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Study of H→Zγ branching ratio at the ILC

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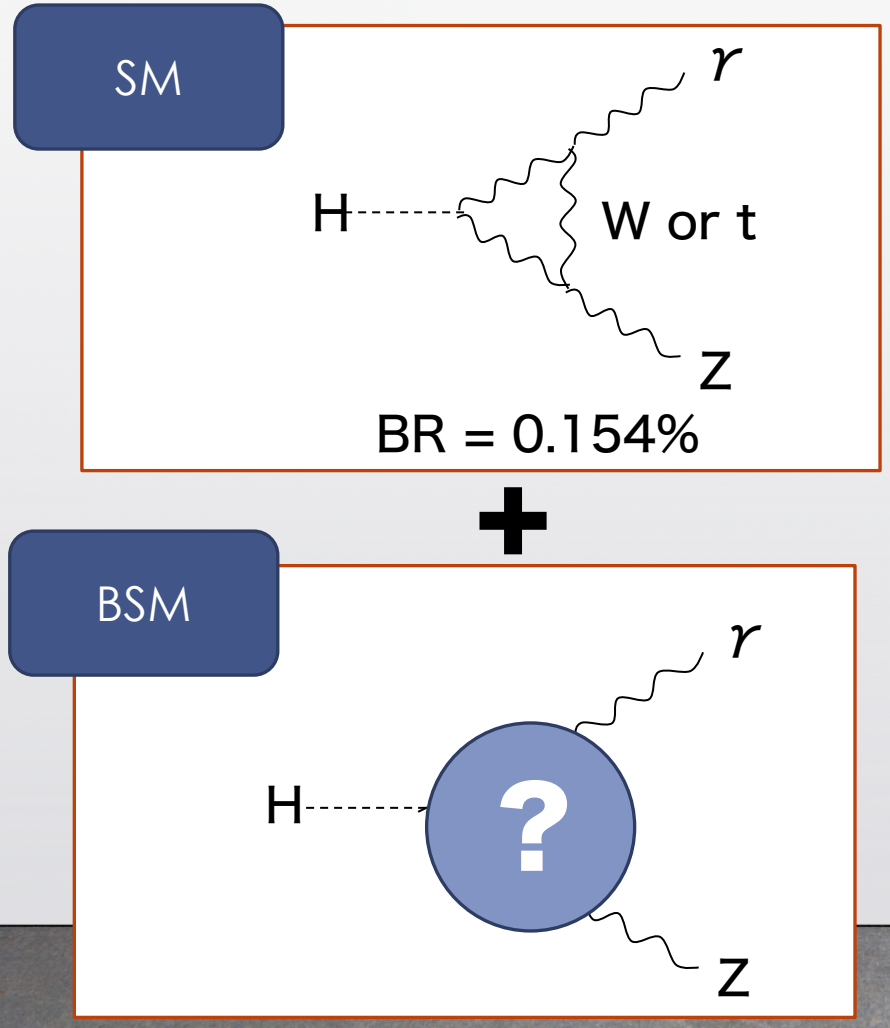
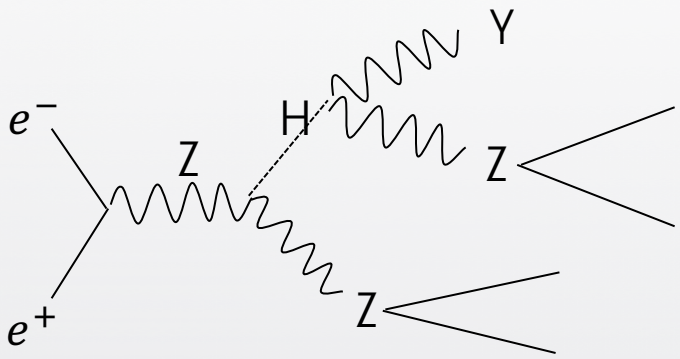
Motivation



- In the SM, the BR of H ->Zγ is about 0.154%.
- If the Higgs decay in non-SM process, the BR of H->Zγ would exceed the SM prediction.
- Deviation between observation and prediction is an indication of new physics (BSM).
- Establish the BR of Higgs ->Zγ process at the ILC 250 GeV and analize the process of Z→HZ→γZZ at ILC .

