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

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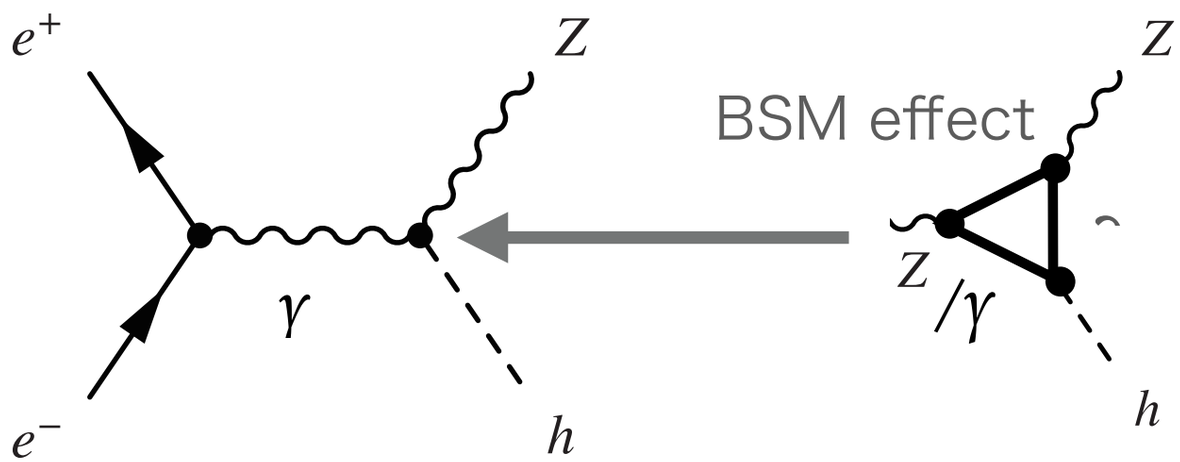
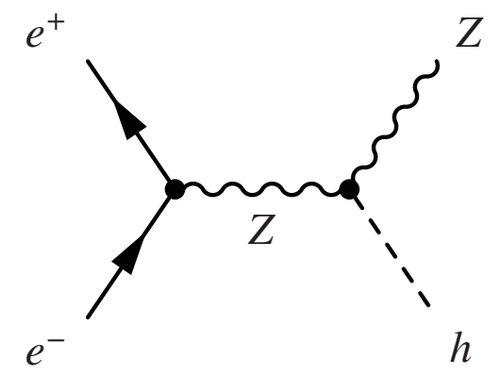
1.Motivation

Find new physics via H$\gamma\gamma$ and HγZ couplings

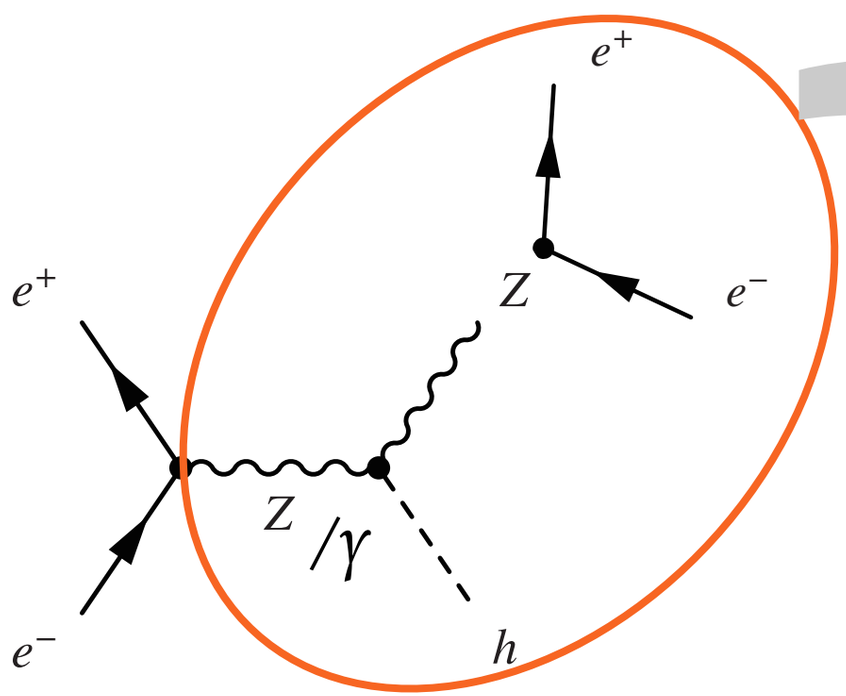
Higgs to γZ coupling in the Standard Model (SM) is a loop induced coupling.

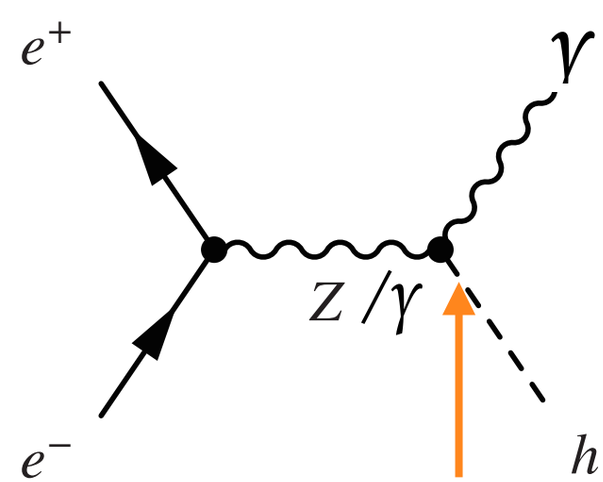




is exists at the tree level

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

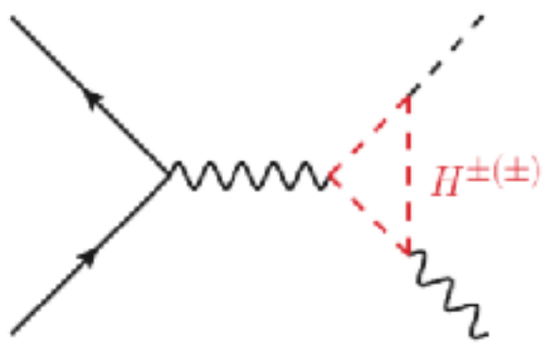




If we get different values of coupling constants with regard to SM, we get a key to new physics.

