Benchmark Reactions for the LOIs

- Study of Higgs Recoil Reaction $ee \rightarrow HZ \rightarrow l^+l^-$ -

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Thanks to T. Barklow, H. Li and G. Tassielli for helping to prepare the talk

References: LOIs by SiD, ILD and 4$^{th}$ Concept + IDAG answer documents
PREL-LC-PHSIM-2009-003
Higgs-strahlung Process

\[ h \rightarrow \ell^+ \ell^- \]

Decay leptons from Z
\( \mu \) Pairs, e pairs

Higgs Mass and ZZH coupling by \textbf{Model Independent} measurement

Higgs Recoil Mass:
\[ M_h^2 = M_{\text{recoil}}^2 = s + M_Z^2 - 2E_Z\sqrt{s} \]

Benchmark Parameters:

\( \sqrt{s} = 250 \text{ GeV} \) – fairly close to HZ threshold
Luminosity 500 fb\(^{-1}\) shared equally between different Beam Polarisation modes:

- \( e^- e^+ : \) \( P_e^- = -80\% \) \( P_e^+ = +30\% \)
- \( e^- e^+ : \) \( P_e^- = +80\% \) \( P_e^+ = -30\% \)

Incoming Beam by GUINEA PIG
Beam Energy Spread 0.18\% for \( e^+ \) and 0.28\% for \( e^- \)
Beam Strahlung in agreement with Yokoya-Chen formula

Results will be given w/o crossing angle of 14mrad!!!
(Main) Background Processes

Boson Pair Production

Example for $e_R^- e_L^+$ Polarisation Mode

Enormous Background $\frac{\sigma_{\text{signal}}}{\sigma_{\text{bkgr.}}} \approx 0$

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Proposed Detector Concepts

SID

Compact Detector with Silicon (Central) Tracking

Calorimeter optimised for Particle Flow

*All units are in cm

ILD

Larger Volume with Gaseous Tracking (TPC)

Tracking with small cell He Drift Chamber

Xtal Calorimeter Dual Readout

4th

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Signal Selection in ILD – Using Calorimetric Information

Muon Channel

\[ E = \frac{N_{\text{true} \cap \text{iden}}}{N_{\text{true}}} = 0.976 \]

\[ P = \frac{N_{\text{true} \cap \text{iden}}}{N_{\text{iden}}} = 0.914 \]

Electron Channel

\[ E = \frac{N_{\text{true} \cap \text{iden}}}{N_{\text{true}}} = 0.963 \]

\[ P = \frac{N_{\text{true} \cap \text{iden}}}{N_{\text{iden}}} = 0.961 \]
Signal Selection in ILD - Track Selection

Signal consists of two oppositely Charged Tracks

**Electron Channel**

**Track Resolution:**

\[
\frac{\Delta P}{P^2} = 2.5 \times 10^{-5} \oplus 8 \times 10^{-4} \frac{1}{P}
\]

**End Caps** \(|\cos \theta| > 0.78\)

**TrackRejected if:**

\[
\frac{\Delta P}{P^2} > 5 \times 10^{-4}
\]

**Barrel Region**

**Track Resolution:**

\[
c(P) = \frac{\Delta P}{P^2} = 2.5 \times 10^{-5} \oplus 8 \times 10^{-4} \frac{1}{P}
\]

**Track Rejected if:**

\[
\frac{\Delta P}{P^2} > 2 \cdot c(P)
\]
Background Rejection

SiD

- Very tight constraint on Z-Mass for dilepton system

ILD

\[ 87 < M_{dl} < 95 \text{ GeV} \]
\[ |\cos \theta_{l+}|, |\cos \theta_{l-}| < 0.99 \]
\[ |\cos \theta_{dl}| < 0.85 \]
\[ |\cos \theta_{\text{miss.}}| < 0.99 \]
\[ P_{T,dl} > 20 \text{ GeV} \]
\[ 80 < M_{dl-} < 100 \text{ GeV} \]
\[ 0.2 < \text{acop} < 3.0 \]
\[ \Delta P_{T_{\text{bal.}}} > 10 \text{ GeV} \]
\[ |\cos \theta_{\text{miss.}}| < 0.99 \]
\[ 115 < M_{\text{recoil}} < 150 \text{ GeV} \]
Dedicated cuts for radiative events
Multivariate Analysis

