Leptonic Higgs Recoil Study at ECM=250, 350 and 500 GeV at the ILC

LCWS2015

International Workshop on Future Linear Colliders

Whistler, BC, Canada Nov 2-6, 2015

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Leptonic recoil mass study

@ECM = 250 GeV, 350 GeV, and 500 GeV

Goal:

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

- By this time, measurement precision has been shown to (at least) meet the expectations in ILC physics documents
- leptonic recoil has been demonstrated to be model independent

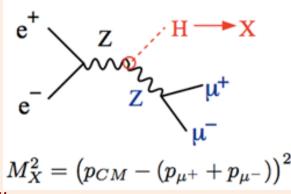
ILC sample used in analysis

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



Recoil mass

Dominant backgrounds

<u>Signatures</u>

• $e+e-\rightarrow ZZ\rightarrow I+I-X$:

forward Z production angle

• e+ e- \rightarrow γ Z \rightarrow γ I+ I- :

energetic ISR y which balance dilepton pt

e+e- → W W → I+I-vv:

broad M_{inv}, M_{rec} distr.

- data selection is based on characteristics of signal / BG
- a final recoil mass window + TMVA cut at the end

Progress since the ALCW 2015 (@KEK)

Last Time

- Analysis for the Zmm channel @
 250, 350 GeV
- Began first steps in minimizing Higgs decay mode dependence

Features of This Time

 precision evaluation of leptonic recoil for all ECM's in ILC running plan

12 scenarios

- 3 x ECM : 250, 350, 500 GeV
- 2 x lepton channels : Zmm, Zee
- 2 x polarizations: (-0.8,+0.3) (+0.8,-0.3)
- For the first time, demonstrated model independence
- Mass measurement using H→bb mode

Layout of this Talk

- Evaluate analysis performance
- **◆** Comparison between different ECM and polarization
- **◆** Demonstration of Higgs decay mode independence
- **♦Summary & Plans**

PART I

The Expected Precision of ZH cross section and Higgs Mass

Lepton Pair Candidate Selection

opposite +/- 1 charge

- E_cluster / P_total : < 0.5 (μ) / > 0.9 (e)
- isolation (small cone energy)
- Minv closest to Z mass
- χ 2 minimization based on Minv and Mrecoil
- $|D0/\delta D0| < 5$
- FSR and bremsstrahlung recovery

Final Selection

- 73 < GeV < M_inv < 120 GeV
- 10 GeV < pt dl < 140 GeV

$$|\overrightarrow{P_{t,sum}}| \equiv |\overrightarrow{P_{t,\gamma}} + \overrightarrow{P_{t,dl}}| > 6 \text{ GeV}$$

- $|\cos(\theta_{missing})| < 0.98$
- $|\cos(\theta_z)| < 0.9$
- 100 GeV < Mrecoil < 200 GeV

TMVA cut

Example of ECM=350 GeV,

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
- $\theta_Z = Z$ production angle

- Effective for cutting $\mu \mu$ / ee BG
- Use info of most energetic photon (pt_{_} γ , cone energy)
- "protection limits" have been placed to minimize bias on signal

red box:

key improvements w.r.t. previous studies

LCWS2015, J.Similar methods applied to all ECM and polarizations

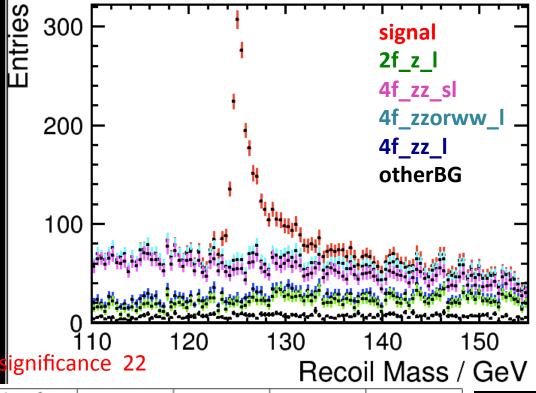
Data Selection Performance

Major residual BG

Zmm

- (1) 4f_ZZ_semileptonic (> 43% @ ECM=250 GeV)
- (2) 2f_z_leptonic (> 26% @ ECM=250 GeV)

Efficiencies after each selection step 250 GeV Zmm (-0.8,+0.3)



Process		signal	signal				
$ m e_L^- e_R^+$	$\mu\mu X$	efficiency	significance	2f_l	4f_l	4f_sl	total BG
expected	2603	100%	0.42	9.54×10^{6}	3.15×10^{6}	4.98×10^{6}	1.98×10^{7}
Lepton ID+PreCuts	2395	92.01%	9.57	20513	31839	7945	60297
$M_{inv} \in [73, 120] \text{ GeV}$	2340	89.90%	10.86	15950	20930	7211	44091
$P_{t,dl} \in [10, 70] \text{ GeV}$	2335	89.70%	11.17	15428	19648	6245	41322
$P_{t,sum}$ < 10 GeV	2333	89.63%	12.86	4739	19594	6238	30570
$ \cos\theta_{miss} < 0.98$	2333	89.63%	12.95	4391	19511	6238	30139
$ \cos\theta_{dl} < 0.90$	2165	83.17%	13.23	2764	16781	5040	24585
TMVA	2060	79.14%	15.57	2145	8844	4450	15439
$M_{rec} \in [110, 155] \text{ GeV}$	2057	79.02%	19.61	1966	2500	4450	8947
$E_{vis} > 10 \text{ GeV}$	2046	78.60%	22.00	1629	2011	2961	6602

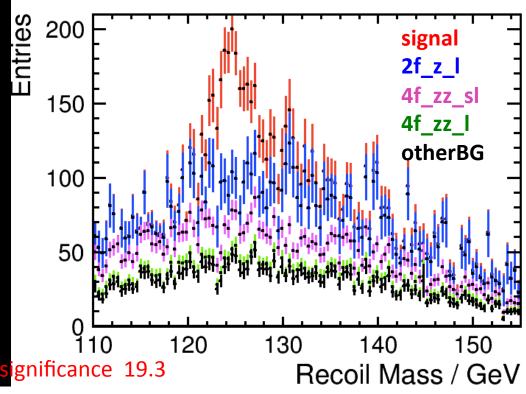
Data Selection Performance

Major residual BG

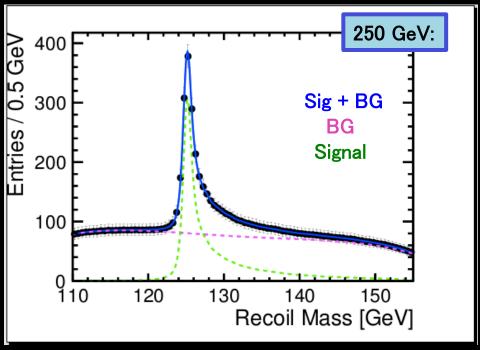
Zee

- (1) 2f_z_leptonic (bhabha)
 - (> 44% @ ECM=250 GeV)
- (2) 4f_ZZ_semileptonic
 - (> 31% @ ECM=250 GeV)

