Right-handed neutrino in extra-dimension model

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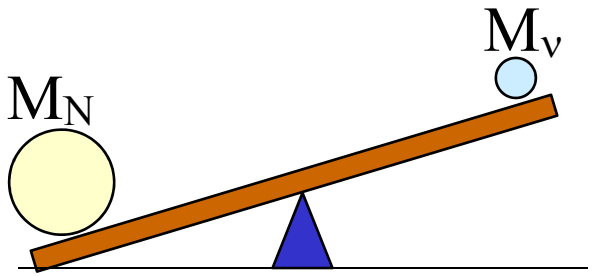
Seesaw mechanism in SM

Seesaw mechanism

• Neutrino mass can be small with the valance with mass of a right-handed neutrino (N):

$$M_\nu = \frac{v^2 y^2}{2M_N}$$

- M_N: Mass of right-handed neutrino
- y: Yukawa-coupling
- v: Vacuum expectation value



• M_N must be 10^{14} GeV to make $M_\nu \sim 0.1$eV for y=1.

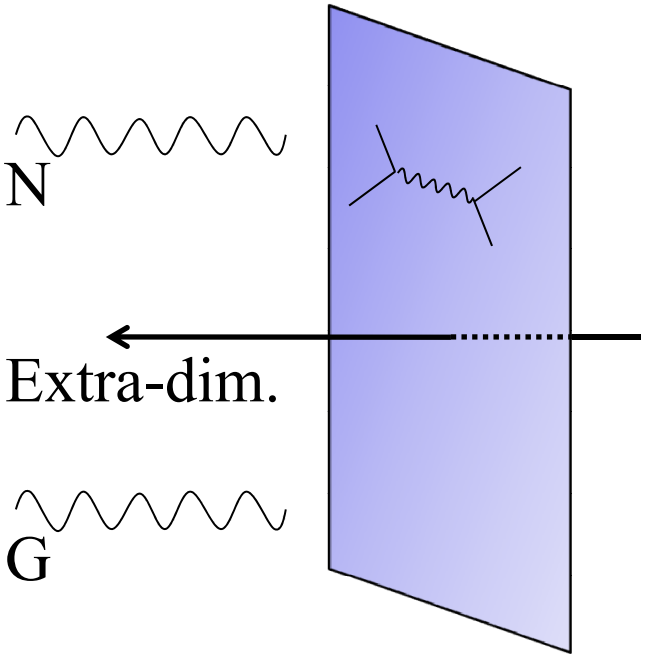
→ M_N is too heavy to observe at an experiment.

How about M_N in extra-dimension model?

N in extra-dimension model

N in extra-dimension model

- N can travel in the extra-dimension.
- M_N has the relation with radius of the extra-dimension (R). (hep-ph:0901.4596)
  - $M_N = (2n-1)/2R$ (n=1, 2, …)
  - n: index of the n-th KK mode
- M_N can be small for 1/R~100GeV
  - M_N: 100GeV for 1/R=100GeV and n=1.



N can be observed at ILC if the extra-dimension exists at TeV scale.

→ We studied the possibility to measure N.

Observation of N

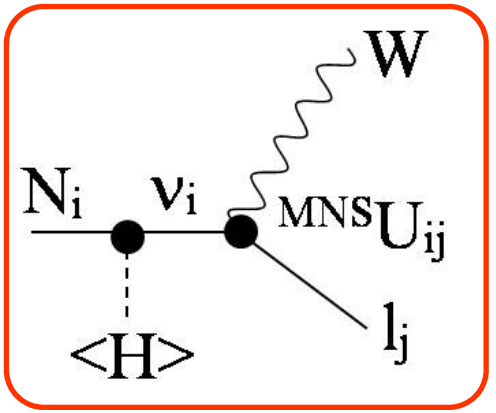
Observation of N

• N interacts with SM particles through Higgs coupling by weak-interaction.

