Invisibles 13

Lumley Castle, UK, July 15, 2013

The experimental neutrino programme

future

oscillation

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ICRR and Kavli-IPMU, Univ. of Tokyo

Outline

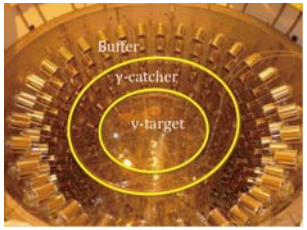
- Introduction
- Next generation neutrino osc. experiments
  - Mass hierarchy?
  - CP violation?
- Summary

Sorry, some experiments are not mentioned…

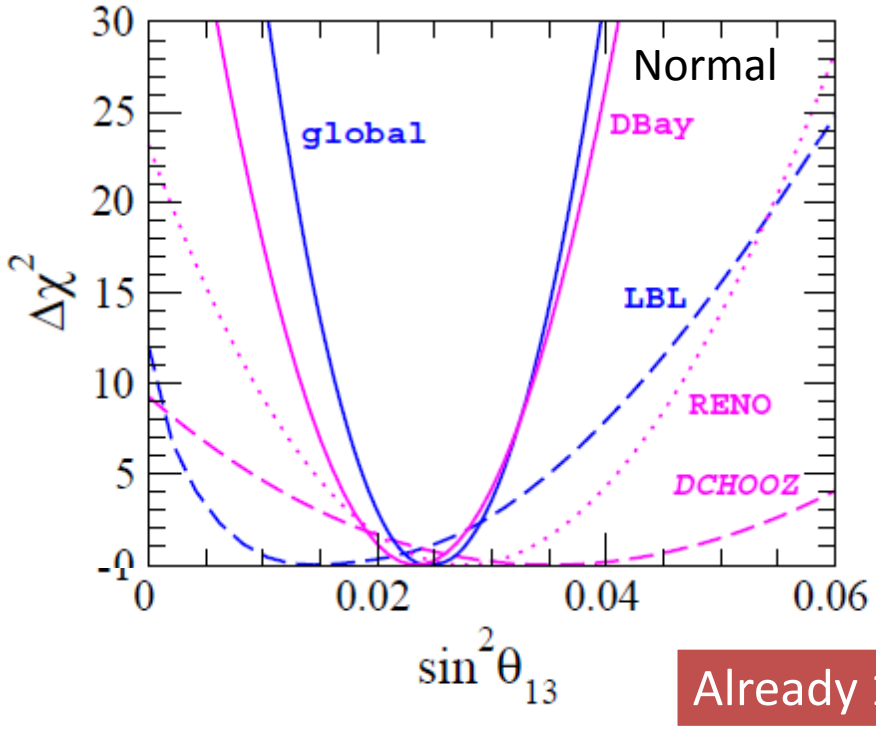
Introduction

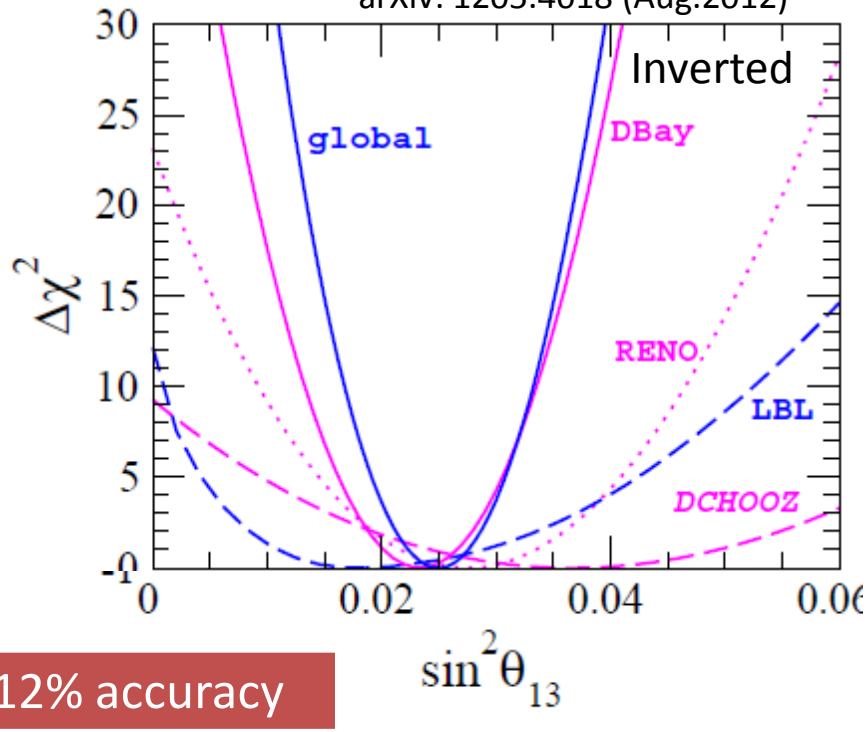
Highlight in 2012: θ_{13}

Double CHOOZ RENO Daya Bay MINOS T2K



arXiv: 1205.4018 (Aug.2012)





Already 12% accuracy

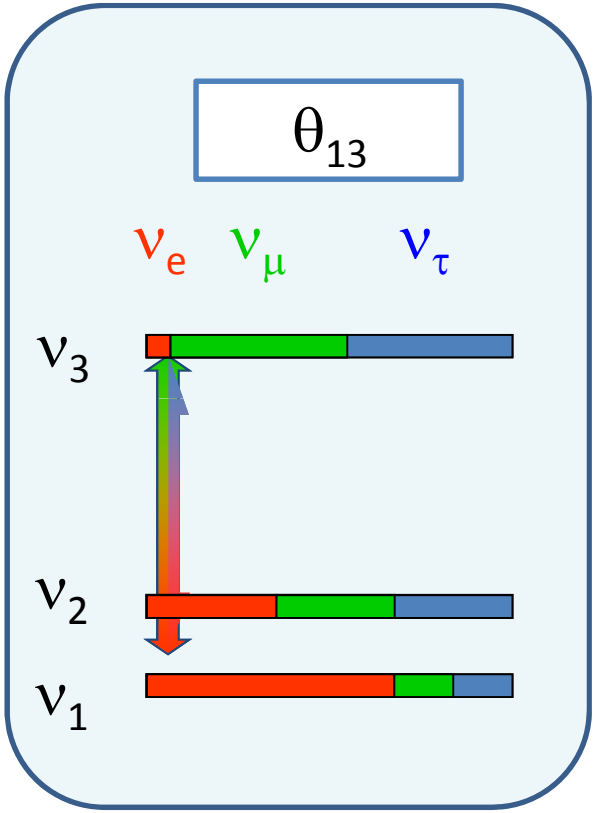
Mixing angles and Δm^2's

arXiv: 1209.3023v3

parameters	3σ range
$\sin^2\theta_{12}$	0.267 – 0.344
$\sin^2\theta_{23}$	0.342 – 0.667
$\sin^2\theta_{13}$	0.0156 – 0.0299
Δm_{12}^2	$(7.00 - 8.09) \times 10^{-5}$ eV^2
$\lvert\Delta m_{13 \text{ or } 23}^2\rvert$	$(2.24 - 2.70) \times 10^{-3}$ eV^2

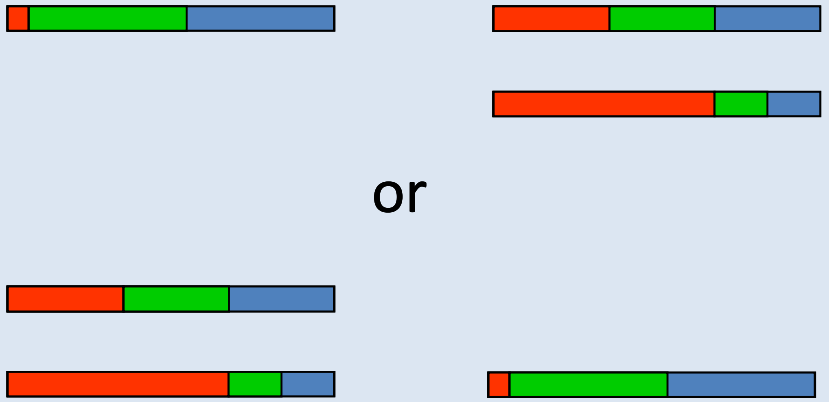
These parameters have been measured accurately.

Beyond θ_{13}



θ_{13} is not very small

Mass hierarchy ?



Is the mass pattern of neutrinos similar to those of quarks and charged leptons?

CP violation ?

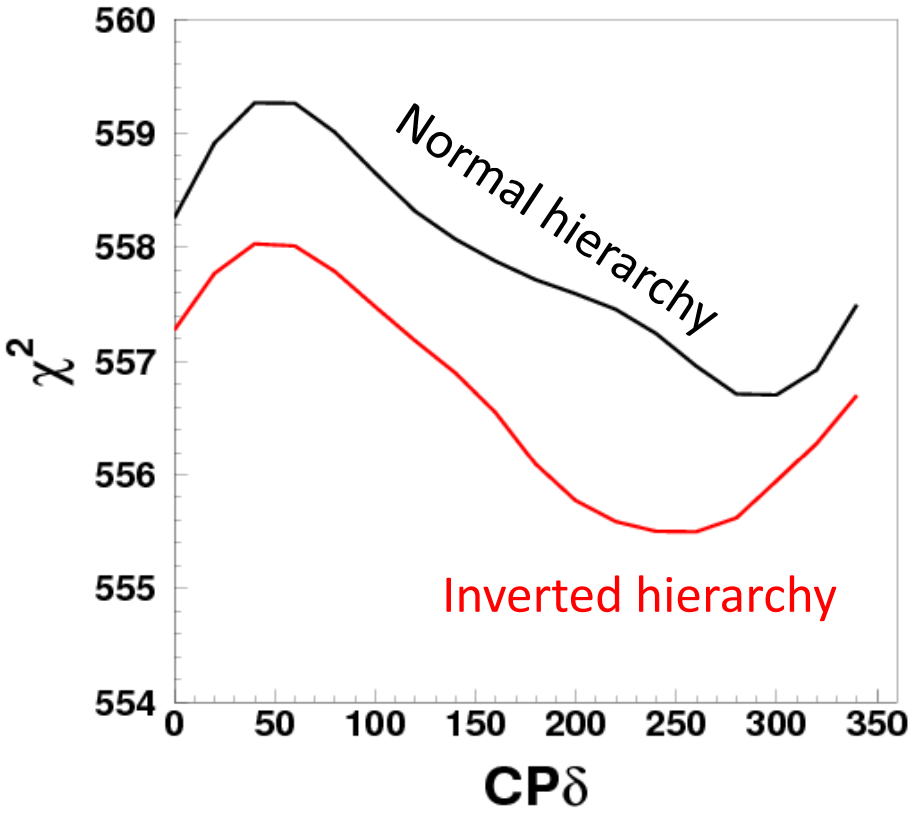
$$P(\nu_\alpha \rightarrow \nu_\beta) \neq P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta) \ ?$$

Baryon asymmetry of the Universe?

