μweek@CERN
Mar. 21, 2002

JHF ν Project

Takashi Kobayashi
IPNS, KEK

Contents

Neutrino mixing

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

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

Weak　　　　Mass eigenstates

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

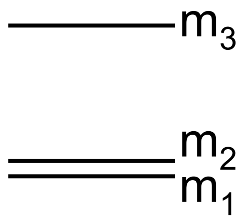
$$= \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 &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

Solar　　　　Atm ν　　　　Reactor, Acc

Neutrino Oscillation

as an unique way to access neutrino (very small) mass and mixing

Oscillation Probabilities when $\Delta m_{12}^2 << \Delta m_{23}^2 \approx \Delta m_{13}^2$



ν_e appearance

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

ν_μ disappearance

$$P_{\mu\to x} = 1 - (P_{\mu\to e} + P_{\mu\to\tau}) \approx 1 - P_{\mu\to\tau}$$

ν_τ appearance

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

Same

CPV

$$A = \frac{P_{\mu\to e} - P_{\bar\mu\to\bar e}}{P_{\mu\to e} + P_{\bar\mu\to\bar e}}$$

All 3angles, 3Δm^2 need to be non-zero

$$\propto \sin\delta \cdot s_{12} \cdot s_{23} \cdot s_{13} \cdot \sin^2\left(\frac{1.27\Delta m_{12}^2 L}{E}\right) \cdot \sin^2\left(\frac{1.27\Delta m_{23}^2 L}{E}\right) \cdot \sin^2\left(\frac{1.27\Delta m_{13}^2 L}{E}\right)$$

L : flight length(km), E_ν : neutrino energy(GeV), $\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$, m_i : mass eigenvalues(eV)

Present knowledge on neutrino

Masses

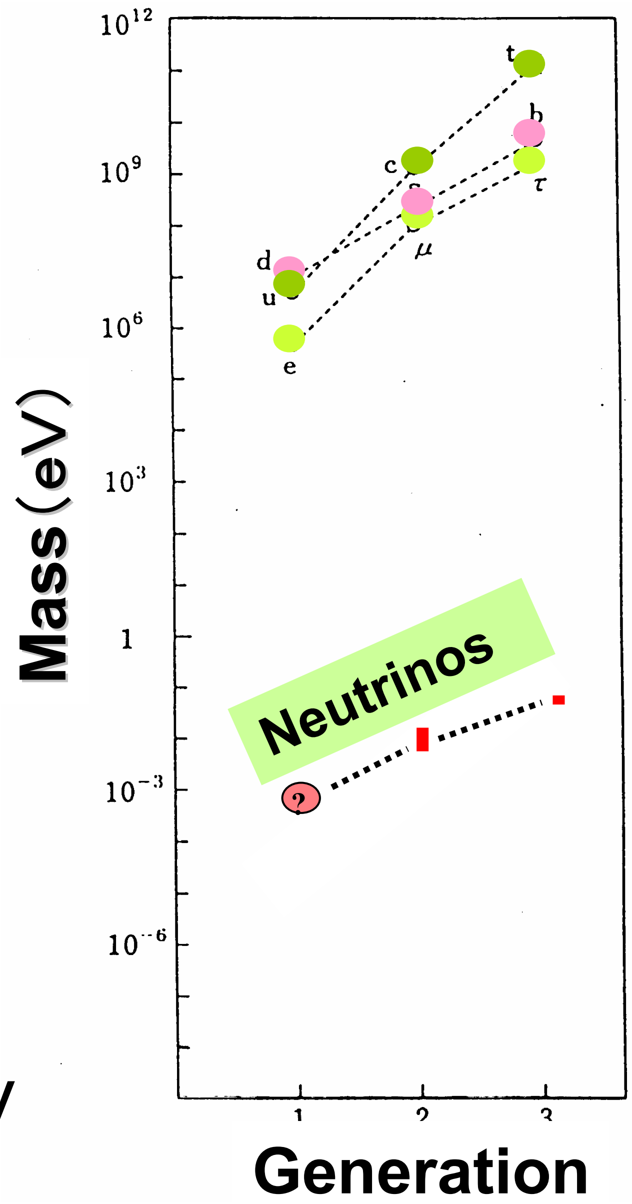
- $\Delta m_{23}^2 \sim 1.6 - 3.6 \times 10^{-3}$ eV^2 (atm ν)
- $\Delta m_{12}^2 \sim 3 - 20 \times 10^{-5}$ eV^2 (sol ν)
- Hierarchical masses:
  - $m_3 \sim$ 0.04 – 0.06 eV
  - $m_2 \sim$ 0.005 – 0.014 eV

Mixing angles

$\sin^2 2\theta_{23} \sim 1$ ($\theta_{23} \sim 45°$)

$\sin^2 2\theta_{12} \sim 0.8$ ($\theta_{12} \sim 30°$)

$\sin^2 2\theta_{13} < 0.12$ ($\theta_{13} < 10°$) @$\Delta m_{13}^2 \sim 3\text{x}10^{-3}$eV^2



- Extremely small masses
- Large mixing
- $\theta_{13} > 0$? → important for CPV

Purposes of JHF-Kamioka experiment

1. **Test 3 flavor neutrino mixing framework**
   - **Discovery of ν_e appearance (θ_{13}>0?)**
     - At the same Δm^2 as ν_μ disapp. →Firm evidence of 3gen. mix.
     - Most impotant and urgent in 1st phase
     - Open possibility to search for CPV
   - **Precision measurements of ocs. params.**

     $\Delta m_{23}, \theta_{23} / \Delta m_{13}, \theta_{13}$

     Comparison w/ quark sector

     Test exotic models (decay, extra dimensions,….)
   - **NC measurement**

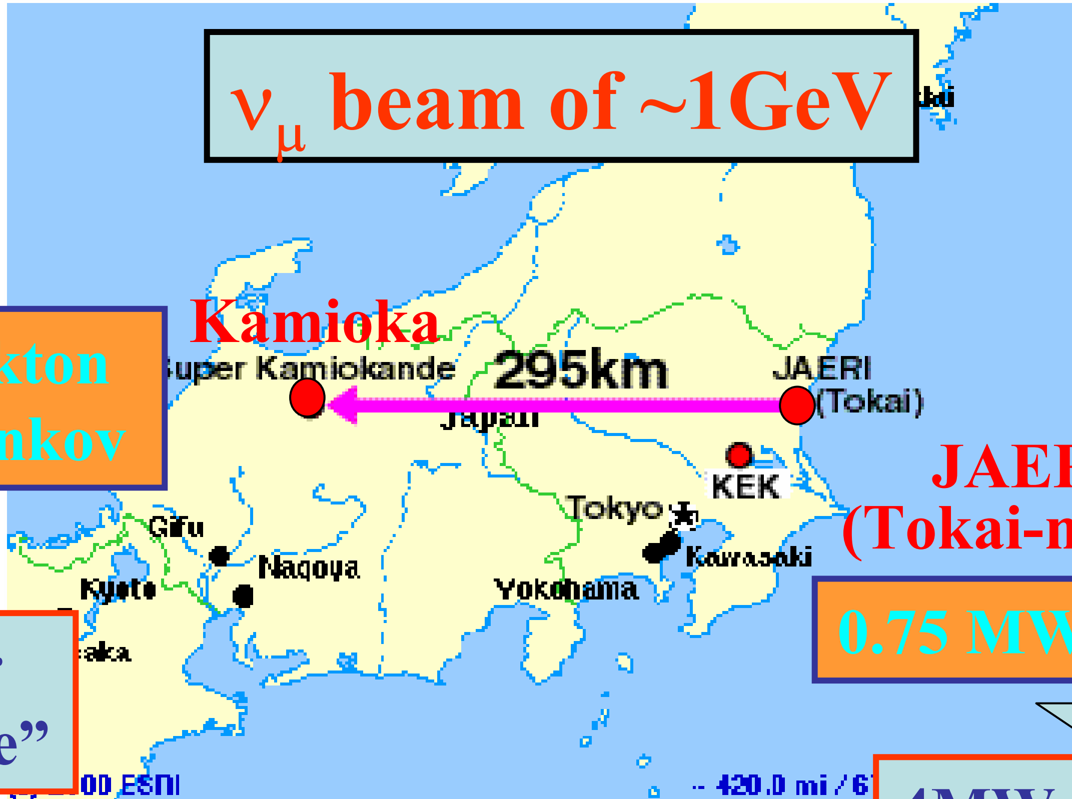
     No additional light “neutrino”?
2. **Search for CPV in lepton sector (2nd phase)**

   Give hint on Matter/Anti-matter asymmetry in the universe
3. **Proton decay search (2nd phase)**

   Direct evidence of Baryon number violation

Overview of experiment

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

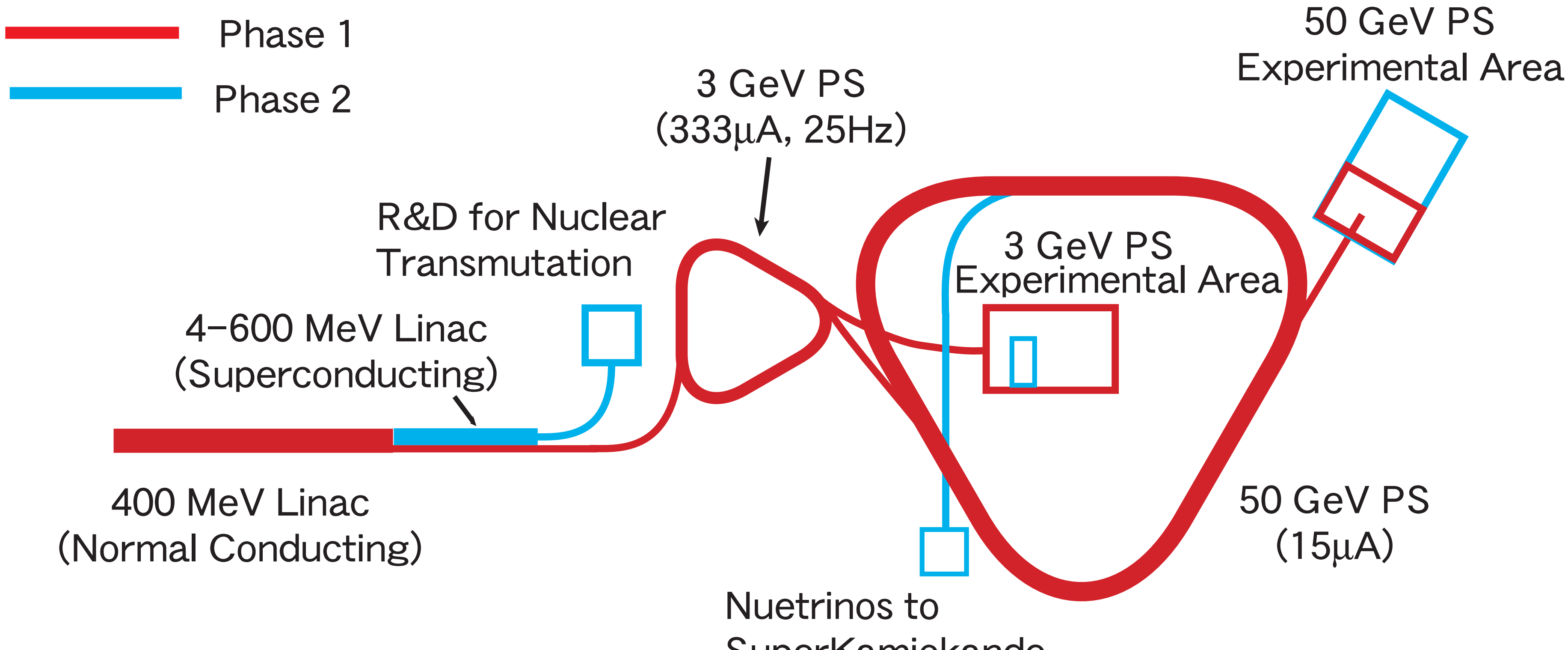
1st Phase

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

2nd Phase

- **CPV**
- **proton decay**

JHF project



Dec. 2000: approved by Japanese gov.

April, 2001: Phase 1 construction started.

Phase 1 + Phase 2 = 1,890 Oku Yen.

Phase 1 = 1,335 Oku Yen for 6 years.

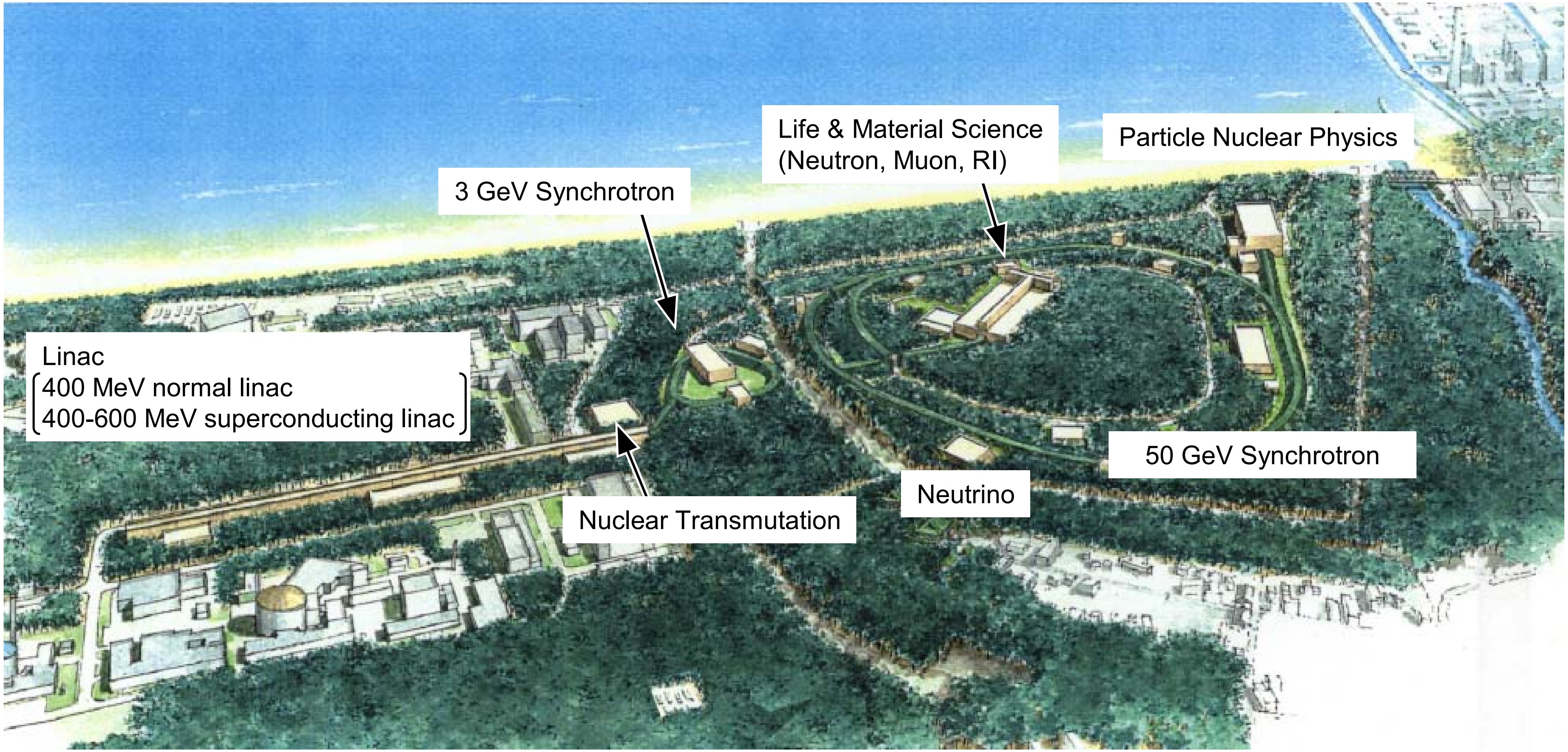
Cash in fund = 30 (JFY00) + 47 (JFY01) Oku Yen.

Construction budget does not include salaries.

