Study of $H\gamma Z$ coupling at the ILC

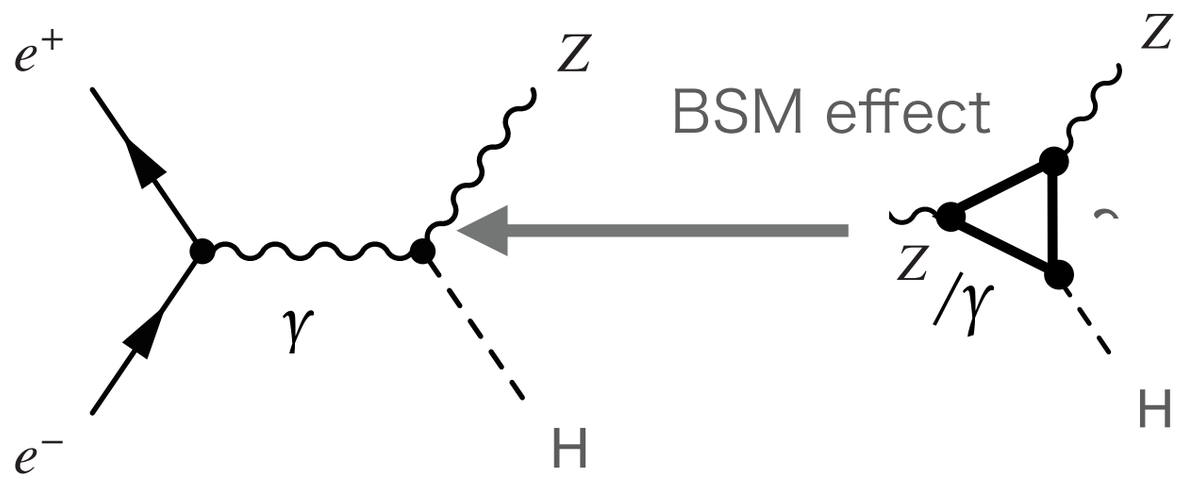
Yumi Aoki(SOKENDAI)
on behalf of ILD concept group
2019.10.31(Thu)

1.Motivation

To find new physics via Hγγ and HγZ couplings

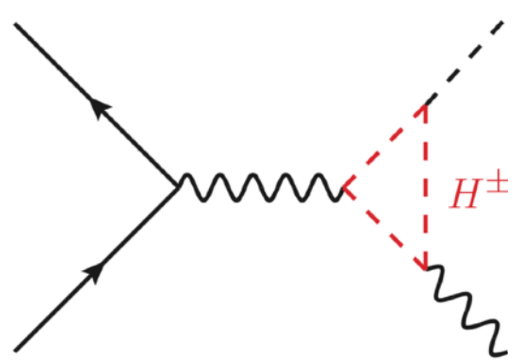
Higgs to γZ coupling in the Standard Model (SM) is a loop induced coupling.

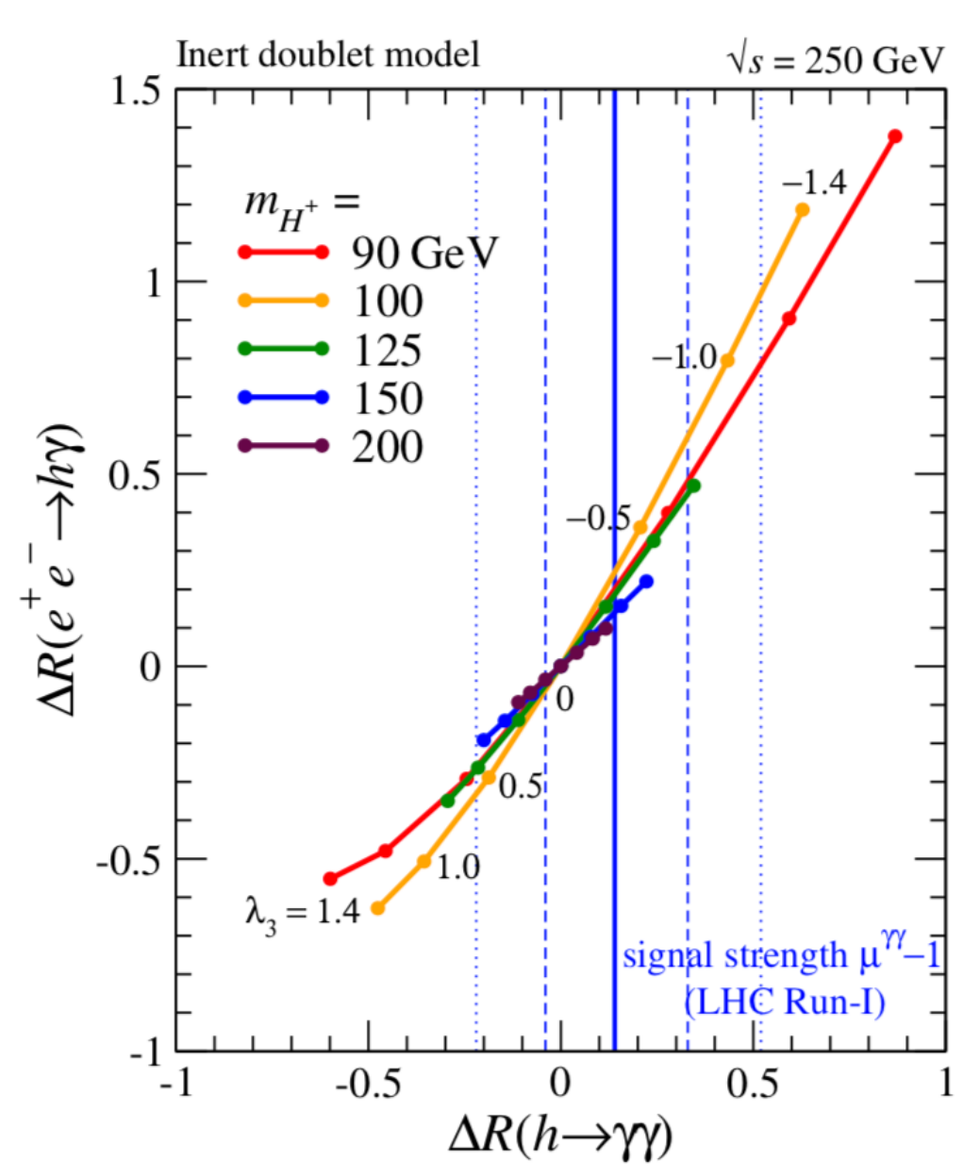
→We expect BSM amplitude can be larger than SM amplitude.



Any deviation of the coupling constants from SM signals new physics.

e.g.： Inert Doublet Model



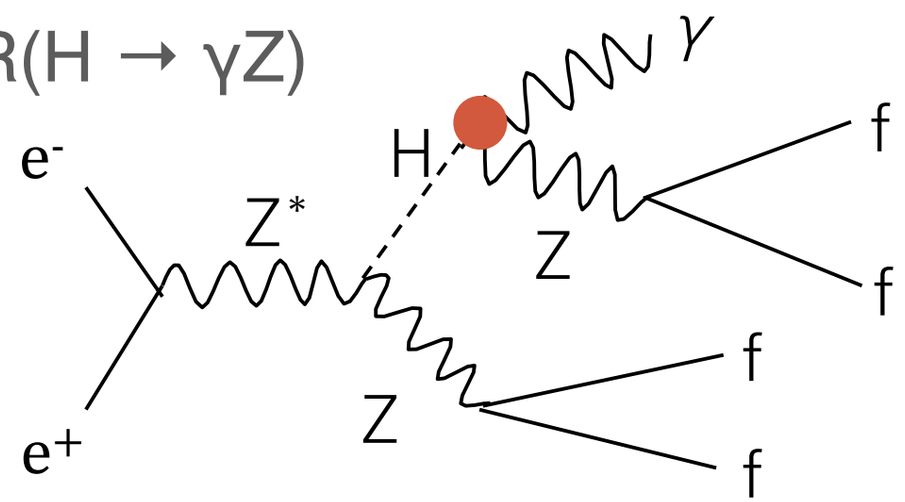


Mawatari, et al, arXiv:1808.10268

2.Two ways to measure HγZ coupling

Higgs decay

BR(H → γZ)

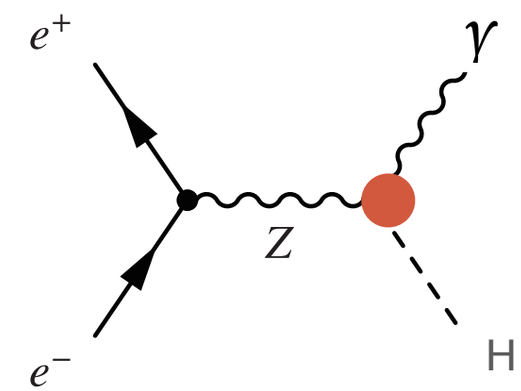


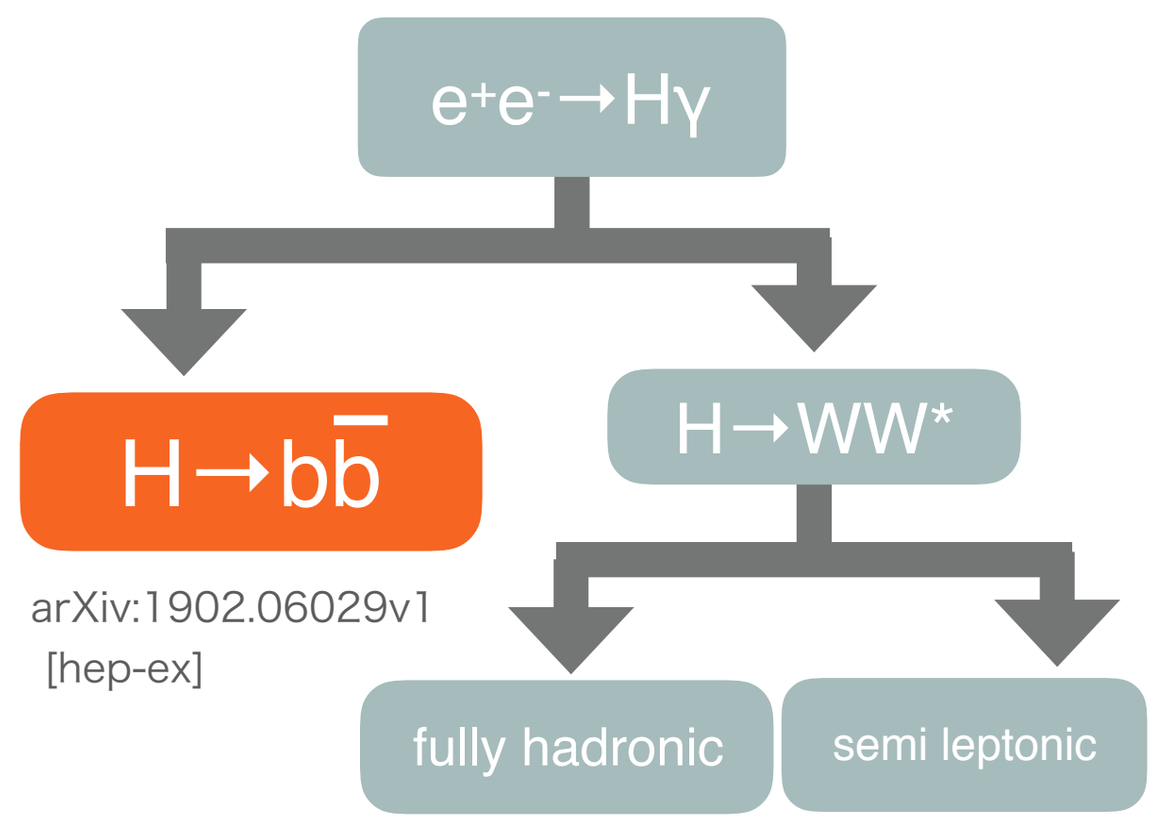
final state	BR
mmqqγ	4.7%
eeqqγ	4.7%
nnqqγ	28.0%
qqqqγ	48.9%
others	13.7%

by Kazuki Fujii at LCWS2018

Higgs production

σ（e+e- →Hγ）



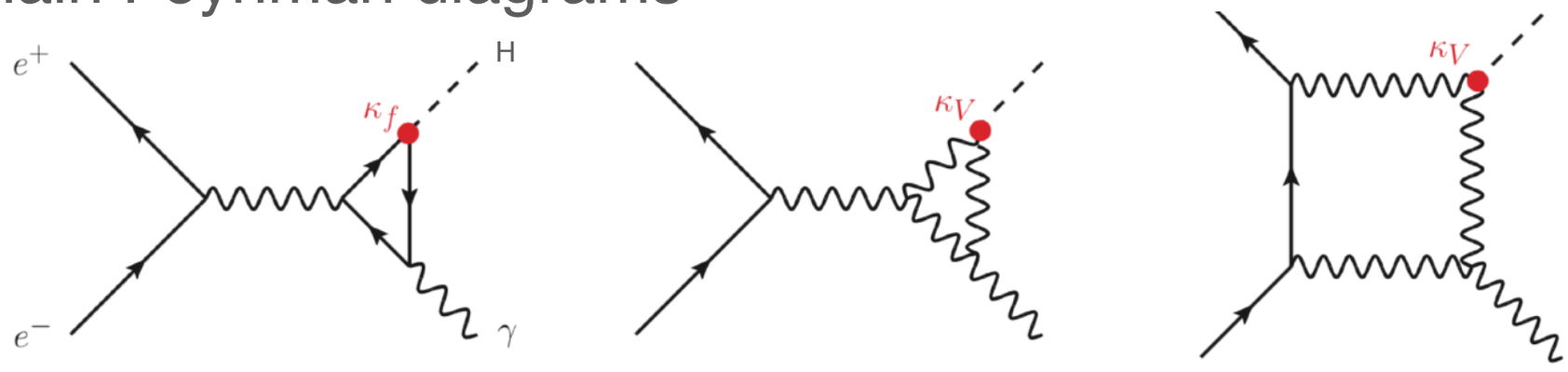


arXiv:1902.06029v1 [hep-ex]

3. Theoretical framework for our analysis

SM one-loop predictions

The main Feynman diagrams



Mawatari, et al, arXiv:1808.10268

SM cross sections by one loop calculation:

e^- e^+

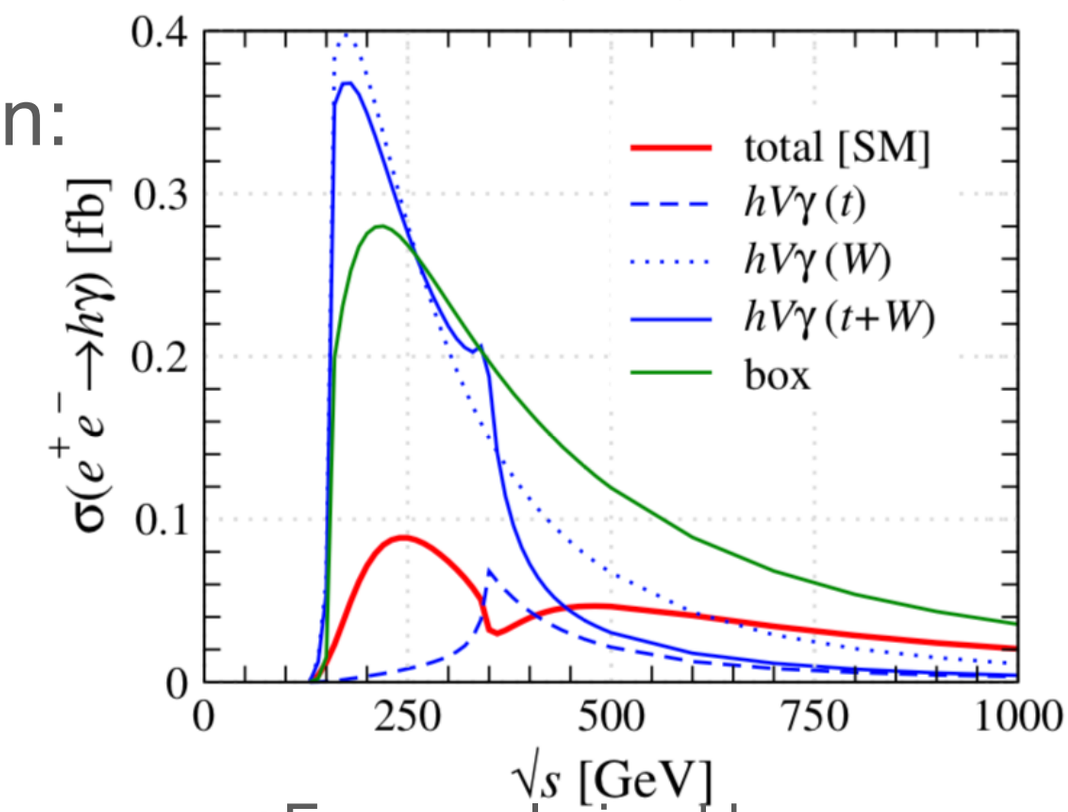
σ_{SM}=0.35 fb for (-100%,+100%)

σ_{SM}=0.016 fb for (+100%,-100%)

σ_{SM}=**0.20 fb** for (-80%,+30%)

$\sqrt{s}$ = 250 GeV

Small !



※For unpolarized beam

This analysis is very challenging.

