Neutrino Experiment
Summary

Seon-Hee Seo
(Sunny Seo)
Seoul National Univ.

June 8-13, 2015
MPIK, Heidelberg
Thank you very much for LOC!
venue, shuttle bus, lunch, excursion, banquet etc...

Many thanks to all the speakers!
excellent talks, some new results, good questions etc...
Session Overview

- Neutrino 1: Reactor $\nu$
- Neutrino 2: Solar/Low E/Atmos $\nu$
- Neutrino 3: Sterile $\nu$
- Neutrino 4: $\nu$ meets astroparticle phys
- Neutrino 5: Longbaseline $\nu$ & theory
- Neutrino 6: Double beta decay
- Neutrino 7: $\nu$ theory
- Neutrino 8: Theory & future R&D

Total 8 sessions: ~30 experimental talks

2 New results
Q1. Why neutrinos are so attractive?
They are standard model (SM) particles
BUT behaves like BSM particles!

Neutrino masses & oscillations

Still mysterious!

Mass ordering, CP violation?,
Dirac vs. Majorana, absolute mass,
Sterile neutrinos?
Q2.
How can we approach to unveil the mysteries?
Use all possibilities!

- Use natural resources
- Use artificial resources
Use all possibilities!

- Use natural resources
- Use artificial resources
- Use different techniques
- Use similar techniques also
Use all possibilities!

• Use natural resources
• Use artificial resources

• Use different techniques
• Use similar techniques also

• Do collaboration:
  exp & exp
  theory & exp
  theory & theory
Use all possibilities!

- Use natural resources
- Use artificial resources
- Use different techniques
- Use similar techniques also
- Do collaboration:
  exp & exp
  theory & exp
  theory & theory
- Think wise & Work hard!
The PMNS matrix (1962) is given by:

\[
\begin{pmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau
\end{pmatrix} =
\begin{pmatrix}
U_{e1} & U_{e2} & U_{e3} \\
U_{\mu1} & U_{\mu2} & U_{\mu3} \\
U_{\tau1} & U_{\tau2} & U_{\tau3}
\end{pmatrix}
\begin{pmatrix}
\nu_1 \\
\nu_2 \\
\nu_3
\end{pmatrix}
\]

- Most \(\nu_e\) content
- Least \(\nu_e\) content

- Pontecorvo
- Maki
- Nakagawa
- Sakaga

Atmos. (\(\nu_\mu - \nu_\mu\) deficit)
Long baseline (\(\nu_\mu\) deficit)

Reactor (\(\overline{\nu}_e\) deficit)
Long baseline (\(\nu_\mu \rightarrow \nu_e\))

Solar (\(\nu_e\) deficit)
Reactor (\(\overline{\nu}_e\) deficit)
Neutrino Oscillation Milestones

Atmos. Neutrino Oscillation

Solar Neutrino Oscillation

Reactor Neutrino Oscillation

\( \theta_{23} \)

\( \sim 45^\circ \) (1998)
Super-K; K2K

3 years

\( \theta_{12} \)

34° (2001)
SNO, Super-K; KamLAND

11 years

\( \theta_{13} \)

9° (2012)
Daya Bay, RENO
Double Chooz

Nature was very kind to us!
First discovery of neutrino is from reactor neutrinos!

In 1956 @Savannah river, S. Carolina
By Reines and Cowan

So it is fair for me to start with reactor neutrinos!
Reactor $\theta_{13}$ Experiments

Double Chooz

@ Chooz, France

RENO

@ Yonggwang, Korea

Daya Bay

@ Daya Bay, China
$\theta_{13}$ Reactor Neutrino Detectors

1. Cylindrical structure (four layers)
2. Neutrino Target: liquid scintillator with 0.1% Gd doping
Comparisons

Reactor Thermal Power ($GW_{th}$)

- Daya Bay
- RENO
- Double Chooz

Target (ton)

- Double
- RENO
- Daya Bay

Manpower

- Daya Bay
- RENO
- Double Chooz

WIN 2015 @ Heidelberg
Double Chooz

\[ \Delta m^2_{31} = 2.44 \times 10^{-3} \text{ eV}^2 \] (MINOS)

2 reactor off data
(7 events in 7.24 days)

2 methods:
RATe + SHAPE
Prompt spectrum fit

n-Gd: Rate+shape

\[ \sin^2(2 \theta_{13}) = 0.090^{+0.032}_{-0.029} \]
\[ \chi^2/\text{ndof} = 52.2/40 \]

n-Gd: Rate-only

\[ \sin^2(2 \theta_{13}) = 0.090^{+0.034}_{-0.035} \]

n-H: Rate-only

\[ \sin^2(2 \theta_{13}) = 0.097 \pm 0.053 \]

