BSM Search using Higgs to Invisible Decay

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The 48th general meeting of the ILC physics working group

Outline

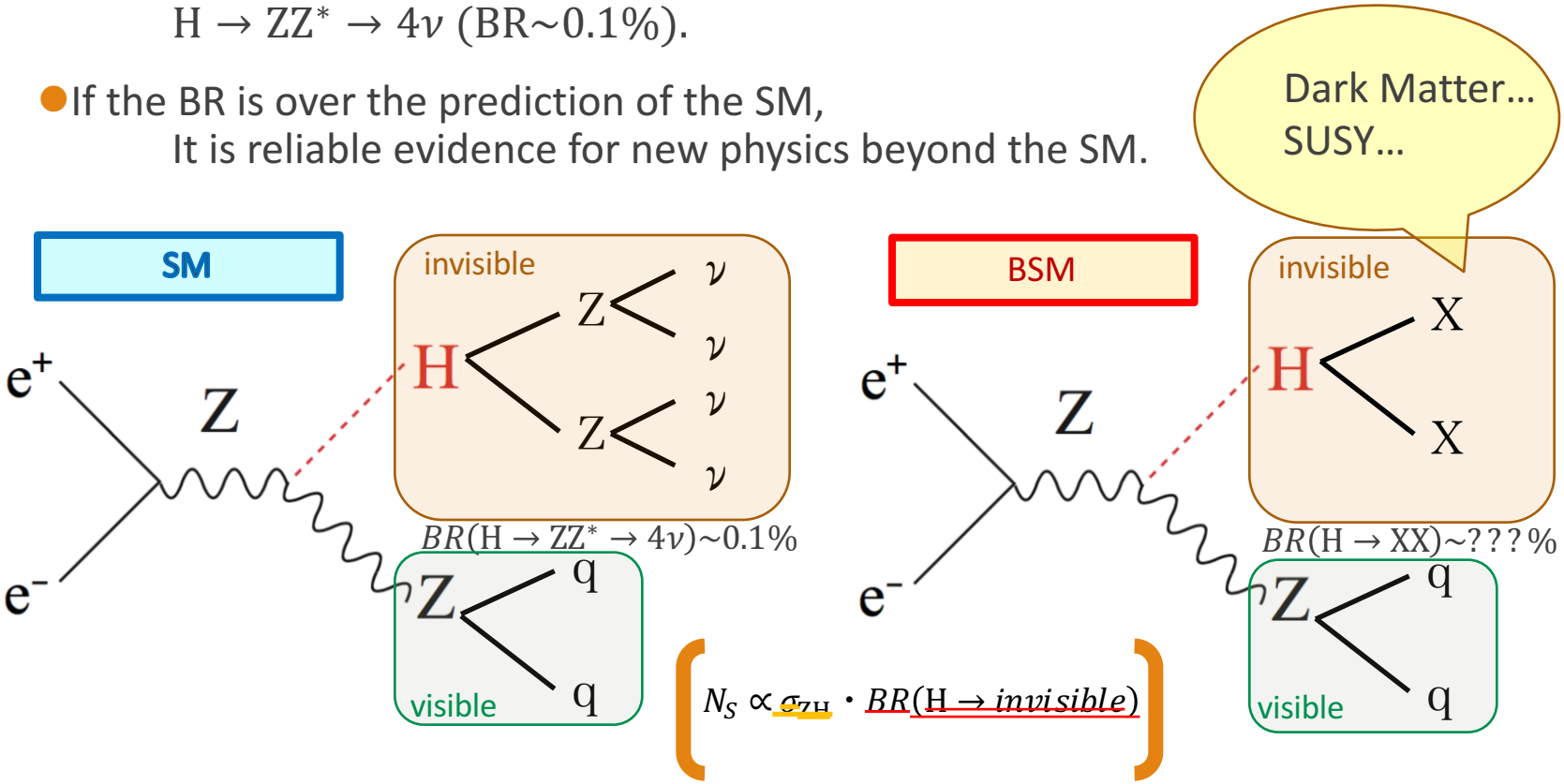
- Status
- Higgs to Invisible Decay
  - Recoil Mass Method
  - Leptonic Channel Analysis
- Plans

Status

- I became a master course 1st year student this April, and joined ILC physics group.
- I plan to study BSM Search using Higgs to invisible decay.
- First, in order to understand analysis method, I reproduced Higgs recoil mass study of Jacqueline san.
- Now I move to study of Higgs to invisible.
- [New] I try to study leptonic channel with the help of Junping san.

Higgs to Invisible Decay

- In the SM, Higgs decays invisibly through the process
  $\mathrm{H} \rightarrow \mathrm{ZZ}^{*} \rightarrow 4\nu$ (BR~0.1%).
- If the BR is over the prediction of the SM,
  It is reliable evidence for new physics beyond the SM.



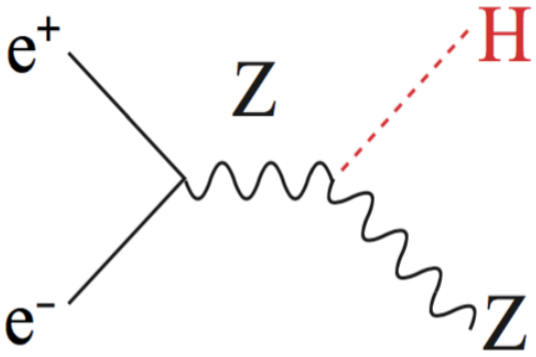
Recoil Mass Method

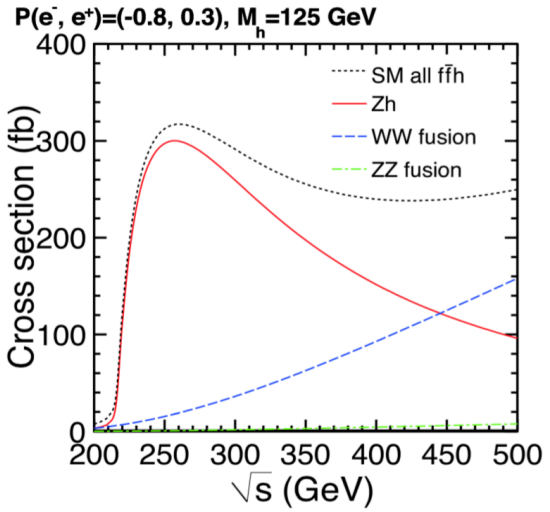
- For my study, I reproduced the study of Higgs Recoil Mass method.
- It is important for Higgs invisible decay study.
- Model independence
  - We can measure Higgs without the direct measurement of it.
  - Measure Higgs cross section and Higgs mass precisely.

