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Search for Invisible Higgs Decays with the ILD Detector at the ILC

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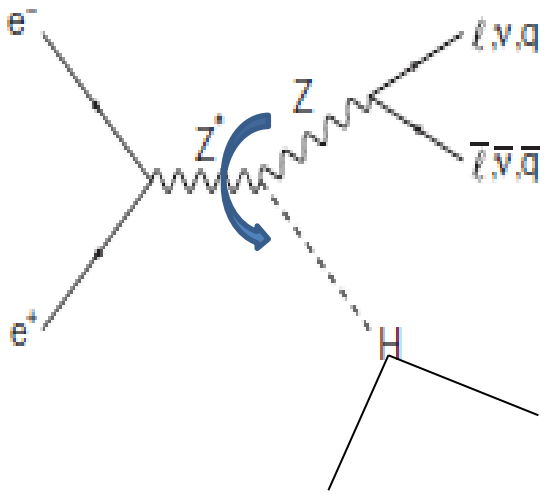
Invisible Higgs Decay

- 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
  - Pseudo signal : e^+e^- → ZH, Z→qq, H→ZZ*→4ν
- Backgrounds
  - found qqll, qqlν and qq$\nu\nu$ final states are the dominant backgrounds.
    - other backgrounds also studied
  - ZZ semileptonic : one Z→qq, the other Z→ll, $\nu_\mu\nu_\mu$, $\nu_\tau\nu_\tau$
  - WW semileptonic : one W→qq, the other W→lν
  - Z$\nu_e\nu_e$, Z→qq
  - Weν_e, W→qq
  - $\nu\nu$H, generic H decays
  - qqH, generic H decays

MC setup and Samples

- Generator : Wizard
  - for both signal and backgrounds
  - E_{CM} = 250GeV
  - Higgs mass 125GeV
  - Polarizations of P(e+,e-)=(+30%,-80%), (-30%, +80%)
    - Throughout the slides, denoted as "Left" and "Right" polarizations
- Samples
  - Official DBD samples
    - Full simulation with the ILD detector
    - Interferences are considered, ex WW→e$\nu_e$qq and eν_eW →e$\nu_e$qq
  - Half of the samples are used for cut determination. The other used for efficiency calculation and backgrounds esitimation.

[fb]	ZZ sl	WW sl	ννZ sl	eνW sl	ννH	qqH	qqH H→4ν
"Left"	857	10993	272	161	78	210	0.224
"Right"	467	759	93	102	43	142	0.151

Overview of the Selections

1. Forced two-jet reconstruction with Durham jet algorithm
2. No isolated leptons
3. Numbers of Particle Flow Objects and Tracks
   - $N_{PFO} > 16$ & $N_{trk} > 6$
   - Eliminate low multiplicity events like $\tau\tau$
4. Z mass reconstructed from di-jet : M_Z
   - $80GeV < M_Z < 100GeV$
   - Also used for Likelihood ratio cut
5. Polar angle of Z direction : $\cos(\theta_Z)$
   - Just apply < 0.99 to eliminate peaky eeZ background before making likelihood ratio
6. Loose Recoil mass selection : M_{recoil}
   - $100GeV < M_{recoil} < 160GeV$
7. Likelihood ratio of M_Z, $\cos(\theta_Z)$, $\cos(\theta_{hel})$ to give the best upper limits : LR
   - $\cos(\theta_{hel})$: Helicity angle of Z
   - LR > 0.3 for “Left” and LR > 0.4 for “Right”
8. Recoil mass
   - The final plot (Signal Box : $120GeV < M_{recoil} < 140$)
   - Perform toy MC by fitting to the recoil mass to set upper limit.

