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arXiv:1604.03315[hep-ph]

The Sign of Universe's Baryon Asymmetry and Neutrino Mass Matrix

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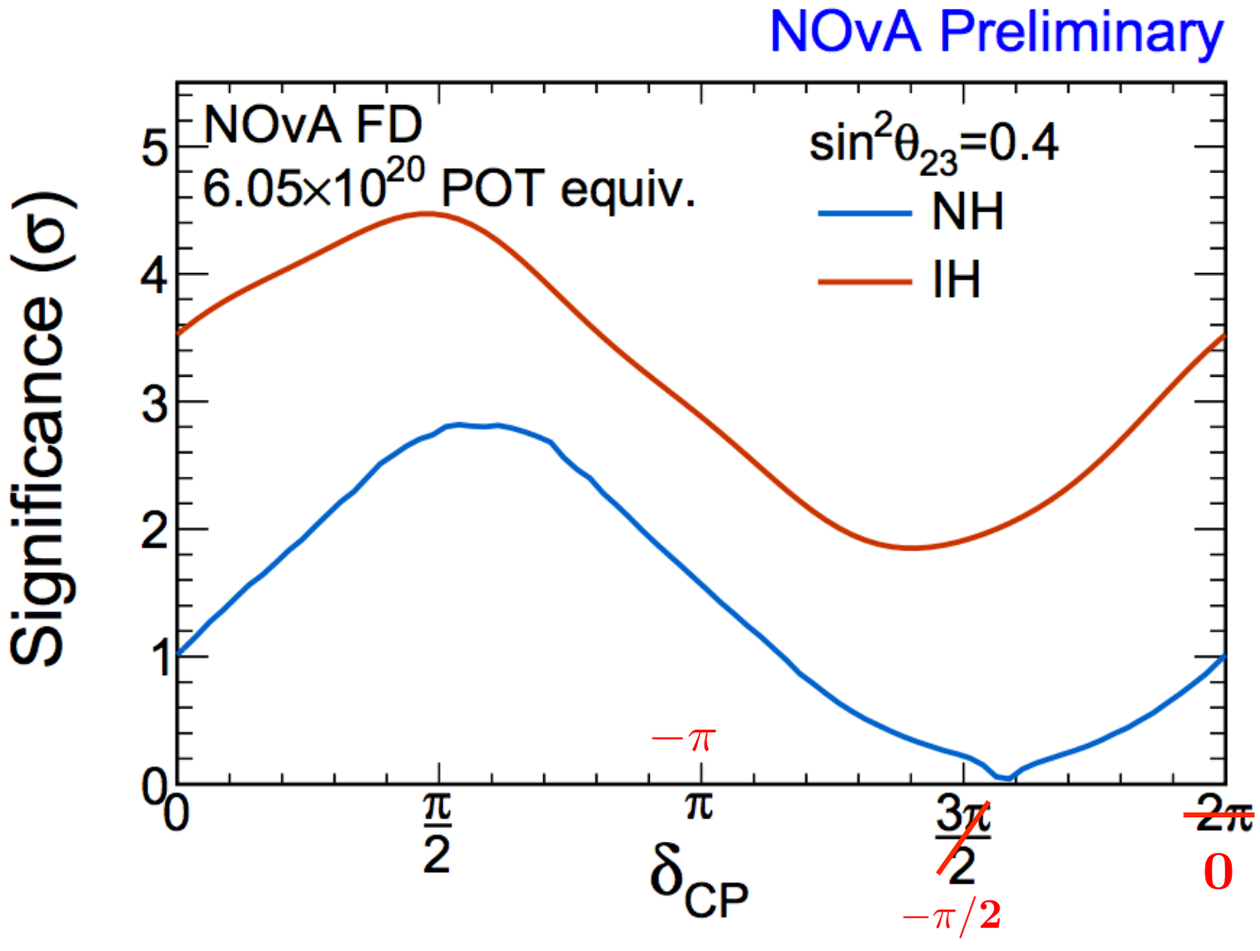
INTRODUCTION

δ_{CP} is defined in PDG.