New result on n-H analysis will come out soon.
\[ \sin^2 2\theta_{13} = 0.087 \pm 0.008\text{(stat.)} \pm 0.008\text{(syst.)} \]

Rate-only: n-Gd \(\sim\)800 days

New result: rate+shape
(n-Gd: \(\sim\)800 days)

Work in progress
Daya Bay

- Far/near relative measurement
- Observed data highly consistent with oscillation interpretation
- Precision of $\sin^2 2\theta_{13}$: 10% → 6%
- Precision of $|\Delta m^2_{ee}|$: 8% → 4%

$$\sin^2 2\theta_{13} = 0.084 \pm 0.005$$

$$|\Delta m^2_{ee}| = (2.42 \pm 0.11) \times 10^{-3} \text{ eV}^2$$

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Seon-Hee Seo, SNU

WIN 2015 @ Heidelberg
The 5 MeV Excess

Seon-Hee Seo, SNU

WIN 2015 @ Heidelberg
The different nuclear database do not agree on the origin of the Bump - the uncertainties in the databases are large.

- ENDF/B-VII.1 predicts that it results from an analogous shoulder in the ILL $^{235}$U $\beta$ spectrum. Also predicts a large bump for $^{238}$U.

- JEFF-3.1.1 does not predict a bump for $^{235}$U or $^{239}$Pu. Agrees with Schreckenbach for both these nuclei. But predicts a significant bump for $^{238}$U.

Dwyer & Langford, PRL, 114 012502 (2015)
Neutrino Mass Ordering: JUNO & RENO-50

Which one?
### JUNO & RENO-50

**Steel Tank**
- Acrylic tank: \( \Phi \sim 34.5 \text{ m} \)
- Stainless Steel tank: \( \Phi \sim 39.0 \text{ m} \)
- Coverage: \( \sim 77\% \)
- \( \sim 18000 \) 20" PMTs

**Water**
- \( \sim 1500 \) 20" VETO PMTs

**Muon detector**
- Steel Tank: \( \sim 20 \text{ kt} \)
- MO: \( \sim 6 \text{ kt} \)

### Table

<table>
<thead>
<tr>
<th></th>
<th>KamLAND</th>
<th>BOREXINO</th>
<th>JUNO</th>
<th>RENO-50</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LS mass</strong></td>
<td>( \sim 1 \text{ kt} )</td>
<td>( \sim 0.3 \text{ kt} )</td>
<td>20 kt</td>
<td>18 kt</td>
</tr>
<tr>
<td><strong>Energy Resol</strong></td>
<td>6%/</td>
<td>5%/</td>
<td>( \sim 3% /)</td>
<td>( \sim 3% /)</td>
</tr>
<tr>
<td><strong>Light yield</strong></td>
<td>250 p.e./MeV</td>
<td>500 p.e./</td>
<td>1300 p.e./MeV</td>
<td>( &gt;1000 ) p.e./MeV</td>
</tr>
</tbody>
</table>
Scientific Potential of JUNO/RENO-50

- Resolve the mass hierarchy
  - \( \sim 4 \) standard-deviation discrimination in 6 years
- Precision determination of neutrino-mixing parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current fractional precision</th>
<th>JUNO/RENO-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sin^2\theta_{12} )</td>
<td>5%</td>
<td>0.7%</td>
</tr>
<tr>
<td>( \sin^2\theta_{23} )</td>
<td>5%</td>
<td>NA</td>
</tr>
<tr>
<td>( \sin^2\theta_{13} )</td>
<td>10%</td>
<td>( \sim 15% )</td>
</tr>
<tr>
<td>( \Delta m^2_{21} )</td>
<td>3%</td>
<td>0.6%</td>
</tr>
<tr>
<td>( \Delta m^2_{31} )</td>
<td>5%</td>
<td>0.6%</td>
</tr>
</tbody>
</table>

- Search for supernova neutrinos
  - \( \sim 5000 \) events for supernovae occur at 8 kpc
- Study geo-neutrinos
  - \( \sim 1000 \) events in a 5-year run

@Recontre du Vietnam 2013
Sterile Neutrino Searches

SOX
NEOS
NuLat
Why Sterile neutrinos ?

