Mar.2,2004
@LaThuile04

J-PARC

Japan Proton Accelerator Research Complex

Status of J-PARC construction and
J-PARC to Kamioka Neutrino project (“T2K”)

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High Energy Accelerator Research Organization (KEK)

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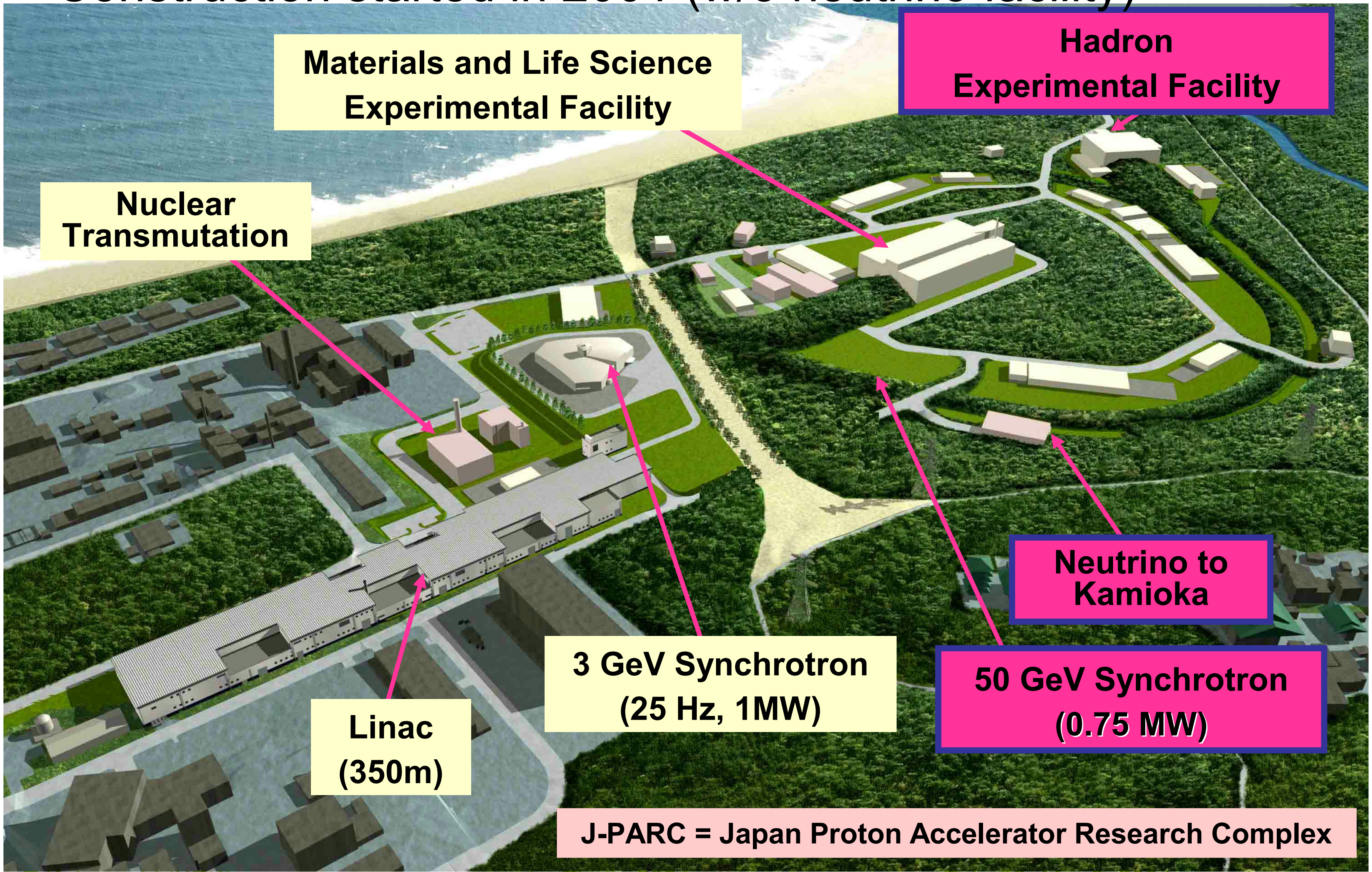
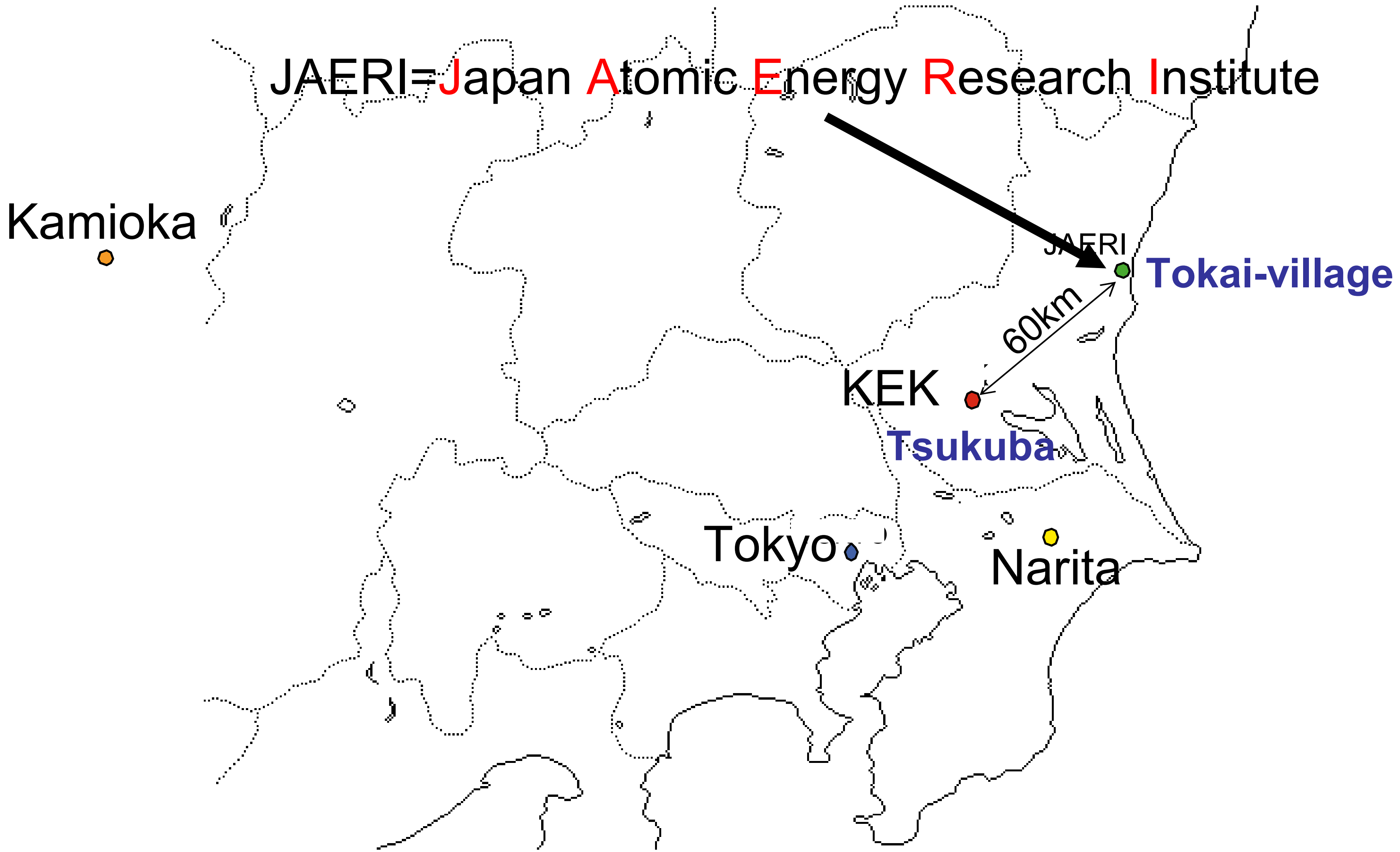
J-PARC

High intensity (~MW) proton accelerator facility @ JAERI
Construction started in 2001 (w/o neutrino facility)

