Lecture 22 Neutrinos

ICPY473 Nuclear Physics, MUIC, 3-Trimester, 2021

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Today Topics

- Neutrino properties
- Interaction with matter
- Flavors oscillation

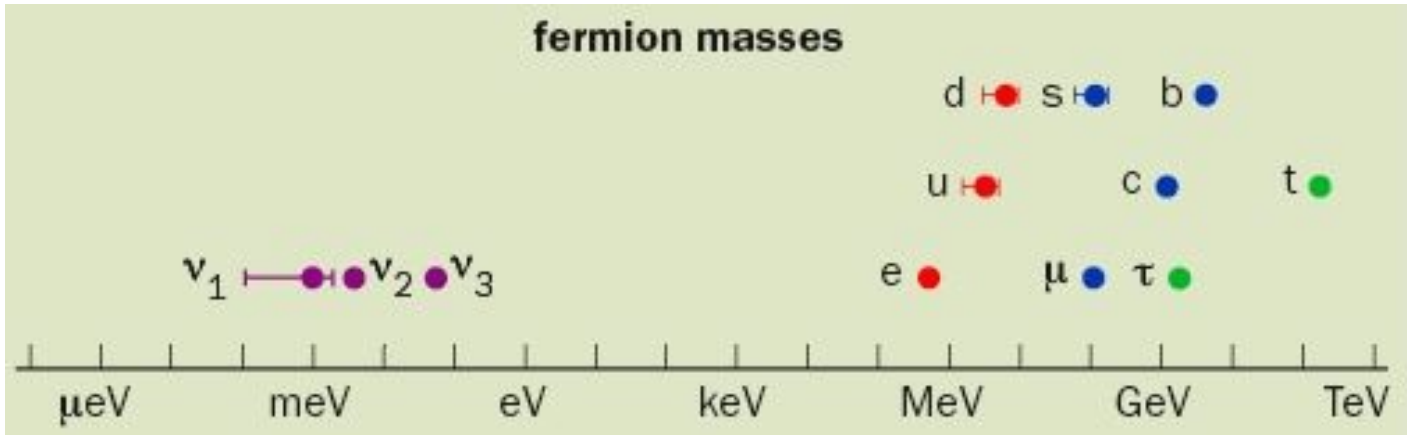
Neutrino Properties

- Neutrino is *ghost* particle in nuclear beta decay, and was first predicted to be exist by W. Pauli. It becomes characteristic of weak interaction.
- It was first observed by Clyde Cowan and Frederick Reines, 1956, from interaction of cosmic rays to the Earth atmosphere. This is the electron neutrino ν_e.
- In 1962, Leon M. Lederman, Melvin Schwartz and Jack Steinberger showed that more than one type of neutrino exists, the muon neutrino ν_μ and tauon neutrino ν_τ.
- Neutrinos are classified to be leptons, from their contribution to weak interaction, and appear in three generations. Together with their partners, e^-, μ^-, τ^-, they from to be a group of six-flavors leptons within the standard model.
- In weak interaction theory, we say that they form to be *lepton doublets* l_e, l_μ, l_τ.

- Lepton doublets

Q/e	$L_e = -1$	$L_\mu = -1$	$L_\tau = -1$
0 +1	$\begin{pmatrix} \overline{\nu}_e \\ e^+ \end{pmatrix}$	$\begin{pmatrix} \overline{\nu}_\mu \\ \mu^+ \end{pmatrix}$	$\begin{pmatrix} \overline{\nu}_\tau \\ \tau^+ \end{pmatrix}$
Q/e	$L_e = 1$	$L_\mu = 1$	$L_\tau = 1$
0 −1	$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}$	$\begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}$	$\begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$

- Neutrinos have small masses when compared to other fermions within the standard model