- The Lepton CP Phase δ_{CP} has begun to be observed!!

NOvA



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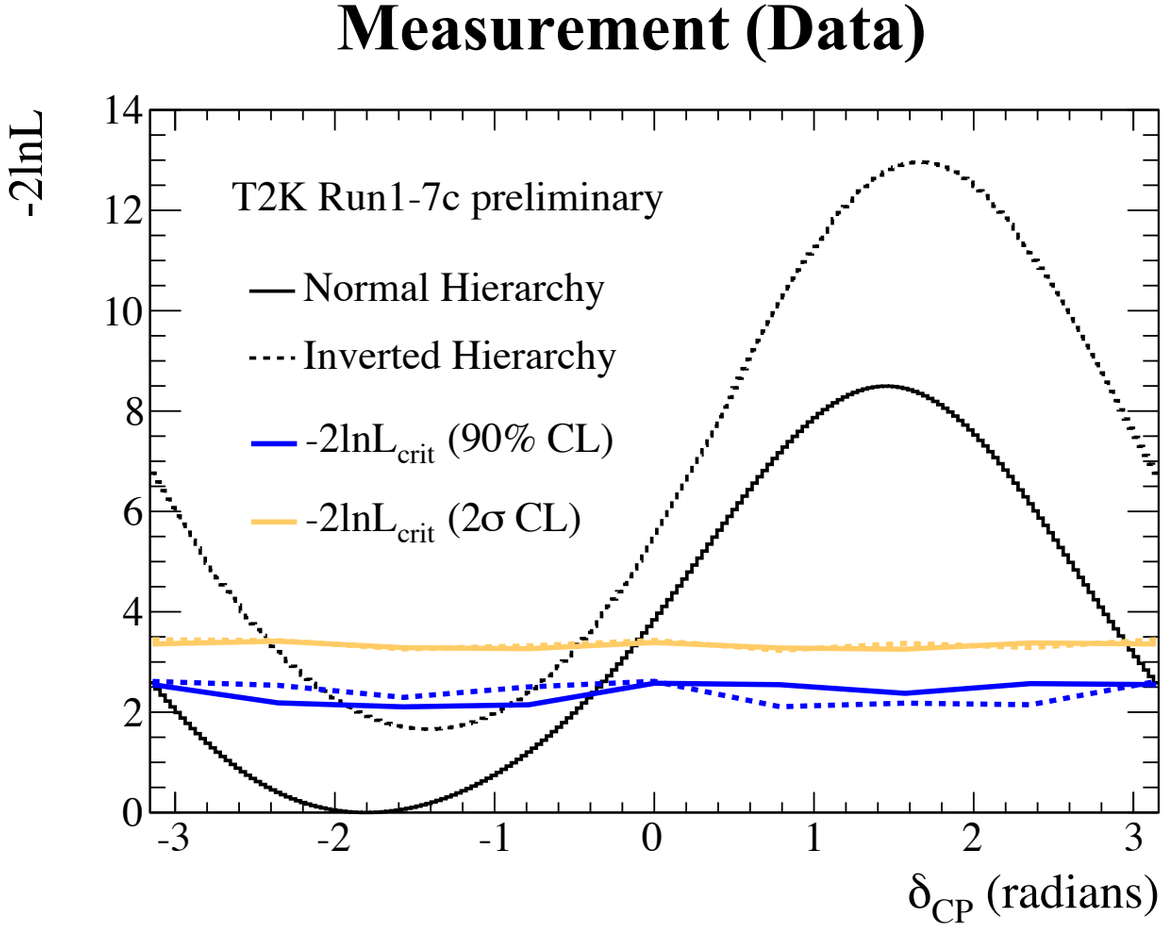

