Detector possibilities: Liquid Argon TPC
Report from GLA2010

Takuya Hasegawa (KEK)

Investment for the "Discovery" in ν Physics
Post T2K/NOvA Era

Significant $\nu_\mu \rightarrow \nu_e$ Signal at T2K/NOvA

⇩

Proceed Immediately to
Lepton Sector CP Violation Discovery

Lepton Sector CP Violation

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & c_{13}s_{12} & e^{-i\delta}s_{13} \\ -s_{12}c_{23} - e^{-i\delta}c_{12}s_{13}s_{23} & c_{12}c_{23} - e^{i\delta}s_{12}s_{13}s_{23} & c_{13}s_{23} \\ -e^{i\delta}c_{12}s_{13}c_{23} + s_{12}s_{23} & -e^{i\delta}s_{12}s_{13}c_{23} - c_{12}s_{23} & c_{13}c_{23} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Effect of CP Phase δ appears as

- ν_e Appearance Energy Spectrum Shape
  - *Peak position and height for 1st, 2nd maximum and minimum
  - *Sensitive to all the non-vanishing δ including 180°
  - *Could investigate CP phase with ν run only
- Difference between ν_e and $\overline{\nu}_e$ Behavior
  - *Need both beam polarities with similar statistics

ν_e Appearance Energy Spectrum Shape Measurement for the investigation of CP Phase δ

Why and How

- Why
  - Existing/near_future_planned conventional super neutrino beam, based on MW class proton synchrotron
    - FNAL MI and beyond
    - CERN?
    - J-PARC MR
  - Physics results within reasonable experimental period (5years)

⇨ Spectrum measurement (1st and 2nd Oscillation Max.) with On-Axis beam with 5years ν beam run, then think next

- How
  - Need excellent π^0 discrimination
  - Need excellent ν energy resolution and reconstruction ability from sub GeV to a few GeV, from single prong to high multiplicity
  - Need long baseline to see 2nd Osc. max, since fixed neutrino energy
  - Need gigantic detector, since finite beam flux and long baseline

⇨ Giant Liquid Argon Time Projection Chamber @ Long Baseline

Naturally, main neutrino detector
tends to be huge.

As a consequence, main neutrino detector gives
us rare and important opportunity for

Proton Decay Discovery

Neutrino Astrophysics

1st International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (GLA2010)

March 29-31 2010, Tsukuba Japan

The aim of the GLA2010

The aim of the workshop is to bring together researchers having common interest in realizing a giant neutrino observatory based on the liquid Argon time projection chamber technology combining next-generation searches for proton decay and neutrino physics with natural and artificial sources. The workshop will review the current worldwide efforts towards large liquid Argon detectors and aims at fostering collaborations on the medium and long time scales.

Apologize to skip technical aspect which is one of the main subjects of GLA2010

Project World Wide

ICARUS (CNGS2): the first large scale LAr experiment

- ICARUS represents a major milestone in the practical realization of a large scale LAr detector. Successfully operated on surface in Pavia in 2002, will soon be operational in the underground HallB of LNGS.
- The T600 at LNGS will collect simultaneously "bubble chamber like" neutrino events events of different nature
- Cosmic ray events
  - ≈ 100 ev/year of unbiased atmospheric CC neutrinos.
  - Solar neutrino electron rates >5 MeV. ~1-2 ev/day
  - Supernovae neutrinos.
  - A zero background proton decay with 3 x 10^{32} nucleons for "exotic" channels.
- CERN beam associated events: 1200 ν_m CC ev/y and 7-8 ν_e CC ev/year
  - Observation of neu-tau events in the electron channel (with sensitivity comparable to OPERA
  - A search fo sterile neutrinos
- Other unexpected phenomena

Looking forward to see start of physics programme !

In Europe ➠ LAGUNA

EC Grant Agreement No. 212343 FP7-INFRA-2007-1

- LAGUNA design study addresses feasibility of large underground detectors at 7 potential sites located in Finland (Pyhäsalmi), France (Fréjus), Italy (Umbria region), Poland (Sieroszowice), Romania (Slanic), Spain (Canfranc) and United Kingdom (Boulby).
- Baselines from CERN: 130 km(Fréjus) to 2300 km(Pyhäsalmi)
  ➥ CERN-Slanic & CERN-Pyhäsalmi offer very long baselines not considered elsewhere in the world → unique physics opportunities
- Three detector options: GLACIER, LENA or MEMPHYS
- LAGUNA consortium will prioritize sites by summer 2010, based on technical, scientific, environmental and political criteria
- Next-step: LAGUNA-next to be submitted in December 2010
- **But:** next generation long-baseline program in Europe needs a new CERN high-intensity, high-energy proton source and high power neutrino beam line (arXiv:1003.1921) → ... SPS 400 GeV provides highest power options until new accelerator is built


Pyhäsalmi
Nuijten
CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE
N62°30'
N57°30'
E 35°
IUS
Institute of Underground Science in Boulby mine, UK
SUNLAB
Polkowice-Sieroszowice, Poland
W 15°
W 5°
Prime Meridian
E 5°
N52°30'
E 15°
Polkowice
IFIN –HH
Unirea Salt Mine
N47°30'
CERN
Fréjus
LSC
Laboratorio Subterraneo de Canfranc, Spain
LSM
Laboratoire Souterrain de Modane, France
Umbria, Italy
100%
ROCKPLAN

LBNE / LAr20 / DUSEL

➠ see Fleming/ Baller

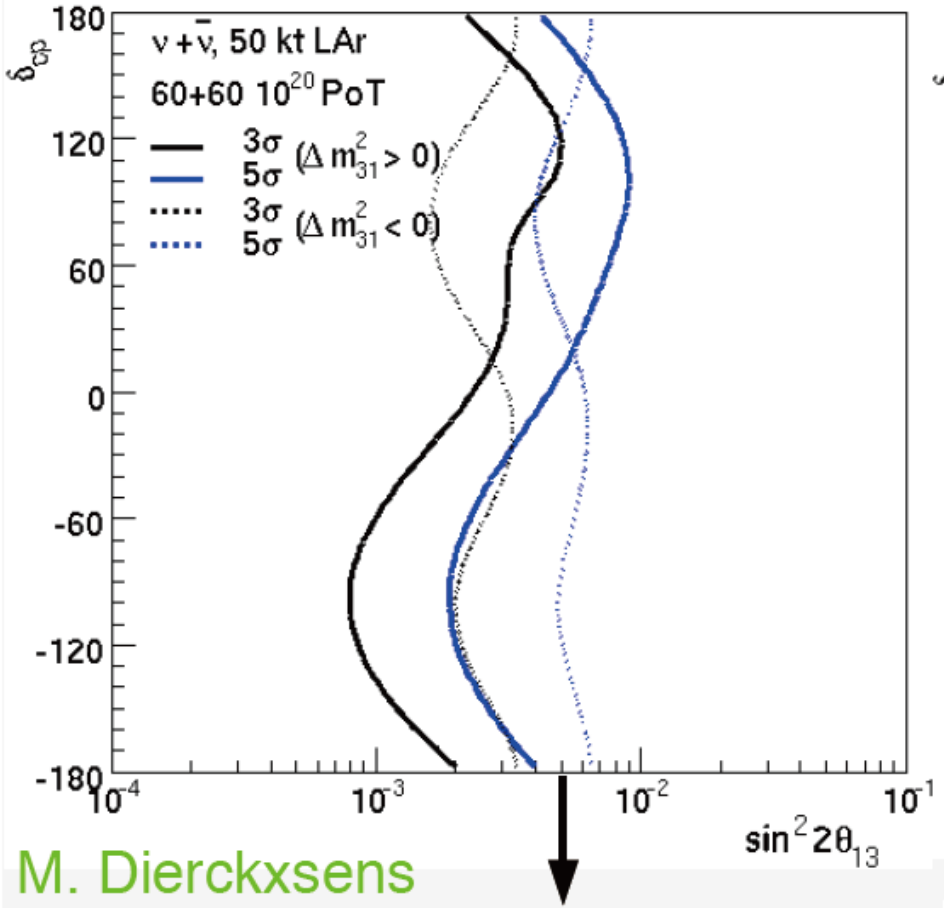
- Plan to build very massive underground detector at the Deep Underground Science and Engineering Laboratory in the Homestake mine
- New beamline from FNAL to DUSEL (700kW SNUMI →2.4MW with ProjectX)
- Two detector options: WC & LAr20
- CD-0 mission statement in January 2010
- CD-1 foreseen by end 2010 ("technology choice" / aggressive schedule)
  - ☑ integrated plan for LAr
  - ☑ impressive progress in design & engineering effort for LBNE
  - ☑ some aspects of design are voluntarily "conservative" (e.g. 2.5 m drift)
  - ☑ embedded cold electronics "*to save the features of the LAr TPC*"
    - ➠ Radeka
- Looking forward to seeing CD-2 decision process!