Example of new physics： Inert Doublet Model

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

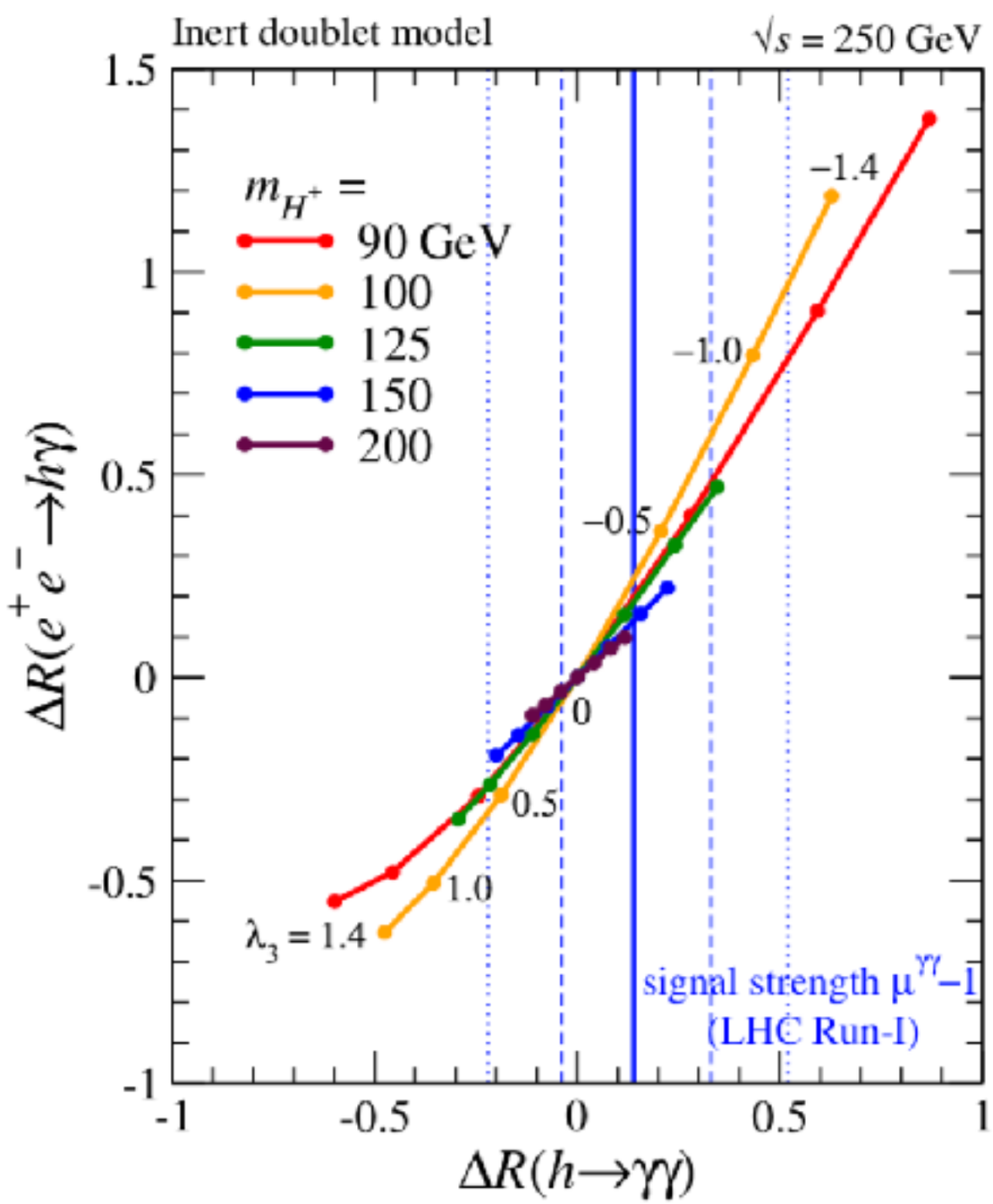


(d)

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%.

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



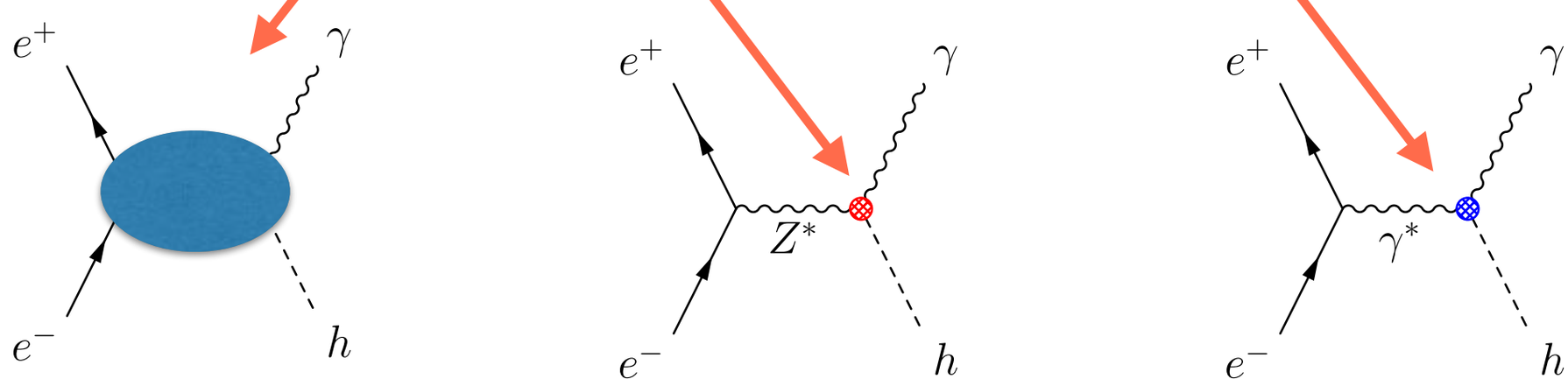
Mawatari, et al, arXiv:1808.10268

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

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



ζ_{AZ} : effective coupling between Higgs and γZ
ζ_A : effective coupling between Higgs and γγ
Aμv, Zμv : field strength tensors

v: vacuum expectation value

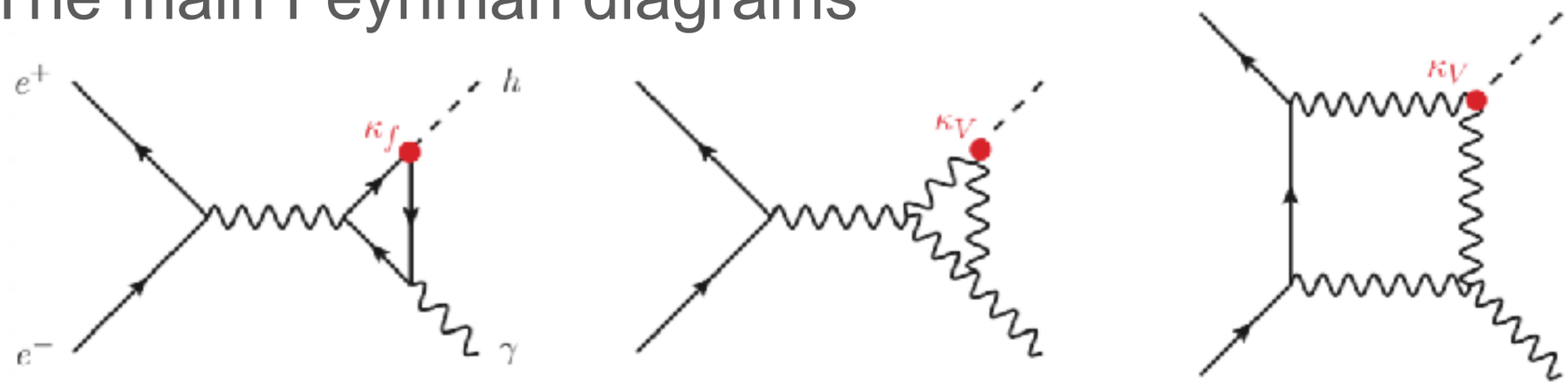
Phys.Rev. D94 (2016) 095015

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



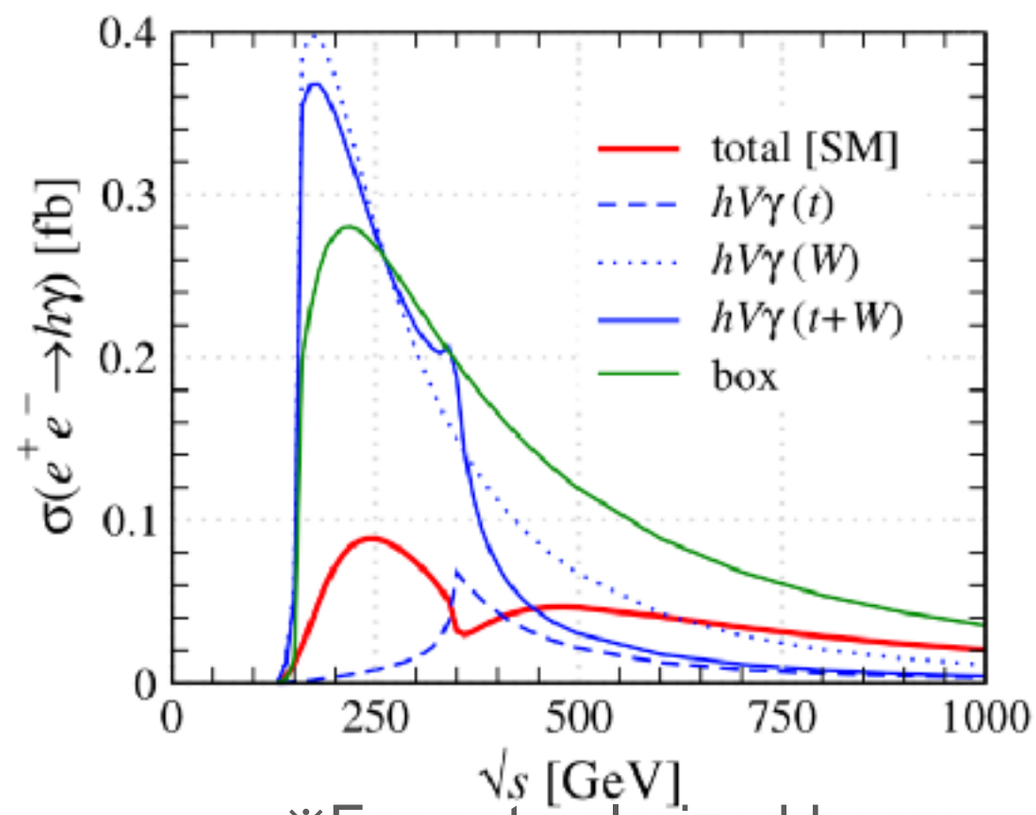
The cross sections by one loop calculation

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%)