Beyond θ_{13}: Status

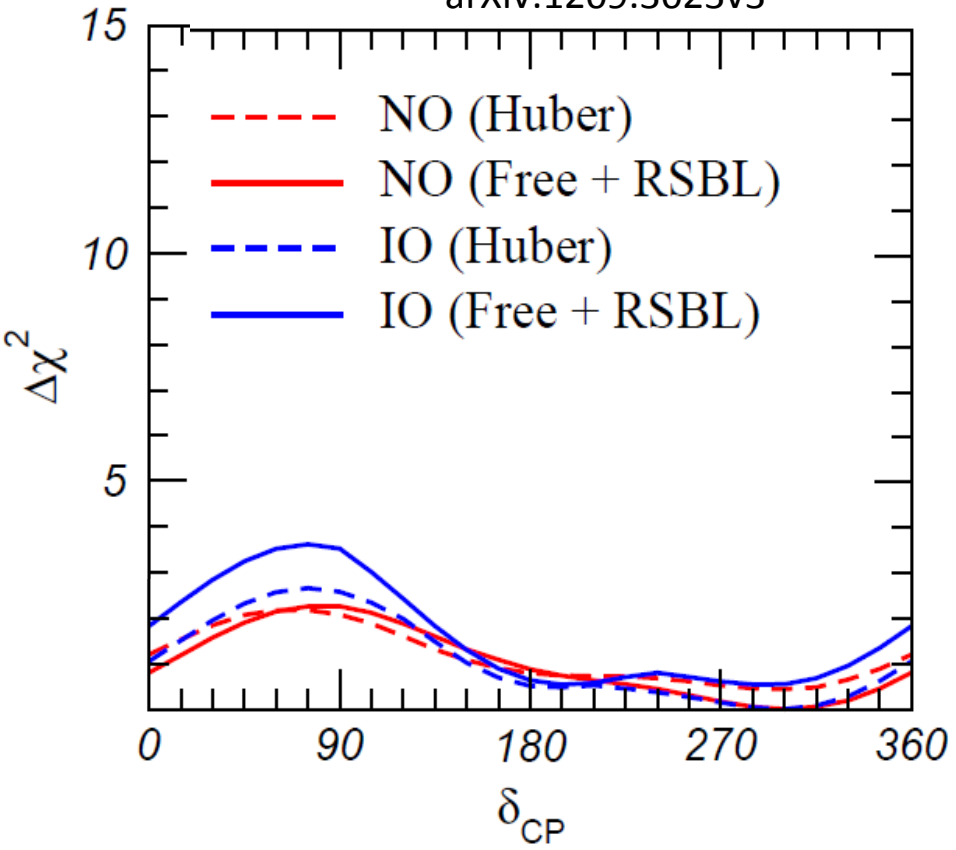
Super-K atm. ν analysis (2012)

Y.Itow Nu2012



Global analysis (example)

arXiv:1209.3023v3



✓Hint for the value of δ_{CP}?

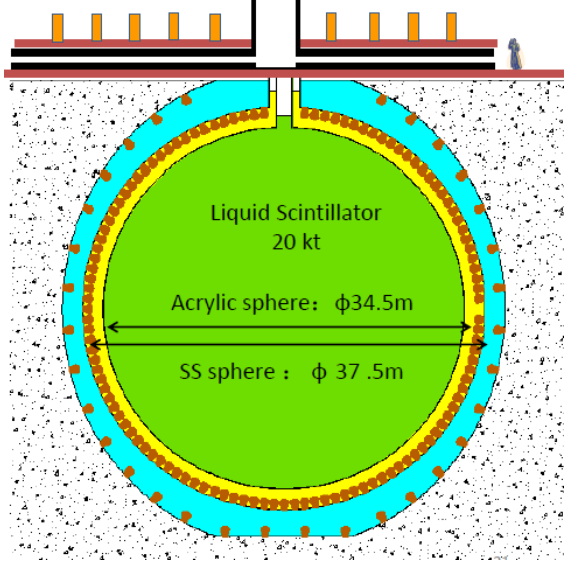
✓Mass hierarchy? The results depend on the analysis and assumptions…

➔ Next generation experiments !

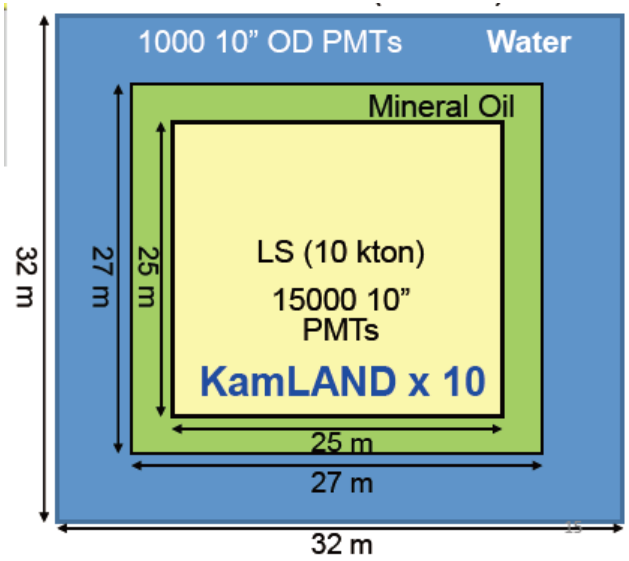
Next generation neutrino osc. experiments

Next generation neutrino osc. experiments

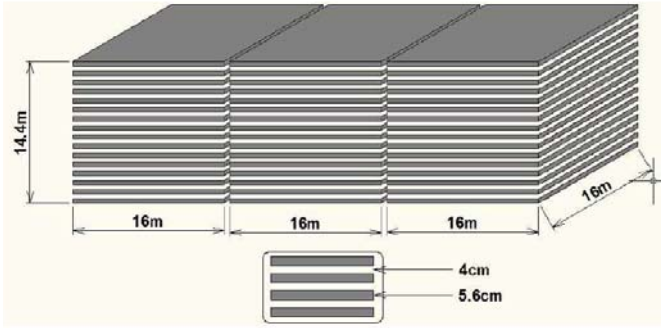
Daya Bay II

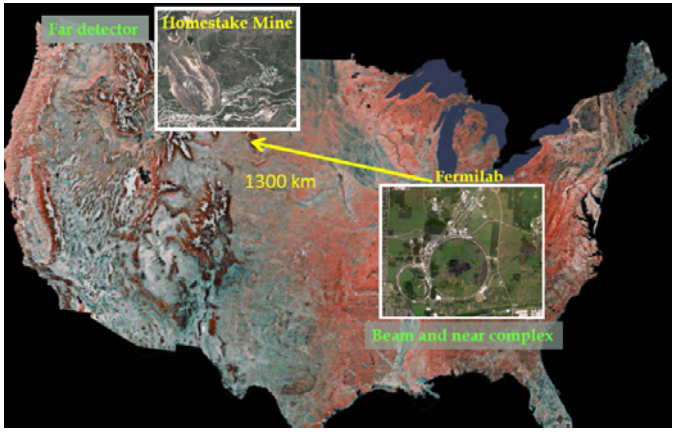


RENO-50

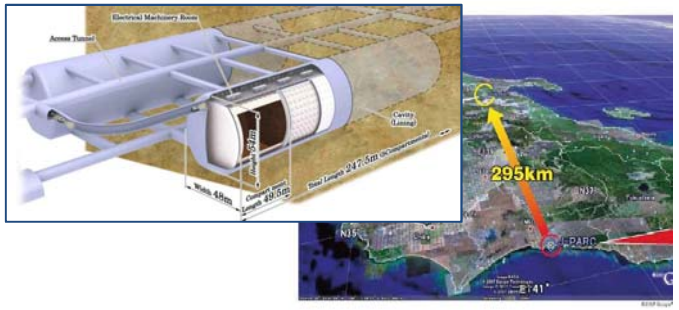


INO





LBNE



Hyper-K

LBNO

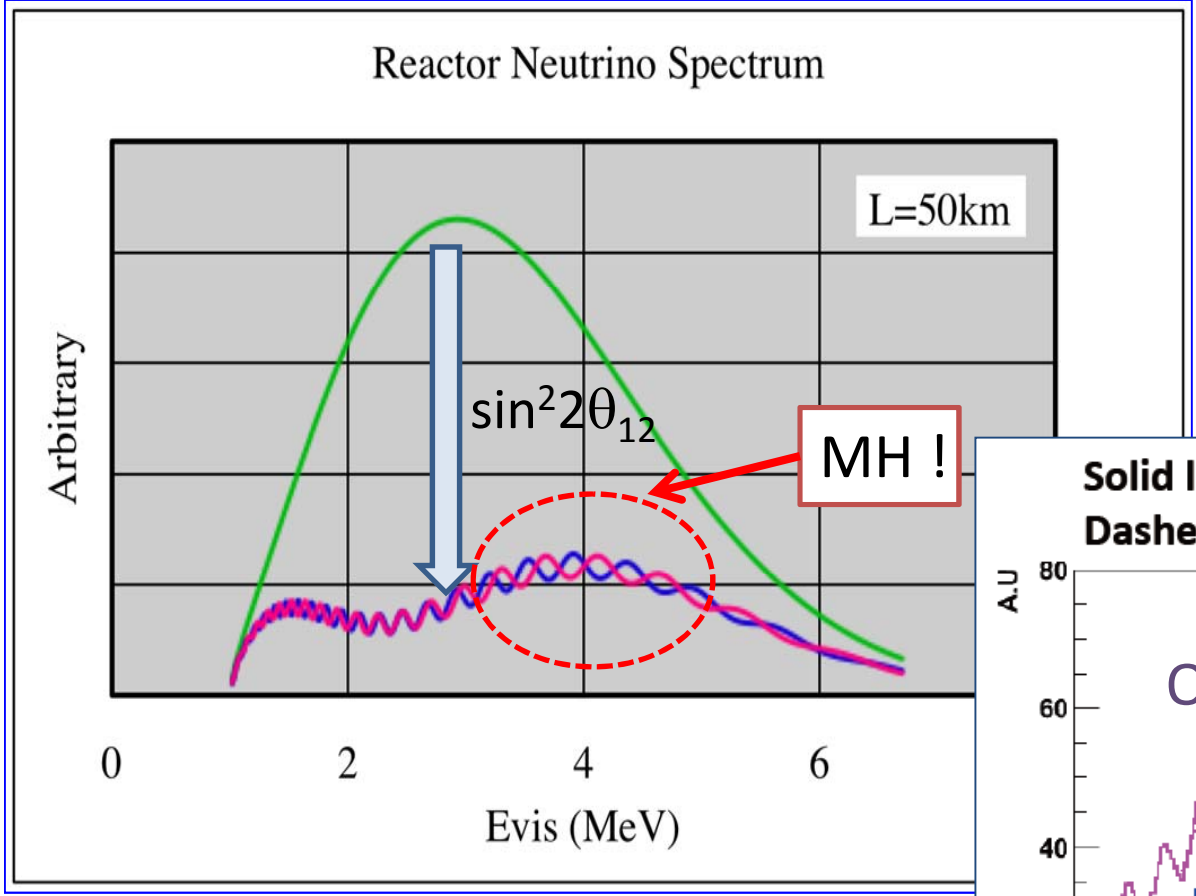
Mass hierarchy

3 methods:

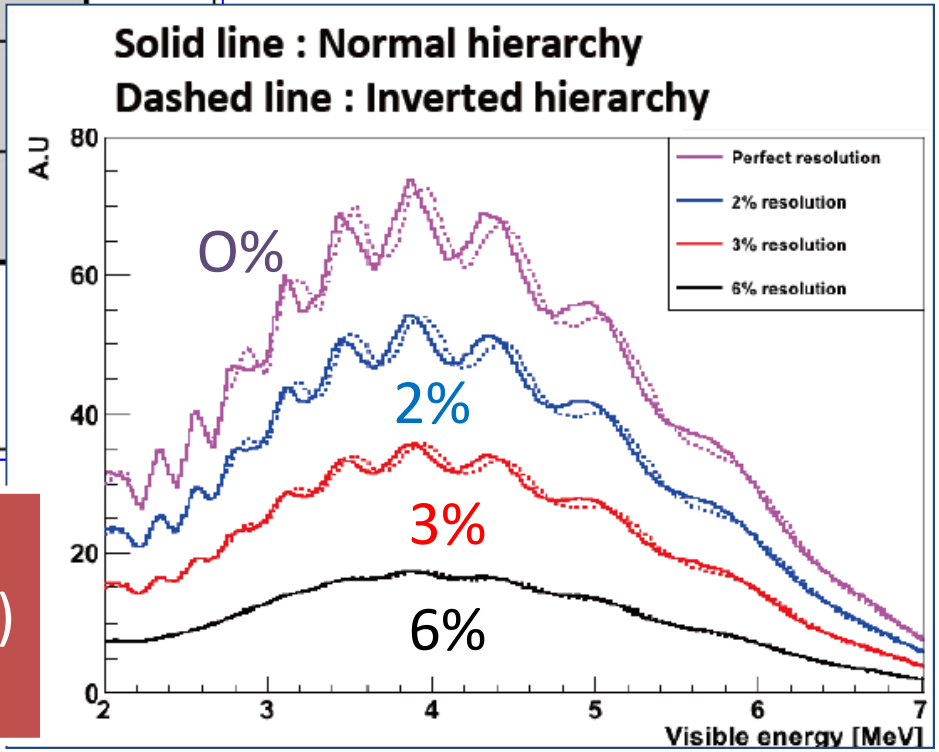
- Reactor ν exp.
- Atmospheric ν exp.
- LBL experiment

