Introduction to RENO-50

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RENO-50
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Korea

Outline

- Short general introduction
- Energy resolution Vs. significance on M.H.
- Precise measurement of osc. parameters
- RENO-50 detector design concept & site
- RENO-50 Physics

Note: RENO-50 MC results and site presented in this talk are discussed more in detail in the last session today.

Session 4:

- 16:30-17:00: Mass hierarchy using medium baseline detector (30): Y. Takaesu (KIAS/SNU)
- 17:00-17:30: Simulation study of RENO-50 (30): J.S. Park (SNU)
- 17:00-17:45: RENO-50 Site (15): J. Choi (DSU)

Measurements of θ_{13}

Future

Mar. 2013	**RENO**	$\sin^2 2\theta_{13} = 0.100 \pm 0.010(stat.) \pm 0.015(syst.)$	5.6 σ
June. 2012	Daya Bay	$\sin^2 2\theta_{13} = 0.089 \pm 0.010(stat.) \pm 0.005(syst.)$	7.7 σ
June. 2012	Double Chooz	$\sin^2 2\theta_{13} = 0.109 \pm 0.030(stat.) \pm 0.025(syst.)$	2.8 σ
Apr. 2012	**RENO**	$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat.) \pm 0.019(syst.)$	4.9 σ
Mar. 2012	Daya Bay	$\sin^2 2\theta_{13} = 0.092 \pm 0.016(stat.) \pm 0.005(syst.)$	5.2 σ

Past

Chooz, Palo Verde, MINOS, T2K, Double Chooz

So, What Next ?

$\sin^2 2\theta_{13} \sim 0.1$

- Relatively large value of θ_{13} allows to explore:

➢ <u>Mass hierarchy:</u>

-- reactor: Daya Bay II, RENO-50

-- atmospheric: PINGU, INO, Hyper-K

-- accelerator: T2K, NoVa, LAGUNA

➢ <u>neutrino CP violation phase (δ):</u>

-- reactor + accelerator

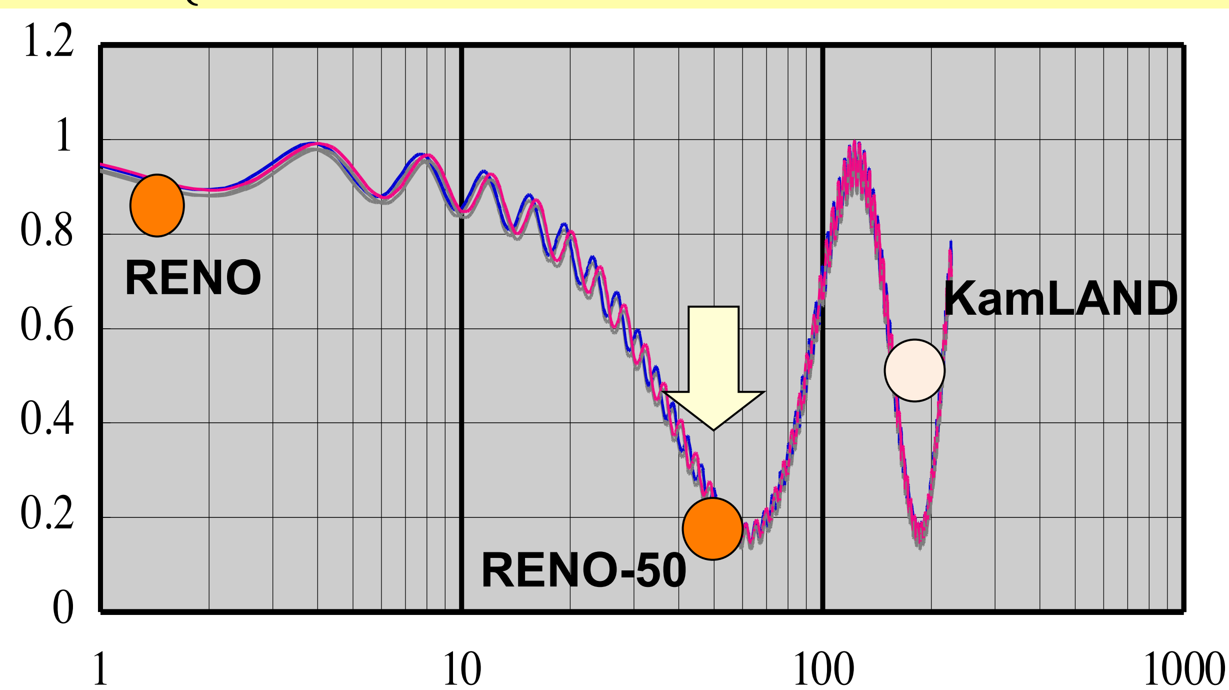
-- very long baseline: LBNE, LBNO, INO, Hyper-K, LAGUNA

Interesting ν physics ahead !

RENO-50

◆ 10 kton (default) liquid scintillator detector at ~ 50 km.

$$P_R(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \left\{ \begin{array}{l} \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21} \\ +\sin^2 2\theta_{13}\sin^2\theta_{12}\left(\cos 2\Delta_{31}\sin^2\Delta_{21} - \frac{1}{2}\sin 2\Delta_{31}\sin 2\Delta_{21}\right) \end{array} \right\}$$