$$\sigma_{\mathrm{ZH}} = \frac{N_S}{BR(\mathrm{Z} \to l^+l^-)\varepsilon_S L}$$

$$M^2_{rec} = (\sqrt{s} - E_{l^+l^-})^2 - |\vec{p}_{l^+l^-}|^2$$

- For this study, I used leptonic channel $Z \to l^+l^-$.
- For the search of BSM, I will also use hadronic channel $Z \to qq$.

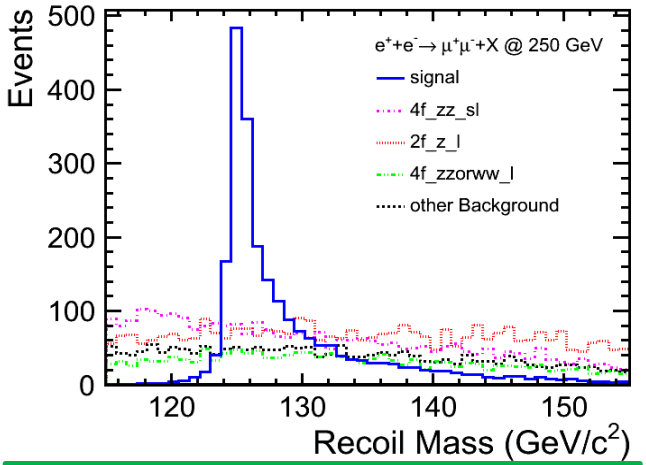




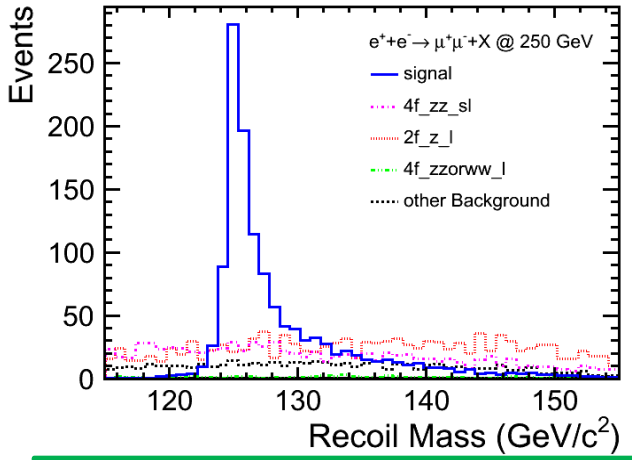
Reproduce Recoil Mass Result

Ref. ： J.Y. et al, arXiv:1604.07524

$e^- + e^+ \to \mu^- + \mu^+ + X$@250GeV



"Left":$P(e^-, e^+) = (-0.8, +0.3)$



"Right":$P(e^-, e^+) = (+0.8, -0.3)$

Isolated lepton selection

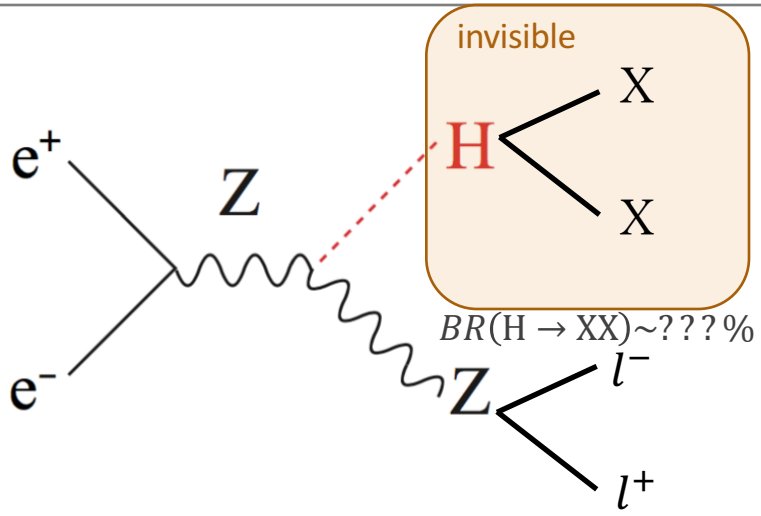
	μ ID	e ID
momentum and energy deposit	$p_{\text{track}} > 5$ GeV	$p_{\text{track}} > 5$ GeV
	$E_{\text{CAL,tot}}/p_{\text{track}} < 0.3$	$0.5 < E_{\text{CAL,tot}}/p_{\text{track}} < 1.3$
	$E_{\text{yoke}} < 1.2$ GeV	$E_{\text{ECAL}}/E_{\text{CAL,tot}} > 0.9$
impact parameter	$\lvert d_0/\delta d_0\rvert < 5$	$\lvert d_0/\delta d_0\rvert < 50$
	$\lvert z_0/\delta z_0\rvert < 5$	$\lvert z_0/\delta z_0\rvert < 5$

Best lepton pair

$$\chi^2\left(M_{l^+l^-}, M_{\text{rec}}\right) = \frac{\left(M_{l^+l^-} - M_Z\right)^2}{\sigma^2_{M_{l^+l^-}}} + \frac{\left(M_{\text{rec}} - M_H\right)^2}{\sigma^2_{M_{\text{rec}}}}$$

