Higgs Precision Prospects at e+e- colliders

Junping Tian (U' of Tokyo)

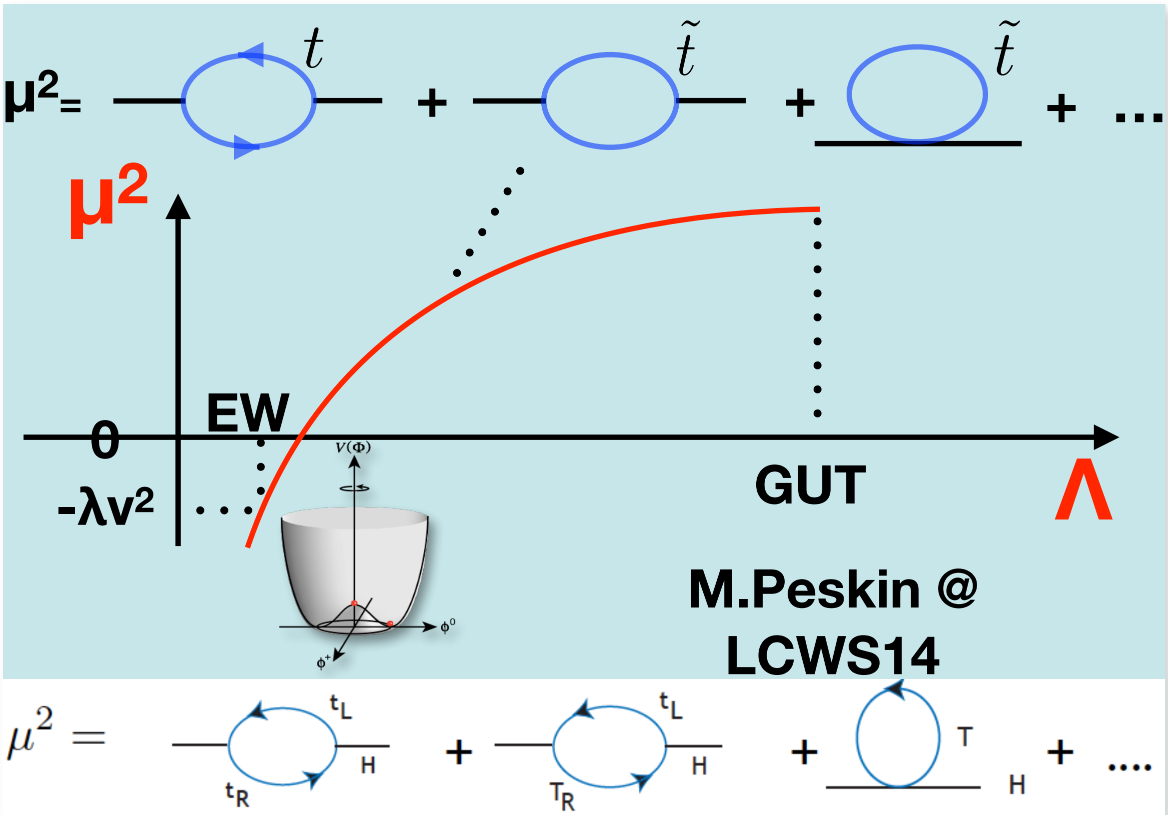
thanks to studies by many of my colleagues
in LCC Physics WG & ILD/SiD concept groups

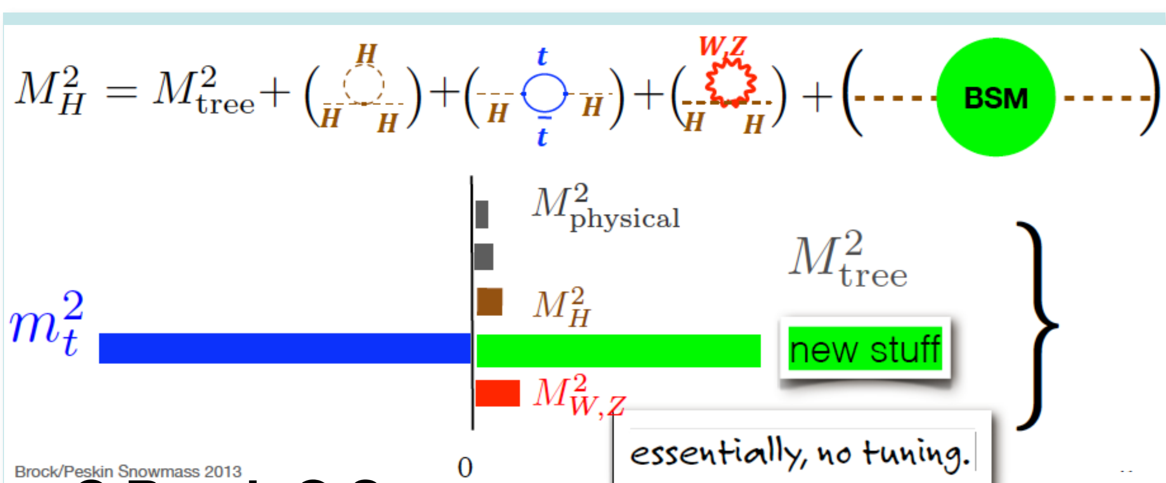
Higgs Mini-Workshop: Precision, BSM and Cosmology,
Sept. 28, 2017 @ Seoul National University

outline

- introduction
- Higgs sector at $\sqrt{s}$ ~ 250 GeV at e+e- colliders
- Higgs sector at $\sqrt{s}$ ~ 350 GeV
- Higgs sector at $\sqrt{s}$ >= 500 GeV
- Higgs sector in EFT
- summary

why Higgs physics





C.Brock @ Snowmass 2013

A. H(125) = H_{SM}? any sibling?

B. Why is $\mu^2 < 0$? what is the dynamics responsible for EWSB?

C. How to explain the naturalness — hierarchy problem?

D. connection to Dark Matter, electroweak baryongenesis, inflation?

Higgs is a window to new physics

why precision higgs physics

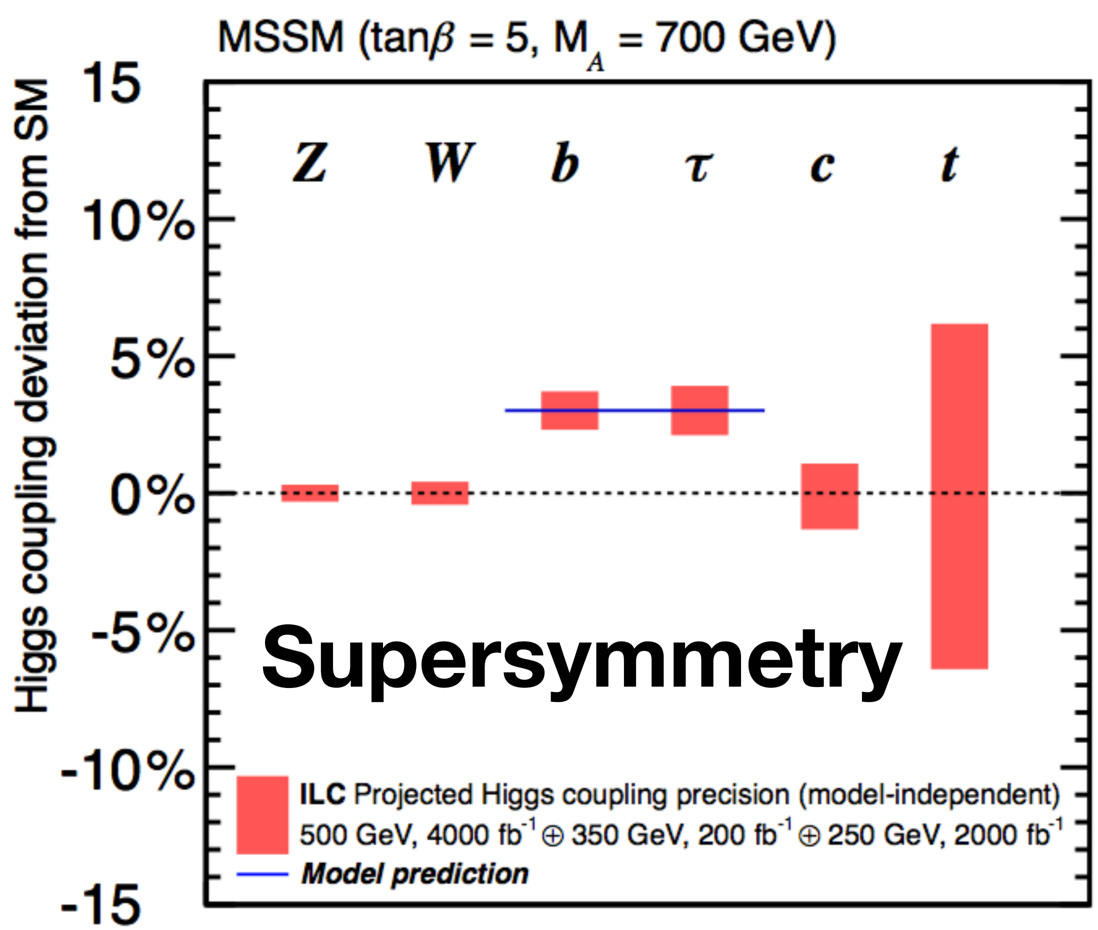
- Haber's decoupling limit, deviation ~ m_h^2/M^2.

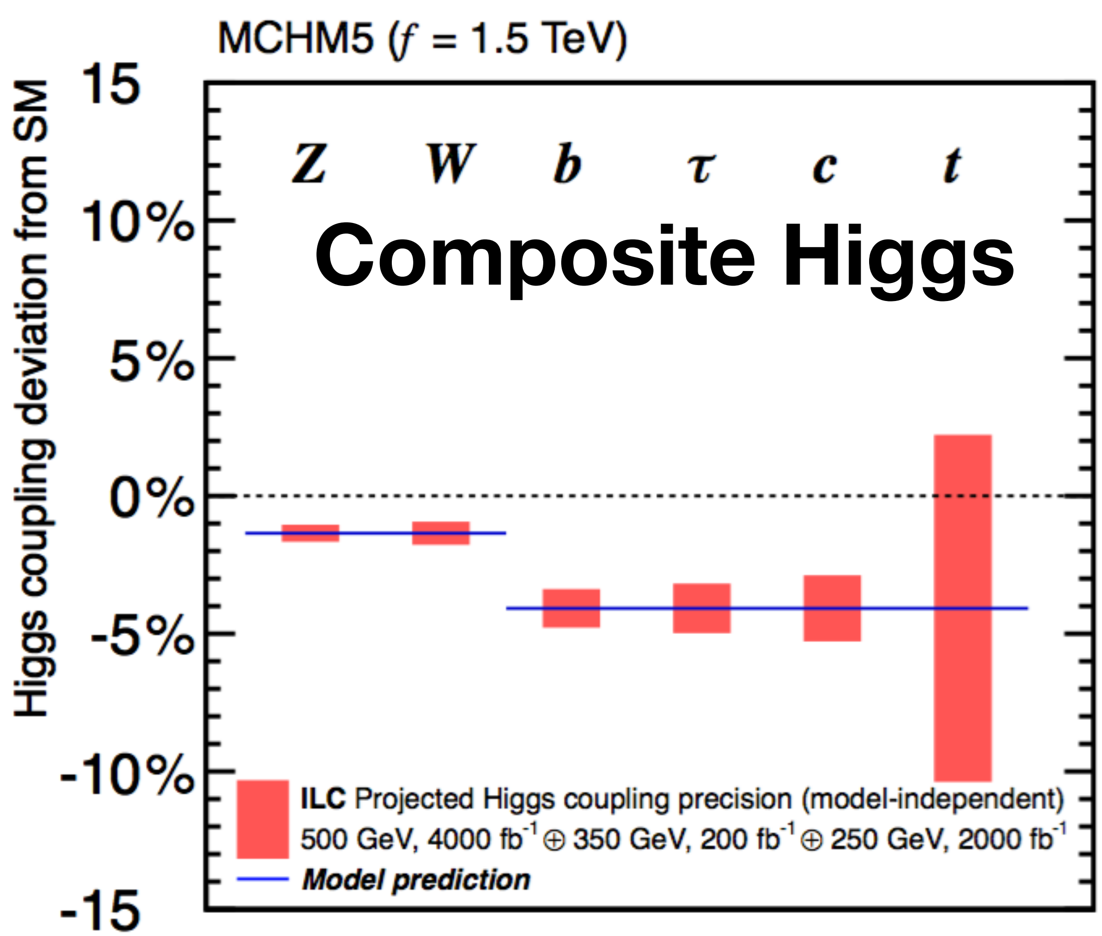
  —> $\Delta g/g$ ~ O(1%) for M ~ 1 TeV

- fingerprint BSM by patterns of deviations

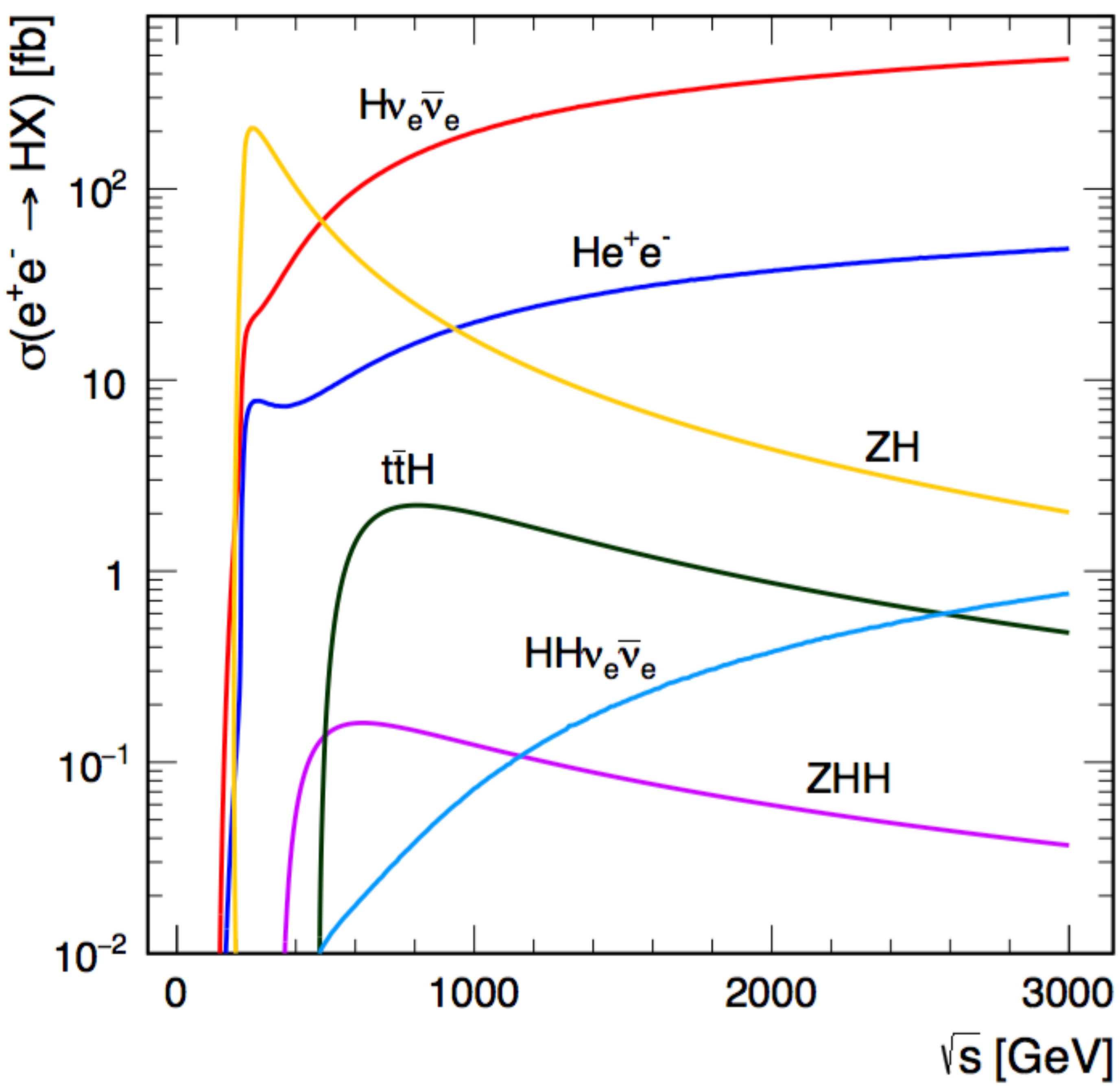
  —> measure as many couplings as possible

