A Large Liquid Scintillator Detector for Neutrino Mass Hierarchy : RENO-50

“International Meeting for Large Neutrino Infrastructures”

Ecole Architecture Paris Val de Seine, APPEC, 23-24 June, 2014

Soo-Bong Kim

Seoul National University

APPEC

ν_e ν_μ ν_τ KNRC Korea Neutrino Research Center

Fundamental Questions on Neutrino

- Absolute neutrino masses? (Why so small?)
- Neutrino mass ordering? (Normal or inverted?)
- Dirac or Majorana? (Neutrinoless double beta decay?)
- Leptonic CP violating phase?
- 3 ν paradigm enough? (Sterile neutrino?)
- Why so large neutrino mixing angles?

※ High precision measurement of neutrino oscillations

→ Precise values of mixing angles and mass difference are necessary for solving those fundamental problems

θ_{13} from Reactor and Accelerator Experiments

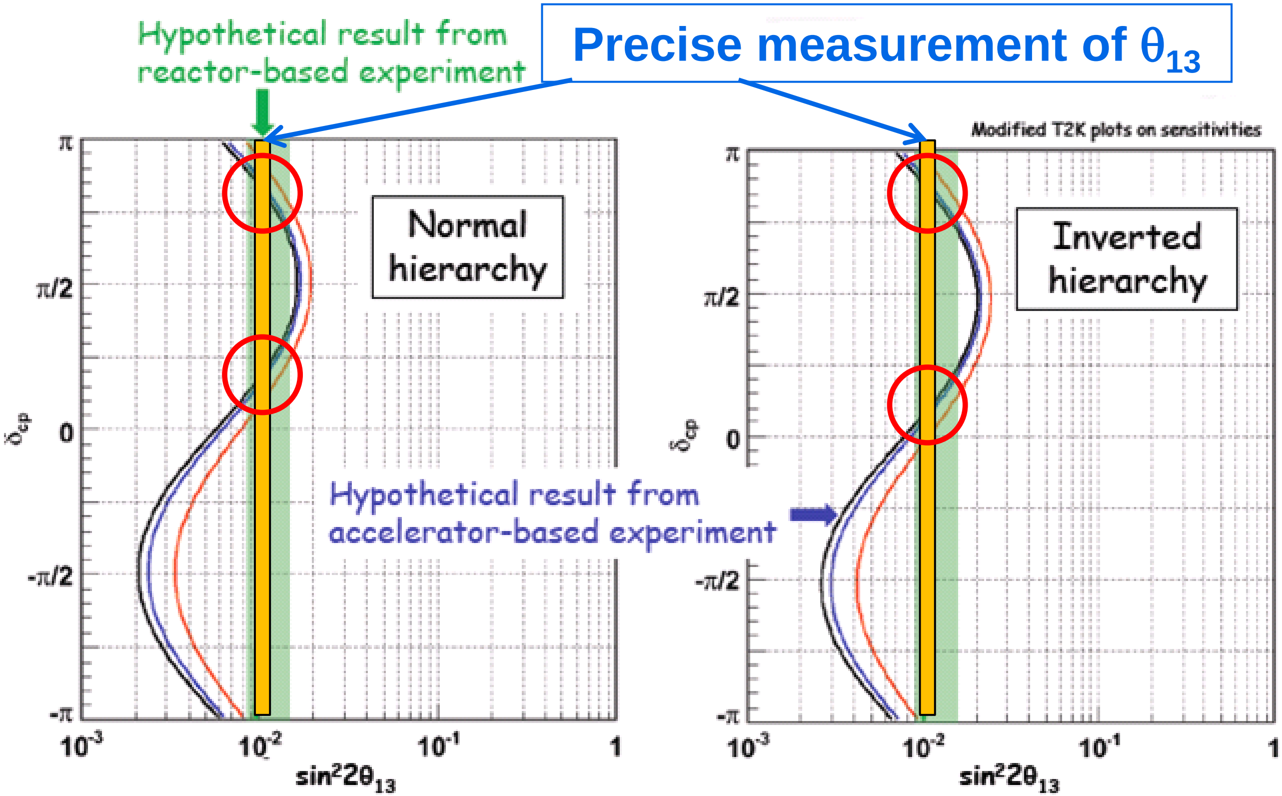
* Reactor

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E_\nu}\right) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right)$$

- Clean measurement of θ_{13} with no matter effects

* Accelerator

- mass hierarchy + CP violation + matter effects



- Complementary :

Combining results from accelerator and reactor based experiments could offer the first glimpse of δ_{CP}.

2012 Particle Data Book

$\Delta m_{21}^2 / |\Delta m_{31(32)}^2| \approx 0.03$

$\delta(\Delta m^2)$=~1% → **determination of mass hierarchy**

LEPTONS

Neutrino Mixing

$\sin^2(2\theta_{12}) = 0.857 \pm 0.024$ **(±2.8%)**

$\Delta m_{21}^2 = (7.50 \pm 0.20) \times 10^{-5}$ eV^2 **(±2.7%)**

$\sin^2(2\theta_{23}) > 0.95$ [i] **(±3.1%)**

$\Delta m_{32}^2 = (2.32^{+0.12}_{-0.08}) \times 10^{-3}$ eV^2 [j] **(+5.2-3.4%)**

$\sin^2(2\theta_{13}) = 0.098 \pm 0.013$ **(±13.3%)**

$\sin^2\theta_{12}$ = 0.312±0.017 (±5.4%)

$\sin^2\theta_{23}$ = 0.42+0.08−0.03 (+19.0 -7.1%)

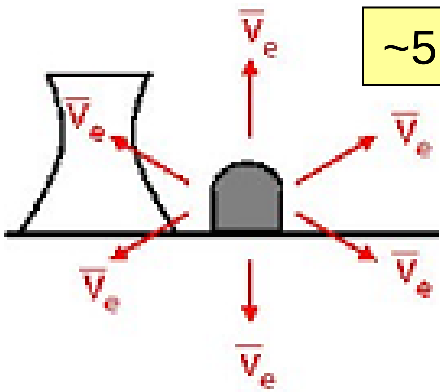
$\sin^2\theta_{13}$ = 0.0251±0.0034 (±13.5%)

Daya Bay & RENO (Neutrino 2014) → ±(~9%)

Needs high precision measurements of oscillation parameters for new discoveries!!

