NNN02@CERN
Jan 17, 2002

JHF Neutrino Beams

Takashi Kobayashi
IPNS, KEK
for JHFν working group/KEK neutrino facility construction group

Contents

The JHF-Kamioka Neutrino Project
Recent development on experiment
Neutrino Beam Facility
Status of R&D
Summary

JHF Neutrino 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)

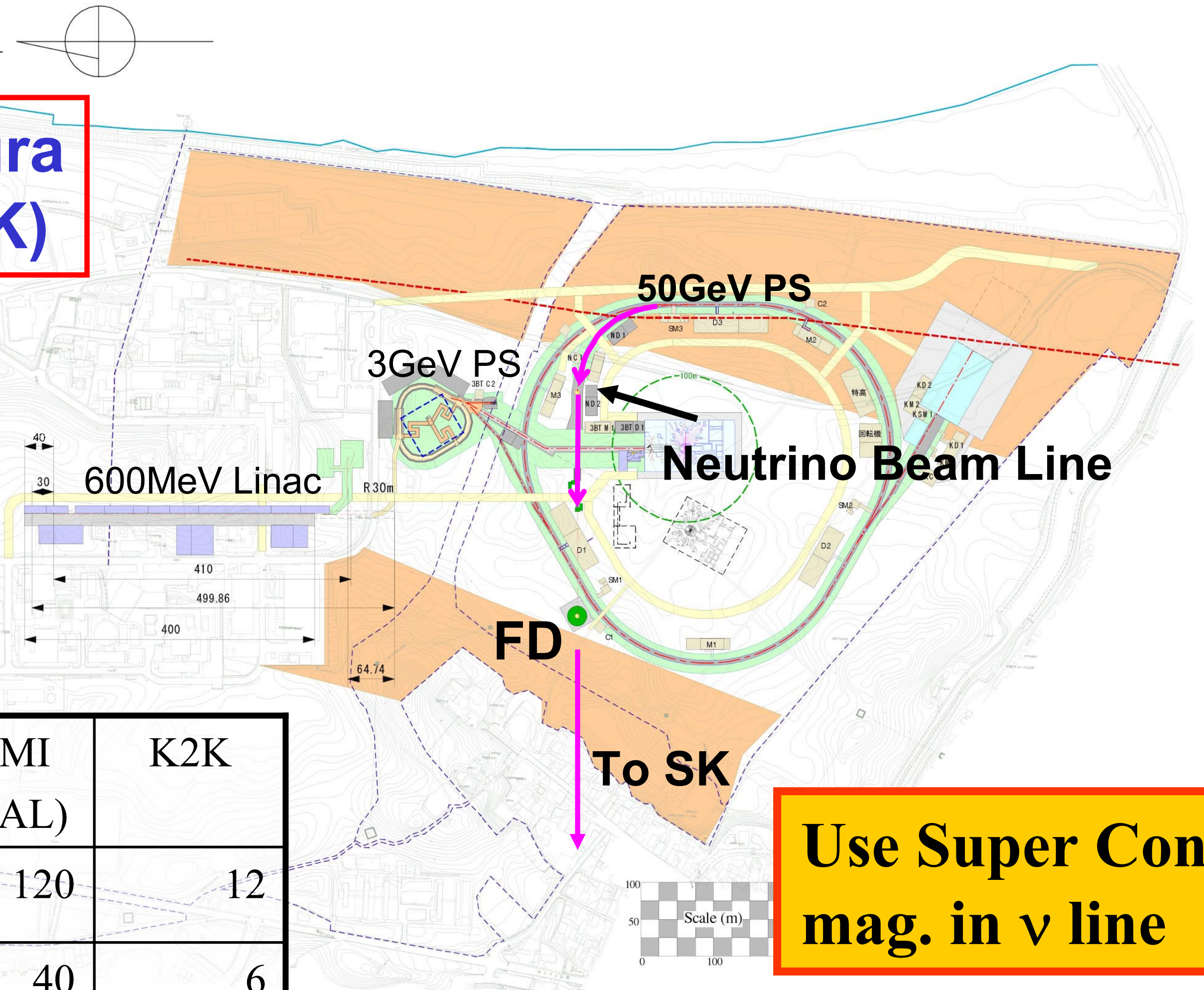
Dec.99: Working group formed.
Mar.00: First Letter of Intent prepared
Jun.01 : Updated LOI released(hep-ex/0106019). Int. WS held.

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)	0.275	0.53	0.45
Power(MW)	0.75	0.41	0.0052

Use Super Con. mag. in ν line

10^{21}POT(130day)≡ "1 year"

Overview of experiment

Convensional ν_μ beam of ~1GeV

Super-K: 50 kton Water Cherenkov

~Mt "Hyper Kamiokande"

JAERI (Tokai-mura)

~1 MW 50 GeV PS

4MW 50GeV PS

1st Phase

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

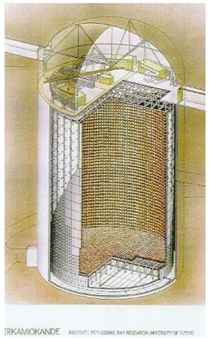
2nd Phase

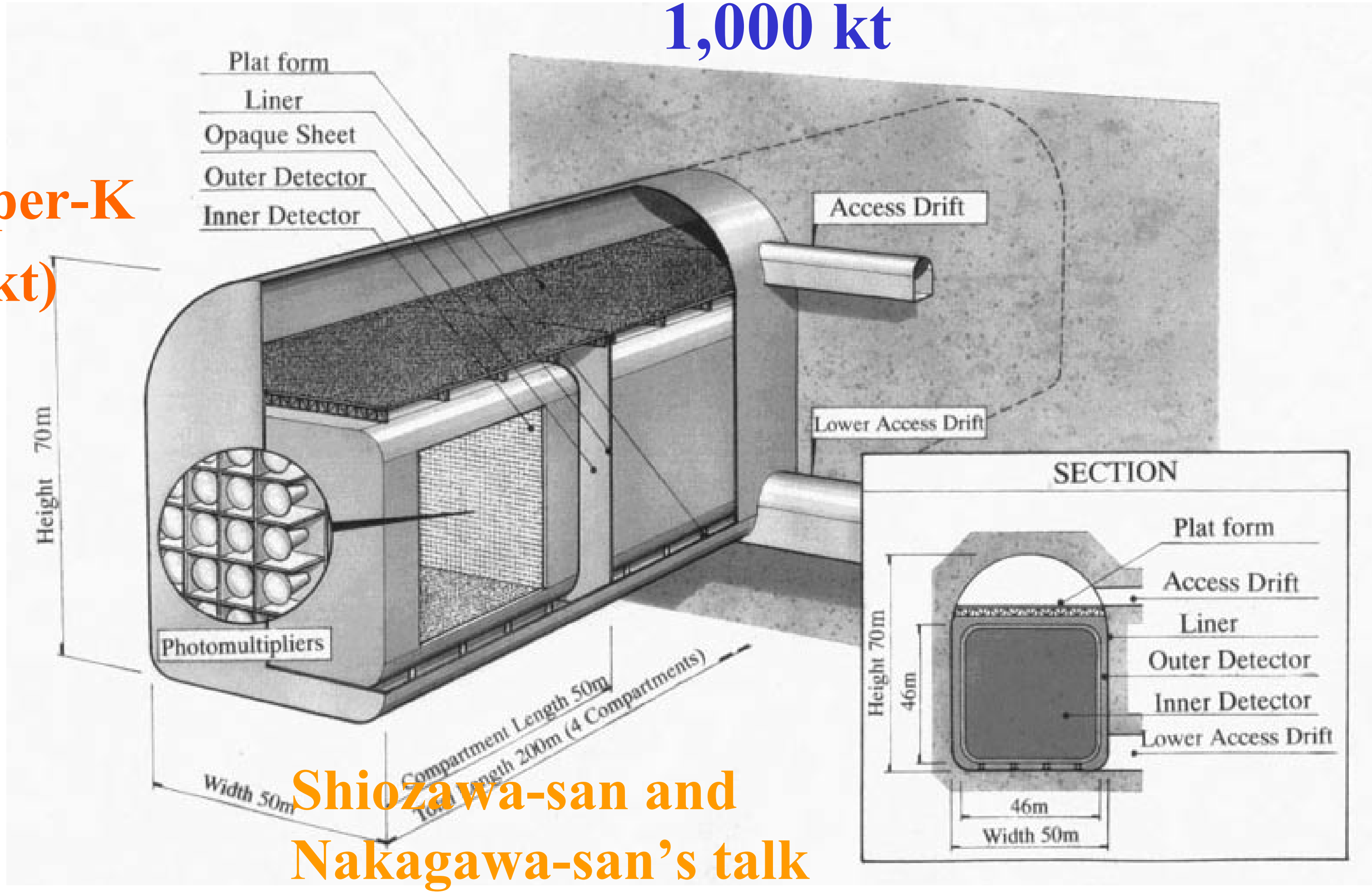
- CPV
- proton decay

Far ν detector

Phase-II: Hyper-K
1,000 kt

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





Shiozawa-san and Nakagawa-san's talk

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 (θ_{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(→ Shiozawa-san's talk in afternoon)

   Direct probe of GUTs

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

$\Delta m^2 = 1.6 \sim 4\times10^{-3}\,\mathrm{eV}^2$

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

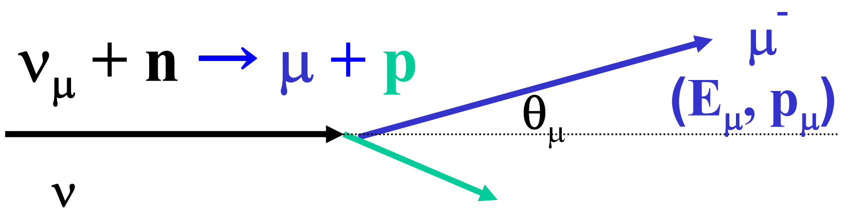
- **Gigantic water Cherenkov detector**
  - High statistics
  - High efficiency for low energy
  - Good PID (e/μ) capability

Neutrino Energy E_ν reconstruction

CC quasi elastic reaction $\Leftrightarrow$

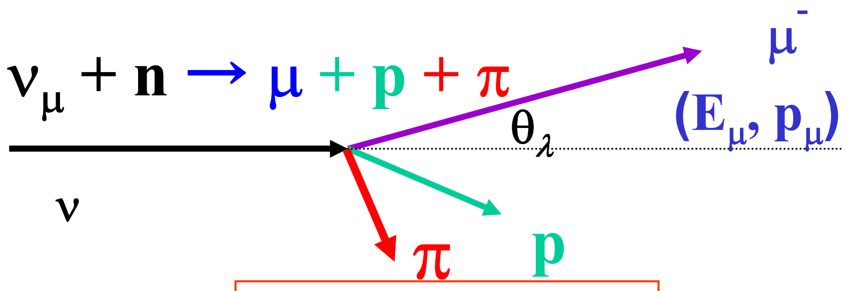
$$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

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

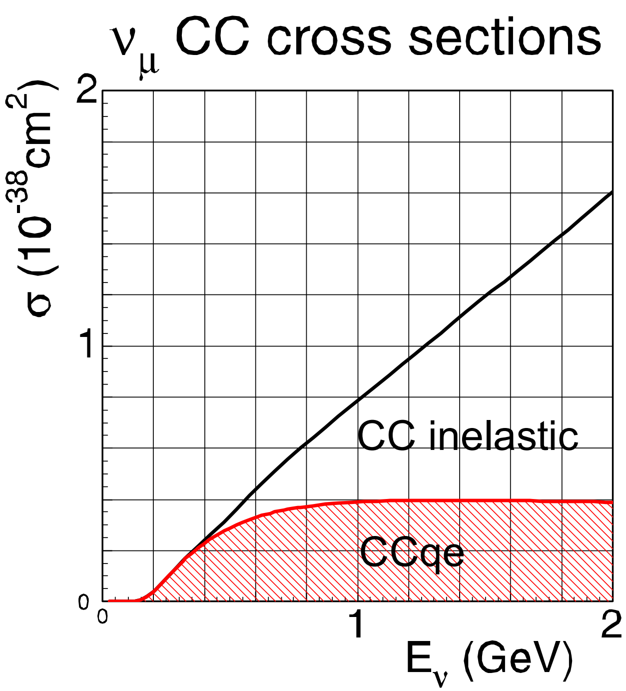


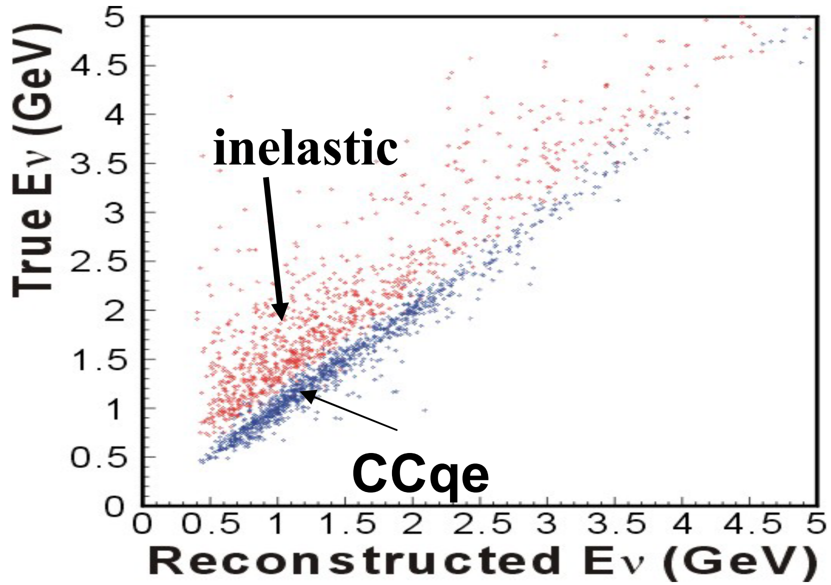
CCqe

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



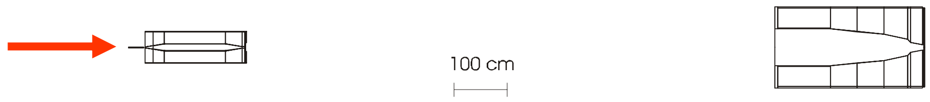
Inelastic (BG)





Possible Beam Configurations

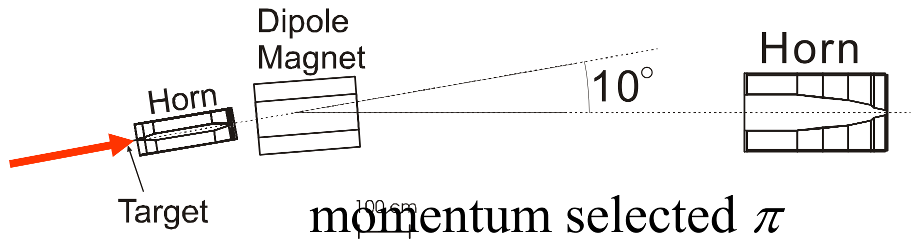
Wide Band Beam



2horns

- ✧Intense
- ✧Wide sensitivity in Δm^2
- ✧BG from HE tail
- ✧Syst. err from spectrum extrapolation

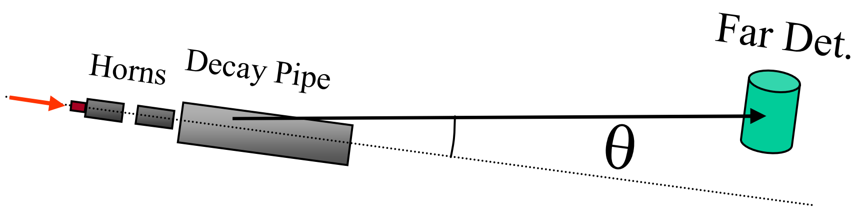
Narrow Band Beam



momentum selected π

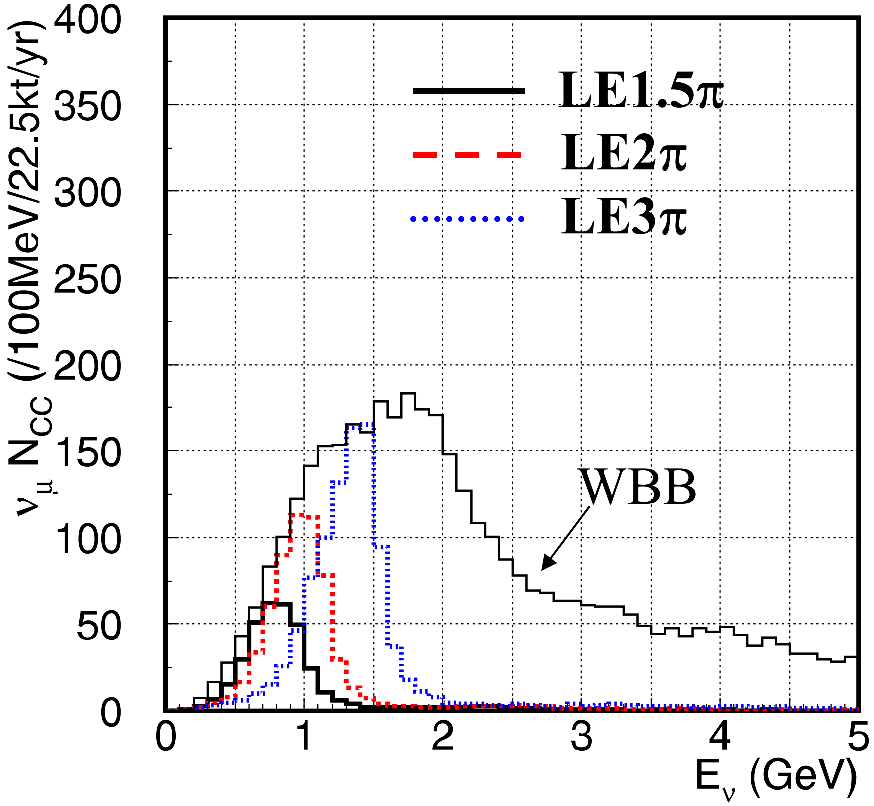
- ✧Less HE tail
- ✧Less sys err from spectrum
  "counting experiment"
- ✧Easy to tune E_ν

