Analysis of 4-jet mode in ZHH

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Introduction

<u>Motivation of ZHH analysis</u>

- ZHH has the information of Higgs self-coupling.

- The detail study is ongoing in some groups for $M_H=120$GeV.

- There are a few study for heavy Higgs case ($M_H>160$GeV).

  ➢ Sensitivity cannot be estimated from light Higgs case since Higgs decays to WW-pairs.
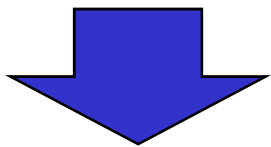
- Any case should be considered before results from LHC.

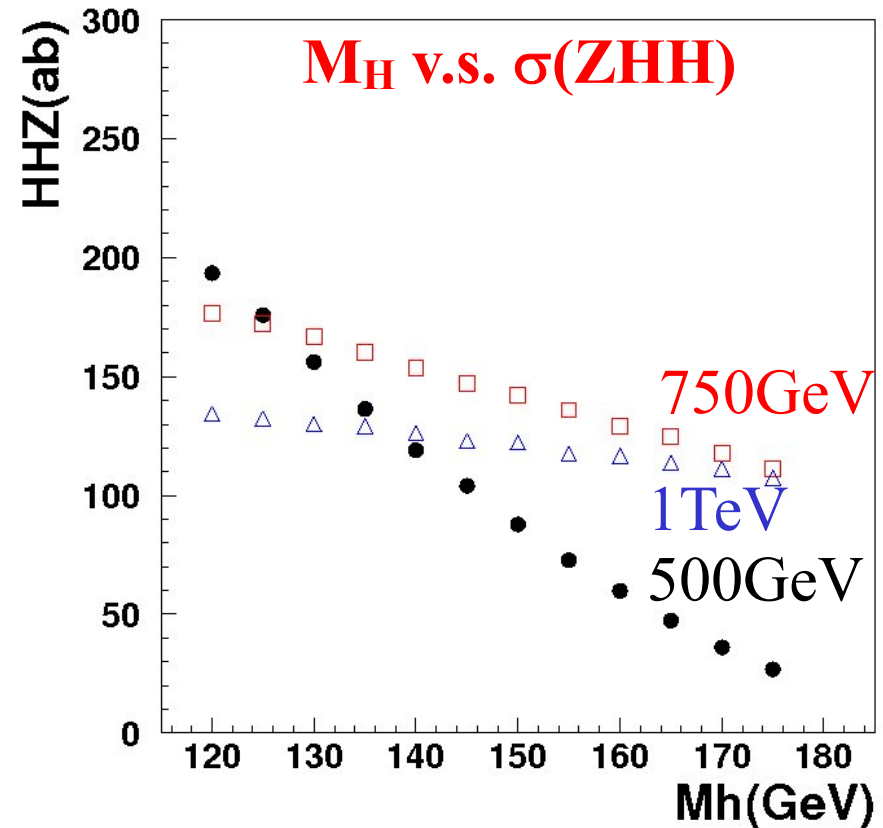 ⇨ **ZHH study for some cases of Higgs mass is started.**
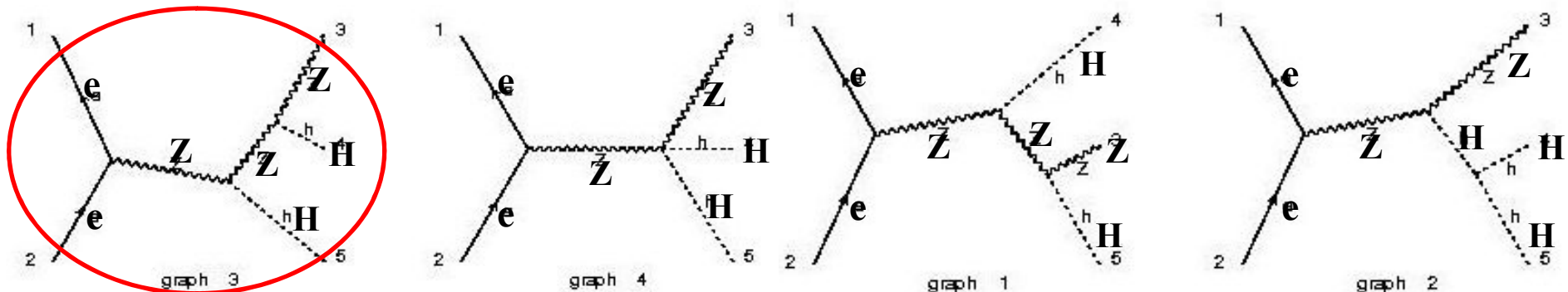
Cross-section of ZHH

σ(ZHH) is calculated by MadGraph as a function of M_H.