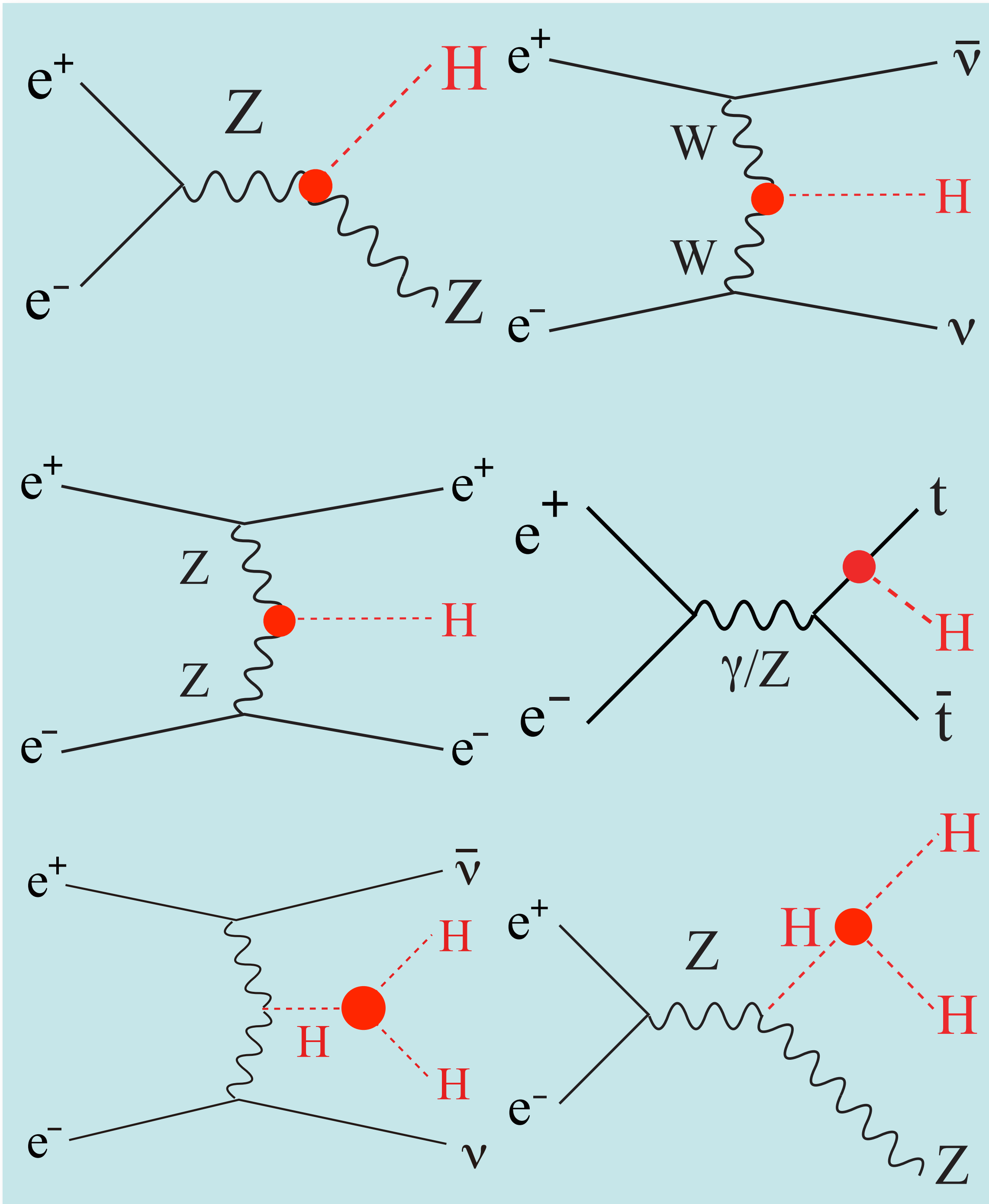
challenging at LHC





Higgs productions at e+e-





two important thresholds:
$\sqrt{s}$ ~ 250 GeV for ZH, ~500 GeV for ZHH and ttH

goal: nail down Higgs sector at future lepton colliders

bottom-up and model independent way

Mass & J^{CP} $\quad M_h \quad \Gamma_h \quad J^{\mathrm{CP}}$

new CP violating source?

L_{Higgs} $\quad hhh: \; -6i\lambda v = -3i\dfrac{m_h^2}{v}, \quad hhhh: \; -6i\lambda = -3i\dfrac{m_h^2}{v^2}$

probe Higgs potential, EWBG?

L_{Gauge}

$$W_\mu^+ W_\nu^- h: \; i\frac{g^2 v}{2} g_{\mu\nu} = 2i\frac{M_W^2}{v} g_{\mu\nu}, \quad W_\mu^+ W_\nu^- hh: \; i\frac{g^2}{2} g_{\mu\nu} = 2i\frac{M_W^2}{v^2} g_{\mu\nu},$$

$$Z_\mu Z_\nu h: \; i\frac{g^2 + g'^2 v}{2} g_{\mu\nu} = 2i\frac{M_Z^2}{v} g_{\mu\nu}, \quad Z_\mu Z_\nu hh: \; i\frac{g^2 + g'^2}{2} g_{\mu\nu} = 2i\frac{M_Z^2}{v^2} g_{\mu\nu}$$

SU(2) nature? m_V from SSB?

L_{Yukawa} $\quad h\bar{f}f: \; -i\dfrac{y^f}{\sqrt{2}} = -i\dfrac{m_f}{v}$

m_f from Yukawa coupling? 2HDM?

L_{Loop} $\quad h\gamma\gamma \quad hgg \quad h\gamma Z$

new particles in the loop?

any deviation to SM predictions —> New Physics

proposals of future lepton colliders

	$\sqrt{s}$	beam polarisation	$\int Ldt$ for Higgs	R&D phase
ILC	0.1 - 1 TeV	e-: 80% e+: 30%	2000 fb^{-1} @ 250 GeV 200 fb^{-1} @ 350 GeV 4000 fb^{-1} @ 500 GeV	TDR completed
CLIC	0.35 - 3 TeV	e-: (80%) e+: 0%	500 fb^{-1} @ 380 GeV 1500 fb^{-1} @ 1.4 TeV 2000 fb^{-1} @ 3 TeV	CDR completed
CEPC	90 - 240 GeV	e-: 0% e+: 0%	5000 fb^{-1} @ 250 GeV	preCDR completed
FCC-ee	90 - 350 GeV	e-: 0% e+: 0%	5000 fb^{-1} @ 250 GeV 1500 fb^{-1} @ 350 GeV	towards CDR

common: Higgs factory with > 1M # higgs events

references when omitted

- ILC: TDR; White Paper; 1506.05992; 1506.07830
- CLIC: 1608.07538; talk by Lukic @ ICHEP16
- CEPC: pre-CDR; talk by Ruan @ ICHEP16
- FCC-ee: 1701.02663; talk by d'Enterria @ ICHEP16

disclaimer

- apologies for personal bias that most of the example measurements are taken from ILC studies
- focus on reach of higgs physics in terms of collision energies
- precision is offen illustrated in kappa formalism
- see Michael's talk for precision in EFT

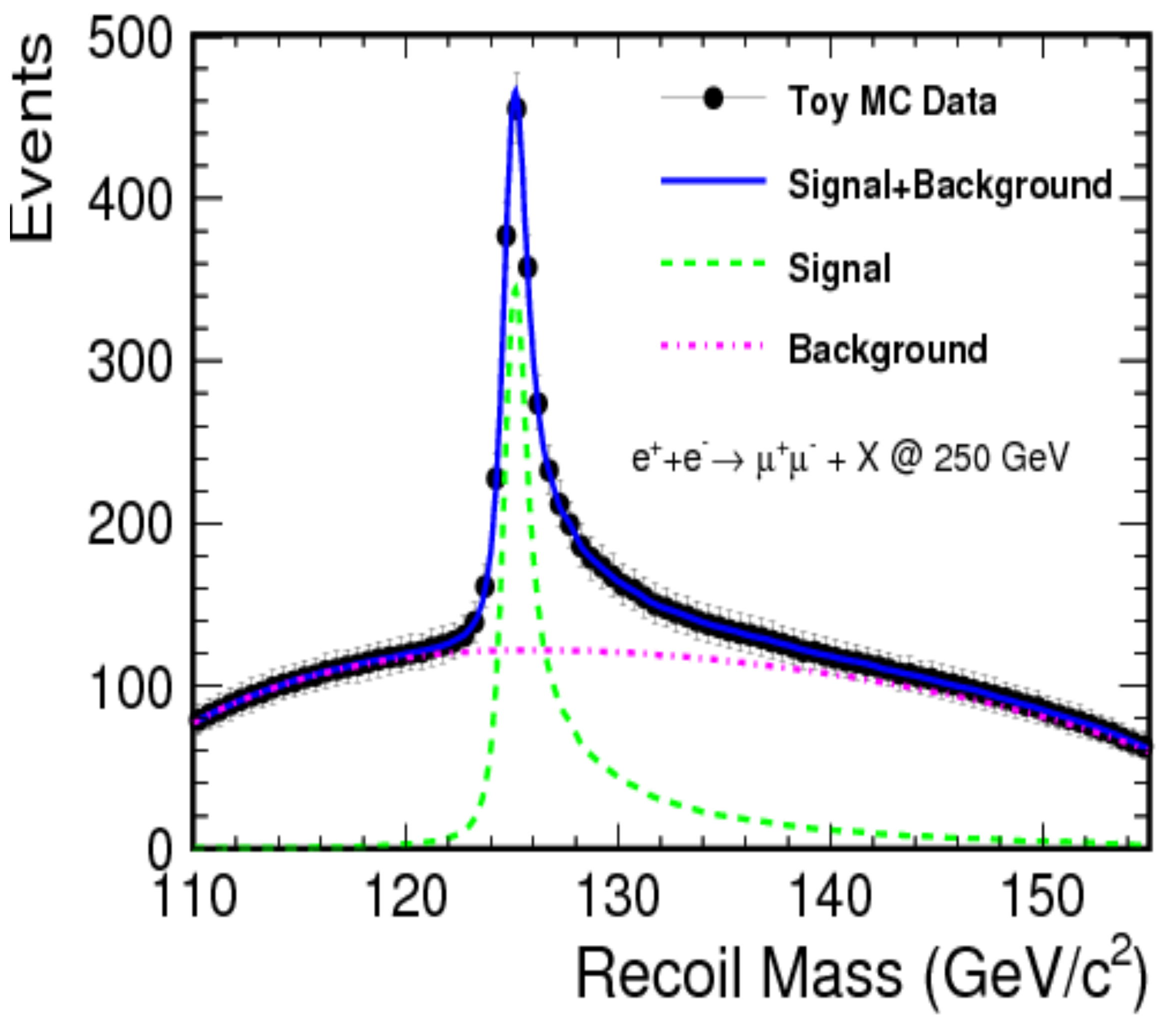
Higgs sector at $\sqrt{s}$ ~ 250 GeV

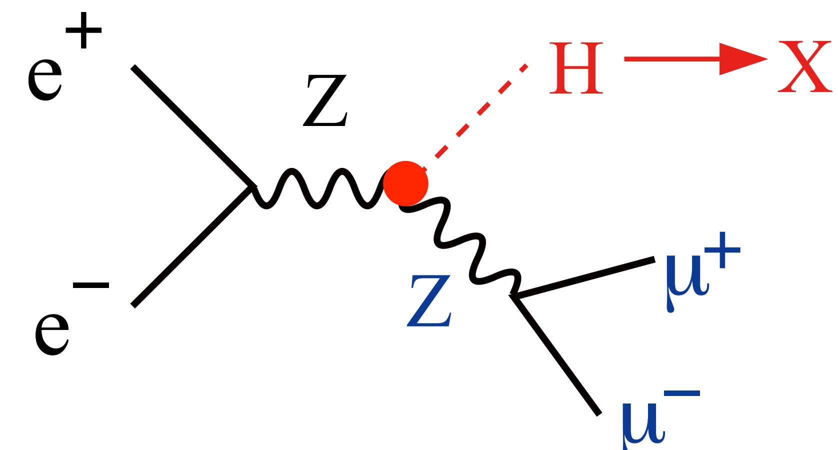
take ILC prospects as examples, $\int L dt = 2000\ fb^{-1}$

most of which are based on full detector simulation

the key of model independence: meas. inclusive σ_{ZH}

Yan, et al, Phys.Rev. D94 (2016) 113002;
Thomson, Eur.Phys.J. C76 (2016) 72





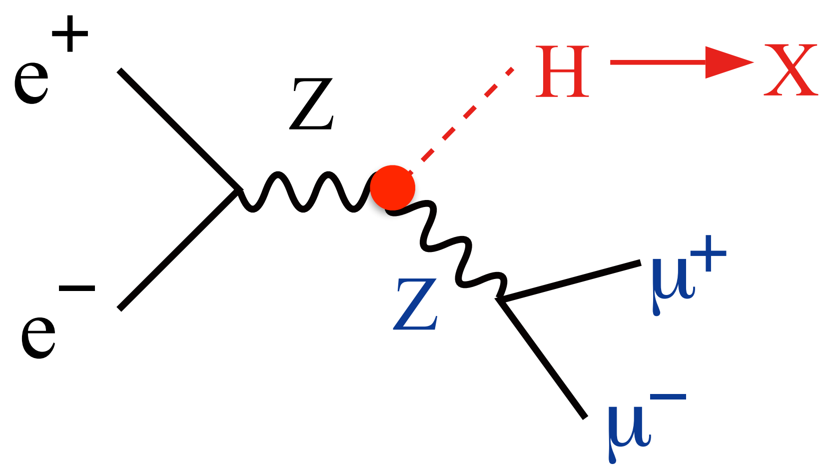
$$M_X^2 = \left(p_{CM} - (p_{\mu^+} + p_{\mu^-})\right)^2$$

- well defined initial states at e+e-
- recoil mass technique —> tag Z only
- Higgs tagged without looking into H decay
- absolute cross section of e^+e^- —> ZH
- absolute HZZ coupling can be given

$\Delta m_H = 14\text{MeV} \quad \delta g_{HZZ} \sim 0.38\% \qquad Y_1 = \sigma_{ZH} \propto g_{HZZ}^2$

- meas. of σ_{ZH} doesn't depend on how Higgs decays
- meas. of σ_{ZH} doesn't depend on underlying models on HZZ vertex

the key: inclusive σ_{Zh} (independent of h decay modes)



is it really easy?

e.g. leptons can come from Higgs decay as well

Yan, et al, Phys.Rev. D94 (2016) 113002;
Thomson, Eur.Phys.J. C76 (2016) 72

$H \to XX$	bb	cc	gg	$\tau\tau$	WW^*	ZZ^*	$\gamma\gamma$	γZ
BR (SM)	57.8%	2.7%	8.6%	6.4%	21.6%	2.7%	0.23%	0.16%
Lepton Finder	93.70%	93.69%	93.40%	94.02%	94.04%	94.36%	93.75%	94.08%
Lepton ID+Precut	93.68%	93.66%	93.37%	93.93%	93.94%	93.71%	93.63%	93.22%
$M_{l^+l^-} \in [73, 120]$ GeV	89.94%	91.74%	91.40%	91.90%	91.82%	91.81%	91.73%	91.47%
$p_T^{l^+l^-} \in [10, 70]$ GeV	89.94%	90.08%	89.68%	90.18%	90.04%	90.16%	89.99%	89.71%
$\lvert\cos\theta_{\rm miss}\rvert < 0.98$	89.94%	90.08%	89.68%	90.16%	90.04%	90.16%	89.91%	89.41%
BDT > - 0.25	88.90%	89.04%	88.63%	89.12%	88.96%	89.11%	88.91%	88.28%
$M_{\rm rec} \in [110, 155]$ GeV	88.25%	88.35%	87.98%	88.43%	88.33%	88.52%	88.21%	87.64%

bias < 0.1% in leptonic recoil mode

still need effort to achieve bias in hadronic recoil mode < 1%

importance of absolute coupling determination

- in some BSM, only normalization of Higgs field gets modified
- Higgs BR, and ratio of Higgs couplings could stay unchanged

$$\mathcal{O}_H = \frac{1}{2}\left(\partial_\mu |H|^2\right)^2$$

N. Craig @ LCWS16
arXiv: 1702.06079

Appears in Lagrangian as $\mathcal{L} \supset \frac{c_H}{\Lambda^2}\mathcal{O}_H$ and after EWSB $H \to v + \frac{1}{\sqrt{2}}h$

$$\frac{c_H}{\Lambda^2}\cdot\frac{1}{2}\left(\partial_\mu |H|^2\right)^2 \to \left(\frac{2c_H v^2}{\Lambda^2}\right)\cdot\frac{1}{2}(\partial_\mu h)^2$$

Correction to Higgs wavefunction in broken phase

Canonically normalizing $h \to \left(1 - c_H v^2/\Lambda^2\right) h$

shifts all Higgs couplings uniformly, e.g.

