TOHOKU UNIVERSITY

Search for Invisible Higgs Decays at the ILC

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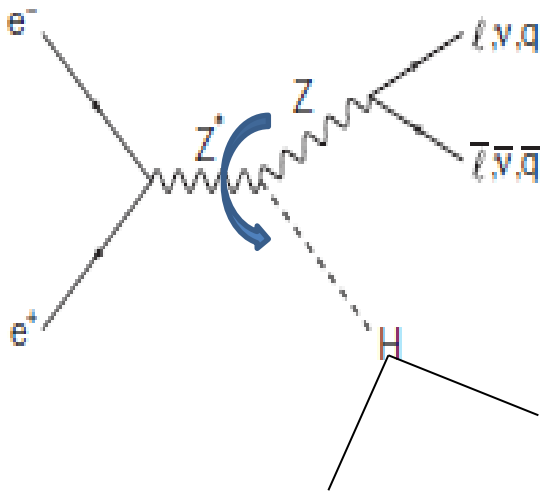
Invisible Higgs Decay

- In the SM, an invisible Higgs decay is H → ZZ* →4ν process and its BF is small ~0.1%
- If we found sizable invisible Higgs decays, it is clear new physics signal.
  - The decay products are dark matter candidates.



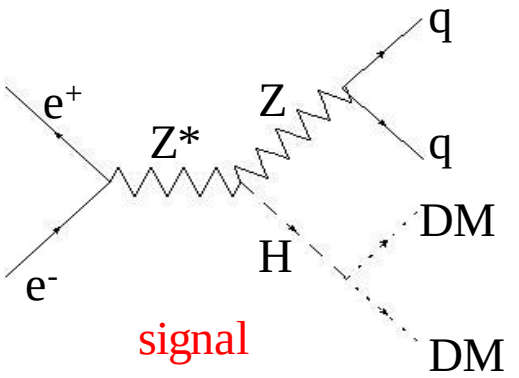
- At the LHC, one can search for invisible Higgs decays by using recoil mass from Z or summing up BFs of observed decay modes with some assumptions.
  - The upper limit is O(10%).
- At the ILC, we can search for invisible Higgs decays using a recoil mass technique with model independent way!
  - e+e- → ZH

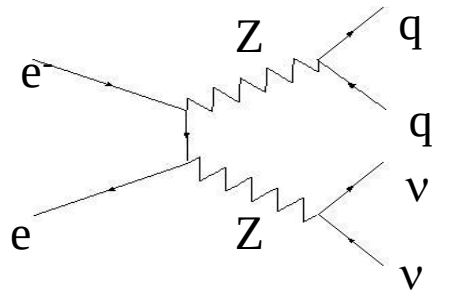
$$P_H = P_{e+e-} - P_Z$$

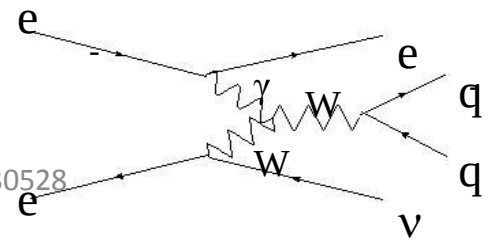
known measured

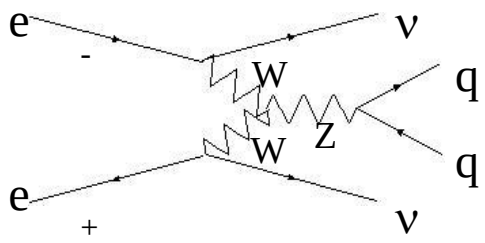
Signal and Backgrounds

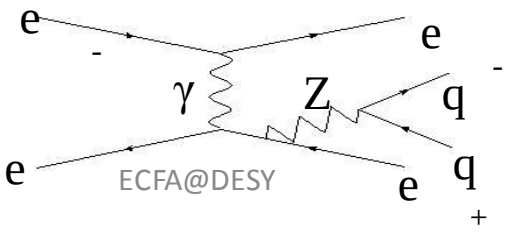
- Signal
  - e+e- → ZH → (qq)(DM DM)
- Backgrounds
  - e+e- → ZZ, ννZ, WW, eνW, eeZ
  - ZH → (qq)(ZZ*) →(qq)(4ν) : irreducible
  - ZH → (νν)(ZZ*) →(νν)(qq)(νν)

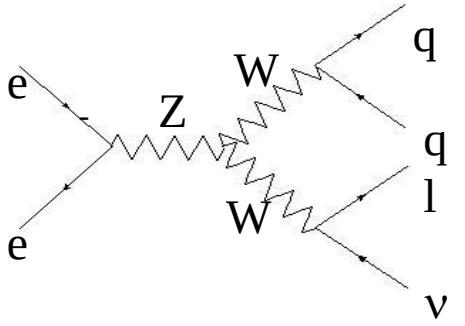












MC setup and Samples

- Generator : physsim
  - for both signal and backgrounds
  - E_{CM} = 250GeV
  - Higgs mass 125GeV
  - H→DM DM
    - Fermion dark matter
    - Dark matter mass 50GeV, well below the pair production threshold
  - Polarization of P(e+,e-)=(-30%,+80%) to suppress W involving background
- Fast simulator : JSFQuickSim
- Samples
  - Two sets of signal and backgrounds
  - One used to determine selections, the other for efficiency and PDF for toy MC
    - 100000 events for each signal sample
    - 1ab^{-1} data for each backgrounds samples.