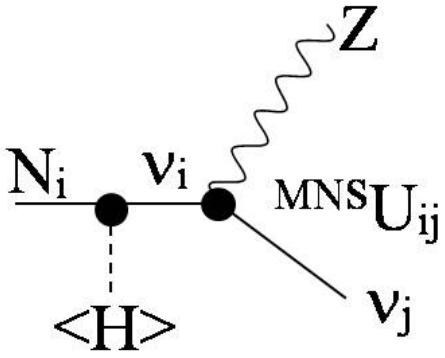
• M_N can be reconstructed by using decay products from N with CC interaction.

- $N_i \rightarrow \nu_j W$. (i, j: lepton-flavor)
- Mixing of i and j is determined by the MNS matrix.

CC interaction



NC interaction



Analysis procedure

• Development of event generator

• Detector simulation

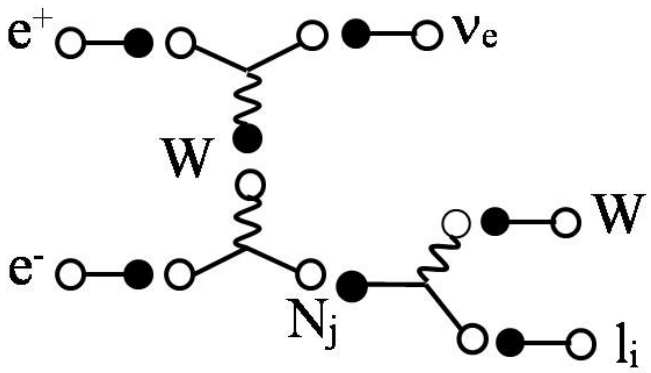
• Analysis

At first, the event generator was developed.

Development of event generator

N event generator

- Physsim was used to develop the event generator.
  - The program based on HELAS library.
  - The functions to connect the external and internal lines of the Feynman diagram is prepared.
- The programs to define the coupling and properties of N were developed.
- The xsec calculated by the event generator was consistent with hand-calculation.
  - Total xsec: 66.1 fb



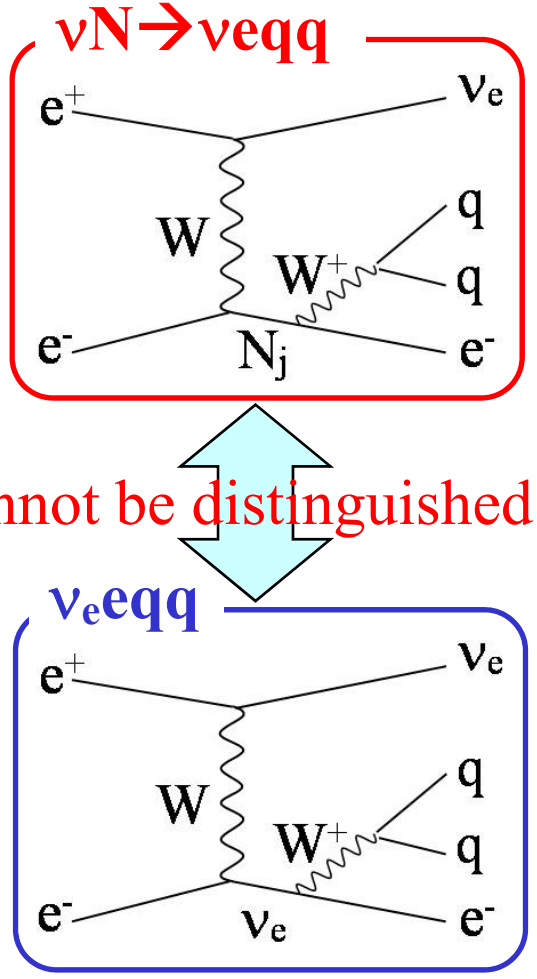
Xsec of νN→νlW

l_i	Xsec	@ 500fb^{-1}
e	19.9 fb	9, 950 ev
μ	14.9 fb	7,450 ev
τ	31.6 fb	15,800 ev

Analysis condition

Analysis condition

- M_N: 100GeV for the 1st KK mode
- E_{CM}: 500GeV
- Integrated luminosity: 500fb^{-1}
- No beam polarization
- Beamstrahlung, ISR, and FSR are included.



