

# WG1 Summary

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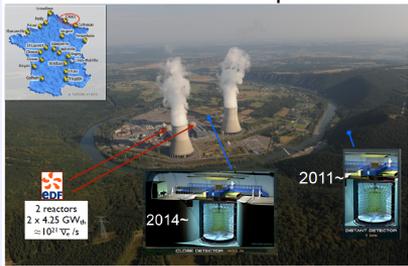
Many thanks to WG1 speakers and contributors.

Alexandre Sousa (University of Cincinnati)

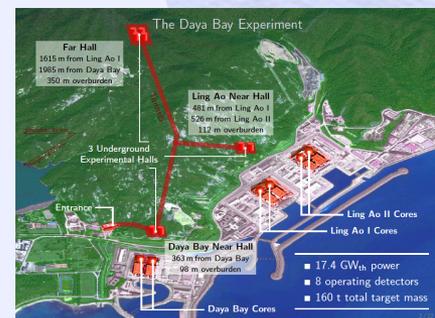
Enrique Fernandez-Martinez(Universidad Autónoma de Madrid/CSIC)

Takeshi Nakadaira(KEK)

## The Double Chooz experiment



# News



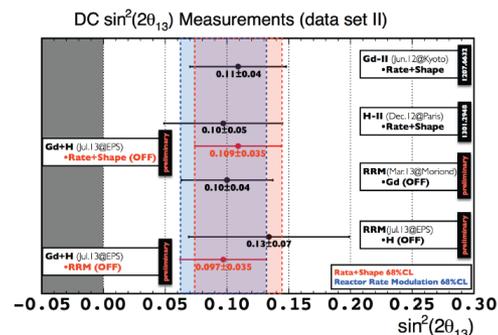
## ◆ Updated Reactor results:

### ◆ Double Chooz

- All analyses showed consistent  $\theta_{13}$
- Rate+Shape (combined):  $\sin^2 2\theta_{13} = 0.109 \pm 0.035$
- RRM (combined):  $\sin^2 2\theta_{13} = 0.097 \pm 0.035$

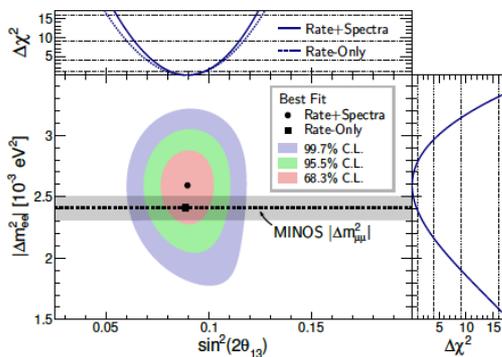
*Ralitsa Sharankova*

## Summary of Double Chooz results



## ◆ Daya Bay

### Rate+Spectra Oscillation Results



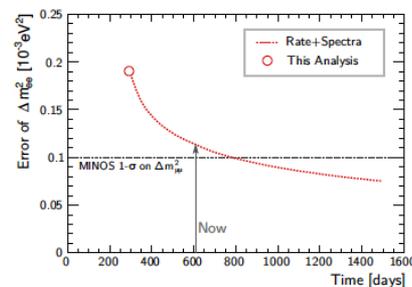
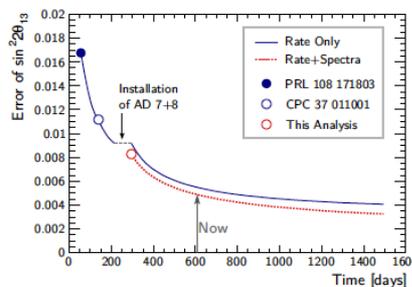
$$\sin^2 2\theta_{13} = 0.090^{+0.008}_{-0.009}$$

$$|\Delta m_{ee}^2| = 2.59^{+0.19}_{-0.20} \cdot 10^{-3} \text{eV}^2$$

$$\chi^2/N_{\text{DoF}} = 162.7/153$$

*Soeren Jetter*

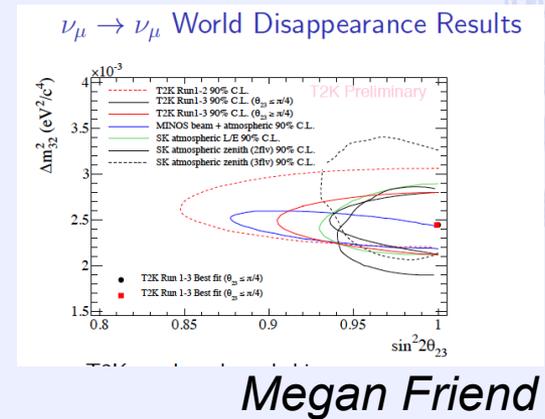
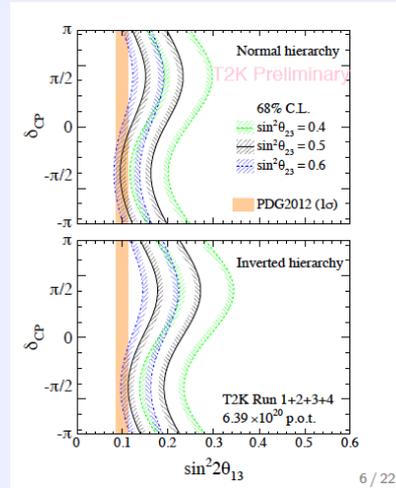
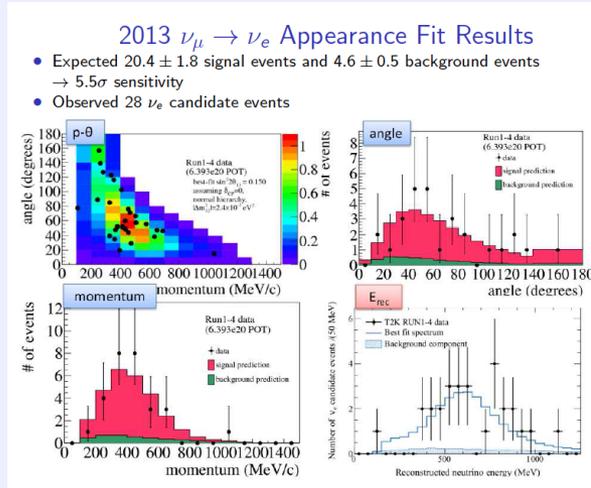
## Sensitivity Projection



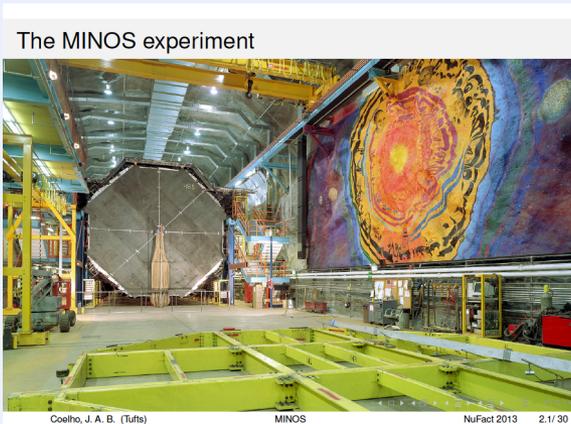
Sensitivity still dominated by statistics

# Latest knowledge by LBL

- ◆ T2K observe  $\nu_e$  appearance.



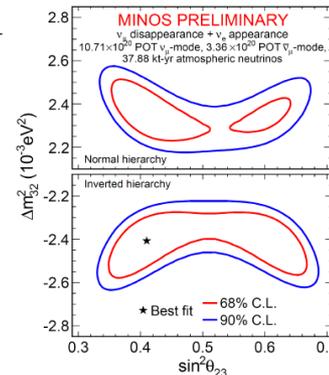
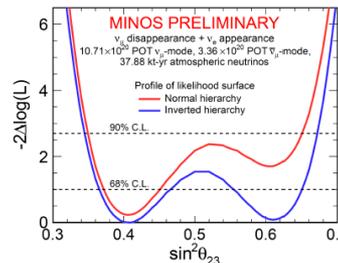
- ◆ MINOS latest results



*Joao Coelho*

## Combined Results

- ◆ Marginal preference for inverted hierarchy and lower octant



# What's next?

- ◆ Neutrino exp. reaches big milestone:  
 $\theta_{13} \neq 0, \nu_e$  appearance
- ◆ Next target of  $\nu$  oscillation experiments
  - ◆  $\theta_{23}$  octant degeneracy if  $\theta_{23} \neq 45$  deg.
  - ◆ Mass hierarchy
  - ◆ CPV
  - ◆ Sterile neutrino?



