@IAC Mar.10,2003

JHFnu at J-PARC
neutrino oscillation experiment

50 GeV PS LOI #12

•International collaboration
•Recent developments in neutrino physics
•Readiness
•Summary

Koichiro Nishikawa
Kyoto University
for JHFnu (proto-)collaboration

International collaboration - Past and Present

- 1999-00 : **Neutrino Working group formed**
  (ICRR/KEK/Kyoto/Kobe/Tohoku/TRIUMF)
  : **Strong endorsement from Japanese high energy community**
  Physics goal
- 2001 : **Facility Construction Group Officially formed in KEK**
  The 3rd physics division (IPNS)
  Cryogenic facility group, Cryogenic Science Center
  Strong support from KEK-PS beam channel group
  : Letter of Intent (hep-ex/0106019) published
- 2002 : **1st IAC report recommended high priority for neutrino exp.**
  : Two meetings to form international group
  : **Japan High Energy Physics Committee appeal for early realization of neutrino experiment**
- Dec.2002 : LOI World-wide interests
  45 physicists from Japan, 110 physicists from Canada, China, France, Italy, Korea, Poland, Russia, Spain, Switzerland, UK and USA

Possible contributions from abroad

- **Accelerator**
  - Fast kicker/abort system (Canada)
  - Beam dynamics in PS (Canada, USA)
- **Beam line**
  - Normal conducting magnets (Canada, Russia)
  - Super conducting magnets (France, USA)
  - Proton beam monitor (UK, USA)
  - Beam dump (UK, USA)
  - Shielding (Russia)
- **280 m Detectors (Canada, Korea, Italy, Spain, UK, USA)**
- **2 km Detectors (Italy, Korea, France, Spain, UK, USA)**

'Possible' : Need formal approval of the project in 'host country' first !
Need every possible supports for the project

Recent Developments in Neutrino Physics

There are two established Δm^2 's

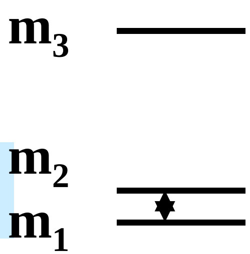
- **Atmospheric ν, K2K(rate & spectrum)**
  - Most likely $\nu_\mu \rightarrow \nu_\tau$ oscillation
  - Indication of oscillation pattern

    $\Delta m_{23}^2 \sim 1.6 - 3.9 \times 10^{-3}$ eV^2 $\quad$ $\sin^2 2\theta_{23} > 0.92$
- **Solar ν, Kamland ($\overline{\nu}$e disappearance)**
  - Large mixing angle solution in ν_e oscillations

    $\Delta m_{12}^2 \sim 3 - 20 \times 10^{-5}$ eV^2 $\quad$ $\sin^2 2\theta_{12} \sim 0.55 - 0.95$
  - ν_μ, ν_τ components in solar neutrinos

- JHFnu became more interesting
- No sign of sterile --- ν_e, ν_μ, ν_τ for now
- Two of the three mixing angles are large ↔ quark case
  - Third mixing angle ?
- Prelude of search for CP violation in leptons

Solar ν ($\nu e \rightarrow \nu e$), Kamland ($\overline{\nu e} \rightarrow \overline{\nu e}$)



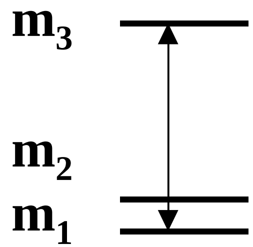
$\Delta m_{12}{}^2 \sim 3 - 20 \times 10^{-5}\ eV^2$

$\sin^2 2\theta_{12} \sim 0.55 - 0.95$

U_{e1}, U_{e2} fairly large

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} |U_{e1}|^2 & |U_{e2}|^2 & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{pmatrix} \nu_1(m_1) \\ \nu_2(m_2) \\ \nu_3(m_3) \end{pmatrix}$$

Atmospheric ν, K2K ($\nu_\mu \rightarrow \nu_\tau$)



$\Delta m_{23}^2 \sim 1.6 - 3.9 \times 10^{-3}\ \mathrm{eV}^2$

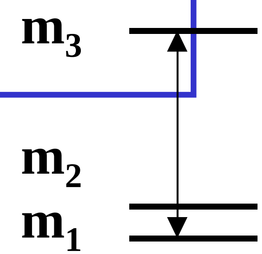
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1}^* & U_{\mu 2}^* & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3}^* \end{bmatrix} \begin{pmatrix} \nu_1(m_1) \\ \nu_2(m_2) \\ \nu_3(m_3) \end{pmatrix}$$

$\sin^2 2\theta_{23} > 0.92$

All elements are large (near max.)

Old reactor experiments (Chooz, Palo Verde)

L ~ 1 km E~1-6 MeV

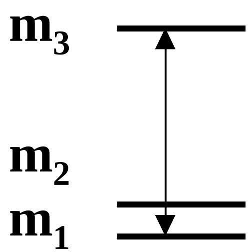


$\sin^2 2\theta_{13} < 0.1$ has not been observed

U_{e3} : small

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} |U_{e1}|^2 & |U_{e2}|^2 & |U_{e3}|^2 \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{pmatrix} \nu_1(m_1) \\ \nu_2(m_2) \\ \nu_3(m_3) \end{pmatrix}$$

Neutrino mixing



$$|U_{lepton}| = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} = \begin{pmatrix} 073-0.89 & 0.44-0.66 & <0.2 \\ 0.23-0.66 & 0.24-0.75 & 0.51-0.87 \\ 0.06-0.57 & 0.40-0.82 & 0.48-0.85 \end{pmatrix}$$

U_{e3} ν_e with m_3

?

$$U_{lepton} = \begin{bmatrix} \frac{1}{\sqrt{2}}(1+\lambda) & \frac{1}{\sqrt{2}}(1-\lambda) & \varepsilon \\ -\frac{1}{2}(1-\lambda+\varepsilon) & \frac{1}{2}(1+\lambda-\varepsilon) & \frac{1}{\sqrt{2}} \\ \frac{1}{2}(1-\lambda-\varepsilon) & -\frac{1}{2}(1+\lambda+\varepsilon) & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{pmatrix} \lambda \approx 0.2 \\ \varepsilon \leq 0.2 \end{pmatrix}$$

Gonzales-Garcia
ICHEP-2002

$$U_{quark} = \begin{bmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ \lambda^3 & -\lambda^2 & 1 \end{bmatrix} (\lambda \approx 0.2)$$

