Summer Student Presentation.

Simulation studies for the total decay width of the Higgs Boson at the International Linear Collider

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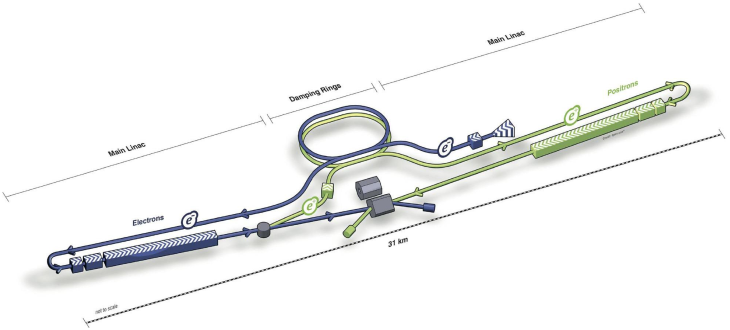
Table of Contents.

International Linear Collider.



- The International Linear Collider will be 31 km long.
- Runs at $\sqrt{s} = 500 GeV$ with possible upgrade to $1 TeV$
- Two detectors: ILD and SiD
- Designed to make precision measurements
- Produces spin polarised beams

Introduction.

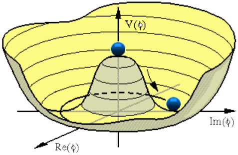
Aim: Explore how accurately the Γ_H^{tot} can be measured at the ILC

- Interested in full simulation at $\sqrt{s} = 500$ GeV and $\mathcal{L} = 500 fb^{-1}$
- Use the WW fusion as signal process $e^+e^- \to H\nu_e\bar{\nu}_e$

Previously a fast simulation was carried out for $m_H = 120$GeV and $\sqrt{s} = 500 GeV/350 GeV$

Niels Meyers: Higgs-Bosons At TESLA: Studies On Production In WW-Fusion And Total Decay Width

Higgs Boson.



The Higgs Mechanism results in *spontaneous symmetry breaking*.
For real scalar field ϕ,

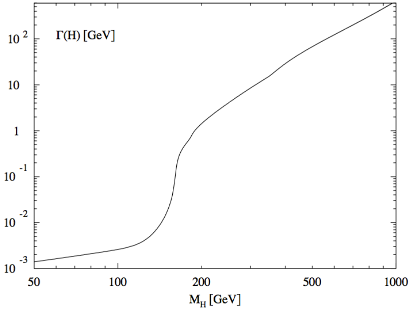
$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2}\mu^2\phi^2 - \frac{1}{4}\lambda\phi^4$$

when $\mu^2 < 0$ we get non-zero minima

$$\phi = \pm\sqrt{-\frac{\mu^2}{\lambda}}$$

This gives *vacuum expectation value*.
Field ϕ can be written in terms of h, real scalar field: Higgs Boson

Decay Width.

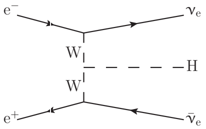


- Decay width of Higgs much for small masses is smaller than experiment resolution
  - $\Gamma_H^{tot} \sim 5\ \text{MeV}$
  - Must be determined indirectly

Higgs Production.

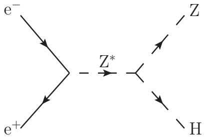
- Dominant method of Higgs formation at linear collider:
  - WW Fusion

$$e^+e^- \longrightarrow \nu_e\bar{\nu}_e H$$



  - Higgs-Strahlung

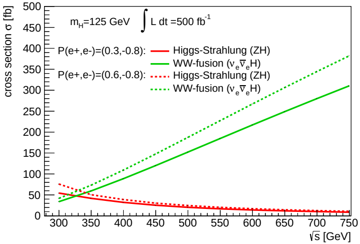
$$e^+e^- \longrightarrow Z^* \longrightarrow ZH$$



  - ZZ fusion also possible but suppressed by weak mixing angle

Cross Sections.

I have calculated the cross section for WW-fusion events and Higgs-Strahlung using *Whizard* as a function of $\sqrt{s}$ for two different beam polarisations:



- WW fusion dominates at $\sqrt{s} = 500$ GeV, Higgs Strahlung dominates at lower energy

Decay Width.