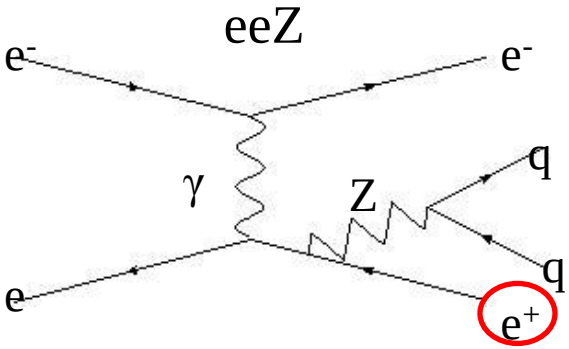
mode	ZZ	ννZ	WW	eνW	eeZ
Cross Section [fb]	982	5	2783	684	3992

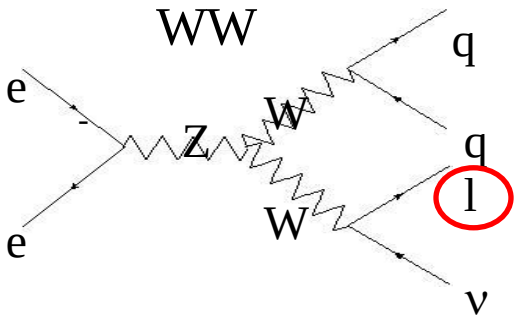
Overview of the Selections

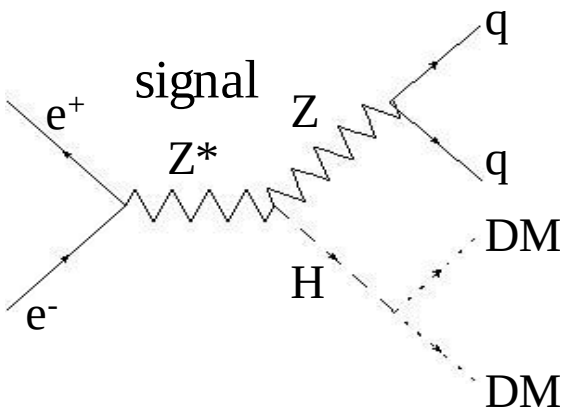
- Durham jet algorithm
  - Two-jet reconstruction
- No isolated leptons
- No forward going electrons
- Z mass reconstructed from di-jet
  - Also used for Likelihood ratio cut
- $\cos(\theta_Z)$
  - Production angle of Z
  - Just apply < 0.99 cut to eliminate peaky eeZ background before making likelihood ratio
- Likelihood ratio of Z mass, $\cos(\theta_Z)$, $\cos(\theta_{hel})$
  - $\cos(\theta_{hel})$: Helicity angle of Z
- Recoil mass
  - The final plot
  - Fitted to set upper limit.

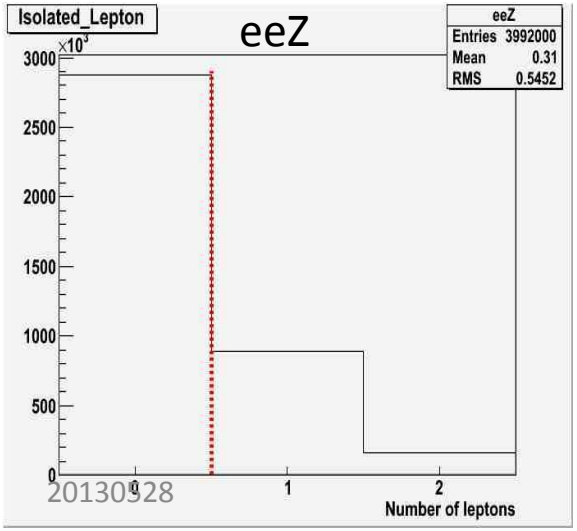
No Isolated Leptons

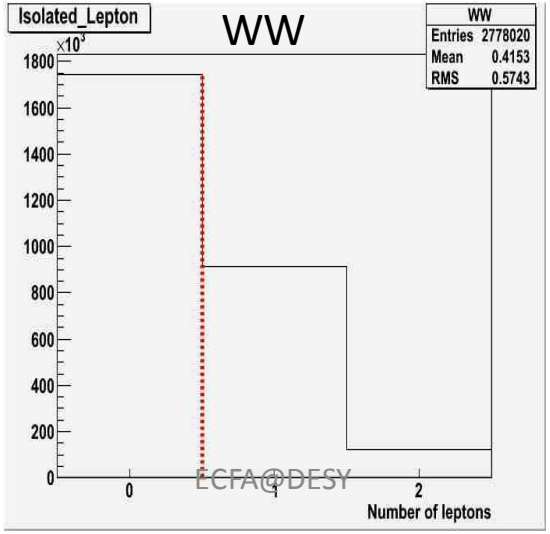
- Isolated lepton selections
  - Lepton candidate energy > 10 GeV
  - Measured energy within a cone of $\cos\theta = 0.94 < 10\text{GeV}$

