RENO-50

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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 $\theta_{12}$, $\Delta m^2_{21}$ and $\Delta m^2_{ee}$
  - Neutrino astronomy, Geo $\nu$, sterile $\nu$ search, etc.

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

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

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RENO-50 @TAUP 2015
Physics Goals with RENO-50

- Determination of neutrino mass hierarchy (very challenging)
  \[\sim 3 \sigma\] sensitivity from \(~10\) years of data

- Precise measurement of \(\theta_{12}\), \(\Delta m^2_{21}\) and \(\Delta m^2_{ee}\)

  \[
  \frac{\delta \sin^2 \theta_{12}}{\sin^2 \theta_{12}} < 1.0\% (1\sigma) \quad \frac{\delta \Delta m^2_{21}}{\Delta m^2_{21}} < 1.0\% (1\sigma) \quad \frac{\delta \Delta m^2_{ee}}{\Delta m^2_{ee}} < 1.0\% (1\sigma)
  \]

  \(\leftrightarrow\) 5.4\%, 2.4\%, 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 $\nu$ and anti-$\nu$ are produced from core collapsing SN. (99% energy of the collapse is carried away by these $\nu$).
- SN explosion mechanism
- $\Rightarrow$ ~5600 events @ 8 kpc in RENO-50
  (A few core-collapse SN per century in our galaxy.)

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

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:
  \[ \nu(\bar{\nu}) + ^{12}\text{C} \rightarrow \nu(\bar{\nu}) + ^{12}\text{C}^* \]
- ~240 events from CC interaction:
  \[ \bar{\nu}_e + ^{12}\text{C} \rightarrow ^{12}\text{B} + e^+ \]
  \[ \nu_e + ^{12}\text{C} \rightarrow ^{12}\text{N} + e^- \]
- ~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
Electron anti-neutrinos from $^{238}$U, $^{232}$Th, & $^{40}$K inside Earth interior.

To reveal the mechanism inside the Earth interior.

$\sim$300 geo neutrinos/year in RENO-50

See A. Ianni & M. Baldoncini talks.
Sterile Neutrino Search (I)

- Super-light ($\sim10^{-5}$ eV$^2$) sterile $\nu$ search @ ~50 km with reactor $\nu$. arXiv: 1308.2823

- Neutrino oscillometry:
  - using strong (anti-) $\nu$ 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)

\[ p + ^9 Be \rightarrow ^8 Li + 2p \]

Example: \(^8 Li\) decay

\[^8 Li \rightarrow ^8 Be + e^- + \bar{\nu}_e\]

Very short baseline
Sterile neutrino search

\[ 6 \text{ MeV} \]

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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

~750 m = ~1800 m.w.e

450 m

~300 m

30°

tunnel

RENO-50
Mt. GuemSeong
Altitude: 450 m

RENO-50 Candidate Site
RENO-50 Candidate Site

Mt. GuemSeong
Altitude : 450 m

Dongshin University

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.

  \[ \text{International Neutrino community’s supports will greatly enhance our opportunities!} \]

- 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!
Conceptual Design of RENO-50 Detector

Cylindrical detector

1000 20” OD PMTs

Mineral Oil

Water

LS (18 kton)

15000 20” PMTs (67%)

37 m

32 m

30 m

32 m

30 m
3 % energy resolution is need to distinguish NH and IH in 0.05 MeV/bin.
## Technical Challenges

<table>
<thead>
<tr>
<th></th>
<th>KamLAND</th>
<th>RENO-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS mass</td>
<td>~1 kt</td>
<td>18 kt</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>6.5%/√E</td>
<td>3%/√E</td>
</tr>
<tr>
<td>Light yield</td>
<td>500 p.e./MeV</td>
<td>&gt; 1000 p.e./MeV</td>
</tr>
<tr>
<td>LS attenuation length</td>
<td>~16 m</td>
<td>~25 m</td>
</tr>
</tbody>
</table>

- 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: \[\times 1.5\] (1.5 g/ℓ PPO → 5 g/ℓ PPO)

→ We need to improve further for 3% E resolution.
Expected Energy Resolution

- PMT coverage: 67% (15,000 20” PMTs)
- Attenuation length: 25 m
- QE: 35%
- High Light Yield LS: ×1.5
• 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

- 55 cm
- 55 cm

Barrel

- 60 cm
- 57 cm

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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**

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

From a Borexino paper
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

MC Study of Precise (<1 %) Determination of Mixing Parameters
Effect of systematic error with 3 year exposure

### Sensitivity vs. background error

- **$\Delta m^2_{21}$**
  - $\sigma_{eff} = 1.5\%$

- **$\sin^2(2\theta_{12})$**
  - $\sigma_{eff} = 1.0\%$
  - $\sigma_{\Delta m_{21}} = 0.4\%$

### Sensitivity vs. detection efficiency

- **$\Delta m^2_{21}$**
  - Fraction of bkg: 7% (blue)
  - Fraction of bkg: 5% (green)
  - Fraction of bkg: 3% (red)
  - Fraction of bkg: 1% (black)
  - fraction of bkg = 5 %
  - $\sigma_b = 8\%$

- **$\sin^2(2\theta_{12})$**
  - fraction of bkg = 5 %
  - $\sigma_b = 8\%$
  - $\sigma_{\Delta m_{21}} = 0.4\%$
Sensitivity vs. year

\[ \sin^2(2\theta_{12}) \]

Reach \( \sim 0.8 \% \) accuracy for 10 years

- fraction of bkg = 5 %
- \( \sigma_b = 8 \% \)
- \( \sigma_{\text{eff}} = 1.0 \% \)
- \( \sigma_{\Delta m^2_{21}} = 0.4 \% \)

\[ \Delta m^2_{21} \]

Reach \( \sim 0.2 \% \) accuracy for 10 years

- fraction of bkg = 5 %
- \( \sigma_b = 8 \% \)
- \( \sigma_{\text{eff}} = 1.5 \% \)

with 3 % energy resolution at 1 MeV
Sensitivity for $|\Delta m_{ee}^2|$ 

**Sensitivity vs. resolution**

- 3 year exposure
- Fraction of bkg = 5 %
- $\sigma_b = 8 \%$
- $\sigma_{\text{eff}} = 1.0 \%$

**Sensitivity vs. year**

- Reach $\sim 0.1 \%$ accuracy for 10 years
- Fraction of bkg = 5 %
- $\sigma_b = 8 \%$
- $\sigma_{\text{eff}} = 1.0 \%$

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)
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

<table>
<thead>
<tr>
<th></th>
<th>Oscillation Reduction</th>
<th>Reactor Neutrino Flux</th>
<th>Detector Size</th>
<th>Syst. Error on ν Flux</th>
<th>Error on sin²θ_{12}</th>
</tr>
</thead>
<tbody>
<tr>
<td>RENO-50 (50 km)</td>
<td>80%</td>
<td>13×6×ϕ₀ [6 reactors]</td>
<td>18 kton</td>
<td>~ 0.3%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>KamLAND (180 km)</td>
<td>40%</td>
<td>0.6×55×ϕ₀ [55 reactors]</td>
<td>1 kton</td>
<td>3%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Figure of Merit</td>
<td>×2</td>
<td>×2.4</td>
<td>×18</td>
<td>×10</td>
<td></td>
</tr>
</tbody>
</table>

(50 km / 180 km)² ≈ 13

- **Observed Reactor Neutrino Rate**
  - RENO-50: ~ 15 events/day
  - KamLAND: ~ 1 event/day

**Determination of mass ordering:**
~ 3σ with ~10 year data