Higgs Recoil Mass Study using Z→ll at ECM=250, 350 GeV and 500 GeV ILC

ILC Physics Meeting

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OUTLINE

- **Improvement after implementing visible energy cut**

  (separate into visible and invisible Higgs decay)

  ➔ **suppress the major BG $ll\nu\nu$**

- **study of Higgs decay mode dependence**

  using high statistics sample generated for EACH DECAY MODE

  previously at 250 GeV

  this time also at 350 GeV

  ➔ improved lepton finder shows effect

Lepton Pair Candidate Selection

opposite +/− 1 charge

- E_cluster / P_total : < 0.5 (μ) / > 0.9 (e)
- isolation (small cone energy)
  → removes nearly all 4f_WW_sl BG
- Minv closest to Z mass
- |D0/δD0| < 5

Data selections designed to guarantee Higgs decay mode independence

Optimized in terms of signal significance and xsec measurement precision

definition

- M_inv : invariant mass of 2 muons
- pt_dl : pt of reconstructed lepton pair
- pt,γ : pt of most energetic photon
- θ_missing = polar angle of undetected particles
- θ_Z = Z production angle

Final Selection

- 73 < GeV < M_inv < 120 GeV
- 10 GeV < pt_dl < 140 GeV
- $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ > 10 GeV
- |cos(θ_missing)| < 0.98
- |cos(θ_Z)| < 0.9
- 100 GeV < Mrecoil < 160 GeV
- Likelihood cut

Example of ECM=350 GeV,

- Effective for cutting $\mu\mu$ / ee BG
- Use info of most energetic photon (pt_γ , cone energy)

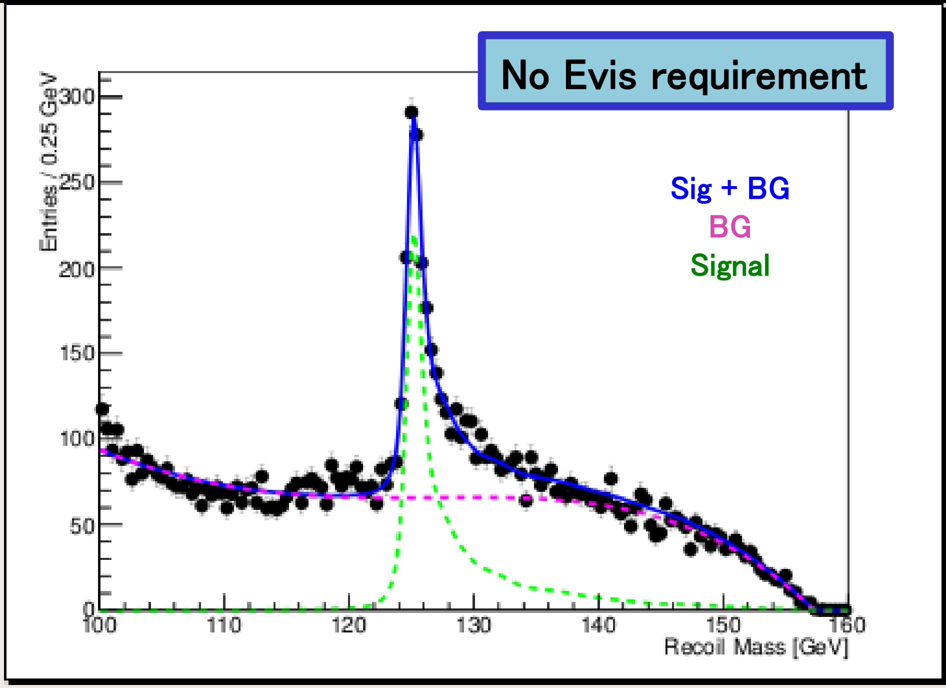
meanwhile minimize bias on signal

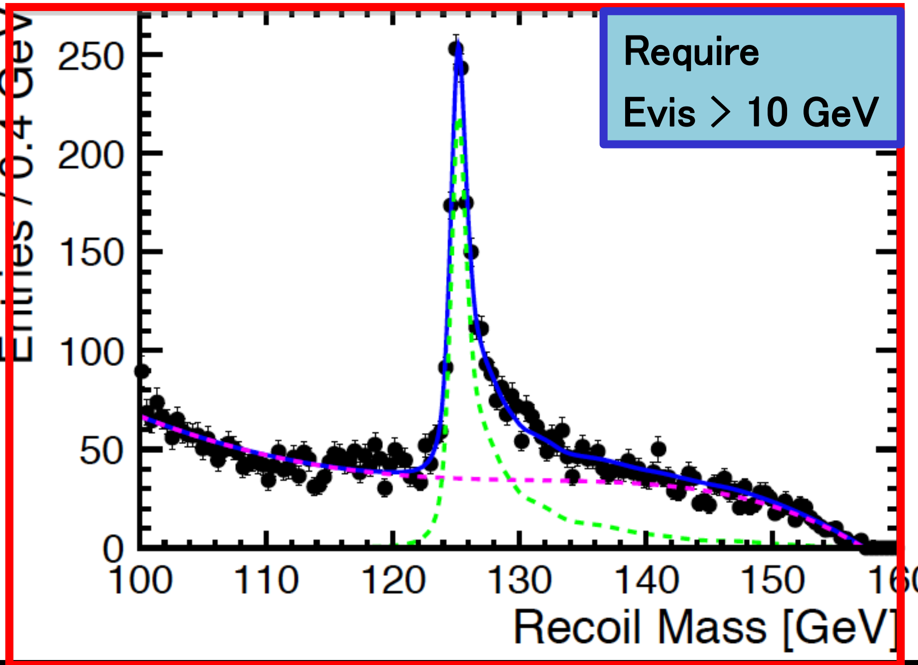
red box:
key improvements w.r.t. previous studies

similar methods applied to all ECM and polarizations

Z→μμ channel

250 GeV : (− 0.8, + 0.3)





after requiring Evis (visible energy) > 10 GeV i.e. only visible Higgs Decay

- signal peak is apparently sharper
- $ll\nu\nu$ (ZZWWMiix) BG reduced by a factor of 5

In order to maintain model independence, xsec errors need to be convoluted with results from invisible Higgs decay analysis (corresponding to BSM)

https://agenda.linearcollider.org/event/6557/session/12/contribution/129/material/slides/0.pdf

the contribution should be small

	250 GeV			350 GeV			500 GeV		
	new	old	improvement	new	old	improvement	new	old	improvement
xsecL	**2.45%**	**2.74%**	**10.58%**	**3.02%**	**3.21%**	**5.92%**	**4.64%**	**5.01%**	**7.39%**
xsecR	**2.83%**	**2.93%**	**3.41%**	**3.43%**	**3.55%**	**3.38%**	**5.17%**	**5.33%**	**3.00%**
massL	**33.8**	**37.9**	**10.82%**	**86.5**	**96.5**	**10.36%**	**456**	**448**	**−1.79%**
massR	**38.2**	**38.4**	**0.52%**	**97.5**	**105**	**7.14%**	**540**	**536**	**−0.75%**
xsecZmmL	2.98%	3.35%	11.04%	3.68%	3.90%	5.64%	6.09%	6.50%	6.31%
xsecZmmR	3.45%	3.57%	3.36%	4.17%	4.31%	3.25%	6.99%	7.27%	3.85%
xsecZeeL	4.30%	4.76%	9.66%	5.26%	5.63%	6.57%	7.25%	7.86%	7.76%
xsecZeeR	4.96%	5.14%	3.50%	6.04%	6.26%	3.51%	7.67%	7.86%	2.42%
massZmmL	36	40.4	10.89%	90.2	101	10.69%	479	468	−2.35%
massZmmR	40.5	40.5	0.00%	104	112	7.14%	580	572	−1.40%
massZeeL	97.4	109	10.64%	306	327	6.42%	1500	1540	2.60%
massZeeR	116	121	4.13%	281	296	5.07%	1480	1530	3.27%

From Junping-san's talk at ALCW2015

BR(inv) upper limit	P(e-,e+) =(-0.8,+0.3)	P(e-,e+) =(+0.8,-0.3)
250 fb^{-1} @ 250 GeV	0.86%	0.61%
330 fb^{-1} @ 350 GeV	1.23%	1.10%
500 fb^{-1} @ 500 GeV	2.39%	1.73%

Combined Higgs visible and invisible decay results

	250 GeV	350 GeV	500 GeV
xsecL	2.49%	3.08%	4.79%
xsecR	2.85%	3.47%	5.24%
massL [MeV]	33.8	86.5	456
massR [MeV]	38.2	97.5	540

250 GeV :

> 10% improvement in precision of both xsec and mass

Now, xsec precision is better than extrapolated result in TDR

xsec and mass scaled to H20 are comparable with the physics case paper

350 GeV:

> 10% improvement in mass precision

About 6% improvement in xsec

500 GeV:

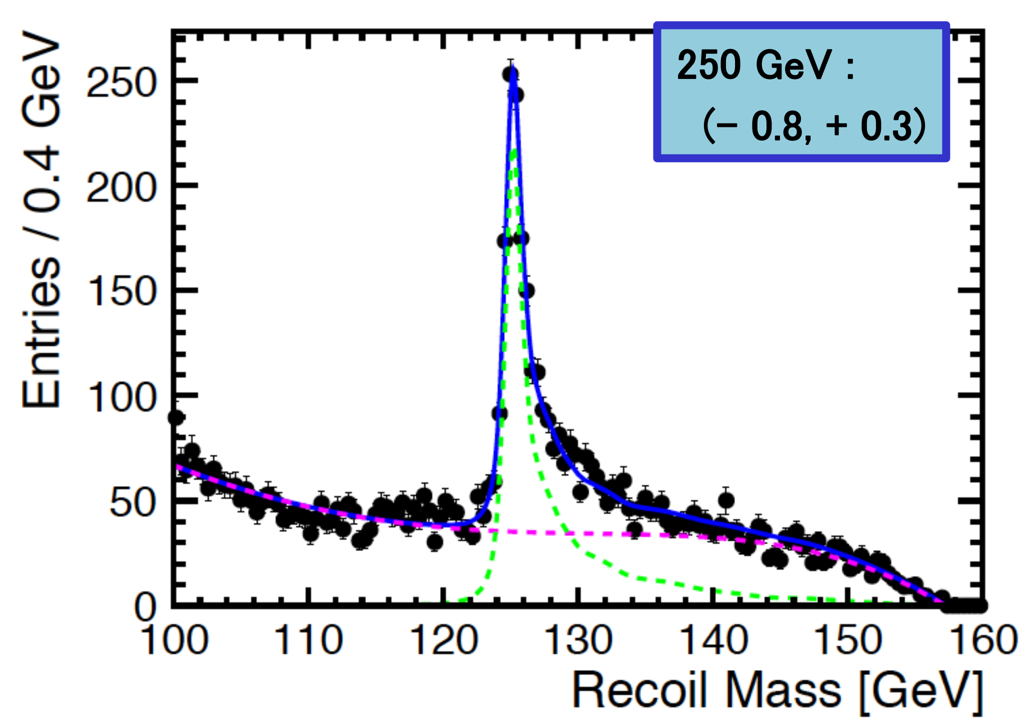
About 7% improvement in xsec precision

Mass is not improved

Anyways we don't depend on 500 GeV for precise mass measurement

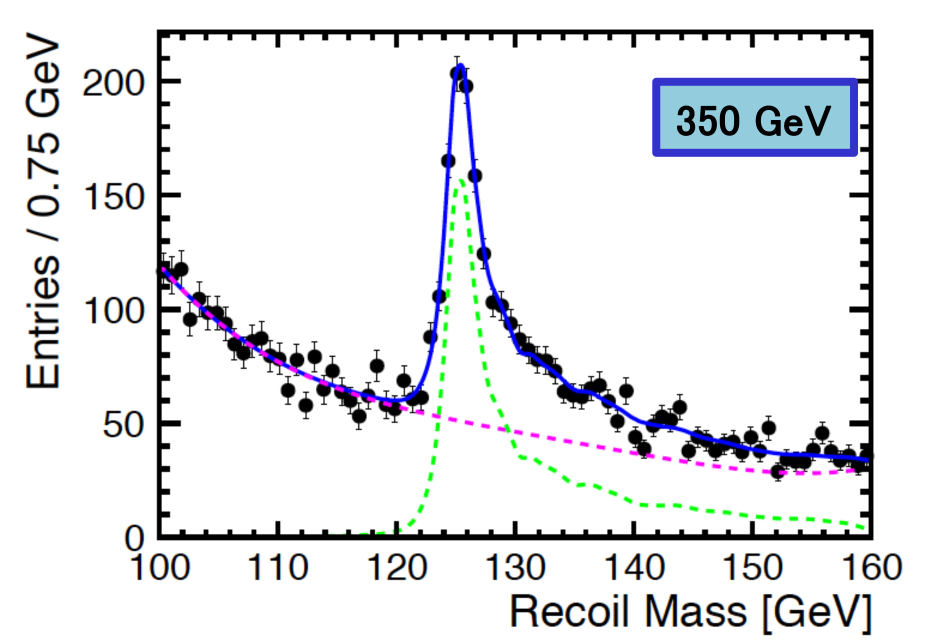
And mass measurement doesn't need to be model independent

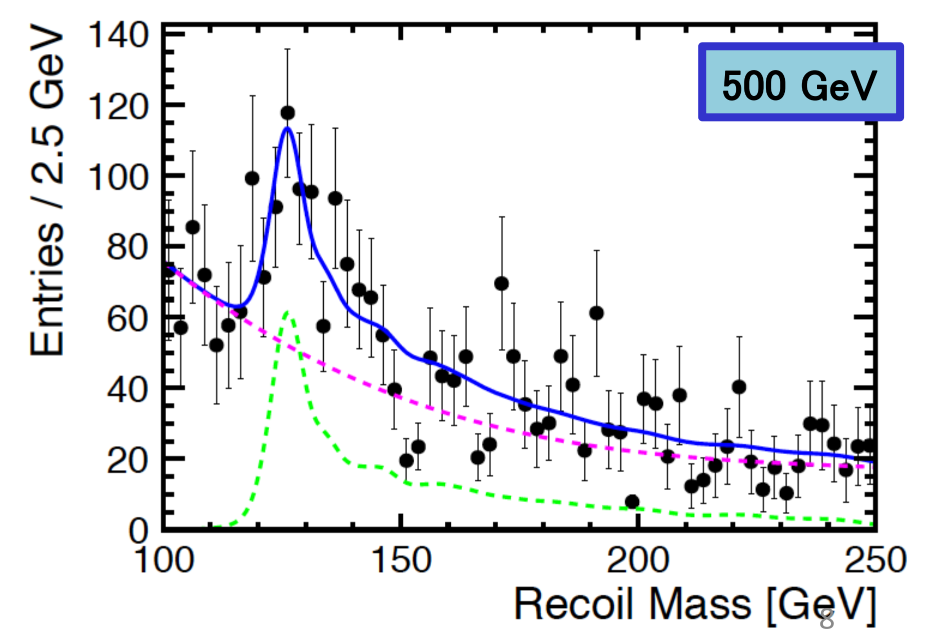
250 GeV shows most significant improvement because vvll BG occupies > 30% of residual BG, whereas < 10% for 350 or 500 GeV



Z→μμ channel

Sig + BG
BG
Signal





+ α

Interesting point that for Zee channel,
dilepton processor efficiency is lower for higher ECM w.r.t. 250 GeV
due to ZZ fusion process
(e.g. 350 GeV is 10% less than 250 GeV)

c.f. Efficiency for Zmm is nearly independent of ECM

Until now
Higgs decay mode bias due to both signal selection AND BG rejection have been studied / suppressed.

Here are the results proving Higgs mode independence

Higgs Decay Mode Bias

Problem#1

isolated lepton finder efficiency is lower for H→ gg, ww

due to more overlap of jets from Higgs decay

already resolved thanks to new weights trained by Junping-san

used **H→gg mode to train weight for TMVA** (before: qqqq

Now: gg mode suffers almost no bias, consistent efficiency with bb, cc

Problem#2

"wrong lepton pairing" for H→ zz, ww

•Even if leptons are from a non−prompt Z, they might satisfy Minv, but not Mrec
leads to low efficiency due to cuts on Invariant mass and recoil mass in analysis stage

IMPROVEMENT: For Zmm channel : **select best pair by minimizing chi^2 based on Mrec and Minv**
(c.f. before: select pair with Minv closest to Z mass)

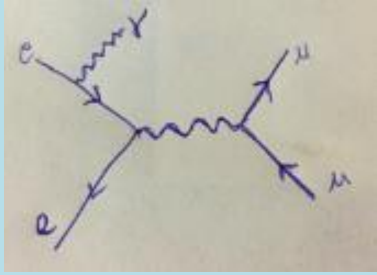
Problem#3

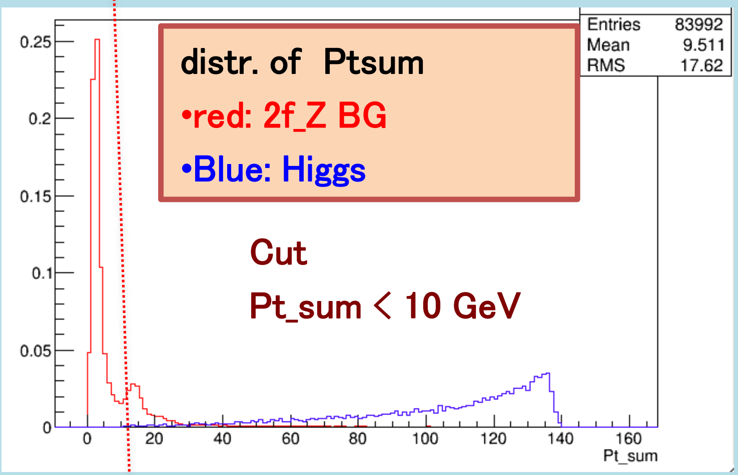
Cos(θmiss) cut and Ptsum cut bias H→ γγ 、 ττ (tolerable ?)

