Heavy neutrinos at Z pole of CEPC

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Outline

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Motivation

- Observables of neutrino oscillation:

  ☼ *http://pdg.lbl.gov*

$$\sum m_\nu < 0.170\ eV$$

$$|\Delta m_{31}^2|^{\frac{1}{2}} \cong 0.0506\ eV$$

$$|\Delta m_{21}^2|^{\frac{1}{2}} \cong 0.0086\ eV$$

- Introduce SU(2) singlet right-handed neutrino N_R:

  ☼ *P.Minkowski, Phys. Lett. B67, 421 (1977)*

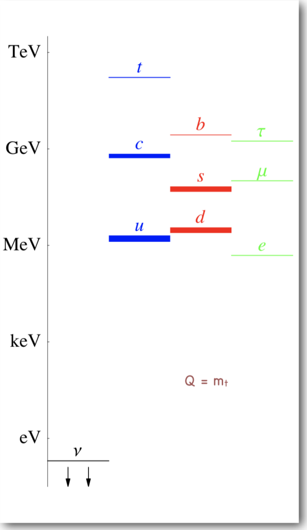
  ☼ *N. Mohapatra and G. Senjanovic, Phys. Rev. Lett. 44, 912 (1980)*

  - Dirac ?

$$M_D = Y_\nu \frac{v}{\sqrt{2}} \tag{1}$$

  - Majorana ?

$$m_\nu \simeq M_D M_N^{-1} M_D^T \tag{2}$$



☼ *Andrea Romanino, Beyond the Standard Model, including Neutrinos.*

Motivation

Experimental constraint :

- Neutrino-less double β ($0\nu 2\beta$) decay:

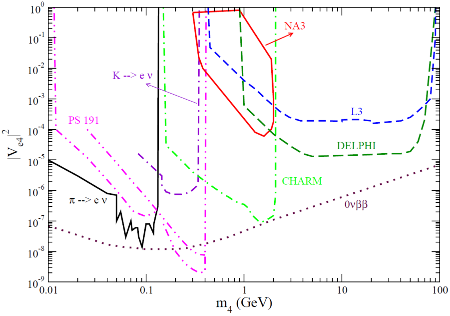
  ☼ *hep-ph/0405078; hep-ph/0501295; arXiv:1106.1334*

$$\sum_N \frac{|V_{eN}|^2}{M_N} < 5 \times 10^{-5}\ TeV^{-1} \tag{3}$$

  leading to $10^{-6} < |V_{eN}|^2 < 10^{-5}$ for 10∼100 GeV scale N_R

- DELPHI Collaboration: for ∼10 GeV scale N_R, $|V_{eN}|^2 \sim 10^{-5}$.

  ☼ *DELPHI Collaboration, Z. Phys. C 74, 57-71 (1997)*



☼ *JHEP 0905 (2009) 030*

Outline

Low energy scale See-saw mechanism

- The scale of heavy neutrino in Type-I See-saw mechanism is $\mathcal{O}(10^{14})$ GeV, which is impossible to be searched in experiment. Therefore, we hope there are some low scale mechanism to explain the origin of neutrino mass.

- Consider the *neutrino Minimal Standard Model*(νMSM), generally, we introduce n right-handed SU(2)×U(1) singlet neutrinos N_{aR} (a=1, ...n), and write down the Lagrangian:
  ☼ *hep-ph/0503065* ☼ *hep-ph/0505013*

$$\delta\mathcal{L} = \overline{N}_a i\partial_\mu\gamma^\mu N_a - f_{ai}\widetilde{\psi}\overline{L}_i N_a - \frac{1}{2}M_N\overline{N}_a^c N_a + h.c. \tag{4}$$

where f_{ai} means Yukawa coupling of neutrinos and $\widetilde{\psi} = i\tau_2 H^*$.

- After spontaneous symmetry breaking:

$$-\mathcal{L}^{\nu}_{mass} = \frac{1}{2}\left(\sum_{m=1}^{3} m_{\nu_m}\bar{\nu}_{mL}\nu^c_{mR} + \sum_{m'=4}^{3+n} M_N \bar{N}^c_{m'L} N_{m'R}\right) \quad (5)$$

consider the mixing relations between flavor and mass eigenstates:

$$\nu_l = \sum_{i=1}^{3} U_{li}\nu_i + \sum_{j=4}^{3+n} V_{lj}N_j \quad (6)$$

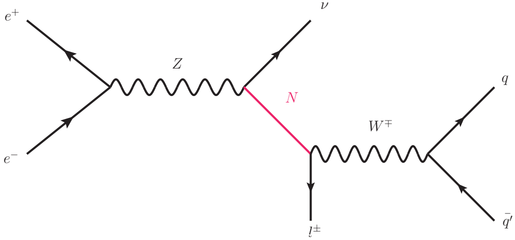
we can rewrite the interactions Lagrangian:

$$-\mathcal{L} = \frac{g}{\sqrt{2}} W^+_\mu \left(\sum_{l=e}^{\tau}\sum_{m=1}^{3} U^*_{lm}\overline{\nu_m}\gamma^\mu P_L l + \sum_{l=e}^{\tau}\sum_{m'=4}^{3+n} V^*_{lm'}\overline{N^c_{m'}}\gamma^\mu P_L l\right) + h.c.$$

$$+ \frac{g}{2cos\theta_W} Z_\mu \left(\sum_{l=e}^{\tau}\sum_{m=1}^{3} U^*_{lm}\overline{\nu_m}\gamma^\mu P_L \nu_l + \sum_{l=e}^{\tau}\sum_{m'=4}^{3+n} V^*_{lm'}\overline{N^c_{m'}}\gamma^\mu P_L \nu_l\right) + h.c.$$