• E_{CM}=500GeV is the best for M_H=120GeV.

• Measurement for M_H>160GeV is difficult at E_{CM}=500GeV.

• E_{CM}>750GeV is necessary to study for M_H>160GeV.

Our analysis menu

• M_H=120GeV, E_{CM}=500GeV ← **My talk**

• M_H=170GeV, E_{CM}=500GeV, 750GeV, 1TeV ← Next speaker

ZHH at M_H=120GeV

According to Z-decay types, there are 3 analysis modes.

- HHZ → HHqq (6-jets)
  - 135.2 fb
  - The most attractive mode due to the largest cross-section.
  - Analysis of 6-jet events is a little bit complicated.

- HHZ → HHνν (4-jets)
  - 38.8 ab
  - Easy to analyze and not bad cross-section.

- HHZ → HHl$^+$l$^-$ (4-jets + 2leptons)
  - 19.8 ab
  - The smallest cross-section.

HHνν was investigated as the first step.

Signal v.s. B.G. for HHνν

ZZ events are serious B.G. for HHνν.

- The cross-section is 10^4 times larger than signal.
  - $\sigma(ZZ)$ = 395.8 fb (21.3fb for bbbb)
  - $\sigma(HH\nu\nu)$ = 38.8 ab (ν : $\nu_e + \nu_\mu + \nu_\tau$)
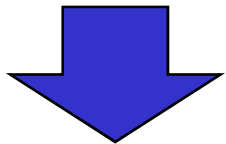
  The number of events for $2ab^{-1}$:
  - HHνν : 80 events
  - ZZ : 792,000 events (42,622 events for bbbb)

- The powerful rejection cut is necessary.

Simulation study is performed, including B.G..

Simulation study

The simulation study was done by using quick-simulator.

- Signal : HH$\nu\nu$

  ➢ Event generator : MadGraph

  ➢ $M_H = 120$ GeV, $E_{CM} = 500$GeV

  ➢ # of events : 2,000 events (50ab^{-1})

- B.G. : ZZ

  ➢ Event generator : physsim

  ➢ # of events : 4,000 events (10fb^{-1})

  ➢ 10,000 events were also prepared for ZZ➔bbbb.

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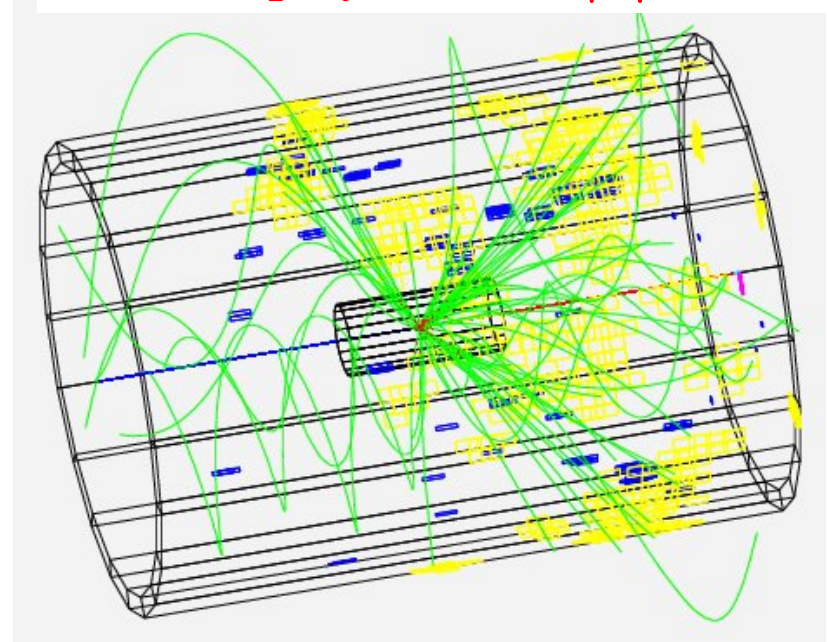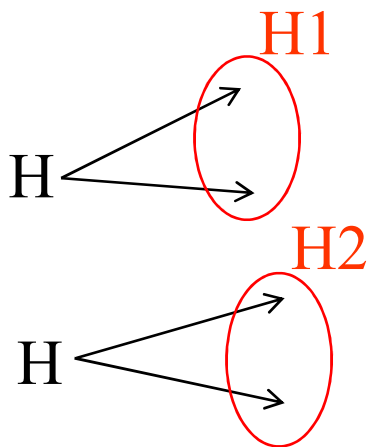

Reconstruction of Higgs mass was performed.

