Neutrino Physics with Project X

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Snowmass at the Mississippi

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Disclaimer

This talk is an attempt to summarize the Neutrino chapter of the *Project X: Physics Opportunities* report arXiv:1306.5009 – I have to apologize that I will not be able to do justice to all the topics covered in the report.

There will be dedicated sessions covering some neutrino related topics in more detail

- nuSTORM
  July 31st, 6:00-7:30pm, Tate 166
- SBL Anomalies
  August 1st, 8:30-10am, Anderson 270
- Three flavor oscillations
  August 2nd, 8:30-10am, Anderson 250

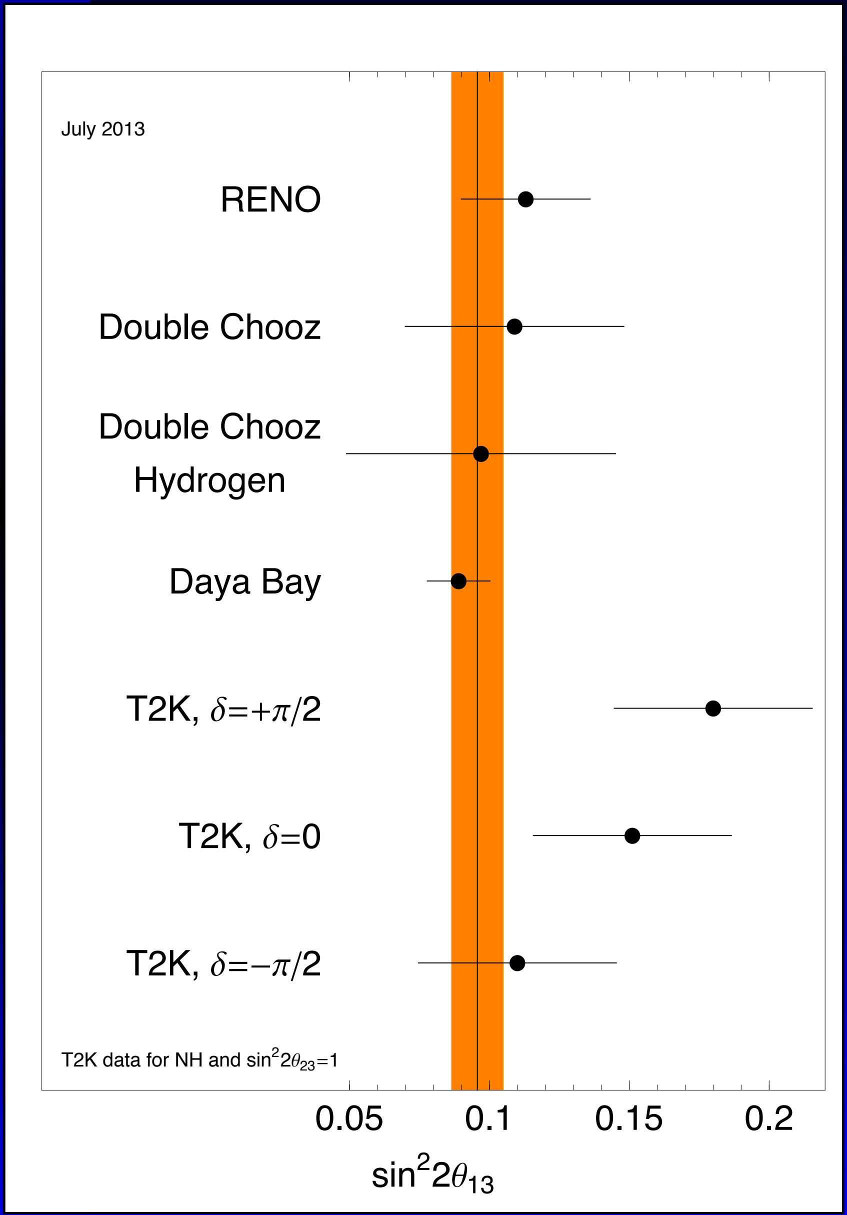
What we want to learn

In the context of neutrino oscillation experiments

- δ_{CP}
- mass hierarchy
- $\theta_{23} = \pi/4$, $\theta_{23} < \pi/4$ or $\theta_{23} > \pi/4$?
- Resolution of LSND and the other short-baseline anomalies
- New physics vs tests of the three flavor framework

Given the current state of the theory of neutrinos we can not say with confidence that any one quantity is more fundamental than any other.

θ_{13} is large!



Many results from reactor and beam experiments

Some single results exceed $5\,\sigma$ significance

All results agree well, including (but not shown) MINOS, solar & KamLAND, atmospheric experiments

