Study of HγZ coupling using e+e- -> γ H at the ILC

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Outline

1. Motivation
2. Theoretical framework
3. Experimental method
4. Simulation framework
5. Event selection
6. Result
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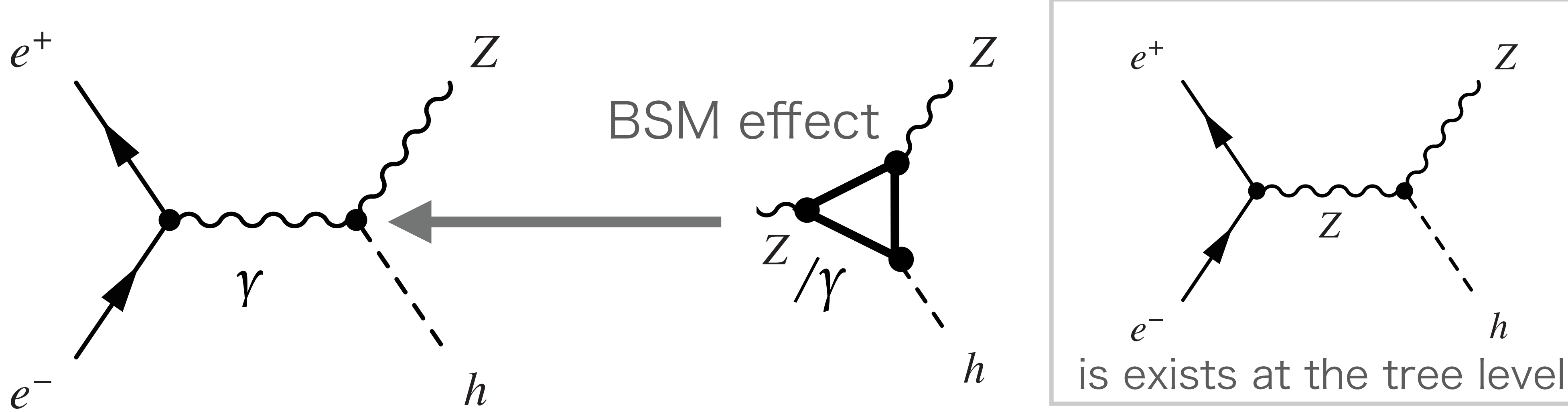
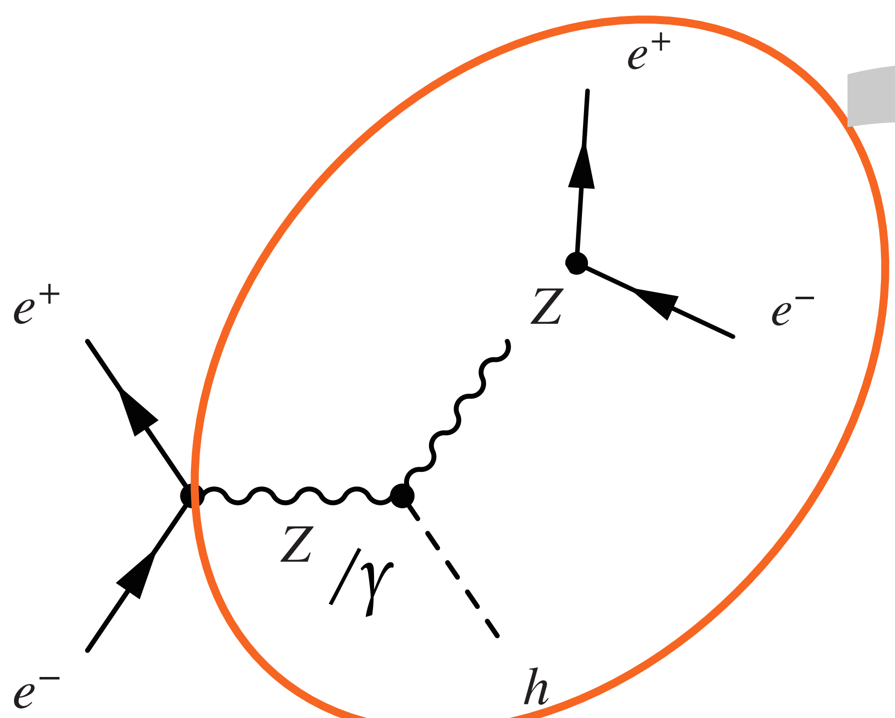
1.Motivation

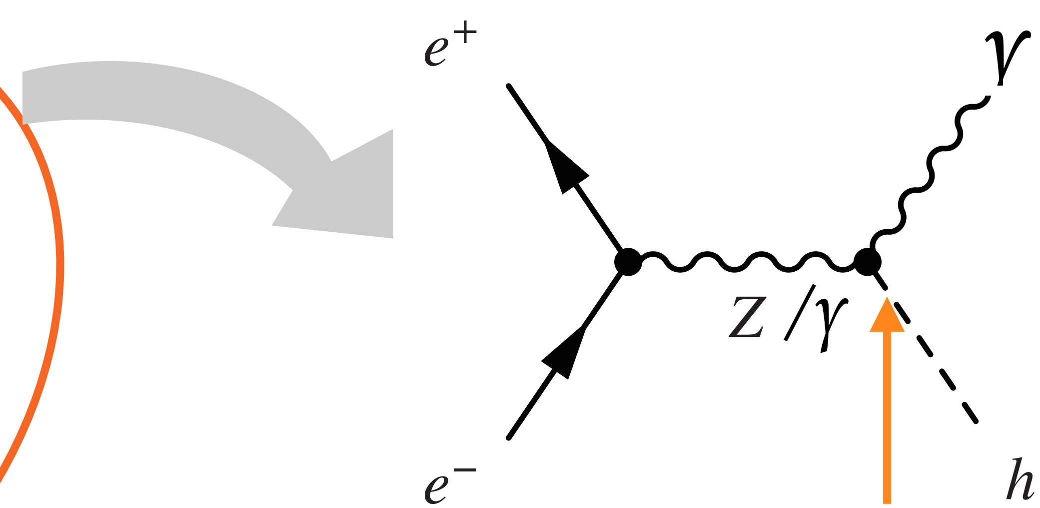
Find new physics via Hγγ and HγZ couplings

Higgs to γZ coupling in the Standard Model (SM) is a loop induced coupling.



However we can't notice which particle is in the loop.

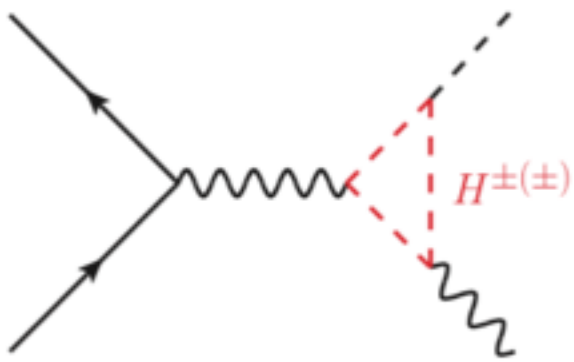




If we get different values of coupling constants with regard to SM, we get a key to new physics.

Example of new physics： Inert Doublet Model

In this Inert Doublet Model, there is charged higgs which can modify this h gamma Z vertex