Cut Summary “Left”

- Number of events scaled to 250fb^{-1} and (Efficiency)

“Left”	ZZ	WW sl	nnZ	enW	nnH	qqH	qqH H→4n Pseudo signal
No cut	214232	2748230	67951	40296	19383	52546	56.07 (1.000)
No lepton	169058	1496080	67703	15482	17766	48244	55.80 (0.995)
Trk and PFO	166373	1490810	65783	15392	16544	48242	55.39 (0.988)
M_Z	75301	174634	47646	1759	1226	77	44.57 (0.795)
$\cos\theta_Z$	63729	166818	46533	1635	1211	77	44.19 (0.788)
Loose M_{Recoil}	27040	38917	27319	600	1146	75	44.10 (0.787)
LR	21577	29685	22587	351	1022	70	41.07 (0.786)
Signal Box	4471	10457	6608	319	448	51	33.49 (0.597)

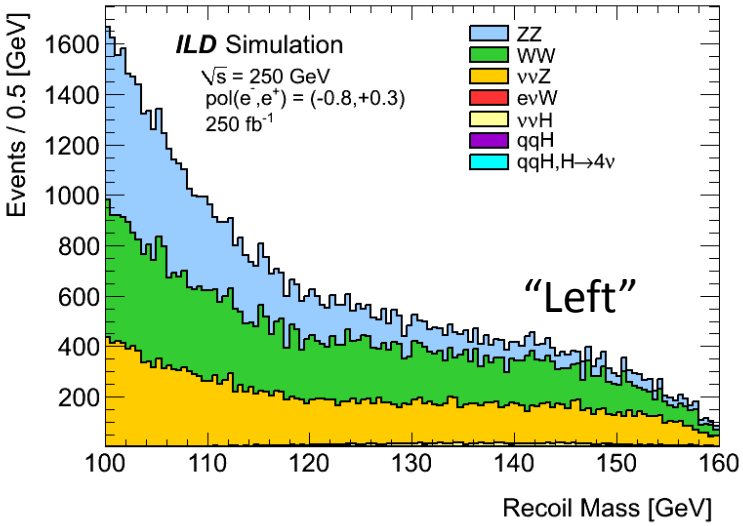
Cut Summary "Right"

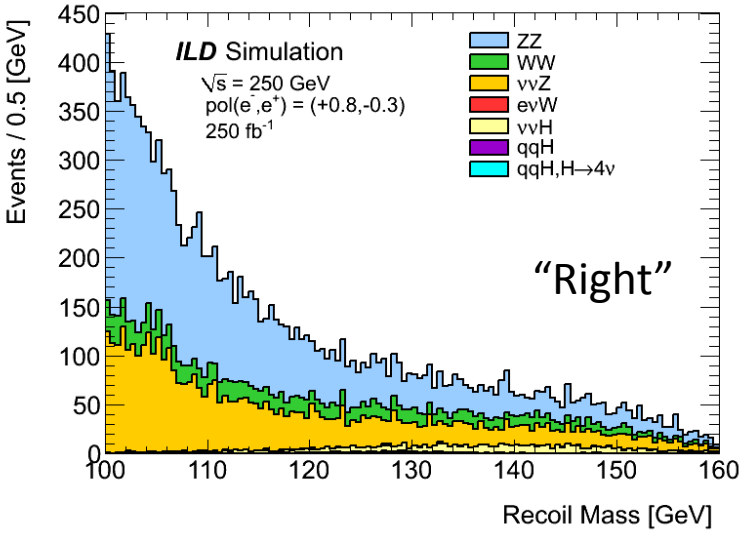
- Number of events scaled to 250fb^{-1} and (Efficiency)