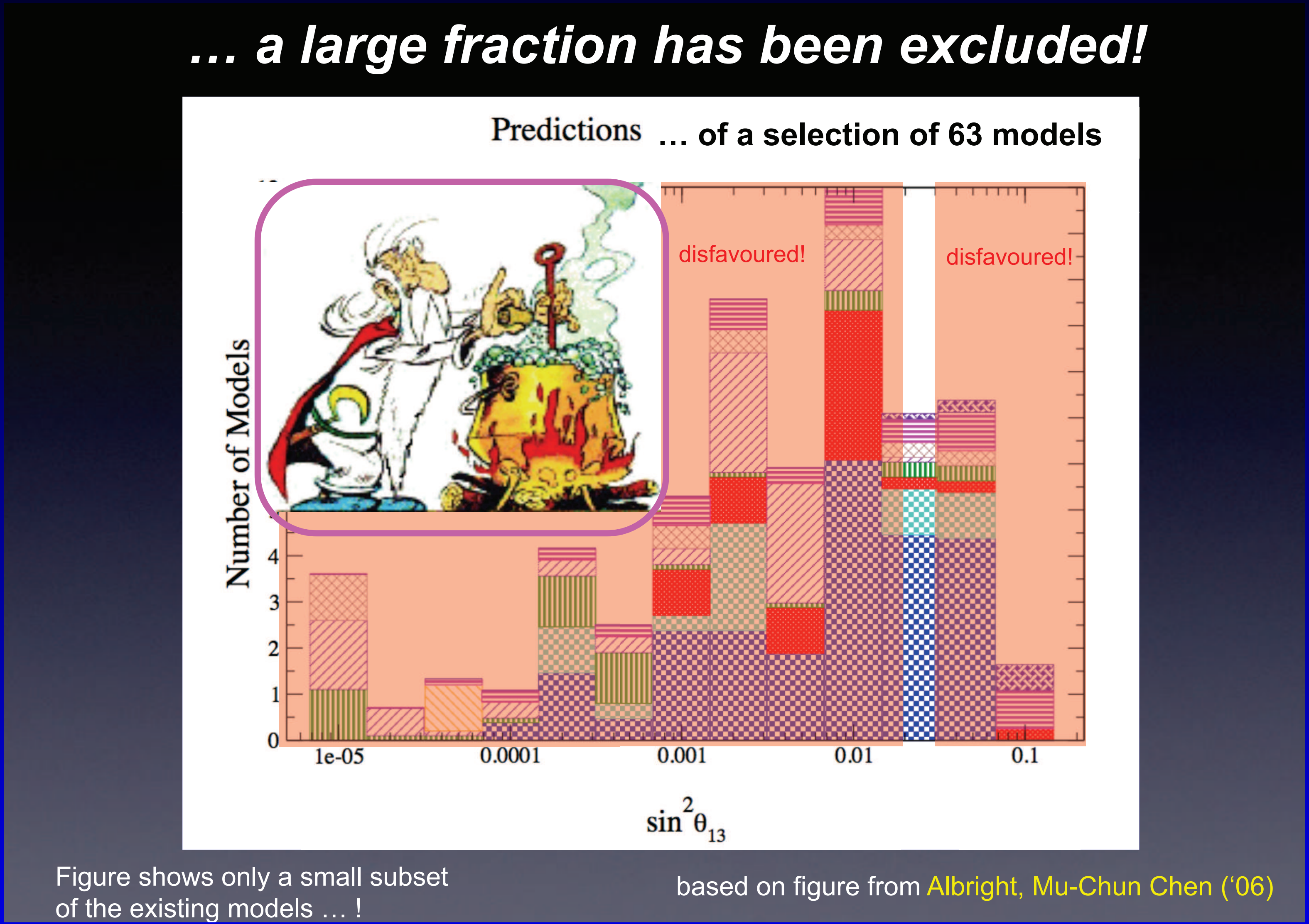
NB – 2 years ago we had only $2\,\sigma$ indications.

Implications

In general, this raises the following questions

- Is neutrino physics essentially done?
- Will the mass hierarchy have been determined before the next generation of long-baseline experiments?
- Are new experiments beyond NOνA and T2K necessary to discover CP violation?
- Are superbeams sufficient for precision neutrino physics?

Model selection



Antusch, 2012

Flavor models

Simplest un-model – anarchy Murayama, Naba, DeGouvea

$$dU = ds_{12}^2\, dc_{13}^4\, ds_{23}^2\, d\delta_{CP}\, d\chi_1\, d\chi_2$$

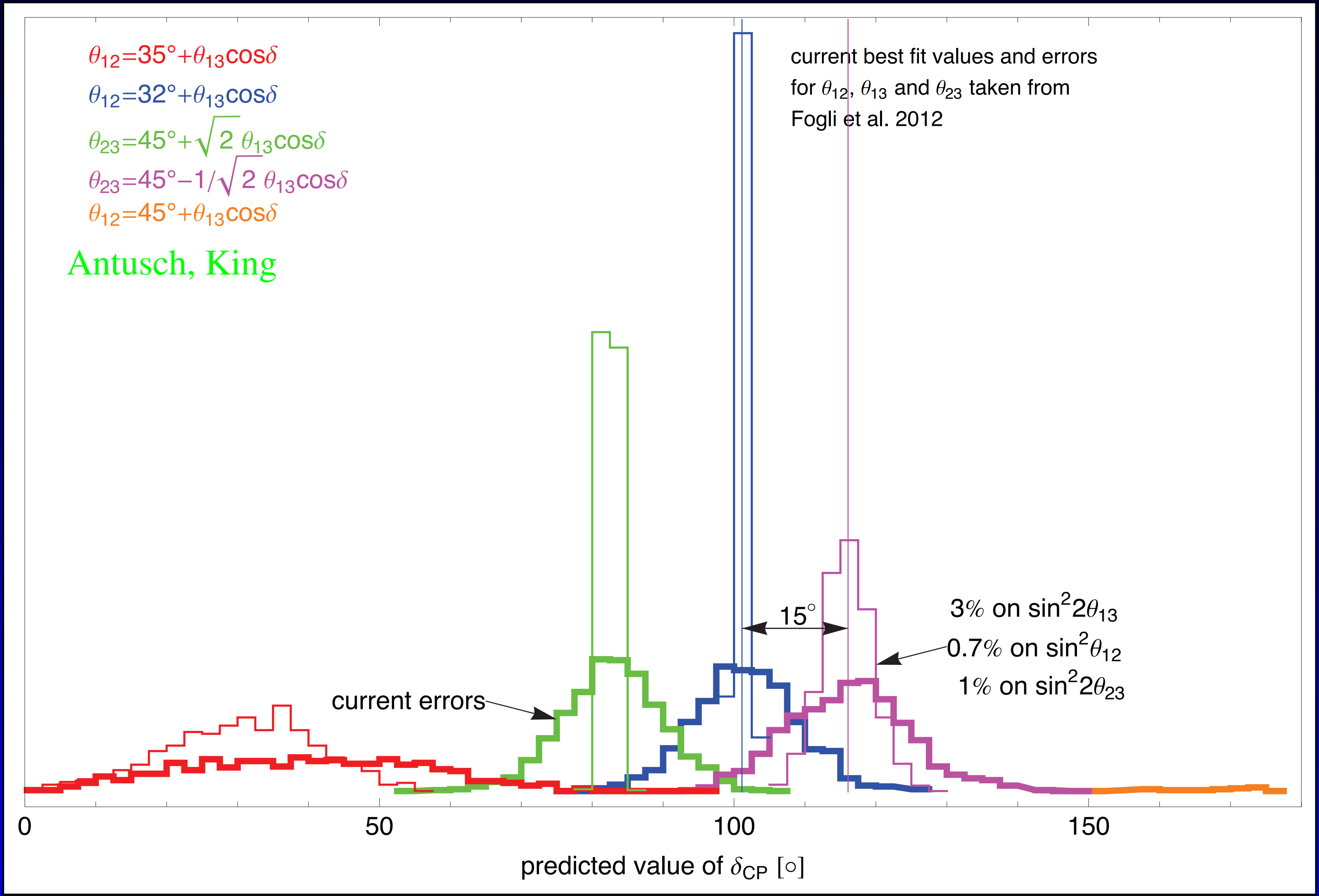
predicts flat distribution in δ_{CP}

Simplest model – Tri-bimaximal mixing Harrison, Perkins, Scott

$$\begin{pmatrix} \sqrt{\frac{1}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

to still fit data, obviously corrections are needed – predictivity?

