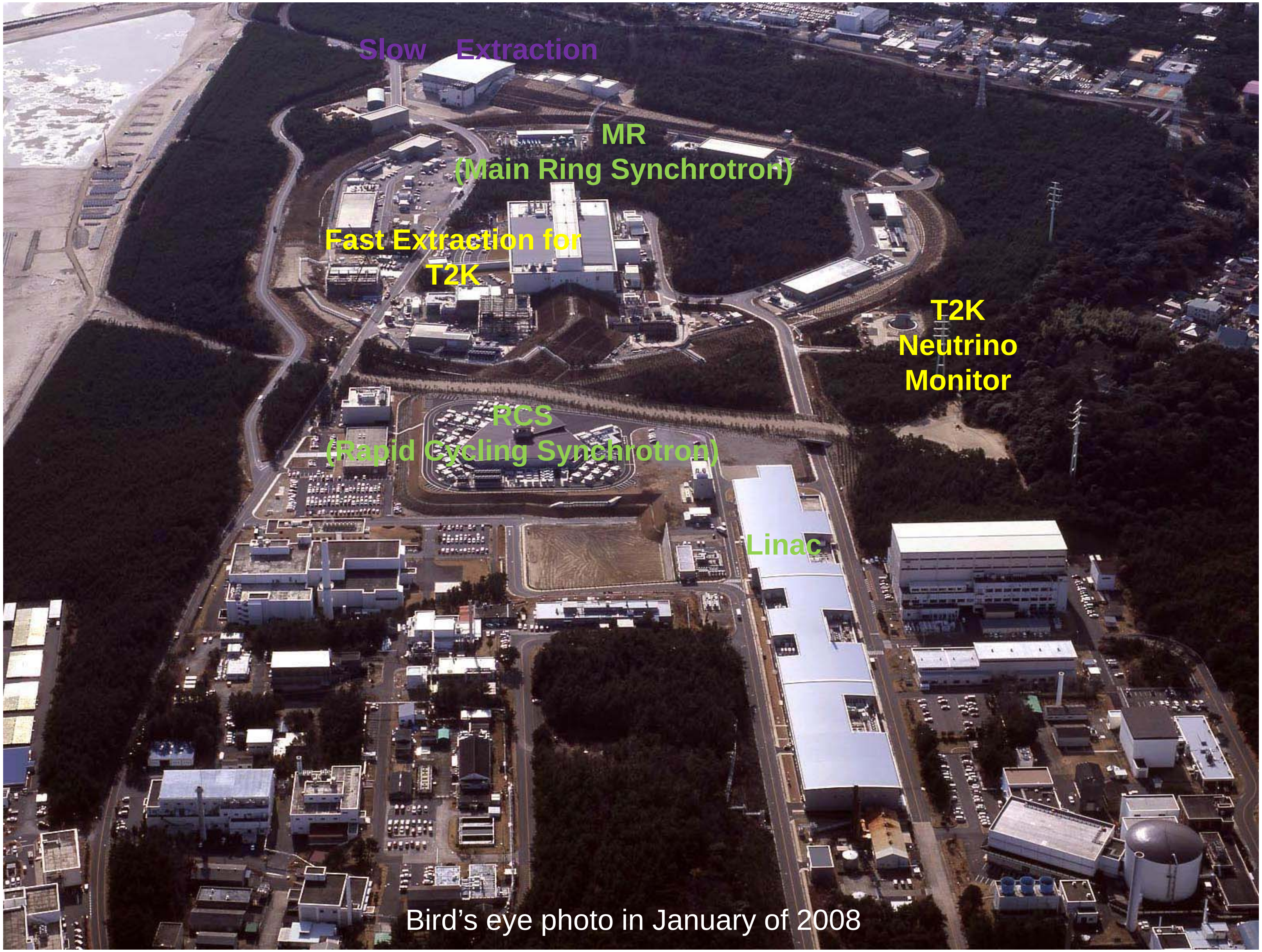
J-PARC Neutrino Beam Upgrade Plan and Far Detector Options

1. J-PARC Accelerator Commissioning Status
2. T2K as a first experiment utilizes J-PARC Neutrino Beam
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－

