Current Status of RENO

(3rd CHIPP Neutrino Workshop

Nov. 17-18, 2008, ETHZ, Swiss)

Soo-Bong Kim
Seoul National Univ.

New Reactor Neutrino θ_{13} Experiment

- CHOOZ : R_{osc} = 1.01 ± 2.8% (stat) ± 2.7% (syst)

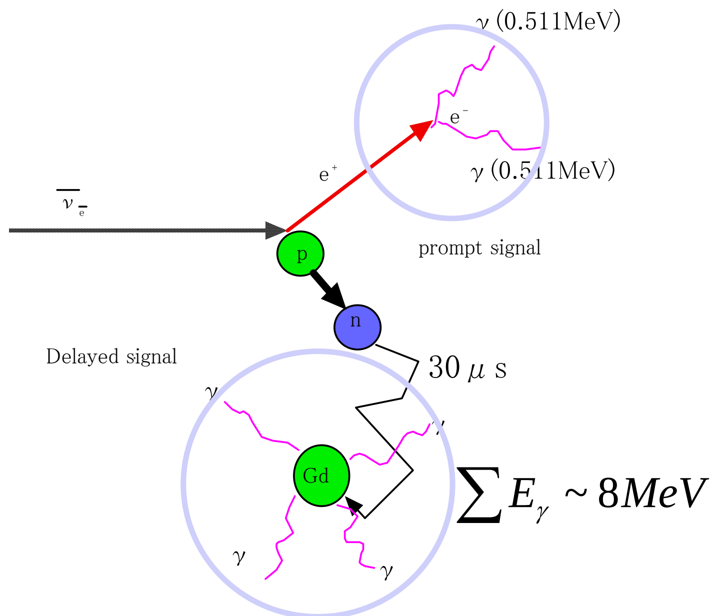
$$\bar{\nu}_e + p \to e^+ + n$$

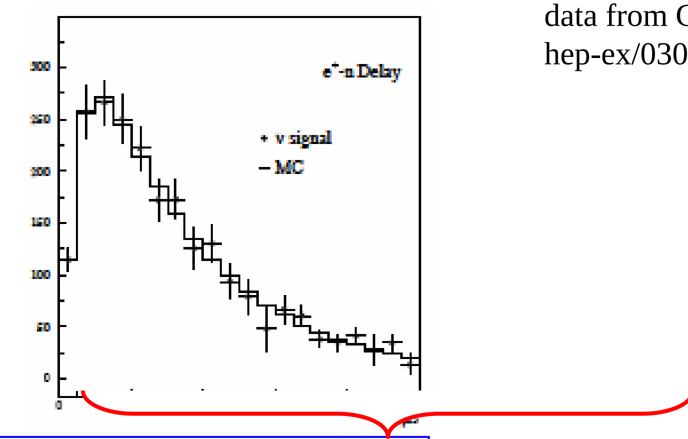
- Larger statistics
  - More powerful reactors (multi-core)
  - Larger detection volume
  - Longer exposure
- Smaller experimental errors
  - Identical multi detectors
- Lower background
  - Improved detector design
  - Increased overburden

→ Obtain ~1% precision !!!

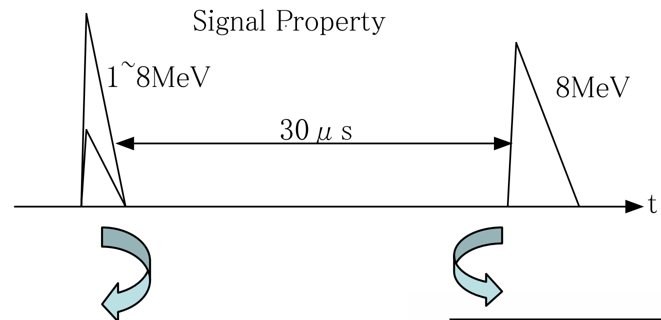
Detection of Reactor Neutrinos

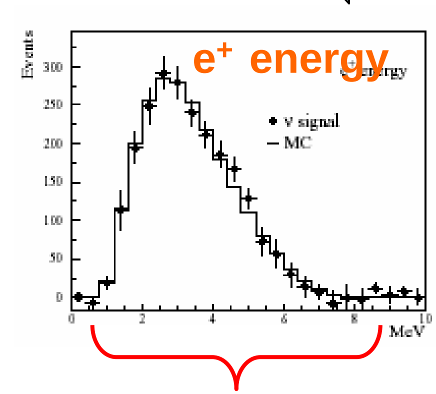
data from CHOOZ
hep-ex/0301017v1

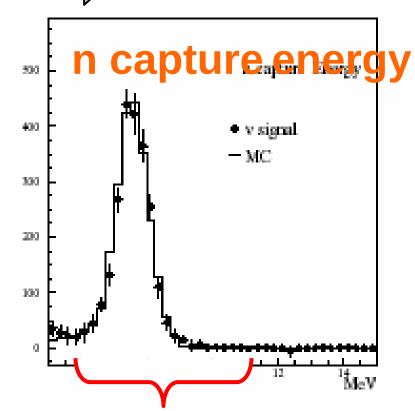




(3) 1μs<ΔT <200μs







(1) 0.7<$E_{prompot}$ <9MeV

(2) 5<$E_{delayed}$ <11MeV

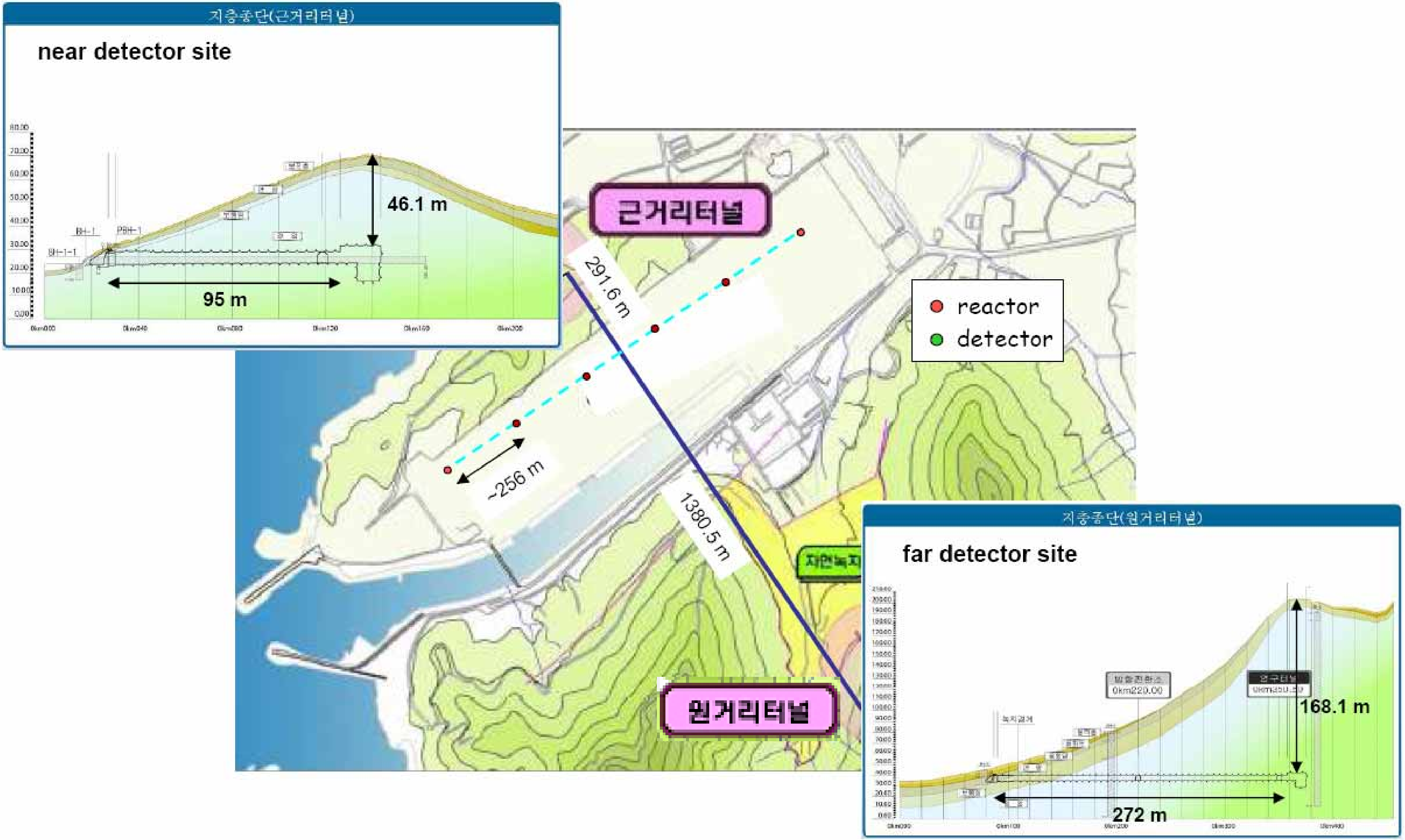
RENO Collaboration

- ❑ Chonnam National University
- ❑ Dongshin University
- ❑ Gyeongsang National University
- ❑ Kyungpook National University
- ❑ Pusan National University
- ❑ Sejong University
- ❑ Seoul National University
- ❑ Sungkyunkwan University
- ❑ Institute of Nuclear Research RAS (Russia)
- ❑ Institute of Physical Chemistry and Electrochemistry RAS (Russia)

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

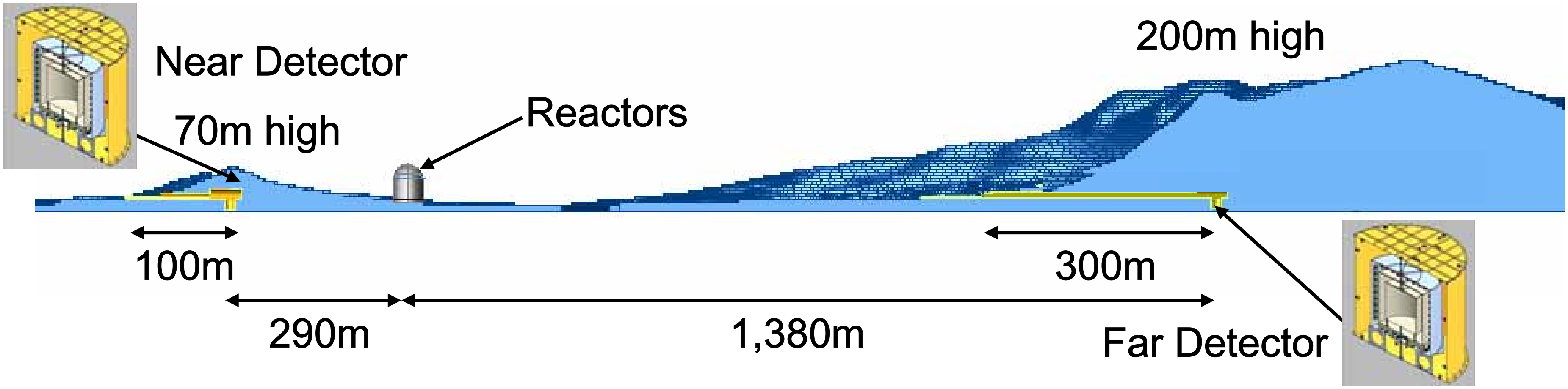
South
Korea
Ulchin
Wolsong
Yonggwang
Kori
Reactors in Korea
Japan

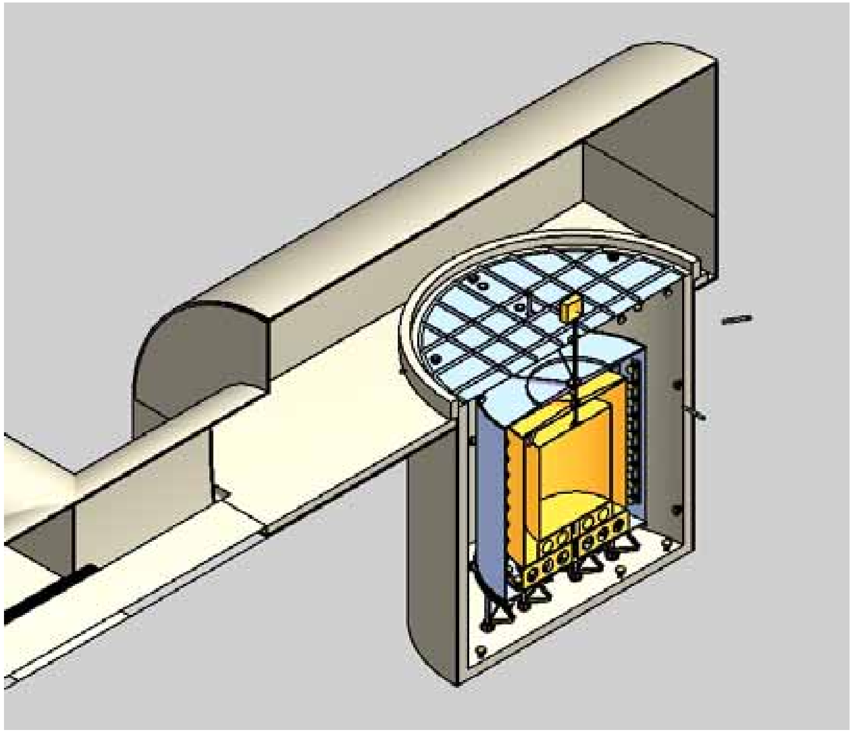
Schematic Setup of RENO at YeongGwang

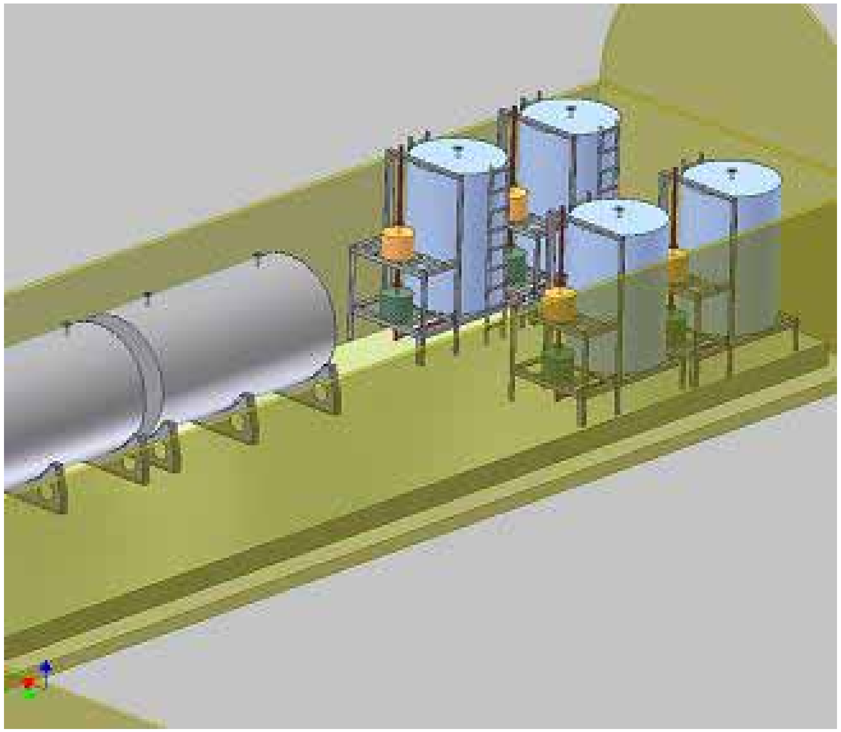


Google Satellite View of YongGwang Site

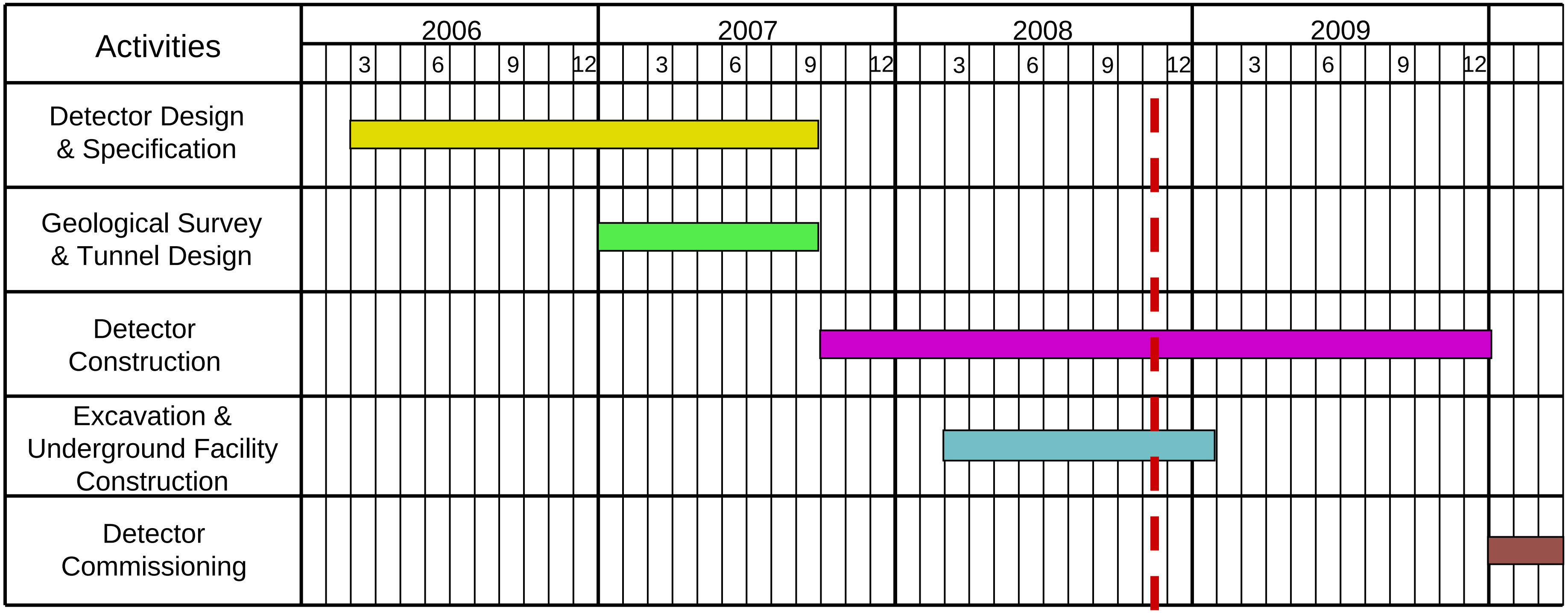
Schematic View of Underground Facility







Schedule



Activities
2006
2007
2008
2009
3
6
9
12
Detector Design & Specification
Geological Survey & Tunnel Design
Detector Construction
Excavation & Underground Facility Construction
Detector Commissioning

Comparison of Reactor Neutrino Experiments

Experiments	Location	Thermal Power (GW)	Distances Near/Far (m)	Depth Near/Far (mwe)	Target Mass (tons)
Double-CHOOZ	France	8.7	280/1050	60/300	10/10
RENO	Korea	17.3	290/1380	120/450	16/16
Daya Bay	China	11.6	360(500)/1985(1613)	260/910	40×2/80

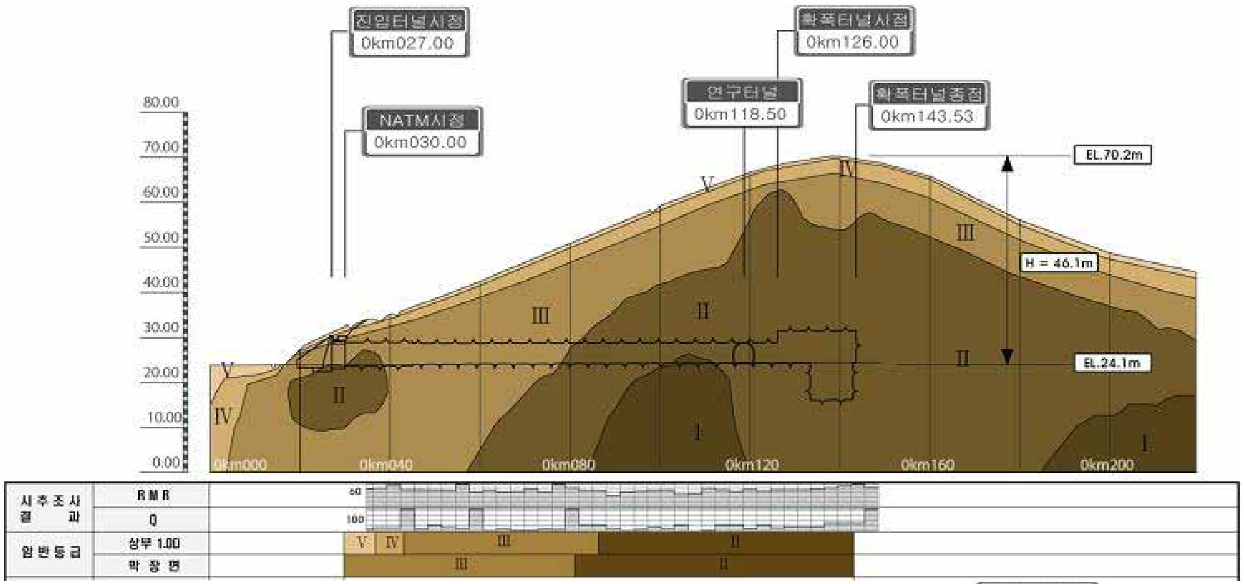
Summary of Construction Status

- 03~10, 2007 : Geological survey and tunnel design are completed.
- 05~12, 2008 : Tunnel construction
- Hamamatsu 10" PMTs are considered to be purchased. (expect to be delivered from March 2009)
- SK new electronics are adopted and delivered in Oct. 2008.
- Steel/acrylic containers and mechanical structure is ordered.
- Liquid scintillator handling system is being designed.
- Mock-up detector (~1/10 in volume) is made in Oct. 2008.