$\sqrt{s}$ = 250 GeV

※For not polarized beam

Destructive interferences

3.Experimental Method

Coupling constant

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

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

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

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

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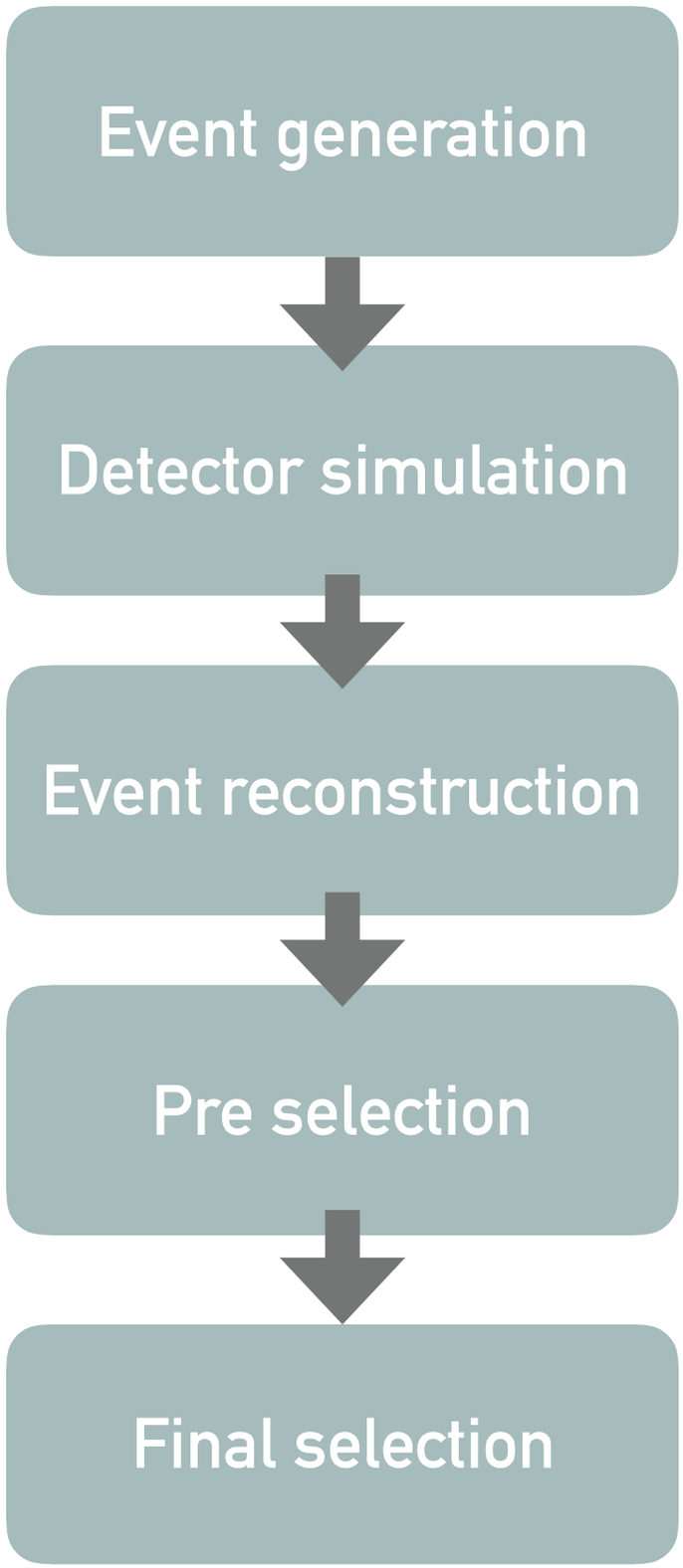
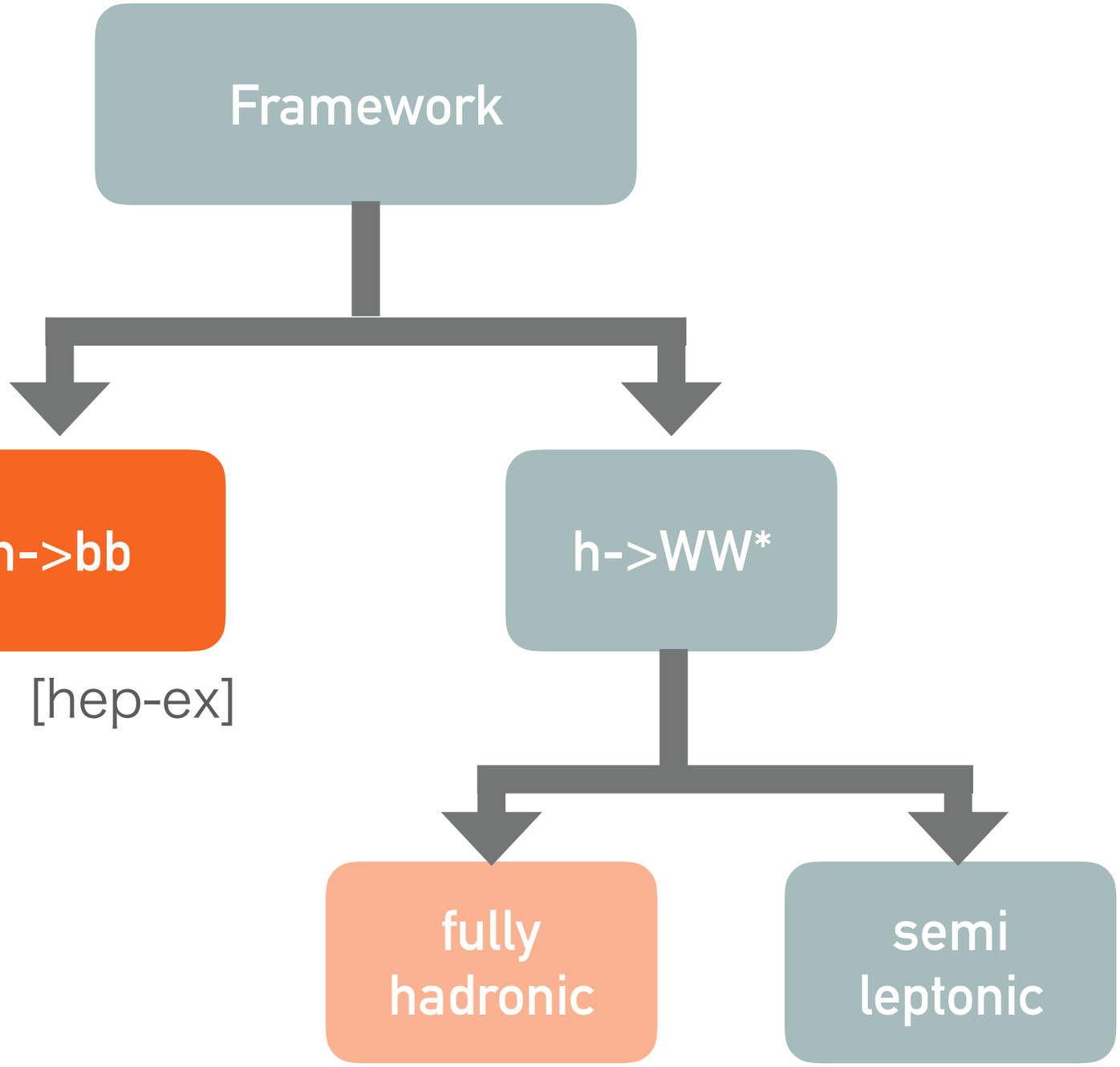
4.Simulation framework



- 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

Strategy



arXiv:1902.06029v1 [hep-ex]

5. Event selection

h->bb

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

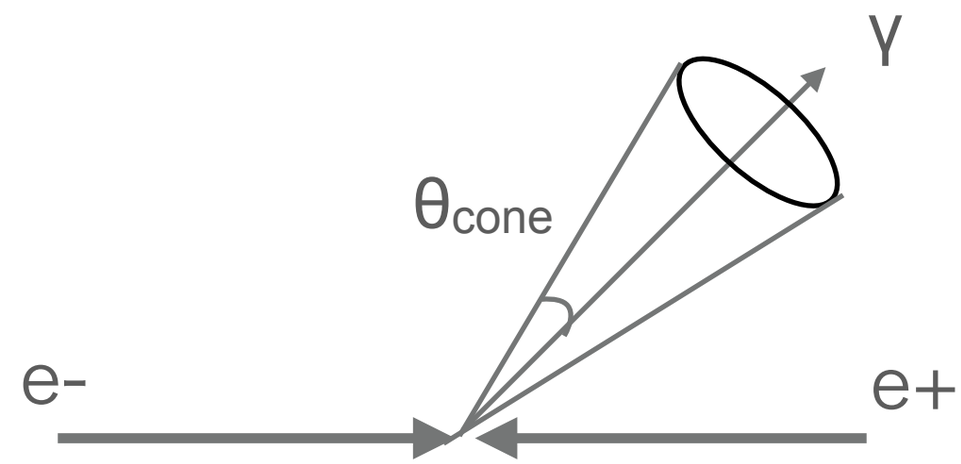
e+e- ->γqq(bar) dominated by e+e- → γZ (radiative return)