Reconstruction of Higgs mass

Higgs mass reconstruction for HHνν events

- $M_H = 120$ GeV, $E_{CM} = 500$ GeV

- All events are reconstructed as 4-jet events.

- Two jet-pairs are selected by minimizing the χ^2 function.

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

- $^{rec.}M_{H1, H2}$: Reconstructed Higgs mass by a jet-pair
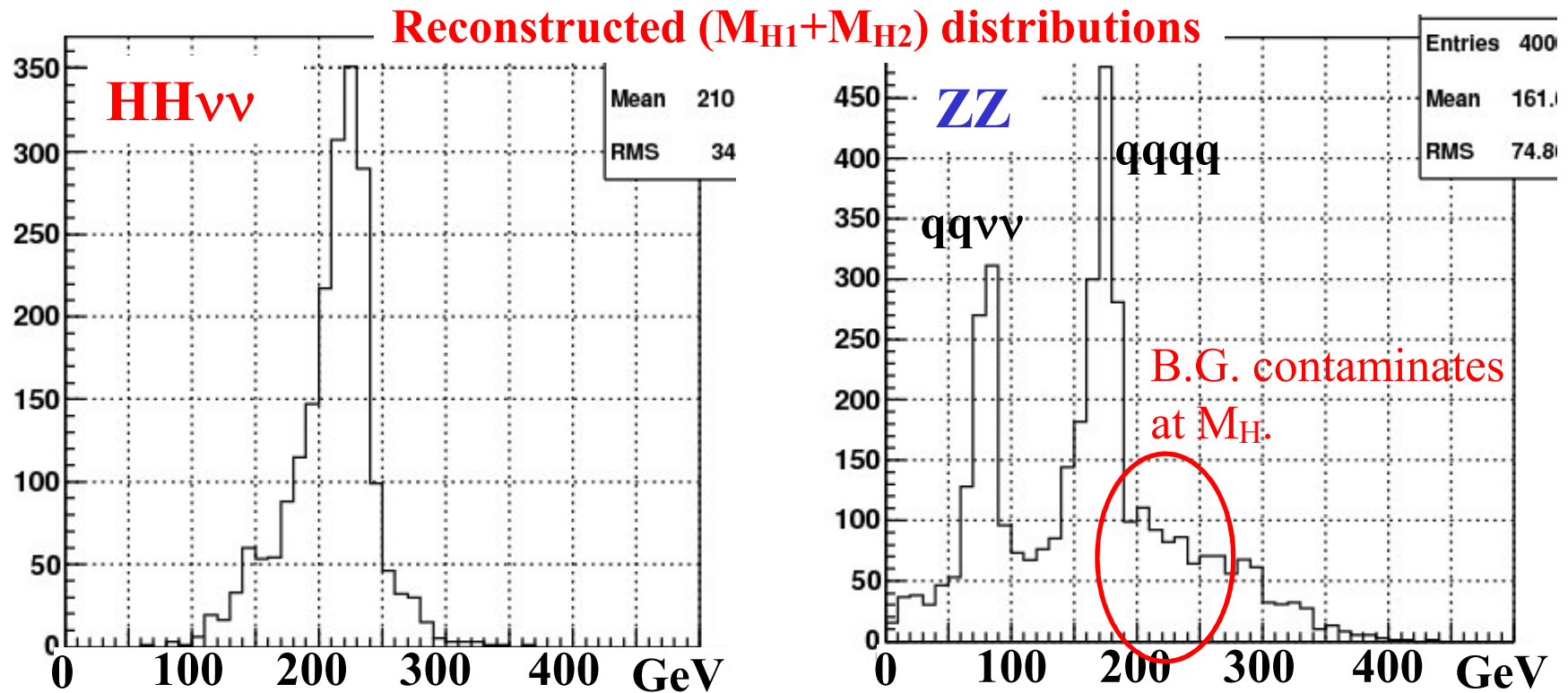- $^{true}M_H$: 120GeV
- $\sigma_{H1, H2}$: 40 MeV (tentatively used)

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

Reconstructed Higgs mass

Higgs mass is reconstructed for HHνν events.