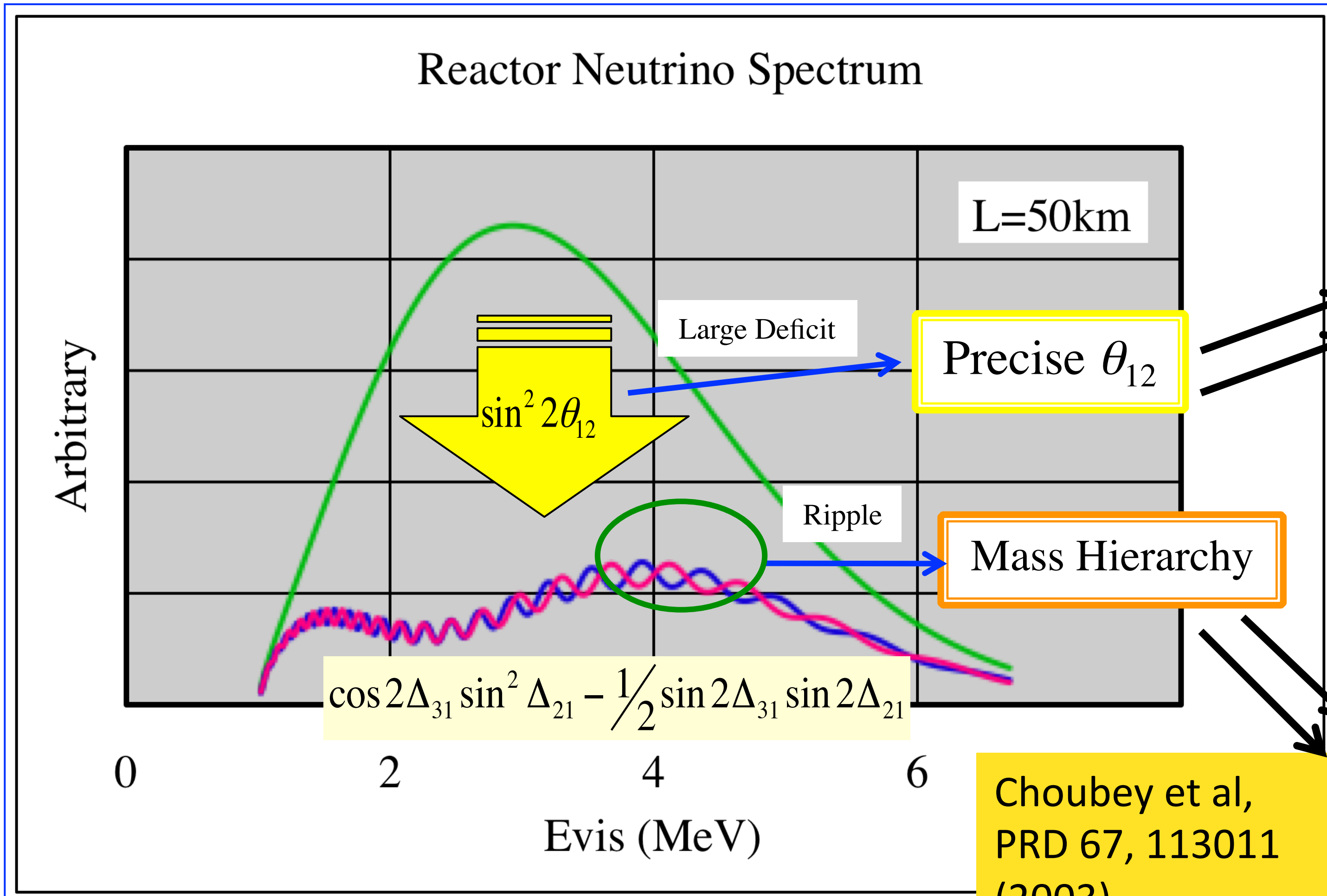
1st Δm^2_{21} nearly Maximum (L~50km) ;

precise value of θ_{12} & Δm^2_{21} + mass hierarchy (Δm^2_{31})

Reactor ν spectrum at 50 km

$$P_R(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \left\{ \begin{aligned} &\cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21} \\ &+ \sin^2 2\theta_{13}\sin^2\theta_{12}\left(\cos 2\Delta_{31}\sin^2\Delta_{21} - \tfrac{1}{2}\sin 2\Delta_{31}\sin 2\Delta_{21}\right) \end{aligned} \right\}$$

→ Akhmedov et al, JHEP 04, 078 (2004)



Bandyopadhyay et al, PRD 67, 113011 (2003)

Bandyopadhyay et al, PRD 72, 033013 (2005)