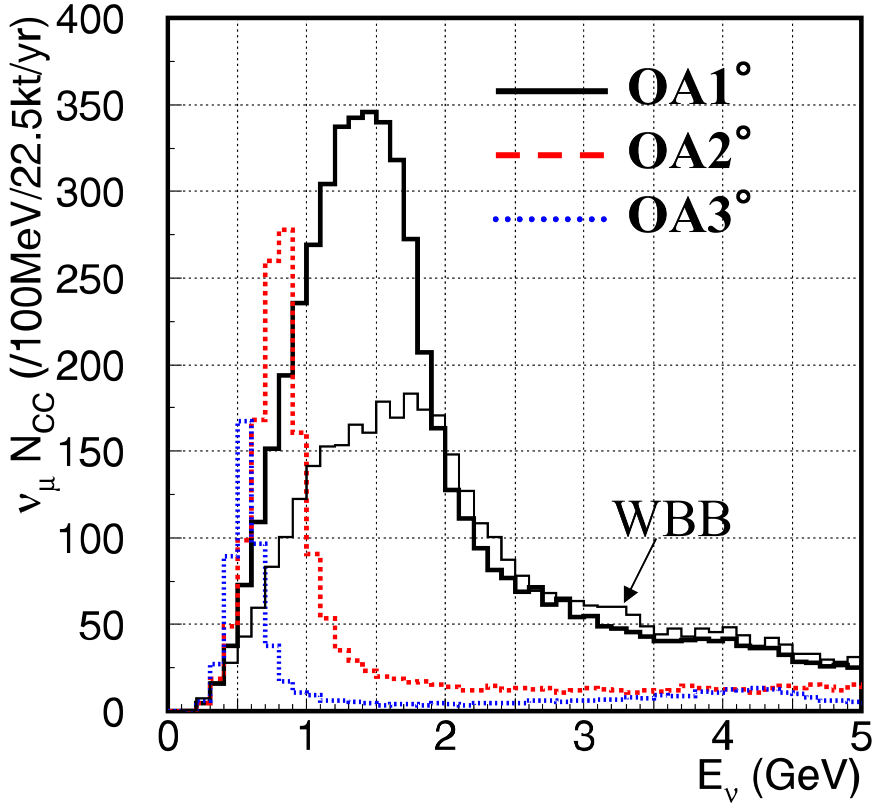
Off Axis Beam



- ✧High int. narrow band beam
- ✧More HE tail than NBB
- ✧Hard to tune E_ν

of CC events of various beams





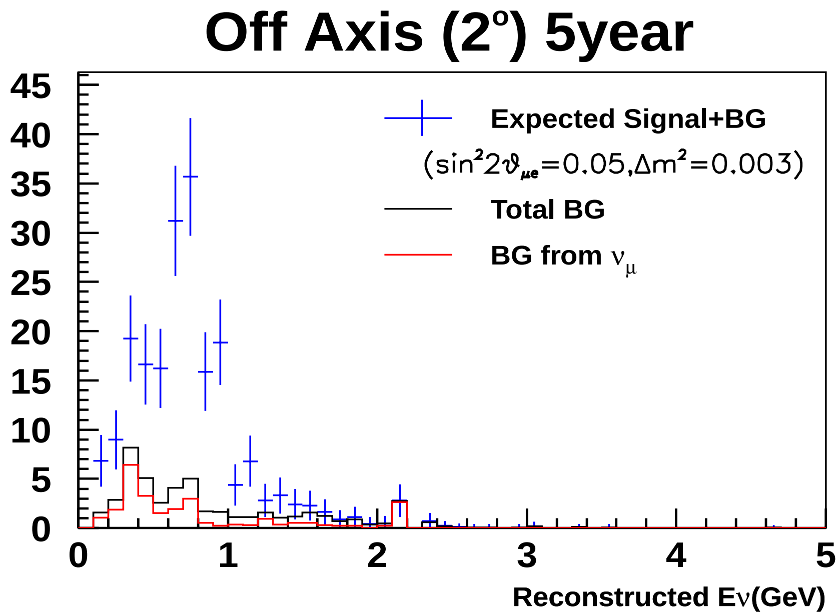
WBB:**5200** CC int./22.5kt/yr

NBB: **620** CC int./22.5kt/yr (2GeV/c π tune)

OAB: **2200** CC int./22.5kt/yr (2degree)

Peak energy can be tuned by changing mag. field(NBB) or angle(OAB)

Expected Backgrounds & Signal



5yr, 22.5kt

Chooz limit

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

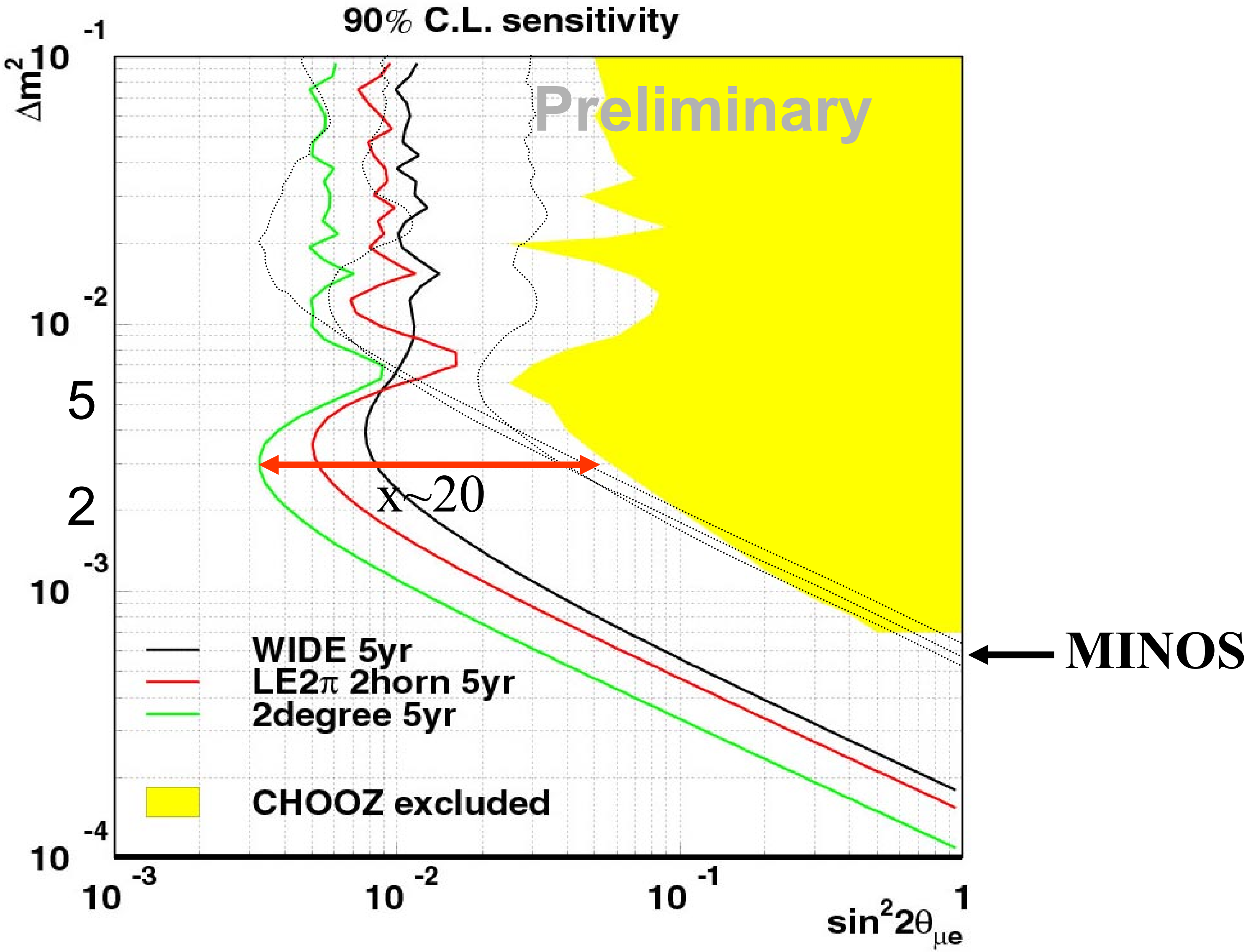
$\sin^2 2\theta_{\mu e} = 0.05$

	ν_μC.C.	ν_μN.C.	Beam ν_e	Osc'd ν_e
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 nm BG from π^0 production

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

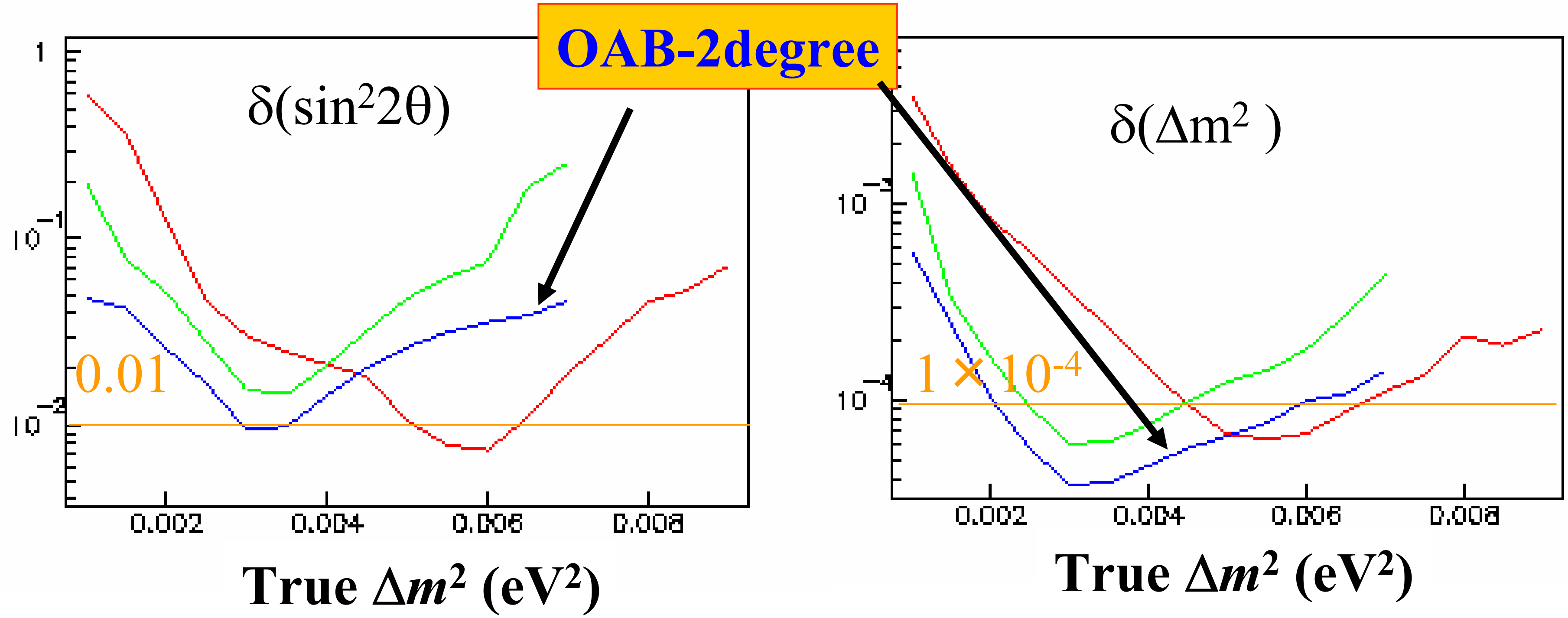
Sensitivity on $\nu_\mu \rightarrow \nu_e$ appearance



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

Big Chance for Discovery!!

5 years precision

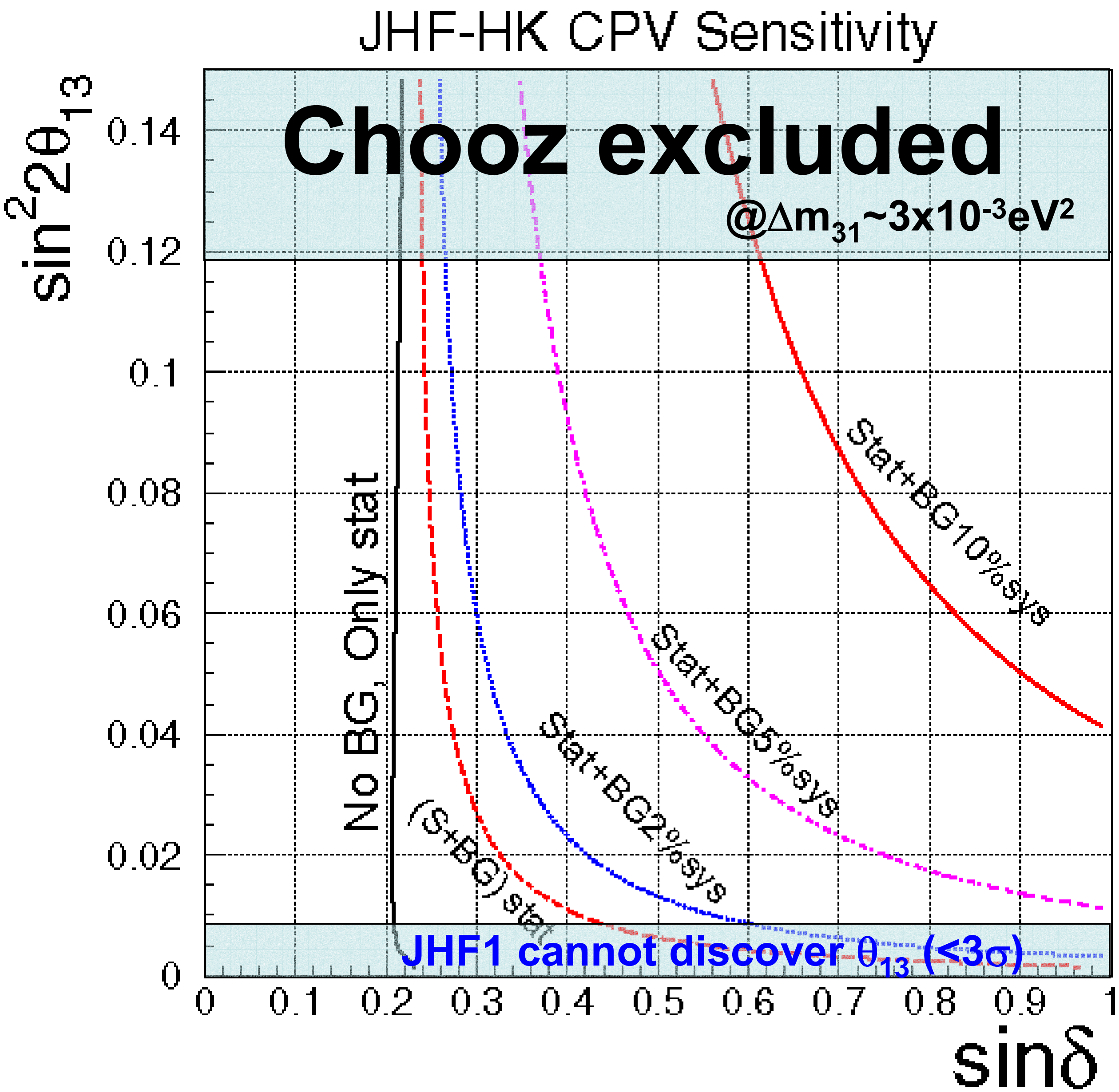


$\delta(\sin^2 2\theta) \sim 0.01$ in 5 years

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

Preliminary

Sensitivity(3σ)



BG sys 2%のとき

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

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

BG reduc./syst err essential.

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

Recent Development

Neutrino beams and strategy in LOI
hep-ex/0106019(June 2001)

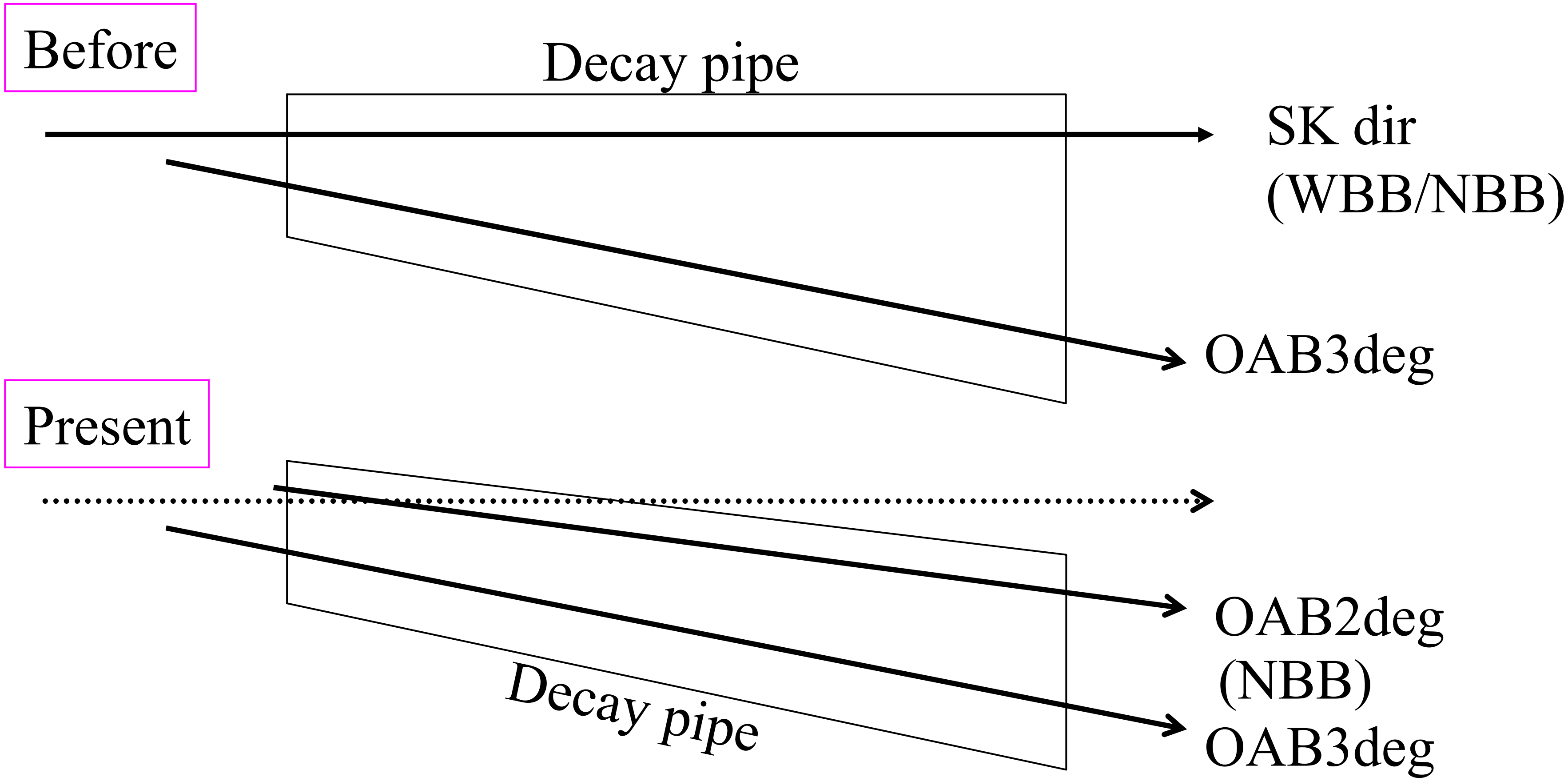
- Three types of beams
- WBB: first ~1year for Δm^2 rough determination
- NBB or OAB: ~5yr. Precision/high sens. measurement of disapp./app. at osc. max.
- NBB: neutrino interaction in near site
- Decay pipe: 80m from target

Current strategy

- Chose OAB for long term(~5yr) LBL measurement
  - Factor 2~3 higher flux than NBB
- Discard WBB option
- NBB only for ν int. study at near site(280m)

