Vanishing effective mass of the neutrino-less double beta decay including light sterile neutrinos

Yu-Feng Li
(Institute of High Energy Physics, Beijing, China)

Based on arXiv:1110.5795 (hep-ph)

@Seoul, 2011-11-14

Contents

(1) Motivations

(2) Cancellation in the standard 3-neutrino mixing scenario

(3) Cancellation in the presence of light sterile neutrinos

(4) Conclusions

Motivations (1)

- The Dirac or Majorana nature of neutrinos is indistinguish-able in the ν oscillation experiments.

- Neutrino-less double beta decay (0νββ) is considered as the most promising way to probe the nature of neutrinos.

- A positive 0νββ signal will prove the Majorana nature, however, non-observation of the 0νββ indicates

(1) the experimental resolution is not good enough;

(2) neutrinos are Dirac particles;

(3) the effective Majorana mass is vanishing.

We will deal with the third possibility !

Motivations (2)

(1) A vanishing effective mass of the Majorana Neutrinos may happen due to the cancellations among different mass eigenstates.

(2) The possible existence of light (eV) sterile neutrinos is renewed by recent experimental and cosmological analyses .

(3) The cancellation between active and sterile neutrinos requires specific relations of the Majorana phases and neutrino mass patterns.

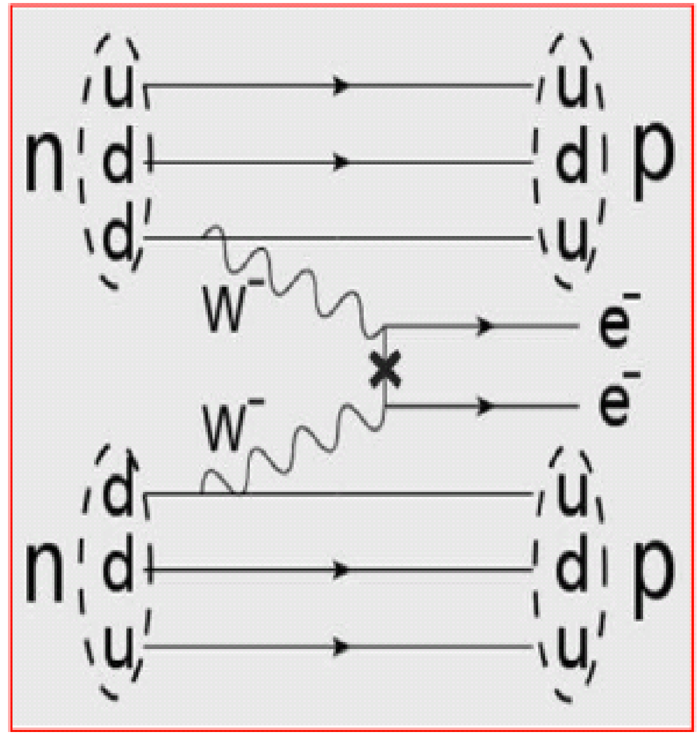
Different Mechanisms of the 0νββ

$$A(Z,N) \rightarrow A(Z+2,N-2)+2e^-$$

➢The standard case: mediated by light active Majorana neutrinos.

$$[T^{0\nu}_{1/2}]^{-1} = G^{\mathcal{N}}_{0\nu}|\mathcal{M}^{\mathcal{N}}_{0\nu}|^2\frac{\langle m\rangle^2_{ee}}{m_e^2}$$

$$\langle m\rangle_{ee} = \left|m_1V_{e1}^2+m_2V_{e2}^2+m_3V_{e3}^2\right|$$



➢The non-standard cases:

(1) mediated by light sterile Majorana neutrinos, which is hinted by SBL neutrino oscillations.

(2) Heavy sterile neutrinos in the different realizations of Seesaw mechanisms.

(3) Other mediators, such as Higgs triplets, Majorons, ……

See recent review, arXiv:1106.1334

Status of Neutrino Oscillations: 3-ν Mixing

- The T2K experiment gave a 2.5-sigma signal of non-zero theta(13).
- MINOS: 1.7 sigma
- Solar+KamLAND 1.5 sigma
- After the T2K and MINOS results, we get a non-zero theta(13) at 3-sigma level in the global analysis.
- Double CHOOZ 1.7-sigma