Experimental anomalies are seen:

Reactor $\nu$ anomaly

Source anomaly

Accelerator $\nu$ anomaly
The Reactor Antineutrino Anomaly

obs/expected=0.94 (~3σ) deficit in the detected antineutrinos from short baseline reactor experiments


The effect mostly comes from the detailed physics involved in the nuclear beta-decay of fission fragments in the reactor


Additional contributions from (1) Off-equilibrium nuclei and (2) Increase in the detection cross section.
Fit to Schreckenbach’s beta spectrum

Different fitting procedures: (1) all allowed; (2) all branches either allowed or forbidden; (3) 30% forbidden equally spaced; (4) 30% forbidden with a bias to higher energies + several different combinations of forbidden operators

Changes in the antineutrino spectrum range from 0-4%
Problem arises because of lack of knowledge on how to treat forbidden transitions
**NEOS**

**Neutrino Experiment for Oscillation at Short baseline**
(previously introduced as Hanaro)

- **1000 L Gd-LS**
  - (0.5%)
- **Baseline:** 25 m

½ year data
95 % CL

Data taking in 2 months
NuLat – Novel Detector for Sterile Neutrino Search with Reactor Neutrinos

- $^6\text{Li}$ doped (0.5%) plastic scintillator
- 2.5 inch cube; 15X15X15
- Full 3D light collection

5X5X5 demonstrator: deployment in 2016
SOX

Michael Wurm

Short-baseline oscillations in Borexino

- 270 ton ultrapure scintillator
- Baseline: 8.5 m
- Fiducial radius: 4 m (~240 ton)

1st phase CeSOX sensitivity

1.5 yrs from 2016 ~10 k events

- 1st phase: $^{144}\text{Ce}$ anti-$\nu_e$ source
- 2nd phase: $^{51}\text{Cr}$ $\nu_e$ source (similar sensitivity)
<table>
<thead>
<tr>
<th>Reactor Proposals</th>
<th>Expected Data Taking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P&lt;sub&gt;th&lt;/sub&gt; (MW)</td>
</tr>
<tr>
<td>Nucifer (FRA)</td>
<td>70</td>
</tr>
<tr>
<td>Poseidon (RU)</td>
<td>100</td>
</tr>
<tr>
<td>Stéréo (FRA)</td>
<td>57</td>
</tr>
<tr>
<td>Neutrino 4 (RU)</td>
<td>100</td>
</tr>
<tr>
<td>Hanaro (KO)</td>
<td>30-2800</td>
</tr>
<tr>
<td>DANSS (RU)</td>
<td>3000</td>
</tr>
<tr>
<td>Prospect (USA)</td>
<td>85</td>
</tr>
<tr>
<td>SoLid (UK)</td>
<td>45-80</td>
</tr>
</tbody>
</table>

Lhuiller @Neutrino 2014

Expected

Data Taking

analyzing

Wish list:
It would be very good to have one sterile \( \nu \) sensitivity plot for all experiments!
Shoart Baseline ν Program @ Fermilab

Jonathan Asaadi

The ICARUS detector is the largest LArTPC ever built

- Adding the large mass allows for precision oscillation search
SBN Sensitivities

Utilizing three similar detectors at three different distances along the same neutrino beam allows for a definitive measurement of the allowed sterile neutrino parameter space.

Anti $\nu$ data is also needed!
MicroBooNE will utilize the electron / photon discrimination power of LArTPC's to determine if the MiniBooNE excess is electron like (from $\nu_e$ appearance) or photon like (unaccounted for background).

By analyzing the topology and the dE/dX of the electromagnetic shower, disentangling the MiniBooNE low energy excess becomes possible.
Atmospheric/Solar/SNR neutrinos

Super-K
GADZOOKS !
BOREXINO
Super-K

Yoshinari Hayato

50 kton Water Cherenkov detector: since 1996

1 km underground
~ 11 k PMTs (20 inch)

Multi-purpose detector

Neutrino oscillation
- Accelerator neutrinos
- Atmospheric neutrinos
- Solar neutrinos

GUT
Proton decay
- $p \rightarrow e^+ + \pi^0$
- $p \rightarrow K^+ + \bar{\nu}$

New physics
- WIMP search
- n-$\bar{n}$ oscillation
- dinucleon decay etc..