May have different mass-mixing scheme

U_{e3} $\nu_\mu \rightarrow \nu_e$ with $\Delta m^2 \sim 3\times10^{-3} eV^2$

$\nu\mu \rightarrow \nu e$ with $\Delta m^2 \sim 1.6 - 3.9 \times 10^{-3}$ eV^2 and CP violation

Interference →CP violation

supressed by small Δm^2

small U_{e3}

$\nu\mu \rightarrow \nu e$

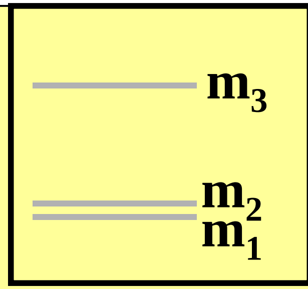
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U^*_{e3} \\ U^*_{\mu 1} & U^*_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{pmatrix} \nu_1(m_1) \\ \nu_2(m_2) \\ \nu_3(m_3) \end{pmatrix}$$

2 independent Δm^2's   3 angles   1 phase

Beyond the ‘confirmation’ of oscillation

Oscillation Probabilities when

$$\Delta m^2_{12} << \Delta m^2_{23} \approx \Delta m^2_{13}$$
$$\Delta m^2_{ij} = m^2_j - m^2_i$$



- θ_{23} :ν_μ disappearance

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

$$\approx$$

- θ_{13} :ν_e appearance

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

- δ: ~~CP~~ in ν_e appearance

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

Physics Goal

★**Precision measurement of neutrino mixing matrix**

$\delta(\sin^2 2\theta_{23})$ ••• 1% (factor 8 improvement)

$\delta(\Delta m^2_{23})$ ••• a few % (factor 10 improvement)

★**Discovery and measurement of non-zero θ_{13}**

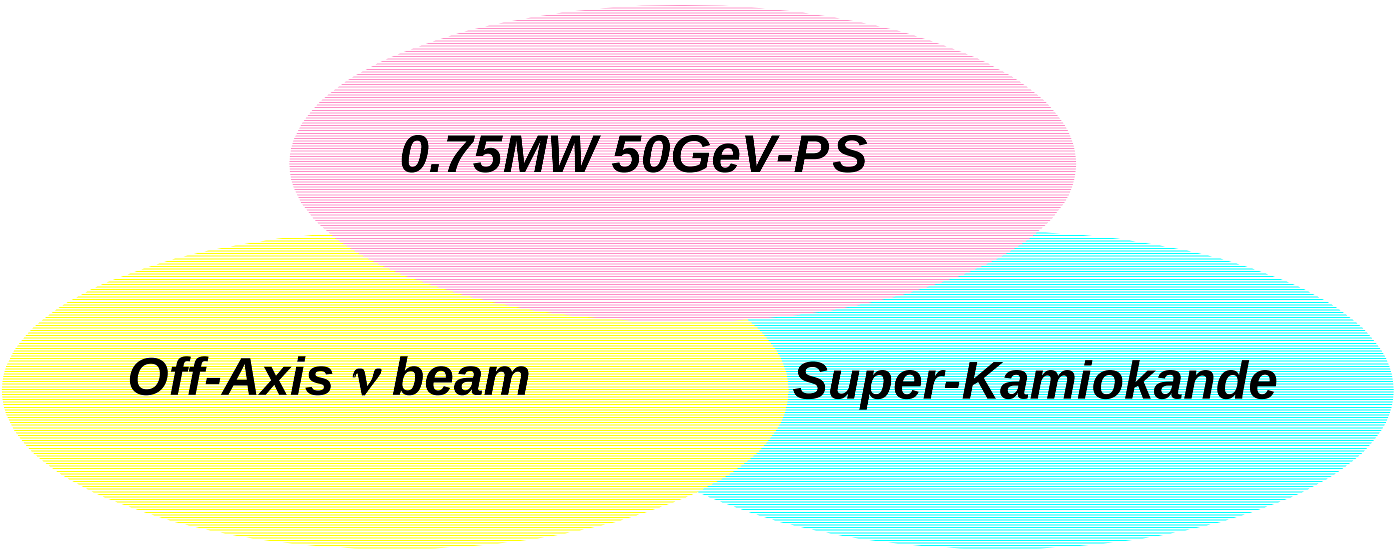
$\sin^2 2\theta_{13}$ ••• > 0.006 (factor 20 improvement)

1st Evidence of 3-flavor mixing !

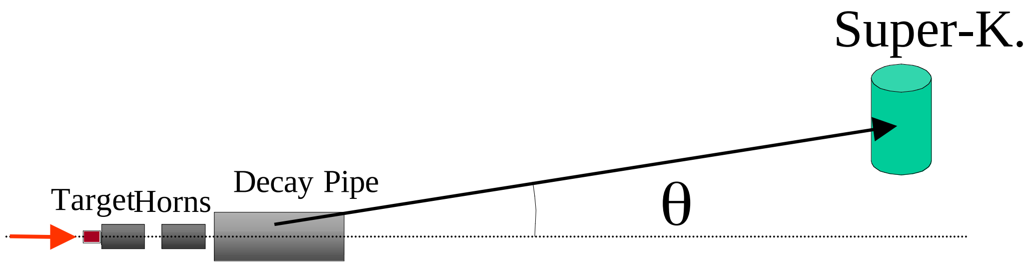
1st step to CP measurement

Strategy

- **High statistics by high intensity ν beam**
- **Tune Eν at oscillation maximum**
- **Sub-GeV ν beam suited for Water Cherenkov, dominated by $\nu_\mu + n \rightarrow \mu + p$: Eν reconstruction**
- **Narrow band beam to reduce BG**



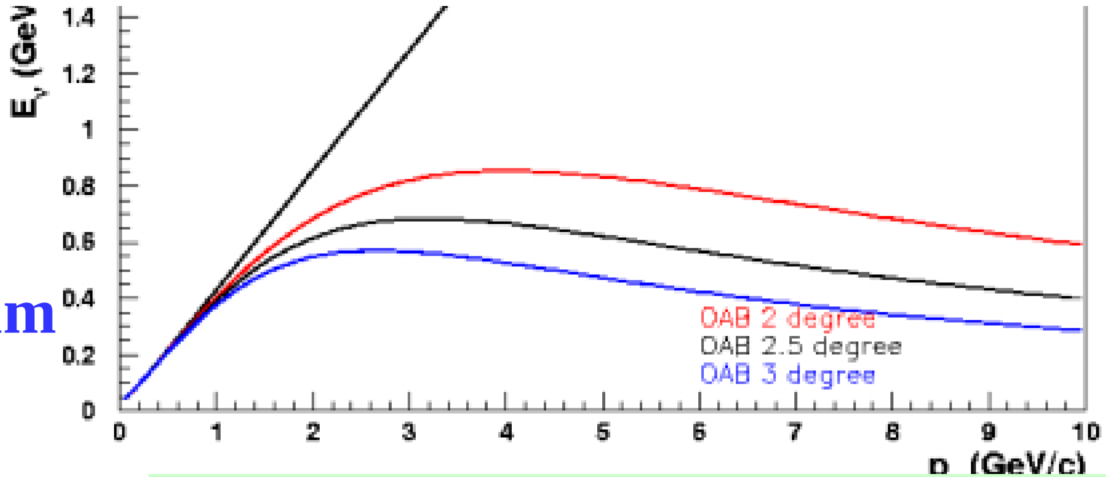
Off Axis Beam



(ref.: BNL-E889 Proposal)