$$Significance = \frac{N_S}{\sqrt{N_S + N_B}}$$

Introduce analysis process



Final state	Branching ratio
μμqqγ	2.3%
eeqqγ	2.3%
ννqqγ	14.0%
qqqqγ	49.0%
others	32.3%

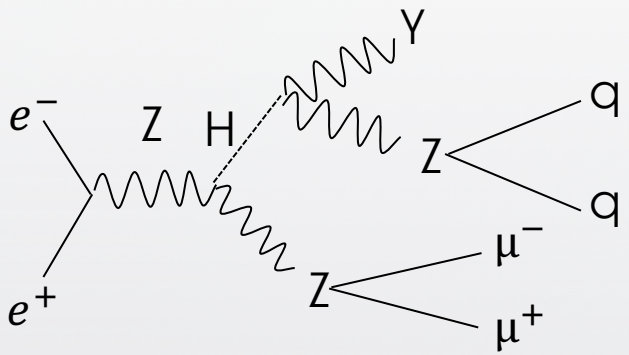
Feynman diagram on the left side is the process used this time.

Cross section of this process is thought to be about 0.5 fb in SM and it is a rare phenomenon.

The table on the right shows the process for each final state, and we will talk about μμqqγ process red painted part in this presentation. For the yellow part, it means the one that analyzes with priority next.

We sum these processes and aimed for Significance to exceed 3.0.

Event rate & Beam Condition



The reason why I choosed this process for first analysis is that it is easy to distinguish signal event from background due to .

Cross section

$$\sigma_{LR} = 35.7\ \text{ab}$$
$$\sigma_{RL} = 22.9\ \text{ab}$$

At $(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$

$\text{Luminosity} = 1000\ \text{fb}^{-1}$

Expected 22 events

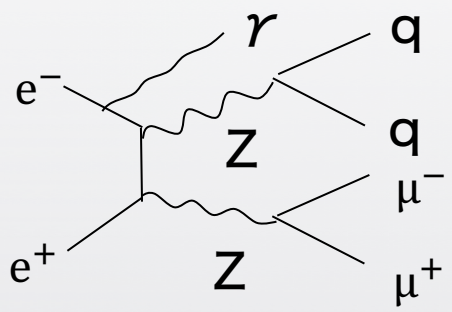
At $(P_{e^-}, P_{e^+}) = (+0.8, -0.3)$

$\text{Luminosity} = 1000\ \text{fb}^{-1}$

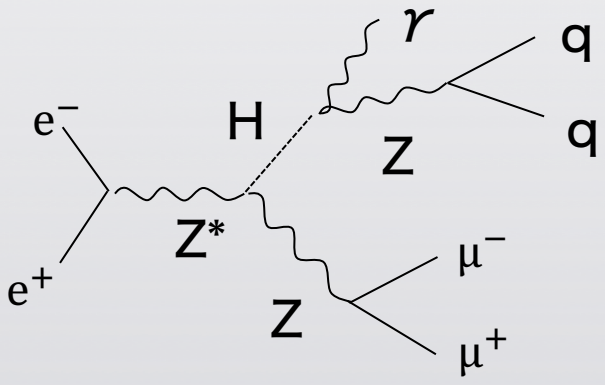
Expected 15 events

Background process

Main Background



One of Signal



- The left is a signal event and the right is a main background event.
- This is 4f_zz_sl process with ISR.
- Most of the processes other than 4f_zz_sl can be removed by Precut explained earlier.
- However, it was difficult to divide these two living things, and event selection was done by using MVA.

Setting

- Simulation set up
  - iLCSoft : v1_16_02
  - Generator : WHIZARD 1.95
  - Samples: DBD sample
    - + Signal sample($e^+e^- \to ZH, Z \to \mu\mu \text{ or } qq, H \to Z\gamma$)
    - + Main background sample (4f_zz_sl process)
  - Detector: ILD full simulation
  - E_{cm} = 250 GeV,
  - $\int Ldt$ = 1000 fb^{-1} , $(P_{e^-}, P_{e^+}) = (-0.8, +0.3)$
  - $\int Ldt$ = 1000 fb^{-1} , $(P_{e^-}, P_{e^+}) = (+0.8, -0.3)$

