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KEKTC01
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The JHF Neutrino Experiment

-- a second generation long baseline neutrino oscillation experiment --

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hep-ex/0106019
KEK Report 2001-4
ICRR-Report-477-2001-7
TRI-PP-01-05

"JHF" is not official name. Soon decided.

JHF Neutrino Working Group

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

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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. Int. WS held.

Physics Goals

1. **Test our current picture of 3 flavor neutrino oscillation**

   → hints on physics beyond the SM (GUTs,…)

   1. **Discovery of ν_e appearance ($\theta_{13}>0$?)**

      Appearance of ν_e at the same Δm^2 as ν_μ disappearance

      Open possibility to detect CPV effect in lepton sector

   2. **Precision measurements of ocs. params.**

      ν_μ disappearance(Δm_{23},θ_{23})/ν_e appearance(Δm_{13},θ_{13})

      Test exotic models (decay, extra dimensions,….)

   3. **NC measurement**

      No additional light “neutrino”?

2. **Search for CPV in lepton sector**

   Leptgenesis?

3. Proton decay search

   Direct probe of GUTs

Neutrino Oscillation

Neutrino Mixing

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

Weak eigenstates — Mass eigenstates

Maki-Nakagawa-Sakata Matrix

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix}$$

$s_{ij}=\sin\theta_{ij}$, $c_{ij}=\cos\theta_{ij}$

Oscillation Probability

ν_e appearance

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

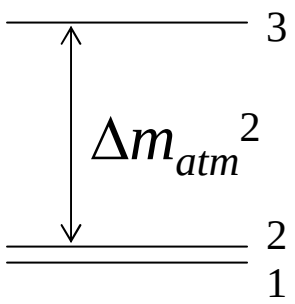
~ 0.5

$\sin^2 2\theta_{\mu e}$

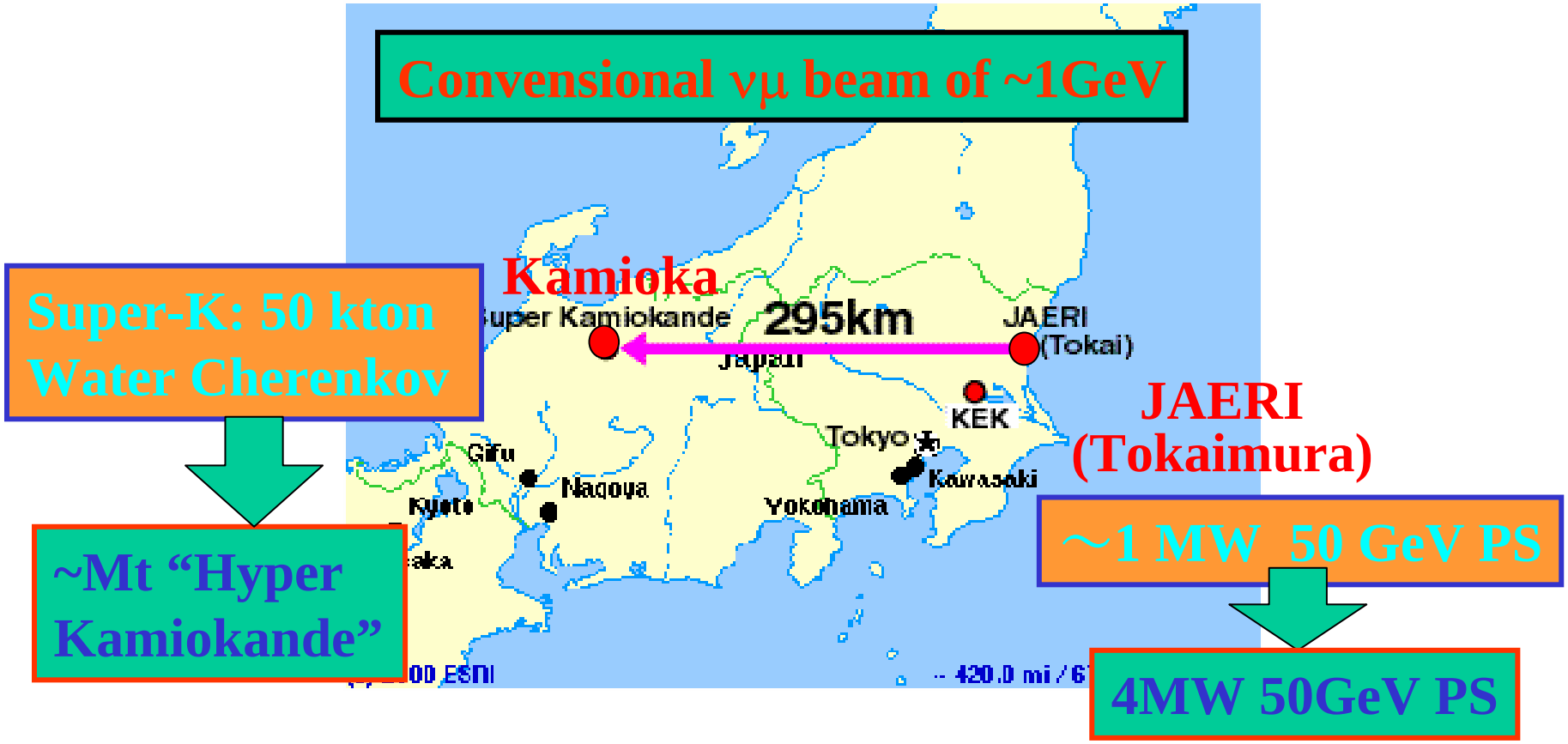
ν_μ disappearance

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

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



Overview



1st Phase

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

2nd Phase

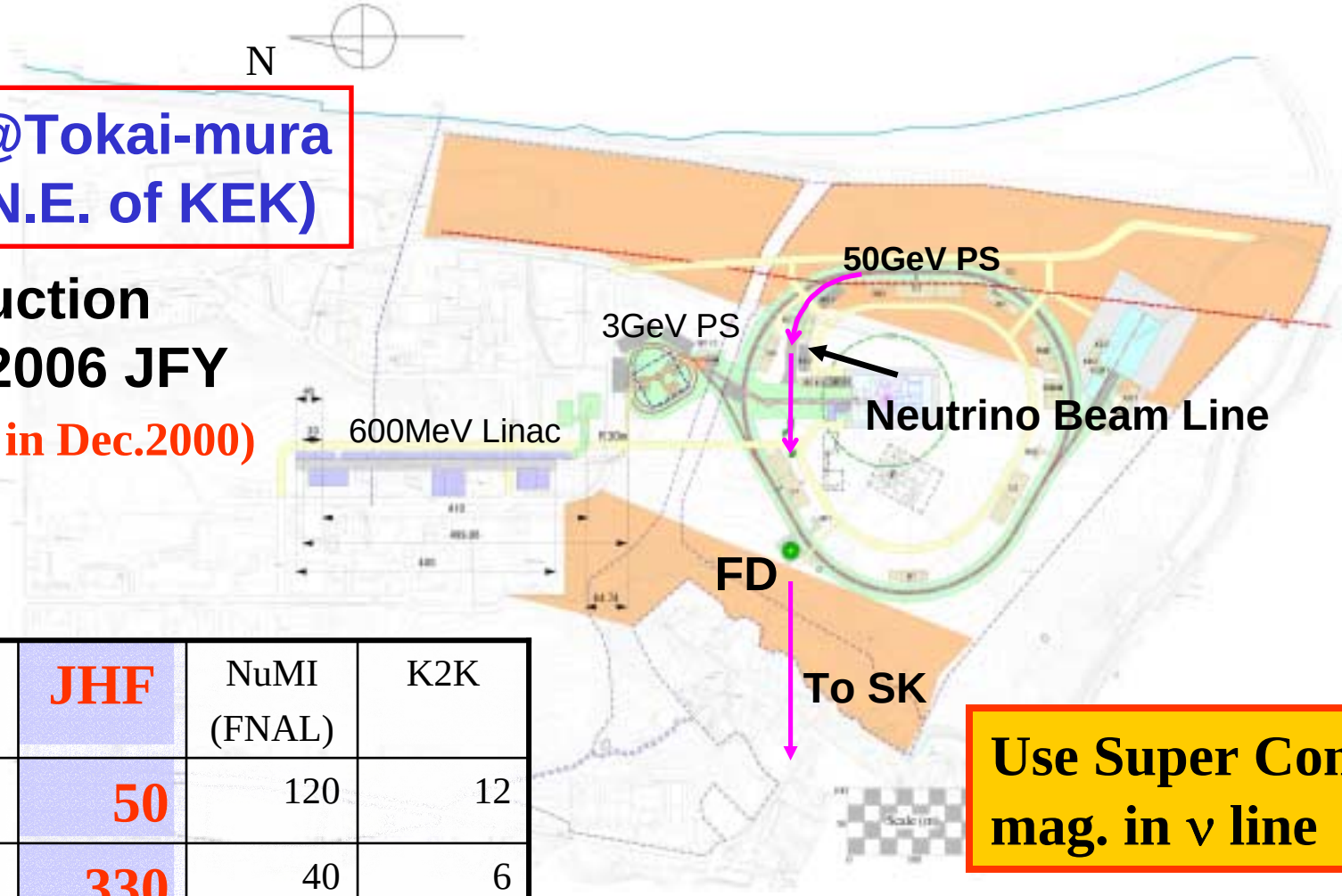
- CPV
- proton decay

JHF project and neutrino beam line

JAERI@Tokai-mura
(60km N.E. of KEK)

