Feasibility study of Higgs pair production in a Photon Collider

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Higgs Physics w/ PLCs

- Two photon decay width of light higgs
  - 2% ~ 8%   for Mh = 129geV ~ 160GeV
- Discovery potential of heavy Mh (LHC wedge)
  - ~< 360GeV
- CP w/ Linear polarization
  - ~10% precision for 120GeV

Feasibilities for standard Higgs processes have been understood

⇒ rare processes

scenario for PLC run before e+e-

Purpose of this study

Final goal: Study of Higgs self-coupling

$$\lambda = \lambda^{SM}(1 + \delta\kappa)$$

Self-coupling constant in the SM

Parameter of deviation from the SM

See feasibility of the measurement of Higgs pair creation in PLC.

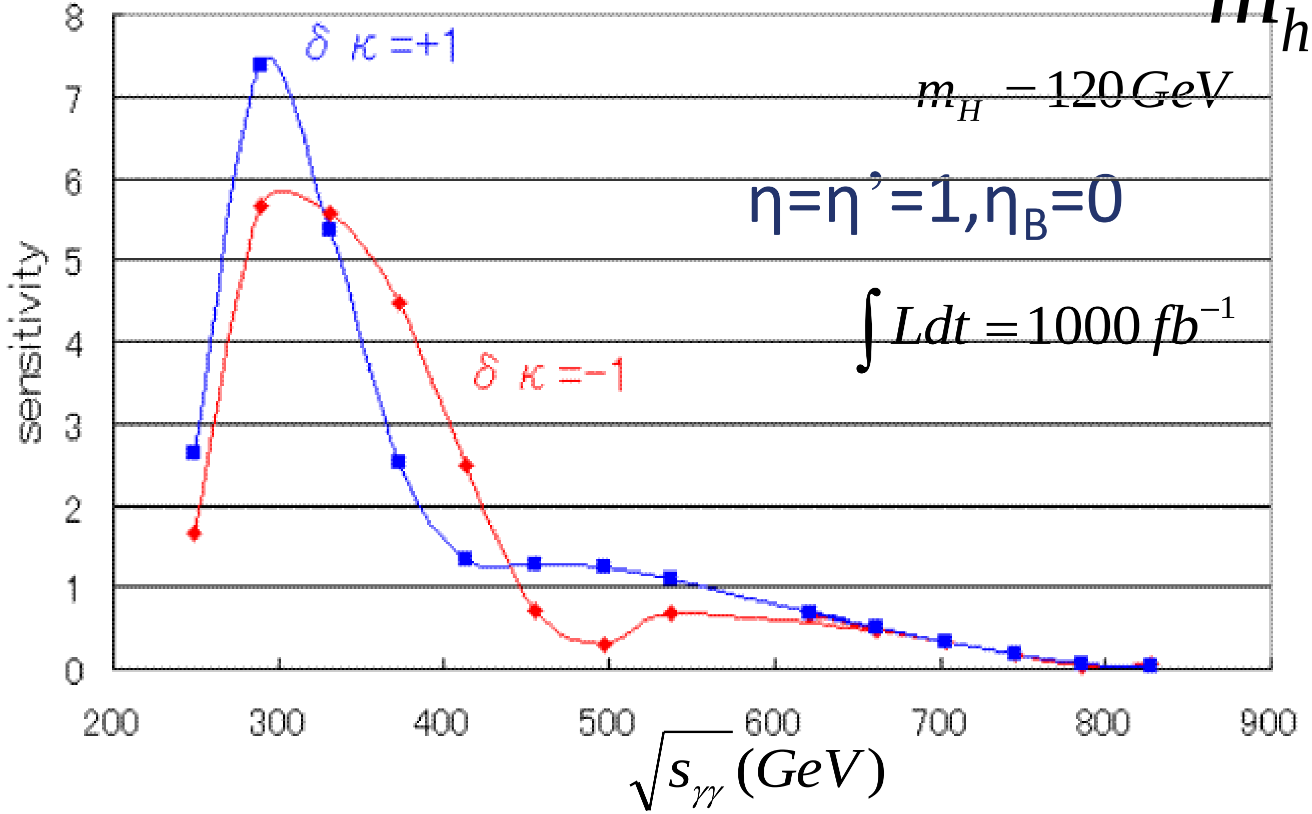
how may events expected?

possible to suppress background?

Sensitivity vs energy

$$sensitivity \equiv \frac{N(\delta\kappa) - N_{SM}}{\sqrt{N_{obs}}} = \frac{L\left|\eta\sigma(\delta\kappa) - \eta'\sigma_{SM}\right|}{\sqrt{L(\eta\sigma + \eta_B\sigma_B)}}$$

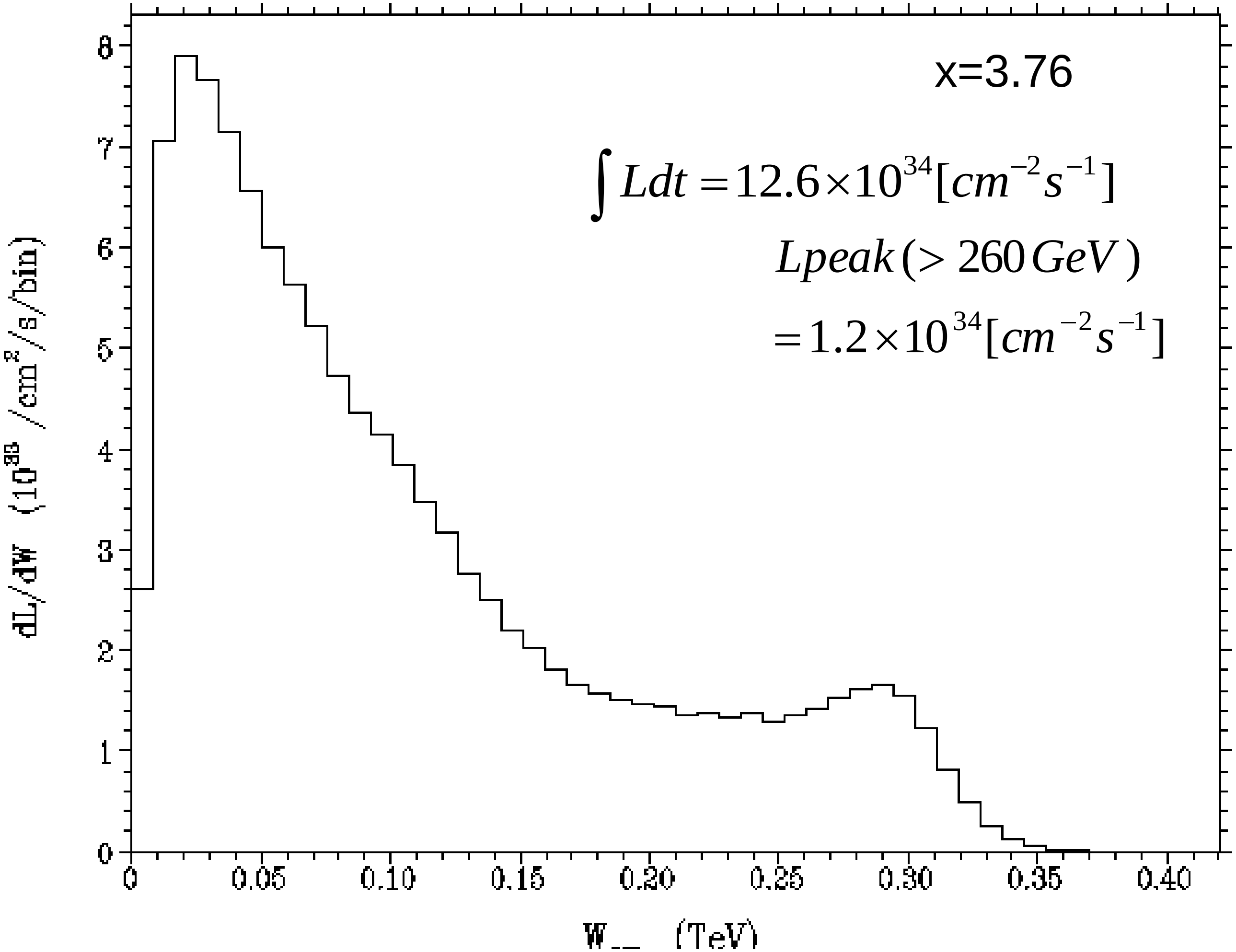
$$m_h = 120 GeV$$



Beam parameters $\sqrt{s_{\gamma\gamma}(peak)} \sim 300GeV$
(based on TESLA optimistic)