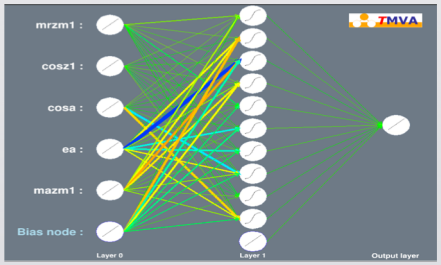
Flow of analysis

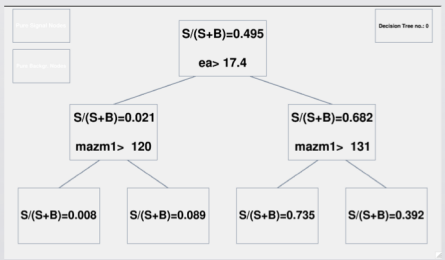
1. Particle Flow Algorithm “PandoraPFA”
2. Isolated lepton pair selection
3. Isolated photon selection
4. 2 jets clustering : Durham(LCFIPlus)
5. Z selection (compare 4 methods)
6. Event selection
   - I. Pre-cut
     - ① lepton pair = μμ
     - ② $80\ \mathrm{GeV} < \mathrm{M}_{z_{ll}} < 100\ \mathrm{GeV},\ 70\ \mathrm{GeV} < \mathrm{M}_{\mathrm{Z}qq} < 110\ \mathrm{GeV}, \mathrm{M}_{\gamma} < 0.1\ \mathrm{GeV}$
     - ③ Number of charged particles in each jet > 2
   - II. MVA cut (compare 3 methods)
     - Toolkit for Multivariate Analysis for Root (TMVA)
     - Use M_H, $M_{\mathrm{Z}recoil}$, $cos\theta_{\mathrm{Z}recoil}$, $cos\theta_{\gamma}$, E_{γ}

Introduce each methods

- Reconstructed method
  1. $\mu\mu\gamma$ or qqγ mass ≒ 125GeV
  2. Recoil mass ≒ 125GeV
  3. $\mu\mu$ or qq momentum ≒ 60GeV
  4. $\mu\mu$ or qq momentum in stationary system of qqγ or $\mu\mu\gamma$ ≒ 30GeV

- MVA method
  1. Multi Layer Perceptron (MLP)
  2. Boosted-Decision Tree with Gradient boosting (BDTG)





1 and 2:
mass is calculated and more suitable one is regarded H.

3 and 4:
Using momentum in two-body collapse.

- Regarding the MVA method, we compared systems using MLP and BDTG which are also used in ILC analysis.

Analysis result

$$Significance = \frac{N_S}{\sqrt{N_S + N_B}}$$

In $(\mathbf{P_{e^-}}, \mathbf{P_{e^+}}) = (\mathbf{-0.8}, \mathbf{+0.3})$

Significance	MLP	BDTG
method1	0.62 ± 0.02	0.74 ± 0.03
method2	0.60 ± 0.02	0.72 ± 0.03
method3	0.60 ± 0.02	0.71 ± 0.03
method4	0.51 ± 0.01	0.72 ± 0.03

In $(\mathbf{P_{e^-}}, \mathbf{P_{e^+}}) = (\mathbf{+0.8}, \mathbf{-0.3})$

Significance	MLP	BDTG
method1	Not converge	0.76 ± 0.03
method2	0.69 ± 0.04	0.72 ± 0.03
method3	0.43 ± 0.2	0.72 ± 0.03
method4	0.59 ± 0.02	0.71 ± 0.06

- It is the result when using each method separately.
- We found that Siginificance is the best when using method 1 for both right and left polarizations.
- Considering a method in which these methods are summed up and the reconstruction success rate is higher.

