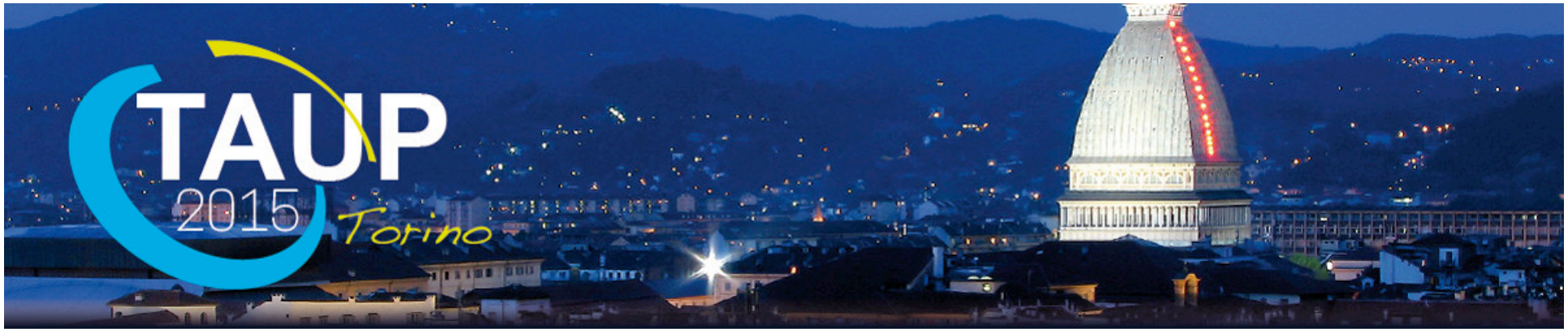


RENO-50

Seon-Hee (Sunny) Seo

Seoul National University

TAUP 2015, Torino
Sept. 7 ~ 11, 2015

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

RENO can be used as Near detector for RENO-50 (reduce sys. error)

- **Goals** : - Determination of neutrino mass hierarchy
- High-precision measurement of θ_{12}, Δm^2_{21} and Δm^2_{ee}

– Neutrino astronomy, Geo ν, sterile ν search, etc.

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

- **Schedule** : 2015 ~ 2020 : Facility and detector construction
2021 ~ : Operation and experiment

Physics Goals with RENO-50

- Determination of neutrino mass hierarchy (very challenging)

  ~3 σ sensitivity from ~10 years of data

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

$$\frac{\delta \sin^2\theta_{12}}{\sin^2\theta_{12}} < 1.0\%(1\sigma) \quad (\leftarrow 5.4\%) \qquad \frac{\delta \Delta m^2_{21}}{\Delta m^2_{21}} < 1.0\%(1\sigma) \quad (\leftarrow 2.4\%) \qquad \frac{\delta \Delta m^2_{ee}}{\Delta m^2_{ee}} < 1.0\%(1\sigma) \quad (\leftarrow 2.8\%)$$

- Neutrino burst from a Supernova in our Galaxy

  ~5,600 events @ 8 kpc

- Geo-neutrinos : **~ 1,500 geo-neutrinos for 5 years**

  - Study the heat generation mechanism inside the Earth

- Solar neutrinos : with ultra low radioacitivity detector

  - Test MSW effect on neutrino oscillation and solar models

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

SuperNova Neutrinos (I)

- All flavors of ν and anti-ν are produced from core collapsing SN.
  (99% energy of the collapse is carried away by these ν).
  → SN explosion mechanism
  → ~ 5600 events @ 8 kpc in RENO-50
  (A few core-collapse SN per century in our galaxy.)

RENO-50 LS: 1.35×10^{33} (free protons), 8.15×10^{32} (^{12}C), 6.24×10^{33} (e^-)

Total ~5600 events @ 8 kpc

- ~3960 events from IBD process: $\bar{\nu}_e + p \rightarrow e^+ + n$
- ~1150 events from deexitation gamma at 15.5 MeV:

$$\nu(\bar{\nu}) + {}^{12}C \rightarrow \nu(\bar{\nu}) + {}^{12}C^*$$

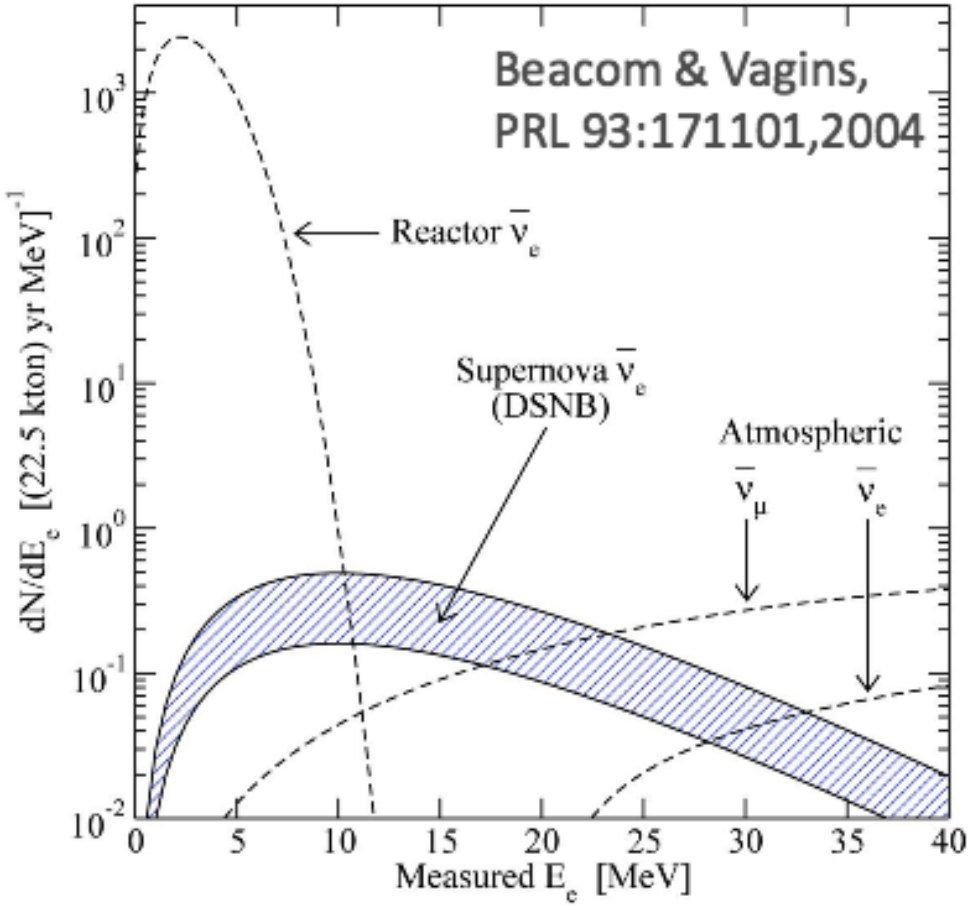
- ~240 events from CC interaction:

$$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$$
$$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$$

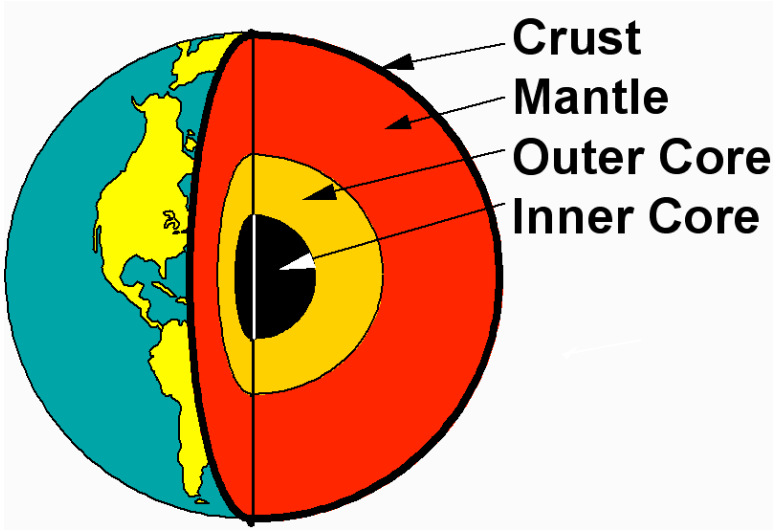
- ~240 events from elastic scattering w/ electron

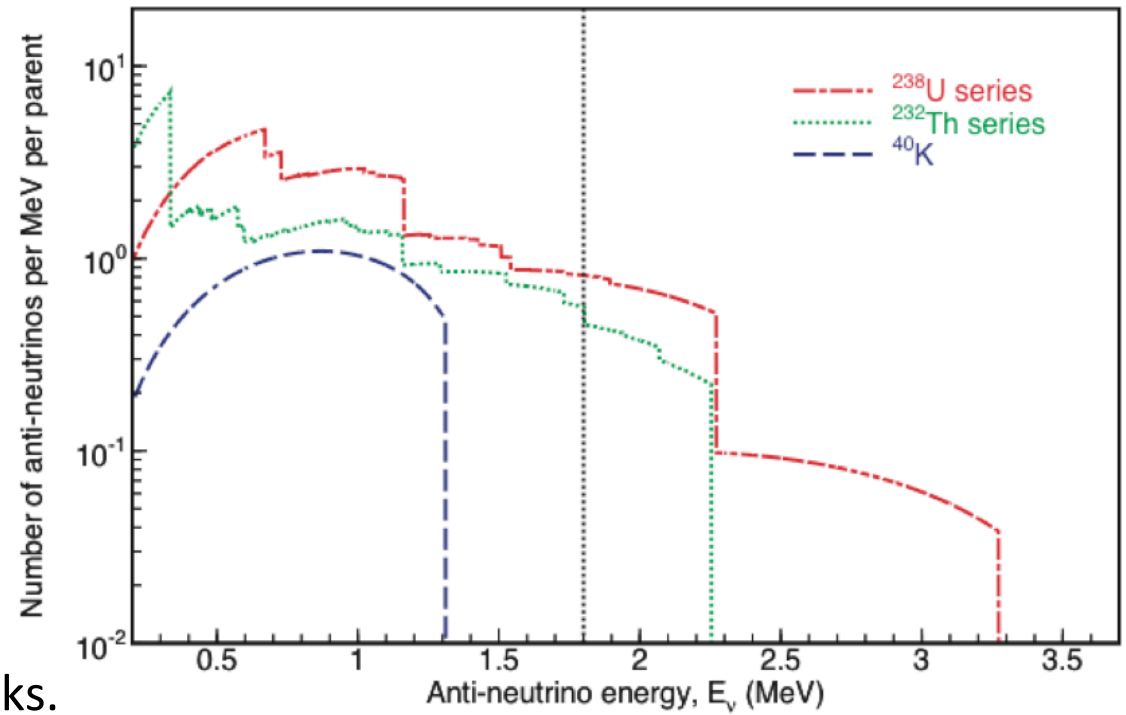
SuperNova Neutrinos (II)

- Diffuse Supernova Neutrino Background (DSNB) search
  → past SN neutrino events
  (a few core-collapse SN/sec in visible universe)
  → increase events statics almost twice than JUNO alone



Geo Neutrinos





See A. Ianni & M. Baldoncini talks.

