Neutrino and Other Beam-lines at J-PARC

Taku Ishida (IPNS, KEK)
For the Neutrino Beam-line Collaboration

- **Physics Motivation**
- **Accelerators, Facilities, and Beam-lines**
- **The Neutrino Beam-line**
- **Summary and Future Prospects**

Physics Motivation

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(IPNS, KEK)
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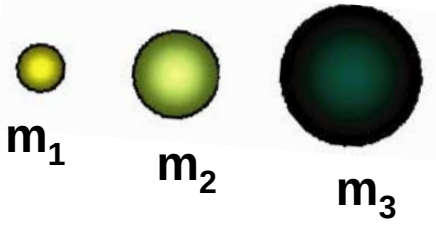
Neutsino Mass and Mixing — Maki-Nakagawa-Sakata (MNS) Matrix

Weak eigenstates
"flavor eigenstates"

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}U_{e1} & U_{e2} & U_{e3}\\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3}\\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3}\end{pmatrix}\cdot\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Mass eigenstates



$$\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\vartheta_{23} & \sin\vartheta_{23}\\ 0 & -\sin\vartheta_{23} & \cos\vartheta_{23}\end{pmatrix}\cdot\begin{pmatrix}\cos\vartheta_{13} & 0 & \sin\vartheta_{13}e^{-i\delta_{CP}}\\ 0 & 1 & 0\\ -\sin\vartheta_{13}e^{i\delta_{CP}} & 0 & \cos\vartheta_{13}\end{pmatrix}\cdot\begin{pmatrix}\cos\vartheta_{12} & \sin\vartheta_{12} & 0\\ -\sin\vartheta_{12} & \cos\vartheta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}$$

$$\Delta m^2_{ij} \equiv m^2_i - m^2_j \qquad (\Delta m^2_{12} + \Delta m^2_{23} + \Delta m^2_{31} = 0)$$

3 mixing angles + 1 complex phase

2 mass squared differences

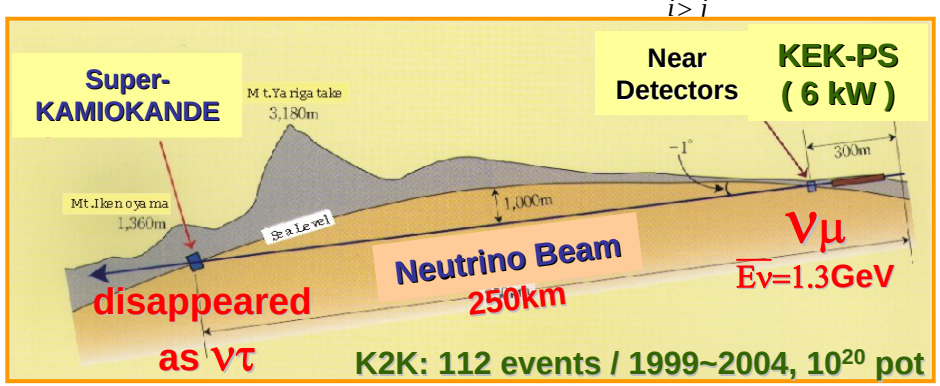
Neutsino Oscillation Experiments

$$P(\nu_\alpha \to \nu_\beta) = \left|\langle \nu_\beta(t) | \nu_\alpha(0)\rangle\right|^2 = \delta_{\alpha\beta} - 4\sum_{i>j}\mathrm{Re}(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\cdot\sin^2\phi_{ij} \mp 2\sum_{i>j}\mathrm{Im}(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\cdot\sin 2\phi_{ij}$$

$$\phi_{ij} = \Delta m^2_{ij}\cdot L / 4E_\nu$$

Flight length (c·t)

Neutrino energy



Reduction of ν_α
E_ν spectrum distortion
Appearance of ν_β

Current knowledge

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(IPNS, KEK)
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- So far we know in 10 years:
  - $\Delta m^2_{atm} = (2.2 \sim 3.0) \times 10^{-3}$ eV^2 , $\sin^2 2\theta_{23} > 0.92$ (Atmospheric ν, K2K/MINOS)
  - $\Delta m^2_{sol} = 8 \times 10^{-5}$ eV^2 , $\sin^2 2\theta_{12} = 0.86$ (KamLAND + solar ν)
  - *No another mass-scale* (Mini-Boone)
  - $\sin^2 2\theta_{13} < 0.15$ at $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 (CHOOZ / Palo Verde)
    - < 0.26 (0.13x2) at $\Delta m^2 = 2.8 \times 10^{-3}$ eV^2 (K2K)
  - δ_{CP}: unknown

T.Kobayashi
FRZKI02

- Oscillation probabilities in our relevant L/E

$$\Delta m^2_{12} \equiv \Delta m^2_{sol} << \Delta m^2_{23} \approx \Delta m^2_{13} \equiv \Delta m^2_{atm}$$

Small contribution from Δm^2_{12}

- ν_e appearance

$$P_{\mu\to e} \approx (\sin^2\theta_{23} \cdot \sin^2 2\theta_{13}) \cdot \sin^2 \Phi_{23} \equiv \sin^2 2\theta_{\mu e} \cdot \sin^2 \Phi_{23}$$

~1/2

$$\Phi_{23} \equiv 1.27 \Delta m^2_{atm} L / E_\nu$$

[eV^2] [km] [GeV]

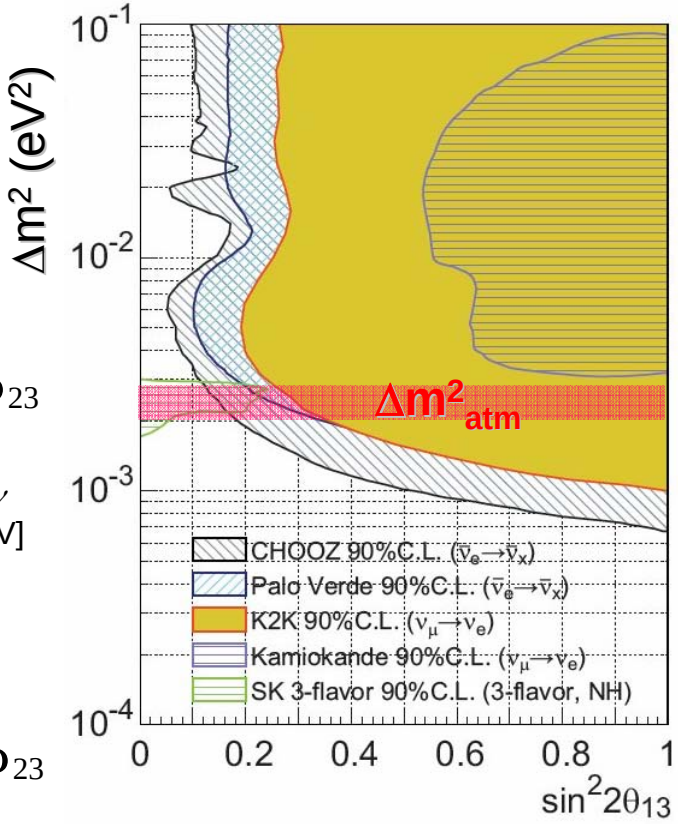
cf. reactor ν_e disappearance

$$P_{e\to x} \approx 1 - \sin^2 2\theta_{13} \cdot \sin^2 \Phi_{23}$$

- ν_μ disappearance

$$P_{\mu\to\tau} \approx (\cos^4\theta_{13} \cdot \sin^2 2\theta_{23}) \cdot \sin^2 \Phi_{23} \equiv \sin^2 2\theta_{\mu\tau} \cdot \sin^2 \Phi_{23}$$

~1



T2K experiment

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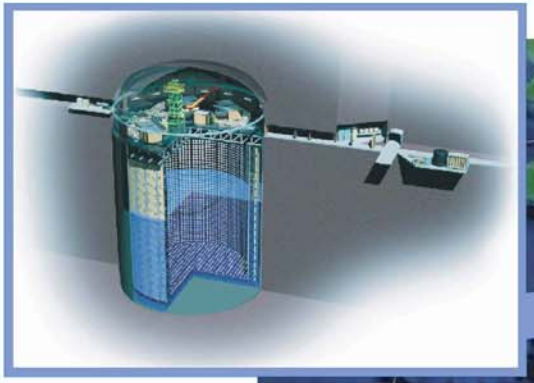
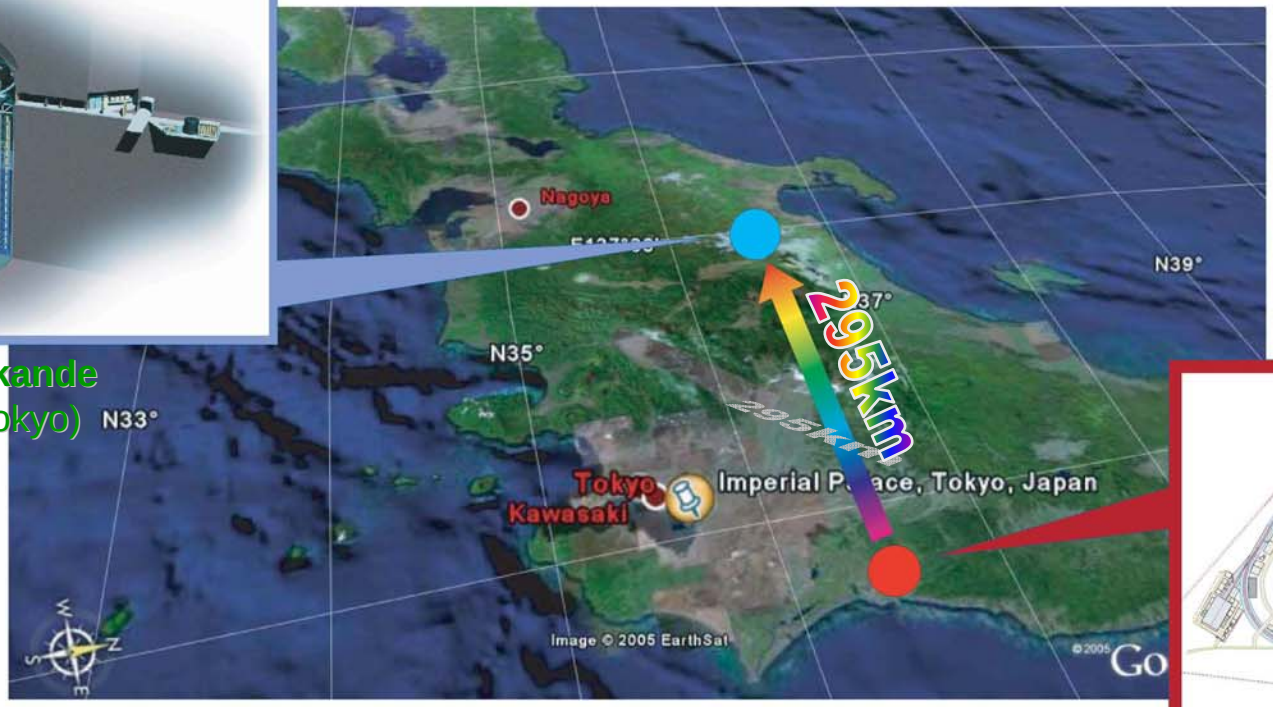
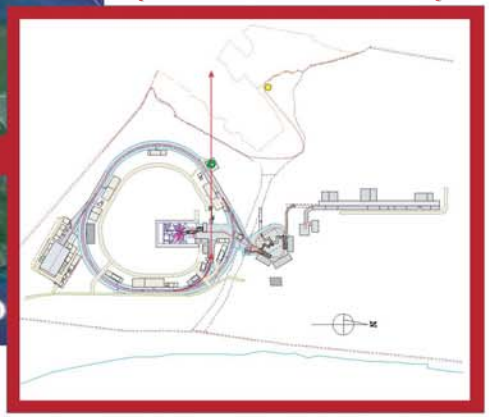
NEUTRINO FACILITY AT J-PARC



Super-Kamiokande
(ICRR, Univ.Tokyo)



J-PARC 50GeV PS
(KEK-JAEA, Tokai)



- A next-generation long-baseline neutrino oscillation experiment, designed to observe the first signal of νe appearance, and further, δ_{CP}
  - Pseudo-monochromatic, low-energy off-axis beam, tunable by changing the off-axis angle between 2° and 2.5° (Eν=0.8GeV ~ 0.65GeV)
  - Quasi-Elastic interactions are dominant, suitable to minimize the electro-magnetic shower background caused by inelastically-produced π^0

Accelerators, Facilities and Beam-lines at J-PARC

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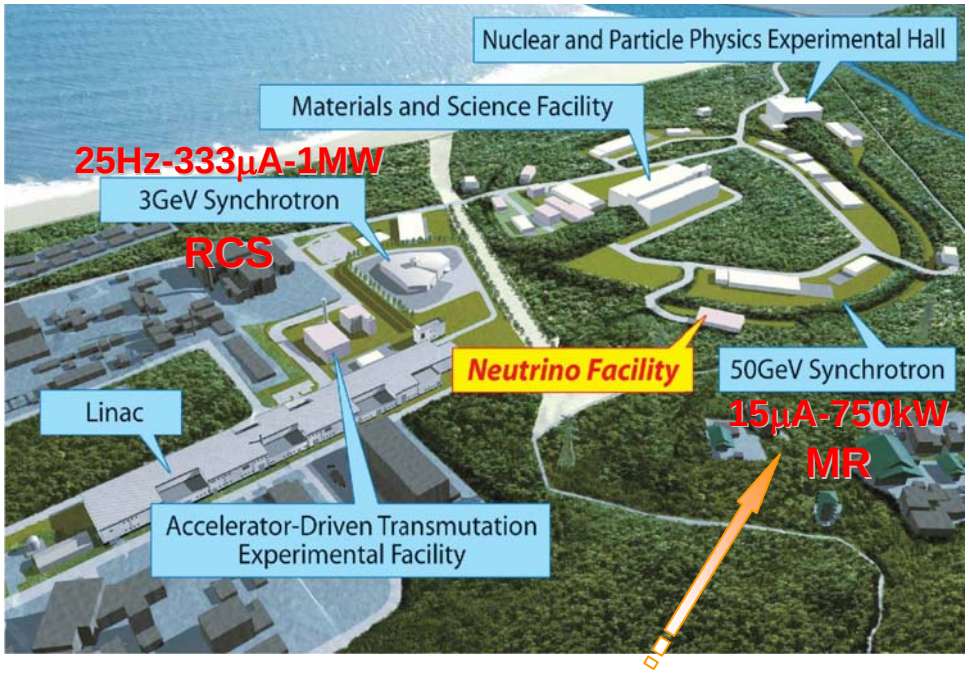
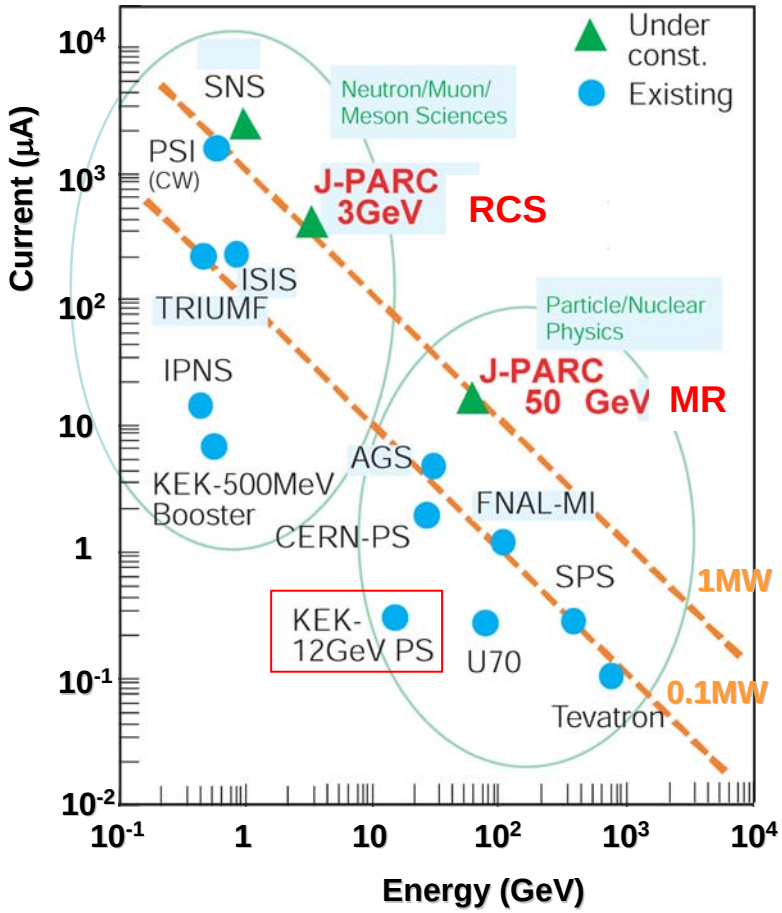
NEUTRINO FACILITY AT J-PARC