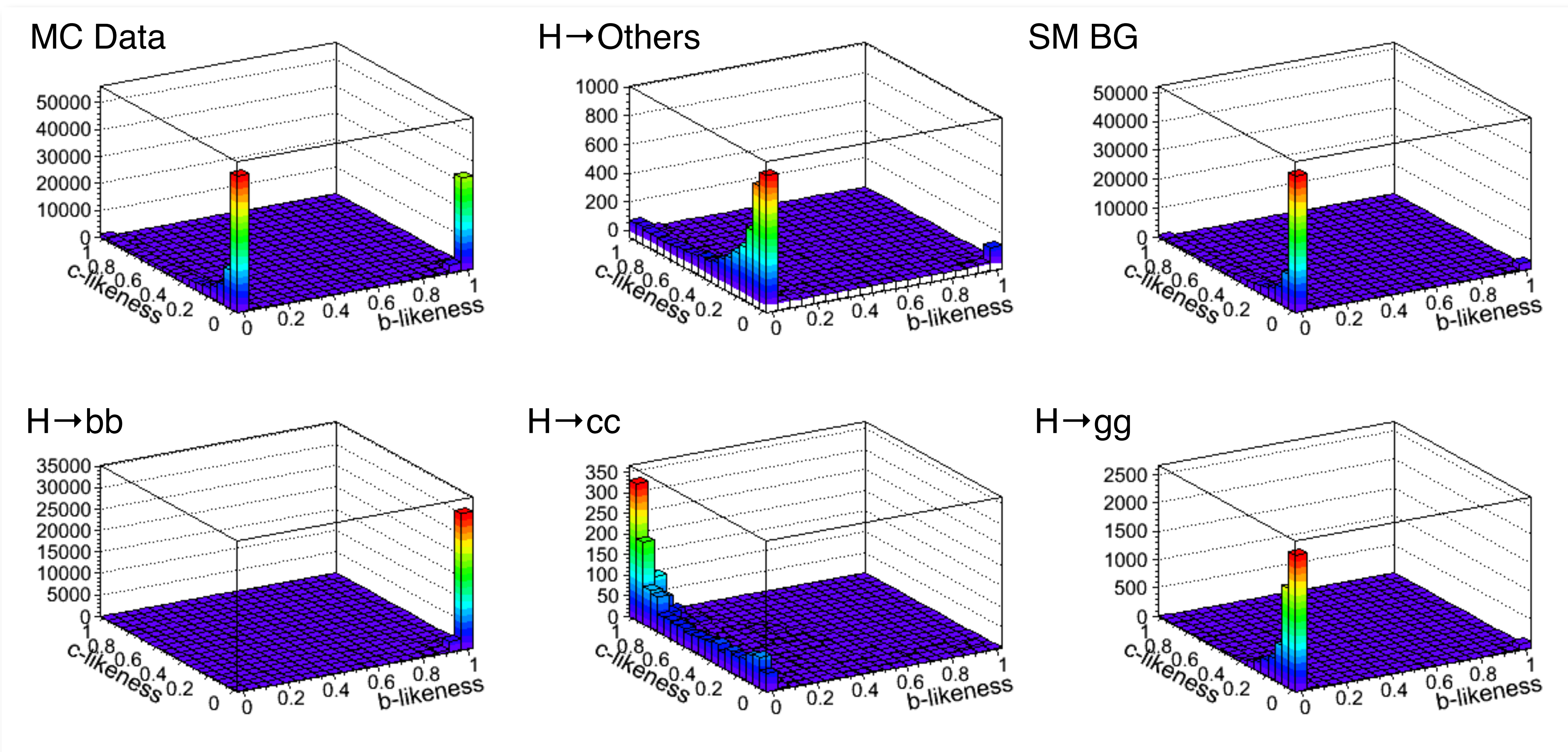
$$\frac{m_Z^2}{v} h Z_\mu Z^\mu \to \frac{m_Z^2}{v}\left(1 - c_H v^2/\Lambda^2\right) h Z_\mu Z^\mu$$

δg_{HZZ} ~ 0.38% —> Λ > 2.8 TeV

Higgs direct couplings to bb, cc and gg

- clean environment at e+e-; excellent b- and c-tagging performance
- bb/cc/gg modes can be separated simultaneously by template fitting

e+e- —> ZH —> ff(jj): b-likeness .vs. c-likeness



directly measured

$$\sigma_{ZH} \cdot \mathrm{Br}(H \to b\bar{b}) \propto g_{HZZ}^2 g_{Hbb}^2 / \Gamma_H$$
$$\sigma_{ZH} \cdot \mathrm{Br}(H \to c\bar{c}) \propto g_{HZZ}^2 g_{Hcc}^2 / \Gamma_H$$
$$\sigma_{ZH} \cdot \mathrm{Br}(H \to gg) \propto g_{HZZ}^2 g_{Hgg}^2 / \Gamma_H$$

with Γ_H

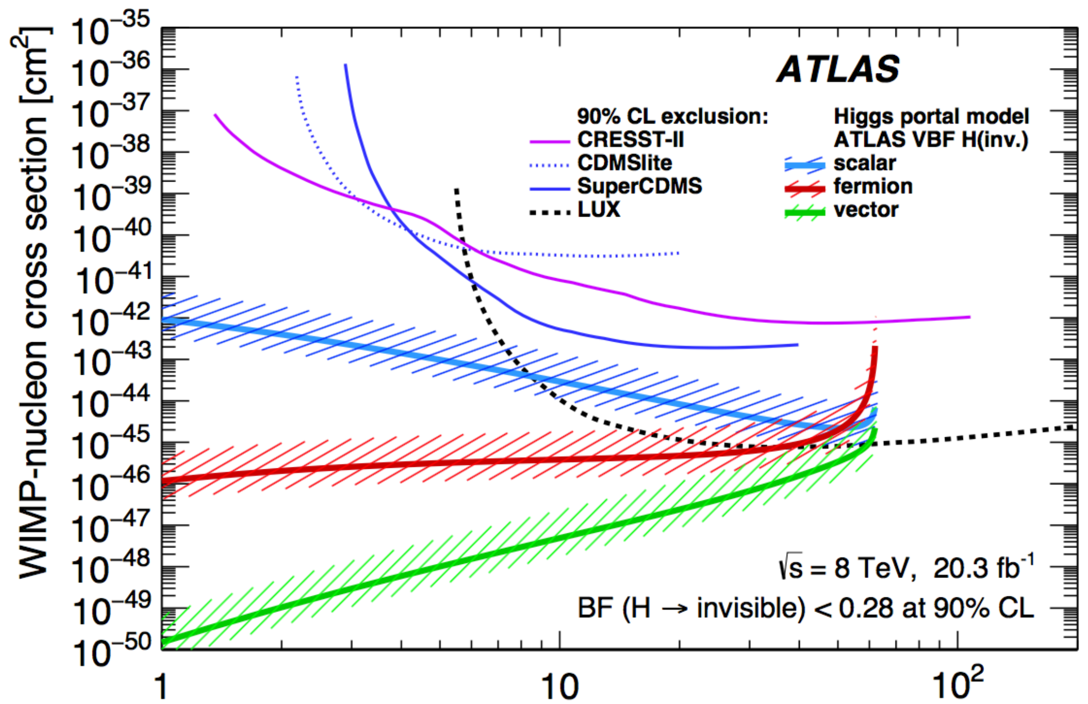
δg_{Hbb}=2.0%
δg_{Hcc}=2.5%
δg_{Hgg}=2.4%

Ono, et. al, Euro. Phys. J. C73, 2343; F.Mueller, PhD thesis (DESY)

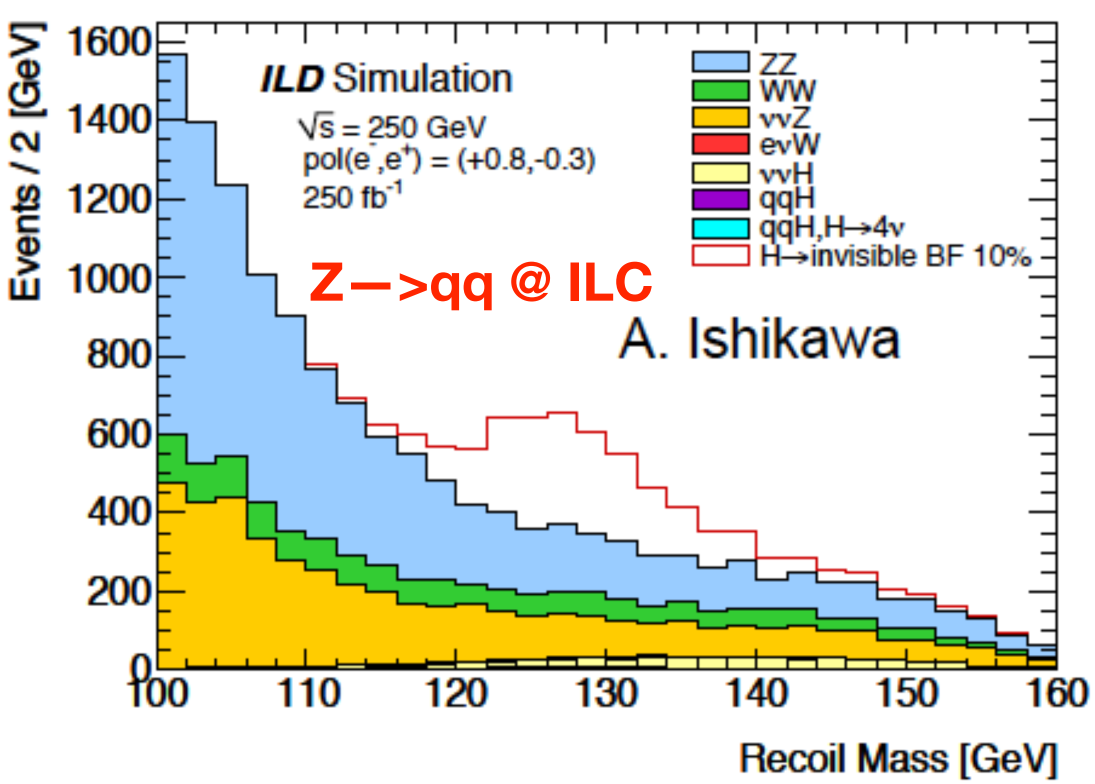
exotic decay: search of Higgs to invisible

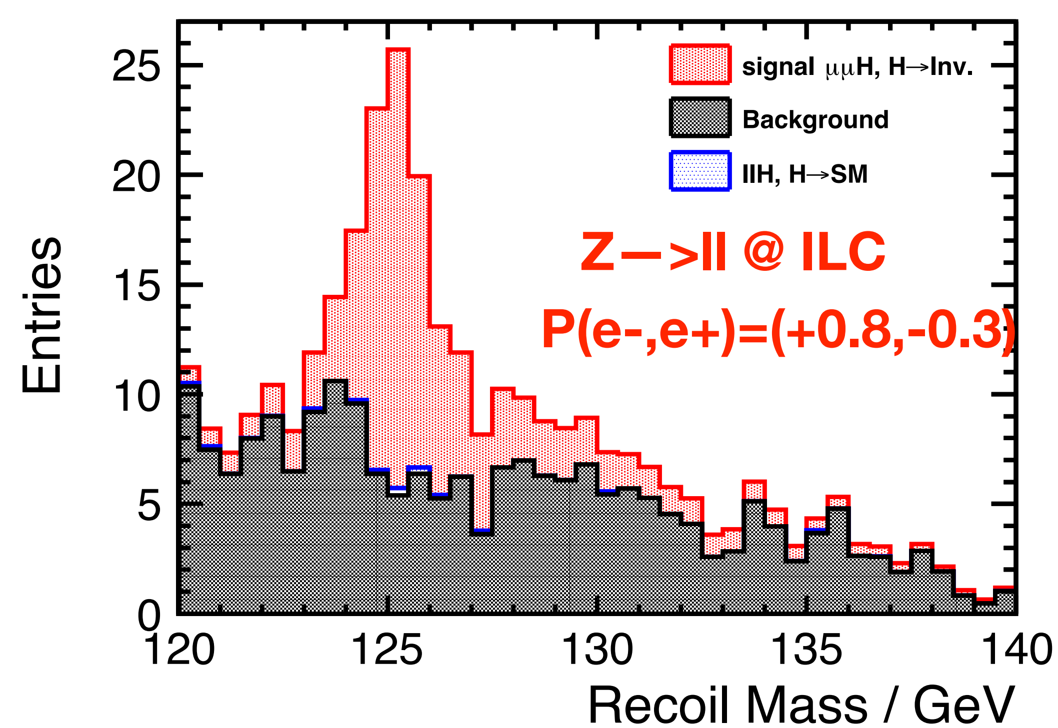
$$e^+ + e^- \to ZH \to l^+l^-/q\bar{q} + \text{Missing}$$

- BR(H—>inv.) < 0.3% (CL95%)
- a sensitive test for Higgs portal dark mater model —> complementary for low mass
- right-handed beam polarisation: much lower background



JHEP 1601 (2016) 172





determine Higgs CP (admixture)

- **find CP-violating source in Higgs sector —> EW baryongenesis**
- **essential to understand structures of all Higgs couplings**

through H—>$\tau^+\tau^-$

$$L_{Hff} = -\frac{m_f}{v} H \bar{f} (\cos\Phi_{CP} + \underline{i\gamma^5 \sin\Phi_{CP}}) f$$

$$\Delta\Phi_{CP} \sim 3.8^\circ$$

D.Jeans @ LCWS16

through HZZ/HWW

$$L_{HVV} = 2C_V M_V^2 (\frac{1}{v} + \frac{a}{\Lambda}) H V_\mu V^\mu + C_V \frac{b}{\Lambda} H V_{\mu\nu} V^{\mu\nu} + \underline{C_V \frac{\tilde{b}}{\Lambda} H V_{\mu\nu} \tilde{V}_{\mu\nu}}$$

(CP-odd)

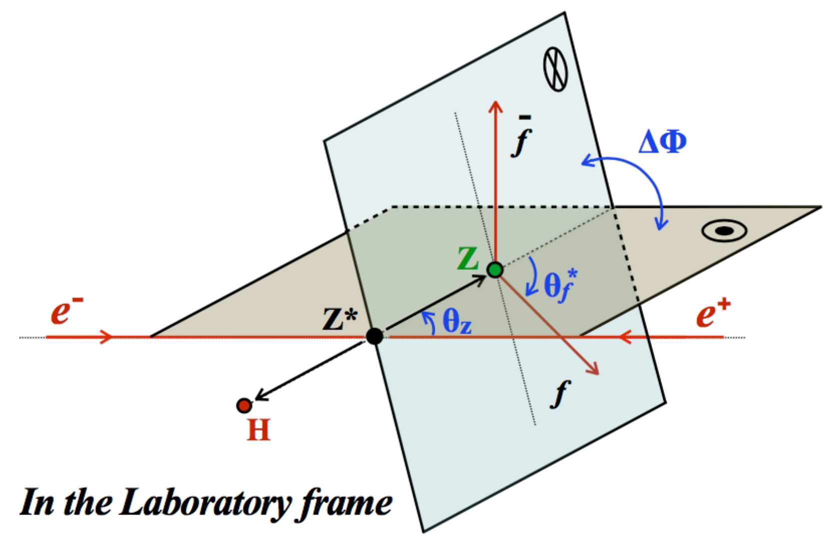
$\Delta\tilde{b} \sim 0.016$ (for Λ=1TeV) T.Ogawa @ LCWS16

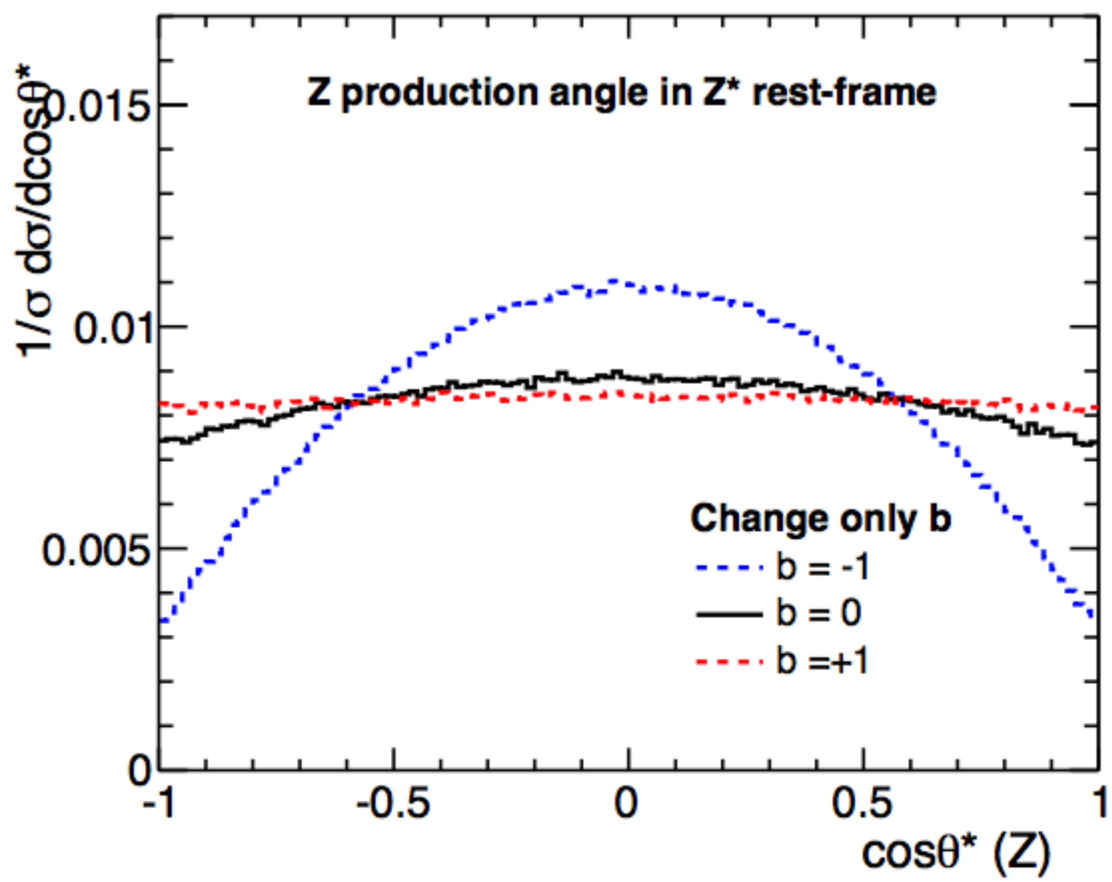
for BR(H—>τ+τ-): Kawada, et. al, Eur.Phys.J. C75 (2015), 617 determine anomalous hVV couplings

