Precision Higgs Physics at the International Linear Collider

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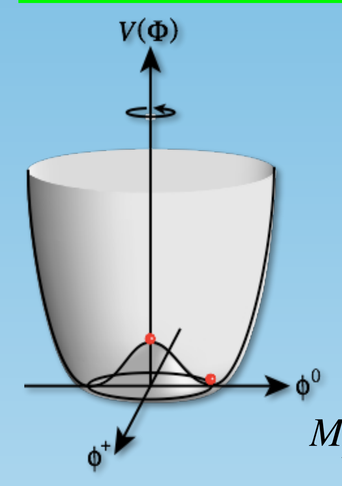
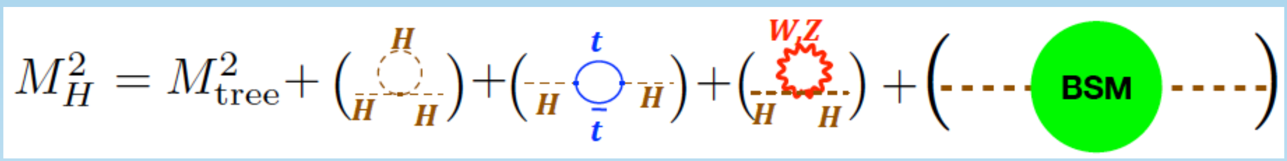
(A) Why precision Higgs physics?



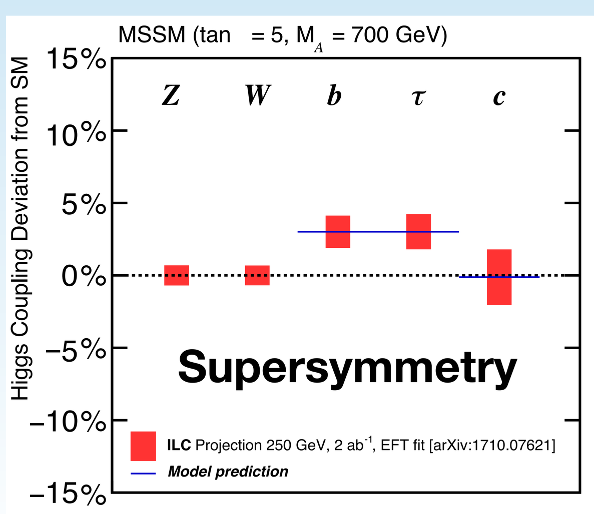
$$V(|\Phi|) = \mu^2 \Phi^\dagger \Phi + \lambda(\Phi^\dagger \Phi)^2$$

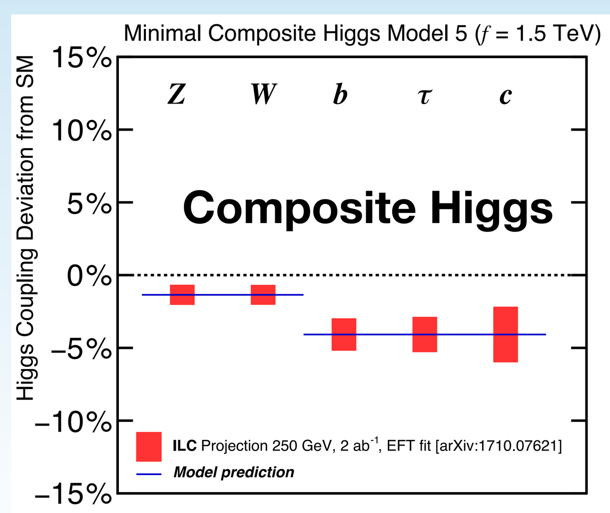
- What is the origin of EWSB?
  - why $\mu^2<0$? BCS theory for Ginzburg-Landau?
- How is m_H stabilized?

$$M_H^2 = 36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}933{,}023$$
$$-36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}917{,}398$$