Rock sampling (DaeWoo Engineering Co.)

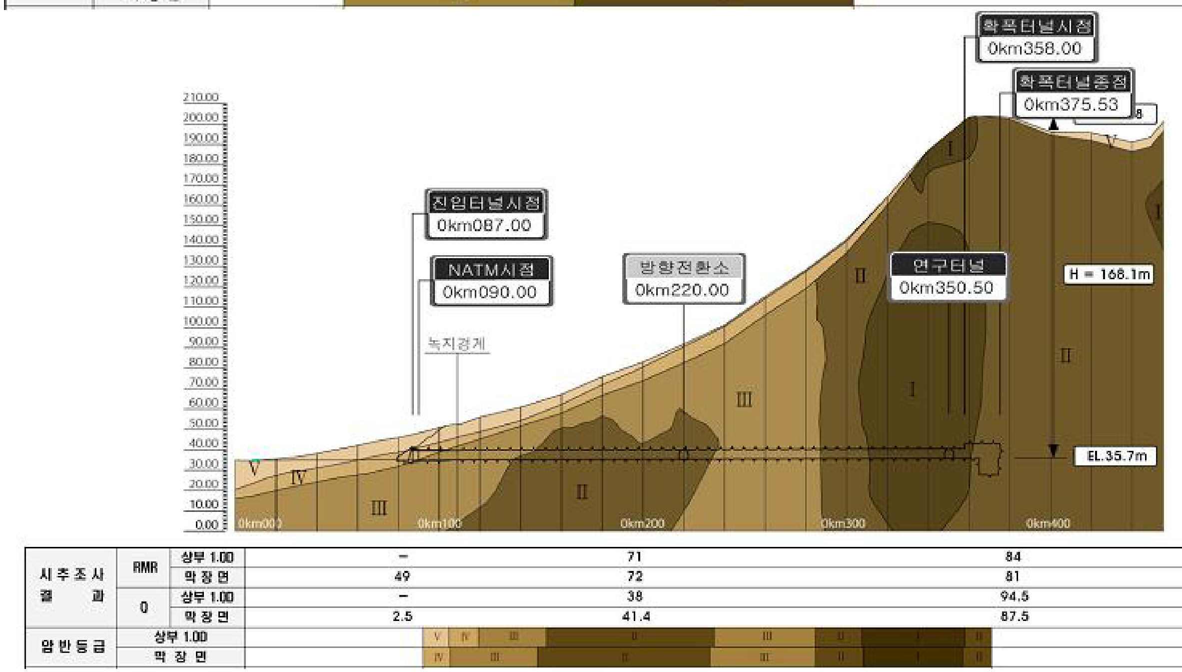
Rock samples from boring

Rock quality map



- Near detector site:
- tunnel length : 110m
- overburden

  height : 46.1m

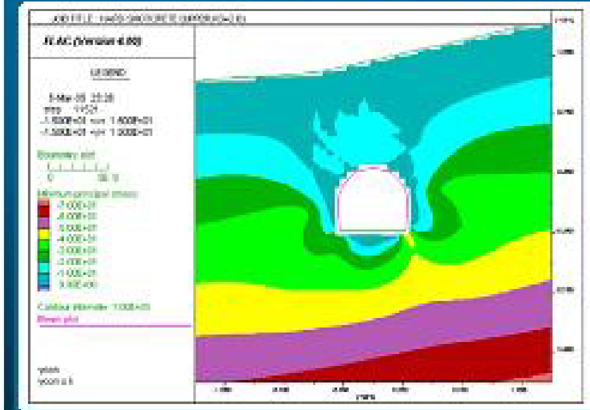


- Far detector site:
- tunnel length : 272m
- overburden

  height : 168.1m

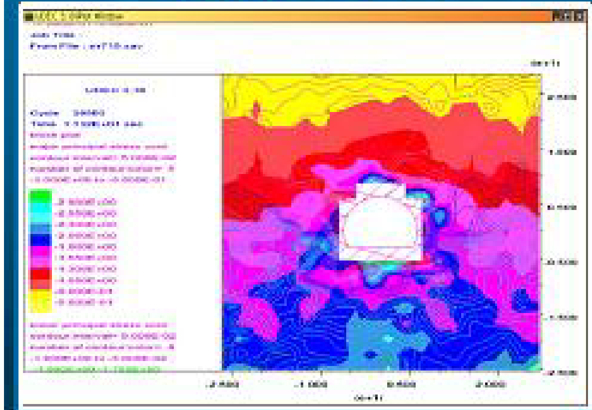
Stress analysis for tunnel design

연속체 안정성 검토



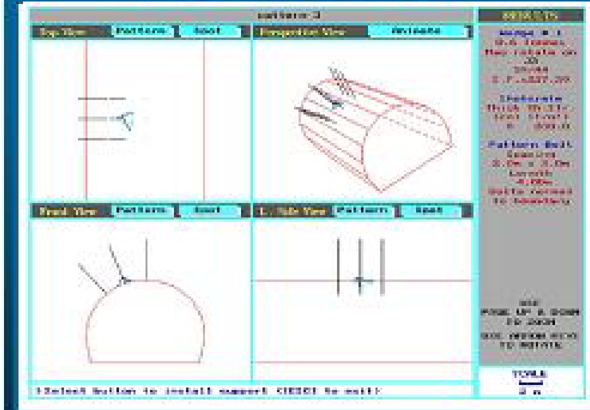
• 터널변위 및 응력해석

불연속체 안정성 검토



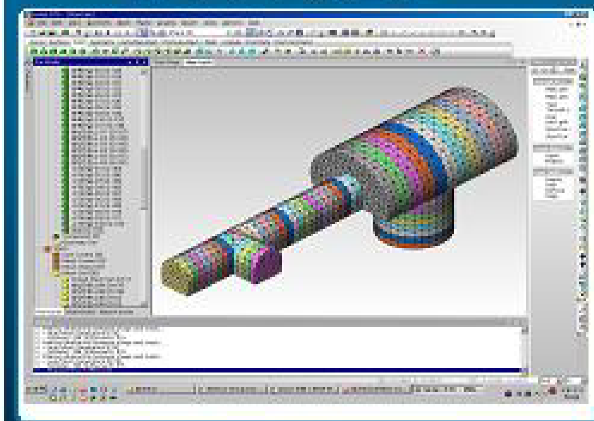
• 터널변위 및 응력해석

키블럭 안정성 검토



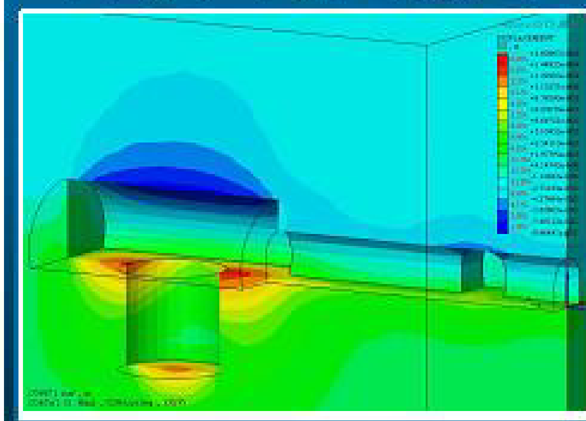
• 암반 블록파괴 검토

접속부 안정성 검토



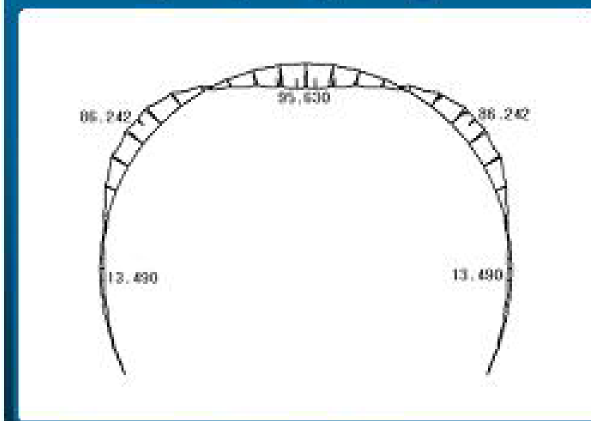
• 접속부변위 및 응력해석

확폭 및 수직터널 안정성 검토



• 터널변위 및 응력해석

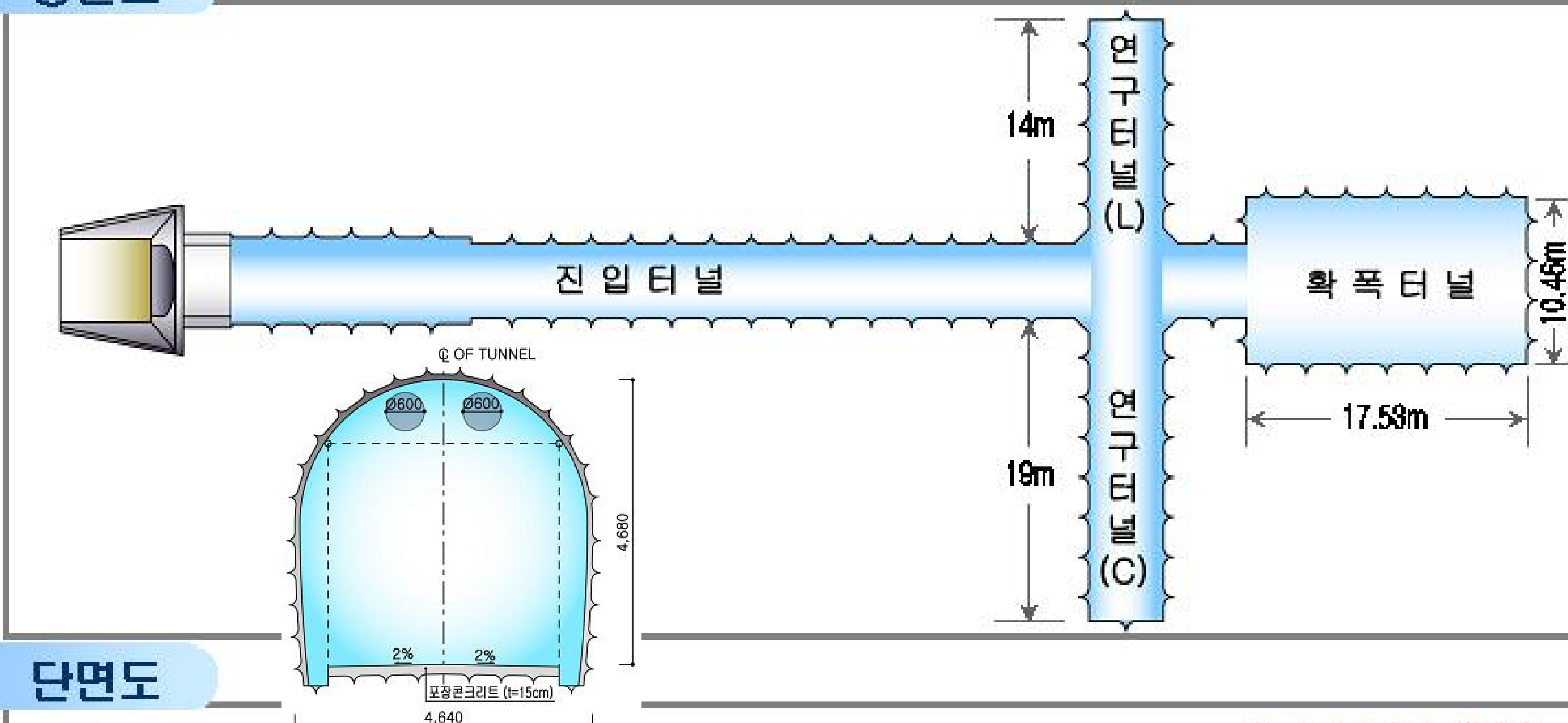
콘크리트 구조 검토



• 구조물 안정성 검토

터널설계

평면도



14m
연구터널(L)
진입터널
확폭터널
10.46m
17.53m
19m
연구터널(C)
℄ OF TUNNEL
Ø600
Ø600
4,680
2%
2%
포장콘크리트 (t=15cm)
4,640

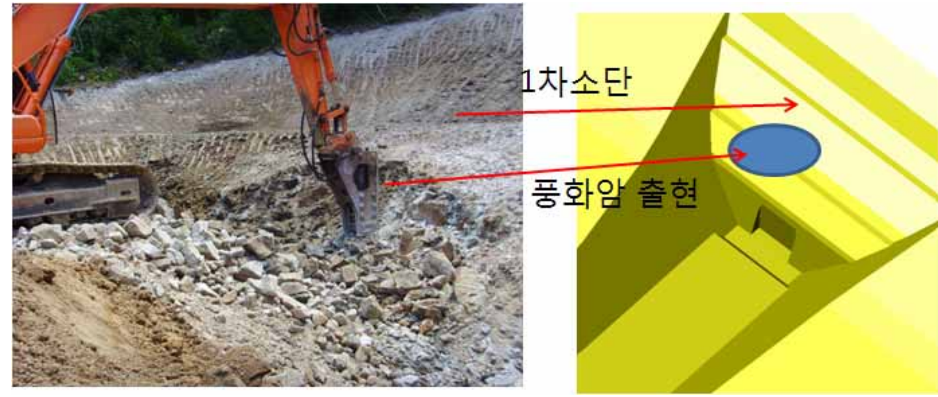
단면도

진입터널
확폭터널
수직터널

Construction for the Far Tunnel

(July, 2008)

(July, 2008)



(Aug, 2008)

(Aug, 2008)

(Aug, 2008)

Construction for the Far Tunnel

(0 m)
(Aug. 26, 2008)

(45m)
(Sep., 2008)

(92m)
(Sep., 2008)

(130m)
(Oct., 2008)

(285m)
(Oct., 2008)

Construction for the Near Tunnel

(July, 2008)

(July, 2008)

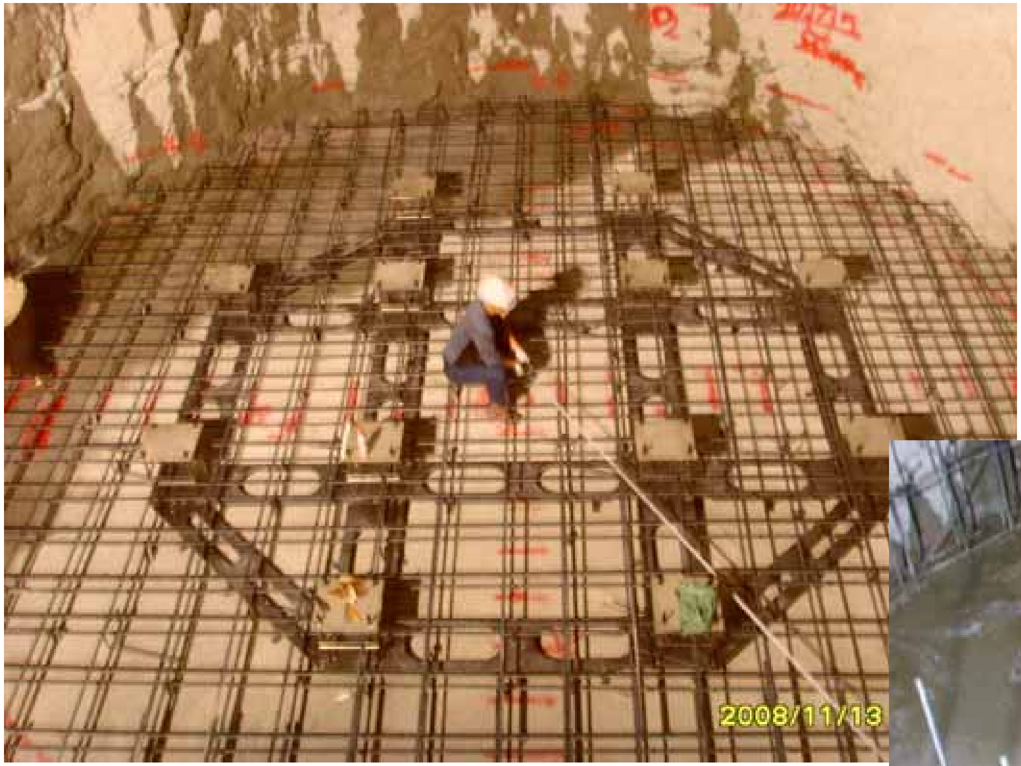
(Sep., 2008)

(40m)
(Oct., 2008)

