Expectations from T2K & NOvA in light of recent Neutrino Data

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References

Based on the papers:

1) *Potential of optimized NOνA for large θ_{13} & combined performance with a LArTPC and T2K*

SKA, S. Prakash, S. Raut, S. Uma Sankar, arXiv: 1208.3644

2) *Resolving the Octant of θ_{23} with T2K and NOνA*

SKA, S. Prakash, S. Uma Sankar, arXiv: 1301.2574

Global Analysis of World Neutrino Data

Reference	Ref. [53]	Ref. [54]	Ref. [55]
$\Delta m^2_{21}(10^{-5}\mathrm{eV}^2)$	7.62 ± 0.19	$7.54^{+0.26}_{-0.22}$	$7.50^{+0.205}_{-0.160}$
$\Delta m^2_{31}(10^{-3}\mathrm{eV}^2)$ (N)	$2.55^{+0.06}_{-0.09}$	$2.43^{+0.06}_{-0.10}$	$2.49^{+0.055}_{-0.051}$
$\Delta m^2_{13}(10^{-3}\mathrm{eV}^2)$ (I)	$2.43^{+0.07}_{-0.06}$	$2.42^{+0.07}_{-0.11}$	$\Delta m^2_{23}(10^{-3}\mathrm{eV}^2) = 2.47^{+0.064}_{-0.073}$
$\sin^2\theta_{13}$ (N)	$0.0246^{+0.0029}_{-0.0028}$	0.0241 ± 0.0025	0.025 ± 0.0023
$\sin^2\theta_{13}$ (I)	$0.0250^{+0.0026}_{-0.0027}$	$0.0244^{+0.0023}_{-0.0025}$	
$\sin^2\theta_{23}$ (N)	$0.427^{+0.034}_{-0.027} \oplus 0.613^{+0.022}_{-0.040}$	$0.386^{+0.024}_{-0.021}$	$0.41^{+0.030}_{-0.029} \oplus 0.60^{+0.020}_{-0.026}$
3σ range	$0.36 \to 0.68$	$0.331 \to 0.637$	$0.34 \to 0.67$
$\sin^2\theta_{23}$ (I)	$0.600^{+0.026}_{-0.031}$	$0.392^{+0.039}_{-0.022}$	
3σ range	$0.37 \to 0.67$	$0.335 \to 0.663$	
$\sin^2\theta_{12}$	$0.320^{+0.016}_{-0.017}$	$0.307^{+0.018}_{-0.016}$	0.31 ± 0.013

SkA, Francesco Lombardi, T. Takeuchi, arXiv1207.3492

Ref. 53: Forero, Tortola, Valle, arXiv:1205.4018
Ref. 54: Fogli, Lisi, Marrone, Montanino, Palazzo, Rotunno, arXiv:1205.5254
Ref. 55: Gonzalez-Garcia, Maltoni, Salvado, Schwetz, arXiv:1209.3023

Event/Background Rates in NOνA/LArTPC

Channels	Old NOνA (15 kt)		New NOνA (14 kt)		LArTPC (10 kt)	
App.	Signal CC	Background (Int+Mis-ID+NC)	Signal CC	Background (Int+Mis-ID+NC)	Signal CC	Background (Int+Mis-ID+NC)
$P_{\mu e}$(NH)	**62**	6+1+4=**11**	**92**	8+5+19=**32**	**123**	18+5+7=**30**
$P_{\mu e}$(IH)	**36**	6+1+4=**11**	**54**	8+5+19=**32**	**72**	19+5+7=**31**
$P_{\bar{\mu}\bar{e}}$(NH)	**26**	6+<1+6=**12**	**30**	5+<1+10=**15**	**28**	17+2+2=**21**
$P_{\bar{\mu}\bar{e}}$(IH)	**34**	5+<1+6=**11**	**38**	5+<1+10=**15**	**36**	14+2+2=**18**
Disapp.	Signal CCQE	Background (NC only)	Signal CCQE	Background (NC+Wrong-Sign muon)	Signal CCQE	Background (NC+Wrong-Sign muon)
$P_{\mu\mu}$(NH)	**173**	**2**	**134**	1+6=**7**	**403**	7+20=**27**
$P_{\mu\mu}$(IH)	**173**	**2**	**134**	1+6=**7**	**402**	7+20=**27**
$P_{\bar{\mu}\bar{\mu}}$(NH)	**102**	**1**	**43**	<1+18=**18**	**136**	2+54=**56**
$P_{\bar{\mu}\bar{\mu}}$(IH)	**103**	**1**	**43**	<1+18=**18**	**137**	2+54=**56**

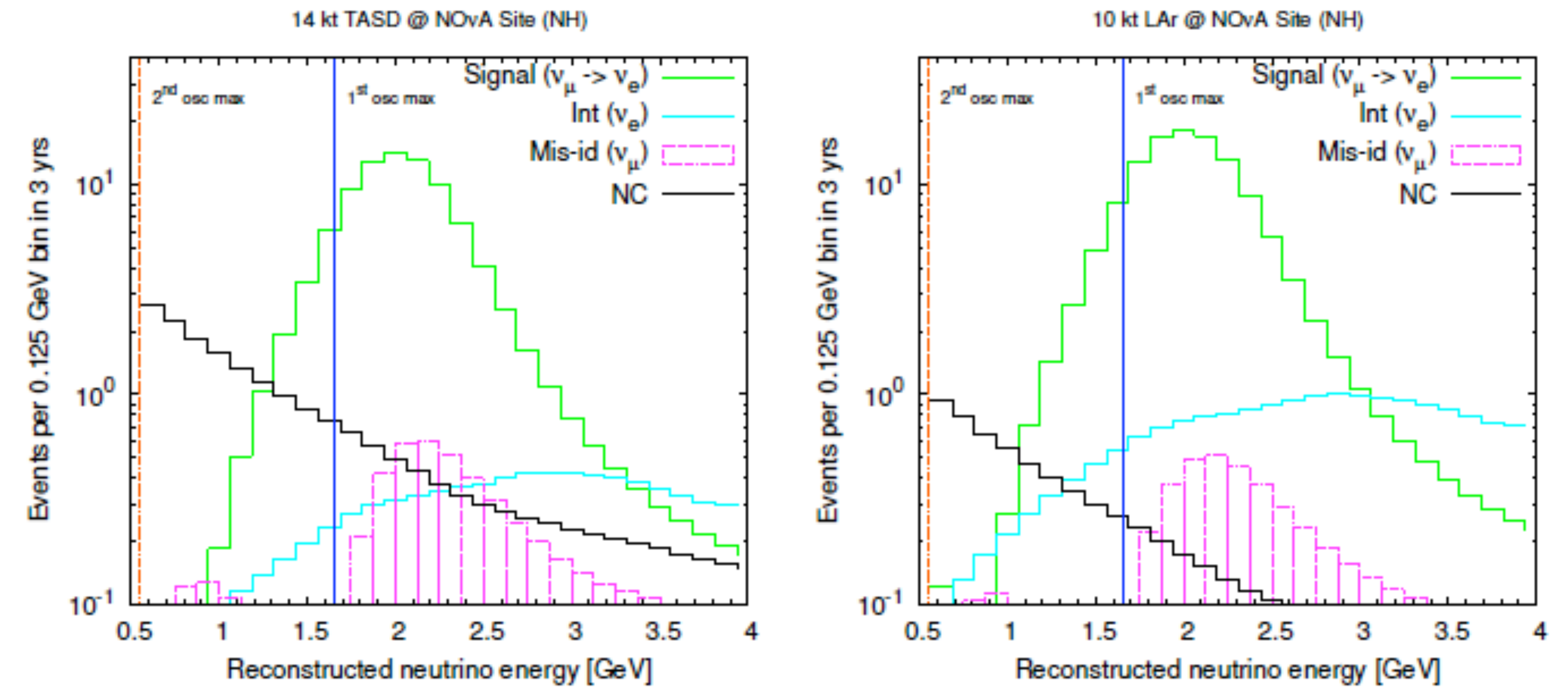
SkA, Prakash, Raut, Uma Sankar, arXiv1208.3644

NOνA has re-optimized its event selection criteria, with more events in both signal and background

