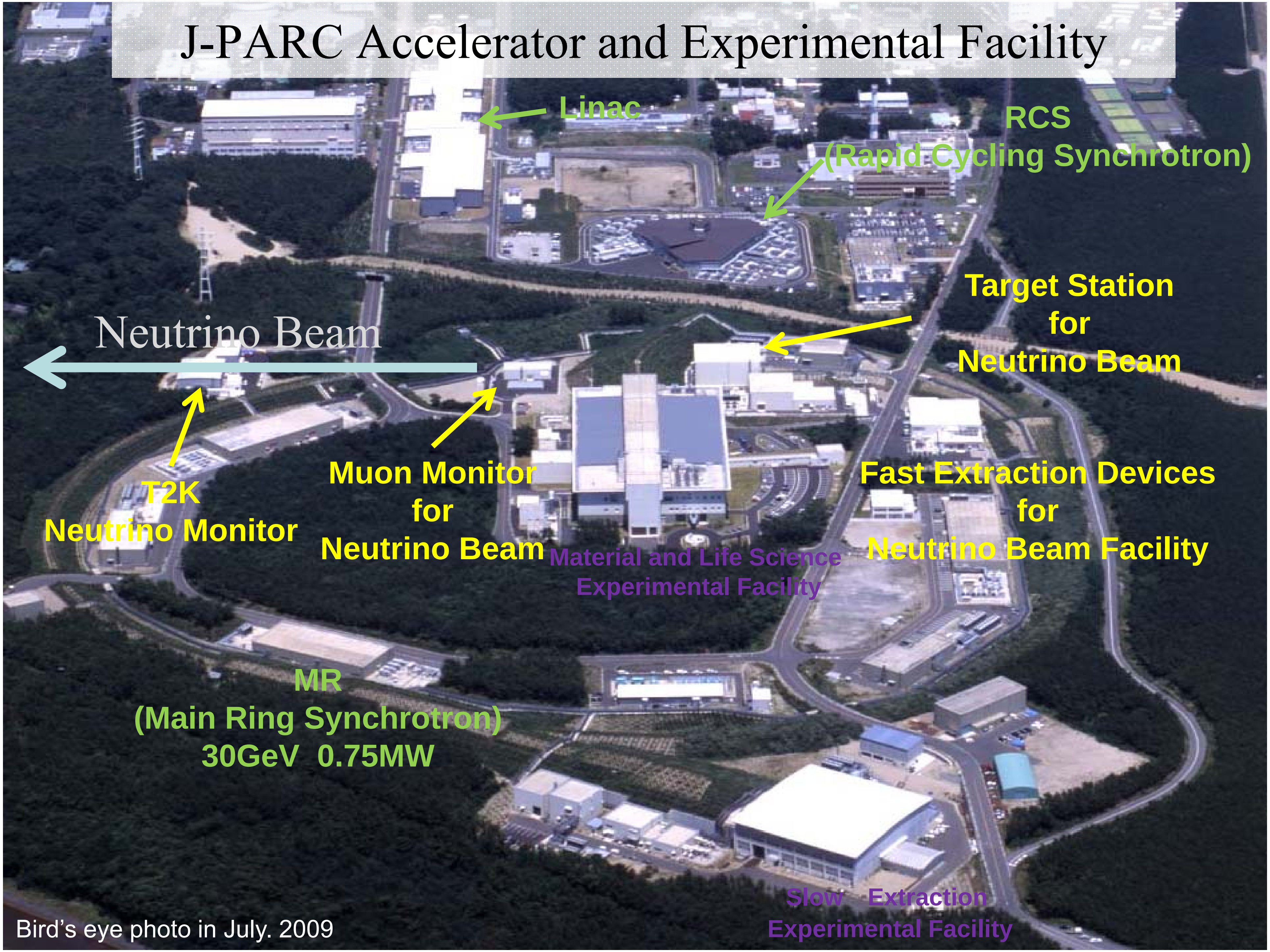
Plans for super-beams in Japan

1. J-PARC Accelerator and Neutrino Beam Facility
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－
5. What we think important for Accelerator Based Neutrino Project in Japan

Takuya Hasegawa (KEK)

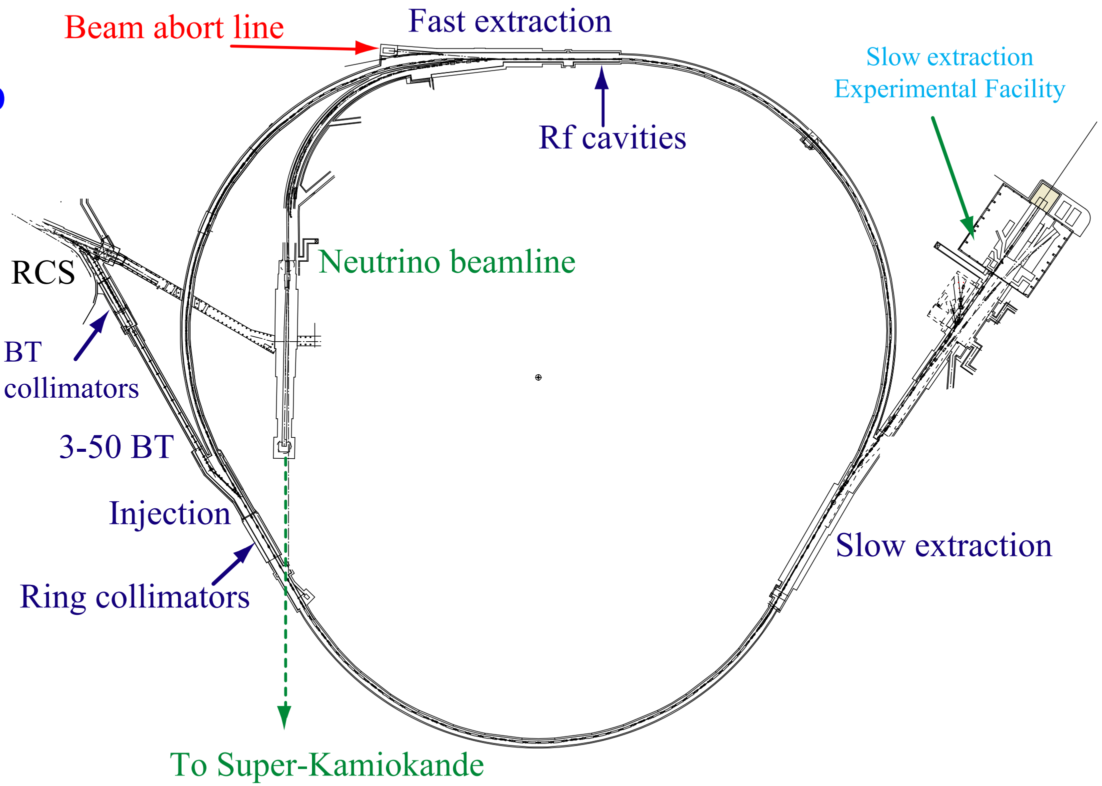
J-PARC Accelerator and Experimental Facility



Bird's eye photo in July. 2009

Overview of MR

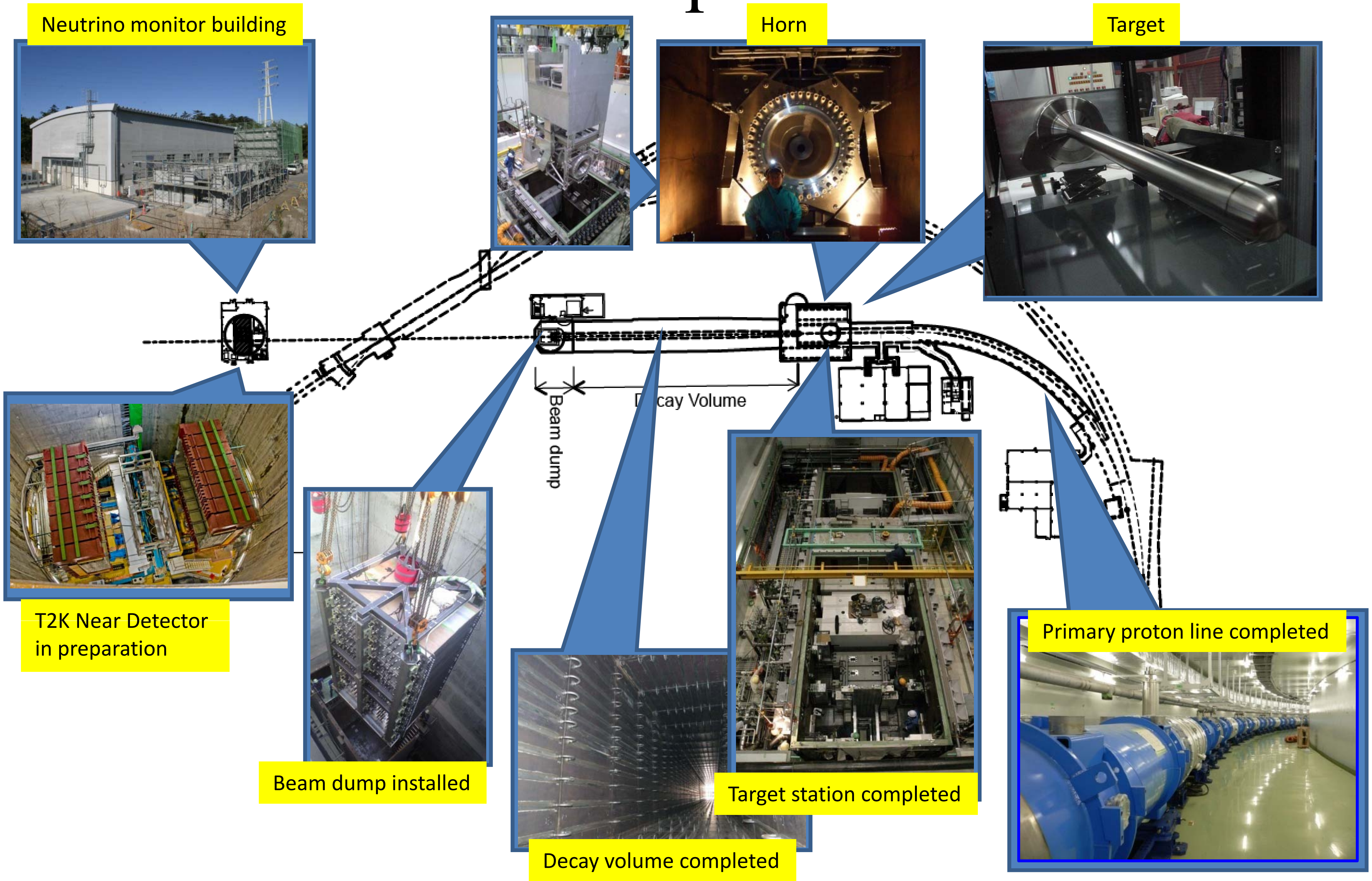
Circumference	**1567.5 m**
Repetition rate	**～0.3 Hz@Start Up**
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
Superperiodicity	**3**
h	**9**
No. of bunches	**8 (6 in day 1)**
Transition γ	**31.7(imaginary)**
Typical tune	**22.4, 20.8**
Transverse emittance	
At injection	**~54 πmm-mrad**
At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

