Overview of ESSnuSB to measure δ_{CP}

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Based on: (i) Blennow, Fernandez-Martinez, Ota, Rosauro, ESSnuSB WP6 physics performance report
(ii) Ghosh, Ohlsson, 1906.05779

Neutrino Oscillation

- Neutrino oscillation: transition from one flavor to another
- Reason: Flavour and mass eigenstates are not same

$$|\nu_\alpha\rangle \quad = \quad \sum_{i=1}^{N} U_{\alpha i}^{\mathrm{PMNS}} |\nu_i\rangle$$

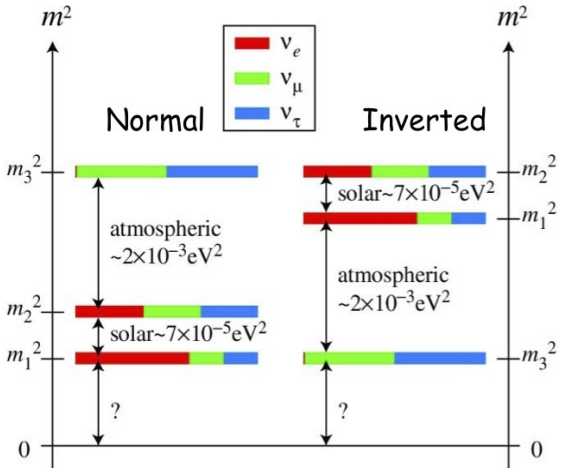
- The transition probability $\nu_\alpha \to \nu_\beta$:

$$P_{\alpha\beta} = |\langle \nu_\beta | \nu_\alpha(t) \rangle|^2$$

Parameters of neutrino oscillation:

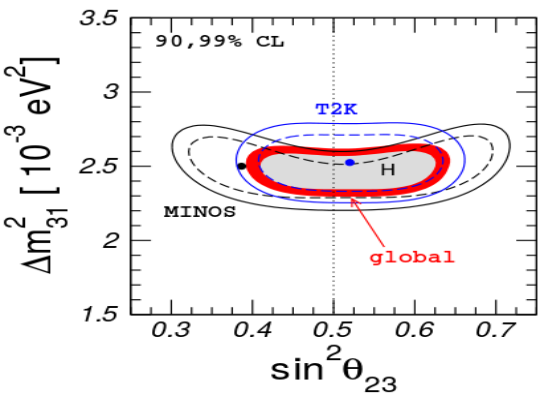
- Elements of U: Three mixing angles and one Dirac phase θ_{12}, θ_{23}, θ_{13}, δ_{CP}
- Two mass squared differences: Appears in $P_{\alpha\beta}$ $\Delta_{21} = m_2^2 - m_1^2$, $\Delta_{31} = m_3^2 - m_1^2$
- L and E