- **Quasi Monochromatic Beam**
- **x 2~3 intense than NBB**

Tuned at oscillation maximum



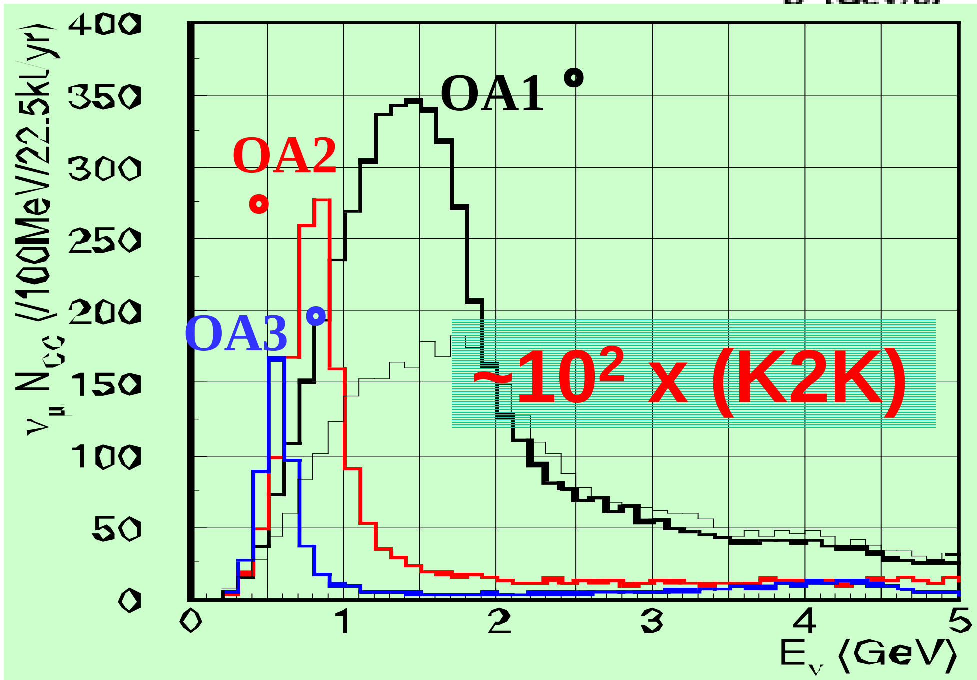
Statistics at SK

(OAB 2 deg,1 yr,22.5 kt)

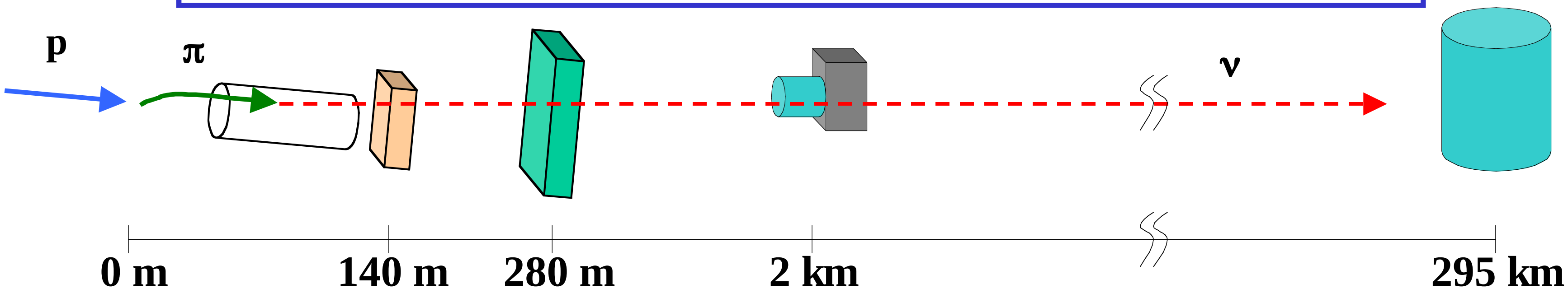
~ 4500 ν_μ tot

~ 3000 ν_μ CC

ν_e ~0.2% at ν_μ peak

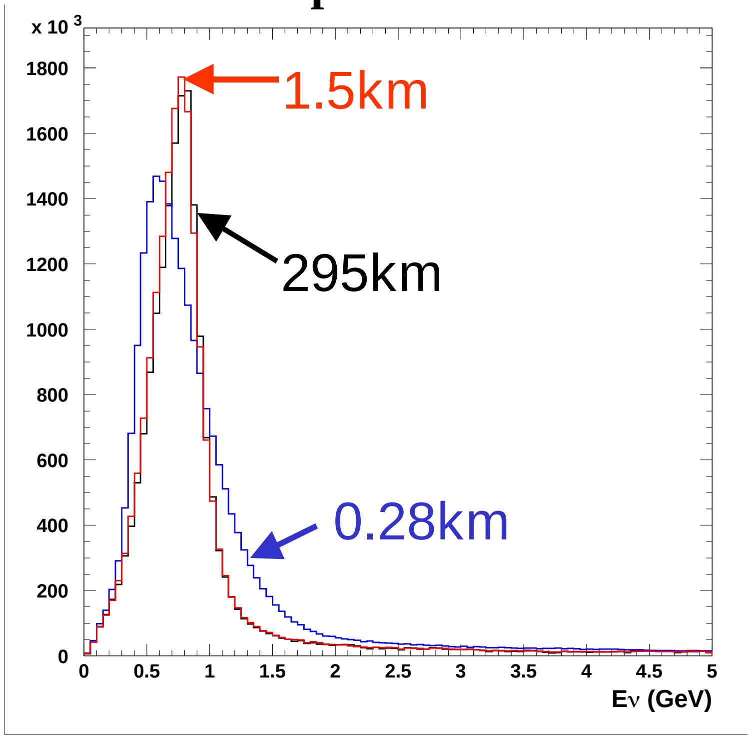


Design Principles for Equipments



- Muon monitors @ ~140m
  – spill-by-spill monitoring of π–beam direction/intensity
- First Front detector @280m
  – 0 degree definition
  – High stat. neutrino inter. studies
- Second Front Detector @ ~2km
  – Ultimate systematics
  – **Now fixing the site**
- Far detector @ 295km
  – Super-Kamiokande (50kt)

