Status of the RENO Reactor Neutrino Experiment

RENO = Reactor Experiment for Neutrino Oscillation

(For RENO Collaboration)

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Seoul National University
November 14, 2011

DBD 2011, November 14-17 2011, Osaka

Outline

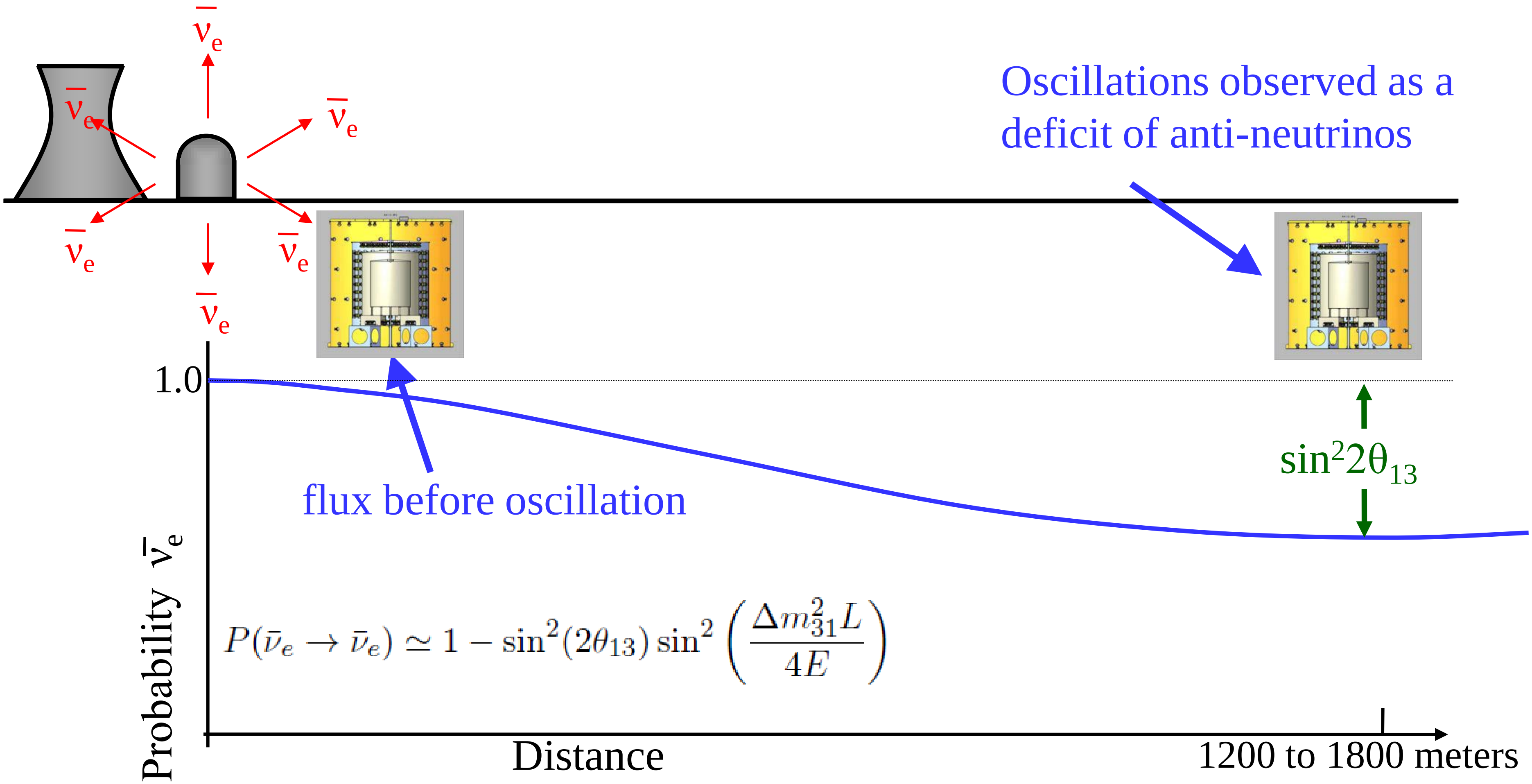
- **Experimental Goal**
  - Systematic & Statistical Uncertainties
  - Expected θ_{13} Sensitivity

- **Overview of the RENO Experiment**
  - Experimental Setup
  - YongGwang Power Plant
  - Detector Construction (completed in Feb. 2011)

- **RENO Data-Taking (start from Aug. 2011)**
  - Status
  - Energy Calibration

- **Summary**

Experimental Method of θ_{13} Measurement



- Find disappearance of $\overline{\nu_e}$ fluxes due to neutrino oscillation as a function of energy
- Identical detectors reduce the systematic errors in 1% level.

Expected Number of Neutrino Events at RENO

- 2.73 GW per reactor $\times$ 6 reactors
- 1.21×10^{30} free protons per targets (16 tons)

- Near : 1,280/day, 468,000/year
- Far : 114/day, 41,600/year

✓3 years of data taking with 70% efficiency

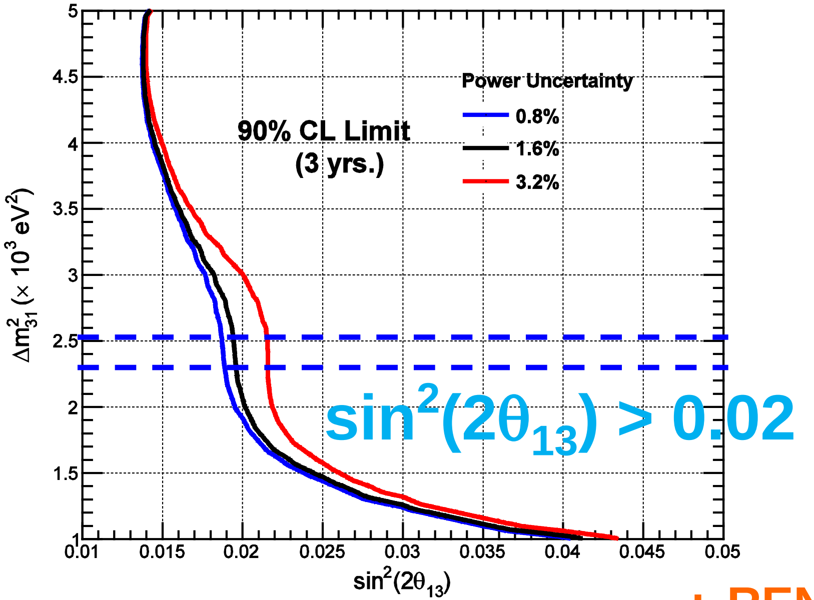
Near : $9.83 \times 10^5 \approx 10^6$ (0.1% error)
Far : $8.74 \times 10^4 \approx 10^5$ (0.3% error)

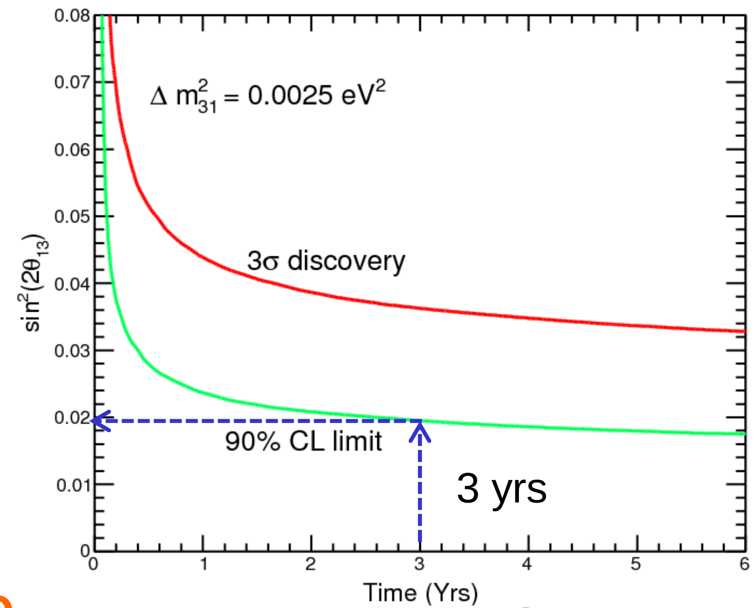
Expected Systematic Uncertainty

Systematic Source		CHOOZ (%)	RENO (%)
Reactor related absolute normalization	Reactor antineutrino flux and cross section	1.9	< 0.1
	Reactor power	0.7	0.2
	Energy released per fission	0.6	< 0.1
Number of protons in target	H/C ratio	0.8	0.2
	Target mass	0.3	< 0.1
Detector Efficiency	Positron energy	0.8	0.1
	Positron geode distance	0.1	0.0
	Neutron capture (H/Gd ratio)	1.0	< 0.1
	Capture energy containment	0.4	0.1
	Neutron geode distance	0.1	0.0
	Neutron delay	0.4	0.1
	Positron-neutron distance	0.3	0.0
	Neutron multiplicity	0.5	0.05
combined		2.7	< 0.5

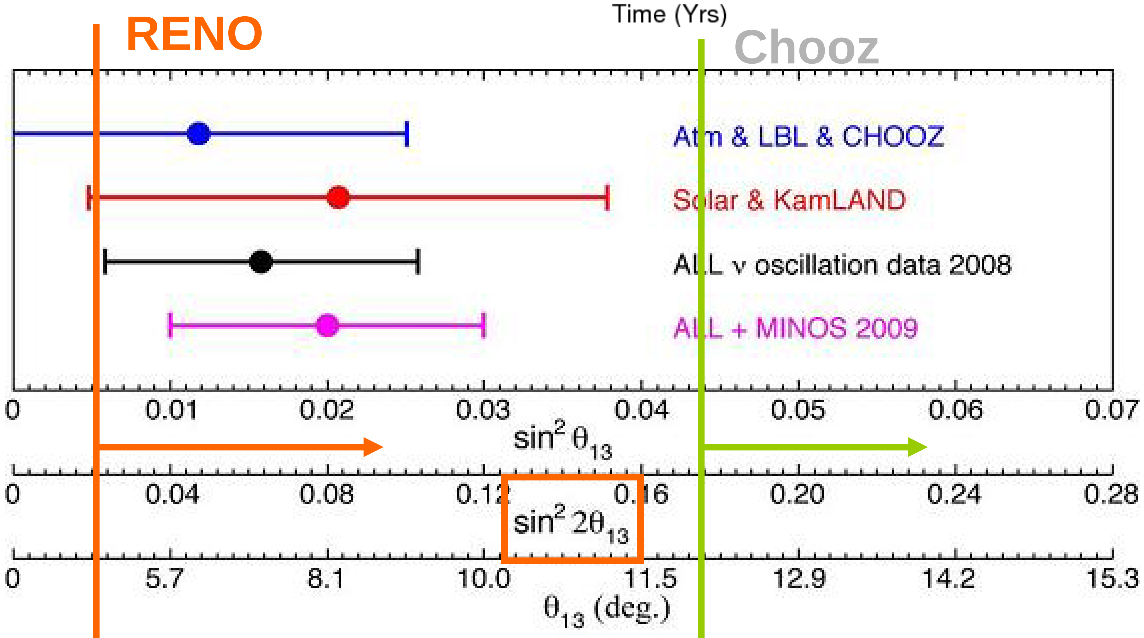
RENO Expected Sensivity

90% CL Limits





- **10 times better sensitivity than the current limit**



G. Fogli *et al.* (2009)

RENO Collaboration

(13 institutions and 40 physicists)

- ❑ Chonbuk National University
- ❑ Chonnam National University
- ❑ **Chung-Ang University**
- ❑ Dongshin University
- ❑ Gyeongsang National University
- ❑ Kyungpook National University
- ❑ Pusan National University
- ❑ Sejong University
- ❑ Seokyeong University
- ❑ Seoul National University
- ❑ Seoyeong University
- ❑ Sungkyunkwan University
- ❑ **California State University Domingez Hills, USA**

