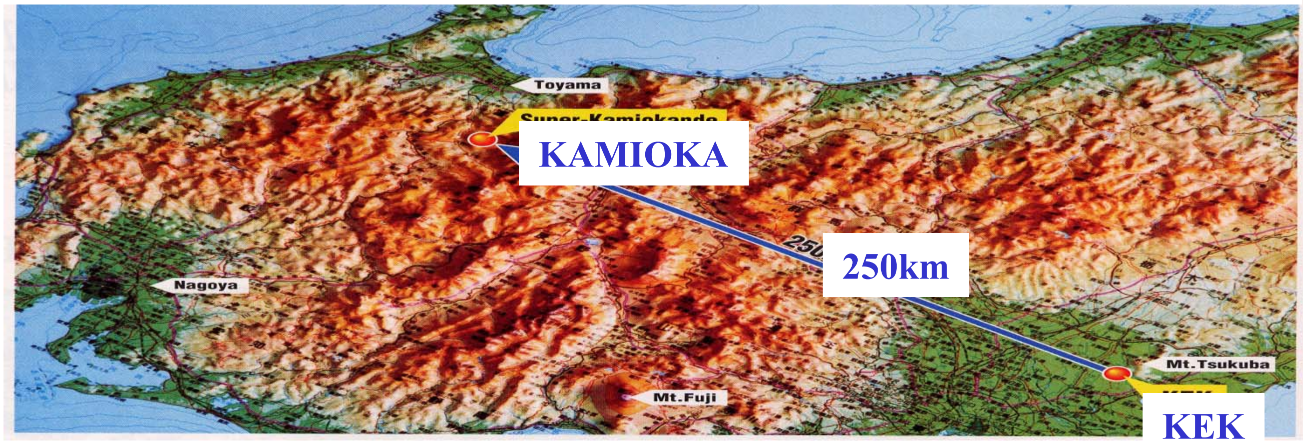
Accelerator based neutrino projects in Japan

Takuya Hasegawa (KEK)

First generation

K2K: First Long-Baseline(250km) Neutrino Experiment in the World



- Definitely Measure the Finite Mass Difference of **ν**'s

  with Pure $\boldsymbol{\nu}_{\mu}$ Beam with Well Defined Energy $\langle E_{\nu} \rangle \sim 1.3$GeV

  with Fixed Long-Baseline $L = 250$km

  (Motivated by the Claim on the Evidence of Neutrino Oscillation by Kamiokande and Super-Kamiokande)

- First Challenge of This Type of Experiment

  Something Unexpected ?? / Something Surprise ??

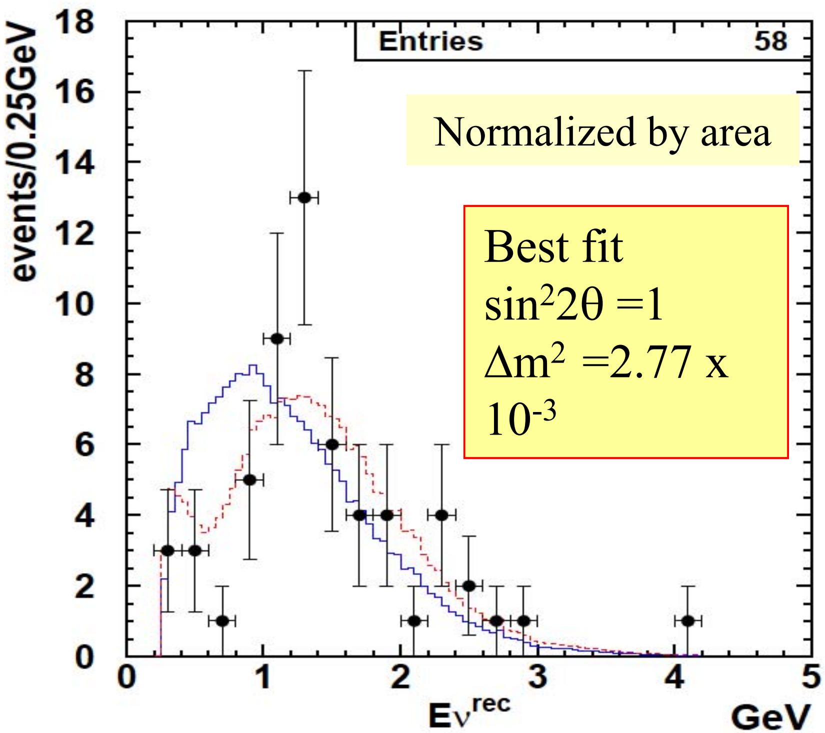
Final results of K2K

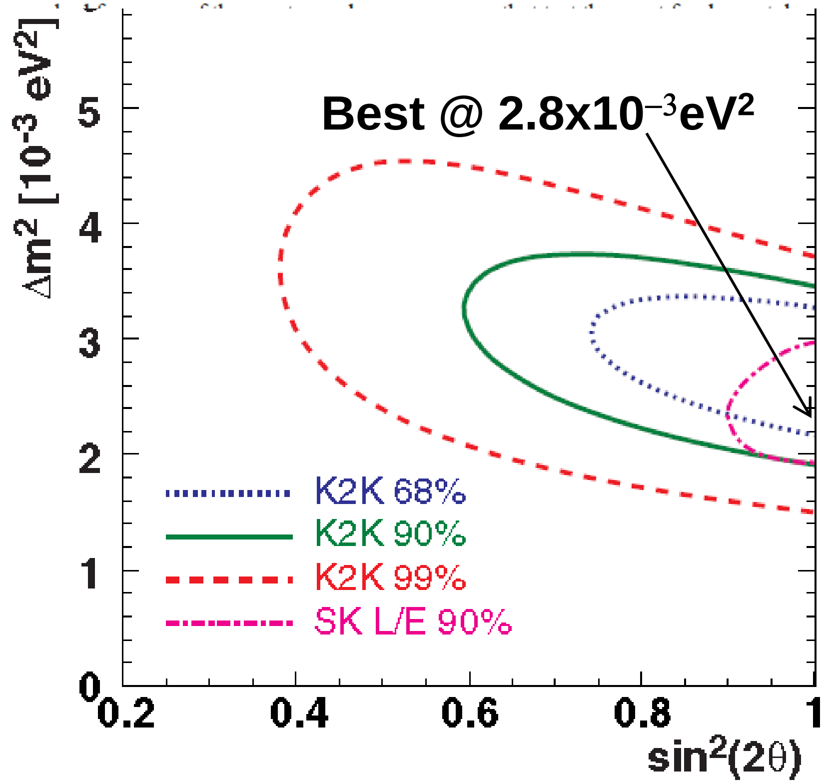
- Obs'ed: 112 evts
- Exp'ed: 158.1 $^{+9.2}_{-8.6}$ evts
- Combined **4.3σ** effect
  - Null osc. Prob. = 0.0015%

12-GeV PS 2008 Review Report

February 22, 2008

First and foremost, the outstanding K2K long baseline neutrino experiment (E362) -- the first to demonstrate flavor changing oscillations with neutrinos produced by an accelerator -- has been the world leader in substantiating that the observed atmospheric disappearance signal is due to neutrino oscillations. This experiment has now moved to its second stage in the form of the T2K experiment at J-PARC which is being constructed by a very large international collaboration. The rare kaon decay ex-

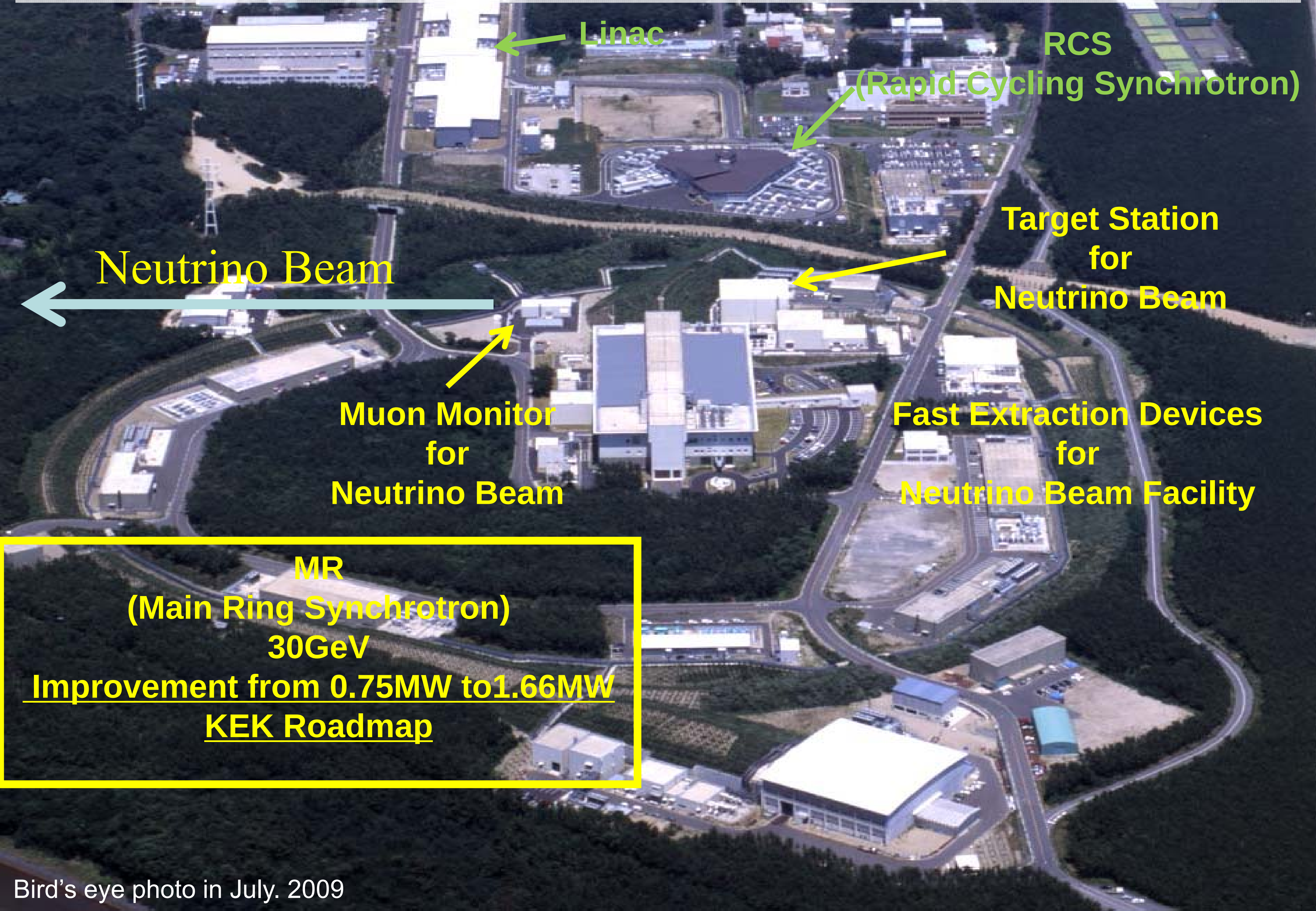




- **Definitely confirmed SK atm. ν results**
- **The crucial principles of accelerator based long baseline neutrino experiment have been proven to work**

Second generation

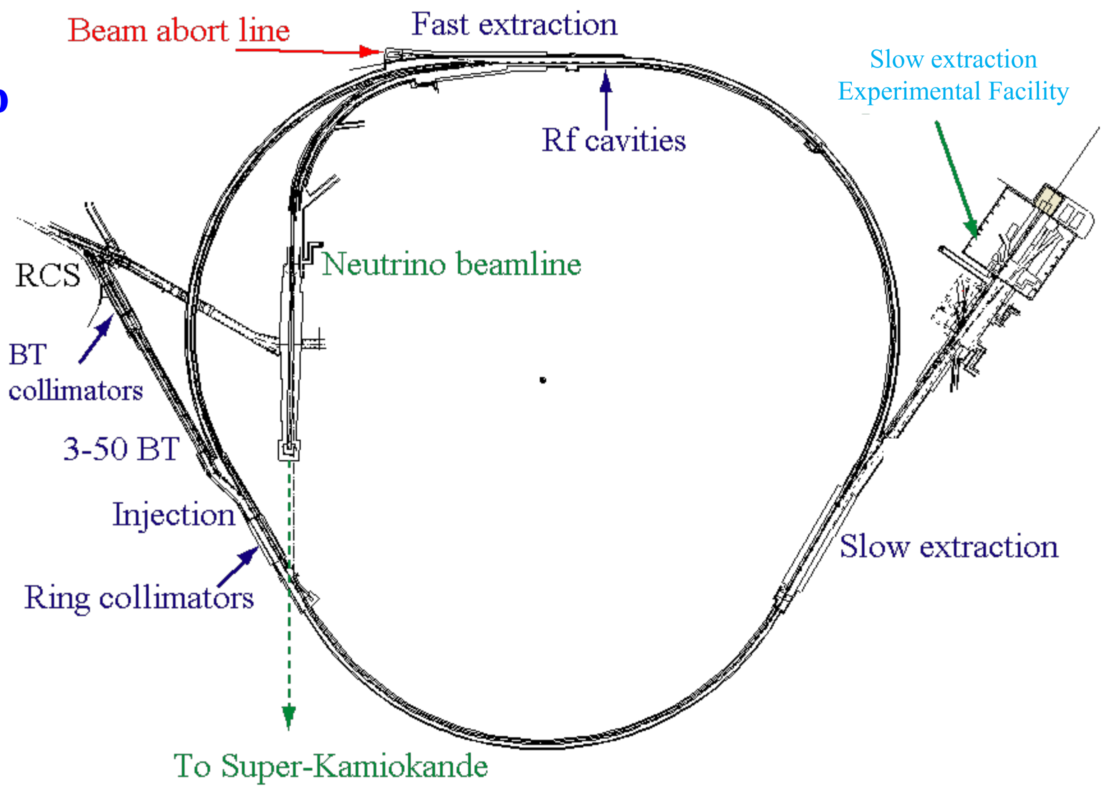
J-PARC MW-class accelerator based neutrino beam



Bird's eye photo in July. 2009

Overview of MR

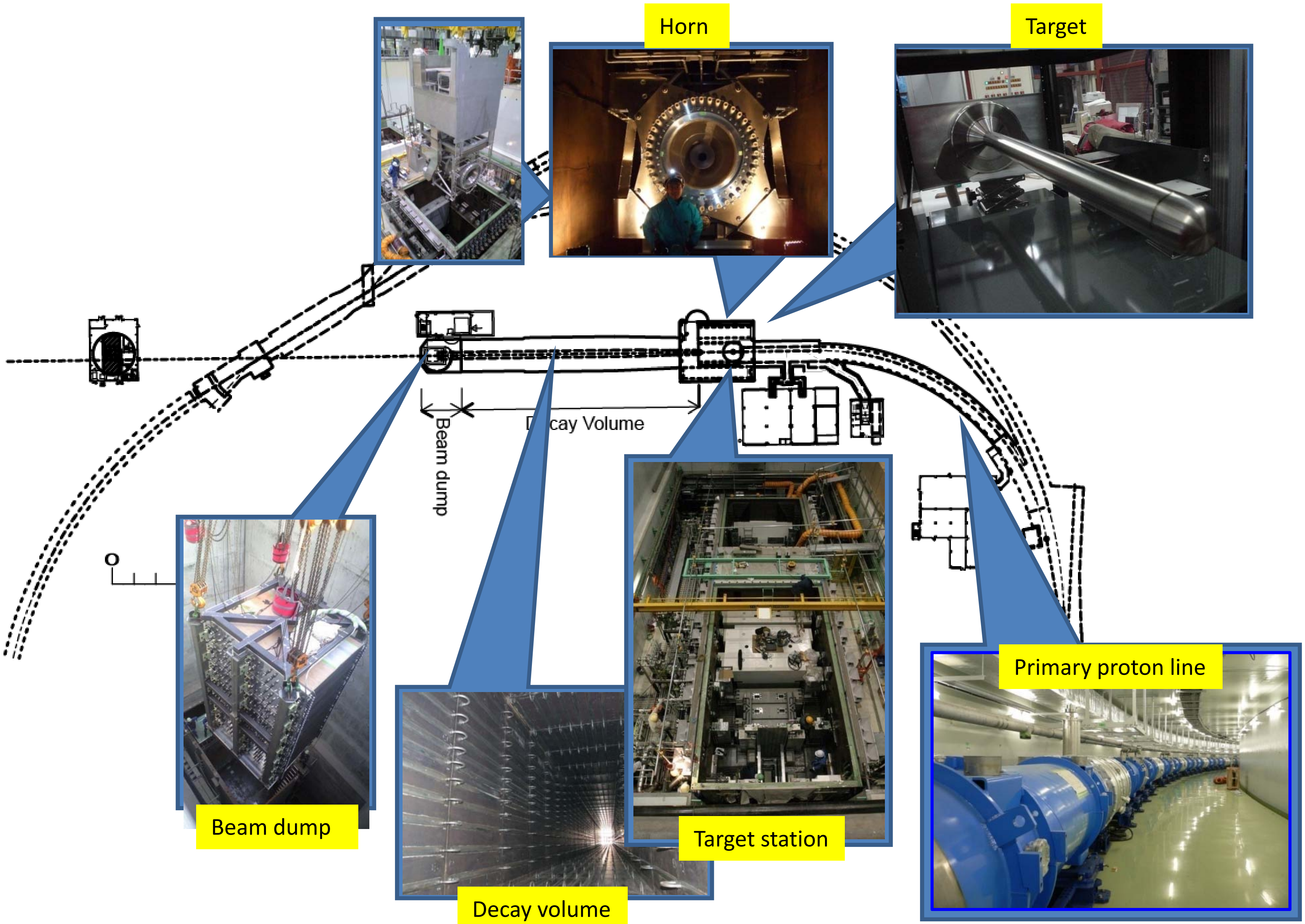
Circumference	**1567.5 m**
Repetition rate	**～0.3 Hz@Start Up**
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
Superperiodicity	**3**
h	**9**
No. of bunches	**8 (6 in day 1)**
Transition γ	**31.7(imaginary)**
Typical tune	**22.4, 20.8**
Transverse emittance	
At injection	**~54 πmm-mrad**
At extraction	**~10 πmm-mrad**
Beam power	**0.75MW**



Three dispersion free straight sections of 116-m long:

- Injection and collimator systems
- Fast extraction (beam is extracted inside/outside of the ring) and RF cavities
  - inside: Neutrino Beamline (intense ν beam to the west)
  - outside: Beam abort line
- Slow extraction
  - to Slow extraction Experimental Facility
  - (K Rare decay, Muon Lepton Flavor Violation, hyper nucleus, etc.)

J-PARC MW-class accelerator based neutrino beam



Concept of J-PARC neutrino beam facility

- Preparation section: matching beam optics to arc section
- Arc section: bending the beam ～90° to SK with superconducting combined function magnet
- Final focus section: matching beam optics to target（position and profile, level of mm control is necessary which correspond to 1mrad ν direction, also not to destroy target）
- Graphite Target and Horn Magnet: produce intense secondary π and focus them to SK (3horn system with 320kA pulse operation)
- Muon Monitor: monitor μ direction (=ν direction) pulse to pulse with measuring center of muon profile
- On Axis Neutrino Monitor(INGRID): monitor ν direction and intensity

*Designed to be up to ～2MW beam power is tolerable

Limited by temperature rise and thermal shock

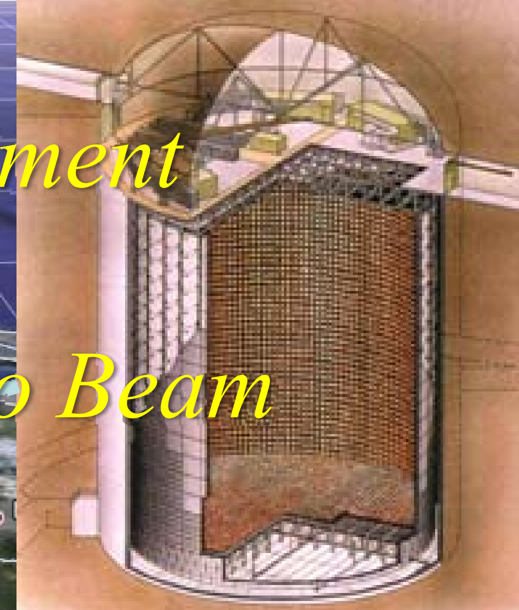
(Al Horn , Graphite Target, Ti Vacuum Window)