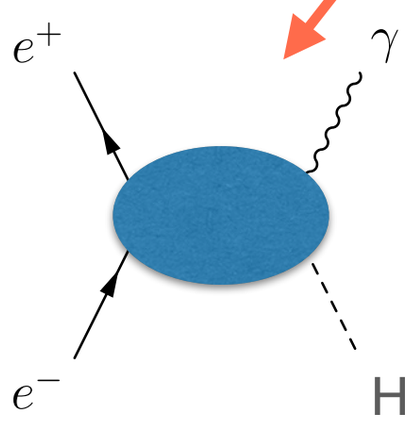
Destructive interference

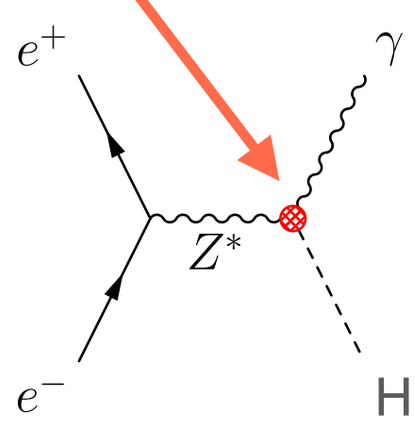
3. Theoretical framework for our analysis

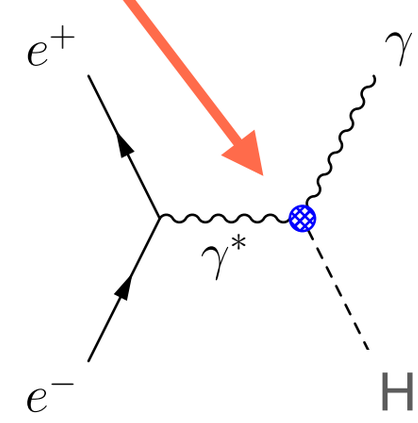
The effective field theory (EFT) Lagrangian to include new physics contributions to the $e^+e^- \to H\gamma$ cross section model-independently

effective $h\gamma Z$ coupling effective $h\gamma\gamma$ coupling

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





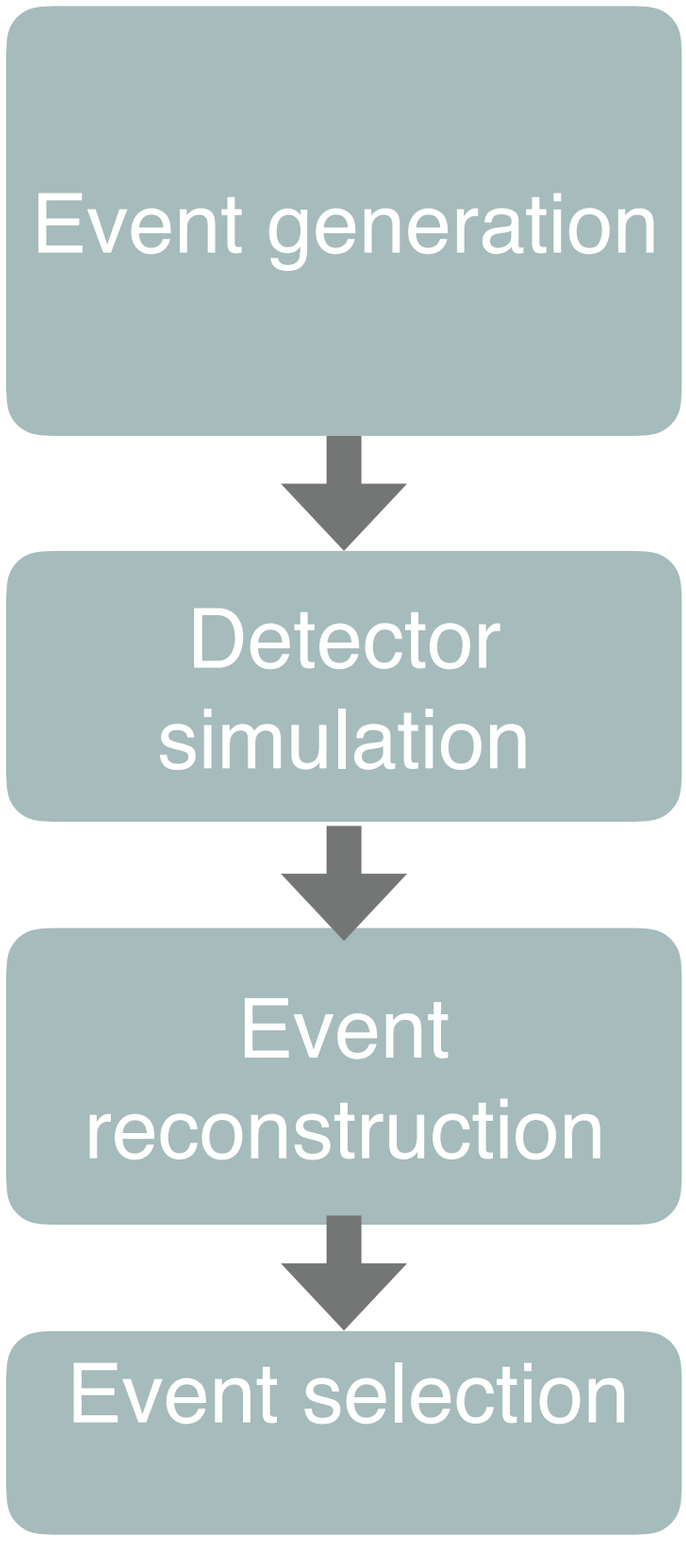


Phys.Rev. D94 (2016) 095015

$A_{\mu\nu}$, $Z_{\mu\nu}$: field strength tensors v: vacuum expectation value

Since ζ_A is already constrained by measurement of $H \to \gamma\gamma$ branching ratio at LHC, we can extract ζ_{AZ} parameter by just measuring cross section for a single beam polarization.

4.Simulation framework



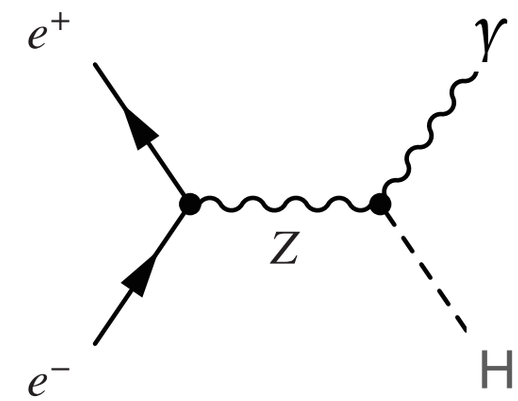
- $\sqrt{s}$=250 GeV
  Integrated Luminosity: 2000 fb^{-1}
- background : 2f,4f (DBD sample)
- ISR and Beamstrahlung effects are included

- ILD full simulation (Mokka)
- Geant4 based, realistic detailed detector model

- Full reconstruction chain from detector signals to 4-vectors
  (iLCSoft v01-16-02/ MarlinReco, PandoraPFA, LCFI+, Isolated photon finder, jet clustering)

5. Signal & Backgrounds

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



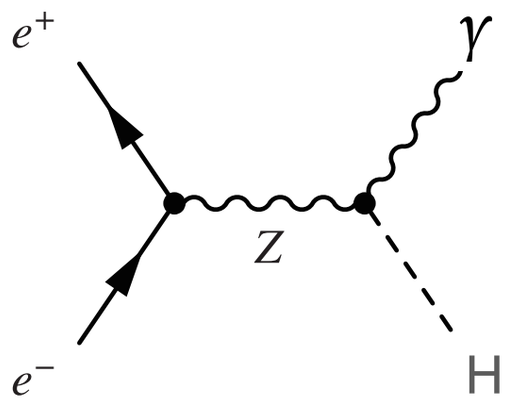
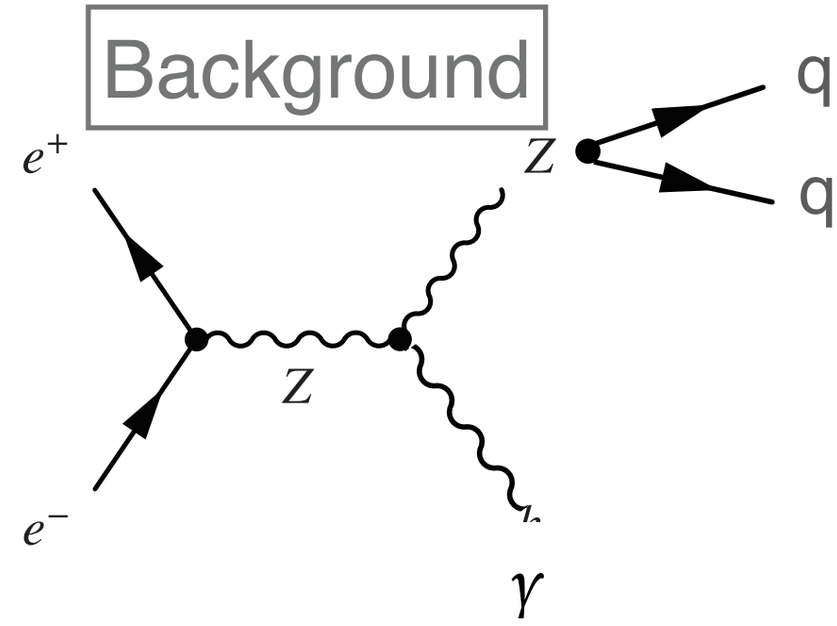
Signal signatures

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

Main backgrounds

$e^+e^- \to \gamma qq$
dominated by $e^+e^- \to \gamma Z$
(radiative return)

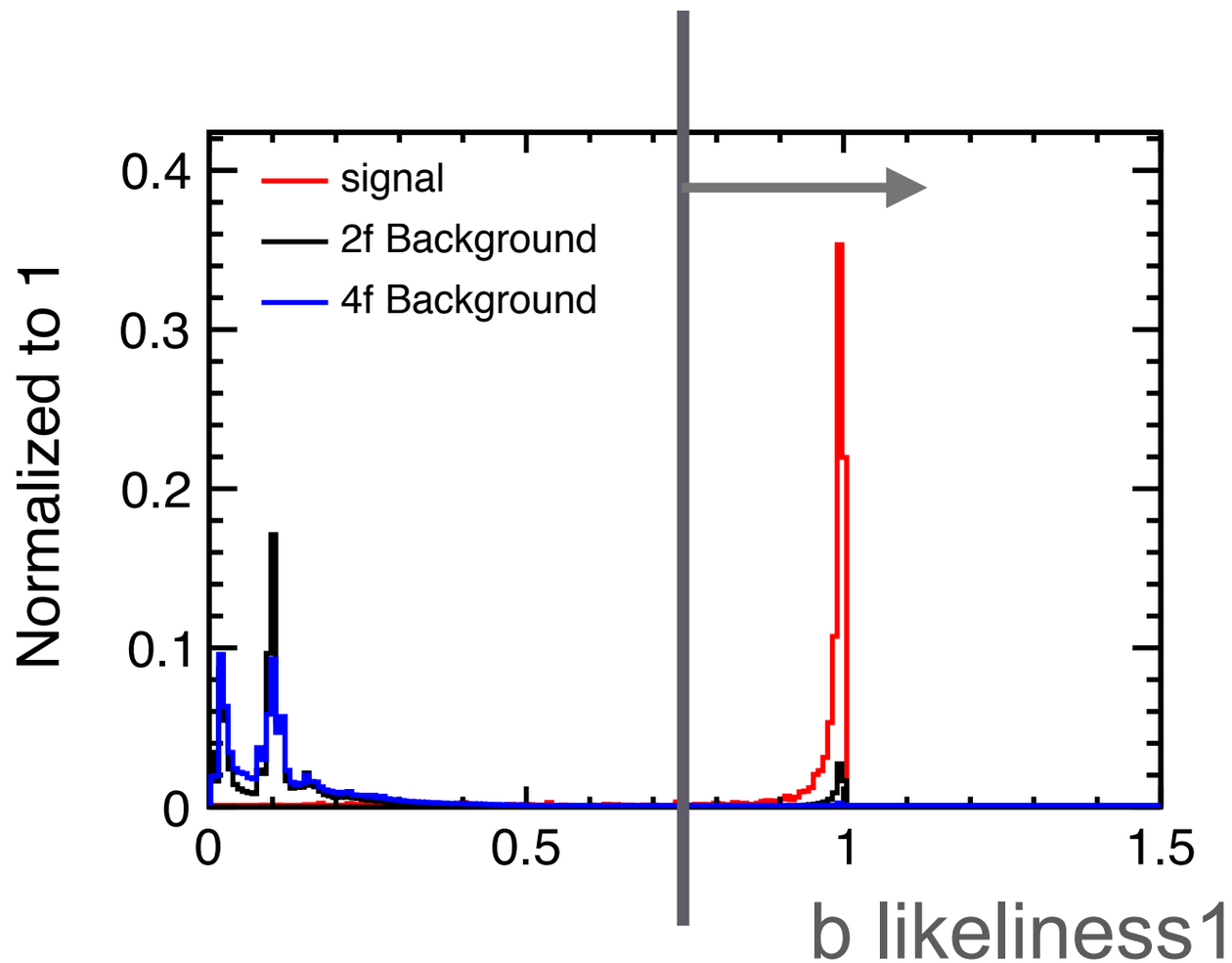
5. Signal & Background - h→bb

Signal		Background
		
$e^+e^- \to \gamma H \to \gamma(b\bar{b})$		$e^+e^- \to \gamma Z \to \gamma qq$ (radiative return)
2 b jets	Btag	qq not necessarily bb
m(2jet)= Higgs mass	m(2jets)	m(2jet)=Z mass
Energy of isolated monochromatic photon ~93 GeV	E_γ	Energy of photon ~108 GeV