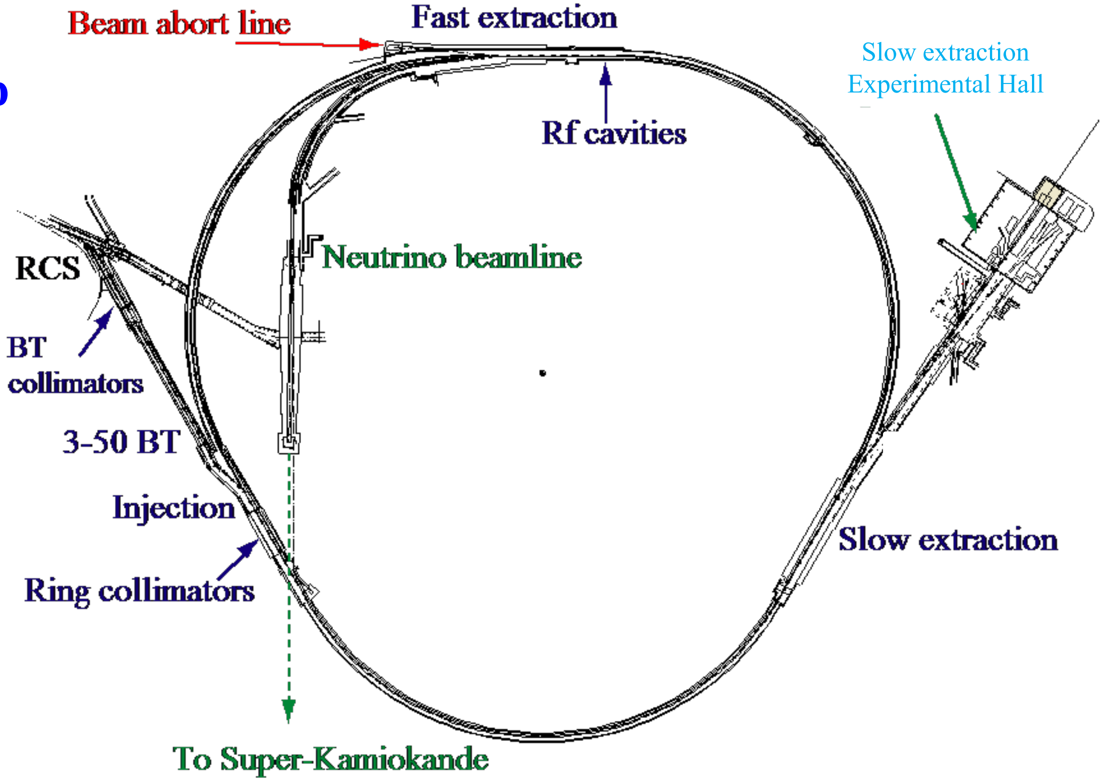
Takuya Hasegawa (KEK)

J-PARC Accelerator and Experimental Facility



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 (at any energies when hardware failure occurs)
- Slow extraction
  to Slow extraction Experimental Hall (K Rare decay, hyper nucleus..)

MR Commissioning Brief History

- 19-May:
  MR Commissioning with beam started
- 20-May:
  3GeV closed orbit is established
- 22-May:
  RF capture is established
  (RF capture, 1000 turns with controlled beam dump)
- 23-May:
  ～1 hour operation with 3.64 sec cycle time
  3GeV (RF capture), 4×10^{11} protons/bunch, single bunch
  controlled abort after 1 sec
- 24-May:
  First round commissioning finished
- 14～21-June:
  Second round beam commissioning
  various optics measurement/tuning has been done

LINAC/RCS as an Injector
Achievement Up to Now

- RCS 213kw equiv. operation for 70 seconds

  (Limited by the authorized capacity of beam dump)
  - RCS operation mode:

    1.77×10^{13} protons per pulse, 2 bunch/pulse, 25Hz
  - LINAC operation mode:

    peak current 15mA, pulse width500μsec, bunch length 420ns
- RCS 353kw equiv. operation for one pulse
  - RCS operation mode: ～35% of 1MW nominal intensity

    2.93×10^{13} protons per pulse, 2 bunch/pulse, 25Hz
  - LINAC operation mode:

    peak current 15mA, pulse width 500μsec, bunch length 700ns

*Now intense study on painting injection(to avoid severe space charge effect) is underway

