Higgs Recoil Mass and Cross-section Analysis: Impacts from the ILC designs

Hengne LI
Hengne.Li@in2p3.fr
LPSC Grenoble
LAL Orsay

Outline

- Motivation
- Importance at Low Energy
- Analysis procedure
- Beam simulation
- Integrated luminosity (assuming 4 years of data taken)
- The Fast Simulation of the ILD detector concept
- Background suppression and fitting to extract the results
- Compare the results based on various ILC designs.
- Conclusion

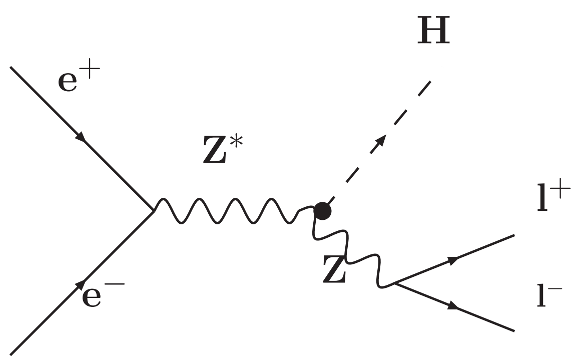
Objective of this task:

To study the impact of the ILC designs on the Higgs recoil mass and cross-section analysis.
(In other words, we use this analysis to optimize the ILC design.)

Importance of the Higgs recoil mass and cross-section analysis at the future ILC:

Advantage: Model independent signature. No assumptions on the Higgs decay are needed.
Only need the *4-momentum of the Z boson* and the *center of mass energy* to reconstruct the Higgs boson.
from detector from accelerator

Higgs-strahlung Process:



$$M_H^2 = (\sqrt{s} - E_Z)^2 - P_Z^2$$
$$g_{ZZH}^2 \propto \sigma = N/L\epsilon$$

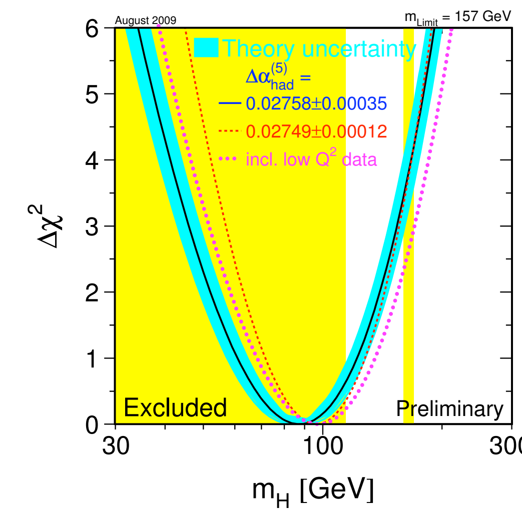
In other words, this analysis will survive even if the Higgs boson is not Standard Model (SM) like.
The model independent signature of this analysis, allows it to serve both as a precision measurement and a searching for new physics.

Importance at Low Energy

One important aspect:

The Higgs recoil mass analysis prefers a low center of mass energy at ILC, just above production threshold, E.g. 230 to 250 GeV

1) Theories (SM and beyond) and experimental evidence prefers a low mass Higgs, (thus, we assume a Higgs mass of 120 GeV through out this study)



2) Cross-section is maximal when center of mass is just above the production threshold

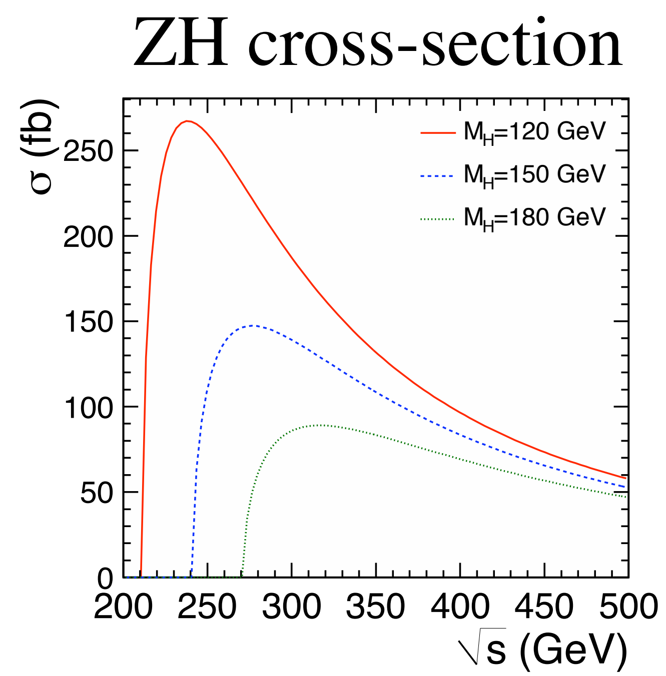
3) Best momentum resolution of lepton track measurement

