# Neutrino plans in Japan

(Neutrino experiments at J-PARC)

T2K:Design, Goal and Status

Future options

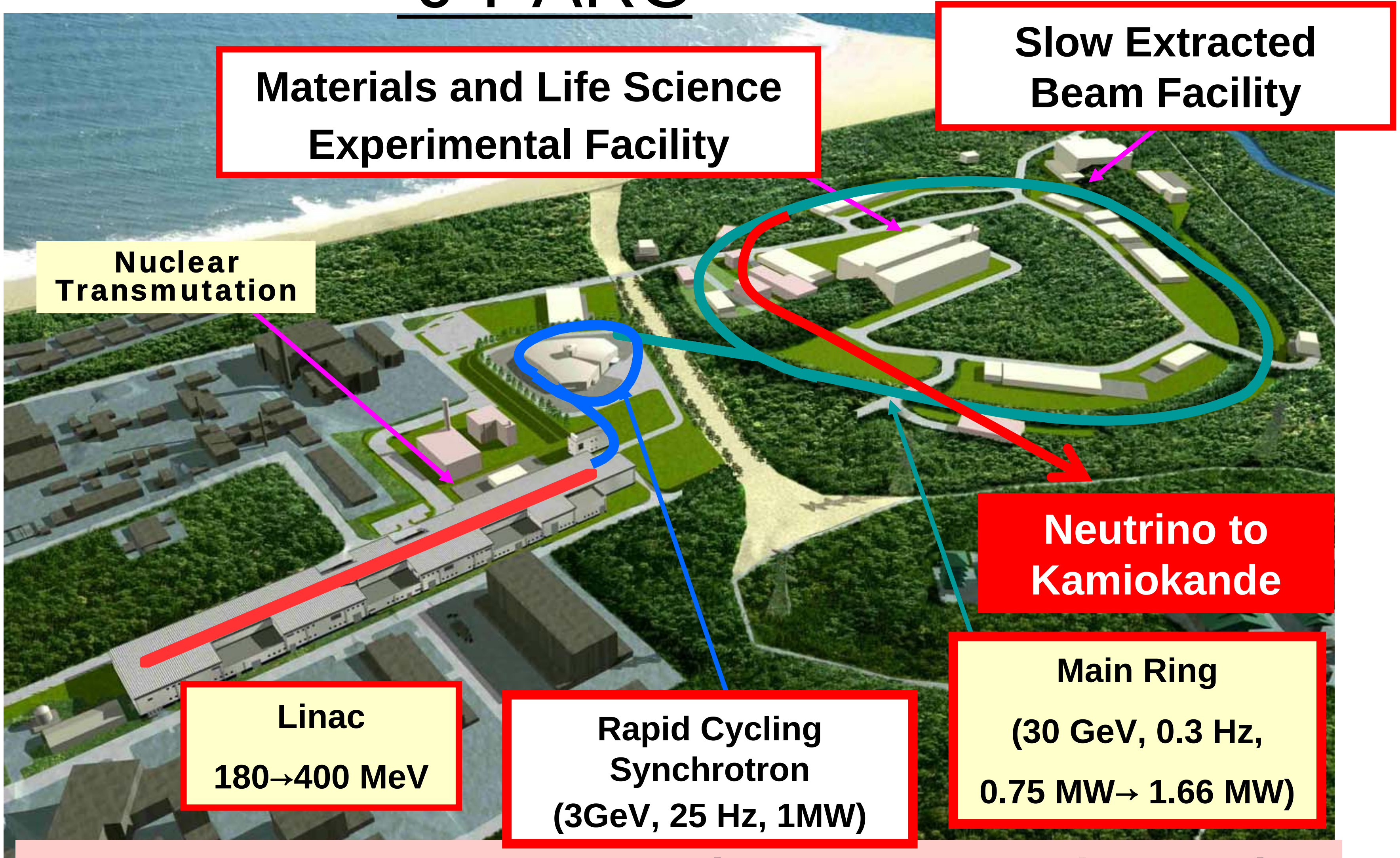
Project X Workshop

November 9-10,  2009

Koichiro Nishikawa

KEK

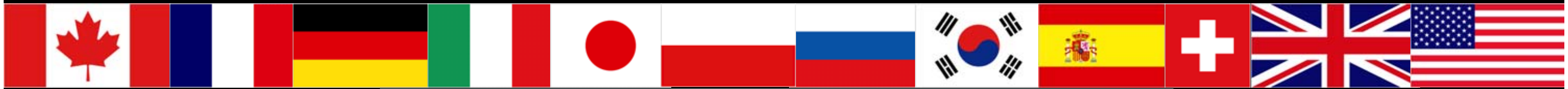
# J-PARC




**J-PARC = Japan Proton Accelerator Research Complex**

**Joint Project between KEK and JAEA**

# 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
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Kyoto U.
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A. Soltan, Warsaw
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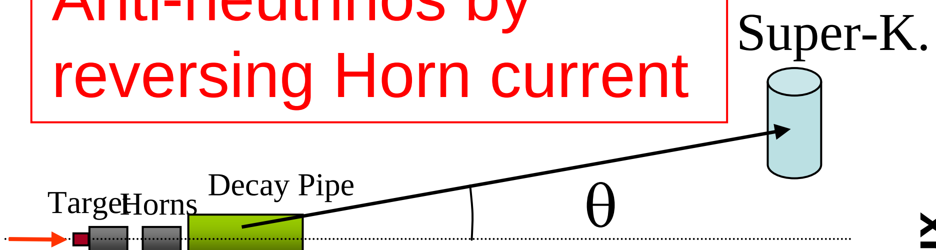
E133°
E135°
Kobe
Osaka
Kyoto
Kanazawa
Kanazawa
Tsu
Nagoya
Gifu
Gifu
E137°
Super-K
Nagano
Nagano
Japan
Kofu
Shizuoka
E139°
295km
Honshu
N37°
Mito
J-PARC
NASA
TerraMetrics
ZENRIN
E141°
100%

# Goal of T2K

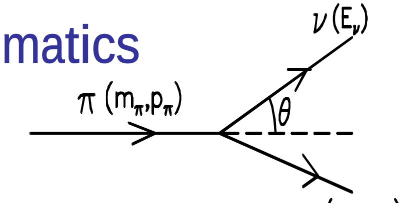
- Neutrino flavor oscillation
  - Explicit demonstration of flavor oscillation by the search of $\nu_e$ appearance in $\nu_\mu$ beam
    - The last of the three mixing angles
    - Possible tool for CPV search in leptons
  - Precision measurement of $\nu_\mu$ disappearance parameters
    - How close the $\theta_{23}$ to $\pi/4$ : maximal mixing?
  - Surprise?
- Deciding the future direction among various options, but the choice depends on :
  - Achievable accelerator power and beam line technologies
  - Detector technology
  - Understanding of sources of systematic errors

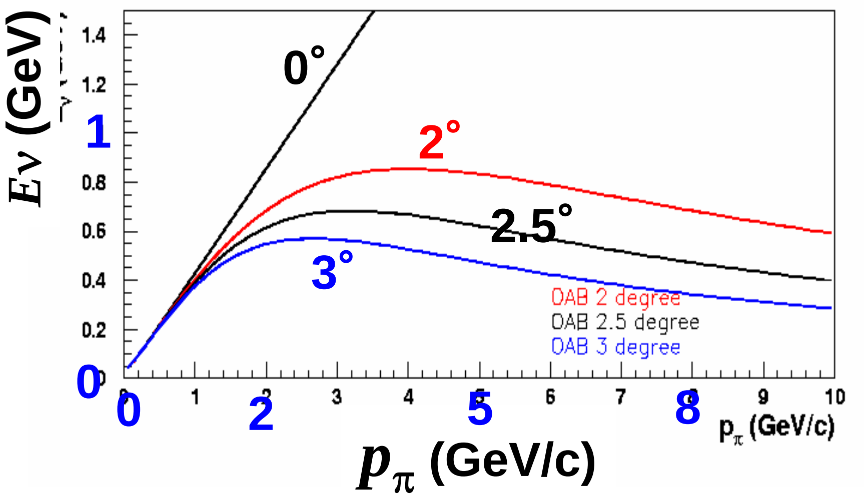
# Narrow intense beam: Off-axis beam

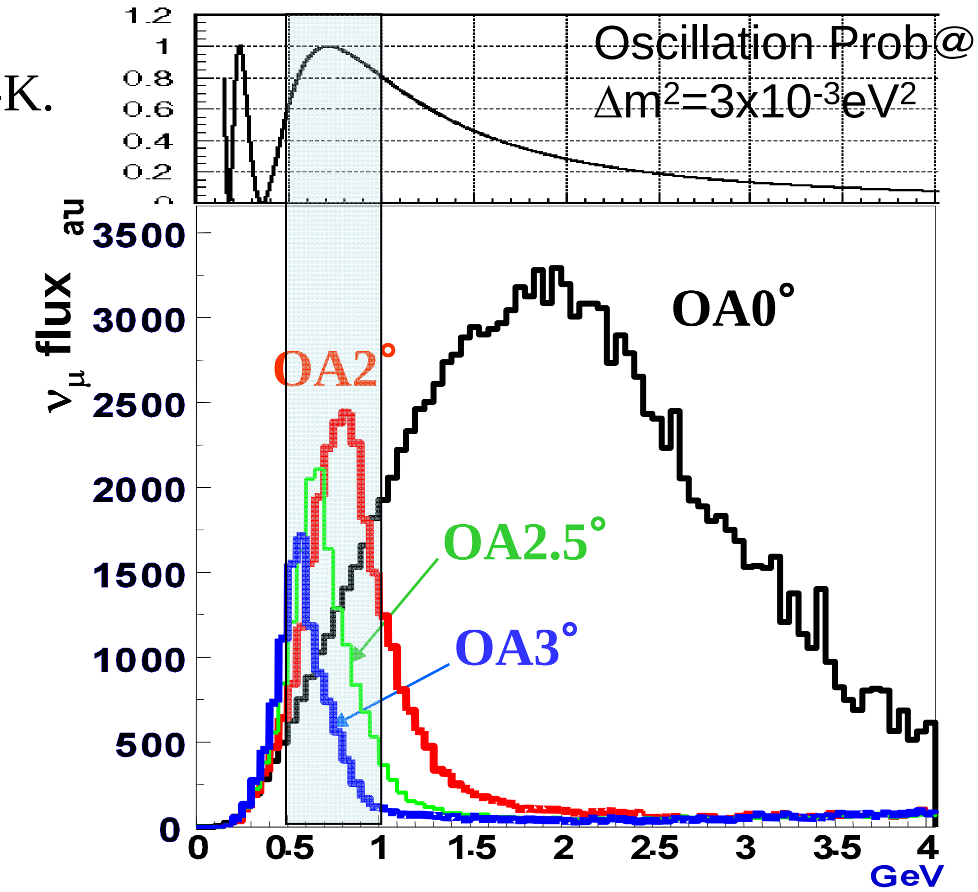
Anti-neutrinos by reversing Horn current




$\pi$ decay Kinematics




- **Quasi Monochromatic Beam**
- **x 2~3 intense than NBB**
- **Tuned at oscillation maximum**

**Statistics at SK**

**(OAB 2.5 deg, 1 yr, 22.5 kt)**

**~ 2200 $\nu_\mu$ tot**

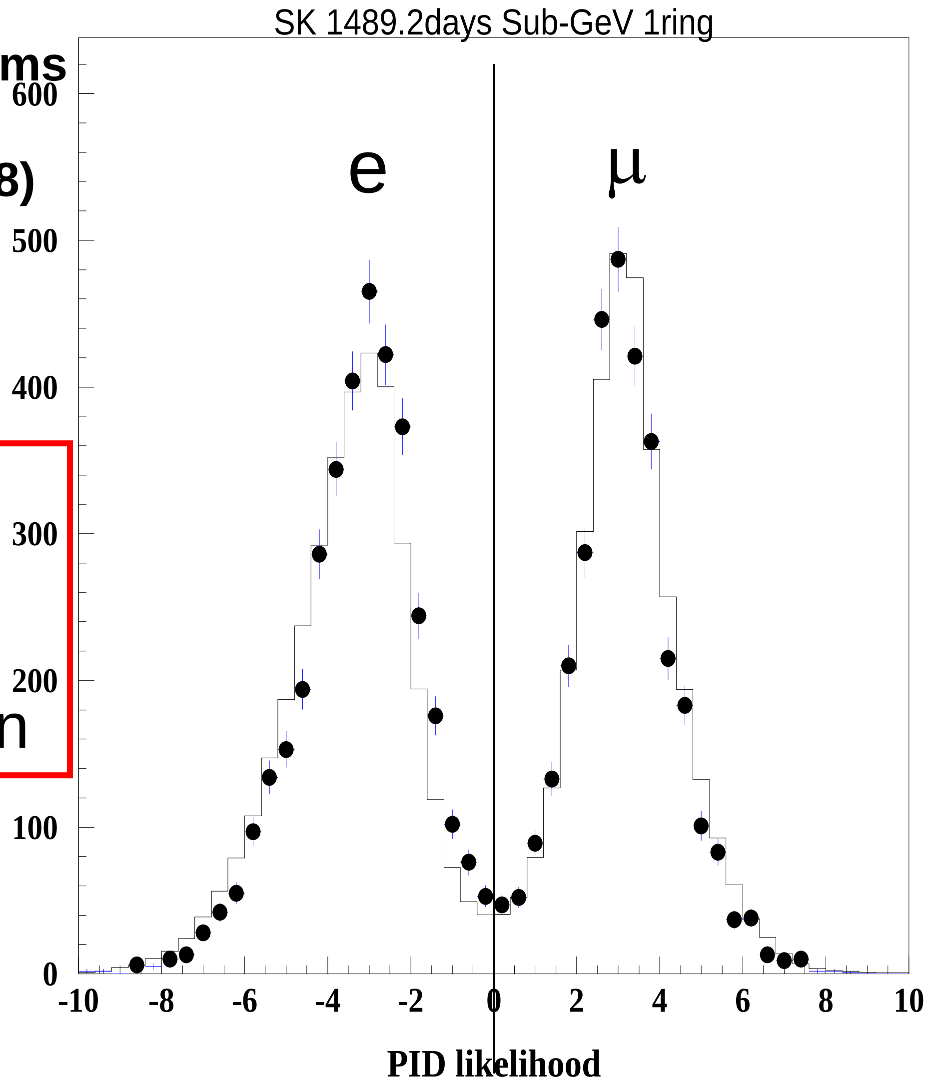
**~ 1600 $\nu_\mu$ CC**

**$\nu_e$ ~0.4% at $\nu_\mu$ peak**

# Particle ID (e & μ) (in single ring events) in Super-Kamiokande

- **An experiment with test beams confirmed the particle ID capability (PL B374(1996)238)**