•These **cannot be sacrificed** due to xsec precision and negligible after weigh by BR

Prevention of signal bias i.e. Higgs decay mode dependence

- the "traditional" dptbal (= |Pt,dl | − |Pt, γ |) cut for removing 2f BG (γ back–to back w.r.t. di–lepton) caused signal bias (esp. H → τ τ , γ γ)



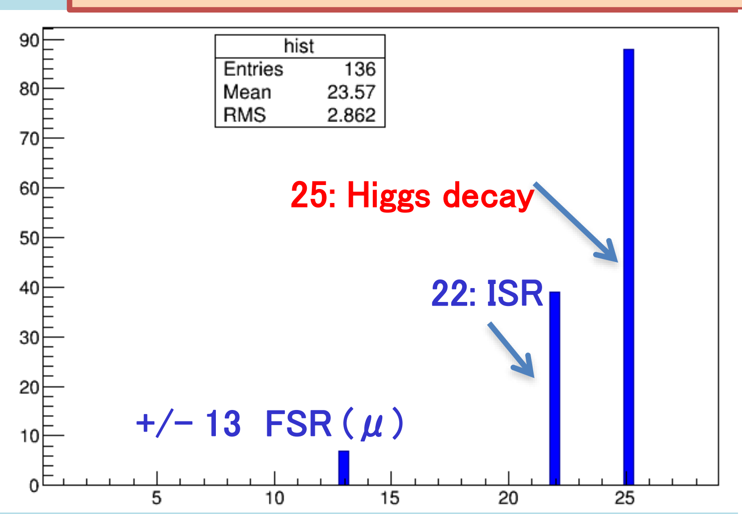


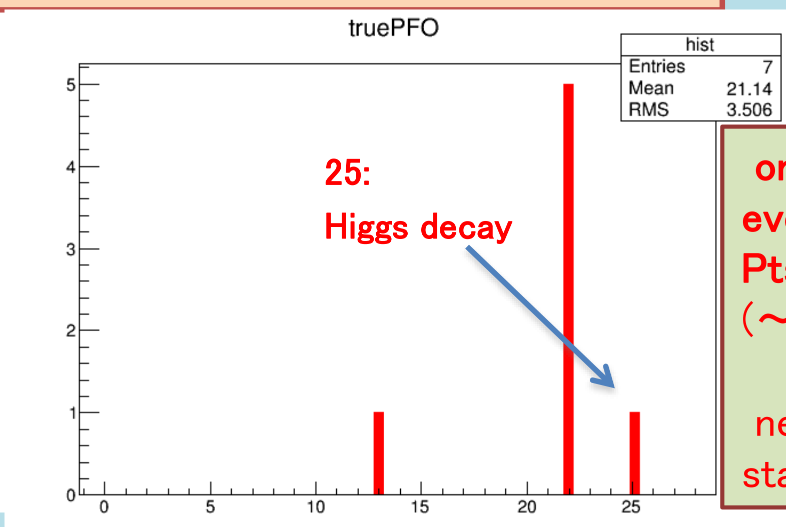
NEW #1 isolated photon finder: γ we look at have small cone energy) not from Higgs decay

NEW #2 Now use $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ (instead of dptbal)

vector direction info singles out back to back events

PDG of γ for events removed by Ptsum /dptbal cut (250 GeV Zmm)





only < few unweighed events removed by Ptsum cut
(∼ 0 weighed events)

negligible compared to statistical uncertainties

∼100 Higgs decay related γ events removed by dptbal cut !!

need more careful study of Higgs decay mode bias using high stat sample

lepton pairing mistake is reduced for ZZ, WW modes without additional bias on other modes

OLD

	250 GeV zz	250 GeV ww	350 GeV zz	350 GeV ww
Total	100.00%	100.00%	100.00%	100.00%
C1	94.66%	98.13%	94.40%	97.69%
C2	4.97%	1.46%	5.32%	2.00%
C3	4.63%	0.46%	4.77%	0.59%

NEW

	250 GeV zz	250 GeV ww	350 GeV zz	350 GeV ww
Total	100.00%	100.00%	100.00%	100.00%
C1	95.47%	98.29%	95.64%	98.27%
C2	4.26%	1.37%	4.08%	1.42%
C3	3.85%	0.48%	3.68%	0.60%

C1: correct

Pairing mistake — C2: two real leptons exist, but at least one wrong lepton

C3: both leptons wrong

- 250 GeV: No apparent improvement on final efficiency (after all other cuts)
- 350 GeV: improvement shows up in final efficiency !!
  (rise by 0.5 – 1%, statistically significant)

H→zz mode BR is very small , so overall 4.3% x 2% ～ 0.09 %

H→WW* has large BR !! *→ is the remaining bias this a worry ?*

350 GeV , OLD

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	93.63 +/-0.078	93.84 +/-0.076	93.31 +/- 0.08	94.1 +/-0.076	94.07 +/-0.075	94.13 +/-0.075	93.94 +/-0.076
Cut1 :	93.63 +/-0.078	93.84 +/-0.076	93.31 +/- 0.08	94.09 +/-0.076	94.03 +/-0.076	93.93 +/-0.076	93.93 +/-0.076
Cut2 :	93.17 +/-0.081	93.36 +/-0.079	92.86 +/-0.082	93.49 +/- 0.08	93.12 +/-0.081	92.9 +/-0.082	92.95 +/-0.081
Cut3 :	91.09 +/-0.091	91.35 +/-0.089	90.8 +/-0.092	91.26 +/-0.091	90.8 +/-0.092	90.46 +/-0.094	90.72 +/-0.092
Cut4 :	90.93 +/-0.092	91.19 +/- 0.09	90.68 +/-0.093	91.09 +/-0.092	90.66 +/-0.093	90.33 +/-0.094	90.62 +/-0.092
Cut5 :	90.89 +/-0.092	91.16 +/- 0.09	90.65 +/-0.093	90.93 +/-0.093	90.61 +/-0.093	90.27 +/-0.095	88.38 +/- 0.1
Cut6 :	87.74 +/- 0.1	88.07 +/- 0.1	87.54 +/- 0.11	89.84 +/-0.098	88.16 +/- 0.1	87.61 +/- 0.11	65.6 +/- 0.15
Cut7 :	82.94 +/- 0.12	83.18 +/- 0.12	82.86 +/- 0.12	84.6 +/- 0.12	83.04 +/- 0.12	82.78 +/- 0.12	62.33 +/- 0.15
Cut8 :	68.01 +/- 0.15	68.24 +/- 0.15	67.98 +/- 0.15	68.5 +/- 0.15	67.08 +/- 0.15	65.2 +/- 0.15	56.9 +/- 0.16
Cut9 :	68.01 +/- 0.15	68.24 +/- 0.15	67.98 +/- 0.15	68.35 +/- 0.15	67.06 +/- 0.15	62.6 +/- 0.15	56.9 +/- 0.16
Cut10:	55.04 +/- 0.16	55.21 +/- 0.16	55.12 +/- 0.16	55.03 +/- 0.16	54.14 +/- 0.16	50.17 +/- 0.16	48.88 +/- 0.16

Cut8 is final cut before fitting

350 GeV, NEW

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	93.63 +/-0.078	93.84 +/-0.076	93.31 +/- 0.08	94.1 +/-0.076	94.07 +/-0.075	94.13 +/-0.075	93.94 +/-0.076
Cut1 :	93.63 +/-0.078	93.84 +/-0.076	93.31 +/- 0.08	94.09 +/-0.076	94.03 +/-0.076	93.93 +/-0.076	93.93 +/-0.076
Cut2 :	93.17 +/-0.081	93.36 +/-0.079	92.86 +/-0.082	93.51 +/- 0.08	93.13 +/-0.081	92.89 +/-0.082	92.95 +/-0.081
Cut3 :	91.08 +/-0.091	91.35 +/-0.089	90.8 +/-0.092	91.2 +/-0.092	90.63 +/-0.093	90.3 +/-0.095	90.72 +/-0.092
Cut4 :	90.92 +/-0.092	91.19 +/- 0.09	90.68 +/-0.093	91.02 +/-0.093	90.49 +/-0.094	90.16 +/-0.095	90.62 +/-0.092
Cut5 :	90.89 +/-0.092	91.16 +/- 0.09	90.65 +/-0.093	90.87 +/-0.093	90.44 +/-0.094	90.11 +/-0.095	88.38 +/- 0.1
Cut6 :	87.73 +/- 0.1	88.07 +/- 0.1	87.54 +/- 0.11	89.77 +/-0.098	87.99 +/- 0.1	87.37 +/- 0.11	65.6 +/- 0.15
Cut7 :	82.93 +/- 0.12	83.18 +/- 0.12	82.86 +/- 0.12	84.53 +/- 0.12	82.91 +/- 0.12	82.54 +/- 0.12	62.33 +/- 0.15
Cut8 :	68.02 +/- 0.15	68.24 +/- 0.15	67.98 +/- 0.15	68.67 +/- 0.15	67.71 +/- 0.15	66.13 +/- 0.15	56.9 +/- 0.16
Cut9 :	68.02 +/- 0.15	68.24 +/- 0.15	67.98 +/- 0.15	68.52 +/- 0.15	67.69 +/- 0.15	63.53 +/- 0.15	56.9 +/- 0.16
Cut10:	55.04 +/- 0.16	55.22 +/- 0.16	55.12 +/- 0.16	55.2 +/- 0.16	54.67 +/- 0.16	51.01 +/- 0.16	48.88 +/- 0.16

Proved that after weighed by SM BR, mode bias is negligible.

Zmm 250 GeV

	eff(final)	dev*BR
bb	82.58%	0.170%
cc	82.59%	0.008%
gg	82.50%	0.018%
tt	82.02%	−0.017%
ww	81.98%	−0.066%
zz	82.02%	−0.007%
aa	68.38%	−0.032%
	avg eff:	82.29%

Zee 250 GeV

	eff(final)	dev*BR
bb	78.14%	0.237%
cc	78.14%	0.011%
gg	77.69%	−0.003%
tt	77.32%	−0.026%
ww	77.44%	−0.063%
zz	75.74%	−0.053%
aa	64.69%	−0.030%
	avg eff:	77.73%

Efficiency values weighed by SM BR

	BR
bb	57.8%
cc	2.7%
gg	8.6%
tt	6.4%
ww	21.6%
zz	2.7%
aa	0.2%

Zmm 350 GeV

	eff(final)	dev*BR
bb	68.02%	0.092%
cc	68.24%	0.010%
gg	67.98%	0.010%
tt	68.67%	0.052%
ww	67.71%	−0.032%
zz	66.13%	−0.046%
aa	56.90%	−0.025%
	avg eff	67.86 %

Zee 350 GeV

	eff(final)	dev*BR
bb	47.02%	0.225%
cc	46.92%	0.008%
gg	46.77%	0.012%
tt	46.98%	0.022%
ww	45.88%	−0.162%
zz	44.79%	−0.049%
aa	47.02%	−0.015%
	avg eff	46.63%

Note !
Overall eff is dragged by ww

Zee suffers more from mistakes

- **upper limit on syst error on xsec from mode bias is**
- **Zmm : 250 GeV: 0.17% 350 GeV: 0.09%**
- **Zee: 250 GeV: 0.24% 350 GeV: 0.23%**

well below the smallest xsec statistical error we expect by end of H20 run
(0.8% , scaled from the 2.6% in TDR)

Higgs recoil study using **e+e- → ZH → l+l-**H (l = μ / e)
@ ECM = 250 , 350 , 500 GeV

Summary

studied impact of ECM and polarization on model – independent measurement of ZH xsec

< best-so-far Preliminary results > (both leptonic channels combined)

	250 GeV	350 GeV	500 GeV
xsecL	**2.49%**	**3.08%**	**4.79%**
xsecR	**2.85%**	**3.47%**	**5.24%**
massL (MeV)	**33.8**	**86.5**	**456**
massR (MeV)	**38.2**	**97.5**	**540**

Model independent

Combined Higgs visible and invisible decay

xsec precision :

- **ECM= 350 GeV worse by 24 % w.r.t. 250 GeV**
- **right pol worse by 10-15 % w.r.t. left pol.**

Higgs mass precision:
ECM=350 GeV worse by factor of < 3 w.r.t. ECM = 250 GeV

- **right pol worse by 10-15 % w.r.t. left pol.**

Note : extrapolated results (TDR) for 250 GeV : xsec error 2.6%, ΔM = 32 MeV
methods are slightly different, hard to directly compare

- **Higgs decay mode dependence has been investigated in depth**
- **systematic error due to mode bias is far below best achievable xsec precision (most likely for any ECM)**

Next Steps: Trying to get started on Higgs hadronic recoil

- **as well as the Higgs recoil paper in progress**

Higgs recoil Paper in progress !!

work on it during KEKcc shutdown

For co-authors, lets review first draft at end of August !!

1. First, the energy deposition in the ECAL (E_{ECAL}), the total energy deposit in both ECAL and HCAL ($E_{CAL,tot}$), and the measured track momentum (P_{tot}) are compared for each final state particle. The basic idea here is that an electron deposits nearly all its energy in the ECAL while a muon in the ILC energy range passes both the ECAL and HCAL as a minimal ionizing particle. Then, prompt decay is guaranteed by requirements on the vertex parameters D_0 and z_0, with respect to their measurement uncertainties. This serves to suppress leptons from τ decay. The observables and cut values are summarised in Table 3.3.

2. Furthermore, the leptons are required to be isolated so as to prevent picking up leptons from jets either from Higgs decay or WW BG processes. This criteria are relatively high P_{tot}, and emptyness surrounding the lepton. The basic idea is to require the energy inside a cone surrounding the lepton to be below a certain value. The isolation requirement is based on a TMVA based double cone method with neural net output [].

	μ ID	e ID
momentum and energy deposit	$P_{tot} > 5$ GeV	$P_{tot} > 5$ GeV
	$E_{CAL,tot}/P_{tot} < 0.3$	$0.5 < E_{CAL,tot}/P_{tot} < 1.3$
	$E_{yoke} < 1.2$ GeV	$E_{ECAL}/E_{CAL,tot} > 0.9$
impact parameter	$\lvert D_0/\delta D_0 \rvert > 5$	$\lvert D_0/\delta D_0 \rvert > 50$
	$\lvert z_0/\delta z_0 \rvert > 5$	$\lvert z_0/\delta z_0 \rvert > 5$

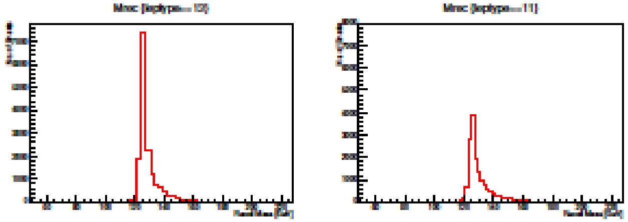
Table 3.3: The criteria for identification of μ and e.

3.2.2 Selection of Best Lepton Pair

It is necessary to distinguish the dilepton system as produced by the Z decay in the Higgsstrahlung process from final state lepton pairs originating from BG processes or Higgs decay. For the Higgs-strahlung process, neglecting detector resolution and radiative effects, the M_{inv} of the dilepton system and M_{rec} should be equal to the Z mass $M_Z \simeq 91.187$ GeV the Higgs mass $m_H = 125$ GeV (in this study), respectively. The best lepton pairs with opposite charges are chosen based on the following criteria.

From the the distributions in Figures 3.2 and 3.1, loose precuts on M_{inv} and M_{rec} are implemented as $|M_{inv} - M_Z| < 40(60)$ GeV for μ (e) and 100 GeV $< M_{rec} <$ 300 GeV, respectively. Next, for the $\mu^+\mu^-$H channel, the lepton pair that minimizes a χ^2 function based on both their M_{inv} and M_{rec} is selected. The rational here is that even though the pair have M_{inv} close to M_Z, it may come from a Z from Higgs decay, in which case its M_{rec} tends to be deviated from Higgs mass. For the e^+e^-H channel, the lepton pair that has M_{inv} closest to M_Z is selected. The χ^2 minimization method is not efficient in this case due to the additional effect from bremsstrahlung. Figure 3.3 compares the distributions of M_{inv} and M_{rec} between "correct" and "wrong" pairs for the case of E_{CM} = 250 GeV. This method os lepton pairing is important for preventing bias on Higgs decay mode dependence, as will be discussed in Sec. ().

