Invisible Decay at Long Baseline experiments

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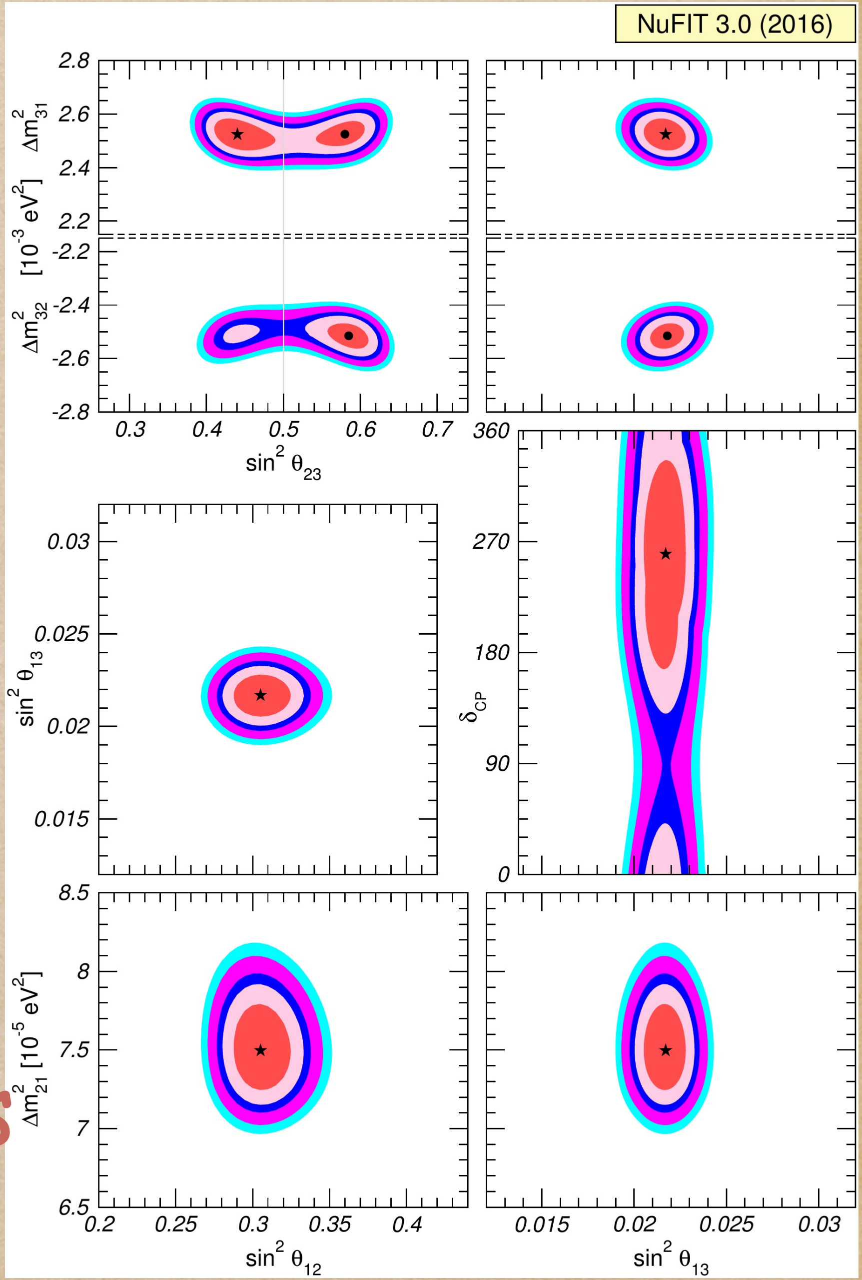
❖Outline

- Current Status of Neutrino Oscillation physics
- Invisible decay of the neutrino
- Current Constraints
- Invisible decay for MINOS & T2K
- Invisible decay for DUNE
- Conclusion

NuFIT 3.0 (2016)

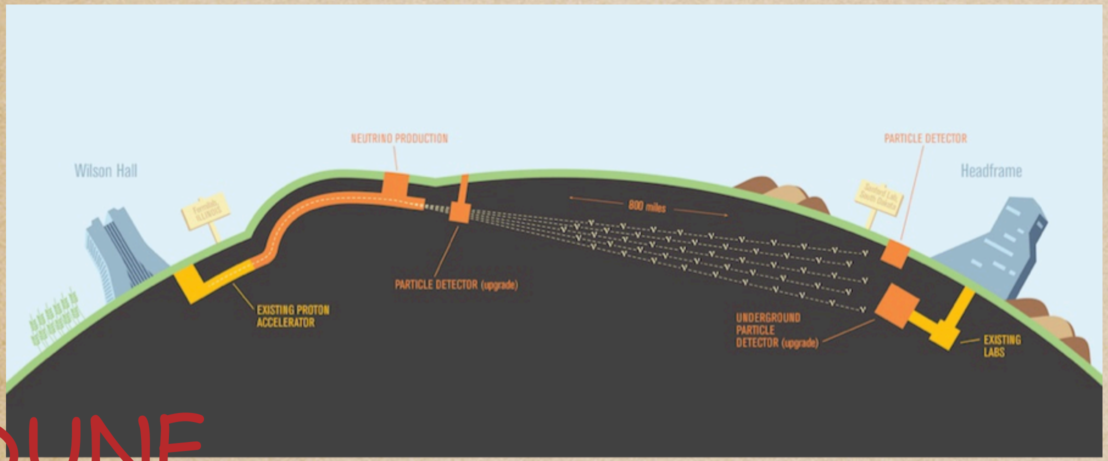
	Normal Ordering (best fit)		Inverted Ordering ($\Delta\chi^2 = 0.83$)		Any Ordering
	bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range	3σ range
$\sin^2\theta_{12}$	$0.306^{+0.012}_{-0.012}$	$0.271 \to 0.345$	$0.306^{+0.012}_{-0.012}$	$0.271 \to 0.345$	$0.271 \to 0.345$
$\theta_{12}/^\circ$	$33.56^{+0.77}_{-0.75}$	$31.38 \to 35.99$	$33.56^{+0.77}_{-0.75}$	$31.38 \to 35.99$	$31.38 \to 35.99$
$\sin^2\theta_{23}$	$0.441^{+0.027}_{-0.021}$	$0.385 \to 0.635$	$0.587^{+0.020}_{-0.024}$	$0.393 \to 0.640$	$0.385 \to 0.638$
$\theta_{23}/^\circ$	$41.6^{+1.5}_{-1.2}$	$38.4 \to 52.8$	$50.0^{+1.1}_{-1.4}$	$38.8 \to 53.1$	$38.4 \to 53.0$
$\sin^2\theta_{13}$	$0.02166^{+0.00075}_{-0.00075}$	$0.01934 \to 0.02392$	$0.02179^{+0.00076}_{-0.00076}$	$0.01953 \to 0.02408$	$0.01934 \to 0.02397$
$\theta_{13}/^\circ$	$8.46^{+0.15}_{-0.15}$	$7.99 \to 8.90$	$8.49^{+0.15}_{-0.15}$	$8.03 \to 8.93$	$7.99 \to 8.91$
$\delta_{CP}/^\circ$	261^{+51}_{-59}	$0 \to 360$	277^{+40}_{-46}	$145 \to 391$	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ \text{eV}^2}$	$7.50^{+0.19}_{-0.17}$	$7.03 \to 8.09$	$7.50^{+0.19}_{-0.17}$	$7.03 \to 8.09$	$7.03 \to 8.09$
$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \text{eV}^2}$	$+2.524^{+0.039}_{-0.040}$	$+2.407 \to +2.643$	$-2.514^{+0.038}_{-0.041}$	$-2.635 \to -2.399$	$\begin{bmatrix} +2.407 \to +2.643 \\ -2.629 \to -2.405 \end{bmatrix}$