Unknowns



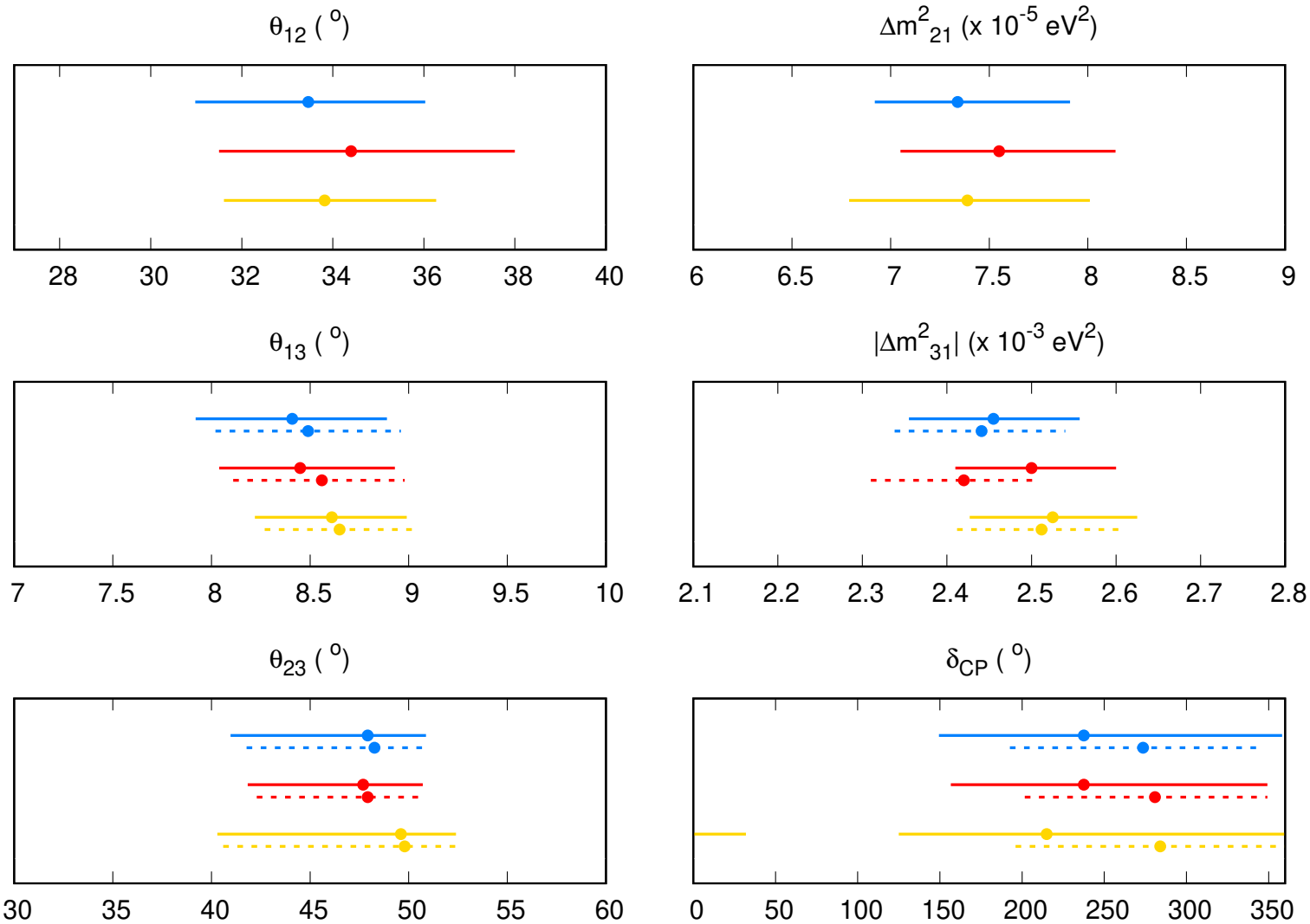
- The sign of Δm^2_{31} i.e.,
  $\Delta m^2_{31} > 0 \Rightarrow$ Normal Hierarchy (NH)
  or
  $\Delta m^2_{31} < 0 \Rightarrow$ Inverted Hierarchy (IH).

- The octant of θ_{23} i.e.,
  $\theta_{23} > 45^\circ \Rightarrow$ Higher Octant (HO) or
  $\theta_{23} < 45^\circ \Rightarrow$ Lower Octant (LO).



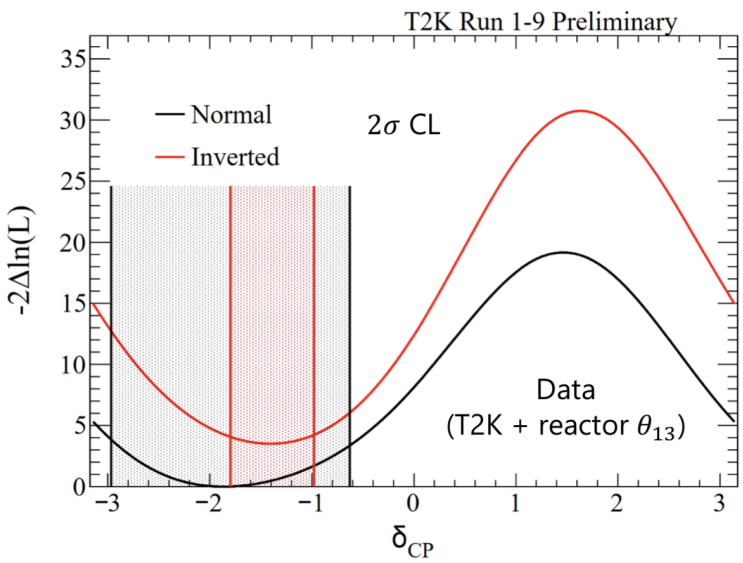
- δ_{CP} (violation and precision)

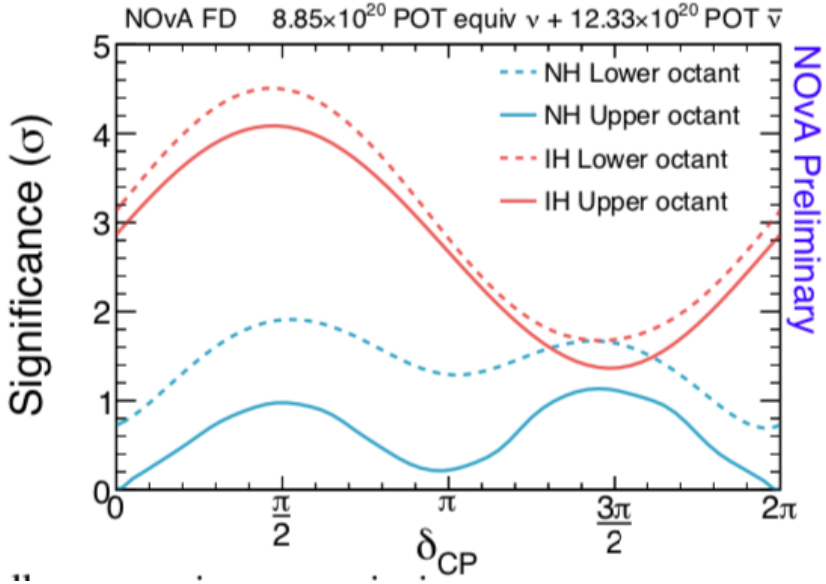
Current status of oscillation parameters