Cut	signal	2f_l	4f_l	4f_sl	total BG	Significance
0.Pre-Cut	2440	2638950	226080	77046	2942620	1.42
1.Lepton ID(muon)	2439	637356	61474	24060	722890	2.86
2.M_ll ∈[73,120]GeV	2382	430593	40072	22265	492929	3.39
3.p_T ∈[10,70]GeV	2335	82272	30227	15666	128164	6.46
4.|cos θ mis|<0.98	2335	42828	29955	15664	88447	7.74
5.BDT>-0.25(MVA)	2333	12822	19906	9058	41785	11.1
6.Evis>10GeV	2330	12422	5470	9058	26950	13.6
7.window	2314	3600	3688	3672	10959	20.1

Signal feature [leptonic channel]



- Two-leptons
- Invisible particle without neutrino
- $M_{ll} \approx M_Z$ $(BR(\mathrm{Z} \to ll) \sim 3.4\%)$
- $M_{recoil} \approx M_{Higgs}$

Major Backgrounds [leptonic channel]

The major backgrounds have the final states with di-lepton & missing energy .

1. ZZ leptonic
2. WW leptonic
3. single Z $(\& \nu_e \nu_e), \mathrm{Z} \to ll$
4. single W & e $\nu_e, \mathrm{W} \to \mathrm{e}\,\nu_\mathrm{e}$
5. $\nu\nu\mathrm{H}, \mathrm{H} \to \mathrm{ZZ}, \mathrm{Z} \to ll$
6. $ll\mathrm{H}, \mathrm{H} \to$ SM decay

Cut List [Ecm=250GeV,$\mu\mu$H]

```
----------Cuts----------
Cut  0
OBJ: TCut
Cut  1
OBJ: TCut              leptype==13
Cut  2
OBJ: TCut              ptz>10&&abs(mz-91.18)<20&&mrecoil>105&&mrecoil<165
Cut  3
OBJ: TCut              ptz>20
Cut  4
OBJ: TCut              mz>80&&mz<100
Cut  5
OBJ: TCut              abs(deltapt)>10
Cut  6
OBJ: TCut              abs(cosmis)<0.99
Cut  7
OBJ: TCut              mrecoil>120&&mrecoil<140
Cut  8
OBJ: TCut              mmis > 100 && evis < 15
```

Cut List

Number	Contents
0	Pre Cut (by Lepton Selection Processor)
1	Lepton ID
2	Loose Cut by Pt_Z > 10GeV & M_Z ∈[71,111]GeV & M_recoil ∈[105,165]GeV
3	Pt_Z > 20GeV
4	M_Z ∈[80,100]GeV
5	|ΔPt|≡|Pt_dl – Pt_γ_max| > 10GeV
6	|cosθmis|< 0.99
7	M_recoil ∈[120,140]GeV
8	M_mis > 100GeV & Evis < 15GeV

※Junping's original code contains MVA cut in No.9.

Cut Table [Ecm=250GeV,250fb^{-1},$\mu\mu$H,Left]

Polarization: (e-,e+) = (-0.8,+0.3)

Reduction Table

Process	:	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	:	38176.9	78046.1	5655.8	18398.3	16799.3	157076	23.4402	1.04112	
Generated	:	5.76948e+06	3.17329e+06	3.14632e+06	4.9795e+06	2.74204e+06		252310	96316	
Expected	:	9.54422e+06	1.95115e+07	1.41395e+06	4.59957e+06	4.19983e+06	3.92691e+07	5860.05	260.28	0.041532
Cut0	:	2.9994e+06	48.9287	277468	80844.6	0.619737	3.35776e+06	5046.32	243.638	0.13286
Cut1	:	670119	0	86756.9	24107.6	0	780983	2471.11	243.638	0.275257
Cut2	:	12980.7	0	15556.2	4789.2	0	33326.2	2361.64	233.477	1.2359
Cut3	:	8081.71	0	13293.4	4317.36	0	25692.5	2252.77	221.442	1.32466
Cut4	:	7163.13	0	8102.52	3962.45	0	19228.1	2150.47	211.05	1.44343
Cut5	:	1244.65	0	7934.34	3877.57	0	13056.6	2127.87	210.764	1.7104
Cut6	:	717.378	0	7551.91	2658.95	0	10928.2	2034.25	210.764	1.85119
Cut7	:	315.529	0	3039.8	767.246	0	4122.57	1909.53	195.308	2.5147
Cut8	:	16.6744	0	2448.41	0	0	2465.08	195.213	190.66	3.69653