6. Event selection

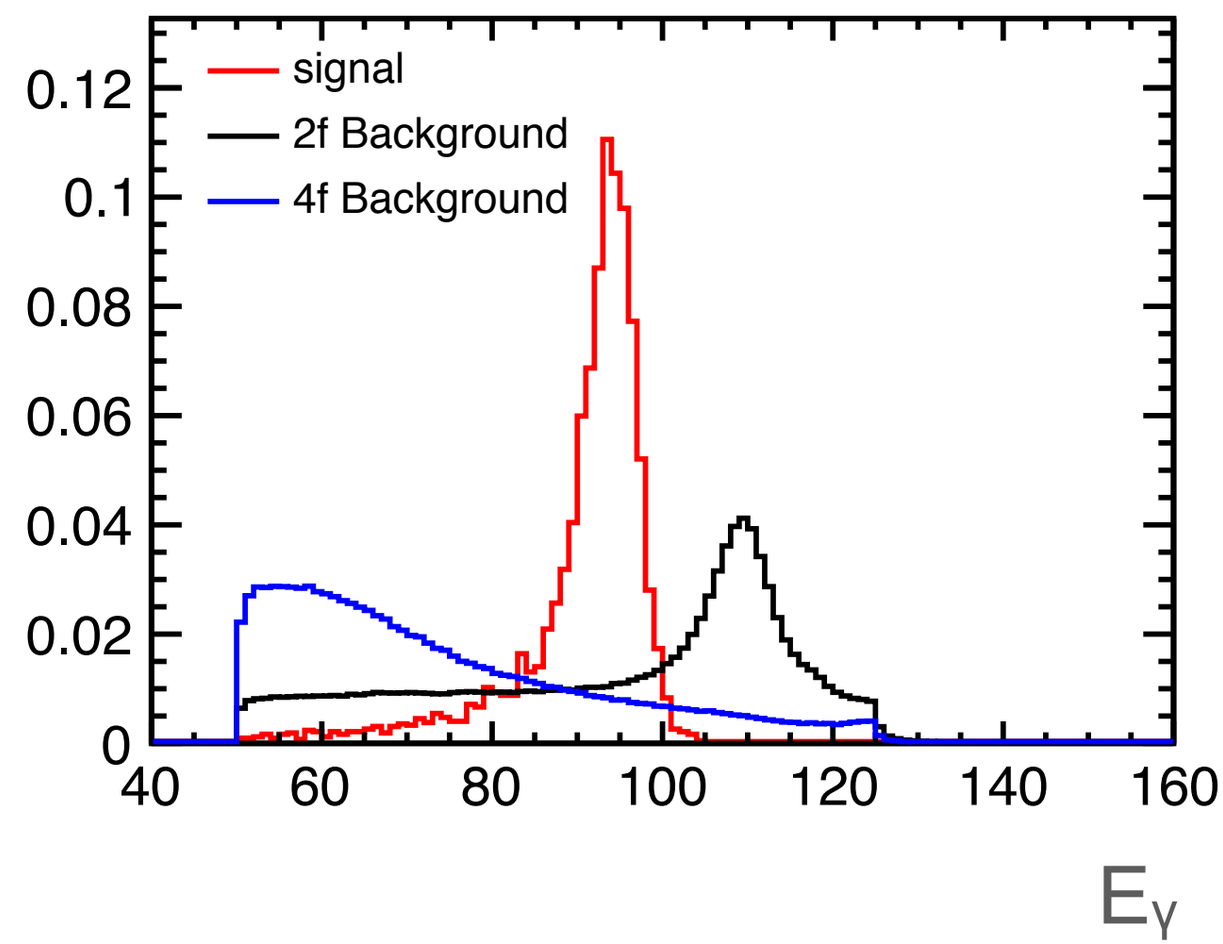
Btag

b likeliness > 0.77



E_γ

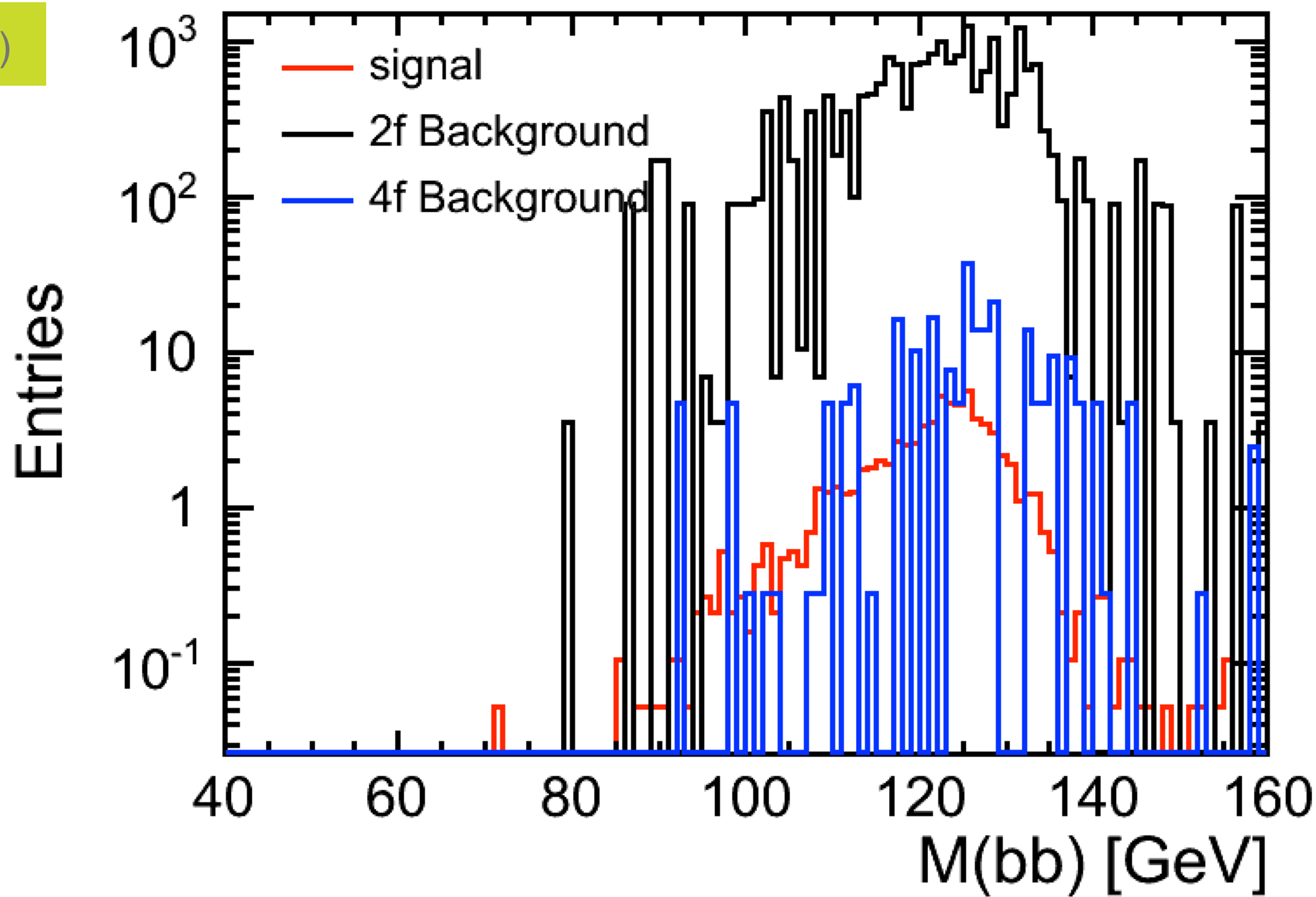
Energy of photon
(later used for MVA)



6. Event selection

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

m(2jets)



7. Result

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

Reduction table Preliminary

N_s:Number of signal
N_B:Number of background

	Signal	background	Significance
Expected	237	3.14×10^8	0.01
Pre selection	222	6.54×10^7	0.02
btag>0.77	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

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}}\sigma_{SM}$

= 4.1 × 0.35 [fb] Significance = 0.53 for SM

=1.43 [fb] （Left handed beam polarization case）

8. Combined result

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

Higgs production (H→bb)

Significance = 0.53 for SM

4.1> @95 % C.L.

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

assume ζ_A =0

Phys.Rev. D94 (2016) 095015

-0.011 < @95 % C.L. ζ_{AZ} <0.0037

Higgs decay (BR(H→Zγ))

Significance = 2.31 ± 0.03 for SM

1.71> @95 % C.L.

$$\frac{\mathrm{BR}(H \to \gamma Z)}{\mathrm{BR}_{SM}} = 1 + 290\zeta_{AZ} \quad >0$$

arXiv:1708.09079v3 [hep-ph]

-0.0034< ζ_{AZ} **<0.0024** @95 % C.L.

Combined expected 1σ bound on ζ_{AZ} **-0.0015 < ζ_{AZ} < 0.0015**

9. Event selection - h→WW*

① Pre selection

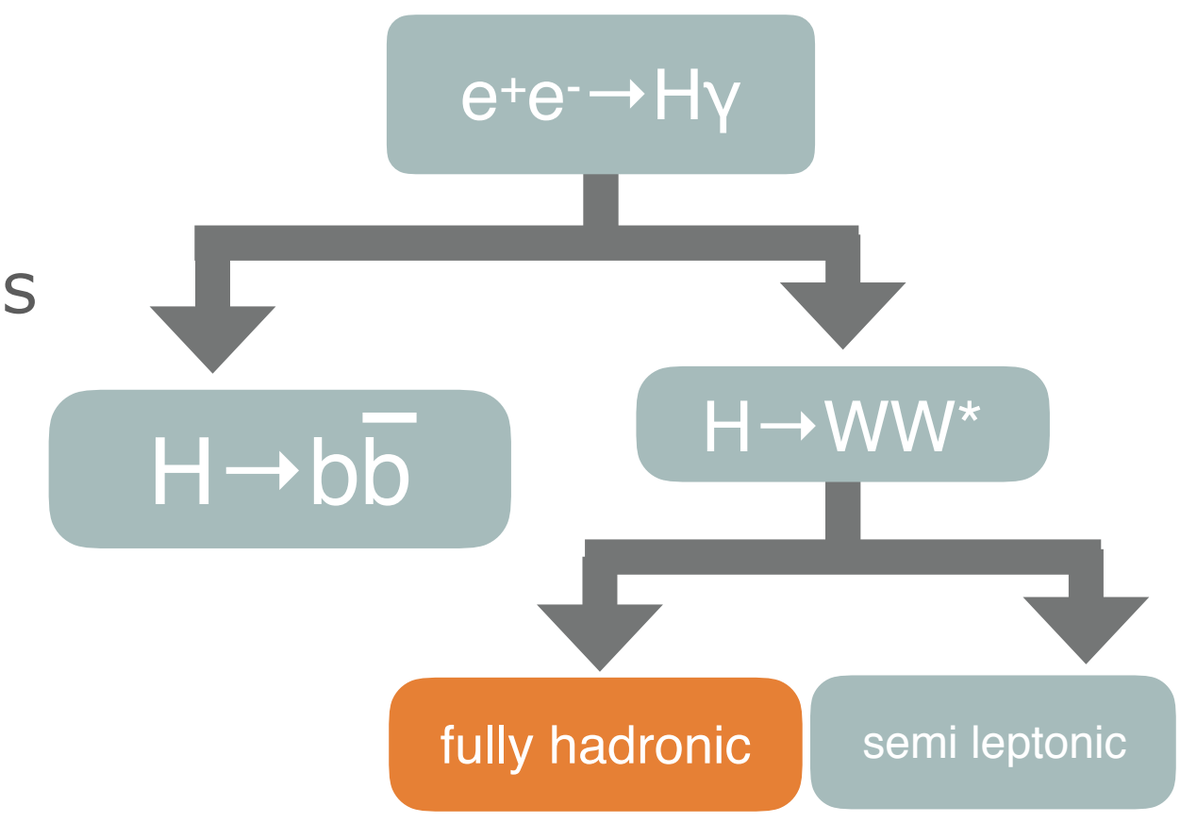
Signal: $e^+e^- \to \gamma h \to \gamma(WW^*) \to \gamma$ (4f)

Signal signatures

1. Isolated monochromatic photon with energy 93 GeV
2. 4 jets (fully hadronic)
3. m(4jet)= Higgs mass
4. one of m(2jet)= W mass

Main backgrounds

$e^+e^- \to W^+W^-(\gamma)$



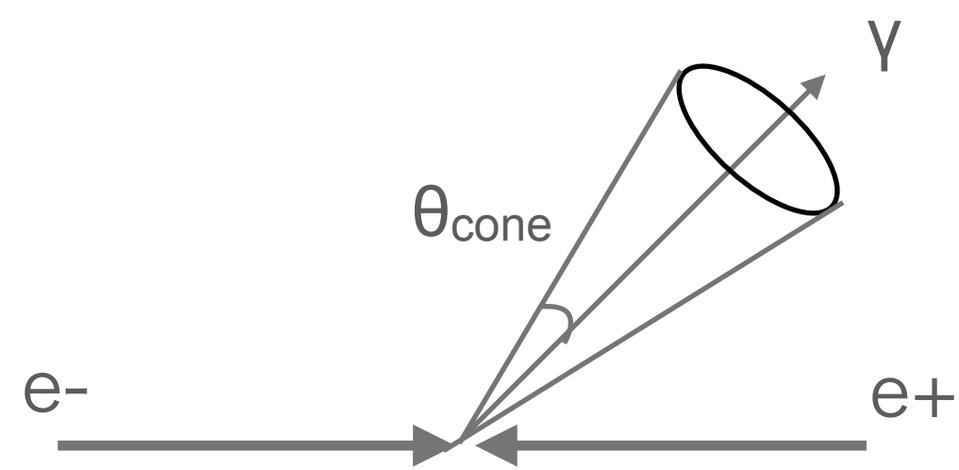
9. Event selection - h→WW*

① Pre-selection

・Isolated photon

➤ Photon ID

➤ $E_\gamma > 50$ GeV



※The split photon clusters within a small cone are recovered

➤ ($\cos\theta_{cone}$=0.998)

→Left events except photon

➤ 4jet clustering (Durham)

➤ Flavor tagged（LCFI+）

For signal

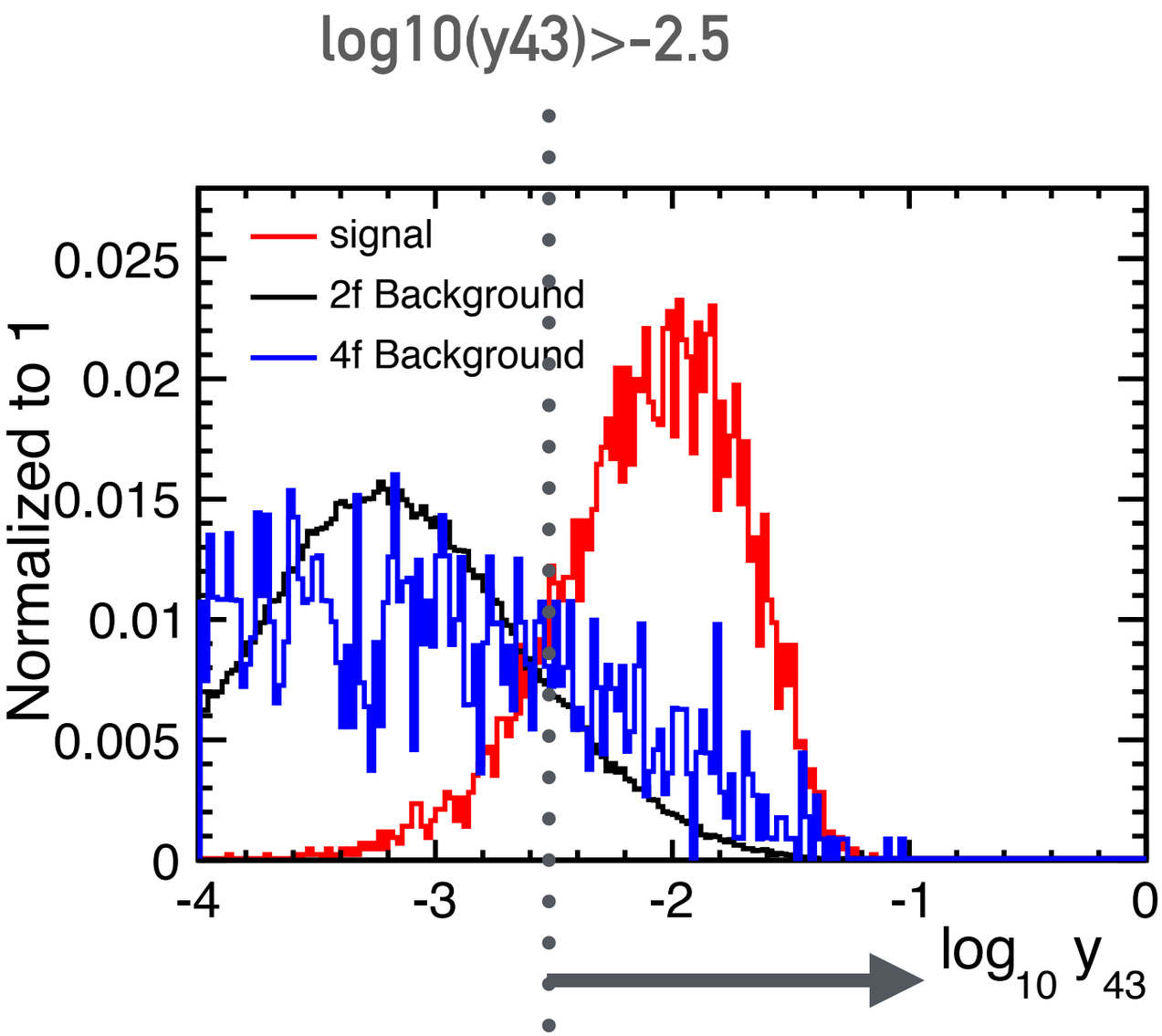
number of decay w to qq=2

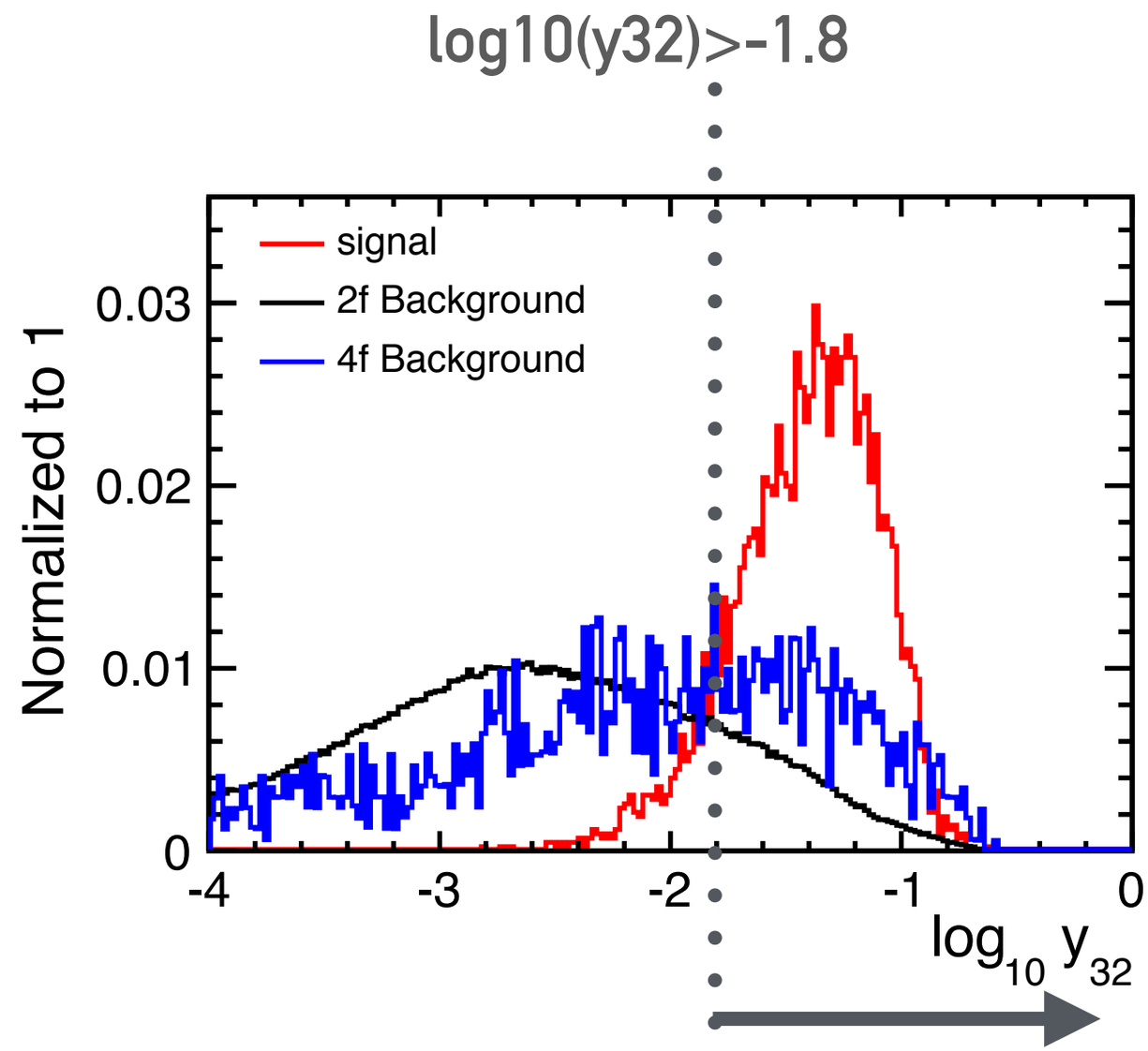
10. Signal & Background - h→WW* (1)