JHEP 01 (2017) 087 [arXiv:1611.01514]

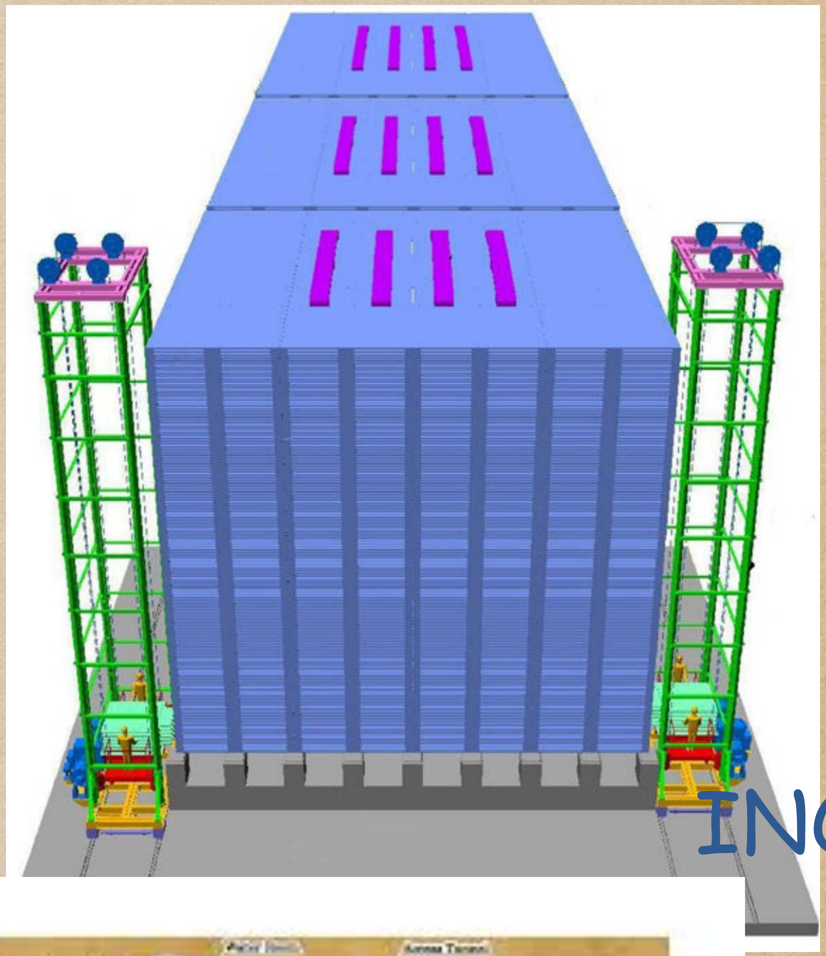


See Agarwalla's talk for details

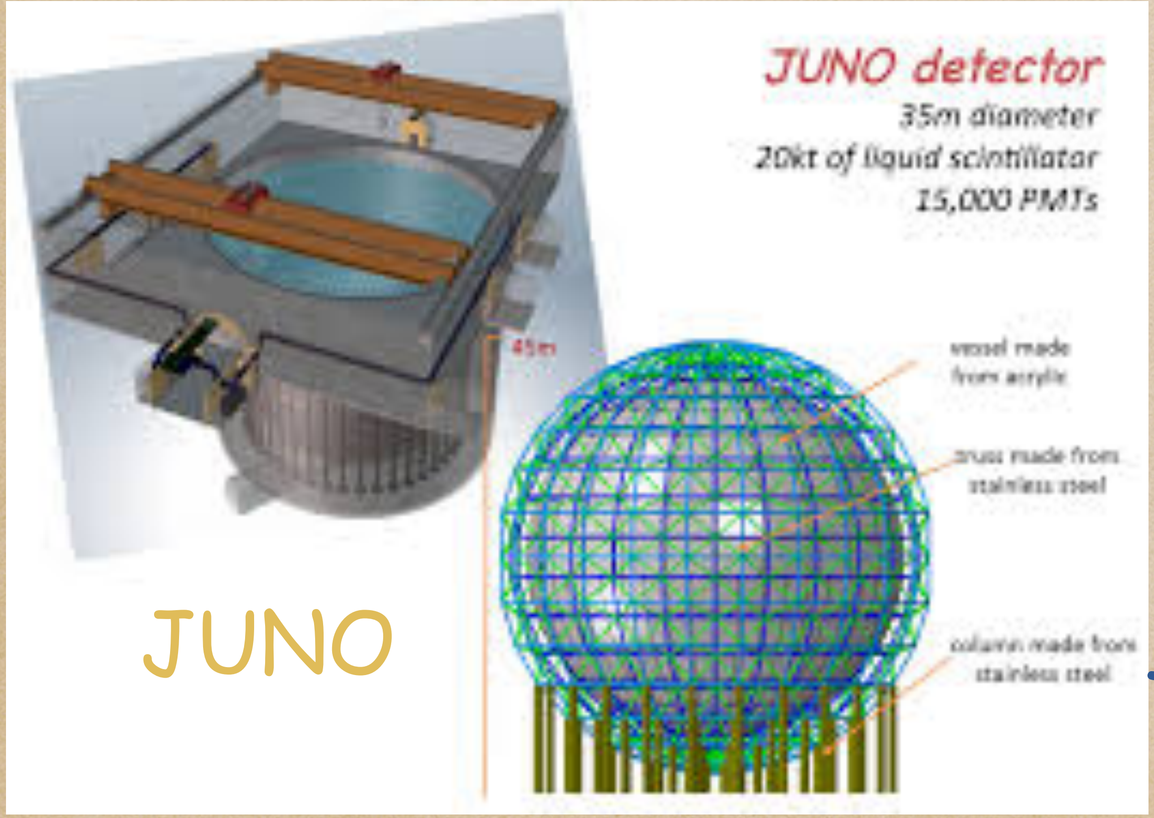
Future Experiments



DUNE



INO



JUNO

Tokai to Hyper Kamiokande
(T2HK & T2HKK)

Possible new-physics

- Light Sterile neutrinos
- NSI (Non standard interactions)
- De-coherence
- Long range force
- Decay
- Large Extra Dimensions, etc.