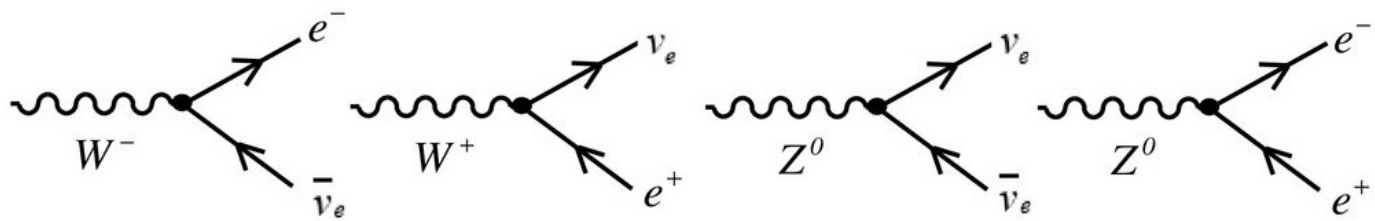


Interaction with Matter

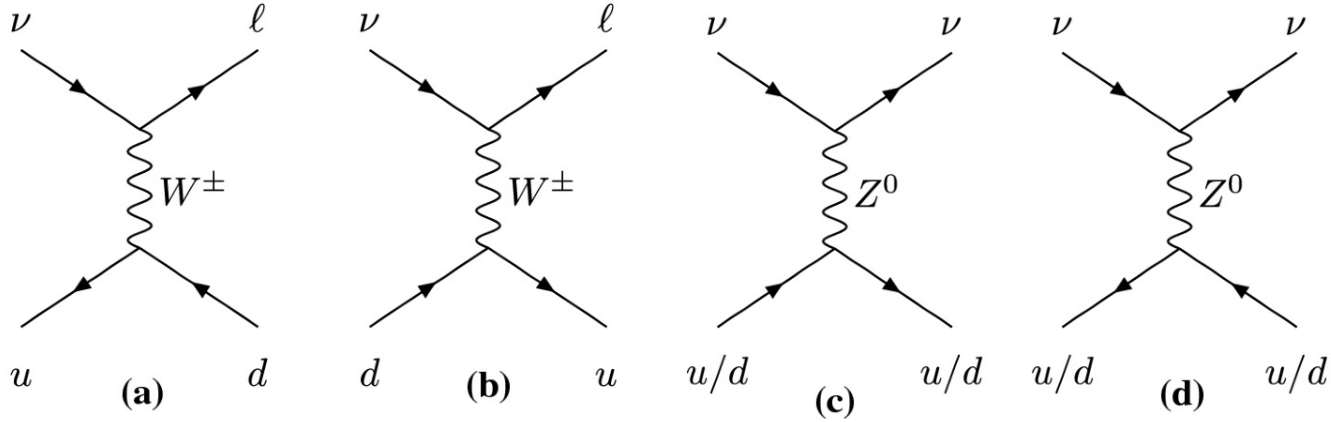
- In weak interaction theory, lepton doublets can coupling to massive charged vector bosons, with coupling constant G_F.