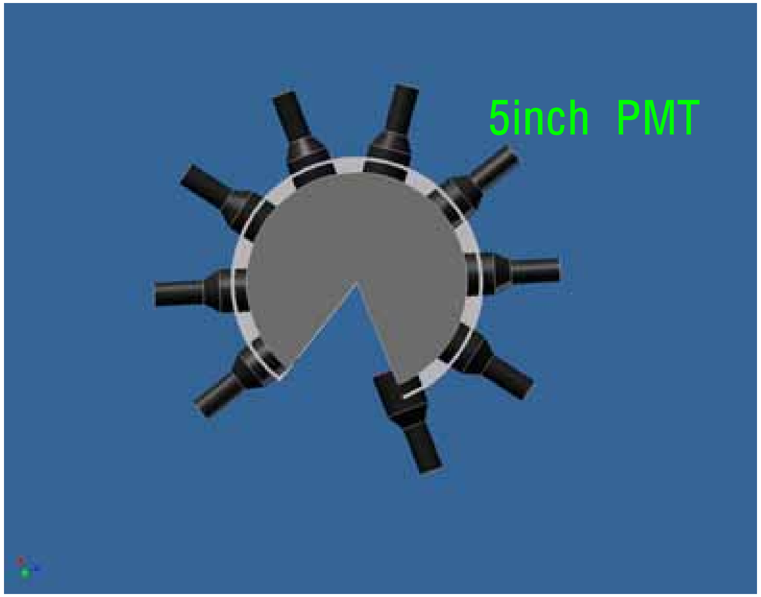
(90m)
(Oct., 2008)

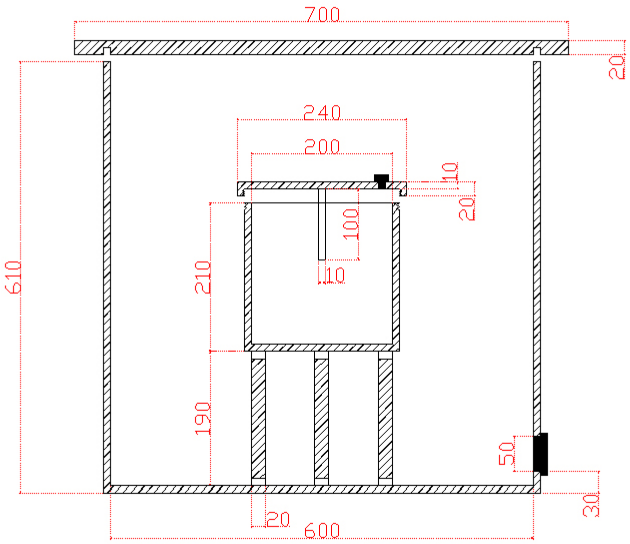
(Oct., 2008)

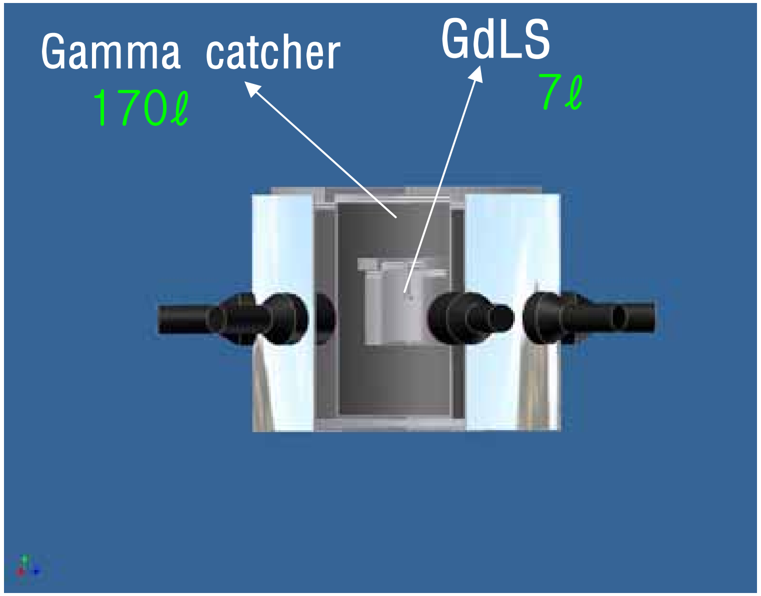
Construction for Experimental Hall



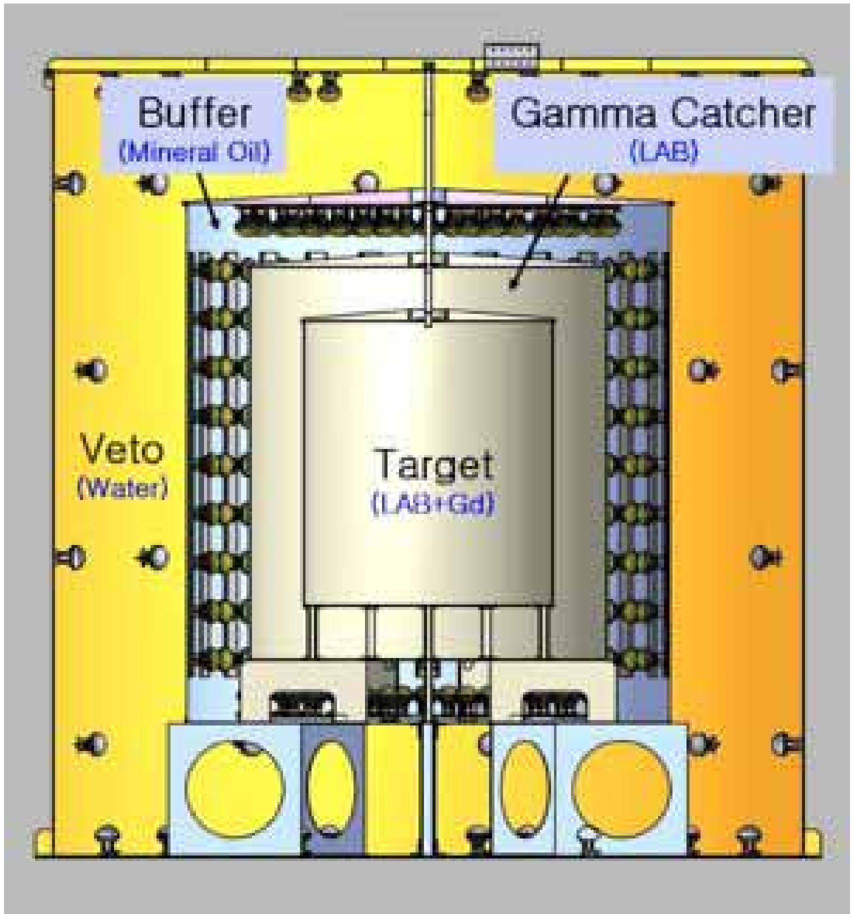
Prototype Detector

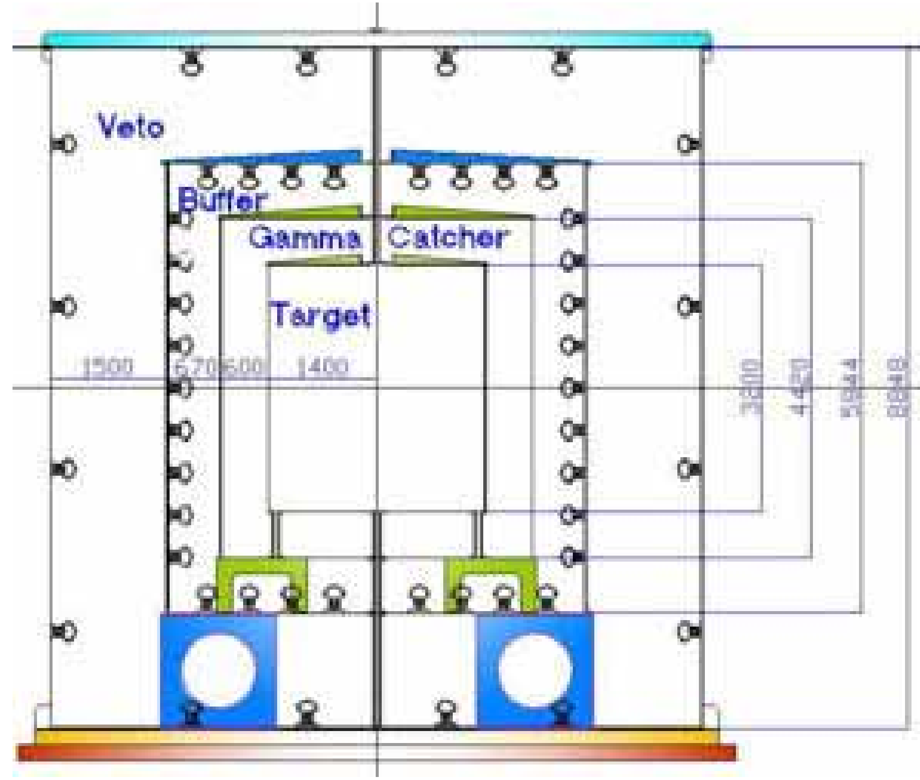






RENO Detector

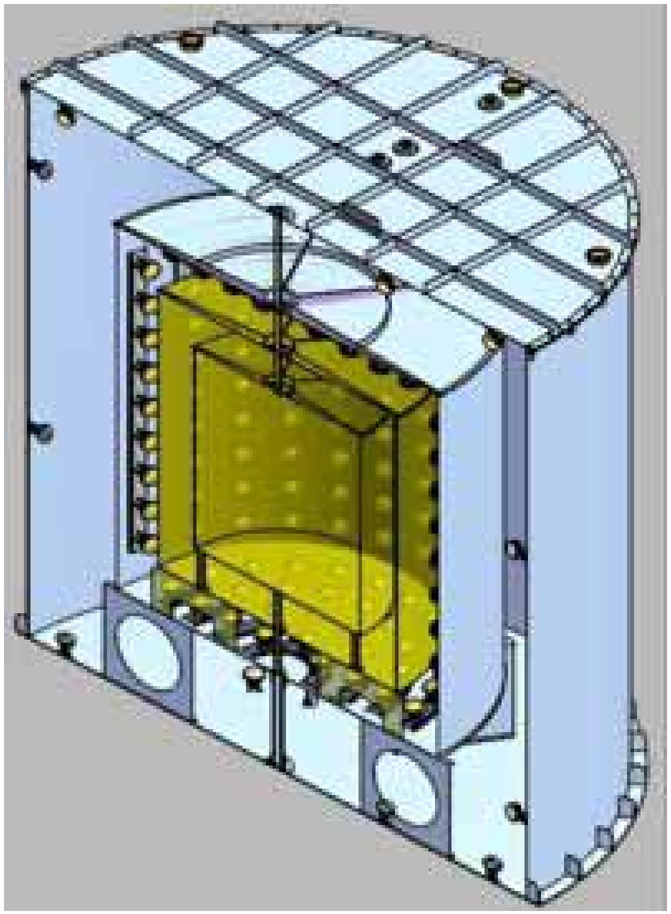
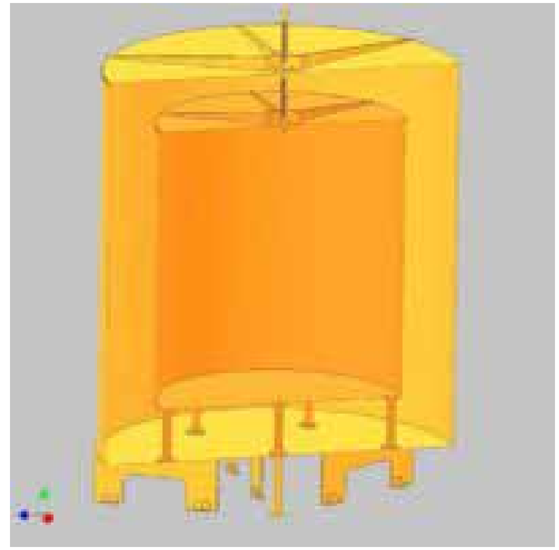
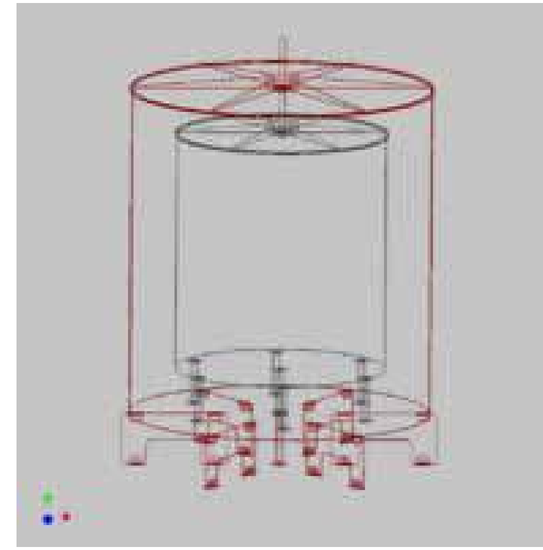
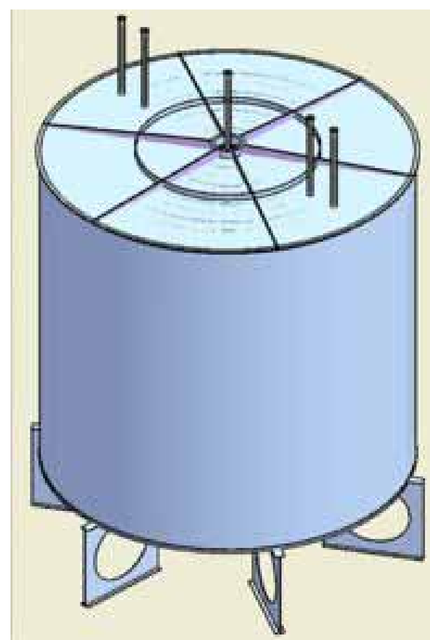
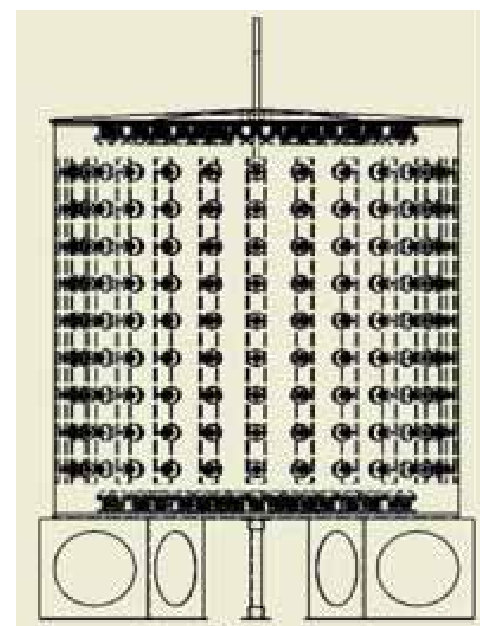




	Inner Diameter (cm)	Inner Height (cm)	Filled with	Mass (tons)
Target Vessel	280	320	Gd(0.1%) + LS	16.5
Gamma catcher	400	440	LS	30.0
Buffer tank	540	580	Mineral oil	64.4
Veto tank	840	880	water	352.6

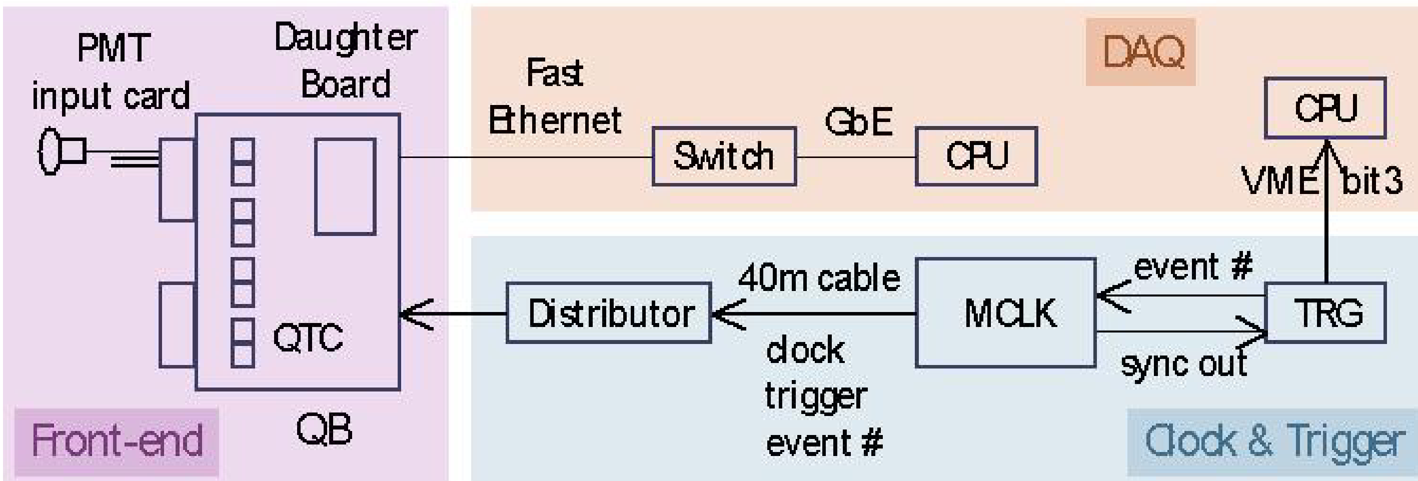
total ~460 tons

RENO Detector

Electronics

Conceptual design of the system

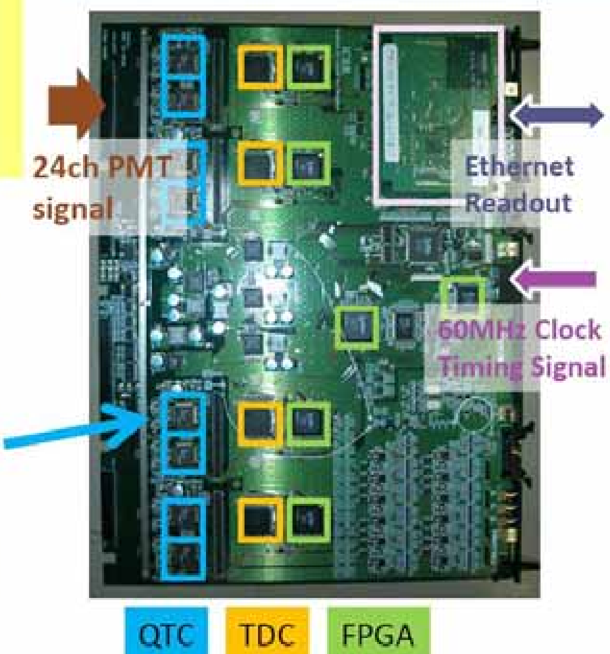


- Use SK new electronics (will be ready in Sep., 2008)

We have developed new elec.