- Electron anti-neutrinos from ^{238}U, ^{232}Th, & ^{40}K inside Earth interior.
- To reveal the mechanism inside the Earth interior.
- ~300 geo neutrinos/year in RENO-50

Sterile Neutrino Search (I)

- Super-light (~10^{-5} eV^2) sterile ν search @ ~50 km with reactor ν.
  arXiv: 1308.2823

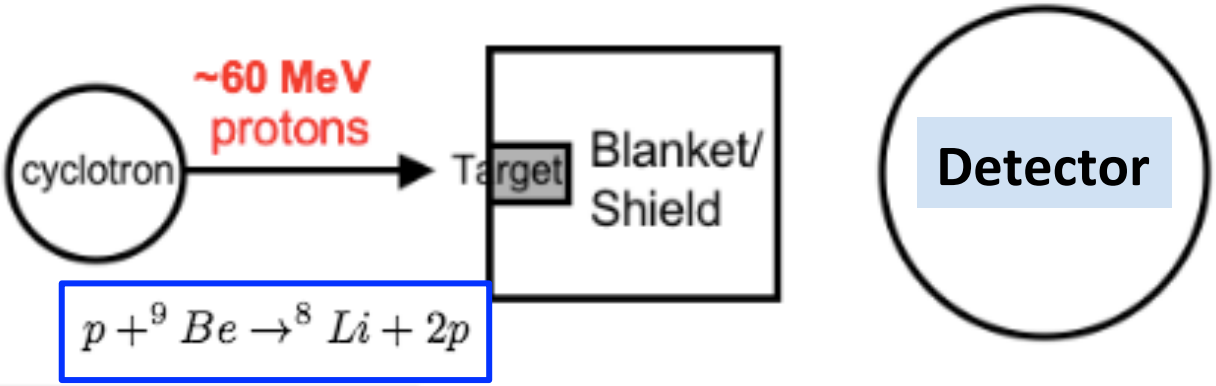
- Neutrino oscillometry:
  -- using strong (anti-) ν sources (^{144}Ce, ^{51}Cr) near top or bottom of the detector
  -- observe disappearance oscillation pattern inside detector
  (test Gallium anomaly: 3 sigma)
  → distinctive signature of oscillation
  -- example: LENA, SOX

- IsoDAR: Isotope Decay At Rest arXiv: 1307.6465
  -- very short baseline sterile neutrino search using Cyclotron

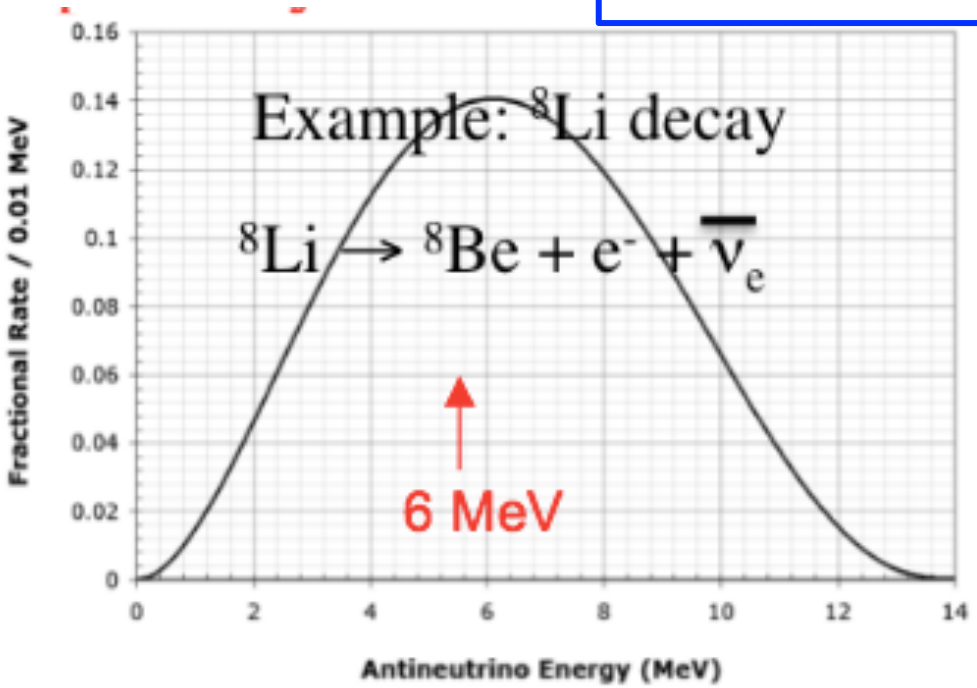
Sterile Neutrino Search (II)

IsoDAR setup:

A. Bungau et al., PRL 109, 141802 (2012)



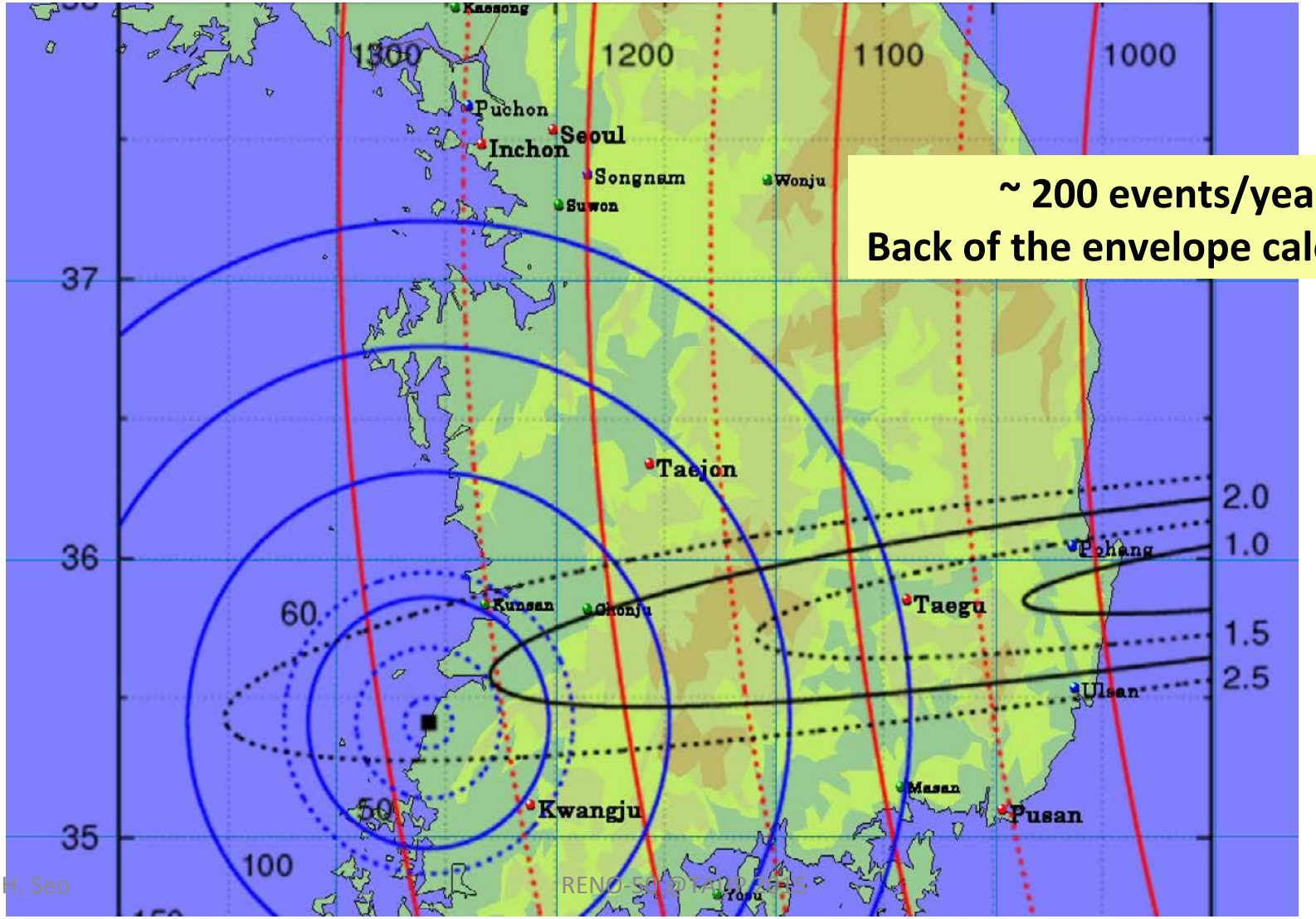
$$p + {}^{9}Be \rightarrow {}^{8}Li + 2p$$



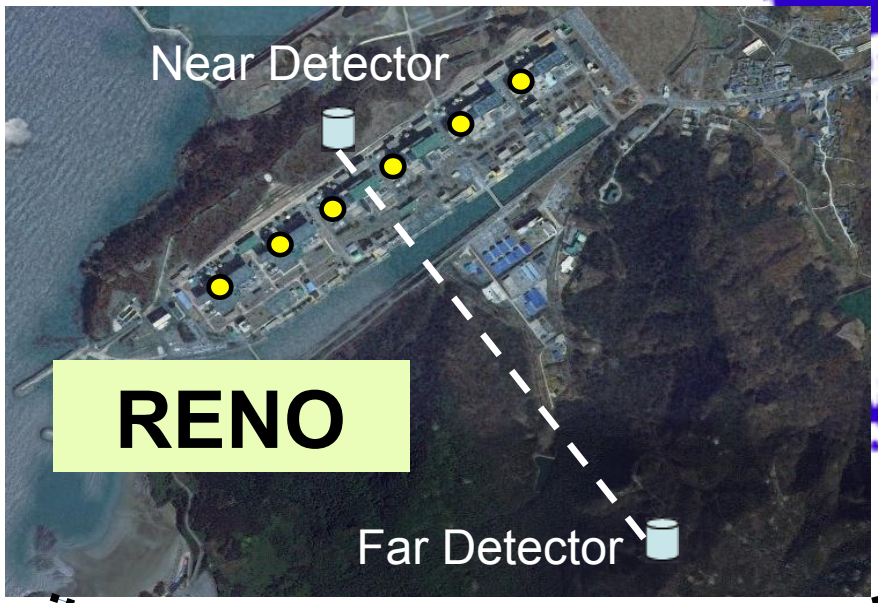
Very short baseline Sterile neutrino search