Signal and BG

- νN→νeqq events have large $\nu_e$eqq BG.

  → The analysis was done for νN→νμqq events.

- Signal: νN→νμqq (10.1 fb)
- BG: WW → νμqq (660fb)

  ZZ → ννqq/llqq (162.6fb)

The detector simulation was performed.

Detector simulation

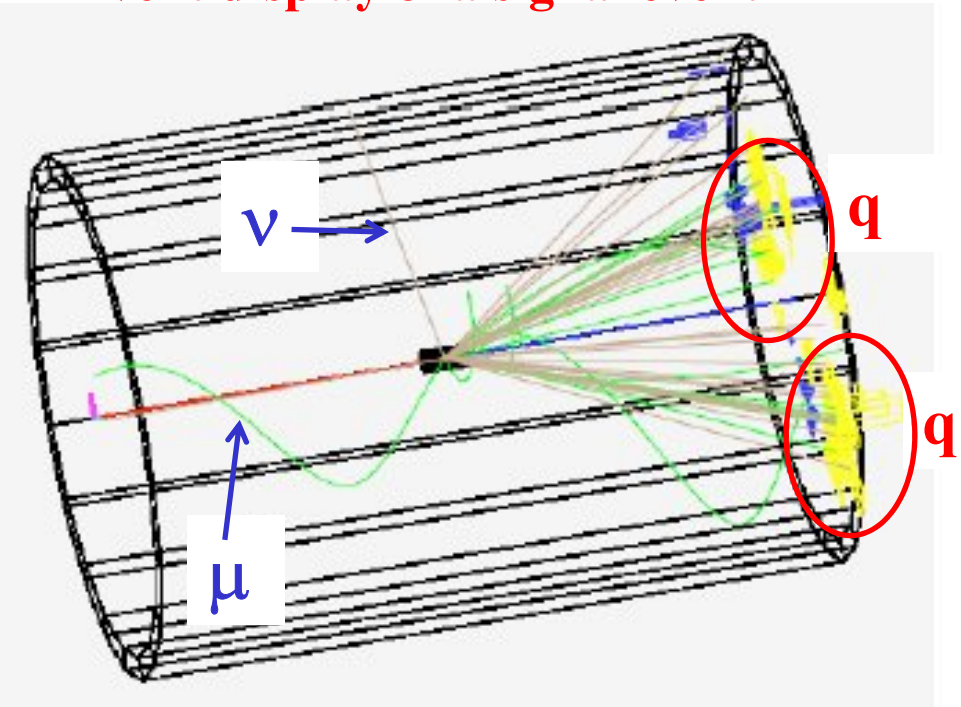
The signal events prepared by the event generator were read by quick-simulator for ILD.

- One isolated charged lepton and 2 jets from W can be seen.

→ The signal events were simulated successfully.

The analysis was done after detector simulation.