$\sin^2 2\theta_{13} = 0.085 \pm 0.051$

Consistent with T2K

Parameter	$\delta m^2/10^{-5}$ eV^2	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	$\Delta m^2/10^{-3}$ eV^2
Best fit	7.58	0.306 (0.312)	0.021 (0.025)	0.42	2.35
1σ range	7.32 – 7.80	0.291 – 0.324 (0.296 – 0.329)	0.013 – 0.028 (0.018 – 0.032)	0.39 – 0.50	2.26 – 2.47
2σ range	7.16 – 7.99	0.275 – 0.342 (0.280 – 0.347)	0.008 – 0.036 (0.012 – 0.041)	0.36 – 0.60	2.17 – 2.57
3σ range	6.99 – 8.18	0.259 – 0.359 (0.265 – 0.364)	0.001 – 0.044 (0.005 – 0.050)	0.34 – 0.64	2.06 – 2.67

G.L. Fogli, *et.al.*, 1106.6028

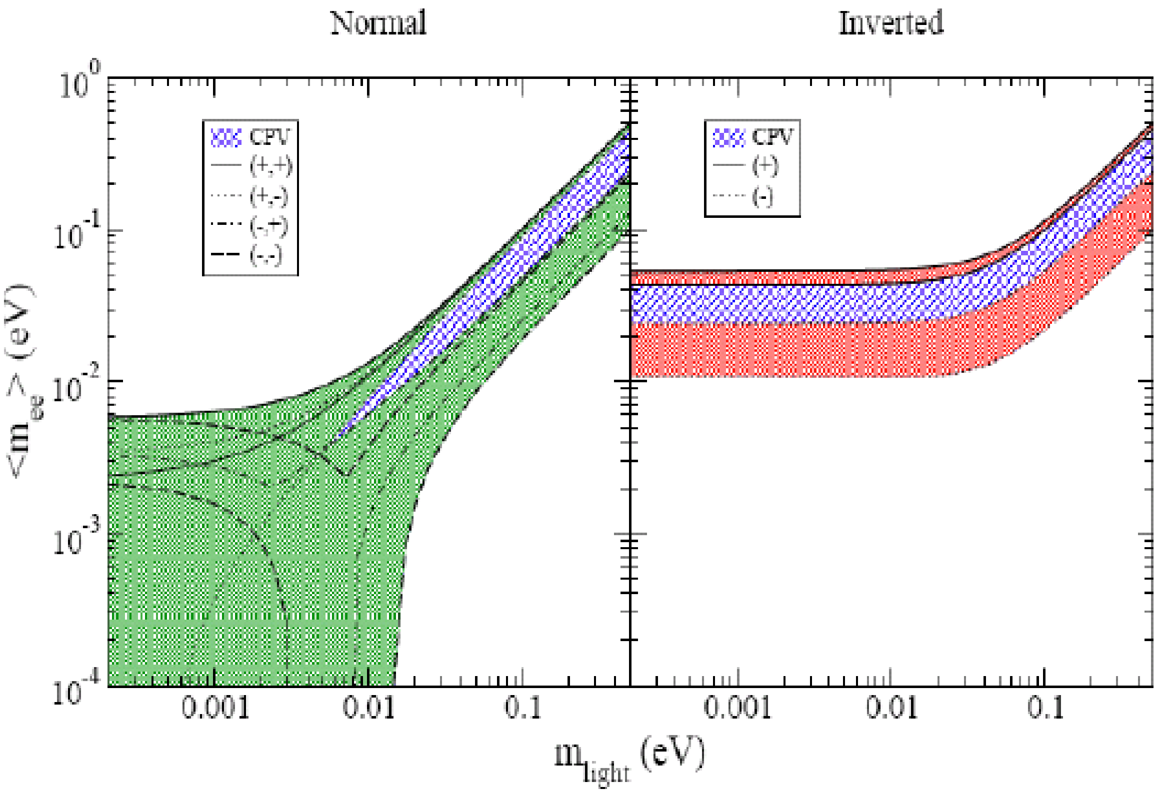
Vanishing Effective mass in the 3-ν Scenario

