# Higgs physics studies with ILC

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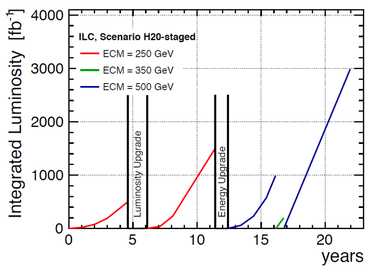
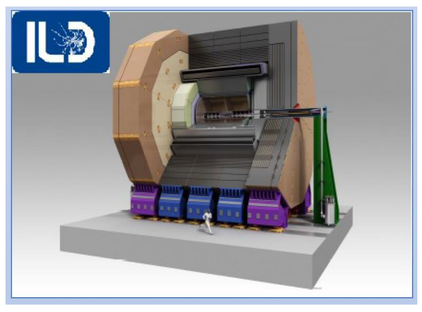
## International Linear Collider

ILC comes as a 'ready to take' project (mature design, proven technologies)

- $\sqrt{s}$ = 250 GeV (upgradable to 500 GeV, 1 TeV)
- Polarized beams ($|P_{e^-}|$ = 80%, $|P_{e^+}|$ = 30%)



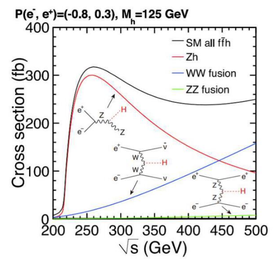

**ILD Detector**
- 3.5 T field
- Optimized for CM energies 90 GeV – 1 TeV w.r.t. the physics programme
- Subdetector resolution requirements up to an order of magnitude higher than at LHC
- Detector components prototyped and tested (CALICE, FCAL, LCTPC,…)



## ILC as a Higgs factory

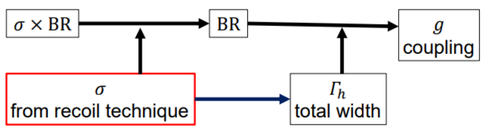
- ~$10^6$ Higgs bosons
- Known initial state
- No PDFs, dominant statistical uncertainty
- **Higgsstrahlung offers model-independence**
- **Absolute normalization of the Higgs couplings** ($\Gamma_H$ measurement in a model independent way)

Clean experimental environment:
- No pile-up
- (practically) QCD free
- Trigger-less readout

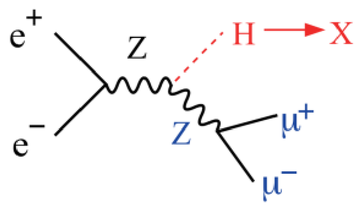



- Numerous Higgs production and decay mechanisms available over the large energy scale
- Recoil mass technique in Higgsstrahlung accommodates Higgs mass, total and invisible width absolute measurements.
- Higher center-of-mass energies enable statistics to access rare Higgs decays, self-coupling and to probe various mechanisms of BSM otherwise inaccessible at HL-LHC.

pp colliders: $\sigma_{prod}$ × BR measurements
ILC: $\sigma_{prod}$ × BR measurements + $\sigma_{prod}$ or HZ measurements



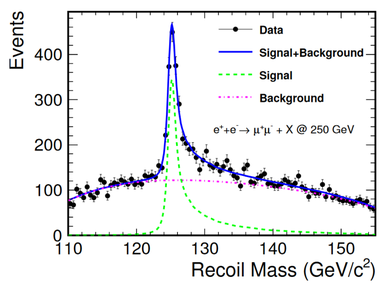

## Higgs recoil mass measurement




Unique measurement at $e^+e^-(f\bar{f})$ colliders

Recoil mass $M_X$ :

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

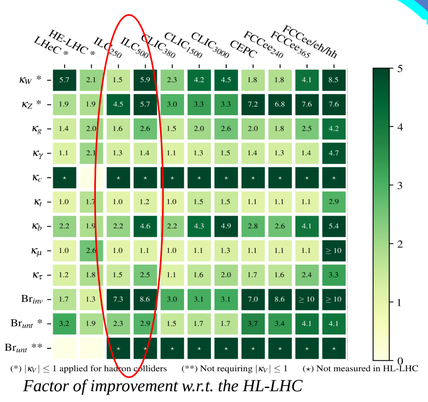



- Combined uncertainty 0.4% on model independent measurement of $g_{HZZ}$.
- Higgs mass determination $\Delta m = 14$ MeV, impact on $\delta\Gamma_{HZZ} = 0.17\%$.
- Projected precision on $\delta\Gamma_{H\to inv}$ 0.5% (95% CL) including ILC 500 GeV. This is particularly important for BSM models where the Higgs sector serves as a portal to DM searches.

