Higgs studies with ILC

Gordana Milutinovic Dumbelovic

On behalf of the ILC IDT Detector & Physics Group
Vinca Institute of Nuclear Sciences, University of Belgrade, Serbia

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Overview

- International Linear Collider
- ILC as a Higgs factory
- Higgs physics at ILC
  - Higgs couplings as a probe to BSM
  - Higgs self-coupling
  - CPV in the Higgs sector
  - Higgs exotic searches
- Summary
International Linear Collider

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

- $e^+e^-$ centre-of-mass energy
  - first stage: 250 GeV
  - tunable
  - upgrades: 500 GeV, 1 TeV
  - further options:
    - running at Z pole & WW threshold

- Luminosity at 250 GeV:
  - $1.35 \times 10^{34}$ /cm$^2$ /s
  - upgrade $2.7 \times 10^{34}$ /cm$^2$ /s (cheap)
  - upgrade $5.4 \times 10^{34}$ /cm$^2$ /s (expensive)

- Beam polarisation
  - $P(e^-) \geq \pm 80\%$
  - $P(e^+) = \pm 30\%$
    - at 500 GeV upgradable to 60%
  - Total length (250 GeV): 20.5 km
Detector models at ILC

- Two validated detector concepts: ILD and SiD
- Physics driven requirements
  - Decades of extensive detector R&D ⇒ mature design (& available technologies)
  - Multiple R&D collaborations involved (CALICE, FCAL, LCTPC,..)

- 5 T field
- More compact (than ILD)
- All Si tracking

- 3.5 T field
- Optimized for CM energies 90 GeV - 1 TeV
- Si/gaseous tracking
ILC as a Higgs factory

- $\sim 10^6$ Higgs bosons
- Known initial state
- No PDFs, dominant statistical uncertainty
- **Absolute normalization of the Higgs partial widths**, once $\sigma_{HZ}$ is known

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

**Higgs production and decay mechanisms**
- Numerous Higgs production and decay mechanisms available over the large energy scale
- Recoil mass technique in Higsstrahlung accommodates Higgs mass, total and invisible widths absolute measurements.
- Higher center-of-mass energies enable statistics to access rare Higgs decays, self-coupling and to probe various BSM realizations inaccessible at HL-LHC
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 $\delta \Gamma_{H \rightarrow inv} 0.16\%$ (95% CL) at 250 GeV ILC. This is particularly important for BSM models where the Higgs sector serves as a portal to DM searches.

Recoil mass distribution in $Z \rightarrow \mu^+ \mu^-$ channel
**Higgs couplings** - the ultimate precision is achieved in a global fit (model-independent in ZH, \(\kappa\)-framework, EFT)

- Clear improvement w.r.t. HL-LHC precision

- All couplings (except rare decays and \(g_{H\tau\tau}\)) <1% already at 250 GeV
Higgs physics at ILC - Higgs self coupling

- $\lambda$ 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 HHvv rate
- High center of mass energies offer particular sensitivity to non-SM values of $\lambda$
Higgs physics at ILC - probing BSM in the Higgs sector

- Typical requirements on Higgs couplings relative precision are of the percent level for most BSM models
- ILC can probe practically all of the models above the discovery limit (already at 250 GeV and practically all with addition of 500 GeV run)
- Clear synergy with HL-LHC
- Clear advantage of high(er) center-of-mass energies
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

CPV mixing angle measurement in H→ττ is a nice illustration of ILC advantages:
- Clean environment
- Different beam polarizations
- Reduction of statistical uncertainty in combination
- Full detector simulation and full statistics Δψ_{CP} = 4°
- Background free assumption with 100% signal reconstruction will give Δψ_{CP} < 1.5°

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<tr>
<th>Name</th>
<th>ατ</th>
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<tbody>
<tr>
<td>HL-LHC</td>
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<tr>
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<tr>
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<td>–</td>
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<td>ILC250</td>
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Higgs exotic decays

- $H \rightarrow \phi \phi (\rightarrow 4b)$
- Full simulation analysis at 250 GeV ILD
- Scalar mediator mass range: 15 - 60 GeV
- 95% CL upper limit on $BR(H \rightarrow \phi \phi \rightarrow 4b) < 0.1\%$

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<thead>
<tr>
<th>$m_\phi$</th>
<th>UL on $BR(H \rightarrow 4b)$</th>
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<tr>
<td>15 GeV</td>
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<tr>
<td>45 GeV</td>
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<tr>
<td>60 GeV</td>
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Summary

- ILC is viable, mature and technologically available option for a future Higgs factory

- It offers clean environment, flexible polarization and upgradeable in energy

- Combination of the above enables utmost precision in Higgs sector measurements

- 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