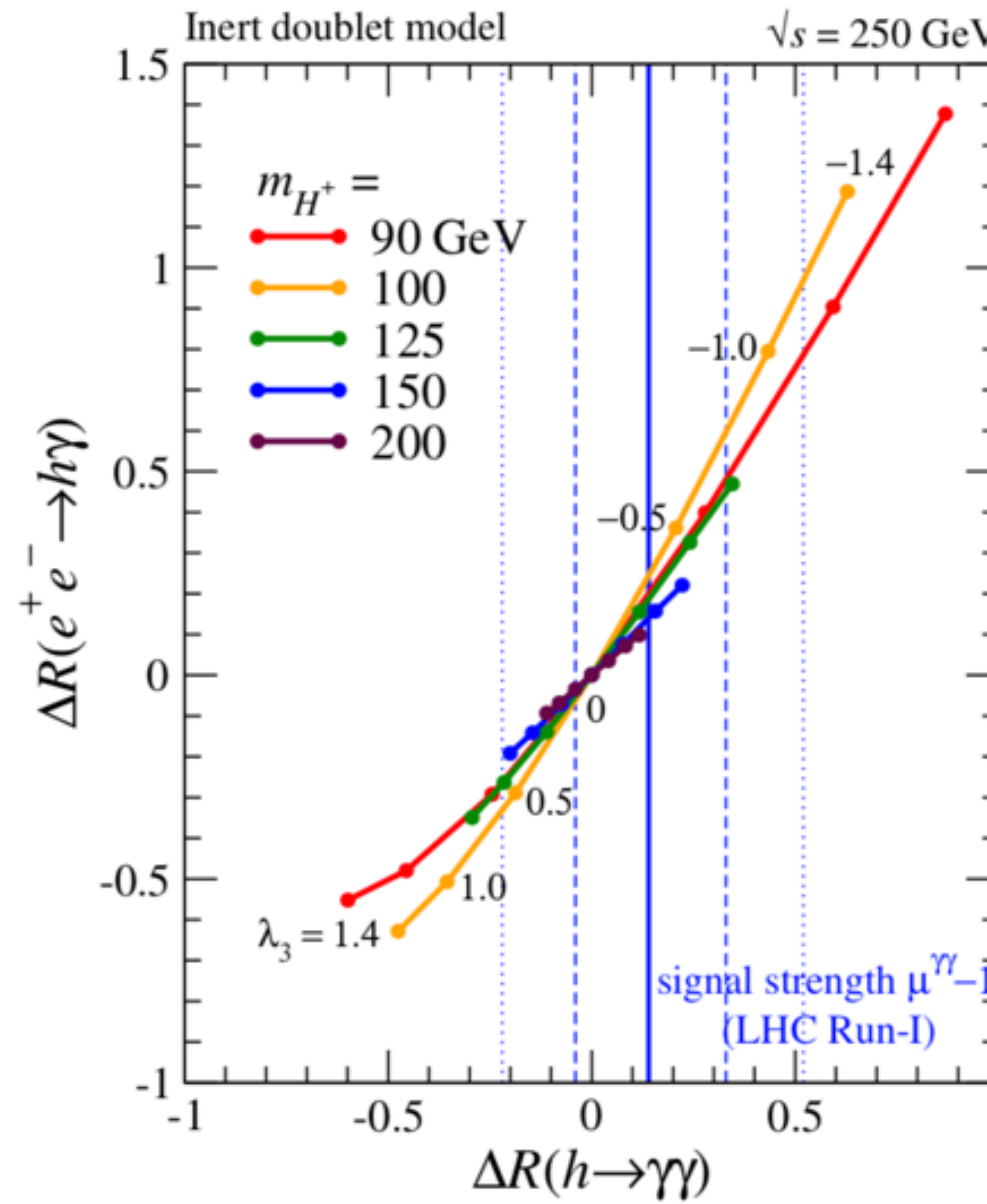


(d)

This plot shows the relative deviations of the e+e- to hγ cross section and the h to γγ decay rate from the Standard Model values.

Depending on model parameters, the deviation can be as large as 100%.

$\Delta R(e+e- \to h\gamma) = \sigma_{h\gamma}/\sigma_{SM} - 1$



Mawatari, et al, arXiv:1808.10268

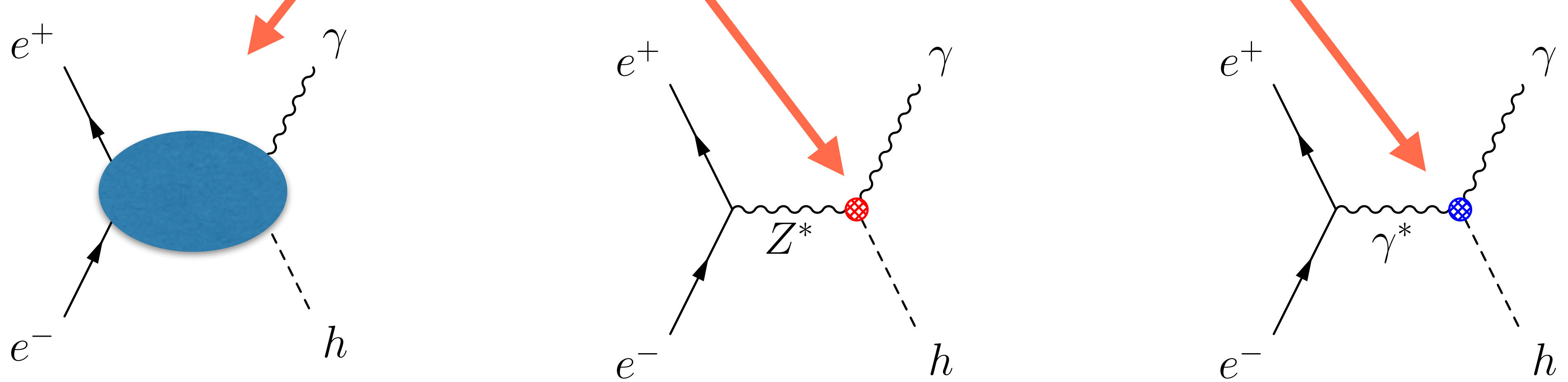
2. Theoretical framework for our analysis

The effective Lagrangian to include new physics contributions to the

e+e- to hγ cross section model-independently

effective hγZ coupling　　　effective hγγ coupling

$$L_{\gamma H} = L_{\rm SM} + \frac{\zeta_{AZ}}{v} A_{\mu\nu} Z^{\mu\nu} H + \frac{\zeta_A}{2v} A_{\mu\nu} A^{\mu\nu} H$$



ζ_{AZ} : effective coupling between Higgs and γZ

ζ_A : effective coupling between Higgs and γγ

Aμν, Zμν : field strength tensors

v: vacuum expectation value

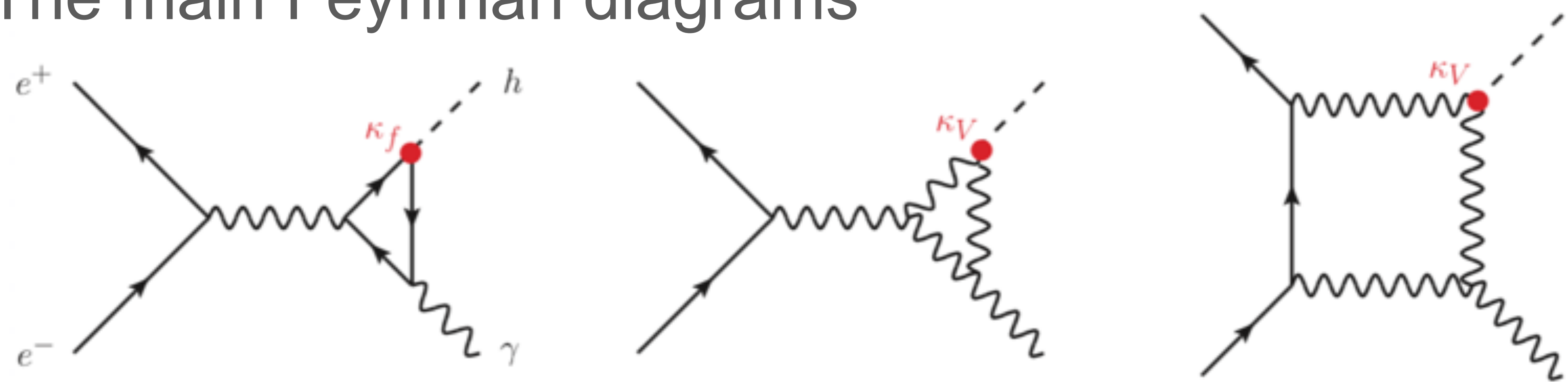
Phys.Rev. D94 (2016) 095015

SM one-loop predictions

e+e- ->h gamma is a loop induced process in SM

The main Feynman diagrams

Mawatari, et al, arXiv:1808.10268



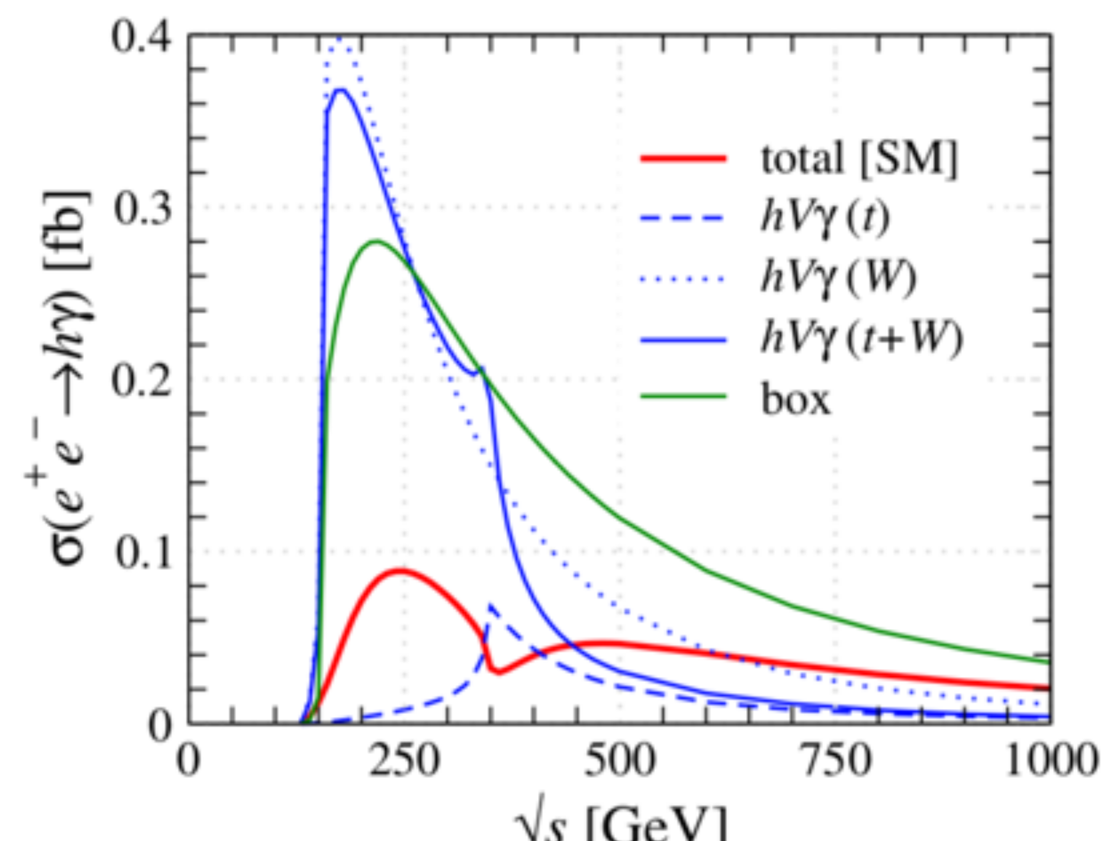
The cross sections by one loop calculation

e- e+

σ_{SM}=0.35 fb for (-100%,+100%)