CPV

MH

$\theta_{23}$  octant

$\theta_{13} \neq 0, \nu_e$  appearance

Sterile?

# Approach for $\theta_{23}$ octant degeneracy

**Questions from NuFact '12:** For how long do we need to run T2K + NOvA to reach the systematic/background limit? How much significance can they provide when they reach that limit? What is the expected sensitivity to deviations of  $\theta_{23}$  from maximality and to its octant at different facilities.

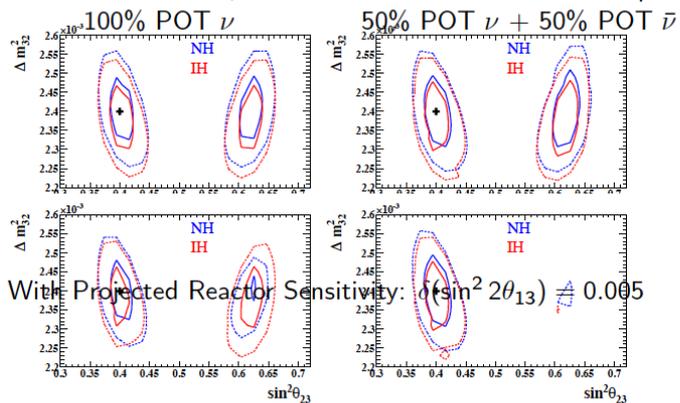
- The  $\theta_{23}$  octant degeneracy can be addressed by T2K and NOvA by mixing  $\nu$ -run and  $\bar{\nu}$ -run.

(Megan Friend, Sanjib Kumar Agarwalla)

Disappearance 90% C.L. Sensitivity at  $7.8 \times 10^{21}$  POT, True  $\sin^2 \theta_{23} = 0.4$

Solid: no sys. err., Dashed: with current sys. err.

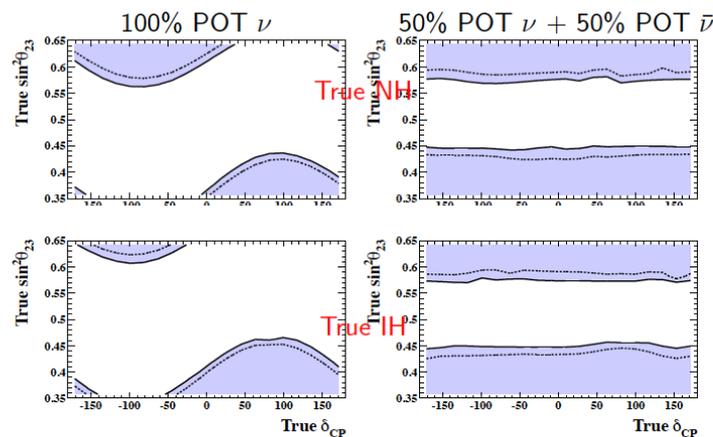
True MH is NH; contours drawn for two MH assumptions



$\sin^2 2\theta_{13} = 0.1$ ,  $\delta_{CP} = 0^\circ$ ,  $\sin^2 \theta_{23} = 0.4$ , and  $\Delta m_{32}^2 = 2.4 \times 10^{-3} \text{ eV}^2$ , NH

$\theta_{23}$  Octant 90% C.L. Discrimination

Solid: no sys. err., Dashed: with current sys. err.



Assuming true:  $\sin^2 2\theta_{13} = 0.1$ ,  $\Delta m_{32}^2 = 2.4 \times 10^{-3} \text{ eV}^2$   
 $\theta_{13}$  constrained by the projected reactor sensitivity:  $\delta(\sin^2 2\theta_{13}) = 0.005$

Megan Friend

# T2K & NOvA is still statistical limited.

- ◆ e-NuMI: Upgrade/Extension of NOvA
  - ◆ +4kT LqS or +6kt LAr
  - ◆ CHIPS

**RADAR – R&D Argon Detector at Ash River**

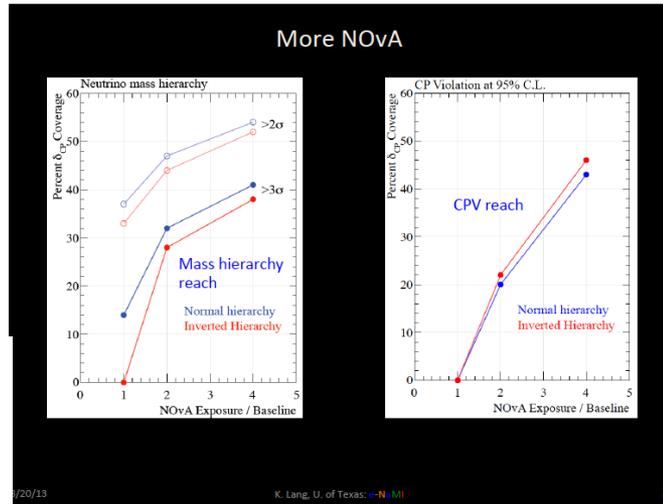
NOvA 14 kton PVC/Liq. Scint. 106 m

RADAR 6 kton LAr 35.5 m

18 m

- ◆ 6 kT LAr modular TPC
- ◆ A step (R&D) towards LBNE
- ◆ Enhances NOvA reach
- ◆ 5 years construction
- ◆ 5 years of running 2018-2023
- ◆ Total cost \$159M with \$58M recoverable for LBNE

8/20/13 K. Lang, U. of Texas: e-NuMI 7

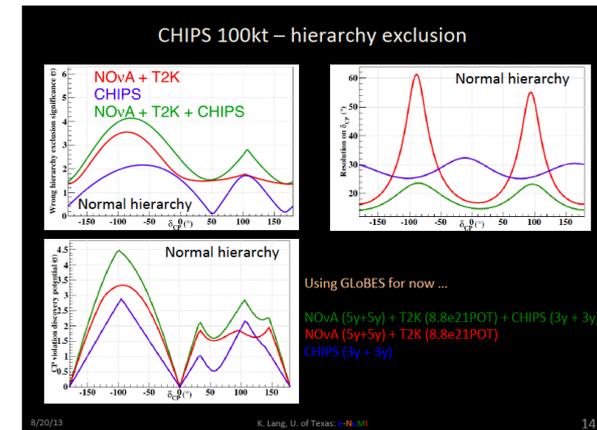
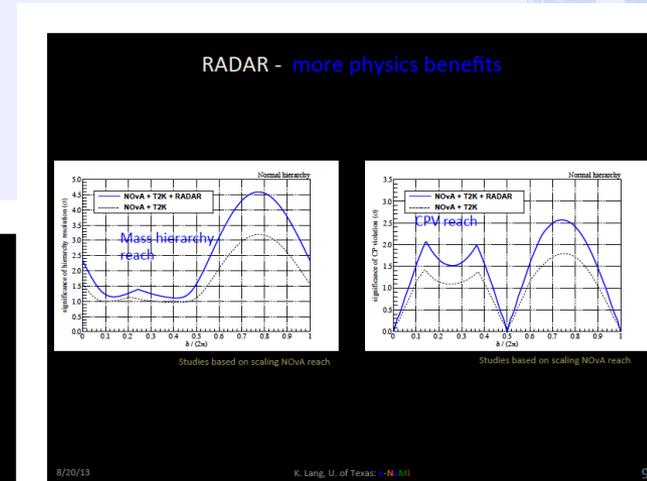


**CHIPS – Water Cherenkov in Mine Pits**

- ◆ Explore large mass with a cost-saving construction approach to reduce the WC costs to ~\$1M/kt (100kt = \$100M)
- ◆ Concept (advanced in earlier studies for LBNE) to use industrial fisheries floating platforms and adopt iceCube PMT (DOM) deployment
- ◆ Benefits from much earlier studies for GRANDE detector
- ◆ Minimize cost of civil construction
- ◆ Requires 30-40m water overburden for CR shielding

Baseline Floating Sinker Tube

8/20/13 K. Lang, U. of Texas: e-NuMI 10



# Towards Mass Hierarchy determination.

**Questions from NuFact '12:** *How much significance for the mass hierarchy can we expect from atmospheric neutrinos, reactor neutrinos, and cosmology? Do we need a dedicated accelerator experiment to reach the 5 sigma level for any value of delta?*

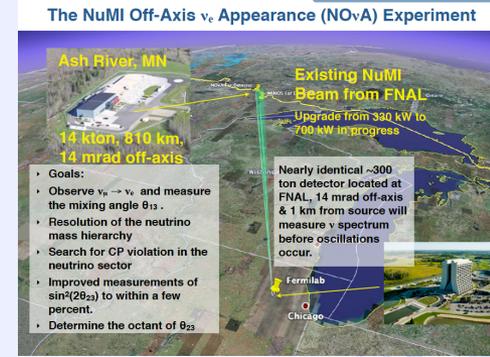
- ◆ Many approaches for MH determination
  - ◆ LBL accelerator neutrino
  - ◆ Atmospheric neutrino
  - ◆ Mid. Baseline reactor
  - ◆ Supernova neutrino
- ◆ Sum of neutrino mass can be constrained from cosmology.