Invisible decay of neutrino

Invisible decay :

$\nu \longrightarrow S$ (sterile state)

If neutrinos are Dirac:

χ is iso-singlet scalar

$\bar{\nu}_{iR}$ is right-handed singlet

$$\nu_j \to \bar{\nu}_{iR} + \chi$$

If neutrinos are Majorana:

$\bar{\nu}_s$ is a sterile neutrino

J is a Majoron

$$\nu_j \to \nu_s + J$$

We assume ν_3 to decay into $\bar{\nu}_4$ and a singlet scalar

$$\nu_3 = \bar{\nu}_4 + J$$

$$\begin{pmatrix} \nu_\alpha \\ \nu_s \end{pmatrix}$$

Now, the flavour and mass basis get related as

$$\begin{pmatrix} \nu_\alpha \\ \nu_s \end{pmatrix} = \begin{pmatrix} U & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_i \\ \nu_4 \end{pmatrix}$$

U is the standard PMNS matrix

The effect of decay can be incorporated in the evolution equation by :

$$i\frac{d}{dx}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \left[U\left[\frac{1}{2E}\begin{pmatrix}0 & 0 & 0\\ 0 & \Delta m^2_{21} & 0\\ 0 & 0 & \Delta m^2_{31}\end{pmatrix} - i\frac{m_3}{2E\tau_3}\begin{pmatrix}0 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 1\end{pmatrix}\right]U^\dagger + \begin{pmatrix}A & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}$$

Note: Here we assume that the mass matrix and the decay matrix can be simultaneously diagonalised

Current Constraints

Bound on τ_2/m_2 from solar neutrino data

[Phys.Lett. B555 (2003) 33-42] $\tau_2/m_2 > 8.5 \times 10^{-7}(s/eV)$

SN1987A supernova data puts bound of $\tau_2/m_2 > 10^{-5}(s/eV)$

[Phys.Lett. B200 (1988) 115-121]

MINOS , T2K data give bounds on τ_3/m_3

[Phys.Lett. B740 (2015) 345-352] $\tau_3/m_3 > 2.8 \times 10^{-12}(s/eV)$ 90 % C.L

Expected sensitivity from JUNO : $\tau_3/m_3 > 7.5 \times 10^{-11}(s/eV)$

[JHEP 1511 (2015) 001] 95 % C.L

Expected sensitivity from 100 TeV neutrino from 1 Gpc source at IceCUBE >10 (s/eV) [Phys.Rev. D95 (2017) no.6]

Some recent works

Constraints on neutrino decay lifetime using long-baseline charged and neutral current data

R.A. Gomes (Goias U. & Argonne) , A.L.G. Gomes (Goias U.) , O.L.G. Peres (Campinas State U. & ICTP, Trieste)

Jul 21, 2014 - 8 pages

Minos & T2k

Phys.Lett. B740 (2015) 345-352

This talk

Visible neutrino decay at DUNE

Pilar Coloma (Fermilab) , Orlando L. G. Peres (Campinas State U. & ICTP, Trieste)

May 9, 2017 - 17 pages

FERMILAB-PUB-17-150-T
e-Print: arXiv:1705.03599 [hep-ph] | PDF

A Study of Invisible Neutrino Decay at DUNE and its Effects on θ_{23} Measurement

Sandhya Choubey (Royal Inst. Tech., Stockholm & Harish-Chandra Res. Inst.) , Srubabati Goswami (Ahmedabad, Phys. Res. Lab) , Dipyaman Pramanik (Harish-Chandra Res. Inst. & HBNI, Mumbai)

May 16, 2017 - 20 pages

This talk

Sensitivity to neutrino decay with atmospheric neutrinos at INO

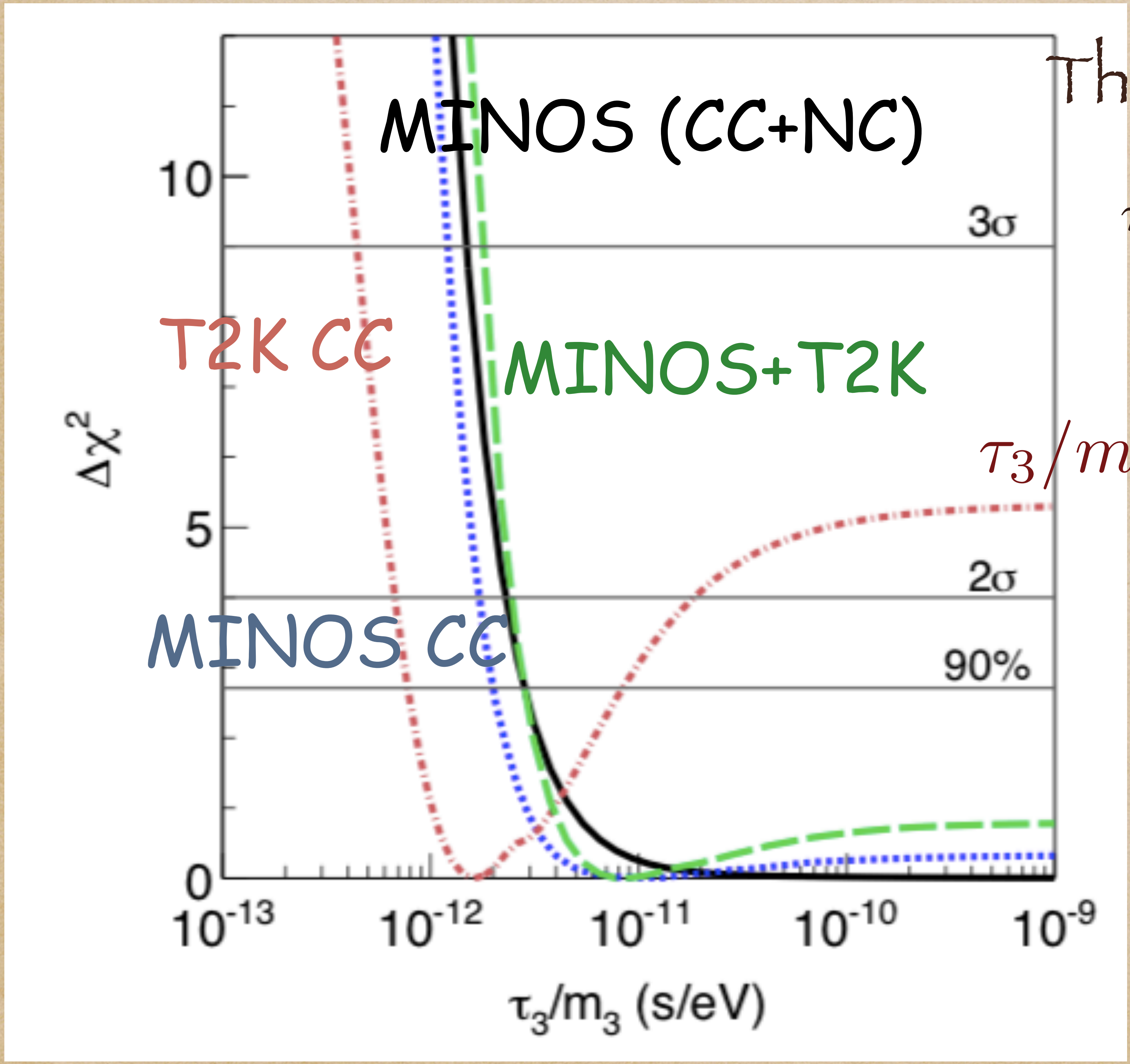
Sandhya Choubey (Royal Inst. Tech., Stockholm & Harish-Chandra Res. Inst. & HBNI, Mumbai) , Srubabati Goswami (Ahmedabad, Phys. Res. Lab) , Chandan Gupta (HBNI, Mumbai & Ahmedabad, Phys. Res. Lab) , S.M. Lakshmi (Ahmedabad, Phys. Res. Lab) , Tarak Thakore (Louisiana State U.)