σ_{SM}=0.016 fb for (+100%,-100%)

σ_{SM}=0.20 fb for (-80%,+30%)



※For not polarized beam

Destructive interferences

$\sqrt{s}$ = 250 GeV

3.Experimental Method

Coupling constant

$$L_{\gamma H} = L_{\rm SM} + \frac{\zeta_{AZ}}{v} A_{\mu\nu} Z^{\mu\nu} H + \frac{\zeta_A}{2v} A_{\mu\nu} A^{\mu\nu} H$$

measure this 2 parameters

① Measure the cross sections of e+e- ->γh

for two different beam polarizations

So that ζ_{AZ} and ζ_A can be determined separately

② Since ζ_A can be constrained already by measurement of h→ γγ branching ratio at LHC, we can extract ζ_{AZ} parameter by just measuring cross section for a single polarization.

3.Experimental Method (Continued)

The total cross section in EFT is calculated by full loop SM amplitude and interference between SM and EFT operators

→The cross section normalized to SM can be written as below

interference between one-loop SM amplitude and EFT

$$\frac{\sigma_{\gamma H}}{\sigma_{SM}} = 1 - 201\zeta_A - 273\zeta_{AZ}$$ (eLpR)

$$\frac{\sigma_{\gamma H}}{\sigma_{SM}} = 1 + 492\zeta_A - 311\zeta_{AZ}$$ (eRpL)

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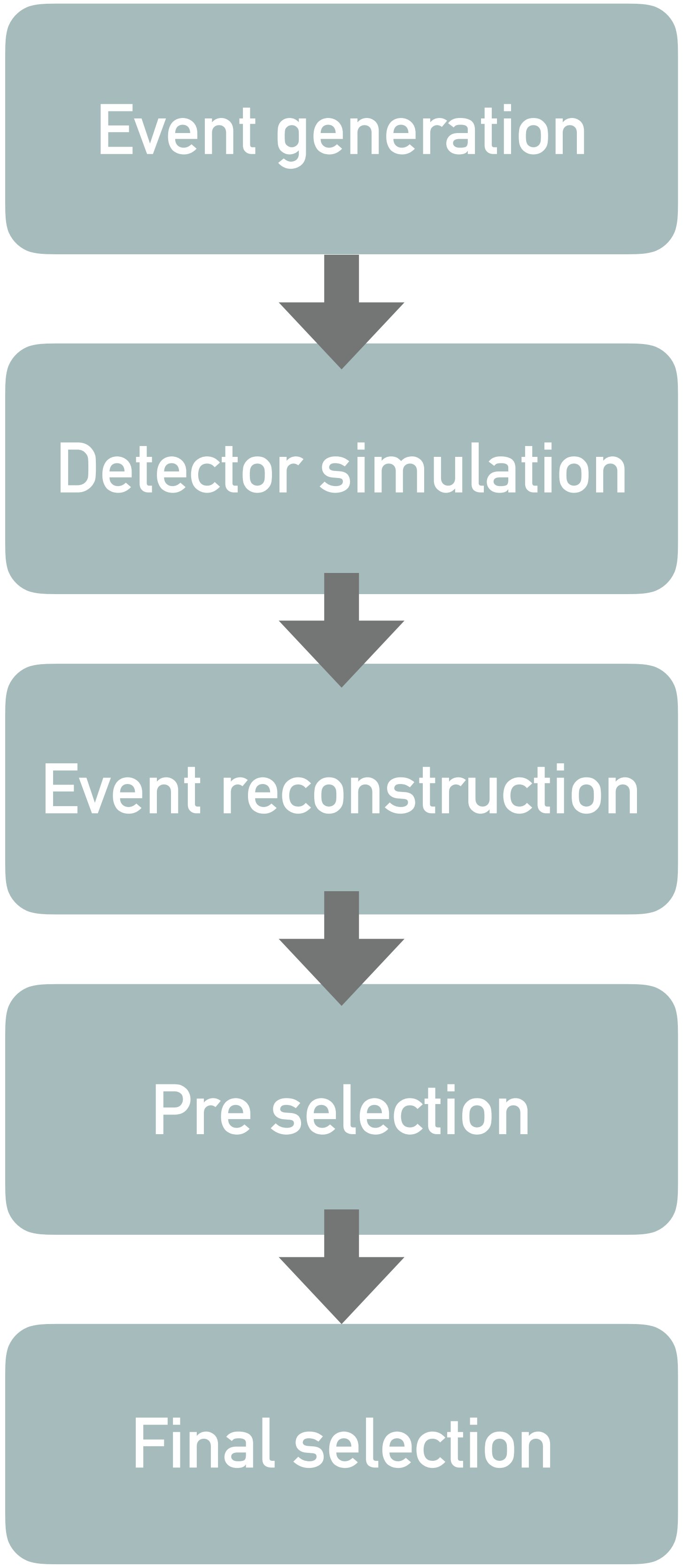
4.Simulation framework



- Physsim
  $\sqrt{s}$=250 GeV
  Integrated Luminosity: 2000 fb^{-1}
  back ground : DBD sample
- ILD full simulation (Mokka)
- iLCSoft v01-16-02
  MarlinReco, PandoraPFA,
  LCFI+, Isolated photon finder, jet clustering

5. Event selection

Signal: $e^+e^- \to \gamma H \to \gamma(b\bar{b})$

Signal signatures

1. Isolated monochromatic photon with energy 93 GeV
2. 2 b jets
3. m(bb)（invariant mass）= higgs mass

Main backgrounds

e+e- ->γqq(bar) dominated by e+e- → γZ (radiative return)

5. Event selection

① Pre-selection

・Isolated photon

- ➤ Photon ID
- ➤ E_γ ＞ 50 GeV

※The split photon clusters within a small cone are recovered

→Left events except photon

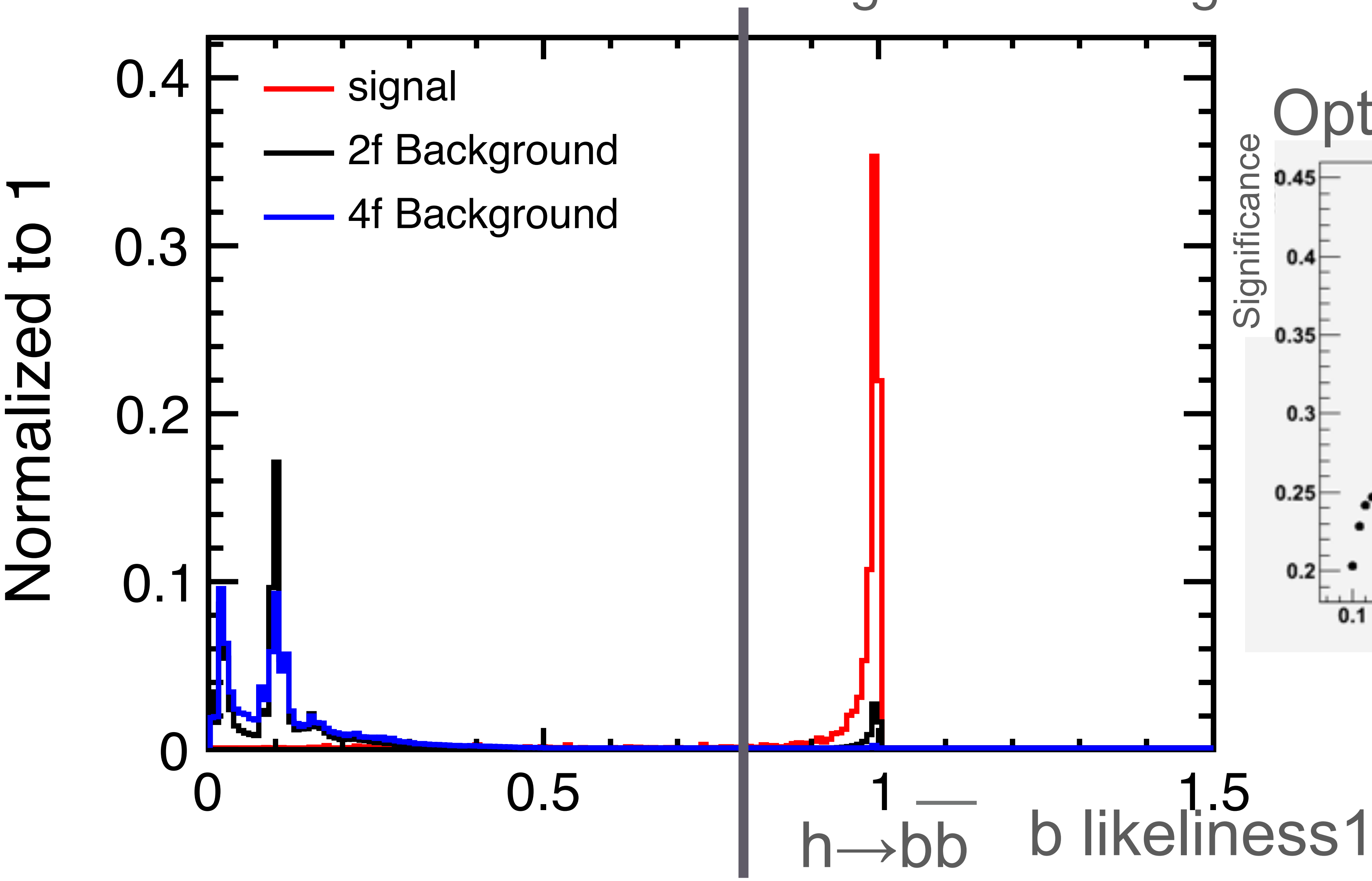
- ➤ 2jet clustering (Durham)
- ➤ Flavor tagged（LCFI+）