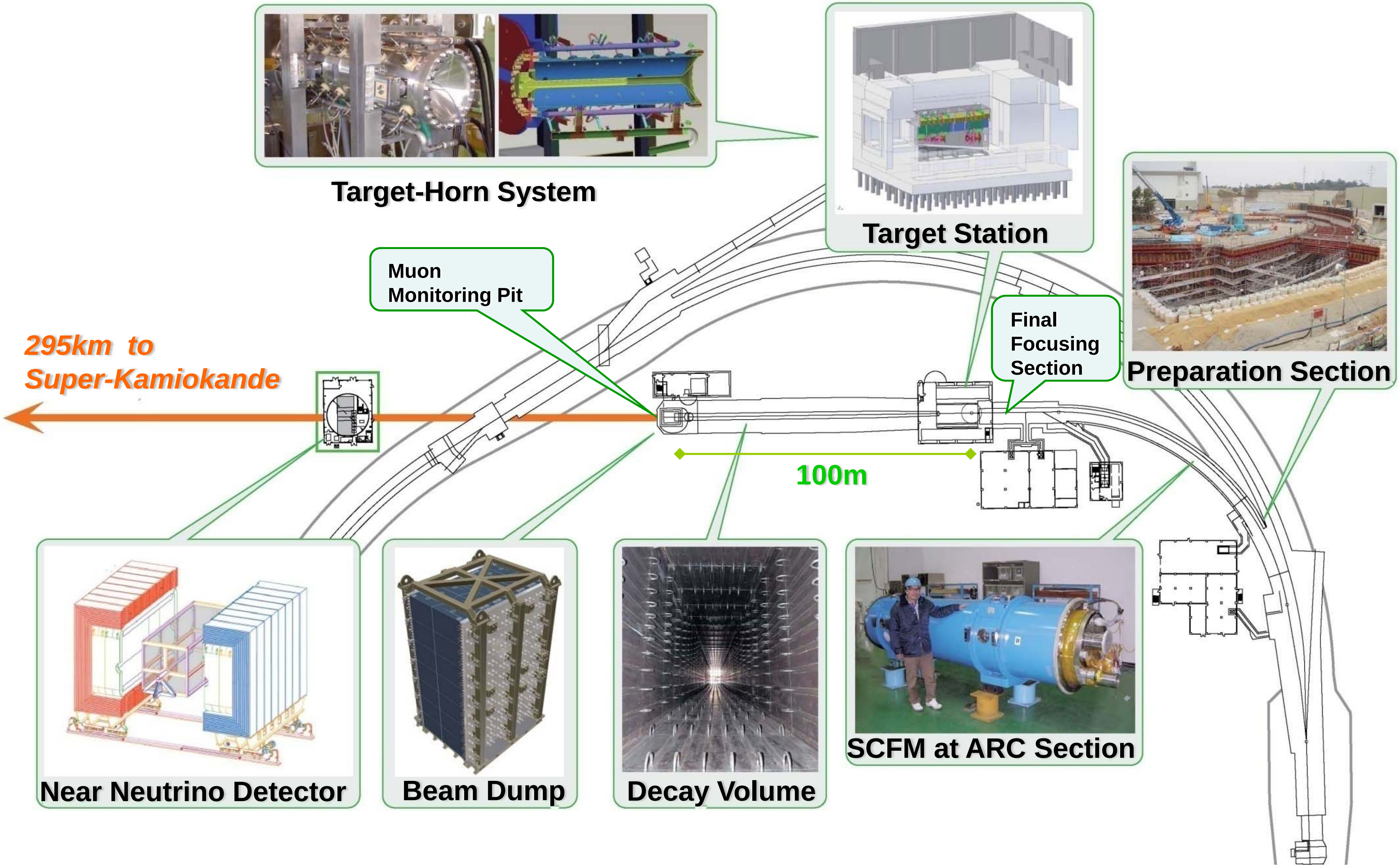
MR Schedule

Installed Kicker Magnet

- Intermission: July08-Nov08
  - Install rest of the fast extraction devices
  - Install slow extraction devices
  - Various tuning/preparation for acceleration/extraction
- Beam Commissioning: Dec08-Feb09
  - Fast extraction system (for beam dump)
  - Acceleration to 30GeV
  - Slow extraction
- Intermission: March09
  - Integrate neutrino beam facility to other radiation restricted area
  - 5^{th} RF system installation
- Beam Commissioning: Apr09-
  - Neutrino beam facility commissioning with beam (Beam Power < 7.2kw Apr-June)

*Accelerator Team is
Doing best to provide 100kw $\times 10^7$sec proton power on target by summer 2010
and
Power improvement toward ～MW after that

The J-PARC Neutrino Beamline



Concept of J-PARC Neutrino Beamline

- 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 beamline components is necessary

Status of the Neutrino Beamline

- Construction is on schedule
  - Primary beamline will be completed by Nov.
  - Commissioning w/o beam from Dec.-
  - Secondary beamline will be completed by Feb.
  - INGRID (Neutrino Direction Monitor) will be installed in Feb.-Mar.