Construction
2001～2006 JFY

(Approved in Dec.2000)



	JHF	NuMI (FNAL)	K2K
E(GeV)	50	120	12
Int.(10^{12}ppp)	330	40	6
Rate(Hz)	0.292	0.53	0.45
Power(MW)	0.77	0.41	0.0052

Use Super Con. mag. in ν line

10^{21}POT(130day)≡ “1 year”

Principle

- **Narrow spectrum tuned at the oscillation maximum.**
  - High sensitivity
  - Less background

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

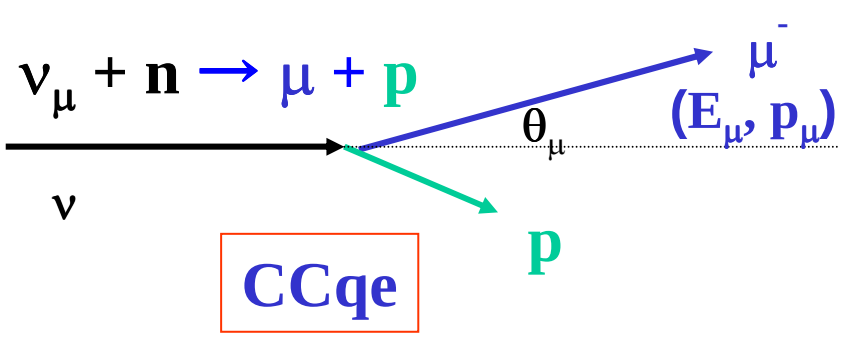
$E_\nu = 0.4 \sim 1 \mathrm{GeV}$

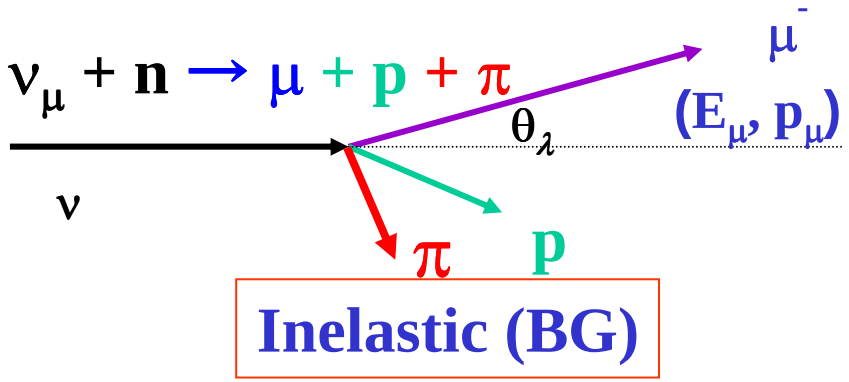
- **Gigantic water Cherenkov detector**
  - High statistics
  - High efficiency for low energy
  - Good PID (e/μ) capability

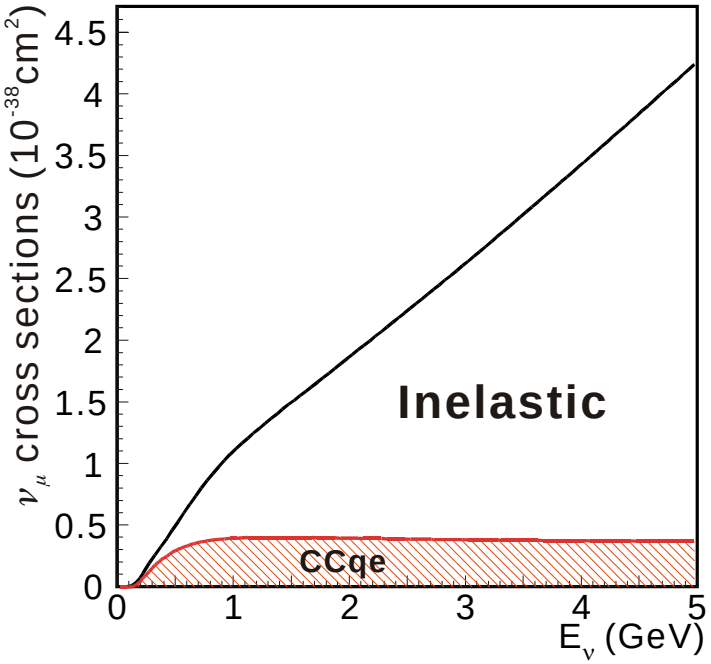
- Neutrino energy reconstruction by using **Quasi-elastic** (QE) interaction.
  - Oscillation pattern measurement
  - BG due to miss-reconstruction of inelastic interaction
    - Greatly improved by using narrow spectrum

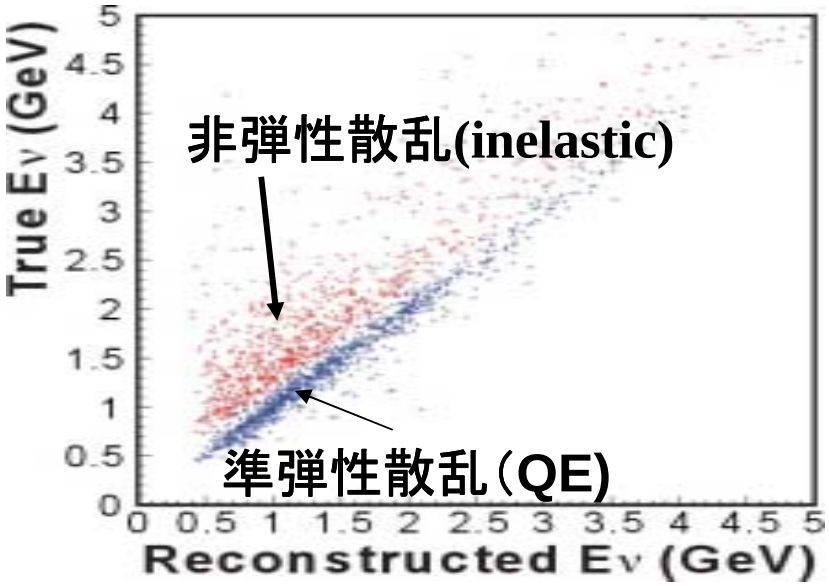
Neutrino Energy E_ν reconstruction

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



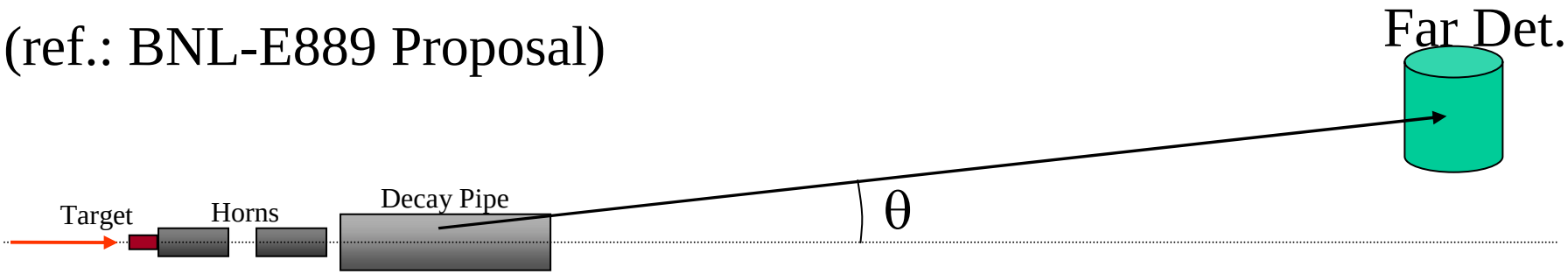






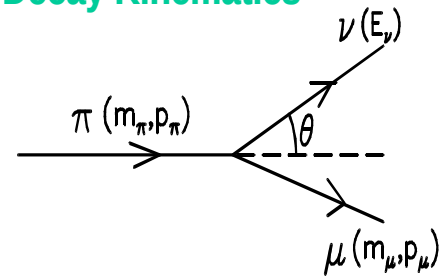
Off Axis Beam

(ref.: BNL-E889 Proposal)