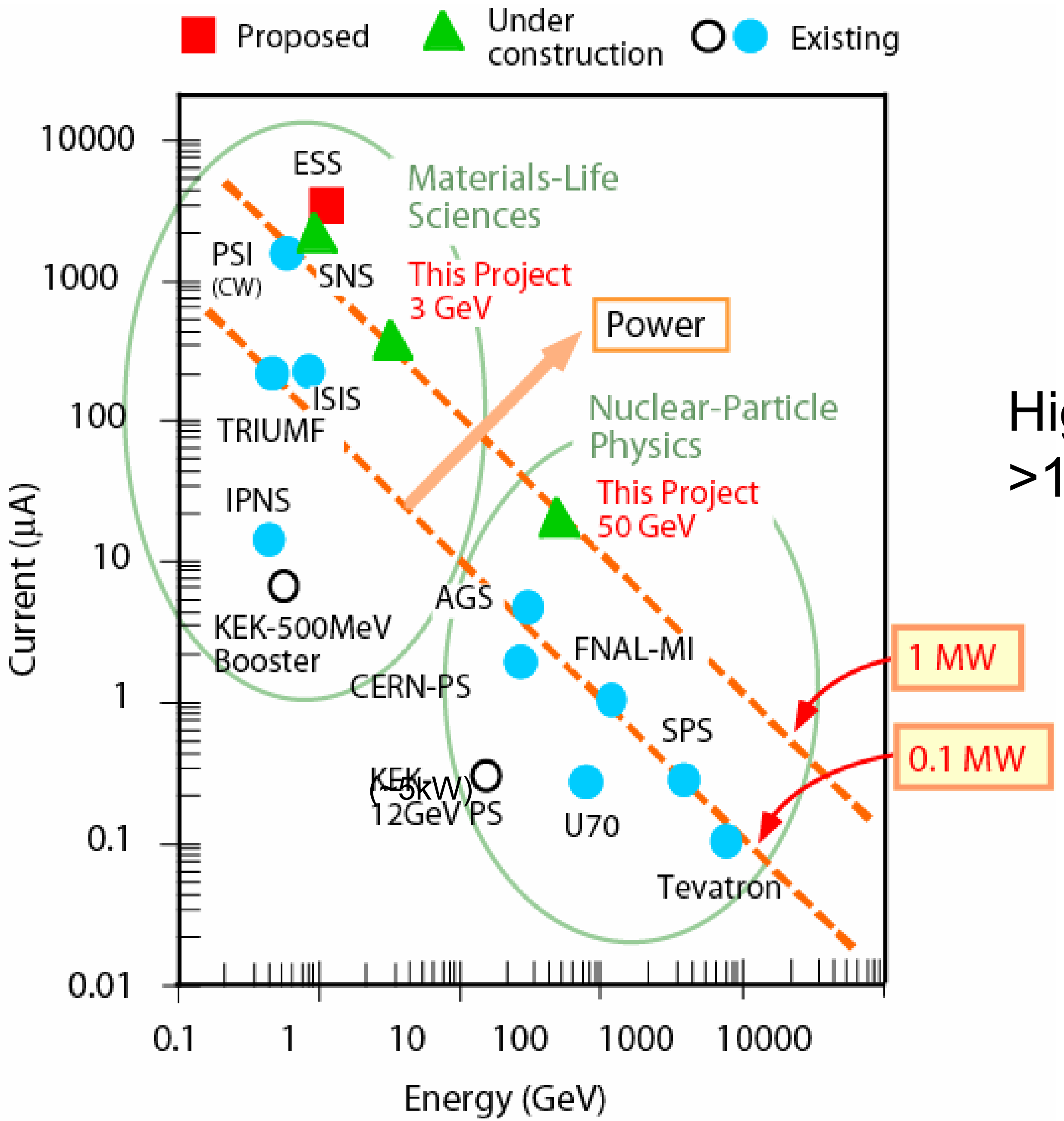


Location of JAERI at Tokai-village

JAERI=Japan Atomic Energy Research Institute



World's Proton Accelerators

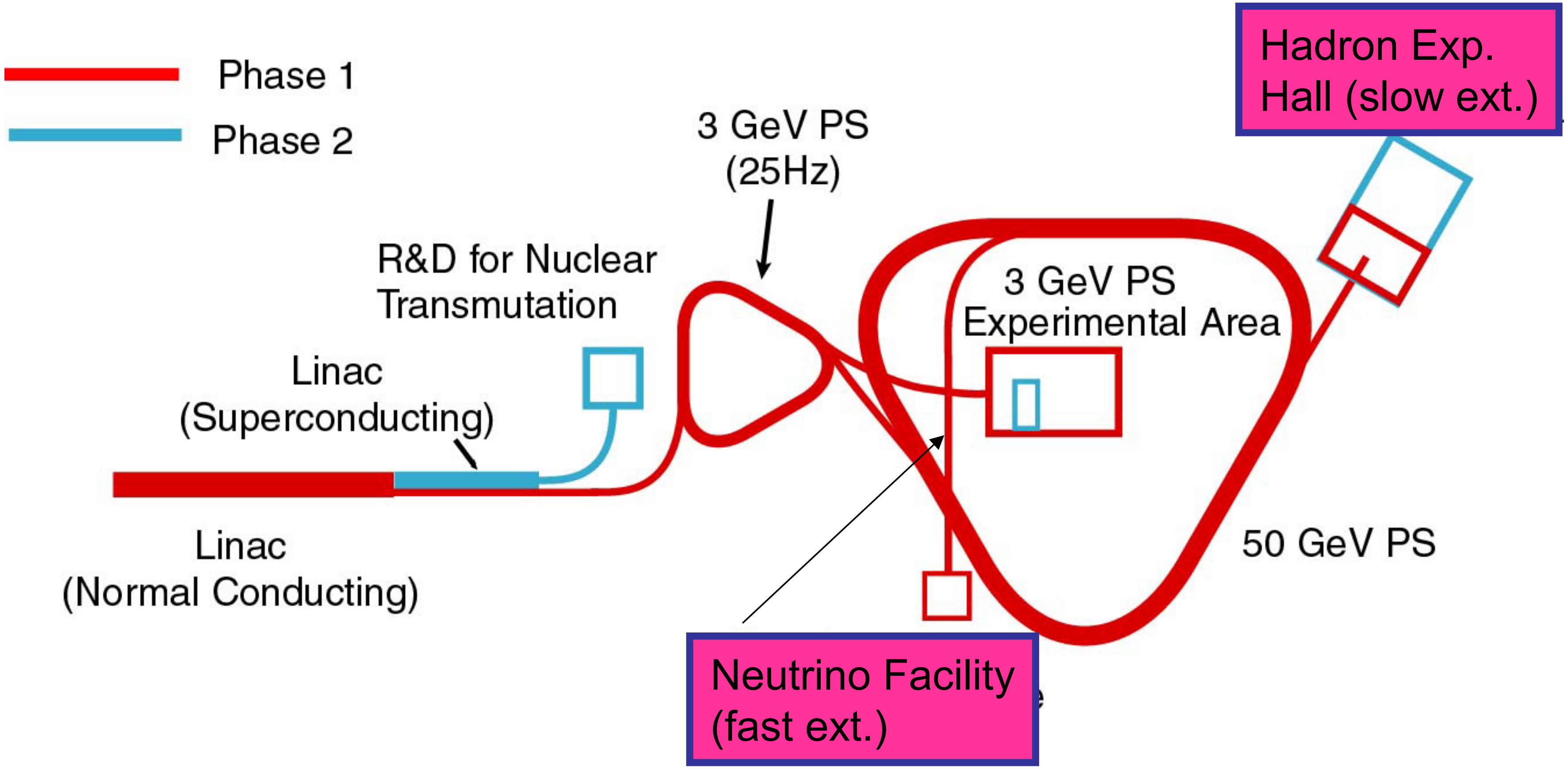


High Intensity Frontier
>100times of KEK-PS

Recent Events & News

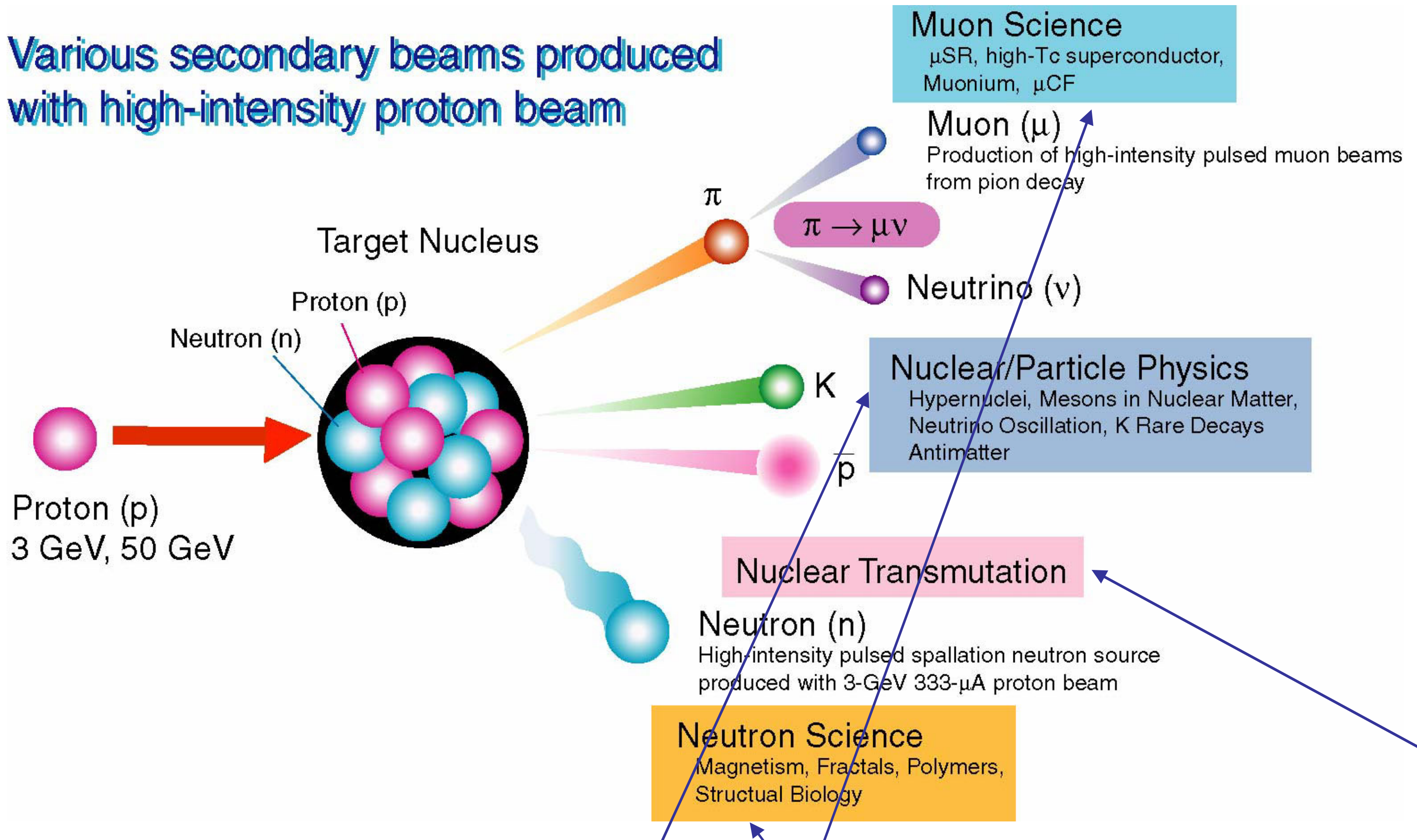
- Review by the Council of Science and Technology Policy (CSTP) Oct.,2003
  - All budget requests from Ministry of Education, etc. (our funding agency) to Ministry of Finance are subject to the review of CSTP.
  - CSTP ranked Phase 1 project to "A" (and the building construction to "S") whereas our neutrino project to "C". (S=Superior, A=Very Good, B=OK, C=Poor).
- Interim Review of the Project was held in Nov., 2003
  - Chair: K. Kodaira (total 12 committee members)
  - Four meetings on Nov. 7, 14, 21 and 27.
  - Major recommendations: Neutrino program must start immediately. The energy recovery of Linac to 400 MeV must be done immediately after the installation of 200 MeV Linac.
  - Finally, both CSTP and the Ministry of Finance agreed to these recommendations.
- Announcement in Late Dec., 2003
  - **Neutrino project approved for construction (total = 16.0 BYen, 5 years).**
  - Approval of the neutron beam line design outside the J-PARC budget.

Phase 1 and Phase 2



- Phase 1 + Phase 2 = 189 billion Yen (= $1.89 billion if $1 = 100 Yen).
- Phase 1 = 151 billion Yen for 7 years.
- Construction budget does not include salaries.

Three Goals at this Facility



- Materials & Life Sciences at 3 GeV
- Nuclear & Particle Physics at 50 GeV
- R&D toward Transmutation at 0.6 GeV

Physics at 50-GeV PS

- ~100 times intensity of KEK-PS
- Nuclear (strong interaction) physics & Particle physics with *K*, π, μ, ν, *pbar*, and other secondary beams

Hadron
Exp. Fac.
(slow ext.)

  - Hypernuclear spectroscopy
  - Hyperon-nucleon scattering
  - Mesons in nuclear matter
  - Hadron spectroscopy
  - Kaon rare decays to measure CKM matrix elements
  - CP violation and other symmetry breaking
  - Low energy QCD in meson decays
  - Flavor mixing and other topics beyond the Standard Model
  - **Long baseline (LBL) Neutrino oscillation experiment using Super-Kamiokande**
- Nuclear physics with primary beams
  - Physics with proton beams (polarized beams in the future)
  - High-density matter with heavy-ion beams in the future

Neutrino mixing

If neutrino have finite mass, weak and mass eigenstates can differ

$$\left|\nu_l\right\rangle = \Sigma U_{li}\left|\nu_i\right\rangle$$

Weak Mass eigenstates

$\boldsymbol{m_i}$: 3 masses, $\boldsymbol{\Delta m_{ij}}$: 2 differences

Maki-**N**akagawa-**S**akata **Matrix** $s_{ij}=\sin\theta_{ij}$, $c_{ij}=\cos\theta_{ij}$

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

3 mixing angles and 1 CPV phase

Unknown 2 parameters

$$= \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix}$$

$\sin^2 2\theta_{12} \sim 0.8$ (Solar)

$\sin^2 2\theta_{23} \sim 1$ (Atm ν)

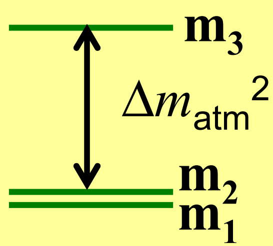
Reactor

Long baseline experiments

What can be measured in LBL exp.