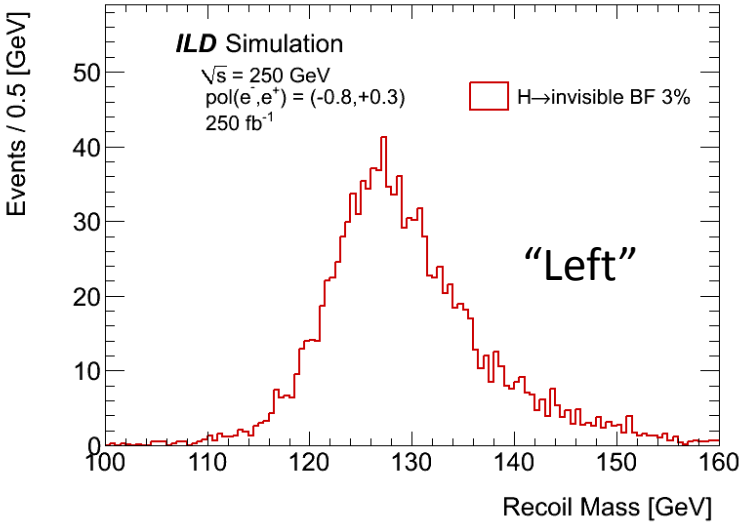
"Right"	ZZ	WW sl	nnZ	enW	nnH	qqH	qqH H→4n Pseudo signal
No cut	116797	189596	23124	25546	10646	35488	37.87 (1.000)
No lepton	91423	102778	23035	10694	9745	32552	37.68 (0.995)
Trk and PFO	89550	102416	22417	10623	9071	32548	37.38 (0.987)
M_Z	37239	12582	15997	1601	672	50	30.13 (0.796)
$\cos\theta_Z$	29694	12093	15553	1486	664	49	29.86 (0.788)
Loose M_{Recoil}	12513	2808	6984	546	634	48	29.78 (0.786)
LR	7603	1759	4434	232	512	41	24.41 (0.645)
Signal Box	1537	641	1037	211	235	31	20.14 (0.532)