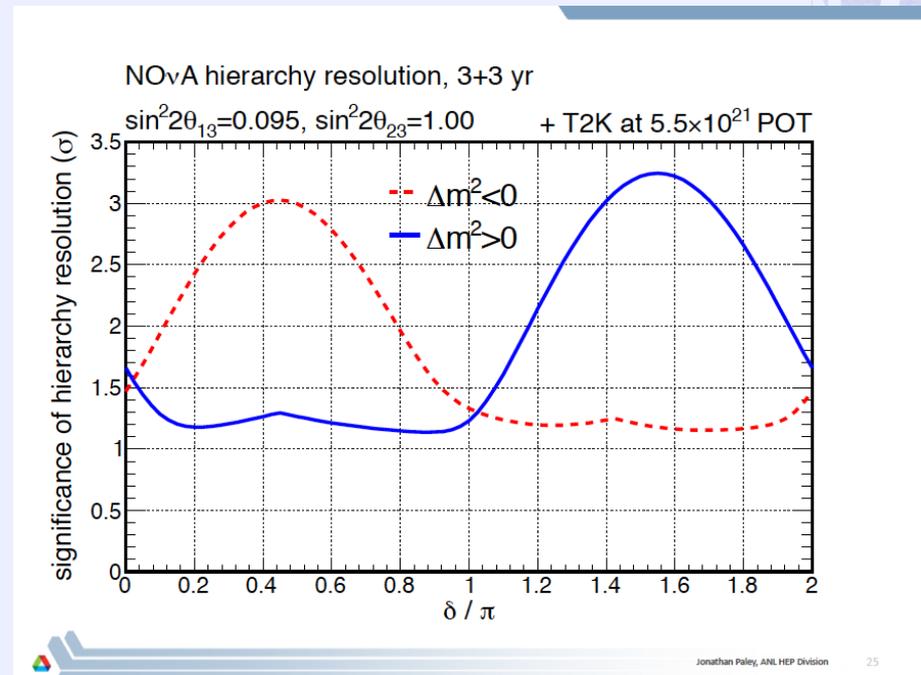
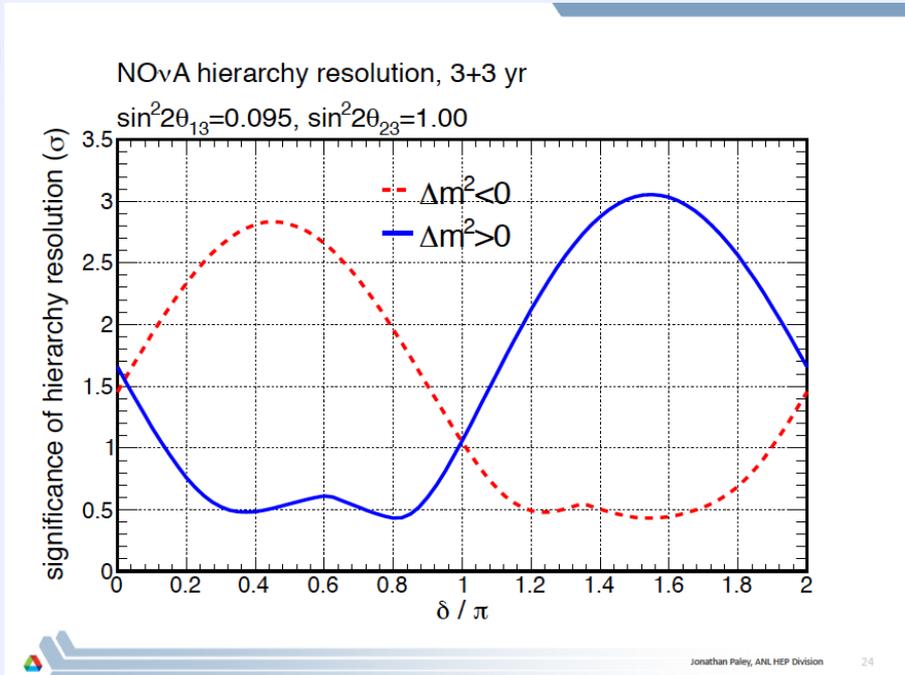
The T2K Experiment (Tokai to Kamioka Long Baseline Neutrino Experiment)



# LBL

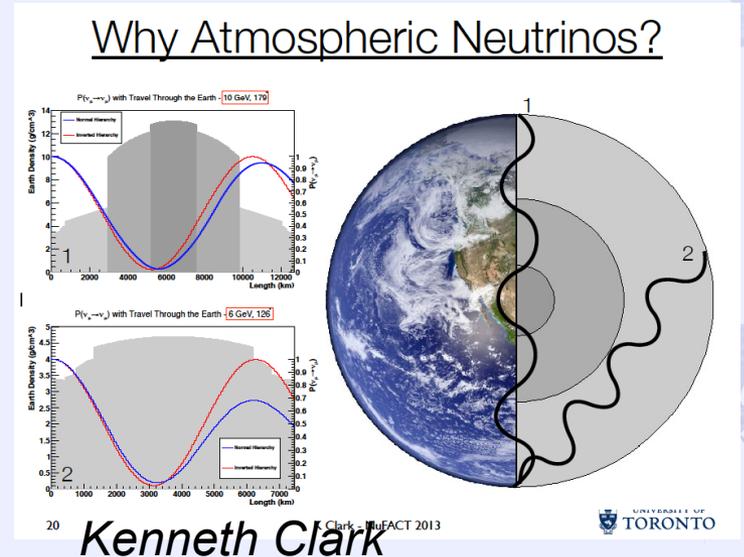


- ◆ Latest T2K & NOvA expectation.
- ◆ Synergy among two base-line is significant!