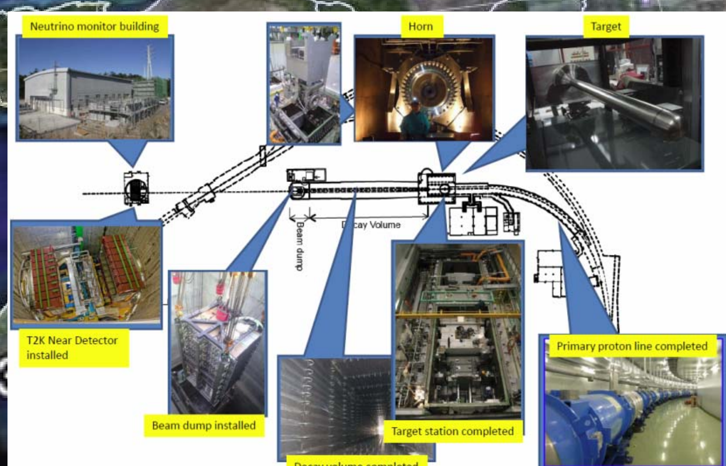
*Everywhere high radiation

Careful treatment of radioactive water and air (～10GBq/3week)is necessary

Maintenance scenario of radio active beam facility components is necessary

T2K: The 1st Experiment with J-PARC Neutrino Beam

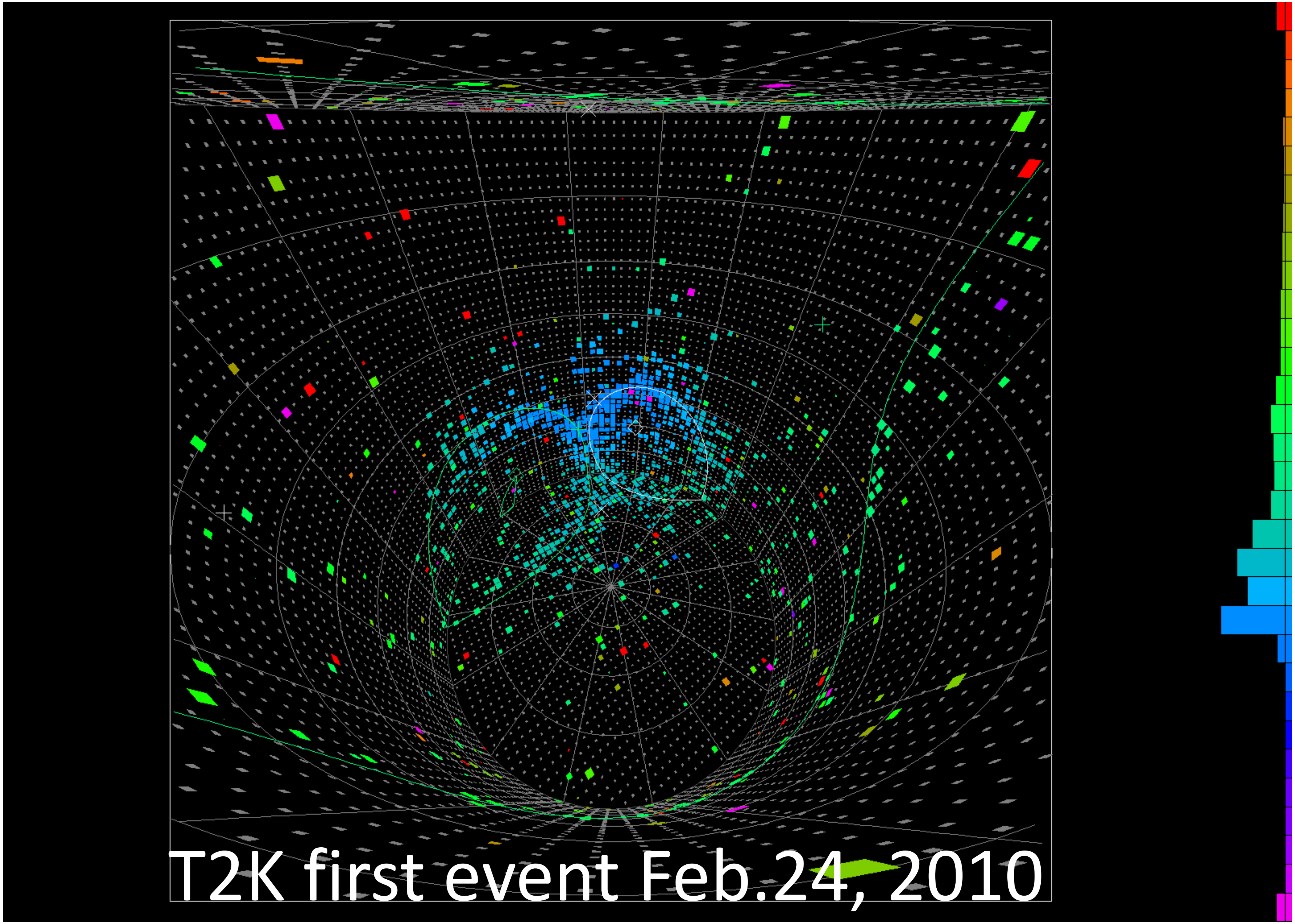




<u>T2K is aiming to "conclude lepton flavor mixing structure"</u>

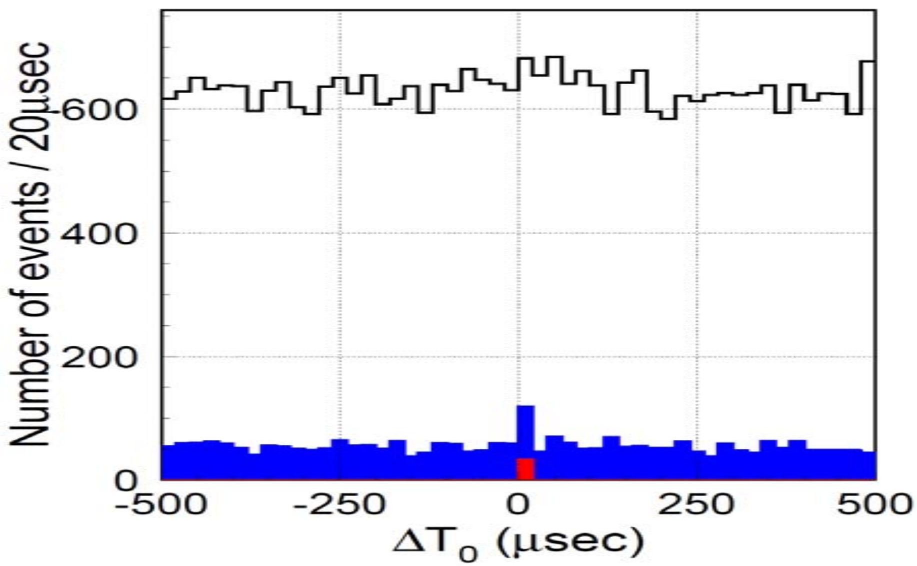
- Discovery of ν_e appearance (Determin θ_{13})
- Precision meas. of ν_μ disappearance (Measure θ_{23} , Δm_{23})

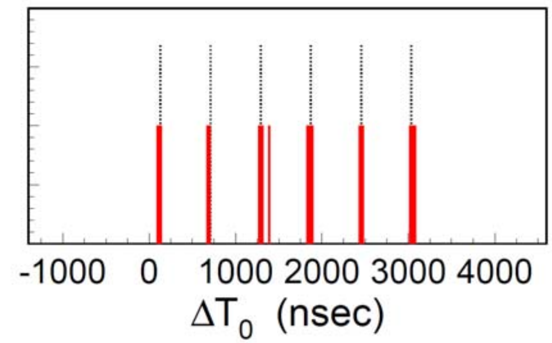
T2K has started January 2010

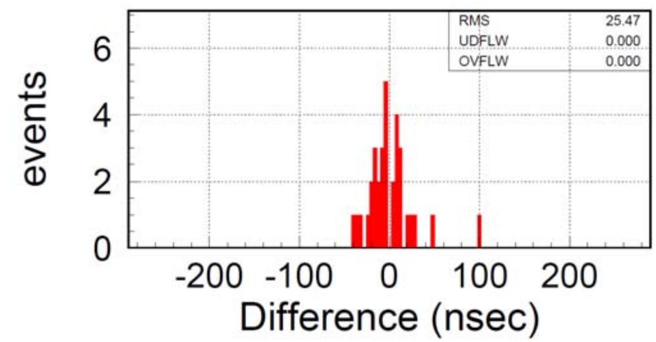


T2K status as of summer 2010

Event time distribution







Class / Beam run	ALL	Exp. BG
Fully-Contained (FC)	**33**	0.0094
+ fiducial volume cut + visible ene. > 30MeV (FCFV)	**23**	0.0011

- Event time distribution clearly show beam structure

Third generation

For discovery experiment in neutrino physics beyond T2K/NOνA era

- T2K is being conducted to explore $\nu_\mu \rightarrow \nu_e$
- Eager to prove that $\theta_{13} \neq 0$ & measure δ_{CP}:
  - If $\nu_\mu \rightarrow \nu_e$ signal is found in T2K,
    Accelerator and **Far Detector** must be **upgraded** to measure $\boldsymbol{\delta_{CP}}$
  - If $\nu_\mu \rightarrow \nu_e$ signal is not found,
    Accelerator and Far Detector must be upgraded to continue quest with improved sensitivity by $\times$ 10
- In Japan, there is a MW-class proton synchrotron within 10 years

⇨ **Giant Liquid Argon TPC** and/or **Giant Water Cherenkov Detector** as **new Far Detector** in **Japan**

Discovery of nucleon decay

Long baseline neutrino experiment requires highly massive main/far detector

As a consequences

Nucleon decay experiment

Research on grand unification

is also possible

⇨ **Giant Liquid Argon TPC** and/or **Giant Water Cherenkov Detector** for **Nucleon Decay Experiment** in **Japan**

Quest for the Origin of Matter Dominated Universe

- Lepton Sector CP Violation
  - Search for CP violation in Neutrino Oscillation Process
    - Also examine mass hierarchy of neutrinos
    - Also examine matter effect in neutrino oscillation process

- Proton Decay
  - $p \rightarrow \nu K$
  - $p \rightarrow e \pi^0$

*Non-equilibrium environment in the evolution of universe is assumed

Same scientific direction as LAGUNA

Three possible scenario studied at NP08 workshop

NP08 is **The 4th International Workshop on Nuclear and Particle Physics at J-PARC**

http://j-parc.jp/NP08

J-PARC Neutrino Beam Upgrade Plan

MR Power Improvement Scenario toward MW-class power frontier machine
— KEK Roadmap —

	Day1 Achieved ! (up to Jul.2010)	Next Step	KEK Roadmap
Power(MW)	0.1	0.45	>1.66
Energy(GeV)	30	30	30
Rep Cycle(sec)	3.5	2.2	1.92～0.5
No. of Bunch	6	8	8
Particle/Bunch	1.2×10^{13}	2.5×10^{13}	$4.1\sim8.3\times10^{13}$
Particle/Ring	7.2×10^{13}	2.0×10^{14}	$3.3\sim6.7\times10^{14}$
LINAC(MeV)	181	181	400
RCS	h=2	h=2	h=2 or 1

Combination of **High rep. cycle** and **High beam density**

Items to be modified from DAY1 toward MW-class power frontier machine

- No. of Bunch in MR(6→8)
  - Fast Rise Time Extraction Kicker Magnet

    → Installation is on-going now

- Increase Repetition Rate (3.5Sec→0.5Sec)
  - RF and Magnet Power Supply Improvement

- RCS h=1 Operation (longer beam bunch to decrease space charge effect)
  - RF Improvement

    h=2: 2 bunches × 4cycle injection to MR

    h=1:Single bunch with doubled no. of proton × 8cycle injection

- LINAC 400MeV Operation (avoid severe space charge effect at RCS injection)

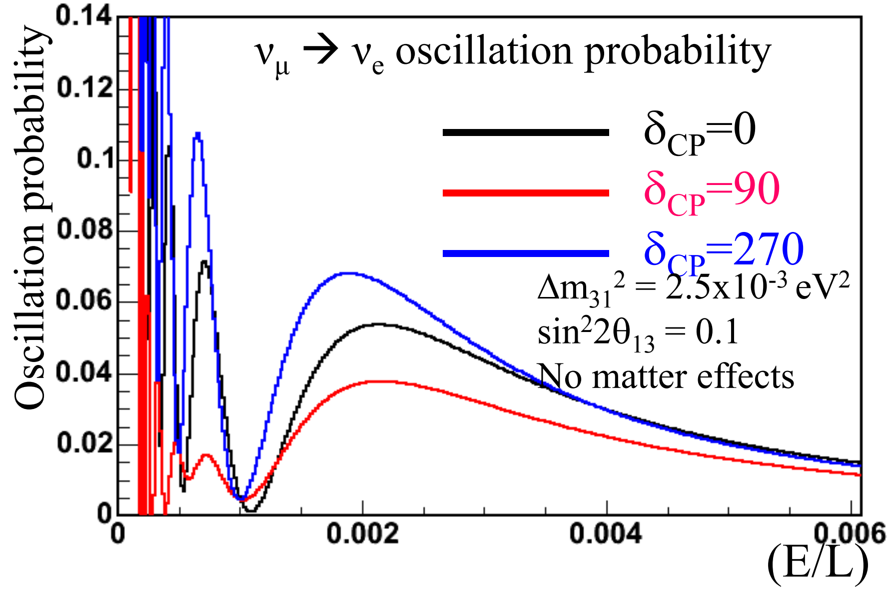
  → Construction of necessary component is approved and started

Far Detector Options

How to approach Lepton Sector CP Violation

Lepton Sector CP Violation

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

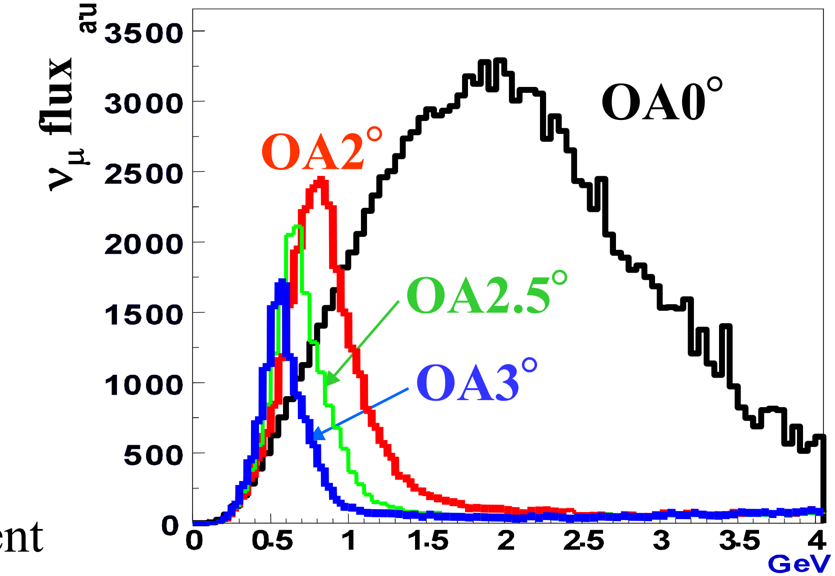
– Difference between ν_e and $\overline{\nu}_e$ Behavior

*Need both ν and $\overline{\nu}$ experiments (different systematics, low $\overline{\nu}$ event rate)

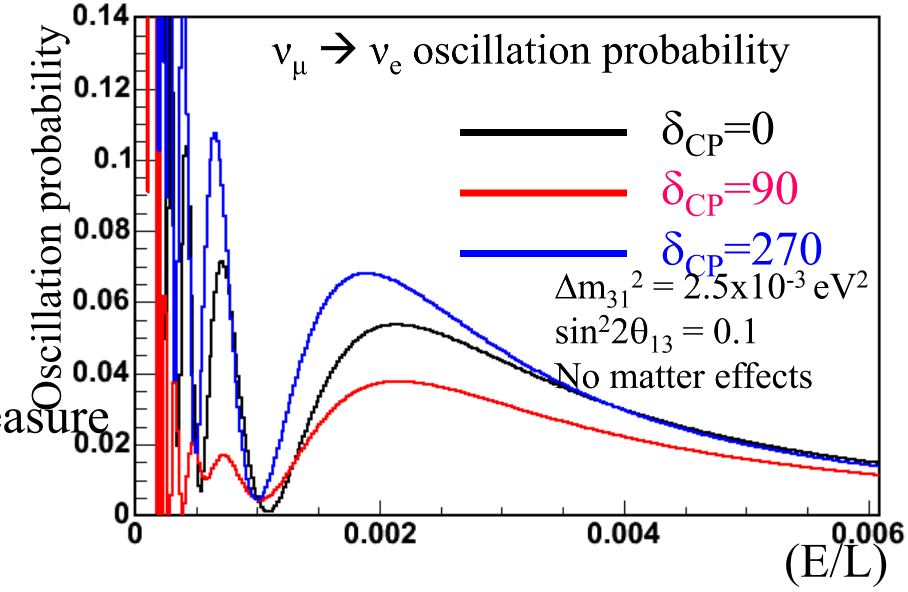
Angle and Baseline

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



Optimal configuration for the investigation of CP Phase δ_{CP} with Liquid Argon TPC

- Reason
  - Excellent ν energy resolution and reconstruction ability from sub GeV to a few GeV, from single prong to high multiplicity
    → Suitable for spectrum measurement with wide energy coverage
  - Excellent π^0/electron discrimination
    → Wide band On-Axis beam is tolerable
  - Neutrino intensity is finite and Energy is set（1.66MW J-PARC MR, 30GeV）
  - Results within reasonable time scale (～5years)

⇨ Spectrum measurement (1st and 2nd Oscillation Max.) with On-Axis beam with 5years ν beam run, then think next ($\bar{\nu}$?)

- Condition
  - Need long baseline(>600km) to see 2nd Osc. max, since fixed neutrino energy
  - Need On-Axis beam for wide energy coverage
  - Need gigantic detector, since finite beam flux and long baseline

⇨ 100 kton Giant Liquid Argon TPC @ Long Baseline, On-Axis

Scenario 1

J-PARC to Okinoshima

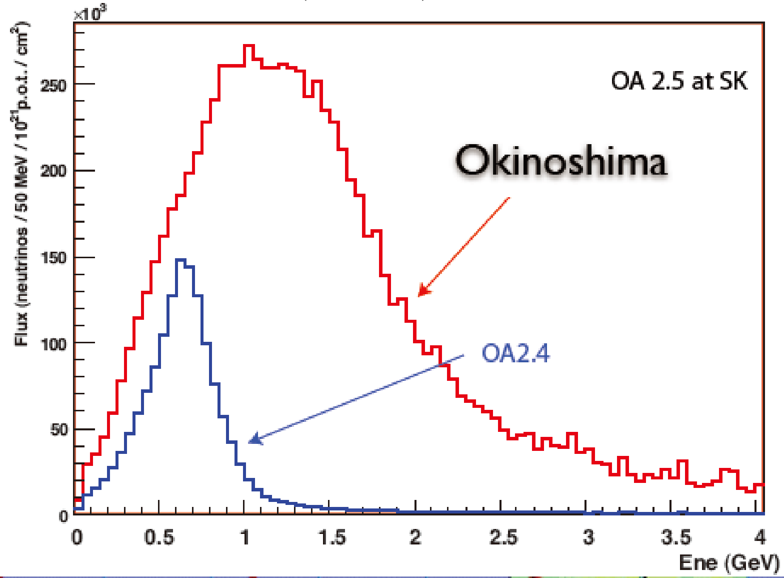
Distance = 658 km

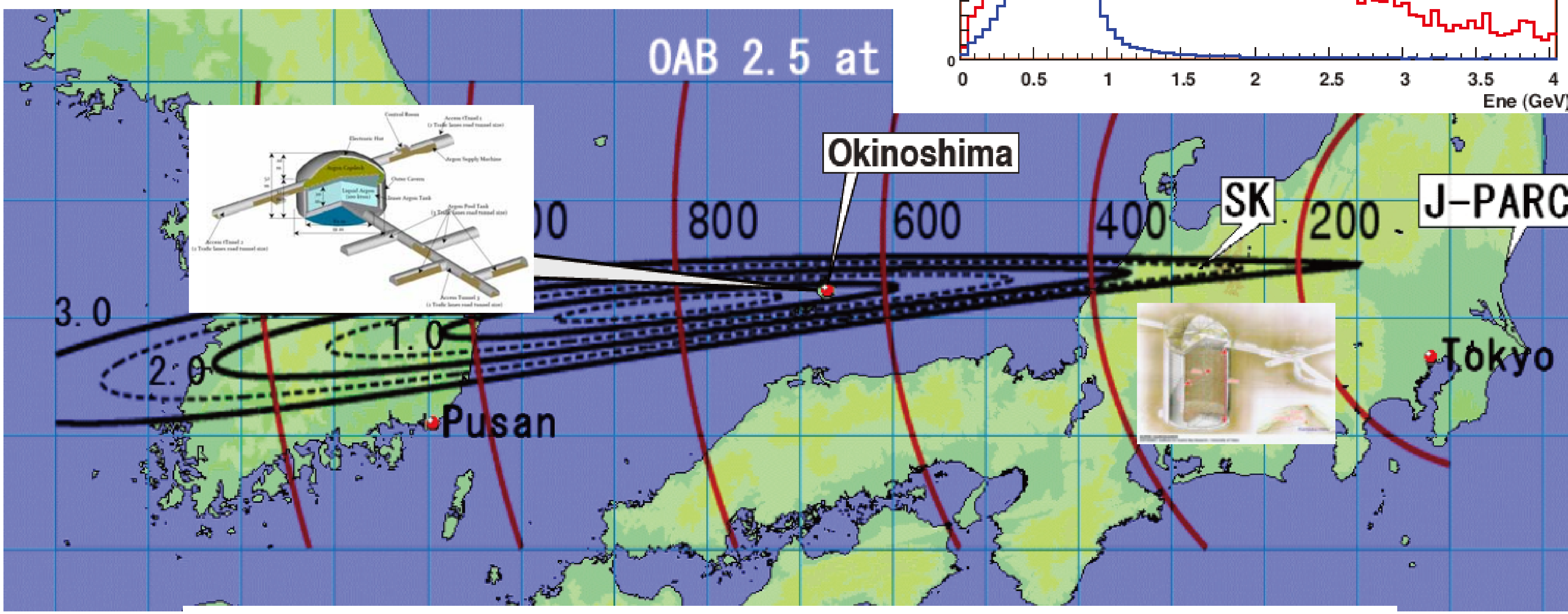
Off-axis angle = 0.76°

(2.5° @ SK)