R. Patterson, Neutrino 2012 talk

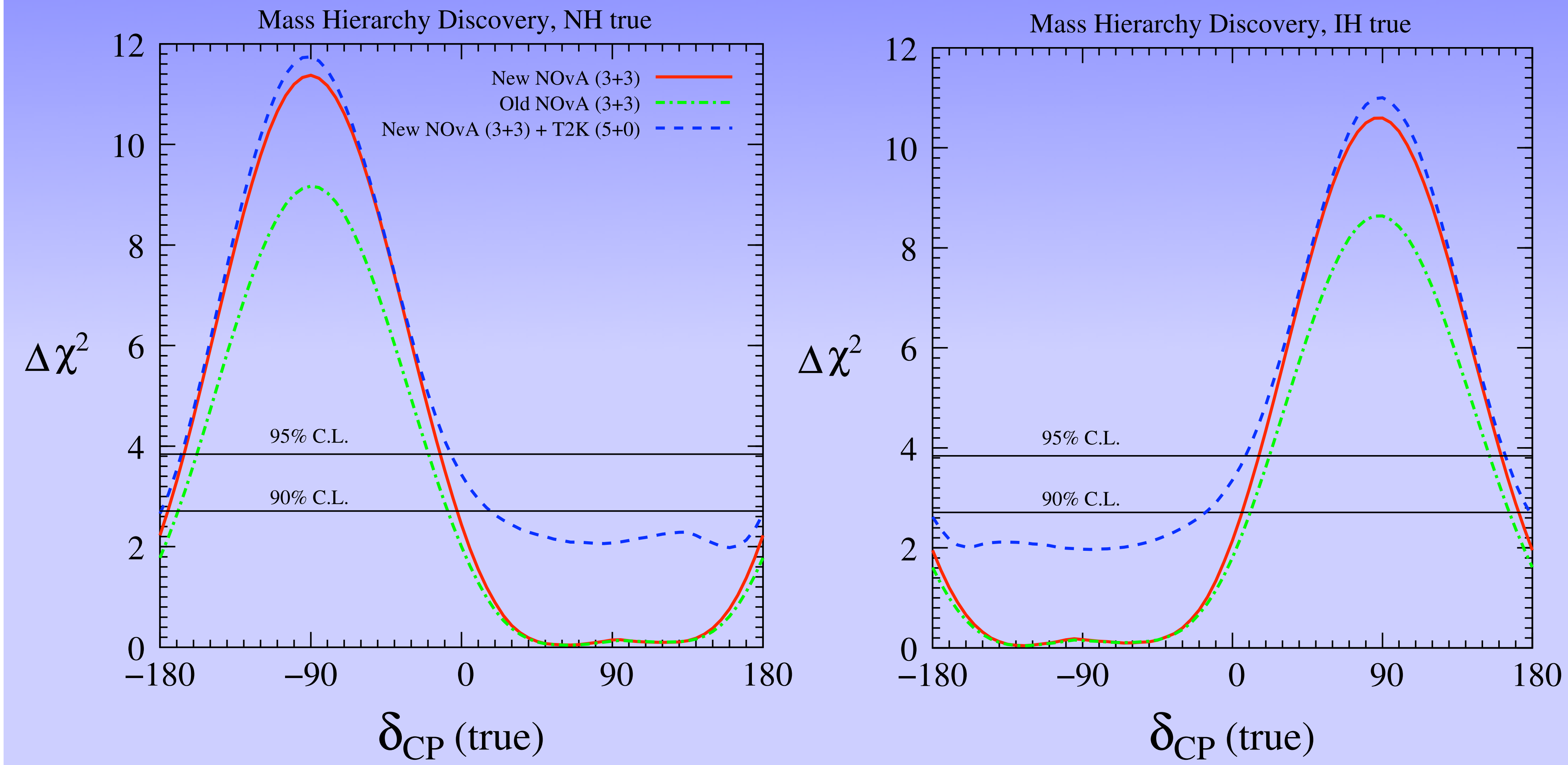
Rise in signal by 50%, background rises by a factor of 3, but we can tolerate that for large θ_{13}

