Constraining Majorana CP Phase in Precision Era of Cosmology and Double Beta Decay Experiment

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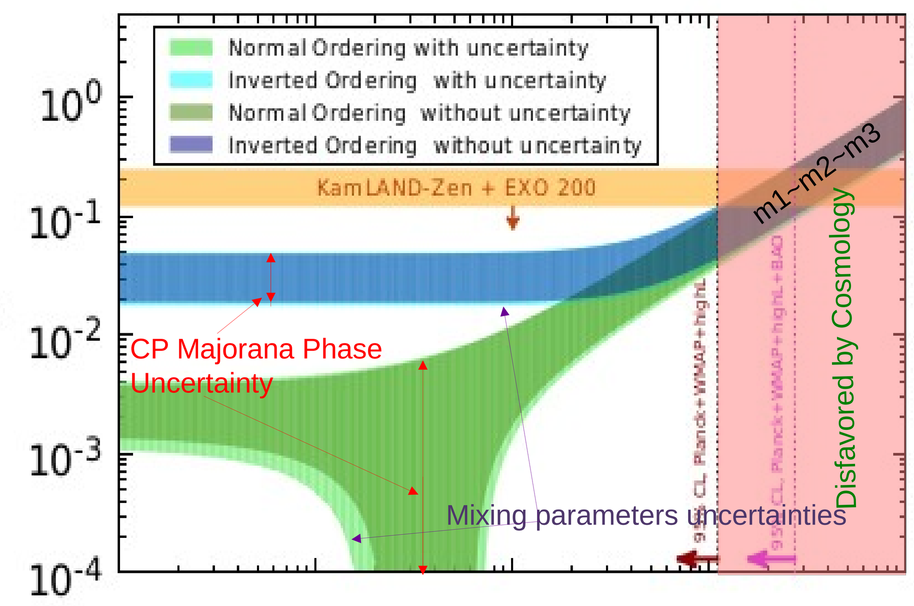
Abstract

We show that precision measurement of sum of neutrino masses by cosmological observation and efective neutrino mass by neutrinoless double beta decay together with beta decay experiments have a synergy which allows us to get information on the Majorana phase of neutrinos. In order to quantify this information we use in addition to the allowed region plots the CP exclusion fraction function as a complementary tool. This function shows how much fraction of the CP phase parameter space can be excluded for a given set of assumed inputs parameters. We find that one of the two CP neutrino phases can be constrained by excluding 10-50% of the phase space at 3σ CL for the lowest neutrino mass of 0.1eV. We also consider if the nuclear matrix element can be constrained by consistency of such measurements.