March,2007: Phase 1 compelete

1 oku Yen= 1M$
when 1$=100yen

Site View of the Project



Organization(ν related)

JHFν working group

- Dec.1999 : formed (ICRR/KEK/Kyoto/Kobe/Tohoku/TRIUMF)
- Jun.2001 : Letter of Intent (hep-ex/0106019)
- Mar.2002 : First meeting to organize int. collaboration (Kyoto)

Facility Construction Group

- Officially formed in KEK on **April, 2001**
- The 3rd physics division, IPNS(~10persons)
- Cryogenic facility group, IPNS(~10persons)
- Cryogenic Science Center (8persons)
- w/ strong support from KEK-PS beam channel group

JHF-ν working group

ICRR/Tokyo-KEK-Kobe-Kyoto-Tohoku-TRIUMF

Y.Itow, T.Kajita, K.Kaneyuki, M.Shiozawa, Y.Totsuka (ICRR/Tokyo)
Y.Hayato, T.Ishida, T.Ishii, T.Kobayashi, T.Maruyama, K.Nakamura,
Y.Obayashi, Y.Oyama, M.Sakuda, M.Yoshida (KEK)
S. Aoki, T.Hara, A. Suzuki (Kobe)
A.Ichikawa, T.Nakaya, K.Nishikawa (Kyoto)
T.Hasegawa, K.Ishihara, A.Suzuki (Tohoku)
A.Konaka (TRIUMF)

(http://neutrino.kek.jp/jhfnu)

Dec.'99: Working group formed.
Mar.'00: First Letter of Intent prepared
Jun.'01: Updated LOI released(hep-ex/0106019). Int. WS held.
Mar.'02: Meeting to organize int'ntl collaboration

Meeting at Kyoto on Mar.9, 2002

- Institutes: Canada(1), Europe(8), US(10), Korea(2)
- Report of latest status of
  - facility design
  - cost estimate
- Discussion on possible items of contribution both in
  - Financially
  - Expertise

2. JHF-Kamioka neutrino experiment

Principle

- Neutrino energy reconstruction by using **Quasi-elastic** (QE) interaction.
  - Oscillation pattern measurement
  - BG due to miss-reconstruction of inelastic interaction
    - Greatly improved by using narrow spectrum
- **Narrow spectrum tuned at the oscillation maximum.**
  - High sensitivity
  - Less background

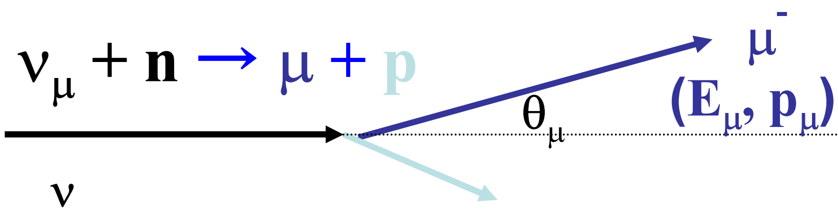
$\Delta m^2 = 1.6 \sim 4 \times 10^{-3}\,\mathrm{eV}^2$

$E_\nu = 0.4 \sim 1\,\mathrm{GeV}$

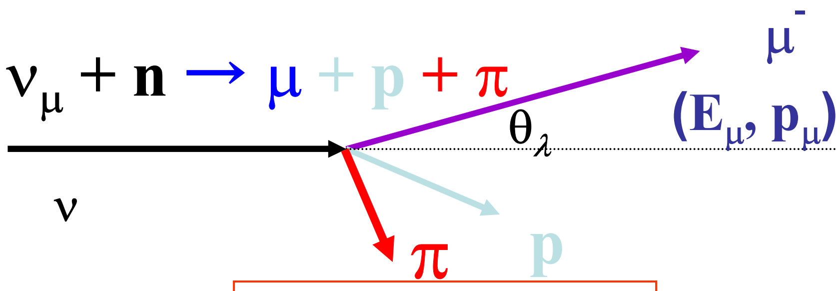
- **Gigantic water Cherenkov detector**
  - High statistics
  - High efficiency for low energy
  - Good PID (e/μ) capability

Neutrino Energy E_ν reconstruction

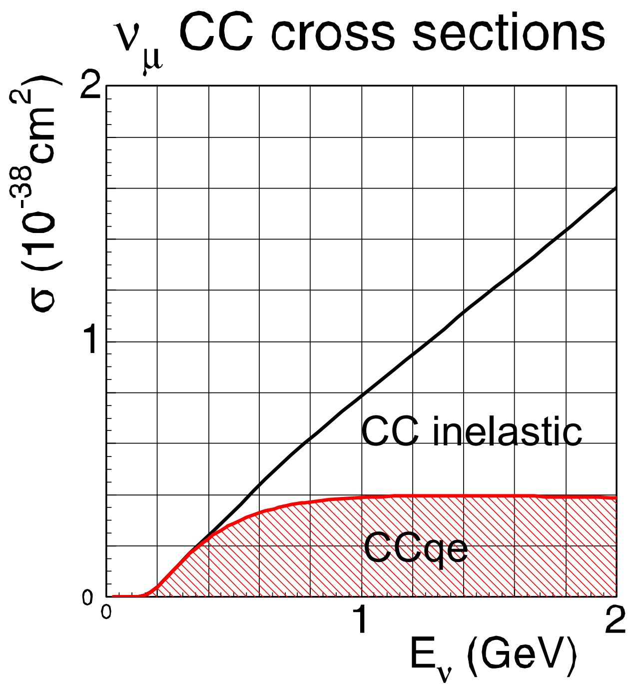
CC quasi elastic reaction ⇔ $$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

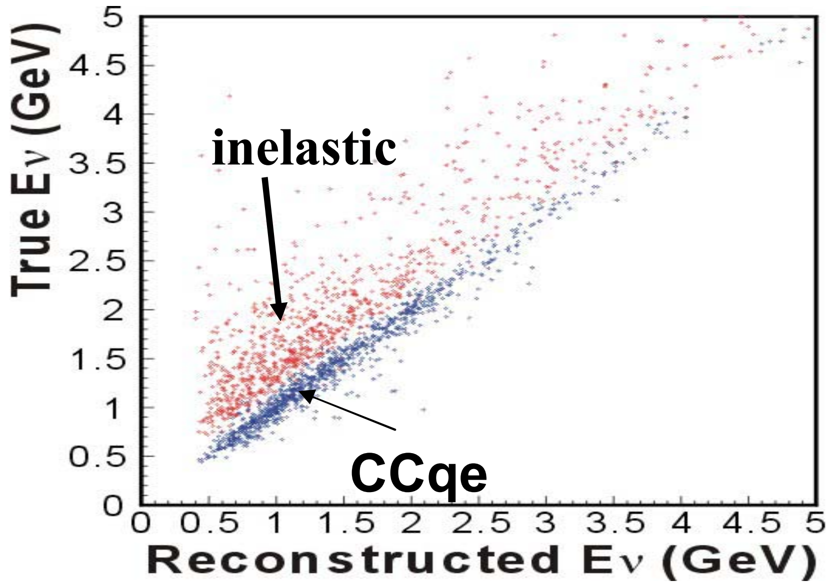


CCqe



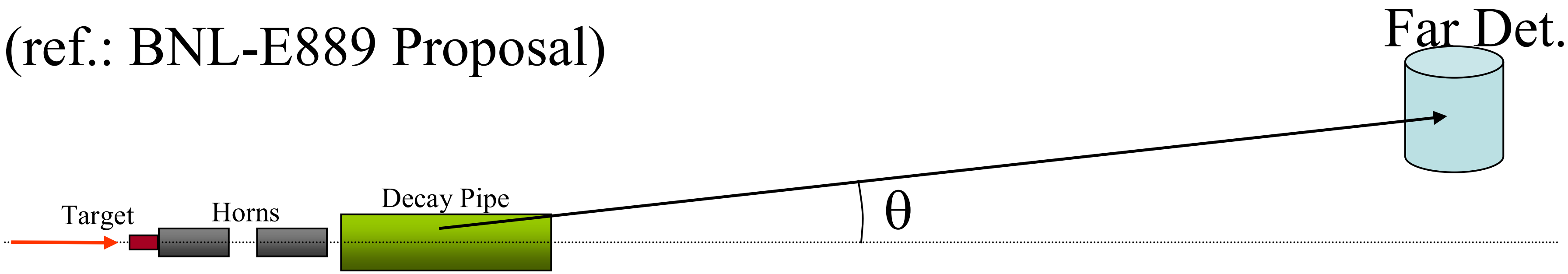
Inelastic (BG)





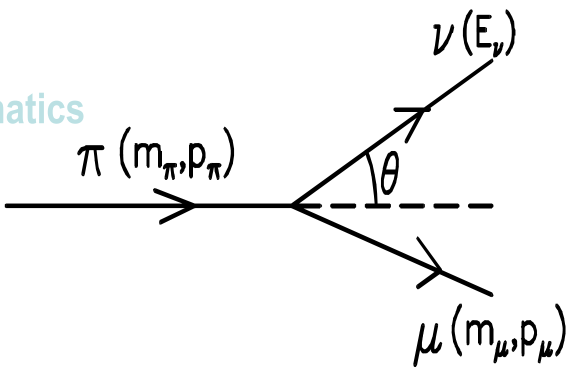
Off Axis Beam (another NBB option)

(ref.: BNL-E889 Proposal)

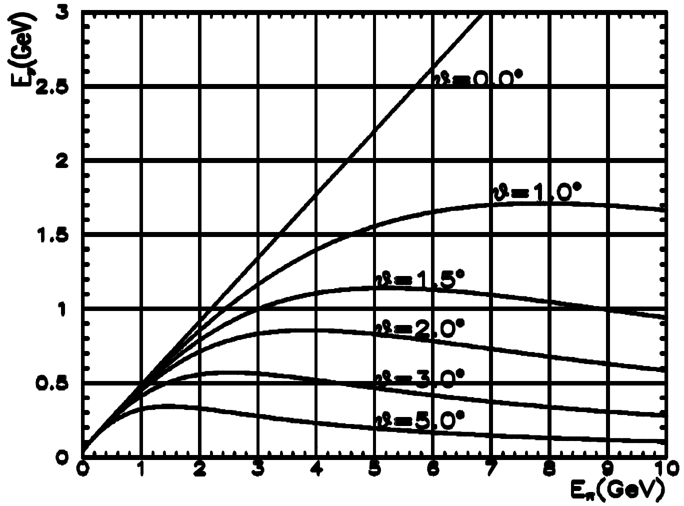


WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics

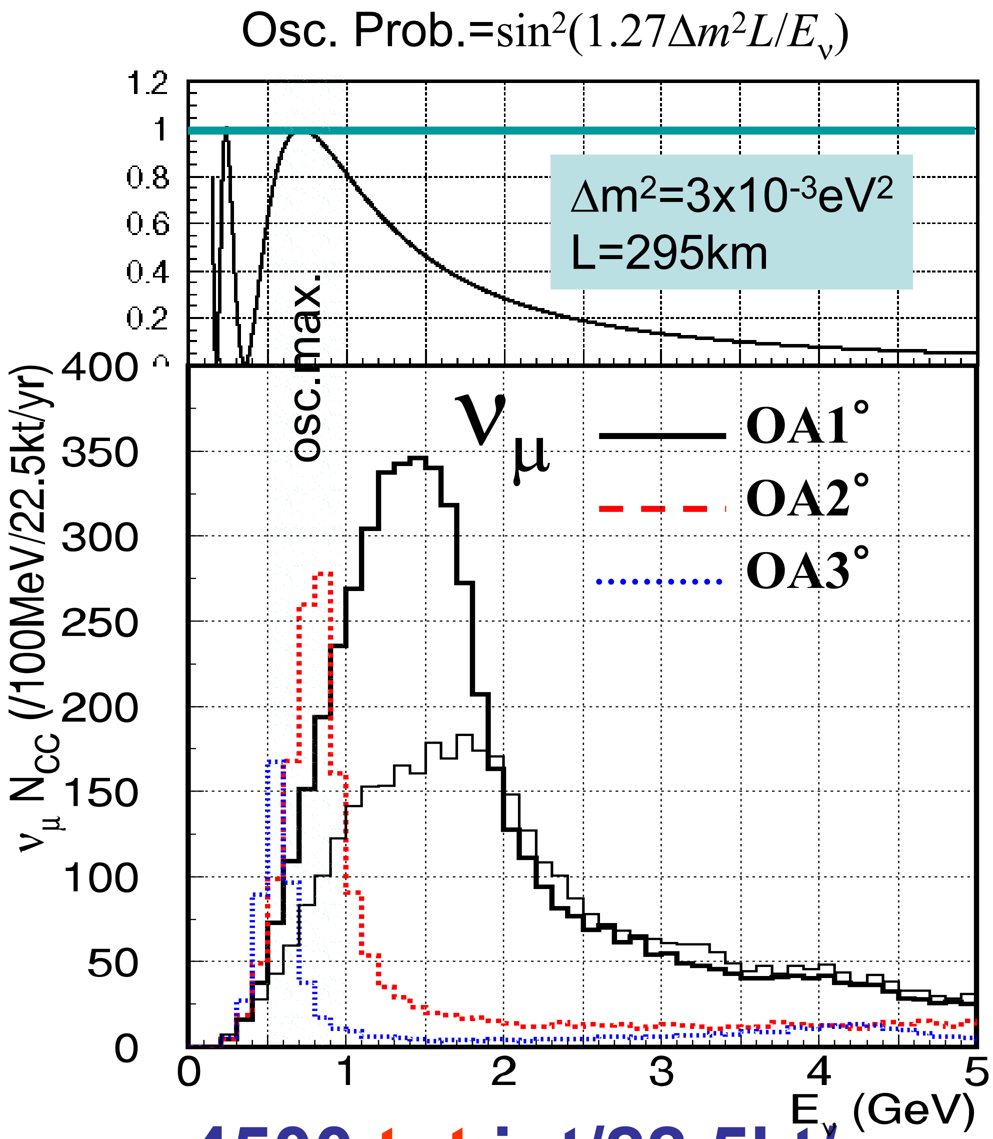


$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\theta)}$$



- Quasi Monochromatic Beam
- x2~3 intense than NBB

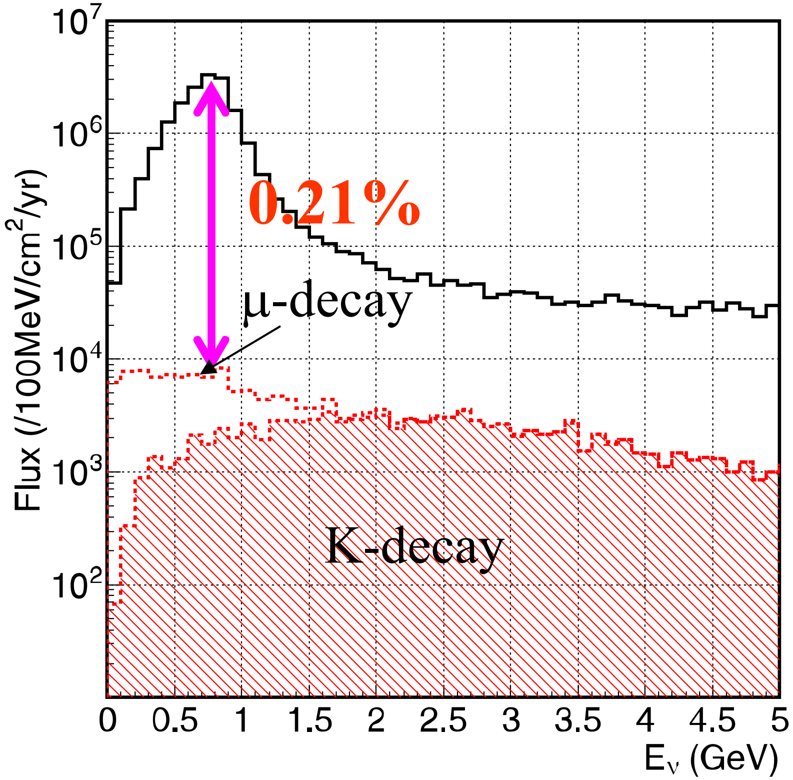
Expected spectrum



~4500 tot int/22.5kt/yr

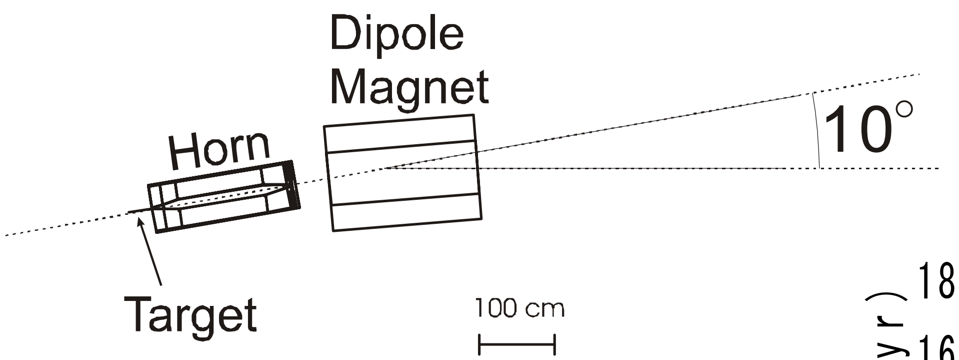
~3000 CC int/22.5kt/yr

ν_e contamination

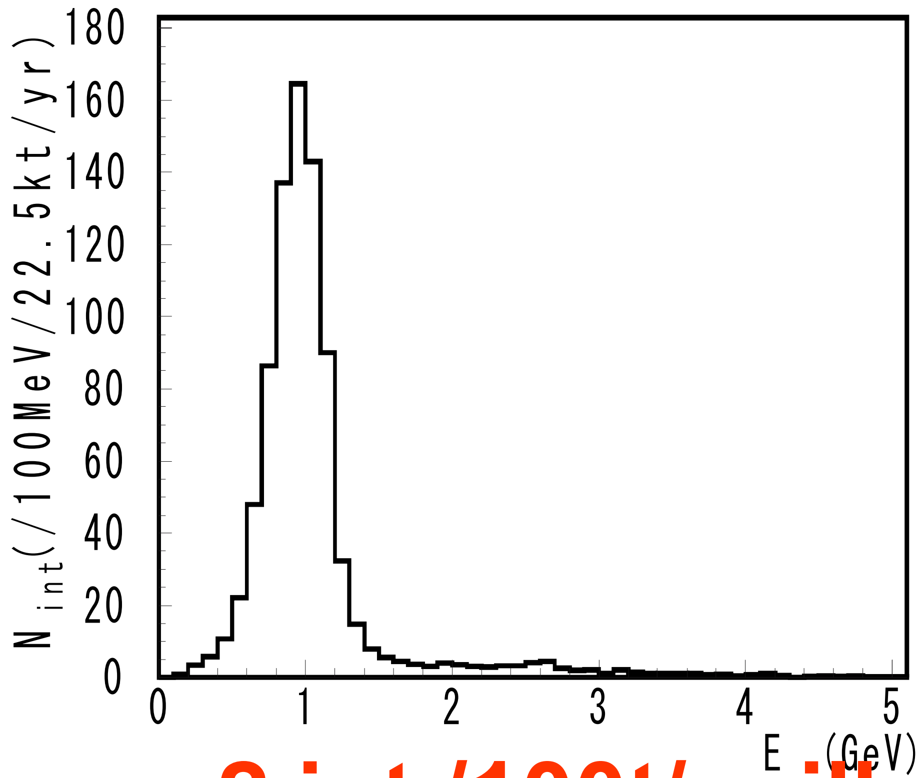


Very small ν_e/ν_μ @ ν_μ peak

Narrow Band Beam for ν int study @ near



- **Easy to tune E_ν**
- Less HE tail (than OAB)