- Relaxed constraint on dilepton Mass
- Cuts more closely 'tailored' to background

Signal/Background > 30%

Remaining background: Boson Pair Production
Bhabha Background

4th

\[ 72 < M_{dl} < 110 \text{ GeV} \]
\[ 102 < M_{\text{recoil}} < 168 \text{ GeV} \]
\[ |\cos \theta_{l+}|, |\cos \theta_{l-}| < 0.98 \]
\[ P_{T,\text{max}} > 20 \text{ GeV} \]
\[ |\cos \theta_{\text{miss.}}| < 0.99 \]
DCA for e,μ < 6mm

Particle ID by muon spectrometer and exploitation of mult r/o of Calorimeter

Additional Tracks in Default Analysis!!!
Signal and Background – Examples

**Dilepton Mass in e-Channel**

Radiative effects lead to widening of peak → Effort to keep these events → later

**P_T Balance: Dileptons ↔ ISR γ**

Efficient cut to suppress lepton pair events
Background reduction by factor 10
Extraction of Results

Results extracted without assumption on shape of spectrum

**SiD**

Linear Least $\chi^2$ fit to bin contents:

$$\hat{N}_i = \hat{N}_{ibkg} + \hat{N}_{i,signal} + \frac{\hat{N}_i}{M_h}(M_h - 120 \ GeV)$$

$$\chi^2(M_h) = \sum \frac{(N_i - \hat{N}_i(M_h))^2}{s_i^2}, \ s_i = \sqrt{\hat{N}_{ibkg} + N_{isignal}}$$

- Calculated using training samples around $M_h = 120 \ GeV$

**ILD**

(Simplified) Kernel Estimation for signal

$$F_s(x) = \frac{1}{N} \sum_{j=1}^{m} n_j G(x; t_j; h_j)$$

- Convolution of Gaussian and Second Order Polynomial

$$h_j = \left(\frac{4}{3}\right)^{1/5} N^{-1/5} \Delta x \sqrt{\frac{N}{n_j}}$$

$$x \rightarrow x' = x - M_h$$

- Background approximated by second order polynomial

**Different/Complementary methods to extract Results**
Results for: $e^-_R e^+_L$: $P_{e^-} = +80\%$  $P_{e^+} = -30\%$

Muon Channel

Very Precise Measurement

Electron Channel

Less Precise Measurement

SiD

$\Delta M_h = 0.046$ GeV
$\Delta \sigma_{HZ}/\sigma_{HZ} = 0.037$

$\Delta M_h = 0.078$ GeV
$\Delta \sigma_{HZ}/\sigma_{HZ} = 0.041$

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Sources of Bremsstrahlung

Landscape of ILD Detector by Bremsstrahlung

Energy loss by Passive Material

Figures from PhD Thesis: H. Li (LAL)

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Bremsstrahlung Recovery

Collecting Bremsstrahlung Photons in elm. Calorimeter
Gain: Higher Statistics in Signal Region
Penalty: Worse resolution by low energetic photons $\sigma/E \sim 17%/\sqrt{E}$

Statistical Gain “beats” modest energy resolution
Bremsstrahlung Recovery in the 4\textsuperscript{th} Xtal calorimeter: superb elm. energy resolution $\sigma/E \sim 3\%/\sqrt{E}$

Muon Channel

Electron Channel

$\Delta M_h = 0.05$ GeV  
$\Delta M_h = 0.06$ GeV

Comparable (statistical) Precision in Electron and Muon Channel!!!
Result of emphasising the role of Calorimetry!!!?