- The Higgs mass can be reconstructed correctly.
- B.G. events contaminate at M_H.

  → B.G. rejection is studied.

Reconstructed ($M_{H1}+M_{H2}$) distributions

HHνν — Mean 210, RMS 34

ZZ — qqνν, qqqq — Entries 400, Mean 161, RMS 74.8

B.G. contaminates at M_H.

B.G. reduction procedure

The selection cuts were applied to reject B.G..

**B.G. reduction procedure**

- Higgs mass cut
  - ➢ The reconstructed mass corresponding to Higgs mass is selected.

- Missing mass cut
  - ➢ Missing mass is used to find Z from ZHH

- Z-angle cut
  - ➢ Z from B.G. is rejected by using spin dependence of the polar angle distribution.

- b-tag cut
  - ➢ b-quark from Higgs is identified.

The reduction procedure is shown.

Higgs mass cut

The Higgs mass cut is applied to select well-reconstructed events.

- Selection : $100\text{GeV} < M_H < 140\text{GeV}$

- This cut is applied to two reconstructed mass separately.

→ The main part in B.G. is rejected.

Reconstructed M_{H1} distributions

HH$\nu\nu$ — Mean 104.? RMS 23.9?

ZZ — Entries 40? Mean 81.? RMS 39.?
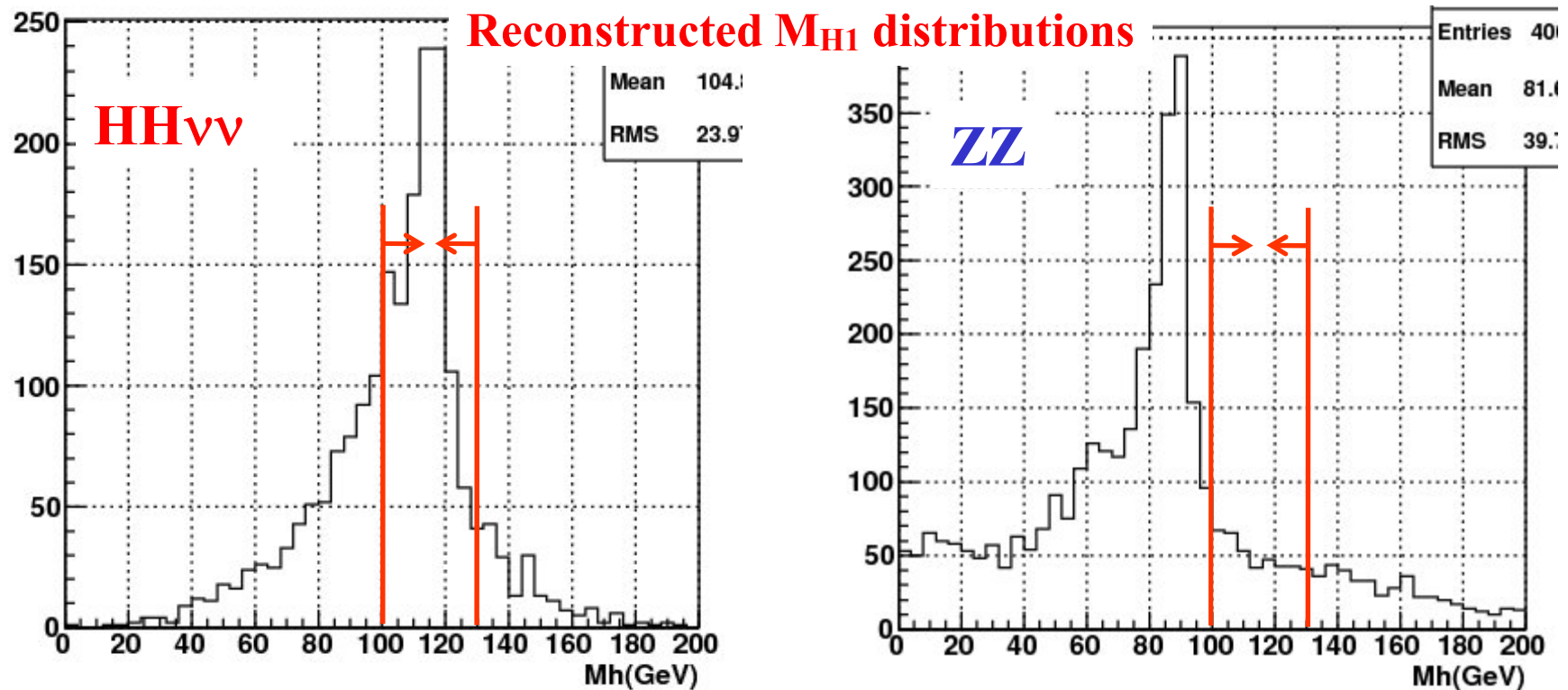
Missing mass cut