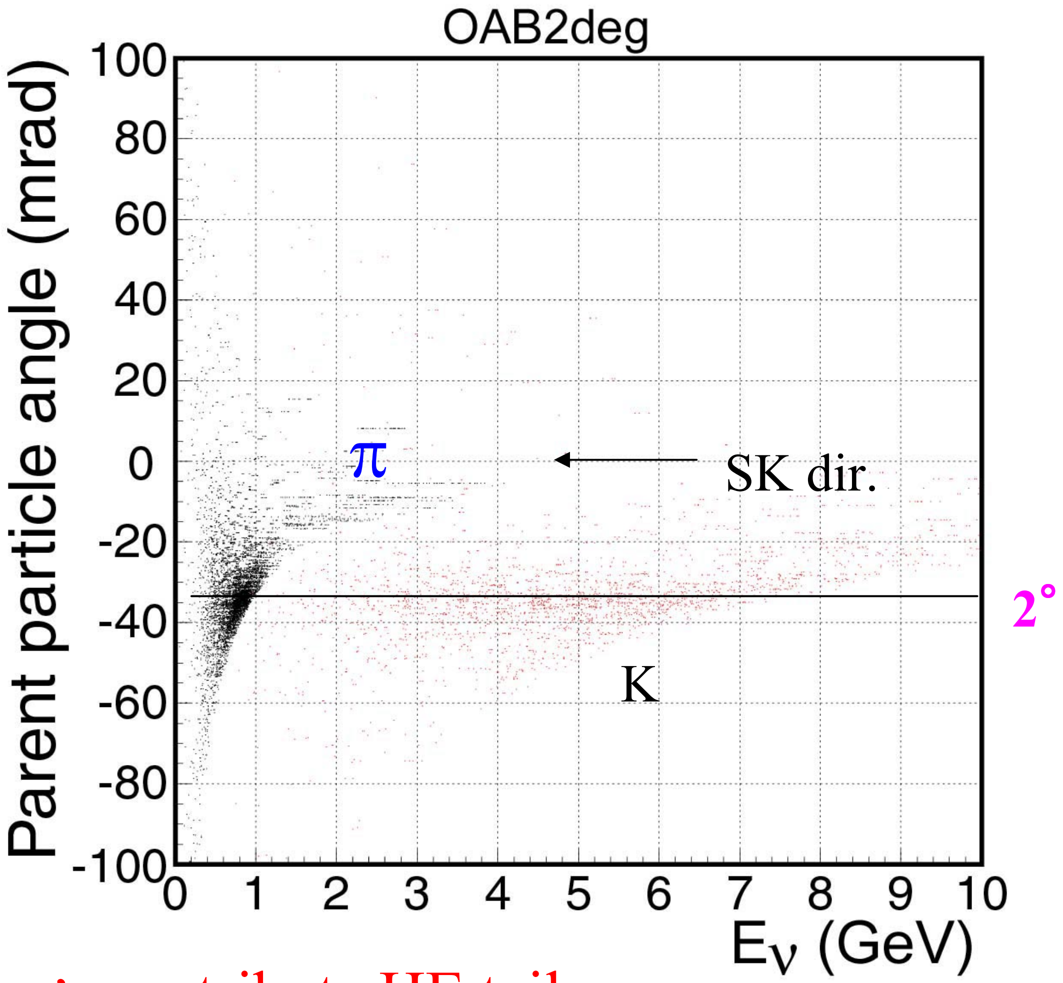
  → smaller decay pipe
- Decay pipe : 80m → 130m for higher flux
  - ~40% increase in peak flux
- Adjustable OAB angle **X±0.5**deg.
  - **X** still to be decided later for max. sensitivity
  - Deadline: ~1year
- Front detector @ ~ 2km → reduce far/near syst.
- Shoot SK and possible HK site (10km=2deg apart) w/ the same beam line

Beams and Shape of Decay Volume



- ✓ Discarding 0deg WBB enables to make narrow DV and hence longer pipe.
- ✓ Scraping 0deg part of DV, HE tail reduced!.

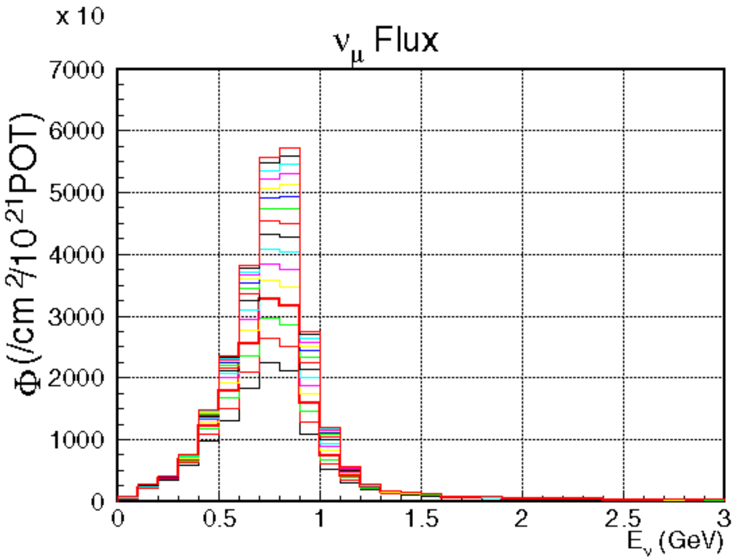
High Energy Tail

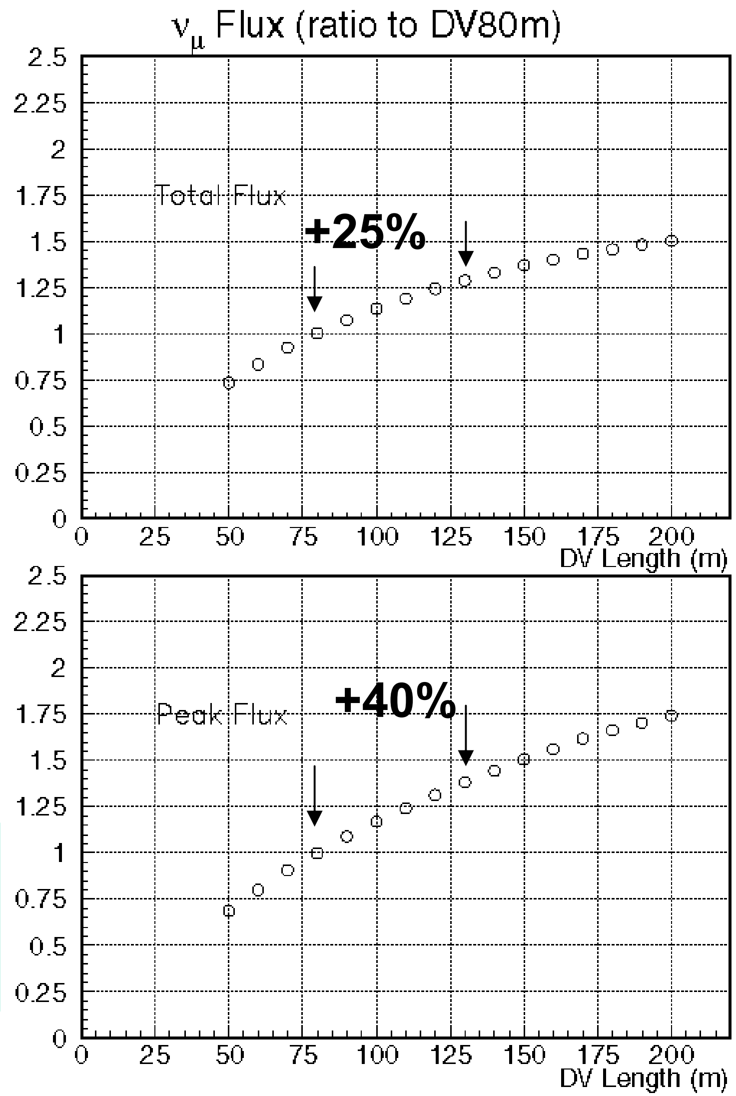


Small angle π's contribute HE tail.

Decay pipe shape optimization might further reduce HE tail.

Decay pipe len 80m→130m





40% increase in peak flux
HE tail relatively decreased

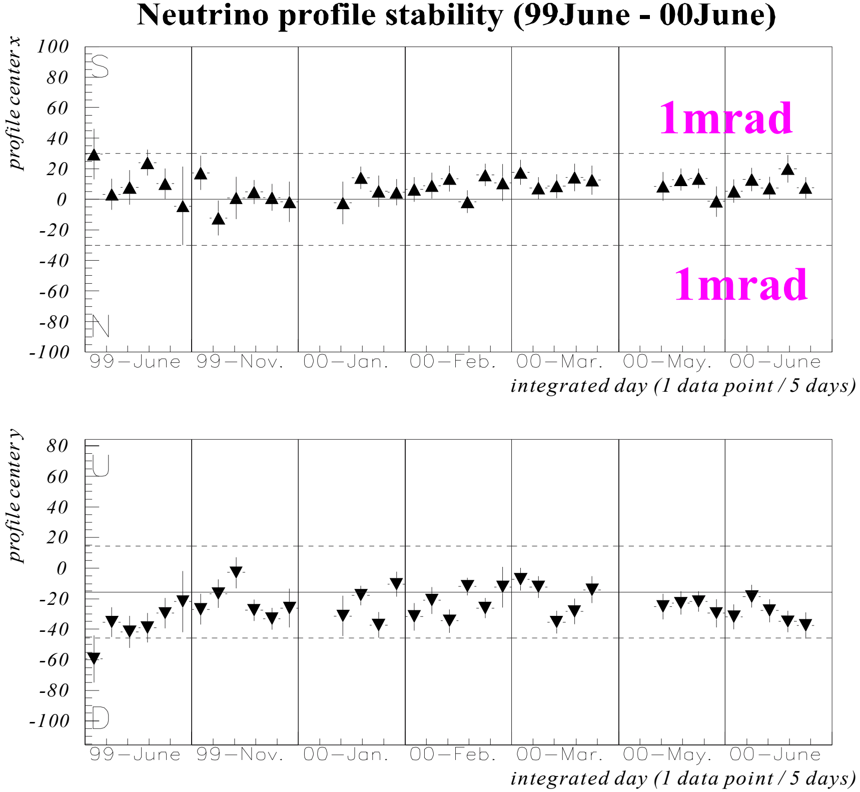
Current Detector Configuration

- Muon monitor
  - Ionization chamber?
  - Behind the beam dump (@~140m from target)
  - Fast spill-by-spill monitoring of beam intensity/direction (indirect)
- Neutrino Monitor (former "front detector")
  - Fine grained detector?
  - @ 280m from the target
  - Direct monitoring of NEUTRINO intensity/direction
  - Study of neutrino interaction w/ NBB
- **Front Detector←NEW!!**
  - Water Cherenkov+Fine grained?
  - ~2km from the target
  - Absolute neutrino spectrum measurement
- Far Detector
  - SK @295km

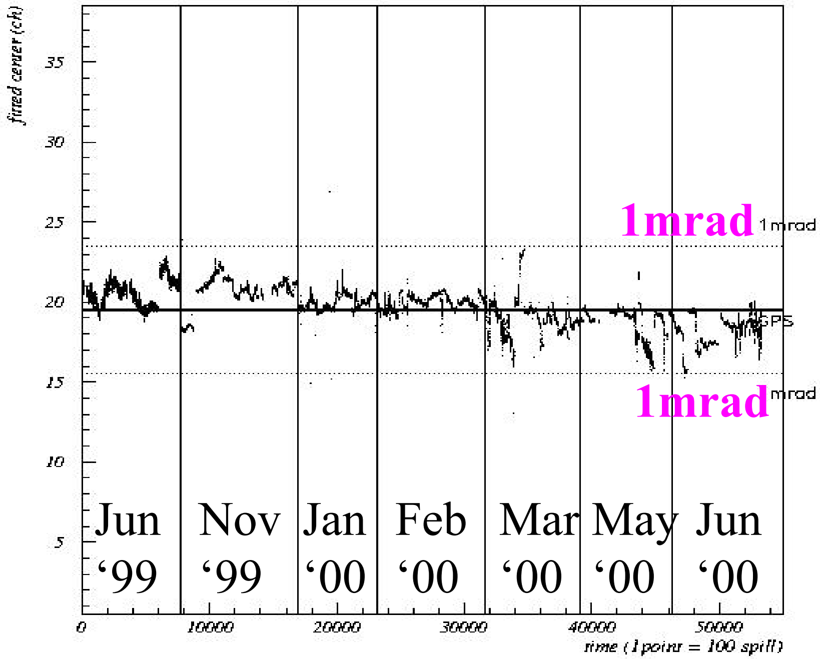
R&D of all components from NOW!!

Stability of K2K beam direction

Center of neutrino profile

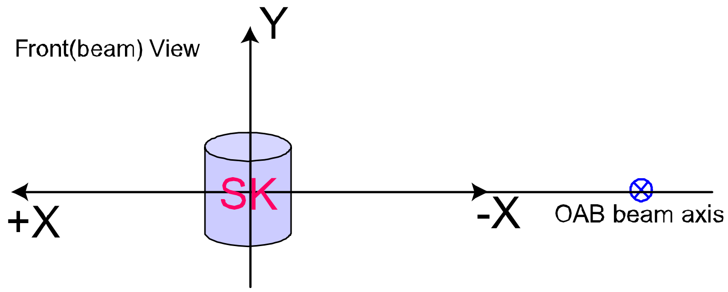


Center of muon profile (fast, spill-by-spill)



Controlled within 1mrad.

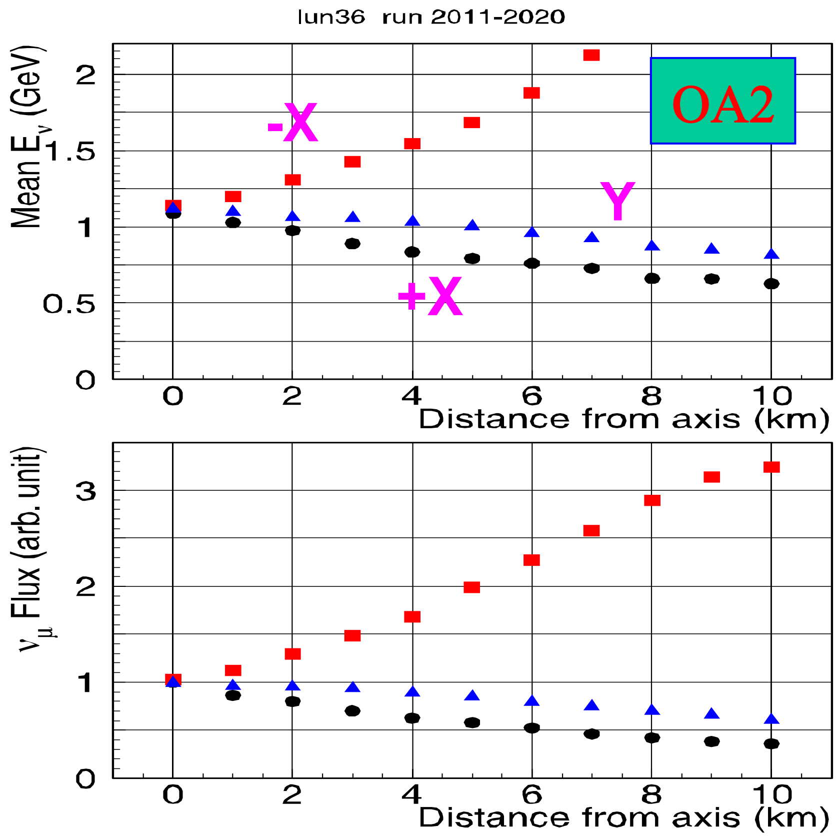
Beam monitoring

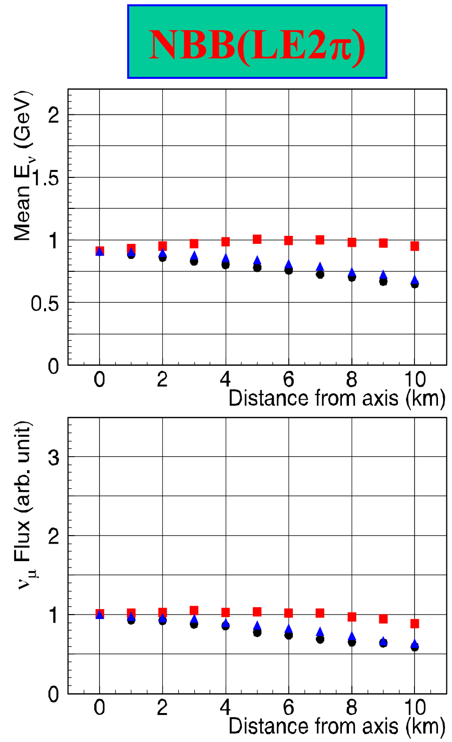


Beam profile @ SK

$<E_\nu>$

$\Phi_{\nu\mu}$





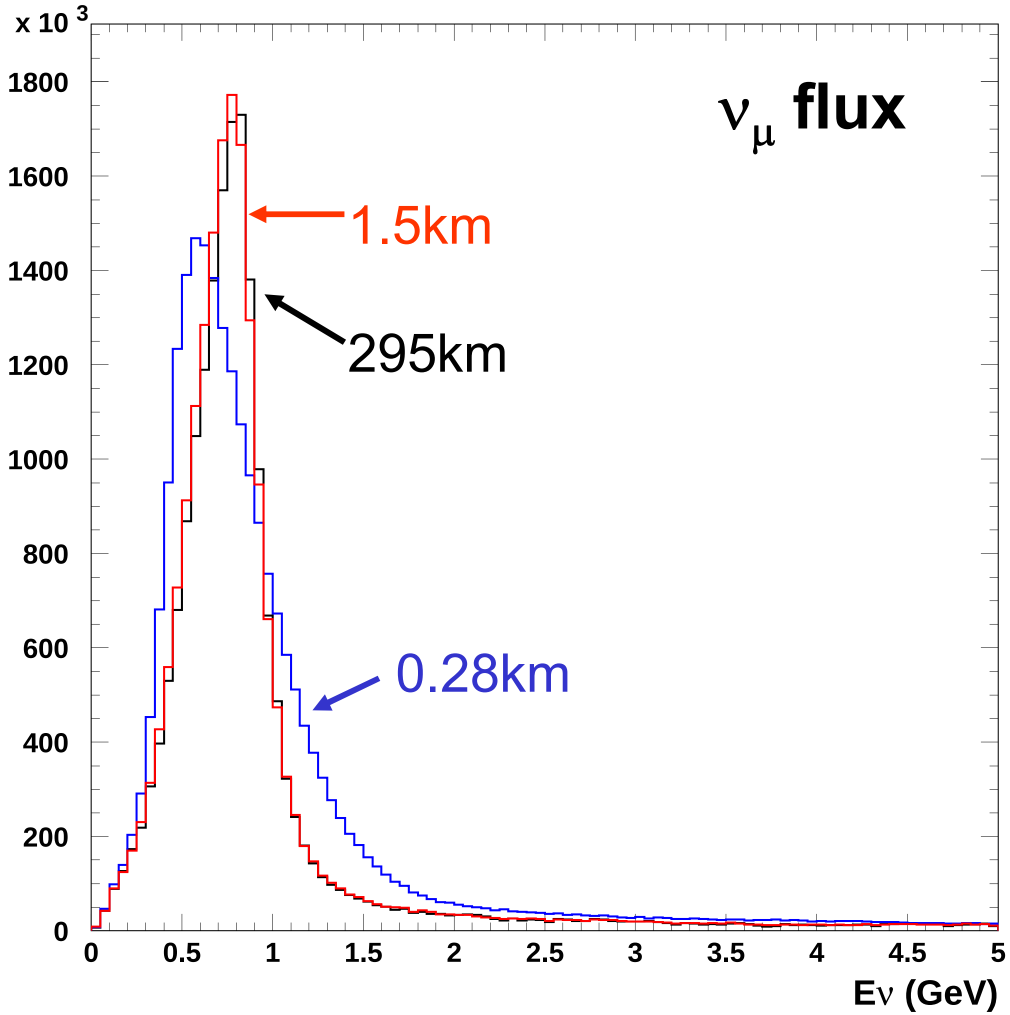
OAB: $<E_\nu>$ ~25MeV/mrad → $\delta(\Delta m^2)$ **~1x10^{-4}eV^2**

$\Phi_{\nu\mu}$ ~4%/mrad

Careful monitoring and control of beam direction necessary.