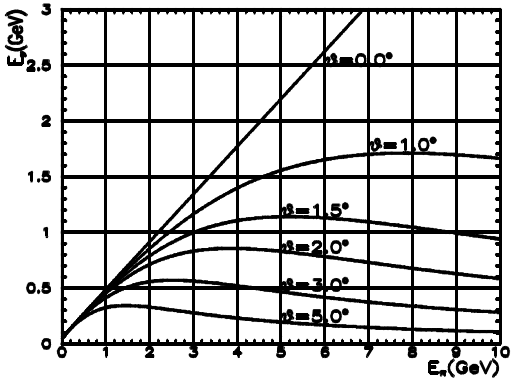


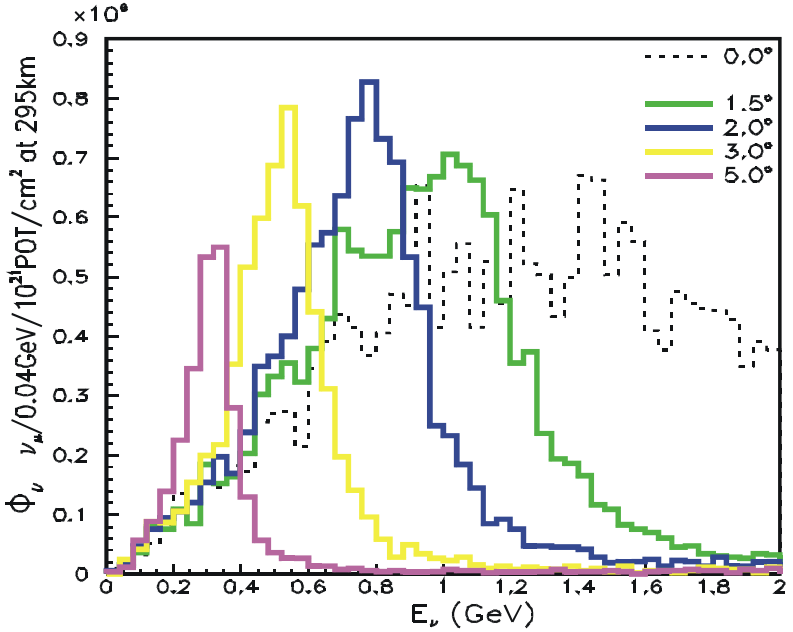
WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics



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

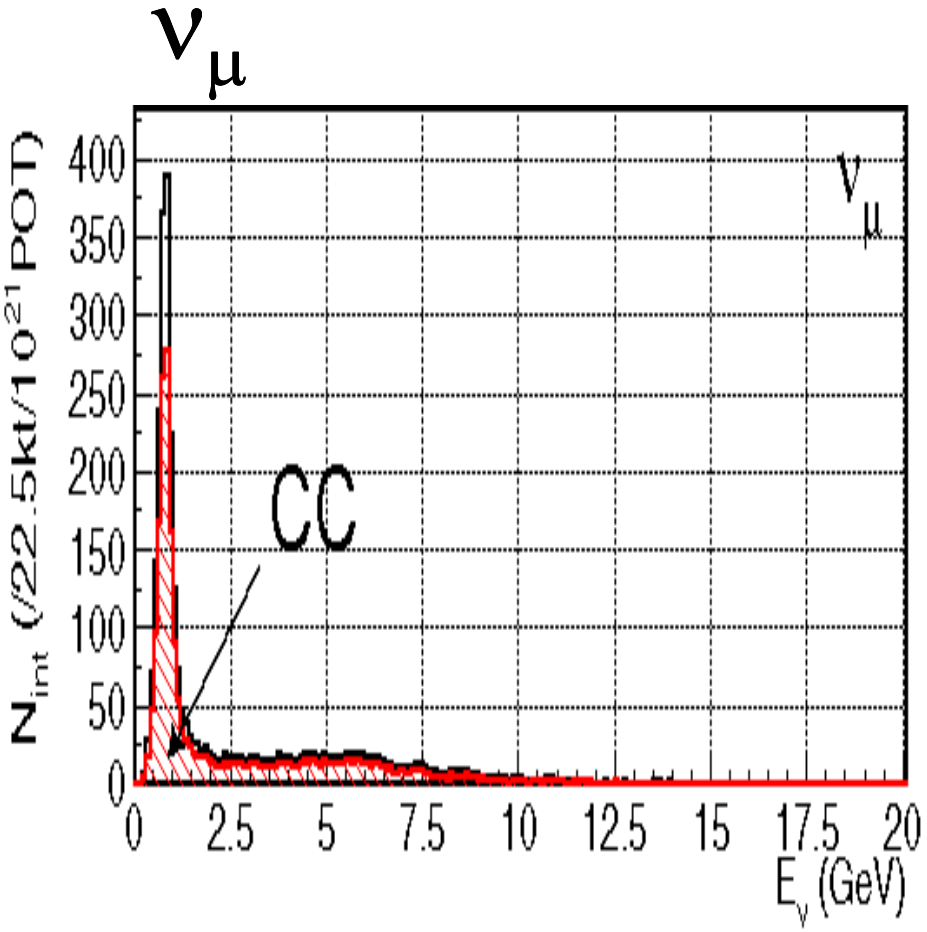


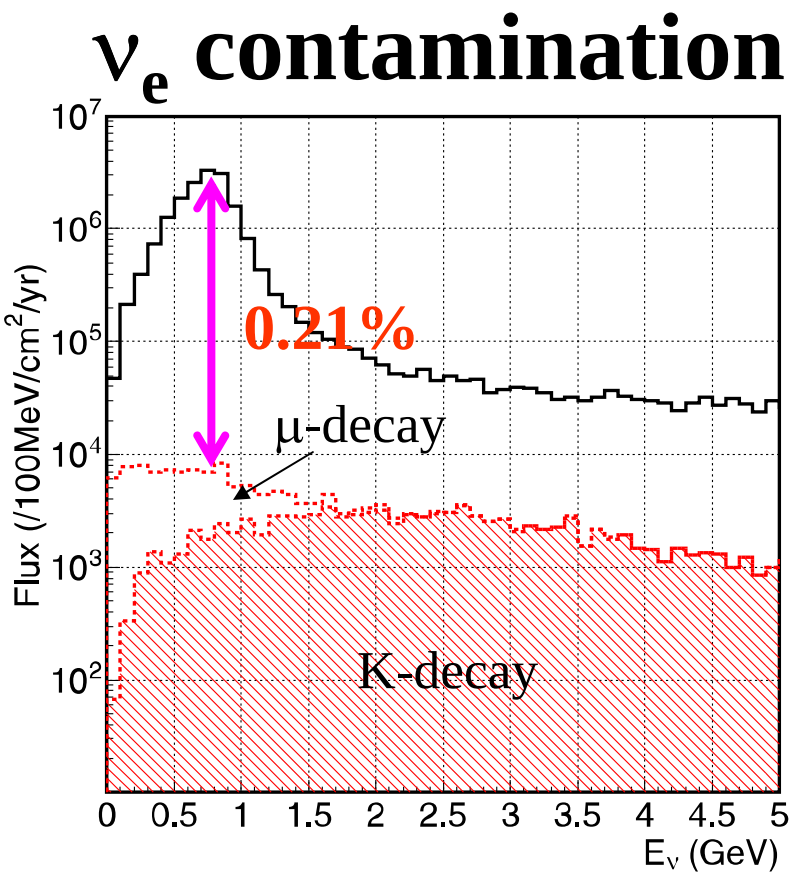


Quasi Monochromatic Beam

Expected spectrum

OAB2°



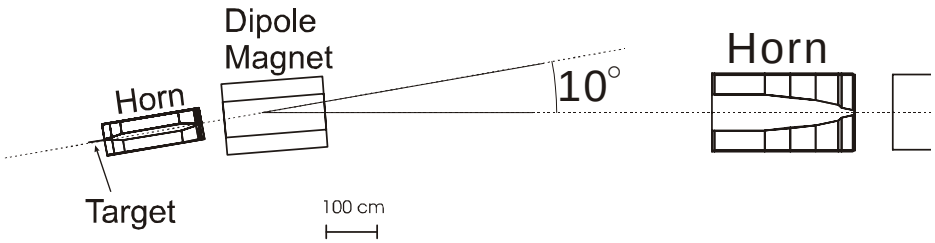


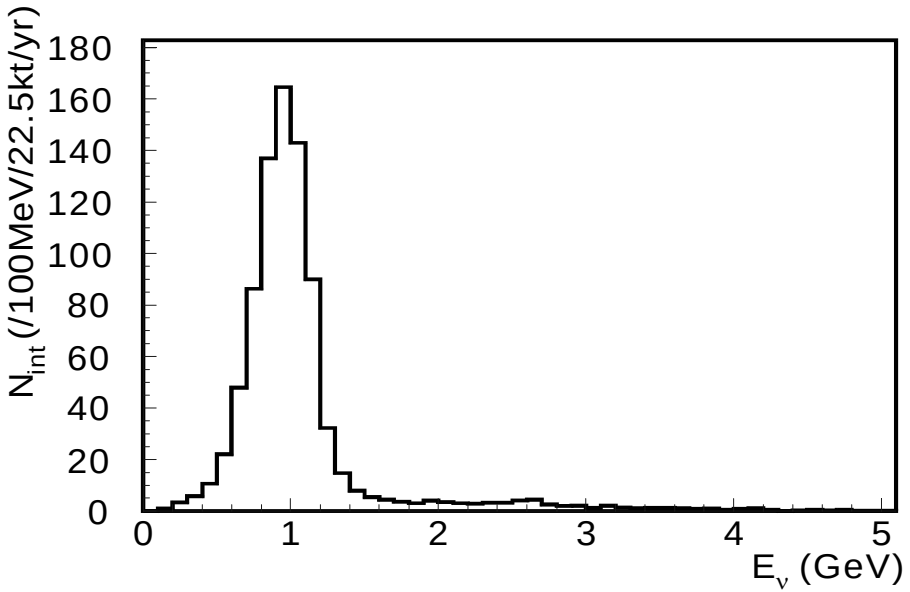
~3100 tot int/22.5kt/yr

~2200 CC int/22.5kt/yr

Very small ν_e/ν_μ @ ν_μ peak

Narrow Band Beam for ν int study @ near

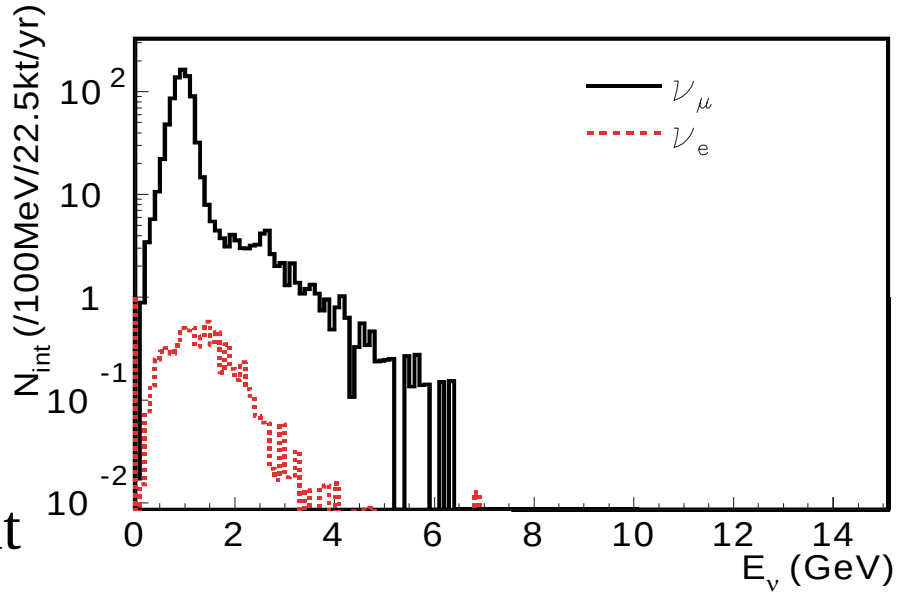




～2 int./100t/spill

ν_e:0.8%(0.3% @ peak)

- **Easy to tune E_ν**
- Less HE tail
- Less sys err from spectrum

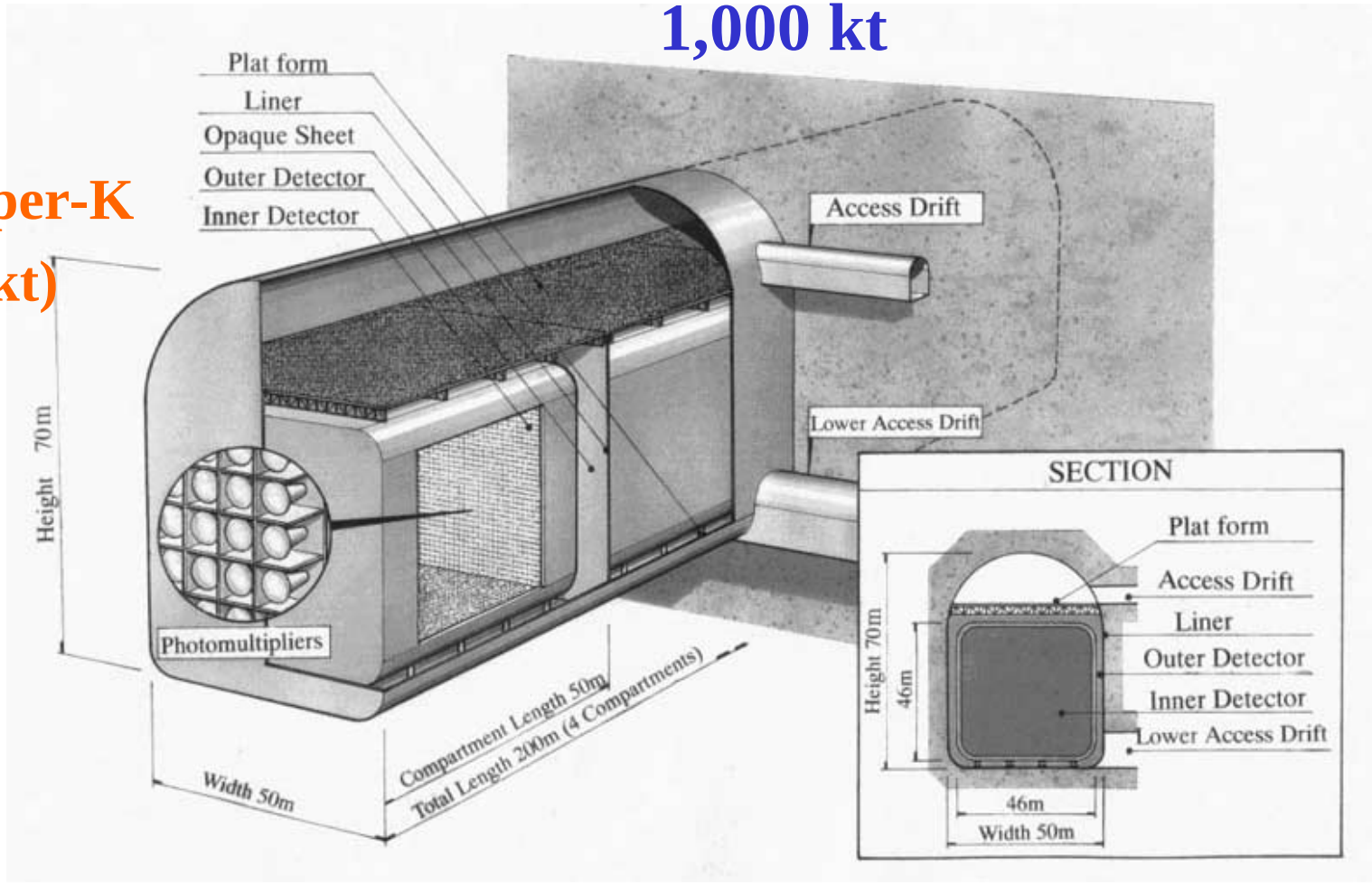


Reduce syst err in SK measurement

Far ν detector

Phase-II: Hyper-K
1,000 kt

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



Strategy and Goal (Phase1)

- ~5years of OAB
  - → Tune peak energy at osc. max.
  - → precise measurement of θ_{23} and θ_{13}.
  - → ν_e appearance search

  Sensitivity (goal):

