What Can Be Learnt From Higgs Studies at ILC

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on behalf of the ILC International Development Team Physics and Detector Working Group

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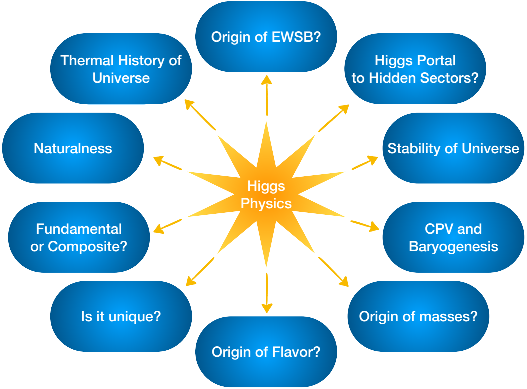
Track 01: Higgs Physics

Outline

Why do we want to build a Higgs factory?

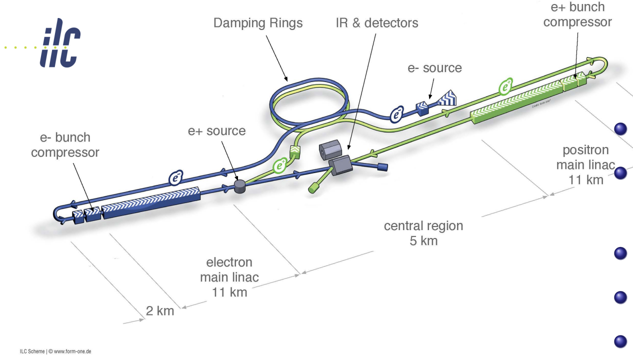
The Higgs boson as the keystone of the Standard Model is connected to numerous fundamental questions that can be investigated by studying it in detail.



arXiv:2209.07510

International Linear Collider

Technical Design (TDR) presented in 2013 arXiv:1306.6328



- superconducting accelerating cavities
- 250 – 500 GeV c.m.s. energy (baseline), 1 TeV upgrade possible
- footprint 20 – 31 km
- polarisation for both e^- and e^+ (80%/30%)
- staged construction, arXiv:1903.01629 starting as 250 GeV Higgs factory

see dedicated contribution on ILC status and plans

ILC running scenario

The unique feature of the ILC is the possibility of having both electron and positron beams polarised! This is crucial for many precision measurements as well as BSM searches.

Four independent measurements instead of one:

- increase accuracy of precision measurements
- more input to global fits and analyses
- remove ambiguity in many BSM studies
- reduce sensitivity to systematic effects

Integrated luminosity planned with different polarisation settings [fb^{-1}]

H-20 $\sqrt{s}$	$\text{sgn}(P(e^-), P(e^+))$ $(-,+)$	$(+,-)$	$(-,-)$	$(+,+)$	Total
250 GeV	900	900	100	100	2000
350 GeV	135	45	10	10	200
500 GeV	1600	1600	400	400	4000

arXiv:1903.01629

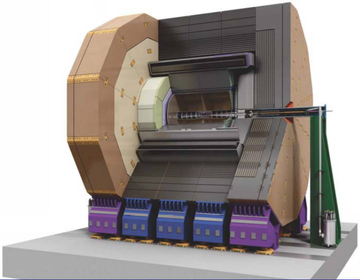
Baseline detector requirements

- Track momentum resolution: $\sigma_{1/p_t} = 2 \cdot 10^{-5}\ \mathrm{GeV}^{-1} \oplus 1 \cdot 10^{-3}/(p_t\ \sin^{1/2}\Theta)$
- Impact parameter resolution: $\sigma_d < 5\mu m \oplus 10\,\mu m\ \mathrm{GeV}/(p\ \sin^{3/2}\Theta)$
- Jet energy resolution: $\sigma_E/E = 3 - 4\%$ (for highest jet energies)
- Hermecity: $\Theta_{min} = 5$ mrad

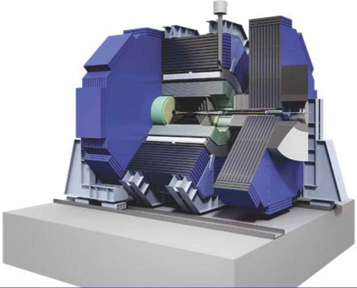
Two detailed ILC detector concepts optimized for particle flow event reconstruction