	x3.7	x4.8
Ee[GeV]	210	195
n(10^{10})	2	2
σ_z(mm)	0.35	0.35
$\gamma\varepsilon_{x/y}$[m rad]	2.5/0.03	2.5/0.03
$\beta_{x/y}$[mm]@IP	1.5/0.3	1.5/0.3
$\sigma_{x/y}$[nm]	96/4.7	99/5.5
λ_L[nm]	1054	770
x	3.76	4.8
Pulse Energy[J]	10	10
Lgeo(e-e-) [$10^{34}cm^{-2}s^{-1}$]	8.7	8.1
Lpeak($\gamma\gamma$) [$10^{34}cm^{-2}s^{-1}$]	1.2	0.7
Ltot($\gamma\gamma$)[$10^{34}cm^{-2}s^{-1}$]	12.6	5.88

Luminosity Distribution



$\frac{1}{Ltot}\int \sigma(w_{\gamma\gamma})\frac{dL}{dw_{\gamma\gamma}}dw_{\gamma\gamma} = 0.0131\,fb$ 13events@Ltot=1000fb^{-1} ~16events/year

Signal & Main backgrounds

Signal : γγ->HH->4b

(16.4events/year)

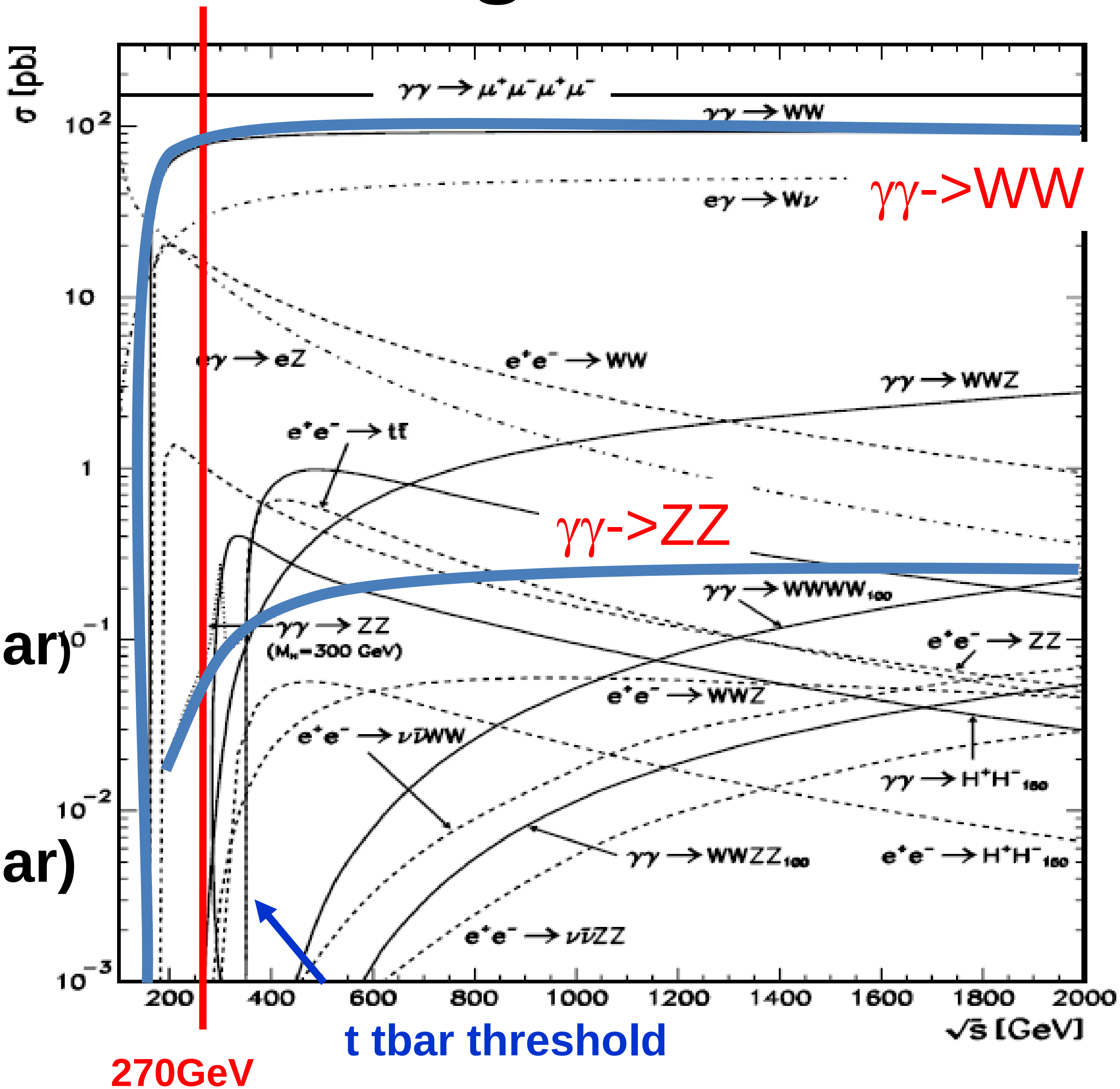
Main backgrounds

- γγ->WW->4q

($1.462*10^7$events/year)

- γγ->ZZ->4b

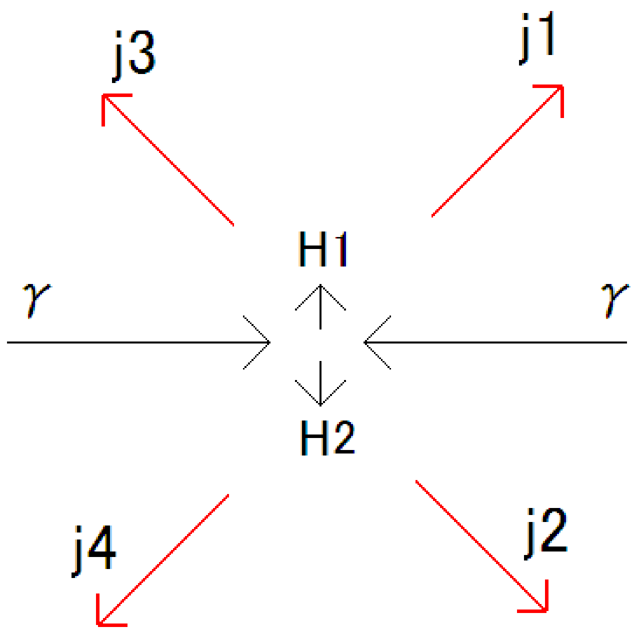
($1.187*10^4$events/year)



Simulation & Analysis

- Event generation and detector simulation
- Reconstruct events
  - Jet clustering (reconstruct jets)
  - b-tagging (identification of b-quark)
    - nsig method was used in this study.
  - Reconstruct particles (determination of jet combination)
- Selection
  - Selection with Neural Network (NN)

Reconstruct particles



We have to choose two jets from 4 jets (j1-j4) in order to reconstruct original particle.

->There are 3 patterns of combination in a event.

