Apr. 27, 2009
GDR

Neutrino roadmap in Japan

Takashi Kobayashi

IPNS, KEK

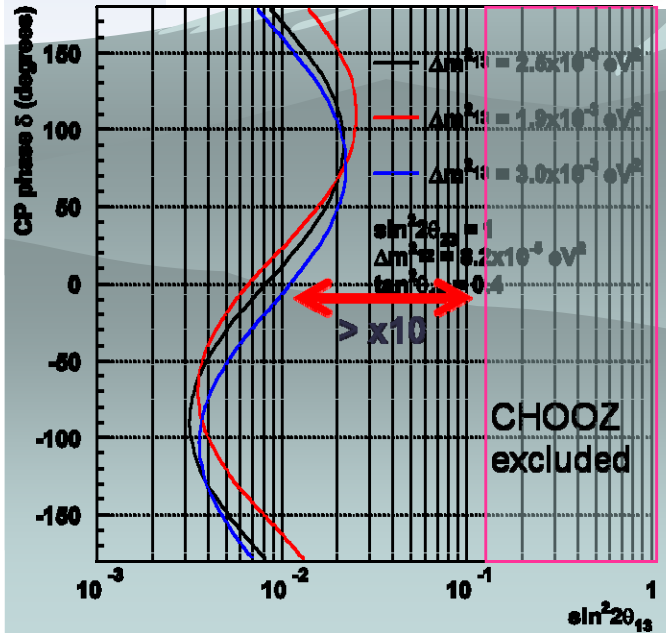
Contents

- T2K status and plan
- Future experiment to find
  - CPV in neutrino
  - proton decay

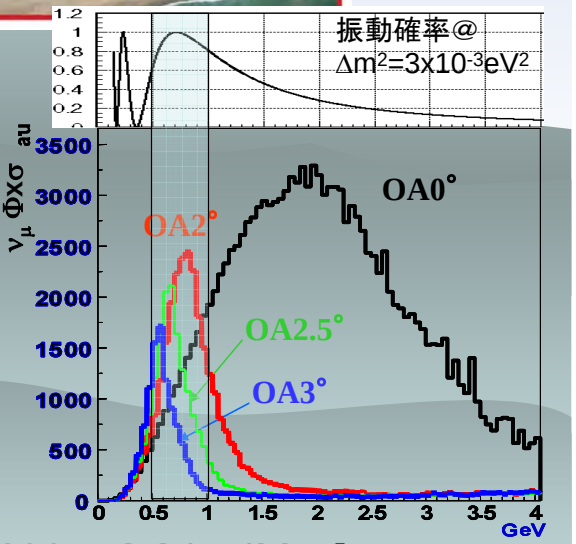
  with upgraded J-PARC and new huge detector
- Summary

Tokai-to-Kamioka (T2K) long baseline neutrino oscillation experiment

ν_e appearance (θ_{13})



- Goal
  - **Discover νe app.**
  - νμ disapp. meas.
- Intense narrow spectrum νμ beam from J-PARC MR
  - Off-axis w/ 2~2.5deg
  - Tuned at osci. max.
- SK: largest, high PID performance



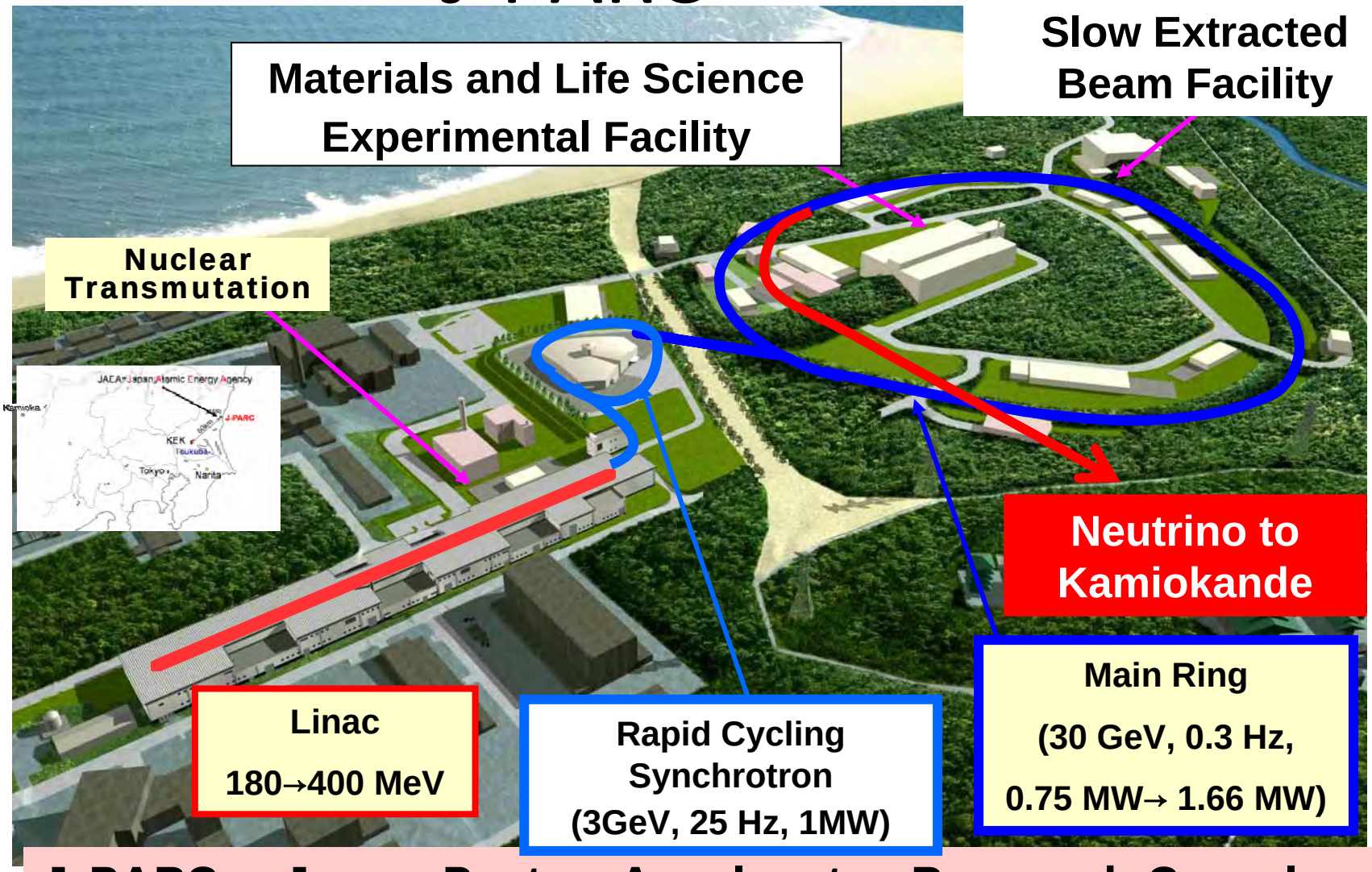
1600ν_μCC/yr/22.5kt (2.5deg)

T2K Collaboration

~ 400 members from 12 Countries

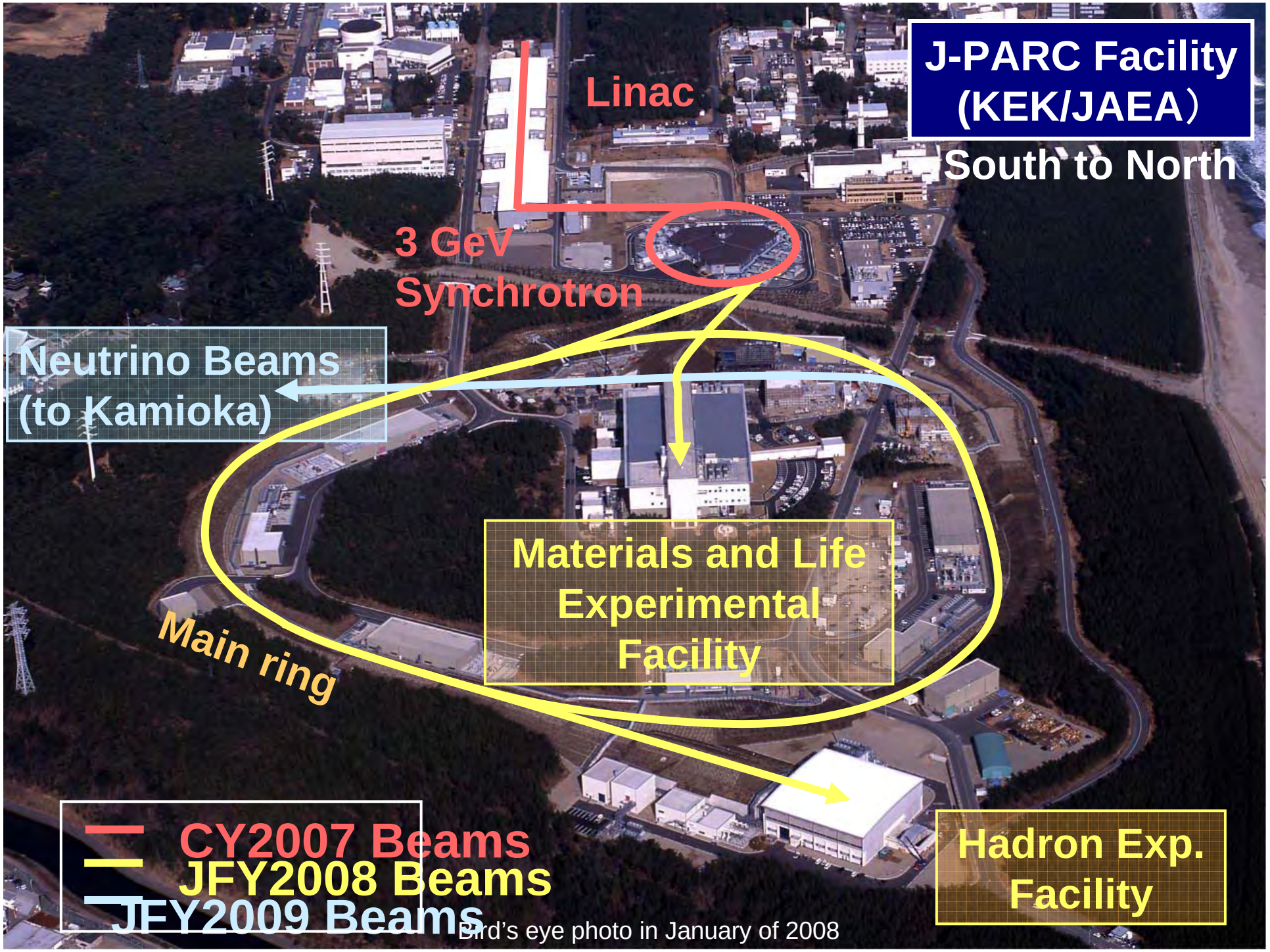
Japan, US, Canada, France, UK, Switzerland, Poland, Korea, Russia, Spain, Italy, Germany