Observables used in the Analysis



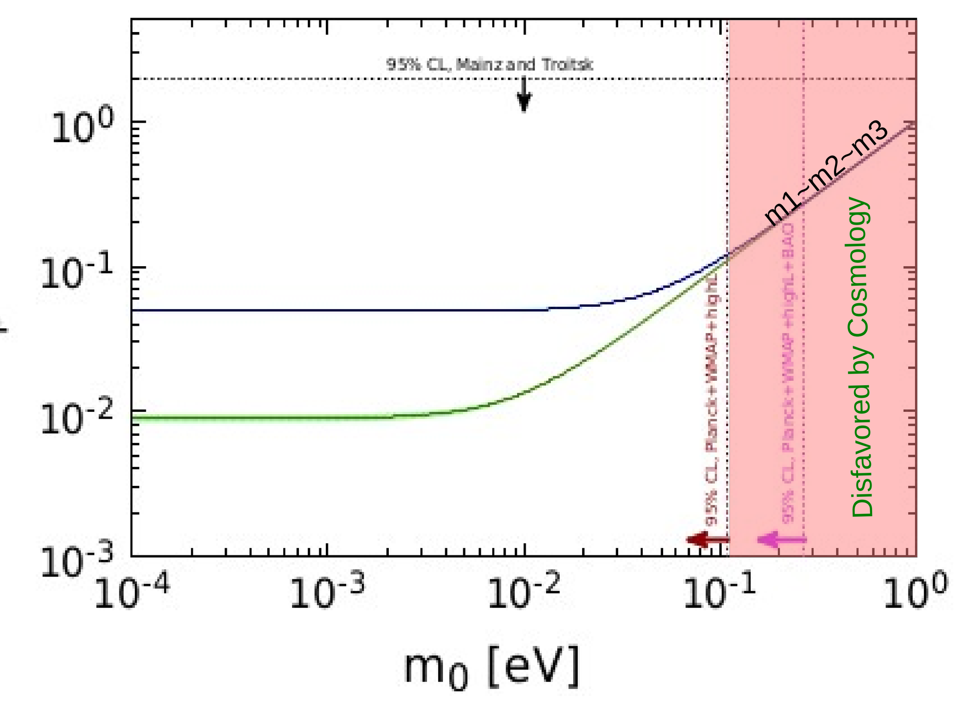
$$N(Z,A) \to N(Z\pm 2, A) + 2e^{\mp}$$

$$[T^{0\nu}_{1/2}]^{-1} = G_{0\nu} |M^{0\nu}|^2 \left(\frac{m_{0\nu\beta\beta}}{m_e}\right)^2$$

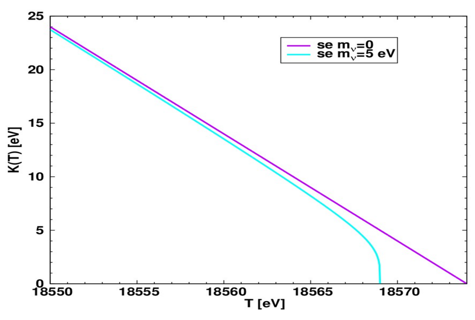
half life time; Phase space factor; Nuclear Matrix Element; Efective neutrino mass

$$m_{0\nu\beta\beta} = |m_1 c_{13}^2 c_{12}^2 + m_2 c_{13}^2 s_{12}^2 e^{i\alpha_{21}} + m_3 s_{13}^2 e^{i\alpha_{31}}|$$

$$m_{0\nu\beta\beta} < 0.1 - 0.25 \text{ eV} \quad (90\% \text{ CL})$$



$$N(Z,A) \to N(Z+1,A) + e^- + \bar{\nu}_e$$



$$m_\beta = [m_1^2 c_{13}^2 c_{12}^2 + m_2^2 c_{13}^2 s_{12}^2 + m_3^2 s_{13}^2]^{1/2}$$

$$m_\beta < \begin{cases} 2.3\,\text{eV} & 95\% \text{ CL; Mainz collaboration} \\ 2.0\,\text{eV} & 95\% \text{ CL; Troitsk collaboration} \end{cases}$$

$$\Sigma = m_1 + m_2 + m_3 \quad \Omega_\nu = \frac{\Sigma}{93.14 h^2\,\text{eV}} \quad \Sigma < \begin{cases} 0.98 \text{ eV} & (\text{Planck + WMAP + CMB}), \\ 0.32 \text{ eV} & (\text{Planck + WMAP + CMB + BAO}), \end{cases}$$

Analysis Method

Errors

$$m^{obs}_{0\nu\beta\beta} = m^0_{0\nu\beta\beta} \pm \sigma_{0\nu\beta\beta} = 0.01\,\text{eV}$$
$$m^{obs}_\beta = m^0_\beta \pm \sigma_\beta = 0.06\,\text{eV}$$
$$\Sigma^{obs} = \Sigma^0 \pm \sigma_\Sigma = 0.05(0.02)\,\text{eV}$$

Procedure

$$\chi^2 \equiv min\left\{\left[\frac{\Sigma^0 - \Sigma^{fit}(m_0)}{\sigma_\Sigma}\right]^2 + \left[\frac{m^0_\beta - m^{fit}_\beta(m_0)}{\sigma_\beta}\right]^2 + \left[\frac{\xi\, m^0_{0\nu\beta\beta} - m^{fit}_{0\nu\beta\beta}(m_0,\alpha_{21},\alpha_{31})}{\sigma_{0\nu\beta\beta}}\right]^2\right\}$$