*Designed to be 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

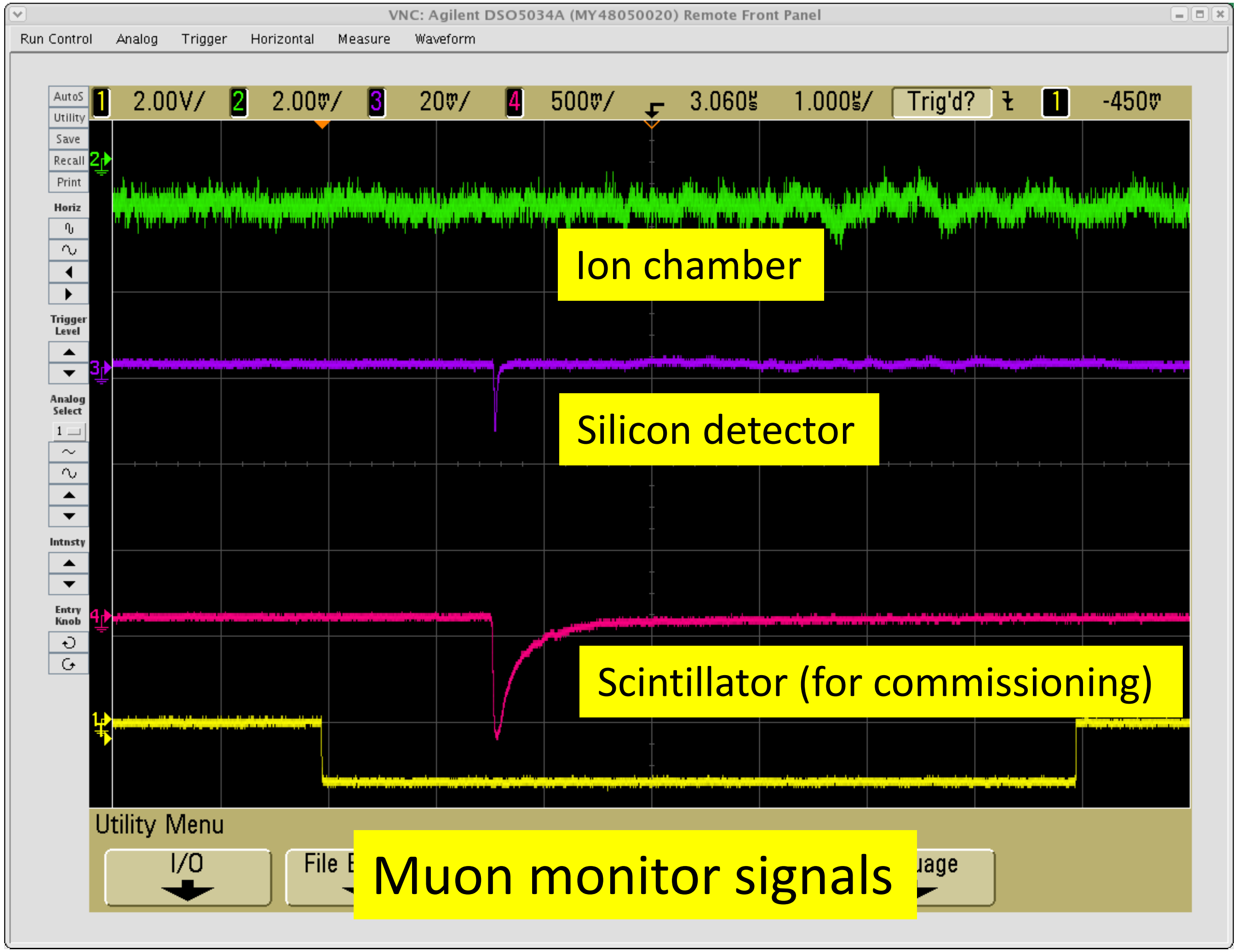
Maintenance scenario of radio active beam facility components is necessary

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

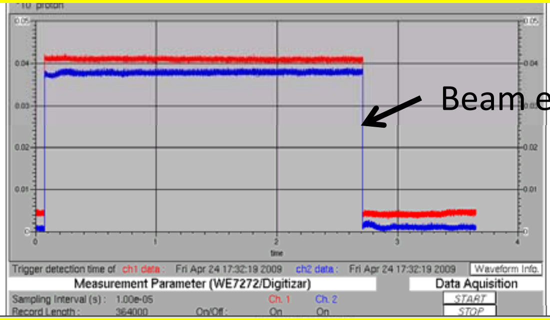


Neutrino production is confirmed by associated muon signal

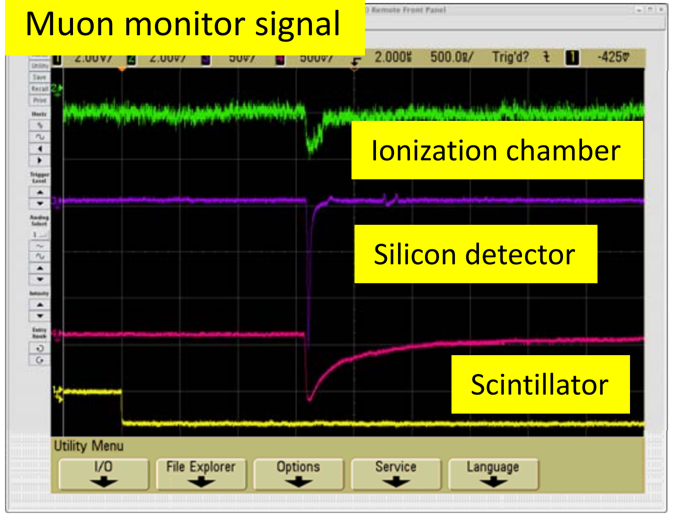
J-PARC Neutrino Beam Facility Start Operation

After 9 shots for tuning, proton beam hits target center

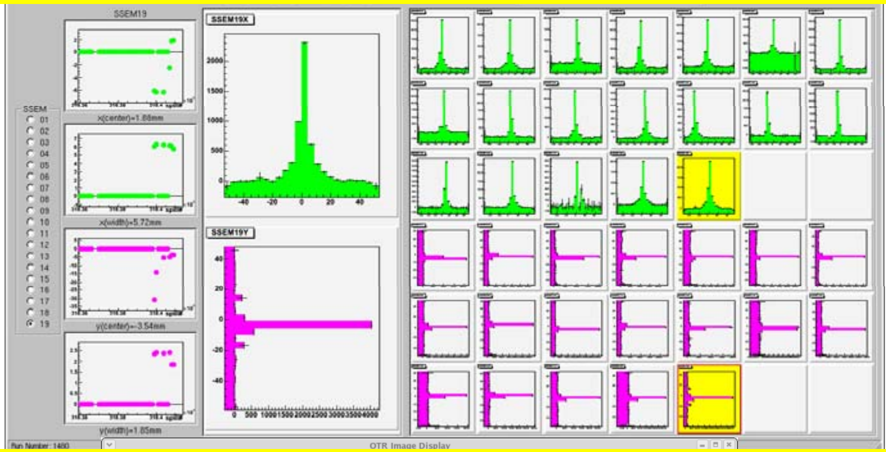
Main Ring intensity as a function of time



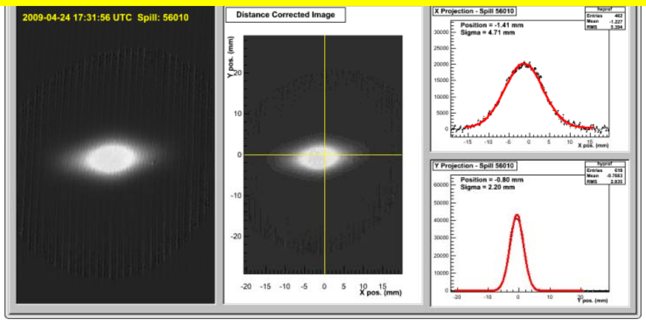
Muon monitor signal



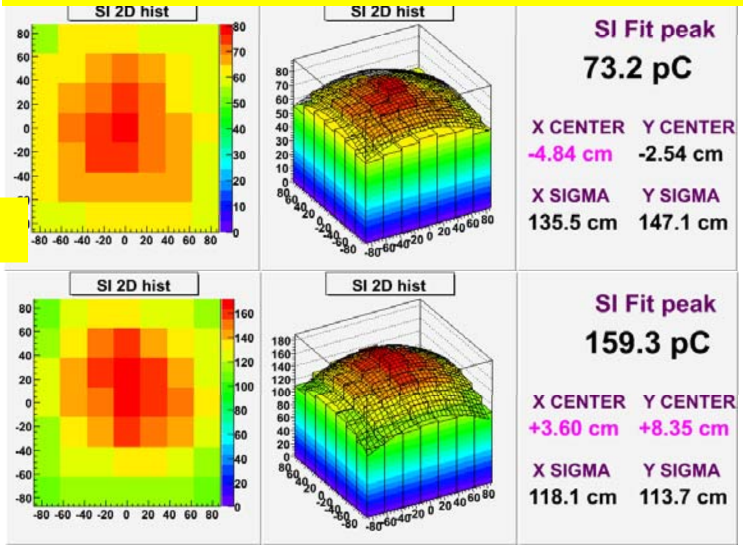
Proton beam profile/position along the primary beam line