Event display of a signal event

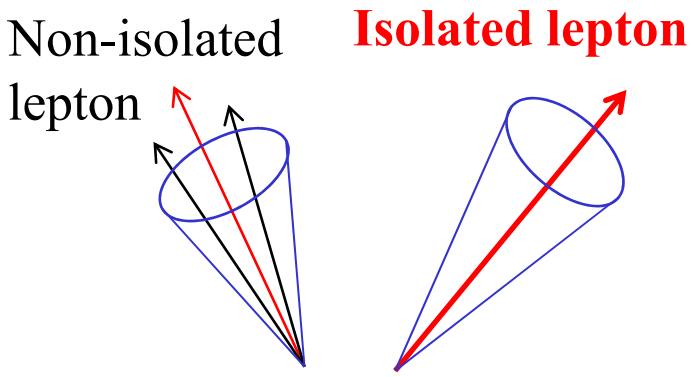


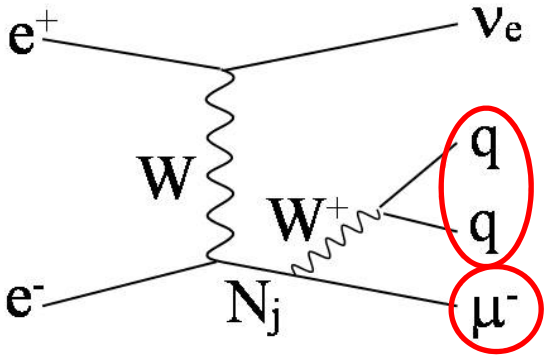
Event reconstruction

N mass was reconstructed by using the information of decay products.

Reconstruction procedure

- Identification of an isolated lepton track
  - The energy deposit of the track around 5 deg. is required to be below 5GeV
  - The most energetic track was selected.
- 2-jet reconstruction
  - W is reconstructed.
- Reconstruction of N mass
  - $P_N = P_W + P_{lep}$

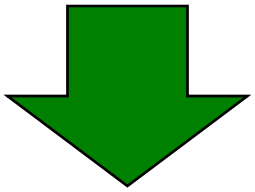




ν_R mass distribution

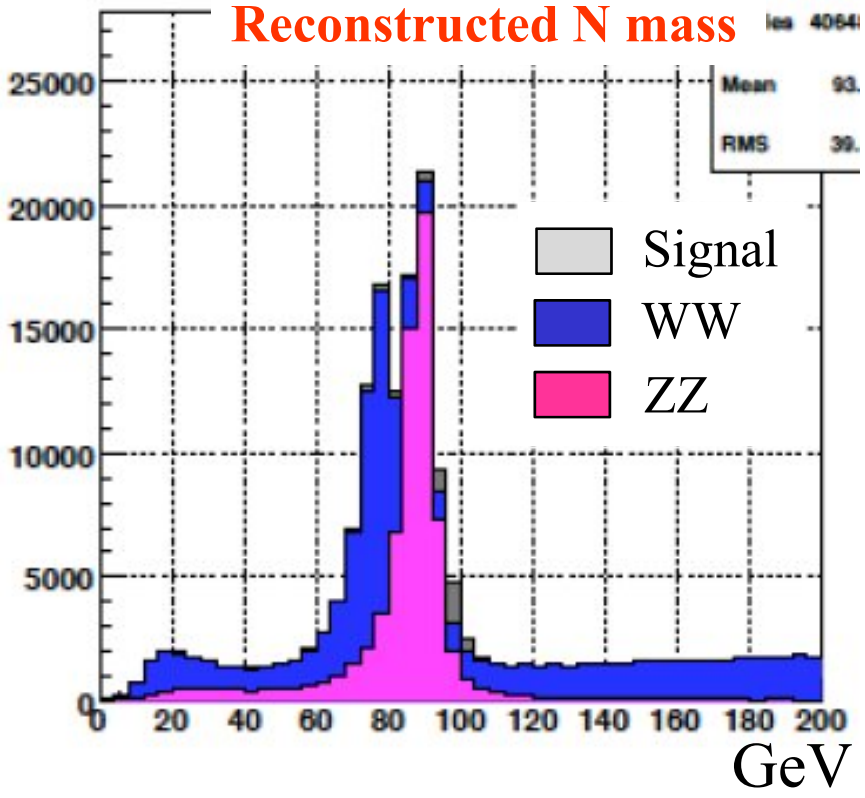
N mass was reconstructed by using the information of reconstructed particles.

- Many BG events contaminate in the signal region.
  - The mass peak of N overlaps with BG.
- The BG rejection is necessary.



The selection cut was studied.

