Global fit to three neutrino mixing

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General Seminar course

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Outline

- Introduction
- Determination of oscillation parameters
- Results of the Global Analysis
- Summary

Introduction

- Neutrino oscillation
- Neutrino oscillation parameters
- Other neutrino parameters
- Neutrino oscillation experiments
- Mass hierarchy

Neutrino oscillation

- Depends:

  Neutrino oscillation parameters

  Neutrino energy

  Source detector distance

$$P_{\nu_\alpha \to \nu_\beta}\left(L,E\right) = \sum_{k,j} U^*_{\alpha k} U_{\beta k} U_{\alpha j} U^*_{\beta j} \exp\left(-i \frac{\Delta m^2_{kj} L}{2E} \right)$$

Neutrino oscillation parameters

- Mixing matrix

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{CP}} \\ -s_{12}c_{13} - c_{12}s_{13}s_{23}e^{i\delta_{CP}} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta_{CP}} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta_{CP}} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta_{CP}} & c_{13}c_{23} \end{pmatrix}$$

$$c_{ij} \equiv \cos\theta_{ij} \qquad s_{ij} \equiv \sin\theta_{ij}$$

- Mass-squared splittings $\Delta m^2_{ij} \equiv m^2_i - m^2_j$

Other neutrino parameters

- Mass of neutrinos:

$$m_1, m_2, m_3$$

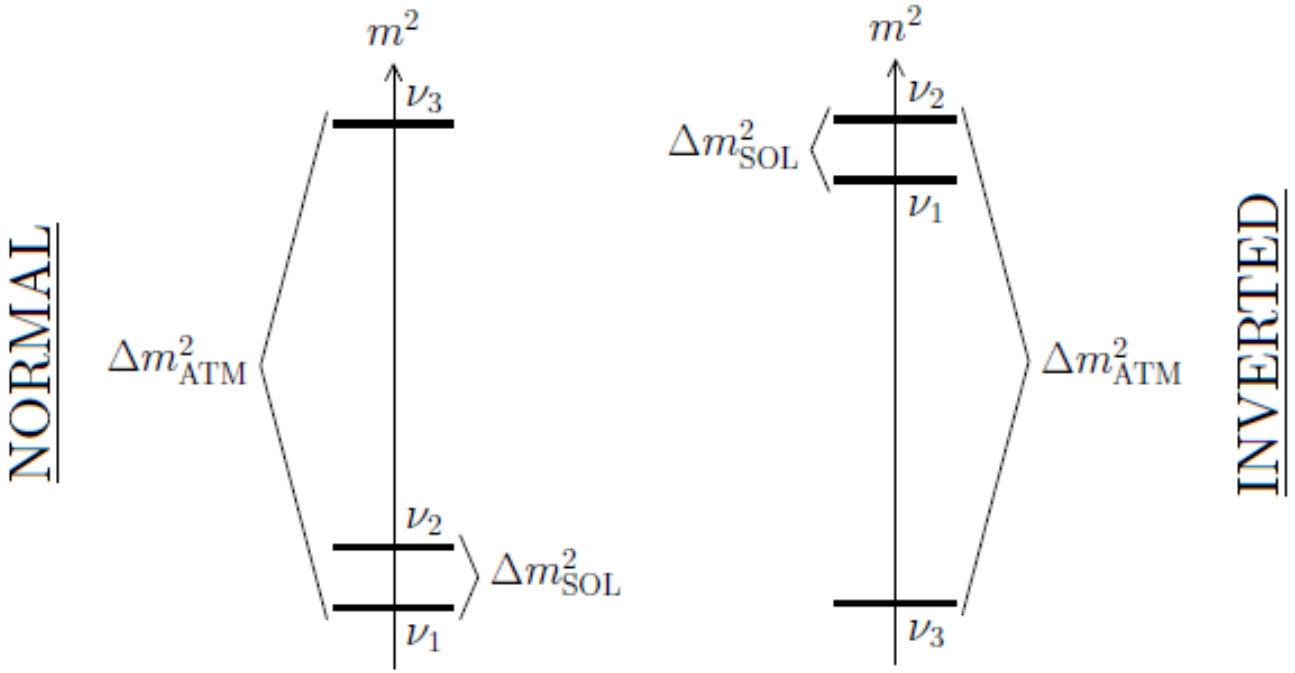
- Majorana phases:

$$\alpha_1 \,\&\, \alpha_2$$

Neutrino oscillation experiments

- Reactor (LBL, VLBL)
- LBL Accelerator
- Atmospheric
- solar

Mass hierarchy



Fundamentals of Neutrino Physics and Astrophysics, Carlo Giunti & Chung W. Kim.

