Feasibility study of measurement of Higgs pair creation in a gamma-gamma collider

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Outline

- Motivation
- Signal & Background
- Simulation & Analysis
- Result
- Summary

T. Takahashi's talk @ IWLC2010

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 improveme
  - $\gamma\gamma$->bbbb backgroud
    - we believe it is small for dangere
  - higher Higgs mass

My talk is including these topics.

Motivation

Final goal : measuring Higgs self-coupling constant λ

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

Higgs self-coupling constant in the SM

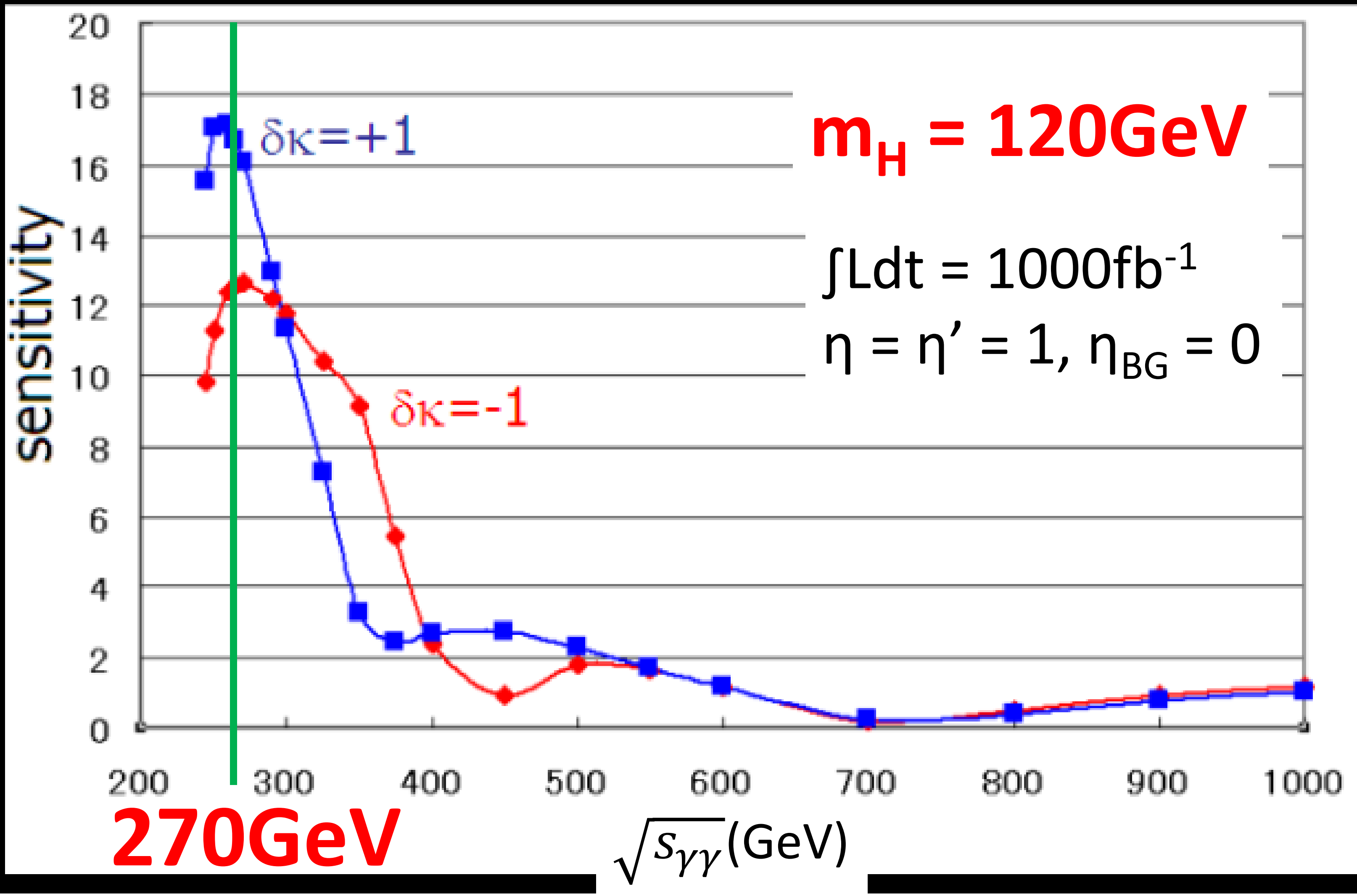
deviation parameter from the SM

Before the final goal…

We have to investigate the feasibility of measurement of Higgs pair creation in a PLC.

Optimizing collision energy

$$\text{sensitivity} \equiv \frac{|N(\delta\kappa) - N_{SM}|}{\sqrt{N_{obs}}} = \frac{L|\eta\sigma(\delta\kappa) - \eta'\sigma_{SM}|}{\sqrt{L(\eta\sigma(\delta\kappa) + \eta_{BG}\sigma_{BG})}}$$