LBNE/DUSEL

➠ Baller

how to safeguard the science ?

ProjectX 2.4 MW, LAr50@DUSEL, L=1300km



M. Dierckxsens

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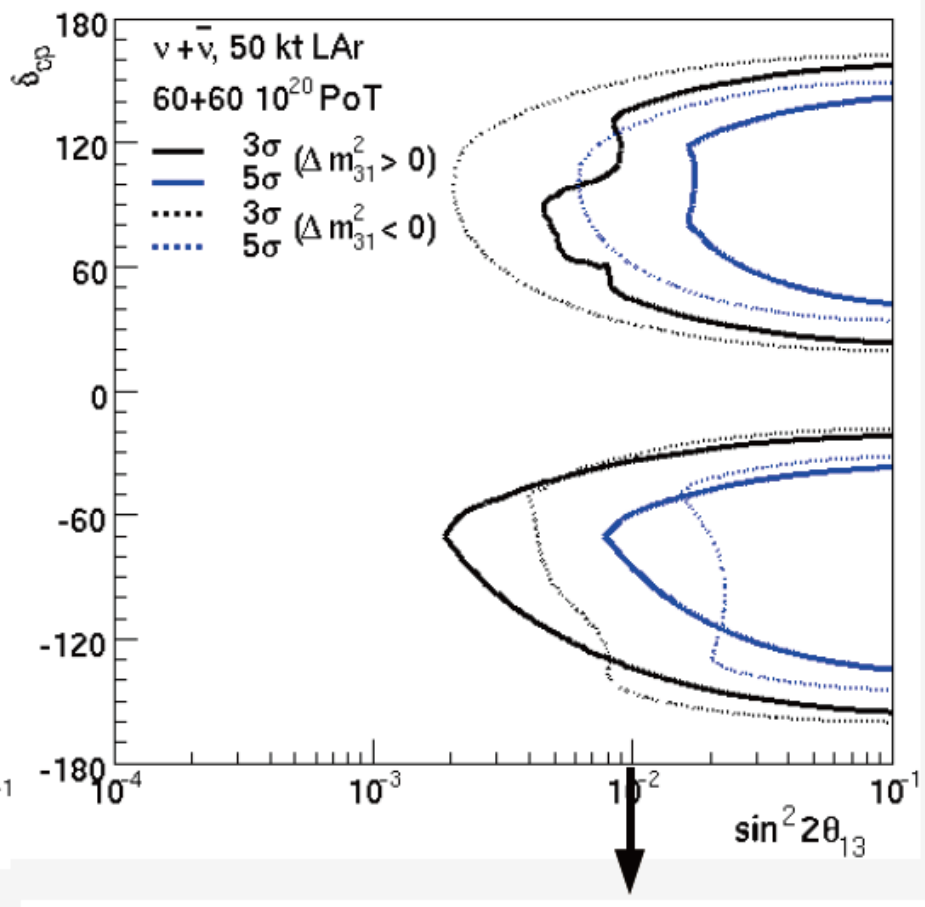

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J-PARC to Okinoshima

w/ 100 kton Giant Liquid Argon Charge Imaging Experiment

arXiv:0804.2111

- <u>1.66 MW J-PARC upgraded neutrino beam</u>:
  - If $\nu_\mu \rightarrow \nu_e$ signal is found in T2K ($\sin^2 2\theta_{13} > \approx 0.01$) experiment will directly address δ_{CP}
  - If $\nu_\mu \rightarrow \nu_e$ signal is not found in T2K, continue the quest with improved sensitivities, down to $\sin^2 2\theta_{13} \approx 0.001$
- <u>Underground detector (rock overburden >600 m.w.e.)</u>:
  - Proton lifetime
  - Atmospheric neutrinos
  - Astrophysical sources of neutrinos

