Future long baseline experiments: option for Japan

1. J-PARC Accelerator and Neutrino Beam Facility
2. T2K as a first experiment utilizes J-PARC Neutrino Beam (already covered by Dr. Hidekazu Kakuno)
3. Possible Future Discovery Experiment with J-PARC Neutrino Beam
   - Neutrino Beam Upgrade Plan (KEK Roadmap)
   - Far Detector Options
4. Summary－Accelerator Based Neutrino Project in Japan－

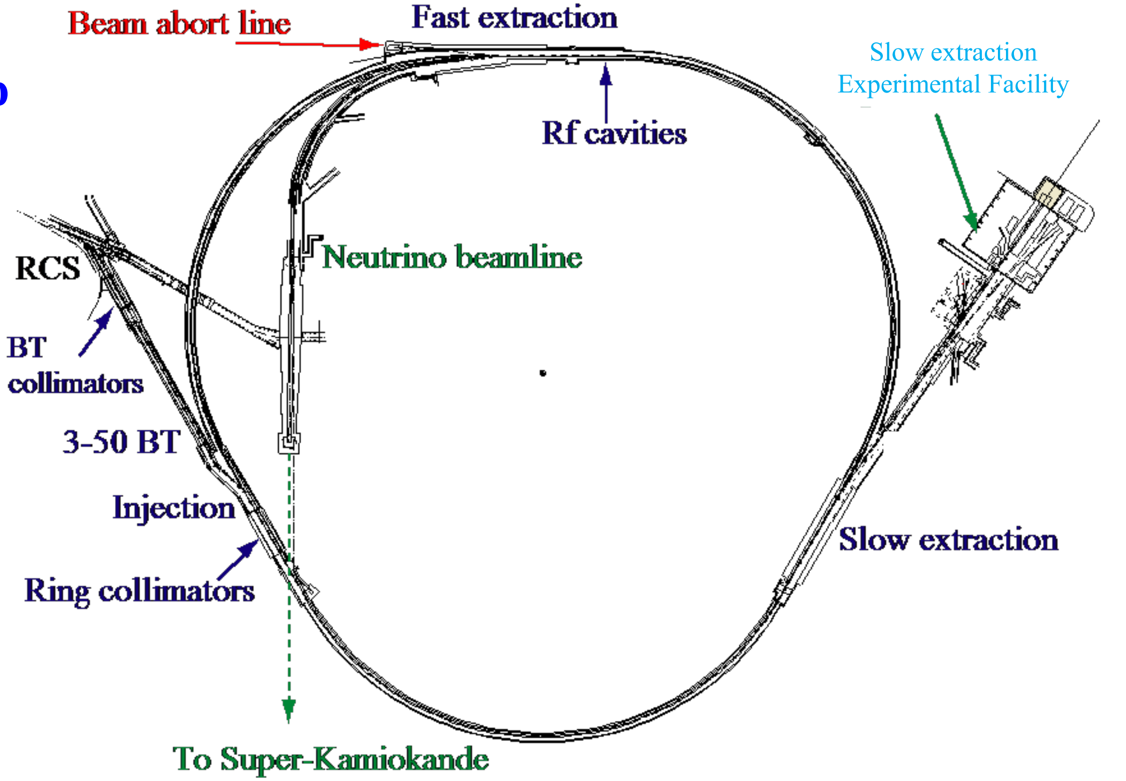
Takuya Hasegawa (KEK)

J-PARC Accelerator and Experimental Facility

Bird's eye photo in July. 2009

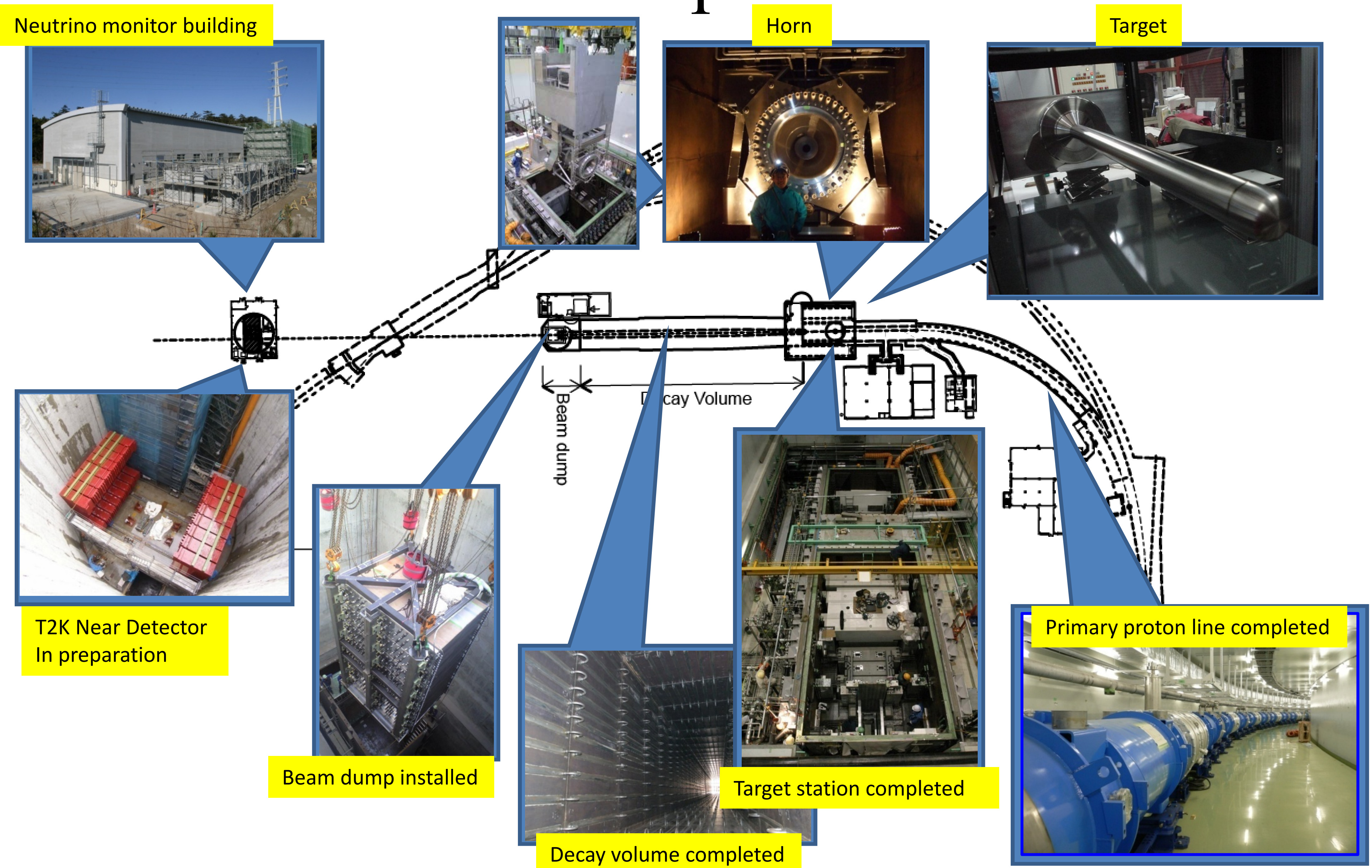
Overview of MR

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 SK located 295 km west)
  - outside: Beam abort line
- Slow extraction
  to Slow extraction Experimental Facility
  (K Rare decay, Muon Lepton Flavor Violation, hyper nucleus, etc.)