Bari, Valencia, Nufit (gnuplot script by Sushant k. Raut)

Results from T2K and NOνA





NOνA best-fit is ruled by T2K $> 2\ \sigma$

More data will clear things

T2K talk by Francis Bench

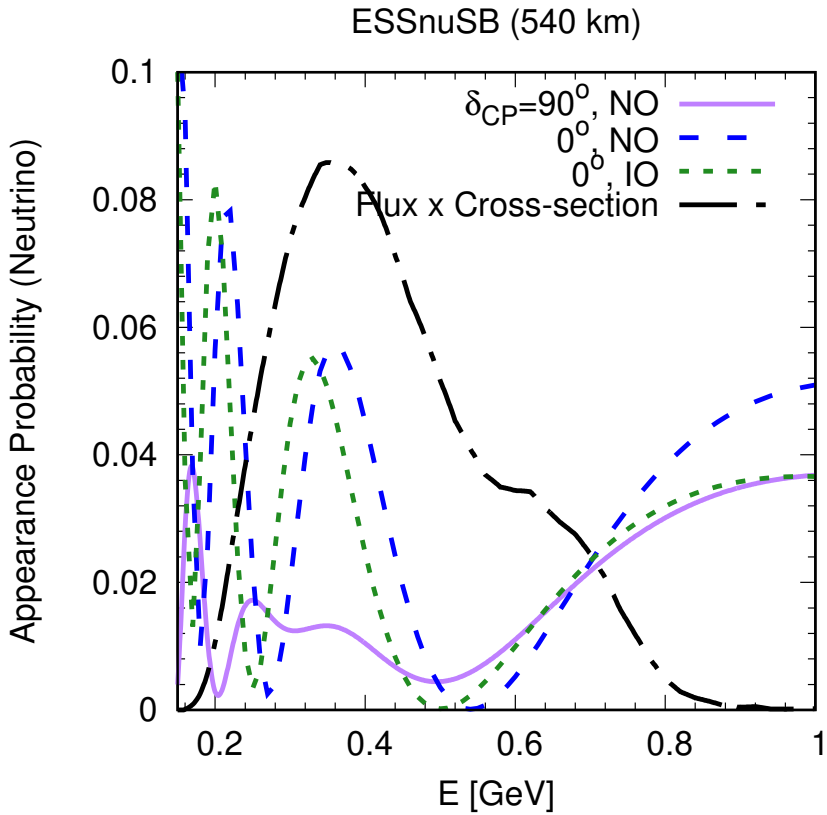
Noνa talk by Erica Smith

The ESSnuSB experiment

- 2.5 GeV proton beam
- 507 kt WC detector
- 10 years of running
- 540 km or 360 km

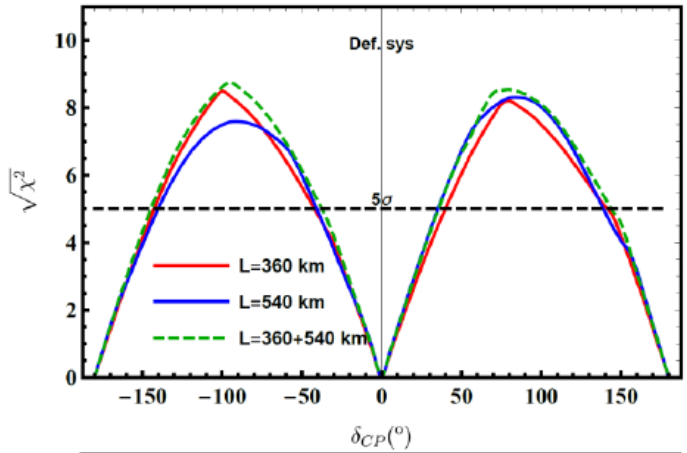
For more details see plenary talk on ESSnuSB by Marcos Dracos on tomorrow 10 AM