Event/Background distribution in NOvA/LArTPC



SkA, Prakash, Raut, Uma Sankar, arXiv1208.3644

Present Generation Experiments: T2K and NOνA

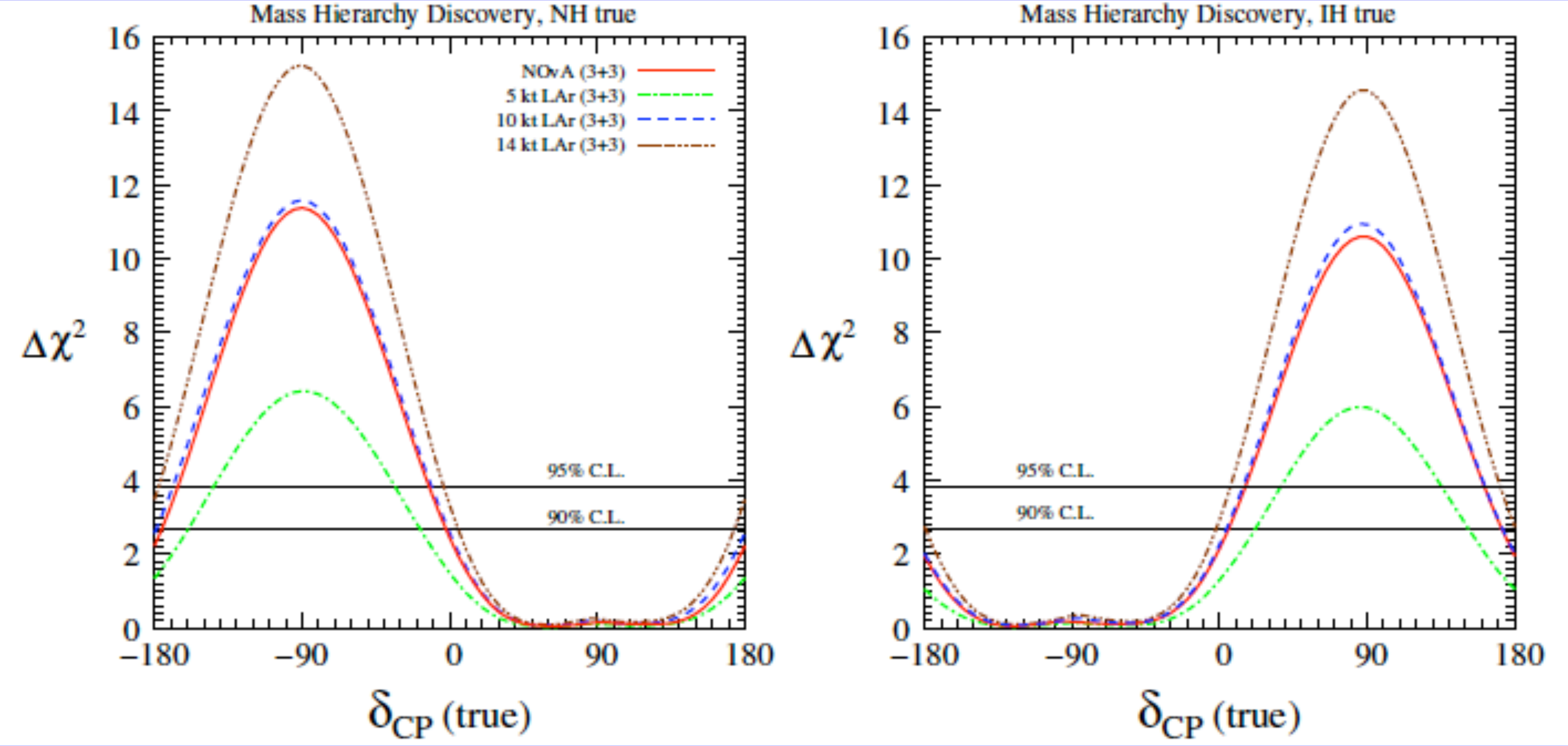


Agarwalla, Prakash, Raut, Uma Sankar, arXiv:1208.3644

Adding data from T2K and NOνA is useful to kill the intrinsic degeneracies

55% CP coverage @ 90% C.L. and 45% CP coverage @ 95% C.L. for MH discovery

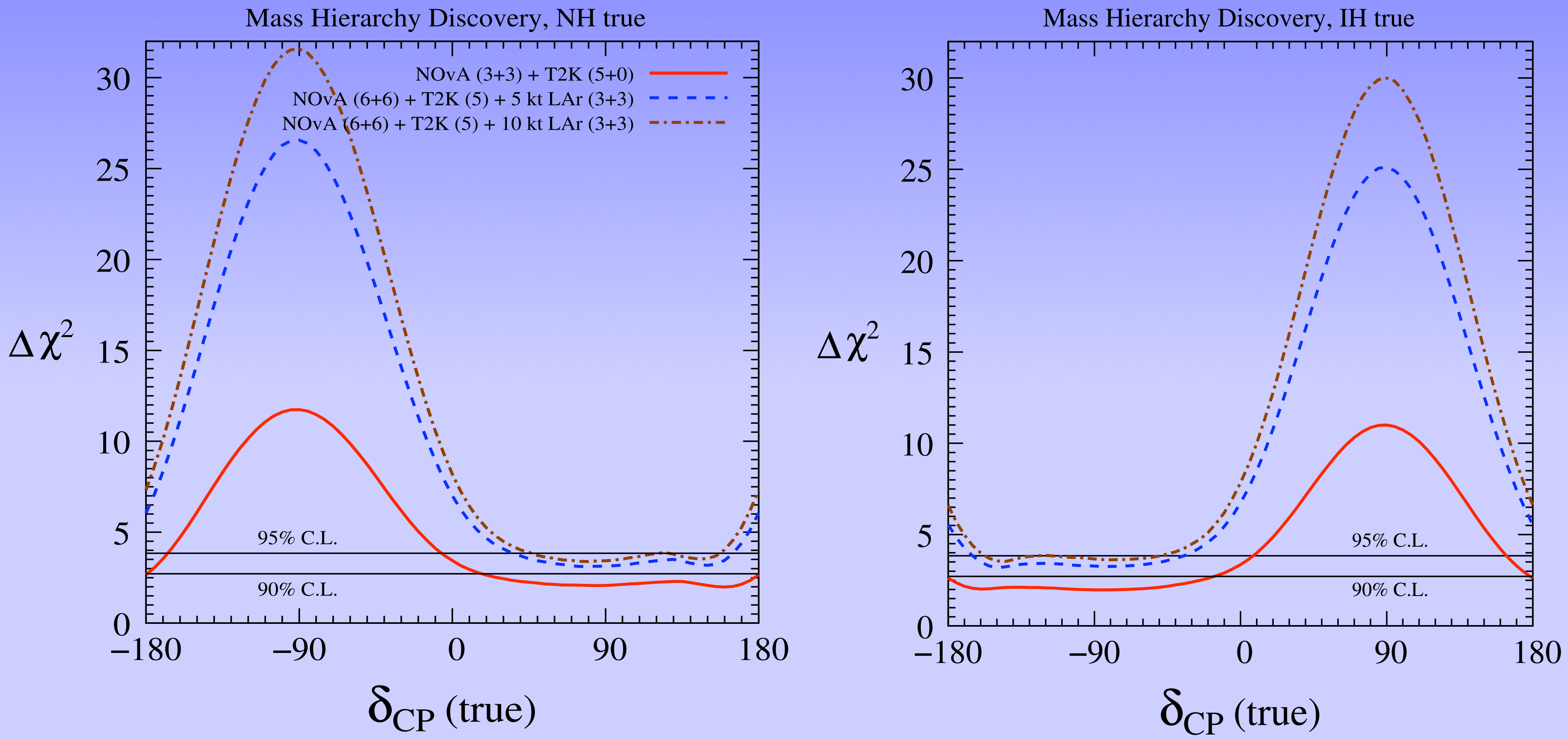
Present Generation Experiments: T2K and NOνA