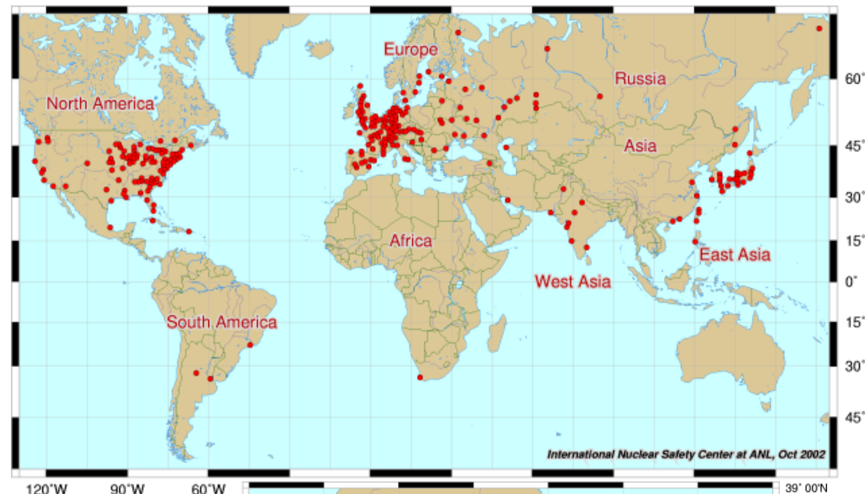
Reactor Neutrinos

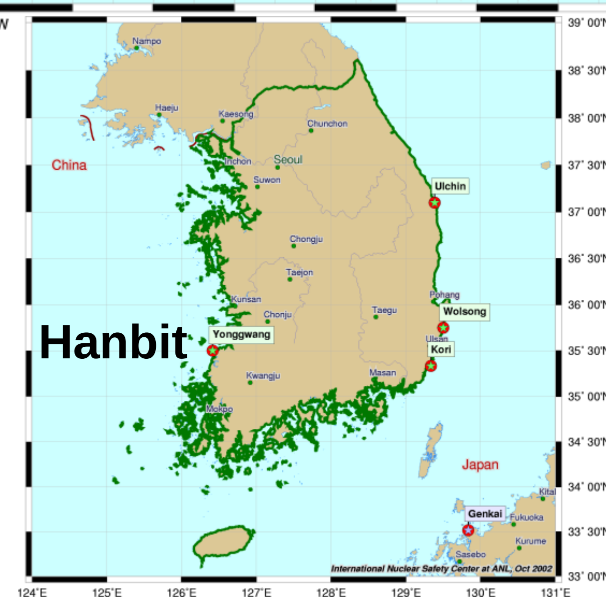
Reactor Neutrinos



$\sim 5 \times 10^{21}\ \nu$/sec

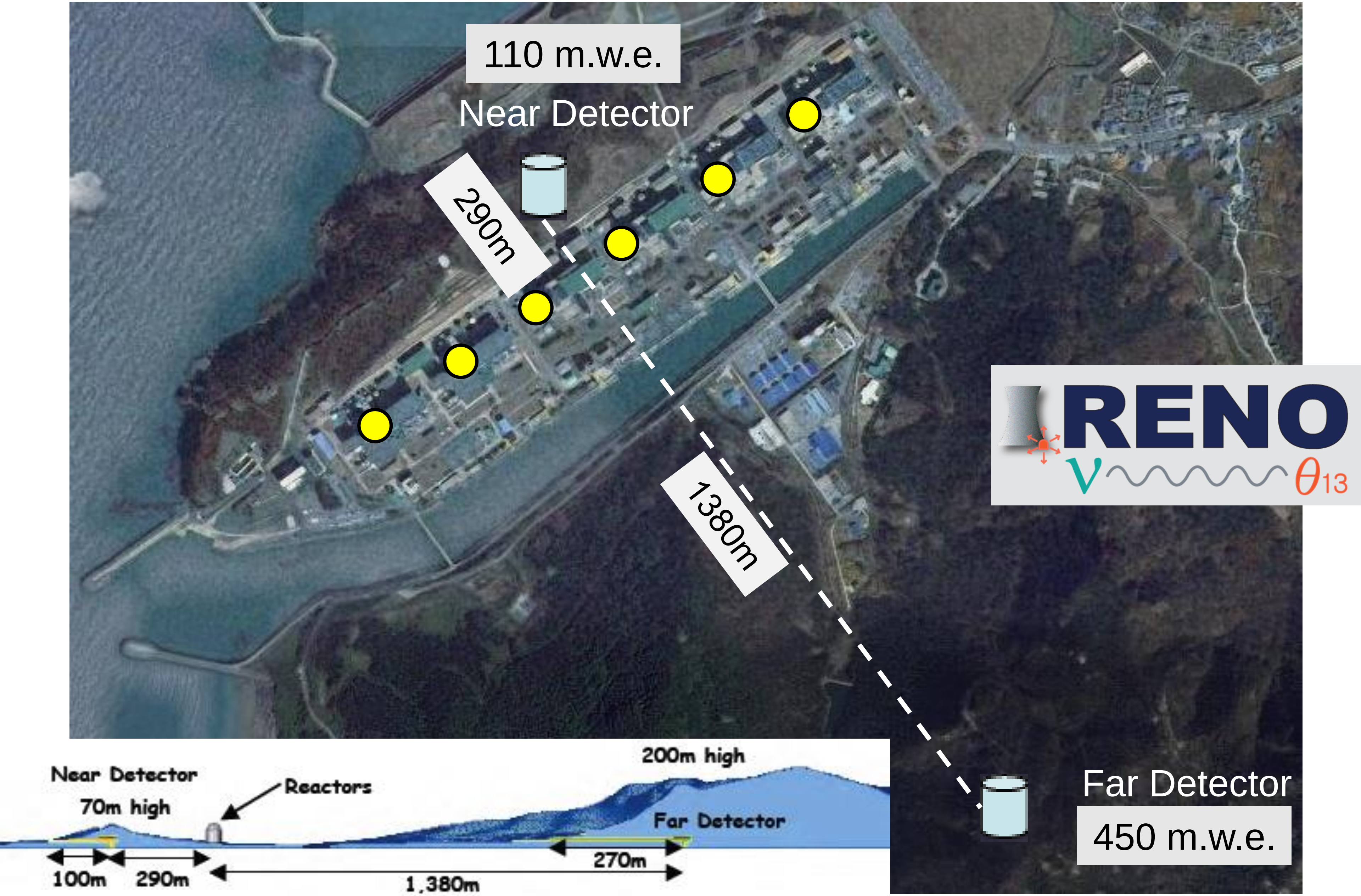
Nuclear Power Plants





- Cost-free, intense, low-energy & well-known neutrino source !

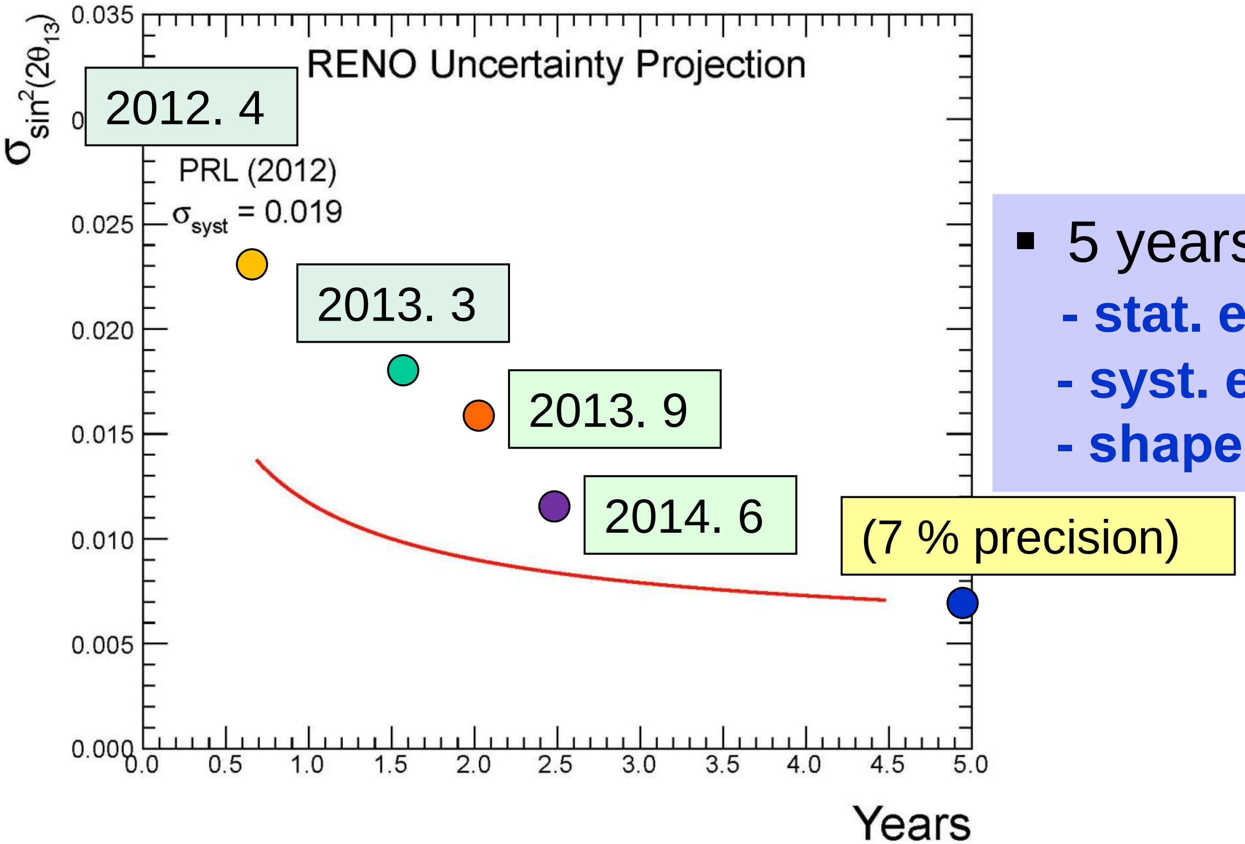
RENO Experimental Setup



RENO's Projected Sensitivity of θ_{13}

Neutrino 2014 $\sin^2 2\theta_{13} = 0.101 \pm 0.008(stat.) \pm 0.010(syst.)$

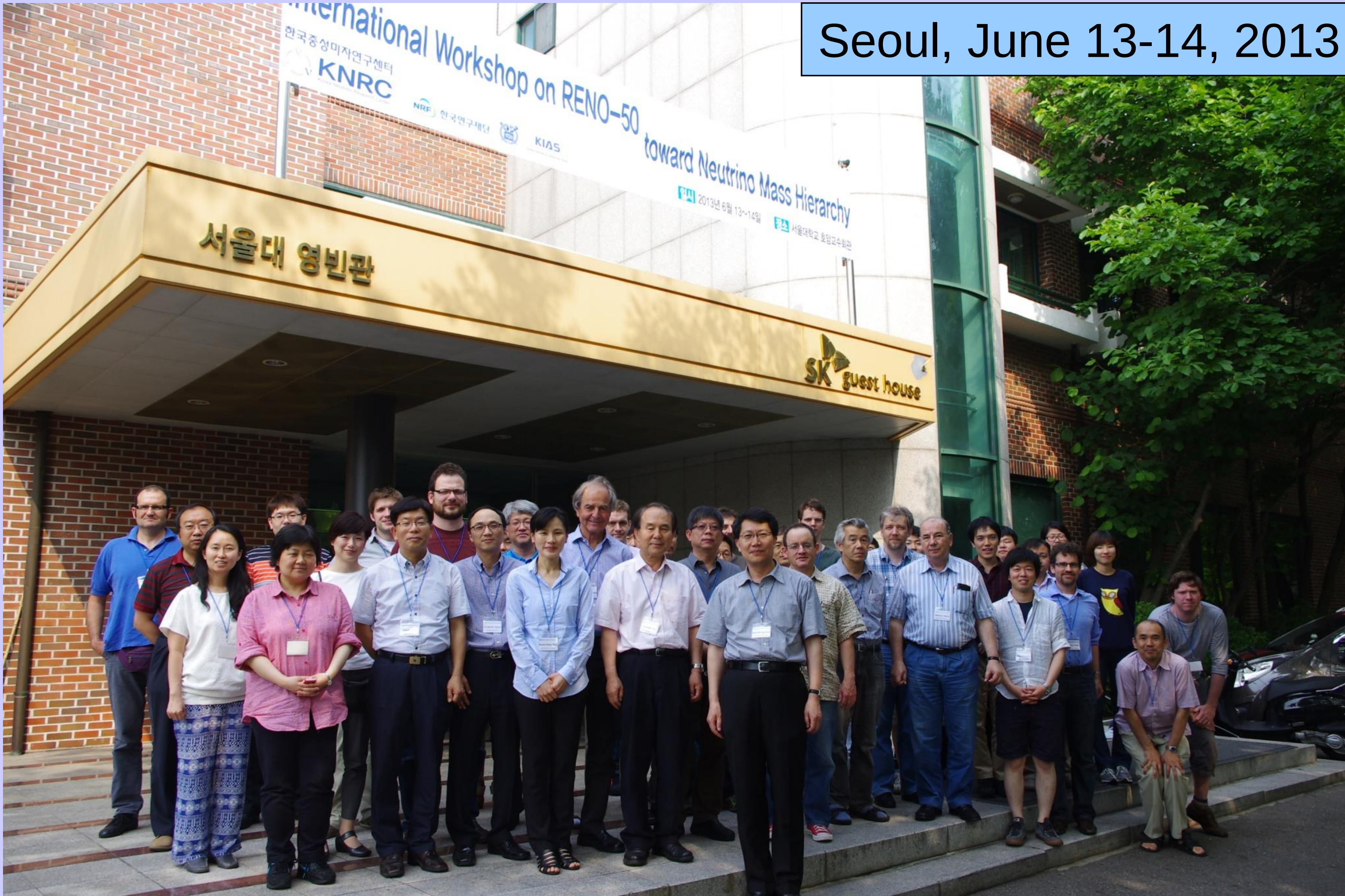
(~800 days) 0.101 ± 0.013 (7.8 σ) (13 % precision) → ± 0.007 (14 σ) (in 3 years) (7 % precision)



