Sensitivity of CP Majorana phases using the synergy between cosmological and neutrinoless double beta decay data at high precision era of measures

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Abstract

We study the detectability of Majorana phase of neutrinos through the precision data of the sum of neutrino masses by cosmological observations, lifetime of neutrinoless double beta decay in ton-scale experiments and the effective neutrino mass measured from single beta decay experiments. We found there is a synergy when data of the three experiments is combined, this allow to constraint one of the Majorana phase (α_{21}) by excluding $10-40\%$ the phase space at the 2σ level of confidence for the lowest neutrino mass of 0.1 eV.

INTRODUCTION

In spite that we are in a era where the oscillation parameters are measured with a high precision [1–3], there are some questions in the neutrino sector that remain open. In this work we want to study one of these open questions, it is the CP Majorana neutrino phases [4, 5]. In order to analyze these phases we need to assume that neutrinos are Majorana particles. We are motivated to analyze these parameters because, nowadays, through an unprecedented precision that observables are being measured by experiments, is possible to get valuable information of the parameters when the data of three observables are combined [6]. In order to quantify our results, we have used a function called "exclusion fraction function" (f_{CPX}) which is defined as a fraction of the CP Majorana phase space that can be excluded with a certain C.L when the inputs parameters are given [7–9].

THE OBSERVABLES

The efective neutrino mass ($m_{0\nu\beta\beta}$) is measured through the half-life time $T^0_{1/2}$ in the neutrinoless double beta decay experiments. Unfortunately this measure have the largest uncertainty in the nuclear matrix element (NME) which introduces an uncertainty with a factor between $2-4$ [10] in the $m_{0\nu\beta\beta}$. The efective neutrino mass can be related to the oscillation parameters as:

$$m_{0\nu\beta\beta} = |m_1 c^2_{13} c^2_{12} + m_2 c^2_{13} s^2_{12} e^{i\alpha_{31}} + m_3 s^2_{13} e^{i\alpha_{31}}|, \tag{1}$$

where m_i is the neutrino masses and $c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$ whereas α_{31}, α_{32} represents the CP Majorana phases in the MNS matrix mixing neutrino [11]. The prevision on future neutrinoless double beta decay experiments is that will cover the inverted mass hierarchy band which means $m_{0\nu\beta\beta} \approx 10\,m\text{eV}$.

The absolute neutrino mass (Σ) is related the oscillation parameters as:

$$\Sigma = m_1 + m_2 + m_3. \tag{2}$$

In recent observations by the Planck Collaboration when baryon acoustic oscillation (BAO) is added they obtained the most severe upper bound $\Sigma < 0.23$eV (Planck + WMAP + highL+BAO) at 95% C.L [12]. However, we must be careful with those results coming from cosmological analysis because depend on a particular model, in our work we assume that the "Standard Model of Cosmology" is well described by the ΛCDM model.

The effective neutrino mass m_β, throught the single beta decay process can be measured with the distorcion caused by $m_\beta \neq 0\,\text{eV}$ in the end point of the electron energy spectrum in the Kurie plot. The effective neutrino mass measured by this tecnhic can be written as:

$$m_\beta^2(\nu_e) = c_{12}^2 c_{13}^2 m_1^2 + s_{12}^2 c_{13}^2 m_2^2 + s_{13}^2 m_3^2. \tag{3}$$

Currently the best upper limit on m_β comes from Mainz [13] and Troitsk [14] each experiment found a limit of $m_\beta < 2.3$eV and $m_\beta < 2.05$eV respectively at 95% CL. There is an experiment called "KATRIN" [15] that will improve these bound by one order of magnitude, the upper bound expected with KATRIN is $m_\beta < 0.2$eV at 90% C.L.

ANALYSIS METHOD

We analize the CP Majorana phases minimizing the χ^2 fuction which is defined as:

$$\chi^2 \equiv \min\left\{\left[\frac{\Sigma^{(0)} - \Sigma^{\text{fit}}}{\sigma_\Sigma}\right]^2 + \left[\frac{m_\beta^{(0)} - m_\beta^{\text{fit}}}{\sigma_\beta}\right]^2 + \left[\frac{\xi\ m_{0\nu\beta\beta}^{(0)} - m_{0\nu\beta\beta}^{\text{fit}}}{\sigma_{0\nu\beta\beta}}\right]^2\right\}, \tag{4}$$

where we have assumed that each observable have a central value (Σ^0, m_β^0, $m_{0\nu\beta\beta}^0$) and 1σ of uncertainty ($\sigma_\Sigma = 0.05\,\text{eV}$, $\sigma_\beta = 0.06\,\text{eV}$, $\sigma_{0\nu\beta\beta} = 0.01\,\text{eV}$) (*for more details see Appendix A in* [9]) whereas the functions $\Sigma^{\text{fit}}(m_0)$, $m_\beta^{\text{fit}}(m_0)$, $m_{0\nu\beta\beta}^{\text{fit}}(m_0, \alpha_{12}, \alpha_{13})$ must be fitted variyng the parameters m_0, α_{13} and α_{12}. In this work is imperative a special attention to the NME uncertainty which is represented by ξ in the equation (4) and is quite similar to the one in [16]. *See also* [9]. We explore four different values of NME uncertainty parameter, $r_{\text{NME}} = 1.1, 1.3, 1.5, 2.0$ where ξ is bounded as $1/\sqrt{r_{\text{NME}}} \leq \xi \leq \sqrt{r_{\text{NME}}}$. In order to quantify our results, we have used " the exclusion fraction function" *see FIG.* 1, it is a useful function which shows us how much the parameters can be excluded