100 kton liquid Argon

P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010), arXiv:0804.2111





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

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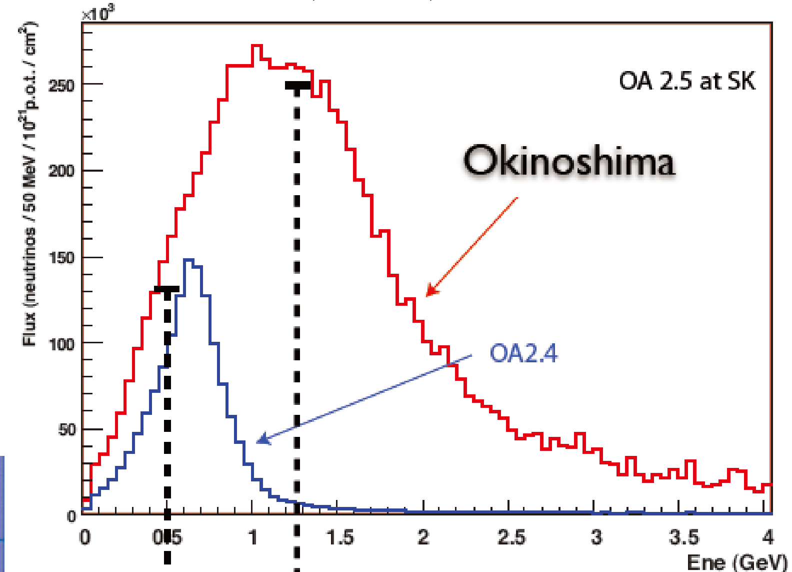
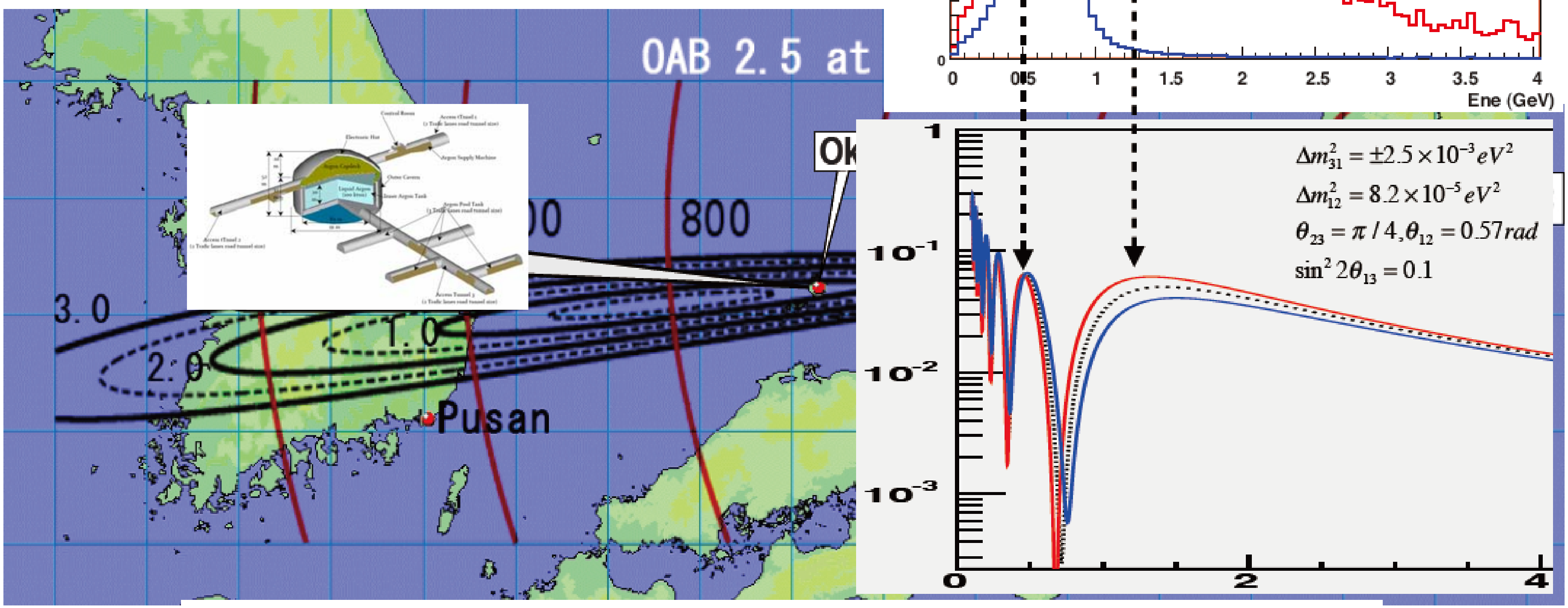




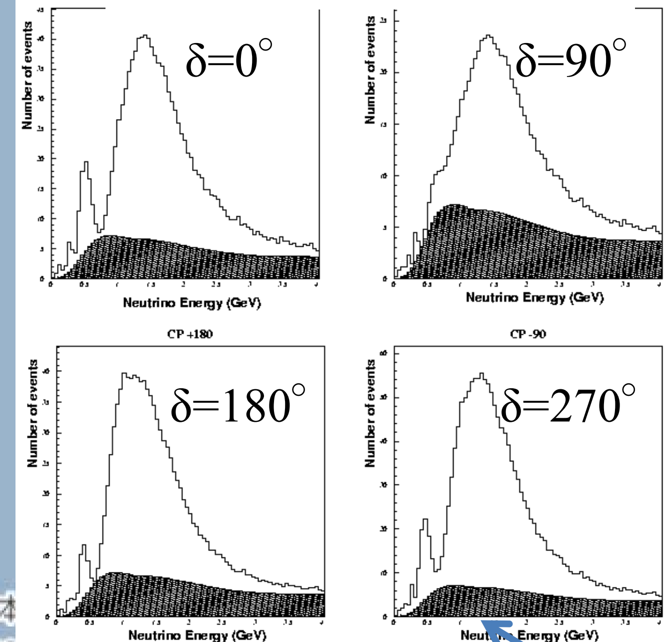
→ Extract δ_{CP} from fit of 1st & 2nd maximum

Scenario 1
J-PARC to Okinoshima

- Cover 1st and 2nd Maximum
- Neutrino Run Only 5Years × 1.66MW
- 100kt Liq. Ar TPC
  - -Good Energy resolution/reconstruction ability
  - -Good e/π^0 discrimination
- Keeping Reasonable Statistics

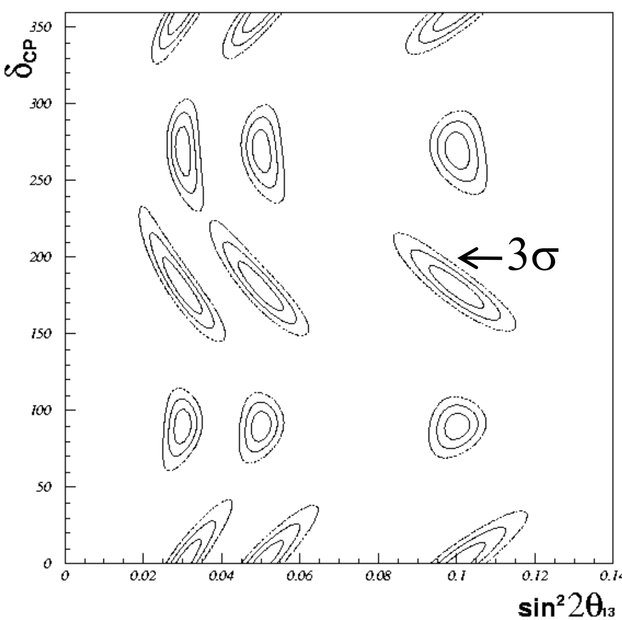
ν_e Spectrum

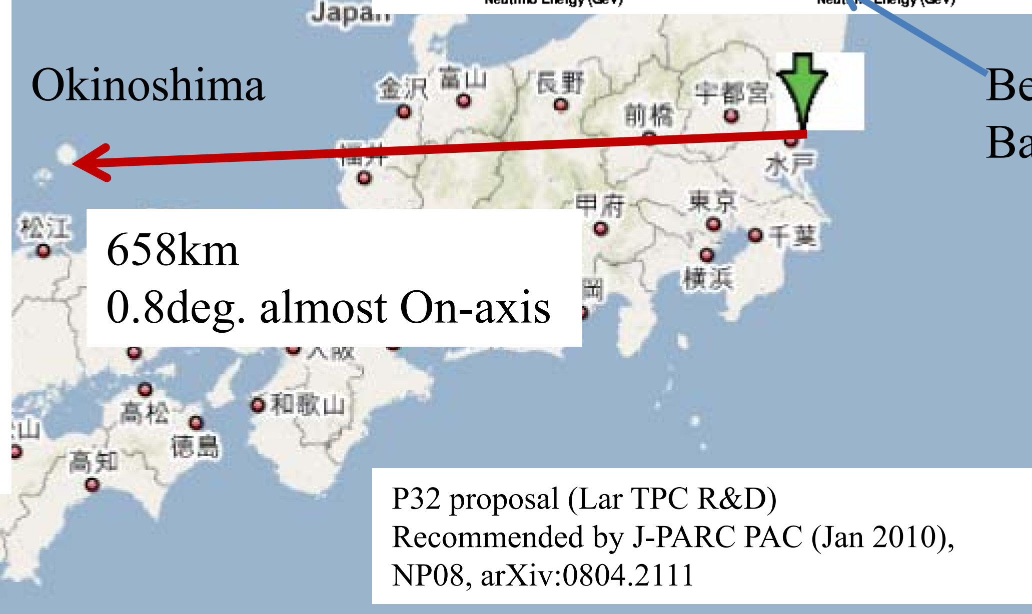
$\sin^2 2\theta_{13}$=0.03,Normal Hierarchy



Beam ν_e Background

CP Measurement Potential





658km
0.8deg. almost On-axis

P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC (Jan 2010),
NP08, arXiv:0804.2111

P32: Proposal submitted to J-PARC PAC
Recommended by J-PARC PAC January 2010

6. **PROPOSAL EVALUATIONS**

1. **P32:** <u>(Towards a Long Baseline Neutrino and Nucleon Decay Experiment with a next-generation 100 kton Liquid Argon TPC detector at Okinoshima and an intensity upgraded J-PARC Neutrino beam)</u>

The proponents propose to develop a suitable scalable Liquid Argon TPC detector with gas amplification in Argon vapor as an R&D for a next-generation long baseline neutrino experiment.

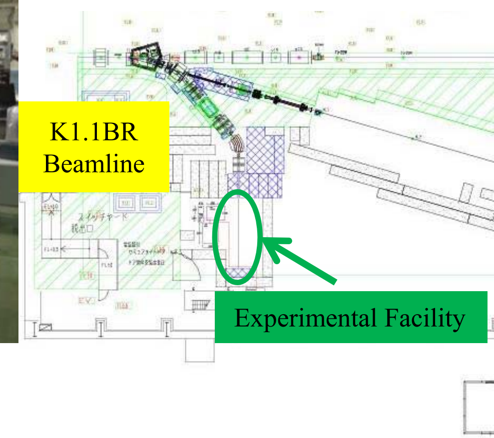
The PAC acknowledges the high scientific merit of a neutrino oscillation experiment with a baseline longer than T2K. The measurements of the mixing angle θ_{13} and a possible CP violation in the lepton sector are of highest significance.

Before large detectors can be considered, it has to be shown that such a technique is adequate for the purpose and superior to alternative schemes. In particular, the readout scheme and the scalability are open questions. Based on a small-scale R&D, a roadmap has to be put forward.

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.**

250L Liq. Ar TPC

P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010)



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The specific P32 pro

low-energy char ... ions

K1.1BR beamli ... ed

development w ... **me**

intensity charge

250L Liq. Ar TPC

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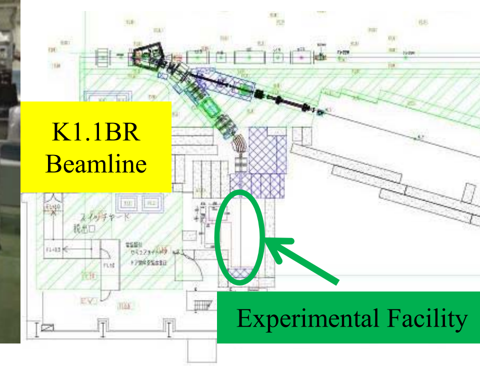
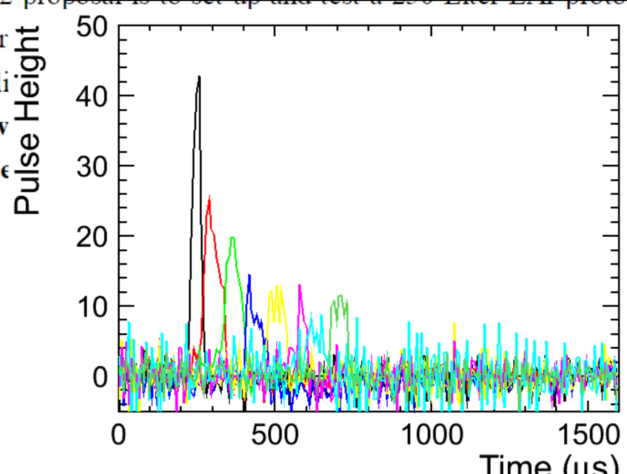
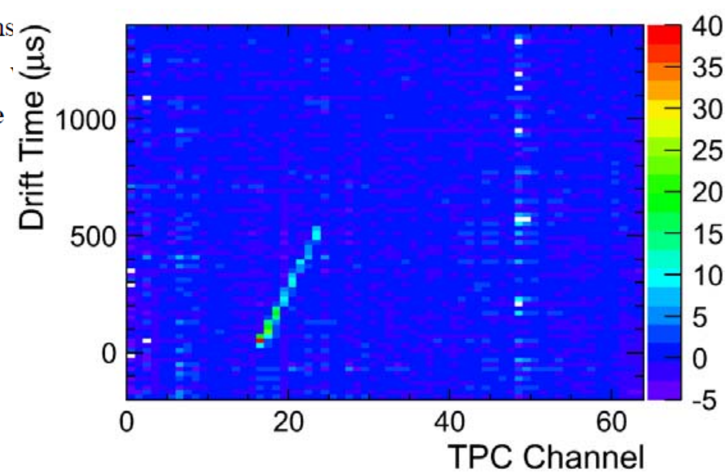


Cosmic ray signal registered with temporary coarse anode





Optimal configuration for the investigation of CP Phase δ_{CP} with Water Cherenkov detector (same concept as T2K)

- Reason
  - Excellent ν detector for sub GeV(Quasi elastic dominant, low multiplicity)
  - Neutrino intensity is finite and Energy is set（1.66MW J-PARC MR, 30GeV）
    → Oscillation maximum at sub GeV
      → Baseline to be ~300km
  - Enhancement of the beam intensity at the oscillation maximum
  - Beam configuration to avoid π^0 originated background is helpfull
    → Narrow band Off-Axis beam is only choice

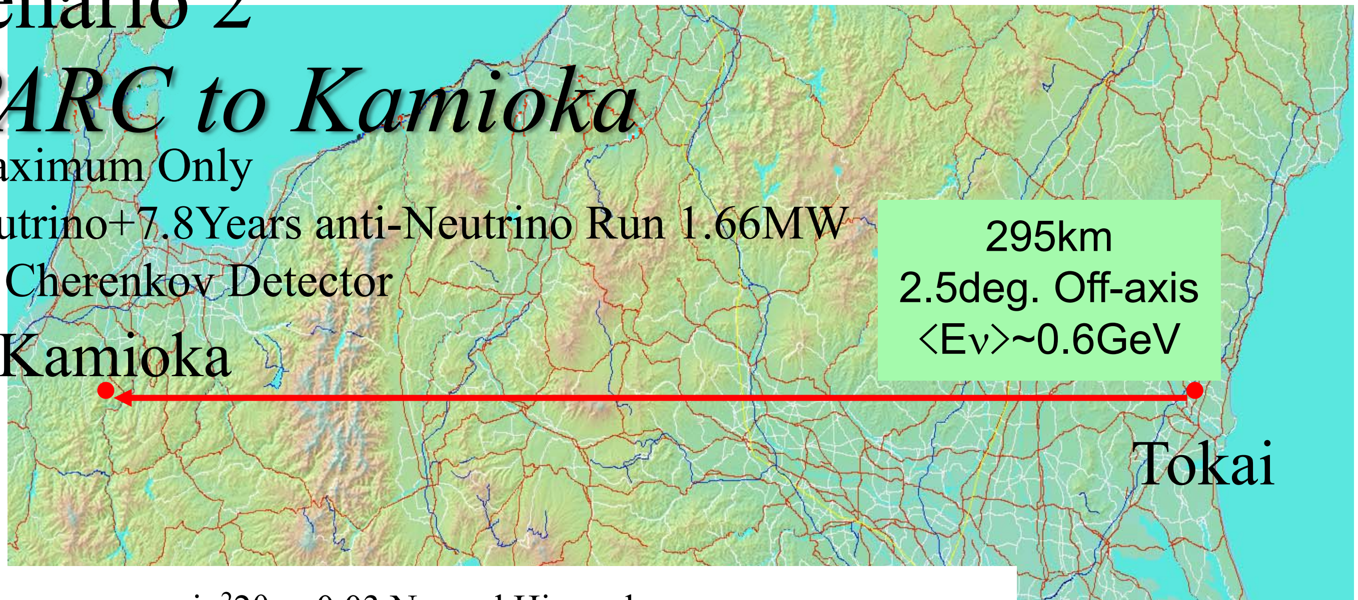
⇨ **Comparison between ν and $\bar{\nu}$ behavior at the oscillation maximum with Off-axis beam**

- Condition
  - Off-Axis beam(2.5^0) for appropriate beam energy and suppress π^0 originated background
  - Baseline to be 275km
  - Need gigantic detector and relatively short baseline, since finite beam flux

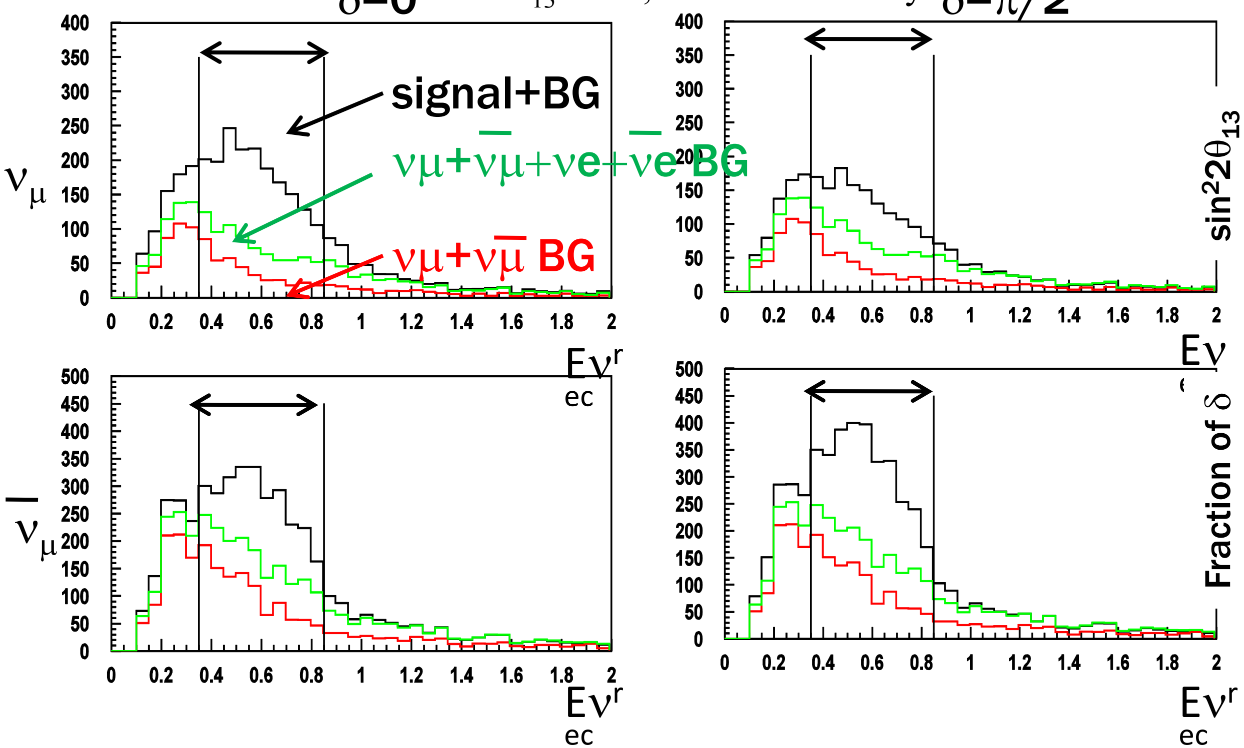
⇨ **270 kton×2 Water Cherenkov Det. @ Kamioka, 2.5deg Off-Axis**

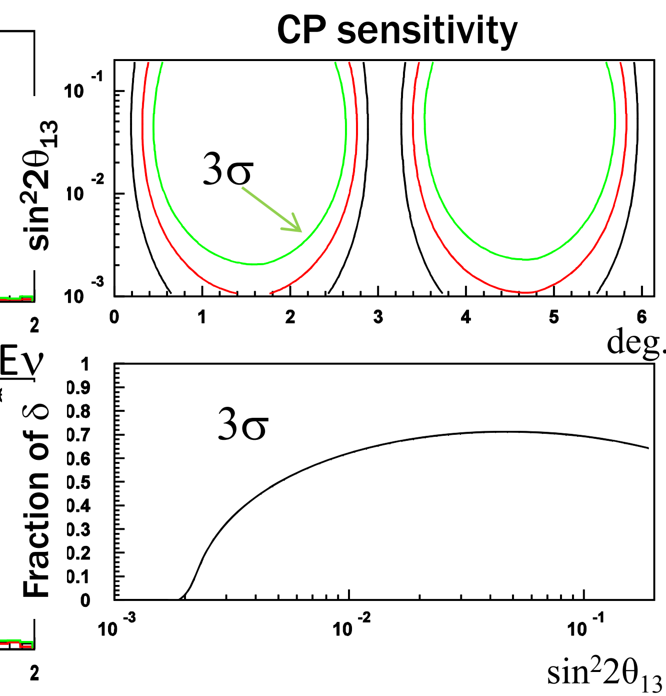
Scenario 2
J-PARC to Kamioka

- Cover 1st Maximum Only
- 2.2Years Neutrino+7.8Years anti-Neutrino Run 1.66MW
- 540kt Water Cherenkov Detector



