Analysis of 6-jet mode in ZHH

’09 4/19 Y. Takubo (Tohoku U.)

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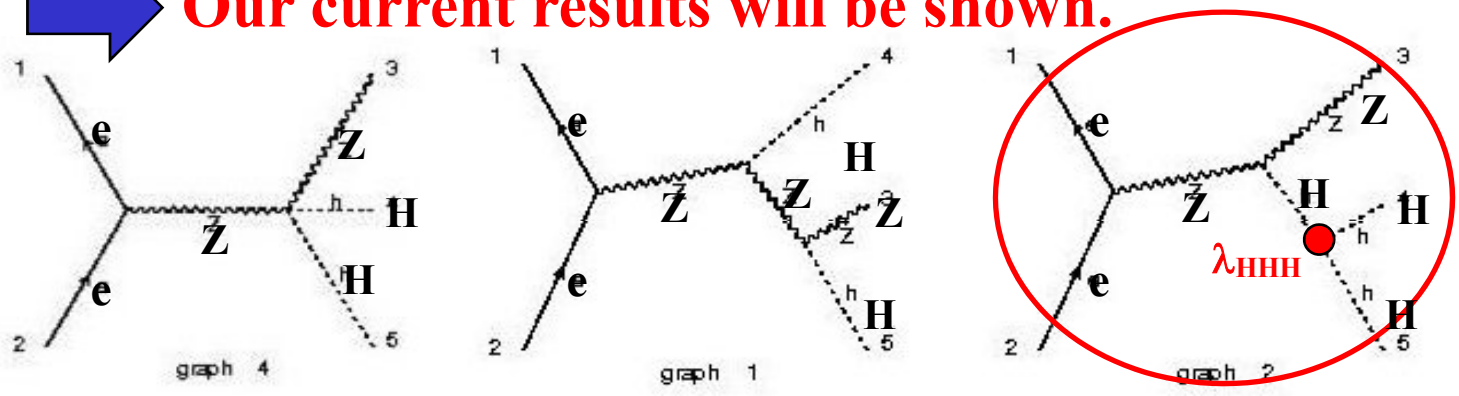
Introduction

ZHH analysis

- ZHH has the information of Higgs self-coupling.
  - $\lambda_{HHH} = 6v\lambda \longleftrightarrow M_H^2 = 2\lambda v^2$
  - Necessary to confirm the Higgs mechanism.
- Analysis mode: ZHH→qqHH
  - Higgs mass: 120 GeV
    - ✓ Higgs mainly decays into bb with ~70% branching ratio.
  - Integrated luminosity: 2 ab^{-1}

Our current results will be shown.



Signal v.s. Background

Many background processes contaminate into qqHH analysis.

qqHH : 135.2ab # of events at 2 ab^{-1} → 270.4

B.G. processes

- tt : 583.6fb • 1,200,000
- ZtZ : 395.78fb • 790,000
  (ZZ→bbbb : 9.05fb) (18,000)
- ZH : 62.1fb • 120,000
- tbtb : 1.2fb • 2,400
- ZZZ : 1.2fb • 2,400

⋮

Powerful B.G. rejection is necessary to derive signal significance.

Simulation study

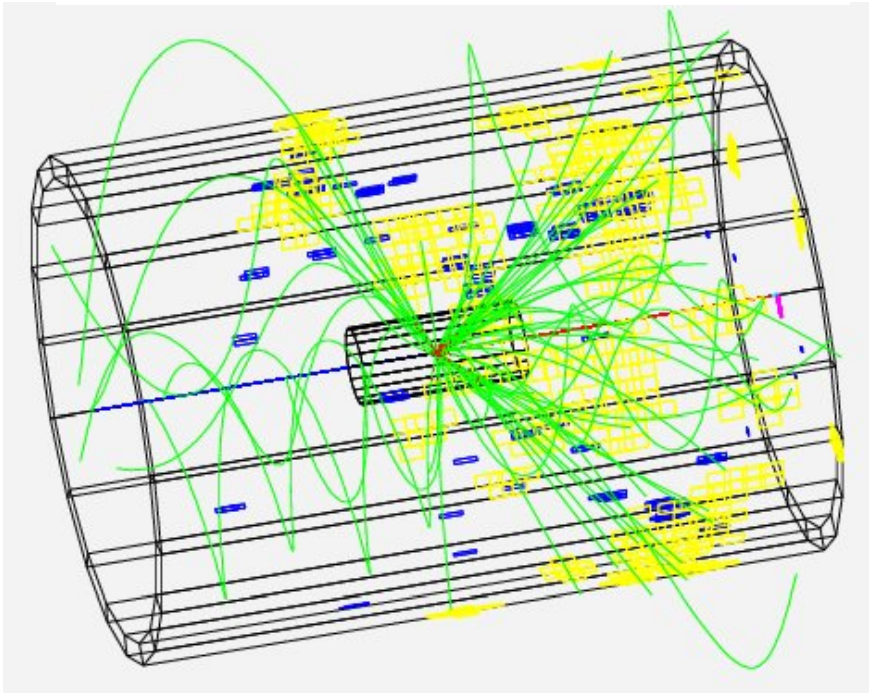
Simulation procedure

- **Event generation**
  - MadGraph
  - Hadronization is done by Pythia
  - ISR, FSR, beamstrahlung, and beam energy spread are ignored.