Sep 29, 2017 - 24 pages

e-Print: arXiv:1709.10376 [hep-ph] | PDF

See Laxmi's talk

From Minos & T2K



This gives a finite best fit

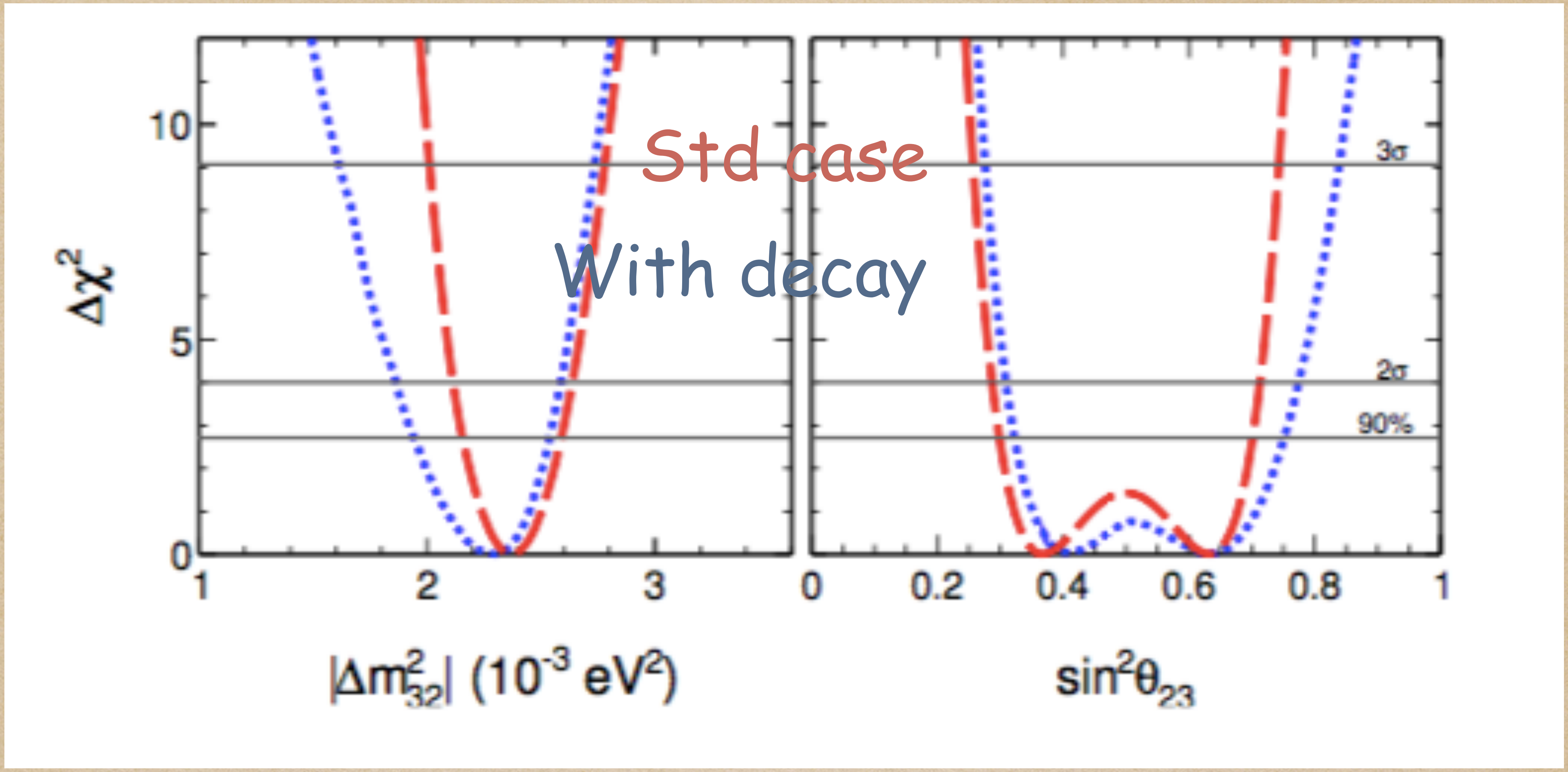
$$\tau_3/m_3 = 1.2 \times 10^{-11}(s/eV)$$