$$\Delta P \propto P^2$$

Near production threshold means the minimal boost of the Z boson,

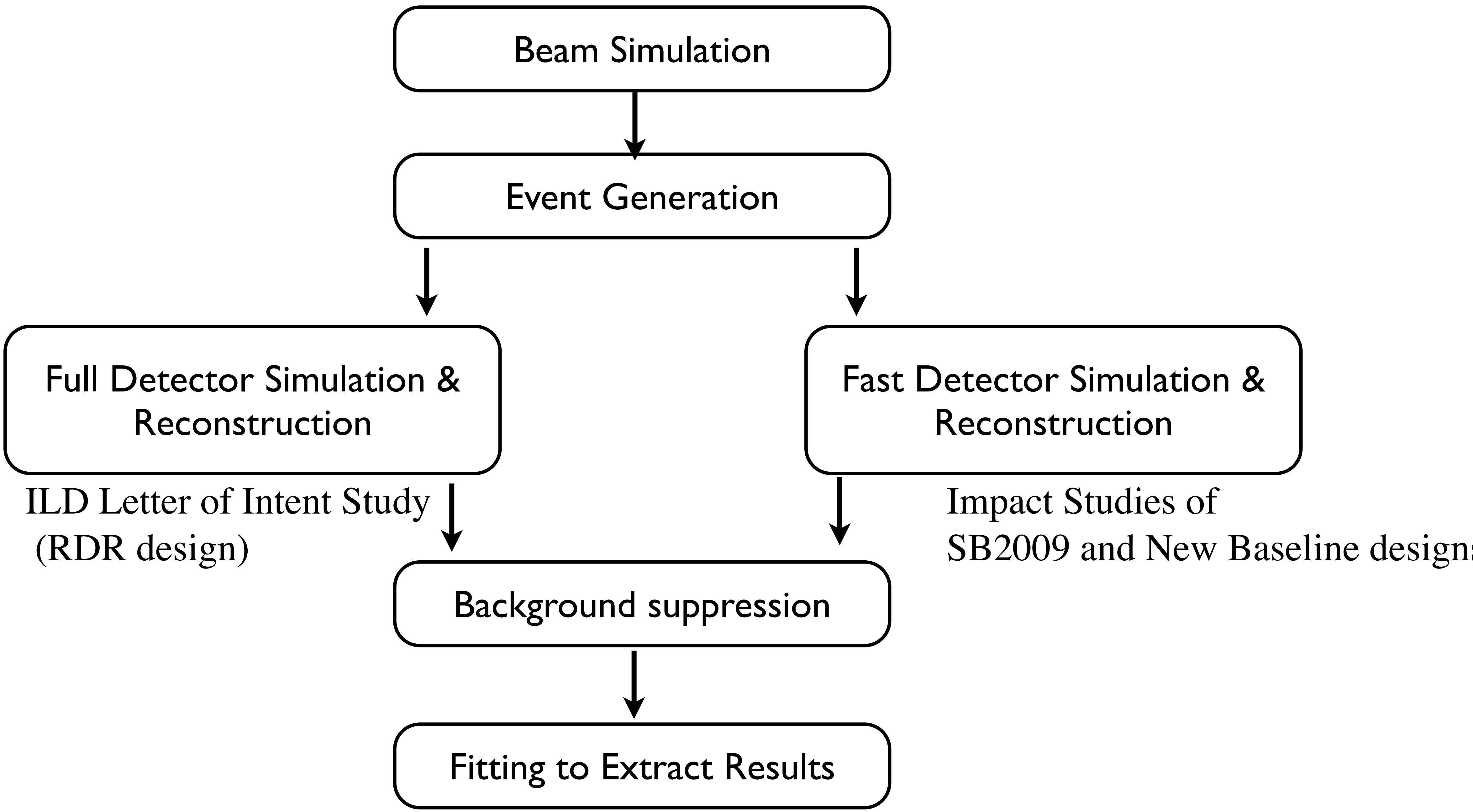
=> the minimal lepton momentum

=> best momentum resolution.



Analysis Procedure

This work is following the general procedure of the physics analysis at ILC, as shown below:

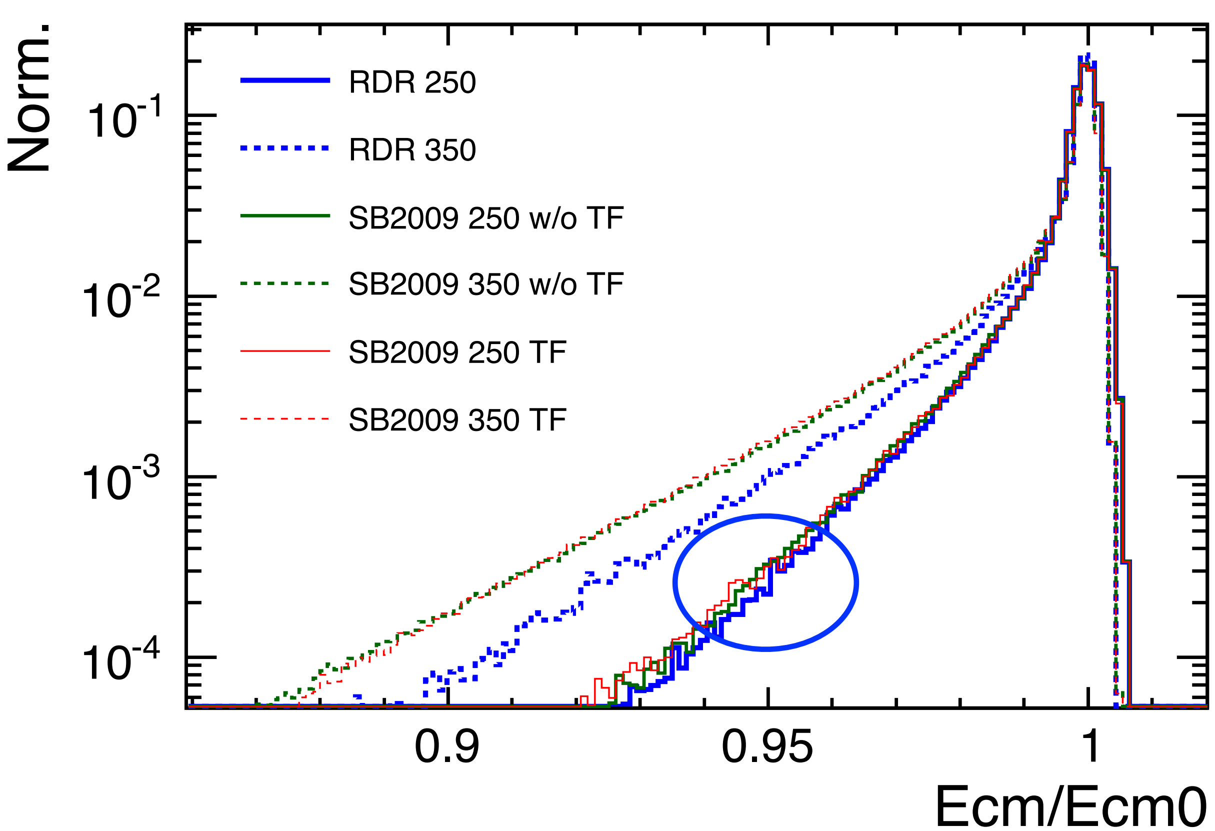


Beam Simulation

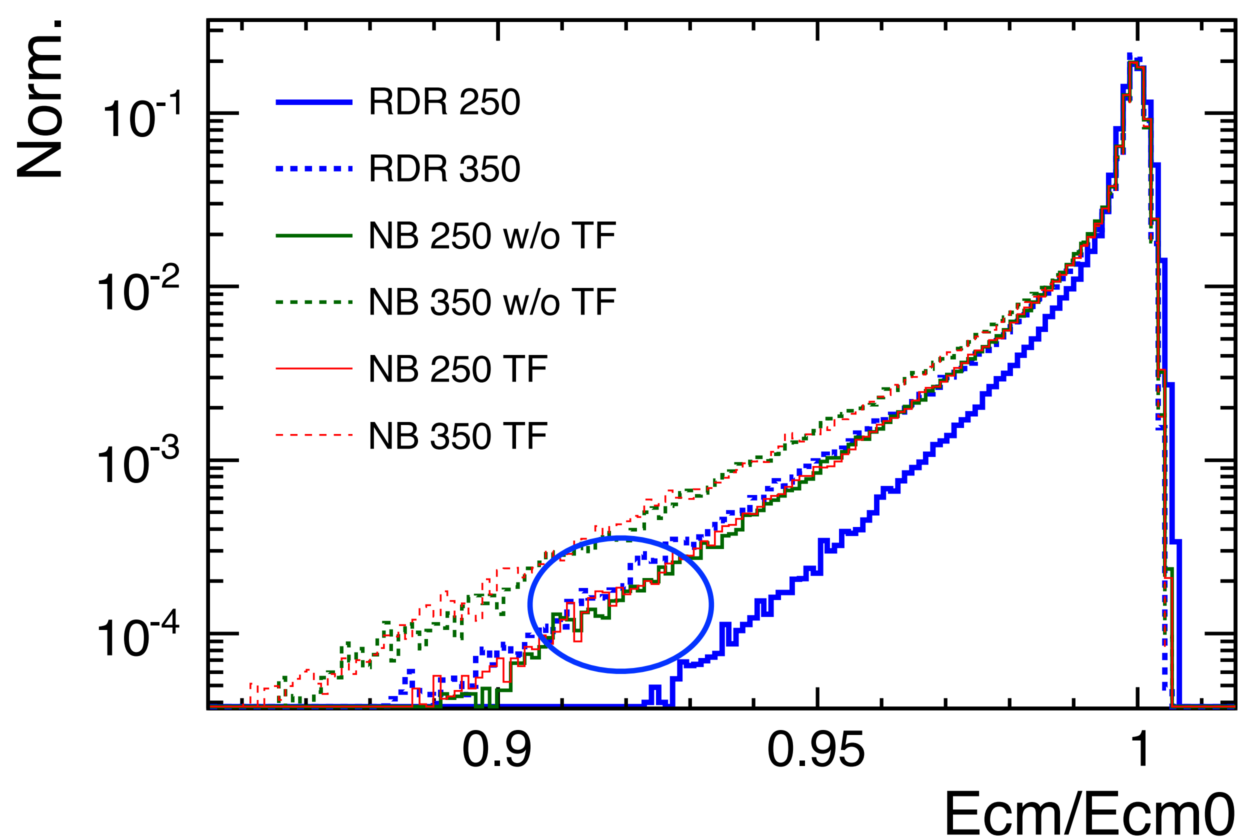
For this impact study, I simulated the beam spectra using GUINEA-PIG, then I used CALYPSO interfacing the beam simulation to PYTHIA for event generation.