- **Detector simulation**
  - Quick-sim for GLD

- **Analysis**
  - ROOT based analysis

Event display of a $HH\nu_\mu\nu_\mu$ event



Reconstruction of Higgs mass

At first, masses of Higgs and Z were reconstructed.

Higgs mass reconstruction

- All the events are reconstructed as 6-jet events.
- Jet-pairs are selected by minimizing the χ^2 function.

$$\chi^2 = \frac{({}^{\text{rec.}}M_{H1} - {}^{\text{true}}M_H)^2}{\sigma_{H1}{}^2} + \frac{({}^{\text{rec.}}M_{H2} - {}^{\text{true}}M_H)^2}{\sigma_{H2}{}^2} + \frac{({}^{\text{rec.}}M_Z - {}^{\text{true}}M_Z)^2}{\sigma_{H2}{}^2}$$

- ${}^{\text{rec.}}M_{H1,\,H2}$: Reconstructed Higgs mass
- ${}^{\text{rec.}}M_Z$: Reconstructed Z mass
- ${}^{\text{true}}M_H$: 120GeV
- $\sigma_{H1,\,H2}$, σ_Z : 40 MeV (tentatively used)

The distribution of the reconstructed Higgs mass was investigated with B.G. events.

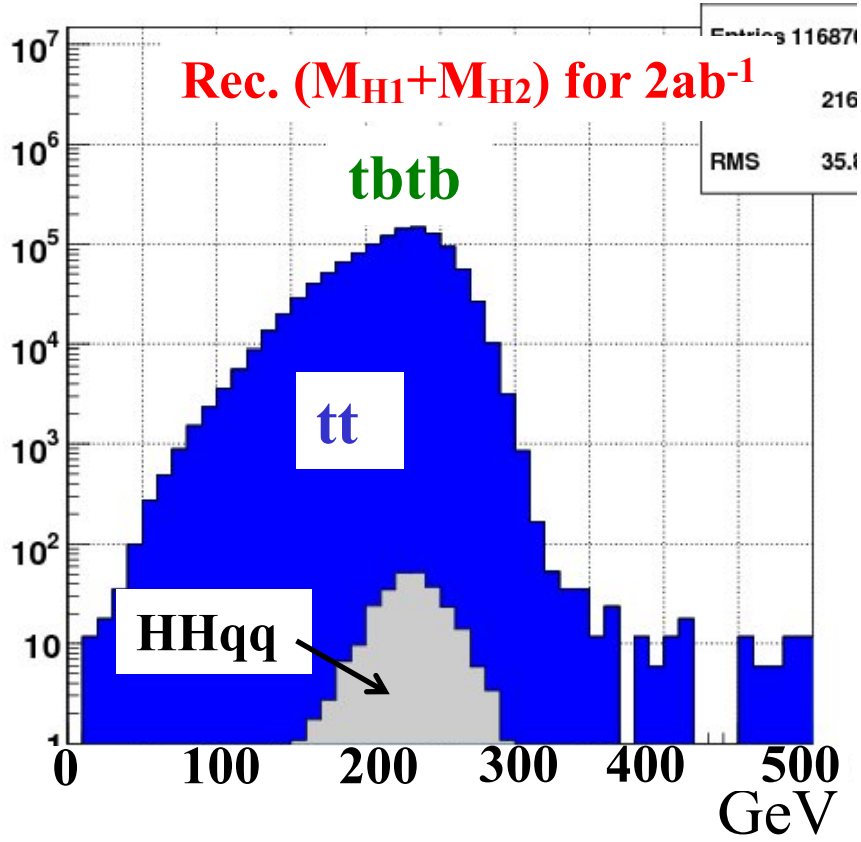
Reconstructed M_H distribution

A large number of B.G. events contaminate in the signal region.

- tt and tbtb were considered as B.G. in this study.
- As the first step, rough selection cut was applied.

