The Study on the right-handed neutrino in extra dimension

(arXiv:0707.4058v3[hep-ph], arXiv:0901.4596v1[hep-ph])

Tomoyuki Saito
(Tohoku Univ.)

2010/03/27
LCWS 2010 @ Beijing

Outline

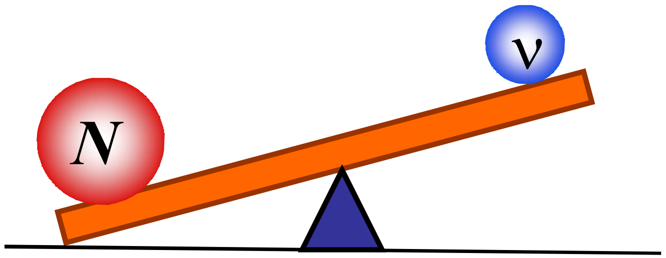
- Physics model
- Simulation
- Analysis at ãs =500 GeV, 1TeV
  - Event reconstruction
  - Error of cross section
- Summary

Seesaw mechanism

Why is ν ôs mass small ?

Seesaw mechanism

Answer.
Because of heavy N



$$M_\nu = \frac{v^2 y^2}{2M_N} \simeq 0.1eV$$

y : Yukawa coupling
v : vaccum expectation value

Too heavy

- $y=1 \rightarrow M_N = 10^{14}$ GeV
- $M_N = 10^2$ GeV $\rightarrow y = 10^{-6}$

Too weak

***N* can not be observed.**

Right-handed neutrino in extra-dimension

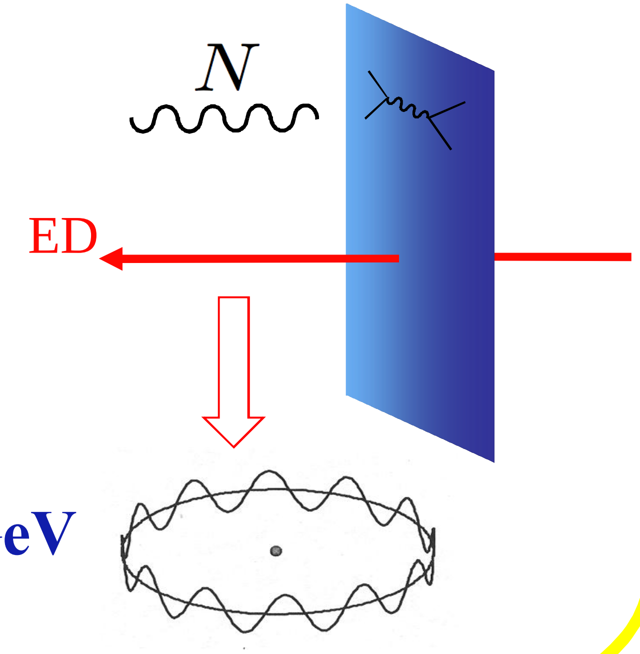
Assume the extra dimension é

$$M_N = \frac{2n-1}{2R} (n = 1, 2, \cdots)$$

(n : Index of KK mode, R : Radius of ED)

☞ If the size of the extra dimension is TeV scale, **$1/R$~100GeV ⇒ M_N~100GeV**

N can travel in ED



☞ The study of N

⇒ *Origin of small neutrino mass and extra-dimension*

N interaction

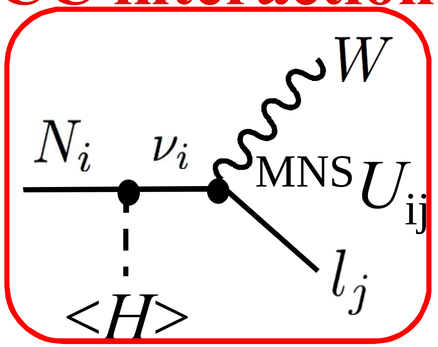
How does N interact ?

N interaction

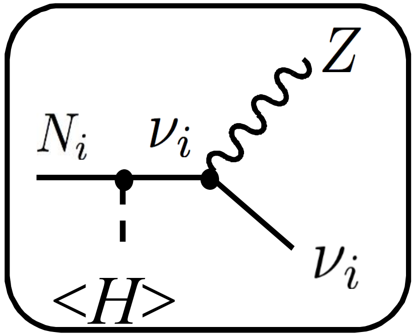
- N interacts with SM particles through Higgs coupling with weak-interaction
- M_N can be reconstructed by using decay products from N for CC interaction.