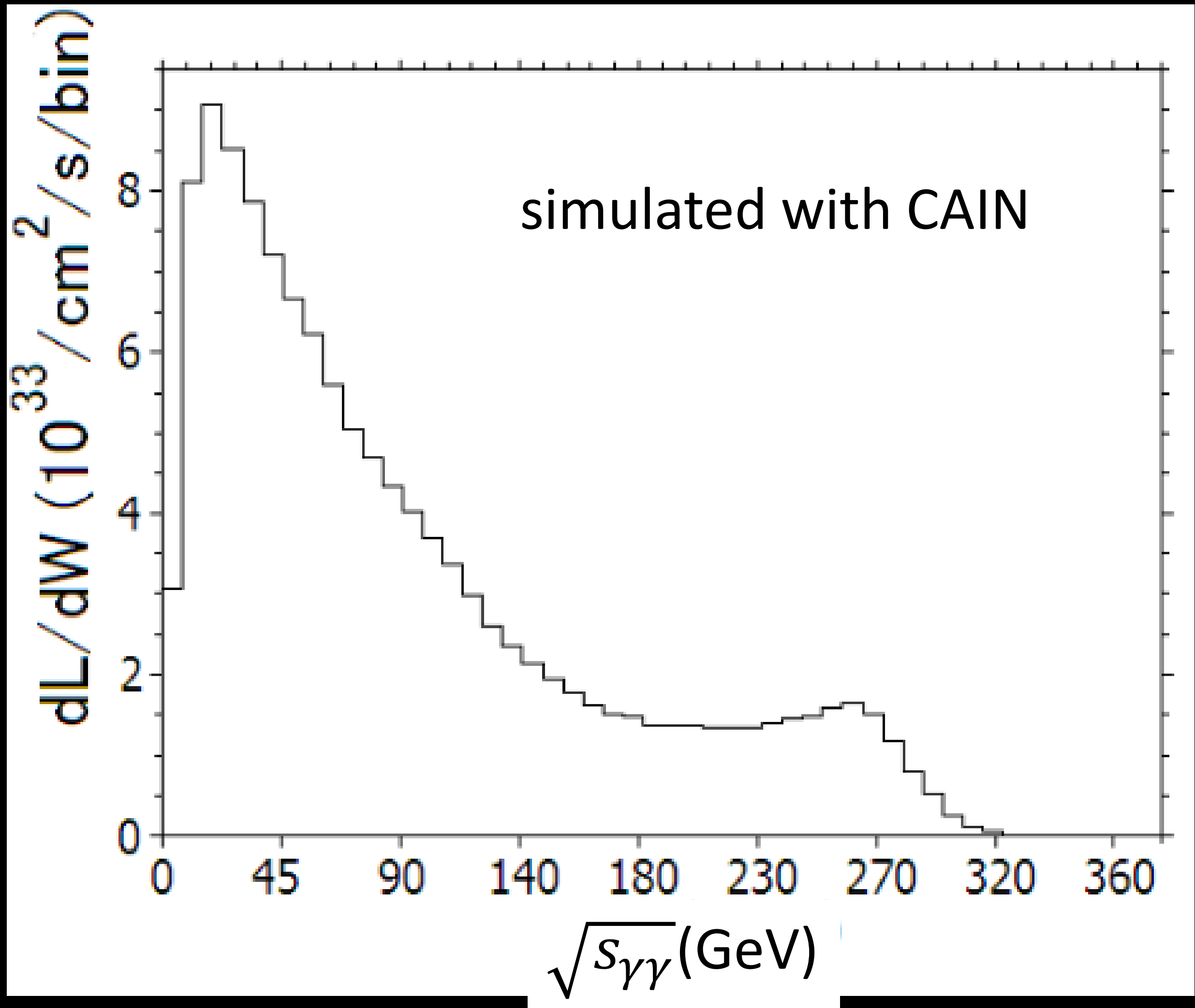
Beam parameters

	x3.76	x4.8
E_e(GeV)	210	195
n(10^{10})	2	2
σ_z(mm)	0.35	0.35
$\gamma\varepsilon_{x/y}$(mrad)	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
$x = 4\omega E_e/m_e^2$	3.76	4.8
Pulse Energy(J)	10	10
L_{geo}(e-e-)[$10^{34}cm^{-2}s^{-1}$]	8.7	8.1
$L_{peak}(\gamma\gamma)$[$10^{34}cm^{-2}s^{-1}$]	1.2	0.7
$L_{tot}(\gamma\gamma)$ [$10^{34}cm^{-2}s^{-1}$]	12.6	5.88

based on TESLA optimistic parameter

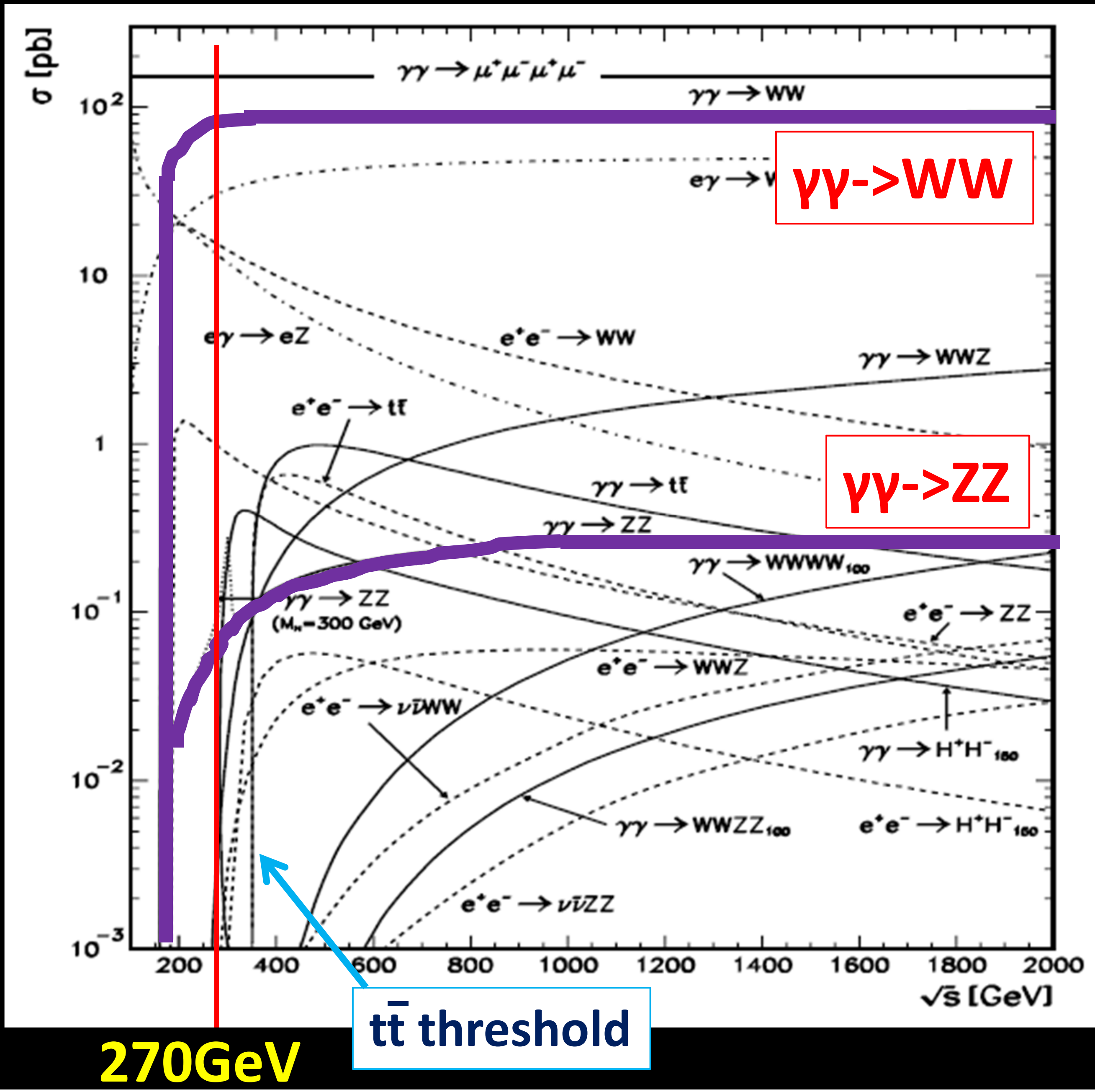
x=3.76 in this study

Luminosity distribution



$$L(/\text{year}) \int \sigma(W_{\gamma\gamma}) \frac{dL}{dW_{\gamma\gamma}} dW_{\gamma\gamma} = \mathbf{16\ events/year}$$

Signal & Backgrounds



of events

$$N\_events = L(/year)\int \sigma(W_{\gamma\gamma})\frac{dL}{dW_{\gamma\gamma}}dW_{\gamma\gamma}$$