->The jet of the least χ^2 was chosen to be the most probable combination.

$$\chi_H{}^2 = \frac{(M_1 - M_H)^2}{\sigma_{2j}^2} + \frac{(M_2 - M_H)^2}{\sigma_{2j}^2}$$

M_1, M_2 : reconstructed particle mass

M_H : Higgs mass

σ_{2j} : mass resolution

Selection (1)

β : Lorentz factor of reconstructed particle

θ : Angle between reconstructed particle and initial photon beam

$$\beta \geq 0.05, \left|\cos\theta\right| \leq 0.99$$

b-tagging
- More than 3 b-flavor jets with (nsig=3.0, noffv=1) analysis
- More than 2 b-flavor jets with (nsig=3.0, noffv=2) analysis

	generate	pre-selection
HH	$5.0*10^4$	29958
WW	$7.5*10^7$	83777
ZZ	$1.0*10^6$	87057

Selection (2) --- Neural Network (NN)

- 9 input parameters：
  - χ_H^2 , χ_Z^2,
  - transverse (longitudinal) momentum,
  - # of b-flavor jets (2 patterns),
  - visible energy,
  - Y_{cut} value of jet clustering,
  - # of tracks
- Maximize statistical significance

$$S_{stat} \equiv \frac{N_{Sig} * \eta_{Sig}}{\sqrt{N_{Sig} * \eta_{Sig} + N_{BG} * \eta_{BG}}}$$

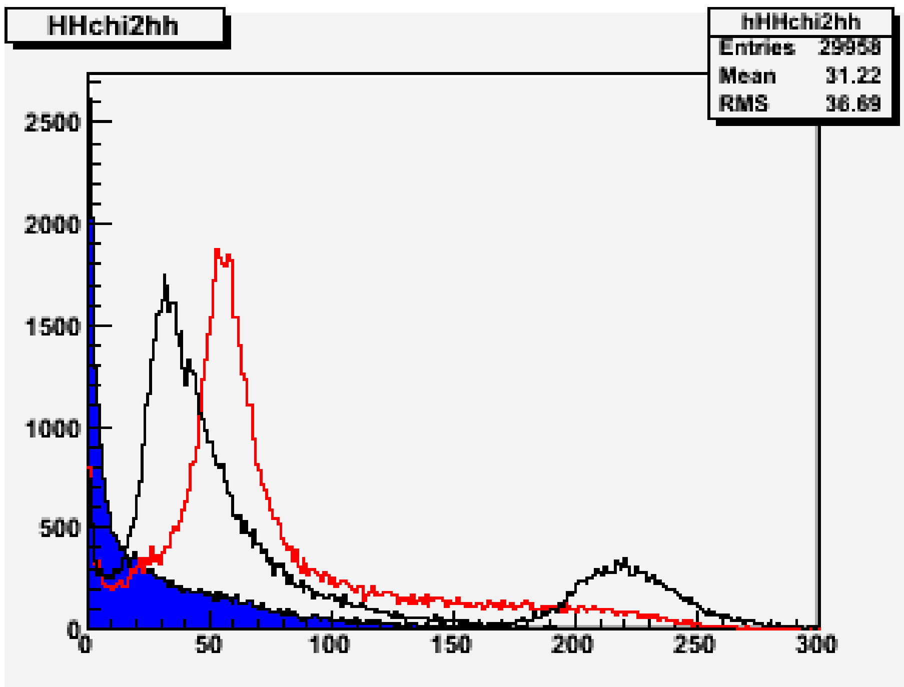
N: # of events occurring in 5 years

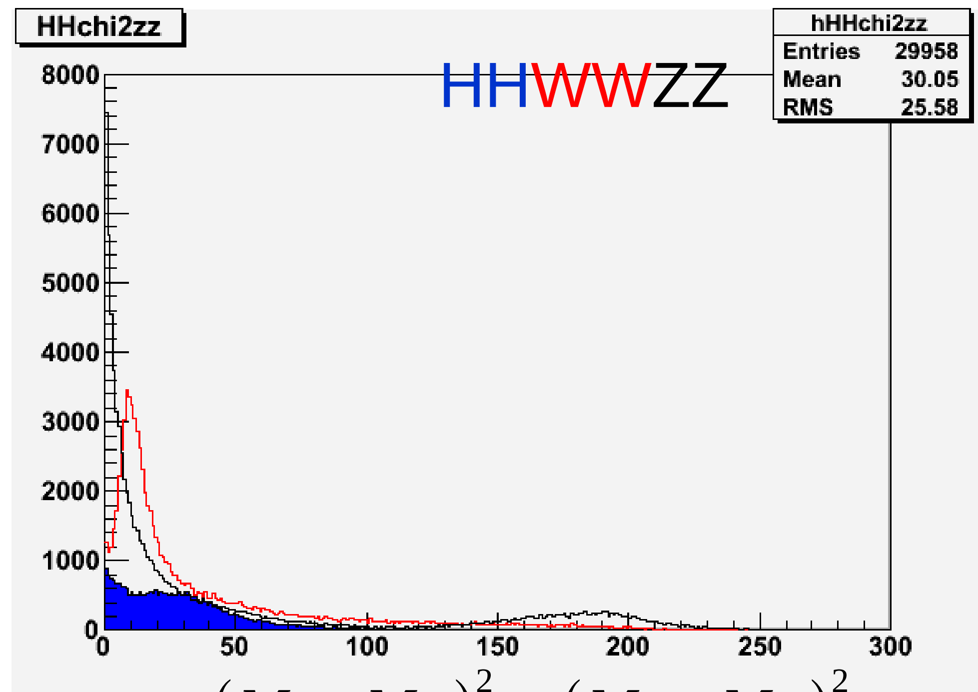
η: selection efficiency

Sig: signal

BG: background

Distribution of input parameters (1)

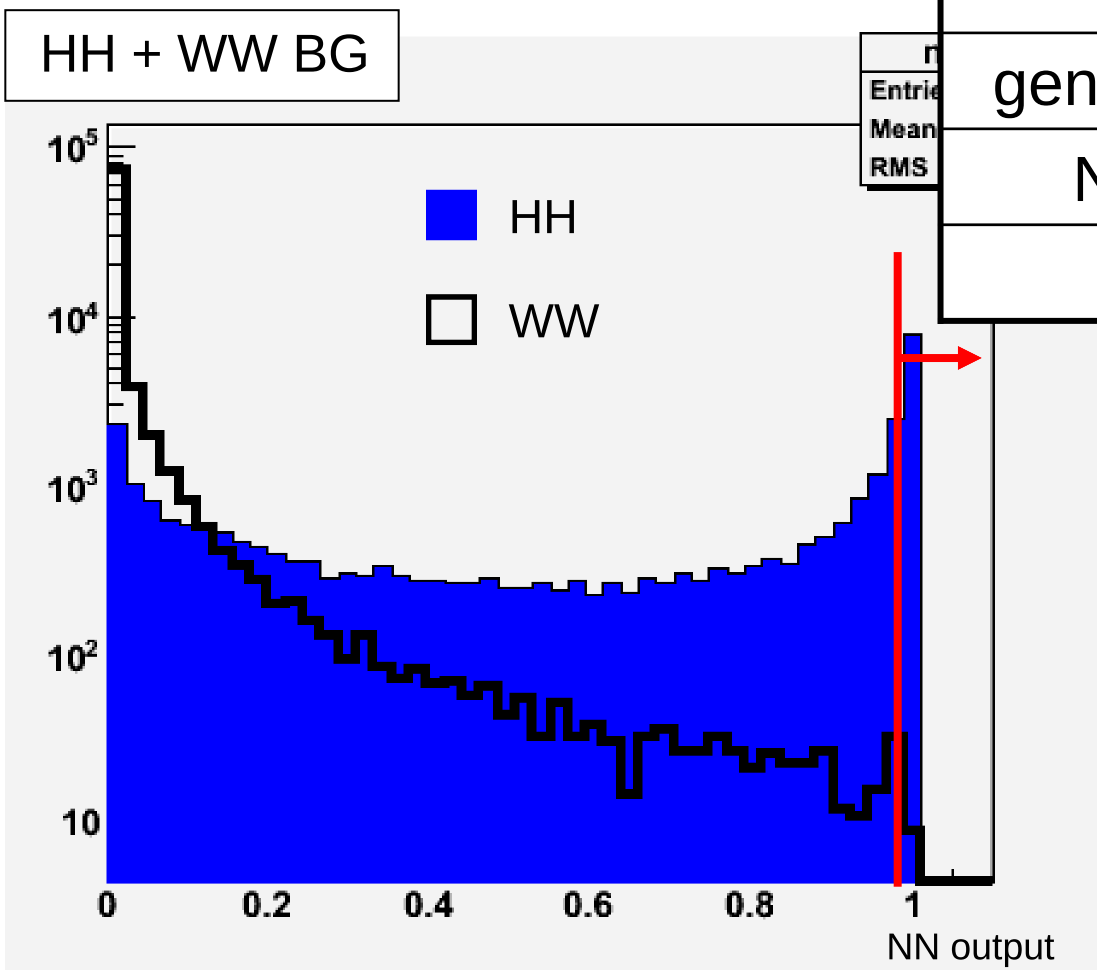




$$\chi_H{}^2 = \frac{(M_1 - M_H)^2}{\sigma_{2j}^2} + \frac{(M_2 - M_H)^2}{\sigma_{2j}^2}$$

