Complementary M_{H} Measurements at ILC

(i) Threshold cross-section, ii) Direct reconstruction

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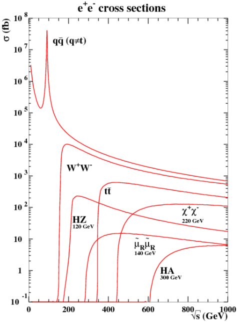
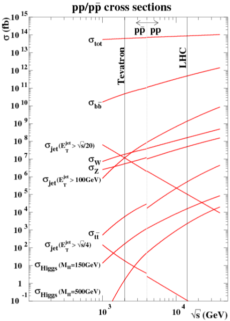




Introduction

Higgs Mass Measurements

- LHC is and will continue to measure M_{H} using direct mass reconstruction in the $\gamma\gamma$ and 4-lepton channels. Current PDG average has an error of 240 MeV based on RunI data.
- ILC can measure the Higgs mass cleanly using the recoil mass in the dilepton channels. H20 precision estimate is 14 MeV. Higher $\sqrt{s}$ of limited utility.

Today: Alternative and Complementary ILC Higgs Mass Measurements

- M_{H} from the Threshold Cross-Section
- Direct reconstruction of M_{H} at ILC. Assume 1M produced Higgs particles over the course of the program. Focus for now on 4l and $\mu\mu$.

For direct reconstruction, the issue for each channel, is can one win statistically and systematically in terms of M_{H} precision compared to LHC.

$$\Delta M = \sigma_M / \sqrt{N}$$

Typically with a factor of 100 more events at LHC, one needs the detector mass resolution to be 10 times better than LHC. LHC systematic wall? 0.01–0.1 σ_M ?

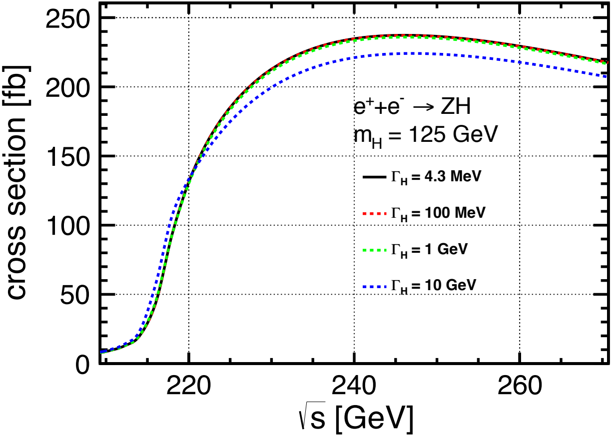
Introduction: M_{H} from Threshold Cross-section

Nominal threshold for ZH production is $M_{\mathrm{H}} + M_{\mathrm{Z}} \approx 216.2$ GeV

Measurement of the ZH cross-section can be used to determine M_{H}.

M_{H} will likely be known to at least 100 MeV, so no need to scan.

Modest statistics - so statistics dominated measurement. Less need and less advantage (than WW threshold) for a (polarized) scan.



Optimal $\sqrt{s} \approx 216.5$ GeV. How accurate? How much lumi?

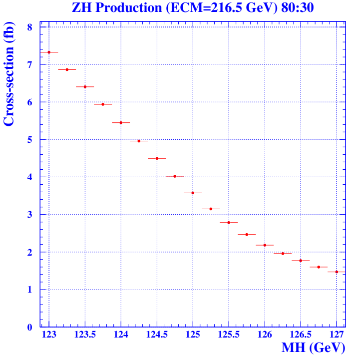
Threshold Cross-section Statistical Sensitivity Study

- Calculate $\mathrm{e^+e^-} \rightarrow \nu_\mu \overline{\nu}_\mu \mathrm{H}$ (ZH-like) cross-sections with Whizard 2.5
- $B(Z \rightarrow \nu_\mu \overline{\nu}_\mu) = 0.067$
- Include ISR. For now have neglected beam-spread and beam-strahlung
- Study various beam polarization scenarios
- Statistical sensitivity from signal statistics depends on the statistical error on the cross-section measurement and the slope of the cross-section dependence on M_H

$$\Delta M_\mathrm{H} = \sqrt{\sigma} \left| \frac{d\sigma}{dM_\mathrm{H}} \right|^{-1} \frac{1}{\sqrt{\varepsilon \mathcal{L}}}$$