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



Muon monitor signal with/without Horn Magnet



Horn Off

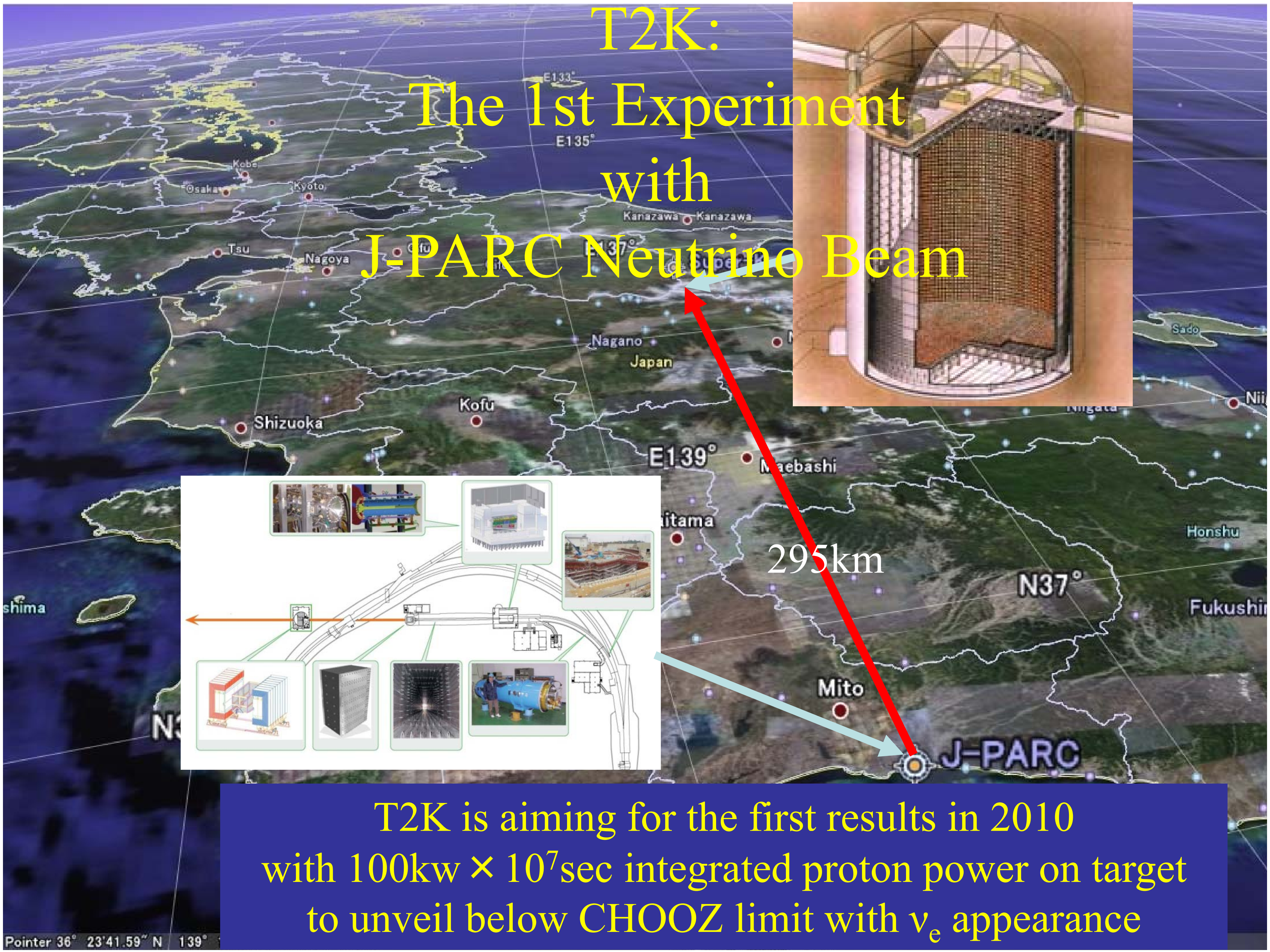
Horn On

Neutrino Facility Commissioning Achievement

* To avoid unnecessary activation of the Target Station, into which 2nd and 3rd Horn installation is foreseen, integrated proton power on target to be minimized. (single shot or at most 6sec cycle of 1.5-14.2 $\times 10^{11}$ protons/pulse)

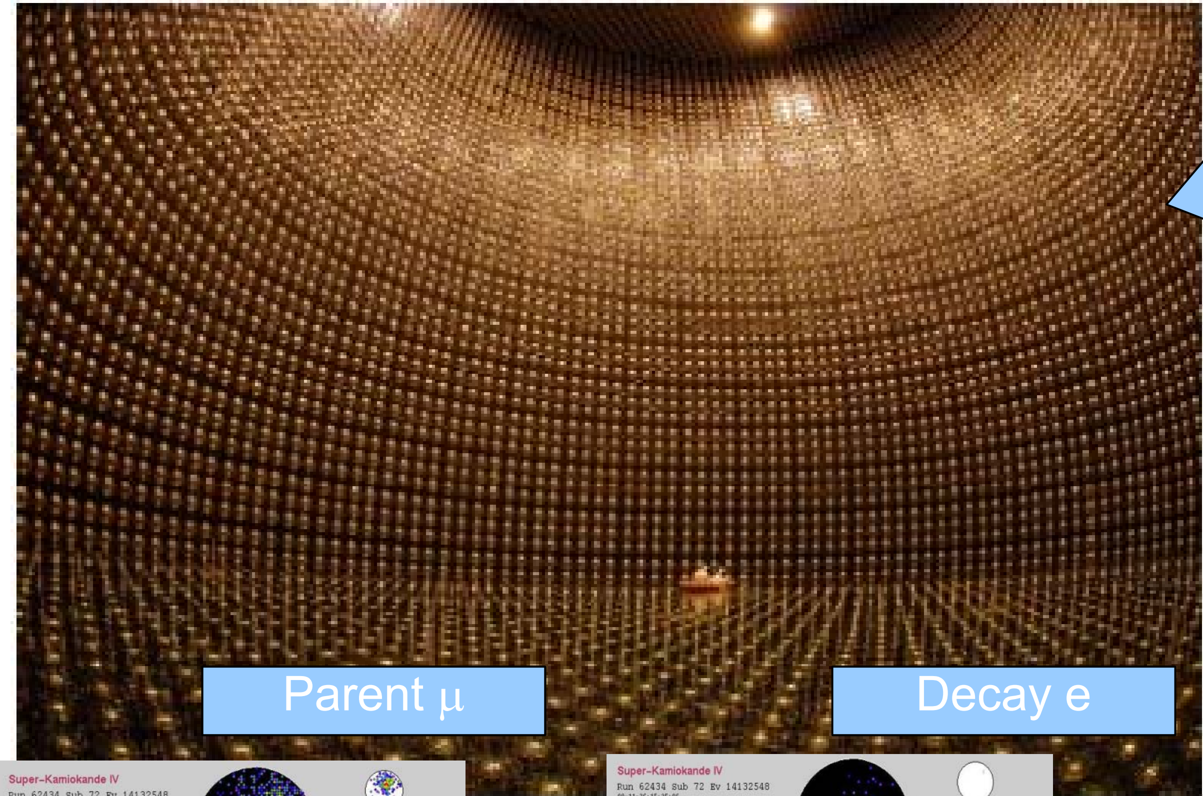
1. Stability of the extraction beam orbit from Main Ring is confirmed
   Tuned within 0.3mm(position), 0.04mrad(direction) w.r.t. design orbit
2. Functionality of the superconducting combined function magnet is confirmed.
3. Beam is lead to the target center without significant beam loss
   Tuned within 3mm level accuracy w.r.t. design orbit
4. Functionality of the beam monitors (beam position, beam profile, beam intensity, beam loss) are confirmed
5. Response function of various magnets are measured
6. Muon signal is observed which confirm neutrino production
   (Muon direction correspond to neutrino direction and muon yield correspond to neutrino yield)
7. The effect of pion focusing with horn magnet is confirmed ($\times 2$ which is consistent with present horn configuration)
8. The information transfer from Tokai to Kamioka on the absolute beam time information is confirmed
9. J-PARC neutrino facility is approved by the government on radiation safety

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

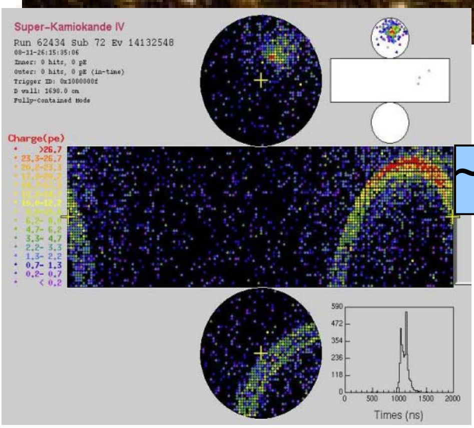


T2K is aiming for the first results in 2010
with 100kw × 10^7sec integrated proton power on target
to unveil below CHOOZ limit with ν_e appearance