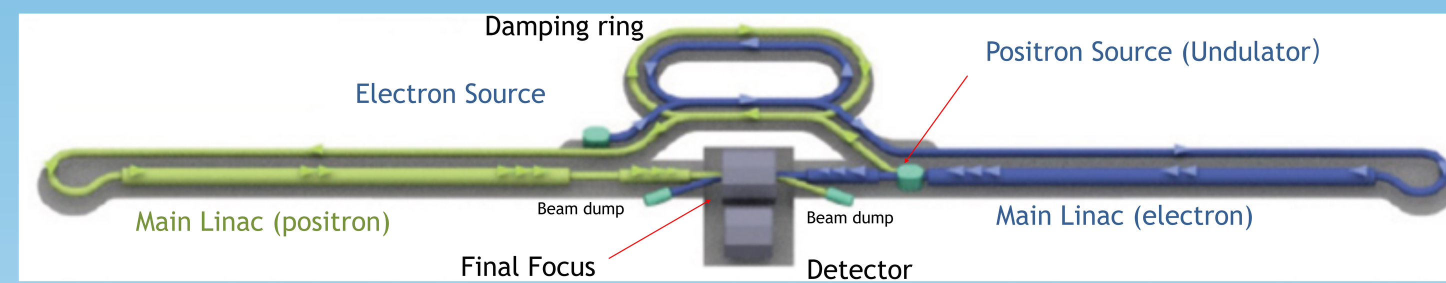


- BSM must be just there (~TeV), and couple to Higgs!
- need 1% precision for many couplings: deviation pattern



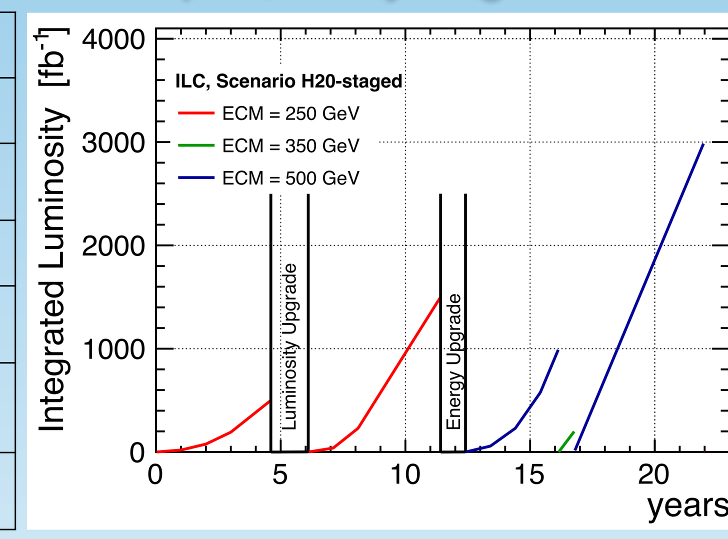


(B) About the International Linear Collider (ILC)