Analysis result2

$$Significance = \frac{N_S}{\sqrt{N_S + N_B}}$$

Success rate of reconstructing(LR)

combine	method1	method2	method3	method4
88.9%	88.8%	79.8%	81.3%	82.6%

In $(\mathbf{P_{e^-}}, \mathbf{P_{e^+}}) = (\mathbf{-0.8}, \mathbf{+0.3})$

Significance	MLP	BDTG
method1	0.62 ± 0.02	0.74 ± 0.03
combine	0.62 ± 0.02	0.74 ± 0.02

In $(\mathbf{P_{e^-}}, \mathbf{P_{e^+}}) = (\mathbf{+0.8}, \mathbf{-0.3})$

Significance	MLP	BDTG
method1	Not converge	0.76 ± 0.03
combine	0.61 ± 0.03	$075. \pm 0.04$

- I made a combined method that maximizes the probability with left polarization.
- The contribution of method 1 for the selection is large, so Significance did not change much.
- About the right polarization, significance decreases and it is necessary to optimize again.

Evaluate UL of BR

- UL was calculated based on the process analyzed this time.
- The maximum Significance obtained with only this process is calculated from the combined method at the left polarization, method 1 in the right polarization.

$$Significance = \sqrt{0.74^2 + 0.76^2}$$
$$= 1.06$$

$$95\%\ UL\ of\ BR = \frac{1.65}{significance}\ BR_{SM}$$
$$= 0.24\%$$

Summary

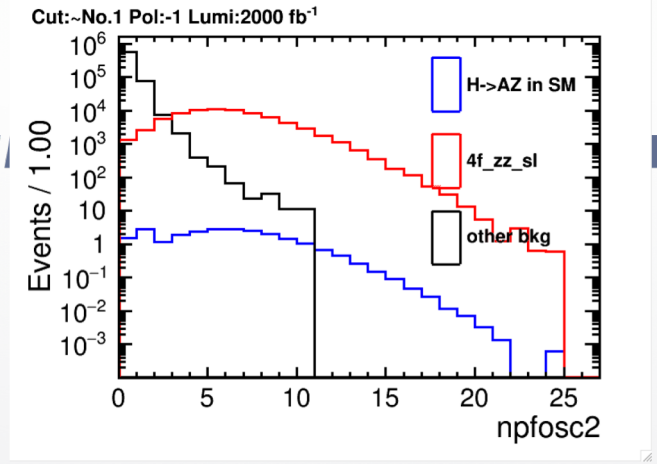
- In order to evaluate the sensitivity of ILC to H → Zγ, we analyzed the final state $\gamma\mu\mu$qq events including this process.
- We have developed a selection method with higher precision using multiple simple reconstruction methods and confirmed its effect.
- We showed that it is possible to observe 1.6 times BR of H→Zγ of about compared to SM with only one type of final state event.

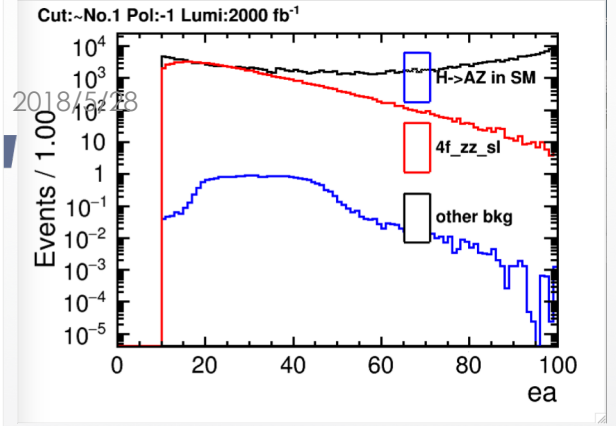
Plan

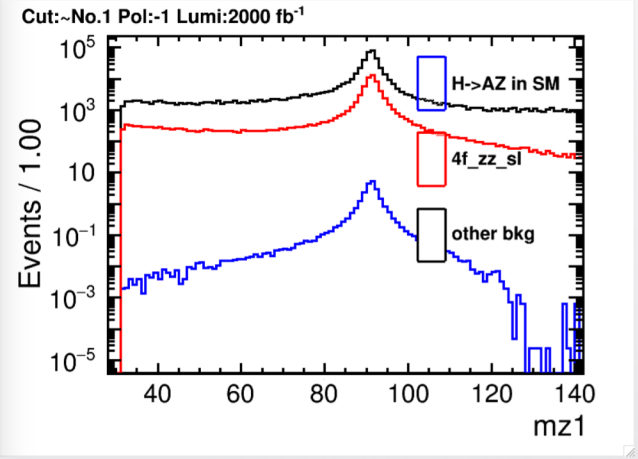
- Since the γeeqq process is very similar in this process, we will proceed with the analysis first.
- We will analyze other processes and aim for significance> 3.0.