5. Event selection

h->bb

① Pre selection

- Isolated photon
  - ➤ Photon ID
  - ➤ $E_\gamma > 50$ GeV
  - ➤ The split photon clusters within a small cone are recovered
    cone angle($\cos\theta_{cone}=0.998$)



- Other particles
  - ➤ clustered into 2jet (using Durham)
  - ➤ Flavor tagged（LCFI+）

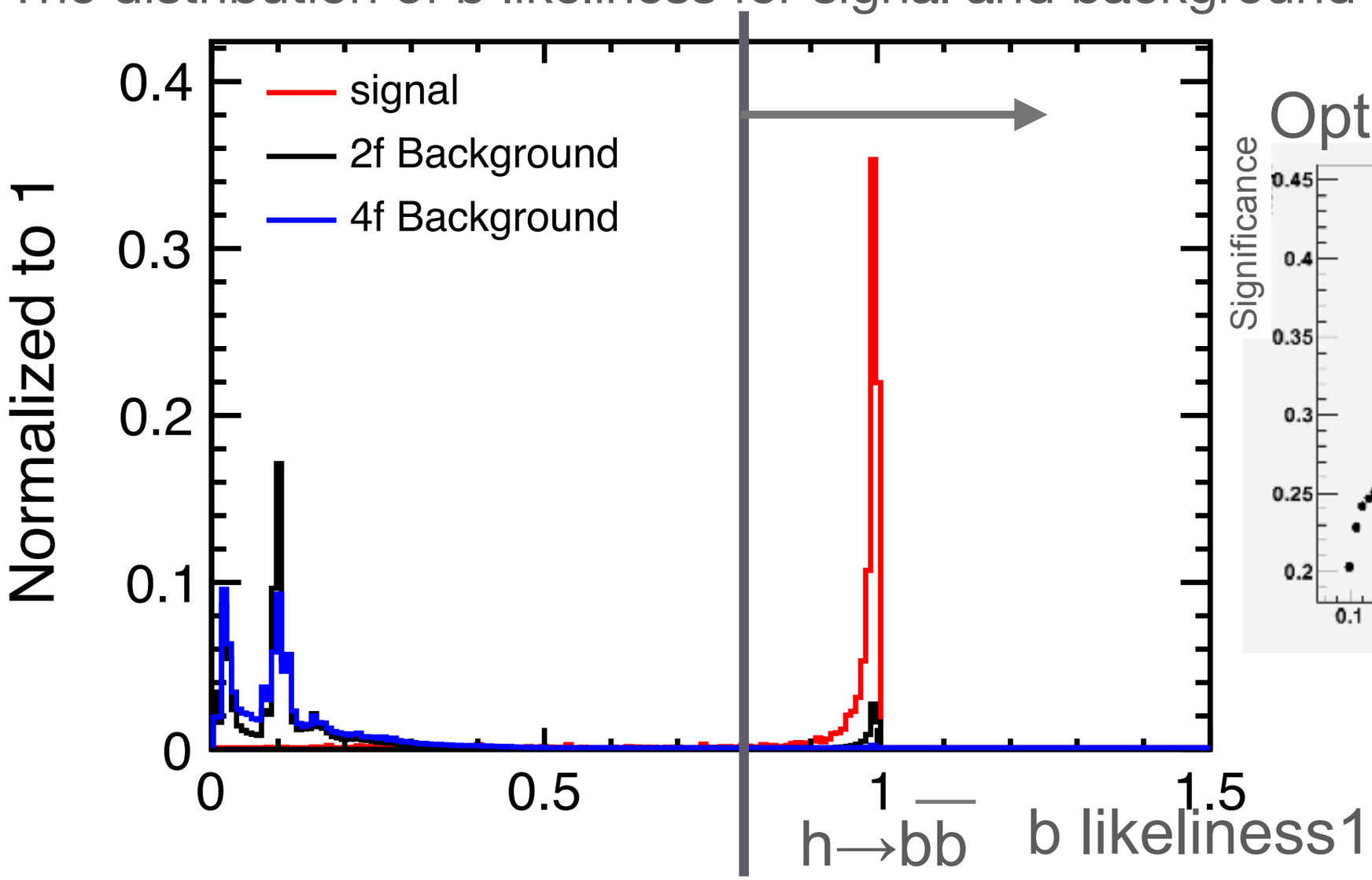
5. Event selection

h->bb

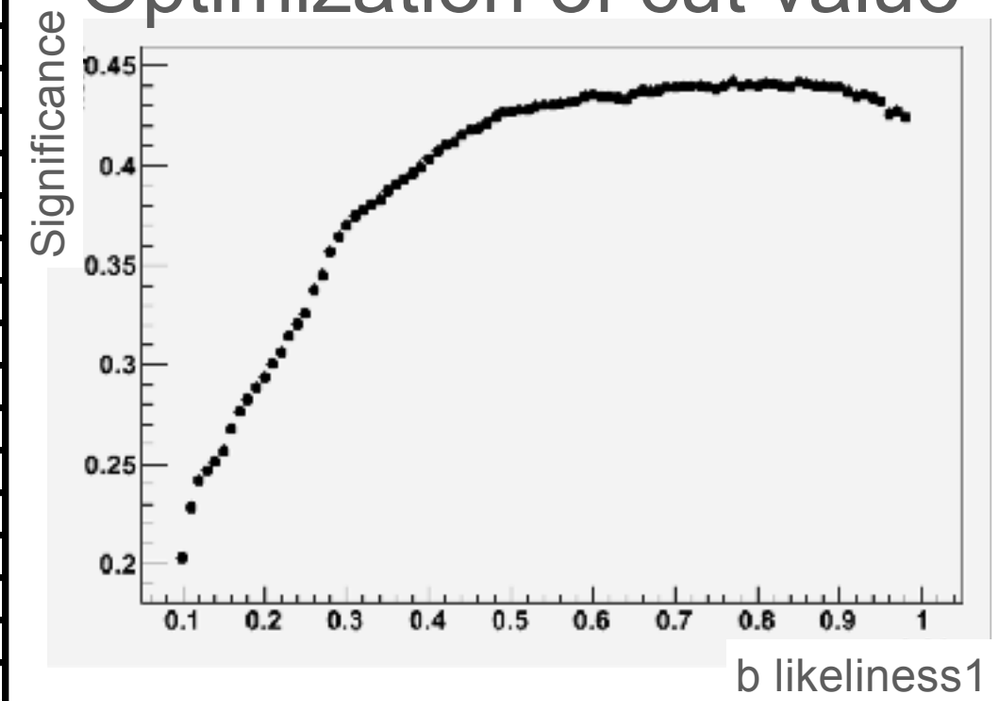