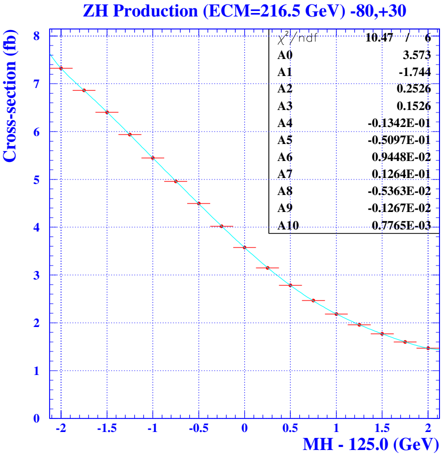
- Similar considerations for M_W at LEP161 led to

$$\Delta M_\mathrm{W} = 29 \ \mathrm{MeV} \ / \ \sqrt{\varepsilon \mathcal{L}(\mathrm{fb}^{-1})}$$



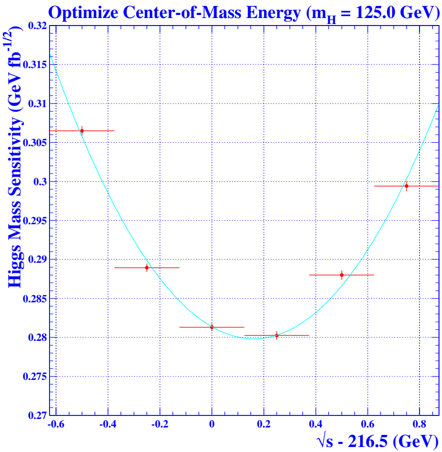
Threshold Cross-section Study Method

- Polynomial fits to $\mathrm{e}^+\mathrm{e}^- \to \nu_\mu \overline{\nu}_\mu \mathrm{H}$ cross-section vs $M_\mathrm{H} - 125.0$ GeV for each $\sqrt{s}$
- Errors are Whizard integration errors
- Increase polynomial degree if resulting χ^2 lowered by more than 1
- $B(Z \to \nu_\mu \overline{\nu}_\mu) = 0.067$
- Statistical sensitivity coefficient, at $M_\mathrm{H} = 125.0$ GeV, $\alpha \equiv \sqrt{\sigma} \left| \frac{d\sigma}{dM_\mathrm{H}} \right|^{-1}$, is given by $\sqrt{A0}/|A1|$. So for $\sqrt{s} = 216.5$ GeV:
- $\alpha = 1.08\ \mathrm{GeV}/\sqrt{\mathrm{fb}}$
- $\alpha_{ZH} \approx \alpha \sqrt{B(Z \to \nu_\mu \overline{\nu}_\mu)} = 280\ \mathrm{MeV}/\sqrt{\mathrm{fb}}$



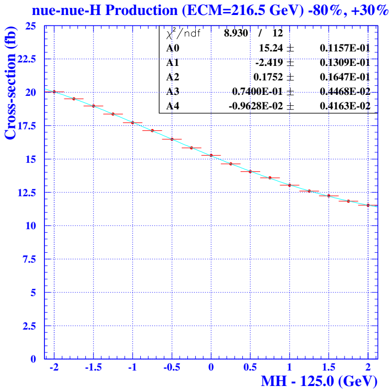
$\sigma = 3.6$ fb. $\sigma_{\mathrm{ZH}} = 53.3$ fb

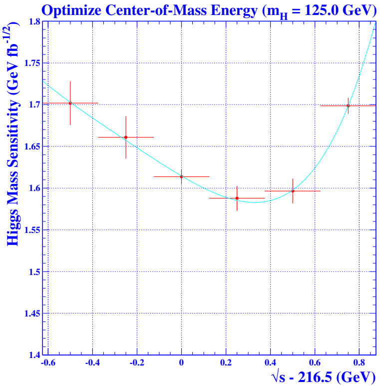
- Check dependence of Higgs mass sensitivity for ZH with $\sqrt{s}$
- Optimal $\sqrt{s} \approx 216.65$ GeV
- Roughly nominal + 0.5 GeV (same as WW)
- Statistical sensitivity factor, 280 MeV/$\sqrt{\mathrm{fb}}$, is ten times less precise (cf 29 MeV/$\sqrt{\mathrm{fb}}$).
- Substantial integrated luminosity needed to target 25 MeV and below.