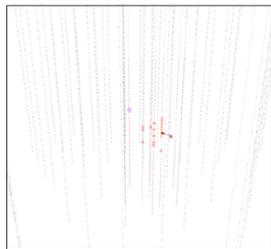


# Atmospheric neutrino

- ◆ LBNE
- ◆ Hyper-K
- ◆ PINGU
- ◆ ORCA/KM3Net
- ◆ INO

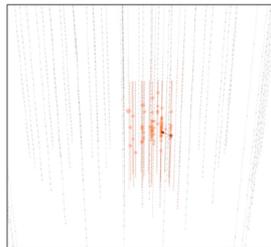


## Improvement with PINGU



IceCube + DeepCore

- 9.28 GeV Neutrino, 4.9 GeV muon, 4.5 GeV cascade



IceCube + DeepCore + PINGU

K Clark - NuFACT 2013

Kenneth Clark

## Thomas Eberl

KM3Net

Artistic view of 1 of several building blocks

The KM3Net Collaboration  
40 institutes in Europe

Th. Eberl, ORCA, NuFACT '13, 21.8.2013

INO Facilities at Pottipuram

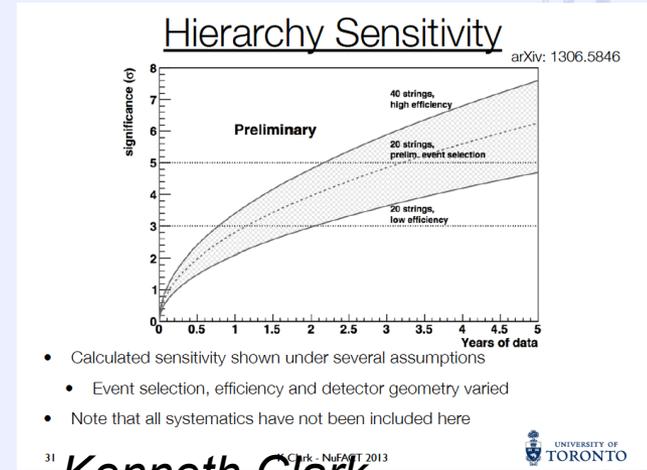
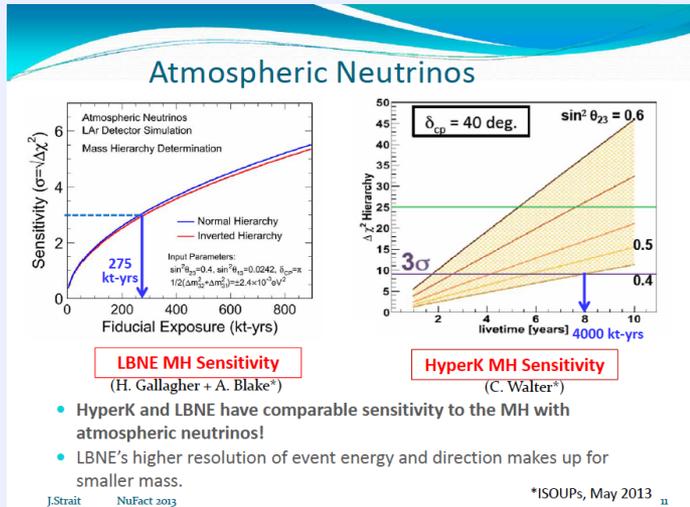
Underground complex

50 kton ICAL Neutrino Detector

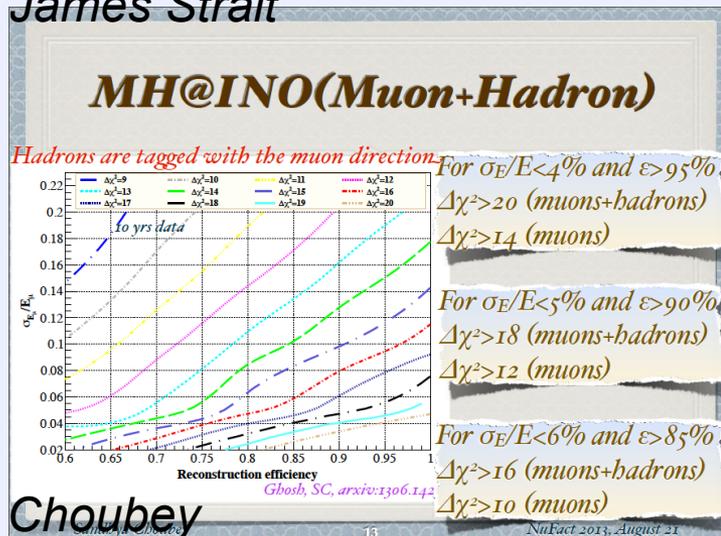
Naba Kumar Mondal

# Atmospheric neutrino

## ◆ Redundant measurements



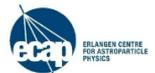
James Strait



Sandhya Choubey

Kenneth Clark

### Significance of mass hierarchy determination

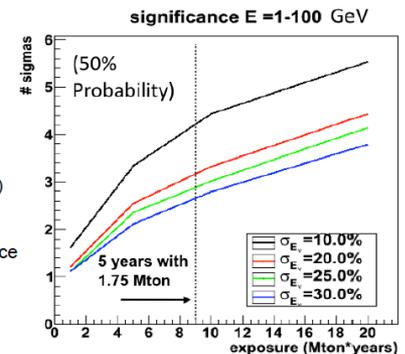


Results of a preliminary study without reconstruction effects

Assumptions:

- Perfect muon zenith angle resolution
- True neutrino vertex contained
- 15 PMT hits (from Geant4 simulation)

① 2.5σ → 4σ in 5 years with reference detector, strong dependence on reconstruction performance



Thomas Eberl

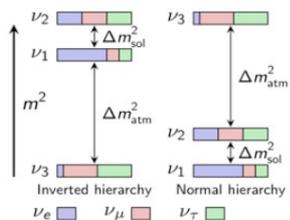
# Mid. base-line reactor

## ◆ MH by Reactor exp. ... Challenge for precise calibration.

Wei Wang



### The Gate to Mass Hierarchy is Open



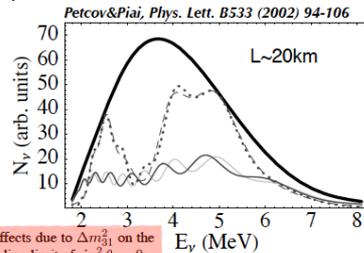
- How to resolve neutrino mass hierarchy using reactor neutrinos
  - KamLAND (long-baseline) measures the solar sector parameters
  - Short-baseline reactor neutrino experiments designed to utilize the oscillation of atmospheric scale
- ✓ Both scales can be studied by observing the spectrum of reactor neutrino flux

$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e} = 1 - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \Delta_{21}$$

$$- \sin^2 2\theta_{13} (\cos^2 \theta_{12} \sin^2 \Delta_{31} + \sin^2 \theta_{12} \sin^2 \Delta_{32})$$

- ✓ Mass hierarchy is reflected in the spectrum
- ✓ Signal independent of the unknown CP phase

- the value of  $\sin^2 \theta$ , which controls the magnitude of the sub-leading effects due to  $\Delta m_{31}^2$  on the  $\Delta m_{21}^2$ -driven oscillations: the effect of interest vanishes in the decoupling limit of  $\sin^2 \theta \rightarrow 0$ .



### Summary and Conclusion

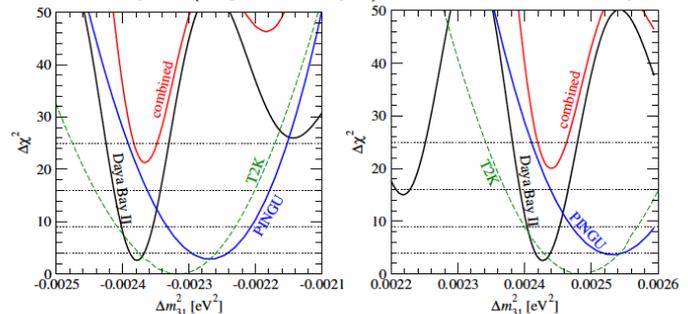


- The mass hierarchy information is definitely in the survival spectrum of reactor antineutrinos (optimized baseline: ~60km)
- To resolve the mass hierarchy, medium-baseline reactor experiments face unprecedented challenges
  - Energy resolution  $< 3\% \sqrt{E}$  (absolutely necessary. JUNO is attacking it from multiple directions)
  - Energy scale uncertainty needs to be controlled  $< 1\%$  (essential.)
    - A 2<sup>nd</sup> detector can mitigate the challenge to some level.
    - Or sub-percent energy scale uncertainty is needed. Sub-percent uncertainty not achieved in massive
- A case to conq
- We h Snow

Outline	Introduction	Synergy effects	PINGU+JUNO	Summary and conclusions
	○○○○	○○○○	○○○○	
Results			○○○	

### Synergy results

PINGU: 1 year (High  $\nu$ , no syst), JUNO: 1000 kt GW year



MB, Schwetz, arXiv:1306.3988

Mattias Blennow

Mattias Blennow  
emb@kth.se



August 21, 2013, NuFact 13, Beijing, China

Based on arXiv:1306.3988, MB and T. Schwetz

Outline	Introduction	Synergy effects	PINGU+JUNO	Summary and conclusions
	○○○○	○○○○	○○○○	
			○○○	



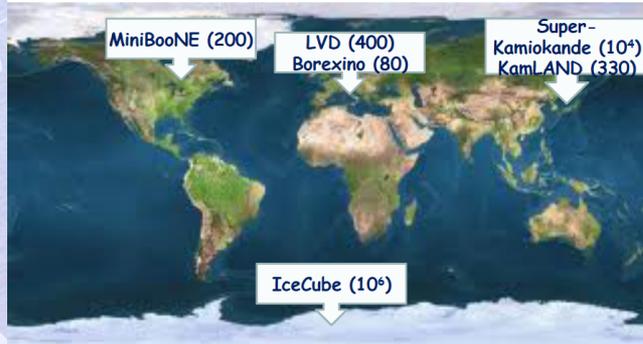
Sovan Chakraborty  
MPI for Physics, Munich  
Beijing, Nufact August 19-24, 2013



