BSM search using Higgs to invisible decay at the ILC

Yu Kato,

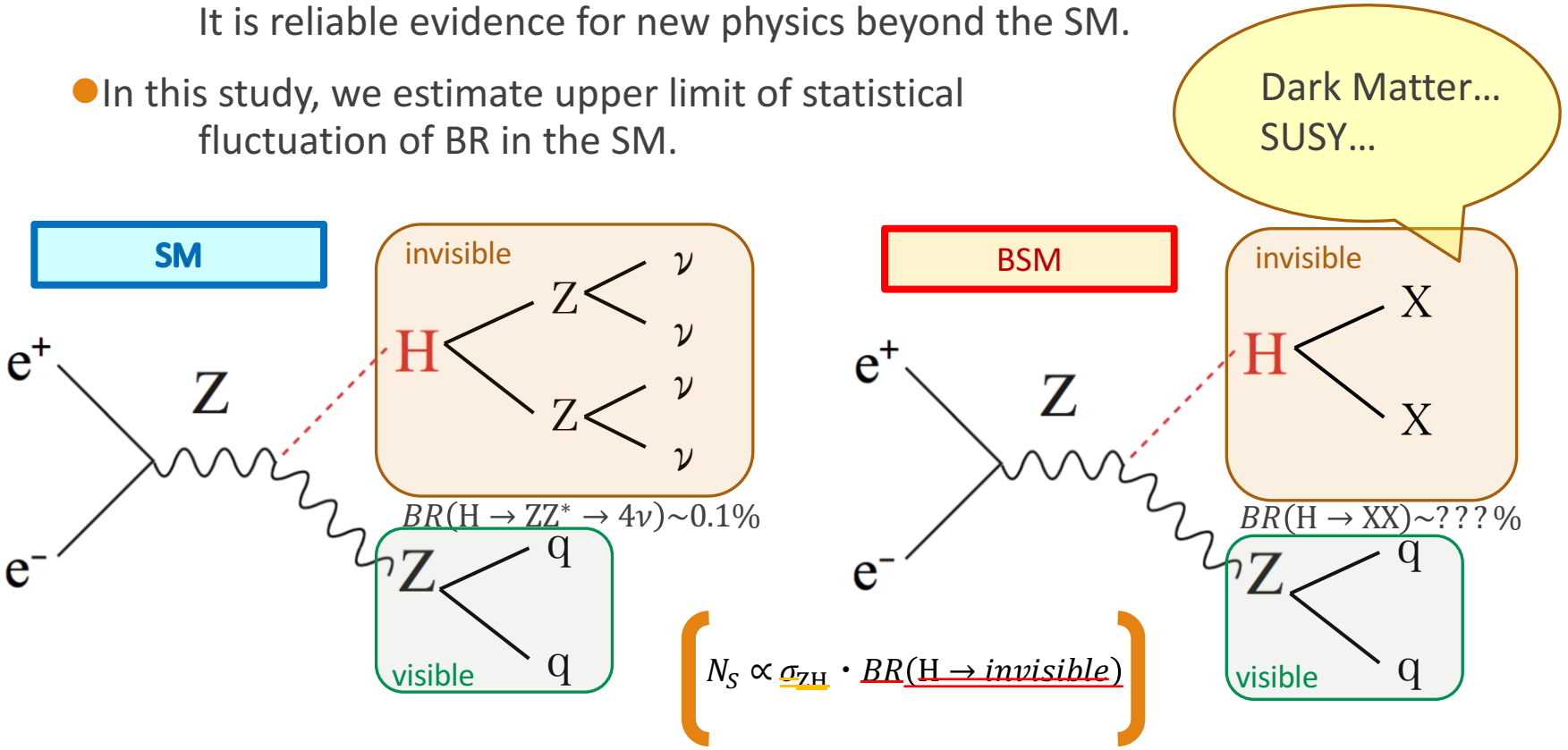
Jacqueline Yan(KEK), Junping Tian, Satoru Yamashita

The University of Tokyo

the 49th General Meeting of ILC Physics Subgroup Nov. 26, 2016

Higgs to Invisible Decay

- In the SM, Higgs decays invisibly through the process
  $\mathrm{H} \to \mathrm{ZZ}^* \to 4\nu$ (BR~0.1%).
- If the BR is over the prediction of the SM,
  It is reliable evidence for new physics beyond the SM.
- In this study, we estimate upper limit of statistical fluctuation of BR in the SM.