The efficiency of the isolated dilepton finder is () for$\mu^+\mu^-$H and () for e^+e^-H. Here, efficiency is defined as the reconstructed number over the generated number for each lepton type.



Leptonic Higgs Recoil Analysis at the ILC

July 28, 2015

Abstract

The expected measurement precision of fundamental Higgs boson properties at the ILC has been carried out in a detailed study based on full simulation of the ILD detector as proposed in the Technical Design Report[1]. The absolute cross section of the Higgsstrahlung process $e^+e^- \to HZ$, is indispensible for extracting branching ratios and couplings of all Higgs decay modes. The Higgs recoil mass provides a window into physics beyond the standard model. Here, the Higgs is produced together with a Z boson which decays into a well measurable dilepton system. This paper shows the results for $Z \to \mu^+\mu^-$, $Z \to e^+e^-$, and the combined results of the two leptonic channels. in accord with the expected schedule of operation of the accelerator. Analysis is carried out for three center of mass scenarios 250, 350, and 500 GeV, and two beam polarization scenarios (e^+e^-) =(-0.8,+0.3) and (+0.8,-0.3). These impact the decision of ILC run scenario[]. Methods of signal selection are optimized to achieve the highest precision in ZH cross section while maintaining Higgs decay mode independence. At 250 GeV, which best detector resolution is obtainable, σ_{ZH} can be determined with a precision of 3.3%, and 40 MeV for Higgs recoil mass. Similar precisions in σ_{ZH} have been shown for 350 GeV. Feasibility have also been shown at 500 GeV, which provides reach for new physics.

1 Introduction

1.1 The Role of the ILC in Particle Physics

The International Linear Collider (ILC) [1] is a proposed e^+e^- collider with a center-of-mass energy rangin from 250 to 500 GeV, with possibility of an upgrade to 1 TeV.

The precision measurements of the Higgs couplings are an integral part of its physics program.

BACKUP

Performance of data selection

in fitting range 100–160 GeV

(−0.8,+0.3)		significance	Nsig	Nbg
250GeV	Zmm	18.3	1879	8692
	Zee	14.4	1502	9394
350GeV	Zmm	17.7	1462	5332
	Zee	14.1	1156	5597
500GeV	Zmm	11.1	626	2572
	Zee	8.7	439	2087

(+0.8,−0.3)		significance	Nsig	Nbg
250GeV	Zmm	19.7	1264	2834
	Zee	12.8	1096	6231
350GeV	Zmm	17	1002	2486
	Zee	12.7	602	1627
500GeV	Zmm	9.9	414	1339
	Zee	8.9	325	1003

- In general, significance is 250 > 350 > 500 GeV, Zmm > Zee
- right hand polarization: case by case:
  (lower BG, but also smaller signal statistics)

Statistical error study results
Z→μμ and Z→ee combined

(−0.8,+0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.35%	40.4
	Zee	4.76%	109
	Total	**2.74%**	**37.9**
350GeV	Zmm	3.90%	101
	Zee	5.63%	327
	Total	**3.21%**	**96.5**
500GeV	Zmm	6.50%	468
	Zee	7.86%	1540
	Total	**5.01%**	**448**

xsec error

- 350 GeV is 17 % worse w.r.t. 250 GeV
- 500 GeV is much worse
- Zee is worse by > 40% w.r.t. Zmm
- right hand pol is worse by 5 – 10 % w.r.t. left hand

Mass error

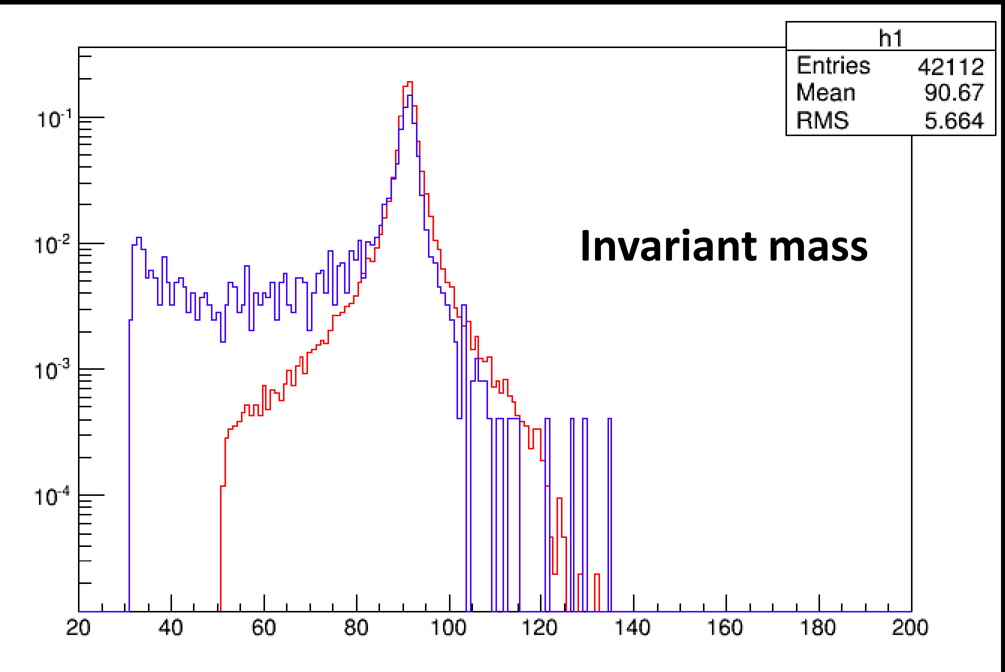
- 350 GeV is worse by factor of slightly less than 3 w.r.t. 250 GeV
- Zee is worse by a factor of 2 – 3 w.r.t. Zmm
- Systematic error of fitted recoil mass is negligible (< few MeV for 250 , 350 GeV)

500 GeV : fitted over wide range

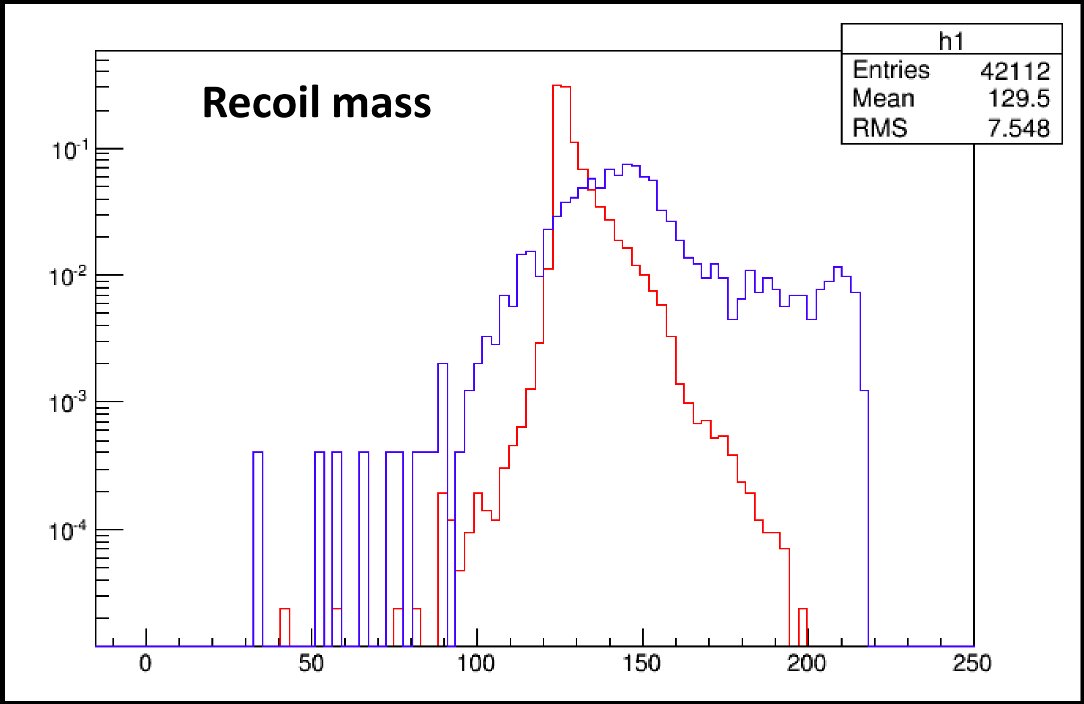
xsec error almost same as past results using GPET

(+0.8,−0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.57%	40.5
	Zee	5.14%	121
	Total	**2.93%**	**38.4**
350GeV	Zmm	4.31%	112
	Zee	6.26%	296
	Total	**3.55%**	**105**
500GeV	Zmm	7.27%	572
	Zee	7.86%	1530
	Total	**5.33%**	**536**

H→zz mode
ECM = 250 GeV



Blue : wrong pair
Red: right pair



Efficiency of each Higgs decay mode (after each cut)

Resolved problem of poor isolation in lepton finder

Weights trained using H→qqqq

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	92.41 +/-0.086	92.43 +/-0.087	91.66 +/- 0.09	93.27 +/-0.081	92.67 +/-0.083	93.01 +/-0.082	92.84 +/- 0.07
Cut1 :	92.41 +/-0.086	92.43 +/-0.087	91.66 +/- 0.09	93.24 +/-0.081	92.64 +/-0.083	92.77 +/-0.083	92.83 +/- 0.07
Cut2 :	90.85 +/-0.094	90.84 +/-0.095	90.05 +/-0.098	91.37 +/-0.091	90.56 +/-0.093	90.6 +/-0.094	90.48 +/- 0.08
Cut3 :	88.92 +/- 0.1	89.07 +/- 0.1	88.23 +/- 0.11	89.39 +/-0.099	88.53 +/- 0.1	88.49 +/- 0.1	88.69 +/-0.086
Cut4 :	88.71 +/- 0.1	88.88 +/- 0.1	88.03 +/- 0.11	89.2 +/- 0.1	88.29 +/- 0.1	88.24 +/- 0.1	88.52 +/-0.087
Cut5 :	88.66 +/- 0.1	88.8 +/- 0.1	87.97 +/- 0.11	88.73 +/- 0.1	88.18 +/- 0.1	88.13 +/- 0.1	86.7 +/-0.092
Cut6 :	88.16 +/- 0.1	88.47 +/- 0.1	87.82 +/- 0.11	87.99 +/- 0.1	87.43 +/- 0.11	87.3 +/- 0.11	73.14 +/- 0.12
Cut7 :	81.72 +/- 0.13	81.74 +/- 0.13	81.23 +/- 0.13	81.62 +/- 0.13	81.04 +/- 0.13	81.14 +/- 0.13	67.98 +/- 0.13
Cut8 :	81.55 +/- 0.13	81.59 +/- 0.13	81.07 +/- 0.13	81.42 +/- 0.13	80.85 +/- 0.13	80.87 +/- 0.13	67.89 +/- 0.13

Weights trained using H→ gg

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	93.7 +/-0.079	93.69 +/- 0.08	93.4 +/-0.081	94.02 +/-0.077	94.04 +/-0.076	94.36 +/-0.074	93.71 +/-0.066
Cut1 :	93.7 +/-0.079	93.69 +/- 0.08	93.4 +/-0.081	93.99 +/-0.077	94.02 +/-0.076	94.15 +/-0.075	93.7 +/-0.066
Cut2 :	92.12 +/-0.087	92.06 +/-0.089	91.76 +/- 0.09	92.14 +/-0.087	91.96 +/-0.087	91.99 +/-0.087	91.21 +/-0.077
Cut3 :	90.09 +/-0.097	90.2 +/-0.098	89.84 +/-0.099	90.06 +/-0.097	89.77 +/-0.097	89.78 +/-0.097	89.35 +/-0.084
Cut4 :	89.88 +/-0.098	90.02 +/-0.098	89.64 +/-0.099	89.87 +/-0.097	89.53 +/-0.098	89.53 +/-0.098	89.17 +/-0.085
Cut5 :	89.83 +/-0.098	89.94 +/-0.099	89.57 +/- 0.1	89.39 +/-0.099	89.43 +/-0.098	89.42 +/-0.099	87.34 +/-0.091
Cut6 :	89.28 +/- 0.1	89.58 +/- 0.1	89.42 +/- 0.1	88.64 +/- 0.1	88.66 +/- 0.1	88.56 +/- 0.1	73.67 +/- 0.12
Cut7 :	82.75 +/- 0.12	82.75 +/- 0.12	82.67 +/- 0.12	82.23 +/- 0.12	82.16 +/- 0.12	82.28 +/- 0.12	68.48 +/- 0.13
Cut8 :	82.58 +/- 0.12	82.59 +/- 0.12	82.5 +/- 0.12	82.02 +/- 0.12	81.98 +/- 0.12	82.02 +/- 0.12	68.38 +/- 0.13
Cut9 :	82.58 +/- 0.12	82.59 +/- 0.12	82.5 +/- 0.12	82.02 +/- 0.12	81.98 +/- 0.12	82.02 +/- 0.12	68.38 +/- 0.13
Cut10:	74.8 +/- 0.14	74.65 +/- 0.14	74.8 +/- 0.14	74.55 +/- 0.14	74.47 +/- 0.14	73.83 +/- 0.14	64.9 +/- 0.13

cut definition

```
Process: ZH --> mu+ mu- H
Polarization: (e-,e+) = (-0.8,+0.3)
----------Cuts----------
Cut  0 :
Cut  1 :    leptype==13
Cut  2 :    Ptdl>10&&abs(Minv-91.18)<40&&Mrec>100&&Mrec<300
Cut  3 :    Minv>73&&Minv<120
Cut  4 :    Ptdl>10&&Ptdl<70
Cut  5 :    (Ptsum<0||Ptsum>10)
Cut  6 :    !((Evis-Elep1-Elep2-Ephotonmax)<10&&Ephotonmax>0&&abs(cosmis)>0.98)
Cut  7 :    abs(cosz) < 0.9
Cut  8 :    Mrec>100&&Mrec<160
```

- Lepton finder efficiency rise by 2% for gg , also higher for ww
- Now gg eff consistent with bb, cc

Check lepton pairing mistake is reduced : Zmm channel

OLD

250 GeV	bb	cc	zz	ww	tautau	gg	aa
Total	100.00%	100%	100.00%	100.00%	100.00%	100%	100.00%
C1	100.00%	100%	94.66%	98.13%	99.35%	100%	99.94%
C2	0.00%	0	4.97%	1.46%	0.51%	0.00%	0.06%
C3	0.00%	0	4.63%	0.46%	0.26%	0.00%	0.00%
C4	0.00%	0	0.36%	0.41%	0.14%	0.00%	0.00%
C5	0.00%	0	0.00%	0.00%	0.00%	0.00%	0.00%

NEW

250 GeV	bb	cc	zz	ww	tautau	gg	aa
Total	100.00%	100%	100.00%	100.00%	100.00%	100%	100.00%
C1	100.00%	100%	95.47%	98.29%	99.41%	100%	99.91%
C2	0.00%	0	4.26%	1.37%	0.49%	0.00%	0.09%
C3	0.00%	0	3.85%	0.48%	0.28%	0.00%	0.00%
C4	0.00%	0	0.27%	0.33%	0.10%	0.00%	0.00%
C5	0.00%	0	0.00%	0.00%	0.00%	0.00%	0.00%

C1: correct

Pairing mistake — C2: two real leptons exist, but at least one wrong lepton

C3: both leptons wrong

C4: only 1 real lepton

C5: no real lepton

Efficiency of each Higgs decay mode (after each cut)

Real data

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	93.7 +/-0.079	93.69 +/- 0.08	93.4 +/-0.081	94.02 +/-0.077	94.04 +/-0.076	94.36 +/-0.074	93.71 +/-0.066
Cut1 :	93.7 +/-0.079	93.69 +/- 0.08	93.4 +/-0.081	93.99 +/-0.077	94.02 +/-0.076	94.15 +/-0.075	93.7 +/-0.066
Cut2 :	92.12 +/-0.087	92.06 +/-0.089	91.76 +/- 0.09	92.14 +/-0.087	91.96 +/-0.087	91.99 +/-0.087	91.21 +/-0.077
Cut3 :	90.09 +/-0.097	90.2 +/-0.098	89.84 +/-0.099	90.06 +/-0.097	89.77 +/-0.097	89.78 +/-0.097	89.35 +/-0.084
Cut4 :	89.88 +/-0.098	90.02 +/-0.098	89.64 +/-0.099	89.87 +/-0.097	89.53 +/-0.098	89.53 +/-0.098	89.17 +/-0.085
Cut5 :	89.83 +/-0.098	89.94 +/-0.099	89.57 +/- 0.1	89.39 +/-0.099	89.43 +/-0.098	89.42 +/-0.099	87.34 +/-0.091
Cut6 :	89.28 +/- 0.1	89.58 +/- 0.1	89.42 +/- 0.1	88.64 +/- 0.1	88.66 +/- 0.1	88.56 +/- 0.1	73.67 +/- 0.12
Cut7 :	82.75 +/- 0.12	82.75 +/- 0.12	82.67 +/- 0.12	82.23 +/- 0.12	82.16 +/- 0.12	82.28 +/- 0.12	68.48 +/- 0.13
Cut8 :	82.58 +/- 0.12	82.59 +/- 0.12	82.5 +/- 0.12	82.02 +/- 0.12	81.98 +/- 0.12	82.02 +/- 0.12	68.38 +/- 0.13
Cut9 :	82.58 +/- 0.12	82.59 +/- 0.12	82.5 +/- 0.12	82.02 +/- 0.12	81.98 +/- 0.12	82.02 +/- 0.12	68.38 +/- 0.13
Cut10:	74.8 +/- 0.14	74.65 +/- 0.14	74.8 +/- 0.14	74.55 +/- 0.14	74.47 +/- 0.14	73.83 +/- 0.14	64.9 +/- 0.13