- Commissioning with Beam from April 1, 2009

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

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

Primary Motivation of T2K

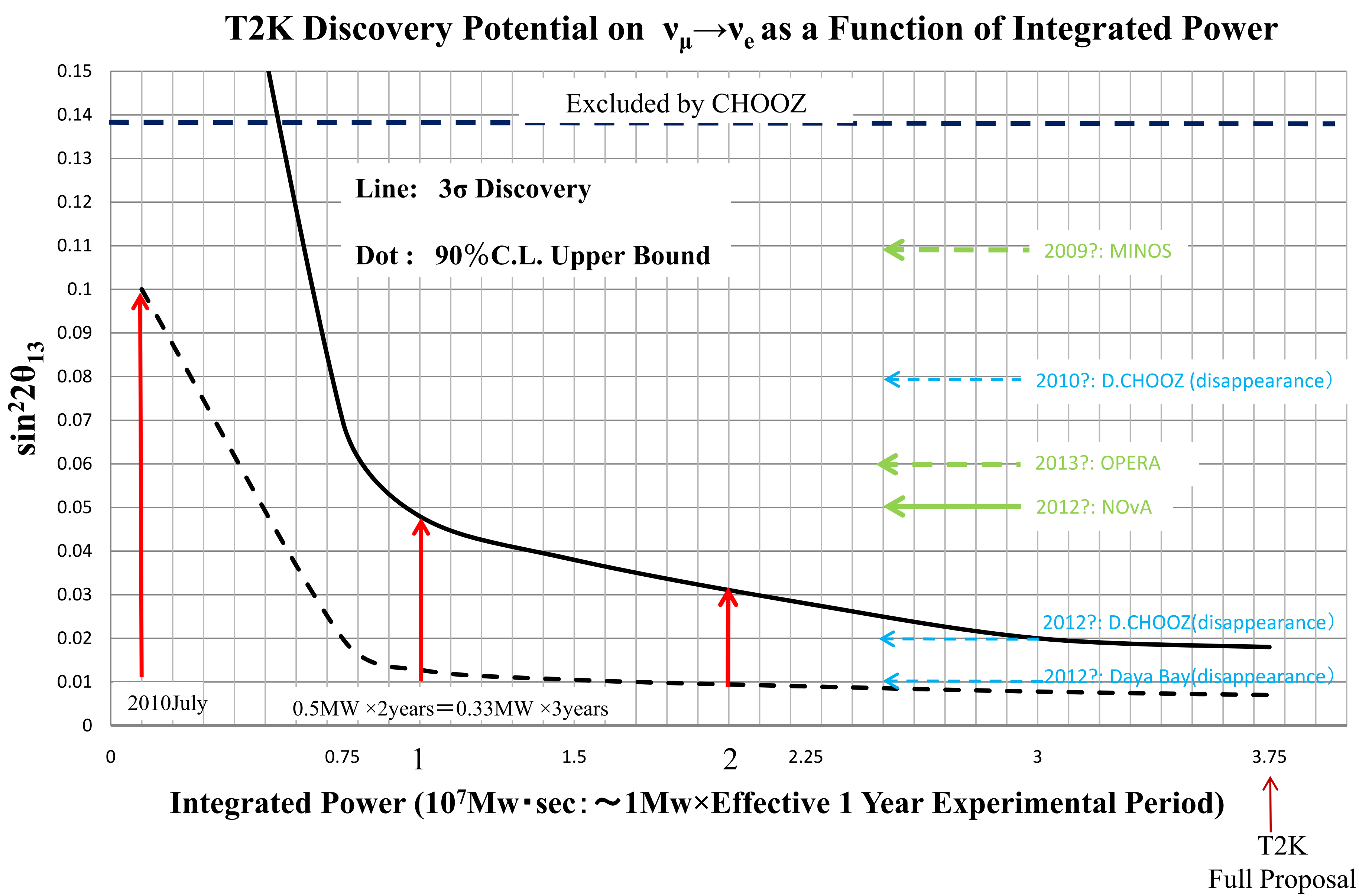
Discover $\nu_\mu \rightarrow \nu_e$ conversion phenomenon prior to any other experiment in the world

Conclude Lepton Flavor Mixing Structure

T2K Proposal Accepted by J-PARC PAC

“We request total integrated beam power larger than 0.75MW × 15000h at any proton energies between 30 and 50 GeV. “

$$15000\ \mathrm{h} = 5 \times 3000\mathrm{h}$$
$$\fallingdotseq 5 \times 10^7 \mathrm{sec}$$



T2K Discovery Potential on $\nu_\mu \rightarrow \nu_e$ 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)
2010July
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 × 10^7seconds

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
  - $p \to \nu K$
  - $p \to e \pi^0$

*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

Neutrino Intensity Upgrade

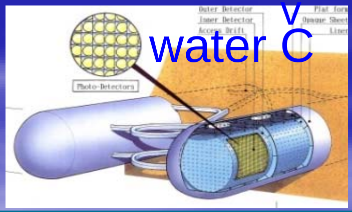
Quest for the Origin of Matter Dominated Universe

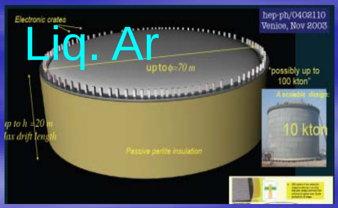
One of the Main Subject of *KEK Roadmap*

T2K (2009~) → Discover ν_e app. → Neutrino Anti-Neutrino meas. → CPV search Proton decay

Intensity Upgrade → CPV search Proton decay

Detector R&D → Tech. Choice → Huge det. Construction → CPV search Proton decay





Possible Timeline

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	4	4	4	4	4	4	4	4	4	4
Linac(400MeV)		?			? →	400MeV				
T2K										
MR Intensity Upgrade					?		?	→	1.66MW	
Detector R&D										

Presented by KEK DG at KEK Roadmap Review Committee 9,10-March 2008

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	

After 2010, plan depends on financial situation

Item to be Modified from DAY1 toward High Intensity

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

- 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)