Recoil Mass Method

- Target: Higgs-strahlung process
- We can measure Higgs without the direct measurement of it.
  → model independent

$$M_{rec}^2 = (\sqrt{s} - E_Z)^2 - |\vec{p}_Z|^2$$

- Production cross section of Higgs-strahlung process is obtained in the leptonic channel study

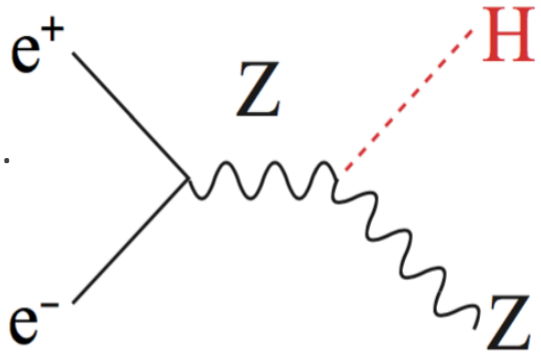
$$\sigma_{\mathrm{ZH}} = \frac{N_S}{BR(\mathrm{Z} \to l^+l^-)\varepsilon_S L}$$

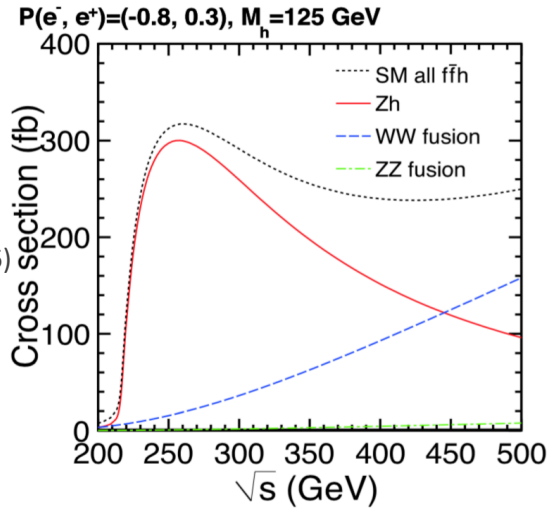
where ε_S: efficiency of signal event selection

L : integrated luminosity

J.Yan(KEK) *et al.* "Measurement of the Higgs boson mass and $e^+e^- \to ZH$ cross section using $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ at the ILC" (2016)

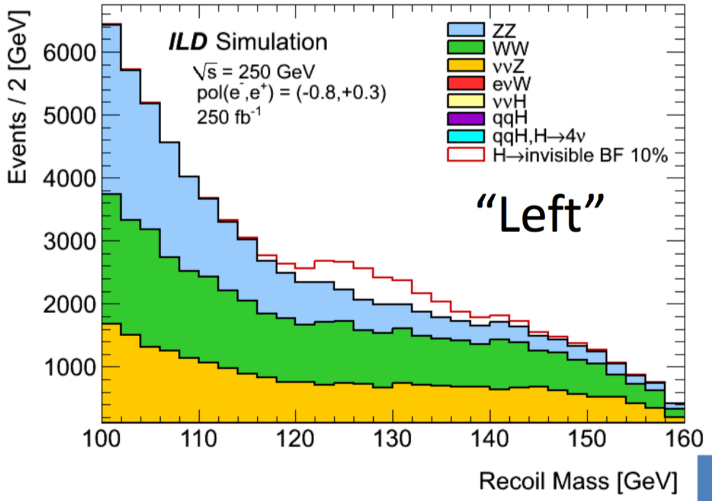
- For the search of BSM, we use hadronic channel $Z \to qq$ and $E_{cm} = 250$ GeV

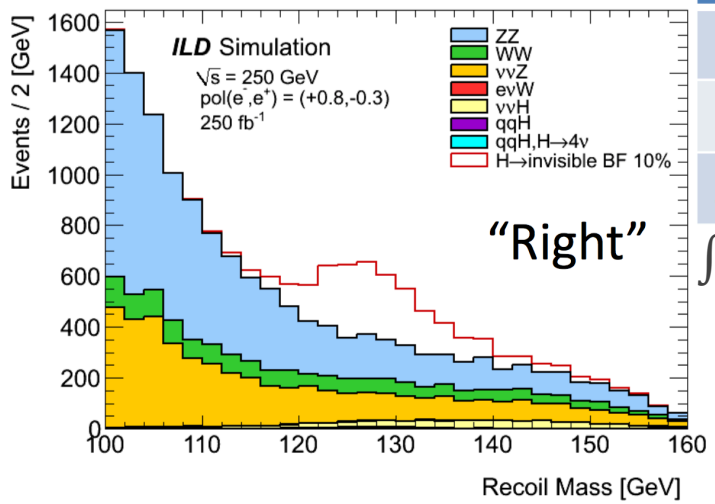




Previous study

Akimasa Ishikawa (Tohoku Unv.),
”Search for Invisible Higgs Decays at the ILC” LCWS2014@Belgrade





- In the previous study the following results were obtained.
- We aim to improve this result.