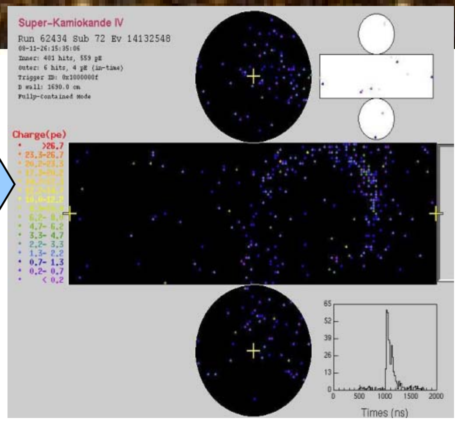
Far Main detector: Super Kamiokande



- 50kt Water Cherenkov detector
- 20”PMT x 10,000
+Anti counter x 2000



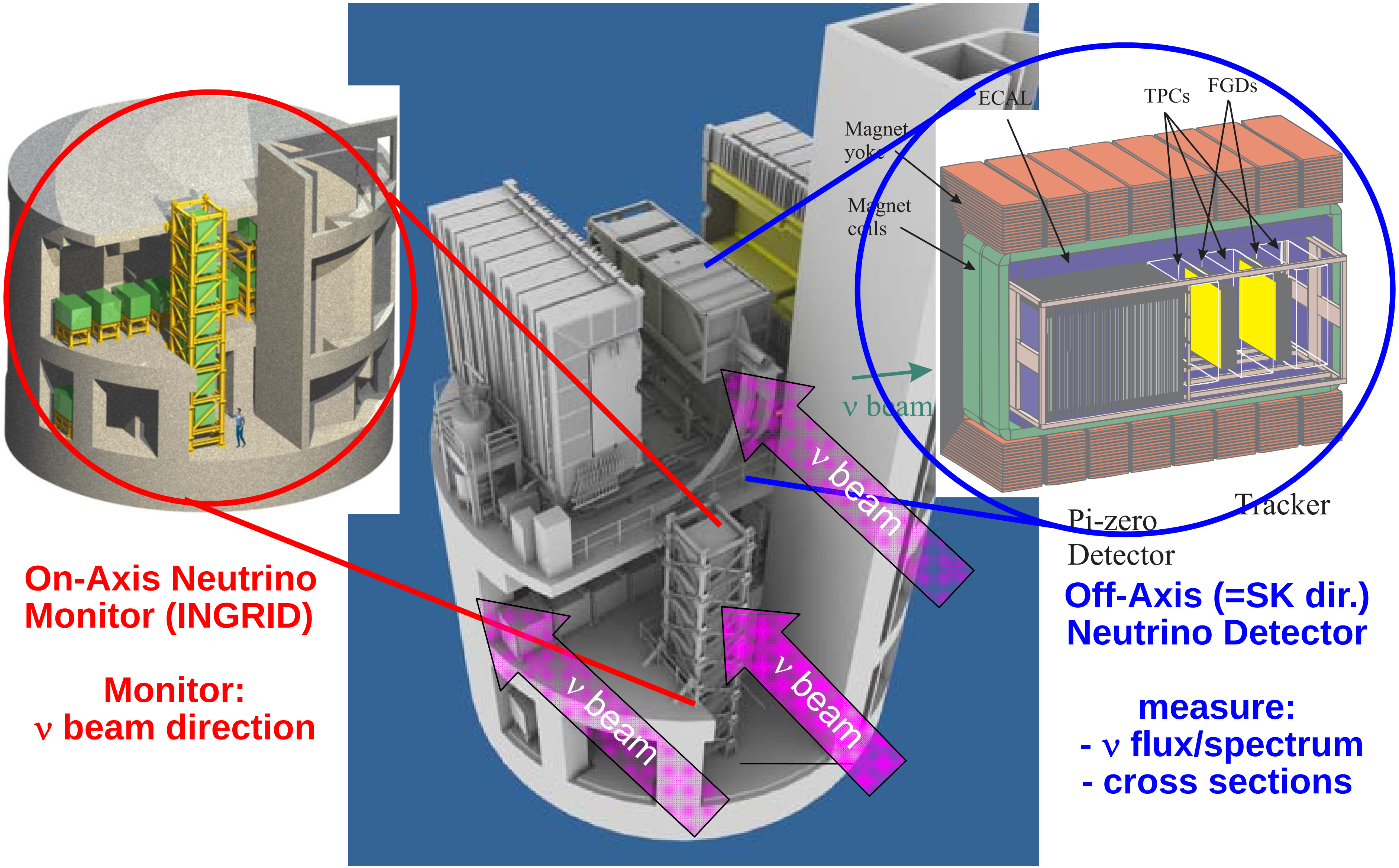
~3.4μs



New electronics installed in summer of 2008. (SK-IV)

- Stable and dead time less DAQ
  → e.g. improvement of decay-e tagging efficiency
- Ready for T2K experiment

Near Detector (ND280)



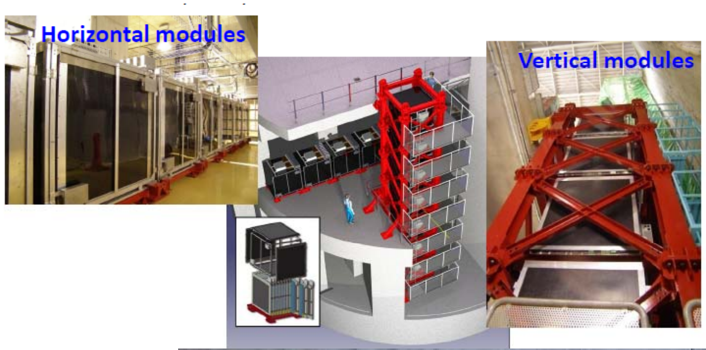
On-Axis Neutrino Monitor (INGRID)

Monitor:
ν beam direction

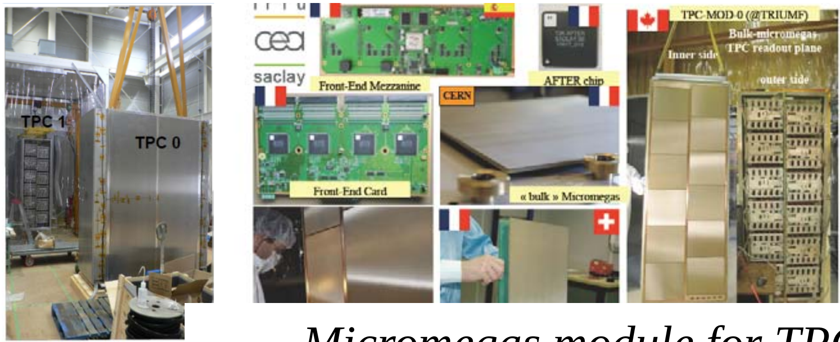
Off-Axis (=SK dir.) Neutrino Detector

measure:
- **ν flux/spectrum**
- **cross sections**

INGRID(On-axis neutrino monitor) is installed

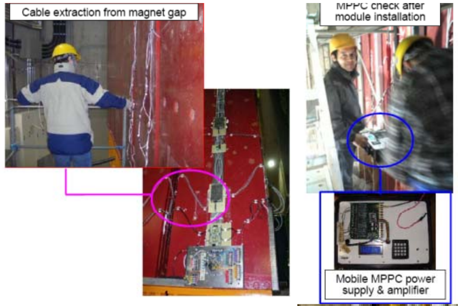


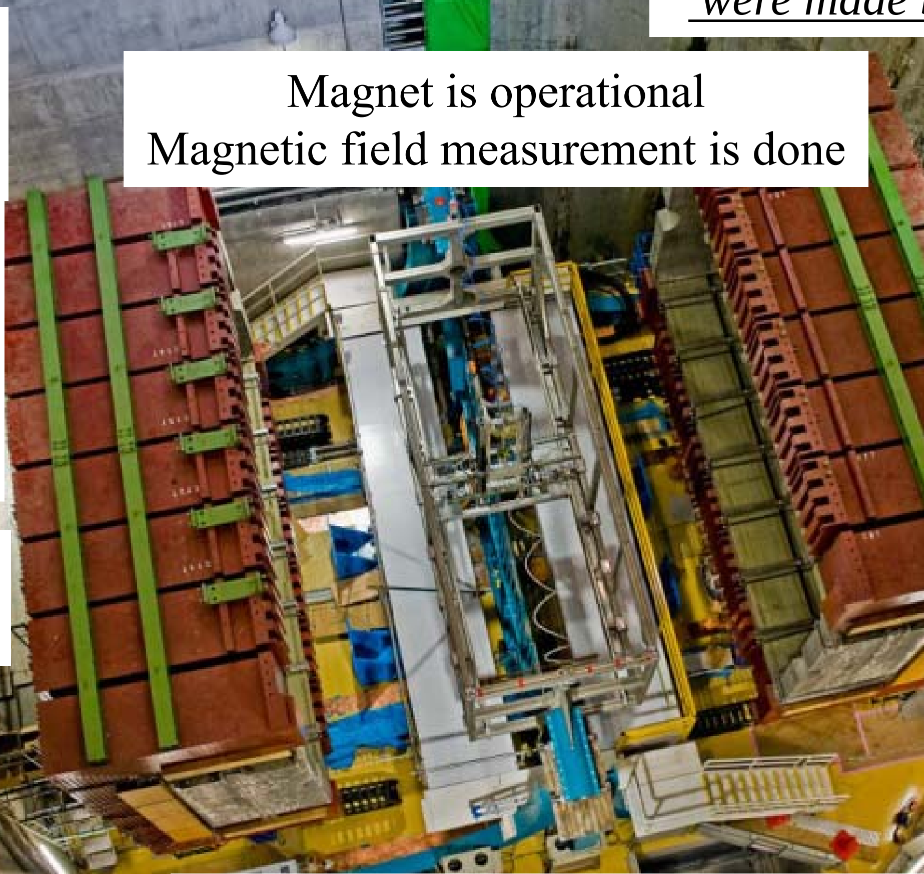
TPC(2 out of 3) is ready for installation



<u>Micromegas module for TPC were made by CERN TS/DEM group</u>

SMRD
(muon catcher in york)
is installed



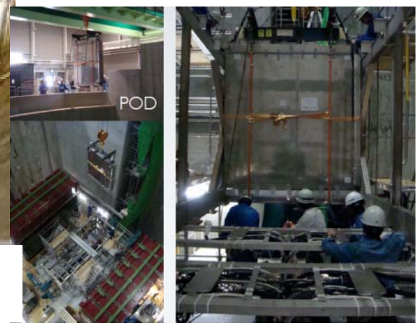


Magnet is operational
Magnetic field measurement is done

Down Stream ECAL
is ready for installation

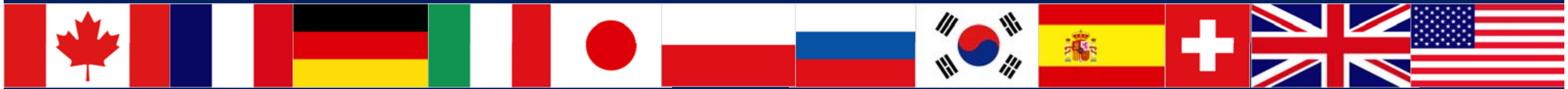
FGD(active target)
is ready for installation

P0D(pi0 detector)
is installed



<u>UA1/NOMAD Magnet is donated by CERN</u>

The T2K Collaboration



477 members, 62 Institutes, 12 countries

Canada
TRIUMF
U. Alberta
U. B. Columbia
U. Regina
U. Toronto
U. Victoria
York U.

France
CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germany
U. Aachen

Italy
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova
INFN, U. Bari

Japan
Hiroshima U.
ICRR Kamioka
ICRR RCCN
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Osaka City U.
U. Tokyo

Poland
A. Soltan, Warsaw
H.Niewodniczanski, Cracow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroklaw

Russia
INR

S. Korea
N. U. Chonnam
U. Dongshin
U. Sejong
N. U. Seoul
U. Sungkyunkwan

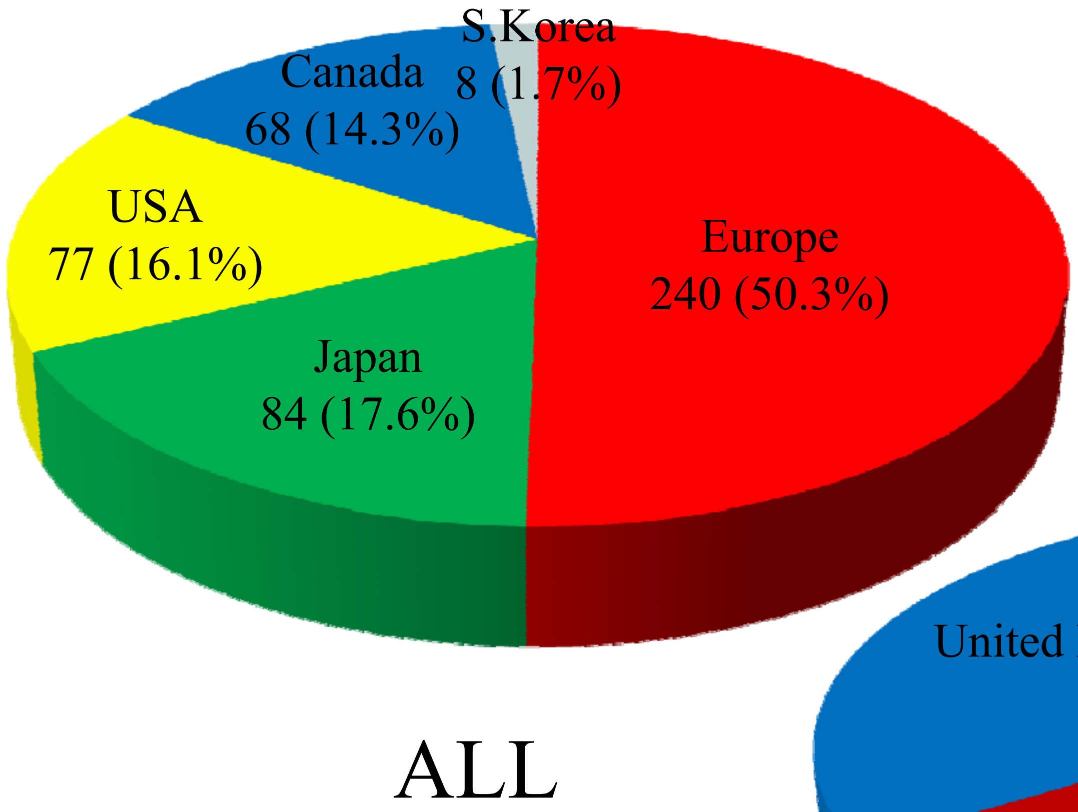
Spain
IFIC, Valencia
U. A. Barcelona

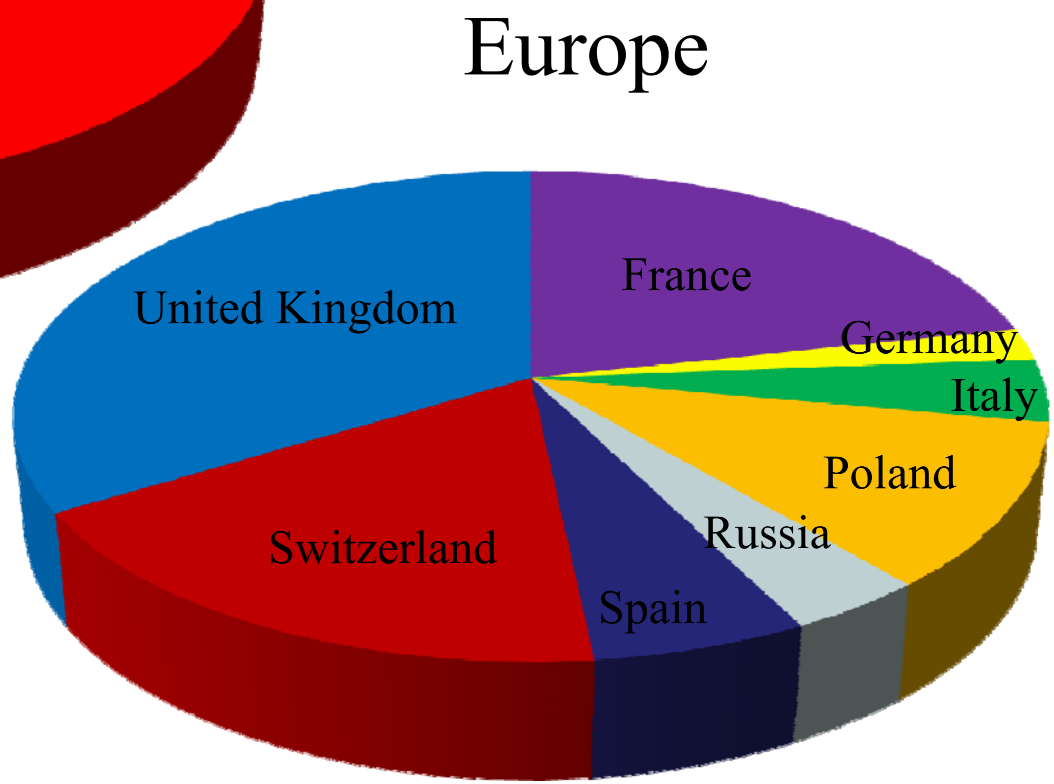
Switzerland
U. Bern
U. Geneva
ETH Zurich

United Kingdom
Imperial C. London
Queen Mary U. L.
Lancaster U.
Liverpool U.
Oxford U.
Sheffield U.
Warwick U.
STFC/RAL
STFC/Daresbury

USA
Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

Participants for T2K

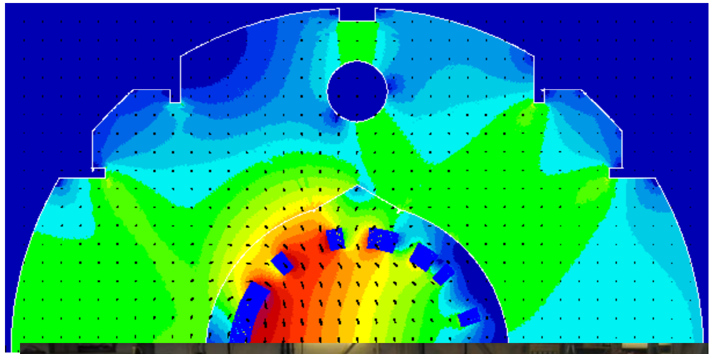




CERN Support to T2K(RE13)

- CERN experiment: NA61 Experiment
- CERN test beam for detectors
- Donation of UA1/NOMAD magnet
- Micromegas production and test by CERN TS/DEM group
- Various technical, administrative support on detector preparation, especially for UA1/NOMAD magnet related issues
- Infrastructure for detector preparation
- CERN-KEK cooperation on super conducting magnet for neutrino beam line

KEK feels grateful to CERN

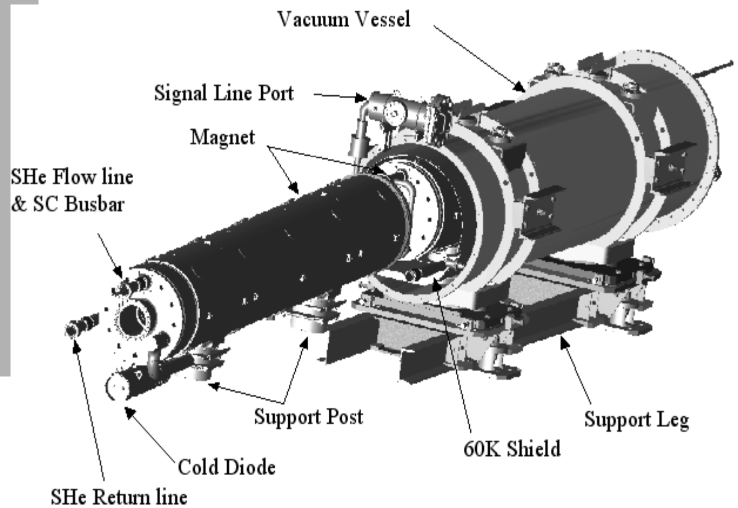


Massage from Toru Ogitsu and Akira Yamamoto

For the T2K primary beam line construction;

Procurement of many components for superconducting combined function magnets (2.6T + 19T/m, 3.3m long)x28 chases large scale procurement for LHC, with the same price!

We would thank CERN for the kindest cooperation given during the cryostat design and fabrication for the JPARC Neutrino SC beam line, using much experience integrated with the LHC accelerator construction and the KEK-CERN technical collaboration on LHC.



Primary Motivation of T2K

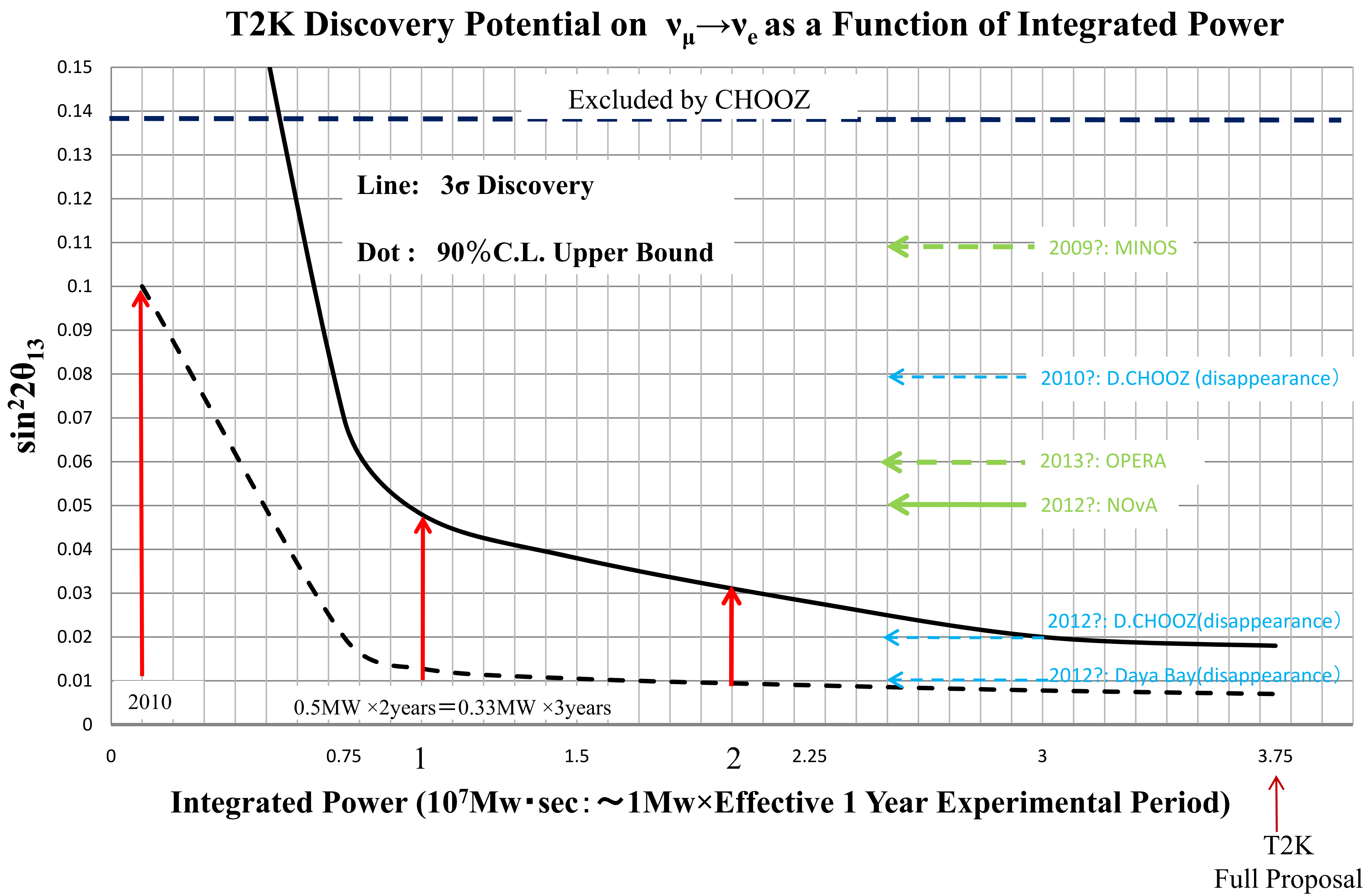
Discover $\nu_\mu \rightarrow \nu_e$ conversion phenomenon
prior to any other experiment in the world