Oscillation probabilities

$$\Delta m_{12}^2 << \Delta m_{23}^2 \approx \Delta m_{13}^2 = \Delta m_{atm}{}^2$$
$$\Delta m_{ij}^2 = m_j^2 - m_i^2$$



➢ ν_μ disappearance: θ_{23}

$$P_{\nu\mu \to \nu\mu} \approx 1 - \underbrace{\cos^4\theta_{13}}_{\sim 1} \cdot \sin^2 2\theta_{23} \cdot \sin^2\left(1.27\, \Delta m_{atm}{}^2 L / E_\nu\right)$$

Same

➢ ν_e appearance: θ_{13}

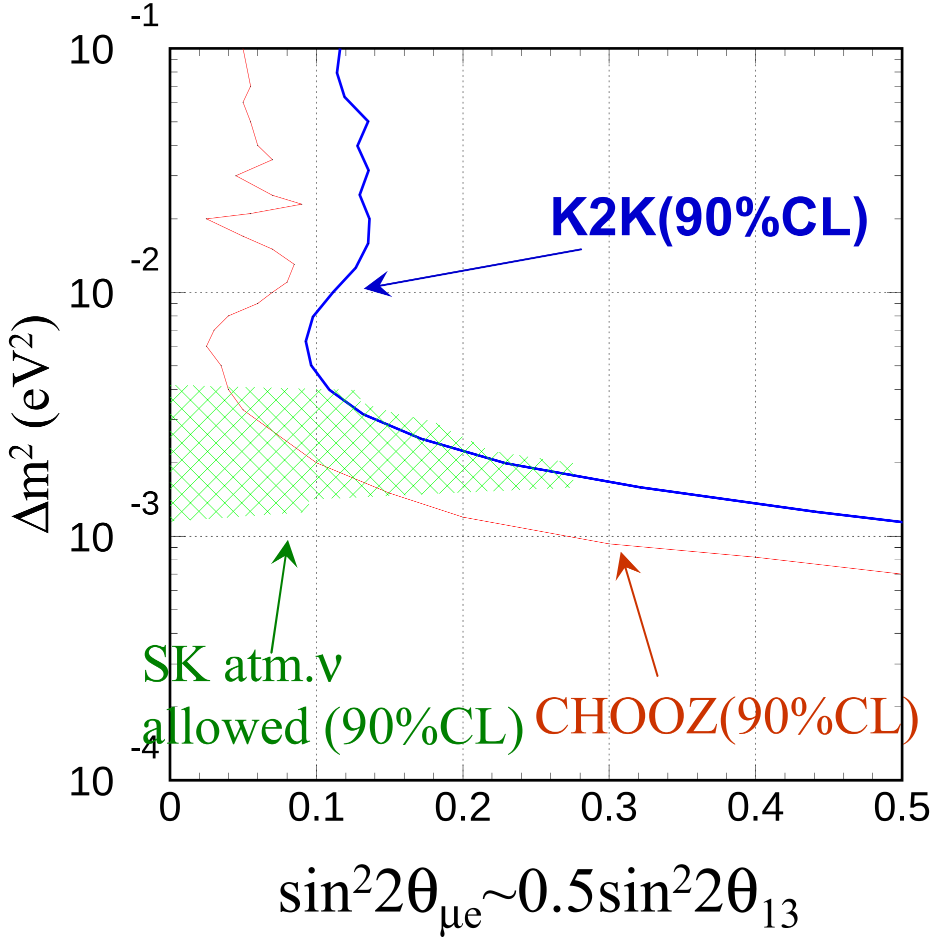
$$P_{\nu\mu \to \nu e} \approx \underbrace{\underbrace{\sin^2\theta_{23}}_{\sim 0.5} \cdot \sin^2 2\theta_{13}}_{\sin^2 2\theta_{\mu e}} \cdot \sin^2\left(1.27\, \Delta m_{atm}{}^2 L / E_\nu\right)$$

➢ δ: $\cancel{CP}$ in ν_e appearance

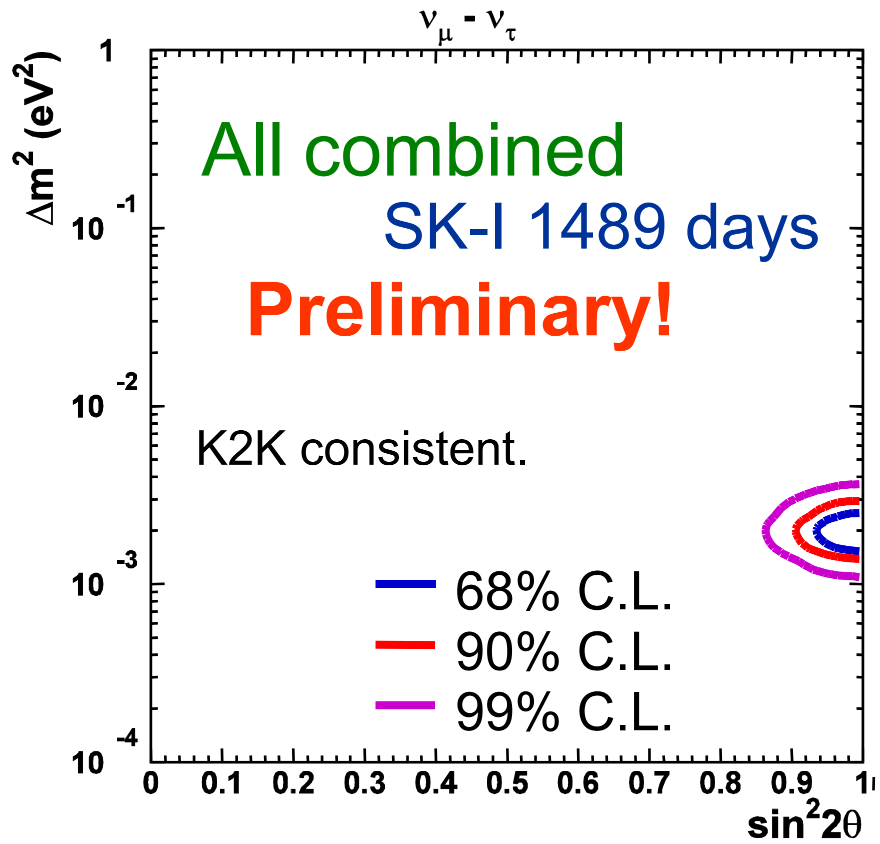
$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \approx \frac{\Delta m_{12}^2}{4E_\nu} \cdot \frac{\sin 2\theta_{12}}{\sin\theta_{13}} \cdot \sin\delta$$

Current status of Δm_{23}^2, θ_{23} and θ_{13}

θ_{13}



θ_{23}



Small!! Only upper limit

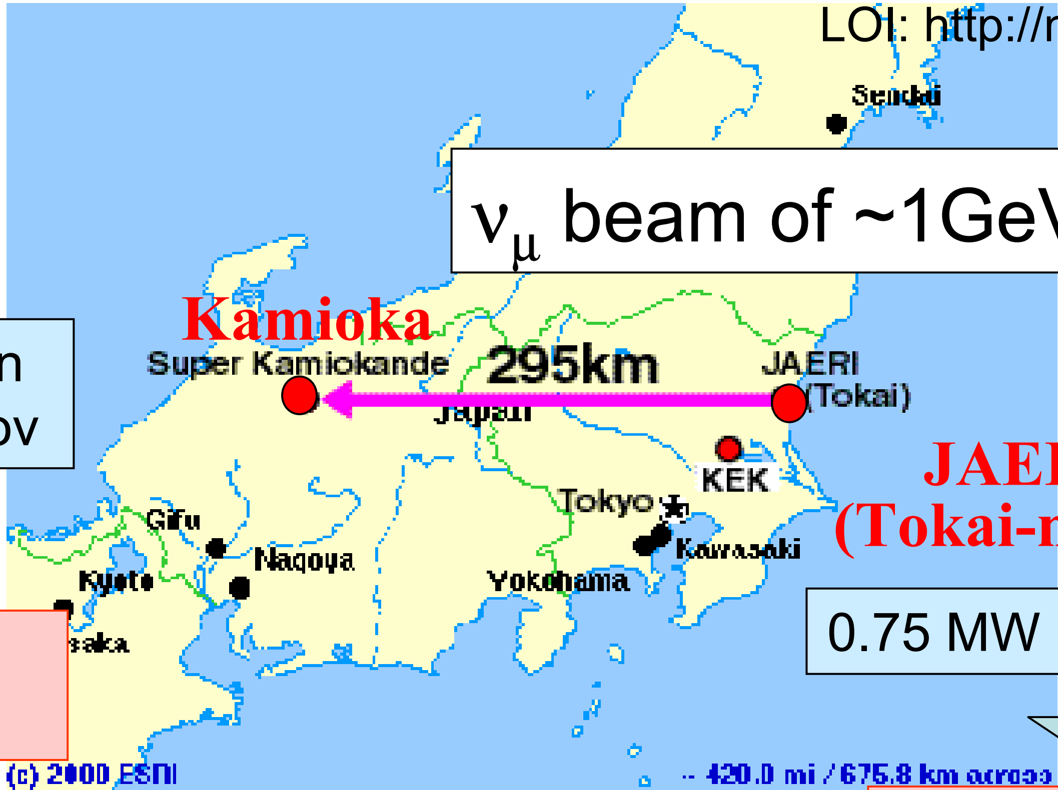
Nearly maxmal!