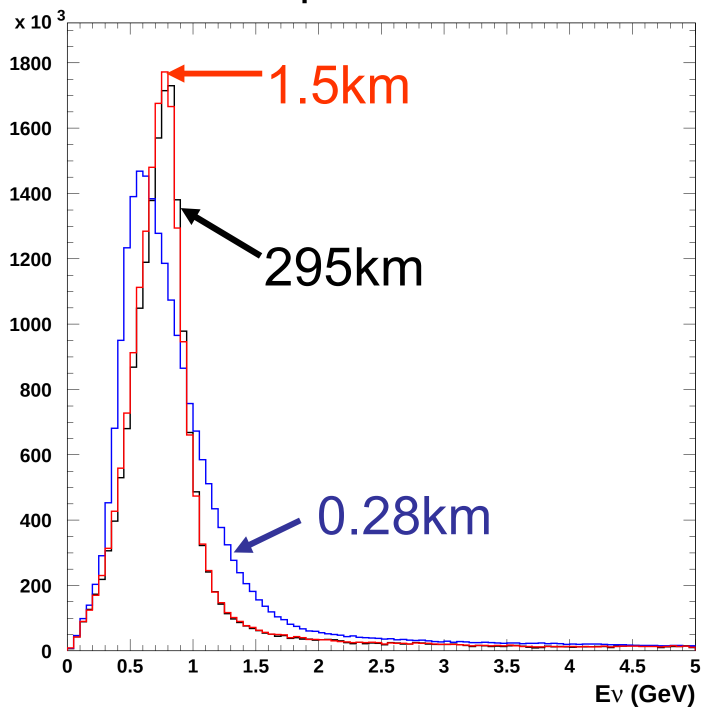


~2 int./100t/spill

Detectors

- **Muon monitors @ ~140m**
  - Behind the beam dump
  - Fast (spill-by-spill) monitoring of beam direction/intensity
- **First Front detector** "Neutrino monitor" @280m
  - Neutrino intensity/direction
  - Study of neutrino interactions
- **Second Front Detector @ ~2km**
  - Almost same E_ν spectrum as for SK
  - Absolute neutrino spectrum
  - Precise estimation of background
- **Far detector @ 295km**
  - **Super-Kamiokande (50kt)**
  - **Hyper-Kamiokande (~1Mt)**

Neutrino spectra at diff. dist

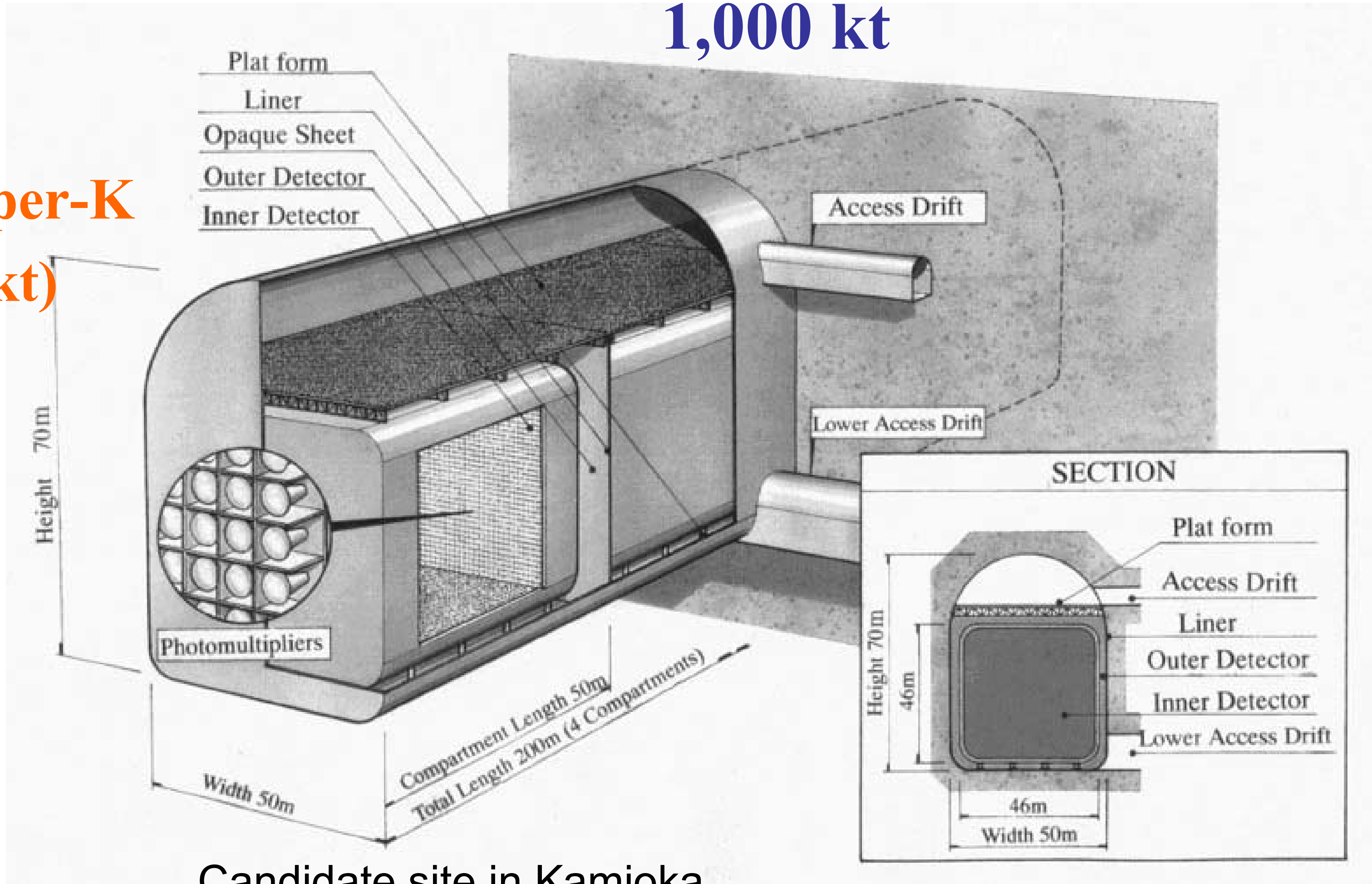


dominant syst. in K2K

Far detector in second phase

Phase-II: Hyper-K
1,000 kt

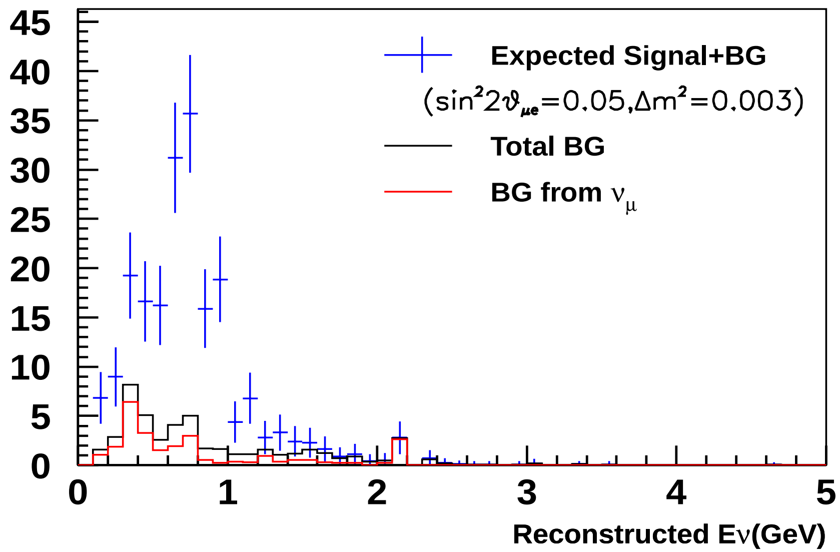
Phase-I: Super-K
22.5kt (50kt)



Candidate site in Kamioka

ν_e appearance

Off Axis (2°) 5year



5yr, 22.5kt

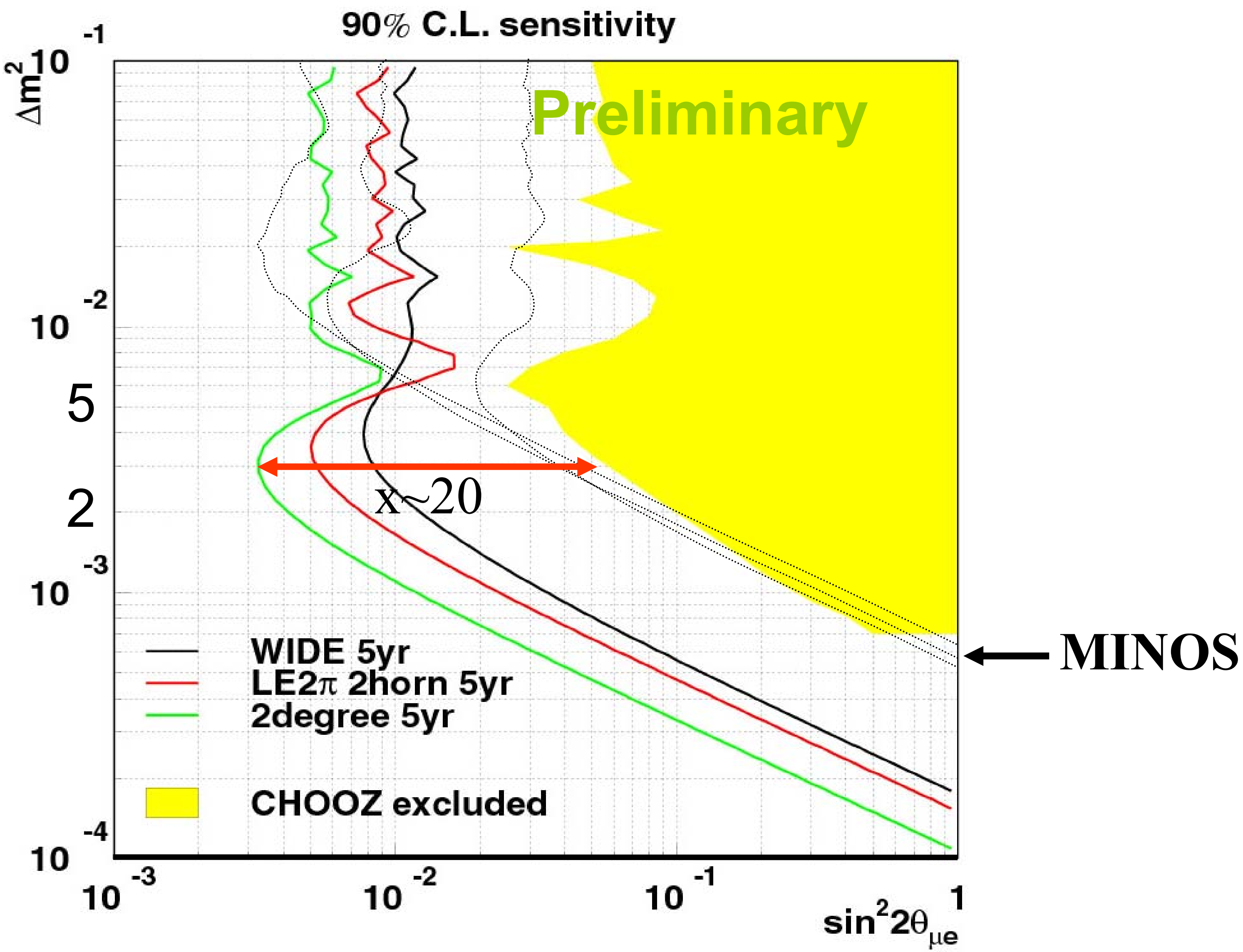
Chooz limit

$\Delta m^2 = 3\times10^{-3} eV^2$,
$\sin^2 2\theta_{13} = 0.1$

	ν_μ C.C.	ν_μ N.C.	Beam νe	Osc'd νe
Generated	10713.6	4080.3	292.1	301.6
Selected $.4<E_\nu^{rec}<1.2$	1.8	9.3	11.1	123.2
red.eff.	0.02%	0.2%	3.8%	40.8%

~90% of ν_μ BG from π^0 production
~60% of ν_μ BG comes from HE tail (E_ν^{true}>1.2GeV)

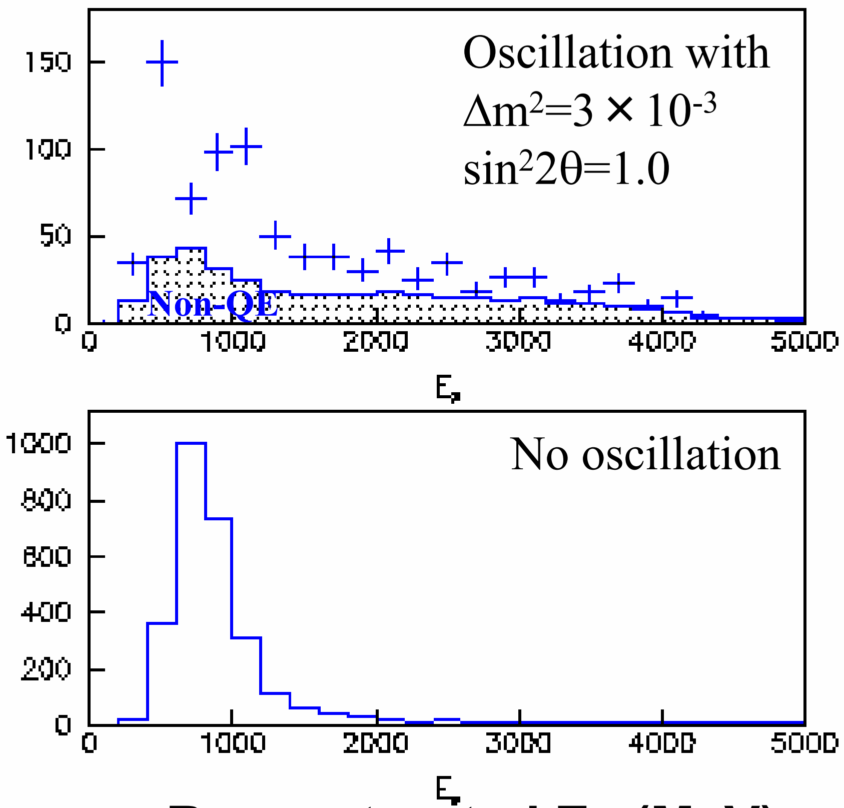
Sensitivity on $\nu_\mu \rightarrow \nu_e$ appearance



Dashed lines: MINOS Ph2le, Ph2me, Ph2he from right
(A.Para, hep-ph/0005012)