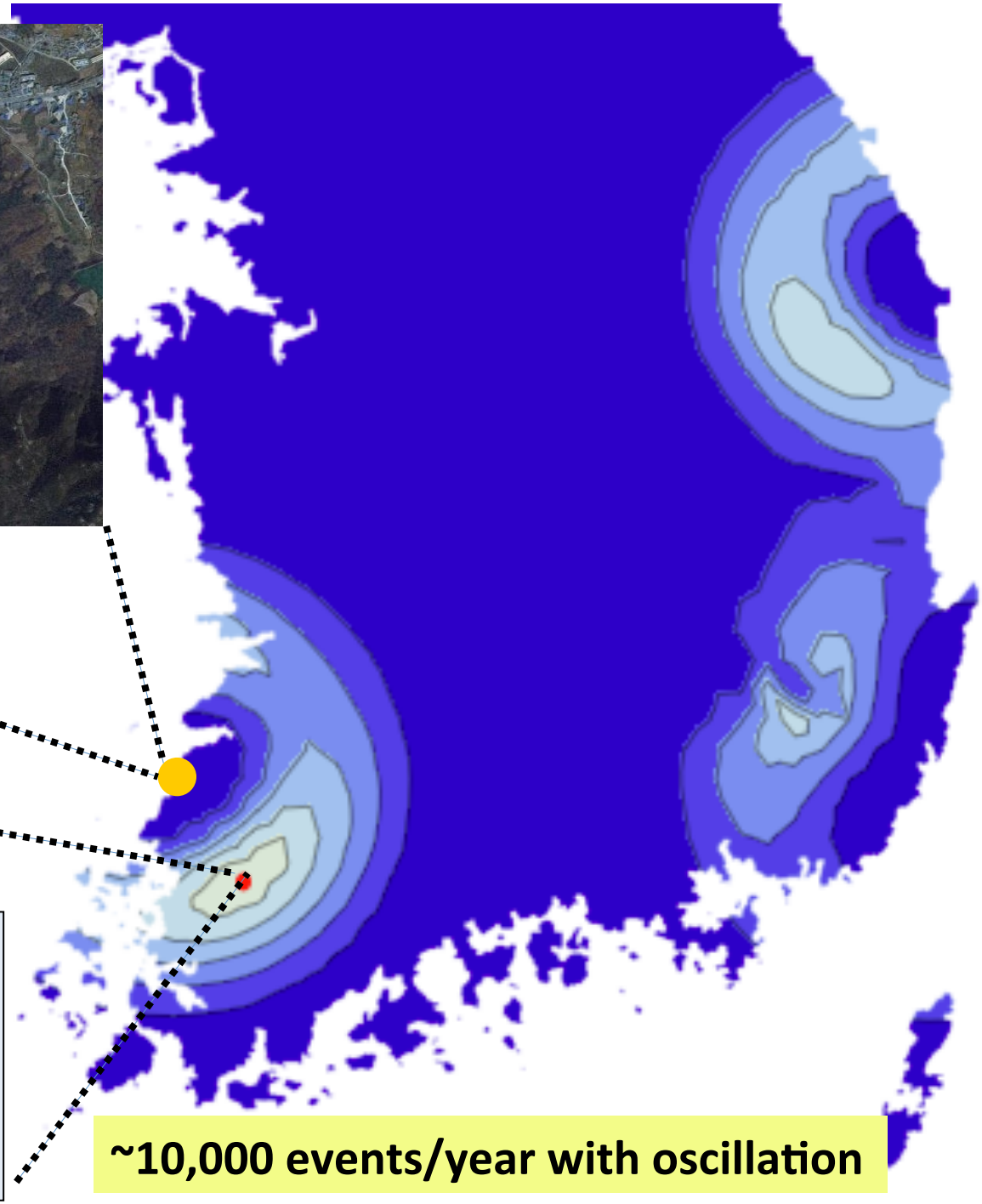
J-PARC neutrino beam

Dr. Okamura & Prof. Hagiwara



~ 200 events/year
Back of the envelope calculation





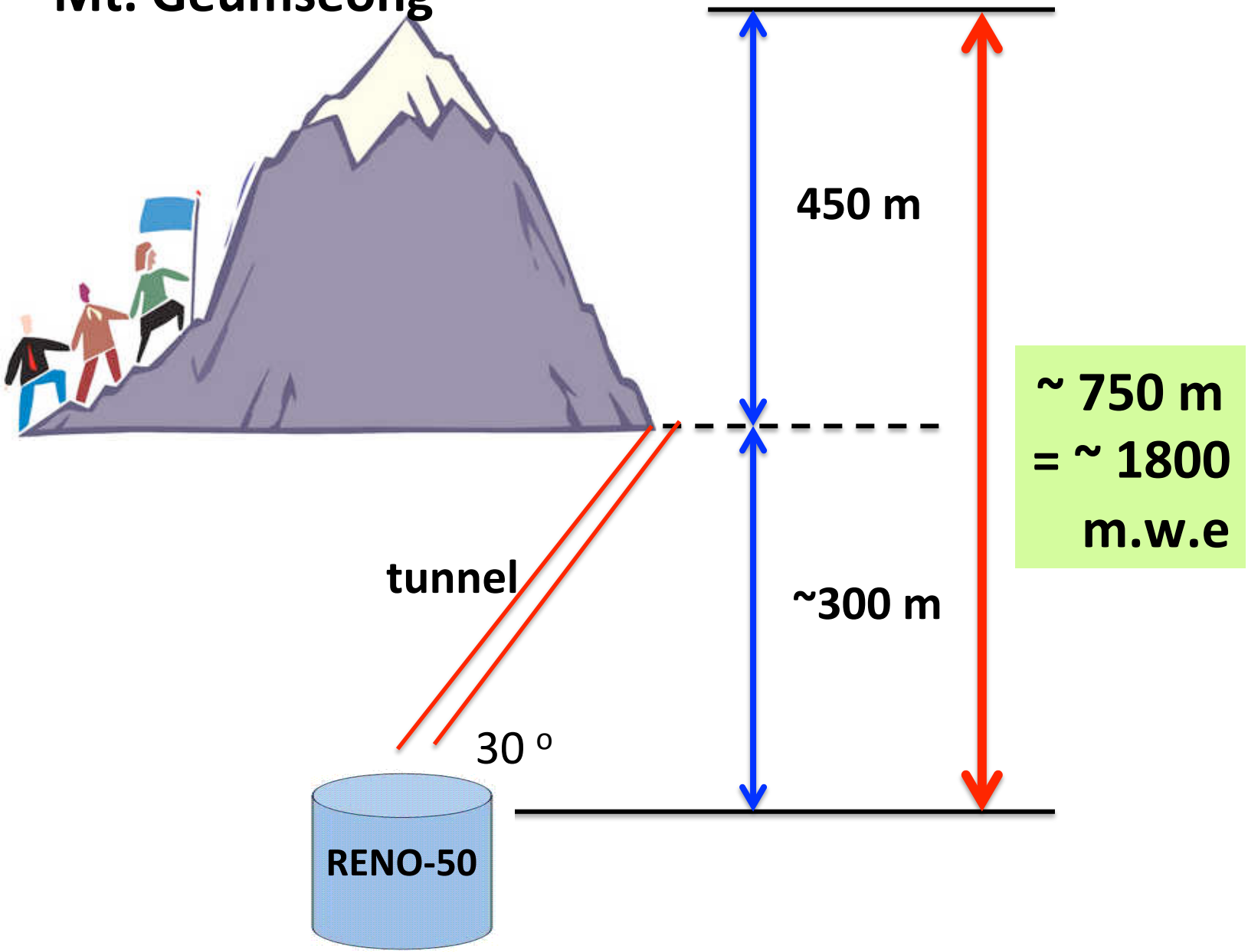
RENO-50

18 kton LS Detector
~47 km from YG reactors

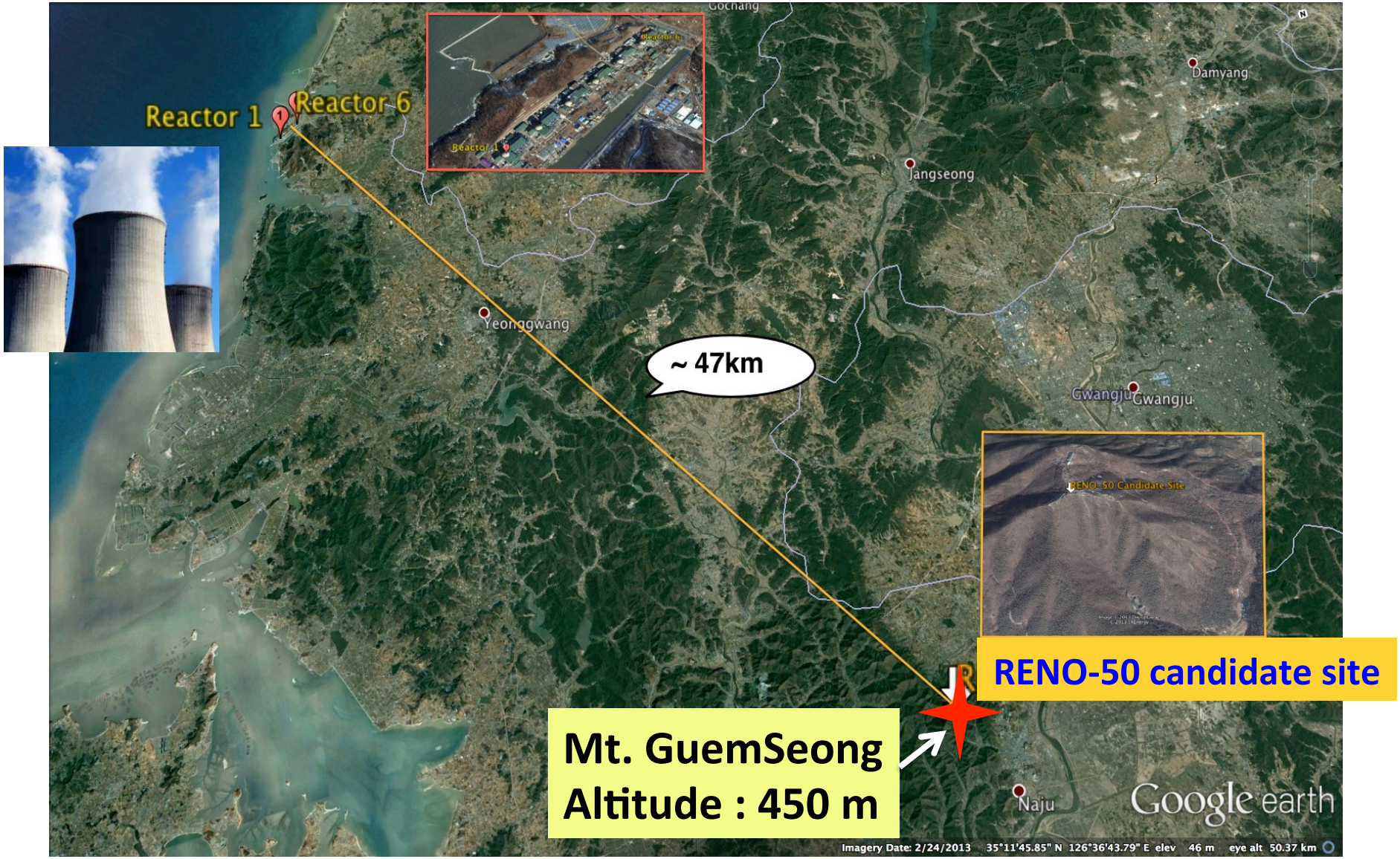
Mt. Guemseong (450 m)
~900 m.w.e. overburden

