

# Deciphering importance of every measurement in SMEFT

Junping Tian (U. Tokyo)

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

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

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

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 ( $Y_i$ )?

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

# examples

why?

**2 ab-1**

**8 ab-1**

**g(hZZ)**

**0.68%**

**0.50%**

**g(hbb)**

**1.1%**

**0.64%**

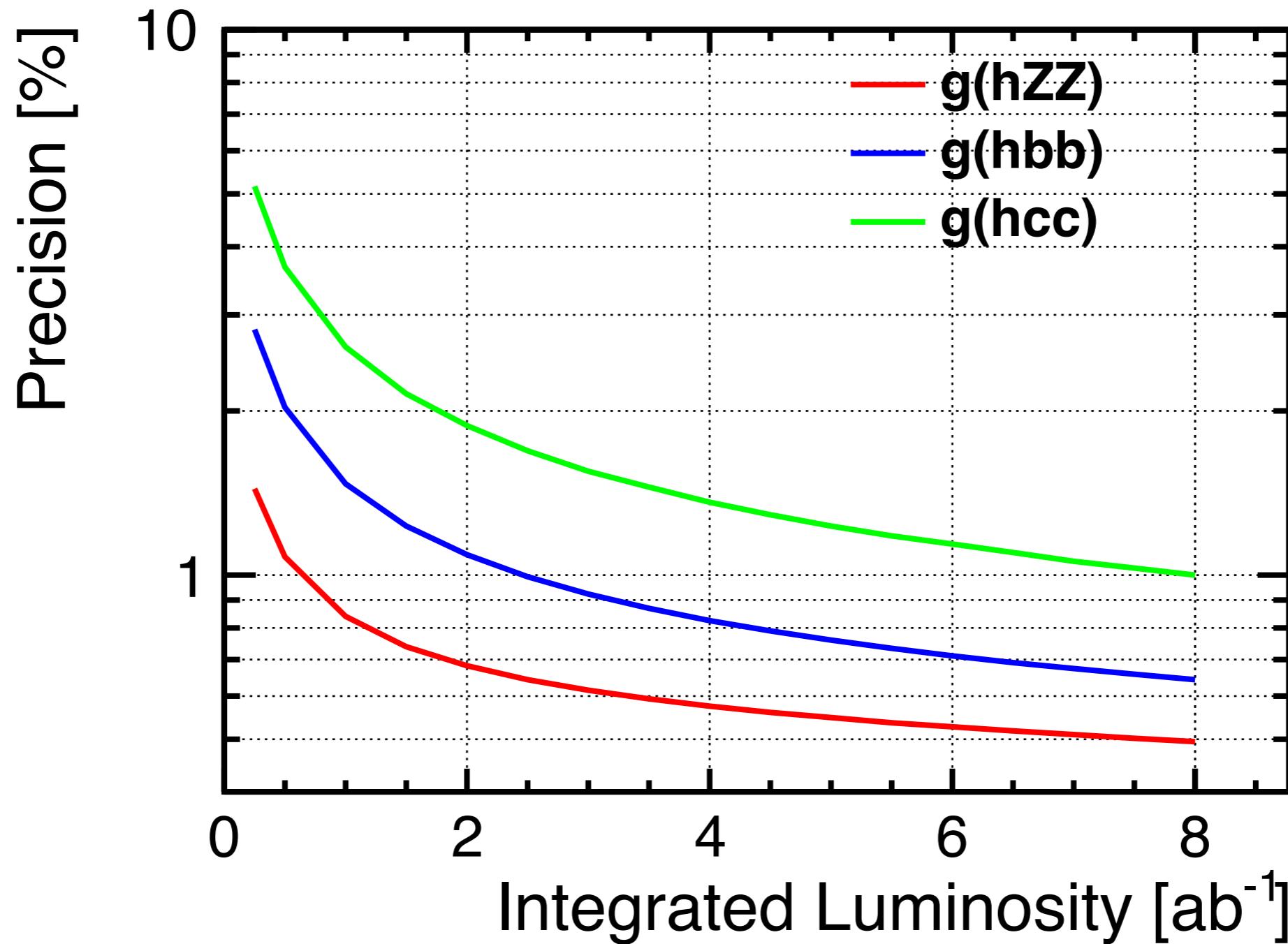
**g(hcc)**

**1.9%**

**1.0%**

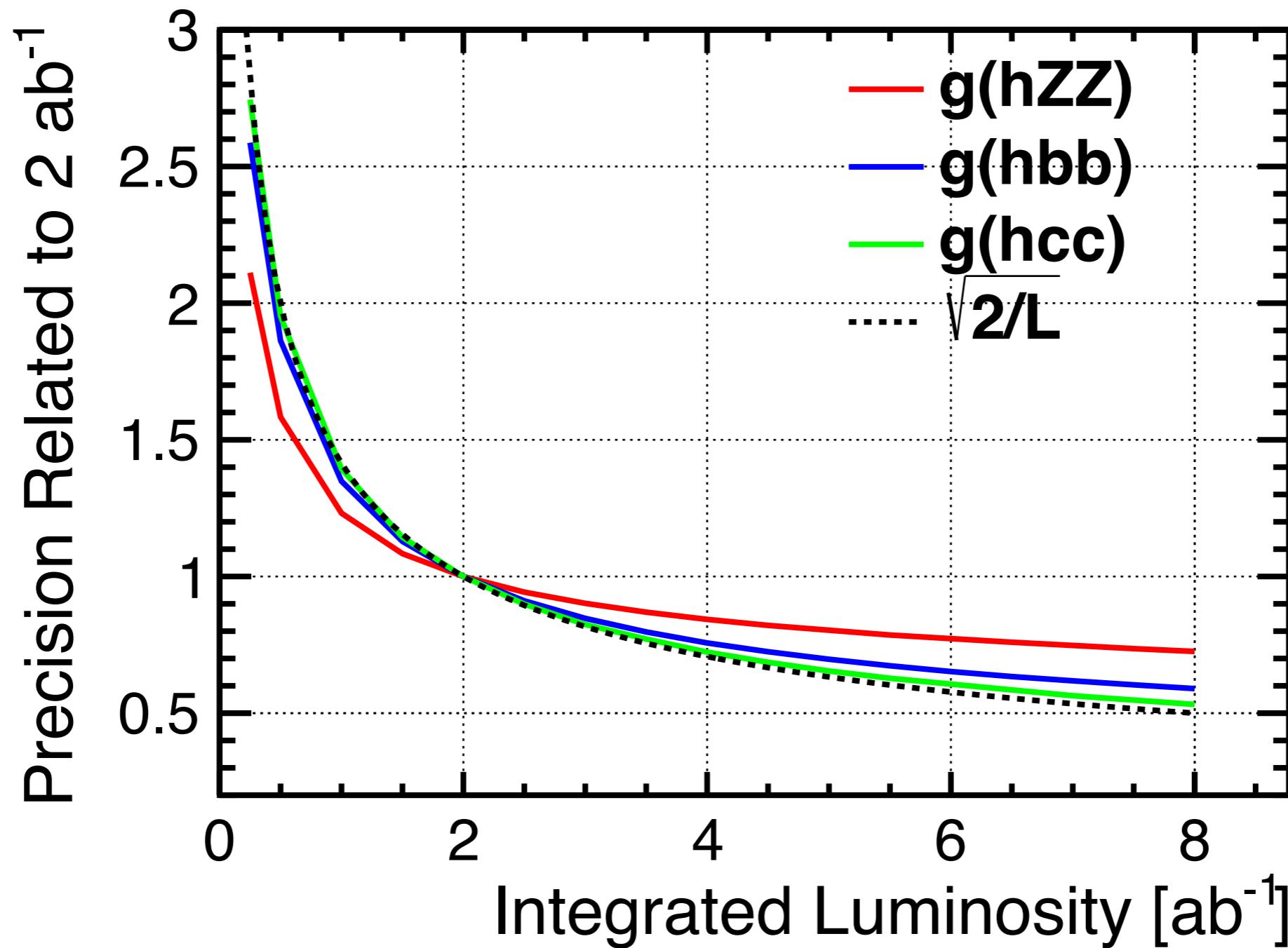
examples

why?