$e^+e^- \to \gamma h \to \gamma(WW^*)$	e^+e^- -> 2f
number of particles in jet →many	number of particles in jet →(l,v)One
# of particle>5	
number of charged particles in jet →many	number of charged particles in jet →One
# of charged particle >1	
y43, y32 →large	y43, y32 →relatively small
y43, y32	

11. Event selection - h→WW*

The distribution of y43 and y32 for signal and background events



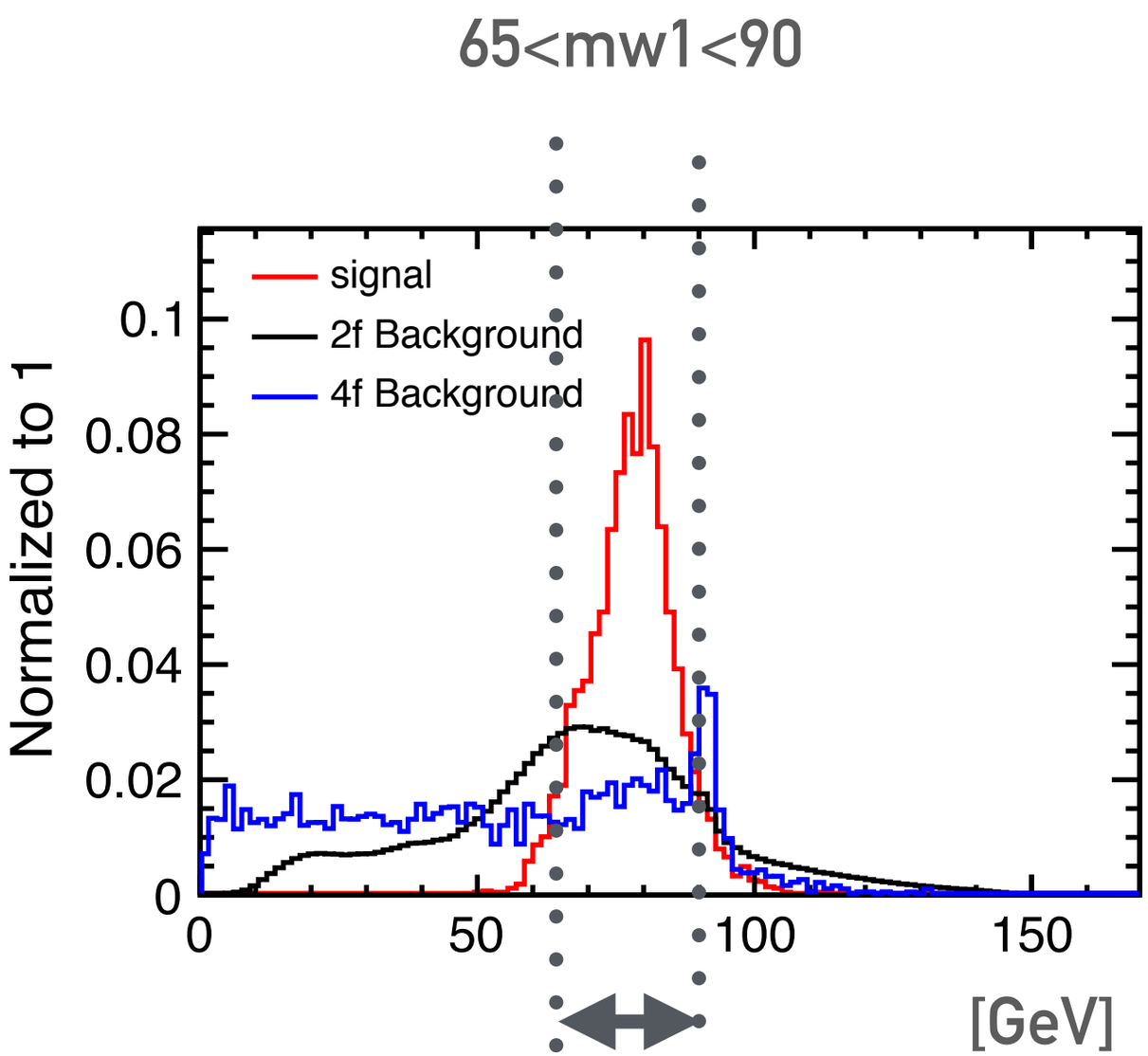


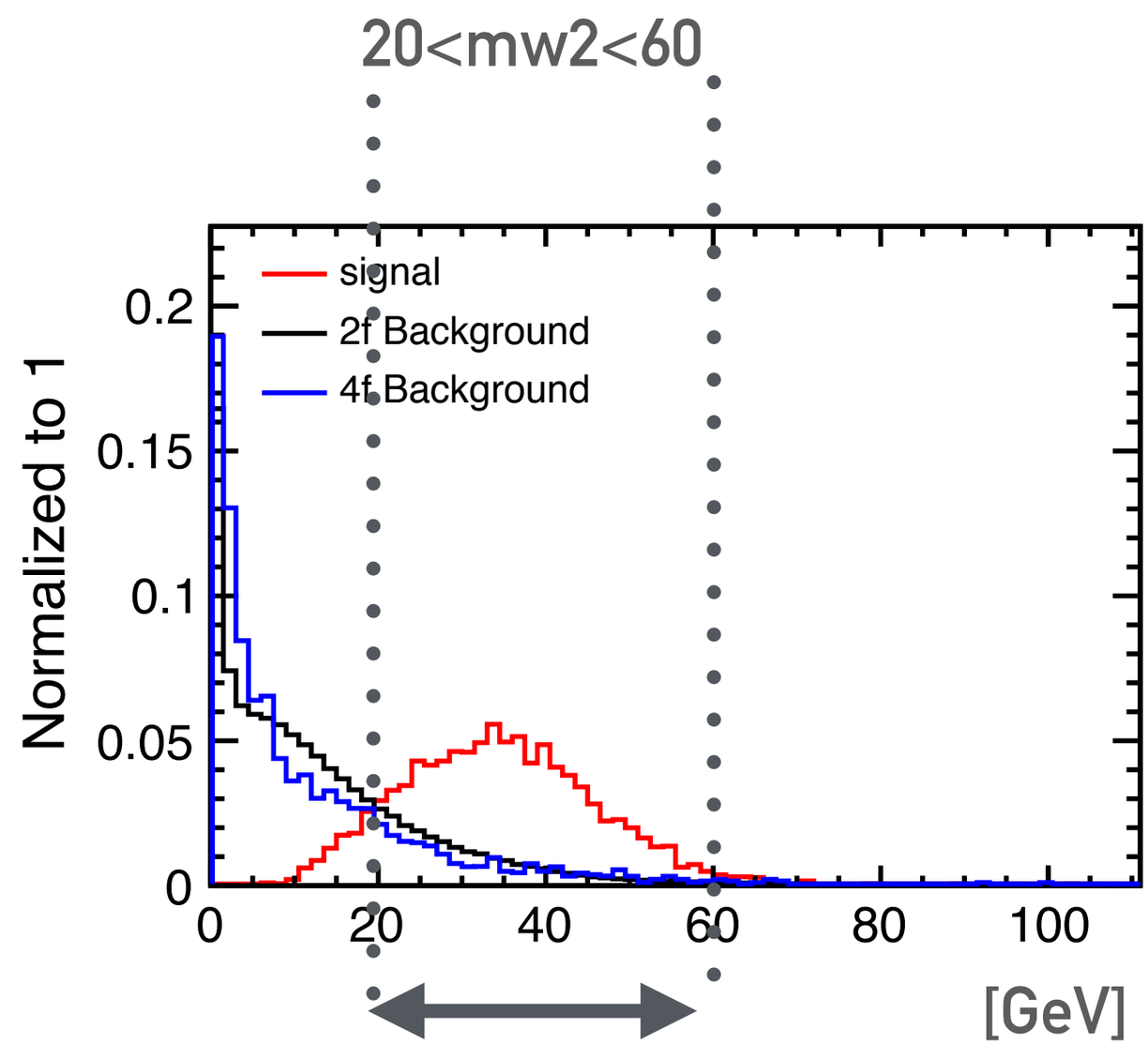
※ This plot is for events after the pre selection

12. Signal & Background - h→WW* (2)

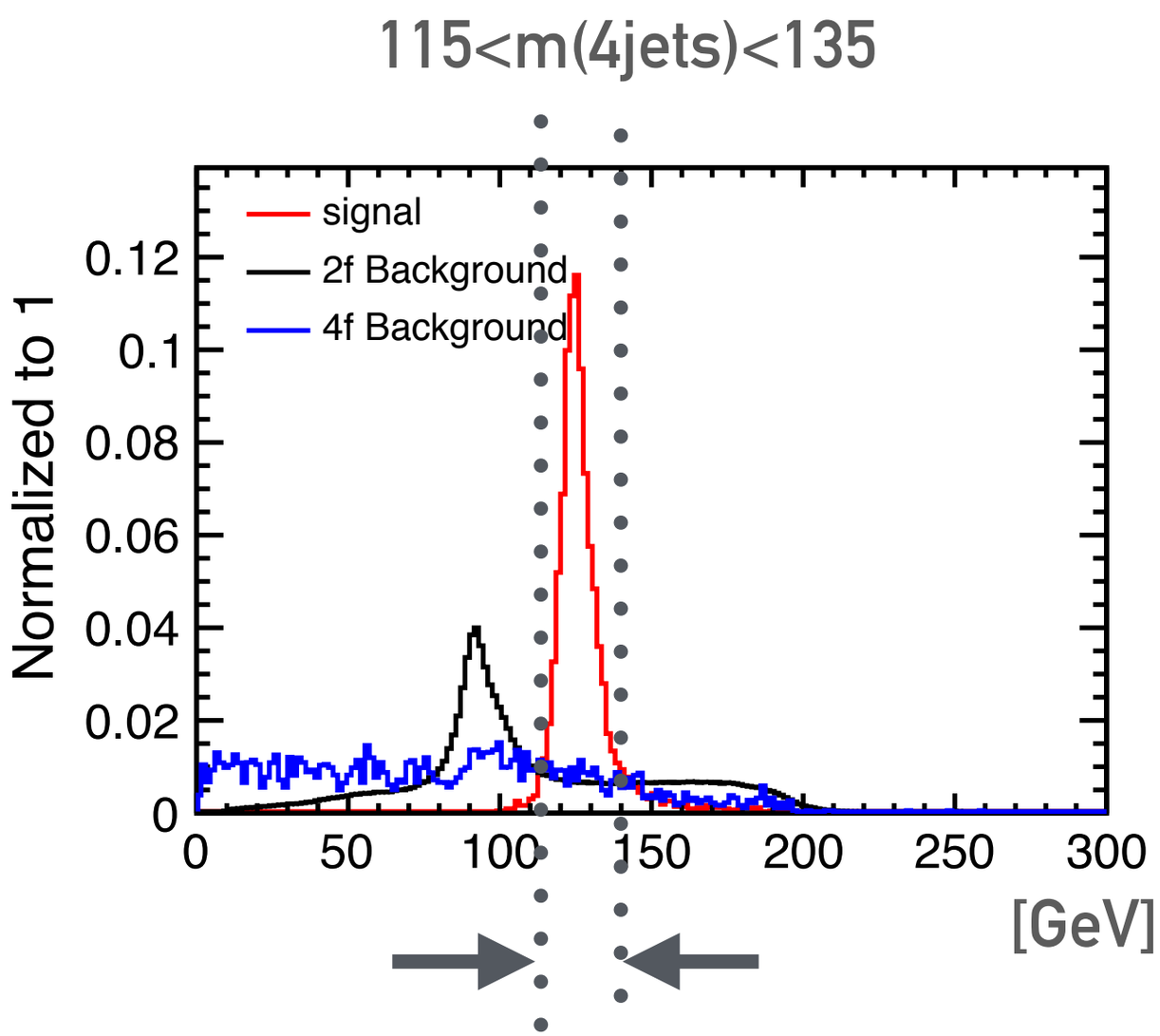
$e^+e^- \to \gamma h \to \gamma(WW^*)$		$e^+e^- \to W^+W^-(\gamma)$
mass other than real W < 50 GeV	m(W2)	mass other than real W ~80 GeV
m(4jets)= higgs mass	m(4jets)	m(4jets)= center mass energy
Energy of isolated monochromatic photon ~93 GeV	$m\gamma$	Energy of photon ~small