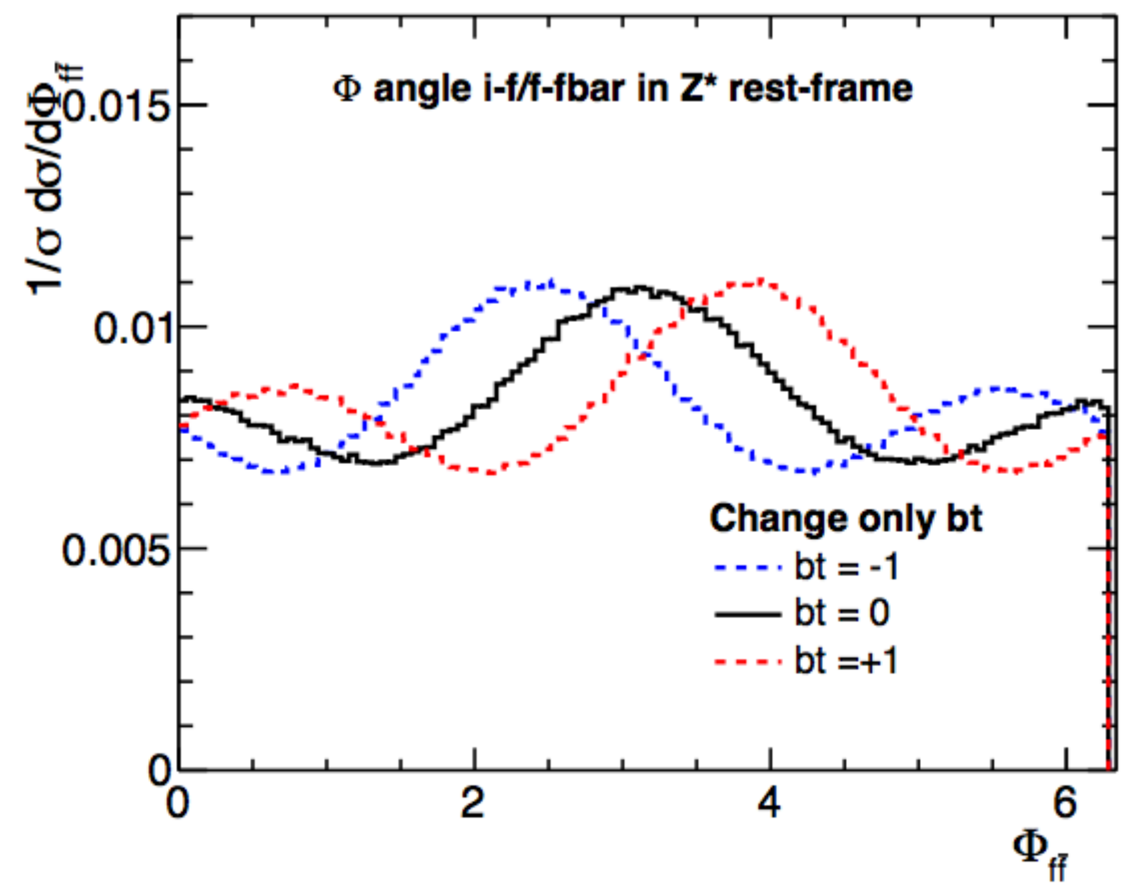
example: how b/b~ changes dσ/dX

$$e^+ + e^- \to Zh \to f\bar{f}h$$

$$@\ \sqrt{s} = 250\mathrm{GeV}$$





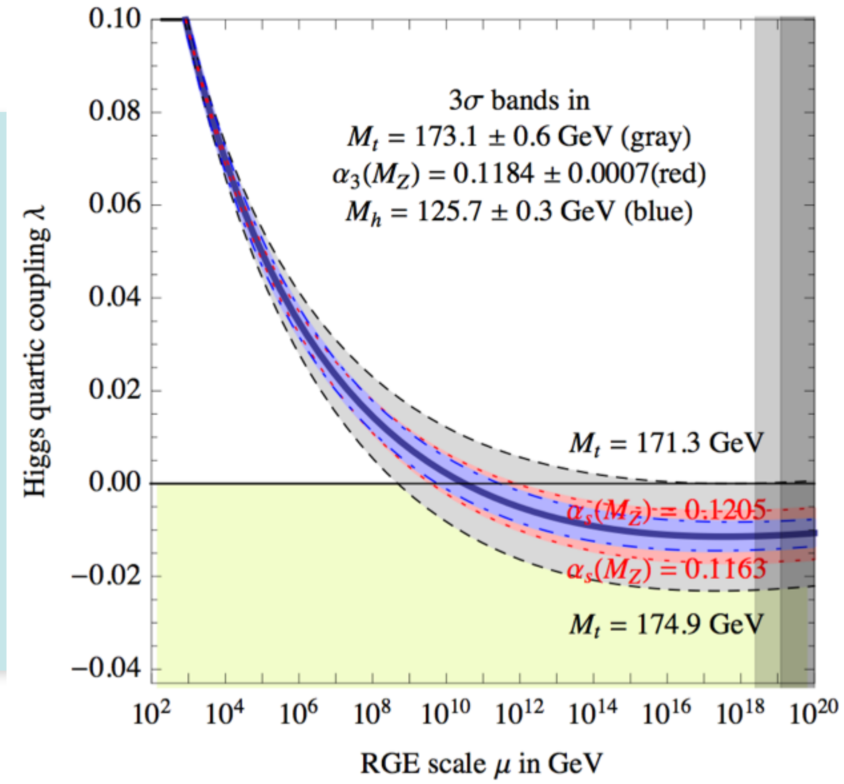


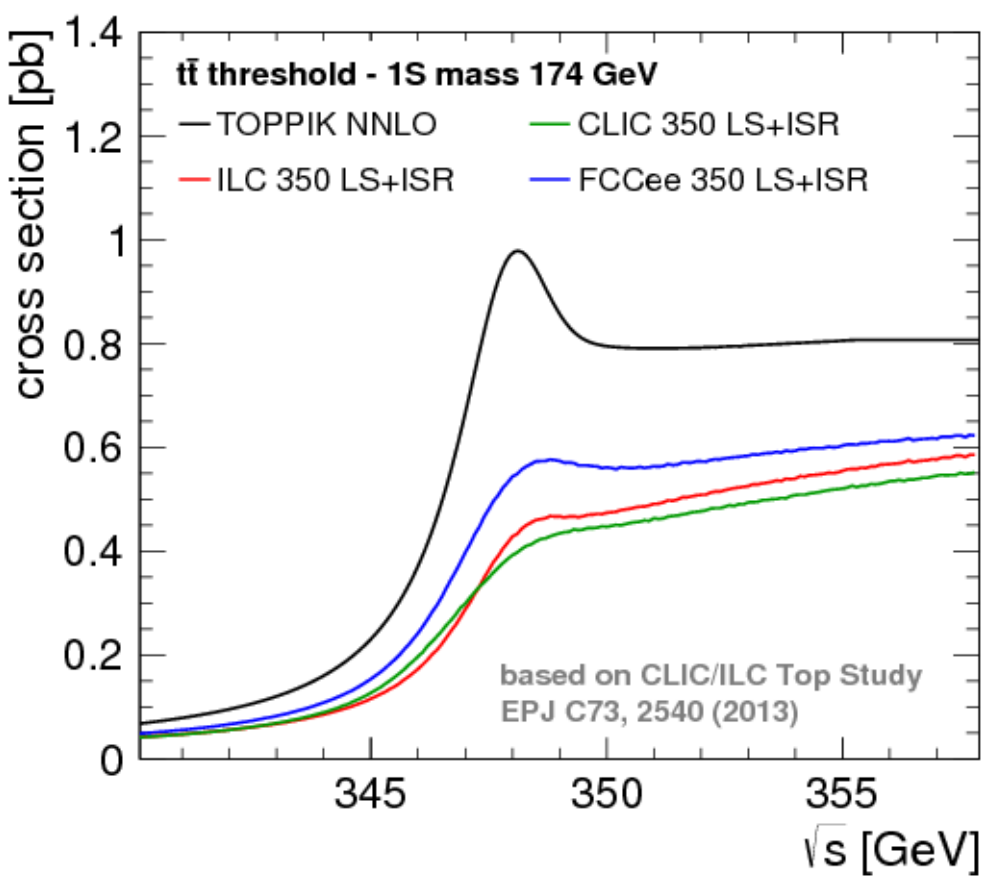
Higgs sector at $\sqrt{s} \sim 350$ GeV

$\int L dt = 200\ \mathrm{fb}^{-1}$

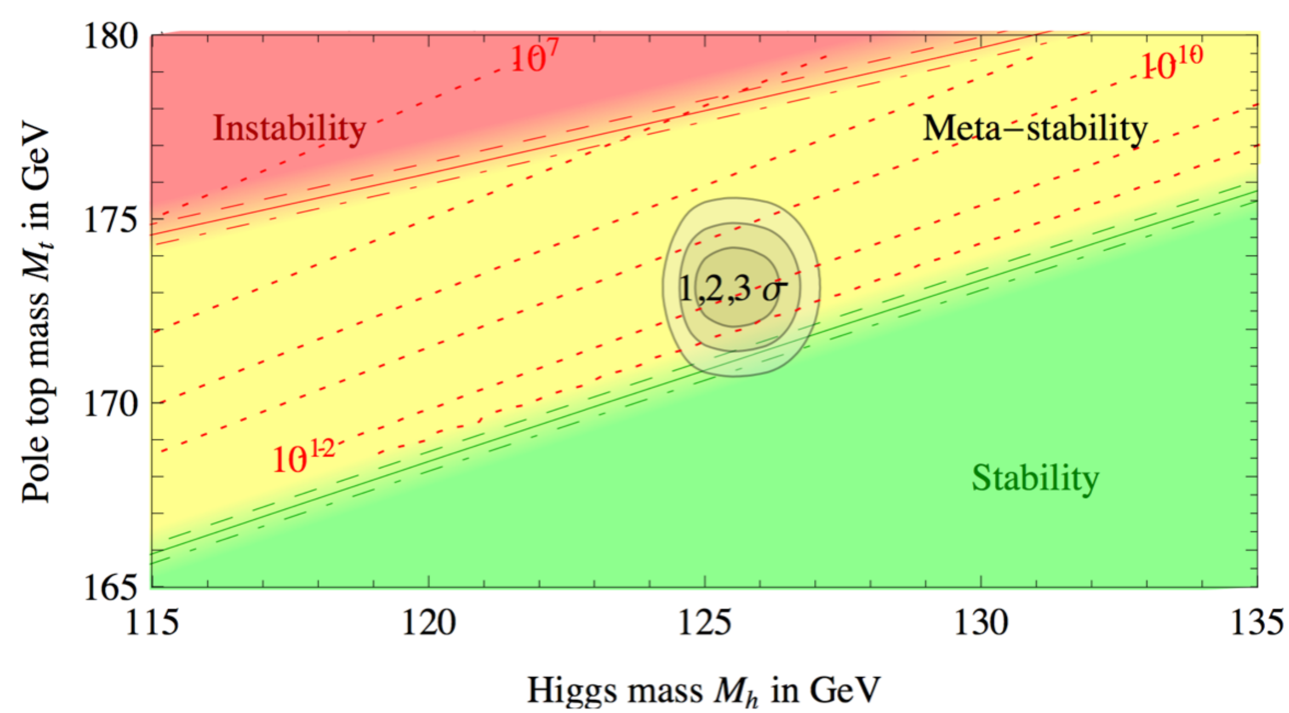
vacuum stability

- **λ runs < 0? top mass precision crucial for vacuum stability**
- **at e+e-: top-pair threshold scan, much lower theory error**
- **Δm_t(MS-bar) ~ 50 MeV (Δm_H=14MeV)**





Degrassi et al, JHEP 1208 (2012) 098



Higgs sector at $\sqrt{s}$ >=500 GeV

$\int L dt = 4000\ fb^{-1}$

HWW coupling & Higgs total width Γ_H

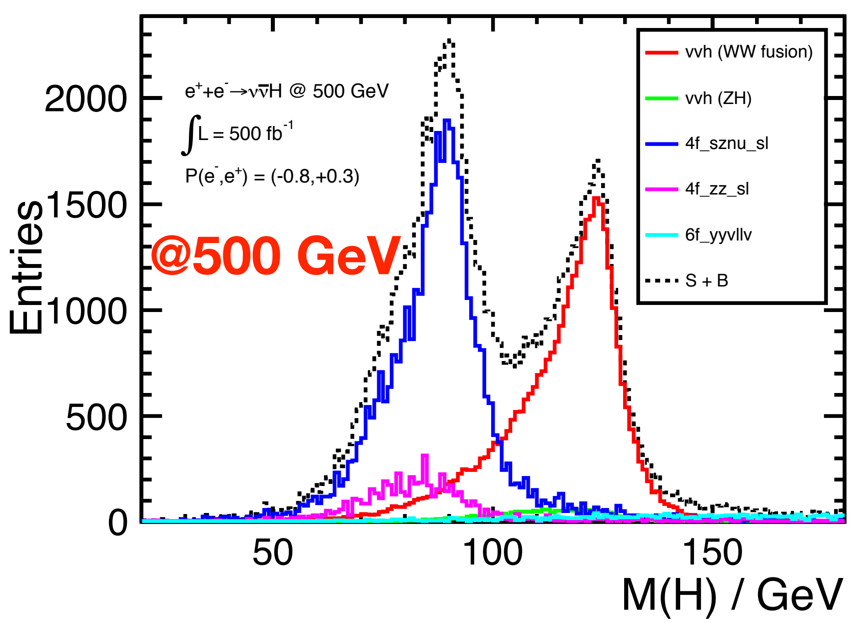
$$\Gamma_H = \frac{\Gamma_{HZZ}}{\mathrm{Br}(H \to ZZ^*)} \propto \frac{g^2_{HZZ}}{\mathrm{Br}(H \to ZZ^*)}$$

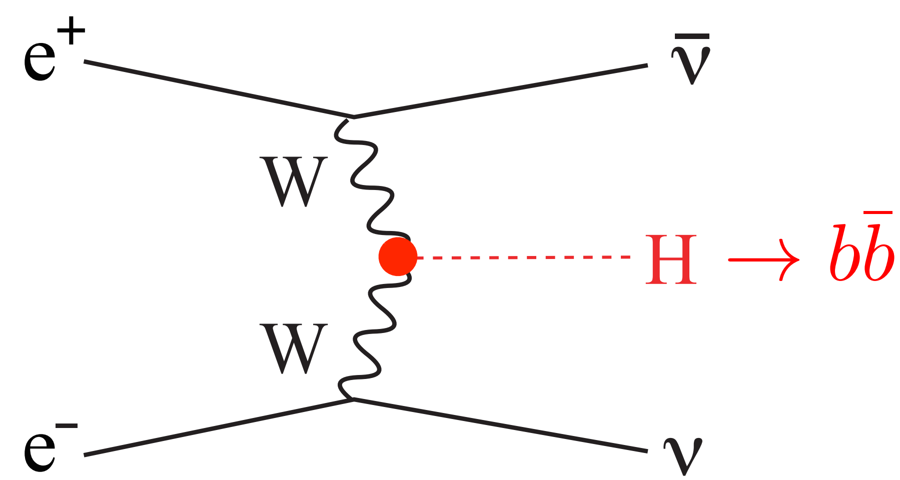
—>Br(H->ZZ*) very small

$$\Gamma_H = \frac{\Gamma_{HWW}}{\mathrm{Br}(H \to WW^*)} \propto \frac{g^2_{HWW}}{\mathrm{Br}(H \to WW^*)}$$

—> better option!

$\delta\Gamma_H$=1.8%



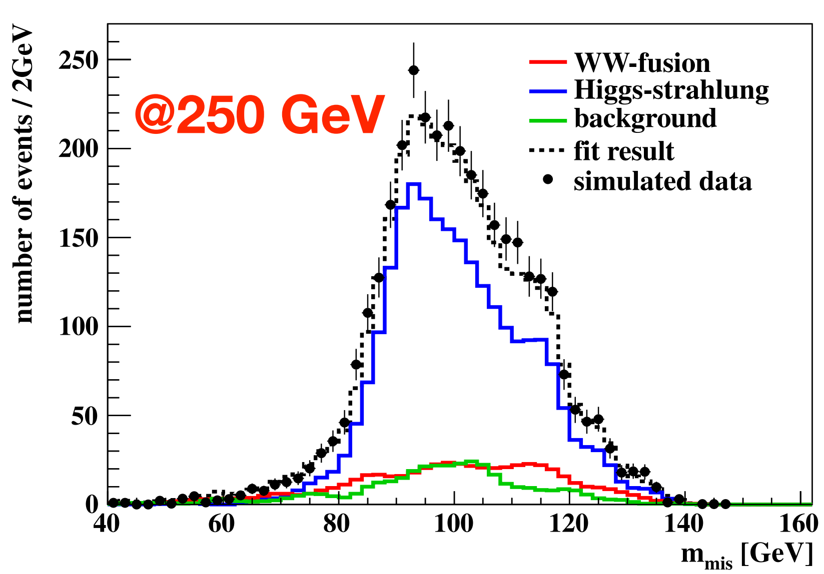


$$Y_2 = \sigma_{\nu\bar{\nu}H} \cdot \mathrm{Br}(H \to b\bar{b}) \propto g^2_{HWW} \cdot \mathrm{Br}(H \to b\bar{b})$$

$$Y_3 = \sigma_{ZH} \cdot \mathrm{Br}(H \to b\bar{b}) \propto g^2_{HZZ} \cdot \mathrm{Br}(H \to b\bar{b})$$

$$g_{HWW} \propto \sqrt{\frac{Y_2}{Y_3}} \cdot g_{HZZ} \propto \sqrt{\frac{Y_1 Y_2}{Y_3}}$$

—>0.4%

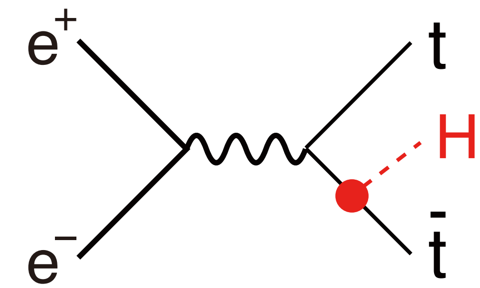


Duerig, et al., arXiv:1403.7734

- **δg_{HWW} is a limiting factor for Γ_H & all other couplings (other than g_{HZZ})**
- **higher $\sqrt{s}$, much larger $\sigma_{\nu\nu H}$**