Selection cut

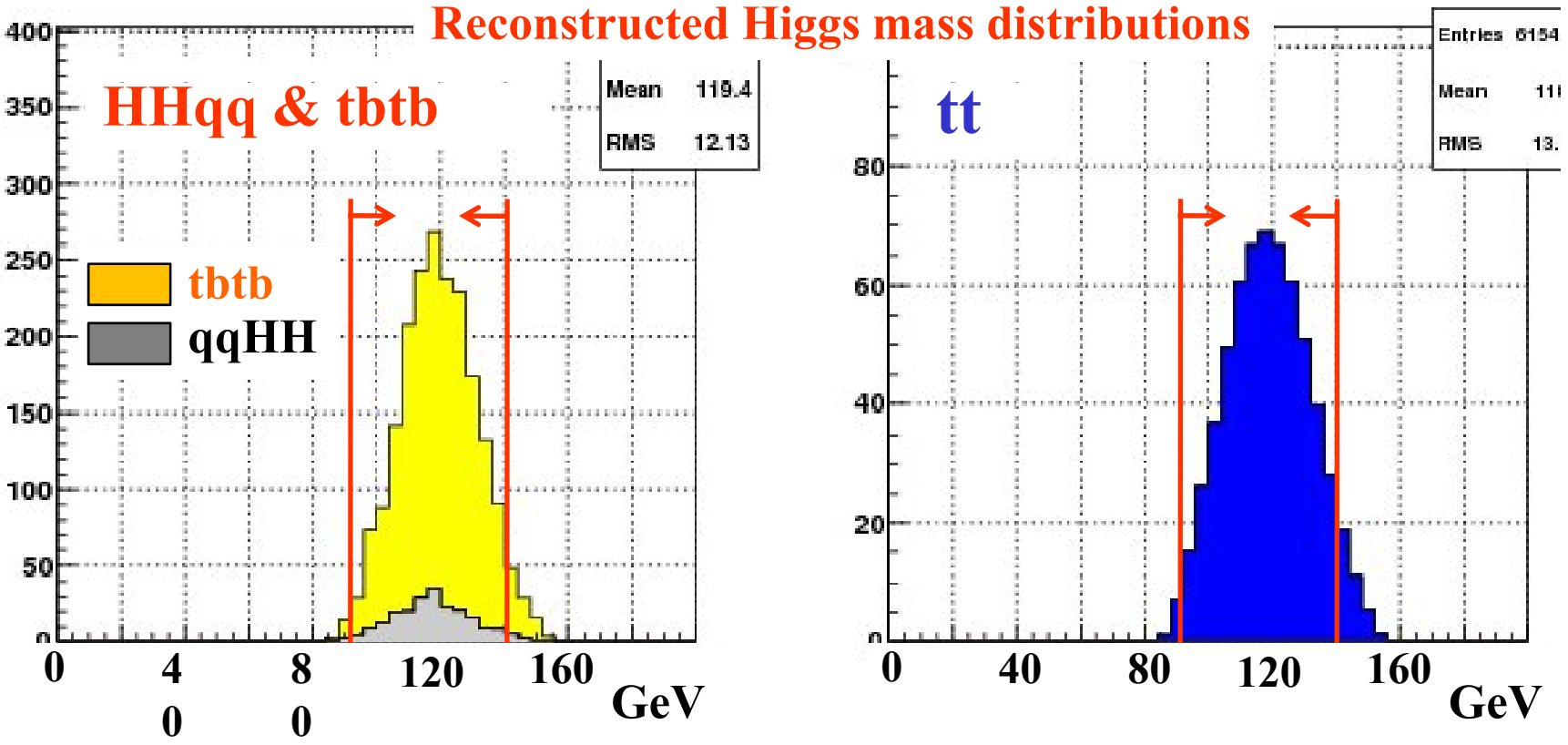
- χ^2 cut
- Higgs and Z mass cut
- Missing energy cut
- Lepton track cut
- b-tag cut



Higgs & Z mass cut

Reconstructed masses of Higgs and Z were chosen after selection of $\chi^2<20$.

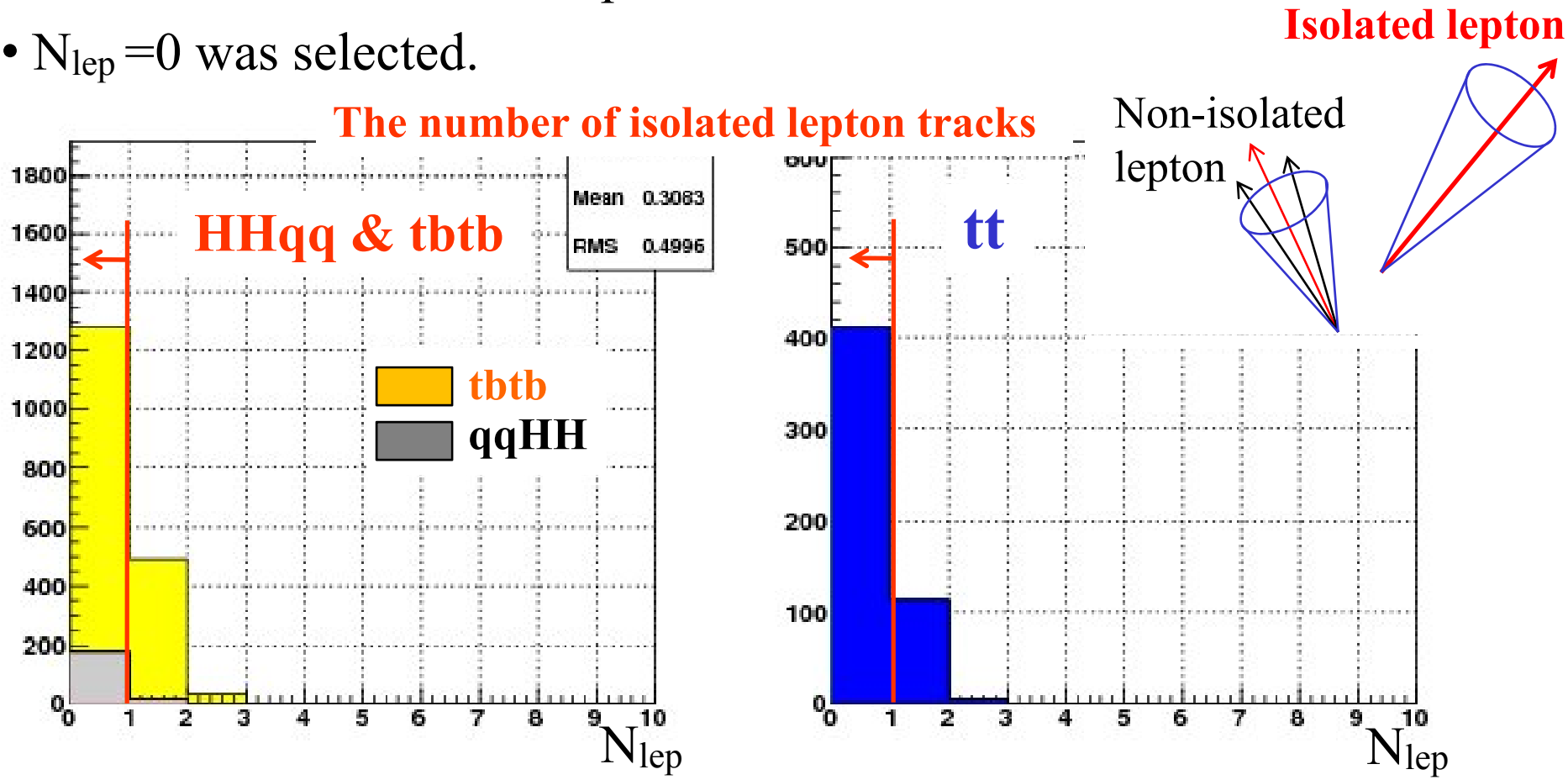
- $90\text{GeV} < M_{H1,2} < 140\text{GeV}$
- $60\text{GeV} < M_Z < 110\text{GeV}$