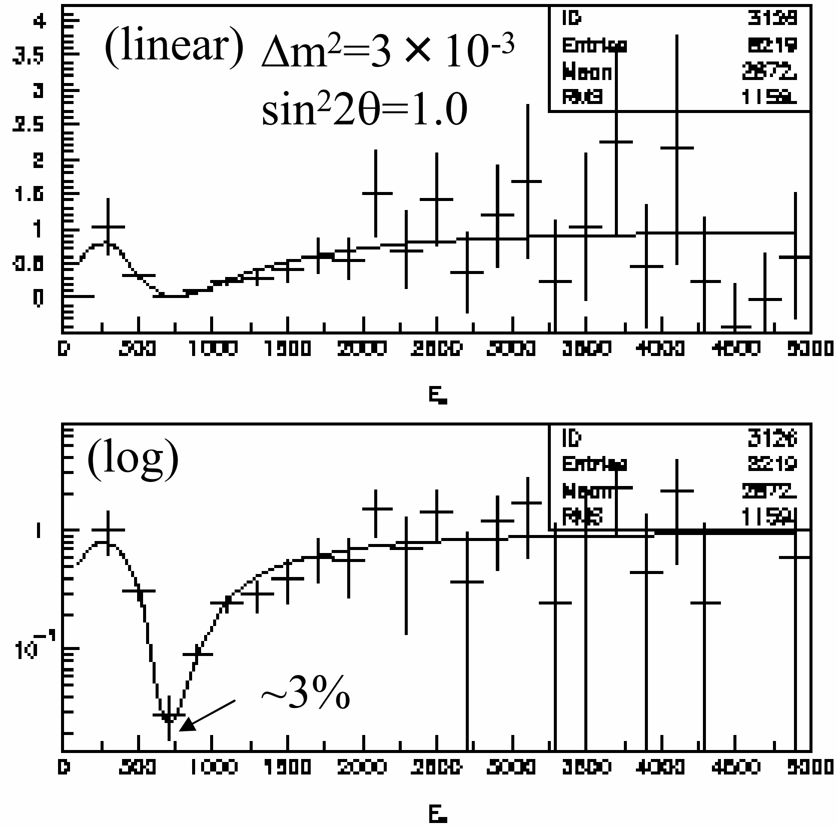
ν_μ disappearance

1ring FC μ-like



Reconstructed Eν (MeV)

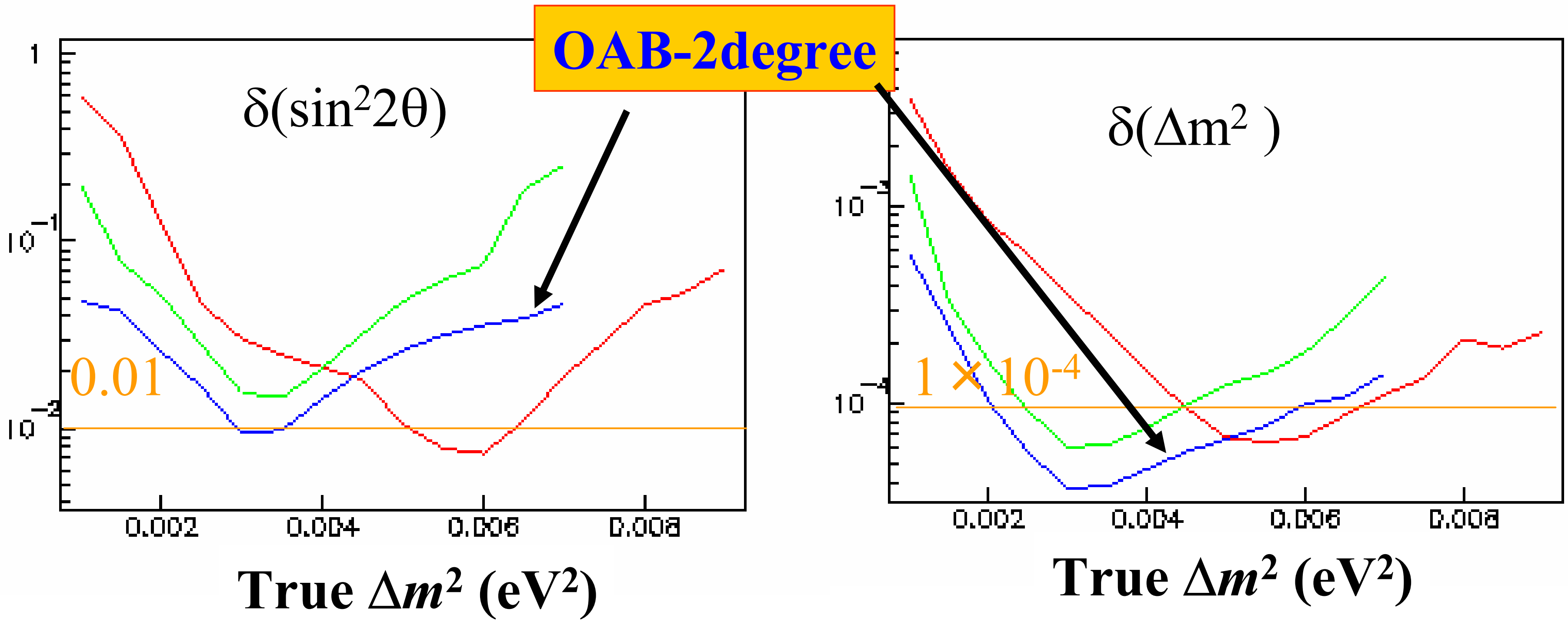
Ratio after BG subtraction



Fit with $1-\sin^2 2\theta \cdot \sin^2(1.27\Delta m^2 L/E)$

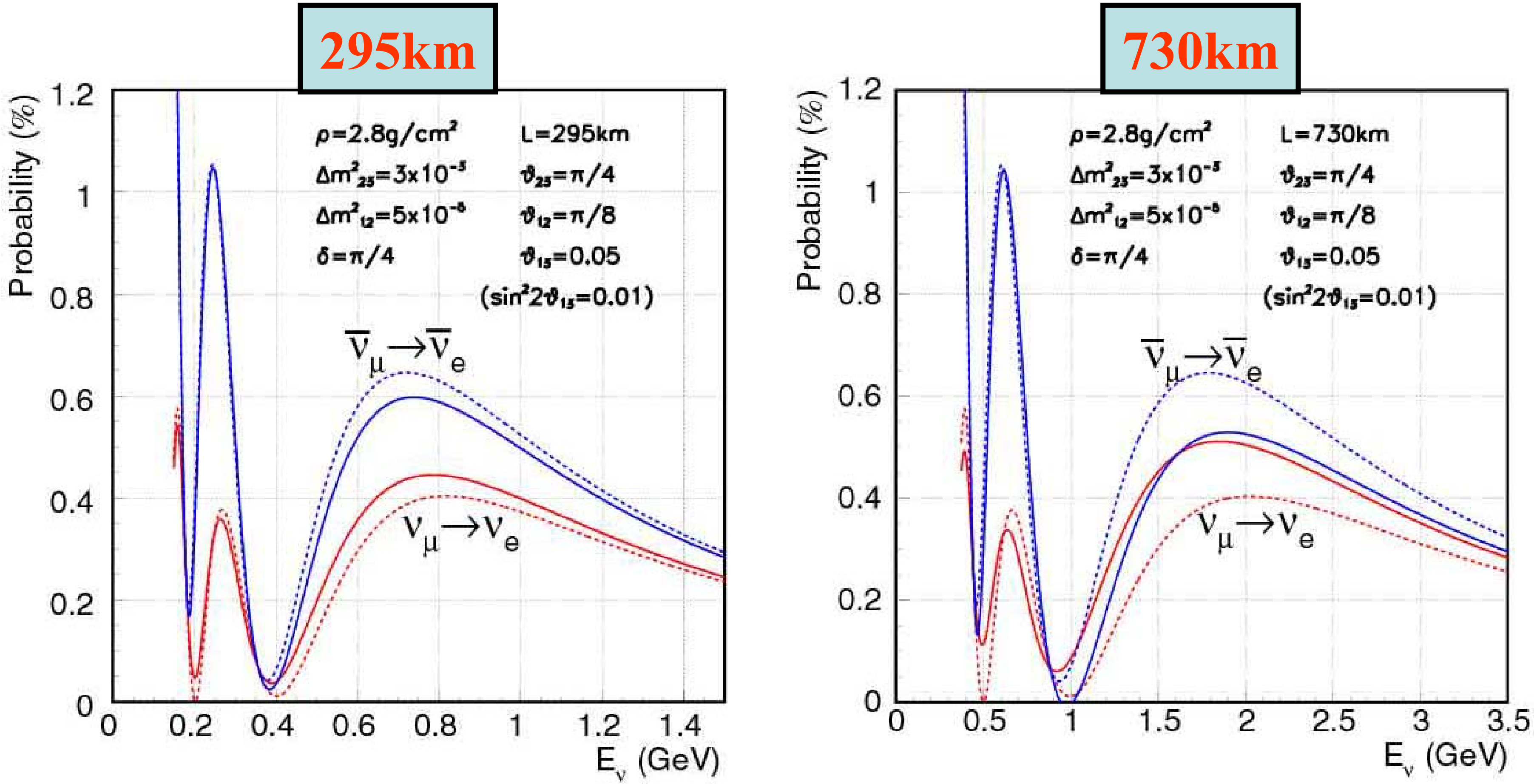
$\nu_\mu \rightarrow \nu_x$ disappearance

5 years precision



$\delta(\sin^2 2\theta) \sim 0.01$ in 5 years
$\delta(\Delta m^2) \sim < 1 \times 10^{-4}$ in 5 years

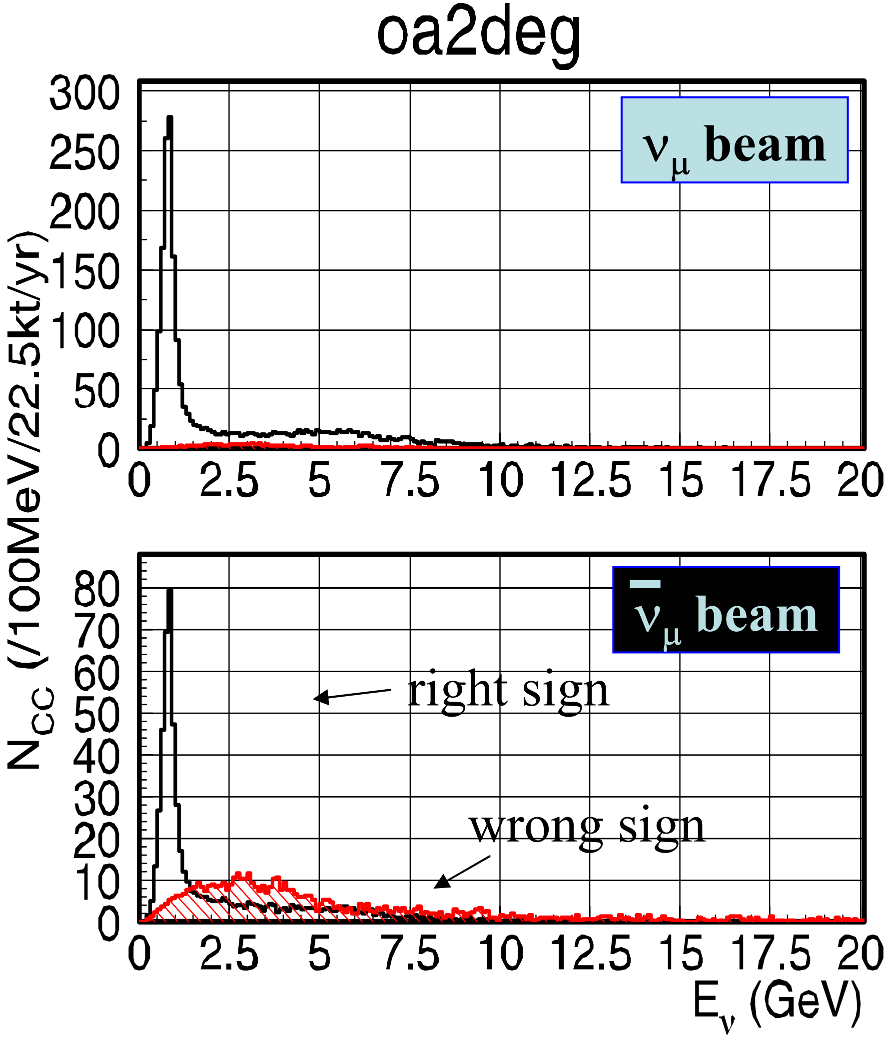
$\nu_\mu \rightarrow \nu_e$ oscillation probability(2)



Solid line: w/ matter
Dashed line: w/o matter

Small Matter Effect at 295km.

$\nu_\mu / \bar{\nu}_\mu$ # of CC int.

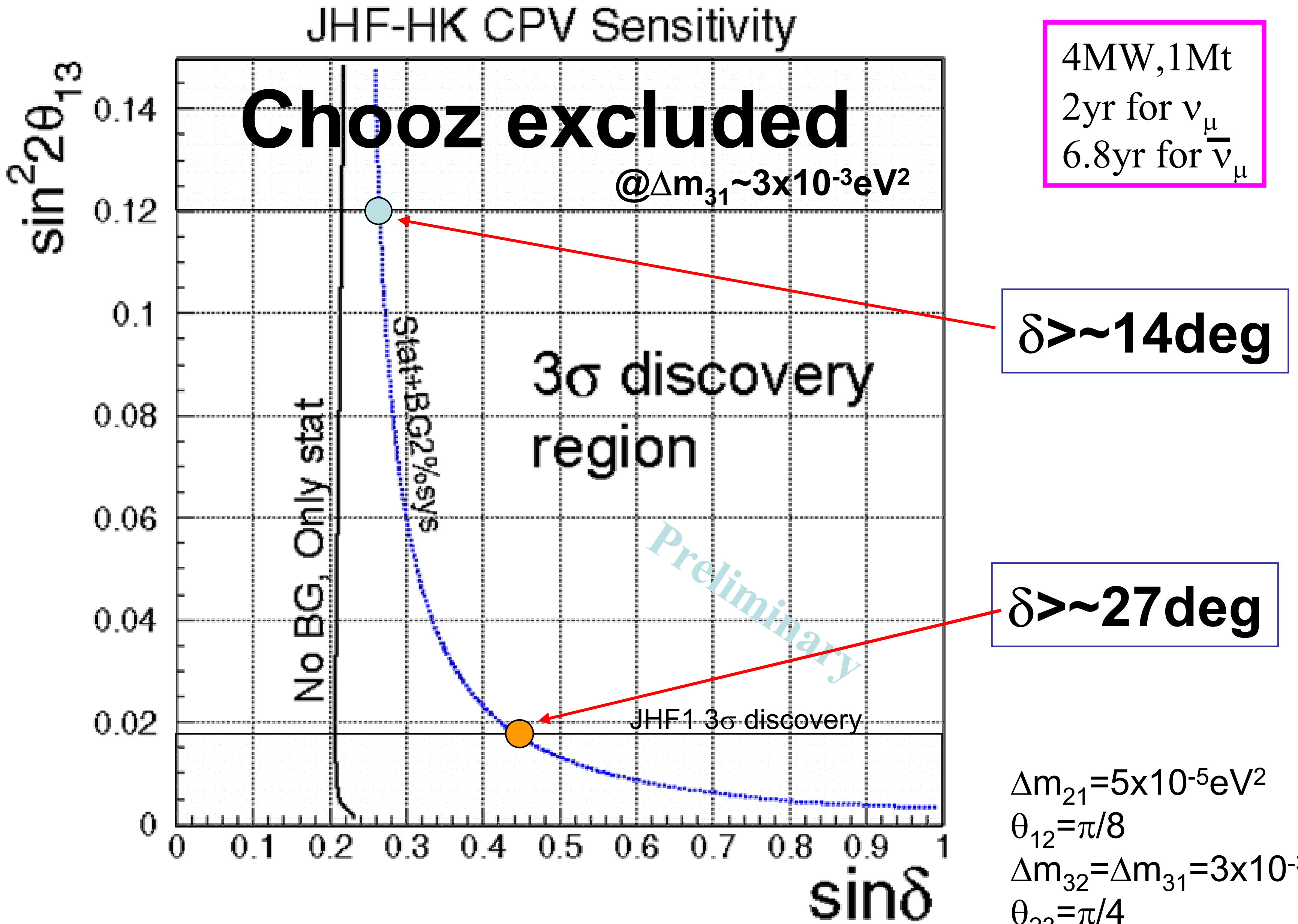


10^{21}pot/yr
(1st phase)

80m pipe

- # of int. for $\bar{\nu}_\mu$ is factor ~3 smaller than ν_μ due to cross section.
- Wrong sign contamination is much higher for anti-ν.