The missing mass was reconstructed.

- The peak is observed at Z-mass in HH$\nu\nu$ events.
- Selection : 90GeV < M_{miss} < 200GeV
- ZZ-B.G. remains at the missing mass above Z-mass.

Distributions of reconstructed missing mass
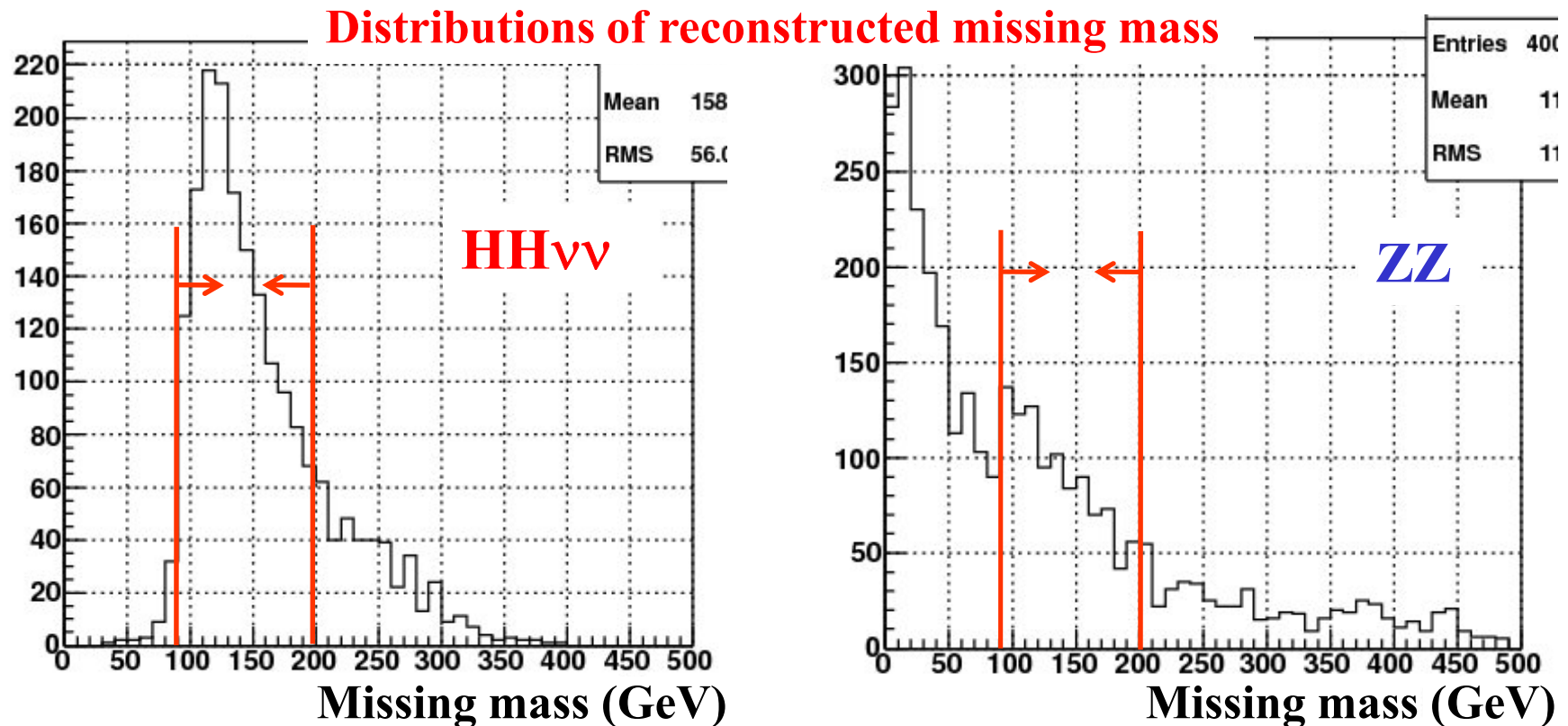
Z-angle cut

The angular distributions of the reconstructed particles are checked.