$\delta=0$ $\sin^2 2\theta_{13}=0.03$, Normal Hierarchy $\delta=\pi/2$

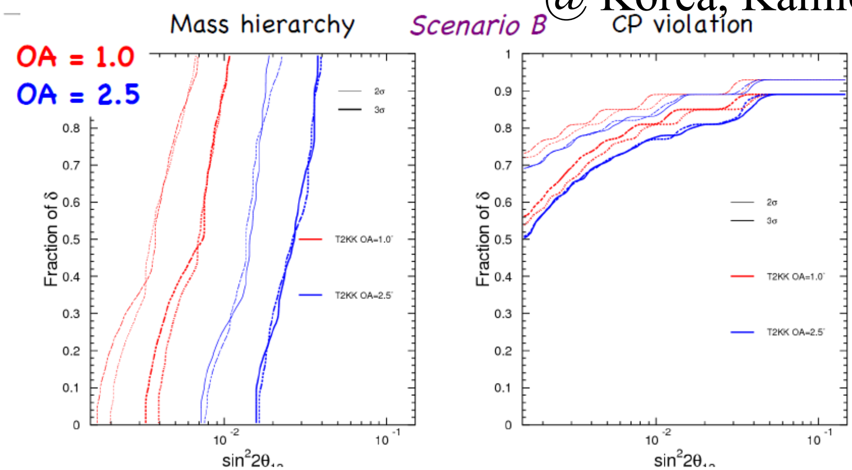


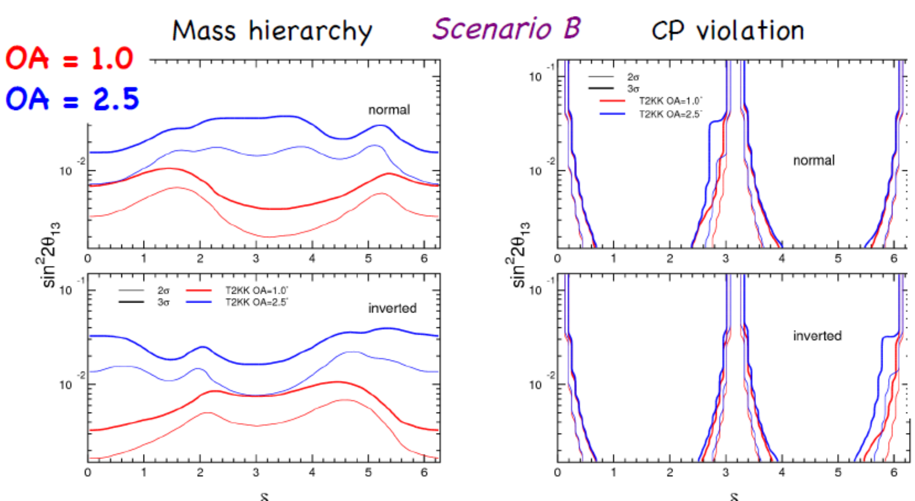


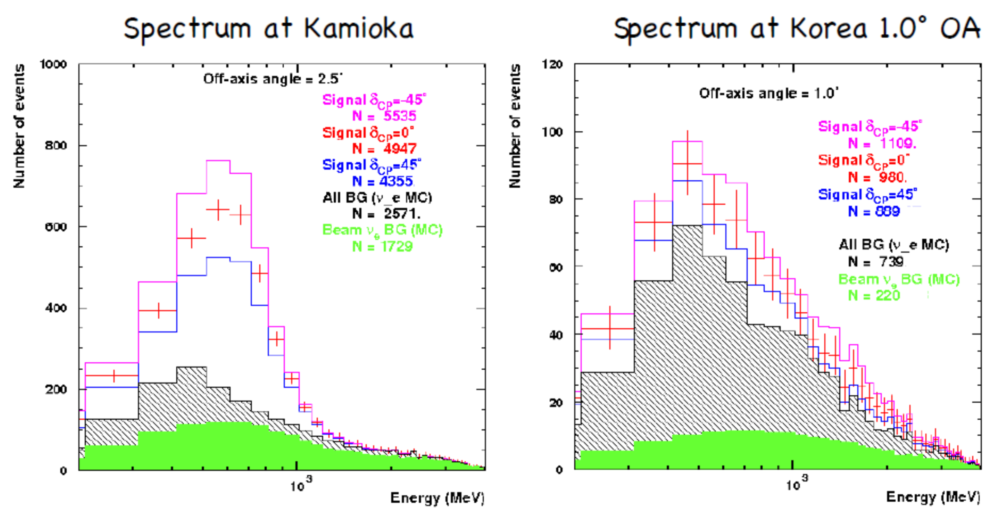
K.Kaneyuki @NP08

Scenario 3
J-PARC to Kamioka and Korea

- Cover 2nd Maximum @ Korea
- Cover 1st Maximum @ Kamioka
- 5Years ν+5Years ν Run 1.66MW
- 270kt Water Cherenkov Detector each @ Korea, Kamioka







$\sin^2(2\theta_{13})$=0.04, neutrino, normal hierarchy, Scenario B

F.Dufour@NP08

(study is initiated by M.Ishitsuka et. al. hep-ph/0504026)

Comparison of Each Scenario

	Scenario 1 Okinoshima	Scenario 2 Kamioka	Scenario 3 Kamioka Korea
Baseline(km)	660	295	295 & 1000
Off-Axis Angle(°)	0.8(almost on-axis)	2.5	2.5 1
Method	ν_e Spectrum Shape	Ratio between ν_e $\overline{\nu}_e$	Ratio between 1st 2nd Max Ratio between ν_e $\overline{\nu}_e$
Beam	5Years ν_{μ}, then Decide Next	2.2 Years ν_{μ}, 7.8 Years $\overline{\nu}_{\mu}$,	5 Years ν_{μ}, 5 Years $\overline{\nu}_{\mu}$,
Detector Tech.	Liq. Ar TPC	Water Cherenkov	Water Cherenkov
Detector Mass (kt)	100	2×270	270+270

Study is continuing to seek for optimum choice

Third generation projects

- Strong physics case for

  New long baseline experiment with expected J-PARC beam

  and to

  Search for nucleon decay

  with

  Giant Liquid Argon TPC and/or Water Cherenkov Detector in Japan

- What's important to realize the project
  - J-PARC MR towards MW-Class power frontier machine
  - Successful R&D and performance evaluation with clear objective towards realization of Giant Detector
  - Decision should be based on T2K results on $\nu_\mu \to \nu_e$

Third generation projects

- Strong physics case for

  New long baseline experiment with expected J-PARC beam

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  Search for nucleon decay

  with

  Giant Liquid Argon TPC and/or Water Cherenkov Detector in Japan

<u>Same scientific direction as LAGUNA</u>

- International collaborative effort is mandatory necessary for this scale of projects
- Fruitful collaboration on Liq. Ar TPC is already existing

➤ Successful R&D and performance evaluation with clear objective towards realization of Giant Detector

➤ Decision should be based on T2K results on $\nu_\mu \rightarrow \nu_e$

Accelerator Based Neutrino Projects in Japan

	K2K	T2K	3rd Generation Exp. (KEK Roadmap)
High Power Proton Synchrotron	KEK PS 12GeV 0.005MW Existing	J-PARC MR 30GeV 0.75MW Brand New	J-PARC MR 30GeV 1.66MW Technically Feasible Upgrade
Neutrino Beamline	K2K Neutrino Beamline Brand New	J-PARC Neutrino Beamline Brand New	J-PARC Neutrino Beamline Existing
Far Detector	Super Kamiokande Existing at KAMIOKA	Super Kamiokande Existing at KAMIOKA	***Brand New*** ***-Detector Technology ?*** ***-Place ?*** ***(Angle and BaseLine)***
1st Priority Physics Case	Neutrino Oscillation ν_μ Disappearance	Neutrino Oscillation $\nu_\mu \rightarrow \nu_e$	Lepton Sector CP Violation + Proton Decay Search

Able to concentrate on Far Detector issue toward the 3rd Generation Experiment after T2K startup

Summary
Accelerator Based Neutrino Projects in Japan

* Long Baseline Neutrino Exp. is initiated with K2K

Short Term

- Beam commissioning of J-PARC MR has started May-2008
- Commissioning of J-PARC Neutrino Beam Facility has started in April-2009
- T2K has started January-2010 to conclude "lepton flavor mixing structure"

Mid Term

- T2K data with 1-2MW $\times$ 10^7sec integrated proton power on target will provide critical information on θ_{13}, which guides the future direction of the neutrino physics *In any case, complete T2K proposal of 3.75MW $\times$ 10^7sec
- KEK Roadmap: MR toward MW-class power frontier machine
- Submit proposal

  "J-PARC to Somewhere Long Baseline Neutrino Experiment and Nucleon Decay Experiment with Giant Detector"

  and construct Giant Detector

Long Term

- Discovery of CP violation in Lepton Sector (also Proton Decay)

P32 and Okinoshima site study

A.Badertscher, A.Curioni, S.DiLuise, U.Degunda, L.Epprecht, L.Esposito, A.Gendotti, S.Horikawa, L.Knecht, C.Lazzaro, D.Lussi, A.Marchionni,
A.Meregaglia, G.Natterer, F.Petrolo, F.Resnati, A.Rubbia, C.Strabel, T.Viant
ETH Zurich, 101 Rämistrasse, CH-8092 Zurich, Switzerland

H.Naito, S.Narita
Iwate University, Morioka, Iwate, 020-8551, Japan

O.Araoka, T.Hasegawa, K.Kasami, N.Kimura, T.Kobayashi, M.Maki, T.Maruyama, K.Nishikawa, M.Tanaka, M.Yoshioka
KEK High Energy Accelerator Research Organization, 1-1, Oho, Tsukuba, Ibaraki, 305-0801, Japan

O.Hirabayashi, K.Kawakami, T.Kaneta, T.Oshimo, S.Taguchi
PENTA-OCEAN construction co., Ltd., 2-2-8 Koraku, Bunkyo-ku, Tokyo, 112-8576, Japan

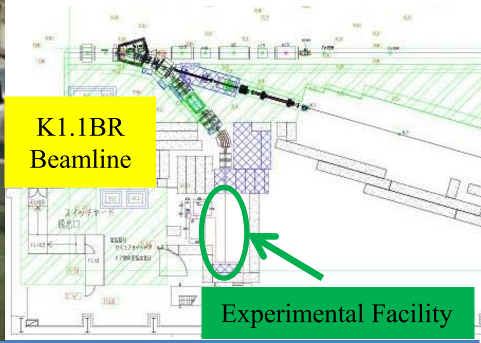
J.Naganoma, Y.Nagasaka, H.Okamoto, K.Yorita
Waseda University 3-4-1 Okuba, Shinjuku-ku, Tokyo 169-8555, Japan

An example of performance evaluation with clear objective: 250L@KEK

Measurements with well defined charged particle test beam

- To benchmark performance of detector
- To develop realistic simulation/reconstruction software

P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010)



- Cryogenic vessel with beam window (originally for MEG liquid Xe calorimeter test module)
- Ultra-Vacuum established
- Cryocooler and liquid Argon filling under investigation
- Liquid Argon purification system under procurement
- Exposure to low-momentum separated K beam @J-PARC

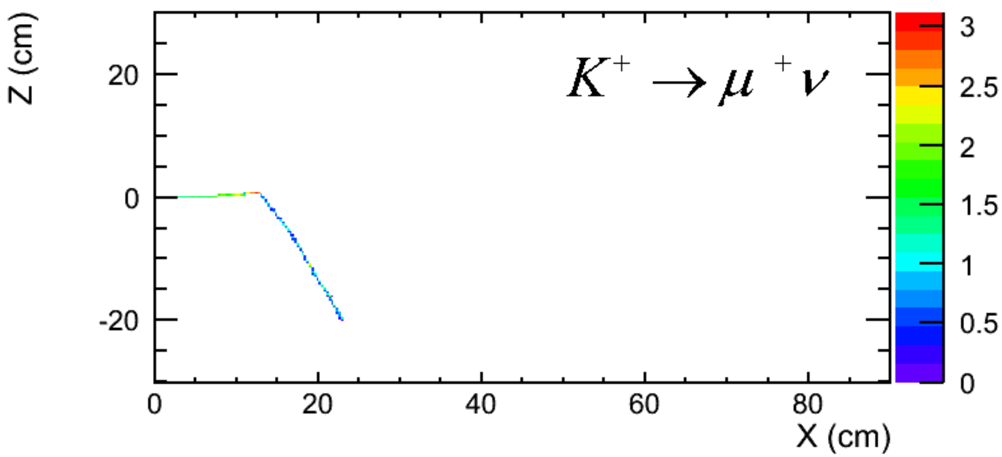
$p \to \nu K$(340MeV/c K^+)

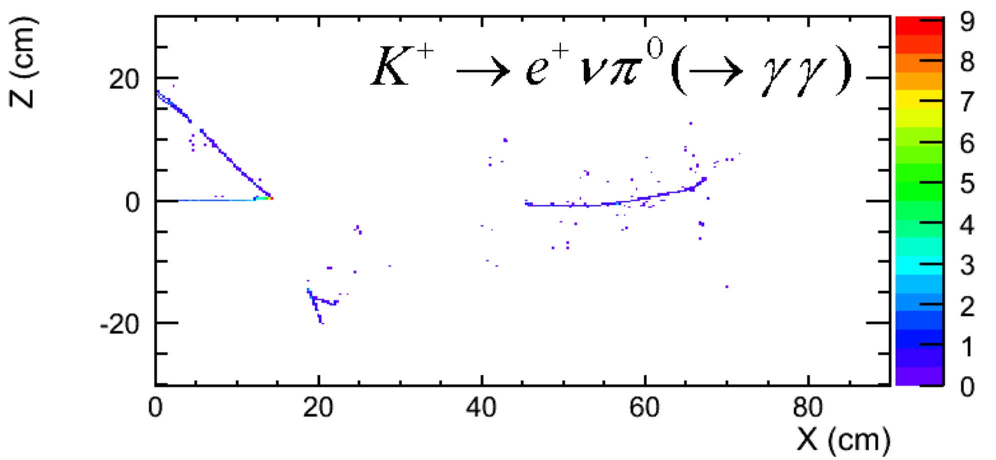
Parameters for 250L@KEK	
Fiducial mass	170 kg
Total Liquid Argon mass	～400 kg
Field cage dimensions	$42 \times 42 \times 78$ cm^3
Fiducial volume	$40 \times 40 \times 76$ cm^3
Drift field	1 kV/cm
Max. drift voltage	40 kV
Readout method	Double phase, Two view anode LEM-TPC
Readout segmentation	Two 40×38 cm^2 LEM-TPC
Readout pitch	3mm in x & y
Number of readout channels	288 per LEM-TPC 576 in total
LEM-TPC effective gain	～25

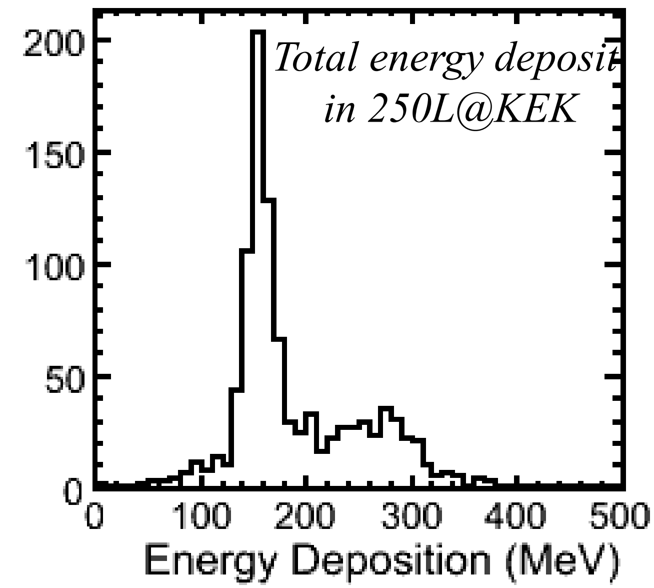
340 MeV/c K⁺ (p→Kν) in 250L@KEK

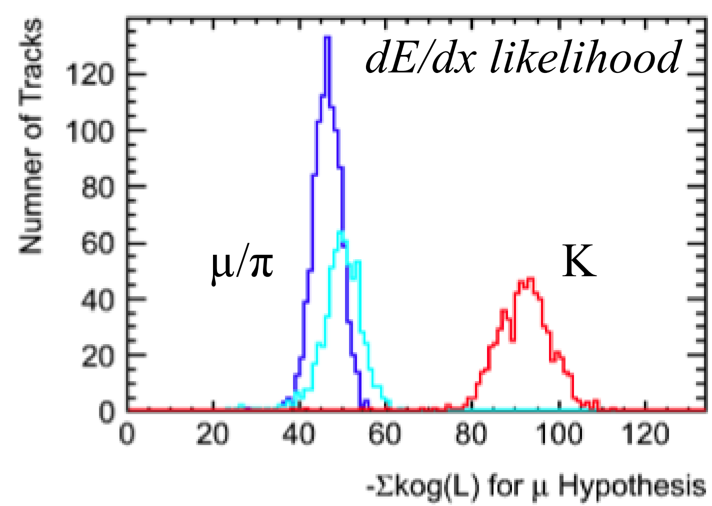
First beam exposure in October 2010

- >90% of slow kaons stop in detector with range ≈10cm (others decay in-flight)
- Many soft decay products are contained
- dE/dx analysis can be performed for particle ID

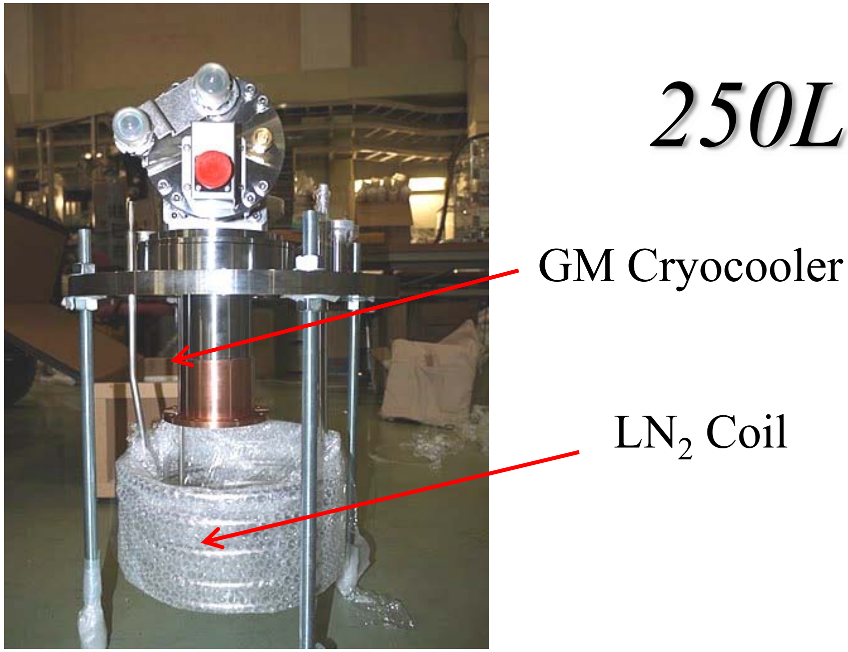








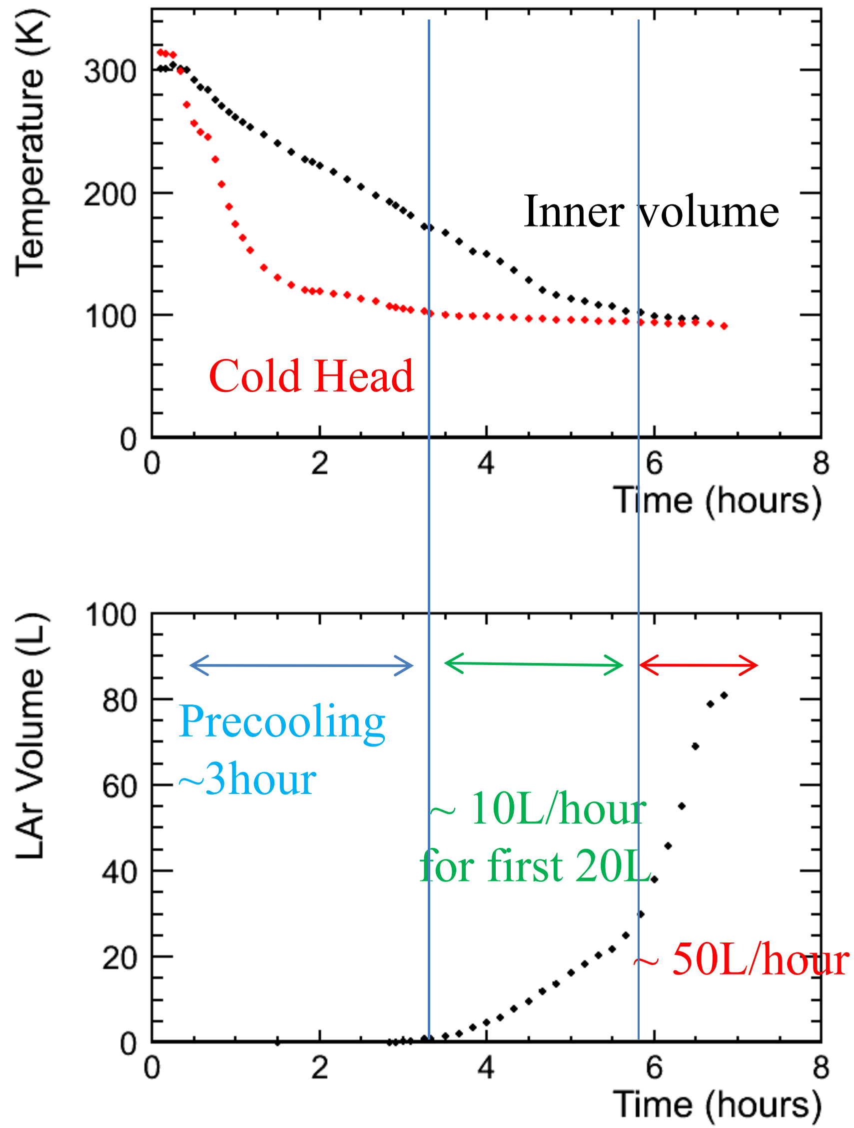
250L@KEK: Cryogenics



- Heat input of 250L cryostat: ~ 30W

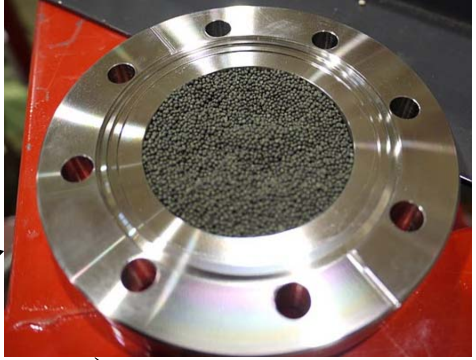
- GM Cryocooler (~150W)
  - For normal operation
- LN_2 heat exchange coil (~500W)
  - Additional cooling equipment for pre-cooling, filling, and recirculation for purification