Commissioning of Neutrino Beam Facility Started April 2009



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

*Tolerable up to ～2MW beam power

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

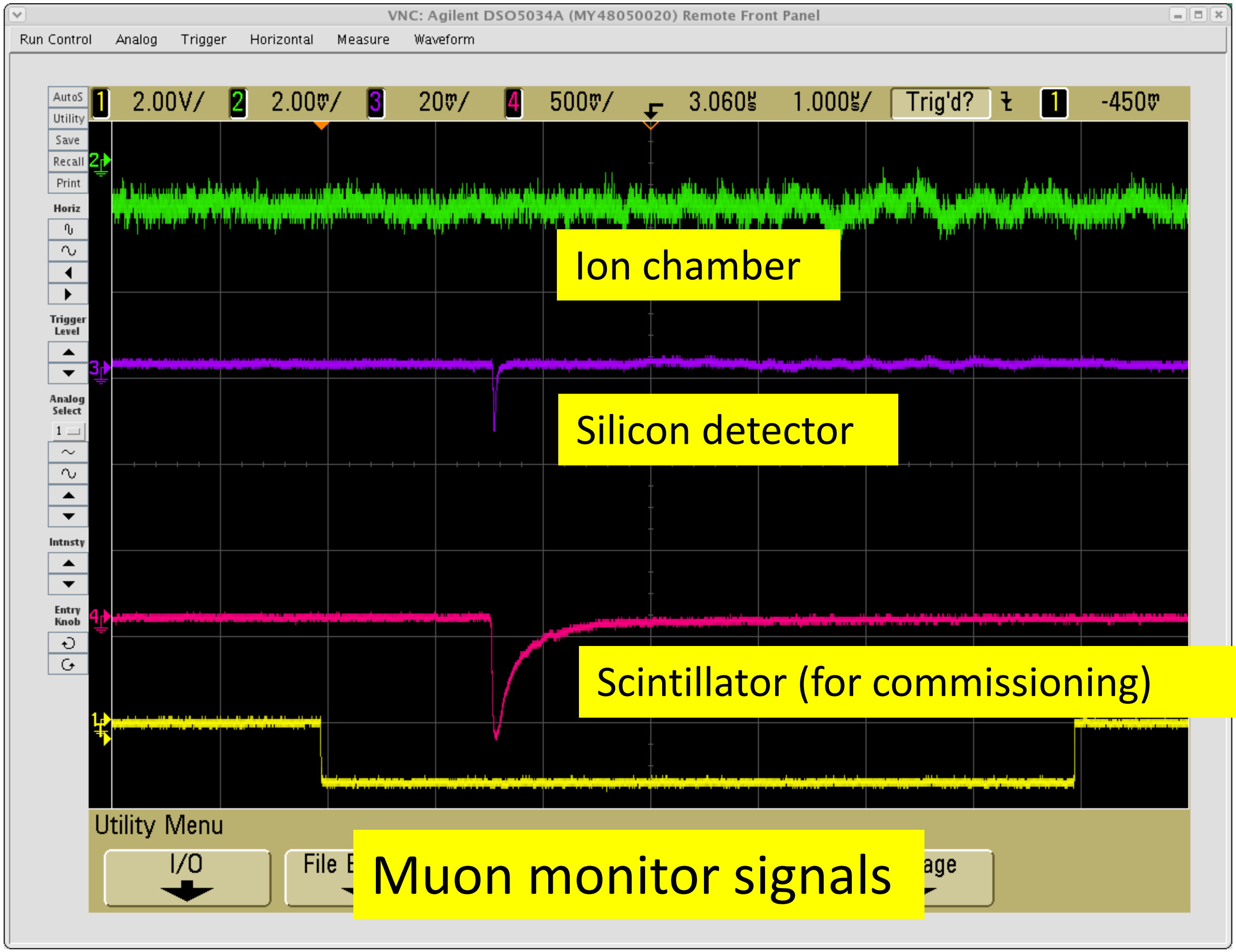
Maintenance scenario of radio active beam facility components is necessary

Brief History of Neutrino Beam Facility Commissioning

- 23-April:
  Neutrino facility beam commissioning started
  19:09 Turned on superconducting magnet and proton beam reached target region
  Neutrino production was confirmed by associated muon signal
- 24-April:
  Proton beam was tuned to be target center with 9 shots after superconducting magnet turned on
  Confirming pion focusing with horn magnet
- 28-April:
  Rehearsal for government inspection
- 22-27 May:
  MR commissioning
  Neutrino facility commissioning
  - Check of the functionality of the beam monitors
  - Check of the response function of the magnets
  - Fine tuning of the primary proton beam orbit/profile
- 28-May:
  Approval of the government inspection of the neutrino facility on radiation safety

J-PARC Neutrino Beam Facility Start Operation

First shot after turning on arc section superconducting magnets at 19:09, Apr.23, 2009

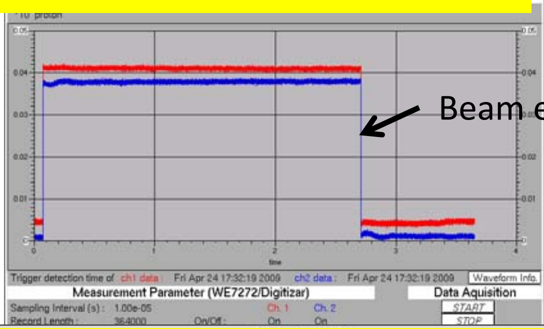


Neutrino production is confirmed by associated muon signal

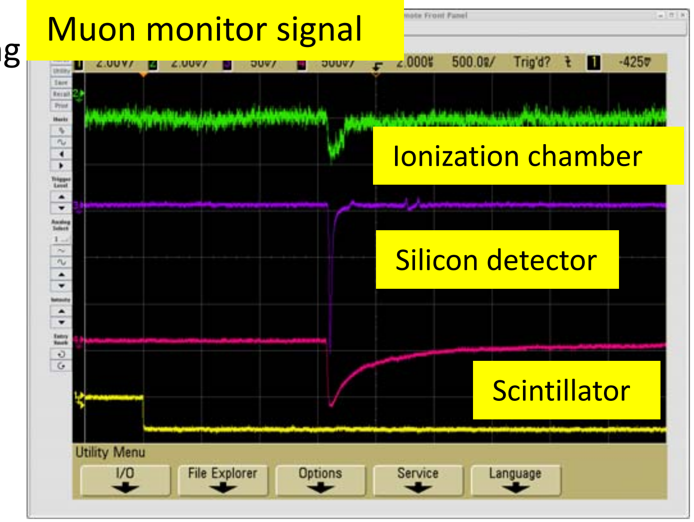
J-PARC Neutrino Beam Facility Start Operation

After 9 shots for tuning, proton beam hits target center

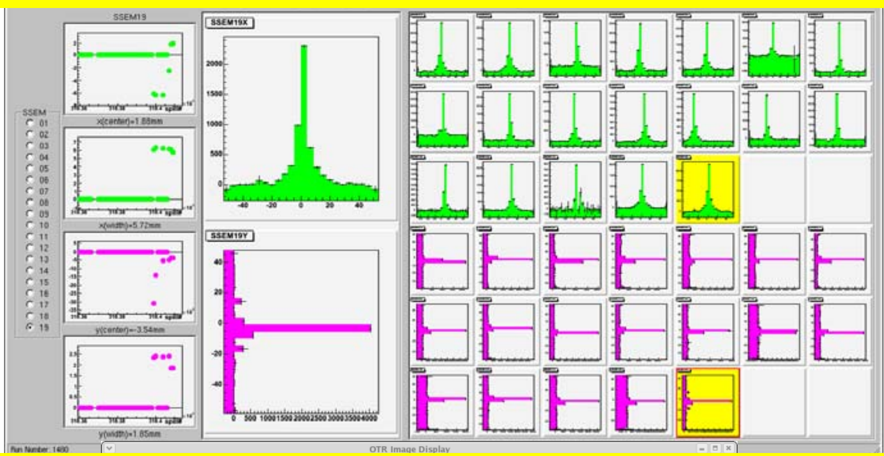
Main Ring intensity as a function of time