$e^+e^- \to N\nu(\bar{\nu}) \to ljj\nu(\bar{\nu})$

- CEPC operates at $\sqrt{s}$ =91.2 GeV with 1 ab^{-1} with 2 years of operation.



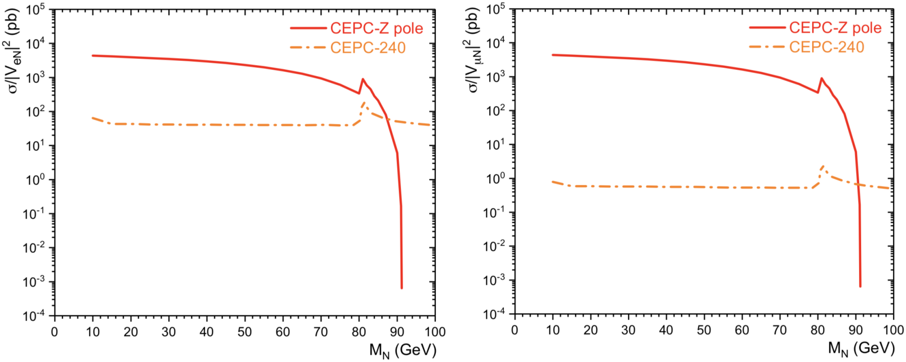
- If we consider the narrow width approximation:

$$\sigma_{e^+e^-\to l\nu jj} = \sigma_{e^+e^-\to N\nu} \times Br(N \to ljj) \tag{7}$$

where $\sigma_{e^+e^-\to N\nu} \propto \sum_i |V_{iN}|^2$ and $Br(N \to ljj) \propto |V_{lN}|^2/\sum_i |V_{iN}|^2$, we obtain the relation between cross section and mixing parameters:

$$\sigma_{e^+e^-\to l\nu jj} \propto |V_{lN}|^2 \tag{8}$$

$e^+e^- \to N\nu(\bar{\nu}) \to ljj\nu(\bar{\nu})$



- $e^+e^- \to N\nu \to ljj\nu$, sum over neutrinos and anti-neutrinos of all flavor.
- For $M_N < M_Z$, $\sigma/|V_{lN}|^2$ is about 10^3 pb at Z pole *vs* 10^2/1 pb at 240.
- For $M_N > M_W$, heavy neutrino will decay to an on-shell W boson, which will increase the amplitude of this process.

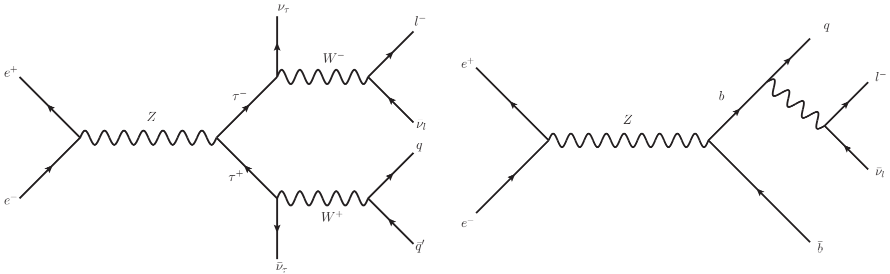
Outline

1. Motivation
2. Low energy scale See-saw mechanism
3. **Phenomenological analysis at CEPC**
4. Summary

Background at Z pole of CEPC

Main background comes from $e^+e^- \to \tau^+\tau^-$ and $q\bar{q}$ production:

- For $\tau\tau$: with one τ decaying to lepton while the other decaying to hadrons.
- For $q\bar{q}$: $e^+e^- \to b\bar{b} \to ljj\not{E}_T$ will be dominant. The lepton decayed from c-quark will be hidden in jets due to the large boost of c-quark.