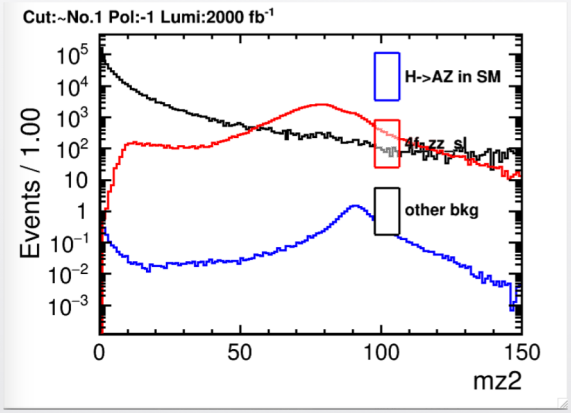
backup

Variables


Cut:~No.1 Pol:-1 Lumi:2000 fb-1
H->AZ in SM
4f_zz_sl
other bkg
Events / 1.00
npfosc2


Cut:~No.1 Pol:-1 Lumi:2000 fb-1
H->AZ in SM
4f_zz_sl
other bkg
Events / 1.00
ea


Cut:~No.1 Pol:-1 Lumi:2000 fb-1
H->AZ in SM
4f_zz_sl
other bkg
Events / 1.00