Signal

γγ->HH : 16 events/year

Main backgrounds

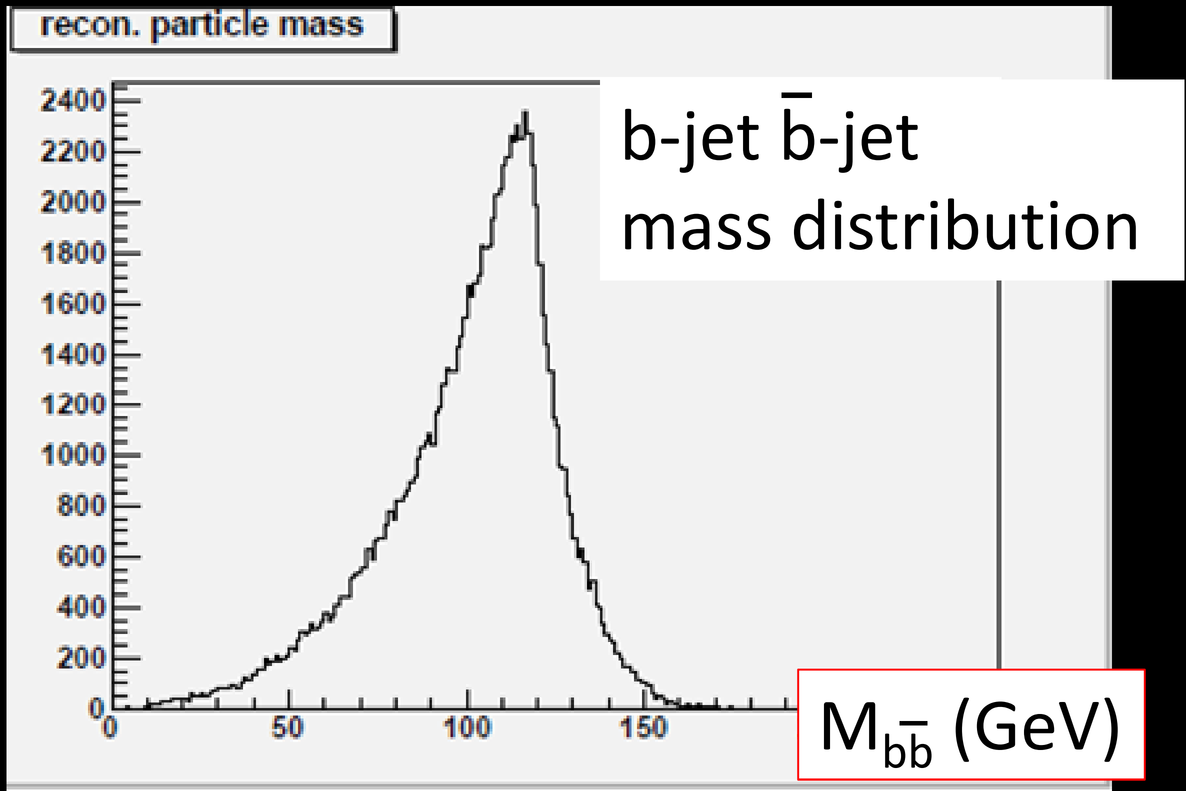
γγ->WW : $1.462*10^7$ events/year

γγ->ZZ : $1.187*10^4$ events/year

γγ->4b : $1.37*10^5$ events/year

Event signature (1)

- $\gamma\gamma$->HH
  - HH->4b
  - $M_{b\bar{b}} = M_H$(120GeV)



Event signature (2)

- γγ->WW
  - $\sigma_{\gamma\gamma\text{->}WW} \sim 10^6 \sigma_{\gamma\gamma\text{->}HH}$
  - suppressed by b-tagging
- γγ->ZZ
  - ZZ->4b same as HH->4b
  - discriminate only by mass difference
- γγ->4b
  - Mass distribution is different from signal, but still have events near signal region (~120GeV).
  - Angular distribution is different from signal.

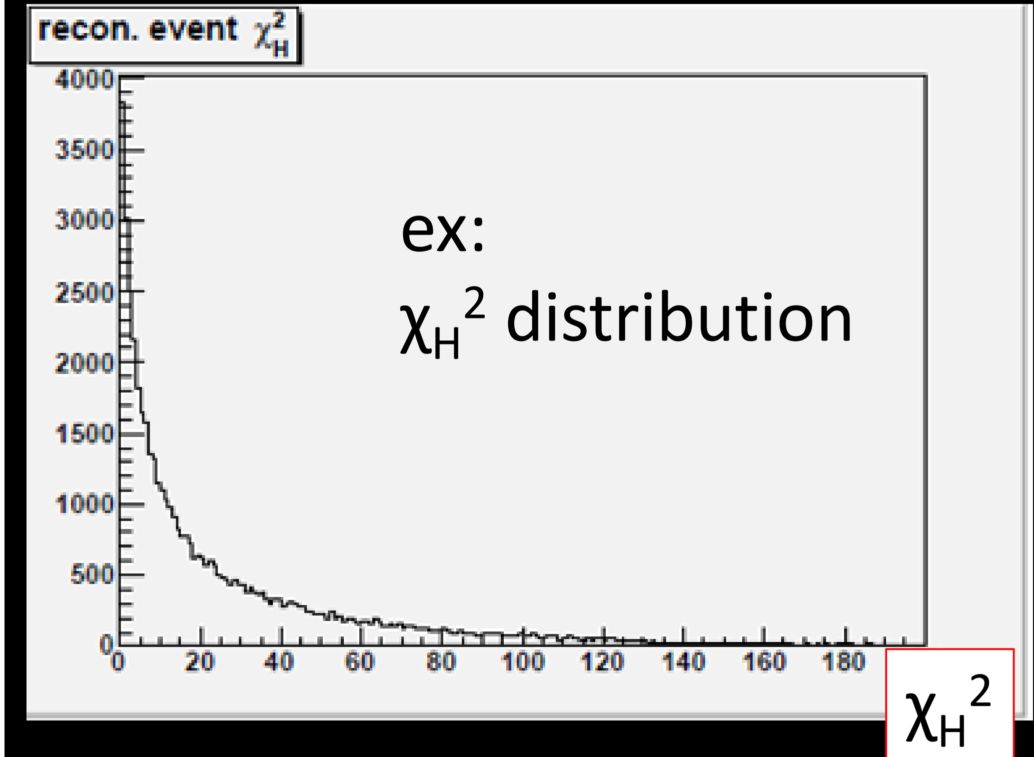
Simulation & Analysis

1. Event generation & Detector simulation
2. Event reconstruction
    1. jet clustering
    2. b-tagging
        - n_{sig} method
    3. jet pairing
3. Event selection
    1. pre-selection
    2. Neural Network (NN)

Event reconstruction (1)

information of mass

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



M_1, M_2 : reconstructed mass

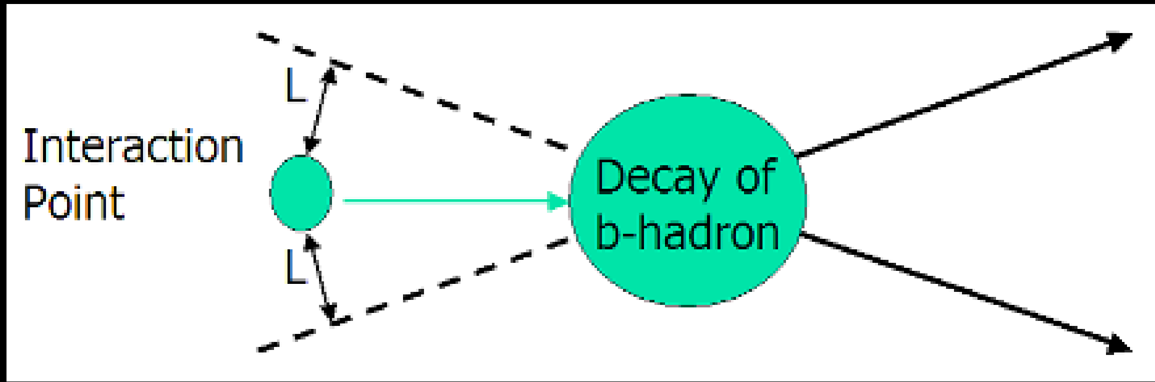
i : H, W, Z, $b\bar{b}$

σ_{2j} : mass resolution

Event reconstruction (2) --- b-tagging

n_{sig} method

$$\frac{L}{\sigma_L} \geq n_{sig}$$



When there are n_{offv} tracks which satisfy this equation, we regarded this quark as a b-quark.