examples

why?



starting point:

full formalism (23 parameters)

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

full formalism  
23 parameters

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

+ 4 SM parameters:  $g, g', v, \lambda$

+ 5 operators modifying h couplings to b, c,  $\tau$ ,  $\mu$ , g

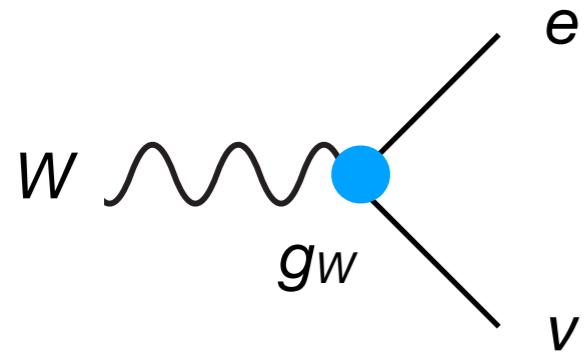
+ 2 parameters for h->invisible and exotic

+ 2 for contact interaction with quarks

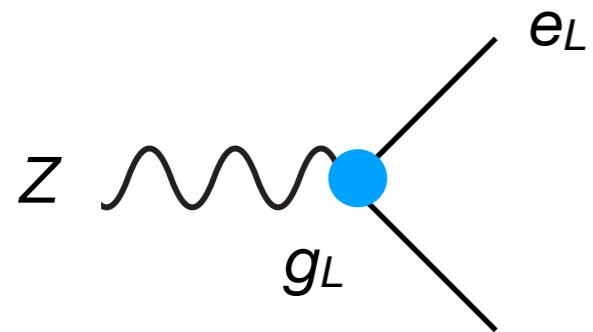
—> decipher importance of every measurement

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

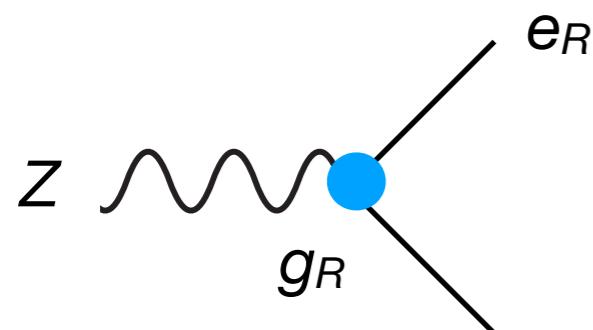
solutions: (1)