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

$\int Ldt$ =250,350,500fb^{-1} for E_{cm} =250,350,500GeV

Setting & Flow of analysis

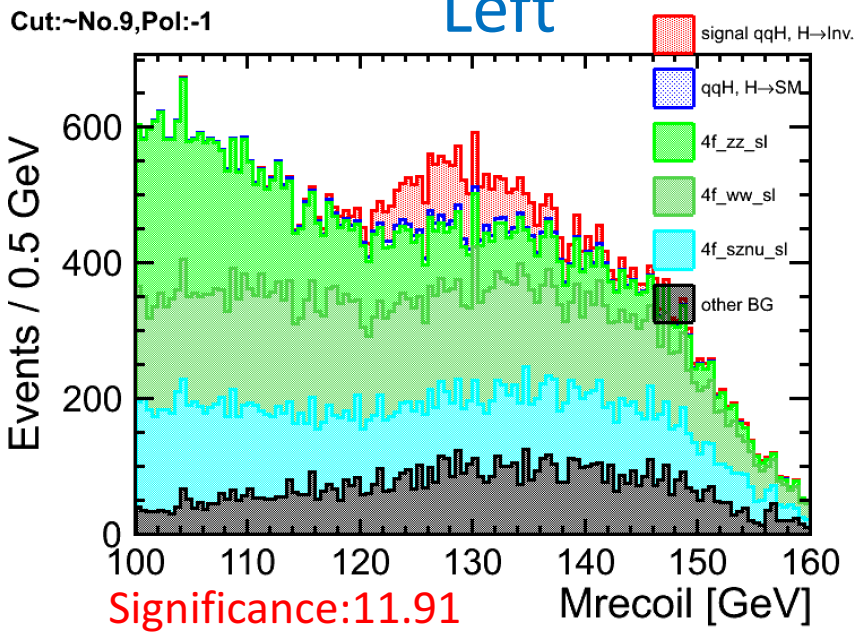
- Setting
  - Generator: WHIZARD
  - Samples: DBD sample + Dirac sample by J.Tian ($e^+e^- \to qqH, H \to ZZ^* \to 4\nu$)
  - Detector: the ILD full simulation
  - E_{cm}=250GeV, $\int Ldt$=250fb^{-1} , $(P_{e^-}, P_{e^+}) = (-0.8, +0.3), (+0.8, -0.3)$
- Flow of analysis
  - Isolated lepton tagging → veto
  - Jet clustering
    1. remove gamma-gamma overlay from particle flow objects (PandoraPFA) by using kt algorithm jet clustering
    2. convert jet to PFOs (for later LCFIPlus jet clustering)
    3. forced 2-jet reconstruction using LCFIPlus
  - Event selection (mention next page)
    - assume BR(H→invisible)=10%
  - Fit & Toy Monte Carlo to set upper limit

Event Selection

1. Isolated lepton veto
2. Loose restriction of transverse di-jet momentum, di-jet invariant mass, and recoil mass from di-jet
3. Number of particle flow objects(PFO) and charged tracks: N_{pfo}, N_{track}
4. Transverse di-jet (Z) momentum: Pt_Z
5. Invariant mass of di-jet (Z mass):M_Z
6. Polar angle of di-jet (Z) direction: θ_Z
7. Acoplanarity angle: $\varphi = \pi - (\phi_1 - \phi_2)$
   (ϕ_i: transverse direction angle of jet)
8. Recoil mass: M_{recoil}
9. Boosted Decision Tree(BDT) method selection (multi-variate analysis)

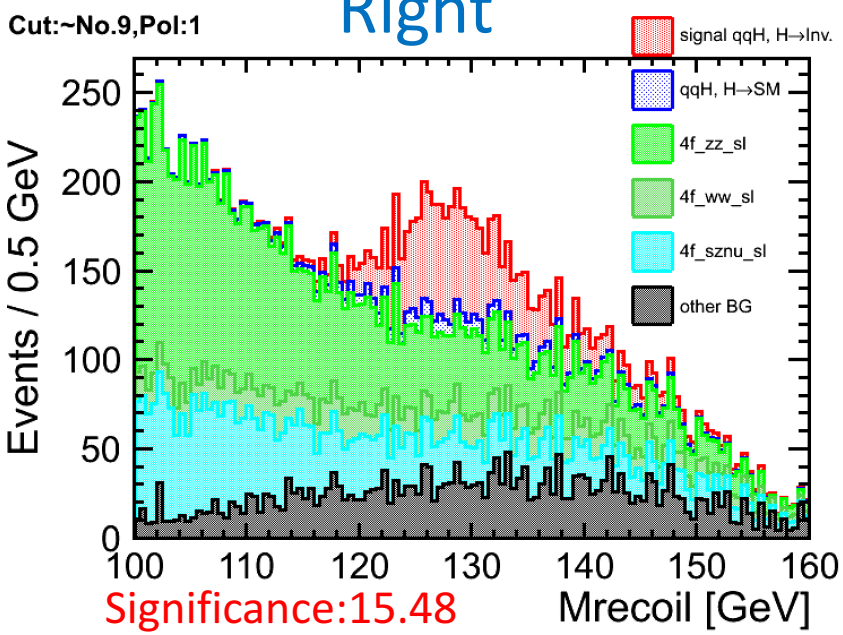
Recoil Mass Plots [Ecm=250GeV,250fb^{-1},BR(H->inv.)=10%]