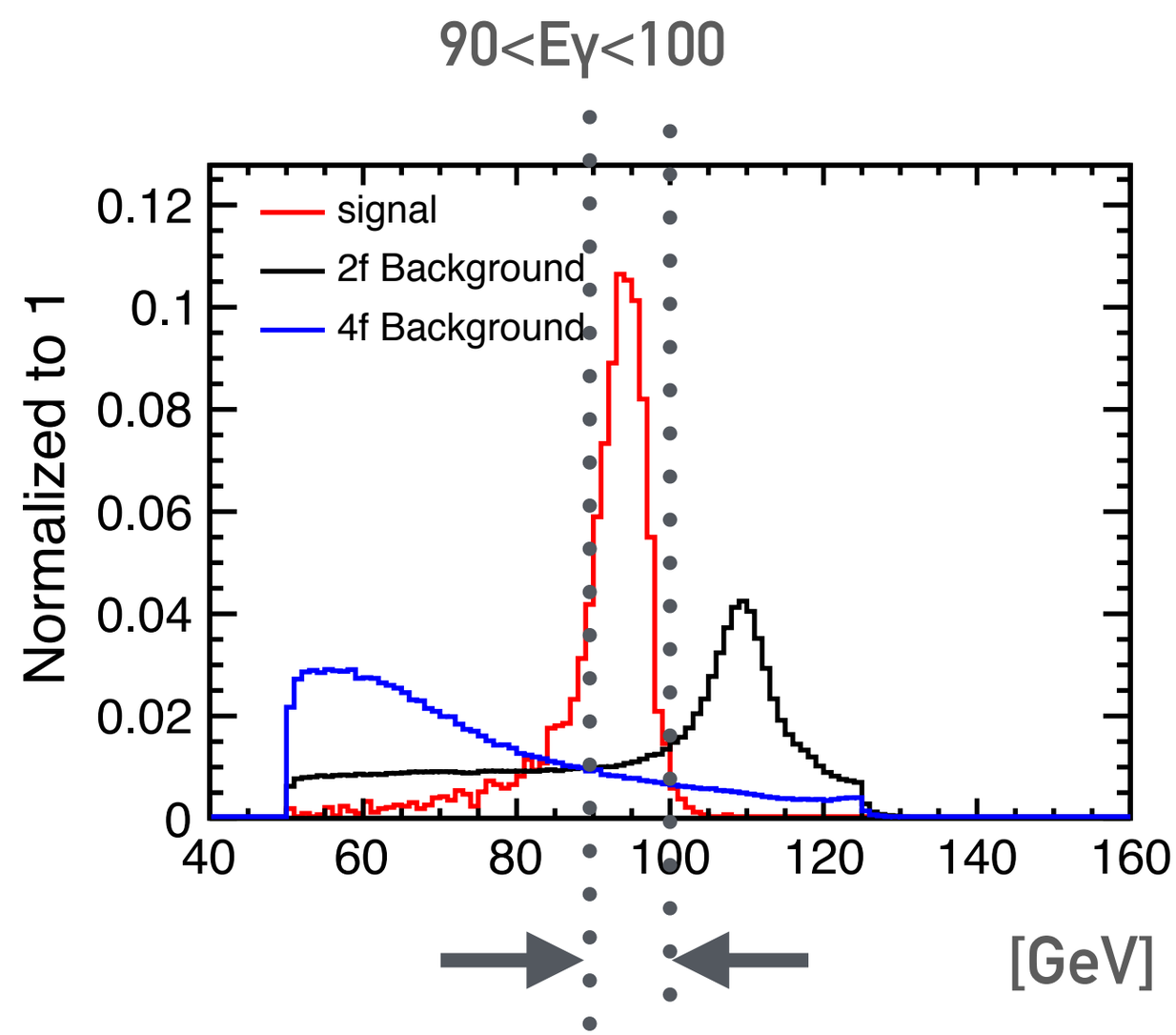
13. Event selection - h→WW*



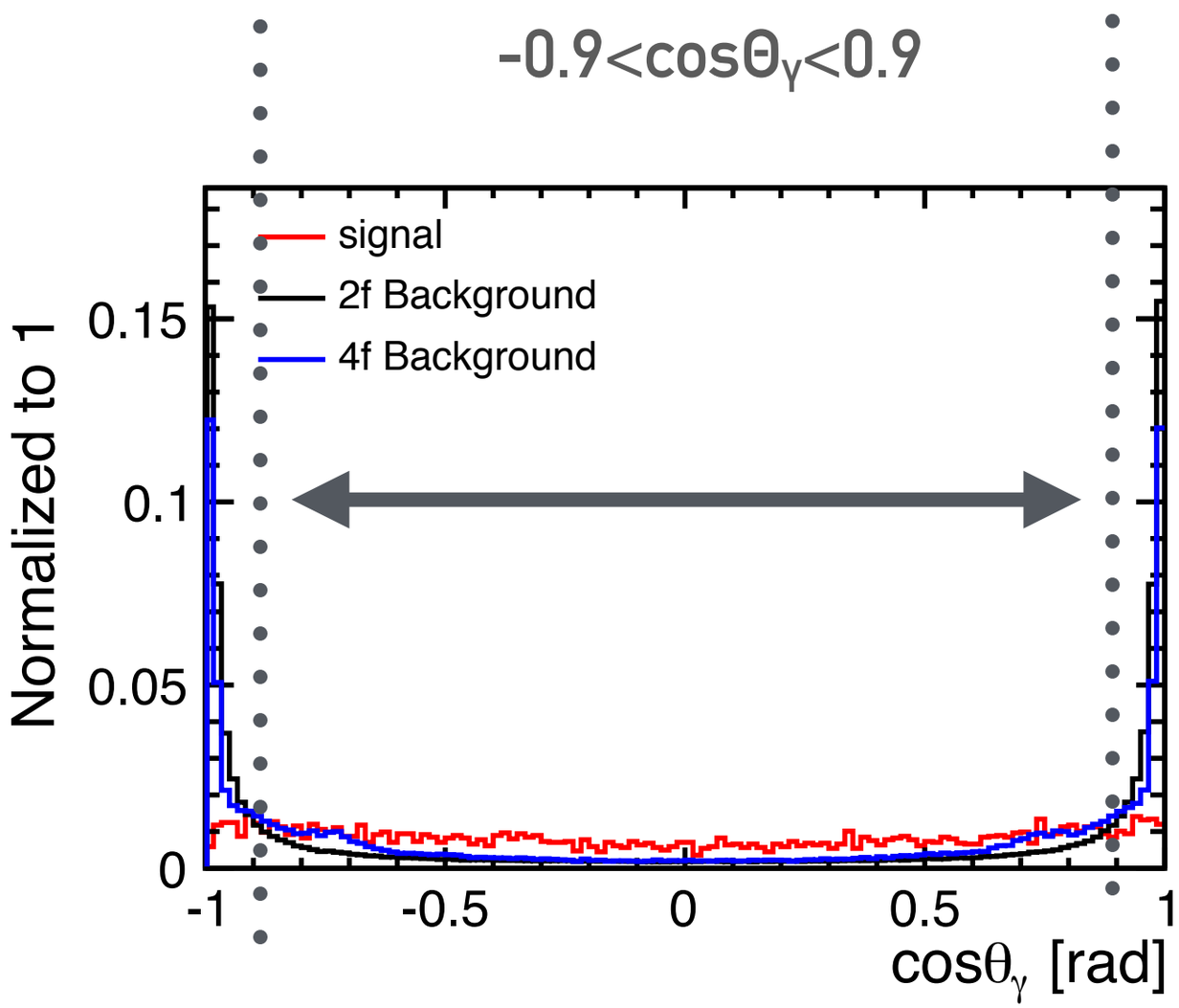


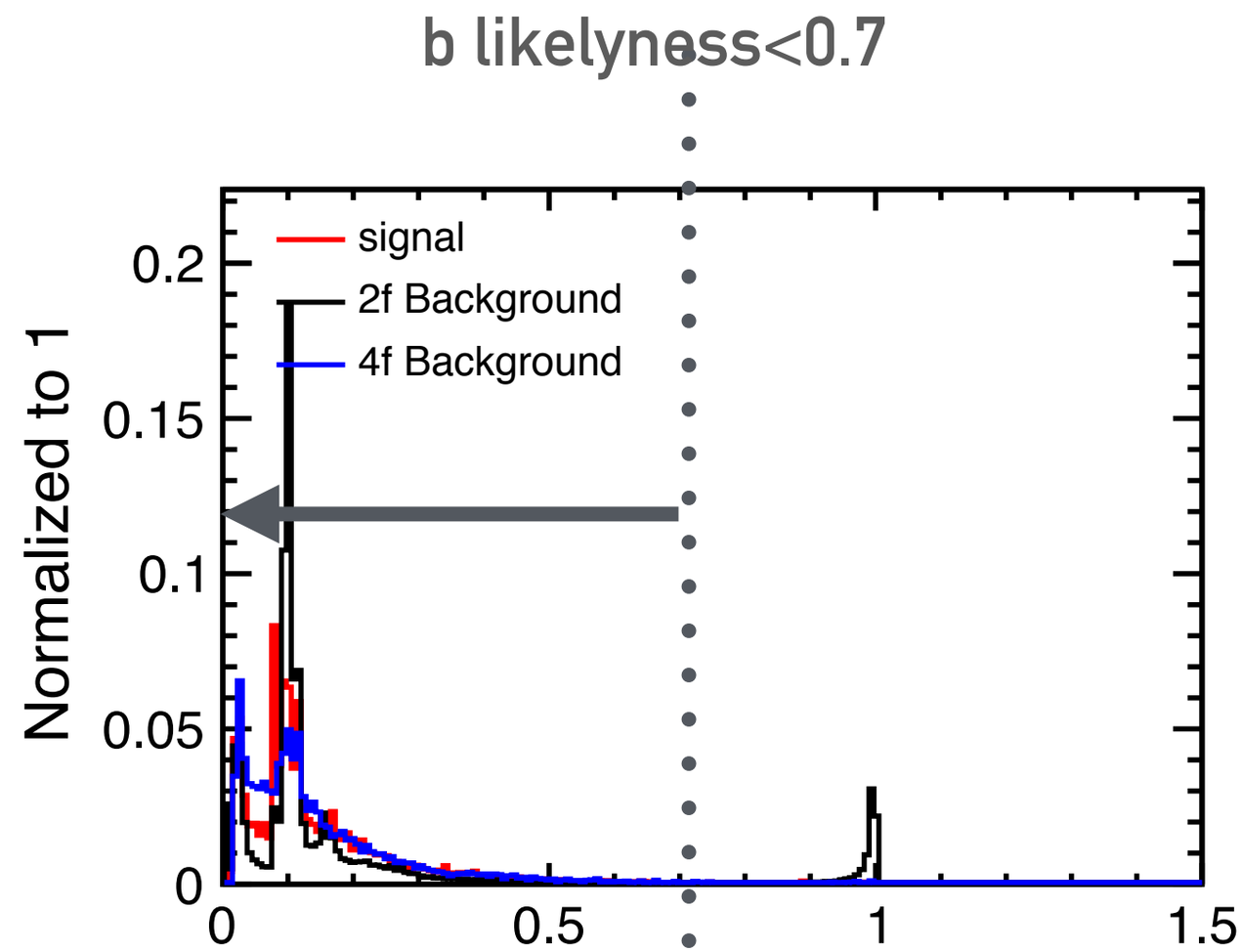
13. Event selection - h→WW*

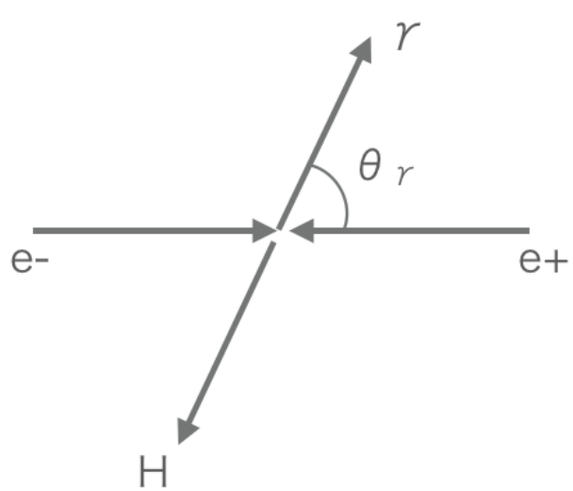




13. Event selection - h→WW*







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

14. Reduction table - h→WW*

	2f_h	4f_h	total bg	Signal	Signal hadronic	Significance
Expected	156093000	33599400	314154000	88.5	40.2	0.005
Pre selection	27978300	760090	61010200	80.5	37.7	0.01
# of particle>5	10295600	681904	11233500	36.5	32.0	0.01
# of charged particle >1	5940470	591493	6646540	28.0	25.9	0.01
log10(y43)>-2.5 log10(y32)>-1.8	951914	527681	1515780	21.8	20.9	0.02
65<mw1<90	348875	495465	860262	19.2	18.9	0.02
20<mw2<60	235286	311623	559275	17.6	17.4	0.02
115<mx<135	53738	15634	74447	15.7	15.6	0.06
90<Eγ<100	21447	5494	27290	11.8	11.8	0.07
-0.9<cosΘ<0.9	10636	3758	14525	10.3	10.3	0.09
bmax1<0.7	9746	3696	13558	10.0	10.0	0.09

Preliminary

9. Summary

We have performed a full simulation study of $e^+e^- \to H\gamma$ at 250 GeV ILC, using ILD detector.

We found signal significance **0.53σ** for SM at $\sqrt{s}$=250 GeV, 2000 fb^{-1}.

To parametrize BSM effects model independently, we adopt an EFT Lagrangian containing an anomalous HγZ coupling.

We found the $e^+e^- \to H\gamma$ process gives the following constraint on the coefficient for this anomalous coupling, ζ_{AZ} :

$$\textbf{-0.011(@95\% C. L.) <} \ \zeta_{AZ} < 0.0037$$

Combining with constraint from BR(H→γZ) measurement at ILC, we found 1σ bound : $-0.0015 < \zeta_{AZ} < 0.0015$

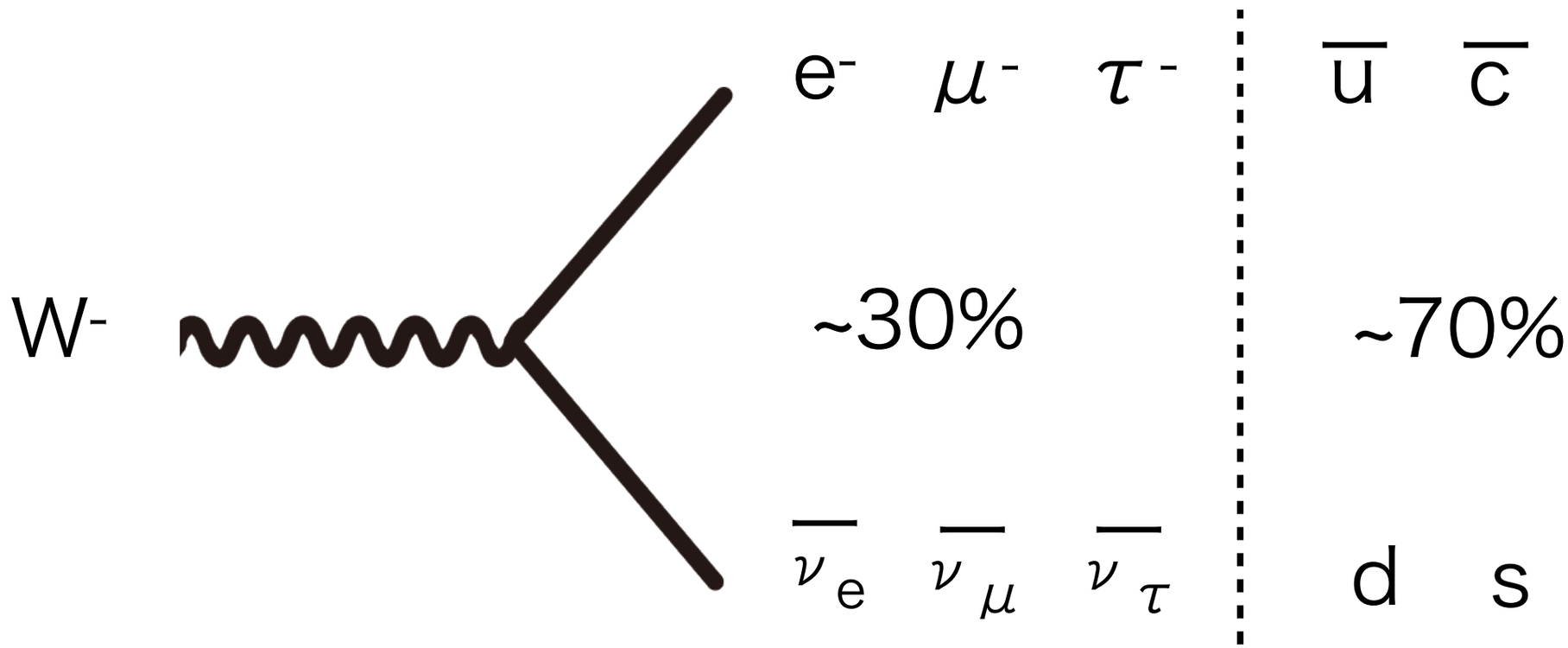
Next step

- Include H→WW* channel (on going).
- Understand the role of this measurement in a global EFT analysis.

Back up

$H \rightarrow WW^*$

Strategy



Fully hadronic	~45 %
semi leptonic	~45 %
Fully leptonic	~10 %

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

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

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

Phys.Rev. D94 (2016) 095015

6. Result

→95% C.L upper limit $\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}} \sigma_{SM}$