# Super nova & cosmology

## ◆ SN: Timing distribution depends on MH.

### Large Detectors for Supernova Neutrinos



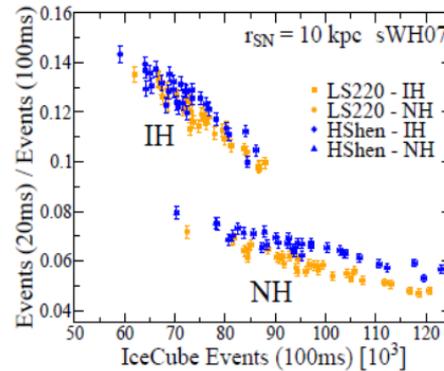
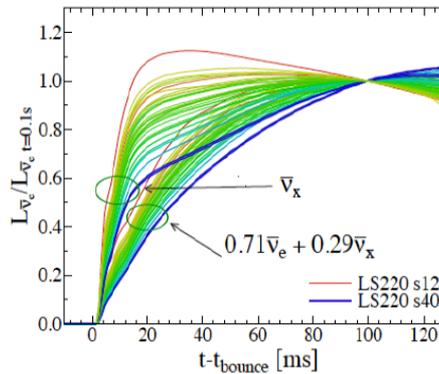
In brackets events for a "fiducial SN" at distance 10 kpc

Sovan Chakraborty

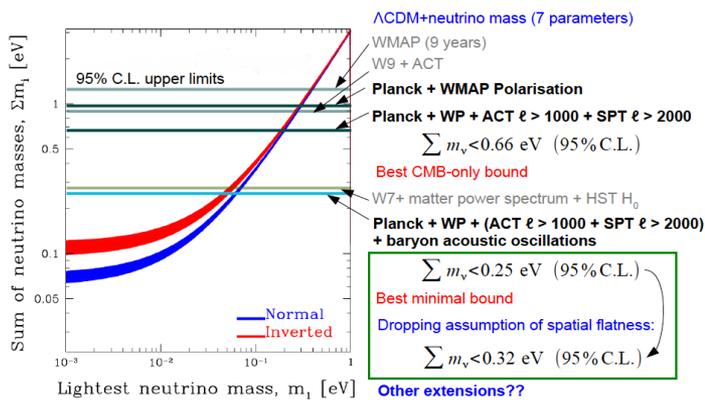
### Rise time Analysis: Hierarchy Determination

Normalized Count rate :  
32 different models

[C.D. Ott et al. Neutrino 2012, Japan, 1212.4250]



Post-Planck... Ade et al. [Planck] 2013



NO Expected sensitivity...

rise time

A 7-parameter forecast: Hamann, Hannestad & Y&W 2012

Data	$10^3 \times \sigma(\omega_{dm})$	$100 \times \sigma(h)$	$\sigma(\sum m_\nu)/eV$
c	2.02	1.427	0.143
cs	0.423	0.295	0.025
cg	0.583	0.317	0.016
cgi	0.828	0.448	0.019
cgb	0.723	0.488	0.039
cgb1	1.165	0.780	0.059
csg	0.201	0.083	0.011
csgx	0.181	0.071	0.011
csgb	0.385	0.268	0.023
csgb,x	0.354	0.244	0.022

Moderate  
2σ+ detection (only shear nonlinearities under control)

Very pessimistic  
No knowledge of nonlinearities

Most optimistic  
Σm<sub>ν</sub> potentially detectable at 5σ+ with Planck+Euclid (assuming nonlinearities to be completely under control)

Yvonne Wong

11~25meV

# How to evaluate power of new experiments?

- ◆ Figure of merit of new experiment when the current experiment give a hint.
- ◆ MH ... discrete quantity => More proper evaluator than  $\sqrt{|\Delta\chi^2|}$  is exist?

Outline Sensitivity measures Conveying the information Summary and conclusions  
Information gain fractions

## 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  $\bar{G}$

Mattias Blennow  
KTH Theoretical Physics  
Evaluating future neutrino oscillation experiments

Outline Sensitivity measures Conveying the information Summary and conclusions  
Information gain fractions

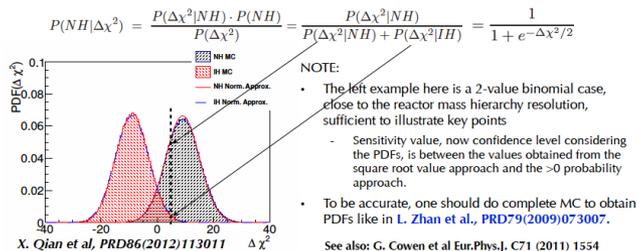
## CP Gain compared to T2K and NOvA

Thick edges = Hierarchy unknown

Mattias Blennow  
KTH Theoretical Physics  
Evaluating future neutrino oscillation experiments

## Confidence Interval using Discriminator PDFs

- The neutrino mass hierarchy measurement is basically a model comparison case, or hypothesis test.
- Not complete if evaluating sensitivity only based on the sign of delta chi-square from Asimov dataset.
- We suggest a confidence interval setting method using discriminator PDFs. (This method has been effectively used in [L. Zhan et al., PRD79\(2009\)073007](#) based on Monte Carlo)



Wei Wang

## Wilks' Theorem Does Not Apply to the Hierarchy

Ref: Qian et al., Phys.Rev. D86 (2012) 113011 (see also Wei Wang's talk)

The neutrino mass hierarchy is *not* a continuous variable, it is a discrete variable.

In the case of the hierarchy one instead defines the statistic

$$\Delta\chi^2 = \chi^2_{(inv)} - \chi^2_{(nor)}$$

where  $\chi^2_{(inv)}$  and  $\chi^2_{(nor)}$  are the  $\chi^2$  statistics obtained by fitting with respect to each hierarchy, with nuisance parameters chosen separately to minimize each  $\chi^2$ .

This is not the quantity described in Wilks' theorem, it is not even necessarily positive.

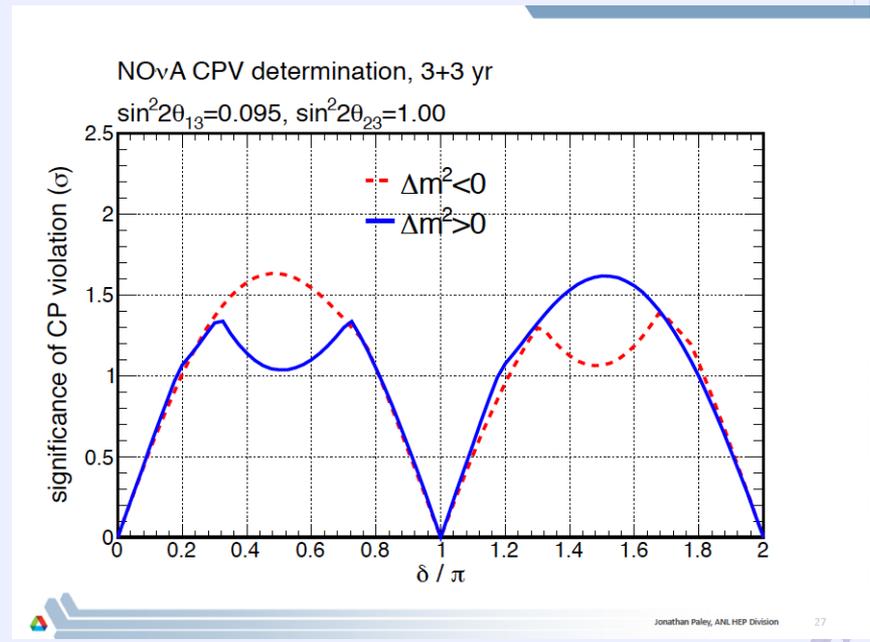
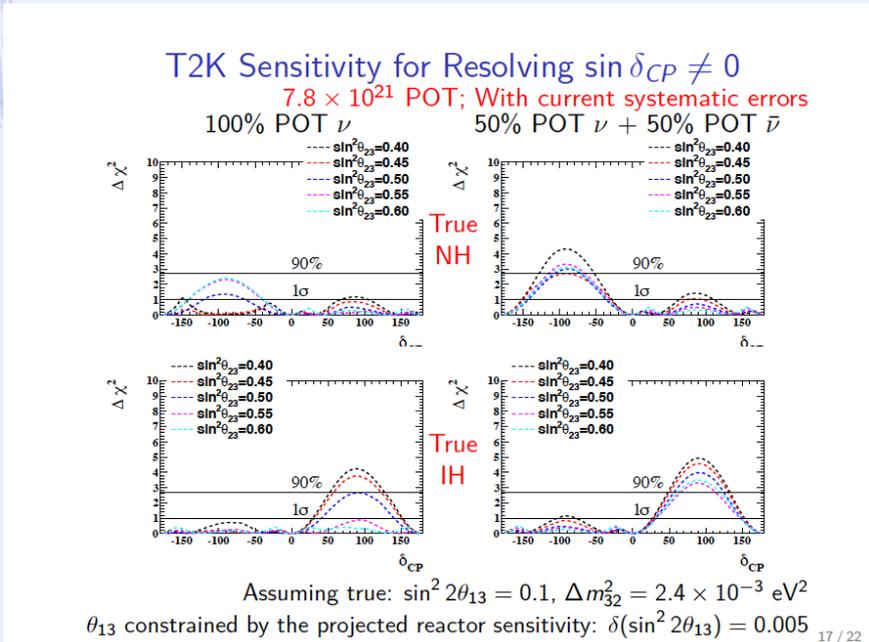
Therefore  $\Delta\chi^2$  does not satisfy a  $\chi^2$  distribution.