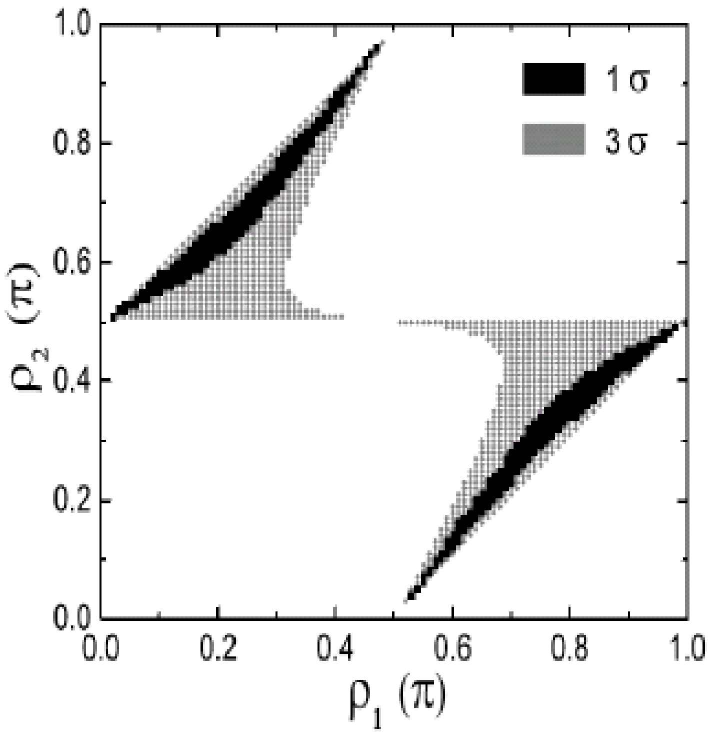
$$\langle m \rangle_{ee} = \left| m_1 |V_{e1}|^2 e^{2i\rho_1} + m_2 |V_{e2}|^2 e^{2i\rho_2} + m_3 |V_{e3}|^2 \right| = 0$$

Z. Z. Xing, hep-Ph/0305195

$$m_1 |V_{e1}|^2 \sin 2\rho_1 + m_2 |V_{e2}|^2 \sin 2\rho_2 = 0 \,,$$
$$m_1 |V_{e1}|^2 \cos 2\rho_1 + m_2 |V_{e2}|^2 \cos 2\rho_2 + m_3 |V_{e3}|^2 = 0$$

Only the NH is allowed.
Lower bound for the IH





In the NH, m_1 should be smaller than 0.02 eV .

Active-Sterile Mixing: the Possible Hints

The **accumulative evidences** of SBL active-sterile oscillations:

(A) The longstanding **LSND anomaly** of antineutrino appearance.

87.9 ± 23.2 (3.8 Sigma), PRD 64 (2001) 112007

(B) The recent **MiniBooNe anomaly** of antineutrino appearance.

43.2 ± 22.5 (1. 9 Sigma), PRL 105 (2010) 181801

(C) The **reactor antineutrino anomaly** of electron antineutrino disappearance after recalculations of the reactor neutrino flux.

$R=0.946 \pm 0.024$ (2.5 Sigma), PRD 83 (2011)073006

(D) The so-called **Gallium anomaly** in the solar neutrino calibration experiments in **SAGE** and **GALLEX**.

$R=0.86 \pm 0.05$ (2.8 Sigma), PRC 83 (2011) 065504

Active-Sterile Mixing: Global Analysis

	Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	Δm^2_{51}	$\lvert U_{e5}\rvert$	$\lvert U_{\mu 5}\rvert$	δ/π	χ^2/dof
3+2	0.47	0.128	0.165	0.87	0.138	0.148	1.64	110.1/130
1+3+1	0.47	0.129	0.154	0.87	0.142	0.163	0.35	106.1/130

Kopp *et.al.*, PRL 107 (2011) 091801

	3+1	3+2
$\chi^2_{\min}$	100.2	91.6
NDF	104	100
GoF	59%	71%
Δm^2_{41} [eV^2]	0.89	0.90
$\lvert U_{e4}\rvert^2$	0.025	0.017
$\lvert U_{\mu 4}\rvert^2$	0.023	0.019
Δm^2_{51} [eV^2]		1.61
$\lvert U_{e5}\rvert^2$		0.017
$\lvert U_{\mu 5}\rvert^2$		0.0061
η		1.51π
$\Delta\chi^2_{\rm PG}$	24.1	22.2
NDF$_{\rm PG}$	2	5
PGoF	6×10^{-6}	5×10^{-4}

Giunti *et.al.*,
PRD 84(2011) 073008

- Although there exist many hints in favor of addtional (sterile) neutrinos, the compatibility among different experiments is still poor.

(1) Appearance-Disappearance tension

(2) Neutrinos-Antineutrinos tension

- The 3+2 scheme with CP violating effects is preferable , but there is still tension between APP and DIS channels.

NO FULLY SATISFACTORY SOLUTION !