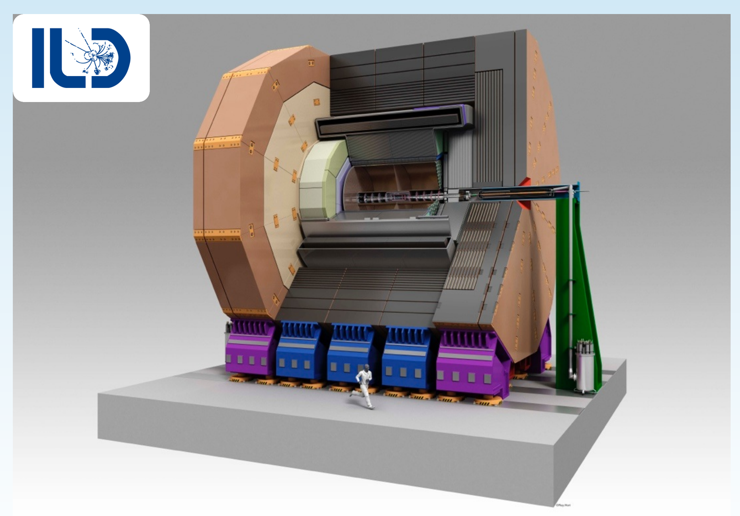


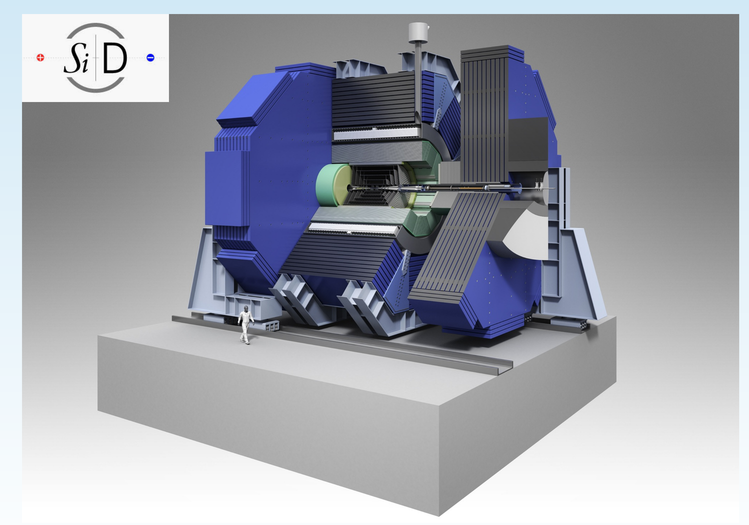
candidate site: Kitakami in Japan; ready to go!

key technology	Superconducting RF: 31.5 MeV / m
	Nano Beam: 7 nm in y at final focus
center-of-mass energy	250 GeV at initial stage
	upgradable to 500 GeV and 1 TeV
	option: Z-pole & WW-threshold
beam polarization	e-: 80%; e+: 30% (20% at 1TeV)
R&D phase	Technical Design Report in 2013

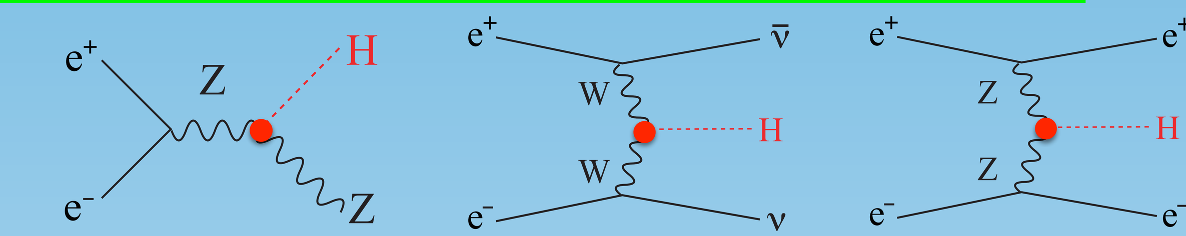


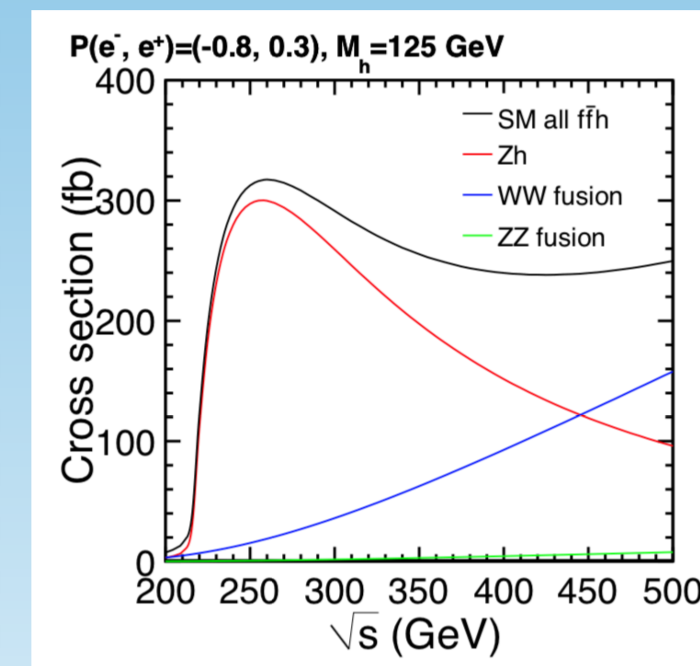
two general purpose detectors proposed: ILD & SiD