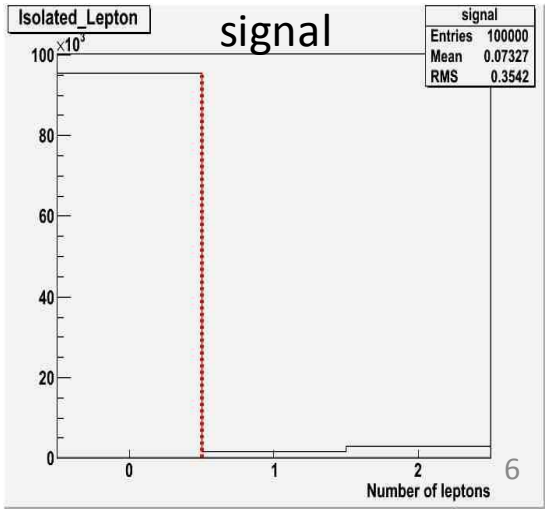






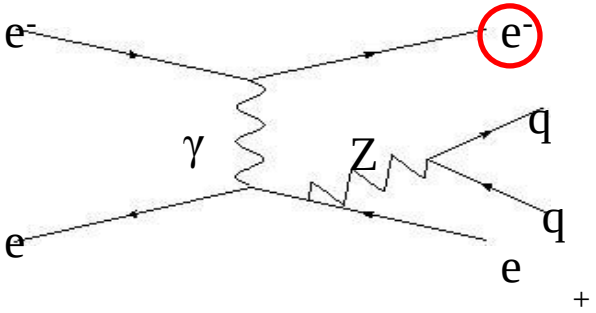




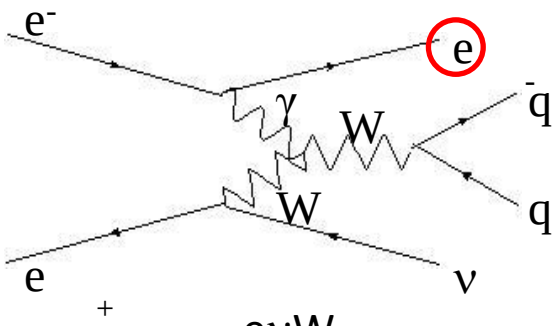


No Forward Going Electrons

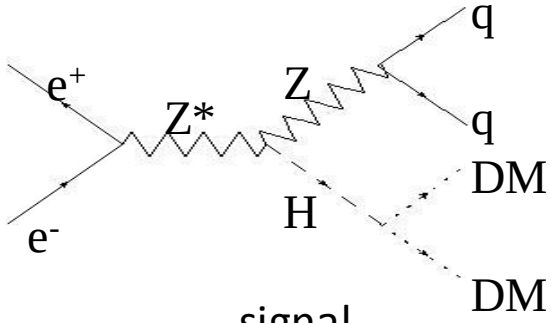
- Since no forward detectors in the QuickSim, we look at generator information.
  - Electron with energy > 5GeV
  - Electron within FCal acceptance, 0.98 < |cosq| < 0.9999875