Determination of oscillation parameters

- Determination of θ_{13}
- Determination of θ_{23}
- Determination of $\left|\Delta m^2_{31}\right|$ with reactor Experiments
- Determination of δ_{CP}

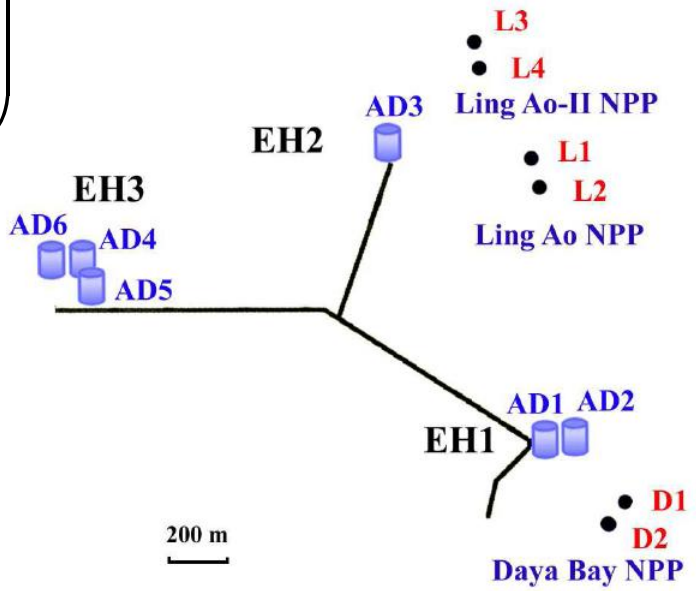
Determination of θ_{13}

- LBL reactor: Double Chooz, Daya Bay & RENO

$$P_{survival} = 1 - \sin^2(2\theta_{13}) \sin^2\left(\frac{\Delta m^2_{31} L}{E}\right)$$

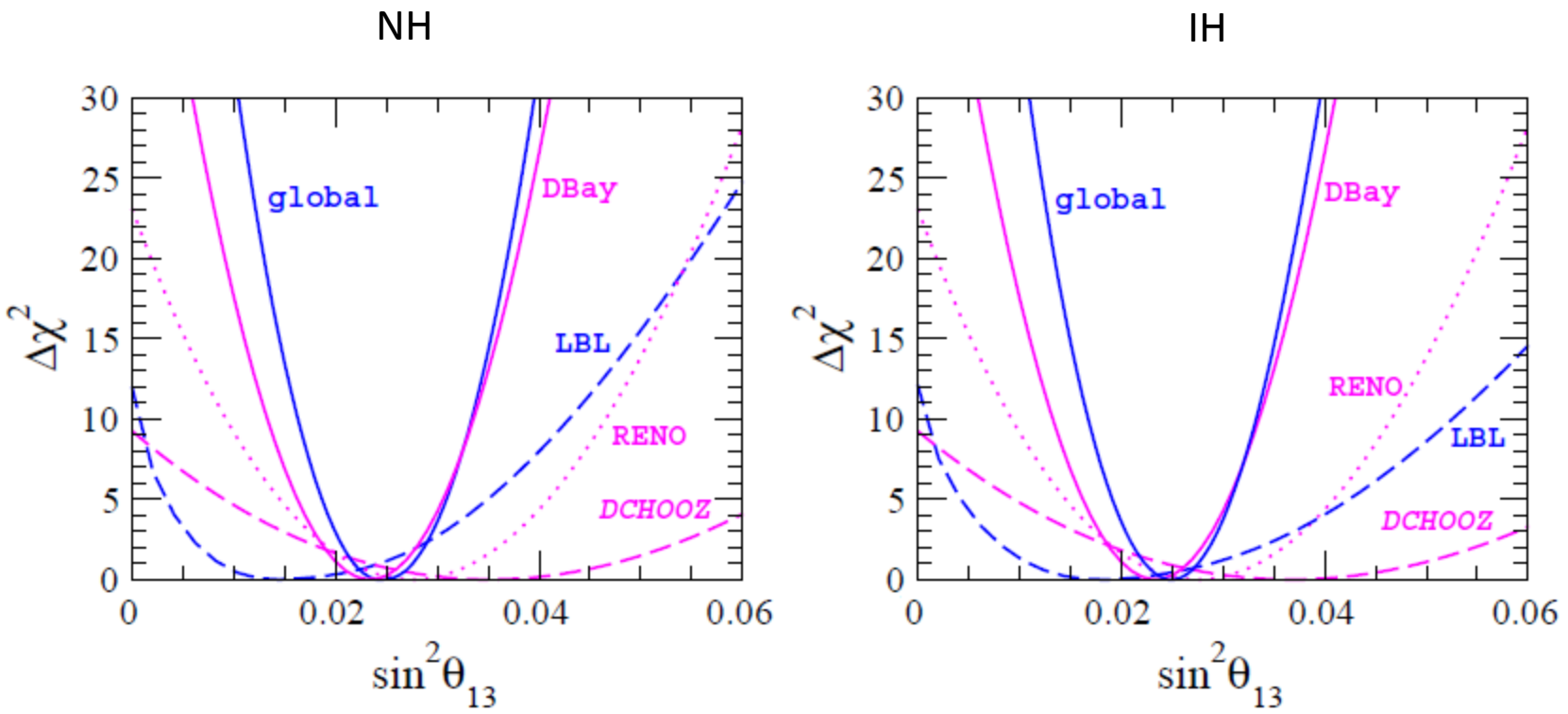
- LBL accelerator:

  T2K & MINOS



Observation of electron-antineutrino disappearance at Daya Bay; arXiv:1203.1669v2

Determination of θ_{13}



Global status of neutrino oscillation parameters after Neutrino-2012, D. V. Forero, M. Tórtola, and J. W. F. Valle; arXiv:1205.4018v4

Determination of θ_{23}

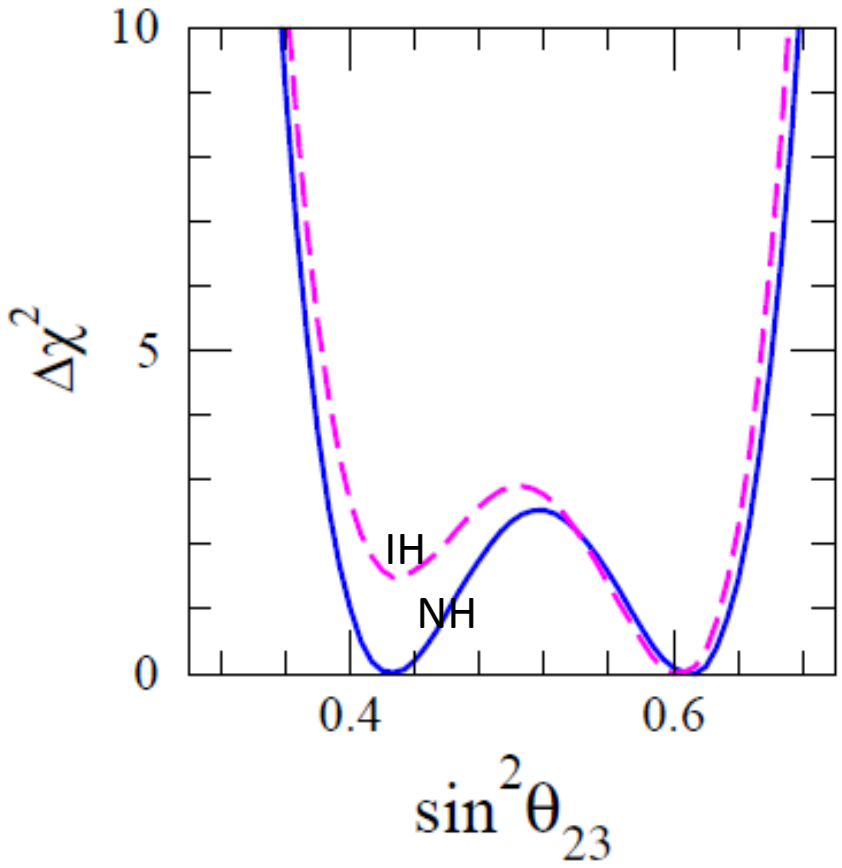
- LBL accelerator: MINOS

$$P_{\nu_\mu \to \nu_\mu} = 1 - 4\sin^2\theta_{23}\cos^2\theta_{13}\left(1-\sin^2\theta_{23}\cos^2\theta_{13}\right)\sin^2\frac{\Delta m^2_{31}L}{4E}$$