Next goals of LBL experiments

- Establish framework of 3 flavor mixing (or find something new)
  - Discovery of ν_e appearance (θ_{13}>0?)
    - At the same Δm^2 as ν_μ disapp. → Firm evidence of 3gen. mix.
    - Open possibility to search for CPV (θ_{any}=0 → No CPV)
  - Precision measurements of ocs. params.
    - Really $\sin^2 2\theta_{23}$=1?? (disappearance)
    - Test exotic models (decay, extra dimensions,….)
  - Confirmation of $\nu_\mu \rightarrow \nu_\tau$
    - NC measurement
- Sign of Δm^2
- Search for CPV in lepton sector
  - Give hint on Matter/Anti-matter asymmetry in the universe

"T2K" (Tokai-to-Kamioka) neutrino experiment

LOI: http://neutrino.kek.jp/jhfnu



ν_μ beam of ~1GeV

Super-K: 50 kton
Water Cherenkov

~Mt "Hyper Kamiokande"

JAERI
(Tokai-mura)

0.75 MW 50 GeV PS

4MW 50GeV PS

1st Phase (x10^2 of K2K)

- $\nu_\mu \rightarrow \nu_x$ disappearance
- $\nu_\mu \rightarrow \nu_e$ appearance
- NC measurement

2nd Phase

- CP violation
- proton decay

WW International Collaboration

Country/Institute		#of collaborators
1.Japan	(9inst's)	45
1	ICRR, U. Tokyo	13
2	KEK	12
3	Tohoku U.	6
4	Hiroshima U.	3
5	Kyoto U.	3
6	Kobe U.	3
7	Osaka City U.	2
8	U. Tokyo	2
9	Miyagi U. of Education	1
2.US	(14inst's)	38
1	UCI	5
2	SUNY-SB	5
3	U. Rochester	5
4	U. Pennsylvania	4
5	Boston U.	4
6	CSU, Dominguez Hills	3
7	BNL	3
8	UCB/LBL	2
9	U. Hawaii	2
10	ANL	1
11	MIT	1
12	LSU	1
13	LANL	1
14	U. Washington	1
3.Korea	(8inst's)	10
1	Seoul National U.	2
2	Chonnam National U.	2
3	Dongshin U.	1
4	Kangwon U.	1
5	Kyungpook National U.	1
6	KyungSang National U.	1
7	SungKyunKwan U.	1
8	Yonsei U.	1

4.Poland	(1inst's)	1
1	Warsaw U.	1
5.Spain	(2inst's)	5
1	U. Barcelona	2
2	U. Valencia	3
6.Switzerland	(1inst's)	2
1	U. Geneva	2
7.Russia	(1inst's)	4
1	INR	4
8.Italy	(4inst's)	7
1	U. Roma	3
2	U. Bari	2
3	U. Napoli	1
4	U. Padova	1
9.France	(1inst's)	5
1	CEA Saclay	5
10.Canada	(6inst's)	20
1	TRIUMF	12
2	U. Alberta	3
3	York U.	2
4	U. Toronto	1
5	U. Victoria	1
6	U. Regina	1
11.China	(1inst's)	4
1	IHEP(Inst. Of High Energy Phys.)	4
12.UK	(4inst's)	7
1	RAL	1
2	Imperial College London	2
3	Queen Mary Westfield College London	1
4	U. Liverpool	3

- Formed in May 2003
- 12 countries, 52 institutions
- 148 collaborators (not incl. students)
- Spokesperson: K.Nishikawa (Kyoto U.)

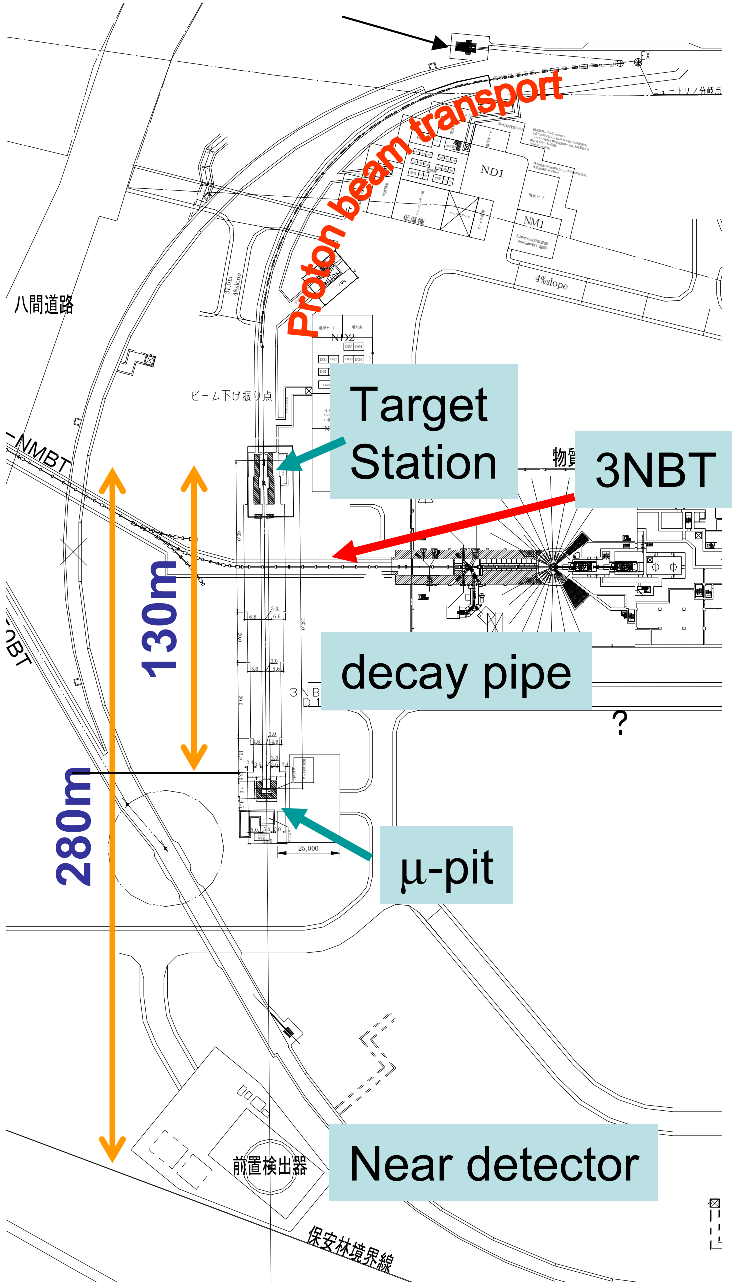
Neutrino facility in J-PARC

“Conventional” beam

$$p + X \rightarrow \pi^{+} + X'$$
$$\hookrightarrow \nu_{\mu} + \mu^{+}$$

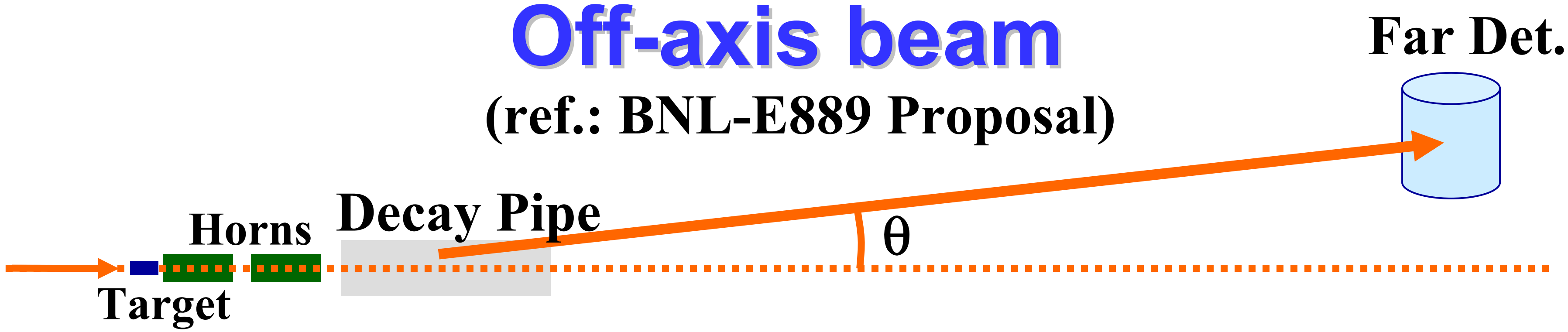
Components

- Primary proton beam line
  - Normal conducting magnets
  - Superconducting arc
  - Proton beam monitors
- Target/Horn system
- Decay pipe (130m)
  - Cover OA angle 2~3 deg.
- Beam dump
- muon monitors
- Near neutrino detector @ 280m from trg.
- Medium detector (@~2km) not approved yet



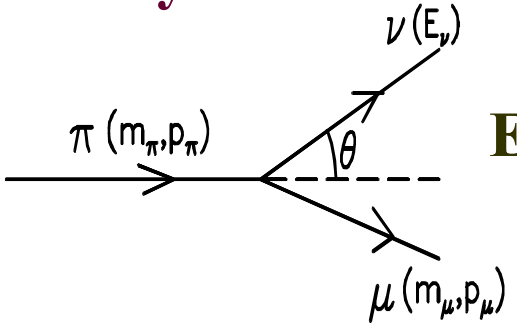
Off-axis beam

(ref.: BNL-E889 Proposal)