- The distribution is flat for HHνν events.
- The peak is seen at cosθ $= \pm 1$ for B.G. due to Z-spin.
- → |cosθ|<0.9 was selected for each two particles (HH or ZZ).

Angle distribution of reconstructed particles
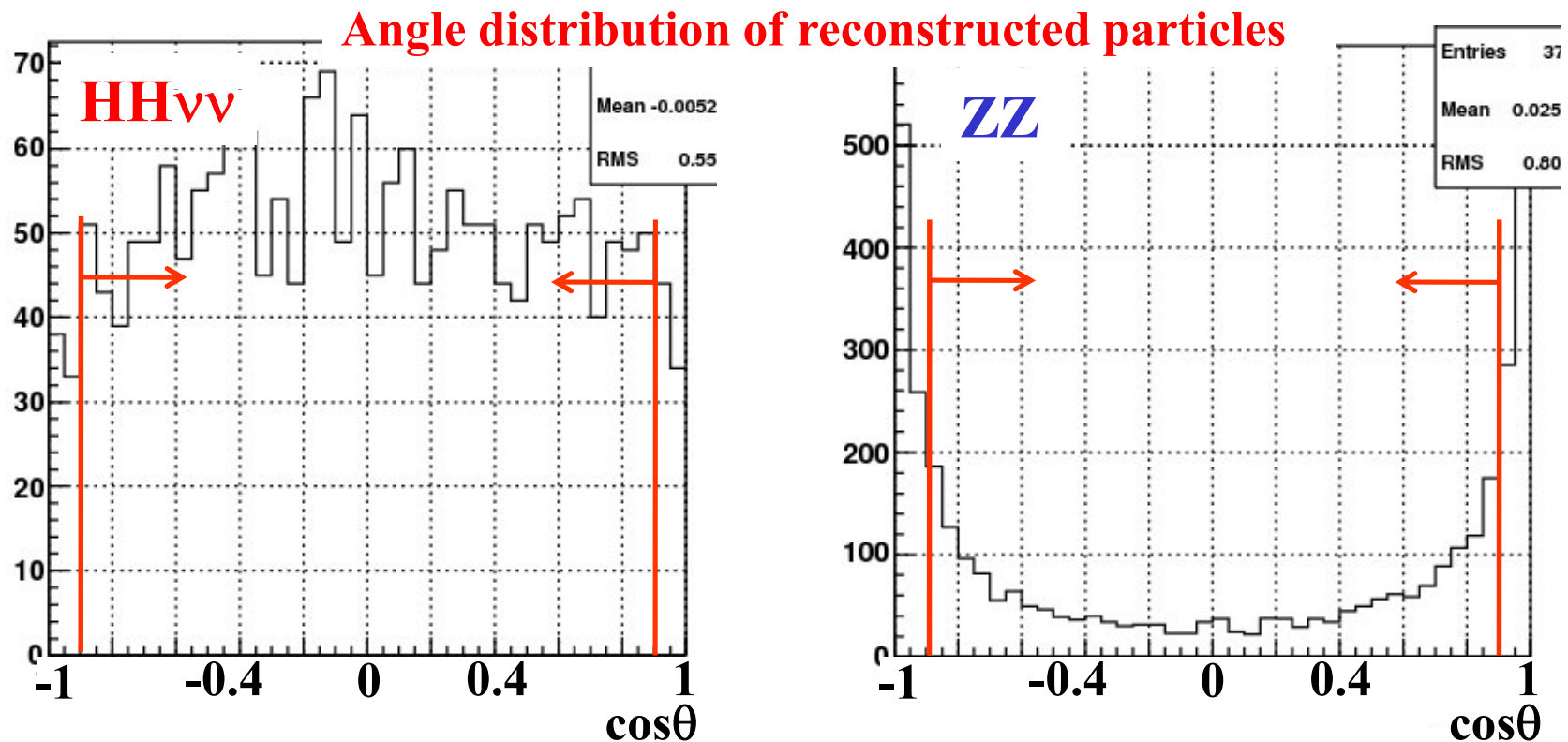
b-tag cut

b-tag is applied to identify Higgs after M_H, M_{miss}, and Z-angle cut.