Reactor experiments for MH

Refs: RENO-50 workshop June 2013



Energy resolution



Keys:

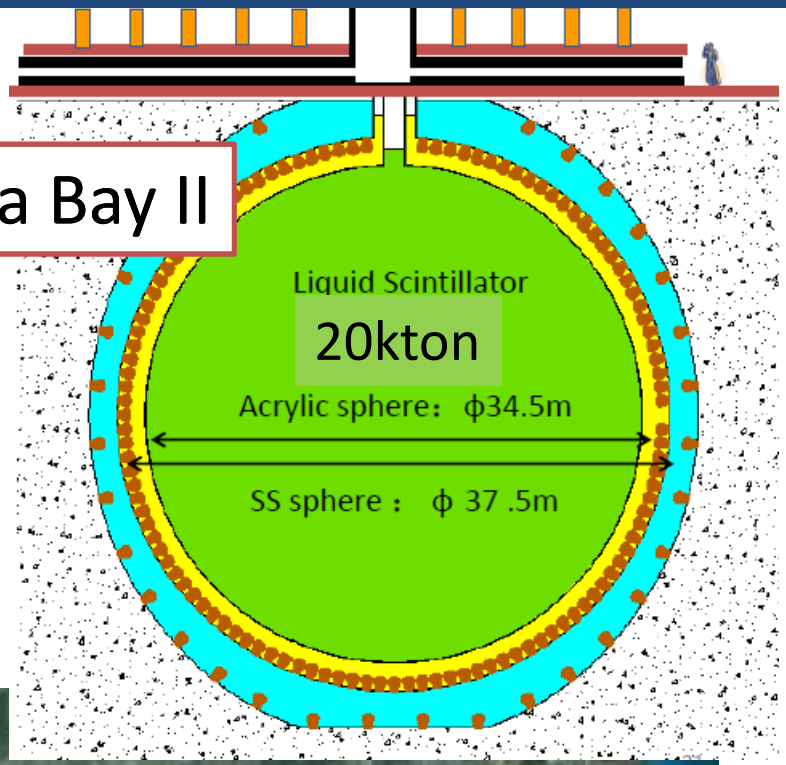
✓Good E. resolution (3% or better?)

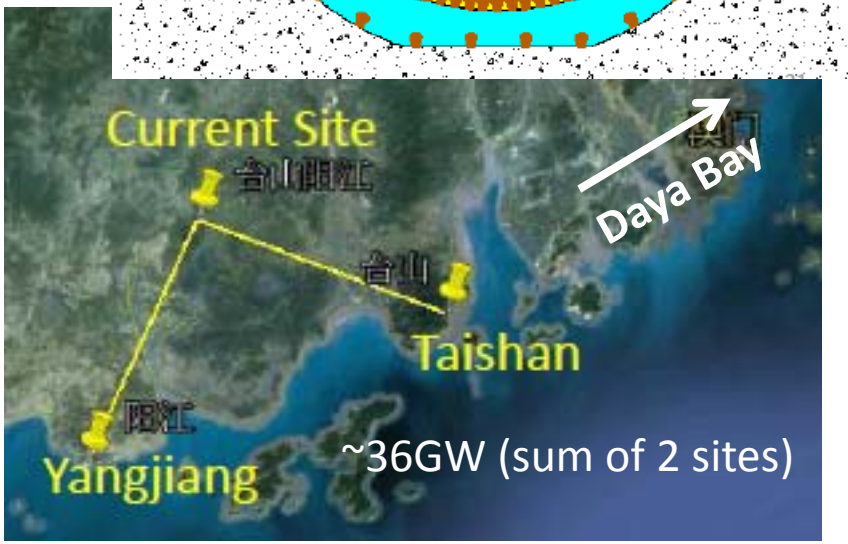
✓High stat. (large detector)