Agarwalla, Prakash, Raut, Uma Sankar, arXiv:1208.3644

14kt NOνA is equivalent to 10 kt LArTPC

Add a small LArTPC in the NOvA Beamline

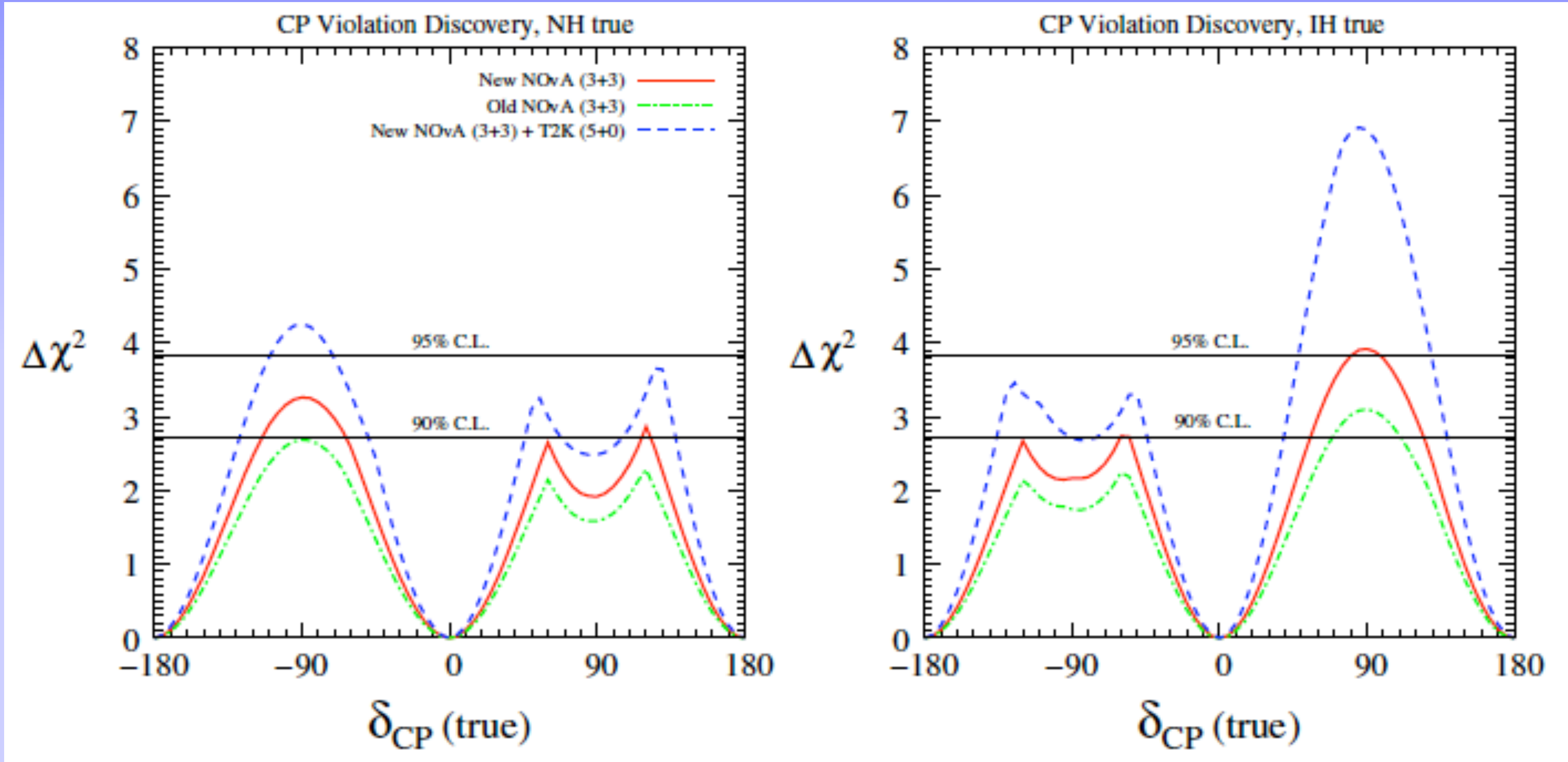


Agarwalla, Prakash, Raut, Uma Sankar, arXiv:1208.3644

Add a small LArTPC (5 to 10 kt) in the NOνA Beamline taking data simultaneously

100% CP coverage @ 90% C.L. and 64% CP coverage @ 95% C.L. w/ 5 kt LArTPC

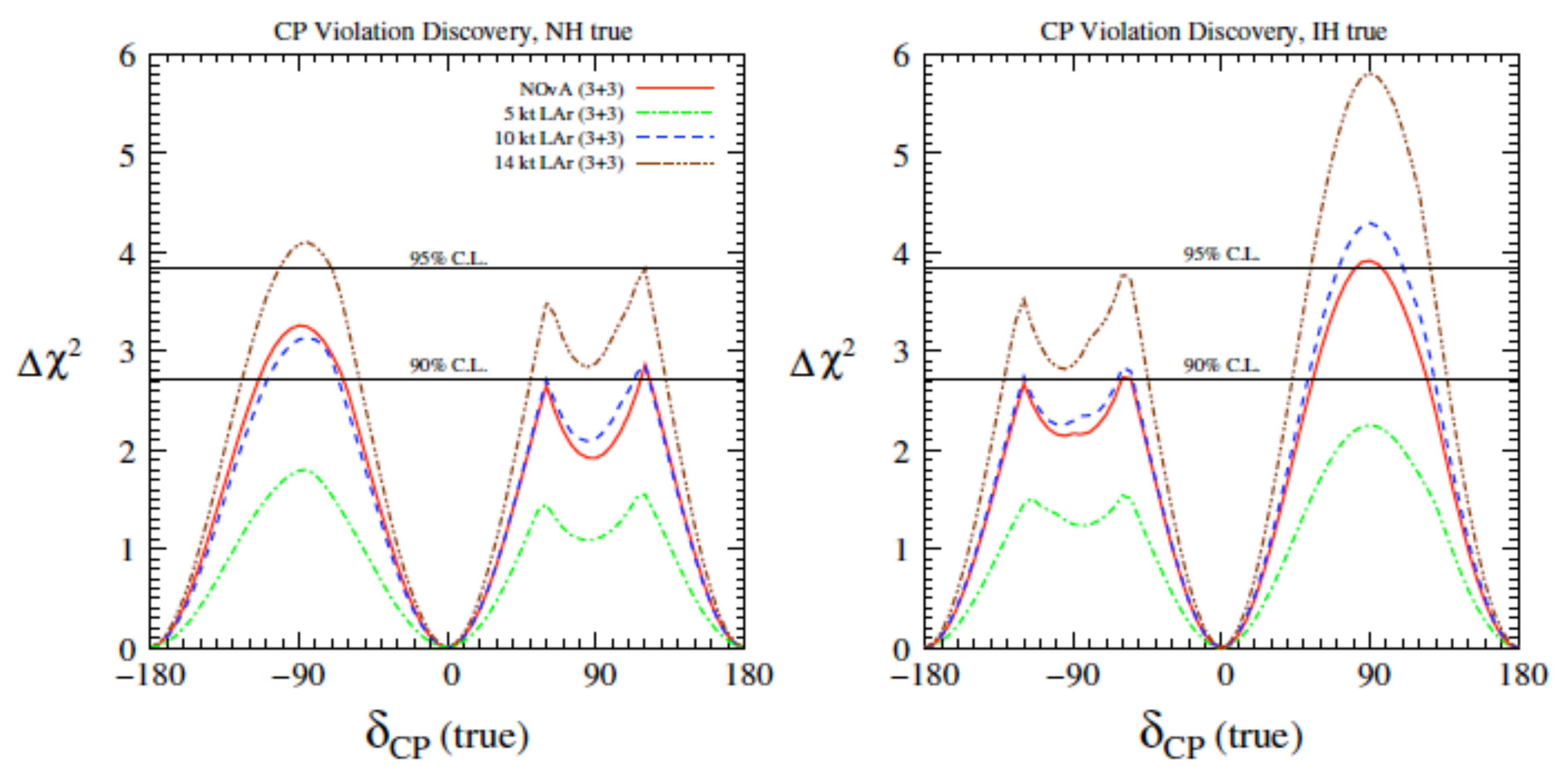
Present Generation Experiments: T2K and NOvA



Agarwalla, Prakash, Raut, Uma Sankar, arXiv:1208.3644

38% CP coverage @ 90% C.L. and 11% CP coverage @ 95% C.L. for CPV discovery

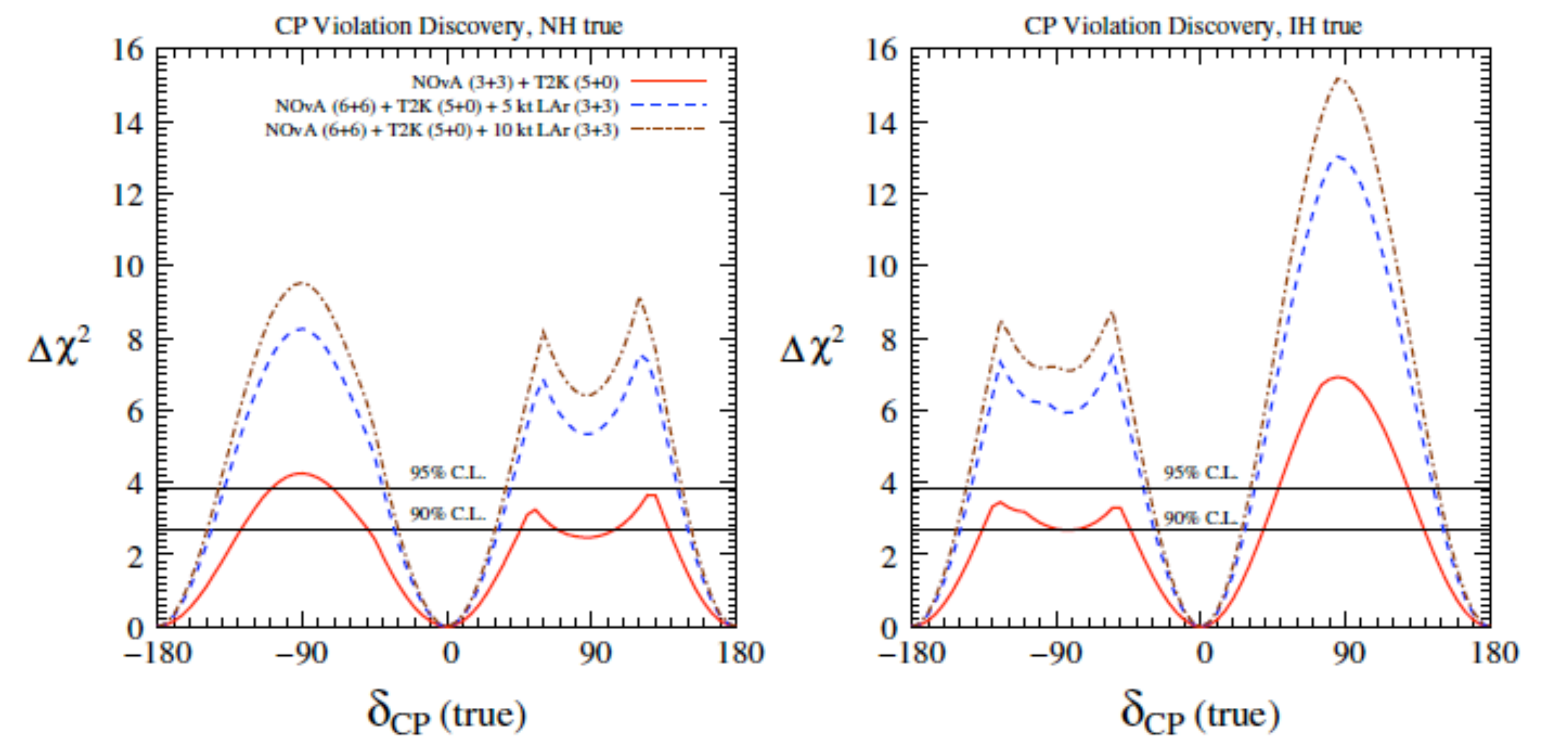
Present Generation Experiments: T2K and NOνA