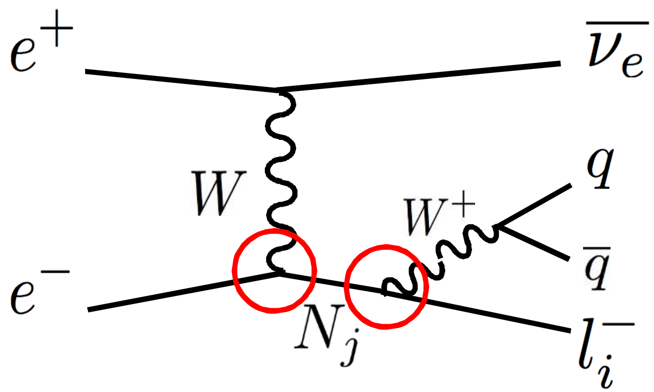
  ⇒ The flavor mixing is occurred with MNS matrix.

CC interaction



NC interaction





Simulation

Simulation condition

Fast simulator of GLD

- ☞ C.M. energy : **500 GeV , 1 TeV**
- ☞ Integrated luminosity : **500 fb-1**
- ☞ Neutrino mass hierarchy : Normal, Inverted, Degenerate
- ☞ **Right-handed neutrino**
  - Majorana neutrino
  - Mass N_1 : **150** GeV

    N_2 : **450** GeV

    N_3 : **750** GeV

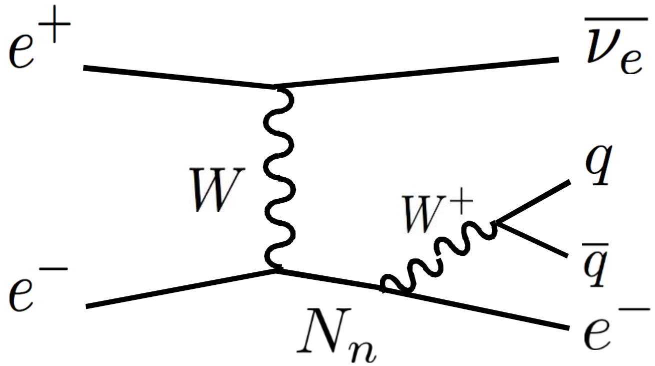
Constrained by LEP

Signal

Signal

☞ The final state
⇒ 1 lepton + 2jets + neutrino
↳ Electron

☞ N has KK mode



Cross section of signal

	Ecm=500 GeV			Ecm=1TeV		
KK mode	**Normal**	**Inverted**	**Degenerate**	**Normal**	**Inverted**	**Degenerate**
1st KK	6.524	297.5	257.1	7.791	355.4	307.1
2nd KK	0.065	2.975	2.571	0.517	23.60	20.40
3rd KK	/	/	/	0.085	3.864	3.340

The analysis results are shown based on the case of the degenerate hierarchy .

Background

Background：The visible final state of 2jets+1lepton

The cross section of background (fb)

Background	Ecm=500GeV	Ecm=1TeV
eνW	4462	10320
WW -> lνqq	660	280.3
ZZ -> llqq+ννqq	163	32.79
tt	531	29.43

The major backgrounds are eνW and WW

Event reconstruction

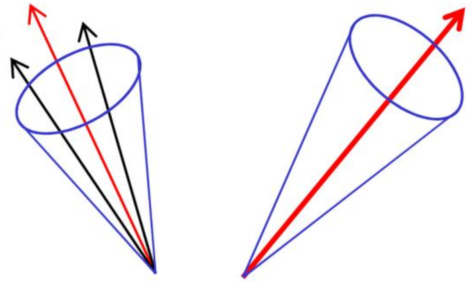
N mass is reconstructed by information of the decay products