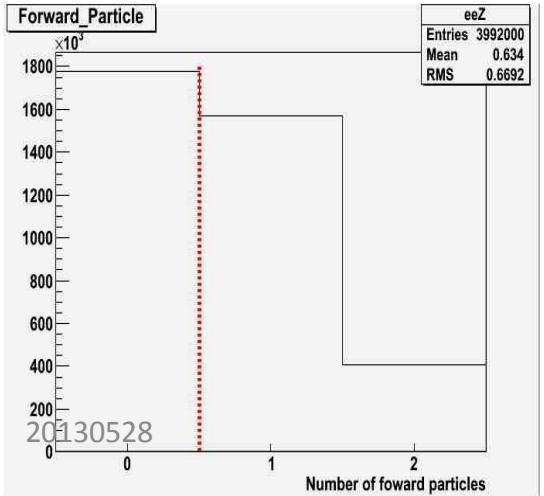
eeZ

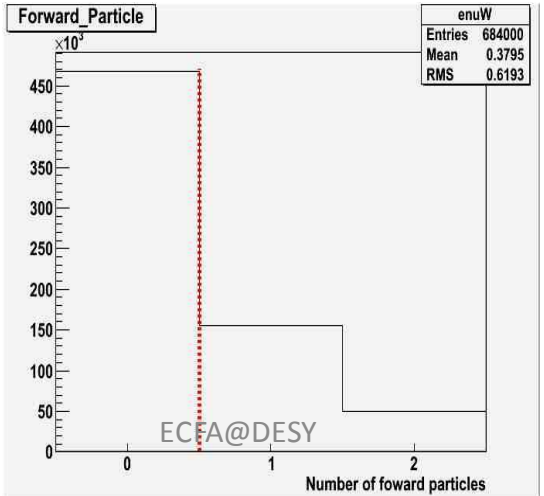


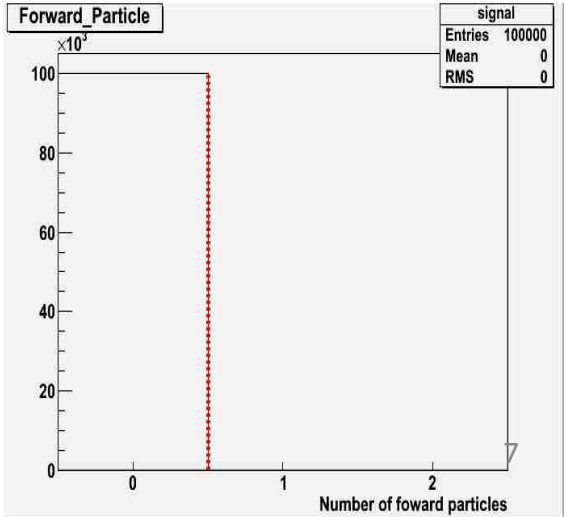
eνW



signal

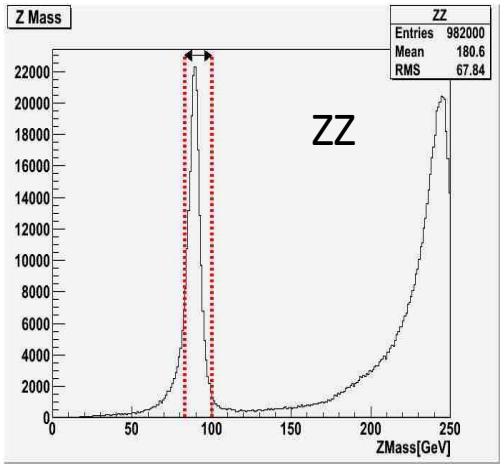


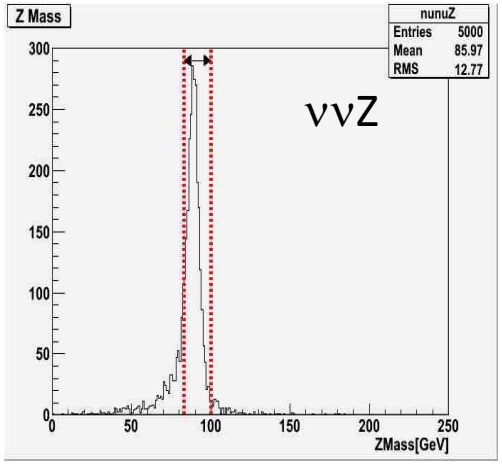


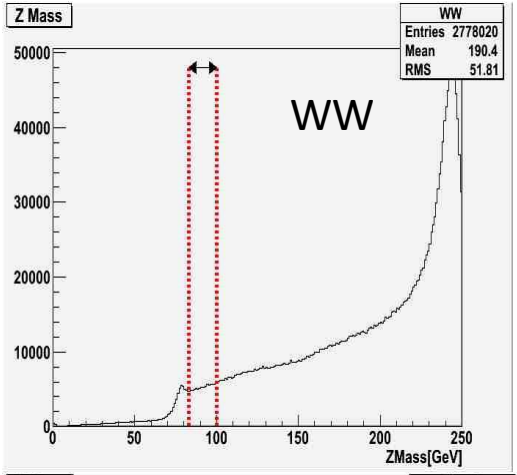


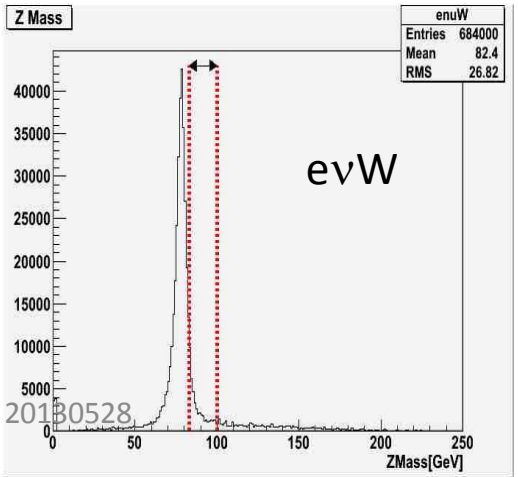
Z mass

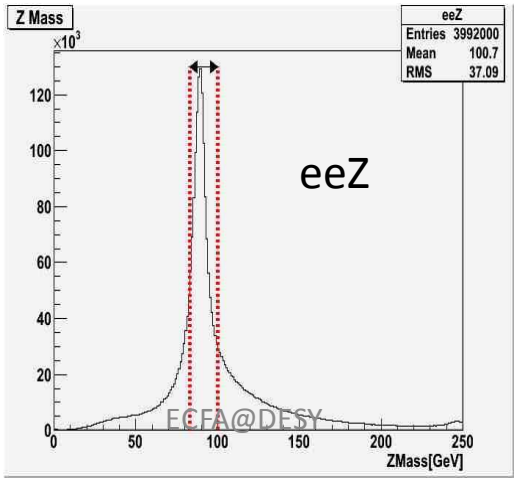
- To suppress backgrounds having W in final states
  - 83 GeV < mZ < 100GeV

