Evaluating future neutrino oscillation experiments

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1 Sensitivity measures

1. Sensitivity measures
2. Conveying the information

What is sensitivity?

- The most common definition:

  The *expected* sensitivity is the confidence level which a *median* experiment will reach

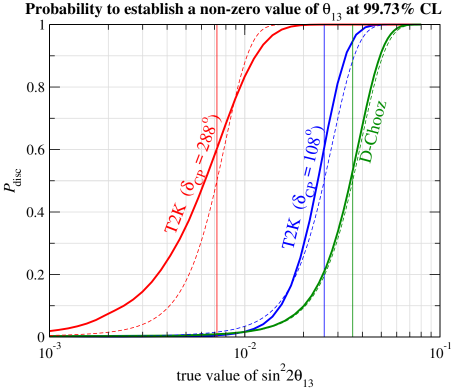
- Only considers the median experiment
- Comparing with a target sensitivity difficult (at what CL do we want to know?)

How do we compute it?

- Assume data = prediction (for some true values)
- Compute $\Delta\chi^2$
- Compare with χ^2 with appropriate number of dof
- Assumes a χ^2 distribution

GLoBES can do most of these steps for you

What is the accuracy?



Schwetz, hep-ph/0612223

- Several reasons for deviations
- Typically boil down to violations of Wilk's theorem
- Although the accuracy seems fairly reasonable
- Mostly conservative

What really interests us?

- We typically require a set CL (5σ) to claim discovery
- Compute $P(5\sigma)$ instead
- Probability to reach the *target* sensitivity
- Fundamentally different question

How do we compute it?

- Have to know the distribution of experiments
- Need full implementation of statistical fluctuations
- It is easy to implement poisson statistics
- It just requires longer running time
- ...and GLoBES does not do it for you
- Does not depend on assumed dof

Experimental setups

We will consider the following experiments

Setup	$E_\nu^{\rm peak}$	L	**OA**	**Det.**	**kt**	**MW**	**Dec/yr**	$(t_\nu,t_{\bar\nu})$
T2K	0.6	295	2.5°	WC	22.5	0.2-0.7	–	Var.
NOνA	2	810	0.8°	TASD	3-14	0-0.7	–	Var.
NF10	6	2000	–	MIND	100	–	7×10^{20}	(10,10)
LBNE	3.0	1290	–	LAr	10-33	0.8	–	(5,5)
T2HK	0.6	295	2.5°	WC	560	1.66	–	(1.5,3.5)

See arXiv:1303.0003 for more details

Parameters

The oscillation parameter status

$$\begin{cases} \sin^2\theta_{12} = 0.302\,^{+0.013}_{-0.012} \\ \sin^2\theta_{13} = 0.0227\,^{+0.0023}_{-0.0024} \\ \sin^2\theta_{23} = 0.413\,^{+0.037}_{-0.025}\,/\,0.594\,^{+0.021}_{-0.022} \end{cases}
\qquad
\begin{cases} \Delta m^2_{21}/10^{-5} = 7.50\,^{+0.18}_{-0.19}\,\mathrm{eV}^2 \\ \Delta m^2_{31}/10^{-3} = 2.473\,^{+0.070}_{-0.067}\,\mathrm{eV}^2\,(\mathrm{NH}) \\ \Delta m^2_{32}/10^{-3} = -2.427\,^{+0.042}_{-0.065}\,\mathrm{eV}^2\,(\mathrm{IH}) \end{cases}$$

Gonzalez-Garcia, Maltoni, Salvado, Schwetz, arXiv:1209.3023

Parameters (2)

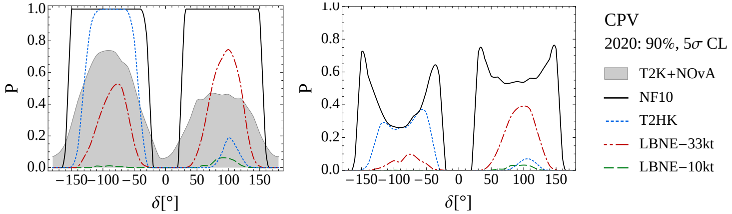
We have used the following true values

$$\begin{aligned}
\theta_{12} &= 34^\circ && (3\ \%\ \mathrm{error}) \\
\theta_{13} &= 9^\circ && (3\ \%\ \mathrm{error}) \\
\theta_{23} &= 45^\circ && (8\ \%\ \mathrm{error}) \\
\Delta m_{21}^2 &= 7.6 \cdot 10^{-5}\ \mathrm{eV}^2 && (2.5\ \%\ \mathrm{error}) \\
\Delta m_{31}^2 &= 2.5 \cdot 10^{-3}\ \mathrm{eV}^2 && (4\ \%\ \mathrm{error})
\end{aligned}$$