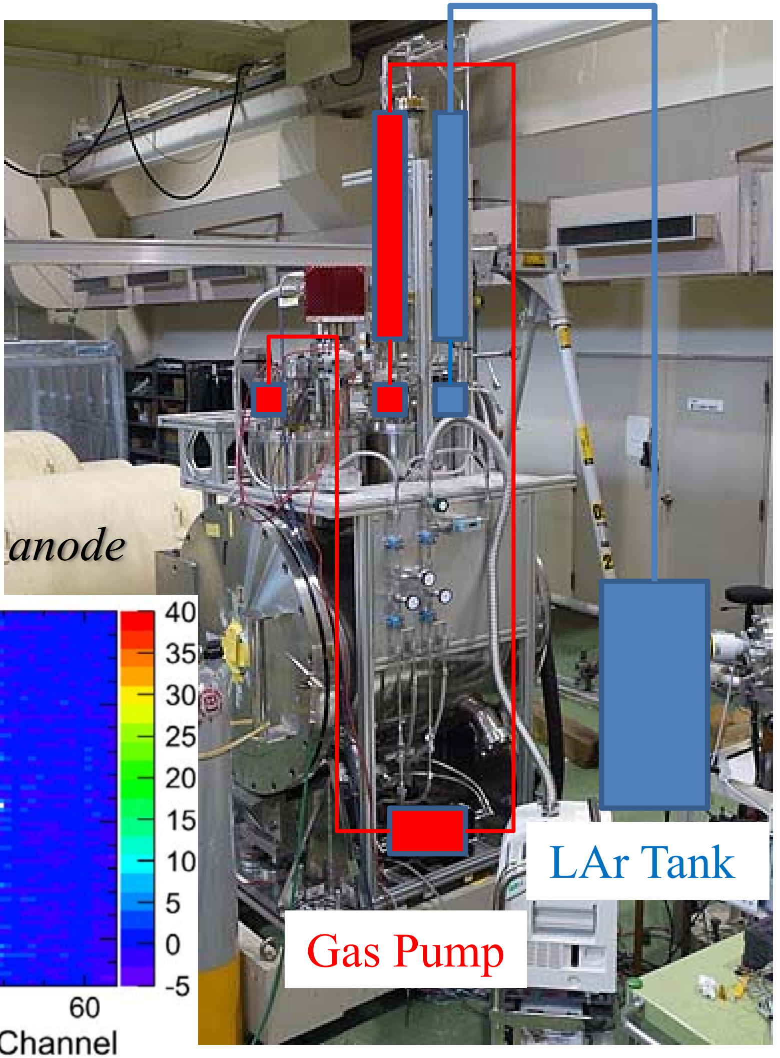
- Successful filling of the vessel
  - ~ 3 hours for pre-cooling
  - 7 hours for 100L filling
  - ~ 50L/hour (in case the vessel is cold enough)
- Stably kept ~1 week with cryocooler



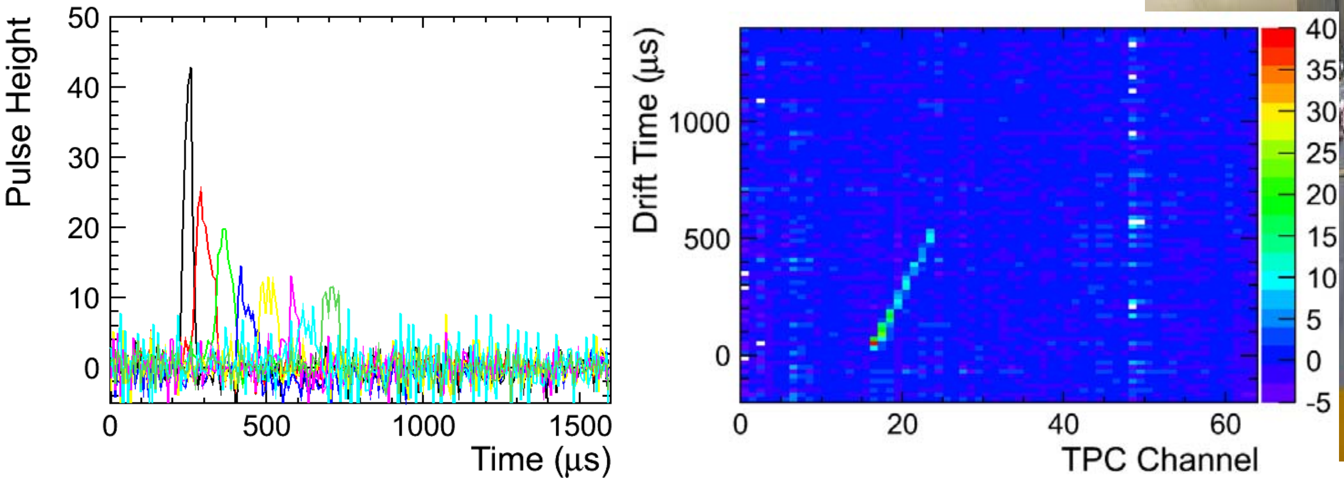
250L@KEK: Purification

- Purification @ initial filling with purification filter
  (Activated Cu + Molecular sieve, possible to regenerate)
  - Initial purity after filling
    <ppb (>50 cm eq. of drift electron att. length)
  - ~3ppb/day purity degradation is observed
    (No degradation if cryocooler is OFF)
- Purity improvement with gas recirculation + high spec. purification filter is under development





Cosmic ray signal registered with temporary coarse anode



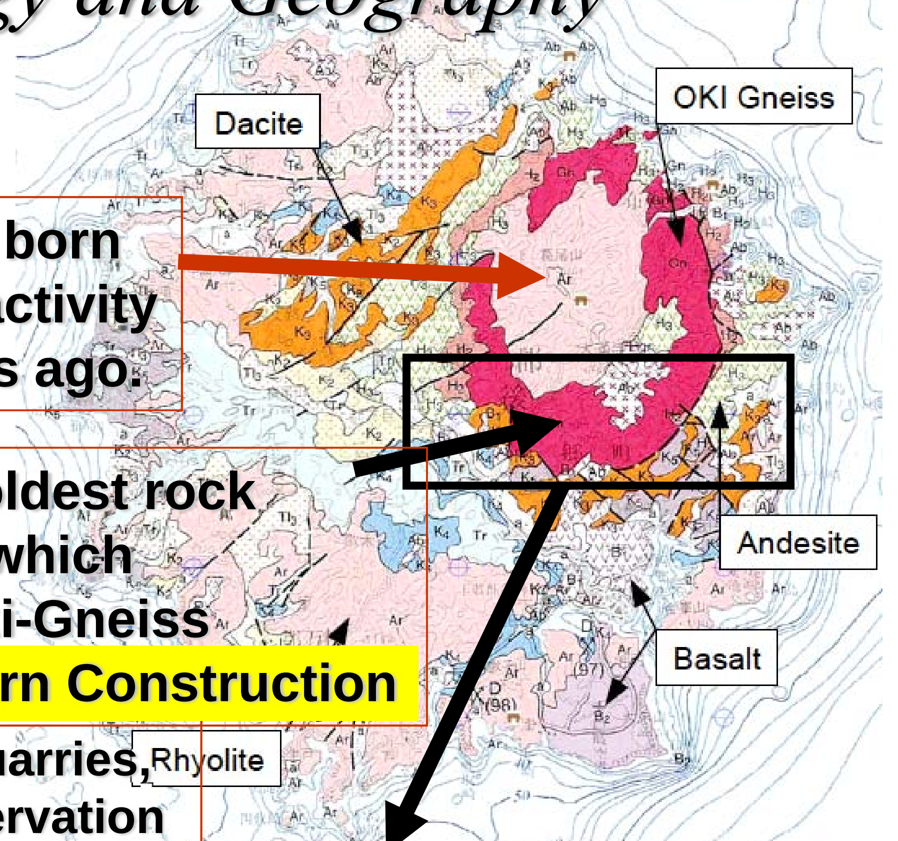
Okinoshima: Geology and Geography

ASAHI quarry

A single layer of the gneiss

TOKUHATA No.2 q

The crackle of the Igneous rock to the gneiss

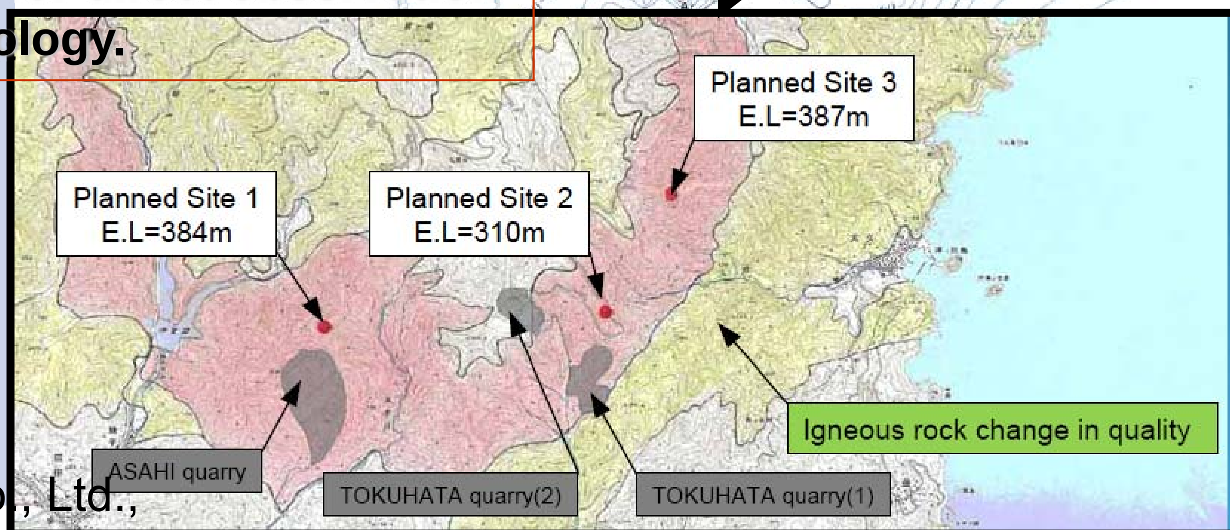


Islands were born by volcanic activity in 5~6M years ago.

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

Suitable for Big Cavern Construction

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



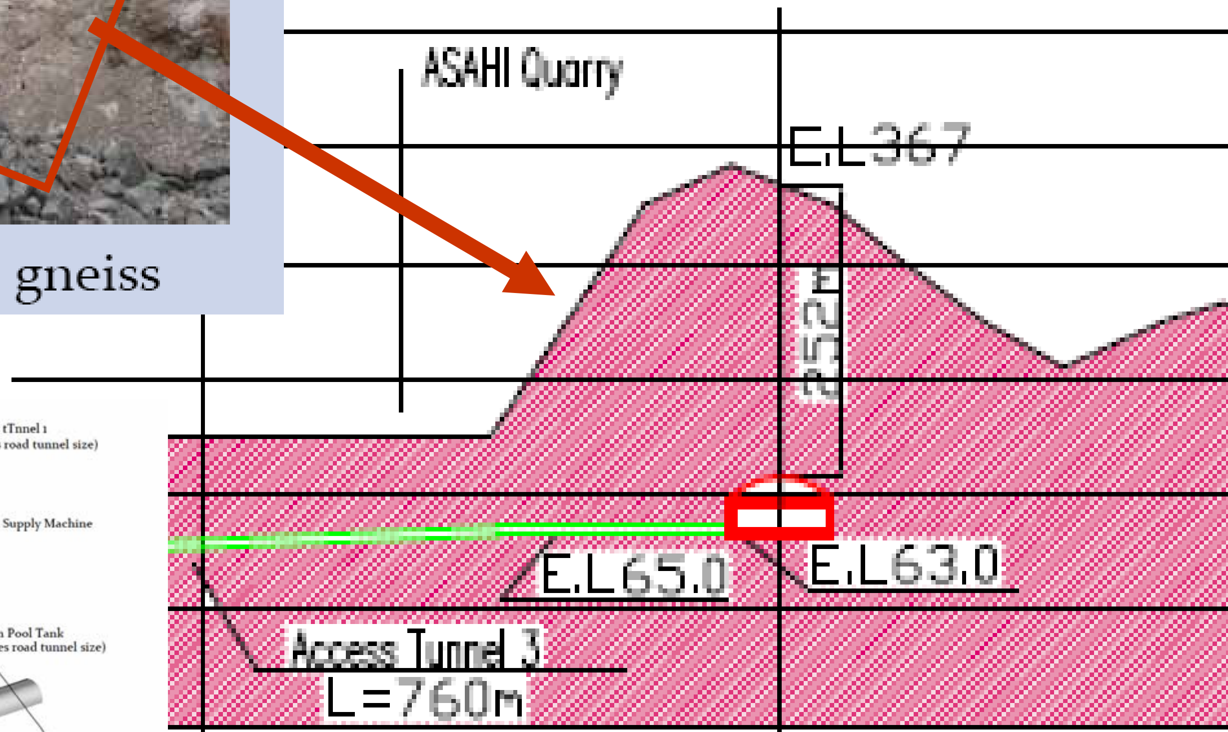
ASAHI quarry

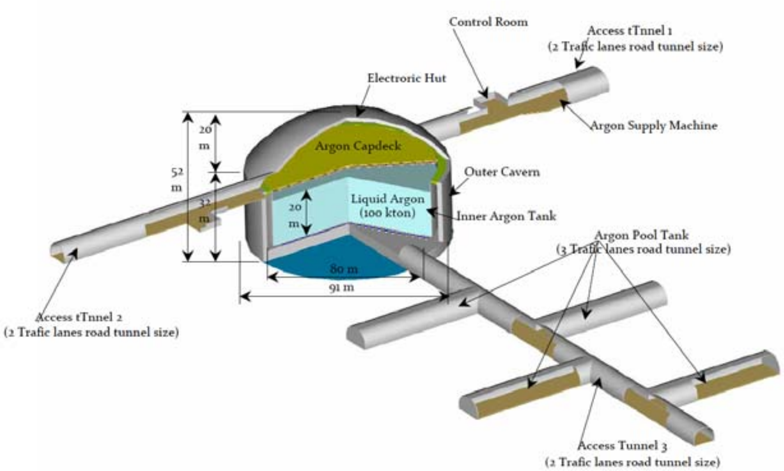
A single layer of the gneiss

Okinoshima: Geology and Geography

A conceptual design

Site No.1





500

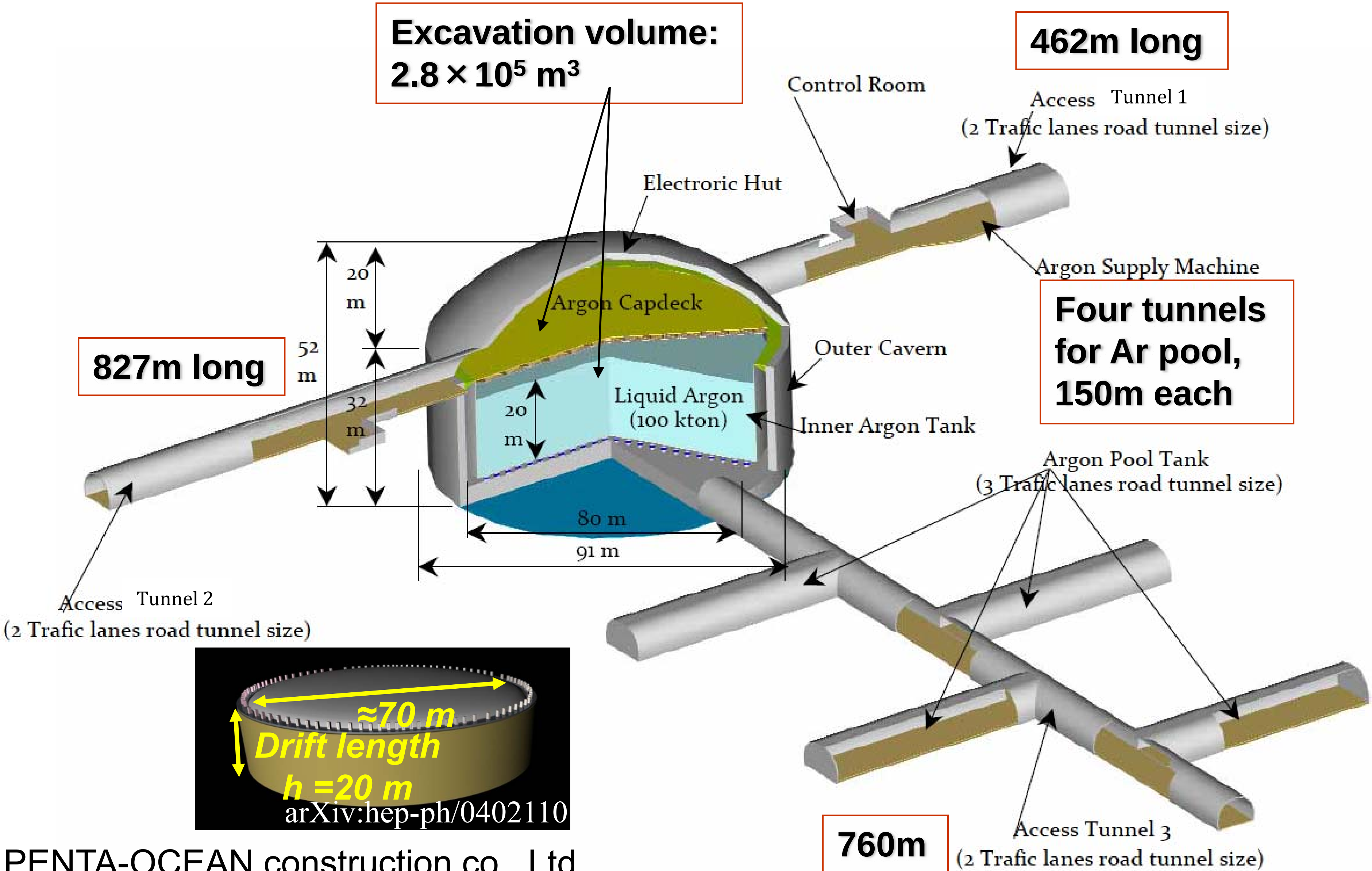
Shallow depth (>600 m.w.e.) is enough to suppress cosmogenic background

(A.Bueno et.al., JHEP 0704,041 (2007))

If more overburden is necessary, inclined access tunnel is also possible

PENTA-OCEAN construction co., Ltd.,

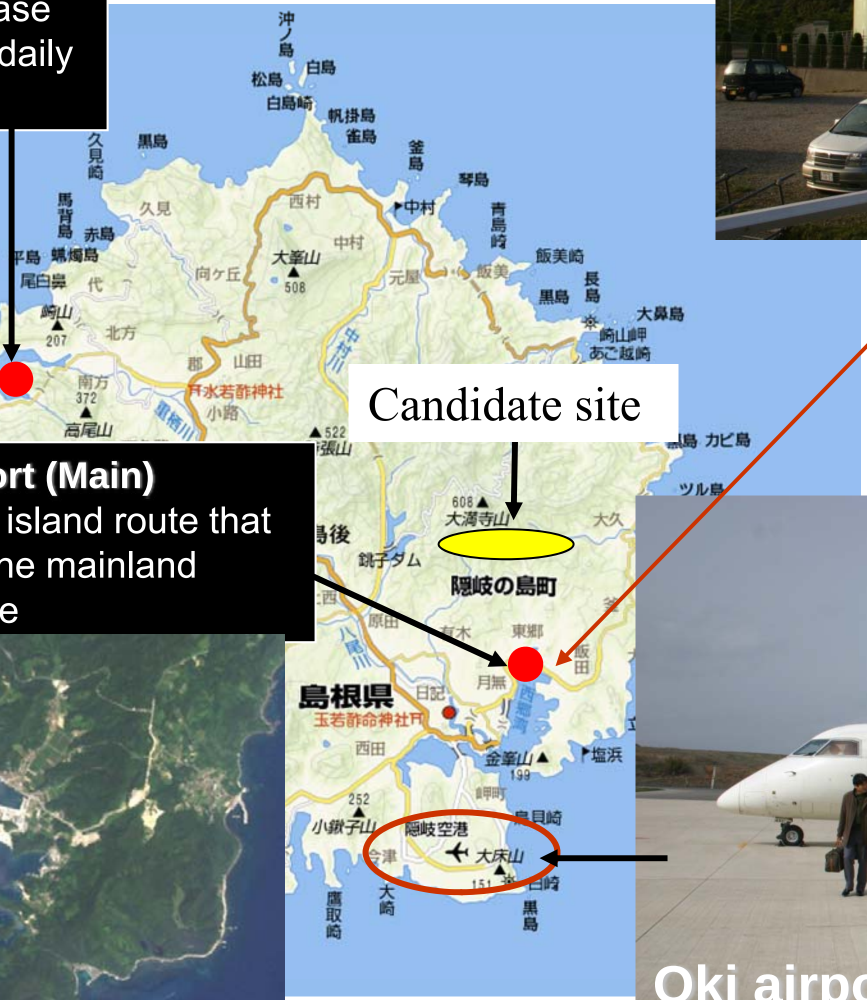
100 kton Giant Liquid Argon TPC
Preliminary design (used for cost estimate)