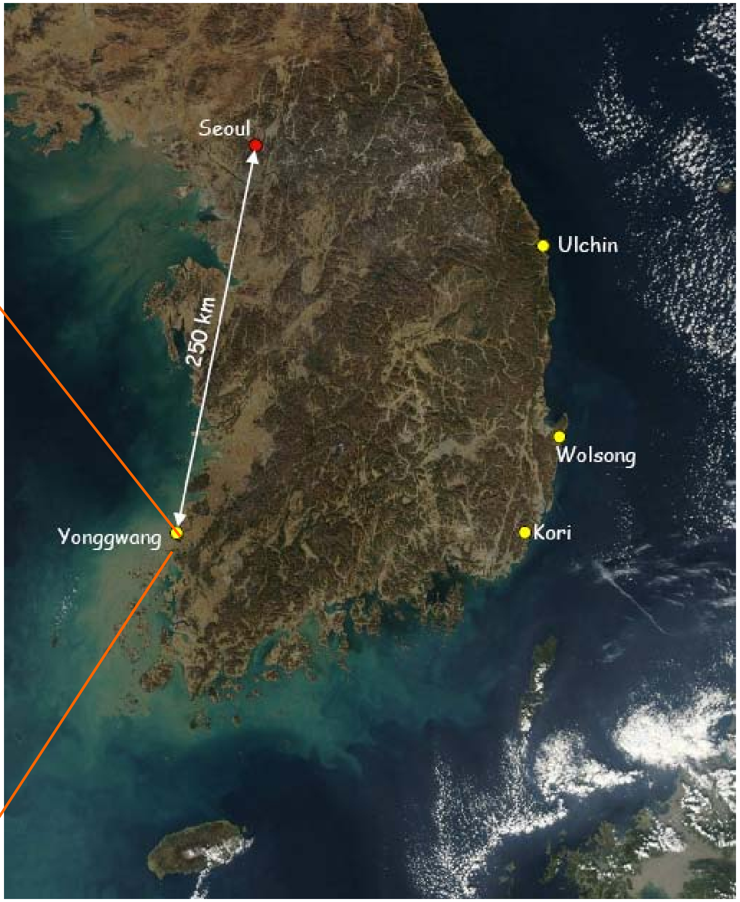
+++ http://reno01.snu.ac.kr/RENO

International collaborators are being invited

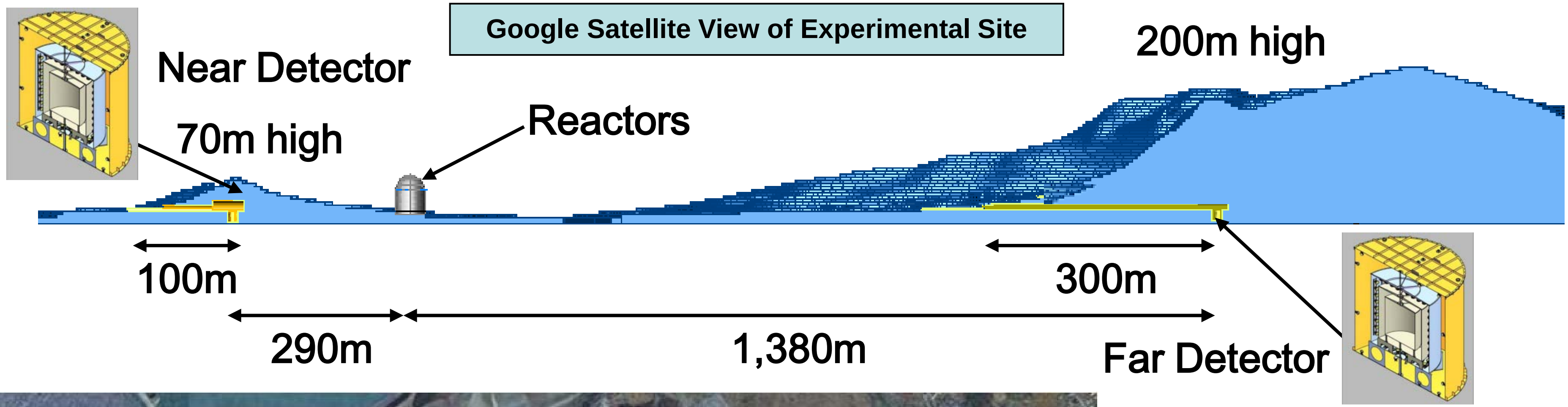
YongGwang Nuclear Power Plant

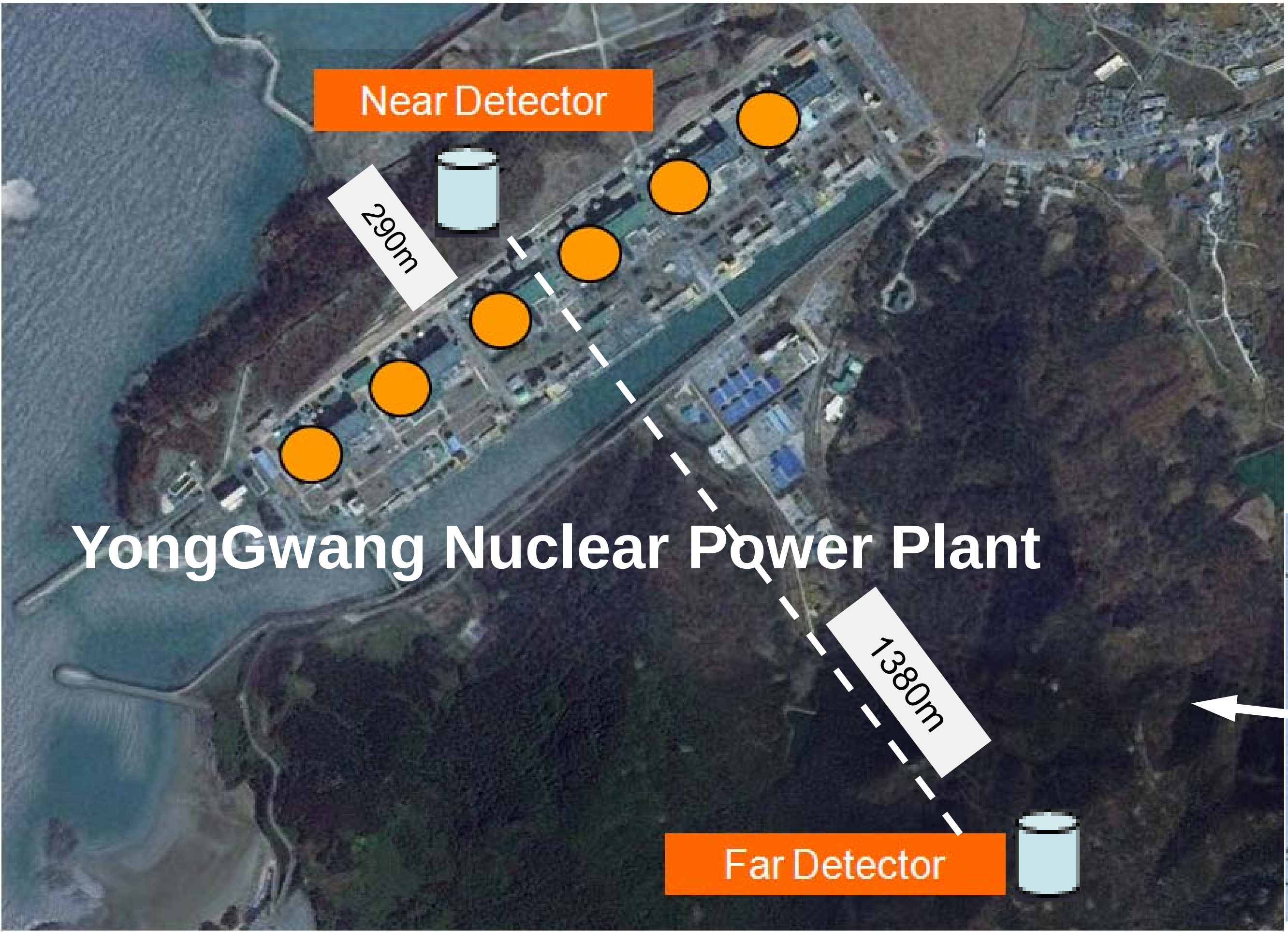
- ❒ Located in the west coast of southern part of Korea
- ❒ ~400 km from Seoul
- ❒ 6 reactors are lined up in roughly equal distances and span ~1.3 km
- ❒ Total average thermal output ~16.4GW$_{th}$ (2nd largest in the world)

YongGwang(靈光):
= glorious[splendid] light
(~ psychic)



Google Satellite View of Experimental Site





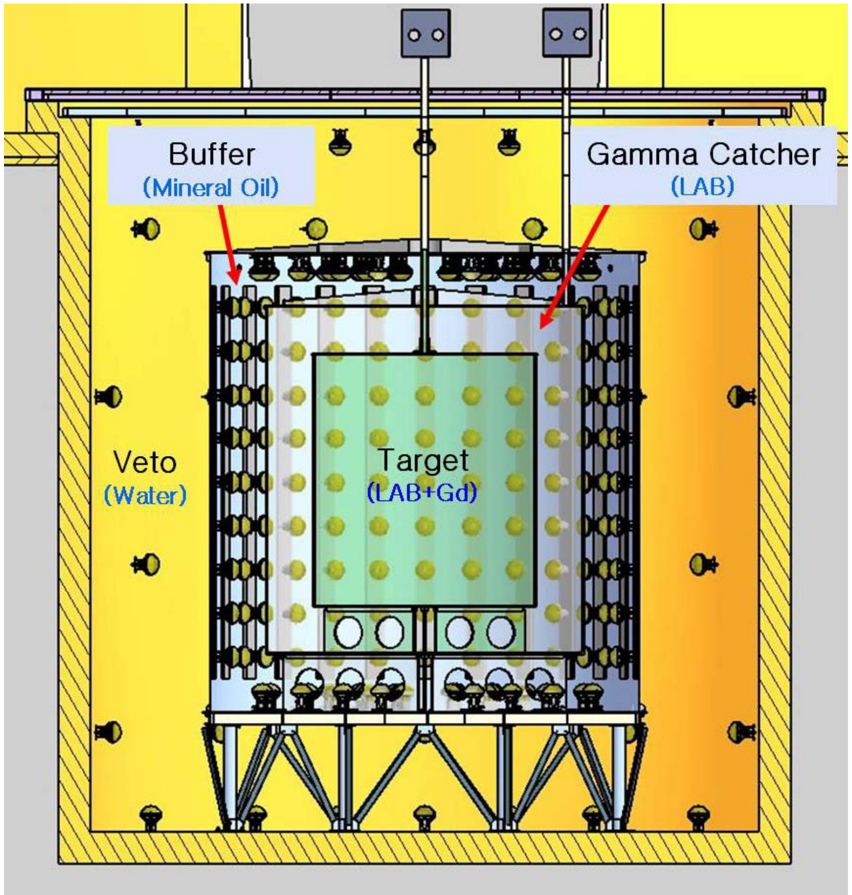
RENO

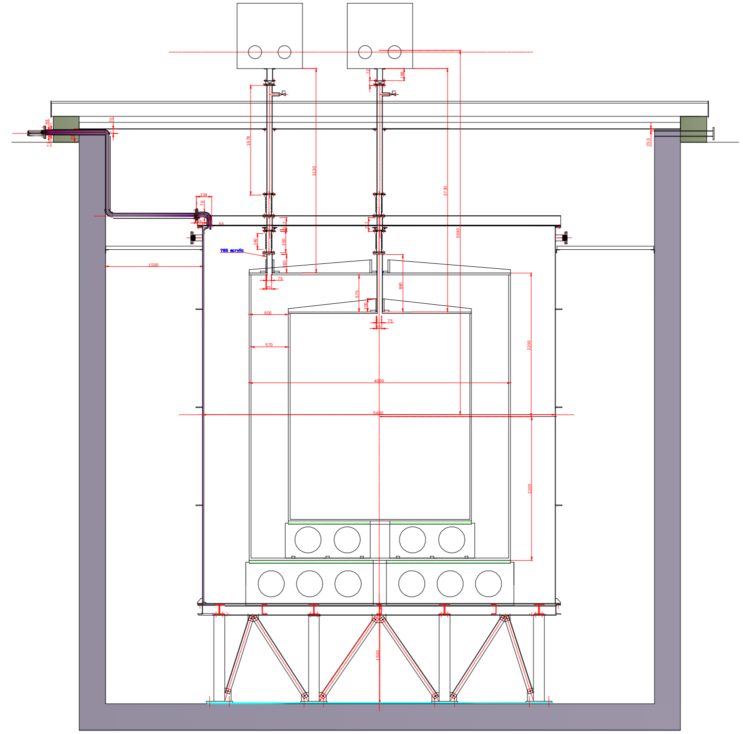
ν θ_{13}

KNRC

Korea Neutrino Research Center

RENO Detector





- **Inner PMTs: 354 10" PMTs**
  - solid angle coverage = 12.6%
- **Outer PMTs: ~ 67 10" PMTs**

	Inner Diameter (cm)	Inner Height (cm)	Filled with	Mass (tons)
Target Vessel	280	320	Gd(0.1%) + LS	16.5
Gamma catcher	400	440	LS	30.0
Buffer tank	540	580	Mineral oil	64.4
Veto tank	840	880	water	352.6

total ~460 tons

Summary of Detector Construction

- 2006. 03 : Start of the RENO project
- 2008. 06 ~ 2009. 03 : Civil construction including tunnel excavation
- 2008. 12 ~ 2009. 11 : Detector structure & buffer steel tanks completed
- 2010. 06 : Acrylic containers installed
- 2010. 06 ~ 2010. 12 : PMT test & installation
- 2011. 01 : Detector closing/ Electronics hut & control room built
- 2011. 02 : Installation of DAQ electronics and HV & cabling
- 2011. 03 ~ 06 : Dry run & DAQ debugging
- 2011. 05 ~ 07 : Liquid scintillator production & filling
- 2011. 07 : Detector operation & commissioning
- 2011. 08 : Start data-taking

Construction of Near & Far Tunnels (2008. 6~2009. 3)