Feynman diagram of backgrounds

Background at Z pole of CEPC

- Simulation:
  - FeynRules: generate MG simulation model;
  - MadGraph: generator for signal and background;
  - Pythia8: parton shower and hadronization;
  - Delphes: fast jet simulation;
- Due to the complex background from $b\bar{b}$, we divide the mass range into 3 areas:
  - light mass: $10 < M_N < 65$ GeV;
  - middle mass: $65 < M_N < 80$ GeV;
  - heavy mass: $80 < M_N < 91$ GeV;
- Observables:

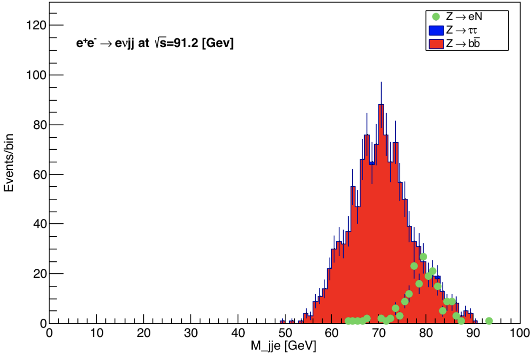
$$R_{ab} = \sqrt{\Delta^2\eta + \Delta^2\phi}$$

$$E_\nu^{th} = \frac{M_Z^2 - M_N^2}{2M_Z}$$

Cuts

- For light mass range ($10 < M_N < 65$ GeV):
  - $P_T^j > 3$ GeV, $|\eta_j| < 2$, $M_{jj} > 2$ GeV, btag < 0.8, TauTag, BTag
  - $P_T^l > 3$ GeV, $|\eta_l| < 1$
  - $\not{E}_T > 20$ GeV
  - $1.0 < R_{mj} < 5.5$, $1.5 < R_{ml} < 5.0$
- For middle mass range ($65 < M_N < 80$ GeV):
  - $P_T^j > 3$ GeV, $|\eta_j| < 2$, $M_j > 1.2$ GeV, $R_{jj} > 0.4$, btag < 0.8, TauTag, BTag
  - $P_T^l > 3$ GeV, $|\eta_l| < 1$,
  - $\not{E}_T > 10$ GeV, $\Gamma_{E_\nu^{exp} - E_\nu^{th}} < \Gamma_{1/2}$
  - $R_{mj} > 1.0$, $1.5 < R_{ml} < 5.0$
- For heavy mass range ($80 < M_N < 91$ GeV):
  - $P_T^j > 10$ GeV, $|\eta_j| < 2$, $M_j > 1.2$ GeV, $M_{jj} > 55$ GeV, $R_{jj} > 0.4$, btag < 0.8, TauTag, BTag
  - $P_T^l > 3$ GeV, $|\eta_l| < 1$
  - $\Gamma_{E_\nu^{exp} - E_\nu^{th}} < \Gamma_{1/2}$
  - $R_{mj} > 1.5$, $1.5 < R_{ml} < 5.0$

Significance

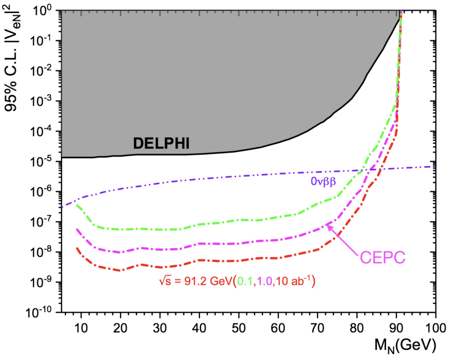


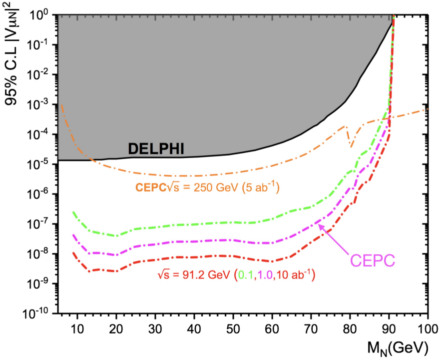
Define significance s as:

$$s = \frac{N_S}{\sqrt{N_B + N_S}} = \frac{N_{S0} \times |V_{lN}|^2/|V_0|^2}{\sqrt{N_B + N_{S0} \times |V_{lN}|^2/|V_0|^2}} \sqrt{\frac{\mathcal{L}}{\mathcal{L}_0}} \tag{9}$$

where $|V_0|^2$ and $\mathcal{L}_0$ mean the mixing parameters and luminosity we used in simulation.

Constraints of mixing parameters at Z pole of CEPC





☼ *Z. Phys. C 74, 57-71(1997); hep-ph/0405078; hep-ph/0501295; arXiv:1106.1334; arXiv:1805.09520*

- Constraint of $|V_{lN}|^2$ can reach $\mathcal{O}(10^{-8})$ with 1 ab^{-1} at Z pole of CEPC;
- Constraints of $|V_{eN}|^2$ is 2 order of magnitude lower than that of $0\nu2\beta$ decay.
- Constraints of $|V_{\mu N}|^2$ is 2 order of magnitude lower than that of higher energy run.

Outline

Summary

1. We study the low energy scale See-saw mechanism with heavy neutrino mass between 10$\sim$90 GeV, and it will have a large number of signal at Z pole of CEPC when the mixing parameters is large enough.

2. Constraint of $|V_{lN}|^2$ is $\mathcal{O}(10^{-8})$ at Z pole of CEPC with 1 ab^{-1}, which is 3 order of magnitude lower than that of DELPHI, and 2 order of magnitude lower than that of $0\nu2\beta$ decay.

3. M_N below Z mass: Z pole run is more sensitive
M_N above Z mass: high energy run win

Thanks for your attention!