Reactor experiments for MH

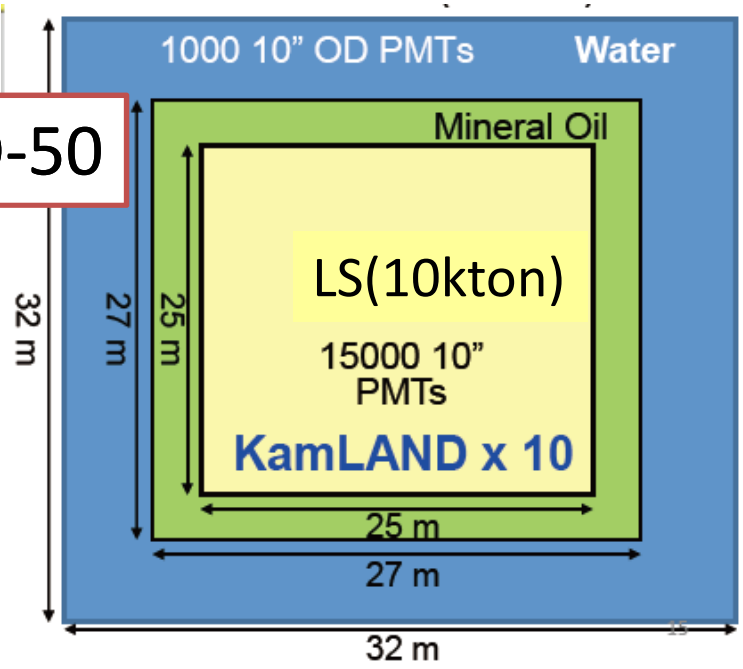
Refs: RENO-50 workshop June 2013

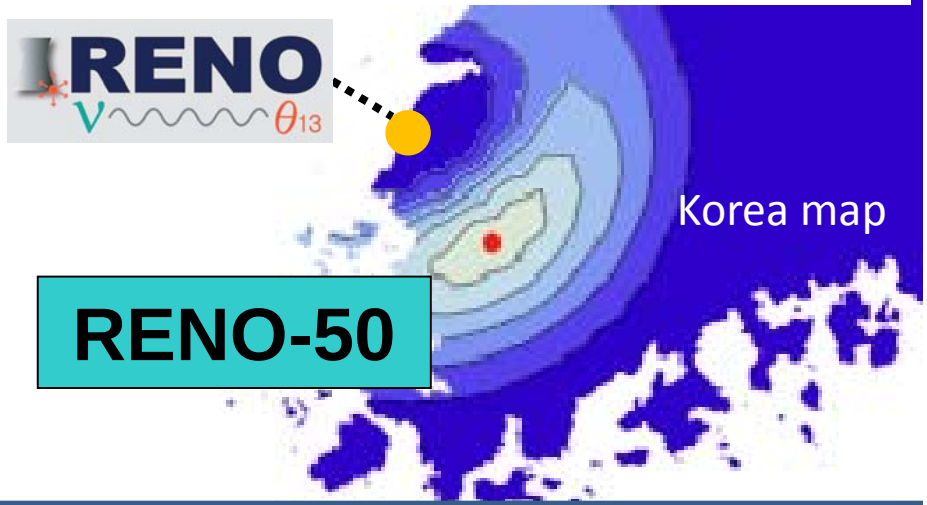
Daya Bay II





RENO-50



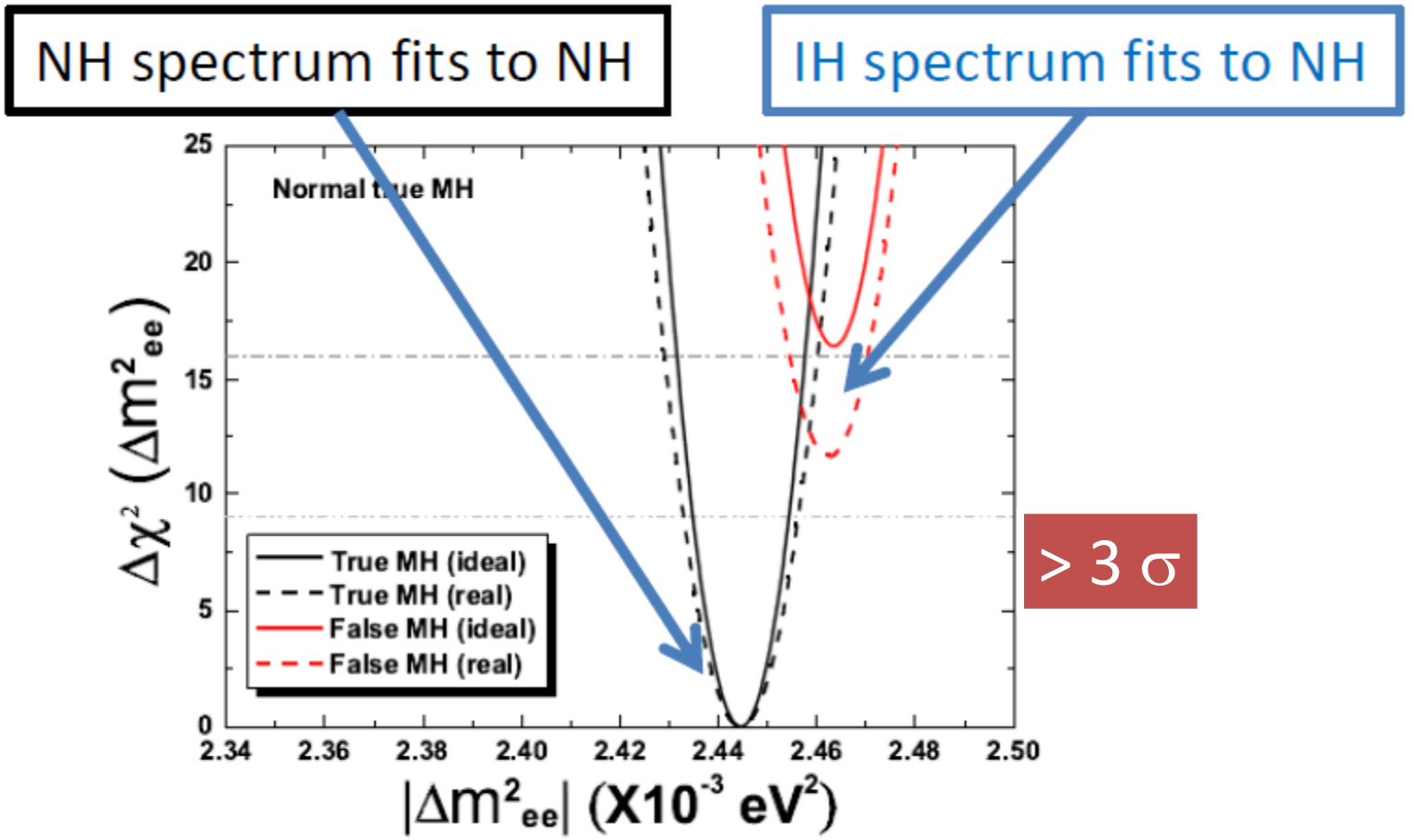


RENO-50

Sensitivity

Daya Bay II

L. Zhan, RENO-50 SK June 2013



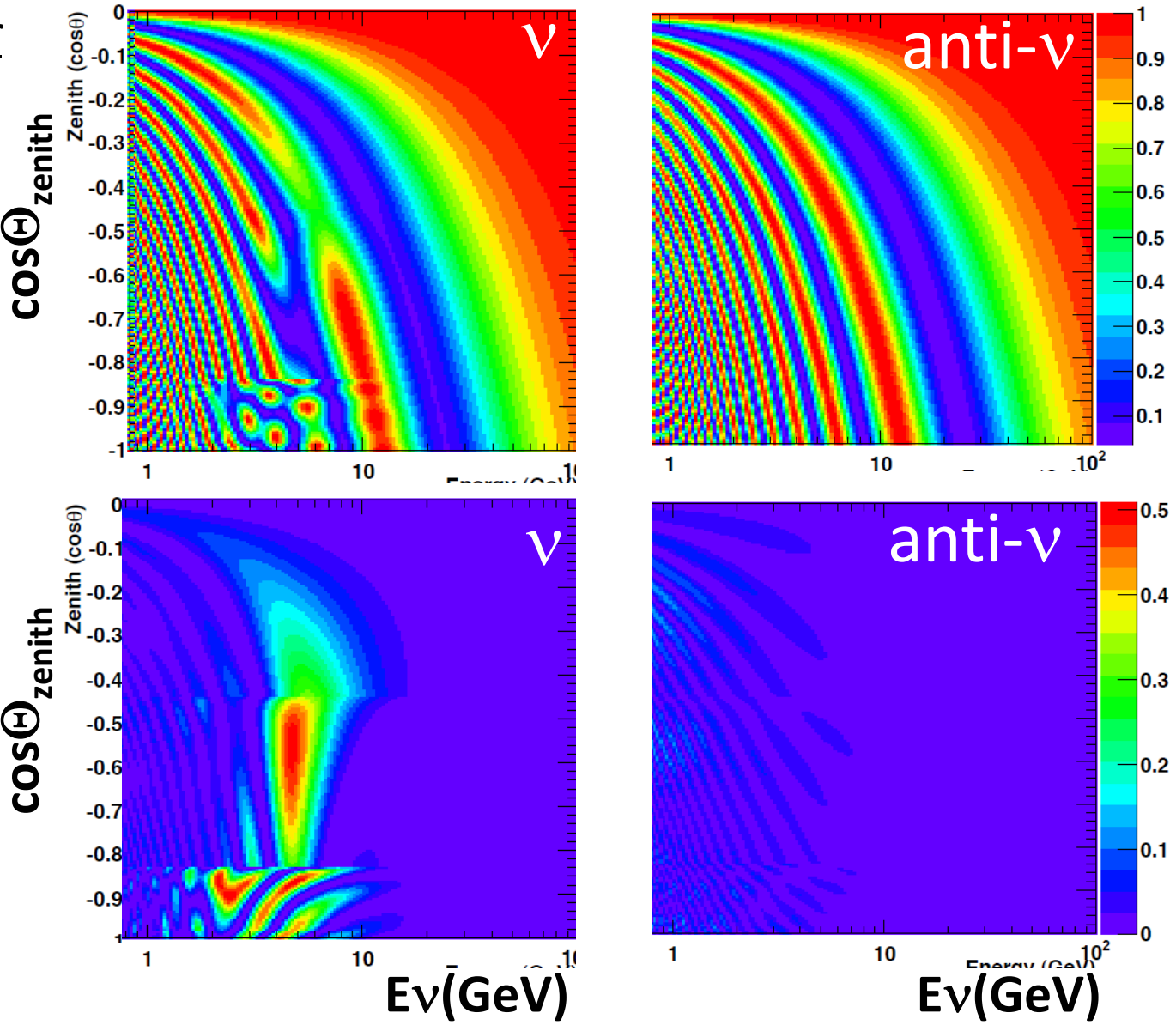
Other physics: precise measurements of θ_{12}, Δm_{12}^2, Δm_{13}^2, supernova neutrinos, …

Atmospheric ν experiments for MH

Osci. Probability for Normal Hierarchy

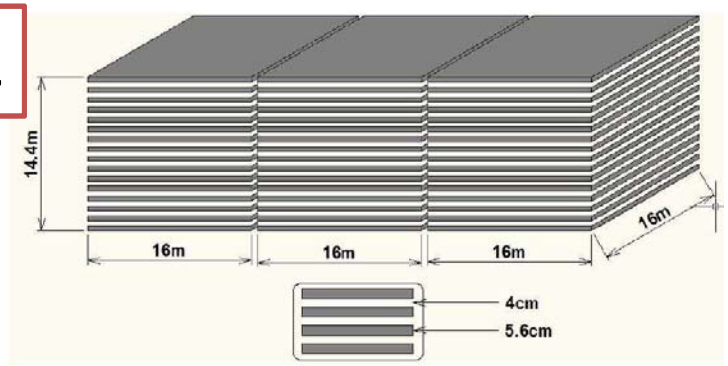
$P(\nu_\mu \rightarrow \nu_\mu)$

$P(\nu_\mu \rightarrow \nu_e)$



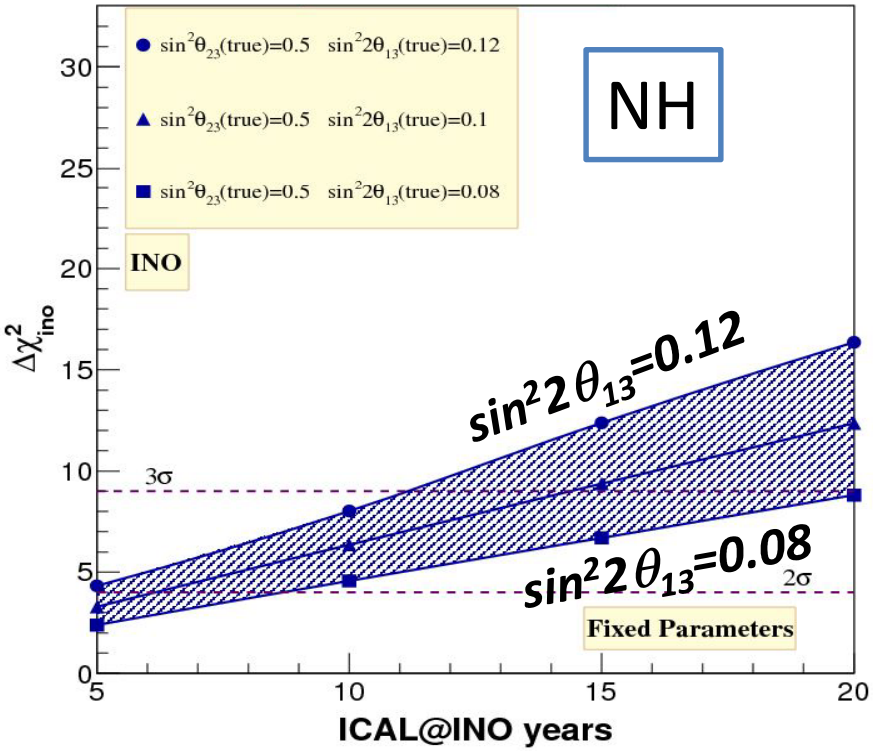
INO

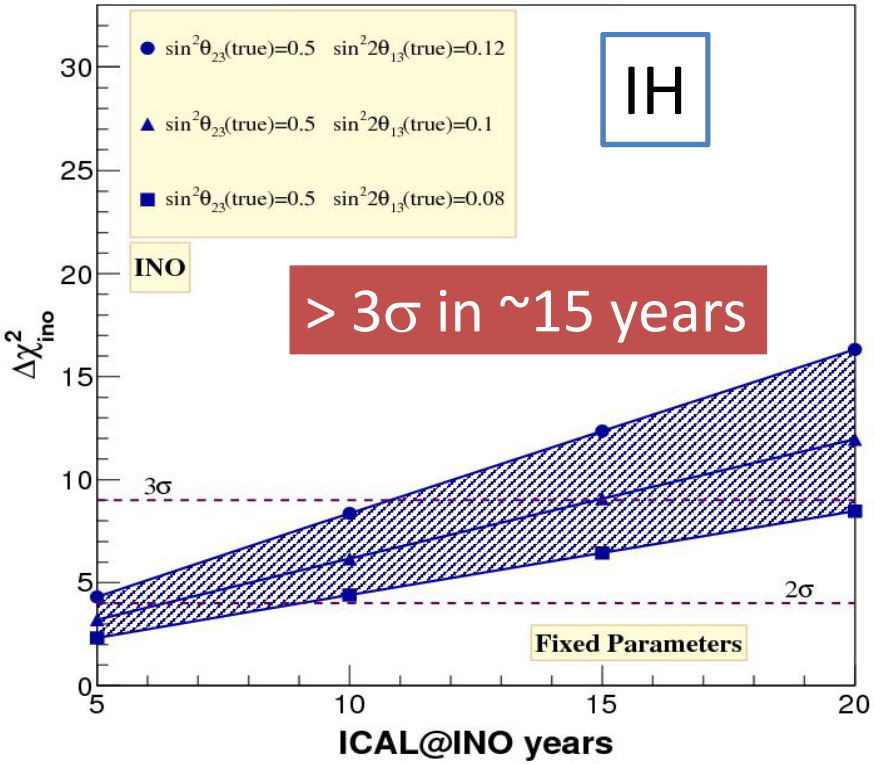
INO-ICAL



N.Mondal, Int. Sym. On Opp. in Und. Grand Phys. May, 2013

- 50 kton magnetized (1.4T) detector
- Will be located 115 km west of Madurai





PINGU proposal as well.

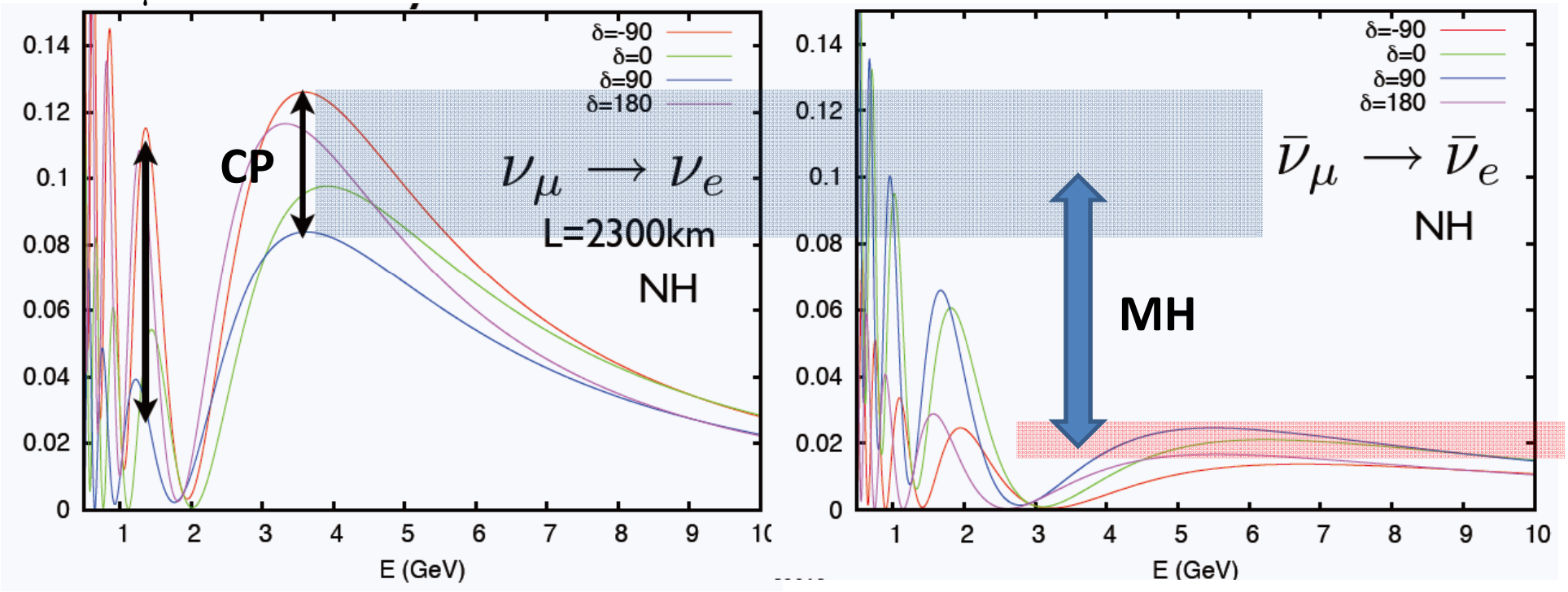
(Hyper-K atm. Later)