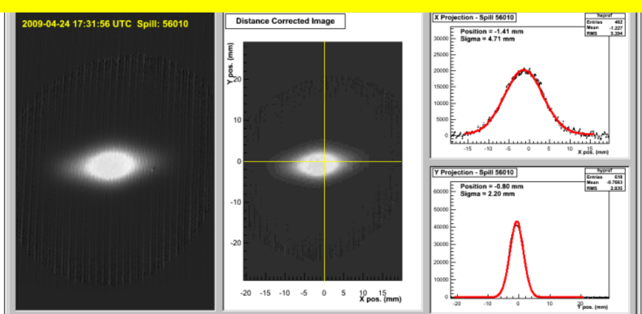
Muon monitor signal



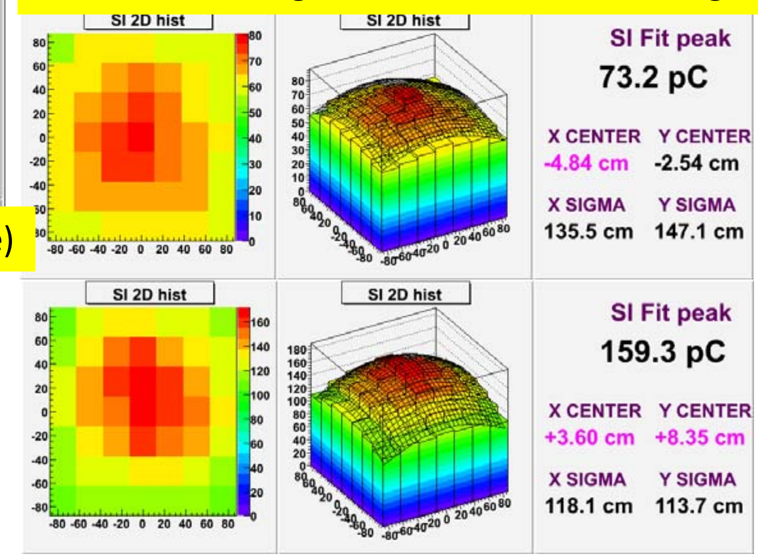
Proton beam profile/position along the primary beam line



Proton profile just in front of the target (fluorescence plate)



Muon monitor signal with/without Horn Magnet



Horn Off

Horn On

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

T2K is aiming for the first results in 2010
with 100kw × 10^{7}sec integrated proton power on target
to unveil below CHOOZ limit with ν_e appearance

Primary Motivation of T2K

Discover $\nu_\mu \rightarrow \nu_e$ conversion phenomenon prior to any other experiment in the world

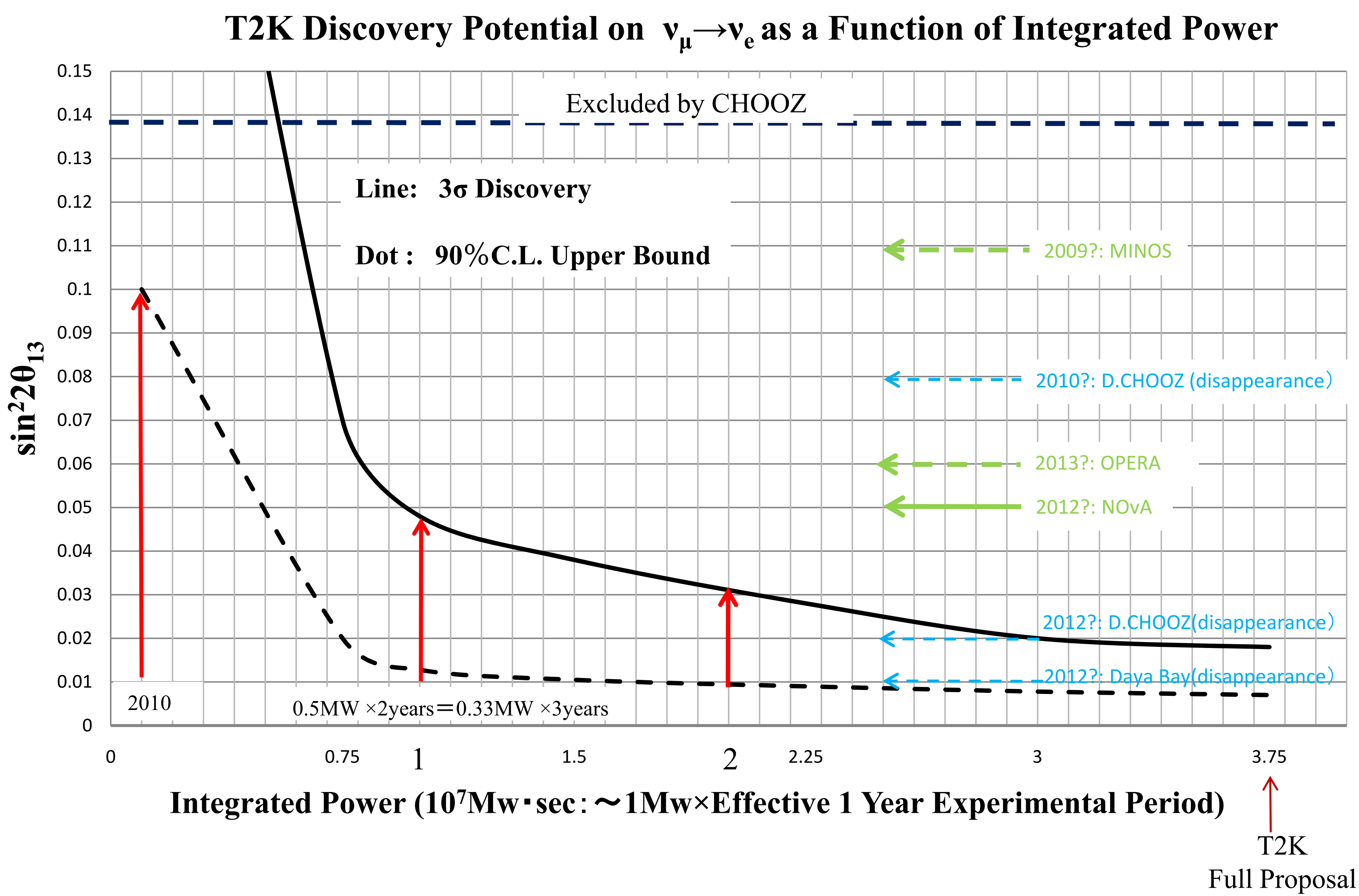
Conclude Lepton Flavor Mixing Structure

T2K Proposal Accepted by J-PARC PAC

"We request total integrated beam power larger than 0.75MW $\times$ 15000h at any proton energies between 30 and 50 GeV."

$$15000\ \text{h} = 5 \times 3000\text{h}$$

$$\fallingdotseq 5 \times 10^7 \text{sec}$$



T2K Discovery Potential on $\nu_\mu \to \nu_e$ as a Function of Integrated Power
Excluded by CHOOZ
Line: 3σ Discovery
Dot : 90%C.L. Upper Bound
2009?: MINOS
2010?: D.CHOOZ (disappearance)
2013?: OPERA
2012?: NOvA
2012?: D.CHOOZ(disappearance)
2012?: Daya Bay(disappearance)
2010
0.5MW ×2years＝0.33MW ×3years
$\sin^2 2\theta_{13}$
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.75
1
1.5
2
2.25
3
3.75
Integrated Power (10^7Mw･sec：～1Mw×Effective 1 Year Experimental Period)
T2K
Full Proposal

Integrated power of 1～2MW × 10^7 seconds

is

a turning point to decide

Next Project utilizing J-PARC Neutrino Beam

Future Investment for the "Discovery" in ν Physics

If **Significant** ν_e Signal →

Proceed Immediately to CP Violation Discovery

MUST: Improve ν Beam Intensity

MUST: Improve the Main(Far) Detector Quality

In terms of

Detector Technology, Volume and Baseline+Angle

Naturally, main neutrino detector tends to be huge.