J-PARC



J-PARC = Japan Proton Accelerator Research Complex

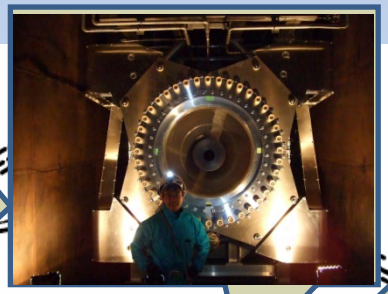
Joint Project between KEK and JAEA


J-PARC Facility
(KEK/JAEA)
South to North
Linac
3 GeV
Synchrotron
Neutrino Beams
(to Kamioka)
Materials and Life
Experimental
Facility
Main ring
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Hadron Exp.
Facility
Bird's eye photo in January of 2008

Neutrino beamline

Neutrino monitor build.

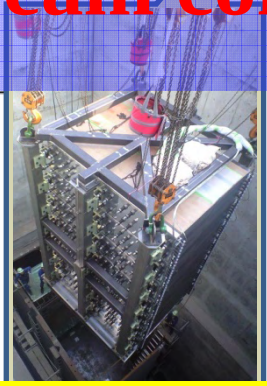
Electromagnetic horn



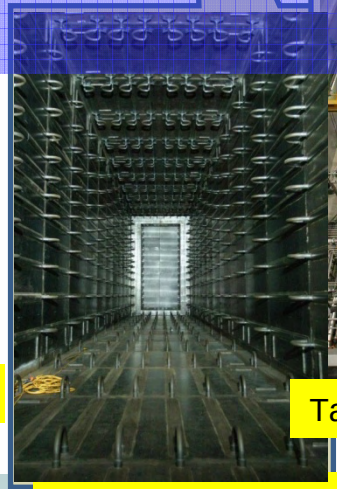
Graphite target

- **5 year construction 2004~2009**
- **Construction completed on schedule!**
- **Start beam commissioning in April 2009!**

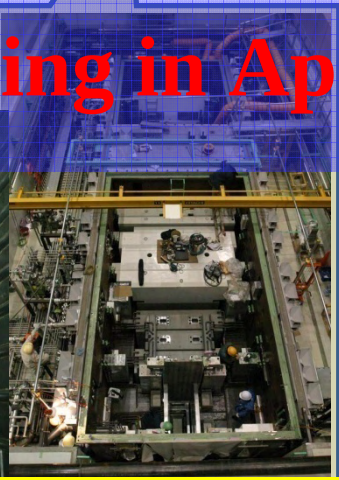
UA1 magnet donated from CERN installed in Apr-Jun, 2008 on schedule



Beam dump completed



Decay volume completed



Target station completed

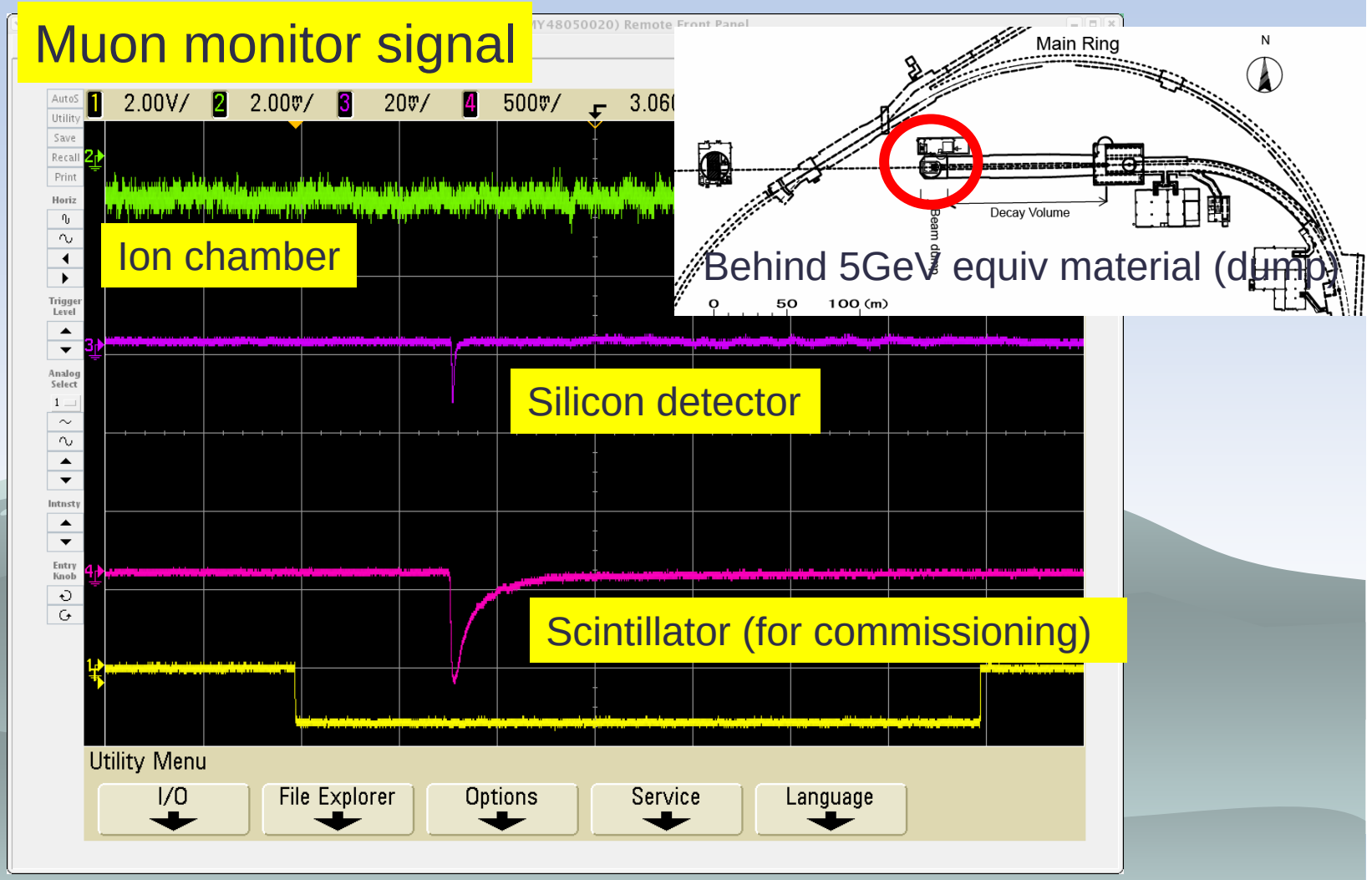
Primary proton beam line completed

Beam commissioning in Apr-May

- Expected condition
  - Beam Intensity: ~0.1% (single bunch) of design int.
    - ~4×10^{11}p/pulse (cf: design ~3×10^{14}p/pulse)
  - Target & Horn1 installed (horn2,3 not yet)
- Goals of the commissioning
  - Extract and transport the proton beam to the target
  - Observe muons which comes from decays of pions produced at the target and focused by the horn1 by muon monitors
  - Pass government inspection during operation

T2K beamline started operation!

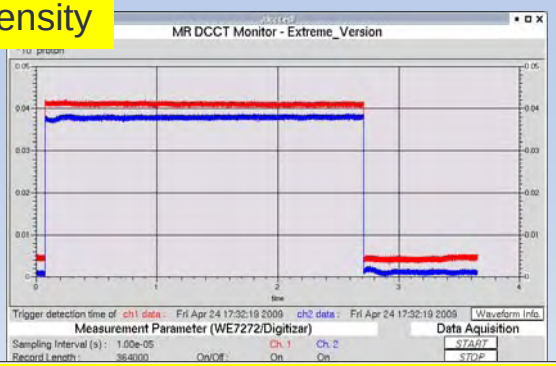
First shot after turning on SC magnets at 19:09, Apr.23, 2009



First observation of muons produced in neutrino beamline

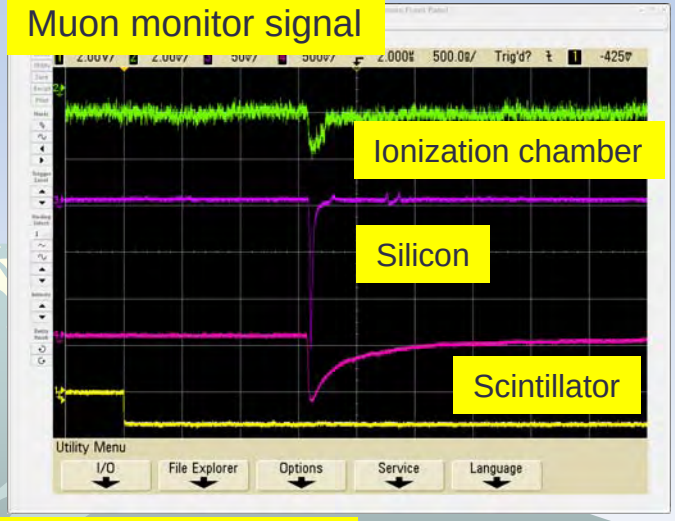
T2K beamline started operation!