  $\delta \sin^2 2\theta_{23} \sim 0.01$

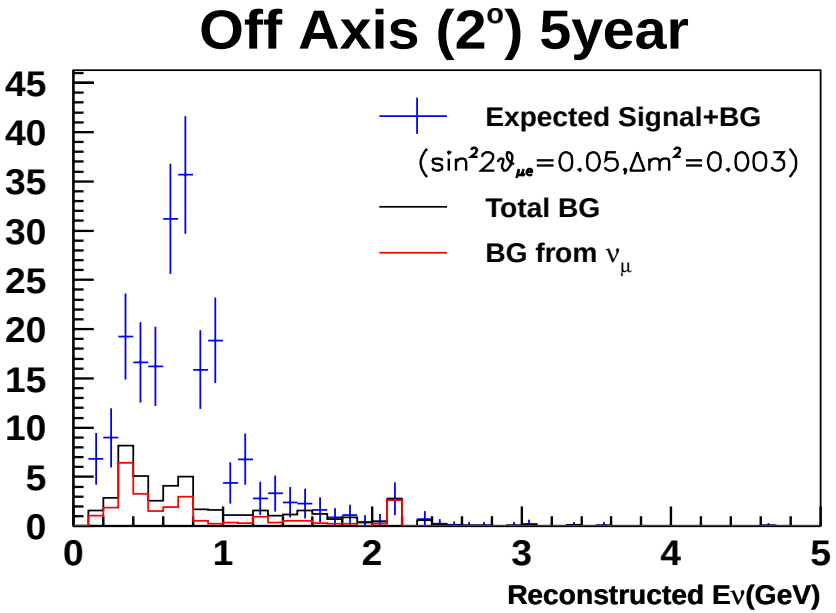
  $\delta \Delta m_{23}^2 < 1 \times 10^{-4} \mathrm{eV}^2$

  $\sin^2 2\theta_{\mu e} \sim$ 0.003 (90% CL)
- Neutrino interaction study w/ NBB at near detector
  - ➔ Reduce systematic error

ν_e appearance (θ_{13})

- Signal
  - Single e-like ring
  - At energy of ν_μ disappearance dip
- Backgrounds
  - **ν_μ NC π^0 production**
    - Lower *E* photon is missed/2 photon rings merged
  - Beam ν_e comtamination
    - Broad *E* dist. Can be reduced w/ energy window.
    - ~0.2% of ν_μ at peak of NBB/OAB

Expected Backgrounds & Signal



JHF(0.77MW) 5yr, 22.5kt

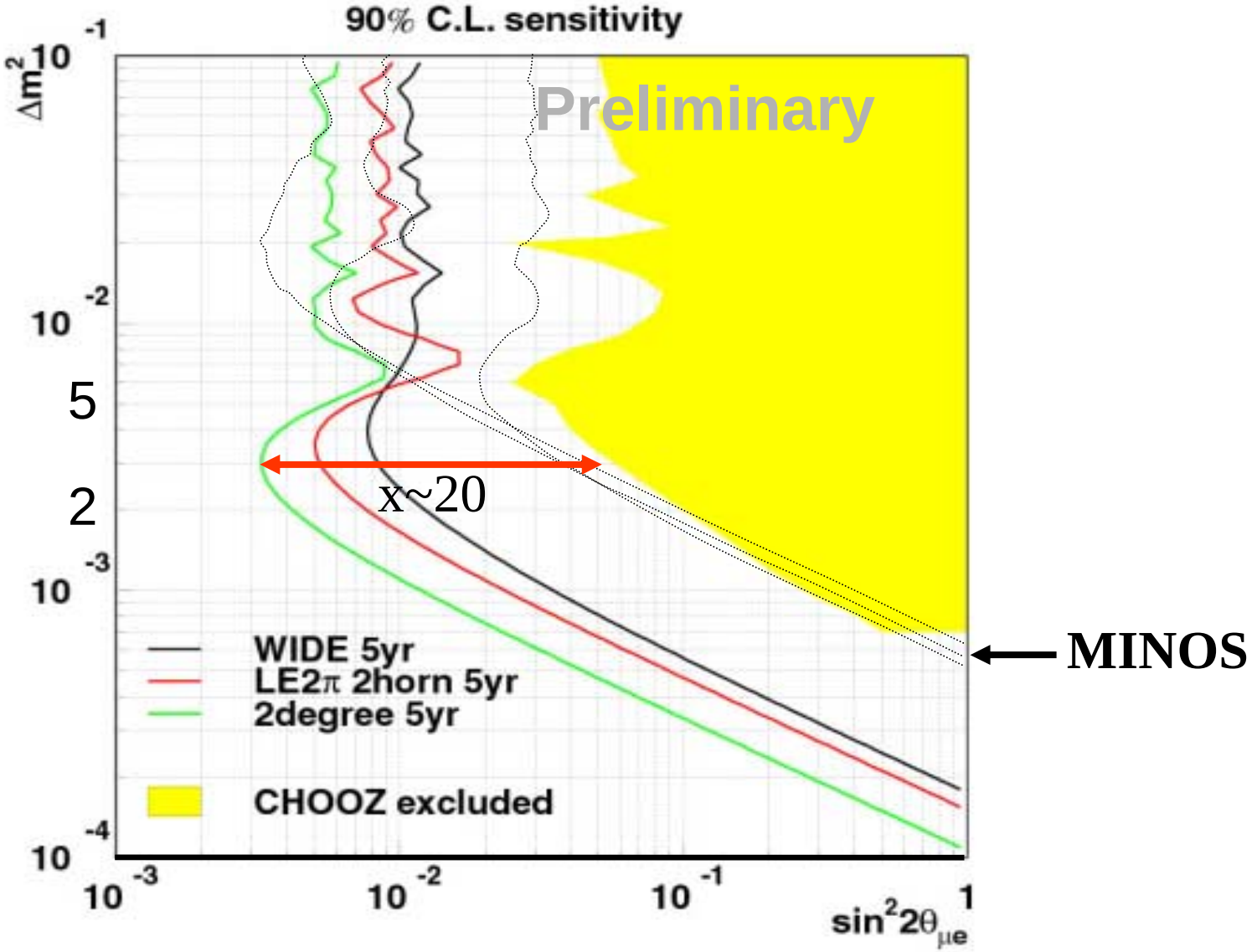
Chooz limit

$\Delta m^2=3\times10^{-3}eV^2$,

$\sin^2 2\theta\mu e=0.05$

	νμC.C.	νμN.C.	Beam νe	Osc'd νe
Generated	10713.6	4080.3	292.1	301.6
Remained	3.5	23.0	21.9	152.2
red.eff.	0.03%	0.6%	7.5%	50.4%
.4<Eν<1.2	1.8	9.3	11.1	123.2
red.eff.	0.02%	0.2%	3.8%	40.8%

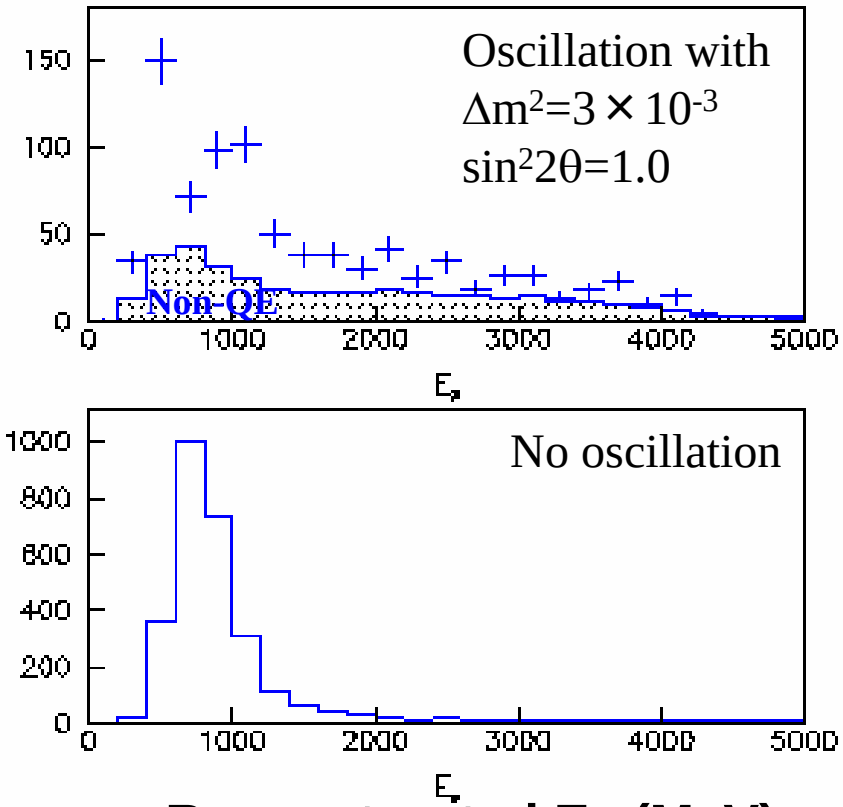
Sensitivity on $\nu_\mu \rightarrow \nu_e$ appearance