② Final selection

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

The distribution of b likeliness for signal and background events



Optimization of cut value

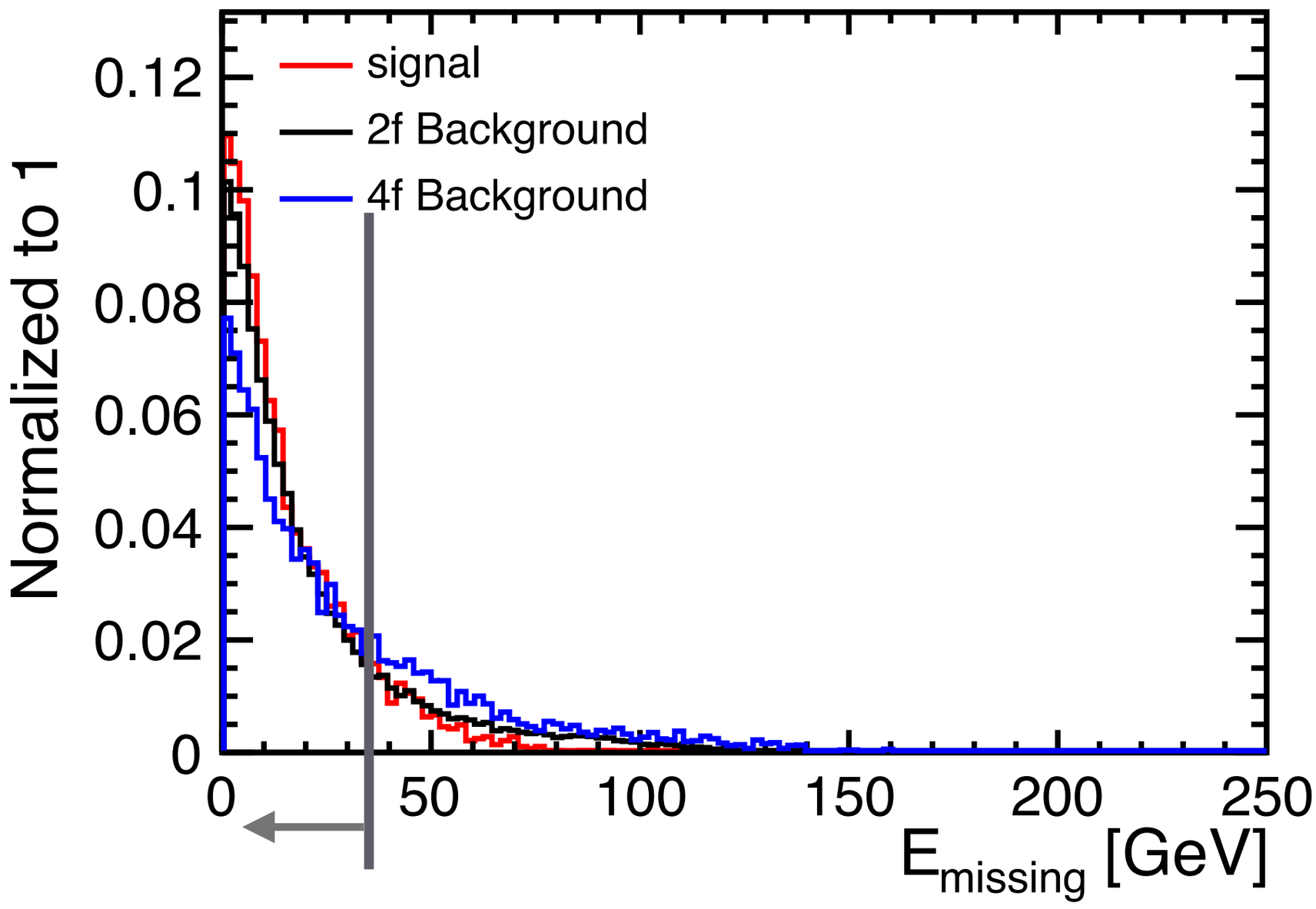


※ This plot is for events after the pre selection

5. Event selection

h->bb

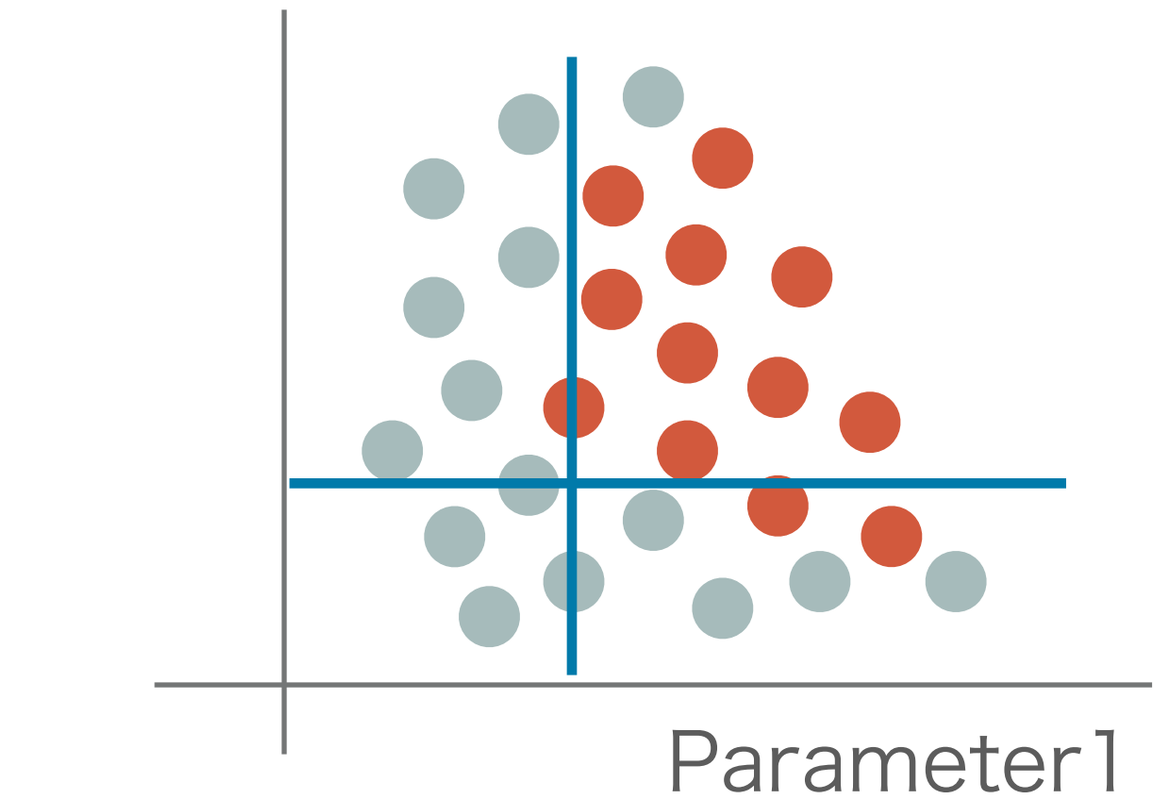
② Final selection
-Cut 2: missing energy<35 GeV