This corresponds roughly to the global status with the following modifications

- Maximal θ_{23}
- We simulate for true normal hierarchy

Target sensitivity probabilities



Left:
$P(> 90\% \text{ CL}|\delta)$ (T2K+NOvA)
$P(> 5\sigma|\delta)$ (others)

Right:
$P(> 5\sigma, B|\delta)$
B : $<$ 90% CL @ T2K+NOvA

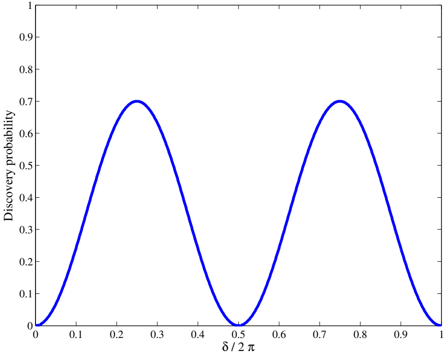
1 Sensitivity measures

2 Conveying the information

3 Summary and conclusions

What is a CP fraction?

- Fraction of δ for which the *mean expected* sensitivity is at least $x\sigma$
- Throws away information on the actual probability



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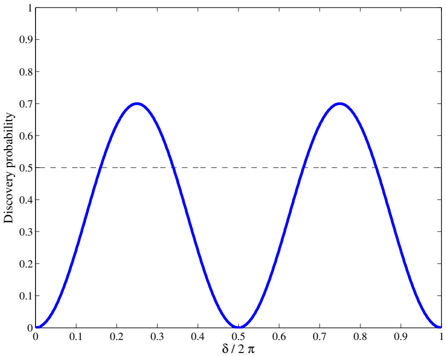

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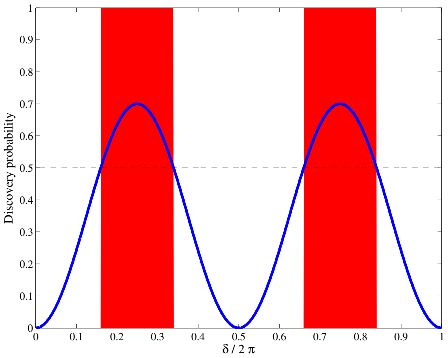

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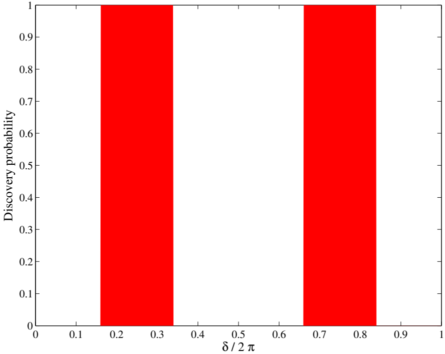

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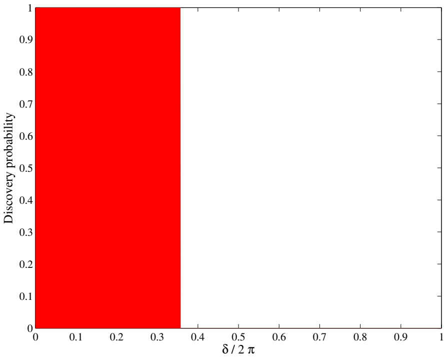
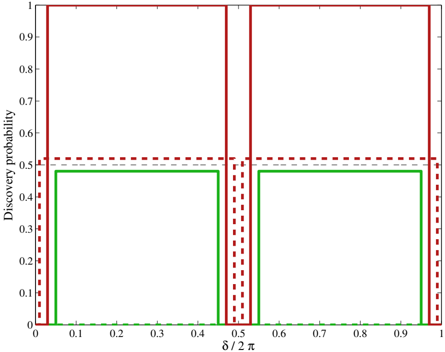
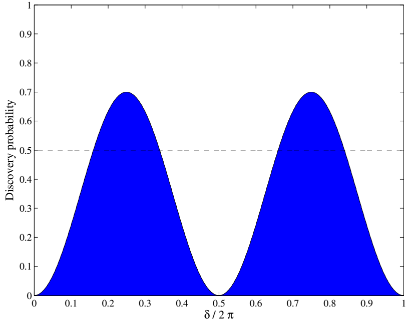


Caveats

- Requires a measure for δ
- The measure is assumed flat
- Would be different for $\cos\delta$ or $\sin\delta$
- It is not a probability, it is a performance indicator



What is the probability of establishing CP violation?