Where:

$$\xi \equiv \frac{M_0^{0\nu}}{M^{0\nu}}$$
Reference value / Unknow true value

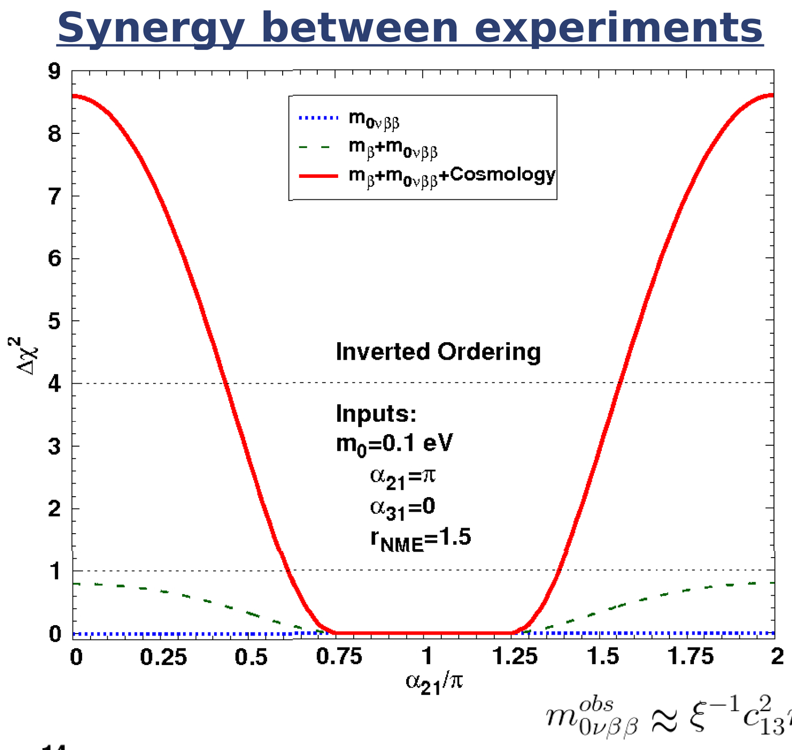
$$M^{0\nu}_{min} \le M^{0\nu} \le M^{0\nu}_{max}$$
NME range

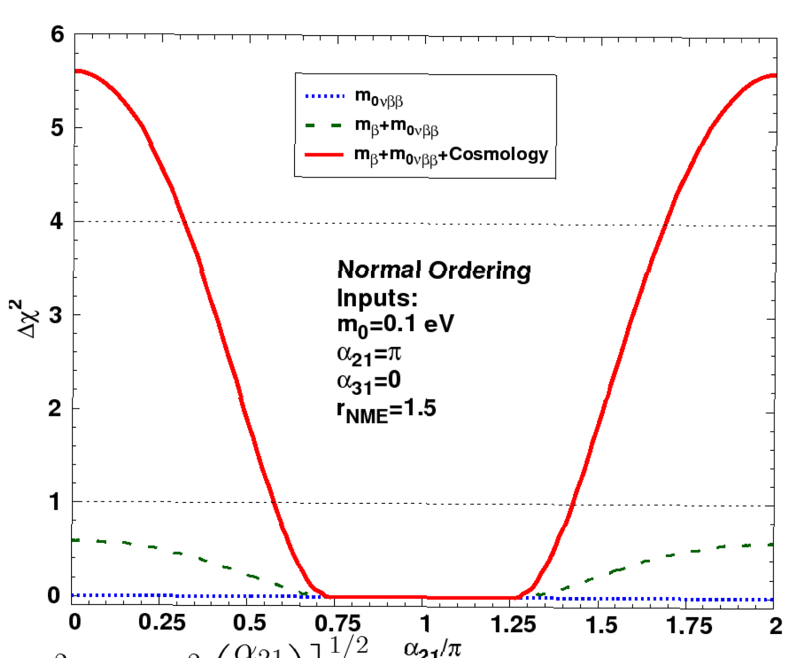
$$M_0^{0\nu} \equiv (M^{0\nu}_{max} M^{0\nu}_{min})^{1/2}$$
Geometric mean

$$M^{0\nu}_{max} = \sqrt{r_{NME}} M_0^{0\nu} \qquad M^{0\nu}_{min} = \frac{1}{\sqrt{r_{NME}}} M_0^{0\nu}$$