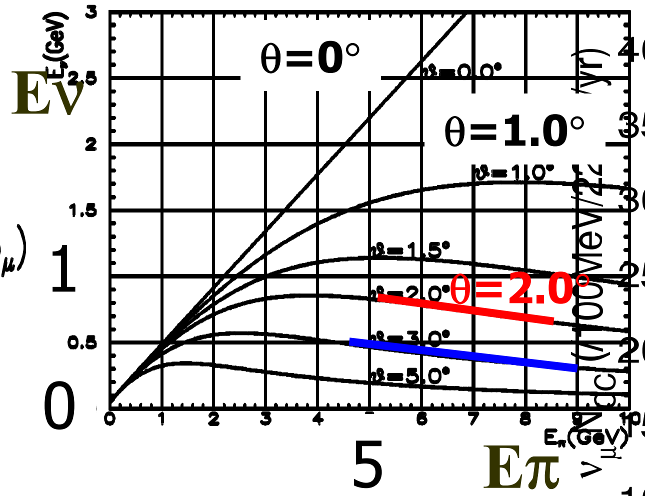


WBB w/ intentionally misaligned beam line from det. axis

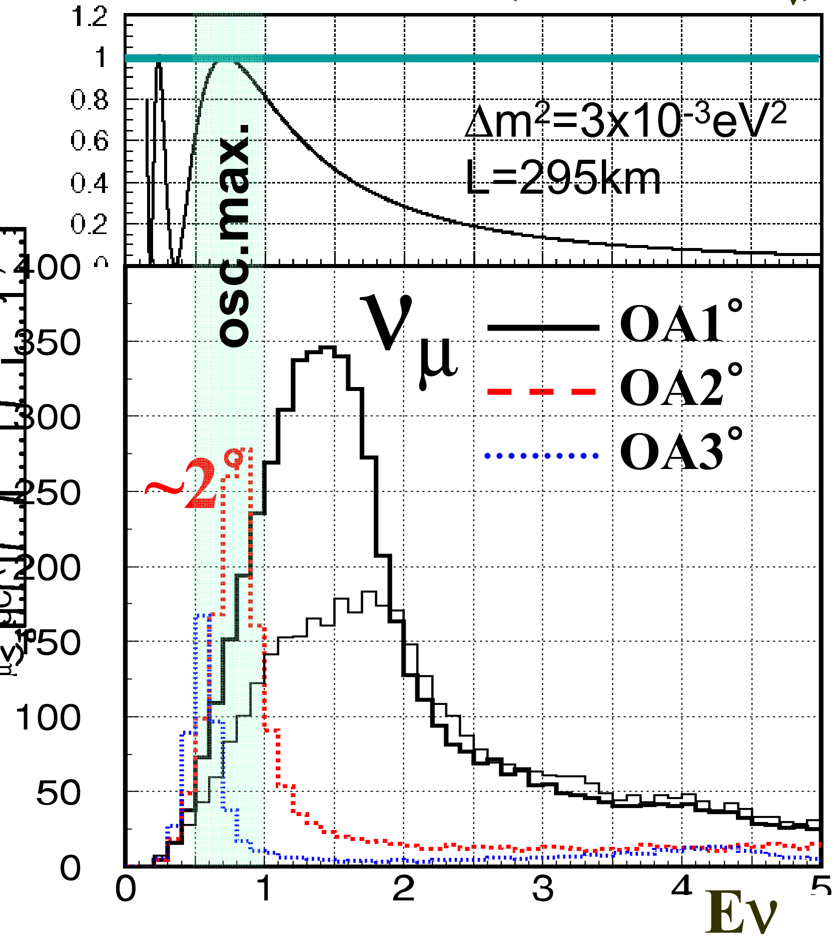
Decay Kinematics



$$E_\nu = \frac{m_\pi^{\ 2} - m_\mu^{\ 2}}{2(E_\pi - p_\pi \cos\theta)}$$



Osc. Prob.=$\sin^2(1.27\Delta m^2 L/E_\nu)$

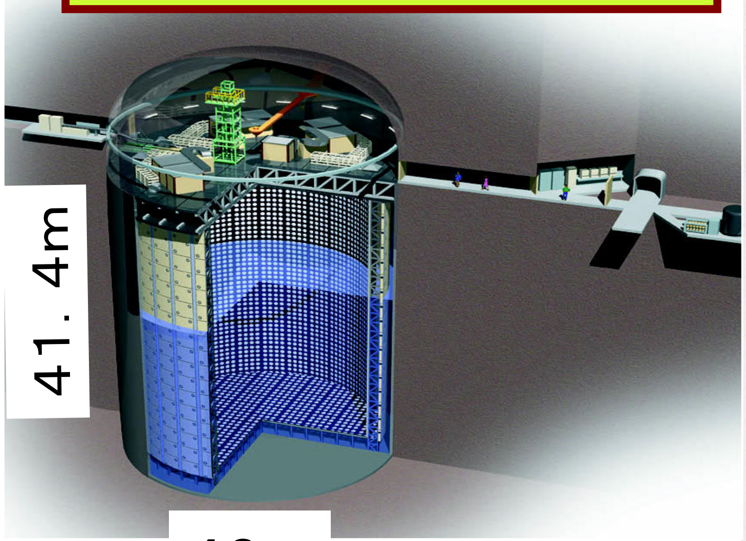


~3000 CC int./22.5kt/yr

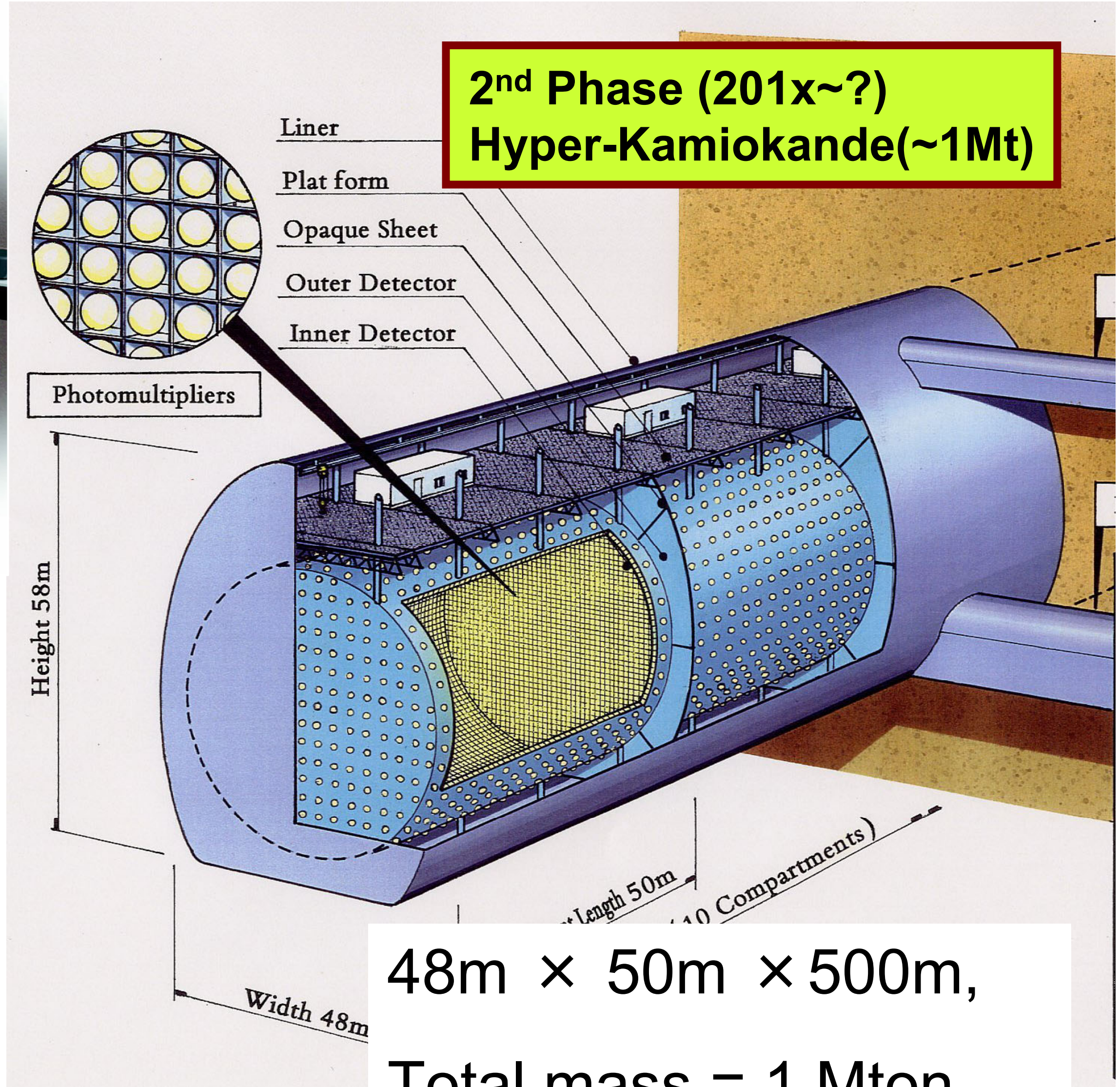
ν_e: 1.0% (0.2% @ peak);

Far Detectors

1st Phase (2009~, ≥5yrs)
Super-Kamiokande(22.5kt)



2nd Phase (201x~?)
Hyper-Kamiokande(~1Mt)