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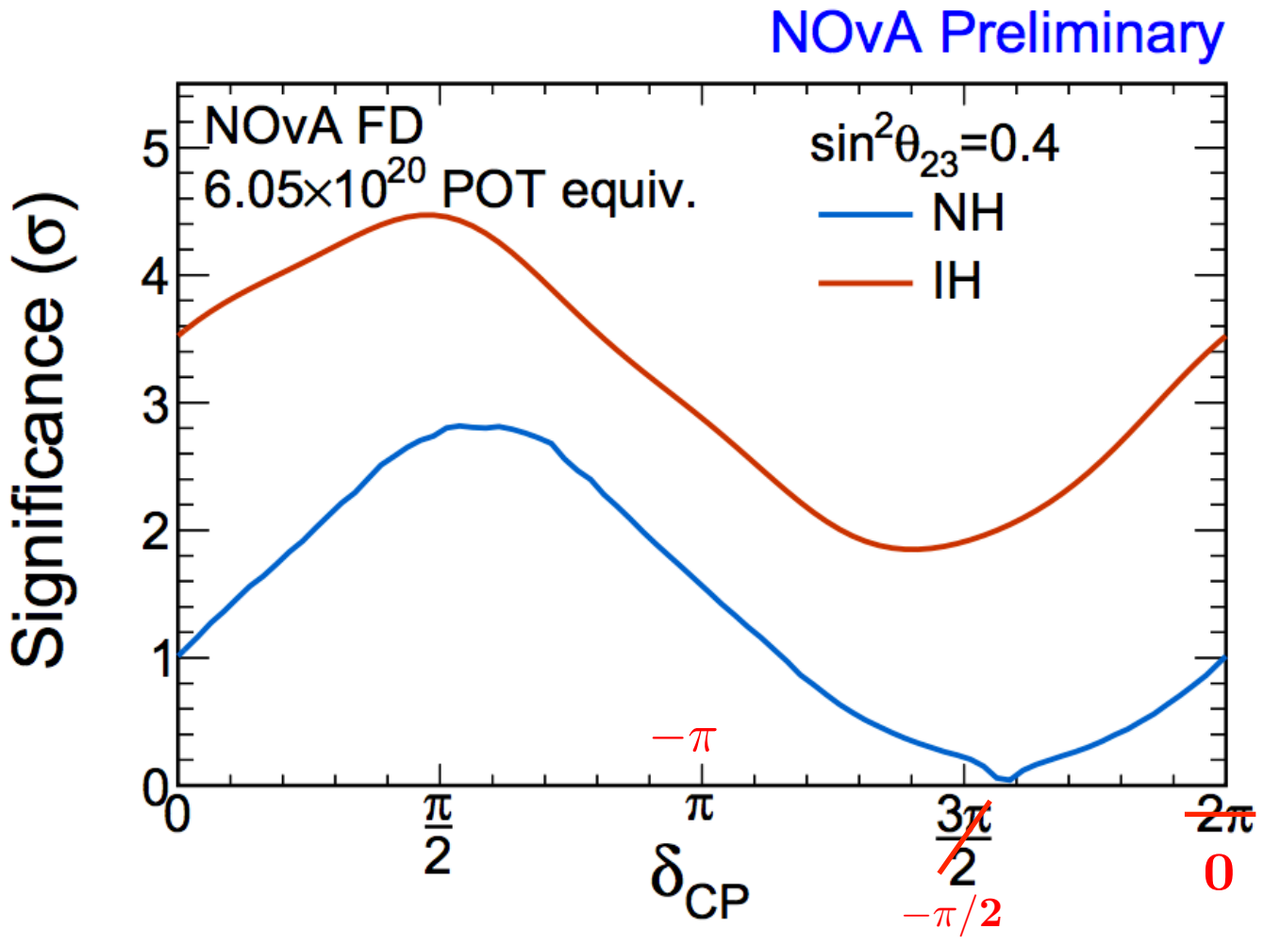