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

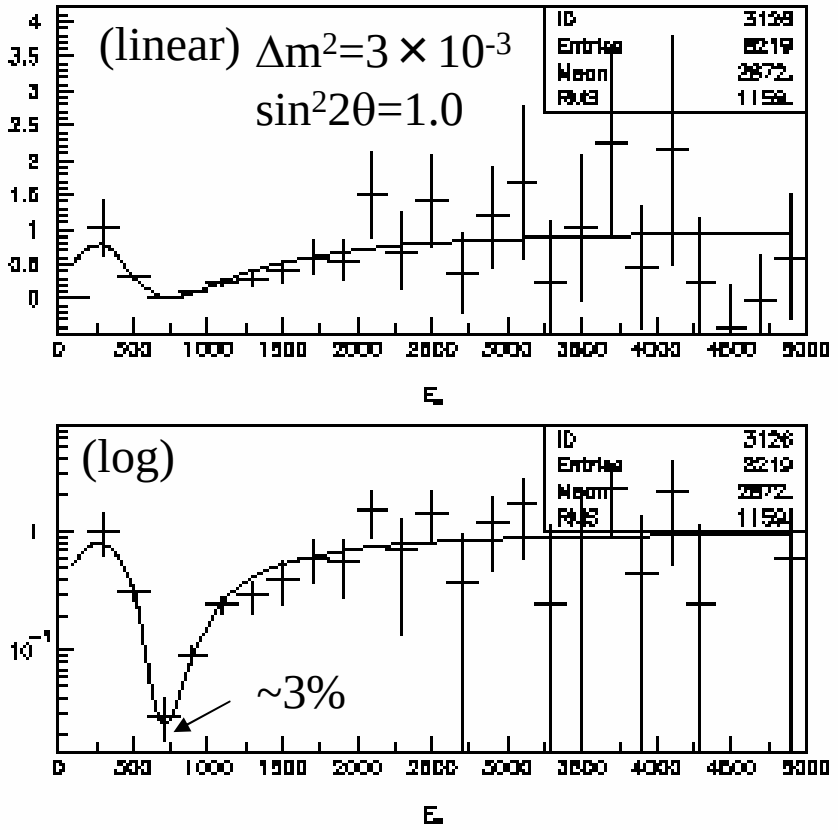
ν_μ disappearance

1ring FC μ-like



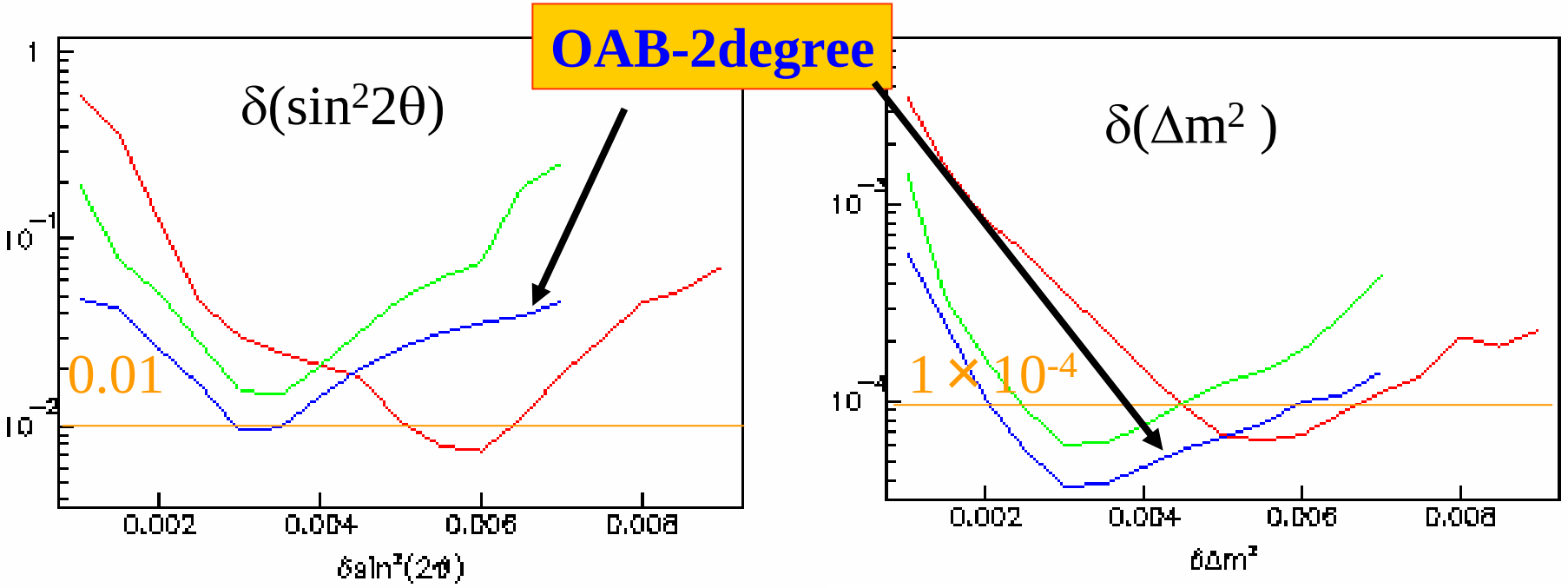
Reconstructed Eν (MeV)

Ratio after BG subtraction



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

5 years precision



δ(sin²2θ)~0.01 in 5 years

δ(Δm²) ~<1×10⁻⁴ in 5 years

JHF-Kamioka Phase-II

Search for CP violation in $\nu_\mu \rightarrow \nu_e$ appearance

Leading CP conserving term suppresed.

~2years for ν_μ and ~6 years for $\overline{\nu_\mu}$ running

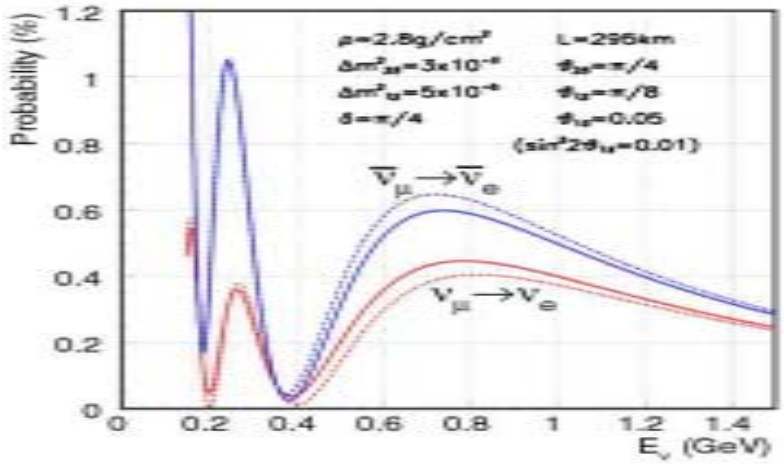
Search for proton decay.

CPV

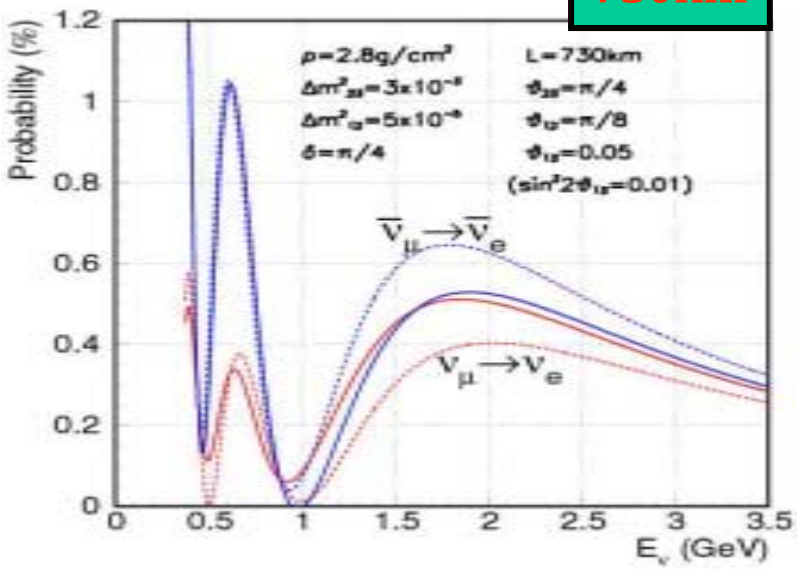
$\nu_\mu \rightarrow \nu_e$ osc. probability w/ CPV/matter

$$P \equiv P(\nu_\mu \rightarrow \nu_e)$$
$$\overline{P} \equiv P(\overline{\nu}_\mu \rightarrow \overline{\nu}_e)$$