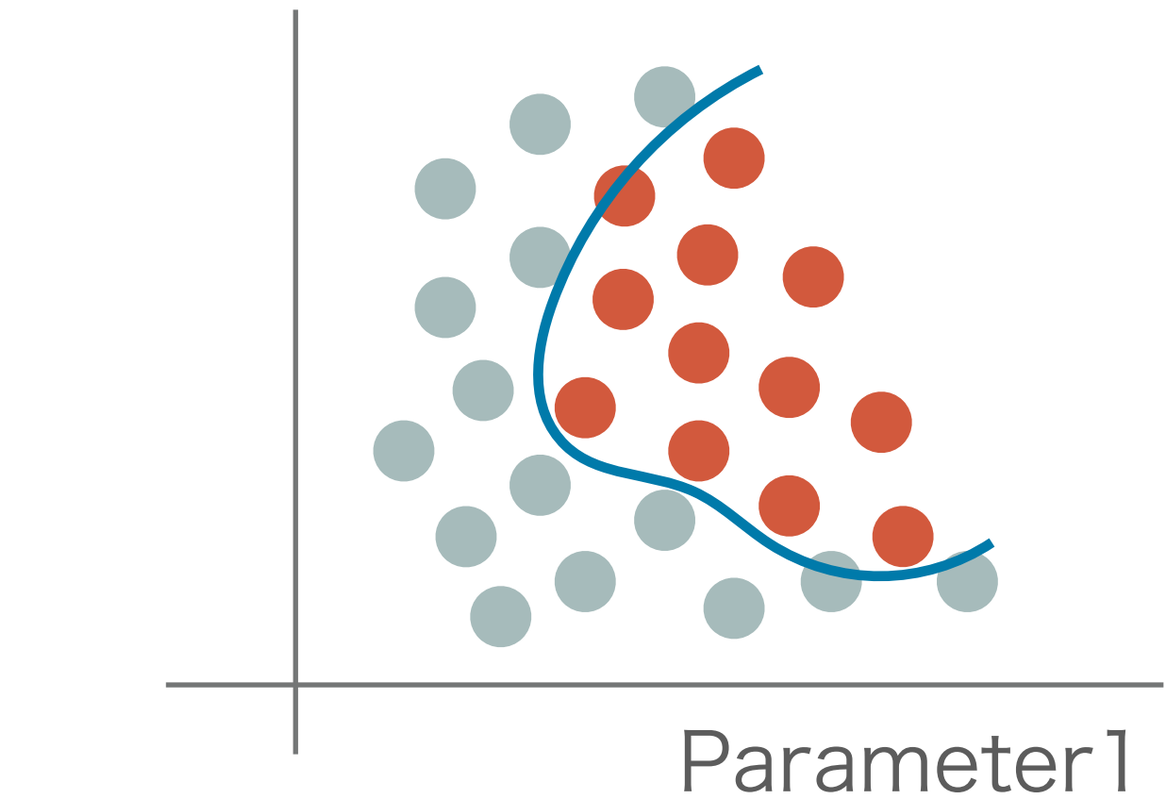
Separation by using TMVA

Multivariate Data Analysis

The cut based analysis



The multivariate data analysis

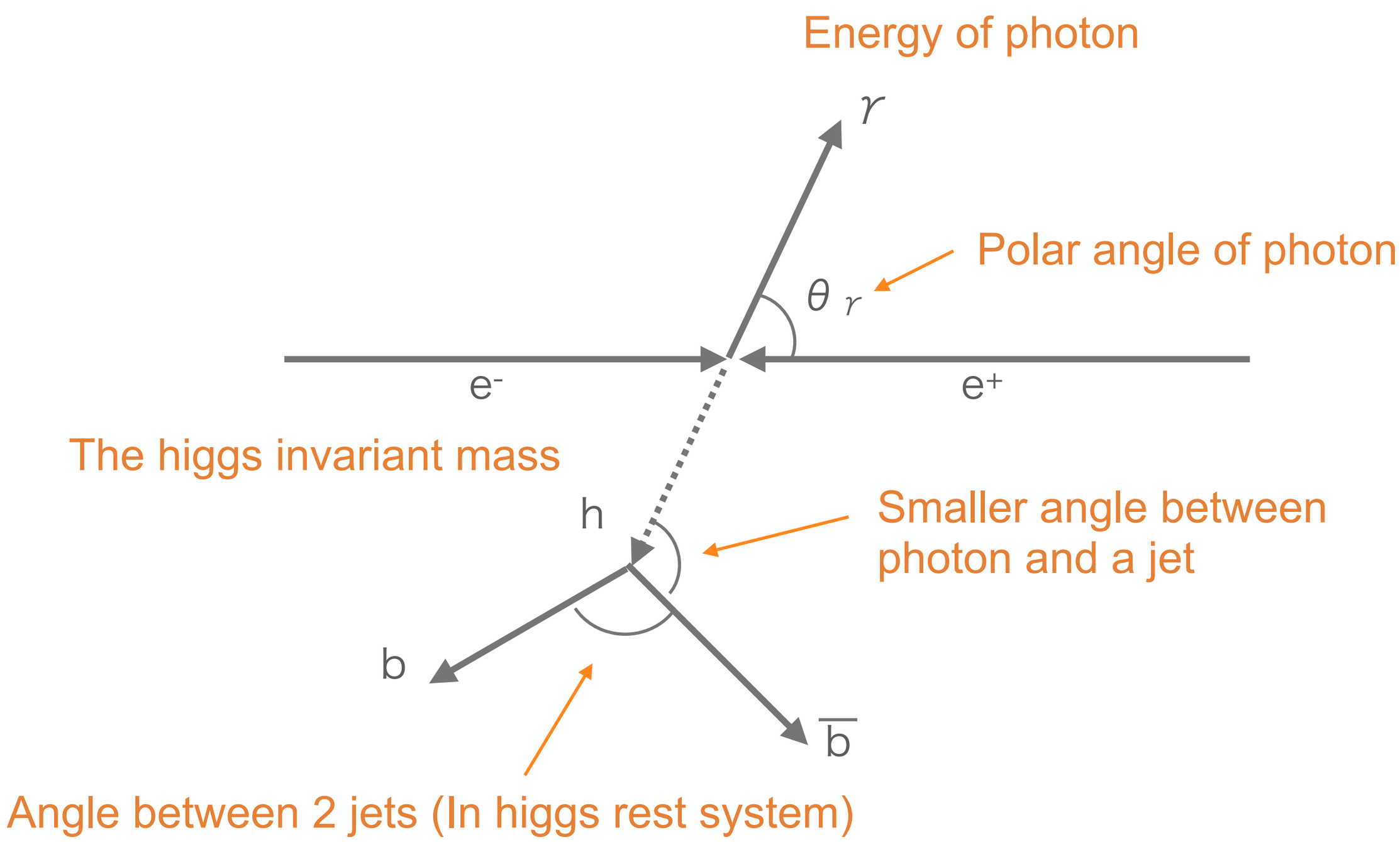


Background Signal

The cut based analysis has its limitation.