Neutrino spectra at diff. dist



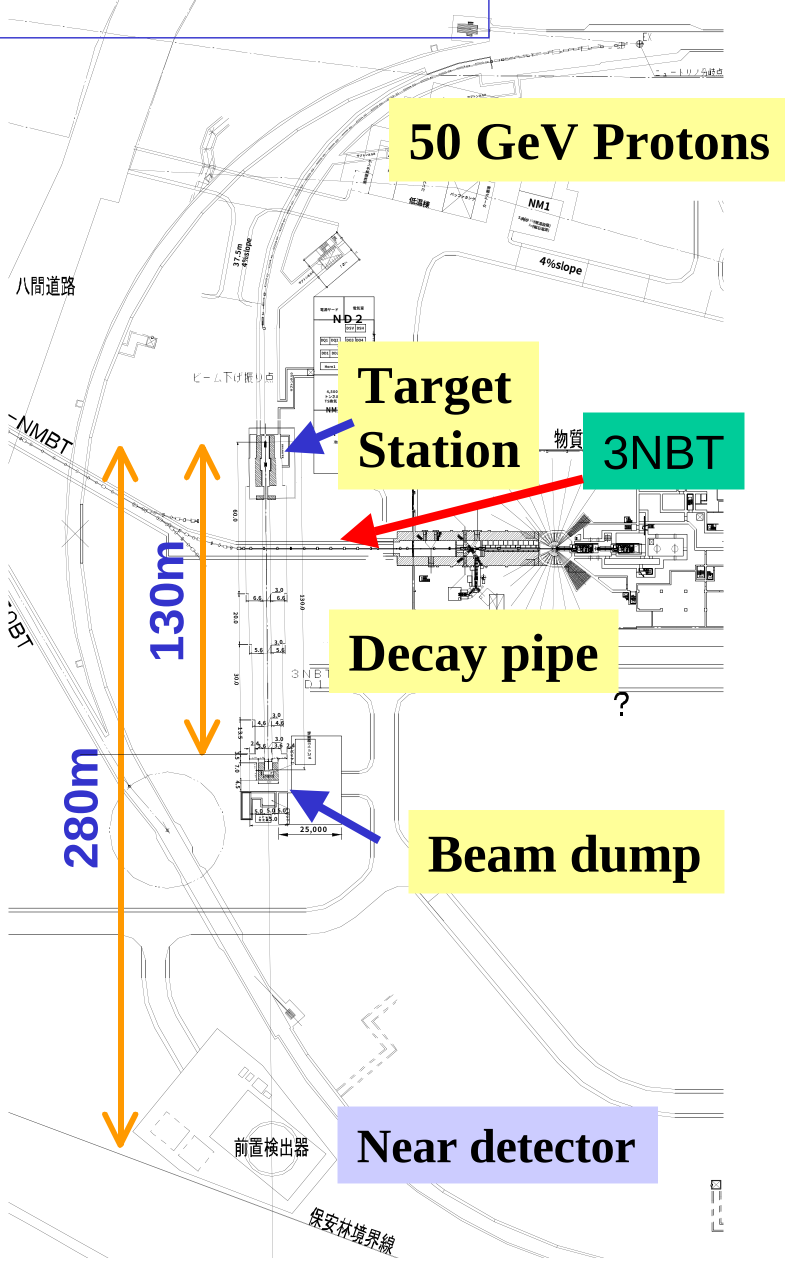
dominant syst. in K2K

Neutrino beam line

✓50 GeV Proton beam line tunnel
  ✓Matching-, Arc-, Final focussing section
✓Decay pipe (130m)
✓Beam dump
✓Target station

✓Designed
●R/D

✓Cryogenics
✓Normal conducting magnets
●Cooling system
●Super conducting magnets
●Target/Horn system
● Beam monitors
● Maintenance equipments
(3300hr~140days)



We are ready to start facility construction !

- **Beam optics : design completed (KEK ,TRIUMF)**
- **Extremely severe radiation and heat environment**
  - **Environmental requirements**

    ex. Target station/decay volume shielding
  - **Local controlled beam loss**

    ex. Scrapers in ‘matching section’
  - **Human exposure when maintenance**

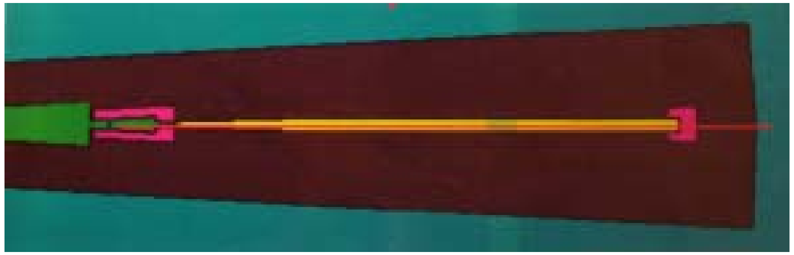
    ex. Target station
- **Cooling scheme**
  - **ex. Decay pipe**

Radiation Shielding (MARS)