Water Cherenkov detector works best for low E ν's
 (simple final state)
with good energy resolution

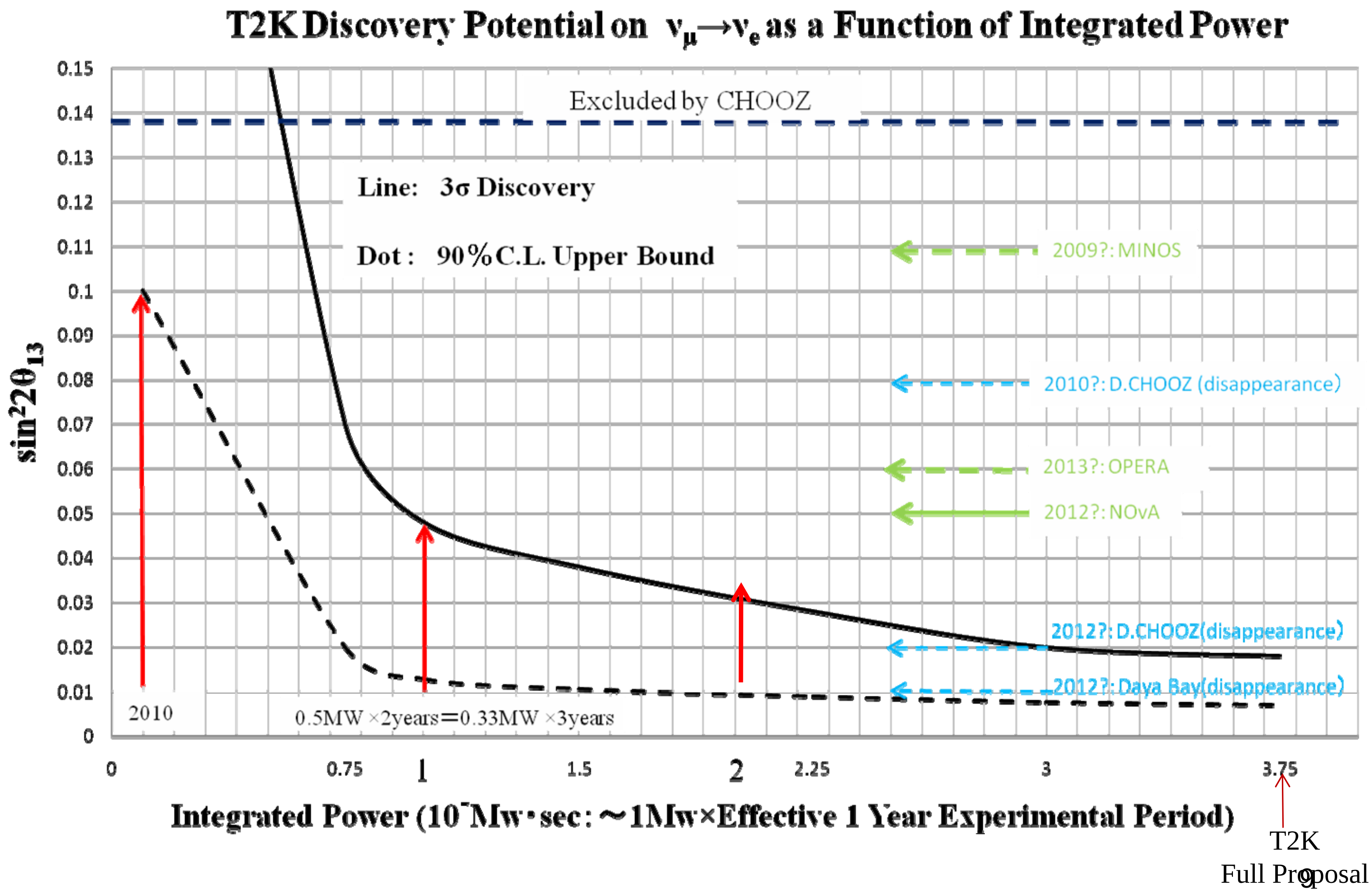


Super-K exist at the distance 295km and $\Delta m^2 \sim 2.5 \times 10^{-3}$ eV $^2$

Oscillation max. at sub-GeV neutrino energy

1. Super-K water Cherenkov detector is an excellent detector for single lepton final state (CCQE) in E, ID
2. New high power accelerator at J-PARC
3. Off axis beam
   - CCQE dominant in sub-GeV
     - Event-by event $E\nu$ reconstruction by kinematics
   - Small high energy tail
     - Small BKG in $\nu e$ search from NC $\pi^0$
     - Almost monochromatic : Extra E(rec.) requirement

| Possible integrated power in 2010 | $\nu e$ signal (at $\sin^2 2\theta_{13}=0.1$) | Expected bkgs. | 90%CL $\sin^2 2\theta_{13}$ limit |
|---|---|---|---|
| 100kW*$10^7$sec | 3.8 | 0.7 | ~0.06 |



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 Mw・sec : ~1Mw×Effective 1 Year Experimental Period)
T2K
Full Proposal

# Neutrino Beamline at J-PARC

# Concept of J-PARC Neutrino Beam Facility

- Preparation section: matching beam optics to arc section
- Arc section: bending the beam ∼90° to SK with SC combined function magnet
- Final focus section: matching beam optics to target（position and profile, mm control is necessary which correspond to 1mrad $\nu$ direction, also not to destroy target）
- Graphite Target and Horn Magnet: (3horn system with 320kA pulse operation)
- Muon Monitor: monitor $\mu$ direction (=$\nu$ direction) pulse to pulse
- On Axis Neutrino Monitor(INGRID): monitor $\nu$ direction and intensity

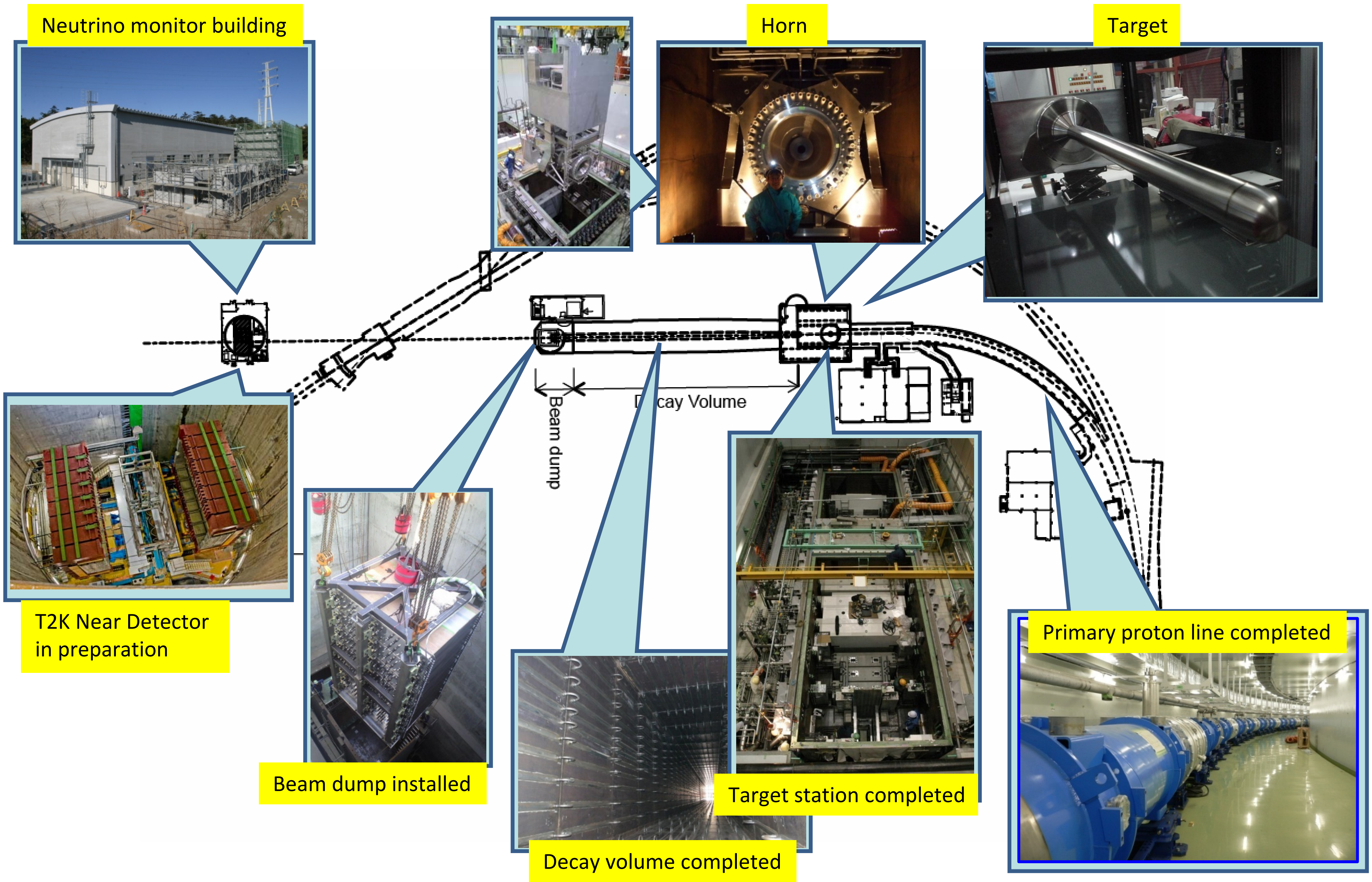
*Designed to be tolerable up to ∼2MW beam power

Limited by temperature rise and thermal shock (Horn , Target, Ti Vacuum Window)

*Everywhere high radiation

Radioactive water and air (∼10GBq/3week )….

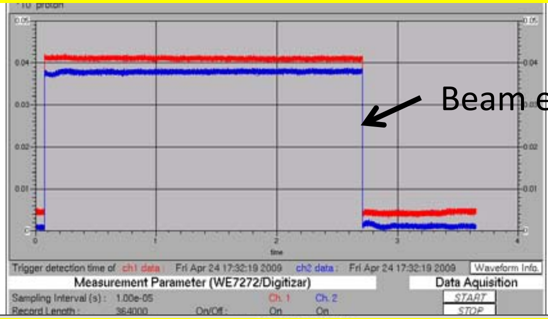
# Commissioning of Neutrino Beam Facility Started April 2009



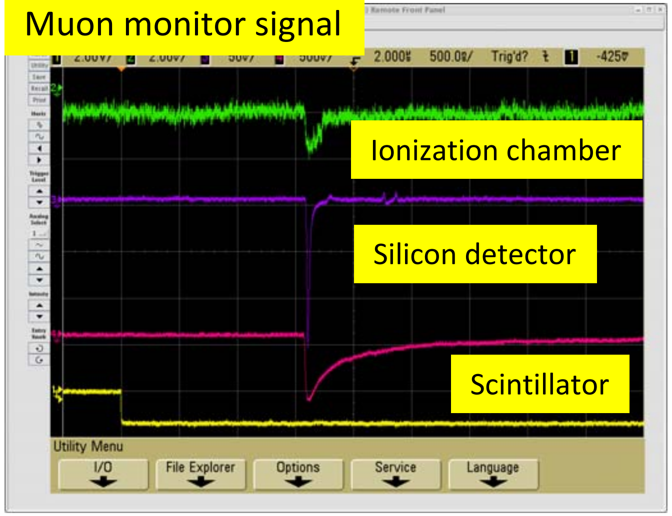
# J-PARC Neutrino Beam Facility Start Operation

After 9 shots for tuning, proton beam hits target center

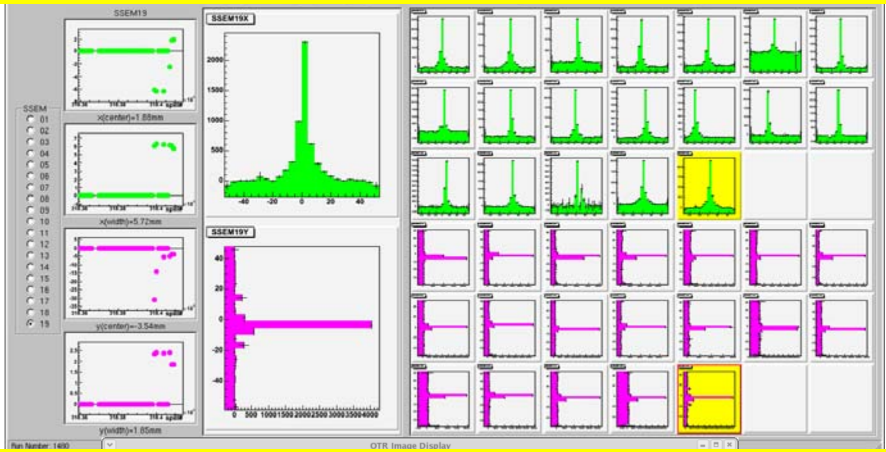
Main Ring intensity as a function of time