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

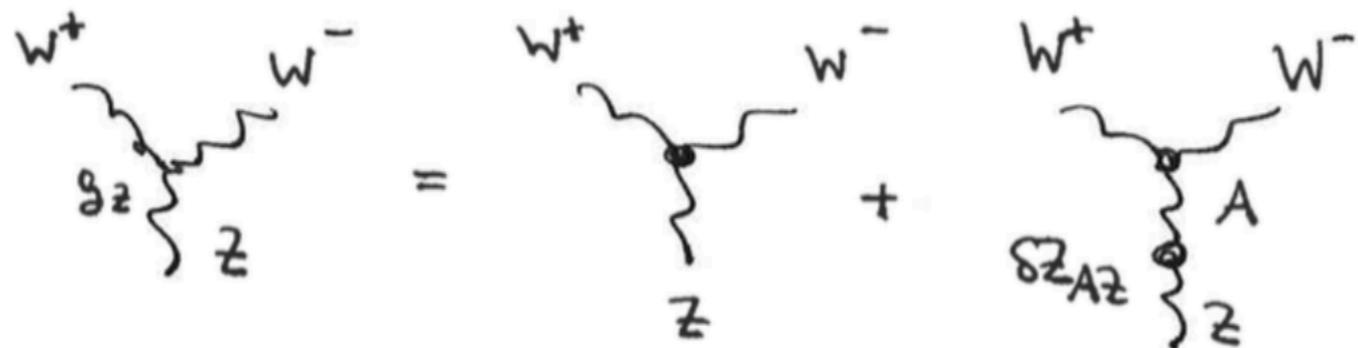


$$\delta g_L = -\frac{1}{2} \underline{\delta m_Z} + \frac{1}{2} \underline{\delta \Gamma_l} + \frac{1}{16} \underline{\delta A_l}$$



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

solutions: (2)



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


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


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solutions: (3)

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

$$+ \frac{1}{159}\delta\Gamma_{\gamma\gamma} - \frac{1}{159}\delta\Gamma_{\gamma Z}$$


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

$$+ \frac{1}{528}\delta\Gamma_{\gamma\gamma} + \frac{1}{159}\delta\Gamma_{\gamma Z}$$


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

$$+ \frac{1}{528}\delta\Gamma_{\gamma\gamma} + \frac{1}{290}\delta\Gamma_{\gamma Z}$$

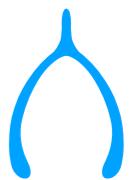
$$\delta Z_W = 8c_{WW} \quad \delta Z_A = \frac{1}{528}\delta\Gamma_{\gamma\gamma} \quad \delta Z_{AZ} = \frac{1}{290}\delta\Gamma_{\gamma Z}$$

solutions: (4)

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

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

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



solutions: (5)

$$\mathbf{P}(\mathbf{e-}, \mathbf{e+}) = (\mathbf{0.}, \mathbf{0.})$$

$$c_H = -0.44\delta G_F - 11\delta e - 11\delta m_W + 2.5\delta m_Z - 2.3\delta m_h - 8.9\delta \Gamma_l \\ - 0.21\delta A_l - 2.8\delta g_{Z,eff} + 3.2\delta \kappa_{A,eff} - \frac{1}{92}\delta \Gamma_{\gamma\gamma} \\ - \frac{1}{36}\delta \Gamma_{\gamma Z} - \delta \sigma_{Zh}$$

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# solutions: validations

**comparing uncertainties between global fit and my analytic calculation**

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

pars.	g	g'	v	gw	gL	gR	gz
$\delta$ (global fitting)	11.0	3.37	5.34	0.622	7.64	9.18	7.09
$\delta$ (my formula)	11.1	3.41	5.34	0.622	7.64	9.18	7.09

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

# solutions: validations

**comparing uncertainties between global fit and my analytic calculation**

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

pars.	$C_T$	$8C_{WW}$	$8C_{WB}$	$8C_{BB}$	$C_{HL}$	$C_{HL}'$	$C_{HE}$	$C_H$
$\Delta$ (global fitting)	5.21	21.3	9.30	21.4	4.39	5.34	8.56	198
$\Delta$ (my formula)	5.21	21.6	9.30	21.6	4.39	5.34	2.65	150

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

solutions: examples

$$\mathbf{P}(\mathbf{e-},\mathbf{e+})=(0.,0.)$$

$$\begin{aligned}\delta g_{hZZ} = & 3.5\delta G_F + 7.4\delta e + 6.9\delta m_W - 2.3\delta m_Z + 8.9\delta m_h - 6\delta \Gamma_l \\& - 0.11\delta A_l + 4.6\delta g_{Z,eff} - 2.5\delta \kappa_{A,eff} - 0.006\delta \Gamma_{\gamma\gamma} \\& - 0.015\delta \Gamma_{\gamma Z} + 0.34\delta \Gamma_Z + 0.5\delta \sigma_{Zh}\end{aligned}$$