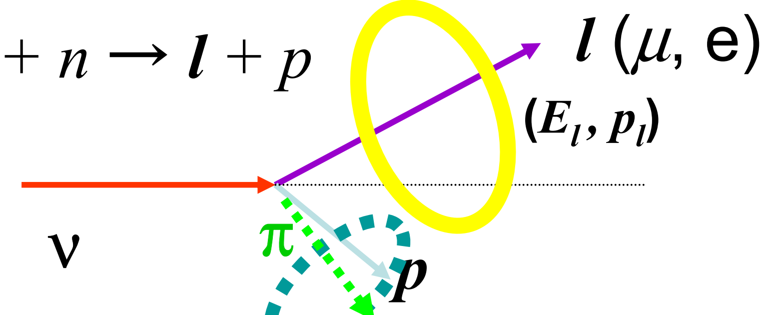
48m × 50m ×500m,

Total mass = 1 Mton

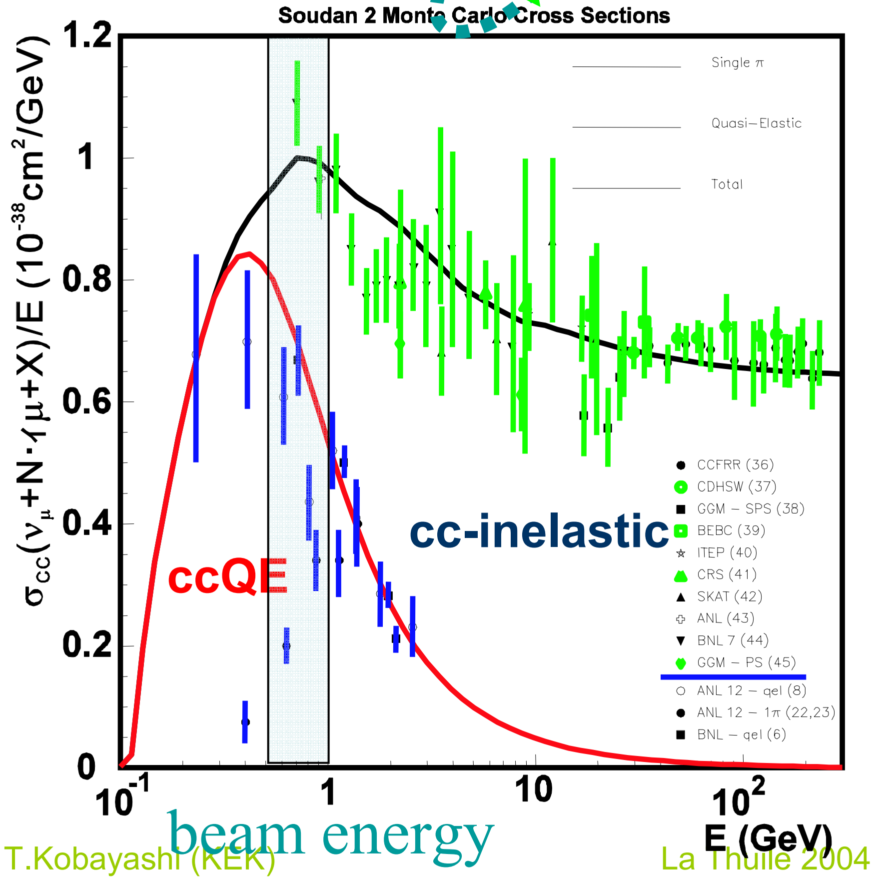
Eν reconstruction in water Cherenkov

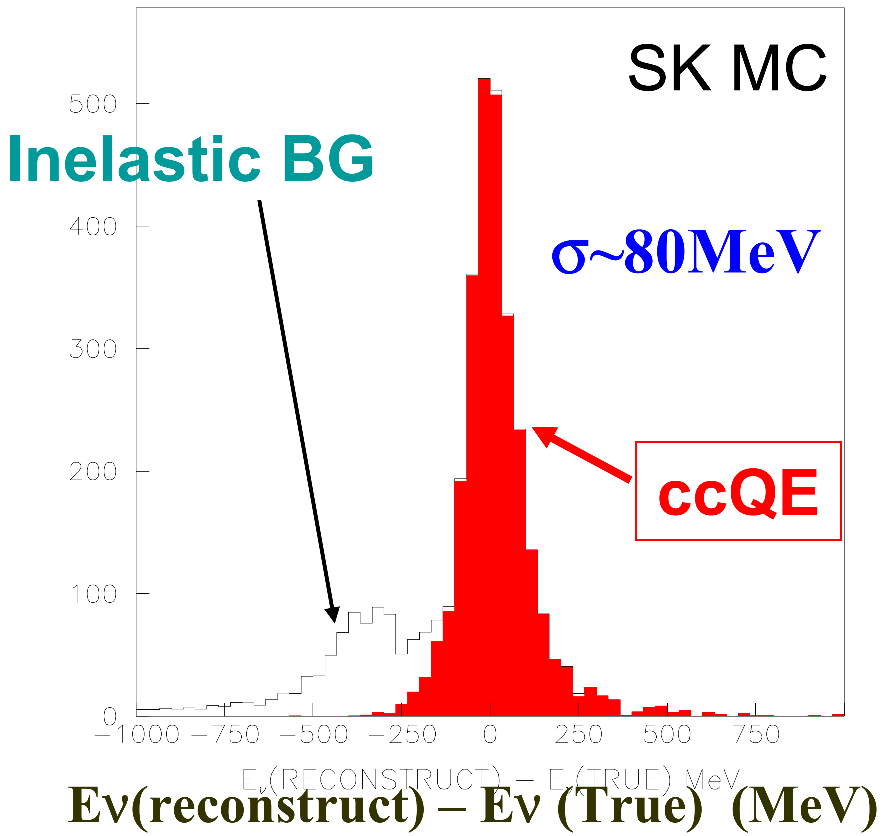
Assume CC Quasi Elastic (QE) reaction

$$\nu_\mu + n \rightarrow l + p$$



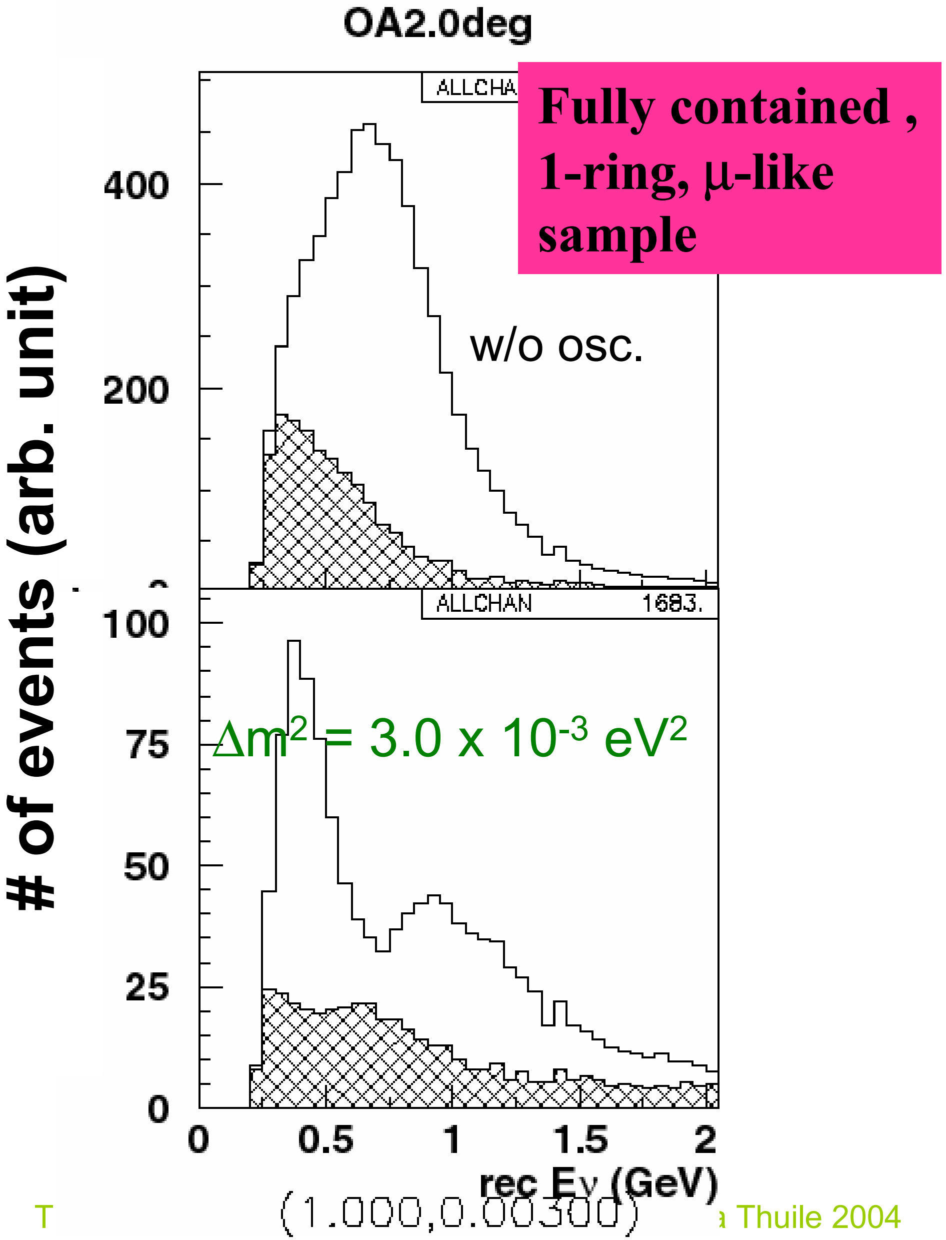
$$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

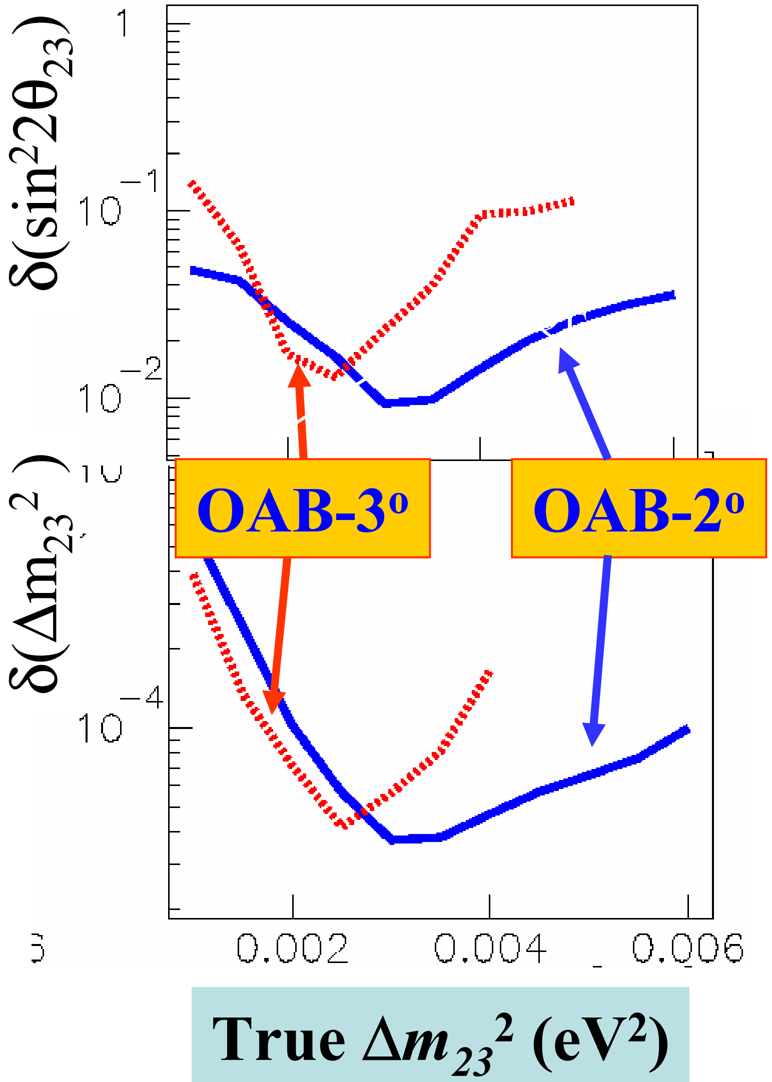




Measurement of $\sin^2 2\theta_{23}$, Δm^2_{23}

ν_{μ} disappearance

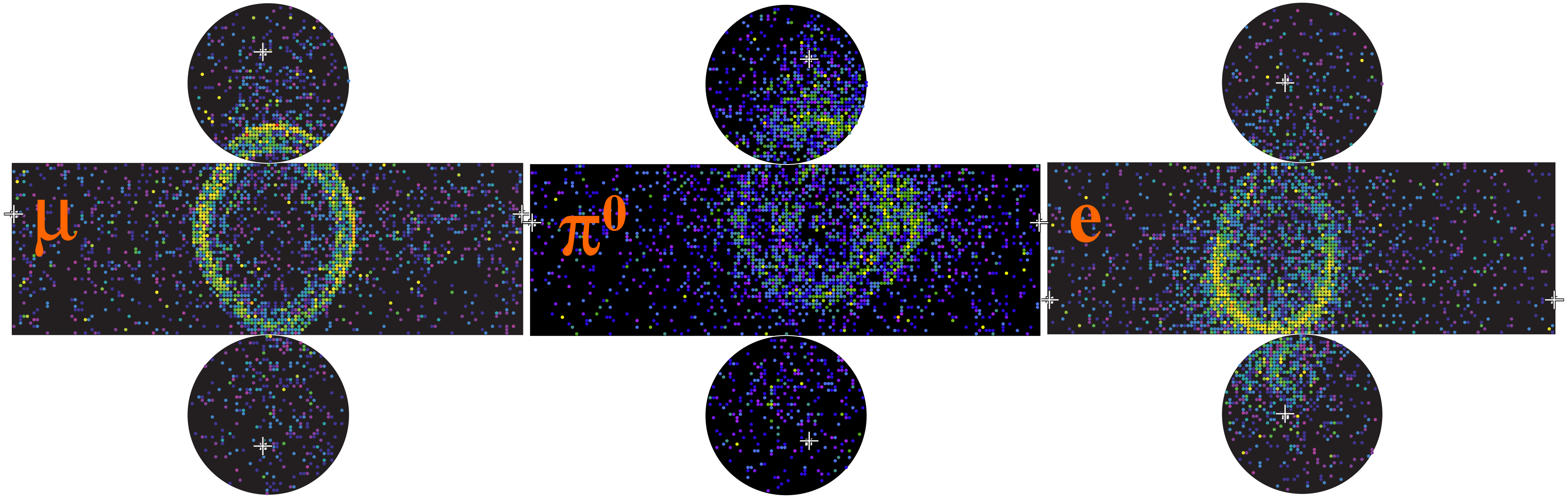




$\delta(\sin^2 2\theta) \sim 0.01$

$\delta(\Delta m^2) \sim \lesssim 1 \times 10^{-4}$

ν_e appearance in "T2K"



