Higgs Recoil Mass and Cross Section Analysis at ILD_00

Hengne Li

LAL Orsay, B. P. 34,

91898 Orsay Cedex,

France

OUTLINE

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    - SM Cut-Chain: Assume SM Higgs Decay
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- Fittings and Results
- Conclusions

Introductory Remarks

ZH Recoil Ana. Group:

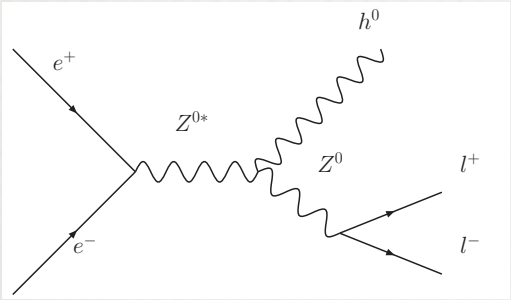
(EU) Hengne Li, Roman Poeschl, Francois Richard, Manqi Ruan, Zhiqing Zhang

(JP) Kazutoshi Ito, Yosuke Takubo, Hitoshi Yamamoto

Reviewers:

(EU) Klaus Desch, (JP) Akiya Miyamoto

- Higgs-Strahlung Process:



- Higgs Recoil Mass:

$$m_{h^0}^2 = s + m_{Z^0}^2 - 2E_{Z^0}\sqrt{s}$$

- Cross Section and Coupling Strength Measurement:

$$g^2 \propto \sigma = N/\mathcal{L}\epsilon$$

- M_H = 120 GeV
- Ecm = 250 GeV
- Beam Energy Spread: 0.3% for each beam
- Beamstrahlung: N/A [a]
- Luminosity: 250 fb^{-1}
- Polarization:
  - $e^-_R e^+_L$: (e^-: +80%, e^+: -30%)
  - $e^-_L e^+_R$: (e^-: -80%, e^+: +80%)
- Detector Model: ILD_00
- Event Generation:
  WIZARD v1.40 (by SLAC)
- Simulation & Reconstruction:
  ILCSoft v01-06 (by DESY & KEK)

[a] Discussed in the conclusions

Introductory Remarks

$e^-_R e^+_L$

μμX

Reactions	Cross-Section
$\mu\mu X$	**7.02 fb**
$\mu\mu$	10.44 pb (137.71 fb)
$\tau\tau$	8117.53 fb
$\mu\mu\nu\nu$	56.10 fb
$\mu\mu ff$	1194.20 fb

eeX

Final State	Cross-Section
eeX	**7.48 fb**
ee	17.30 nb (650.894fb)
$\tau\tau$	8117.53 fb
$ee\nu\nu$	105.49 fb
$eeff$	4148.93 rb

$e^-_L e^+_R$

μμX

Final State	Cross-Section
$\mu\mu X$	**10.40 fb**
$\mu\mu$	8.12 pb (200.85 fb)
$\tau\tau$	10454.80 fb
$\mu\mu\nu\nu$	498.28 fb
$\mu\mu ff$	1282.22 fb

eeX

Final State	Cross-Section
eeX	**11.11 fb**
ee	17.30 nb (692.53 fb)
$\tau\tau$	10454.80 fb
$ee\nu\nu$	625.45 fb
$eeff$	4283.07 fb

(1) *μμνν* and *eeνν* have major contribution from WW, but also from ZZ.

(2) *μμff* refers to *μμee* + *μμμμ* + *μμττ* + *μμqq*,
eeff* refers to *eeμμ* + *eeee* + *eeττ* + *eeqq

Pre-cuts for ee and μμ:
(cross-sections after pre-cuts are in blankets)

Pre-cuts for $\mu\mu$:

- $M_{\mu^+\mu^-} \in (71.18, 111.18)\ GeV$
- $P_{T\mu^+\mu^-} > 10\ GeV$
- $M_{recoil} \in (105, 165)\ GeV$

Pre-cuts for ee:

- $|cos\theta_{e^+/e^-}| < 0.95$
- $M_{e^+e^-} \in (71.18, 111.18)\ GeV$
- $P_{Te^+e^-} > 10\ GeV$
- $M_{recoil} \in (105, 165)\ GeV$

Preparations

1) Cuts for lepton ID:

	μ-Identification	e-Identification
E_{ECAL}/E_{total}	< 0.5	> 0.6
E_{total}/P_{track}	< 0.3	> 0.9

Efficiency of lepton pair ID:
(pair selection according to Z^0 Mass)

μμX (muon ID) : 95.4%
eeX (electron ID) : 98.8%

2) ΔP/P² criterion on tracks in the selection of lepton candidates

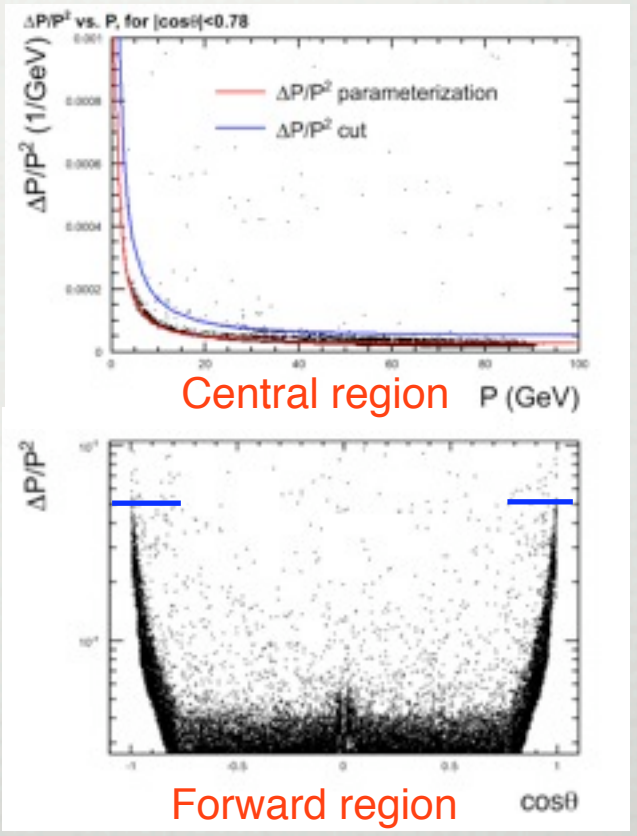
- Parameterize ΔP/P² for central region

$$\Delta P/P^2 = a \oplus b/P;$$
$$where\ a = 2.5 \times 10^{-5};\ b = 8 \times 10^{-4}$$

- The criterion ΔP/P² applied

$$|cos\theta| < 0.78: \quad \Delta P/P^2 < 2 \times (2.5 \times 10^{-5} \oplus 8 \times 10^{-4}/P)$$
$$|cos\theta| > 0.78: \quad \Delta P/P^2 < 5 \times 10^{-4}$$

ΔP is propagated from tracking error matrix



Analysis Procedures

<table>
<tr><td>Higgs Decay Model</td><td>Model Independent (MI)</td><td>SM Higgs Decay (SM)</td></tr>
<tr><td rowspan="2">Background Rejection</td><td>MI Cut-chain</td><td>SM Cut-chain</td></tr>
<tr><td colspan="2">Likelihood Further Rejection</td></tr>
<tr><td colspan="3">Fitting and Results</td></tr>
</table>

- Background Rejection
  - Rejection by Cuts
    - MI Cut-Chain: Independent of Higgs Decay Modes
    - SM Cut-Chain: Assume SM Higgs Decay
  - Further Rejection by Likelihood with Model Independent variables
- Fitting and Results

Background Rejection by Cuts: MI Cut-Chain

Pol. $e^-_R e^+_L$ for illustration

MI Cut-Chain & Nevts after each cuts:

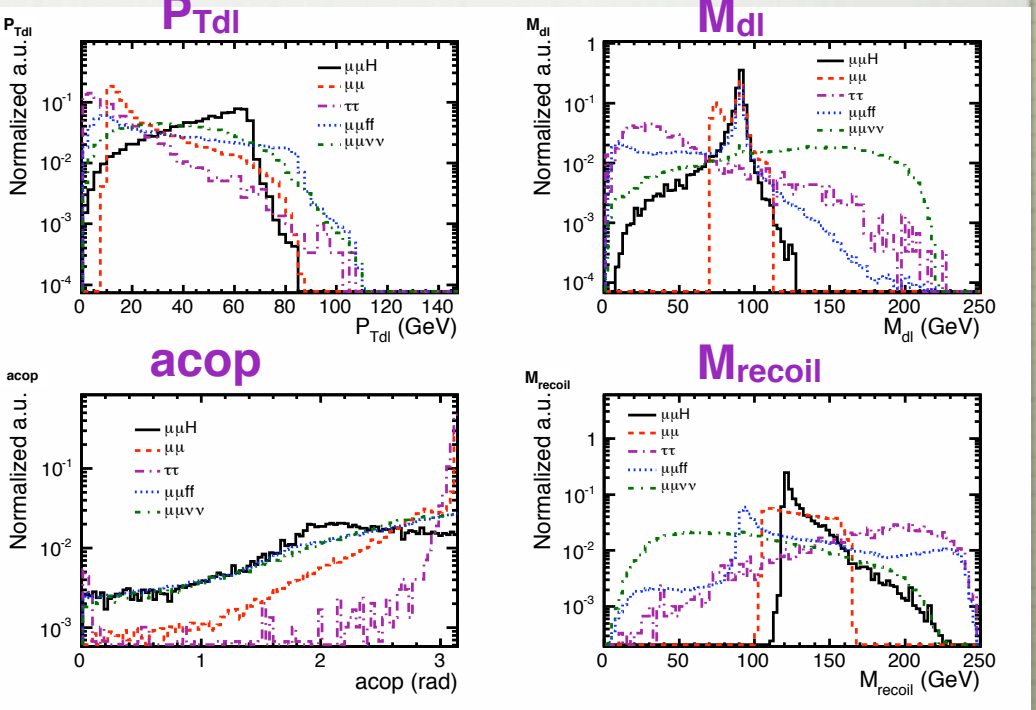
Nevts remained:	μμX	μμ	ττ	μμνν	μμff
before any restriction:	1754	2.0M	2.0M	14k	299k
Both μ id + pre-cuts	1478(84.27%)	30k	4528	2481	10k
+ $P_{Tdl} > 20$ GeV	1402(79.97%)	15k	3139	2223	7390
+ $M_{dl} \in (80, 100)$GeV	1299(74.10%)	11k	1750	1633	5257
+ acop (0.2, 3.0)	1211(69.05%)	9402	0	1505	4741
+ $\Delta P_{Tbal.} > 10$ GeV	1188(67.75%)	529	0	1464	4367
+ $\lvert\Delta\theta_{2tk}\rvert > 0.01$	1186(67.65%)	226	0	1448	4340
+ $M_{recoil} \in (115, 150)$ GeV	1156(65.93%)	165	0	900	2729

Nevts remained:	eeX	ee	ττ	eevv	eeff
before any restriction:	1869	4.3G	2.0M	26k	1.0M
Both e id + pre-cuts	1172(62.71%)	119k	6778	3155	9430
+ $P_{Tdl} > 20$ GeV	1100(58.86%)	90k	4694	2808	7909
+ $M_{dl} \in (80, 100)$ GeV	937(50.13%)	48k	2556	1929	5317
+ acop (0.2, 3.0)	879(47.06%)	44k	222	1807	4823
+ $\Delta P_{Tbal.} > 10$ GeV	857(45.88%)	2962	139	1712	4389
+ $\lvert\Delta\theta_{2tk}\rvert > 0.01$	856(45.80%)	1653	111	1692	4365
+ $M_{recoil} \in (115, 150)$GeV	828 (44.29%)	1230	28	1043	2675

Cuts based on lepton pair properties:

- $P_{Tdl} > 20\ GeV$
- $M_{dl} \in (80,\ 100)\ GeV$
- $acop \in (0.2,\ 3.0)$

- muon channel with pol. $e^-_R e^+_L$ for illustration
- μμ are pre-cutted



Background Rejection by Cuts: Independent of Higgs Decay Model

ISR P_T balance for μμ and ee rejection

Idea: (Thanks to Francois' idea)

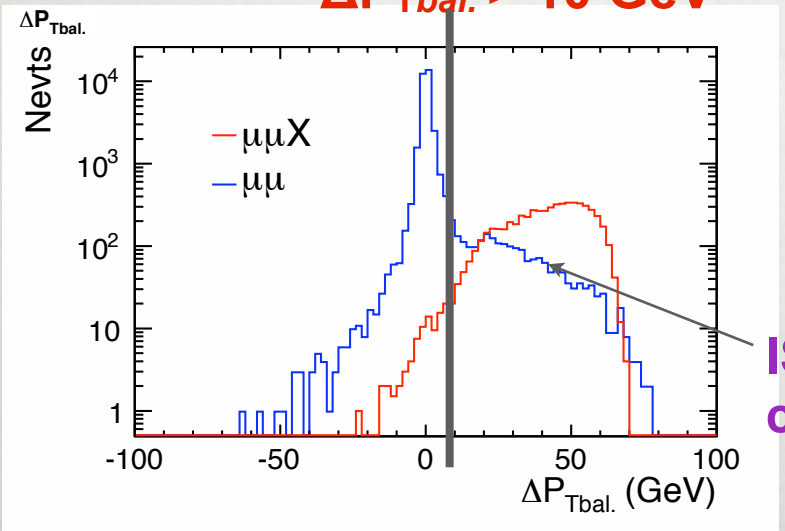
- For μμ and ee: P_T of ISR photon should balance the P_T of di-lepton system;
- For signal: Impossible to have ISR to balance Z P_T, independent of Higgs decay model.

Requirements:

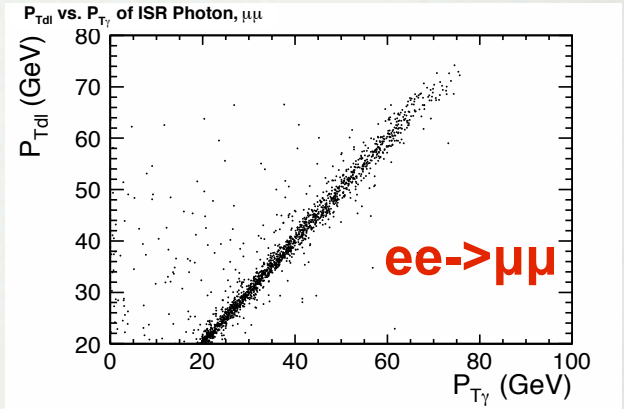
- $M_{dl} \in (80, 100)$ GeV: large FSR events are removed
- $P_{Tdl} > 20$ GeV: Large P_T ISR photon can be detected

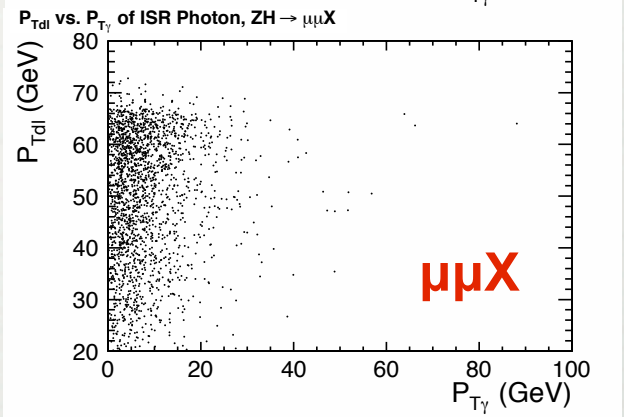
Define $\Delta P_{Tbal.} = P_{Tdl} - P_{T\gamma}$

$\Delta P_{Tbal.} > 10$ GeV



Reduces μμ and ee further by 1 to 2 orders of magnitude
Signal lost: ~1%





ISR photon conversions

To reject the ISR Photon conversions:

- Cut $|\Delta\theta_{2tk}|>0.01$: Only apply on events with 2 additional tracks
- Reject μμ and ee Further by a factor of 2.