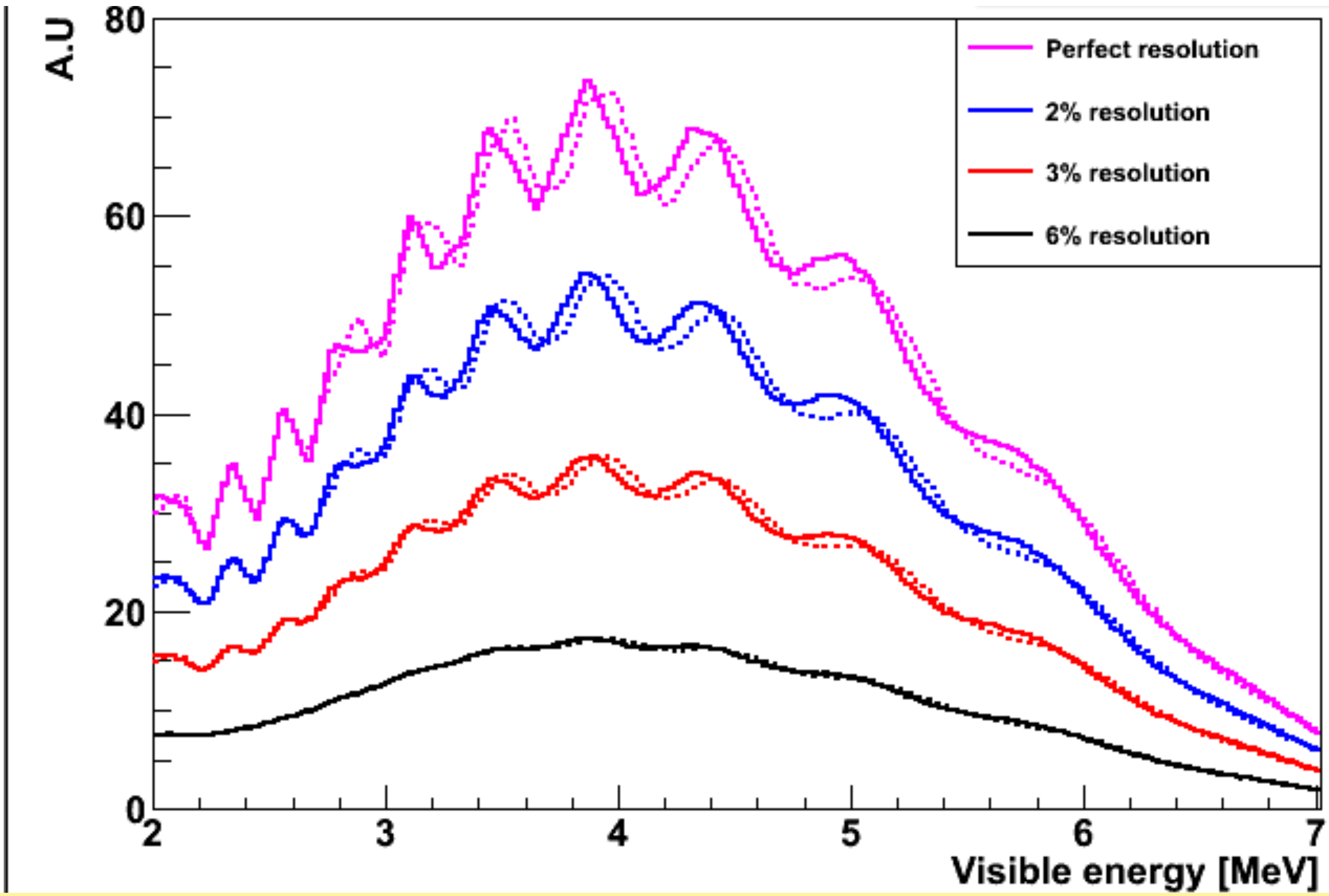
Petcov & Piai PLB 533, 94 (2002)

Choubey et al, PRD 67, 113011 (2003)

MC: RENO-50

Solid line : Normal hierarchy
Dashed line : Inverted hierarchy

See talk by J.S. Park



◆ Better than 3% energy resolution is required.

Energy resolution

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E/MeV}} \propto \frac{1}{\sqrt{N_{pe}}}$$

Better energy resolution (a) for the increased N_{pe}.

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E/MeV}} + b$$

b: energy independent term.

caused by random processes,
such as,
PMT noise,
thermal noise,
electronic noise

χ^2 Analysis for M.H.

$$\chi^2 = \sum_k \frac{\left(N_k^{obs} - N_k^{theory}\right)^2}{\sigma_k^2}$$

S. Choubey et.al. hep-ph/030601
M. Batygov et.al. arXiv: 0810.2580
P. Ghoshal et.al. arXiv: 1011.1646

- For correct mass hierarchy:
  → smaller χ^2_{min} value

$$\Delta\chi^2 = \chi^2_{min}(IH) - \chi^2_{min}(NH)$$

→ The bigger $\Delta\chi^2$ value, the better discrimination of mass hierarchy.

$\sqrt{\Delta\chi^2} \neq N \cdot \sigma$ significance

(→ See talk by J. Evslin)

E. Ciuffoli et al. arXiv:1305.5150

RENO-50: 10 kton, 5 yrs, 16.5 GW_{th}

See talk by Y.Takaesu

Energy resolution	$\Delta\chi^2$ $(\chi^2_{IH} - \chi^2_{NH})$	significance Frequentist	significance Bayesian
a = 6%, b = 1%	0.27	1.0 σ	0.72 σ
b=0.5%	0.30	1.0 σ	0.73 σ
b = 0%	0.31	1.1 σ	0.74 σ
a = 3%, b = 1%	4.8	2.3 σ	1.6 σ
b=0.5%	6.6	2.8 σ	2.1 σ
b = 0%	7.3	2.9 σ	2.2 σ
a = 2%, b = 1%	14	3.9 σ	3.3 σ
b=0.5%	19	4.5 σ	4.0 σ
b = 0%	22	4.8 σ	4.3 σ

To achieve better E resolution

✧ **Default RENO-50 detector:**

--PMT coverage: 24 % (15,000 PMTs)
--Atten. Length: 12.45 m
--PMT QE: 24 %

$$\frac{6.8\%}{\sqrt{E/MeV}}$$

- Increasing PMT coverage (x5/3): 6.8 → 5.8 %
- Increasing attenuation length (x2): 6.8 → 5.9 %
- Increasing PMT QE (x1.5): 6.8 → 6.7 %

→ Combined result: ~ 4.5 %/sqrt(E/MeV)
→ Increasing light yield (x2):
~ 3.3 %/sqrt(E/MeV)

See talk by J.S. Park

Precise measurements of ν Osc. Param.