Very LBL experiments

Normal hierarchy

L=2300km

$P(\nu_\mu \rightarrow \nu_e)$



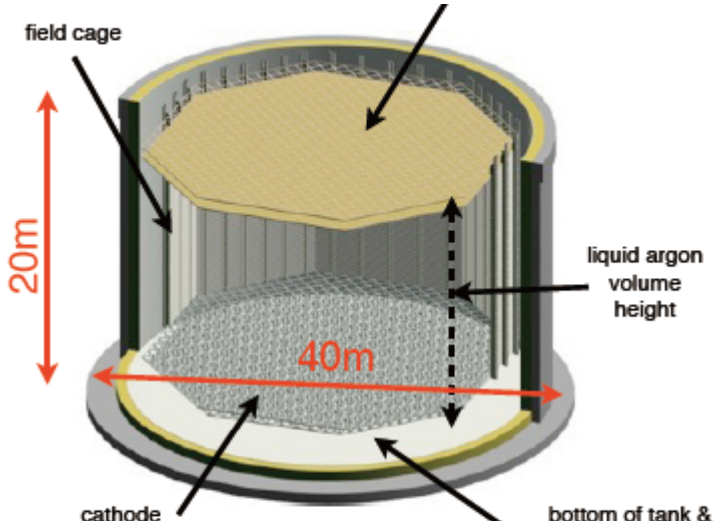
(Essential features similar at L=1300km with less matter effect)

Very LBL experiment: LBNO

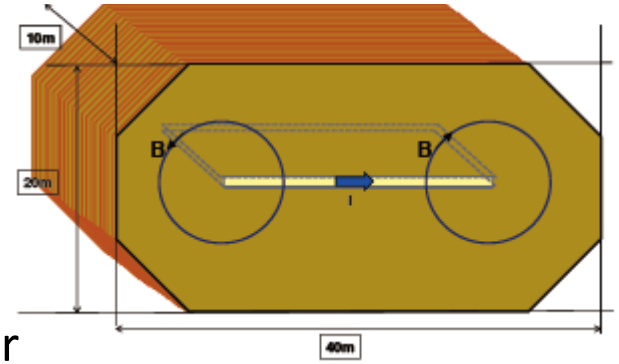
A.Rubbia, Int. Sym. On Opp. in Und. Grand Phys. May, 2013

LBNO

20kton double-phase LAr TPC



+ 34 kton magnetized Muon Detector



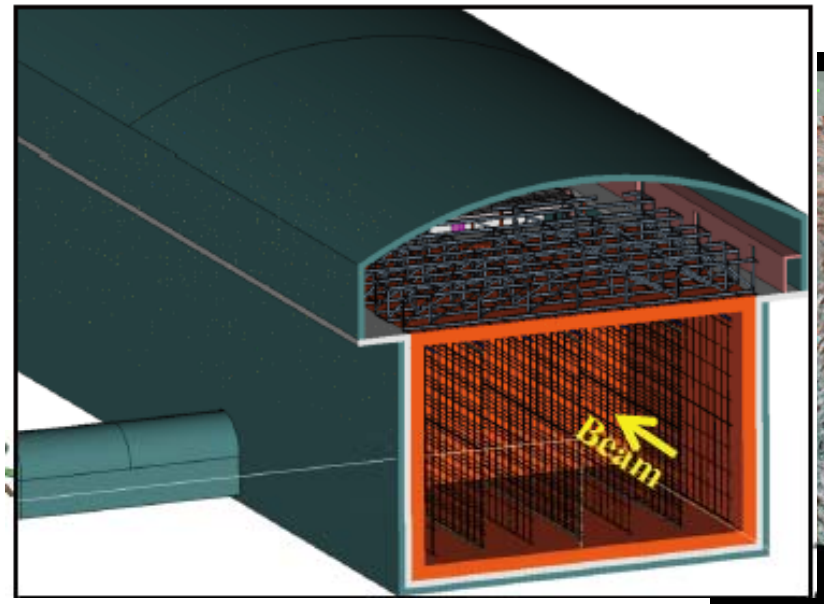
SPS: (0.8-1.3) × 10^{20}pot /year

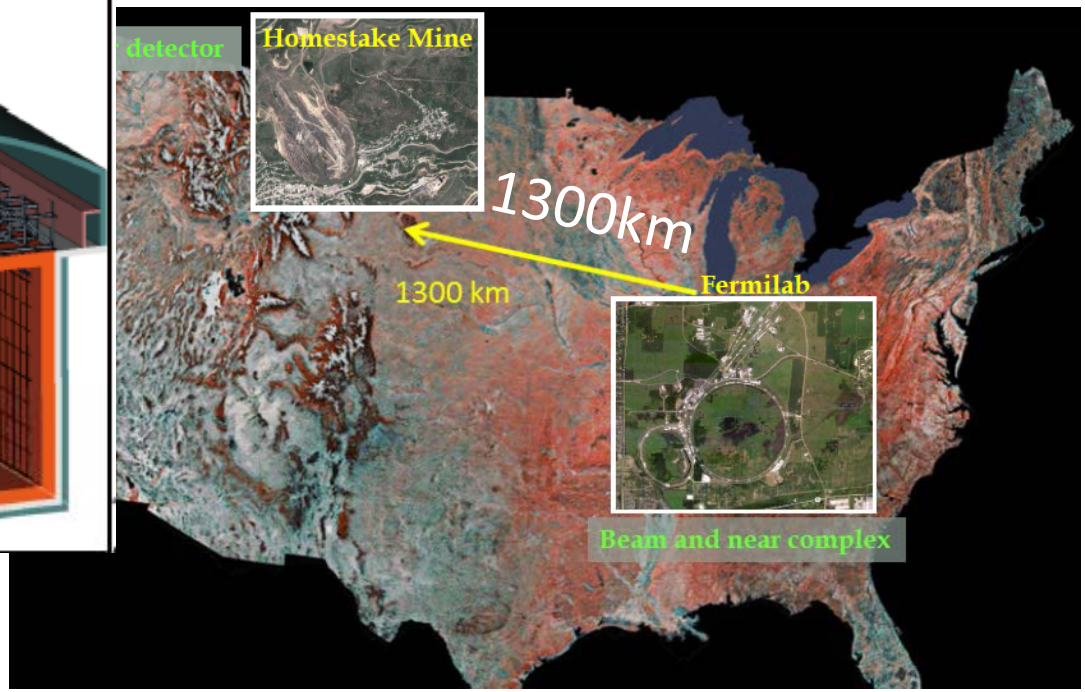
(1 – 1.5) × 10^{21}pot /12year

Very LBL experiment: LBNE

LBNE

M.Diwan, Int. Sym. On Opp. in Und. Grand Phys. May, 2013





Far detector:

10kton LAr at surface (LBNE10),

or

>10kton LAr underground,

or

34kton LAr underground

$60 < E_{proton} < 120GeV$

700kW,

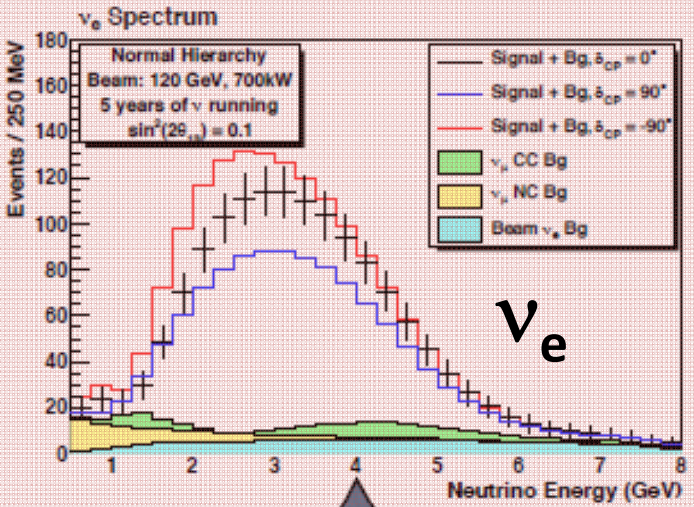
upgradable to 2,3MW (Project X)