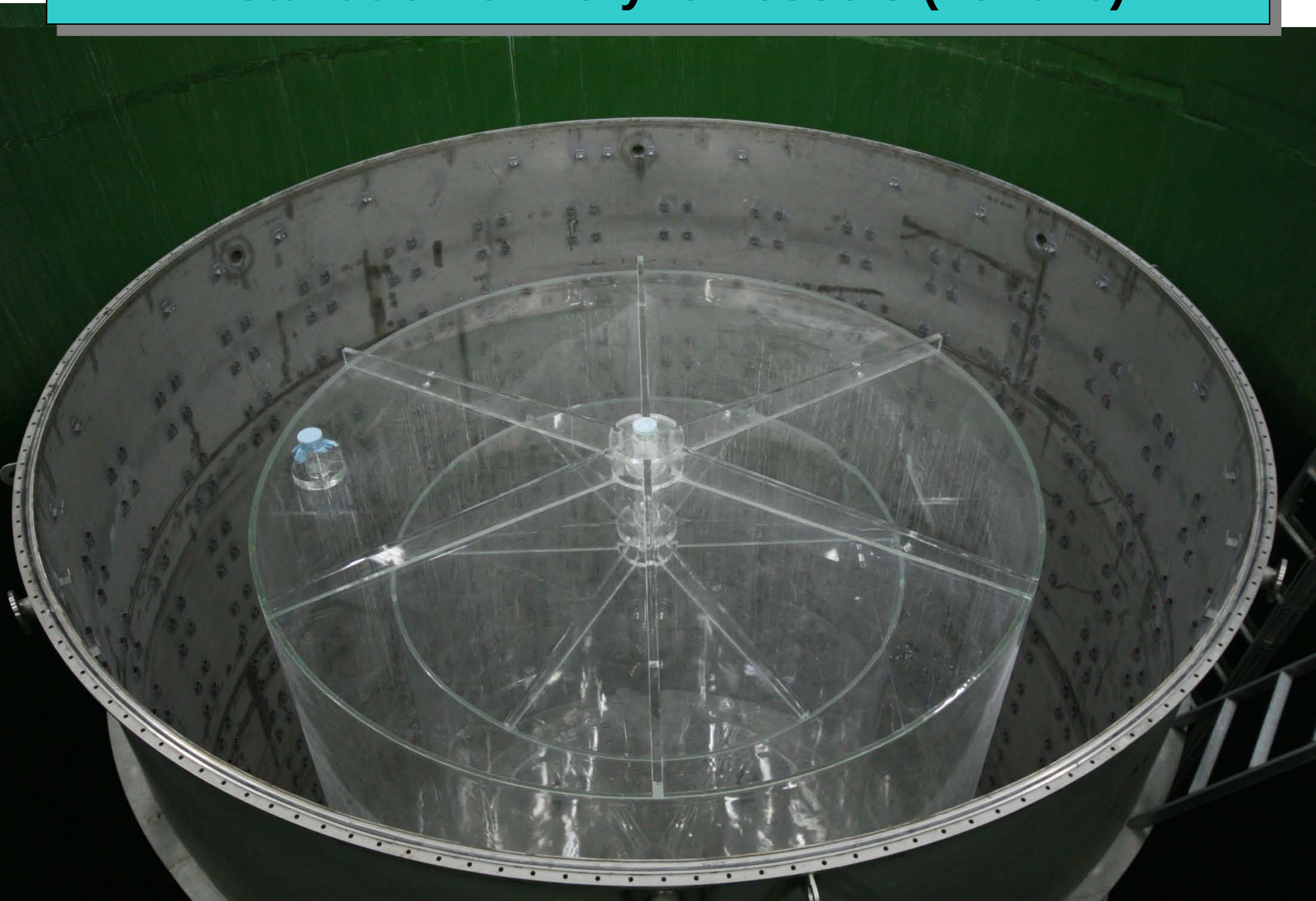
by Daewoo Eng. Co. Korea

Far site

Near site

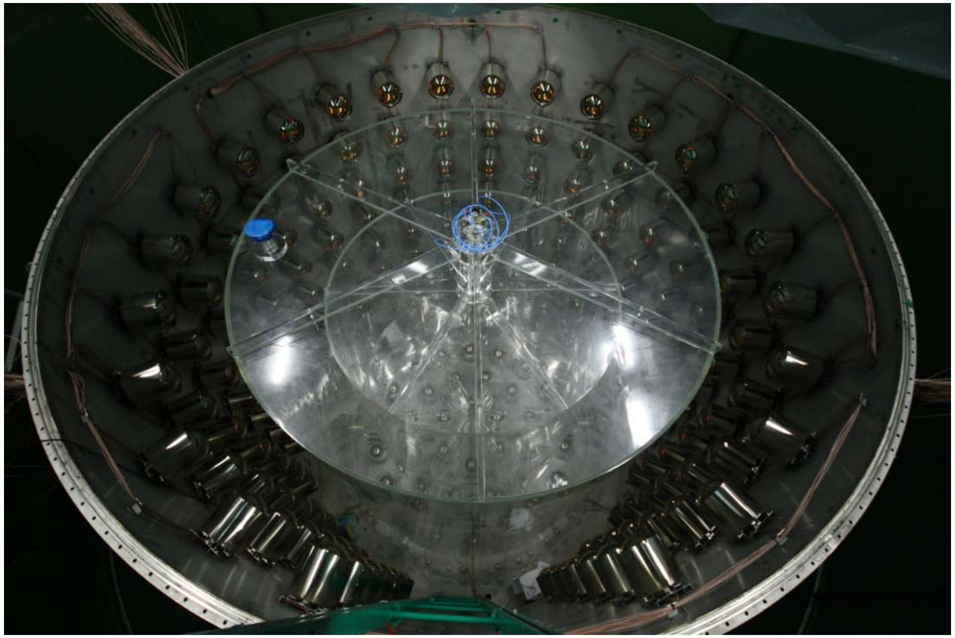
by KOATECH Co. Korea
(2009.7~2010.6)

Installation of Acrylic Vessels (2010. 6)



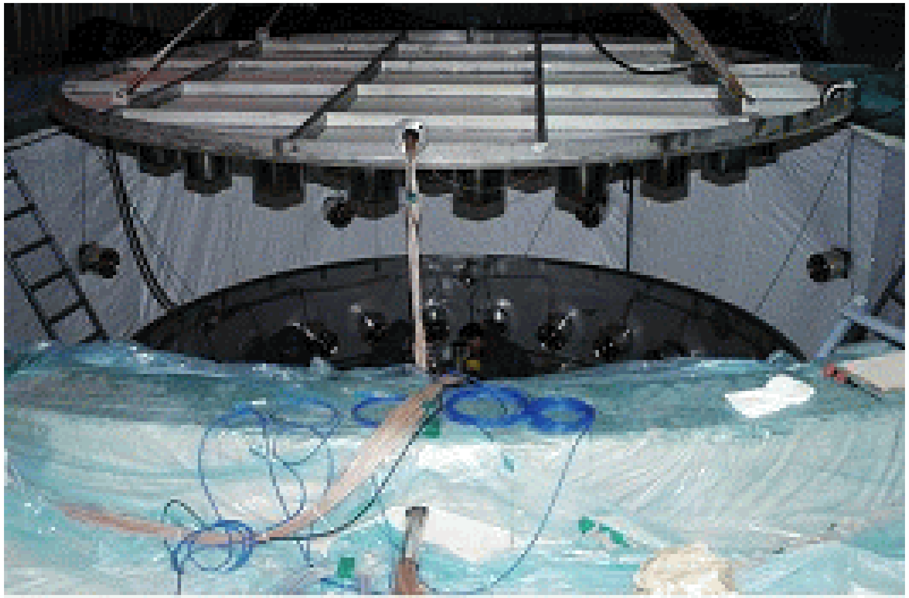
PMT Mounting (2010. 8~10)

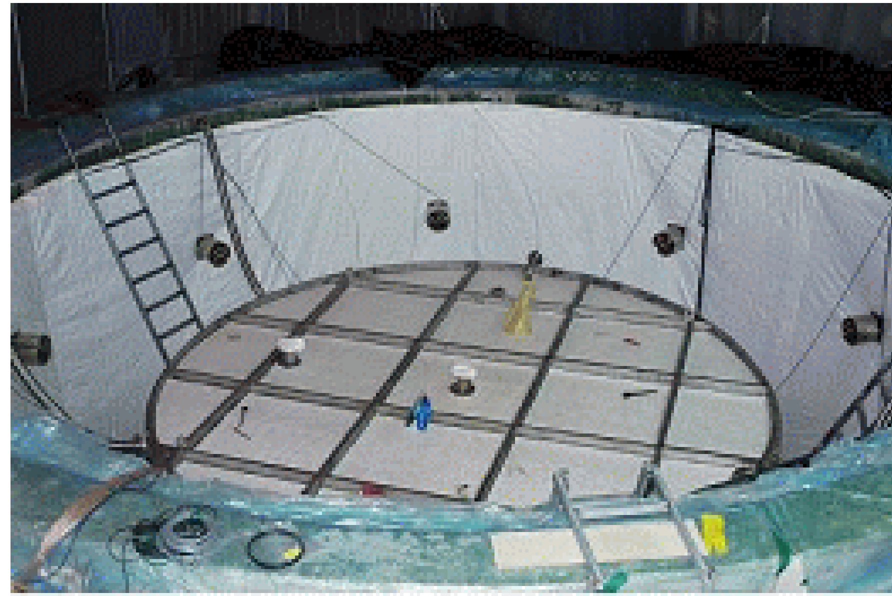
PMT Mounting (2010. 8~10)

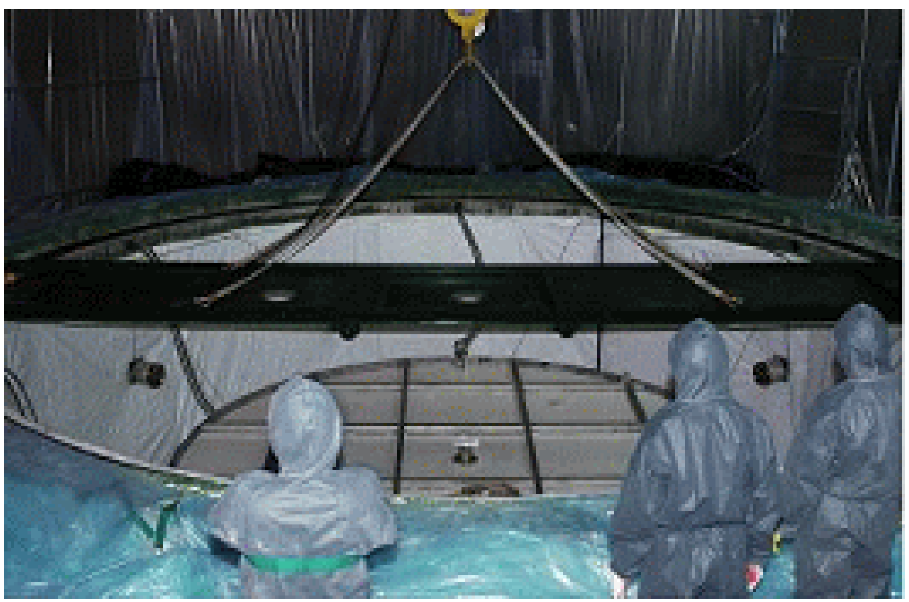


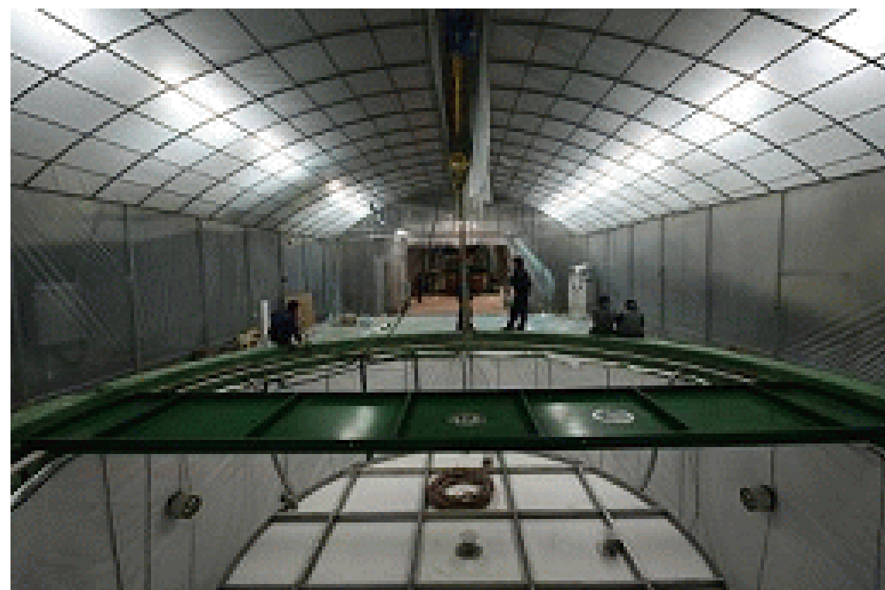
Finishing PMT installation (2011. 1)

Detector Closing (2011. 1)