- I have used just **WW-fusion** as the signal for this simulation

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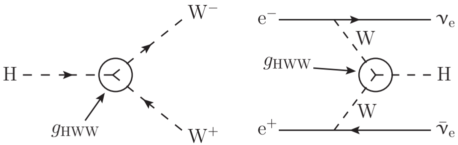
- Measurement of $\sigma_{wwfusion}$ allows Γ_H^{tot} to be determined:



$$\Gamma(H \to WW) \propto g_{HWW}^2 \qquad \sigma_{wwfusion} \propto g_{HWW}^2$$

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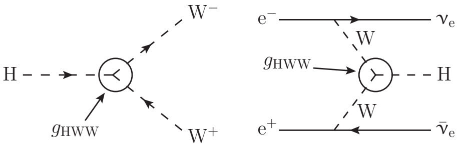

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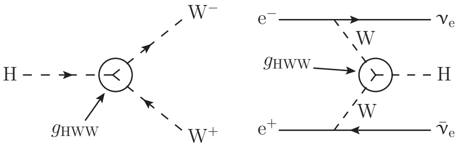

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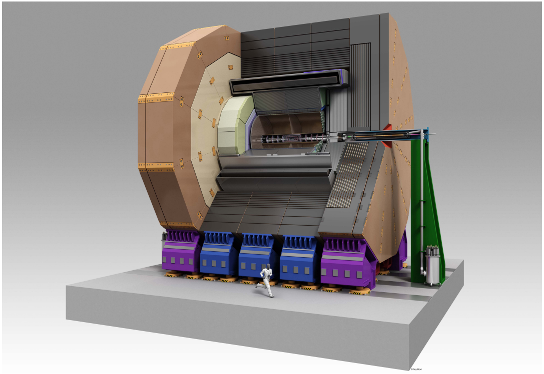
- For $m_H = 125$ GeV the decay $H \rightarrow b\bar{b}$ is largest

$$\sigma_{WWfusion} = \frac{N'_{WW}}{\epsilon \cdot \mathcal{L}}$$

International Large Detector (ILD).



Full simulation of ILD

- $\sqrt{s} = 500$ GeV and $\mathcal{L} = 500$ fb^{-1}
- Simulations generate Monte Carlo data sets
- Takes into account detector design

Signal and Background Processes.

Signal: $e^+e^- \rightarrow H\nu_e\bar{\nu}_e \rightarrow b\bar{b}\nu_e\bar{\nu}_e$

- Total number of WW fusion events is $N_{wwfusion} = 7.6 \times 10^4$.

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Background:

Type	Decay	N_{events}
Semileptonic	$W^+W^- \longrightarrow \nu_\ell \ell^\pm q\bar{q}$	2,785,120
Hadronic	$W^+W^- \longrightarrow q\bar{q}q\bar{q}$	2,245,500
Semileptonic	$ZZ \longrightarrow \ell\bar{\ell}q\bar{q}$	182,999
Hadronic	$ZZ \longrightarrow q\bar{q}q\bar{q}$	203,310
Semileptonic	$W^\mp e^\pm \nu_e \longrightarrow e^\pm \nu_e q\bar{q}$	2,283,520
Semileptonic	$Ze^+e^- \longrightarrow q\bar{q}e^-e^+$	603,845
Hadronic	$Z \longrightarrow q\bar{q}$	9,805,180
Semileptonic	$Z\nu\bar{\nu} \longrightarrow q\bar{q}\nu\bar{\nu}$	279,408

- Total no. of background events is $N_{Background} = 1.8 \times 10^7$.
- Total no. of Higgs Strahlung events is $N_{HiggsStrahlung} = 1.0 \times 10^4$.

Event Selection and Cuts.