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. "

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


T2K Discovery Potential on νμ→νe as a Function of Integrated Power
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
sin²2θ13
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
0
0.75
1
1.5
2
2.25
3
3.75
Integrated Power (10⁷Mw･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

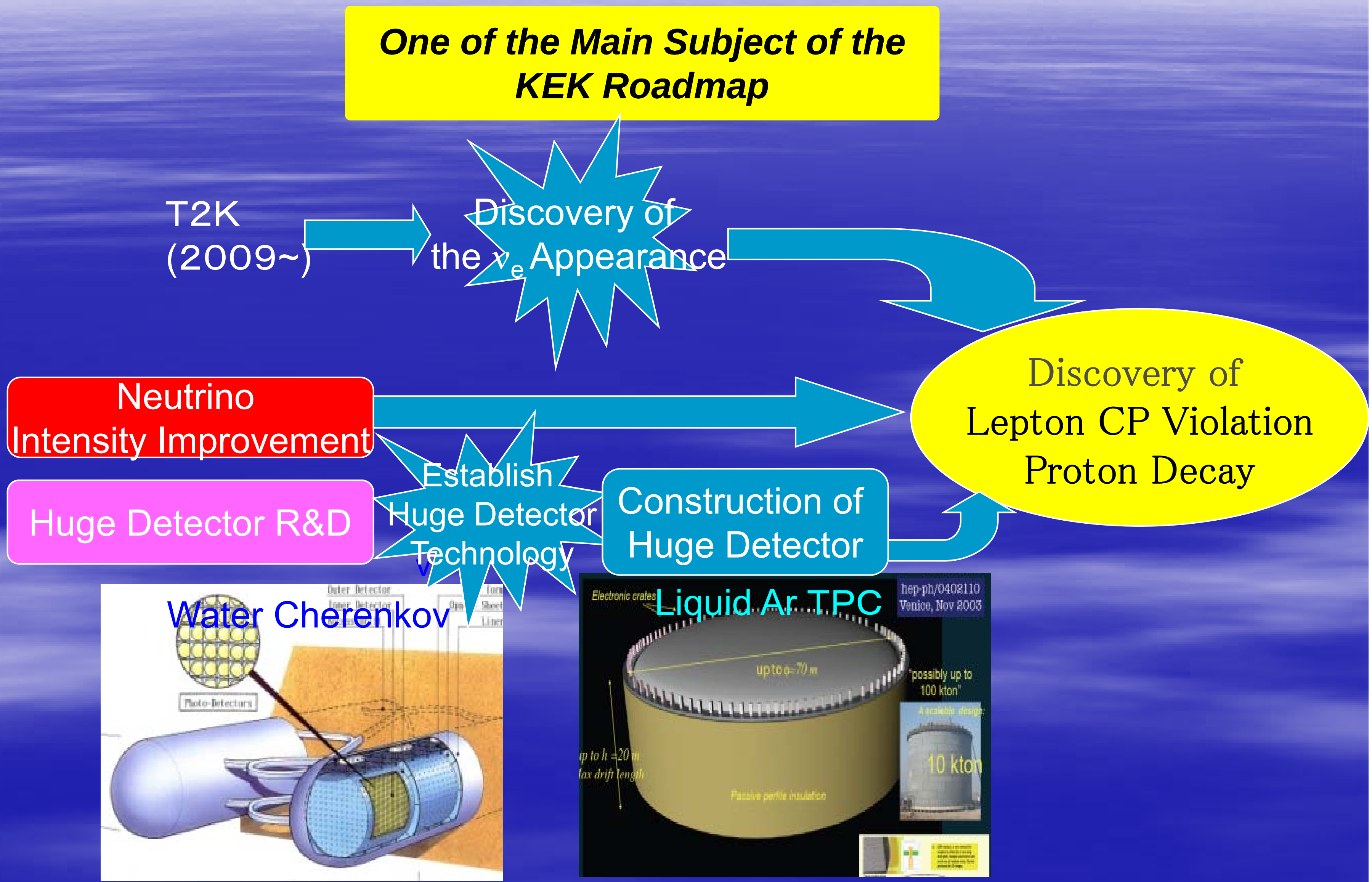
- Lepton Sector CP Violation
  - Search for CP violation in Neutrino Oscillation Process
    - Also examine mass hierarchy of neutrinos
    - Also examine matter effect in neutrino oscillation process

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

*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



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

MR Power Improvement Scenario toward MW-class power frontier machine — 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}	$<4.1 \times 10^{13}$	8.3×10^{13}	
Particle/Ring	7.2×10^{13}	$<3.3 \times 10^{14}$	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

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

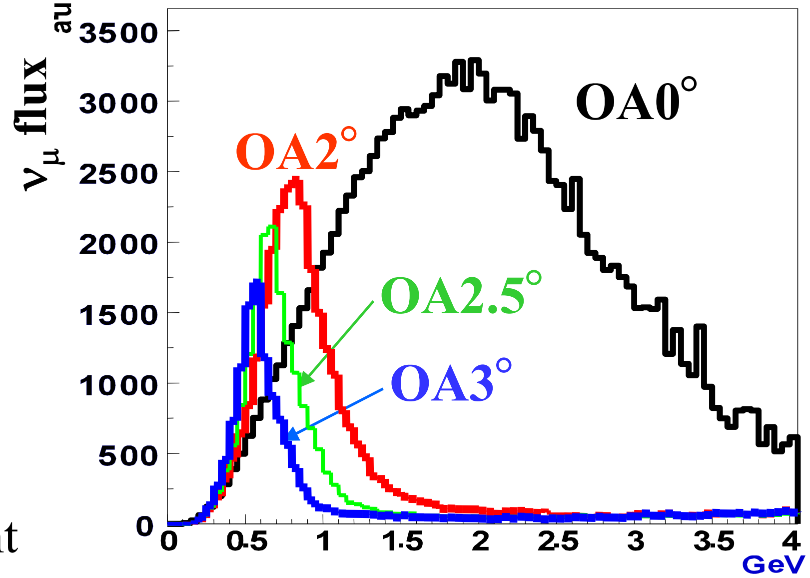
Effect of CP Phase δ appear as

- ν_e Appearance Energy Spectrum Shape
  - *Peak position and height for 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