Differential Luminosity Spectra

RDR vs. SB2009



RDR vs. New Baseline (NB)



From the spectrum itself, you may say: Oh, SB2009 has smaller beamstrahlung than the updated New Baseline! But wait... Let's look at the integrated luminosity first on the next slide...

Integrated Luminosity

Let's estimate the integrated luminosity assuming a four-years data taken at the future ILC.

Scale the integrated luminosity of RDR 500 GeV according the peak luminosity:

$$\mathcal{L}_{\mathrm{int}} = \frac{\mathcal{L}_{\mathrm{peak}}}{\mathcal{L}_{\mathrm{peak,RDR500}}} \cdot \mathcal{L}_{\mathrm{int,RDR500}}$$

Integrated Luminosity comparing RDR, SB2009 and New Baseline

	RDR			SB2009 w/ TF			NB w/ TF		
$\sqrt{s}$ (GeV)	250	350	500	250	350	500	250	350	500
Peak L ($10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	0.75	1.2	2.0	0.27	1.0	2.0	0.8	1.0	2.0
Integrated L (fb^{-1})	188	300	500	68	250	500	200	250	500

Thanks to GDE colleagues for the dedicated improvement at Low Energy! (reminding the importance at low energy)

For the ILD Letter of Intent study based on RDR design, we use the full GEANT4 simulation of the ILD detector.

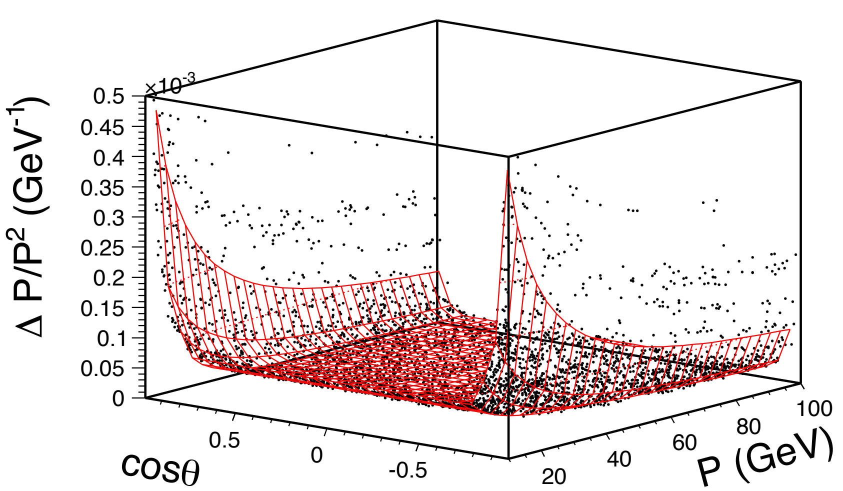
For the later on impact studies of the SB2009 and New Baseline designs, detailed detector simulation is not necessary.

We prefer fast response on every changes of the ILC design.

Thus, I developed a Fast Simulation Algorithm of the ILD detector dedicated for the Higgs recoil mass analysis using ZH->μμX channel.

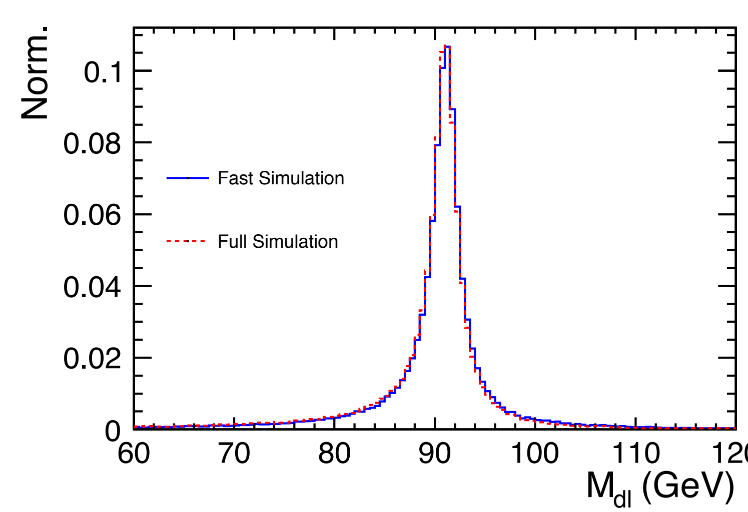
(1) Parameterize the momentum resolution using the ILD full simulation

(2) Smear the muon momentum truth according to the parameterization.