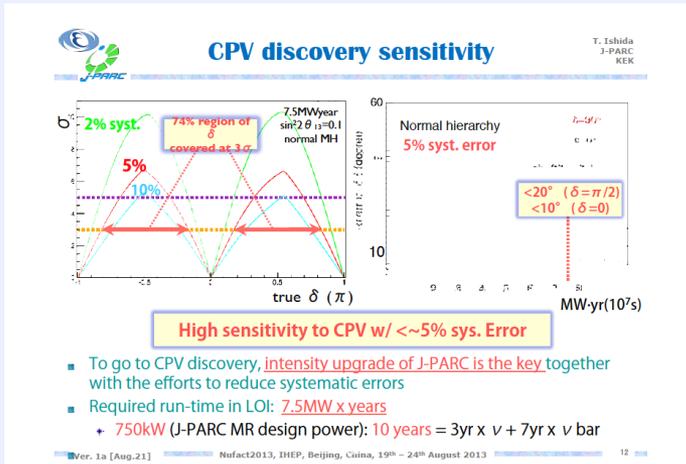
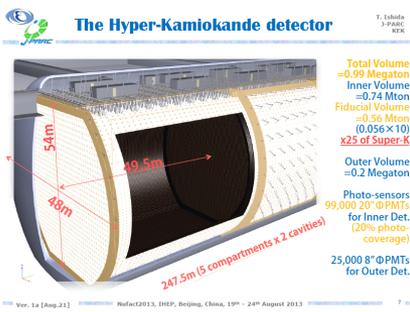
Jarah Evslin

# Towards CP Violation search

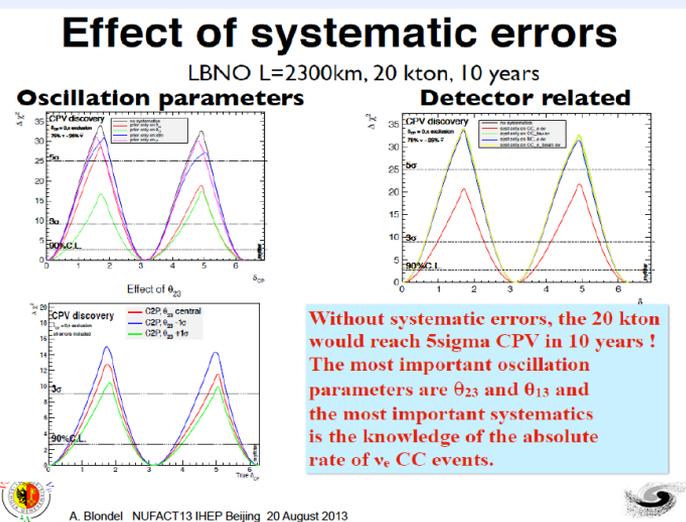
**Questions from NuFact '12:** Do we need to and can we re-optimize the design of future facilities for large  $\theta_{13}$ ? Are off-axis beams still interesting for large  $\theta_{13}$ ? Do we need a neutrino factory to confirm or rule out leptonic CP violation?

- ◆ Reach by T2K + NOvA is presented.

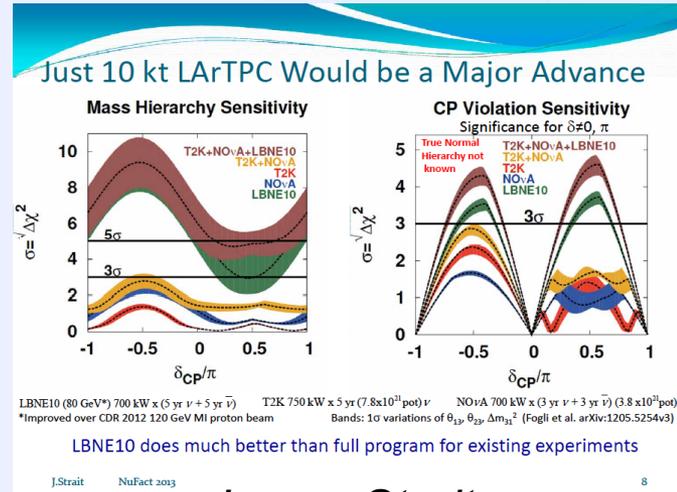




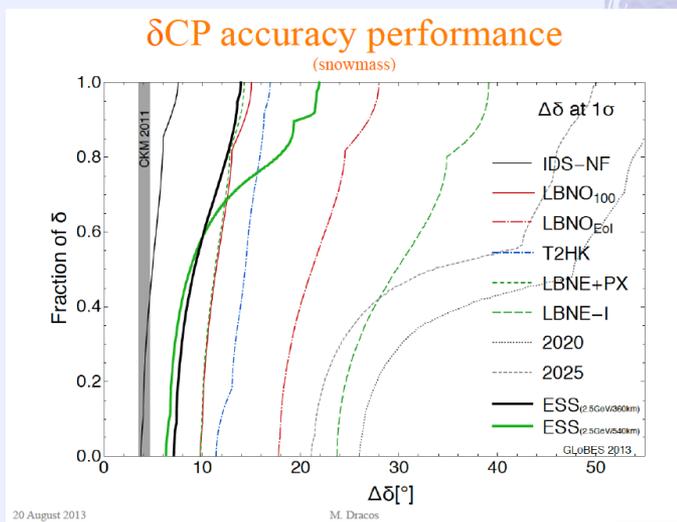
Taku Ishida



Alain Blondel

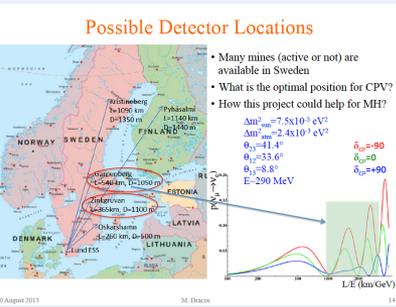
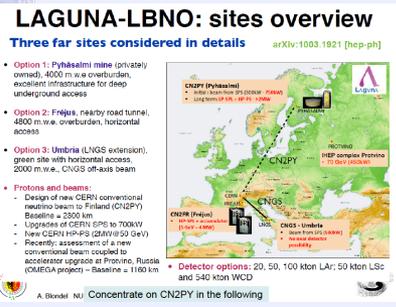


James Strait



Marcos Dracos

- ◆ Hyper-K
- ◆ LBNE
- ◆ LBNO
- ◆ ESS



# Neutrino Factory

- ◆ Sensitivity reaches CKM level measurement.

**Full Luminosity Neutrino Factory**

- Use a single 2000 km baseline with 10 GeV stored  $\mu^\pm$
- Neutrinos from a cooled muon beam
  - Known flavour content
  - Known energy distribution
  - Reduced beam uncertainties ( $< 1\%$ )
- Magnetized detector needed for charge separation.

R. Bayes (University of Glasgow) MIND NUFAC, August 2013 3 / 15

**MIND: A Magnetized Iron Neutrino Detector**

- Octagonal cross-section  $14 \times 14 \text{ m}^2$
- Fe plates 3 cm thick
- Space points from paired array of Scint bars  $3 \times 1 \text{ cm}^2$
- Toroidal magnetic field in steel.
- Field induced by 100 kA-turns.
- Current carried by multiple turns of STL through detector axis.<sup>a</sup>

<sup>a</sup>IDS-NF-020, Interim Design Report

R. Bayes (University of Glasgow) MIND NUFAC, August 2013 5 / 15

**Systematics Explorations** *Ryan Bayes*

- Consider the case of no improvement in systematic uncertainties
  - Signal systematic: 4%
  - Background systematic: 40%
- $\Delta\delta_{CP}$  between  $6^\circ$  and  $10^\circ$ .
- Consider analysis systematic.
- Increase the threshold on BDT cut so that  $S/\sqrt{S+B}$  increases by 1.
- Small change ( $< 0.1^\circ$ ) in precision.