Motivation of 2km detector

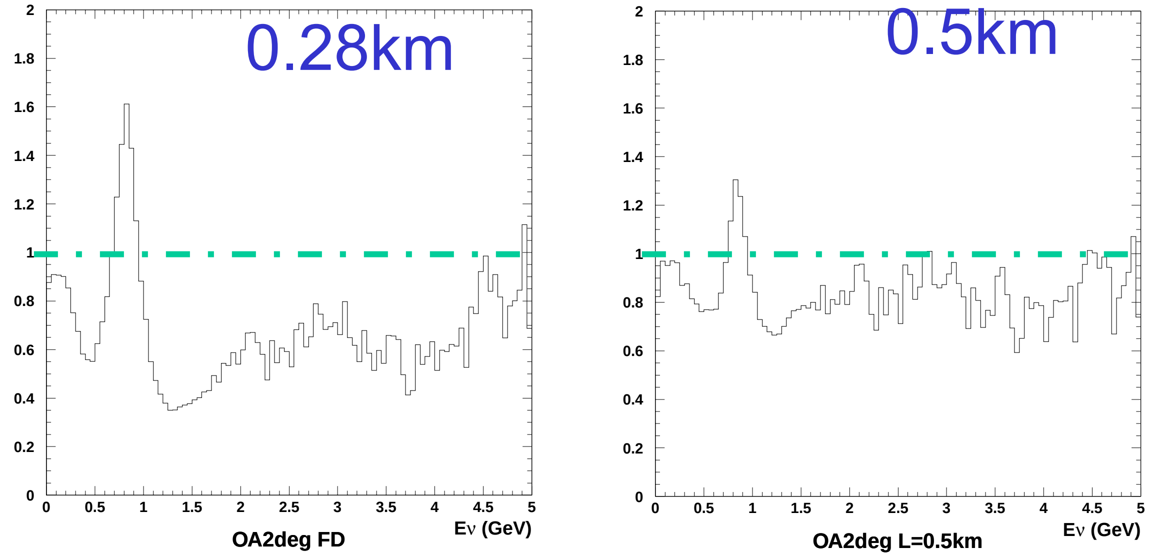
Spectrum difference btw. far/near

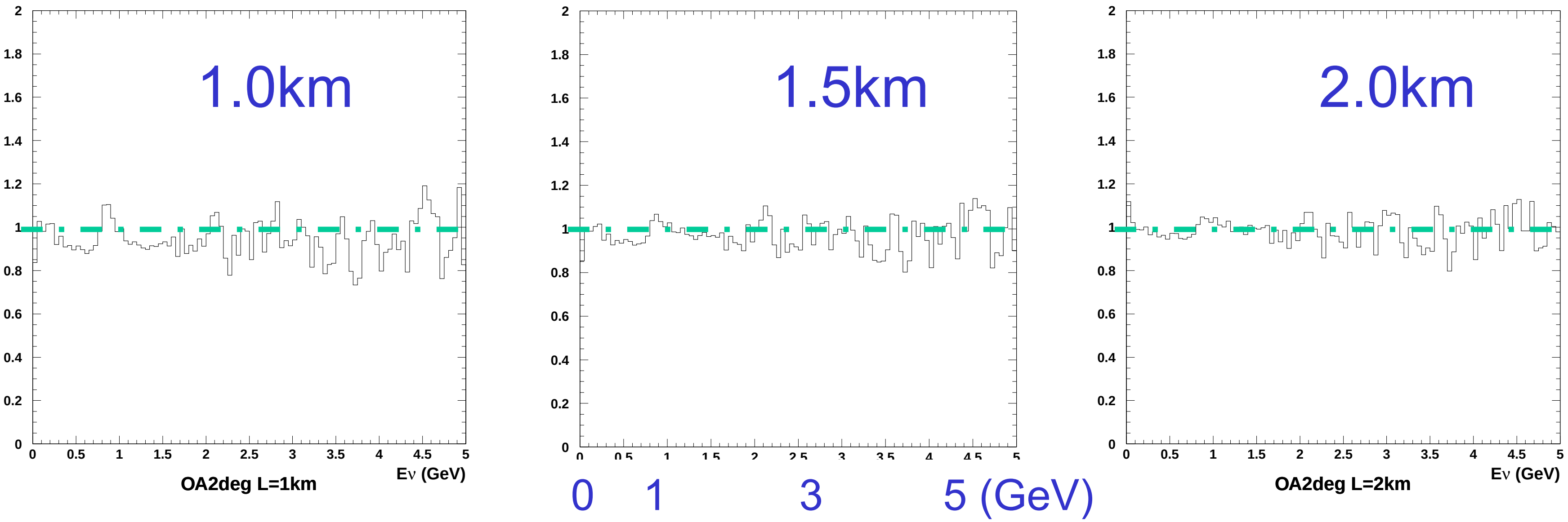


Far/near flux ratio

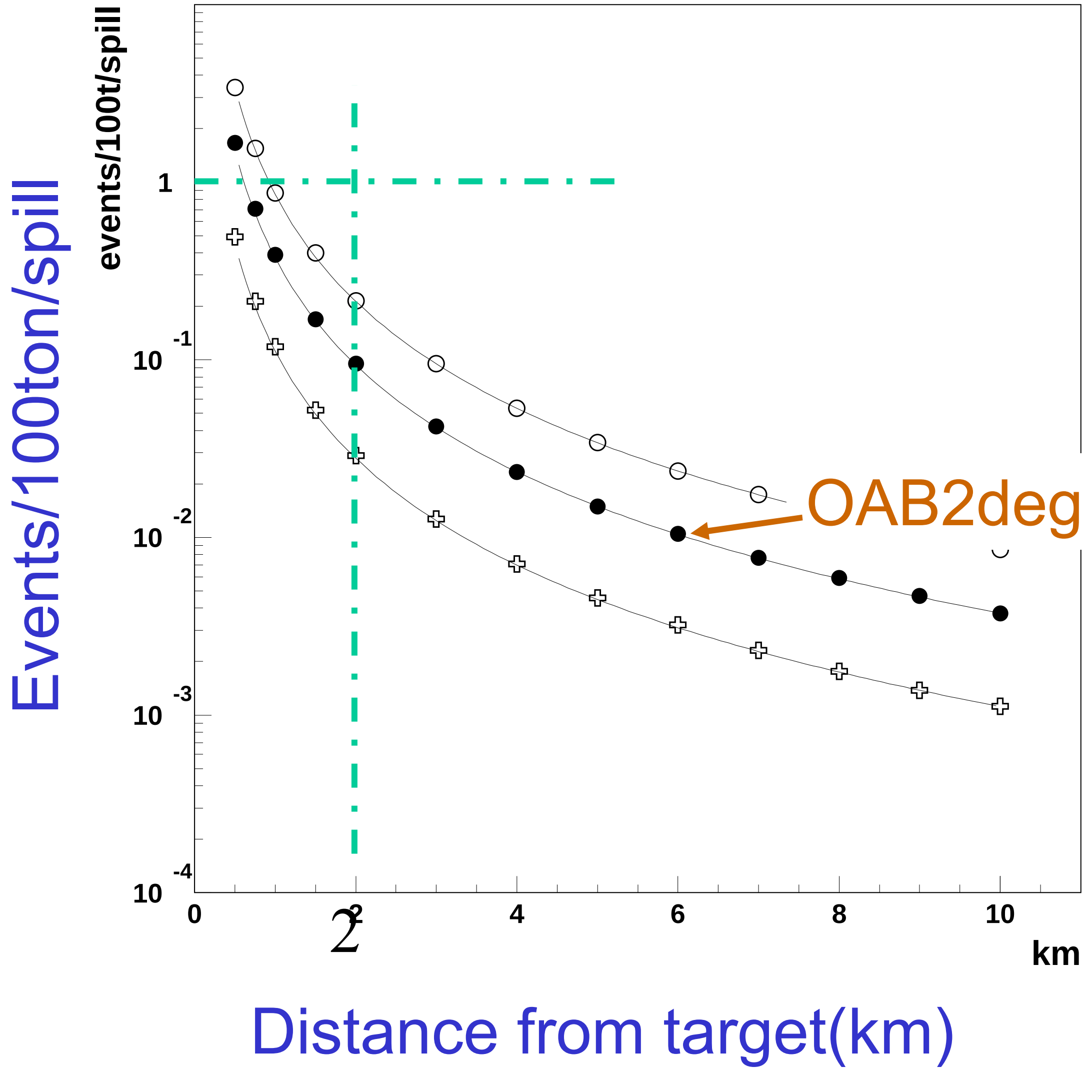
$$\frac{\Phi_{far}(E_\nu)\cdot L_{far}^2}{\Phi_{near}(E_\nu)\cdot L_{near}^2}$$

Flat >~1.5km



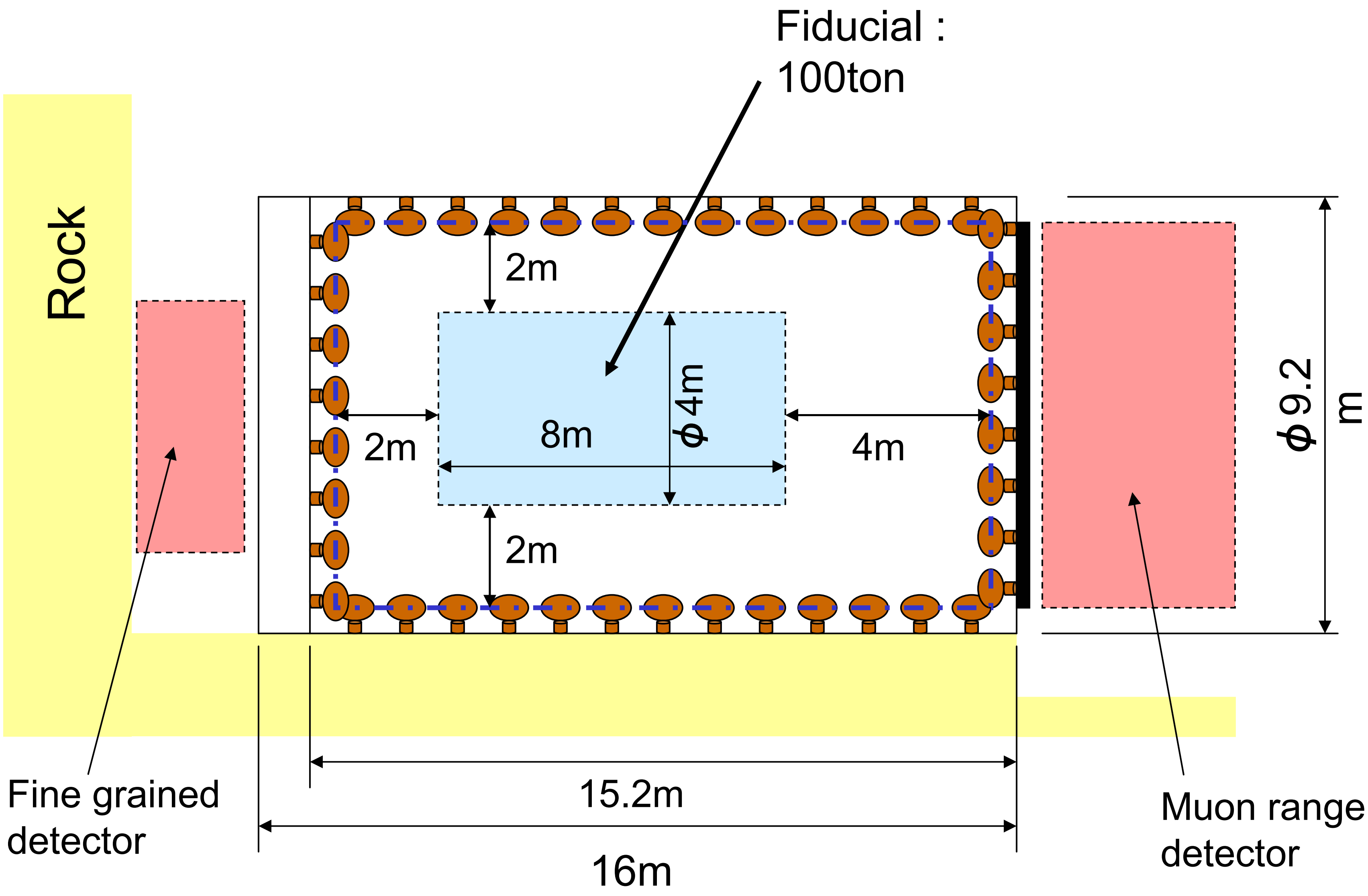


of events in fiducial volume



- ~2km is comfortable for Water Cherenkov detector

Possible Concept of 2km front neutrino detector



Necessity of hadron production data @ 50GeV

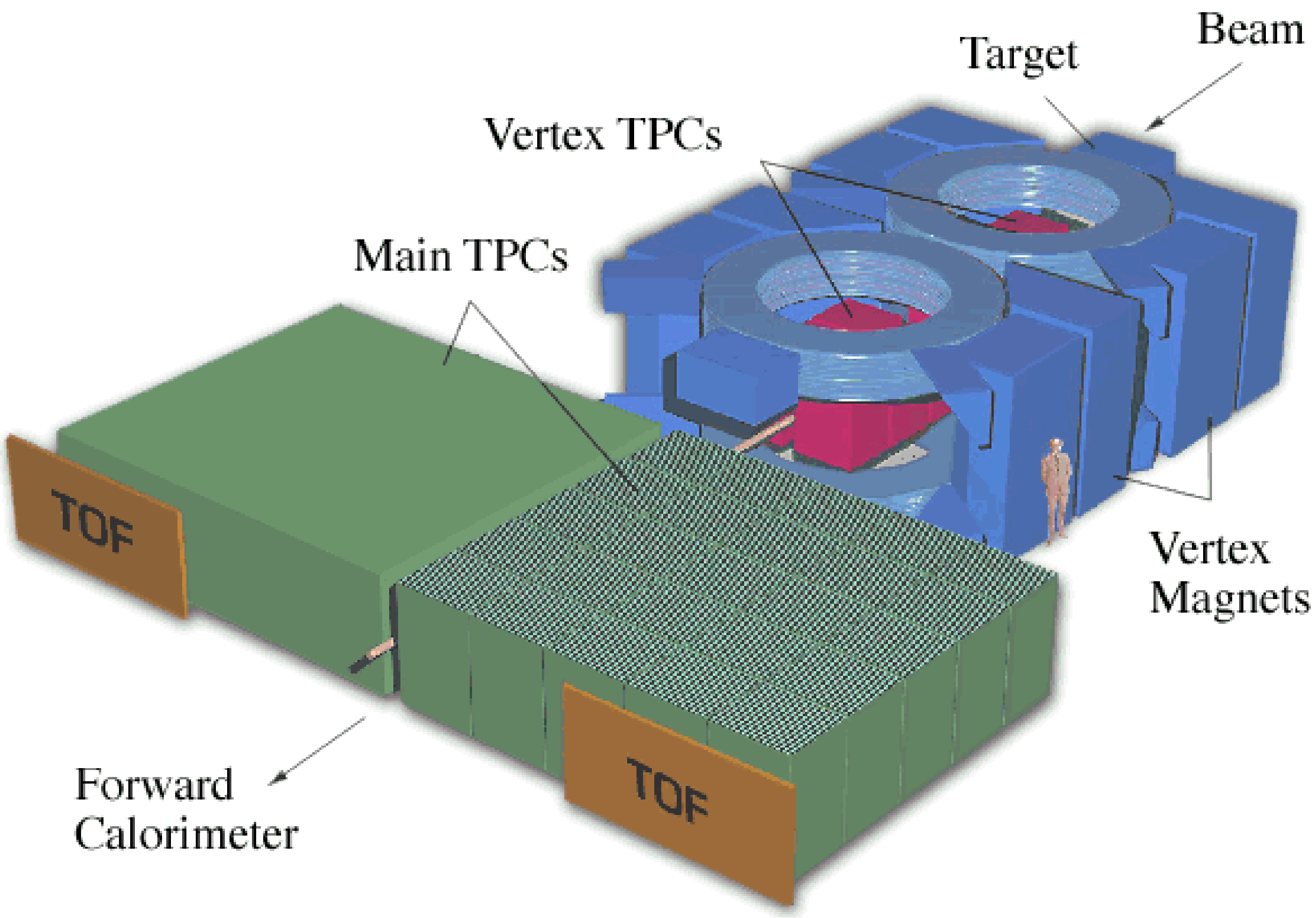
- We decide to (try to) put 2km detector
- No far/near problem
- ➔No need for precise hadron production data ?
- Yes we need! Very impotant!!
- We need proof(s) of "No far/near problem" statement. We cannot just trust beam MC.
- How?
  - Measure neutrino spectrum at 280m and 2km and reproduce the difference by MC ➔ reliable MC

    ➔ Require full-equipped det. both at 280m/2km
  - Measure hadron production precisely and predict 2km spectrum and confirm it by data.
- Only 2nd choice is realistic from various viewpoints.
- We need the data beforehand, in order to know
  - Expected # of events
  - Expected spectrum/ν_e → estimate BG

➔ **"HARPIII"**

Large Acceptance Hadron Detector for an Investigation of Pb-induced Reactions at the CERN SPS