Proton beam kinetic energy	50GeV (30GeV@T=0)
# of protons / pulse	3.3×10^{14} *ppp*
Beam power	750kW
Bunch structure	8 bunches
Bunch length / spacing	58 ns / 598ns
Spill width	4.2μs
Beam Emittance	6π mm.mr (10π@30GeV)
Cycle	3.64 sec (2.1sec@30GeV)



- MR: 1×10^{21} *p.o.t.* per year
  [130day operation / year @ 50GeV]

Bird's-eye view (Feb. 2006)

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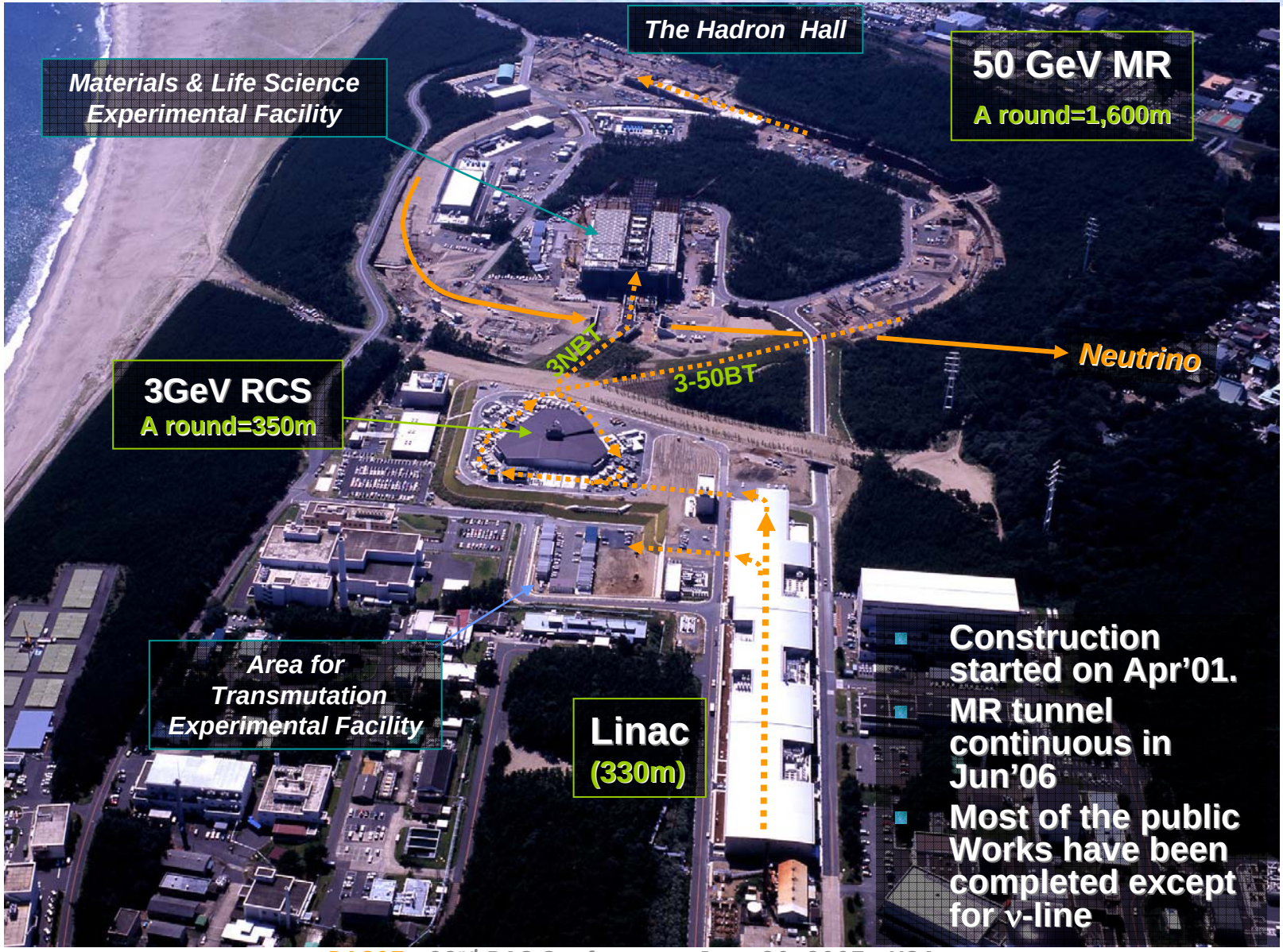

Linac

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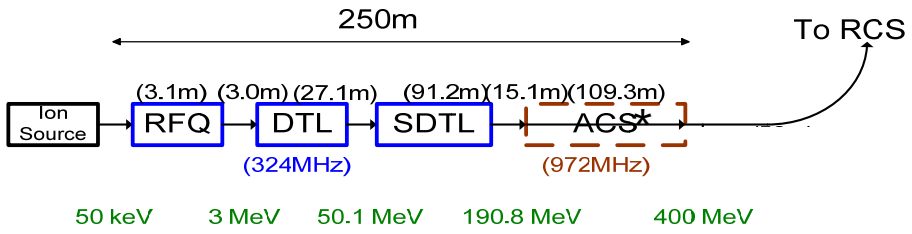

*ACS: Annular ring Coupled Structure

- Beam commissioning started in last November
- 180MeV Acceleration in success (Jan. 2007)
- ACS to be constructed in FY2008~2011

K.Hasegawa THYAB02

RCS / MR

T.Koseki
TUODKI01

T.Ishida
(IPNS, KEK)
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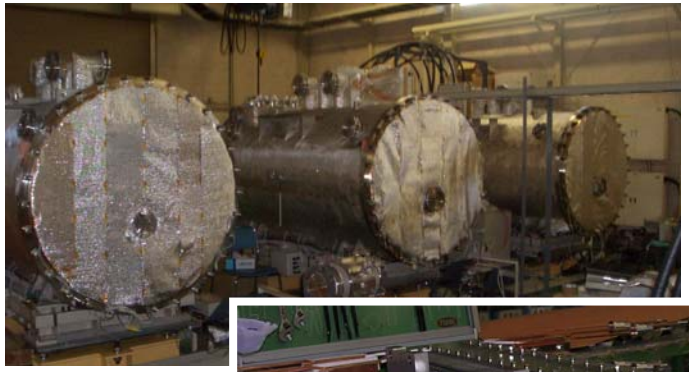

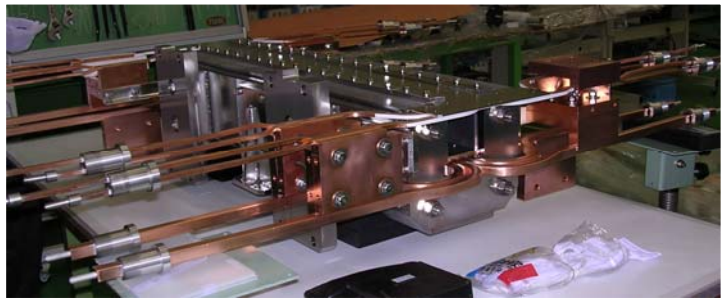

Kicker & Septum Magnets for fast extraction

Materials and Life science experimental Facility (MLF)

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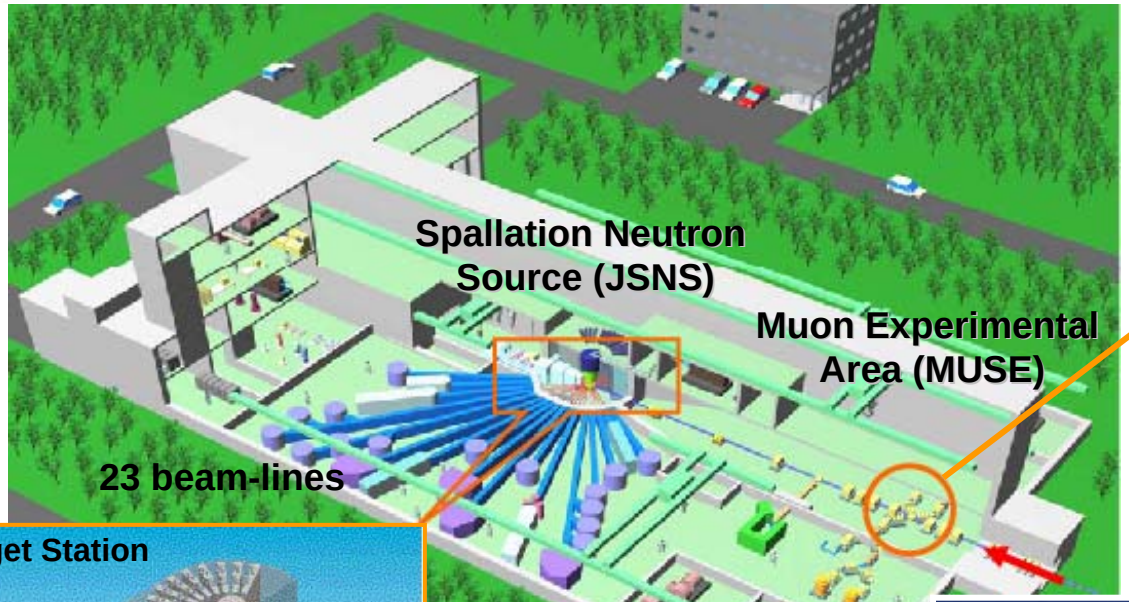

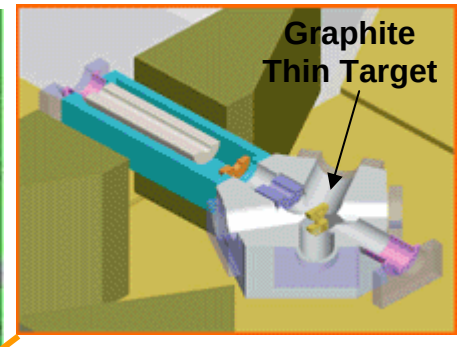

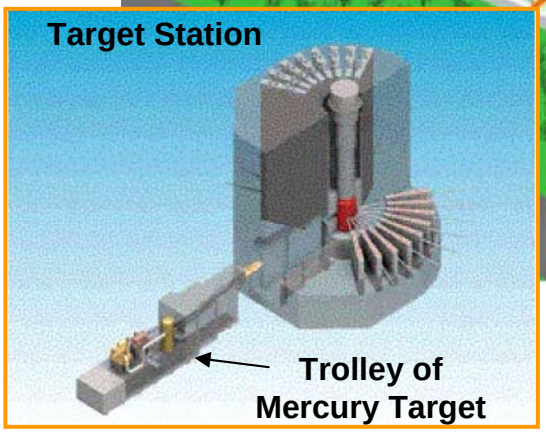

Construction of the Hall Completed (Apr. 2007)

- World-highest neutron & muon flux to promote variety of researches in material and life science

MLF (Cont.d)

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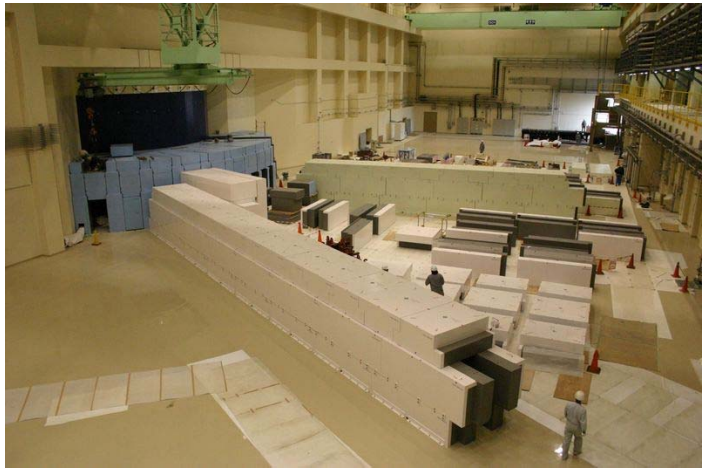

Neutron Source from the Top

Muon Production Target

- First beam to MLF: Early JFY2008

The Hadron Hall

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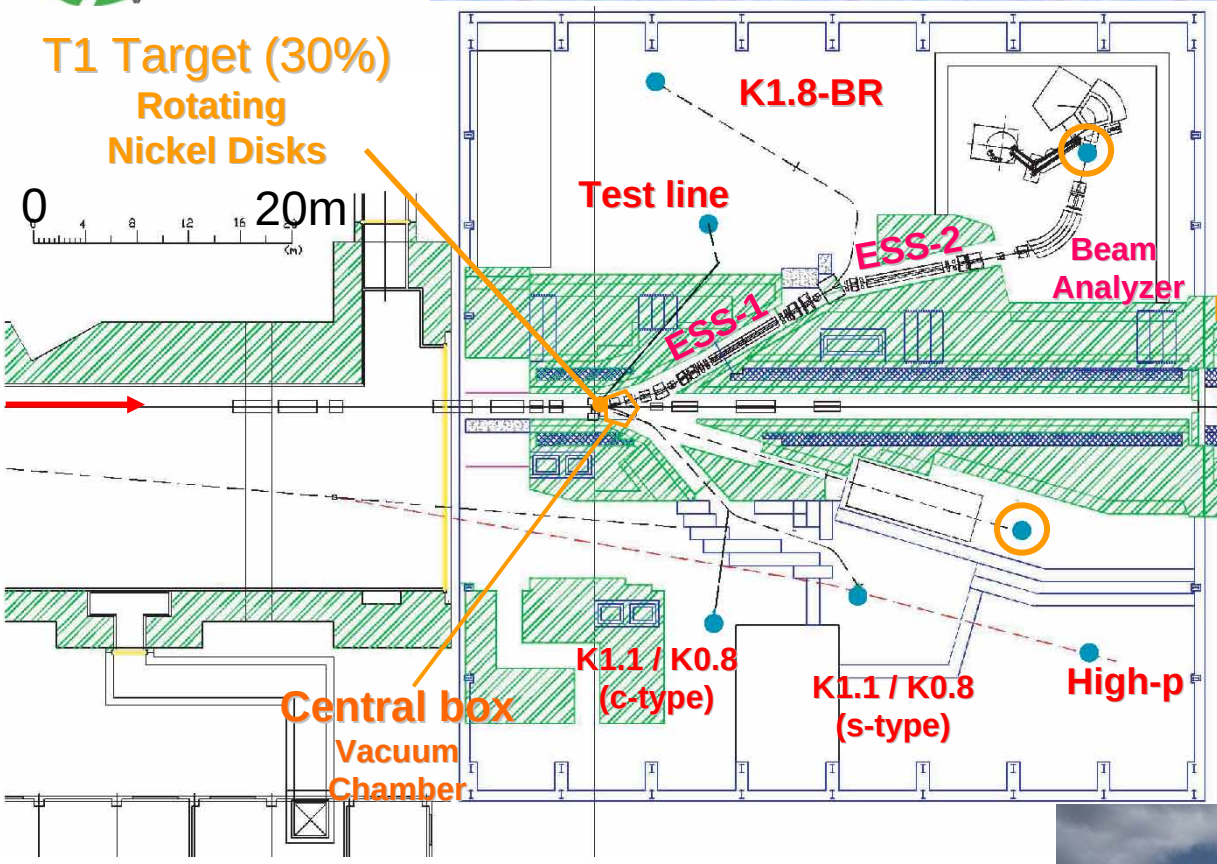

K1.8 Day-1 line for E05/E13

Ξ hypernuclear spectroscopy with Superconducting Kaon Spectrometer

- K^- single rate: 8×10^6ppp
- 1.8GeV/c: 1.4×10^6ppp
- K^-/π^- = 7

Ξ100 events / 1 month (270kW 30GeV-9μA)

Λ gamma-ray spec. with Ge detector (hyperball-J)

KL for E14 $Br(K_L\rightarrow\pi^0\nu\bar{\nu})$

Direct CP violation
So far < 2.1×10^{-7}(KEK PS E391a)
Upto 10^{-13} (SM = 2.8×10^{-11})

- Kaon-factory for hyper-nuclear spectroscopy, studies for strangeness degree in the nuclear matter, kaon rare decay, hadron spectroscopy *etc.*