R. Bayes (University of Glasgow) MIND NUFAC, August 2013 6 / 15

## NuMAX

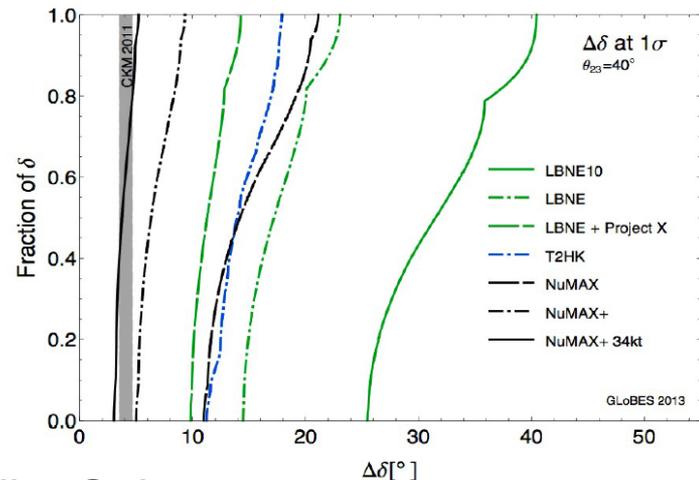
Neutrinos from Muon Accelerators at project X

NuMAX

NuMAX+

- |  |   |  |
|--|---|--|
| • 1 MW, 3 GeV protons from PX-II                   | → | • 3 MW, 3 GeV protons from PX-II                 |
| • No muon cooling                                  | → | • Muon cooling                                   |
| • Acceleration to 5 GeV                            | → | • Acceleration to 5 GeV                          |
| • $1.6 \times 10^{20}$ useful muon decays per year | → | • $1 \times 10^{21}$ useful muon decays per year |

## Future upgrades to a full NuFact



*Pilar Coloma*

# Systematic uncertainty: WG1+WG2

**Questions from NuFact '12:** What is the sensitivity to the different sources of systematic errors at future facilities? Which of these sources are uncorrelated between neutrino and antineutrinos? Are these systematic errors reasonable assumptions? Can we do precision experiments without a Near Detector?

- ◆ State of arts: T2K  $\sim 8.8\%$  w/ ND measurement.
- ◆ Active discussion was happened:  
**The excellent Near Detector is necessary to reduce the uncertainty to much less than 10%.**

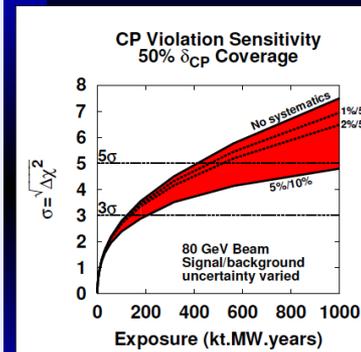
## Oscillation Analysis Systematic Uncertainties

Error source	$\sin^2 2\theta_{13} = 0.1$		
	w/o ND280 fit	w/ ND280 fit	
Beam only	11.6	7.5	Correlated
$M^{QE}$	21.5	3.2	
$M^{RES}$	3.3	0.9	
CCQE norm. ( $E_\nu < 1.5$ GeV)	9.3	6.3	
CC1 $\pi$ norm. ( $E_\nu < 2.5$ GeV)	4.2	2.0	
NC1 $\pi^0$ norm.	0.6	0.4	
CC other shape	0.1	0.1	
Spectral Function	6.0	6.0	
$pf$	0.1	0.1	
CC coh. norm.	0.3	0.2	
NC coh. norm.	0.3	0.2	
NC other norm.	0.5	0.5	
$\sigma_{\nu_e}/\sigma_{\nu_\mu}$	2.9	2.9	
W shape	0.2	0.2	
pion-less $\Delta$ decay	3.7	3.5	
SK detector eff.	2.4	2.4	
FSI	2.3	2.3	
PN	0.8	0.8	
SK momentum scale	0.6	0.6	
Total	28.1	8.8	

From ND280  
 SK only

units: percentage error on  $N_{SK}$

## Luminosity scaling



arXiv:1307.7335

Extrapolating super-beam performances beyond several 100 kt MW years is entirely dependent on the assumptions on systematics!

Maximum useful exposure depends strongly on systematics

# Systematic uncertainties

- ◆ NuMI-X: Synergy to understand the flux
- ◆ Common treatment on  $\nu$ -interaction model is proposed for the consistent comparison among the experiments.

## NuMI land: NuMI-X

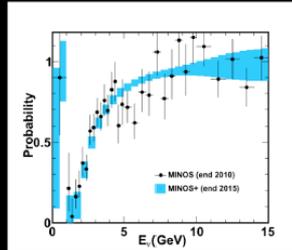
- ◆ Facts:
  - ✓ 5 detectors (on-, off-, and off-off- axis) in one beam line
  - ✓ Better knowledge and improved simulations of flux is essential for future 'precision' neutrino experiments
  - ✓ Flux modeling undermanned in all NuMI experiments

- ◆ "NuMI-X is a consortium comprising Fermilab neutrino experiments collaborating on the modeling of NuMI beam. Its goal is to develop and maintain the best knowledge about NuMI neutrino fluxes relevant to all NuMI experiments."

- ◆ The consortium includes

- ✓ MINOS, MINOS+, MINERvA, ArgoNeuT
- ✓ NOvA, MicroBooNE.

- ◆ "Collaborating experiments agree to unlimited use of data, code, notes, and documents released to NuMI-X and essential for its mission."
- ◆ Improved hadron production data, including exposures of NuMI target replicas, is anticipated through the US NA61 effort
- ◆ Tools and methods developed by NuMI-X will not only improve the NuMI program but will be directly applicable to LBNE and other beams



## Personal remark

Many experiments, like T2K, have done a fine job with their systematics and developed a large number of tools.

These tools would be very useful to the rest of the community, especially for the purpose of planning future experiments.

We, as a community, would be well advised to share all relevant information and tools freely – instead of reinventing the wheel at every opportunity (see Nuance, GENIE, Neugen, NuWro . . .)

# Sterile?

**Standing questions:** Are there sterile neutrinos? Are LSND and MiniBooNE results evidence for light sterile neutrinos?

- ◆ ICURUS, MicroBooNE, MINOS+
- ◆ Proposal/LOI:
  - ◆ US: LAr1, MiniBooNE+, MiniBooNE- II, OscSNS
  - ◆ JP: J-PARC MLF
  - ◆ EU: ICARUS @ CERN NA

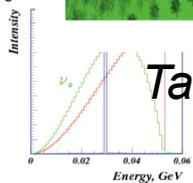
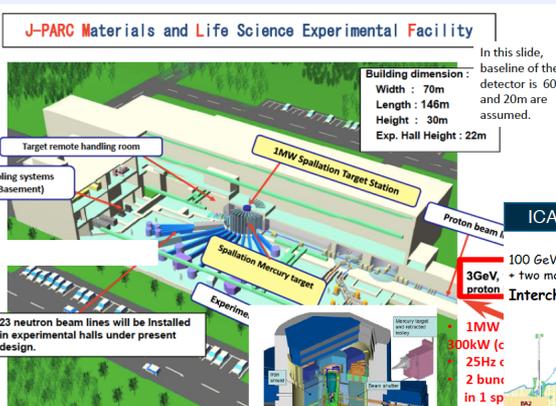
LAr1

- Run along MicroBooNE
- Definitive test of LSND and MiniBooNE both in neutrino and antineutrino mode
- Staged program
- Phase 1 detector@100m (40t fiducial)
  - study L/E dependence and  $\nu_\mu$  disappearance
- Phase 2 detector@700m (1kt)
  - test antineutrinos



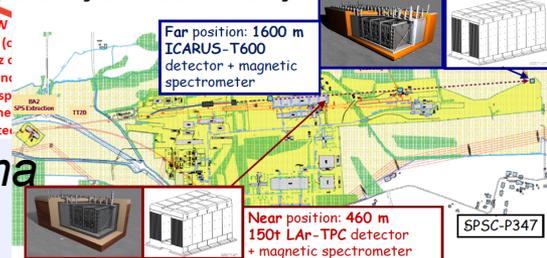
OscSNS

- Spallation neutron source at ORNL
  - Free source of neutrinos
  - 1GeV protons on Hg target (1.4MW)
- Well understood flux of neutrinos
- Decisive test of LSND appearance signal



ICARUS at the (proposed) CERN North Area Neutrino Facility  
New CERN SPS 2 GeV neutrino facility in North Area

100 GeV primary proton beam fast extracted from SPS in North Area: C-target station + two magnetic horns, ≈100 m decay pipe, Fe/graphite dump, followed by  $\mu$  stations.  
Interchangeable n and anti-n focussing.