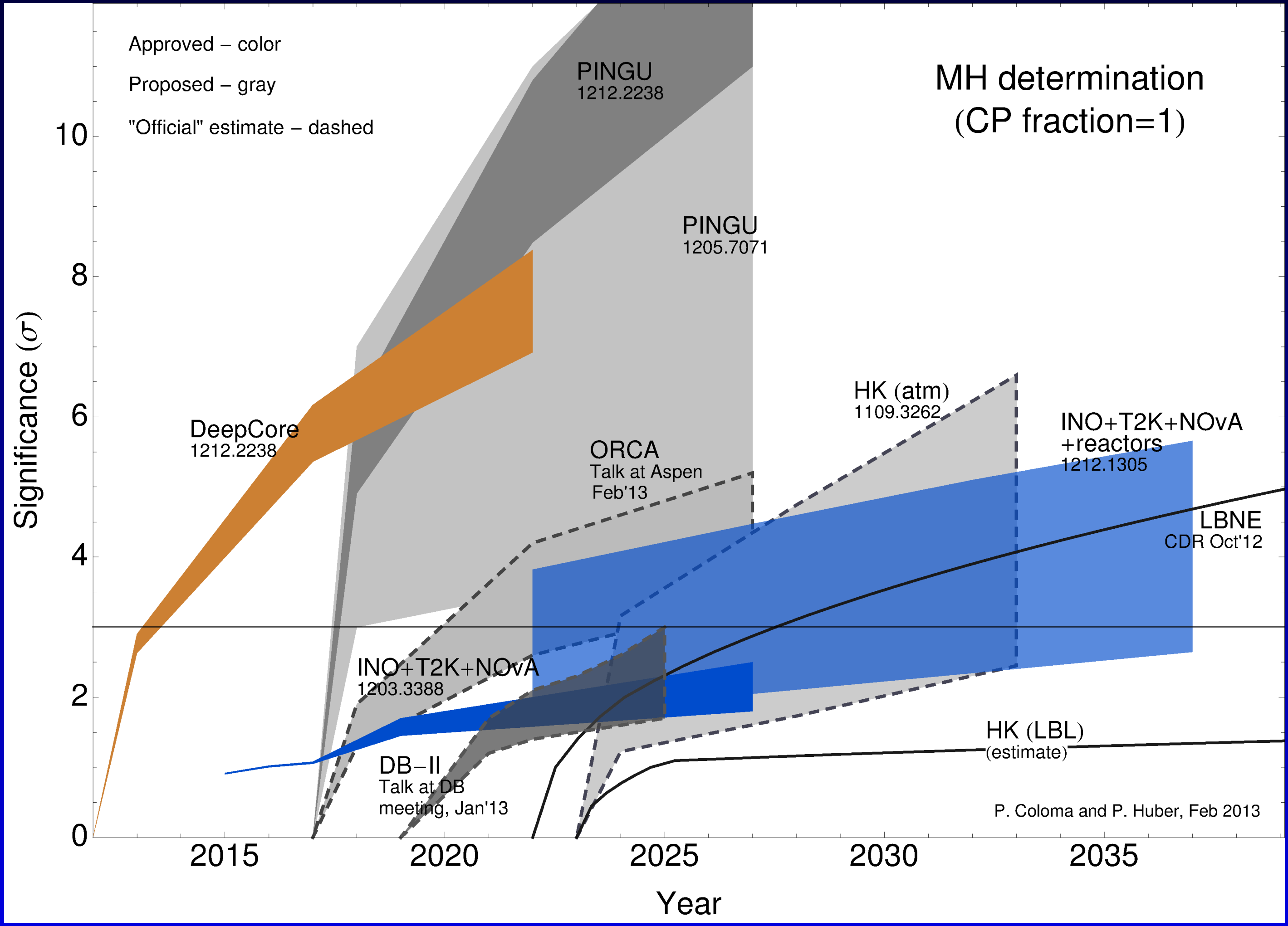
Sum rules



$3\,\sigma$ resolution of 15° distance requires 5° error. NB – smaller error on θ_{12} requires dedicated experiment like JUNO