The NA49 Experimental Set-up



Neutrino Facility

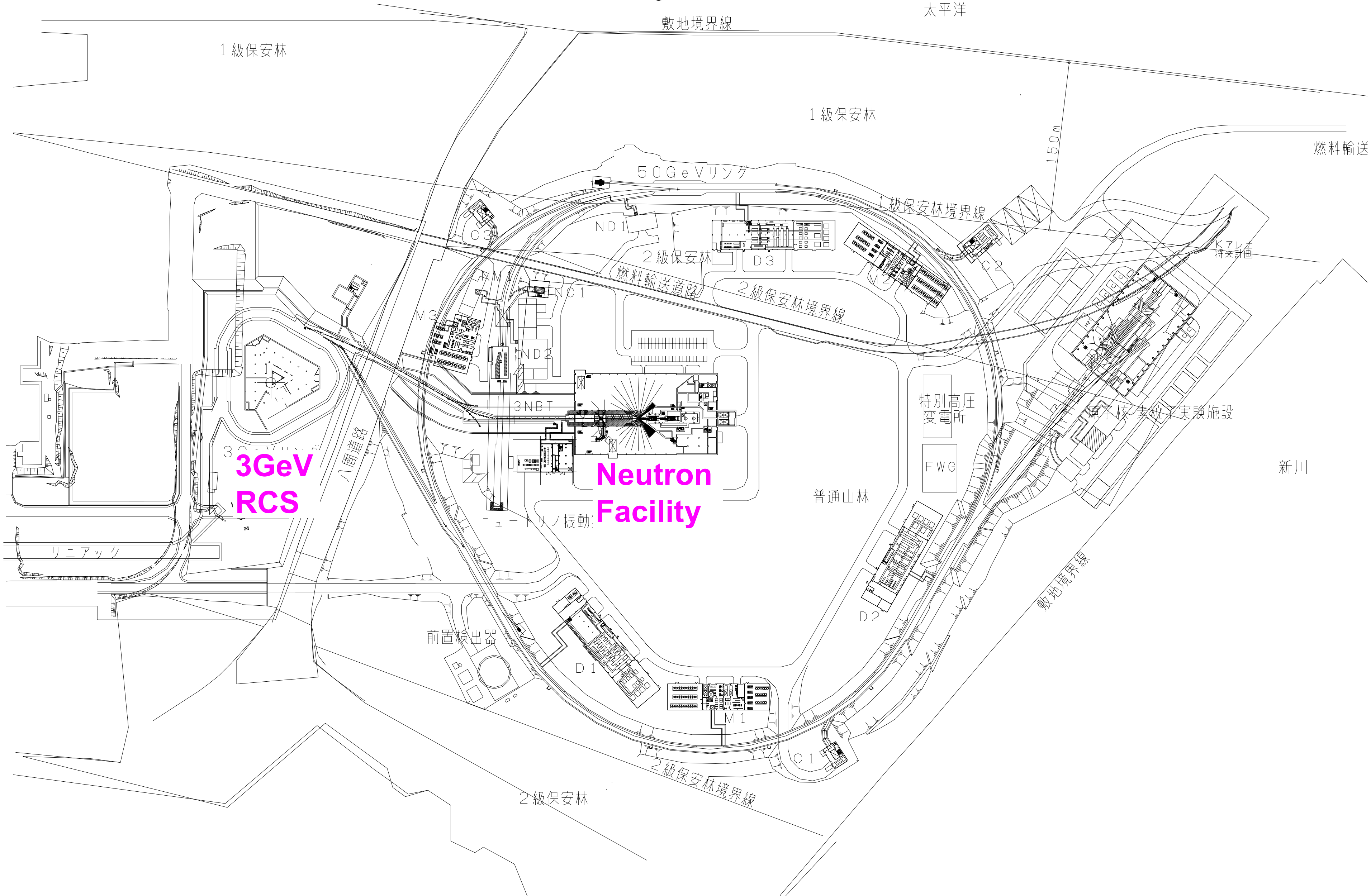
All drawings are preliminary

Recent changes have not been reflected in the drawings yet

JHF neutrino facility construction group

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

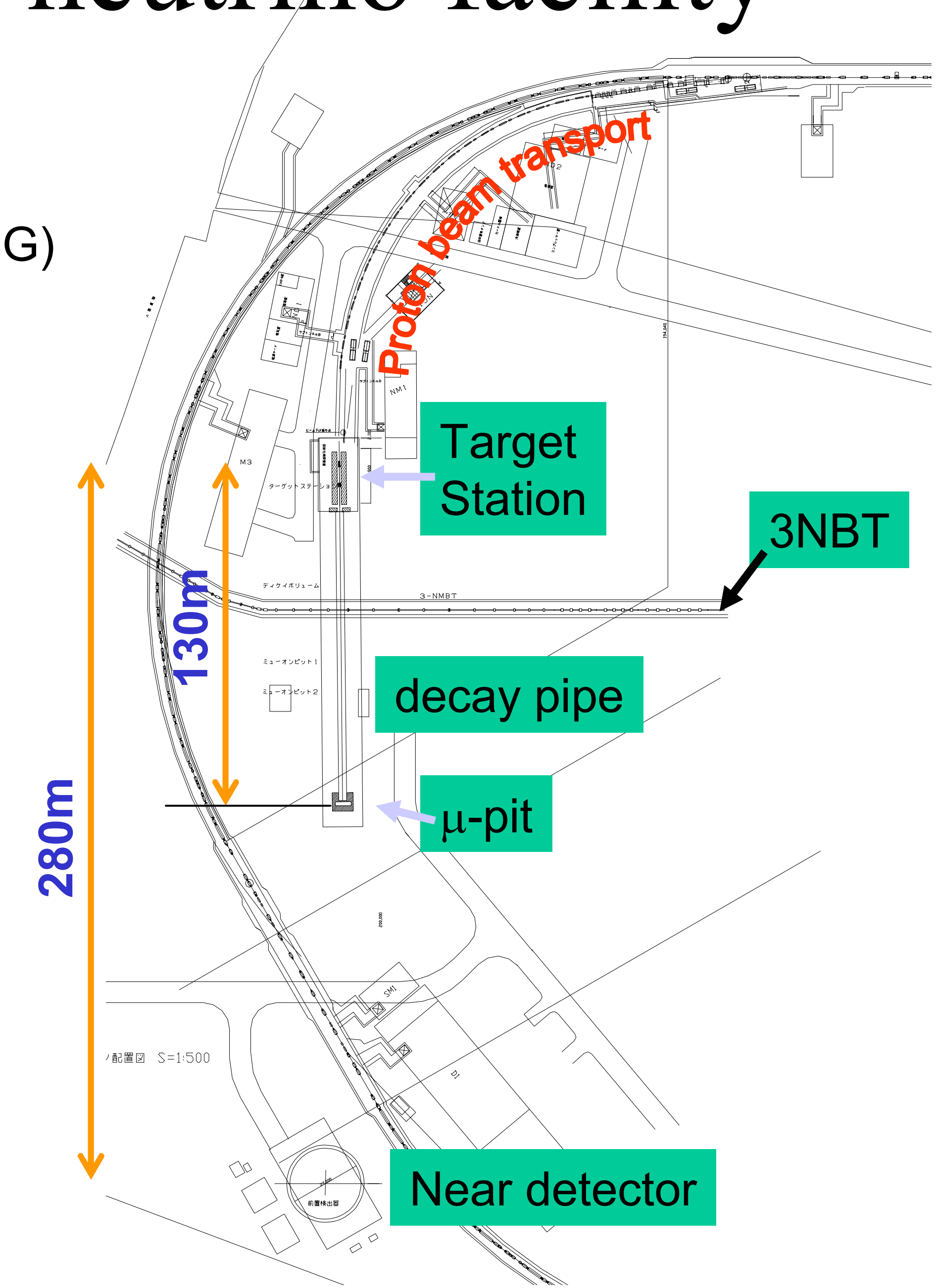
Layout



敷地境界線
太平洋
1級保安林
1級保安林
燃料輸送
50GeVリング
150m
1級保安林境界線
ND1
2級保安林
D3
C3
C2
M2
燃料輸送道路
2級保安林境界線
NM1
NC1
M3
ND2
3NBT
特別高圧
変電所
原子核・素粒子実験施設
八間道路
3GeV
RCS
Neutron
Facility
FWG
新川
普通山林
リニアック
D2
敷地境界線
前置検出器
D1
M1
C1
2級保安林境界線
2級保安林

Overview of neutrino facility

- Beam line tunnel
- Extraction system(covered by acc. G)
  - Kicker and septum magnets
- Proton beam transport
  - Preparation section
  - Arc section (Super cond.)
  - Final focusing
- Target/Horn system
  - NBB/OAB changeable
- Decay pipe
  - Cross w/ 3NBT
  - Target-Dump: 130m
  - "Trapezoid" shape
- Pit for muon monitor
- Beam dump
- Near detector
  - @280m in JAERI site
  - @~2km



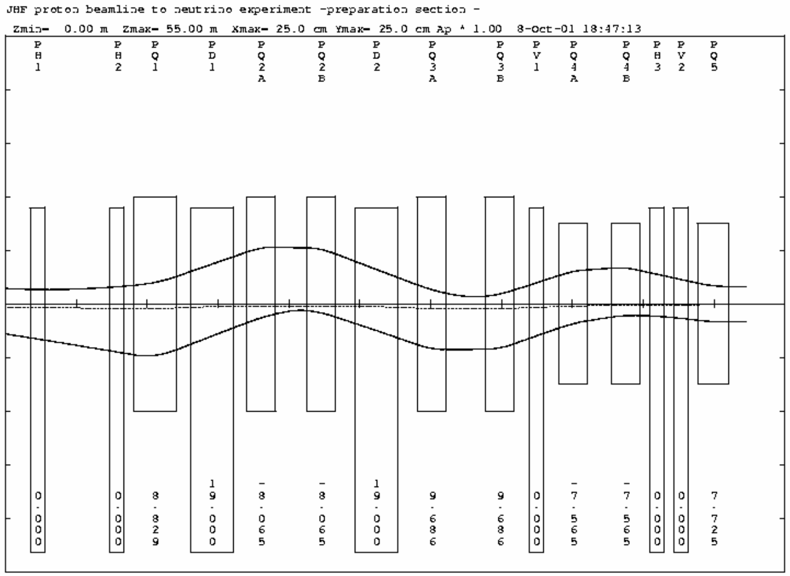
Specification

Beam kinetic energy	50GeV
Protons/pulse	3.3×10^{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	0.275Hz
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
Distance to near detectors	280m/~2km
Distance to SK	~295km
Target-SK beam decline	-1.25deg

Recent progress

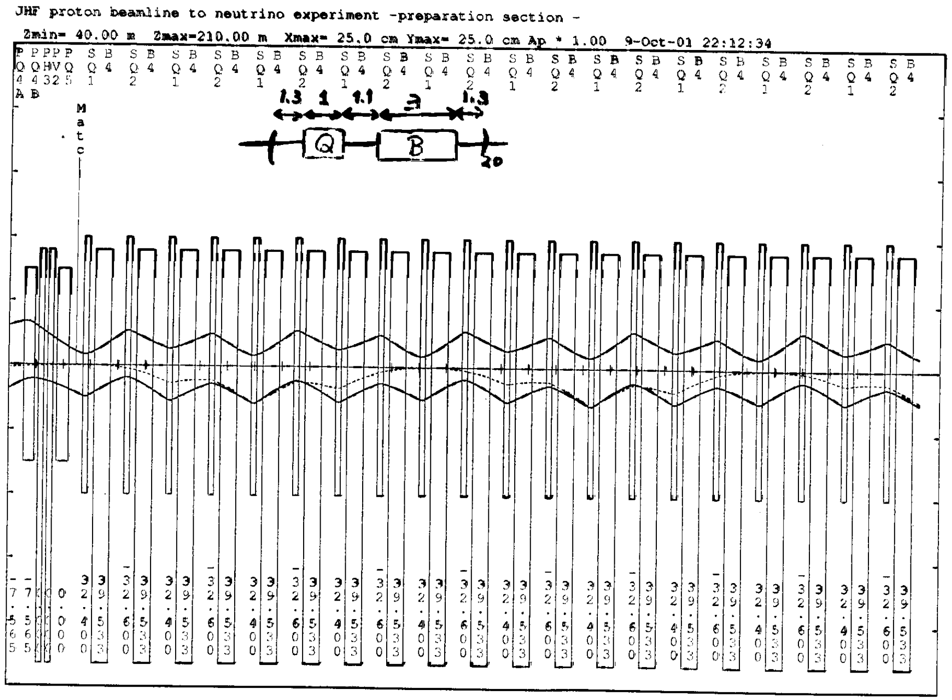
- Primary proton beam optics almost fixed (Ichikawa/Doornboss@TRIUMF)
- Design of norm. cond. mags started (Kusano)
  - ✓ Preparation section/Final focusing
- Design of super conducing magnets(Cryo. Sci Center)
- Conceptual design of low T facility done.
- Optimization of target/horn system started(Hayato/Ichikawa)
- Radiation shielding design(Oyama)
- Decay pipe
  - ✓ decide to fill He
  - ✓ heat dissipation simulated(Hayato)
  - ✓ Common decay pipe design for SK and HK
  - ✓ Started engineering design w/ company
- Long baseline GPS survey finished(Noumi)
- Plan to include 2km detector in the same budget request
- Aiming to submit budget request in 2002
  - ➔ Will get answer by the end of 2002.

Optics design of primary proton beam



Upstream normal cond.

Arc. super cond. part



FODO

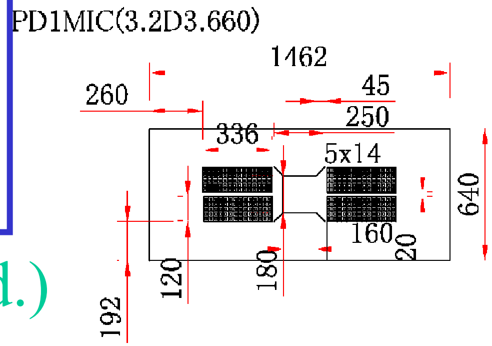
Ichikawa

Design of normal conducting magnets

E.Kusano

Upstream preparation section
Downstream final focus
Dipole for NBB

Under severe
Radiation
Esp., for NBB dipole



Some mags use MIC(mineral insulation cond.)

Summary of normal conducting magnets

E.Kusano, Jan.9,2002

No	Name	Type	B[T]		Len	Gap[mm]		Size[mm]			Max			Normal operation			Weight
											I	V	Power	I	V	Power	
			Max	Opr	[mm]	V	H	W	H	L	[A]	[V]	[kW]	[A]	[V]	[kW]	[ton]
1	PH1	2D420MIC	2.0	1.000	1,000	100	200(300)	1,400	500	1,600	2,000	70	140.0	1,000	35	35.0	10
2	PH2	2D420MIC	2.0	1.000	1,000	100	200(300)	1,400	500	1,600	2,000	70	140.0	1,000	35	35.0	10
3	PQ1	Q460MIC	1.0	0.883	3,000	200		1,280	1,280	3,500	2,500	220	550.0	2,208	194	428.8	30
4	PD1	2.4D3.660MIC	2.0	1.900	3,000	180	160(250)	1,500	700	3,600	2,500	220	550.0	2,375	209	496.4	26
5	PQ2A	Q440MIC	1.0	0.807	2,000	200		1,280	1,280	2,500	2,500	100	250.0	2,018	81	162.8	21
6	PQ2B	Q440MIC	1.0	0.807	2,000	200		1,280	1,280	2,500	2,500	100	250.0	2,018	81	162.8	21
7	PD2	3.2D3.260	2.0	1.900	3,000	160	160	1,300	500	3,400	2,500	140	350.0	2,375	133	315.9	16
8	PQ3A	Q440	1.0	0.969	2,000	200		1,280	1,280	2,500	2,500	100	250.0	2,423	97	234.7	18
9	PQ3B	Q440	1.0	0.969	2,000	200		1,280	1,280	2,500	2,500	100	250.0	2,423	97	234.7	18
10	PV1	3D3.220	2.0	1.000	1,000	150	160	1,100	500	1,400	2,000	100	200.0	1,000	50	50.0	7
11	PQ4A	Q340	1.0	0.757	2,000	150		1,200	1,200	2,500	2,000	60	120.0	1,514	45	68.8	20
12	PQ4B	Q340	1.0	0.757	2,000	150		1,200	1,200	2,500	2,000	60	120.0	1,514	45	68.8	20
13	PH3	3D3.220	2.0	1.000	1,000	150	160	1,100	500	1,400	2,000	100	200.0	1,000	50	50.0	7
14	PV2	2D220	2.0	1.000	1,000	100	100(200)	1,000	500	1,500	2,000	70	140.0	1,000	35	35.0	4
15	PQ5	Q340	1.0	0.773	2,000	150		1,200	1,200	2,500	2,000	60	120.0	1,546	46	71.7	20
Sub total													3,630.0			2,450.4	248
16	FQ1A	Q340	1.0	0.874	2,000	150		1,200	1,200	2,500	2,000	60	120.0	1,747	52	91.6	20
17	FQ1B	Q340	1.0	0.874	2,000	150		1,200	1,200	2,500	2,000	60	120.0	1,747	52	91.6	20
18	FQ2A	Q450	1.0	0.914	2,500	200		1,280	1,280	3,000	2,500	130	350.0	2,285	119	271.6	22
19	FQ2B	Q450	1.0	0.914	2,500	200		1,280	1,280	3,000	2,500	130	350.0	2,285	119	271.6	22
20	FQ3A	Q460	1.0	0.903	3,000	200		1,280	1,280	3,500	2,500	150	400.0	2,257	135	305.7	25
21	FQ3B	Q460	1.0	0.903	3,000	200		1,280	1,280	3,500	2,500	150	400.0	2,257	135	305.7	25
22	FQ4	Q360	1.0	0.812	3,000	150		1,200	1,200	3,500	2,000	90	200.0	1,625	73	118.8	25
23	FD1	3D490MIC	2.0	2.000	4,500	150	200				2,500	280	700.0	2,500	280	700.0	40
24	FD2	15D1124MIC	1.5	1.200	1,200	550	750	2,300	1,400	1,200	2,500	350	900.0	2,000	280	560.0	32
Sub total													3540.0			2,716.5	231
Total													7,170.0			5,166.9	479

24 mag.
5.2MW

Super conducting magnet design

• Specification

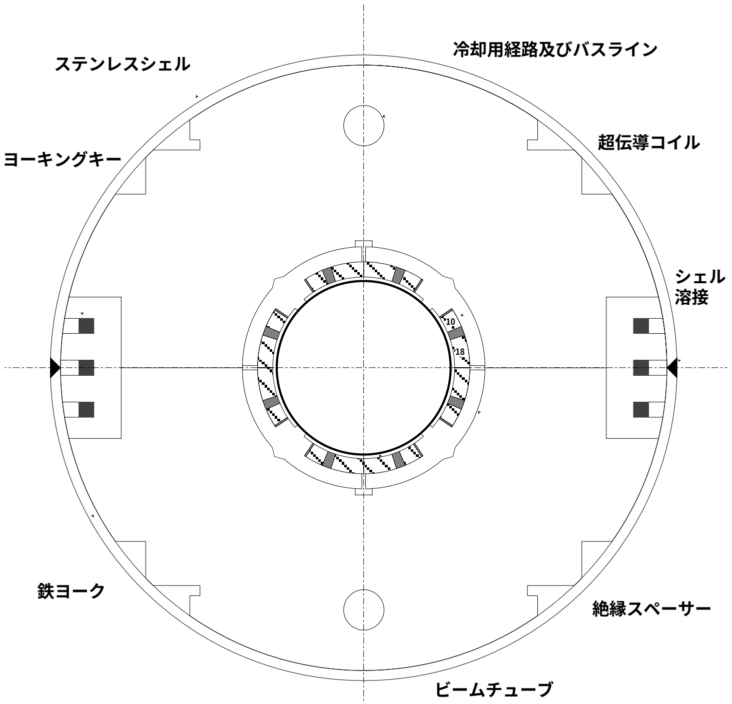
Type	Magnetic Length	Operation Field	Number
Dipole	3 m	3.95 T	20
Quadrupole	1 m	32.4 T/m	20