Name	Cut
Isolated lepton removal	No. isolated lep ≤ 1
Visible mass	$105\text{ GeV} \leq m_{vis} \leq 135\text{ GeV}$
Visible energy	$105\text{ GeV} \leq E_{vis} \leq 255\text{ GeV}$
Visible P_t	$5\text{ GeV} \leq \sum P_T \leq 200\text{ GeV}$
Polar angle of jet	$\|\cos\theta_{Jet}\| \leq 0.9$
Angle between jets	$\cos\alpha \leq 0.2$
Acoplanarity	$\text{Acop} \geq 10^\circ$
Durham, Y_{12} (minus)	$0.2 \leq Y_{12} \leq 0.8$
b-tagging	b-tag ≥ 0.5
Number of tracks	$10 \leq N \leq 60$

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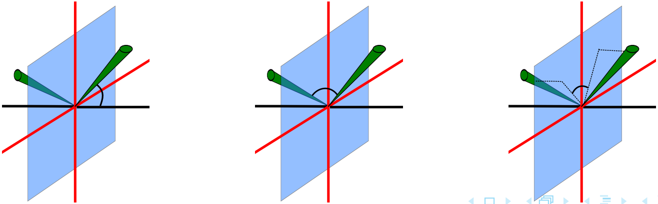
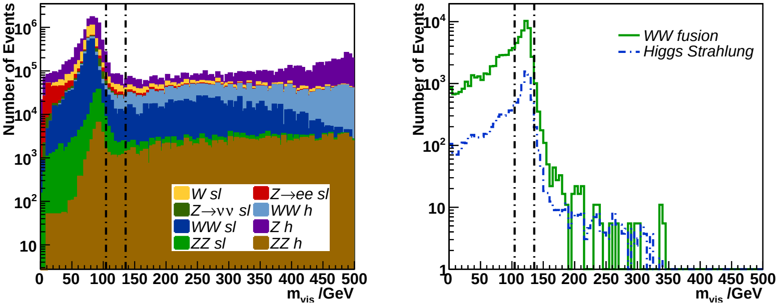


Background and Signal Distributions.

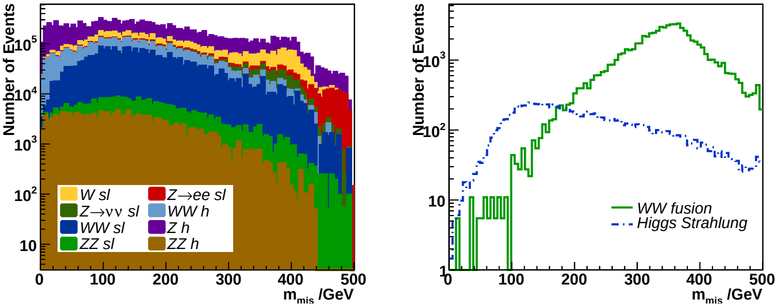


- The distribution of the visible mass, m_{vis}, before any cuts are applied

$$m_{vis} = \sqrt{E_{vis}^2 - |\mathbf{p}_{vis}|^2}$$

Background: $m_{vis} \approx m_Z$ or m_W **WW fusion/Higgs Strahlung:** $m_{vis} \approx m_H$

Missing Mass Distribution.



$$m_{mis} = \sqrt{E_{mis}^2 - |\mathbf{p}_{mis}|^2}$$

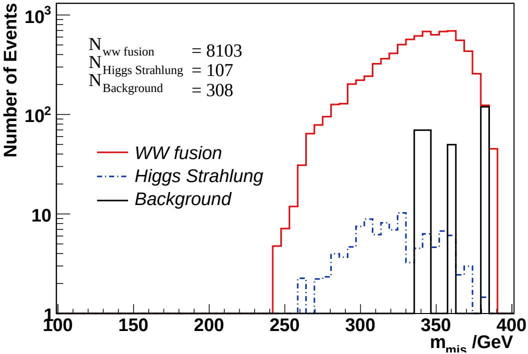
$$\mathbf{p}_{mis} = -\mathbf{p}_{vis} \text{ and } E_{mis} = \sqrt{s} - E_{vis}$$

We expect different characteristics for the $\nu\bar{\nu}$ invariant mass:

Higgs Strahlung: $m_{mis} \approx m_Z$	**WW fusion:** Higher peak

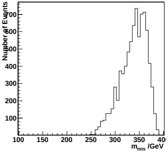
Missing Mass After Cuts.

After cuts have been applied:

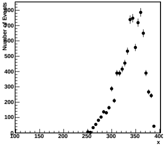


- Background affected by low statistics
- Low m_{mis} missing due to Y_{12} cut

Missing Mass Fit.