~10,000 events/year with oscillation

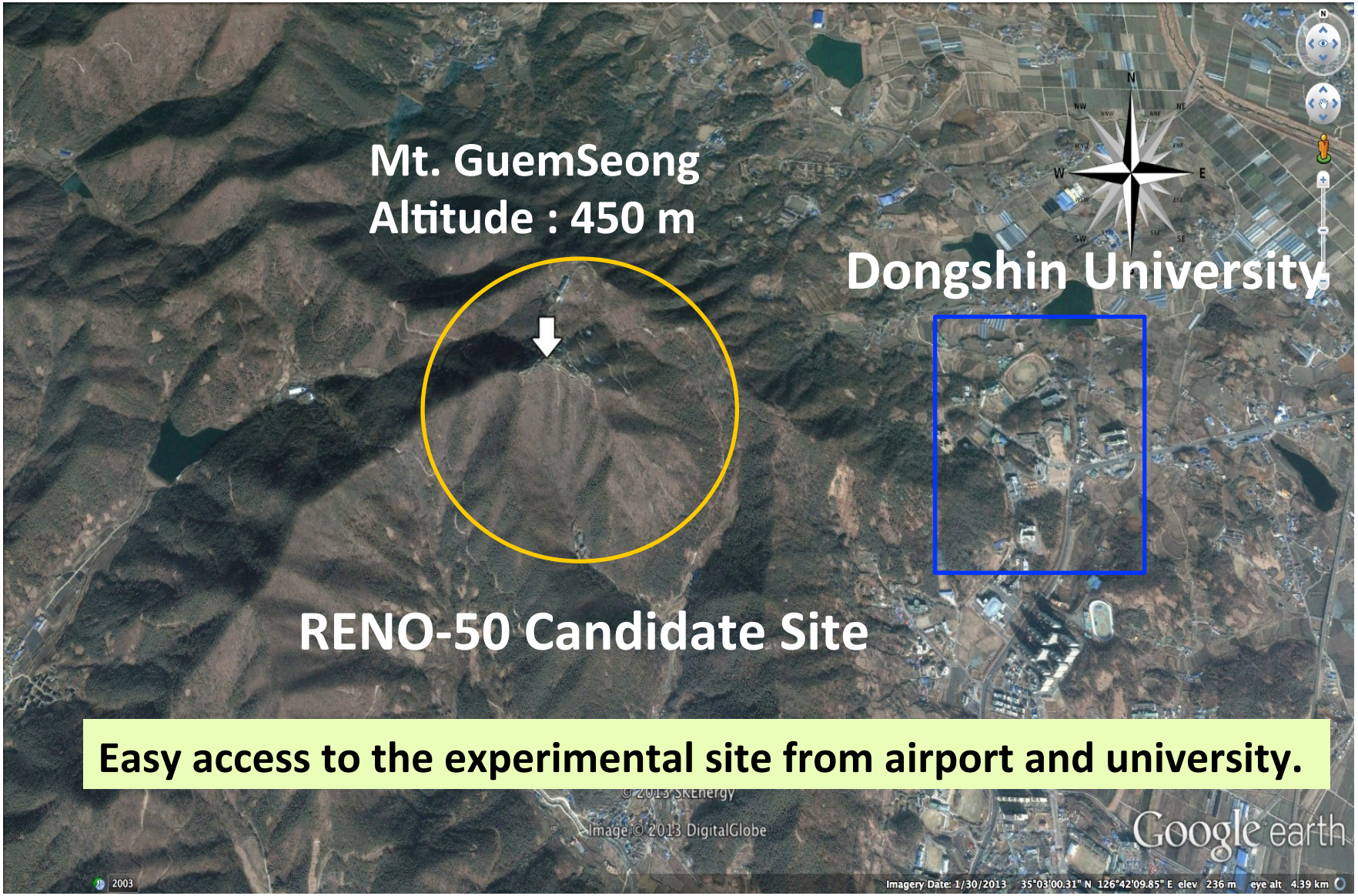
Mt. Geumseong



RENO-50 Candidate Site



RENO-50 Candidate Site



Easy access to the experimental site from airport and university.

Status of Funding and R&D

- An R&D funding (US $ 2M in 3 years, 2015~2017) is given by the Samsung Science & Technology Foundation.

- A proposal has been submitted to obtain construction funding.

  → **International Neutrino community's supports will greatly enhance our opportunities !**

- A domestic symposium and an international workshop were held in 2013 to discuss the feasibility and physics opportunities.

- R&D has just begun for LS, PMT, DAQ, MC and detector design, in order to prepare a Technical Design Report (TDR).

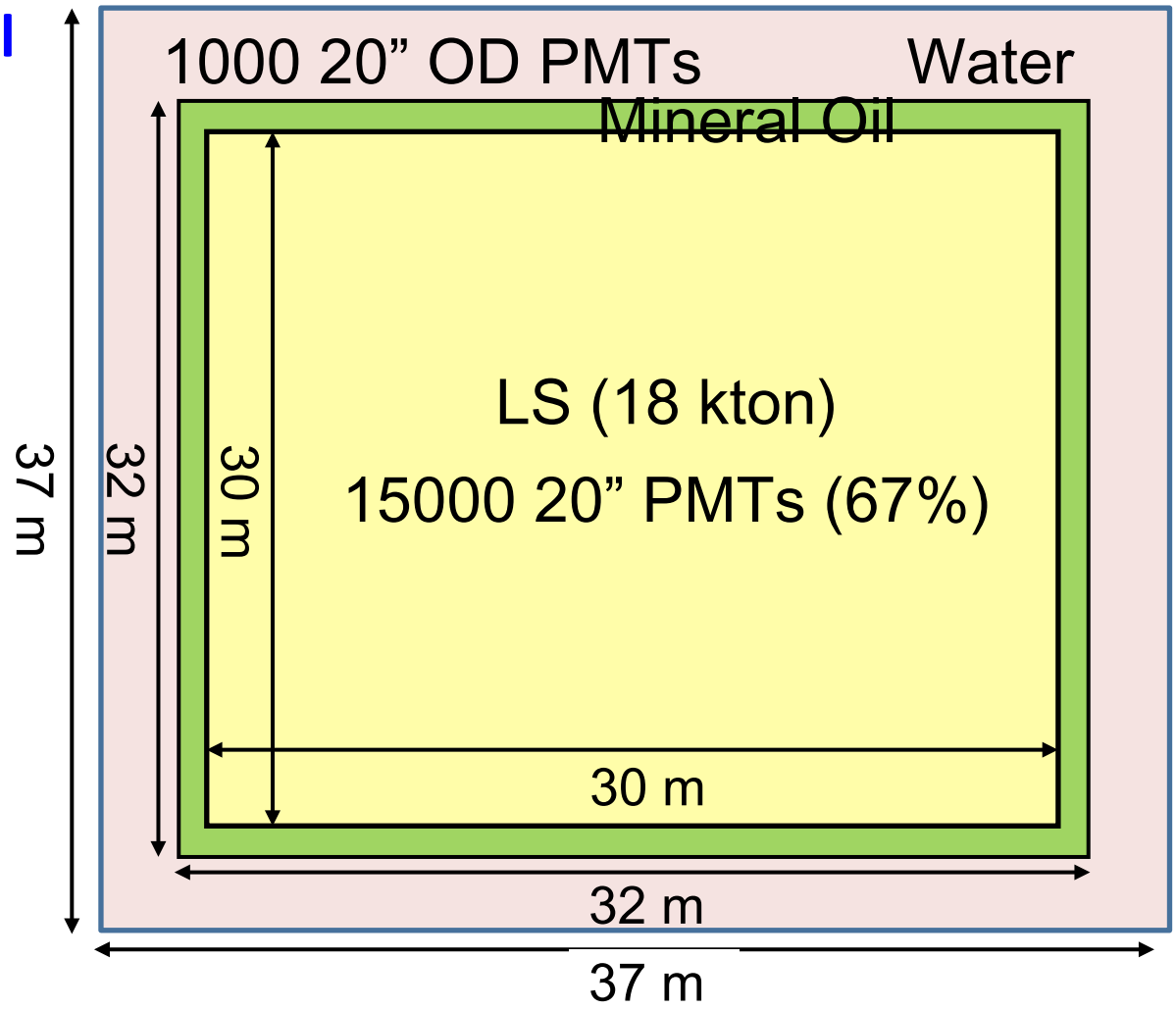
- International collaboration is expected to be formed.
  You are welcome to join us for R&D and detector construction!