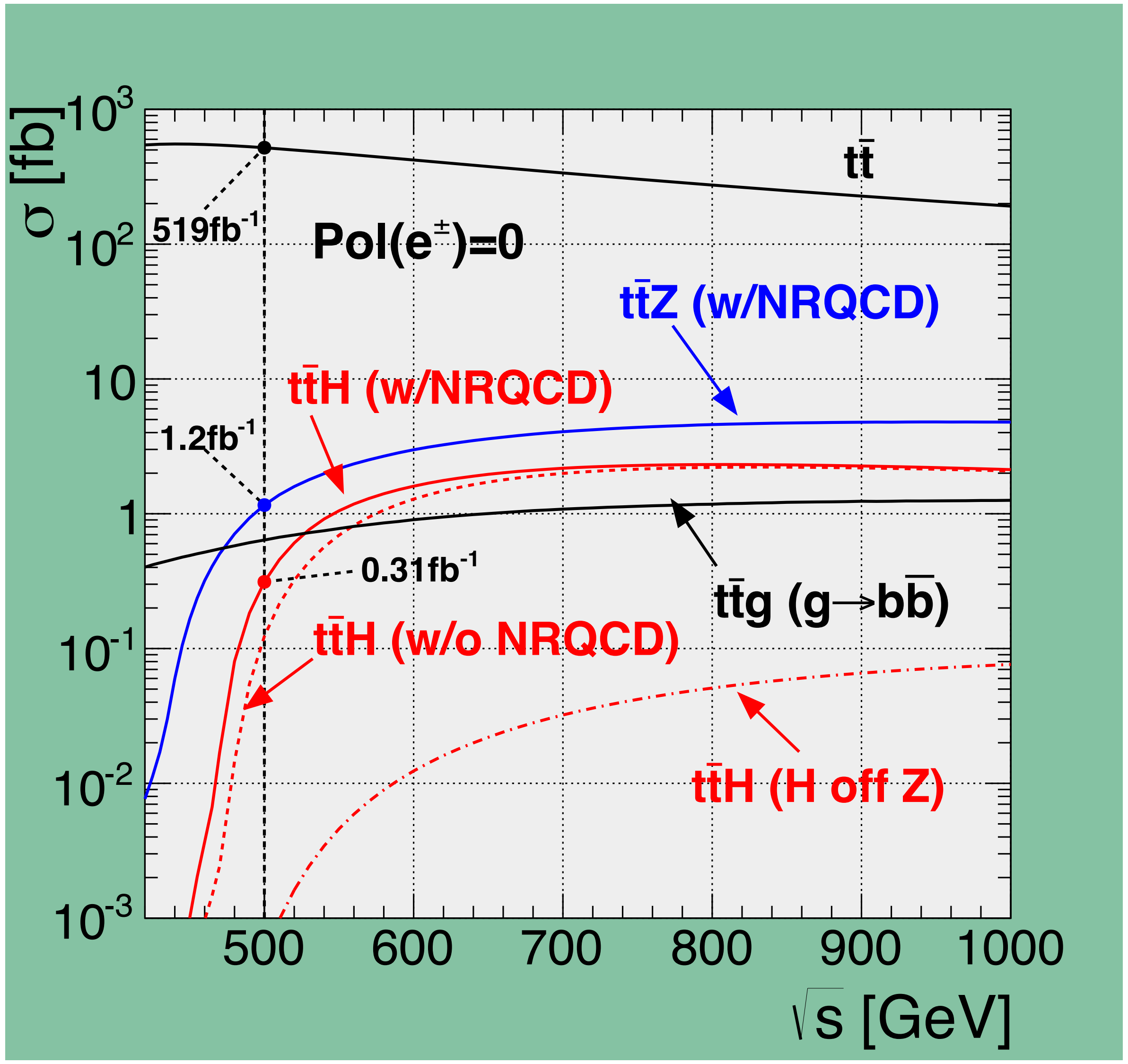
Top-Yukawa coupling

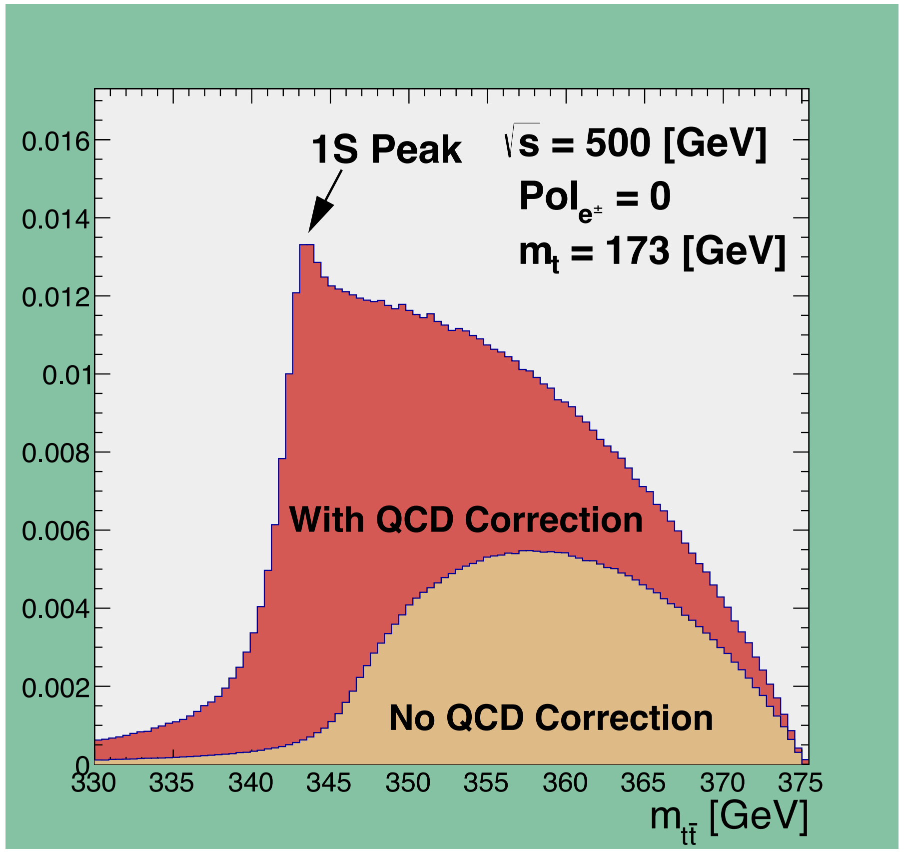
- largest Yukawa coupling; crucial role in theory
- non-relativistic tt-bar bound state correction: enhancement by ~2 at 500 GeV
- Higgs CP measurement



H-> bb

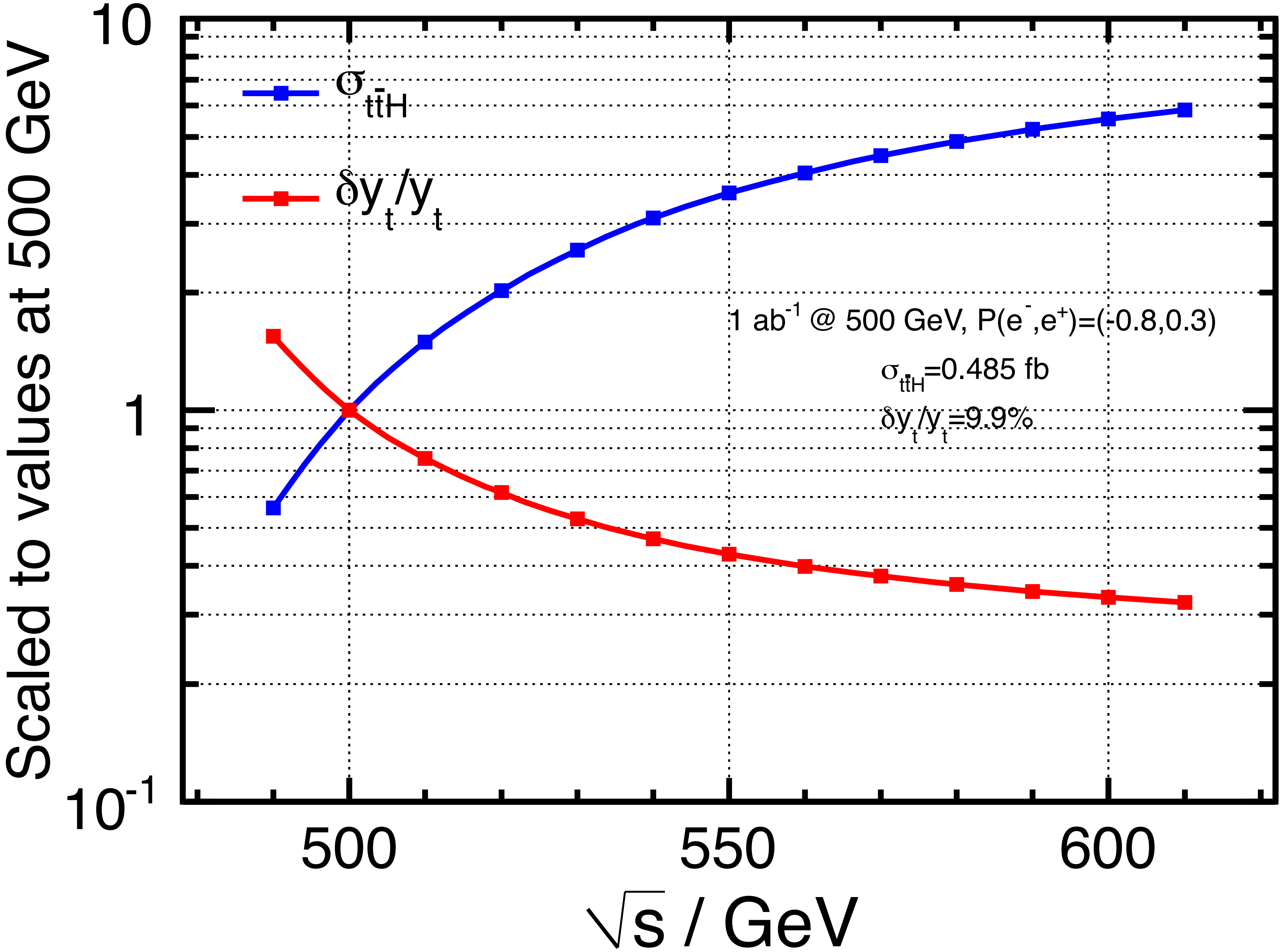
$\Delta g_{ttH}/g_{ttH}$	500 GeV	+ 1 TeV
Snowmass	7.8%	2.0%
H20	6.3%	1.5%





Yonamine, et al., PRD84, 014033;
Price, et al., Eur. Phys. J. C75 (2015) 309

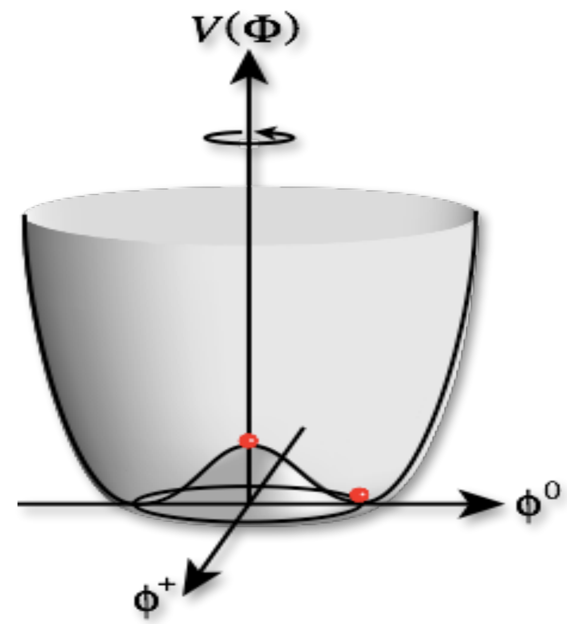
Top-Yukawa coupling



Y. Sudo

Higgs self-coupling

- direct probe of the Higgs potential
- test Electroweak baryongenesis models
- large deviation, could be ~100%
- √s>=500 GeV, e+e- —> ZHH
- √s>=1 TeV, e+e- —> vvHH (WW-fusion)