Agarwalla, Prakash, Raut, Uma Sankar, arXiv:1208.3644

For CPV discovery: 14kt NOνA is equivalent to 10 kt LArTPC

Present Generation Experiments: T2K and NOvA



Agarwalla, Prakash, Raut, Uma Sankar, arXiv:1208.3644

64% CP coverage @ 90% C.L. and 56% CP coverage @ 95% C.L. w/ 5 kt LArTPC

Snapshot of MH & CPV discovery

$\sin^2 2\theta_{13}$ = 0.101, $\sin^2\theta_{23}$ = 0.5 — Setups	Fraction of δ_{CP}(true)			
	MH		**CPV**	
	NH true	IH true	NH true	IH true
NOνA (3+3)	0.48 (0.43)	0.46 (0.41)	0.16 (0)	0.21(0.04)
NOνA (3+3) + T2K (5+0)	0.55 (0.45)	0.54 (0.43)	0.38 (0.11)	0.49 (0.23)
NOνA (6+6) + T2K (5+0) + 5 kt LArTPC (3+3)	1 (0.64)	1 (0.64)	0.64 (0.56)	0.68 (0.61)
NOνA (6+6) + T2K (5+0) + 10 kt LArTPC (3+3)	1 (0.71)	1 (0.73)	0.67 (0.60)	0.71 (0.64)

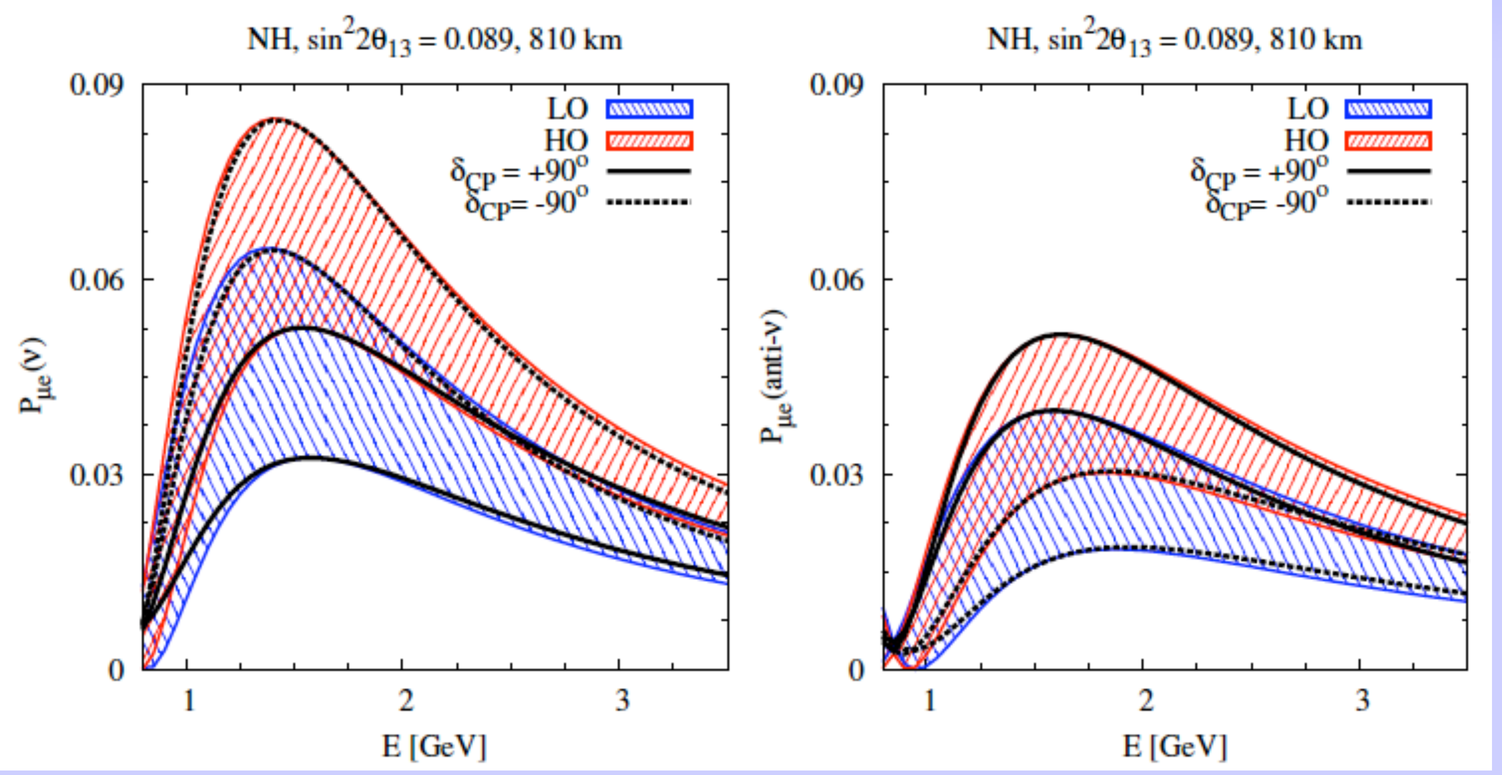
$\sin^2 2\theta_{13}$ = 0.089, $\sin^2\theta_{23}$ = 0.413 — Setups	Fraction of δ_{CP}(true)			
	MH		**CPV**	
	NH true	IH true	NH true	IH true
NOνA (3+3)	0.39 (0.33)	0.37 (0.31)	0.2 (0.1)	0.22 (0.13)
NOνA (3+3) + T2K (5+0)	0.41 (0.34)	0.39 (0.31)	0.28 (0.22)	0.3 (0.25)
NOνA (6+6) + T2K (5+0) + 5 kt LArTPC (3+3)	0.78 (0.5)	0.89 (0.48)	0.68 (0.45)	0.71 (0.51)
NOνA (6+6) + T2K (5+0) + 10 kt LArTPC (3+3)	1 (0.54)	1 (0.54)	0.7 (0.53)	0.73 (0.63)

Agarwalla, Prakash, Raut, Uma Sankar, arXiv:1208.3644

Non-maximal 2-3 mixing & Issue of Octant

Preliminary results of MINOS indicate that θ_{23} is not maximal

Global fits to world neutrino data suggest two nearly degenerate solutions for θ_{23} : one in the lower octant (LO: θ_{23} < 45 degree) and the other in the higher octant (HO: θ_{23} > 45 degree)

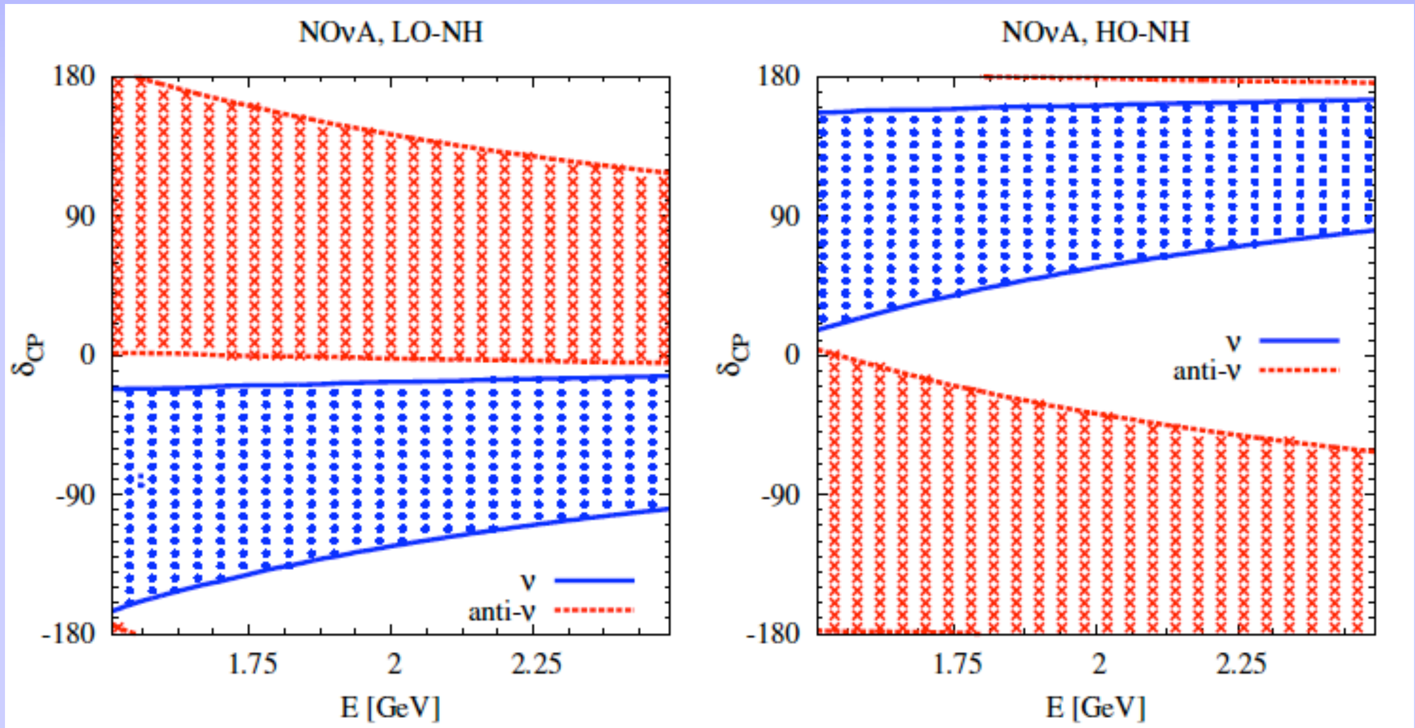


Agarwalla, Prakash, Uma Sankar, arXiv:1301.2574

Octant-δ_{CP} degeneracy

$$P_{\mu e}(\mathrm{LO}, \delta_{\mathrm{CP}}^{\mathrm{LO}}) = P_{\mu e}(\mathrm{HO}, \delta_{\mathrm{CP}}^{\mathrm{HO}})$$

