EF2. What are the key questions involving the Higgs boson that the ILC can answer whereas hadron colliders cannot? What do we learn about new physics scenarios from percent-level Higgs couplings measurements?

Real goal is to search for New Physics that touches the Higgs.

- Additional source for particle masses beyond the 126 GeV Higgs

– New scalar(s) mixing with the SM Higgs doublet and/or contributing to the EWSB vacuum condensate: extended Higgs sector.

– Top-partner mixing with SM top quark.

– Composite Higgs: physical excitation nonlinearly related to mass generation.

- New particles that couple to Higgs running in loops

– colored or charged particles: hgg, $h\gamma\gamma$, $hZ\gamma$ (no SM tree-level coupling).

– Even particles neutral under the SM shift all Higgs couplings via Higgs propagator correction (wavefunction renormalization).

- Size of deviation(s) sets an **upper bound** on NP mass scale.
- Pattern of deviations among multiple couplings gives clues to the nature of the new physics.

To exclude x% at 95% CL: need x/2% measurement.

To discover x% at 5σ: need x/5% measurement.

Work needed to push theory uncertainties below 1%.

MSSM (2nd doublet, constrained potential; $c \sim 1$ is loops; $\tan\beta >$ few (=5 in last row)):

$$\frac{\Delta g_{hVV}}{g_{hVV}} \simeq -2c^2 \cot^2\beta \frac{M_Z^4}{M_A^4} \qquad \frac{\Delta g_{htt,cc}}{g_{htt,cc}} \simeq -2c \cot^2\beta \frac{M_Z^2}{M_A^2} \qquad \frac{\Delta g_{hbb,\tau\tau}}{g_{hbb,\tau\tau}} \simeq 2c \frac{M_Z^2}{M_A^2}$$

2% $\rightarrow$ $M_A \sim 130$ GeV $\qquad M_A \sim 180$ GeV $\qquad M_A \sim 920$ GeV

Composite Higgs (Minimal model; composite resonances at $g_{TC} \cdot f < 4\pi f$):

$$\frac{g_{hVV}}{SM} = \sqrt{1 - v^2/f^2} \qquad \frac{g_{hff}}{SM} = \begin{cases} \sqrt{1 - v^2/f^2} & \text{(MCHM4)} \\ (1 - 2v^2/f^2)\sqrt{1 - v^2/f^2} & \text{(MCHM5)} \end{cases}$$

2% $\rightarrow$ $f \sim 1200$ GeV $\qquad f \sim 1200$ GeV / 2800 GeV

$M_{res} < 15$ TeV $\qquad M_{res} < 15$ TeV / 35 TeV

Top-partners (for quadratic divergence cancellation; assume no mixing):

$$\frac{\Delta g_{hgg,\gamma\gamma,Z\gamma}}{g_{hgg,\gamma\gamma,Z\gamma}} \simeq \text{(loop factor)} \times \left(\frac{m_t^2}{m_T^2}\right)$$

2% $\rightarrow$	$m_T \sim 850$ GeV (gg)	$m_T \sim 450$ GeV $(\gamma\gamma)$	[scalar pair]
	$m_T \sim 1200$ GeV (gg)	$m_T \sim 640$ GeV $(\gamma\gamma)$	[fermion]

backup slides

MSSM (2nd doublet, constrained potential; $c \sim 1$ is loops; $\tan\beta >$ few (=5 in last row)):

$$\frac{\Delta g_{hVV}}{g_{hVV}} \simeq -2c^2 \cot^2\beta \frac{M_Z^4}{M_A^4} \qquad \frac{\Delta g_{htt,cc}}{g_{htt,cc}} \simeq -2c \cot^2\beta \frac{M_Z^2}{M_A^2} \qquad \frac{\Delta g_{hbb,\tau\tau}}{g_{hbb,\tau\tau}} \simeq 2c \frac{M_Z^2}{M_A^2}$$

1% → $M_A \sim 150$ GeV $M_A \sim 260$ GeV $M_A \sim 1300$ GeV

Composite Higgs (Minimal model; composite resonances at $g_{TC} \cdot f < 4\pi f$):

$$\frac{g_{hVV}}{SM} = \sqrt{1 - v^2/f^2} \qquad \frac{g_{hff}}{SM} = \begin{cases} \sqrt{1 - v^2/f^2} & \text{(MCHM4)} \\ (1 - 2v^2/f^2)\sqrt{1 - v^2/f^2} & \text{(MCHM5)} \end{cases}$$

1% → $f \sim 1700$ GeV $f \sim 1700$ GeV / 3900 GeV

$M_{res} \lesssim 20$ TeV $M_{res} \lesssim 20$ TeV / 50 TeV

Top-partners (for quadratic divergence cancellation; assume no mixing):

$$\frac{\Delta g_{hgg,\gamma\gamma,Z\gamma}}{g_{hgg,\gamma\gamma,Z\gamma}} \simeq (\text{loop factor}) \times \left(\frac{m_t^2}{m_T^2}\right)$$

1% → $m_T \sim 1200$ GeV (gg) $m_T \sim 630$ GeV $(\gamma\gamma)$ [scalar]

$m_T \sim 1700$ GeV (gg) $m_T \sim 900$ GeV $(\gamma\gamma)$ [fermion]

N.B. To exclude 1% at 95% CL: need 0.5% measurement.
N.B. To discover 1% at 5σ: need 0.2% measurement.