- stable DAQ for next 10~20 yrs
- wider dynamic range
- hi speed & dead-time-less

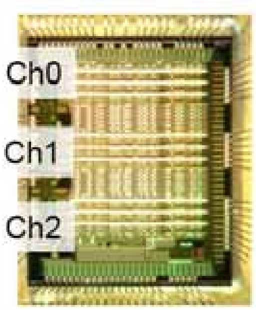
QBEE (QTC-Based Electronics with Ethernet)



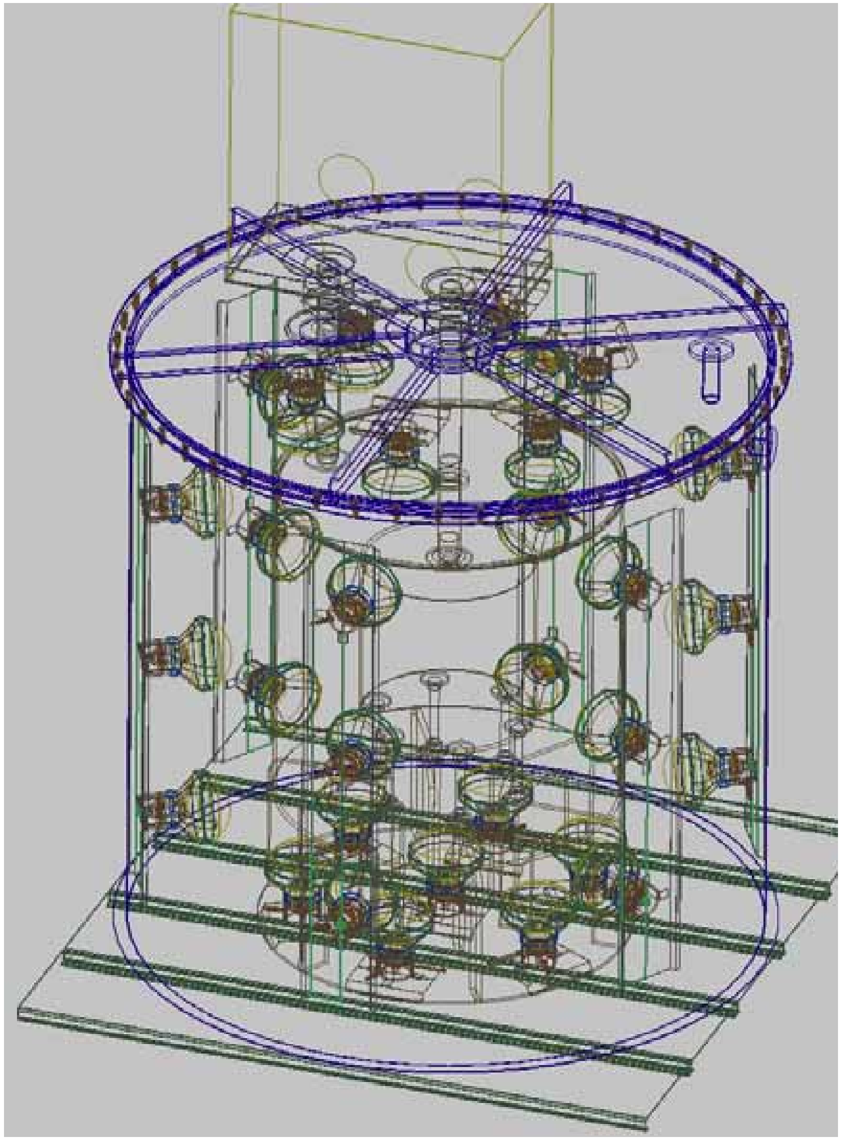
Custom ASIC QTC

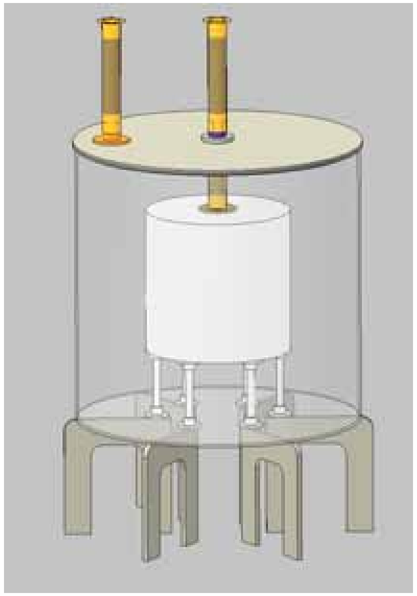
3 ch x 3 gain

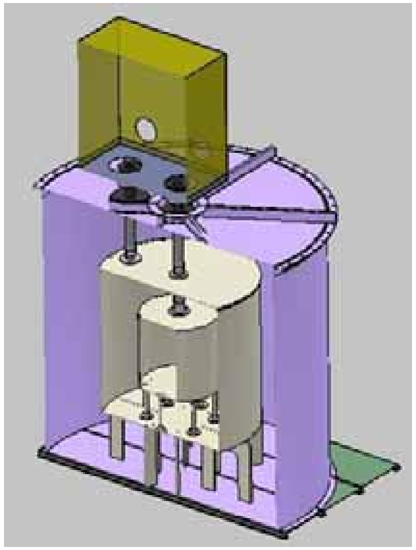
0.35um CMOS



Mockup Detector







Target + Gamma Catcher
Acrylic Containers

(PMMA: Polymethyl Methacrylate or Plexiglass)

Target	Diameter	61 cm
	Height	60 cm
Gamma Catcher	Diameter	120 cm
	Height	120 cm
Buffer	Diameter	220 cm
	Height	220 cm

Buffer
Stainless Steel Tank

Mockup Detector Assembly

Mockup Detector Assembly

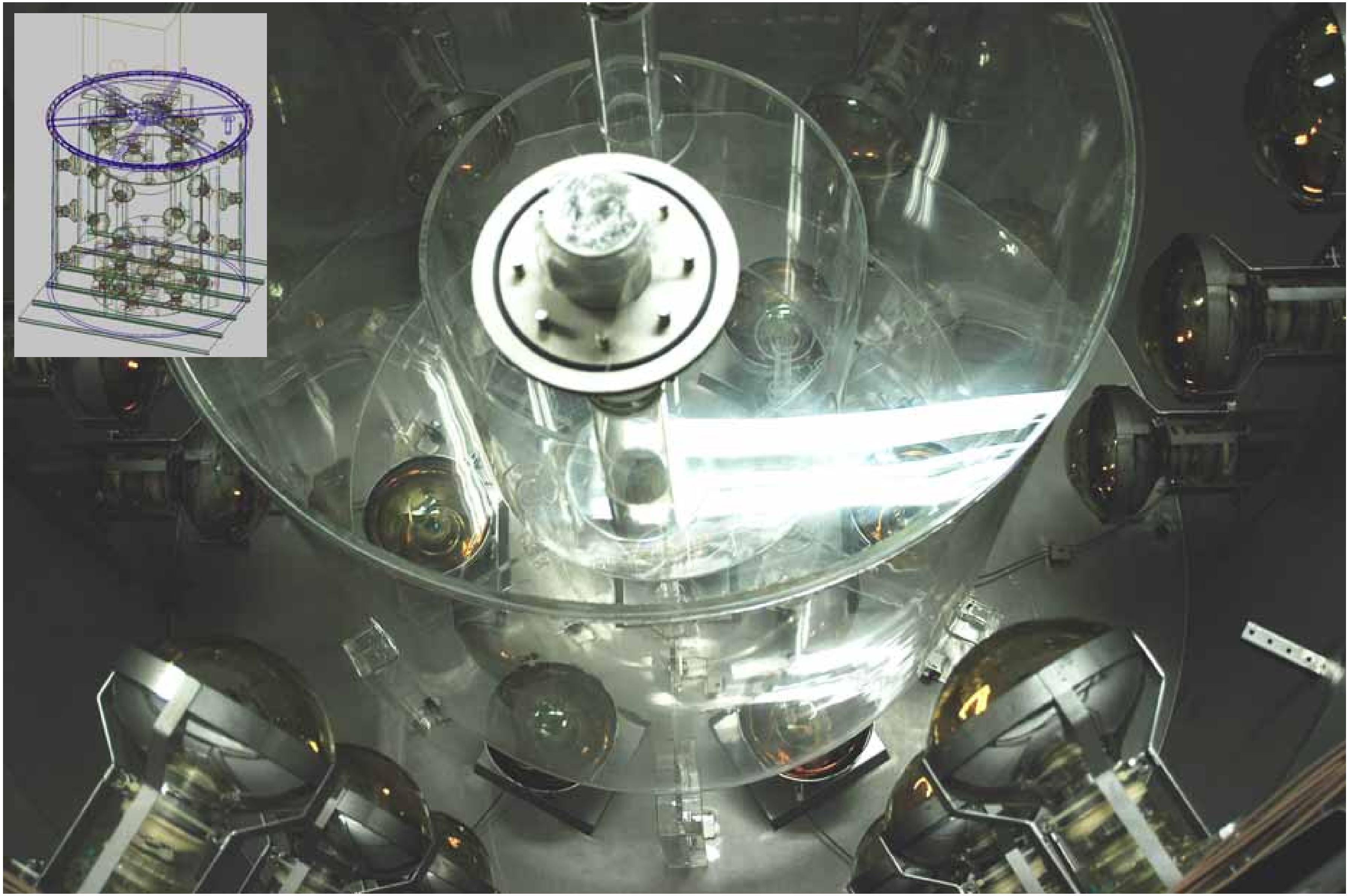




Mockup Detector Assembly

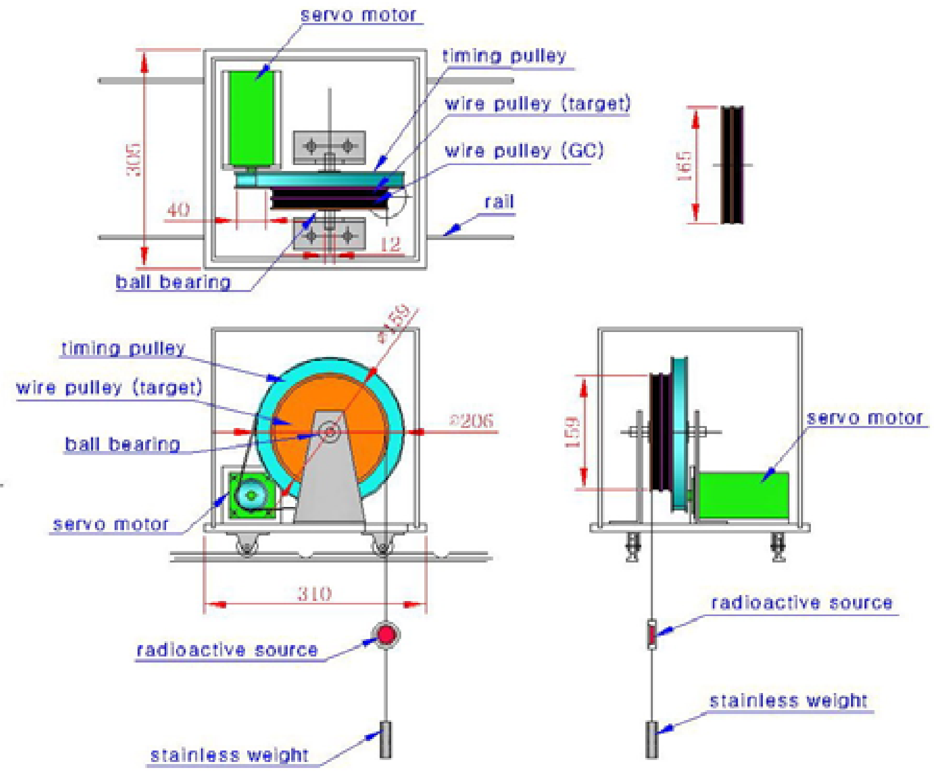
Mockup Detector Assembly

Mockup Detector Assembly

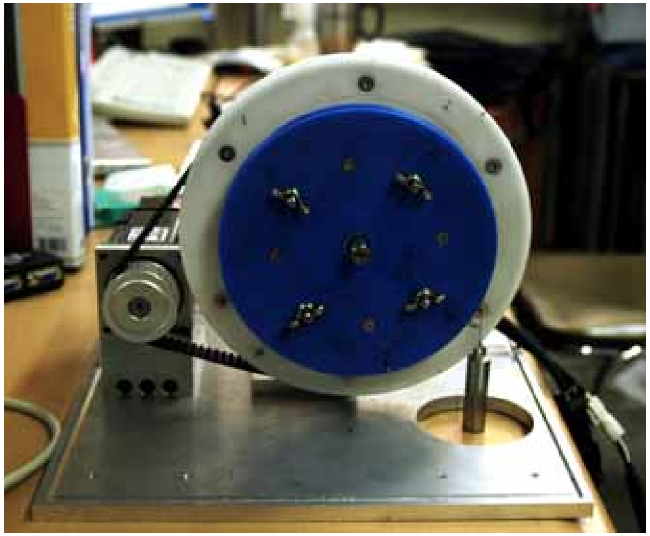


Mockup Detector Assembly

Mockup Detector Assembly



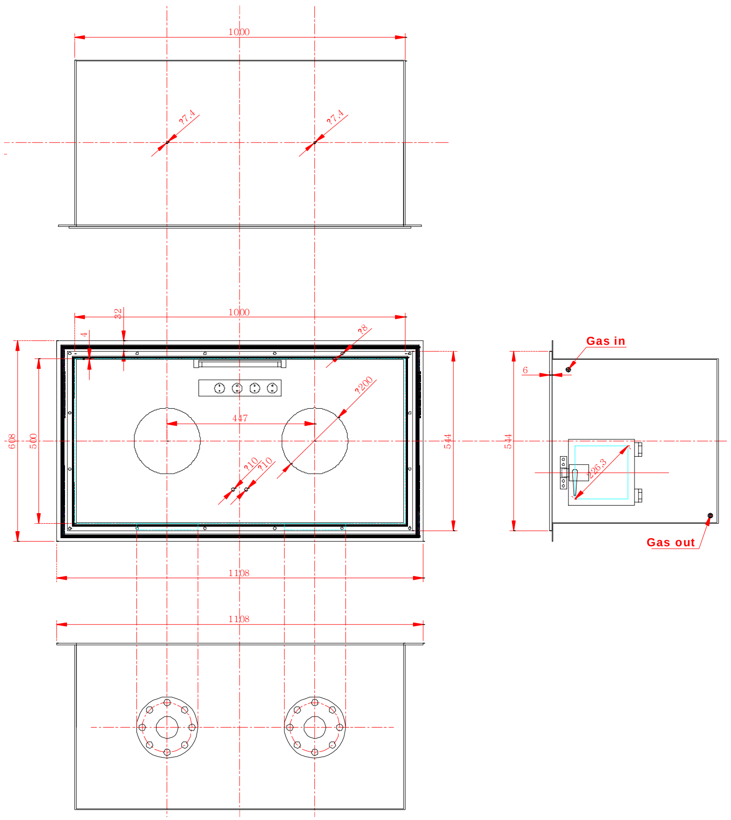
Design of the source driving system

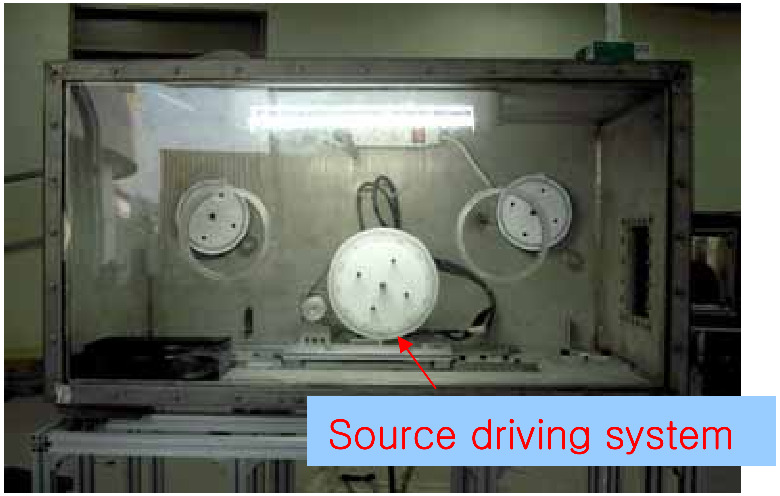


PC interface for calibration system

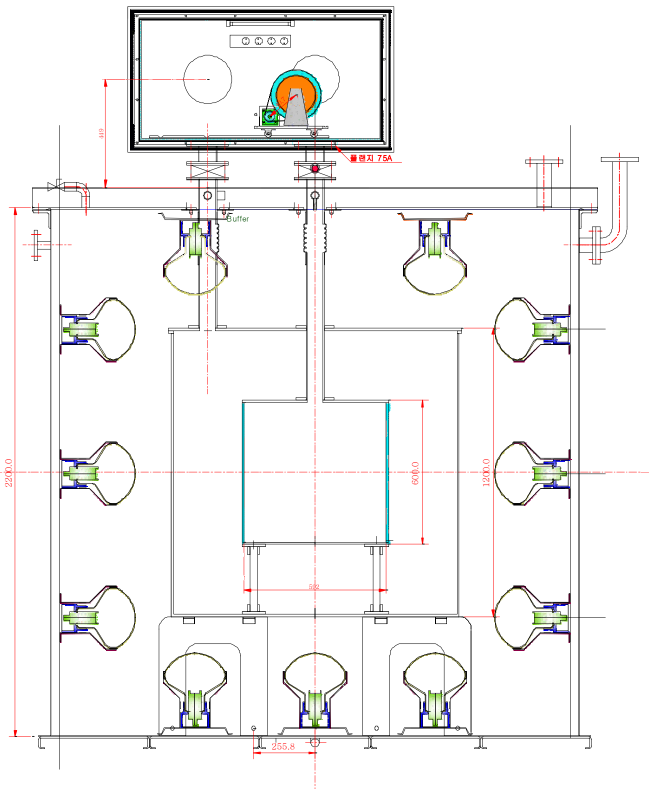
Mockup Detector Assembly

Glove box 제작





Mockup Detector Assembly



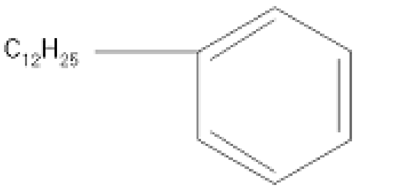
Gd Loaded Liquid Scintillator

❑ Recipe of Liquid Scintillator :

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

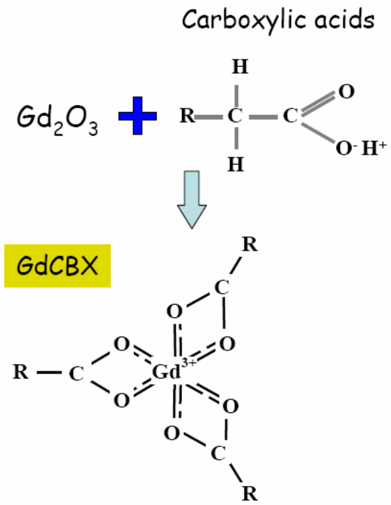
❑ R&D on LAB(Linear Alkyl Benzene) properties :

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



Linear Alkyl Benzene (LAB)

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



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

- CBX : MVA (2-methylvaleric acid), TMHA (trimethylhexanoic acid)