International Workshop on RENO-50

Seoul, June 13-14, 2013

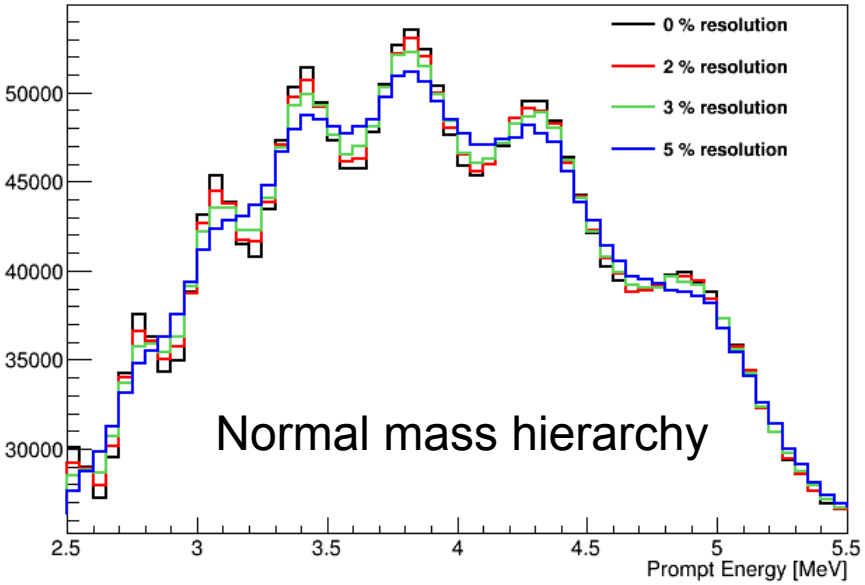
Conceptual Design of RENO-50 Detector

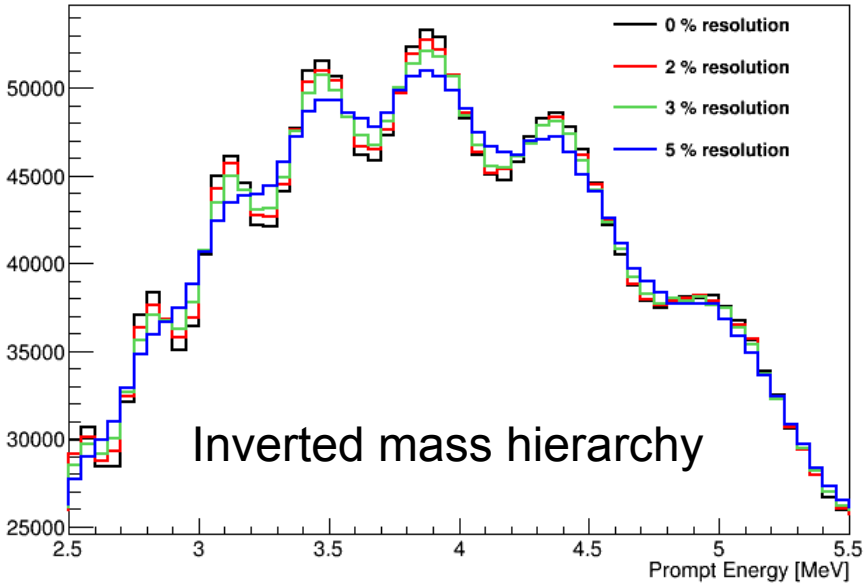
Cylindrical detector

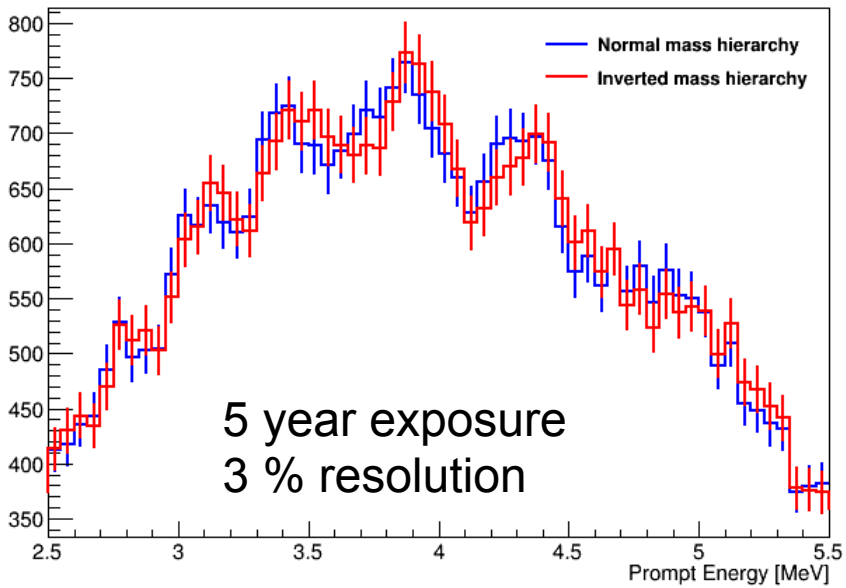


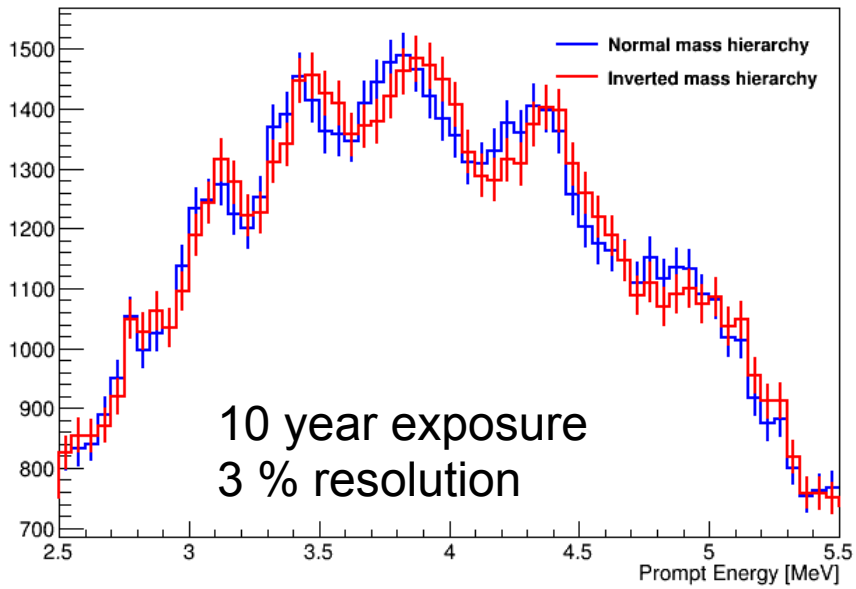
Energy Resolution for Mass Hierarchy

- 3 % energy resolution is need to distinguish NH and IH in 0.05 MeV/bin









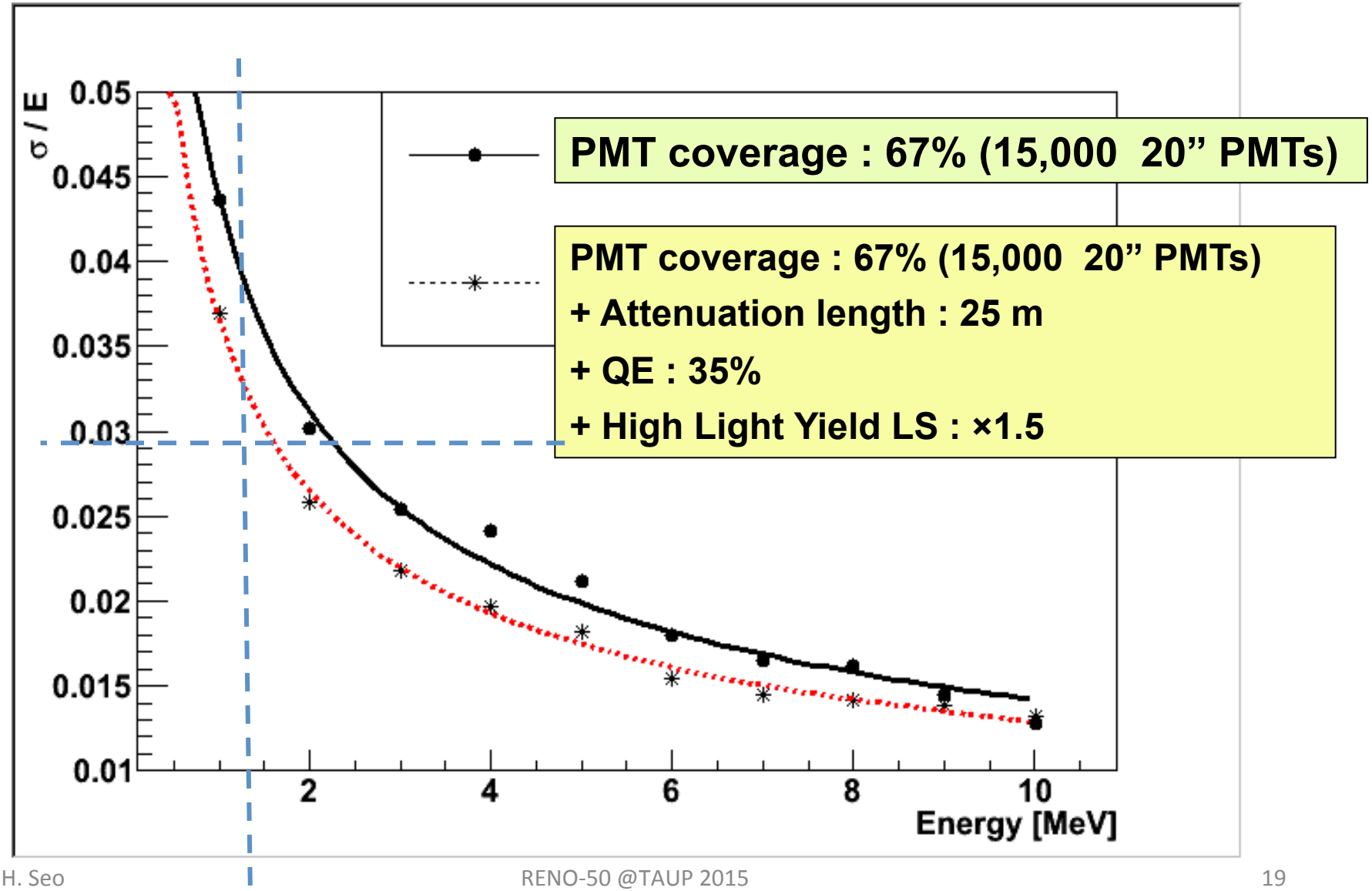
Technical Challenges

	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

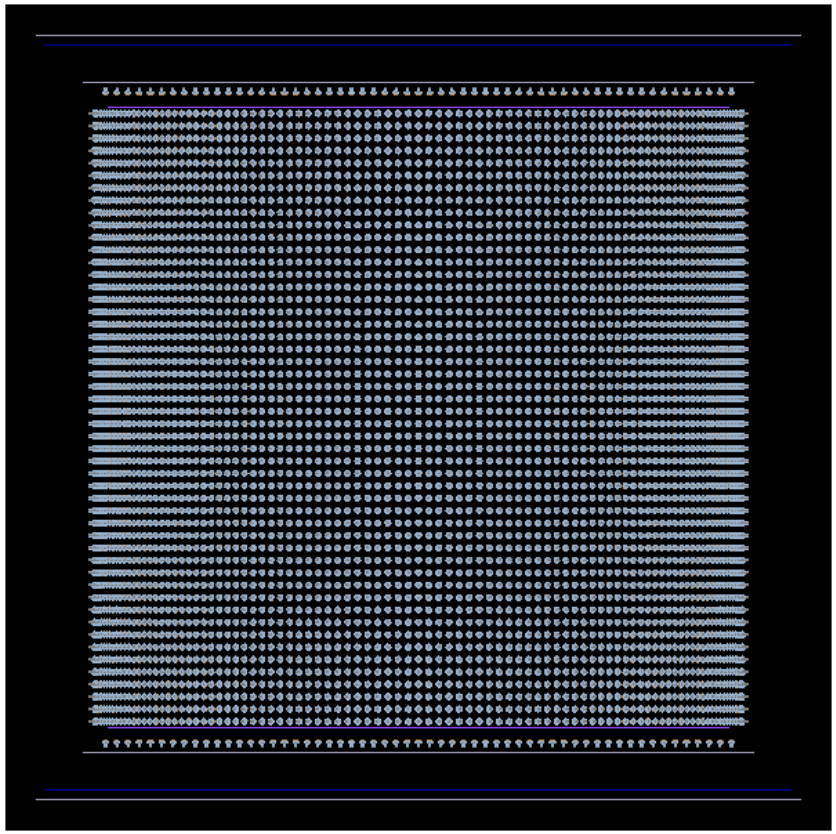
- R&D for 3% energy resolution :