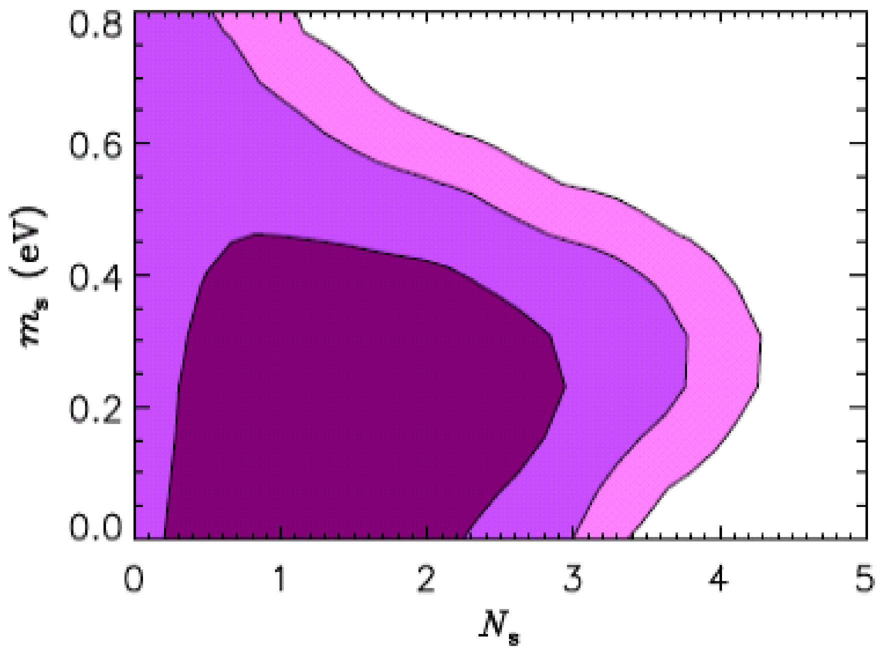
Cosmological Hints and Constraints on Sterile Species

New CMB and LSS measurements imply additional radiation degrees:

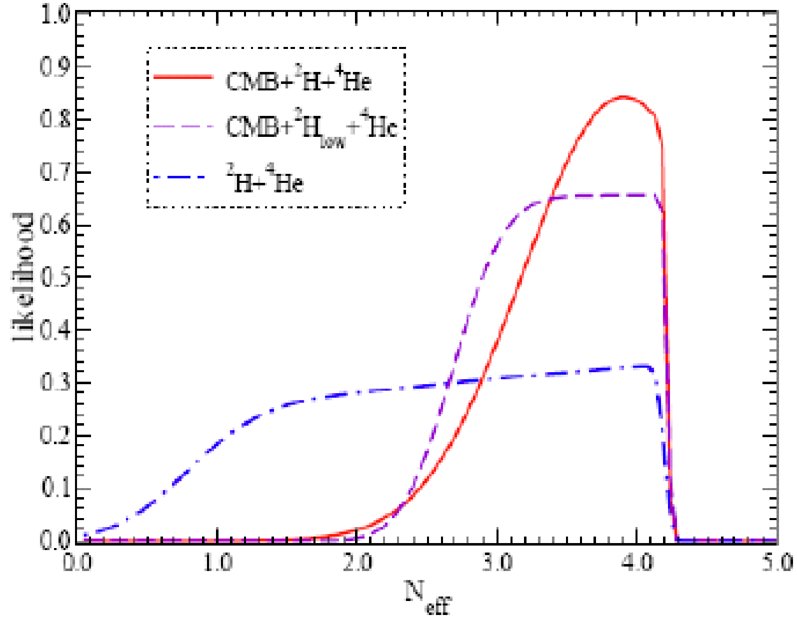
N_s = 1.3 ± 0.9 and m_s < 0.66 eV (95% CL)

BBN Constraint from the primordial He-4 abundance

N_s < 1.2 (95% CL)



Hamann *et al.*, PRL 105 (2010) 181301



Mangano *et al.*, PLB701 (2011) 296

Vanishing Effective Mass in the Presence of Light Sterile Neutrinos

With the additional eV sterile neutrinos, we can re-consider the effects of a vanishing effective Majorana mass.

$$\langle m \rangle_{ee} = \left| m_1 |V_{e1}|^2 e^{2i\rho_1} + m_2 |V_{e2}|^2 e^{2i\rho_2} + m_3 |V_{e3}|^2 + \sum_{j=4}^{3+N_s} m_j |V_{ej}|^2 e^{2i\rho_j} \right|$$

$$m_0 |V_{e0}|^2 e^{2i\rho_0} \equiv \sum_{j=4}^{3+N_s} m_j |V_{ej}|^2 e^{2i\rho_j}$$

$$\begin{aligned} m_0 |V_{e0}|^2 \sin 2\rho_0 + m_1 |V_{e1}|^2 \sin 2\rho_1 + m_2 |V_{e2}|^2 \sin 2\rho_2 &= 0 \\ m_0 |V_{e0}|^2 \cos 2\rho_0 + m_1 |V_{e1}|^2 \cos 2\rho_1 + m_2 |V_{e2}|^2 \cos 2\rho_2 + m_3 |V_{e3}|^2 &= 0 \end{aligned}$$

In the numerical analysis,

- we use the active neutrino parameters from G.L. Fogli, *et.al.*, 1106.6028 and the sterile neutrino parameters from Kopp *et.al.*, 1103.4570;
- we assume the inclusion of sterile neutrinos do not significiant-ly affect the values of active neutrino parameters.