- Sensitive to $\sin^2 2\theta_{23}$ in limit of $\theta_{13} \to 0$
- $\sin^2 2\theta_{23}$ is not maximal C.L. 1.7σ - 2σ
- Octant or degeneracy θ_{23}
- LBL ν_e appearance sensitive

$$\cos^2\theta_{13}\sin^2\theta_{13}\sin^2\theta_{23}$$

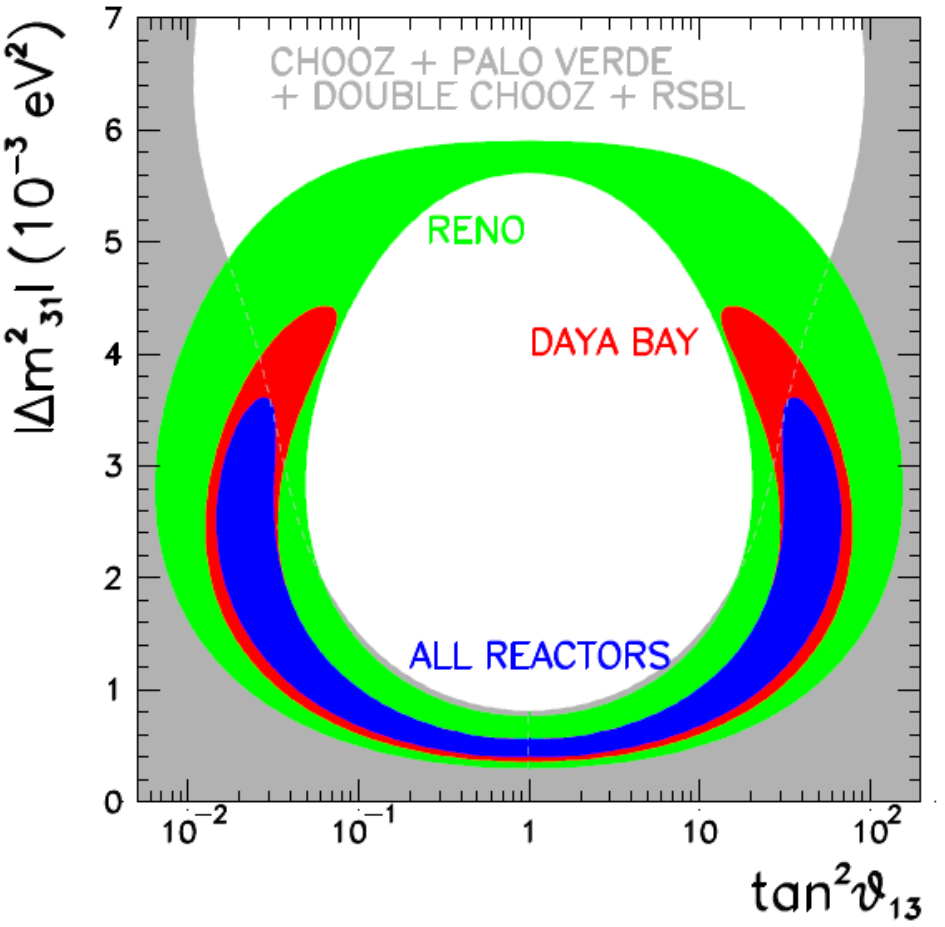
Determination of θ_{23}



Global status of neutrino oscillation parameters after Neutrino-2012, D. V. Forero, M. Tórtola, and J. W. F. Valle; arXiv:1205.4018v4