Efficiencies after each selection step 250 GeV Zee (-0.8,+0.3)



Process		signal	signal				
$ m e_L^- e_R^+$	eeX	efficiency	significance	2f_l	$4\mathrm{f}_{-\!1}$	$4\mathrm{f_sl}$	total BG
expected	2729	100%	0.44	9.54×10^{6}	3.15×10^{6}	4.98×10^{6}	1.98×10^{7}
Lepton ID+PreCuts	2374	86.99%	5.19	145980	45854	15016	207079
$M_{inv} \in [73, 120] \text{ GeV}$	2306	84.50%	6.69	80302	25728	10314	116499
$P_{t,dl} \in [10, 70] \text{ GeV}$	2300	84.28%	6.78	79066	24425	9289	112933
$P_{t,sum}$ < 6 GeV	2299	84.24%	8.47	37890	24142	9259	71445
$ \cos\theta_{miss} < 0.98$	2299	84.24%	8.94	30526	23884	9232	63796
$ \cos\theta_{dl} < 0.90$	2127	77.94%	9.53	20513	20000	7022	47677
TMVA	1673	61.30%	15.59	3138	4108	2574	9833
$M_{rec} \in [110, 155] \text{ GeV}$	1670	61.19%	18.23	3098	1033	2574	6718
$E_{vis} > 10 \text{ GeV}$	1664	60.97%	L G\9 .33015, J.	^{Yan} 2767	934	2043	5758

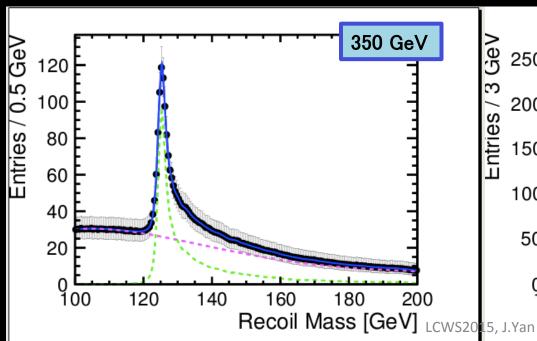


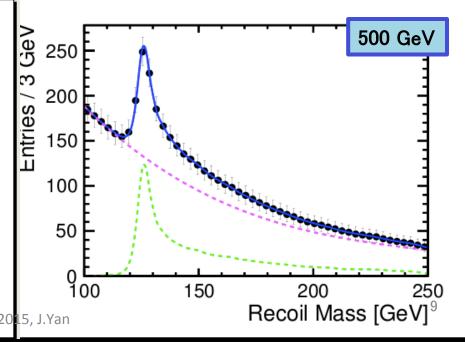
recoil mass histogram after data selection

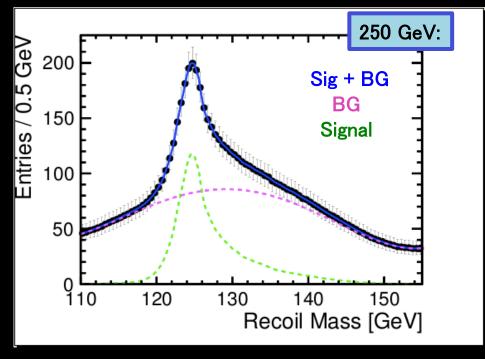


Pol: (- 0.8, +0.3)

Toy MC data based on the fitted results of the "real" MC data





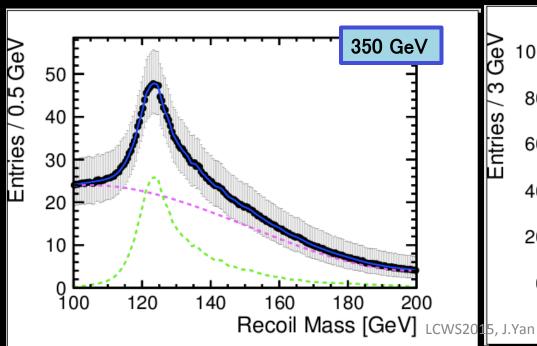


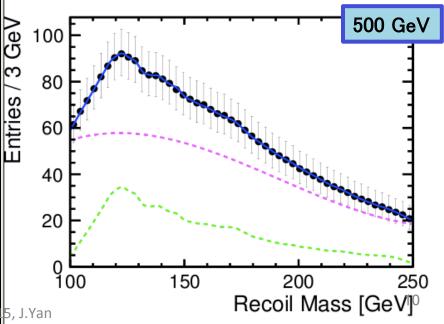
recoil mass histogram after data selection



Pol: (- 0.8, +0.3)

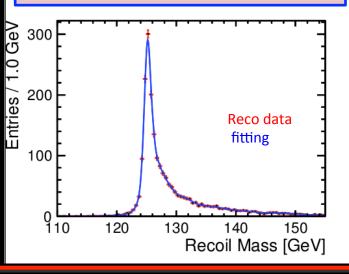
Toy MC data based on the fitted results of the "real" MC data



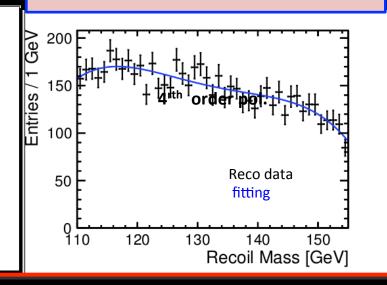


Fitting of recoil mass spectrum





BG: 3rd or 4^{rth} order polynomial



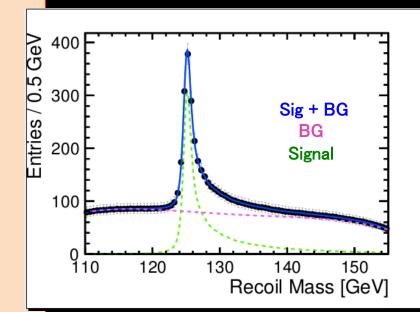
Toy MC study

goal:

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



LCWS2015, J.Yan

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Statistical error study results

ECM=250) GeV	xsec	mass[MeV]	
Zmm left		3.14%	38	
	right	3.61%	42	
Zee	left	4.01%	125	
	right	4.73%	148	
ECM=350) GeV	xsec	mass	
Zmm	left	3.88%	98.3	
	right	4.38%	113	
Zee	left	5.13%	446	
	right	6.09%	489	
ECM=500GeV		xsec	mass	
Zmm	left	6.23%	540	
	right	7.51%	634	
Zee	left	6.96%	1190	
	right	7.53%	1260	

$Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ combined

250GeV		xsec	mass[MeV]
	left	2.47%	36
	right	2.87%	40
350GeV	left	3.09%	96
	right	3.56%	110
500GeV	left	4.64%	492
	right	5.32%	566

xsec error

- 350 GeV is worse by 25% w.r.t. 250 GeV
- Zee is worse by 30% w.r.t. Zmm
- right hand pol is worse by ~ 15 % w.r.t. left hand pol

Mass: 350 GeV is 2-3 times worse w.r.t. 250 GeV

 $250 \, \text{fb}^{-1} @ 250 \, \text{GeV}$ $m_H = 125 \, \text{GeV}$

$$\Delta \sigma_H / \sigma_H = 2.6\%$$

 $\Delta m_H = 30 \, \mathrm{MeV}$

BR(invisible) < 1% @ 95% C.L.