CP Invariance Cases

Conditions for CP invariance:

$$\rho_i = n_i\pi/2 \text{ with } n_i \text{ being arbitrary integers}$$

$$(-1)^{l_0} m_0 |V_{e0}|^2 + (-1)^{l_1} m_1 |V_{e1}|^2 + (-1)^{l_2} m_2 |V_{e2}|^2 + m_3 |V_{e3}|^2 = 0$$

By using the active and sterile neutrino parameters, the mass spectrum of active and sterile neutrinos is fully determined.

For (l_0, l_1, l_2):

(a): (0, 1, 0) and (1, 0, 1) are permitted for both mass hierarchies.

m_1 : 0.08 eV or m_3 : 0.06 eV

(b): (1, 0, 0) and (0, 1, 1) are allowed only for the case of NH.

m_1 : 0.03 eV

(c): All the other possibilities are ruled out.

The Cases with one massless neutrino (1)

NH (m_1=0):

$$\frac{m_2}{m_0} = -\frac{|V_{e0}|^2}{|V_{e2}|^2}\frac{\sin 2\rho_0}{\sin 2\rho_2}\,, \qquad \frac{m_3}{m_0} = +\frac{|V_{e0}|^2}{|V_{e3}|^2}\frac{\sin\left(2\rho_0 - 2\rho_2\right)}{\sin 2\rho_2}$$

IH(m_3=0) :

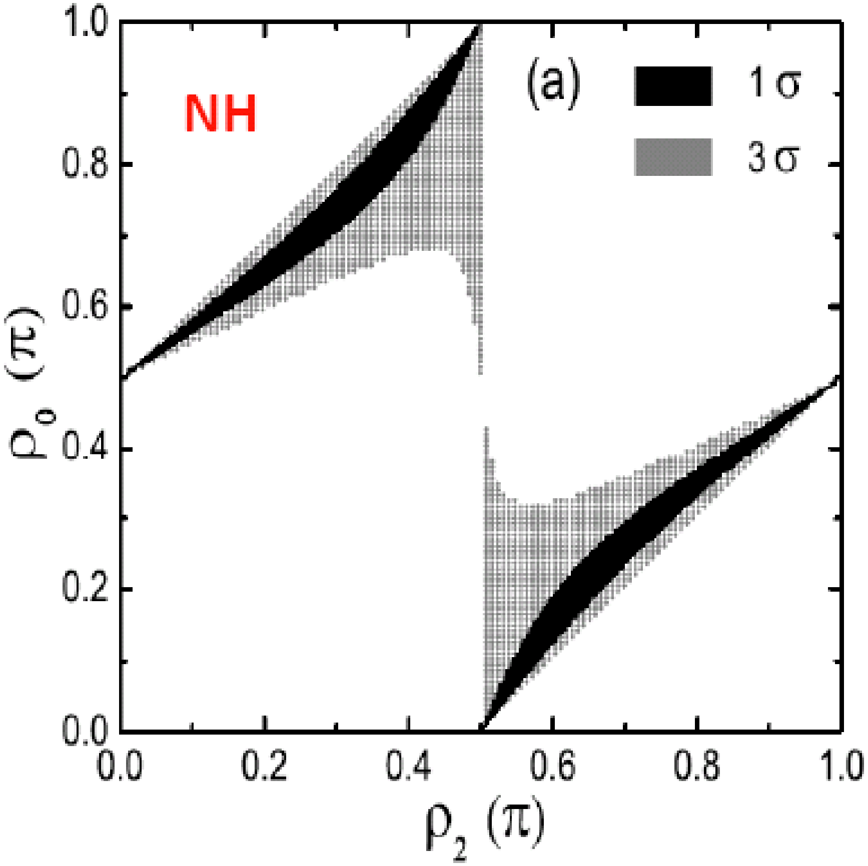
$$\frac{m_2}{m_0} = -\frac{|V_{e0}|^2}{|V_{e2}|^2}\frac{\sin\left(2\rho_0 - 2\rho_1\right)}{\sin\left(2\rho_2 - 2\rho_1\right)}\,, \qquad \frac{m_1}{m_0} = +\frac{|V_{e0}|^2}{|V_{e1}|^2}\frac{\sin\left(2\rho_0 - 2\rho_2\right)}{\sin\left(2\rho_2 - 2\rho_1\right)}$$