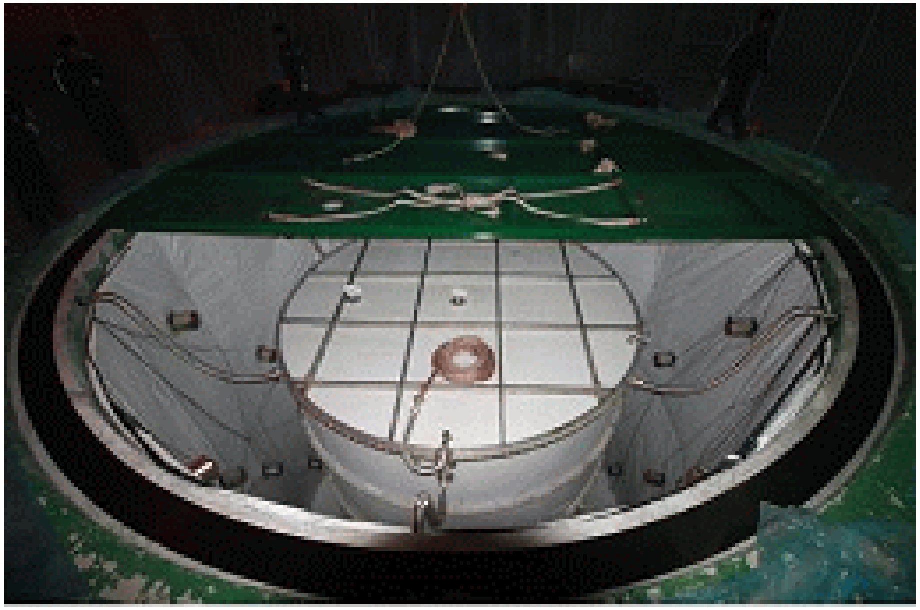




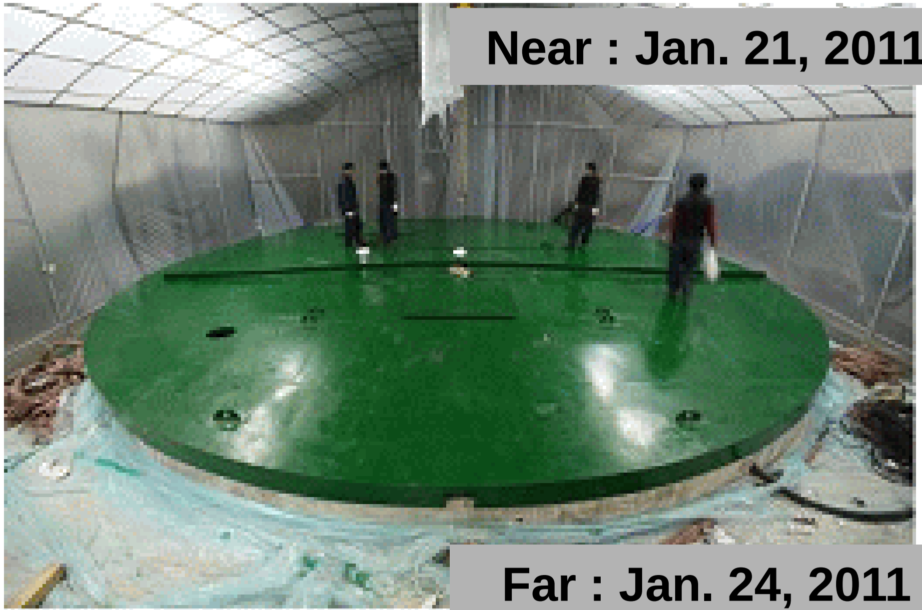




Detector Closing (2011. 1)



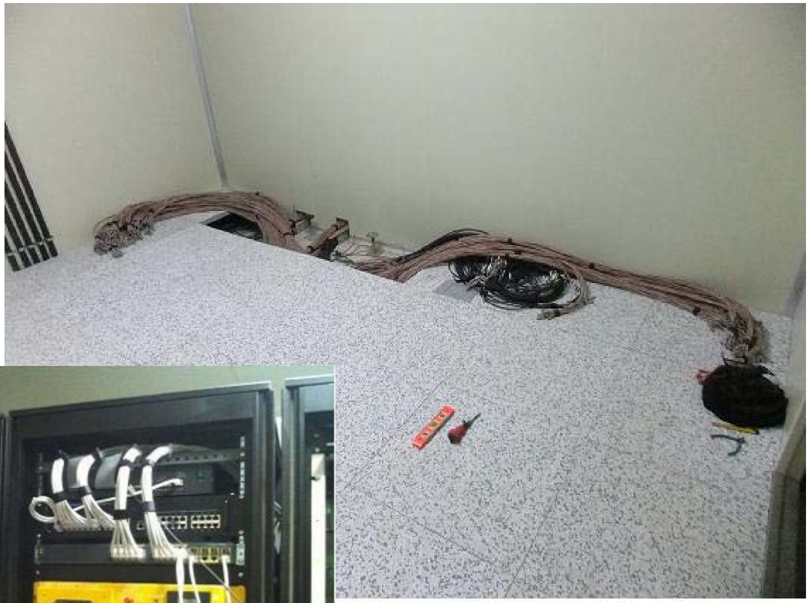
Near : Jan. 21, 2011

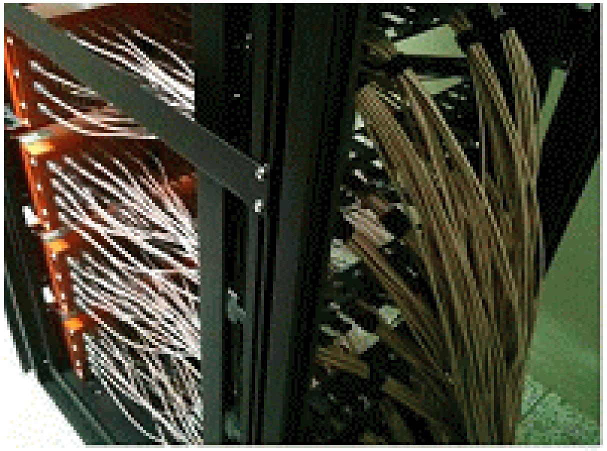


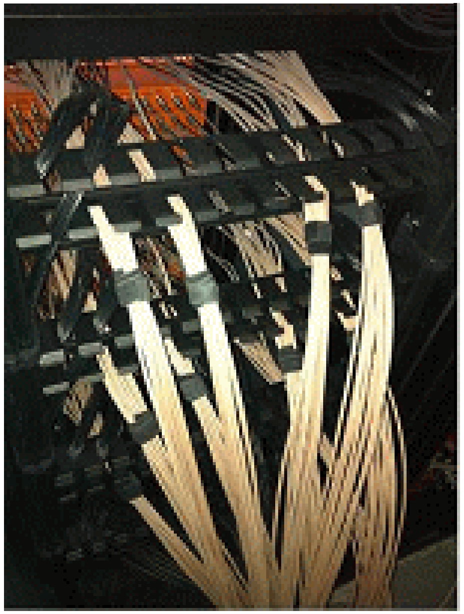
Far : Jan. 24, 2011

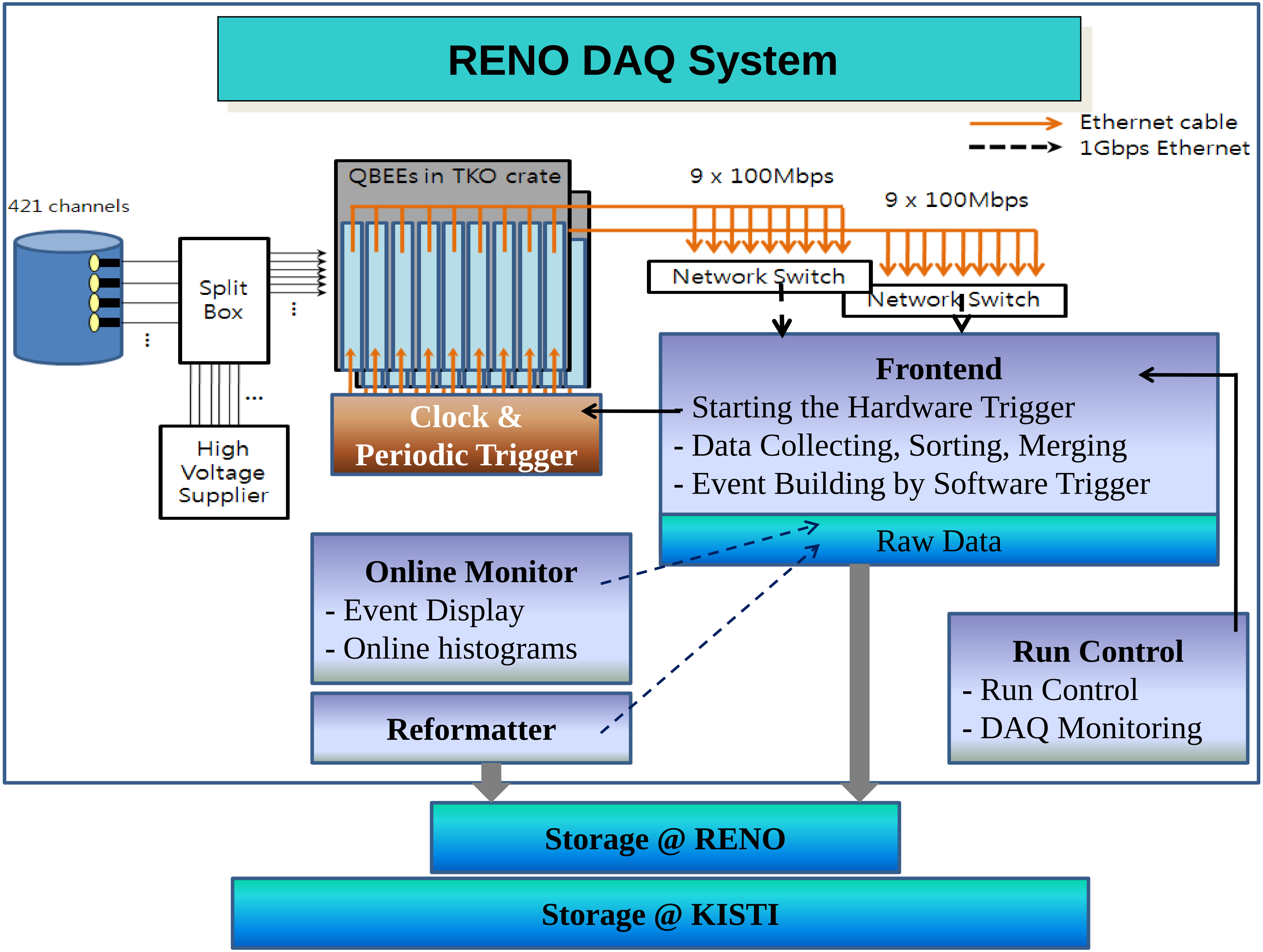
Electronics Hut & Control Room Installed (2011. 1)

PMT Cable Connection to DAQ Electronics (2011. 2)