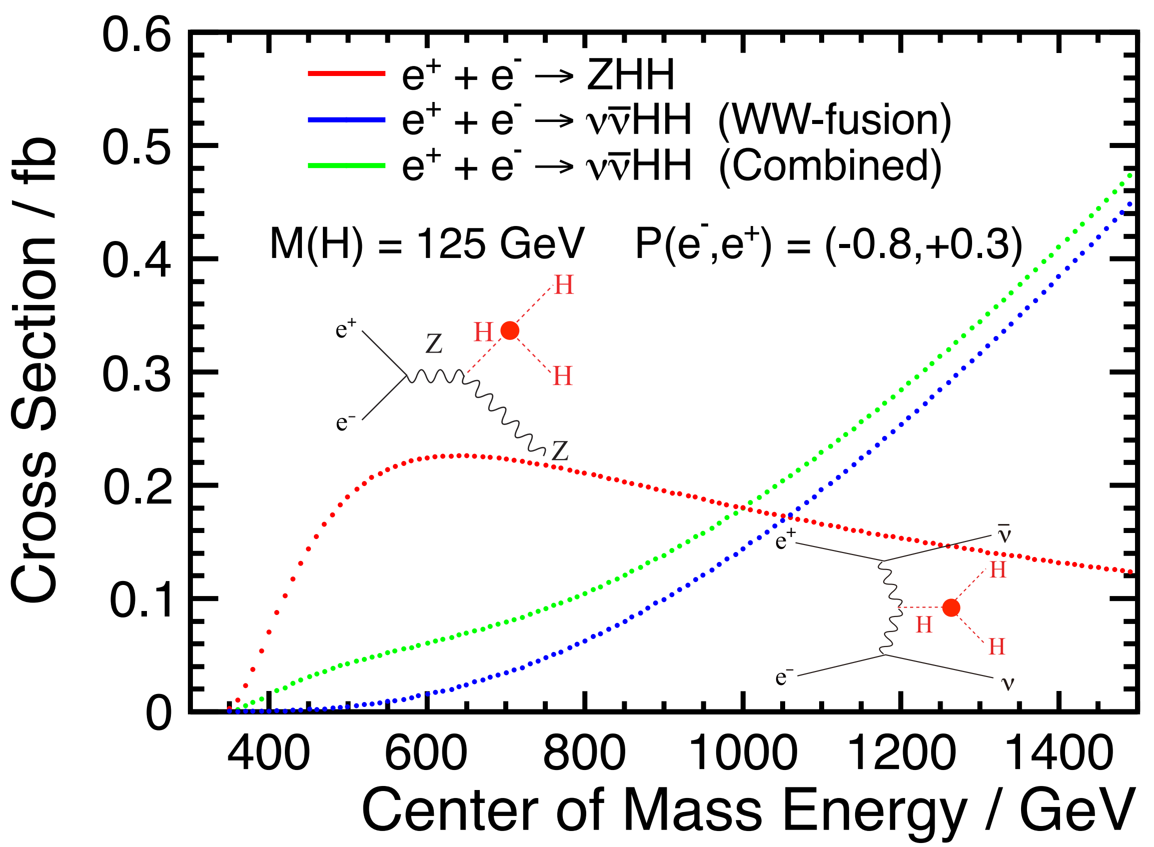


ILC

$\Delta\lambda_{HHH}/\lambda_{HHH}$	500 GeV	+ 1 TeV
Snowmass	46%	13%
H20	27%	10%

CLIC

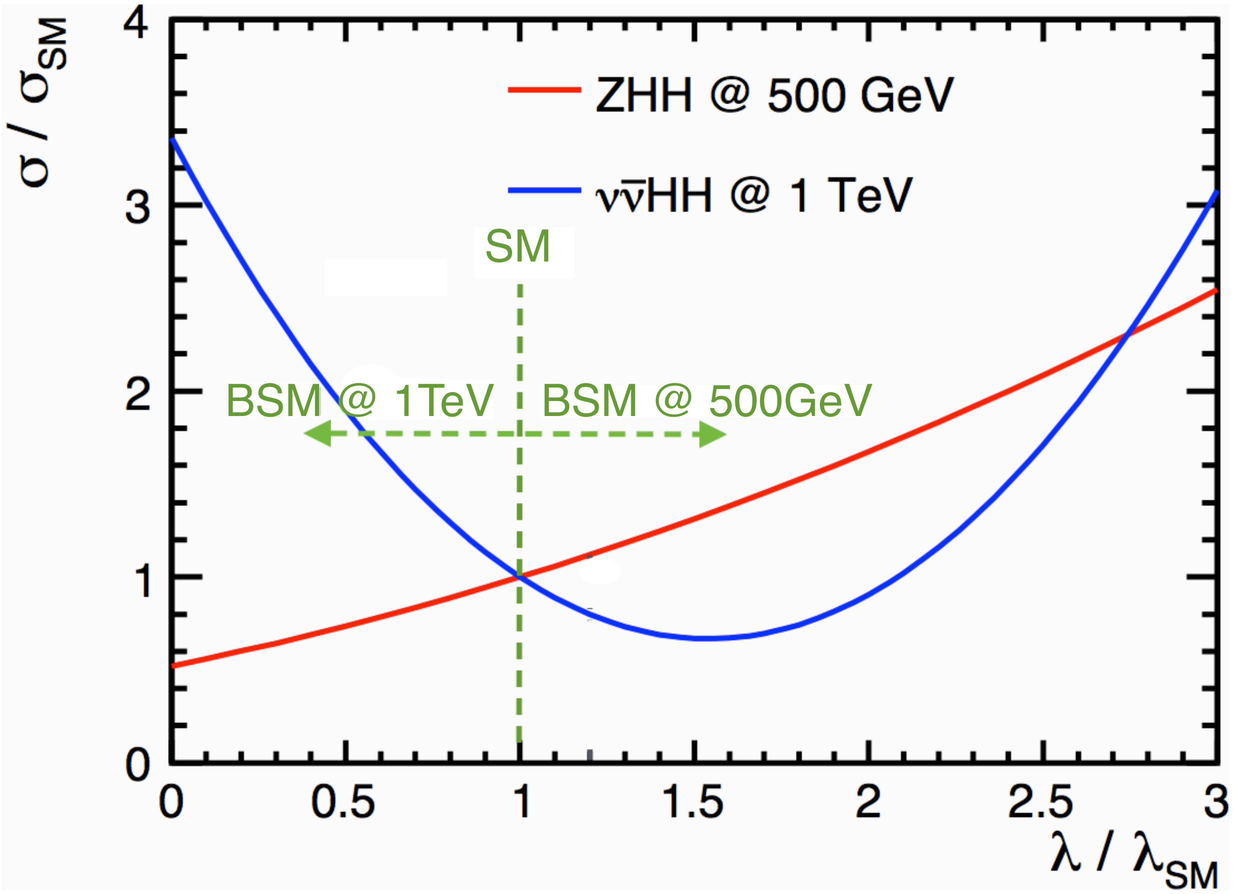
1.4 TeV	+3 TeV
24%	11%

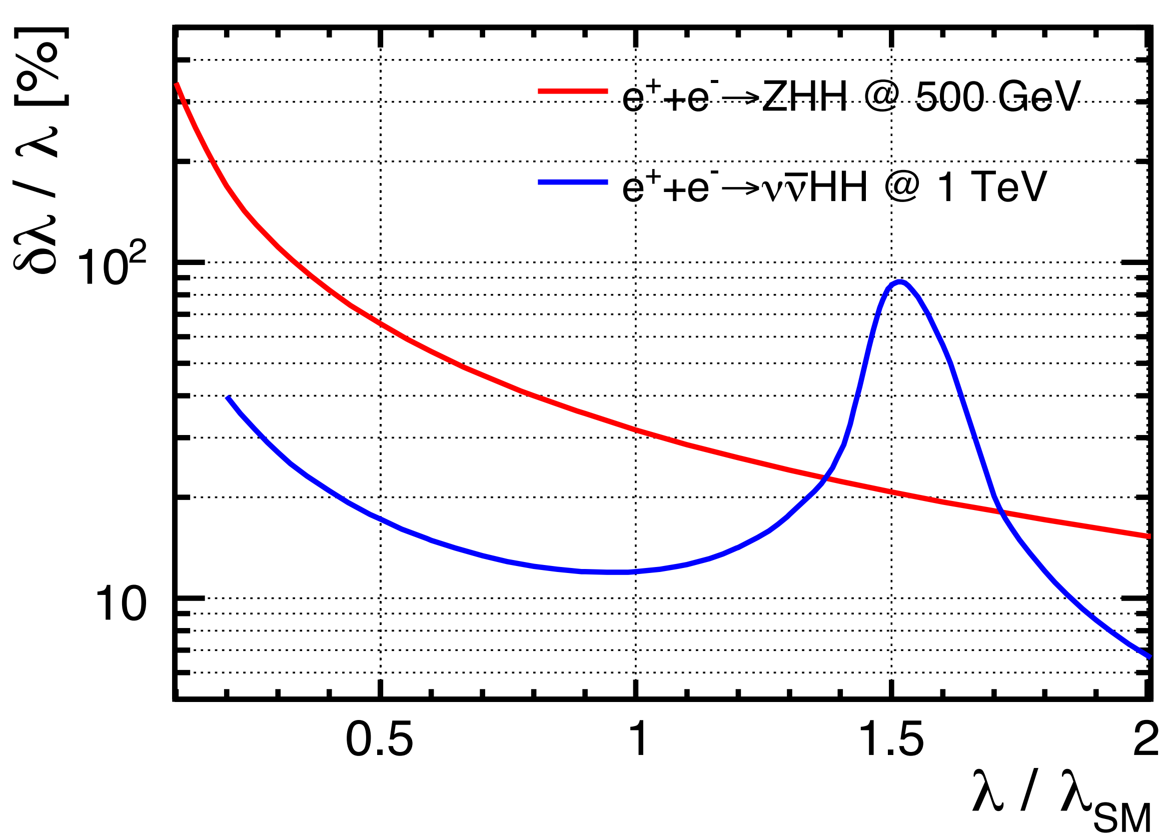


Higgs self-coupling: when $\lambda_{HHH} \neq \lambda_{SM}$?

- constructive interference in ZHH, while destructive in ννHH (& LHC) —> complementarity between ILC & LHC, between $\sqrt{s}$ ~500 GeV and >1TeV
- if $\lambda_{HHH} / \lambda_{SM} = 2$, Higgs self-coupling can be measured to ~15% using ZHH at 500 GeV e+e-

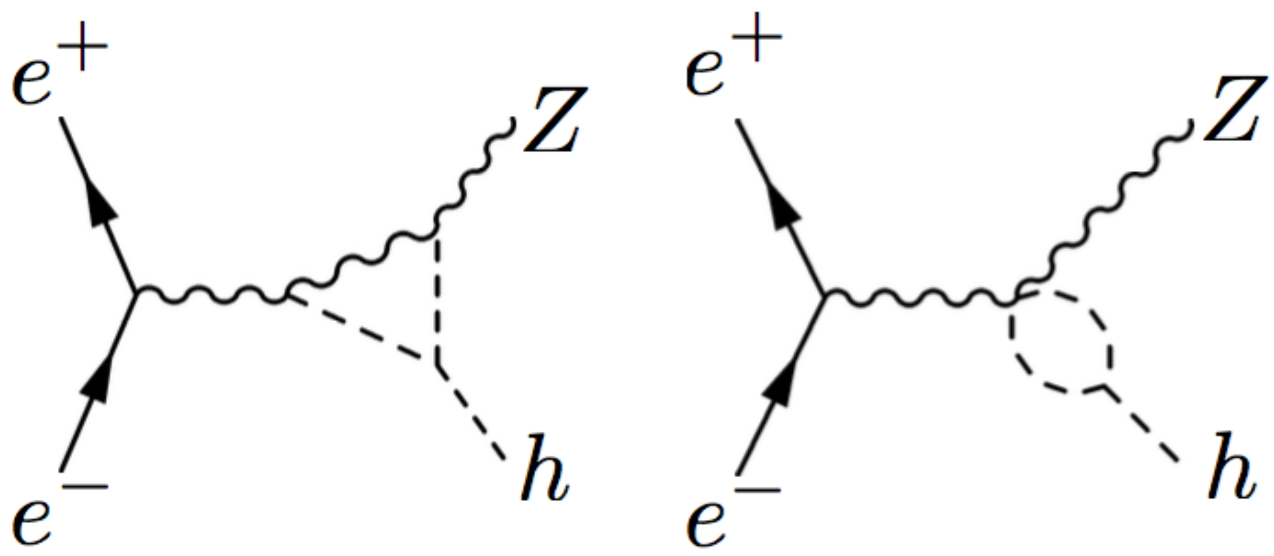
Duerig, Tian, et al, paper in preparation





references for large deviations e.g. Grojean, et al., PRD71, 036001; Kanemura, et al., 1508.03245; Kaori, Senaha, PHLTA,B747,152; Perelstein, et al., JHEP 1407, 108

Higgs self-coupling: indirect determination



McCullough, 1312.3322

$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$

- if only δh is deviated —> δh ~ 28%
- if both δz and δh deviated —> δh ~ 90%
- δσ could receive contributions from many other sources
- open question: what happens after taking into account all possible modifications (e.g. EFT approach)

expected precisions of Higgs couplings

arXiv:1708.08912

	2 ab^{-1} w. pol.	2 ab^{-1} 350 GeV	5 ab^{-1} no pol.	+ 1.5 ab^{-1} at 350 GeV	full ILC 250+500 GeV
$g(hb\bar{b})$	1.04	1.08	0.98	0.66	0.55
$g(hc\bar{c})$	1.79	2.27	1.42	1.15	1.09
$g(hgg)$	1.60	1.65	1.31	0.99	0.89
$g(hWW)$	0.65	0.56	0.80	0.42	0.34
$g(h\tau\tau)$	1.16	1.35	1.06	0.75	0.71
$g(hZZ)$	0.66	0.57	0.80	0.42	0.34
$g(h\gamma\gamma)$	1.20	1.15	1.26	1.04	1.01
$g(h\mu\mu)$	5.53	5.71	5.10	4.87	4.95
$g(hbb)/g(hWW)$	0.82	0.90	0.58	0.51	0.43
$g(hWW)/g(hZZ)$	0.07	0.06	0.07	0.06	0.05
Γ_h	2.38	2.50	2.11	1.49	1.50
$\sigma(e^+e^- \to Zh)$	0.70	0.77	0.50	0.22	0.61
$BR(h \to inv)$	0.30	0.56	0.30	0.27	0.28
$BR(h \to other)$	1.50	1.63	1.09	0.94	1.15

new game

political change

- to meet required cost reduction, ILC is proposed as a 250 GeV machine in the initial stage —> hopefully for an early realization (check out recent JAHEP statement)

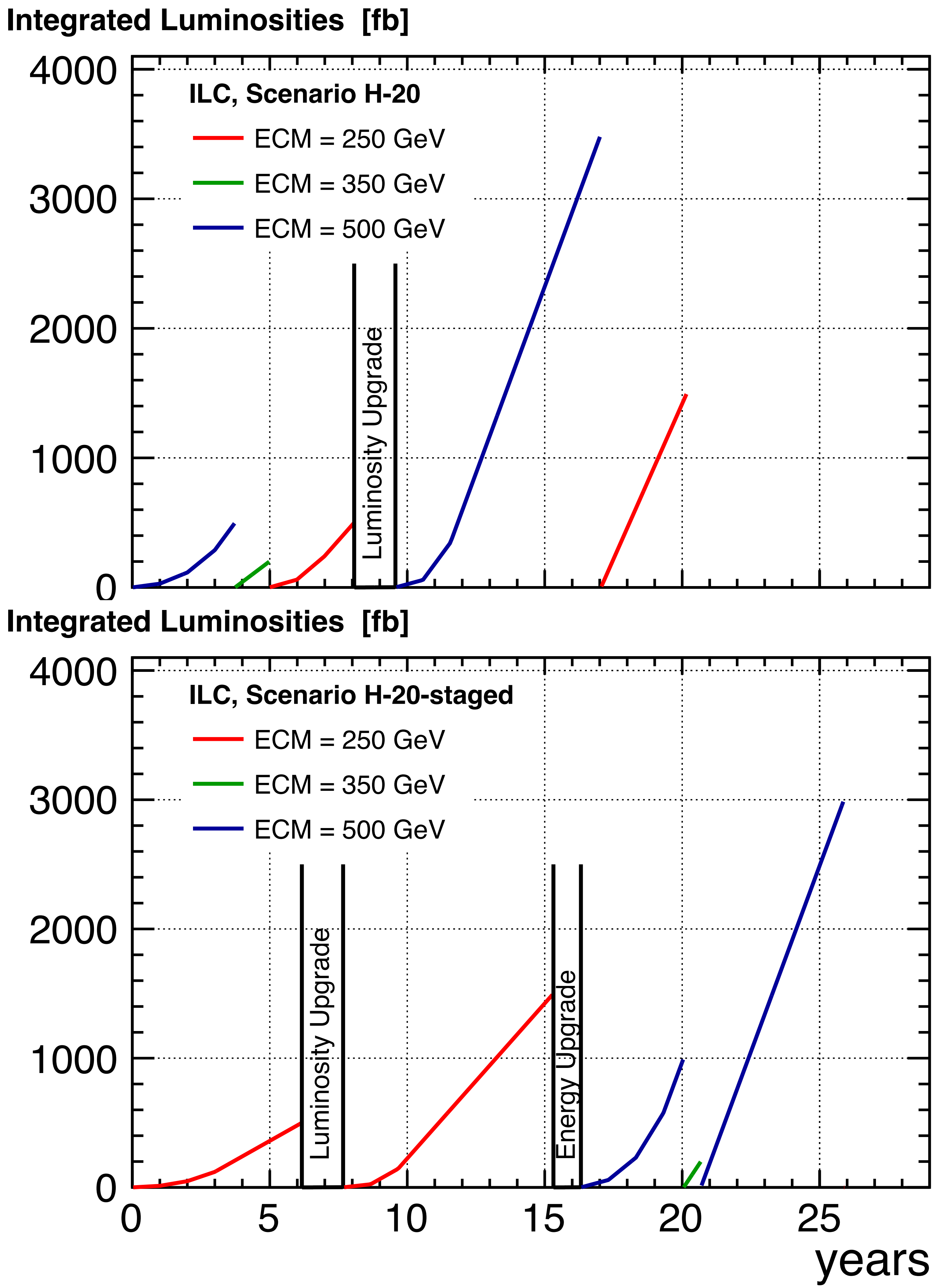
Japan Association of High Energy Physicists

Scientific Significance of ILC and Proposal of its Early Realization
in light of the Outcomes of LHC Run 2

scientific change

- Higgs couplings in effective theory formalism -> view of coupling measurement at 250 GeV is dramatically changed (find details in Michael's talk)

scenario:
example

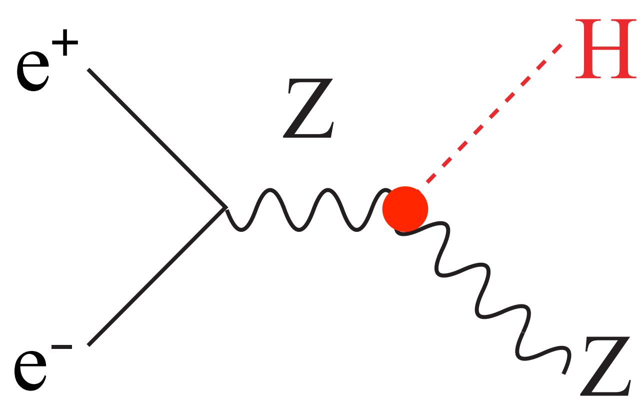


ILC500
H20

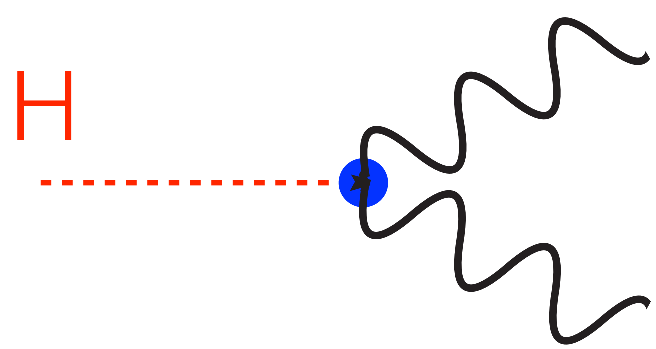
ILC250
H20 staged

top physics starts
after > 16y
in total ~ 6y longer

question 1: can we assume σ(e+e- ->Zh) ∝ Γ(h->ZZ*)?



$$\propto ? \; \kappa_Z^2$$

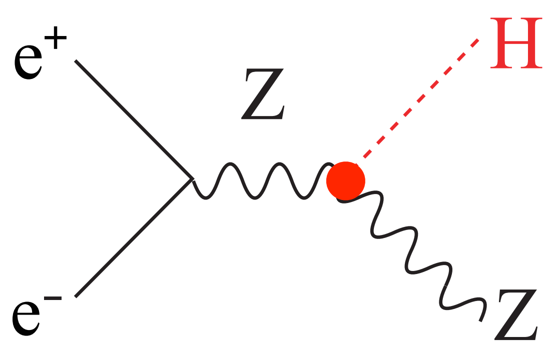


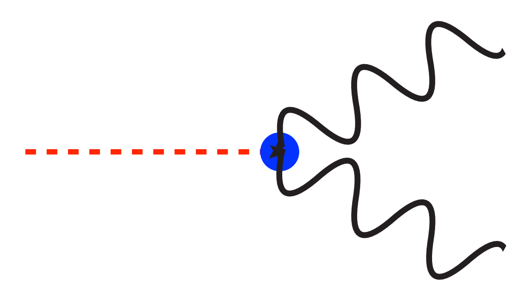
BSM territory -> can deviations be represented by single κ_Z?

answer by EFT:

- σ(e+e- ->Zh) ∝ κ²(hZZ) ∝Γ(h->ZZ*) not any more: kappa-formalism is model-dependent —> EFT is more general