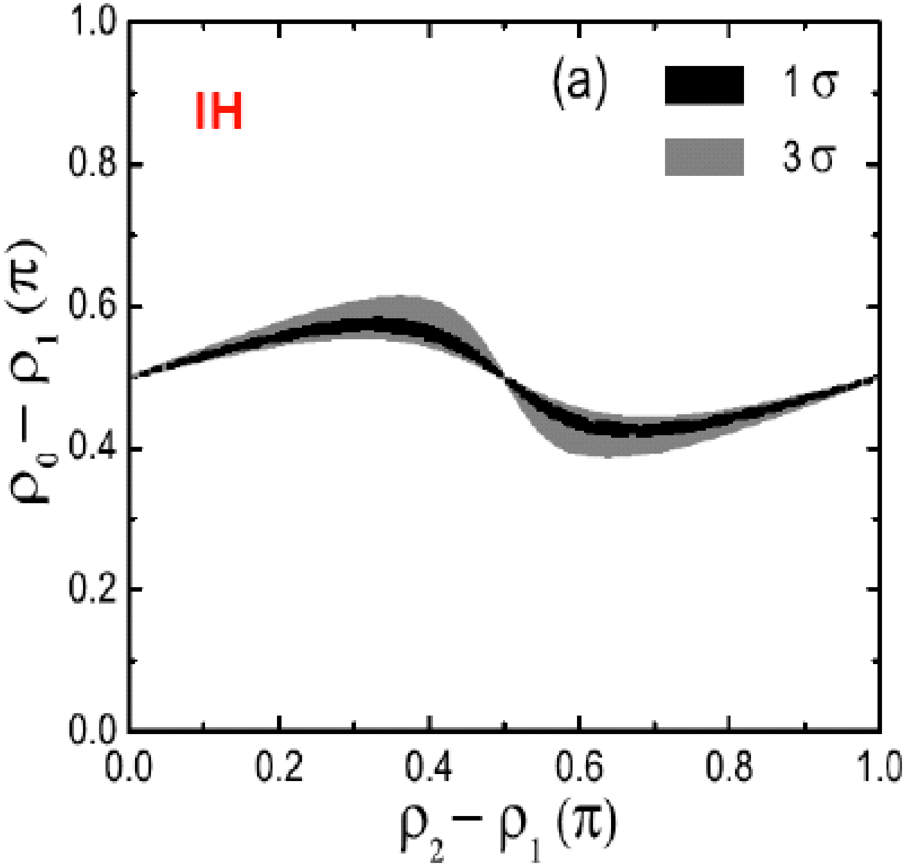
All the neutrino masses are fixed if the smallest one is zero.

After getting rid of (m_0, |V_e0|), we can derive correlations of the Majorana phases.

We can obtain the regions of (m_0, |V_e0|) both from the active neutrino results and from the sterile neutrino parameters.