Synthesis of Gd-carboxylate

precipitation

$$\mathrm{RCOOH + NH_3 \cdot H_2O \rightarrow RCOONH_4 + H_2O}$$

$$\mathrm{3RCOONH_4(aq.) + GdCl_3(aq.) \rightarrow Gd(RCOO)_3 + 3NH_4Cl}$$

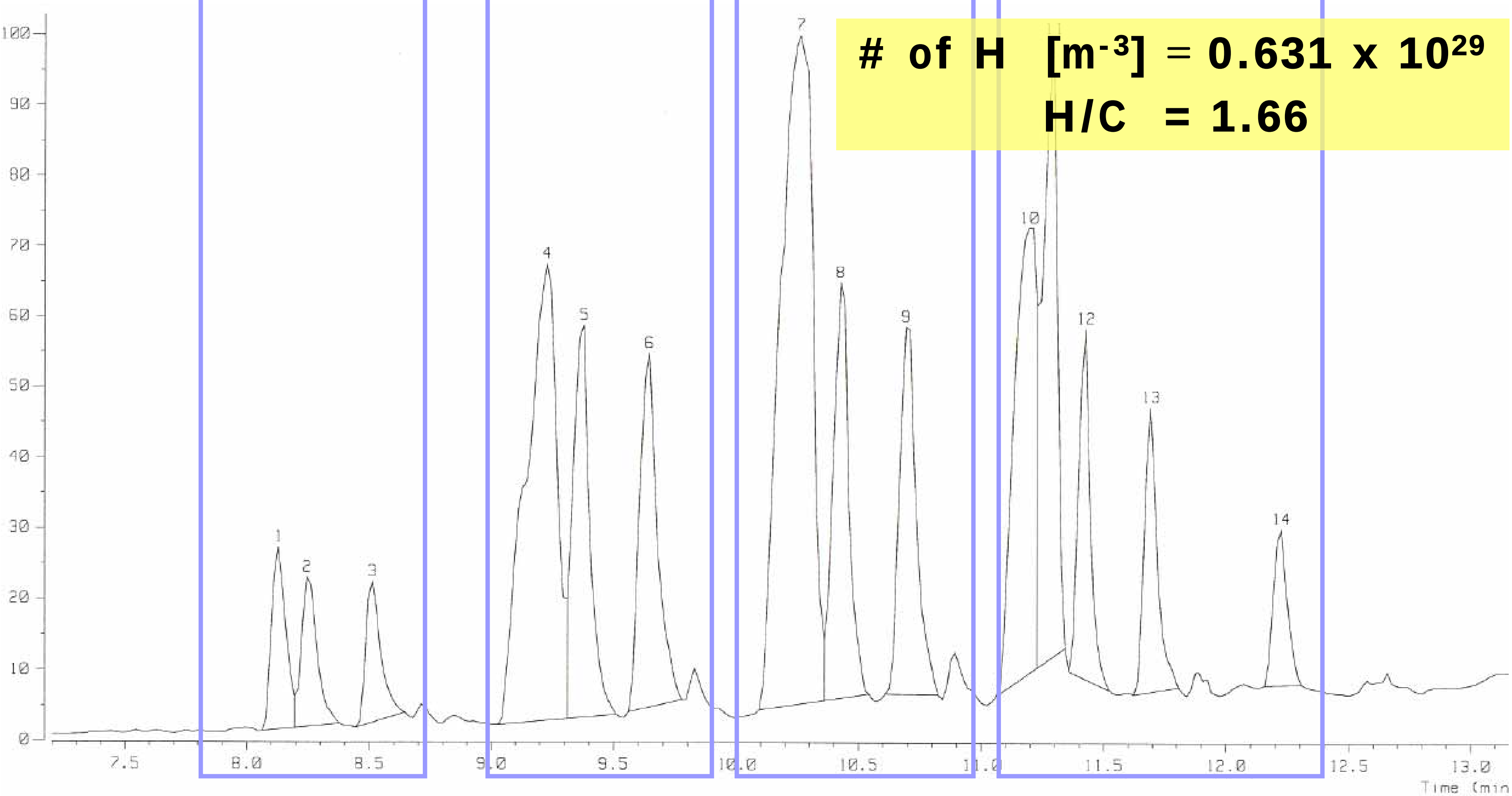
Rinse with 18MΩ water

Dryer

Measurement of LAB Components with GC-MS

LAB : $(C_6H_5)C_NH_{2N+1}$

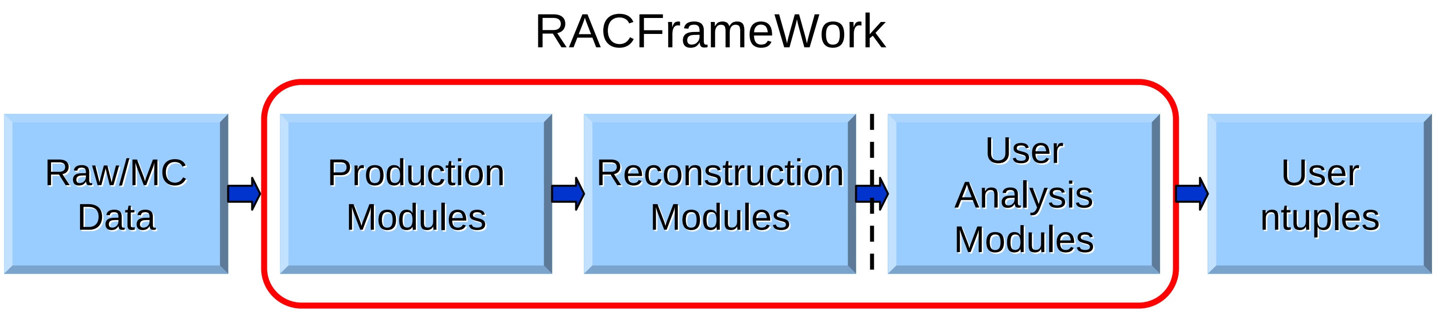
$C_{16}H_{26}$	$C_{17}H_{28}$	$C_{18}H_{30}$	$C_{19}H_{32}$
7.17%	27.63%	34.97%	30.23%



\# of H [m^{-3}] = 0.631×10^{29}

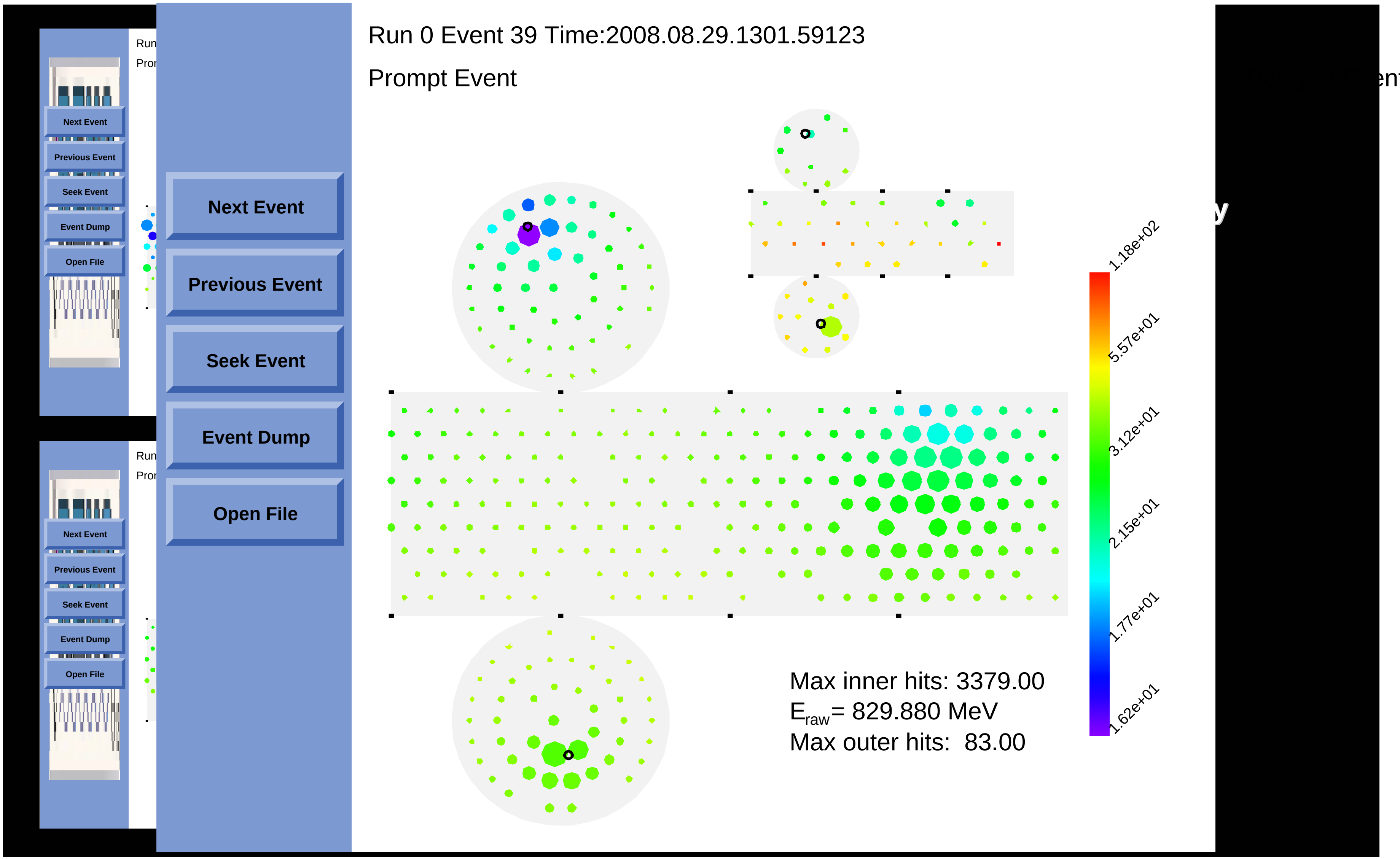
H/C = 1.66

RENO Analysis Control



- default modules **data input and output, database access for run configuration and calibration**
- Has **talk-to function** for changing input parameters without recompiling
- **Addition of modules by user**
- Modules can be set as **filter module** for selecting events
- Easy to use and build in RENO software environment

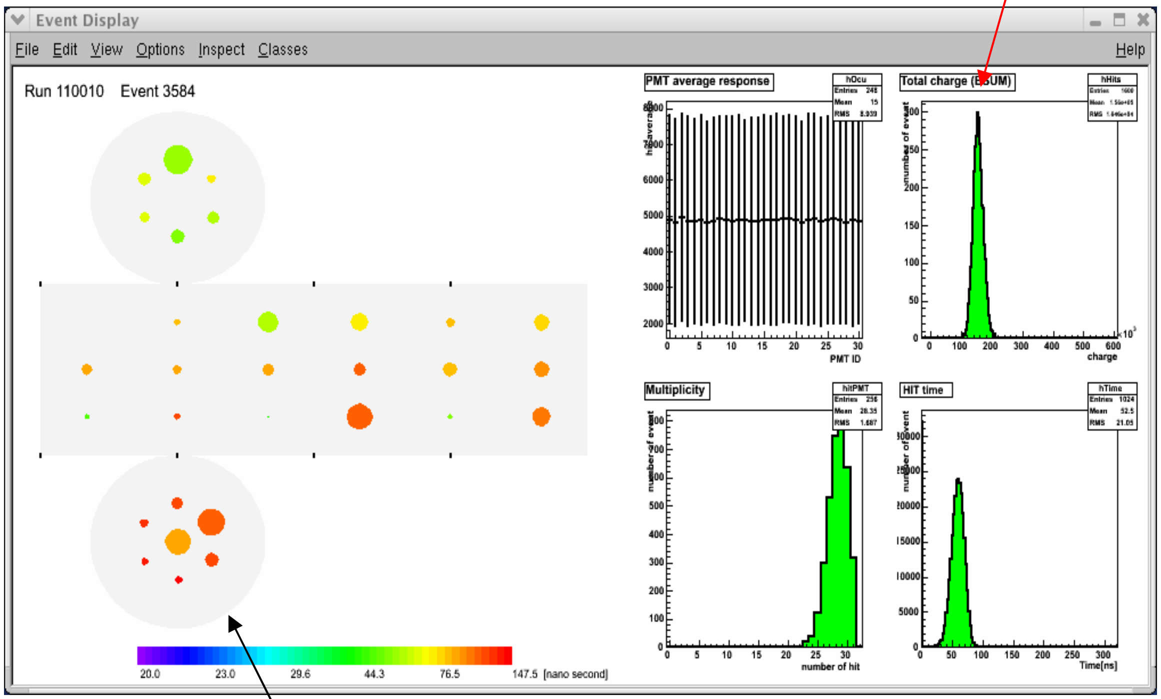
RENO Event Display



Mockup Event Display

Real time display: Online monitoring tool

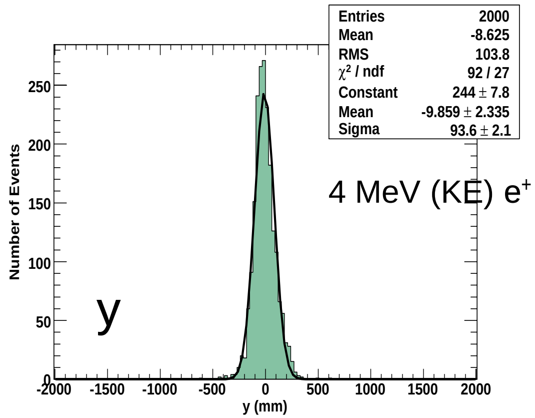
Basic information on histograms

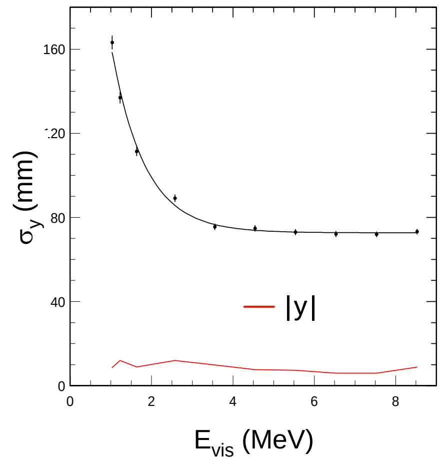


PMT hit display

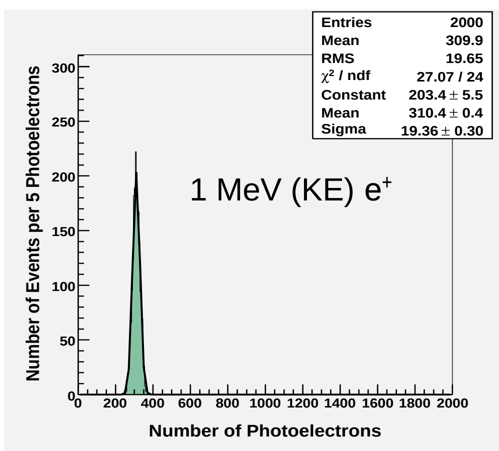
Reconstruction : vertex & energy

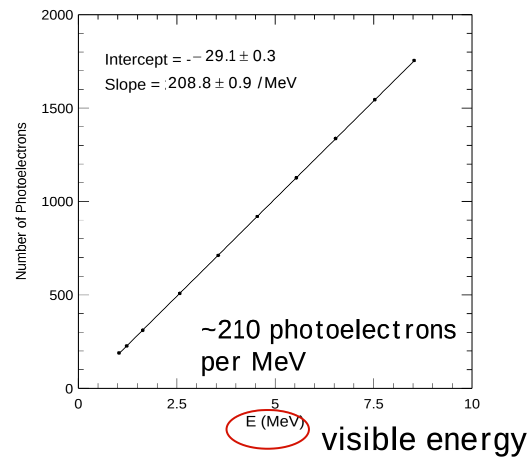
- Reconstructed vertex: σ **~8cm** at the center of the detector

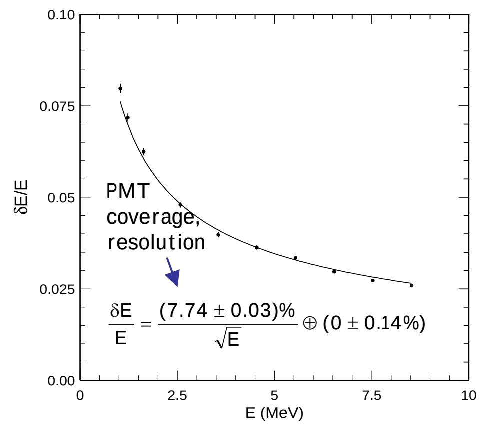




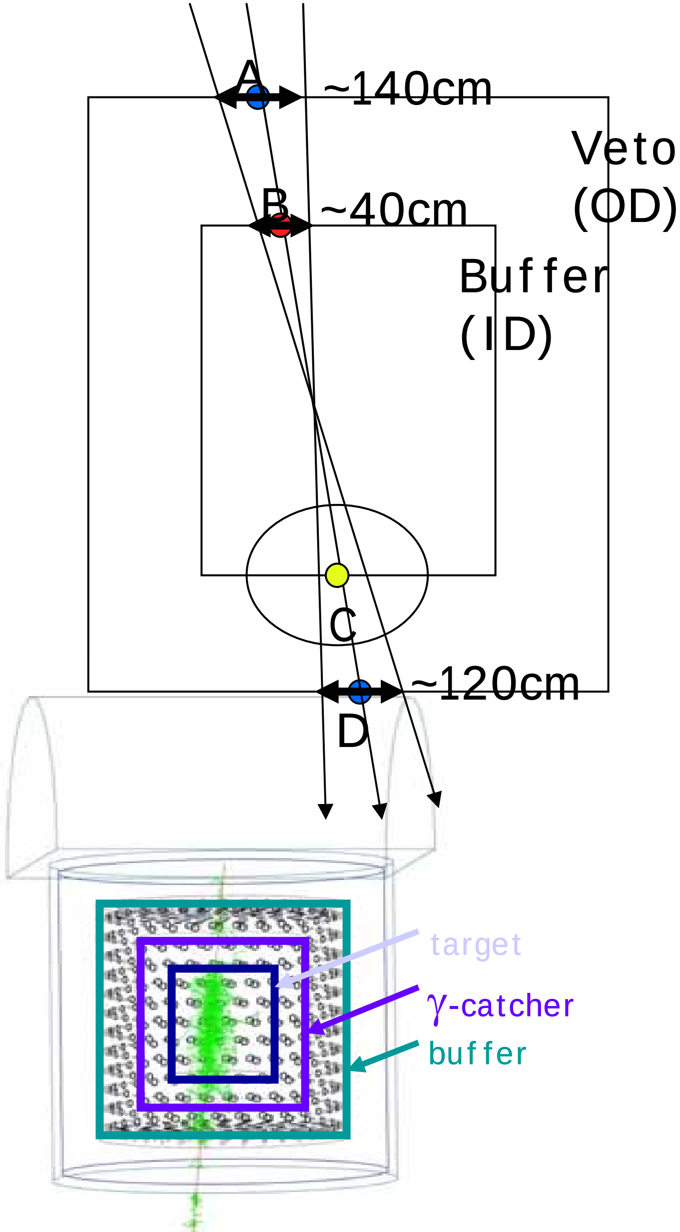
- Energy response and resolution:

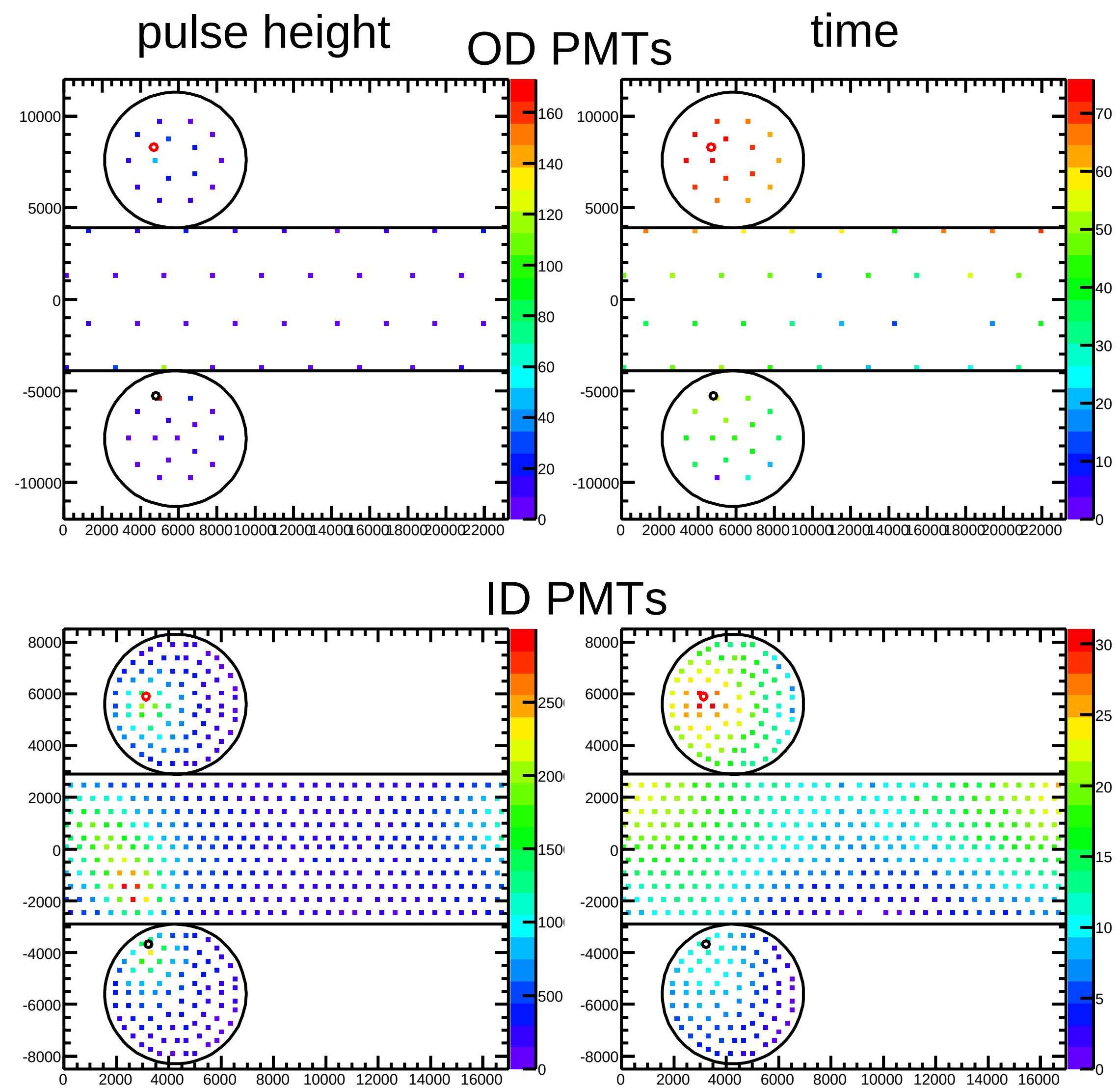






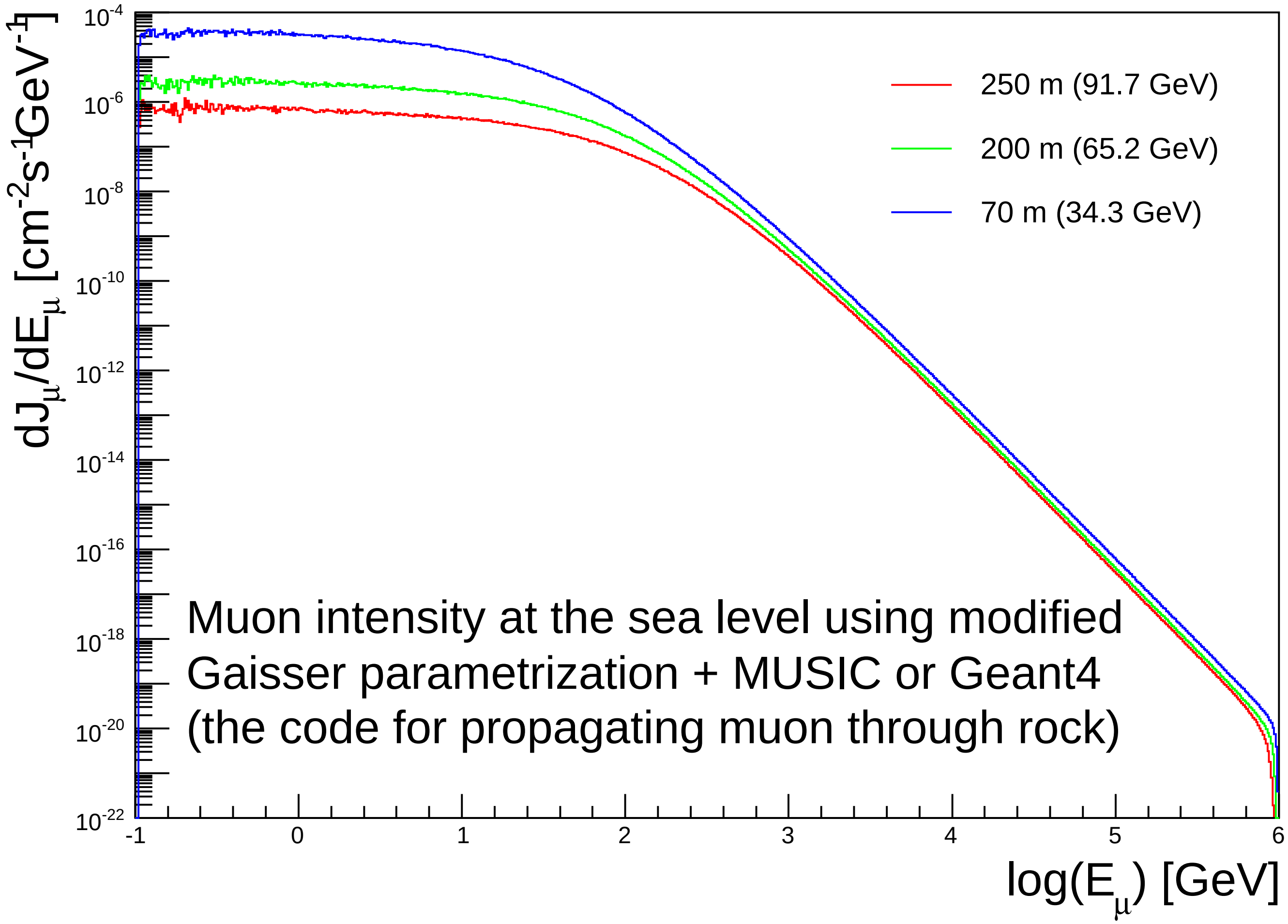
Reconstruction of Cosmic Muons





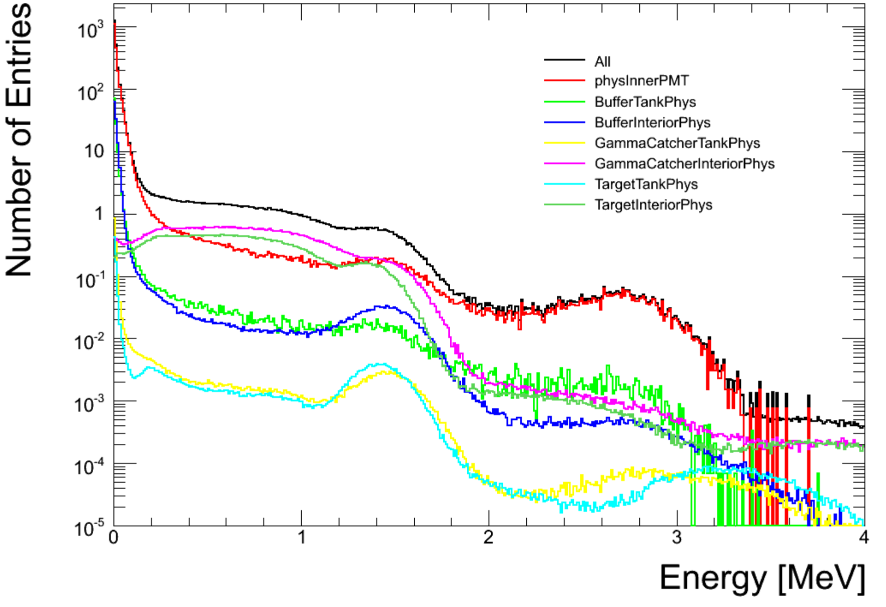
Calculation of Muon Rate at the RENO Underground

		J_μ [$cm^{-2}s^{-1}$]	$\langle E_\mu \rangle$ [GeV]
Far	250 m	2.9×10^{-5}	91.7
	200 m	8.5×10^{-5}	65.2
Near	70 m	5.5×10^{-4}	34.3



Calculation of Background Rates due to Radioactivity

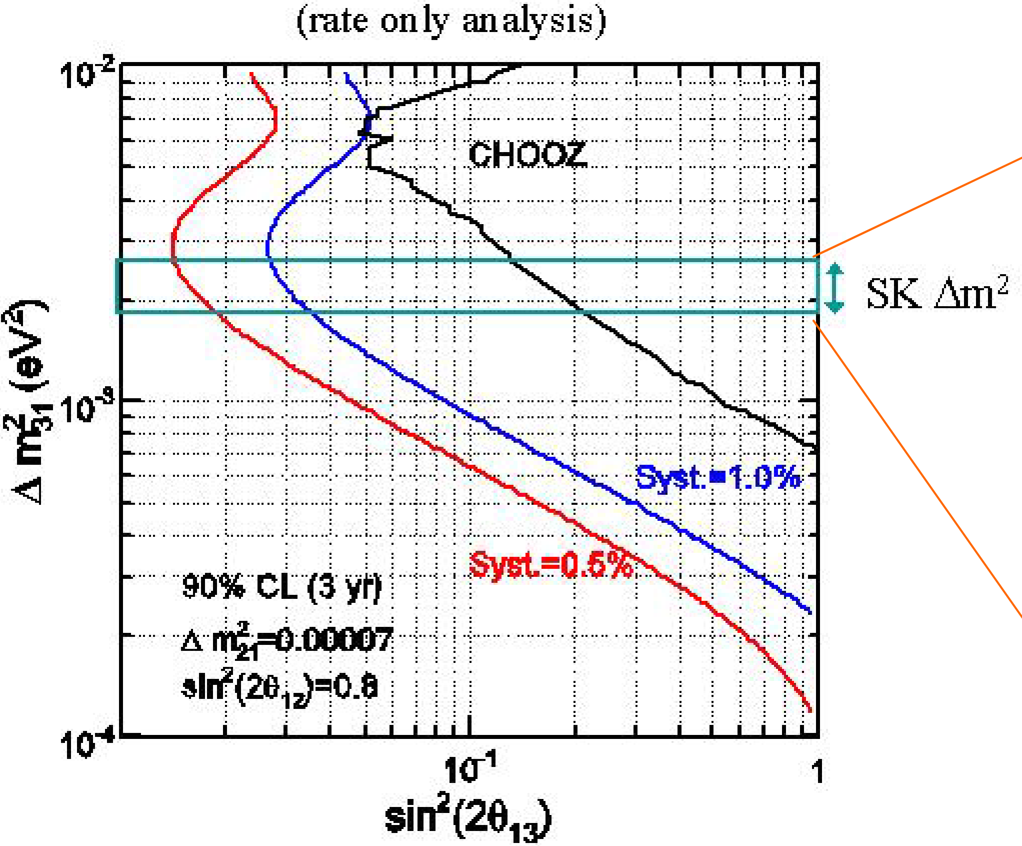
	Concentration ^{40}K (ppb)	Concentration ^{232}Th (ppb)	Concentration ^{238}U (ppb)	^{40}K [Hz]	^{232}Th [Hz]	^{238}U [Hz]	Total [Hz]
Rock	4.33(ppm)	7.58(ppm)	2.32(ppm)	1.06	7.14	0.99	9.19
LS in Target	0.001	0.001	0.001	0.90	0.09	0.26	1.25
Target Contatiner	0.008	0.05	0.008	0.08	0.06	0.03	0.17
LS in Gamma Catcher	0.001	0.001	0.001	1.52	0.13	0.38	2.03
Gamma Catcher Container	0.008	0.05	0.008	0.07	0.04	0.03	0.14
LS in Buffer	0.001	0.001	0.001	0.08	~ 0	0.03	0.11
Buffer Tank	0.06	0.9	0.9	0.03	0.10	0.20	0.33
PMT	13.6	208.5	49.4	2.50	5.23	2.99	10.72
Total							**~24**



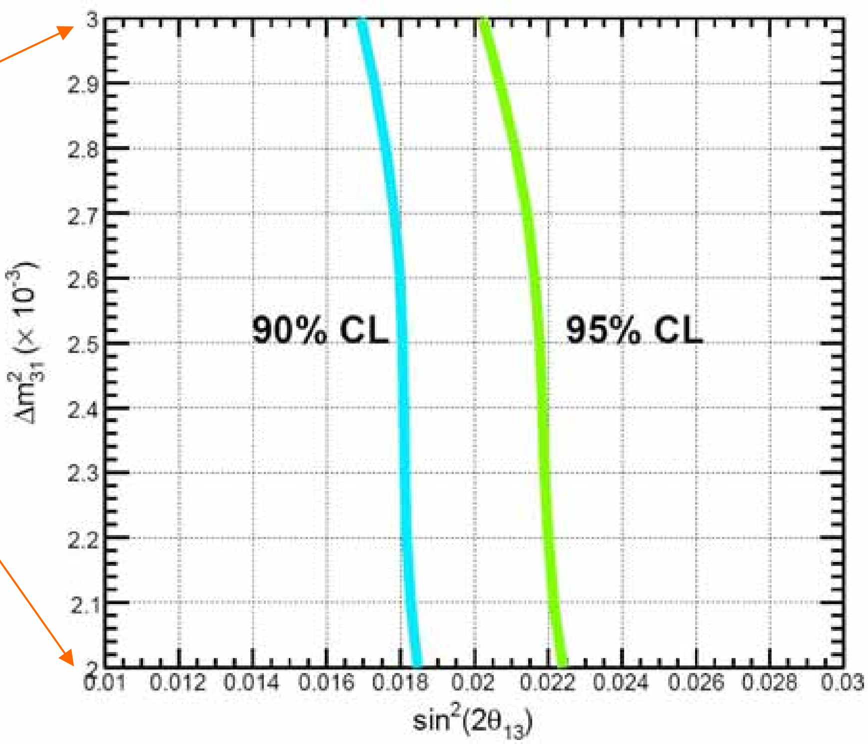
Systematic Errors

Systematic Source		CHOOZ (%)	RENO (%)
Reactor related absolute normalization	Reactor antineutrino flux and cross section	1.9	< 0.1
	Reactor power	0.7	< 0.1
	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	0.2
	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	< 0.6

RENO Expected Sensitivity



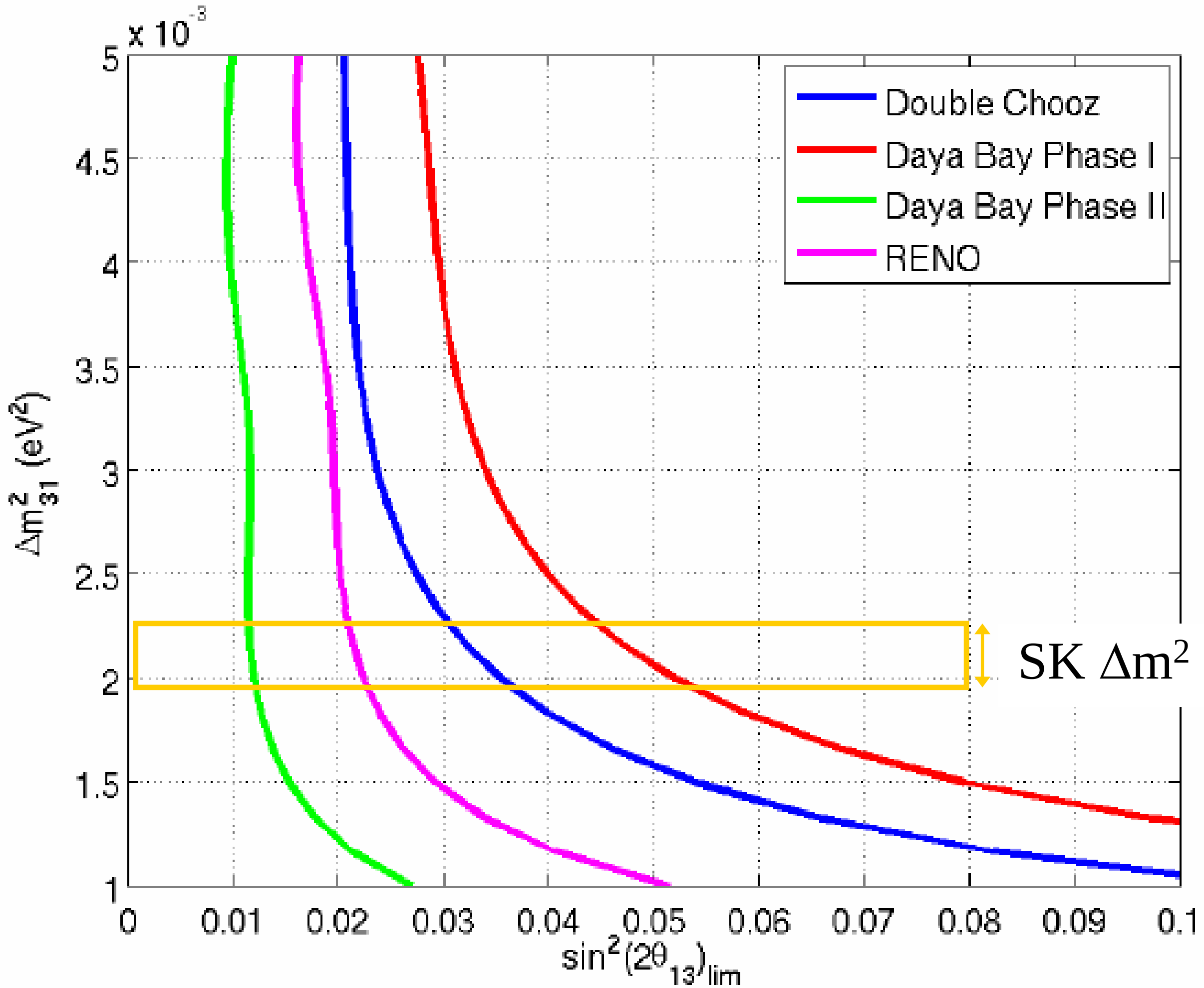
New!! (full analysis)



10x better sensitivity than current limit

GLoBES group workshop@Heidelberg – Mention's talk

- 3 first generation experiments: **Double Chooz**, **RENO** sensitivity ~ 0.02 to 0.03 (depending on sytematics, Δm^2 value, and backgrounds) and **Daya Bay Phase I** with sensitivity ~ 0.04 to 0.05 (1 year) ~ 0.03 to 0.035 (3 years)



Exposure:

DC, DB II & RN: 3 years

DB I: 1 year

Status Report of RENO

- ❑ RENO is suitable for measuring θ_{13} **($\sin^2(2\theta_{13}) > 0.02$)**

- ❑ Geological survey and design of access tunnels & detector cavities are completed → Tunnel construction will be finished in December, 2008.