MR intensity

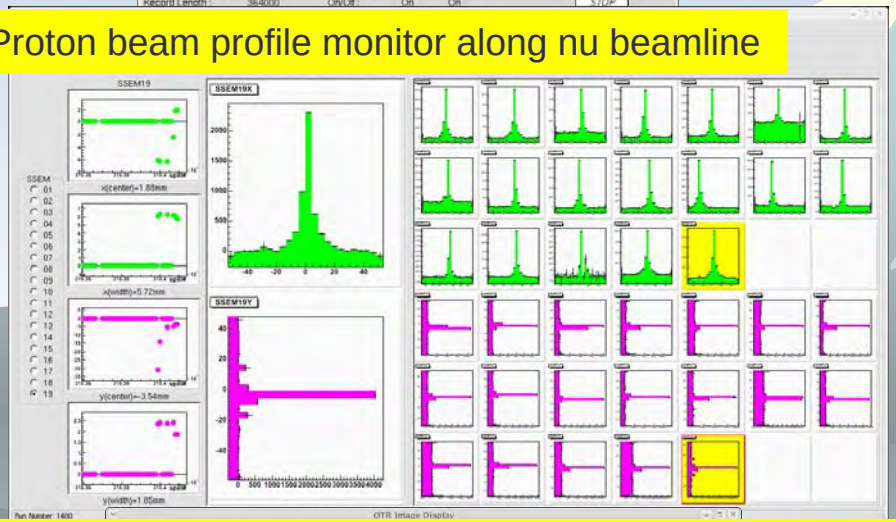


After ~10 shots for tuning, proton beam hit around target center

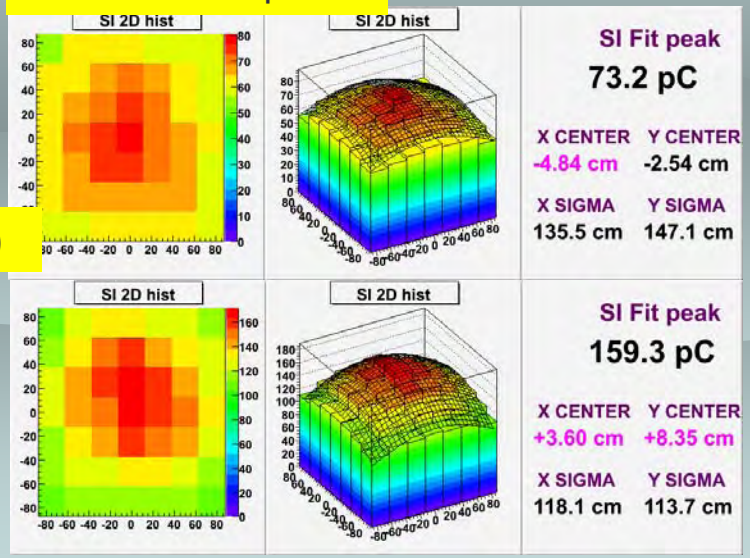
Muon monitor signal



Proton beam profile monitor along nu beamline



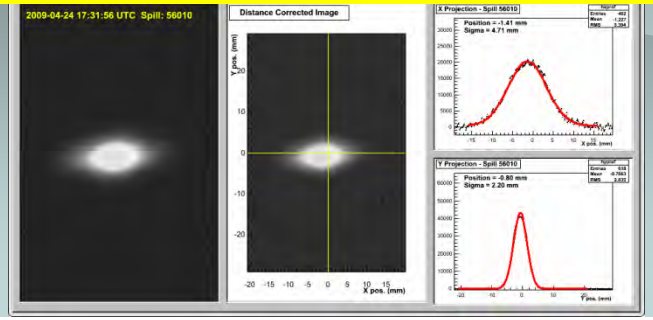
Muon monitor profile



Horn Off

Horn 250kA

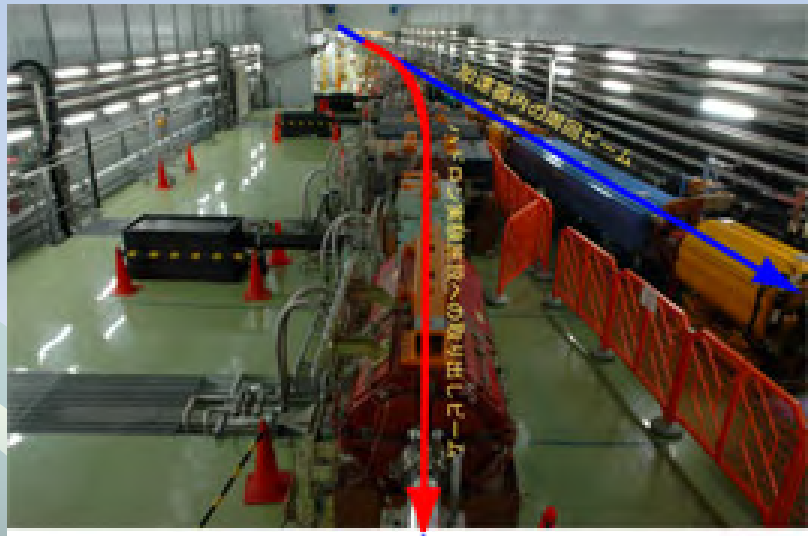
OTR detector just in front of target (fluorescence plate)



T2K beamline started operation!

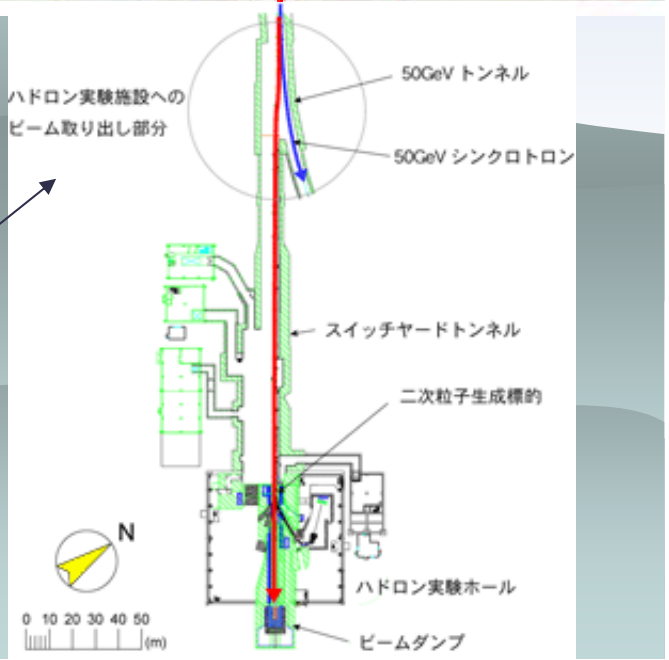
J-PARC Accelerator Status and Commissioning Plan

@ PAC meeting



Recent milestones:

- ➢December 23, 2008:
  - ❖30 GeV beam acceleration and fast extraction to the beam abort dump
  - ❖MLF user run (20kW)
- ➢January 27, 2009:
  - ❖Beam extraction to the Hadron Experimental hall using slow beam extraction system
- ➢February 19, 2009:
  - ❖ Government inspection for radiation safety



Beam commissioning has been accomplished on schedule,
BUT with low intensity.
Real challenge toward the power frontier machine just started.

1. Many issues (unreliable components, design etc.) to be solved
2. Beam must be provided to the users
3. Power upgrade should be also accomplished steadily.

- RFQ discharge problem:
- RF core long term stability problem:
- Stability of MR power supply and beam loss

  - No problem for fast extraction with a level of 100kW operation
  - Need more stability for slow extraction

  - Clearly need major improvement for MW operation

Plan of MR 100 kW trial in JFY2009

- **First Quarter: April, May, June-run**
  - Fast extraction: establish neutrino primary beam line orbit
  - Hadron hall: Construction of beam line
  - Neutrino Target Station (Installation of horn #2&3 from july)
- **Second Quarter: July, August, September - Machine Shutdown**
  - Installation of EQ and RQ for spill control
  - Maintenance and/or upgrade of troubled components
- **Third Quarter: October, November, December-run**
  - FX: Power upgrade
  - SX: Spill control and power upgrade by reducing beam loss
- **Fourth Quarter: January, February, March-run**
  - FX : Power upgrade

- Beyond 100kW from 2010: 100→500kW
  - Space charge effect and collimator scenario
- Long term: toward MW and beyond
  - Enlarging aperture of accelerator
  - Improvement of power supply
    (high repetition cycle, stability→minimize beam loss)
  - LINAC 400MeV operation and RCS h=1 operation

T2K Mid-term Schedule

- April-May, 2009
  - First beam commissioning w/ target/horn1
  - Mid. May: Pass governmental inspection
- June~Sept, 2009 (during scheduled shutdown)
  - Horn 2 and 3 installation and operation test
- Fall~Winter, 2009
  - Beam/Detector commissioning w/ full configuration
    - Target/horn1,2,3
    - Full 280m detector configuration
- Winter JFY2009 ~ Summer 2010
  - As soon as ~100kW stable acc operation achieved,
  - Physics run at ~100kW x10^7s by Summer 2010
  - First physics results in 2010
  - → Exceed sensitivity of present world record result from Chooz experiment
- After Summer 2010 (after RFQ replacement)
  - Physics data taking with > a few 100kW
  - Next milestone: 1~2MW.yr = ~300kWx3~6yr= ~500kWx2~4yr
  - Final goal: 3.75MW.yr (approved by PAC)

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  - CPV in neutrino
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  with upgraded J-PARC and new huge detector
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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.