Compared with TDR (extrapolated from mH=120GeV results)

NOTE!) methods are different TDR uses uncertainty on ratio of signal, not from fitting

- Assumed luminosities (TDR)
- ECM=250 GeV, 250 fb-1
- ECM=350 GeV, 333 fb-1
- ECM=500 GeV, 500 fb-1

Combined Higgs visible and invisible decay results

ECM	Pol	xsec precision
250 GeV	left	2.62%
	right	2.93%
350 GeV	left	3.33%
	right	3.73%
500 GeV	left	5.22%
	right	5.59%

contribution from invisible decay is very small

Invisible decay results

- Assumed luminosities (TDR)
- ECM=250 GeV, 250 fb-1
- ECM=350 GeV, 333 fb-1
- ECM=500 GeV, 500 fb-1

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%

LCWS2015, J.Yar

Precision scaled to the H20 scenario

After the full H20 run:
σZH error 0.89%,
MH error: 13 MeV

Compared with arXiv:1506.07830v1 (by

ILC Parameter Joint Working Group , based on TDR studies) (Jun 25, 2015)
ΔmH: 15 MeV

 $\Delta \sigma / \sigma$: sub - % level

(combined with hadronic recoil)

(combined with hadronic recor

Lumi _	\sqrt{s}	∫£dt
	[GeV]	[fb ⁻¹]
Physics run	500	500
Physics run	350	200
Physics run	250	500
Shutdown		
Physics run	500	3500
Physics run	250	1500
- polovization		fra

Run long time at 250, 500 GeV,

ECM=250GeV

(2 ab-1)

ECM=350GeV

(0.2 ab-1)

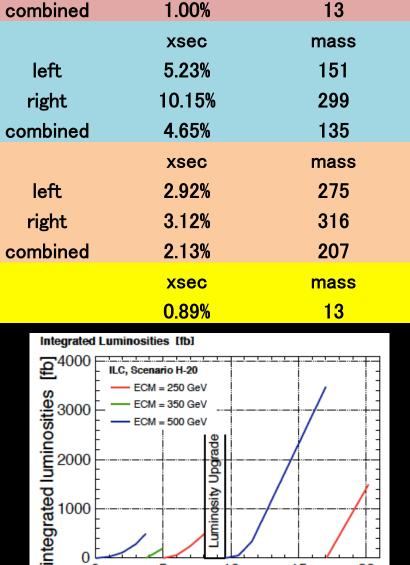
ECM=500GeV

(4 ab-1)

All channels

(full H20 run)

Physics run	250	1500	sn	ort at 350 Ge	V	
polarization	fraction with $sgn(P(e^-), P(e^+)) =$					
p 0 1 at 1 at 2 at 2 at 1	(-,+)		(+,-)	(-,-)	(+,+)	
\sqrt{s}	[%]		[%]	[%]	[%]	
250 GeV	67.5		22.5	5	5	
350 GeV	67.5		22.5	5	5	
500 GeV	40		40	10	LCWS20150J.Yar	



5

10

15

vears

Xsec_err

1.13%

2.18%

left

right

Mass_err [MeV]

15

30

More precise Higgs mass measurement using H→bb mode signal

since Higgs mass measurement does not need to be model-independent

the only major residual BG is 4f_zz_sl

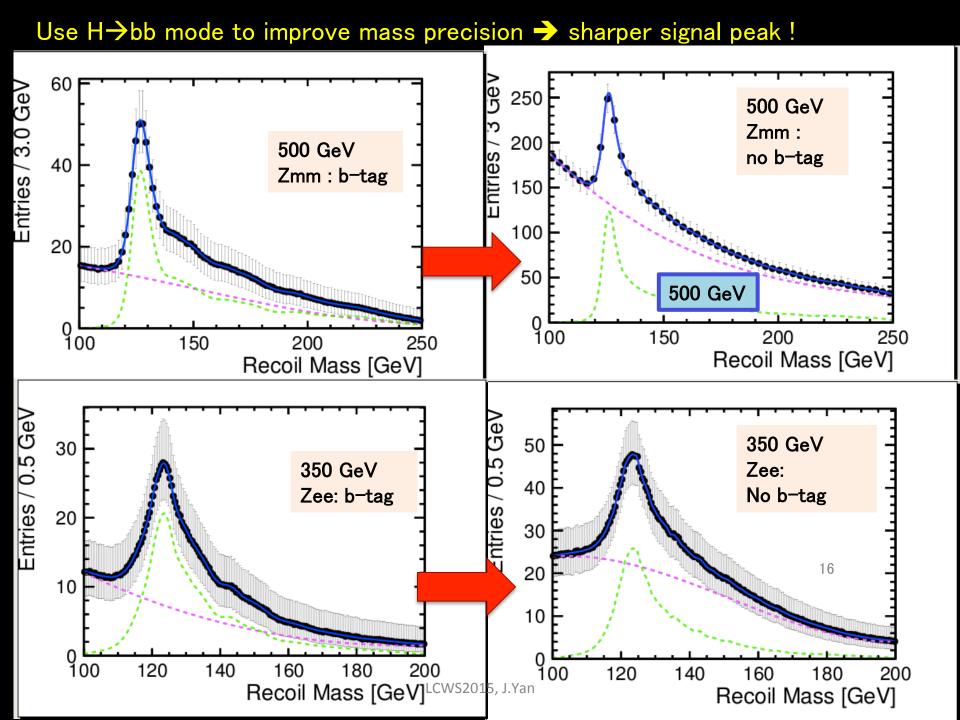
vents	Zee: b-ta	g signal
No. of Events		2f BG
10 ⁻²		~
10 ⁻³ E	0 0.2 0	.4 0.6 0.8 1
ement		b-likelihood

			mass error [M	leV]	improvement
250GeV	Zee	left	125	106	15.2%
	Zee	right	148	127	14.2%
350GeV	Zee	left	446	351	21.3%
	Zee	right	489	464	5.1%
500GeV	Zmm	left	540	414	23.3%
	Zmm	right	634	561	11.5%
	Zee	left	1190	1000	16.0%
	Zee	right	1260	1000	20.6%

Red: 2f BG Blue: signal

Improvement (up to $\sim 25\%$) mainly seen for Zee channel (2f BG is more serious for Zee) this is equal to saving a lot of accelerator run time!!