(C) How Higgs is produced and measured





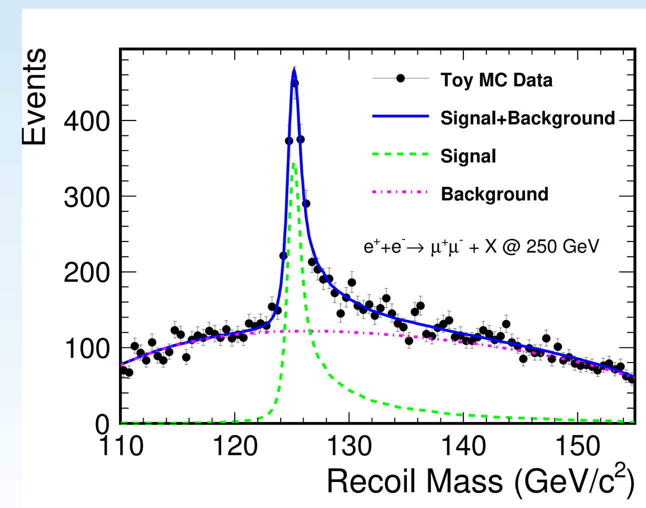
three important $\sqrt{s}$

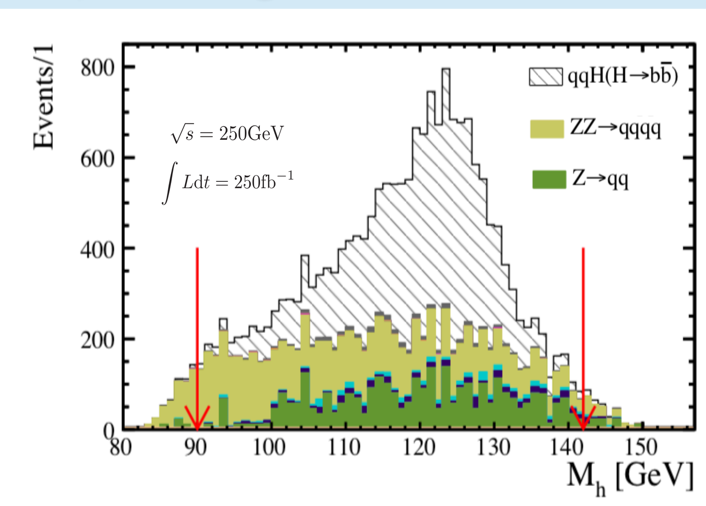
- 250 GeV: ZH retains largest cross section; Higgs factory
- 350 GeV: tt threshold; important for Higgs sector about vacuum stability
- 500 GeV: ZHH and ttH; for triple Higgs and top-Yukawa couplings