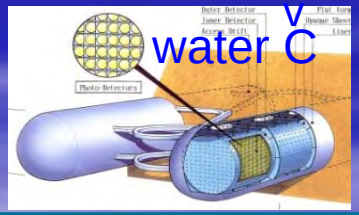
Intensity Upgrade

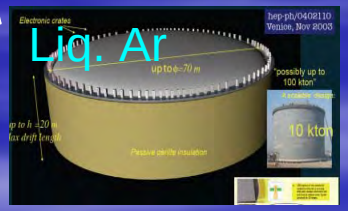
Detector R&D

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

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

h=2: 2 bunches × 4cycle injection to MR
h=1:Single bunch with doubled no. of proton × 8cycle injection

Lepton Sector CP Violation

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

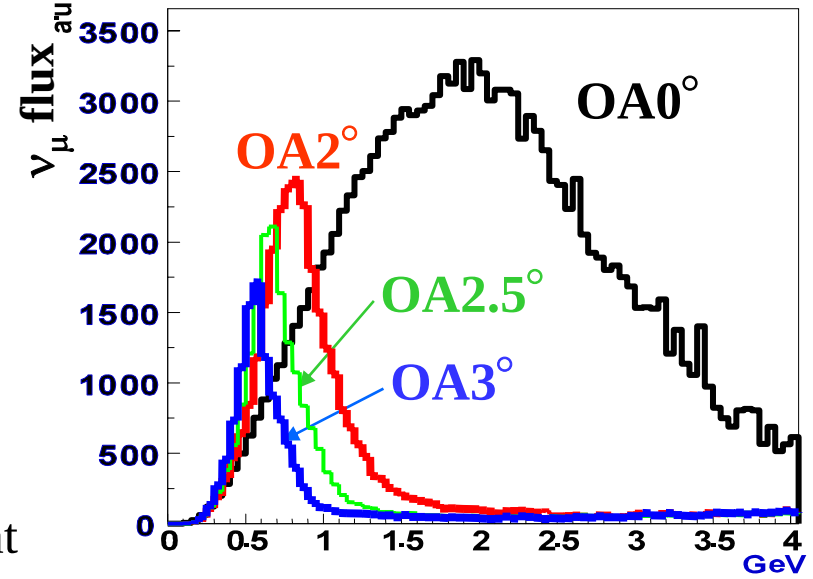
Effect of CP Phase δ appear as

- 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

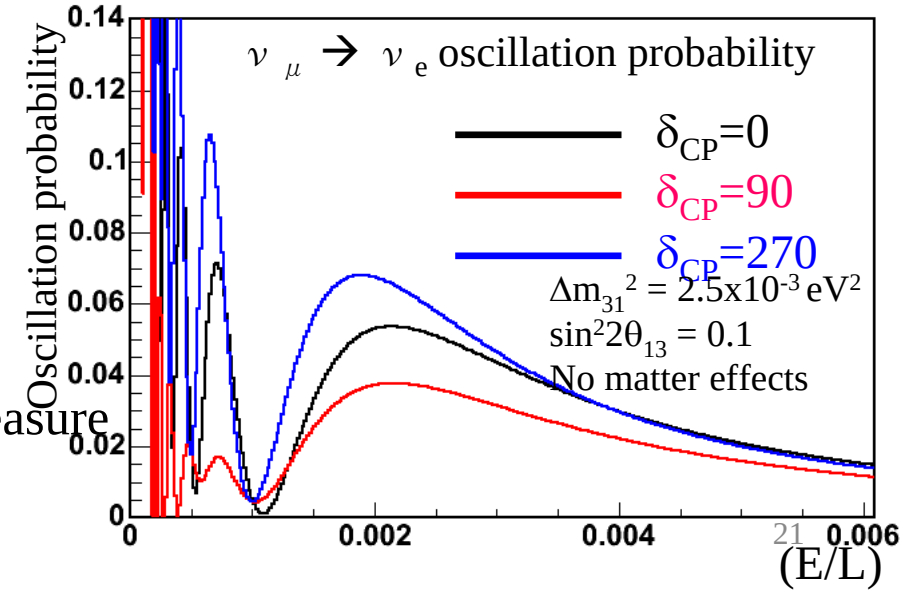
Angle and Baseline

- Off-axis angle
  - 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

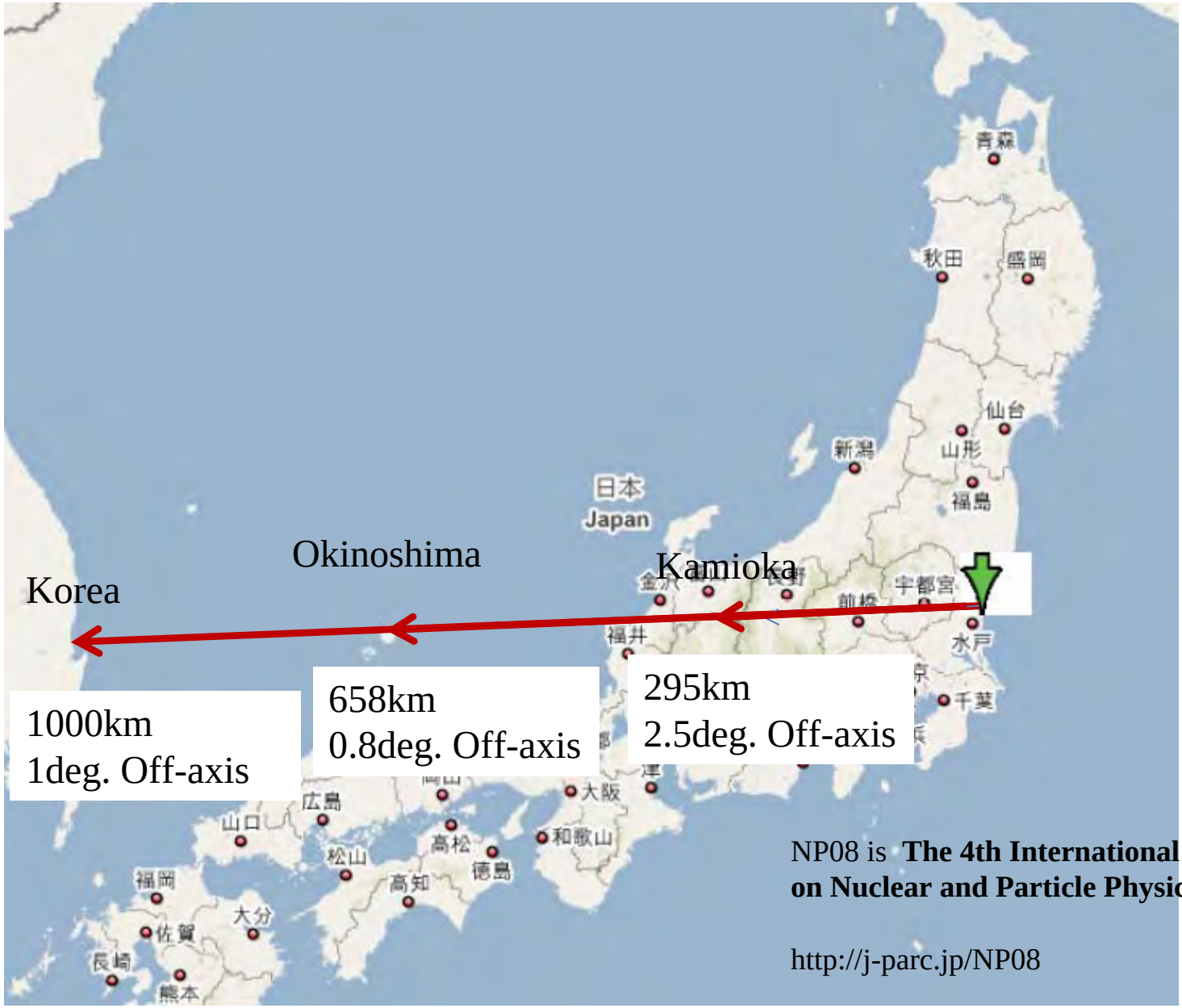
→ Counting Experiment



- 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**

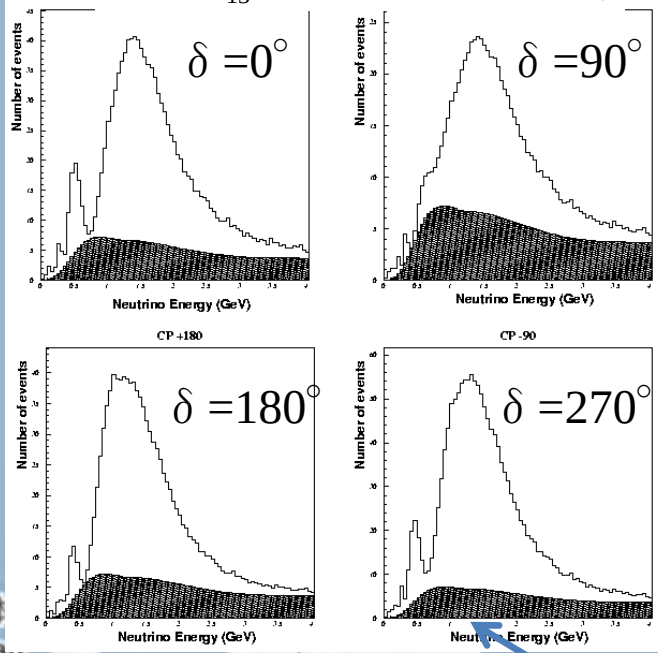
http://j-parc.jp/NP08

Scenario 1

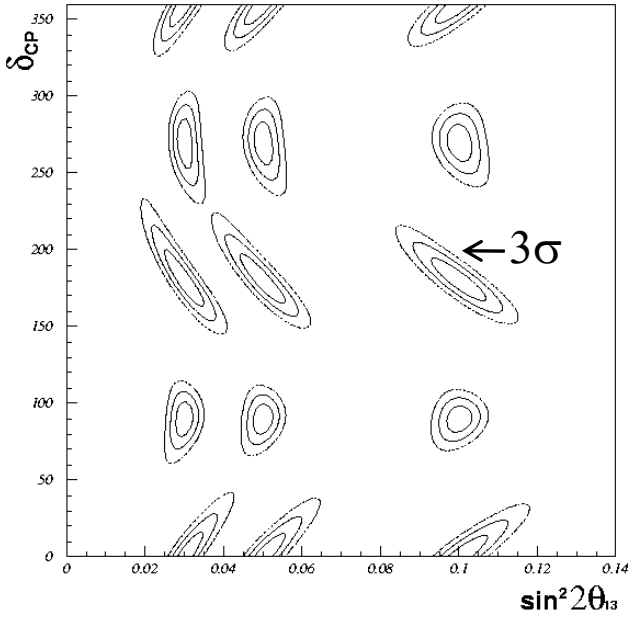
- Cover 1st and 2nd Maximum
- Neutrino Run Only 5Years × 1.66MW
- 100kt Liq. Ar TPC
  - -Good Energy Resolution
  - -Good e/π^0 discrimination
- Keeping Reasonable Statistics