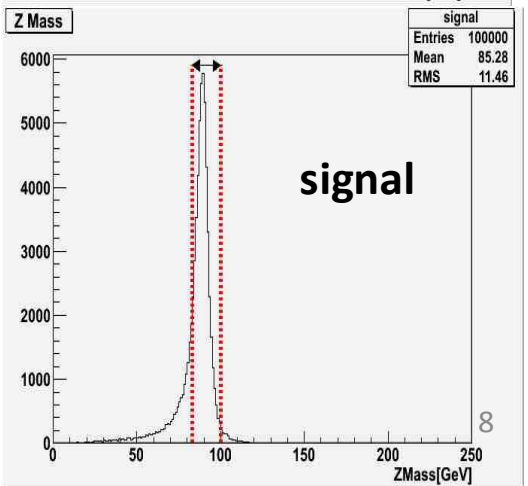










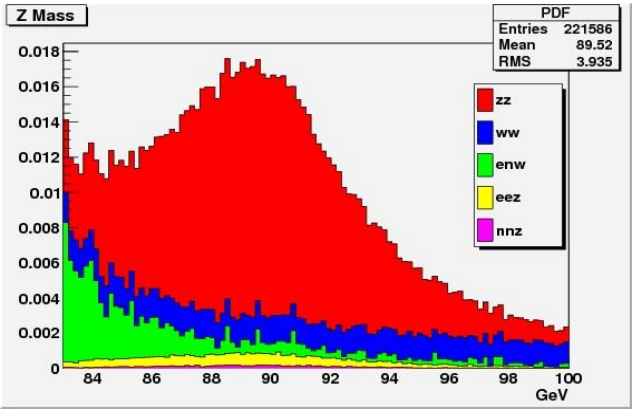


Variables for Likelihood Ratio

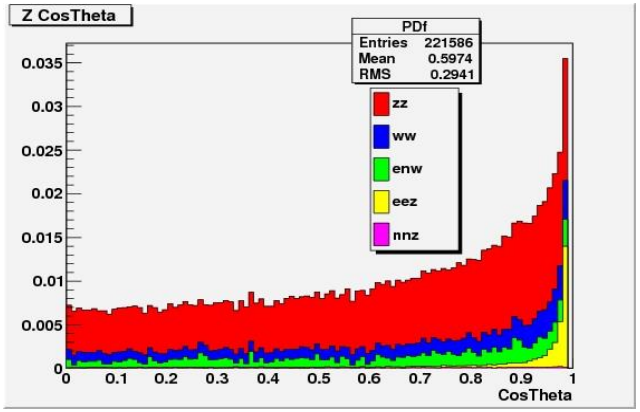
■ Background

ZZ background WW background eνW background

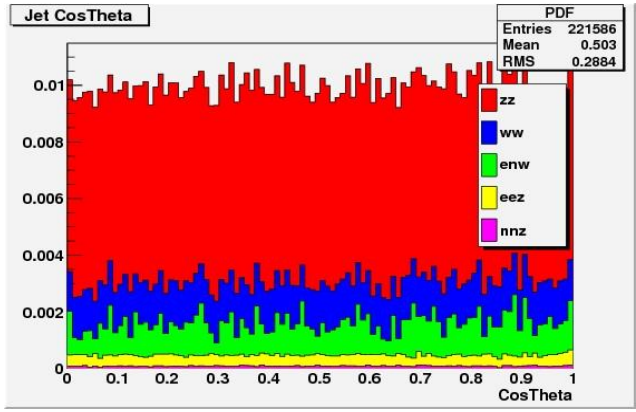
eeZ background ννZ background



Zmass

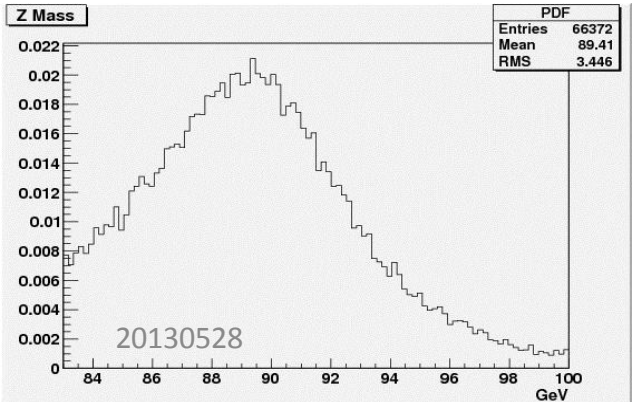


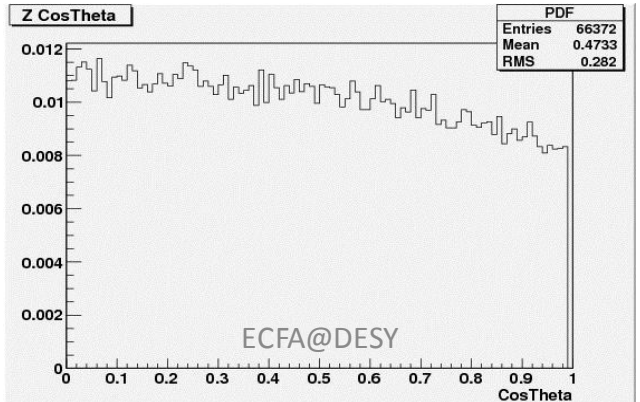
$\cos\theta_z$

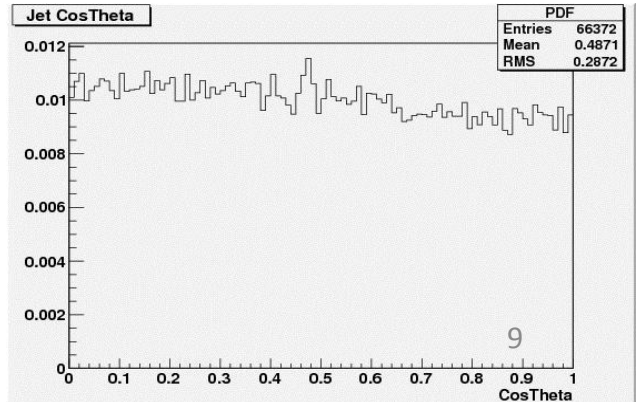


$\cos\theta_{qq}$

■ Signal

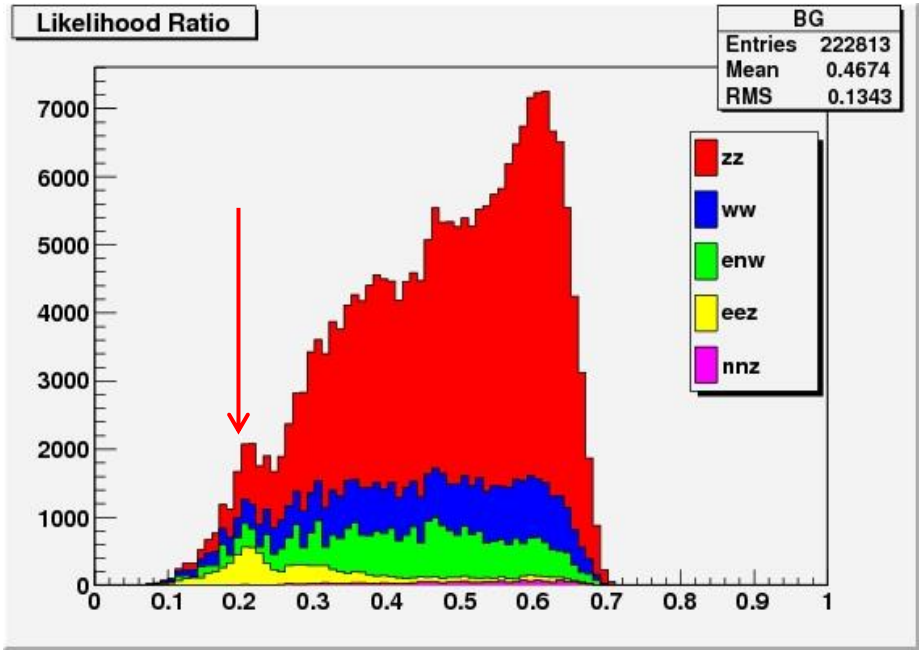




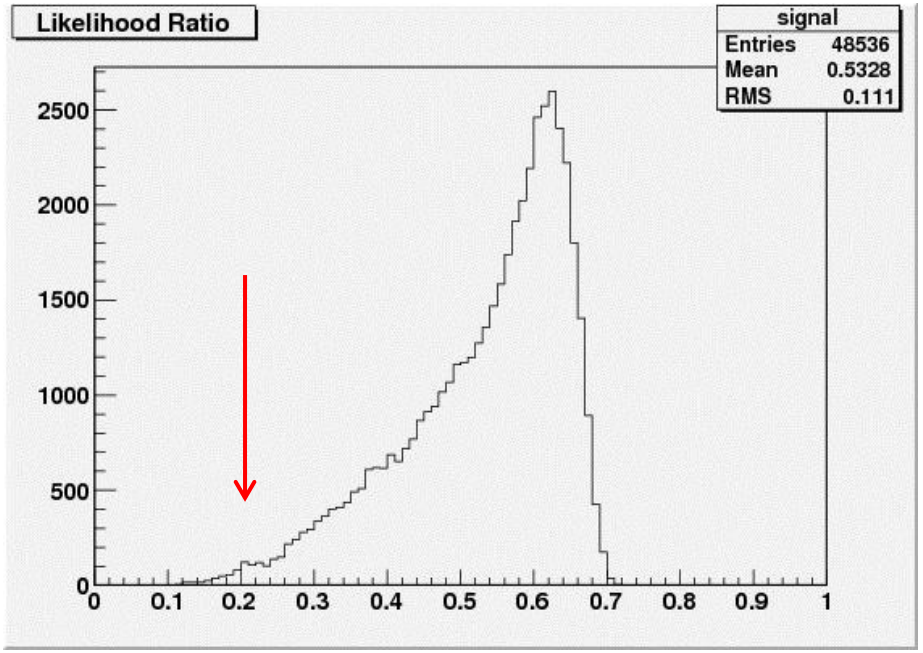


Likelihood Ratio

$$LikelihoodRatio = \frac{L_{sig}}{L_{sig} + L_{bg}} > 0.2$$