Sensitivity(3σ) to CPV(2nd phase)



4MW,1Mt
2yr for ν_μ
6.8yr for $\bar{\nu}_\mu$

$\Delta m_{21}=5\times10^{-5}eV^2$
$\theta_{12}=\pi/8$
$\Delta m_{32}=\Delta m_{31}=3\times10^{-3}eV^2$
$\theta_{23}=\pi/4$

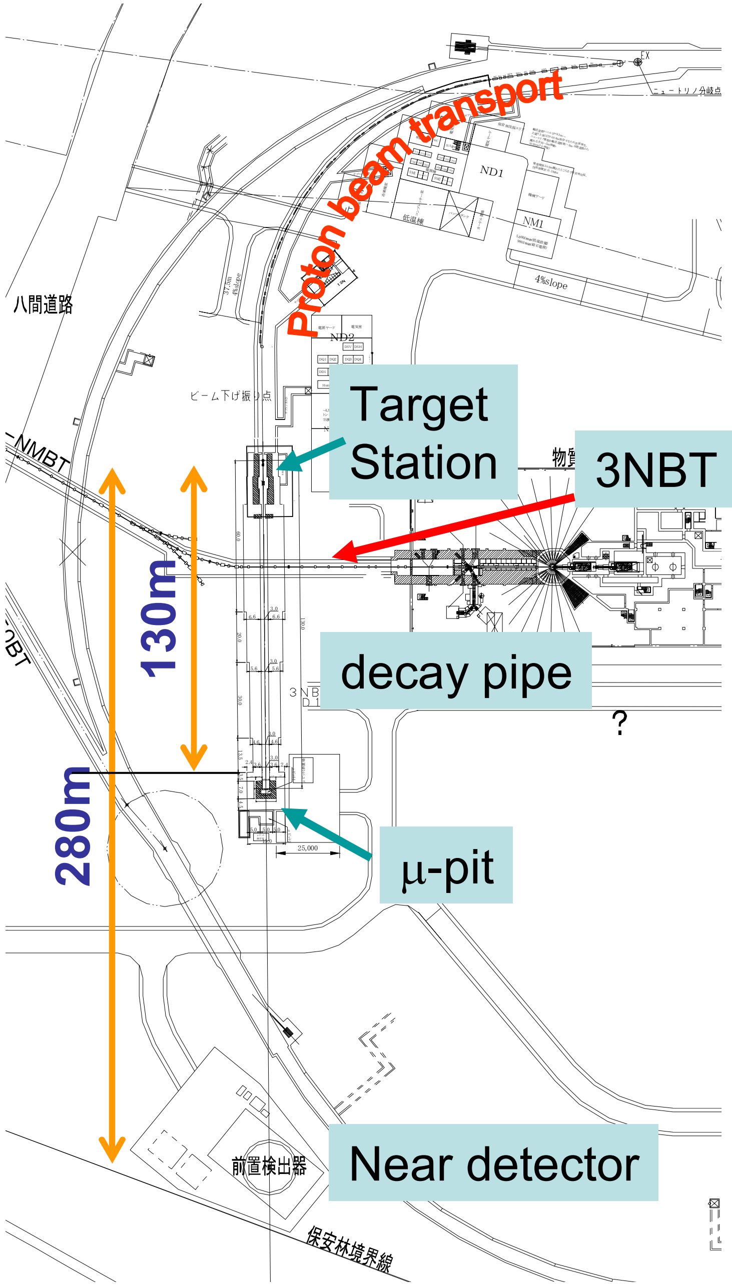
Neutrino Facility

Neutrino beam line

p+(target)→ π → ν_μ + μ

Components

- Proton beam transport
  - Preparation section
  - **Arc section (Supercond.)**
  - Final focusing
- Target/Horn system
- Decay pipe (130m)
- Beam dump



- Single turn fast extraction
- 8 bunches/~5μs
- 3.3×10^{14} proton/pulse
- 3.94 (3.64) sec cycle
- 1yr≡10^{21}proton on target(POT)

(3300hr~140days)

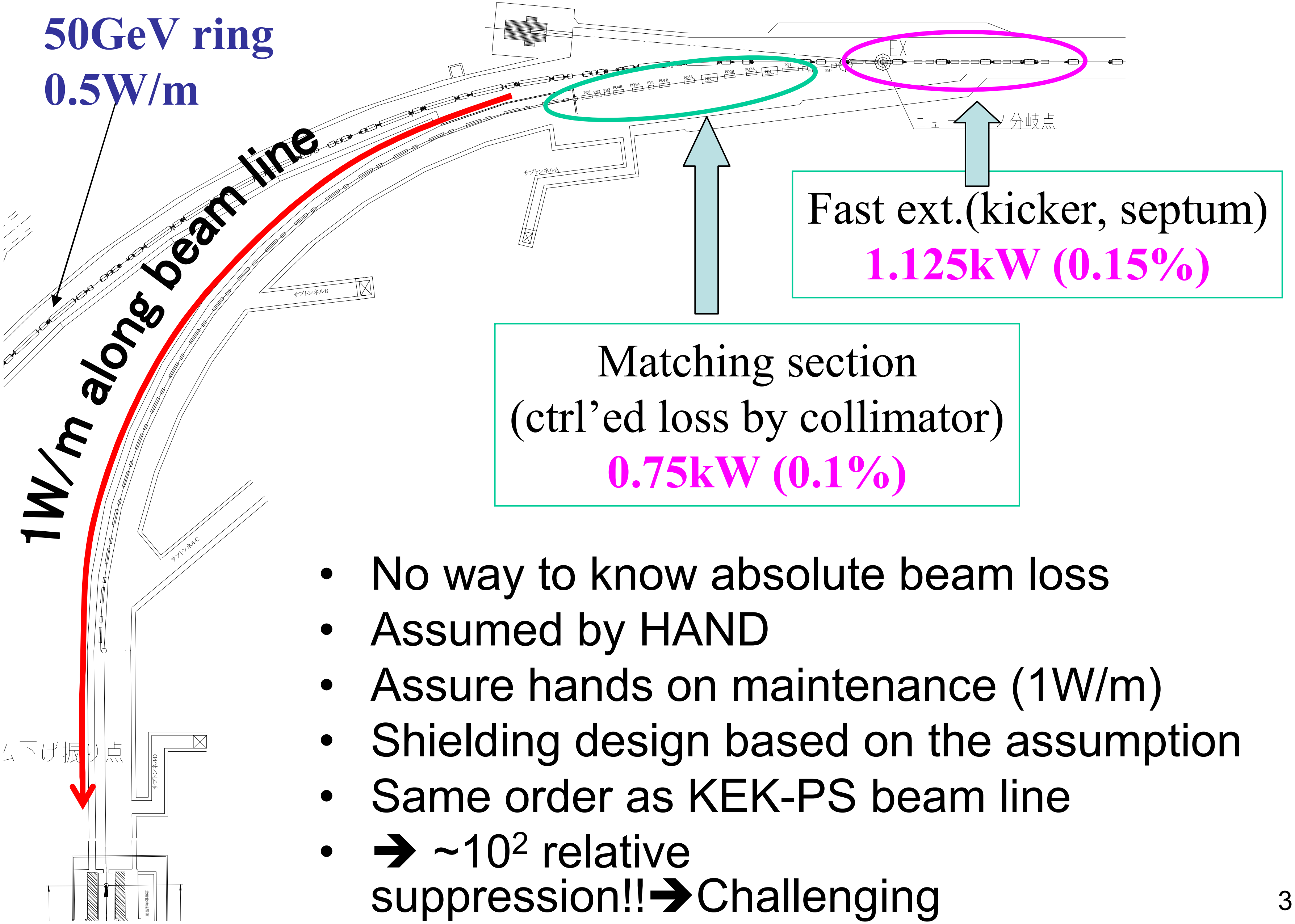
Specification

Beam kinetic energy	50GeV
Protons/pulse	$3.3x10^{14}$
Beam current	15μA
Beam power	750kW
Extraction	Single turn fast extraction
Micro structure	8bunches/9 RF buckets
Bunch spacing	598ns
Spill width	~5μs
Cycle	3.64~3.94sec
Rep rate	0.254~0.275Hz
Proton beam emittance	6.1πmm.mrad
Physical acceptance	60πmm.mrad
Beam loss(proton transport)	1W/m
Curvature of arc	106m
Decay pipe length (target-dump)	130m (from target)
Distance to near detectors	280m/~2km
Distance to SK	~295km
Target-SK beam decline	-1.25deg

Key Issues on neutrino facility

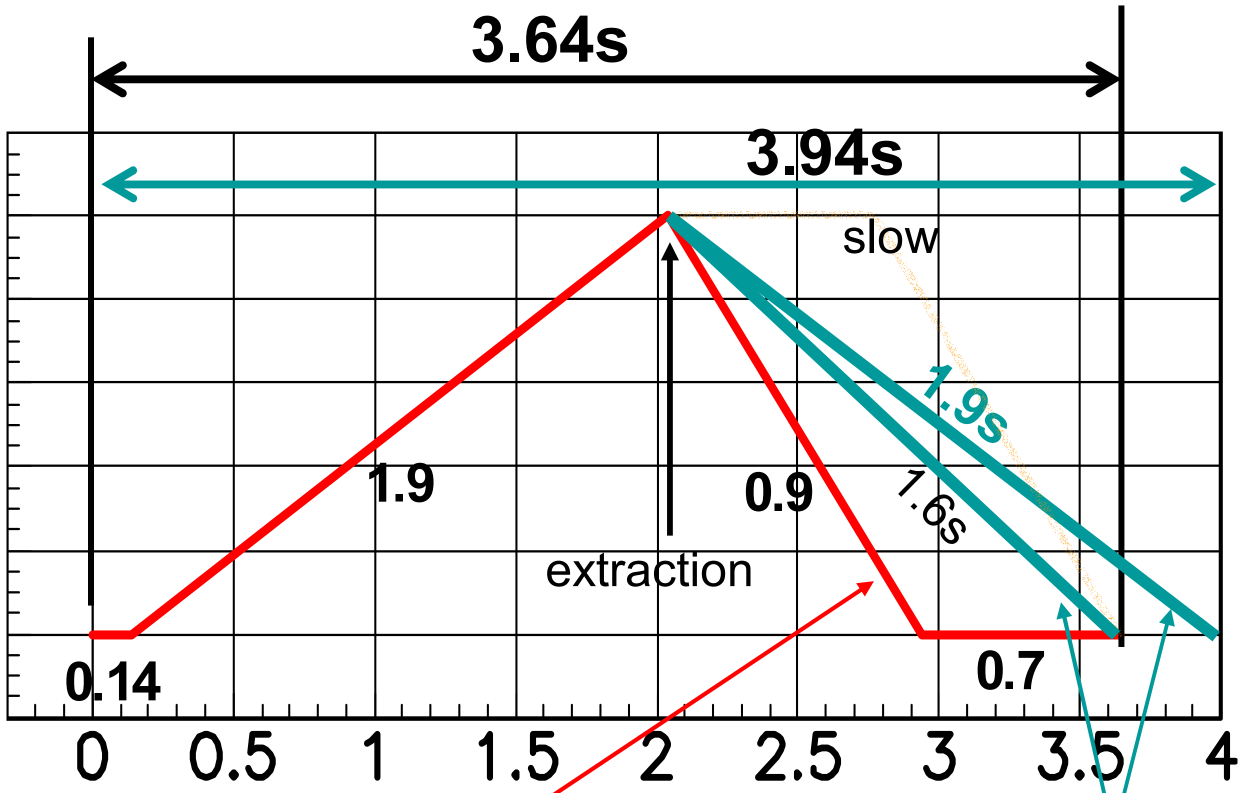
- Extremely severe radiation environment
  - Human exposure when maintenance
  - Damage to instruments
- Large heat load in a short time
  - cooling scheme, shock wave, quenching
- Key items
  - Beam abort in 50GeV ring (being developed.)
  - Beam scraping at matching sect.(→just started)
  - Radiation resistant magnets (→ Kusano)
  - Heat-load resistant SC magnets
  - Target/Horn (cooling, shock wave) (→Hayato)
  - Target station (cooling!, maintenance)
  - Decay volume (cooling) (→Hayato)
  - Beam dump (cooling) (→Hayato)
  - Radiation shielding (DV, Dump→Oyama)
- + K2K issues (timing, direction, …)

Beam loss



- No way to know absolute beam loss
- Assumed by HAND
- Assure hands on maintenance (1W/m)
- Shielding design based on the assumption
- Same order as KEK-PS beam line
- ➔ ~10^2 relative suppression!!➔Challenging

Acceleration cycle



When 50GeVfast abort available: 3.64s

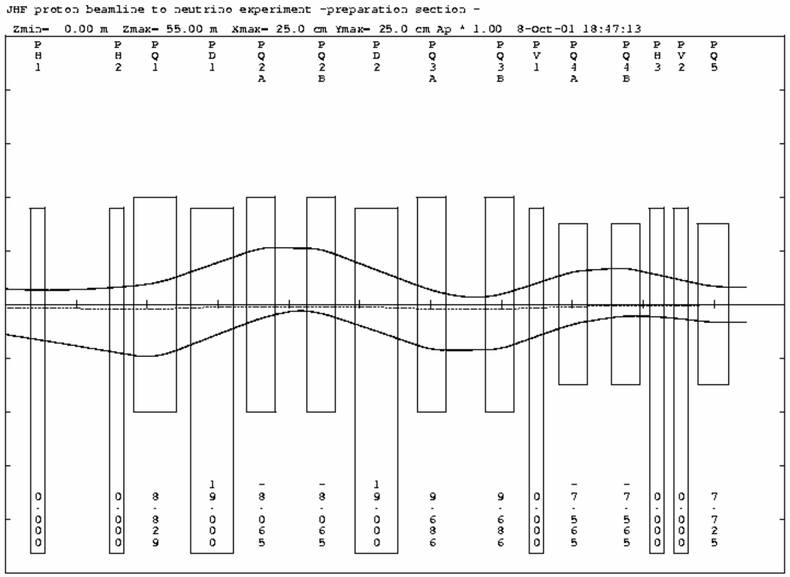
Injection : 0.14s
acceleration : 1.9s
current down : 0.9s
nothing : 0.7s

When fast abort not available: 3.94(3.64)s

Injection : 0.14s
acceleration : 1.9s
deceleration : 1.9(1.6)s

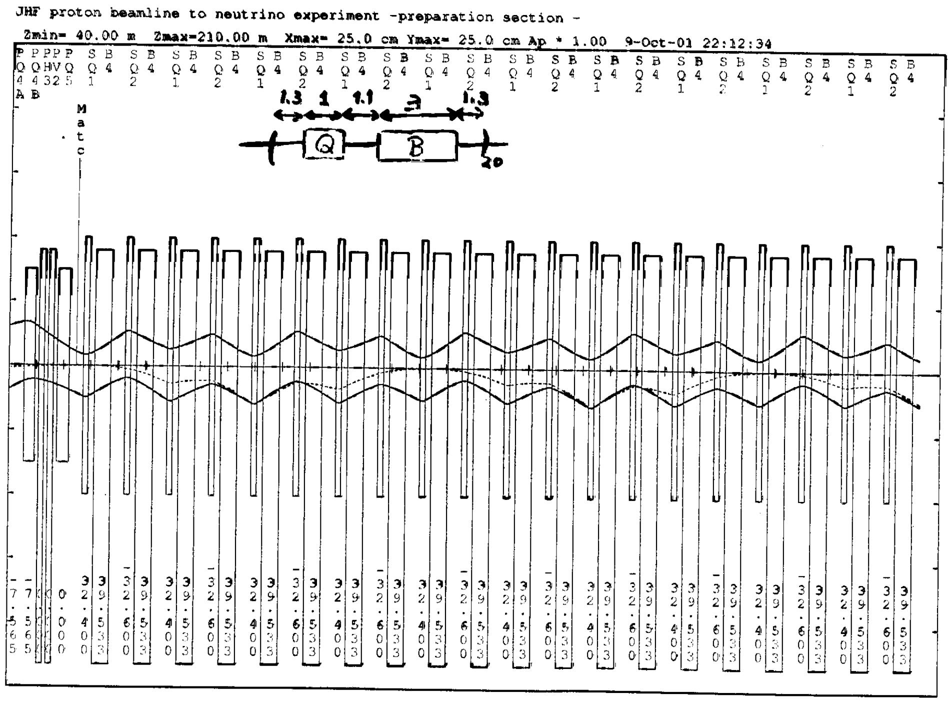
Current default option

Optics design of primary proton beam



Upstream normal cond.