Background Rejection by Cuts: SM Cut-Chain

Pol. ($e^-_R e^+_L$) for illustration

SM Cut-Chain & Nevts after each cuts:

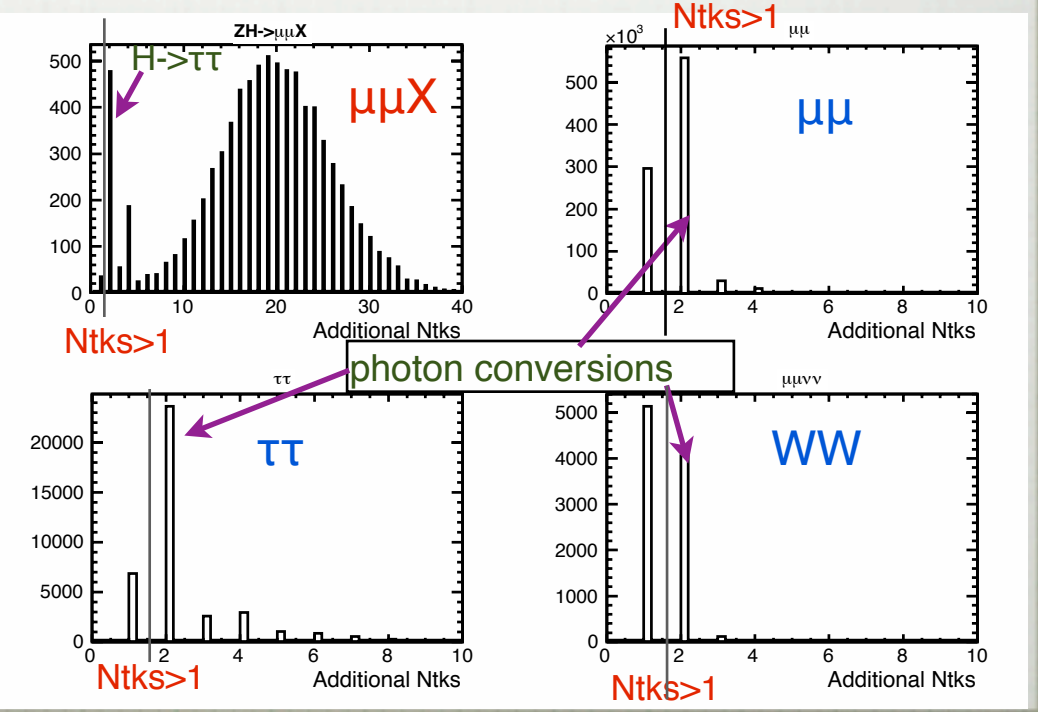
Nevts remained:	μμX	μμ	ττ	μμνν	μμff
before any restriction:	1754	2.0M	2.0M	14k	299k
Both μ id + pre-cuts	1478(84.27%)	30k	4528	2481	10k
+ Ntks>1 :	1469(83.78%)	1813	472	31	8537
+ $\|\Delta\theta_{2tk}\|>0.01$	1467(83.63%)	162	361	3	8423
+ $\|\Delta\theta_{min}\|>0.01$	1444(82.36%)	105	111	0	7487
+ acop (0.2, 3.0)	1336(76.16%)	0	0	0	6635
+ $M_{recoil}\in$(115, 150) GeV	1263(72.00%)	0	0	0	4119

Nevts remained:	eeX	ee	ττ	eevv	eeff
before any restriction:	1869	4.3G	2.0M	26k	1.0M
Both e id + pre-cuts	1172(62.71%)	119k	6778	3155	9430
+ Ntks>1 :	1160(62.10%)	7215	1889	50	8455
+ $\|\Delta\theta_{2tk}\|>0.01$	1158(61.99%)	1114	1361	5	8397
+ $\|\Delta\theta_{min}\|>0.01$	1140(61.01%)	324	278	0	7905
+ acop (0.2, 3.0)	1058(56.61%)	275	0	0	7060
+ $M_{recoil}\in$(115, 150)GeV	969(51.87%)	172	0	0	4367

For SM Higgs decay, multiplicity in the final states is the most efficient criterion to reject the 2f and WW

- In order to keep the H->ττ in the signals :
  - At most: Ntks>1
  - How to reject evts with Ntks==2 in μμ, ττ and WW ?

Additional Number of Tracks besides the two lepton candidates

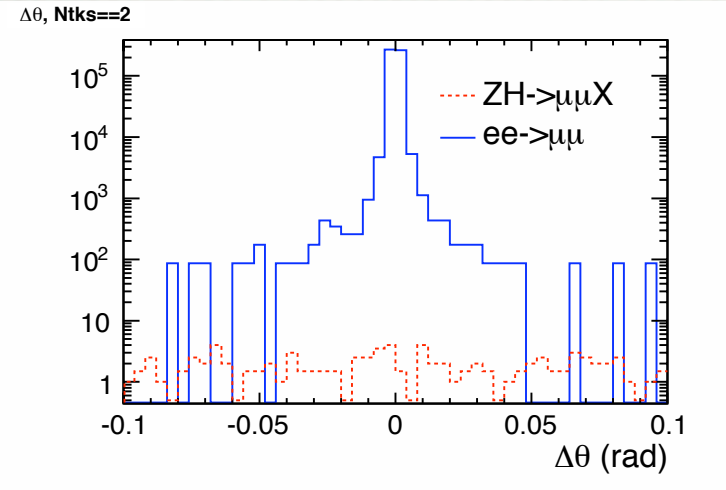


Background Rejection by Cuts: SM Cut-Chain

To reject evts with Ntks==2 in μμ, ττ and WW

1)

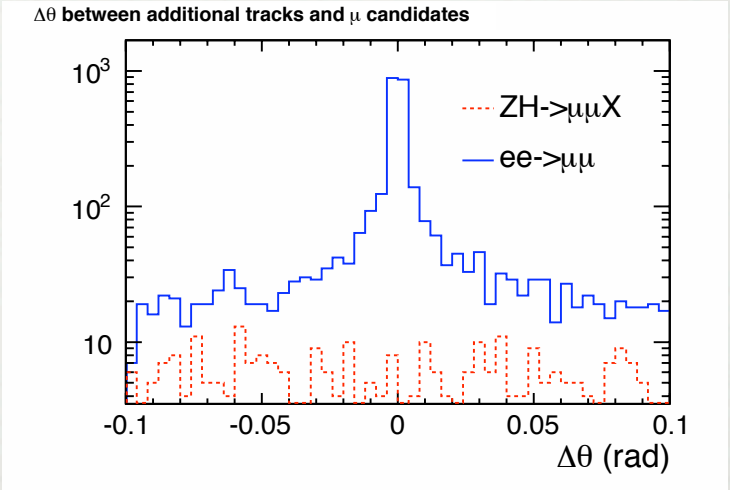
- Define $\Delta\theta_{2tk}$: $\Delta\theta$ between these two additional tracks for Ntks==2.
- Apply $|\Delta\theta_{2tk}|>0.01$ to reject photon conversions



- Reduced the μμ/ee and WW further by ~ 1 order of magnitude, with a signal lost of only ~ 0.2%

2)

- Define $\Delta\theta_{min}$: the smallest $\Delta\theta$ between the additional tracks and the lepton candidates



- Because mis-identification of photon conversions to be lepton candidates

BK Further Rejection by Likelihood

After Cuts Rejection, Apply Further Rejection using Likelihood Method

Likelihood:

$$L = \prod_i P_i$$

Probability

i th Variable

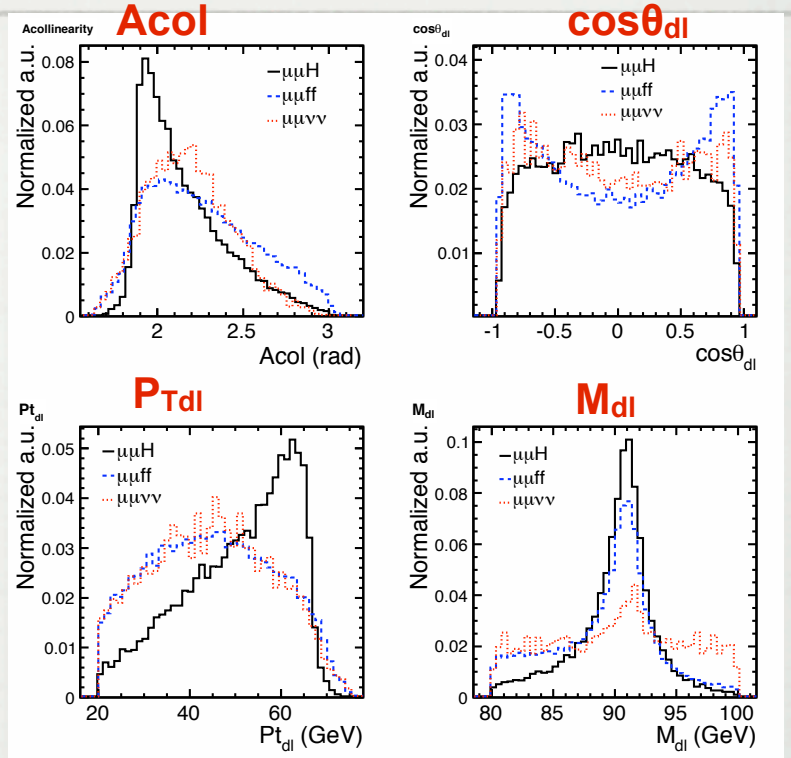
Likelihood Fraction:

$$f_L = L_S/(L_S + L_B)$$

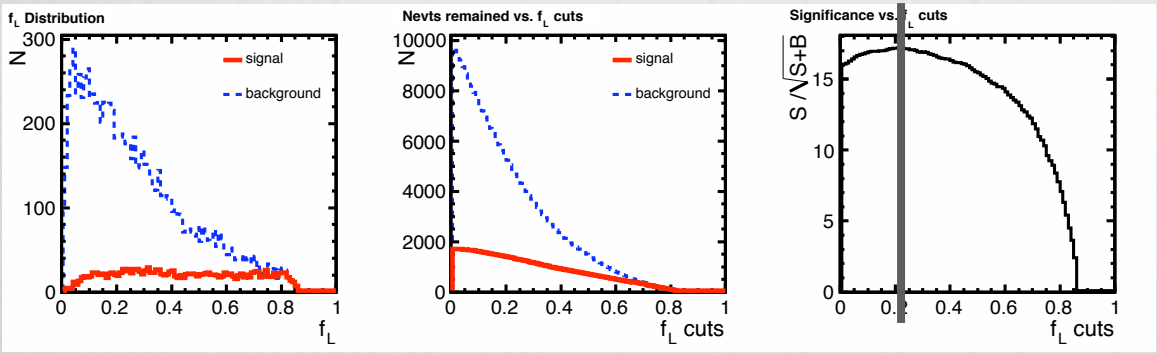
within (0, 1)

Decide the f_L cut by the maximum significance

PDFs



f_L > 0.22



f_L Distribution **Nevt vs. f_L** **Significance**

Taken:

Pol. $e^-_L e^+_R$
muon channel
MI Analysis

For illustration

Background Rejection Summary Table

Ana.	Pol.	Ch.	Cuts	μμX/eeX		μμ/ee	ττ	μμνν/eevv	μμff/eeff	B	S/B	S/√(S+B)
MI	$e^-_R e^+_L$	μ	MI cut-chain:	1156	(65.93%)	165	0	900	2729			
			+ f_L>0.26	849	(48.40%)	84	0	437	1140	1661	0.51	16.9
		e	MI cut-chain:	828	(44.29%)	1230	28	1043	2675			
			+ f_L>0.16	715	(38.28%)	684	0	665	1587	2936	0.24	11.8
	$e^-_L e^+_R$	μ	MI cut-chain:	1709	(65.71%)	245	0	5482	4175			
			+ f_L>0.22	1368	(52.60%)	141	0	2654	2157	4952	0.28	17.2
		e	MI cut-chain:	1235	(44.47%)	1313	56	5488	3665			
			+ f_L>0.19	1025	(36.90%)	655	0	3041	2048	5744	0.18	12.5
SM	$e^-_R e^+_L$	μ	SM cut-chain:	1263	(72.00%)	49	0	0	4119			
			+ f_L>0.33	1054	(60.09%)	10	0	0	1743	1753	0.60	19.9
		e	SM cut-chain:	969	(51.87%)	172	0	0	4367			
			+ f_L>0.39	769	(41.16%)	49	0	0	1799	1848	0.42	15.0
	$e^-_L e^+_R$	μ	SM cut-chain:	1872	(71.96%)	68	0	0	6189			
			+ f_L>0.32	1568	(60.28%)	13	0	0	2824	2837	0.55	23.6
		e	SM cut-chain:	1444	(52.00%)	184	0	5	5913			
			+ f_L>0.36	1183	(42.62%)	56	0	1	2680	2737	0.43	18.9

Fitting Methods

Functions:

Signal:

Gaussian Peak Exponential Tail (GPET):

$$f(x) = N \begin{cases} e^{-\frac{(x-x_0)^2}{2\sigma^2}} & : \frac{x-x_0}{\sigma} \leq k \\ \beta e^{-\frac{(x-x_0)^2}{2\sigma^2}} + (1-\beta) e^{-(x-x_0)\frac{k}{\sigma}} e^{\frac{k^2}{2}} & : \frac{x-x_0}{\sigma} > k \end{cases}$$

Convolution of Empirical with Gaussian (CEG): (K. Ito, / Tohoku U.)

$$F(x) = N e^{-Ax} \int_{x_0-x}^{\sqrt{s}-x} F_H(x+t) e^{-\frac{t^2}{2\sigma^2}} dt;$$

$$F_H(x) = \left(\frac{x-x_0}{\sqrt{s}-x_0}\right)^{\beta-1}$$

Background: Polynomial with 3 coefficients

Build Composite Model: $F(x) = N_S f_S(x) + N_B f_B(x)$

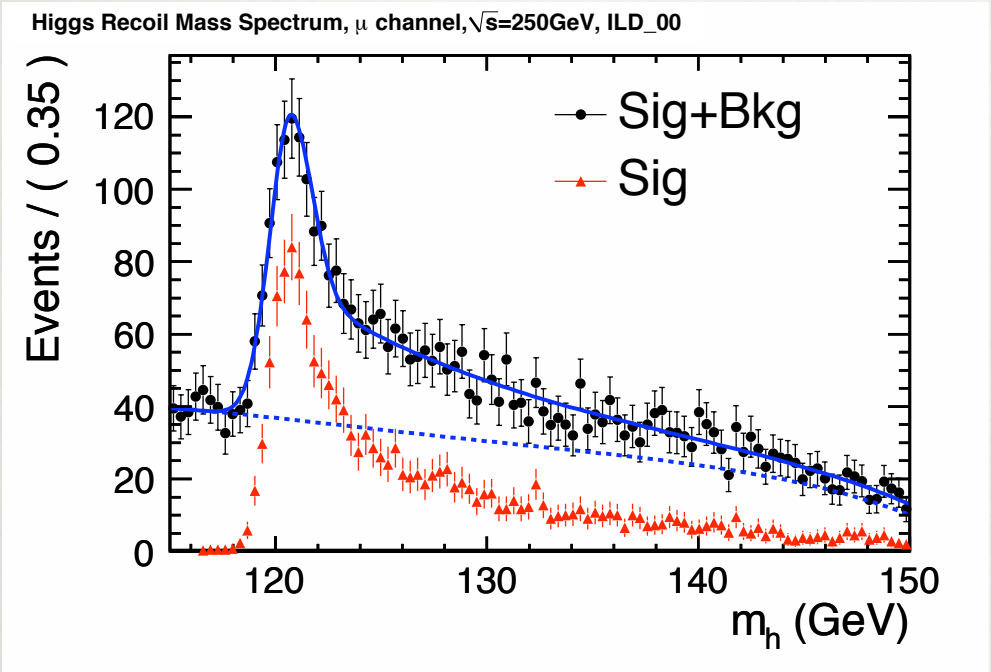
Fitting:

1) Determine fitting parameters from MC (a separate data set)
2) Fix all the parameters except the Ns, $(N_B)^*$ and M_H
3) Fit to the "Sig+Bkg" to get the results

*Note: The results reported in ILD LOI has the N_B free, I also report the the results with N_B fixed, in order to be comparable with SiD

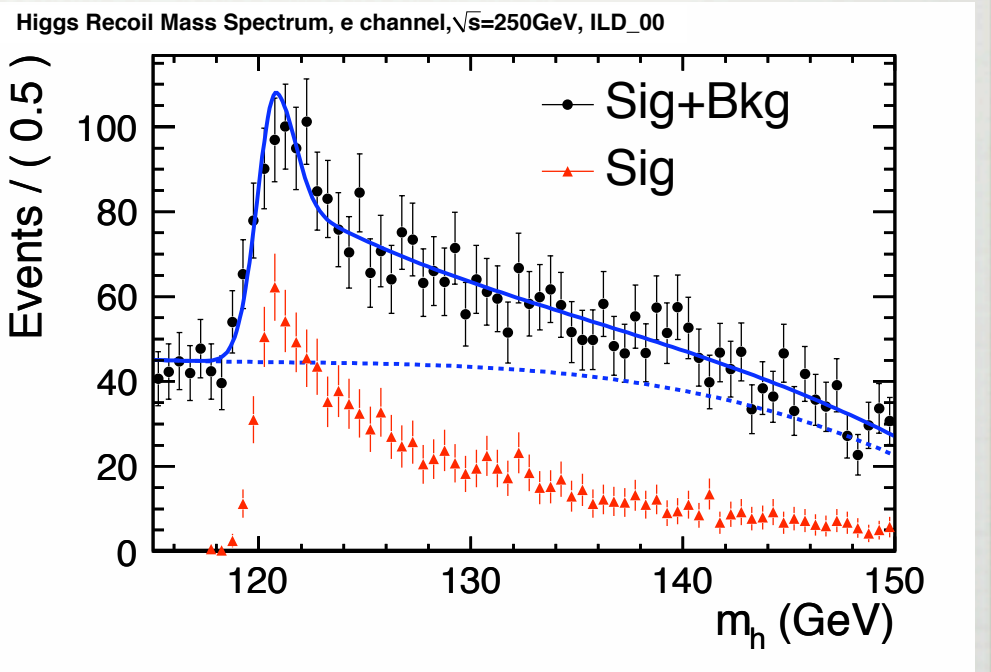
Example Fitting I: (GPET)