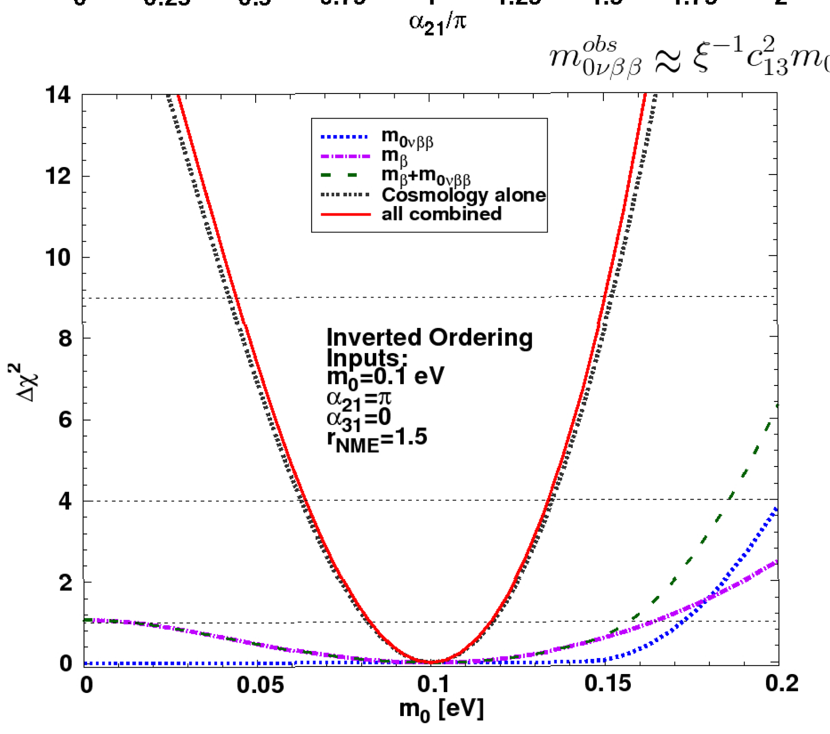
therefore $r_{NME} = \frac{M^{0\nu}_{max}}{M^{0\nu}_{min}}$ — NME uncertainty parameter