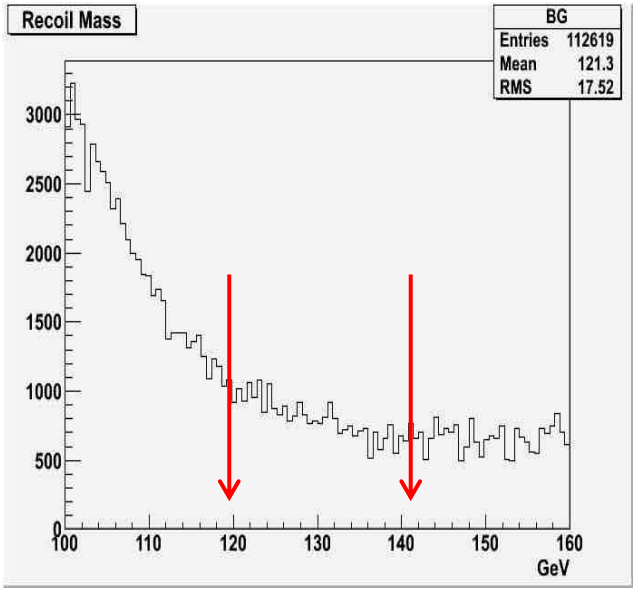
backgrounds



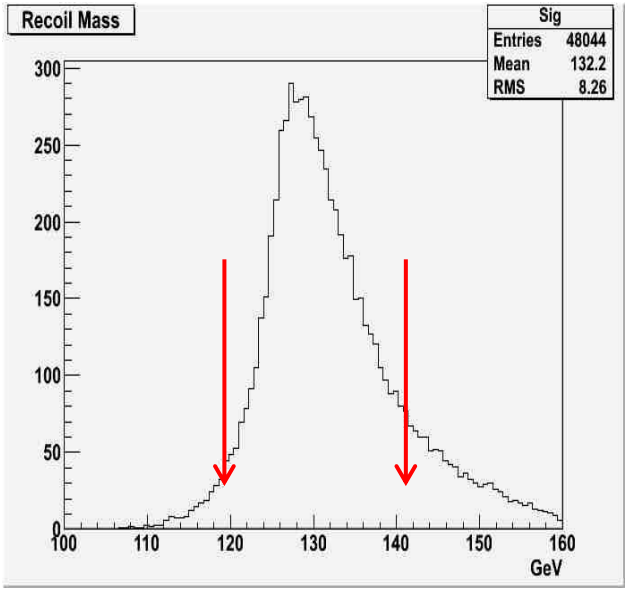
signal

Recoil Mass

- 120 GeV < M_{recoil} < 140 GeV



background



signal

Signal eff and BG Cross Section

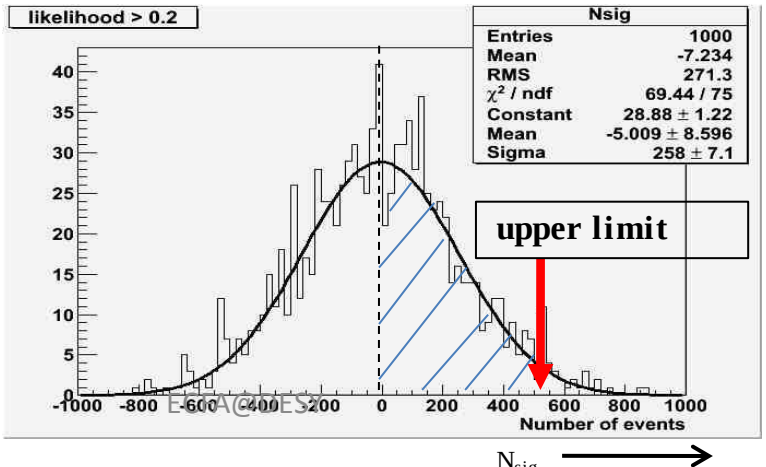
Signal Efficiency is 42% and background cross section is 22fb after all selections.

Cut / σ[ab]	Signal [%]	ZZ	ννZ	WW	eνW	eeZ
No cut	100.00	982000	5000	2783000	684000	3992000
Isolated lepton	95.55	835853	4767	1745868	545711	2878061
Forward electron veto	95.55	586409	3971	1269207	455945	1709386
Z mass	48.92	156627	1966	34445	26718	752847
$\cos(\theta_z)$	48.54	153362	1920	33041	25806	8651
LR	48.04	150800	1893	30629	24231	6542
Recoil mass	42.10	20073	705	3695	7733	430

Set the upper limits on σ and BF

Toy MC

- Recoil mass distributions before cut is used for ToyMC.
- Recoil mass distributions with no signal are generated for each Likelihood ratio cut to minimize the upper limits.
  - Two backgrounds from ZH process are added to toy MC
    - ZH → (qq)(ZZ*) → (qq)(4ν) : irreducible, the BF~0.1%
    - ZH → (νν)(ZZ*) → (νν)(qq)(νν) : can be suppressed by recoil mass
- Fit to Recoil mass distributions and extract Number of signals
- Repeat 1000 times and make Number of signals distribution.
- Set the 95% CL Limits on signal yield and cross section.