New ideas for mass hierarchy

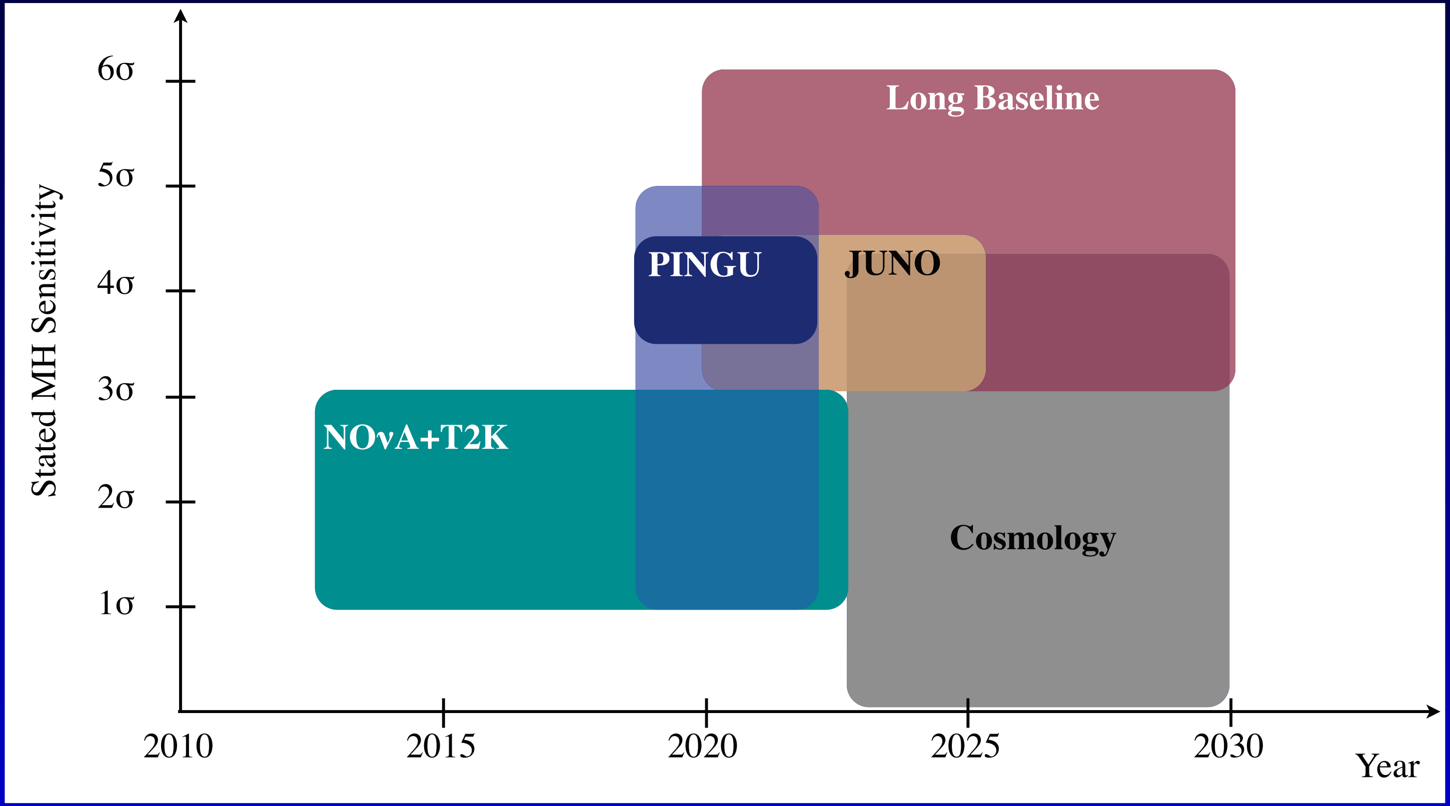
Literature survey



The dashed ones are from collaborations – solid lines are phenomenological papers

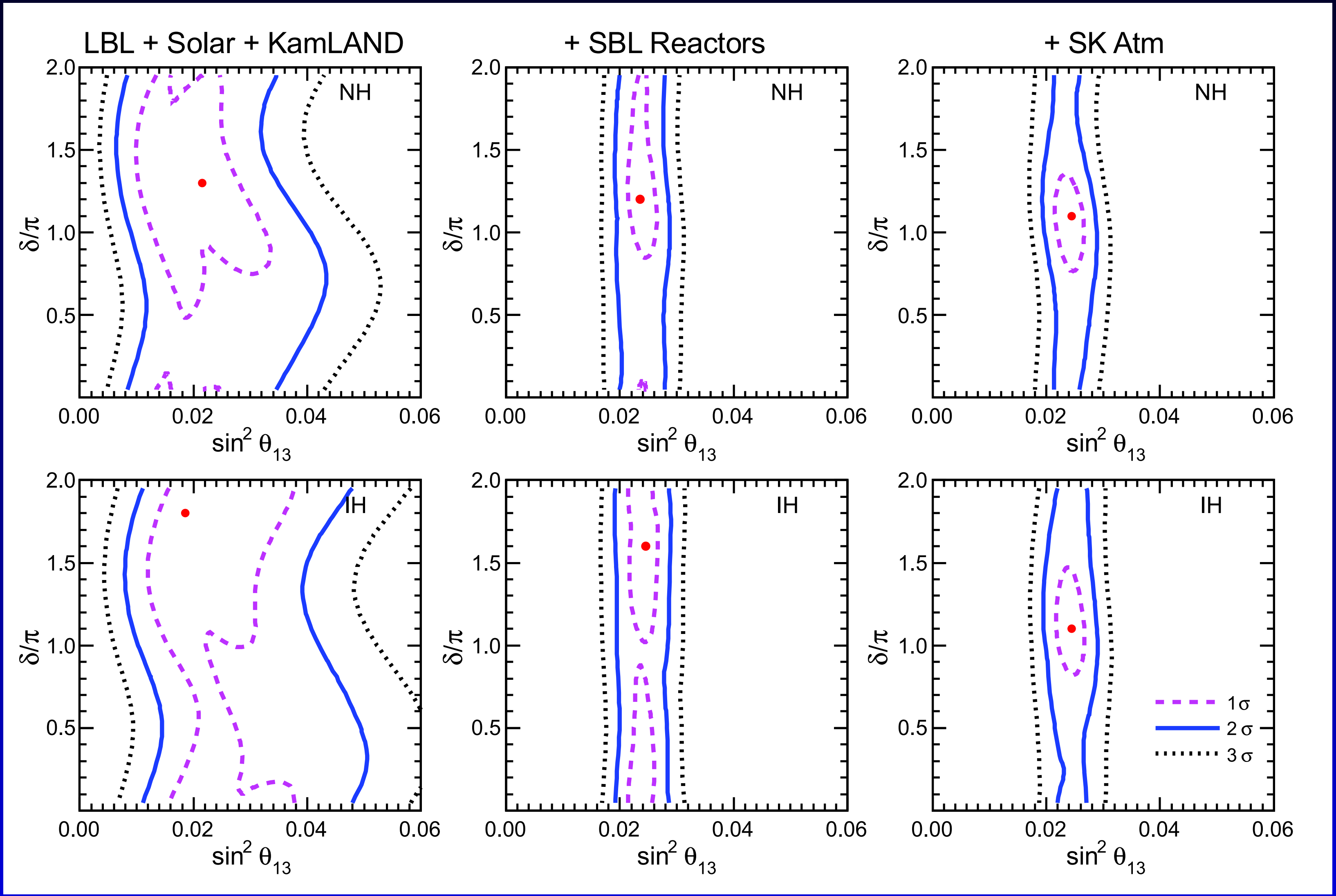
New ideas for mass hierarchy

Literature survey from arXiv:1307.5487



Many experiments are expected to have a result at or above 3 σ within a decade from now – mass hierarchy largely settled in the Project X era

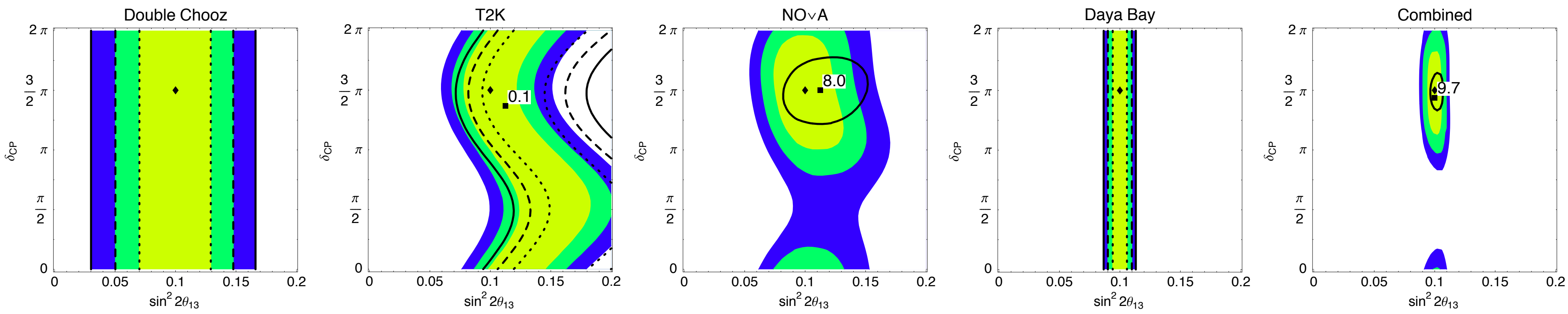
Early “hints” for CP?