1. Allow more precise measurements of other mixing parameters.

2. More precise measurement of PMNS matrix (3 flavors) will help to constrain a new physics, such as, sterile neutrinos, CP violation etc…

Measurements of ν Osc. Params @ 50 km

	PDG 2012	RENO-50 10 kton, 5 yrs a = 6%, b = 1%
Δm_{21}^2	2.6 %	< 0.4 %
$\sin^2(2\theta_{12})$	2.8 %	< 0.4 %
Δm_{31}^2	4.3 %	< 0.8 %

See talk by Y.Takaesu

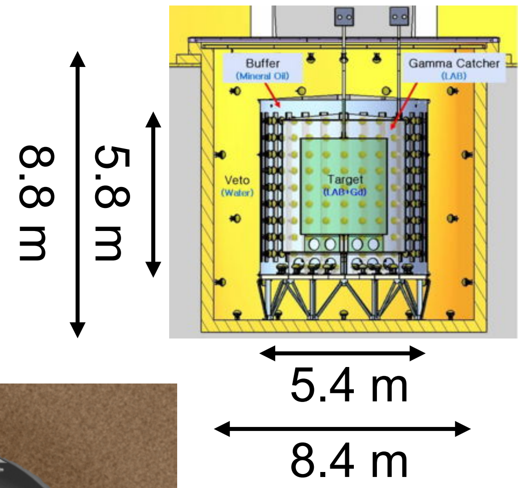
for known mass hierarchy for Δm_{31}^2 case

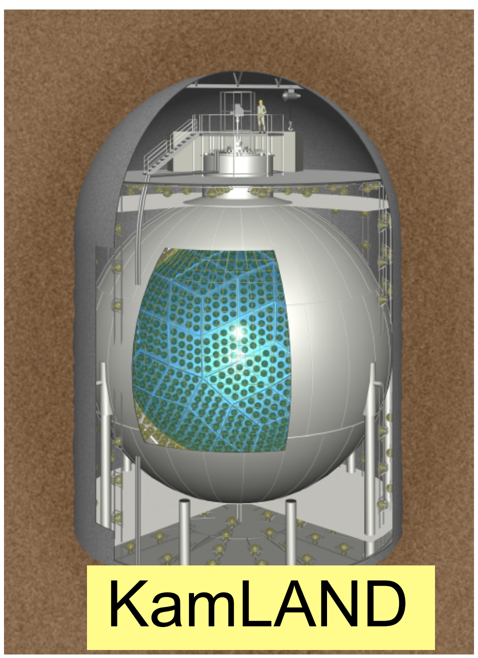
◆ Only Δm_{31}^2 is sensitive to the E resolution and becomes 0.4 % level accuracy at 3 % resolution.

RENO-50 Detector Concept

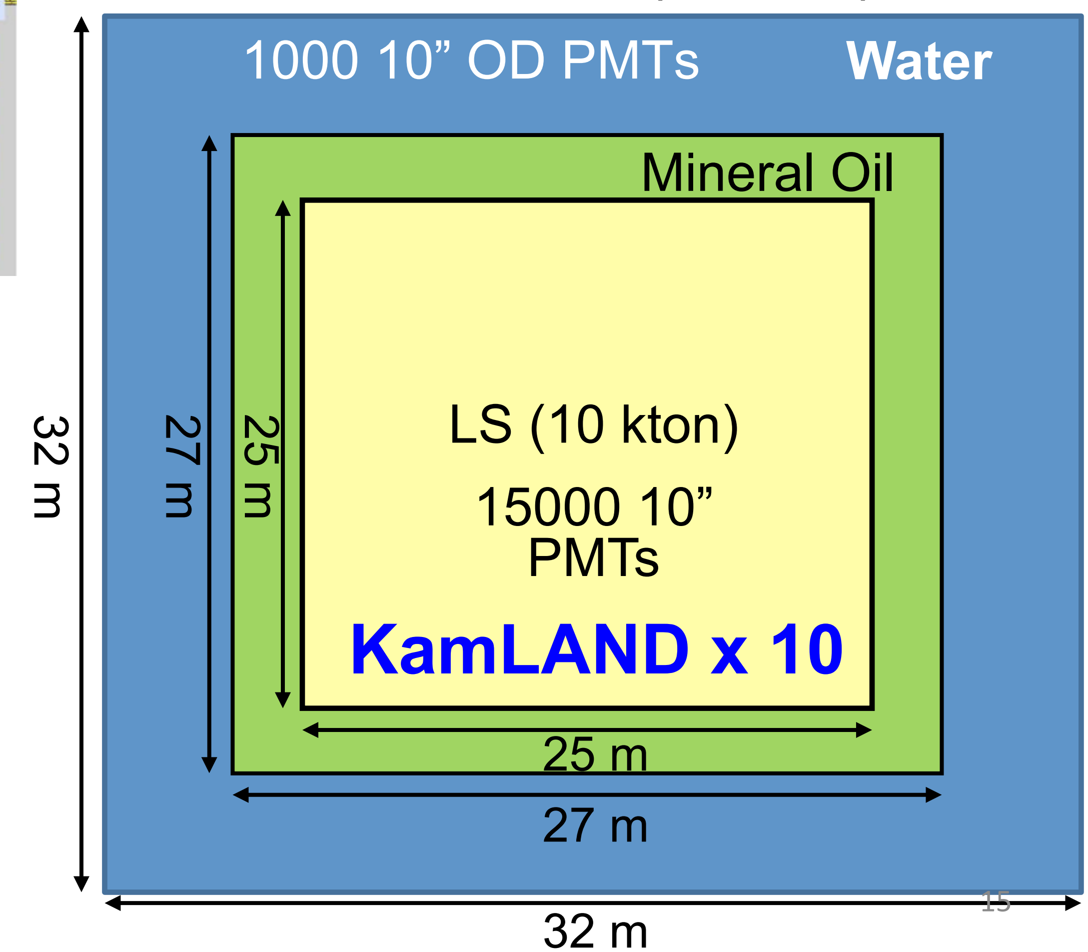
- 10 kton ultra-low-radioactivity Liquid Scintillation Detector