Bound from this :

$$\tau_3/m_3 > 2.8 \times 10^{-12}(s/eV)$$

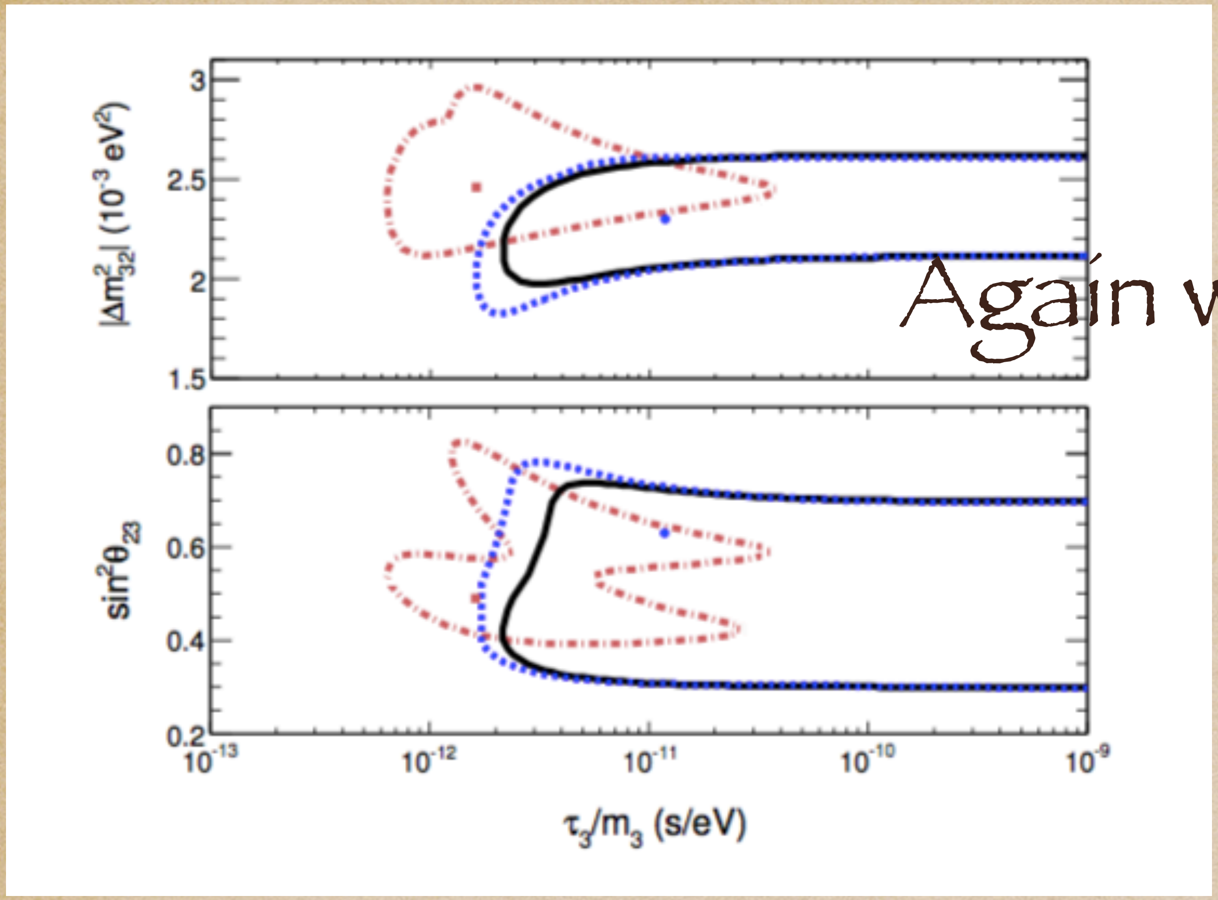
90 % C.L

[Phys.Lett. B740 (2015) 345-352]



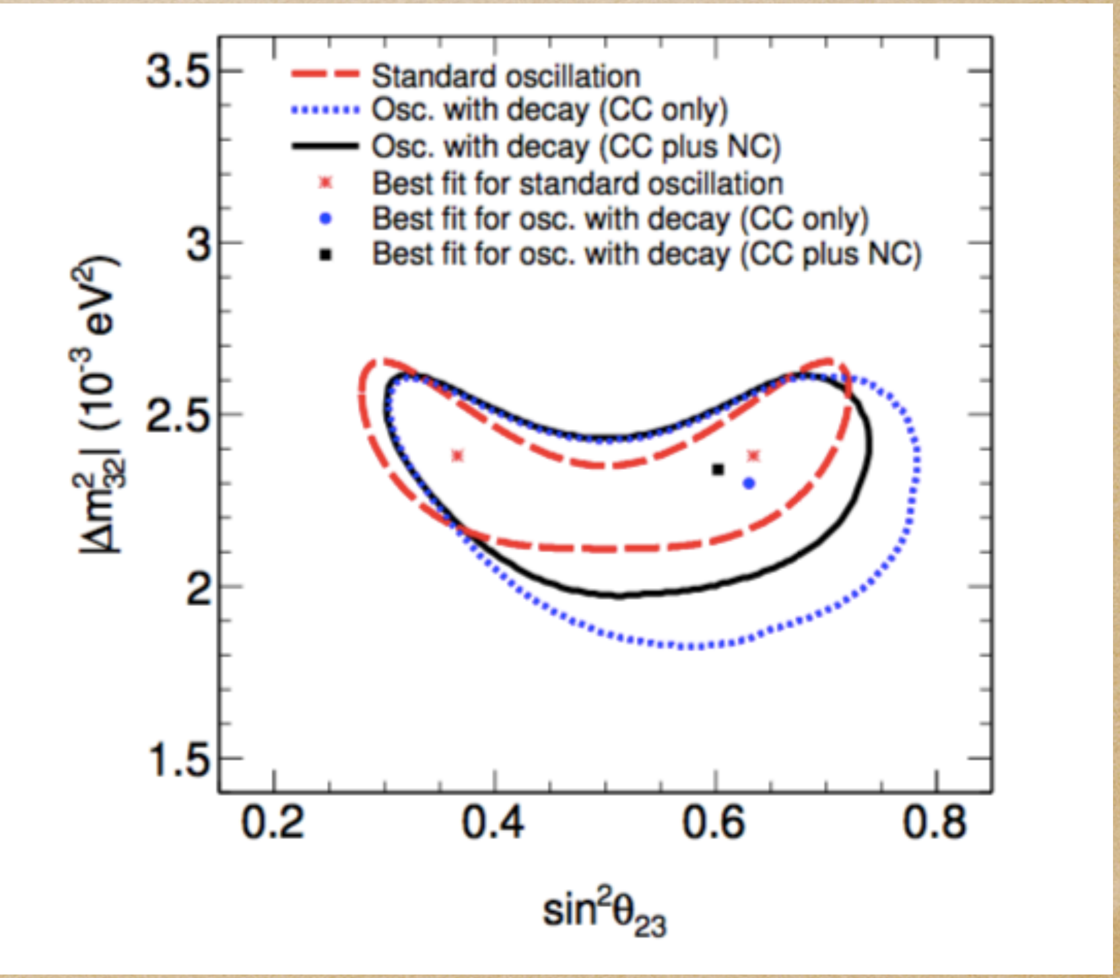
We can see some change in the stendard parameters