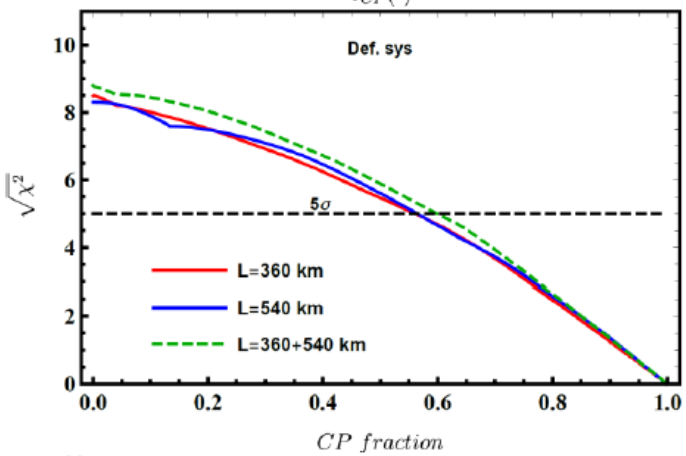
Probability and flux

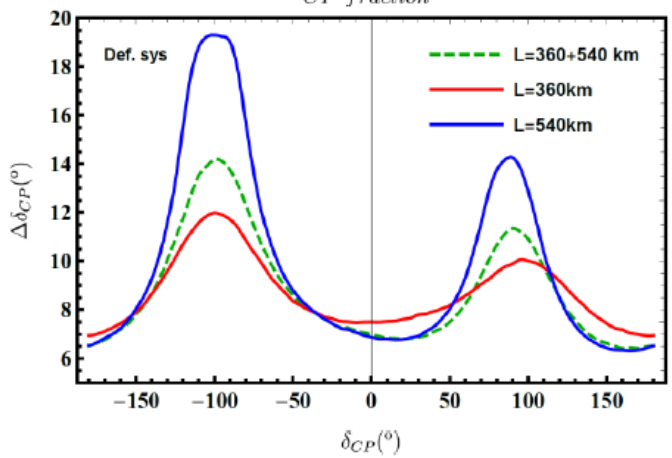


- Designed to study physics at 2nd maximum
- Variation of probability wrt to δ_{CP} is larger in 2nd maximum
- Powerful experiment to measure δ_{CP} even with lower statistics