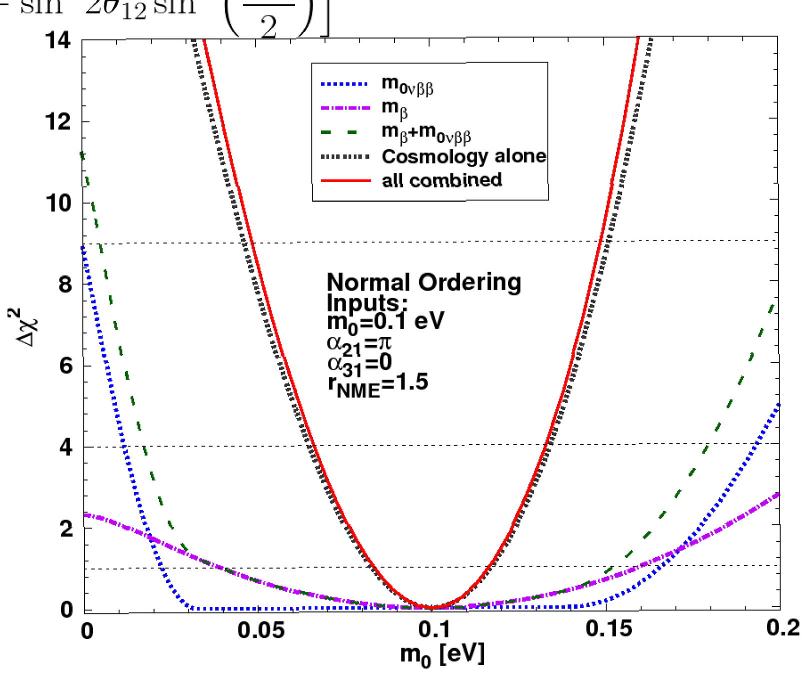
Synergy between experiments



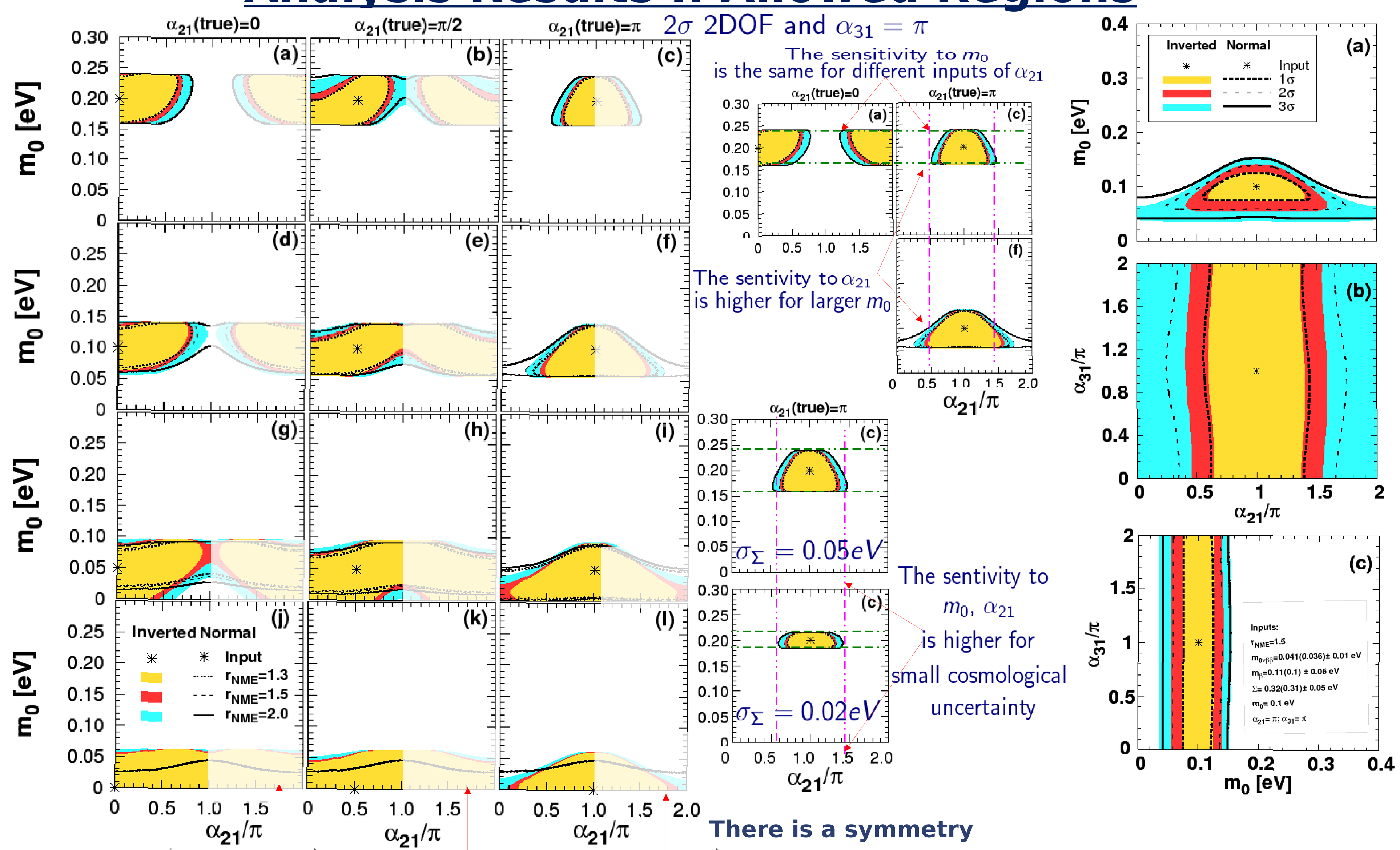


$$m^{obs}_{0\nu\beta\beta} \approx \xi^{-1} c_{13}^2 m_0 \left[1 - \sin^2 2\theta_{12} \sin^2\left(\frac{\alpha_{21}}{2}\right)\right]^{1/2}$$