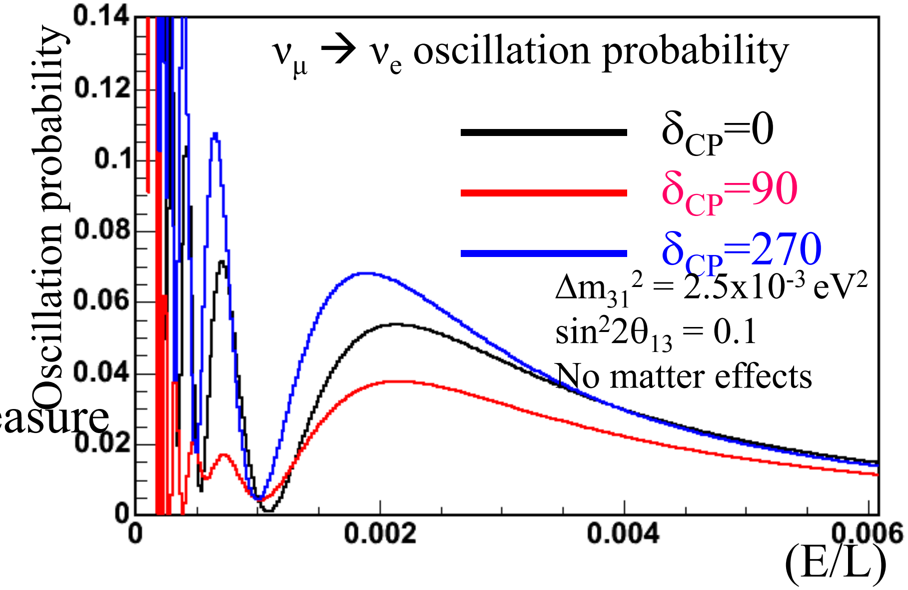
Angle and Baseline

- 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

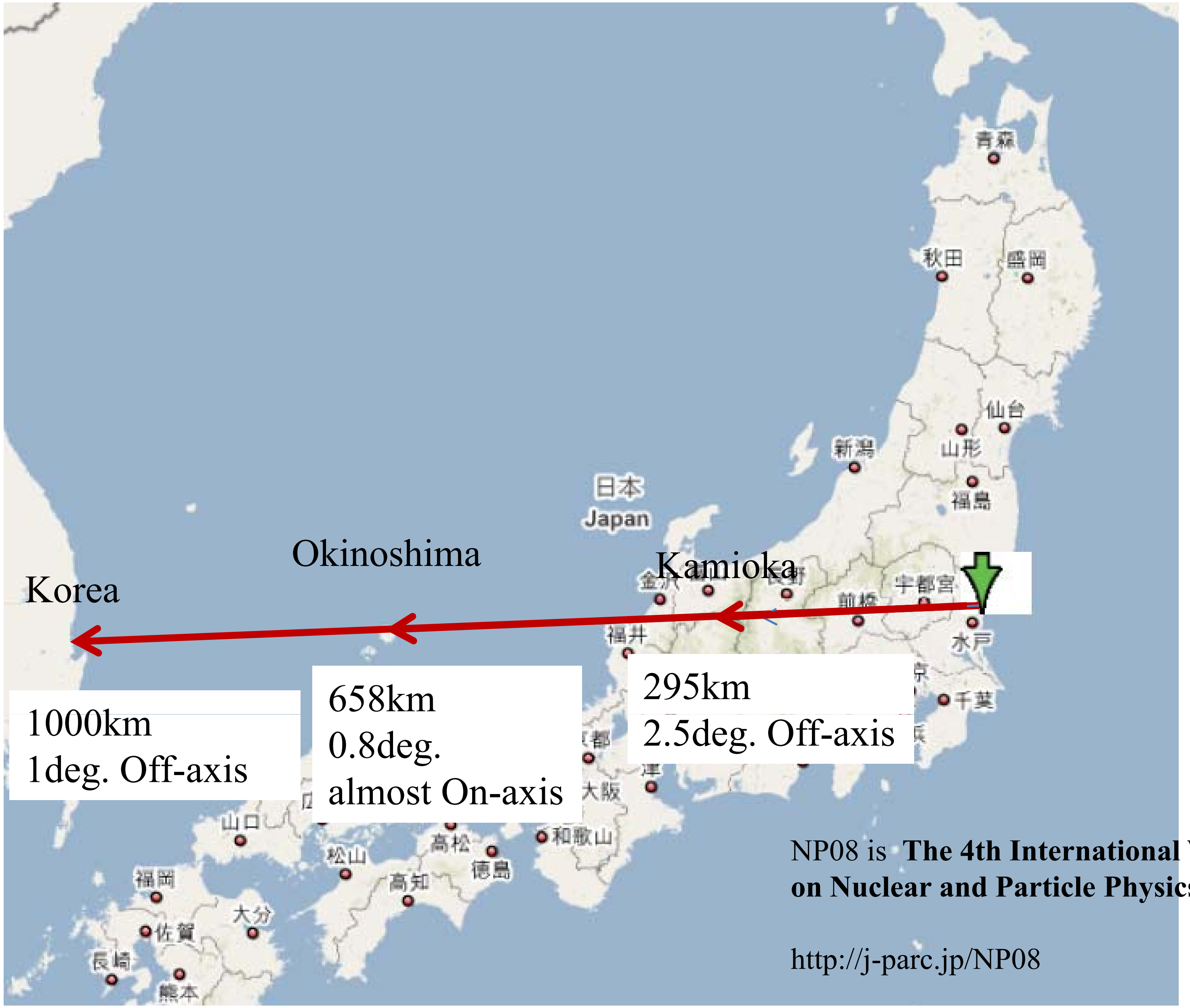
    → Counting Experiment



- 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



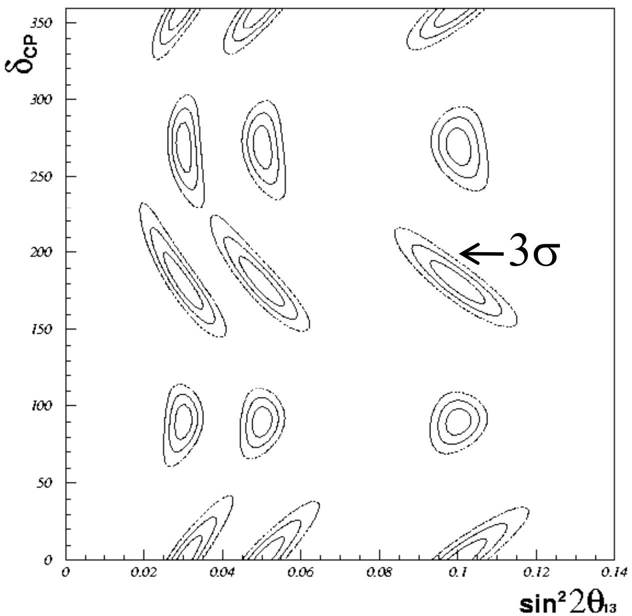
NP08 is **The 4th International Workshop on Nuclear and Particle Physics at J-PARC**

http://j-parc.jp/NP08

Scenario 1

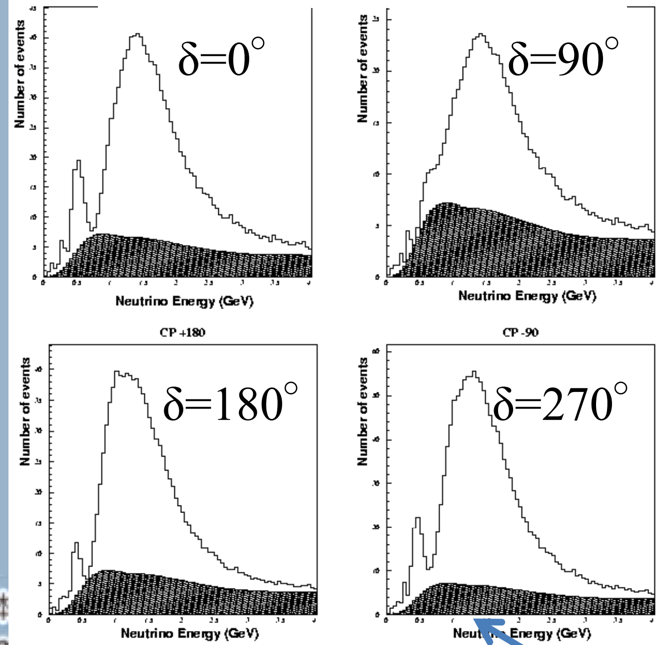
- Cover 1st and 2nd Maximum
- Neutrino Run Only 5Years × 1.66MW
- 100kt Liq. Ar TPC
  - -Good Energy Resolution
  - -Good e/π^0 discrimination
- Keeping Reasonable Statistics