δ_{CP} Sensitivity

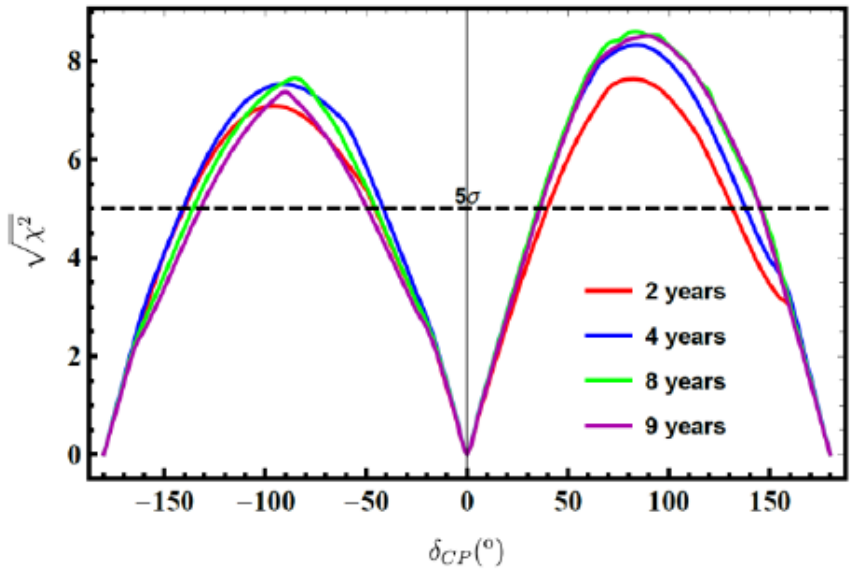


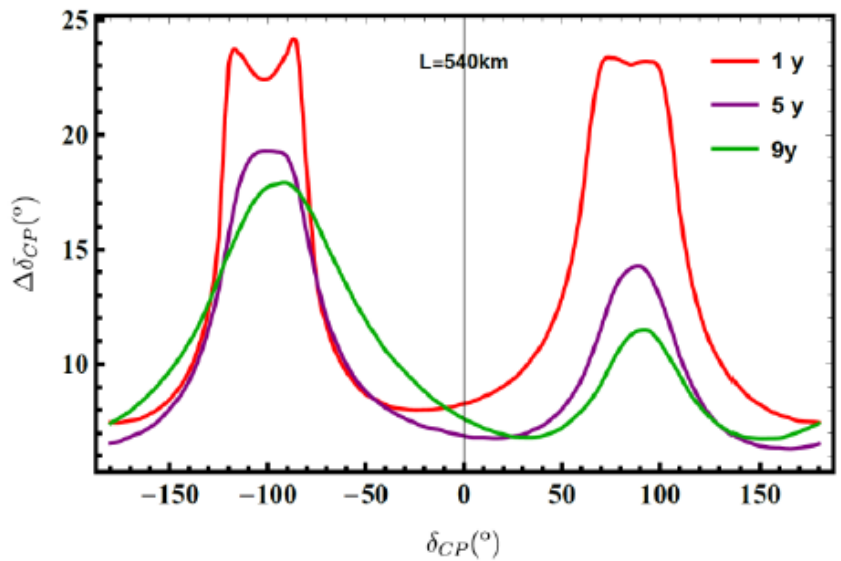




- 5+5 running
- 8 σ for maximal CPV
- 60% CP coverage for 5 σ CPV
- upto 6° CP precision