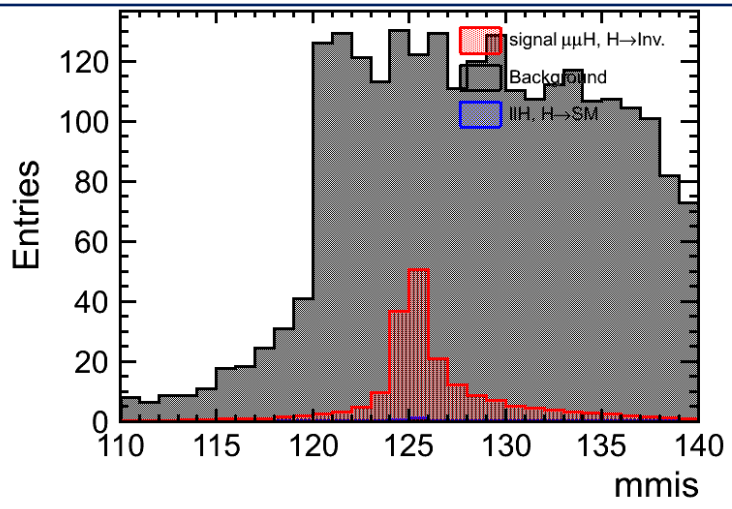
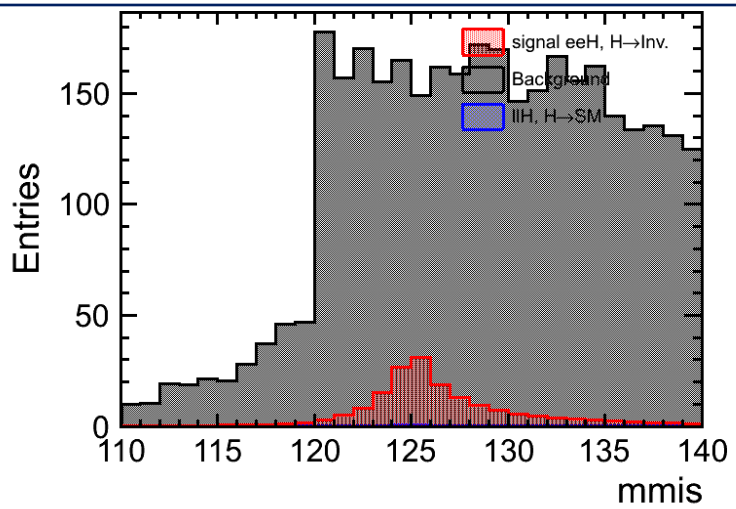
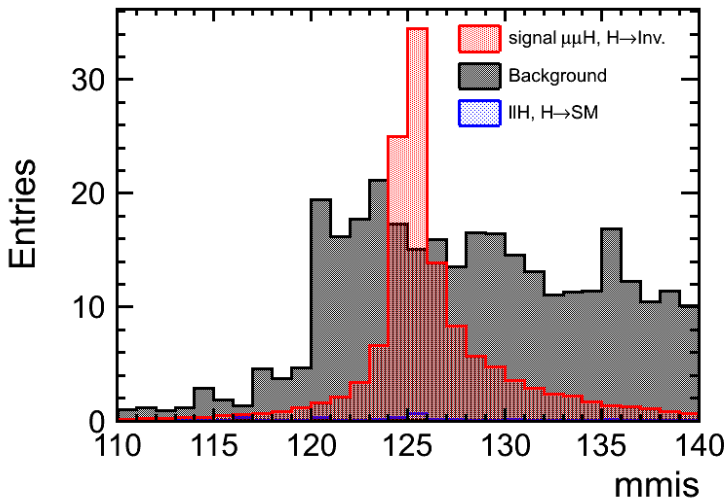
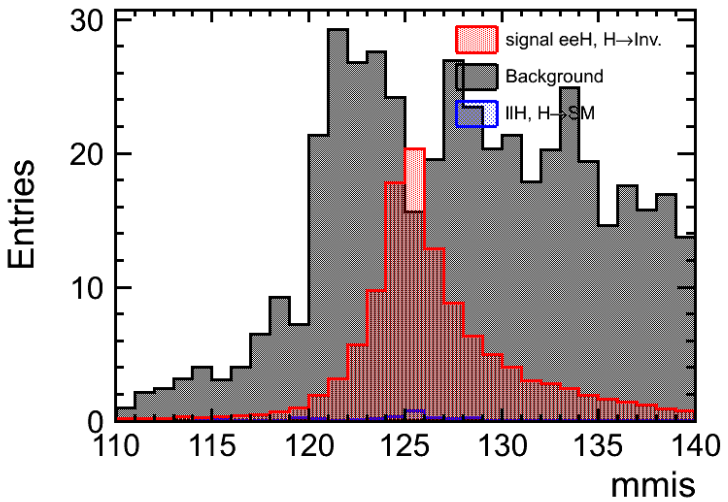
Cut Table [Ecm=250GeV,250fb^{-1},$\mu\mu$H,Right]

Polarization: (e-,e+) = (+0.8,-0.3)