$$\chi_Z{}^2 = \frac{(M_1 - M_Z)^2}{\sigma_{2j}^2} + \frac{(M_2 - M_Z)^2}{\sigma_{2j}^2}$$

Results of NN analysis --- WW BG



	HH	WW
generate	$5.0*10^4$	$7.5*10^7$
NN	7713	9
η	0.154	**$1.2*10^{-7}$**

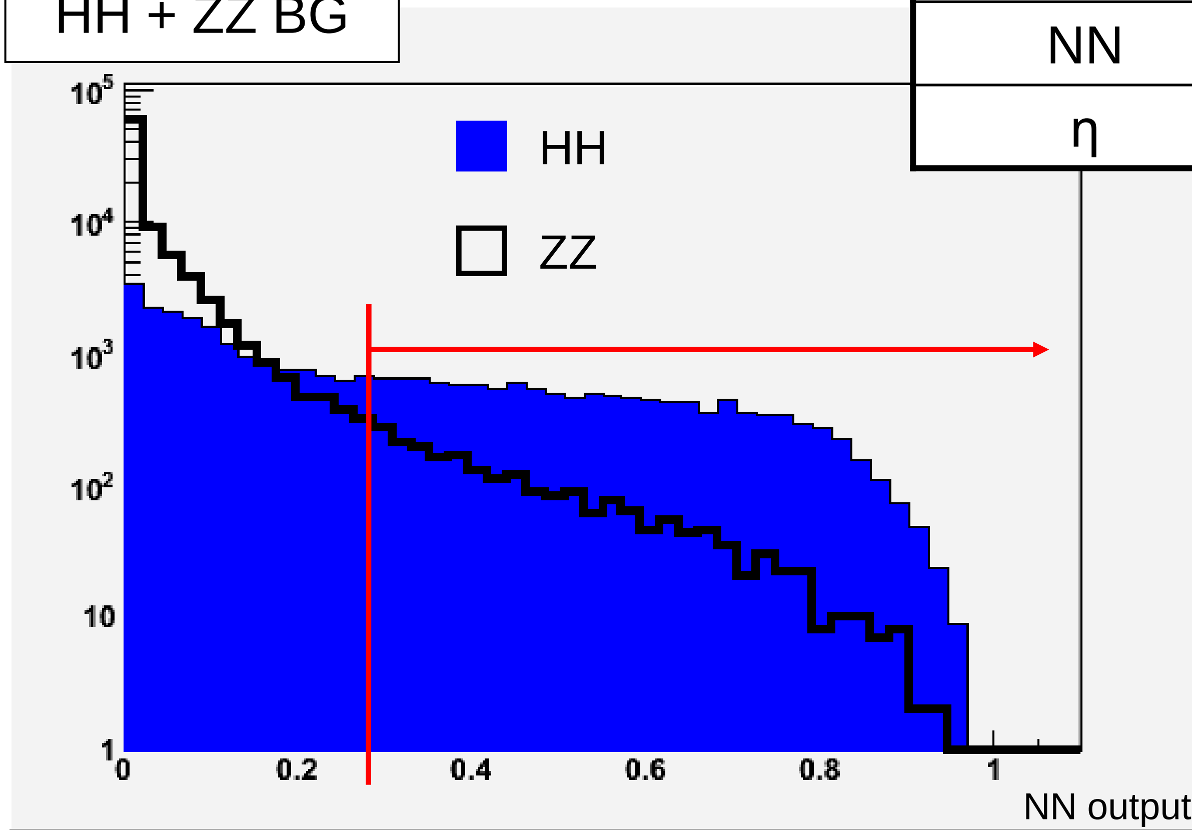
$$S_{stat} = 2.7$$

almost suppress WW background.

Results of NN analysis --- ZZ BG

	HH	ZZ
generate	$5.0*10^{4}$	$1.0*10^{6}$
NN	11532	1907
η	0.231	$1.91*10^{-3}$

HH + ZZ BG



$$S_{stat} = 1.6$$

not bad but not enough

attempt for improvement

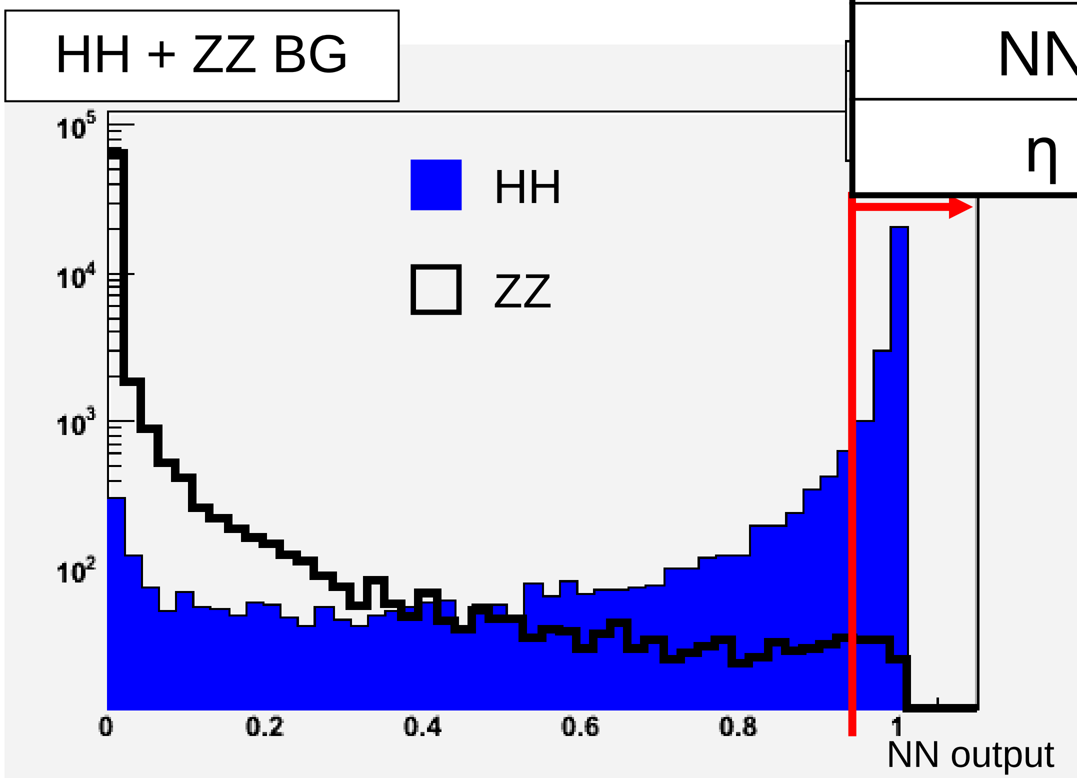
- previous analysis apply NN selection for WW and ZZ background separately.