ν_e Spectrum

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



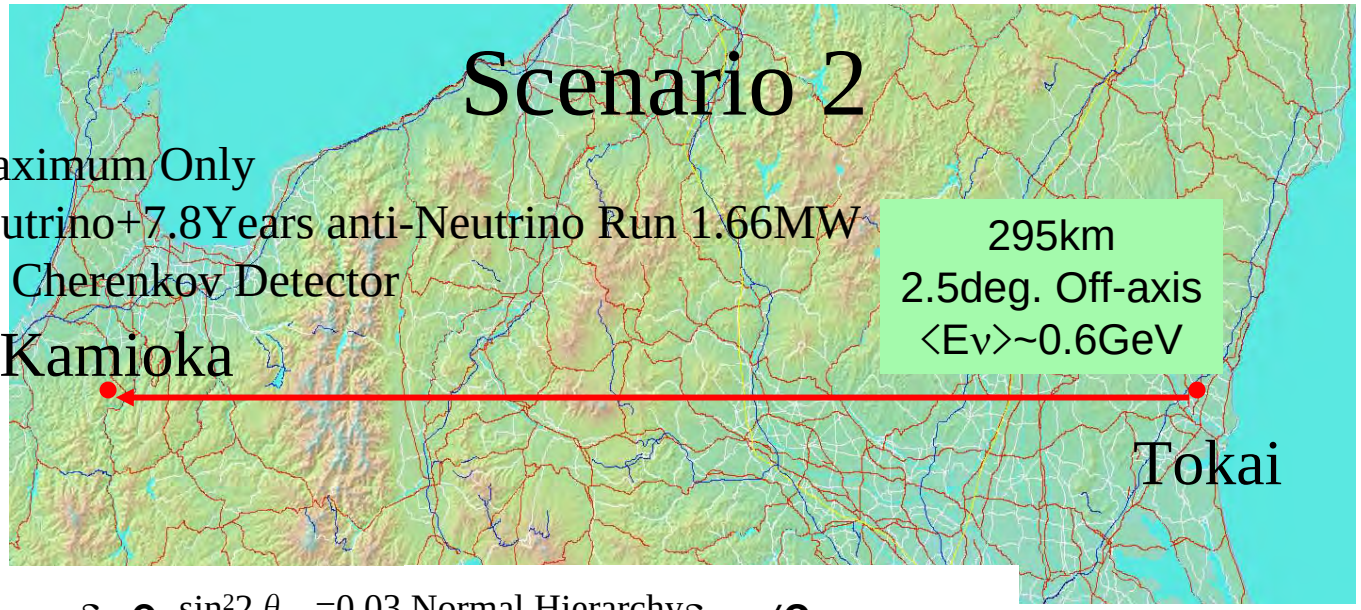
CP Measurement Potential

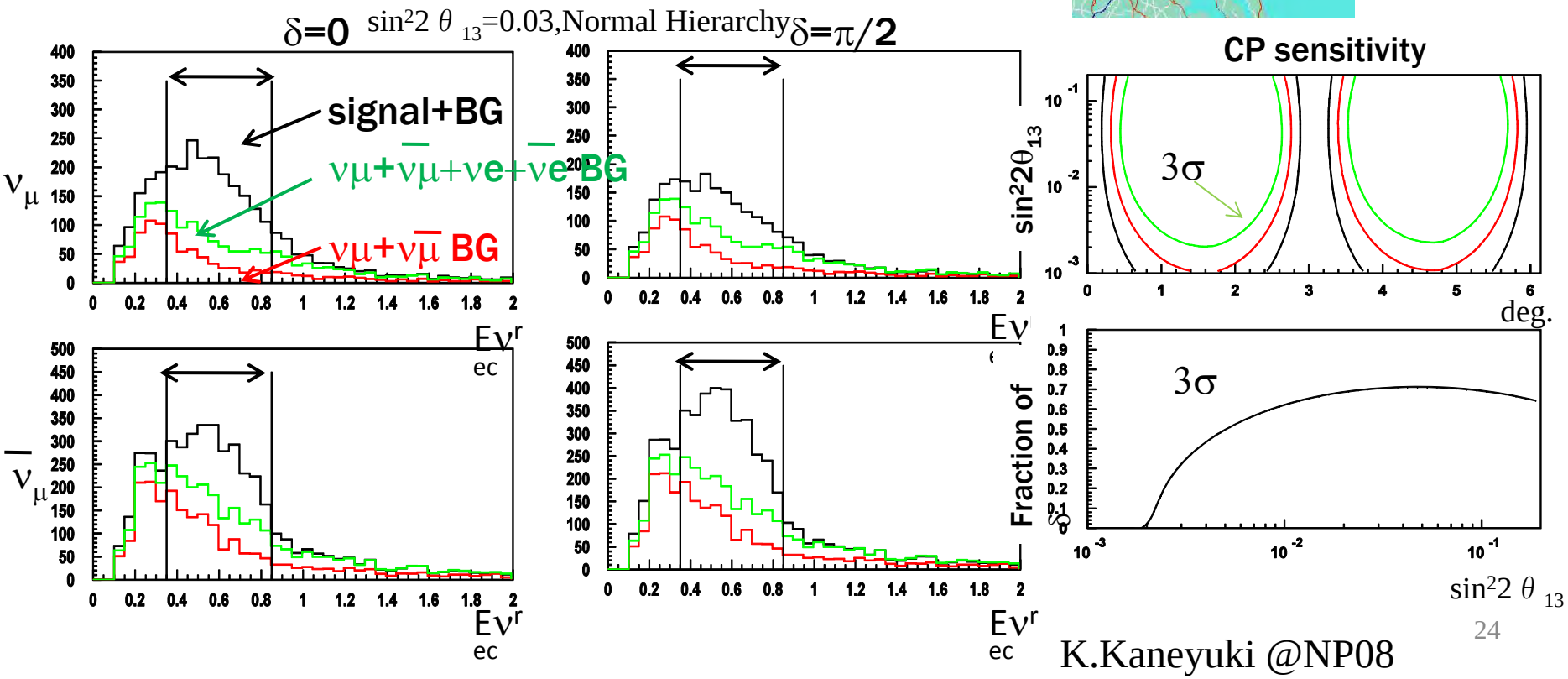


NP08, arXiv:0804.2111

Scenario 2

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

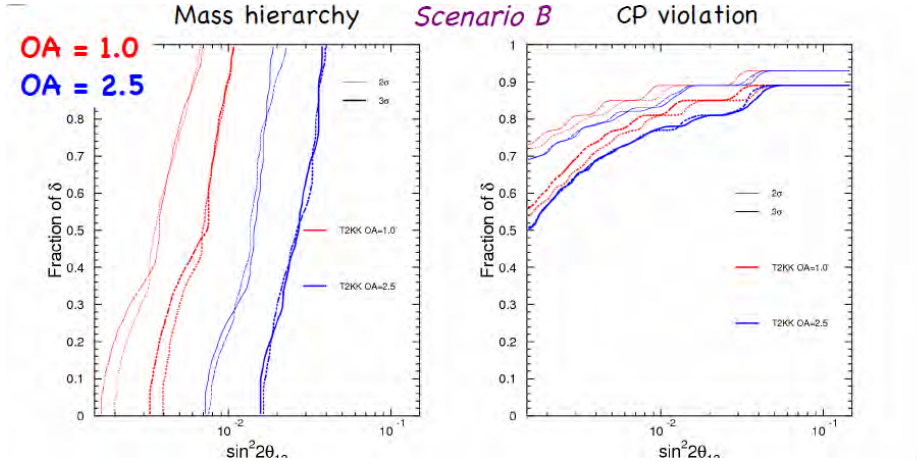


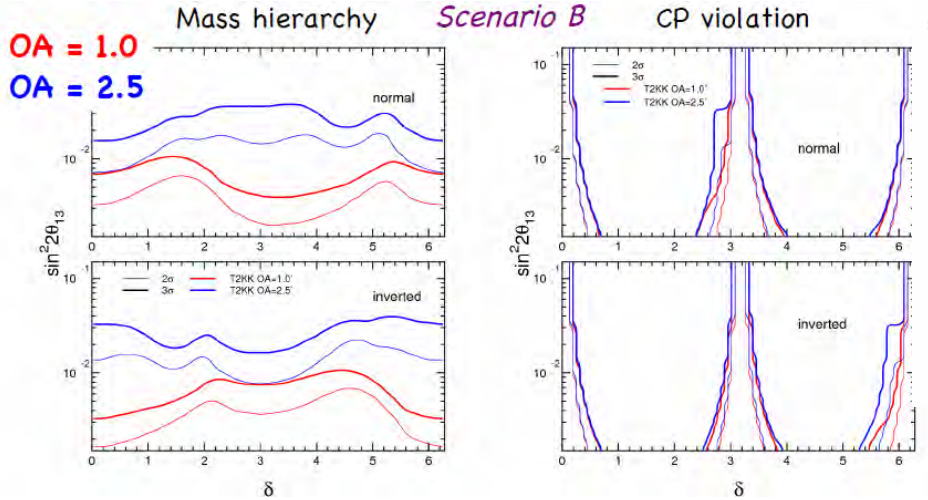


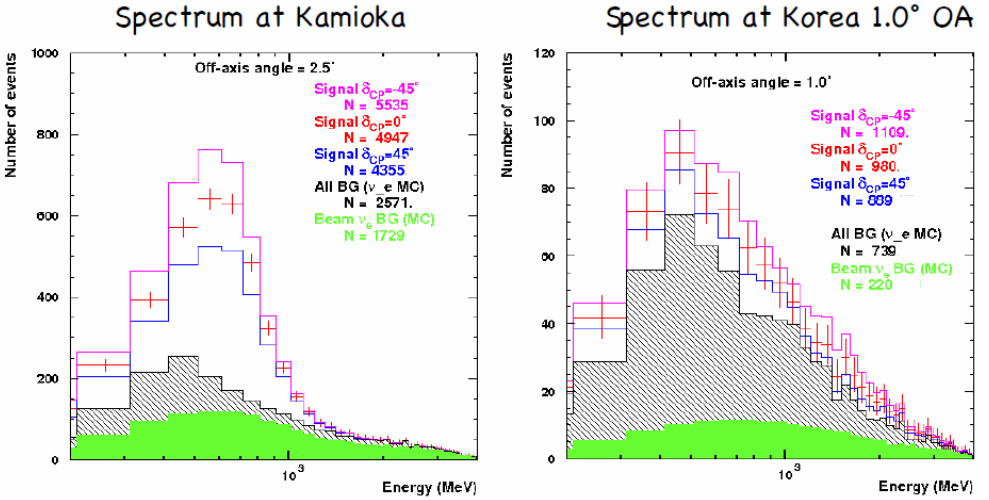
K.Kaneyuki @NP08

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

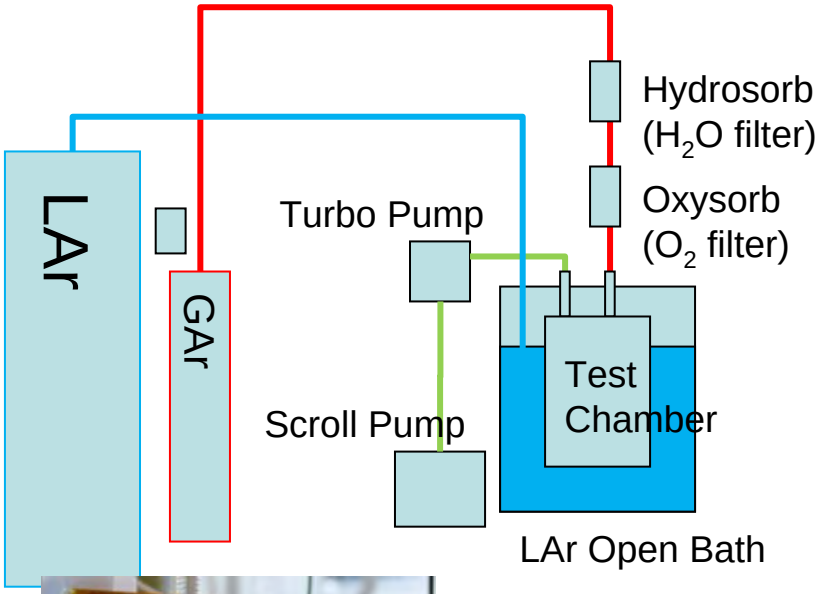