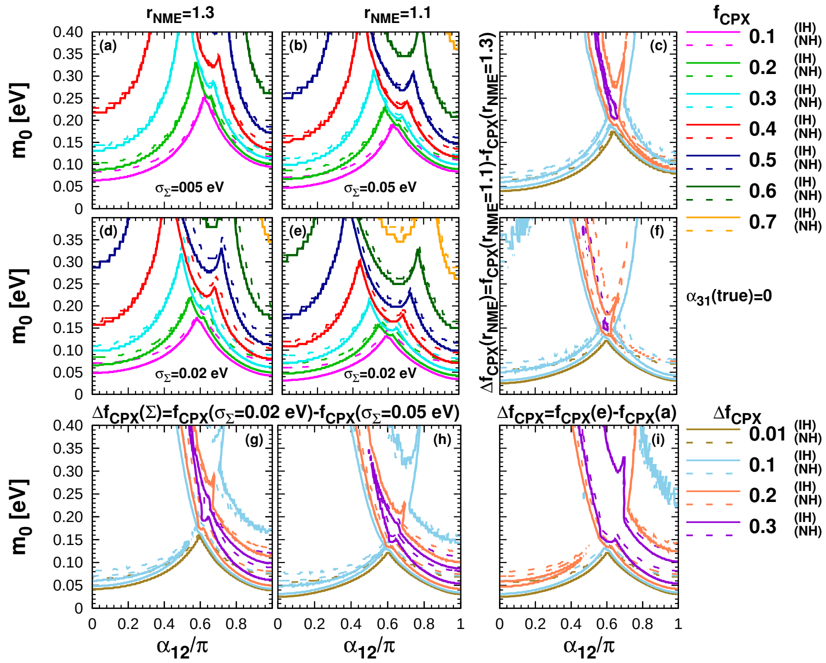

FIG. 1. In (a), (b), (d), (e) Contours of $f_{\rm CPX}$ determined at 3 σ C.L for the Inverted and Normal Hierarchy (IH, NH). (1 DOF) projected into the plane of the true values of α_{21}/π and the lightest neutrino mass m_0 for the cases where true value of $(\sigma_\Sigma, r_{\rm NME})$ = (a) (0.05 eV, 1.3), (b) (0.05 eV, 1.1), (d) (0.02 eV, 1.3) and (e) (0.02 eV, 1.1) are shown. In (c) and (f), we show, respectively, for $\sigma_\Sigma = 0.05$ eV and 0.02 eV, the iso-contours of $\Delta f_{\rm CPX}(r_{\rm NME}) \equiv f_{\rm CPX}(r_{\rm NME} = 1.1) - f_{\rm CPX}(r_{\rm NME} = 1.3)$ whereas in (g) and (h), we show, respectively, for $r_{\rm NME} = 1.3$ and 1.1, the iso-contours of $\Delta f_{\rm CPX}(\Sigma) \equiv f_{\rm CPX}(\sigma_\Sigma = 0.02 \text{ eV}) - f_{\rm CPX}(\sigma_\Sigma = 0.05 \text{ eV})$. In (i) we show the iso-contours of $\Delta f_{\rm CPX}(\Sigma, r_{\rm NME}) \equiv f_{\rm CPX}(\sigma_\Sigma = 0.02 \text{ eV}, r_{\rm NME} = 1.1) - f_{\rm CPX}(\sigma_\Sigma = 0.05 \text{ eV}, r_{\rm NME} = 1.3)$.

SUMMARY AND REMARKS

- The dependence of $m_{0\nu\beta\beta}$ on α_{13} is very weak due to the small value of s_{13}^2 and there is a very weak dependence between α_{12} and α_{13}. *For more details see* [9],
- The best and worse sensitivities to α_{12} is when the true value of α_{12} are 0 or π and $3\pi/2$ respectively. See figure (1),
- The sensitivity to α_{12} increase to low values of true m_0 in the inverted ordering case, whereas for larger values of m_0 there is an increase of the sensitivity for any value of NME. See figure (1),

- The sensitivity to α_{12} increases when the uncertainty of the NME decreases and also when the uncertainty of the Σ decreases, See figure (1). In this point, we expect that in the near future, with the cosmological data coming with an unprecedent presicion, the interest of the Cosmology on the neutrino sector be renewed,
- There is a synergy between $m_{0\nu\beta\beta}$ and Σ data which play a interesting role to constraint the CP Majorana phase α_{12}. As we can see in the equation (2) even without dependence of Σ on α_{12}, we found that when the cosmological data are added to equation (4) the sensitivity to α_{12} increases. *For more details see* [9].

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