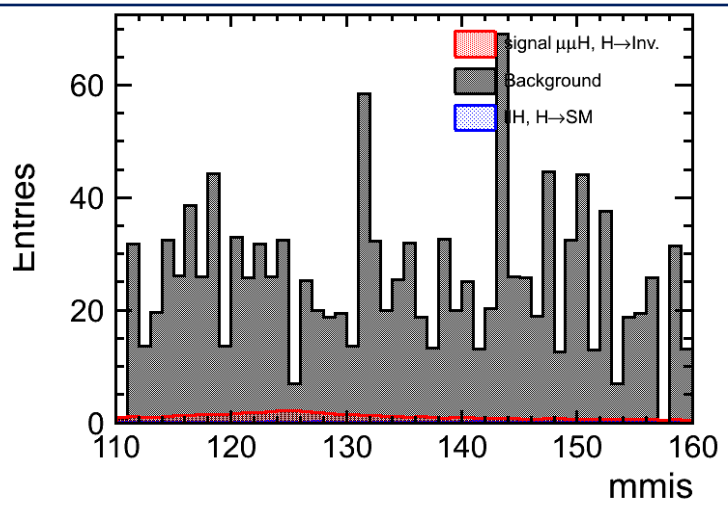
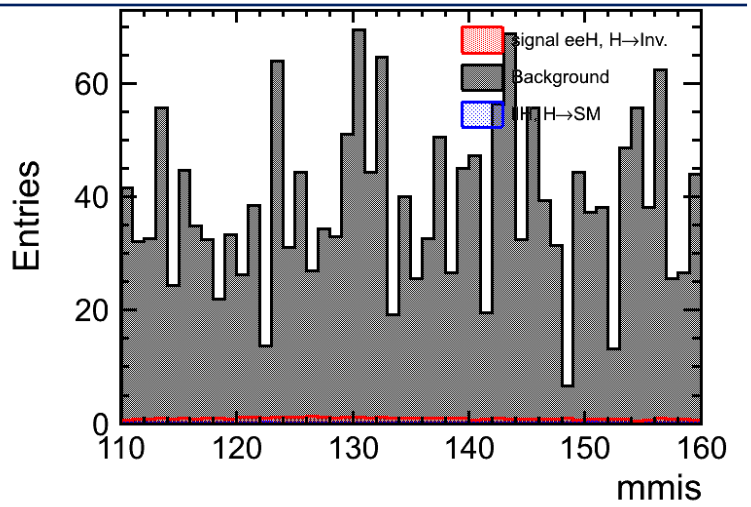
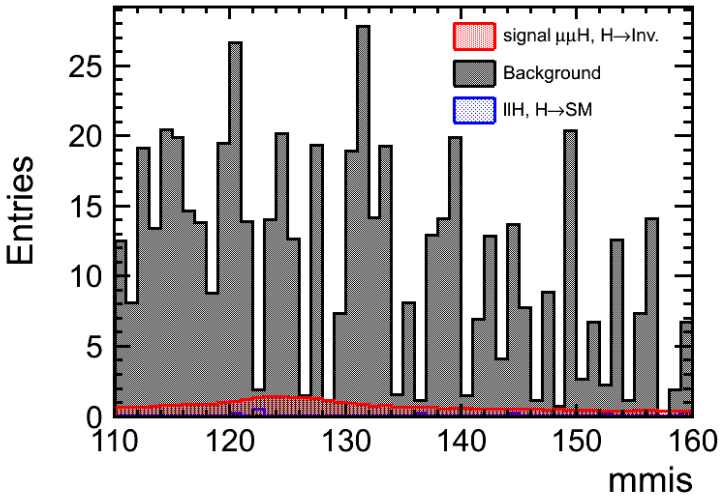
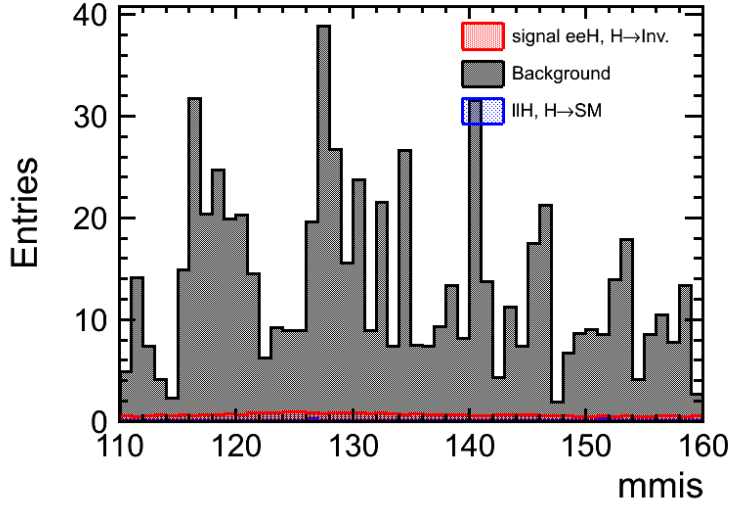
Reduction Table

Process	:	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	:	34983.6	46214.9	1467.78	2063.18	1568.29	86297.8	15.8171	0.70232	
Generated	:	5.76948e+06	3.17329e+06	3.14632e+06	4.9795e+06	2.74204e+06		252310	96316	
Expected	:	8.74591e+06	1.15537e+07	366946	515794	392073	2.15744e+07	3954.27	175.58	0.0377977
Cut0	:	2.73197e+06	97.6004	95276.5	51897.2	0.619684	2.87925e+06	3392.82	163.973	0.0965776
Cut1	:	483442	0	17909.1	12382.5	0	513733	1670.92	163.973	0.228401
Cut2	:	8993.84	0	2832.74	2120.56	0	13947.1	1597.19	157.181	1.2607
Cut3	:	5609.44	0	2356.36	1903.75	0	9869.55	1517.38	149.353	1.39962
Cut4	:	4968.58	0	1692.23	1709.65	0	8370.46	1445.25	142.451	1.43782
Cut5	:	838.18	0	1633.35	1660.92	0	4132.45	1427.72	142.278	1.90807
Cut6	:	512.225	0	1387.65	1046.12	0	2946	1370.25	142.278	2.16564
Cut7	:	215.636	0	518.416	288.035	0	1022.09	1284.53	131.864	2.7456
Cut8	:	11.1999	0	308.716	0	0	319.916	131.906	128.866	6.06253

Leptonic Channel Analysis [Ecm=250GeV,250fb^{-1}]

	$\mu\mu H, H \rightarrow inv(BR = 0.1)$	$eeH, H \rightarrow inv(BR = 0.1)$
Left		
Right		

Leptonic Channel Analysis [Ecm=500GeV,500fb^{-1}]

	$\mu\mu H, H \rightarrow inv(BR = 0.1)$	$eeH, H \rightarrow inv(BR = 0.1)$
Left		
Right		

Summary

- I plan to study BSM Search using Higgs to invisible decay.
- Understood recoil mass method.
- Reproduction of recoil mass result has been done.
- Started leptonic channel analysis.

Significance 250GeV,250fb^{-1},H→inv(BR=0.1)	$\mu\mu$H	eeH
Left	3.70	2.90
Right	6.06	4.77

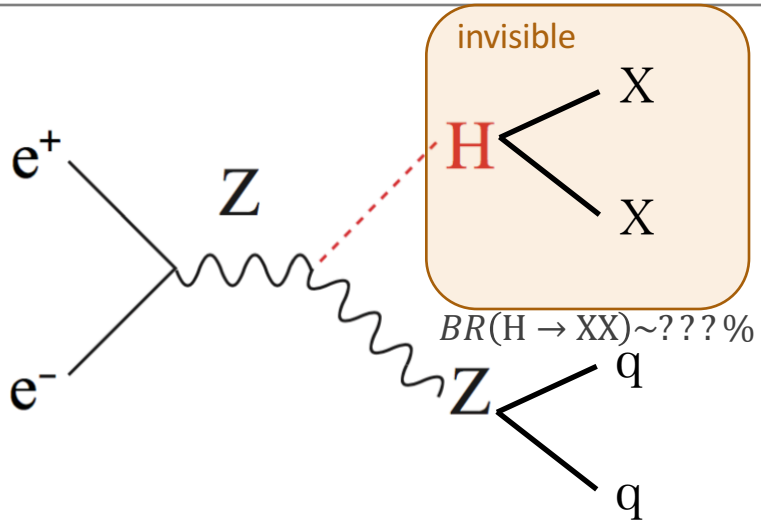
- I'm gradually catching on analysis code.