= 19.2 × 0.35 [fb] Significance = 0.09 for SM

=6.72 [fb] （Left handed）

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

asume ζ_A =0

-0.066> ζ_{AZ} >0.0037

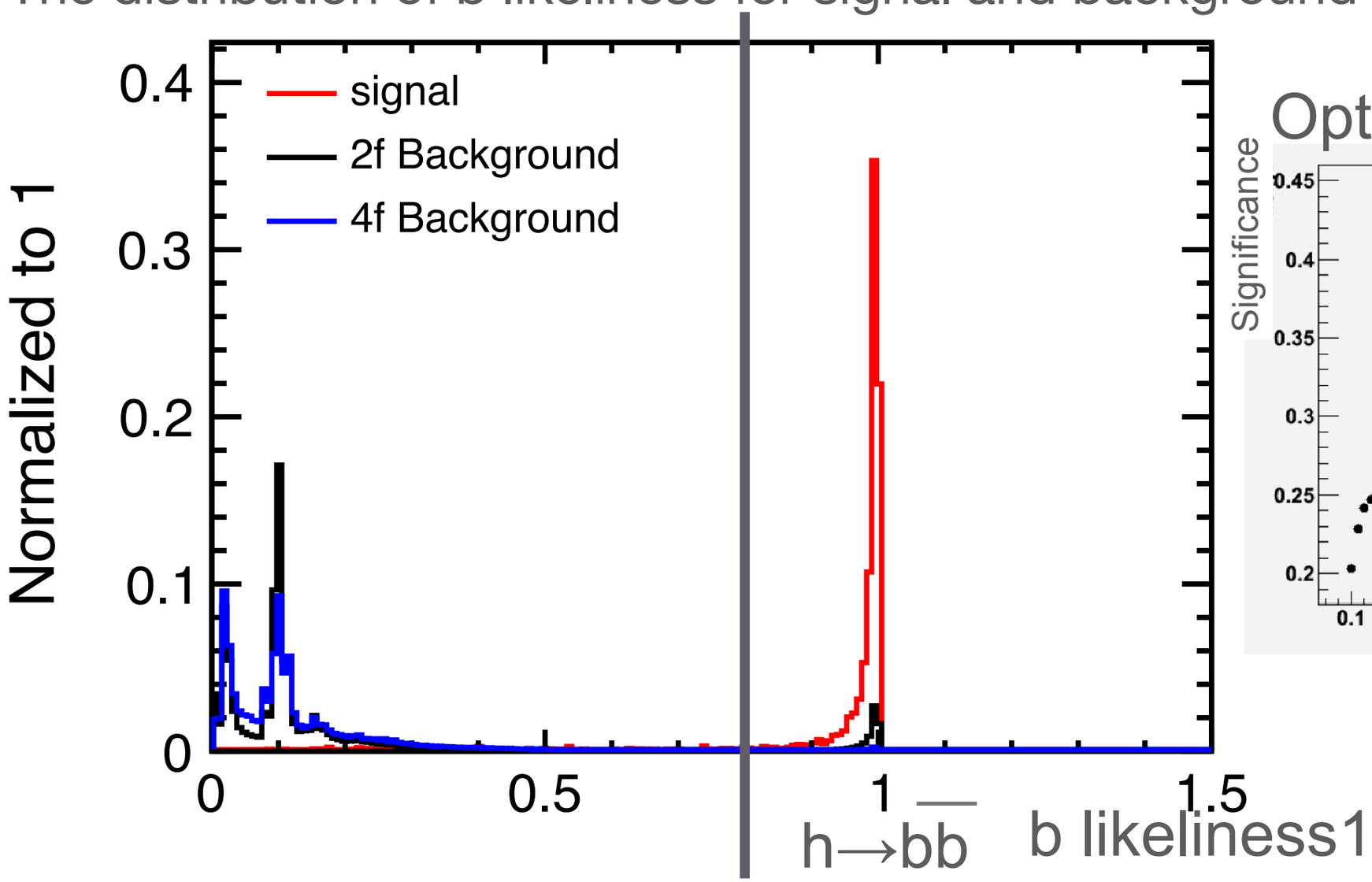
$H \rightarrow bb$

5. Event selection

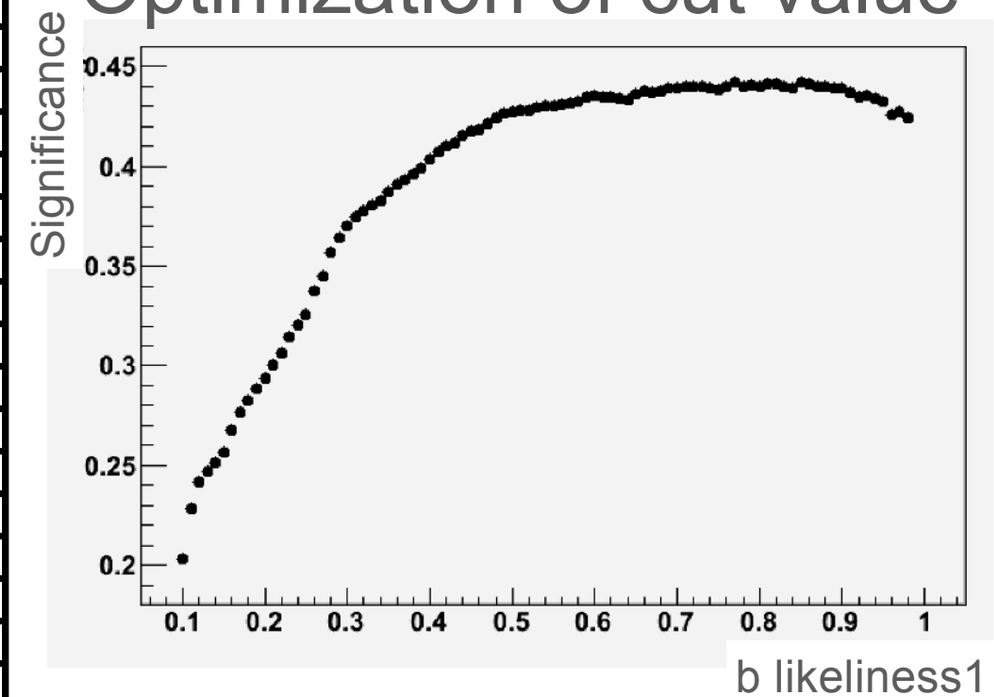
② Final selection

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

The distribution of b likeliness for signal and background events



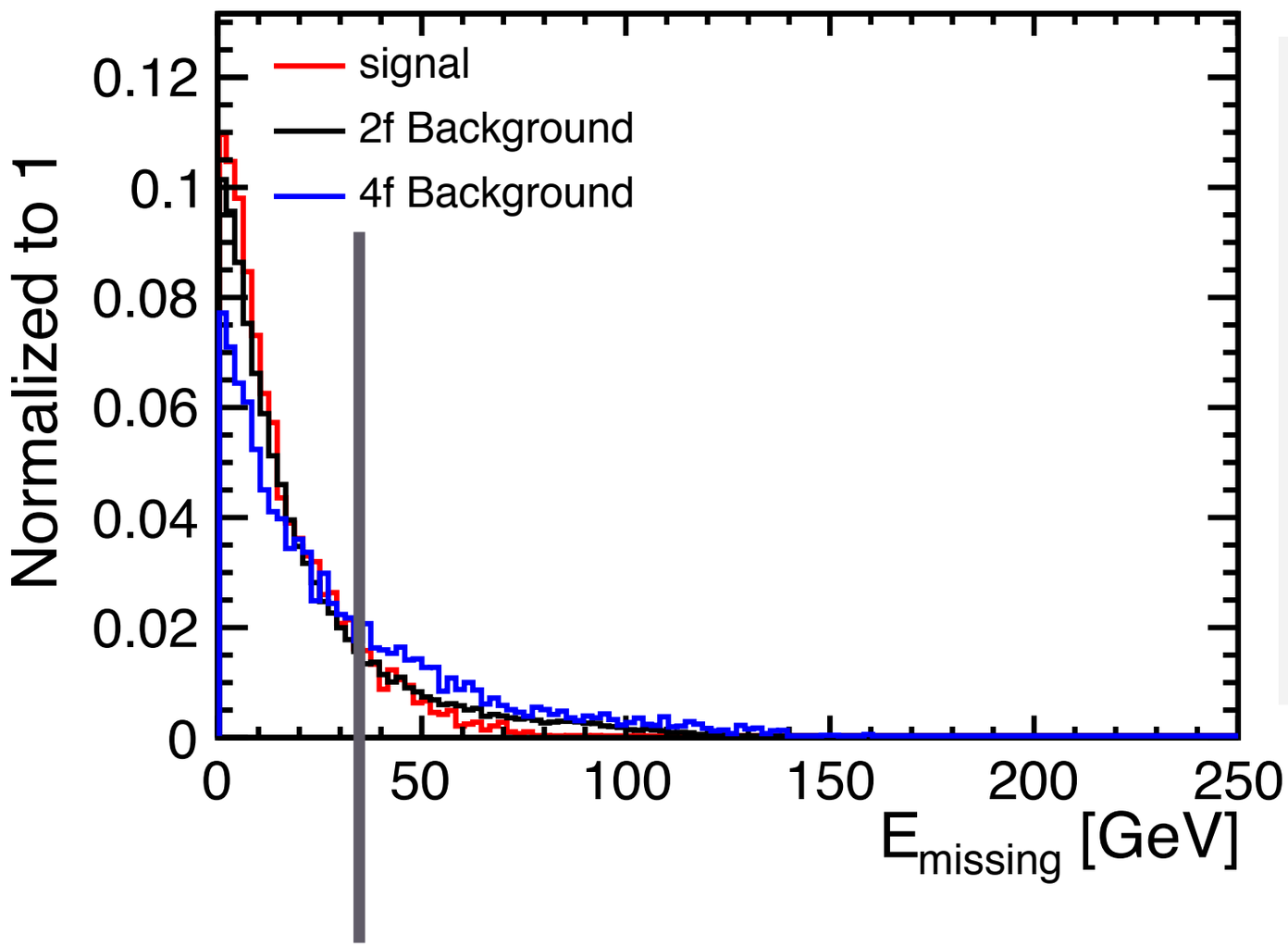
Optimization of cut value

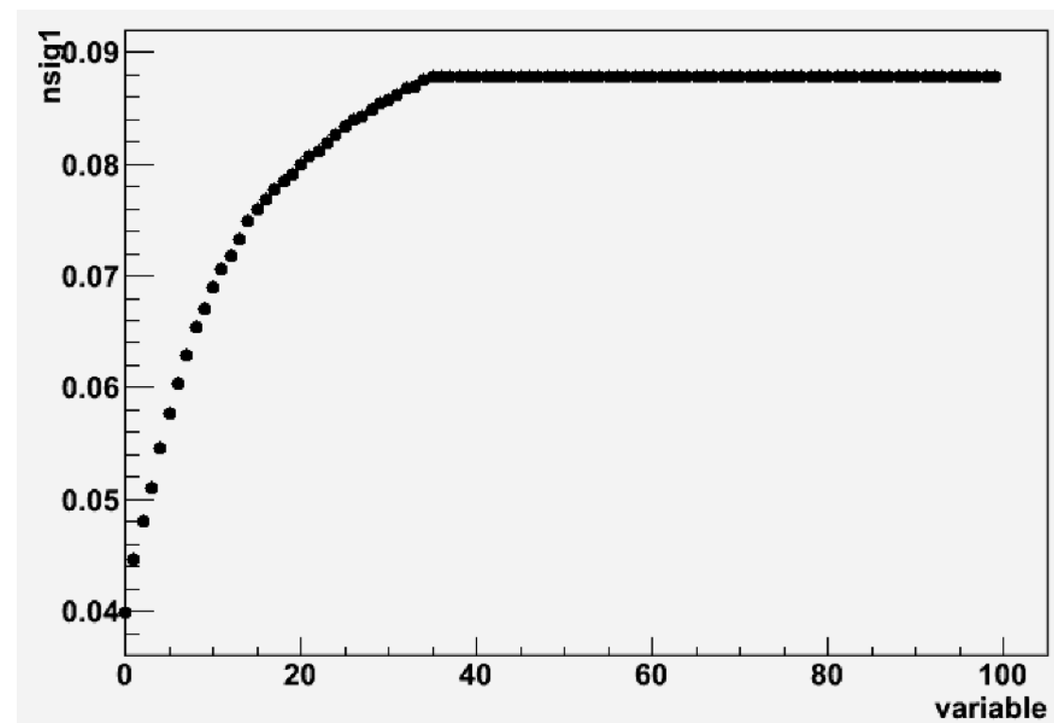


※ This plot is for events after the pre selection

5. Event selection

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

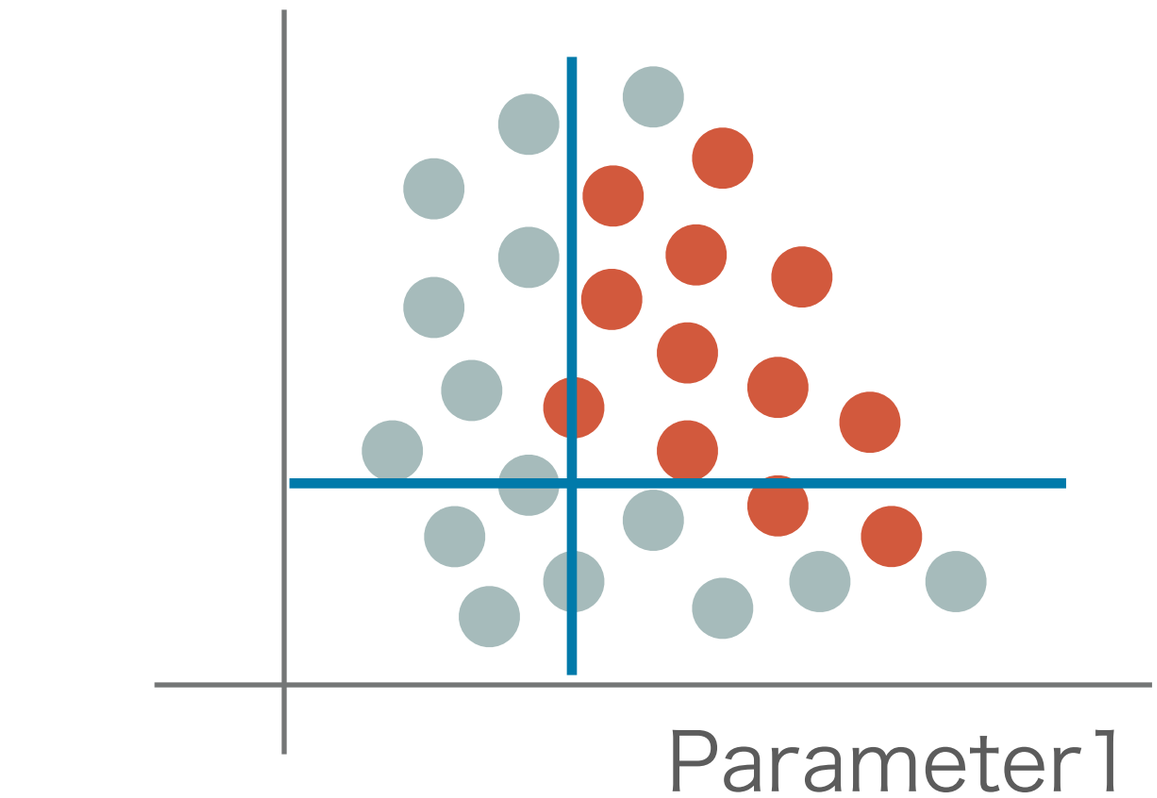




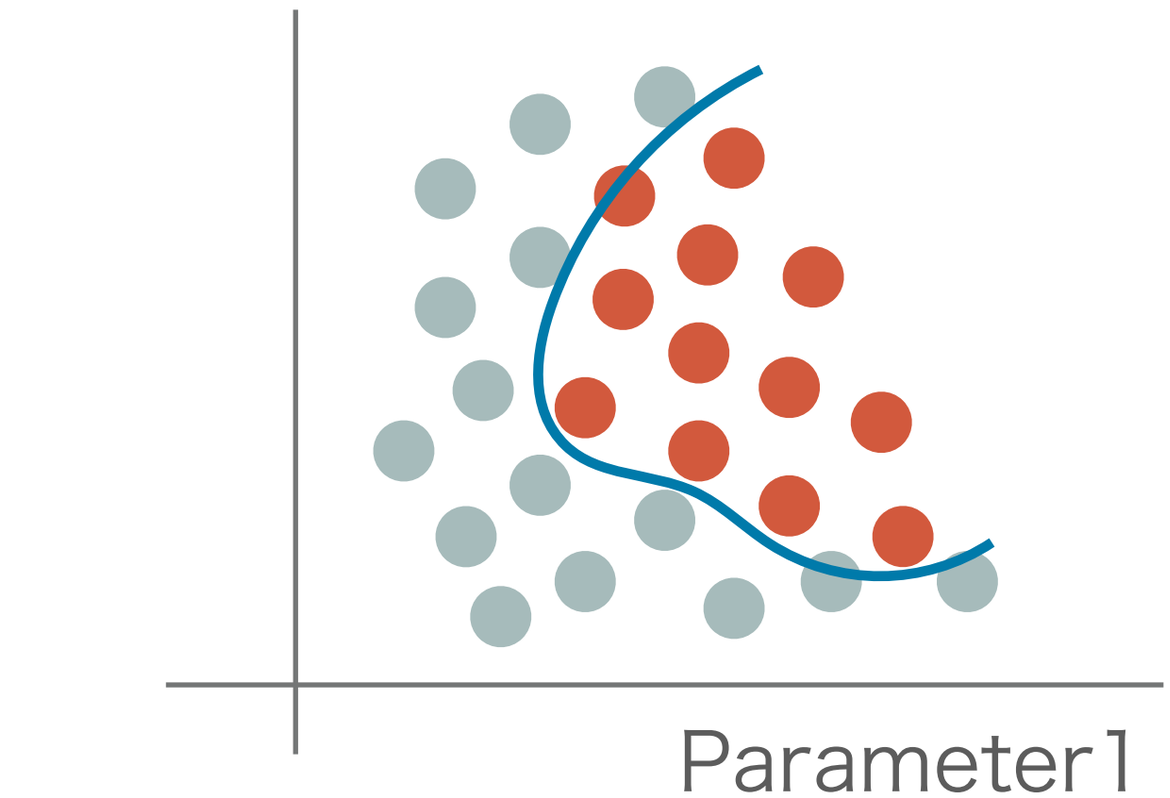
Separation by using TMVA

Multivariate Data Analysis

The cut based analysis



The multivariate data analysis

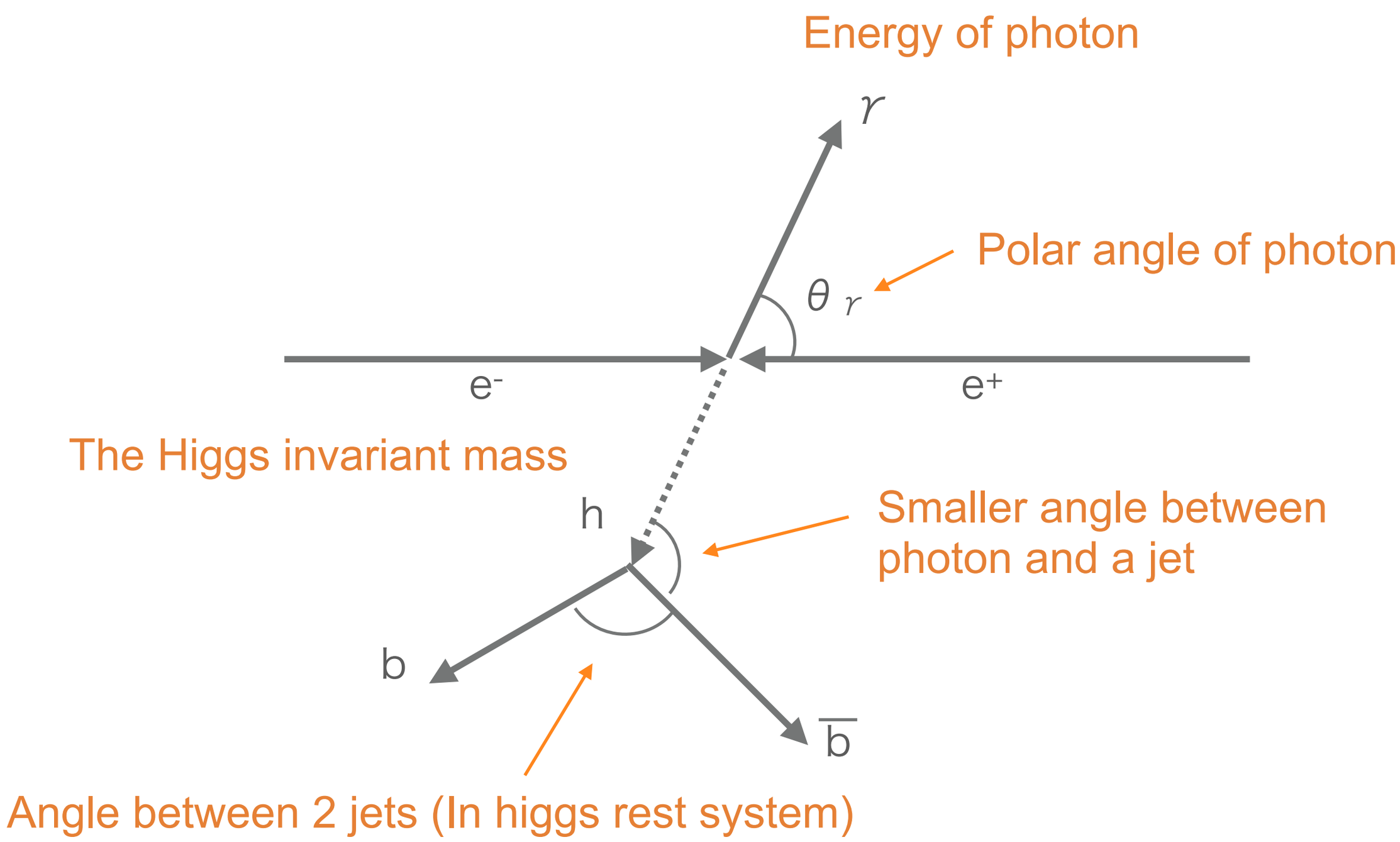


Background Signal

The cut based analysis has its limitation.