- 2f BG is greatly reduced, but mass precisions limited by signal statistics
- still more room for optimization (??)LCWS2015, J.Yan



Confirmed Necessity of FSR/ Bremsstrahlung Recovery

• brem/FSR photon is identified using θ w.r.t. final state lepton

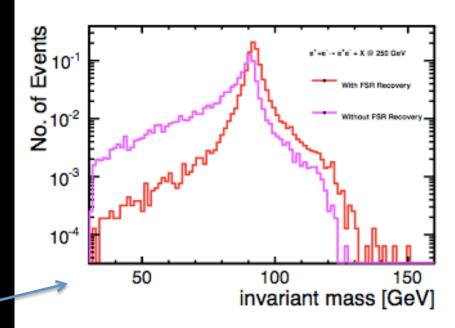
if $\cos \theta > 0.99$, γ four momenta combined with dilepton momenta

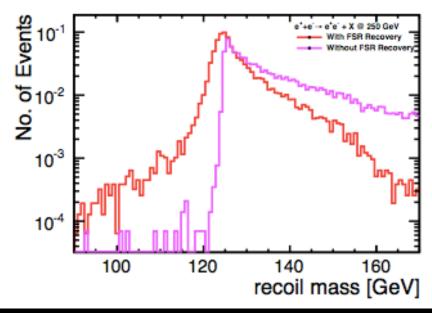
Minv and Mrec before and after brem/ FSR recovery is visibly different for Zee

Without FSR recovery in Zee channel:

- $\Delta \sigma ZH$ worsens by up to 65% (ex: Zee@ECM=250 GeV: $4.0\% \rightarrow 6.6\%$)
- Δ mH worsens by up to 14%

Not much difference for Zmm





PART II Higgs Decay Mode Independence

 It is crucial to not only achieve the goal precision but also to <u>maintain Higgs decay mode independence</u>

For the first time, leptonic recoil analysis has been demonstrated to be mode-independent!

- Detailed study using high statistics samples
- Extensive efforts to design data selection strategies so as to minimize bias

Details coming up

Efforts to reduce bias

 Investigated several algorithms for highest probability of correctly pairing two leptons from prompt Z boson decay example of improvement:

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92.44 + /- 0.10 \% \rightarrow 93.17 + /- 0.10\% (Zmm, ECM=250 GeV)
```

- Improved brem / FSR recovery algorithm to minimize bias on H→γγ mode
- Adjust Ptsum cut (without big damage on xsec and mass precisions)
- Optimized TMVA cut (choice of variables and tightness)
- significantly reduced muon contamination in Zee mode by carefully re-investigating χ 2(Minv, Mrec) in the end

Details coming up

C0	number of generated events	Performance of le	pton pairing
C1	number of selected μ (e) for $\mu^+\mu^-\mathrm{H}$ and $\mathrm{e^+e^-H}$		
C2	correct pairs		Affects
C3	1 prompt and 1 non-prompt lepton selected, however with 2	prompt leptons found	H→ZZ*
C4	2 non-prompt leptons selected, however with 2 promp	t leptons found	H→WW*
C5	only 1 prompt lepton found		
C6	no prompt leptons found		Η→ττ

Minimize a χ^2 function formed from Minv and Mrec

(previously only used Minv close to Z mass)

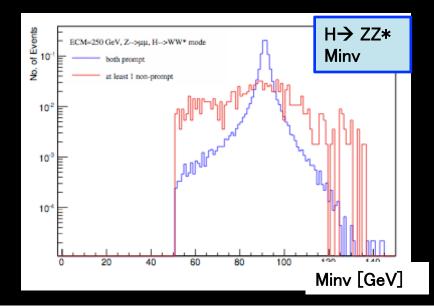
$$\chi^2 \left(M_{inv}, M_{rec} \right) = rac{\left(M_{inv} - M_Z
ight)^2}{\sigma_{M_{inv}}^2} + rac{\left(M_{rec} - m_H
ight)^2}{\sigma_{M_{rec}}^2}$$

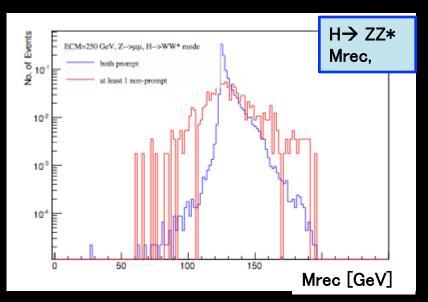
Also tried TMVA method with additional kinematic variables

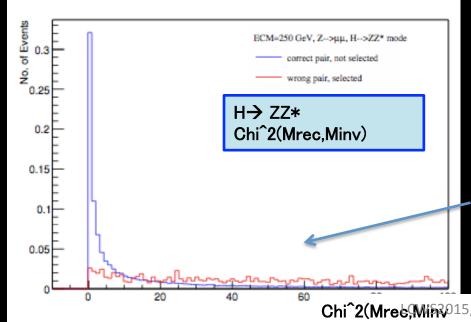
Compare algorithms: Chi², TMVA, are (equally) much better than Minv only

method	$\chi^2\left(M_{inv},M_{rec} ight)$				TMVA	M_{inv}		
mode	$H \rightarrow WW^*$	$\mathrm{H} ightarrow \mathrm{ZZ}^*$	$\mathrm{H} \rightarrow \tau \tau$	$H \rightarrow WW^*$	$\mathrm{H} ightarrow \mathrm{ZZ}^*$	$\mathrm{H} \rightarrow \tau \tau$	$\mathrm{H} ightarrow \mathrm{WW}^*$	$ ext{H} o ext{ZZ}^*$
C0	100%	100%	100%	100%	100%	100%	100%	100%
C1	94.01%	94.15%	94.00%	94.01%	94.15%	94.00%	94.01%	94.15%
C2	92.86%	93.17%	93.70%	93.02%	93.18%	93.72%	92.72%	92.44%
C3	0.831%	0728%	0.204%	0.670%	0.715%	0.188%	0.970%	1.46%
C4	0%	0.342%	0.002%	0%	0.421%	0.002%	0%	1.13%
C5	0.315%	0.250%	0.092%	0.315%	0.250%	0.092%	0.315%	0.250%
C6	0.002%	0.002%	0%	0.002%	0.002%	0%	0.002%	0.002%

- ◆ "wrong lepton pairing" : at least one of the leptons from Higgs decay
- Minv ~ MZ might be satisfied, but Mrec is deviated from Higgs mass







Red: at least one wrong lepton

Blue: both leptons correct

Best method:

select best pair by minimizing chi² based on Mrec and Minv

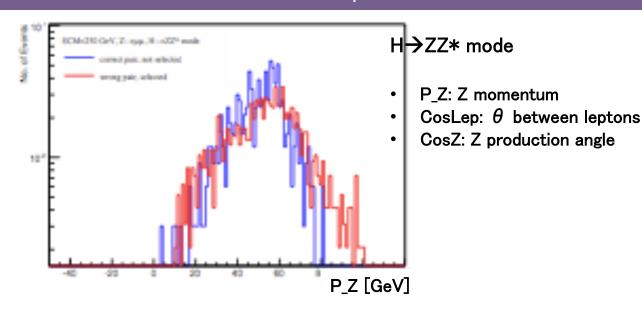
(previously: Minv closest to Z mass)

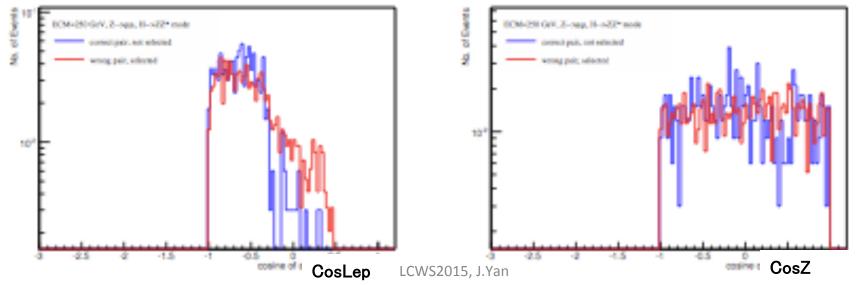
$$\chi^2\left(M_{inv}, M_{rec}
ight) = rac{\left(M_{inv} - M_Z
ight)^2}{\sigma_{M_{inv}}^2} + rac{\left(M_{rec} - m_H
ight)^2}{\sigma_{M_{rec}}^2}$$

The reason why TMVA cannot improve lepton pairing. the lepton kinematic parameters (Minv, Mrec, P_Z, Cos) are about same between selected "wrong pairs" and not-selected "correct pairs"

Besides, there were only a few 100 "wrong events" for TMVA background training

Blue: prompt dilepton, but not selected red: selected "wrong pair"



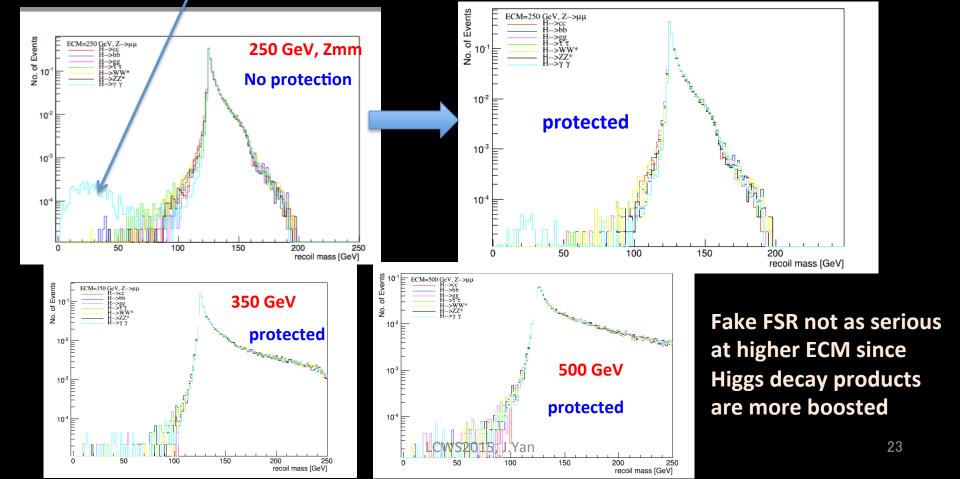


Protection on Brem/FSR Recovery

- discovered a bump in lower Mrec region for H→yy (cyan color)
- hard γ from Higgs decay ("fake FSR") are re-combined → large Minv i.e. small Mrec

if |recovered Miny - M_Z| > 10 GeV: inspect "should undo the FSR recovery?"

criteria |Minv_temp-M_Z| < |Minv – M_Z| OR Mrec<100 GeV AND Mrec_temp >120 GeV
 ("temp": tentatively remove recovered γ)



Significant bias reduction due to loosening Ptsum cut !!!

- $H \rightarrow \gamma \gamma$ is most guilty, due to Ptsum cut
- before: "Ptsum > 10 GeV" → loosened to "Ptsum > 6 GeV"

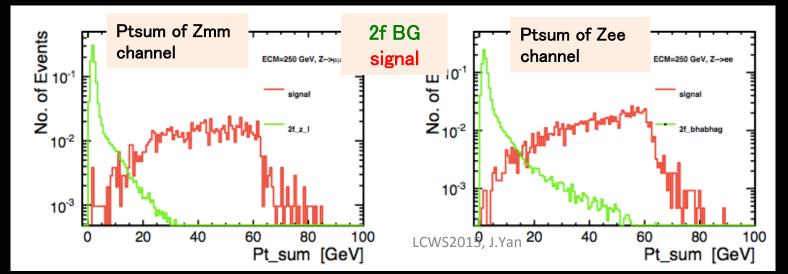
This modification played a major role in removing residual bias

Discrepancy in efficiency reduced by factor of > 2 for Zmm @ ECM= 250 GeV xsec and mass precisions are not severely degraded

Ptsum cut	Zmm	mass err	# of signal
[GeV]	xsec	[MeV]	lost
0	3.43%	40	0
6	3.14%	36.8	1.35
8	3.12%	36.6	1.69
10	3.10%	36.3	3.05
13	3.10%	36.2	5.24
15	3.09%	36.1	6.45

Zee		# -£ -:	# -£ -:		
	mass err	# of signal			
xsec	[MeV]	lost			
4.10%	117	0			
4.04%	115	1.66			
4.02%	114	2.85			
4.00%	113	4.28			
3.95%	111	7.11			
3.92%	110	8.42			

These are weighed numbers. bias is much more visible using high stat samples



The residual Higgs decay mode bias is very small!!

Syst error on xsec : $\sigma = N/L/\varepsilon$:: $\Delta \sigma/\sigma = \Delta \varepsilon/\varepsilon$

deviation from average efficiency (no assumption on BR)

pessimistic scenario ←→ upper limit on bias

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

Cut Efficiency Table, example of Zmm @ 250 GeV, Pol (-0.8,+0.3)

$H \to XX$	bb	cc	gg	au au	WW*	ZZ^*	$\gamma\gamma$
Lepton Finder	93.70%	93.69%	93.4%	93.99%	94.01%	93.74%	93.74%
Lepton ID+PreCuts	92.16%	92.11%	91.8%	92.36%	92.33%	92.21%	92.01%
$M_{inv} \in [73, 120] \text{ GeV}$	90.14%	90.27%	89.89%	90.38%	90.27%	90.38%	90.16%
$P_{t,dl} \in [10, 70] \text{ GeV}$	89.94%	90.08%	89.68%	90.18%	90.04%	90.16%	89.99%
$P_{t,sum}$ < 6 GeV	89.92%	90.06%	89.67%	90.03%	90.01%	90.13%	89.34%
$ \cos\theta_{miss} < 0.98$	89.92%	90.06%	89.67%	90.02%	90.01%	90.12%	89.32%
$ \cos\theta_{dl} < 0.90$	83.24%	83.12%	82.89%	83.29%	83.35%	83.53%	82.76%
TMVA	79.48%	79.20%	78.93%	79.36%	79.36%	79.49%	78.87%
$M_{rec} \in [110, 155] \text{ GeV}$	78.94%	78.67%	78.40%	78.82%	78.84%	79.02%	78.30%

similarly very small deviation for all other channels

final efficiency

(statistical uncertainty = 0.16%) no visible bias beyond 1 sigma

IF assume SM decay modes and BR, Max biassworst. and eff. $\sim 0.1\%$ for Zmm, $\sim 0.4\%$ for Zee 25