Plans

- Study analysis code [Continuously]
  - I got the analysis code from Junping san.
  - First, reproduce the leptonic channel, then study hadronic channel
- Understand analysis method [Continuously]
  - Jet clustering algorithm
    - Apply to the hadronic channel
  - Kinematic Fitting
    - For good resolution
  - MVA
    - BDT
    - MLP
    - Likelihood
- Think of ways to improve measurement precision [Finally]

Back Up

Signal feature [hadronic channel]



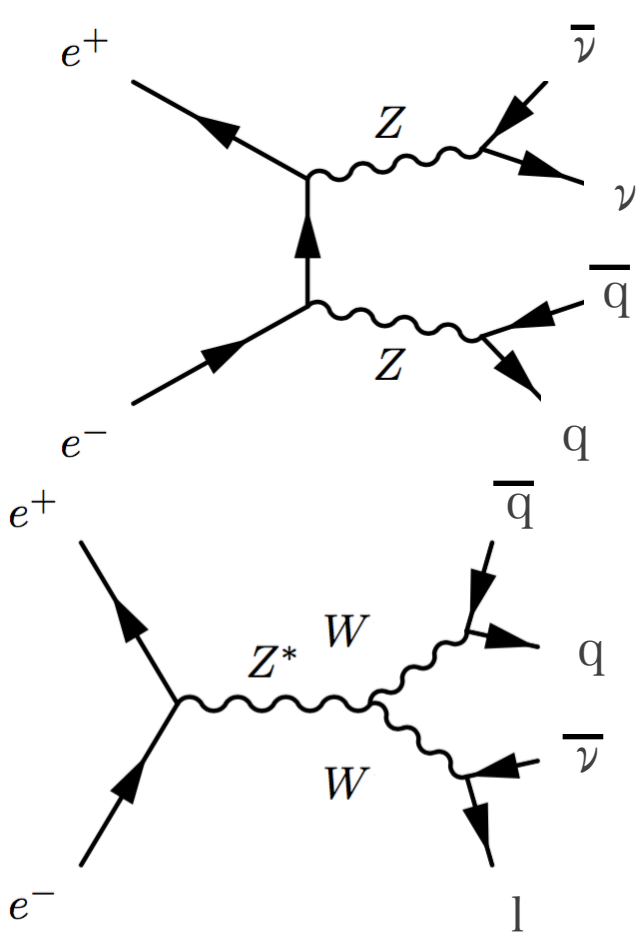
- Two-Jet
- Invisible particle exist
- $M_{qq} \approx M_Z$ $(BR(\mathrm{Z} \to qq) \sim 70\%)$
- $M_{recoil} \approx M_{Higgs}$

Major Backgrounds [hadronic channel]

The major backgrounds have the final states qqll,qqlv,qqvv.

1. ZZ semileptonic
2. WW semileptonic
3. $\mathrm{Z}\nu_e\nu_e, \mathrm{Z} \to \mathrm{qq}$
4. $\mathrm{W}\nu_e\nu_e, \mathrm{W} \to \mathrm{qq}$
5. $\nu\nu\mathrm{H}, \mathrm{H} \to \mathrm{ZZ}, \mathrm{Z} \to qq$
6. $\mathrm{qqH}, \mathrm{H} \to$ SM decay

Background


e^+
$\bar{\nu}$
Z
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e^+
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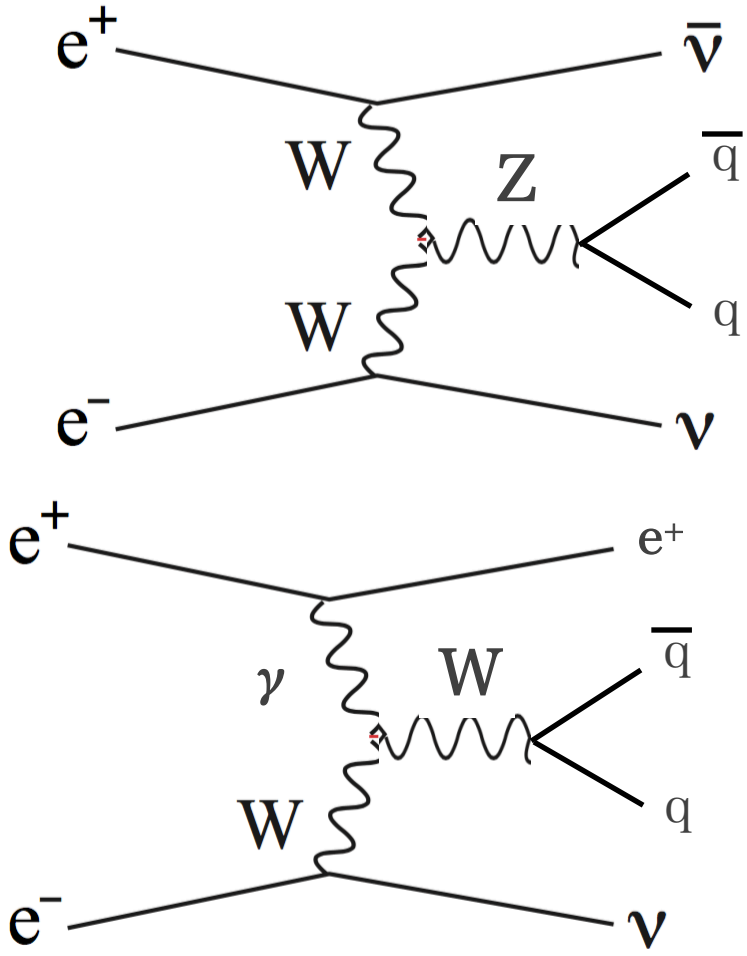
e^+
$\bar{\nu}$
W
Z
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e^+
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$\bar{q}$
W
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e^-
ν