→TMVA describes signal-background boundary more flexibly

Input variables for MVA



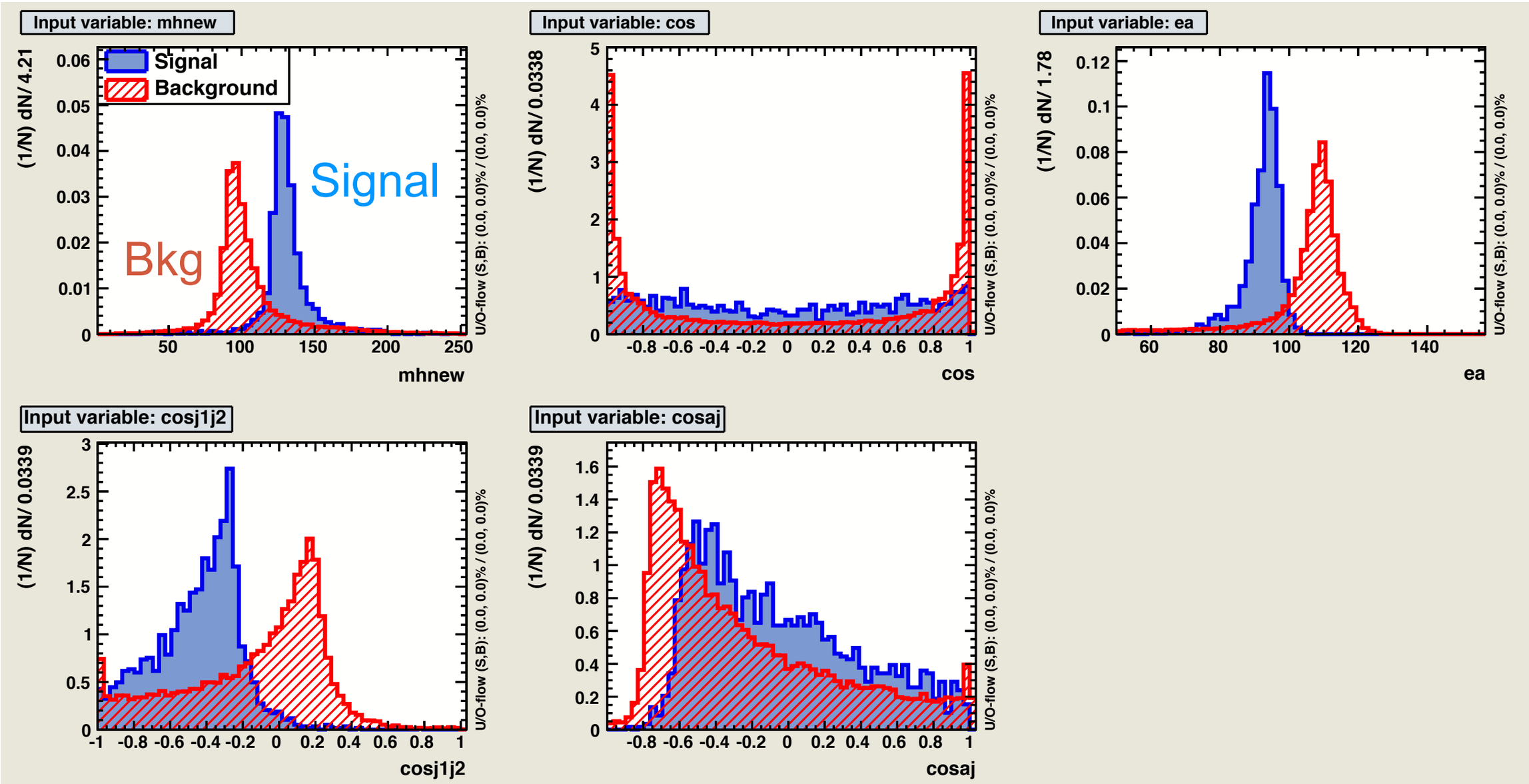
Input variables for MVA

The distributions of each variable for signal and background

The higgs invariant mass

Polar angle of photon

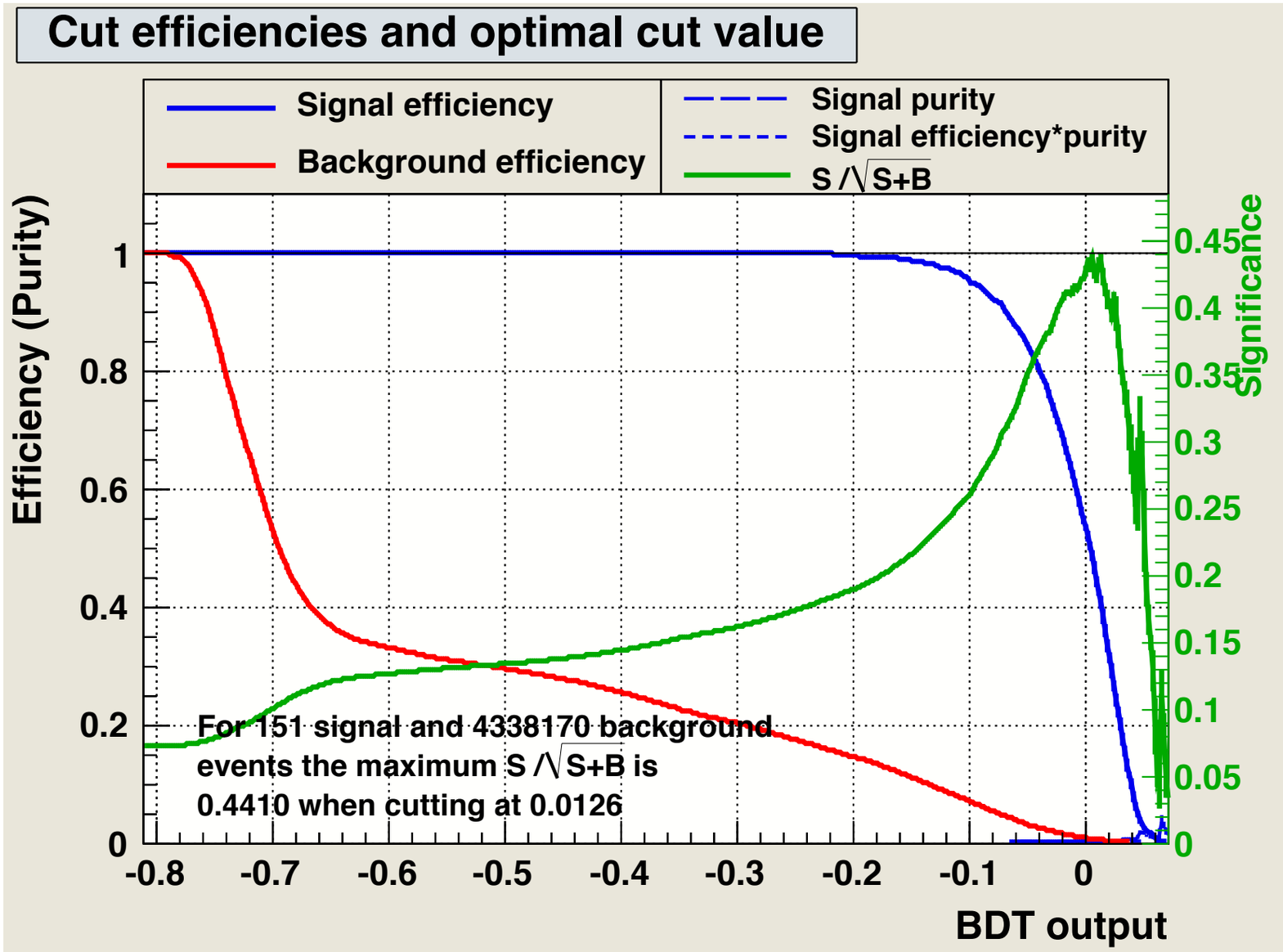
Energy of photon



Angle between 2 jets

Smaller angle between photon and a jet

7. Separation by using TMVA



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

Significance = 0.44

6. Result

h->bb

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

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

5. Event selection

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

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

5. Event selection

① Pre-selection

- Isolated photon
  - ➤ Photon ID
  - ➤ $E_\gamma > 50$ GeV

※The split photon clusters within a small cone are recovered

→Left events except photon

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

For signal

number of decay w to qq=2

Strategy

$e^+e^- \to \gamma h \to \gamma(WW^*)$	e^+e^- -> 2f
number of particles in jet →many	number of particles in jet →(l,v)One

# of particle>5

y43, y32 →large

y43, y32

y43, y32 →relatively small

Strategy

h->WW

$e^+e^- \to \gamma h \to \gamma(WW^*)$		e^+e^- ->$W^+W^-(\gamma)$
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	mγ	Energy of photon ~small

h->WW

6. Reduction table

	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

7. Summary

- I simulated and analyzed e+e- -> h gamma process
  - ➤ Significance for e+e- ->hγ process（h->bb）

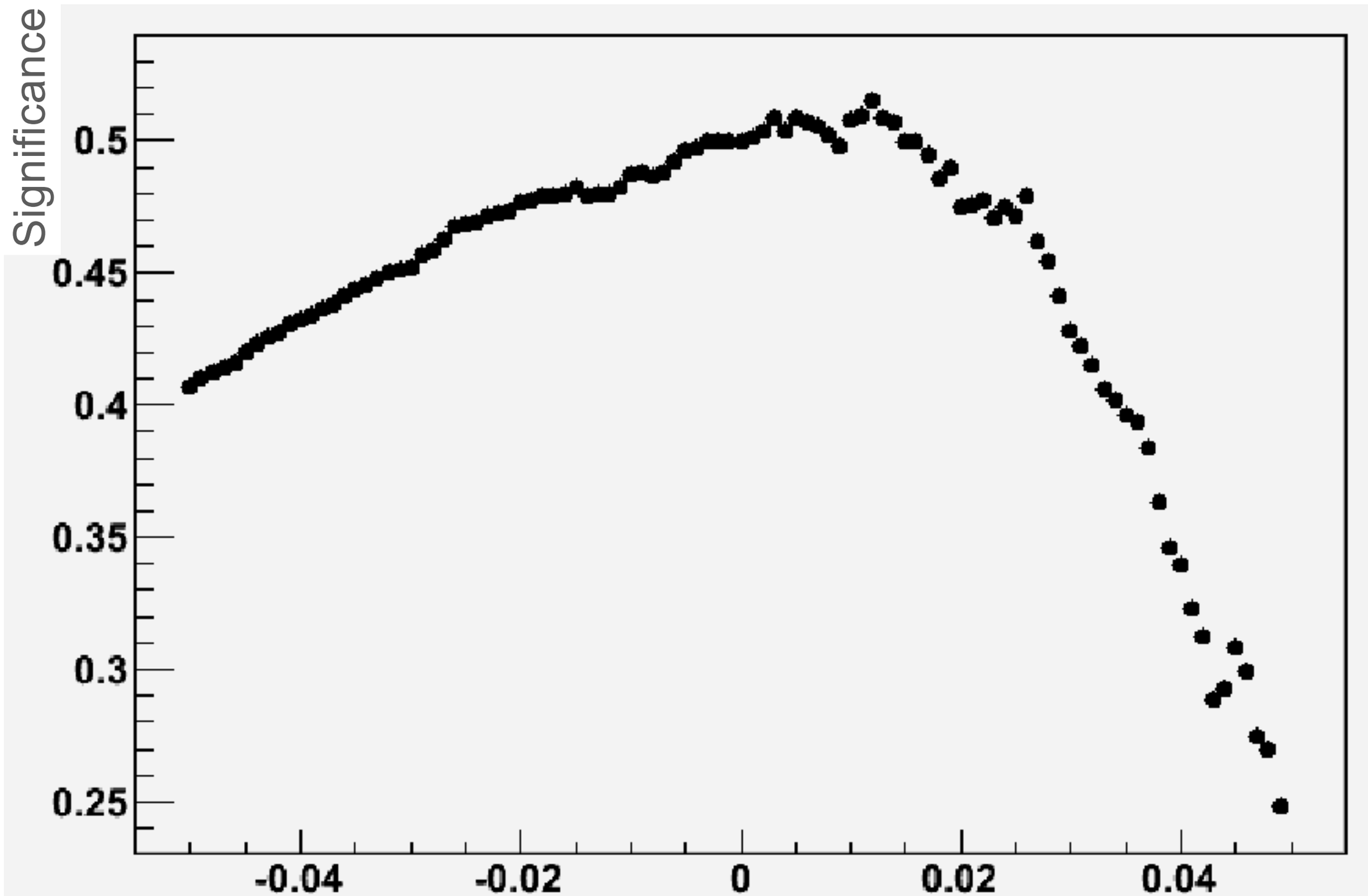
    ~ 0.53σ for SM at √s=250 GeV, 2000 fb^{-1}
  - ➤ h->WW* : on going

Next step

- Fully hadronic
  - -Cut based : + b likeliness cut
  - -TMVA
- Semi leptonic (lvqq)