Note: Results here for Model Dependant Analysis (Requirement of add. Charged Tracks)
Results for: $e_L^- e_R^+ : P_{e^-} = -80\% \ P_{e^+} = 30\%$

Model Dependant Analysis: Additional Tracks required

**Muon Channel**

<table>
<thead>
<tr>
<th>Mean</th>
<th>$\chi^2$/ndf</th>
<th>Constant</th>
<th>$M_h$</th>
<th>$\Delta M_h$</th>
<th>$\Delta \sigma_{HZ}/\sigma_{HZ}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>54.6972 / 117</td>
<td>219.253</td>
<td>120.283</td>
<td>0.06 GeV</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>0.501688 ± 0.046852</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.617285 ± 0.064140</td>
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<td></td>
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<tr>
<td></td>
<td>0.156632 ± 0.028496</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>3002.37 ± 730.48</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>-64.993 ± 16.667</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>0.480376 ± 0.125756</td>
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<tr>
<td></td>
<td>-0.00119536 ± 0.00031422</td>
<td></td>
<td></td>
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</tr>
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</table>

**Electron Channel**

<table>
<thead>
<tr>
<th>Mean</th>
<th>$\chi^2$/ndf</th>
<th>Constant</th>
<th>$M_h$</th>
<th>$\Delta M_h$</th>
<th>$\Delta \sigma_{HZ}/\sigma_{HZ}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>113.9</td>
<td>34.7693 / 117</td>
<td>239.844</td>
<td>120.153</td>
<td>0.049 GeV</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>0.75976 ± 0.05963</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.628297 ± 0.086107</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>0.171913 ± 0.045465</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4453.75 ± 1212.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-95.5175 ± 27.8625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.711136 ± 0.211825</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.00178039 ± 0.000053341</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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\( \gamma - \text{Background} \)

Processes: \( \gamma \gamma \rightarrow e^+e^- \quad \gamma \gamma \rightarrow \mu^+\mu^- \quad \gamma \gamma \rightarrow \text{hadrons} \)

Beam Background has only little effect on recoil mass spectrum
Influence of Machine Parameters

Muon Channel

\[ \Delta M_{\text{tot}} = 650 \text{ MeV} \]
\[ \Delta M_{\text{mach.}} = 560 \text{ MeV} \quad \Delta M_{\text{det.}} = 330 \text{ MeV} \]

Electron Channel

\[ \Delta M_{\text{tot}} = 750 \text{ MeV} \]
\[ \Delta M_{\text{mach.}} = 560 \text{ MeV} \quad \Delta M_{\text{det.}} = 500 \text{ MeV} \]

Uncertainties of incoming beams are dominant source of Statistical Error (even in Electron Channel)
Shopping List beyond LOI

- Do we want/need to compare the performance of Detector Concepts?
  Agreement on common set of cuts would be helpful!

- Study of systematic errors entirely missing (Lack of time, manpower)
  Need to identify major sources of systematic errors
  Knowledge of Detector R&D needs to go into Physics Studies
  e.g. Answers to IDAG contain parameters on tracking precision
  More guidance to Detector R&D by Physics Studies!?
  Disjunct groups !!?  

- Conclusions for Detector R&D from LOIs?
  LOI should lead to directions for R&D, does it?

- Feedback to change of Machine Parameters
  Need ability to ponder timely the influence of Physics Performance
Conclusions and Outlook

- Detector Concepts promise precision measurement of Higgs-strahlungs Process
  $\Delta M_h: \mathcal{O}(40 \text{ MeV})$
  $\Delta \sigma_{HZ}: < 5\%$
  Detector Layout allow for Efficient Background suppression
  $\rightarrow$ up to Six Orders of Magnitude!!!!
  LOIs witness enormous physics potential of ILC and its Detectors!!!

- Electron Channel “suffers” from Bremsstrahlung
  Material Budgets need to be watched closely!!
  First Algorithms for recovery successfully applied!!
  Excellent Calorimetry can help!?  

- Higgs Recoil mass channel is very sensitive to Beam Parameters!!!