PENTA-OCEAN construction co., Ltd.,

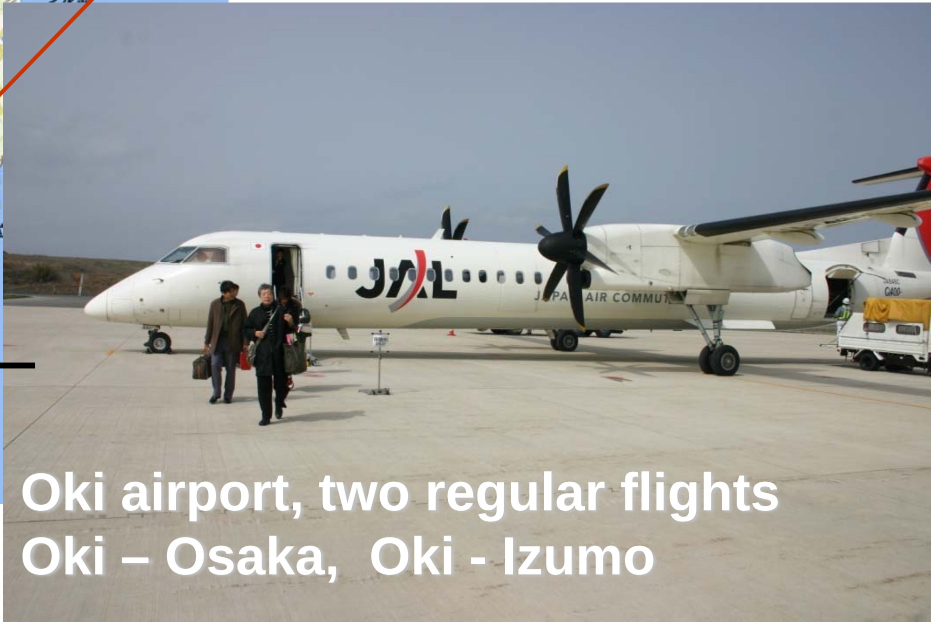
Okinoshima: Infrastructure

OMOSU port (local)
- Coastal fishery base
- Landing place of daily commodities



SAIGOU port (Main)
- Base of the remote island route that links Oki Islands to the mainland
- Coastal fishery base

SAIGOU
Large electric power station enough for our facility



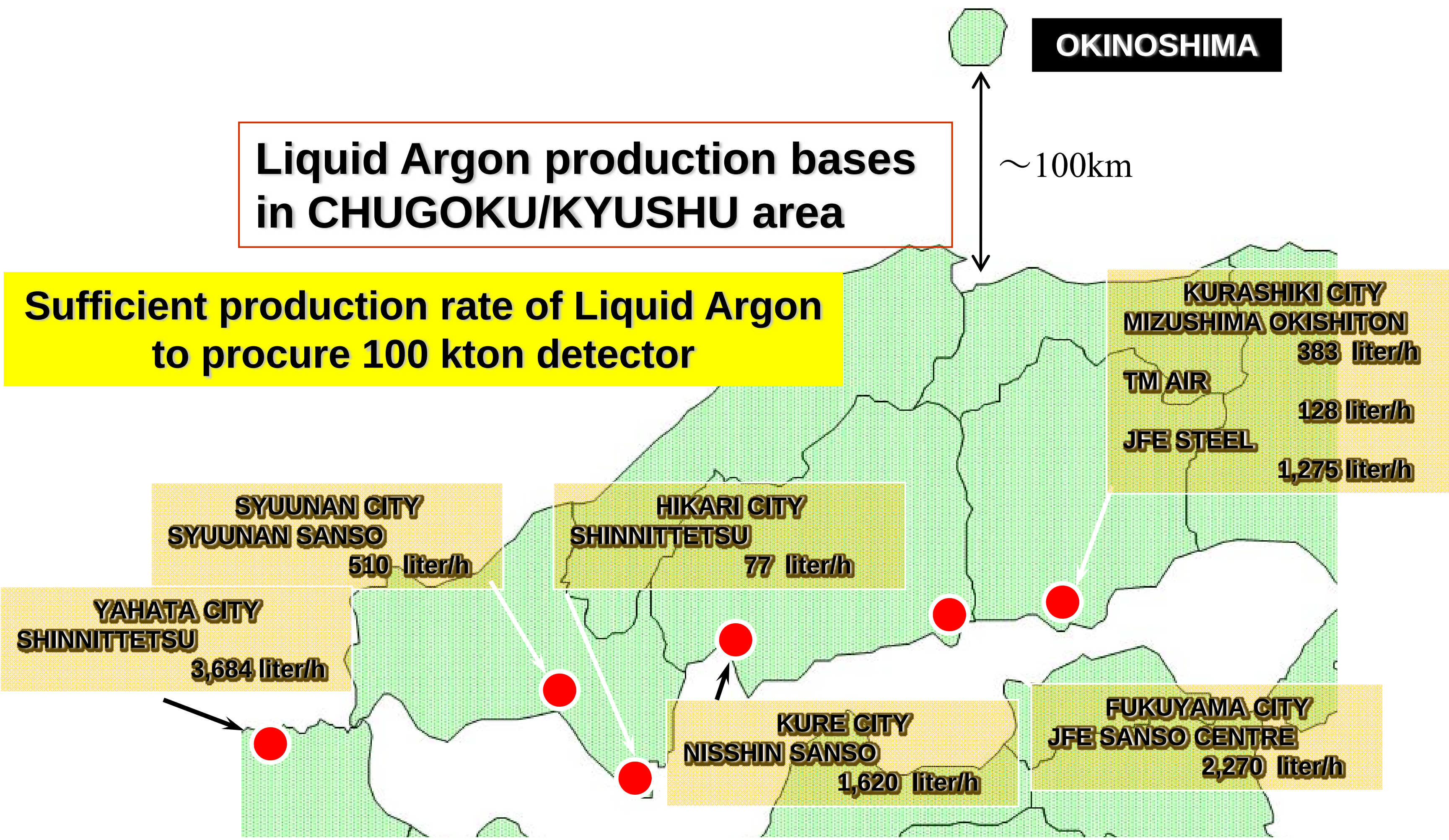
Oki airport, two regular flights
Oki – Osaka, Oki - Izumo

Okinoshima: Liquid Argon supply

Most efficient way is to use presently available ferry liner

Liquid Argon production bases in CHUGOKU/KYUSHU area

Sufficient production rate of Liquid Argon to procure 100 kton detector



Neutrino event rate and experimental sensitivity

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

No Osc.	ν_μ CC	ν_e CC	$\overline{\nu_\mu}$ CC	$\overline{\nu_e}$ CC
5 years	82000	750	1460	35

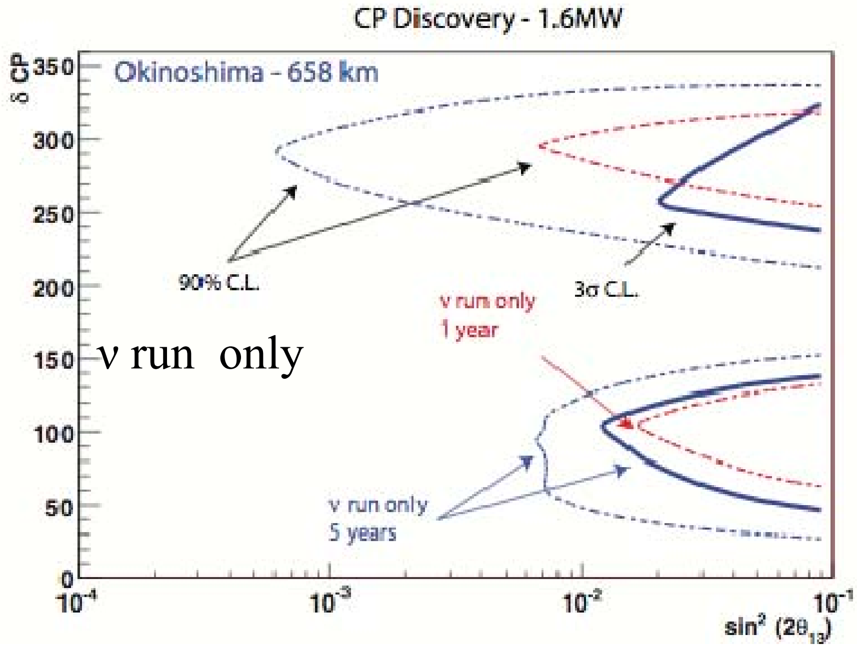
δ_{cp} (deg)	0	90	180	270
$\sin^2 2\theta_{13}=0.1$	2867	2062	2659	3464
$\sin^2 2\theta_{13}=0.05$	1489	1119	1342	1908
$\sin^2 2\theta_{13}=0.03$	942	506	829	1266

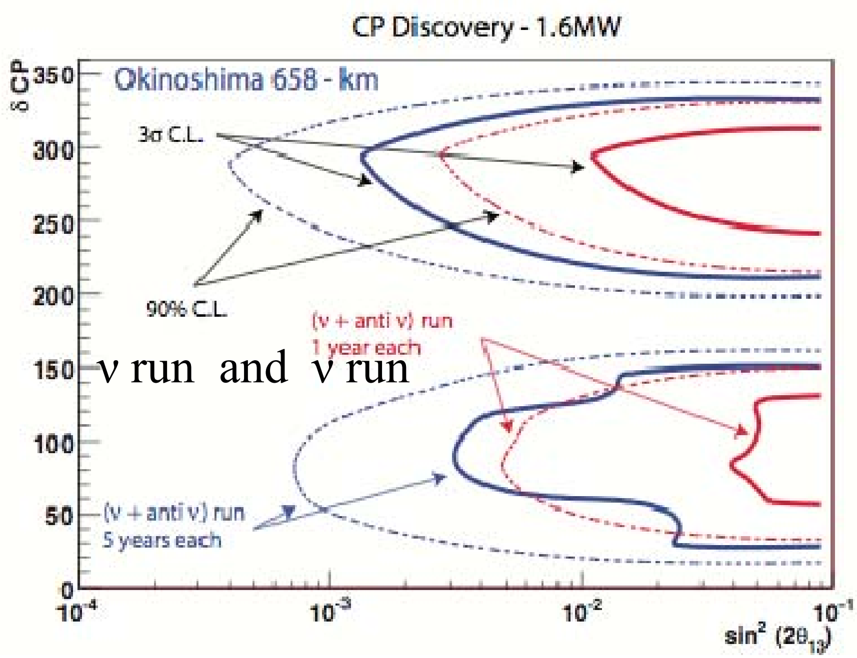
* $\times$10 larger total events than T2K
* High detection efficiency, excellent background suppression, high precision electron neutrino energy spectrum measurement

- CP discovery exceeds 3σ for $\sin^2 2\theta_{13}>0.02$
- measure θ_{13} with $\delta\sin^2 2\theta_{13}\approx\pm0.01$ and test CP at better than 90%CL if $\sin^2 2\theta_{13}>0.01$
- $\sin^2 2\theta_{13}<0.001$ @ 90%CL (if no signal is found) one order better than T2K

J-PARC to Okinoshima

CP Discovery potential





J-PARC to Okinoshima

Mass hierarchy investigation

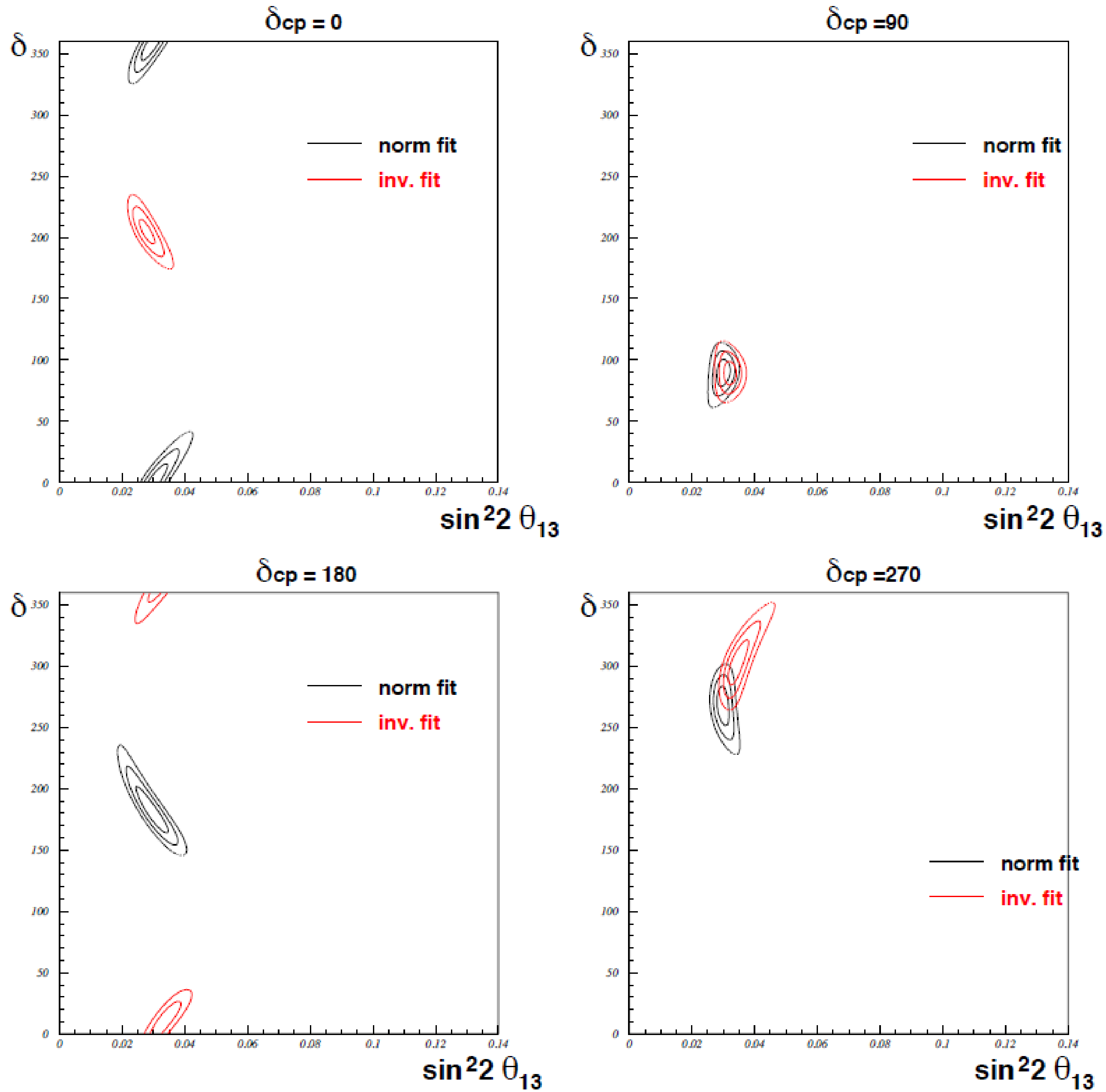


Fig. 7: Mass hierarchy investigation with neutrino run only. If fits with both hierarchy hypotheses provide neither 0 nor 180°, one can declare discovery of CP violation in the leptonic sector. If any of the fits results in a δ_{CP} of 0 or 180°, then an anti-neutrino run could be envisaged.

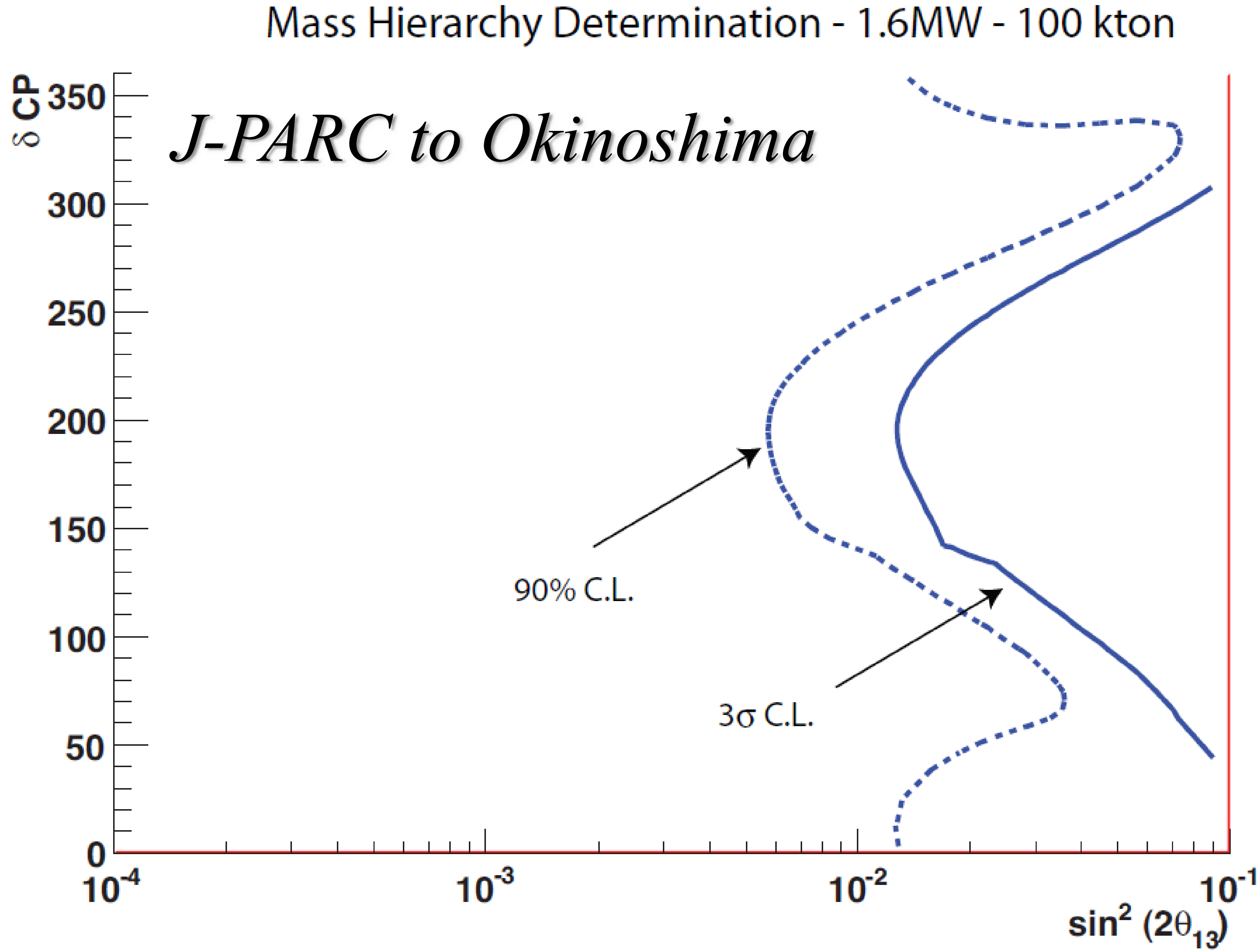
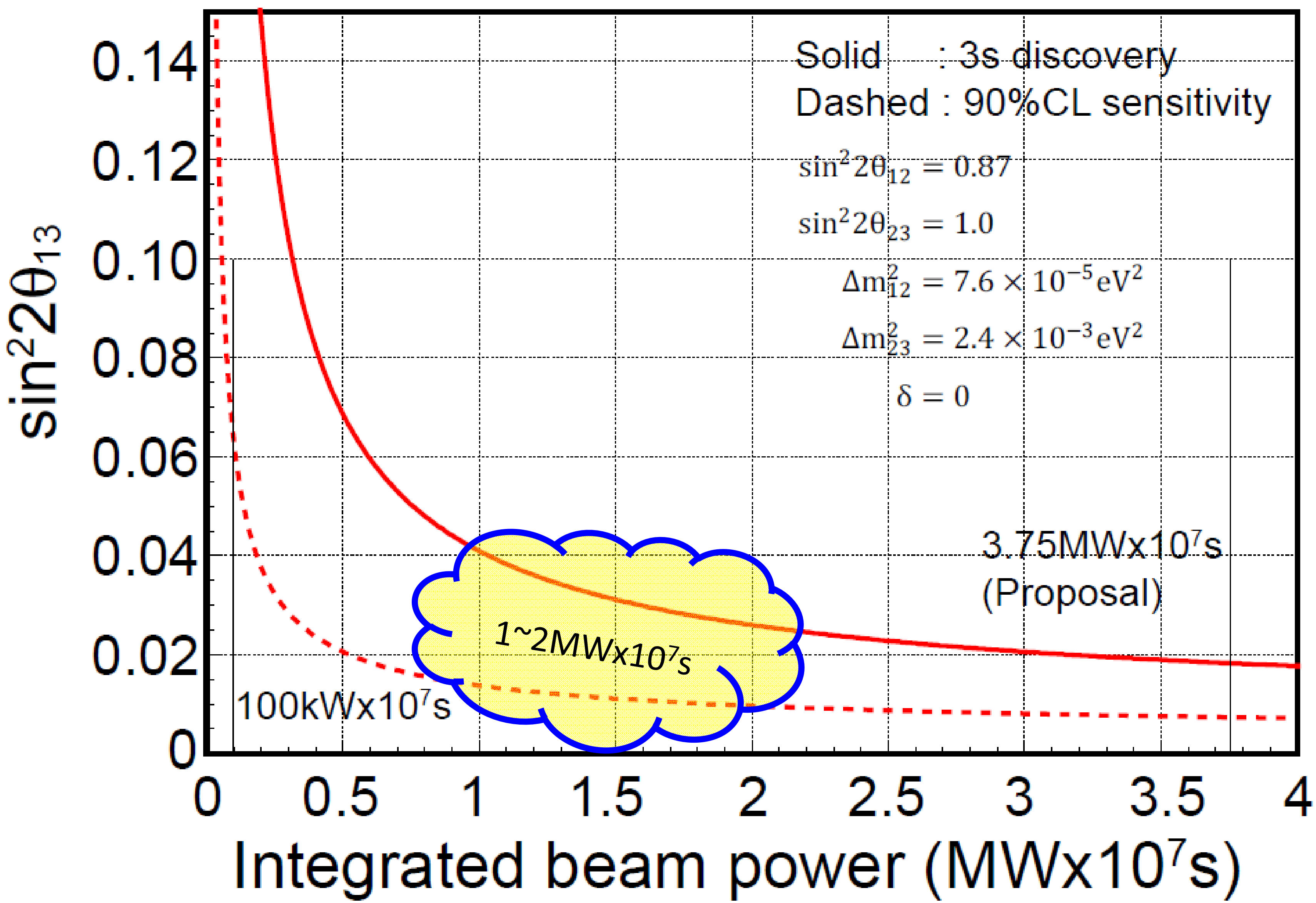
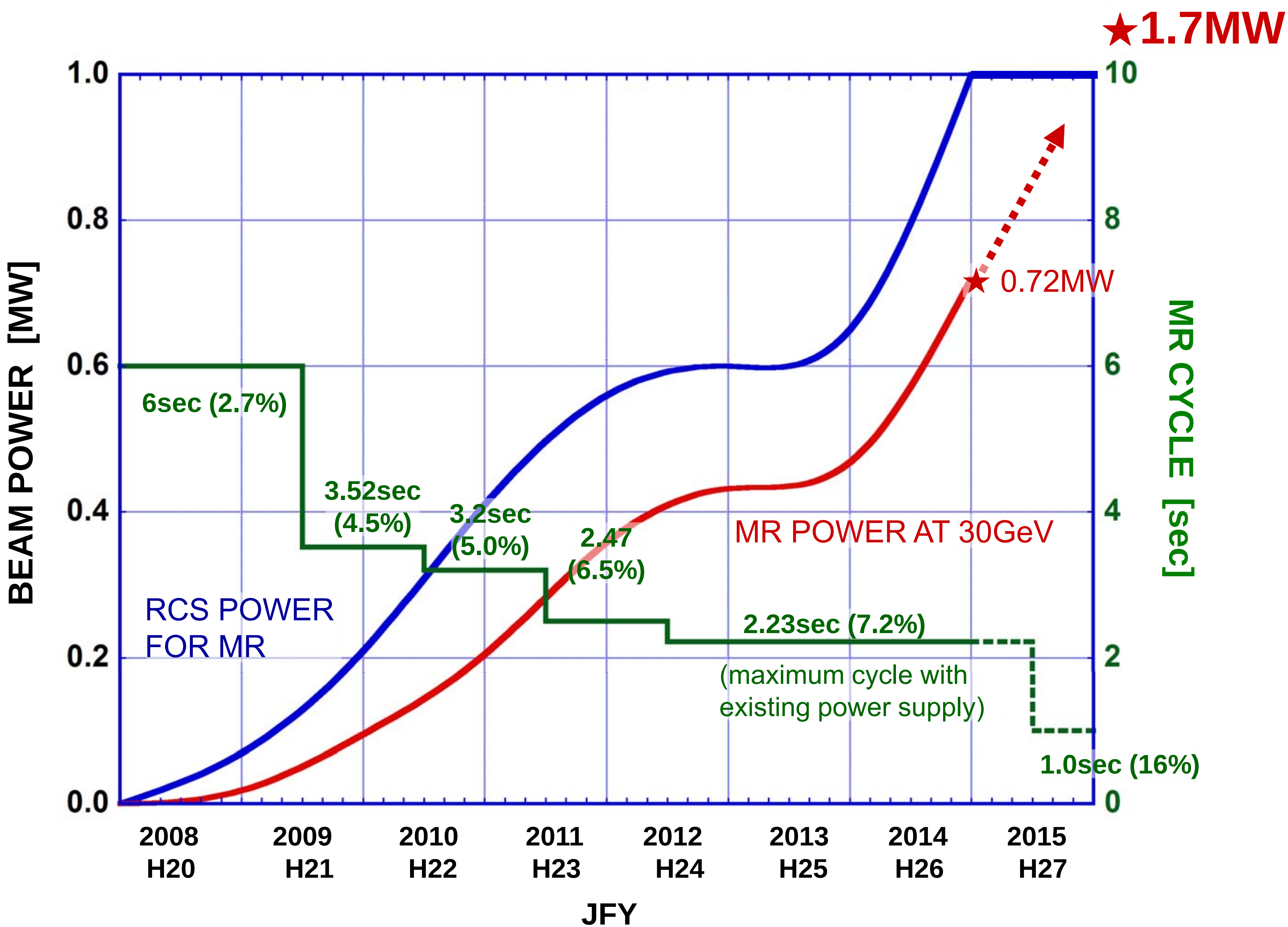