solutions: examples to see importances

$$\mathbf{P}(\mathbf{e}-,\mathbf{e}+) = (-0.0, +0.0)$$

$$\delta g_{hZZ} = 11 \oplus 62 \oplus 10 \oplus 20 \oplus 14 \oplus 46 \oplus 35 \oplus .. \quad \times 10^{-4}$$

$$\Gamma_l$$

$$h \rightarrow \gamma Z$$

$$g_{Z\text{eff}}$$

$$\sigma_{Zh}$$

$$\mathbf{m}_h$$

$$\mathbf{A}_l$$

$$\mathbf{K}_{A\text{eff}}$$

solutions: examples

$$\mathbf{P}(\mathbf{e-},\mathbf{e+})=(0.,0.)$$

$$\delta g_{hbb} = 10 \oplus 55 \oplus 9 \oplus 14 \oplus 11 \oplus 50 \oplus 35 \oplus 23 \oplus 81 \oplus .. \times 10^{-4}$$

$$\Gamma_1$$

$$h \rightarrow \gamma Z$$

$$h \rightarrow WW^*$$

$$\sigma_{Zh}$$

$$h \rightarrow bb$$

$$m_h$$

$$A_l$$

$$g_{Ze\text{ff}}$$

$$K_{A\text{eff}}$$

redundancy (i): impact of WW-fusion measurement

**e+e- → vvh**

$$\begin{aligned}\delta\sigma(250) = & 2\eta_W - 2\delta v + 2\delta g_W - 1.6\delta m_W - 3.7\delta m_h \\ & - 0.22\delta Z_W - 6.4c'_{HL} - 0.37(c_{HL} - c'_{HL})\end{aligned}$$

**impact: ~10% relative improvement for hWW, hZZ couplings**

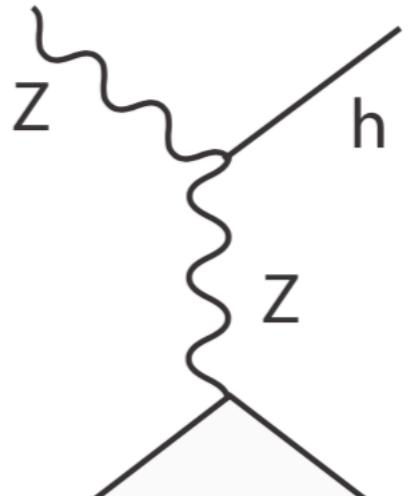
## redundancy (ii): impact of differential measurement

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

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

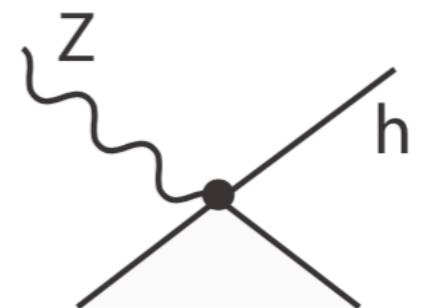
redundancy (iii): impact of beam polarizations

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



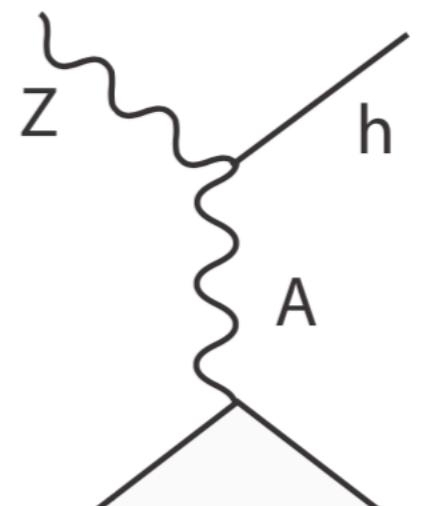
$$a_L = \delta g_L + 2\delta m_Z - \delta v + \eta_Z + \frac{(s - m_Z^2)}{2m_Z^2(1/2 - s_w^2)} (c_{HL} + c'_{HL}) + k_Z \delta m_Z + k_h \delta m_h$$

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



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

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



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

backup