$S_{stat} < 1$ if both WW and ZZ cut are applied

- possible improvement by jet clustering

Analysis with CheatJetFinder --- ZZ BG

Cheated JetFinder:
100% correct parton assignment using generator information



	HH	ZZ
generate	$5.0*10^4$	$1.0*10^6$
NN	24191	85
η	0.484	**$8.5*10^{-5}$**

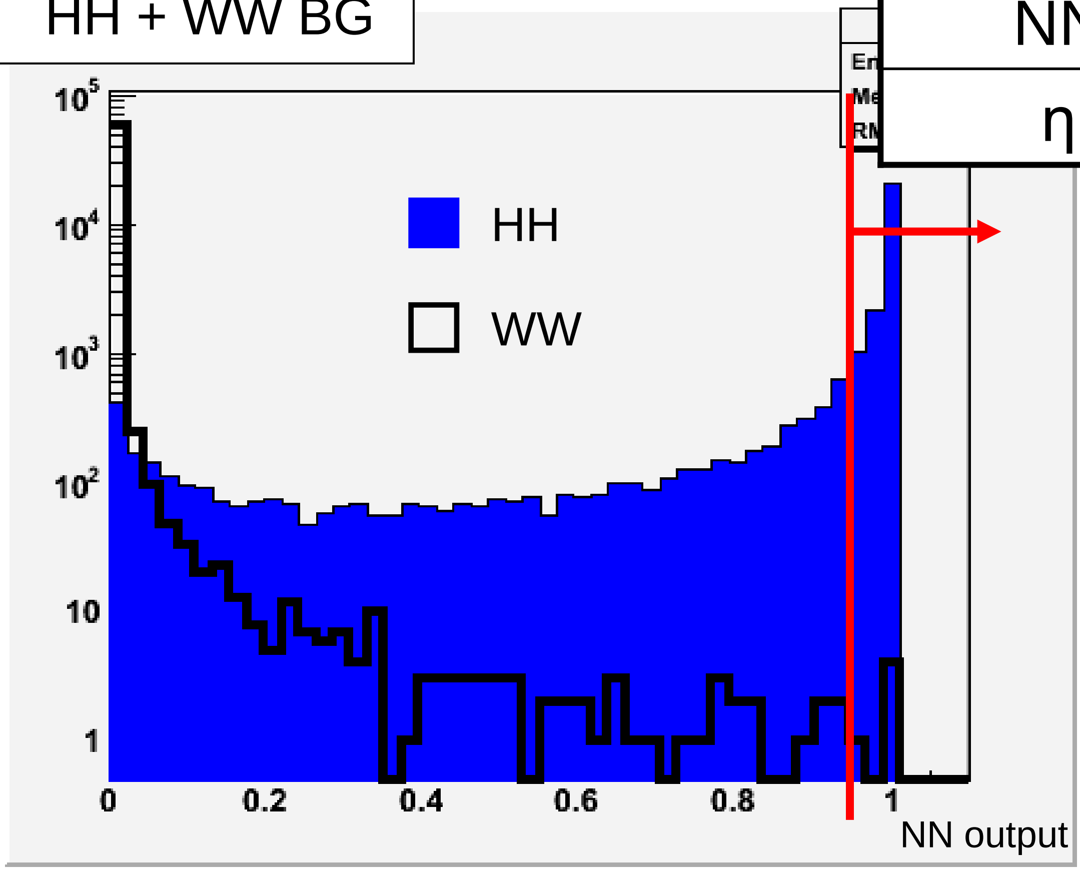
$$S_{stat} = 5.9$$

suppress ZZ background w/ improved cluctering

Analysis with CheatJetFinder --- WW BG

	HH	WW
generate	$5.0*10^4$	$7.5*10^7$
NN	24115	5
η	0.482	**$6.67*10^{-8}$**

HH + WW BG



$$S_{stat} = 5.9$$

good background suppresion for WW too

Summary

- We tried to see $\gamma\gamma$ -> HH in a photon collider based on TESLA optimistic parameters.
- gg CM energy of 270GeV is optimum for mh =120GeV
- backdournds
  - $\gamma\gamma$->WW has 10^6 times lager cross section
  - $\gamma\gamma$->ZZ has 10^3 times lager cross section
- It seems possible to suppress backgrounds with improved jet clustering technique.
  - statistical significance of 4.6 expected for WW and ZZ cut with perfect jet clustering
- more to do
  - optimize NN training
  - study jet clustering improvement (it is not just for HH analysis
  - $\gamma\gamma$->bbbb backgroud
    - we believe it is small for dangerous kinematical region
  - higher Higgs mass

Backup slide

Optimization of CM energy

$$sensitivity = \sqrt{L}\,\frac{\left|\sigma(\delta\kappa)-\sigma_{SM}\right|}{\sqrt{\sigma(\delta\kappa)}}$$

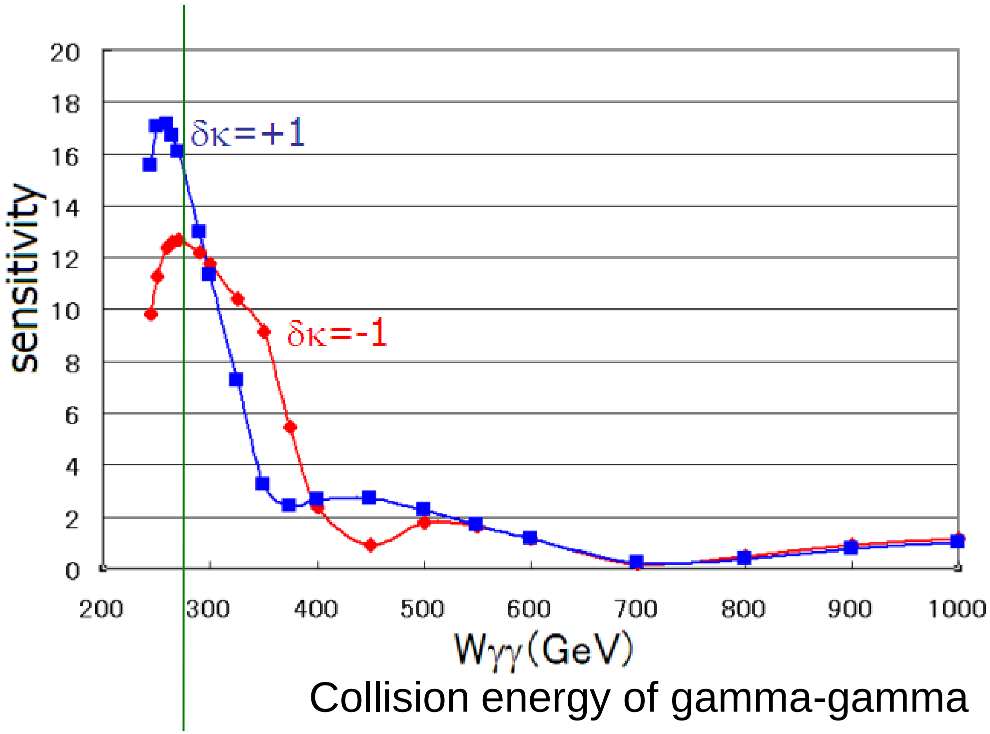
L : luminosity (1000fb^{-1})

σ : cross-section

SM : standard model

δκ : deviation from the standard model

In order to simplify the discussion, we set the detection efficiency to be 100% and there are no background.