Cheat pairing using MC truth

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	93.7 +/-0.079	93.68 +/- 0.08	93.4 +/-0.081	93.89 +/-0.077	93.62 +/-0.078	93.86 +/-0.077	93.7 +/-0.066
Cut1 :	93.7 +/-0.079	93.68 +/- 0.08	93.4 +/-0.081	93.89 +/-0.077	93.62 +/-0.078	93.86 +/-0.077	93.7 +/-0.066
Cut2 :	92.12 +/-0.087	92.06 +/-0.089	91.76 +/- 0.09	92.17 +/-0.087	91.95 +/-0.087	92.28 +/-0.086	91.24 +/-0.077
Cut3 :	90.09 +/-0.097	90.2 +/-0.098	89.84 +/-0.099	90.21 +/-0.096	90.05 +/-0.096	90.45 +/-0.094	89.38 +/-0.084
Cut4 :	89.88 +/-0.098	90.01 +/-0.098	89.64 +/-0.099	90.01 +/-0.097	89.84 +/-0.097	90.24 +/-0.095	89.21 +/-0.084
Cut5 :	89.83 +/-0.098	89.94 +/-0.099	89.57 +/- 0.1	89.54 +/-0.099	89.74 +/-0.097	90.13 +/-0.096	87.38 +/- 0.09
Cut6 :	89.28 +/- 0.1	89.58 +/- 0.1	89.42 +/- 0.1	88.79 +/- 0.1	88.97 +/- 0.1	89.31 +/-0.099	73.71 +/- 0.12
Cut7 :	82.75 +/- 0.12	82.75 +/- 0.12	82.67 +/- 0.12	82.36 +/- 0.12	82.49 +/- 0.12	82.97 +/- 0.12	68.51 +/- 0.13
Cut8 :	82.58 +/- 0.12	82.59 +/- 0.12	82.5 +/- 0.12	82.17 +/- 0.12	82.3 +/- 0.12	82.83 +/- 0.12	68.41 +/- 0.13
Cut9 :	82.58 +/- 0.12	82.59 +/- 0.12	82.5 +/- 0.12	82.17 +/- 0.12	82.3 +/- 0.12	82.83 +/- 0.12	68.41 +/- 0.13
Cut10:	74.8 +/- 0.14	74.65 +/- 0.14	74.8 +/- 0.14	74.72 +/- 0.14	74.79 +/- 0.14	75.52 +/- 0.14	64.95 +/- 0.13

eff for H→ZZ, ww is high now

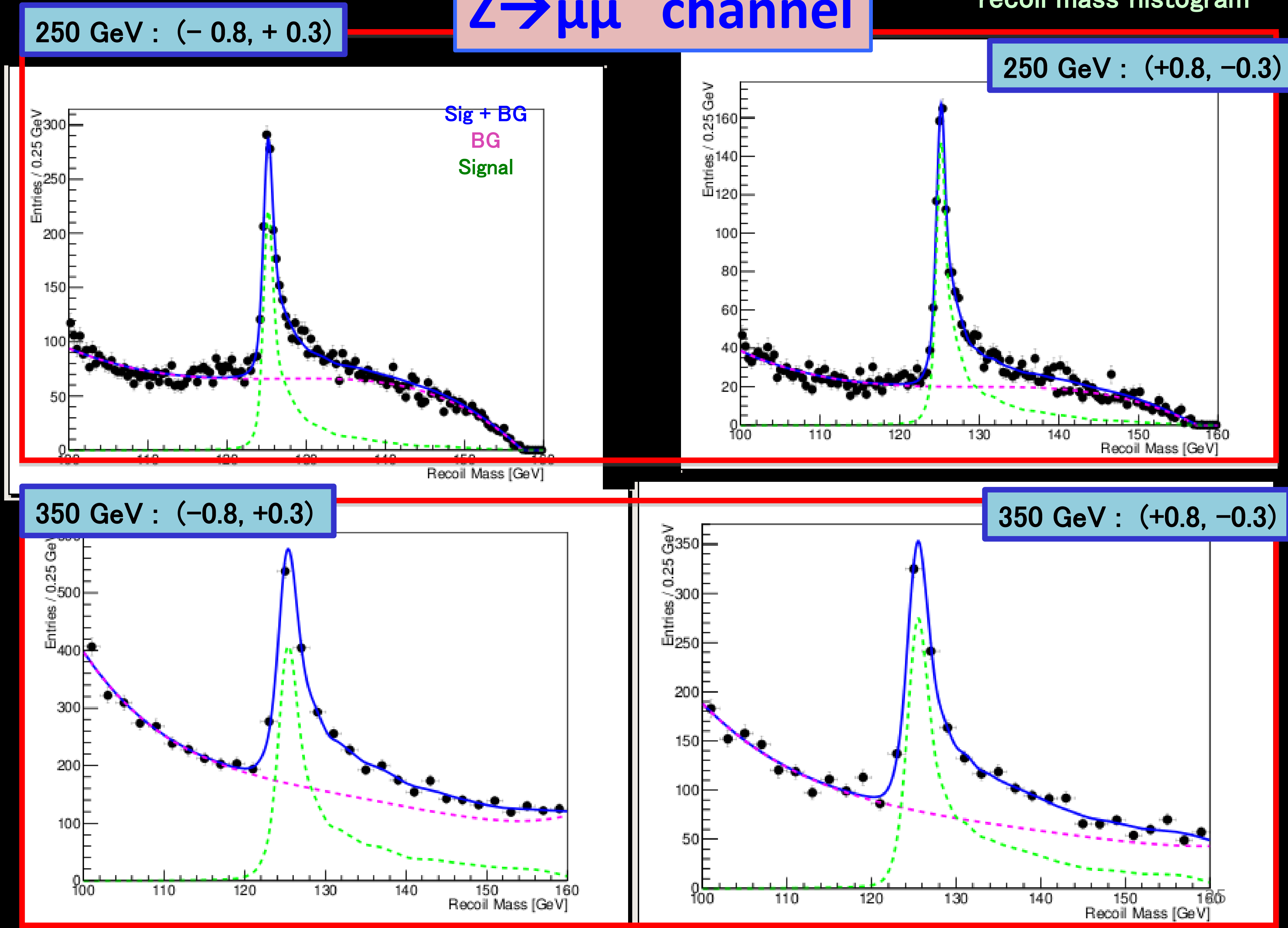
difference between real and cheat		MC stat error
bb	0.00%	0.12%
cc	0.00%	0.12%
gg	0.00%	0.12%
tt	−0.15%	0.12%
ww	−0.32%	0.12%
zz	−0.85%	0.12%
aa	−0.03%	0.13%

"cheat pairing" (MC truth) results indicate that indeed the problem is due to paring non-prompt Z decay leptons.

maybe the only problem left

Z→μμ channel

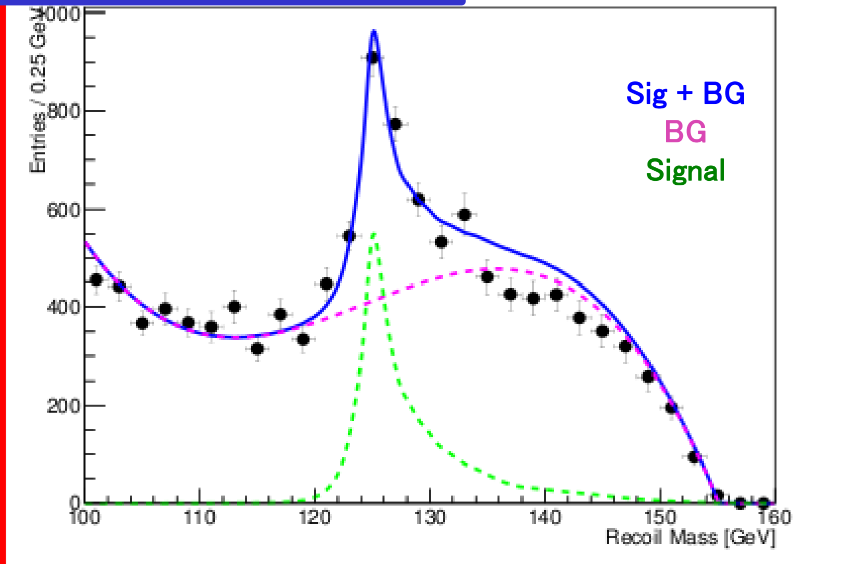
Reconstructed data
recoil mass histogram



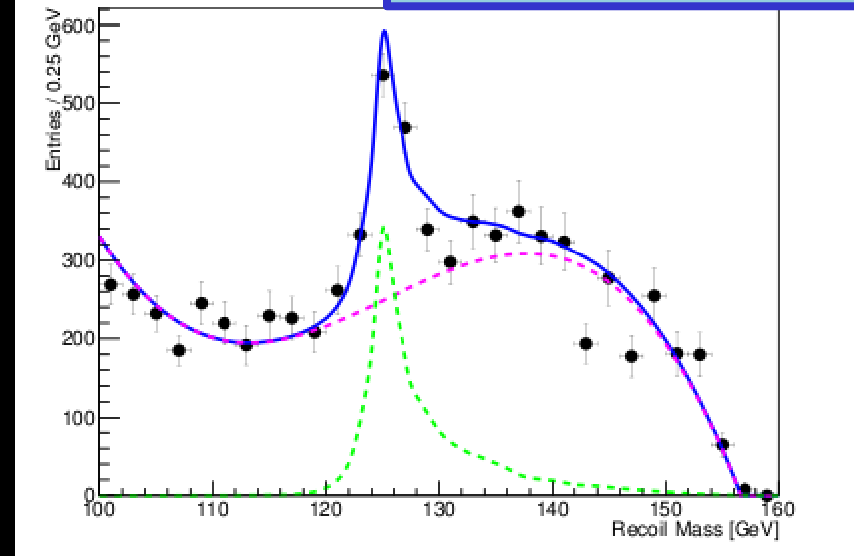
Z→ee channel

Reconstructed data
recoil mass histogram

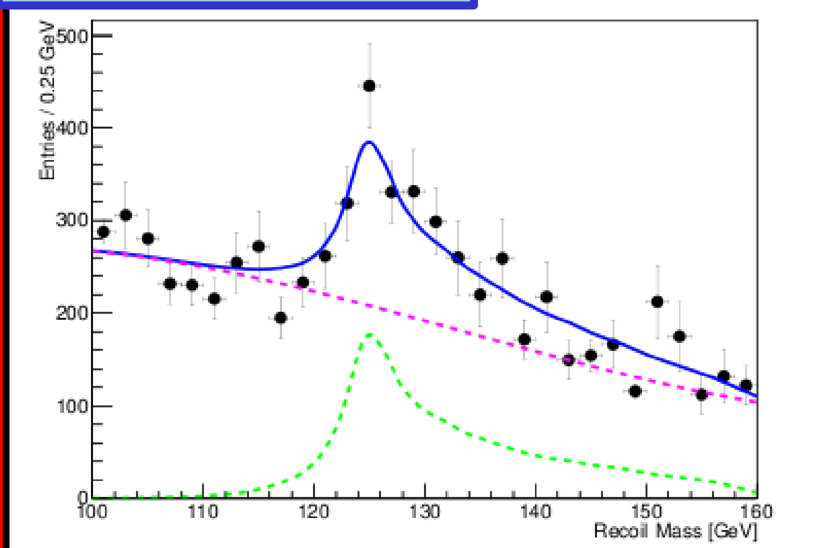
250 GeV : (− 0.8, + 0.3)



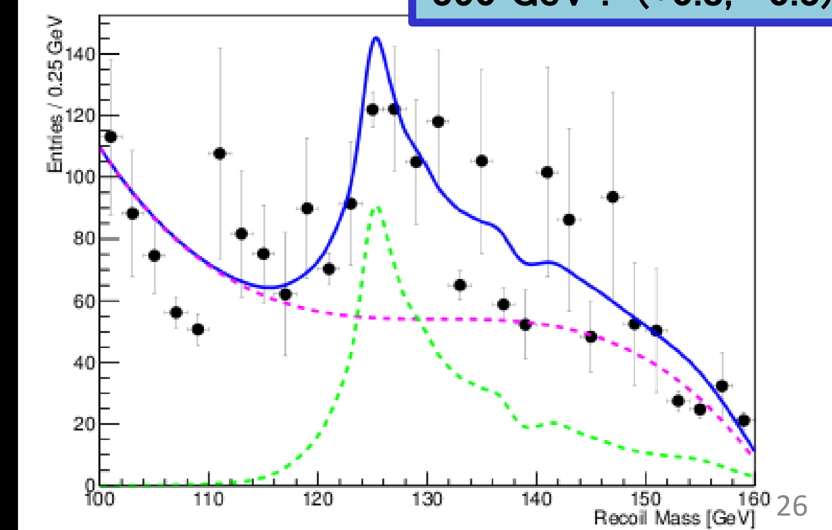
250 GeV : (+0.8, −0.3)



350 GeV : (−0.8, +0.3)

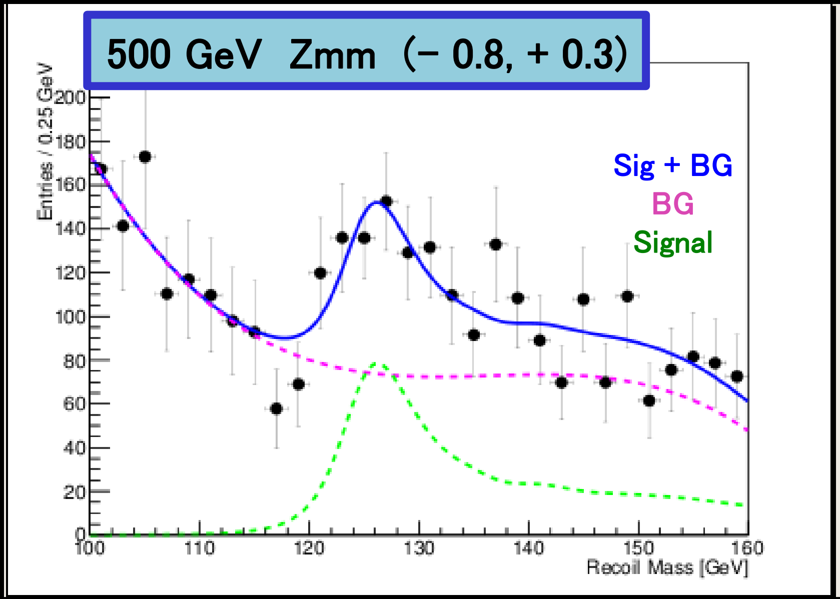


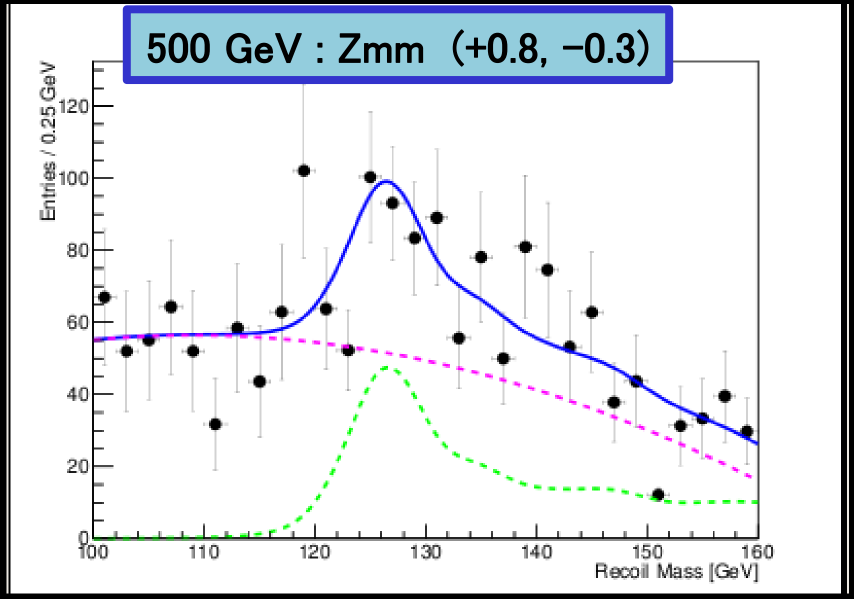
350 GeV : (+0.8, −0.3)