1, Identification of an isolated lepton track

① **Energy sum of the track around 20 deg. < 5 GeV**

② **The most energetic track of ①**

⇒ **Lepton candidate**

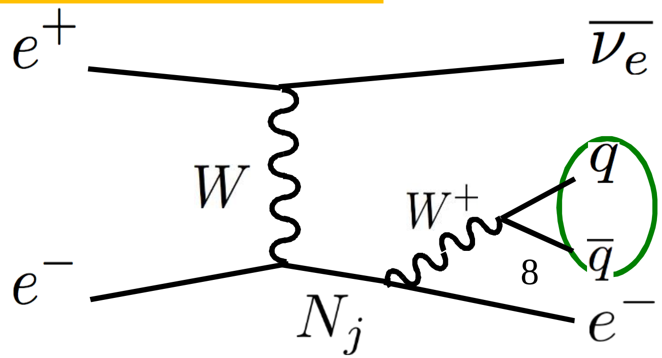


2, Forced 2jet reconstruction except for the lepton

⇒ **W is reconstructed**

3, Reconstruction of N mass

$$P_N = P_W + P_l$$



Analysis at 500 GeV

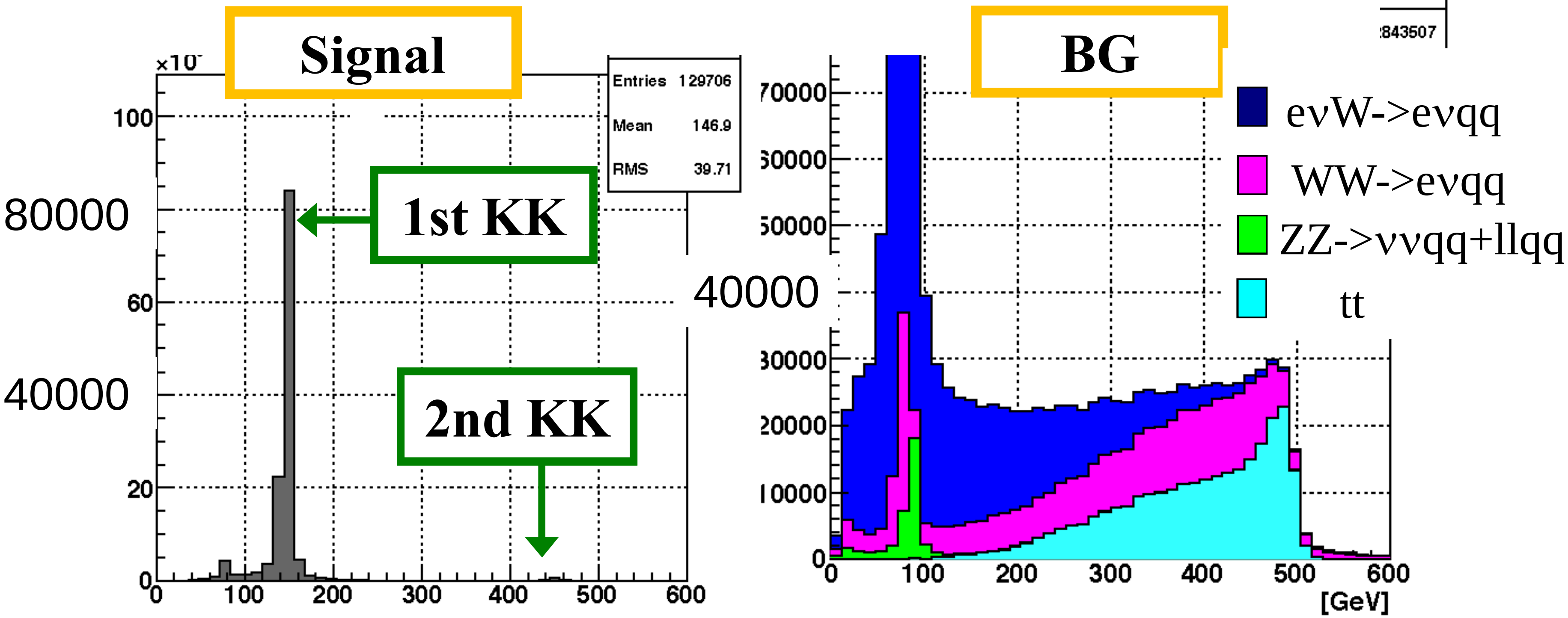
1st KK *N*

2nd KK *N*

Reconstructed *N* mass

N mass is reconstructed by using information of reconstructed particles

Right-handed neutrino mass



Background reduction is necessary

Cut summary at 500GeV

The selection cut is applied to the 1st KK mode

	1stKK	evW	WW	ZZ	tt
before cut	153540	5160000	140150	16395	14715
10 < Lepton Energy < 300	53291	254672	60704	1612	6177
60 < 2jet mass < 100	35428	126965	40436	78	317
140 < N mass < 160	30331	9386	778	4	112
efficiency (%)	**19.8%**	**0.2%**	**0.6%**	**0.0%**	**0.8%**

Background is rejected effectively.