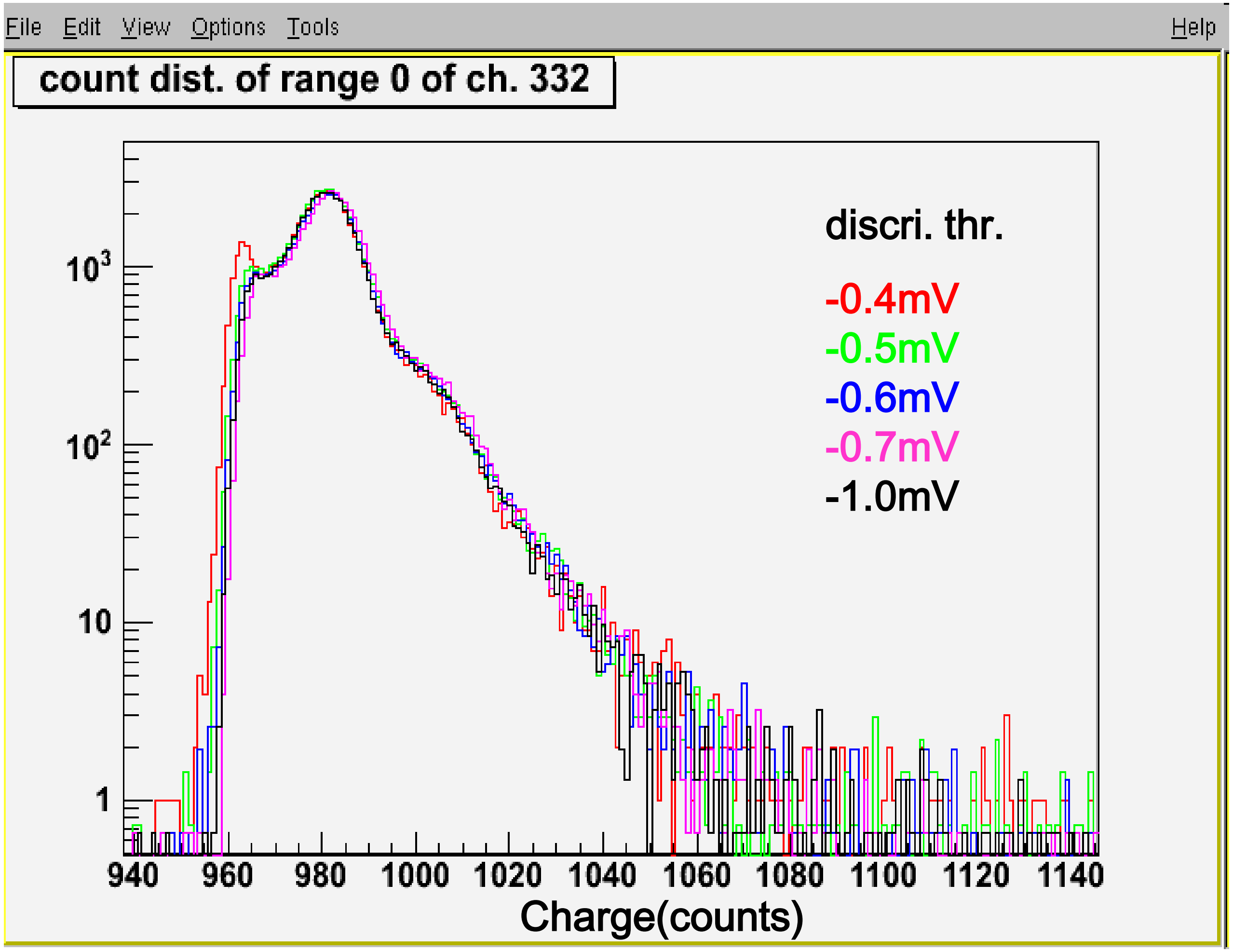





RENO DAQ System
Ethernet cable
1Gbps Ethernet
421 channels
Split Box
High Voltage Supplier
QBEEs in TKO crate
9 x 100Mbps
9 x 100Mbps
Network Switch
Network Switch
Clock & Periodic Trigger
Frontend
- Starting the Hardware Trigger
- Data Collecting, Sorting, Merging
- Event Building by Software Trigger
Raw Data
Online Monitor
- Event Display
- Online histograms
Reformatter
Run Control
- Run Control
- DAQ Monitoring
Storage @ RENO
Storage @ KISTI

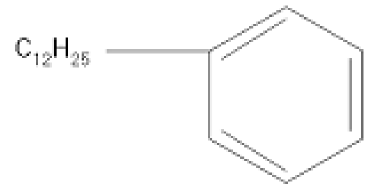
Dry Runs (2011. 3 ~ 5)

- Electronics threshold : 1mV based on PMT test with a bottle of liquid scintillator and a ^{137}Cs source at center

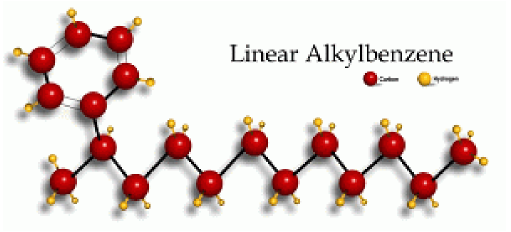


Gd Loaded Liquid Scintillator

C_nH_{2n+1}-C_6H_5 (n=10~14)



Linear Alkyl Benzene (LAB)

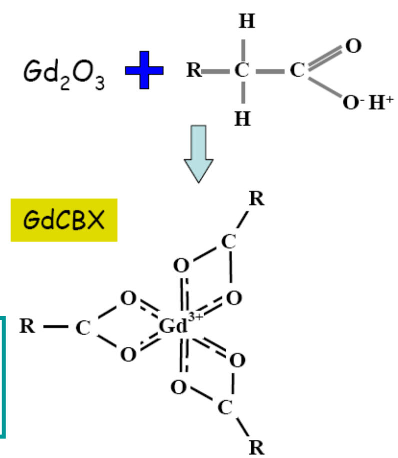


❑ Recipe of Liquid Scintillator

Aromatic Solvent & Flour	WLS	Gd-compound
LAB	PPO + Bis-MSB	0.1% Gd+TMHA (trimethylhexanoic acid)

- High Light Yield : not likely Mineral oil(MO)
- replace MO and even Pseudocume(PC)
- Good transparency (better than PC)
- High Flash point : 147^{o}C (PC : 48^{o}C)
- Environmentally friendly (PC : toxic)
- Components well known (MO : not well known)
- Domestically available: Isu Chemical Ltd.

Carboxylic acids

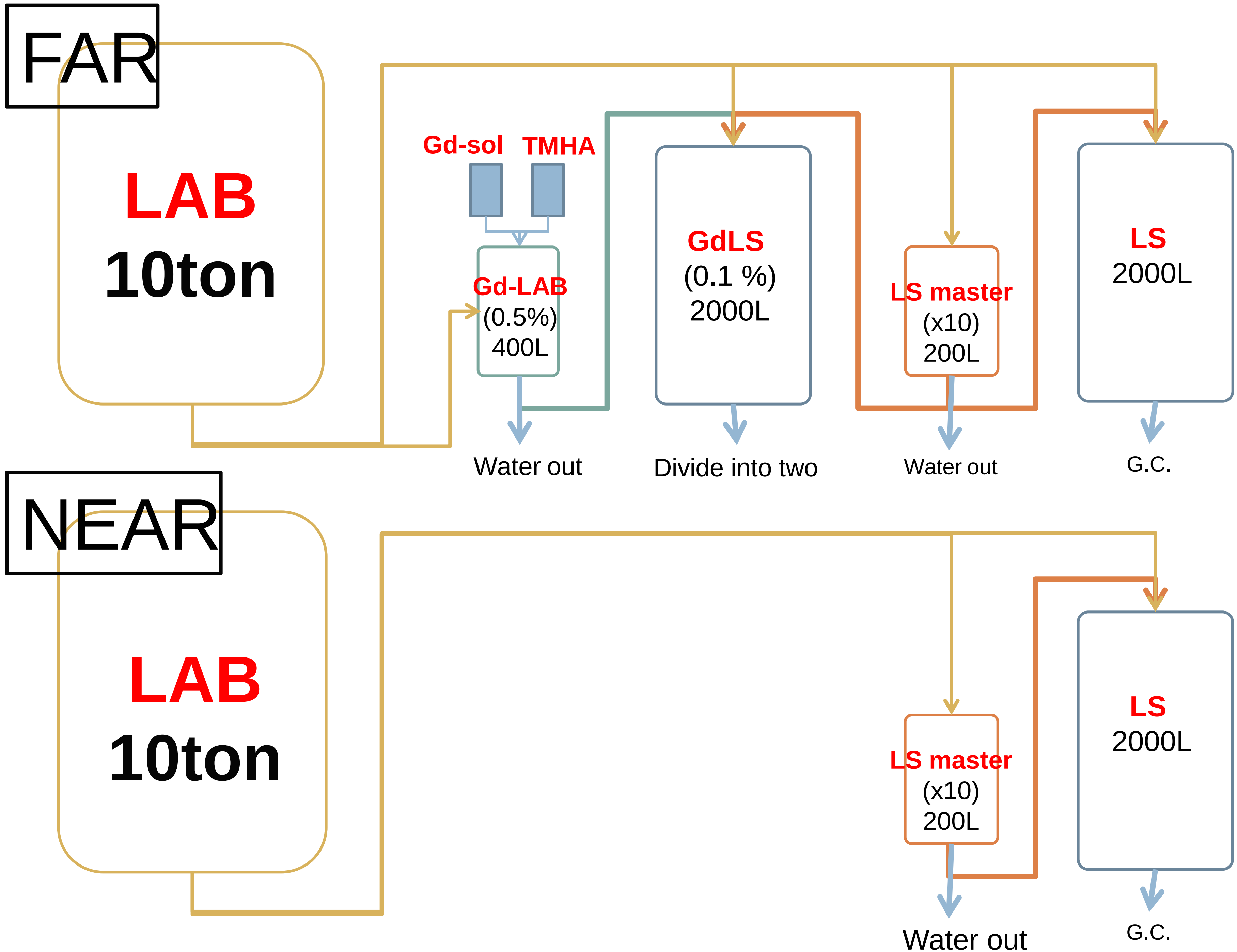


❑ Solvent-solvent extraction method

$$RCOOH + NH_3 \cdot H_2O \rightarrow RCOONH_4 + H_2O$$
$$3RCOONH_4(aq) + GdCl_3(aq) \rightarrow Gd(RCOO)_3 + 3NH_4Cl$$

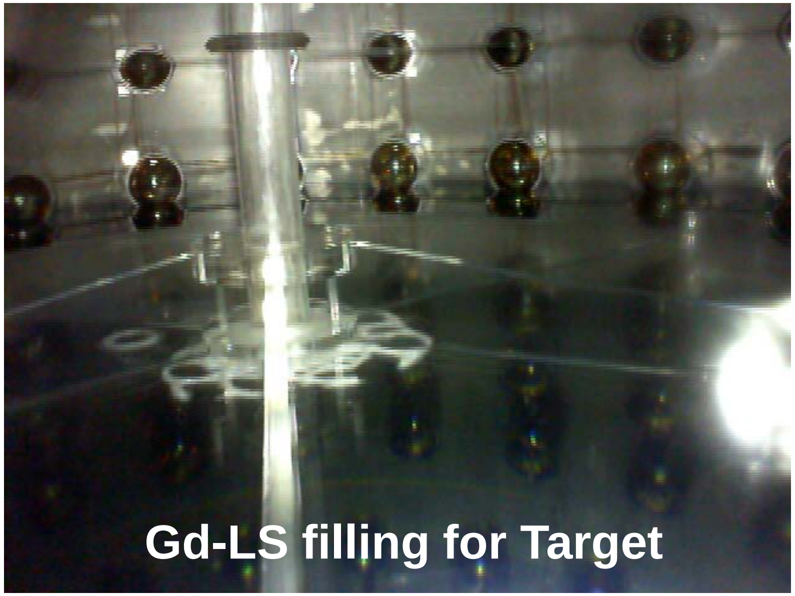
❑ 0.1% Gd compounds with CBX (Carboxylic acids; R-COOH)

- CBX : TMHA (trimethylhexanoic acid)


FAR
LAB
10ton
Gd-sol
TMHA
Gd-LAB
(0.5%)
400L
GdLS
(0.1 %)
2000L
LS master
(x10)
200L
LS
2000L
Water out
Divide into two
Water out
G.C.
NEAR
LAB
10ton
LS master
(x10)
200L
LS
2000L
Water out
G.C.

Liquid Production System (2010. 11~2011. 3)

Liquids Filling

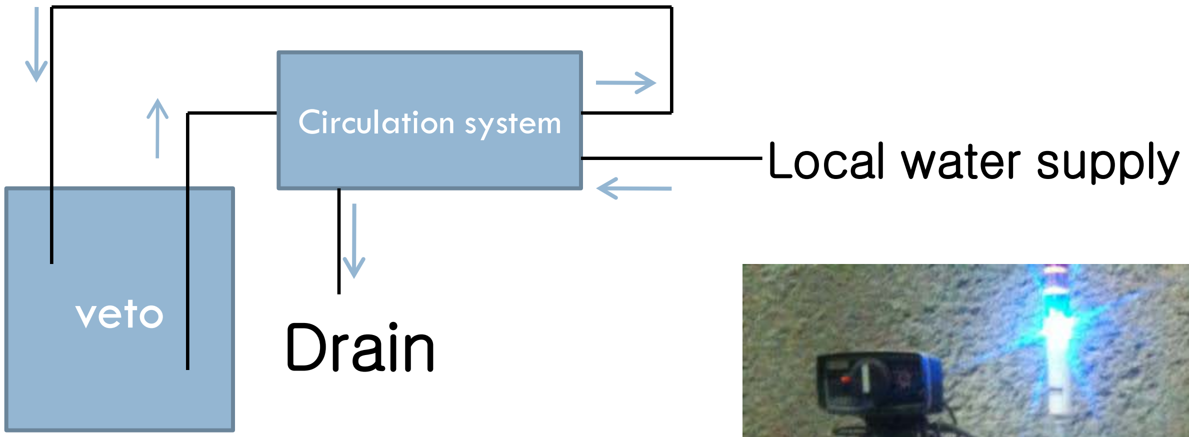

Gd-LS filling for Target


LS filling for Gamma Catcher


Water filling for Veto

- Both near and far detectors are filled with Gd-LS, LS & mineral oil as of July 5, 2011.
- Veto water filling is completed at the end of July, 2011.