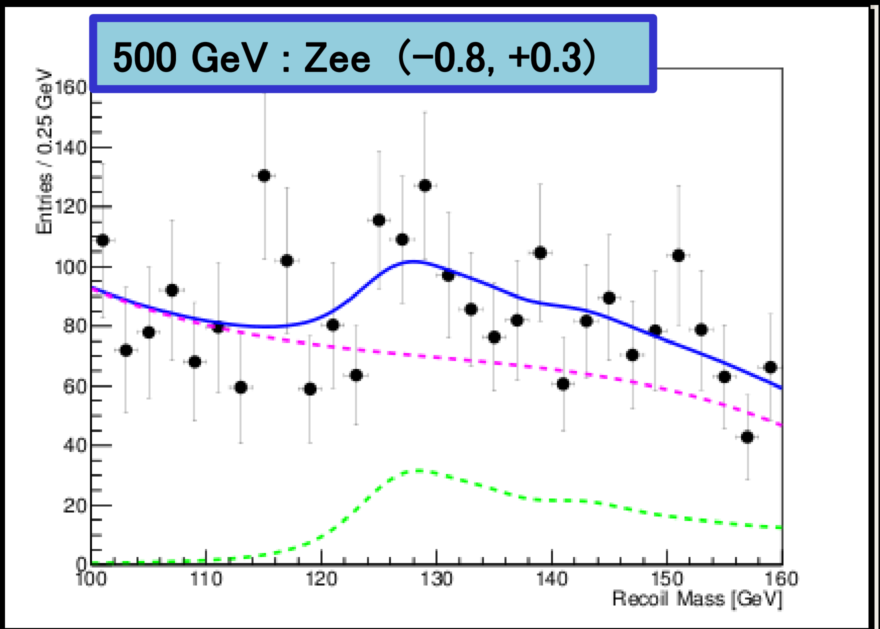


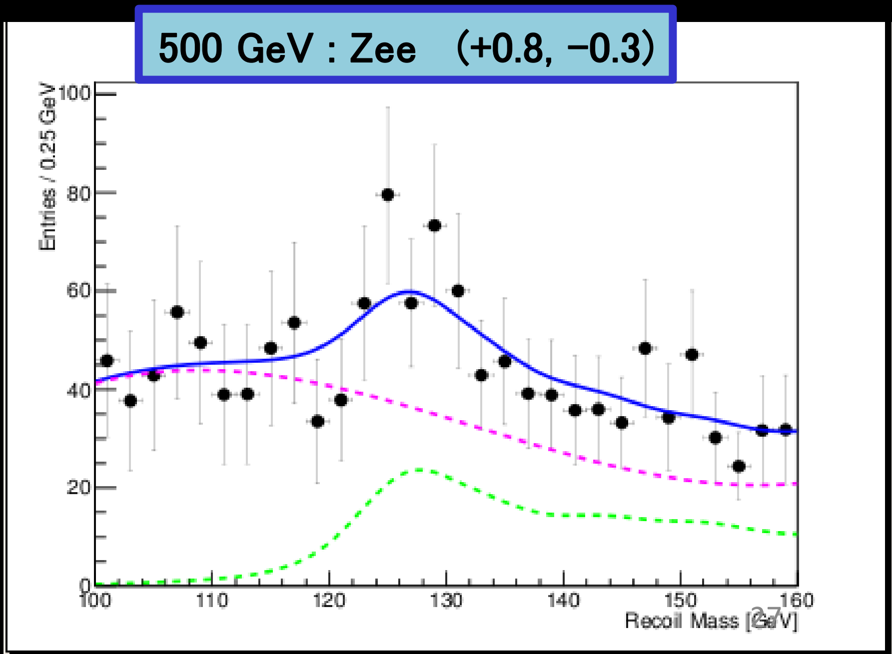
500 GeV

many challenges remaining : low statistics, low S/B ratio , ect…



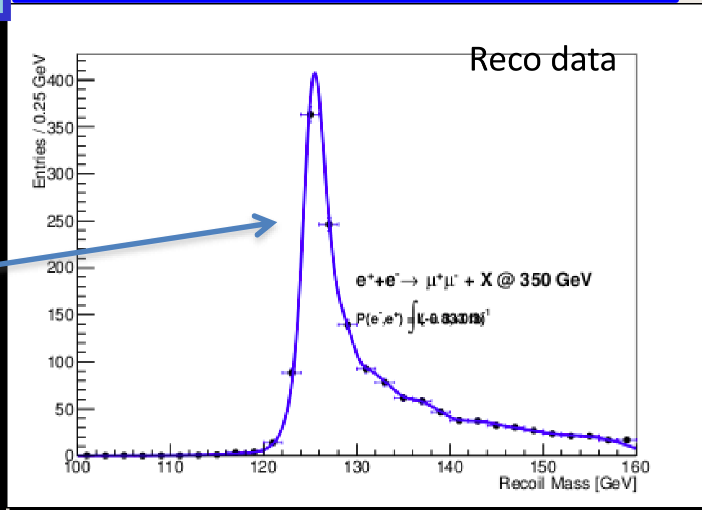




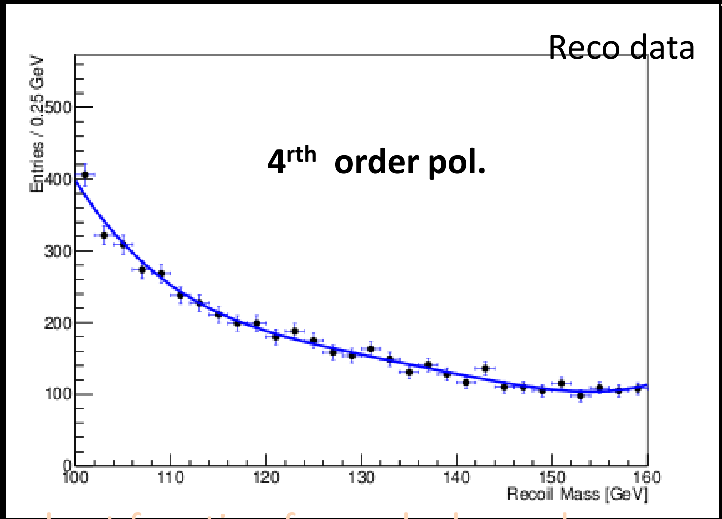


Fitting of recoil mass spectrum

Signal : Kernel function



BG : 3rd or 4rth order polynomial



Kernel function fitting does not cause significant systematic bias in recoil mass (c.f. GPET)

Observe distribution to determine best function for each channel

Toy MC study

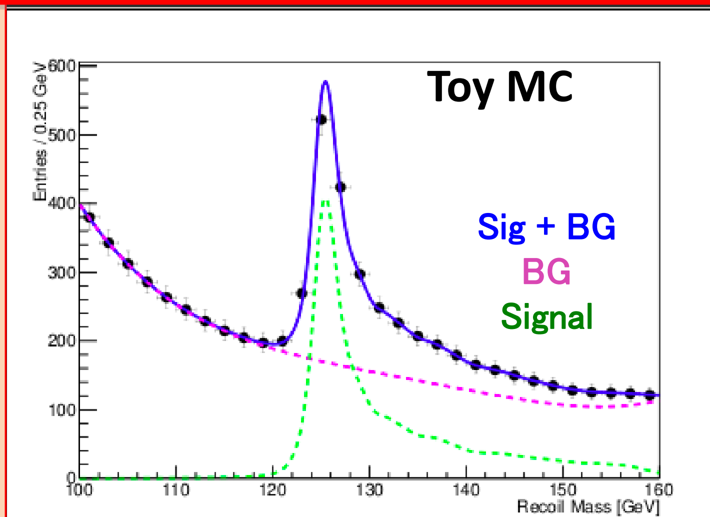
goal: test quality of fitting method

evaluate precision of xsec and recoil mass

method :

- generate MC events with 1000 x statistics according to fitted result of "real" data
- fit Toy events with same function : Kernel + polynomial

→ get signal yield, mass shift, and errors



Time Line (Current Status)

•Produced **preliminary set of leptonic recoil results for all 3 center of mass energies** (ECM=250, 350, 500 GeV)　compatible with H20 scenario
（review will be given today, and at ILC Summer Camp 7/21）

•**Detailed study of Higgs decay mode dependence (= systematic errors)** for 250 GeV using high stat samples
demonstrated mode bias is negligible even compared with the best $\Delta\sigma$ stat (H20)

•making efforts to further improve xsec precision and suppress bias
e.g. **semi-model independent analysis:**
separate Higgs visible and invisible decay modes. → this will suppress the major BG $ll\nu\nu$

We are currently writing a paper on leptonic Higgs recoil

Title (preliminary) : **Leptonic Higgs Recoil Analysis at the ILC**

•personal plan to complete first draft by end of August (entire paper by end of year?)

•Then we can use draft as a "skeleton with some flesh"
to visualize what else we can add / improve

Time Line (Plans)

The importance of recoil mass measurement (both leptonic and hadronic) for H20 scenario has been emphasized.

- **<u>Important to improve leptonic recoil at 500 GeV AND begin on hadronic recoil</u>**
- at least, these need to be done in parallel with further improving precision of leptonic recoil at 250 (350) GeV

(1)Converge to the best data selection methods to minimize **Higgs decay mode dependence (= systematic errors)** ***actually already quite negligible***

(1)generate higher statistics sample for 350 and 500 GeV
then use these to further improve precision for leptonic channel at 500 GeV
as well as do ZZ fusion analysis

(3) Study **systematic error from beam spectrum** → ***need much time***

(4) Begin **hadronic recoil at 500 GeV**
strategy : for now carry out same method as what Miyamoto-san did for Snowmass
and investigate Higgs decay mode dependence the same way as I did for (1)

Abstract of Leptonic Higgs Recoil Paper

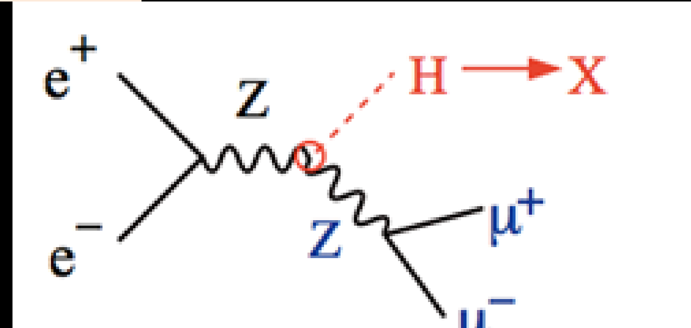
Leptonic Higgs Recoil Analysis at the ILC

This paper reports **on the expected precision for the model independent measurement of the absolute Higgs boson production cross section for the Higgsstrahlung process at the ILC.** Only possible at the ILC, this unique measurement is **indispensable for extraction of all Higgs branching ratios and couplings** from event rates. Also reported is the expected **precision for the Higgs recoil mass**, which provides a window into physics beyond the Standard Model. The study here is based on full simulation of the ILD detector as proposed in the Technical Design Report. In the clean Higgsstrahlung process, the Higgs Boson is produced together with a Z boson which decays into a well-measurable dilepton system (Z--> $\mu\mu$ or Z-->ee). In accordance with the most up to date plan of ILC accelerator operation, analysis has been carried out for three center of mass energies (Ecm) of 250, 350, and 500 GeV, and alternative beam polarization scenarios. **Methods of signal selection are optimized to achieve the best ZH cross section precision while maintaining Higgs decay mode independence.** At Ecm=250 GeV, where the best detector resolution is obtainable, the **ZH cross section can be determined with a precision of 3.3%, while the expected Higgs mass precision is 39 MeV.** (Reasonable precision a have also been demonstrated for the higher energies of 350 and 500 GeV which extend the physics reach).

recoil mass study using leptonic channes
ECM = 250 GeV, 350 GeV, and 500 GeV

signal

H decay mode independent



Higgs recoil against di-lepton system

$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

precise model-independent measurement of absolute Higgs cross section and recoil mass

- σ_{ZH} is a "must-have" for measurement of total Higgs width & couplings
- **study impact of ECM and polarization**
- contribute to the decision for ILC run scenario

originally study was focused on the new field of 350 GeV since many physics become important → this time, extended to all ECM and both leptonic channels

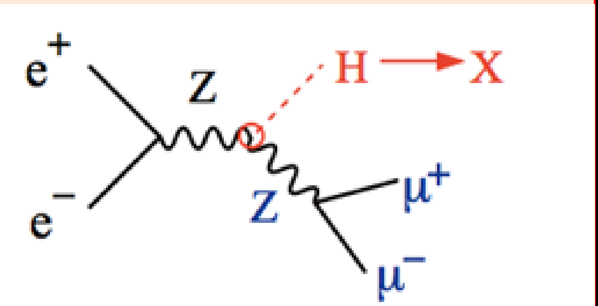
ILC sample used in analysis

chanel	mH	ECM	L	Spin polarization	Detector simulation
e+e→Zh->μμh e+e→Zh->eeh	125 GeV	250 GeV 350 GeV 500 GeV	250 fb-1 333 fb-1 500 fb-1	P(e-,e+) = (-0.8,+0.3) (+0.8,-0.3)	Full ILD (ILD_01_v05 DBD ver.)

Data Selection Method

Signal signature

a pair of isolated energetic leptons (μ / e) with invariant mass (M_{inv}) close to Z mass



$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

Recoil mass

Dominant backgrounds	**Signatures**
• e+ e- → Z Z → l+ l- X :	forward Z production angle
• e+ e- → γ Z → γ l+ l- :	energetic ISR γ which balance dilepton pt
• e+ e- → W W → l+ l- ν ν :	broad M_{inv} distr.

- data selection is based on signal / BG characteristics
- a final recoil mass window (100 – 160 GeV) is effective for cutting BG

Progress since the last (41th) General Meeting (April 11)

Last Time

- only Z→ μμ channel
- only ECM = 250 GeV and 350 GeV
- only study of xsec precision
- slight Higgs decay mode bias caused by BG rejection method

Features of This Time

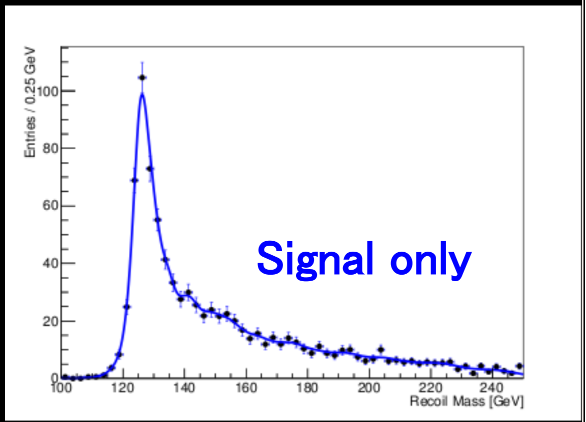
- both Z→μμ and Z→ee channels
- all three ECM (250 , 350 , 500 GeV)
- study of both xsec and mass precision
- signal bias is minimized due to improved techniques (details later)

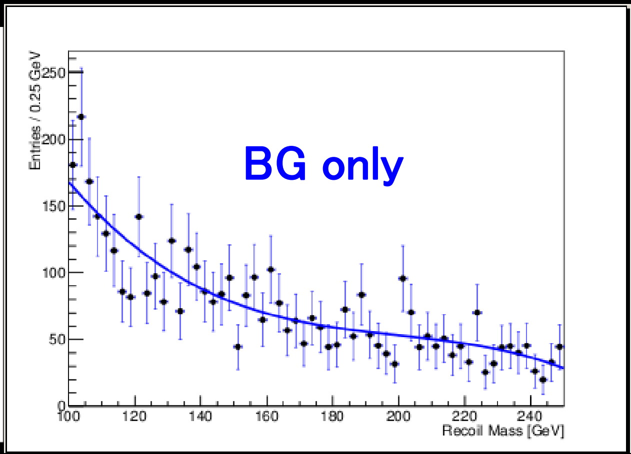
+ *deeper study of the signal and BG statistics of each channel*

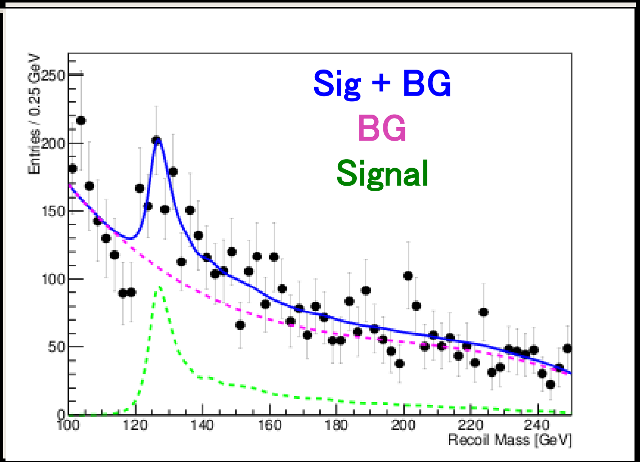
- Converged to a **full set of statistical error study results**
- **optimized data selection method for each of the 12 scenarios** (3 ECM x 2 leptonic channels x 2 polarizations) in aim of best xsec and mass precision
- Removed systematic bias due to method of fitting or data selection