The Hadron Hall (Cont.d)

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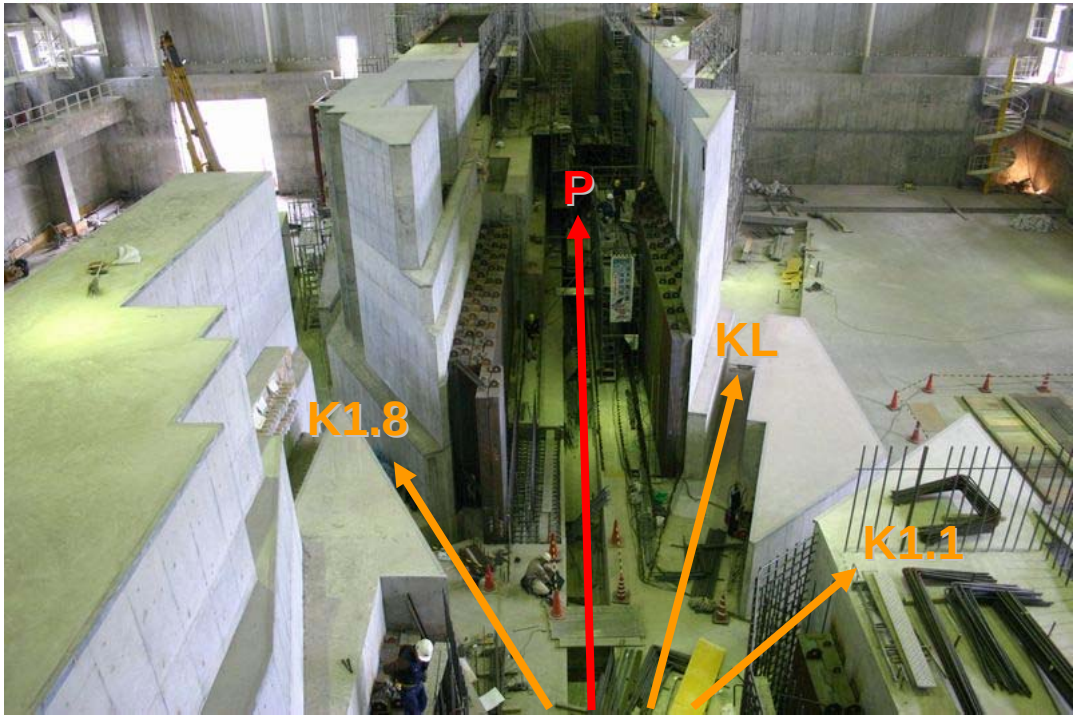
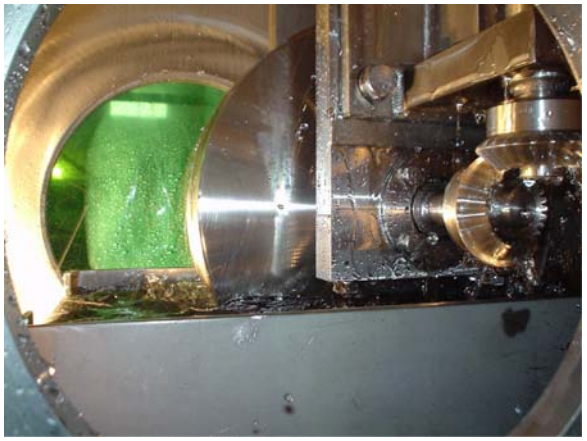


- 1st operation scheduled in December'08



Long-term operation test for Ni-rotating disk target

6m-long Electro-Static Separator

The Neutrino Beam-Line

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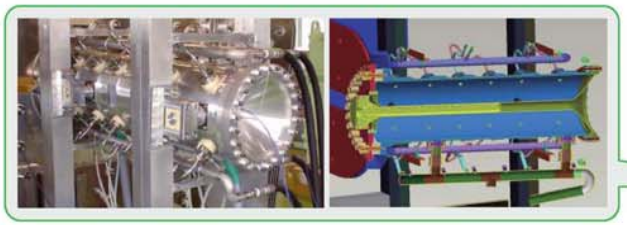
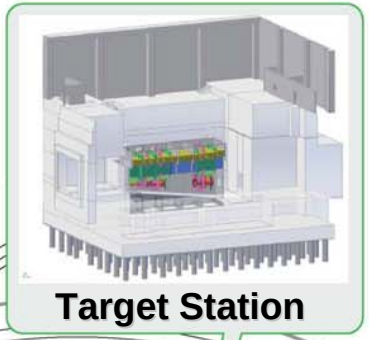


Target-Horn System



Target Station

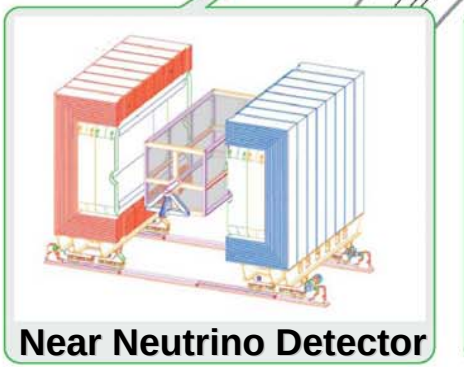
Preparation Section

Muon Monitoring Pit

Final Focusing Section

295km to Super-Kamiokande

100m



Near Neutrino Detector

Beam Dump

Decay Volume

SCFM at ARC Section

Neutrino Beam-line collaboration

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NEUTRINO FACILITY AT J-PARC

KEK

- Neutrino group, IPNS (Core)
  - Every beam line components (except S.C.magnets / cryo.)
- Hadron group, IPNS
  - Monitor / N.C.magnets / Power supply
- Cryogenics group, IPNS
  - Cryogenics / Target Helium circulation system
- Cryogenics science center
  - Superconducting magnet / Cryogenics
- Mechanical Engineering Center
- Radiation Science Center

K.Nishikawa(KEK)
T2K Spokesperson
Divison leader

D.L.Wark(STFC)
Co-Spokesperson

T.Kobayashi(KEK)
Construction G. Leader

In collaboration with

- U. Tokyo: Primary beam monitor
- Kyoto U: Primary beam monitor, Muon monitor
- UK: Target, Target remote handling, Beam window, Baffle, Dump
- Canada : Remote chamber for the most downstream monitors, OTR, Remote maintenance
- US: Horn, Beam monitor, S.C. corrector magnets, GPS, Monitor electronics
- France: Quench detection system
- Korea: Proton monitor electronics

T2K layout

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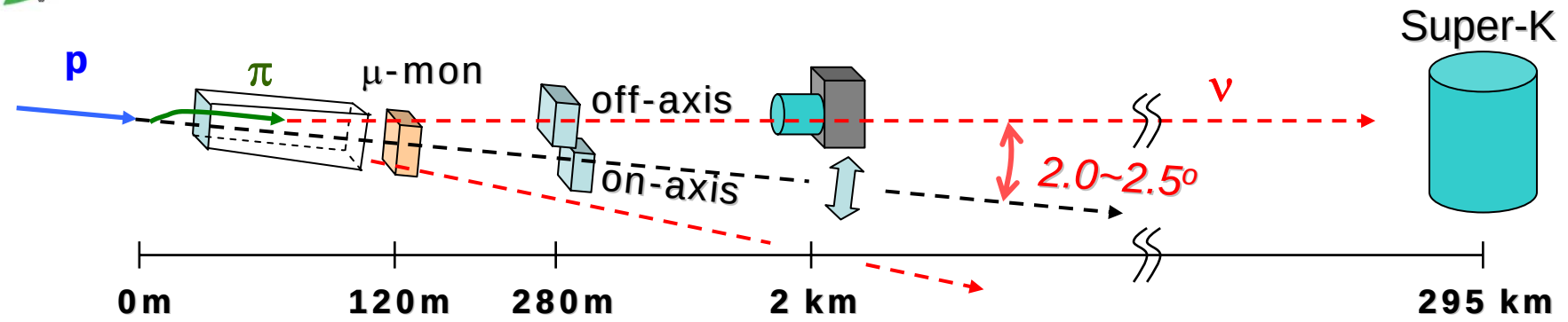

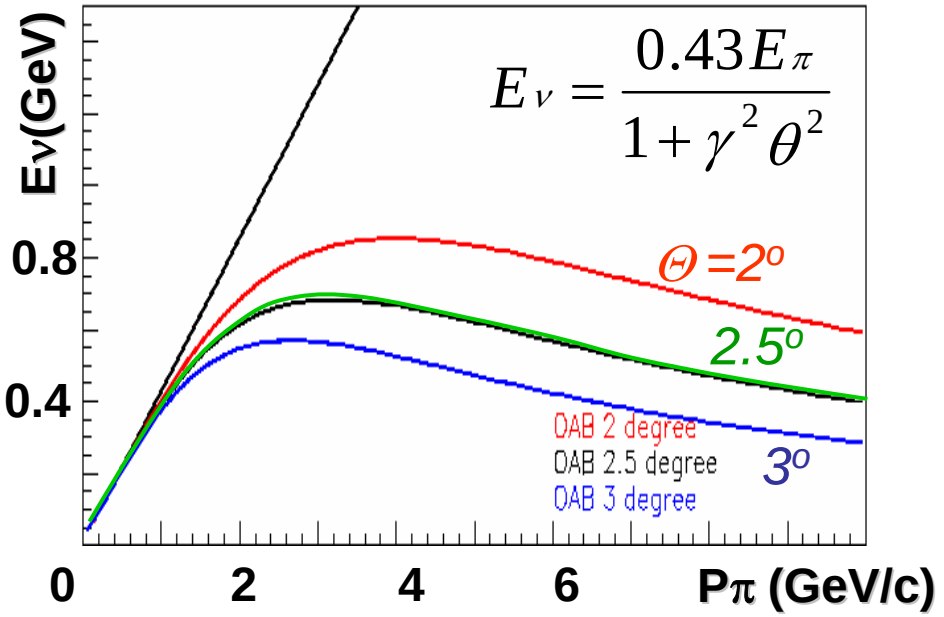

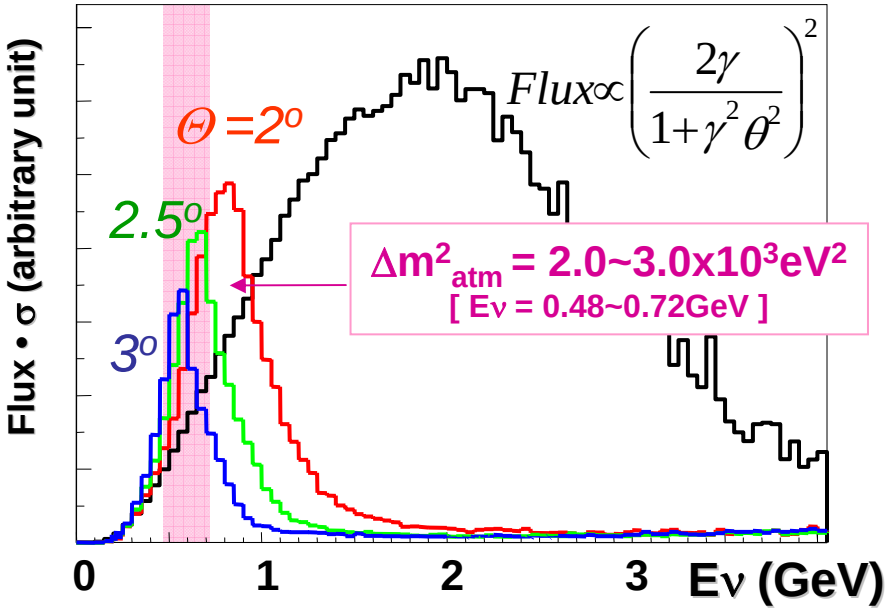

- Quasi-monochromatic, tunable sub-GeV Off-Axis Beam
- ~ 2,200 (~1,600) νμ (CC) interactions at Super-K [OAB 2.5°, 22.5 kt-yr]

NEUTRINO FACILITY AT J-PARC

Civil construction

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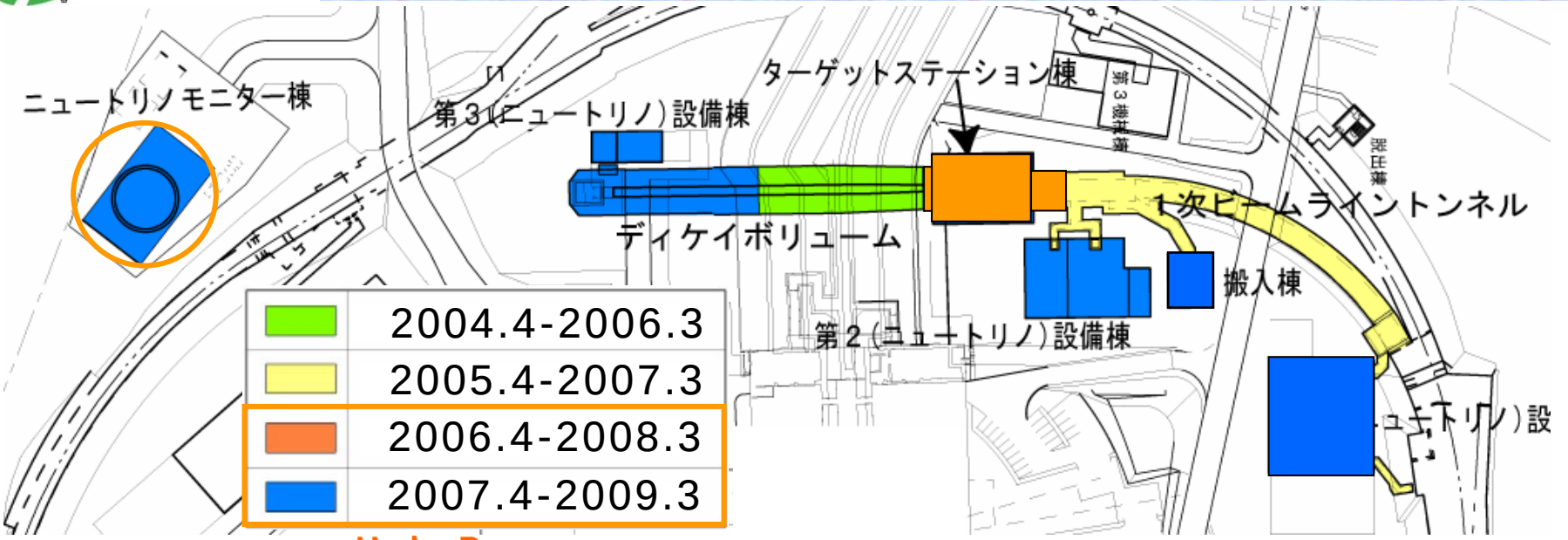

Under Progress

***Shinto* Ceremony at ν Near Detector Cite (June 21,'07)**

Decay volume (Under 3NBT)

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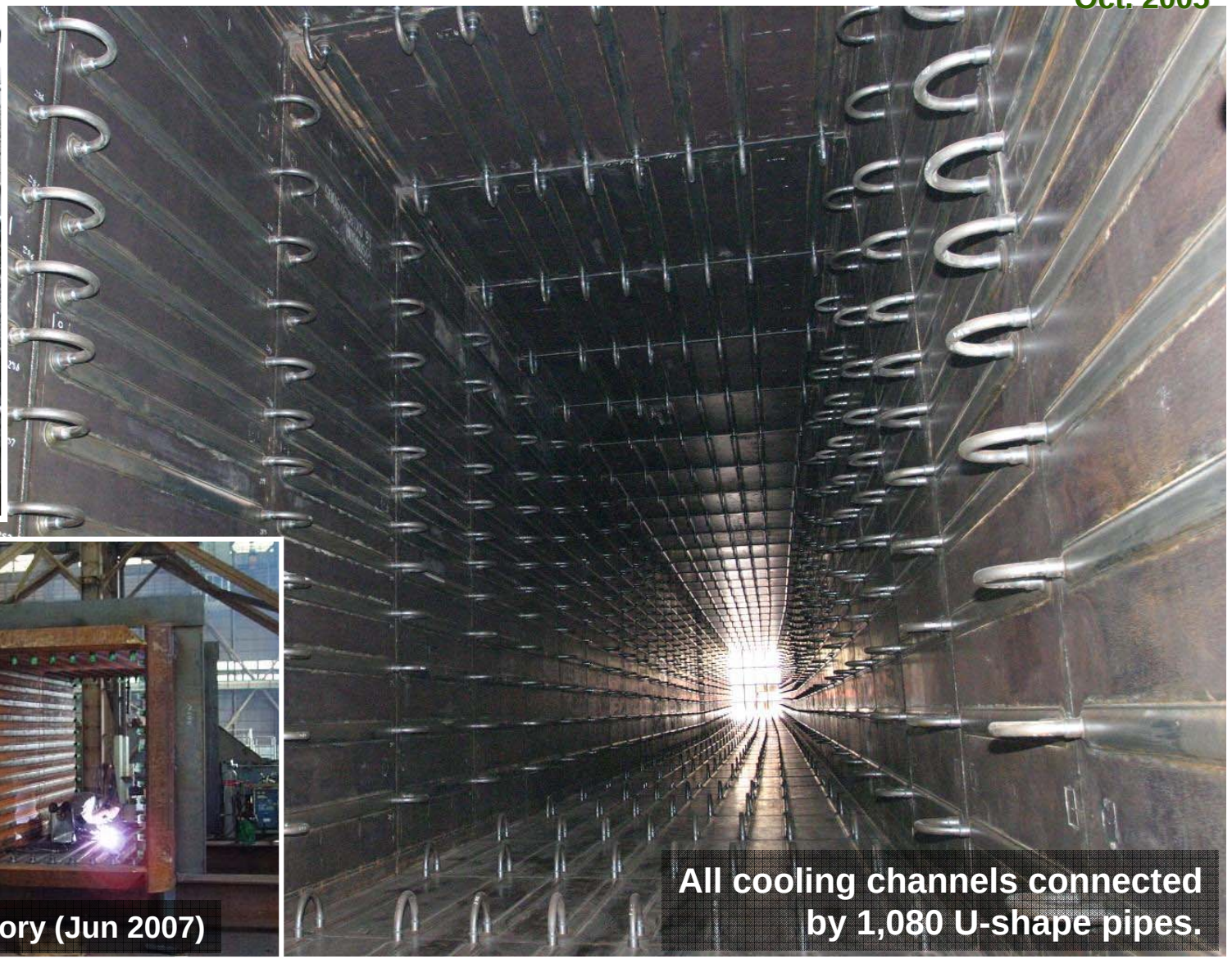
Oct. 2005



DV upstream in a factory (Jun 2007)

All cooling channels connected by 1,080 U-shape pipes.