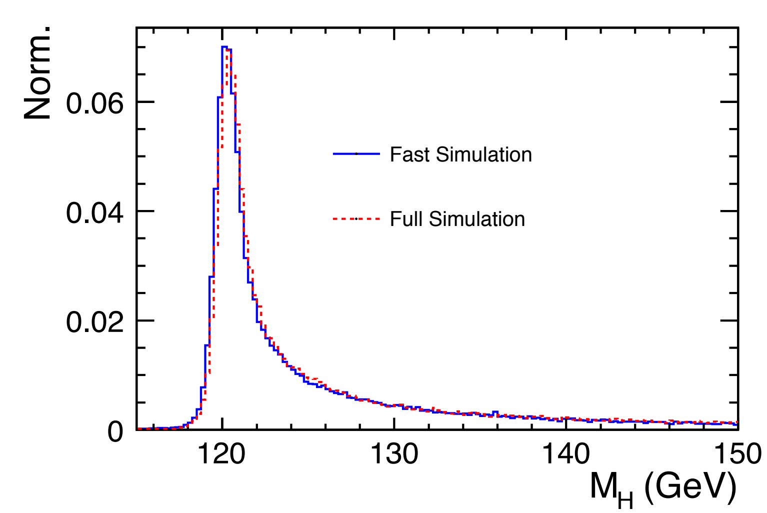


Parameterization of momentum resolution

Z invariant mass



Higgs recoil mass

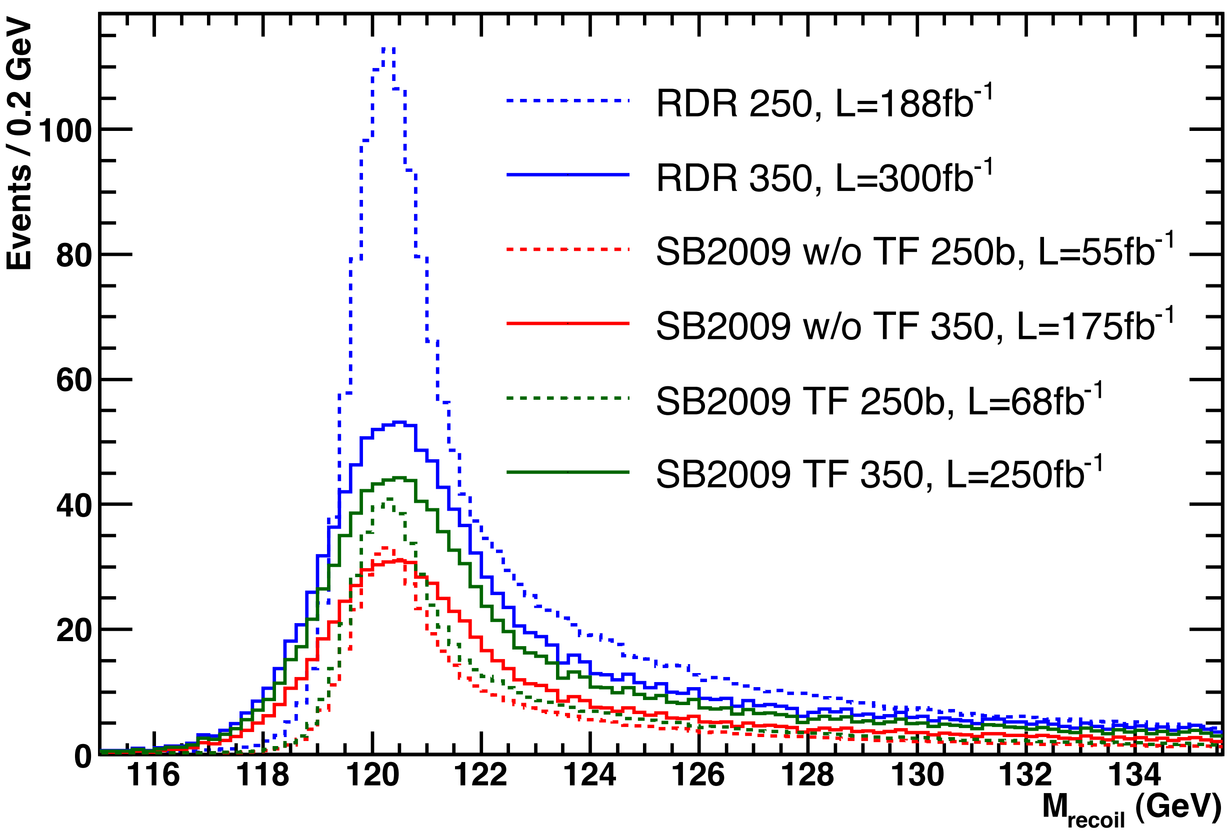


Comparing Fast Simulation with Full Simulation

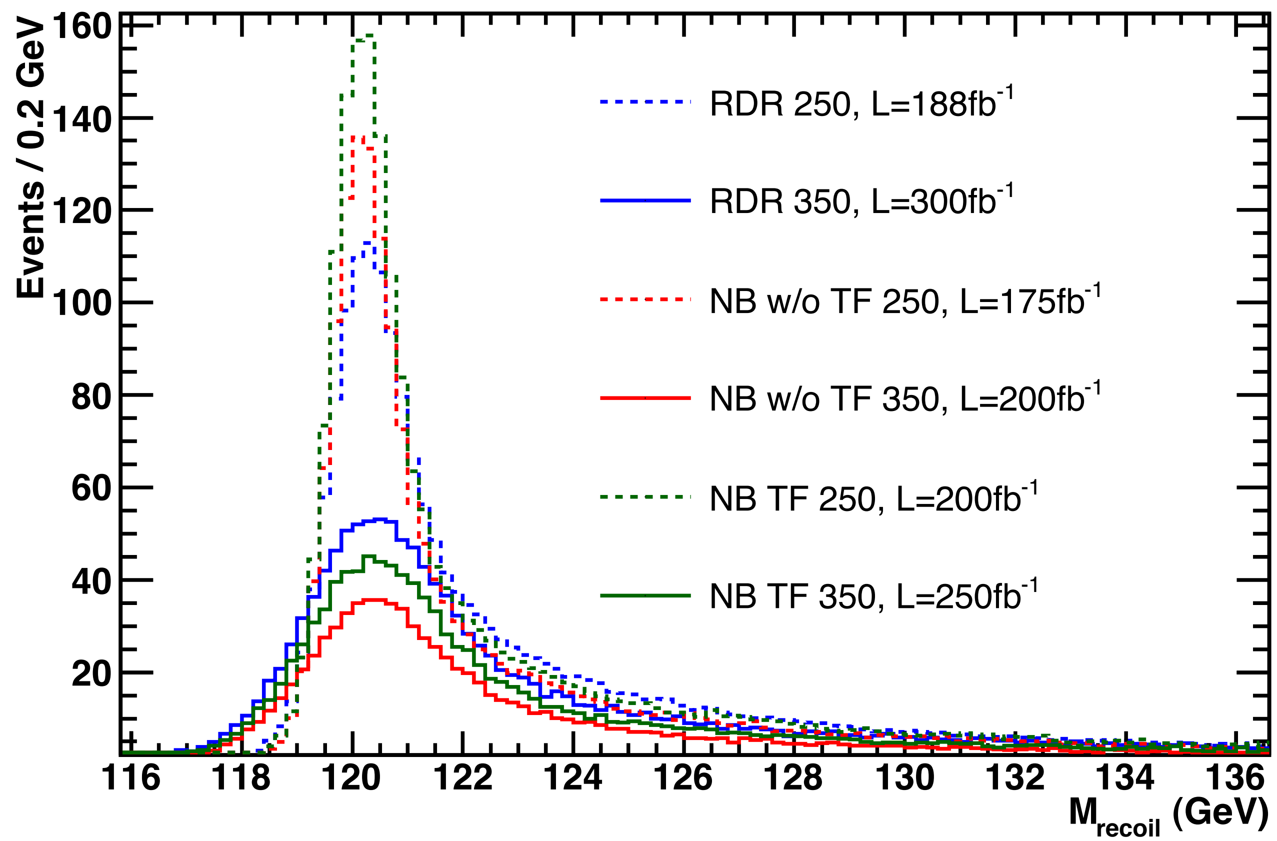
Higgs Recoil Mass Spectra after Fast Simulation

Integrated Luminosity of a 4-years data taken

RDR vs. SB2009



RDR vs. New Baseline



Comparison shows:

- 250 GeV center of mass energy gives narrower peak than 350 GeV: momentum resolution

- Luminosity is a key factor impacts this analysis.

- NB @ 250 GeV, peak is narrower compared to RDR @ 250 GeV:

Smaller beam energy spread: RDR250 (e^- 0.28%, e^+ 0.18%) vs. NB250 (e^- 0.22%, e^+ 0.14%)

Background Suppression

The ILD Letter of Intent full simulation study based on RDR design considers all the 2-lepton and 4-lepton final states backgrounds. It shows only the ZZ and WW backgrounds are irreducible.

Thus, the impact study for SB2009 and New Baseline designs only takes the ZZ and WW backgrounds under consideration.