Can precision can be slightly improved if we fit over a wider range ? assuming we can neglect the H*→WW bump beyond 160 GeV

500 GeV, Zee (-0.8,+0.3) **fit in 100 – 250 GeV** (c.f. 100-160 GeV)

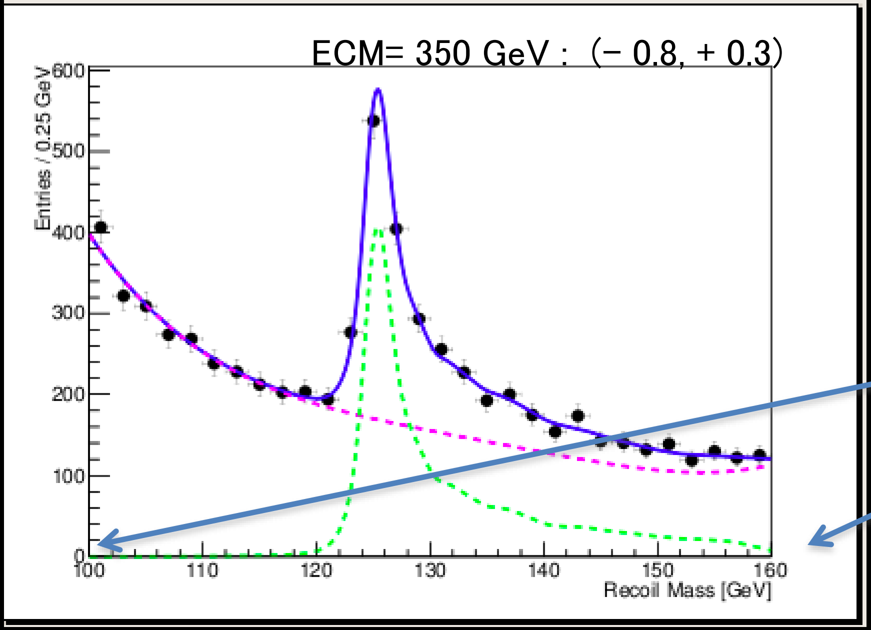






		xsec error (%)		mass error (MeV)	
(−0.8,+0.3)		narrow	wide	narrow	wide
500GeV	Zmm	6.95%	6.50%	474	468
	Zee	9.89%	7.86%	1540	1540
	Total	**5.69%**	**5.01%**	**453**	**448**
(+0.8,−0.3)					
500GeV	Zmm	8.36%	7.27%	613	572
	Zee	9.85%	7.86%	1510	1530
	Total	**6.37%**	**5.33%**	**568**	**536**

10-20 % improvement on xsec and a few % on mass precision



BG level fluctuation is controlled by fitting recoil mass over a wide range (100 – 160 GeV)

an improvement from previous studies

- BG level is usually fixed for Toy MC (optimistic scenario)
- xsec error is about 10 % worse if we float BG (pessimistic scenario)
  not a big degradation since I fit recoil mass spectrum over a wide range

GOOD

Example:

Zmm	xsec	Recoil mass	BG fluc
250GeV	3.35% → 3.62%	40 MeV, no change	1.23%
350GeV	3.90% → 4.39%	101 → 95 MeV	1.67%

Check lepton pairing mistake : Zee channel

250 GeV	bb	cc	zz	ww	tautau	gg	aa
Total elec	100.00%	100%	100.00%	100.00%	100.00%	100.00%	100.00%
C1	99.91%	100%	97.36%	96.89%	98.35%	99.92%	98.15%
C2	0.05%	0.03%	1.97%	2.16%	1.06%	0.01%	1.38%
C3	0.00%	0.00%	1.17%	0.01%	0.01%	0.00%	0.02%
C4	0.04%	0.02%	0.66%	0.89%	0.52%	0.01%	0.41%
C5	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%

C1: correct

Pairing mistake

C2: two real leptons exist, but at least one wrong lepton

C3: both leptons wrong

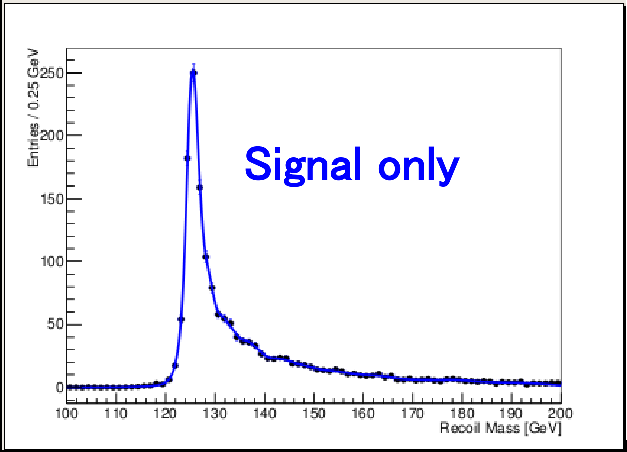
C4: only 1 real lepton

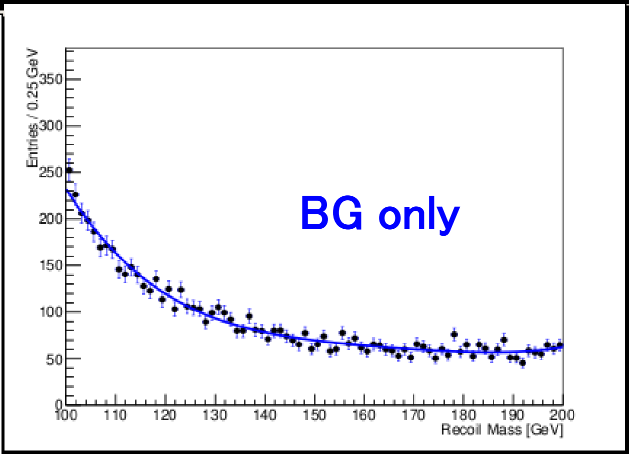
C5: no real lepton

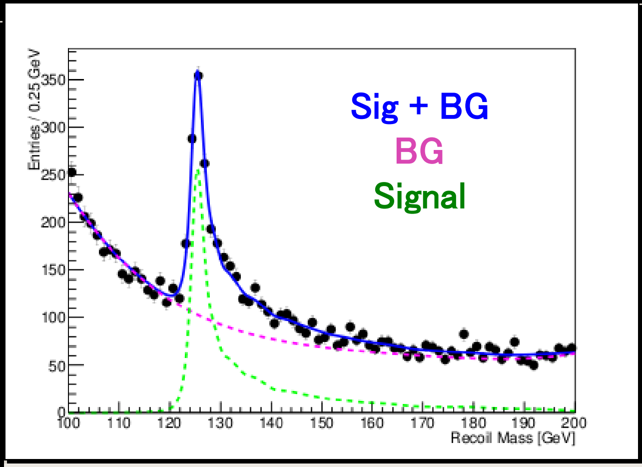
Can precision can be slightly improved if we fit over a wider range ??
assuming we can neglect the H*→WW bump beyond 160 GeV

350 GeV, Zee (-0.8,+0.3)

fit in 100 – 200 GeV (c.f. 100-160 GeV)







		xsec error (%)		mass error (MeV)	
(−0.8,+0.3)		narrow	wide	narrow	wide
350GeV	Zmm	3.90%	3.83%	101	103
	Zee	5.63%	5.48%	327	340
	Total	3.21%	3.14%	96.5	98.6
(+0.8,−0.3)					
350GeV	Zmm	4.31%	4.24%	112	113
	Zee	6.26%	6.15%	296	328
	Total	3.55%	3.49%	105	107

Not much room for improvement

Statistical error study results
Z→μμ and Z→ee combined

(−0.8,+0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.35%	40.4
	Zee	4.76%	109
	Total	**2.74%**	**37.9**
350GeV	Zmm	3.90%	101
	Zee	5.63%	327
	Total	**3.21%**	**96.5**
500GeV	Zmm	6.95%	474
	Zee	9.89%	1540
	Total	**5.69%**	**453**

xsec error

- 350 GeV is 17 % worse w.r.t. 250 GeV
- 500 GeV is much worse
- Zee is worse by > 40% w.r.t. Zmm
- right hand pol is worse by 5 – 10 % w.r.t. left hand

Mass error

- 350 GeV is worse by factor of slightly less than 3 w.r.t. 250 GeV
- Zee is worse by a factor of 2 – 3 w.r.t. Zmm
- Systematic error of fitted recoil mass is negligible (< few MeV for 250 , 350 GeV)

(+0.8,−0.3)		xsec err	mass err [MeV]
250GeV	Zmm	3.57%	40.5
	Zee	5.14%	121
	Total	**2.93%**	**38.4**
350GeV	Zmm	4.31%	112
	Zee	6.26%	296
	Total	**3.55%**	**105**
500GeV	Zmm	8.36%	613
	Zee	9.85%	1510
	Total	**6.37%**	**568**

xsec error almost same as past results using GPET

250 GeV	e2e2_Lpol				deviation	deviation
	N(100-160)	N_err	eff	eff_err	from avg	from ALL
bb	1885	5	72.40%	0.15%	0.42%	0.21%
cc	1882	5	72.29%	0.15%	0.31%	0.10%
tt	1883	5	72.33%	0.14%	0.35%	0.15%
gg	1872	5	71.91%	0.15%	-0.08%	-0.28%
ww	1866	5	71.67%	0.14%	-0.31%	-0.51%
zz	1856	5	71.29%	0.15%	-0.69%	-0.90%
all modes	1883	9	72.19%	0.27%		
		avg of 6	71.98%			

Efficiency of each Higgs decay mode (after all cuts)

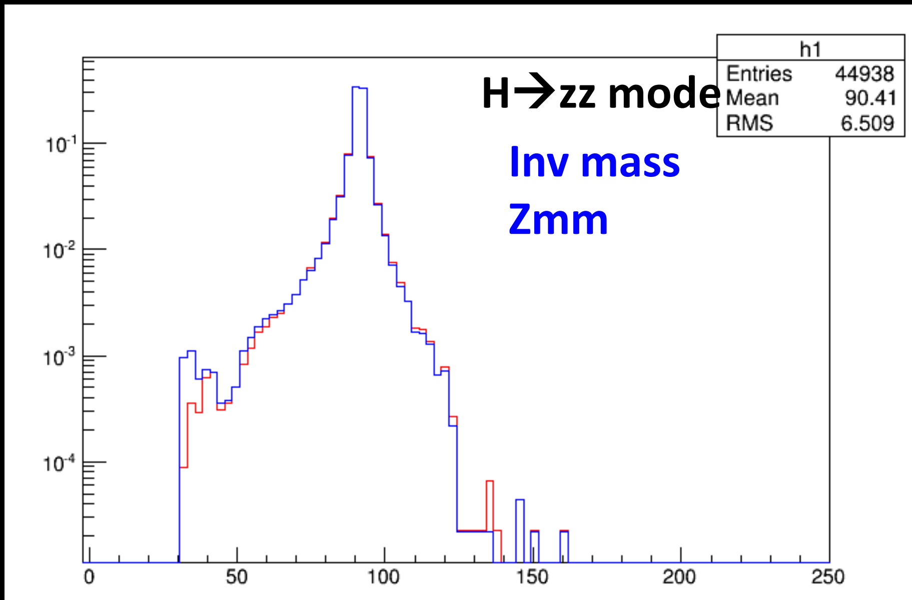
- systematic bias is < **1.3% for Zmm. < 4.2% for Zee**
- **H→zz, H→ww most affected**

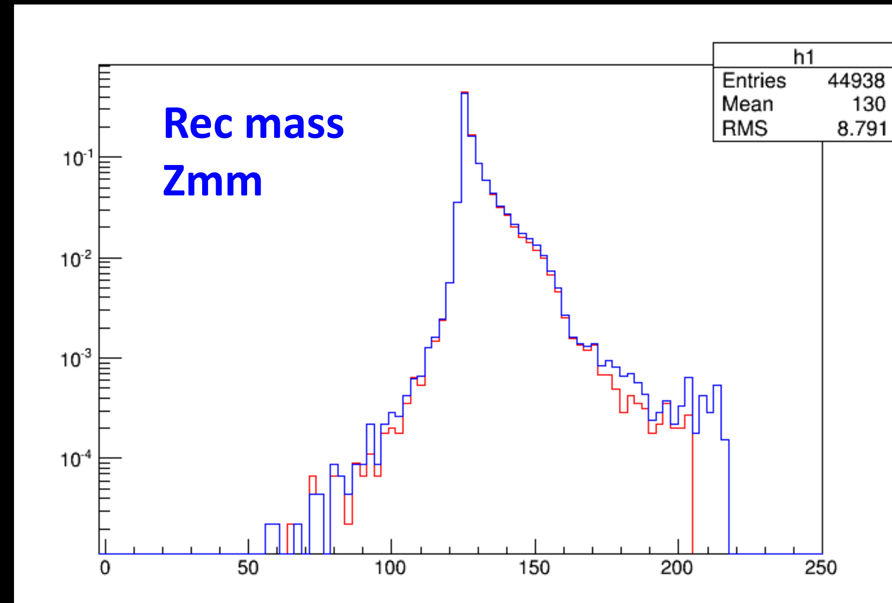
(lepton pair containing lepton not from prompt Z decay)

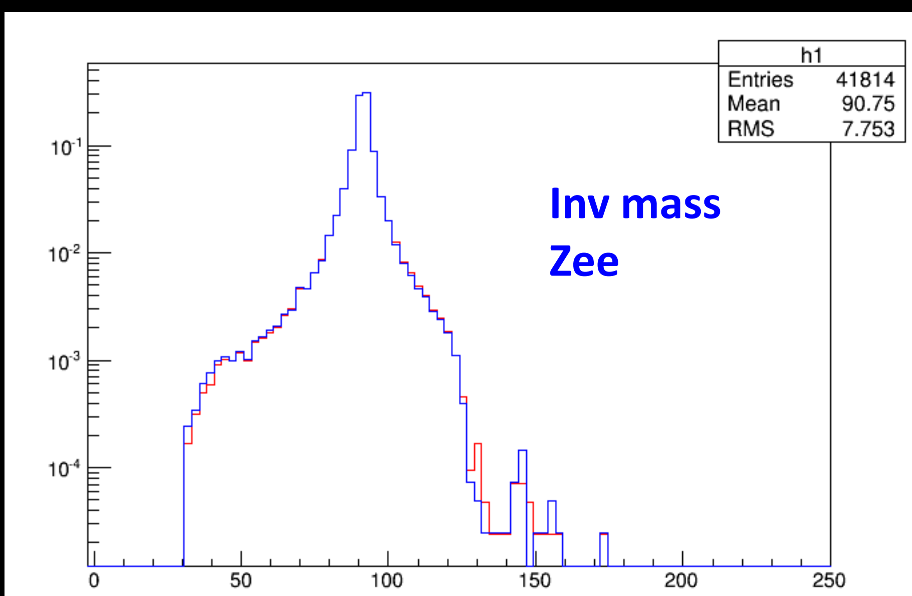
250 GeV	e1e1_Lpol				deviation	deviation
	N(100-160)	deltaN	eff	eff_err	from avg	from ALL
bb	1491	6	54.65%	0.17%	-1.15%	-0.39%
cc	1497	6	54.86%	0.16%	-0.94%	-0.18%
tt	1480	6	54.21%	0.16%	-1.58%	-0.83%
gg	1484	6	54.38%	0.16%	-1.42%	-0.66%
ww	1469	6	53.83%	0.16%	-1.96%	-1.21%
zz	1442	6	52.83%	0.16%	-2.96%	-2.21%
all modes	1502	10	55.04%	0.28%		
		avg of 6	54.13%			

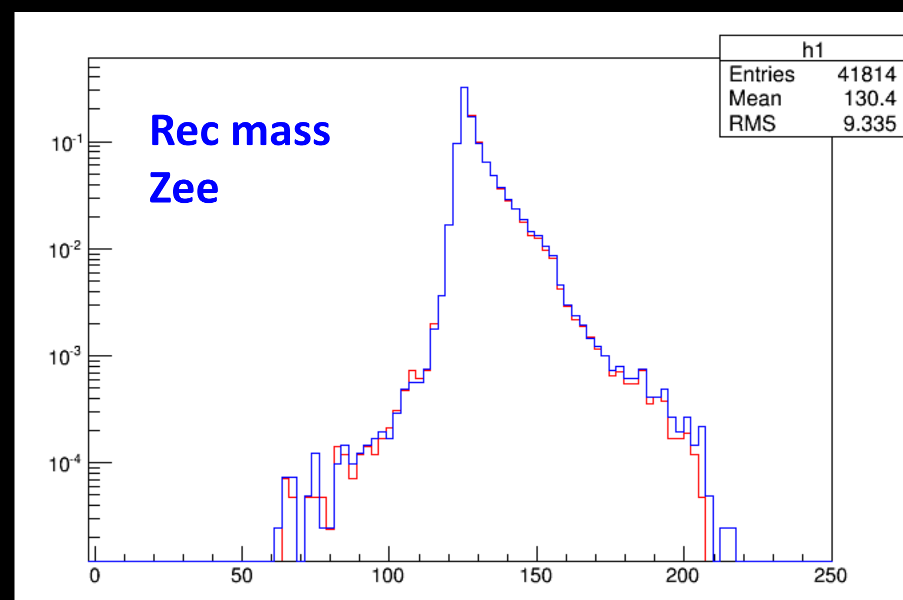
Blue : old

Red: new : inv mass and recoil mass are not as spread out









Efficiency of each Higgs decay mode (after each cut)