Arc. supercond. part



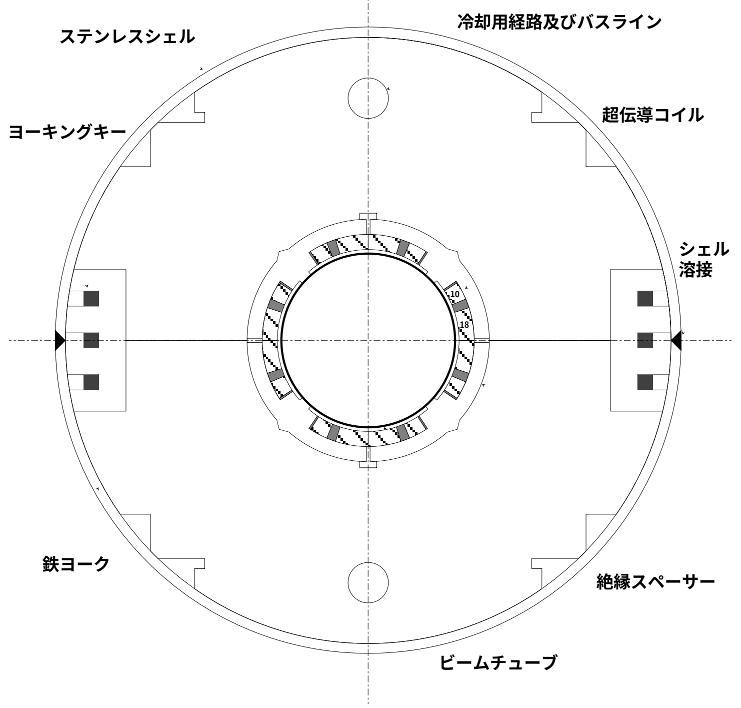
FODO

Ichikawa

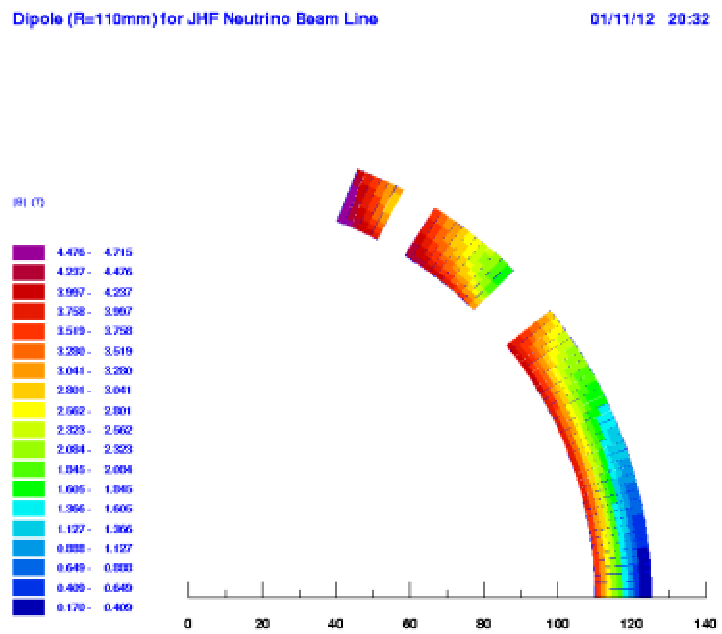
Design of Super con. mag started

Type	Magnetic Length	Operation Field	Number
Dipole	3 m	3.95 T	20
Quadrupole	1 m	32.4 T/m	20

Bore: 180 or 220mm

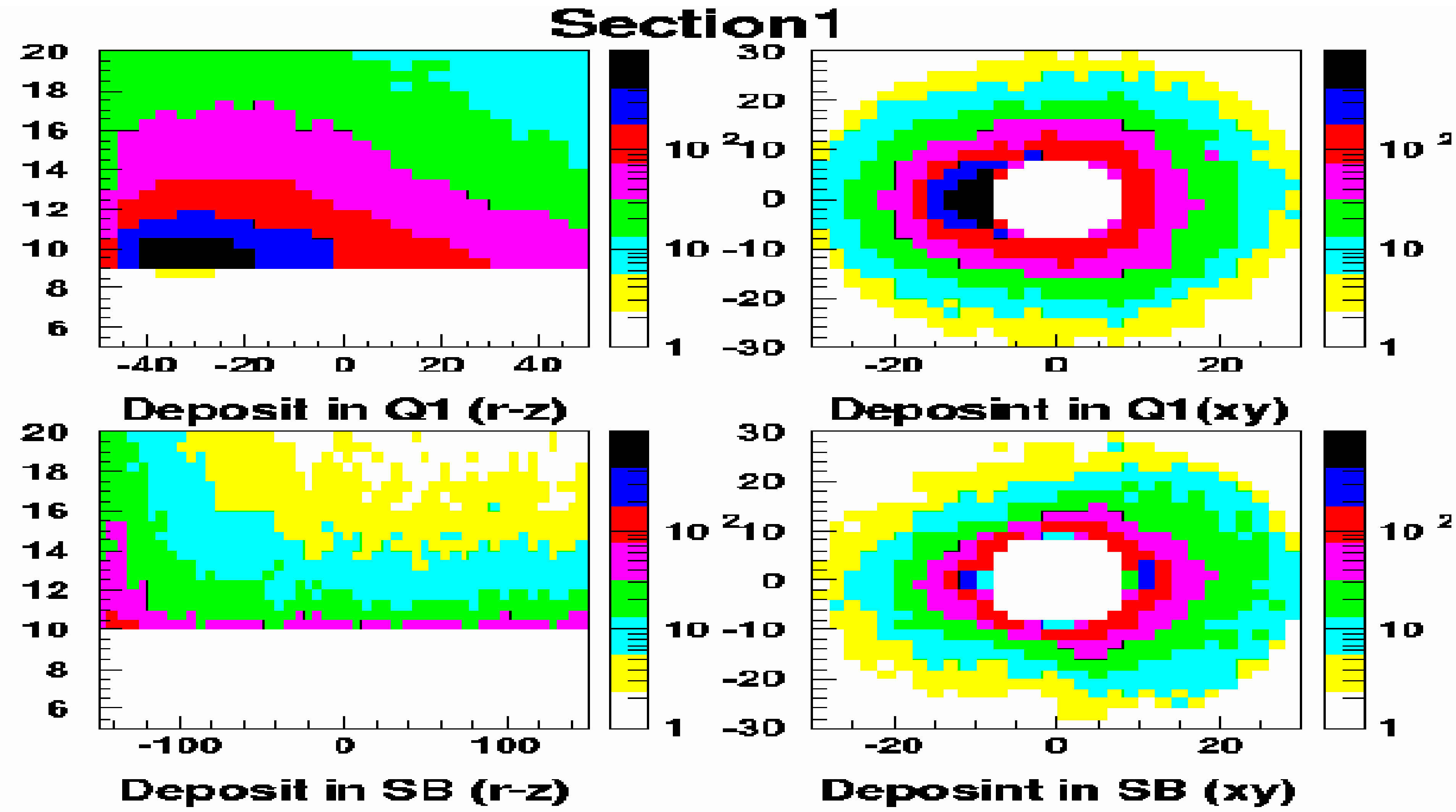


B field simulation



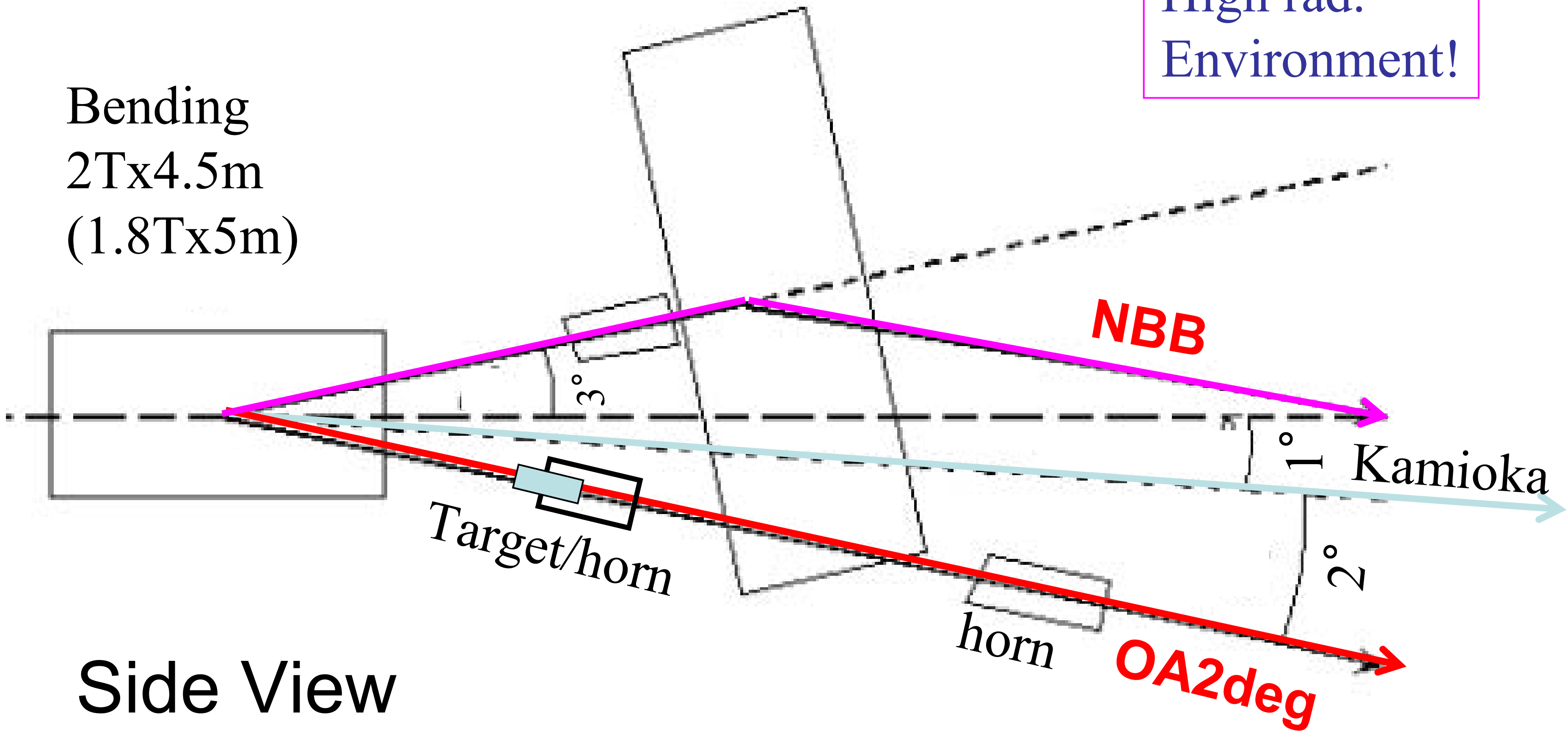
Cryo. Science Center of KEK

Heat load dist. on upstream most SC magnets



Concept of target station

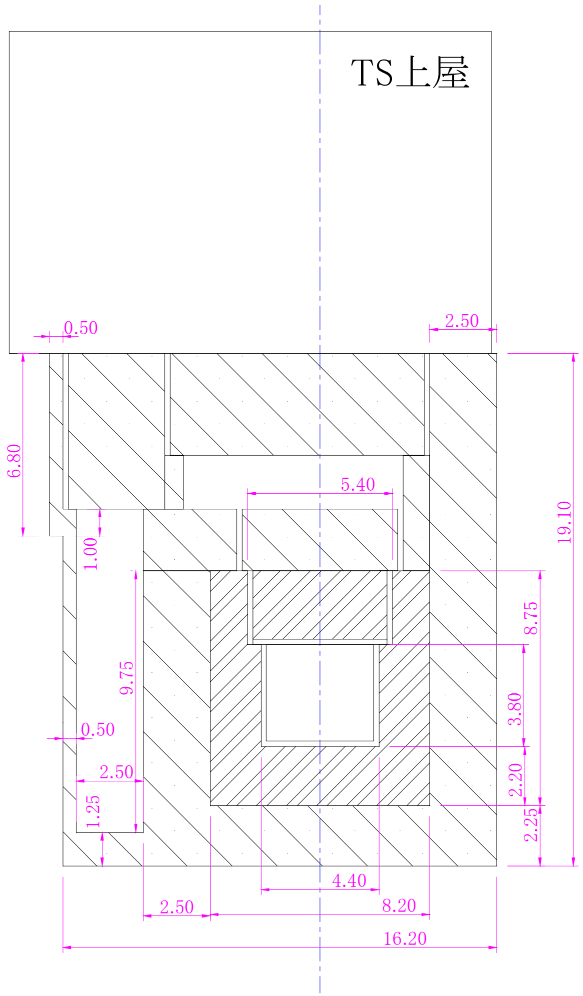
Extremely
High rad.
Environment!