RENO





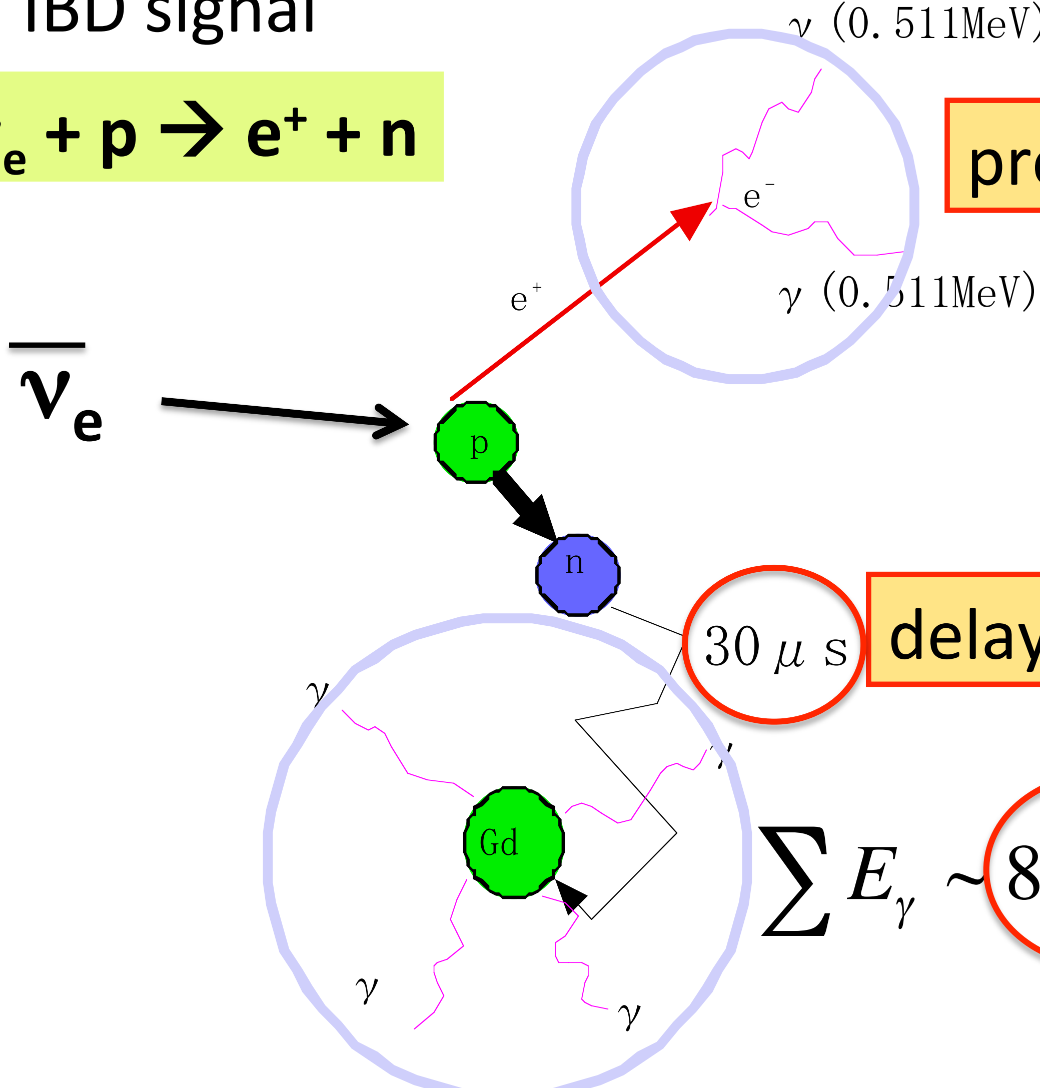
RENO-50 (default)



Liquid Scintillator w/o Gd

IBD signal

$\nu_e + p \rightarrow e^+ + n$



prompt signal

delayed signal

$\sum E_\gamma \sim 8MeV$

H capture:

200 μs

2.2 MeV

Liquid Scintillator w/o Gd (cont.)

- **Pros:**

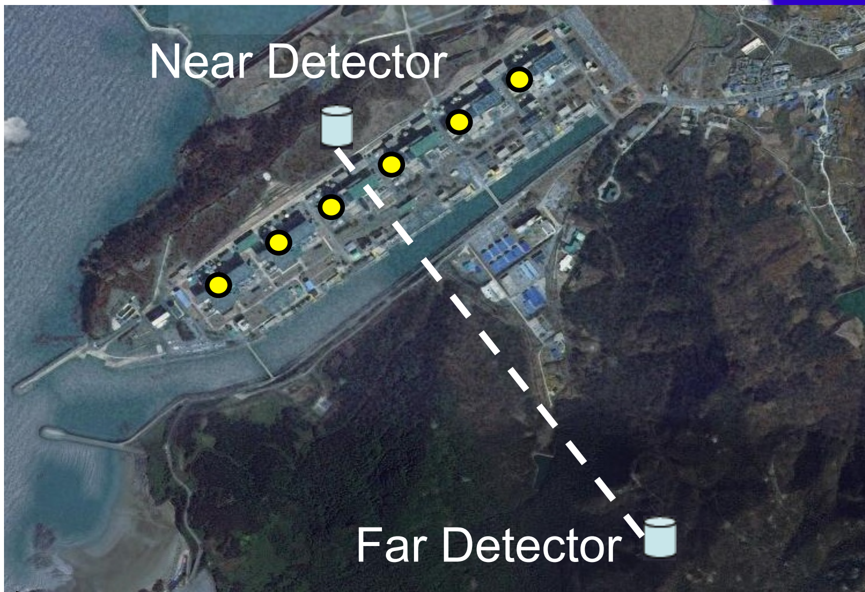
-- Better E resolution due to better attenuation length