We didn't ignore the possibility of unknown exotic decay modes!

- any exotic decay modes should resemble these wide kinematic range of SM modes **Strategy:**
- (1) assign 10% of "unknown mode" to one of the known SM modes
- (2) fluctuate remaining SM modes by the largest BR uncertainty predicted from HL-LHC (7-8%) (Ref: snowmass report from higgs working group, arXiv: 1310.8361)

Pushing all 10% (big ratio!) of an unknown decay mode to a certain signature is a very pessimistic (conservative) assumption

E_{CM}	$250~{ m GeV}$		$350~{ m GeV}$		$500~{ m GeV}$	
$ll\mathrm{H}$	$\mu^+\mu^- { m X}$	$\mathrm{e^+e^-}X$	$\mu^+\mu^- { m X}$	$\mathrm{e^+e^-}X$	$\mu^+\mu^-{ m X}$	$\mathrm{e^+e^-}X$
syst. error	0.13%	0.43%	0.13%	0.34%	0.16%	0.13%

syst error on $\sigma ZH = maximum bias relative to avg efficiency$

< ~ 0.15% for Zmm < ~ 0.45% for Zee

This is the most realistic evaluation of bias !!

conclusion: current systematic error is well below even the best statistical uncertainty expected from full H20 run

Extensive efforts have been made to reduce systematic error to this stage!

Summary

Two main "first-time" features:

- (1) leptonic recoil results (σZH and mH) for ALL scenarios of ILC run plan based on full ILD detector simulation
- Precision compatible w.r.t. TDR and H20
- scaled to H20:

$$\Delta \sigma / \sigma = 0.89\%$$
, $\Delta MH = 13 MeV$

- (2) leptonic recoil measurement demonstrated to be model independent
- extensive efforts made to suppress bias on Higgs decay modes
- Systematic error is negligible even when compared with the best $\Delta \sigma$ stat (H20)

Others:

- Improve precision of mH by using H→bb mode (~25%)
- preliminary study on hadronic recoil@ 500 GeV: positive prospects for model independence

Ζ→μμ аі	nd Z → ee c	ombined	ΔmH
ECM	Pol	xsec	[MeV]
250			
GeV	left	2.62%	36
7	right	2.93%	40
350			
GeV	left	3.33%	96
	right	3.73%	110
500			
GeV	left	5.22%	492
	right	5.59%	566

Paper on Leptonic Higgs Recoil

First draft completed

title : "Measurement of Higgs mass and $\sigma(e+e-\rightarrow ZH)$ using Recoil Against

Z→I+I- at the ILC" + reference paper on study of model independence

Currently undergoing revision Plan: submit paper by end of year (?)

Abstract

This paper presents the performance evaluation of model independent measurement of the absolute cross section of the Higgsstrahlung process $e^+e^- \rightarrow ZH$ and the Higgs mass at the ILC. Detailed study has been carried out based on full simulation of the ILD detector as proposed in the Technical Design Report (TDR). The absolute ZH cross section (σ_{ZH}) is indispensable for extracting the Higgs couplings and branching ratios, which in turn provides a window into physics beyond the Standard Model. The Higgs mass (m_H) precision ultimately limits the precision of these observables. The study here employs the leptonic recoil method, in which the Higgs is produced together with a Z boson which decays into a well measurable dilepton system. Results are shown for the individual and combined results for the $Z \to \mu^+\mu^-$, $Z \to e^+e^-$ leptonic channels. In accordance with the expected schedule of operation of the accelerator, analysis is carried out for three center of mass energies $E_{CM}=250,\ 350,\ {\rm and}\ 500$ GeV, and two beam polarizations $(Pe^+, Pe^-) = (-80\%, +30\%)$ and (+80%, -30%). Methods of signal selection and background rejection are optimized to achieve the highest σ_{ZH} precision. Assuming an integrated luminosity of 250 fb^{-1} at 250 GeV, where best detector resolution is obtainable, σ_{ZH} can be determined with a precision of 2.58%, while the expected m_H precision is 35 MeV. These exceed the predicted precisions in the TDR. Scaled to the luminosity assumed in the H20 scenario, the expected precisions for σ_{ZH} and m_H at $E_{CM} = 250$ GeV are 0.8% and 13 MeV, respectively. Reasonable precisions in σ_{ZH} have also been shown for the higher E_{CM} which are important for the search of new physics. Another important achievement is that the analysis methods have been designed so as to minimize systematic errors due to bias on Higgs decay modes. The results presented are expected to serve as a benchmark for the optimization of the ILC detector system as well as contribute to planning of the ILC run scenario.

Next Steps In This Research

- (1) Finalize paper on leptonic recoil paper
- (2) Study systematic error due to beam spectrum
- (3) Recently began systematic error check on hadronic recoil @500GeV For now, preserved Miyamoto-san's exact analysis steps http://arxiv.org/pdf/1311.2248v1.pdf

results look promising

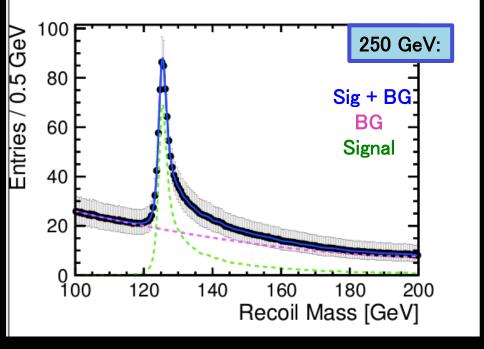
- → to be continued
- Minimize model dependence (just as for leptonic)
- improve precision

The results reported today owes to the immense support (advice and active daily discussions)

from Fujii-san, Junping-san, and everyone in the ILC Physics Working Group

Many thanks !!!

BACKUP

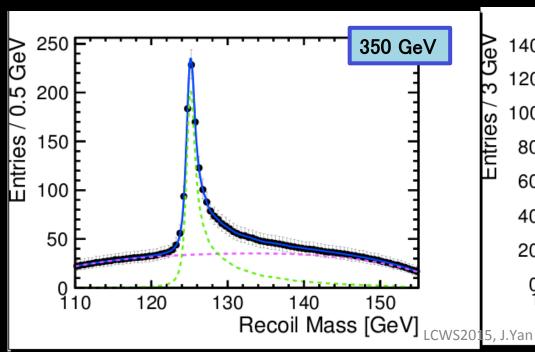


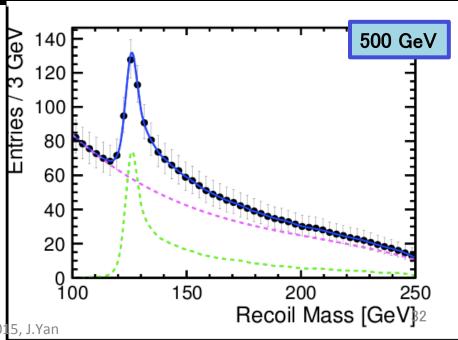
recoil mass histogram after data selection

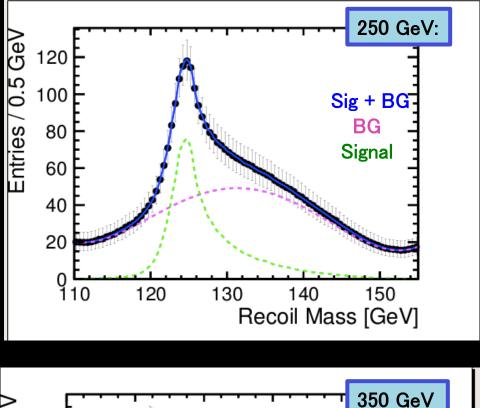


Pol: (+ 0.8, -0.3)

Toy MC data





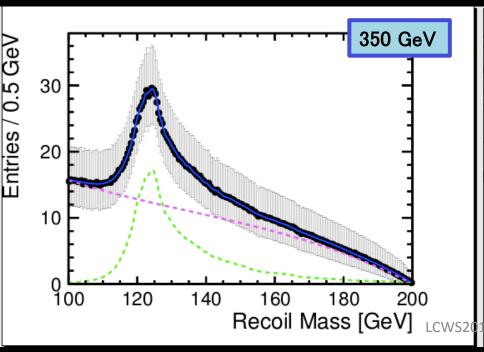


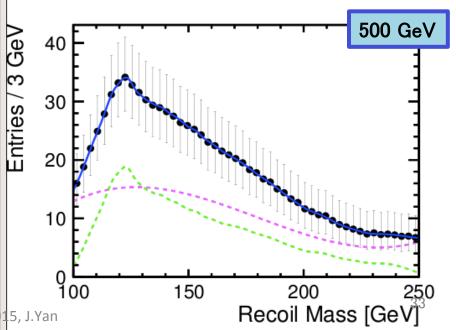
recoil mass histogram after data selection

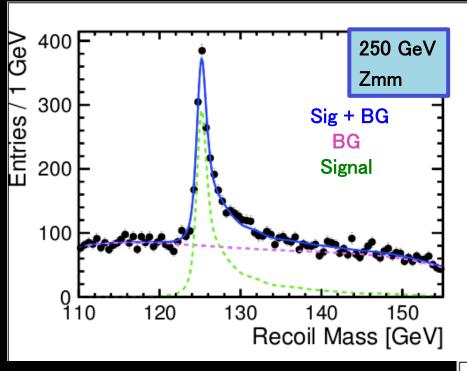


Pol: (+ 0.8, -0.3)

Toy MC data

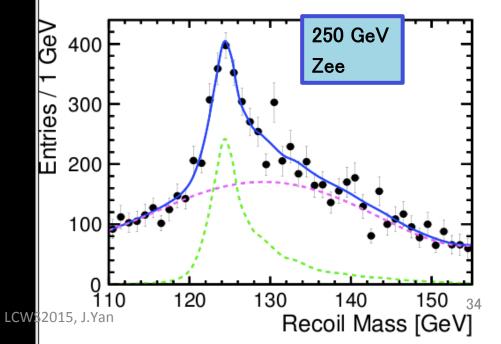






Reconstructed MC data recoil mass histogram

Pol: (- 0.8, +0.3)



Cut Efficiency Table, example shown for 250 GeV, Pol (-0.8,+0.3)

Cut 0 OBJ: TCut **Zmm**