Fogli, *et al.*, 2012

NB – 1 σ range for $\delta = 30 - 35°$

Early hints for CP?



PH, *et al.*, 2009

At lower confidence levels some indications maybe obtained – impact on future program?

This measurement is driving the need for the next generation of oscillation experiments

LBNE – facility

Long-Baseline Neutrino Experiment

LBNE10

- 10 kt LAr TPC above ground at SURF
- a new beamline capable of 2.3MW
- a 700kW beam

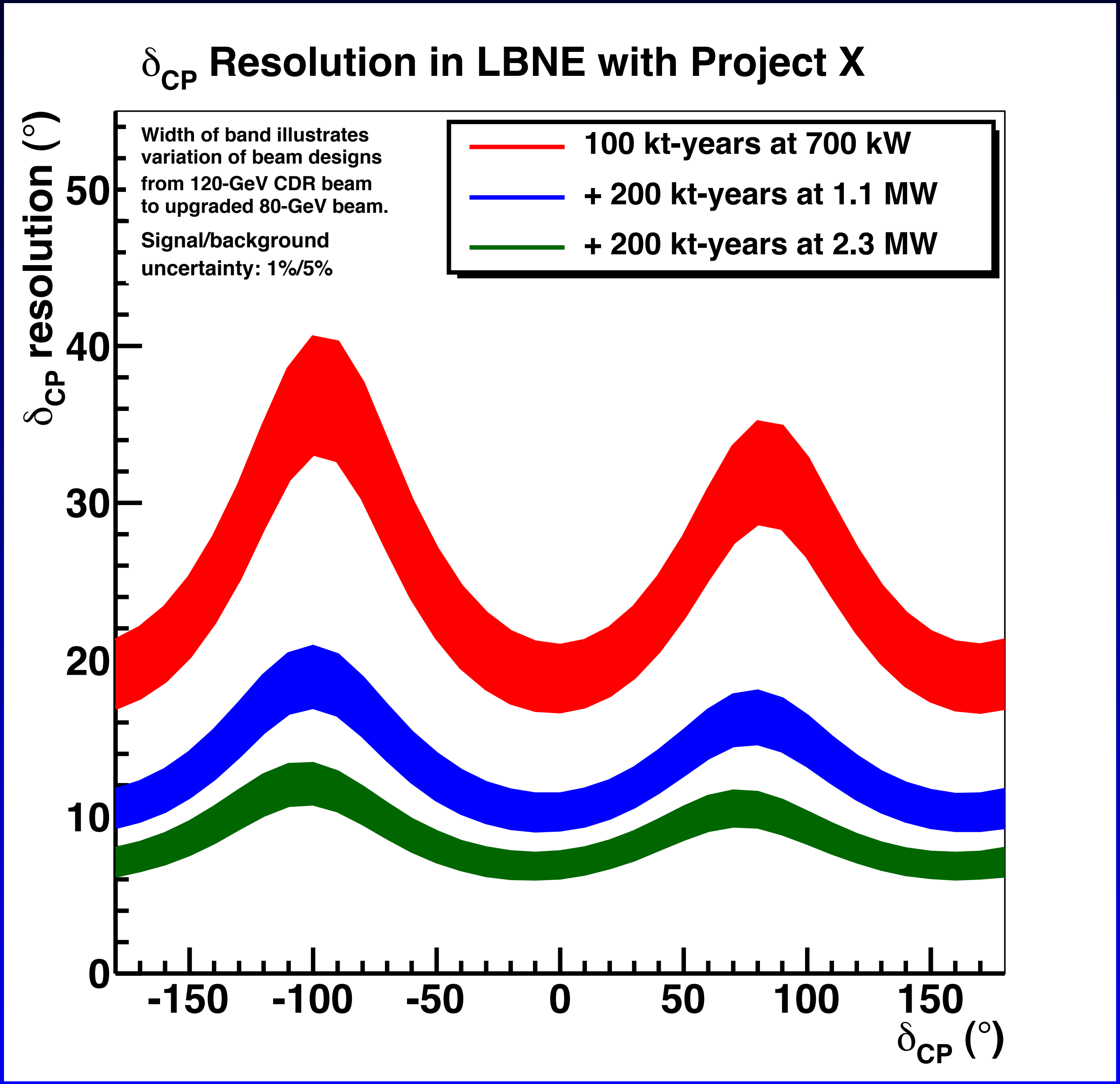
LBNE

- 34 kt LAr TPC under ground at SURF
- a near detector
- a new beamline capable of 2.3MW
- a 700kW beam