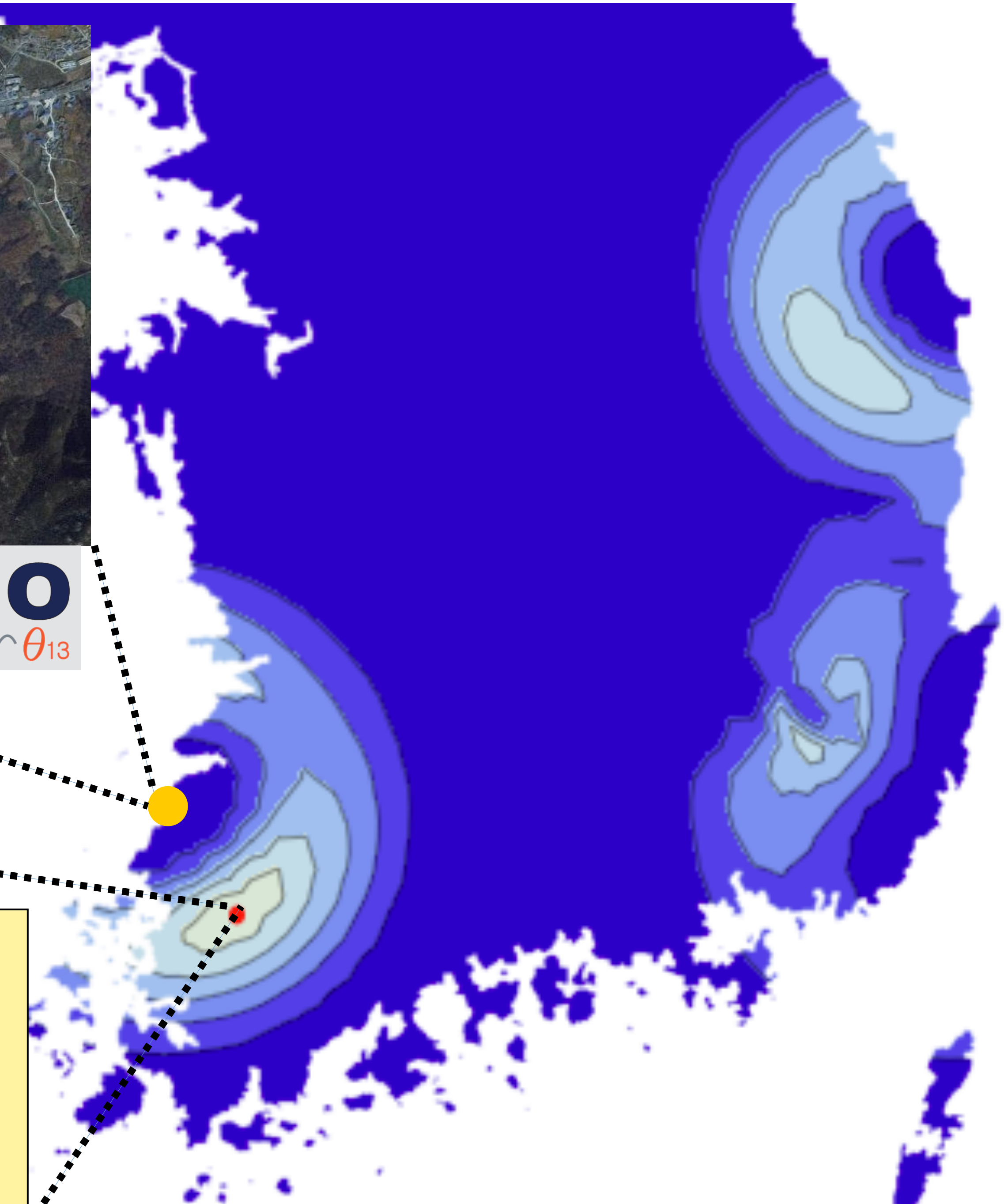
-- Lower irreducible accidental BG from LS.

-- Long term stability

- **Cons:**

Increased accidental BG due to longer capture time & lower energy of delayed signal





See talk by J.H Choi

RENO-50 Site

Mt. Guemseong (450 m)

- ✓ **~900 m.w.e. overburden**
- ✓ **~47 km baseline**
- ✓ **Best sensitivity**

◆ RENO can be used as near detector for RENO-50.
→ Reduces systematic error of nu flux.

While Daya Bay II can not use Daya Bay detector as near detector.
→ To reduce neutrino interference effect from other reactors.

✧ Baseline difference should be < 500 m.

Li, Cao, Wang, Zhan: arXiv: 1303.6733

Ciuffoli, Evslin, Zhan: arXiv: 1302.0624

Comparisons

	Osc. Reduction	Reactor ν Flux	Detector Size	Sys. Error (Flux)	Error of Mixing param
KamLAND (180 km)	40 %	53	1 kton	3 %	$\sin^2(2\theta_{12})$: 5.4 %
RENO-50 (47 km)	77 %	6 * 14.7	10 kton	~0.3 %	< 0.4 %
Daya Bay II (58 km)	85 %	X * 9.6	20 kton	3 %	< 0.4 %

Physics with RENO-50

■ Determination of mass hierarchy : very challenging

✓ Requires extremely good (better than 3 %) energy resolution.
→ ~ 3 σ significance with 10 kton, 5 yrs data

■ Precise measurement of ν mixing parameters : < 0.5 %

$$\frac{\delta \sin^2\theta_{12}}{\sin^2\theta_{12}} \sim 1.0\%(1\sigma)$$ in < 1 year (← **5.4%)**

$$\frac{\delta \Delta m^2_{12}}{\Delta m^2_{12}} \sim 1\% \quad (1\sigma)$$ in ~2 years (← **2.6%)**