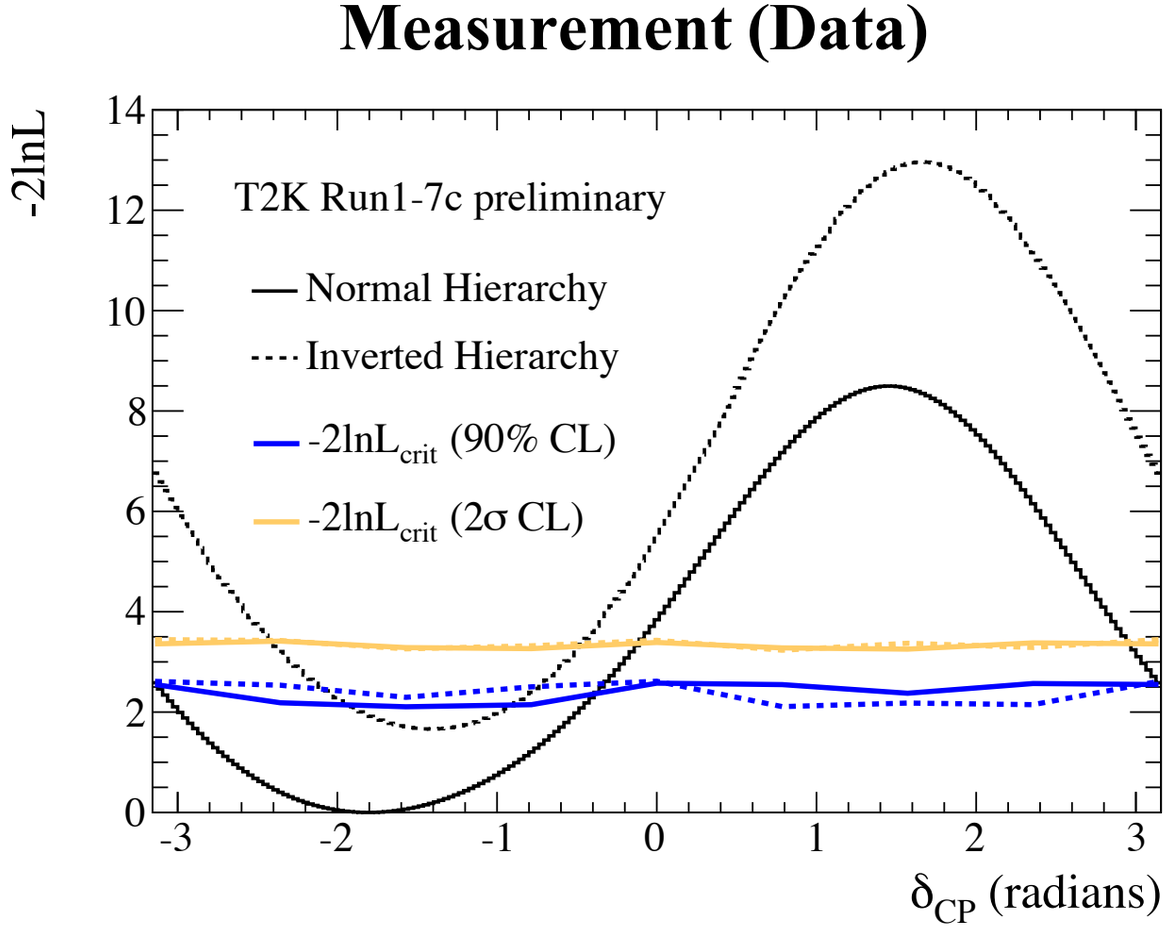
INTRODUCTION