LBNE10 has CD1 approval from DOE

LBNE + Project X will eventually increase beam power to 2.3MW

LBNE – CP sensitivity



NuMAX – facility

Neutrinos from Muon Accelerators at Project X

NuMAX

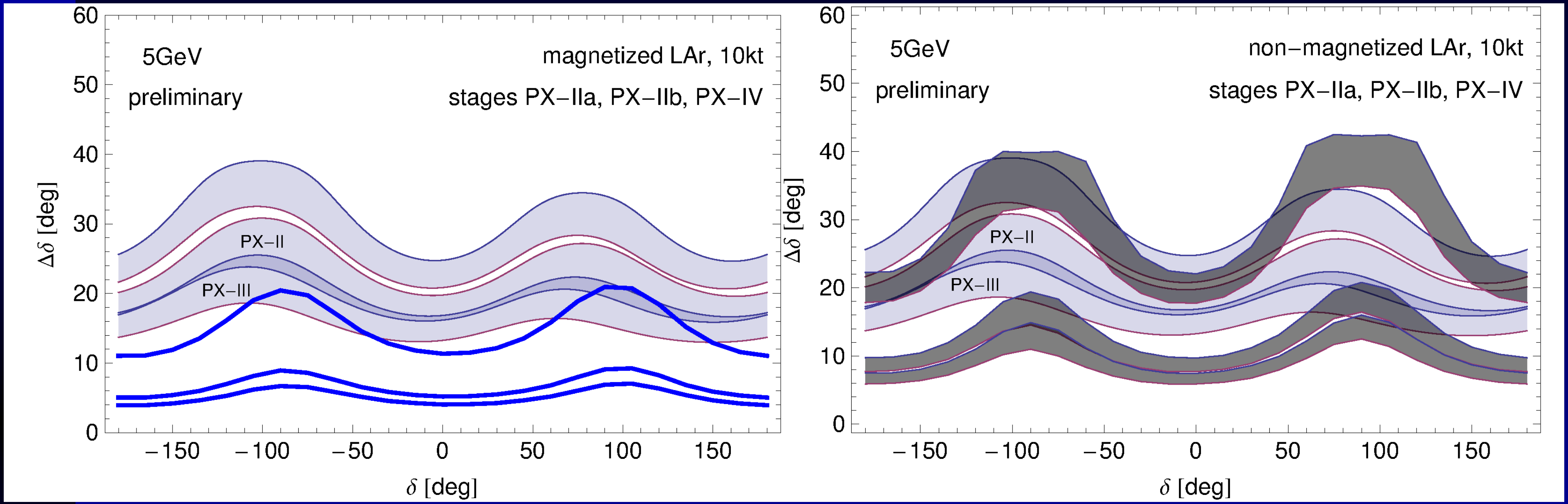
- 1MW, 3GeV protons from PX stage II
- no muon cooling
- acceleration to 5GeV
- 8×10^{19} useful muons per year and polarity

NuMAX+

- 3MW, 3GeV protons from PX stage II
- muon cooling
- acceleration to 5GeV
- 5×10^{20} useful muons per year and polarity

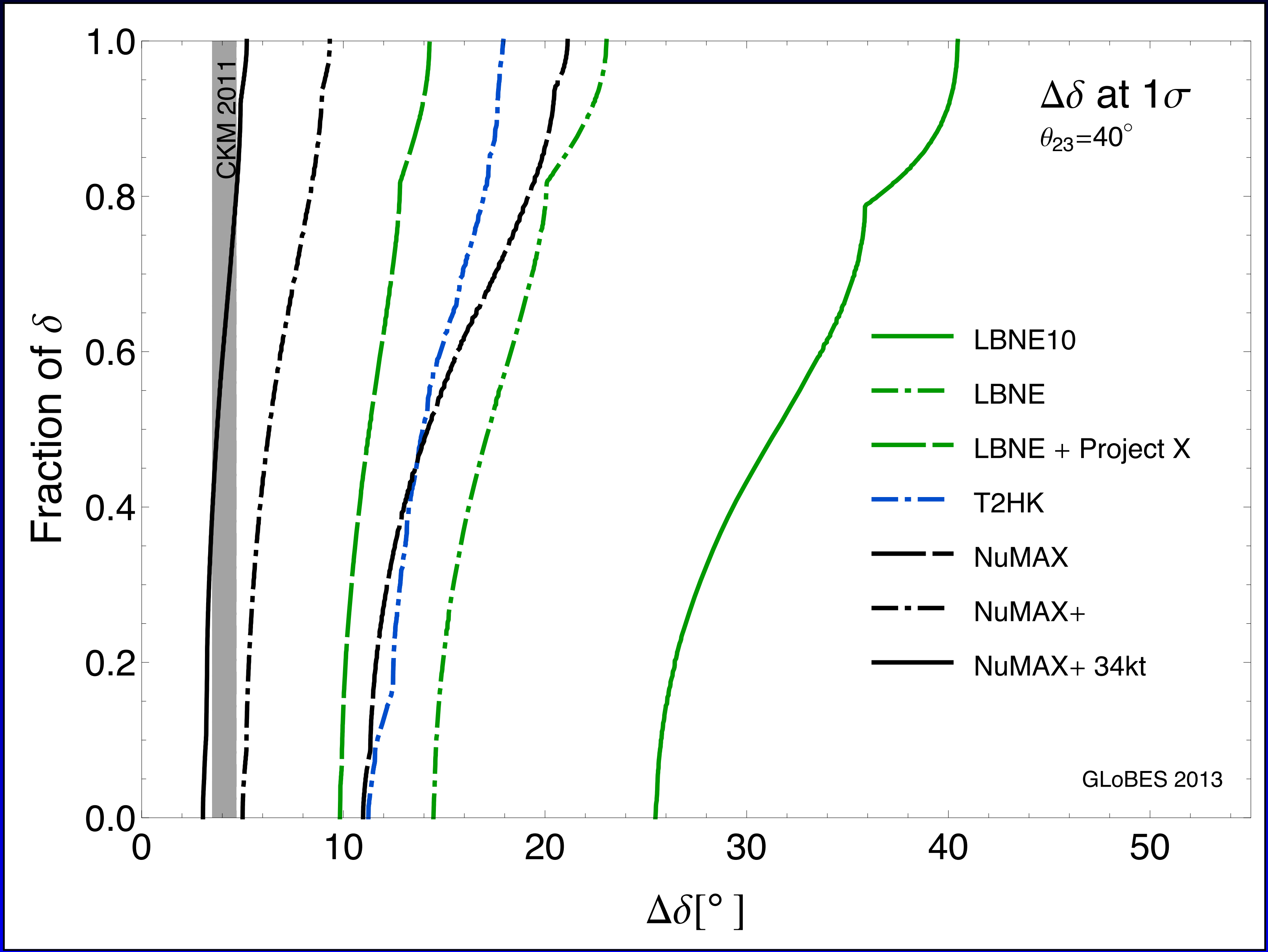
Detector at SURF, 10kt magnetized LAr – fallback 5-10 times larger magnetized iron detector