Measurement accuracy

The measurement accuracy is evaluated by the fitting N mass distribution.

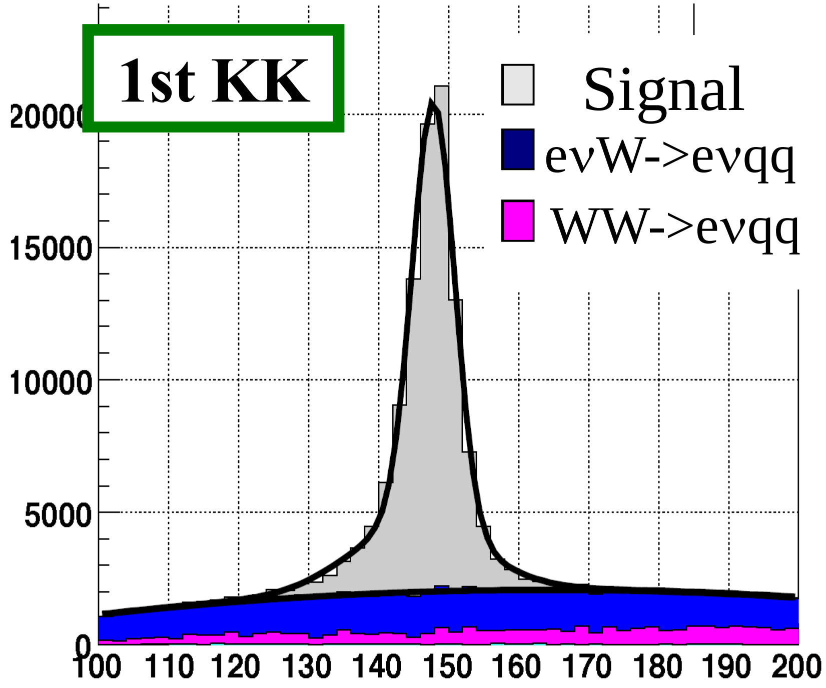
Fitting function

Double gaussian + 2nd order polynominal

Measurement accuracy

0.4%

Reconstructed N mass after cut



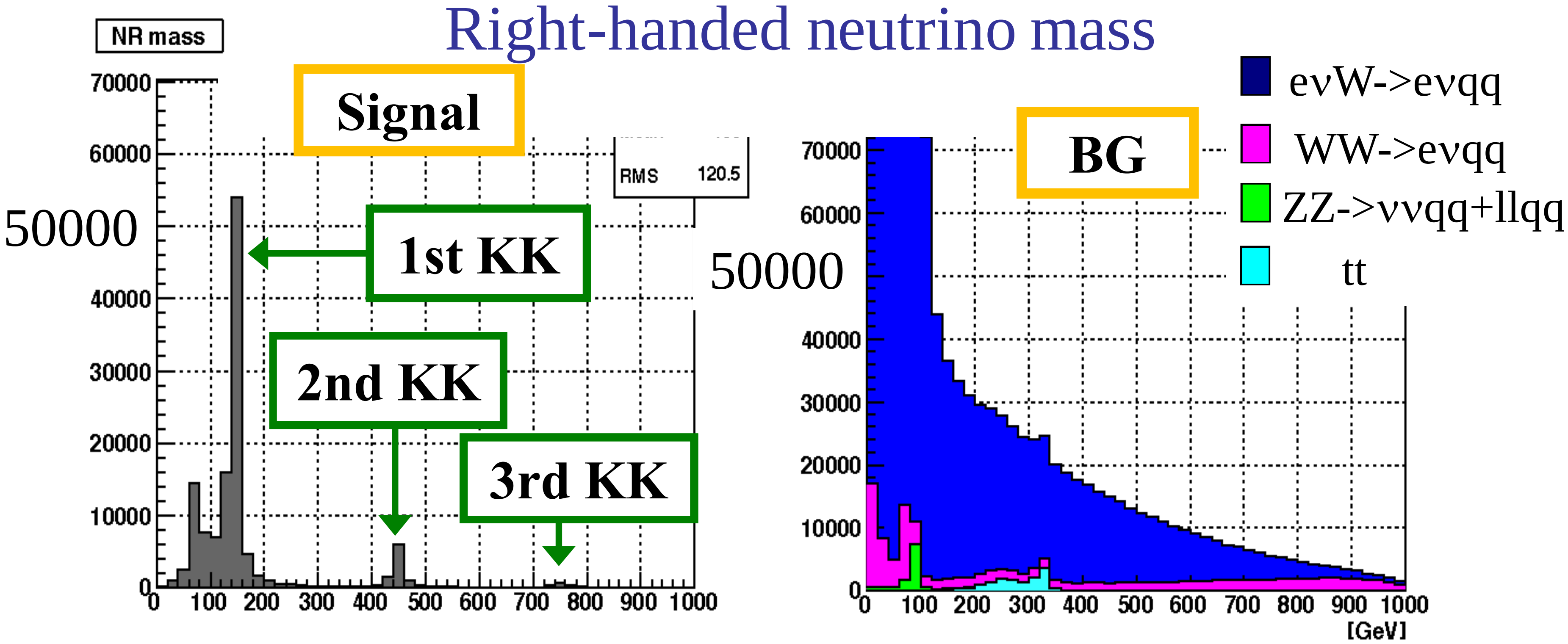
The cross section of the 1st KK mode can be measured with good sensitivity.