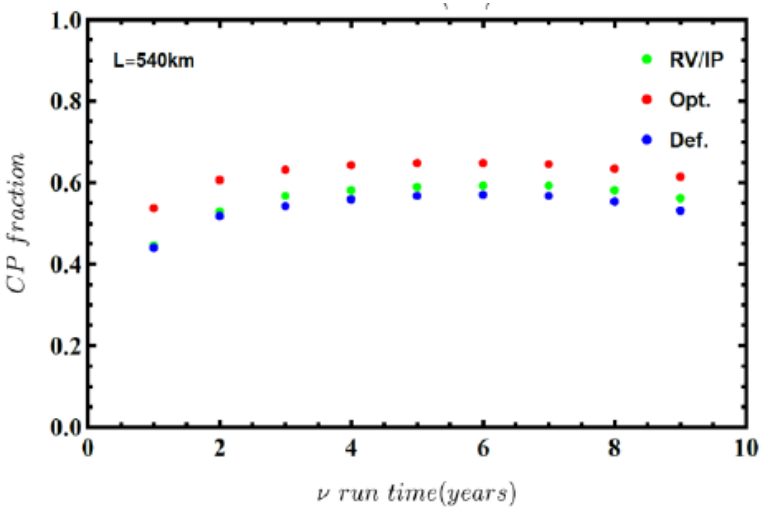
Effect of run-time

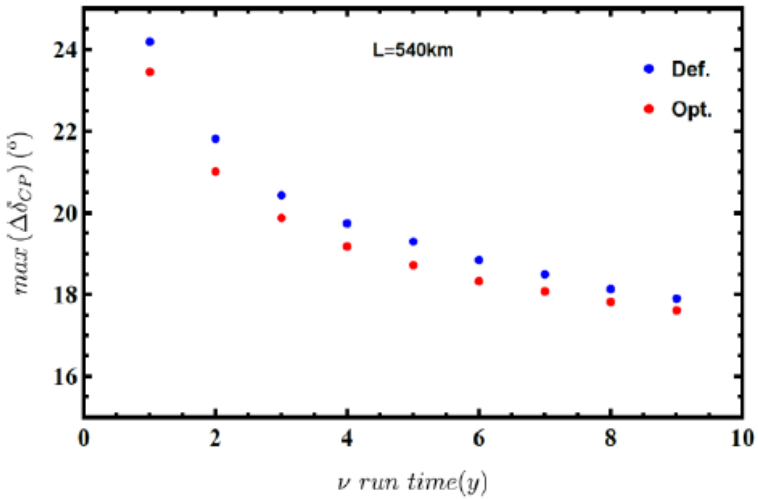




The rest of the 10 years running in antineutrino mode

Effect of Systematics



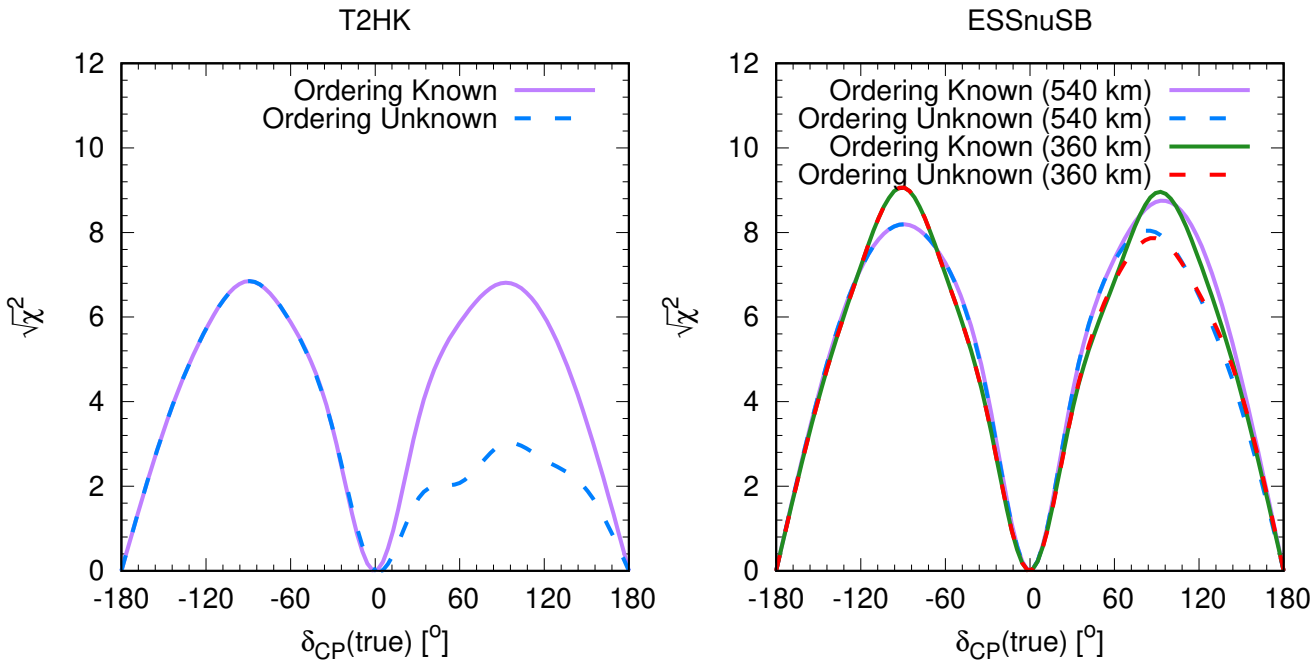


Detector	Systematic uncertainty on near detector fiducial volume	0.5%	0.2%
Detector	Systematic uncertainty on far detector fiducial volume	2.5%	1%
Beam	Systematic uncertainty signal neutrino component	7.5%	5%
Beam	Systematic uncertainty background neutrino component	15%	10%
Detector	Systematic uncertainty on QE cross section	15%	10%
Detector	Systematic uncertainty on electron to muon neutrino ratio of QE cross	11%	3.5%
Location	Systematic uncertainty on matter density along neutrino beam	2%	1%

RV/IP: 374 kt with 3% overall systematics (cf T2HK)