Φ- symmetrical geometry
with virtual concrete layers

Radiation level at concrete surface

5mSv/h



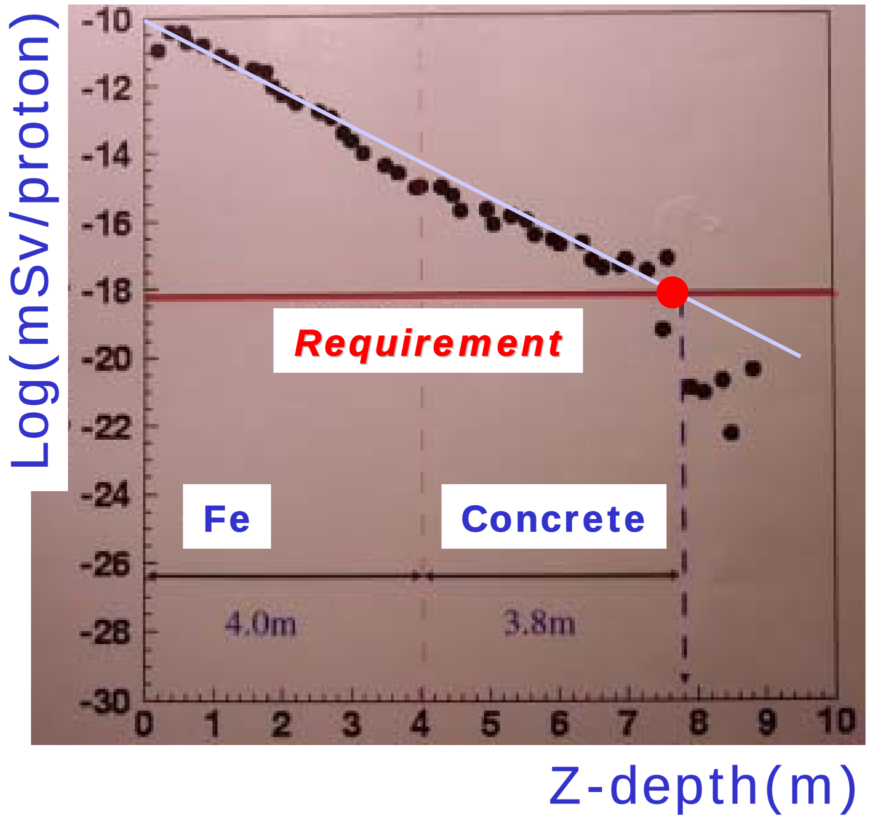
Estimated by MARS

Follow exponential raw

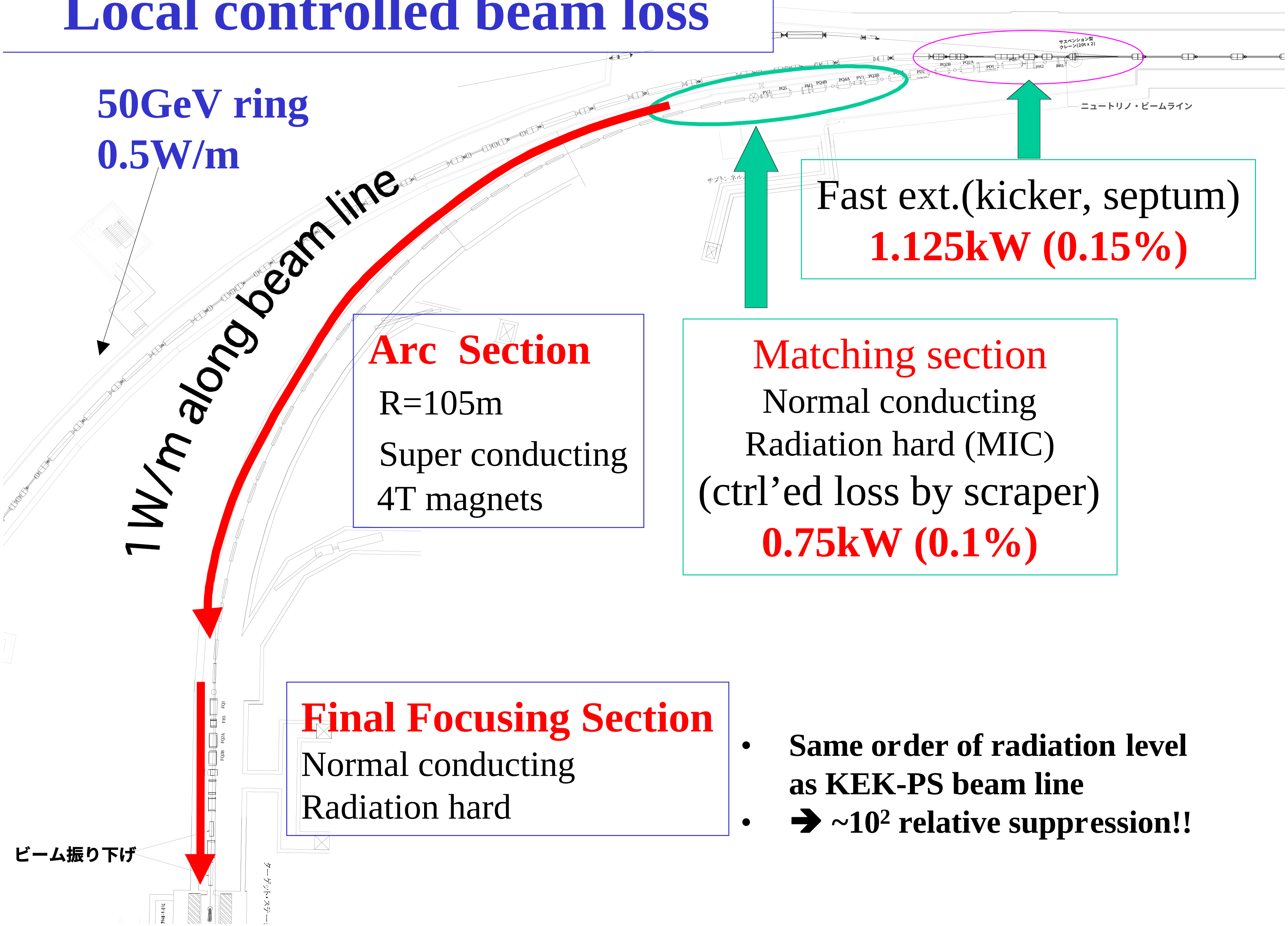
as Moyer’s Eq.

↓

Dump : ~ 4m Fe + 3.8m concrete
Decay pipe : 5.8m~6.3m concrete



Local controlled beam loss



Arc Section

R=105m

Super conducting

4T magnets

Fast ext.(kicker, septum)

1.125kW (0.15%)

Matching section

Normal conducting

Radiation hard (MIC)

(ctrl'ed loss by scraper)

0.75kW (0.1%)

Final Focusing Section

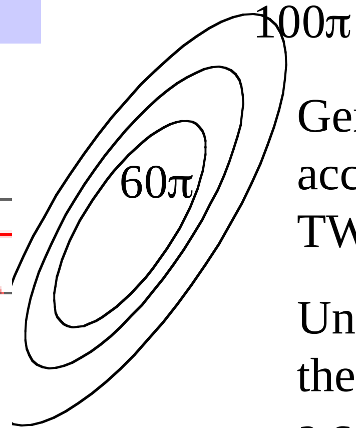
Normal conducting

Radiation hard

- **Same order of radiation level as KEK-PS beam line**
- **➔ ~10^2 relative suppression!!**