Analysis at 1TeV

(1st KK
2nd KK
3rd KK)

Reconstructed *N* mass

N mass is reconstructed by using information of reconstructed particles.



Background is needed to reject

Cut condition at 1TeV

Background is rejected by

- ☞ **Lepton energy cut**
- ☞ **2jet mass cut**
- ☞ **2jet energy cut**
- ☞ **Signal region cut**

Reduction table

	1st KK		2nd KK		3rd KK	
	Signal	**BG**	**Signal**	**BG**	**Signal**	**BG**
Before cut	153540	5331260	10200	5331260	1670	5331260
After cut	30331	9386	5567	17478	829	6440
Efficiency (%)	**19.8**	**0.18**	**36.7**	**0.33**	**49.6**	**0.12**

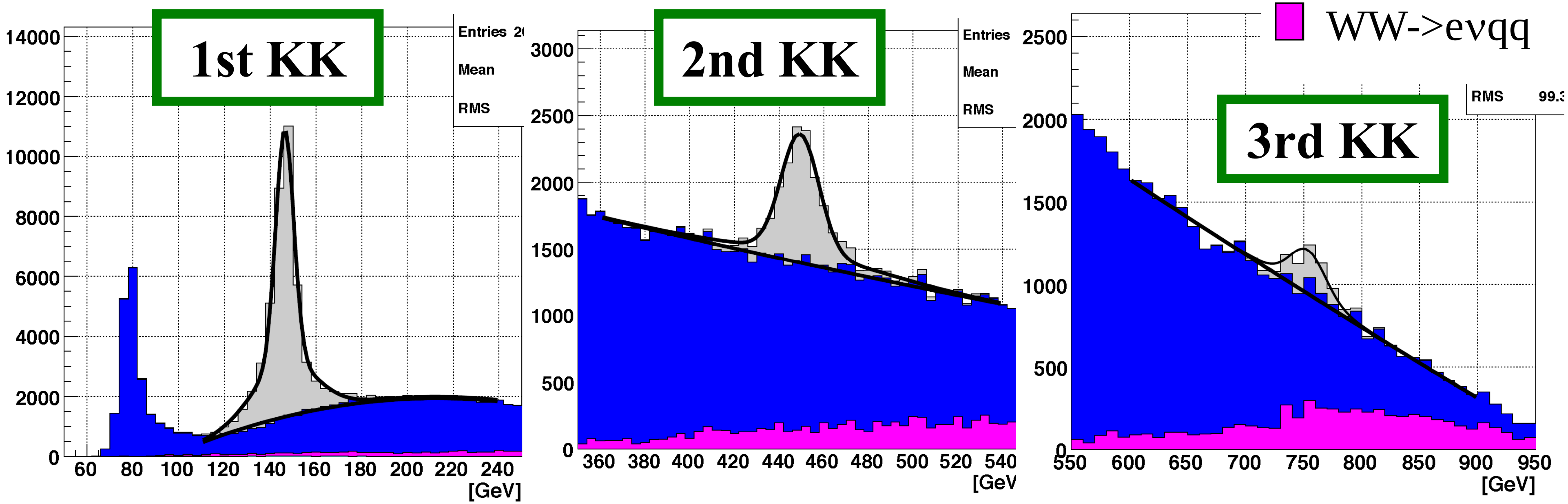
Background is rejected effectively.