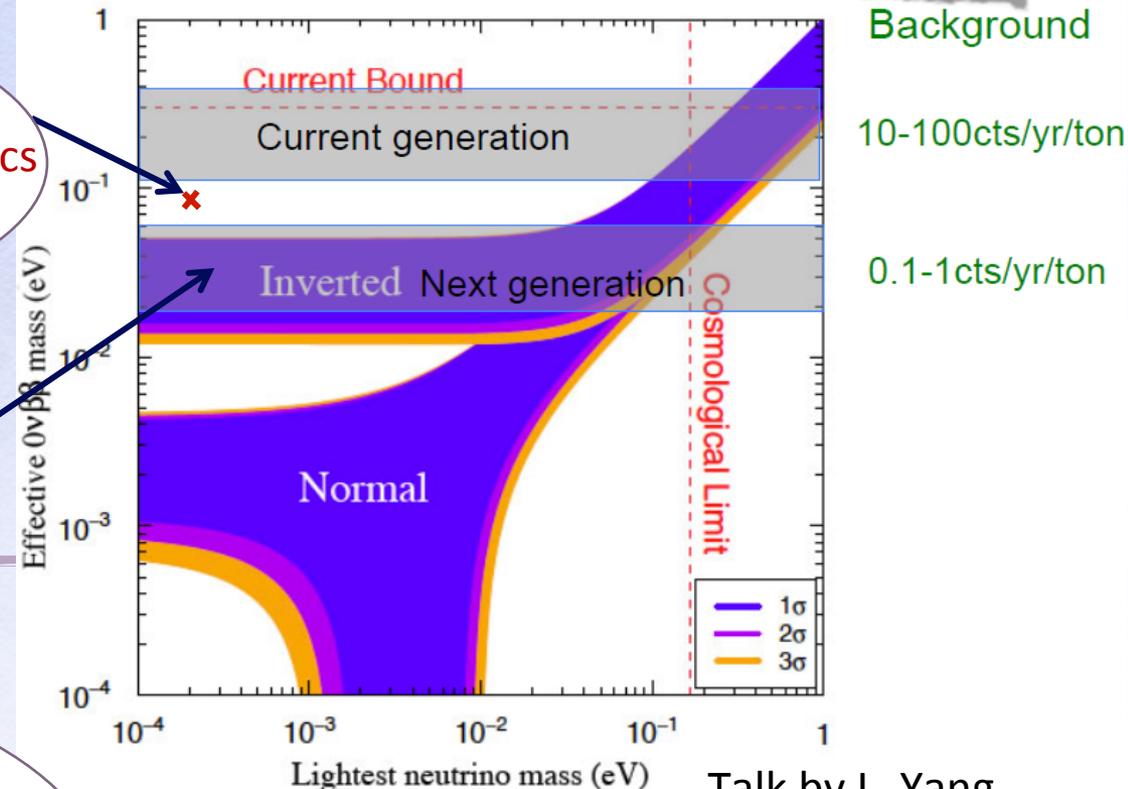
paola sala

Takasumi Maruyama

Pavlovic Zarko

**Questions from NuFact '12:** What can we learn about the Majorana nature of neutrinos from a measurement of the mass hierarchy combined with neutrinoless double beta decay probes? If the hierarchy is inverted and we don't find  $0\nu\beta\beta$  decay, are neutrinos Dirac particles?

If  $0\nu\beta\beta$  measurement is larger than expected from oscillations **new physics needed!!** See talk by T. Ota



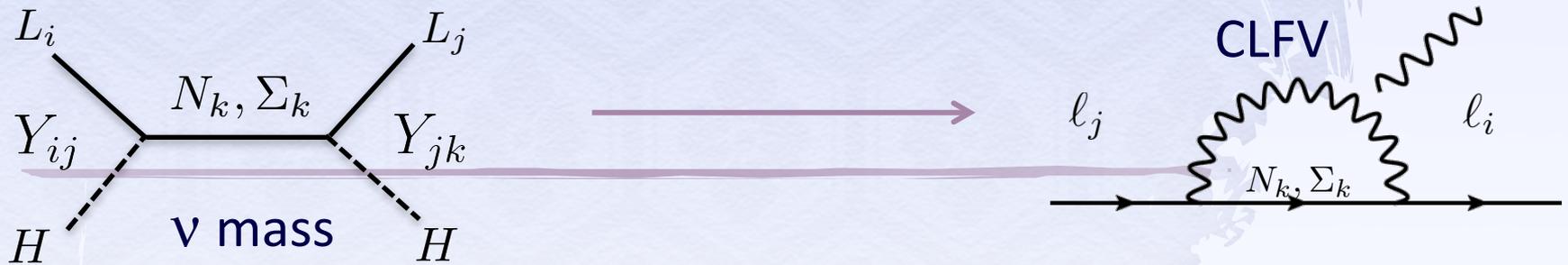
If hierarchy is inverted but we don't find  $0\nu\beta\beta$ , neutrinos can be Dirac, but also Majorana with **new physics** at low scale. See talk by J. Lopez-Pavon

Combination of  $0\nu\beta\beta$  searches with oscillations powerful test of new physics.

**Question:** What can neutrino physics learn from charged lepton physics measurements?

Most natural mechanisms behind neutrino mass generation imply new states that mediate CLFV

### TYPE I, III seesaws



From F. R. Joaquim talk (see also talks by B. Gavela and L. Calibbi)

To probe the model CLFV and oscillation data need to be combined

$$\mathbf{Y} = i \frac{\sqrt{2}}{v} \sqrt{\mathbf{M}_{\text{diag}}} \mathbf{R} \sqrt{\mathbf{m}_{\text{diag}}} \mathbf{U}^\dagger$$

What is next work?

# Questions to Nufact2014

*If improved precision in oscillation parameters results in tension between measurements, which new physics beyond the 3-flavor mixing paradigm would we be probing (NSI, steriles, unitarity, CPT, etc.)? And between oscillations and other searches (neutrinoless double beta decay, CLFV, cosmology...).*

*What symmetries can we identify from the PMNS matrix element relative sizes? What level of precision is required to rule out models like tribimaximal mixing?*

*Can we reach 1-2% level in systematic uncertainties for superbeam appearance experiments in order to measure leptonic CP violation? What level of optimization of the ND is required? To which level do we need to reduce the cross-section uncertainties on neutrino interactions in water, argon, carbon? Is NuStorm enough to achieve those reductions? Do we need a dedicated hadron production effort?*

# Questions to Nufact2014 (cont'd)

*How do we account for differences in neutrino interaction generators used by each experiment to model their data when we compare or combine sensitivities or results from different experiments? For WG2?*

*When will the combined reach of all experiments resolve the mass hierarchy at more than  $3\sigma$  for all  $\delta$ ? and  $5\sigma$ ? What impact would such measurement have on the design of future large facilities such as LBNE, T2HK, LBNO or ESS? Can we identify synergies between them?*

*What are the prospects for determining the  $\theta_{23}$  octant over the next decade for current facilities? What is the sensitivity to the  $\theta_{23}$  octant of medium-term atmospheric neutrino experiments such as INO, PINGU, KM3Net-ORCA?*

# Questions to Nufact2014 (cont'd)

*Evidence for sterile neutrinos is dominated by the LSND result. What are the prospects for rejecting or confirming LSND at more than  $5\sigma$  before NuStorm is built?*

*What is the effect of results from Daya Bay, RENO and Double Chooz on the reactor neutrino anomaly? Can we test the gallium anomaly with future projects?*

*What constraints can we place on light sterile neutrinos using direct mass measurements?*

See you in NuFact2014.

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**THANK YOU.**