5. Event selection

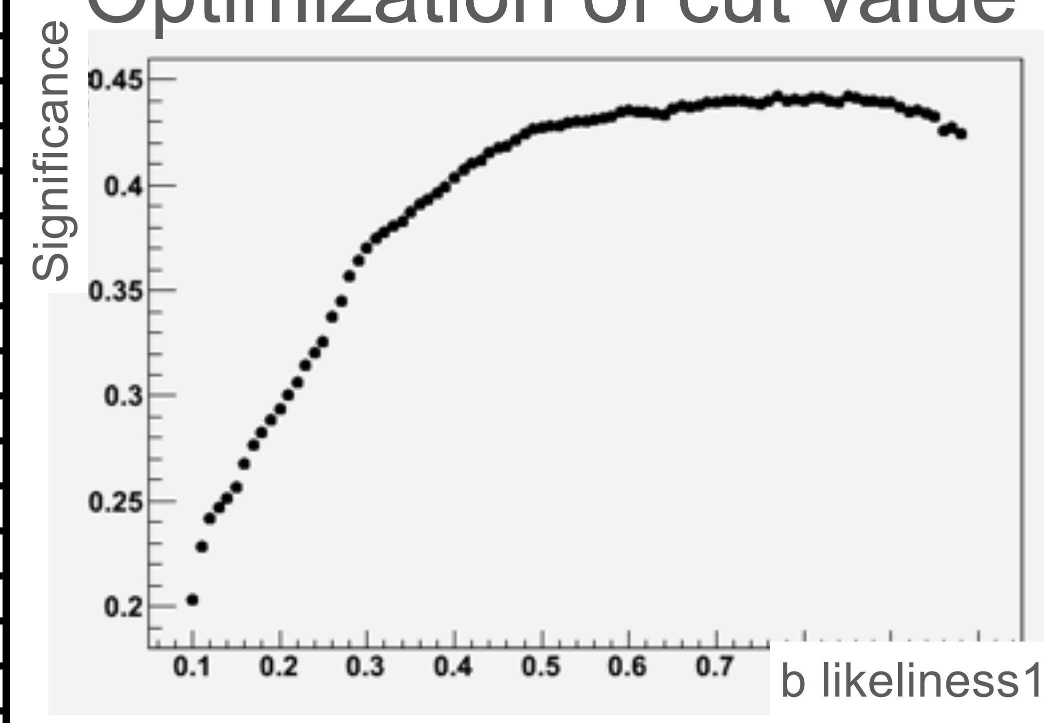
② Final selection

-Cut 1:b likeliness1>0.77 →Suppress light flavor γqq

The distribution of b likeliness for signal and background events



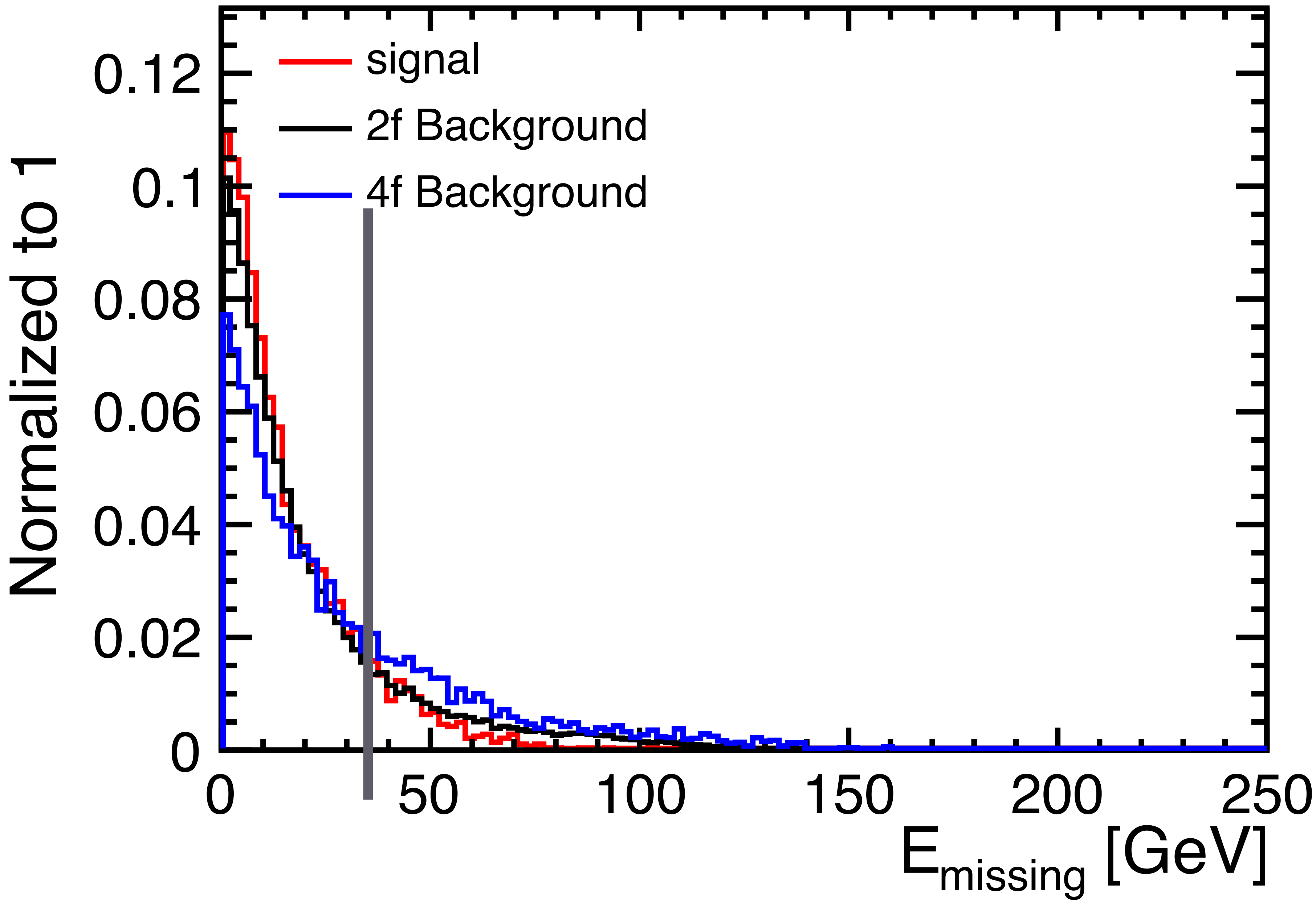
Optimization of cut value



※ This plot is for events after the pre selection

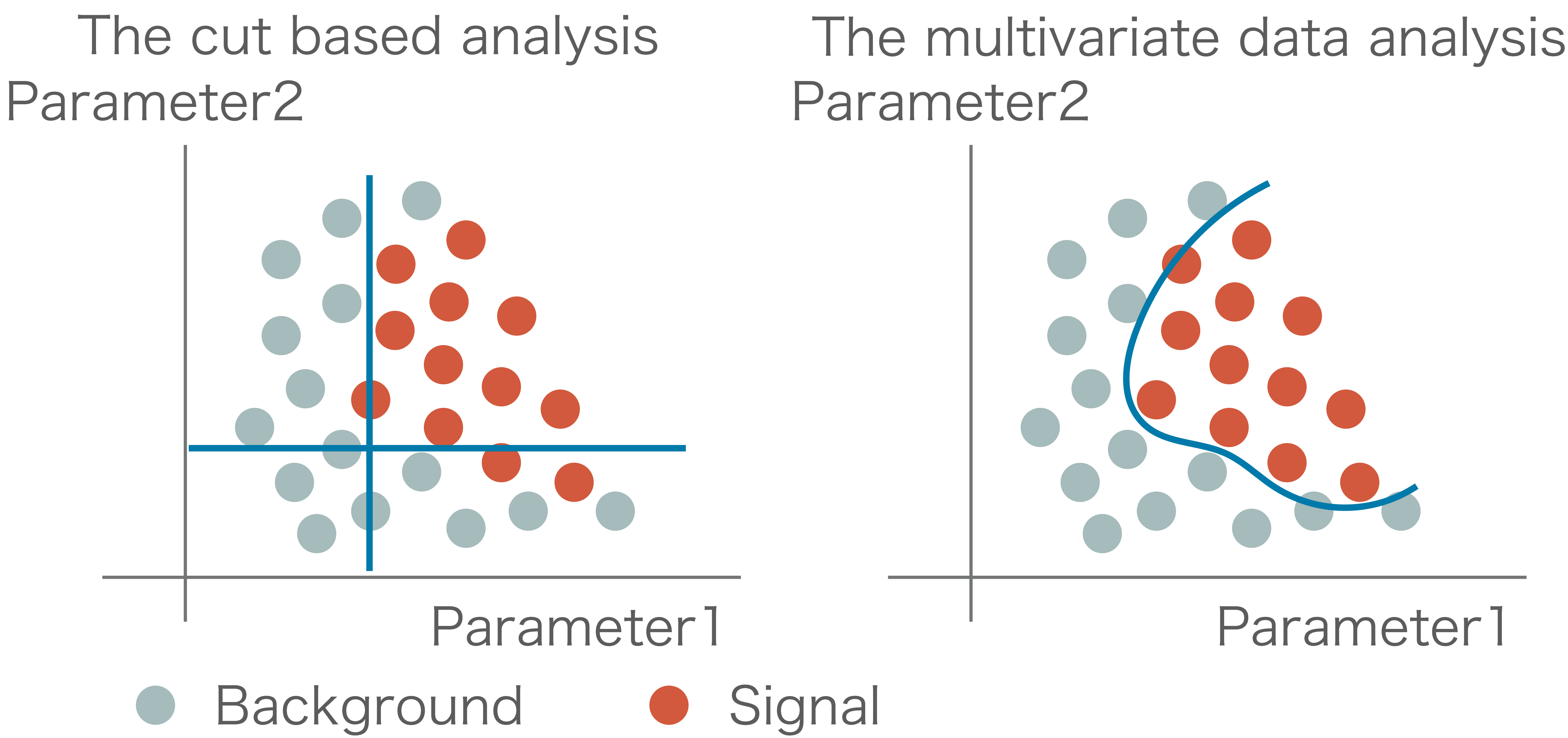
5. Event selection

② Final selection
-Cut 2: missing energy<35 GeV



Separation by using TMVA

Multivariate Data Analysis

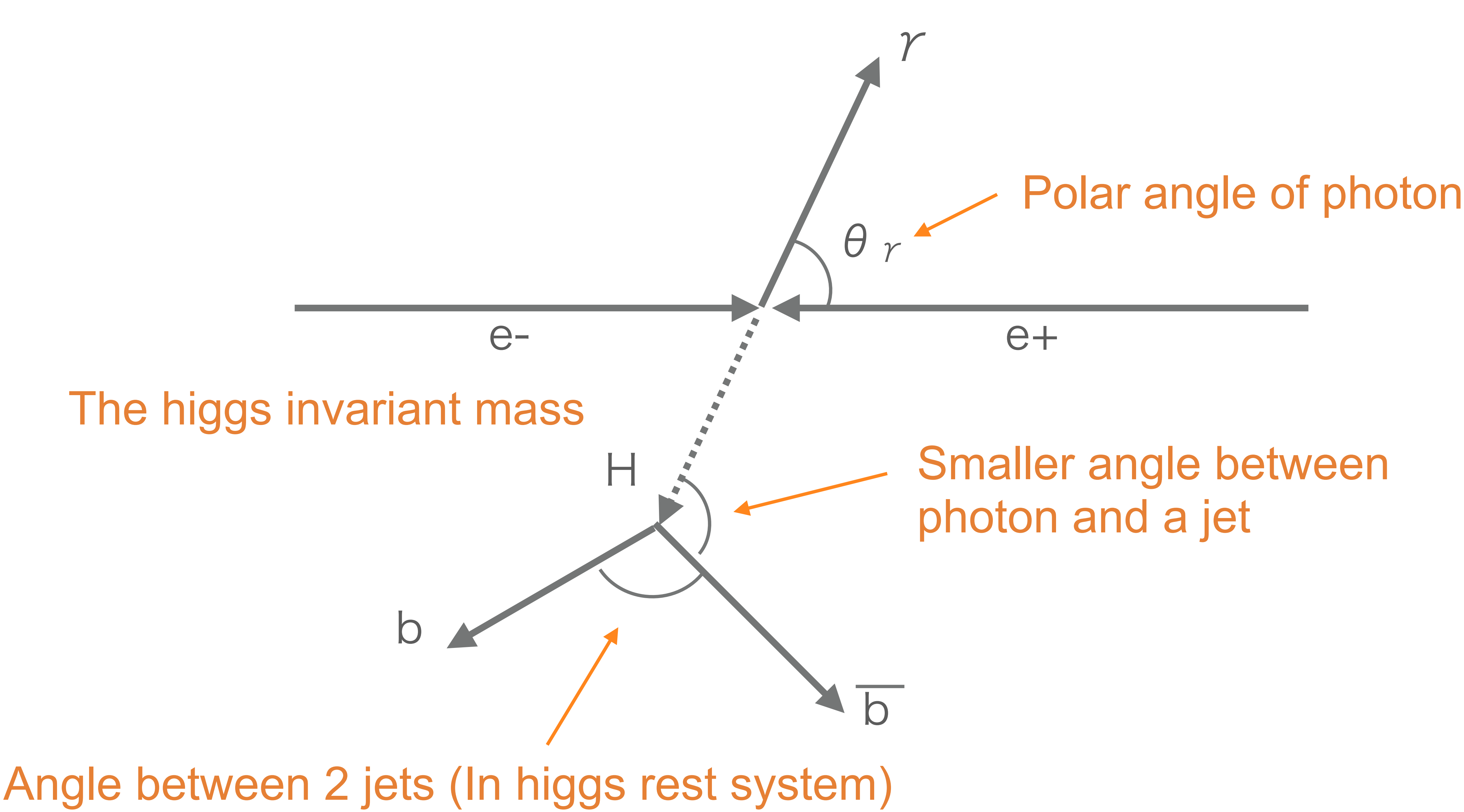


The cut based analysis has its limitation.