- 5 years of data : ±7%
  - **stat. error : ±0.008 → ±0.005**
  - **syst. error : ±0.010 → ±0.005**
  - **shape information** → ±5%

International Workshop on RENO-50

Seoul, June 13-14, 2013



RENO-50 at Snowmass

Opportunities in ν Oscillations

Summary talk on Intensity Frontier by J. Hewett at Snowmass meeting (Aug. 2013)

Category	Experiment	Status	Osc params
accelerator	T2K	data-taking	MH/CP/octant
accelerator	NOνA	commissioning	MH/CP/octant
accelerator	RADAR	R&D	MH/CP/octant
accelerator	CHIPS	R&D	MH/CP/octant
accelerator	T2HK	design/ R&D	MH/CP/octant
accelerator	LBNE	design/ R&D	MH/CP/octant
accelerator	DAEδALUS	design/ R&D	CP
reactor	JUNO	design/R&D	MH
reactor	RENO-50	design/R&D	MH
atmospheric	Super-K	data-taking	MH/CP/octant
atmospheric	Hyper-K	design/R&D	MH/CP/octant
atmospheric	LBNE	design/R&D	MH/CP/octant
atmospheric	INO	design/R&D	MH/octant
atmospheric	PINGU	design/R&D	MH
atmospheric	ORCA	design/R&D	MH
supernova	existing	N/A	MH

T2HK plays an important role

Low Energy Astrophysical ν Detectors

Table 1-6. *Summary of low-energy astrophysics detectors. **indicates significant potential, and * indicates some potential but may depend on configuration.*

Detector Type	Experiment	Location	Size (kton)	Status	Solar	Geo	Supernova
Liquid scintillator	Borexino	Italy	0.3	Operating	**	**	*
Liquid scintillator	KamLAND	Japan	1.0	Operating	**	**	*
Liquid scintillator	SNO+	Canada	1.0	Construction	**	**	*
Liquid scintillator	RENO-50	South Korea	18	Design/R&D	*	*	**
Liquid scintillator	JUNO (DB II)	China	20	Design/R&D	*	*	**
Liquid scintillator	Hanohano	TBD (USA)	20	Design/R&D	*	**	**
Liquid scintillator	LENA	TBD (Europe)	50	Design/R&D	*	**	**
Liquid scintillator	LENS	USA	0.12	Design/R&D	**		*
Water Cherenkov	Super-K	Japan	50	Operating	**		**
Water Cherenkov	IceCube	South Pole	2000	Operating			**
Water Cherenkov	Hyper-K	Japan	990	Design/R&D	**		**
Liquid argon	LBNE	USA	35	Design/R&D	*		**

Summary talk on Intensity Frontier by J. Hewett at Snowmass meeting (Aug. 2013)

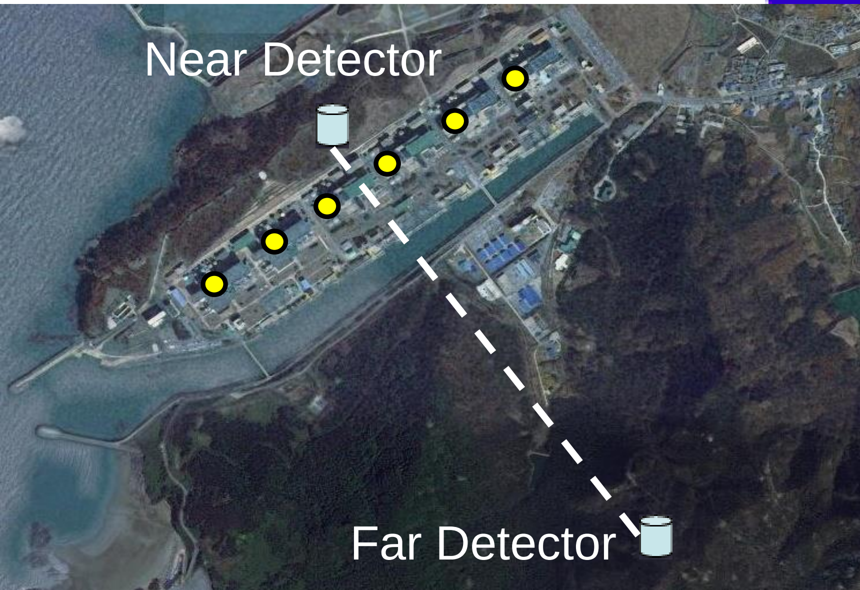
Overview of RENO-50

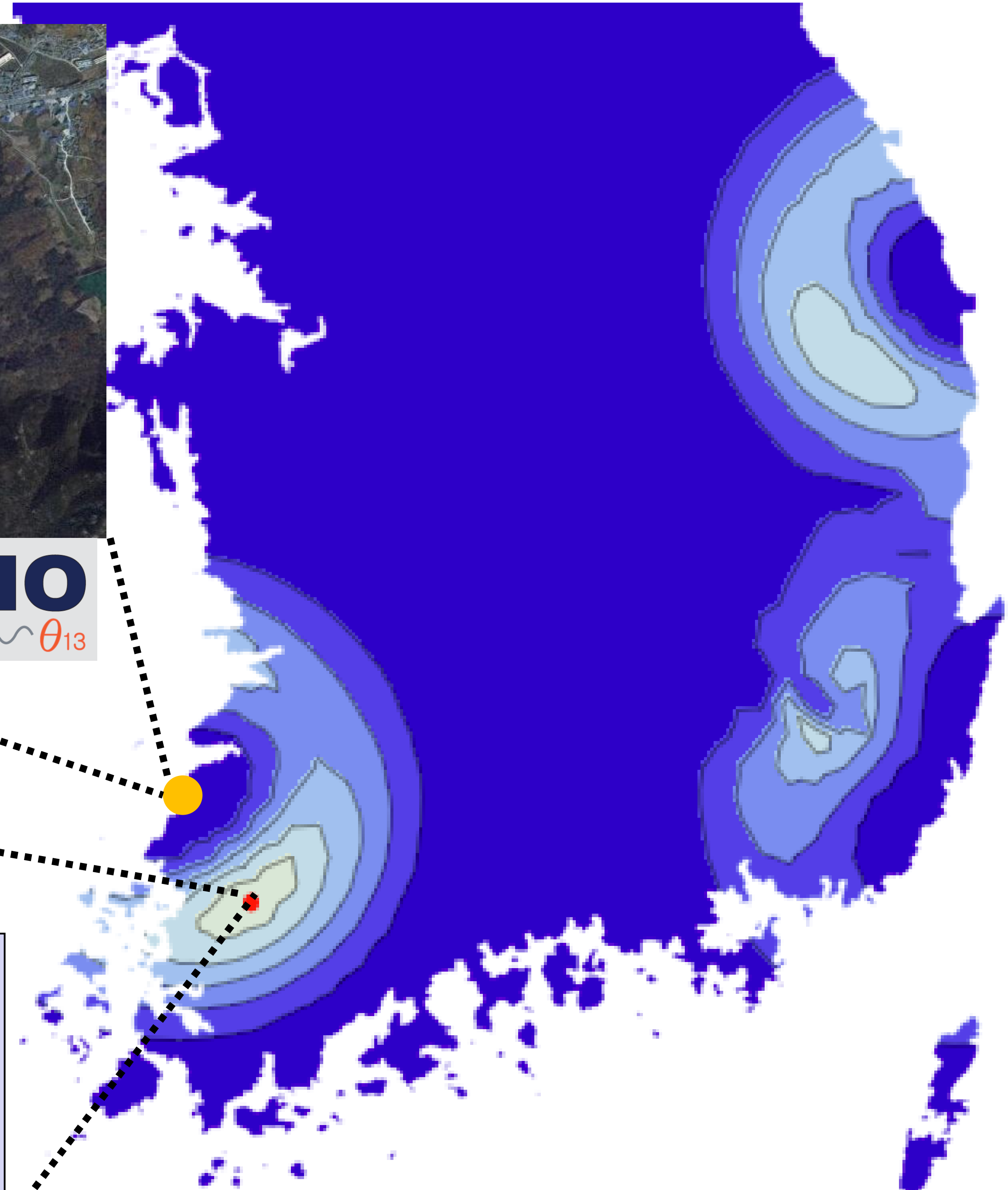
- **RENO-50** : An underground detector consisting of 18 kton ultra-low-radioactivity liquid scintillator & 15,000 20” PMTs, at 50 km away from the Hanbit(Yonggwang) nuclear power plant

- **Goals** : - Determination of neutrino mass hierarchy
  - High-precision measurement of θ_{12}, Δm^2_{21} and Δm^2_{31}
  - Study neutrinos from reactors, the Sun, the Earth, Supernova, and any possible stellar objects

- **Budget** : $ 100M for 6 year construction
  (Civil engineering: $ 15M, Detector: $ 85M)

- **Schedule** : 2014 ~ 2019 : Facility and detector construction
  2020 ~ : Operation and experiment