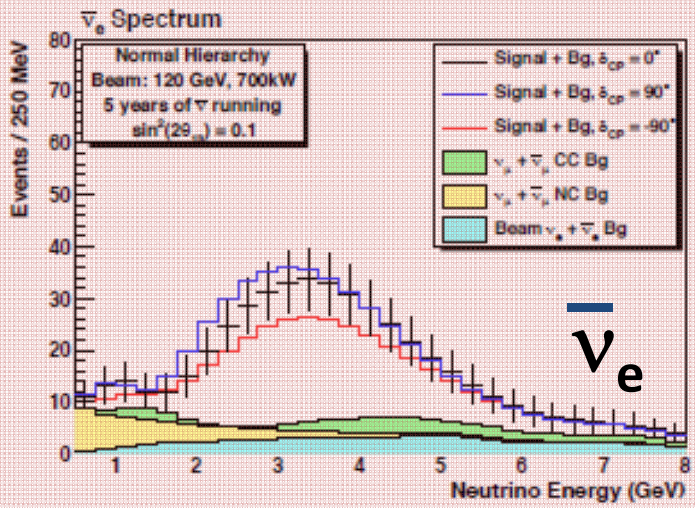
Expected electron signals

M.Diwan, Int. Sym. On Opp. in Und. Grand Phys. May, 2013

NH

1074



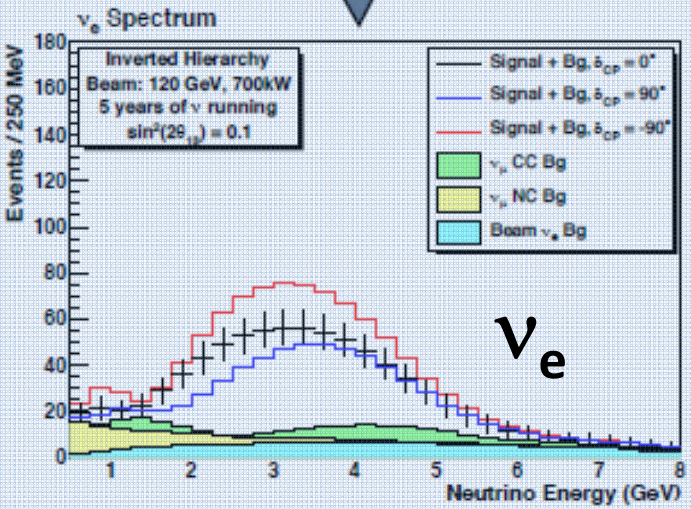


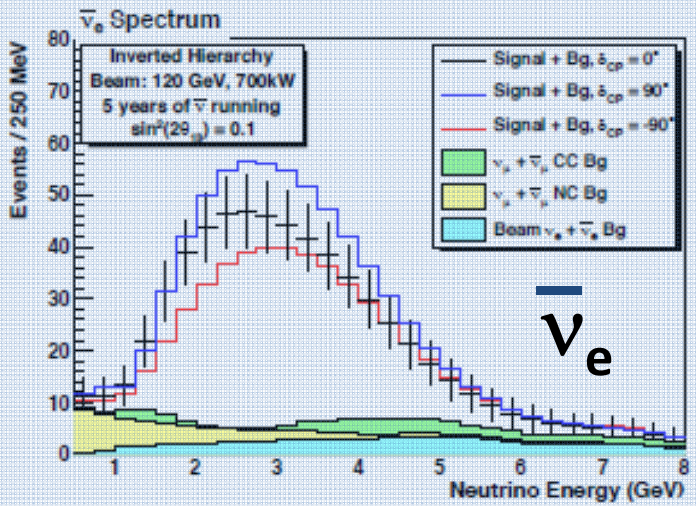
279

diff due to mass ordering

IH

477



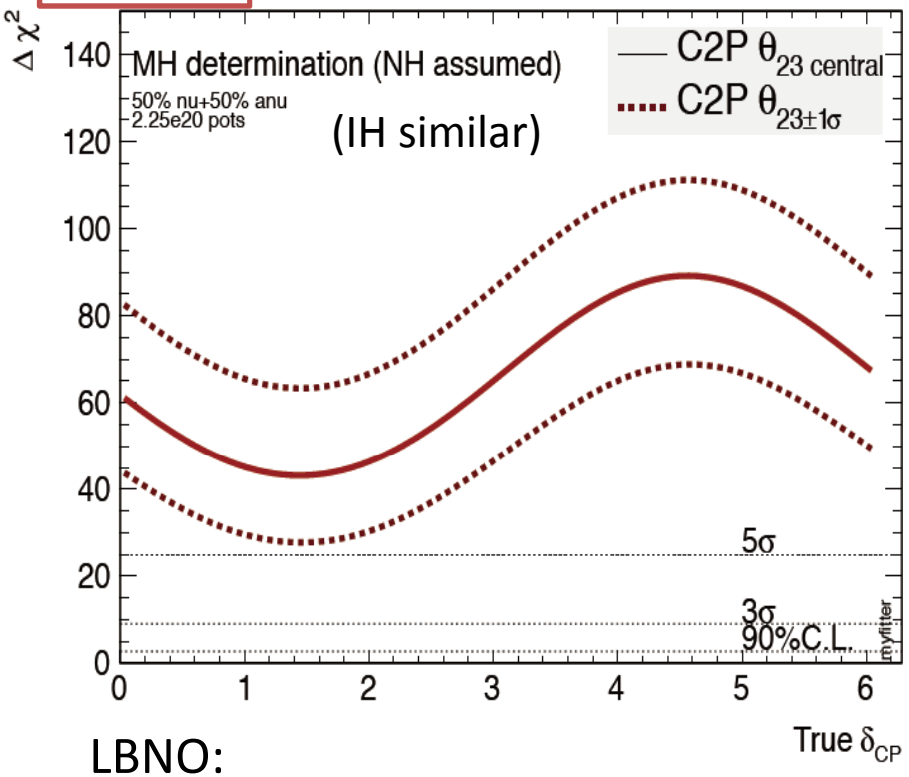


440

Sensitivity to mass hierarchy

LBNO

A. Rubbia, Int. Sym. On Opp. in Und. Grand Phys. May, 2013



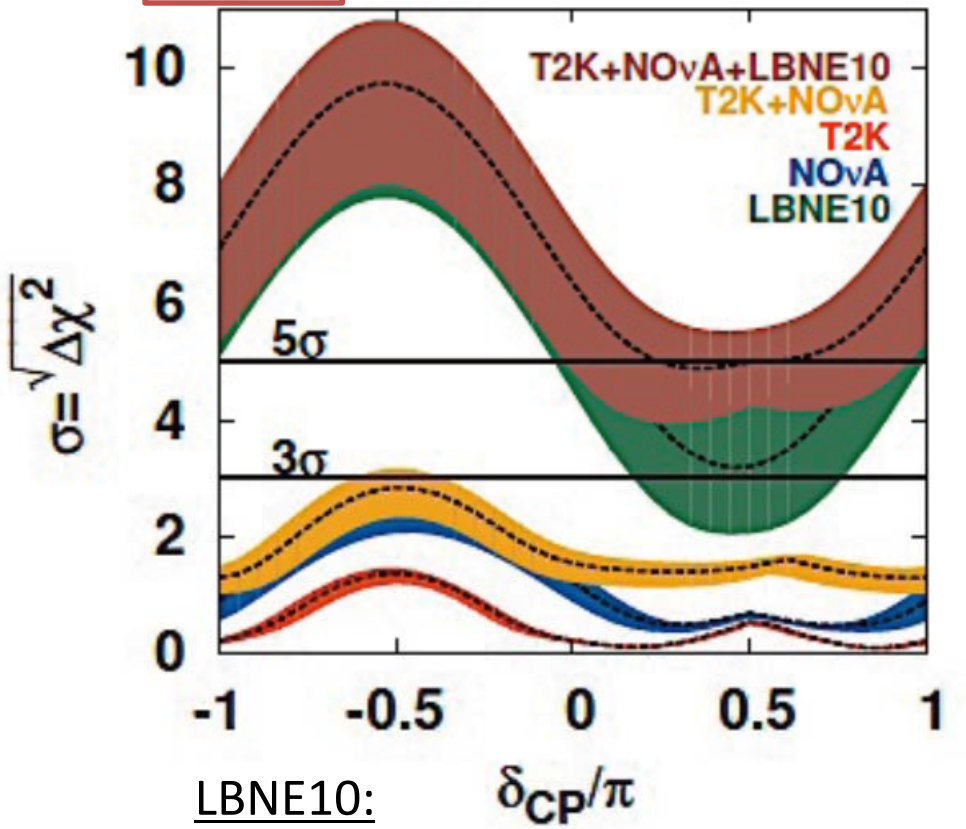
LBNO:

2.25 × 10^{20} pot (~2yr)

= 700kW × (1yr ν + 1yr anti-ν)

LBNE

M.Diwan, Int. Sym. On Opp. in Und. Grand Phys. May, 2013



LBNE10:

700kW × (5yr ν + 5yr anti-ν)

High sensitivity determination of the MH independent of θ_{23} and CP-δ
Longer baseline better

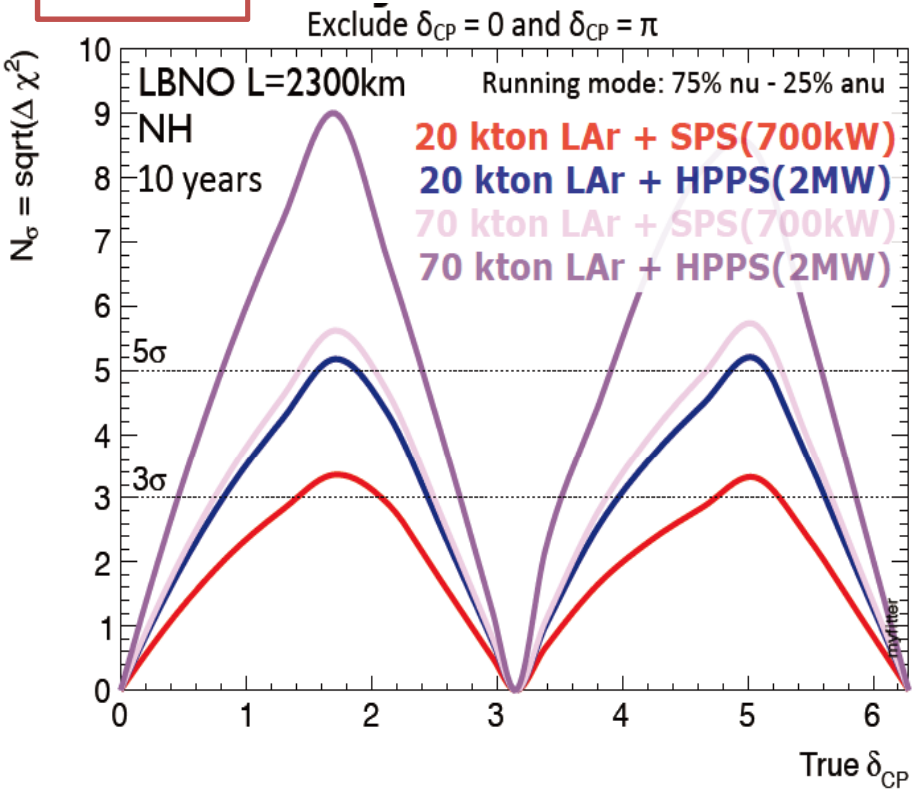
CP violation

- LBL experiment

CP violation with very LBL experiments

LBNO

A. Rubbia, Int. Sym. On Opp. in Und. Grand Phys. May, 2013

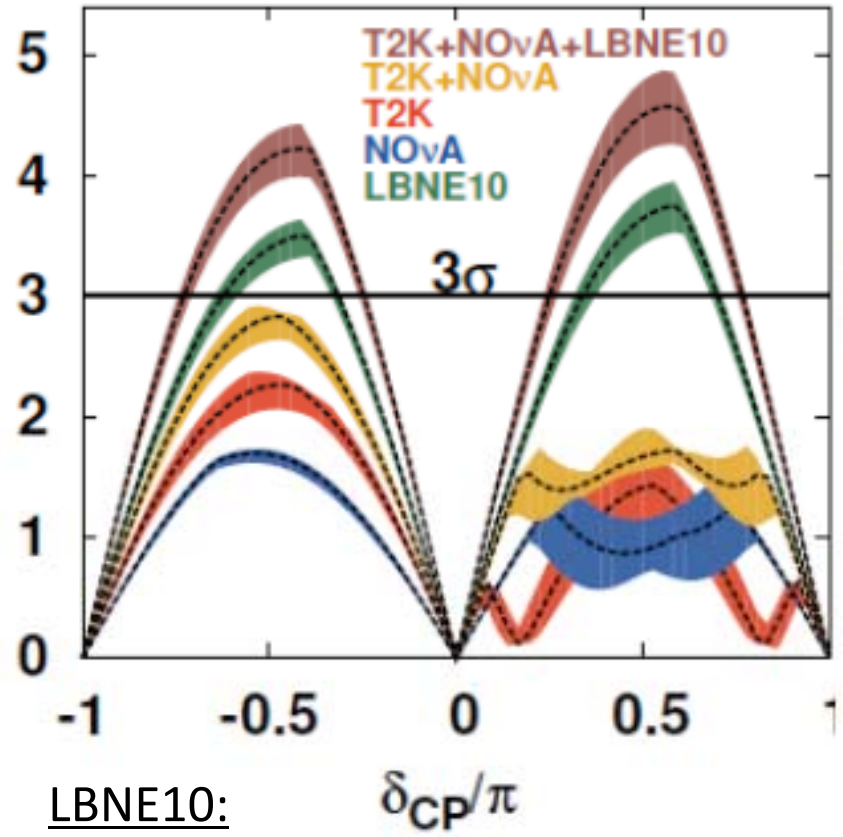


LBNO:

700kW × (7.5yr ν + 2.5yr anti-ν)

LBNE

M.Diwan, Int. Sym. On Opp. in Und. Grand Phys. May, 2013



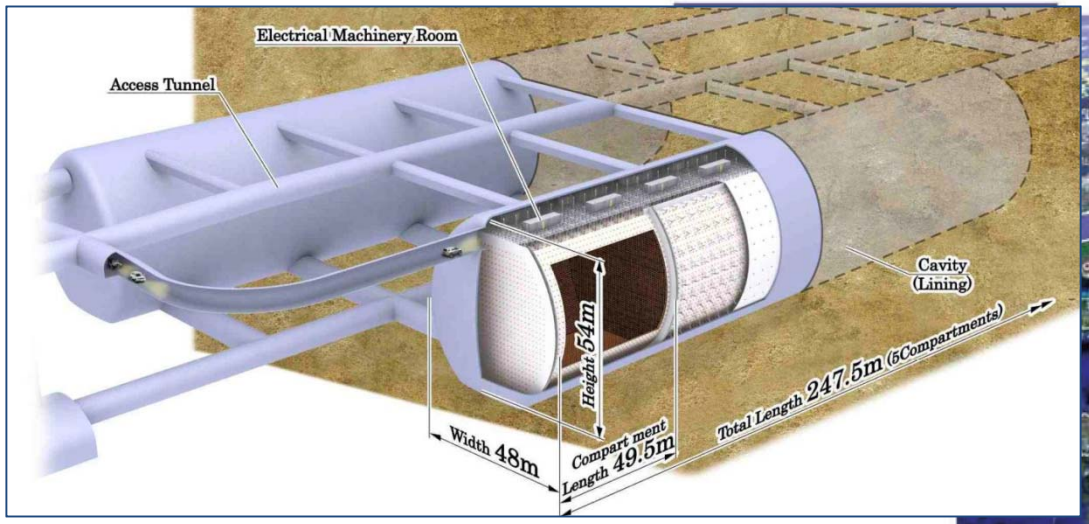
LBNE10:

700kW × (5yr ν + 5yr anti-ν)

CPV sensitivity reaches 3σ for some values of δ
Shorter baseline slightly better

Hyper-Kamiokande with J-PARC

arXiv:1109.3262



- Cavity : 48m(W) x 54m(H) x 250m(L) x 2
- Water volume :
  - Total : 0.496x2 = 0.99 Mton
  - Fiducial volume = 0.56 Mton (25x SK)
  - Depth of tank water : 48m
- Photo-detectors :
  - ID : ~99,000 20” PMTs, 20% photo-coverage
  - OD : ~25,000 8” PMTs, same coverage as SK