→TMVA describes signal-background boundary more flexibly

Input variables for MVA

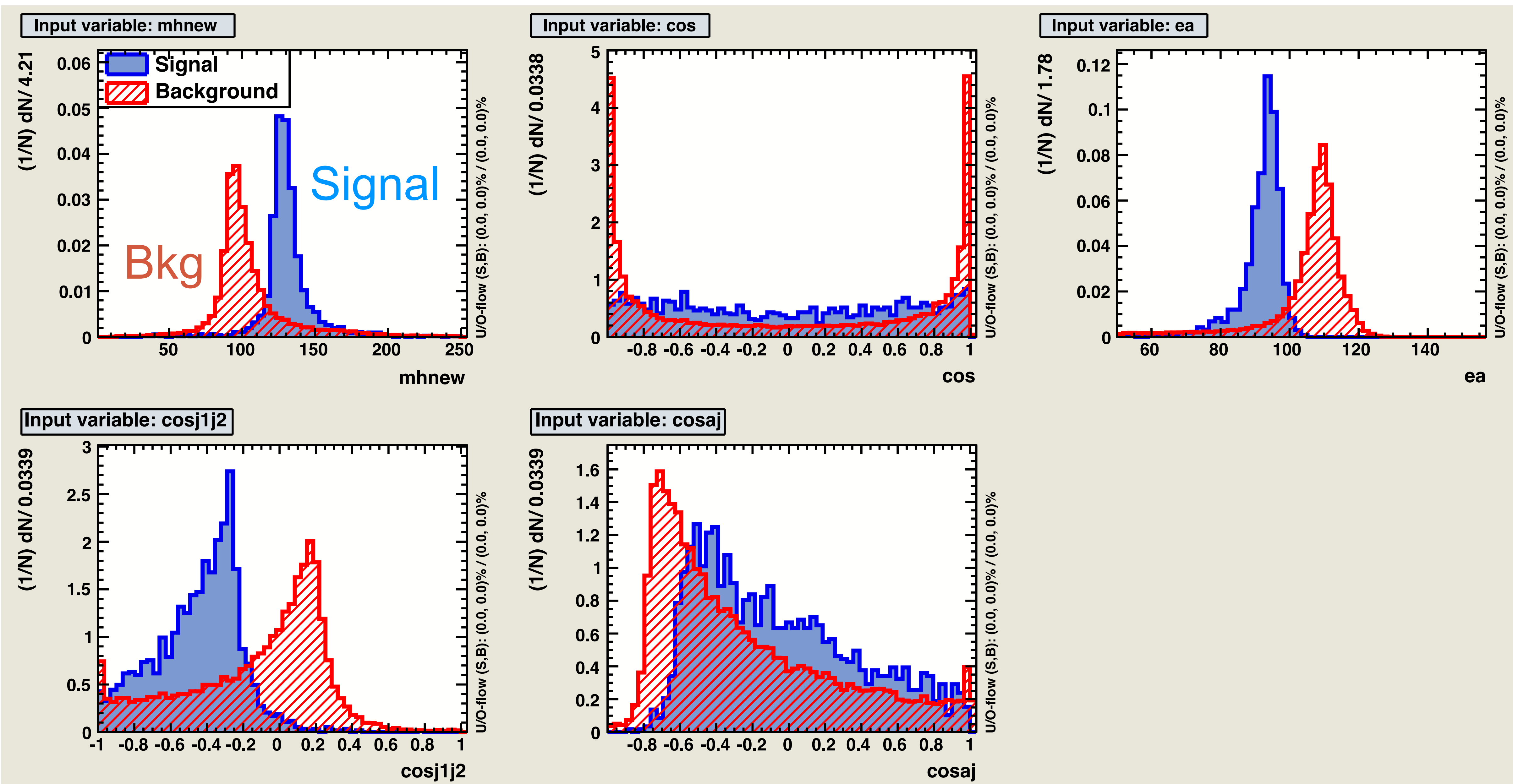
I used 5 parameters for MVA



Input variables for MVA

The distributions of each variable for signal and background

The higgs invariant mass | Polar angle of photon | Energy of photon

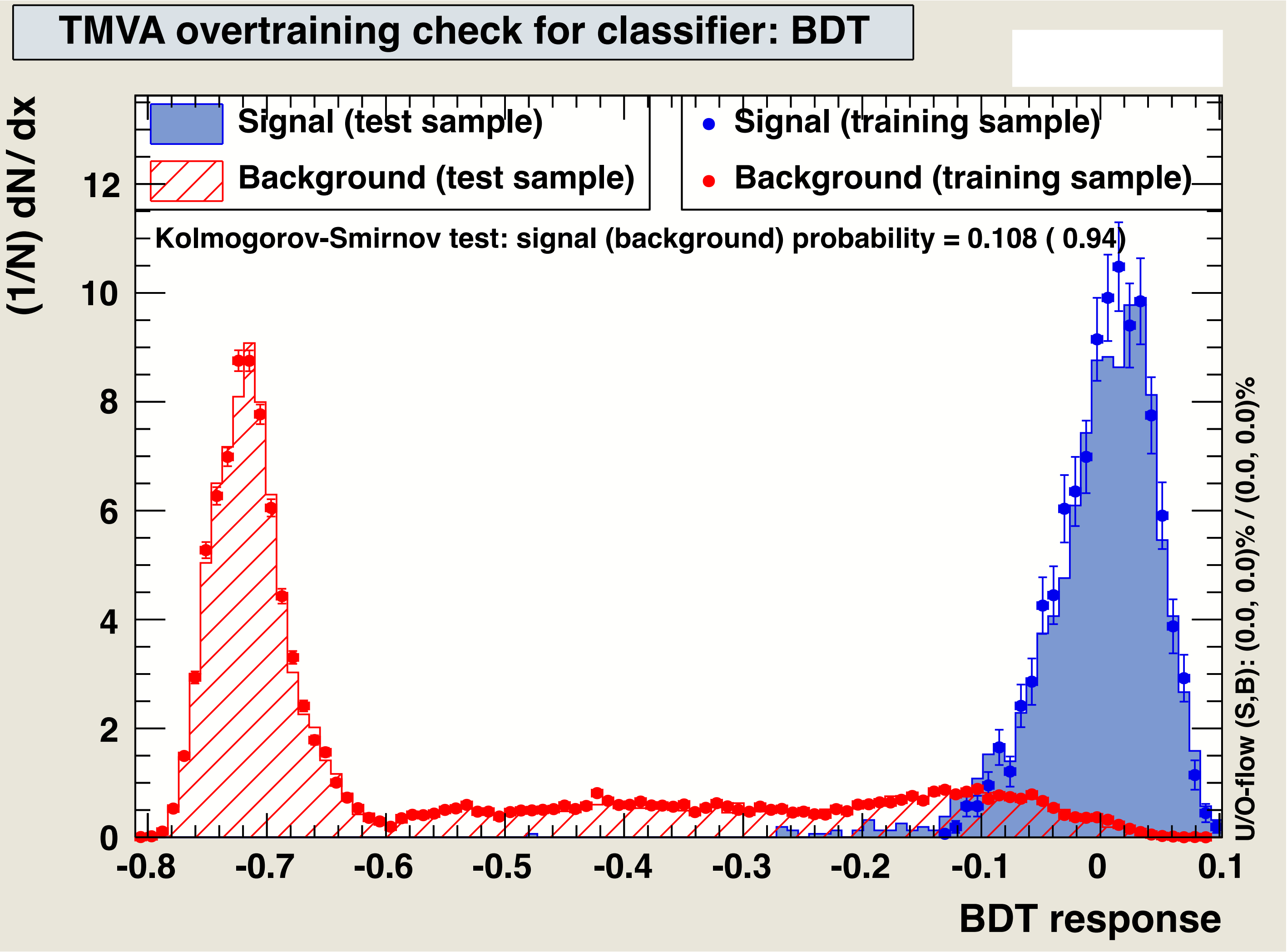


Angle between 2 jets | Smaller angle between photon and a jet

Separation by using TMVA

TMVA analysis procedure

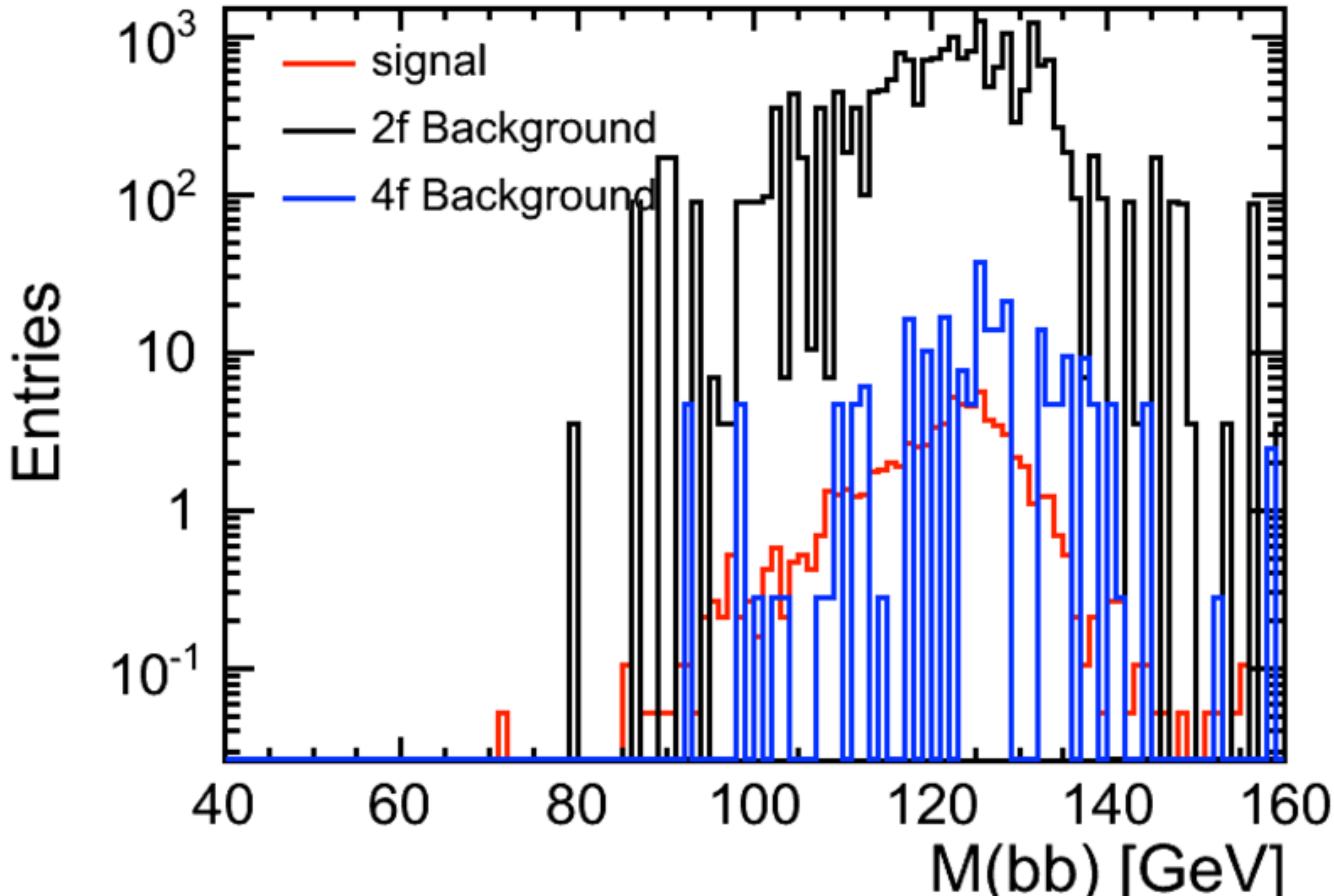
1. [Training step]Teach TMVA the characteristics of signal using signal and background training samples
2. Apply the training result to real signal and background



Make sure over training is exist or not.