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

Discover Proton Decay

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

J-PARC to Somewhere
Long Baseline Neutrino Experiment
and
Nucleon Decay Experiment
with
Huge Volume Detector

Quest for the Origin of Matter Dominated Universe

One of the Main Subject of the KEK Roadmap

T2K (2009~) → Discovery of the ν_e Appearance

Neutrino Intensity Improvement

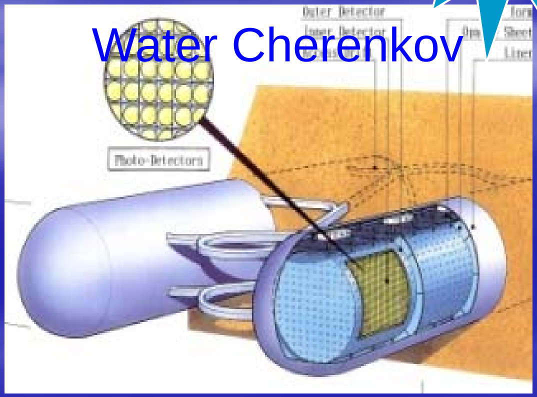
Huge Detector R&D

Establish Huge Detector Technology

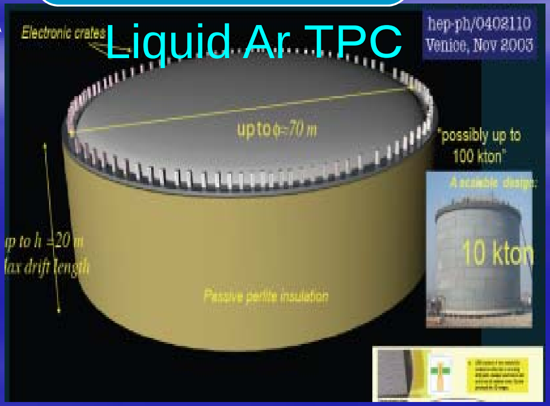
Construction of Huge Detector

Discovery of Lepton CP Violation Proton Decay

Water Cherenkov



Liquid Ar TPC



Future Investment for the “Discovery” in ν Physics

If **Significant** ν_e Signal →

Proceed Immediately to CP Violation Discovery

MUST: Improve ν Beam Intensity

MUST: Improve the Main(Far) Detector Quality

In terms of

Detector Technology, Volume and Baseline+Angle

J-PARC Neutrino Beam Upgrade Plan

Technically Feasible MR Power Improvement Scenario — KEK Roadmap —

	Day1 (up to Jul.2010)	Next Step	KEK Roadmap	Ultimate
Power(MW)	0.1	0.45	1.66	?
Energy(GeV)	30	30	30	
Rep Cycle(sec)	3.5	3-2	1.92	
No. of Bunch	6	8	8	
Particle/Bunch	1.2×10^{13}	$<4.1\times10^{13}$	8.3×10^{13}	
Particle/Ring	7.2×10^{13}	$<3.3\times10^{14}$	6.7×10^{14}	
LINAC(MeV)	181	181	400	
RCS	h=2	h=2 or 1	h=1	

Item to be Modified from DAY1 toward High Intensity

- No. of Bunch in MR(6→8)
  - Fast Rise Time Extraction Kicker Magnet
    → Installation is foreseen in 2010 summer
- Increase Repetition Rate (3.5Sec→1.92Sec)
  - 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

Future Investment for the "Discovery" in ν Physics

If **Significant** ν_e Signal →

Proceed Immediately to CP Violation Discovery

MUST: Improve ν Beam Intensity

MUST: Improve the Main(Far) Detector Quality

In terms of

Detector Technology, Volume and Baseline+Angle

Depend on how to approach Lepton Sector CP Violation

Far Detector Options

How to approach Lepton Sector CP Violation

Lepton Sector CP Violation

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

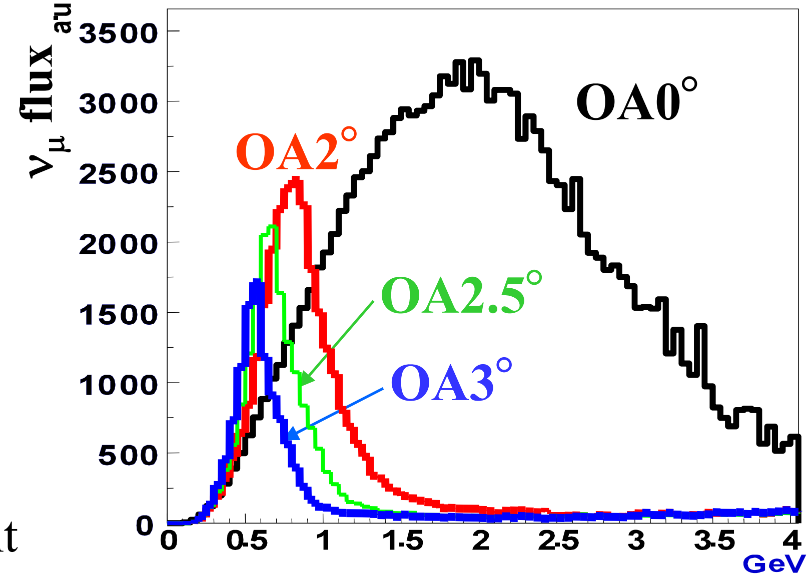
Effect of CP Phase δ appear as

- ν_e Appearance Energy Spectrum Shape
  - *Peak position and height for 1^{st}, 2^{nd} 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