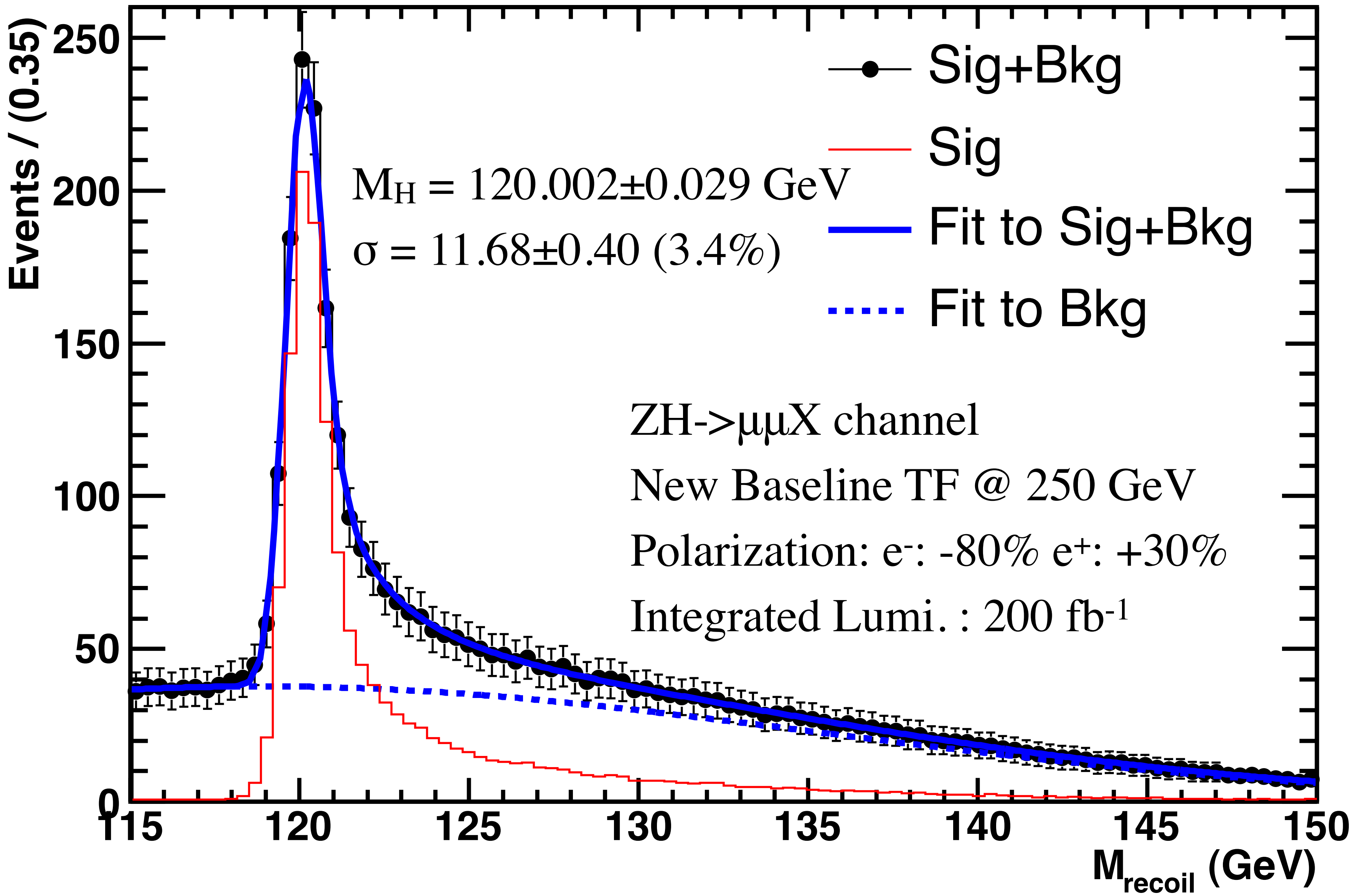
Same Strategy as developed in the Letter of Intent study:

Cut-Chain
(1) $\lvert\cos\theta_\mu\rvert < 0.99$
(2) $P_{Tdl} > 20$ GeV
(3) $M_{dl} \in (80,\ 100)$ GeV
(4) $acop \in (0.2,\ 3.0)$
(5) $M_{recoil} \in (115,\ 150)$ GeV
(6) Likelihood Further Rejection
(using variables P_{Tdl}, $\cos\theta_{dl}$, M_{dl} and $acol$)

The remaining background is mostly the ZZ production.

The Higgs mass and cross-section is thereafter extracted by fitting a composed function to the signal-plus-background spectrum.

A typical fit of the signal-plus-background spectrum:



ZH->μμX channel

Polarization: e-: -80% e+: +30%

Beam Par	$\mathcal{L}_{\text{int}}$ (fb^{-1})	ϵ	S/B	M_H (GeV)	σ (fb) ($\delta\sigma/\sigma$)
RDR 250	188	55%	62%	120.001 ± 0.043	11.63 ± 0.45 (3.9%)
RDR 350	300	51%	92%	120.010 ± 0.087	7.13 ± 0.28 (4.0%)
SB2009 w/o TF 250	55	55%	62%	120.001 ± 0.079	11.63 ± 0.83 (7.2%)
SB2009 w/o TF 350	175	51%	92%	120.010 ± 0.110	7.13 ± 0.37 (5.2%)
SB2009 w/TF 250	68	55%	62%	120.001 ± 0.071	11.63 ± 0.75 (6.4%)
SB2009 w/TF 350	250	51%	92%	120.010 ± 0.092	7.13 ± 0.31 (4.3%)
NB w/o TF 250	175	61%	62%	120.002 ± 0.032	11.67 ± 0.42 (3.6%)
NB w/o TF 350	200	52%	84%	120.003 ± 0.106	7.09 ± 0.35 (4.9%)
NB w/TF 250	200	63%	59%	120.002 ± 0.029	11.68 ± 0.40 (3.4%)
NB w/TF 350	250	51%	89%	120.005 ± 0.093	7.09 ± 0.31 (4.4%)