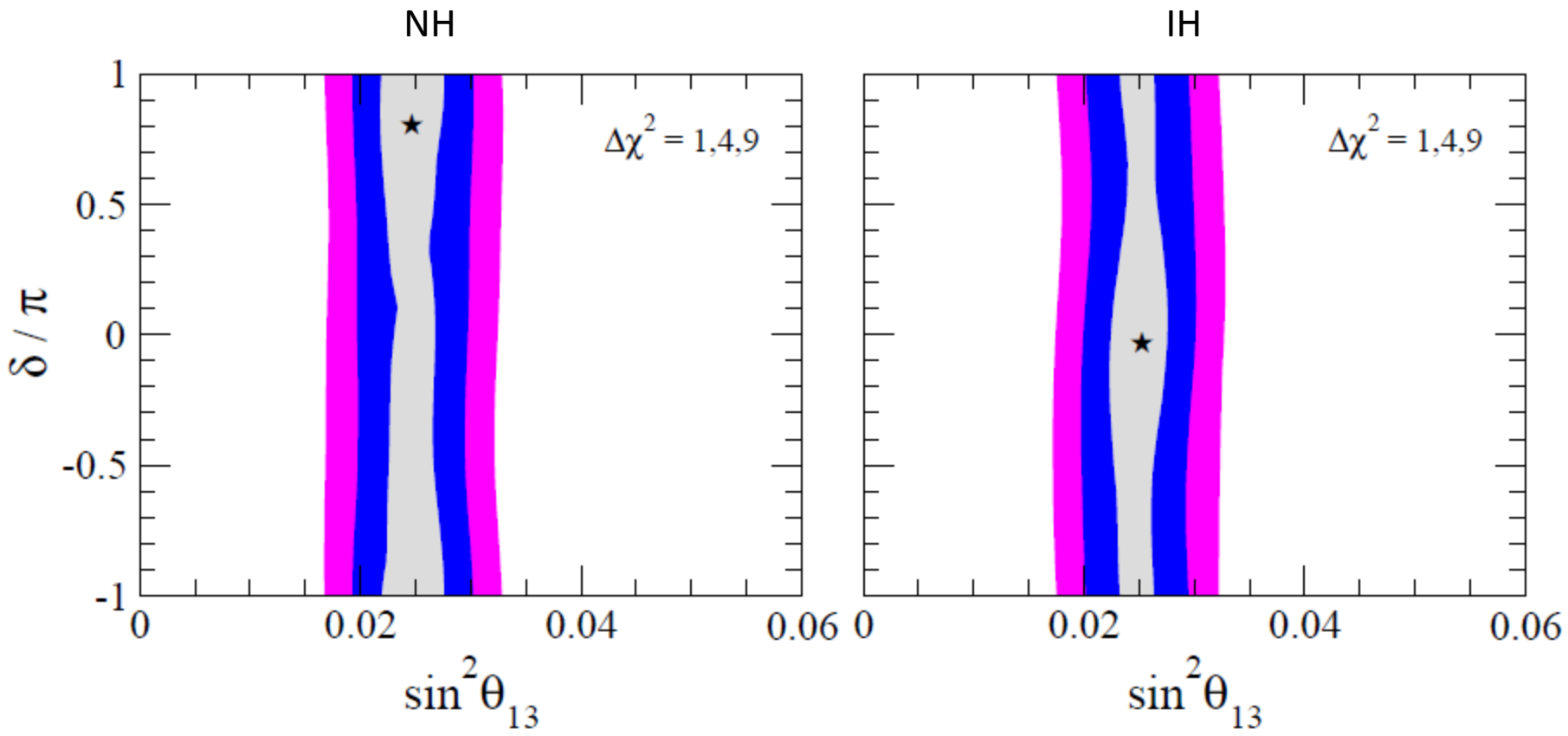
Determination of $\left|\Delta m^2_{31}\right|$ with reactor Exp.

- $\left|\Delta m^2_{31}\right|$ determined by atmospheric & KamlAND



Global t to three neutrino mixing: critical look at present precision; M. C. Gonzalez-Garcia, Michele Maltoni, Jordi Salvado, Thomas Schwetze; arXiv:1209.3023v3