full detector simulations

recoil mass technique

unique: inclusive σ(e+e- -> ZH) high S/B: H->bb



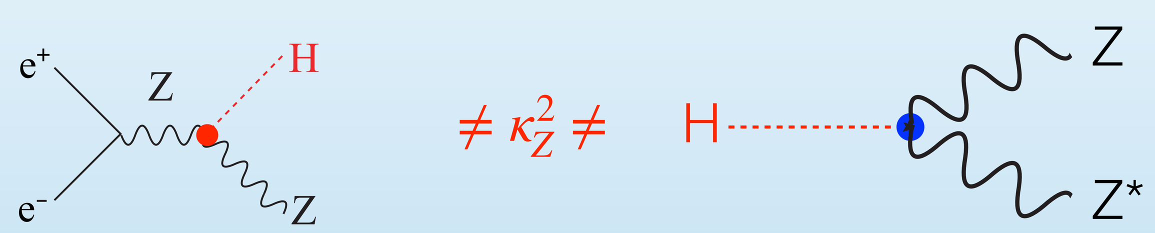


(D) Higgs coupling determination

kappa formalism is model dependent

$$\delta\mathcal{L} = (1+\eta_Z)\frac{m_Z^2}{v}hZ_\mu Z^\mu + \zeta_Z\frac{h}{2v}Z_{\mu\nu}Z^{\mu\nu}$$

- BSM can induce corrections that can not be represented by single κ_Z



$$\neq \kappa_Z^2 \neq$$

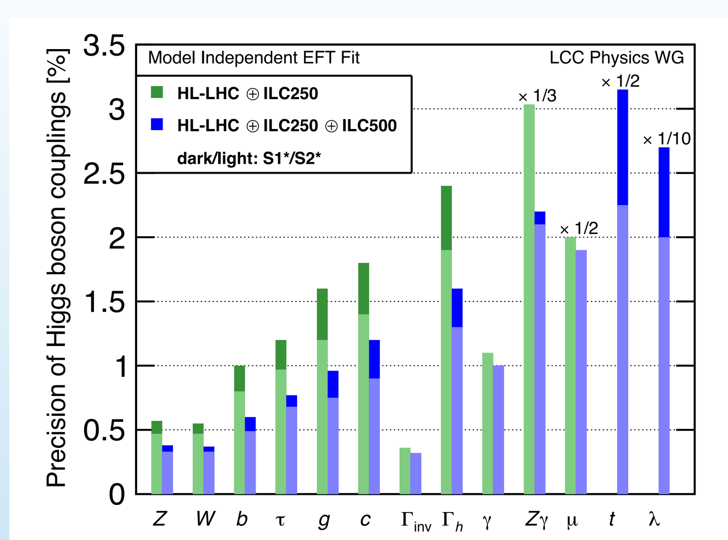
$$\frac{\sigma(e^+e^- \to ZH)}{SM} = 1 + 2\eta_Z + (5.5)\zeta_Z \qquad 1 + 2\eta_Z - (0.50)\zeta_Z = \frac{\Gamma(H \to ZZ^*)}{SM}$$

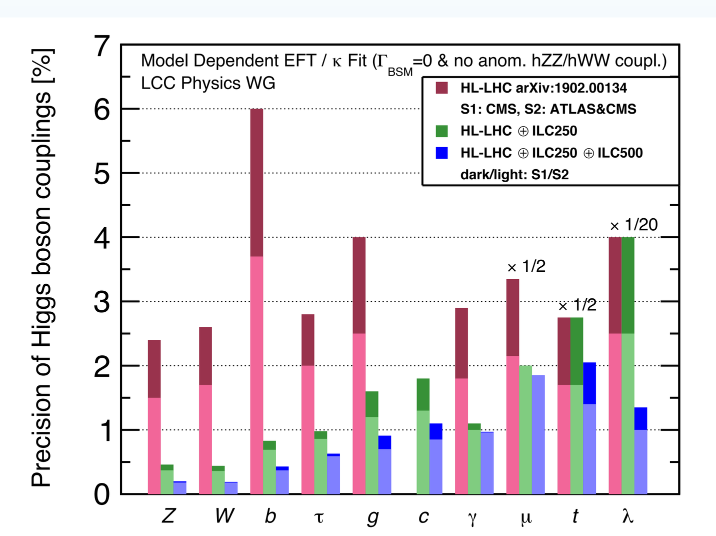
new strategy: SM Effective Field Theory

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

- model independent formalism for Higgs coupling determination
- general BSM effects represented by higher dimension operators
- respect $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge symmetries
- consistent quantum field theory unifying BSM effects in Higgs, W/Z, top, 2-fermion physics
- a complete set of D-6 operators can be determined simultaneously