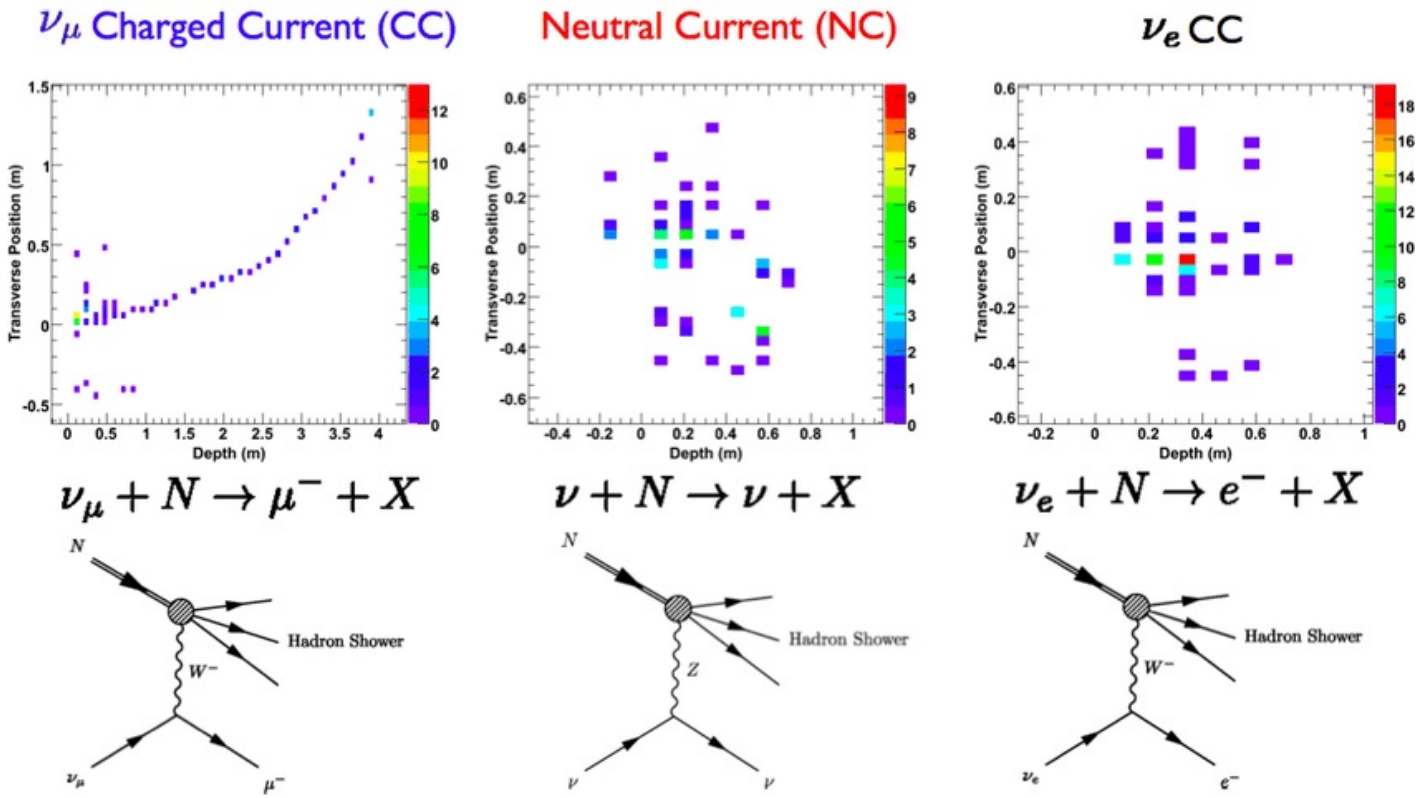
$$\begin{aligned} W^- &\to e^- + \nu_e & W^+ &\to e^+ + \bar{\nu}_e \\ &\to \mu^- + \nu_\mu & &\to \mu^+ + \bar{\nu}_\mu \\ &\to \tau^- + \nu_\tau & &\to \tau^+ + \bar{\nu}_\tau \end{aligned} \tag{22.1}$$

- The neutral massive vector boson Z^0 will couple to $e^- e^+$ pair, or $\nu_e \bar{\nu}_e$