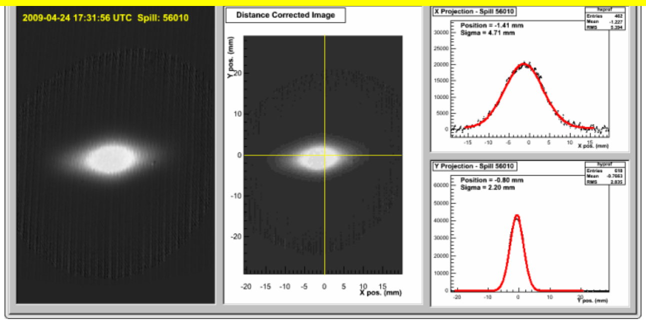

Muon monitor signal



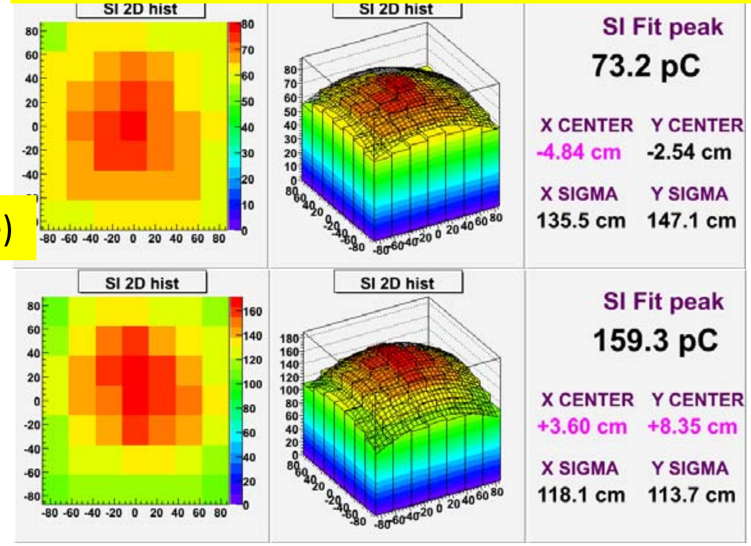

Proton beam profile/position along the primary beam line



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




Muon monitor signal with/without Horn Magnet




Horn Off

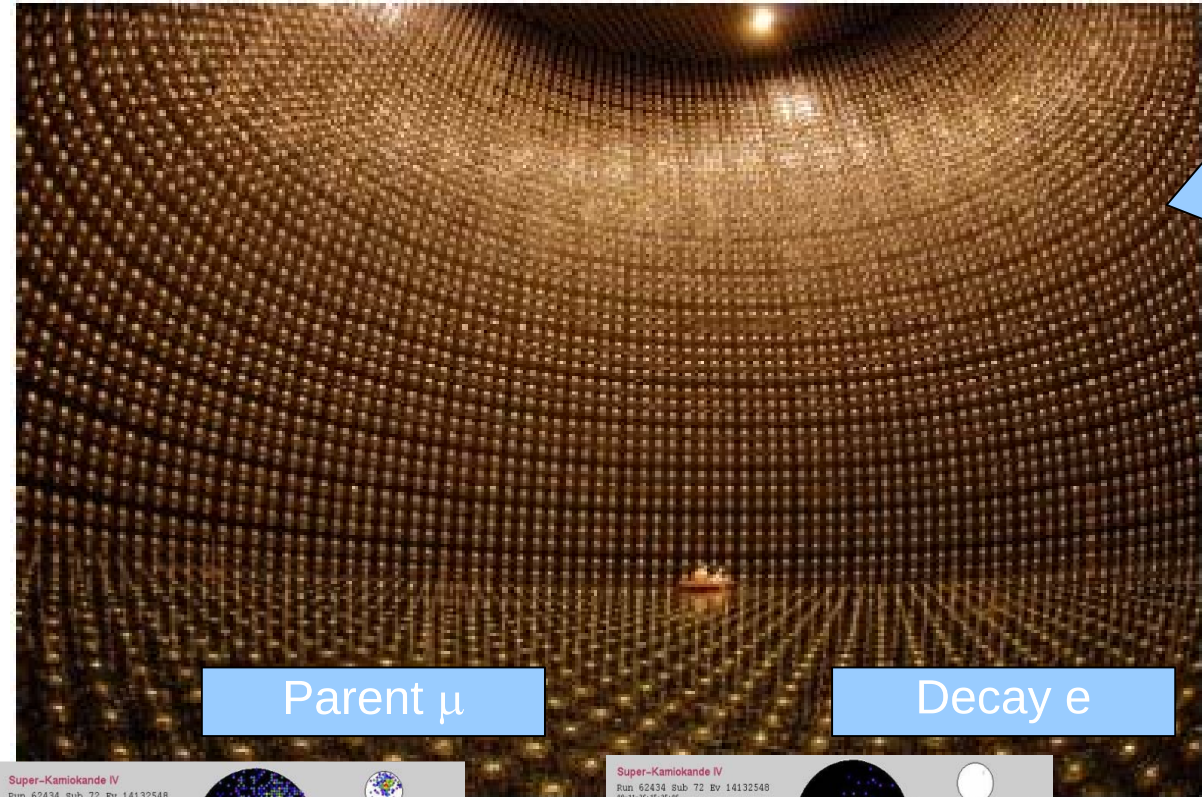
Horn On

# Neutrino Facility Commissioning Achievement April 23-May 28, 2009

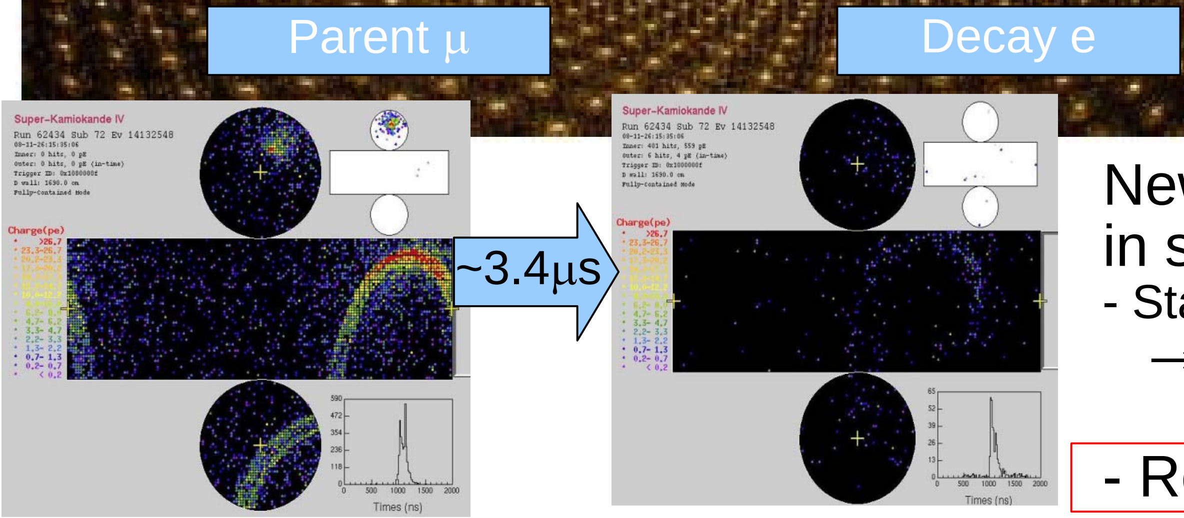
1. Stability of the extraction beam orbit from Main Ring
2. Tuned within 0.3mm(position), 0.04mrad(direction) w.r.t. design orbit
3. Functionality of the superconducting combined function magnet
4. Beam is lead to the target center without significant beam loss
   Tuned within 3mm level accuracy w.r.t.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

Basic functions of all components confirmed

# Far Main detector: Super Kamiokande



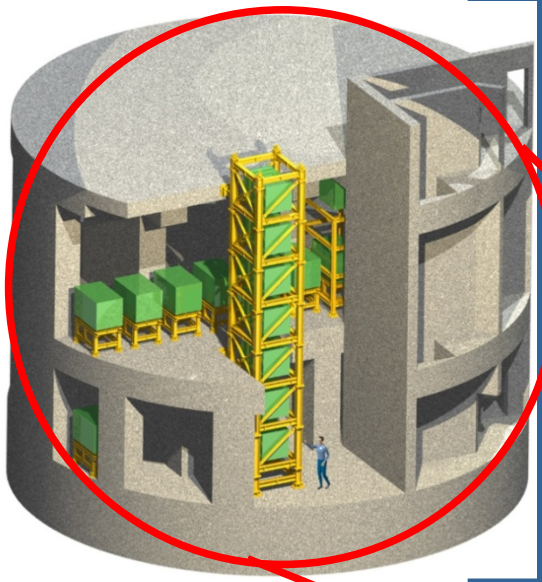
- 50kt Water Cherenkov detector
- 20”PMT x 10,000
+Anti counter x 2000




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

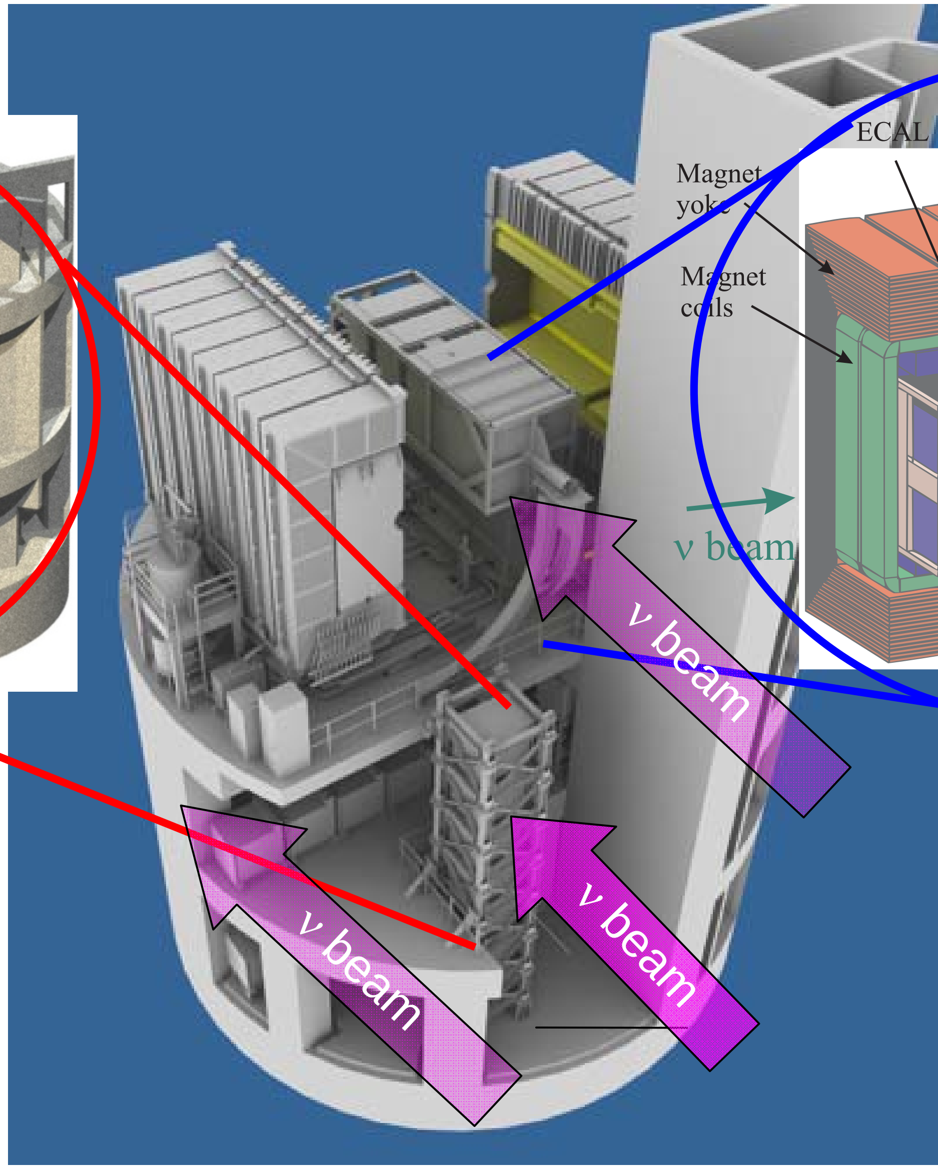
- Stable and dead time less DAQ
  → e.g. improvement of decay-e tagging efficiency
- Ready for T2K experiment