see dedicated contribution on ILD detector concept

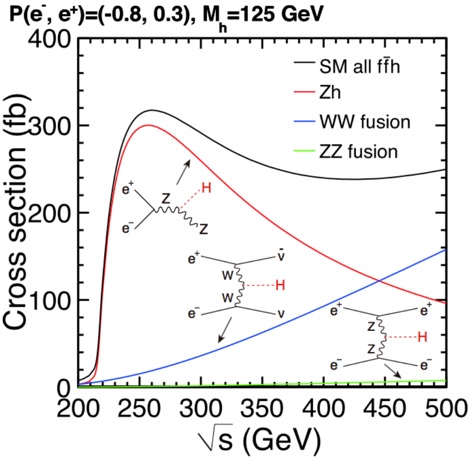
ILD



SiD

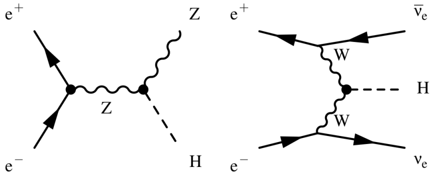


Higgs production



ILC running at 250 GeV will focus on precision Higgs couplings measurements

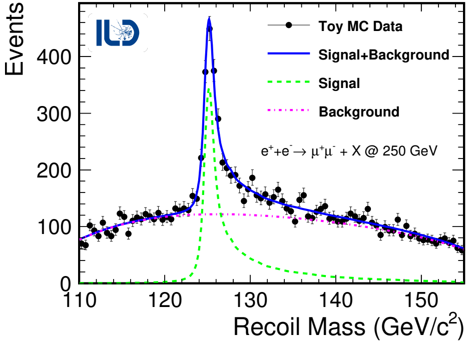
Two relevant production channels:



Associated ZH production dominates below 450 GeV
$\Rightarrow$ allows for fully model independent analysis

Event reconstruction

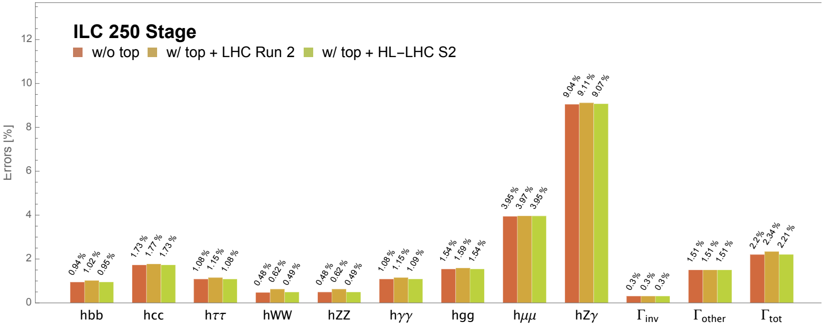
In the ZH production channel we can use "Z-tagging" (with Z$\rightarrow e^+e^-/\mu^+\mu^-$ in particular) for unbiased selection of Higgs production events



We avoid any dependence on the Higgs decay channel! Absolute cross section measurement.

Higgs couplings

ILC sensitivity to the different Higgs boson couplings, from general EFT-based analysis



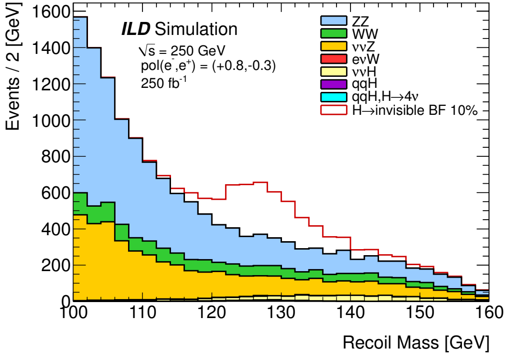
arXiv:2006.14631

Sub-percent level precision already at the first energy stage

Direct measurement of top Yukawa coupling and Higgs self-coupling require higher energies!...

Invisible decays

Recoil mass technique results also in high sensitivity to invisible Higgs boson decays