■ Neutrino burst from a Supernova in our Galaxy :

-- ~3000 events (@8 kpc)

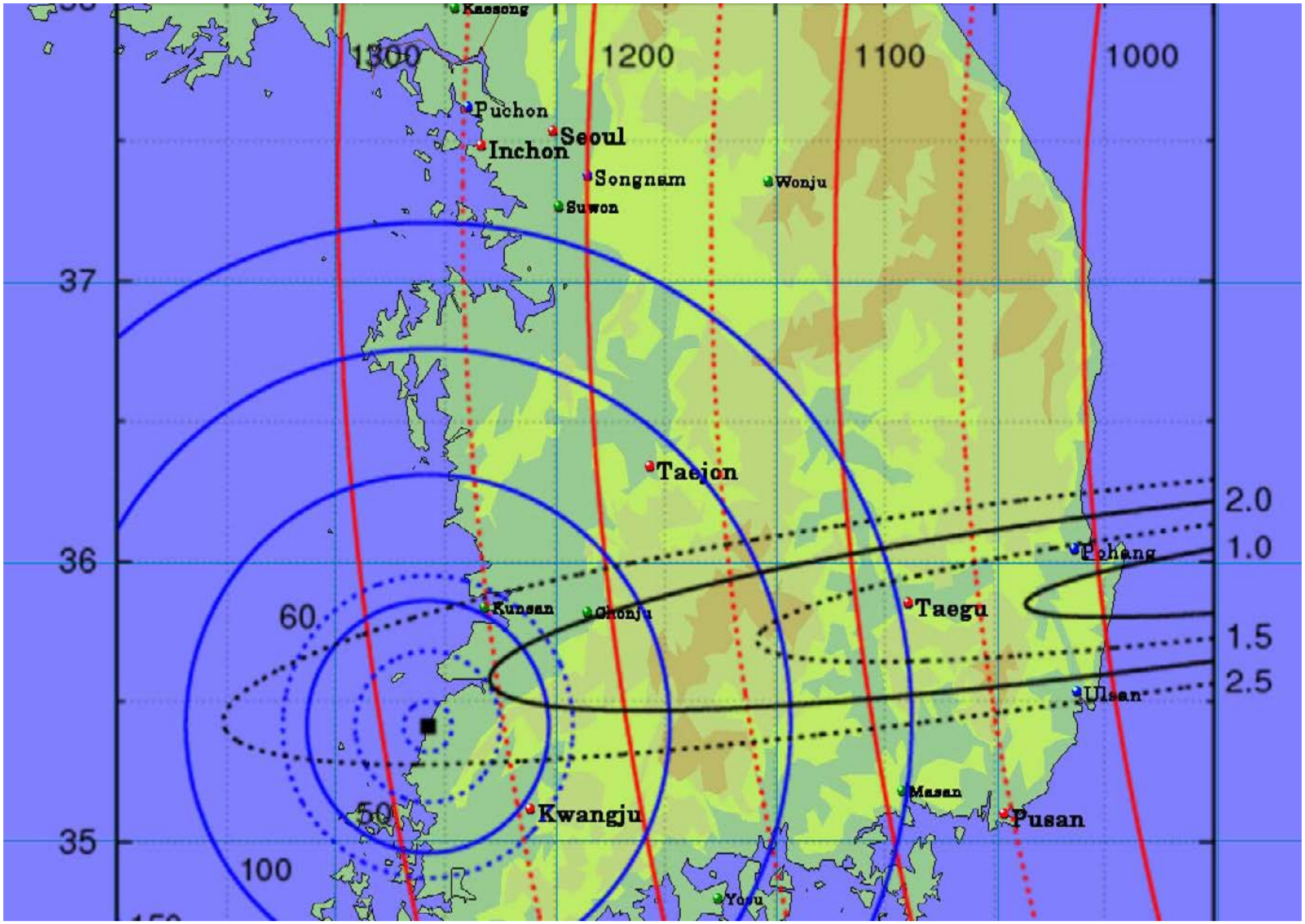
-- a long-term (> 10 years) neutrino telescope

Physics with RENO-50 (cont.)

- Solar neutrinos : with ultra low radioacitivity (Borexino level)
  - -- Matter effects on neutrino oscillation
  - -- Probe the center of the Sun and test the solar models
- Geo-neutrinos : ~ 500 geo-neutrinos for 5 years
  - -- Study the heat generation mechanism inside the Earth
- Reactor physics : to check nuclear non-proliferation treaty
- Detection of J-PARC beam : ~200 events/year
- Test of non-standard physics : sterile/mass varying neutrinos