Isolated lepton tracks

of isolated lepton tracks was checked after the mass selection.

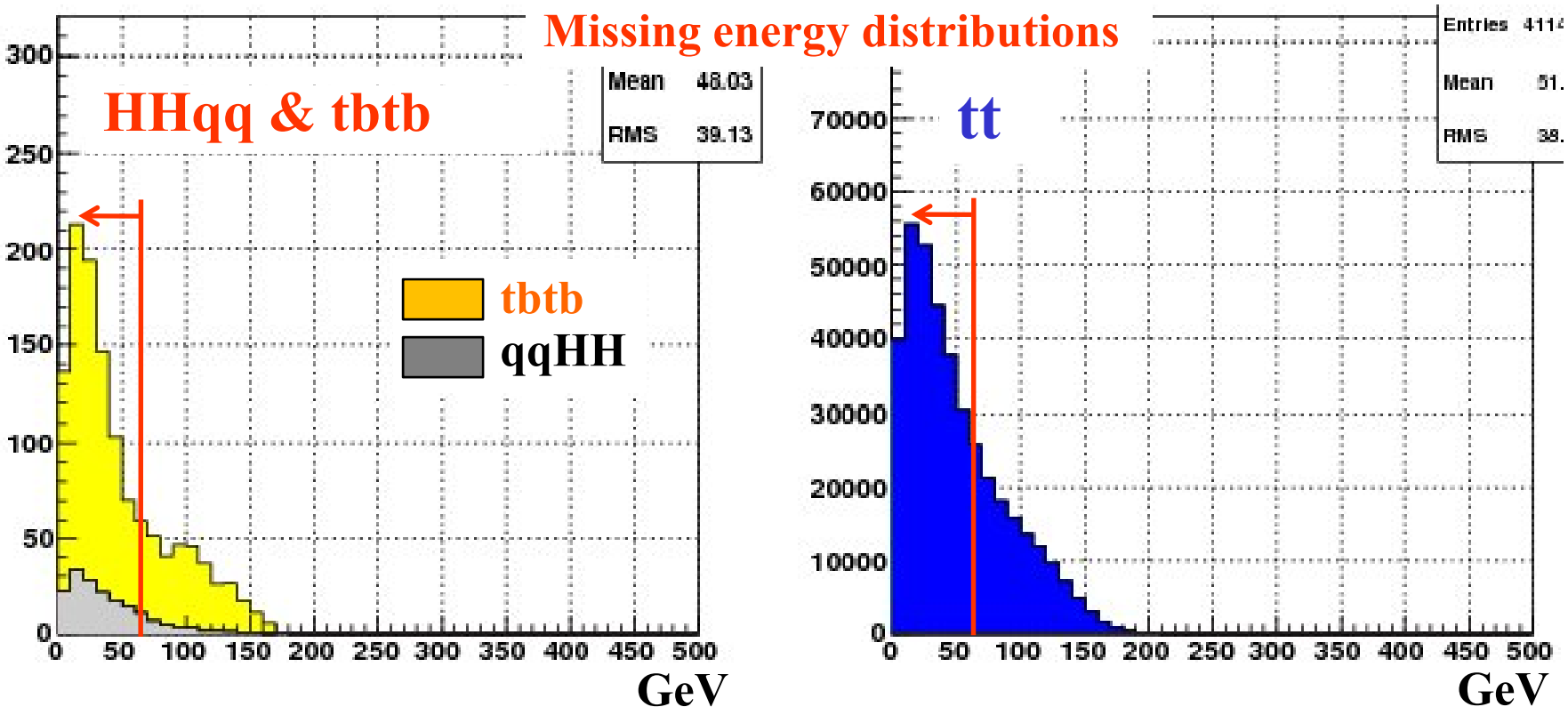
- The total energy within 20 deg. around the lepton tracks was used to select the isolated lepton tracks.
- N_{lep} =0 was selected.



Missing E cut

Missing energy was investigated.