RENO-50

18 kton LS Detector
~47 km from YG reactors

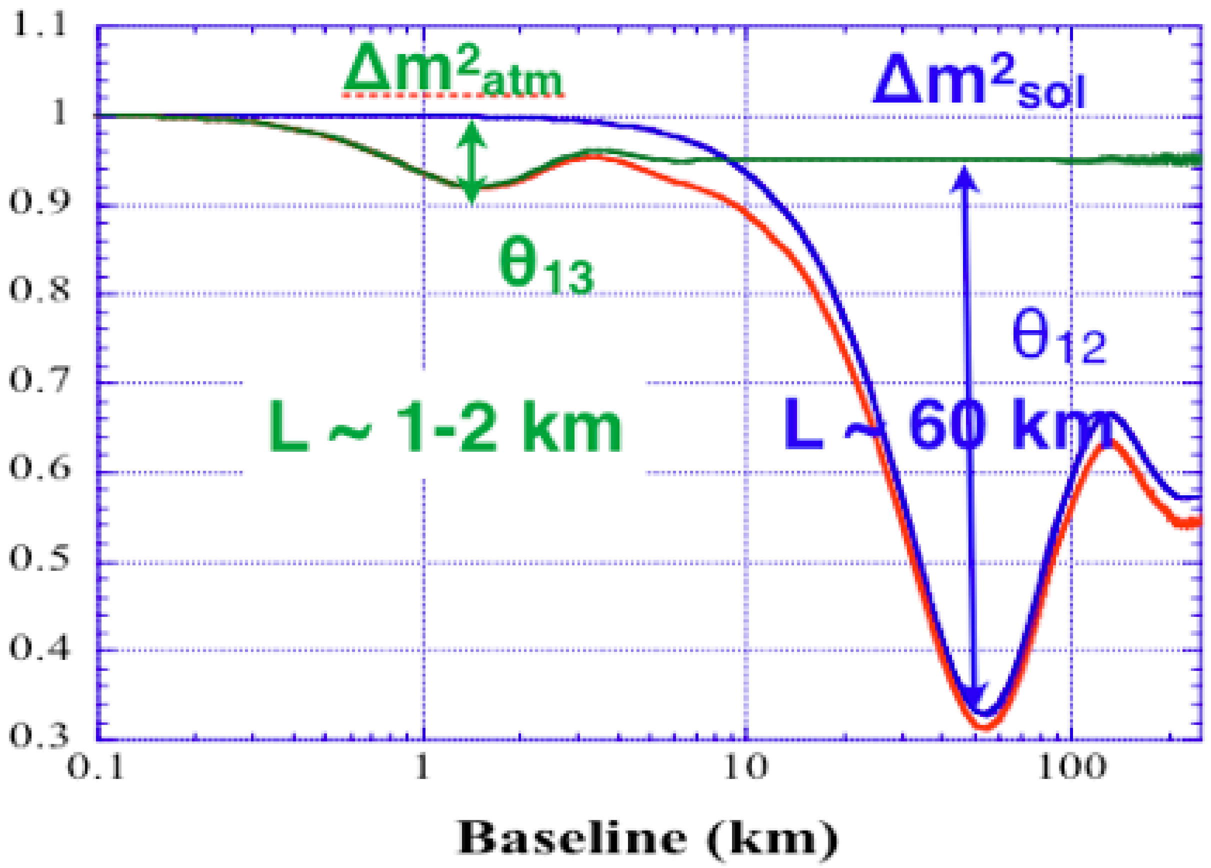
Mt. Guemseong (450 m)
~900 m.w.e. overburden

RENO-50 Candidate Site

RENO-50 Candidate Site

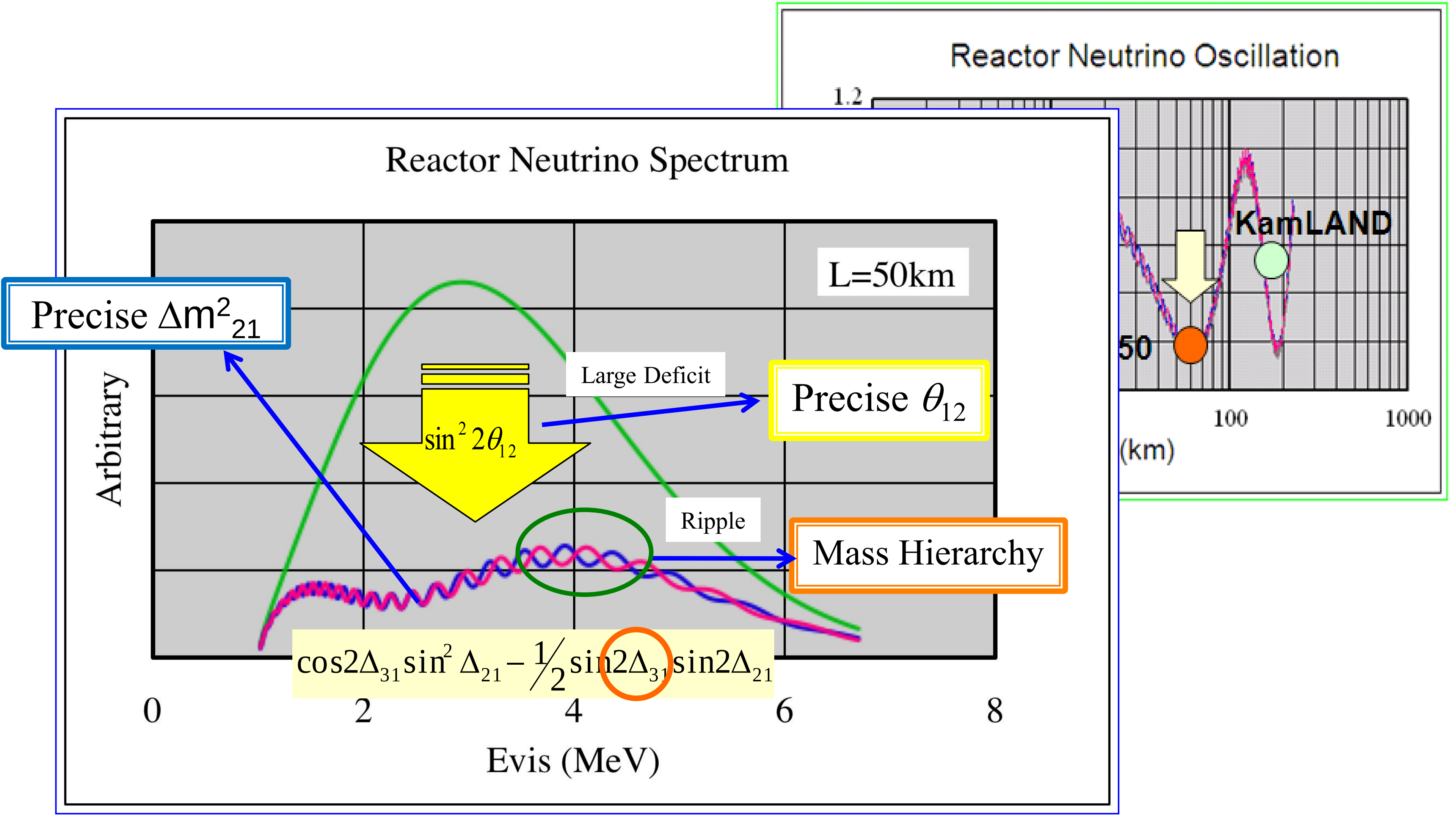
Reactor Neutrino Oscillations

$$P(\nu_e \to \nu_e) \approx 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\left(\frac{1.27\,\Delta m^2_{12} L}{E_\nu}\right) - \sin^2 2\theta_{13}\sin^2\left(\frac{1.27\,\Delta m^2_{13} L}{E_\nu}\right)$$