μμX



M Higgs :
119.905 ± 0.077 GeV
Cross-Section:
10.11 ± 0.38 fb (3.76%)

eeX

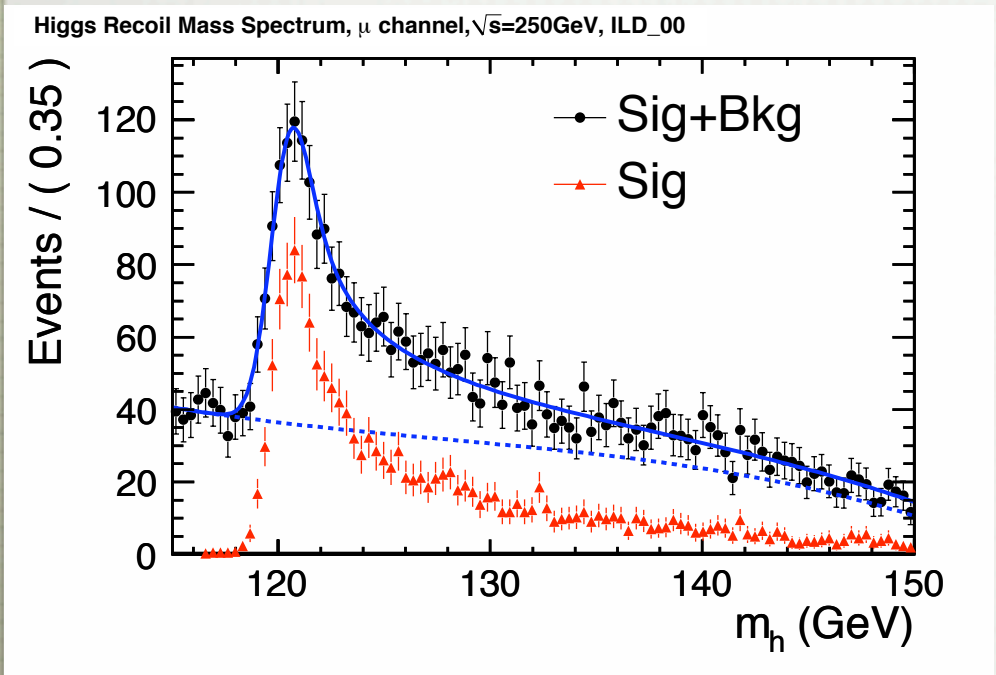


M Higgs :
119.871 ± 0.135 GeV
Cross-Section:
10.98 ± 0.53 fb (4.83%)

Pol. $e^-_L e^+_R$, SM analysis for illustration

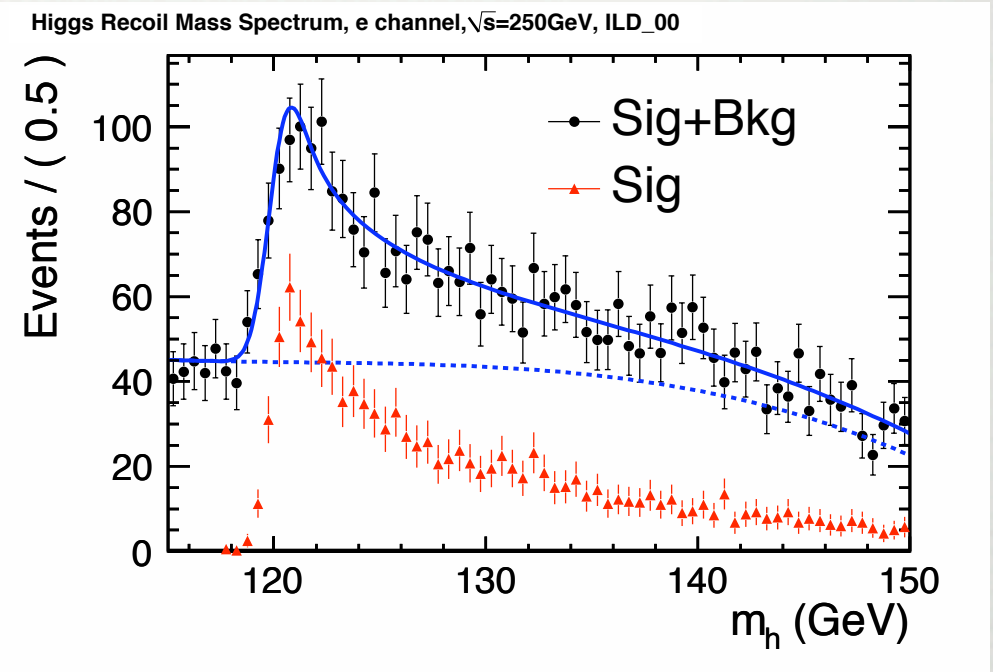
Example Fitting II: (CEG)

μμX



M Higgs :
120.177 ± 0.080 GeV
Cross-Section:
10.48 ± 0.39 fb (3.72%)

eeX



M Higgs :
120.053 ± 0.149 GeV
Cross-Section:
10.98 ± 0.53 fb (4.83%)

Pol. $e^-_L e^+_R$, SM analysis for illustration

Results [a]

Ana.	Pol.	Ch.	δM_H (MeV)	$\delta\sigma$ (fb) [d]	
MI	$e^-_R e^+_L$	μμX	90±7	0.50 (7.0%)	0.36 (5.1%)
		eeX	182±24	0.87 (12.2%)	0.54 (7.3%)
		merged [c]	81±5	0.43 (6.1%)	0.30 (4.2%)
	$e^-_L e^+_R$	μμX	85±6	0.70 (6.6%)	0.49 (4.8%)
		eeX	150±16	1.15 (9.8%)	0.74 (6.5%)
		merged	74±4	0.60 (5.5%)	0.41 (3.9%)
	Joint [b]	μμX	87±6		
		eeX	164±20		
		merged	77±5		

Ana.	Pol.	Ch.	δM_H (MeV)	$\delta\sigma$ (fb)	
SM	$e^-_R e^+_L$	μμX	93±6	0.45 (6.5%)	0.31 (4.4%)
		eeX	204±20	0.74 (10.3%)	0.45 (6.1%)
		merged	85±8	0.38 (5.5%)	0.26 (3.6%)
	$e^-_L e^+_R$	μμX	80±8	0.55 (5.4%)	0.38 (3.8%)
		eeX	149±14	0.85 (8.0%)	0.53 (4.8%)
		merged	70±7	0.46 (4.5%)	0.31 (3.0%)
	Joint	μμX	86±8		
		eeX	170±16		
		merged	77±7		

[a] **Results from GPET fitting function, see the backup slides for all the results.**

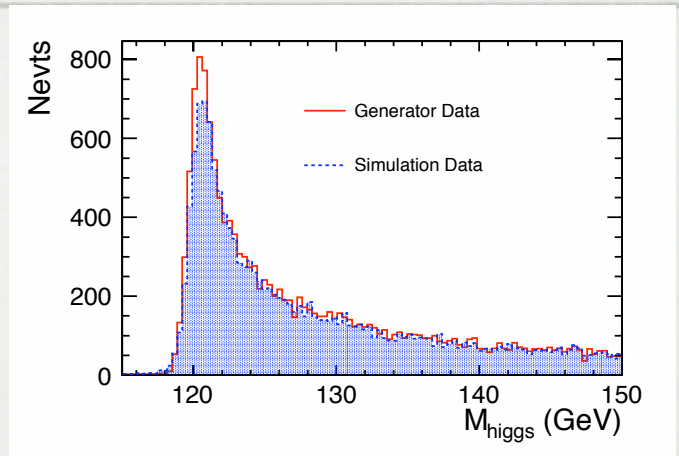
[b] **Joint: Taken 125fb^{-1} Luminosity from each Pol., with a total Luminosity of 250fb^{-1}**