MC truth , with costhetamiss

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	92.41 +/-0.086	92.43 +/-0.087	91.66 +/- 0.09	93.1 +/-0.082	92.19 +/-0.086	92.41 +/-0.085	92.83 +/- 0.07
Cut1 :	92.41 +/-0.086	92.43 +/-0.087	91.66 +/- 0.09	93.1 +/-0.082	92.19 +/-0.086	92.41 +/-0.085	92.83 +/- 0.07
Cut2 :	90.85 +/-0.094	90.84 +/-0.095	90.05 +/-0.098	91.41 +/- 0.09	90.56 +/-0.093	90.86 +/-0.093	90.51 +/- 0.08
Cut3 :	88.92 +/- 0.1	89.07 +/- 0.1	88.23 +/- 0.11	89.52 +/-0.099	88.74 +/- 0.1	89.11 +/- 0.1	88.72 +/-0.086
Cut4 :	88.71 +/- 0.1	88.88 +/- 0.1	88.03 +/- 0.11	89.33 +/- 0.1	88.54 +/- 0.1	88.91 +/- 0.1	88.55 +/-0.087
Cut5 :	88.66 +/- 0.1	88.8 +/- 0.1	87.97 +/- 0.11	88.87 +/- 0.1	88.44 +/- 0.1	88.8 +/- 0.1	86.73 +/-0.092
Cut6 :	88.16 +/- 0.1	88.47 +/- 0.1	87.82 +/- 0.11	88.12 +/- 0.1	87.69 +/- 0.11	88.01 +/- 0.1	73.17 +/- 0.12
Cut7 :	81.72 +/- 0.13	81.74 +/- 0.13	81.23 +/- 0.13	81.74 +/- 0.12	81.29 +/- 0.12	81.76 +/- 0.12	68.01 +/- 0.13
Cut8 :	81.55 +/- 0.13	81.59 +/- 0.13	81.07 +/- 0.13	81.54 +/- 0.13	81.12 +/- 0.13	81.61 +/- 0.12	67.92 +/- 0.13
Cut9 :	81.55 +/- 0.13	81.59 +/- 0.13	81.07 +/- 0.13	81.54 +/- 0.13	81.12 +/- 0.13	81.61 +/- 0.12	67.92 +/- 0.13
Cut10:	74 +/- 0.14	73.88 +/- 0.14	73.63 +/- 0.14	74.22 +/- 0.14	73.8 +/- 0.14	74.53 +/- 0.14	64.49 +/- 0.13

MC Truth, no costhetamis

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	92.41 +/-0.086	92.43 +/-0.087	91.66 +/- 0.09	93.1 +/-0.082	92.19 +/-0.086	92.41 +/-0.085	92.83 +/- 0.07
Cut1 :	92.41 +/-0.086	92.43 +/-0.087	91.66 +/- 0.09	93.1 +/-0.082	92.19 +/-0.086	92.41 +/-0.085	92.83 +/- 0.07
Cut2 :	90.85 +/-0.094	90.84 +/-0.095	90.05 +/-0.098	91.41 +/- 0.09	90.56 +/-0.093	90.86 +/-0.093	90.51 +/- 0.08
Cut3 :	88.92 +/- 0.1	89.07 +/- 0.1	88.23 +/- 0.11	89.52 +/-0.099	88.74 +/- 0.1	89.11 +/- 0.1	88.72 +/-0.086
Cut4 :	88.71 +/- 0.1	88.88 +/- 0.1	88.03 +/- 0.11	89.33 +/- 0.1	88.54 +/- 0.1	88.91 +/- 0.1	88.55 +/-0.087
Cut5 :	88.66 +/- 0.1	88.8 +/- 0.1	87.97 +/- 0.11	88.87 +/- 0.1	88.44 +/- 0.1	88.8 +/- 0.1	86.73 +/-0.092
Cut6 :	88.66 +/- 0.1	88.8 +/- 0.1	87.97 +/- 0.11	88.87 +/- 0.1	88.44 +/- 0.1	88.8 +/- 0.1	86.73 +/-0.092
Cut7 :	82.09 +/- 0.12	82.01 +/- 0.13	81.35 +/- 0.13	82.25 +/- 0.12	81.93 +/- 0.12	82.32 +/- 0.12	80.3 +/- 0.11
Cut8 :	81.92 +/- 0.12	81.86 +/- 0.13	81.19 +/- 0.13	82.06 +/- 0.12	81.76 +/- 0.12	82.18 +/- 0.12	80.12 +/- 0.11
Cut9 :	81.92 +/- 0.12	81.86 +/- 0.13	81.19 +/- 0.13	82.06 +/- 0.12	81.76 +/- 0.12	82.18 +/- 0.12	80.12 +/- 0.11
Cut10:	74.35 +/- 0.14	74.11 +/- 0.14	73.74 +/- 0.14	74.63 +/- 0.14	74.38 +/- 0.14	75.01 +/- 0.14	72.98 +/- 0.12

cut definition

```
--------------------------
Process: ZH --> mu+ mu- H
Polarization: (e-,e+) = (-0.8,+0.3)
----------Cuts----------
Cut  0 :
Cut  1 :    leptype==13
Cut  2 :    Ptdl>10&&abs(Minv-91.18)<40&&Mrec>100&&Mrec<300
Cut  3 :    Minv>73&&Minv<120
Cut  4 :    Ptdl>10&&Ptdl<70
Cut  5 :    (Ptsum<0||Ptsum>10)
Cut  6 :    !((Evis-Elep1-Elep2-Ephotonmax)<10&&Ephotonmax>0&&abs(cosmis)>0.98)
Cut  7 :    abs(cosz) < 0.9
Cut  8 :    Mrec>100&&Mrec<160
```

If omit costhetamiss cut

- Bias on aa mode is greatly reduced by a factor of 10
- Remaining bias from Minv and Ptsum cut

Efficiency of each Higgs decay mode (after each cut)

MC truth , with costhetamiss

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	87.86 +/- 0.11	87.72 +/- 0.11	87.02 +/- 0.11	88.21 +/- 0.1	87.91 +/- 0.11	87.98 +/- 0.1	88.84 +/-0.083
Cut1 :	87.86 +/- 0.11	87.72 +/- 0.11	87.02 +/- 0.11	88.21 +/- 0.1	87.91 +/- 0.11	87.98 +/- 0.1	88.84 +/-0.083
Cut2 :	86.23 +/- 0.12	86.12 +/- 0.11	85.33 +/- 0.11	86.45 +/- 0.11	86.3 +/- 0.11	86.24 +/- 0.11	86.06 +/-0.091
Cut3 :	84.15 +/- 0.12	84.05 +/- 0.12	83.28 +/- 0.12	84.23 +/- 0.12	84.17 +/- 0.12	84.09 +/- 0.12	83.89 +/-0.096
Cut4 :	84.05 +/- 0.12	83.96 +/- 0.12	83.2 +/- 0.12	84.13 +/- 0.12	84.06 +/- 0.12	83.99 +/- 0.12	83.8 +/-0.097
Cut5 :	84 +/- 0.13	83.88 +/- 0.12	83.13 +/- 0.12	83.68 +/- 0.12	83.97 +/- 0.12	83.88 +/- 0.12	82.09 +/- 0.1
Cut6 :	83.51 +/- 0.13	83.54 +/- 0.12	82.95 +/- 0.12	83 +/- 0.12	83.19 +/- 0.12	83.13 +/- 0.12	70.04 +/- 0.12
Cut7 :	77.41 +/- 0.14	77.53 +/- 0.14	76.82 +/- 0.14	77.22 +/- 0.13	77.15 +/- 0.14	77.36 +/- 0.13	65.13 +/- 0.13
Cut8 :	77.22 +/- 0.14	77.3 +/- 0.14	76.56 +/- 0.14	77 +/- 0.14	76.93 +/- 0.14	77.11 +/- 0.13	64.97 +/- 0.13
Cut9 :	77.22 +/- 0.14	77.3 +/- 0.14	76.56 +/- 0.14	77 +/- 0.14	76.93 +/- 0.14	77.11 +/- 0.13	64.97 +/- 0.13
Cut10:	68.76 +/- 0.16	68.64 +/- 0.15	68.35 +/- 0.15	68.83 +/- 0.15	68.48 +/- 0.15	69 +/- 0.15	60.27 +/- 0.13

MC Truth, no costhetamis

Eff. (%)	bb	cc	gg	tt	ww	zz	aa
Cut0 :	87.86 +/- 0.11	87.72 +/- 0.11	87.02 +/- 0.11	88.21 +/- 0.1	87.91 +/- 0.11	87.98 +/- 0.1	88.84 +/-0.083
Cut1 :	87.86 +/- 0.11	87.72 +/- 0.11	87.02 +/- 0.11	88.21 +/- 0.1	87.91 +/- 0.11	87.98 +/- 0.1	88.84 +/-0.083
Cut2 :	86.23 +/- 0.12	86.12 +/- 0.11	85.33 +/- 0.11	86.45 +/- 0.11	86.3 +/- 0.11	86.24 +/- 0.11	86.06 +/-0.091
Cut3 :	84.15 +/- 0.12	84.05 +/- 0.12	83.28 +/- 0.12	84.23 +/- 0.12	84.17 +/- 0.12	84.09 +/- 0.12	83.89 +/-0.096
Cut4 :	84.05 +/- 0.12	83.96 +/- 0.12	83.2 +/- 0.12	84.13 +/- 0.12	84.06 +/- 0.12	83.99 +/- 0.12	83.8 +/-0.097
Cut5 :	84 +/- 0.13	83.88 +/- 0.12	83.13 +/- 0.12	83.68 +/- 0.12	83.97 +/- 0.12	83.88 +/- 0.12	82.09 +/- 0.1
Cut6 :	84 +/- 0.13	83.88 +/- 0.12	83.13 +/- 0.12	83.68 +/- 0.12	83.97 +/- 0.12	83.88 +/- 0.12	82.09 +/- 0.1
Cut7 :	77.82 +/- 0.14	77.82 +/- 0.14	76.96 +/- 0.14	77.71 +/- 0.13	77.82 +/- 0.13	77.91 +/- 0.13	76.11 +/- 0.11
Cut8 :	77.62 +/- 0.14	77.59 +/- 0.14	76.71 +/- 0.14	77.49 +/- 0.13	77.6 +/- 0.14	77.67 +/- 0.13	75.87 +/- 0.11
Cut9 :	77.62 +/- 0.14	77.59 +/- 0.14	76.71 +/- 0.14	77.49 +/- 0.13	77.6 +/- 0.14	77.67 +/- 0.13	75.87 +/- 0.11
Cut10:	69.11 +/- 0.16	68.9 +/- 0.15	68.46 +/- 0.15	69.24 +/- 0.15	69.08 +/- 0.15	69.46 +/- 0.15	67.84 +/- 0.12

cut definition

```
------------------------
Process: ZH --> e+ e- H
Polarization: (e-,e+) = (-0.8,+0.3)
----------Cuts----------
Cut  0 :
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Cut  3 :    Minv>73&&Minv<120
Cut  4 :    Ptdl>10&&Ptdl<70
Cut  5 :    (Ptsum<0||Ptsum>10)
Cut  6 :    !((Evis-Elep1-Elep2-Ephotonmax)<10&&Ephotonmax>0&&abs(cosmis)>0.98)
Cut  7 :    abs(cosz) < 0.9
Cut  8 :    Mrec>100&&Mrec<160
```
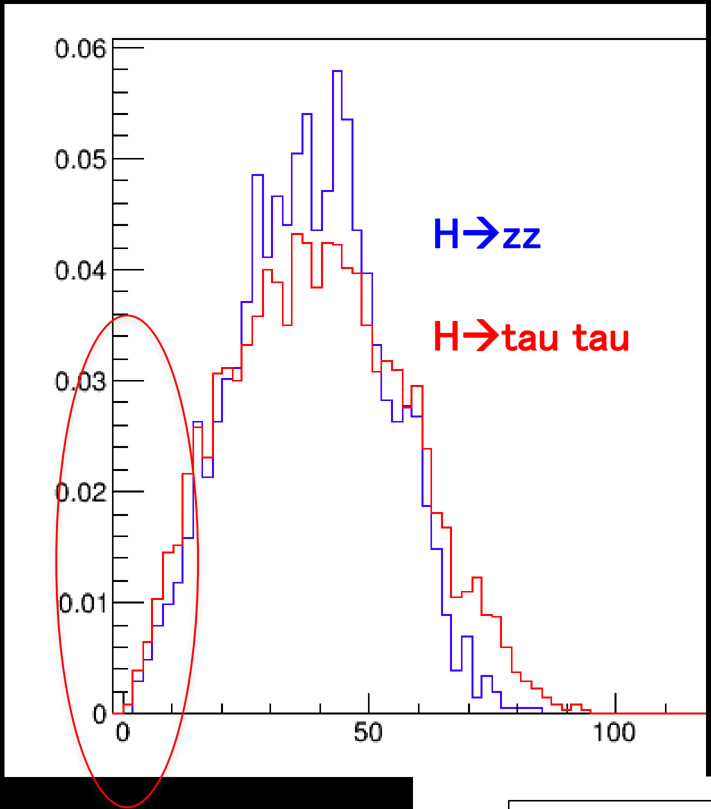
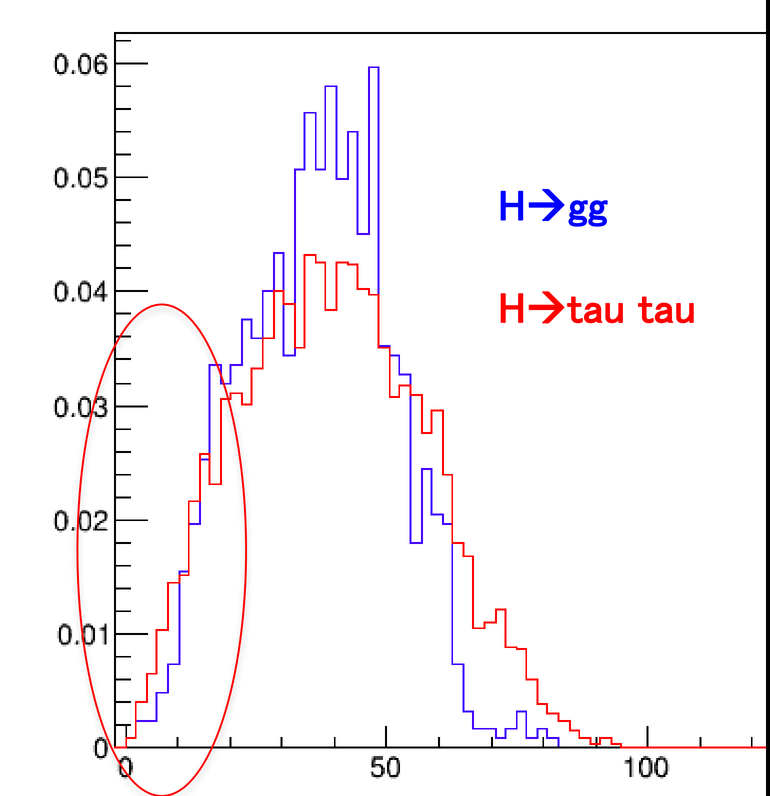

If omit costhetamiss cut

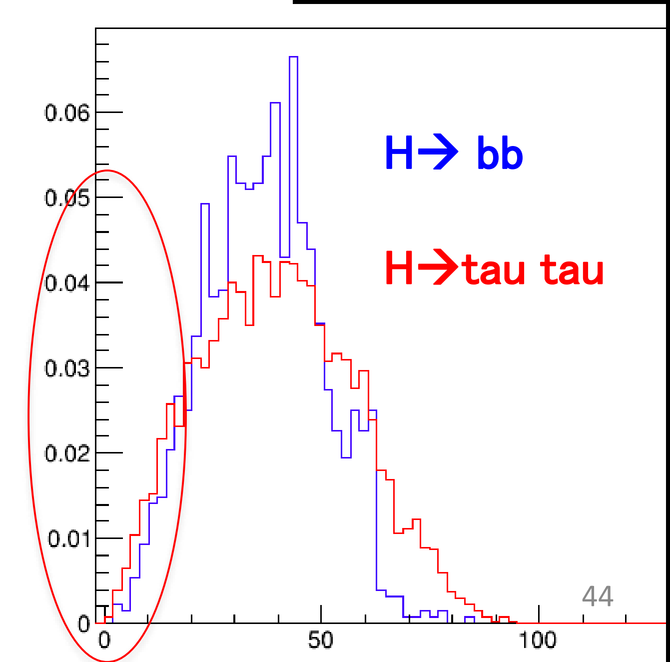
- Bias on aa mode is greatly reduced by a factor of 10
- Remaining bias from Minv and Ptsum cut

observation of Ptsum distr
(at stage just before Ptsum cut)
Zmm channel

Compare to other modes,
H→tau tau seem very slightly biased in region of Ptsum < 10