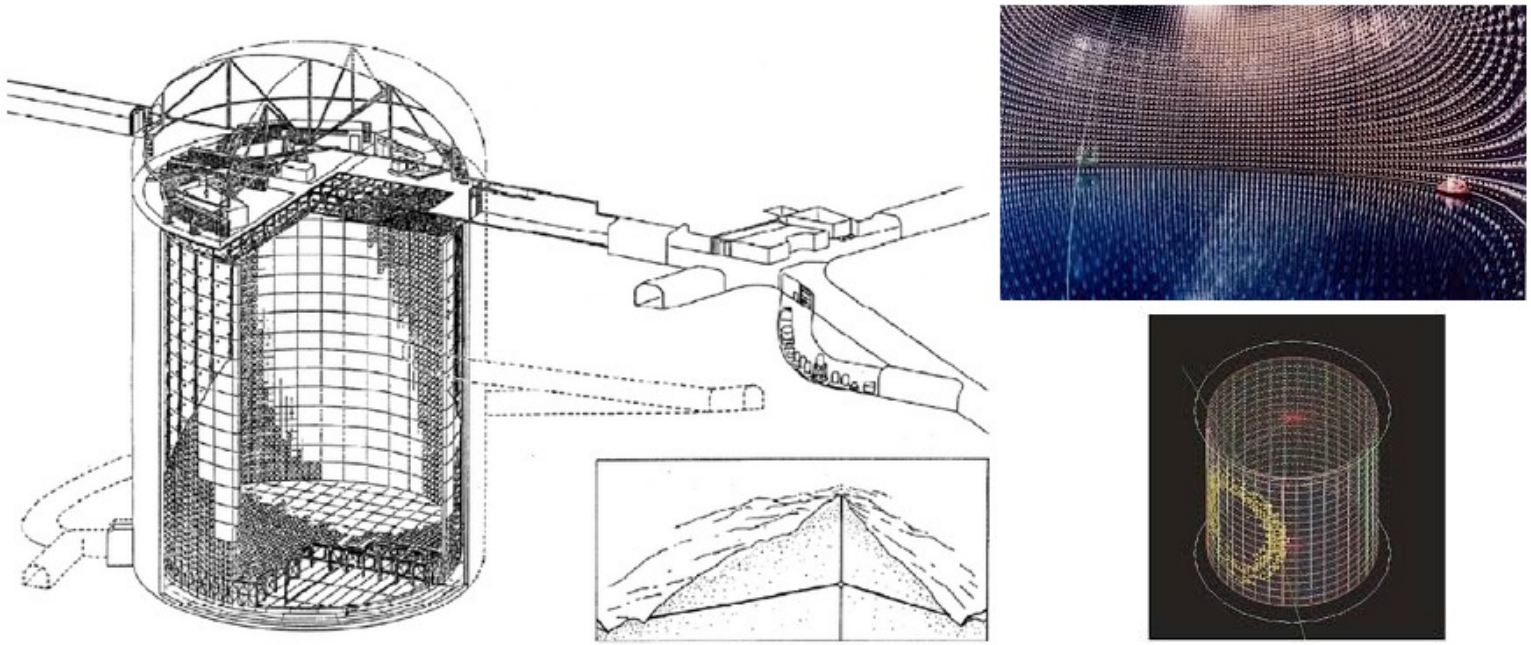


- Interactions of neutrino with nuclear matter



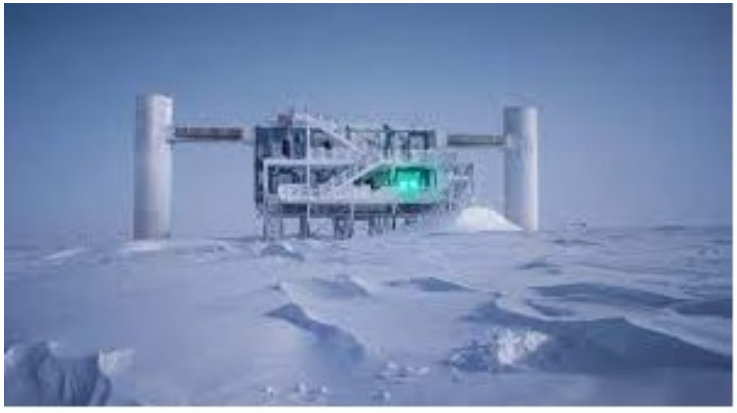


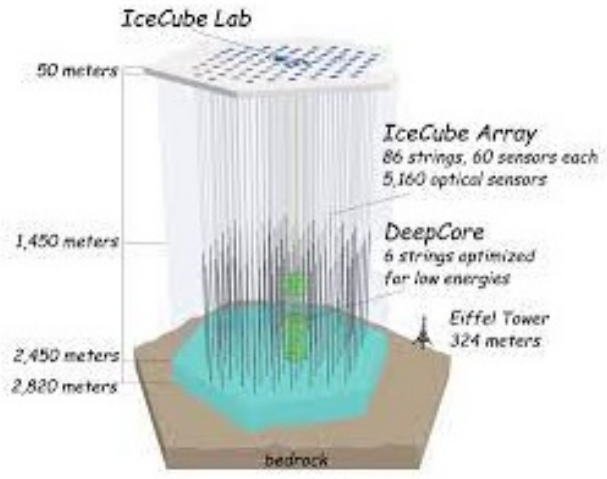
- Neutrino experiments
  - Kamiokande (Japan): $\nu_e + e \rightarrow \nu_e + e$, with water detector + cherenkov radiation detection