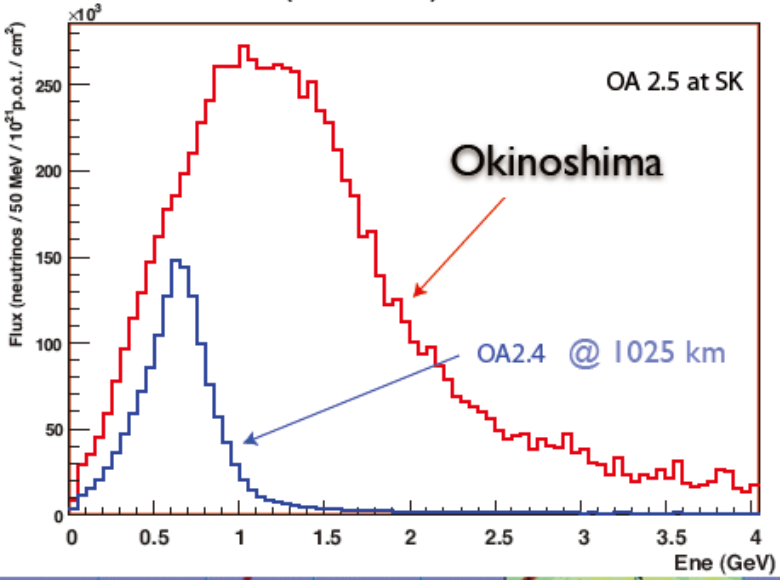
J-PARC to Okinoshima

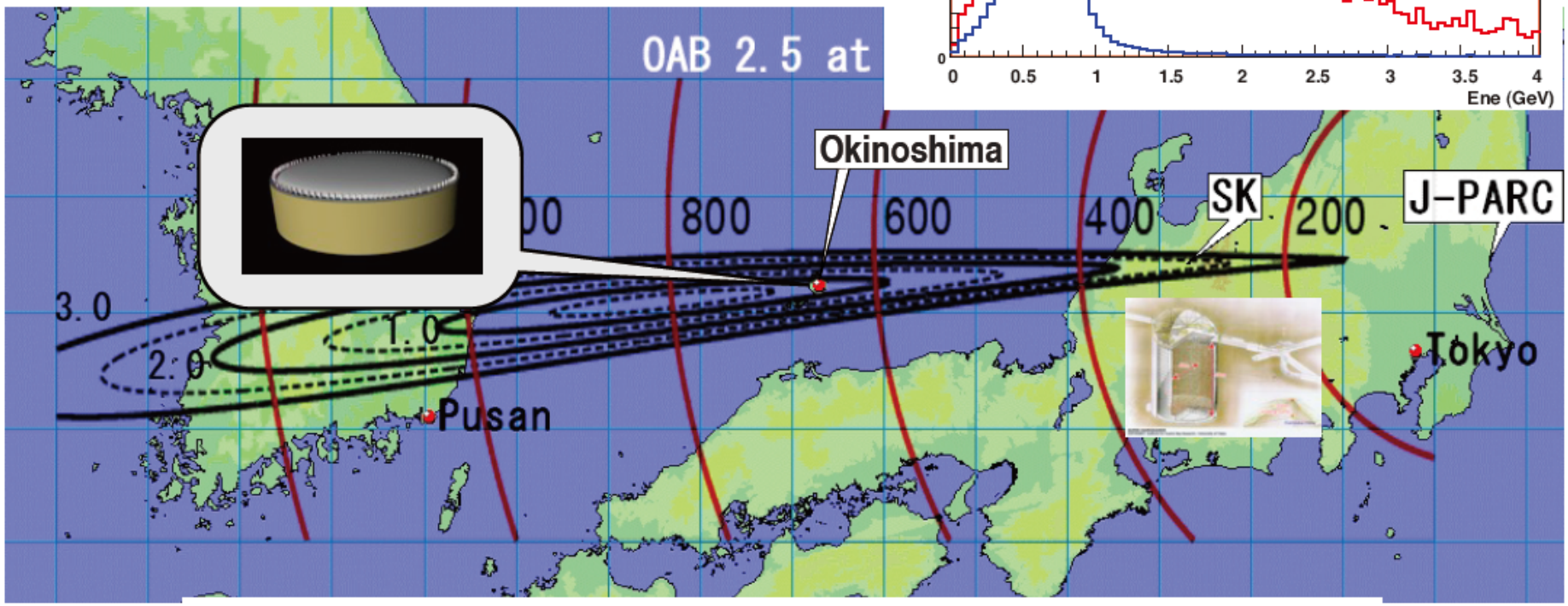
P32 proposal (LAr TPC R&D)
recommended by J-PARC PAC
(Jan 2010)

Distance = 658 km

Off-axis angle = 0.76°
(2.5° @ SK)

100 kton liquid Argon





→ Extract δ_{CP} from fit of 1st & 2nd maximum

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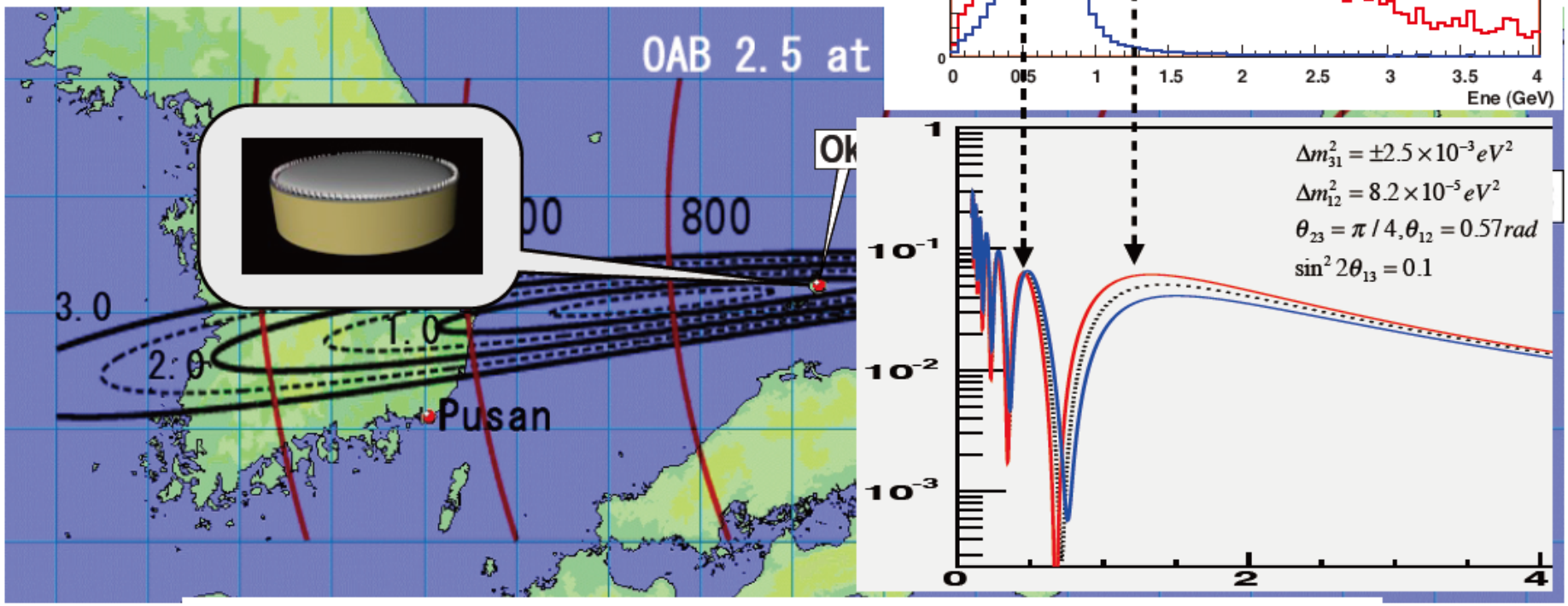
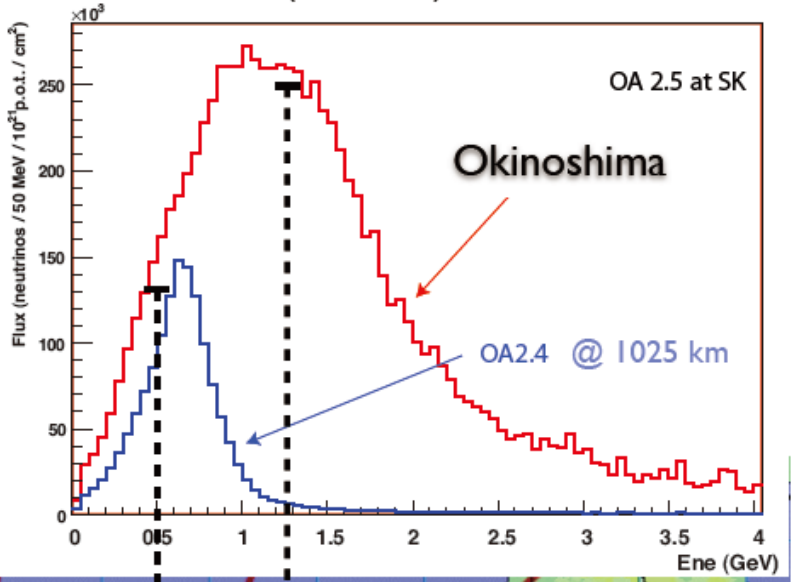