(E) Projection of Higgs coupling precision





☑ goal of 1% precision can indeed be achieved from already 250 GeV

complementarity with LHC

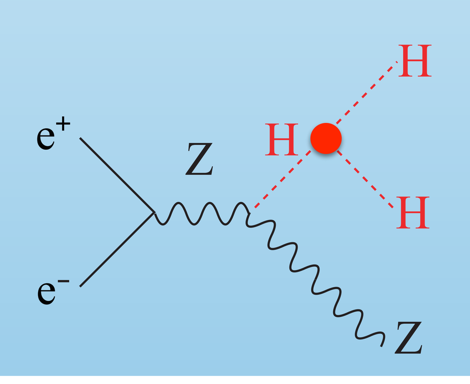
- qualitatively:
  - model independence
  - hcc, hgg
- quantitatively (<1%):
  - hZZ, hWW, hbb, h τ τ
  - h->invisible / exotic
- synergy
  - hγγ, hγZ, hμμ, htt, λ_{hhh}

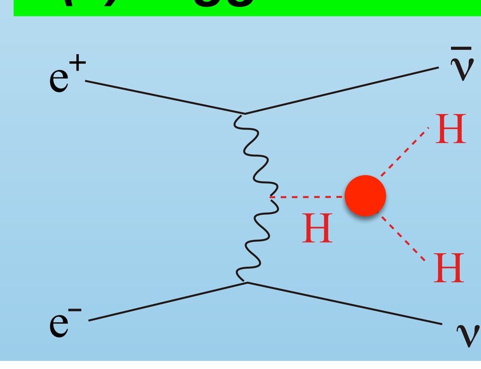
role of beam polarization

coupling	2/ab-250 pol.	+4/ab-500 pol.	5/ab-250 unpol.	+ 1.5/ab-350 unpol
HZZ	0.50	0.35	0.41	0.34
HWW	0.50	0.35	0.42	0.35
Hbb	0.99	0.59	0.72	0.62
$H\tau\tau$	1.1	0.75	0.81	0.71
Hgg	1.6	0.96	1.1	0.96
Hcc	1.8	1.2	1.2	1.1
$H\gamma\gamma$	1.1	1.0	1.0	1.0
$H\gamma Z$	9.1	6.6	9.5	8.1
$H\mu\mu$	4.0	3.8	3.8	3.7
Htt	-	6.3	-	-
HHH	-	27	-	-
Γ_{tot}	2.3	1.6	1.6	1.4
Γ_{inv}	0.36	0.32	0.34	0.30
Γ_{other}	1.6	1.2	1.1	0.94

☑ 250 GeV: power of 2 ab-1 polarized ≈ 5 ab-1 unpolarized

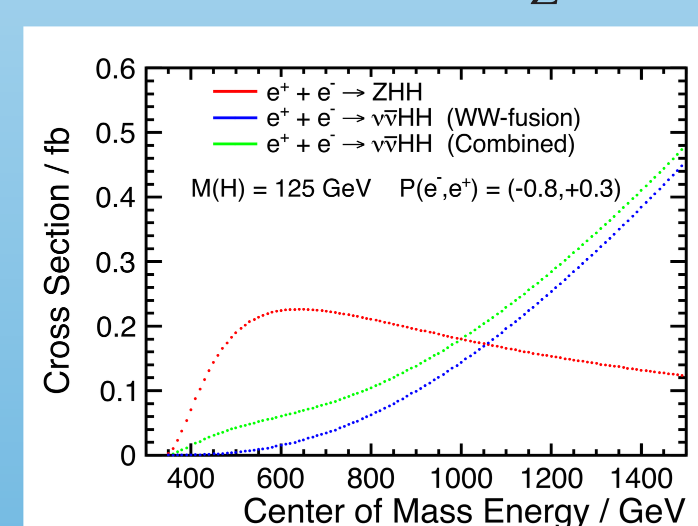
(F) Higgs self-coupling & top-Yukawa coupling