Left



Significance:11.91

Right



Significance:15.48

MVA input variables	
mz	cosj1
cosz	cosj2

TMVA v-4.2.0

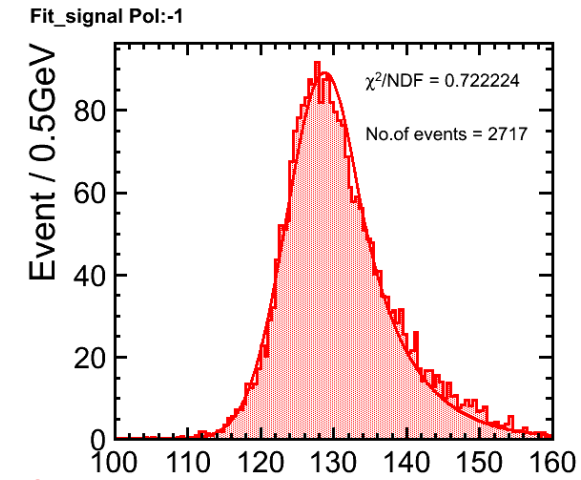
No.	Cut	No.	Cut
1	Isolated lepton veto	6	|cosθZ|<0.9
2	Loose Cut (Ptz,Mz,Mrecoil)	7	Acoplanarity < 3.0
3	Npfo>15 & Ntrack>6 & Ntrackji>1	8	100 < Mrecoil < 160
4	20 < Ptz < 80	9	BDT cut
5	80 < Mz < 100		

Fit signal & bkg

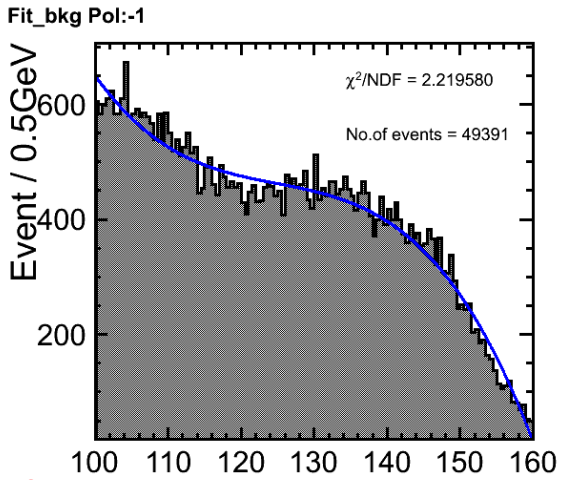
signal: GPET (Gaussian + Exponential)