For -80%(L) e^-, +30%(R) e^+

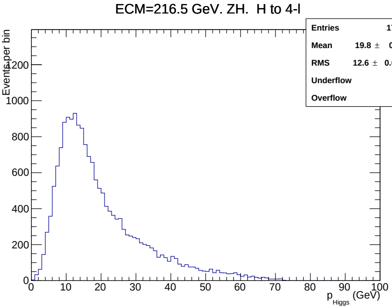
Process has contributions from ZH and WW-fusion. WW-fusion contribution dilutes M_{H} sensitivity significantly. (1.58 GeV/$\sqrt{\mathrm{fb}}$ cf 1.08 GeV/$\sqrt{\mathrm{fb}}$ for $e^+e^- \to \nu_\mu\overline{\nu}_\mu H$)

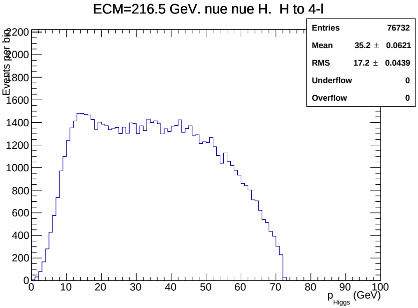




[Initial indication: $e^+e^- \to e^+e^- H$ is ZH-like with no significant dilution from ZZ fusion]

Separating ZH from WW-fusion





- There is scope to use kinematic cuts to reduce WW-fusion contribution and/or categorize events as more or less ZH-like recuperating some of the lost sensitivity.
- It may also be feasible by kinematic cuts/criteria to increase the slope of σ vs M_{H} in some of the channels. (suppressing ISR, mass cuts on the Z and the H candidates etc.)
- NB. So far no considerations at all about background contributions NOR on event selection efficiency. Study assumes 100% efficiency for all channels, and no background.

Higgs Sensitivity Numbers from Threshold Cross-section

For various beam polarization configurations. For ZH, beam polarization is of some use.

Mass Sensitivities ($\sqrt{s} = 216.5$ GeV, $M_{\mathrm{H}} = 125.0$ GeV)

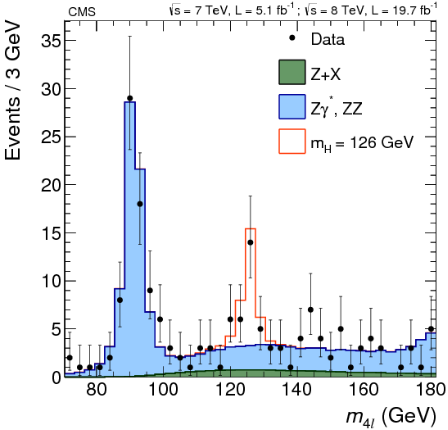
Setting	$\alpha_{HZ}[\mathrm{MeV}/\sqrt{\mathrm{fb}}]$	ΔM_{H} [MeV] (50 fb^{-1})	ΔM_{H} [MeV] (0.5 ab^{-1})
−80, +30	279	39.5	12.5
−90, +60	250	35.3	11.2
−80, +60	255	36.1	11.4
−90, +30	268	37.9	12.0
+80, −30	342	48.4	15.3
−80, −30	366	51.7	16.4
+80, +30	422	59.7	18.9
−80, 0	310	43.9	13.9
+80, 0	376	53.2	16.8
0, 0	341	48.2	15.2
−100, +100	218	30.8	9.8
+100, −100	272	38.5	12.2

NB. Signal statistical error only. 100% efficiency, no background.