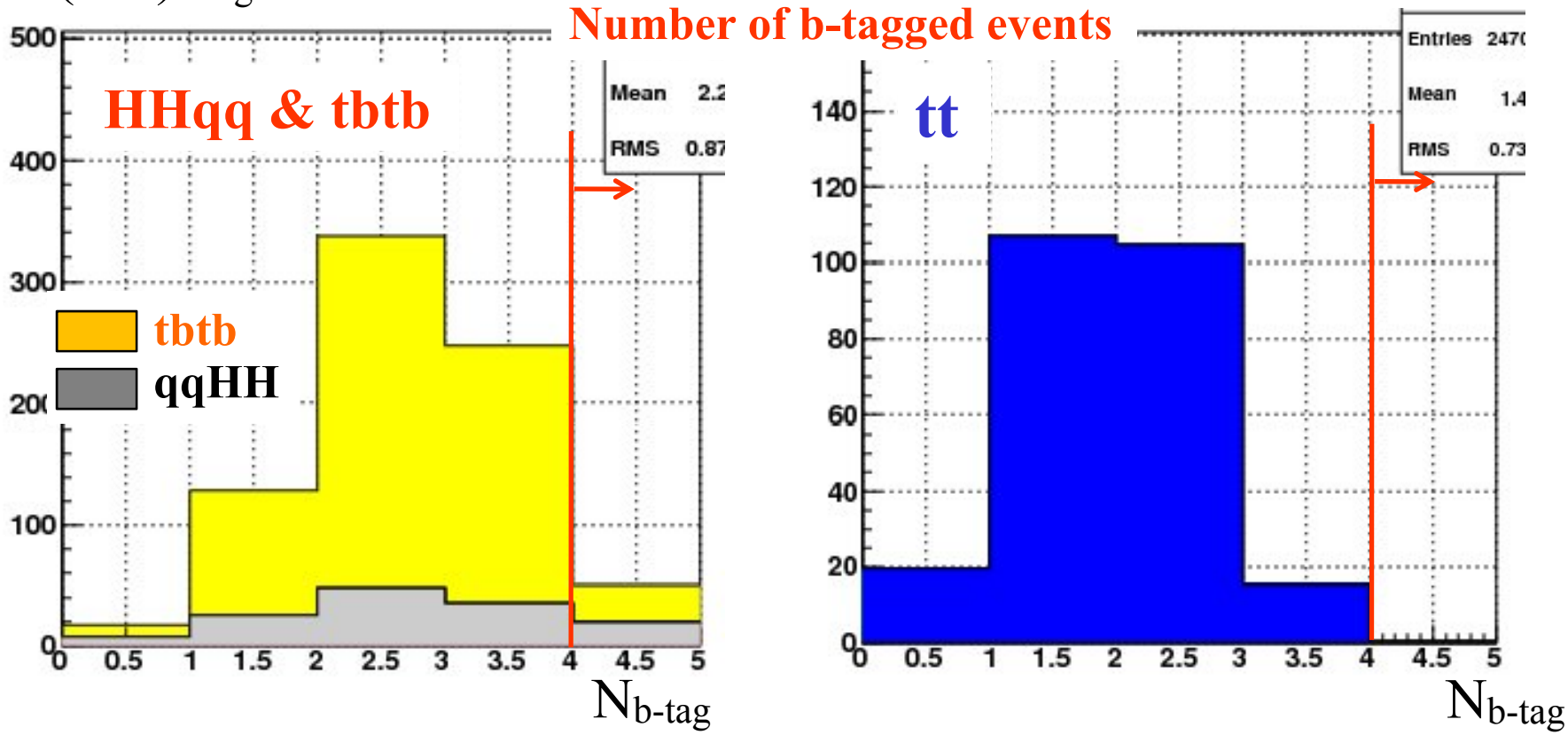
- tt events have broader distribution to higher energy.
- $^{miss}E < 70GeV$ was selected.
  - tt: 302953, tbtb: 816



b-tag selection for Higgs candidate

The b-tagging was applied to jets for the Higgs candidates.