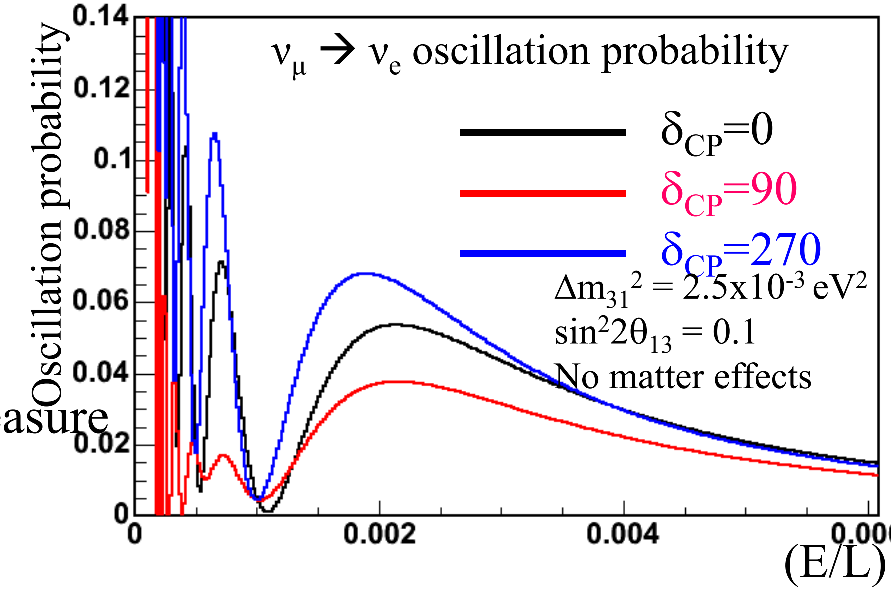
Angle and Baseline

- 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



Three Possible Scenario Studied at NP08 Workshop

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

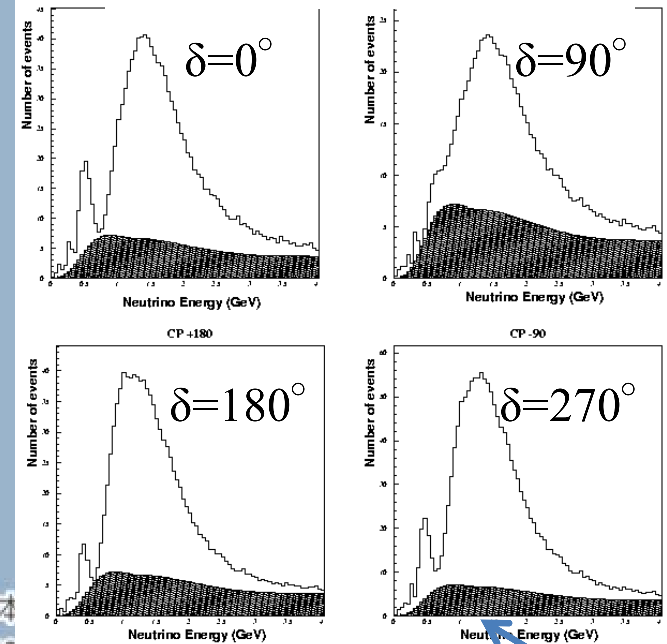
http://j-parc.jp/NP08

Scenario 1

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

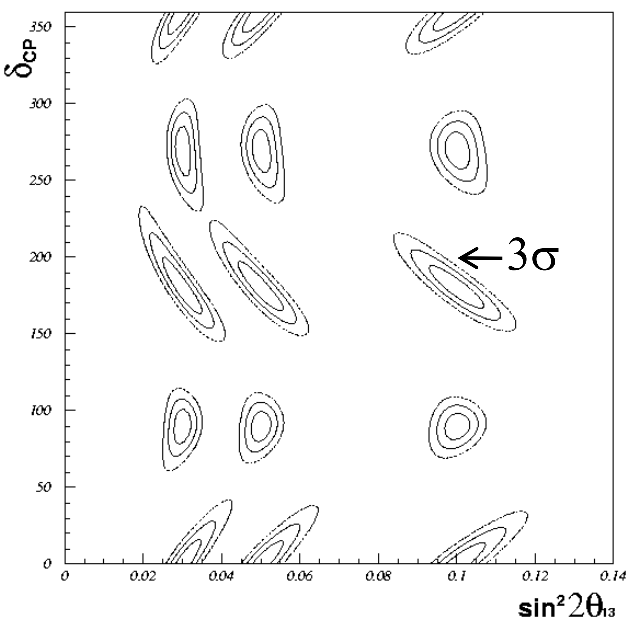
ν_e Spectrum

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



Beam ν_e Background

CP Measurement Potential



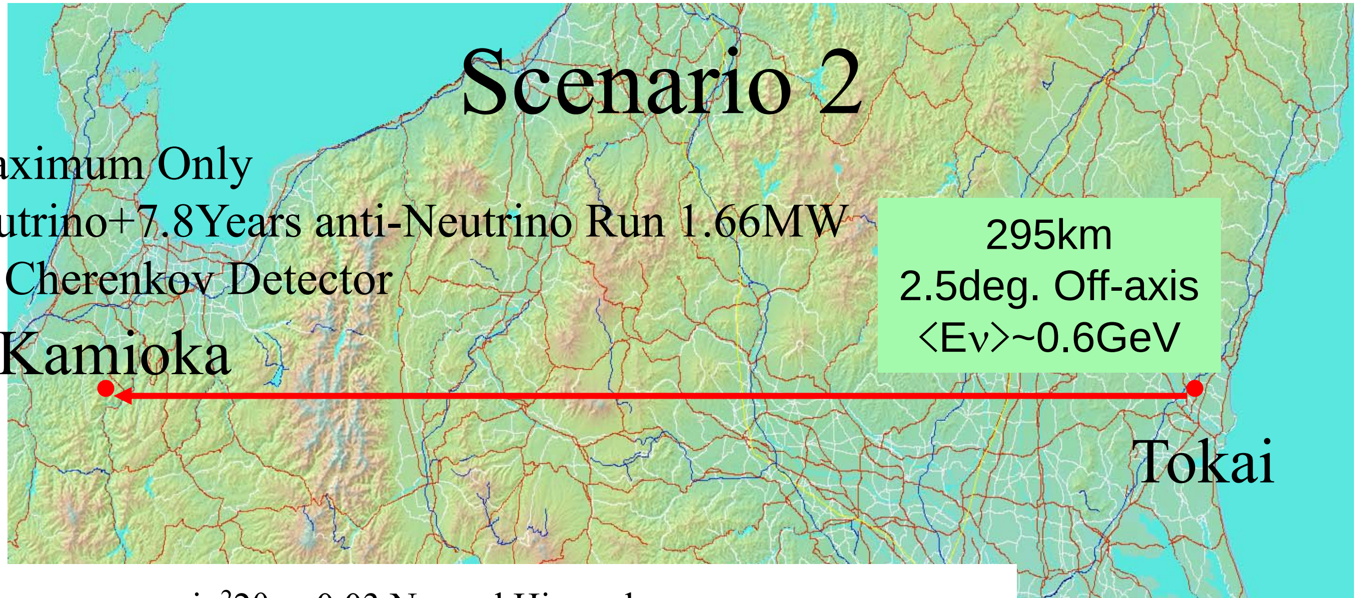
Okinoshima

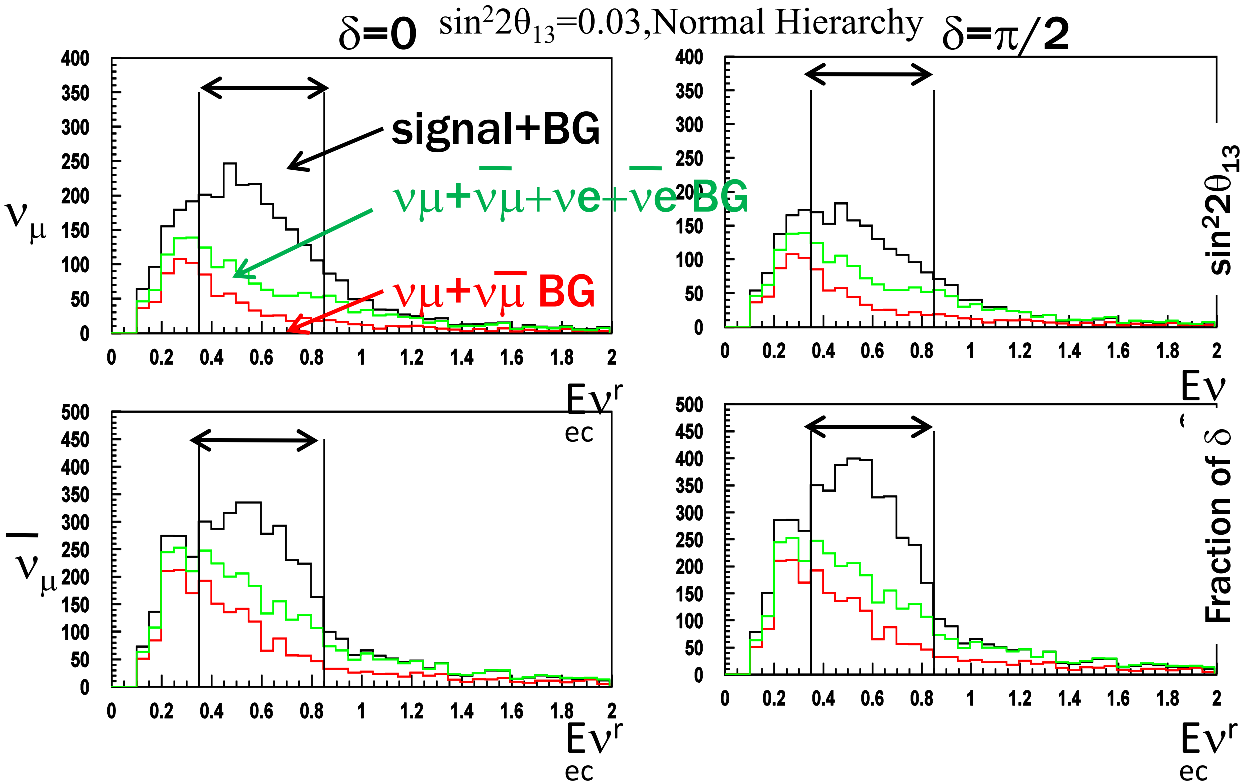
658km
0.8deg. Off-axis

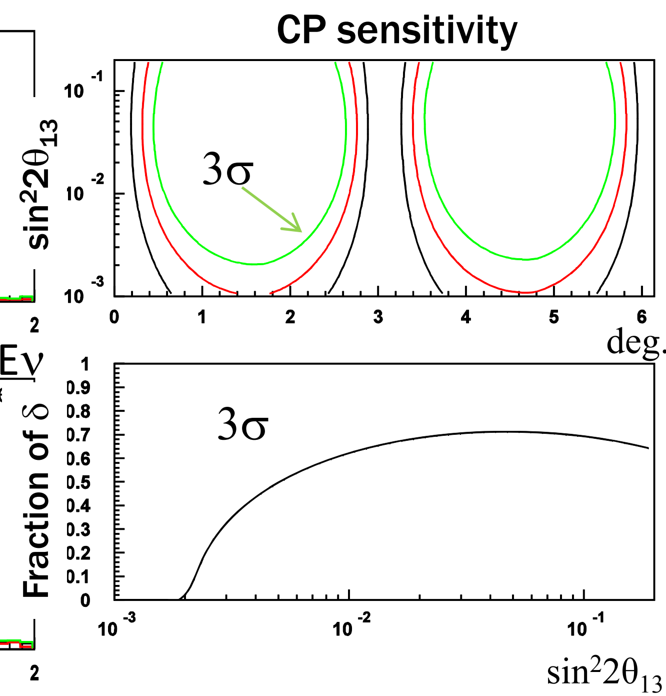