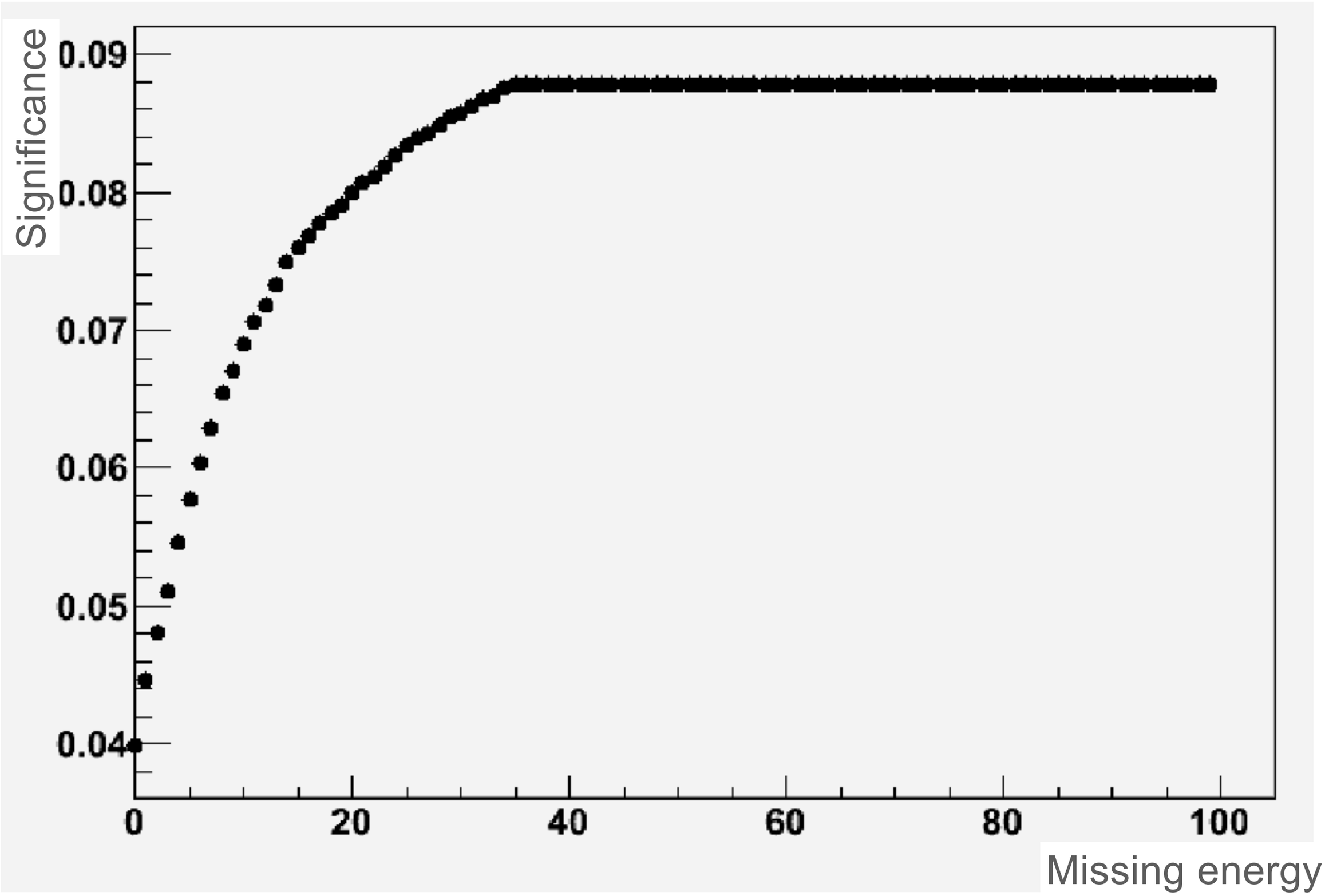
Back up

Optimization of mva



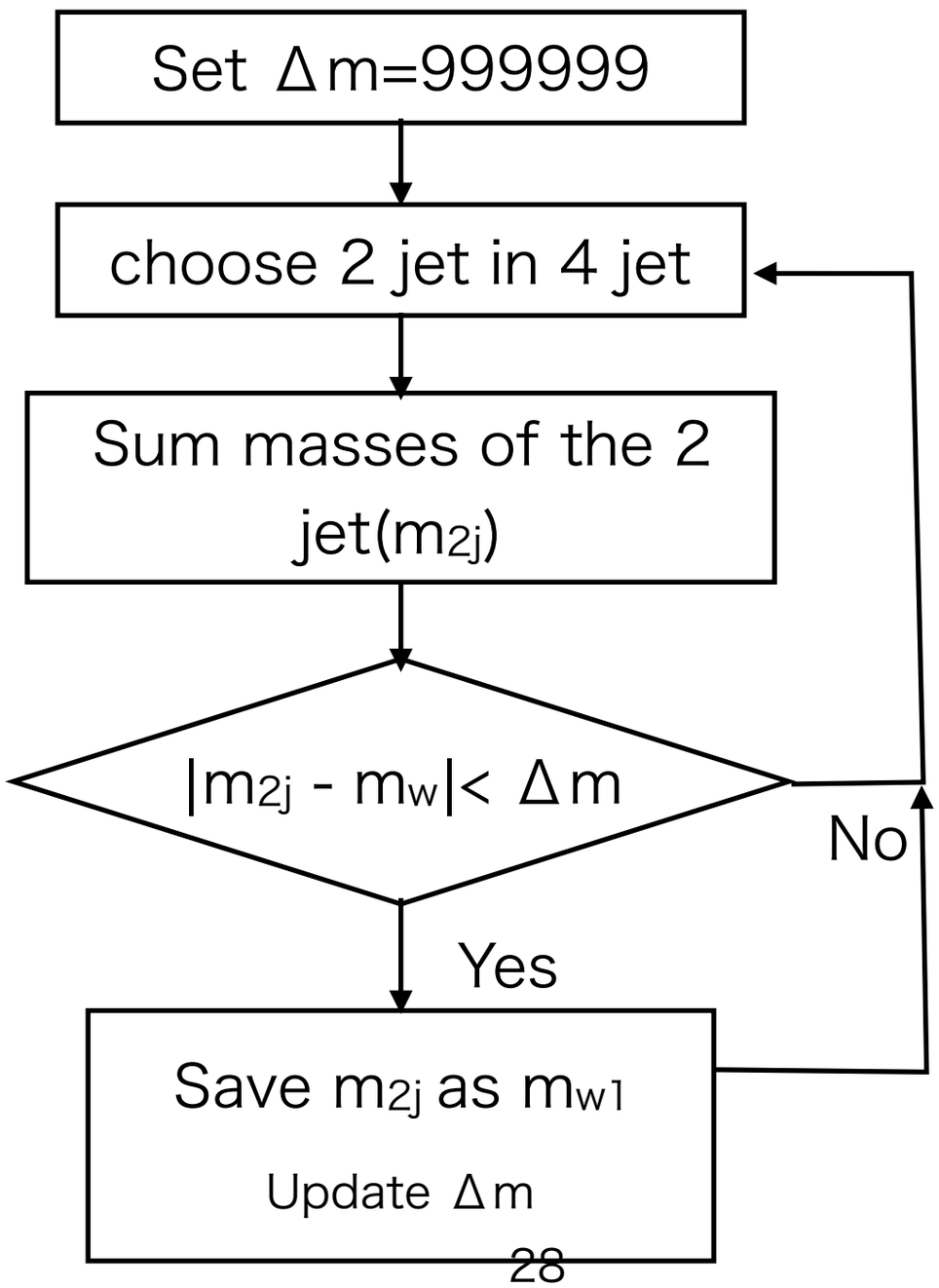
MVA DBT

Optimization of missing energy



W reconstruction

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



Jet clustering

General strategy

Merge a pair of particles whose "**Distance**" is the smallest until a condition meets "**Criteria**"

"**Distance**"

Durham algorithm : $Y_{ij} = 2\frac{\min\left[E_i^2, E_j^2\right](1-\cos\theta_{ij})}{E_{vis}^2}$, θ_{ij} : angle between P_i and P_j

k_t algorithm : $d_{ij} = \min\left[p_{T_i}^2, p_{t_j}^2\right]\frac{R_{ij}}{R}$ or $d_{iB} = p_{t_i}^2, R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$

η : pseudo rapidity, ϕ azimuthal angle

"**Criteria**"

- Number of remaining particles is equal to N_{Req}
- The smallest distance is smaller than D_{Req}

Slide From Y. Sato

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