Collision energy of gamma-gamma

~270GeV

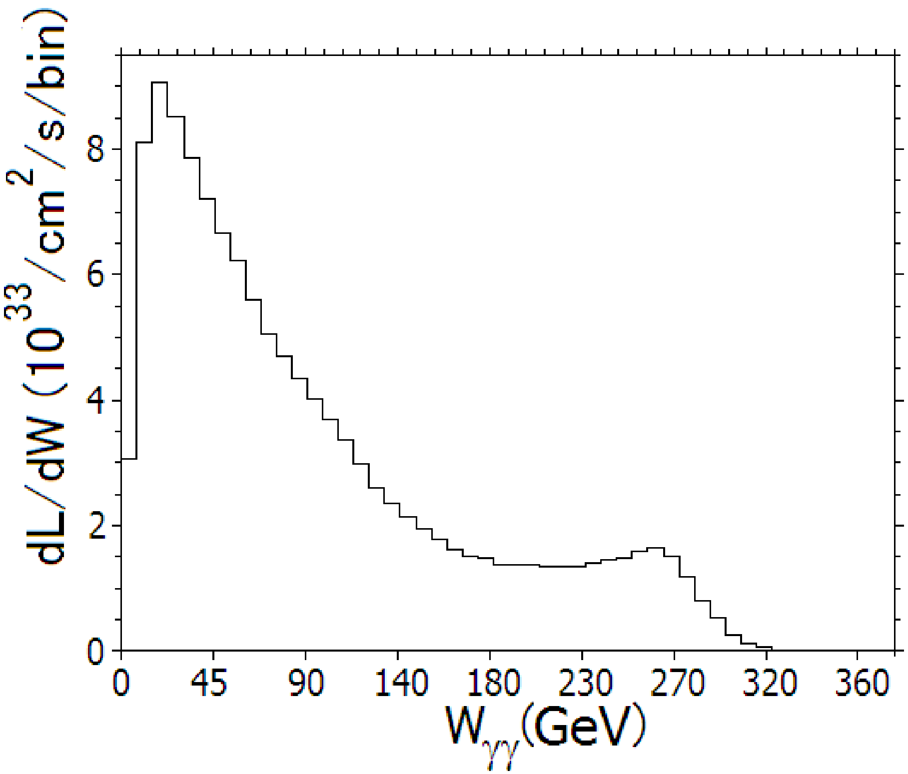
We set the optimized CM energy is equal to 270GeV.

Luminosity distribution

We adjusted the parameters of the laser and e- beam to have a peak at the optimum energy.

Effective cross-section of Higgs pair creation was calculated 0.013fb.

16.4events/year (1year = 10^7sec)



Effective cross-section

- AA->HH: 0.013fb
- AA->WW: 11.6pb
- AA->ZZ: 9.42fb

Policy of analysis

表 4: ヒッグス粒子の主な崩壊モードとその分岐比

モード	$b\bar{b}$	WW	gg	$\tau\tau$	$c\bar{c}$	ZZ	$\gamma\gamma$	γZ
分岐比	0.6774	0.1331	0.0713	0.06916	0.02982	0.0152	0.002231	0.001084

The highest decay branching ratio is HH->4b mode (45.9%)

表 2: W ボゾンの主な崩壊モードとその分岐比

モード	ud	cs	$\nu_e e$	$\nu_\mu \mu$	$\nu_\tau \tau$	us	cd	cb	ub
分岐比	0.3209	0.3201	0.1084	0.1084	0.1083	0.0166	0.0166	0.0006	0.00005

表 3: Z ボゾンの主な崩壊モードとその分岐比

モード	$d\bar{d}$	$s\bar{s}$	$b\bar{b}$	$u\bar{u}$	$c\bar{c}$	$\nu_e\bar{\nu}_e$	$\nu_\mu\bar{\nu}_\mu$	$\nu_\tau\bar{\nu}_\tau$	e^+e^-	$\mu^+\mu^-$
分岐比	0.154	0.154	0.152	0.120	0.120	0.069	0.069	0.069	0.034	0.034

WW->4b mode: 0% ZZ->4b mode: 2.3%

⇩

We tried to reconstruct events which generated 4b.

Jet clustering

We can obtained the information of 4-momentum of original quark if we can obtain the information of original jets, so we have to reconstruct original jets first.

JADE clustering

$$\frac{\left(p_i + p_j\right)^2}{E_{vis}{}^2} < Y_{cut}$$

When particle i and j satisfy this equation, we calculate 4-momentum of sum of these particles.

->**reconstruct jets**

p_i: 4-momentum of particle

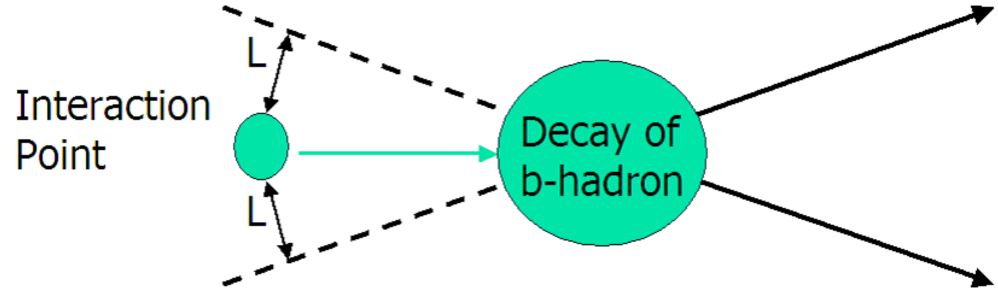
E_{vis}: Visible energy

Y_{cut}: Any value

Since HH->4b reaction is 4-jets mode, we applied forced 4-jets analysis.

b-tagging

Method of identify b-quark.



nsig method

$$\frac{L}{\sigma_L} \geq nsig$$

L: The least approach to the interaction point of the track in the plane perpendicular to the beam

σ_L: Distance resolution of detector

nsig、noffv： Any value

When there are noffv tracks which satisfy this equation, we regarded this quark as b-quark.