[Phys.Lett. B740 (2015) 345-352]



Again we can see the finite decay for

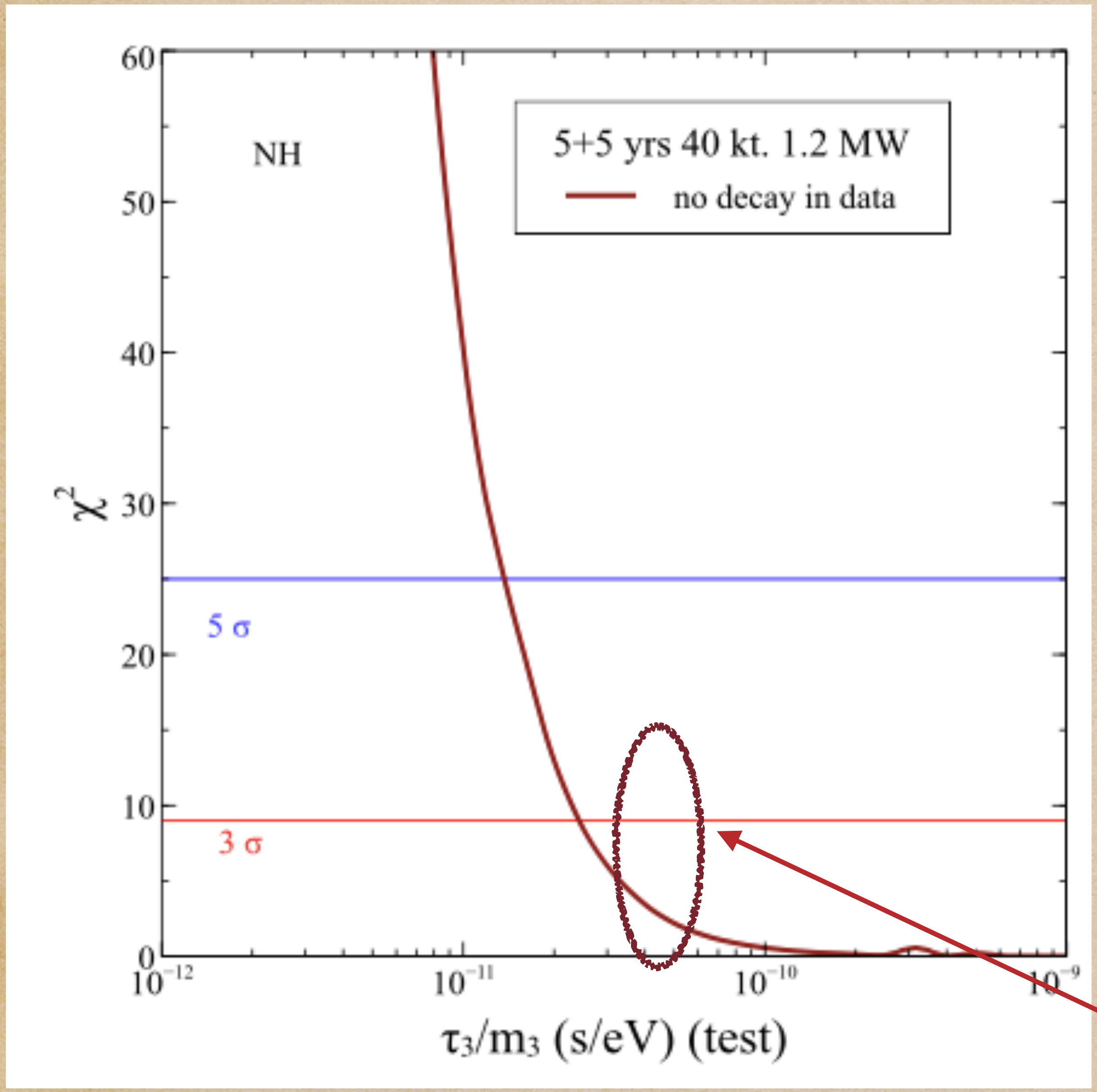
For T2K



[Phys.Lett. B740 (2015) 345-352]

Invisible Decay for DUNE

[arXiv:1705.05820]



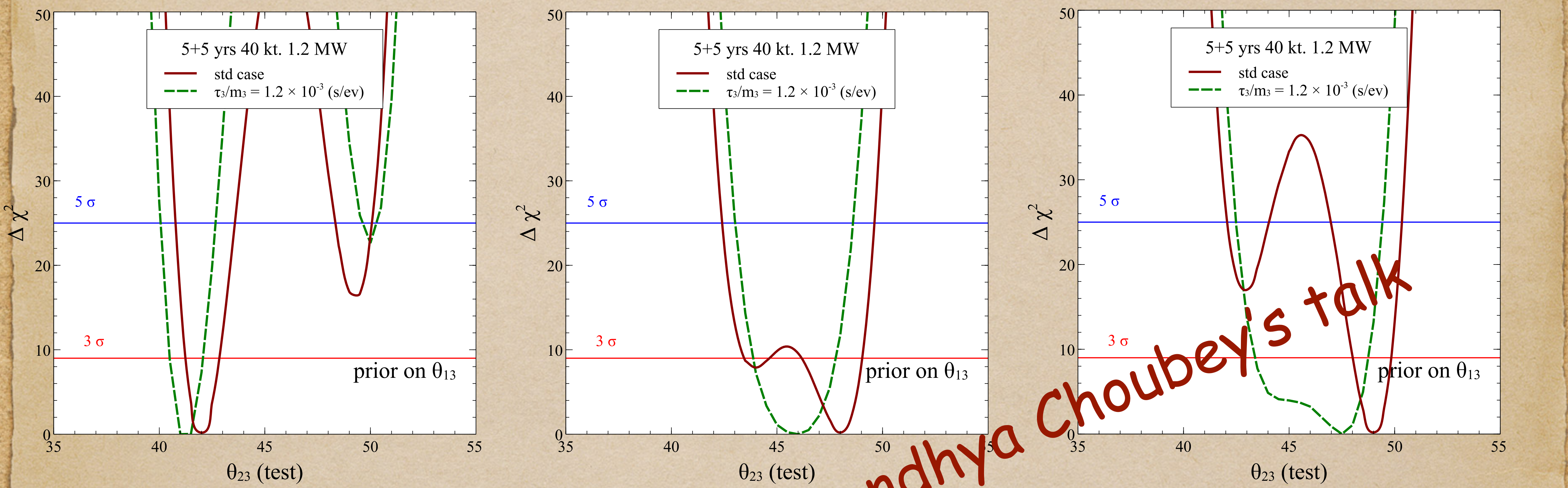
Expected sensitivity at DUNE

We assume here no decay in the simulated data

We fit the data with decay marginalising over all the relevant parameters with appropriate priors