NEUTRINO FACILITY AT J-PARC

Primary beam-line

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TUXKI03

March, 2006

Completed in Last December

July, 2006

Target Station

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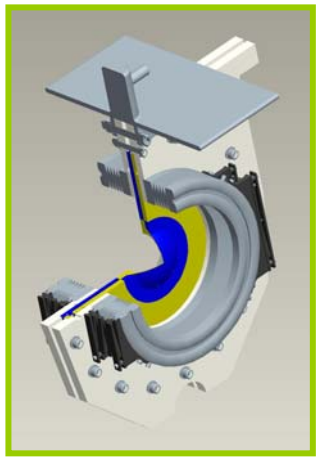

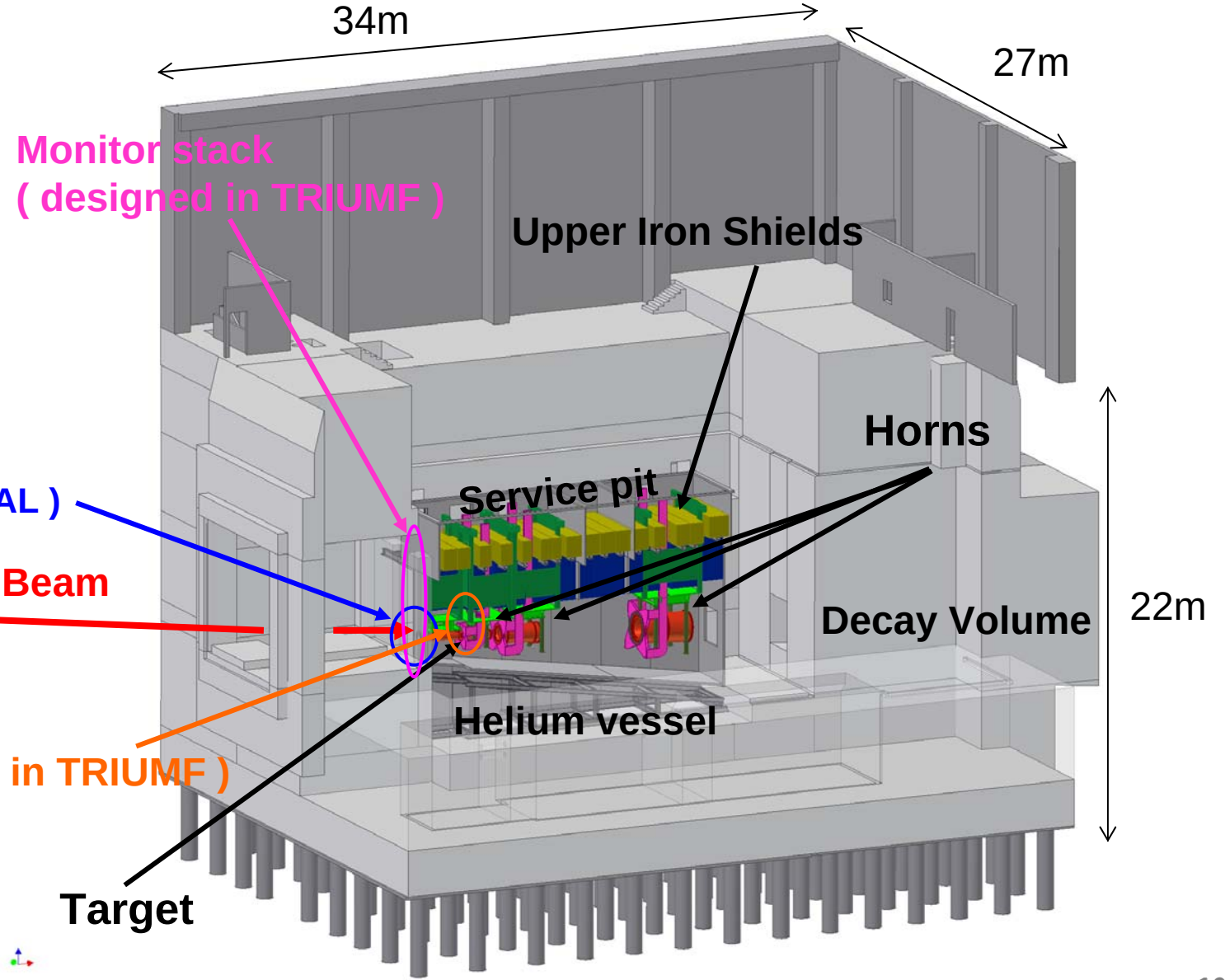

TS helium vessel

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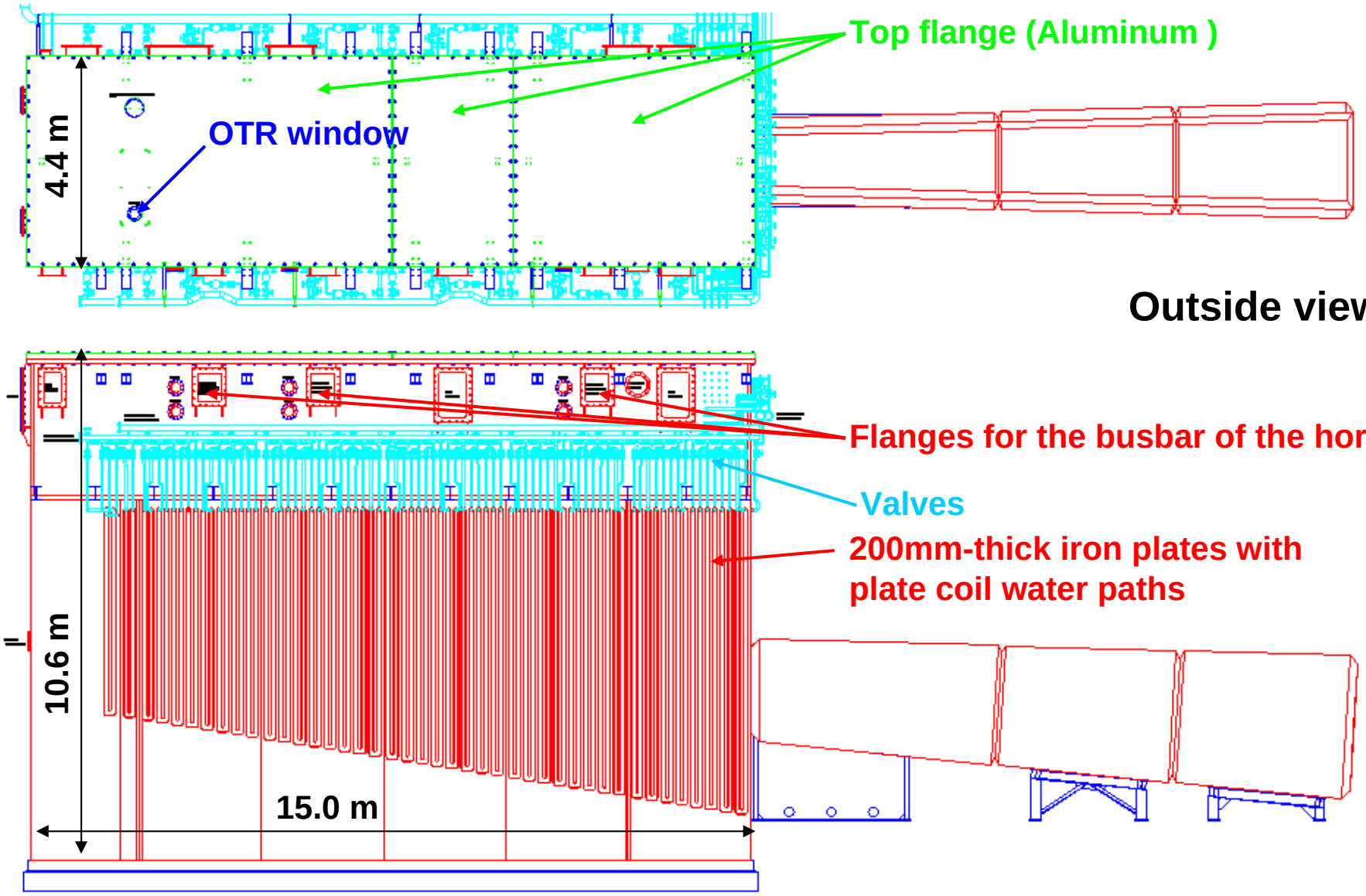

Construction / vessel production
(As of June, 2007)

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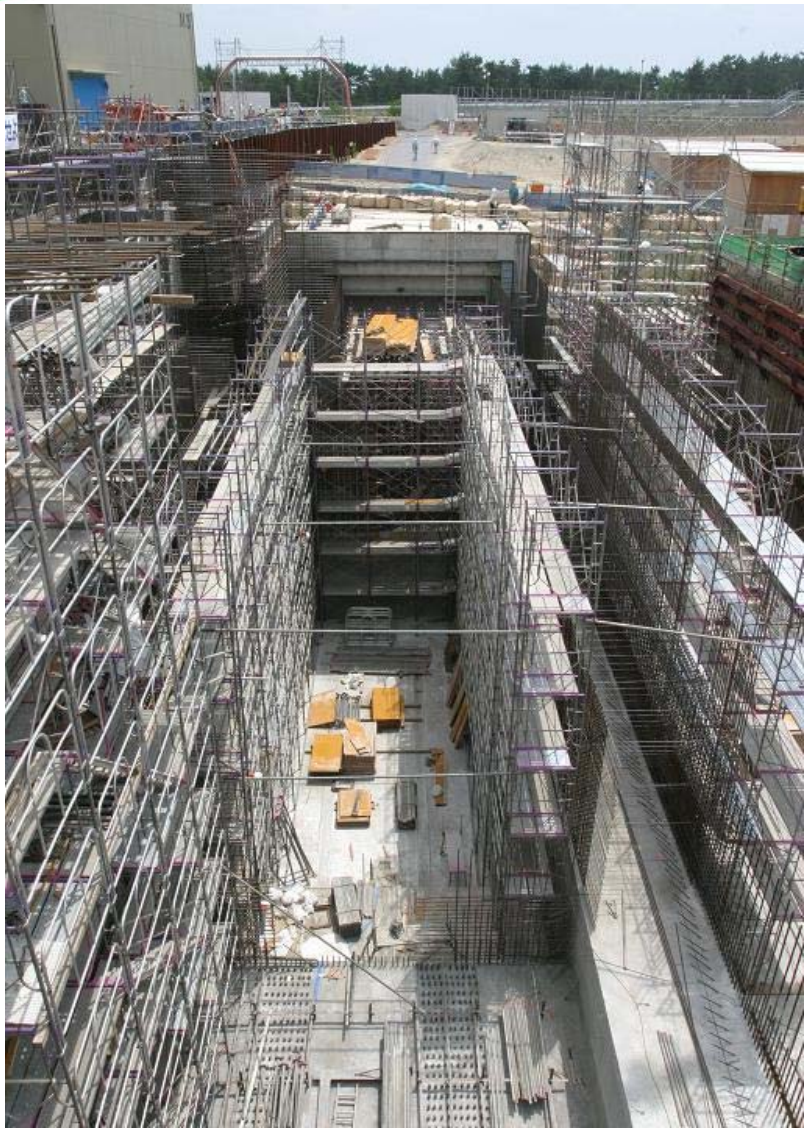

- Installation This Summer !

Normal conducting magnets

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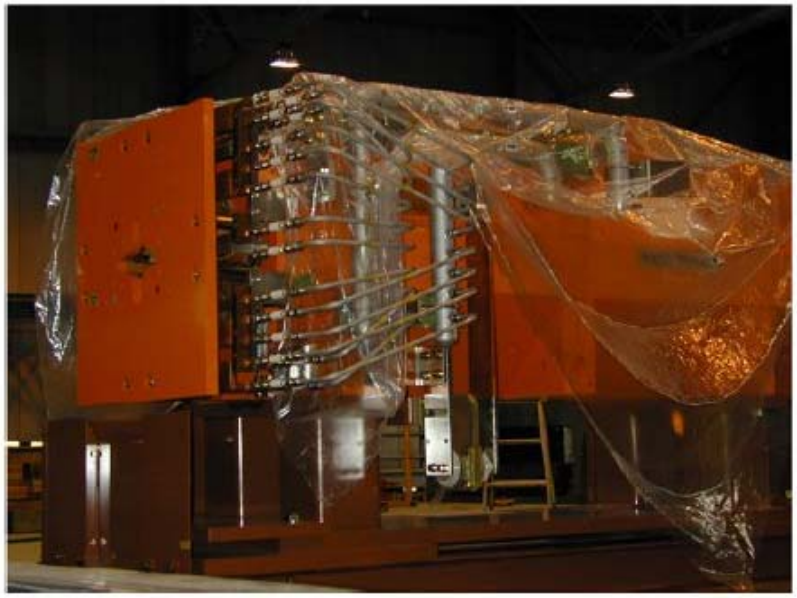
The first horizontal steering with a Ti-duct.



Q magnet wating for a duct installation.