Cut Table [Ecm=250GeV,eeH]

```
----------Cuts----------
Cut  0
OBJ: TCut
Cut  1
OBJ: TCut               leptype==11
Cut  2
OBJ: TCut               ptz>10&&abs(mz-91.18)<20&&mrecoil>105&&mrecoil<165&&abs(coslep1)<0.98&&abs(coslep2)<0.98
Cut  3
OBJ: TCut               ptz>20
Cut  4
OBJ: TCut               mz>80&&mz<100
Cut  5
OBJ: TCut               abs(deltapt)>10
Cut  6
OBJ: TCut               abs(cosmis)<0.99
Cut  7
OBJ: TCut               mrecoil>120&&mrecoil<140
Cut  8
OBJ: TCut               mmis > 100 && evis < 15
```

Cut Table [Ecm=250GeV,eeH,Left]

Polarization: (e-,e+) = (-0.8,+0.3)

Reduction Table

Process	:	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	:	38176.9	78046.1	5655.8	18398.3	16799.3	157076	23.4402	1.06866	
Generated	:	5.76948e+06	3.17329e+06	3.14632e+06	4.9795e+06	2.74204e+06		252310	97112	
Expected	:	9.54422e+06	1.95115e+07	1.41395e+06	4.59957e+06	4.19983e+06	3.92691e+07	5860.05	267.165	0.0426306
Cut0	:	2.9994e+06	48.9287	277468	80844.6	0.619737	3.35776e+06	5046.32	237.181	0.129339
Cut1	:	2.32928e+06	48.9287	190711	56737	0.619737	2.57678e+06	2575.21	237.181	0.147681
Cut2	:	75163.9	0.874546	20602	7289.86	0.034982	103057	2362.04	220.217	0.678253
Cut3	:	41903.1	0.874546	17484.8	6373.78	0.034982	65762.6	2235.19	208.698	0.800332
Cut4	:	25023.9	0.437273	10169.9	5077.26	0	40271.5	2078.79	194.874	0.946949
Cut5	:	9586.47	0.437273	9926.8	4942.83	0	24456.5	2054.21	194.654	1.19551
Cut6	:	7558.5	0.437273	9729.15	3692.76	0	20980.8	1964.31	194.654	1.28504
Cut7	:	2873.84	0	4000.3	1105.34	0	7979.48	1800.82	177.429	1.7941
Cut8	:	82.7408	0	3311.67	0	0	3394.41	177.442	173.3	2.89969

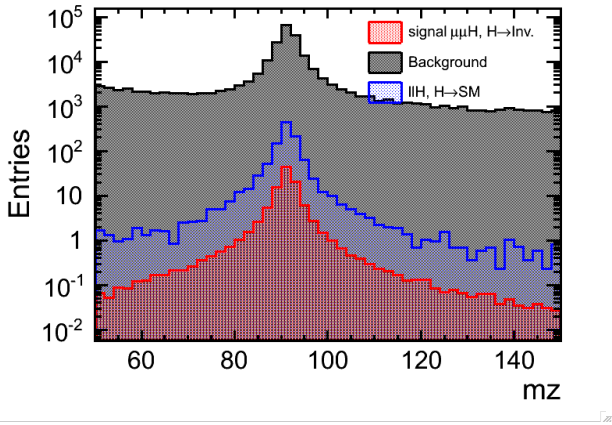
Cut Table [Ecm=250GeV,eeH,Right]

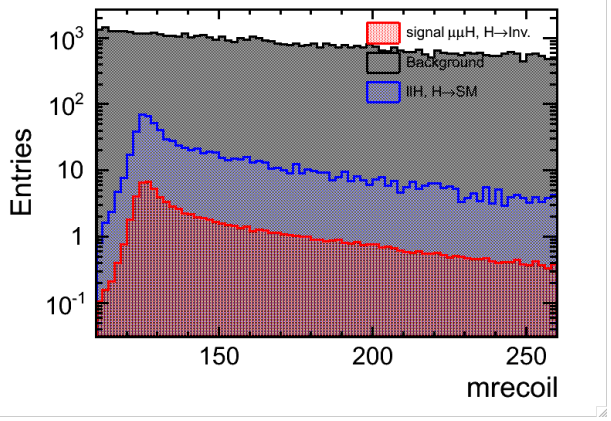
Polarization: (e-,e+) = (+0.8,-0.3)