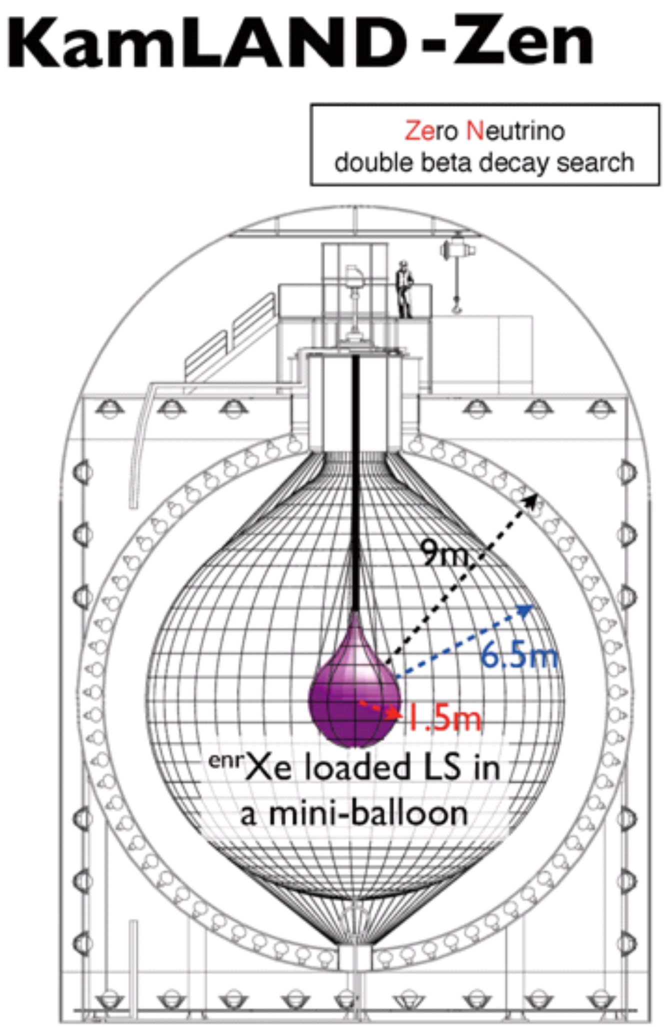
J-PARC Neutrino Beam

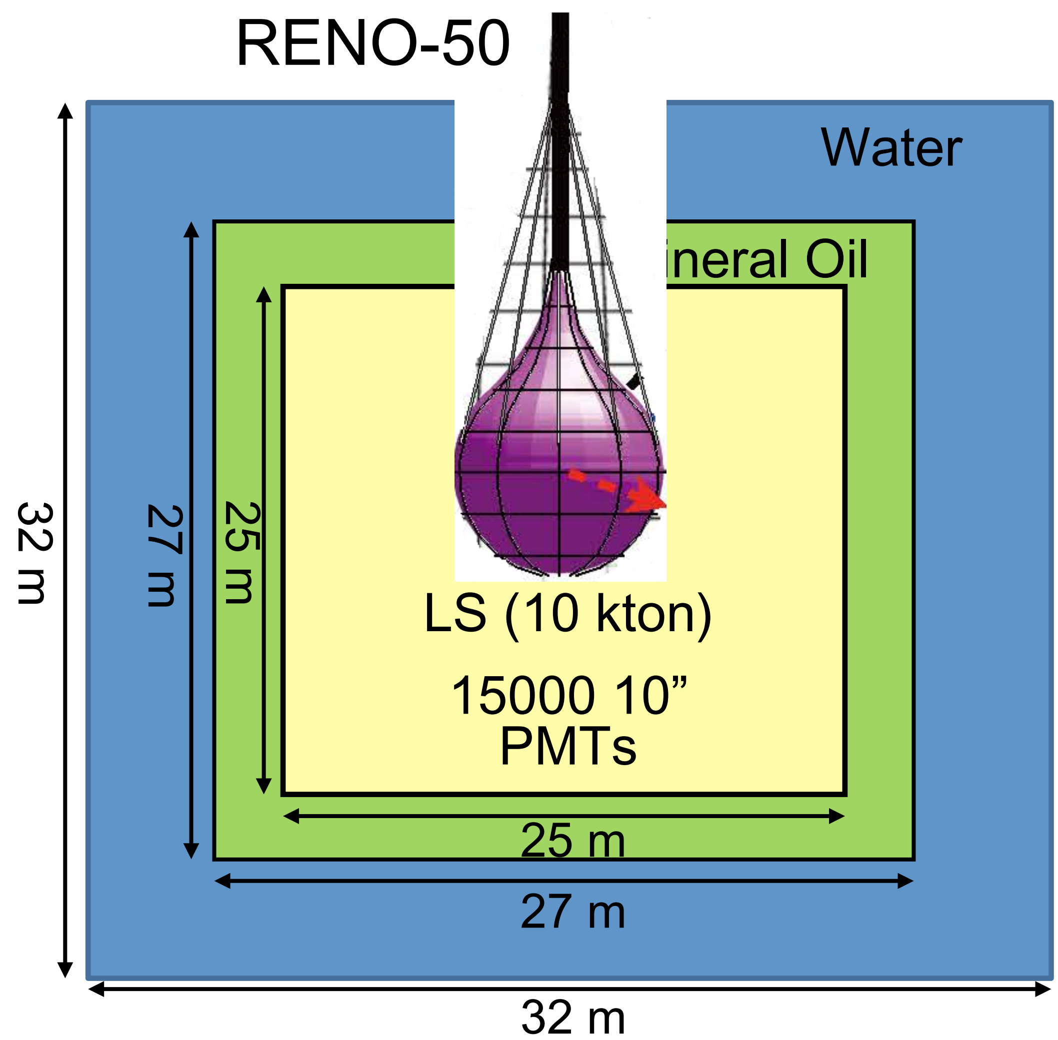
Dr. Okamura & Prof. Hagiwara



Physics with RENO-50 (cont.)

- Search for neutrinoless double beta decay





Summary

- The default RENO-50: 10 kton LS detector, 15000 PMTs @ ~ 47 km (site: Mt. Geumseong, ~ 900 m.w.e).
- RENO-50 can use RENO as a near detector.
- Determining mass hierarch is very challenging but not impossible with very good E resolution. (~ 3 σ significance with a=3% and b=0% for 5 years)
- ν oscillation params. can be very precisely measured (< 0.5 % level), which can constraint new physics.
- RENO-50 is a long term and multi-purpose detector.

International collaborators
are very welcome
to join RENO-50 !

Talk to Prof. **Soo-Bong Kim**
sbk@snu.ac.kr
if you are interested in joining.

Thank you very much !