NP08, arXiv:0804.2111

Scenario 2

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



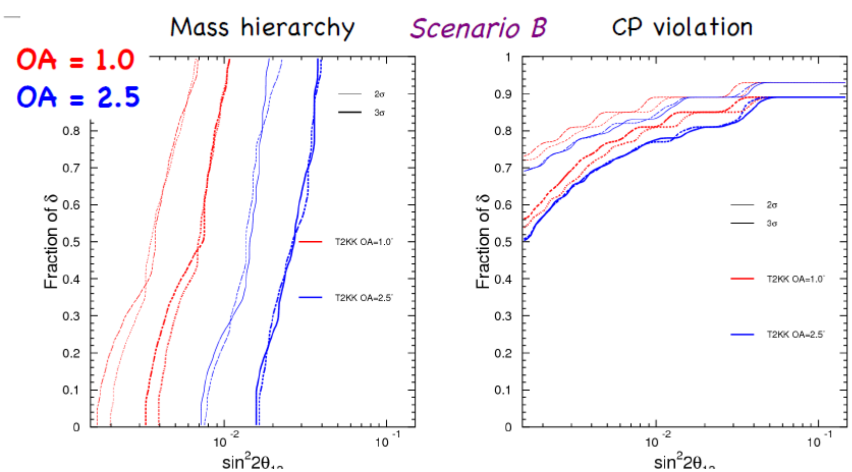


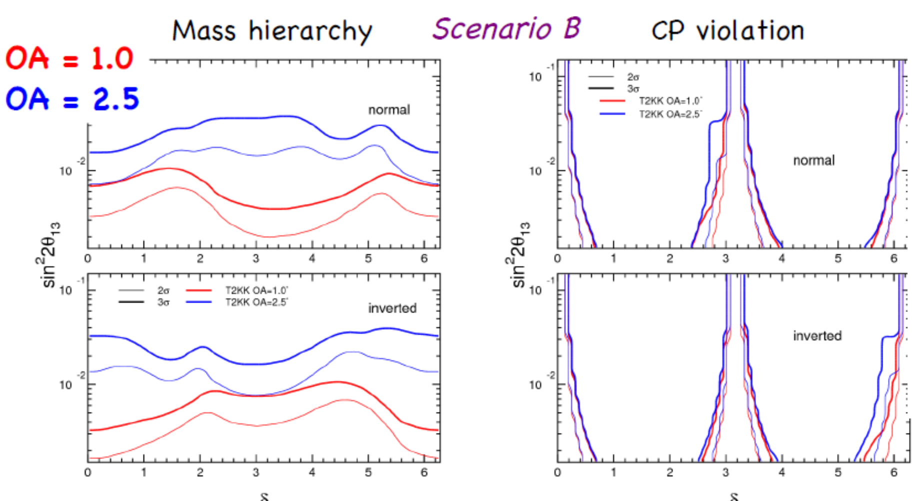


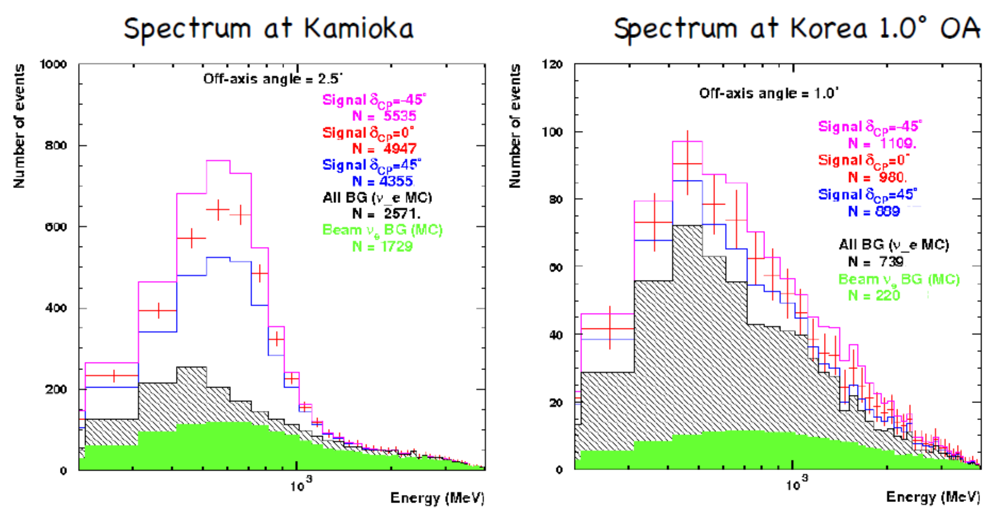
K.Kaneyuki @NP08

Scenario 3

- •Cover 2nd Maximum @ Korea
- •Cover 1st Maximum @ Kamioka
- •5Years ν+5Years $\overline{\nu}$ 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_eSpectrum Shape	Ratio between $\nu_e \overline{\nu}_e$	Ratio between 1st 2ndMax Ratio between $\nu_e \overline{\nu}_e$
Beam	5Years $\nu_{\mu,}$ then Decide Next	2.2 Years $\nu_{\mu,}$ 7.8 Years $\overline{\nu}_{\mu,}$	5 Years $\nu_{\mu,}$ 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