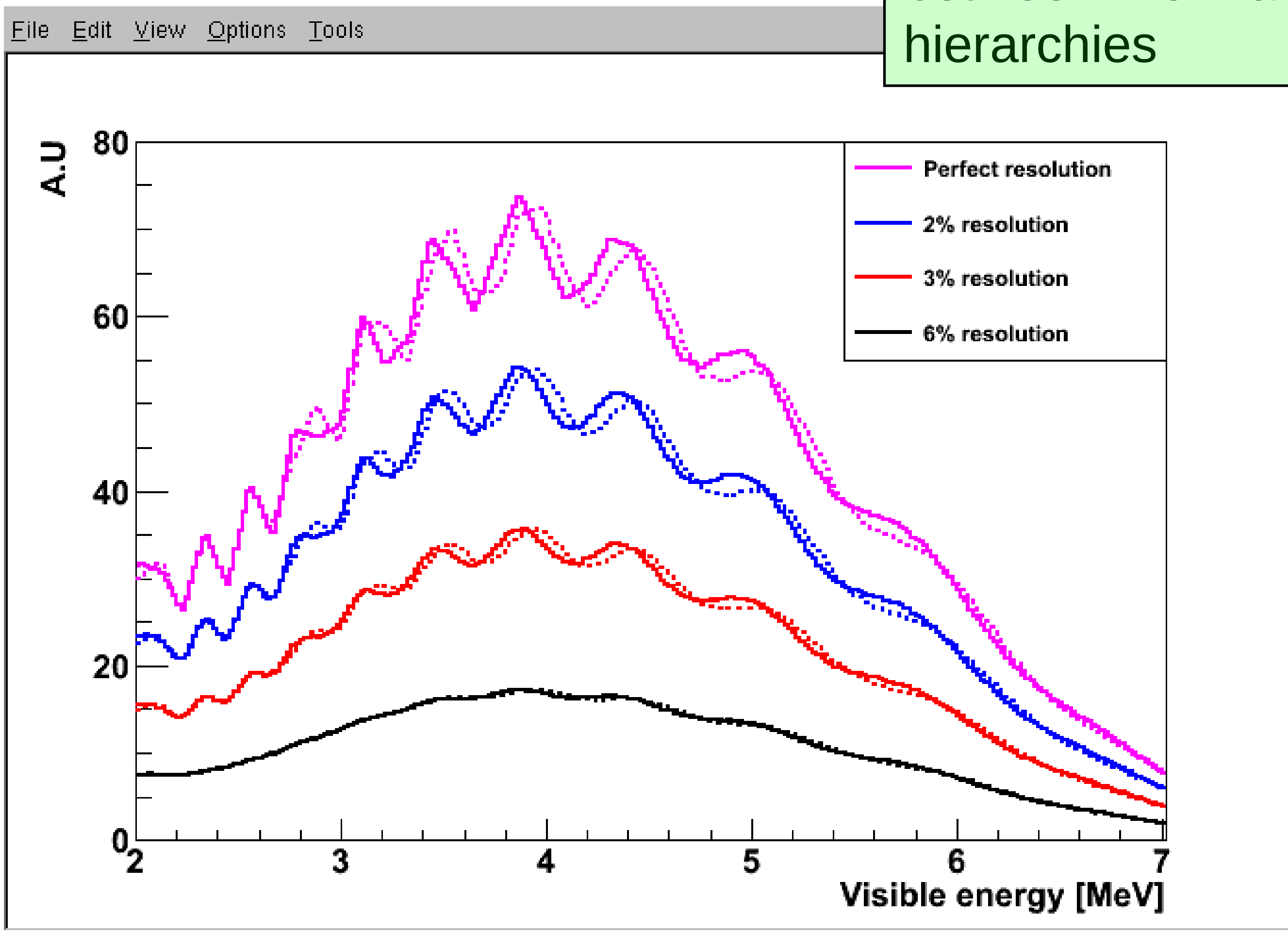
Reactor Neutrino Oscillations at 50 km

Neutrino mass hierarchy (sign of Δm^2_{31})+precise values of θ_{12}, Δm^2_{21} & Δm^2_{31}

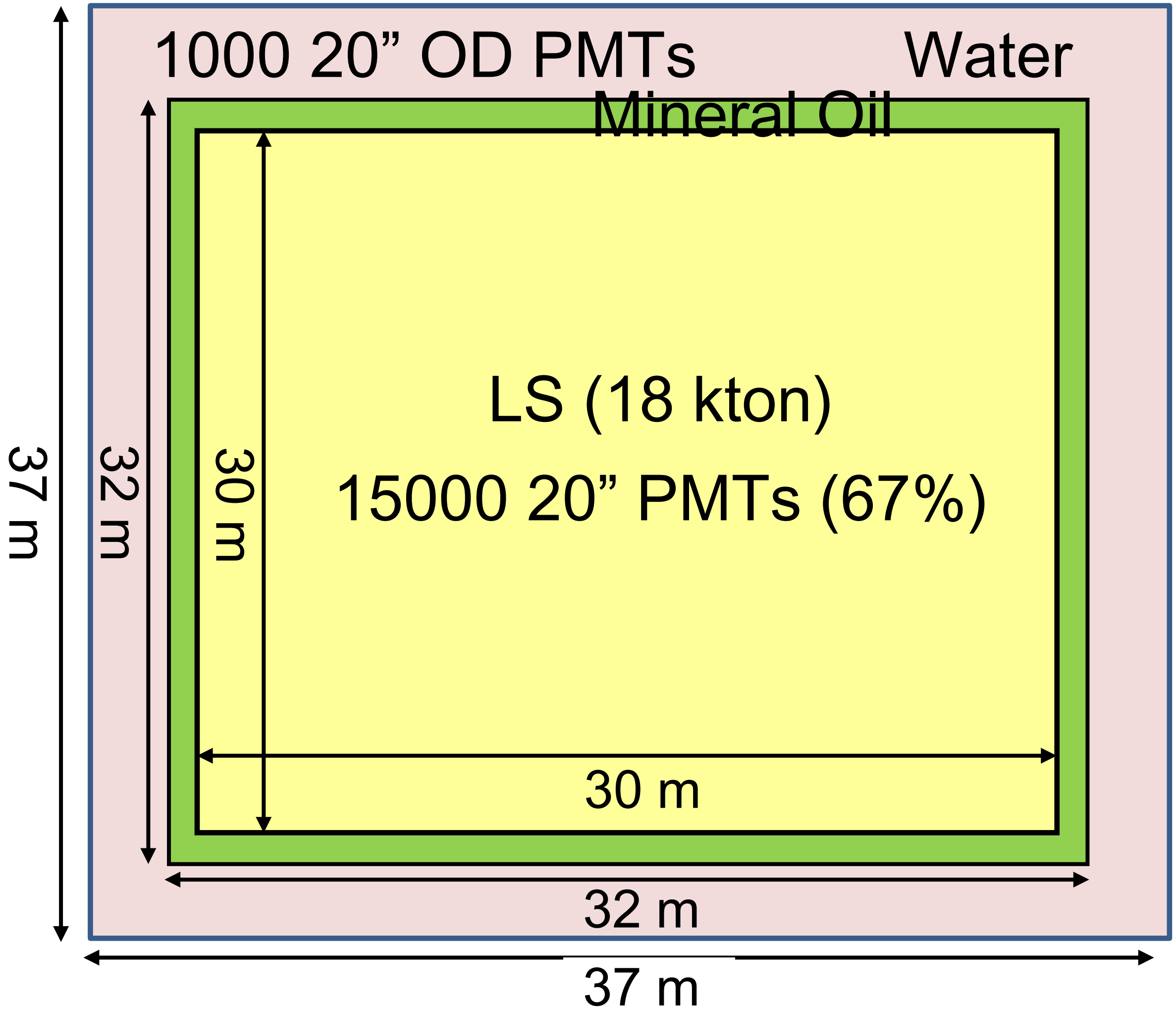


Energy Resolution for Mass Hierarchy

3% energy resolution essential for distinguishing the oscillation effects between normal and inverted mass hierarchies



Conceptual Design of RENO-50

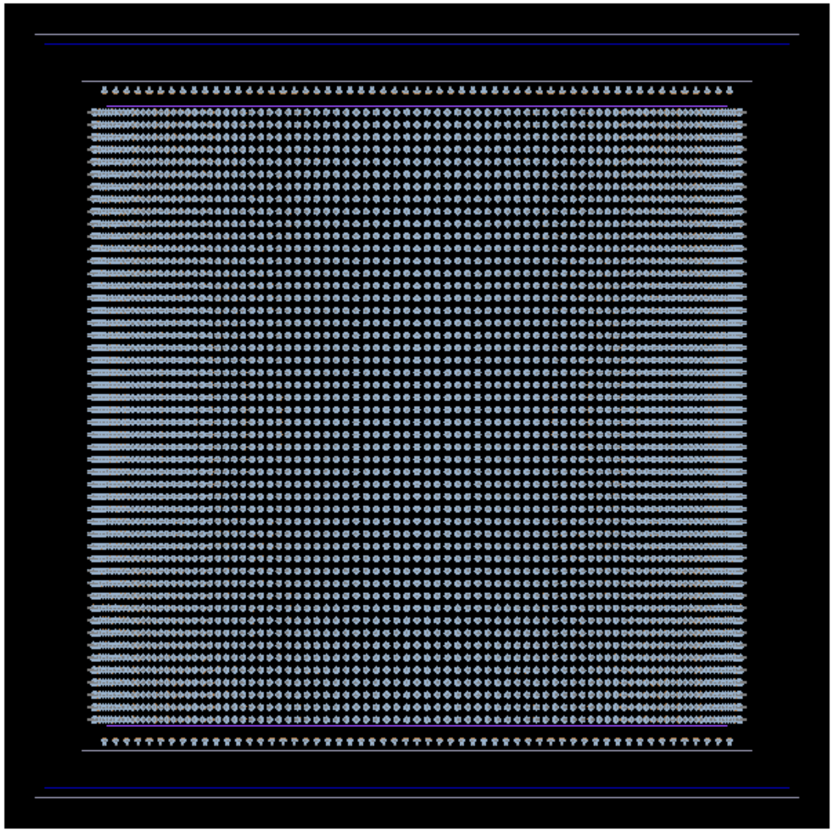


Technical Challenges

	KamLAND	RENO-50
LS mass	~1 kt	18 kt
Energy resolution	6.5%/√E	3%/√E
Light yield	500 p.e./MeV	>1000 p.e./MeV
LS attenuation length	~16 m	~25 m

- R&D for 3% energy resolution :
  - High transparency LS : 15 m → 25 m (purification & better PPO)
  - Large photocathode coverage : 34% → 67% (15,000 20” PMT)
  - High QE PMT : 20% → 35% (Hamamatsu 20” HQE PMT)
  - High light yield LS : ×1.5 (1.5 g/ℓ PPO → 5 g/ℓ PPO)

MC Simulation of RENO-50



• R&D with optimization of detector design by a MC study

• Increase of photosensitive area up to ~60% using 15,000 20" PMTs to maximize the light collection

▪ PMT arrangement scheme.