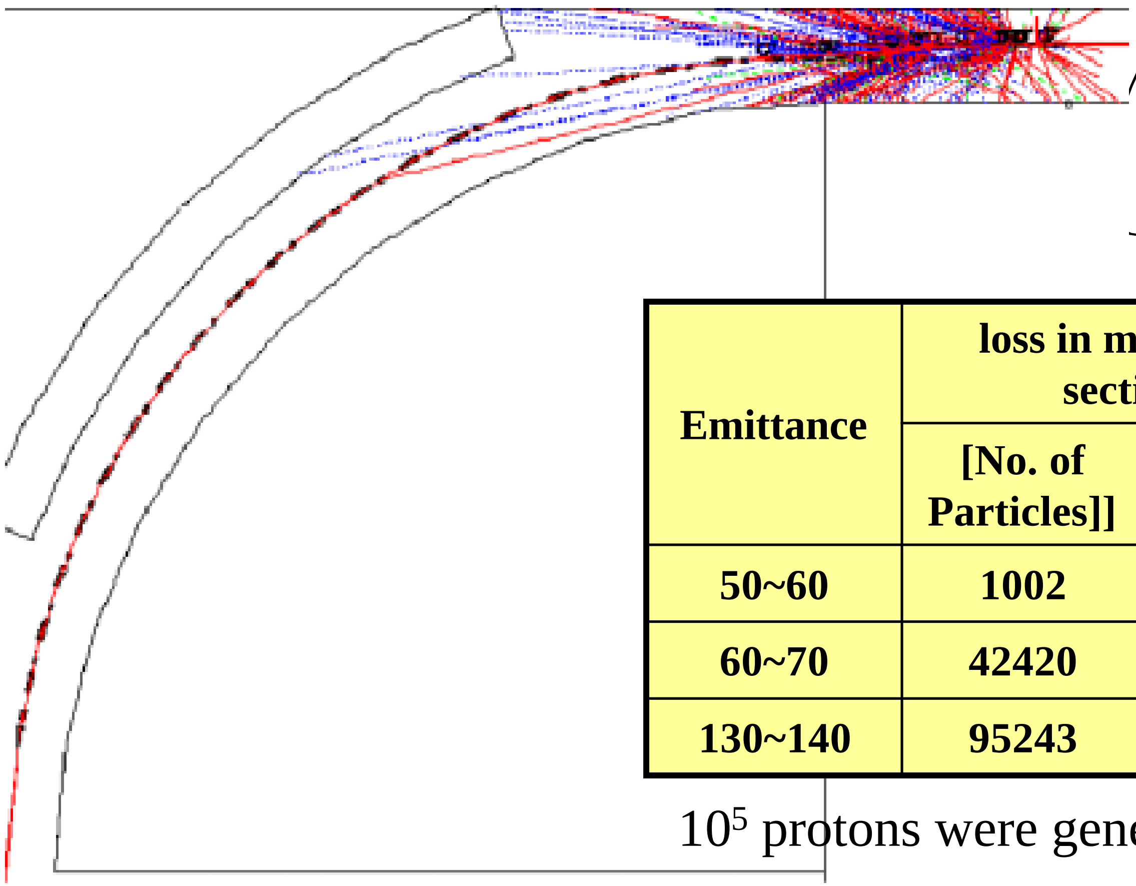
Scraper –beam loss-

Using beamline simulation by Geant



Generate particles according to extraction TWISS parameter

Uniformly distributed in the phase space ellipse of a certain emittance.



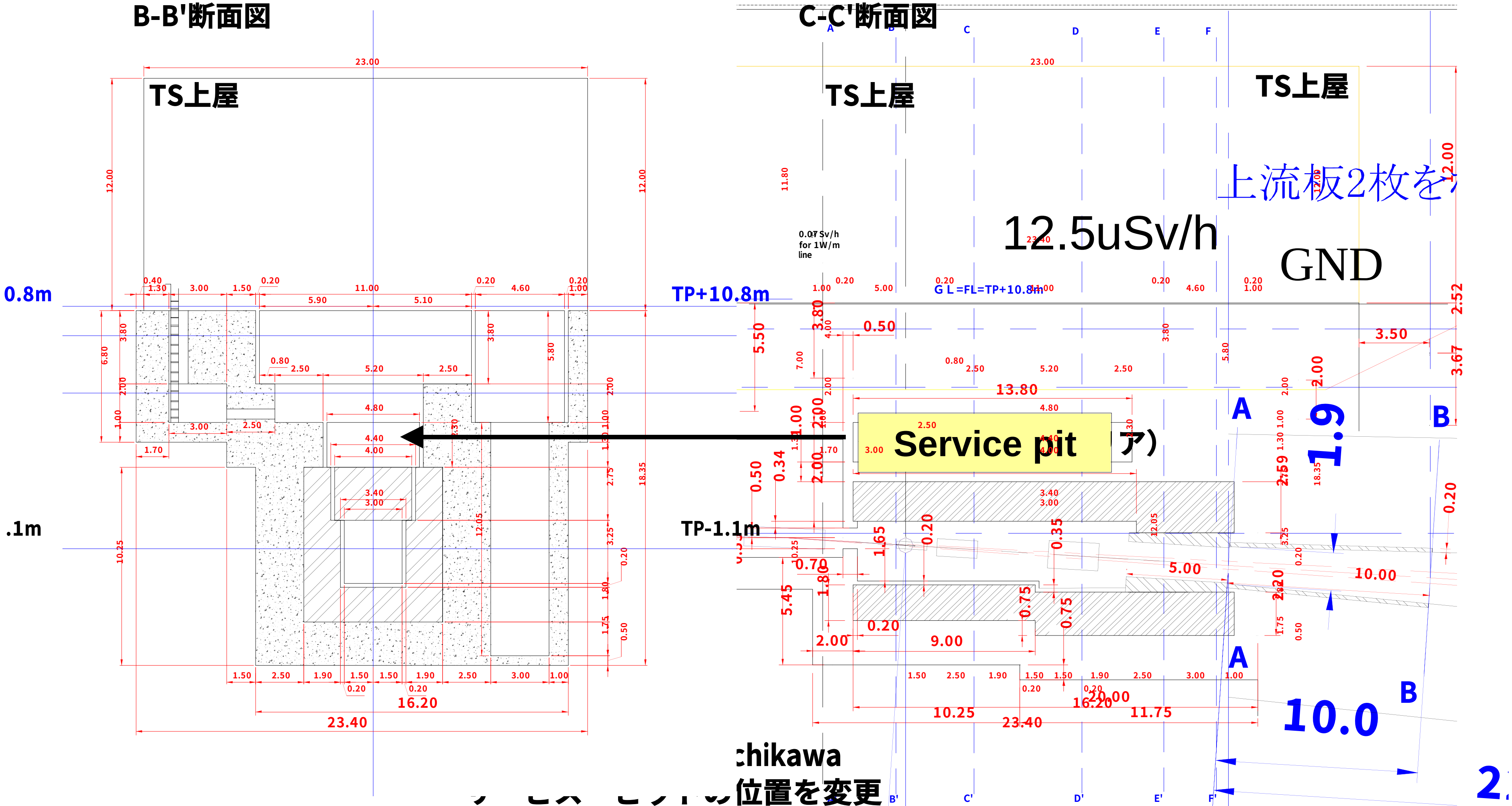
Emittance	**loss in matching section**		**loss in Arc section**		
	[No. of Particles]]	**[W]**	**[No. of Particles]**		**[W]**
50~60	**1002**	**750**	**0**		**7.3**
60~70	**42420**	**750**	**0**		**7.1**
130~140	**95243**	**750**	**263**		**1.2**