$2.38 \times 10^{-11} (s/eV)$

Effect on measurement of θ_{23}

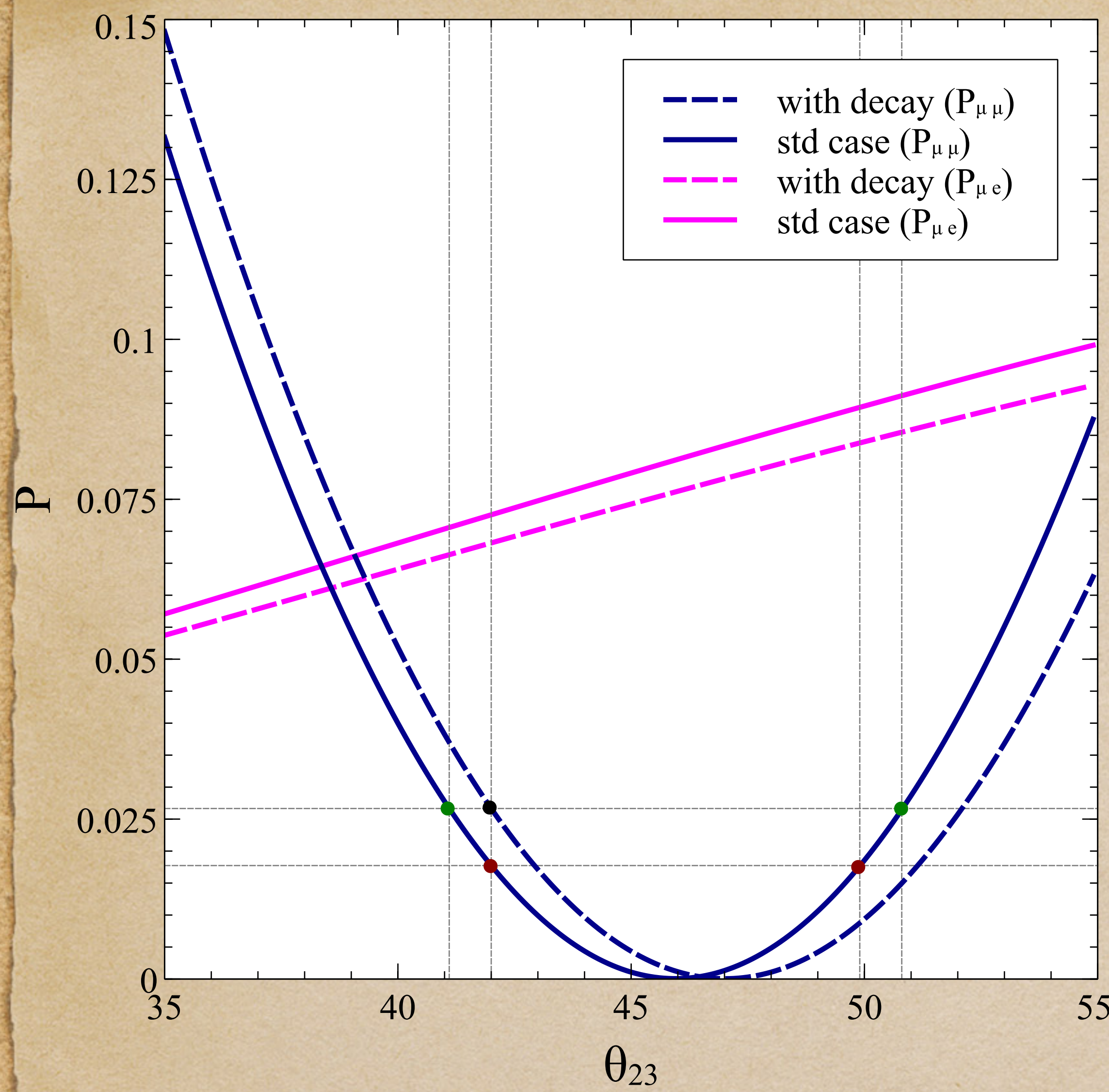


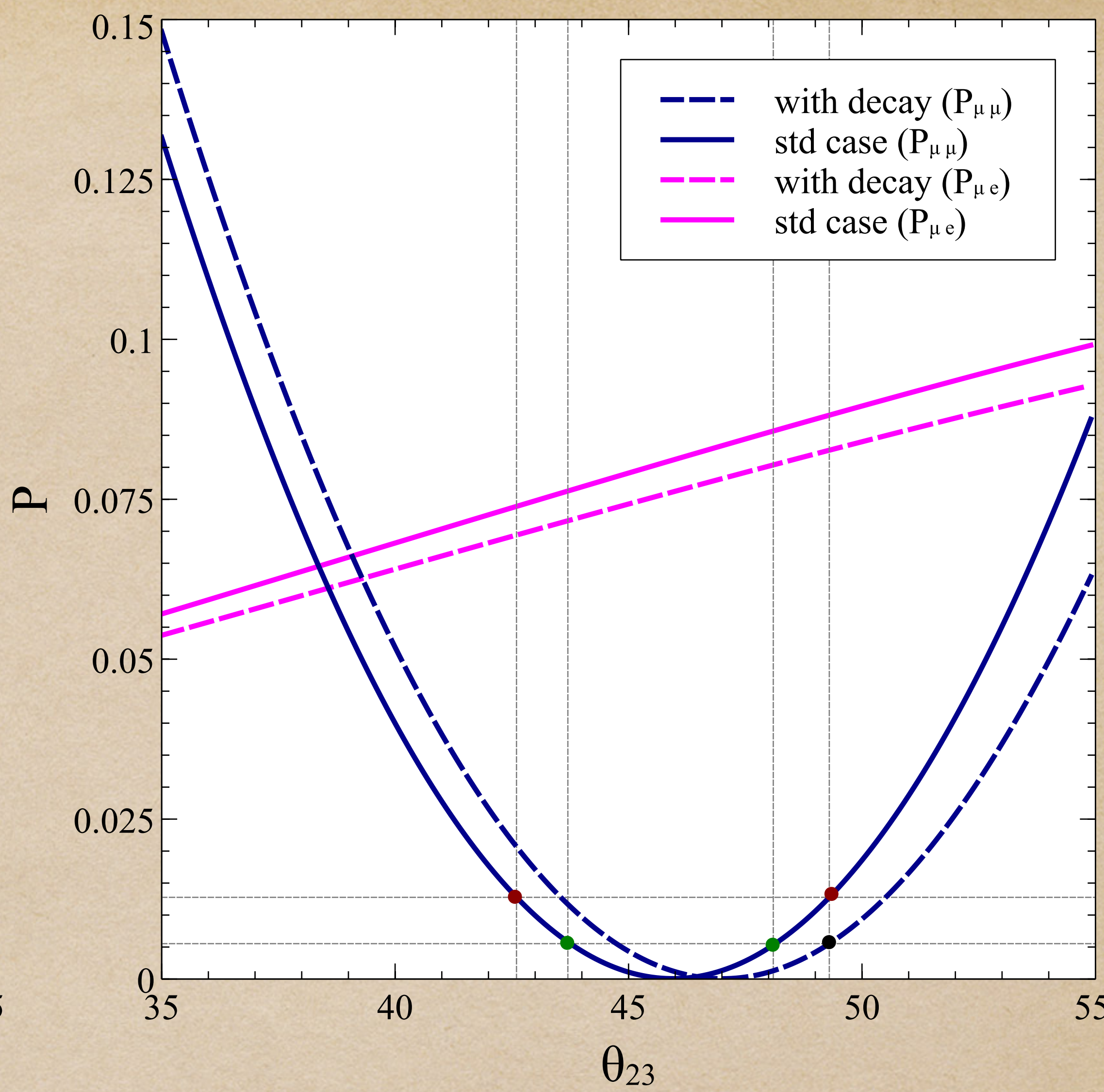
See Prof. Sandhya Choubey's talk

$$\sin\theta_{23}^{LO} = \frac{\sin\theta_{\mu\mu}^{LO}}{\cos\theta_{13}} \quad ; \quad \sin\theta_{23}^{HO} = \frac{\sin\theta_{\mu\mu}^{HO}}{\cos\theta_{13}}$$

$$\theta_{\mu\mu}^{LO} = 90^\circ - \theta_{\mu\mu}^{HO} \,,$$

[S. K. Raut, Mod. Phys. Lett. A28, 1350093 (2013), 1209.5658]