→ Extract δ_{CP} from fit of 1st & 2nd maximum

Expected rates at Okinoshima

Events in 100 kton, 658 km, 5 years @ 1.66 MW

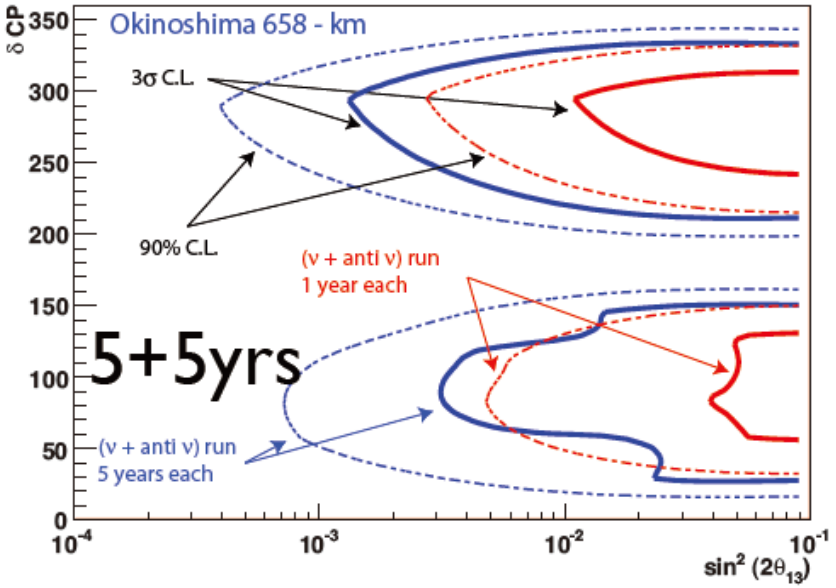
	ν_μ CC	ν_eCC	$\bar{\nu}_\mu$CC	$\bar{\nu}_e$CC
Beam components (null oscillation)	82000	750	1460	35
	$\nu_\mu \rightarrow \nu_e$ oscillations			
$\delta_{CP} =$	0°	90°	180°	270°
$\sin^2 2\theta_{13} = 0.1$	2867	2062	2659	3464
$\sin^2 2\theta_{13} = 0.05$	1489	1119	1342	1908
$\sin^2 2\theta_{13} = 0.03$	942	506	829	1266

➙ x10 more statistics than in T2K

➙ Electron appearance with high signal efficiency, strong background rejection and good energy resolution:

- ◉$\sin^2 2\theta_{13}$<0.001 @ 90%CL (if no signal is found)
- ◉measure θ_{13} with $\delta\sin^2 2\theta_{13} \approx \pm 0.01$ and test CP at better than 90%CL if $\sin^2 2\theta_{13}$>0.01
- ◉CP discovery exceeds 3σ for $\sin^2 2\theta_{13}$>0.02

J-PARC P32 (Jan2010)



2. Geology and geography for GLA cavern

ASAHI quarry

A single layer of the gneiss

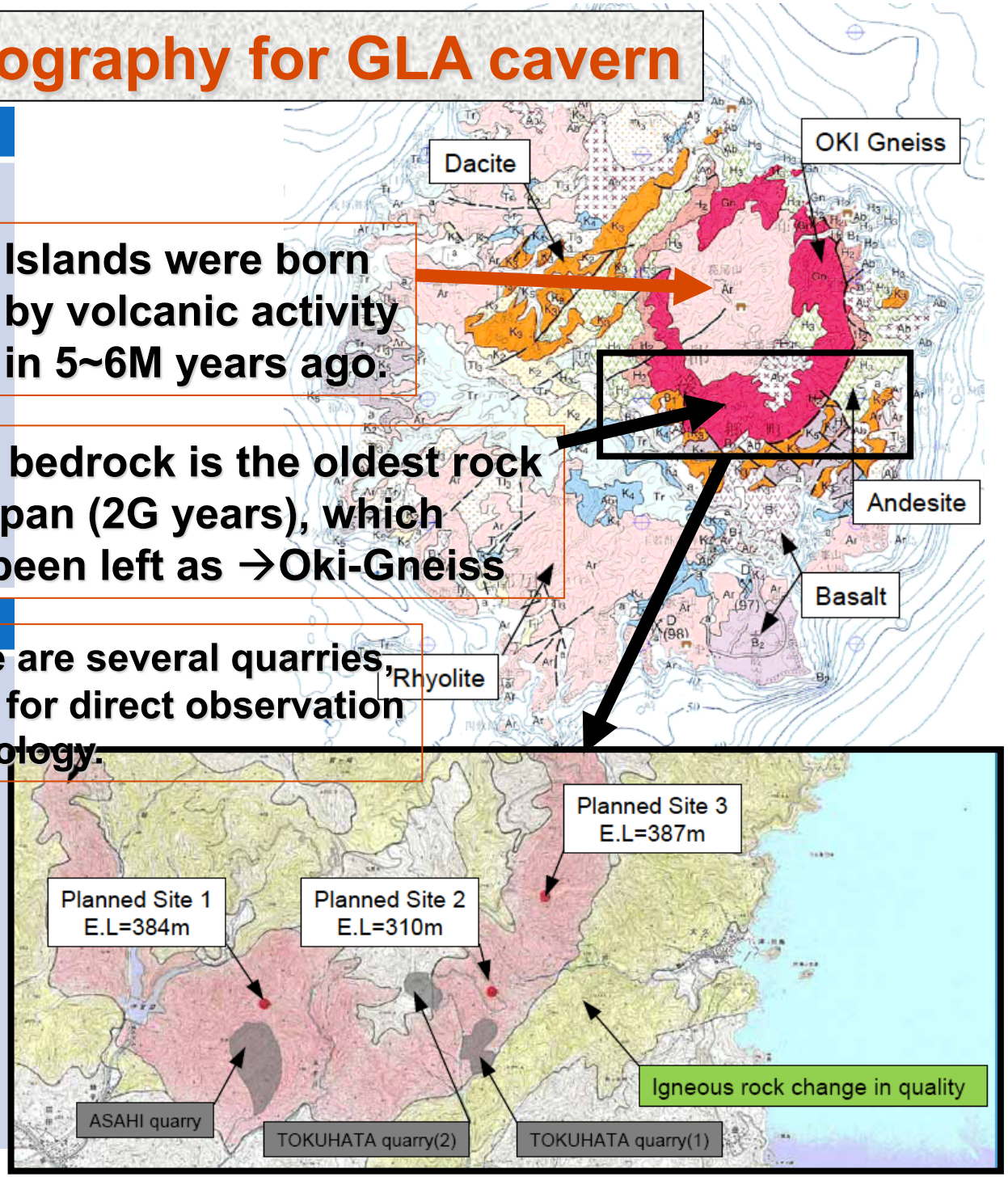
TOKUHATA No.2 quarry

The crackle of the Igneous rock to the gneiss

Islands were born by volcanic activity in 5~6M years ago.

BUT, bedrock is the oldest rock in Japan (2G years), which has been left as →Oki-Gneiss

There are several quarries, good for direct observation of geology.