NuMAX – CP sensitivity

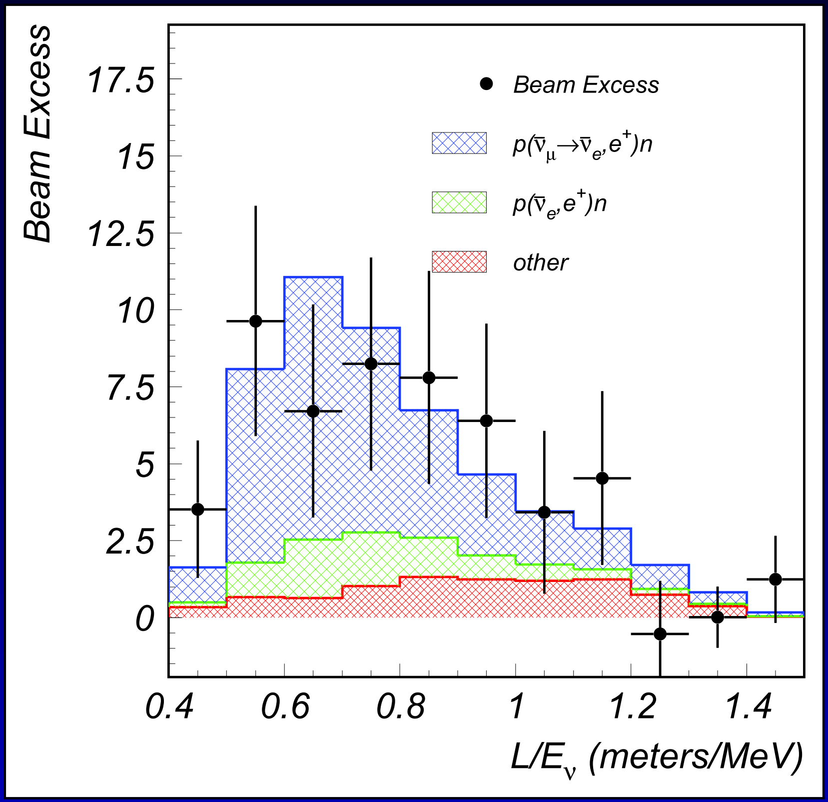


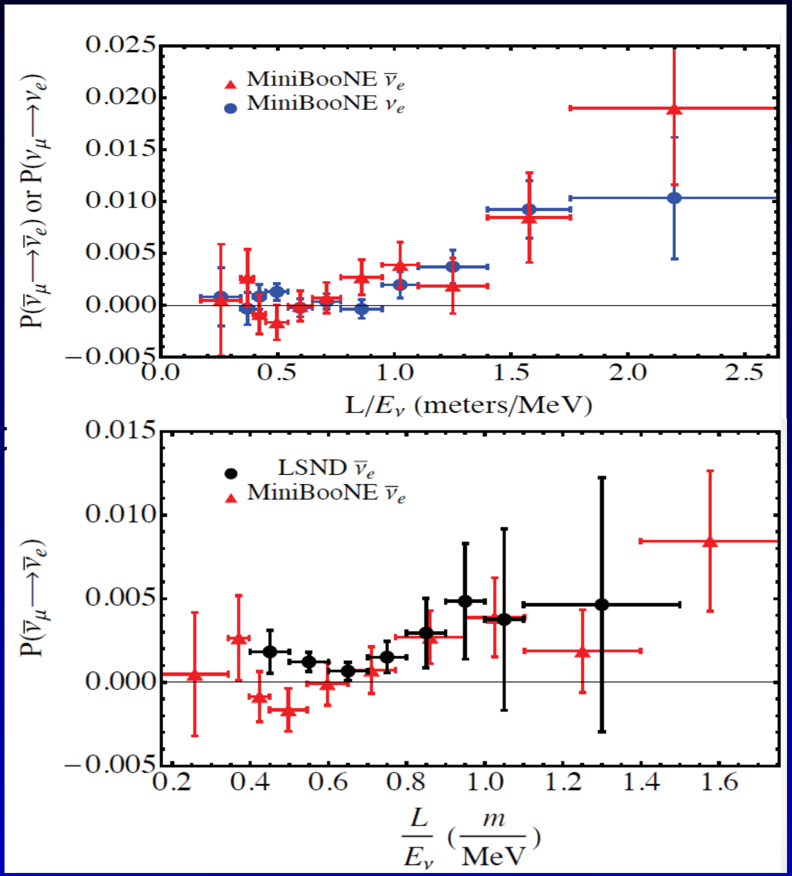
– Synergy with LBNE facilities
– Magnetization can be replaced by increased luminosity
– Natural staging
– No new technologies

CP accuracy comparison



LSND and MiniBooNE

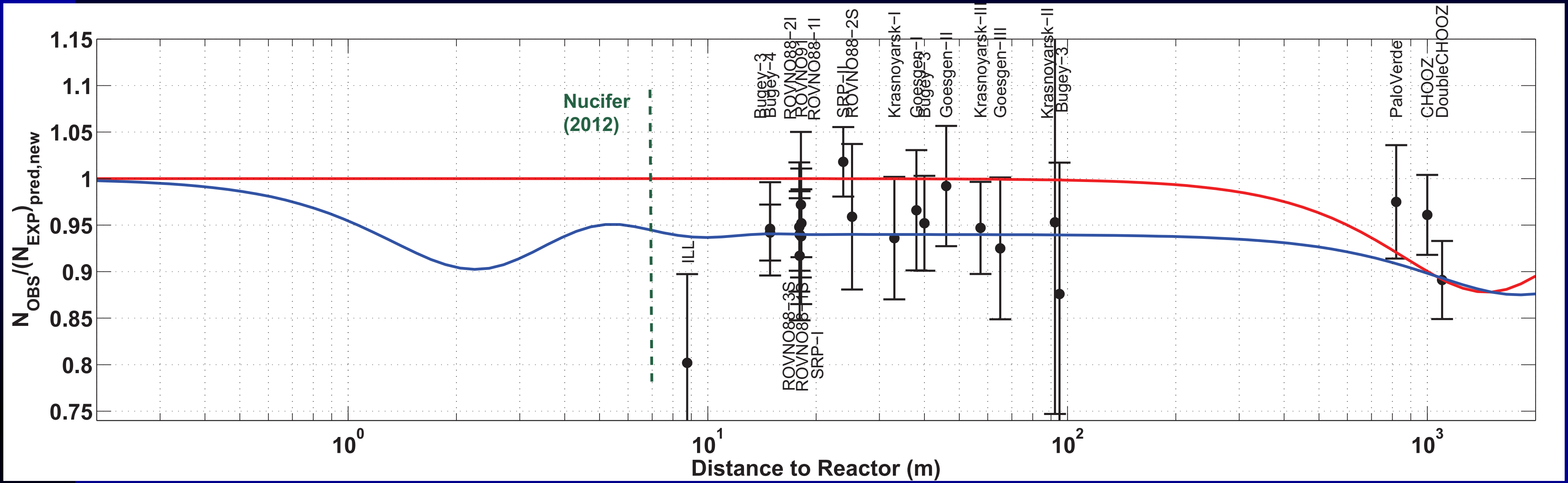




$$P(\bar{\nu}_\mu \to \bar{\nu}_e) \simeq 0.003$$

Requires a new beam experiment to be resolved.