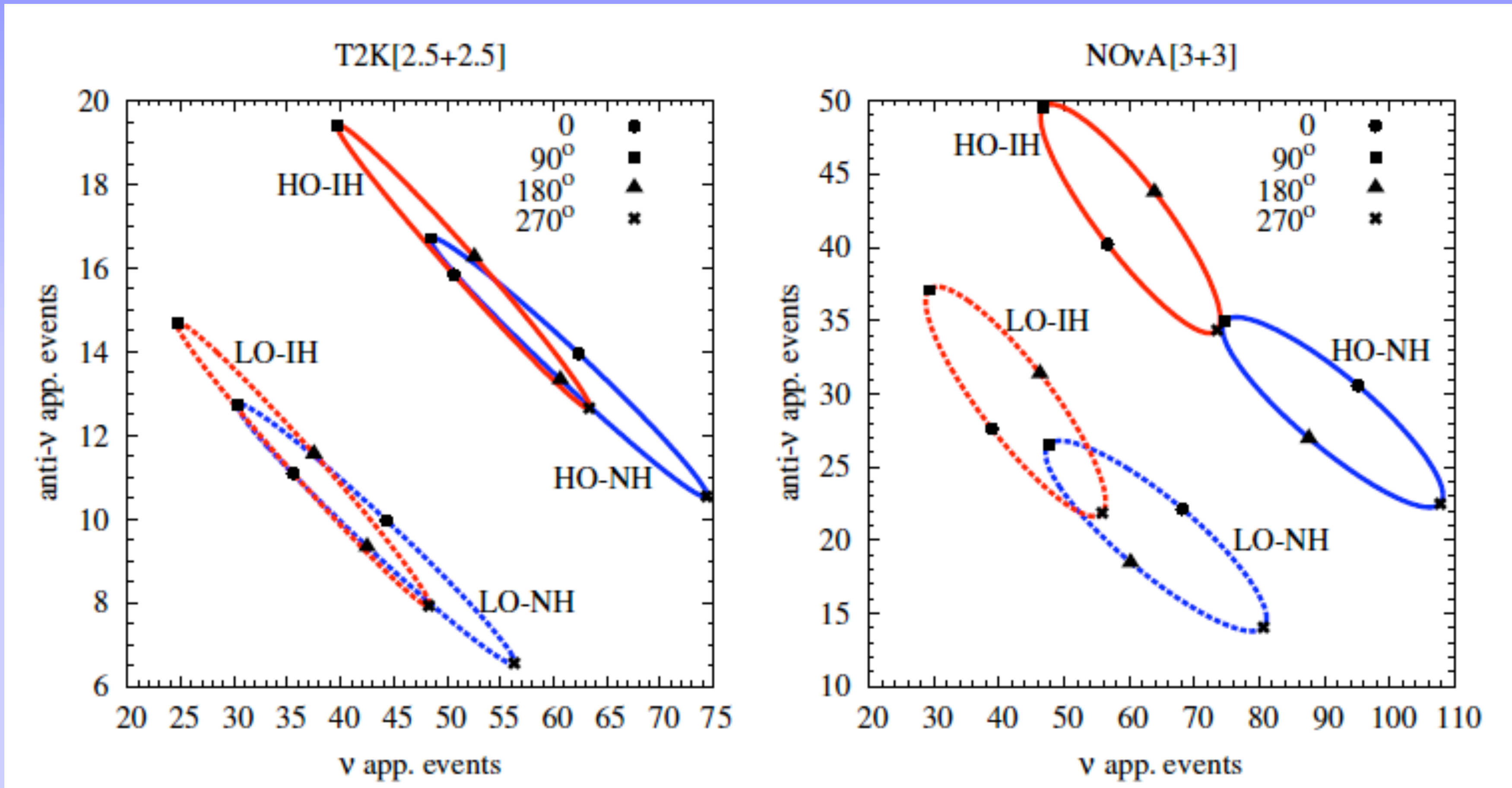
For L=810 km and E=2 GeV, we get for NH and ν $\cos(\hat{\Delta} + \delta_{\mathrm{CP}}^{\mathrm{LO}}) - \cos(\hat{\Delta} + \delta_{\mathrm{CP}}^{\mathrm{HO}}) = 1.7$



Agarwalla, Prakash, Uma Sankar, arXiv:1301.2574

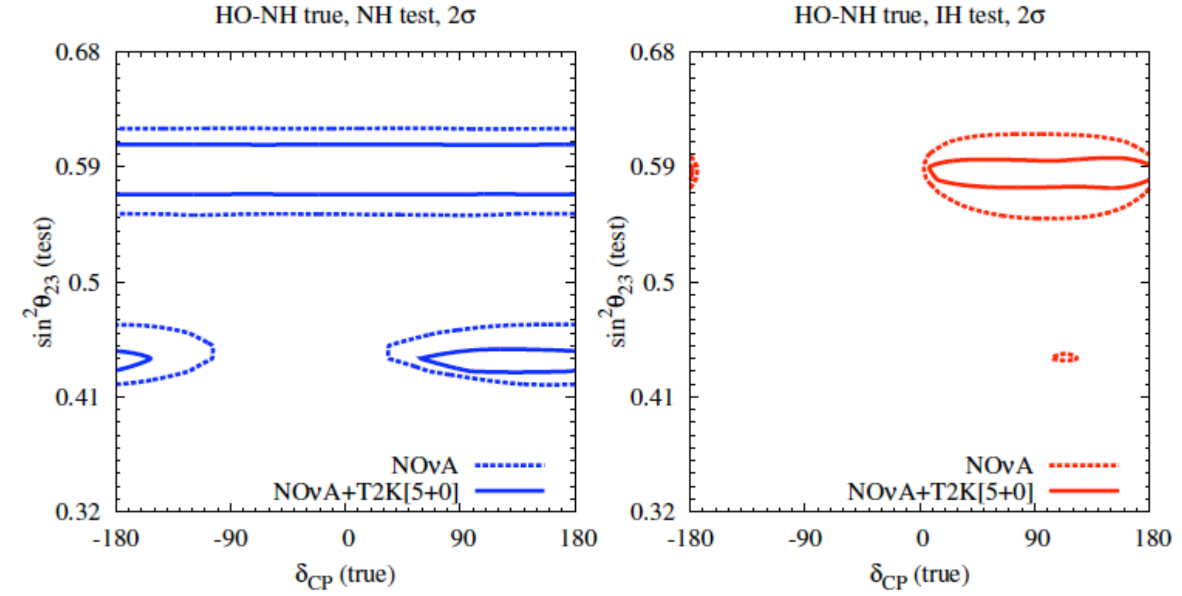
$P_{\mu e}(\mathrm{LO}, -116^\circ \leq \delta_{\mathrm{CP}} \leq -26^\circ)$ is degenerate with $P_{\mu e}(\mathrm{HO}, 64^\circ \leq \delta_{\mathrm{CP}} \leq 161^\circ)$