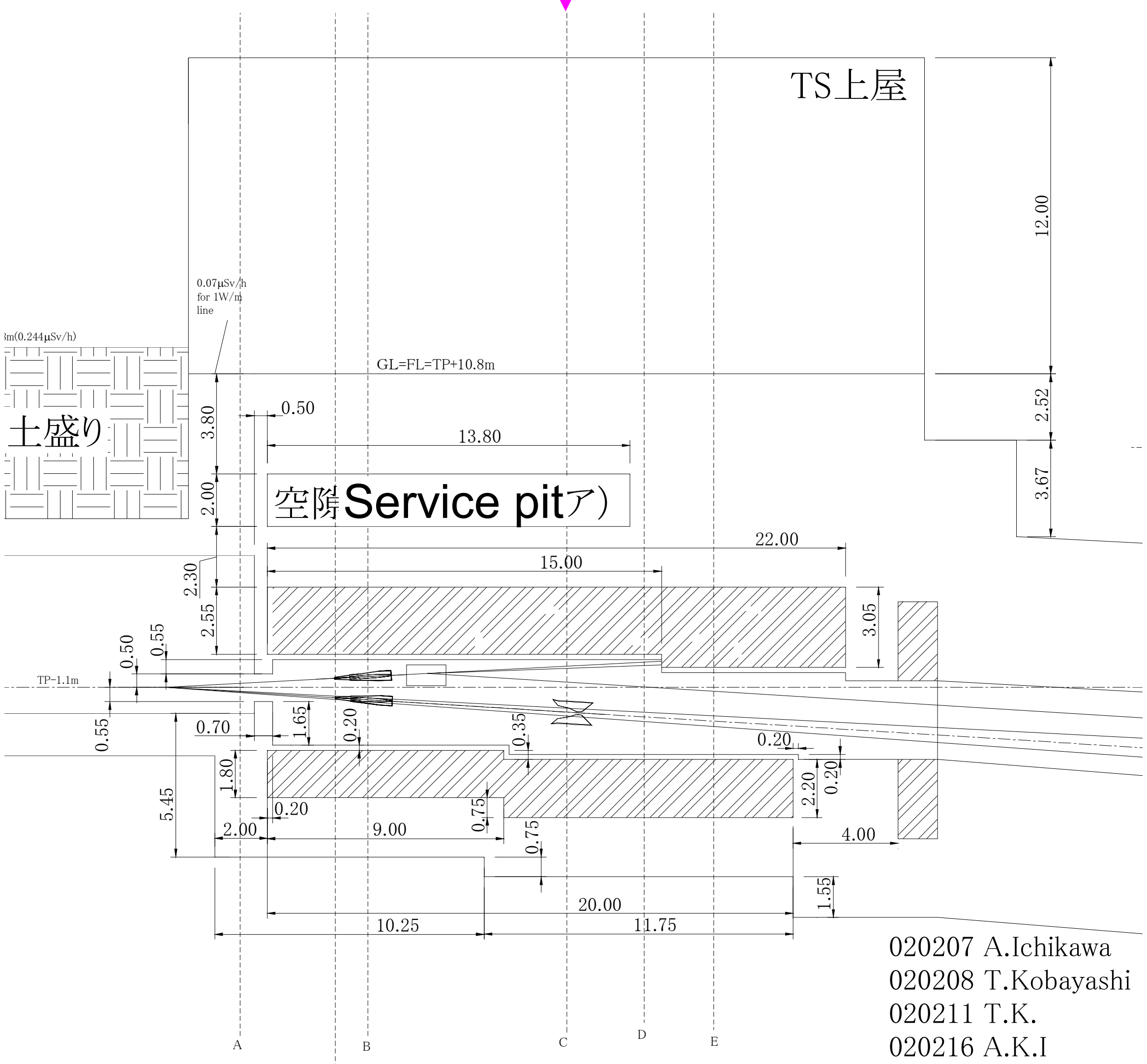
Side View

Design of target station

Front view

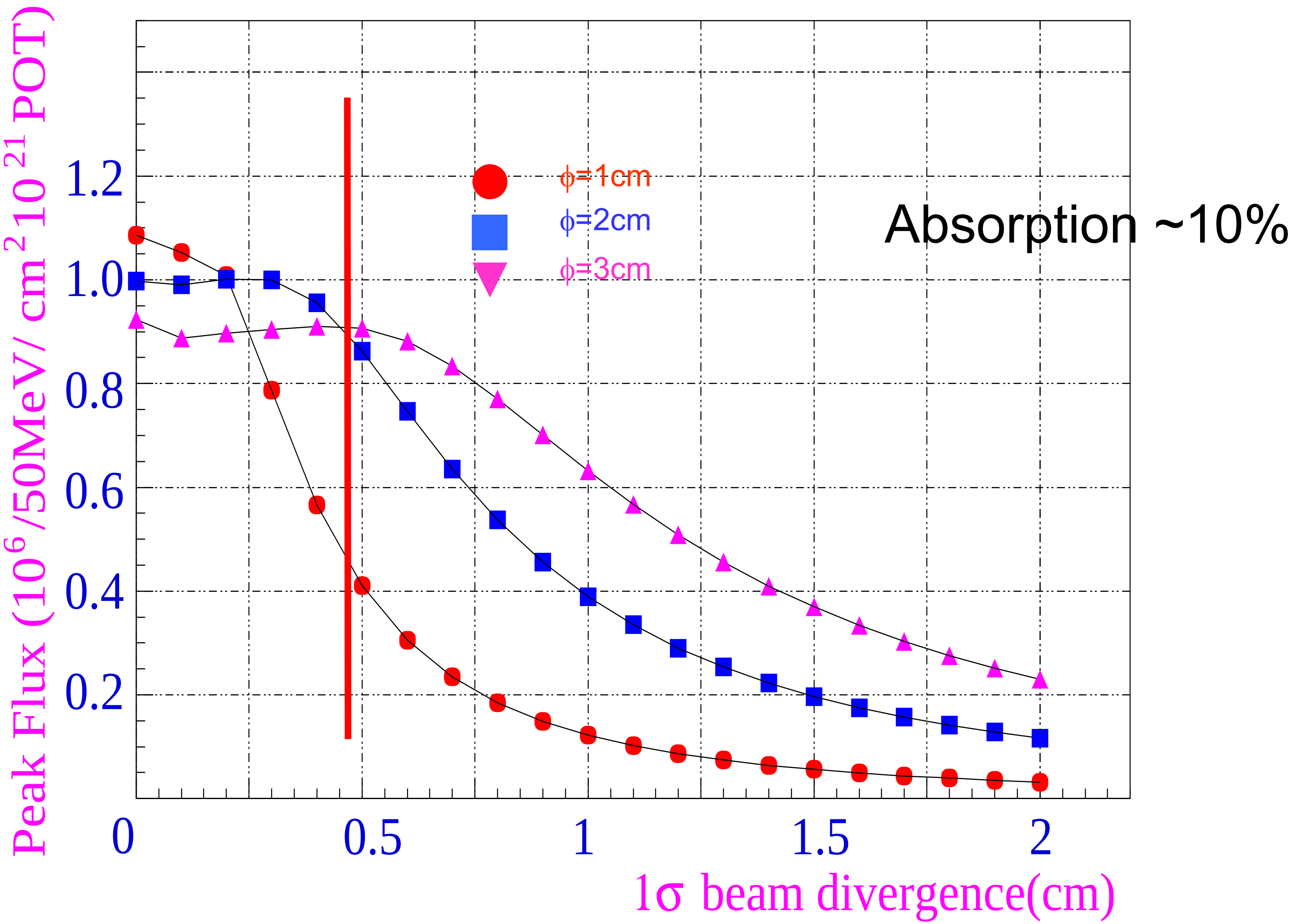


Side view

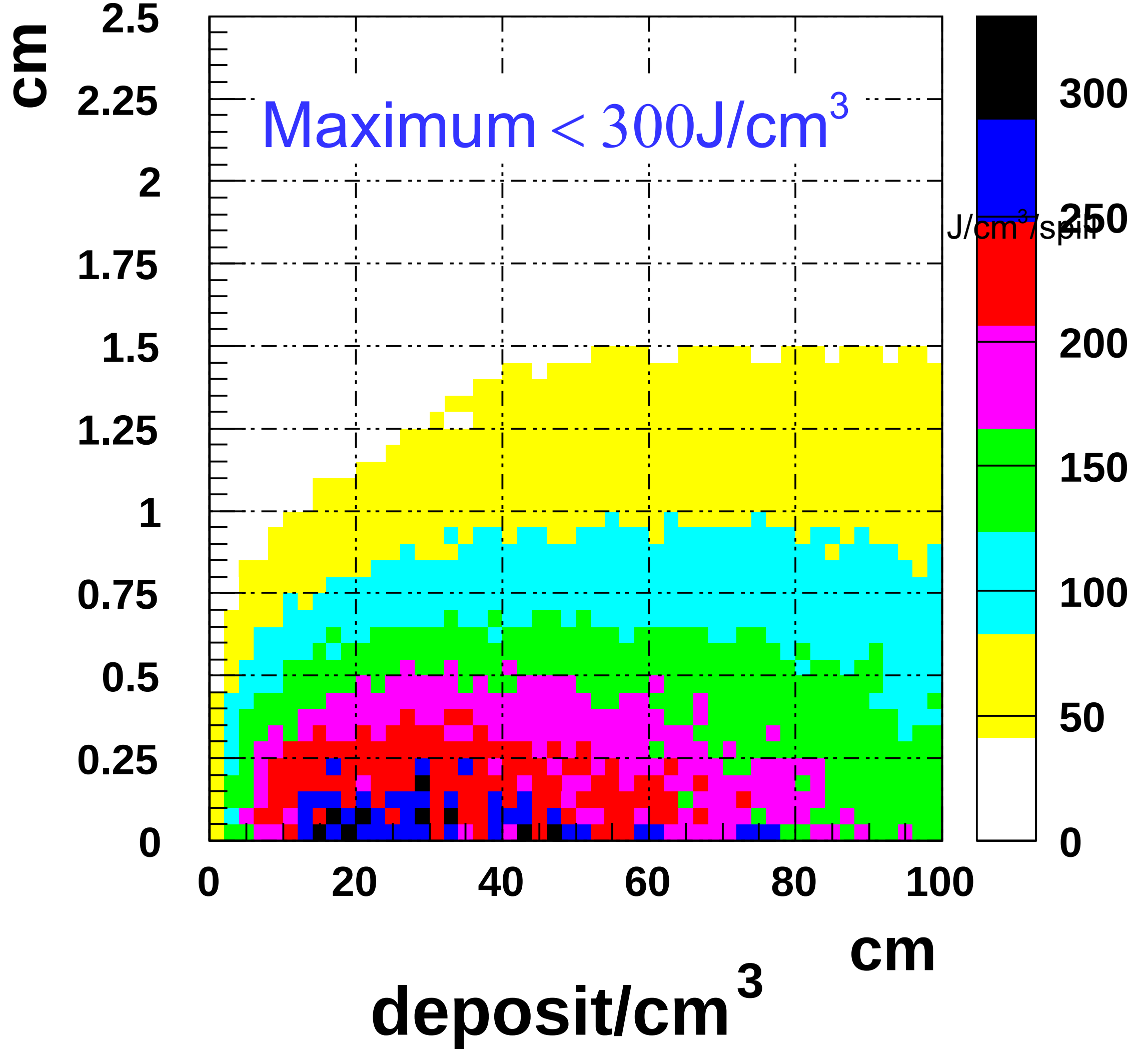


Preliminary

Target shape optimization



Energy deposit in the target



$\phi = 3\text{cm}, \sigma_{beam} = 0.6\text{cm}$

Carbon (density $1.81 g/cm^3$)

Time dependence of temperature

Maximum temperature

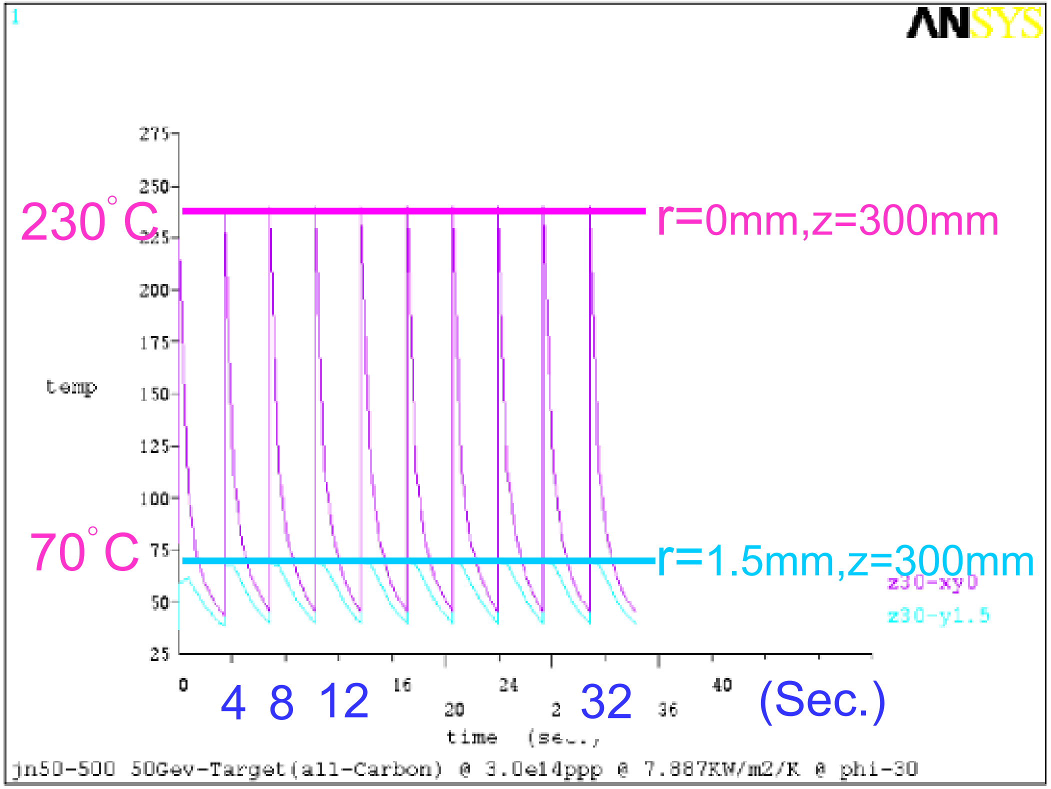
At the center

~ 230°C

Far below the melting temperature

On the surface

~ 70°C

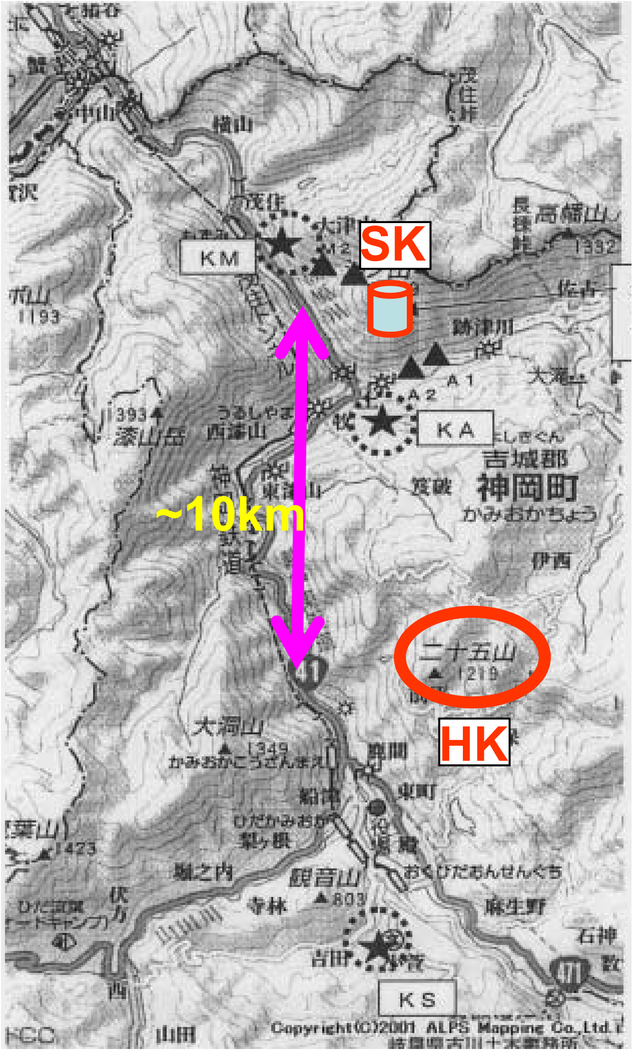


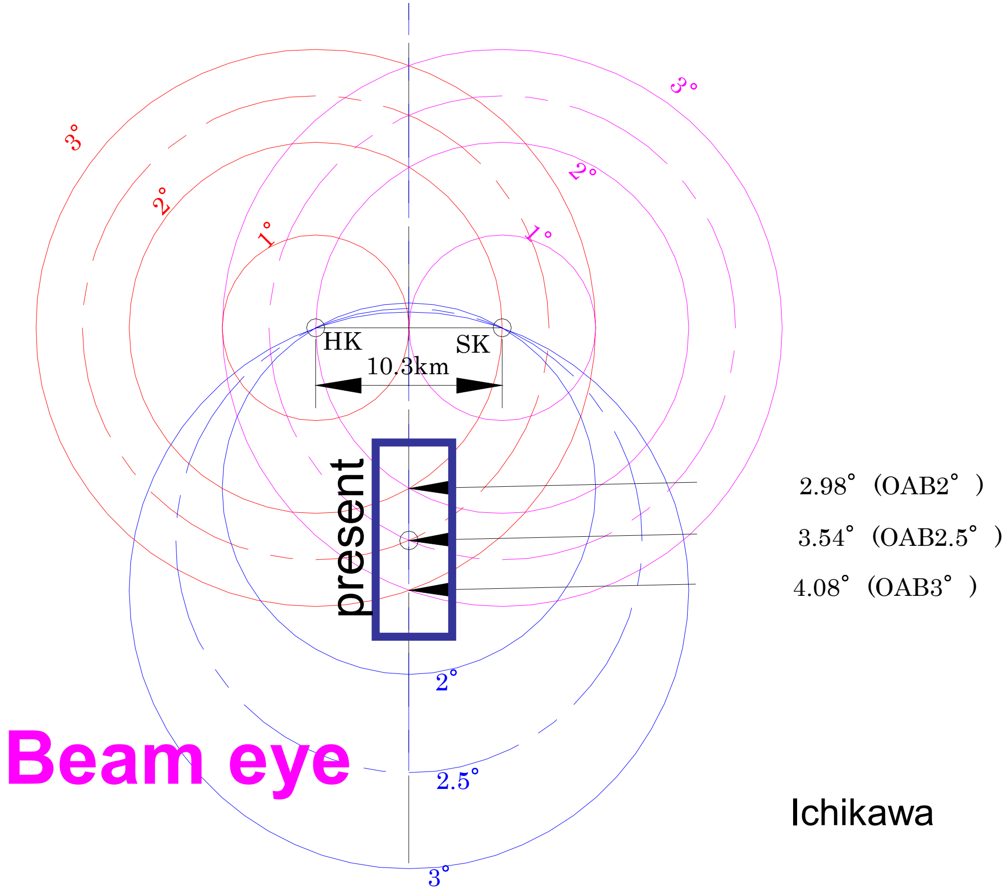
This should be lower than 100°C for water cooling.

(Thermal convection coefficient on the surface should be larger than ~3000 kW/m^2/K to satisfy this condition.)

Decay pipe common for SK/HK

Possible site for Hyper-K

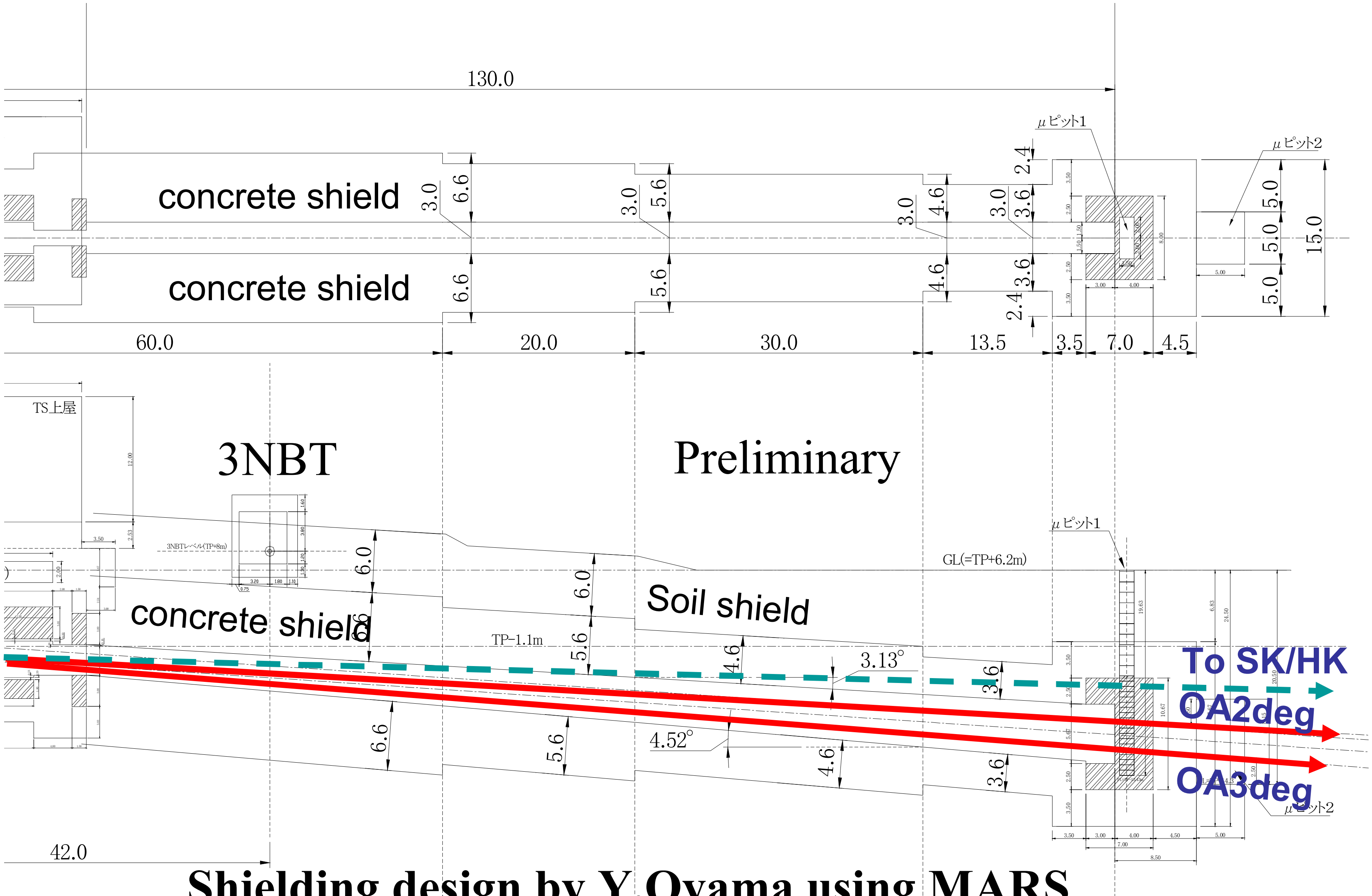




Ichikawa

p/π beam axis
-(3~4)deg

Design of decay volume and beam dump



Shielding design by Y.Oyama using MARS

Energy deposit around the tunnel

Assume the cylindrical decay volume.

radius of the tunnel is constant (r=1.5m).