295km



730km



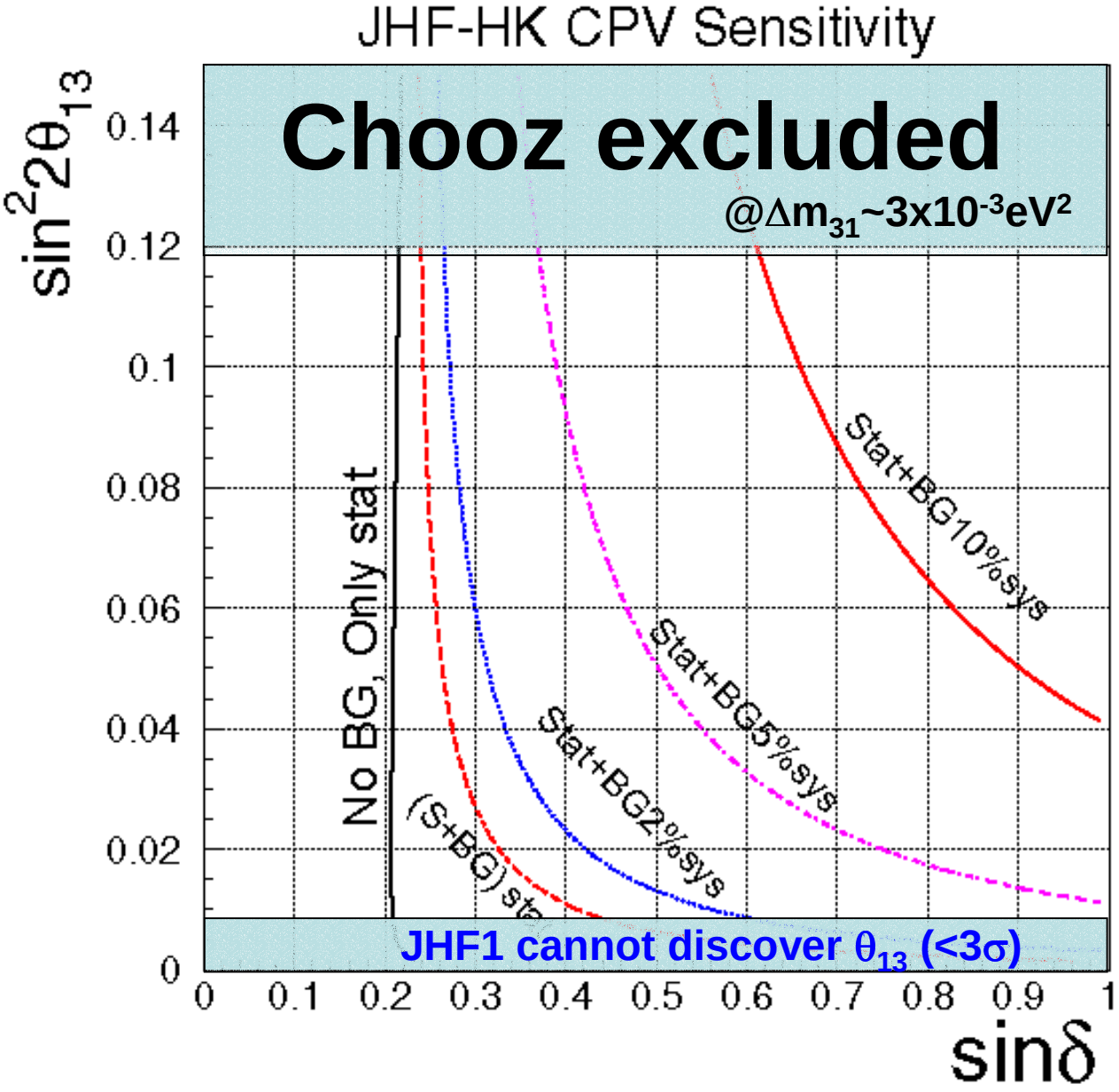
CP Asymmetry

$$A_{CP} \equiv \frac{P - \overline{P}}{P + \overline{P}} \approx \frac{\Delta m^2_{12} L}{E} \cdot \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \cdot \sin \delta$$

Small fake asymmetry by matter effect at low energy

Preliminary

Sensitivity(3σ)



BG sys 2%のとき

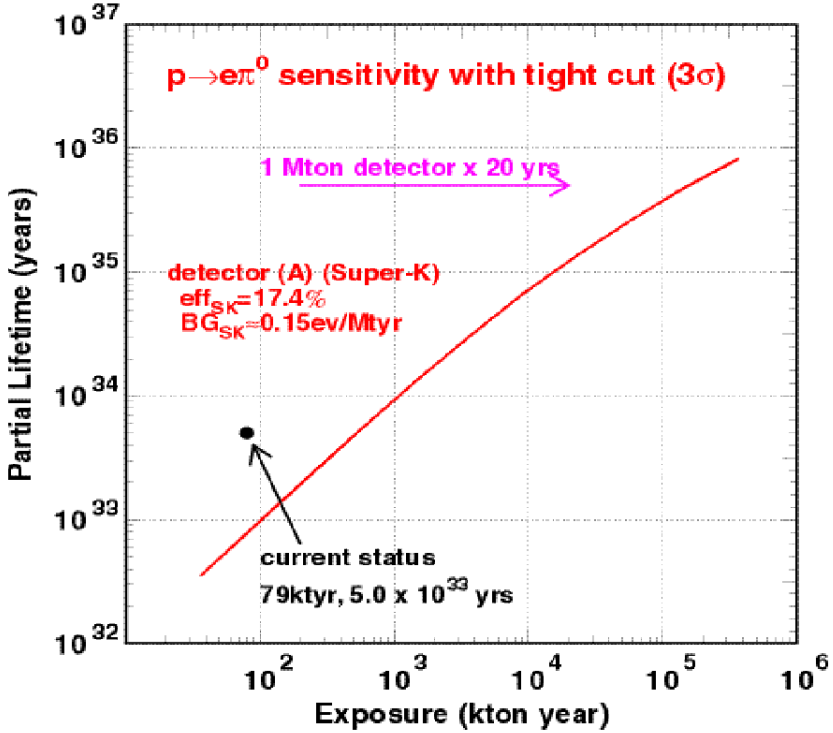
$\sin^2 2\theta_{13}$=0.01
→sinδ>0.55
(~33deg)

large $\sin^2 2\theta_{13}$
→sinδ>0.25
(~14deg)

BG reduc./syst err essential.
➔ need more study

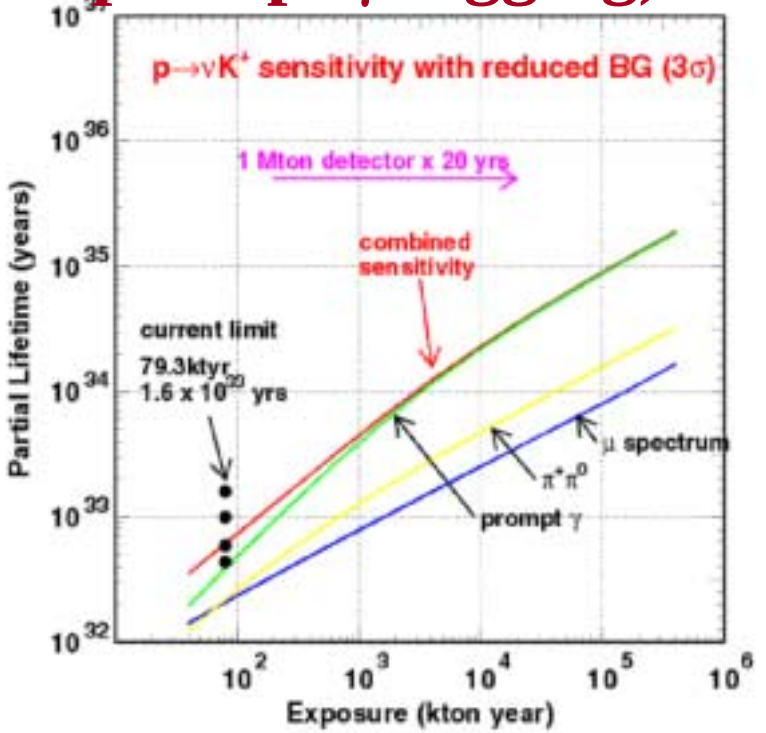
Discovery Potential on Proton Decay

$p \rightarrow e\pi^0$ mode



With 3σ (99.73%) level
- 1Mton ×20 years
  → ~1×10^{35} years lifetime

$p \rightarrow \nu K^+$ mode (w/ prompt γ tagging)



With 3σ (99.73%) level
- 1Mton ×20 years
  → ~3×10^{34} years lifetime

Recent development of the Project

- **Experiment** **since last April**
  - Decide to use OAB for LBL experiment
  - NBB only for ν int. study at near
  - Decay pipe longer (80m→130m) for higher flux (~40% increase)
  - Carefully investigating possibility of near det. @ ~2km (far/near spec. diff very small)
- **Facility**
  - Not approved yet.
  - Construction group **OFFICIALLY** formed in KEK (Apr.2001)
  - Technical design work is intensively being done.