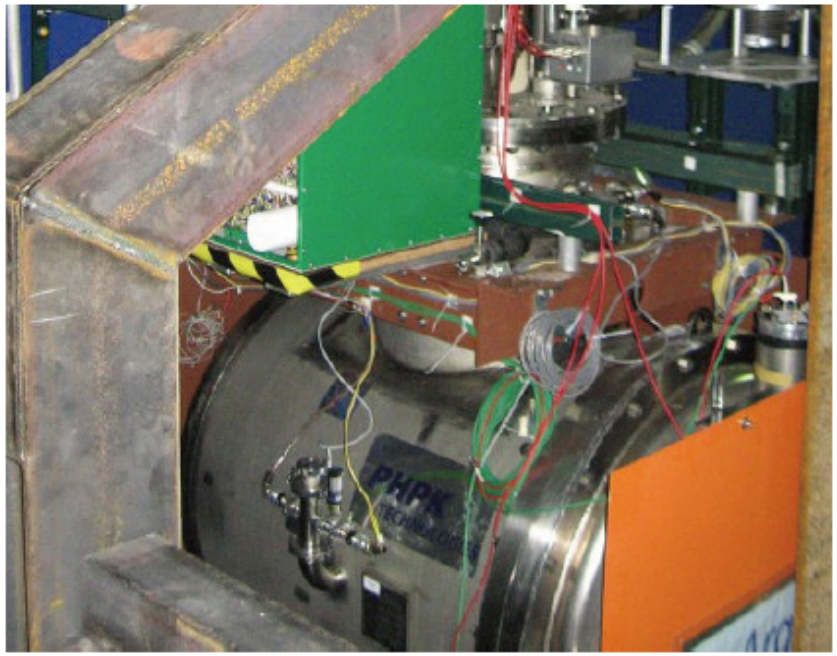
More on small scale R&D efforts

- R&D efforts targeted at developing further the technology towards large scale detectors and assessing performance
- On particle beams
  - ICARUS 50L
  - ArgoNEUT
  - 250L @ J-PARC
- With DM searches
  - WArP
  - ArDM
  - DEAP/CLEAN
  - but also MEG XENON/XMASS

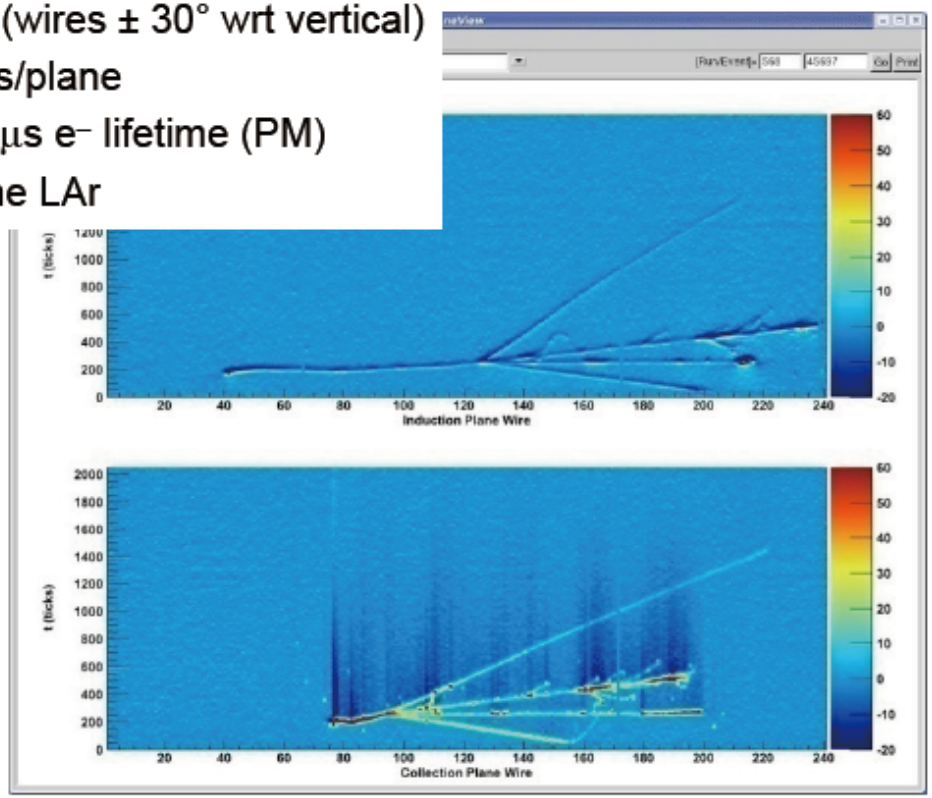
ArgoNEUT @ FNAL

➠ Fleming, Bromberg

- First neutrino interactions in US LAr TPC !
  - 1/4-ton TPC, 3 wire planes, 2 readout planes (wires ± 30° wrt vertical)
  - 4 mm pitch, 4 mm plane separation, 240 wires/plane
  - Cryo-cooler driven purification system, ~ 500 μs e^- lifetime (PM)
  - Bias voltage distribution/decoupling caps in the LAr



~175 lt on NuMI ν beam



Analysis of several 1000's of υ events in progress !

J-PARC PAC recommendation

Beam test of LAr
Charged particle beam

6. PROPOSAL EVALUATIONS

1. **P32:** (Towards a Long Baseline Neutrino and Nucleon Decay Experiment with a next-generation 100 kton Liquid Argon TPC detector)

The PAC acknowledges the high scientific merit of a neutrino oscillation experiment with a baseline longer than T2K. The measurements of the mixing angle θ_{13} and a possible CP violation in the lepton sector are of highest significance.

The specific P32 proposal is to set up and test a 250 Liter LAr prototype TPC in a low-energy charged particle beam at J-PARC, preferentially with kaons from the K1.1BR beamline. **The PAC encourages the team to proceed with this development work and recommends the allocation of beam time of a low intensity charged particle beam at J-PARC for this test.**

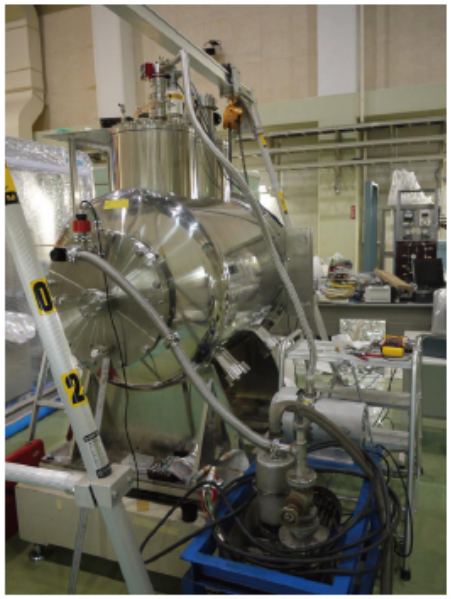
KEK's first step toward LAr !

J-PARC P32

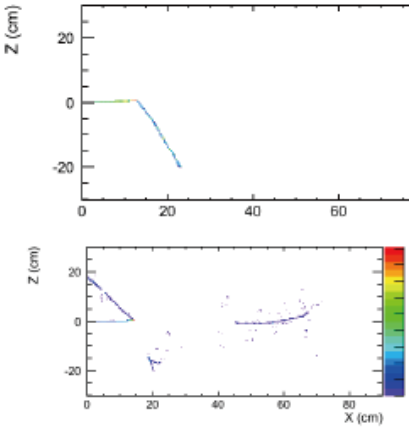
➠ Maruyama

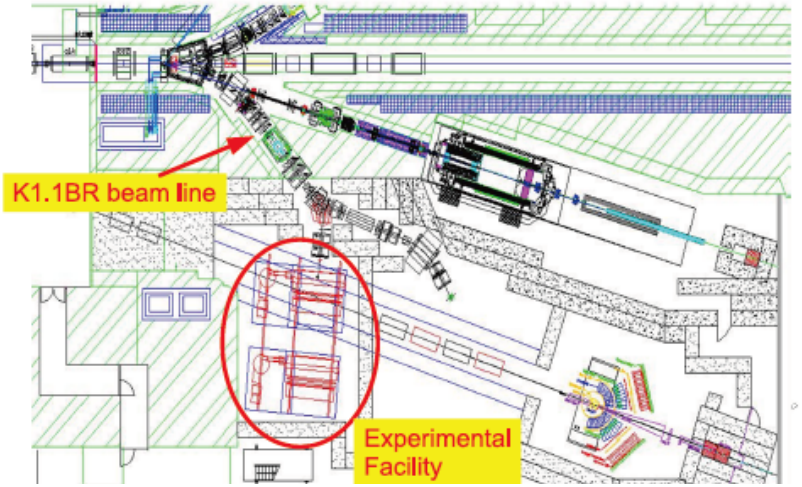
Project to build a small-scale LAr TPC in Japan

- Cryogenic vessel originally built for MEG liquid xenon calorimeter
- Vessel currently at KEK LAr lab
- Ultra-Vacuum established
- Cryocooler and liquid argon filling under investigation
- Liquid argon purification system under procurement
- Chamber being designed and built
- Exposure to low-momentum separated kaon beam @ JPARC



340 MeV/c K+





So what are the main show stoppers?