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





$$\sigma(e^+e^- \to Zh) = (SM)\cdot (1+2\eta_Z+(5.5)\zeta_Z)$$

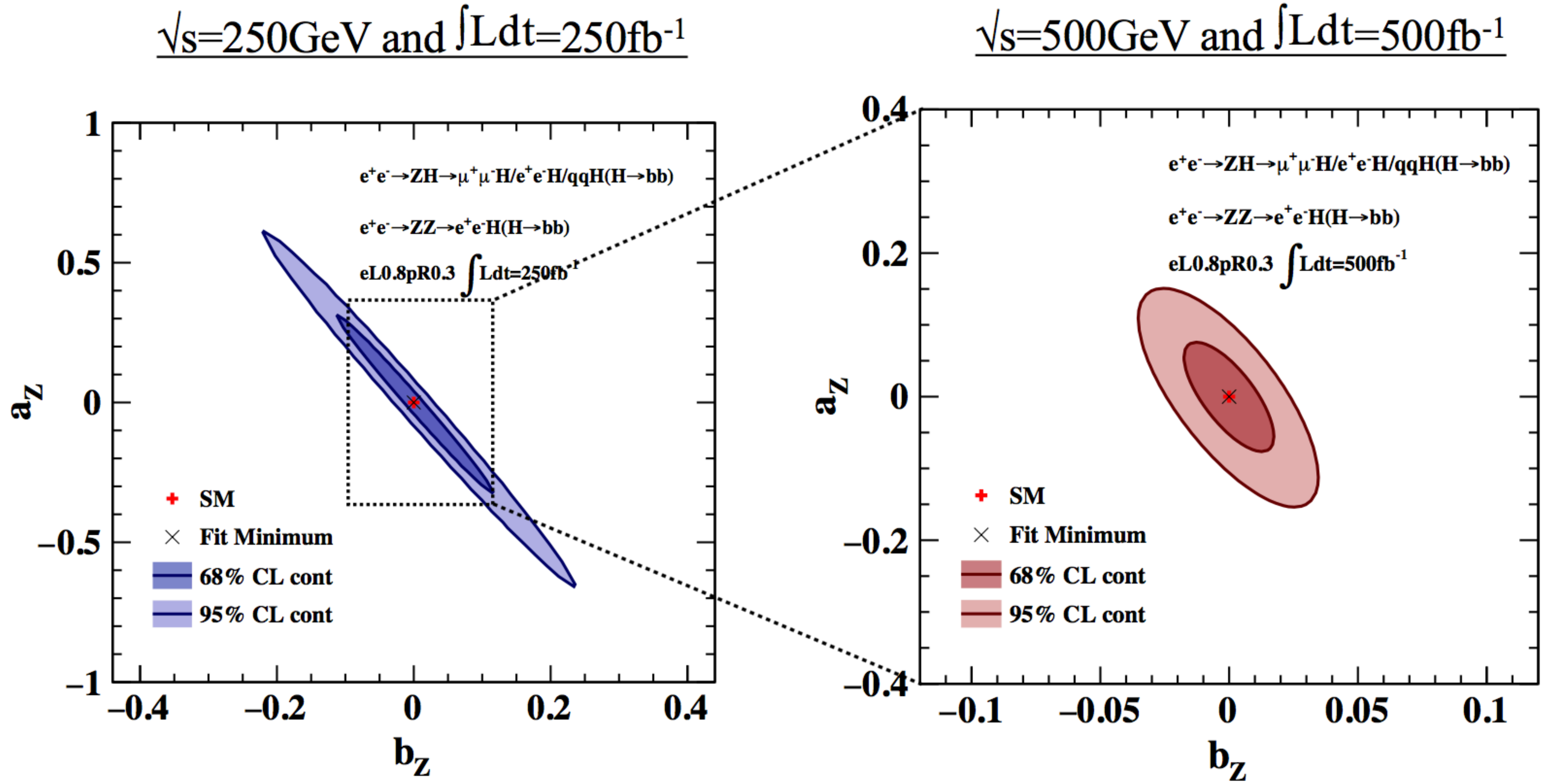
$$\neq$$

$$\Gamma(h \to ZZ^*) = (SM)\cdot (1+2\eta_Z-(0.50)\zeta_Z)$$

- full EFT analysis is not only more general: taking advantage of relation between Higgs and EWPO helps a lot, otherwise by direct measurement only…

$$L_{hZZ} = M_Z^2(\frac{1}{v} + \frac{a}{\Lambda})hZ_\mu Z^\mu + \frac{b}{2\Lambda}hZ_{\mu\nu}Z^{\mu\nu} + \frac{\tilde{b}}{2\Lambda}hZ_{\mu\nu}\tilde{Z}_{\mu\nu}$$

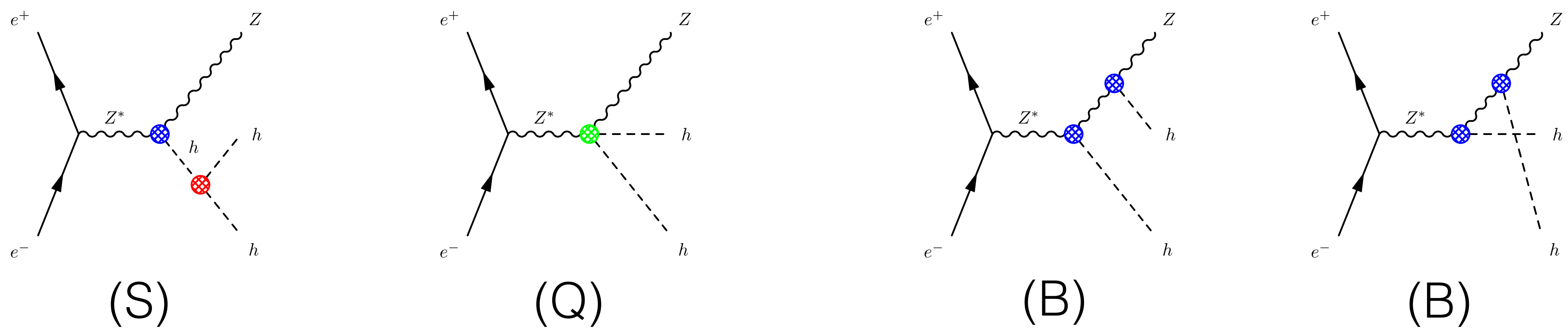
$\Lambda = 1$ TeV

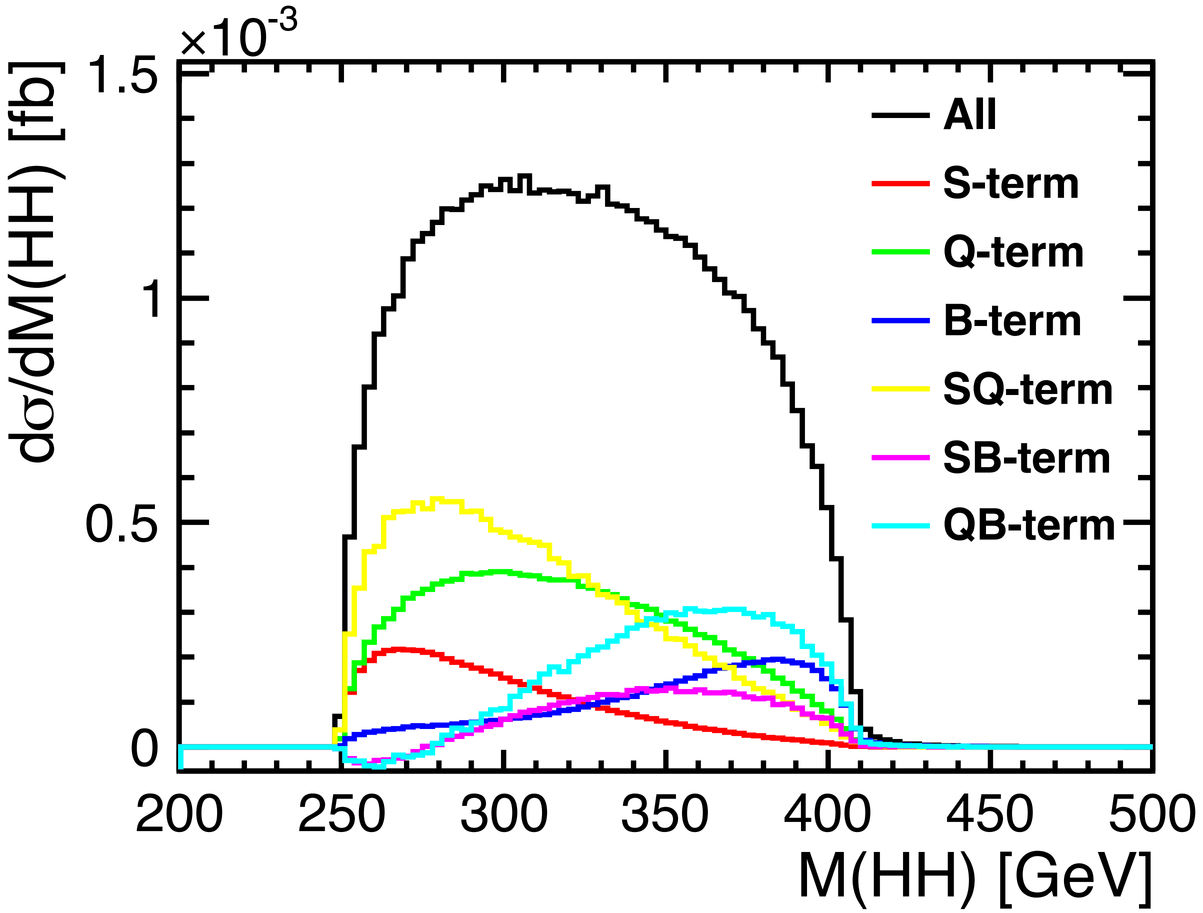


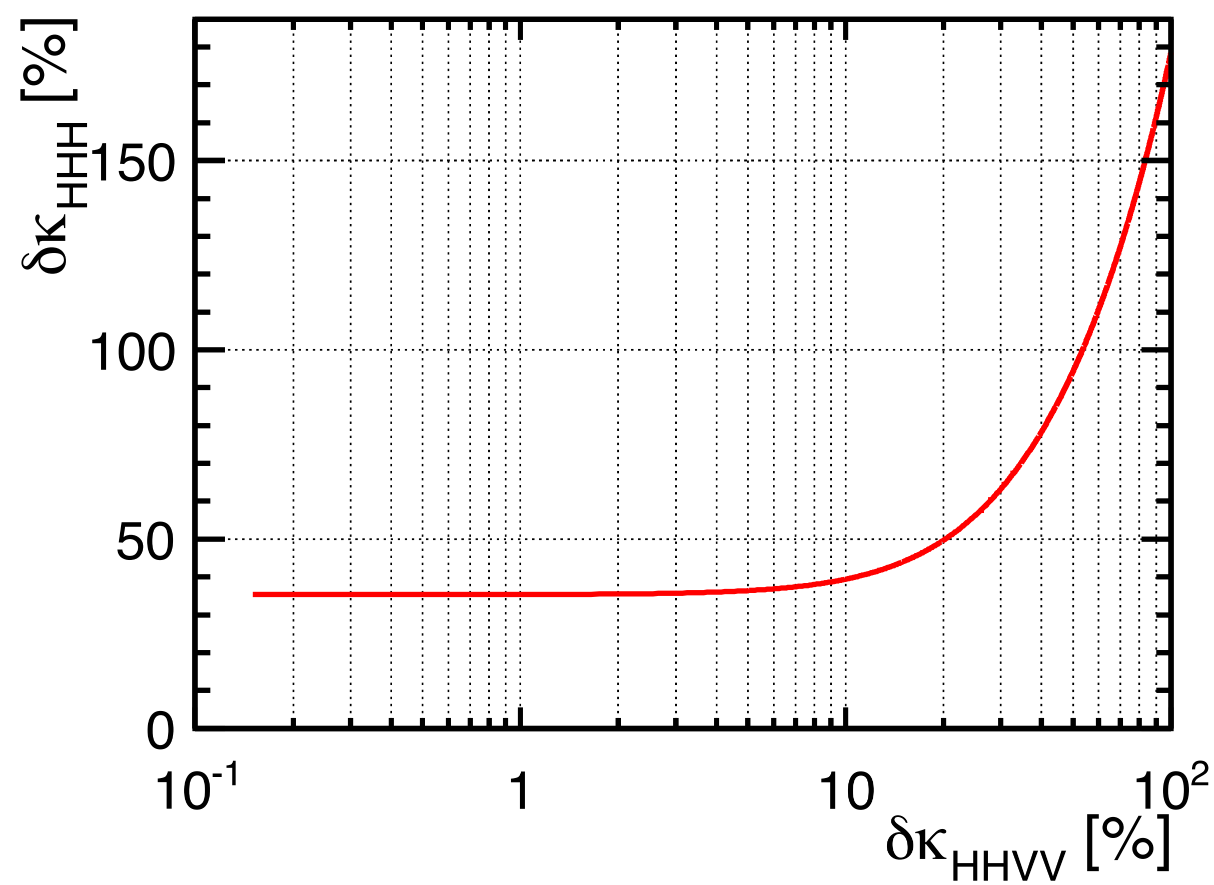
for 2 ab-1 @ 250 GeV —> ηZ (a) ~ 3% >> 0.38%

Ogawa, Fujii, Tian, EPS-HEP 2017

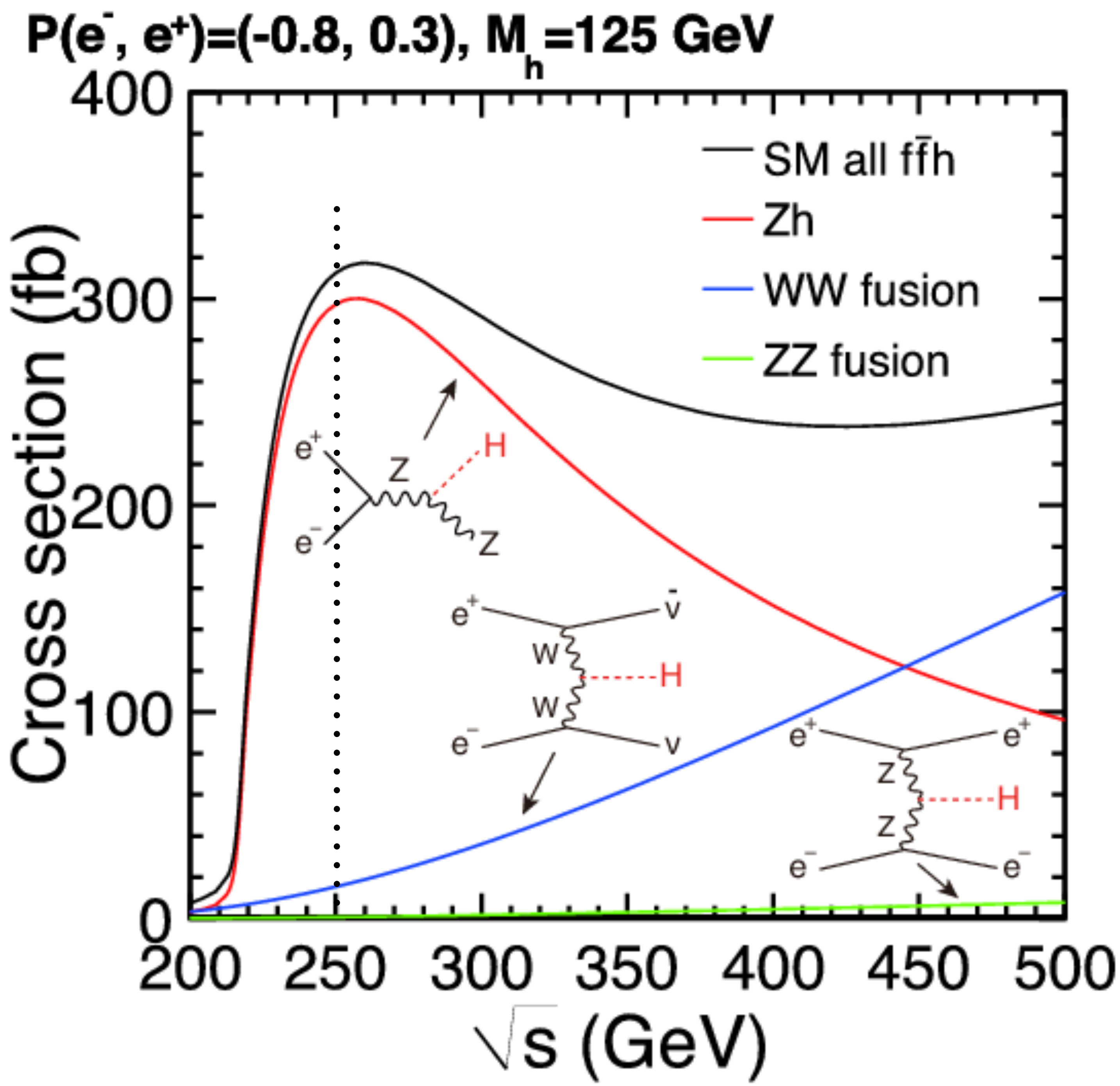
hhVV, hVV and λ_{hhh} in e+e- —> Zhh







$\delta\kappa_{hhVV}$ < 5% would be needed —> challenging by shape question 2: can we determine hWW precisely at $\sqrt{s}$ = 250 GeV?