- All generated ZZ events (4,000 events) are rejected.
- ZZ→bbbb (10,000events) are used to estimate remaining B.G..
  - ➢ 64 events still remain for 2ab^{-1}.

Number of b-jet after M_H and M_{miss}, Z-angle cut
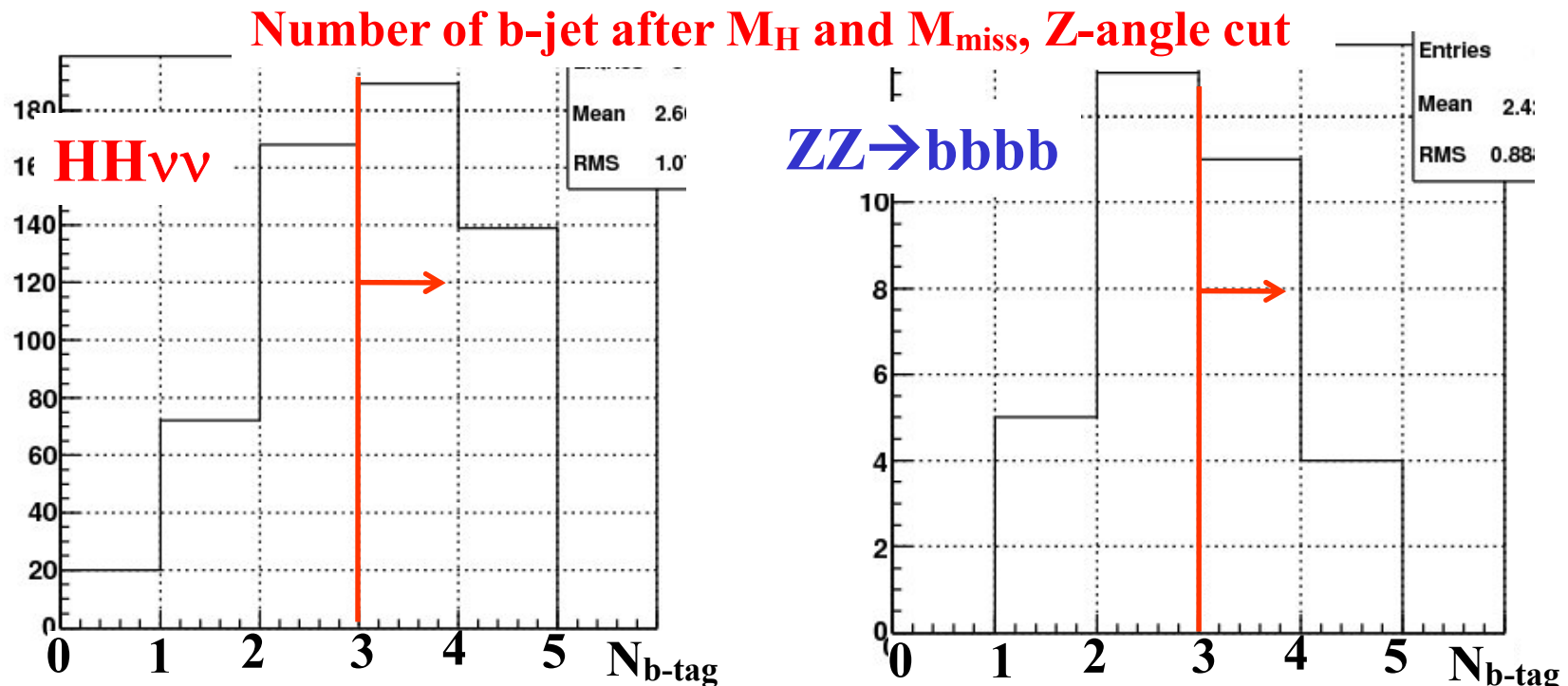
The reduction rate is summarized for each selection cut.

Reduction summary

Reduction rate is summarized for signal and B.G..