Additional requirement for far detector optimization

- Proton Decay Discovery Performance

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

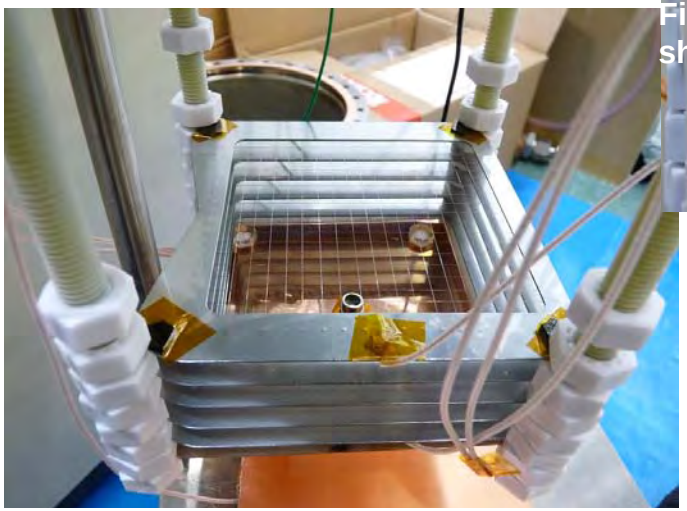
KEK started R&D for Huge Liq. Ar TPC

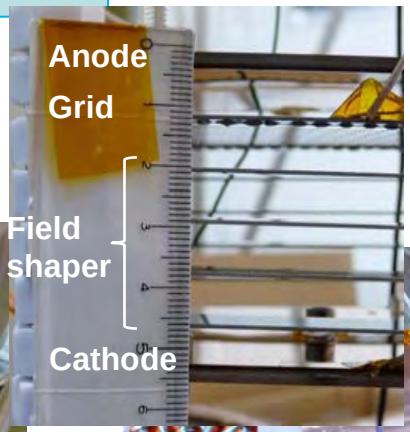
Liquid Argon TPC R&D (KEK)

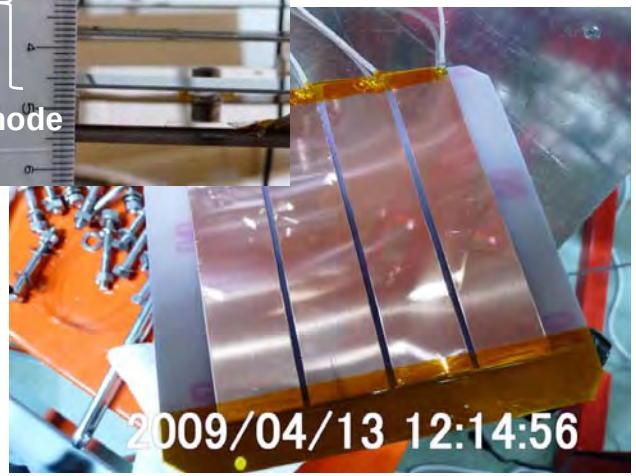


- 10L Liquid Argon teststand was set up at KEK.
  - Gas Argon is liquefied after purification.
  - Test chamber is evacuated and baked before lique-faction.