Neutrino astrophysics
- Super nova burst neutrino
- Super nova relic neutrino
Super-K: Atmospheric $\nu$

- 3 flavor $\nu$ oscillation analysis: $1\sigma$ preference to NH & 2$^{\text{nd}}$ octant (using 4538 days data)
- No evidence of sterile $\nu$: for 3+N model: $|U_{\mu 4}|^2 < 0.041$ @90% CL
- neutron tagging effi. (20.5%): Atm. $\nu$ oscillation, proton decay

$\nu_\tau$ appearance (2806 days)

180.1 ± 44.3 (stat) +17.8-15.2 (sys) events (3.8$\sigma$)
Super-K: Solar $\nu$

$^8{\text{B}}$ flux:

$$2.344 \pm 0.034 \times 10^6/cm^2/s$$

Pierce Weatherly
Super-K: Solar $\nu$

Day Night asymmetry: $\sim 3 \sigma$

$\rightarrow$ evidence for MSW effect

See also A. Smirnov’s plenary talk!
 borexino: Solar ν

Solar Neutrinos

- First measurement of the interaction rate of the $^7\text{Be}$ mono-energetic 862 keV solar neutrinos with accuracy of 5%
- Exclusion of any significant day-night asymmetry of the $^7\text{Be}$ solar neutrino flux
- First direct observation of the mono-energetic 1440 keV pep solar neutrinos
- Set of the strongest upper limit of the CNO solar neutrinos flux
- Measure of the $^8\text{B}$ solar neutrinos with an energy threshold of 3 MeV
- First spectroscopic measurement of the pp spectrum.

Nicola, Rossi

Down to 150 keV solar ν
GADZOOKS! M. Ikeda

Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super!

- Goal: discovery of SN relic n
- Sensitivity: few for 10 yrs

[10, 30] MeV search window
To remove BKG to enhance signal, dissolve 0.2% Gd

EGADS
Evaluating Gadolinium's Action on Detector Systems
200 m³ tank with 240 PMTs

Committee has started reviewing this project.

To study Gd water quality
Long baseline neutrinos

NOvA
T2K
MINOS/MINOS+
NOvA

NuMI Off-Axis $\nu_e$ Appearance Experiment

- Construction: 2009-2014
- Cosmic bkg rejection: $40 \text{ M} \rightarrow 1$
- 1$^{\text{st}}$ year data is being analyzed. (420 kW; $1.9 \times 10^{20}$ POT)
  $\rightarrow \nu_e$ appearance results are expected by this fall.
recent T2K oscillation analyses:

- combined $\nu_\mu + \nu_e$ analysis with reactor constraint
- preference for values of $\delta_{CP}$ around $-\pi/2$
- weakly favored normal hierarchy and octant $\sin^2 \theta_{23} > 0.5$
- first $\nu_\mu$ disappearance result
- consistent with T2K $\nu_\mu$ disappearance measurements and MINOS $\nu_\mu$ disappearance result
- analysis of $\nu_e$ appearance is underway
MINOS/MINOS+

Adam Schreckenberg

Near Detector
0.98 kt, 1.04 km downstream
Steel scintillator

Far Detector
5.4 kt, 735 km downstream
Steel scintillator

MINOS 3ν osc best fit

Inverted Hierarchy

\[ |\Delta m^2_{32}| = 2.37^{+0.11}_{-0.07} \times 10^{-3} \text{eV}^2 \]
\[ \sin^2 \theta_{23} = 0.43^{+0.19}_{-0.05} \]
\[ 0.36 < \sin^2 \theta_{23} < 0.65 \text{ (90\% C.L.)} \]

MINOS+ Preliminary

νμ mode
MINOS simulation: 10.56×10^{39} POT
MINOS+ simulation: 12×10^{39} POT
Full MINOS systematics

Sterile ν search

Seon-Hee Seo, SNU
WIN 2015 @ Heidelberg
Future R&D

DUNE
LBNO-DEMO (WA105)
ESSnuSB
CHIPS
Deep Underground Neutrino Exp.

- Baseline: 1300 km (S. Dakoda)
- Megawatt beam covering 1\textsuperscript{st}, 2\textsuperscript{nd} osc. Max
- Near & Far detectors
- LArTPC: 40 kt @Far
- 6~10 yrs running
- 50% $\nu$, 50% anti-$\nu$

Single vs. double phase LArTPC
R&D: LBNO-DEMO (WA105)
(CERN neutrino platform)
DUNE Sensitivities