Fig. 10: Mass hierarchy discrimination at 90%C.L. and 3σ for 5+5 years neutrino-antineutrino runs.

T2K θ_{13} sensitivity

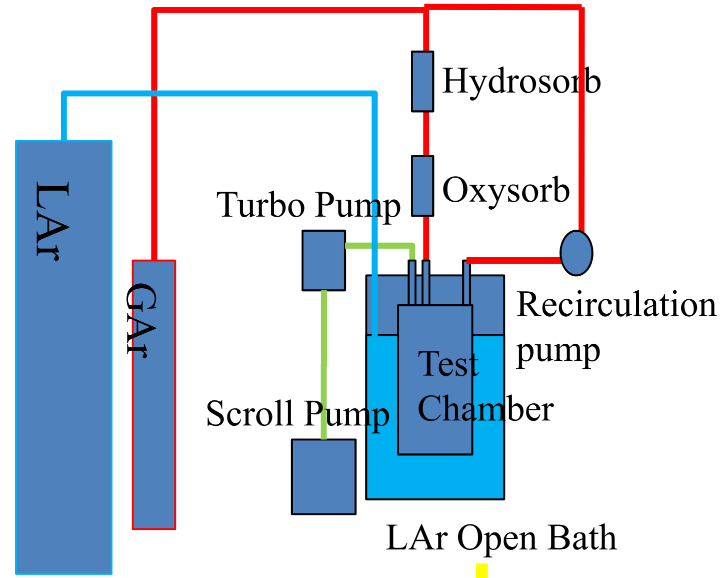




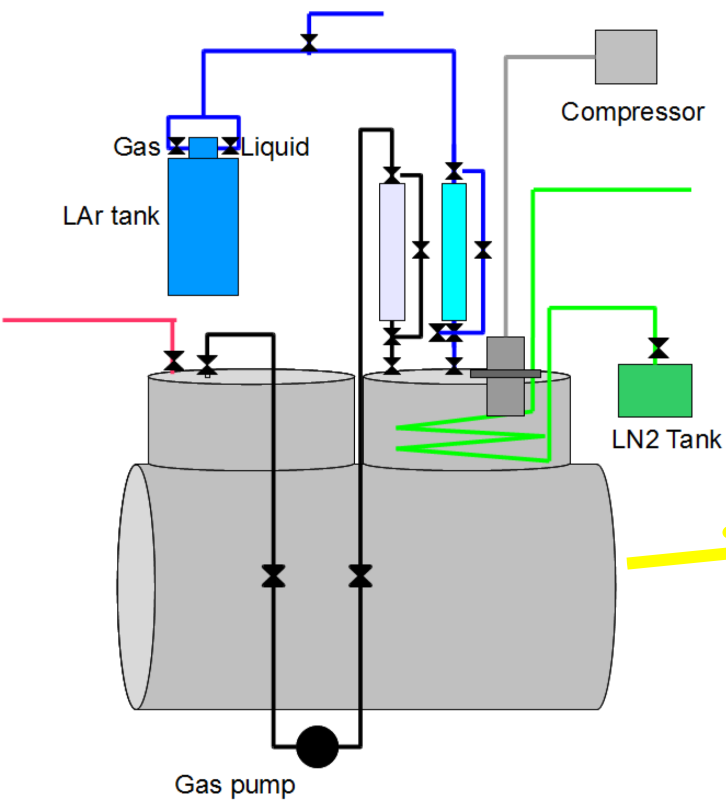
★1.7MW
BEAM POWER [MW]
1.0
0.8
0.6
0.4
0.2
0.0
MR CYCLE [sec]
10
8
6
4
2
0
★ 0.72MW
6sec (2.7%)
3.52sec
(4.5%)
3.2sec
(5.0%)
2.47
(6.5%)
MR POWER AT 30GeV
RCS POWER
FOR MR
2.23sec (7.2%)
(maximum cycle with
existing power supply)
1.0sec (16%)
2008
H20
2009
H21
2010
H22
2011
H23
2012
H24
2013
H25
2014
H26
2015
H27
JFY

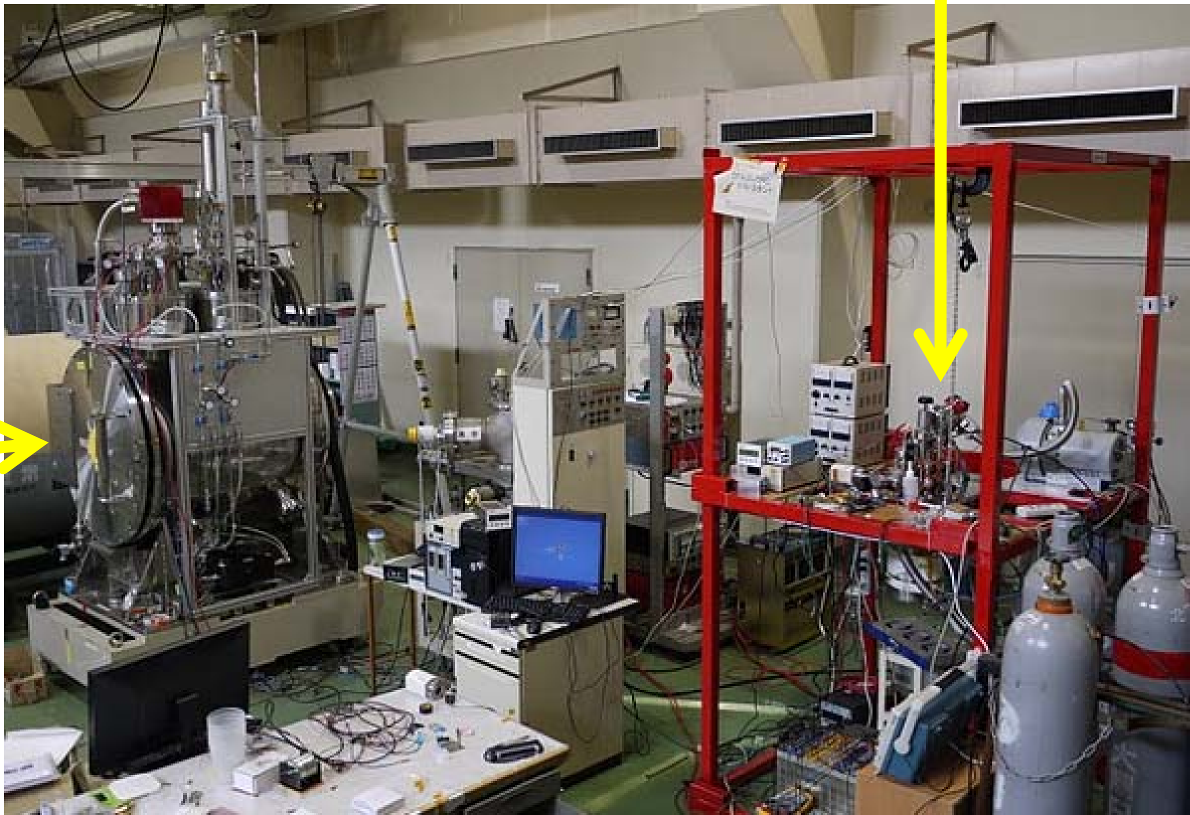
Liquid Argon TPC Lab.@KEK

10L@KEK

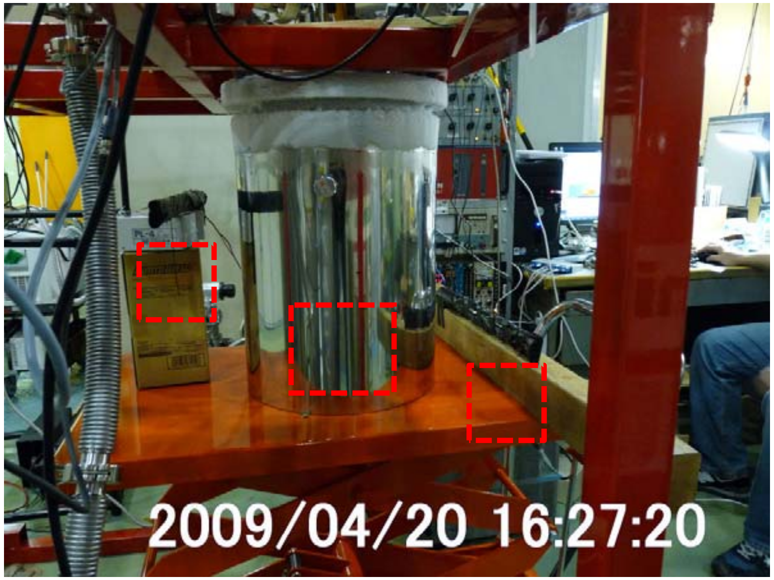


250L@KEK

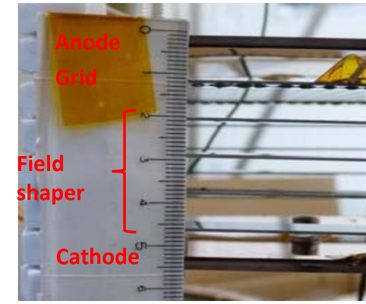


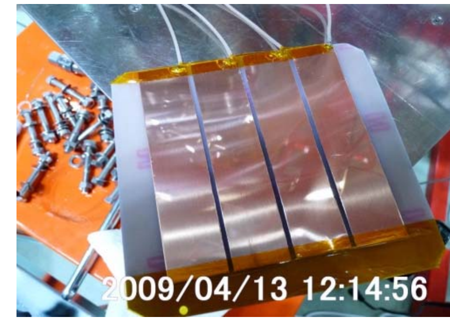


1st Liq. Ar TPC Signal with Cosmic Ray in Japan



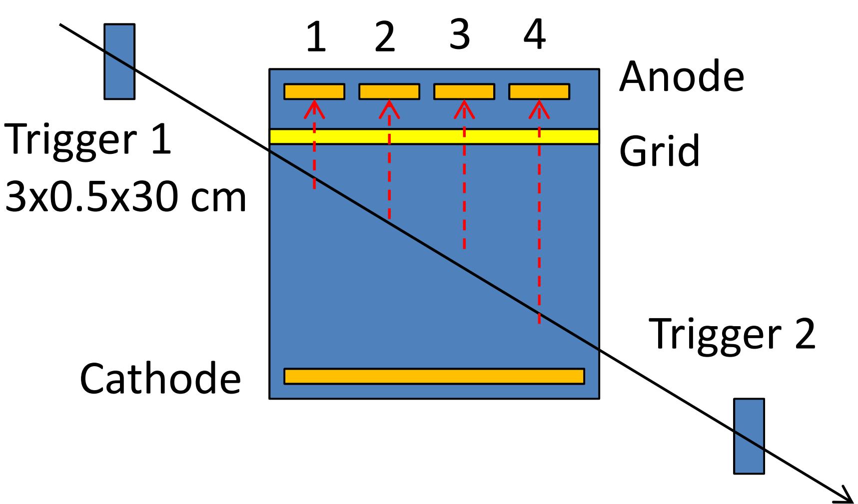
- HV setting
  - Cathode -2500 V
  - Grid -1000 V
  - Cathode-anode; 5cm
- Oscilloscope waveform
  - Ch1 is the fastest signal
  - Drift time ~20 μs

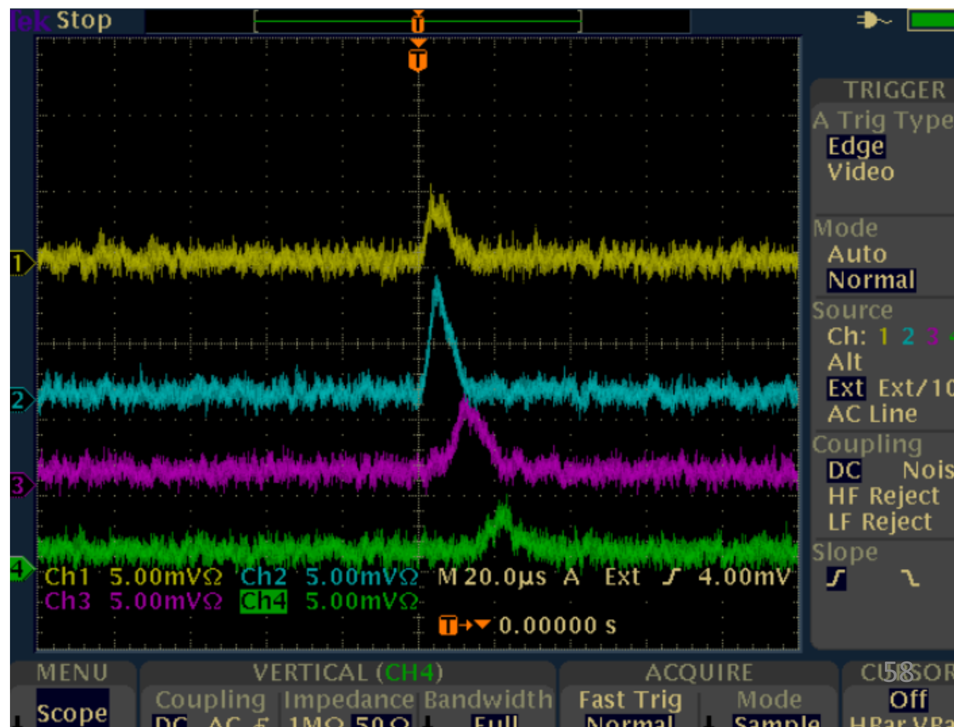




Anode: 4ch × 2.2cm × 9cm

Trigger Counter set up



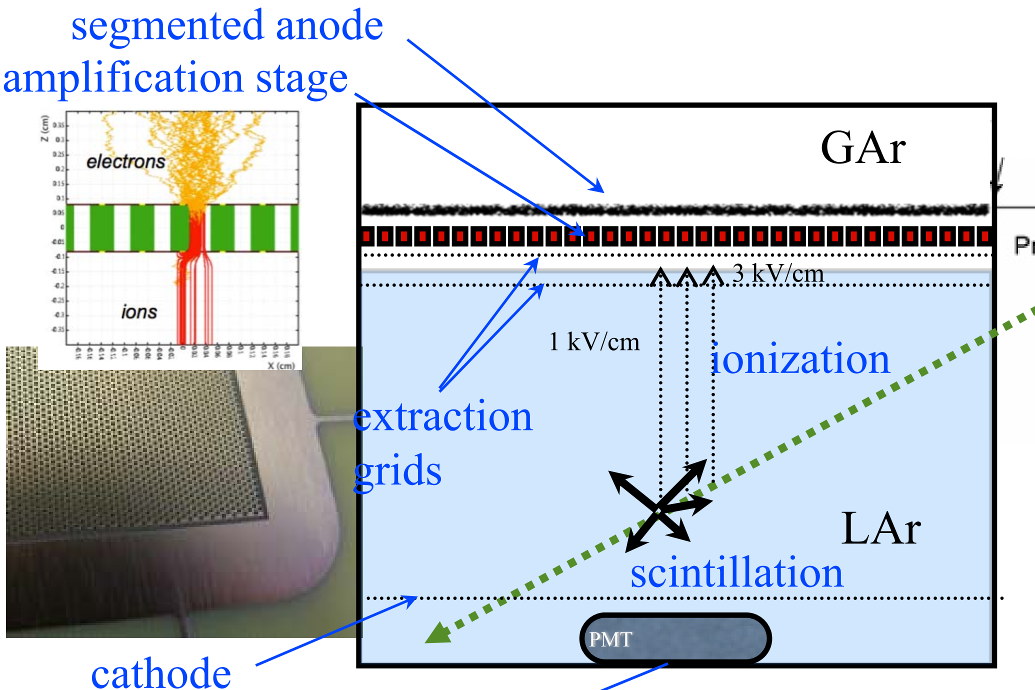


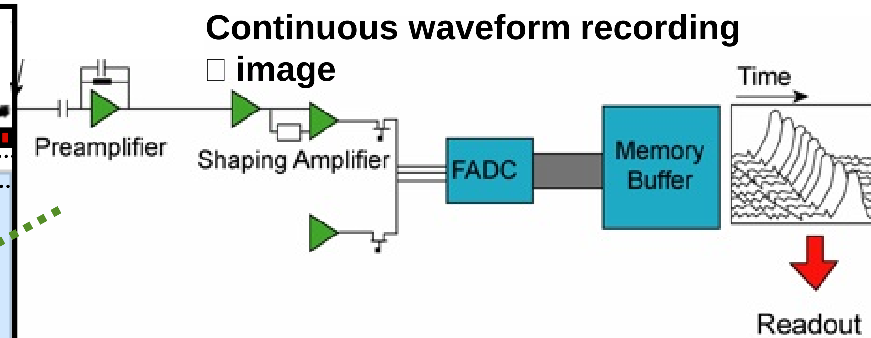
The new LAr LEM-TPC

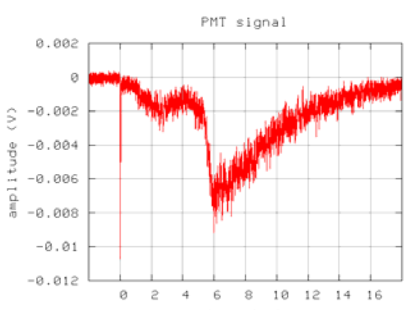
- LAr LEM TPC = Double phase TPC with gain in GAr vapor