• Design Concept

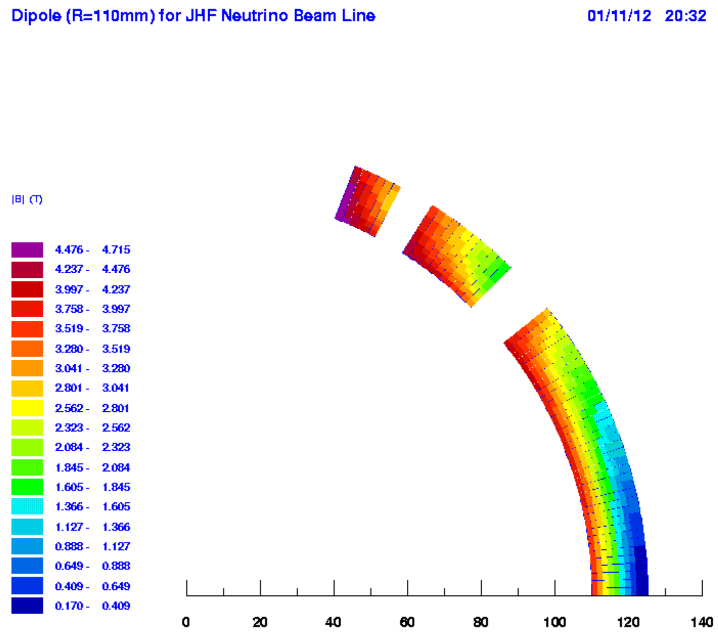
- Superconducting Cable: LHC dipole inner/outer cable (NbTi/Cu).
- Cross section: Single layer coil surrounded by plastic spacers and iron yokes.
- Plastic Spacer: No use of metallic collars → Ground insulation film are not needed.
- Some materials are commonly used in both Dipole and Quadrupole.
- Self-protected design for the magnet quench. (RHIC dipole at BNL)

Design of Super con. mag started

Bore: 180 or 220mm

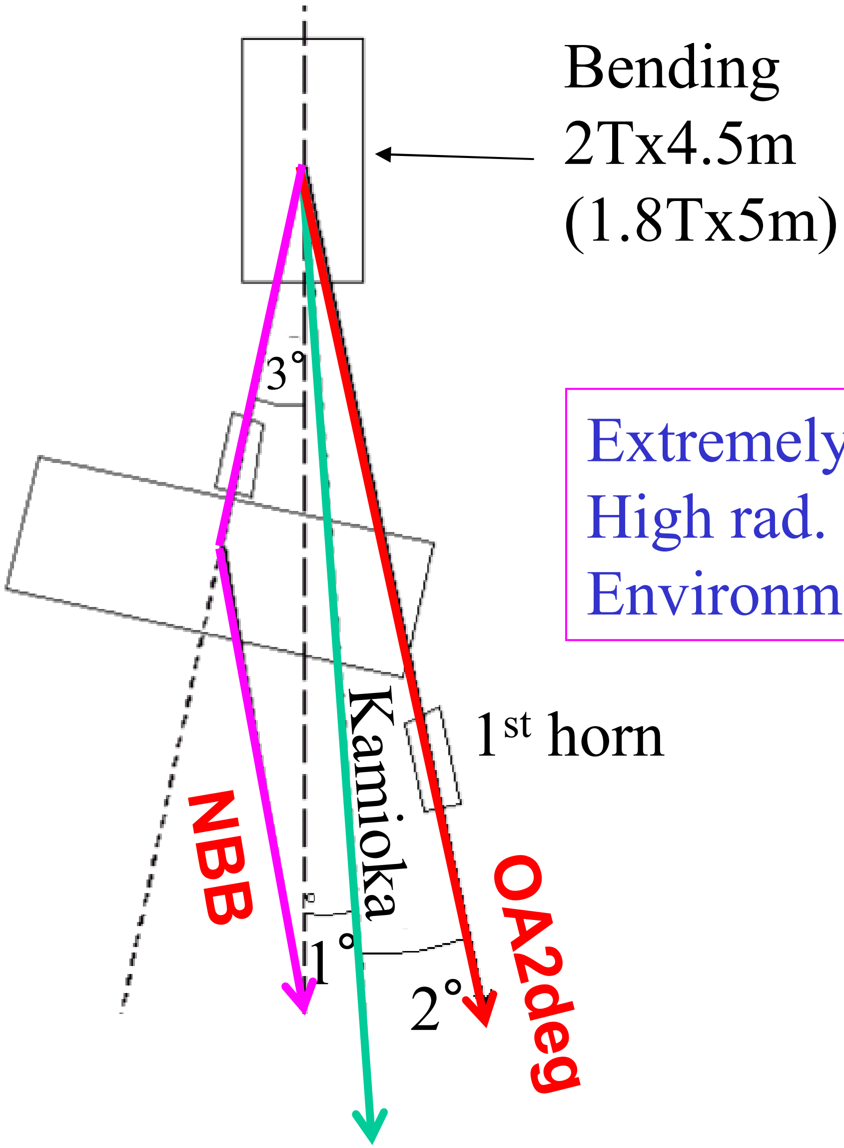


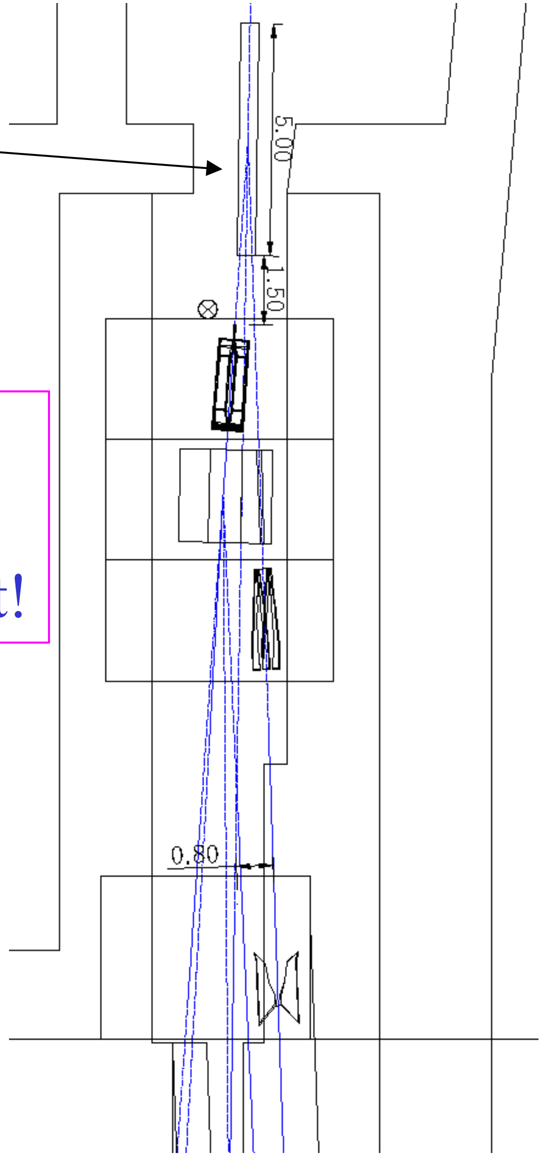
B field simulation



Cryo. Science Center of KEK

Conceptual design of target station (side view)

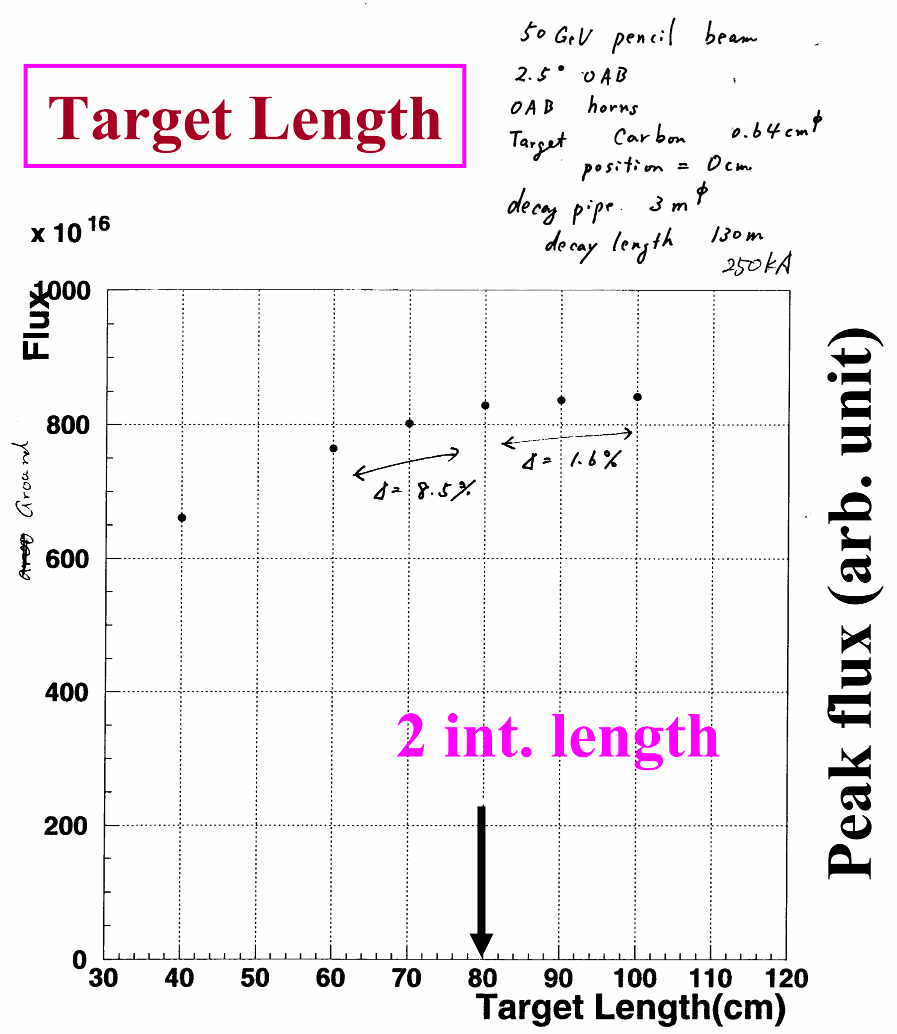




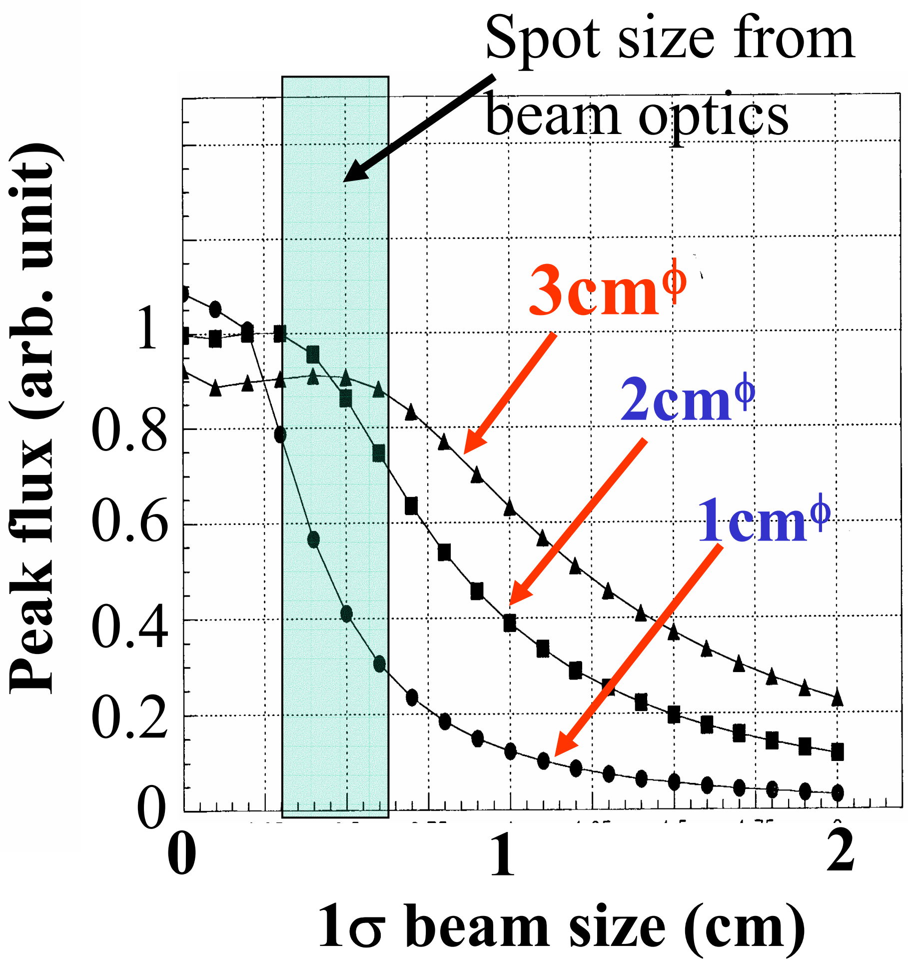
Extremely High rad. Environment!

Target optimization (Just started)

Target Length

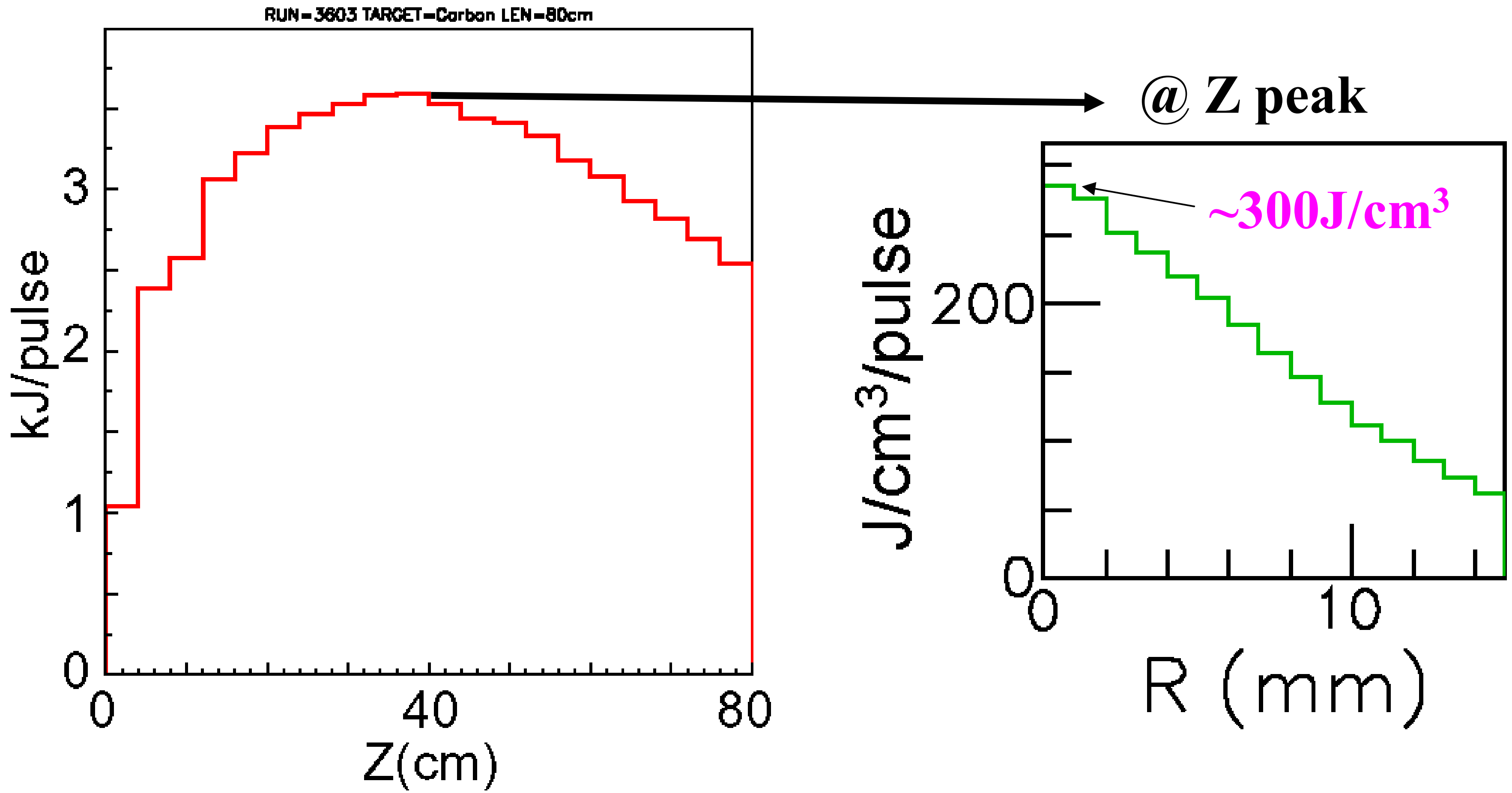


Target radius & beam size



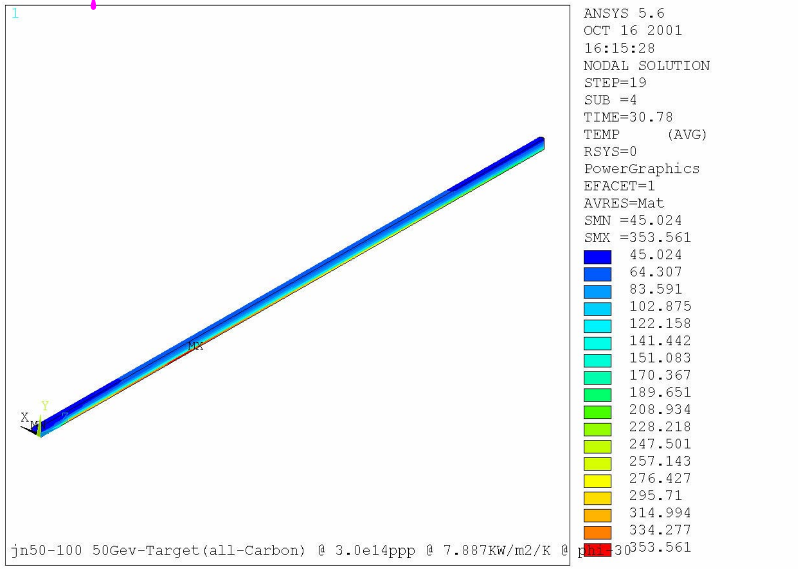
Energy Deposit in Carbon target

Total 60.8kJ/pulse

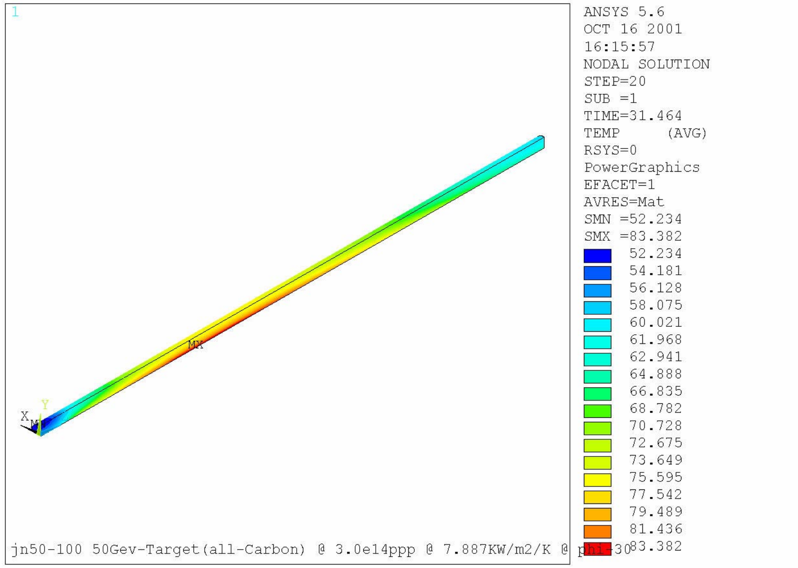


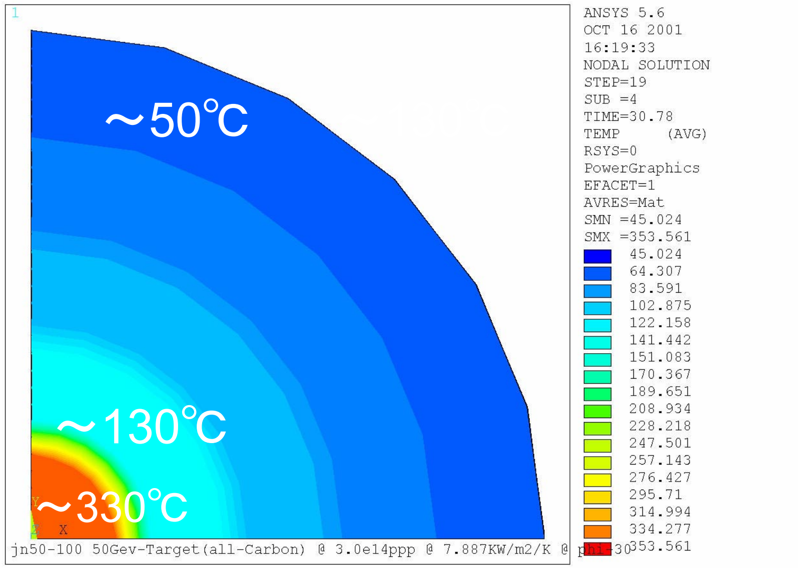
Result of heat load simulation(I)