	Dipole	Quad.	Steer.	Total	(MIC)
Prep.	2(H)	5	3(H)+2(V)	12	(5)
FF	2(V)	4	2(H)+2(V)	10	(0)
Total	4	9	9	22	(5)

- Prep. Sec. : All fabricated, Installation in July 07
- F.F.: Production in FY07, Installation in FY08

Vacuum system

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(IPNS, KEK)
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- Installation of beam ducts into magnets in progress.
  - Ti and Al-alloy ducts for D
  - “Cross-shaped” aluminum ducts for Q
  - Semi-remote flange mover and hands-on clamp
- Beam plug made and tested
  - Installation: coming July


Ti duct in PH1


Flange Mover


Beam Plug

Superconducting magnets

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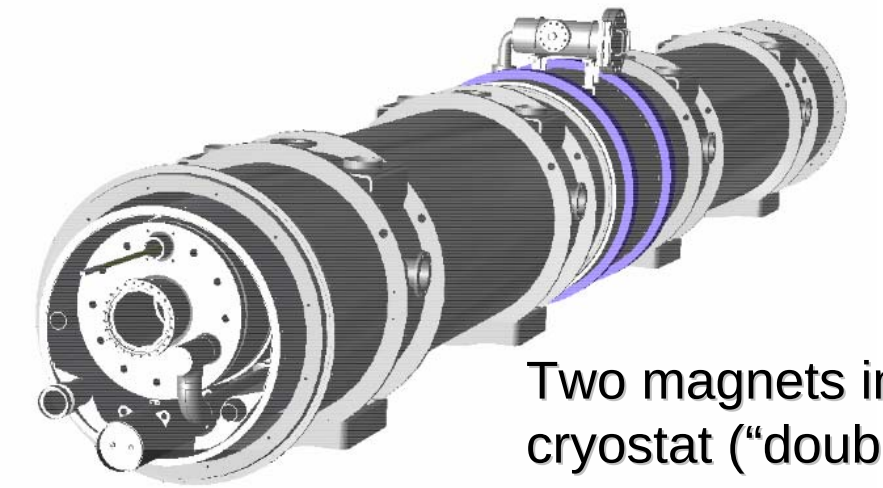
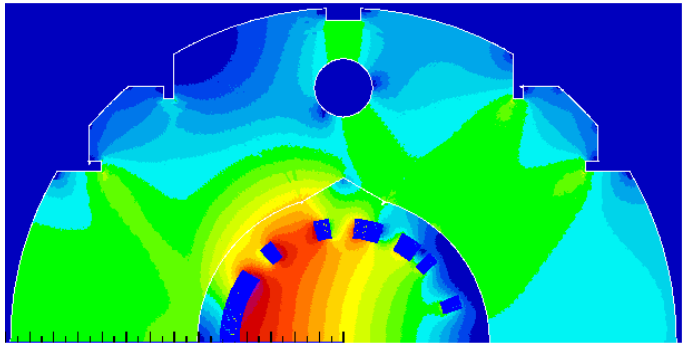


Two magnets in 1 cryostat (“doublet”)



Superconducting Combined Function Magnet SCFM

28 SCFMs in total, D: 2.6 T, Q: 18.6 T/m
Length: 3.3m
Current: 7,345A @ 50GeV

- Mass production status
  - 6 doublets in FY06
  - 6 in FY07, 2 in FY08
- Partial installation in FY07
- *System testing in FY’08*

Beam Monitors

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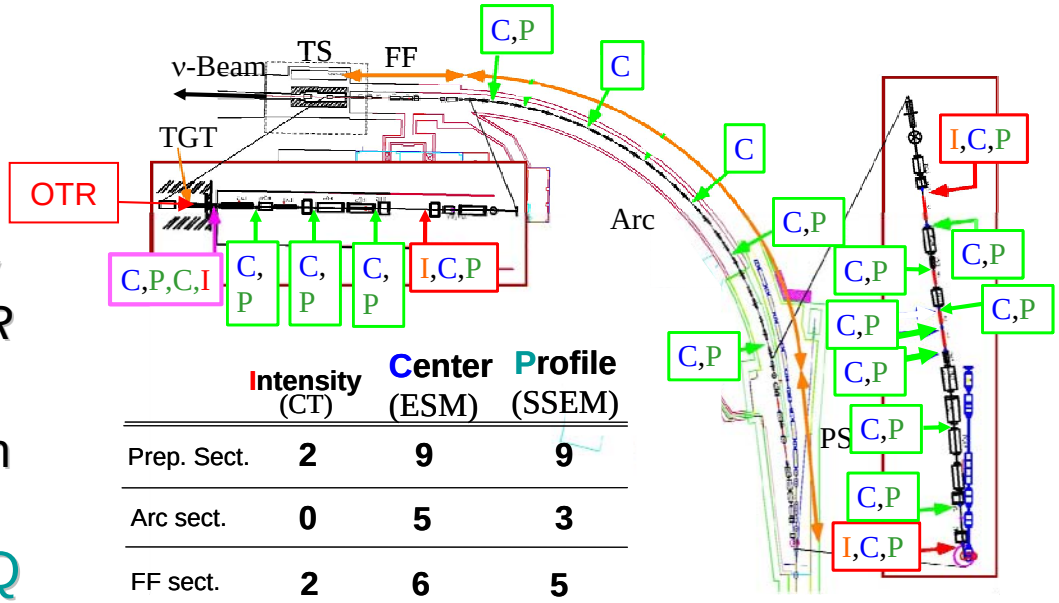
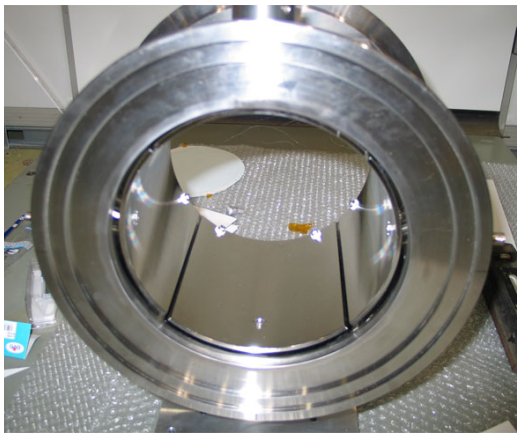
(IPNS, KEK)
TUXKI03

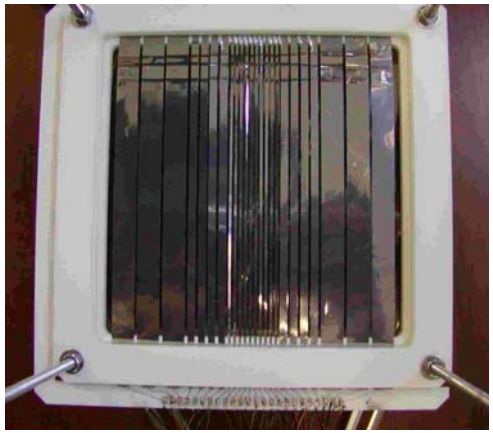
- Configuration
  - Position : Electro-static monitor (ESM)
  - Profile : Segmented Secondary Emission Monitor (SSEM), *OTR*
  - Intensity : CT
  - Loss monitors (BLM): Ionization chamber
- Readout by COPPER/KEK-DAQ

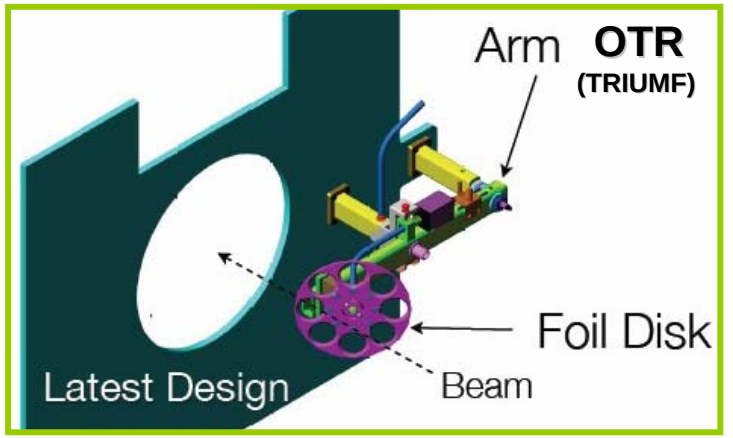


	Intensity (CT)	Center (ESM)	Profile (SSEM)
Prep. Sect.	2	9	9
Arc sect.	0	5	3
FF sect.	2	6	5

Beam loss monitor will be placed along the beam line.







Horn & support module

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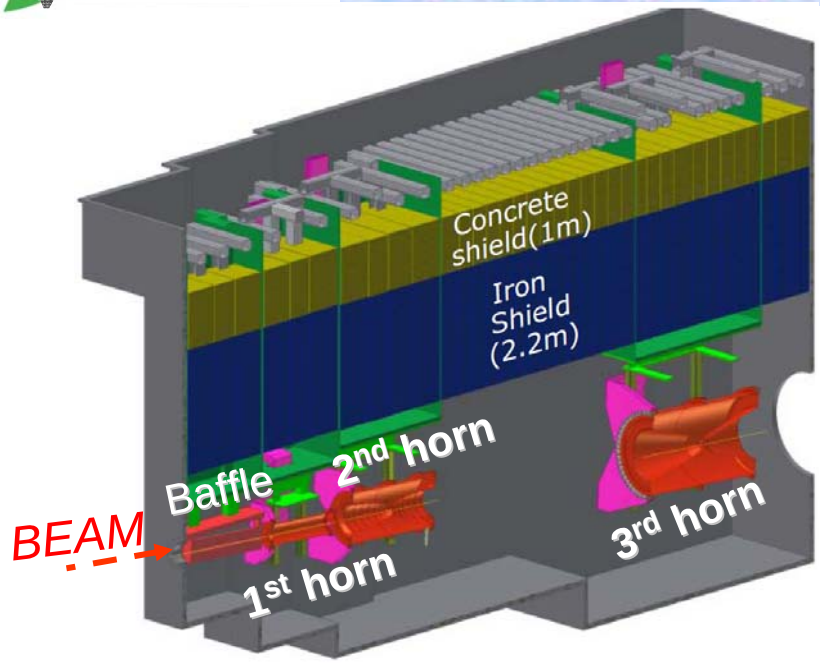
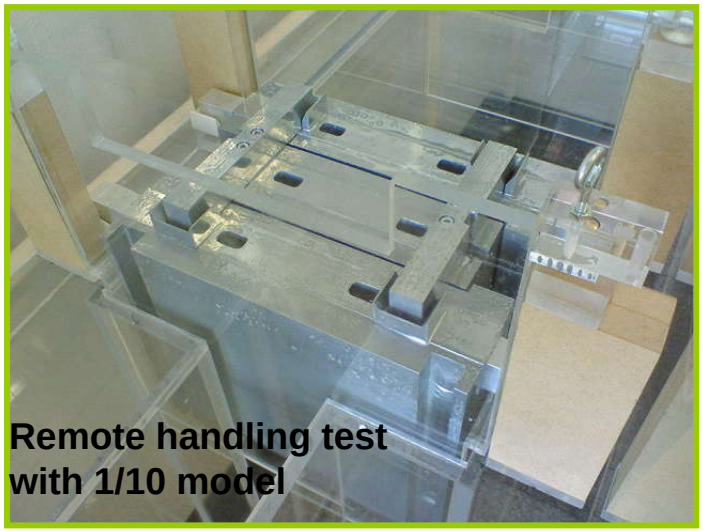
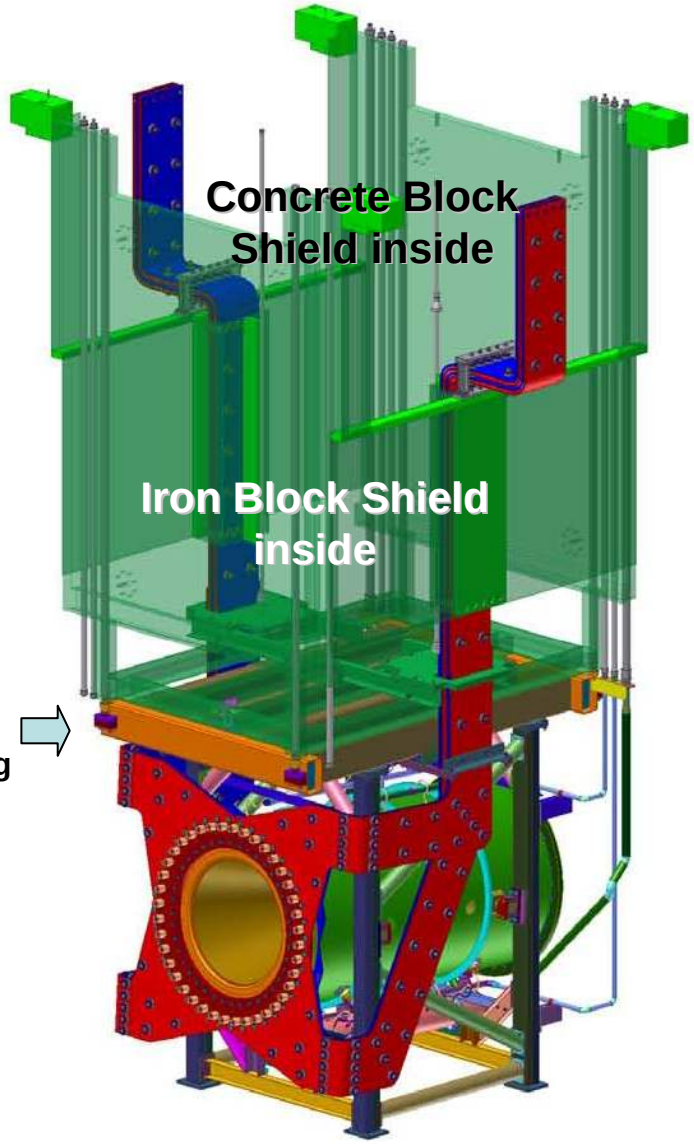



Remote handling test with 1/10 model

Remote coupling



Horn Operation Test

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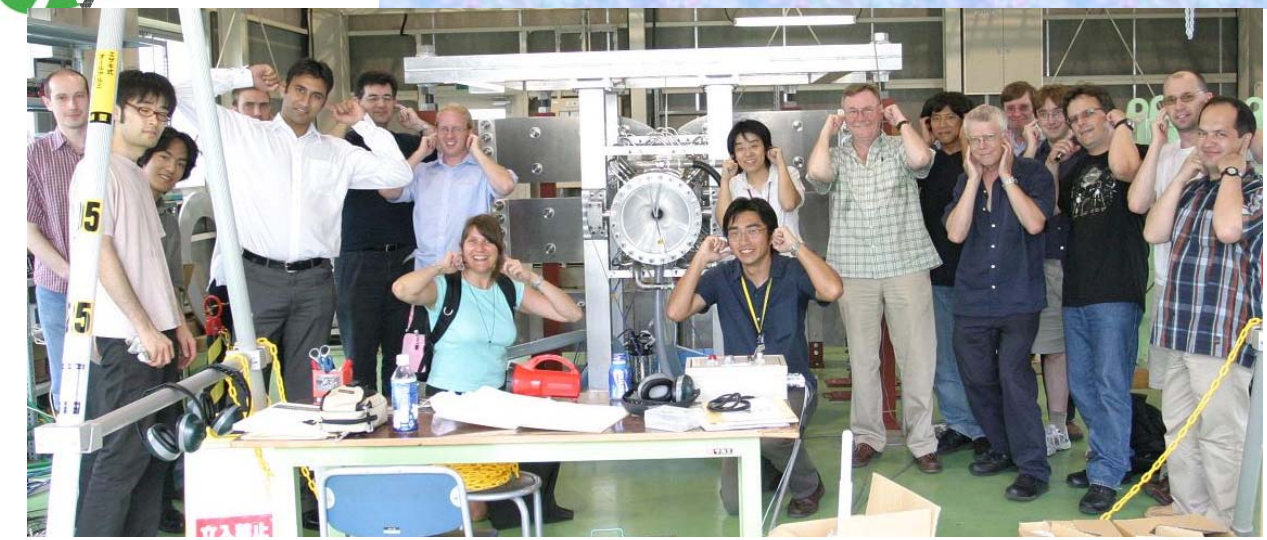
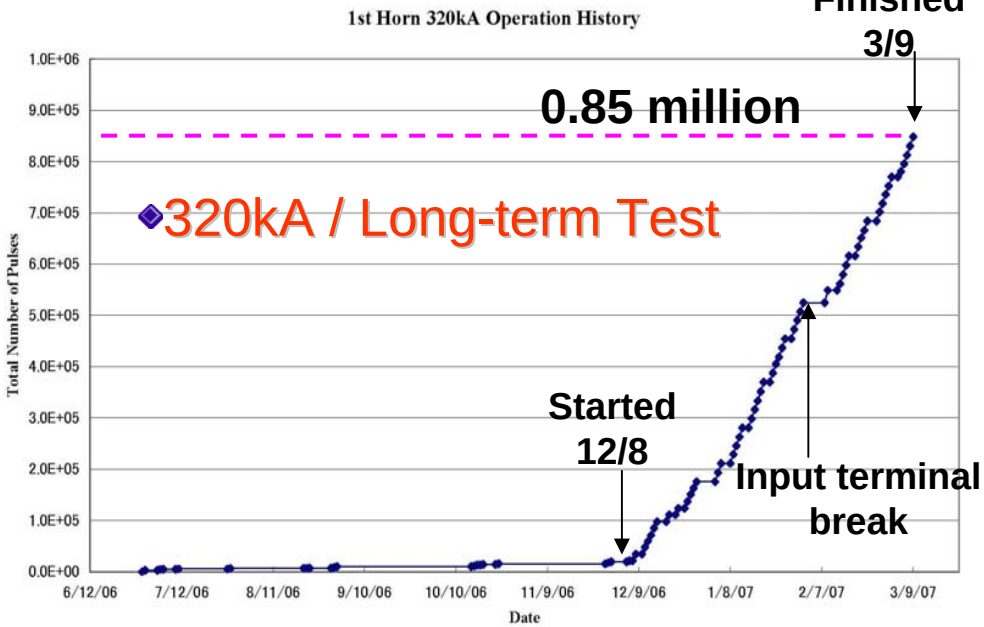
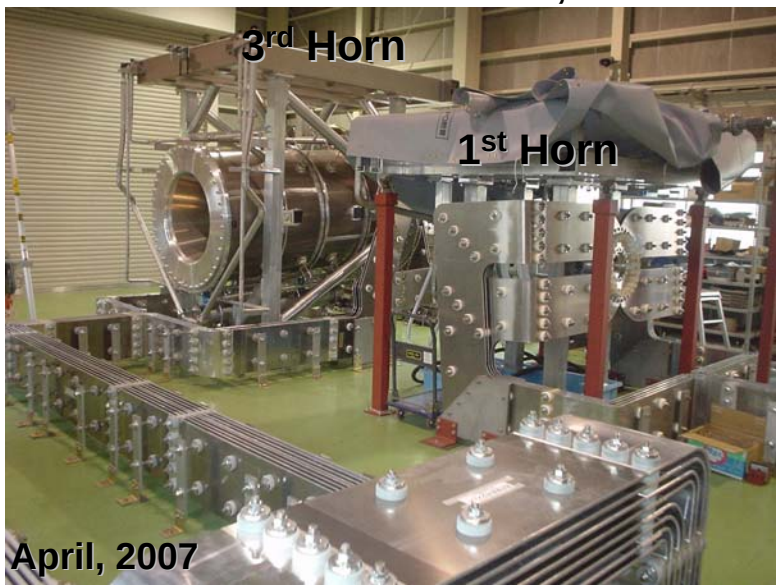