  - High transparency LS : 15 m → 25 m (purification & better PPO)
  - Large photocathode coverage : 34% → 67% (15,000 20" PMT)
  - High QE PMT : 20% → 35% (Hamamatsu 20" HQE PMT)
  - High light yield LS : ×1.5 (1.5 g/ℓ PPO → 5 g/ℓ PPO)

→ **We need to improve further for 3% E resolution.**

Expected Energy Resolution



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

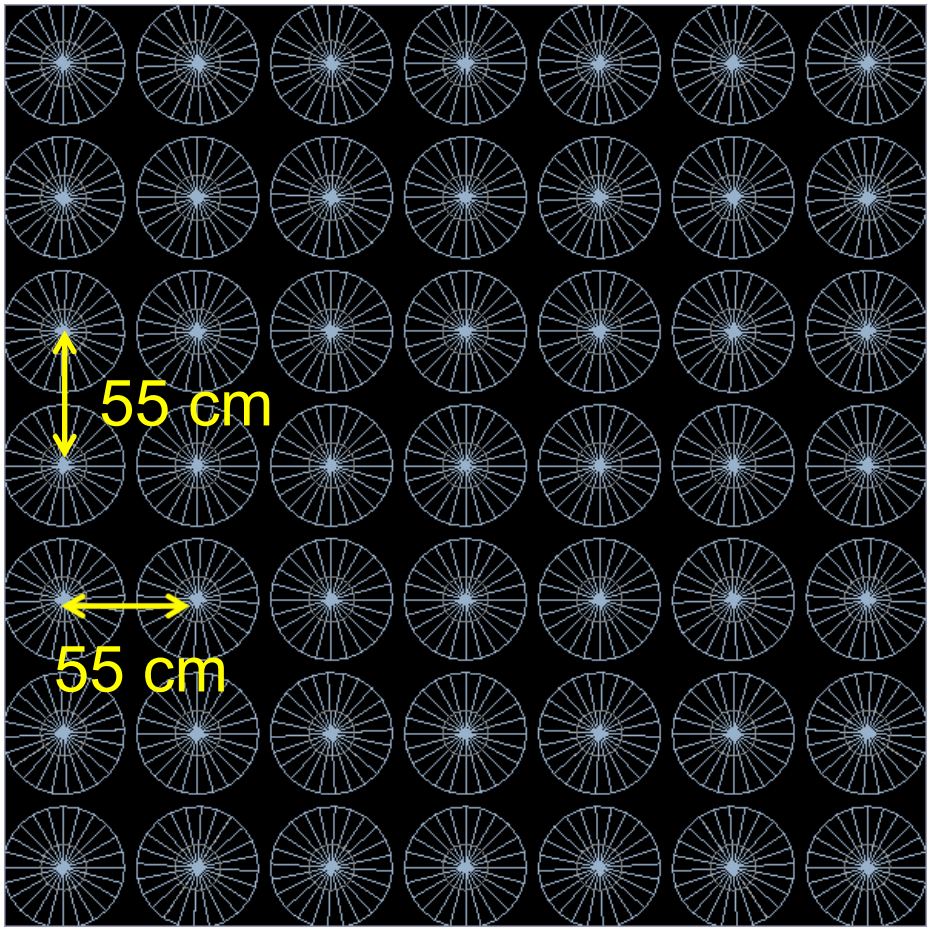
▪ PMT arrangement scheme.

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

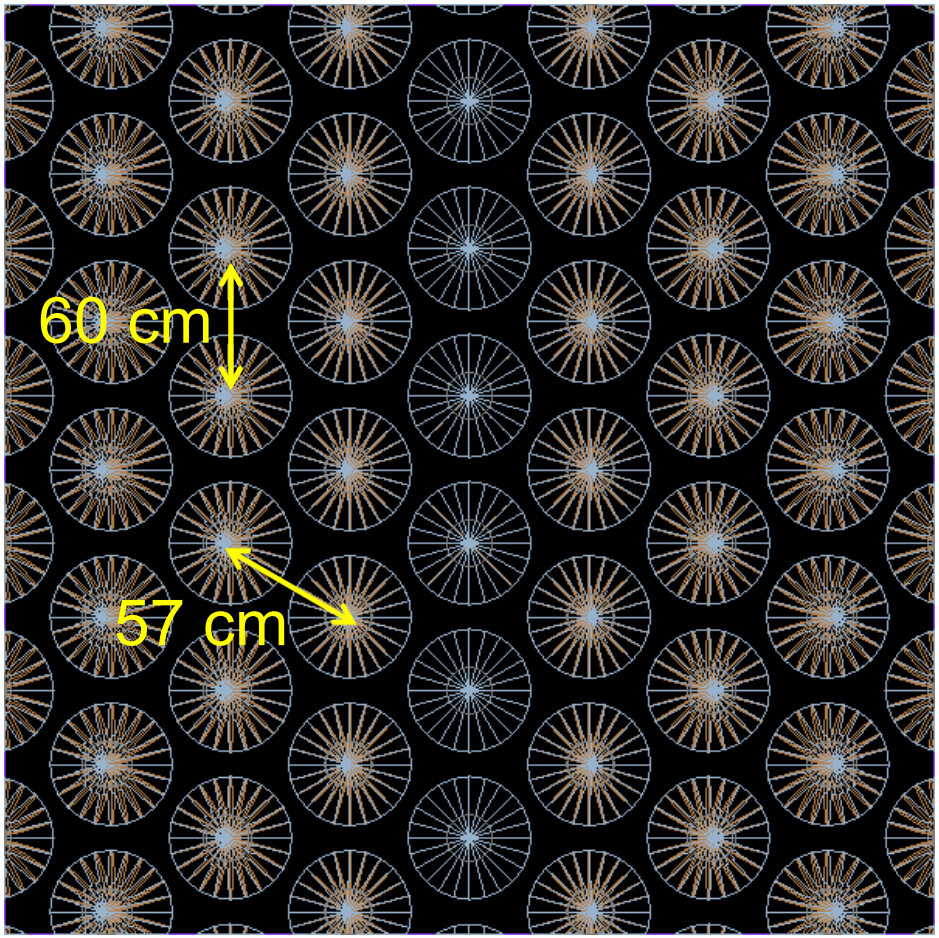
- Target : Acrylic, 30m*30m
- Buffer : Stainless-Steel, 32m*32m
- Veto : Concrete, 37m*37m