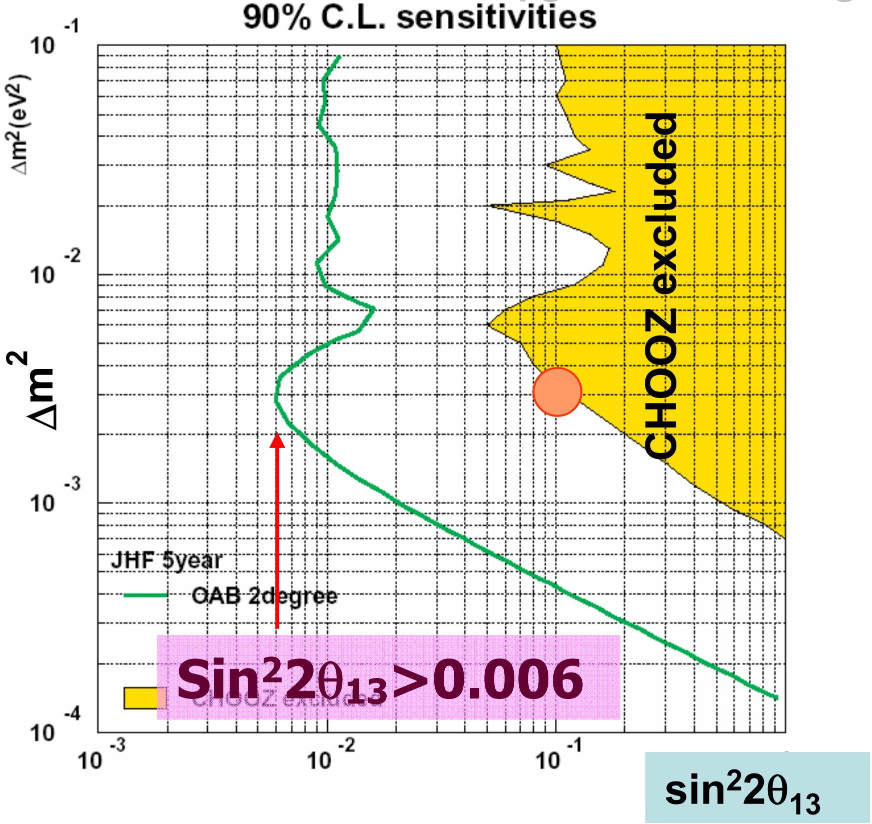
Back ground for ν_e appearance search

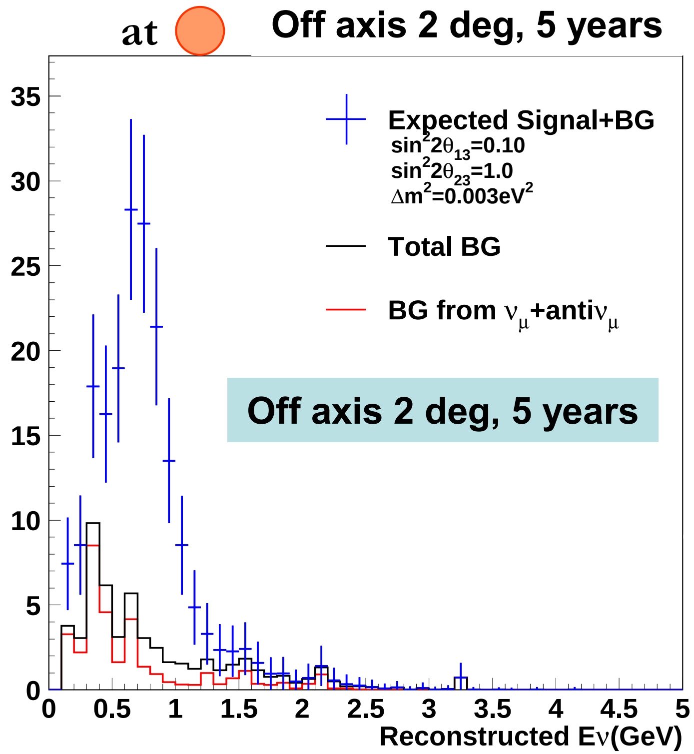
- Intrinsic ν_e component in initial beam
- Merged π^0 ring from ν_μ interactions

Requirement ⇨ 10% uncertainty for BG estimation

The K2K 1kt π^0 data will be studied for exercise

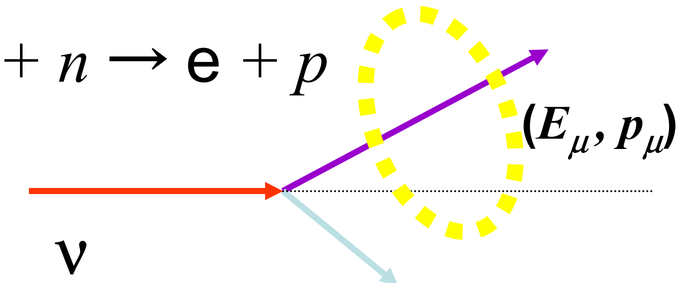
$\sin^2 2\theta_{13}$ from ν_e appearance