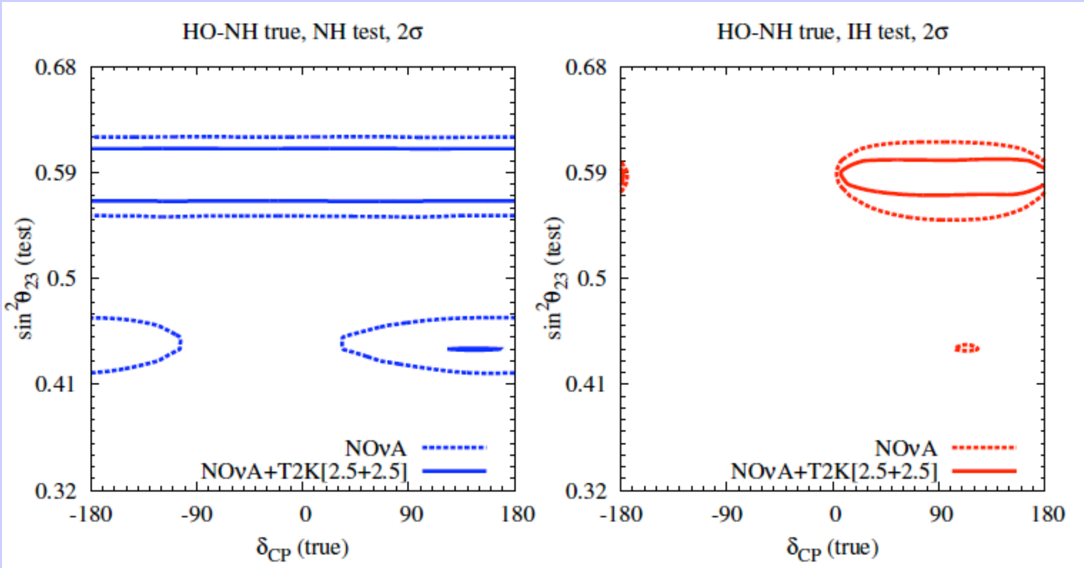
Octant-Hierarchy combinations: T2K and NOvA



Agarwalla, Prakash, Uma Sankar, arXiv:1301.2574

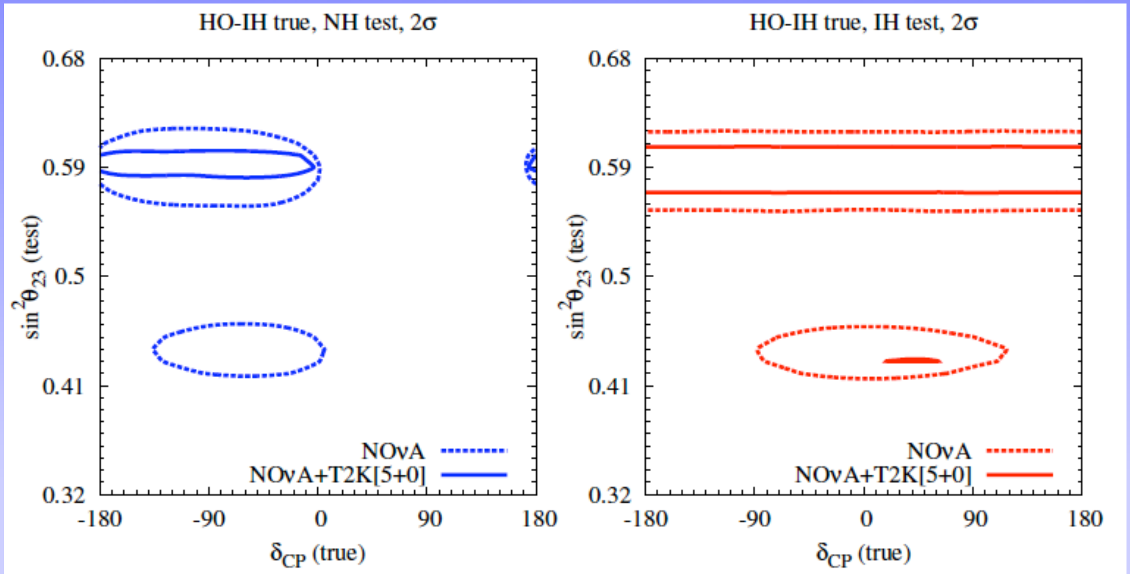
Octant Resolution: T2K and NOνA

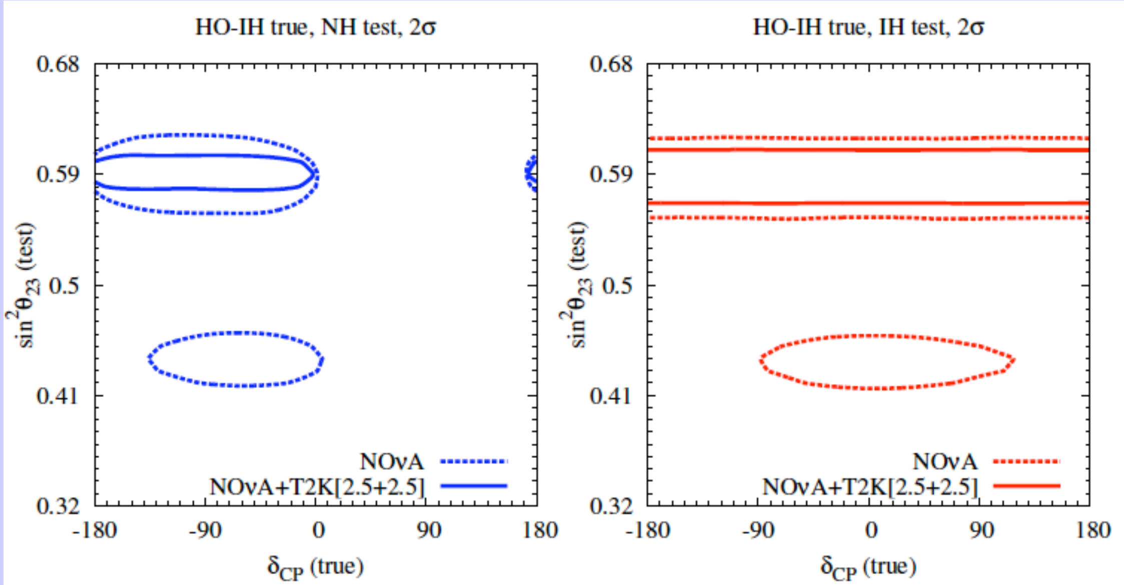




Agarwalla, Prakash, Uma Sankar, arXiv:1301.2574

Octant Resolution: T2K and NOνA





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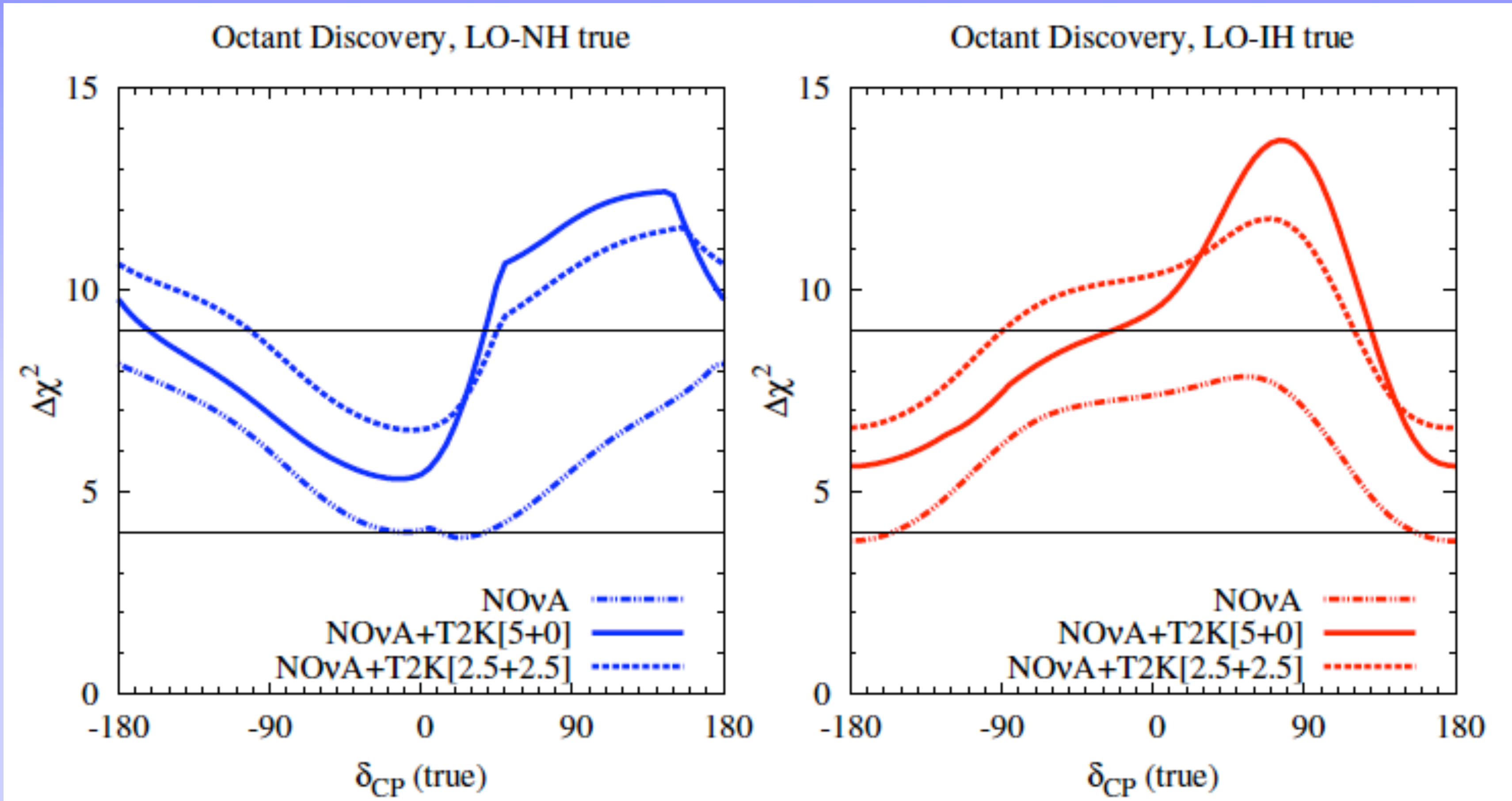
Octant Discovery: T2K and NOνA