Toy MC ⟶



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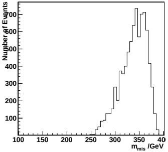
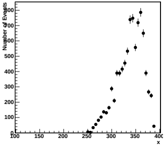
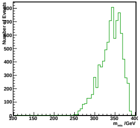
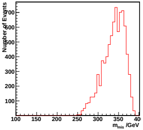


Toy MC $\longrightarrow$

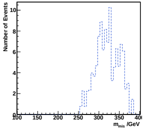




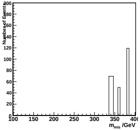
= a



+ b



+ c



Fit WW Fusion Higgs Strahlung Background

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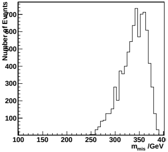

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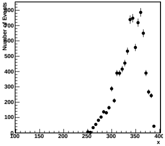
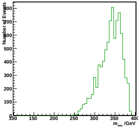
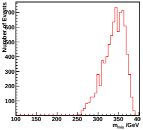
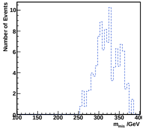




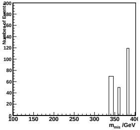
$= a$



$+ b$



$+ c$

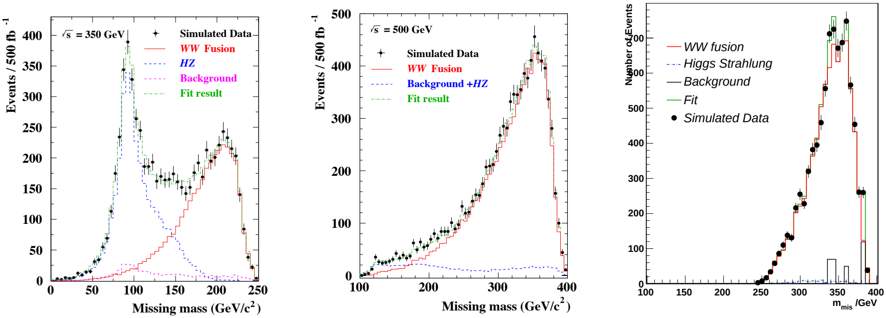


Fit WW Fusion Higgs Strahlung Background

Adjust co-effecients **a** **b** and **c** such that the χ^2 function is minimised:

$$\chi^2 = \sum_i^{Nbins} \left(\frac{N_{MCdata,i} - N_{pred,i}}{\sigma_{MCdata,i}} \right)^2$$

Comparison.



$N_{WWFusion}$	3421 ± 75	8181 ± 98	8049 ± 160
$N_{HiggsStrahlung}$	3192 ± 83	229 ± 21	101 ± 124
$N_{Background}$	363 ± 88	348 ± 38	340 ± 39

*first two from *Niels Meyers: Higgs-Bosons At TESLA (2000)*

Obtaining Uncertainty.

The overall uncertainty on the total width can be calculated using propagation of errors

- The fit gives us the value $\left(\frac{\Delta N'_{WW}}{N'_{WW}}\right) = 1.99\%$

$$\left(\frac{\Delta\sigma_{WWfusion}}{\sigma_{WWfusion}}\right) = \sqrt{\left(\frac{\Delta N'_{WW}}{N'_{WW}}\right)^2 + \left(\frac{\Delta BR(H\rightarrow b\bar{b})}{BR(H\rightarrow b\bar{b})}\right)^2} = 2.48\%$$

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- The uncertainties for the branching ratios come from previous studies
- *Fast simulation found* $\left(\frac{\Delta N'_{WW}}{N'_{WW}}\right) = 1.2\%$ *for* $m_H = 120\ GeV$ *and* $\left(\frac{\Delta N'_{WW}}{N'_{WW}}\right) = 2.4\%$ *for* $m_H = 130\ GeV$

Summary.

- Conducted full simulation of Γ_H^{tot} at $\sqrt{s} = 500$ GeV
- Used selection cuts to keep WW fusion events
- Generated toy MC data and fitted data
- Propagated uncertainty using branching ratio uncertainties
- Calculated overall uncertainty to be $\left(\frac{\Delta\Gamma_H^{tot}}{\Gamma_H^{tot}}\right) = 2.8\%$
- Result consistent with previous analysis