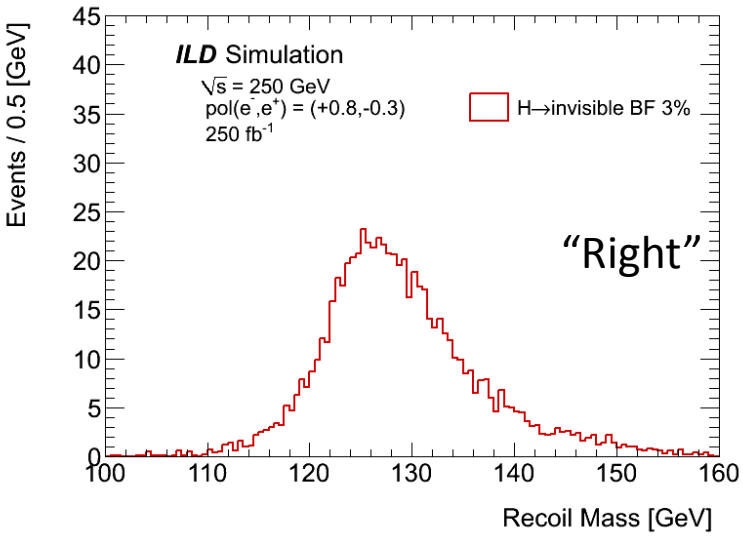
Final Recoil Mass

- Dominant backgrounds are ZZ, WW, νν̄Z



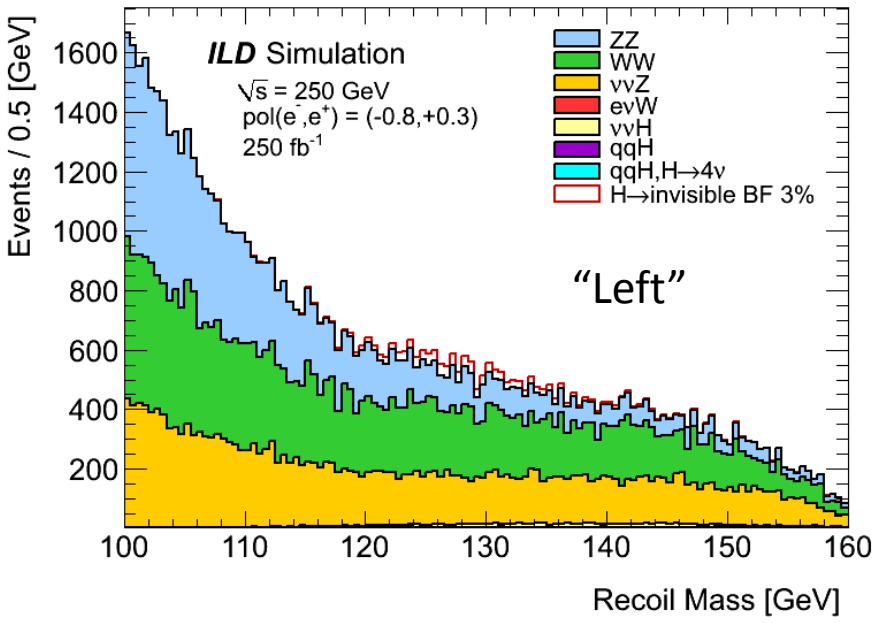


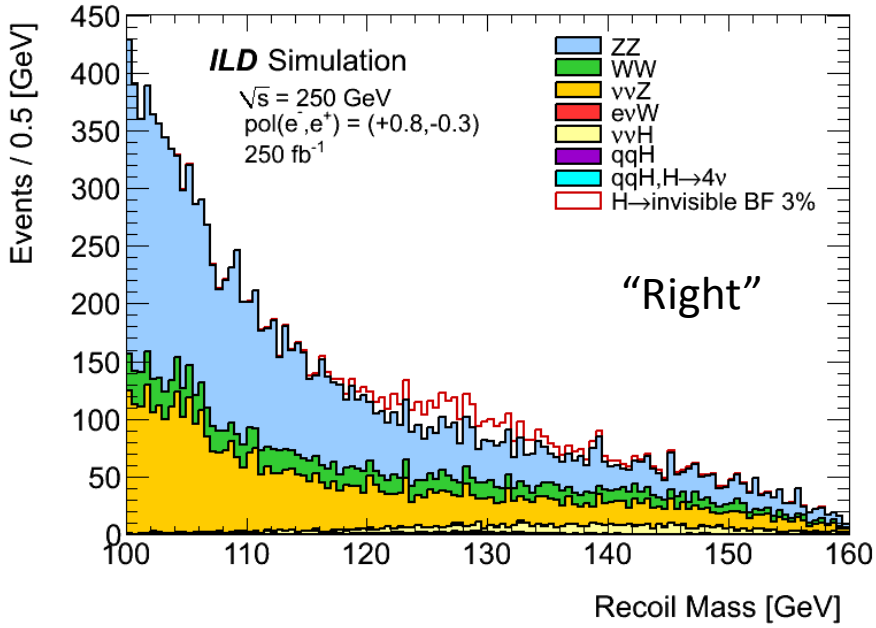




Signal Overlaid

- If BF(H→invisible) = 3%
  - Signal is clearly seen for “Right” polarization





Toy MC

- Toy MC are performed to set upper limits on the BF
  - In the fitting to M_{recoil}, Only yields for signal and backgrounds are floated.
    - The backgrounds include a peaking ZH, H→4ν component
  - 10000 pseudo experiments for each polarization
- The results with 250fb^{-1}
  - "Left" polarization : BF (H→invisible) < 0.95% @ 95% CL
  - "Right" polarization : BF (H→invisible) < 0.69% @ 95% CL
    - The invisible does not include a H→ZZ*→4ν final state.
  - If 1150fb^{-1} data is accumulated, 0.44% and 0.32% for "Left" and "Right"
- The "Right" result is consistent with fast simulator results I presented at ECFA@DESY
  - BF < 0.7% @ 95% CL

- From a crude toy MC scan, 5σ observation down to 2.8% and 2.0% for "Left" and "Right", respectively.
  - Need much more toy MC events.

Summary and Plan

- Full simulation studies of search for invisible Higgs decays at the ILD with ILC using Recoil mass technique are performed
  - e+e- →ZH, Z→qq processes
  - E_{CM}=250 GeV, ∫Ldt = 250fb^{-1} and Pol(e-,e+) = (-0.8, +0.3) and (+0.8, -0.3)
- The 95% CL upper limits on BF and lowest BFs for observation
  - 0.95% and 2.8% for “Left” polarization
  - 0.65% and 2.0% for “Right” polarization

- Estimation of the lowest BF for 5σ observation by high stat toy MC
- Combination with leptonic Z decays
- Combination with the results at E_{CM} = 350GeV and 500GeV
- Inclusion to ILC Higgs white paper