Comparison:

- New Baseline design @ 250 GeV gives the best results: better than the RDR design
- Importance at the low energy: Even with 4 times smaller luminosity (68fb^{-1}/250fb^{-1}), SB2009 @ 250 GeV can still give better result on the Higgs mass measurement than SB2009 @ 350GeV.
- 350 GeV center of mass energy gives better signal over background (S/B)

Conclusion

- Model independent signature of the Higgs recoil mass and cross-section analysis
- The Higgs recoil mass and cross-section analysis at ILC prefers a low center of mass energy (230 to 250 GeV).
  - E.g. at 350GeV we cannot get better result than at 250GeV, even with a 4 times larger integrated luminosity.
- The New Baseline design favorites very well the Higgs recoil mass and cross-section analysis at low center of mass energy (250 GeV):
  - $\delta(M_H)$: 34 MeV (RDR) => 29 MeV (NB w/TF)
  - $\delta(\sigma)$: 3.9% (RDR) => 3.4% (NB w/TF)

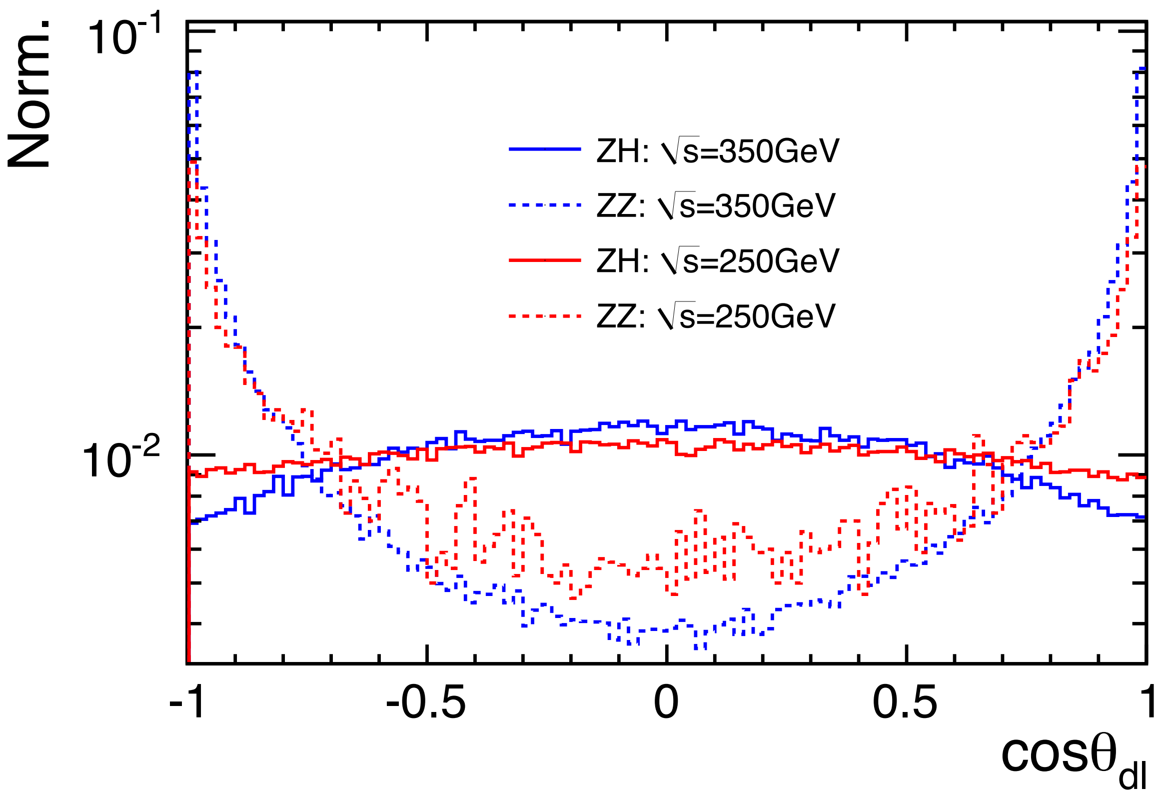
Backup Slides

S/B ratio higher @ 350 GeV

The signal over background ratio (S/B) is higher at 350 GeV center of mass than at 250 GeV, because the kinetics at 350 GeV allows better signal-background separation:

For example, the two variables below are used in the background suppression. At 350 GeV, we indeed can observe better separation between signal and background.

Z cosθ distribution of ZH and ZZ



Z momentum distribution of ZH and ZZ