relatively simple b-tagging method

⇒ can be improved by further study

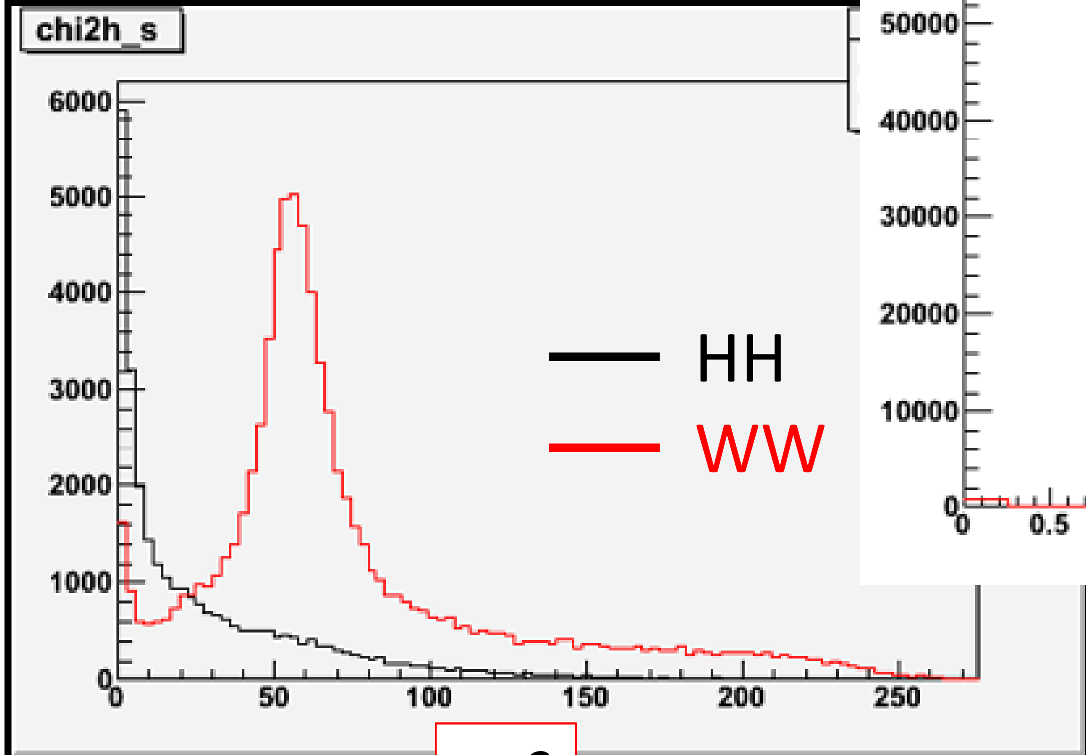
Event selection by Neural Network (NN)

- 3 steps
  1. W filter
  2. 4b filter
  3. Z filter
- Maximize statistical significance

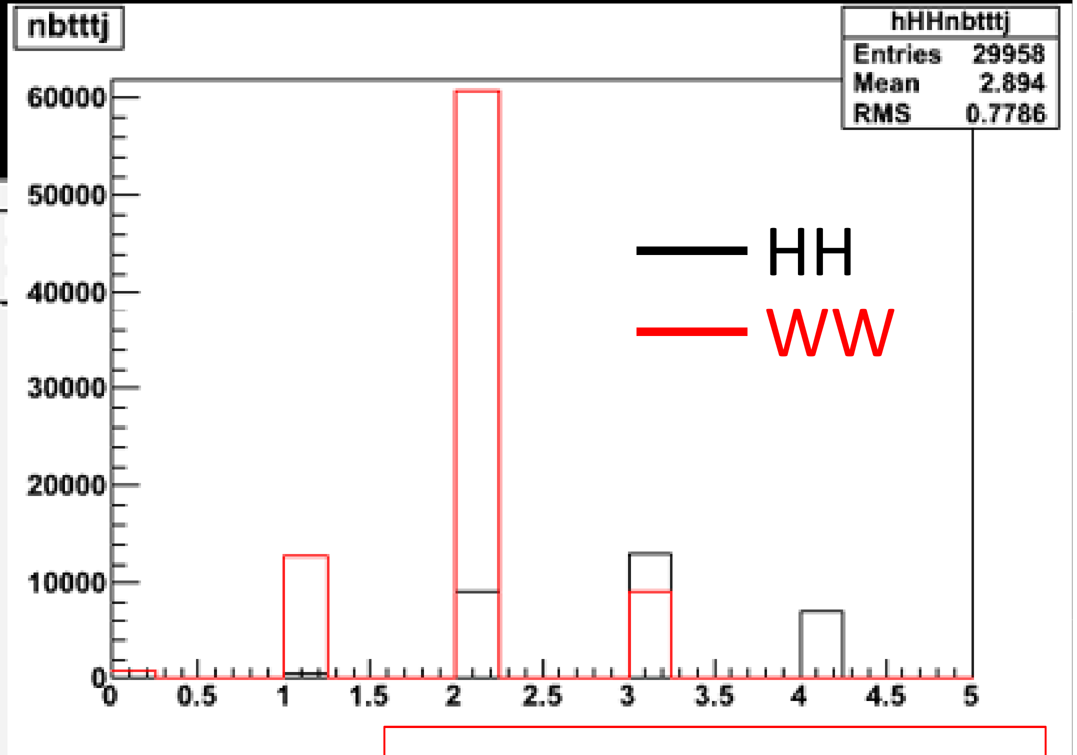
$$\text{significance} \equiv \frac{N_{signal}}{\sqrt{N_{signal} + N_{BG}}}$$