Reactor and Gallium anomalies

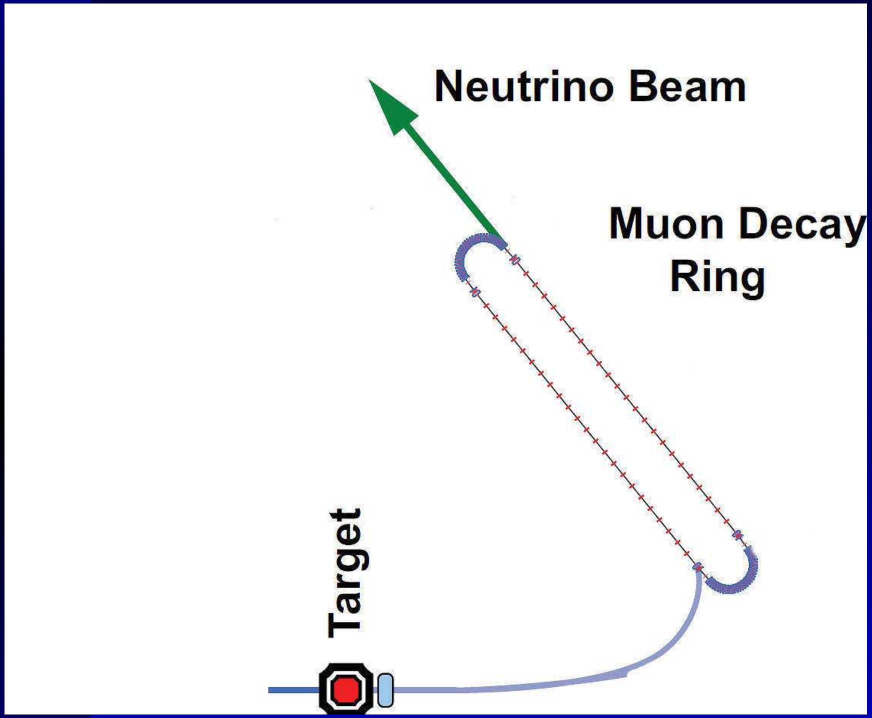


	GALLEX		SAGE	
k	G1	G2	S1	S2
source	^{51}Cr	^{51}Cr	^{51}Cr	^{37}Ar
$R^k_{\rm B}$	0.953 ± 0.11	$0.812^{+0.10}_{-0.11}$	0.95 ± 0.12	$0.791 \pm ^{+0.084}_{-0.078}$
$R^k_{\rm H}$	$0.84^{+0.13}_{-0.12}$	$0.71^{+0.12}_{-0.11}$	$0.84^{+0.14}_{-0.13}$	$0.70 \pm ^{+0.10}_{-0.09}$
radius [m]	1.9		0.7	
height [m]	5.0		1.47	
source height [m]	2.7	2.38	0.72	

Likely to be addressed before Project X era.

NuStorM facility

Neutrinos from Stored Muons



Proposed by D. Neuffer in 1980

60-120GeV proton beam, $\sim$100kW target, horn focused

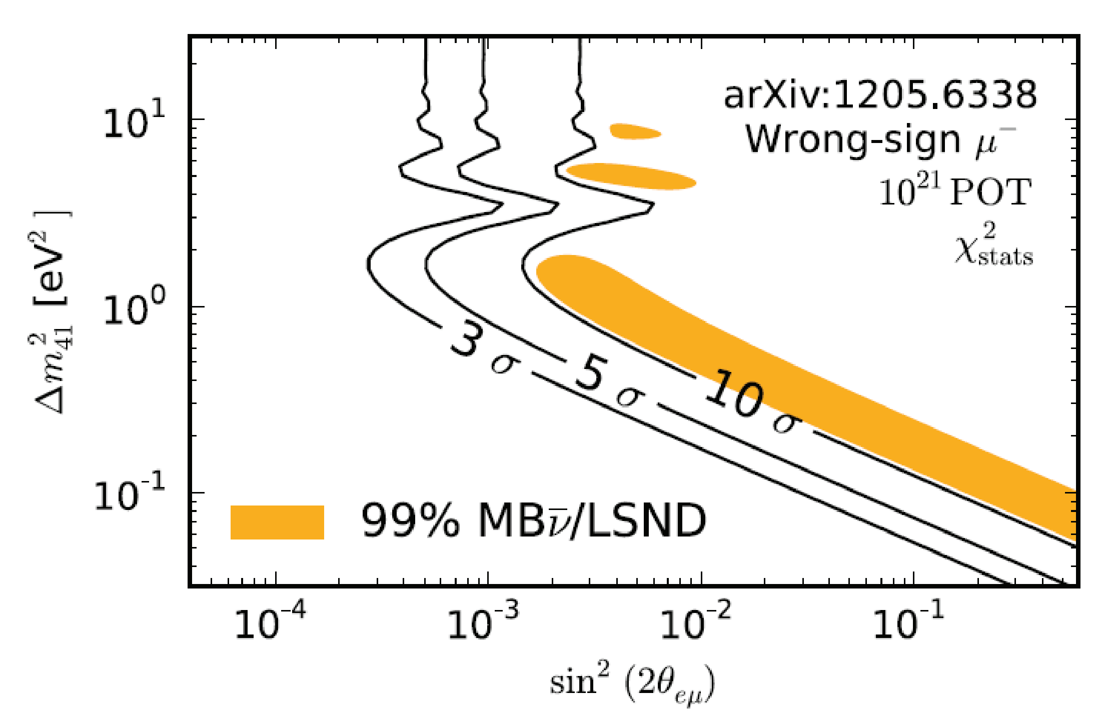
3.8GeV muons stored in ring with 10% momentum acceptance

10^{21} pot yield 2×10^{18} useful muon decays

1.3kt magnetized iron detector, 2km baseline

Project X upgrades luminosity by a factor of few.

NuStorM physics reach



$\bar{\nu}_\mu$ disappearance

ν_e disappearance with right detectors

Precision flux <1% allows cross section measurements for both ν_μ and ν_e

Excellent sensitivity to $\nu_e \rightarrow \nu_\mu$

First step in a program of stored muon beams.

Synergies

In *Project X: Physics Opportunities* we conclude that:

A staged muon-based program starting with nuSTORM can evolve in various, adjustable steps to a full neutrino factory, which, eventually, sets the stage for a muon collider. This pathway seems to be a very attractive option, producing outstanding physics with every step. At the same time, it crucially requires Project X and, thus, could be one of the most compelling motivations for Project X.

Summary

- Neutrino oscillation is solid evidence for new physics
- Precision measurements help to exclude a vast number of models
- Precision measurements have the best potential to uncover even “newer” physics

In combination this warrants a rich experimental program – driven by protons, delivered by Project X