- Requires a measure $d\mu_\delta$ (flat $\Longrightarrow d\mu_\delta = \frac{d\delta}{2\pi}$)
- Mixed frequentist-bayesian statement
- The integral

$$P(> x\sigma) = \int P(> x\sigma|\delta) d\mu_\delta$$

How much value does an experiment add?

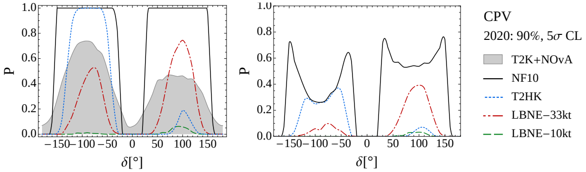
- Is there a point to building a particular experiment if T2K+NOvA does not see a hint of CP violation?
- How much information does a new experiment add?
- What do we want to aim for, establishing a possible hint or complementarity if there is none?
- It is a decision - it *should* have a bayesian component!

Gain from performing an experiment

- What is the probability of establishing CP violation (A) if T2K+NOvA has a hint at 90 % CL (B)?

$$P(A|B) = \frac{P(A,B)}{P(B)} \quad \text{alternatively} \quad P(A|\bar{B}) = \frac{P(A,\bar{B})}{P(\bar{B})}$$

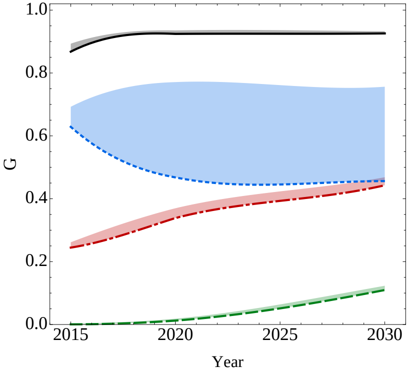
- We will call these quantities G and $\bar{G}$

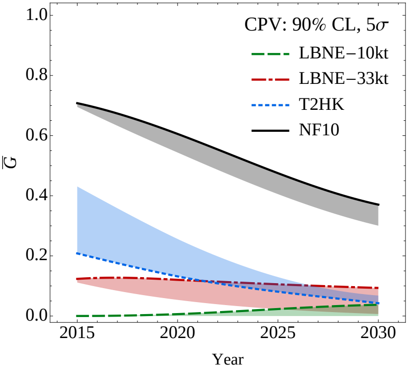


A note on priors

- Why a flat prior in δ?
- $\cos\delta$ and $\sin\delta$ mainly appear in probabilities
- The Haar measure on a unitary matrix is flat in δ

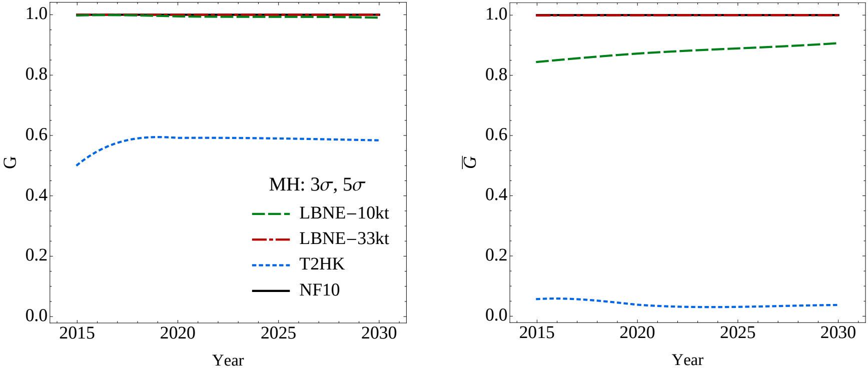
CP Gain compared to T2K and NOvA





Thick edges = Hierarchy unknown

Hierarchy Gain compared to T2K and NOvA



Thick edges = Hierarchy unknown

Outlook

- If T2K+NOvA data is known at decision time, G can be conditioned on the data rather than the level of signal
- Have to compare the gain with the cost of constructing the facility
- As always, decisions will be based on theoretical bias (we just attached a number to it)

Summary and conclusions

- Discussed performance indicators for future oscillation experiments
- Proposed a new performance indicator related to the probability of measuring CP violation
- Seen how it can relate new experiments to existing ones depending on strategy
- Case study for T2K+NOvA compared to next generation facilities
- Any performance indicator which is a single number will be based on parameter assumptions
- Given the bias, we belive G contains the most useful information