->**identification of b-quark**

Accuracy of b-tagging

Efficiency for AA->HH->4b events

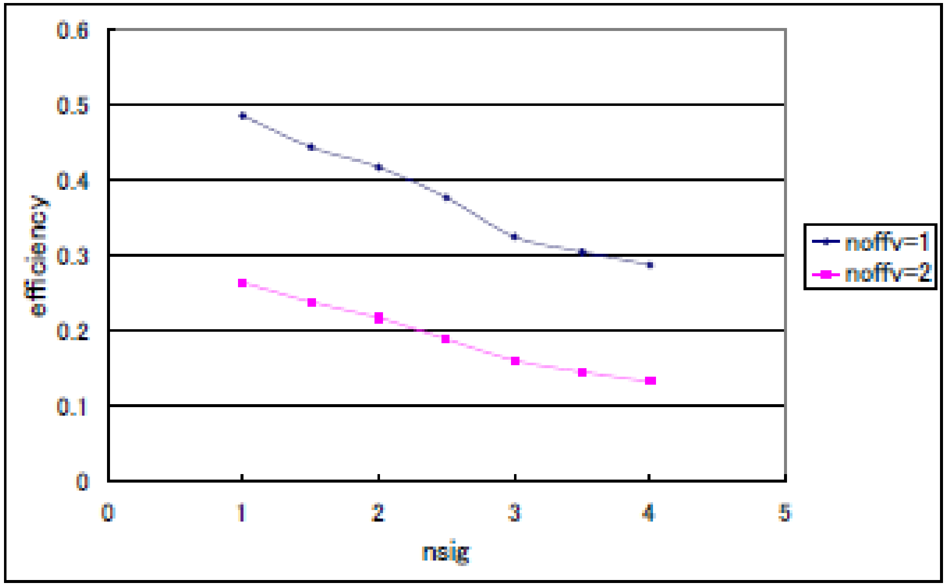


図 43: b フレーバジェット識別の精度

Contamination for AA->WW events

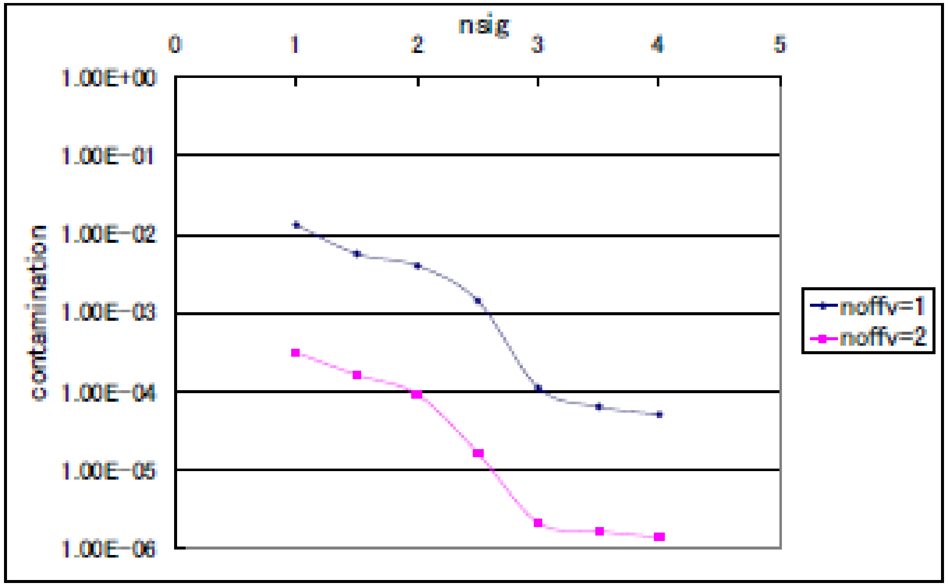
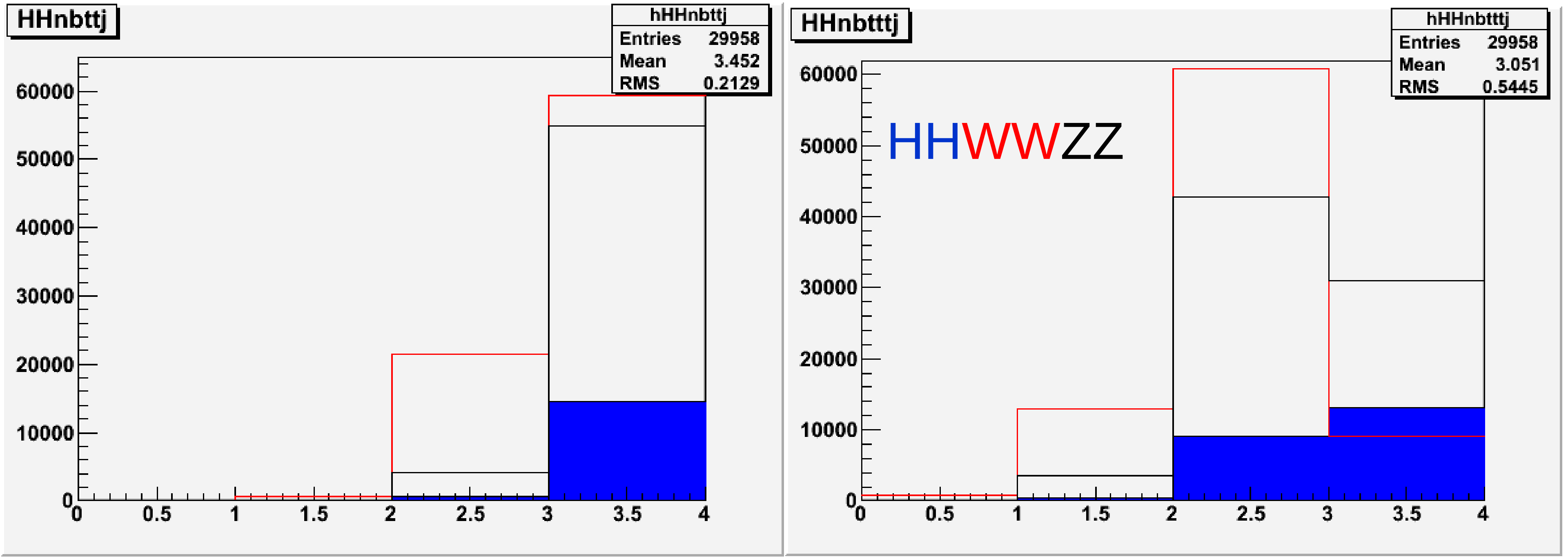


図 44: b フレーバジェット識別の誤判定率

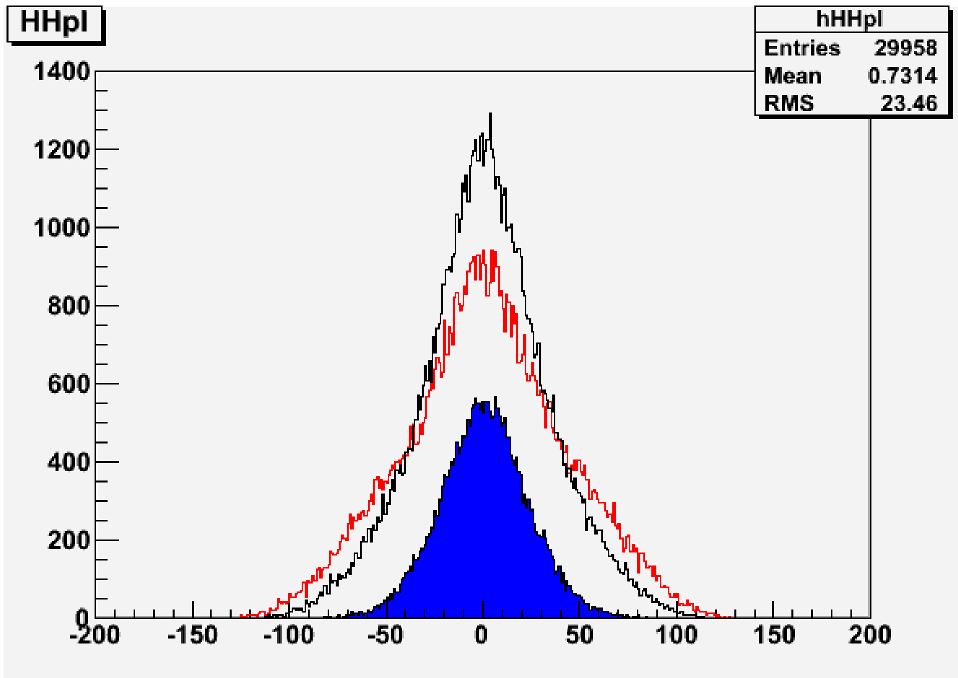
Distribution of input parameters (2)



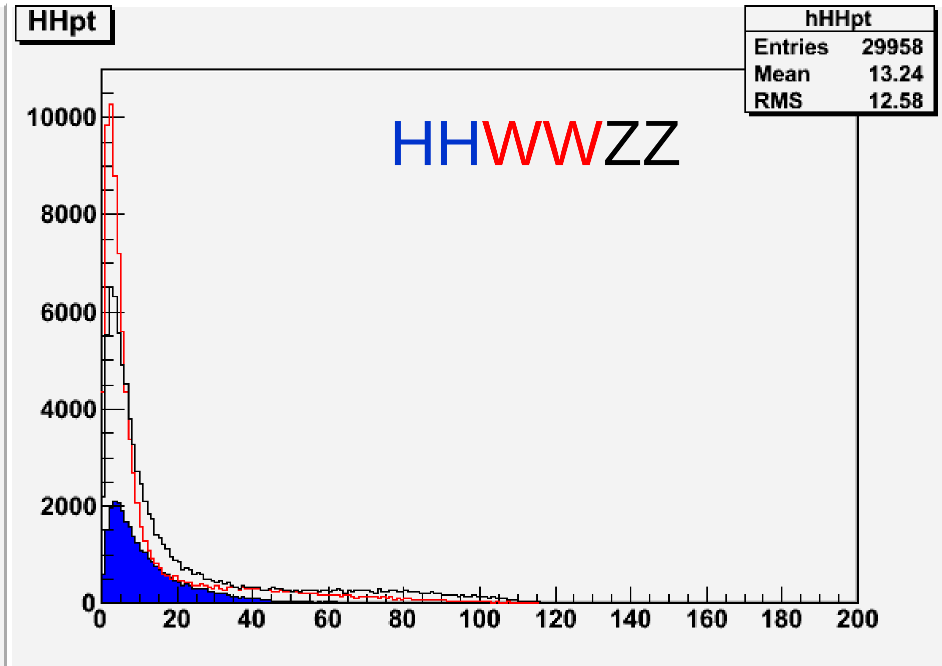
# of b-flavor jets with
(nsig=3.5, noffv=1) analysis