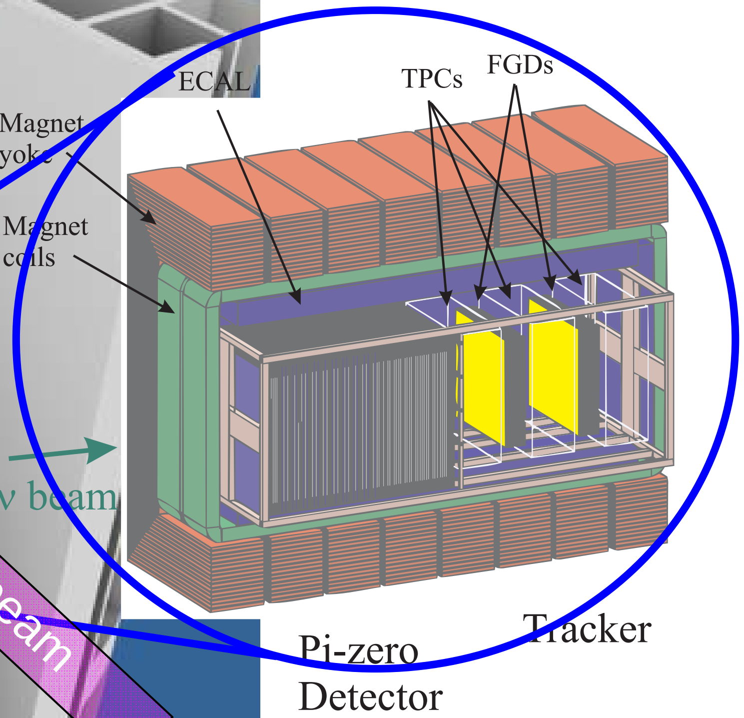
# Near Detector (ND280)



On-Axis Neutrino Monitor (INGRID)