N : # of events

Distribution of NN inputs --- WW

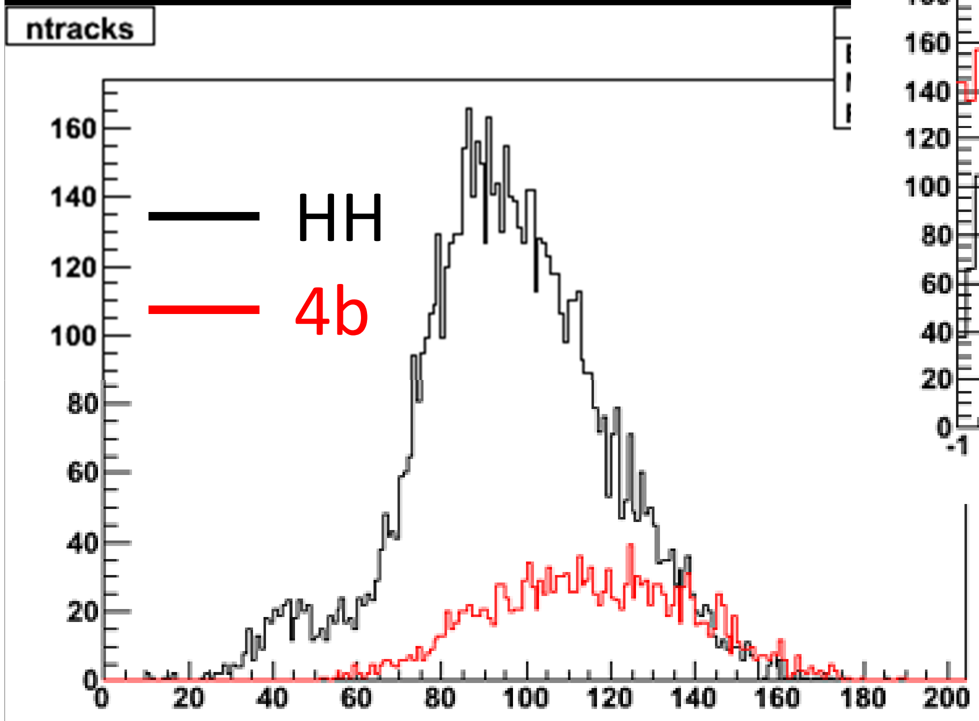


$\chi_H{}^2$

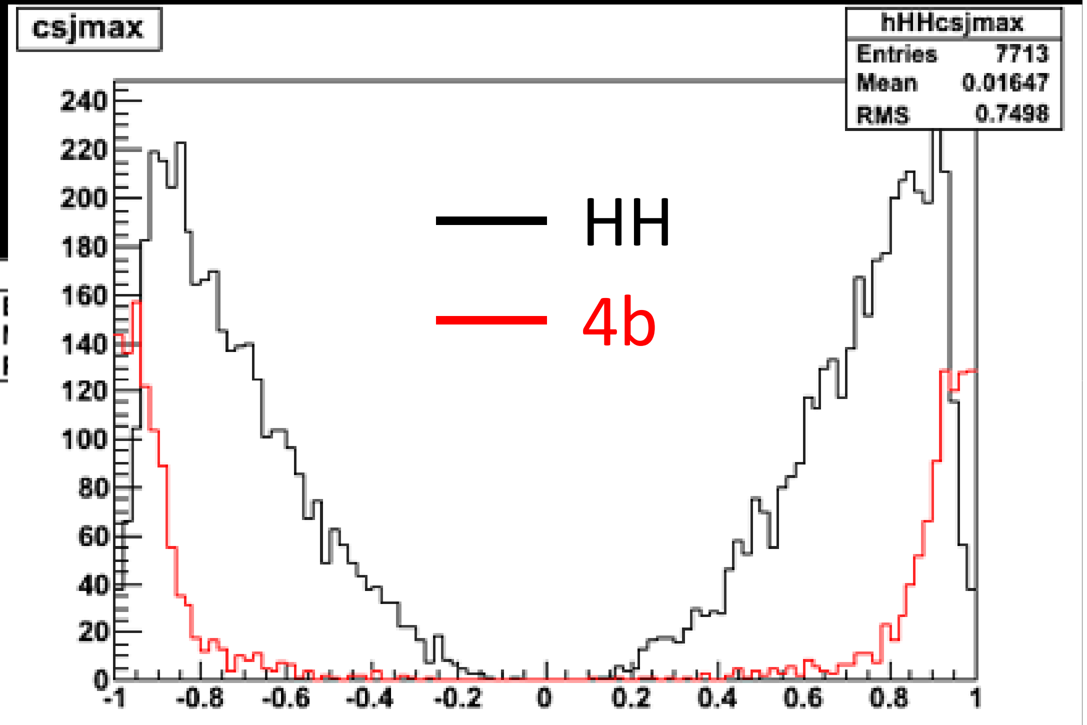


# of b-flavor jet with (n_{sig} = 3.5, n_{offv} = 2) analysis

Distribution of NN inputs --- 4b

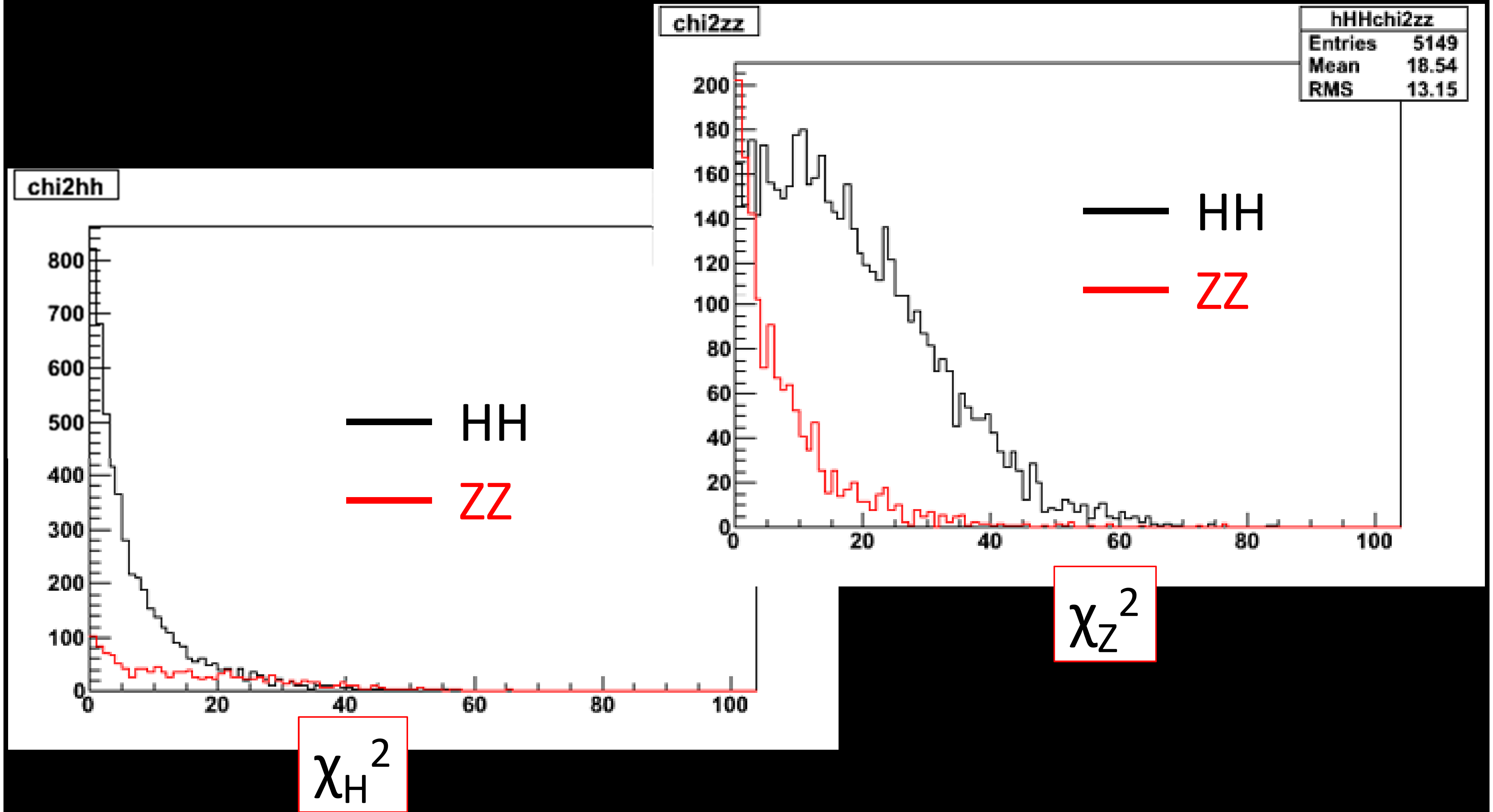


# of tracks



maximum |cosθ of jet|

Distribution of NN inputs --- ZZ



Cut summary

	HH	WW	ZZ	4b
expected events (# of MC samples)	80 (50000)	73100000 (75000000)	59350 (1000000)	293600 (1000000)
pre-selection	47.93 (29958)	81655 (83777)	5167 (87057)	84491 (287776)
W filter	12.34 (7713)	8.772 (9)	193.4 (3259)	568.4 (1936)
4b filter	8.238 (5149)	0 (0)	84.40 (1422)	13.21 (45)
Z filter	**4.994 (3121)**	**0 (0)**	**7.359 (124)**	**5.872 (20)**

$$\text{significance} = \frac{N_{signal}}{\sqrt{N_{signal} + N_{BG}}} = 1.17$$

Further improvement

- WW BG : almost completely suppressed!
- 4b & ZZ BG remained
- Possible improvement --- **jet clustering**