Determination of δ_{CP}



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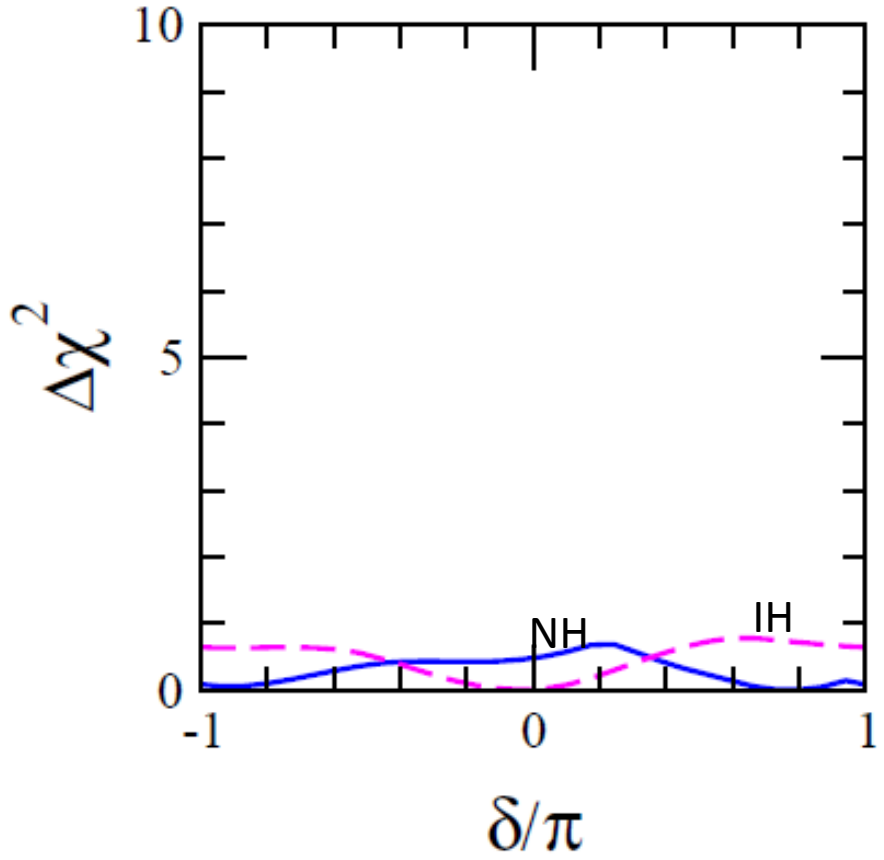
Determination of δ_{CP}



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Results of the Global Analysis

parameter	best fit	1σ range	2σ range	3σ range	
Δm^2_{21} $[10^{-5}\mathrm{eV}^2]$	7.62	7.43–7.81	7.27–8.01	7.12–8.20	
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\mathrm{eV}^2]$	2.55	$2.46 - 2.61$	$2.38 - 2.68$	$2.31 - 2.74$	NH
	2.43	$2.37 - 2.50$	$2.29 - 2.58$	$2.21 - 2.64$	IH
$\sin^2\theta_{12}$	0.320	0.303–0.336	0.29–0.35	0.27–0.37	
$\sin^2\theta_{23}$	0.613 $(0.427)^a$	0.400-0.461 & 0.573–0.635	0.38–0.66	0.36–0.68	NH
	0.600	0.569–0.626	0.39–0.65	0.37–0.67	IH
$\sin^2\theta_{13}$	0.0246	0.0218–0.0275	0.019–0.030	0.017–0.033	NH
	0.0250	0.0223–0.0276	0.020–0.030		IH
δ	0.80π	$0 - 2\pi$	$0 - 2\pi$	$0 - 2\pi$	NH
	-0.03π				IH

Global status of neutrino oscillation parameters after Neutrino-2012, D. V. Forero, M. Tórtola, and J. W. F. Valle; arXiv:1205.4018v4

Results of the Global Analysis

- Δm^2_{21} solar + Kamland
- $\left|\Delta m^2_{31}\right|$ LBL (MINOS)
- $\sin^2\theta_{12}$ solar + Kamland
- $\sin^2\theta_{23}$ atmospheric
- $\sin^2\theta_{13}$ Daya Bay
- δ

Summary

- Introduction of neutrino oscillation parameters
- Experiments determine these parameters
- Determination these parameters
- Quantity of these parameters

References

- Global status of neutrino oscillation parameters after Neutrino-2012, D. V. Forero, M. Tórtola, and J. W. F. Valle; arXiv:1205.4018v4
- Global t to three neutrino mixing: critical look at present precision; M. C. Gonzalez-Garcia, Michele Maltoni, Jordi Salvado, Thomas Schwetze; arXiv:1209.3023v3

Thanks for your attention