- Barrel : 50 raw * 200 column
- Top & Bottom: 2500 PMTs for each region

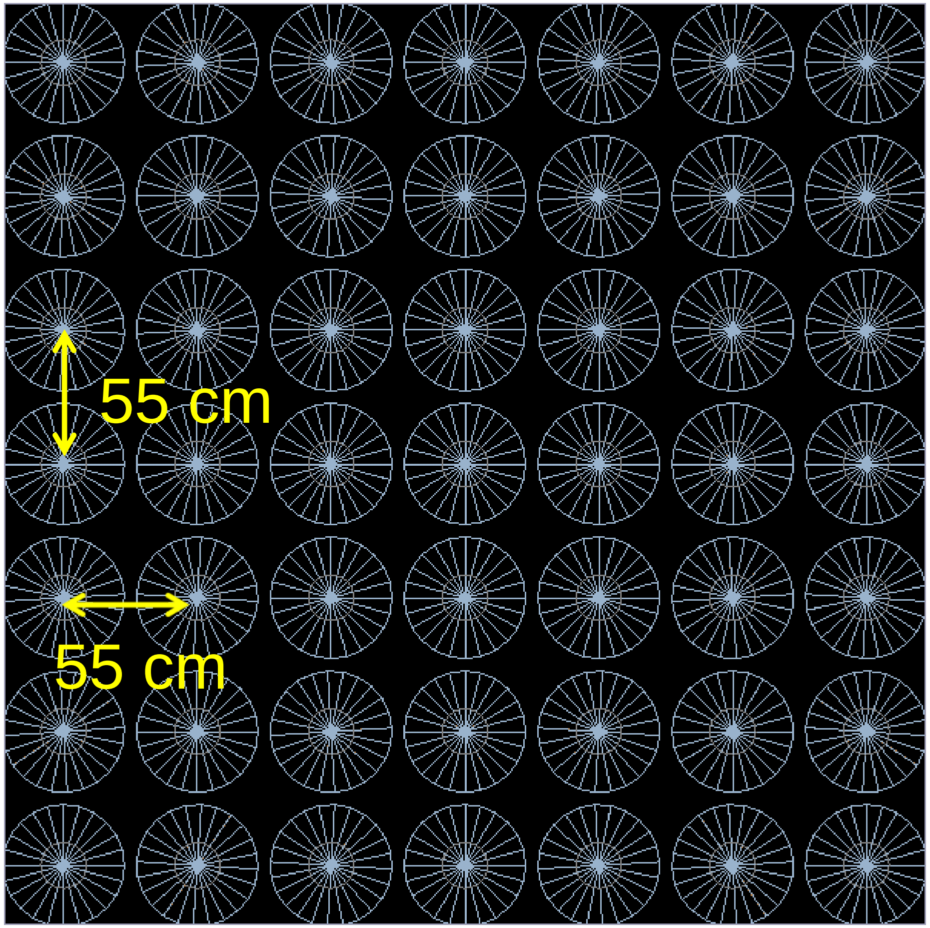
Target : Acrylic, 30m*30m

Buffer : Stainless-Steel, 32m*32m

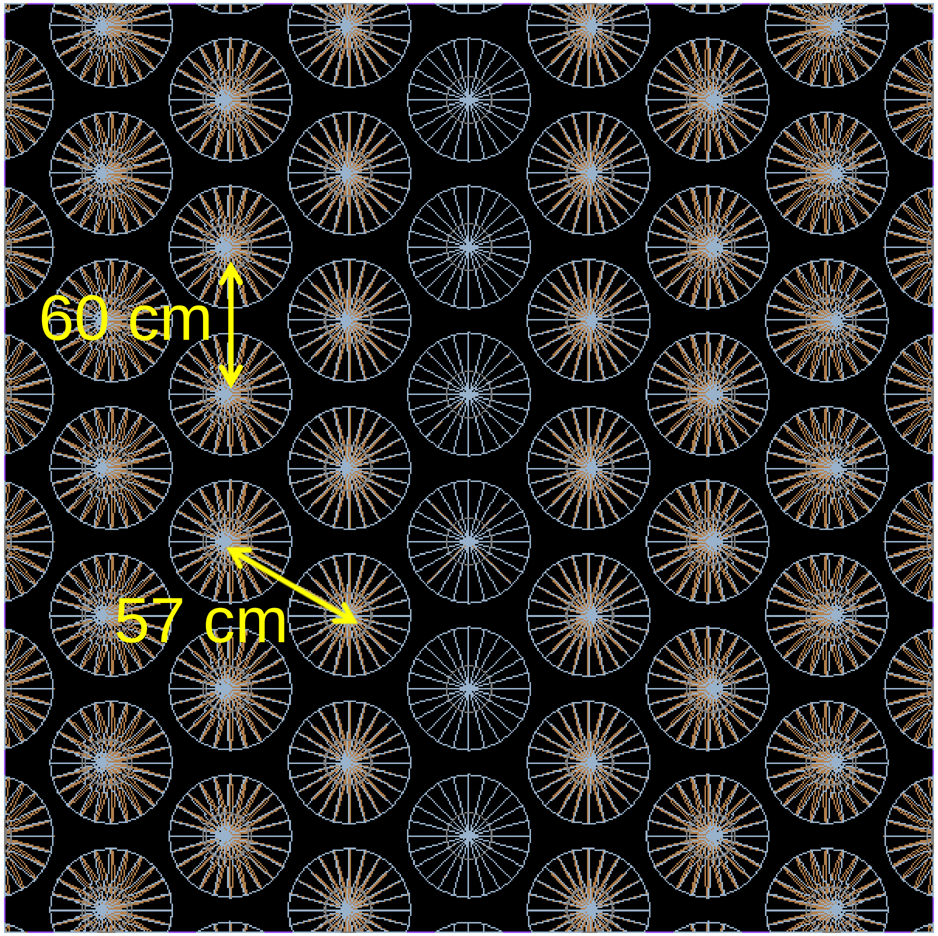
Veto : Concrete, 37m*37m

RENO-50 PMT Arrangement

Top & Bottom

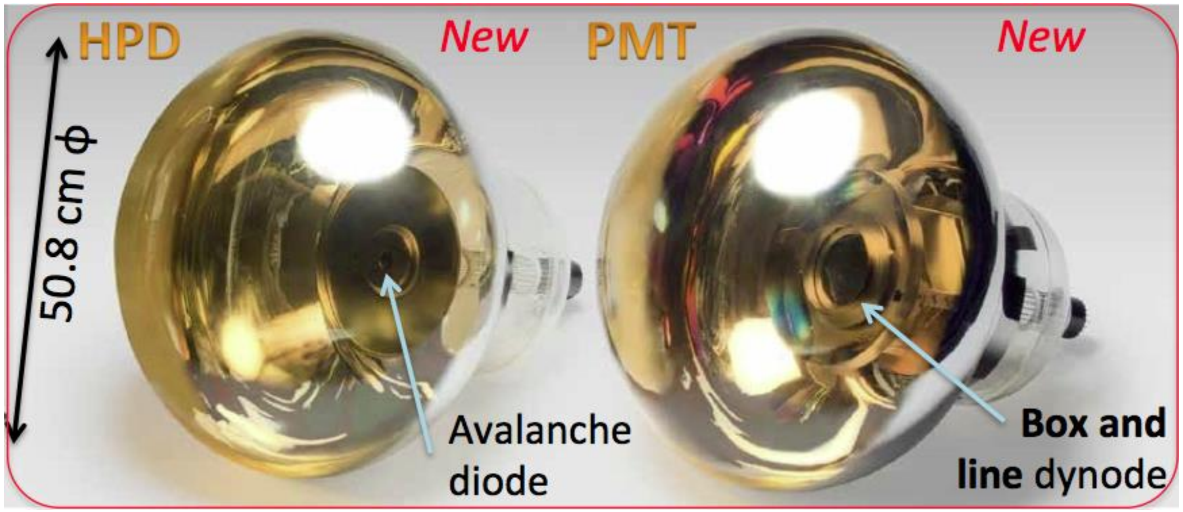


Barrel

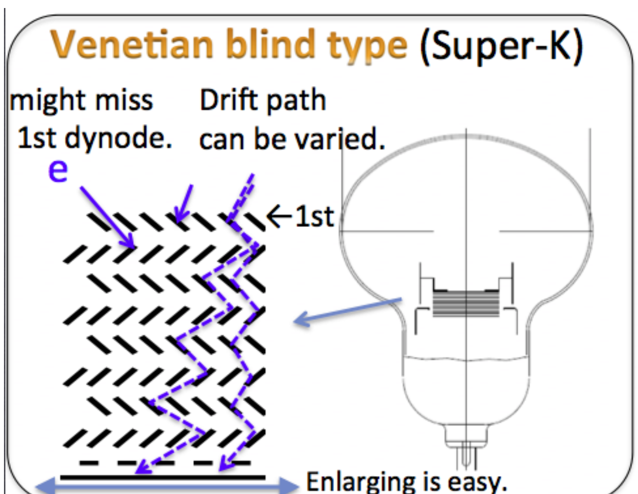


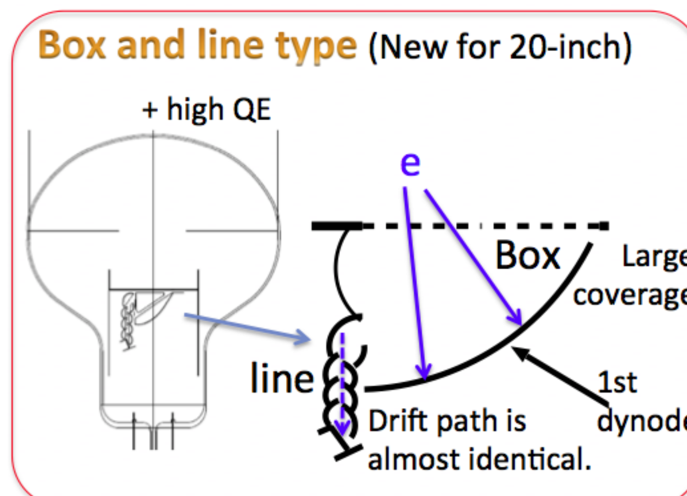
High QE PMTs

• Use of high, 35%, quantum efficiency PMTs in development



Hamamatsu HQE PMT, R12860





LS Purification Scheme

- Develop efficient methods for mass purification of radioactivity in LS

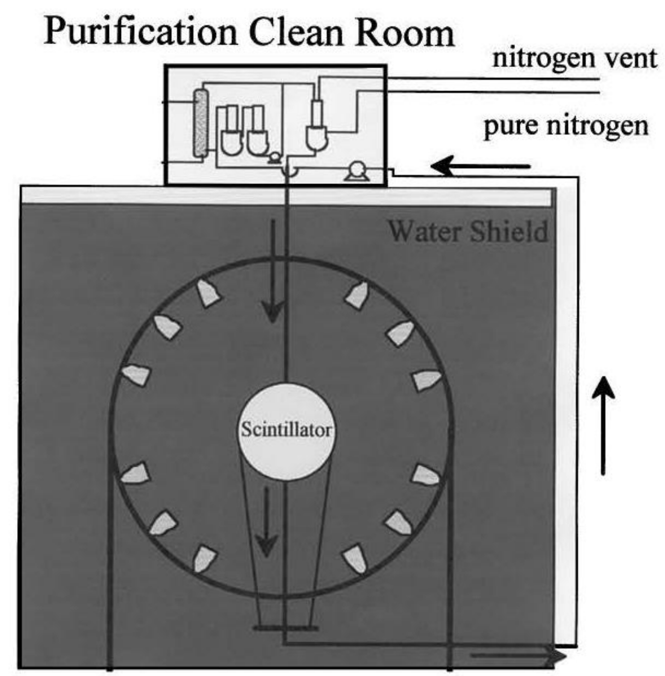
Radio-isotopes	Source	Typical concentration	Required concentration	Strategy for reduction
^{14}C	Cosmogenic bombardment of ^{14}N	$^{14}C/^{12}C \leq 10^{-12}$	$^{14}C/^{12}C \leq 10^{-18}$	**Use of LAB from petroleum derivative (old carbon)**
^{7}Be	Cosmogenic bombardment of ^{12}C	3×10^{-2} Bq/t-carbon	$<10^{-6}$ Bq/t-carbon	**Distillation, or underground storage of scintillator**
^{238}U ^{232}Th	Dust or surface contamination	2×10^{-5} g/g-dust	$<10^{-16}$ g/g LAB	**Water extraction +Distillation +Filtration +pH control**
^{40}K	Dust or contamination in fluor	2×10^{-6} g/g-dust	$<10^{-13}$ g/g in LAB $<10^{-11}$ g/g in fluor	**Water extraction**
^{222}Rn	Air and emanation from material	100 Rn atom/t-LAB	1 Rn atom/t-LAB	**Nitrogen stripping**

From a Borexino paper

LS Purification & Test Facility