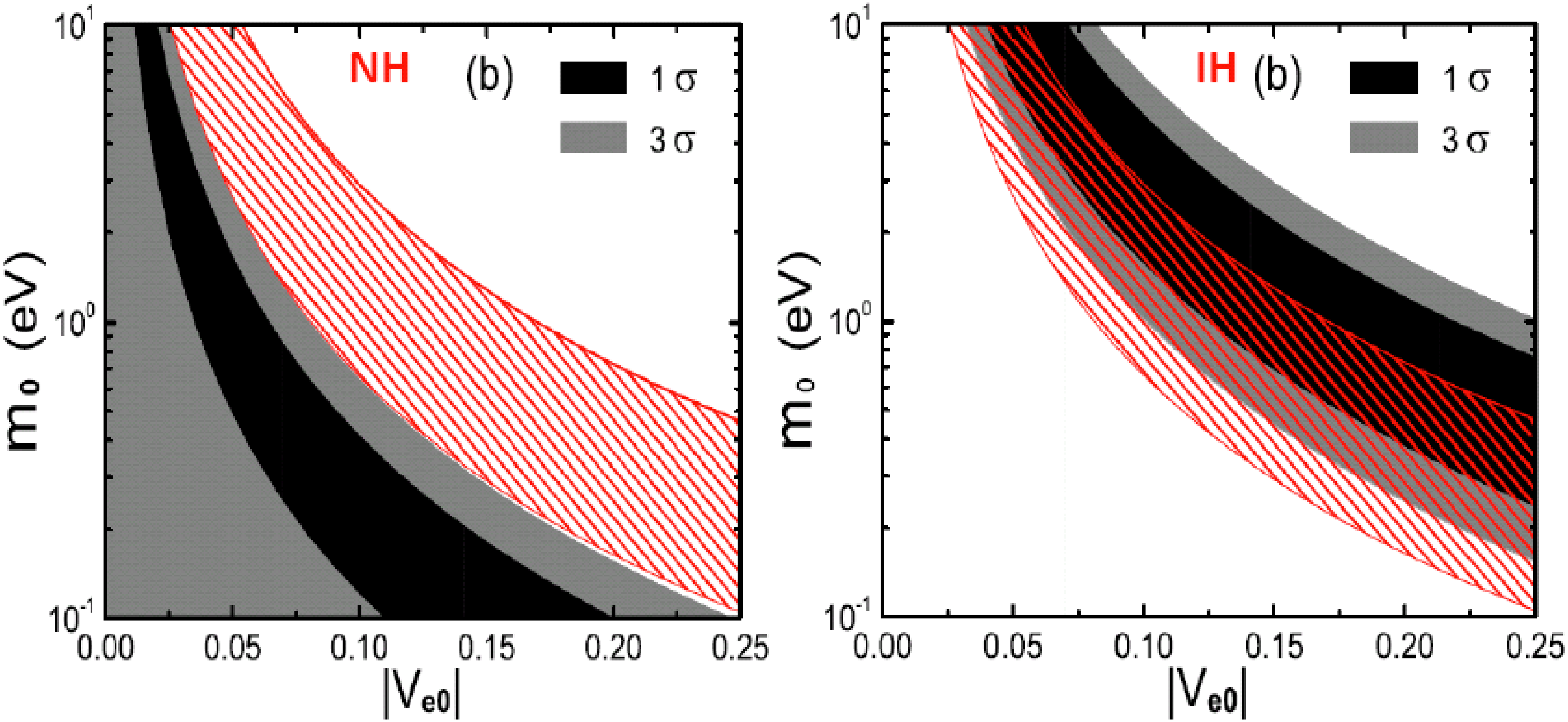
The Cases with one Massless Neutrino (2)-the Phases





(a): rho_3=0 for convention (b): the area is related to the uncertainty of V_e3. (c): the allowed region is invariant under (X_i →pi - X_i).

The Cases with one massless neutrino (3)-the mass patterns



(a): for NH, there is no overlap between active and sterile constraints.

(b): for IH, active and sterile constraints overlap within 1-sigma.

(c): the IH case is favored over the NH case.

The Generic Case (1)

When the neutrino mass scale changes, we have these two relations:

$$m_0^2|V_{e0}|^4 = m_1^2|V_{e1}|^4 + m_2^2|V_{e2}|^4 + m_3^2|V_{e3}|^4 + 2m_1m_2|V_{e1}|^2|V_{e2}|^2\cos(2\rho_1 - 2\rho_2)$$
$$+2m_1m_3|V_{e1}|^2|V_{e3}|^2\cos 2\rho_1 + 2m_2m_3|V_{e2}|^2|V_{e3}|^2\cos 2\rho_2 \,,$$