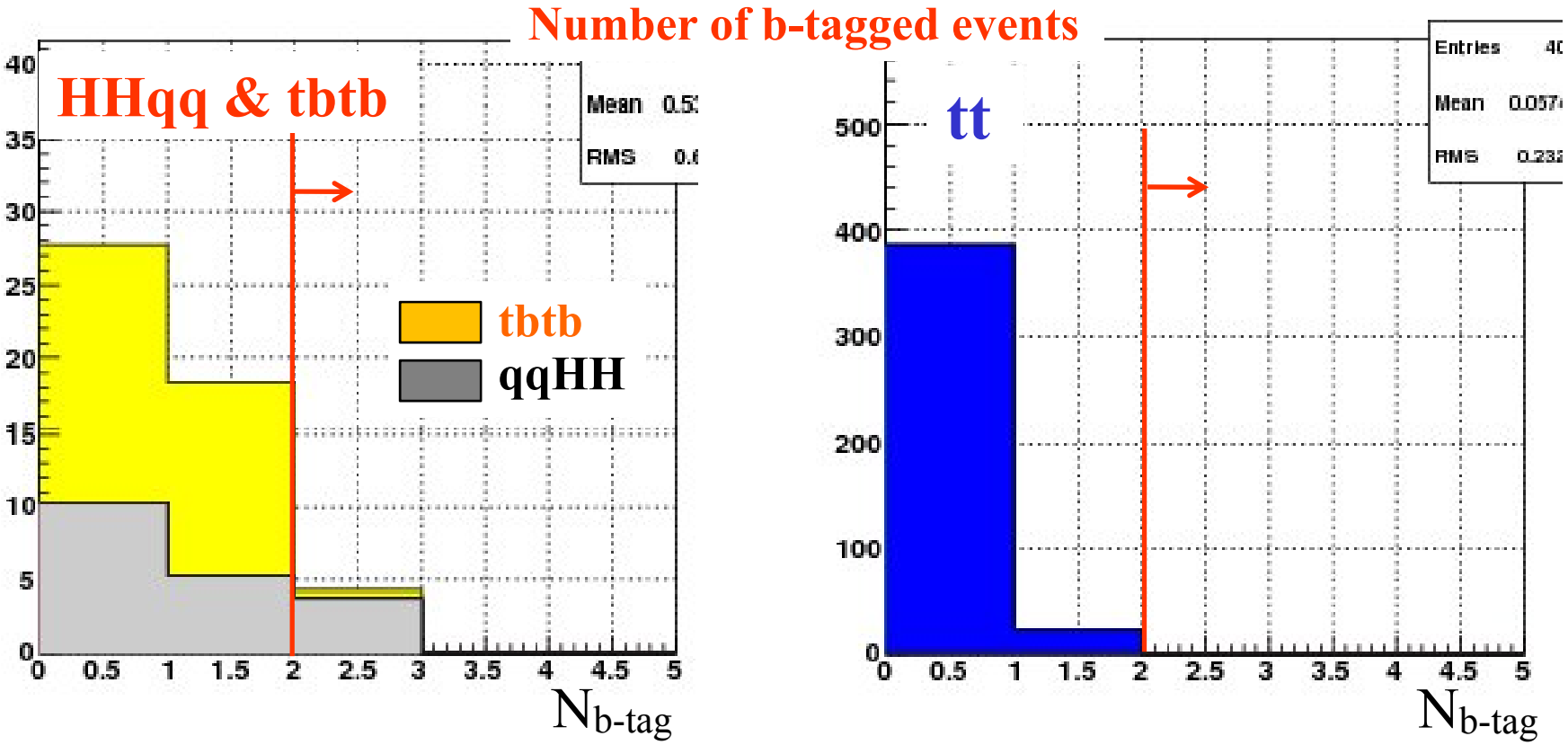
- b-tag. requirement: 3 tracks with 3σ separation from IP.
- tt events have a peak at $N_{b\text{-}tag}$=1~2.
- $N(HH)_{b\text{-}tag}$=4 was selected.



b-tag selection for Z candidate

The b-tagging was applied to jets for the Z candidates.

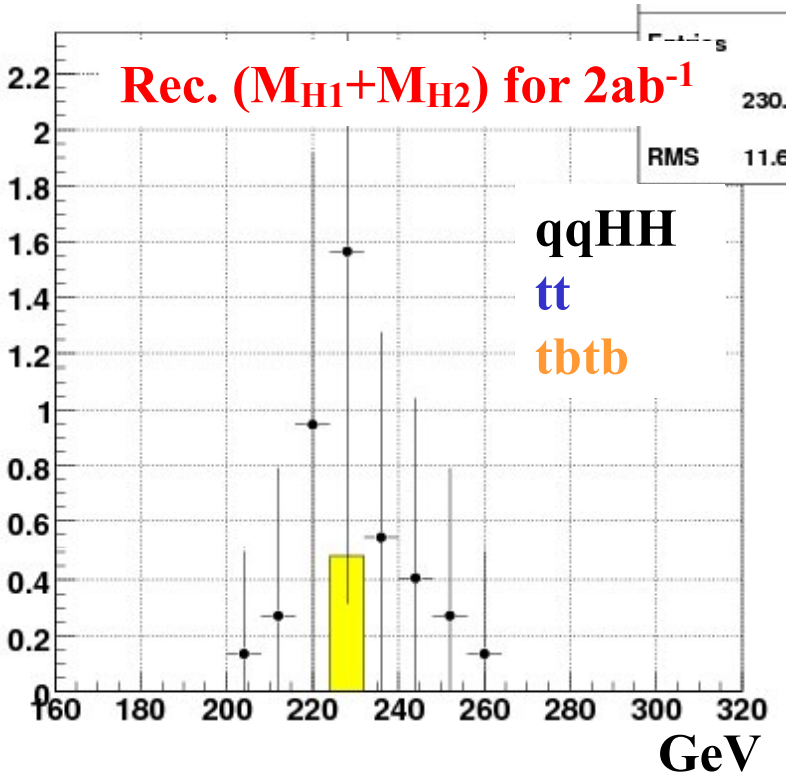
- $N(Z)_{b\text{-}tag}=2$ was selected.
  - tt: 0, tbtb: 0.6



Reduction summary & Signal significance

The reduction rate at each cut was summarized for 2 ab^{-1}.

	qqHH	tt	tbtb
• No cut	: 270	1167290	2154
• $\chi^2 < 20$	: 219	615456	1810
• $90 < M_{H1,2} < 140$GeV $60 < M_Z < 110$GeV	: 196	529501	1607
• Nlepton=0	: 178	411467	1102
• missing E < 70GeV	: 156	302953	816
• $N(HH)_{b\text{-}tag}$ =4	: 20.1	475	38.7
• $N(Z)_{b\text{-}tag}$ =2	: 4.3	0	0.6



Significance : ~3 (← near confident observation)