δ_{CP} is defined in PDG.

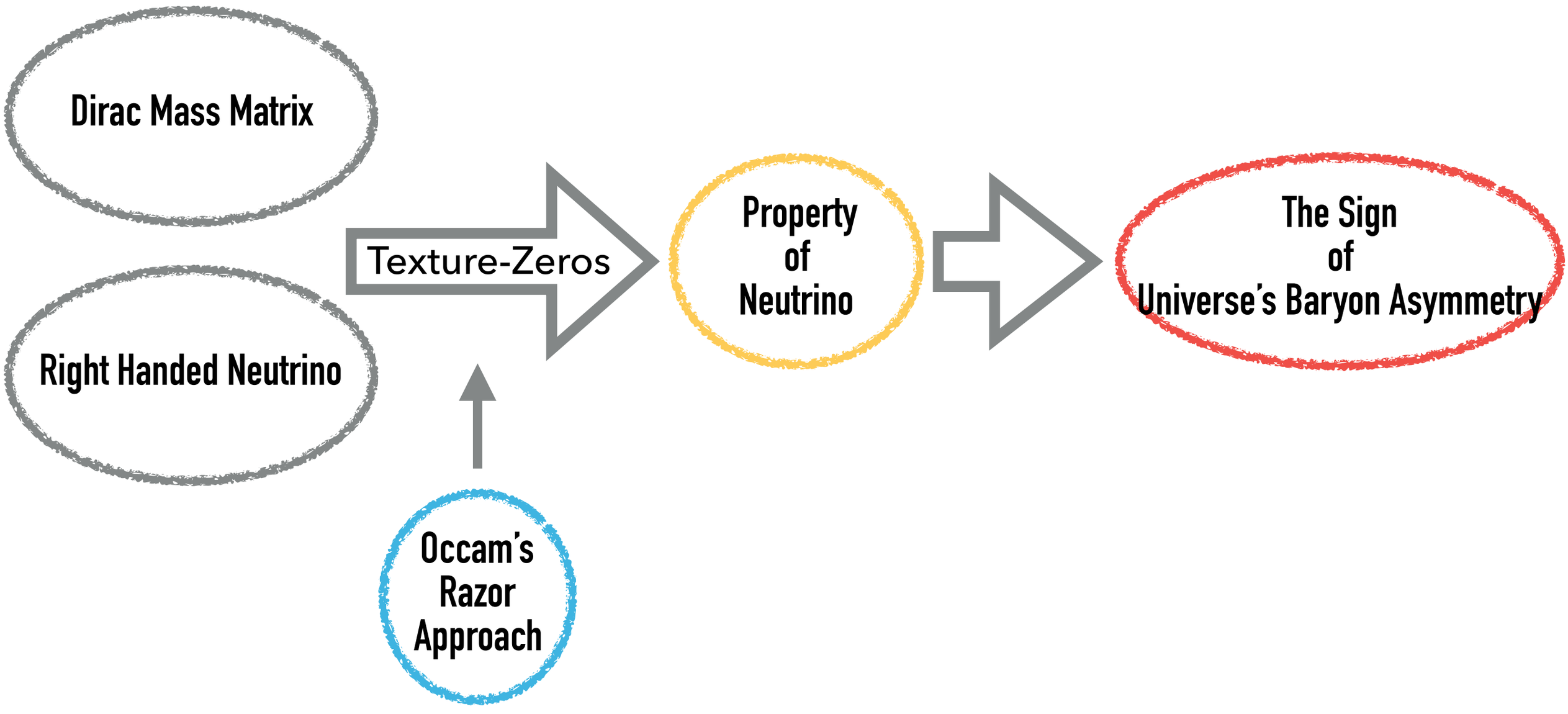




- $\delta_{CP} \sim -\pi/2$ **?**
- **Normal hierarchy of neutrino masses is favored ?**

We aim to explain these property by a few parameters.
We consider mass matrix texture !!