Monitor:
ν beam direction

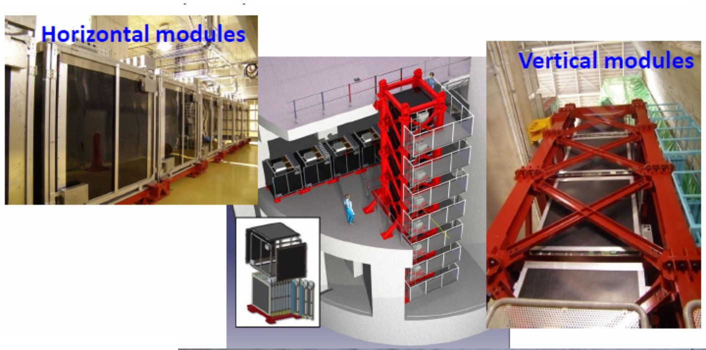


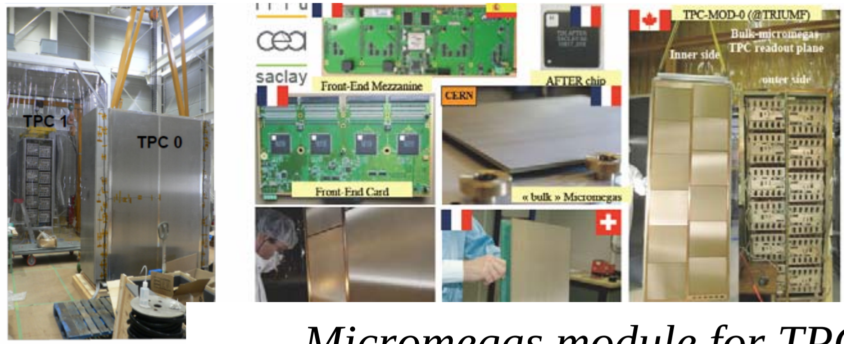

Off-Axis (=SK dir.) Neutrino Detector

measure:
- ν flux/spectrum
- cross sections

INGRID(On-axis neutrino monitor) is installed

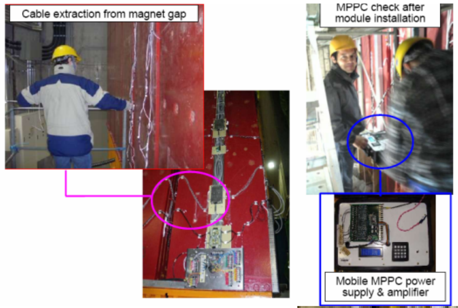



TPC(2 out of 3) is ready for installation

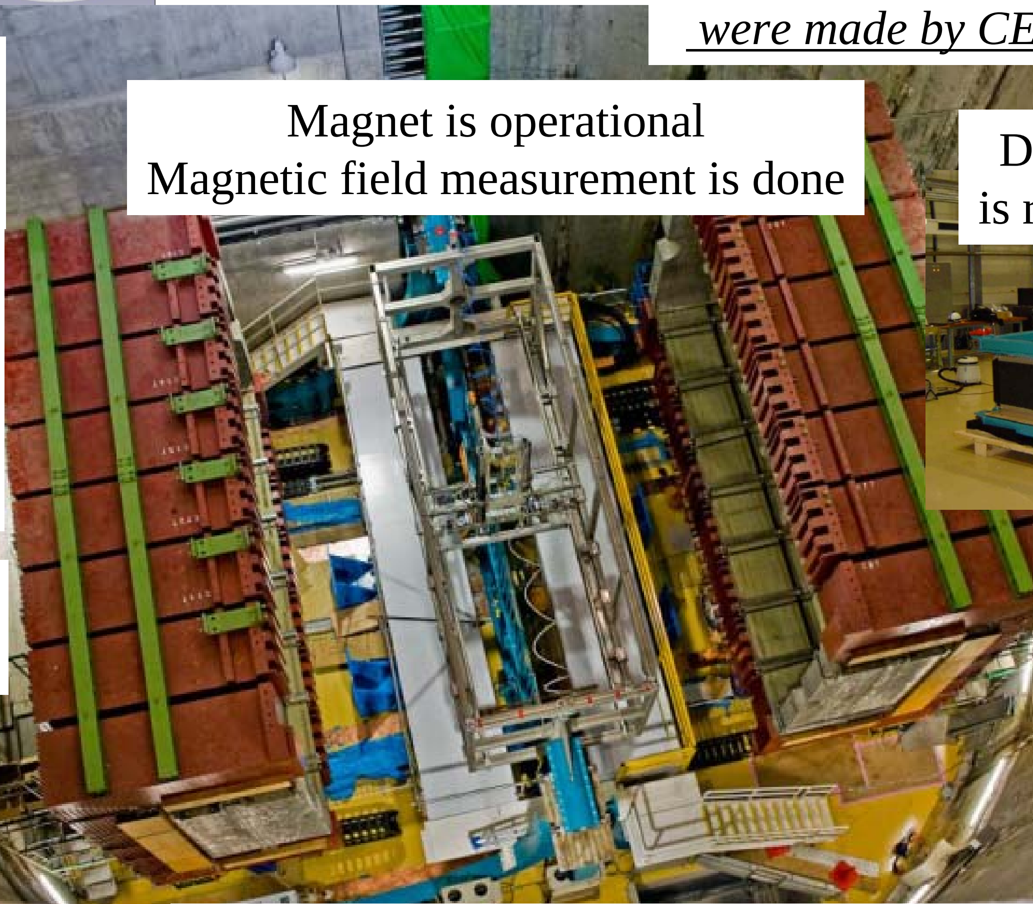



*Micromegas module for TPC*
*were made by CERN TS/DEM group*

SMRD
(muon catcher in york)
is installed



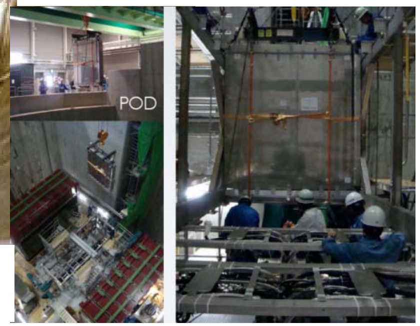

Magnet is operational
Magnetic field measurement is done



Down Stream ECAL
is ready for installation

FGD(active target)
is ready for installation

P0D(pi0 detector)
is installed



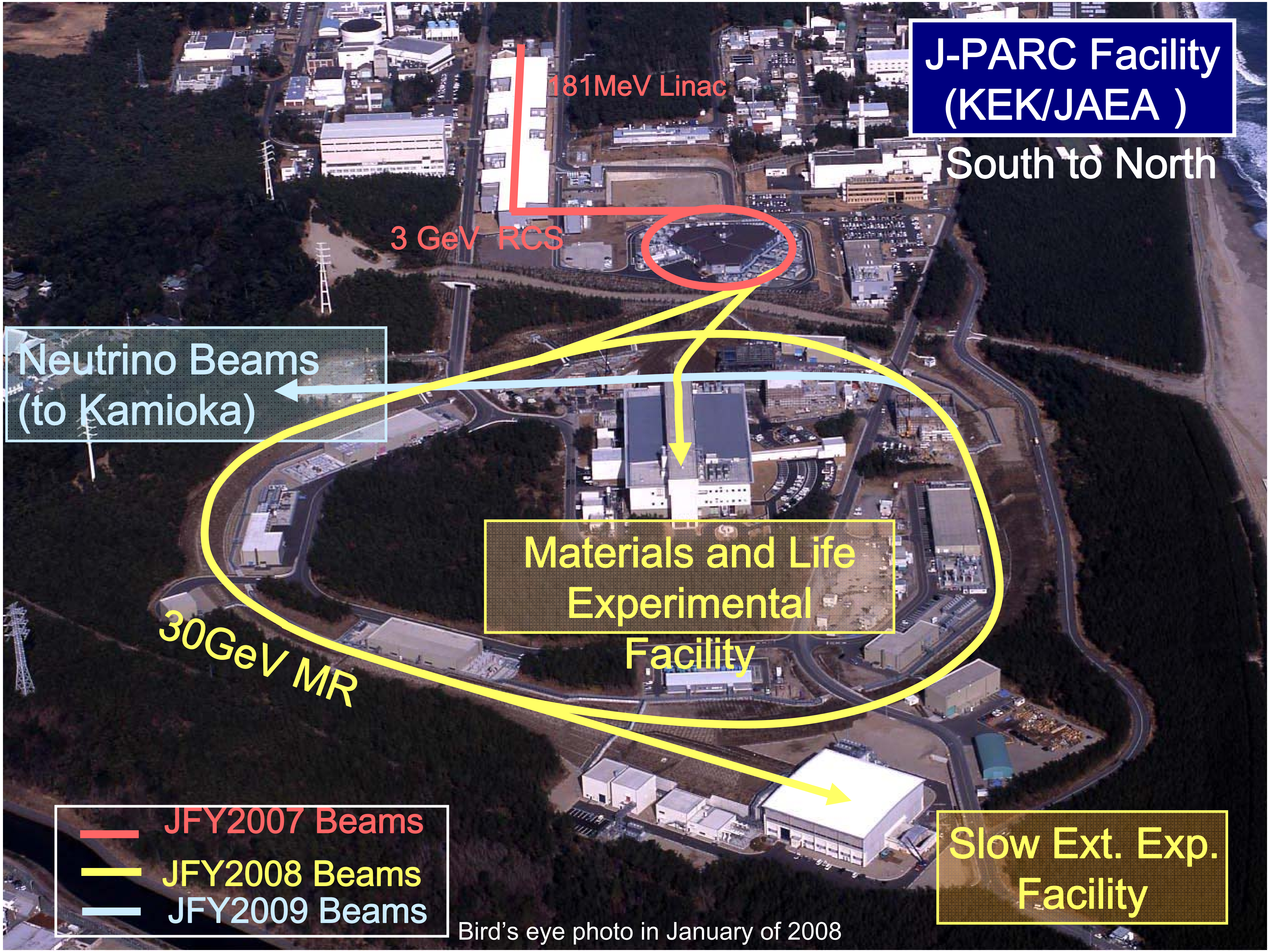

*UA1/NOMAD Magnet is donated by CERN*

# Status of accelerator development since summer 2009

3 major problems

Rep. rate

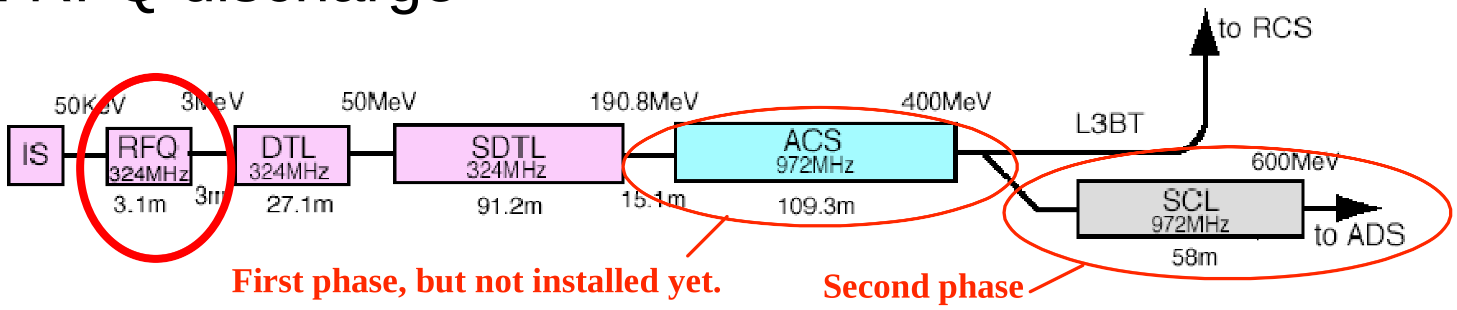
LINAC energy upgrade in preparation



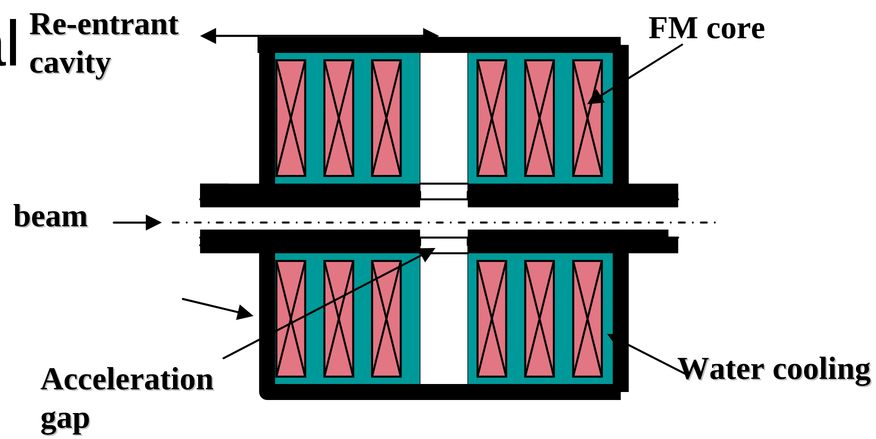
Bird's eye photo in January of 2008

# 3 major problems before summer

1 RFQ discharge

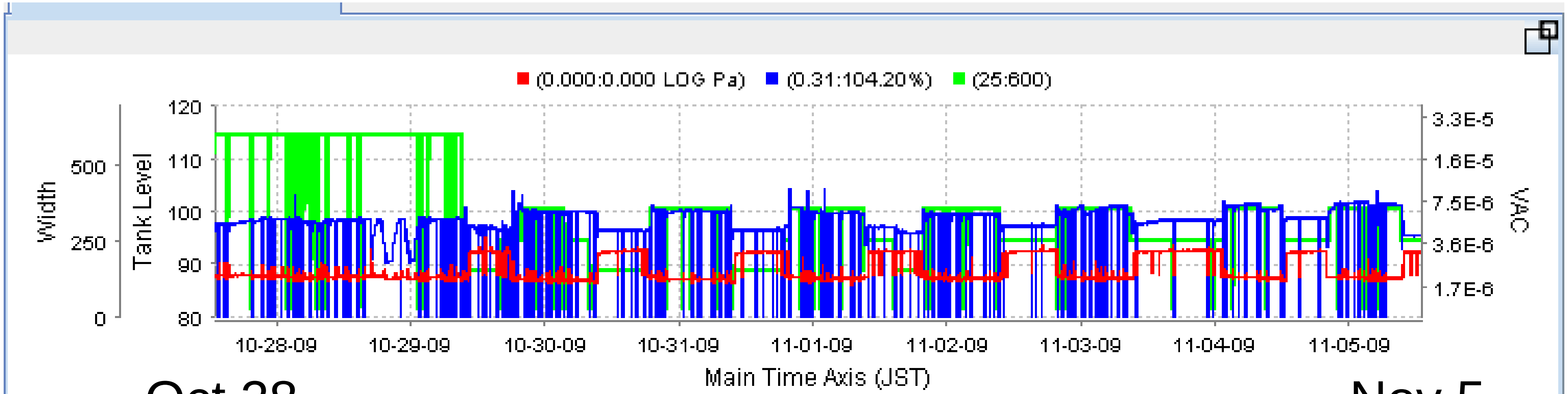



2 RF FM core mechanical collapse




3 Power supply ripple

# RFQ improvement in last 7 days




Oct.28 Tank level , width, Vacuum Nov.5

**Oct : 5mA/100μs**
**Nov : 15mA/200μs RCS 120kW equivalent**

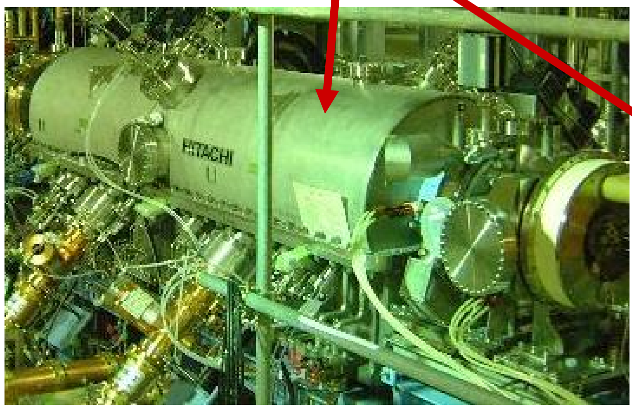
- Serious discharge problem in RFQ since 2008
  - Operation was limited to 5mA/100us (RCS20kW)
- Various improvements in vacuum in Mar/Jul/Aug,2009
- Conditioning Sep.~, Beam started Oct.
- Good chance of MR 100kW running in early 2010

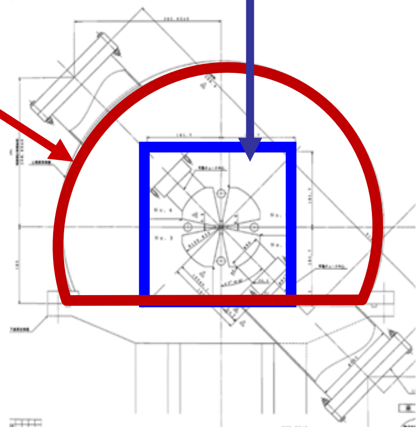
# RFQ, in operation (No.1), Back-up (No.2) and Final version (No.3)

| | No.1, in | No.2, BACKUP | No.3, FINAL |
|---|---|---|---|
| CURRENT | 30mA | 30mA | 50mA |
| RF STRUCTURE | IN-VACUUM | DIRECT | DIRECT |

VACUUM VESSEL

RF STRUCTURE



~1m × 3 unit = ~3m

Direct evacuation

# RF core problem

- Problem has been identified
- Occurred only for one type of core
  - Method of coating and procurement

| | Collapse<br>座屈 | Glass cloth separation<br>ガラスクロスの剥がれ | total cores<br>全数 |
|---|---|---|---|
| Type1 | 0 | 0 | 13 |
| Type2 | 0 | 8 | 35 |
| Type3 | 25 | 0 | 42 |

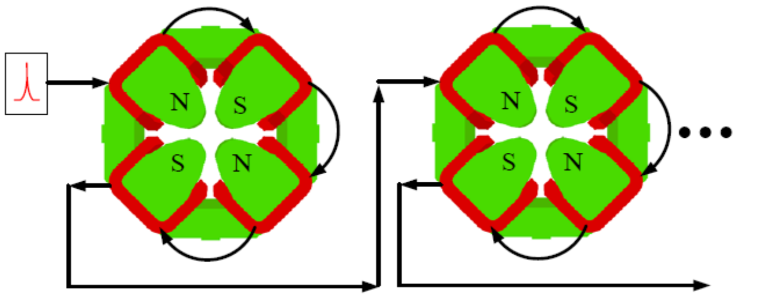
含浸及びコーティングタイプ別のコア据付け状況を以下に示す。

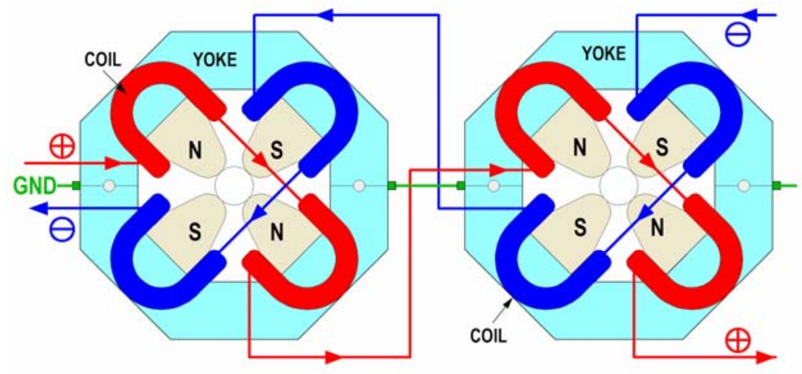
Number of cores of each type　　Already replaced

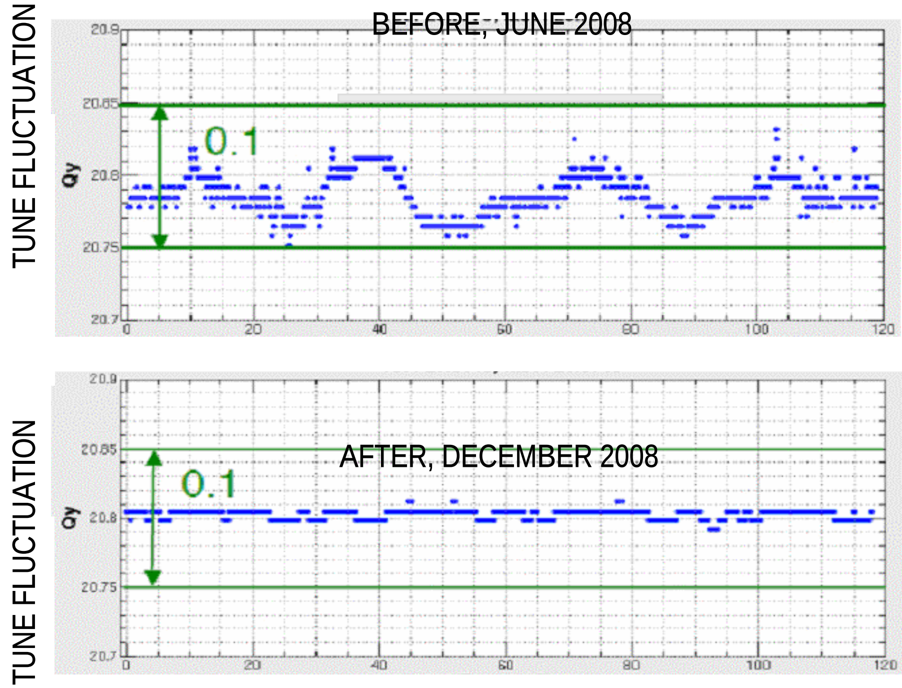
| | Cav.1 | Cav.2 | Cav.3 | Cav.4 | Cav.5 | Cav.6 | Cav.7 | Cav.8 | Cav.9 | Cav.10 | Cav.11 | 合計 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type1 | 0 | 7 | 0 | 0 | 0 | 9 | 4 | 0 | 6 | 6 | 0 | 32 |
| Type2 | 8 | 5 | 9 | 12 | 12 | 0 | 0 | 8 | 4 | 6 | 0 | 64 |
| Type3 | 10 | 6 | 9 | 6 | 6 | 9 | 14 | 10 | 8 | 6 | 18 | 102 |

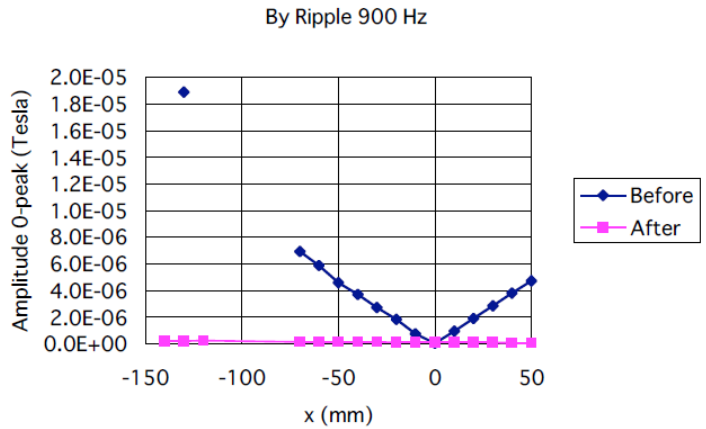
# Cabling Network improvements

K. Sato and H. Toki NIM A565(2006) 351, JPSJ Vol.78 No.9(2009)




Symmetric configuration:

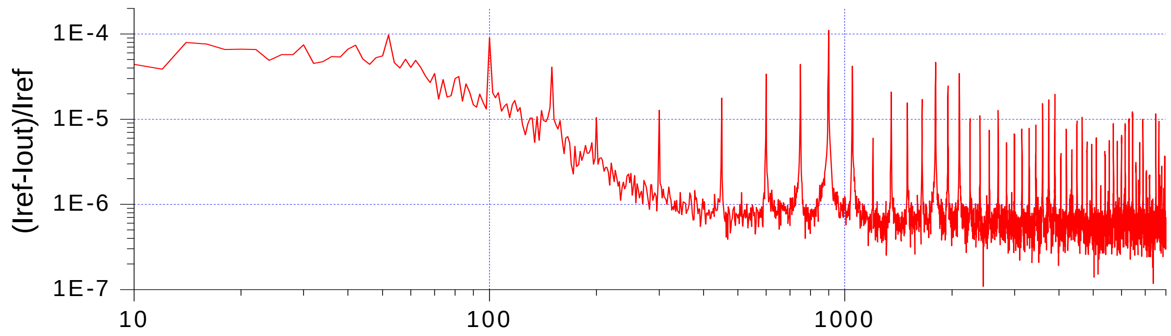
decouple normal and common mode

Same pole connection:

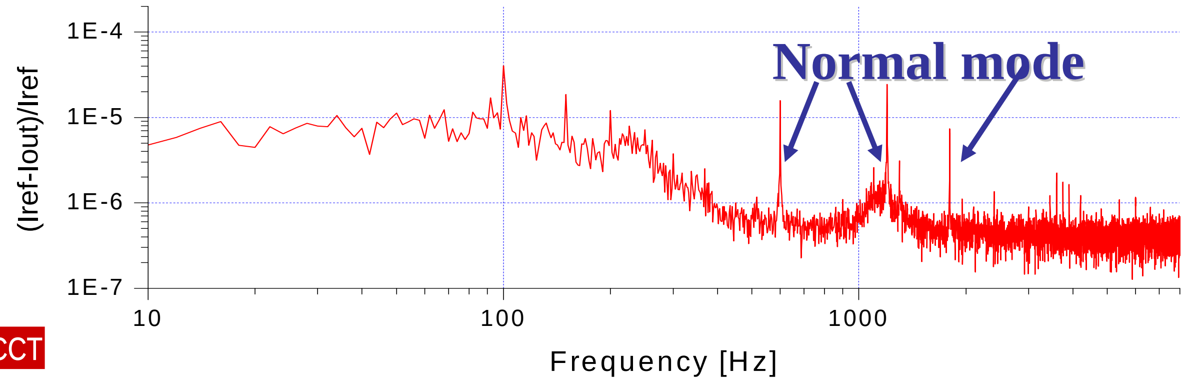
eliminate magnetic field by common mode

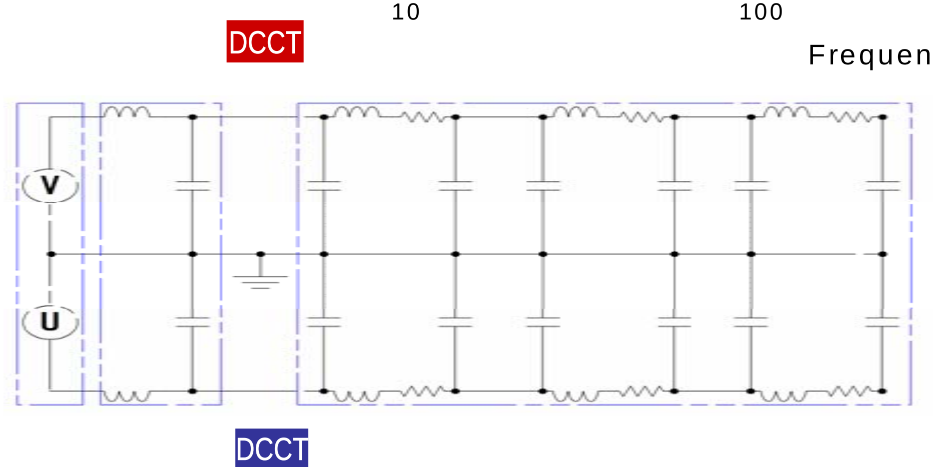
# FFT of P-N current

**Before symmetry (10/8)**




**After symmetry Q,B chain (10/29)**



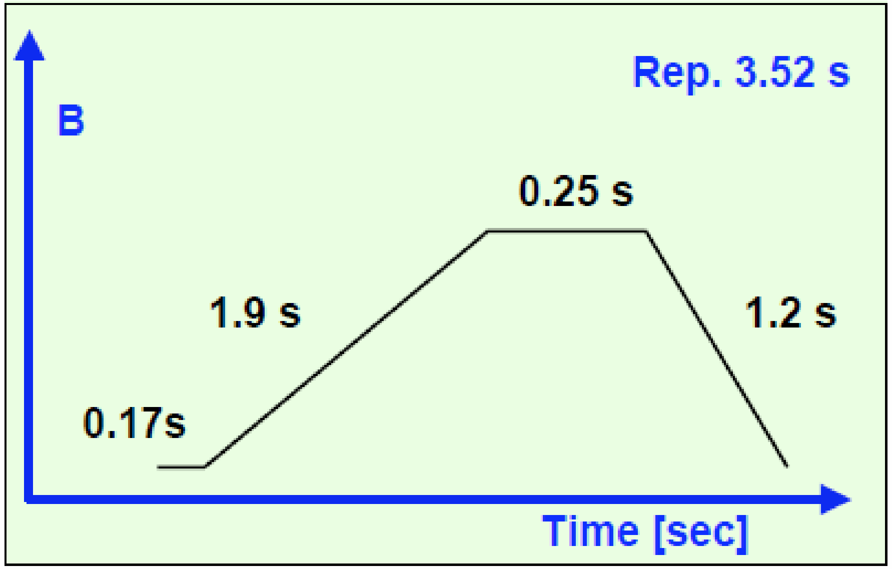
# Improvements in 2009 summer shutdown (July - September)

- Installation of spill feedback system for Slow Extraction
- Symmetric cabling of sextupole PS's for common mode noise reduction

For high repetition

- Installation of 5 th rf system
- Tuning of main magnet power supplies for higher repetition

5 th rf system installed in MR

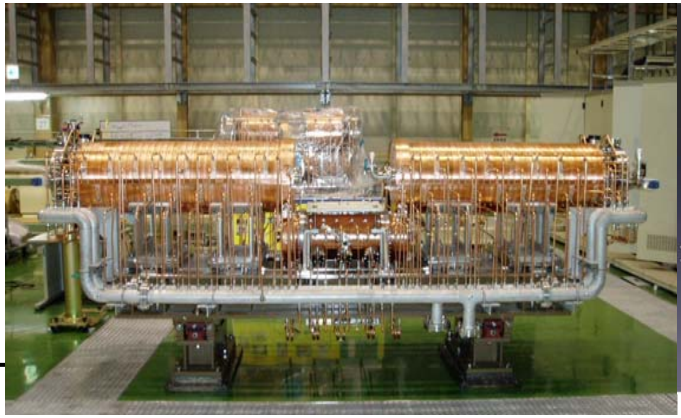


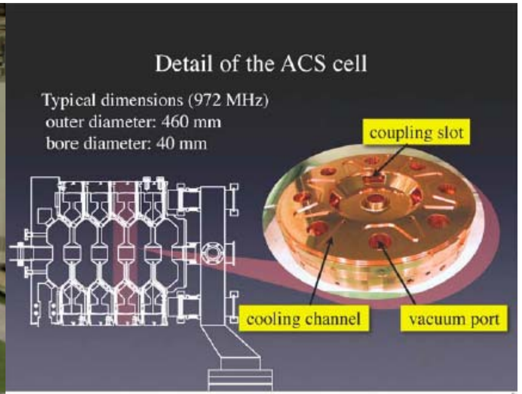

Main magnet pattern of FX operation for 2009 autumn RUN

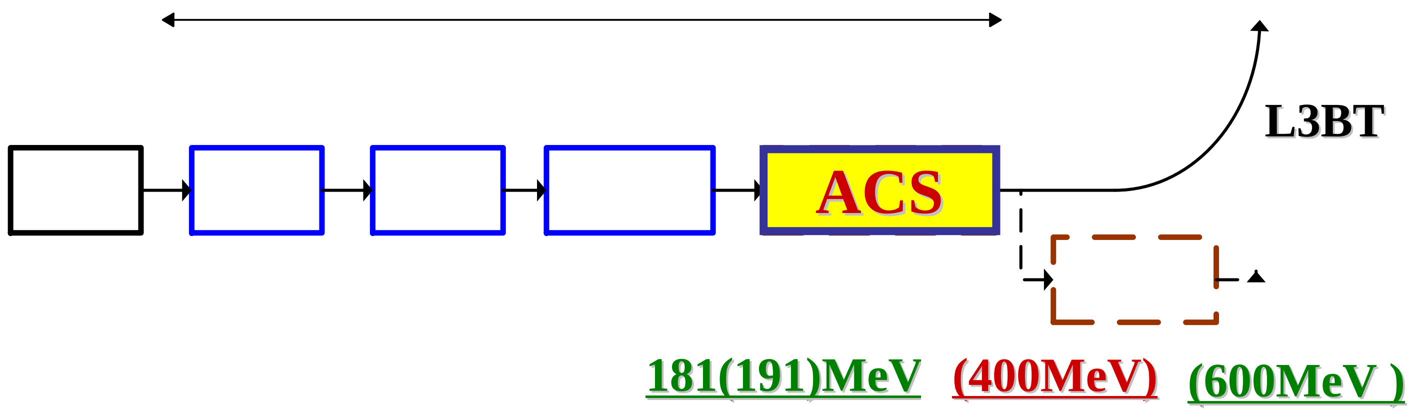
# By 2011 - Energy upgrade of the Linac: 181 to 400 MeV

- The current linac energy 181 MeV limits RCS power <600kW
- RCS 400 MeV injection is the necessary condition to achieve RCS 1MW- and MR 750 kW-operation
- The budget for 400 MeV energy upgrade was funded (2008~2011)
- The mass production of ACS (annular coupled structure) for high-β section is well underway

| | | |
|---|---|---|
| Energy | 190.8-400 | MeV |
| Frequency | 972 | MHz |
| Section Length | 108.3 | m |
| E0 | 4.1 | MV/m |
| RF pulse width | 0.6 | ms |
| Duty factor | 3 | % max |
| Number of modules | 21 | Acceleration |
| | 2 | Bunchers |
| | 2 | Debunchers |





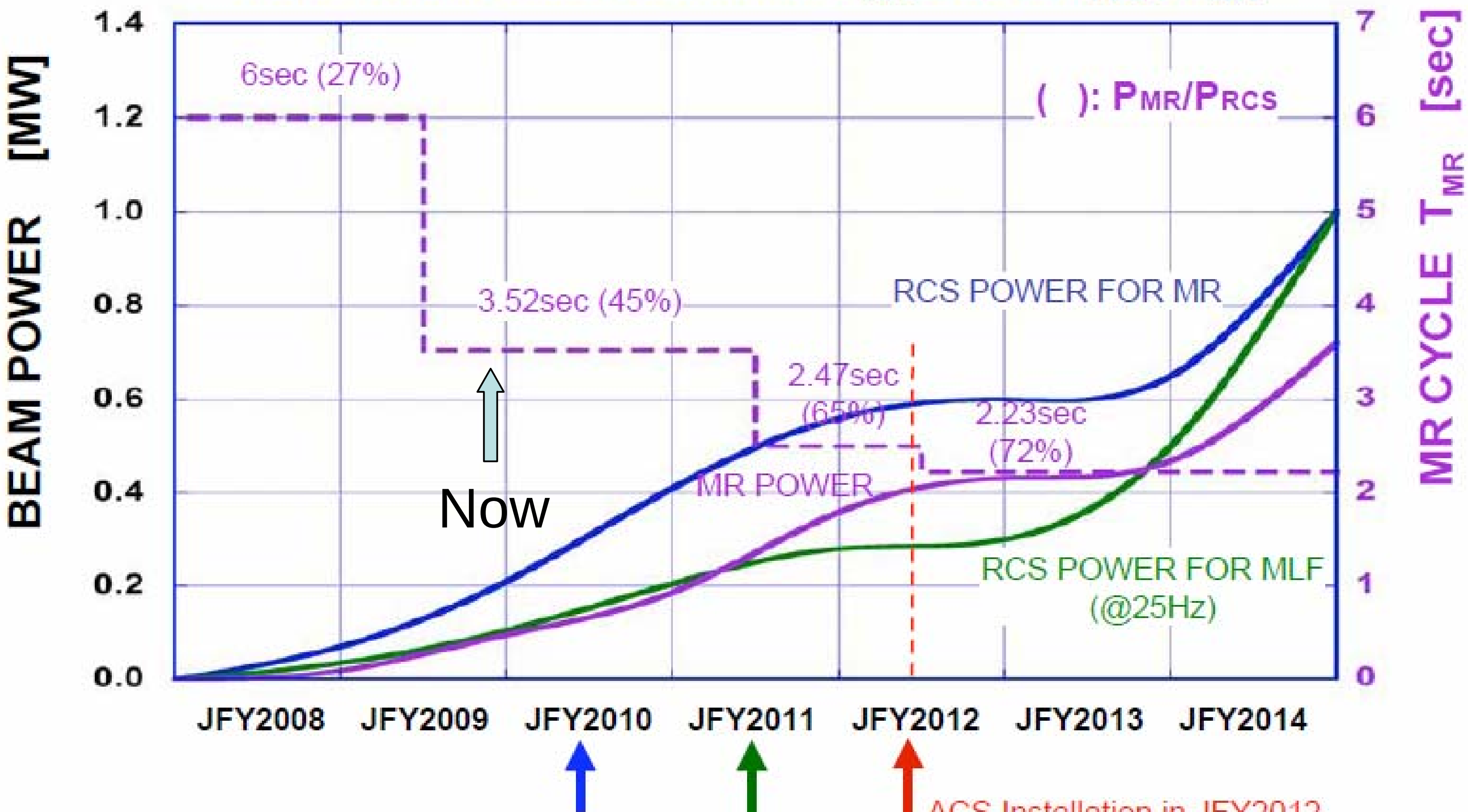

Block Diagram of the Linac



27

# Power upgrade plan of MR

For 8 bunches, 30 GeV at MR: $P_{MR}=1.6 \times (P_{RCS}/T_{MR})$




Collimator shields, RF (1st HH), FX kicker

Collimator shields, RF (6th F, 2nd HH), Inj. Sep 1

ACS Installation in JFY2012
400 MeV injection in the RCS

RF (3rd HH), Inj. Sep 2, FX Septa, ..