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

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

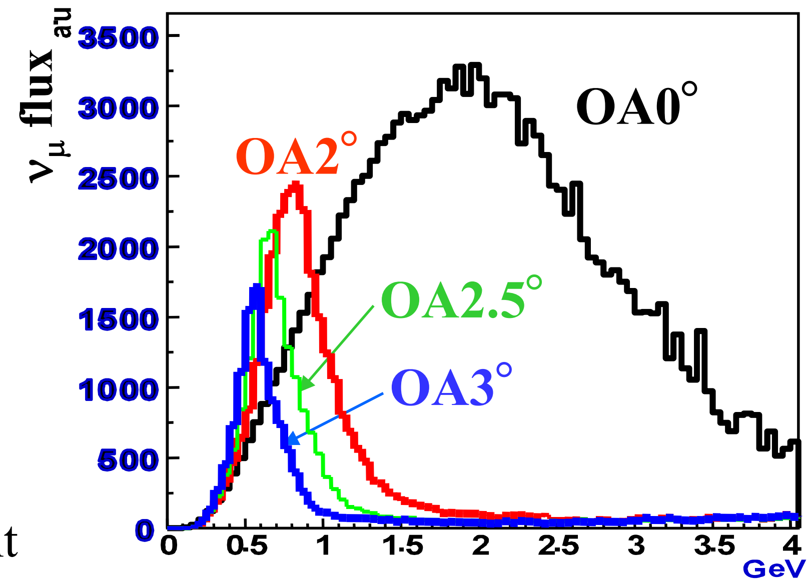
Effect of CP Phase δ appear as

- 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

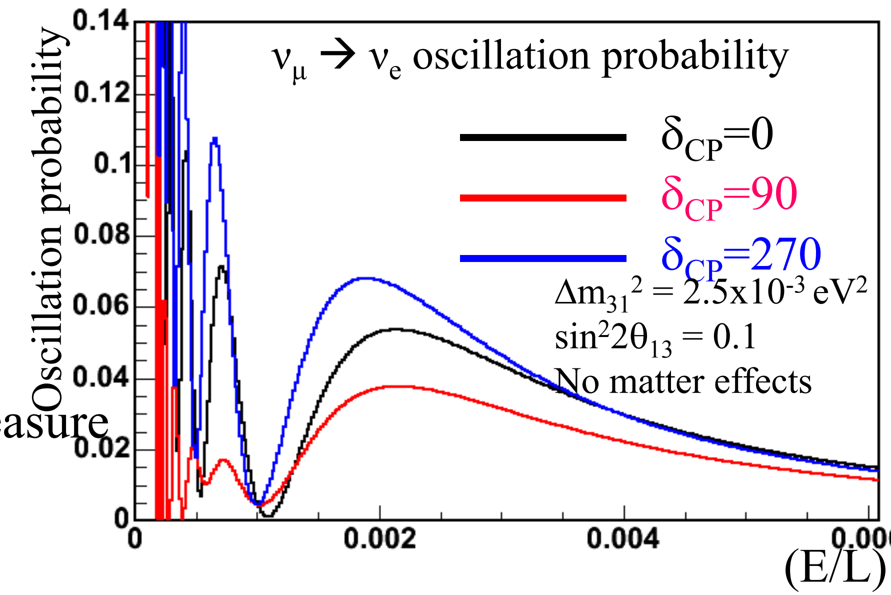
Angle and Baseline

- 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:
    - ○ 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