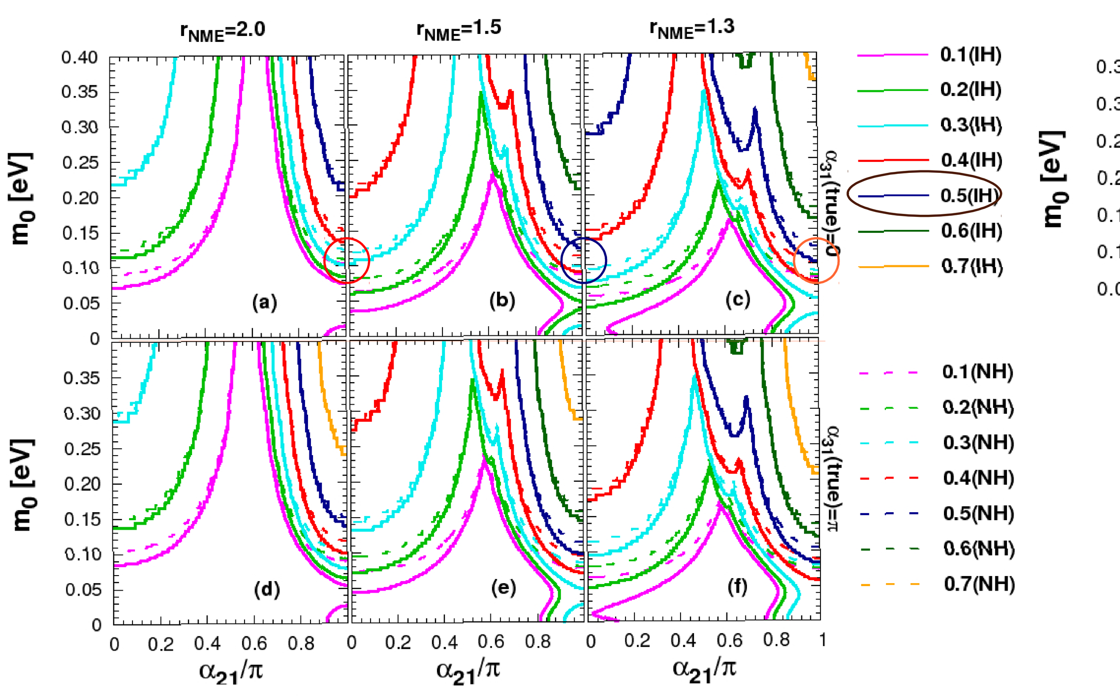
Analysis Results I: Allowed Regions

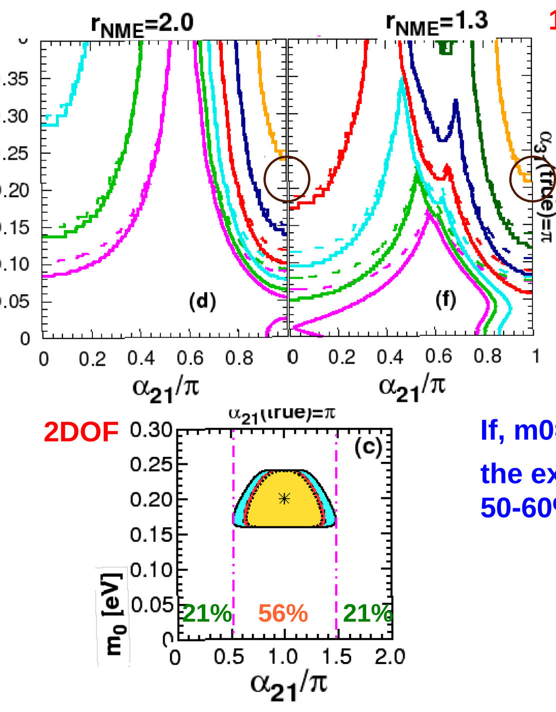


There is a symmetry

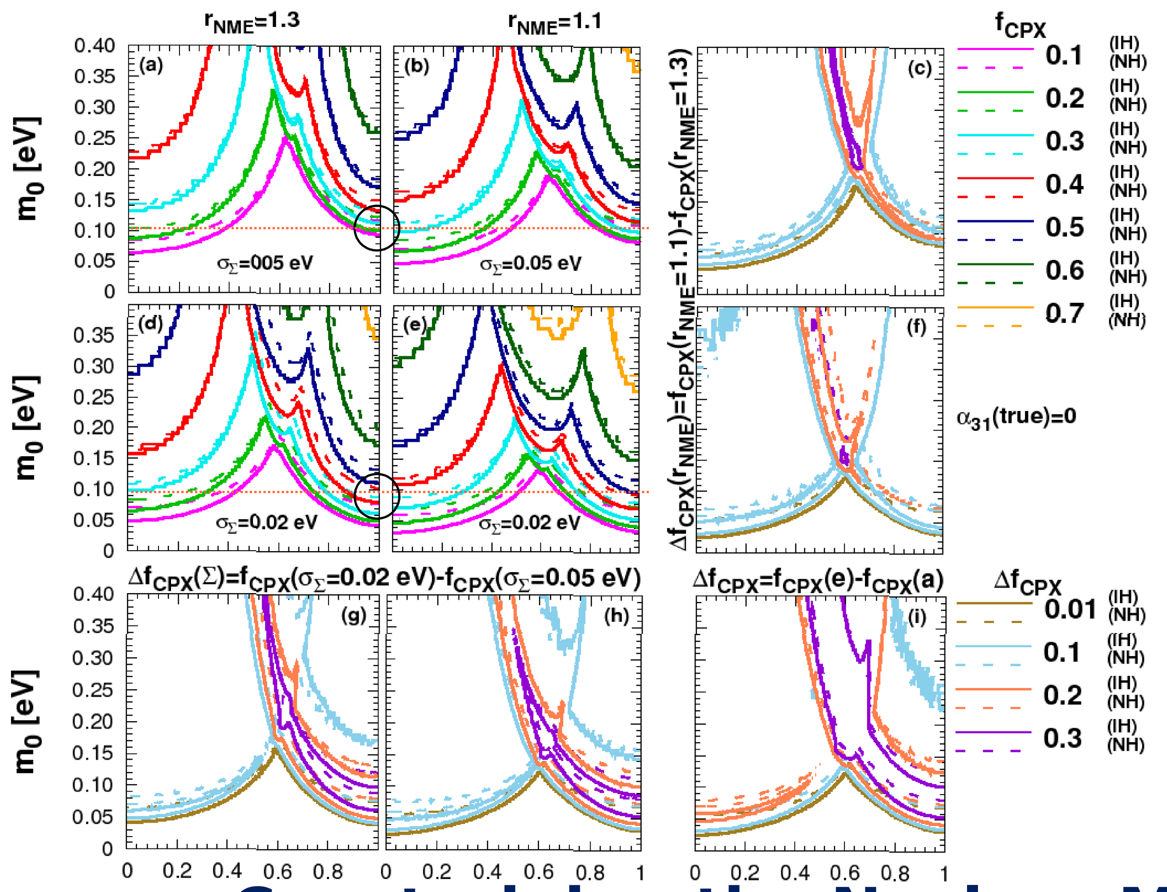
$$m_{0\nu\beta\beta}(m_0,\alpha_{21},\alpha_{31}) = m_{0\nu\beta\beta}(m_0, 2\pi - \alpha_{21}, 2\pi - \alpha_{31})$$

Analysis Results II: CP Exclusion Fraction





If, m0=0.2 eV and α_{21}=π, the exclusion fraction is 50-60%.



m_0=0.1eV **The Exclusion**

- α_{21}=0 then f_{CPX}=0.1-0.2; α_{21}=π then f_{CPX}=0.3
- α_{21}=0 then f_{CPX}=0.25-0.3; α_{21}=π then f_{CPX}=0.4
- α_{21}=0 then f_{CPX}=0.3-0.35; α_{21}=π then f_{CPX}=0.5