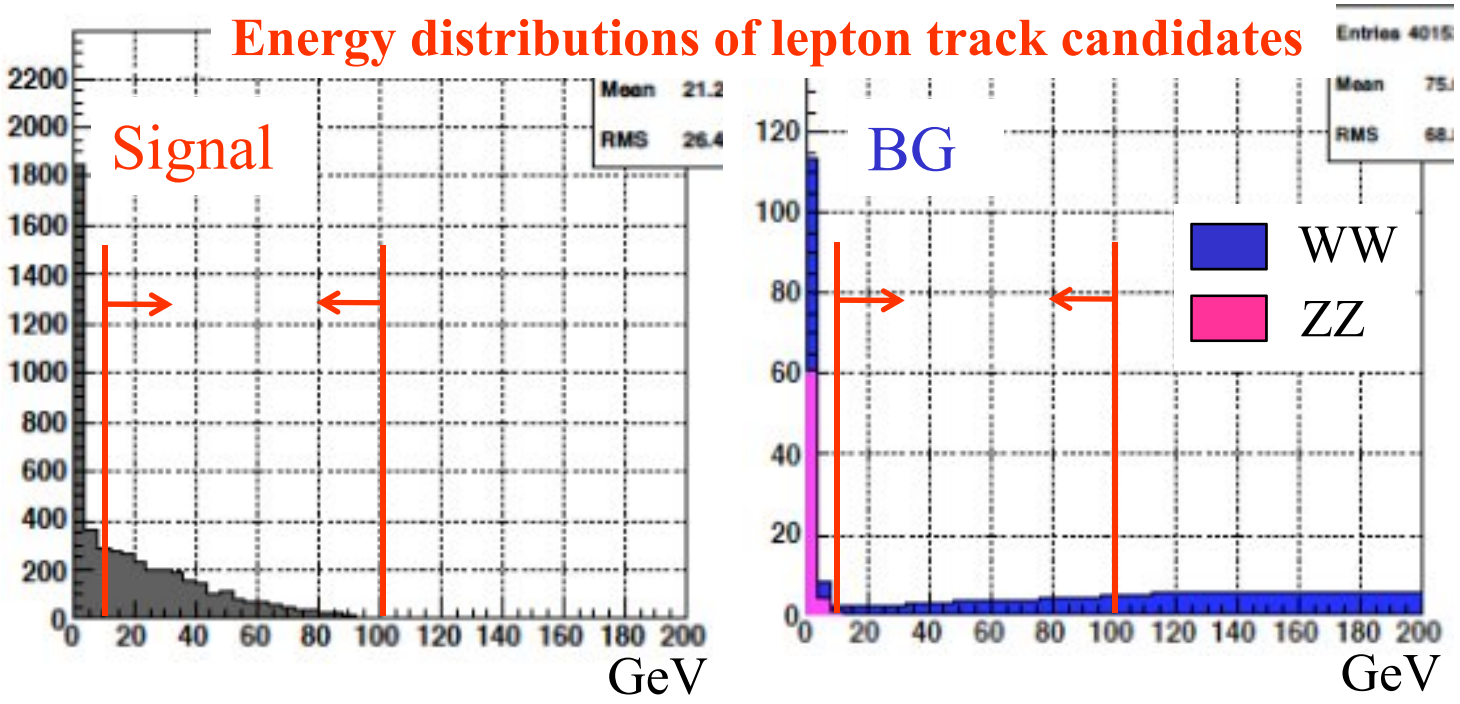
- Lepton energy cut
- W mass cut
- W energy cut

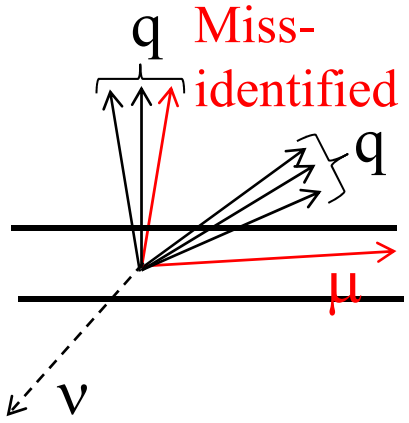


Isolated lepton track selection

The energy distribution of lepton track candidates was investigated.