5 σ mass ordering determination: 2034~2035
ESSnuSB @ 2nd Maxima

ESS Lund to Garpenberg mine: 540 km

- Complementary to DUNE
  - WC detector: 0.5 Mt fiducial volume
  - better coverage of $\delta$ & better sensitivity
- Data taking in 10 yrs if no politics
- Adding a $\nu$ facility to ESS

arXiv:1309.7922

$\delta(3\pi/2)/\delta(\pi/2) = 105/22 = 4.8$
• 40 additional strings
  60 DOMs/string
• 3 k $\nu_\tau$/year $\rightarrow$
  $\nu_\tau$ appearance: 5 $\sigma$ in a month
• Integral part of IceCube-Gen2
CHIPS

CHerenkov detectors In mine PitS (CH)

CHIPS-M
33 t WC, 4 DOMs
Under 60 m water
1\textsuperscript{st} run: 2014-2015
2\textsuperscript{nd} run: Aug. 2015

CHIPS-10kt
Install in 2017
MICE approved to:
- Design, build, commission and operate a realistic section of cooling channel
- Measure its performance in a variety of modes of operation and beam conditions
  - Results will allow Neutrino Factory [and Muon Collider] complex to be optimised

Requirements:
- Normalised transverse emittance: 0.1%
  - Requires selection of 99.9% pure muon sample

MICE will unlock the exploitation of muon accelerators by providing the essential demonstration of ionization cooling:

- Starting now:
  - Investigation of the effect of material, emittance, momentum on the cooling effect
- Starting 2017:
  - Demonstration of ionization cooling;
  - Systematic study of factors that affect cooling performance
Double Beta Decay

GERDA
EXO/nEXO
CUORE-0/CUORE
AMoRE

Heavy neutrinos in LHC
Double Beta Decay

$0\nu\beta\beta$

If Majorana $\nu$
If lepton number violated
Hint to Abs. neutrino mass
Hint to neutrino mass hierarchy
\[
(T_{1/2}^{0\nu})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)|\mathcal{M}_{0\nu}(A, Z)|^2|m_{\beta\beta}|^2
\]

effective Majorana mass:
\[
|m_{\beta\beta}| \equiv \left| \sum_i U_{ei}^2 m_i \right| = \left| c_{12}^2 \ c_{13}^2 \ m_1 + s_{12}^2 \ c_{13}^2 \ m_2 \ e^{i2\alpha} + s_{13}^2 \ m_3 \ e^{i2\beta} \right|
\]

**Sizable background case**;

\[
T_{1/2}^{0\nu}(\text{exp}) = (\ln 2) N_a \ \frac{a}{A} \ \varepsilon \ \sqrt{\frac{MT}{b\Delta E}}
\]

- \(b\) = background index in cts/(keV kg y)
- \(\Delta E\) = FWHM energy resolution at \(Q_{\text{pp}}\) in keV
- \(M\) = mass of detector in kg
- \(A\) = mass number of candidate material
- \(\varepsilon\) = detection efficiency at \(Q_{\text{pp}}\)
- \(\alpha\) = \(\beta\beta\) isotope fraction (Enrichment)
- \(T\) = measured time in years

**“Zero” background case**;

\[
T_{1/2}^{0\nu}(\text{exp}) = (\ln 2) N_a \ \frac{a}{A} \ \varepsilon \ \frac{MT}{n_{CL}}
\]
## Current Status on DBD

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Isotopes</th>
<th>$T_{1/2}^{0\nu}$ (year) @ 90% CL</th>
<th>$&lt;m_{\beta\beta}&gt;$ [eV]</th>
<th>Speaker (WIN2015)</th>
</tr>
</thead>
</table>
| GERDA: I Phase II   | $^{76}\text{Ge}$ | $> 2.1 \times 10^{25}$  
$> 10^{26}$ (2yr)    | 0.25 - 0.42  | Matteo Agostini |
| KAMLAND-ZEN         | $^{136}\text{Xe}$ | $> 1.9 \times 10^{25}$    | 0.14 - 0.34  | PRL 110 062502 (2015) |
| EXO-200 nEXO       | $^{136}\text{Xe}$ | $> 1.1 \times 10^{25}$  
$> 6.6 \times 10^{27}$ (5yr) | 0.19 - 0.45  | Raymond Tsang |
| NEMO-3              | $^{100}\text{Mo}$ | $> 1.1 \times 10^{25}$    | 0.34 - 0.87  | RRD 89 111101 (2014) |
| CUORE-0 CUORE      | $^{130}\text{Te}$ | $> 2.7 \times 10^{24}$  
$> 9.5 \times 10^{25}$ (5yr) | 0.31 - 0.76  
0.05 – 0.13 | Fabio Bellini |
| SNO+                | $^{130}\text{Te}$ | $> 7 \times 10^{26}$ (5yr) | ---  | Valentina Lozza |
| AMoRE-pilot AMoRE-10 AMoRE-200 | $^{100}\text{Mo}$ | $> 1.1 \times 10^{24}$  
$3 \times 10^{25}$ (2yr)  
$10^{27}$ (4yr) | $< 0.3 \sim 0.9$  
0.06 ~ 0.18  
0.01 ~ 0.03 | Loredana Gastaldo |
## Presented talks in WIN 2015