Additional Requirement for Far Detector Optimization

- Proton Decay Discovery Performance

- Realization of the Huge Detector
  - Test of the key components
  - Prove the detector performance experimentally
    - if necessary, good prototyping
      (to be able to predict Huge Detector Performance)

    - Test with the particles is important

*KEK started R&D for Huge Liq. Ar TPC with ETH Zürich

R&D

towards

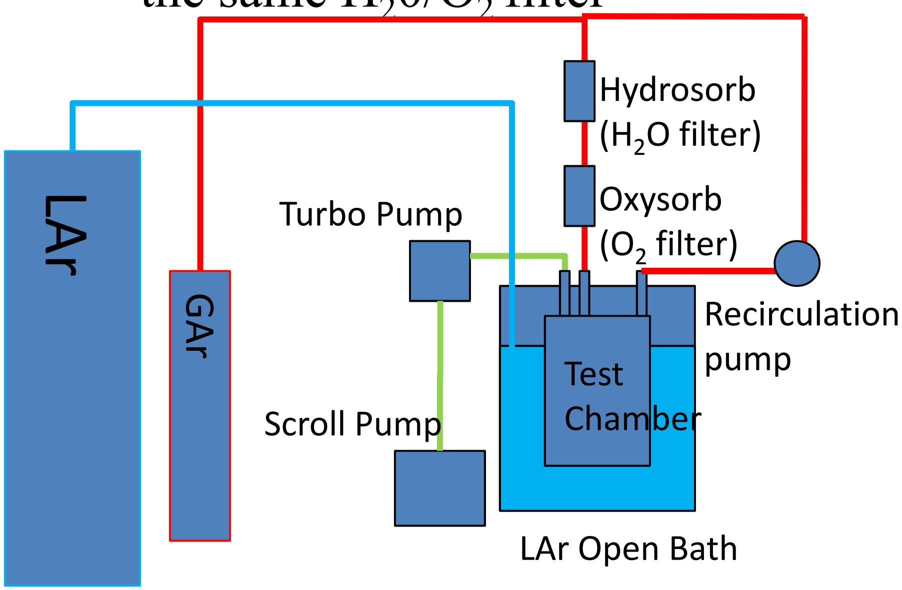
Giant Liquid Argon Observatory

for

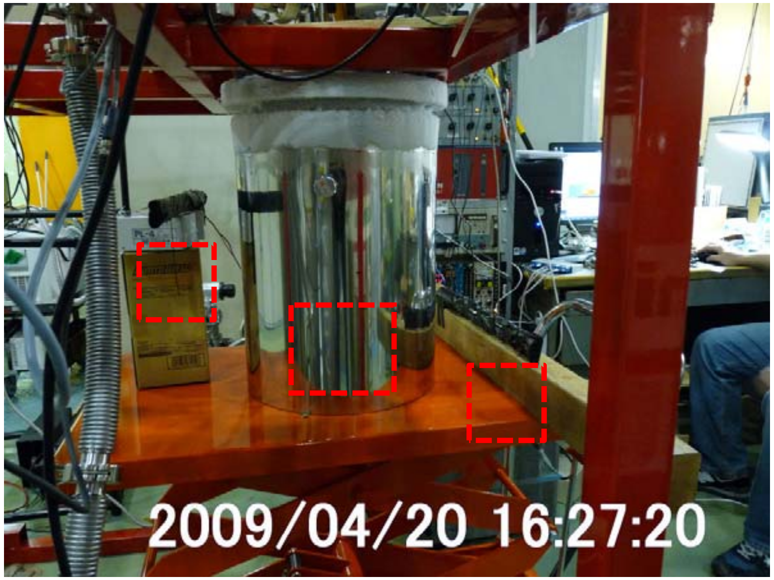
Nucleon Decay, Neutrino Astrophysics and CP-violation in the Lepton Sector

First Step: 10L detector

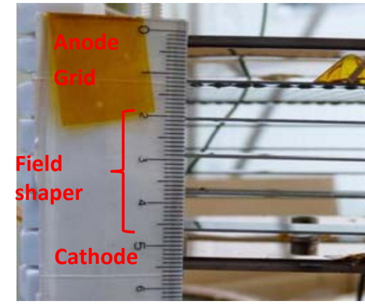
- Refer to the system invented by Prof. Carlo Rubbia in 1985
- Main Features
  - Oxysorb (O_2 filter) + Hydrosorb (H_2O filter)
  - Gas purification and liquefaction at initial filling
  - Initial filling and recirculation share the same H_20/O_2 filter

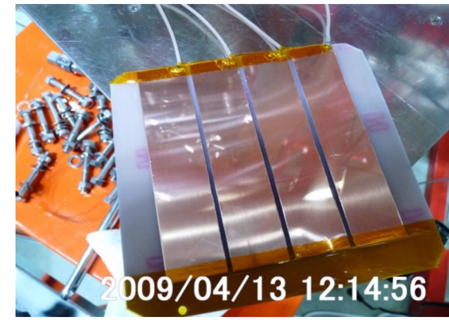


1st Liq. Ar TPC Signal with Cosmic Ray in Japan



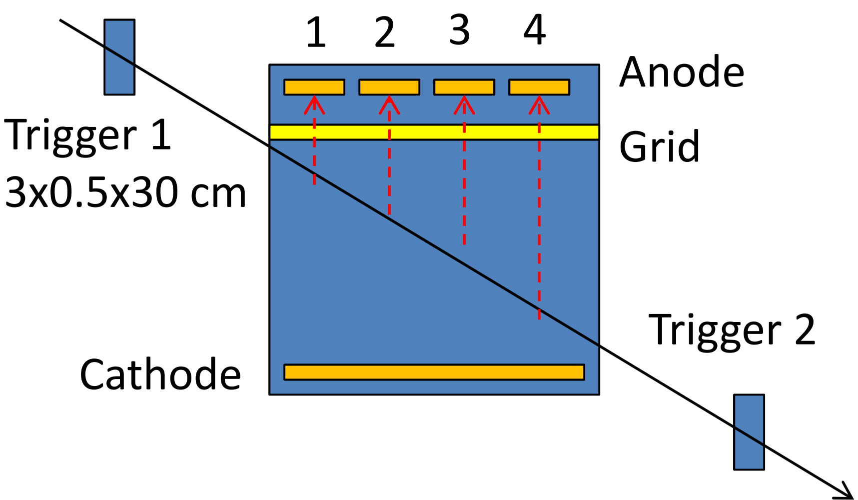
- HV setting
  - Cathode -2500 V
  - Grid -1000 V
  - Cathode-anode; 5cm
- Oscilloscope waveform
  - Ch1 is the fastest signal
  - Drift time ~20 μs