- There are many events in low energy region for both signal and BG.
  - Many isolated lepton tracks escape into the beam pipe.
  - Charged tracks from jets are identified as the isolated lepton tracks.
- $10<E_{lep}<100$GeV was required to select correct isolated lepton tracks.

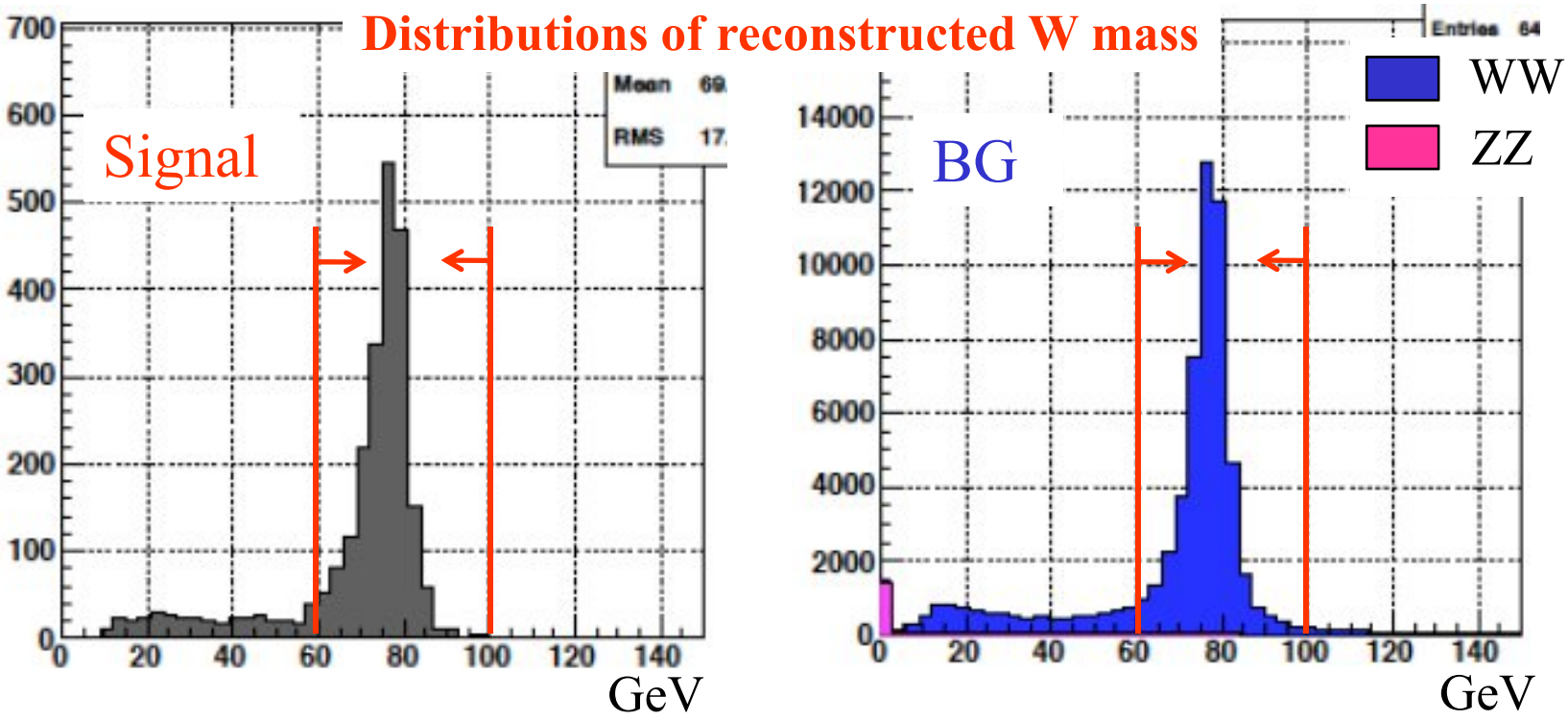




W mass cut

A distribution of the reconstructed W mass was checked.