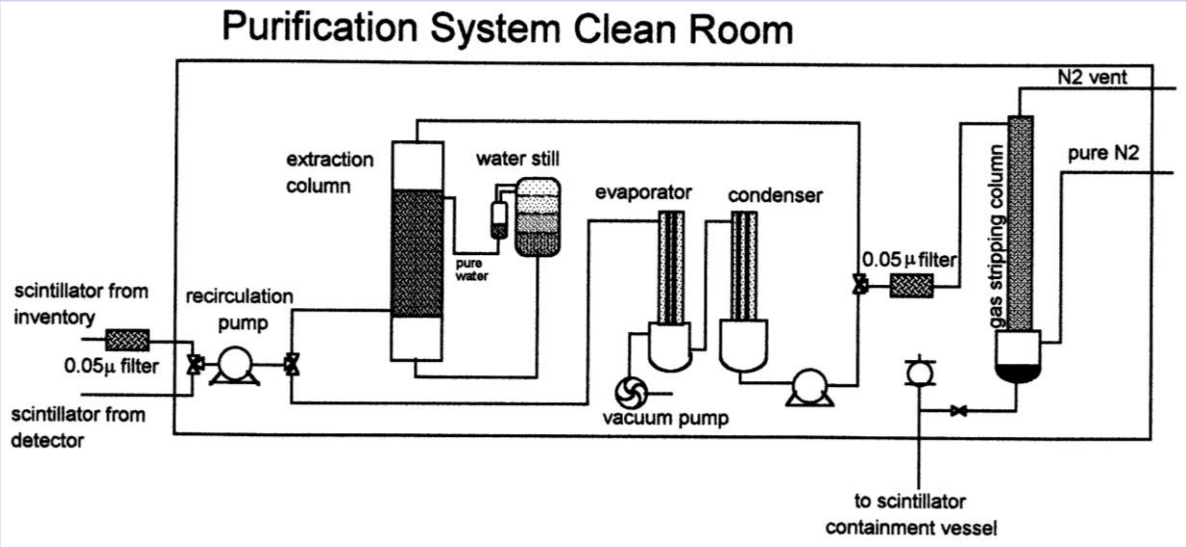
- Develop a test purification facility of ~5 ton LS and build a water shield tank of scintillation detector to measure radioactivity in LS

- Water extraction: removal of polar and charged impurities
- Vacuum distillation: removal of radioactive and chemical impurities
- Filtration with a 0.05 mm Teflon filter: removal of particulates
  (* suspended dust particles that may contain U, Th and K)
- Nitrogen stripping: removal of water and dissolved noble gases of Kr

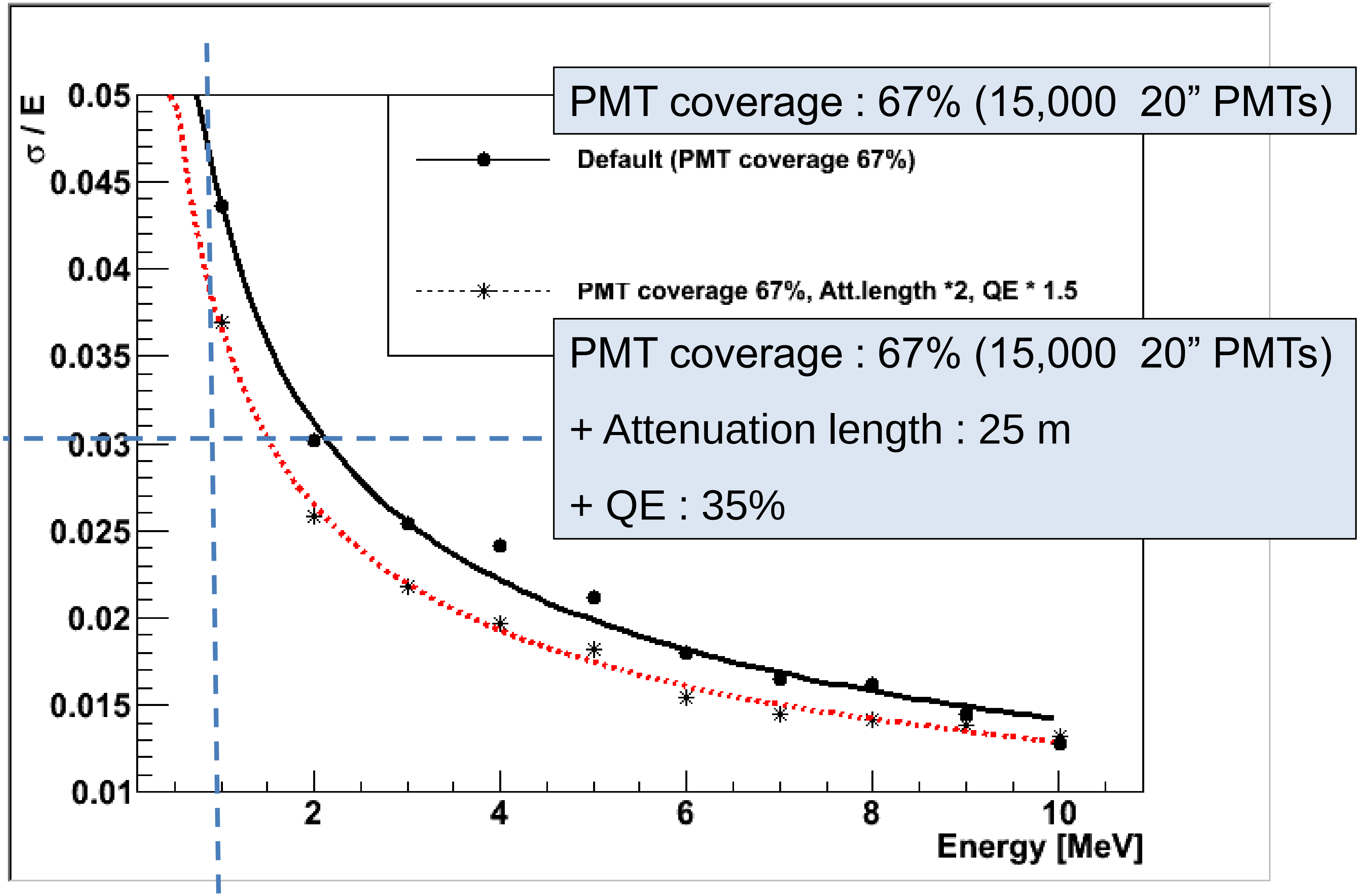


Test facility of Borexino

Ref. J.B. Benzinger *et al.*, NIM A 417, 278-296 (1998)



Expected Energy Resolution



RENO-50 vs. KamLAND

	Oscillation Reduction	Reactor Neutrino Flux	Detector Size	Syst. Error on ν Flux	Error on $\sin^2\theta_{12}$
RENO-50 (50 km)	80%	$13 \times 6 \times \phi_0$ [6 reactors]	18 kton	~ 0.3%	< 1%
KamLAND (180 km)	40%	$0.6 \times 55 \times \phi_0$ [55 reactors]	1 kton	3%	5.4%
Figure of Merit	×2	×2.4	×18	×10	

$(50\text{ km} / 180\text{ km})^2 \approx 13$

Observed Reactor Neutrino Rate

- RENO-50 : ~ 15 events/day
- KamLAND : ~ 1 event /day

⇨ Determination of mass ordering: ~ 3σ with 5 year data

2012 Particle Data Book

LEPTONS

Neutrino Mixing

$\sin^2(2\theta_{12}) = 0.857 \pm 0.024$ **(±2.8%)**

$\Delta m^2_{21} = (7.50 \pm 0.20) \times 10^{-5}$ eV^2 **(±2.7%)**

$\sin^2(2\theta_{23}) > 0.95$ [i] **(±3.1%)**

$\Delta m^2_{32} = (2.32^{+0.12}_{-0.08}) \times 10^{-3}$ eV^2 [j] **(+5.2-3.4%)**