RENO-50 PMT Arrangement

Top & Bottom



Barrel

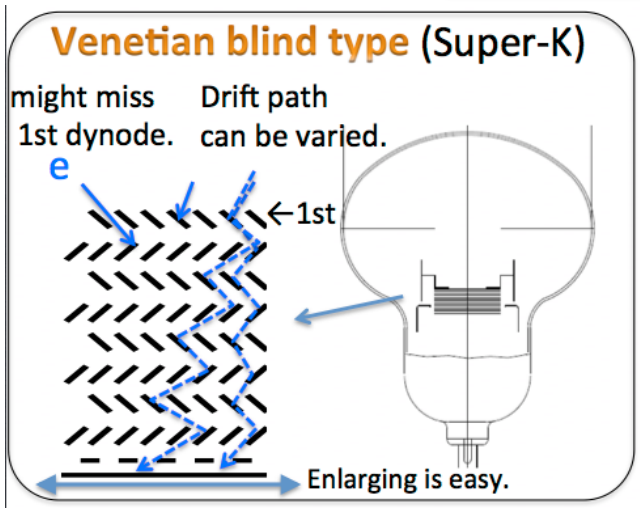


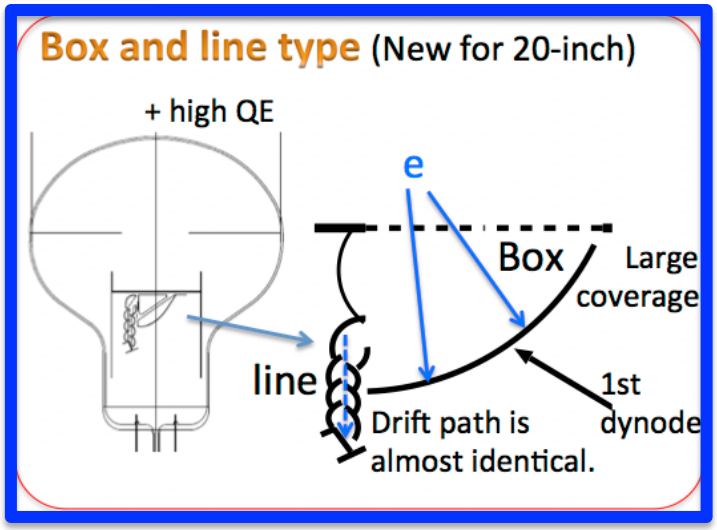
High QE PMTs

- **Use of high, 35%, quantum efficiency PMTs in development**

Hamamatsu HQE PMT R12860

→ **For RENO-50**





LS Purification Scheme

- **Develop efficient methods for mass purification of radioactivity in LS**

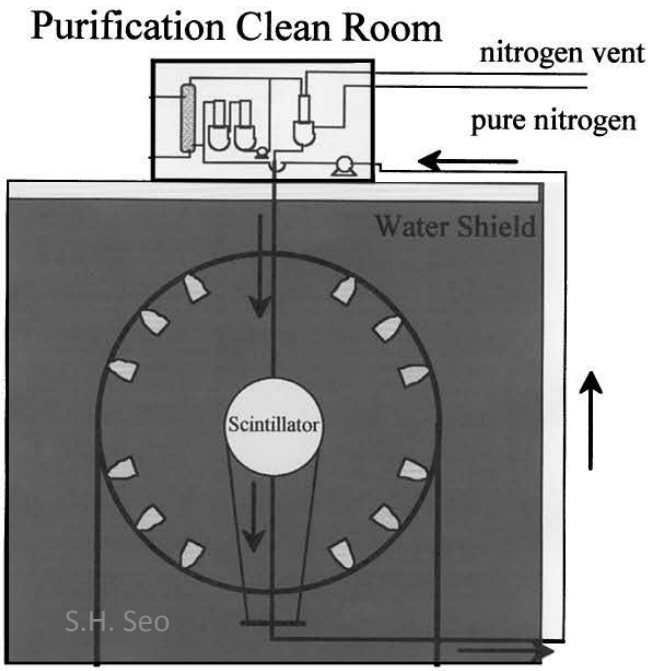
Radio-isotopes	Source	Typical concentration	Required concentration	Strategy for reduction
^{14}C	Cosmogenic bombardment of ^{14}N	$^{14}C/^{12}C \leq 10^{-12}$	$^{14}C/^{12}C \leq 10^{-18}$	**Use of LAB from petroleum derivative (old carbon)**
^{7}Be	Cosmogenic bombardment of ^{12}C	3×10^{-2} Bq/t-carbon	$<10^{-6}$ 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

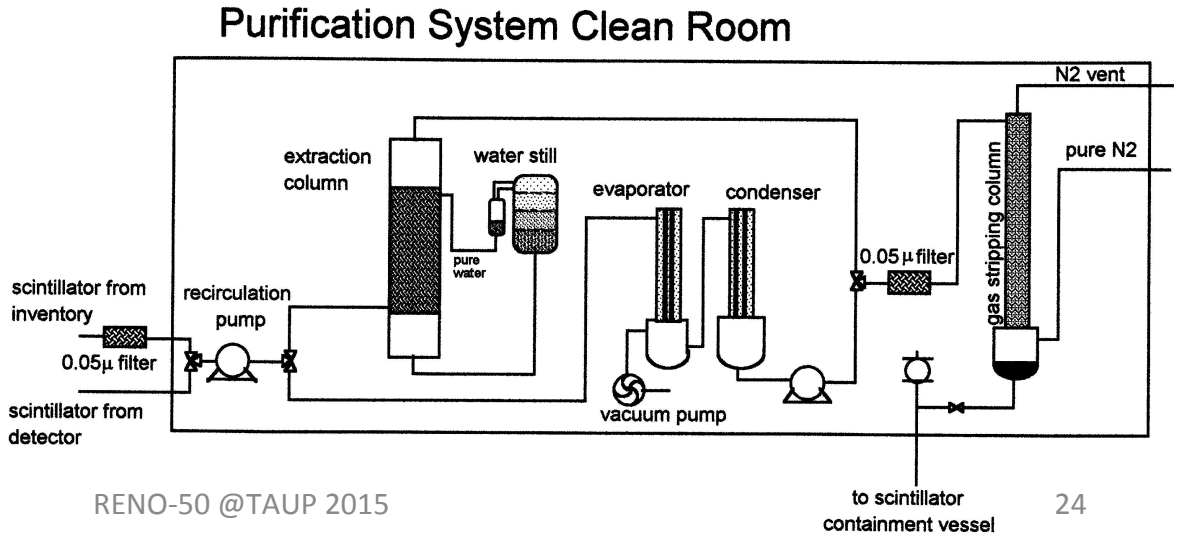
- Develop a **test purification facility of ~5 ton LS** and build a water shield tank of scintillation detector to measure radioactivity in LS

- 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)

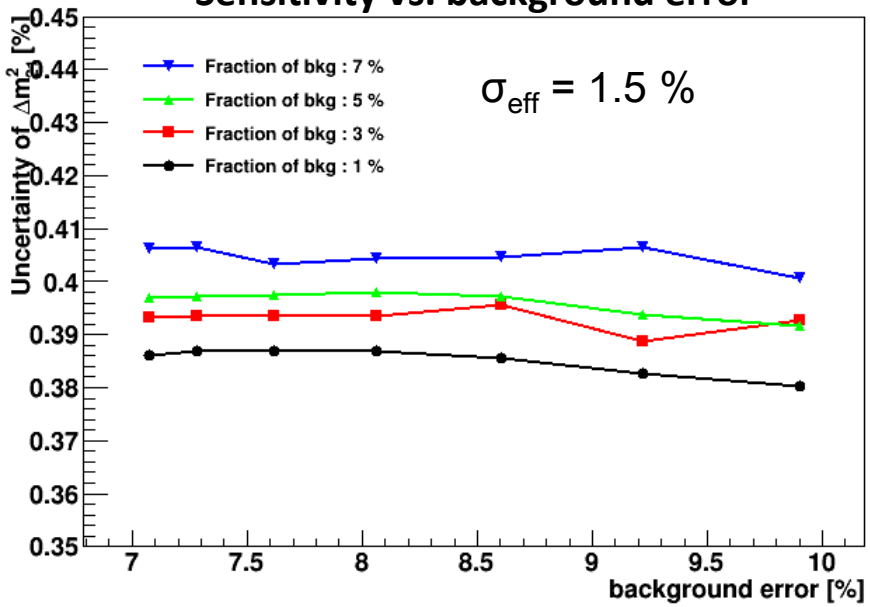


MC Study of Precise (<1 %) Determination of Mixing Parameters

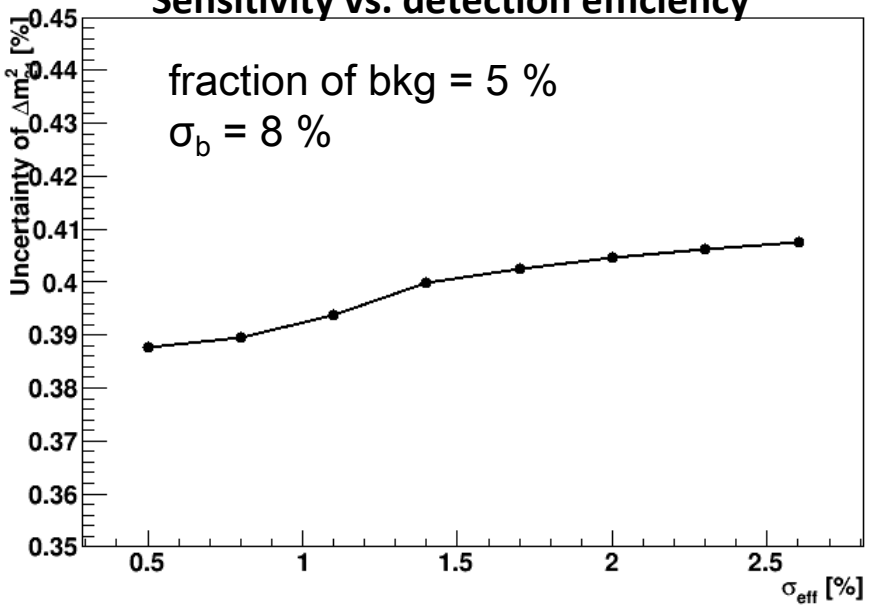
Effect of systematic error with 3 year exposure