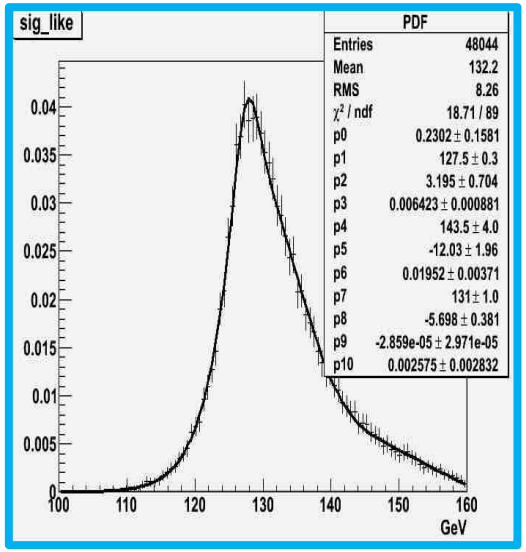


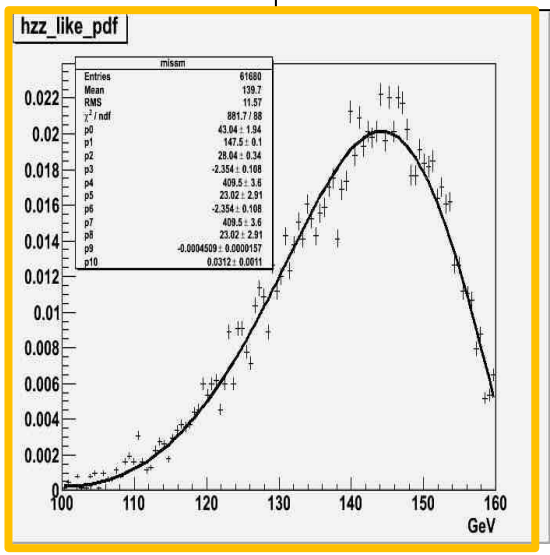
PDF for Toy MC Generation

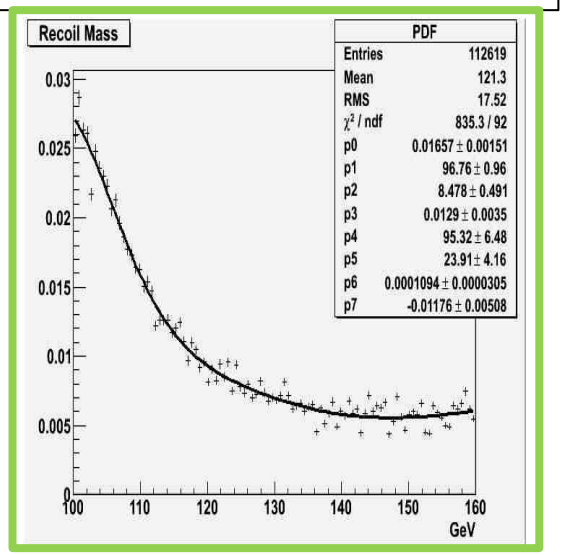
$$P = (N_{sig} + N_{h\to 4\nu})P_{sig} + N_{h\to ZZ^*\to q\bar{q}(\nu\nu)}P_{h\to ZZ^*\to q\bar{q}(\nu\nu)} + N_{bg}P_{bg}$$

Fit Parameters : N_{sig}, N_{bg}

Fixed values : $N_{h\to 4\nu}$, $N_{h\to ZZ^*\to qq(\nu\nu)}$ assuming the SM







signal

$e^+e^- \to ZH \to q\bar{q}ZZ^* \to q\bar{q}\,\nu\nu\nu\nu$

$B.e^+e^- \to ZH \to \nu\nu ZZ^* \to \nu\nu q\bar{q}\,\nu\nu$

BG:ZZ+ννZ+WW+eνW+eeZ

Results

- Set the upper limit with 250fb^{-1},
  - σ (e+e- → ZH, H → invisible) < 1.7 fb at 95% CL

Note. This "invisible" does not include 4 neutrinos final state

- From the σ(e+e- → ZH) = 240fb, upper limit on BF is obtained.
  - BF (H→invisible) < 0.70% at 95% CL with 250 fb^{-1}

likelihood ratio	N_{sig}(C.L 95%)	efficiency	upper limit [fb]
0	218	0.483	1.804
0.1	213	0.483	1.762
0.2	202	0.480	1.682
0.3	198	0.463	1.711
0.4	182	0.415	1.753
0.5	148	0.328	1.806
0.6	88	0.162	2.174

Summary and Plan

- We have estimated the upper limits on the cross section and BF of invisible Higgs decays at the ILC at the E_{CM} of 250 GeV, with an integrated luminosity of 250 fb^{-1} and polarization of P(e+,e-)=(-30%,+80%) .
  - σ (e+e- → ZH, H→ invisible) < 1.7 fb at 95% CL
  - BF (H→invisible) < 0.70% at 95% CL with 250 fb^{-1}
- Study with a full simulator.
- Add leptonic Z decays.
- Combine studies at E_{CM} = 350GeV and 500GeV.