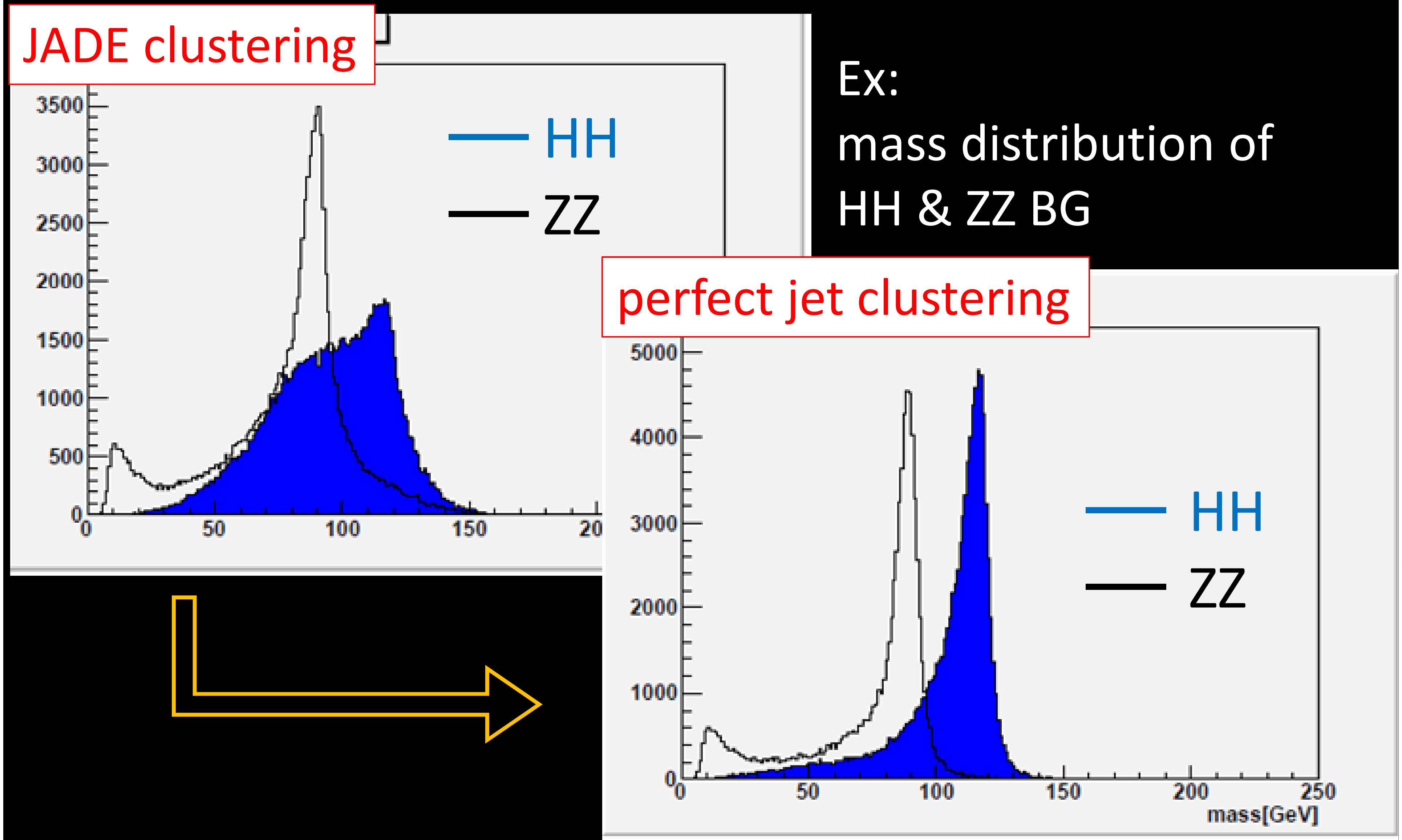
correct color singlet information

⇒ improve mass resolution, b-tagging efficiency

We investigated using generator information for HH, WW, ZZ (not for 4b).

Improve mass resolution

Ex:
mass distribution of
HH & ZZ BG



Cut summary with perfect jet clustering

	HH	WW	ZZ	4b
expected events (# of MC samples)	80 (50000)	73100000 (75000000)	59350 (1000000)	293600 (1000000)
pre-selection	46.64 (29152)	55836 (57287)	4172 (70292)	84491 (287776)
W filter	38.58 (24115)	4.873 (5)	98.84 (1667)	2179 (7422)
4b filter	34.50 (21562)	2.924 (3)	27.66 (466)	2.642 (9)
Z filter	**33.06 (20662)**	**2.924 (3)**	**5.935 (100)**	**2.642 (9)**

$$\text{significance} = \frac{N_{signal}}{\sqrt{N_{signal} + N_{BG}}} = 4.95$$

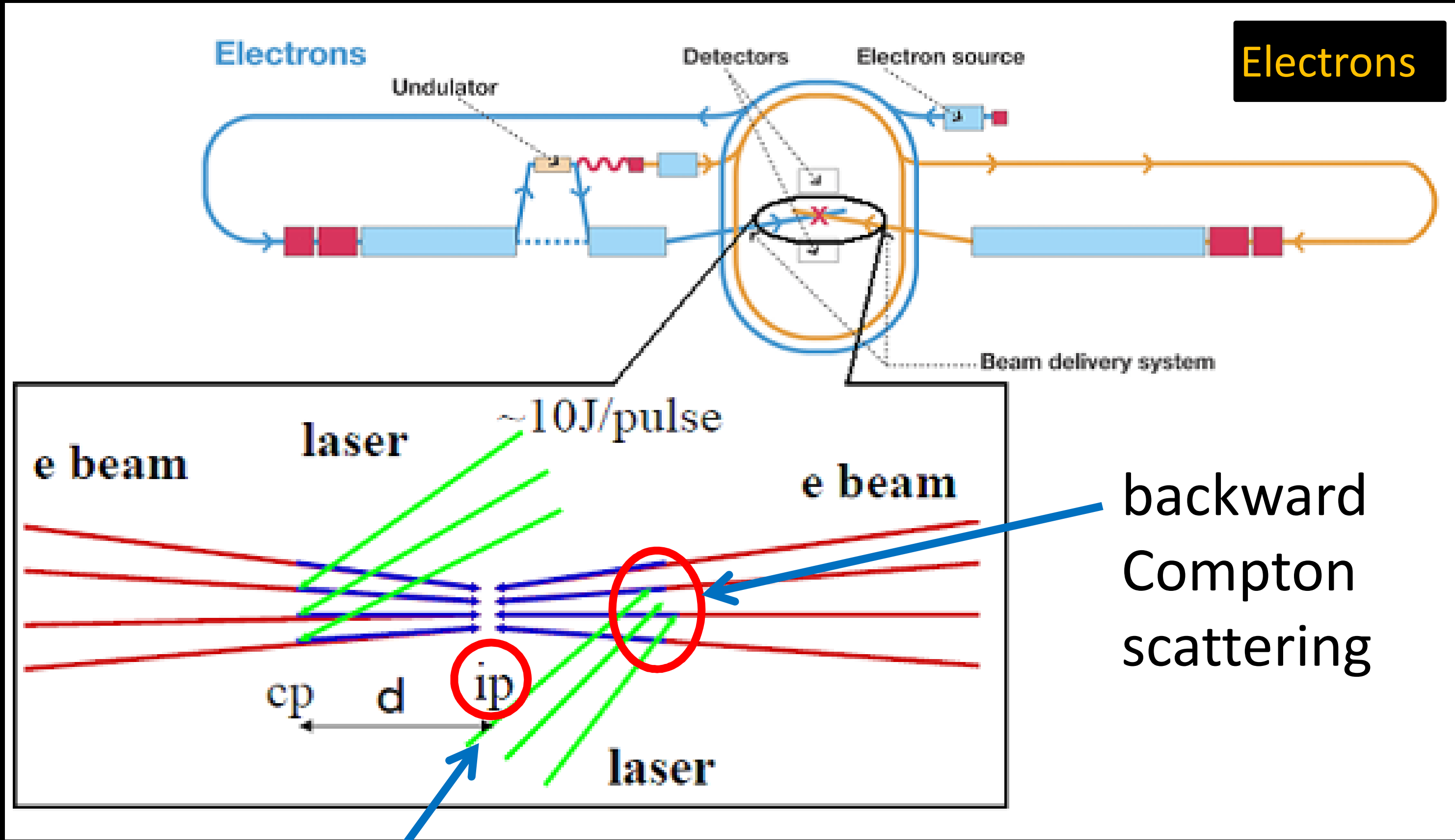
Summary

- We investigated γγ->HH in a gamma-gamma collider based on TESLA optimistic parameters.
- Possible to suppress huge backgrounds with improved jet clustering.
  - Significance ~ 5 with 5 year PLC run
- Further study
  - jet clustering
  - b-tagging