→TMVA describes signal-background boundary more flexibly

Input variables for MVA



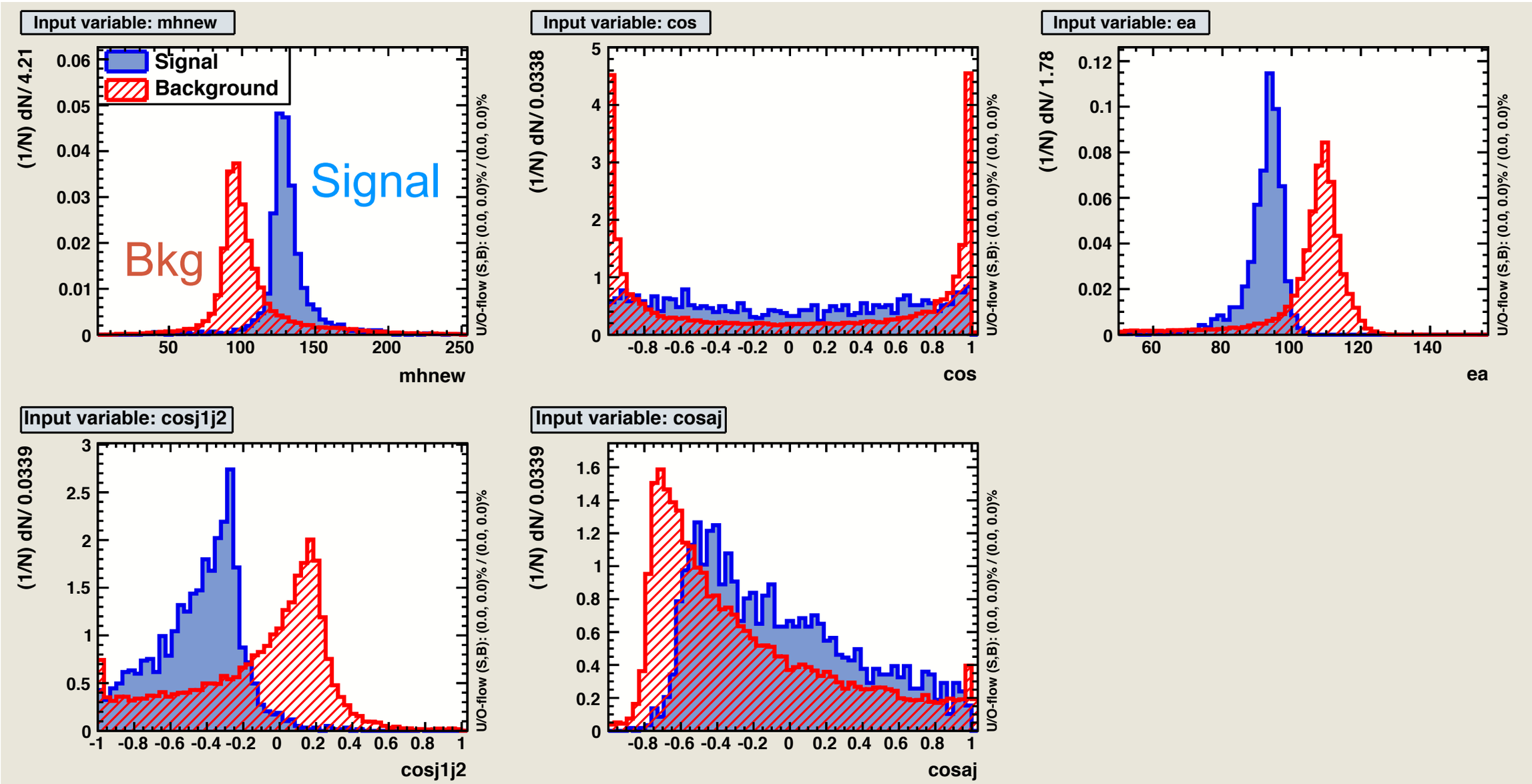
Input variables for MVA

The distributions of each variable for signal and background

The higgs invariant mass

Polar angle of photon

Energy of photon



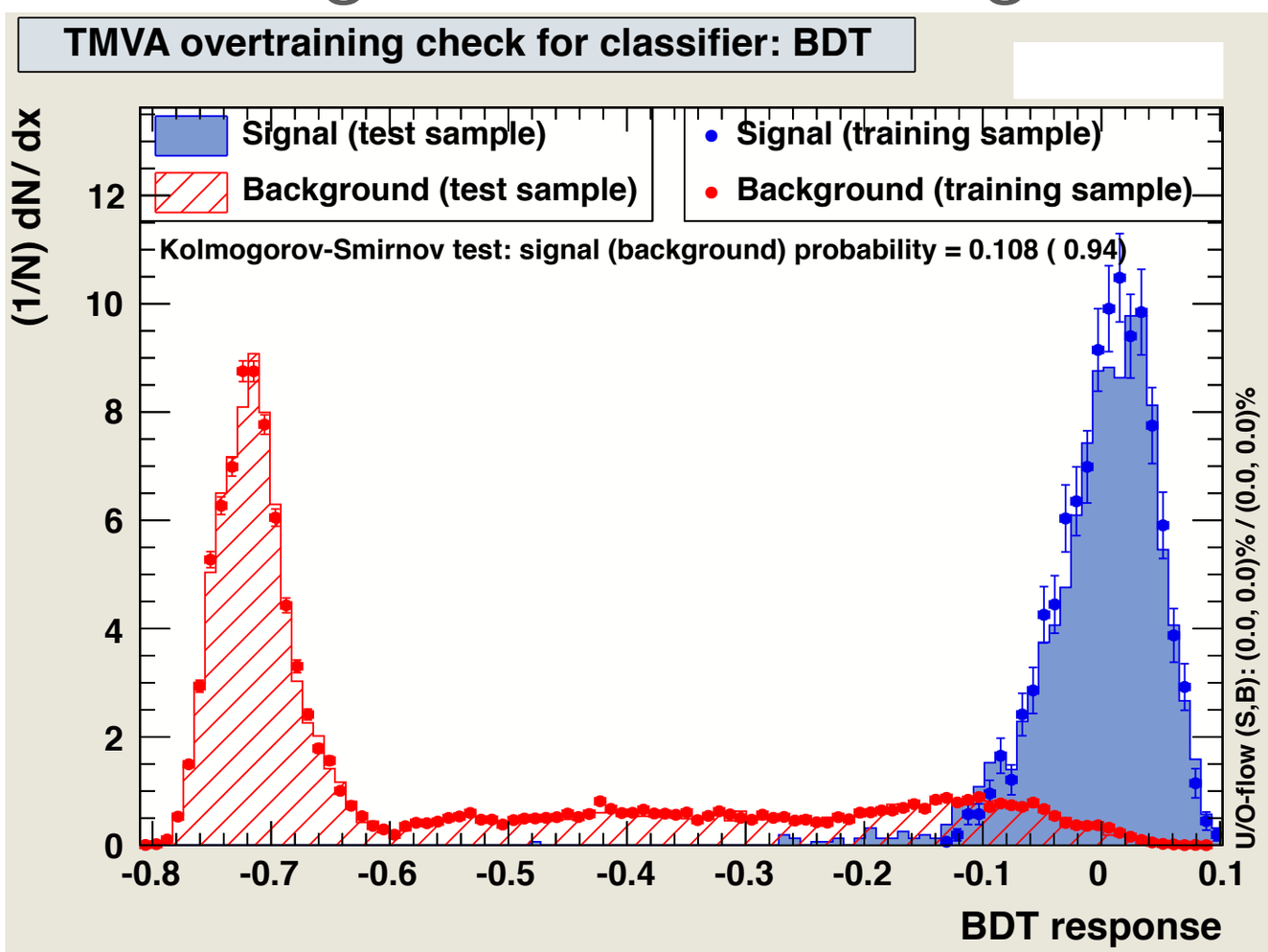
Angle between 2 jets

Smaller angle between photon and a jet

Separation by using TMVA

TMVA analysis procedure

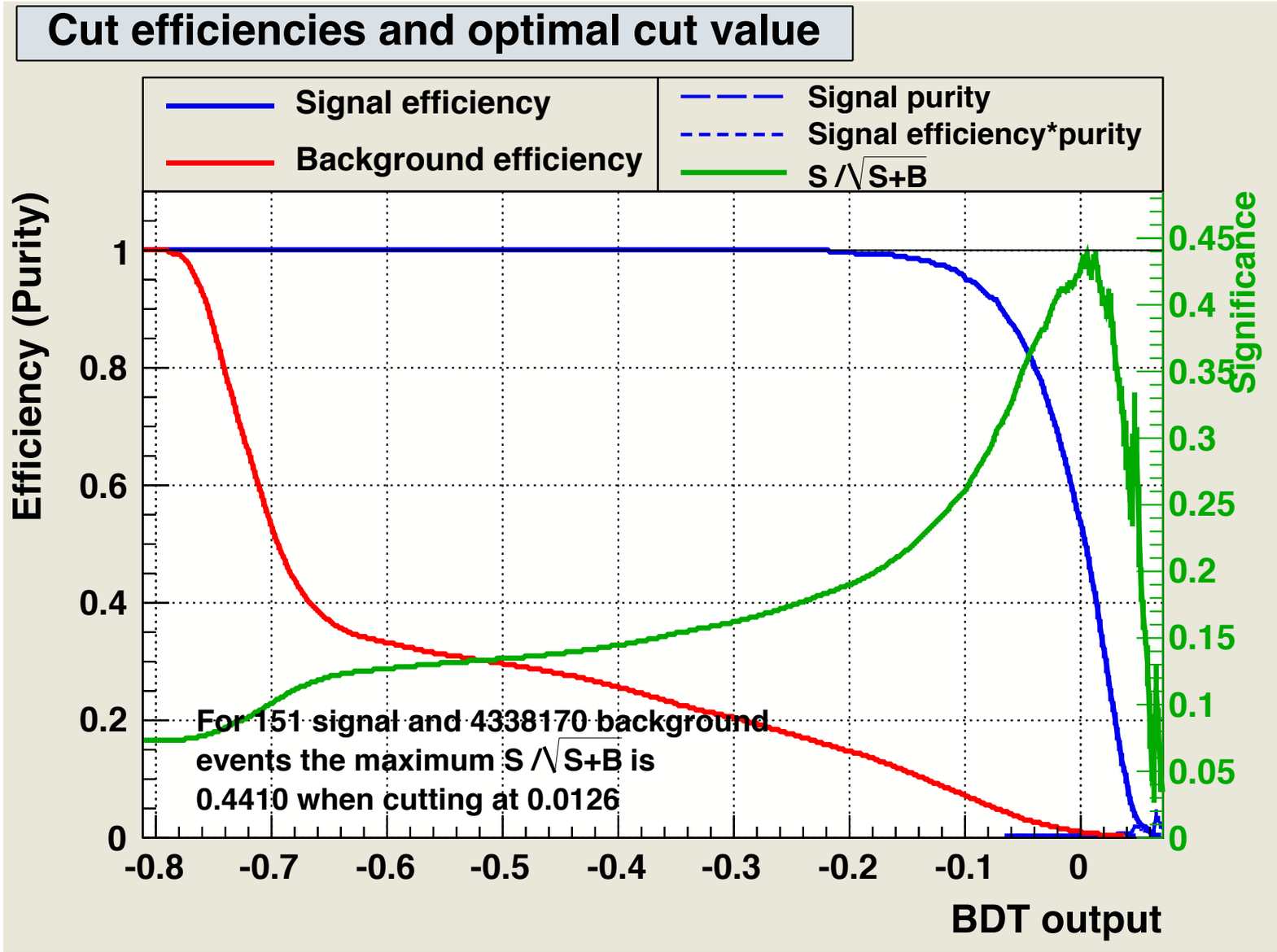
1. [Training step]Teach TMVA the characteristics of signal using signal and background training samples
2. Apply the training result to real signal and background



Make sure over training is exist or not.

for 63 signal and 20342 background

7. Separation by using TMVA



	Before cut	After cut
# of signal	151	63
# of background	4338170	20342

Significance = 0.44

6. Result

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

Reduction table Preliminary

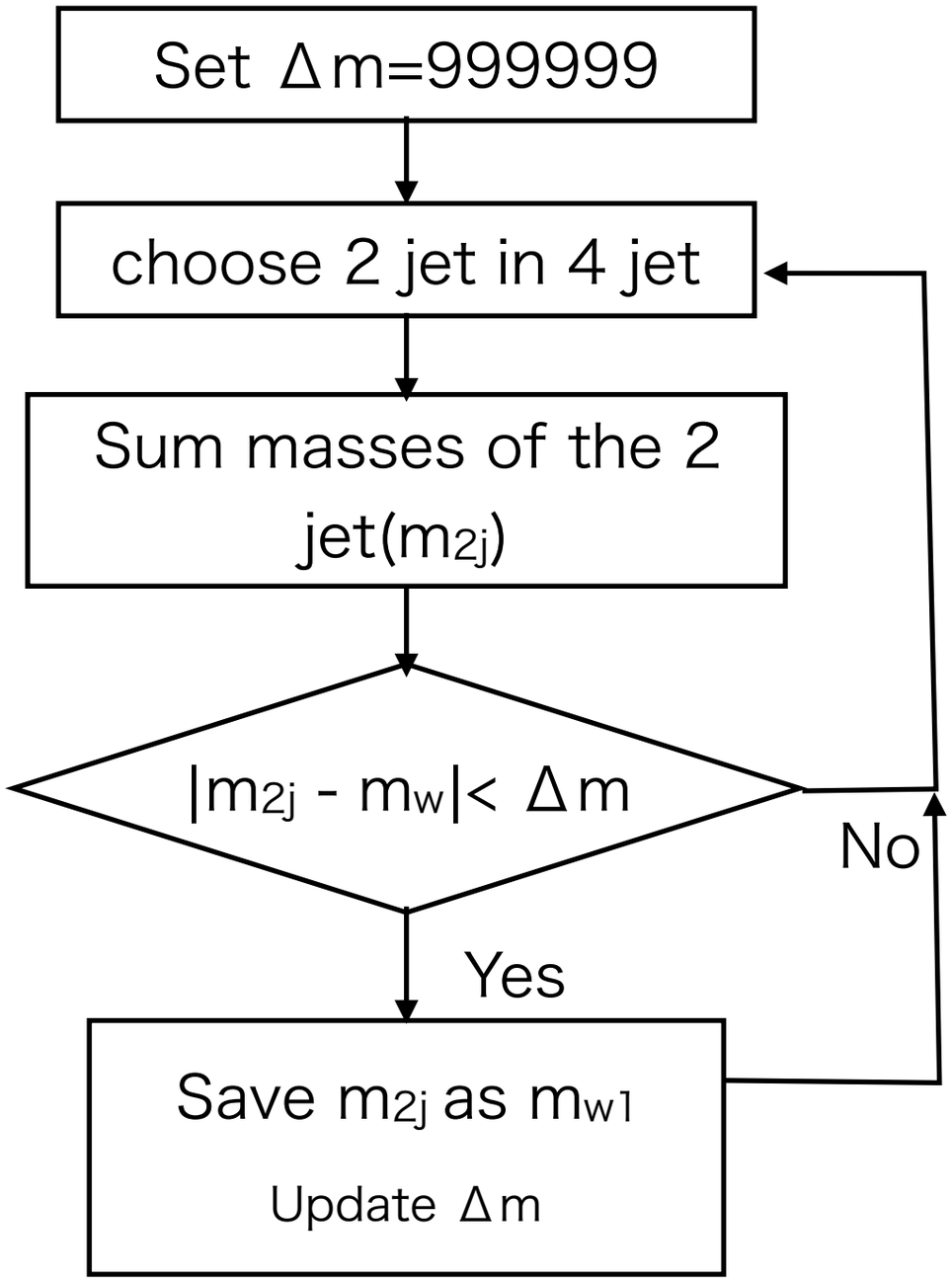
N_s:Number of signal
N_B:Number of back ground

	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

OTHERS

4jet clustering

- We need to find combination of 2 jet from 4 jet of real W (m_w=80.379)