bkg : 3rd order polynomial

Left

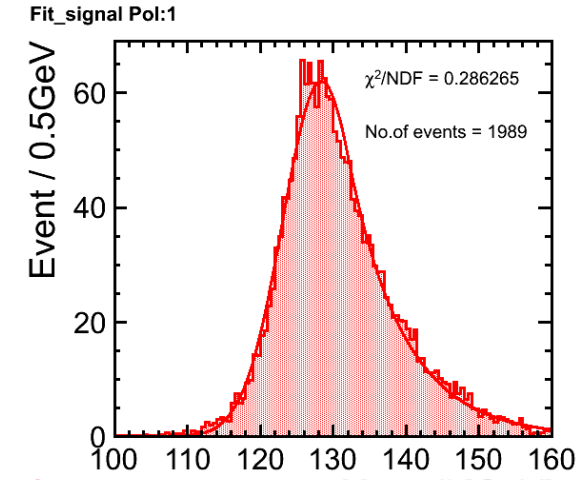


$\chi^2/\mathrm{NDF} = 0.722$

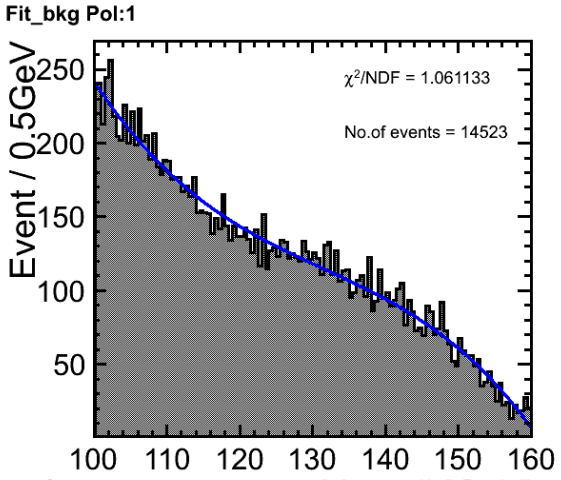


$\chi^2/\mathrm{NDF} = 2.22$

Right

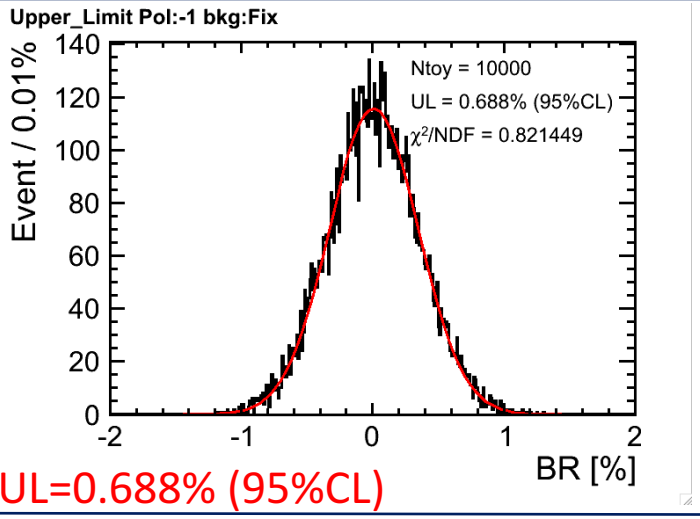
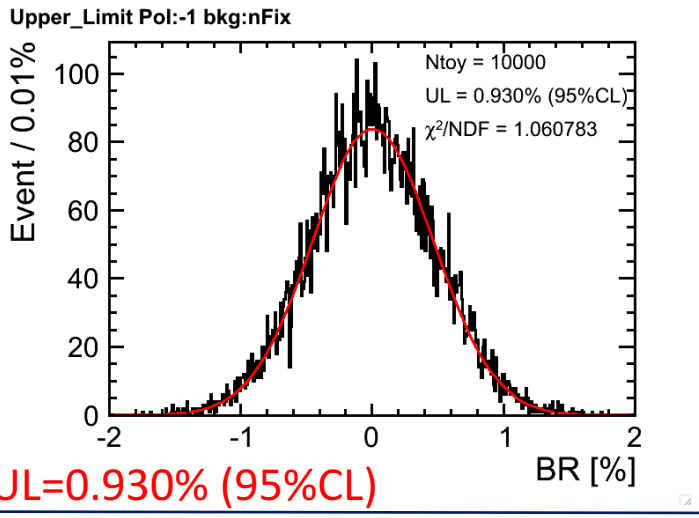
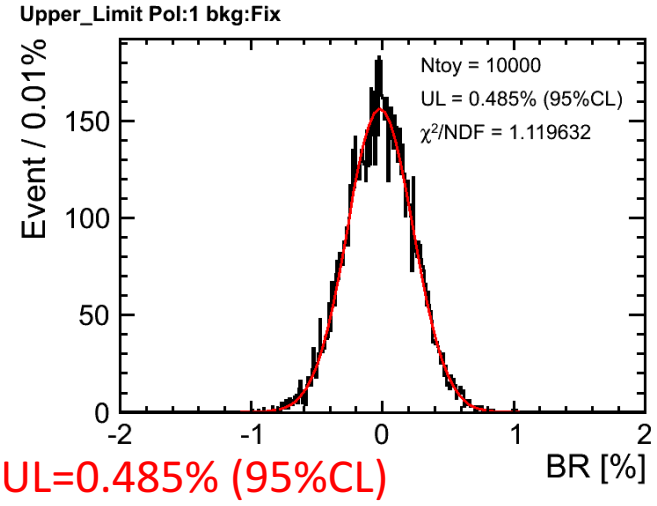
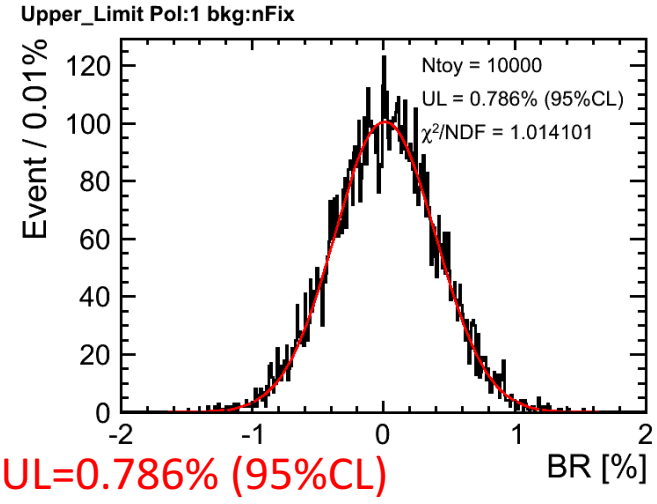