Separation by using TMVA

The distribution of m(bb) after all the other cuts, normalized to Integrated Luminosity: 2000 fb^{-1}



LCWS2017 ※Using EFT

6. Result

$$significance = \frac{N_s}{\sqrt{N_s + N_B}}$$

Reduction table Preliminary

N_s:Number of signal
N_B:Number of back ground

	Signal	background	Significance
Expected	196	314,154,000	0.01
Pre selection	184	68,287,700	0.02
btag>0.8	164	4,914,990	0.07
E_{mis}<35	150	4,268,840	0.07
75<Eγ<98	135	415,621	0.21
-0.9<cosθγ<0.9	126	290,768	0.23
106<M(b,b)<145	108	129,259	0.30

6. Result

$$significance = \frac{N_s}{\sqrt{N_s + N_B}}$$

Reduction table Preliminary

N_S:Number of signal
N_B:Number of back ground

	Signal	background	Significance
Expected	237	3.14×10^8	0.01
Pre selection	222	6.54×10^7	0.02
btag>0.8	200	4.96×10^6	0.09
$E_{mis}<35$	182	4.30×10^6	0.09
mvabdt > 0.0126	75	1.98×10^4	0.53

6. Result

→95% C.L upper limit $\sigma = \frac{1.64}{significance}\sigma_{SM}$

Significance = 0.53 for SM

= 3.09 × 0.35 [fb]

=1.08 [fb] （Left handed）

3.09> $\frac{\sigma_{\gamma H}}{\sigma_{SM}} = 1 - 201\zeta_A - 273\zeta_{AZ}$ >0

asume ζ_A =0

-0.0077> ζ_{AZ} >0.0037

7. Summary

- I simulated and analyzed e+e- -> h gamma process
- TMVA
- Significance for e+e- ->hγ process

  ~ 0.53σ for SM at $\sqrt{s}$=250 GeV, 2000 fb^{-1}

- model independent upper limit for cross section : $\sigma_{\gamma H}$< 1.08 fb(95% C.L.)
- Corresponding bounds : -0.0077> ζ_{AZ} >0.0037