Δm^2_{21}

Sensitivity vs. background error

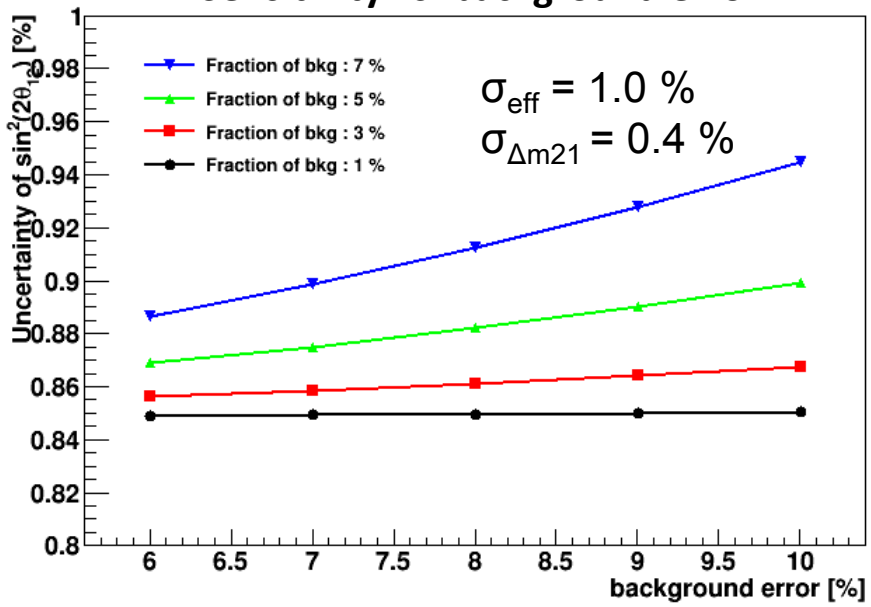


Sensitivity vs. detection efficiency

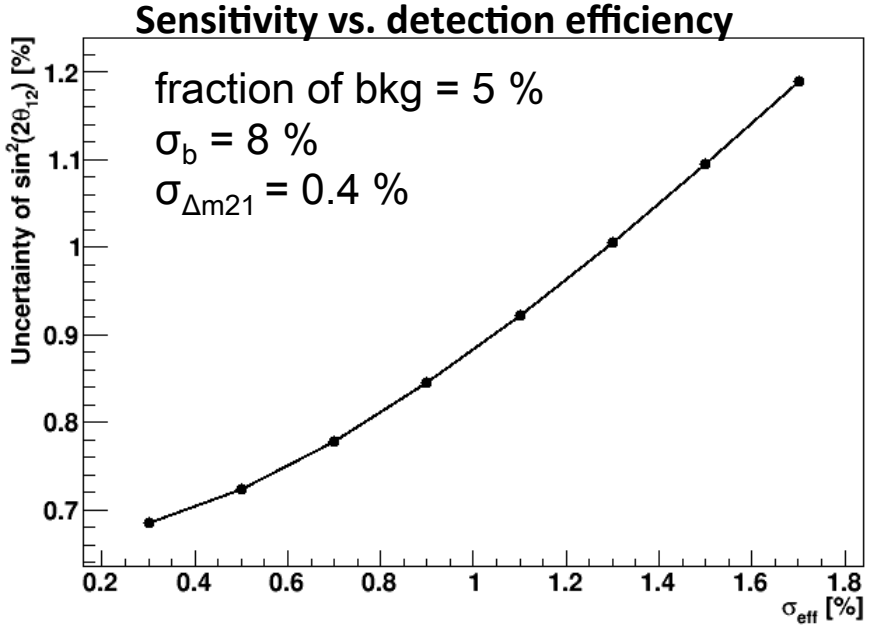


$\sin^2(2\theta_{12})$

Sensitivity vs. background error

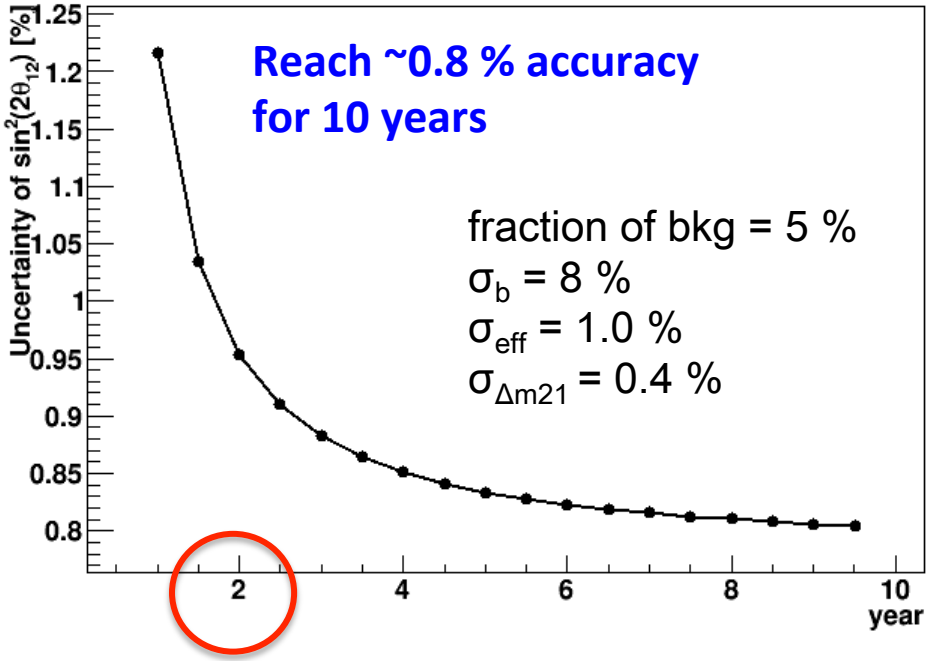


Sensitivity vs. detection efficiency

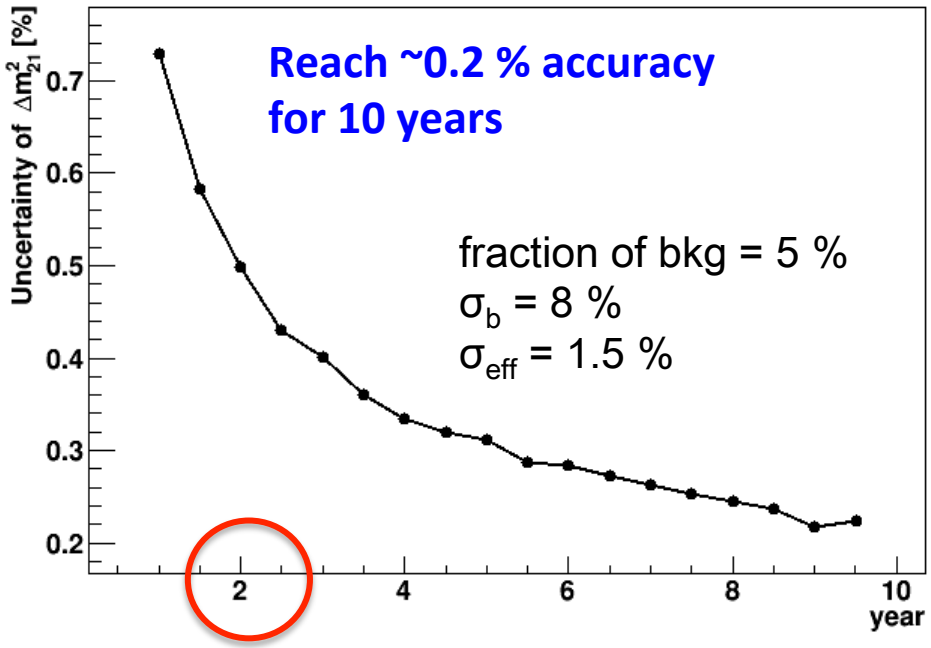


Sensitivity vs. year

$\sin^2(2\theta_{12})$



Δm_{21}^2

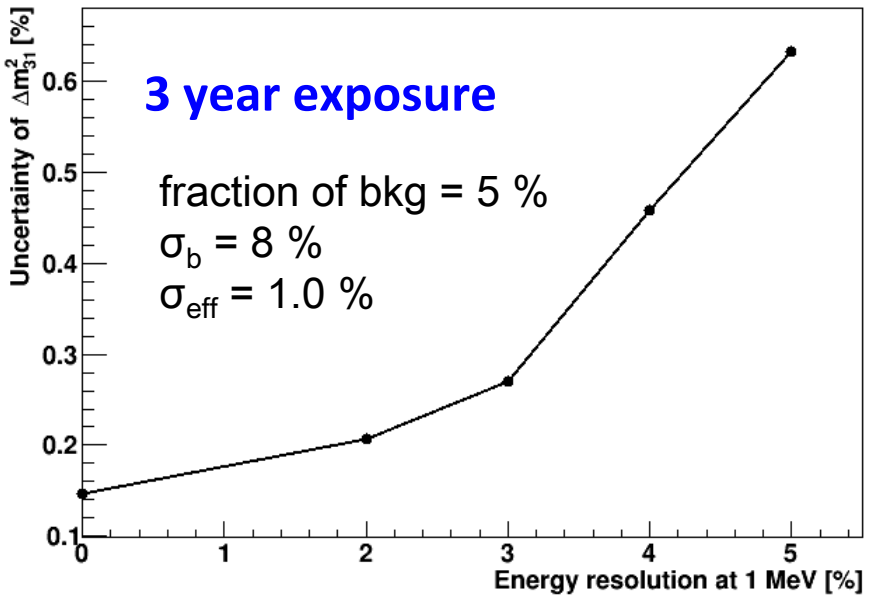


with 3 % energy resolution at 1 MeV

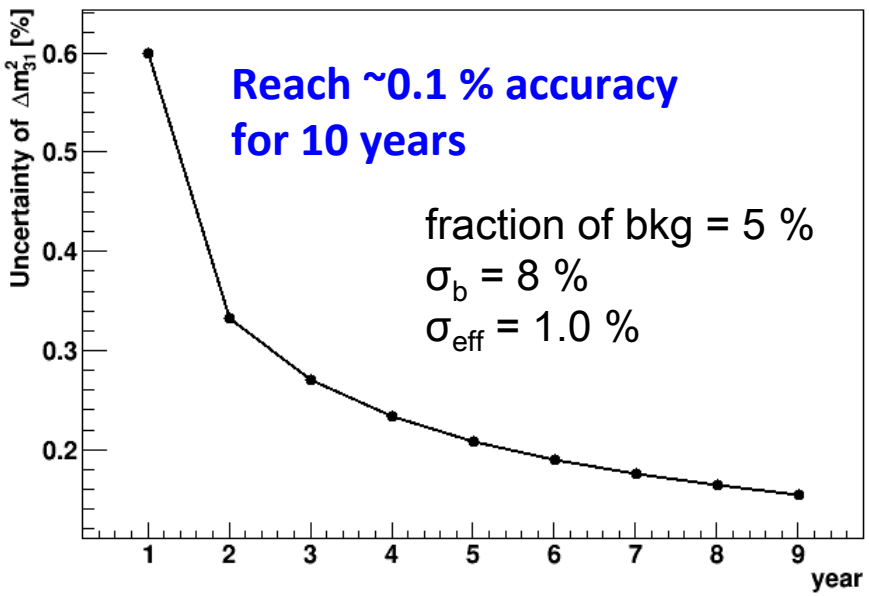
Sensitivity for $|\Delta m_{ee}^2|$

$|\Delta m_{ee}^2|$

Sensitivity vs. resolution



Sensitivity vs. year



with 3 % energy resolution at 1 MeV

Schedule

- 2015 : Group organization
  Detector simulation & design
  Geological survey
- 2016 ~ 2017 : 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
- 2018 ~ 2020 : Detector construction
- 2021 ~ : Data taking & analysis

RENO-50 R&D has started

- ✓ Clean room installation (done)
- ✓ HPGe detector purchase (done)
- ✓ 20 inch high QE PMT purchase (done) and test (soon)
- ✓ Optical property measurement device purchase (done)
  -- construction of LS attenuation length measurement system
- ✓ Radio activity measurement & reduction plan for LS, PMT (soon)

Clean room

RENO-50 R&D Collaboration

The 3% energy resolution is very challenging to achieve.
→ Therefore R&D becomes very important.

You are very welcome to join us for the R&D efforts !

There are big opportunities here.

Thank you very much for your attention!

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%	$13\times6\times\phi_0$ [6 reactors]	18 kton	~ 0.3%	< 1%
KamLAND (180 km)	40%	$0.6\times55\times\phi_0$ [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 ~10 year data