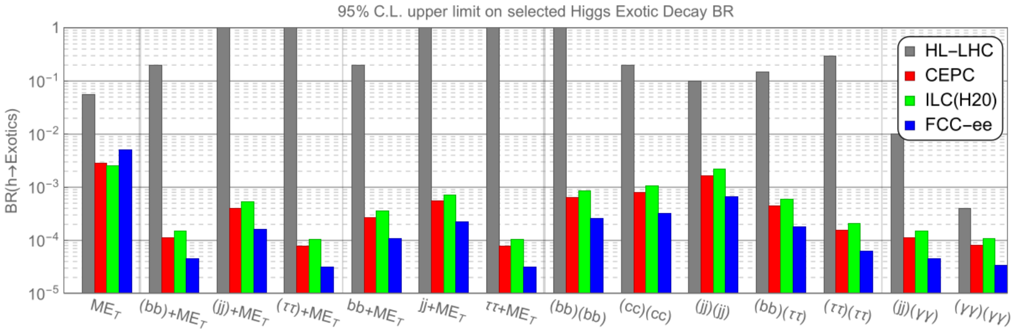


Expected 95% C.L. limit for $2\,\text{ab}^{-1}$ collected at 250 GeV ILC: 0.23%

Yu Kato @ EPS-HEP 2019

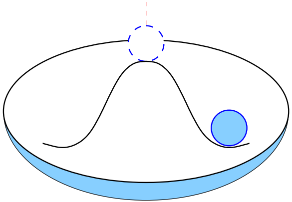
Exotic decays

Exotic 125 GeV Higgs decays expected in many extensions of the SM



arXiv:1612.09284

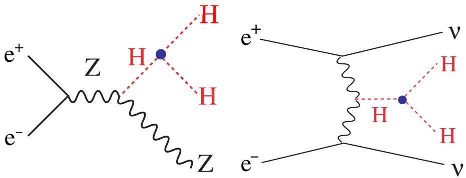
Higgs self-coupling



Measurement of the Higgs self-coupling is crucial for the validation of the EWSB mechanism of the Standard Model.

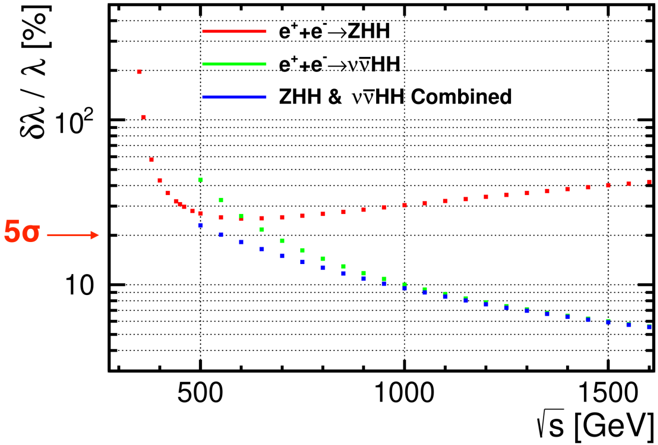
Via loop corrections, it gives $\mathcal{O}(1\%)$ contribution to Higgs production at 250 GeV $\Rightarrow$ only $\mathcal{O}(100\%)$ precision possible and not model independent

It is crucial to have direct access to this coupling via di-Higgs production with running at ≥500 GeV



Higgs self-coupling

Estimated precision on the self-coupling determination in two production channels:



ZHH channel only at 500 GeV:

27% uncertainty (4 ab^{-1})

arXiv:1903.01629

Significant improvement when combined with WW-fusion channel:

23% at 500 GeV

20% at 550 GeV

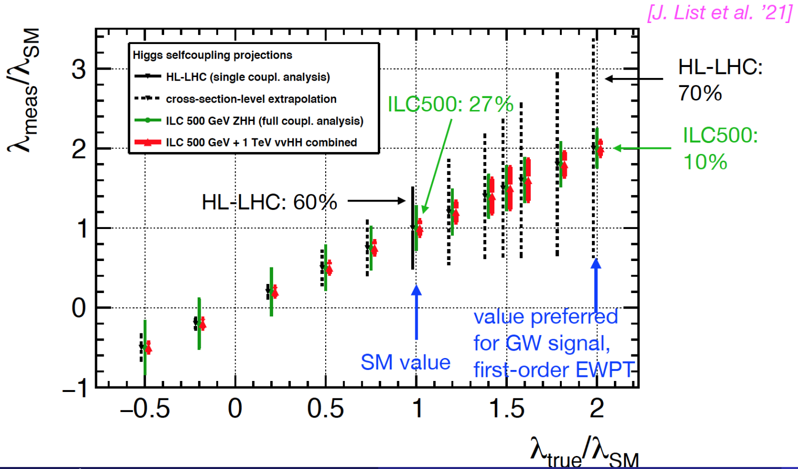
18% at 600 GeV

After 1 TeV upgrade

10% uncertainty (8 ab^{-1})

Higgs self-coupling

Estimated precision on the self-coupling determination for different BSM scenarios:



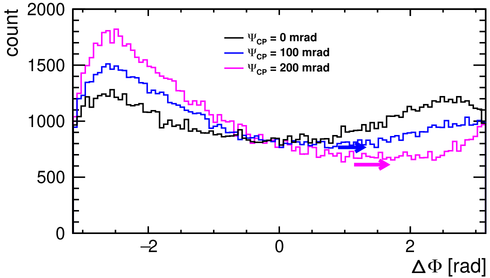
Precision improves with λ_{true}

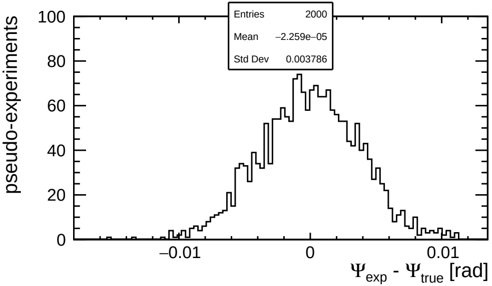
Value of $\lambda = 2$ preferred for GW signal and first-order EWPT

CPV mixing in the Higgs sector

arXiv:2405.05820 and dedicated contribution

Unique possibility in the Z boson fusion process $e^+e^- \to e^+e^- H$ at 1 TeV ILC





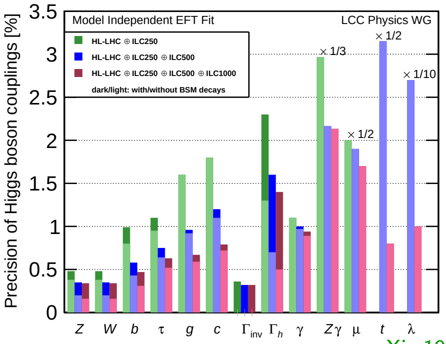
Distribution of the azimuthal angle between electron and positron scattering planes is sensitive to mixing phase in Higgs sector

Mixing angle can be measured with statistical uncertainty of 3.8 mrad
⇒ CP parameter f_{CP}^{HZZ} to $1.44 \cdot 10^{-5}$

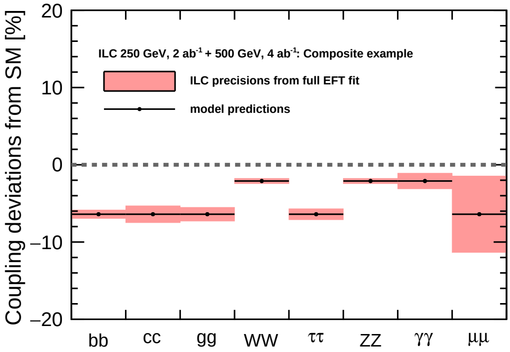
Complementary to CP mixing measurement in fermionic couplings via $H \to \tau^+\tau^-$ arXiv:1804.01241

Expected deviations

ILC sensitivity to the different Higgs boson couplings, and the expected BSM deviations



arXiv:1908.11299



arXiv:1708.08912

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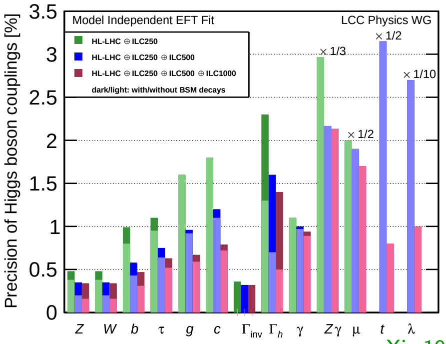

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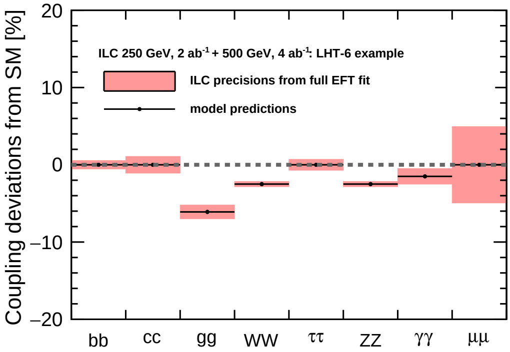

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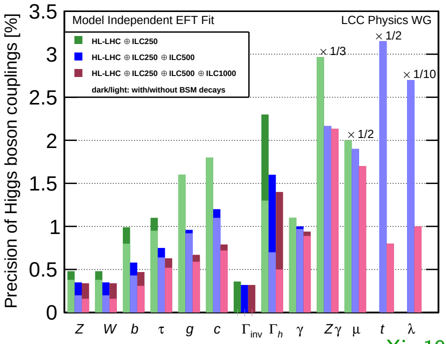

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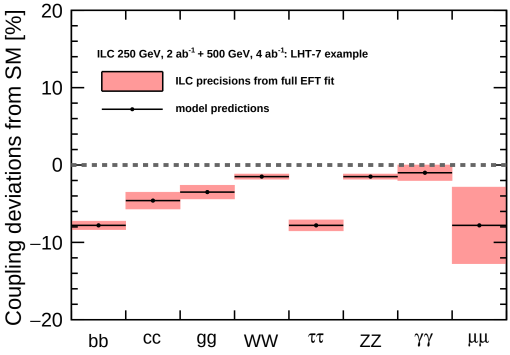