- Several groups are now engaged in R&D programs towards very large liquid Argon detector. So what are the "main" reasons for not proposing the 100 kton detectors as of today?

- The most important "show stoppers" seems to be today the following:
  - Is the physics performance of LAr detector fully understood(signal eff., Backgrounds)?
    - Need to study 10^6 ν and $\overline{\nu}$ interactions on LAr
  - What are the plausible maximum drift length & highest purity?
    - Need experience with long drift detectors of smaller size
  - How to get the funding agencies to commit about 500M€?
    - Need results from T2K/NOvA and LHC to have very strong arguments for finding CPV & proton decay

A precursor step

View on a 1kt @ CERN PS

(A step beyond MicroBooNE with 10× statistics)

- Search for ν_e and $\overline{\nu}_e$ appearance with very large statistics
  - Answer open questions (e.g. LSND oscillations and/or address whether the MiniBooNE low energy excess is due to electrons or photons)
  - Unique opportunity to test in realistic beam conditions the LAr TPC performance for future long baseline program
- Statistically precise exclusive neutrino and antineutrino differential cross-section measurements in the GeV range
  - With more than 10^6 interactions with low neutrino beam flux systematics, with both horn polarities
  - To study backgrounds in future long baseline and future non-accelerator physics measurements with high statistical accuracy(×10 expected backgrounds)
- A technical precursor of a 100 kton underground future neutrino physics and proton decay experiment
  - The largest possible detector to minimize extrapolation to 100 kton
  - The smallest possible detector to minimize cost and timescale for realization

Comparison event statistics

	MiniBOONE (running)	MicroBOONE (CD1)	1kton @ PS
Det. mass	500 t	70 t	1000 t
Distance L (m)	541	541	850
υμCC energy (peak)	0.8 GeV	0.8 GeV	1.5 GeV
E/L (eV^2)	1.8	1.8	2.2
Proton energy (GeV)	8	8	20
Pots	6.46×10^{20}(υ-run) 5.5×10^{20}(antiυ-run)	6×10^{20}(υ)	1.25×10^{20}(υ)* few 10^{20}(antiυ)
υμ CC(CCQE)	υ: 7×10^5(4.2×10^5) antiυ: 1×10^5	1×10^5(6×10^4)	1.2×10^6(4.8×10^5) antiυ: 5×10^5

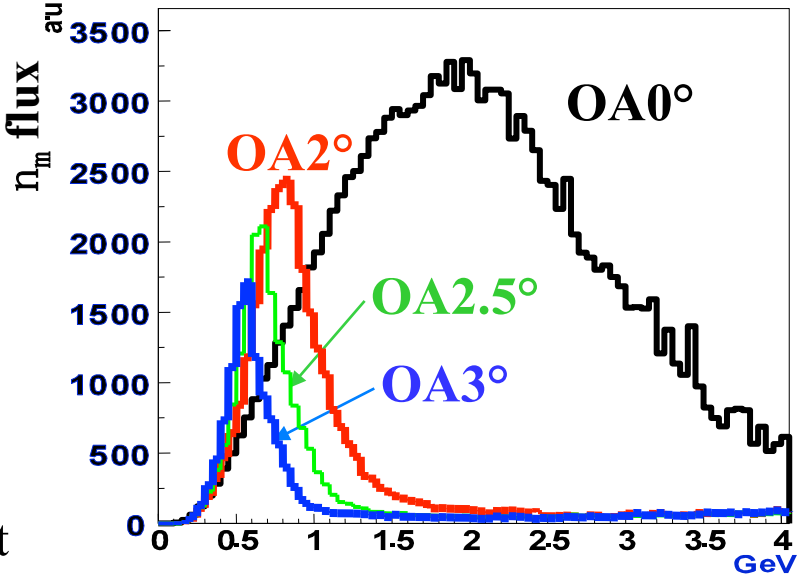
(*) 6×10^{19}pot/yr for 2yrs running (R. Steerenberg)
(**) antineutrino horn polarity rate being computed (Ludovici)

Outlook

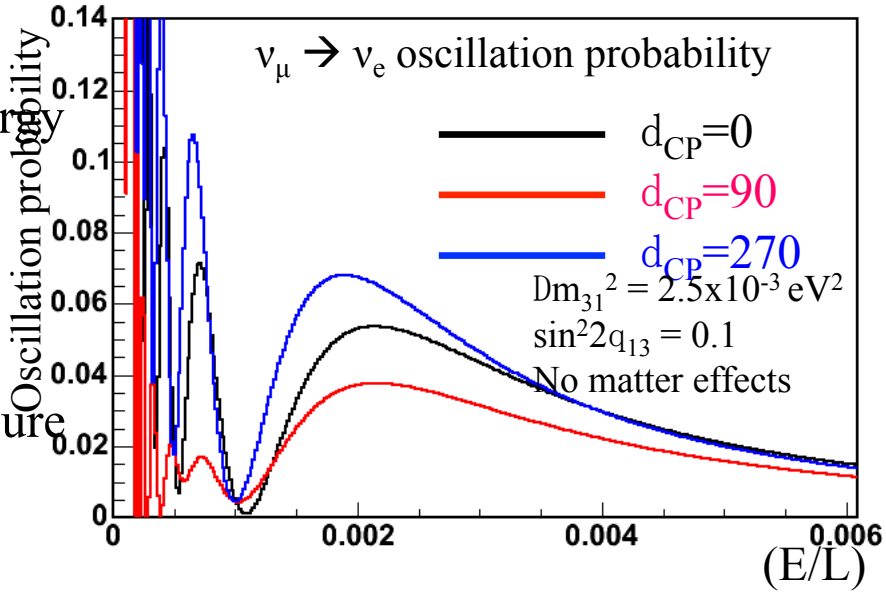
- We all look forward to ICARUS T600(1.5m drift , 50k wires) starting commissioning @ LNGS and produce physics results.
- A 20 kton LAr TPC (2.5m drift, 500k wires) is part of LBNE program @ DUSEL with a deliberately chosen conservative design (e.g. 2.5m drift) but with some challenging aspects (e.g. fully embedded cold electronics) → indeed a great opportunity to build 1/5 of the 100kton! Currently getting to CD1-review, waiting for CD-2.
- In parallel, smaller technical "precursor step" of a 100 kton detector in the range of the 1 kton mass, which could perform a sensible neutrino physics program in addition to being the playground for future technical solutions, has been considered since a while.
- Its feasibility @ CERN PS, presumably after MicroBooNE startup, could provide an ideal setting, however needs much more detailed studies and assessment of physics performance→ an expression of interest ?
- A significant part of this detector(e.g. cryogenic components, purification systems, detectors, electronics, etc…) could be eventually deployed underground as an "pilot underground experiment".
- It looks like LAr technology has very exciting times ahead !