Inside chamber

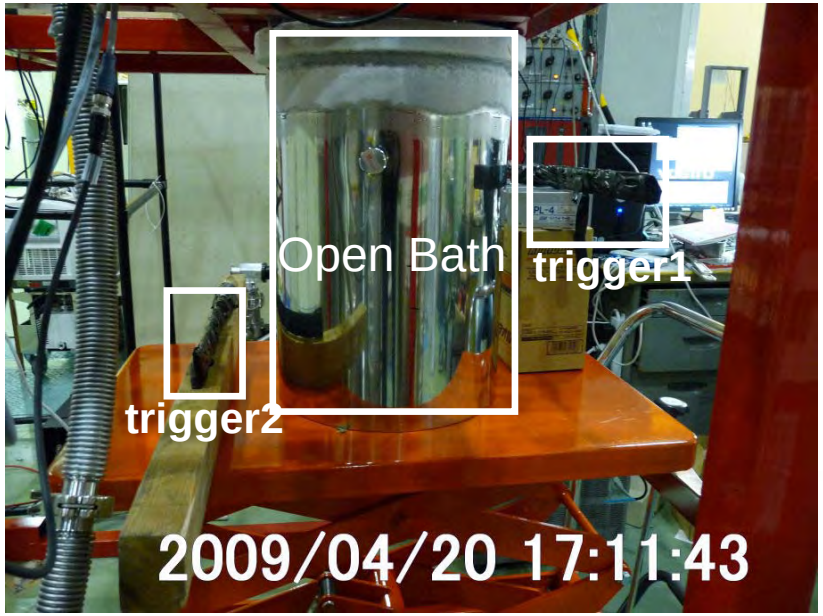




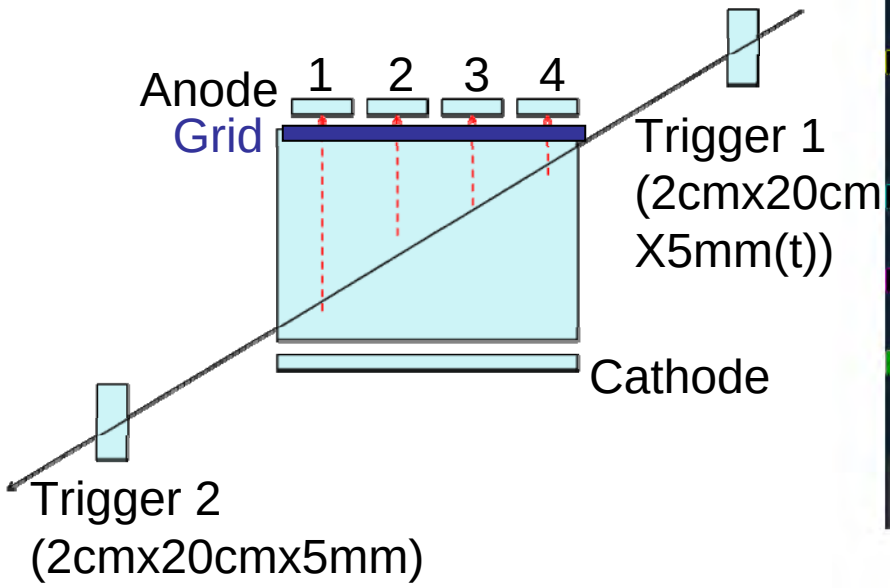


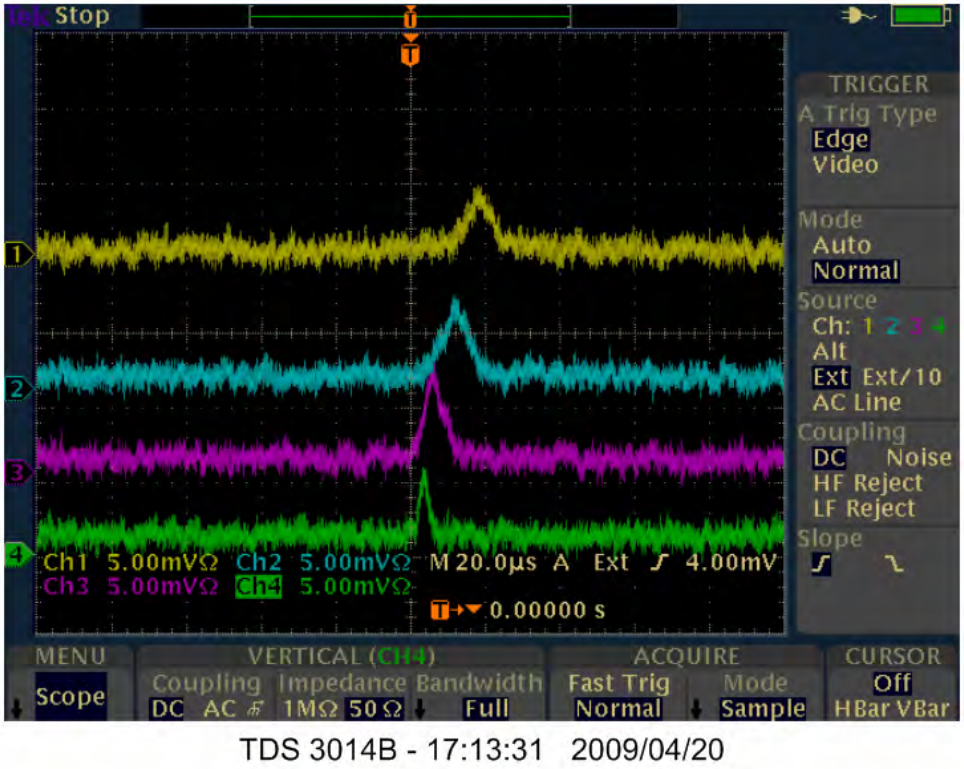
- 4 channel strip was used for read out. (anode plane)
- Field shapers and grid plane are pre-pared.
- Sensitive area is ~ 9x9x5cm^3

First cosmic ray track was seen at KEK



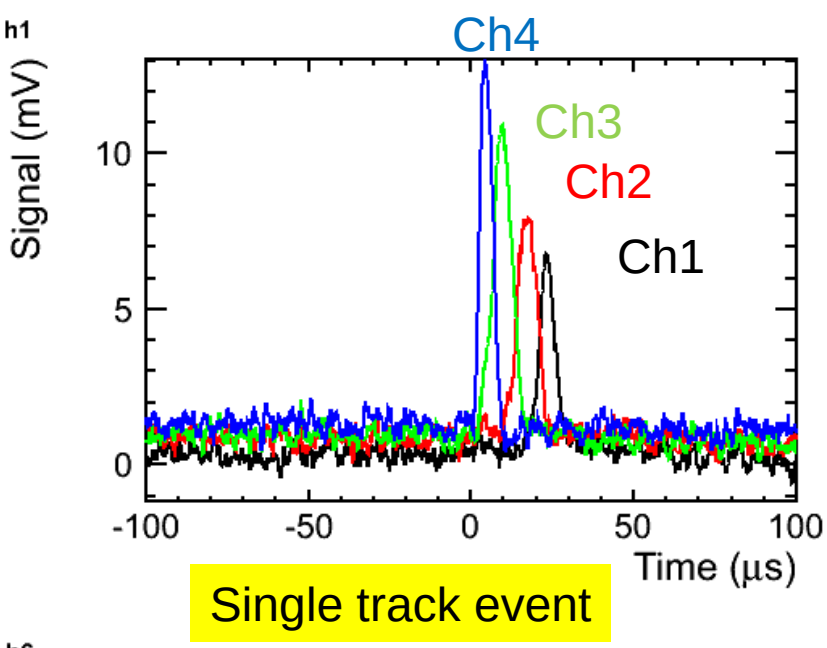
- Trigger counters was set to measure cosmic ray track.
- We see the cosmic ray signal using the TPC (oscilloscope signal is shown below).
  - Signal timing is as expected.
  - First cosmic ray track at KEK



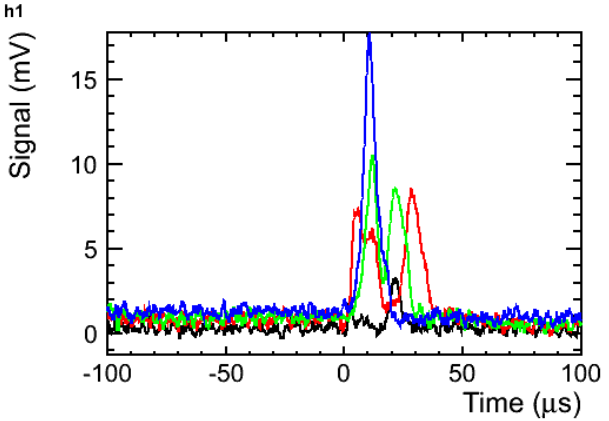


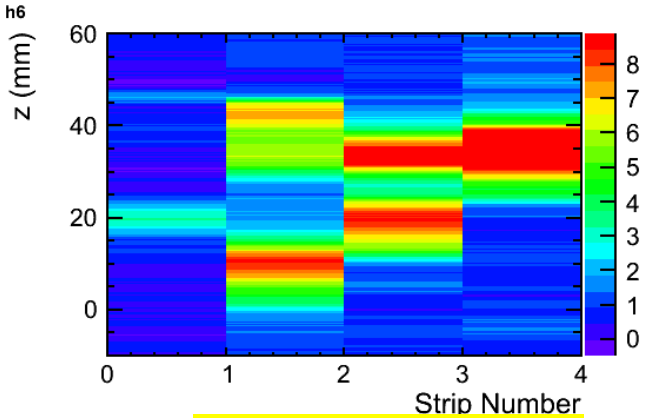
Tracking

- Analyze oscillo-scope waveforr
- Drift time > z pos.