- Systematic Effects
  Algorithms developed for LOIs allow for study of systematic errors
  e.g. via $ee \rightarrow ZZ$

- LOIs are not the end but the start
  Directions for R&D emerging from LOIs?
Tables with Quantitative Results
ILD - Model independent Analysis

<table>
<thead>
<tr>
<th>Pol.</th>
<th>Ch.</th>
<th>$M_H$ (GeV)</th>
<th>$\sigma$ (fb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^-_R e^+_L$</td>
<td>$\mu^+ e^- X$</td>
<td>$120.006 \pm 0.039$</td>
<td>$7.89 \pm 0.28$ (3.55 %)</td>
</tr>
<tr>
<td></td>
<td>$e^+ e^- X$</td>
<td>$120.005 \pm 0.092$</td>
<td>$8.46 \pm 0.43$ (5.08 %)</td>
</tr>
<tr>
<td></td>
<td>merged</td>
<td>$120.006 \pm 0.036$</td>
<td>$8.06 \pm 0.23$ (2.91 %)</td>
</tr>
<tr>
<td>$e^-_L e^+_R$</td>
<td>$\mu^+ e^- X$</td>
<td>$120.008 \pm 0.037$</td>
<td>$11.70 \pm 0.39$ (3.33 %)</td>
</tr>
<tr>
<td></td>
<td>$e^+ e^- X$</td>
<td>$119.998 \pm 0.085$</td>
<td>$12.61 \pm 0.62$ (4.92 %)</td>
</tr>
<tr>
<td></td>
<td>merged</td>
<td>$120.006 \pm 0.034$</td>
<td>$11.96 \pm 0.33$ (2.76 %)</td>
</tr>
</tbody>
</table>

Table 13: Resulting Higgs mass $M_H$ and cross section $\sigma$ of the MI Analysis using Kernel Estimation.

For details and further results using alternative fit methods and a Model Dependant Analysis, see PREL-LC-PHSIM-2009-003
### SiD - Model independent Analysis

<table>
<thead>
<tr>
<th>80eR lumi</th>
<th>80eL lumi</th>
<th>Mode</th>
<th>$\Delta M_H$ (GeV)</th>
<th>$\Delta \sigma_{ZH} / \sigma_{ZH}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 fb⁻¹</td>
<td>0 fb⁻¹</td>
<td>$e^+e^-H$</td>
<td>0.078</td>
<td>0.041</td>
</tr>
<tr>
<td>250 fb⁻¹</td>
<td>0 fb⁻¹</td>
<td>$\mu^+\mu^-H$</td>
<td>0.046</td>
<td>0.037</td>
</tr>
<tr>
<td>250 fb⁻¹</td>
<td>0 fb⁻¹</td>
<td>$e^+e^-H + \mu^+\mu^-H$</td>
<td>0.040</td>
<td>0.027</td>
</tr>
<tr>
<td>0 fb⁻¹</td>
<td>250 fb⁻¹</td>
<td>$e^+e^-H$</td>
<td>0.066</td>
<td>0.067</td>
</tr>
<tr>
<td>0 fb⁻¹</td>
<td>250 fb⁻¹</td>
<td>$\mu^+\mu^-H$</td>
<td>0.037</td>
<td>0.057</td>
</tr>
<tr>
<td>0 fb⁻¹</td>
<td>250 fb⁻¹</td>
<td>$e^+e^-H + \mu^+\mu^-H$</td>
<td>0.032</td>
<td>0.043</td>
</tr>
</tbody>
</table>

**Source:** Tim Barklow, e-mail of 28/9/09

**W.r.t. LOI and LOI update for IDAG:**
Correction for 14mrad crossing angle included
<table>
<thead>
<tr>
<th></th>
<th>Mass</th>
<th>StError</th>
<th>sigma</th>
<th>StError</th>
</tr>
</thead>
<tbody>
<tr>
<td>mumu</td>
<td>120.28</td>
<td>0.05</td>
<td>0.69</td>
<td>0.05</td>
</tr>
<tr>
<td>5 trk: ee</td>
<td>120.47</td>
<td>0.10</td>
<td>0.83</td>
<td>0.09</td>
</tr>
<tr>
<td>ee+Cal</td>
<td>120.15</td>
<td>0.06</td>
<td>0.76</td>
<td>0.06</td>
</tr>
<tr>
<td>mumu</td>
<td>120.24</td>
<td>0.06</td>
<td>0.61</td>
<td>0.05</td>
</tr>
<tr>
<td>MI: ee</td>
<td>120.51</td>
<td>0.41</td>
<td>0.81</td>
<td>0.39</td>
</tr>
<tr>
<td>ee+Cal</td>
<td>120.16</td>
<td>0.24</td>
<td>0.73</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Mail by Giovanni Tassielli 26/09/09