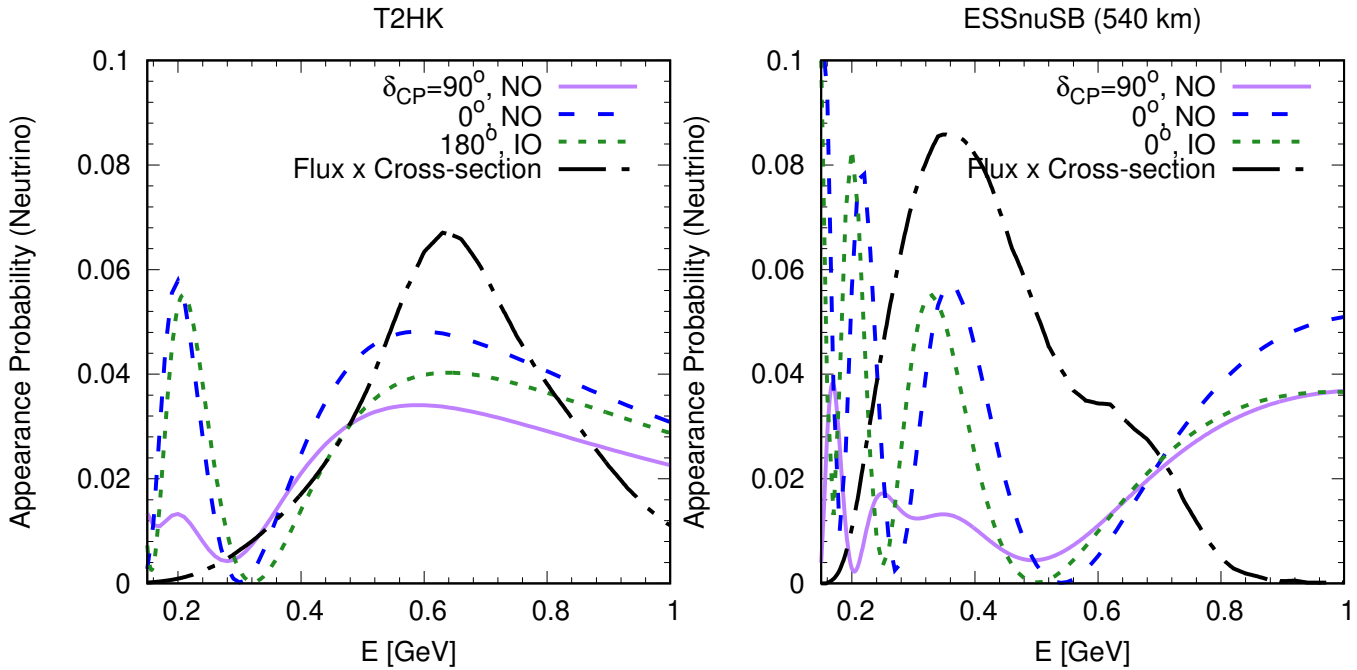
Comparison with T2HK

Effect of hierarchy



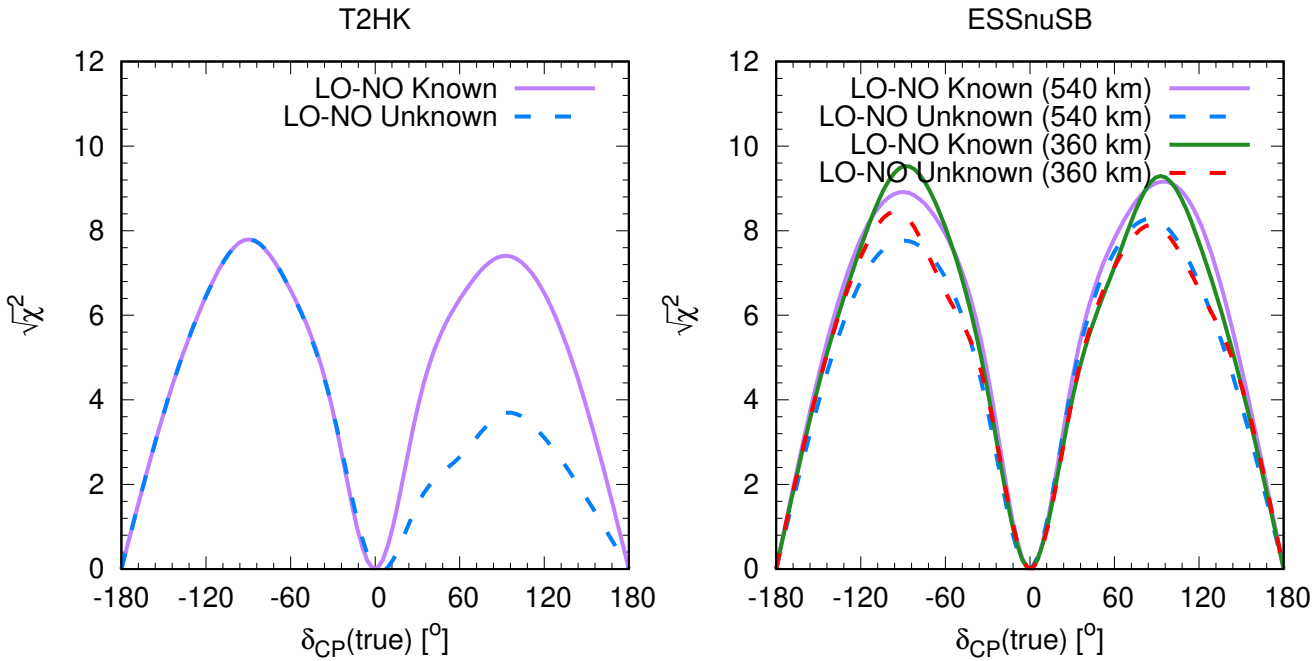
- $\theta_{23} = 45^\circ$, 5+5
- Drop at $+90^\circ$ is not significant for ESSnuSB
- CP sensitivity of ESSnuSB is independent of hierarchy information