June 30, 2006





Full-setup test for the 3rd Horn

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- **Current operation test in full setup: coming Fall**

Target

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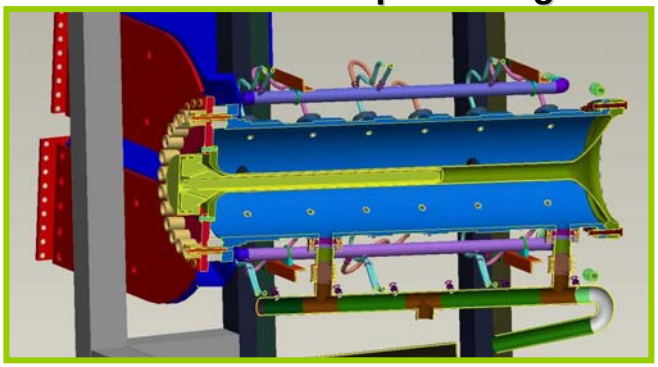
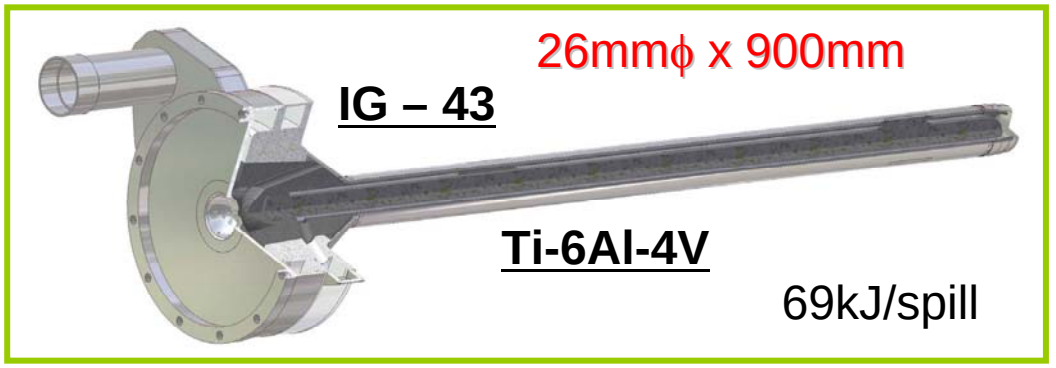
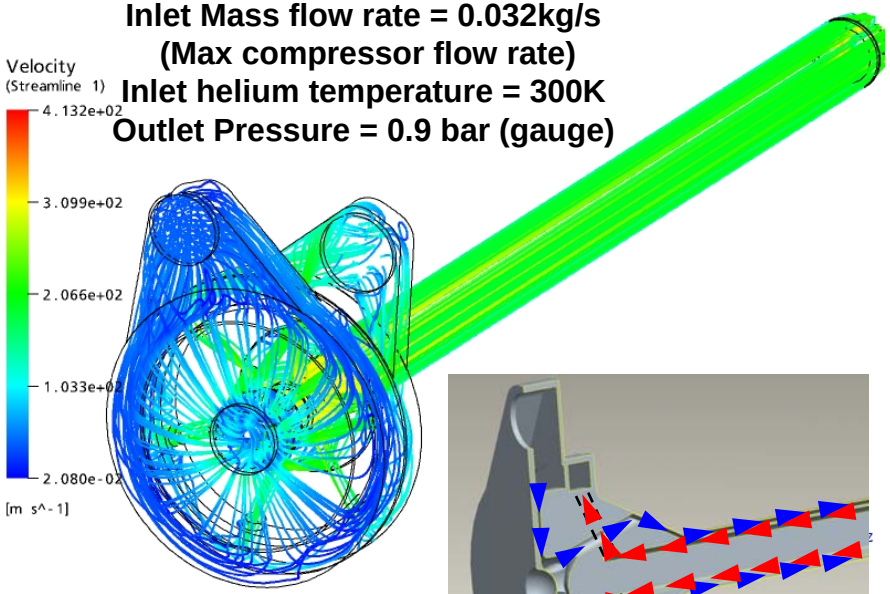
Helium-Cooled Graphite Target in the 1st Horn

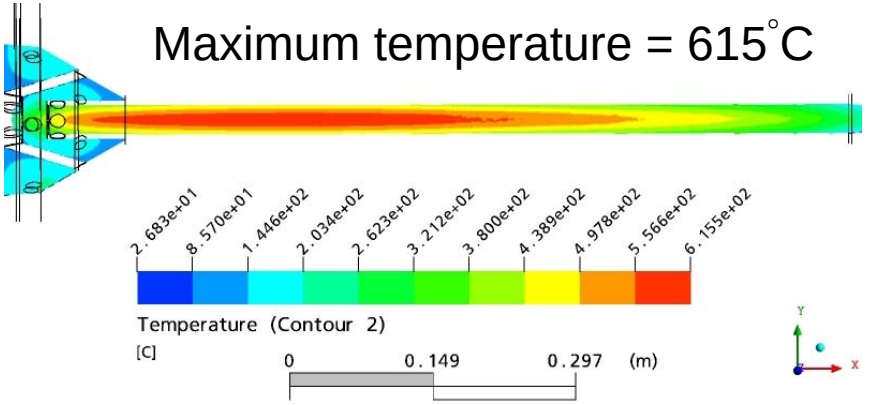


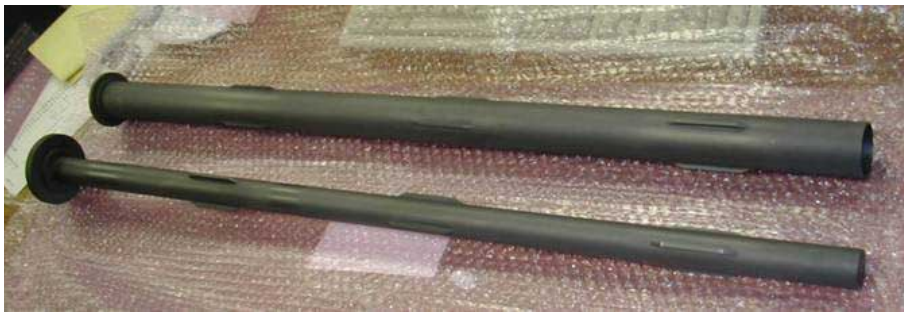


Inlet Mass flow rate = 0.032kg/s
(Max compressor flow rate)
Inlet helium temperature = 300K
Outlet Pressure = 0.9 bar (gauge)



Working design almost in hand.





Beam Dump

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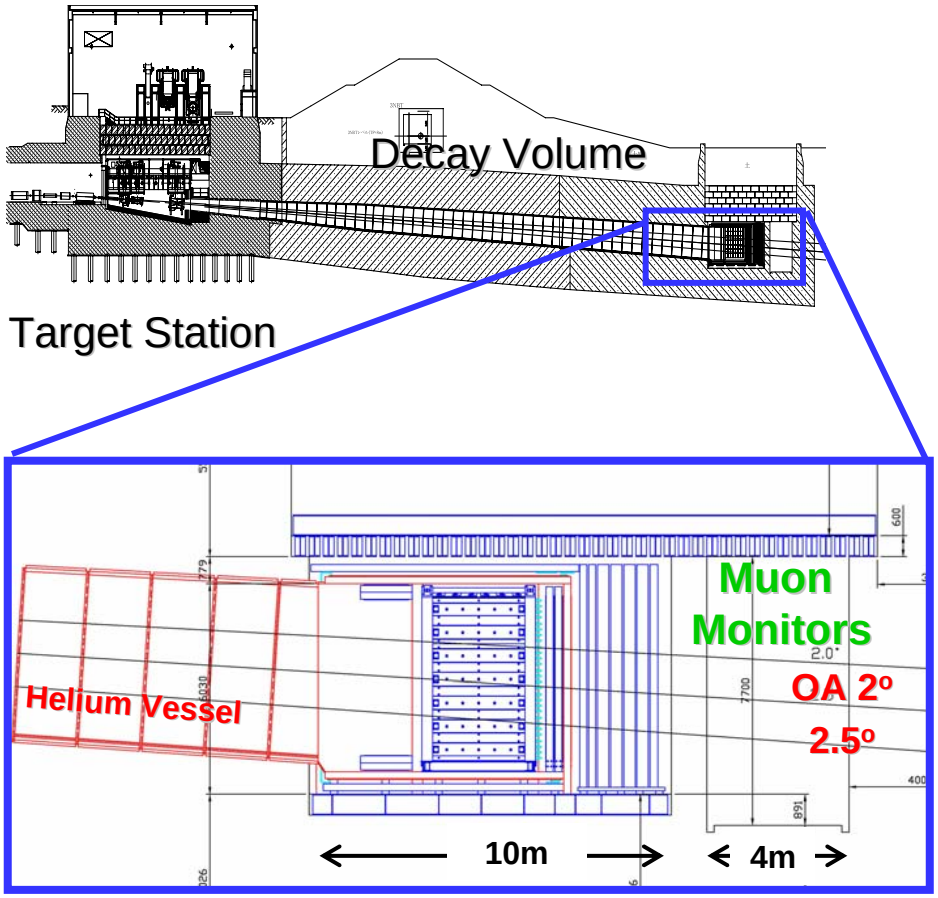

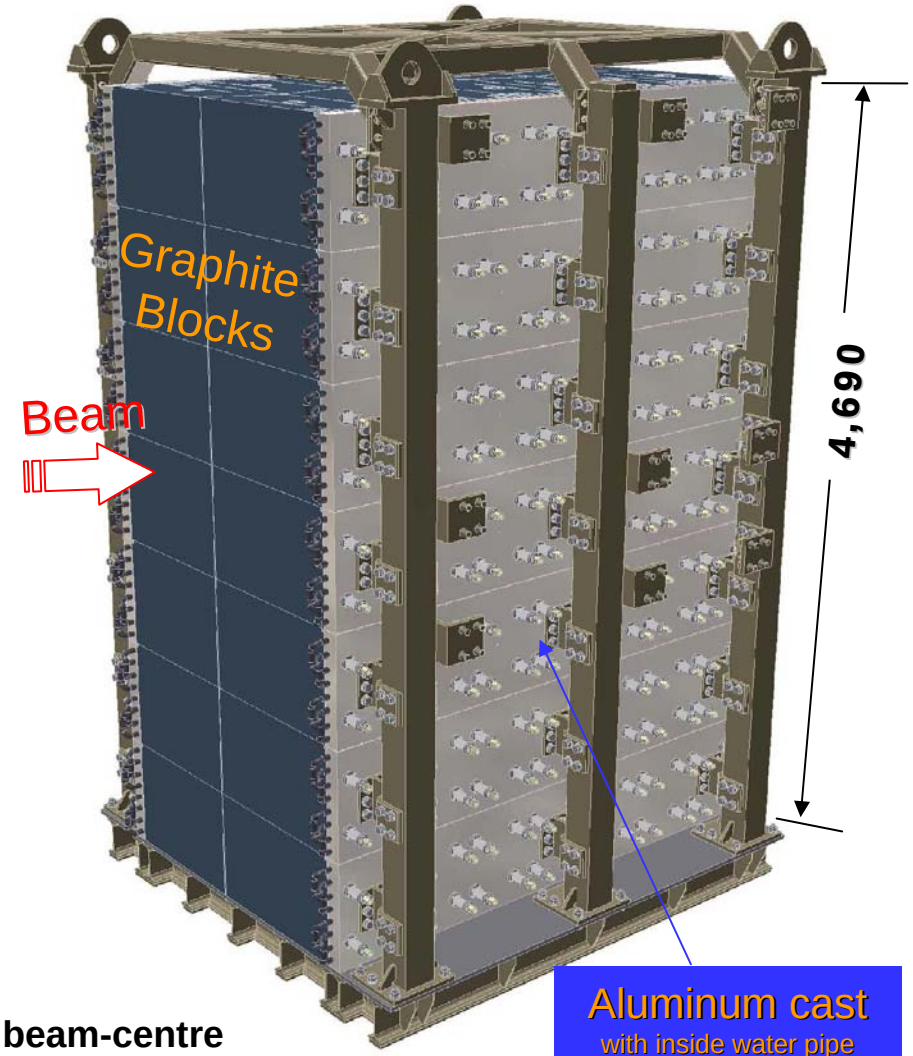

- Semiconductor detector array
- Ionization chamber array

To monirtor beam-centre spill-by-spill

Hadron Absorber Module

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(IPNS, KEK)
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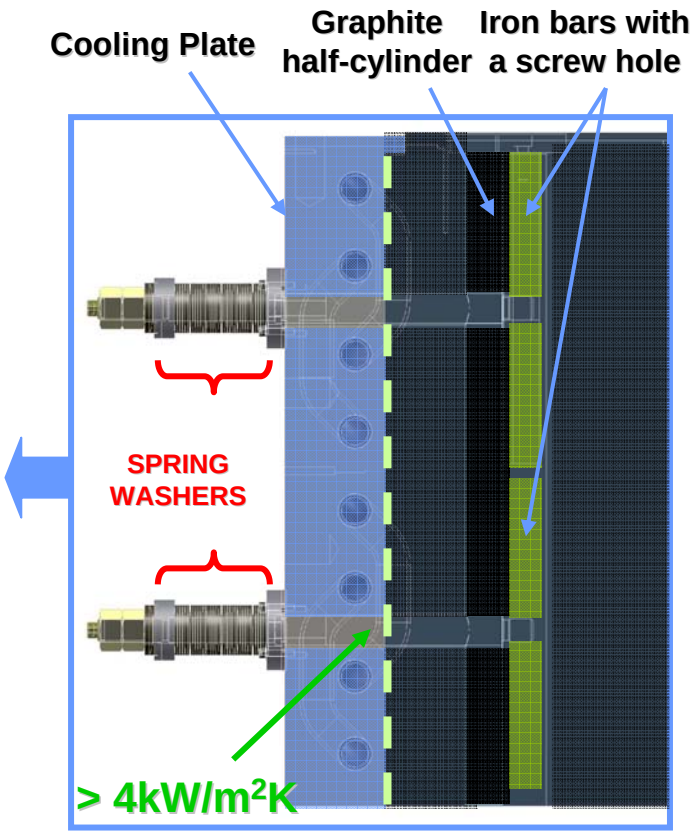

- A design with multiple spring washers was adopted, to control joint force between graphite blocks and an aluminum cast cooling plate
  - Minimize the reduction of joint force (heat convection) by temperature rise
- Flatness of the cooling surface and the loading surface < 0.1 mm
  - Machine 7 graphite blocks at once