$\chi^2/\mathrm{NDF} = 0.286$



$\chi^2/\mathrm{NDF} = 1.06$

Toy Monte Carlo to set upper limit

	only yields are floated	bkg shape also floated
Left	 UL=0.688% (95%CL)	 UL=0.930% (95%CL)
Right	 UL=0.485% (95%CL)	 UL=0.786% (95%CL)

Summary & Plans

- BR of Higgs to invisible decay is reliable indicator of the BSM.
- We estimate the upper limit of statistical fluctuation of BR in the SM.

UL of BR [%] (95%CL)	Left polarization	Right polarization
only yields are floated	0.688	0.485
bkg shape also floated	0.930	0.786
previous study result	0.95	0.69

- Plans
  - improve fit function

Back Up

Hadronic Channel Analysis

Cut table [Ecm=250GeV,250fb^{-1},Left]

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

Reduction Table

Process	2f_l	2f_h	4f_l	4f_sl	4f_h	llH	BG	qqH	Signal	Signf
Cross Section	38176.9	78046.1	5655.8	18398.3	16799.3	109.233	157186	210.184	21.0184	
Generated	5.76948e+06	3.17329e+06	3.14632e+06	4.9795e+06	2.74204e+06	280686		568687	39601	
Expected	9.54422e+06	1.95115e+07	1.41395e+06	4.59957e+06	4.19983e+06	27308.2	3.92964e+07	52546	5254.6	0.837615
Cut0	9.16132e+06	1.94897e+07	1.35278e+06	4.59883e+06	4.19983e+06	27124.7	3.88296e+07	52546	5254.06	0.84254
Cut1	1.71542e+06	1.93796e+07	162691	1.64702e+06	4.19268e+06	19411.4	2.71168e+07	47847.5	5248.7	1.00695
Cut2	151655	385894	38813	351506	112295	9742.59	1.04991e+06	3541.23	4900.03	4.76305
Cut3	858.166	301045	329.353	261376	104008	9056.2	676673	3288.26	4757.17	5.749
Cut4	447.409	56407.6	261.745	224864	94406.5	8332.75	384720	3043.3	4522.98	7.22142
Cut5	150.217	11283.9	108.044	96769.5	17966.9	2578.67	128857	976.355	3560.58	9.74882
Cut6	145.312	5988.7	99.5936	85404.1	15545.7	2516.72	109700	910.916	3439.33	10.1842
Cut7	10.7462	5252.55	88.5166	81391.3	15258.4	2381.82	104383	889.332	3305.78	10.0323
Cut8	10.6587	5208	85.6002	81088.7	15240.2	2367.81	104001	888.704	3301.29	10.0366
Cut9	6.1032	1360.8	53.2566	41402.1	4634.01	1451.31	48907.6	484.159	2717.91	11.9063