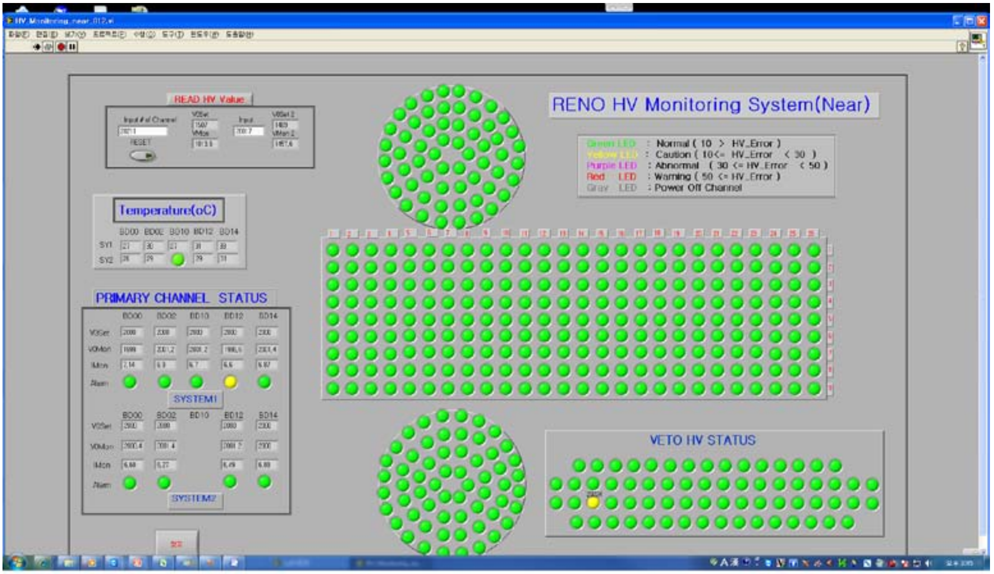
Water Circulation System



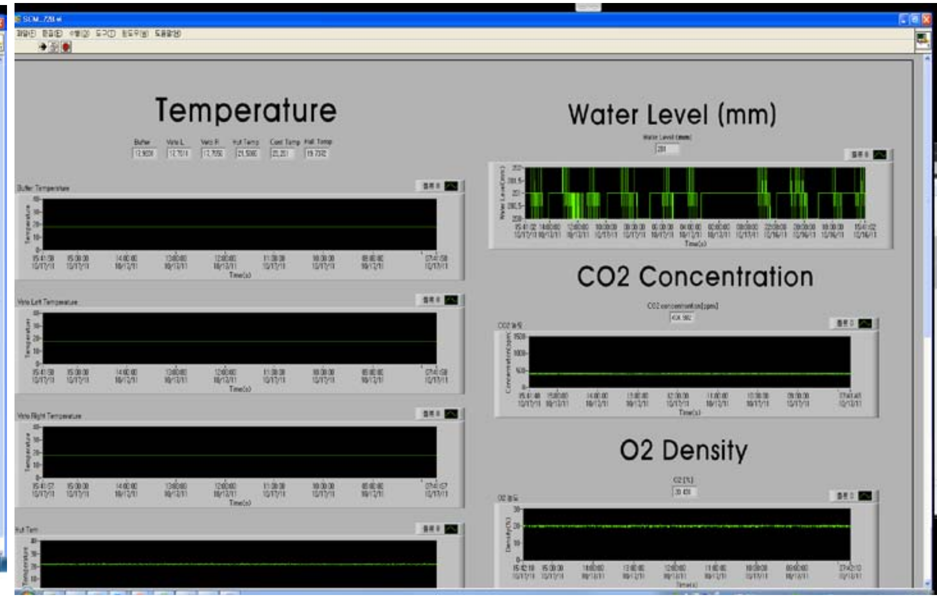
- Ultra-pure water system is important for VETO.
- Solenoid valve : Auto on/off
- Feedback from the ultrasonic level sensor of water level

Slow Control & Monitoring System

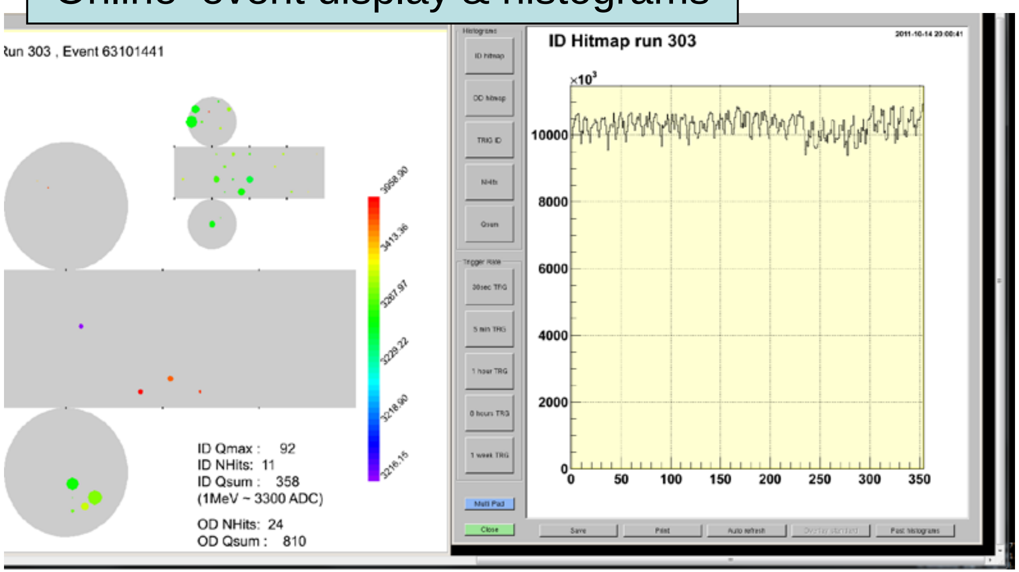
HV monitoring system



Environmental monitor



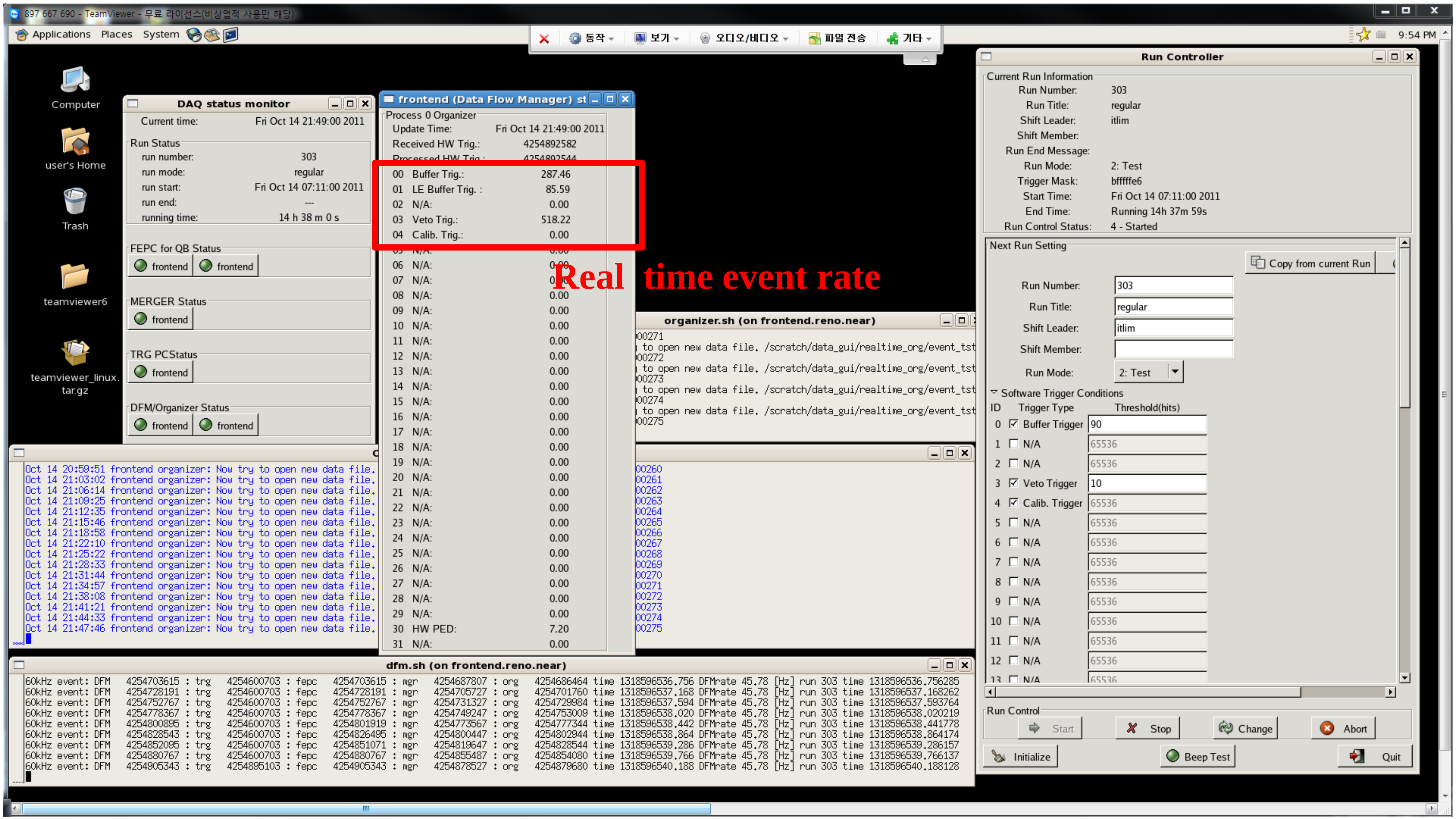
Online event display & histograms



Why slow monitoring ?

1. To be required to control systematic effects
2. To allow automated scans of parameters such as thresholds and high voltages
3. To provide alarms, warnings, and diagnostic information to the operators

RUN Control & DAQ Monitoring

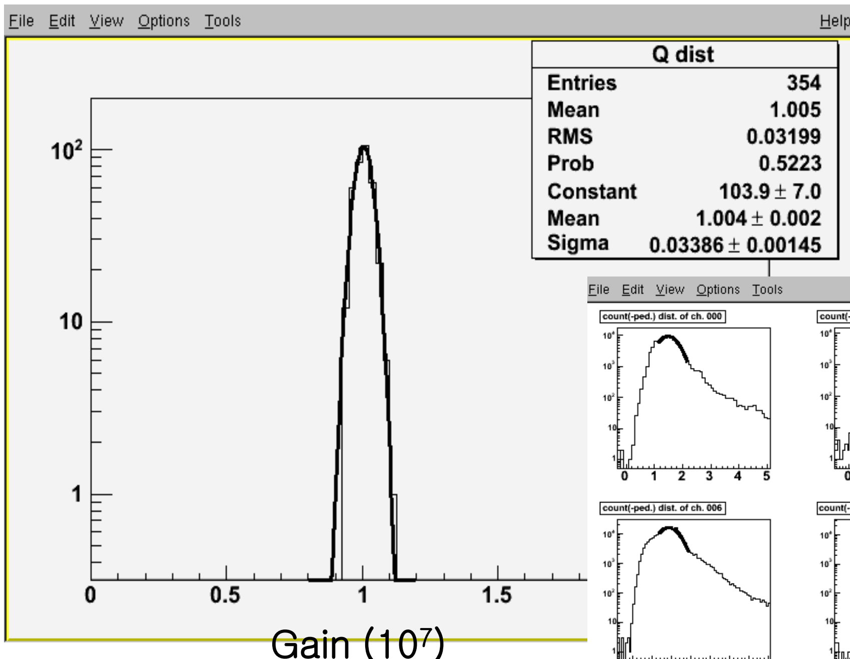


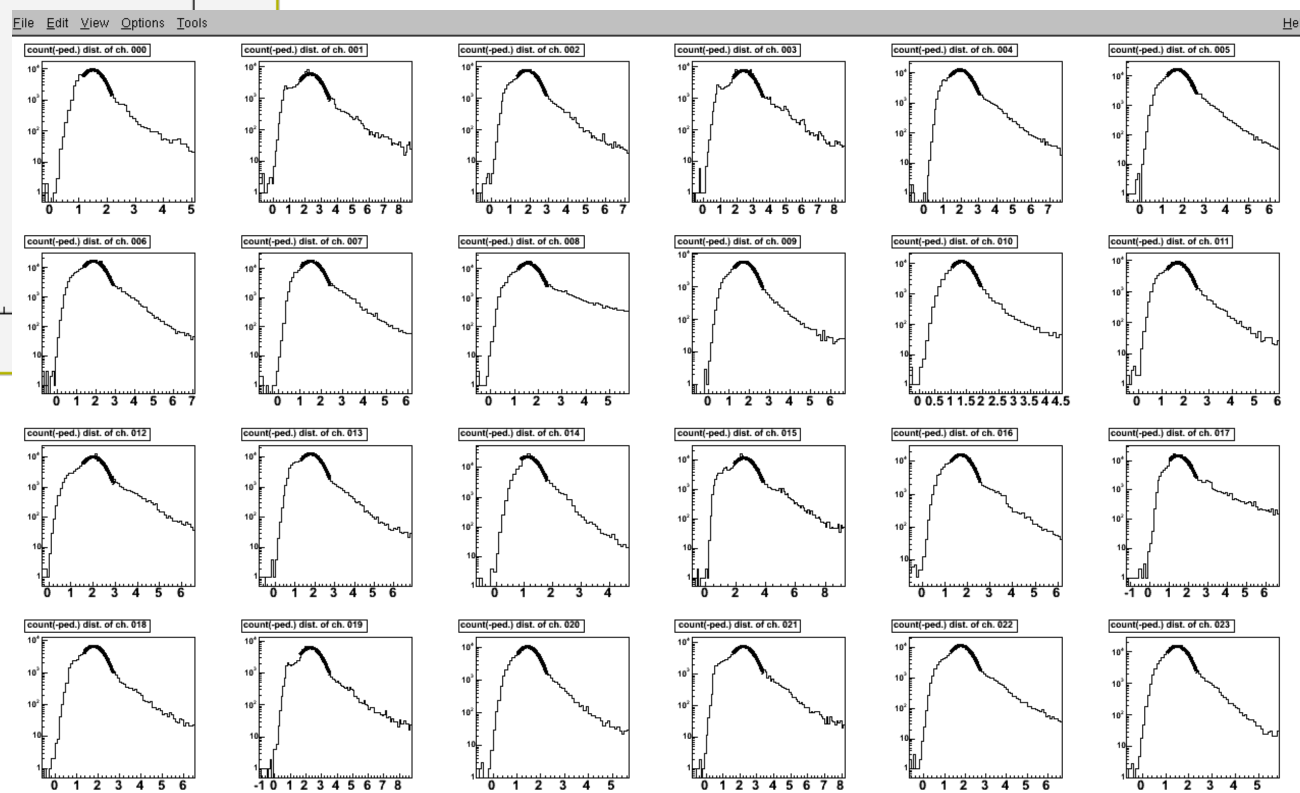
IP Camera System with Central Management System

- ❑ Two detectors (ND/FD) are controlled & monitored from one (far) site
- ❑ Both systems are quite stable & working smoothly

PMT Gain Matching

- PMT gain : set 1.0×10^7 using a ^{137}Cs source at center
- Gain variation among PMTs : 3% for both detectors.