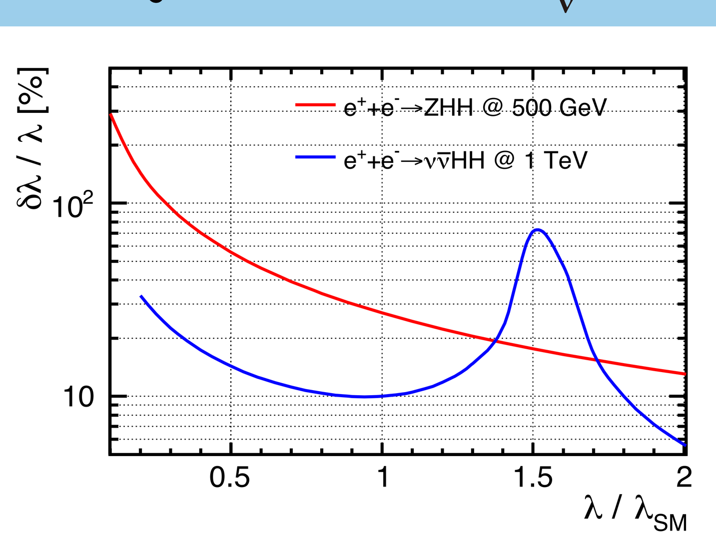


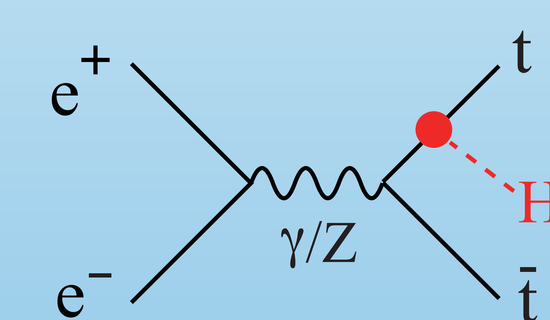


$$\frac{\Delta\lambda_{HHH}}{\lambda_{HHH}}$$

- SM
  - 27% by ZHH@500 GeV
  - 10% by ννHH@1 TeV
- BSM
  - 15% by ZHH@500 GeV
  - if λ gets 100% larger



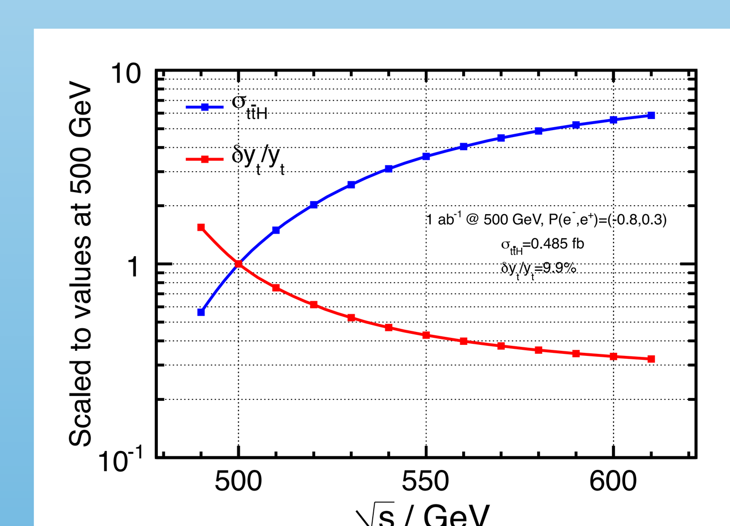




$$\frac{\Delta g_{Htt}}{g_{Htt}}$$

- 6% @ 500 GeV
- 3% @ 550 GeV
- 2% @ 1 TeV

☑ projection by full simulation



Find more information and details in references; arXiv: 1903.01629; 1710.07621; 1708.09079; 1708.08912; 1506.05992; ILC TDR Volume 1-4