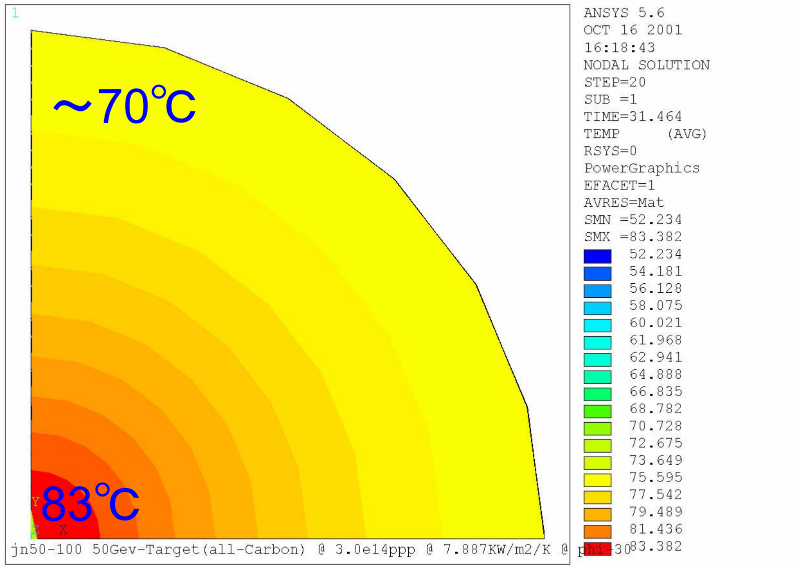
5μs



0.684s

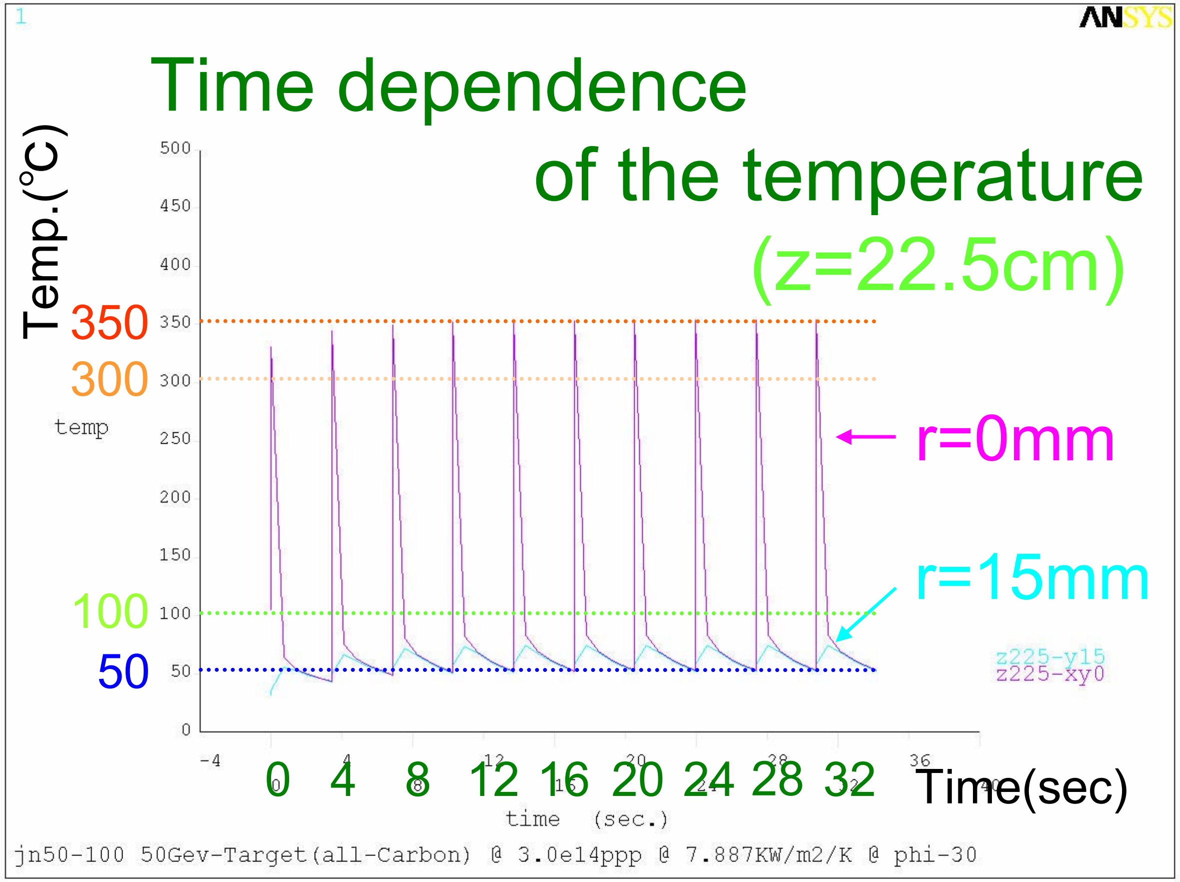






By M.Minakawa

Result of heat load simulation (II)



At the center

~350°C

At surface

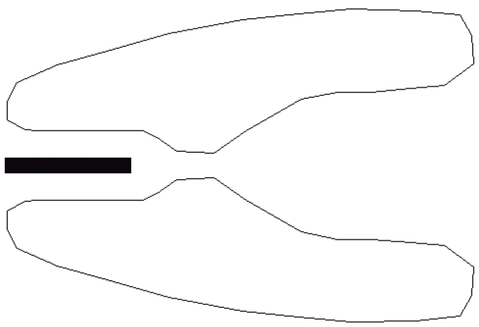
<100°C

Seems OK
for heat
(w/ this assumption)

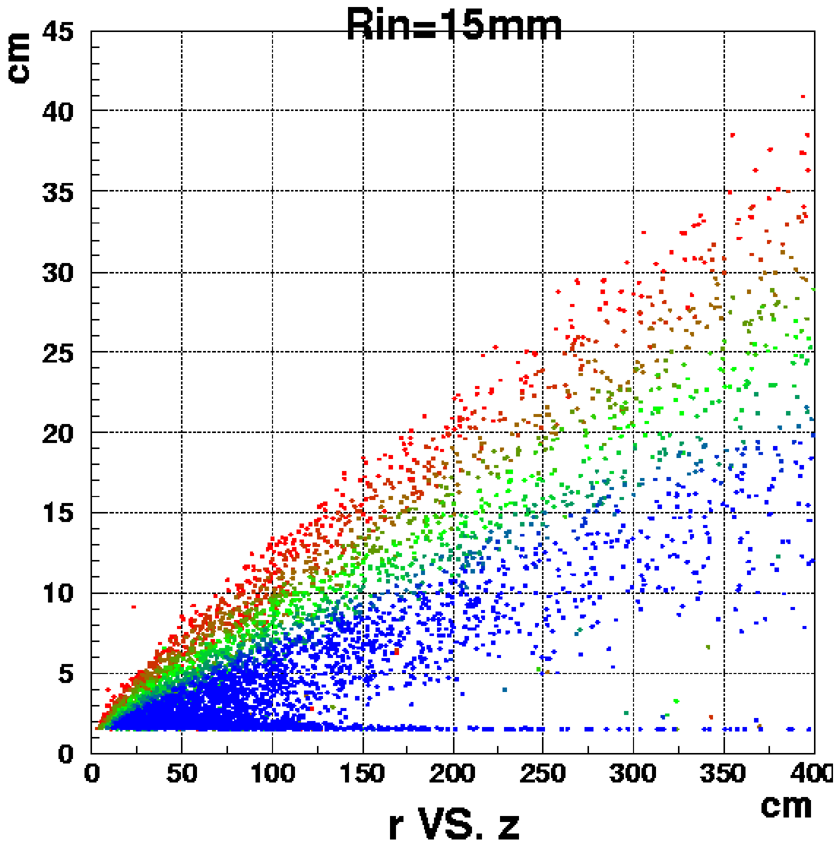
Next,
More realistic thermal conductivity with realistic design
Stress from shock wave

Opitimization of Horn (ichikawa)

Separate target from horn but inside 1st horn



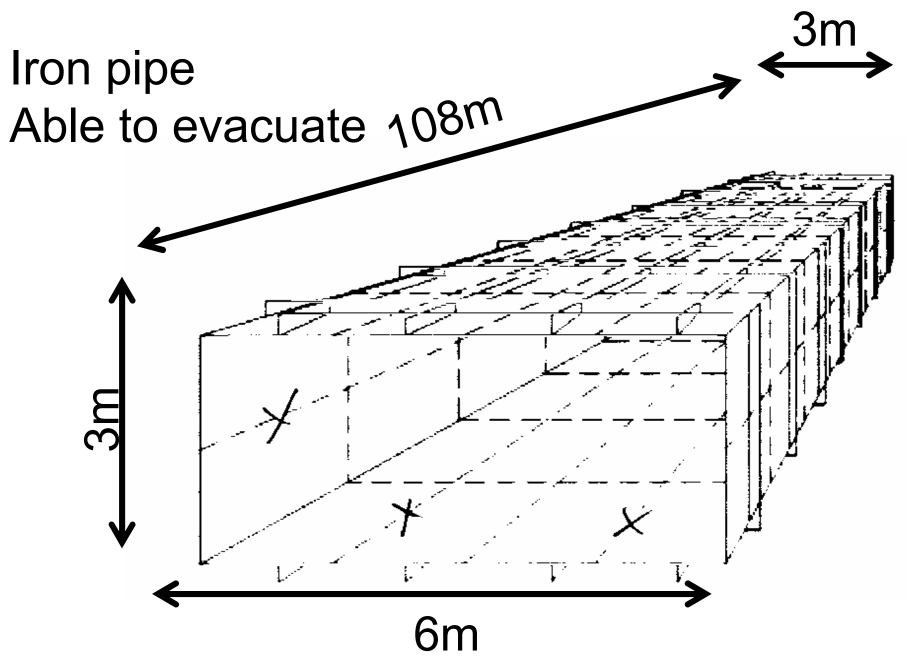
Points of pions with 0 angle



An example of simulation
to optimize Horn shape

Just started.

Conceptual design of decay pipe



Have to manufacture in 2002

at least the part beneath 3NBT

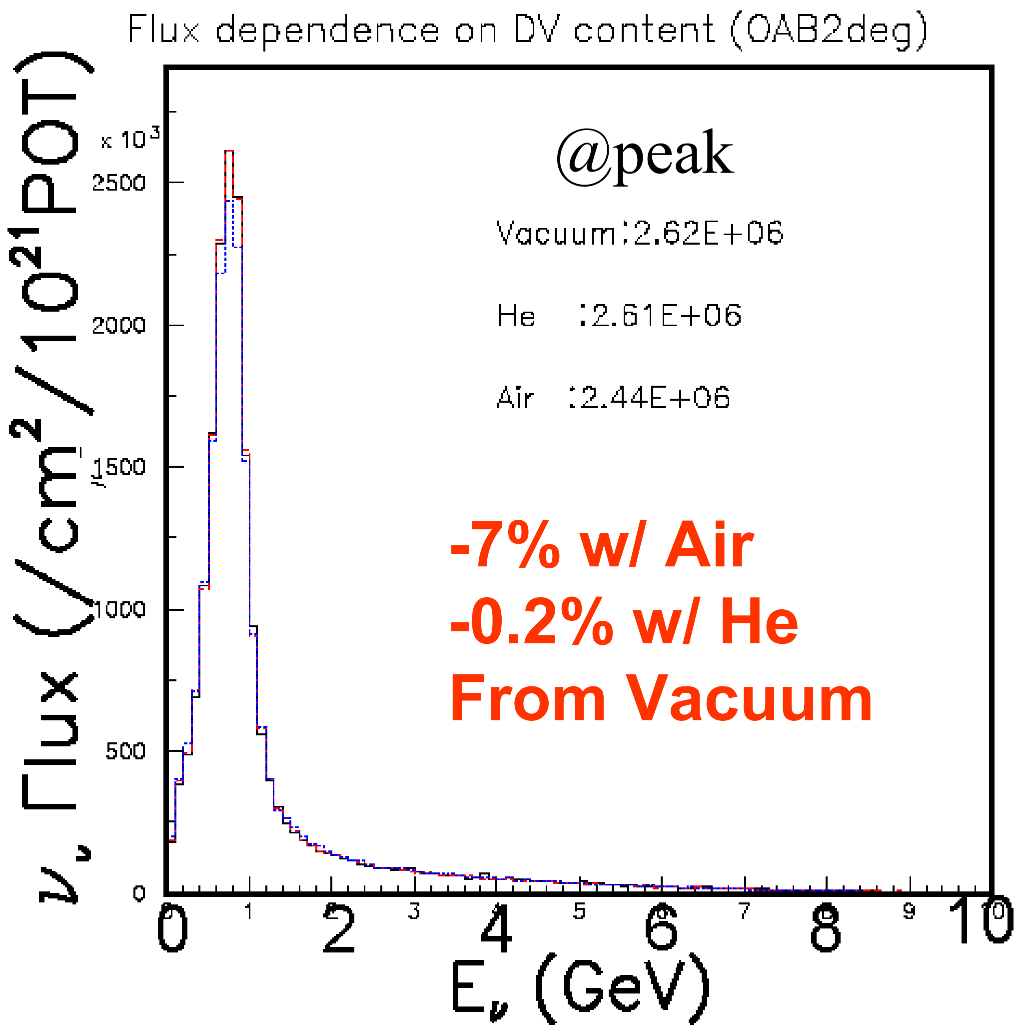
Comparison of pipe shape

Shape	Cost	Manufacturing	Assemble	Total
丸 ○	1．2	×	△	△
楕円（上面，下面は平板）	1．3	△	△	×
四角 □	1．0	○	○	○

Trapezoid pipe is best

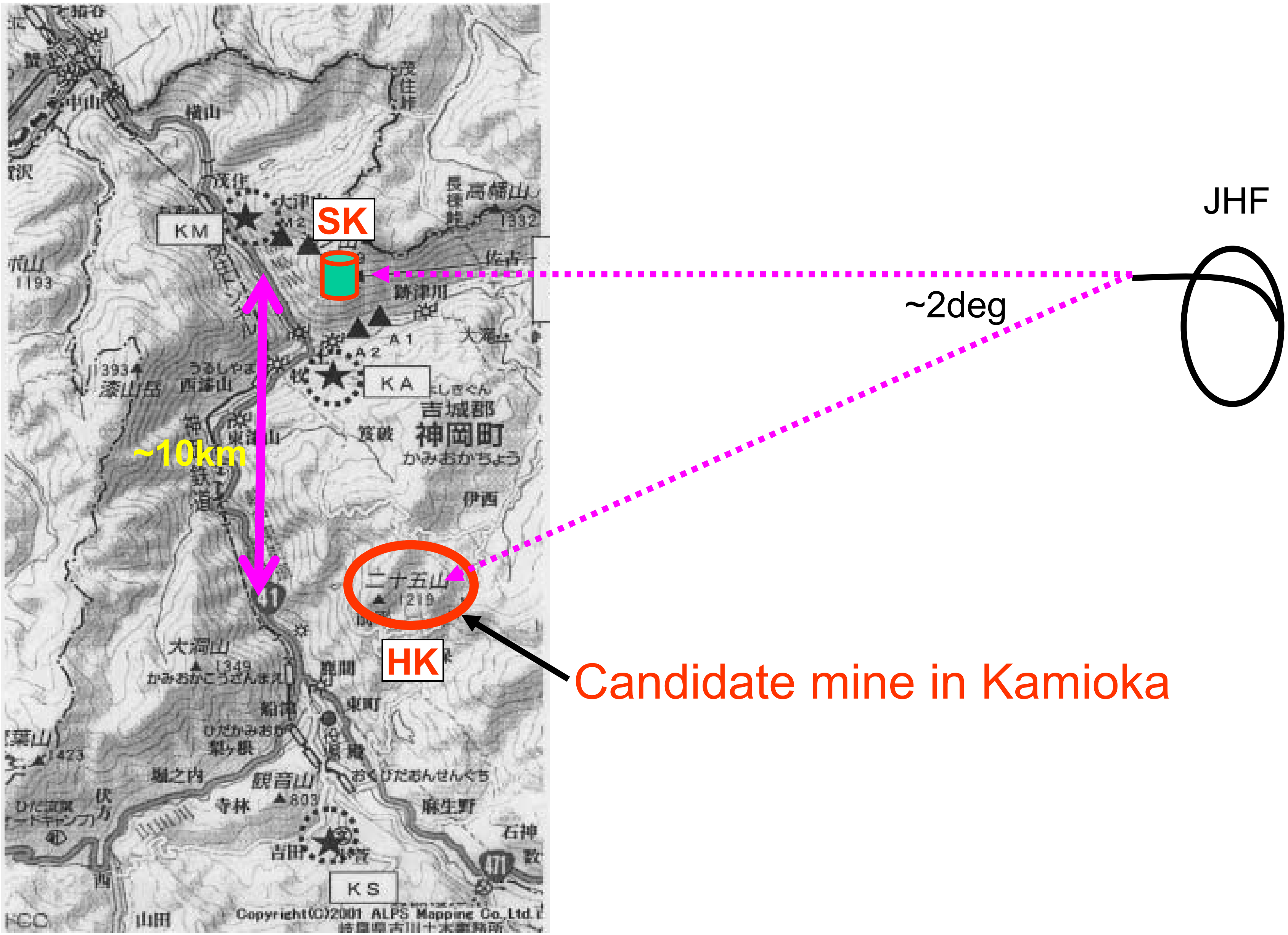
Cooling scheme to be developed.