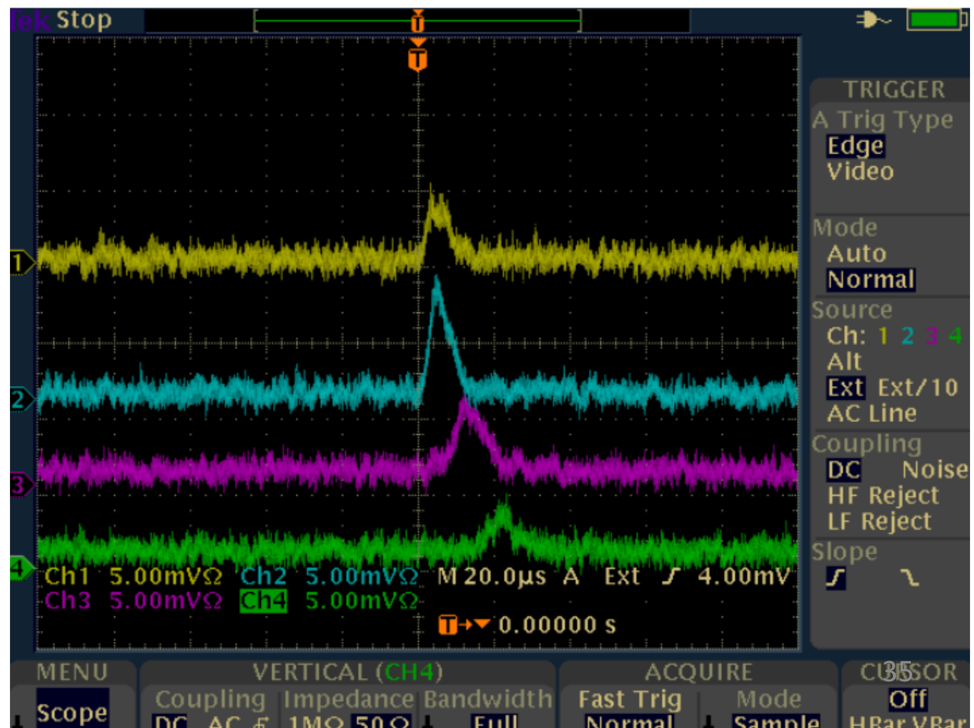




Anode: 4ch × 2.2cm × 9cm

Trigger Counter set up





Trial with double phase readout

Signal amplification at gas phase

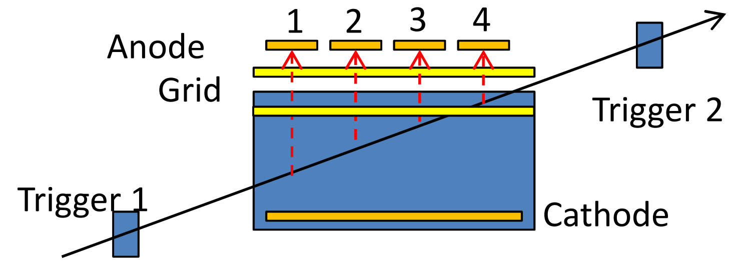
to obtain good signal/noise

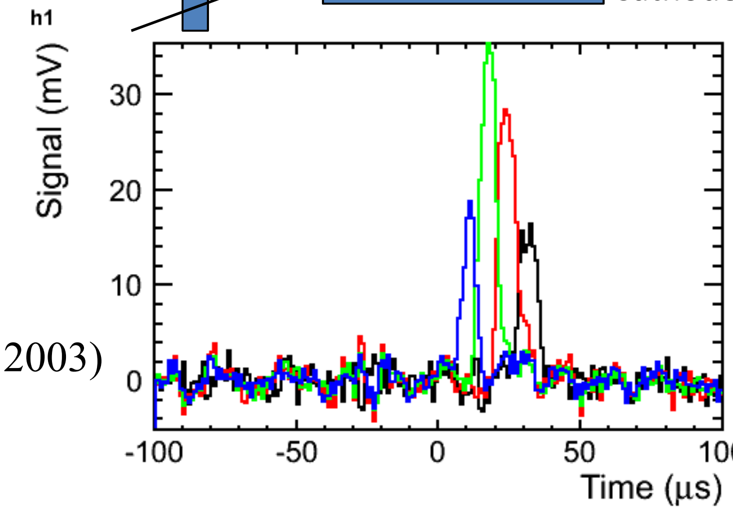
after long drift distance

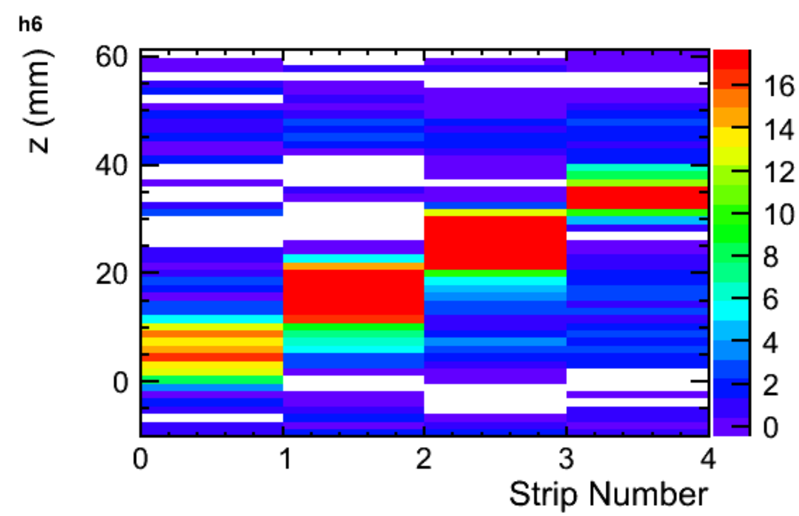
GLACIER Concept

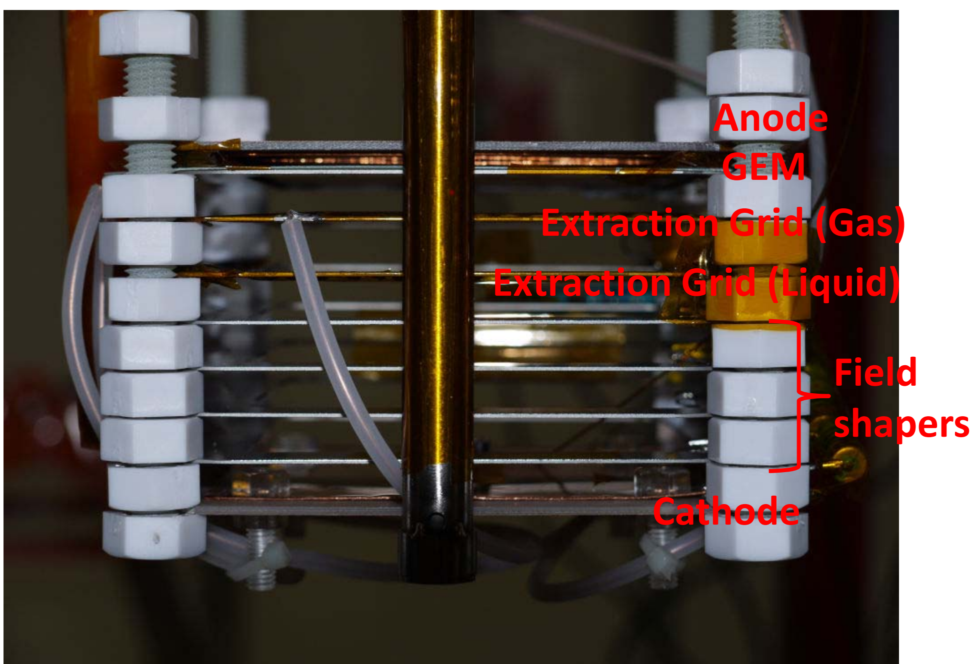
(André Rubbia, hep-ph/0402110,

Venice, NO-VE 2003)









Second Step: 0.4t detector
(ETHZ-KEK joint effort)

Test Plan

- Experience with basic functionality
  - ➢Operation of ～ton scale detector
  - ➢TPC with ～500 channel readout

- Examine particle identification/calorimetric capability
  - ➢Cosmic muon
  - ➢Charged particle/gamma test beam

- Possibly neutrino exposure at J-PARC

Accelerator Based Neutrino Project in Japan

	K2K	T2K	3rd Generation Exp. (KEK Roadmap)
High Power Proton Synchrotron	KEK PS 12GeV 0.005MW Existing	J-PARC MR 30GeV up to 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 Project in Japan

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 is aiming for the first results in 2010 with 100kw $\times$ 10^7sec integrated proton power on target to unveil below CHOOZ limit with ν_e appearance

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
- KEK Roadmap MR power improvement plan for 1.66MW
- Submit proposal

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

  and construct Huge Detector

Long Term

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