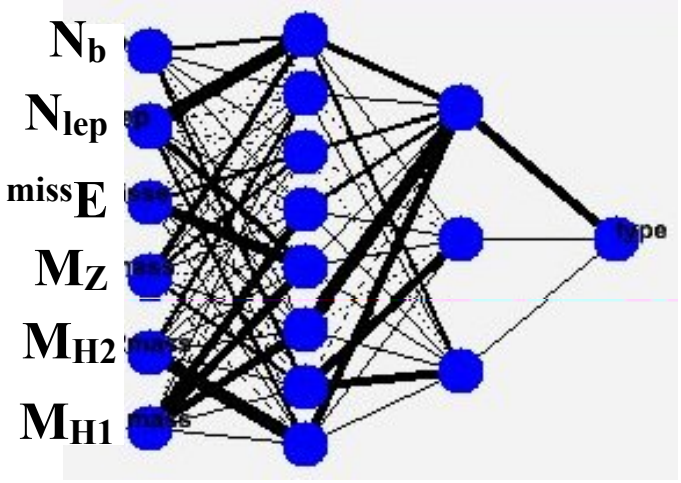
- Improvement of the b-tagging is necessary to obtain more significance.

Neural-net analysis

The neural-net method was applied to the current analysis.

Input for NN analysis

- M_{H1}
- M_{H2}
- M_Z
- ^{miss}E
- N_{lep}
- $N_b(N(HH)_{b\text{-}tag} + N(Z)_{b\text{-}tag})$

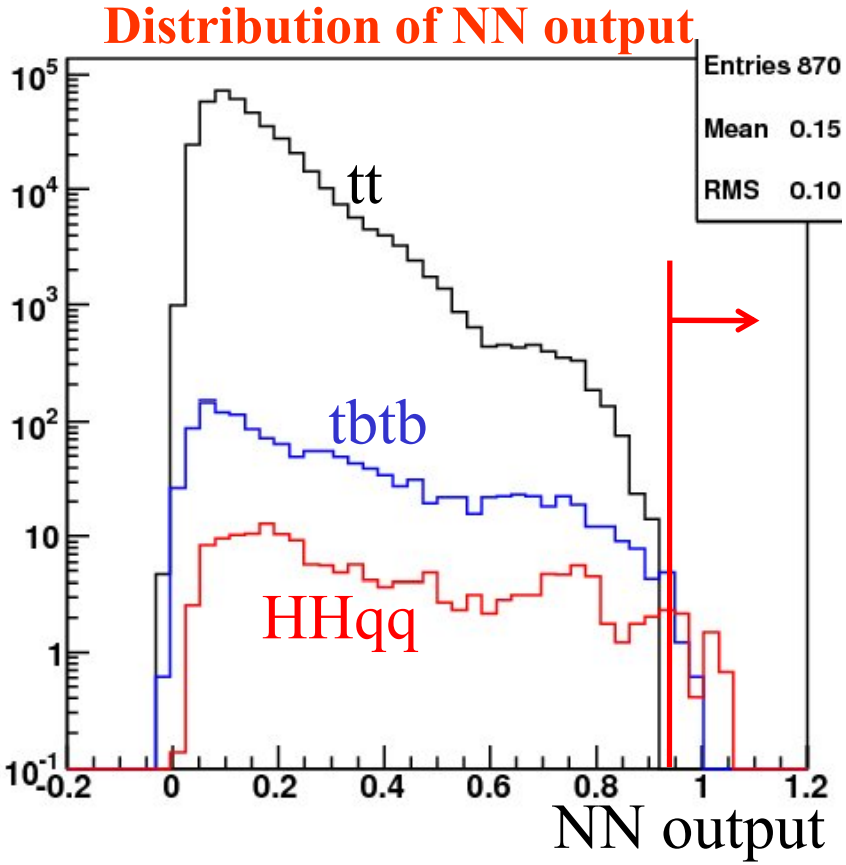


Training condition

- Hidden layer : 10
- Epoch: 100
- Training sample
  - Signal: 10000
  - B.G.: 50000(tt) + 4000(tbtb)
- The training condition was adopted tentatively.
  - To be optimized.

NN output

NN output above 0.95 was selected tentatively.



NN output > 0.95

- HHqq: 4.2
- tt: 0
- tbtb: 1.8

→ Significance: ~3

To be done

- The proper input valuables must be considered.
- The weight for the NN inputs and the number of the hidden layers should be optimized.

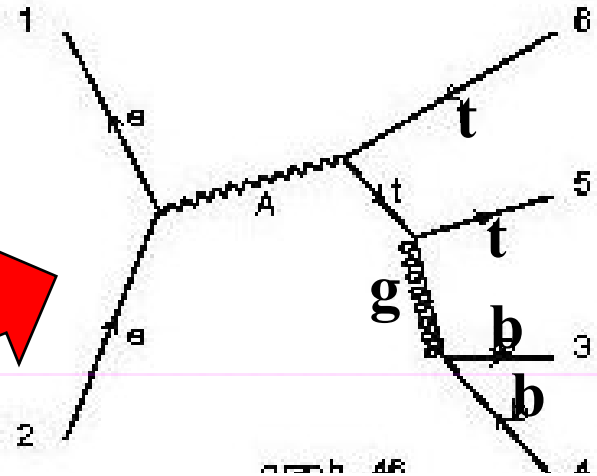
Summary

- ZHH→qqHH is studied to investigate the ILC performance for Higgs self-coupling.
- The signal significance of ~3 was obtained by cut based and neural-net analysis.
  - Excellent b-tagging is essential for this study.
  - The sufficient input valuables must be considered for the neural-net analysis.
- The analysis will be done by the full simulation.
  - The analysis can be done realistically, especially for the b-tagging.

tbtb diagram in MadGraph

ttg and ttH seem to be dominant in tbtb events.