To do

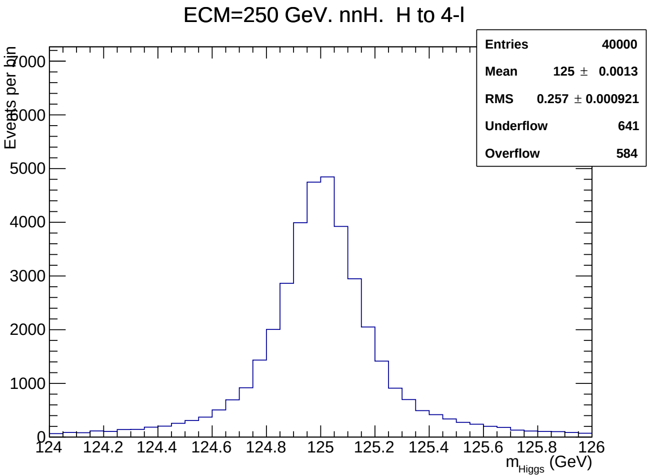
If you agree that this is of some interest, need some estimate of backgrounds, to clarify feasibility. Clearly need more channel-by-channel event selection procedure to keep backgrounds under control.

Note that running at threshold is likely not so attractive for other measurements ....



$$\sigma_M \approx 2.0 \text{ GeV}$$

Direct Reconstruction. ILC 4-lepton mass



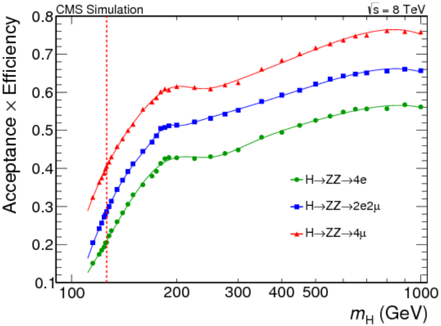
$$\sigma_M \approx 0.19 \text{ GeV}$$

Estimated using PYTHIA8 events including FSR. Assumes tracking-like momentum resolution for electrons and muons. ECAL-like resolution for photons. Possibly OK for $\mu\mu\mu\mu$, likely underestimate for $ee\mu\mu$ and $eeee$.

Numerology

LHC cross-sections are substantial.

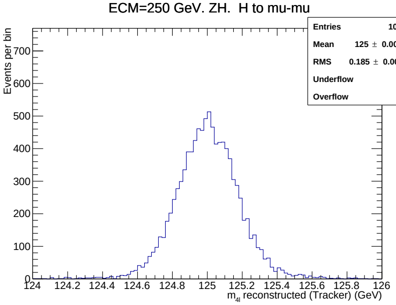
- ggFusion (8 TeV) = 21 pb
- ggFusion (13 TeV) = 49 pb
- ggFusion (14 TeV) = 55 pb.



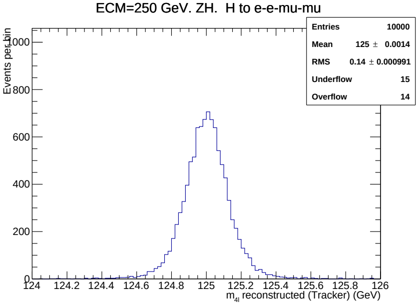
acceptance*efficiency modest - more so (I think) at 13 TeV. Backgrounds often substantial (especially $\gamma\gamma$)

Simulations

Generated Higgs events both with Whizard and Pythia8. 4-vector smearing based on ILD type tracker, ECAL, HCAL and PFA resolutions. Pythia8 samples include FSR (final-state radiation).
Most promising channels appear to be Higgs decays to $\mu^+\mu^-$ and Higgs to 4 leptons.
The 2-body decay has higher momenta (worse resolution). Four-leptons have lower momenta (better resolution). Following are Whizard samples with NO FSR.