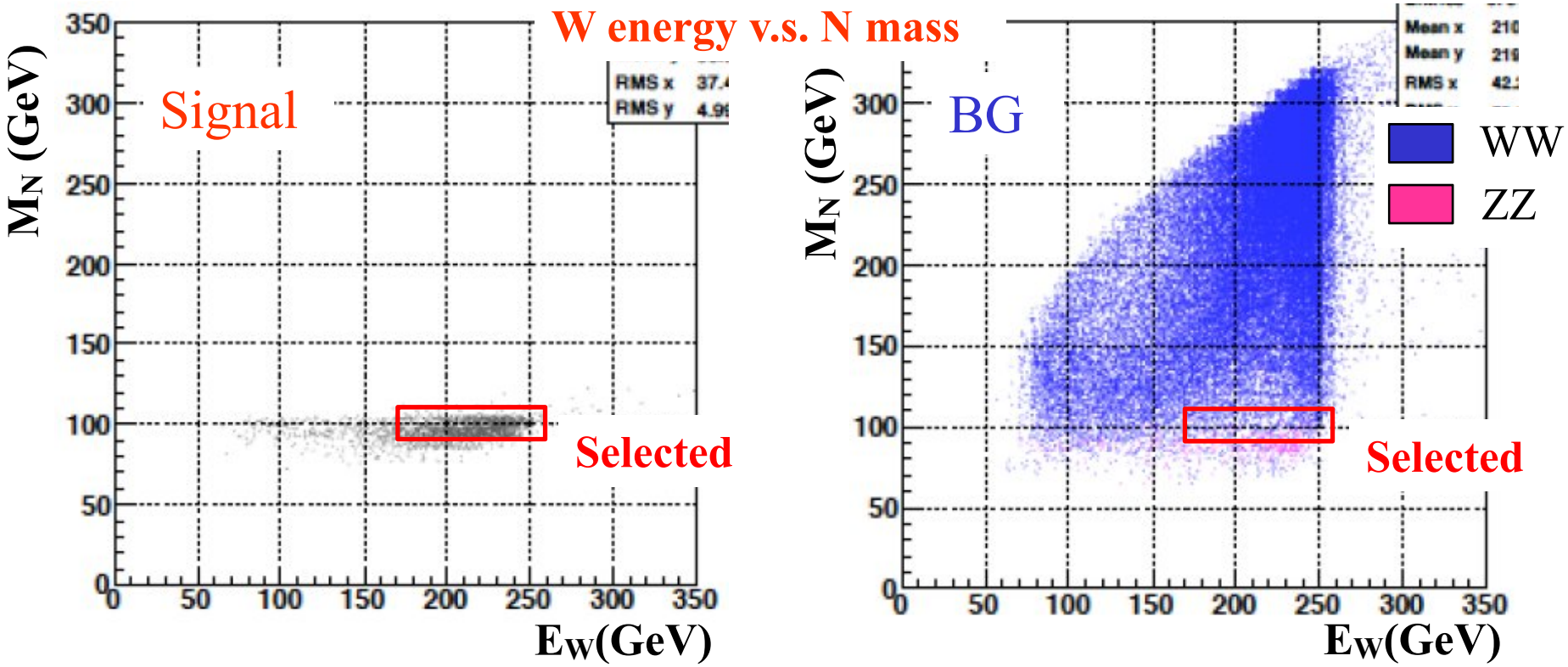
- There is a tail due to mis-reconstruction of jets.
- $60 < M_W < 100$GeV was selected.



W energy cut

A distribution of the reconstructed N mass and W energy was checked.

- Signal region was set to 90-110GeV.
  - Many BG contaminates in the signal region.
- 170< E_W<260GeV was required to reject BG in the signal region.



Cut summary

of events at each selection cut is summarized.