mz1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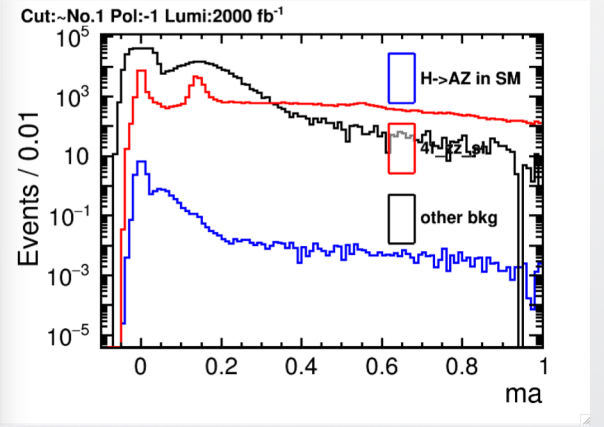
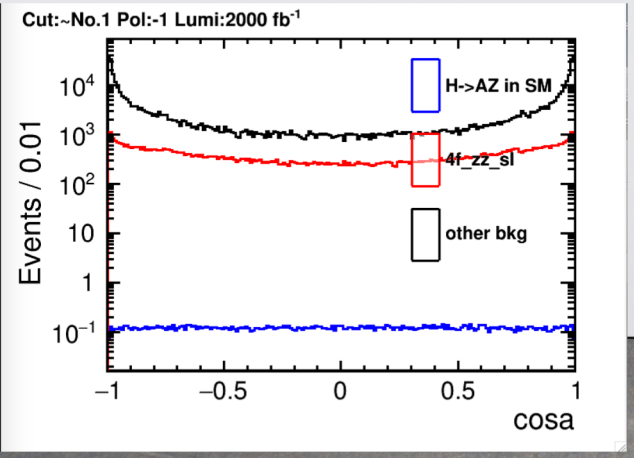
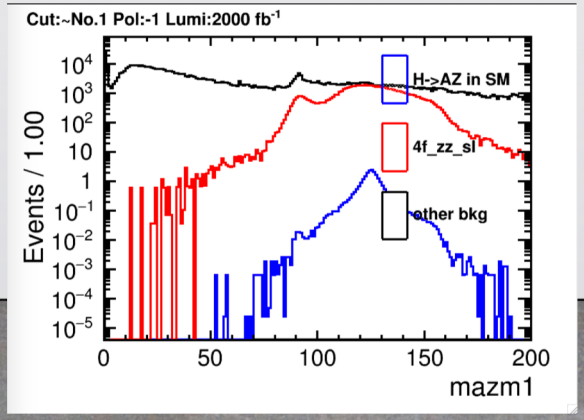
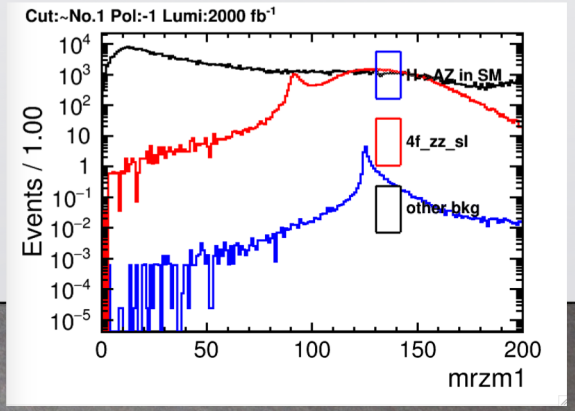
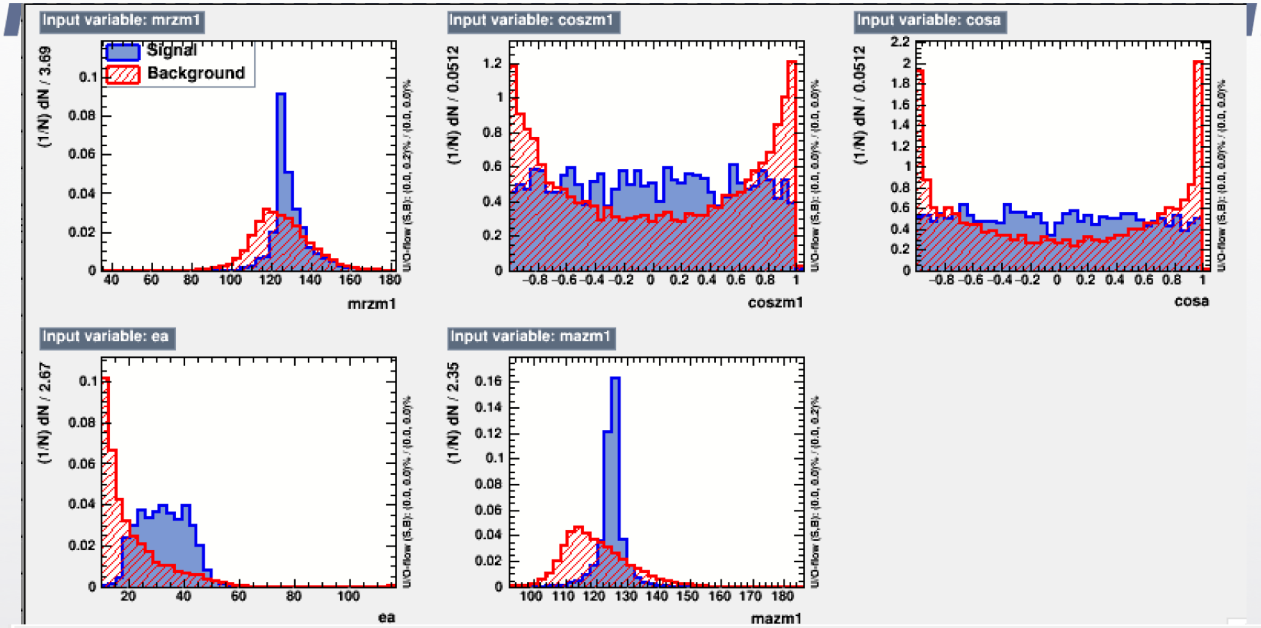
H->AZ in SM
4f_zz_sl
other bkg
Events / 1.00
mz2