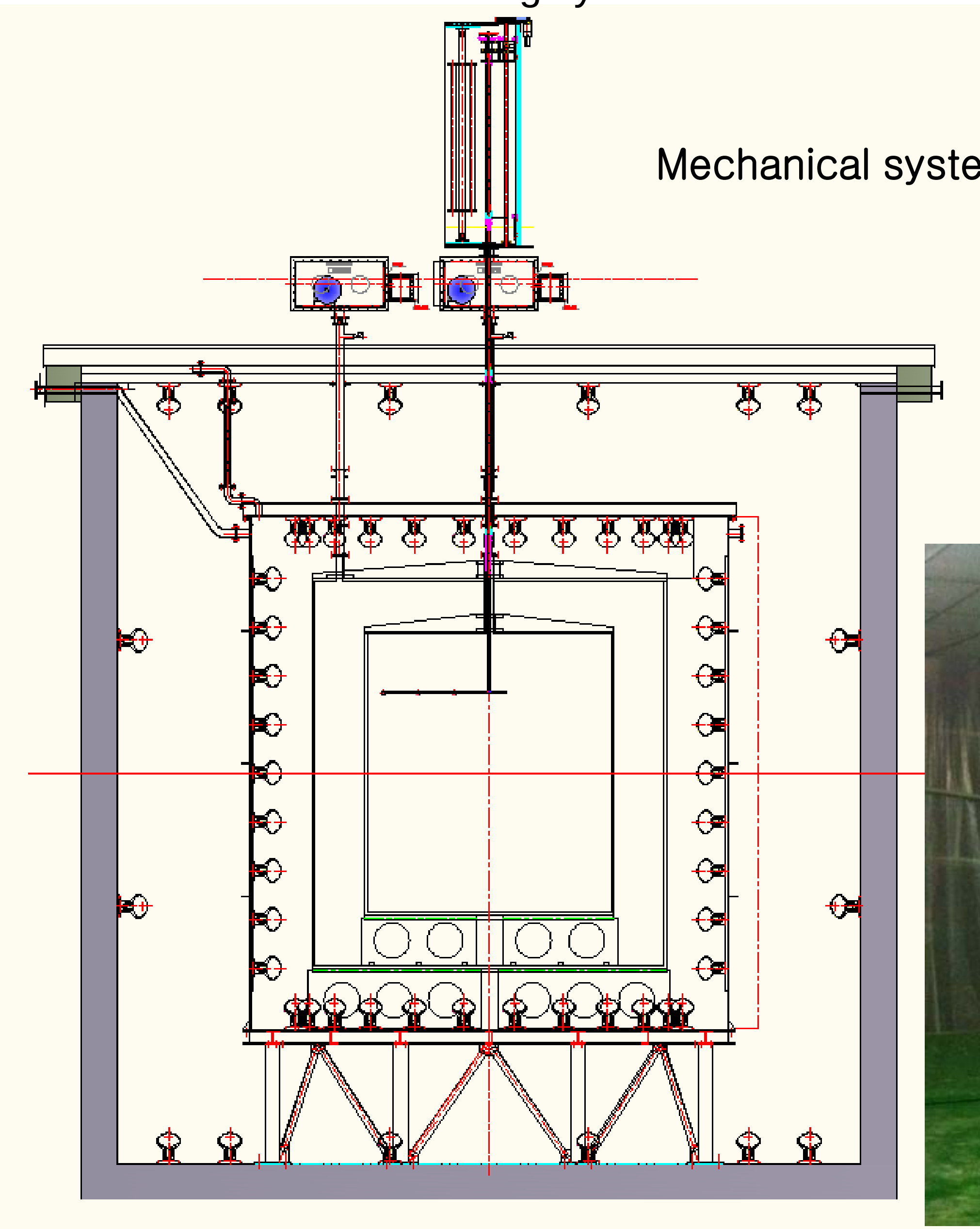


Data Taking with Near & Far Detectors

- Data taking began on Aug. 1, 2011 with both near and far detectors and has been in smooth progress.
- DAQ efficiency > 90%.
- Trigger rate of single low energy events : 70~80 Hz
  (Nhit > 90, i.e. E>0.5~0.6 MeV)
- Trigger rate of veto events : ~ 60 Hz (FD), ~530Hz (ND)
- Data taking shifts
  - Aug. 1 ~ Sep. 30 : 6 shifts per day inside both tunnels
  - Oct. 1 : 3 shifts per day in front of the far tunnel
    (remote control of both ND & FD detectors)

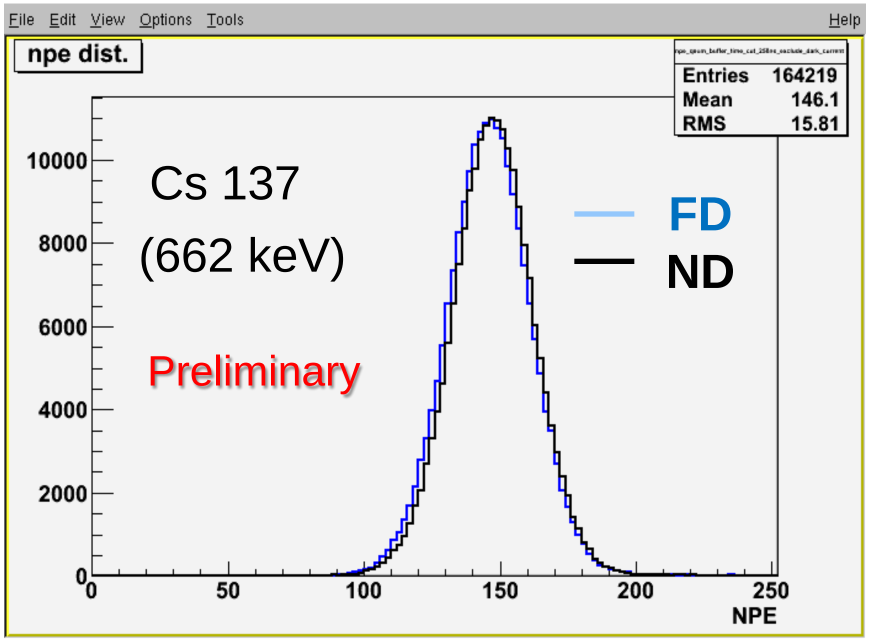
1D/3D Calibration System (2010. 8 ~ 2011. 7)

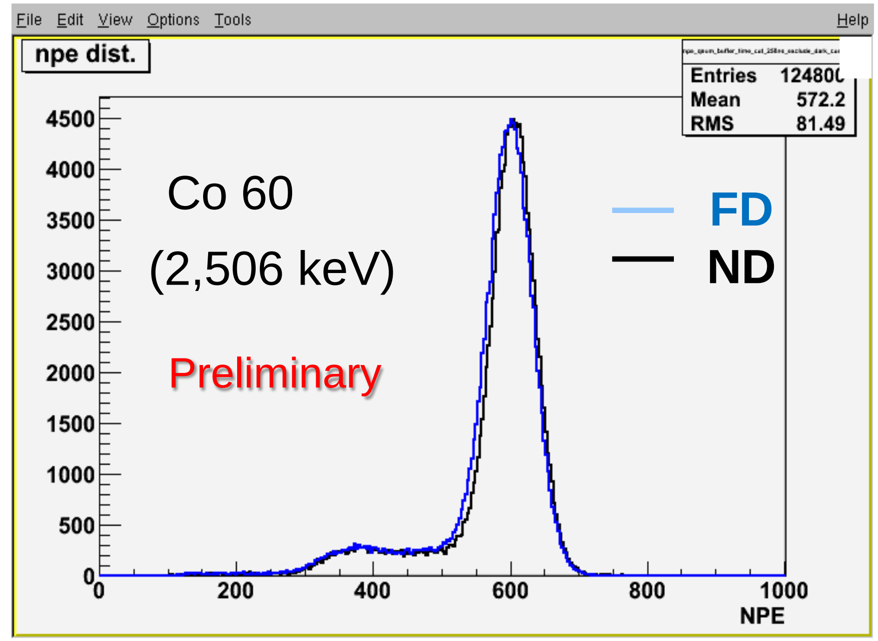
Two identical source driving systems at the center of TARGET and one side of GAMMA CATCHER