Angle and Baseline

- Angle w.r.t On-Axis
  - On-Axis: Wide Energy Coverage,
    - ○Energy Spectrum Measurement
    - ×Control of π^0 Background
  - Off-Axis: Narrow Energy Coverage,
    - ○Control of π^0 Background
    - ×Energy Spectrum Measurement
    - → Counting Experiment



- Baseline
  - Long:
    - ○ 2nd Osc. Max. at Measurable Energy
    - × Less Statistics
    - ? Large Matter Effect
  - Short:
    - ○ High Statistics
    - × 2nd Osc.Max.Too Low Energy to Measure
    - ? Less Matter Effect



Skeleton of the GLA2010

- Learn experiences thoroughly, and
  Integrate presently available knowledge
  - Special session “The ICARUS Liquid Argon TPC”
  - Lessons on Liquid Argon Charge Imaging technology from ongoing developments
  - Lessons from Xe based Liquids Imaging detectors
  - Studies on physics performance
- Push present efforts forward coherently
  - Ways to improve the Liquid Argon Charge Imaging technology
- Toward realization of Giant Liquid Argon TPC
  - Localization studies
  - Future Steps towards the realization of Giant Liquid Argon Charge Imaging detectors
- Needless to say, Based on physics argument
  - Main goals of Giant Liquid Argon Charge Imaging Experiments

GLA2010 Program

1st International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (GLA2010)

from Sunday 28 March 2010 (14:00) to Wednesday 31 March 2010 (13:45) Asia/Tokyo at KEK

Sunday 28 March 2010 | Monday 29 March 2010 | Tuesday 30 March 2010 | Wednesday 31 March 2010

Sunday 28 March 2010

19:00->21:00 **Reception at Okura Frontier Hotel Tsukuba (Buffet style dinner with drink)**

Monday 29 March 2010

09:00->09:45 **Introduction** (Convener: Andre Rubbia (*ETH Zurich*))
- 09:00 Welcome address — Atsuto Suzuki (*KEK*)
- 09:05 Message from CERN on neutrino physics — Sergio Bertolucci (*CERN*)
- 09:15 Message from FNAL on neutrino physics — Young Kee Kim (*FNAL*)
- 09:25 Message from KEK on neutrino physics — Koichiro Nishikawa (*KEK*)
- 09:35 Introductory remark on GLA2010 — Takuya Hasegawa (*KEK*)

09:45->10:30 **Special session** (Convener: Koichiro Nishikawa (*KEK*))
- 09:45 The ICARUS Liquid Argon TPC — Carlo Rubbia (*CERN*)

10:30 Coffee break

11:00->12:00 **Main goals of Giant Liquid Argon Charge Imaging Experiments I** (Convener: Takashi Kobayashi (*KEK*))
- 11:00 Results from massive underground detectors (non accelerator) — Takaaki Kajita (*ICRR, U. of Tokyo*)
- 11:30 Present long baseline neutrino experiments — Chang Kee Jung (*SUNY Stony Brook*)

12:00->12:10 **Workshop picture**

12:10 Lunch break

14:00->14:50 **Main goals of Giant Liquid Argon Charge Imaging Experiments II** (Convener: Takashi Kobayashi (*KEK*))
- 14:00 Physics goals of the next generation massive underground experiments — David Wark (*Imperial College London*)
- 14:30 Near detectors for long baseline neutrino experiments — Tsuyoshi Nakaya (*Kyoto U.*)

14:50->17:10 **Lessons on Liquid Argon Charge Imaging technology from ongoing developments** (Convene Chang Kee Jung (*SUNY Stony Brook*))
- 14:50 WARP — Claudio Montanari (*U. of Pavia*)
- 15:20 ArDM — Alberto Marchionni (*ETH Zurich*)
- 15:50 From ArgoNeuT to MicroBooNE — Bonnie Fleming (*Yale U.*)
- 16:20 250L — Takasumi Maruyama (*KEK*)
- 16:50 The DEAP/CLEAN project — Mark Boulay (*Queen's U.*)

17:10 Coffee break

17:30->18:30 **Lessons from Xe based Liquids Imaging detectors** (Convener: Flavio Cavanna (*U. of L'Aquila*))
- 17:30 MEG — Satoshi Mihara (*KEK*)
- 17:50 The XENON project — Elena Aprile (*Columbia U.*)
- 18:10 XMASS — Hiroyuki Sekiya (*ICRR, U. of Tokyo*)

18:30->19:35 **Studies on physics performance** (Convener: Bonnie Fleming (*Yale U.*))
- 18:30 Supernovae neutrino detection — Ines Gil-Botella (*CIEMAT*)
- 18:50 Neutrino cross-section in Liquid Argon in the GeV range — Flavio Cavanna (*U. of L'Aquila*)
- 19:05 Analysis of the ArgoNeuT neutrino data — Carl Bromberg (*Michigan State U.*)
- 19:20 Neutrino event reconstruction — Gary Barker (*U. of Warwick*)

Tuesday 30 March 2010

09:00->10:50 **Ways to improve the Liquid Argon Charge Imaging technology I** (Convener: Christos Touramanis (*U. of Liverpool*))
- 09:00 Liquid Argon LEM TPC — Filippo Resnati (*ETH Zurich*)
- 09:30 Micromegas for charge readout of double phase liquid Argon large TPCs — Alain Delbart (*Saclay*)
- 09:50 Development of Thick-GEMs for GEM-TPC Tracker — Fuminori Sakuma (*RIKEN*)
- 10:10 Optical readout of the ionization — Neil Spooner (*U. of Sheffield*)
- 10:30 Scintillation light readout — Kostas Mavrokoridis (*U. of Liverpool*)

10:50 Coffee break

11:10->13:20 **Ways to improve the Liquid Argon Charge Imaging technology II** (Convener: Alberto Marchionni (*ETH Zurich*))
- 11:10 Development of cold electronics — Veljko Radeka (*BNL*)
- 11:40 Development of a frontend ASIC and DAQ system — Dario Autiero (*IPN Lyon*)
- 12:00 CAEN digitizers — Carlo Tintori (*CAEN*)
- 12:20 Recent results from Liquid Argon R&D activity — Masashi Tanaka (*KEK*)
- 12:40 Results from the materials test stand and status of LAPD — Brian Rebel (*FNAL*)
- 13:00 Purging and purification: 6 m^3 @CERN — Alessandro Curioni (*ETH Zurich*)

13:20 Lunch break

14:30->20:00 **Trip to J-PARC to visit T2K Beam Facility and Near Detector**

20:00->22:00 **Workshop dinner at Okura Frontier Hotel Tsukuba**

Wednesday 31 March 2010

09:00->10:05 **Ways to improve the Liquid Argon Charge Imaging technology III** (Convener: Takasumi Maruyama (*KEK*))
- 09:00 ArgonTube and UV laser ionization — Biagio Rossi (*U. of Bern*)
- 09:25 Detector magnetization — Andreas Badertscher (*ETH Zurich*)
- 09:40 HV system — Sosuke Horikawa (*ETH Zurich*)

10:05->11:15 **Localization studies** (Convener: Takuya Hasegawa (*KEK*))
- 10:05 Okinoshima site study — Masakazu Yoshioka (*KEK*)
- 10:25 LAGUNA sites study — Guido Nuijten (*Rockplan*)
- 10:55 FNAL/DUSEL project — Regina Rameika (*FNAL*)

11:15 Coffee break

11:35->13:05 **Future steps towards the realization of Giant Liquid Argon Charge Imaging detectors** (Convener: Takuya Hasegawa (*KEK*))
- 11:35 LBNE Liquid Argon option — Bruce Baller (*FNAL*)
- 12:05 Towards a 100 kton Liquid Argon experiment — Andre Rubbia (*ETH Zurich*)
- 12:35 Discussion

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Presentation files are available at "AGENDA" of http://neutrino.kek.jp/GLA2010

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(Be careful, it is keep changing.)