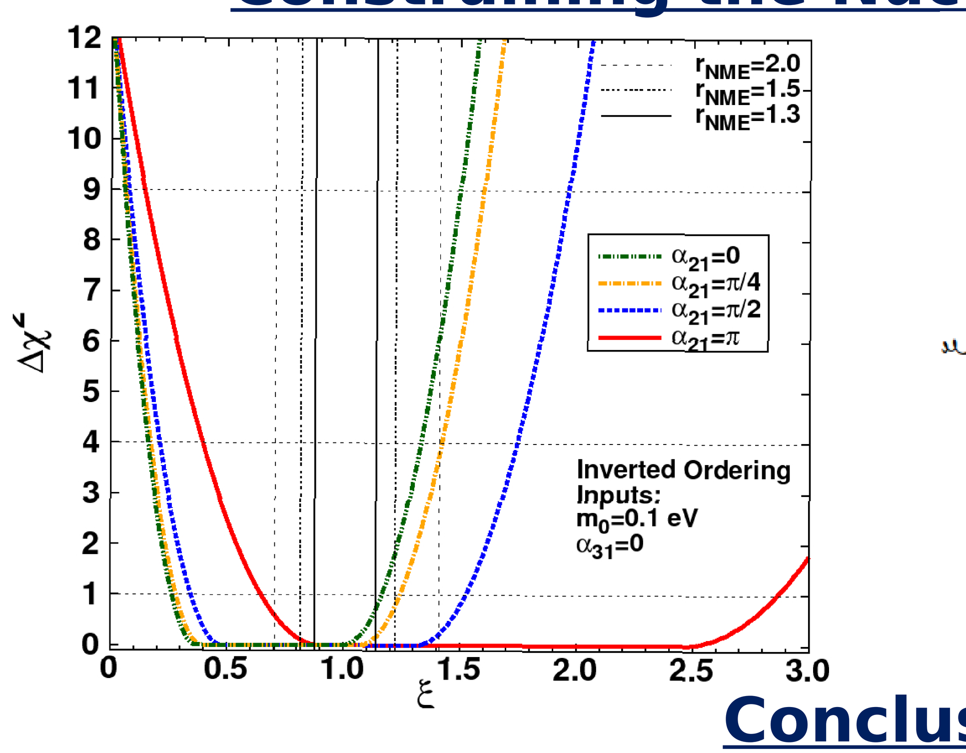
1DOF 2σ

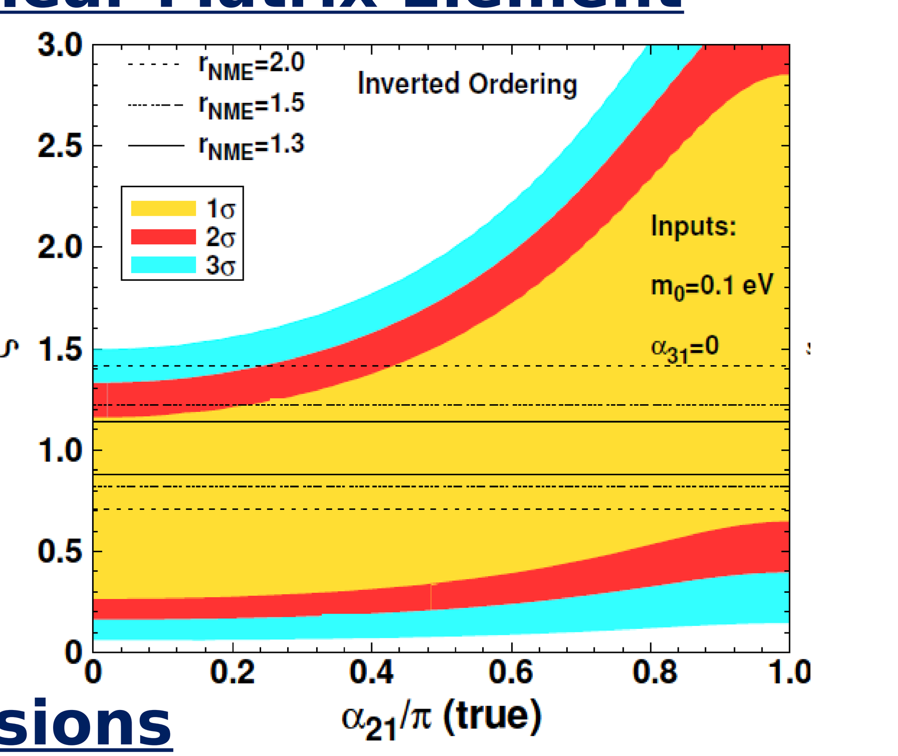
$\sigma_\Sigma = 0.05eV \to \sigma_\Sigma = 0.02eV$

α_{21}=π then f_{CPX}=0.1-0.2
α_{21}=π then f_{CPX}=0.4-0.5

m_0=0.1eV 1DOF 3σ

Constraining the Nuclear Matrix Element





Conclusions

- There is a synergy between Σ and 0νββ in constraining the Majorana phase α_{21},
- It is possible to obtain constraints to the α_{21} if accurate measurement of σ_Σ is added,
- The α_{21} can be constrained by excluding ~10-40% of the phase space of α_{21} with m_0=0.1eV, r_{NME}=1.5, 2σ CL and σ_Σ=0.05eV. If σ_Σ=0.02eV then ~10-50%,
- The sensitivity to α_{21} become significantly better when the NME uncertainty is reduced 2 to 1.5,
- The accuracy measurement of Σ probably requires the Euclide Satellite as well as the next generation of galaxy surveys,
- A better constraint on α_{21} also requires a accuracy measurement of lifetime of 0νββ decay in a ton scale experiments with a very low background which would allow a measurement of $m_{0\nu\beta\beta}$ as small as ~0.01eV,
- It is possible to constraint the NME when α_{21}~0 or π, it can be used as consistency check of its theoretical calculation.

References

H. Minakata, H.Nunokawa and Alexander. A. Quiroga (2014), arXiv:1402.6014

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