CP Measurement Potential



ν_e Spectrum

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



Okinoshima

658km

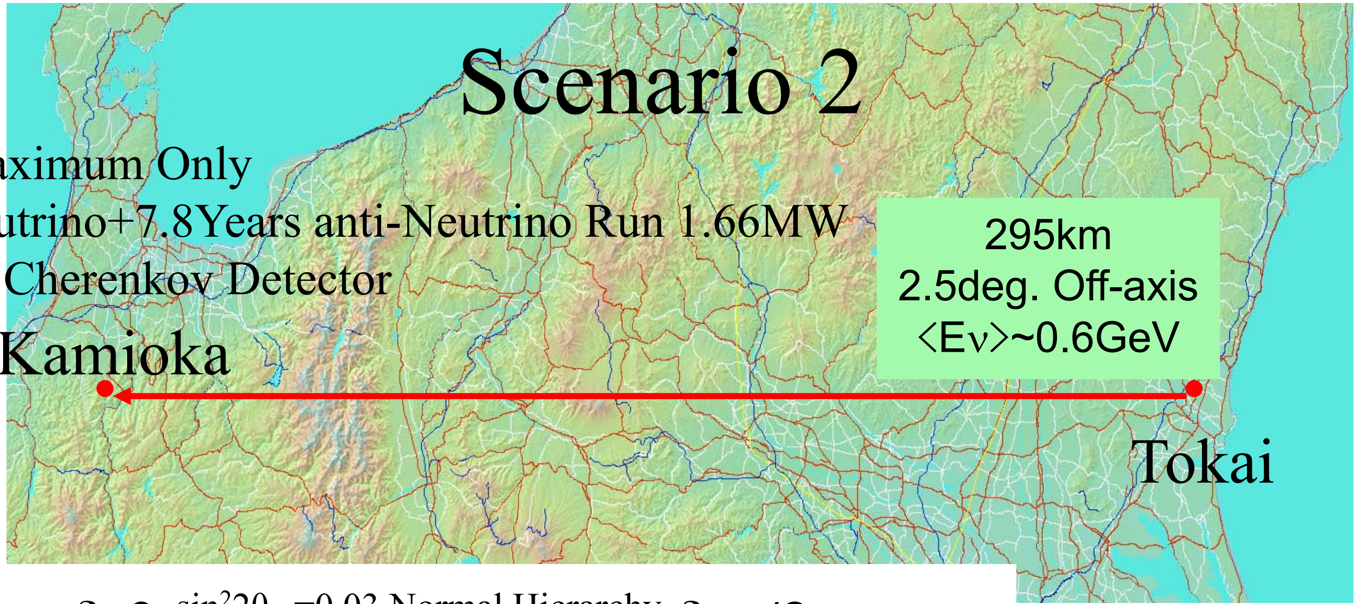
0.8deg. almost On-axis

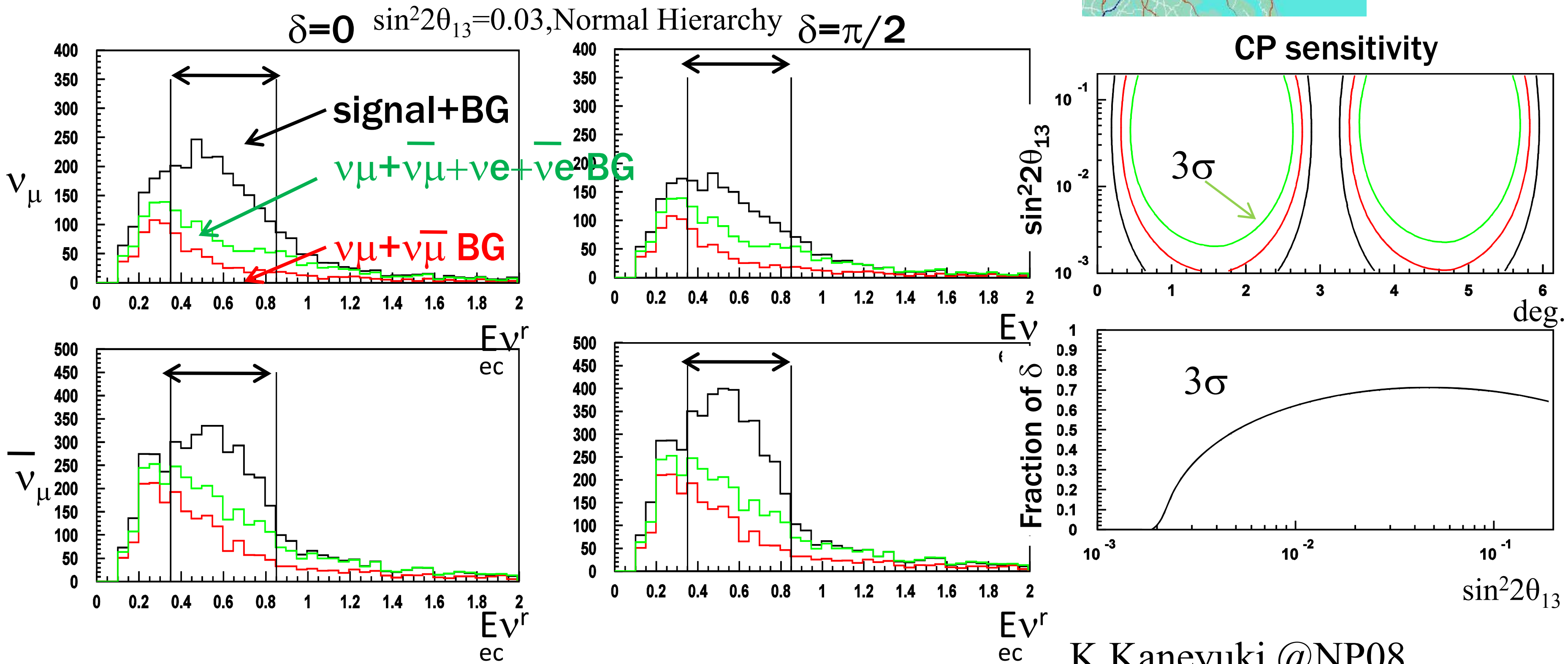
Beam ν_e Background

NP08, arXiv:0804.2111

Scenario 2

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

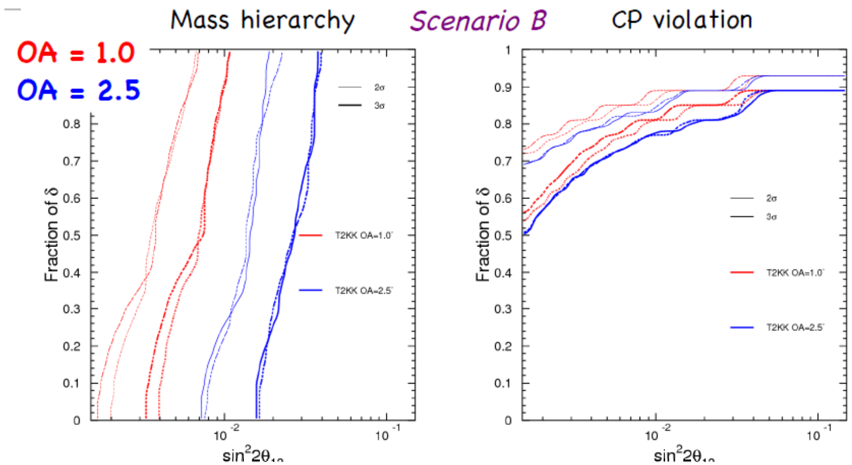


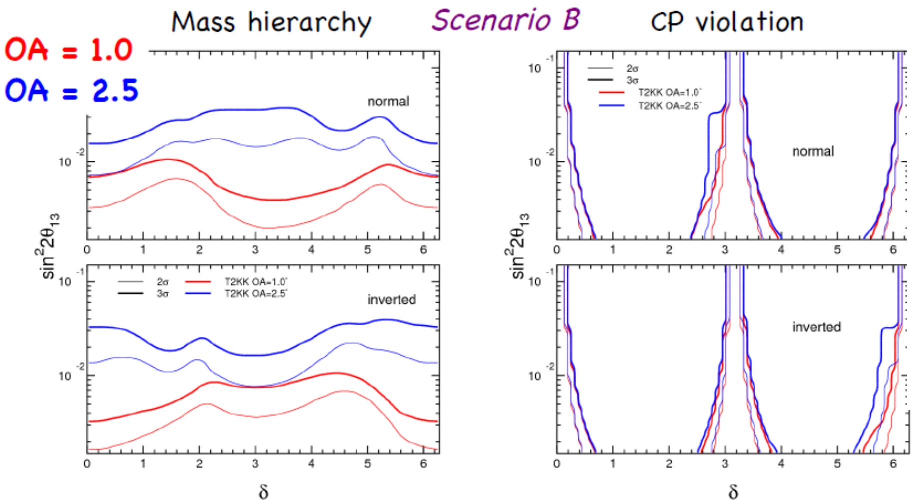


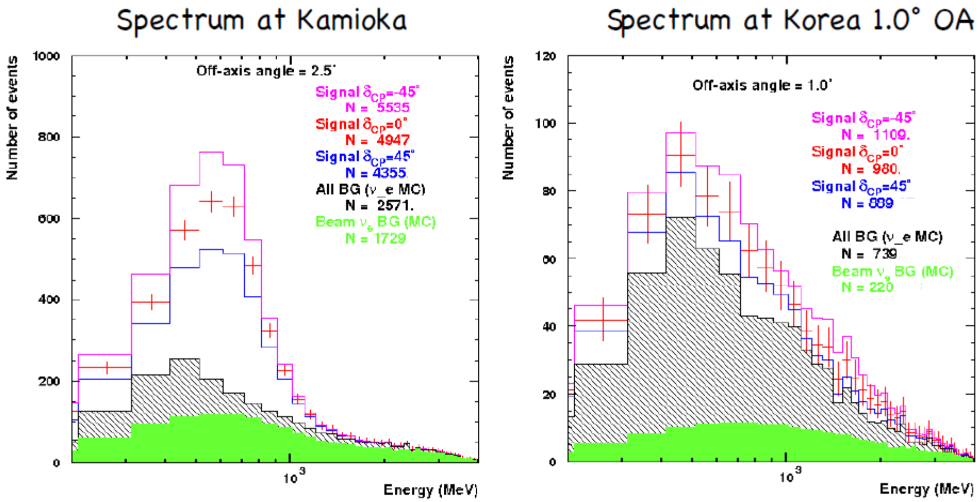
K.Kaneyuki @NP08

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 $\nu_e \bar{\nu}_e$	Ratio between 1st 2ndMax Ratio between $\nu_e \bar{\nu}_e$
Beam	5Years $\nu_{\mu,}$ then Decide Next	2.2 Years $\nu_{\mu,}$ 7.8 Years $\bar{\nu}_{\mu,}$	5 Years $\nu_{\mu,}$ 5 Years $\bar{\nu}_{\mu,}$
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

→ see Dr. Alberto Marchionni's talk in Detector Session

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 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 $\times 10^7$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 *In any case, complete T2K proposal of 3.75MW $\times 10^7$sec
- KEK Roadmap: MR toward MW-class power frontier machine
- 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)

What we think important for Accelerator Based Neutrino Project in Japan

- Deliver high quality experimental output from T2K as soon as possible

- Quick improvement of accelerator power toward MW-class power frontier machine

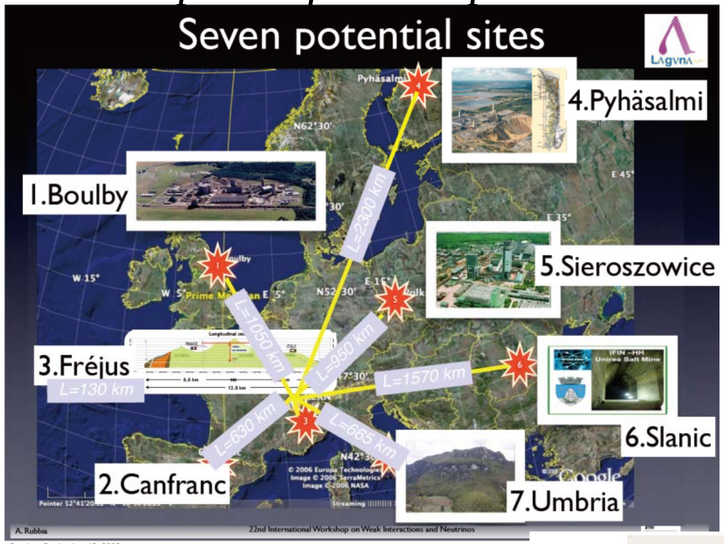
- Validate beam line components tolerance (especially pion production target related issues) toward MW proton beam

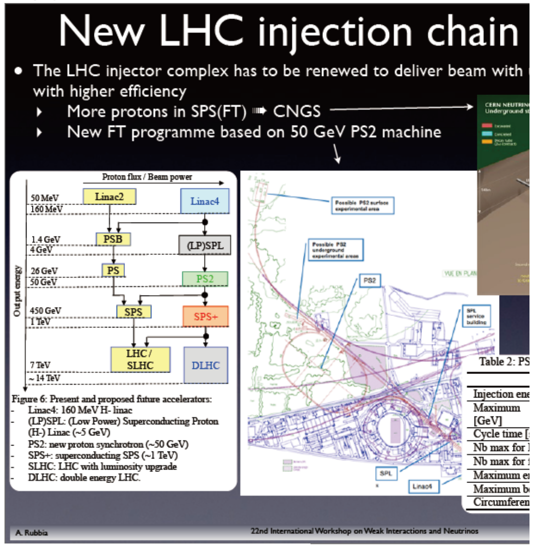
- R&D on realization of Huge Detector
  - Liq. Ar TPC
  - Water Cherenkov Detector

We welcome cooperation in any aspects

Healthy Scientific Competition and Cooperation between Asia, EU and USA

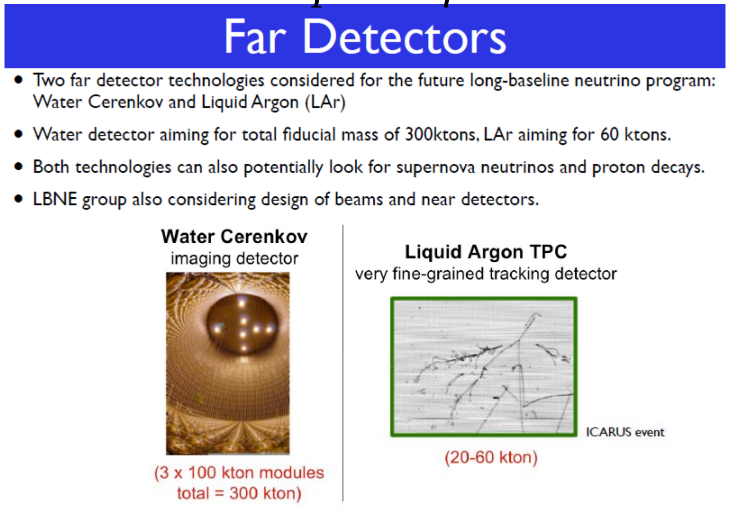
Options for Europe

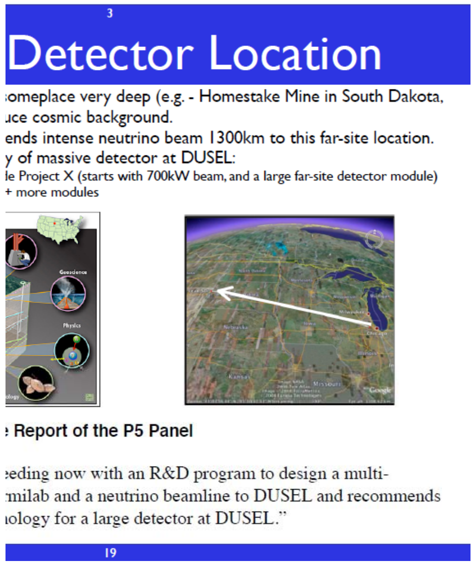




A.Rubbia @ WIN09

Options for USA





M.Soderberg @ WIN09

Options for Japan