$\sigma_M = 0.168$ GeV

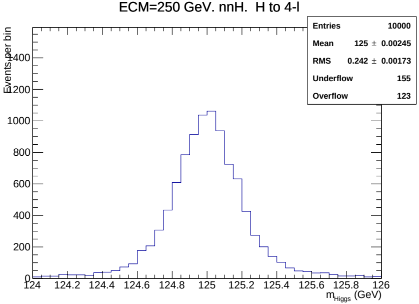


$\sigma_M = 0.121$ GeV

WW-fusion events with Pythia8. These include FSR (final-state radiation). ISR photons are flagged at "truth level" and not included in the mass estimation. Most promising channels appear to be Higgs decays to $\mu^+\mu^-$ and Higgs to 4 leptons.

The 2-body decay has higher momenta (worse resolution). Four-leptons have lower momenta (better resolution). But more leptons so more FSR. Following are $\mu^+\mu^-$ and $\mu^+\mu^-\mu^+\mu^-$. Better ECAL resolution would help ...

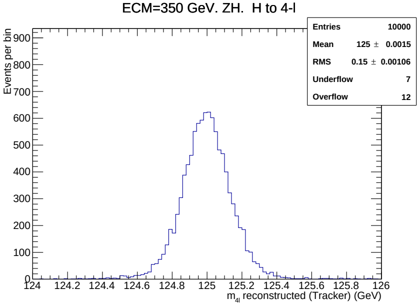
Mass resolutions estimated from Voigtian fit.

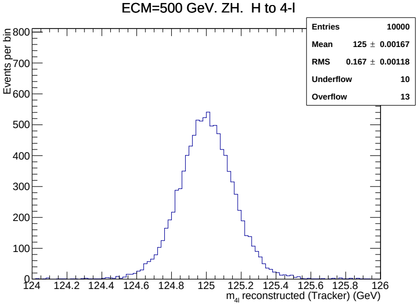


$\sigma_M = 0.21$ GeV $\qquad\qquad$ $\sigma_M = 0.17$ GeV

Could benefit from event-by-event mass resolution given the importance of FSR.

Whizard ZH samples with $H \to \mu\mu\mu\mu$.
At $\sqrt{s} = 250$ GeV, $\sigma_M = 0.121$ GeV.
Now $\sqrt{s} = 350$ GeV and $\sqrt{s} = 500$ GeV.





$\sigma_M = 0.134$ GeV $\sigma_M = 0.156$ GeV

This is in contrast to the recoil mass. And additionally the WW-fusion production can be utilized at high $\sqrt{s}$

BRs, mass resolution estimates, ΔM guesstimates

Assume 1M produced (and detected) Higgs particles for ILC with negligible background.

Mass Uncertainty Prospects

Decay Mode	BR	LHC σ_M [GeV]	σ_M [GeV]	ΔM_{H} [MeV]
bb	0.5824	X	3.1	(4.1)
cc	0.0289	X	3.1	(18.2)
gg	0.0819	X	3.1	(10.8)
$\gamma\gamma$	22.70×10^{-4}	1.6	2.2	46.2
$\mu^+\mu^-$	2.176×10^{-4}	X	0.21	14.2
$\mu^+\mu^-\mu^+\mu^-$	3.249×10^{-5}	1.7	0.17	29.8
$e^+e^-\mu^+\mu^-$	5.897×10^{-5}	2.3	(0.19)	24.7
$e^+e^-e^+e^-$	3.254×10^{-5}	2.8	(0.22)	38.6
Others		X		

Averaging the four leptonic channels one gets an overall statistical uncertainty of 10.9 MeV.

Summary and Conclusions

Threshold

- Threshold Cross-Section Method Statistical Sensitivity Factor is 280 MeV.
- Higgs mass uncertainties from threshold of 50 MeV or less will likely need at least 50 fb^{-1}.
- Need to dedicate lots of luminosity to be competitive with recoil mass etc.
- Firm conclusions needs more attention to backgrounds.

Direct Reconstruction

- Direct reconstruction of the Higgs mass in "golden channels" looks to be very competitive with LHC and other ILC methods. One single event can give a mass resolution better than the current world average.
- This deserves more study with full simulation.
- Electron reconstruction (tracking) needs more attention.
- ECAL energy resolution is an issue for FSR reconstruction.

Backup Slides