Near Neutrino Detectors

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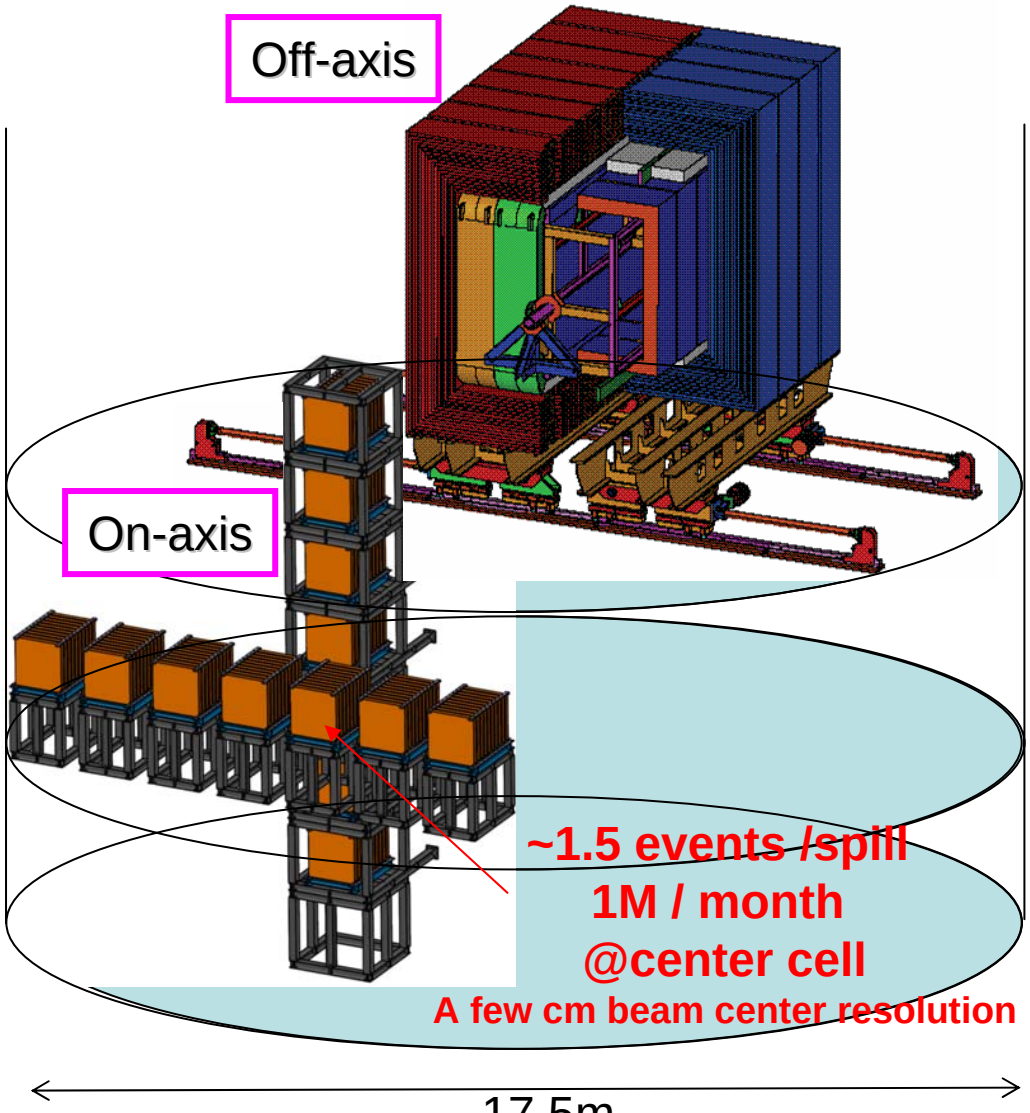
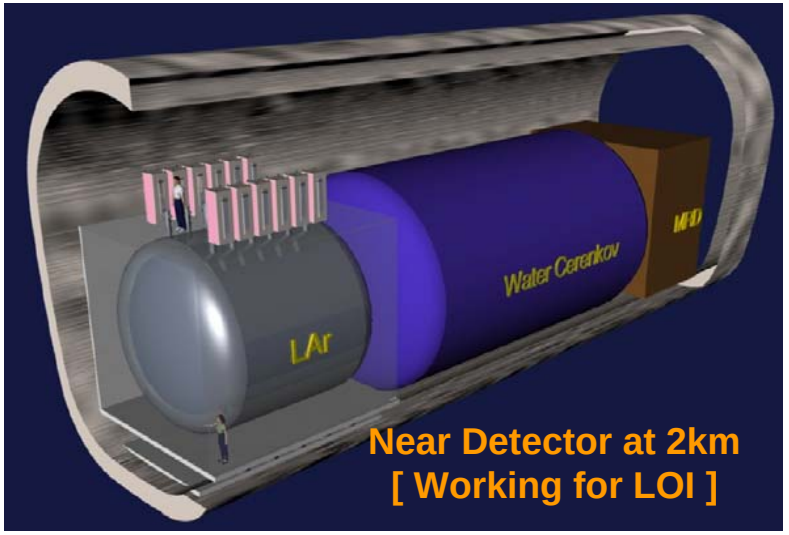


- **Off-axis detector**
  - FGD, TPC, Ecal,.. In UA1 magnet
  - Spectrum / Cross section / νe contamination
- **On axis detector: NGRID**
  - 1mx1mx[0.1mx10lyr]
  - Monitor beam directiorn
- **Scintillator+WLS fiber with**
  - MRS APD (Russia)
  - MPPC (Hamamatsu)



Far Detector: SK-III

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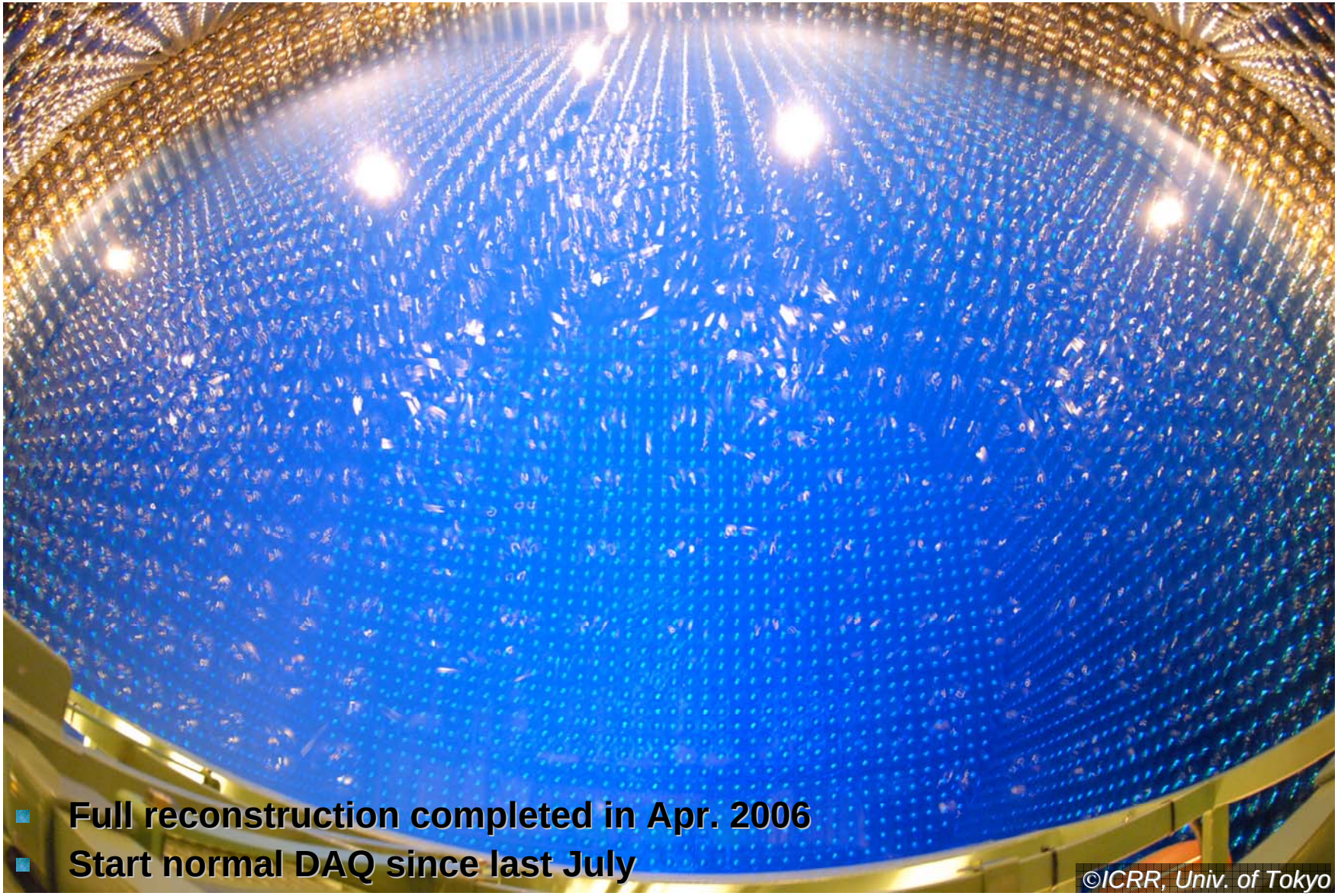

- Full reconstruction completed in Apr. 2006
- Start normal DAQ since last July

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Summary and Future Prospects

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- Various kinds of intense secondary beam-lines are to be operated in J-PARC.
  - Neutron / Muon beam-lines at MLF
  - Kaon beam-lines at the Hadron Hall
  - **Neutrino beam-line for the next generation experiment (T2K)**
- Neutrino beam-line facility construction is going as scheduled:
  - Decay volume (50m finished), primary beam line, target station
  - DV downstream, beam dump, near detector hall are now being started
- Beam-line equipment:
  - Rapid progress of production / fabrication
  - International contributions for crucial parts of the beam line components
- We have cleared critical milestones:
  - Production of SCFM doublets
  - 1st Horn long-term operation with 320 kA
  - Hadron absorber core module
  - ….

Much of struggle from now, towards beam commissioning in April, 2009

And towards new result in ~ 2010 !

Sensitivity to θ_{13}

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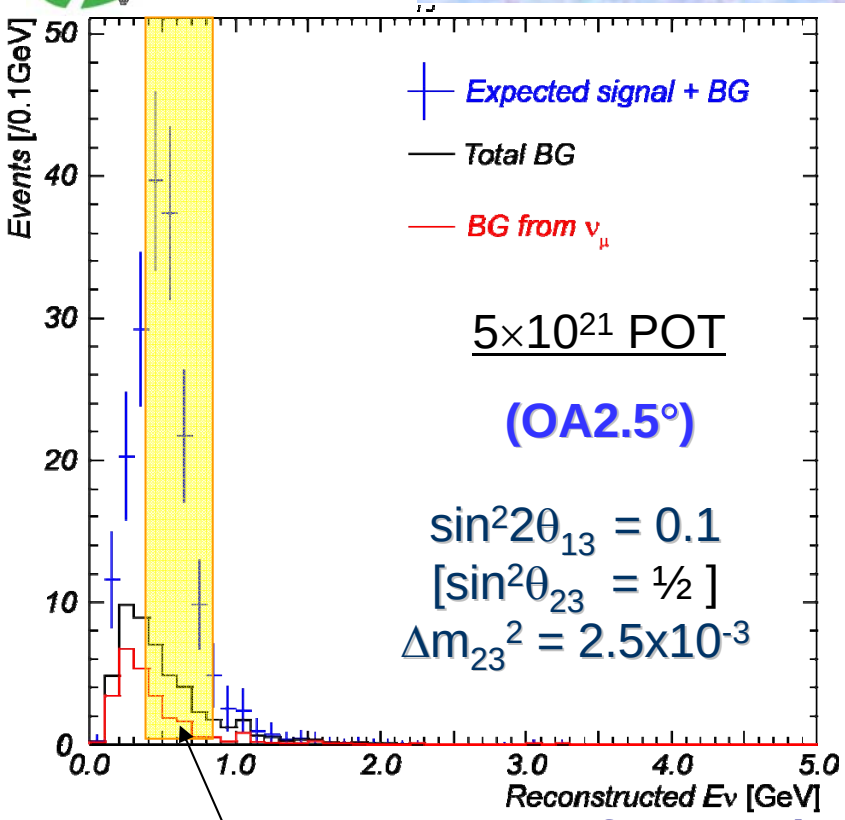

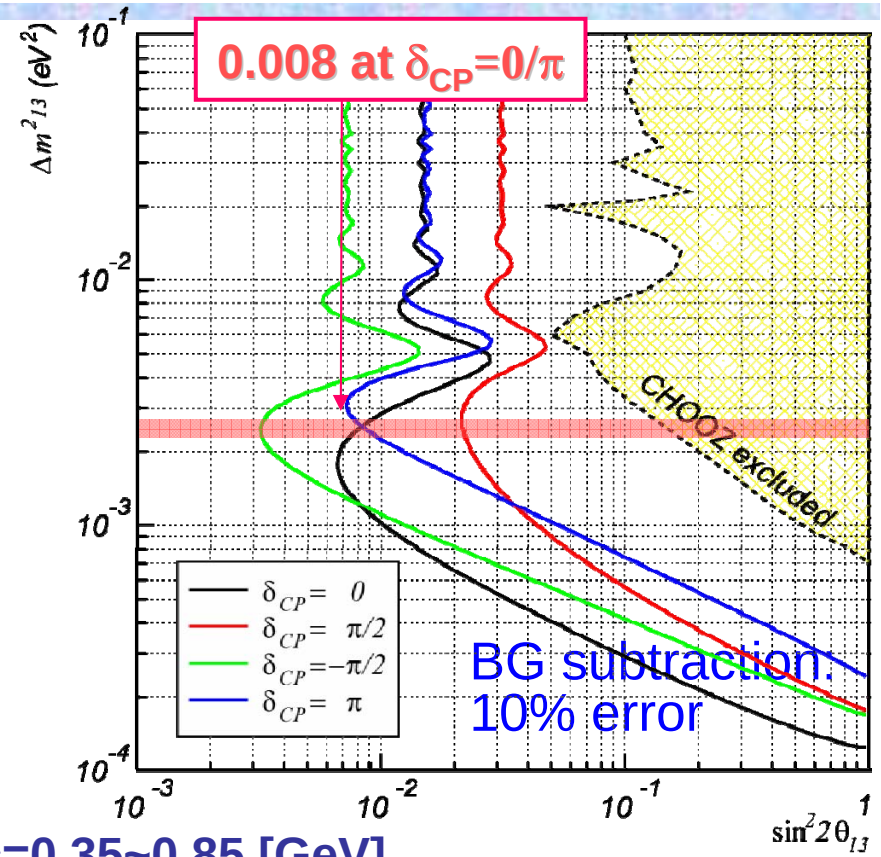

of events in Eνrec=0.35~0.85 [GeV]

$\sin^2 2\theta_{13}$	Background in Super-K			Signal [~40% eff]	Signal + BG
	ν_μ	ν_e	total		
0.1	10	13	23	103	126
0.01				10	33