10^5 protons were generated.

Design of target station

Front view

Side view



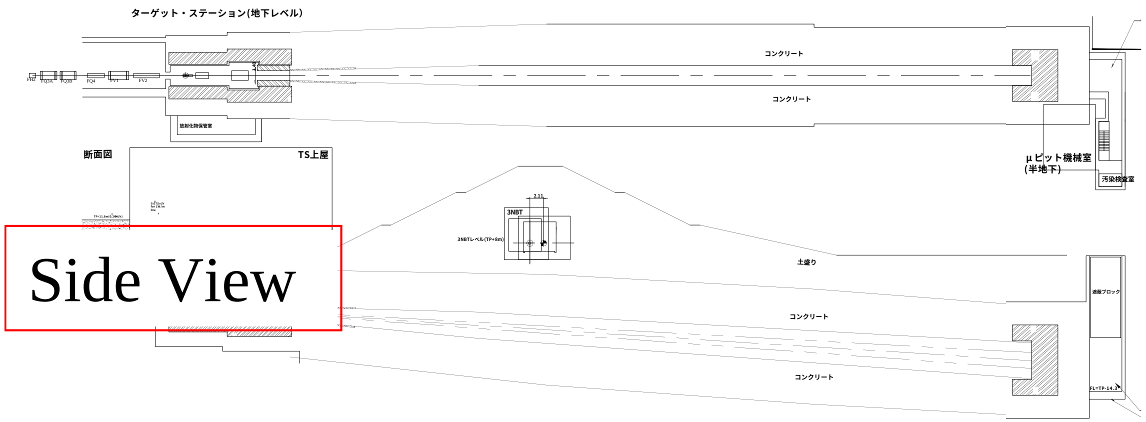
Preliminary

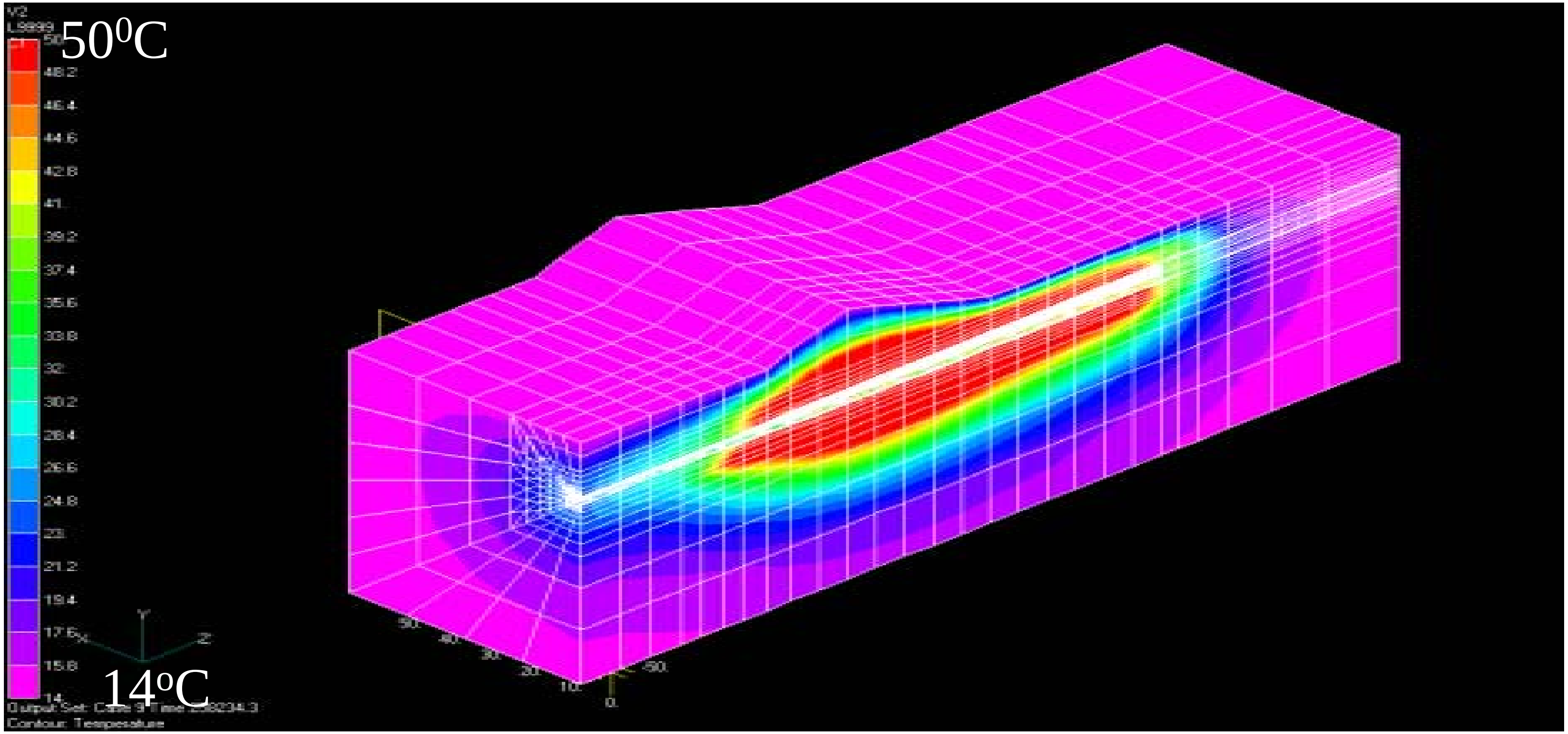
Construction of Decay Pipe with Water Cooling Pipe