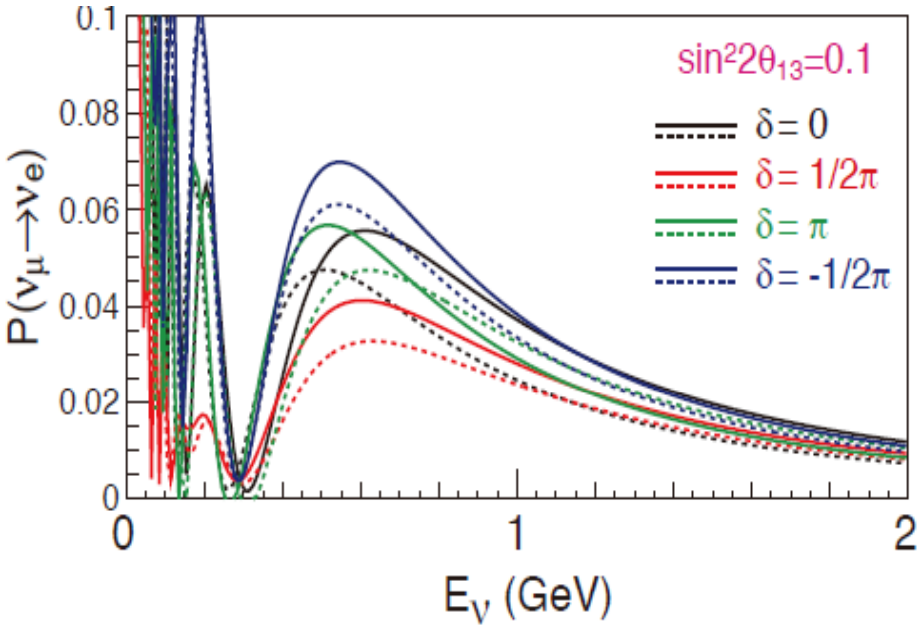
•750 kW (assumed)

2.5 degree off-axis
295km baseline length

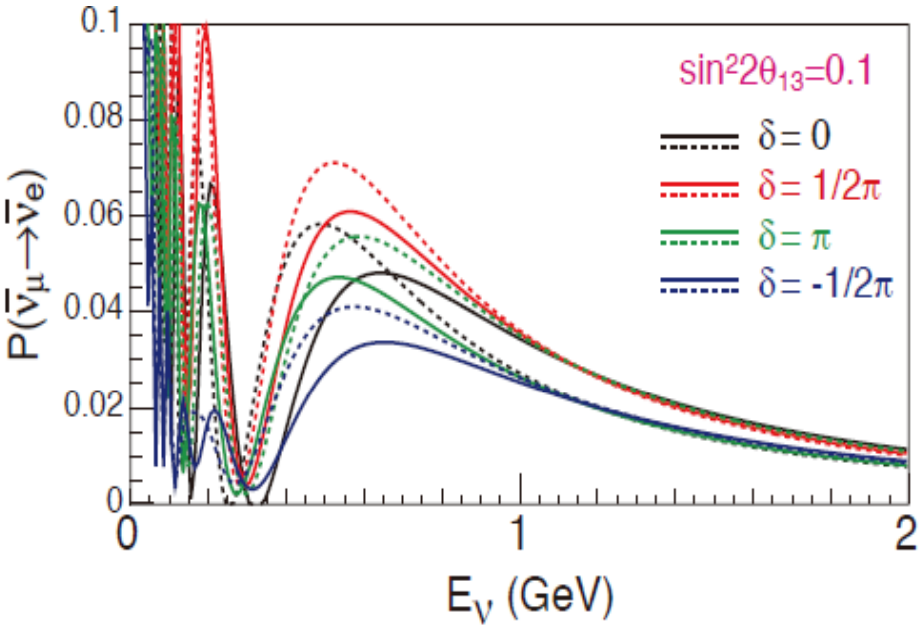
$\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e$ probability @295km

arXiv:1109.3262

neutrino



anti-neutrino



Solid: normal hierarchy
Dashed: inverted hierarchy

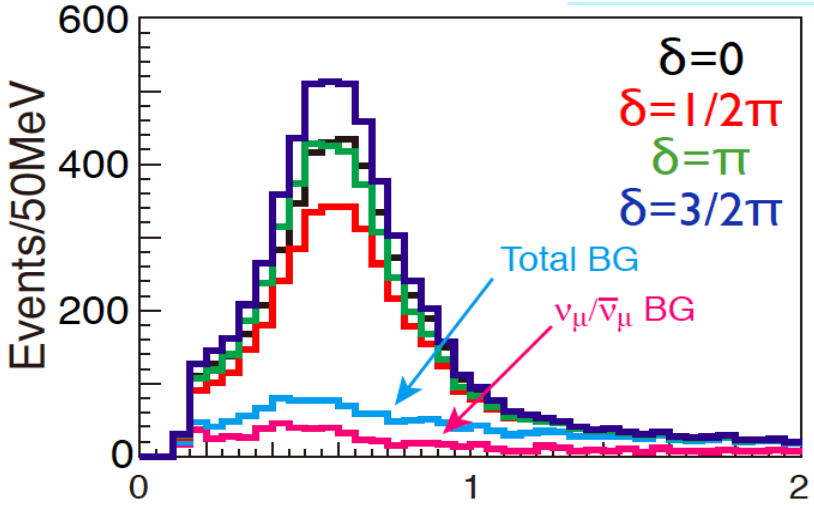
CP violation effect as large as +/- 25%
Matter effect relatively small