INTRODUCTION



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The Occam's Razor Approach

See-Saw Mechanism & The Texture Zeros

We introduce Right Handed Neutrino to SM.

$$\overline{l_L} m_D N + \frac{1}{2} \overline{N^C} M_R N + h.c.$$

Neutrino Mass Matrix

$$M = \begin{pmatrix} 0 & m_D \\ m_D^T & M_R \end{pmatrix} \xrightarrow{\text{diagonalization}} \begin{pmatrix} m_\nu & 0 \\ 0 & M_I \end{pmatrix}$$

It relates to active neutrino mass $m_\nu = -m_D M_R^{-1} m_D^T$

It explains small active neutrino mass $m_\nu \quad (m_D \ll M_R)$

SEE-SAW MECHANISM

['77 P. Minkowski; '79 T. Yanagida; '79 Gell-Mann, Ramond, Slansky]

We consider *Texture Zero* for m_D **(in diagonal base** M_R **).**

The Occam's Razor Approach

K. Harigaya, M. Ibe, T. T. Yanagida
Phys. Rev. D 86, 013002

Lepton mass term : $\overline{l_L} M_E e_R + \overline{l_L} m_D N + \frac{1}{2}\overline{N^C} M_R N + h.c.$

1. **Diagonal base** $M_E \quad M_R$
2. **Impose Zeros to components of** m_D **.**

5 physical values are observed by experiments

$\Delta m^2_{\rm sol} \quad \Delta m^2_{\rm atm} \quad \theta_{12} \quad \theta_{23} \quad \theta_{13}$

NOW

Prune parameters in neutrino sector to be #5.

They discussed two generations of M_R (m_D is 3×2 matrix)

OCCAM'S RAZOR

RESULTS

They predicted the δ_{CP}
and discovered that hierarchy of neutrino is IH only.

We aim to find the NH case !!

The Occam's Razor Approach

YK, Y. Shimizu, M. Tanimoto, T. T. Yanagida
[arXiv:1604.03315]

Lepton mass term : $\overline{l_L} M_E e_R + \overline{l_L} m_D N + \frac{1}{2} \overline{N^C} M_R N + h.c.$

We discuss three generations of M_R

1. **Diagonal base** $M_E \ M_R$ **(m_D and M_R are 3×3 matrices)**
   Add 1 complex parameter (2 real parameters).
   Total number of parameters is 7 now.

Experiments will observe 7 physical values

$\Delta m^2_{\rm sol}$ $\Delta m^2_{\rm atm}$ θ_{12} θ_{23} θ_{13} δ_{CP} m_{ee}

In the Future

2. **Impose Zeros to components of** m_D **.**
   Four-Zeros Dirac mass matrix
   is the maximal number of zeros.

(Our set up) Occam's Razor

We can predict baryon asymmetry!

δ_{CP} - φ_A , φ_B

YK, Y. Shimizu, M. Tanimoto, T. T. Yanagida
[arXiv:1604.03315]

Lepton mass term : $\overline{l_L} M_E e_R + \overline{l_L} m_D N + \frac{1}{2}\overline{N^C} M_R N + h.c.$

For example,

So called Fritzsch type mass matrix

$$m_D = \begin{pmatrix} 0 & ae^{i\phi_B/2} & 0 \\ ae^{i\phi_A/2} & 0 & b \\ 0 & be^{i\phi_B/2} & c \end{pmatrix} \qquad M_R = M_0 \begin{pmatrix} \frac{1}{K_1} & 0 & 0 \\ 0 & \frac{1}{K_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

See-Saw mechanism

$$m_\nu = \frac{1}{M_0} \begin{pmatrix} a^2 K_2 e^{i\phi_B} & 0 & abK_2 e^{i\phi_B} \\ 0 & a^2 K_1 e^{i\phi_A} + b^2 & bc \\ abK_2 e^{i\phi_B} & bc & b^2 K_2 e^{i\phi_B} + c^2 \end{pmatrix}$$

These matrices give Jarlskog invariant and δ_{CP}

$$J_{\rm CP} \simeq \frac{a^4 b^4 c^2 K_1 K_2^3 \{a^2 \sin(\phi_A - \phi_B) + b^2 \sin(\phi_A + \phi_B)\}}{(\Delta m^2_{\rm atm})^2 \Delta m^2_{\rm sol}}$$

$$\sin\delta_{\rm CP} = J_{\rm CP}/(s_{23}c_{23}s_{12}c_{12}s_{13}c^2_{13})$$

φ_A , φ_B relate to δ_{CP} .