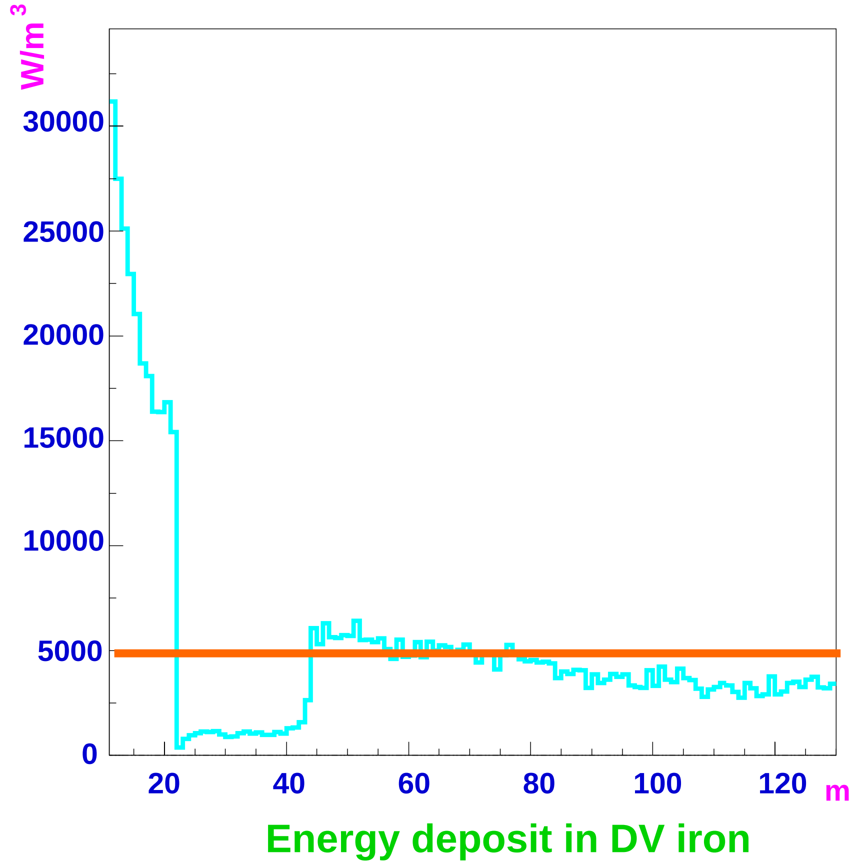
Thickness of iron : 1.6cm
(wall of the decay tunnel)

Estimated energy deposit
(from 45m to 130m)

4500 ~ 6000W/m^3

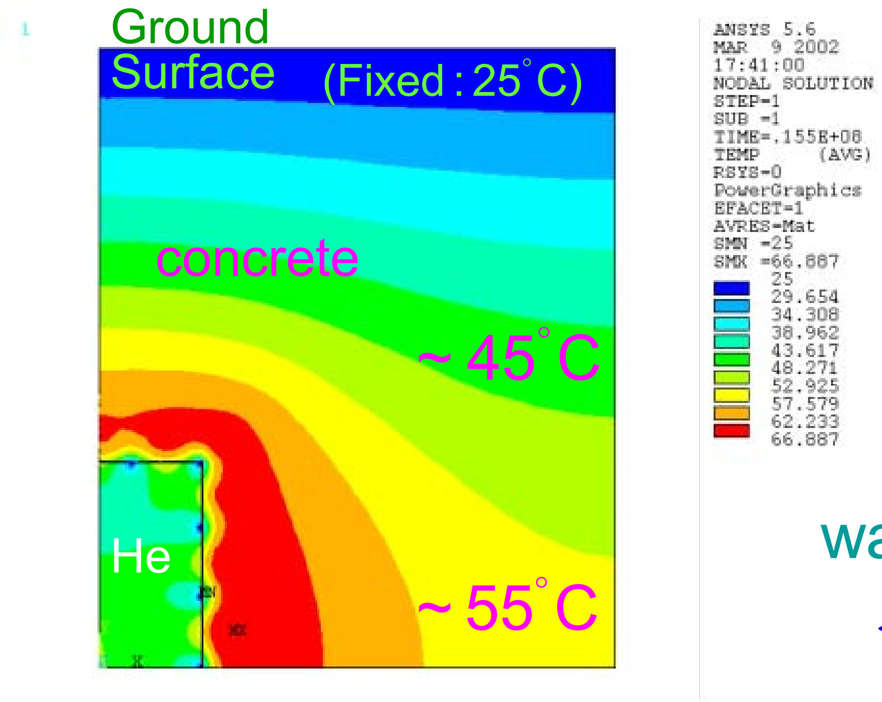
→ Deposited energy
(actual width 3m, height 3~6m)

800 ~ 1200W/m

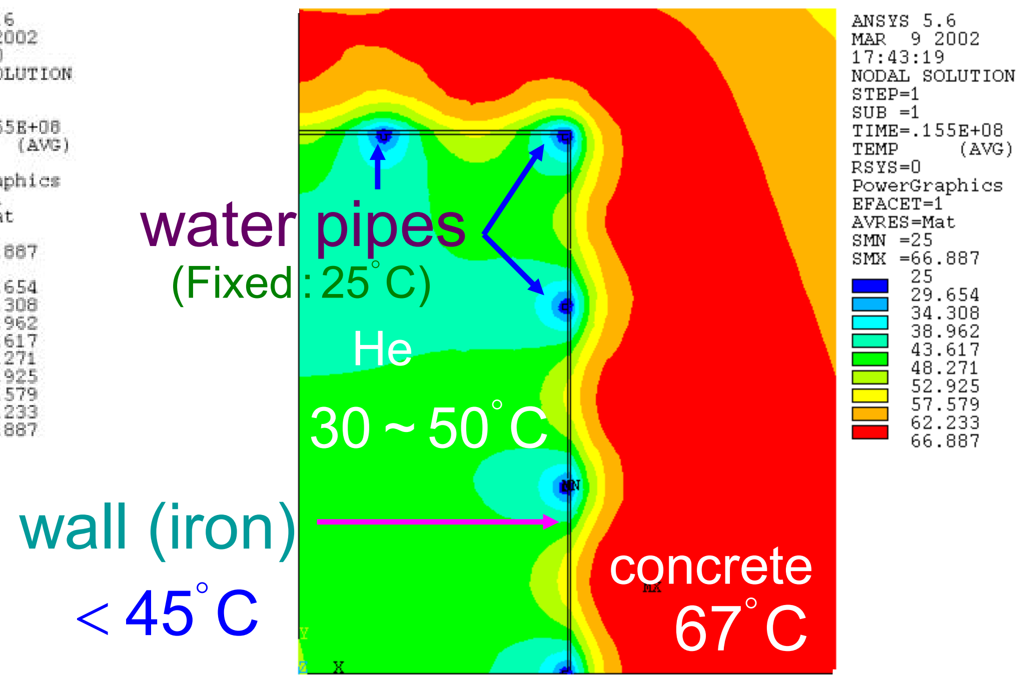


Cooled decay volume (example)

Entire volume



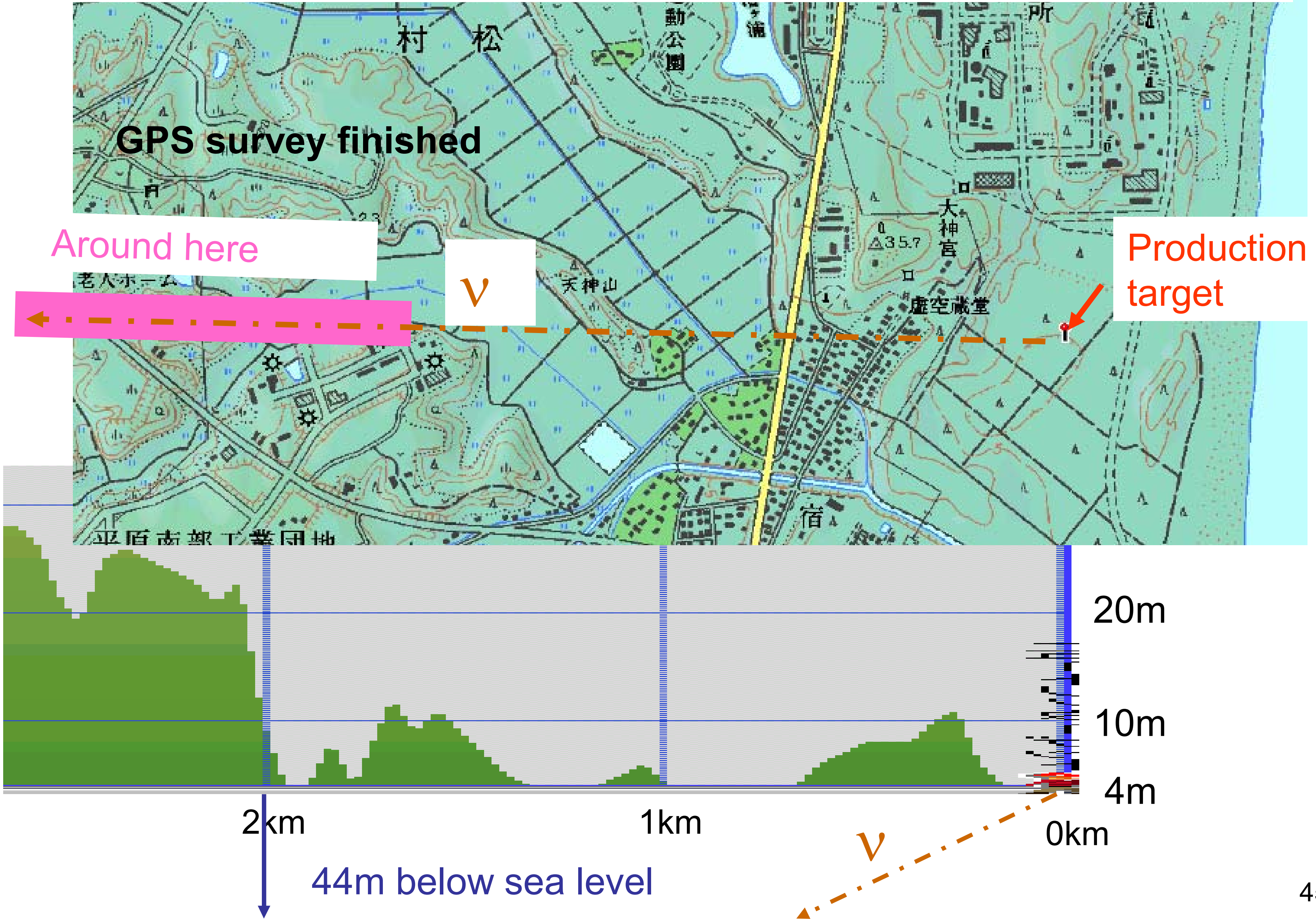
Around the tunnel



Maximum temperature (after 6 months)

Iron (wall)	less than 45°C
Concrete	67°C at maximum

Candidate sites for 2km front detector

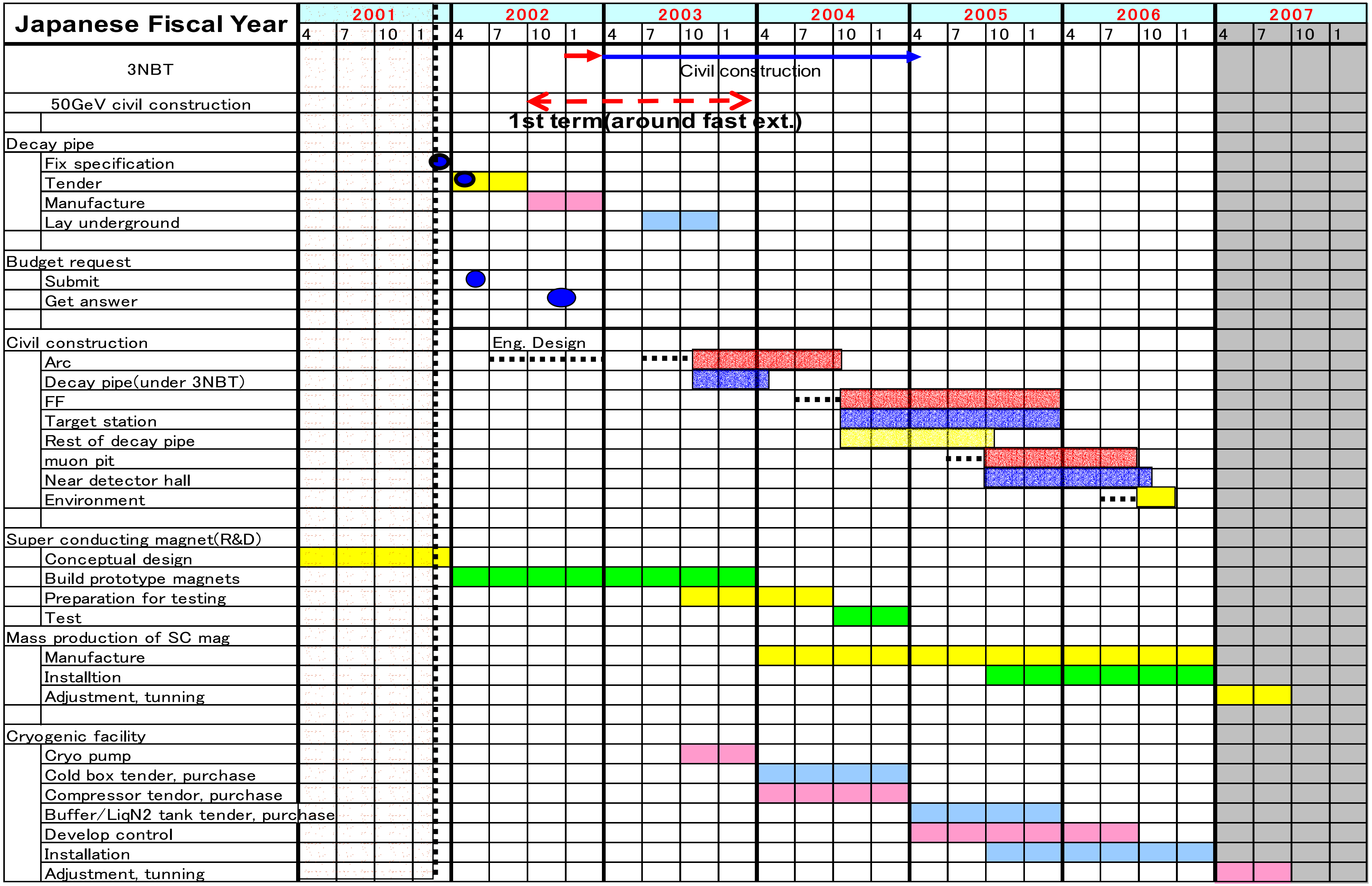


GPS survey

Nov.19~22: long baseline GPS survery @ Kamioka/Tokai simultaneously

Noumi/Ishii/Shiino

Mile stones/Schedule



We absolutely need budget from 2003 to complete by JFY2006

Summary (1)

1. JHF-Kamioka neutrino experiment will explore neutrino flavor physics w/ unprecedented precision and reach
   - **$\sin^2 2\theta_{13} > 0.006$**
   - **$\delta(\sin^2 2\theta_{23}) \sim 0.01$, $\delta(\Delta m_{23}^2) \sim 1\times10^{-4} eV^2$**
   - CPV phase $\delta \sim > 20$deg (3σ) (2nd phase)
   - Proton decay (2nd phase)

   Owing to unique features
   - High intensity (750kW)
   - low energy (<1GeV) OAB tuned at osc. max.
   - Gigantic water Cherenkov detector(SK→HK)
2. Facility design & development work started
   1. Superconducting proton transport line
   2. Common facility for SK/HK and OAB/NBB
   3. etc.

Summary (2)

- JHF approved but, neutrino facility not approved
- We strongly desire to start experiment in Apr. 2007
- Budget request for Gov. will be submitted in 2002 ➔ Answer will come Dec.2002
- Started to organize international collaboration

Future Prospect

2002 : JHFn budget request&approval

2003 : start construction

2005 : K2K final results

2007

JHF1

$\sin^2 2\theta_{13} > 0.018$?

201x

3σ discovery

JHF2
CPV
precision meas. θ_{13}
Proton decay

Hint?

JHF2
Search $\theta_{13} < 10^{-3}$
Proton decay

20xx Future SuperBeam, VLBL, ν-fact for very small θ_{13}, CPV, sign of Δm^2