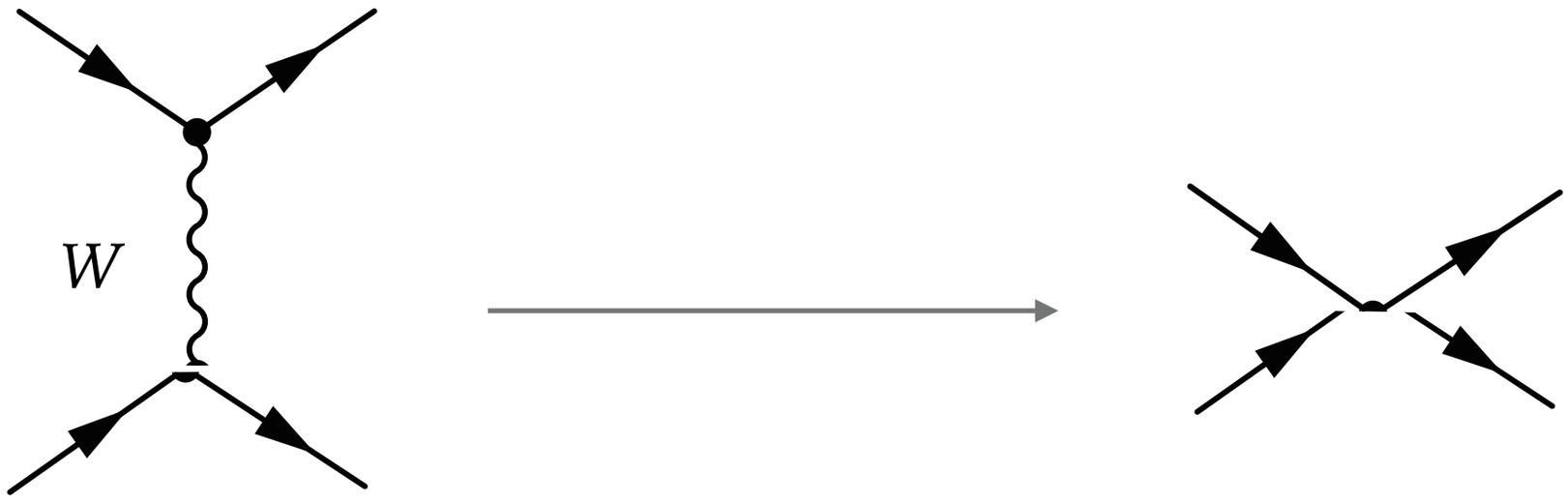
5. Event selection

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)

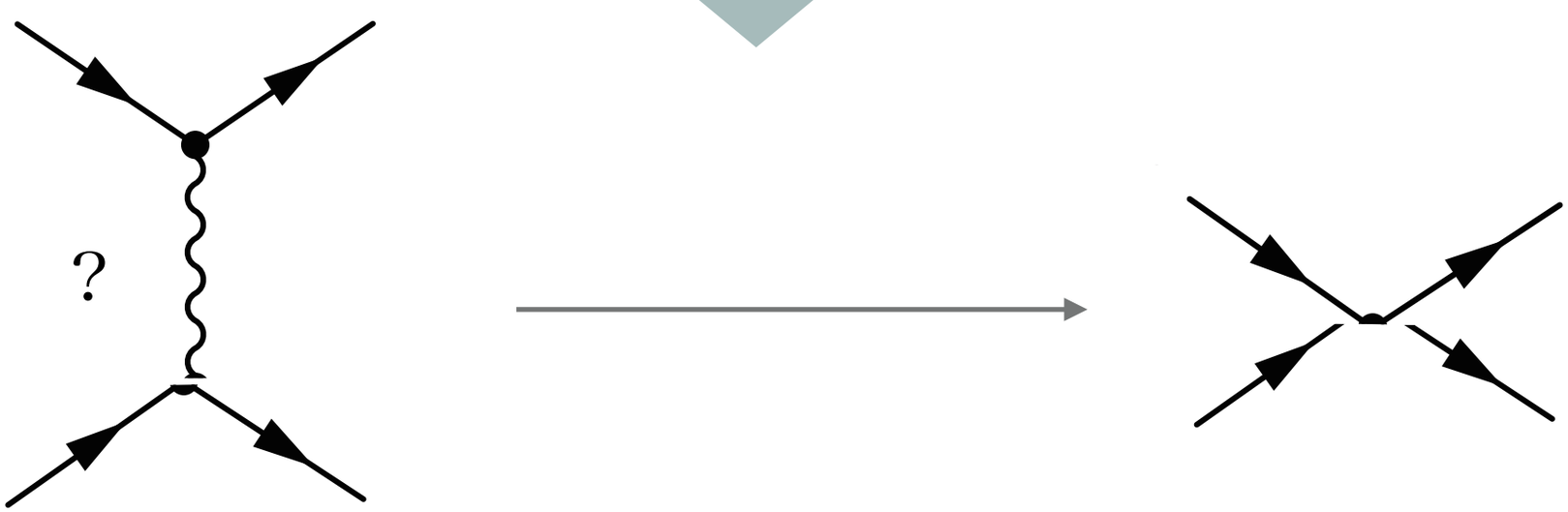
l:lepton q:quark j:jet v:neutrino

Effective field theory



Higher energy scale rather than W

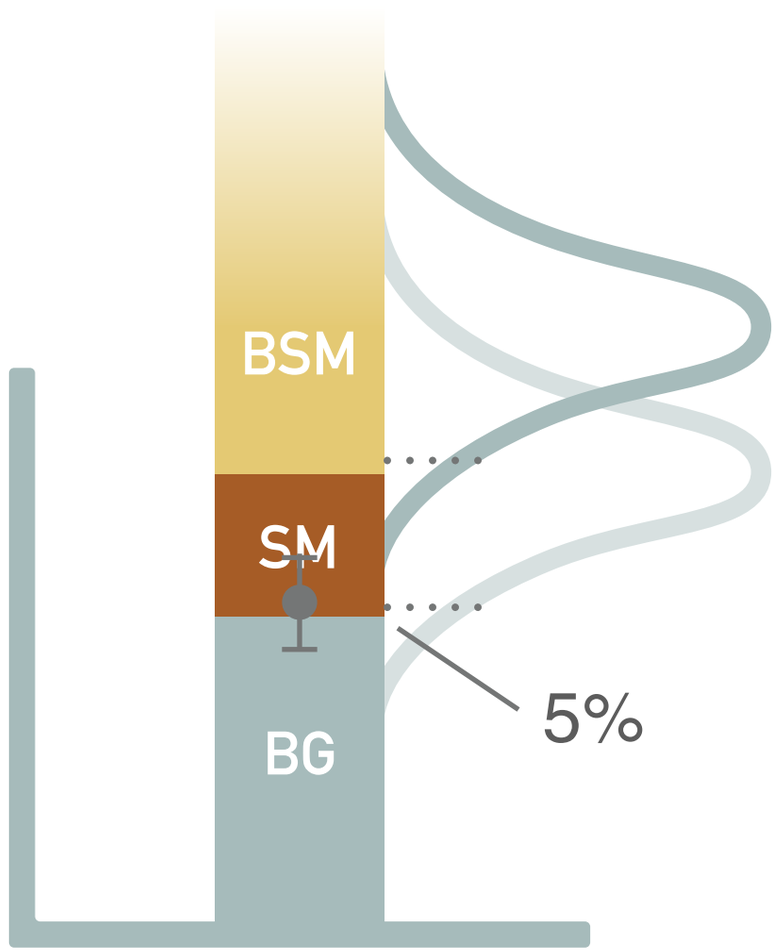
Lower energy scale rather than W



Higher energy scale rather than new physics

Looking at ILC250 GeV

How to calculate the 95% C.L upper limit



$$\sigma_{\gamma H} = \sigma_{SM} + \frac{1.64}{\text{significance}} \sigma_{SM}$$

Significance we got this simulation is in SM,

so to calculate in BSM, we need to add σ_{SM}.

How to combine 2 measurement

$$\frac{B_\gamma}{B_{\gamma SM}} = \begin{pmatrix} Y_1 \\ \sigma_{Y_1} \end{pmatrix} \qquad \frac{\sigma}{\sigma_{SM}} = \begin{pmatrix} Y_2 \\ \sigma_{Y_2} \end{pmatrix}$$

σ:error

$$Y_i = f_i(\xi) = \begin{cases} 1 + 290\zeta & (i = 1) \\ 1 - 273\zeta & (i = 2) \end{cases}$$

$$\chi^2(\zeta) = \sum_i \left(\frac{Y_i - f_i(\zeta)}{\sigma_{Y_i}} \right)^2 \xrightarrow[\text{x2 fit}]{} \frac{\partial \chi^2}{\partial \zeta}(\zeta) = 0$$

ζ_0:best fit value

$$\zeta = \zeta_0 + \Delta\zeta$$

$$= \sum_i \left(\frac{Y_i - f_i(\zeta_0 + \Delta\zeta)}{\sigma_\gamma} \right)^2 \simeq \sum_i \left(\frac{Y_i - f_i(\zeta_0) - \left(\frac{df_i(\beta_0)}{d\zeta_0}(\zeta_0)\Delta\zeta \right)}{\sigma_{\gamma_0}} \right)^2$$

$$= \sum_i \left(\frac{Y_i - f_i(\zeta_i)}{\sigma_{Y_i}} \right)^2 - 2\sum_i \frac{(Y_i - f_i(\zeta_0))\left(\frac{df}{d\zeta}(\zeta_0) \right)}{\sigma_{Y_i^2}} \cdot \Delta\zeta + \sum_i \left(\frac{\left(\frac{df_i}{d\zeta}(\zeta_0) \right)}{\sigma_{Y_i}} \right)^2 \Delta\zeta^2$$

$$\chi^2(\zeta_0) = \sum_i \left(\frac{Y_i - f_i(\zeta_\alpha)}{\sigma_{Y_i}} \right)^2 = \chi_0^2 \qquad \chi^2 \simeq \chi_0^2 + \sum_i \left(\frac{df_i(\zeta_0)}{\sigma_{Y_i}} \right)^2 \Delta\zeta^2$$

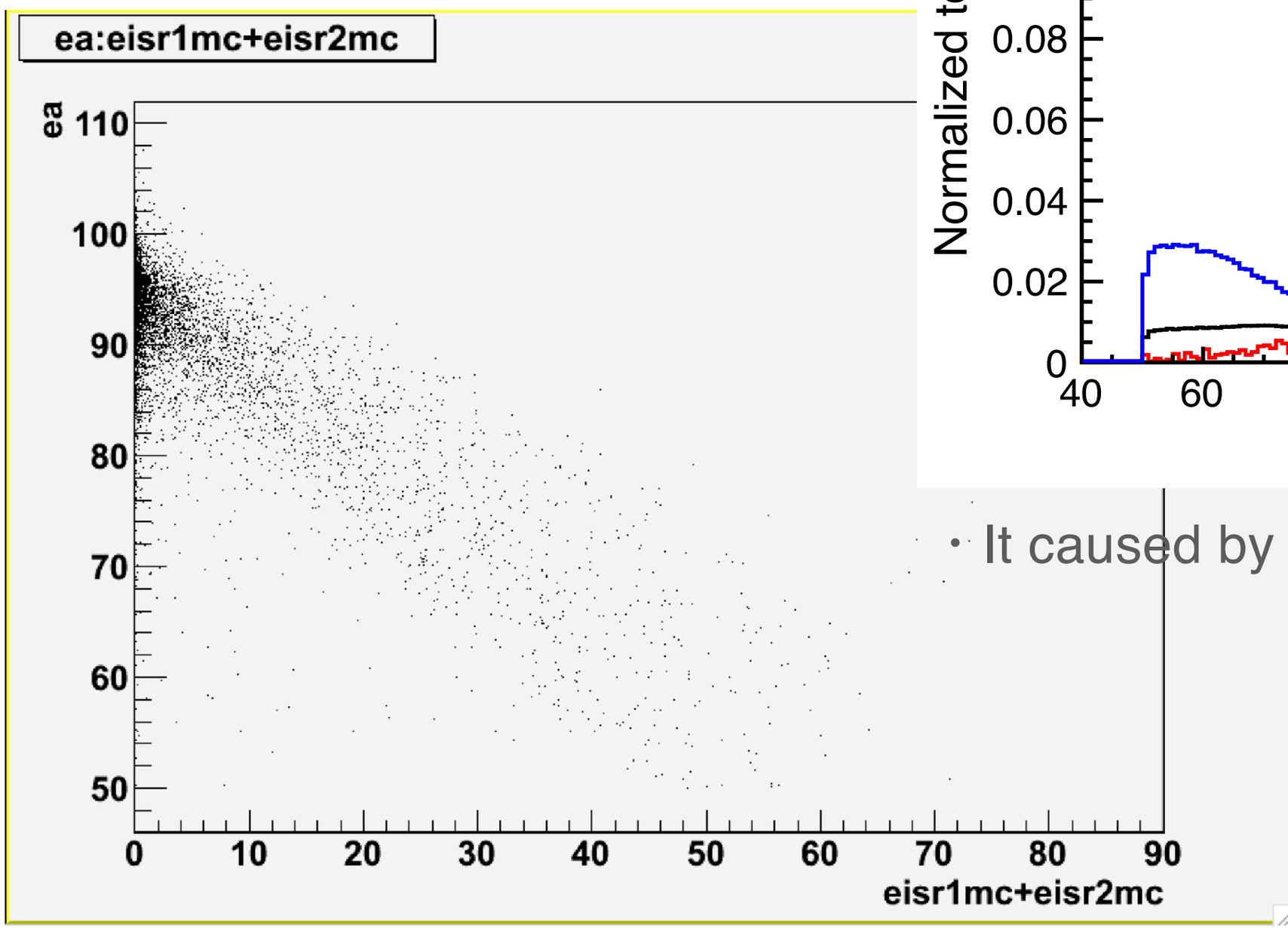
How to combine 2 measurement(continued)

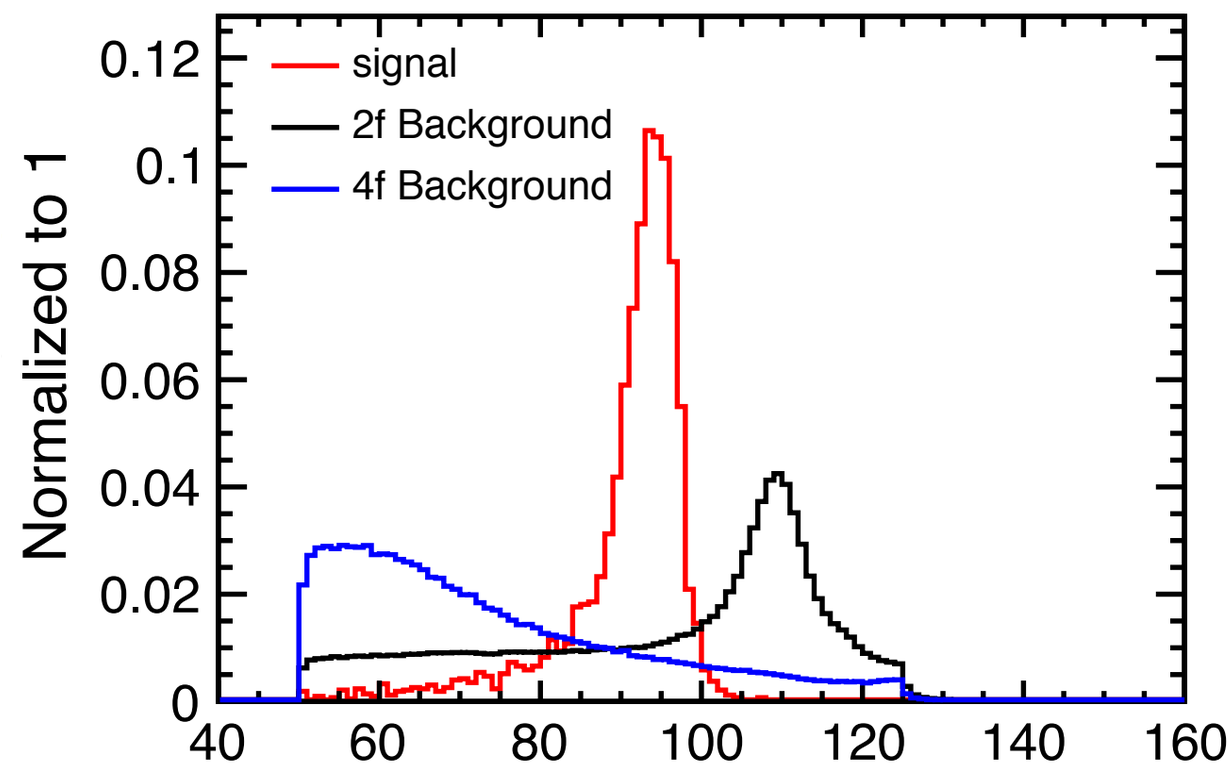
$$= \chi_0^2 + \left(\frac{\Delta\zeta}{\sigma_{\Delta\zeta}}\right)^2 \Rightarrow \frac{1}{\sigma_{\Delta\zeta}^2} = \sum_i \left(\frac{df_i}{d\zeta}\right)^2 \frac{1}{\sigma_{Y_i}^2}$$

$$\frac{1}{\sigma_{\Delta\zeta}^2} = (290)^2(2.31)^2 + (-273)^2(0.53)^2$$

$-0.0015 < \sigma_{\Delta\zeta} = \zeta_{AZ} < 0.0015$

About tail of energy of photon





- It caused by ISR and bremsstrahlung