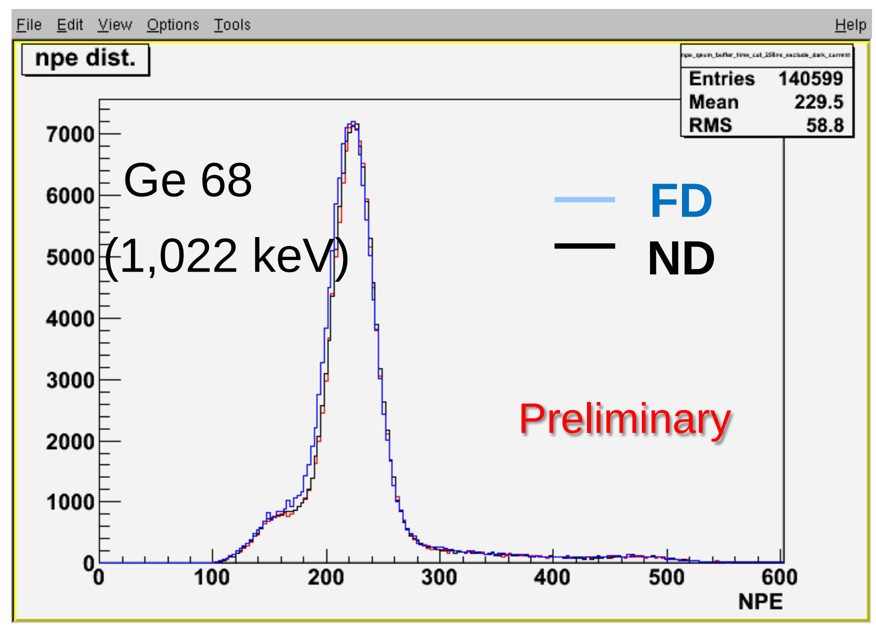


Mechanical system

Energy Calibration and Comparison of ND & FD



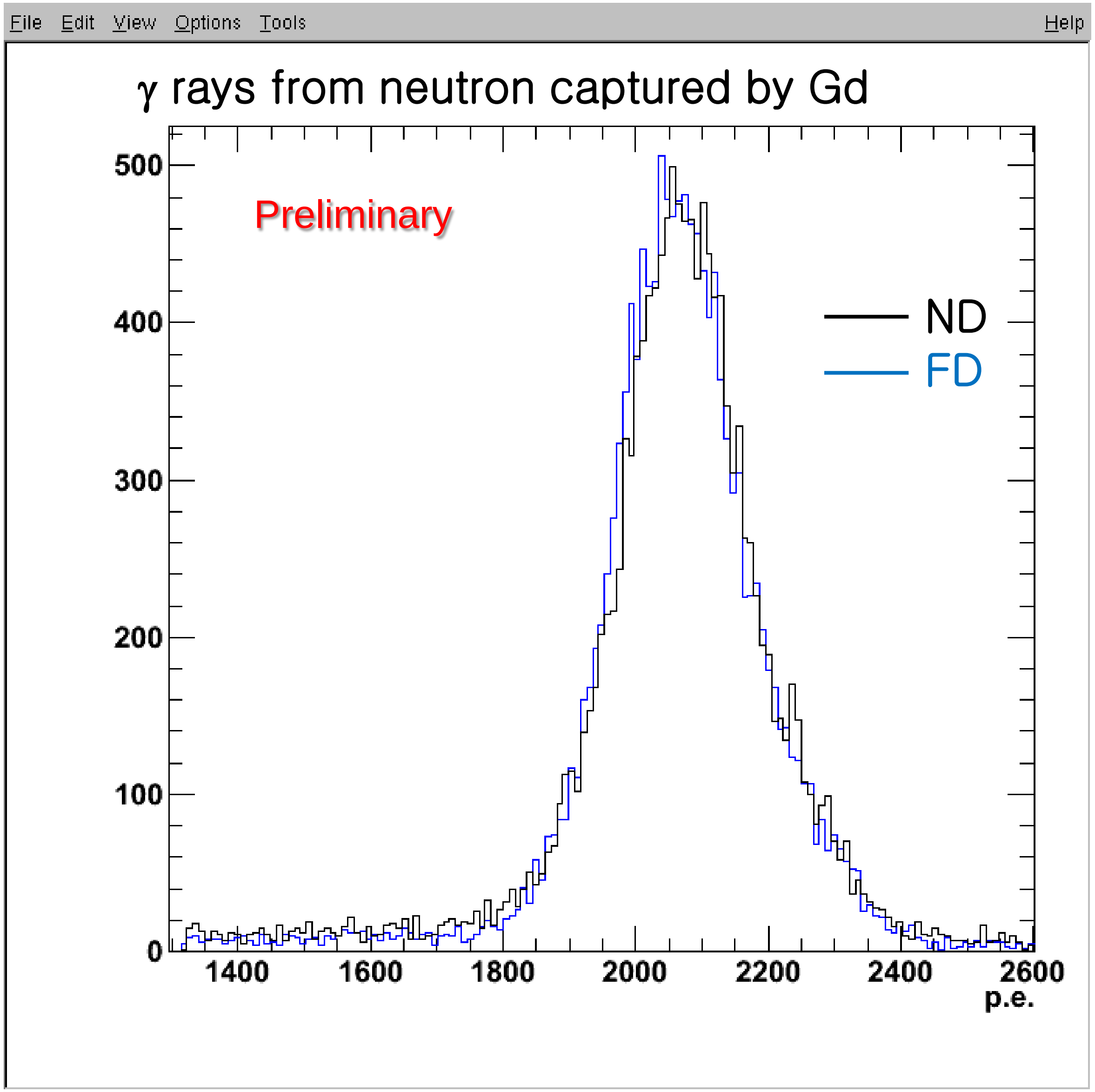




- ~ 230 pe/MeV (sources at center)
- Identical energy response (< 1%) of ND & FD

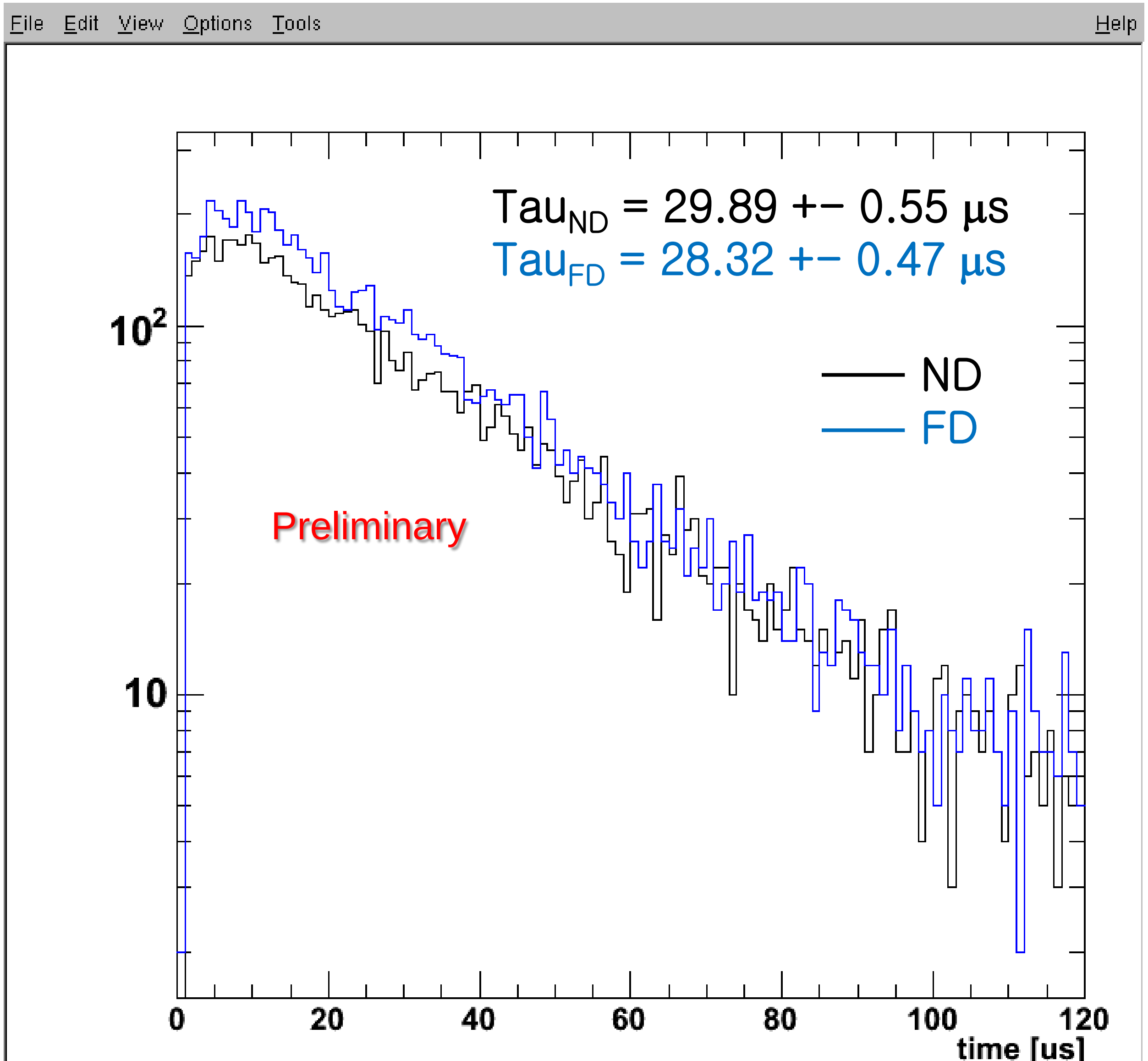
Gd neutron capture signal

^{252}Cf source



- **We are observing Gd capture as expected by simulation at both detectors**

Capture Time Distribution

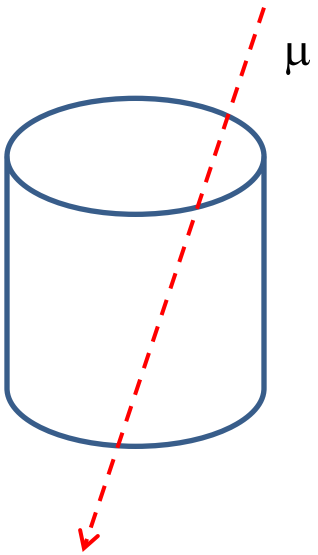


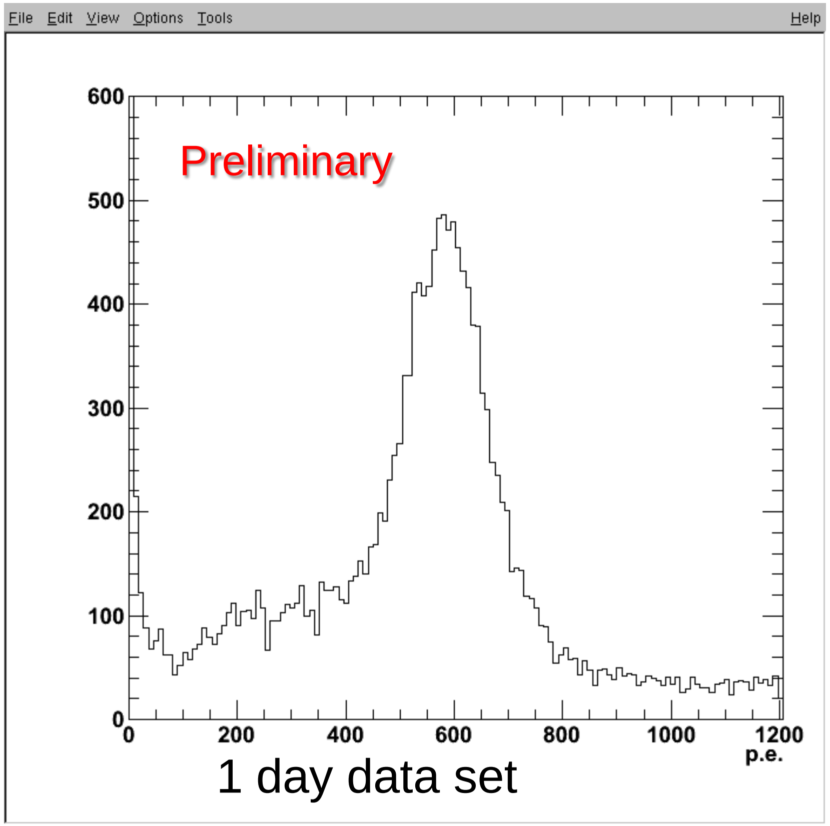
Both detectors have capture time ~30 μs

BG Analysis

2.2 MeV γ rays from cosmic muon induced neutron capture by Hydrogen

β-neutron Cascades
(Cosmogenics)



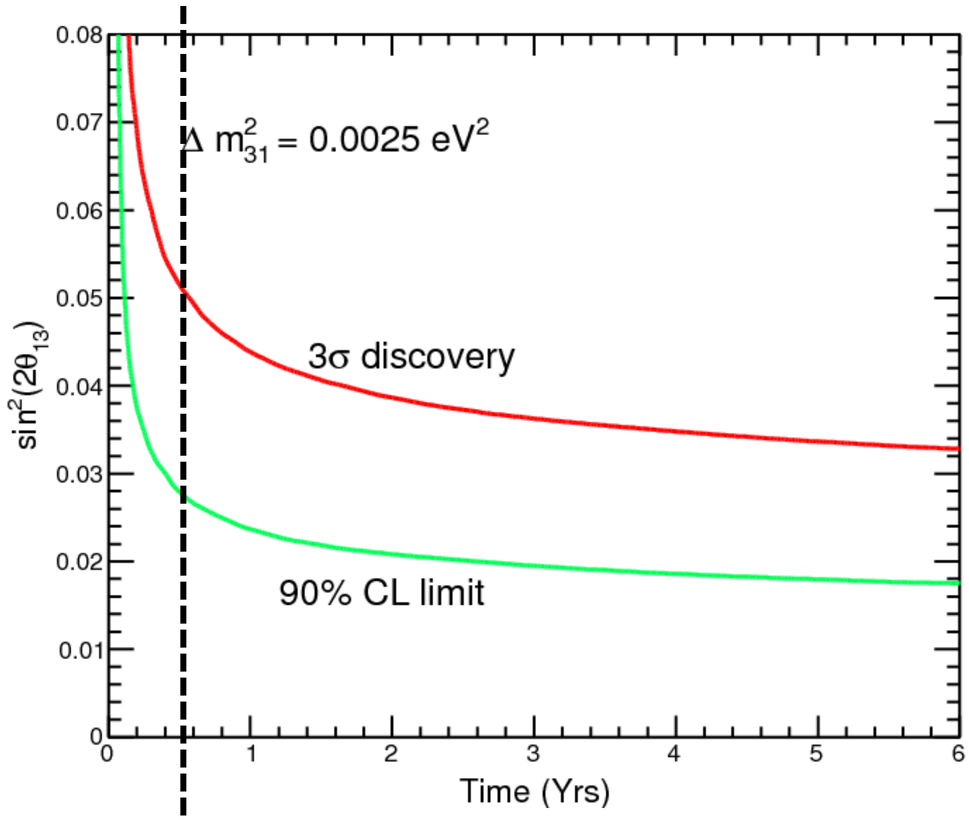


- ✓ **Cosmic muons crossing the detector create neutrons**
- ✓ **Neutron could be later captured on Hydrogen & release ~2.2 MeV**
- ✓ **We know that how many produced per day & this BG can be measured and subtracted**

Summary of RENO Status

- Construction of both near and far detectors at RENO are completed in Feb. 2011
- All the liquids including Gd-LS are produced and filled by end of July 2011
- Regular data-taking with NEAR & FAR detectors began from August 1, 2011
  - Preliminary result shows satisfactory detector performance
  - Detector calibration and comparison of ND & FD are performed
- Data reduction, source calibration, and Monte-Carlo reconstruction efforts are on progress & going on smoothly

- First results on $\sin^2(2\theta_{13})$ ~0.05 are expected to be available within a half year
  - Goal: ~0.07 (end of this yr)
    ~0.05 (March, 2012)



- RENO group hope to tell the value of $\sin^2(2\theta_{13})$ at the anticipated time
  - **Goal: Neutrino 2012 @ Kyoto (June, 2012)**