    } T. Suehara's talk, T. Tanabe's talk in this workshop
  - other decay modes

Backup slides

About PLC

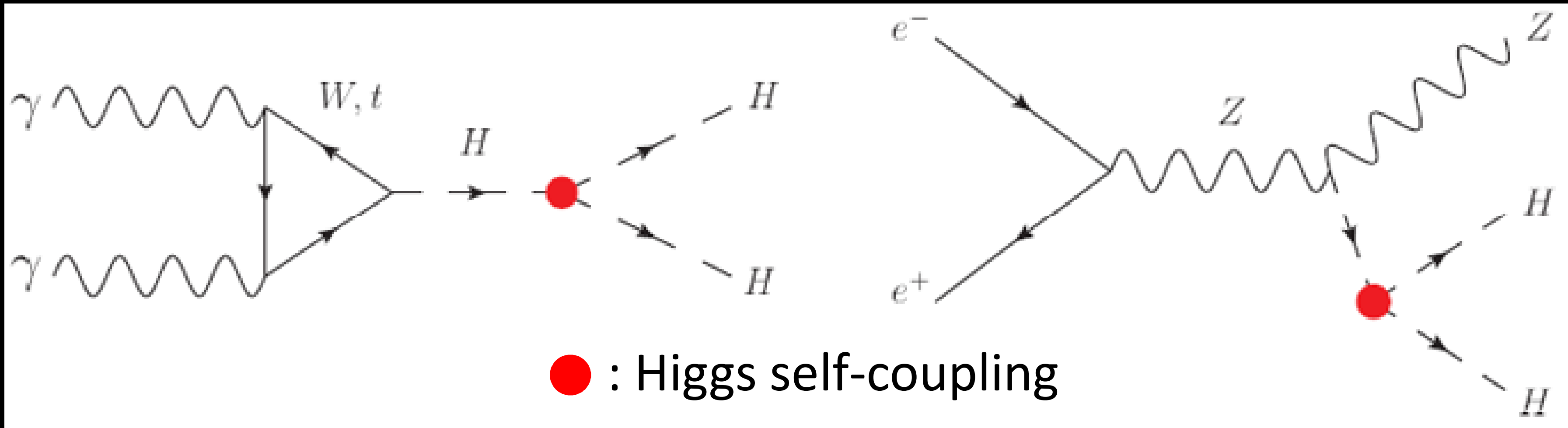


backward Compton scattering

gamma-gamma collision

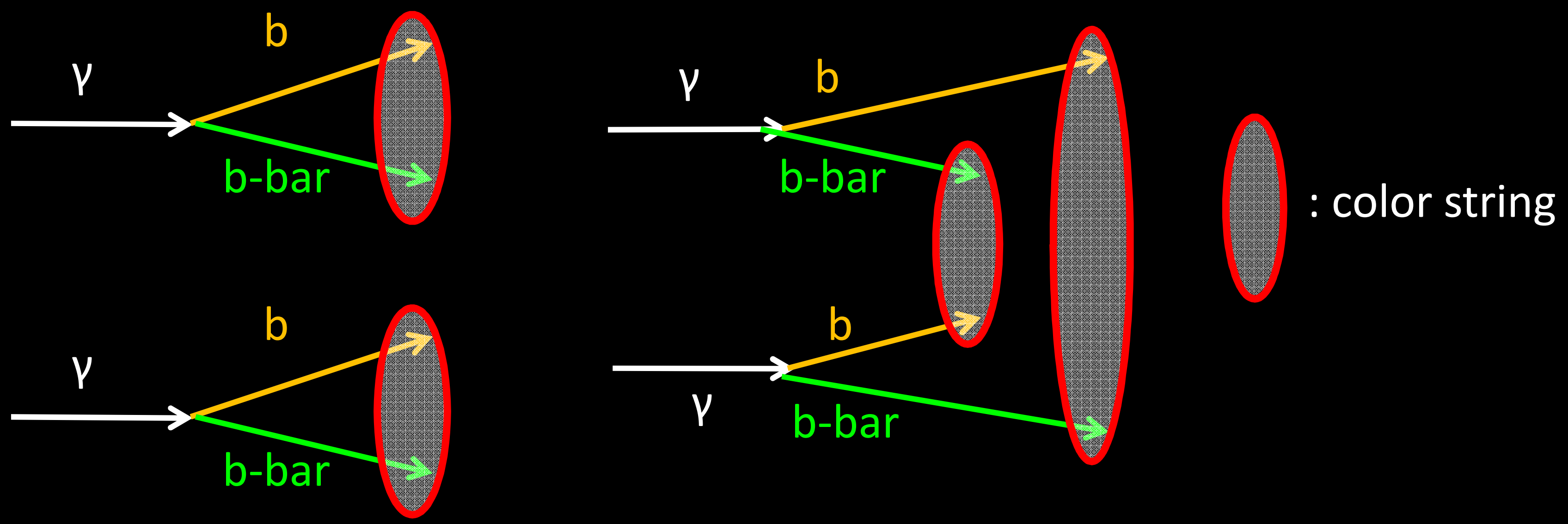
Comparison of γγ and e^+e^- process

$\gamma\gamma \rightarrow HH$ $\quad$ $e^+e^- \rightarrow ZHH$



Contribution of self-coupling is different way.
Energy threshold of γγ process is lower than e^+e^- process.