	HH $\nu\nu$	ZZ	ZZ$\rightarrow$bbbb
• No cut	: 77 (1.00)	791,560 (1.00)	42,534 (1.00)
• 100GeV < $M_{H1,2}$ <130GeV	: 27 (0.35)	8,510 (1.1×10^{-2})	957 (2.2×10^{-2})
• 90GeV < M_{miss} < 200GeV	: 26 (0.34)	2,770 (3.5×10^{-3})	404 (9.5×10^{-3})
• $|\cos\theta_{1,2}|$ < 0.9	: 22 (0.29)	594 (7.5×10^{-4})	141 (3.3×10^{-3})
• $N_{b\text{-tag}} \geqq 3$	: 12 (0.16)		64 (1.5×10^{-3})

$\left\{\begin{array}{l} \bullet \text{ The signal efficiency is 16\%.} \\ \bullet \text{ A large number of events are lost at } M_H \text{ cut and b-tag.} \end{array}\right.$
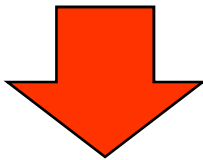
$\rightarrow$ Can these event recover?

Signal significance was estimated at this stage.

Signal significance

The signal significance was estimated for 2ab⁻¹

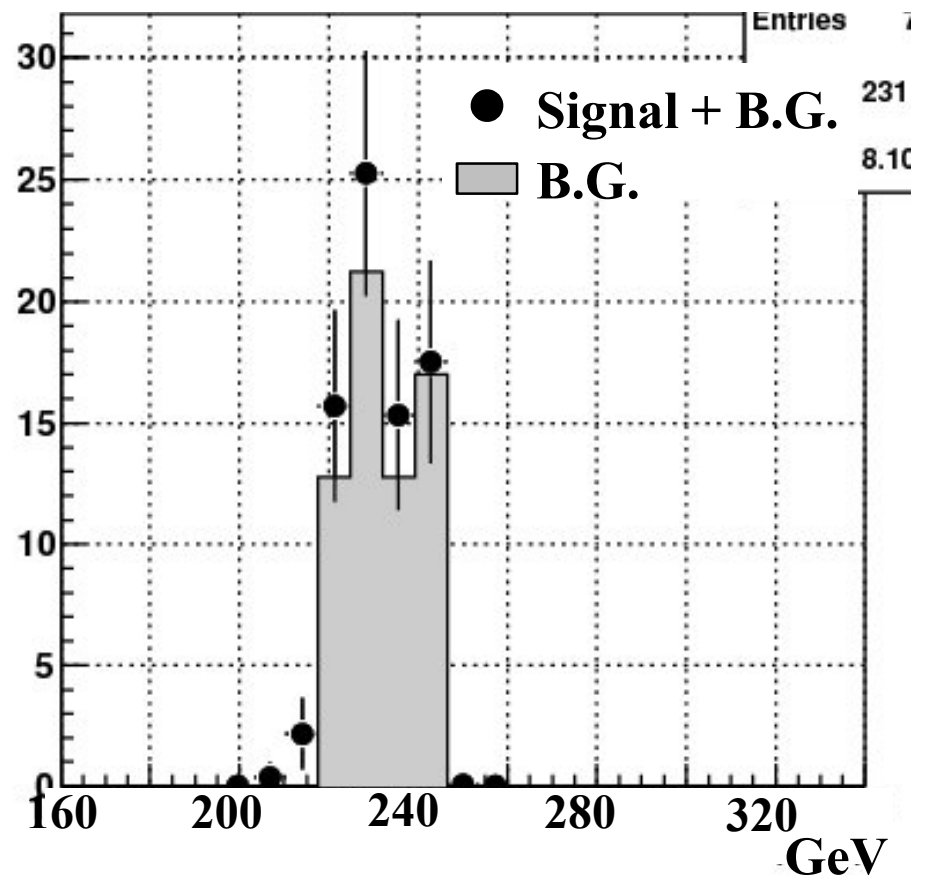- • Signal : 12 events
- • B.G. (bbbb) : 64 events

Significance : 1.4 σ

Significance is weak at this situation.

→ Next step

- • Modification of selection cut
- • Combination with other modes

Rec. ($M_{H1}+M_{H2}$) distributions for 2ab⁻¹

Summary

- ZHH is studied to investigate ILC performance for some Higgs mass cases.

- HH$\nu\nu$ is investigated for M_H=120GeV as the first step.

- ZZ events are serious B.G. for HH$\nu\nu$.

  ➢ 10^4 times larger than signal.

- Significance of 1.4σ was obtained after the selection cuts.

  ➢ Modification of the selection criteria is necessary.

  ➢ The other modes (6-jet events, etc.) should be analyzed.