*Recoil mass distribution in $Z \to \mu^+\mu^-$ channel*

## Higgs couplings & BSM

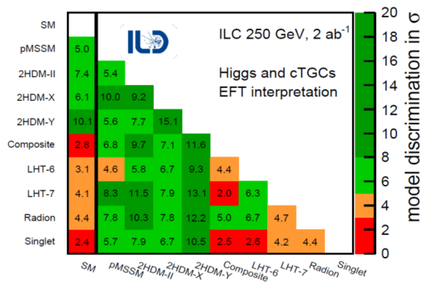
**Higgs couplings** - the ultimate precision is achieved in a global fit (model-independent in ZH, κ-framework, EFT)
- Clear improvement w.r.t. HL-LHC precision
- All couplings (except $H_{\mu\mu}$ and $H_{\tau\tau}$)<1% in combination with HL-LHC ⇒ evident synergy



*Factor of improvement w.r.t. the HL-LHC*

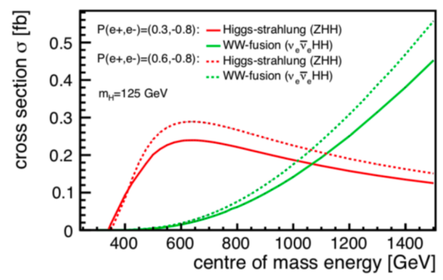
*Higgs@Future Colliders WG EPPSU*

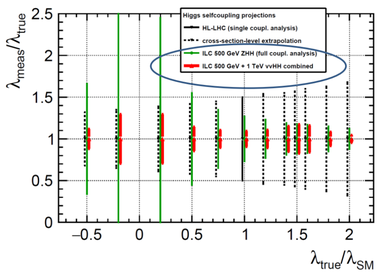
- Typical requirements on Higgs couplings relative precision are of the percent level for most BSM models (hardly accessible at HL-LHC).
- ILC can probe practically all of the models above the discovery limit (in combination with HL-LHC)




## Higgs self-coupling

Direct probe of the Higgs potential




- λ is determined from the total rate of HH events
- High energy (double) Higgs production is the most sensitive to deviations of the Higgs self-coupling
- Polarization (i.e. –80%) almost doubles the HHνν rate
- High center of mass energies offer particular sensitivity to non-SM values of λ

68% CL for $\lambda=\lambda_{SM}$

| collider | excl. from HH |
|---|---|
| HL-LHC | 50% |
| ILC 500 | 27% |
| ILC 1000 | 10% |
| CLIC 1500 | 36 % |
| CLIC 3000 | [-7%, 11%] |
| FCCee (4IP) | 27% |
| FCChh | < 8% |

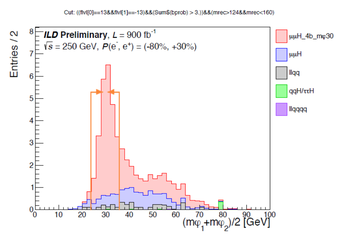
## CPV and exotic searches

*[J. de Blas et al, JHEP 01 (2020) 139]*

**CP violation in the Higgs sector**
- Higgs can be a CPV mixture of scalar and pseudoscalar states – mixing angle to be determined
- Several vertices to be probed (Hττ, HZZ, HWW) in Higgs production and decays
- The most precise result in H→ττ decays comes from ILC/ILD

| Name | $\alpha_\tau$ |
|---|---|
| HL-LHC | 8° |
| HE-LHC | — |
| CEPC | — |
| FCC-ee$_{240}$ | 10° |
| ILC$_{250}$ | 4° |

**Higgs exotic decays**
- H→φφ(→4b)
- Full simulation analysis at 250 GeV ILD
- Scalar mediator mass range: 15 - 60 GeV
- 95% CL upper limit on BR(H→φφ→4b) < 0.1%




*T. Basso, Higgs 2021*

**- Well understood and technologically available accelerator & detector, clean environment and upgradeable energy, flexible polarization of both beams.**
**- Broad range of Higgs precision measurements (couplings, self-coupling, invisible, rare and exotic decays) available to probe the Higgs potential, CP structure and possible realizations of BSM in the Higgs sector.**

FIRST ECFA WORKSHOP ON $e^+e^-$ Higgs/EW/Top FACTORIES, October 5-7 2022, Hamburg