$\sin^2(2\theta_{13}) = 0.098 \pm 0.013$ **(±13.3%)**

$\sin^2\theta_{12}$ = 0.312±0.017 (±5.4%)

$\Delta m_{21}{}^2 / |\Delta m_{31(32)}{}^2| \approx 0.03$

- Precise measurement of θ_{12}, Δm^2_{21} and Δm^2_{32}

$$\frac{\delta \sin^2\theta_{12}}{\sin^2\theta_{12}} < 1.0\%(1\sigma) \quad (\leftarrow 5.4\%)$$

$$\frac{\delta \Delta m^2_{21}}{\Delta m^2_{21}} < 1.0\%(1\sigma) \quad (\leftarrow 2.7\%)$$

$$\frac{\delta \Delta m^2_{32}}{\Delta m^2_{32}} < 1.0\%(1\sigma) \quad (\leftarrow 5.2\%)$$

Additional Physics with RENO-50

- Neutrino burst from a Supernova in our Galaxy
  - ~5,600 events (@8 kpc) (* NC tag from 15 MeV deexcitation γ)
  - A long-term neutrino telescope

- Geo-neutrinos : ~ 1,000 geo-neutrinos for 5 years
  - Study the heat generation mechanism inside the Earth

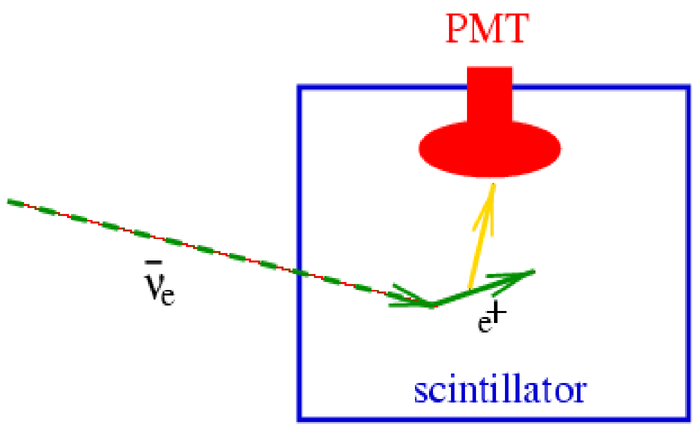
- Solar neutrinos : with ultra low radioacitivity
  - MSW effect on neutrino oscillation
  - Probe the center of the Sun and test the solar models

- Detection of J-PARC beam : ~200 events/year

- Neutrinoless double beta decay search : possible modification like KamLAND-Zen

Scintillation detectors

(by Kate Scholberg, Neutrino 2014)



Liquid scintillator C_nH_{2n} volume surrounded by photomultipliers

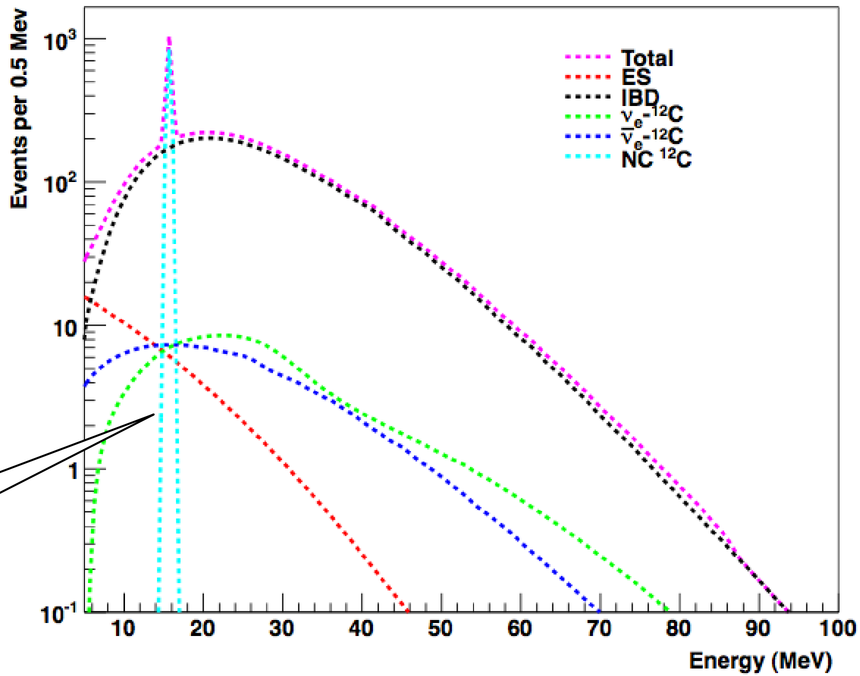
- few 100 events/kton (IBD)

- low threshold, good neutron tagging possible

- little pointing capability (light is ~isotropic)

- coherent elastic NC scattering on protons for ν spectral info

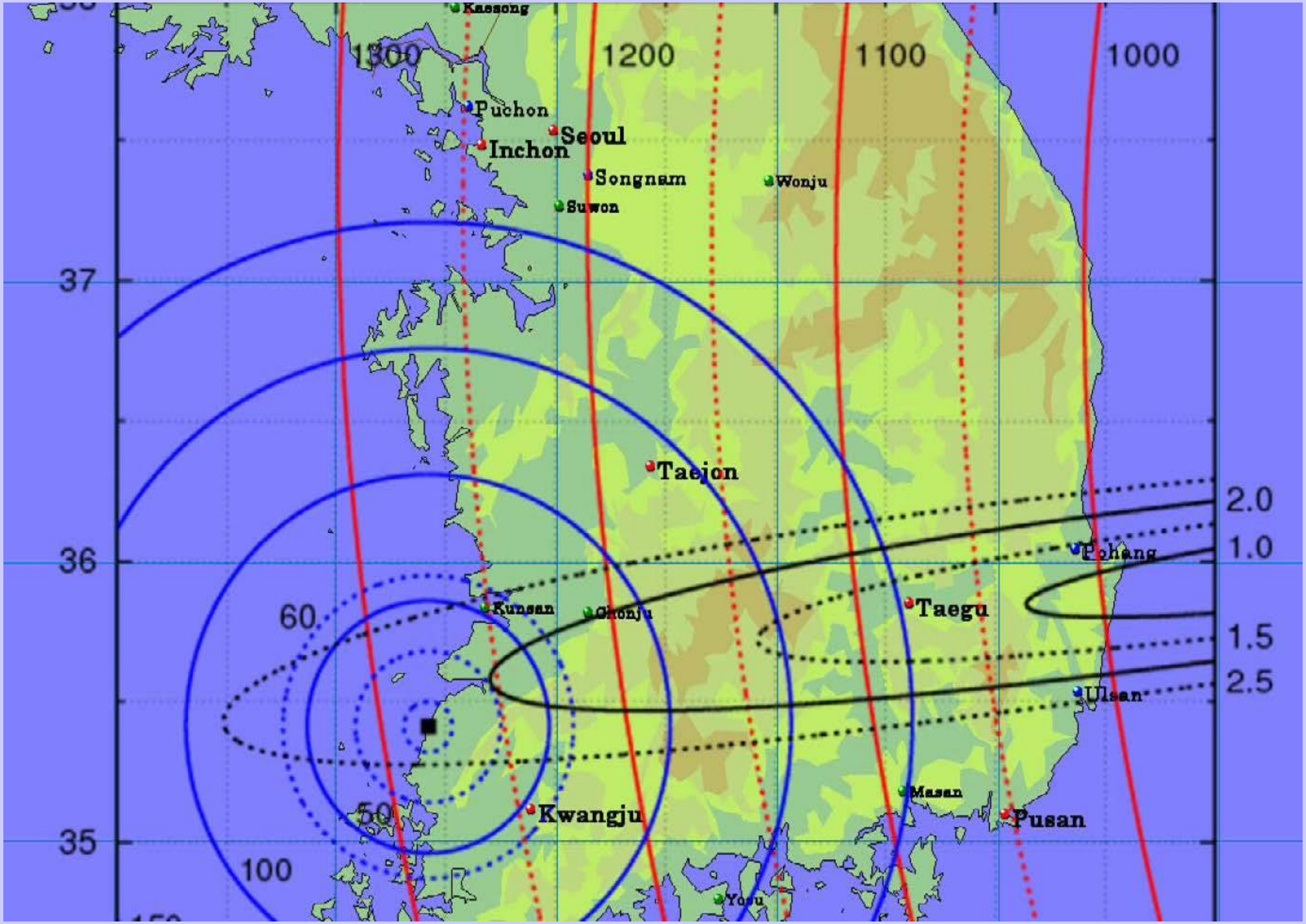
NC tag from 15 MeV deexcitation γ (no ν spectral info)



50 kt @ 10 kpc

J-PARC neutrino beam

Dr. Okamura & Prof. Hagiwara



Schedule

- 2014 : Group organization
  Detector simulation & design
  Geological survey
- 2015 ~ 2016 : Civil engineering for tunnel excavation
  Underground facility ready
  Structure design
  PMT evaluation and order,
  Preparation for electronics, HV, DAQ & software tools,
  R&D for liquid scintillator and purification
- 2017 ~ 2019 : Detector construction
- 2020 ~ : Data taking & analysis

Summary

- Longer baseline (~50 km) reactor experiments is under pursuit to determine the mass hierarchy in 3σ for 5 years of data-taking, and to perform high-precision (<1%) measurements of θ_{12}, Δm^2_{21}, & Δm^2_{31} .

- Domestic and international workshops held in 2013 to discuss the feasibility and physics opportunities

- Proposals have been submitted to obtain full or R&D funding.

- New idea : A bigger size of water Cherenkov detector in 1st phase
  $\rightarrow$ Convert it into a LS detector in 2nd phase

Thanks for your attention!