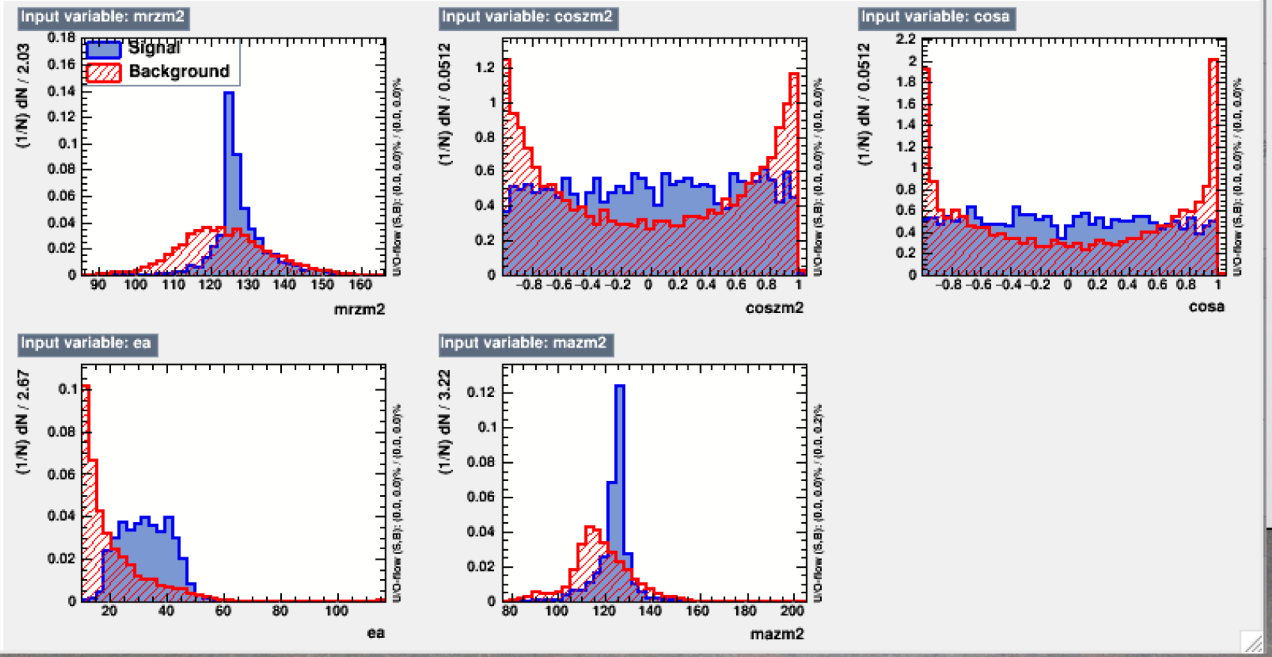

Cut:~No.1 Pol:-1 Lumi:2000 fb-1
H->AZ in SM
4f_zz_sl
other bkg
Events / 0.01
ma

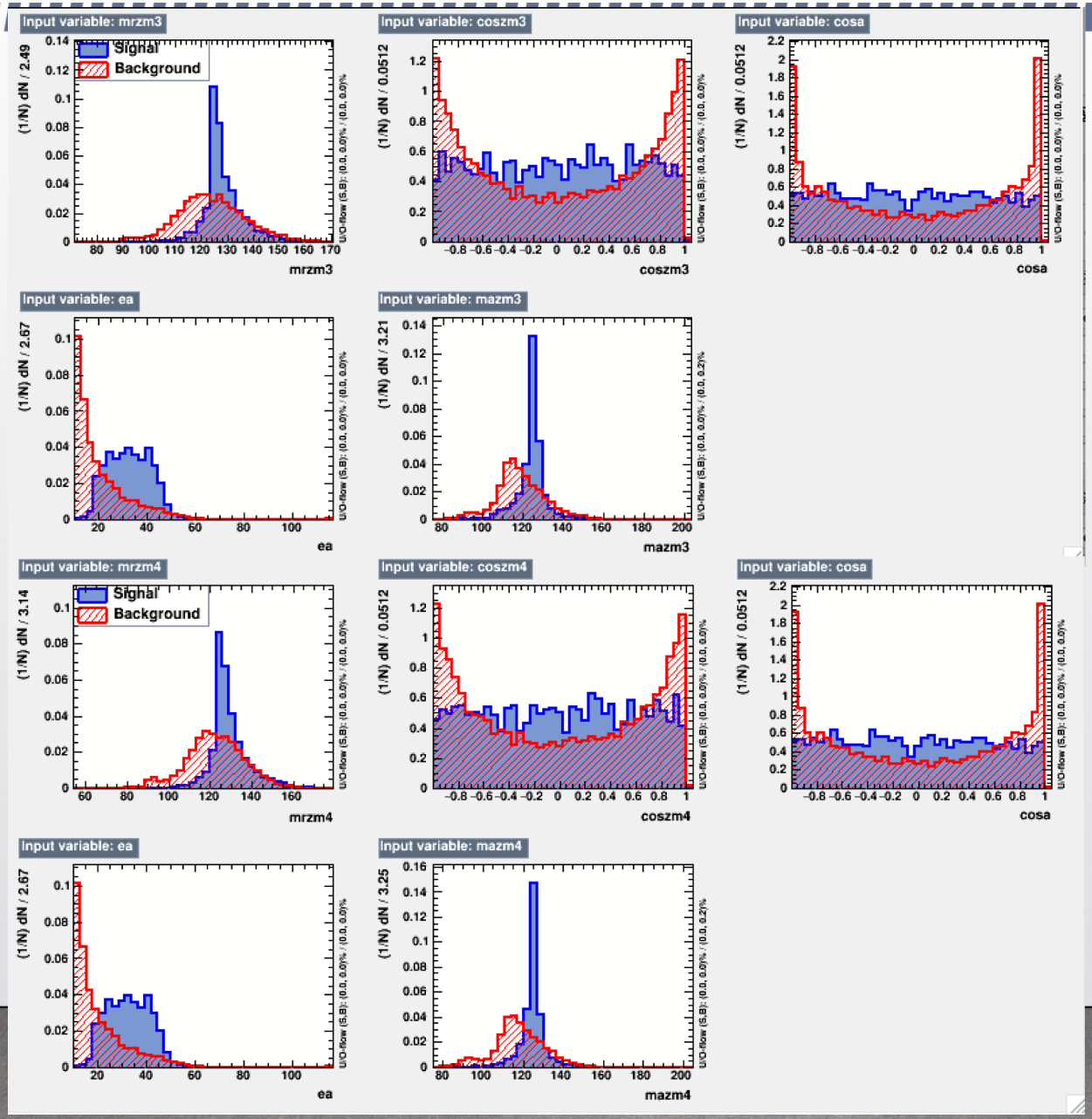

Cut:~No.1 Pol:-1 Lumi:2000 fb-1
H->AZ in SM
4f_zz_sl
other bkg
Events / 0.01
cosa


Cut:~No.1 Pol:-1 Lumi:2000 fb-1
H->AZ in SM
4f_zz_sl
other bkg
Events / 1.00
mazm1


Cut:~No.1 Pol:-1 Lumi:2000 fb-1
H->AZ in SM
4f_zz_sl
other bkg
Events / 1.00
mrzm1


Input variable: mrzm1
Signal
Background
(1/N) dN / 3.69
mrzm1
Input variable: coszm1
(1/N) dN / 0.0512
coszm1
Input variable: cosa
(1/N) dN / 0.0512
cosa
Input variable: ea
(1/N) dN / 2.67
ea
Input variable: mazm1
(1/N) dN / 2.35
mazm1


Input variable: mrzm2
Signal
Background
(1/N) dN / 2.03
mrzm2
Input variable: coszm2
(1/N) dN / 0.0512
coszm2
Input variable: cosa
(1/N) dN / 0.0512
cosa
Input variable: ea
(1/N) dN / 2.67
ea
Input variable: mazm2
(1/N) dN / 3.22
mazm2


Input variable: mrzm3
Signal
Background
(1/N) dN / 2.49
mrzm3
Input variable: coszm3
(1/N) dN / 0.0512
coszm3
Input variable: cosa
(1/N) dN / 0.0512
cosa
Input variable: ea
(1/N) dN / 2.67
ea
Input variable: mazm3
(1/N) dN / 3.21
mazm3
Input variable: mrzm4
Signal
Background
(1/N) dN / 3.14
mrzm4
Input variable: coszm4
(1/N) dN / 0.0512
coszm4
Input variable: cosa
(1/N) dN / 0.0512
cosa
Input variable: ea
(1/N) dN / 2.67
ea
Input variable: mazm4
(1/N) dN / 3.25
mazm4

Convined method of Z selection

- When four match, the result is used.
- When three match, When three matches, method 1 obeys if μ μ comes from Hicks, otherwise majority vote
- When two match, adopt method1