Impact of ILC Tracker Design on
$e^+e^- \to H^0Z^0 \to \mu^+\mu^- X$ Analysis

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Physics Motivation

To determine a suitable ILC SiD tracker momentum resolution capable of making a direct measurement of $e^+e^- \rightarrow H^0Z^0 \rightarrow \mu^+\mu^- X$
Cross Section of $H Z \rightarrow \mu^+ \mu^- X$
MC Generator & Analysis Tool

$\rightarrow e^+e^- \rightarrow H^0Z^0 \rightarrow \mu^+\mu^- X$

- Based on ILC350 beam setup
- Polarization of $e^-$ is -85%, $e^+$ is 0
- PandoraV2.3 (modified for $H \rightarrow \mu^+\mu^-$ decay, thanks to Michael E. Peskin) and PythiaV3.3
- Java Analysis Studio V2.2.5
- SDMar01, Fast MC Simulation and 1000 fb$^{-1}$
- Track momentum resolution for SDMar01
  $$\Delta(1/p_t) = \sqrt{(2*10^{-5})^2 + (7*10^{-4}/p_t/\sqrt{\sin \theta})^2}$$
Monte Carlo Samples

- **Signal** – 10K: $e^+e^- \rightarrow H^0Z^0 \rightarrow \mu^+\mu^- X$
  - $M_H$=100, 110, 120, 130, 140, 150 GeV
  - Cross sections are 51, 46, 38, 27, 16, 7 ab, respectively.
  - Expected counts are 51, 46, 38, 27, 16, 7 for 1000 fb$^{-1}$
- **Background** $e^+e^- \rightarrow Z^0Z^0 \rightarrow \mu^+\mu^- X$ – 100 K, 31.6 fb
- **Background** $e^+e^- \rightarrow W^+W^- \rightarrow \mu^+\mu^- \nu\nu$ – 400 K, 149.68 fb
- **Background** $e^+e^- \rightarrow Z/\gamma \rightarrow \mu^+\mu^- \gamma$ – 500K, 2574.0 fb
- **Background** $e^+e^- \rightarrow Z\gamma \rightarrow \mu^+\mu^- \gamma$ – 400K, 416.3 fb
- **Background** $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^- H$
  - $M_H$=100, 110, 120, 130, 140, 150 GeV
  - 10K events for each Higgs mass point
Preselection Cuts

- “Good” $\mu$:
  - a) $P_\mu > 20$ GeV
  - b) $|\cos \Theta_\mu| < 0.8$
- At least 2 “Good” $\mu$
- Eff_signal $\sim 62.4\% - 65\%$
Selection Cuts ($M_H = 100$ GeV)

Opening angle between two $\mu$

Polar angle of two $\mu$

![Graph showing opening angle and polar angle distributions.](image)
Selection Cuts ($M_H=120$ GeV)

Opening angle between two $\mu$

Polar angle of two $\mu$
Selection Efficiency

| $M_{\mu\mu}$ (GeV) | $\cos\theta_{\mu\mu,\text{opening}}$ | $|\cos\theta_{\mu\mu,\text{polar}}|$ | Eff | $Z\nu\mu$ | $ZZ$ | $WW$ | $\mu\mu$ | $Z\gamma$ | $Z(\mu\mu)H$ |
|-----------------|------------------------------------|--------------------------------|-----|-----------|-----|-----|-------|-------|-------------|
| 100 ± 1         | > −0.2                             | < 0.6                          | 37.6% | 19.3     | 76.6 | 3.4 | 0.0   | 1.04  | 17.0       |
| 110 ± 1         | > −0.2                             | < 0.6                          | 34.7% | 15.9     | 19.4 | 0.0 | 0.0   | 0.0   | 4.2        |
| 120 ± 1         | > −0.3                             | < 0.7                          | 36.6% | 13.9     | 8.95 | 1.12| 0.0   | 0.0   | 1.5        |
| 130 ± 1         | > −0.4                             | < 0.7                          | 34.3% | 9.4      | 2.5  | 4.5 | 0.0   | 0.0   | 0.9        |
| 140 ± 1         | > −0.4                             | < 0.7                          | 28.0% | 4.5      | 0.5  | 2.8 | 0.0   | 0.0   | 0.8        |
| 150 ± 1         | > −0.4                             | < 0.8                          | 24.3% | 1.8      | 0.0  | 1.24| 0.0   | 0.0   | 0.0        |

→ Lower efficiency for higher Higgs mass, which is mainly caused by wider opening angle between $\mu\mu$ decay from Higgs.
M_{\mu\mu} vs Track Momentum Resolution

ILC350, SDMar01, Z→all, H→\mu\mu, 1000 fb^{-1}

Events / 10 MeV

Rescaling factor of Δ(1/p_{t})

- × 0.05
- × 0.10
- × 0.15
- × 0.25
- × 0.50
- × 1.0

M_{H}=100 GeV

M_{H}=120 GeV

Invariant Mass of \mu\mu (GeV)
The $H \rightarrow \mu\mu$ significance is improved with better track resolution.

- Optimize Higgs significance for each Higgs mass point.
Branching Ratio Uncertainty

The detection significance improves significantly with improved momentum resolution, but branching ratio of $H \rightarrow \mu \mu$ improves only modestly.
Higgs Mass Resolution

ILC350, SDMar01, Z→all, H→μμ, 1000 fb⁻¹

![Graphs showing the invariant mass of μμ (GeV) distribution with two different scaling factors (1/\(p_t\) and 0.5)].

- For \(\Delta(1/\(p_t\))*1.0\):
  - \(\chi^2/\text{d.f.}\): 0.1908 / 57
  - Constant: 0.2937
  - Mean: 120.0
  - Sigma: 0.1875

- For \(\Delta(1/\(p_t\))*0.50\):
  - \(\chi^2/\text{d.f.}\): 0.1952 / 37
  - Constant: 0.6086
  - Mean: 120.0
  - Sigma: 0.9157E-01
Higgs Mass Resolution

ILC350, SDMar01, Z→all, H→μμ, 1000 fb⁻¹

ILC350, SDMar01, Z→all, H→μμ, 1000 fb⁻¹

\[ \Delta(1/p_t)^*0.25 \]

\[ \Delta(1/p_t)^*0.10 \]

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Better Higgs mass resolution with better track resolution.

Graphs showing the Higgs mass resolution as a function of the Higgs mass for different values of the rescaling factor of $\Delta(1/p_t)$.
Preliminary Conclusions

The SD tracker with nominal track momentum resolution makes it possible but still hard to measure $e^+e^- \rightarrow H^0 Z^0 \rightarrow \mu^+\mu^- X$.

But the direct measurement is feasible (>5 sigma for light Higgs mass ~ 100-140GeV) if the track momentum resolution is improved by a factor of ~ 2 or more.