Leptogenesis

M. Fukugita, T. Yanagida, *Phys. Lett. B* 174(1986) 45.

$$\epsilon = \frac{\Gamma(N_1 \to l\phi) - \Gamma(N_1 \to \bar{l}\bar{\phi})}{\Gamma(N_1 \to l\phi) + \Gamma(N_1 \to \bar{l}\bar{\phi})}$$

$$= -\frac{1}{8\pi}\frac{1}{v^2}\frac{1}{(m_D^\dagger m_D)_{11}}\sum_i \mathrm{Im}\left[\left\{(m_D^\dagger m_D)_{i1}\right\}^2\right] f(\frac{M_i^2}{M_1^2})$$

For example,

$$m_D = \begin{pmatrix} 0 & ae^{i\phi_B/2} & 0 \\ ae^{i\phi_A/2} & 0 & b \\ 0 & be^{i\phi_B/2} & c \end{pmatrix} \qquad m_D^\dagger m_D = \begin{pmatrix} a^2 & * & * \\ 0 & * & * \\ abe^{i\phi_A/2} & * & * \end{pmatrix}$$

$$\approx -\frac{1}{8\pi}\frac{1}{v^2} b^2 \frac{M_3}{M_1} \sin\phi_A$$

Lepton number violation transfers baryon number violation by Sphaleron process.

$$Y_B = -\frac{28}{79} Y_L \propto -\epsilon \qquad \left(Y_B \equiv \frac{n_B - n_{\bar{B}}}{s}\right)$$

The Sign of Universe's Baryon Asymmetry

YK, Y. Shimizu, M. Tanimoto, T. T. Yanagida
[arXiv:1604.03315]

We introduced 7 physical parameters.
If 7 physical values are exactly determined,
there are no degree of freedom in the matrix!!

$$\Delta m^2_{\rm sol}\ \Delta m^2_{\rm atm}\ \theta_{12}\ \ \theta_{23}\,\theta_{13}\ \ \delta_{CP}\ m_{ee}$$

$$\left.\begin{aligned} Y_B &= -\frac{28}{79} Y_L \propto -\epsilon \\ \epsilon &\approx -\frac{1}{8\pi}\frac{1}{v^2} b^2 \frac{M_3}{M_1} \sin\phi_{\rm A} \end{aligned}\right\} \Rightarrow\ Y_B \propto \sin\phi_A$$

In Fritzsch type mass matrix

"Why is baryon selected by universe, is not anti-baryon?"