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Isotope</th>
<th>Mass of Isotope [kg]</th>
<th>Sensitivity T^{0v} [yr]</th>
<th>Sensitivity m_{\beta\beta} [eV]</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>GERDA</td>
<td>^{76}\text{Ge}</td>
<td>18</td>
<td>3 \times 10^{25}</td>
<td>0.2 \div 0.4</td>
<td>running</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>2 \times 10^{26}</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000</td>
<td>6 \times 10^{27}</td>
<td>0.03</td>
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<tr>
<td>CUORE</td>
<td>^{130}\text{Te}</td>
<td>200</td>
<td>1 \times 10^{26}</td>
<td>0.04 \div 0.1</td>
<td>in progress</td>
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<tr>
<td>MAJORANA</td>
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<td>2 \times 10^{26}</td>
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<td>1000</td>
<td>6 \times 10^{27}</td>
<td>0.03</td>
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<tr>
<td>EXO</td>
<td>^{136}\text{Xe}</td>
<td>200</td>
<td>5 \times 10^{25}</td>
<td>0.08 \div 0.3</td>
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<tr>
<td></td>
<td></td>
<td>1000</td>
<td>8 \times 10^{26}</td>
<td>0.01 \div 0.03</td>
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<tr>
<td>SuperNEMO</td>
<td>^{82}\text{Se}</td>
<td>7</td>
<td>6.5 \times 10^{24}</td>
<td>0.2 \div 0.4</td>
<td>in progress</td>
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<tr>
<td></td>
<td></td>
<td>100</td>
<td>1 \times 10^{26}</td>
<td>0.04 \div 0.10</td>
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<tr>
<td>KamLAND-Zen</td>
<td>^{136}\text{Xe}</td>
<td>400</td>
<td>4 \times 10^{26}</td>
<td>0.06</td>
<td>in progress</td>
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<tr>
<td></td>
<td></td>
<td>1000</td>
<td>1 \times 10^{27}</td>
<td>0.02</td>
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<tr>
<td>NEXT</td>
<td>^{136}\text{Xe}</td>
<td>100</td>
<td>5 \times 10^{25}</td>
<td>0.08 \div 0.13</td>
<td>in progress</td>
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<tr>
<td></td>
<td></td>
<td>1000</td>
<td>5 \times 10^{26}</td>
<td>0.03 \div 0.07</td>
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<tr>
<td>SNO+</td>
<td>^{130}\text{Te}</td>
<td>200</td>
<td>1 \times 10^{26}</td>
<td>0.06 \div 0.1</td>
<td>in progress</td>
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<tr>
<td></td>
<td></td>
<td>800</td>
<td>1 \times 10^{27}</td>
<td>0.02 \div 0.06</td>
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<td>AMoRE</td>
<td>^{100}\text{Mo}</td>
<td>1-1.5</td>
<td>&gt; 1.1 \times 10^{24}</td>
<td>&lt; 0.3 \sim 0.9</td>
<td>2015</td>
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<td></td>
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<td>10</td>
<td></td>
<td>0.06 \sim 0.18</td>
<td>R&amp;D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200</td>
<td></td>
<td>0.01 \sim 0.03</td>
<td></td>
</tr>
</tbody>
</table>

*Presented talks in WIN 2015 by Seon-Hee Seo, SNU. C. Macolino@NeuTel2015.*
LHC has explored Type I, III, and LRSM.

Fresh new results from ATLAS 3 days ago !!

Type I $\rightarrow$ SS dimuon + 2 jet
Heavy Neutrinos @ LHC

Un-ki Yang

2.8 S EXCESS IN CMS (SS+OS) but no excess (SS) in ATLAS
Where is next surprise?

Neutrino CP violation?

Neutrino mass ordering?

Sterile neutrinos?

Absolute masses?

Dirac or Majorana?
We don’t know where our nature has kept her secrets.

Future is up to us! (and to nature)

Let’s be positive & continue searches!
Danke !    Thank you !

감사합니다 !