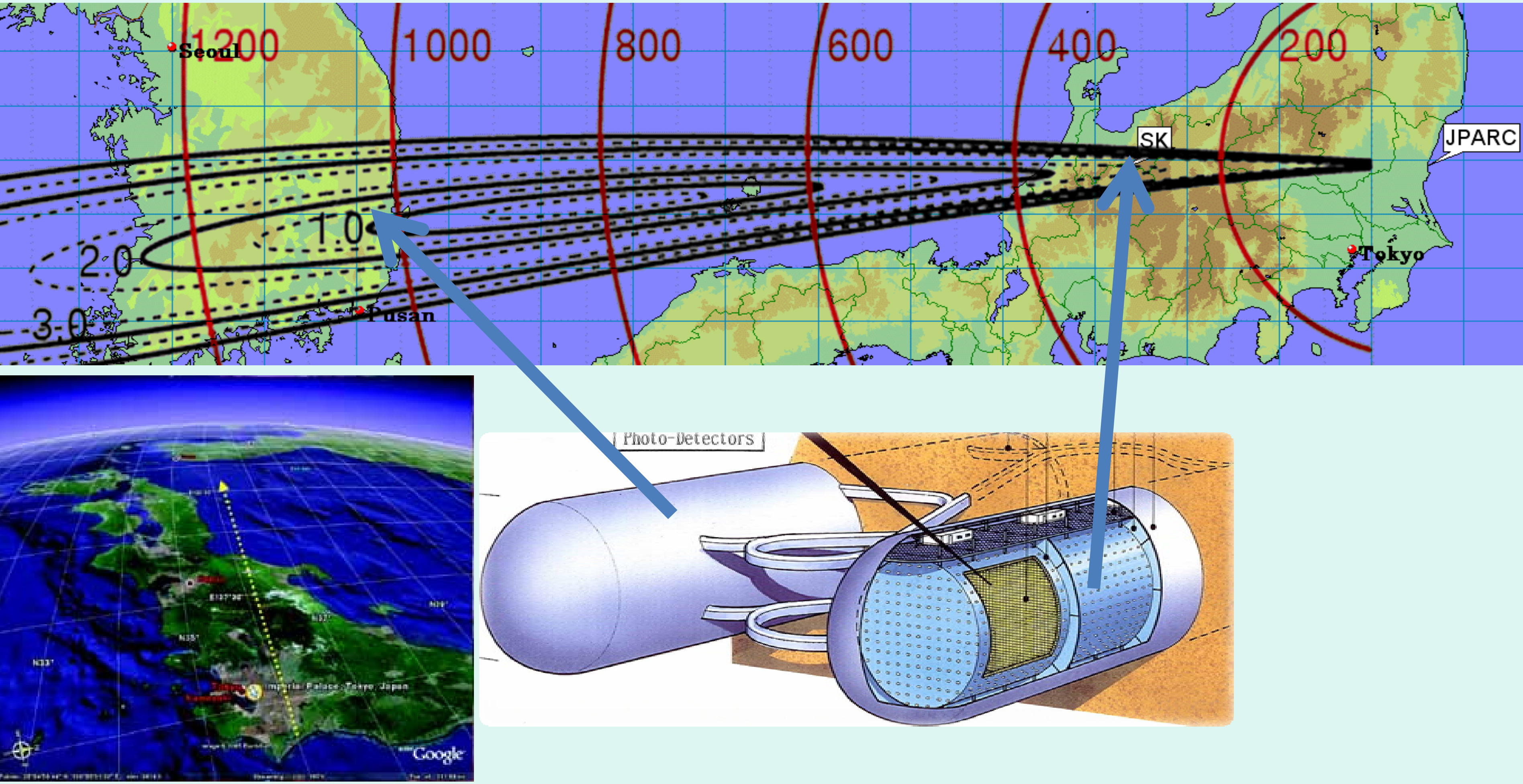
- ❑ RENO is under construction phase.

- ❑ Data –taking is expected to start in early 2010.

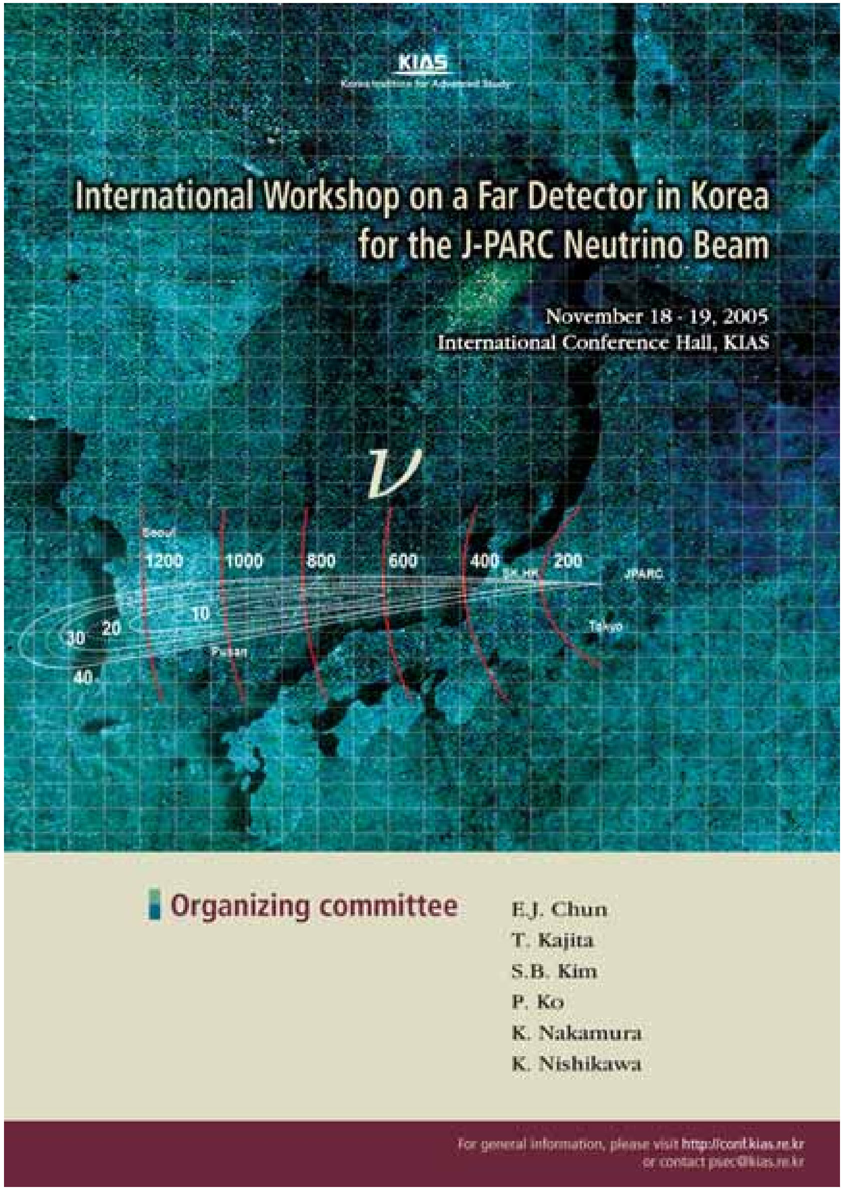
- ❑ International collaborators are being invited.

서울대 김수봉 교수가 이끄는 RENO 실험팀. 30여년간 관측에 실패한 마지막 중성미자 변환상수를 밝히기 위해 프랑스 중국과 치열한 경주를 벌이고 있다.

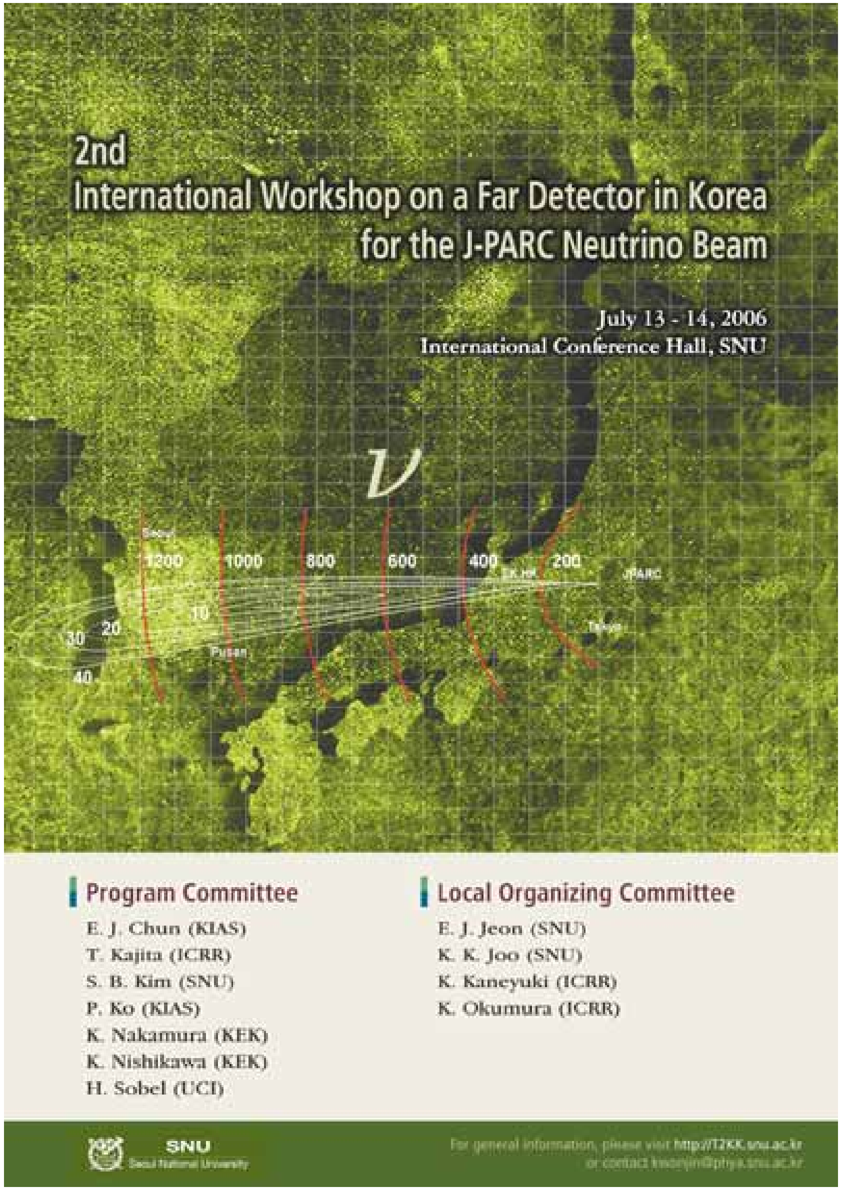
T2KK Workshop



1st & 2nd Workshops on T2KK

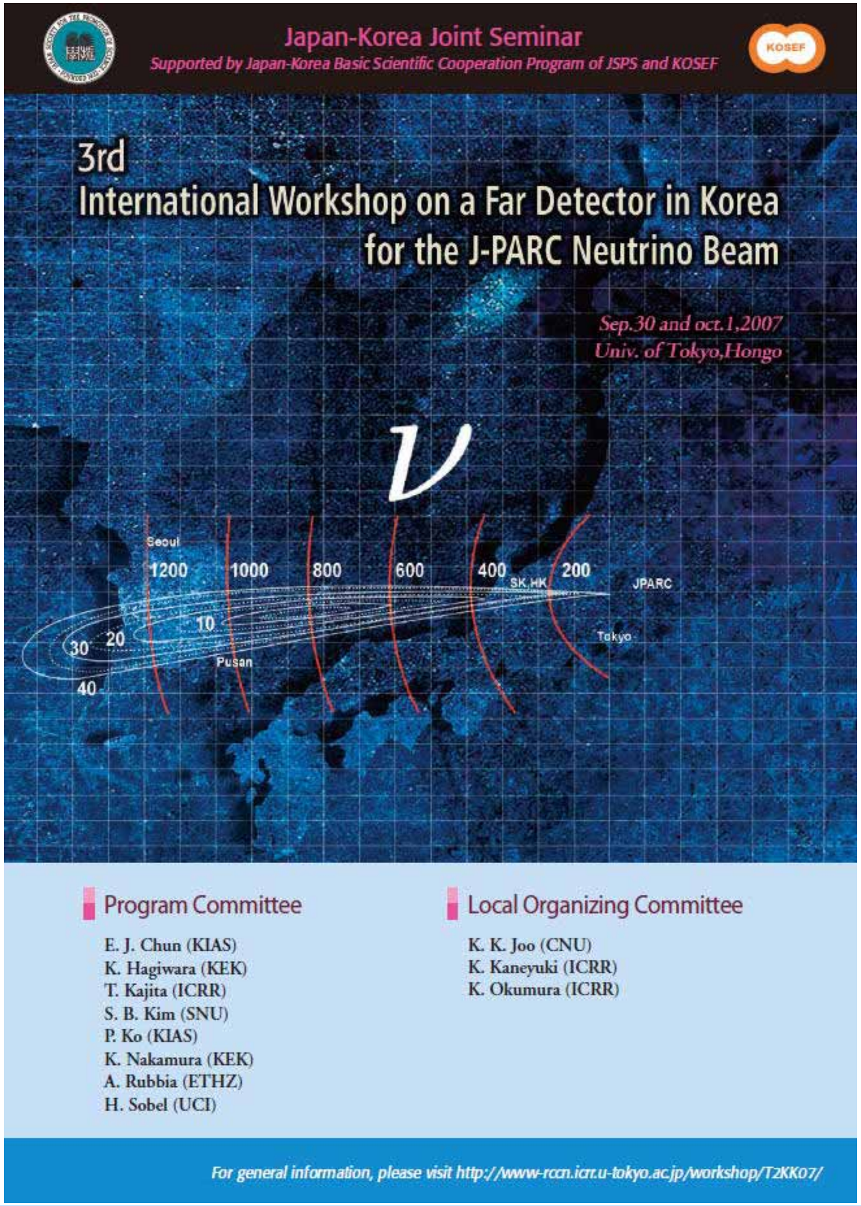


http://newton.kias.re.kr/~hepph/J2K



http://T2KK.snu.ac.kr

3rd Workshop on T2KK



University of Tokyo, Tokyo

9/30-10/1, 2007

- Site study for HK and one in Korea
  (N. Wakabayashi, C. Ryu)
- BNL-Fermilab LBL/J-PARC /Systematics at Superbeam exp.
  (M. Diwan, T. Ishida, P. Huber)
- Oscillation parameter degeneracy
  (S.K. Kang, J. Valle)
- T2KK sensitivity in resolving degeneracy
  (F. Dufour, C. Ishihara, N. Okamura,
  K. Okumura, A. Rubbia, K. Senda)
- NSP/Test of Unitarity (P. Ko, K. Kimura)