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Backups

Measurement of θ_{23} , Δm_{23}^2

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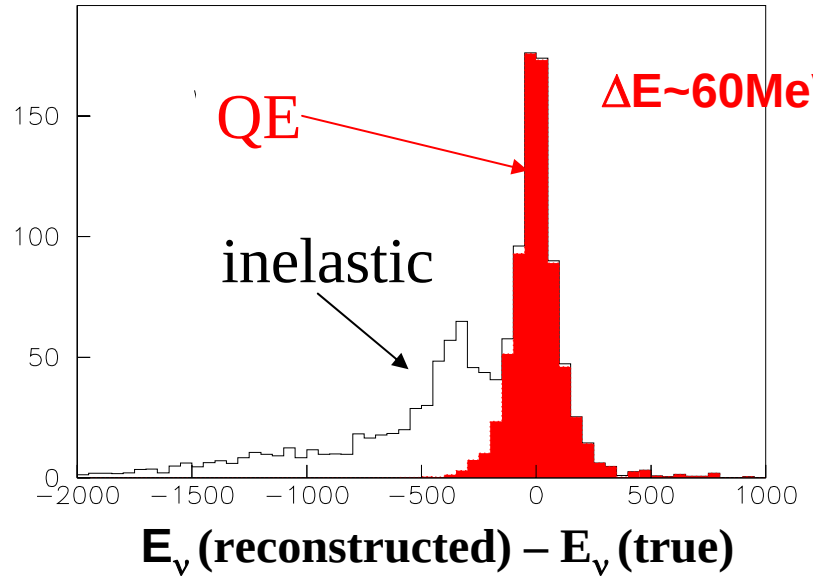
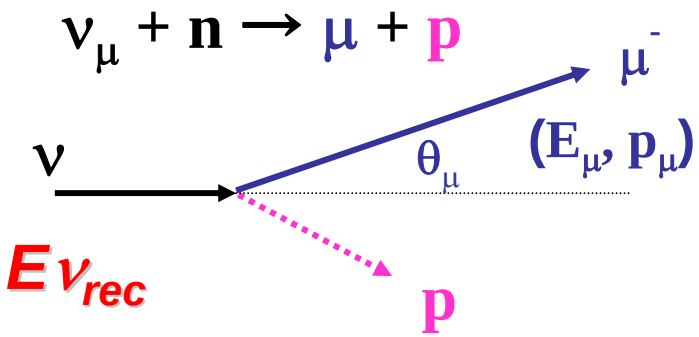
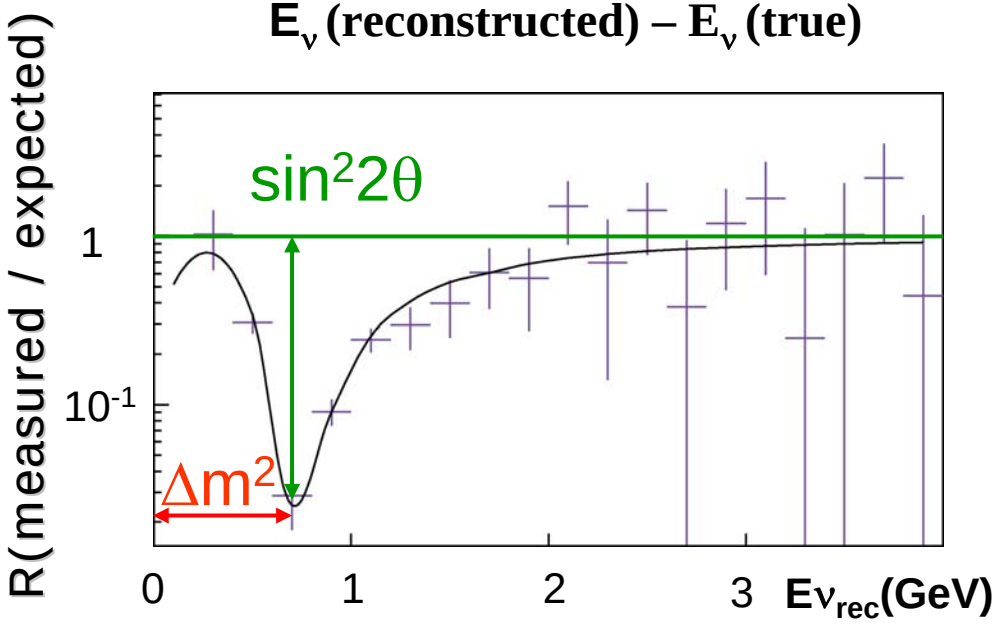
(IPNS, KEK)
TUXK103

- Use 1R μ-like events
  - Large QE fraction
  - Beam with small high energy tail
  - ⇔ $\sin^2 2\theta$ less sensitive to systematics
- Clear deficit is expected in the reconstructed ν energy
  - $\delta E = \delta(E\nu rec - E\nu true) \sim 60$MeV
  - ⇔ < 10% measurement on Δm^2





$$E_{vrec} = \frac{m_N E_\mu - m_\mu^{\,2}/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$



Sensitivity for $\sin^2 2\theta_{23}$, Δm_{23}^2

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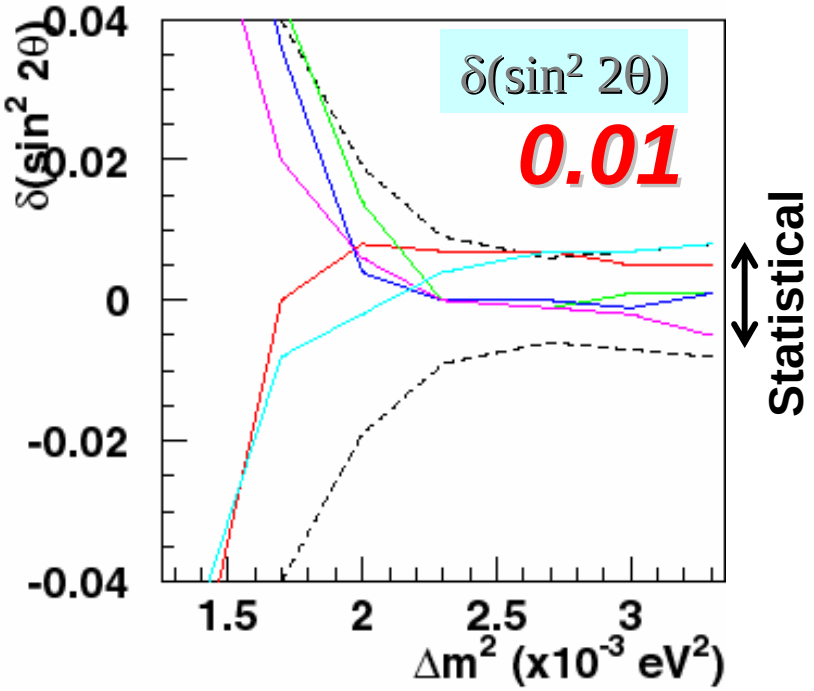
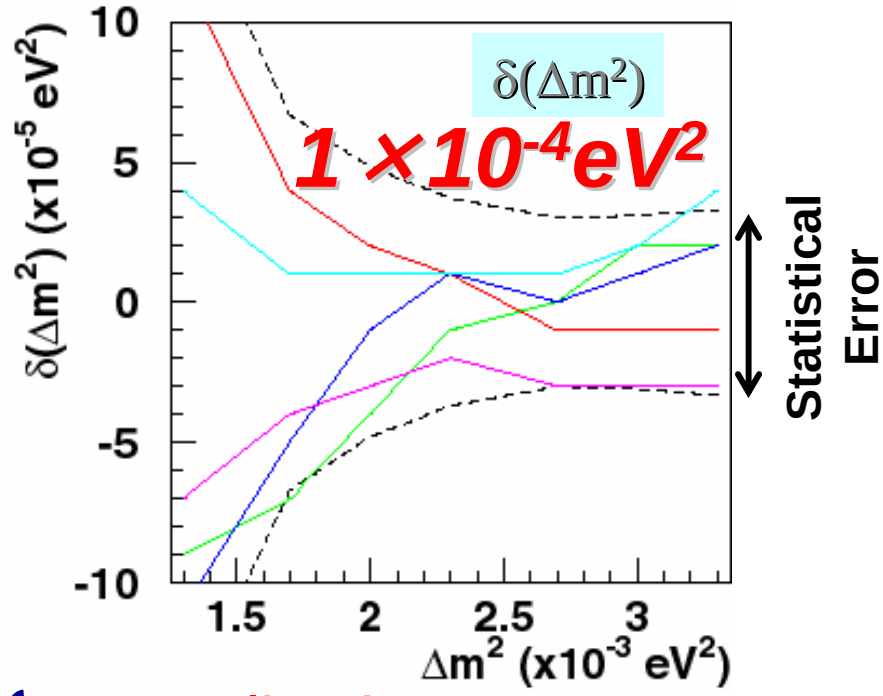
TUXK103





OA2.5°, 5×10^{21} POT
~ 5 years @ full Intensity
Assumed Systematic Errors

Normalization	5%
non-QE/QE ratio	5%
Energy scale	1%
Spectrum Shape	20%
Beam Width	5%

FLUKA / MARS

- Errors will be further reduced by near detector measurements and pion production measurements (CERN NA49)

CPV and Matter Effect

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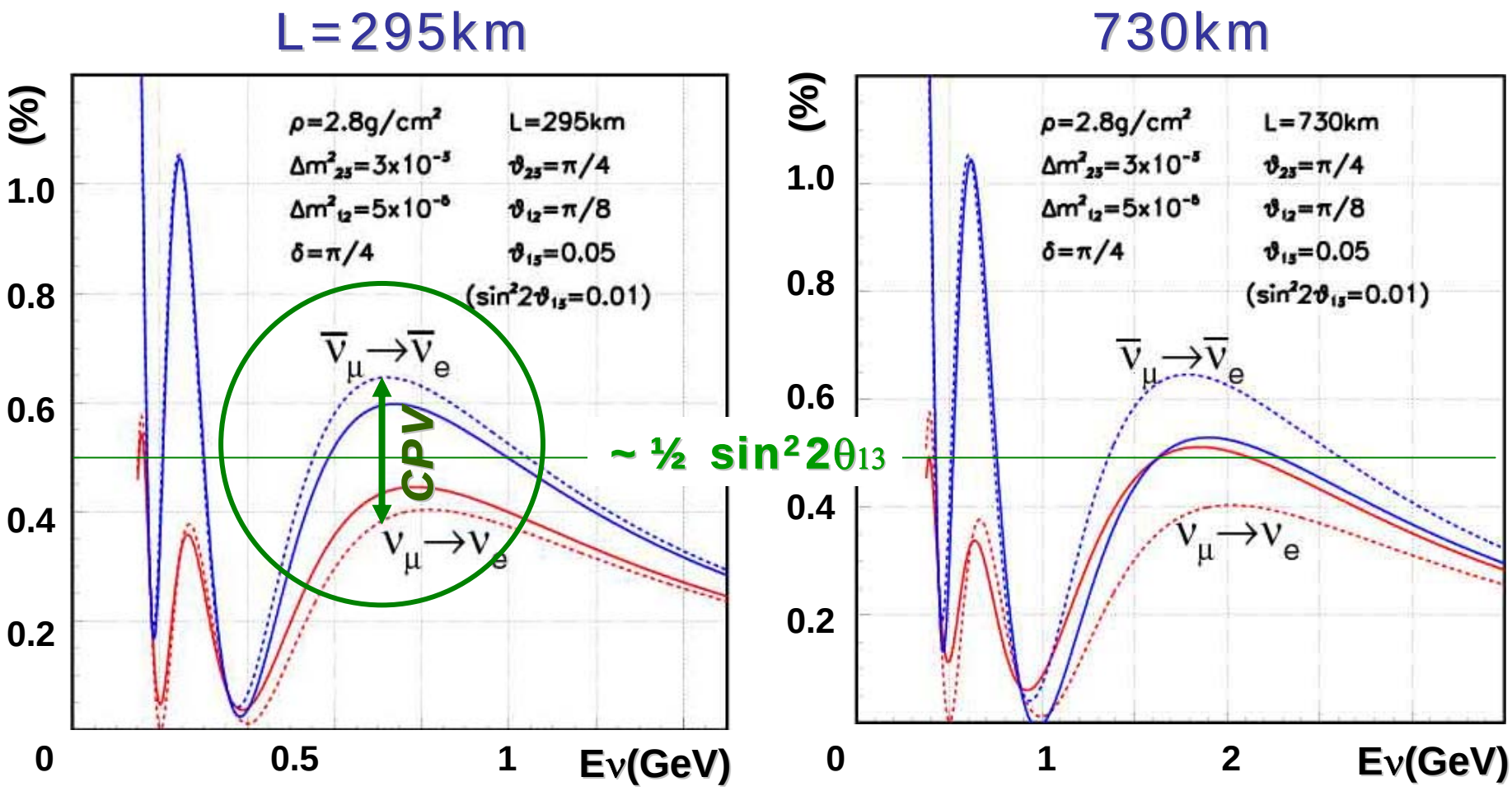
Solid lines: w/ matter, Dashed lines: w/o matter



- Asymmetry can be seen at oscillation maximum ~0.7GeV
- Smaller matter effect at 295km

3σ Sensitivity for CPV in T2K-II

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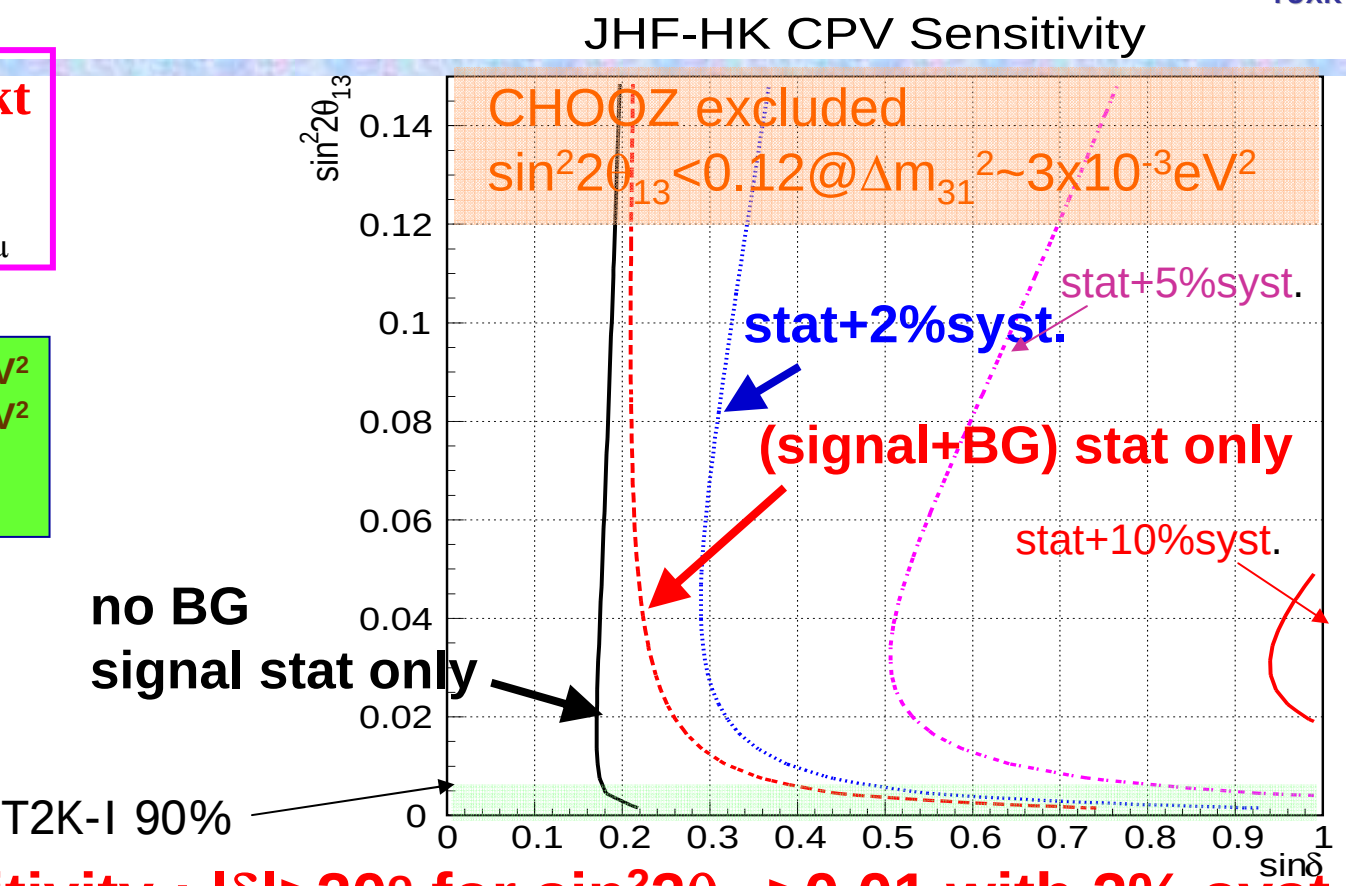
Neutrino Facility at J-PARC

4MW, 540kt
2yr for ν_μ
6~7yr for $\bar{\nu}_\mu$

$\Delta m_{21}^2=6.9\times10^{-5}eV^2$
$\Delta m_{32}^2=2.8\times10^{-3}eV^2$
$\theta_{12}=0.594$
$\theta_{23}=\pi/4$



3σ CP sensitivity : $|\delta|>20^o$ for $\sin^2 2\theta_{13}>0.01$ with 2% syst.

	signal		background				
	δ=0	δ=π/2	total	ν_μ	$\bar{\nu}_\mu$	ν_e	$\bar{\nu}_e$
$\nu_\mu\rightarrow\nu_e$	536	229	913	370	66	450	26
$\bar{\nu}_\mu\rightarrow\bar{\nu}_e$	536	790	1782	399	657	297	430