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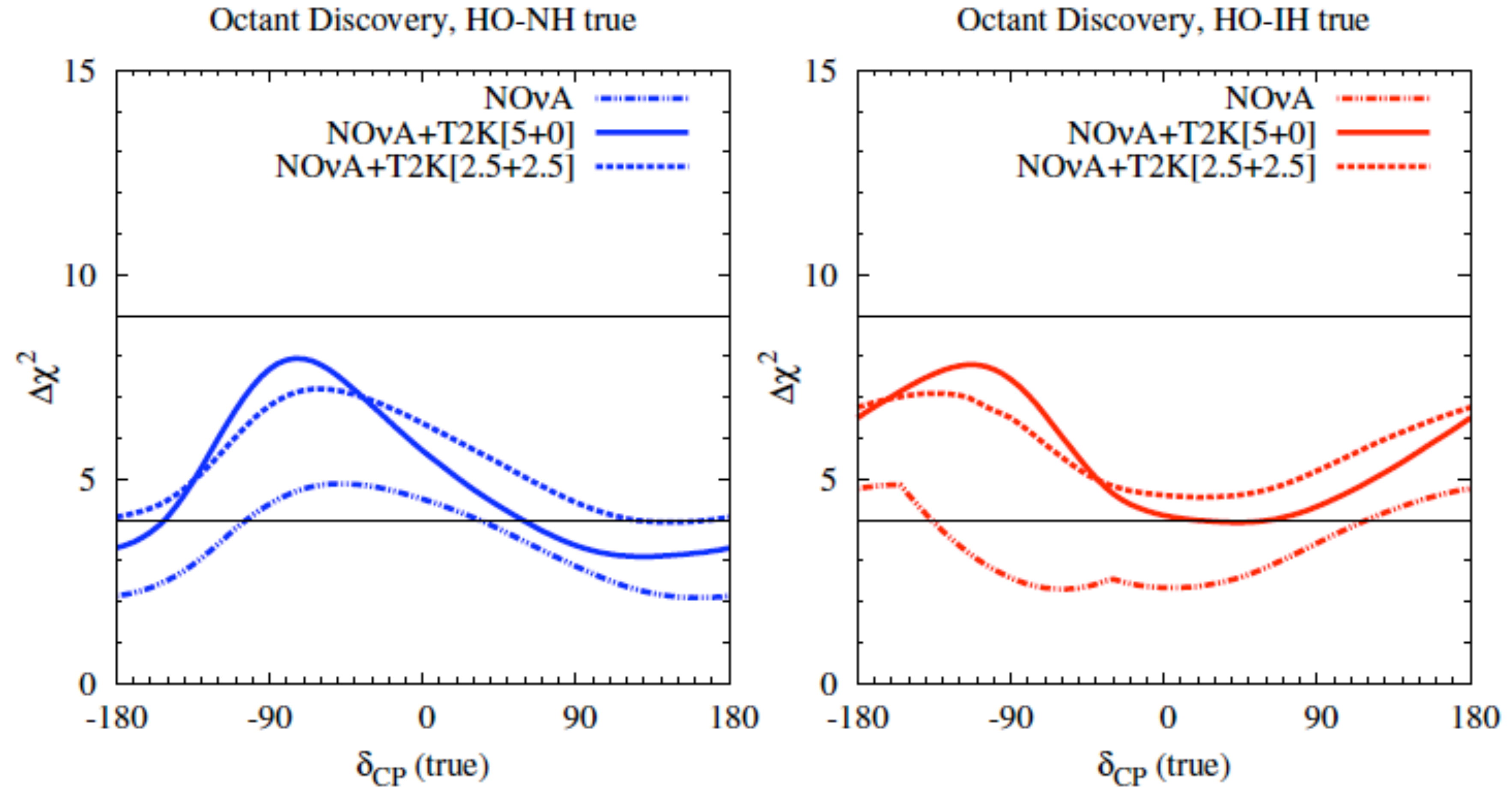
Octant Discovery: T2K and NOvA



Agarwalla, Prakash, Uma Sankar, arXiv:1301.2574

Octant Discovery: T2K and NOνA

- If LO is the true octant, then NOνA can rule out HO at 2σ C.L., irrespective of the hierarchy and CP phase
- Addition of T2K data improves the octant sensitivity
- If HO and normal hierarchy are the true choices, then the combined data from NOνA & T2K with its designed five years run in neutrino mode, is incapable of a 2σ resolution of the octant for all CP phases
- A 2σ resolution of the octant, for all combinations of neutrino parameters, becomes possible if T2K has balanced neutrino and anti-neutrino runs of 2.5 years each

Thank you!

Platinum Channel ($P_{\mu e}$)

The appearance probability $(\nu_\mu \to \nu_e)$ in matter, upto second order in the small parameters $\alpha \equiv \Delta m^2_{21}/\Delta m^2_{31}$ and $\sin 2\theta_{13}$,

$$P_{\mu e} \simeq \underbrace{\sin^2 2\theta_{13} \sin^2\theta_{23}}_{0.05} \frac{\sin^2[(1-\hat{A})\Delta]}{(1-\hat{A})^2} \quad \Rightarrow \theta_{13} \text{ Driven}$$

$$- \underbrace{\alpha \sin 2\theta_{13}\,\xi}_{0.0096} \sin\delta_{CP} \sin(\Delta) \frac{\sin(\hat{A}\Delta)}{\hat{A}} \frac{\sin[(1-\hat{A})\Delta]}{(1-\hat{A})} \quad \Rightarrow \text{CP odd}$$

(5.2 times)

$$+ \alpha \sin 2\theta_{13}\,\xi \cos\delta_{CP} \cos(\Delta) \frac{\sin(\hat{A}\Delta)}{\hat{A}} \frac{\sin[(1-\hat{A})\Delta]}{(1-\hat{A})} \quad \Rightarrow \text{CP even}$$

$$+ \alpha^2 \cos^2\theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(\hat{A}\Delta)}{\hat{A}^2}; \quad \Rightarrow \text{Solar Term}$$

where $\Delta \equiv \Delta m^2_{31} L/(4E)$, $\xi \equiv \cos\theta_{13} \sin 2\theta_{21} \sin 2\theta_{23}$,
and $\hat{A} \equiv \pm(2\sqrt{2}G_F n_e E)/\Delta m^2_{31}$

Cervera etal., hep-ph/0002108
Freund etal., hep-ph/0105071