Next step

- try h->WW* channel

- Understand the role of this measurement in one global EFT analysis

Back up

Input variables for MVA

The higgs invariant mass

$p_{x1}=|p1| \sin\theta_1 \cos\phi_1$

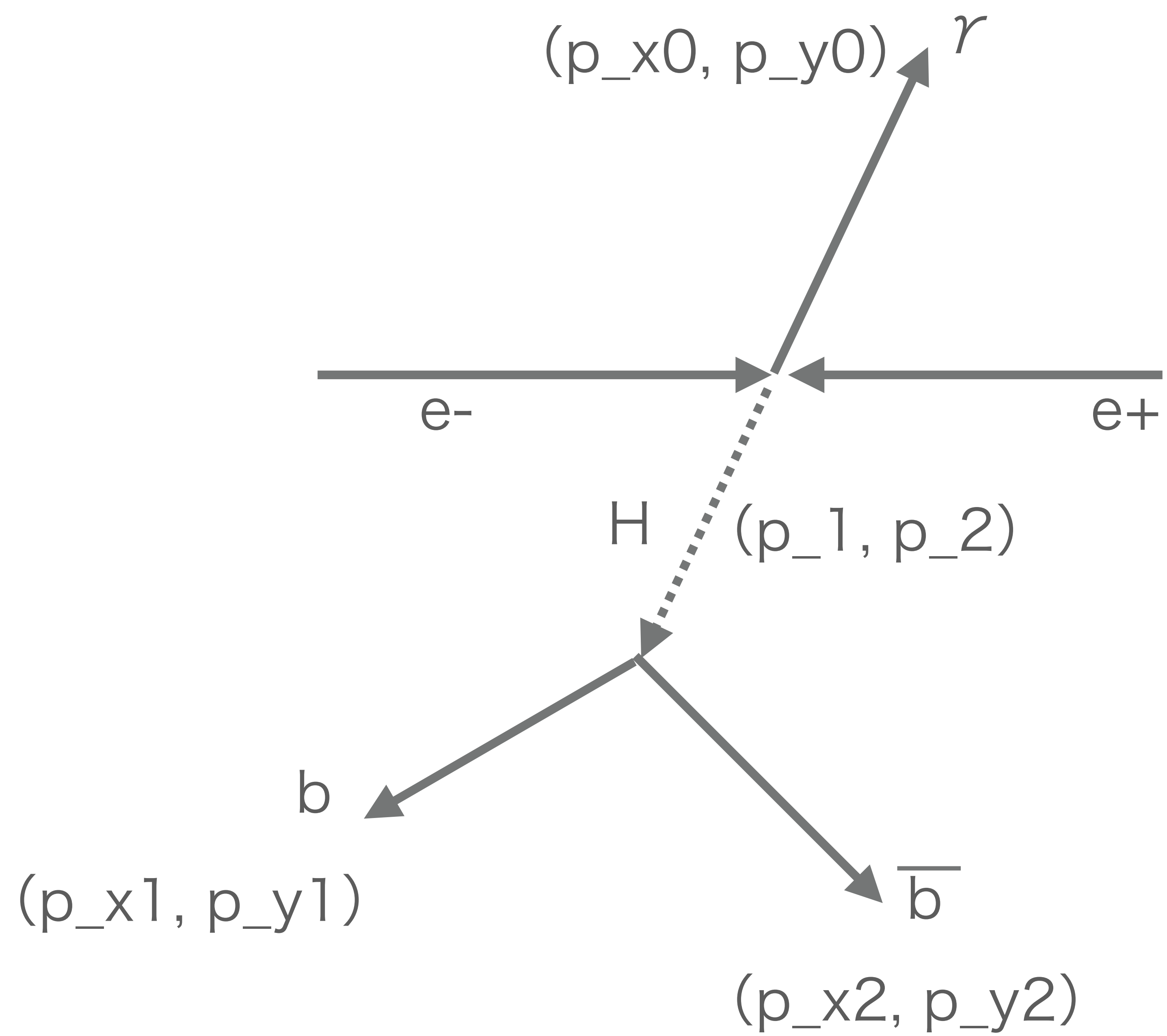
$p_{y1}=|p1| \sin\theta_1 \sin\phi_1$

$p_{x2}=|p1| \sin\theta_2 \cos\phi_2$

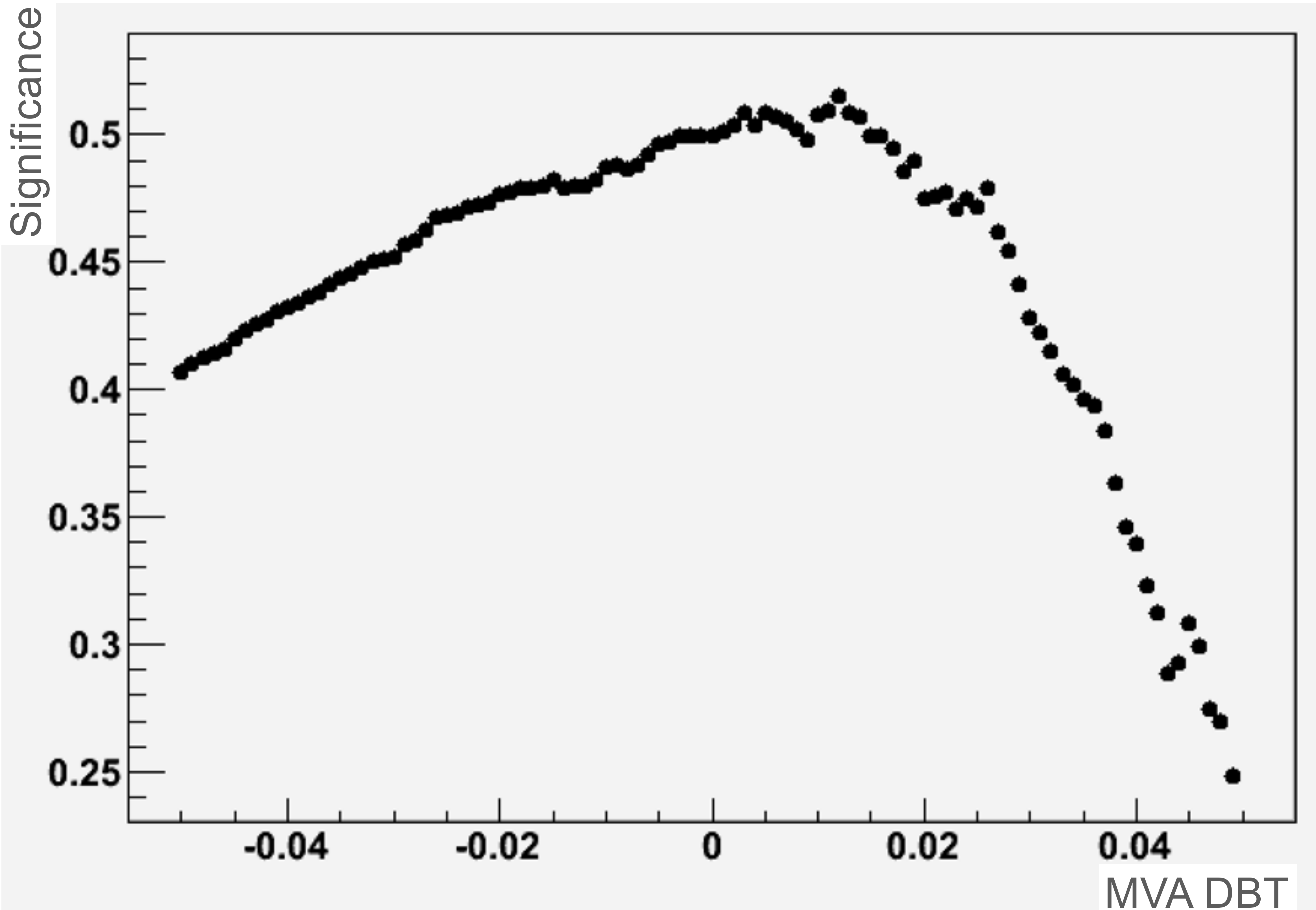
$p_{y2}=|p1| \sin\theta_2 \sin\phi_2$

$p_{x1}+p_{x2}=-p_{x0}$

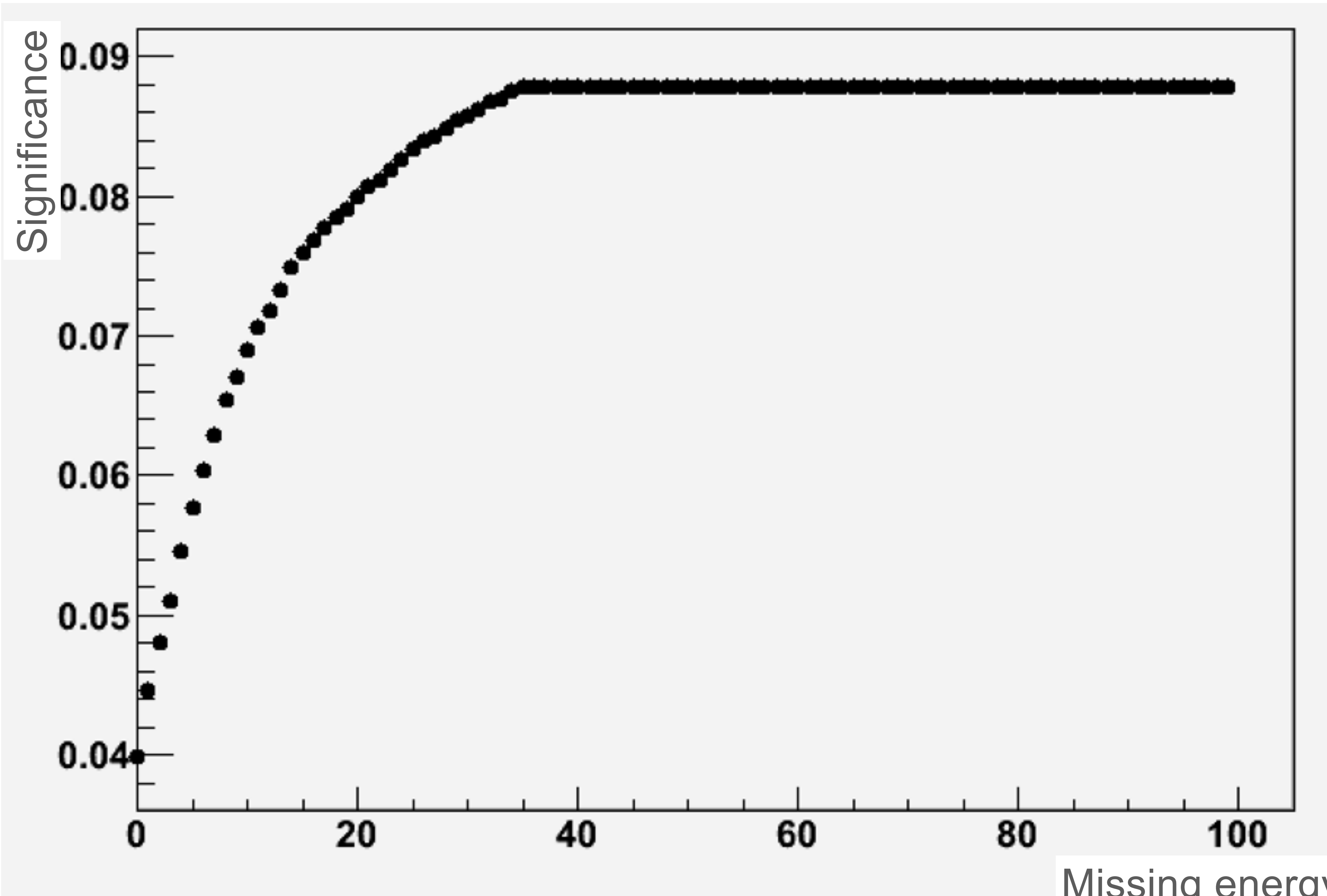
$p_{y1}+p_{y2}=-p_{y0}$



Optimization of mva



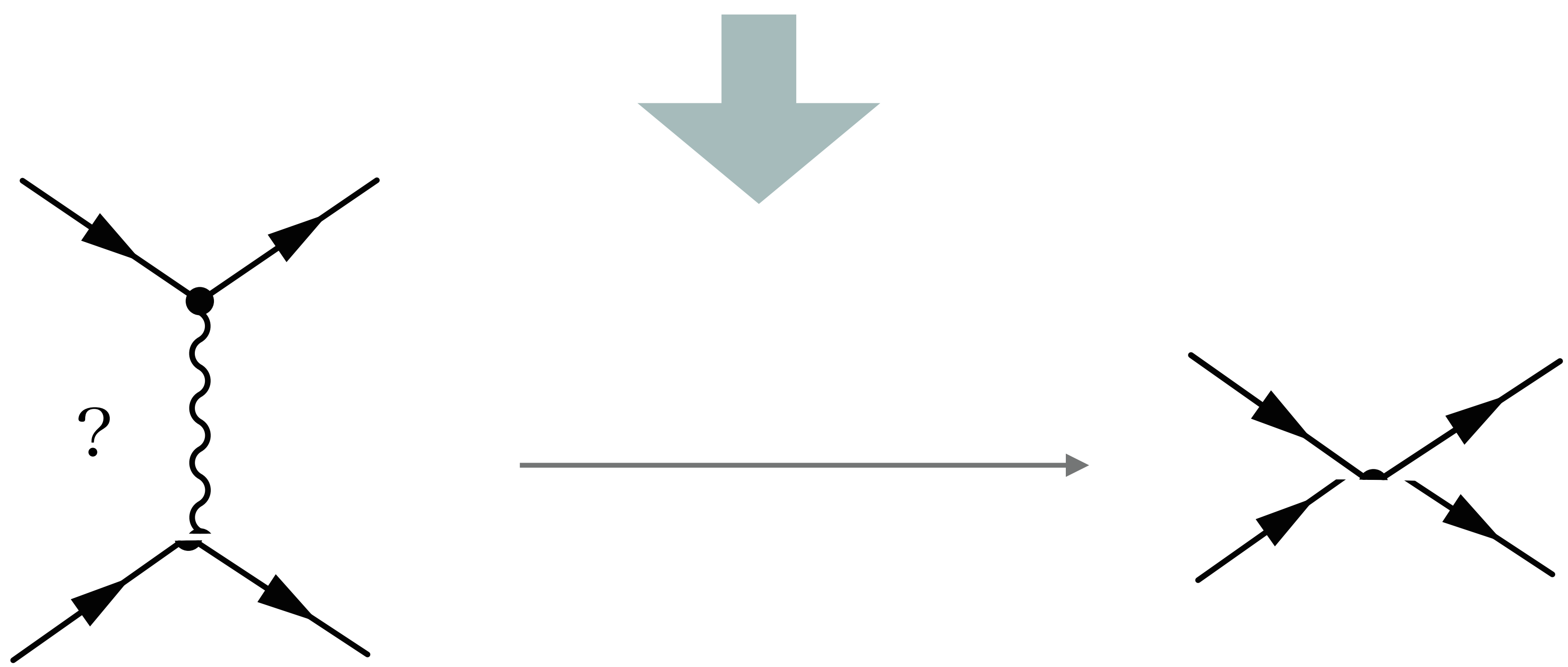
Optimization of missing energy



Effective field theory

Higher energy scale rather than W

Lower energy scale rather than W



Higher energy scale rather than new physics

Looking at ILC250 GeV

5. Event selection

Back ground

		characteristic	How to remove
f f		back to back	cosθ2f
γZ→γ(f f)	γll	few track number	nTrack
	γqq,γcc	no b	b-tag
	γbb	different angular distribution	Eγ,cosθγ
	common	m(bb)~m(Z)	m(ff)
Z^+Z^- W^+W^-→4f	4j	4 jet	Y3→2, Eγ
	2j+2l	Nisolep=2	N_{isolep}=0, Eγ
	2j+vv	large missing energy	E_{miss},Eγ
	2j+lv	missing energy	N_{isolep}=0, E_{miss}
	common	m(ff)=m(W)	b-tag, m(ff)

l:lepton q:quark j:jet v:neutrino