[c] **Merged: Results with merged statistics of μμX and eeX.**

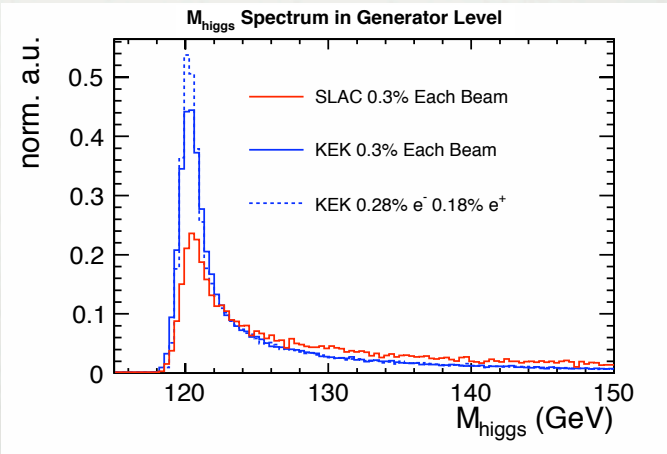
[d] **Cross-Sections, in Red: free parameters N_S and M_H.**
in Blue: free parameters N_S, N_B and M_H, the results in ILD LOI

Conclusions

- Realistic Methods and Techniques are developed for the Higgs Recoil Mass and Higgs-strahlung Cross-section measurement
- Measurements Precision achieved: (a)
  - Higgs Mass: merged result:
    ± 70 MeV
  - Cross-Section: merged result:
    ± 0.46 fb^{-1} (4.5%) (b)
    ± 0.31 fb^{-1} (3.0%) (c)
- The Higgs Recoil Mass measurement is very sensitive to several issues beside the detector uncertainty:
  - **Beam Energy Spread:** Increases the width of recoil mass peak, thus reduce the accuracy of the measurement.
  - **Beamstrahlung:** Largely reduces the effective statistics on the recoil mass peak



Comparisons of recoil mass spectra in generator level and after full simulation, with 0.3% beam energy spread for each beam, (of μμX)



Comparisons of recoil mass spectra in generator level of SLAC and KEK versions, where, the SLAC version is used in the all the 3 LOIs, and the KEK version is produced by Akiya Miyamoto with Andrei Seryi's beam parameters

(a) SM, $e^-_L e^+_R$ results.
(b) Fitting with free parameters N_S, N_B and M_H
(c) Fitting with free parameters N_S and M_H

Thanks!

Backup Slides

Mass Resolution

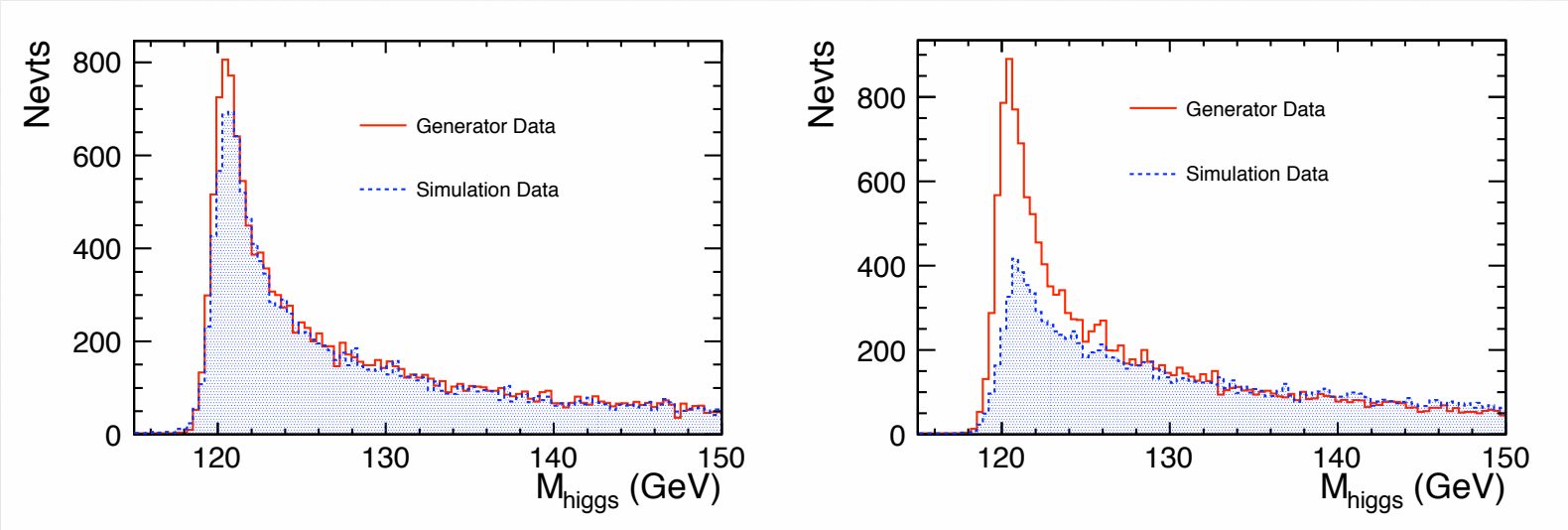
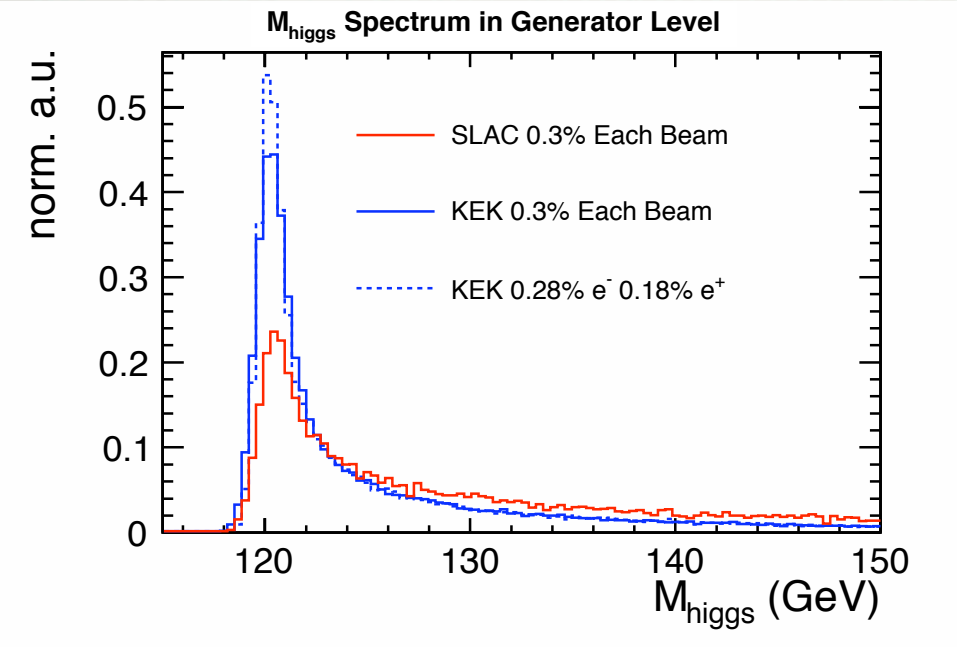