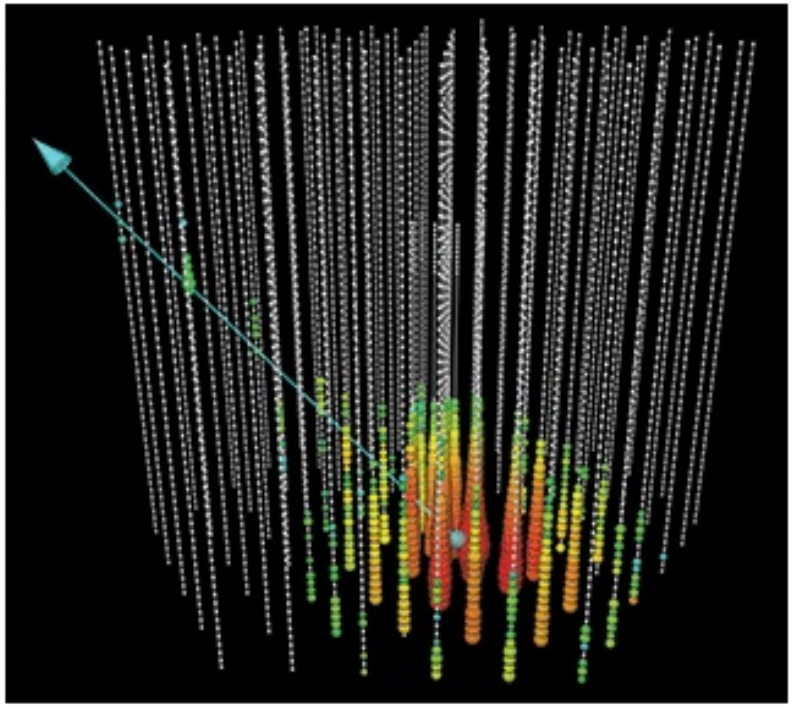


  - Today it was developed to be super-kamiokande and hyper-kamiokande

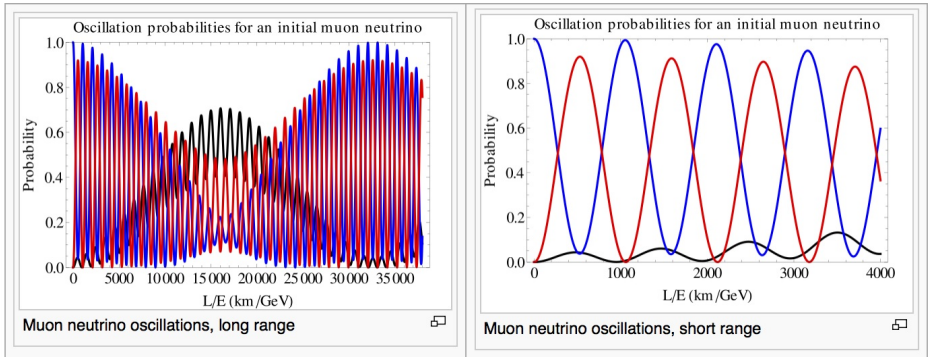
- Neutrino experiments
  - IceCube (International): $\nu + N \rightarrow \nu + X$, with Ice detector + Cherenkov radiation detection







- Neutrinos oscillation



- Neutrio masses and their oscillation

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta_{CP}}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Global fit – Normal hierarchy