Decay pipe w/water cooling

Top view

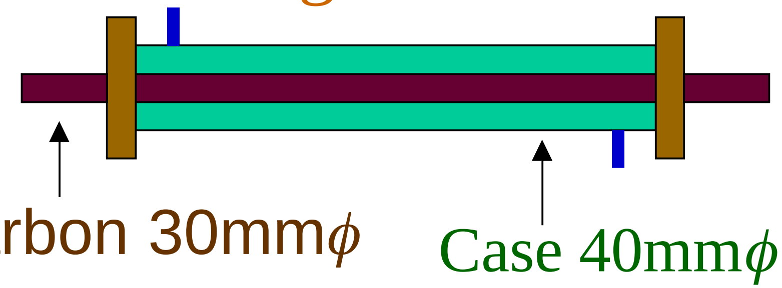
Side View

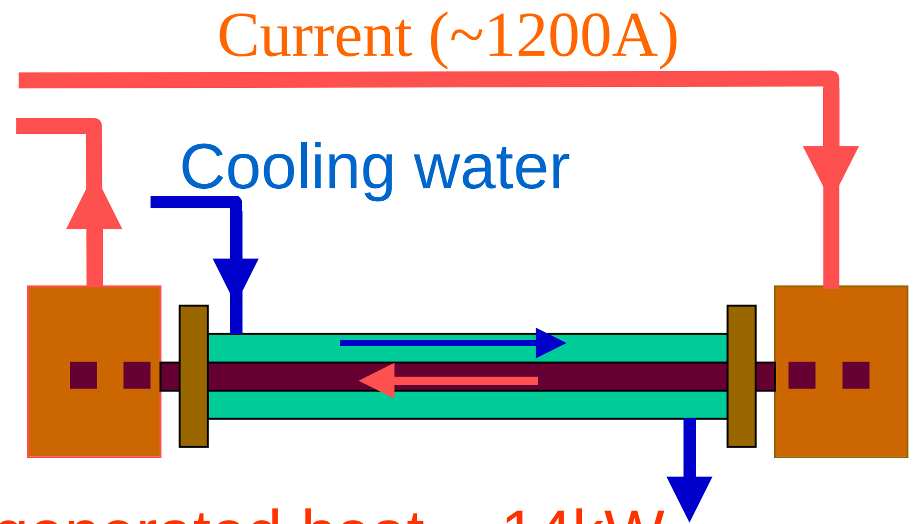




Target -Cooling test -

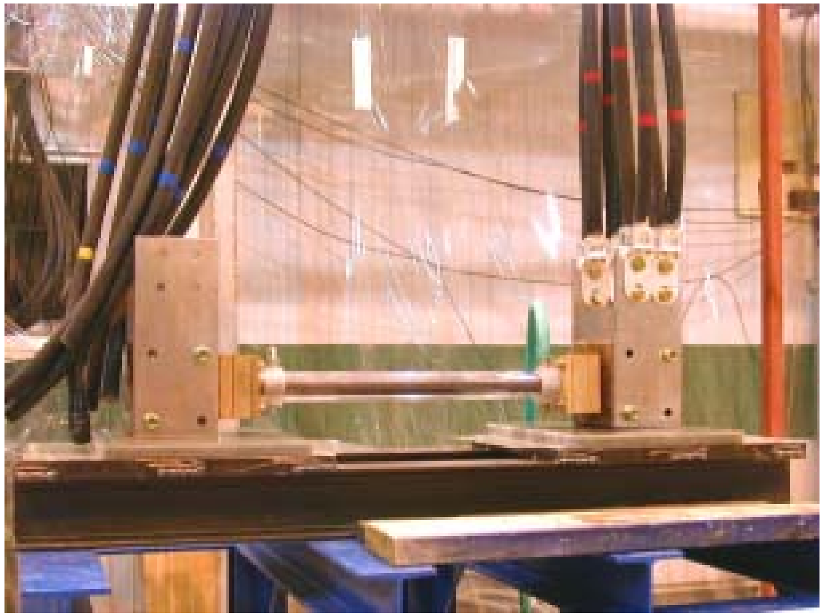
Use electric current
to heat the target



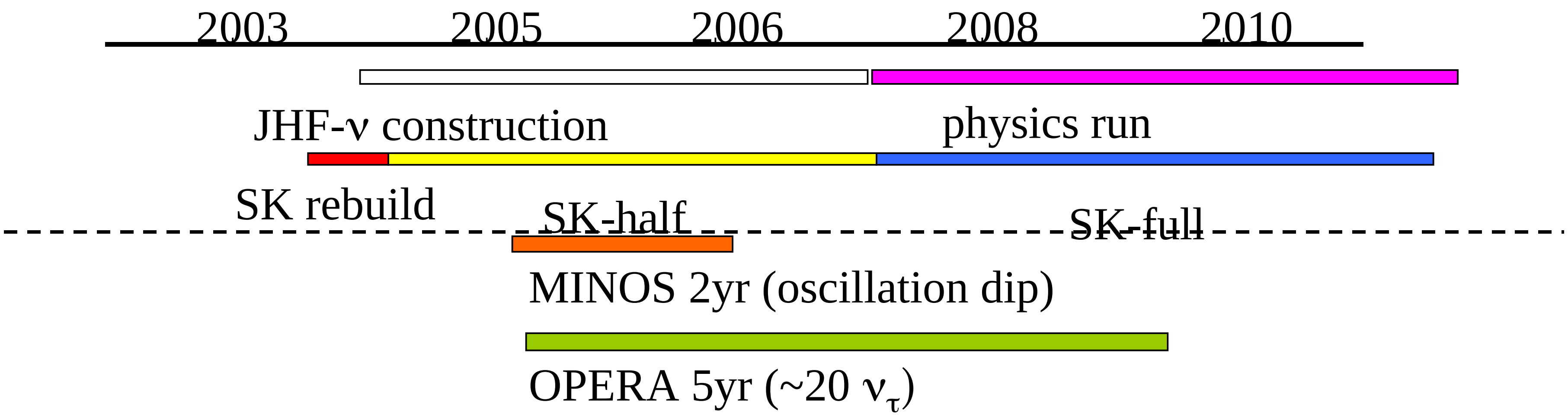


generated heat ~ 14kW

Try to cool by the water.



Schedule & Summary



- **Beyond the 'confirmation' of neutrino oscillation**
- **Best possible measurements of neutrino oscillation with present technology**
- **World-wide interests to join the experiment**
  - **Asking IAC for a clear statement**

- **Possible upgrade in future**
  - **4MW Super-JHF + Hyper-K (1Mt water Cherenkov)**
  - **CP violation in lepton sector**