Reason



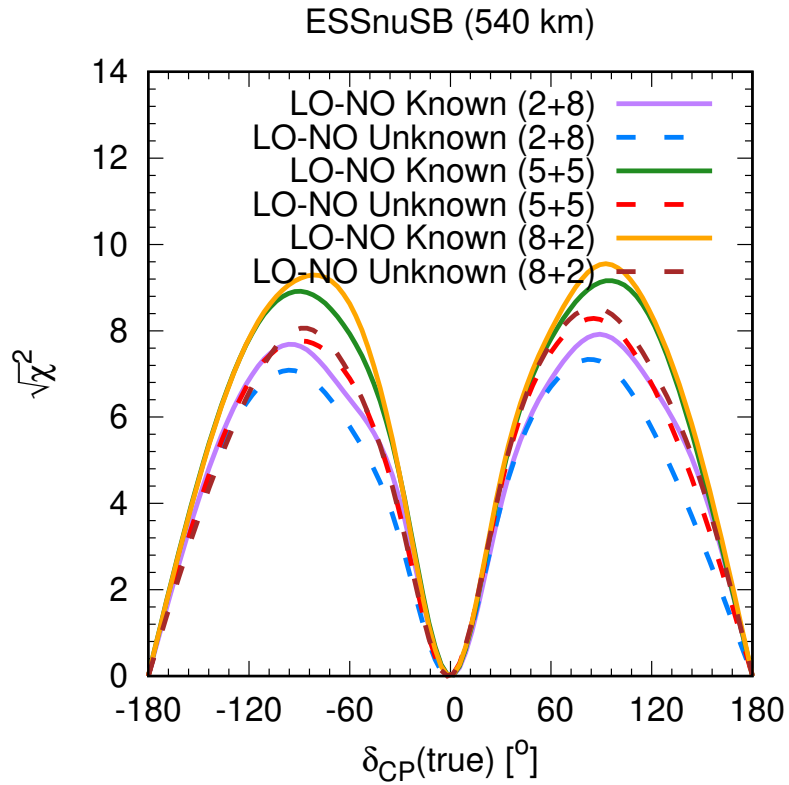
- CPV sensitivity is the separation between the solid and dashed curves
- Green dashed and purple solid is closer in T2HK
- Hierarchy degeneracy is negligible at 2nd maximum

Effect of octant



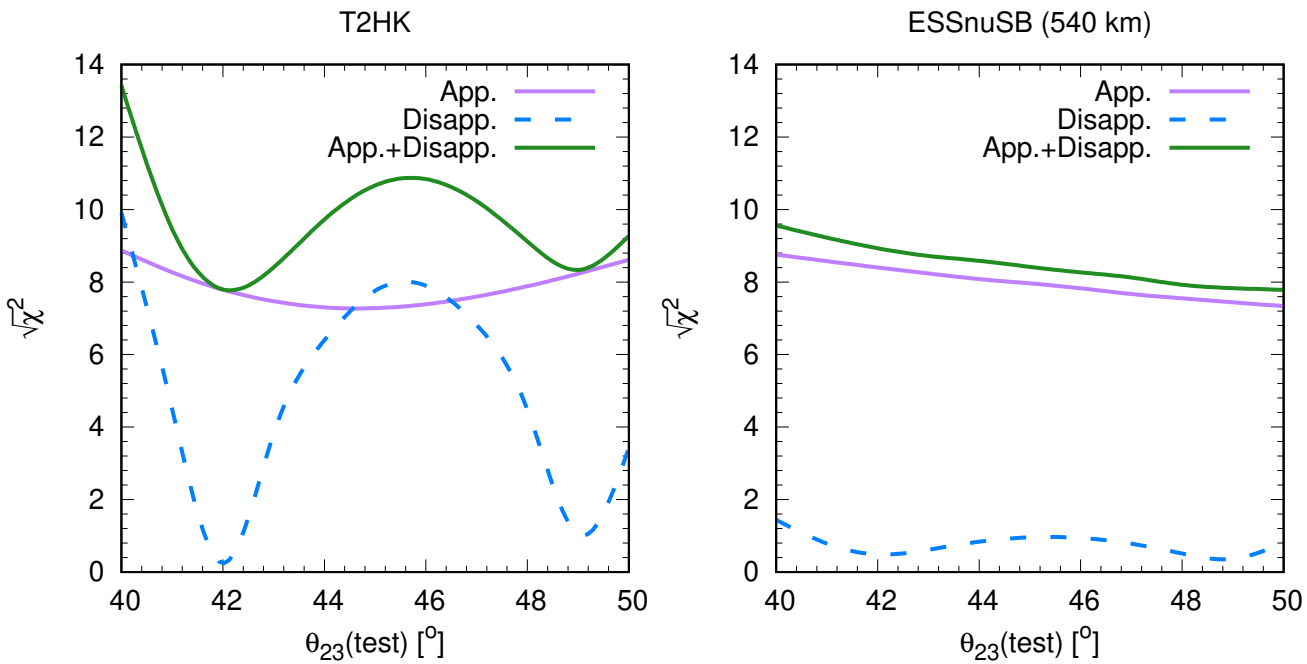
- $\theta_{23} = 42^\circ$, 5+5
- Small drop at -90° for ESSnuSB
- Octant degeneracy affects ESSnuSB

Resolving Octant degeneracy



- Dominant antineutrino run is required to reduce the effect
- But this also reduce the sensitivity

Comment on θ_{23} precision



- $\theta_{23}(true) = 42°$, $\delta_{CP}(true) = -90°$, 5+5
- Disap channel of ESSnuSB is very shallow
- This affect the CP sensitivity

Summary

- ESSnuSB is a powerful experiment to measure δ_{CP} at 2nd maximum
- Sensitivity in terms of run-time and systematics have been discussed
- Both T2HK and ESSnuSB are complementary to each other

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Thank you