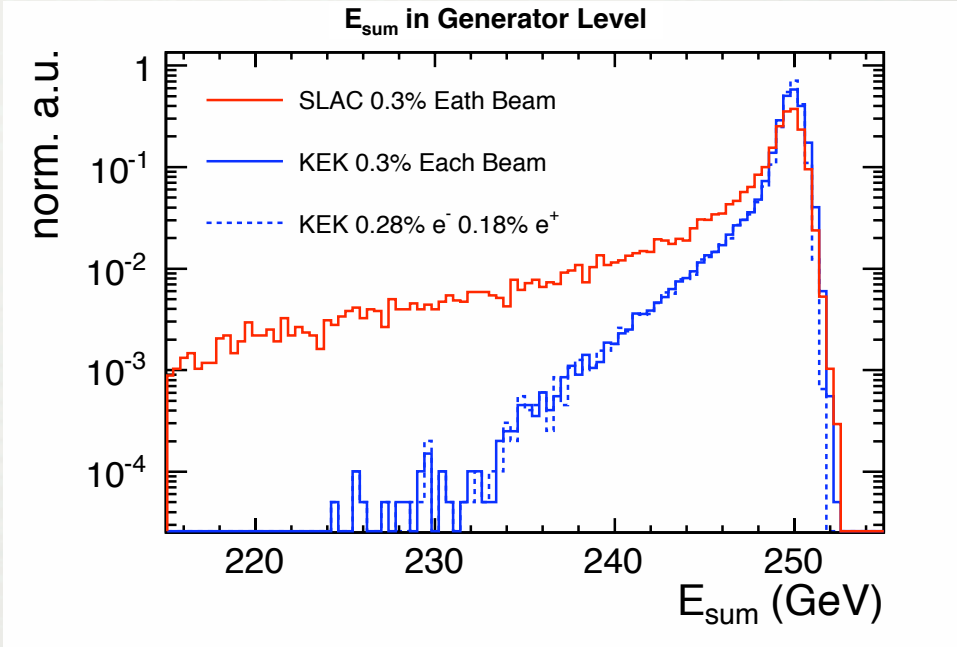
Figure 25: Comparisons of recoil mass spectra in generator level and after full simulation, for the $\mu\mu X$-channel (left) and the eeX-channel (right).

	$\Delta M_{tot.}$ (MeV)	$\Delta M_{mac.}$ (MeV)	$\Delta M_{dec.}$ (MeV)
$\mu\mu X$	870	730	470
eeX	970	730	640

Table 22: Mass Resolution with contributions by machine ($\Delta M_{mac.}$) and detector ($\Delta M_{det.}$) separated.

Beam Affects





- Comparisons of recoil mass spectra in generator level of SLAC and KEK versions, where,
  - the SLAC version is used in the all the 3 LOIs, and
  - the KEK version is produced by Akiya Miyamoto with Andrei Seryi's beam parameters
- The SLAC version has larger beamstrahlung than expected.

Results: MI , Free Pars: N_S, M_H

Fit.	Pol.	Ch.	M_H (GeV)	σ (fb)
GPET	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.984 $\pm$(0.090 $\pm$ 0.0066)	7.05 $\pm$ 0.36 (5.11 %)
		eeX	120.042 $\pm$(0.179 $\pm$ 0.0234)	7.37 $\pm$ 0.54 (7.33 %)
		merged	119.996 $\pm$(0.080 $\pm$ 0.0051)	7.15 $\pm$ 0.30 (4.19 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.854 $\pm$(0.086 $\pm$ 0.0060)	10.24 $\pm$ 0.49 (4.79 %)
		eeX	119.924 $\pm$(0.152 $\pm$ 0.0168)	11.32 $\pm$ 0.74 (6.54 %)
		merged	119.871 $\pm$(0.075 $\pm$ 0.0044)	10.57 $\pm$ 0.41 (3.87 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	119.916 $\pm$(0.088 $\pm$ 0.0063)	
		eeX	119.973 $\pm$(0.164 $\pm$ 0.0196)	
		merged	119.929 $\pm$(0.077 $\pm$ 0.0048)	
CEG	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.085 $\pm$(0.099 $\pm$ 0.0080)	6.97 $\pm$ 0.36 (5.16 %)
		eeX	119.953 $\pm$(0.240 $\pm$ 0.0420)	7.37 $\pm$ 0.54 (7.33 %)
		merged	120.066 $\pm$(0.092 $\pm$ 0.0067)	7.09 $\pm$ 0.30 (4.22 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.079 $\pm$(0.096 $\pm$ 0.0075)	10.57 $\pm$ 0.50 (4.73 %)
		eeX	120.010 $\pm$(0.188 $\pm$ 0.0258)	11.34 $\pm$ 0.74 (6.53 %)
		merged	120.065 $\pm$(0.085 $\pm$ 0.0058)	10.81 $\pm$ 0.41 (3.83 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	120.082 $\pm$(0.097 $\pm$ 0.0077)	
		eeX	119.988 $\pm$(0.209 $\pm$ 0.0319)	
		merged	120.065 $\pm$(0.088 $\pm$ 0.0062)	

Results: SM , Free Pars: N_S, M_H

Fit.	Pol.	Ch.	M_H (GeV)	σ (fb)
GPET	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.951 $\pm$(0.084 $\pm$ 0.0057)	7.00 $\pm$ 0.31 (4.43 %)
		eeX	119.704 $\pm$(0.200 $\pm$ 0.0292)	7.39 $\pm$ 0.45 (6.09 %)
		merged	119.914 $\pm$(0.077 $\pm$ 0.0048)	7.13 $\pm$ 0.26 (3.58 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.906 $\pm$(0.078 $\pm$ 0.0049)	10.11 $\pm$ 0.38 (3.76 %)
		eeX	119.866 $\pm$(0.131 $\pm$ 0.0125)	10.98 $\pm$ 0.53 (4.83 %)
		merged	119.896 $\pm$(0.067 $\pm$ 0.0035)	10.41 $\pm$ 0.31 (2.97 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	119.927 $\pm$(0.081 $\pm$ 0.0053)	
		eeX	119.817 $\pm$(0.155 $\pm$ 0.0175)	
		merged	119.903 $\pm$(0.072 $\pm$ 0.0041)	
CEG	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.123 $\pm$(0.093 $\pm$ 0.0070)	7.02 $\pm$ 0.31 (4.42 %)
		eeX	119.684 $\pm$(0.201 $\pm$ 0.0295)	7.40 $\pm$ 0.45 (6.08 %)
		merged	120.046 $\pm$(0.084 $\pm$ 0.0057)	7.14 $\pm$ 0.26 (3.57 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.178 $\pm$(0.081 $\pm$ 0.0053)	10.48 $\pm$ 0.39 (3.72 %)
		eeX	120.047 $\pm$(0.146 $\pm$ 0.0155)	10.98 $\pm$ 0.53 (4.83 %)
		merged	120.147 $\pm$(0.071 $\pm$ 0.0040)	10.66 $\pm$ 0.31 (2.95 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	120.154 $\pm$(0.086 $\pm$ 0.0061)	
		eeX	119.922 $\pm$(0.167 $\pm$ 0.0203)	
		merged	120.105 $\pm$(0.077 $\pm$ 0.0047)	

Results: MI , Free Pars: N_S, NB and M_H

Fit.	Pol.	Ch.	M_H (GeV)	σ (fb)
GPET	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.984 $\pm$(0.090 $\pm$ 0.0066)	7.11 $\pm$ 0.50 (7.03 %)
		eeX	120.046 $\pm$(0.182 $\pm$ 0.0241)	7.15 $\pm$ 0.87 (12.17 %)
		merged	119.996 $\pm$(0.081 $\pm$ 0.0052)	7.12 $\pm$ 0.43 (6.09 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.854 $\pm$(0.085 $\pm$ 0.0059)	10.54 $\pm$ 0.70 (6.64 %)
		eeX	119.922 $\pm$(0.150 $\pm$ 0.0164)	11.72 $\pm$ 1.15 (9.81 %)
		merged	119.871 $\pm$(0.074 $\pm$ 0.0043)	10.86 $\pm$ 0.60 (5.51 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	119.915 $\pm$(0.087 $\pm$ 0.0062)	
		eeX	119.972 $\pm$(0.164 $\pm$ 0.0195)	
		merged	119.928 $\pm$(0.077 $\pm$ 0.0047)	
CEG	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.086 $\pm$(0.100 $\pm$ 0.0081)	6.91 $\pm$ 0.50 (7.24 %)
		eeX	119.961 $\pm$(0.244 $\pm$ 0.0434)	7.15 $\pm$ 0.87 (12.17 %)
		merged	120.068 $\pm$(0.093 $\pm$ 0.0068)	6.97 $\pm$ 0.43 (6.22 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.078 $\pm$(0.095 $\pm$ 0.0073)	10.83 $\pm$ 0.72 (6.65 %)
		eeX	120.007 $\pm$(0.185 $\pm$ 0.0249)	11.75 $\pm$ 1.15 (9.79 %)
		merged	120.063 $\pm$(0.085 $\pm$ 0.0057)	11.09 $\pm$ 0.61 (5.50 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	120.082 $\pm$(0.097 $\pm$ 0.0077)	
		eeX	119.990 $\pm$(0.208 $\pm$ 0.0317)	
		merged	120.065 $\pm$(0.088 $\pm$ 0.0062)	