```
Cut 1
OBJ: TCut
                         leptype==13
Cut 2
OBJ: TCut
                         Ptdl>10&&abs(Minv-91.18)<50&&Mrec>100&&Mrec<300
Cut
     3
                        Minv>73&&Minv<120
OBJ: TCut
Cut 4
                         Ptdl>10&&Ptdl<70
OBJ: TCut
Cut
     5
                         (Ptsum<0||Ptsum>6)
OBJ: TCut
Cut
OBJ: TCut
                         !((Evis-Ephotonmax)<15&&Ephotonmax>0&&TMath::Abs(cosmis)>0.98)
Cut 7
                         TMath::Abs(cosz) < 0.9
OBJ: TCut
Cut
     8
OBJ: TCut
                         mvazhllxmbdt >-0.25
Cut
     9
OBJ: TCut
                        Mrec>110&&Mrec<=155
Cut 10
OBJ: TCut
                         Evis>10
Eff. (%)
                 bb
                                                                             tt
                                                                                                                    ZZ
                                                                                                                                        aa
                                     CC
                                                         gg
                                                                                                WW
            93.7 +/-
Cut0:
                      0.1
                               93.69 +/- 0.1
                                                    93.4 +/- 0.11
                                                                      94.02 +/-
                                                                                  0.1
                                                                                          94.04 +/-
                                                                                                              94.36 +/-0.099
                                                                                                                                  93.75 +/-0.083
Cut1:
            93.7 +/-
                      0.1
                               93.69 +/- 0.1
                                                    93.4 +/- 0.11
                                                                      93.99 +/-
                                                                                 0.1
                                                                                          94.01 +/-
                                                                                                     0.1
                                                                                                              93.74 +/-
                                                                                                                         0.1
                                                                                                                                 93.74 +/-0.083
Cut2:
           92.16 +/- 0.11
                               92.11 +/- 0.12
                                                    91.8 +/- 0.12
                                                                      92.36 +/- 0.11
                                                                                          92.33 +/- 0.11
                                                                                                              92.21 +/- 0.11
                                                                                                                                  92.01 +/-0.092
Cut3:
           90.14 +/- 0.12
                               90.27 +/- 0.13
                                                   89.89 +/- 0.13
                                                                      90.38 +/- 0.12
                                                                                          90.27 +/- 0.12
                                                                                                              90.38 +/- 0.12
                                                                                                                                  90.16 +/- 0.1
Cut4:
           89.94 +/- 0.13
                               90.08 +/- 0.13
                                                   89.68 +/- 0.13
                                                                      90.18 +/- 0.12
                                                                                          90.04 +/- 0.12
                                                                                                              90.16 +/- 0.12
                                                                                                                                  89.99 +/-
                                                                                                                                             0.1
                               90.06 +/- 0.13
Cut5:
           89.92 +/- 0.13
                                                   89.67 +/- 0.13
                                                                      90.03 +/- 0.12
                                                                                          90.01 +/- 0.12
                                                                                                              90.13 +/- 0.12
                                                                                                                                  89.34 +/- 0.1
           89.92 +/- 0.13
Cut6:
                               90.06 +/- 0.13
                                                   89.67 +/- 0.13
                                                                      90.02 +/- 0.12
                                                                                          90.01 +/- 0.12
                                                                                                              90.12 +/- 0.12
                                                                                                                                  89.32 +/-
                                                                                                                                             0.1
Cut7:
           83.24 +/- 0.15
                               83.12 +/- 0.15
                                                   82.89 +/- 0.15
                                                                      83.29 +/- 0.15
                                                                                          83.35 +/- 0.15
                                                                                                              83.53 +/- 0.15
                                                                                                                                  82.76 +/- 0.12
Cut8:
           79.48 +/- 0.16
                                79.2 +/- 0.16
                                                   78.93 +/- 0.16
                                                                      79.36 +/- 0.16
                                                                                          79.36 +/- 0.16
                                                                                                              79.49 +/- 0.16
                                                                                                                                  78.87 +/- 0.13
Cut9:
           78.94 +/- 0.16
                               78.67 +/- 0.16
                                                   78.4 +/- 0.16
                                                                      78.82 +/- 0.16
                                                                                          78.84 +/- 0.16
                                                                                                              79.02 +/- 0.16
                                                                                                                                  78.3 +/- 0.13
Cut10:
           78.94 +/- 0.16
                               78.67 +/- 0.16
                                                    78.4 +/- 0.16
                                                                      78.55 +/- 0.16
                                                                                          78.82 +/- 0.16
                                                                                                              75.95 +/- 0.16
                                                                                                                                  78.3 +/- 0.13
```

Cut Efficiency Table, example shown for 250 GeV, Pol (-0.8,+0.3)

Zee

