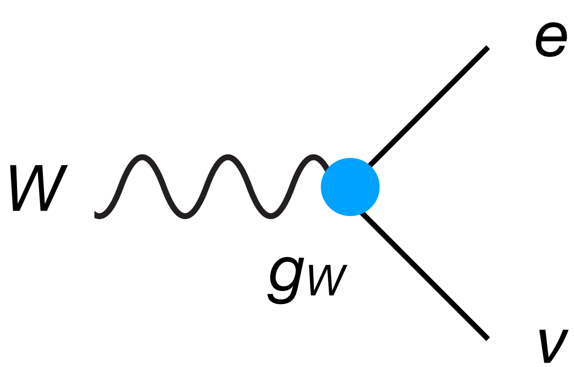
+ 2 parameters for h->invisible and exotic

+ 2 for contact interaction with quarks

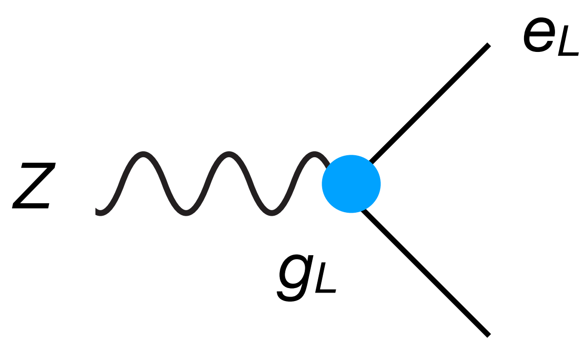
—> decipher importance of every measurement

start with no beam polarization case
(almost no redundant observables)

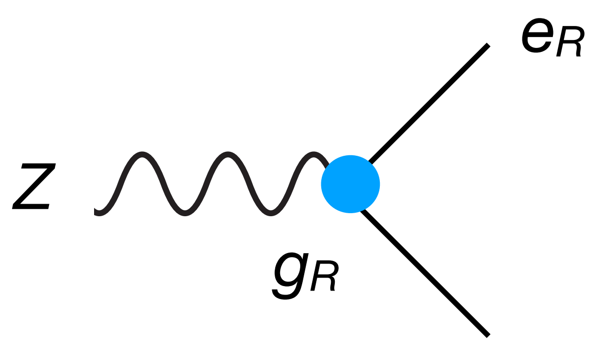
solutions: (1)



$$\delta g_W = \frac{1}{2}\delta G_F + \delta m_W$$

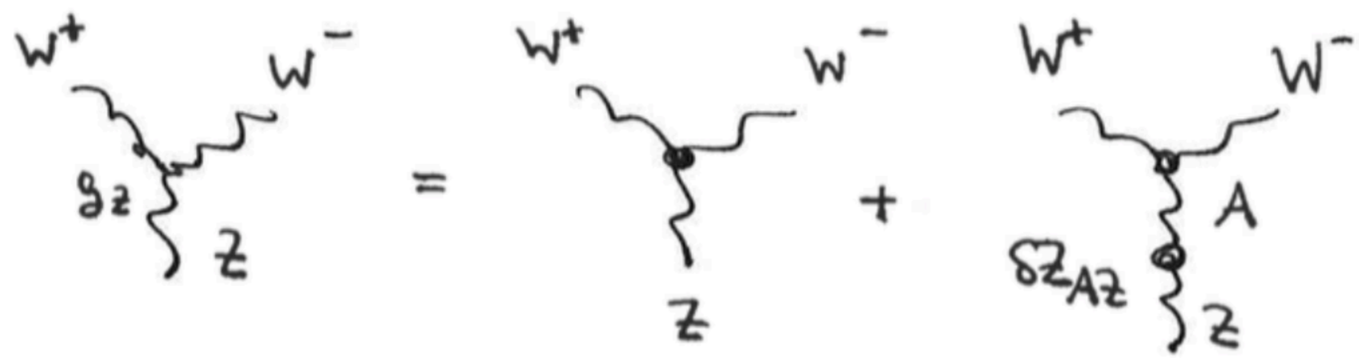


$$\delta g_L = -\frac{1}{2}\delta m_Z + \frac{1}{2}\delta\Gamma_l + \frac{1}{16}\delta A_l$$



$$\delta g_R = -\frac{1}{2}\delta m_Z + \frac{1}{2}\delta\Gamma_l - \frac{1}{12}\delta A_l$$

solutions: (2)



$$g_Z = 1.3\delta G_F + 2.6\delta m_W + \frac{1}{2}\delta m_Z - \frac{1}{2}\delta\Gamma_l + \frac{1}{53}\delta A_l + \delta g_{Z,eff}$$

$$8c_{WB} = \delta G_F - 2\delta e + 2\delta m_W - 0.081\delta A_l + \delta\kappa_{A,eff}$$

solutions: (3)

$$8c_{BB} = \delta G_F - 2\delta e + 2\delta m_W - \frac{1}{12}\delta A_l + \delta\kappa_{A,eff} + \frac{1}{159}\delta\Gamma_{\gamma\gamma} - \frac{1}{159}\delta\Gamma_{\gamma Z}$$

$$8c_{WW} = \delta G_F - 2\delta e + 2\delta m_W - \frac{1}{12}\delta A_l + \delta\kappa_{A,eff} + \frac{1}{528}\delta\Gamma_{\gamma\gamma} + \frac{1}{159}\delta\Gamma_{\gamma Z}$$

$$\delta Z_Z = 1.3\delta G_F - 2.6\delta e + 2.6\delta m_W - \frac{1}{9.5}\delta A_l + 1.3\delta\kappa_{A,eff} + \frac{1}{528}\delta\Gamma_{\gamma\gamma} + \frac{1}{290}\delta\Gamma_{\gamma Z}$$

$$\delta Z_W = 8c_{WW} \qquad \delta Z_A = \frac{1}{528}\delta\Gamma_{\gamma\gamma} \qquad \delta Z_{AZ} = \frac{1}{290}\delta\Gamma_{\gamma Z}$$

solutions: (4)

$$c'_{HL} = -0.5\delta G_F + 0.23\delta e - \delta m_W - 0.38\delta m_Z + 0.38\delta\Gamma_l + 0.014\delta A_l - 0.77\delta g_{Z,eff}$$

$$c_{HL} = -0.5\delta G_F + 0.09\delta e - \delta m_W - 0.38\delta m_Z + 0.38\delta\Gamma_l + 0.014\delta A_l - 0.23\delta g_{Z,eff} + 0.3\delta\kappa_{A,eff}$$

$$c_{HE} = -0.28\delta e - 0.46\delta g_{Z,eff} + 0.60\delta\kappa_{A,eff}$$