Hadronic Channel Analysis

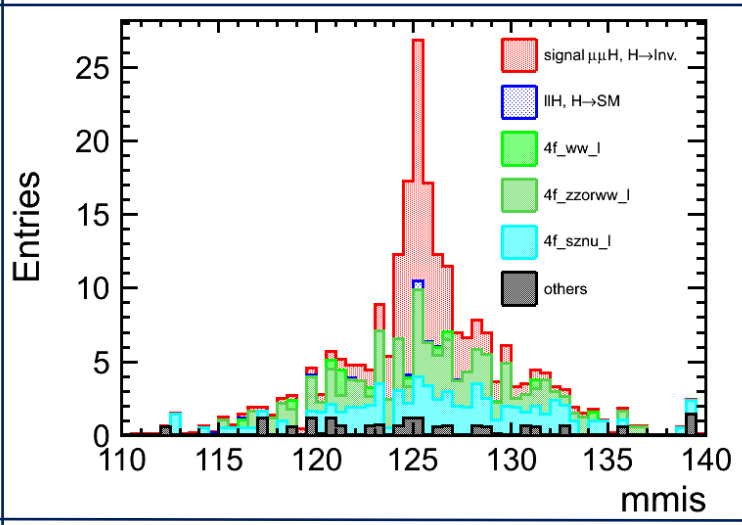
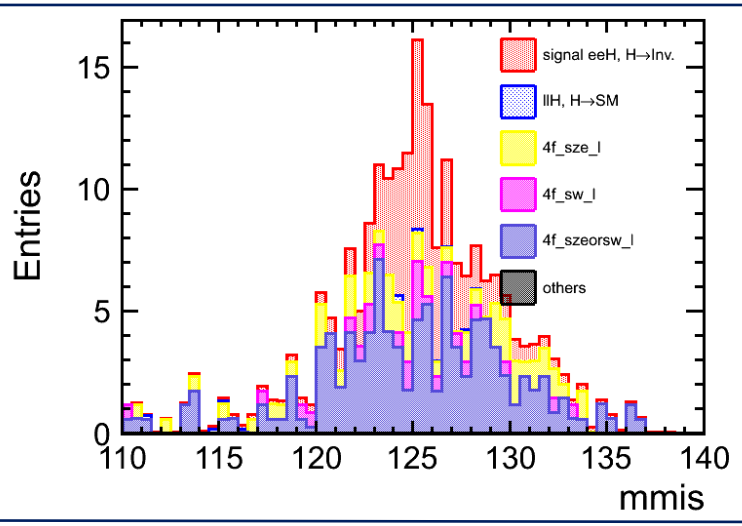
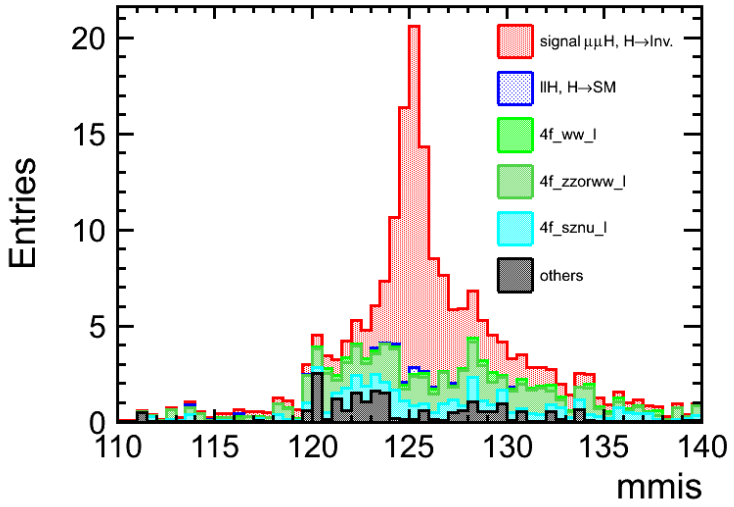
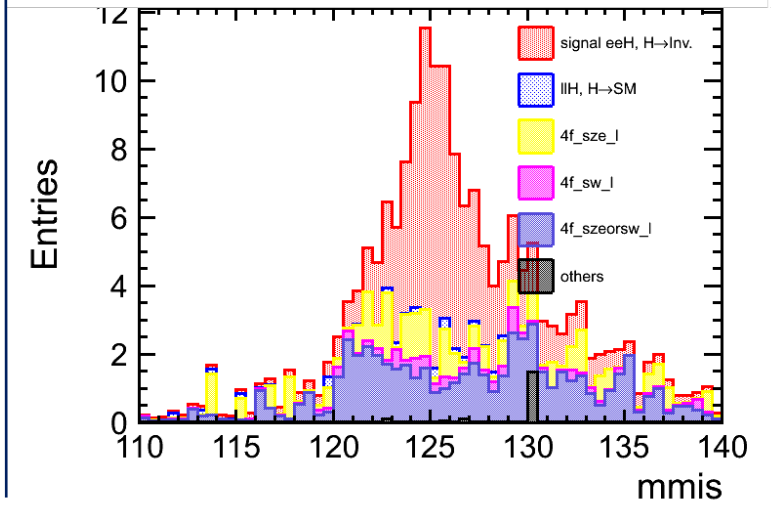
Cut table [Ecm=250GeV,250fb^{-1},Right]