```
Cut 0
OBJ: TCut
Cut 1
OBJ: TCut
                         leptype==11
     2
Cut
OBJ: TCut
                         Ptdl>10&&abs(Minv-91.18)<50&&Mrec>100&&Mrec<300
     3
Cut
OBJ: TCut
                        Minv>73&&Minv<120
Cut
     4
OBJ: TCut
                         Ptdl>10&&Ptdl<70
Cut
     5
OBJ: TCut
                         (Ptsum<0||Ptsum>6)
Cut
     6
OBJ: TCut
                         !((Evis-Ephotonmax)<40&&Ephotonmax>0&&TMath::Abs(cosmis)>0.98)
     7
Cut
OBJ: TCut
                         TMath::Abs(cosz) < 0.9
Cut
     8
                         mvazhllxebdt > 0.02
OBJ: TCut
Cut
     9
OBJ: TCut
                         Mrec>110&&Mrec<=155
Cut 10
OBJ: TCut
                         Evis>10
Eff. (%)
                  bb
                                                                             tt
                                     CC
                                                                                                ww
                                                                                                                    ZZ
                                                                                                                                        aa
                               88.92 +/- 0.13
Cut0:
           89.12 +/- 0.13
                                                   88.51 +/- 0.13
                                                                       89.5 +/- 0.13
                                                                                          89.87 +/- 0.12
                                                                                                              90.15 +/- 0.12
                                                                                                                                  89.83 +/-0.089
Cut1:
           89.12 +/- 0.13
                               88.92 +/- 0.13
                                                   88.51 +/- 0.13
                                                                       89.49 +/- 0.13
                                                                                          89.84 +/- 0.12
                                                                                                              89.06 +/- 0.13
                                                                                                                                  89.83 +/-0.089
           86.96 +/- 0.14
                               86.86 +/- 0.14
                                                   86.33 +/- 0.14
                                                                       86.97 +/- 0.14
                                                                                          87.36 +/- 0.14
                                                                                                              86.69 +/- 0.14
                                                                                                                                  85.98 +/-
Cut2:
                                                                                                                                             0.1
Cut3:
           85.19 +/- 0.14
                               84.97 +/- 0.15
                                                   84.42 +/- 0.15
                                                                       84.63 +/- 0.14
                                                                                          84.74 +/- 0.14
                                                                                                              84.58 +/- 0.14
                                                                                                                                  83.87 +/-
                                                                                                                                             0.1
                                                                      84.42 +/- 0.15
Cut4:
           84.96 +/- 0.15
                               84.76 +/- 0.15
                                                   84.24 +/- 0.15
                                                                                          84.47 +/- 0.15
                                                                                                              84.32 +/- 0.15
                                                                                                                                  83.65 +/-
                                                                                                                                            0.1
           84.94 +/- 0.15
                               84.75 +/- 0.15
                                                   84.22 +/- 0.15
                                                                      84.23 +/- 0.15
                                                                                          84.43 +/- 0.15
                                                                                                              84.28 +/- 0.15
                                                                                                                                  83.01 +/- 0.11
Cut5:
           84.94 +/- 0.15
                               84.75 +/- 0.15
                                                   84.22 +/- 0.15
                                                                      84.12 +/- 0.15
                                                                                          84.41 +/- 0.15
                                                                                                              84.14 +/- 0.15
                                                                                                                                  82.78 +/- 0.11
Cut6:
Cut7:
           78.59 +/- 0.16
                               78.47 +/- 0.16
                                                   77.84 +/- 0.16
                                                                      77.97 +/- 0.16
                                                                                          78.06 +/- 0.16
                                                                                                              78.05 +/- 0.16
                                                                                                                                  76.66 +/- 0.11
Cut8:
           62.08 +/- 0.17
                                61.9 +/- 0.17
                                                   61.53 +/- 0.17
                                                                       61.4 +/- 0.17
                                                                                          61.15 +/- 0.17
                                                                                                               61.4 +/- 0.17
                                                                                                                                  60.31 +/- 0.12
Cut9:
           61.83 +/- 0.17
                                61.7 +/- 0.17
                                                   61.29 +/- 0.17
                                                                      61.14 +/- 0.17
                                                                                          60.91 +/- 0.17
                                                                                                              61.16 +/- 0.17
                                                                                                                                  60.06 +/- 0.12
                                61.7 +/- 0.17
                                                   61.29 +/- 0.17
           61.83 +/- 0.17
                                                                      60.92 +/- 0.17
                                                                                          60.89 +/- 0.17
                                                                                                              58.85 +/- 0.16
                                                                                                                                  60.06 +/- 0.12
Cut10:
```

Necessity of FSR/Brem recovery

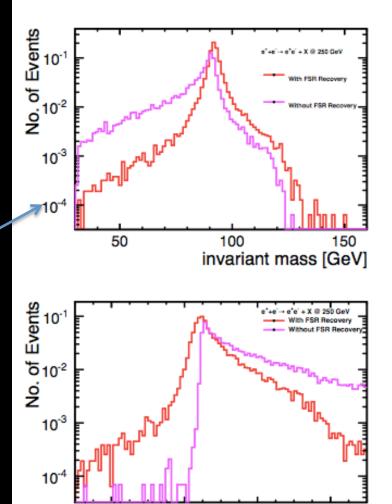
• bremsstrahlung/FSR photon is identified using θ w.r.t. final state lepton if $\cos\theta > 0.99$, γ four momenta combined with dilepton momenta

Minv and Mrec before and after brem/FSR recovery is visibly different for Zee

Without FSR recovery in Zee channel:

- σ ZH worsens by up to 65%
- mH worsens by up to 14%

Not much difference for Zmm



120

140

100

		with FSR Rec	no FSR Rec	diff	with FSR Rec	no FSR Rec	ditt
		With Fort 100	no i dit ito	dill	WIGHT OIL TOO	no i divito	dill
ECM=250 GeV		Xsec_err	Xsec_err		mass_err [MeV]		
Zmm	left	3.14%	3.26%	3.85%	38	37.1	-2.37%
	right	3.61%	3.71%	2.78%	42	40.6	-3.33%
Zee	left	4.01%	6.61%	64.90%	125	142	13.60%
	right	4.73%	7.54%	59.49% LG	148 015, J.Yan	159	7.43%

160

recoil mass [GeV]