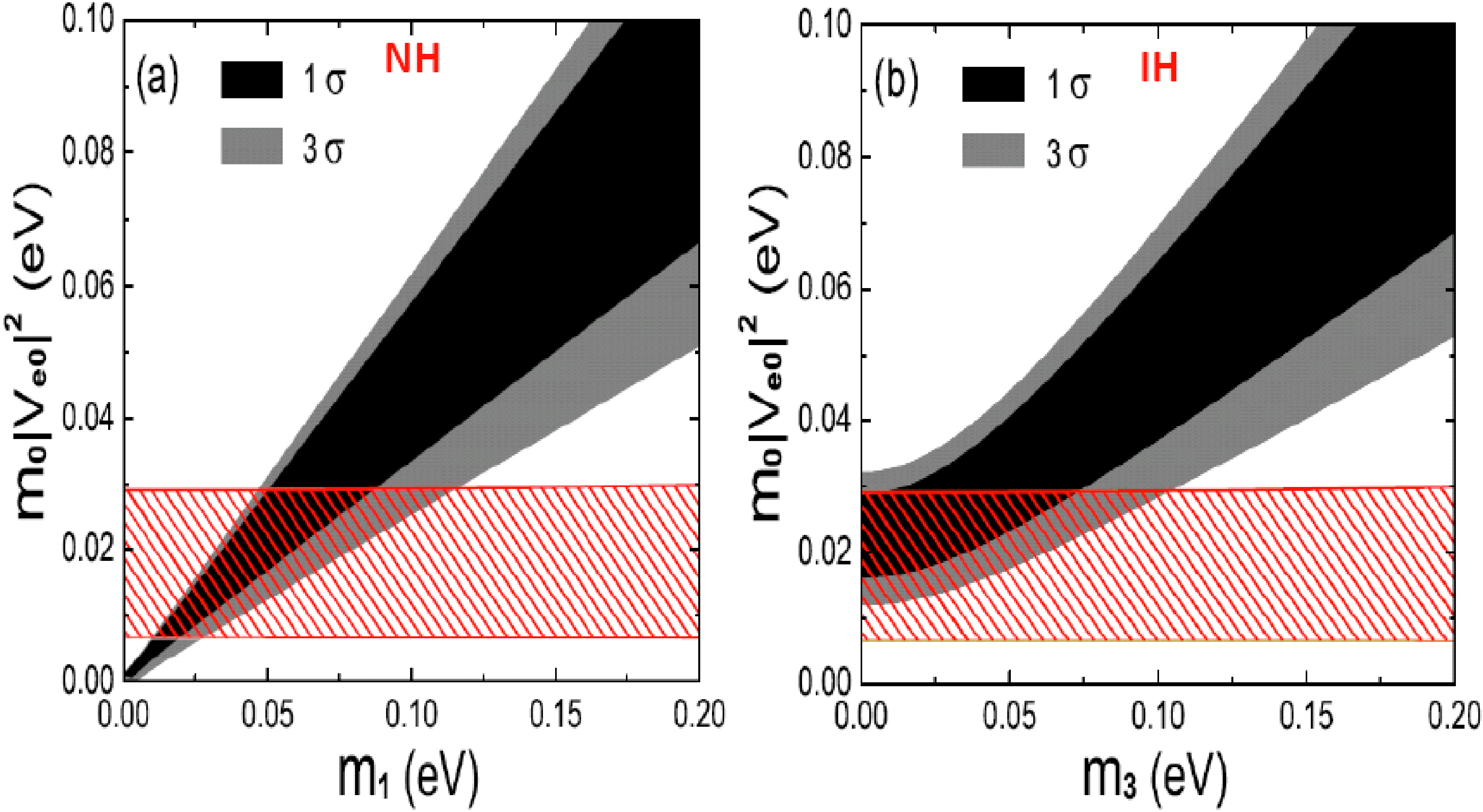
$$\tan 2\rho_0 = \frac{m_1|V_{e1}|^2\sin 2\rho_1 + m_2|V_{e2}|^2\sin 2\rho_2}{m_1|V_{e1}|^2\cos 2\rho_1 + m_2|V_{e2}|^2\cos 2\rho_2 + m_3|V_{e3}|^2}$$

(a) From the concellation conditions, we can constrain the sterile contribution of the effective mass (m_0|V_e0|^2) from active or sterile parameters.

(b) The overlaps give the allowed regions.

(c) Numerically, the parameter rho_0 is unconstrained.

The Generic Case (2)



$0.009\ \mathrm{eV} \lesssim m_1 \lesssim 0.116\ \mathrm{eV}$ $\quad$ $0 \lesssim m_3 \lesssim 0.106\ \mathrm{eV}$

$0.006\ \mathrm{eV} \lesssim m_0|V_{e0}|^2 \lesssim 0.029\ \mathrm{eV}$ $\quad$ $0.012\ \mathrm{eV} \lesssim m_0|V_{e0}|^2 \lesssim 0.029\ \mathrm{eV}$

Discussions

➢Our discussions assumed that the light Majorana neutrinos dominate in the 0νββ process. However, the 0νββ-rates may not be zero even if <m>_ee is vanishing. arXiv:1106.1334

(1) Radiative corrections: in the type I seesaw mechanism, threshold corrections can generate a non-zero <m>_ee even if it is zero in the light effective mass matrix.

(2) Other LNV mediators may contribute to the 0νββ process.

(3) The flavor-blind Planck scale term may give a v^2/M_pl level correction to <m>_ee.

(4)……

Conclusions

- A vanishing effective Majorana mass of the 0νββ process is permitted by current active and sterile oscillation data.

- In the CP Invariance cases, only some specific CP parities are allowed.

- When the smallest neutrino mass being zero, the IH is favored over the NH case. This possibility is rather different from 3-neutrino mixing scenario.

- In general, both mass hierachies of active neutrinos are allowed.

$0.009\ \mathrm{eV} \lesssim m_1 \lesssim 0.116\ \mathrm{eV}$ $\qquad$ $0 \lesssim m_3 \lesssim 0.106\ \mathrm{eV}$

Thanks