Three Possible Scenario Studied at NP08 Workshop

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

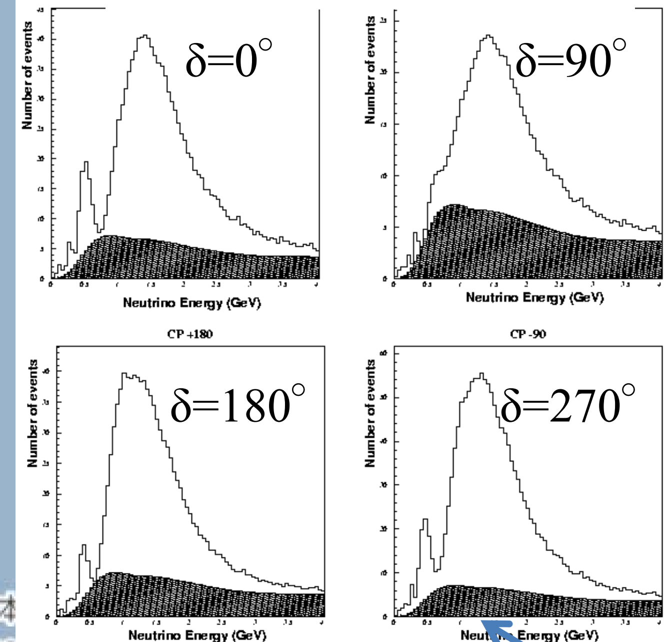
http://j-parc.jp/NP08

Scenario 1

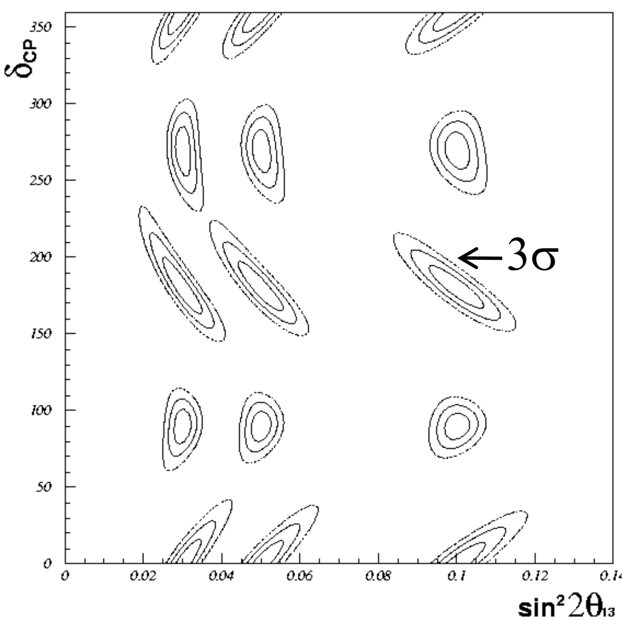
- Cover 1st and 2nd Maximum
- Neutrino Run Only 5Years×1.66MW
- 100kt Liq. Ar TPC
  - -Good Energy Resolution
  - -Good e/π^0 discrimination
- Keeping Reasonable Statistics