⇩

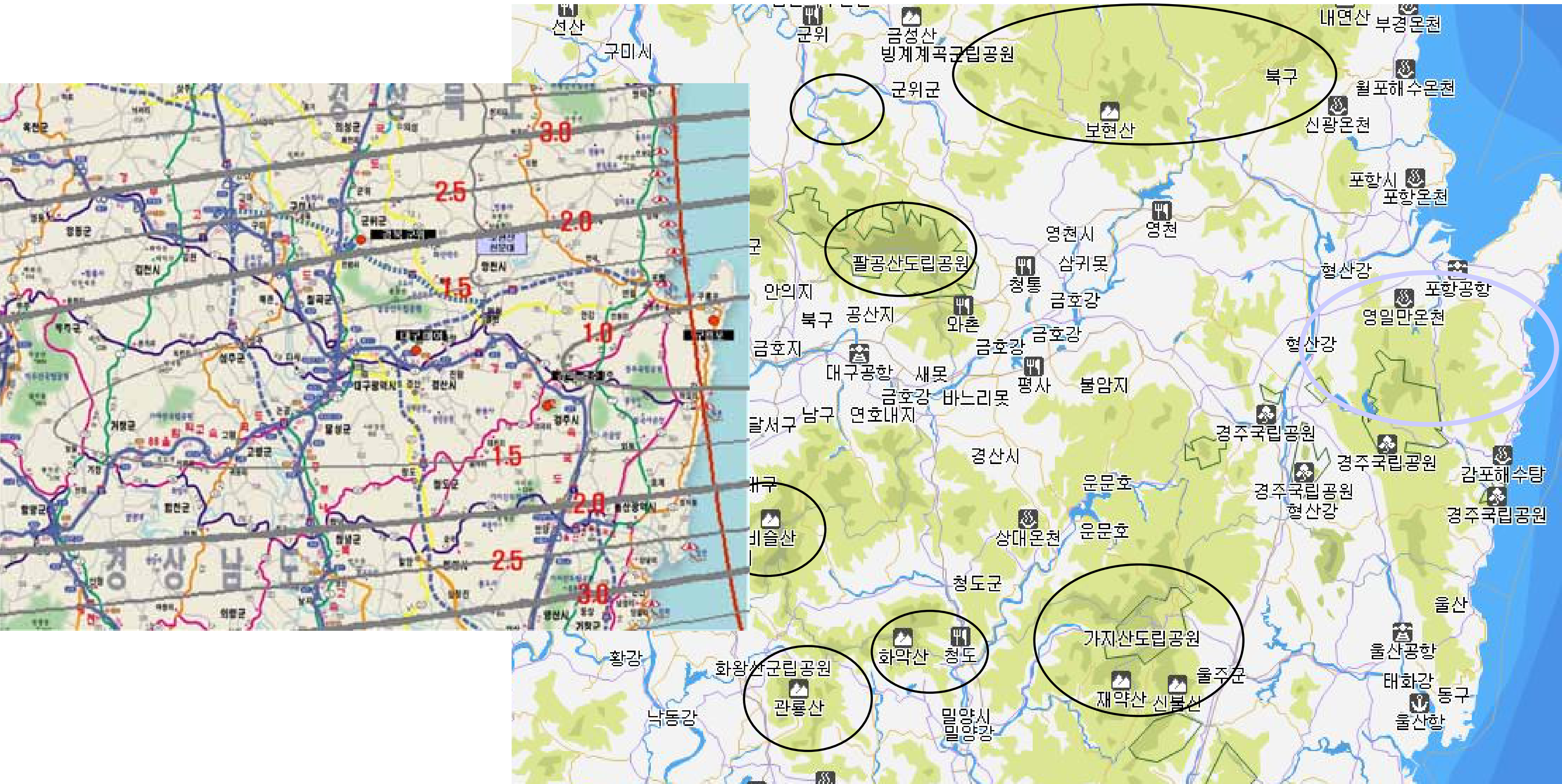
4th workshop at KIAS, Seoul

fall, 2009

http://www-rccn.icrr.u-tokyo.ac.jp/workshop/T2KK07/

Site Study for the Korean Detector

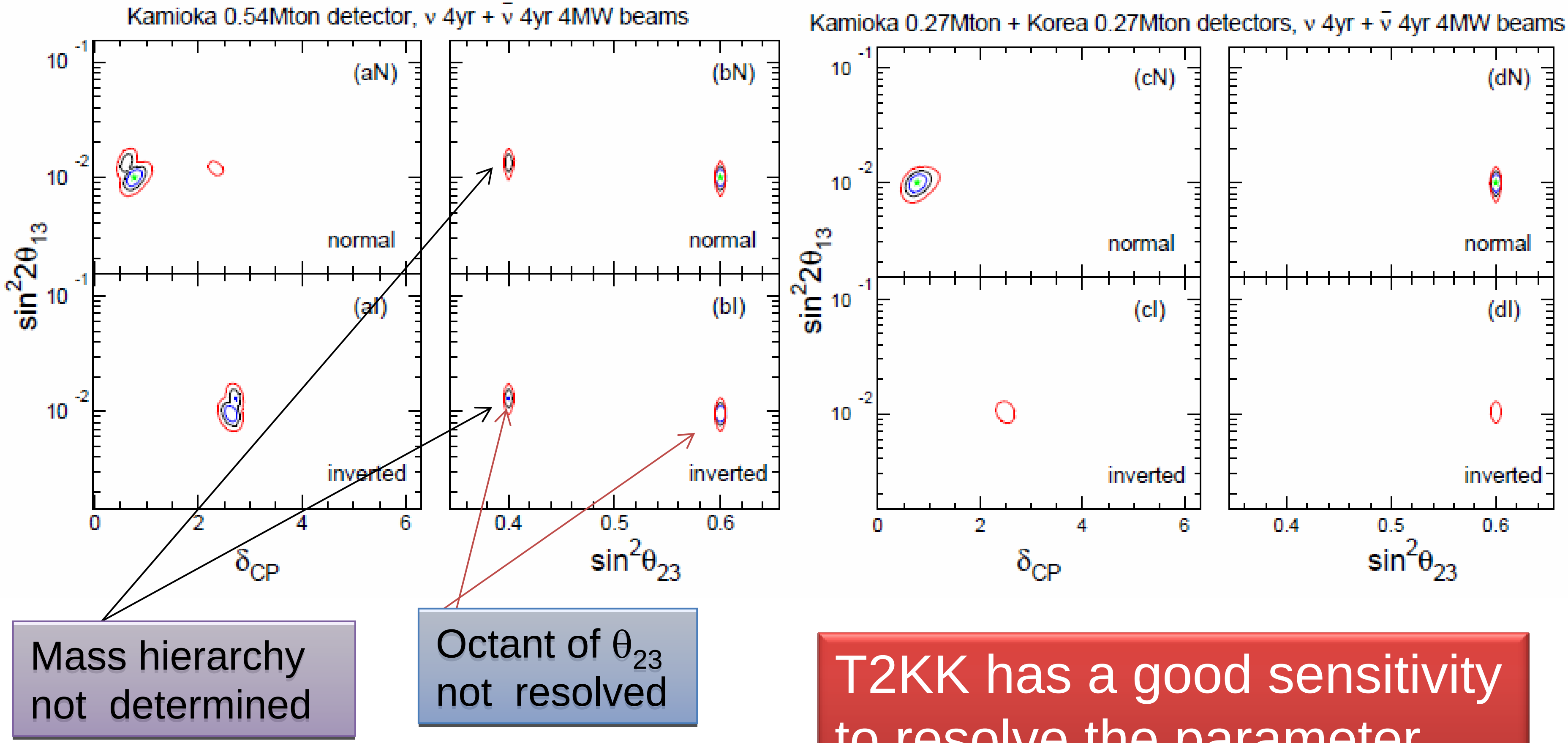
- ❑ mountains of 1,200 meters in height are found almost everywhere in the interesting region of Korea → Search for a candidate site (D.Son, T2KK05, C.Ryu, T2KK06/07)



Resolving the degeneracy: T2K-II vs. T2KK

T2K-II (Kamioka only)

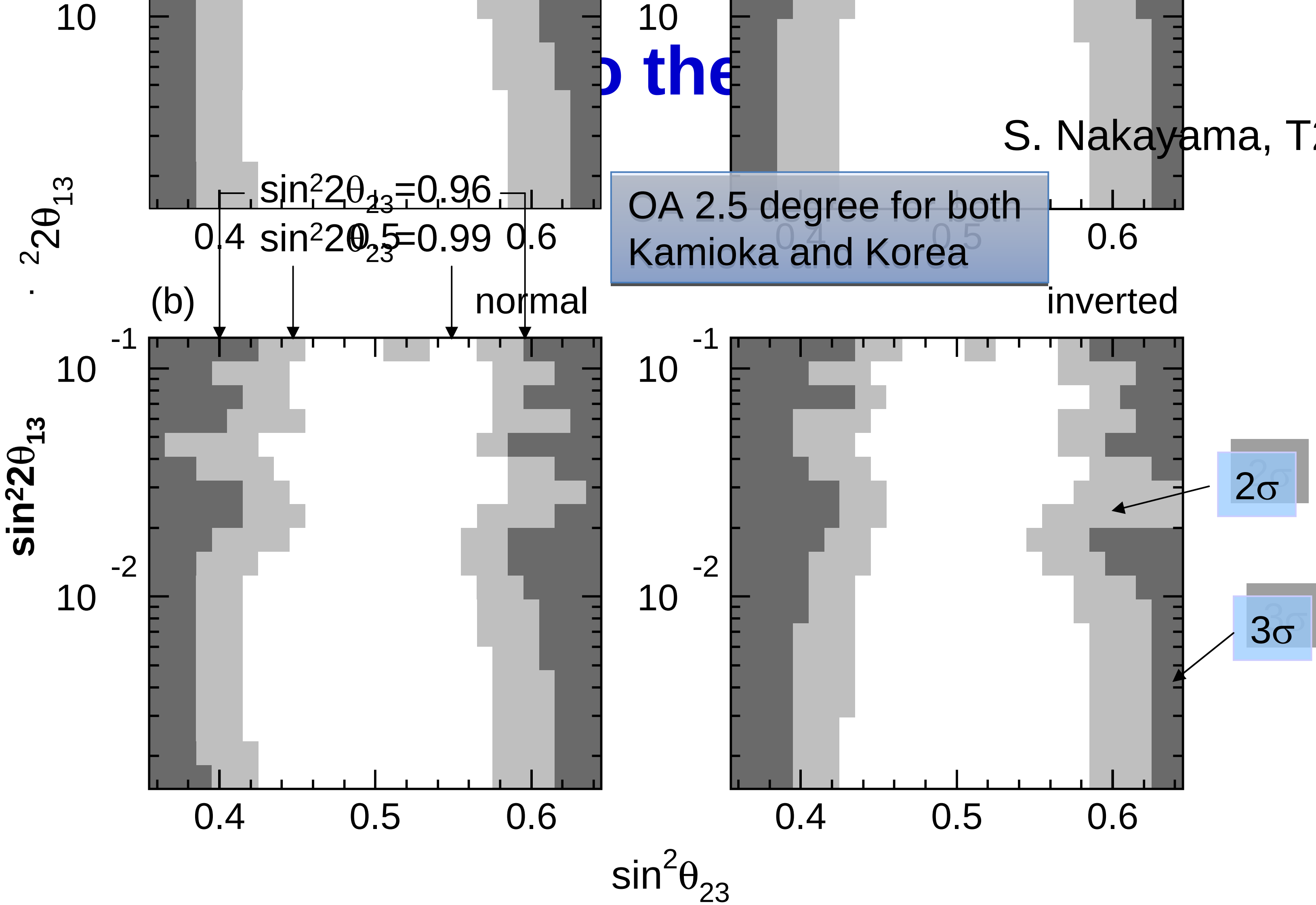
T2KK (Kamioka + Korea)



T2KK has a good sensitivity to resolve the parameter degeneracies.

S. Nakayama, T2KK06

OA 2.5 degree for both Kamioka and Korea

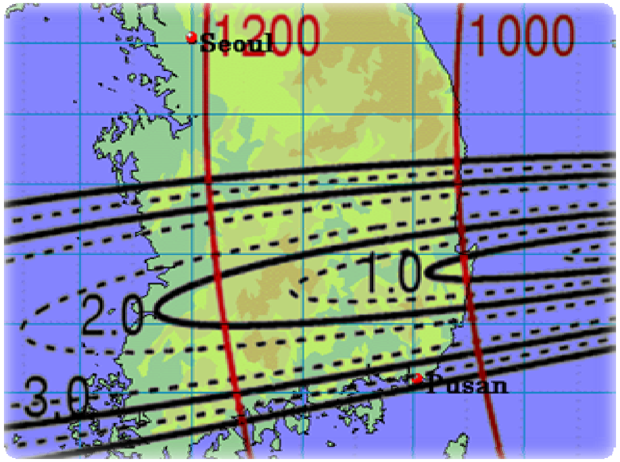


Octant ambiguity of θ_{23} can be resolved at 2σ if $\sin^2 2\theta_{23} < \sim 0.97$
(almost independent of the value of $\sin^2 2\theta_{13}$ and mass hierarchy).

T2KK could resolve the 8 hold degeneracy of the oscillation parameters.

Beam Energy Profiles at Sites in Korea

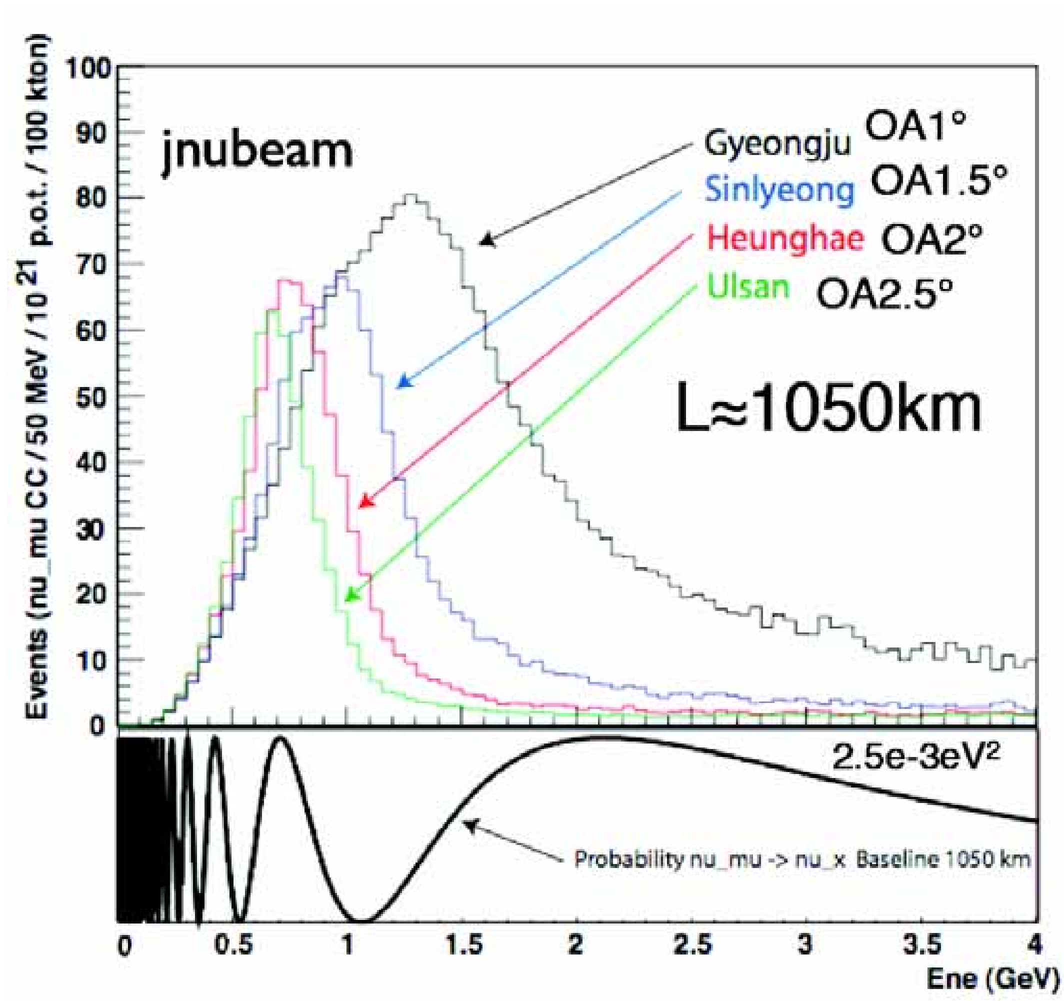
A. Rubbia, T2KK07



1.0 to 3.0 degree off-axis beam available in Korea.

Given the baseline, possibility to cover 1st & 2nd maximum depending on OA angle

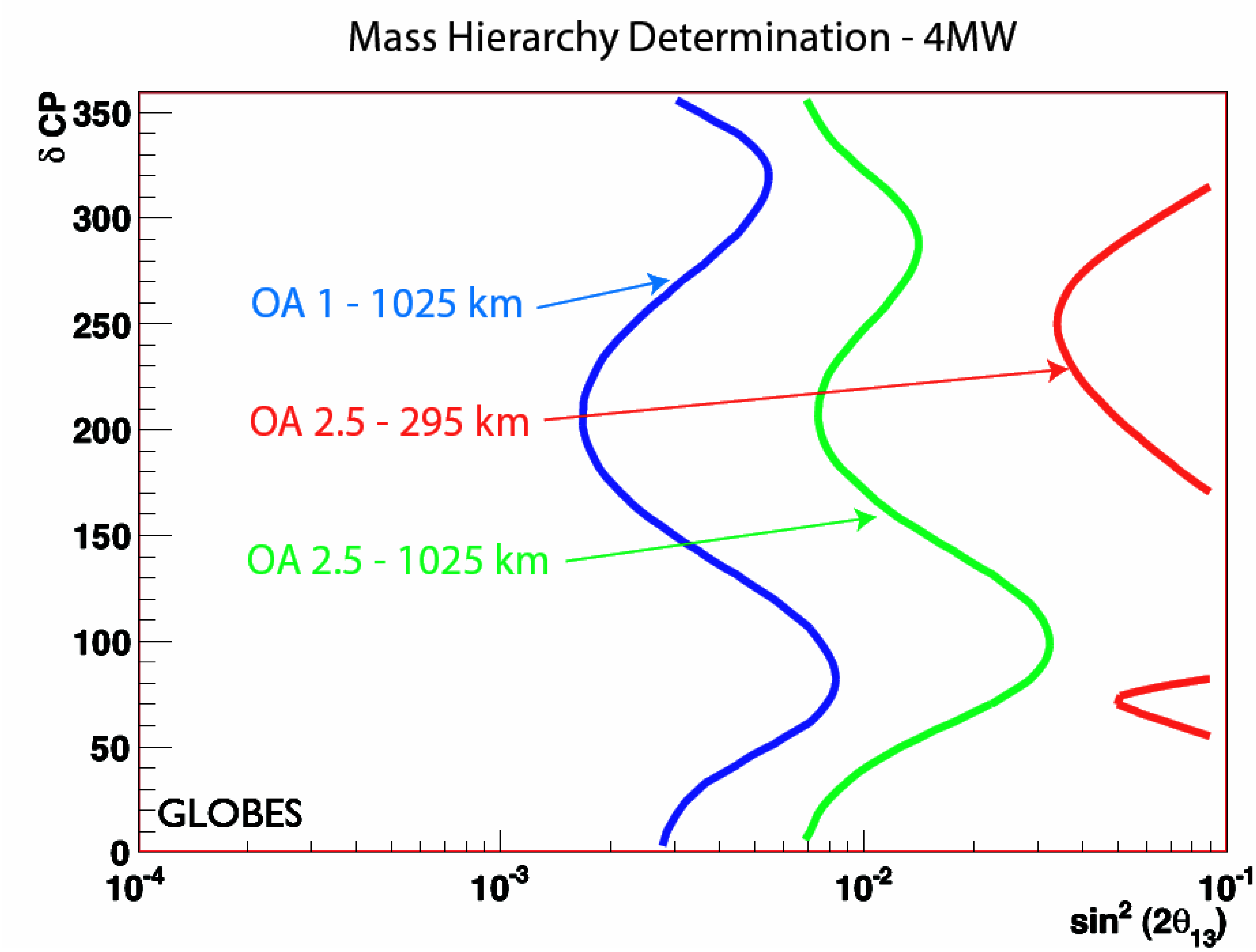
➠Concentrate on OA1 or OA2.5 in Korea and OA2.5 at Kamioka (see our talk T2KK 06)



Sensitivity of Mass Hierarchy

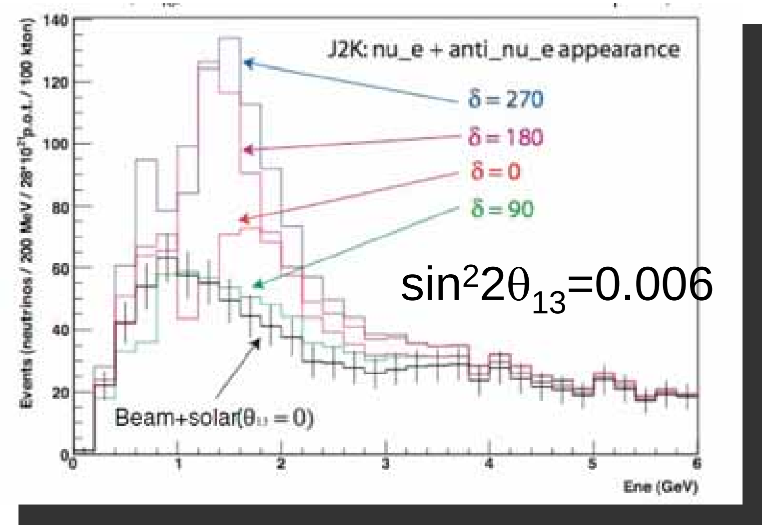
A. Rubbia, T2KK07

- ❑ The longer baseline & higher rate improves mass hierarchy determination



Sensitivity of Liquid Ar Detector

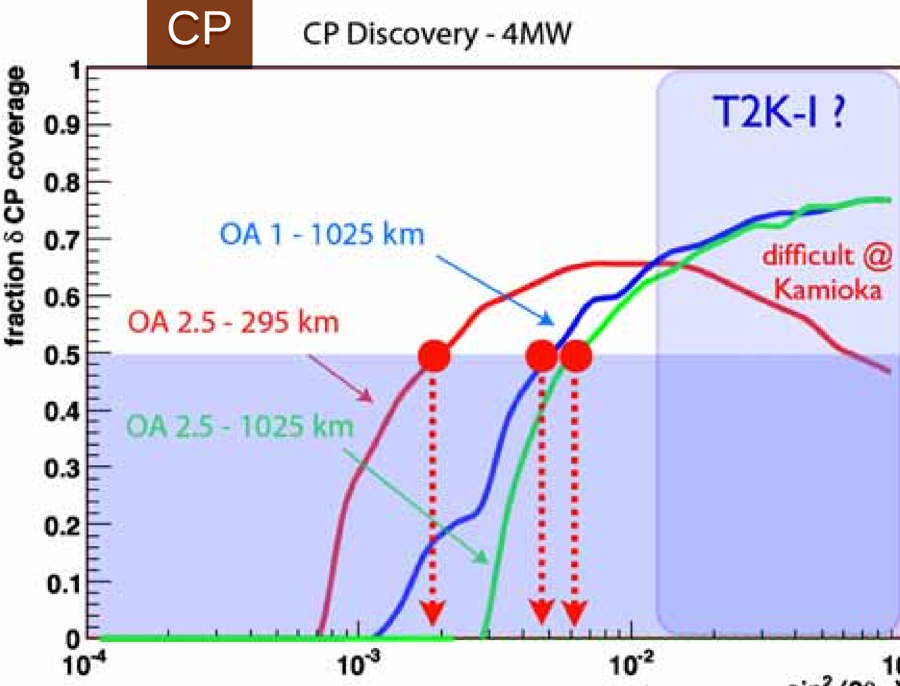
A. Rubbia, T2KK05/06/07



OA 1.0 deg, 28 × 10^{21}pot, 100 kton mass

Very high sensitivity, especially in the very small $\sin^2 2\theta_{13}$ region.

CP



Mass Hierarchy