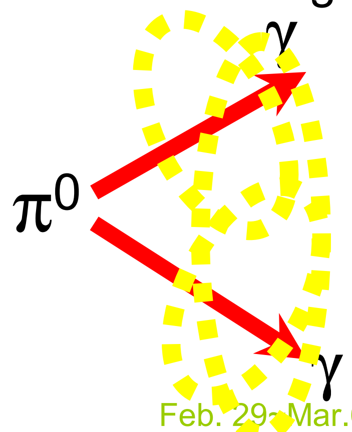


Signal

$$\nu_e + n \rightarrow e + p$$



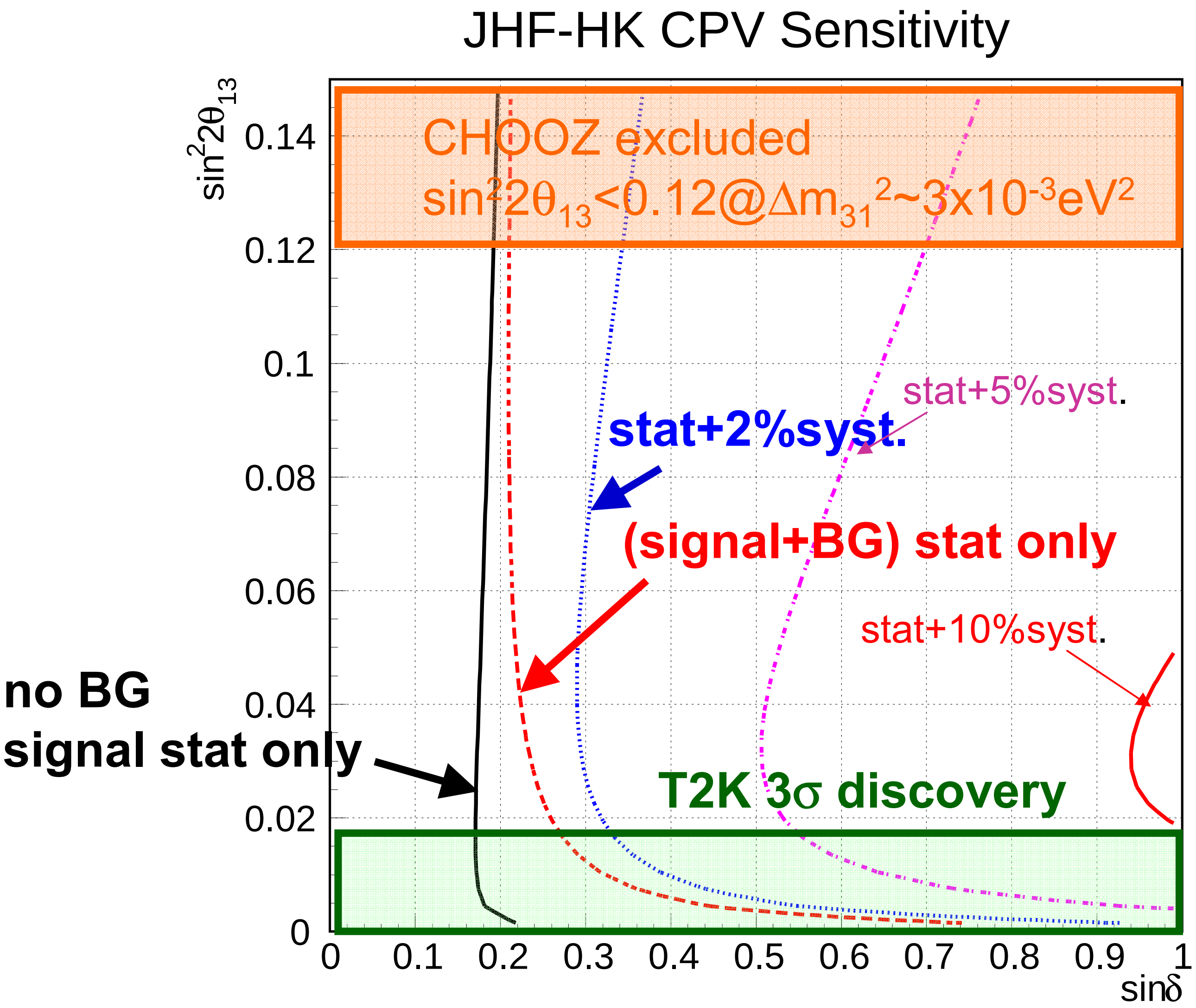
2-ring merged to 1-ring



BG

$\left\{ \begin{array}{l} \text{beam } \nu_e \\ \pi^0 \end{array} \right.$

Future Extension: Search for CPV



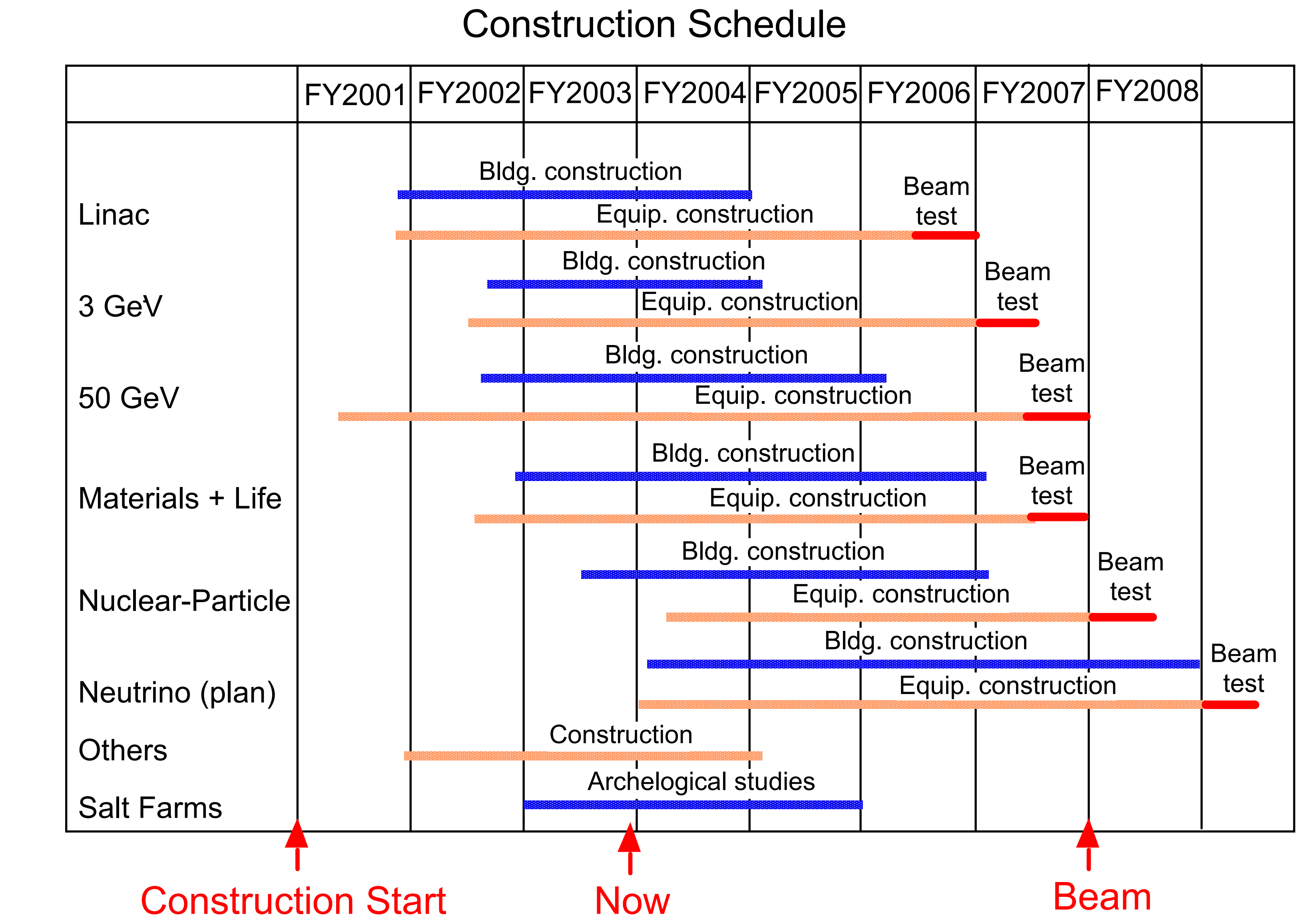
4MW, 540kt

2yr for ν_μ

6~7yr for $\bar{\nu}_\mu$

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

Construction Schedule



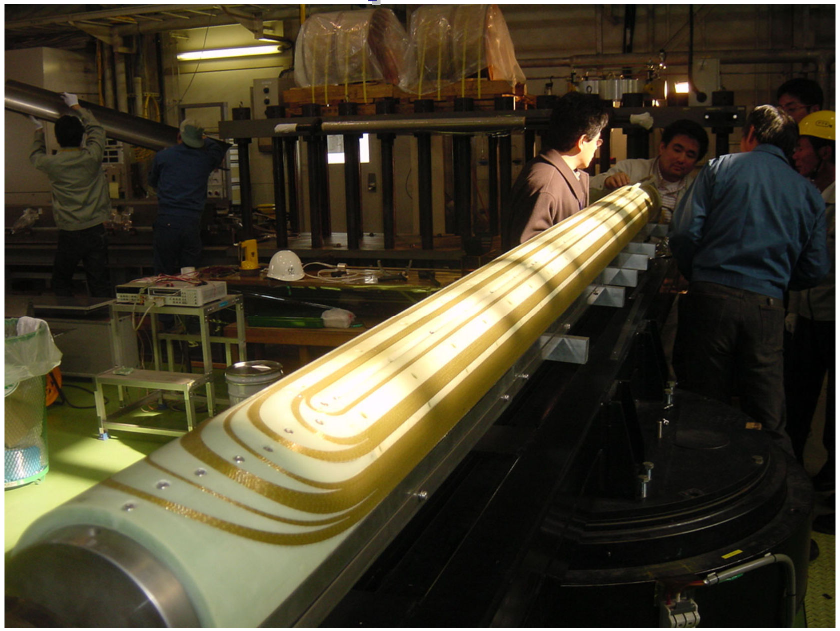

Ancient Salt Farm
December, 2003

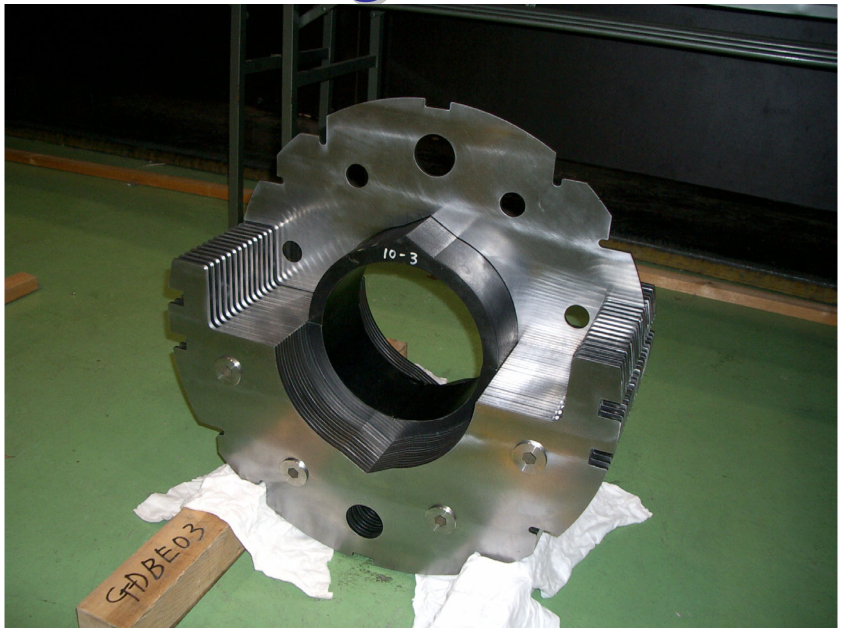

3 GEV AREA


3 GEV TO 50 GEV

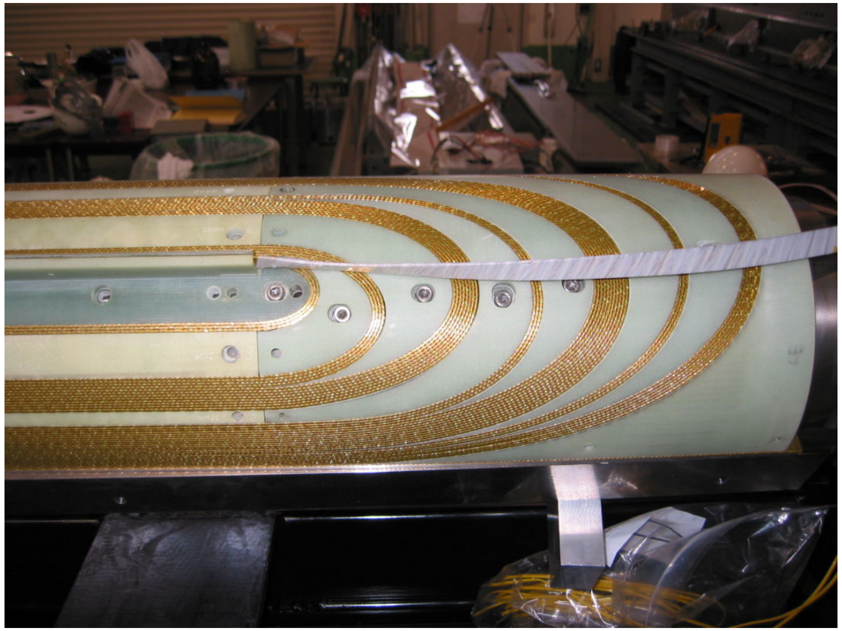

50 GEV

Development of Superconducting matnets





Trial coil winding



Trial magnet
(Plastic collar, Iron yoke)

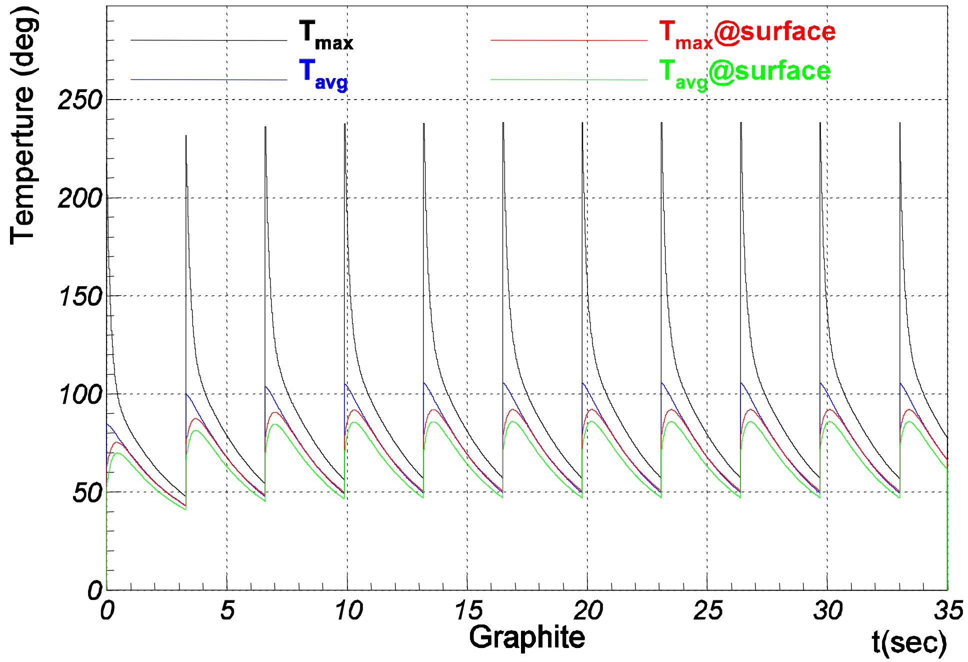
Cryo.Sci.C. KEK

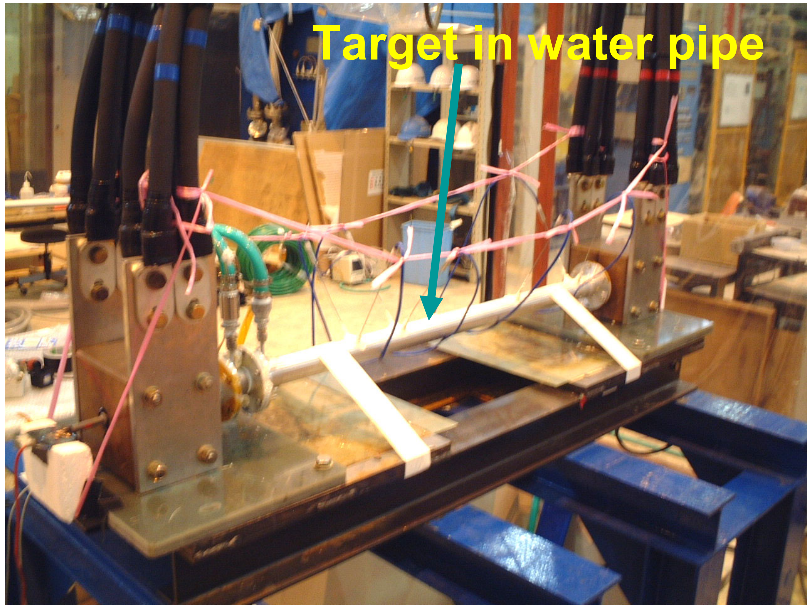
Target R&D

- Cooling
  - Water or He gas cooling
  - FEM (& analytical) calc. → max. T=~240deg w/ water cooling.
- Thermal stress
  - FEM analysis
  - Max. stress 6.8MPa (safety fact. 3~4 available.)
- Radiation damage
- And so on,..

Example of FEM (by T.Nakadaira)

Target temperature vs time (α=6kW/m^2/K)





Water cooling test

- Heat load by DC
- Confirmed 20kW can be removed by direct water cooling

Summary

- J-PARC construction is going well
  - 3 goals (Neutron, Nuclear&Particle, Transmutation)
  - 7 year construction (JFY2001~2007)
- **J-PARC neutrino facility approved!**
  - 5 years construction (JFY2004~2008)
- Expected neutrino beam
  - ~3000 CC int./yr @ SK (w/o osc.)
  - ~0.2% ν_e contamination
- Physics sensitivity of T2K experiment
  - $\sin^2\theta_{13} \lesssim 0.006$ (90%CL)
    $\delta(\Delta m^2) \lesssim 3\%$, $\delta(\sin^2\theta_{23}) \sim 1\%$
  - can discover CPV if $\delta \gtrsim 20^o$ (in 2nd phase)
- First neutrino beam planned in 2009