Measurement accuracy

The mass peak for the 1st, 2nd and 3rd KK mode can be observed clearly.

signal
eνW->eνqq
WW->eνqq

Right-handed neutrino mass



The error of the cross section

1st KK	2nd KK	3rd KK
0.67%	**2.69%**	**8.38%**

Summary

Measurement accuracy of the right-handed neutrino in ED model is investigated.

The error of the cross section (%)

Ecm	KK mode	Normal	Inverted	Degenerated
500 GeV	**1st KK**	7.0	0.36	0.40
	1st KK	13.0	0.53	0.67
1TeV	**2nd KK**	-	2.4	2.7
	3rd KK	-	7.0	8.4

KK tower can be observed at 1TeV → Clear evidence of ED!

Plan ☞ Analysis of ***N*Ÿ τW mode** to investigate branching ratio

Back up

Lagrangian

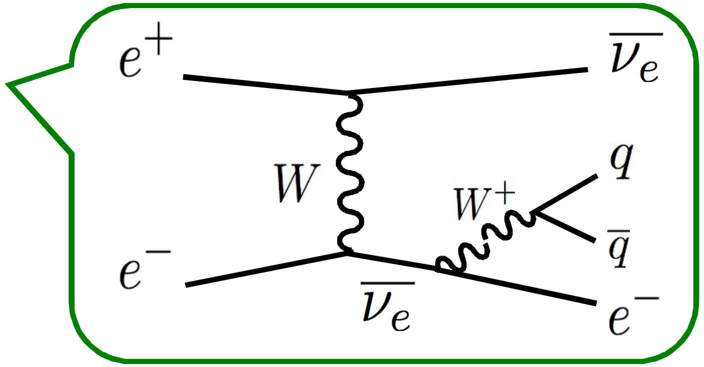
$$
\begin{aligned}
\mathcal{L}_{\rm int} &= -\frac{g}{\sqrt{2}}\bar{e}\not{W} U_{\rm MNS} P_L \nu + h.c. \\
&\quad -\frac{g}{\sqrt{2}}\sum_{n=1}^{\infty}\frac{1}{\pi R m_n}\bar{e}\not{W} X P_L N^{(n)} + h.c. \\
&\quad -\frac{g_Z}{2}\sum_{n=1}^{\infty}\frac{1}{\pi R m_n}\bar{\nu}\not{Z}\left(\frac{2m_\nu}{\mathcal{M}}\right)^{1/2}\mathcal{O} P_L N^{(n)} + h.c. \\
&\quad -\frac{g_Z}{2}\sum_{n,m=1}^{\infty}\frac{1}{\pi^2 R^2 m_n m_m}\bar{N}^{(n)}\not{Z}\left(\frac{2m_\nu}{\mathcal{M}}\right) P_L N^{(m)} \\
&\quad -\sum_{n=1}^{\infty}\frac{1}{\pi R v} h\bar{\nu}\left(\frac{2m_\nu}{\mathcal{M}}\right)^{1/2}\mathcal{O} P_R N^{(n)} + h.c. \\
&\quad -\sum_{n,m=1}^{\infty}\frac{1}{\pi^2 R^2 v m_m} h\bar{N}^{(n)}\left(\frac{2m_\nu}{\mathcal{M}}\right) P_L N^{(m)} + h.c.
\end{aligned}
$$

Background

Background：The visible final state of 2jets+1lepton

The cross section of background (fb)

Background	Ecm=500GeV	Ecm=1TeV
eνW	4462	10320
WW -> lνqq	660	280.3
ZZ -> llqq+ννqq	163	32.79
tt	531	29.43



The major backgrounds are eνW and WW

Neutrino mass hierarcy

	Normal	Inveted	Degenerate
ν_e (eV)	0	0.041	0.20
ν_μ (eV)	0.009	0.05	0.21
ν_τ (eV)	0.059	0	0.26