Results: SM , Free Pars: N_S, NB and M_H

Fit.	Pol.	Ch.	M_H (GeV)	σ (fb)
GPET	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.951 $\pm$(0.084 $\pm$ 0.0057)	6.98 $\pm$ 0.45 (6.45 %)
		eeX	119.713 $\pm$(0.204 $\pm$ 0.0303)	7.18 $\pm$ 0.74 (10.31 %)
		merged	119.916 $\pm$(0.078 $\pm$ 0.0048)	7.03 $\pm$ 0.38 (5.47 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	119.905 $\pm$(0.077 $\pm$ 0.0048)	10.26 $\pm$ 0.55 (5.36 %)
		eeX	119.871 $\pm$(0.135 $\pm$ 0.0133)	10.67 $\pm$ 0.85 (7.97 %)
		merged	119.897 $\pm$(0.067 $\pm$ 0.0035)	10.38 $\pm$ 0.46 (4.45 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	119.926 $\pm$(0.080 $\pm$ 0.0052)	
		eeX	119.823 $\pm$(0.159 $\pm$ 0.0185)	
		merged	119.905 $\pm$(0.072 $\pm$ 0.0041)	
CEG	$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.122 $\pm$(0.093 $\pm$ 0.0070)	7.03 $\pm$ 0.44 (6.26 %)
		eeX	119.689 $\pm$(0.204 $\pm$ 0.0303)	7.23 $\pm$ 0.74 (10.24 %)
		merged	120.047 $\pm$(0.085 $\pm$ 0.0057)	7.08 $\pm$ 0.38 (5.34 %)
	$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu\mu X$	120.177 $\pm$(0.080 $\pm$ 0.0052)	10.64 $\pm$ 0.57 (5.36 %)
		eeX	120.053 $\pm$(0.149 $\pm$ 0.0162)	10.67 $\pm$ 0.85 (7.97 %)
		merged	120.149 $\pm$(0.070 $\pm$ 0.0039)	10.65 $\pm$ 0.47 (4.45 %)
	Joint $\mathcal{L} = 125$ fb^{-1}($e^-_R e^+_L$) +125 fb^{-1}($e^-_L e^+_R$)	$\mu\mu X$	120.154 $\pm$(0.086 $\pm$ 0.0060)	
		eeX	119.926 $\pm$(0.170 $\pm$ 0.0211)	
		merged	120.108 $\pm$(0.077 $\pm$ 0.0047)	

MI vs. SM Rejection, LR, Muon

MI

N_{evts} left:	$\mu\mu X$	$\mu\mu$	$\tau\tau$	$\mu\mu\nu\nu$	$\mu\mu ff$
Before any restriction	2601	2.6M	2.6M	125k	321k
+ Both μ identified	2488 (95.65%)		79k (3.0%)	108k (86.6%)	186k (57.9%)
+ Pre-cuts	2193 (84.33%)	44k (1.7%)	5639 (0.2%)	17k (13.6%)	15k (4.5%)
+ $P_{Tdl} > 20\,\mathrm{GeV}$	2078 (79.91%)	22k (0.8%)	3806 (0.15%)	15k (11.8%)	11k (3.4%)
+ $M_{dl} \in (80,\ 100)\,\mathrm{GeV}$	1919 (73.79%)	17k (0.6%)	2111 (0.08%)	9124 (7.3%)	8005 (2.5%)
+ $acop \in (0.2,\ 3.0)$	1787 (68.72%)	14k (0.5%)	28	8548 (6.8%)	7213 (2.2%)
+ $\Delta P_{Tbal.} > 10\,\mathrm{GeV}$	1752 (67.38%)	796 (0.03%)	0	7969 (6.4%)	6747 (2.1%)
+ $\lvert\Delta\theta_{2tk}\rvert > 0.01$	1750 (67.28%)	335 (0.01%)	0	7871 (6.3%)	6719 (2.1%)
+ $M_{recoil} \in (115,\ 150)\,\mathrm{GeV}$	1709 (65.71%)	245	0	5284 (4.2%)	4175 (1.3%)

SM

N_{evts} left:	$\mu\mu X$	$\mu\mu$	$\tau\tau$	$\mu\mu\nu\nu$	$\mu\mu ff$
Before any restriction:	2601	2.61M	2.61M	125k	321k
Both μ identified	2488 (95.66%)		79k (3.0%)	108k (86.6%)	186k (57.9%)
+ Pre-cuts	2193 (84.33%)	44k (1.7%)	5639 (0.22%)	17k (13.62%)	15k (4.5%)
+ $N_{add.TK} > 1$	2179 (83.8%)	2643 (0.1%)	667 (0.03%)	290 (0.23%)	13k (4.0%)
+ $\Delta\theta_{2tk} > 0.01$	2176 (83.66%)	244	500 (0.02%)	34 (0.03%)	12.5k (3.9%)
+ $\Delta\theta_{min} > 0.01$	2140 (82.29%)	155	111	2	11k (3.5%)
+ $acop \in (0.2, 3.0)$	1977 (76.03%)	114	0	2	10k (3.1%)
+ $M_{recoil} \in (115, 150)\,\mathrm{GeV}$	1872 (71.96%)	68	0	0	6189 (1.9%)

MI vs. SM Rejection, LR, Electron

MI

N_{evts} left:	eeX	ee	$\tau\tau$	$ee\nu\nu$	$eeff$
Before any restriction	2777	4.3G	2.6M	156k	1.0M
+ Both μ identified	2728 (98.24%)		294k (11.3%)	120k (77.1%)	404k (40.4%)
+ Pre-cuts	1739 (62.64%)	127k	8972 (0.34%)	19k (12.2%)	12k (1.2%)
+ $P_{Tdl} > 20\ GeV$	1641 (59.10%)	96k	6195 (0.24%)	16k (10.6%)	10k (1.0%)
+ $M_{dl} \in (80,\ 100)$ GeV	1399 (50.38%)	51k	3500 (0.13%)	9784 (6.3%)	7186 (0.72%)
+ $acop \in (0.2,\ 3.0)$	1314 (47.33%)	46k	278 (0.01%)	9168 (5.9%)	6564 (0.66%)
+ $\Delta P_{Tbal.} > 10$ GeV	1281 (46.15%)	3156	194	8222 (5.3%)	6066 (0.61%)
+ $\lvert\Delta\theta_{2tk}\rvert > 0.01$	1279 (46.07%)	1764	167	8069 (5.2%)	6041 (0.6%)
+ $M_{recoil} \in (115,\ 150)$ GeV	1235 (44.47%)	1313	56	5488 (3.5%)	3665 (0.37%)

SM

N_{evts} left:	eeX	ee	$\tau\tau$	$ee\nu\nu$	$eeff$
Before any restriction:	2777	4.3G	2.61M	156k	1.0M
Both e identified	2728 (98.24%)		294k (11.3%)	120k (77.1%)	404k (40.4%)
+ Pre-cuts	1739 (62.64%)	127k	8972 (0.34%)	19k (12.21%)	12k (1.23%)
+ $N_{add.TK} > 1$	1724 (62.08%)	7660	2528 (0.10%)	463 (0.30%)	11k (1.13%)
+ $\Delta\theta_{2tk} > 0.01$	1721 (61.98%)	1190	1806 (0.07%)	76 (0.05%)	11k (1.13%)
+ $\Delta\theta_{min} > 0.01$	1696 (61.06%)	344	361 (0.01%)	10	10.7k (1.07%)
+ $acop \in (0.2, 3.0)$	1579 (56.86%)	293	0	10	9589 (0.96%)
+ $M_{recoil} \in (115, 150)$ GeV	1444 (52.00%)	184	0	5	5913 (0.59%)

Lepton ID

Cuts for lepton ID:

muon ID

$$E_{ecal}/E_{total} < 0.5$$
$$E_{cal}/P_{track} < 0.3$$

electron ID

$$E_{ecal}/E_{total} > 0.6$$
$$E_{cal}/P_{track} > 0.9$$

Cuts (for P>15GeV): single particle	μμX (muon ID)	eeX (electron ID)
Efficiency ($N_{true \cap iden}/N_{true}$)	97.6%	96.3%
Purity ($N_{true \cap iden}/N_{iden}$)	91.4%	96.1%
Efficiency lepton pair ID: (no P request, select according to Mz)	**95.4%**	**98.8%**