$\Delta m^2_{21} = 7.50^{+0.19}_{-0.17} \times 10^{-5}\text{eV}^2$

$\Delta m^2_{31} = 2.457^{+0.047}_{-0.047} \times 10^{-3}\text{eV}^2$

$\theta_{12} = 33.48^{+0.78}_{-0.75}(^\circ)$

$\theta_{23} = 42.3^{+3.0}_{-1.6}(^\circ)$

$\theta_{13} = 8.50^{+0.20}_{-0.21}(^\circ)$

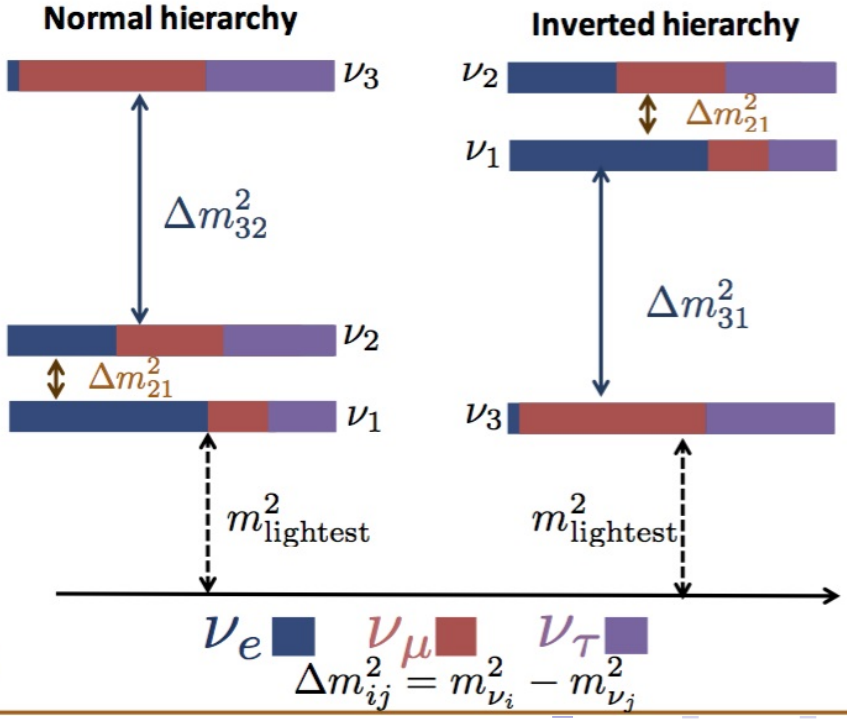
$\text{sign}(\Delta m^2_{32}) = ?$

θ_{23} is maximal ?

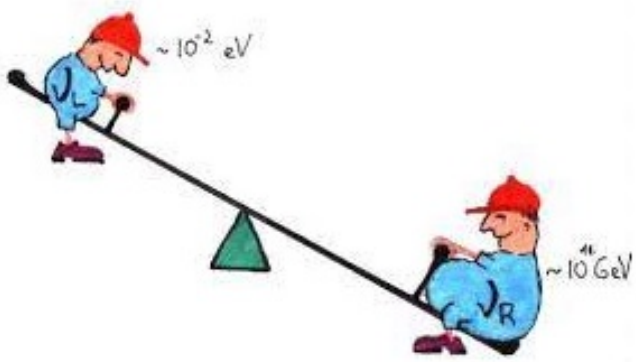
$\delta_{CP} = ?$

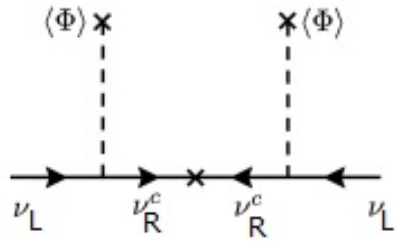
$m_{\text{lightest}} = ?$

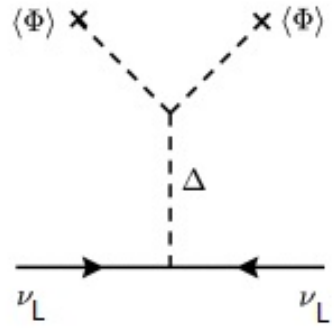
Gonzalez-Garcia *et al.*, arXiv:1512.06856



- Neutrino mass generation by see-saw model







- Do neutrinos be Dirac or Majorana particles