# of b-flavor jets with
(nsig=3.5, noffv=2) analysis

Distribution of input parameters (3)

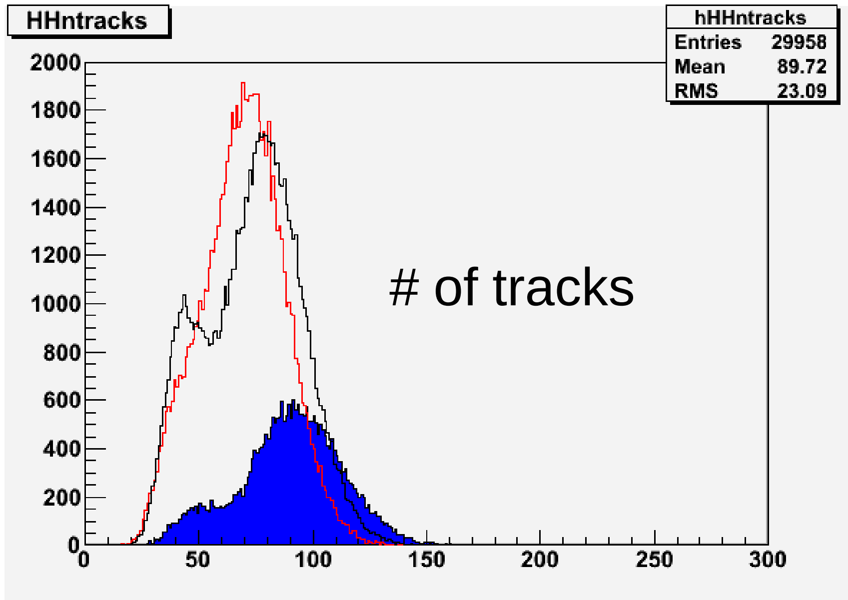


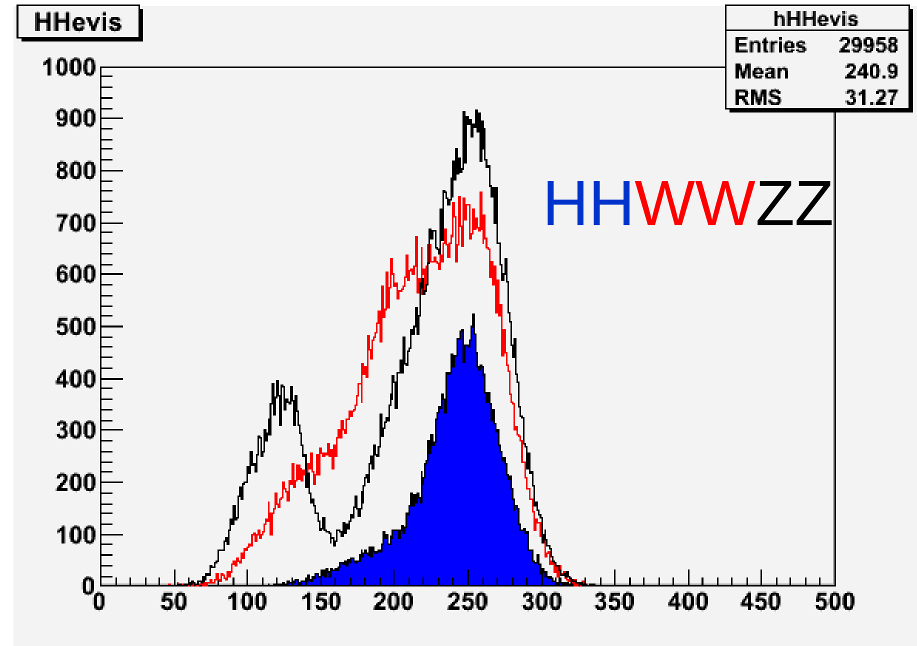
longitudinal momentum



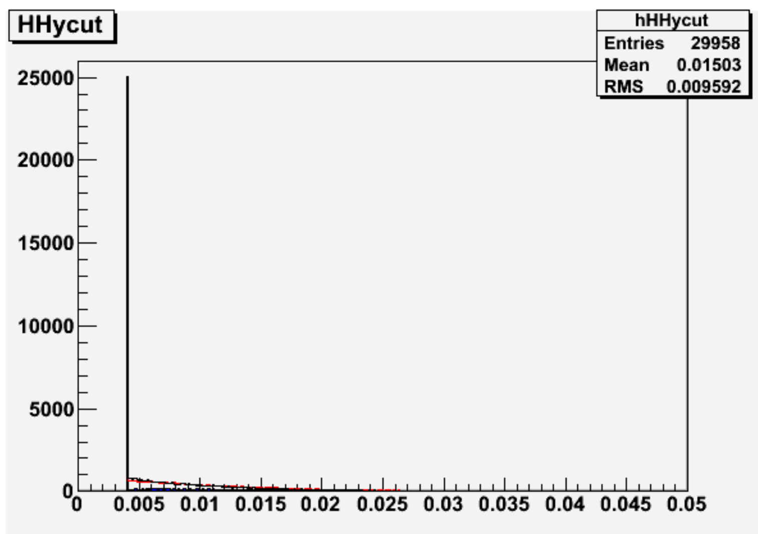
transverse momentum

Distribution of input parameters (4)





visible energy



Y_{cut} value of jet clustering

Verification of statistical error of NN training

weights / events	Maeda	Kawada ON	Kawada OFF1	Kawada OFF2
Maeda 29935 86944	13089 2729 1.55	13263 2916 1.52	13276 2941 1.52	13788 3041 1.55
Kawada-ON 29958 87484	13047 2832 1.52	14254 3488 1.50	13880 3293 1.51	13738 3144 1.52
Kawada-OFF1 29958 87057	13047 2735 1.54	13168 2896 1.52	13575 3057 1.52	13738 3057 1.54
Kawada-OFF2 29823 87142	13391 2904 1.54	12830 2723 1.52	12538 2575 1.53	13291 2846 1.54

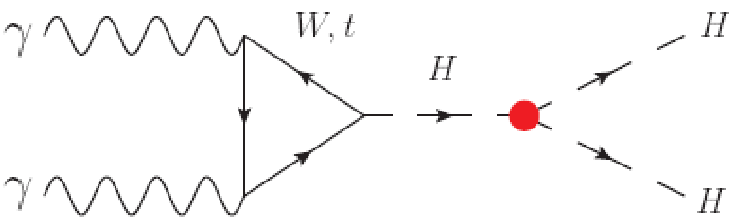
# of remained HH, # of remained ZZ, Maximum significance

Features of Higgs pair creation in PLC

Gamma Gamma process

Final state: 2 particles

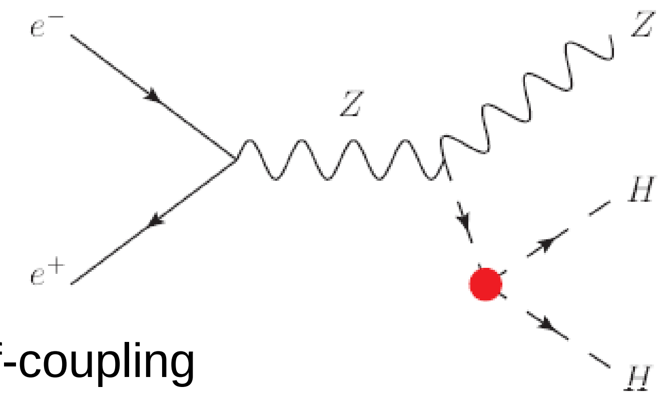
$$\gamma\gamma \to HH$$



cf: e+ e- process

Final state: 3 particles

$$e^+e^- \to ZHH$$



● : Higgs self-coupling

Comparing with e+e- collision

Self coupling contribute different way

Lower energy threshold