γγ->b b-bar b b-bar (4b) events

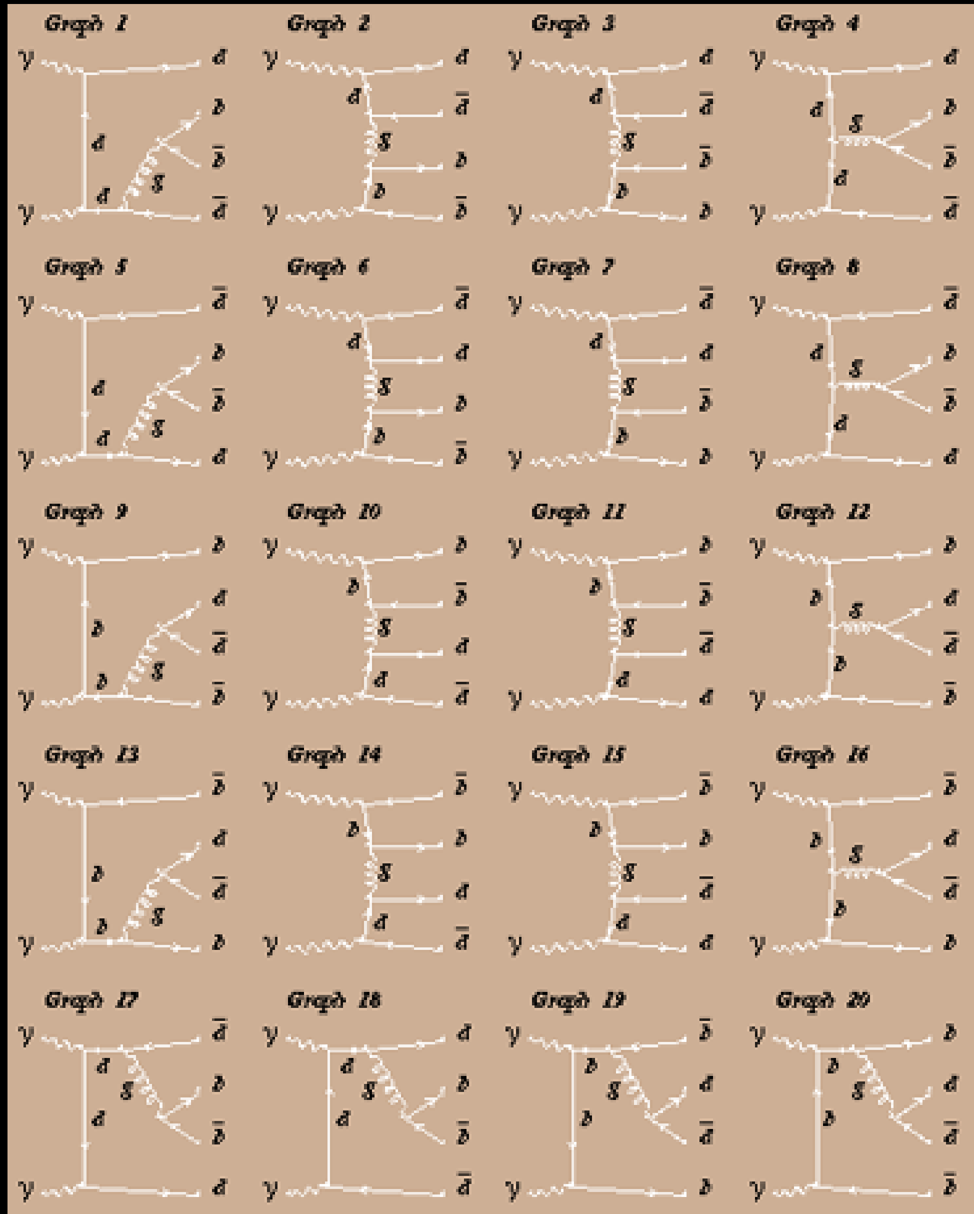


(2-jet invariant mass) < 15GeV were cut.
We assume that we can cut these events.
--> $5.872*10^4$ events/year

Calculation of 4b BG

d -> b

ELWK = 2
QCD = 2
Calculated with GRACE



Jet clustering

JADE clustering

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

p_i : 4-momentum of particle i
E_{vis} : visible energy
Y_{cut} : Y_{cut} value of jet clustering

Event selection --- pre-selection

pre-selection

β>0.05, |cosθ|<0.99

more than 3 b-flavor jets with (n_{sig} = 3.0, n_{offv} = 1) analysis

more than 2 b-flavor jets with (n_{sig} = 3.0, n_{offv} = 2) analysis

β : Lorentz factor of reconstructed particle

θ : angle between reconstructed particle and beam axis

b-tagging

to suppress huge WW BG mainly

Sphericity, Y-value

normalized momentum tensor M_{ab}

$$M_{ab} = \sum_i p_{ia} p_{ib} \,/\, \sum_i p_i^2$$

p_i : momentum of particle i

3*3 matrix

→ eigenvalue $Q_1, Q_2, Q_3 (Q_1 \leq Q_2 \leq Q_3)$

$$\text{sphericity} = \frac{3}{2}(Q_1 + Q_2)$$

$$\text{Y} - \text{value} = \frac{\sqrt{3}}{2}(Q_2 - Q_1)$$

W filter

- 9 input parameters
  - χ_H^2, χ_Z^2
  - visible energy
  - # of tracks
  - Y_{cut} value of jet clustering
  - longitudinal momentum, transverse momentum
  - # of b-flavor jets (nsig = 3.5, noffv = 1 analysis)
  - # of b-flavor jets (nsig = 3.5, noffv = 2 analysis)

4b filter

- 17 input parameters
  - no relation to χ^2 (11)
    - visible energy, # of tracks, Y_{cut} value of jet clustering, thrust, sphericity, Y-value, cosθ of jet (4), maximum |cosθ of jet|
  - jet pairing of least χ_H^2 (3)
    - χ_H^2, cosθ of 2-jet (2)
  - jet pairing of least χ_γ^2 (3)
    - χ_γ^2, cosθ of 2-jet (2)

$$\chi_\gamma^2 = \frac{(M_1 - 10)^2}{\sigma_{2j}^2} + \frac{(M_2 - 10)^2}{\sigma_{2j}^2}$$

10 : invariant mass of b b-bar system

Z filter

- 10 input parameters
  - χ_H^2, χ_W^2, χ_Z^2
  - energy of 2-jet (2)
  - visible energy
  - # of tracks
  - longitudinal momentum
  - # of b-flavor jets (nsig = 3.5, noffv = 1 analysis)
  - # of b-flavor jets (nsig = 3.5, noffv = 2 analysis)

Cut summary
JADE clustering & 4b (optimistic)

	signal	WW	ZZ	4b (opt)
expected events (# of MC samples)	80 (50000)	73100000 (75000000)	59350 (1000000)	293600 (1000000)
pre-selection	47.93 (29958)	81655 (83777)	5167 (87057)	70851 (241318)
W filter	12.34 (7713)	8.772 (9)	193.4 (3259)	318.0 (1083)
4b (opt) filter	7.262 (4539)	1.949 (2)	73.89 (1245)	7.340 (25)
Z filter	**4.823 (3018)**	**0.9747 (1)**	**9.377 (158)**	**3.817 (13)**

$$\text{significance} = \frac{4.823}{\sqrt{4.823 + 0.9747 + 9.377 + 3.817}} = 1.11$$

Cut summary
JADE clustering & 4b (pessimistic)

	signal	WW	ZZ	4b (pes)
expected events (# of MC samples)	80 (50000)	73100000 (75000000)	59350 (1000000)	293600 (1000000)
pre-selection	47.93 (29958)	81655 (83777)	5167 (87057)	84491 (287776)
W filter	12.34 (7713)	8.772 (9)	193.4 (3259)	568.4 (1936)
4b (pes) filter	8.238 (5149)	0 (0)	84.40 (1422)	13.21 (45)
Z filter	**4.994 (3121)**	**0 (0)**	**7.359 (124)**	**5.872 (20)**

$$\text{significance} = \frac{4.994}{\sqrt{4.994 + 0 + 7.359 + 5.872}} = 1.17$$

Cut summary
perfect jet clustering & 4b (optimistic)

	signal (cheat)	WW (cheat)	ZZ (cheat)	4b (opt)
expected events (# of MC samples)	80 (50000)	73100000 (75000000)	59350 (1000000)	293600 (1000000)
pre-selection	46.64 (29152)	55836 (57287)	4172 (70292)	70851 (241318)
W (cheat) filter	38.58 (24115)	4.873 (5)	98.84 (1667)	1331 (4535)
4b (opt) filter	35.56 (22223)	3.899 (4)	41.78 (704)	3.817 (13)
Z (cheat) filter	**33.26 (20787)**	**1.949 (2)**	**5.045 (85)**	**3.817 (13)**

$$\text{significance} = \frac{33.26}{\sqrt{33.26 + 1.949 + 5.045 + 3.817}} = 5.01$$

Cut summary
perfect jet clustering & 4b (pessimistic)

	signal (cheat)	WW (cheat)	ZZ (cheat)	4b (pes)
expected events (# of MC samples)	80 (50000)	73100000 (75000000)	59350 (1000000)	293600 (1000000)
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W (cheat) filter	38.58 (24115)	4.873 (5)	98.84 (1667)	2179 (7422)
4b (pes) filter	34.50 (21562)	2.924 (3)	27.66 (466)	2.642 (9)
Z (cheat) filter	**33.06 (20662)**	**2.924 (3)**	**5.935 (100)**	**2.642 (9)**

$$\text{significance} = \frac{33.06}{\sqrt{33.06 + 2.924 + 5.935 + 2.642}} = 4.95$$