# Future Beyond T2K

- Study of CPV in lepton
  - MUST: Improve $\nu$ Beam Intensity further
  - MUST: Improve the Far Detector Quality in terms of volume and reconstruction precision
  - MUST consider Baseline+Angle ($E_\nu$ spectrum)

- Huge neutrino detector gives us rare and important opportunity to Discover Proton Decay
- Super Kamiokande has accumulated about 150 kton-year) and will continue to accumulating

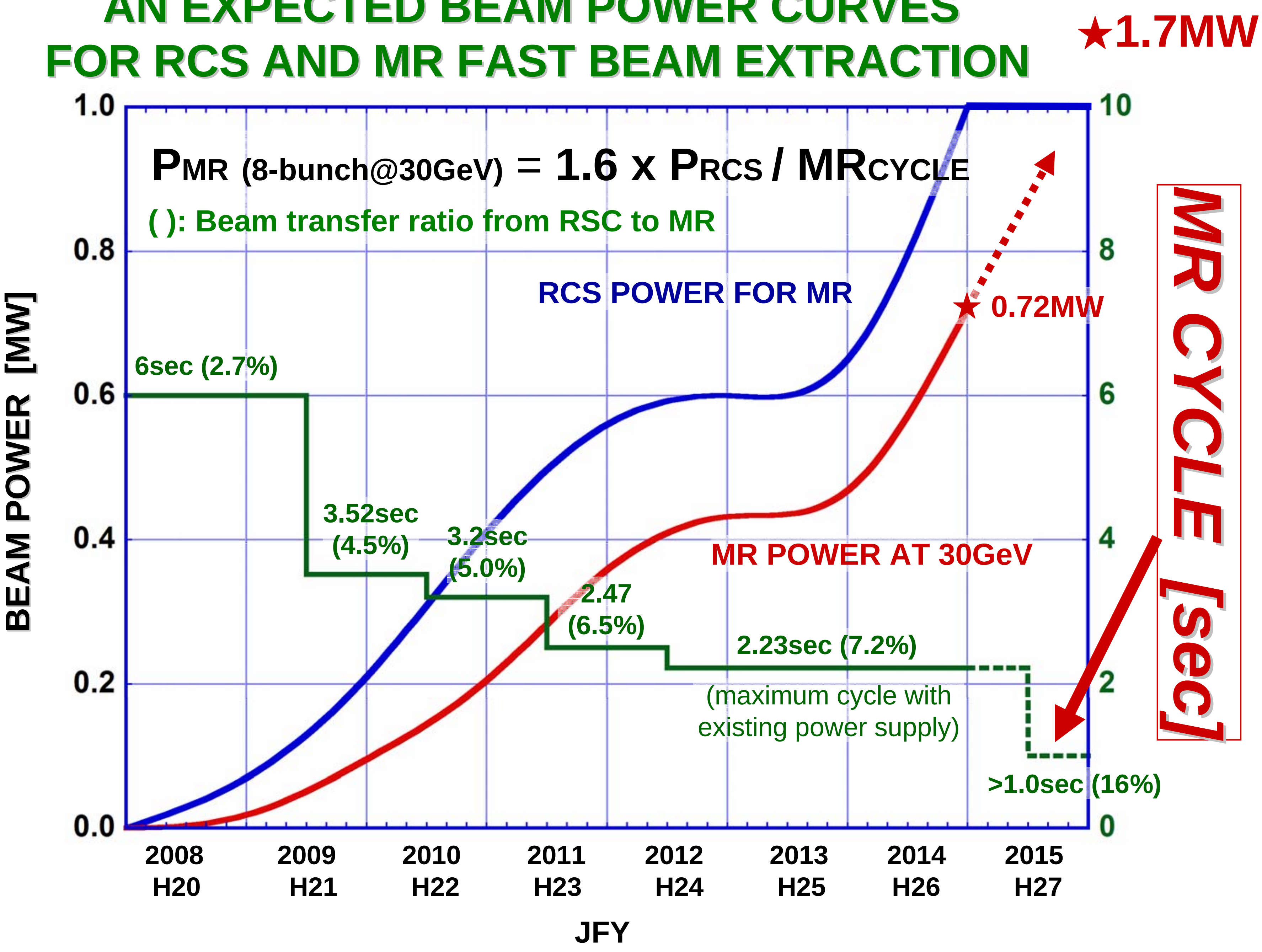
# Beyond MW beam

- Start continuous operation in end of 2009
  - RCS 300kW
  - MR >100kW

- 400MeV Linac energy upgrade is essential
  - RCS 1 MW
  - MR 750 kW
  - Installation in 2012

- Start R&D now toward realizing KEK Road map (MR 1.7 MW) by higher repetition rate
  - Magnet power supply
    - Compact, symmetric and standardized system
  - High gradient RF system (starting from material survey)

# AN EXPECTED BEAM POWER CURVES FOR RCS AND MR FAST BEAM EXTRACTION



# Experimental Options

How to approach Lepton Sector CP Violation

# $\delta$ : CP Violation in Lepton Sector

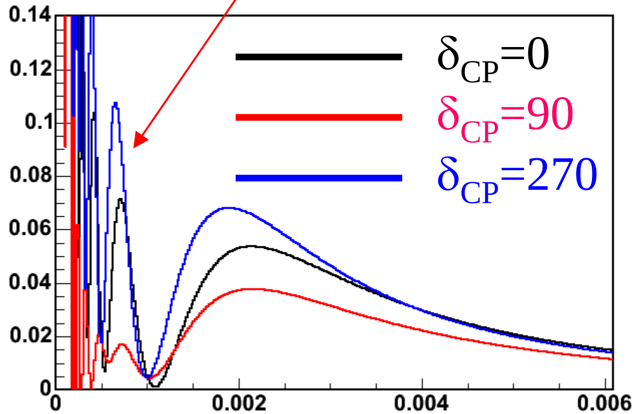
## Two approaches

$$P_{\alpha\beta} = \delta_{\alpha\beta} - 4\sum_{j>i} \mathrm{Re}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin^2 \frac{(m_j^2 - m_i^2)L}{4E_\nu}$$

$$\mp 2\sum_{j>i} \mathrm{Im}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin \frac{(m_j^2 - m_i^2)L}{2E_\nu}$$

Second Max.

$\propto \sin\theta_{12} \sin\theta_{23} \sin\theta_{13} \Delta m^2_{12} (L/E) \sin\delta$




$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\overline{\nu_\mu} \to \overline{\nu_e})}{P(\nu_\mu \to \nu_e) + P(\overline{\nu_\mu} \to \overline{\nu_e})} \approx \frac{\Delta m^2_{12}}{4E_\nu} \cdot \frac{\sin 2\theta_{12}}{\sin\theta_{13}} \cdot \sin\delta$$

E/L

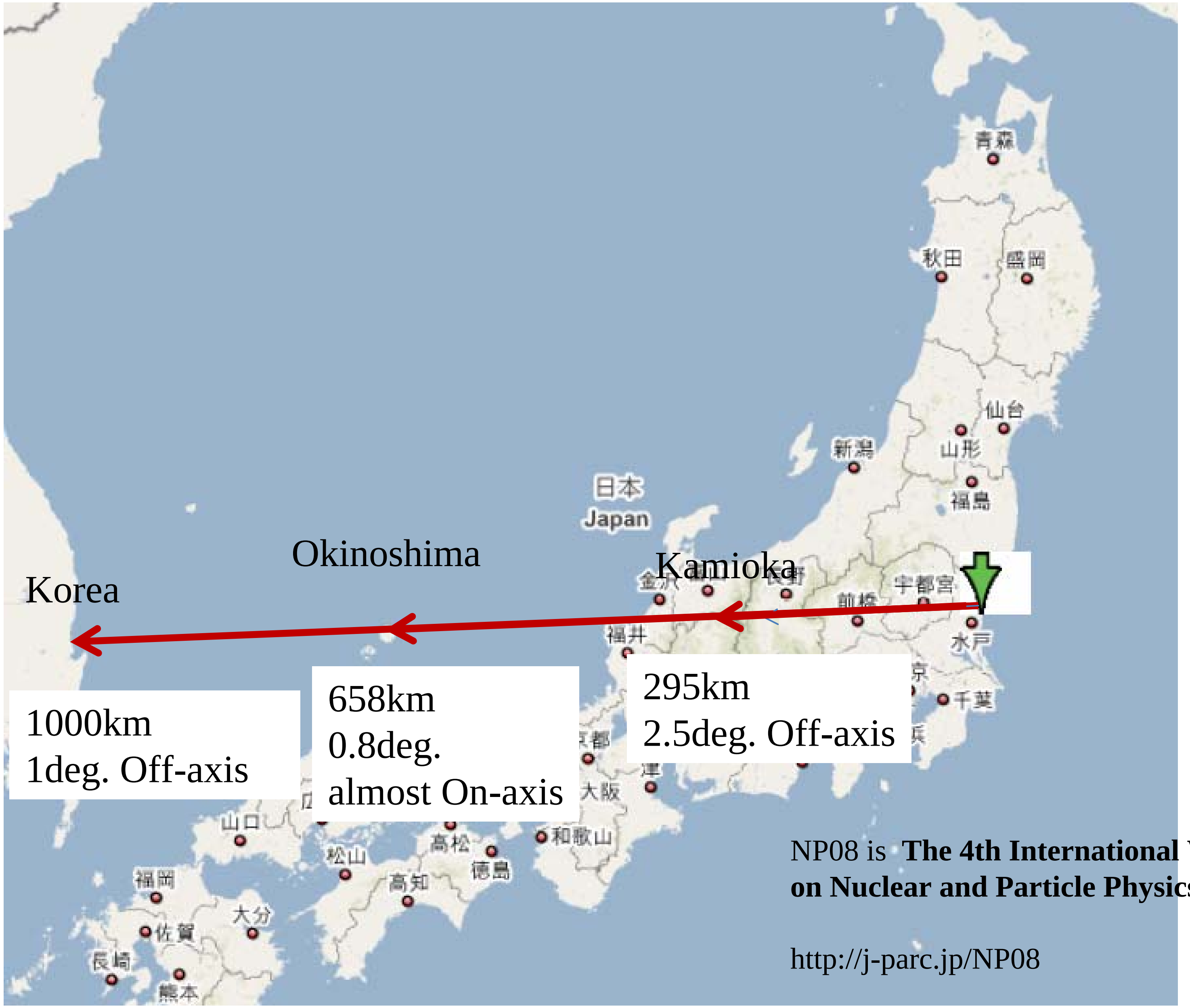
$\Delta m_{31}^2 = 2.5\times10^{-3}\ eV^2$
$\sin^2 2\theta_{13} = 0.1$
No matter effects

# Two Approaches to Lepton Sector CP Violation

- Effect of CP Phase $\delta$ appear as
  1. $\nu_e$ Appearance Energy Spectrum Shape
     - Peak position and height for 1st, 2nd maximum and minimum
     - Could investigate CP phase with $\nu$ run only
     - Need detector which has uniform reconstruction / bkg rejection efficiency over wide energy region sub-~several GeV
  2. Difference between $\nu_e$ and $\bar{\nu}_e$ oscillation
     - Neutrino & anti-neutrino cross section difference, contamination ($\nu \rightarrow$anti-$\nu$) , ….

- CP violation in K,B have NOT been discovered by the differences of particle and anti-particle
- Will it true also in neutrinos?

# 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

# Comparison of possible scenarios

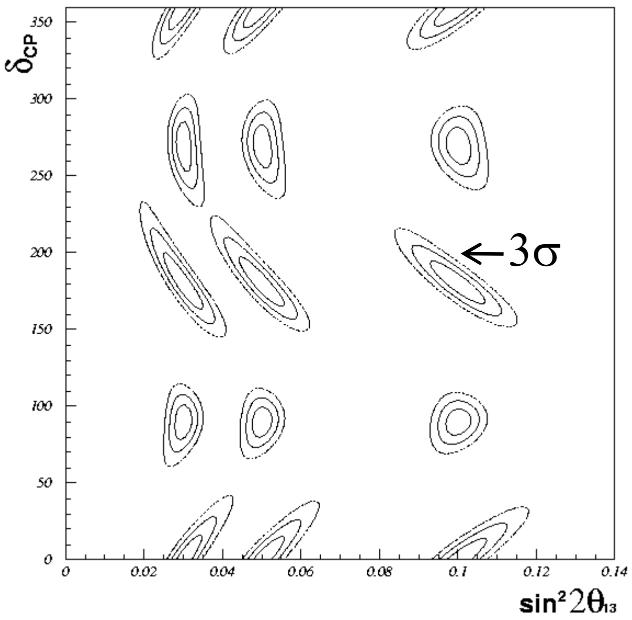
| | Scenario 1 Okinoshima | Scenario 2 Kamioka | Scenario 3 Kamioka Korea |
|---|---|---|---|
| Baseline(km) | 660 | 295 | 295 & 1000 |
| Off-Axis Angle(° ) | 0.8(almost on-axis) | 2.5 | 2.5 1 |
| Method | $\nu_e$Spectrum Shape | Ratio between $\nu_e$ $\bar{\nu}_e$ | Ratio between 1st 2ndMax<br>Ratio between $\nu_e$ $\nu_e$ |
| Beam | 5 Years $\nu_{\mu}$,<br>then Decide Next | 2.2 Years $\bar{\nu}_{\mu}$,<br>7.8 Years $\nu_{\mu}$, | 5 Years $\bar{\nu}_{\mu}$,<br>5 Years $\nu_{\mu}$, |
| 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

