Effect of Energy Spread on LC Mass Measurements

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Study Effect of Energy Spread on Top, Higgs, and SUSY Mass Meas

\textit{Normalized} Lumi Weight Ecm Distributions
including Beamstralung & Linac Energy Spread

\( \sqrt{s} = 350 \text{ GeV} \)

NLC
FWHM \( \approx \) 0.6\% (peak region)

TESLA
FWHM \( \approx \) 0.2\% (peak region)
Top Pair-Prod. Cross Section @ Threshold

- need knowledge of E-spread FWHM to level of ~0.1%
- top mass error still under study, but statistical improvement should be small when E-spread is reduced from 0.6% FWHM to 0.2% FWHM

from ACFA report hep-ph/0109166

FWHM = 0.1%  (dotted for flat-top, solid for double-peaked)
0.4%
0.7%
1.0%
1.4%
m_t = 175 GeV
\alpha_s = 0.12
|V_{tb}|^2 = 1
\( e^+ e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \) Threshold Scan \( 20 \text{ fb}^{-1} \) per point

SPS1a \( \tilde{\chi}_1^+ \): \( \text{BR}(\tilde{\chi}_1^+ \rightarrow \tilde{\tau}^+ \nu_\tau) \approx 100\% \) \( \Gamma_{\tilde{\chi}_1^+} = 8 \text{ MeV} \)

Energy Spread Comparison

NLC \( \Delta M_{\tilde{\chi}^+} = 42 \text{ MeV} \)

TESLA \( \Delta M_{\tilde{\chi}^+} = 38 \text{ MeV} \)
Simdet Detector Simulation of $e^+ e^- \rightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-$ \hspace{1cm} $\sqrt{s} = 500 \text{ GeV} \hspace{0.1cm} L = 500 \text{ fb}^{-1}$

$M_{\tilde{\mu}_R} = 223.6 \text{ GeV}$ \hspace{0.5cm} vs \hspace{0.5cm} $M_{\tilde{\mu}_R} = 224.4 \text{ GeV}$
Energy Spread Comparison

Estimate Statistical Error on Smuon Mass Assuming Perfect MC Simulation

\[ \sqrt{s} = 500 \text{ GeV} \quad L = 500 \text{ fb}^{-1} \]

\[ \frac{dN_{\text{bin}}}{dE_{\tilde{\mu}}} \bigg|_{M \tilde{\mu} = 224 \text{ GeV}} \]

**NLC**
\[ \Delta M_{\tilde{\mu}} = 35 \text{ MeV} \]

**TESLA**
\[ \Delta M_{\tilde{\mu}} = 34 \text{ MeV} \]
Simdet Detector Simulation of $e^+e^- \rightarrow Zh$  

$Z \rightarrow e^+e^-, \mu^+\mu^-$  

$\sqrt{s} = 350 \, GeV$ $L = 500 \, fb^{-1}$

with background

Recoil Mass (GeV)
Energy Spread Comparison
Estimate Statistical Error on Higgs Mass Assuming Perfect MC Simulation

$$\sqrt{s} = 350 \text{ GeV} \quad L = 500 \text{ fb}^{-1}$$

\[ \frac{dN_{bin}}{dM_h} \mid_{M_h=120} \]

NLC
\[ \Delta M_h = 143 \text{ MeV} \]

\[ \frac{dN_{bin}}{dM_h} \mid_{M_h=120} \]

TESLA
\[ \Delta M_h = 117 \text{ MeV} \]
Energy Scale Error

\[ \frac{\Delta E_b}{E_b} = 0 \quad \text{black} \]

\[ \frac{\Delta E_b}{E_b} = 0.008 \quad \text{green} \]

\[ e^+ e^- \to Zh \]

\[ \sqrt{s} = 350 \text{ GeV} \]

\[ e^+ e^- \to \tilde{\mu}_R^+ \tilde{\mu}_R^- \]

\[ \sqrt{s} = 500 \text{ GeV} \]

\[ \Delta M_h \approx \frac{2E_b}{M_h} \Delta E_b = 2.9 \Delta E_b \quad \Rightarrow \]

\[ \frac{\Delta E_b}{E_b} = \frac{M_h^2}{2E_b^2} \Delta M_h = 0.235 \frac{\Delta M_h}{M_h} \]

\[ \Rightarrow \frac{\Delta E_b}{E_b} = 100 \text{ ppm} \]

for \( \Delta M_h = 50 \text{ MeV} \)

\[ \Delta M_{\tilde{\mu}} \approx 0.05 \Delta E_b \quad \Rightarrow \]

\[ \frac{\Delta E_b}{E_b} = 20 \frac{M_{\tilde{\mu}}}{E_b} \frac{\Delta M_{\tilde{\mu}}}{M_{\tilde{\mu}}} = 9.0 \frac{\Delta M_{\tilde{\mu}}}{M_{\tilde{\mu}}} \]

\[ \Rightarrow \frac{\Delta E_b}{E_b} = 700 \text{ ppm} \]

for \( \Delta M_{\tilde{\mu}} = 17 \text{ MeV} \)
TESLA Study of $M_H$ measurement using kinematic fit of $qqll$ and $qqbb$

Energy scale error

\[ \delta M_h = 1.0 \delta E_e \quad (qqll) \]
\[ \delta M_h = 0.8 \delta E_e \quad (bbqq) \]

\[ \delta E_{e^+} = \delta E_e = \pm 25 \text{ MeV results in a mass shift} \]
\[ \sim 25 \text{ MeV for } HZ \quad qqll \]
\[ \sim 20 \text{ MeV for } HZ \quad bbqq \]

Effect of beam spread
- statistical accuracy degrades
  - from 45 to 50 MeV in $HZ \rightarrow bbqq$ channel
  - from 70 to 80 MeV in $HZ \rightarrow bbll$ channel
  - if one assumes 0.5\% beam spread for both $e^+$ and $e^-$

$\Rightarrow$ statistical accuracy degrades
  - from 72 to 76 MeV (6\%) for TESLA$\rightarrow$ NLC ($bbll$)
  - from 46 to 48 MeV (4\%) for TESLA$\rightarrow$ NLC ($bbqq$)
<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$\delta M_h$ in MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TESLA $\delta E/E=0$</td>
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<tr>
<td>recoil mass</td>
<td>110</td>
</tr>
<tr>
<td>$ZH \to l^+l^-q\bar{q}$</td>
<td>70</td>
</tr>
<tr>
<td>$ZH \to q\bar{q}b\bar{b}$</td>
<td>45</td>
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<tr>
<td>Combined</td>
<td>38</td>
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</tbody>
</table>

MSSM theory error on $m_h$ : (S. Heinemeyer)

Current theory uncertainty: $\delta m_h^{\text{theo,today}} \approx 3$ GeV

Future theory uncertainty: $\delta m_h^{\text{theo,future}} \lesssim 0.5$ GeV necessary/possible

Future parametric uncertainty: $\delta m_h^{\text{para,future}} = \mathcal{O}(0.2$ GeV) ($m_t$, $\alpha_s$)
Summary

• The degradation in statistical error for m(SUSY) is negligible for the endpoint technique when the energy spread is increased from 0.1% to 0.3%. The degradation is of $O(10\%)$ for small width fermion threshold scans (42 MeV vs 38 Mev).

• There is a 20% degradation in the statistical error for m(Higgs) when the energy spread is increased from 0.1% to 0.3%, assuming the recoil mass technique (143 Mev vs 117 Mev). Other Higgs mass measurement techniques, such as a kinematic fit of $llbb$ and $qqbb$, have a much smaller degradation.