Single track event

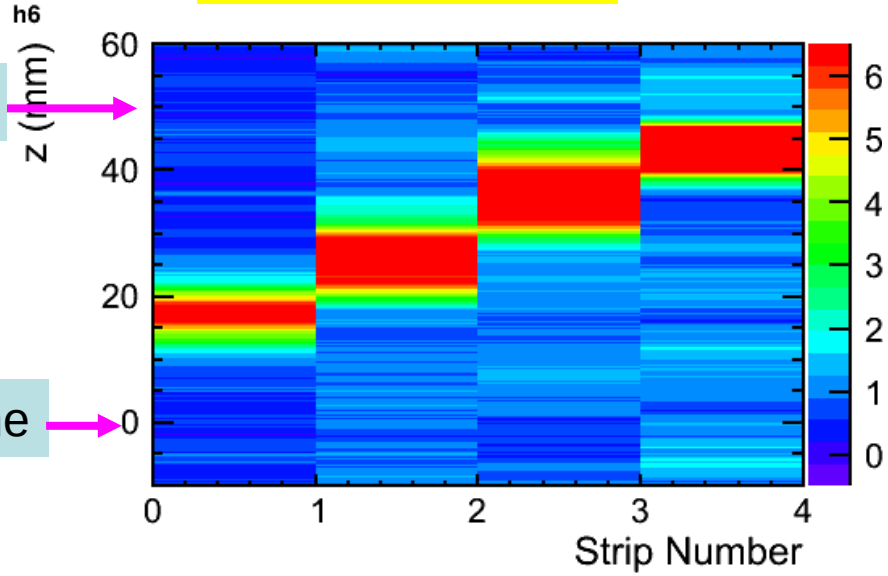




Multi-track event

Anode plane

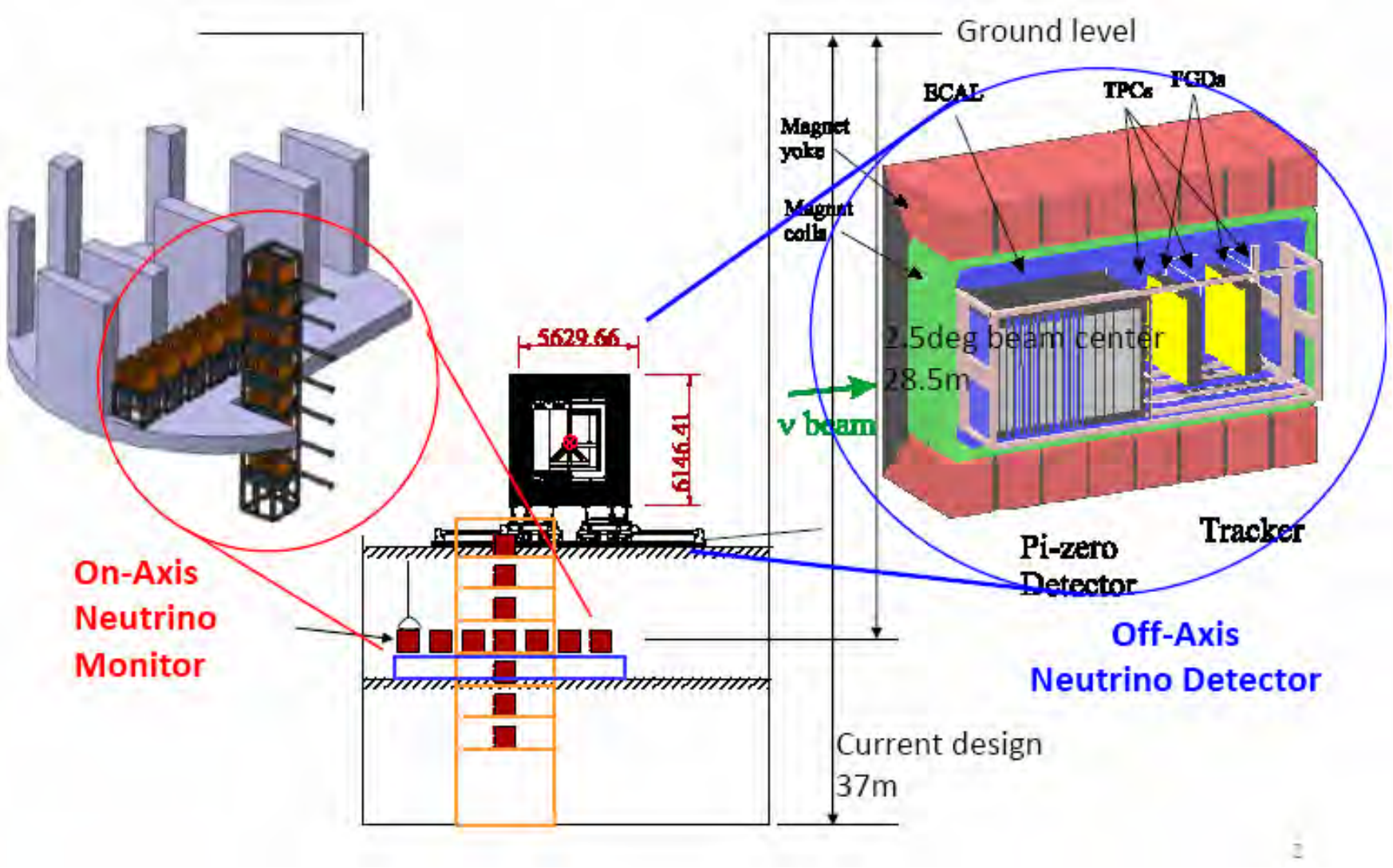
Cathode plane



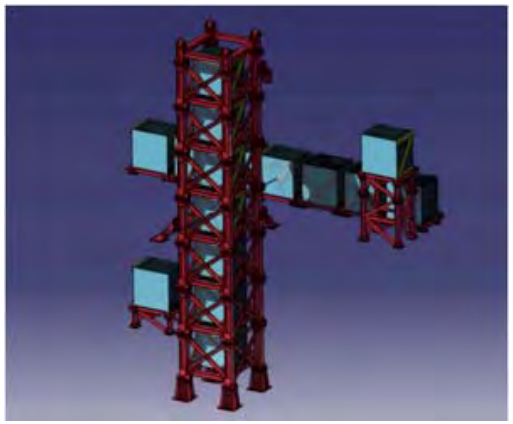
Summary

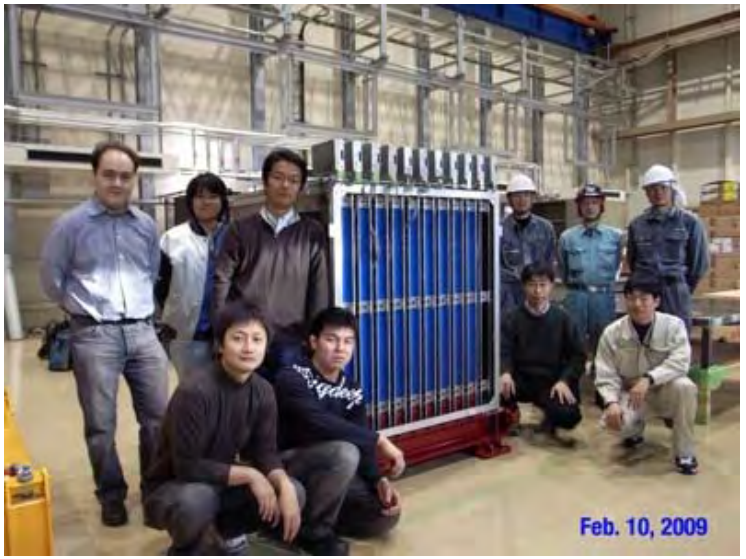
- **Aim to realize an experiment to discover CPV in neutrino and Proton decay with**
  - Upgraded J-PARC 0.75MW ➔ 1.66MW (➔??MW)
  - Huge, high sensitivity detector
- Studies are continuing
  - Optimization of physics potential
    - Distance and off-axis angle of detector
      - Okinoshima(658km), Kamioka (295km), Korea (1000km)
    - Detector technology: ~100kt Liq. Ar TPC/~1Mt Water Cherenkov
  - Detector R&D. **KEK started R&D of Liq Ar TPC**
- To realize the experiment, it is essential to
  - Commission and improve intensity of J-PARC accelerator immediately
  - Discover ν_e appearance in T2K
    - **First beam on Apr. 23, 2009**
    - First T2K physics result in 2010 w/ 100kWx10^7s equivalent data
  - Acquire experience of high intensity beam operation

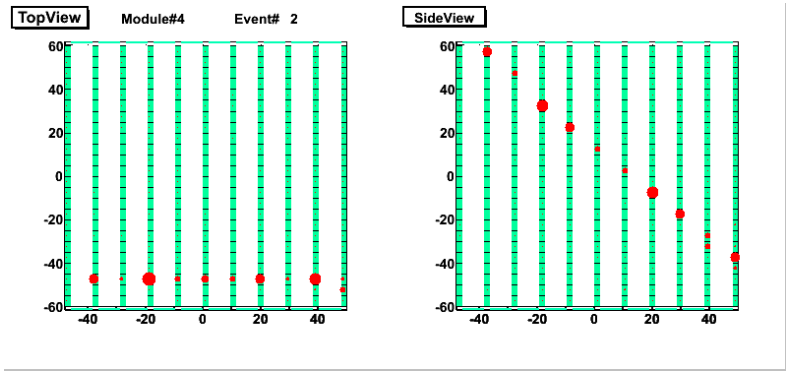
280m Near detectors



On-axis detector: INGRID





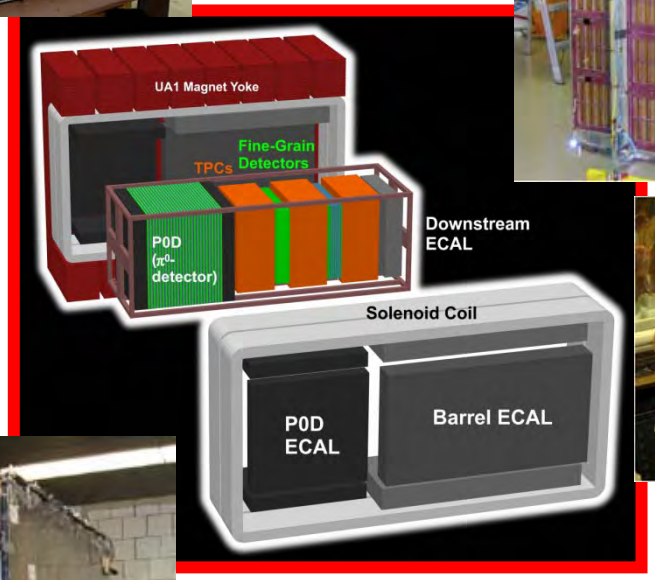


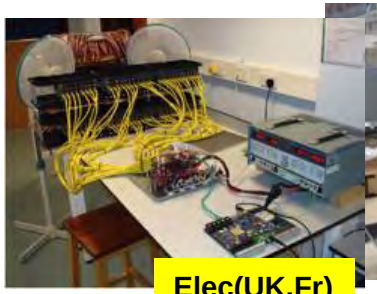
- Assembly of 228 tracking planes completed
- **First module completed and installed. Ready for beam**
- Remaining 15 modules will be installed in summer

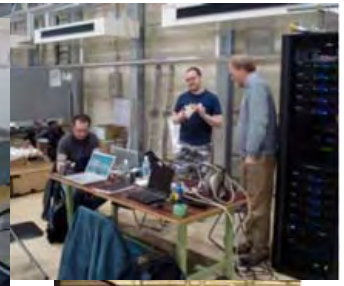
Off-axis Detectors

FGD(Canada)

TPC(Canada/Fr)



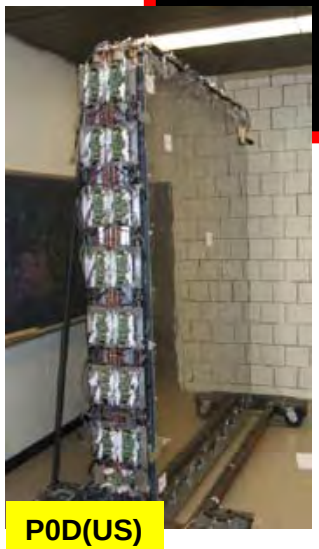




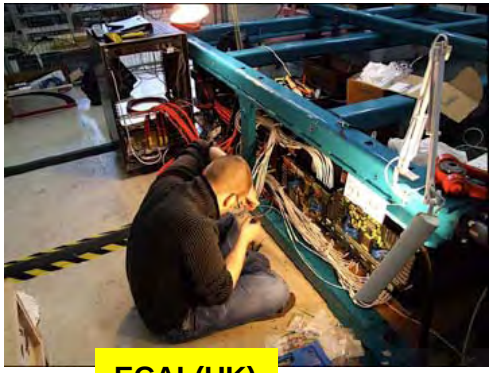
Elec(UK,Fr)

12-FEM board stack-up before burn-in phase

- Under construction and testing in each country
- Installation after August
- To be ready for the beam from Winter



P0D(US)



ECAL(UK)

SMRD(Jp,US,Pol,Rus)