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

Reduction Table

Process	: 2f_l	2f_h	4f_l	4f_sl	4f_h	llH	BG	qqH	Signal	Signf
Cross Section	: 34983.6	46214.9	1467.78	2063.18	1568.29	63.9953	86361.8	141.951	14.1951	
Generated	: 5.76948e+06	3.17329e+06	3.14632e+06	4.9795e+06	2.74204e+06	280686		568687	39601	
Expected	: 8.74591e+06	1.15537e+07	366946	515794	392073	15998.8	2.15904e+07	35487.8	3548.78	0.763055
Cut0	: 8.3892e+06	1.15318e+07	355972	515506	392073	15895.6	2.12004e+07	35487.8	3548.26	0.769916
Cut1	: 1.47311e+06	1.14602e+07	54961.3	220242	391346	10916.8	1.36107e+07	32298.4	3544.2	0.959414
Cut2	: 107981	241389	4395.3	52923.6	11049.2	5664.63	423403	2376.08	3303.43	5.04307
Cut3	: 530.851	185648	34.1624	44254.5	10254.8	5275.35	245998	2209.22	3204.19	6.39037
Cut4	: 255.591	29948.8	26.4309	38270.7	9234.84	4917.57	82654	2047.21	3037.24	10.2538
Cut5	: 78.9459	5488.86	8.79024	22133	2002.74	1484.08	31196.5	657.579	2381.7	12.872
Cut6	: 69.9076	2688.71	7.5148	19426.4	1720.71	1449.48	25362.7	619.917	2305.86	13.7097
Cut7	: 9.38775	2448.04	6.85208	18506.1	1692.47	1376.41	24039.3	607.134	2208.31	13.4757
Cut8	: 7.92505	2423.53	6.67759	18462.6	1690.81	1368.73	23960.2	606.369	2205.93	13.4818
Cut9	: 4.73756	846.263	5.5476	11387.7	789.307	1065.89	14099.5	424.513	1989.68	15.4832

Missing Mass Plots [Ecm=250 GeV, 250 fb^{-1}]

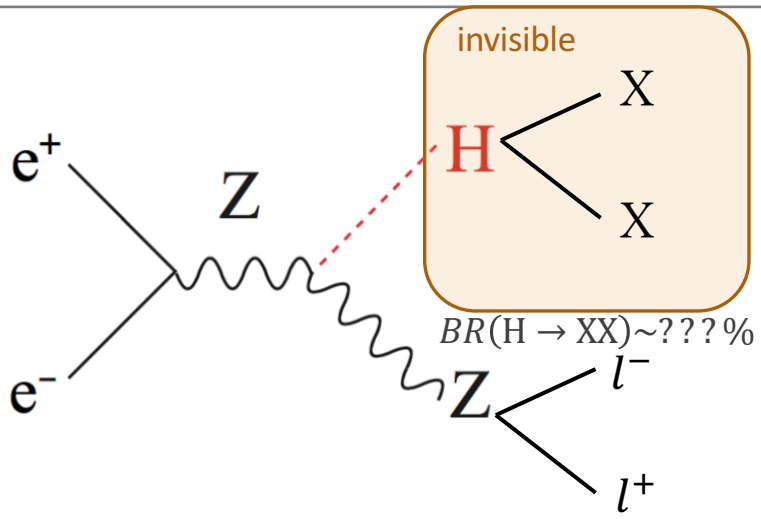
	$\mu\mu H, H \rightarrow inv(BR = 0.1)$	$eeH, H \rightarrow inv(BR = 0.1)$
Left		
Right		

Improvements

- modified cut variables and trained MVA again
  - In the previous MVA, I used SM sample as signal.←corrected
- Significance improved, while efficiency decreased.
  - ➢Which has higher priority ?

250GeV,250fb^{-1},H→inv(BR=0.1)		significance	efficiency
$\mu\mu$H	Left	4.86 → 5.69	47.4% → 33.5%
	Right	6.48 → 7.39	67.9% → 58.9%
eeH	Left	4.07 → 4.51	43.9% → 24.9%
	Right	5.61 → 6.39	52.7% → 48.2%

Signal feature [leptonic channel]



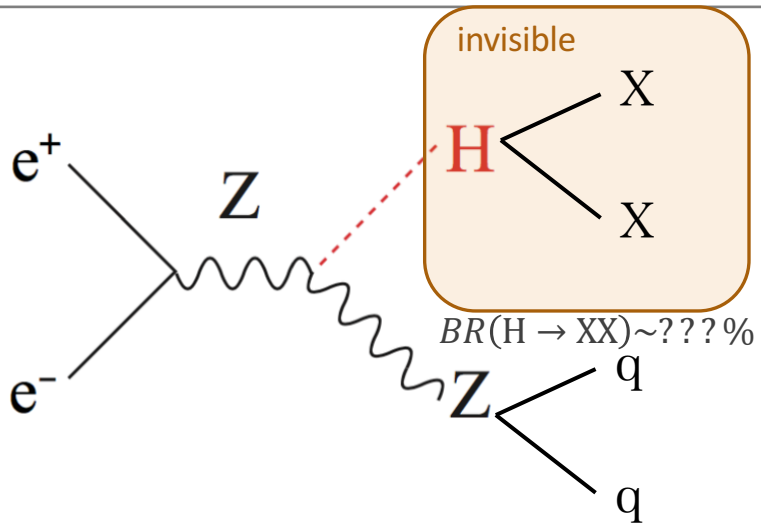
- Two-leptons
- Invisible particles without neutrino
- $M_{ll} \approx M_Z$ $(BR(\mathrm{Z} \to ll) \sim 3.4\%)$
- $M_{recoil} \approx M_{Higgs}$

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

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