Graph	Cross Sect(ab)	E
Sum	1213.812	
G46	314.110	
G38	313.320	
G49	133.770	
G41	132.730	
G50.008	67.235	
G42.008	66.999	
G15	32.768	
G19	32.723	



What final states remain after the selection cuts?

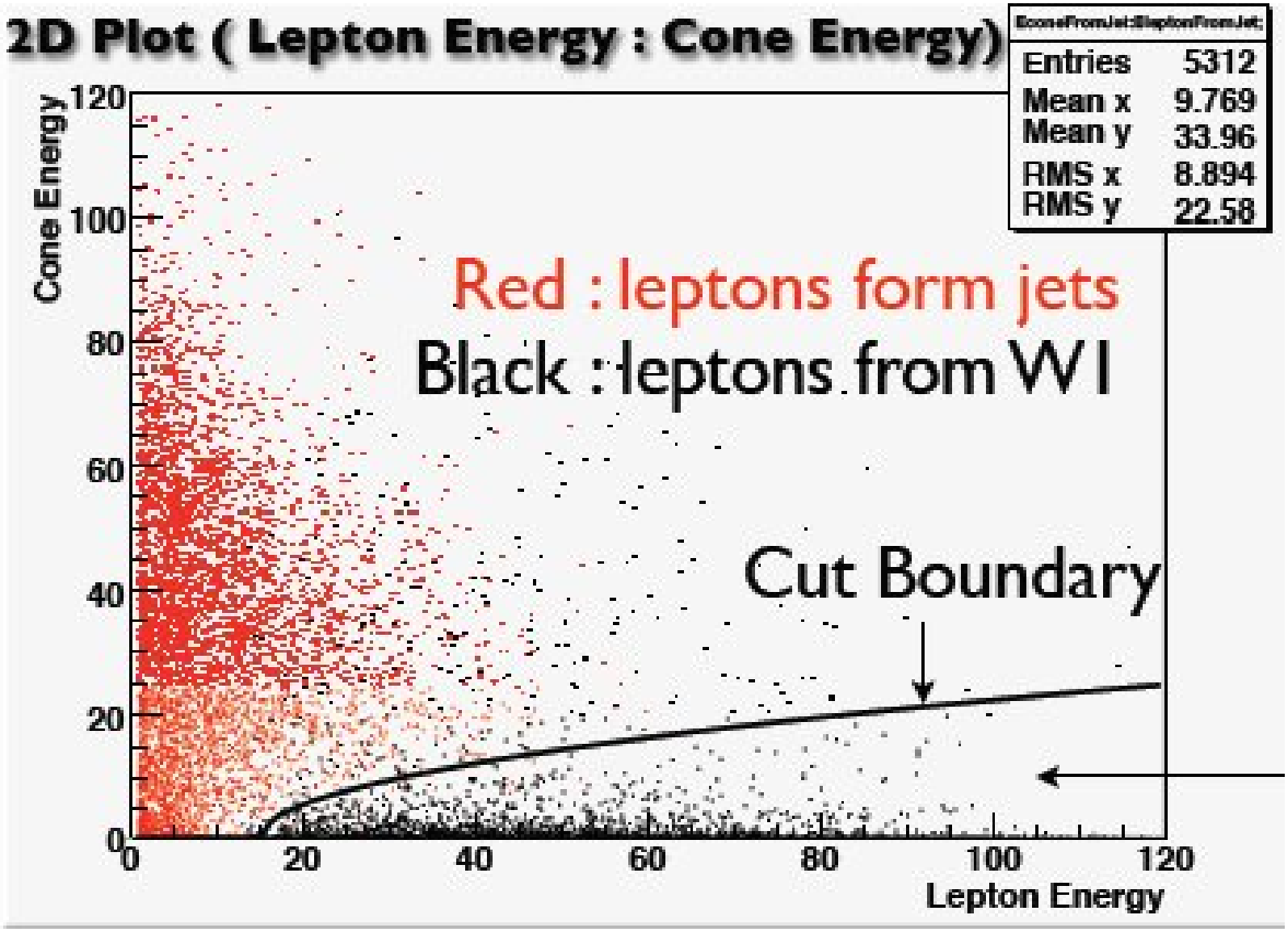
Remaining tbtb events

The remaining tbtb events were checked after the selection cuts.

	HHqq	tt	tbtb bbbjjbjj	tbtb bbbjjblv	tbtb Anything
• No cut	: 270	1167200	1119	526	2420
• $\chi^2 < 10$	: 169	409513	800	253	1382
• $90 < M_{H1,2} < 140$GeV $60 < M_Z < 110$GeV	: 163	393069	761	247	1336
• Nlepton=0	: 149	322834	761	85	947
• missing E < 70GeV	: 134	249078	707	12	726
• $N(HH)_{b\text{-tag}} = 4$	: 19	414	31	0.4	36
• $N(Z)_{b\text{-tag}} > 0$	: 9.1	23.5	14.9	0.1	15.7
• $N(Z)_{b\text{-tag}} = 2$	: 3.8	0	2.0	0.	0.6

- Leptonic decay mode of W is rejected effectively.
- The hadronic decay mode is the main background.

Isolated lepton tracks



Yonamine