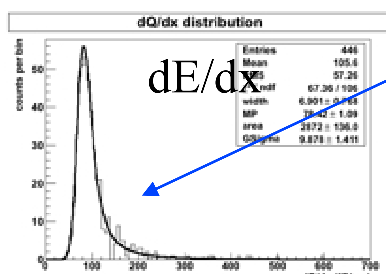
Motivated by the very long drift path needed in giant detectors and DM applications (keV detection)

hep-ph/0402110, arXiv:0811.3384, NIM A617(2010)188, J.Phys.Conf.Ser.171:012020,2009, arXiv:1001.0076

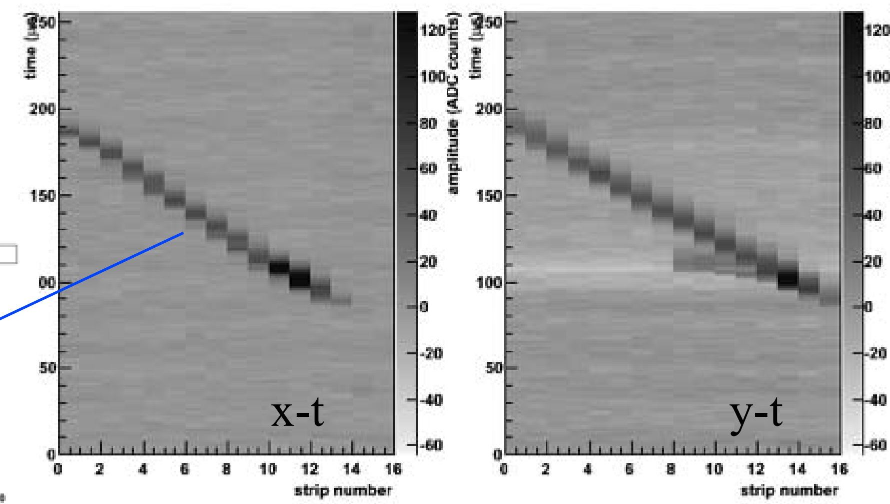




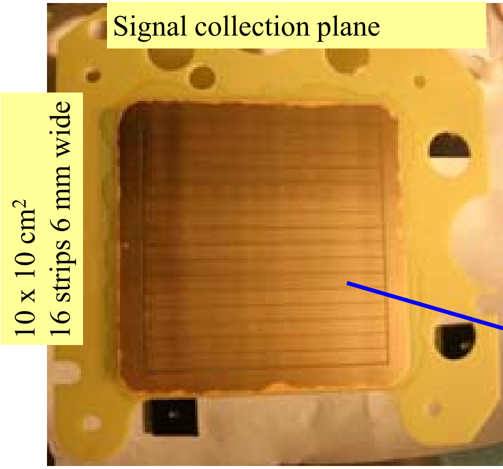




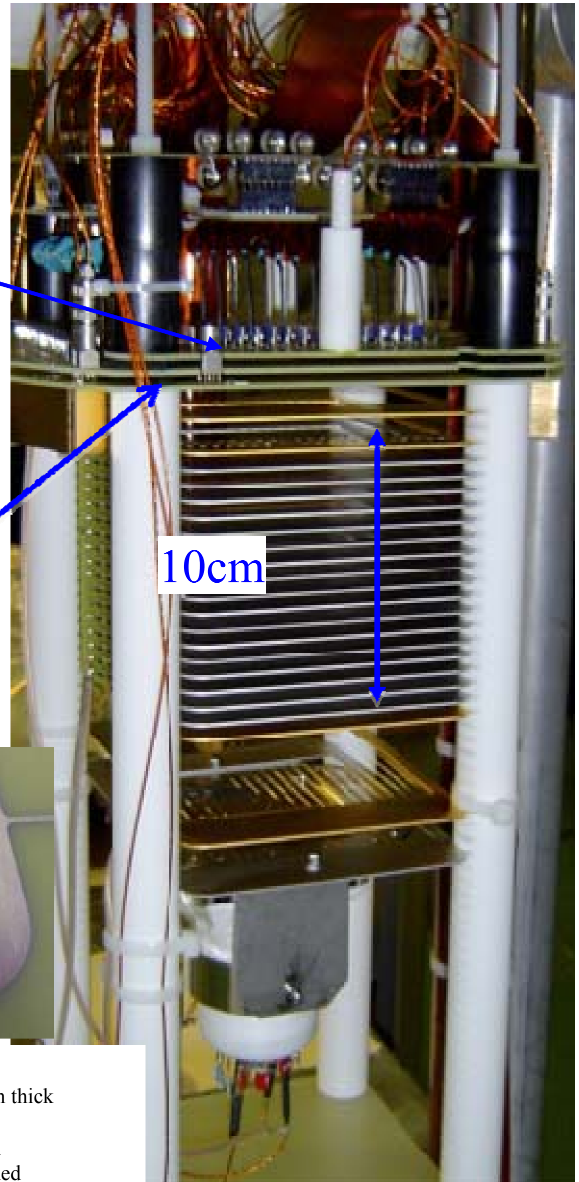
Cosmic tracks in 3 lt prototype (G≈6):

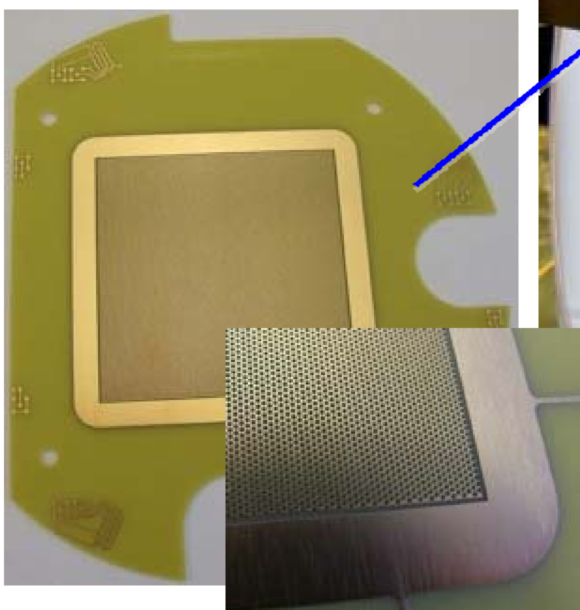


LAr LEM-TPC 3L@CERN



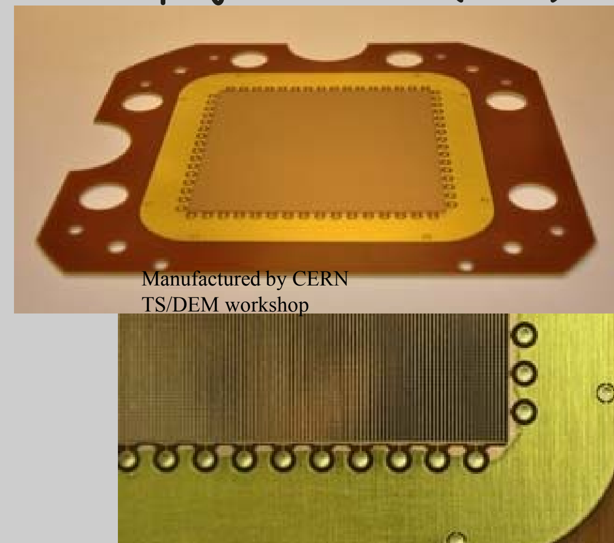
100 x 100 mm² test setup





- Produced by standard PCB technique
- Double-sided copper-clad (18 µm layer) FR4 plates, 1.6 mm thick
- Precision holes made by drilling
- Gold deposition on Cu (<~ 1 µm layer) to avoid oxidization
- HV decoupling (cryo-) capacitors & surge arrestors embedded

X-Y projective anode (NEW)



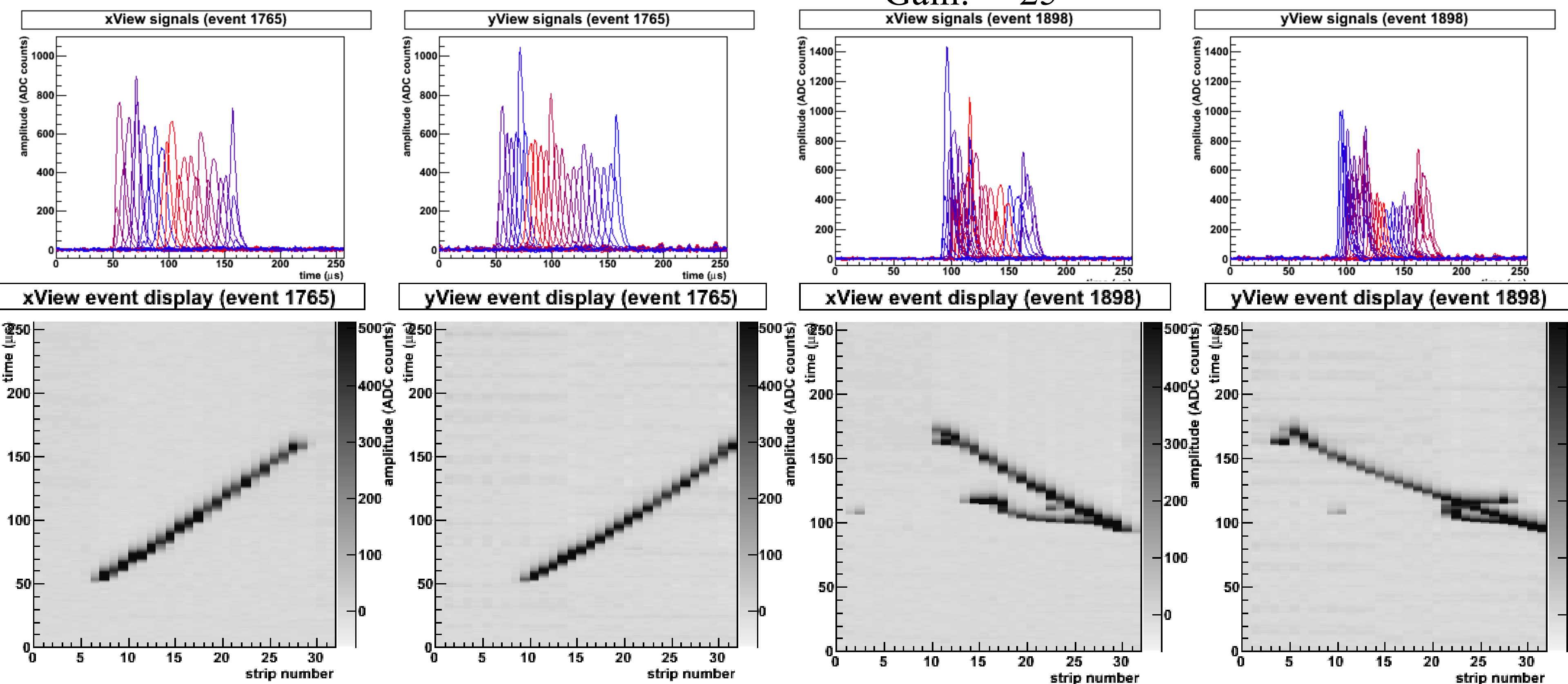
600 µm physical strips width •3 mm readout segmentation

Cosmic tracks in 3L@CERN with new two view anode

Two view anode

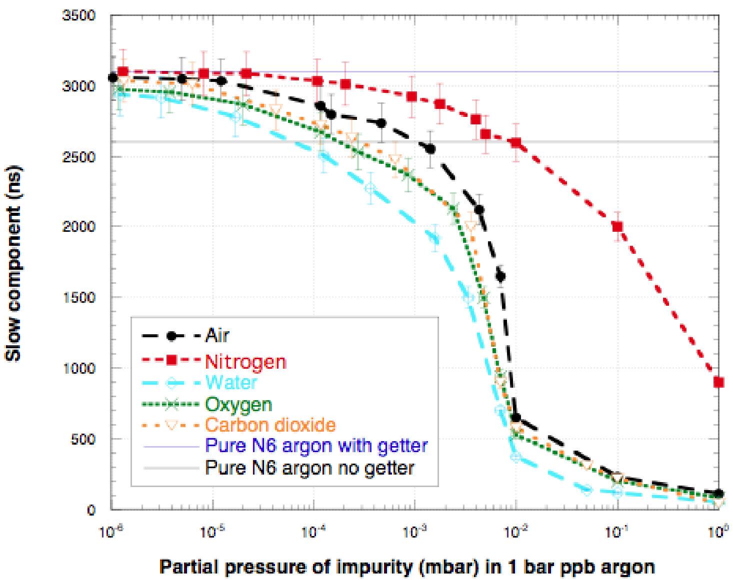
- ➢ Decouple the amplification and the readout stages
- ➢ The charge is equally shared between X and Y strips
- ➢ Same signal shape of both coordinates

- Double phase (1.0 bar, 87K)
- Single stage LEM amplification
- Two view anode charge readout (3mm pitch)
- O_2 contamination: ～2ppb
- Gain: ～25

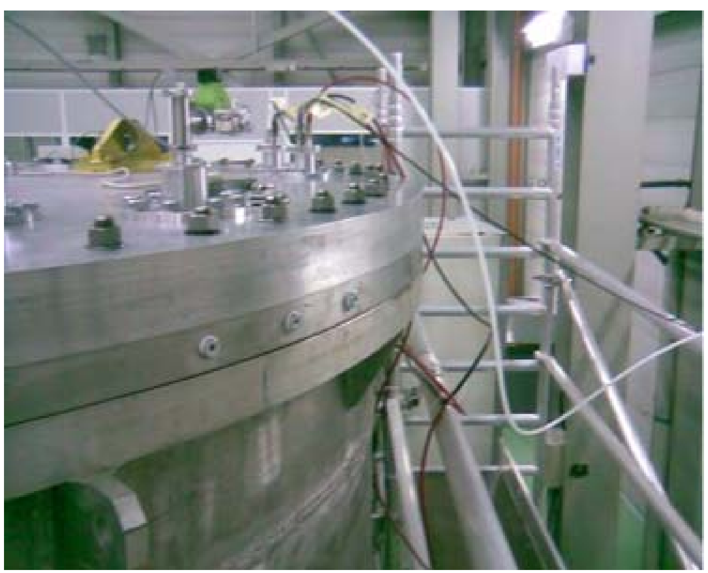


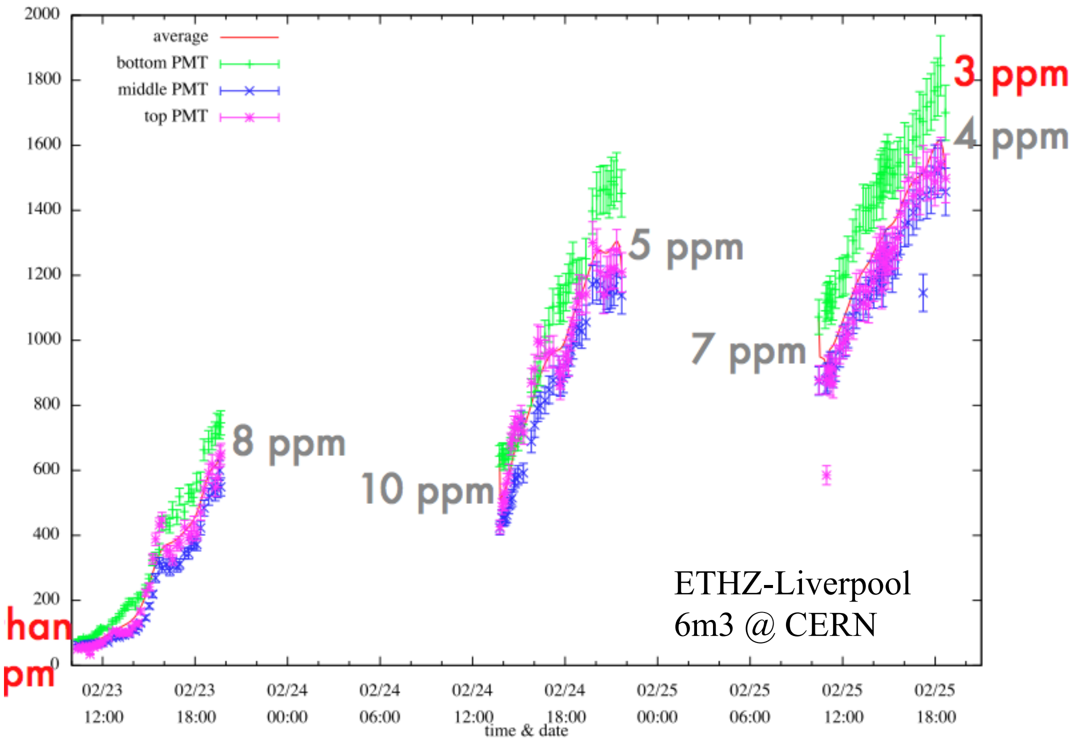
6m3 @ CERN

A. Curioni et al., GLA2010 workshop



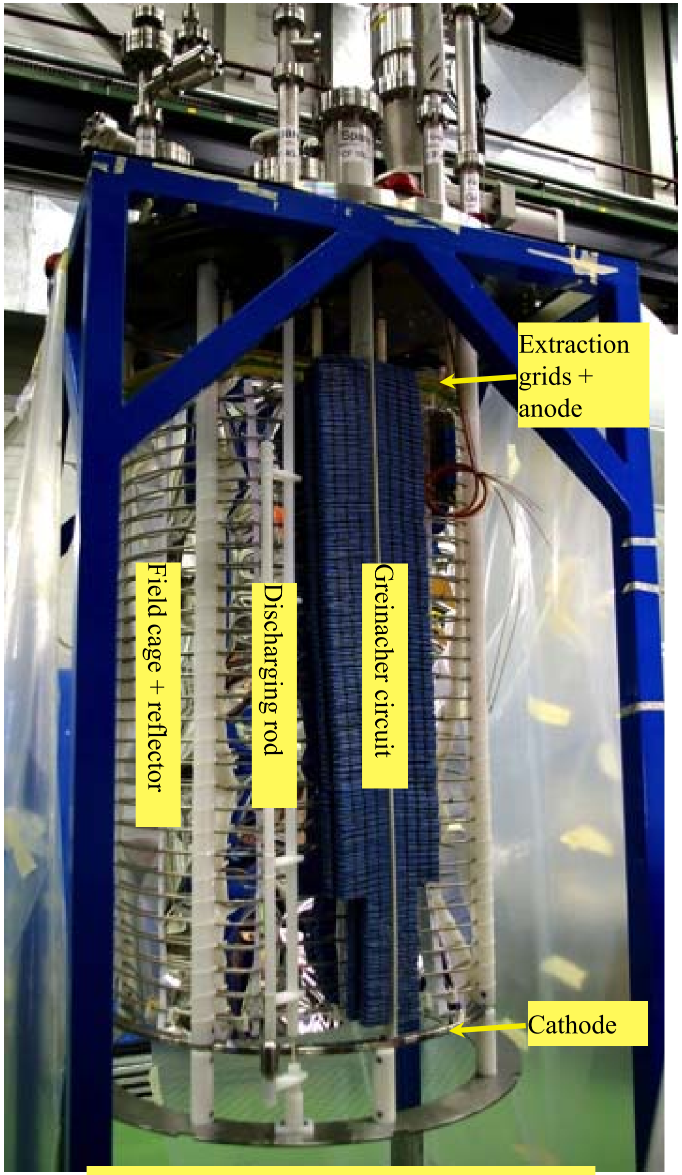
- R&D towards non evacuated vessels on large vessel
- Purity measured with direct scintillation light measurement !
- First test purging - satisfactory!
- Piston effect seen
- Reached **3ppm** O_2 contamination via flushing
- Gas recirculation under construction



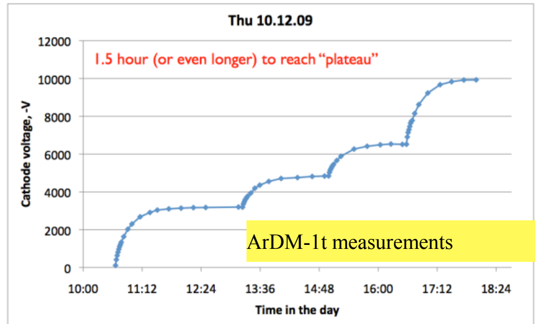


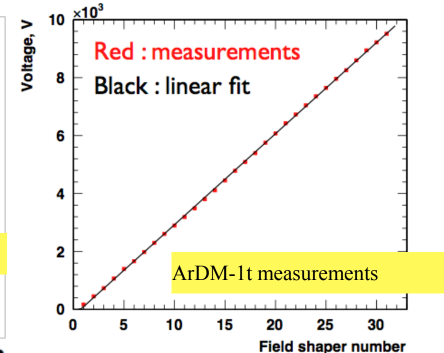
Very high drift "high" voltage...

S. Horikawa et al., GLA2010 workshop



ArDM-1t detector





Extrapolation to long drift

Extrapolation of the ArDM design

Changing Cs for fixed Cp = 2.35 pF and Vpp-in = 2E = 2.5 kV

		ArDM				
Drift length	m	1.24	5	10		20
Total output voltage for 1 kV/cm	V	124k	500k	1M		2M
Input voltage Vpp-in = 2E	V	820	2.5k	2.5k	$\times\sqrt{2}$	3.5k
Shunt capacitance, Cp	F	2.35p	2.35p	2.35p	$\times 1/2$	1.18p
Capacitor	F	328/164n	475n	1.90μ		1.90μ
Number of stages, N	–	210	319	638		903
N per 10 cm	–	16.9	6.38	6.38		4.51
Total capacitance	F	125μ	303μ	2.43m		3.43m
Capacitance per 10 cm	F	10.4μ	5.99μ	24.3μ		17.2μ
Total stored energy	J	21.7	948	7.58k		21.5k

Actual ArDM parameters are given just for comparison.

For extrapolation, 2γN = 1.42 is always assumed.

LAr vaporization heat 160 kJ/kg

$$V_{\max} = \frac{E}{\gamma}, \ \gamma \approx \sqrt{\frac{C_p}{C_s}}$$