ν_e Spectrum

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



CP Measurement Potential



Okinoshima

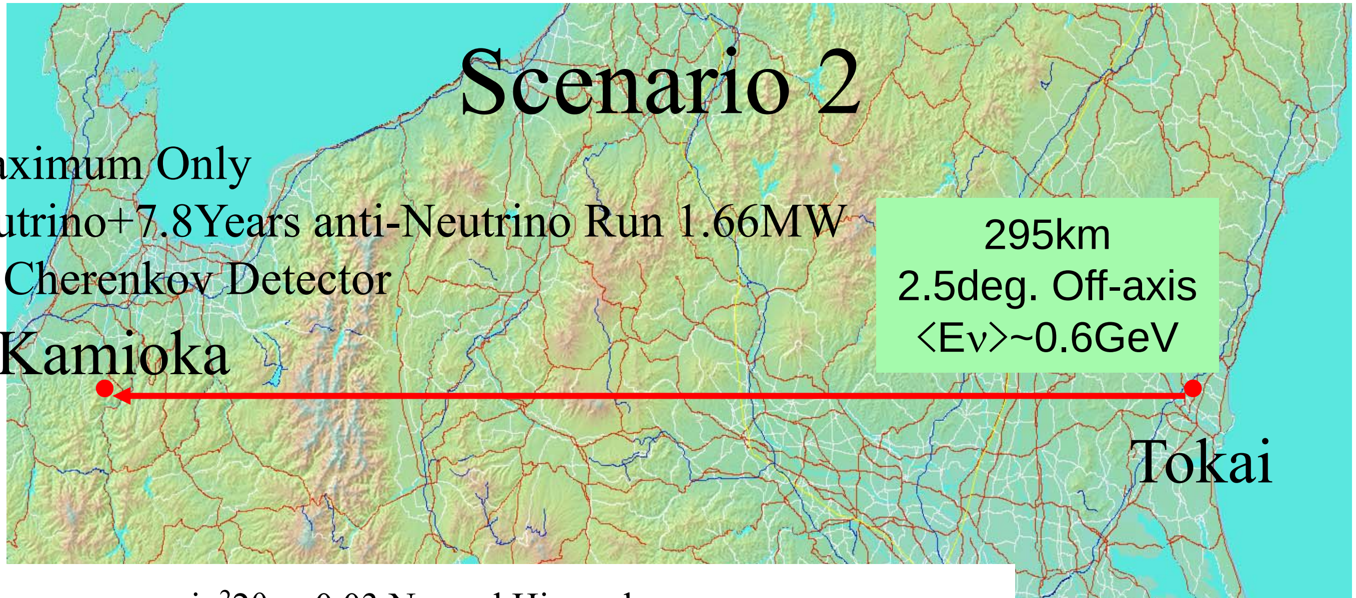
658km
0.8deg. Off-axis

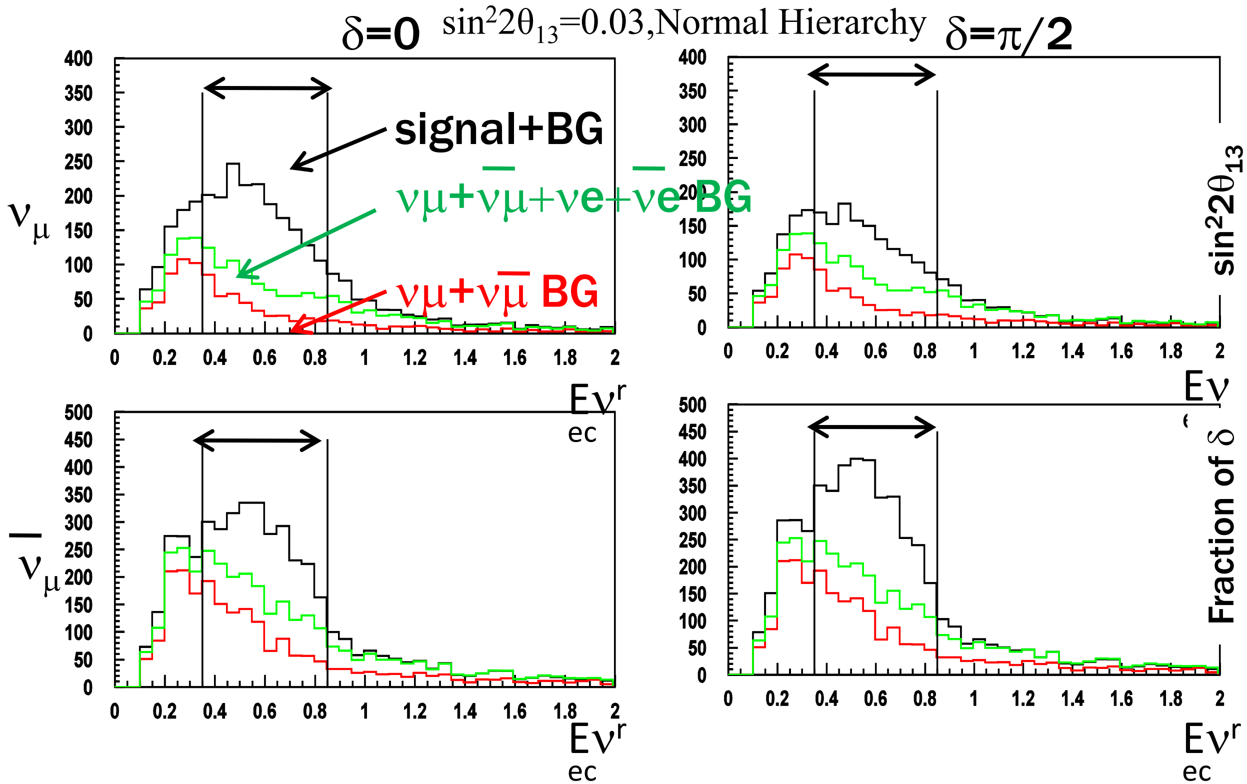
Beam ν_e Background

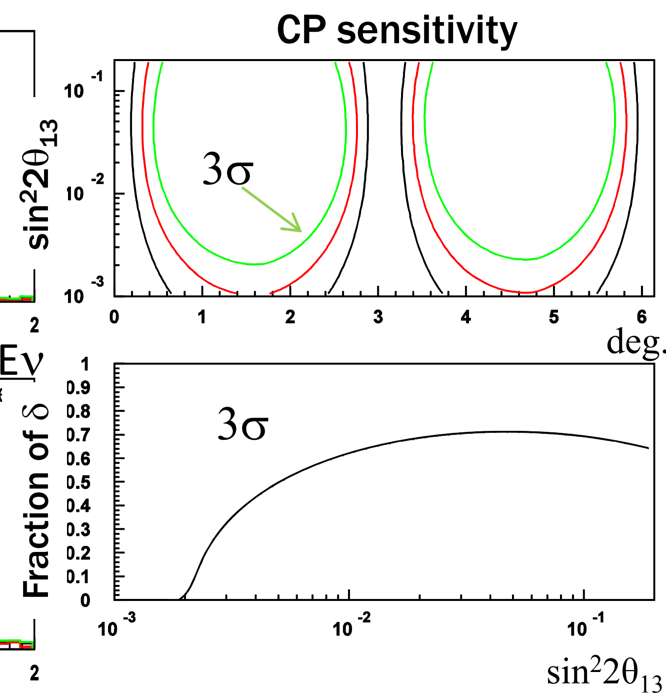
NP08, arXiv:0804.2111

Scenario 2

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



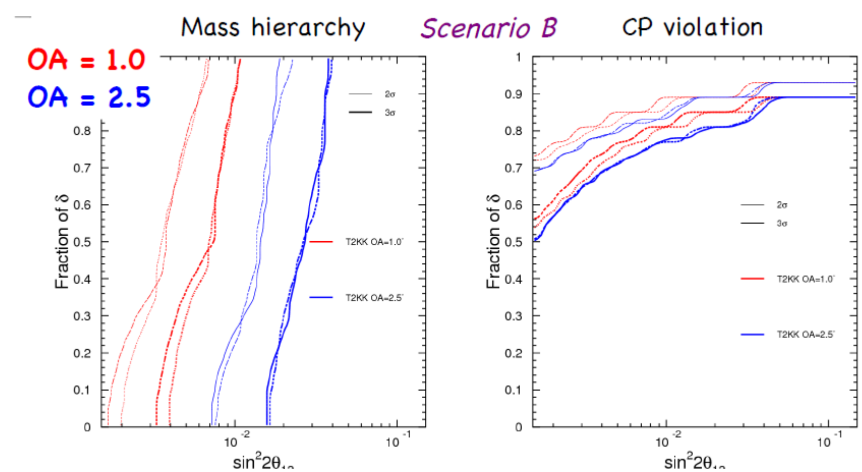


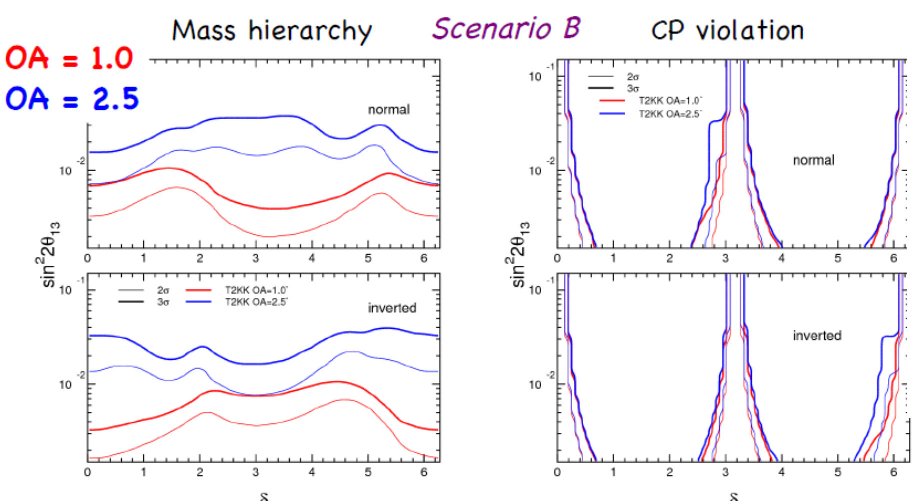


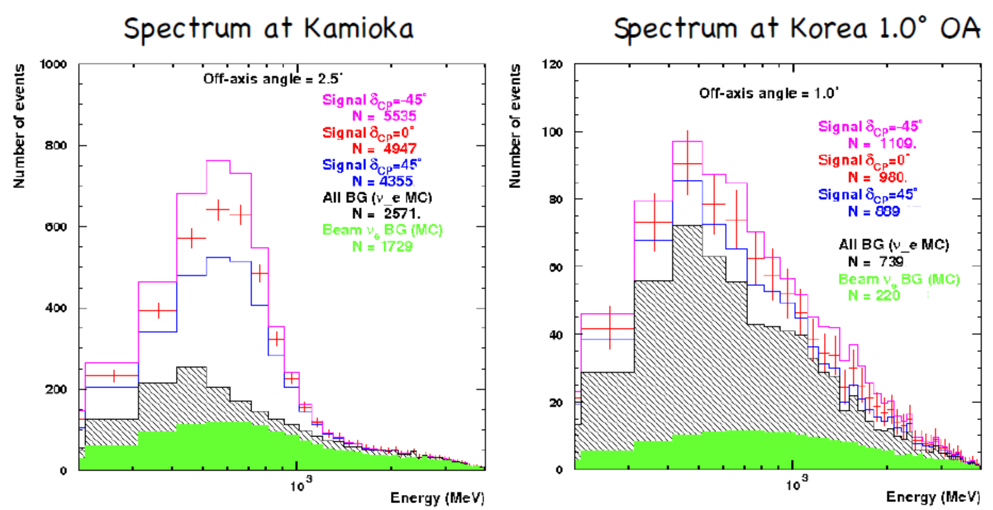
K.Kaneyuki @NP08

Scenario 3

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







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

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(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 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

Additional Requirement for Far Detector Optimization

- Proton Decay Discovery Performance

- Realization of the Huge Detector
  - Test of the key components
  - Experimentally prove the detector performance
    - if necessary, good prototyping
      (able to predict Huge Detector Performance well)
      is important
    - Test with the beam is important

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

KEK has started Huge Liq. Ar TPC R&D because

- R&D itself is interesting and fun
- Liq. Ar TPC and the Water Cherenkov are two possible choices for "J-PARC to …."
- In Japan, there is fruitful and successful experience on Water Cherenkov Detector Technology, already (Kamiokande, Super-Kamiokande and Hyper-K R&D)

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
- Construction of J-PARC Neutrino Beamline is on time

  Commissioning will start in April-2009
- T2K is aiming for the first results in 2010 with 100kw $\times 10^7$sec integrated proton power on target to unveil below CHOOZ limit with ν_e appearance

Mid Term

- T2K data with 1-2MW $\times 10^7$sec 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)