2nd International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (GLA2011)

2011, Europe

Present situation

ICARUS T600 is the largest detector built and operated to date

Since its successful operation in Pavia in 2001, there has been tremendous, imaginative efforts - often independent from one another –

and

worldwide to go beyond that stage

➪ GLA2010 confirms this trend

Giant underground caverns

➠ Nuijten, Yoshioka, Rameika

☑ USA LAr20 @ DUSEL

- CD-1 → CD-2 approval process

☑ Japan Okinoshima

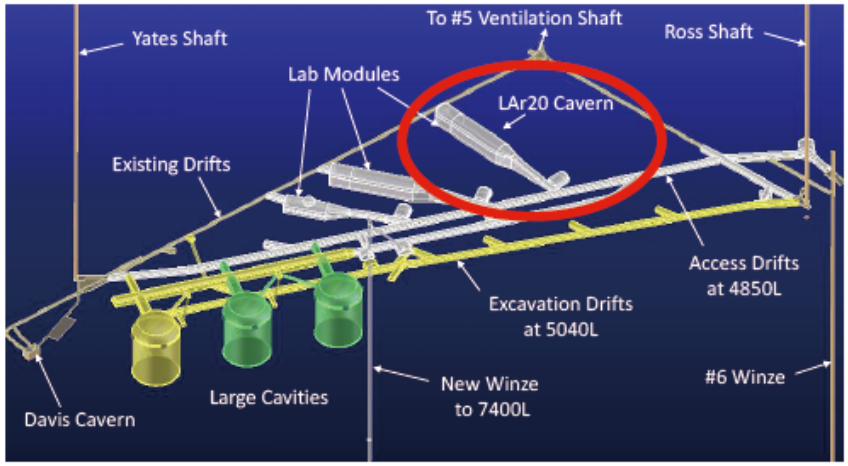
- Site visit; potential location found, feasibility study started and preliminary concept defined (Penta-Ocean Co)

☑ Europe 7 potential sites studied in LAGUNA

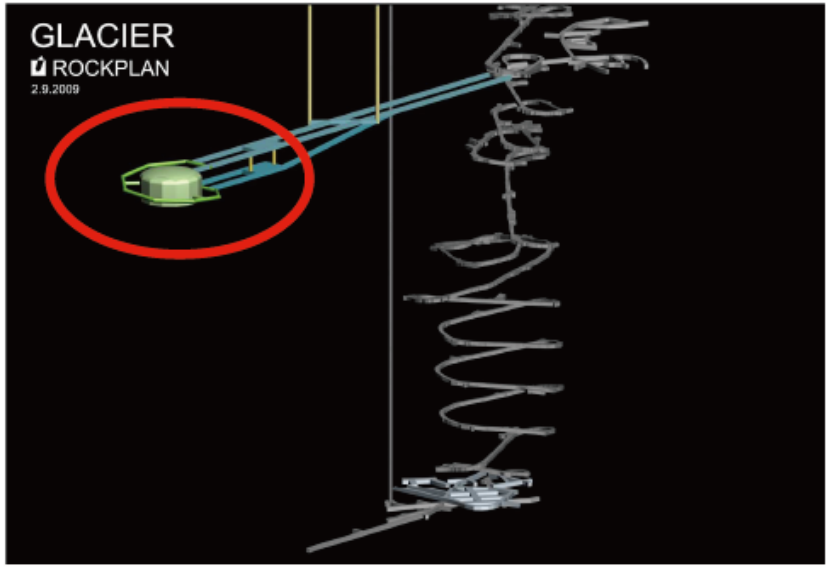
- FP7 design study to select among promising locations in Europe: Pyhäsalmi, Slanic, Sieroszowice, Umbria, Canfranc; concepts and prices for main cavern excavation, ancillary infrastructure and access tunnel available

☑ For safety horizontal access is probably easier than vertical !

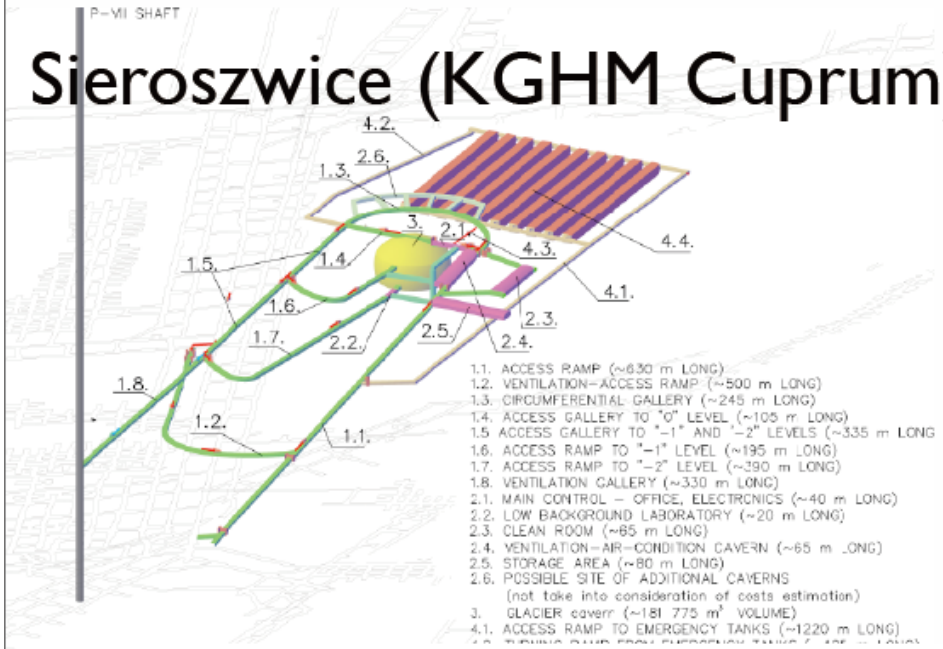
DUSEL (LBNE)



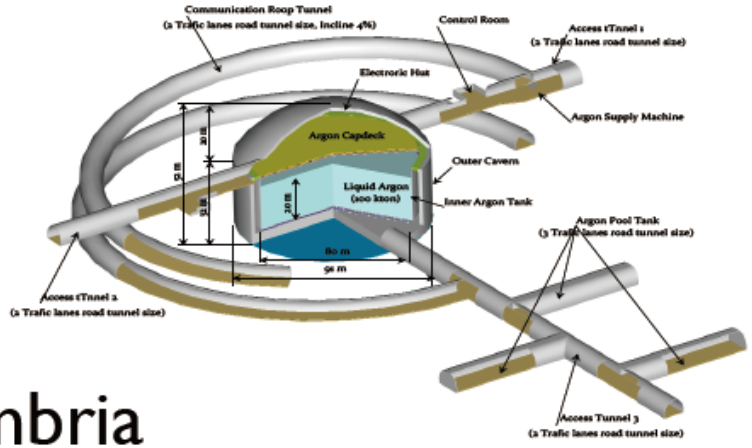
Pyhäsalmi (Rockplan)



Sieroszwice (KGHM Cuprum)



Okinoshima (Penta-Ocean)



Also Canfranc, Fréjus, Slanic, Umbria