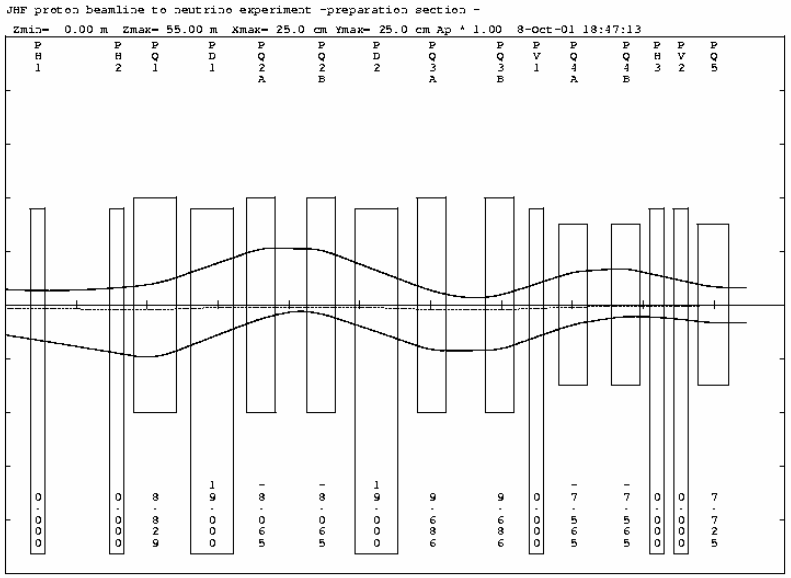
    ➔ **Aim to submit budget request in 2002**

One of the activities: GPS survey

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

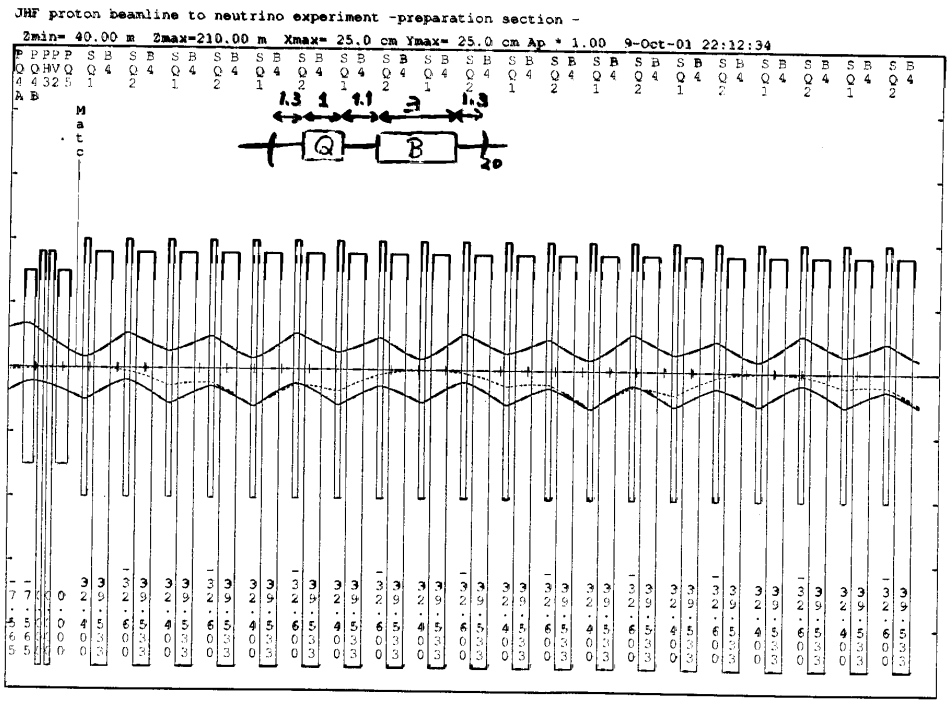
Noumi/Ishii/Shiino

Optics design of primary proton beam



Upstream normal cond.

Almost fixed.

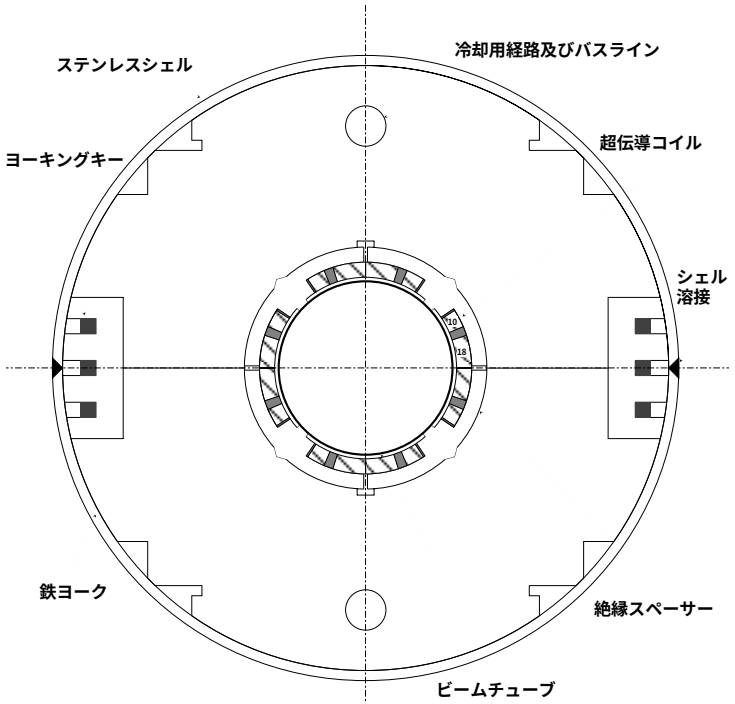


Arc. super cond. part

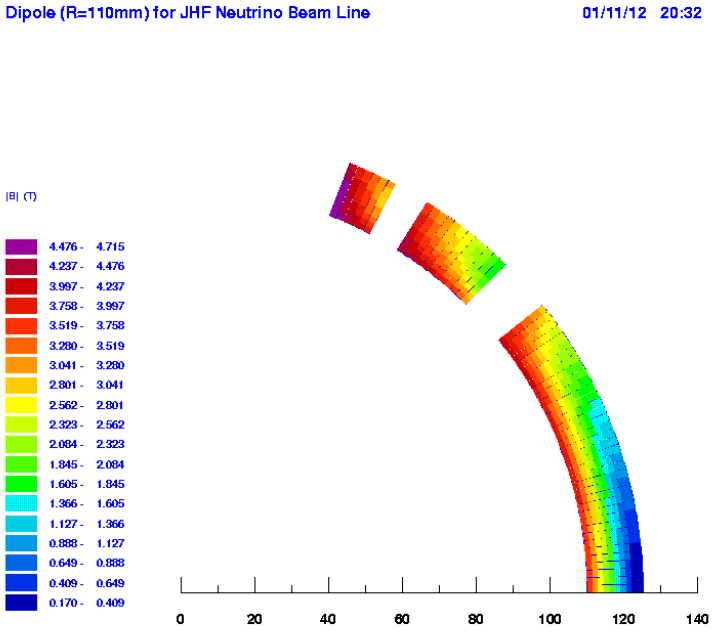
Ichikawa

Design of Super con. mag started

Bore: 180 or 220mm



B field simulation



Cryo. Science Center of KEK

Summary(I)

- **JHF-Kamioka Neutrino project**
  - ✓ **～MW 50GeV** PS @ JHF
  - ✓ **Super-Kamiokande**@ 295km as far detector
  - ✓ Low energy(～1GeV) conventional ν_μ **beam tuned at osc. max**.
  - ✓ Energy reconstruction by using **QE**
  - ✓ **Narrow OAB** to reduce background and syst. err.
  - ✓ NBB to study neutrino interaction for syst. error reduction
- **Physics sensitivity in first phase**
  - ✓ $\sin^2 2\theta_{13} \sim 0.003$ (90% CL)
  - ✓ $\delta \sin^2 2\theta_{23} \sim 0.01$
  - ✓ $\delta \Delta m_{23}^2 < 1 \times 10^{-4} \mathrm{eV}^2$
  - ✓ ν_s existence can be tested.
- **2nd phase 4MW PS & Mt "Hyper-Kamiokande" detector**
  - → Sensitive to CPV of δ>10~20° with LMA solution
  - → Proton decay 3σ dicovery upto $\tau \sim 1\times10^{35}(>3\times10^{34})$yr for $e\pi^0(\nu K)$ mode

Summary(II)

- **Plan to start data taking in Apr. 2007**
  No change due to SK accident at all
  (refer Totsuka's statement)
- **Neutrino facility not approved yet but…**
- **Facility construction group has been officially formed in KEK**
  ➔ Aim to submit budget request in 2002