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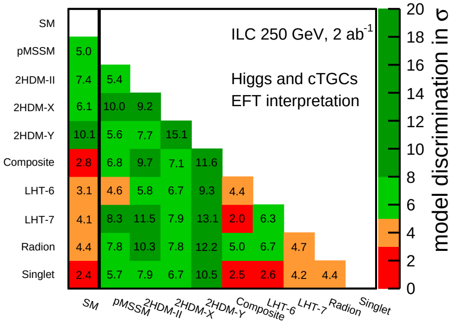
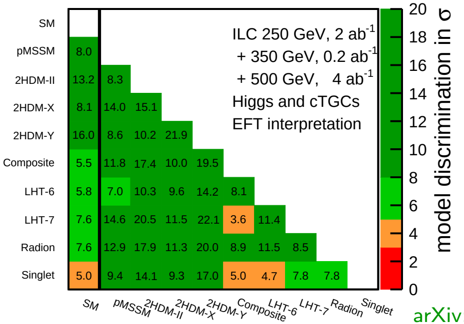
Model discrimination

Precision of e^+e^- colliders allows to distinguish the SM expectations and other models from the global analysis of the Higgs boson couplings





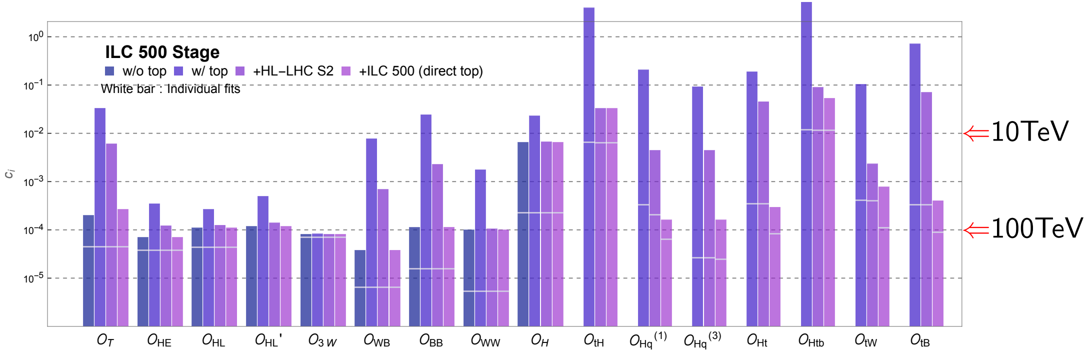
arXiv:1710.07621

Significant ($> 5\sigma$) differences between most scenarios already at 250 GeV (left)
All considered BSM scenarios can be identified at $\geq 5\sigma$ after full ILC programme (H-20)

Combined EFT analysis

arXiv:2006.14631

Global-fit results for the ILC250+ILC500 results, including Higgs, top and EW measurements. 1σ bounds on the operator coefficients assuming $Q_0 = 1$ TeV



Indirect limits from precision measurements at ILC sensitive to $\mathcal{O}(100\text{TeV})$ scales

Prospects

New developments

Most results presented are based on the full simulation results for the ILD baseline design.
However, both detector design and software tools are evolving.

New detector options considered for improved particle identification:

- pixel readout for the TPC $\Rightarrow$ higher reconstruction precision and cluster counting
- high precision time-of-flight counters
- additional Cherenkov counters

New reconstruction tools:

- jet clustering based on supervised learning
- flavour tagging with ML (ParticleNet)
- comprehensive partricle identification framework

Significant improvement expected for Higgs self-coupling, also $H \to s\bar{s}$ can be accessed.

see also dedicated contribution on new reconstruction tools for ILD

Conclusions

Precise determination of Higgs parameters is crucial for validation of the Standard Model
(or any alternative BSM theory)

Clean environment, high measurement precision and beam polarization
$\Rightarrow$ per mile level coupling measurements, high BSM sensitivity in EFT framework

BSM scales of $\mathcal{O}(100$ TeV$)$ indirectly accessible already at 250 GeV ILC

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BSM scales of $\mathcal{O}(100\ \text{TeV})$ indirectly accessible already at 250 GeV ILC

With high luminosity, ILC offers high precision measurements also at higher energy stages.
Prospects of Higgs self-coupling measurement to around 10%

Studies ongoing within the ECFA study on e^+e^- Higgs factory

$\Rightarrow$ many new or updated results expected soon...

Thank you!