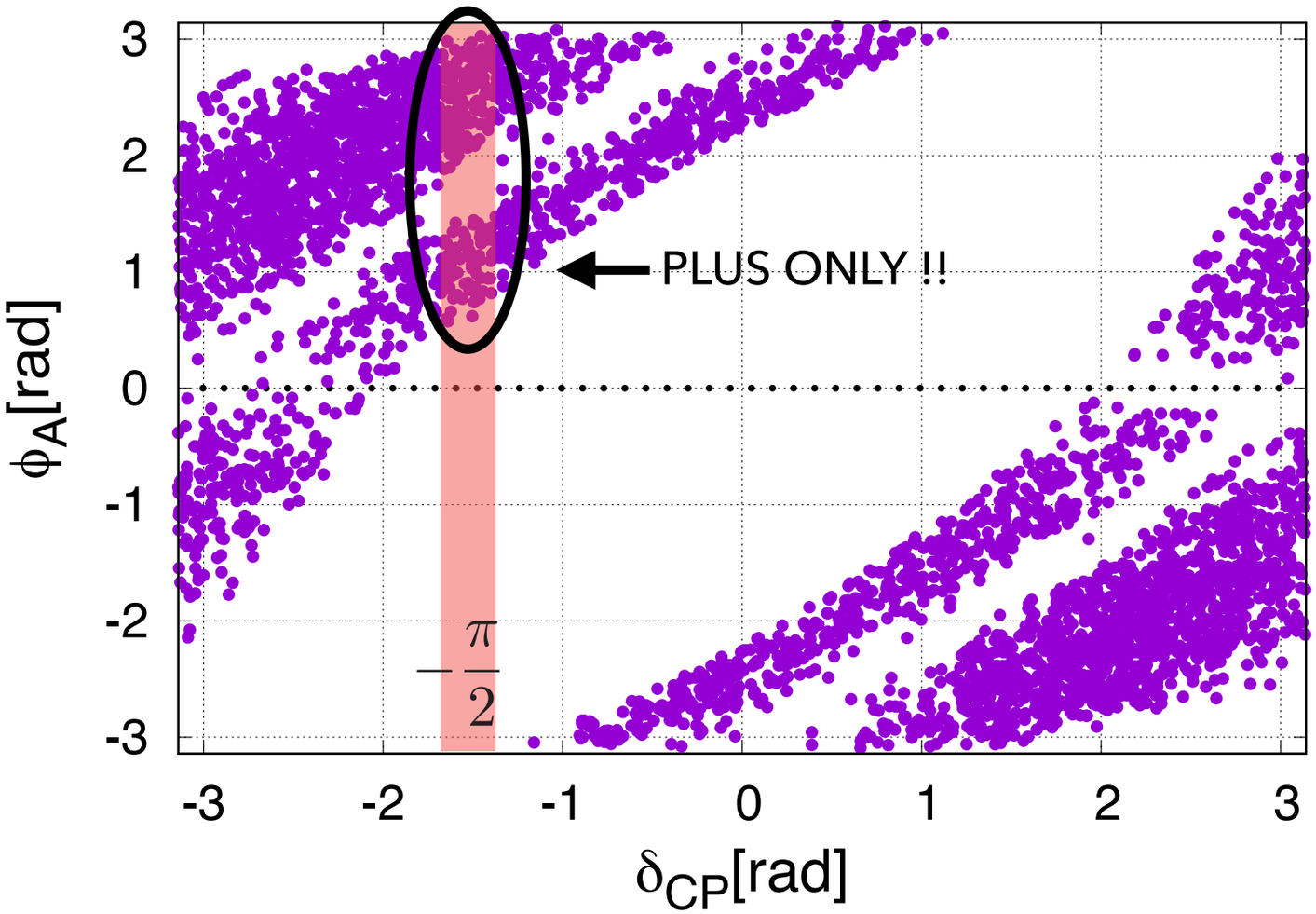
We can determine the sign of baryon asymmetry!!!

Numerical Analysis

The Sign of Universe's Baryon Asymmetry

$$m_D = \begin{pmatrix} 0 & a_2 e^{i\phi_B/2} & a_3 \\ b_1 e^{i\phi_A/2} & 0 & 0 \\ c_1 e^{i\phi_A/2} & 0 & c_3 \end{pmatrix}_{LR}$$

$$Y_B \propto +\sin\phi_A$$



constraint by

$(\Delta m^2_{\rm sol},\ \Delta m^2_{\rm atm},\ \theta_{12},\ \theta_{23},\ \theta_{13})$

in 90% C.L.

If $\delta_{\rm CP}$ will be fixed close to $-\pi/2$,

The matrix is candidate of determining the sign of Universe's Baryon Asymmetry!!

Summary

Summary

- ``Occam's Razor Approach" imposes zeros in the mass matrix elements.

  We succeed to find the texture with NH by using Occam's Razor Approach.

  - By introducing 3 Right-handed neutrinos to get NH,
    we have found Four-Zeros mass matrices for m_D,
    which are consistent with observed neutrino masses and mixing angles.

- We have shown a possibility of answering the question that "Why is baryon selected by universe, is not anti-baryon?"

We will be able to determine the sign of universe's baryon asymmetry by inputting δ_{CP}.