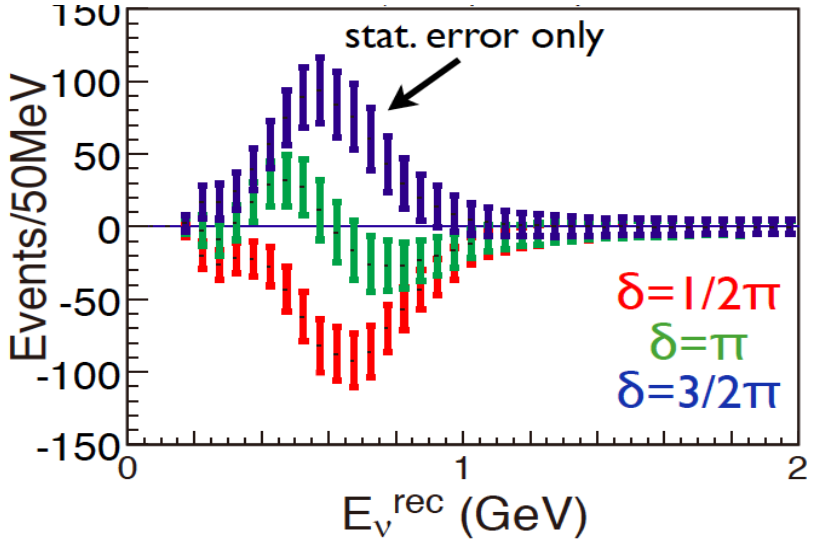
Expected $\overset{(-)}{\nu}_e$ events

normal hierarchy

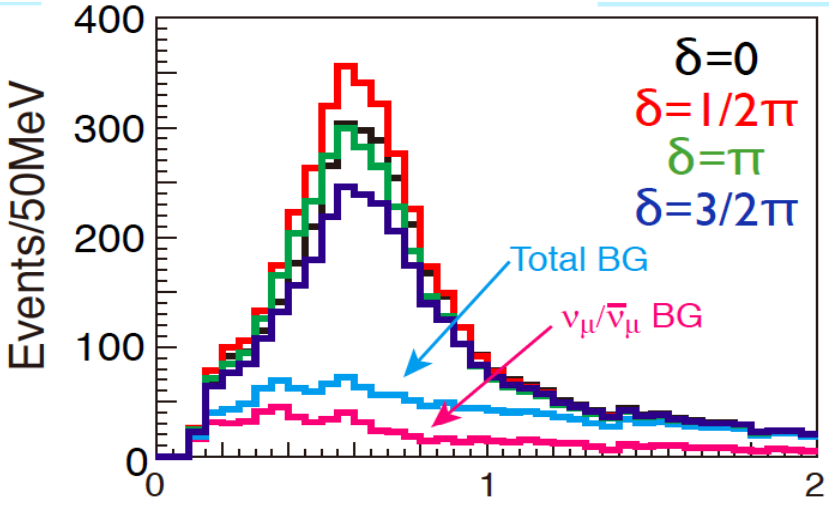
arXiv:1109.3262

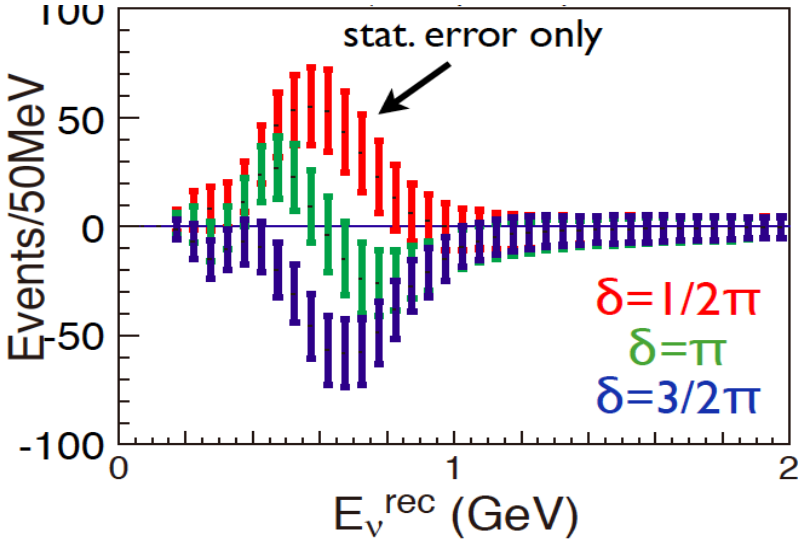
ν mode: 0.75MWx3yrs





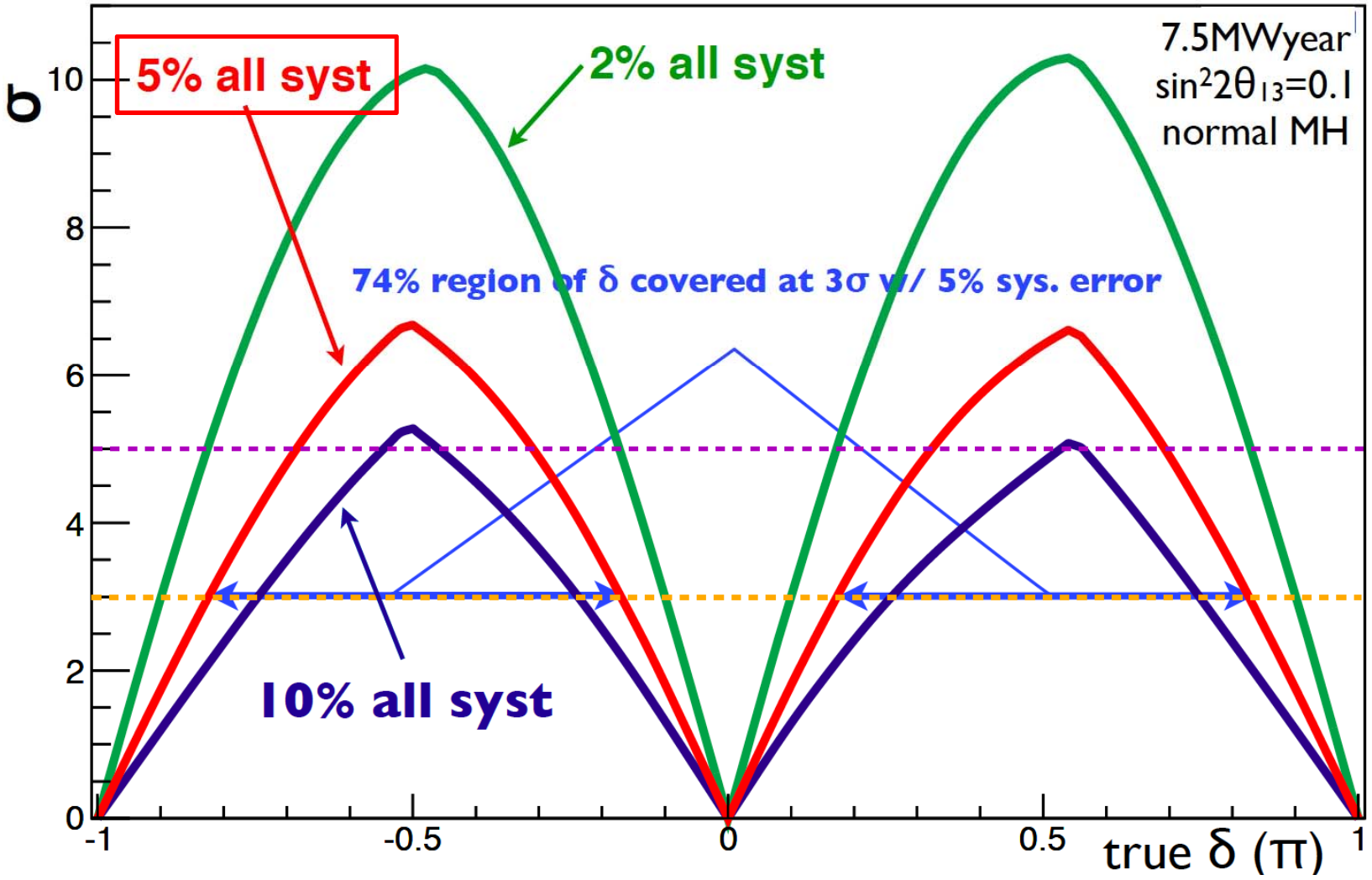
anti-ν mode: 0.75MWx7yrs





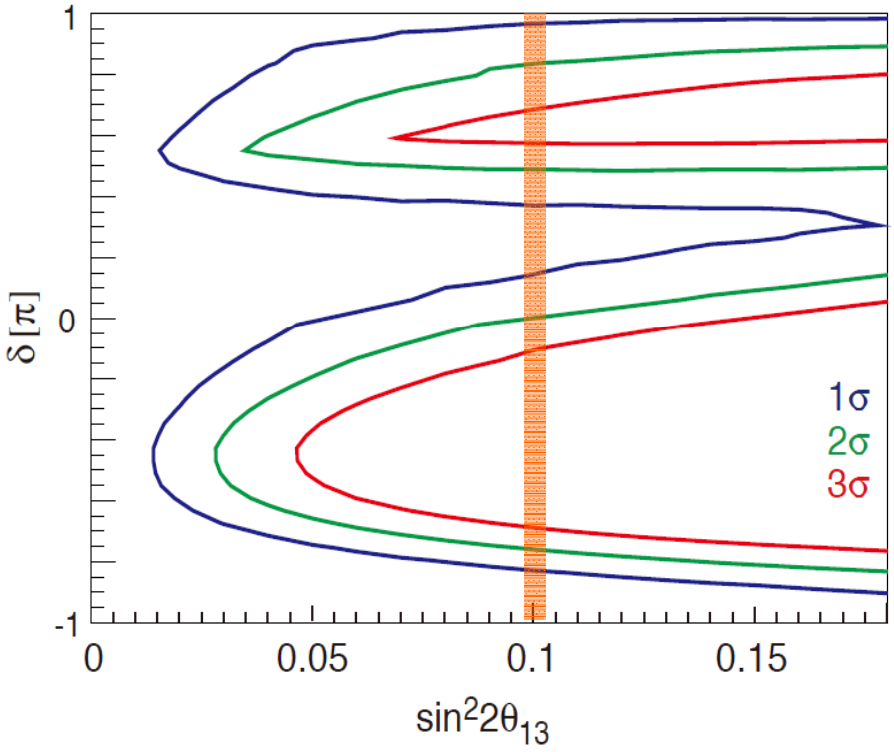
CP violation sensitivity

MH known: Normal hierarchy



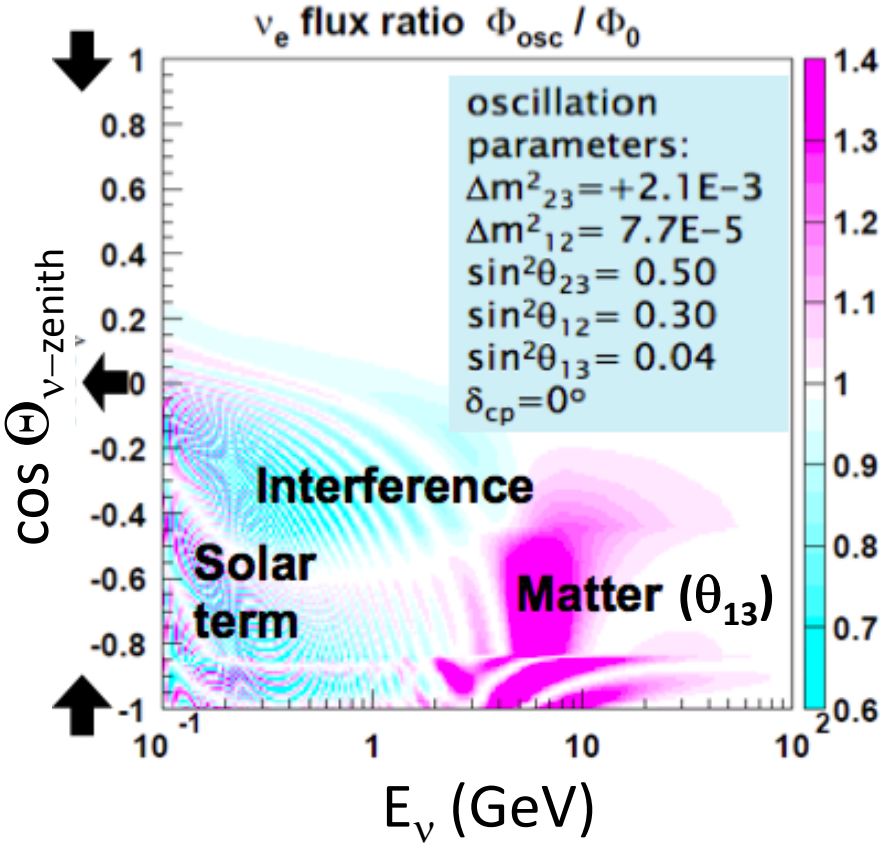
Mass hierarchy measurement

Beam only
(3yrs ν + 7 years anti-ν)



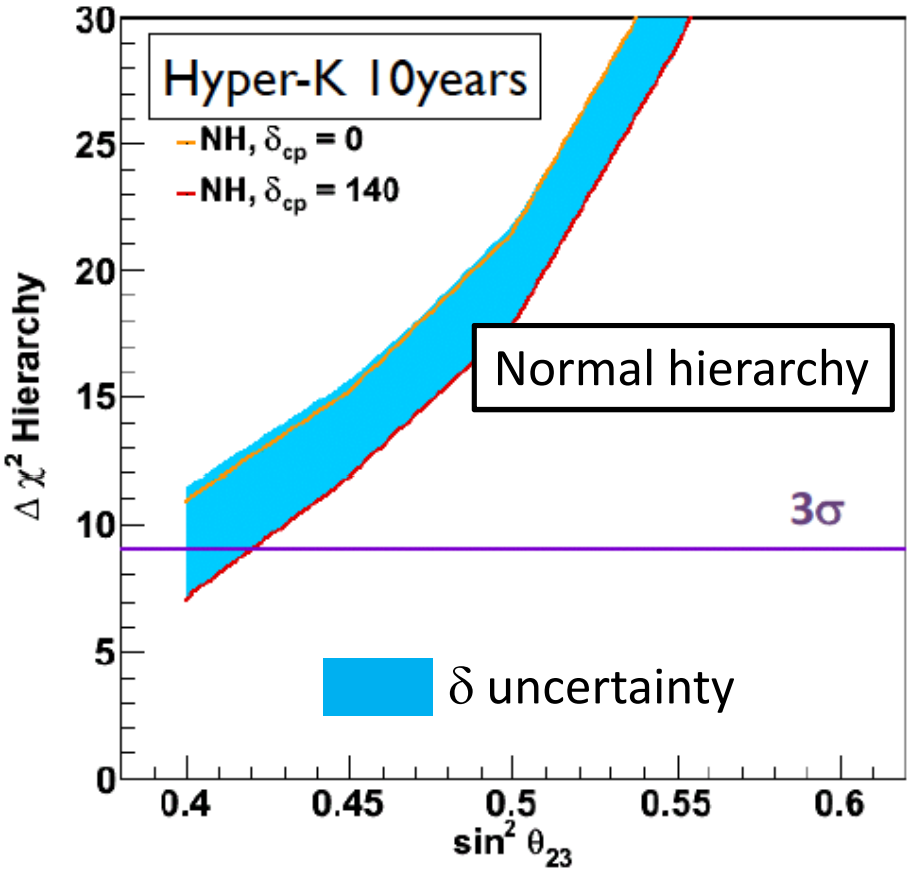
30 ~ 40% chance
(by J-PARC – Hyper-K beam ν only)

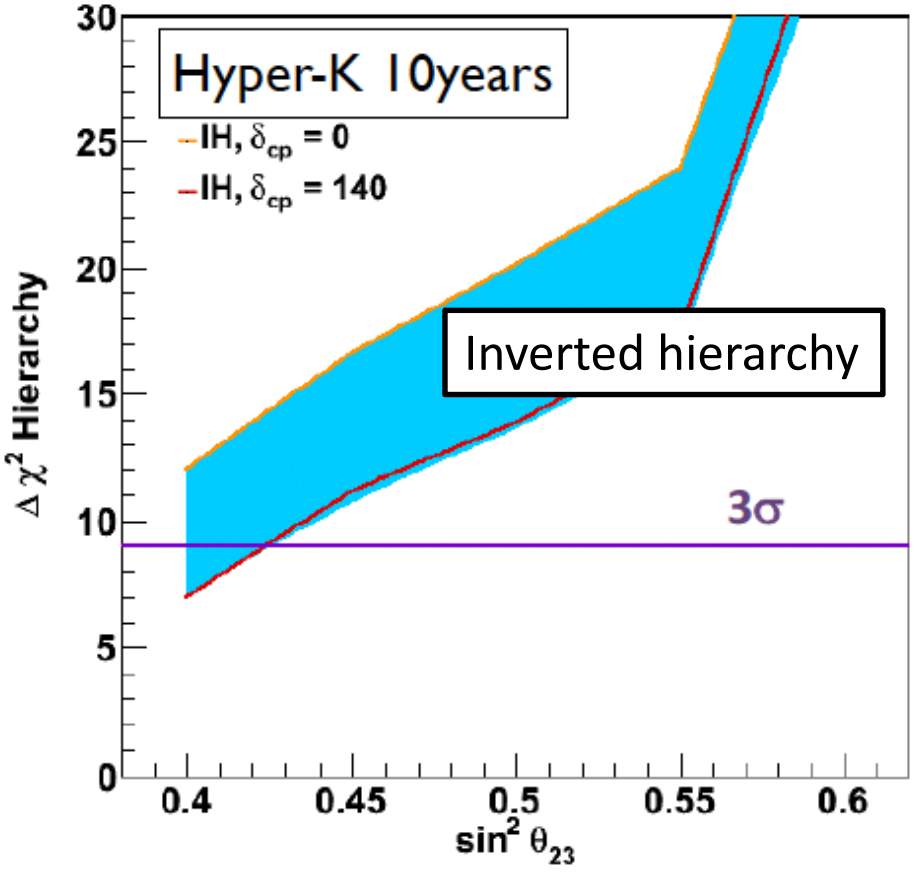
Atmospheric neutrinos
Expected ϕ(osc)/ϕ(no-osc)



Mass hierarchy measurement

Atmospheric neutrinos only





- 10 years HK atmospheric ν data can determine the MH at >~3σ
- Sensitivity depends on θ_{23} , and slightly on CP-δ and the MH itself.
- Cross check by beam and atmospheric.

Schedules

Exp	Hoped/expected/ scheduled start construction	Hoped/expected/ scheduled start data taking	Remarks
Daya Bay II	2014	2020	
RENO-50	2014	2019	
INO-ICAL		~2017	Waiting for the full project approval from Govt. of India
LBNO	2016	2023	
LBNE	Sorry… I did not find the dates..		CD-1 approval (Dec.2012)
Hyper-K	2016	2023	

Summary

- Full of excitement so far.
- Now, we know that θ_{13} is not small.
- The neutrino mass hierarchy and CP violation phase (δ) can be measured with the current technologies.
- It is good that various new experiments are discussed/prepared/in progress.

Looking forward to another exciting years to come!