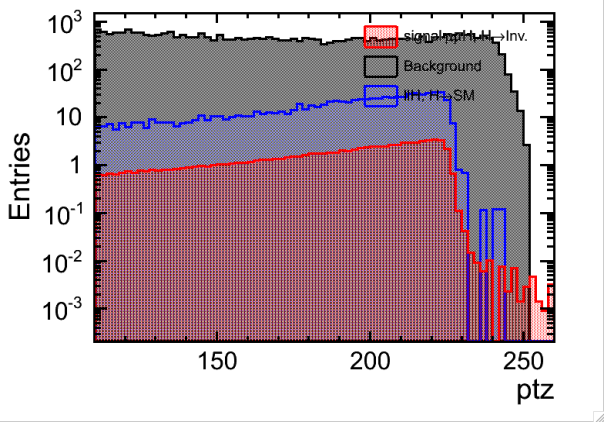
Reduction Table

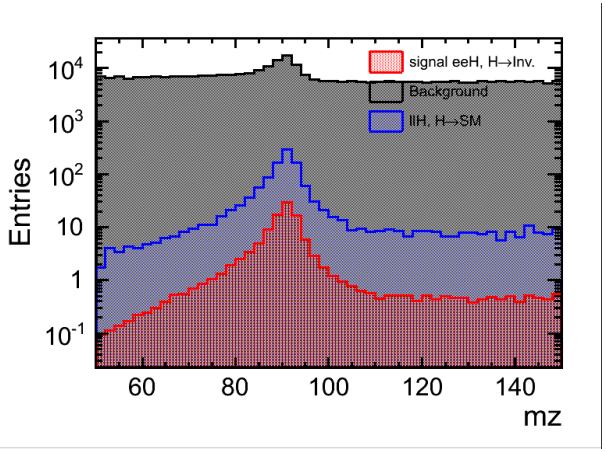
Process	2f_l	2f_h	4f_l	4f_sl	4f_h	BG	llH	Signal	Signf
Cross Section	34983.6	46214.9	1467.78	2063.18	1568.29	86297.8	15.8171	0.71446	
Generated	5.76948e+06	3.17329e+06	3.14632e+06	4.9795e+06	2.74204e+06		252310	97112	
Expected	8.74591e+06	1.15537e+07	366946	515794	392073	2.15744e+07	3954.27	178.615	0.0384511
Cut0	2.73197e+06	97.6004	95276.5	51897.2	0.619684	2.87925e+06	3392.82	157.851	0.0929721
Cut1	2.24853e+06	97.6004	77367.4	39514.7	0.619684	2.36551e+06	1721.9	157.851	0.102595
Cut2	69040.7	14.6174	4200.61	3738.13	0.584698	76994.6	1577.54	146.729	0.523458
Cut3	38455.4	14.6174	3279.73	3184.18	0.584698	44934.5	1499.19	139.028	0.645189
Cut4	22303	7.30871	2065.2	2425.39	0	26800.9	1394.03	130.316	0.776089
Cut5	8424.21	7.30871	1937.97	2352.38	0	12721.9	1381.01	130.176	1.09617
Cut6	6811.71	7.30871	1772.45	1660.36	0	10251.8	1329.03	130.176	1.20965
Cut7	2710.66	0	662.207	495.614	0	3868.48	1224.93	118.681	1.66294
Cut8	52.2948	0	417.841	0	0	470.136	119.353	115.899	4.77356

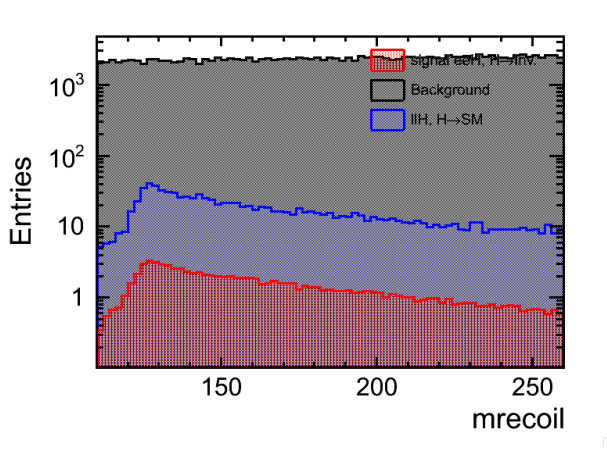
Mz Mrecoil Ptz [Ecm=500GeV]

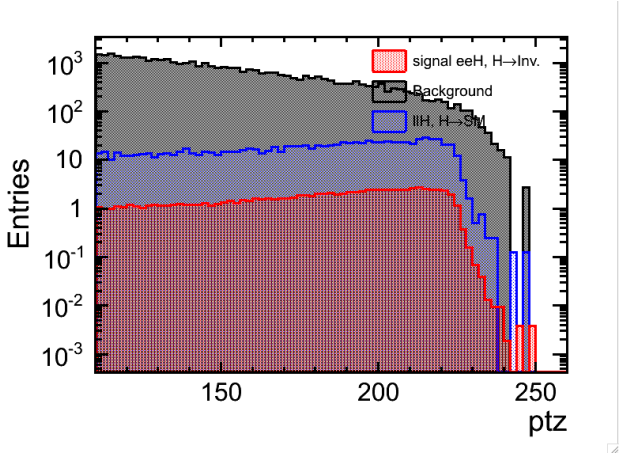






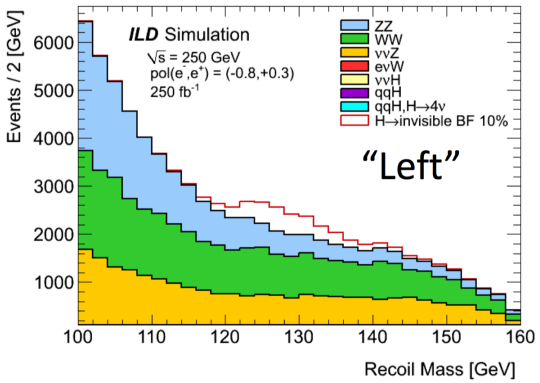


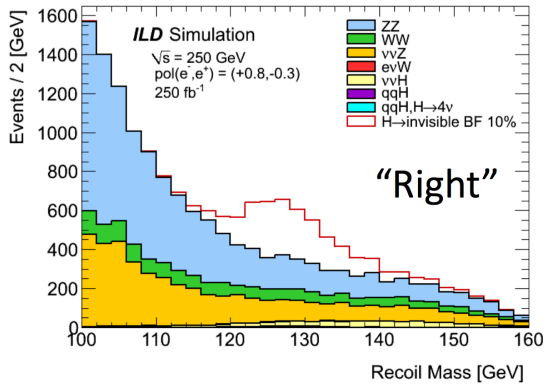




[先行研究]

引用:LCWS14 石川さんのスライドより





Signal

- Z由来のジェット対
- エネルギー損失がヒッグス質量に相当

Event Selection

1. jetの再構成[Durhamアルゴリズム]
2. 孤立レプトン除去
3. PFOの数、荷電粒子の飛跡数
4. jetからZ質量の再構成
5. Zの極角:$cos\theta_Z$
6. 反跳質量
7. 最尤法

by Toy MC

UL on BF [%]	"Left"	"Right"
250GeV	0.95	0.69
350GeV	1.49	1.37
500GeV	3.16	2.30