- BG events can be rejected efficiently.
- Efficiency for signal was 31%.

→ The sensitivity to the signal was evaluated.

	Signal	WW→νμqq	ZZ→ννqq/ llqq
No cut	5,040	330,000	81,300
$10 < E_{lep} < 100$GeV	2,488	71,493	4,854
$60 < M_W < 100$GeV	2,060	57,342	395
$170 < E_W < 260$GeV	1,693	46,737	287
$90 < M_N < 110$GeV	1,537	696	104
Efficiency	30.5%	0.2%	0.1%

Signal significance

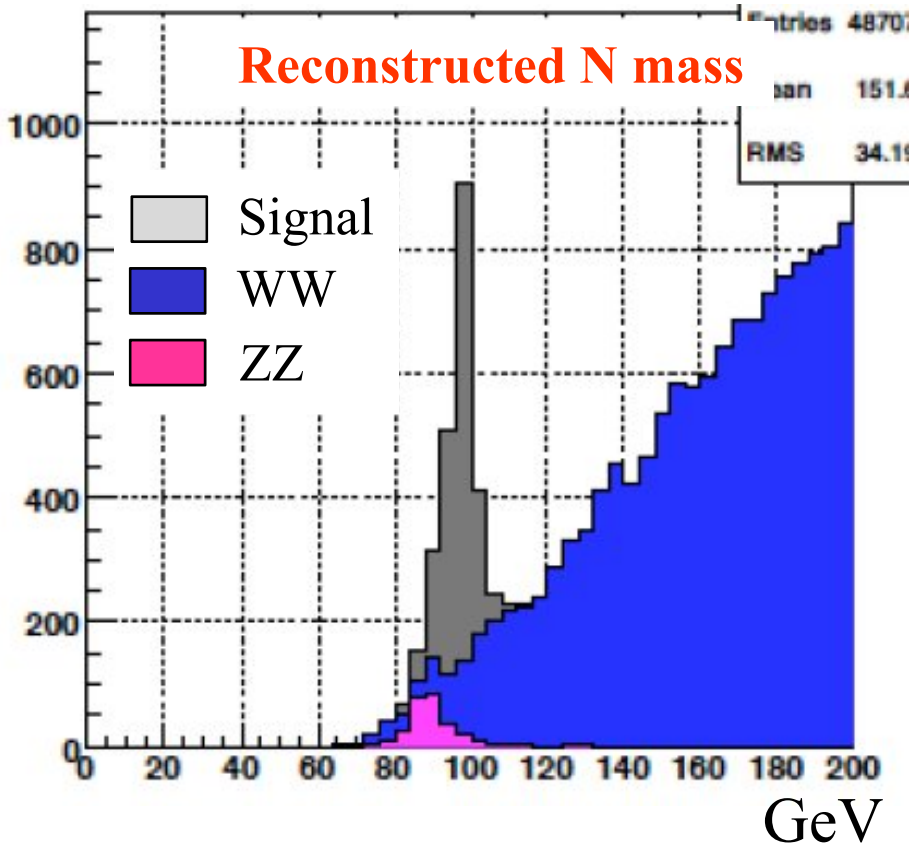
The sensitivity to N was estimated after the selection cut.

- Singal: 1,537
- BG: 800

→ Signal significance : 31.6

→ $\Delta\sigma(\nu N \rightarrow \nu\mu qq)$: 3.2%

Right-handed neutrinos of the 1st KK mode can be observed at ILC.



The next step

- Xsec measurement of electron and muon modes.
- Study of the 2nd KK mode.

Summary

- The sensitivity of ILC to right-handed neutrino (N) in the extra-dimension model was investigated.
- The mass of N becomes about 100 GeV if 1/R=100GeV~1TeV.
- The event generator for this model was developed with Physsim.
- The mass peak of the 1st KK mode was observed clearly.
  - WW and ZZ BG can be rejected by selection cut.
- Xsec measurement of electron and muon modes and the 2nd KK mode will be studied as the next step.