WW-fusion is smaller by x10 than 500 GeV answer to Q2: hWW is determined as precisely as hZZ @ $\sqrt{s}$ = 250 GeV

- hWW/hZZ ratio can be determined to <0.1%: gift by SU(2) x U(1) gauge symmetry

$$\Gamma(h \to ZZ^*) = (SM) \cdot (1 + 2\eta_Z - (0.50)\zeta_Z) \ ,$$

$$\Gamma(h \to WW^*) = (SM) \cdot (1 + 2\eta_W - (0.78)\zeta_W)$$

SM-like hVV

$$\eta_W = -\frac{1}{2} c_H$$

$$\eta_Z = -\frac{1}{2} c_H - c_T$$

custodial symmetry

$c_i \sim O(10^{-4}\text{-}10^{-3})$

anomalous hVV

$$\zeta_W = (8c_{WW})$$

$$\zeta_Z = c_w^2(8c_{WW}) + 2s_w^2(8c_{WB}) + (s_w^4/c_w^2)(8c_{BB})$$

typical precisions by EFT: combined EWPO+TGC+Higgs fit

ILC $\int L dt$ = 2 ab^{-1} @ 250 GeV

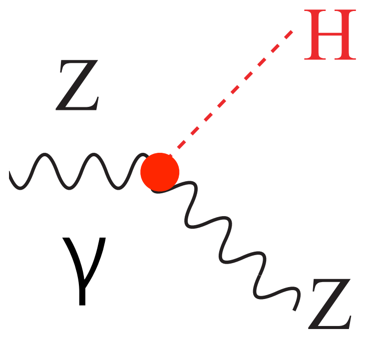
coupling $\Delta g/g$	kappa-fit	EFT-fit
hZZ	0.38%	0.66%
hWW	1.9%	0.65%
hbb	2.0%	1.0%
Γ_h	4.2%	2.4%

(for hZZ and hWW couplings: 1/2 of partial width precision)

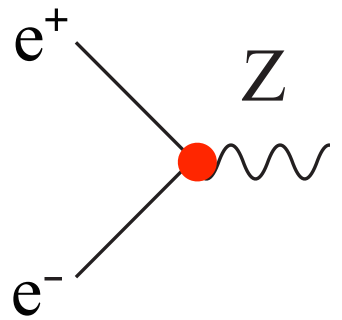
comments on beam polarizations

- not changed: useful for systematics control, nature of new particle (once found), e.g. Higgsino, WIMPs
- new roles in EFT

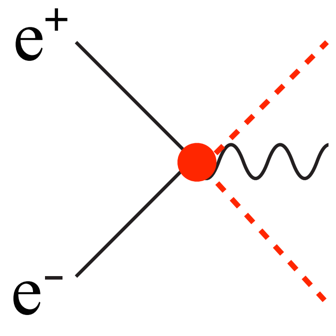
-> separate hZZ and hγZ couplings



-> improve A_{LR} in Z-e-e coupling



important to constrain contact interaction



	no pol.	80%/0%	80%/30%
$g(hb\bar{b})$	1.33	1.13	1.04
$g(hc\bar{c})$	2.09	1.97	1.79
$g(hgg)$	1.90	1.77	1.60
$g(hWW)$	0.98	0.68	0.65
$g(h\tau\tau)$	1.45	1.27	1.16
$g(hZZ)$	0.97	0.69	0.66
$g(h\gamma\gamma)$	1.38	1.22	1.20
$g(h\mu\mu)$	5.67	5.64	5.53
$g(hb\bar{b})/g(hWW)$	0.91	0.91	0.82
$g(hWW)/g(hZZ)$	0.07	0.07	0.07
Γ_h	2.93	2.60	2.38
$\sigma(e^+e^- \to Zh)$	0.78	0.78	0.70
$BR(h \to inv)$	0.36	0.33	0.30
$BR(h \to other)$	1.68	1.67	1.50

Table 4: Projected relative errors for Higgs boson couplings and other Higgs observables with 2 ab^{-1} of data at 250 GeV, comparing the cases of zero polarization, 80% e^- polarization and zero positron polarization, and 80% e^- polarization and 30% positron polarization. In each case, the running is equally divided into two samples with opposite beam polarization orientation.

	2 ab^{-1} w. pol.	2 ab^{-1} 350 GeV	5 ab^{-1} no pol.	+ 1.5 ab^{-1} at 350 GeV	full ILC 250+500 GeV
$g(hb\bar{b})$	1.04	1.08	0.98	0.66	0.55
$g(hc\bar{c})$	1.79	2.27	1.42	1.15	1.09
$g(hgg)$	1.60	1.65	1.31	0.99	0.89
$g(hWW)$	0.65	0.56	0.80	0.42	0.34
$g(h\tau\tau)$	1.16	1.35	1.06	0.75	0.71
$g(hZZ)$	0.66	0.57	0.80	0.42	0.34
$g(h\gamma\gamma)$	1.20	1.15	1.26	1.04	1.01
$g(h\mu\mu)$	5.53	5.71	5.10	4.87	4.95
$g(hbb)/g(hWW)$	0.82	0.90	0.58	0.51	0.43
$g(hWW)/g(hZZ)$	0.07	0.06	0.07	0.06	0.05
Γ_h	2.38	2.50	2.11	1.49	1.50
$\sigma(e^+e^- \to Zh)$	0.70	0.77	0.50	0.22	0.61
$BR(h \to inv)$	0.30	0.56	0.30	0.27	0.28
$BR(h \to other)$	1.50	1.63	1.09	0.94	1.15

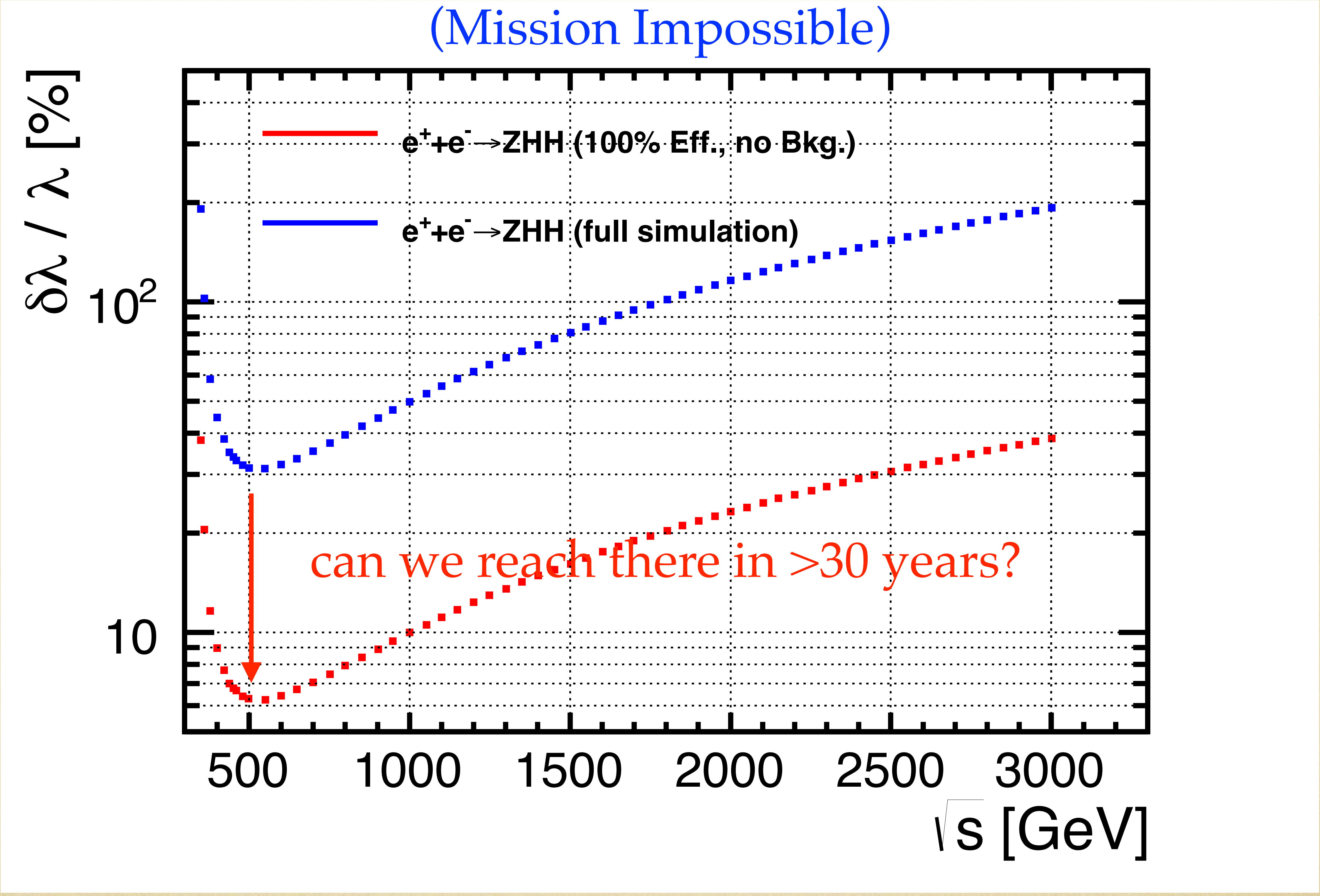
Table 3: Projected relative errors for Higgs boson couplings and other Higgs observables, in %, comparing the full EFT fit described in Section 4 to other possible e^+e^- collider scenarios. The second column shows a fit with 2 ab^{-1}, with 80% electron and zero positron polarization, and with a higher energy of 350 GeV. The third and fourth columns show scenarios with no polarization but higher intergrated luminosity, 5 ab^{-1} at 250 GeV in the third column and 5 ab^{-1} at 250 GeV plus 1.5 ab^{-1} at 350 GeV in the fourth column. The fifth column gives the result of the fit described in Section 6 including data from 250 and 500 GeV. The notation is as in Table 1.

Summary

- precision Higgs measurement at e+e- will open a new window to new physics
- at $\sqrt{s}$~250 GeV: O(1%) precision on many of the Higgs couplings; CP admixture; invisible and exotic decay
- at $\sqrt{s}$~350 GeV: <50 MeV top mass (+14 MeV on m_H) —> vacuum stability
- at $\sqrt{s}$>=500 GeV: top-Yukawa (2-6%), Higgs self-coupling (10-30%) —> Higgs potential, EWBG, pin down Higgs sector
- EFT plays a crucial role
- many e+e- proposals; go for any of them, why not?

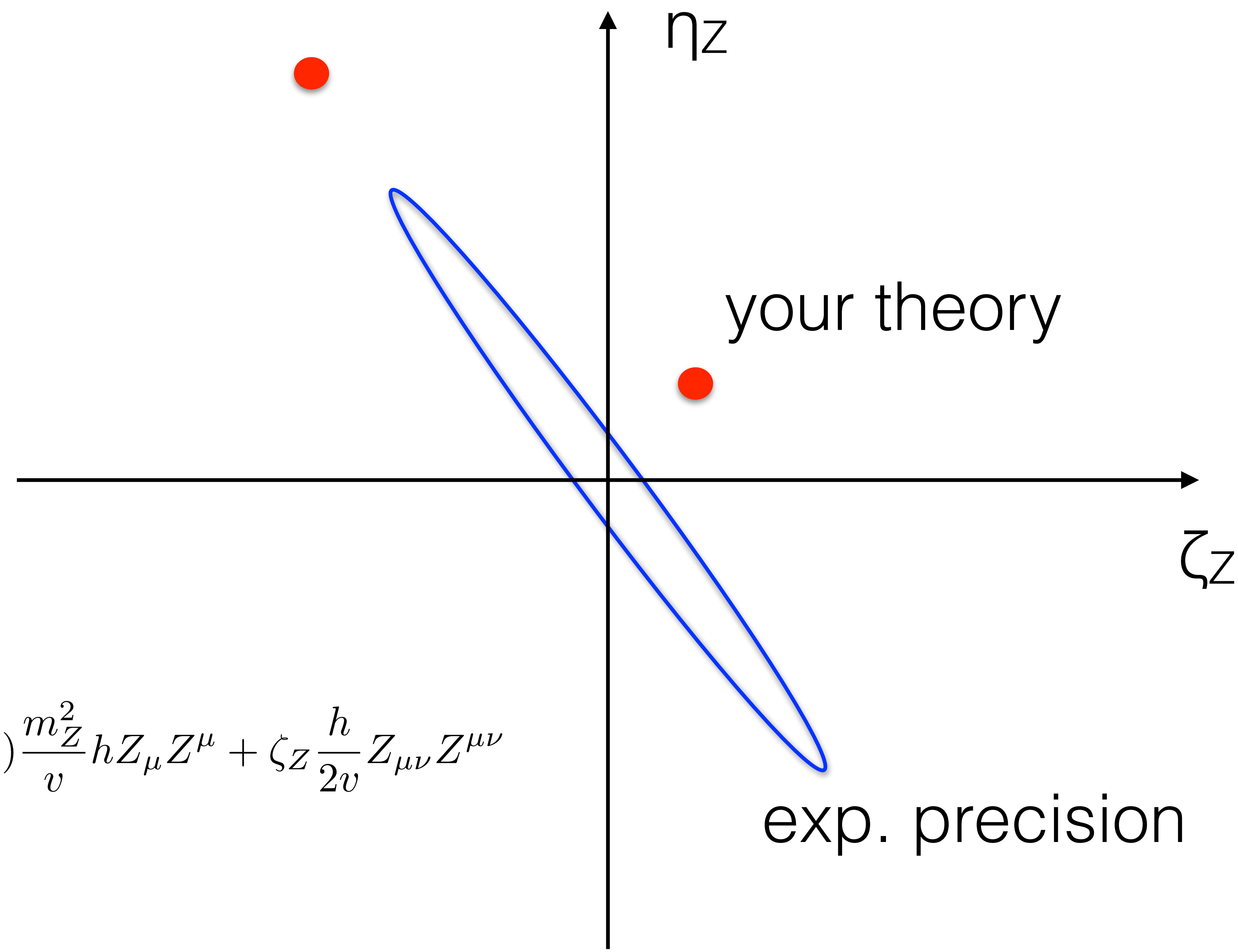
backup

Project A: Higgs self-coupling



proposals (to theorists)

- can you calculate (all) the EFT coefficients in your preferred BSM models? ($c_i/v^2 \sim g/\Lambda^2$)

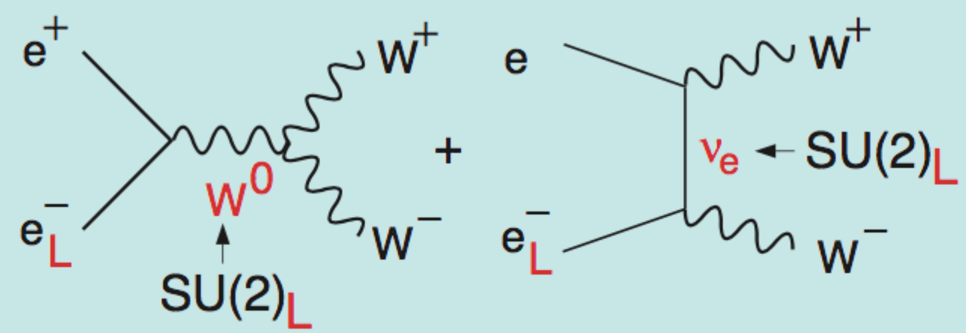


$$\delta\mathcal{L} = (1+\eta_Z)\frac{m_Z^2}{v} h Z_\mu Z^\mu + \zeta_Z \frac{h}{2v} Z_{\mu\nu} Z^{\mu\nu}$$

Power of Beam Polarization

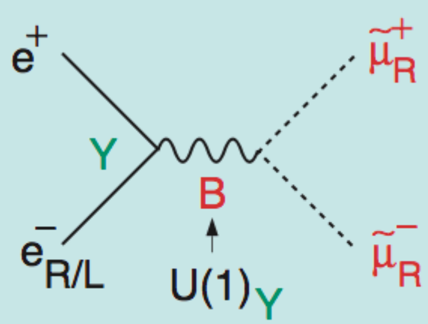
W^+W^- *(Largest SM BG in SUSY searches)*

BG Suppression



In the symmetry limit, $\sigma_{WW} \to 0$ for e^-_R !

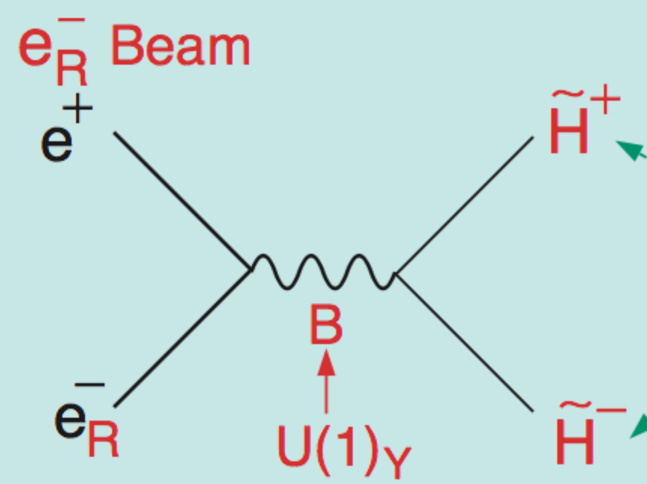
Slepton Pair



$$\begin{cases} Y_L = -1/2 : e^-_L \\ Y_R = -1 \quad : e^-_R \end{cases}$$

In the symmetry limit, $\sigma_R = 4\,\sigma_L$!

Chargino Pair



Only $\tilde{H}^\pm$ components in $\tilde{\chi}^\pm_1$ contribute !

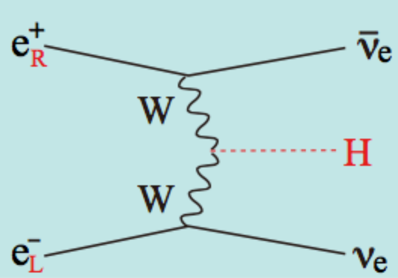
cf.) $e^+e^- \to W^+W^-$

$$\tilde{\chi}^\pm_1 = \bigcirc \cdot \tilde{W}^\pm + \bullet \cdot \tilde{H}^\pm$$

$$\bullet = \langle \tilde{H}^\pm | \tilde{\chi}^\pm_1 \rangle$$

Decomposition

WW-fusion Higgs Prod.



	ILC
Pol (e^-)	-0.8
Pol (e^+)	+0.3
$(\sigma/\sigma_0)_{\nu H}$	1.8x1.3=2.34

Signal Enhancement

homework from EFT (limiting factors other than usual Higgs observables)

- TGC: full simulation at 250 GeV
- improve hγZ couplings: using both h->γZ and e+e- ->γh
- better constrain contact interactions:
  - improve A_{LR}
  - improve Γ(Z->ee)
  - improve Γ(W->eν)