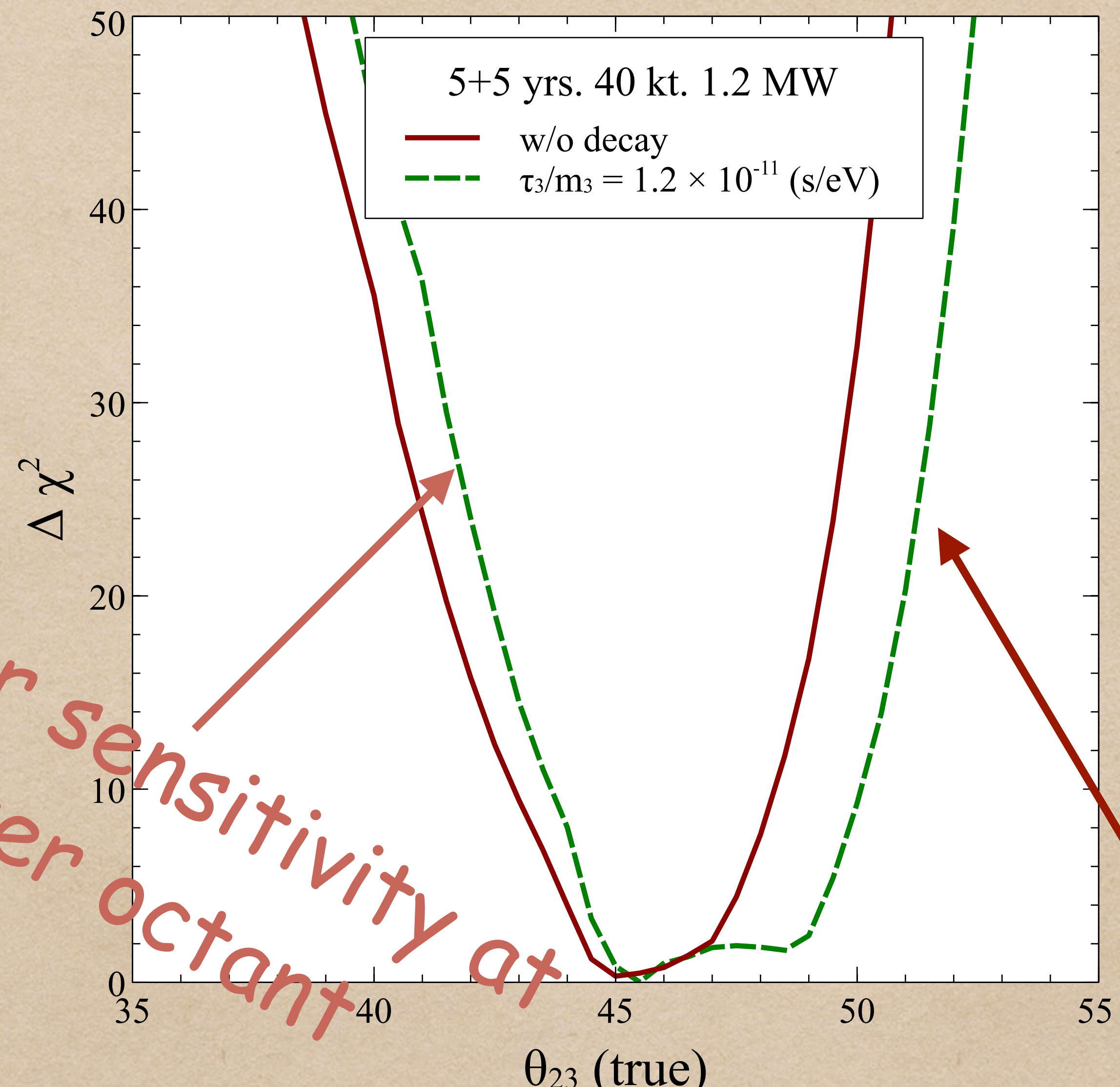


Note:

In appearance the probability Increases monotonically

In disappearance this is complicated

Octant



Higher sensitivity at Lower octant

Lower sensitivity at Higher octant

❖Conclusion

- Neutrino Oscillation has reached its precision era.
- Invisible decay of neutrinos in Long-baseline experiments is a many of the possible new physics scenario.
- There are some degeneracy between decay and some standard oscillation parameters.

Thank You