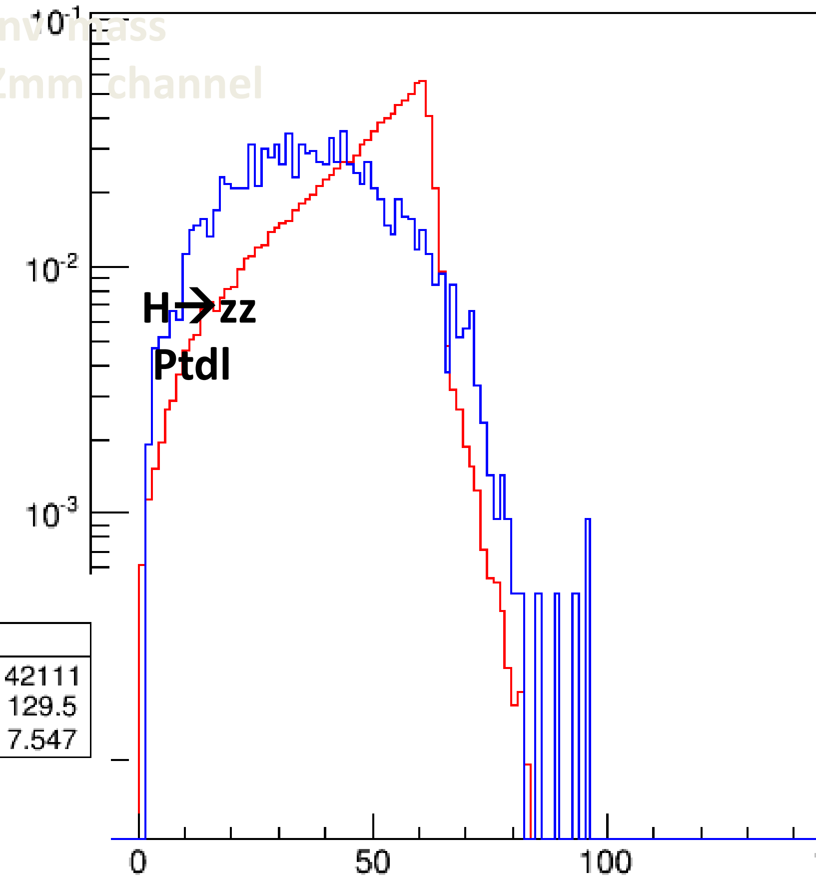


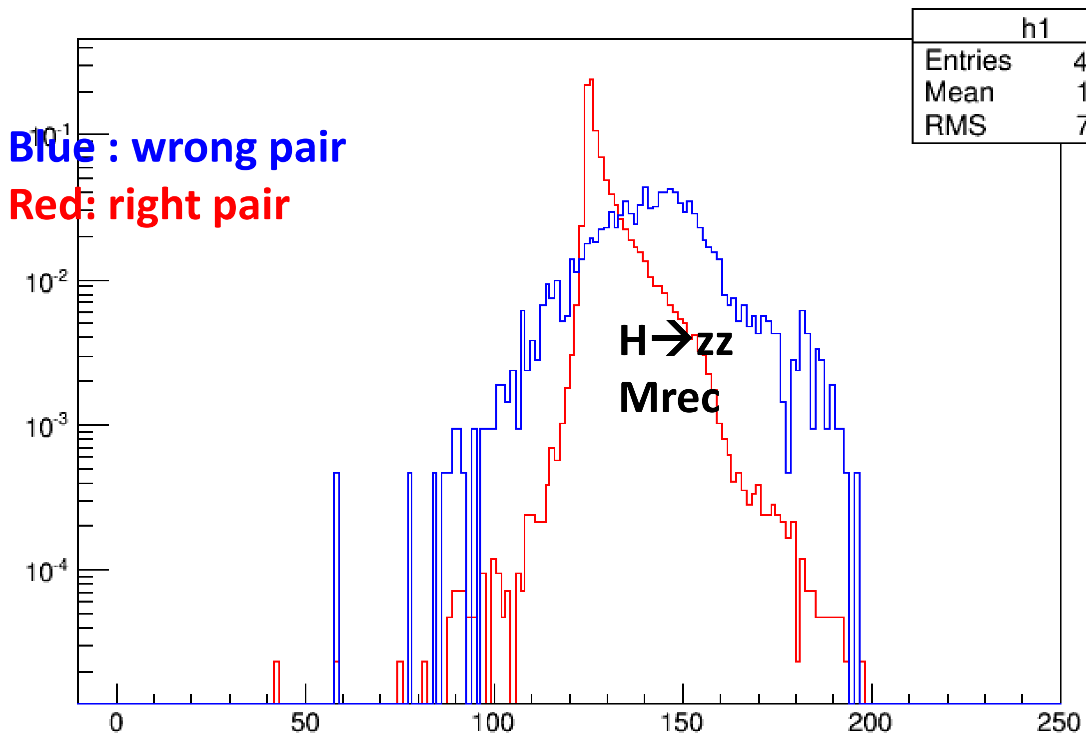


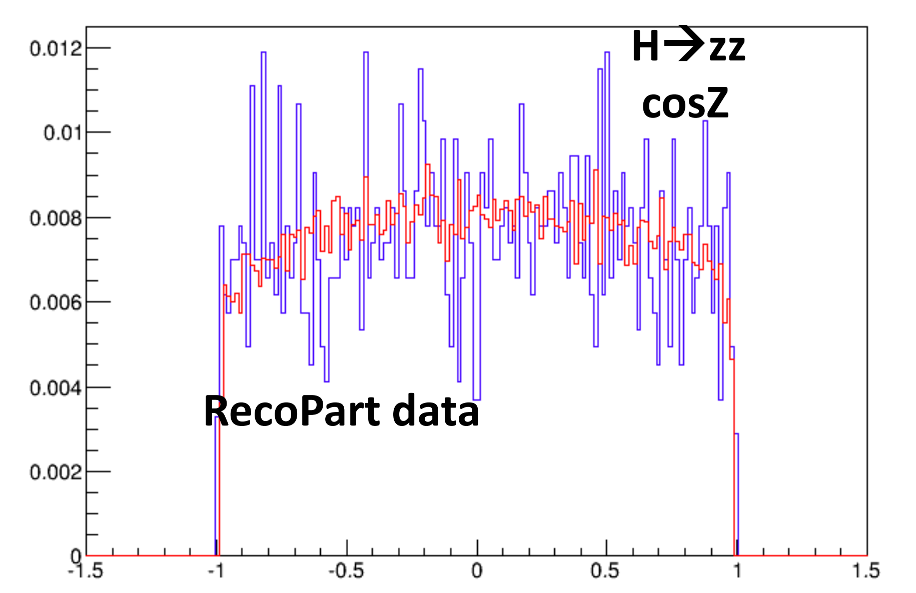


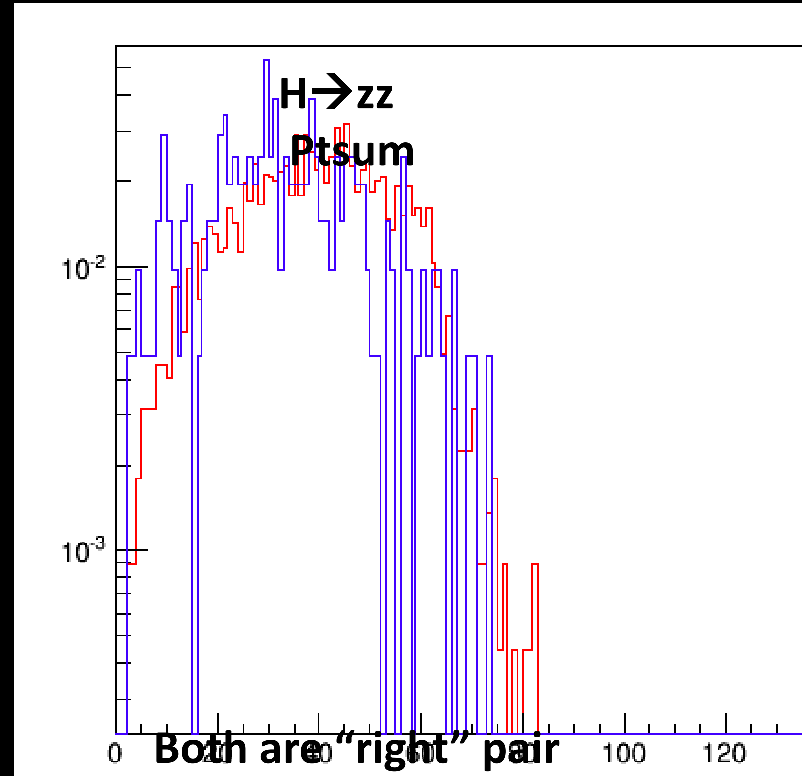
H→zz mode

Events satisfy |Minv-MZ|<40 GeV



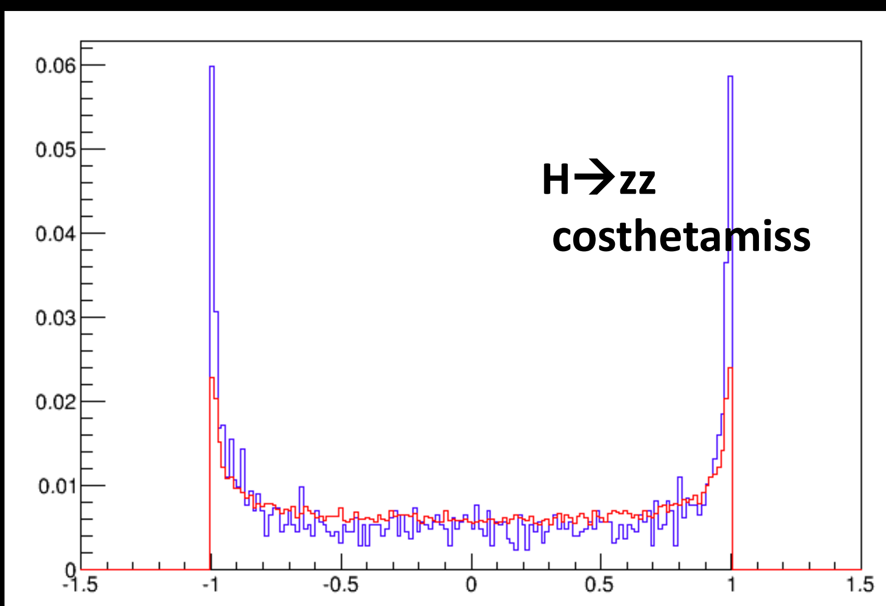


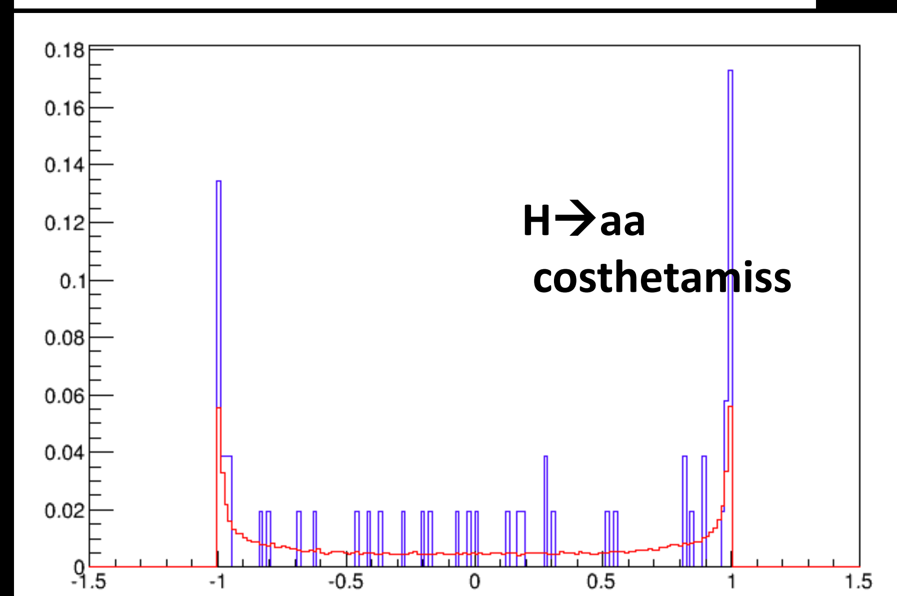




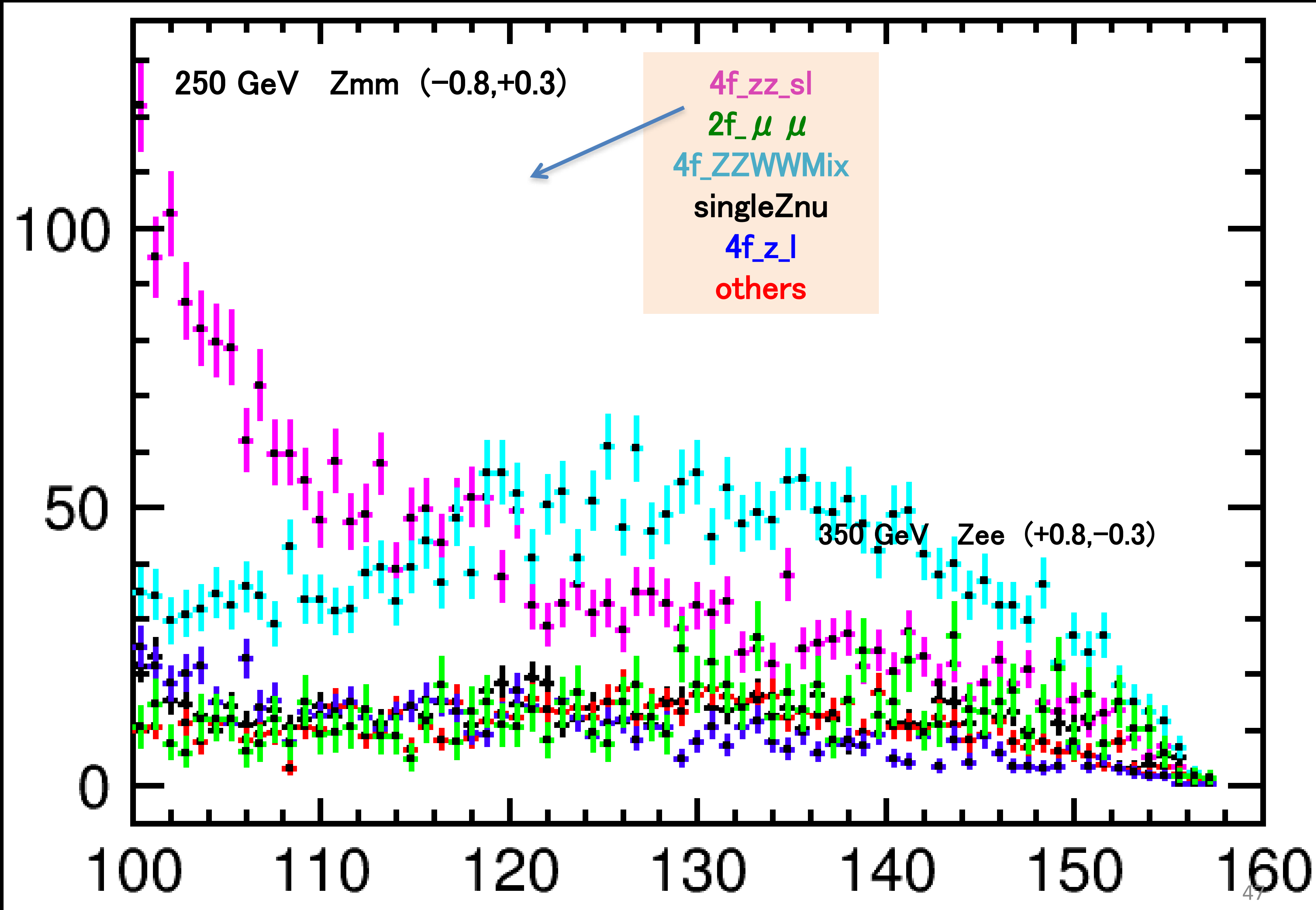
Blue : wrong pair

Red: right pair





250 GeV Zmm left pol



250 GeV Zmm left pol