# Scenario 1

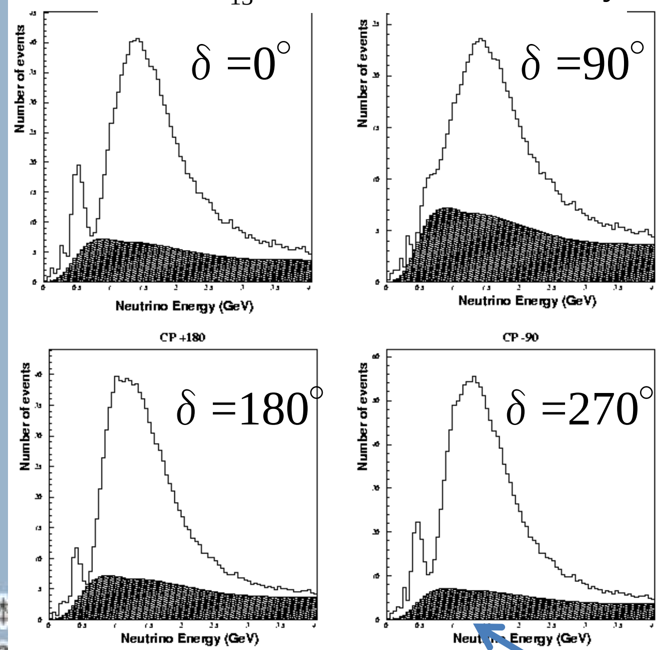
- Cover 1st and 2nd Maximum
- Neutrino Run Only 5Years × 1.66MW
- 100kt Liq. Ar TPC
  - -Good Energy Resolution
  - -Good e/$\pi^0$ discrimination
- Keeping Reasonable Statistics

CP Measurement Potential




$\nu_e$ Spectrum

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




Beam $\nu_e$ Background

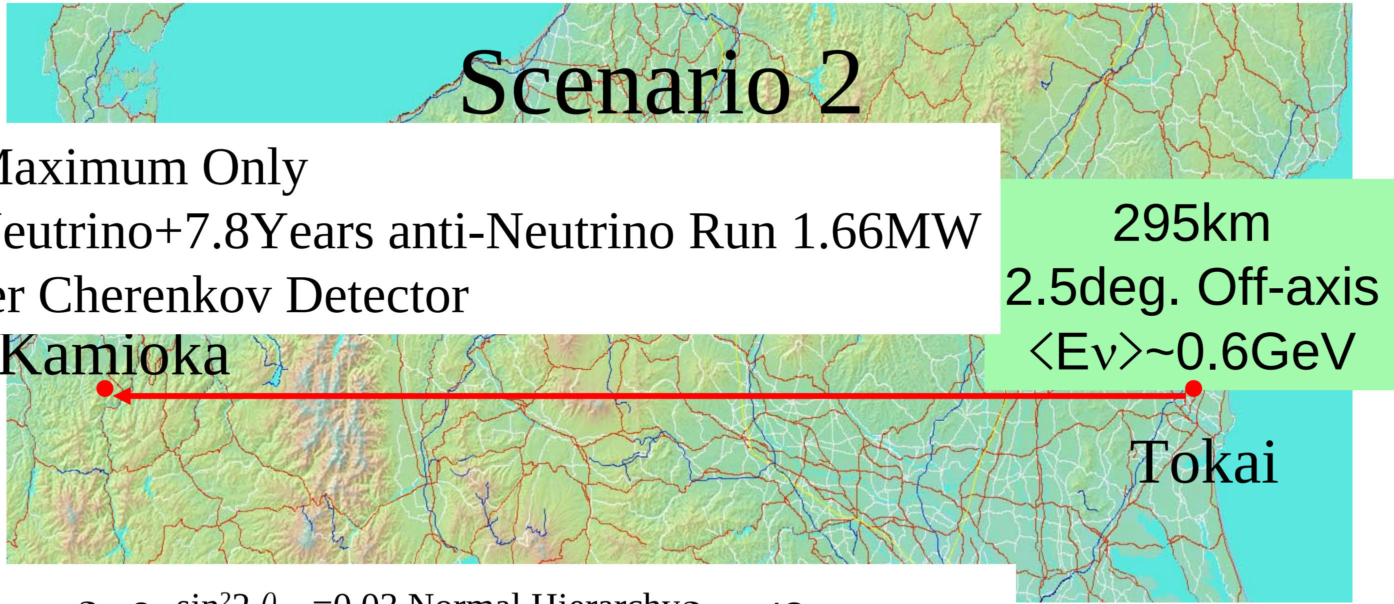
Okinoshima

658km
0.8deg. almost On-axis

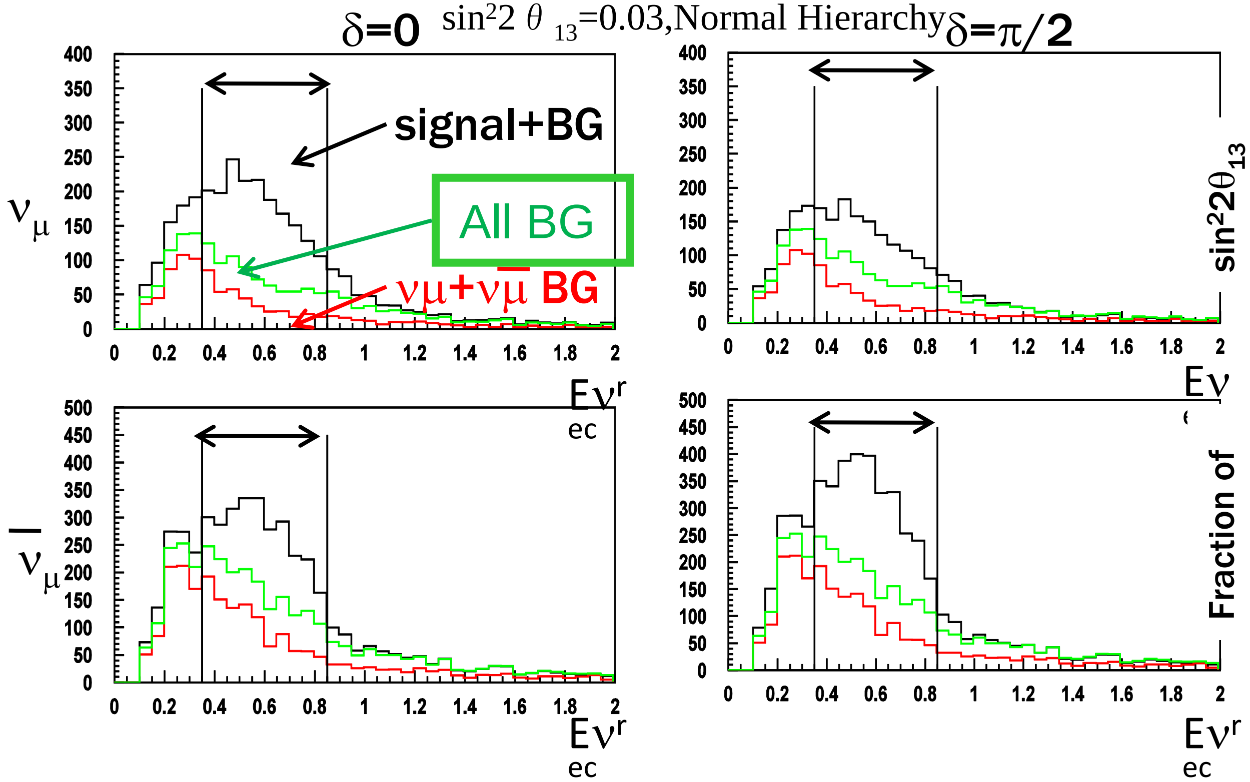
NP08, arXiv:0804.2111

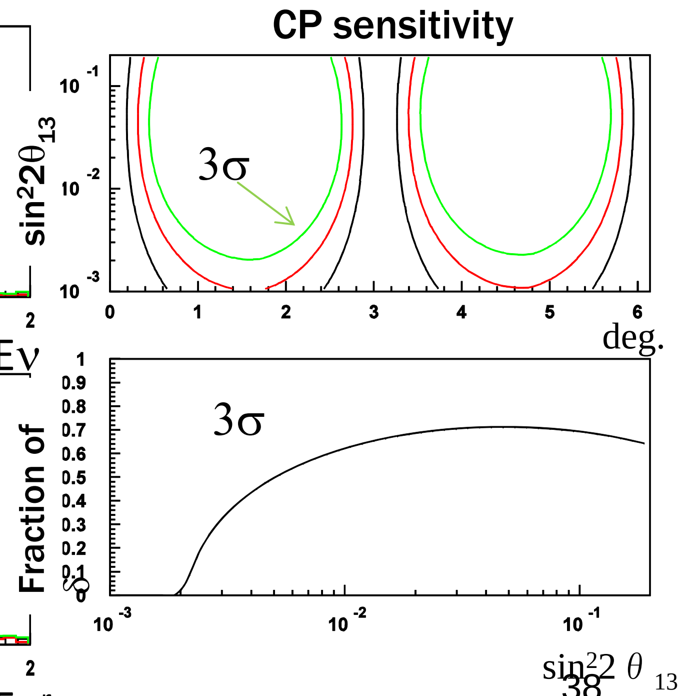
# Scenario 2

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




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

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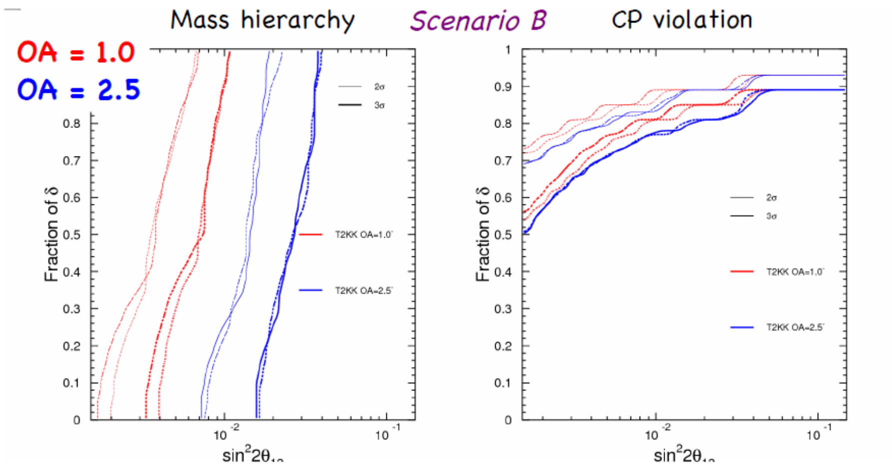
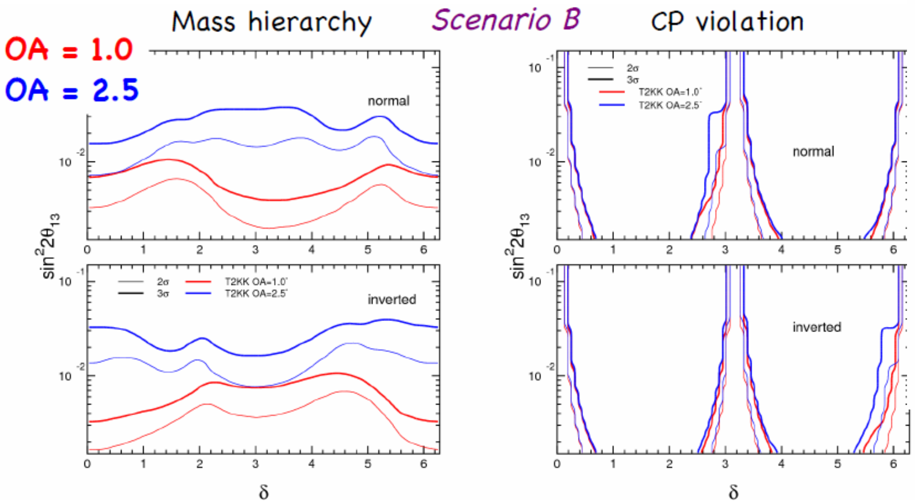
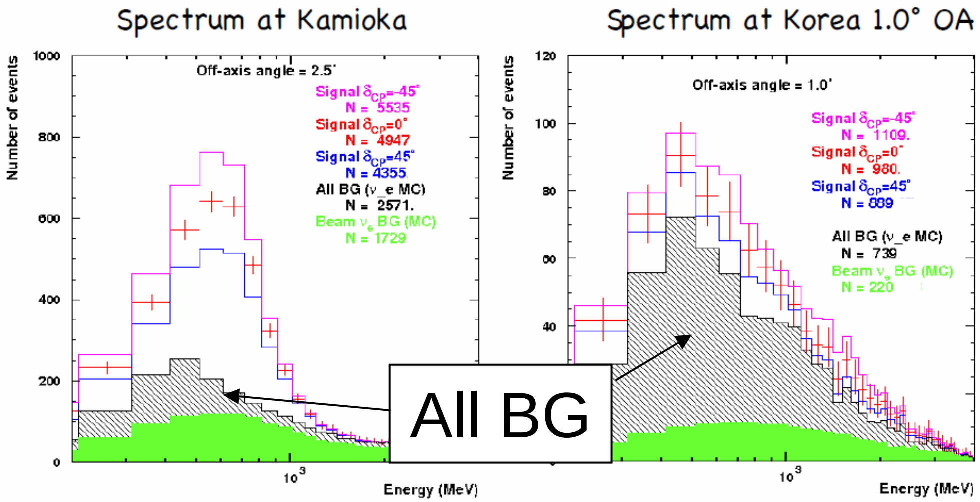
# Scenario 3

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


Sin²(2θ13)=0.04, neutrino, normal hierarchy, Scenario B

F.Dufour@NP08

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

# Summary
# Accelerator Based Neutrino Project in Japan

## Short Term

- Beam commissioning of J-PARC MR and of J-PARC Neutrino Beam Facility has started
- 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 $\nu_e$ appearance
- Start R&D toward MW-class power frontier machine and large detector

## Mid Term

- T2K data with 1-2MW $\times 10^7$sec integrated proton power on target will provide critical information on $\theta_{13}$, which guides the future direction
- Complete T2K proposal of 3.75MW $\times 10^7$sec
- Fix next experiment

## Long Term

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