Gas in decay volume

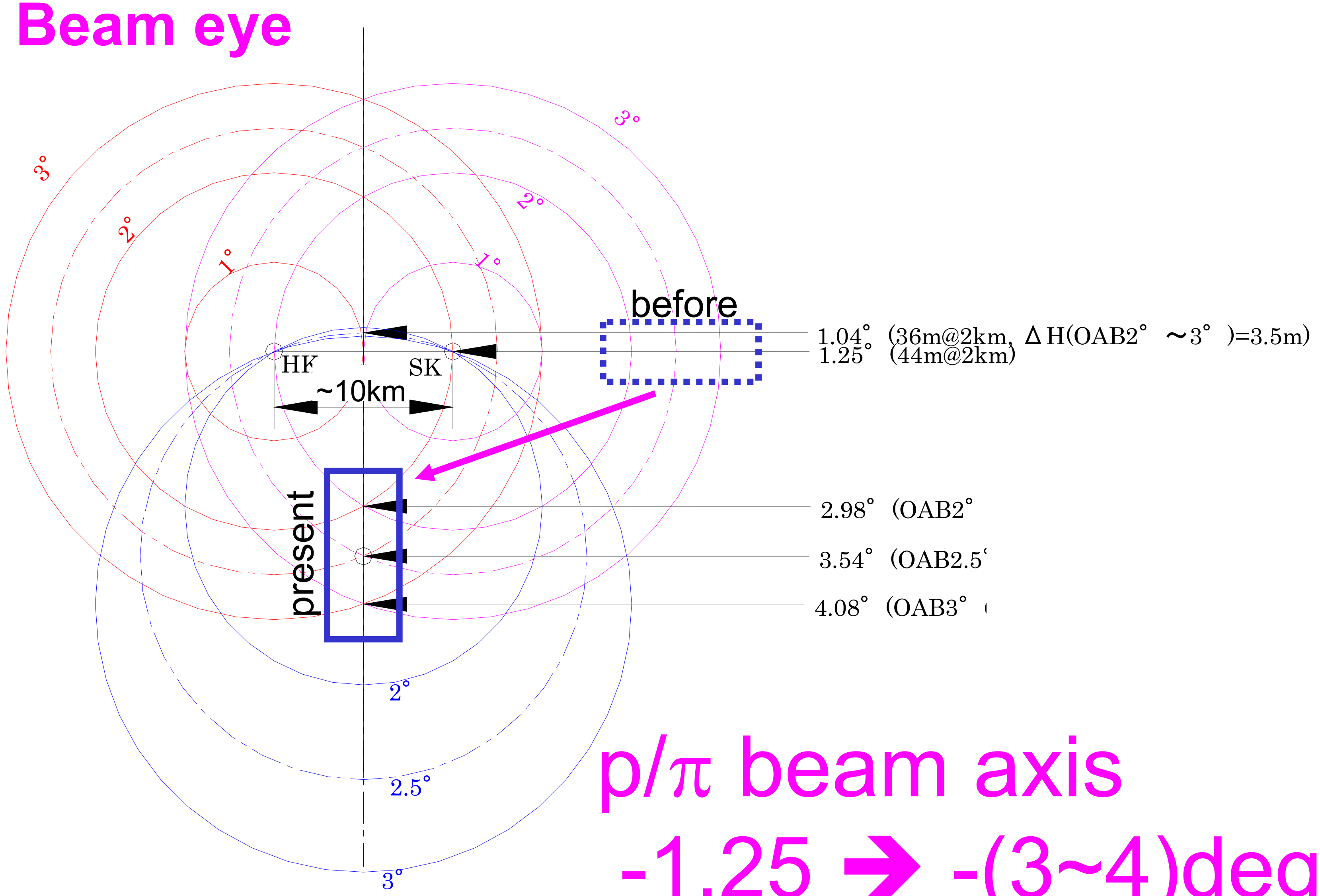


Use Helium

SK and Possible HK site



Common decay pipe for SK/HK

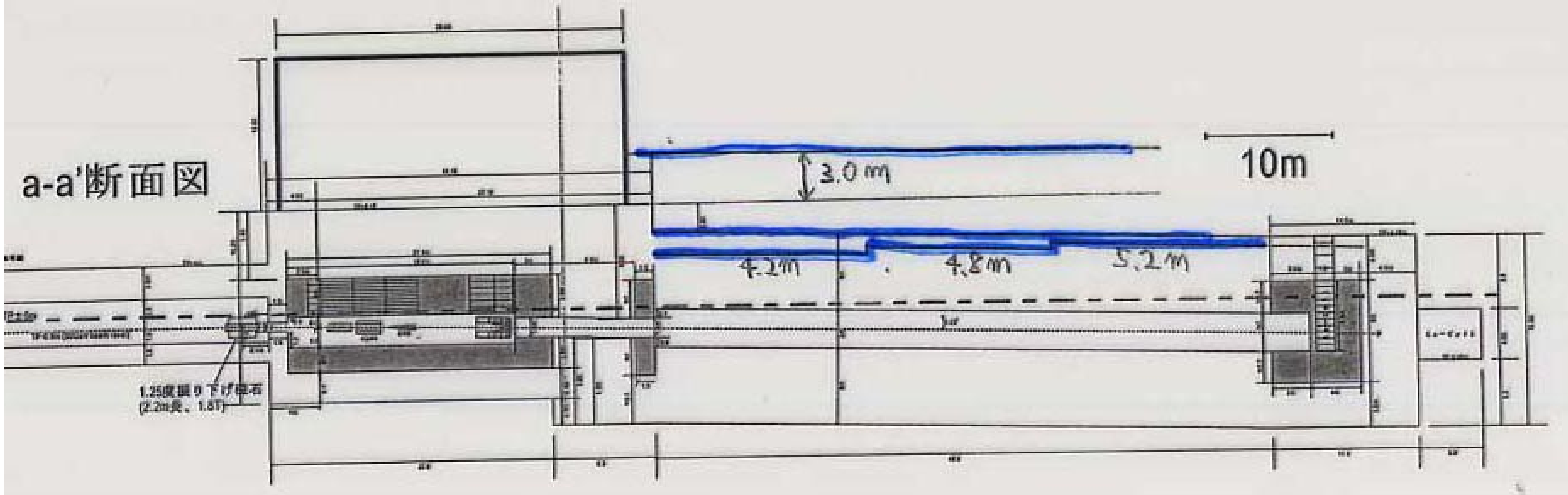


p/π beam axis
-1.25 ➔ -(3~4)deg

Ichikawa

Optimization of radiation shielding of target station and decay pipe

- The thickness of the concrete shielding should be 4.2m ~ 5.2m, where the original design is 6m.
- 3m of soil are needed over the ground level.



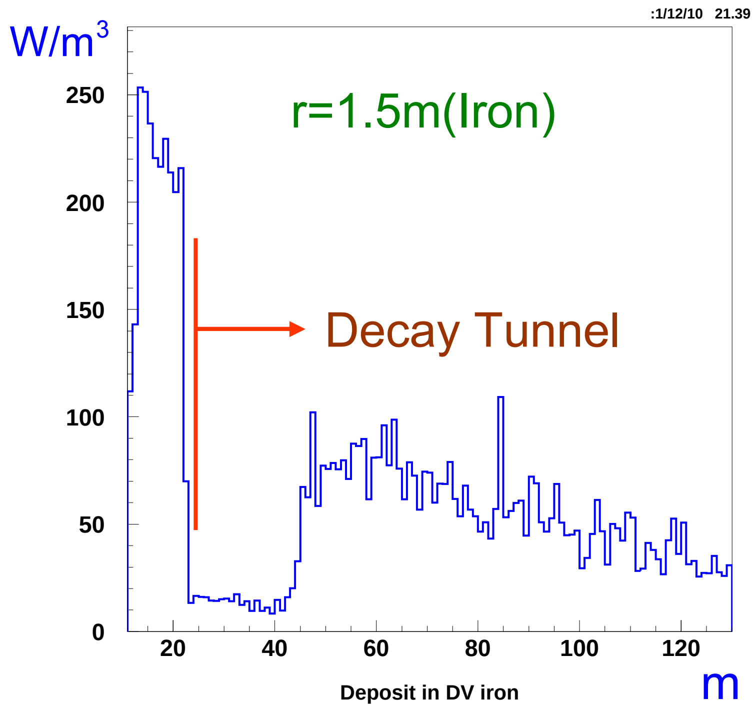
Heat load simulation in decay pipe

Simulation of the energy deposit

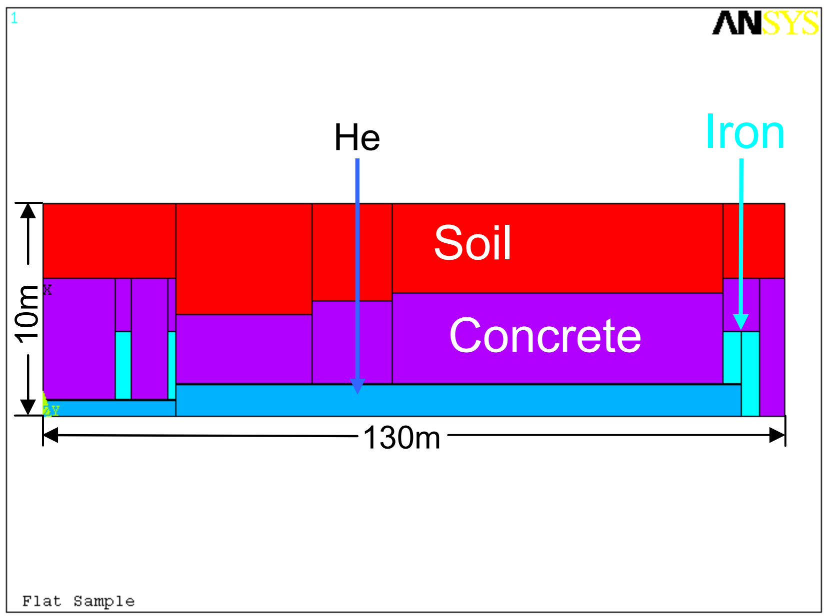
Material (Wall & Shield)	Iron + concrete
Size of the tunnel	3mϕ
Thickness of the wall	16mm of Iron
Beam	50GeV, 2.64MJ/pulse
Target	Sapphire
Simulator	GEANT + GCALOR

Simulation of the heat generation in the decay tunnel

Energy deposite (from GEANT)

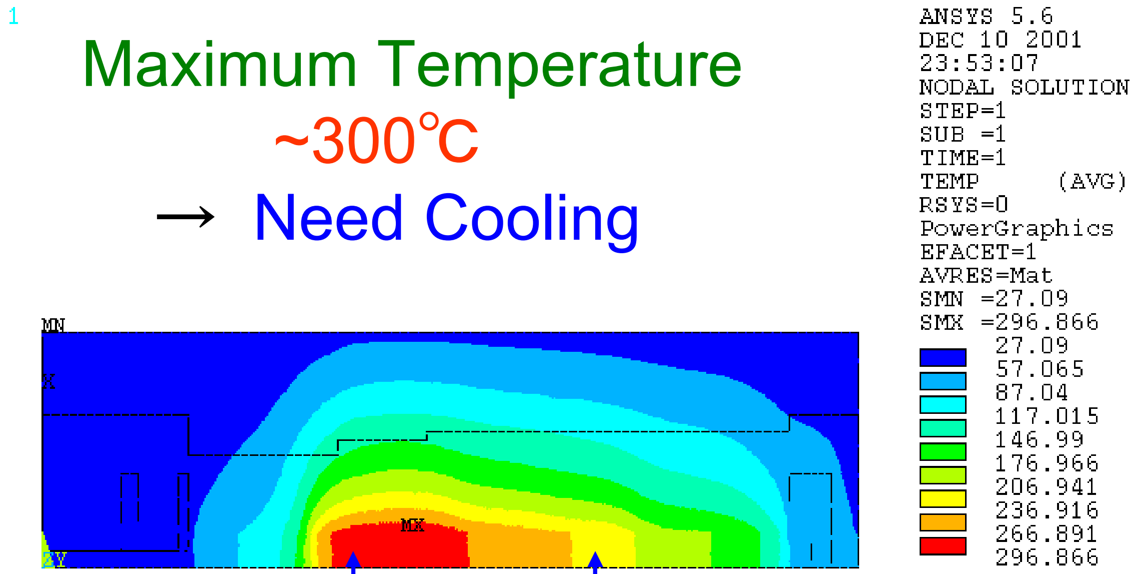


Shape of the decay tunnel and the shield



Result

Maximum Temperature
~300℃
→ Need Cooling



300℃ 220℃

Possible solutions:

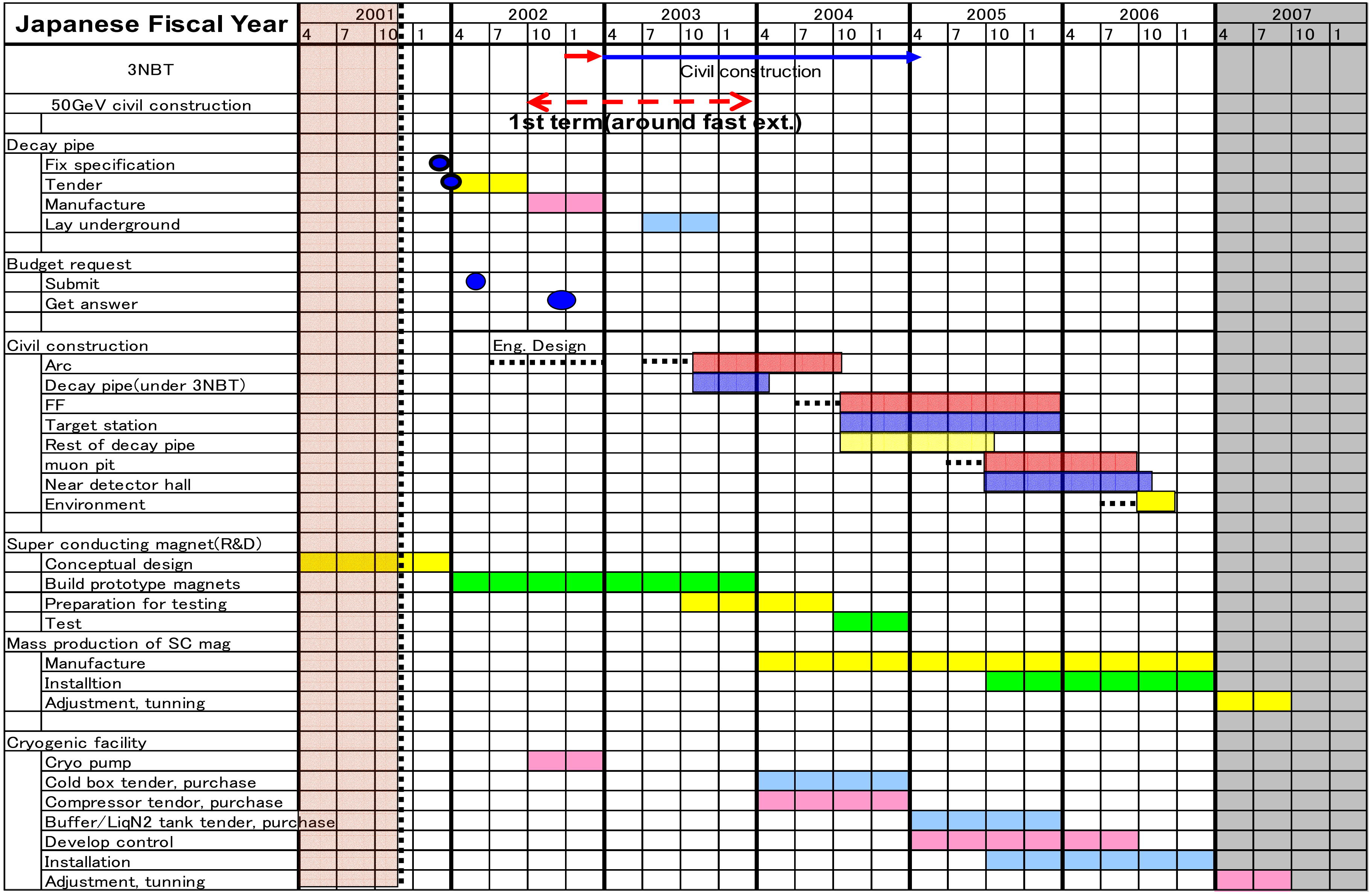
- Water cooling of the wall of the decay tunnel
- Circulation of He in the decay volume
- etc…

GPS survey

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

Noumi/Ishii/Shiino

Mile stones/Schedule



Not all items listed. We aim to complete construction by the end of JFY2006

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)
  - ✓ $\delta\sin^2 2\theta_{23} \sim 0.01$
  - ✓ $\delta\Delta m_{23}^2 < 1 \times 10^{-4} eV^2$
  - ✓ 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 $\tau \sim 1x10^{35}$($>3x10^{34}$)yr for $e\pi^0$(νK) mode

Summary(II)

- **Things are rapidly changing**
  - Choose OAB, discard WBB, NBB only for nuint.
  - 2km detector, 130m DV, common beam for SK/HK
  - But, importance of had. prod. data not changed.
- **Design, R&D of neutrino beam line have been started**
  - Facility construction group has been officially formed in KEK
  - Many things to be developed. ← **Intensity frontier!!**
- **Plan to start data taking in Apr. 2007**

  No change due to SK accident at all
- **Neutrino facility not approved yet but…**

  Plan to submit budget request in 2002

  (and answer will come Dec. 2002…….)

Supplement

$\nu_\mu \rightarrow \nu_e$ oscillation probability(1)

Control size **Control matter effect**

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2} (1 - 2S_{13}^2)\right)$$

$$+8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \sin \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$

CPV

$$+4S_{12}^2 C_{13}^2 \left\{C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta\right\} \sin^2 \frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 S_{13}^2 S_{23}^2 \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \frac{aL}{4E} (1 - 2S_{13}^2)$$

$\delta \rightarrow -\delta$, $a \rightarrow -a$ for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

Matter eff.:

$$a = 7.56 \times 10^{-5} [\mathrm{eV}^2] \cdot \left(\frac{\rho}{[\mathrm{g/cm^3}]}\right) \cdot \left(\frac{E}{[\mathrm{GeV}]}\right)$$

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

CP measurement

Observables

$$N_e(E_{rec}) = N_{obs}(E_{rec}) - N_{BG}(E_{true})$$
$$= \int dE_{true} \Phi_\mu(E_{true}) \cdot P_{\mu\to e}(E_{true}) \cdot \sigma_e(E_{true}) \cdot \varepsilon_e(E_{true}) \cdot r_e(E_{true}, E_{rec})$$

μ flux **cross sec.** **det.eff** **det.responce**

unfold det. responce

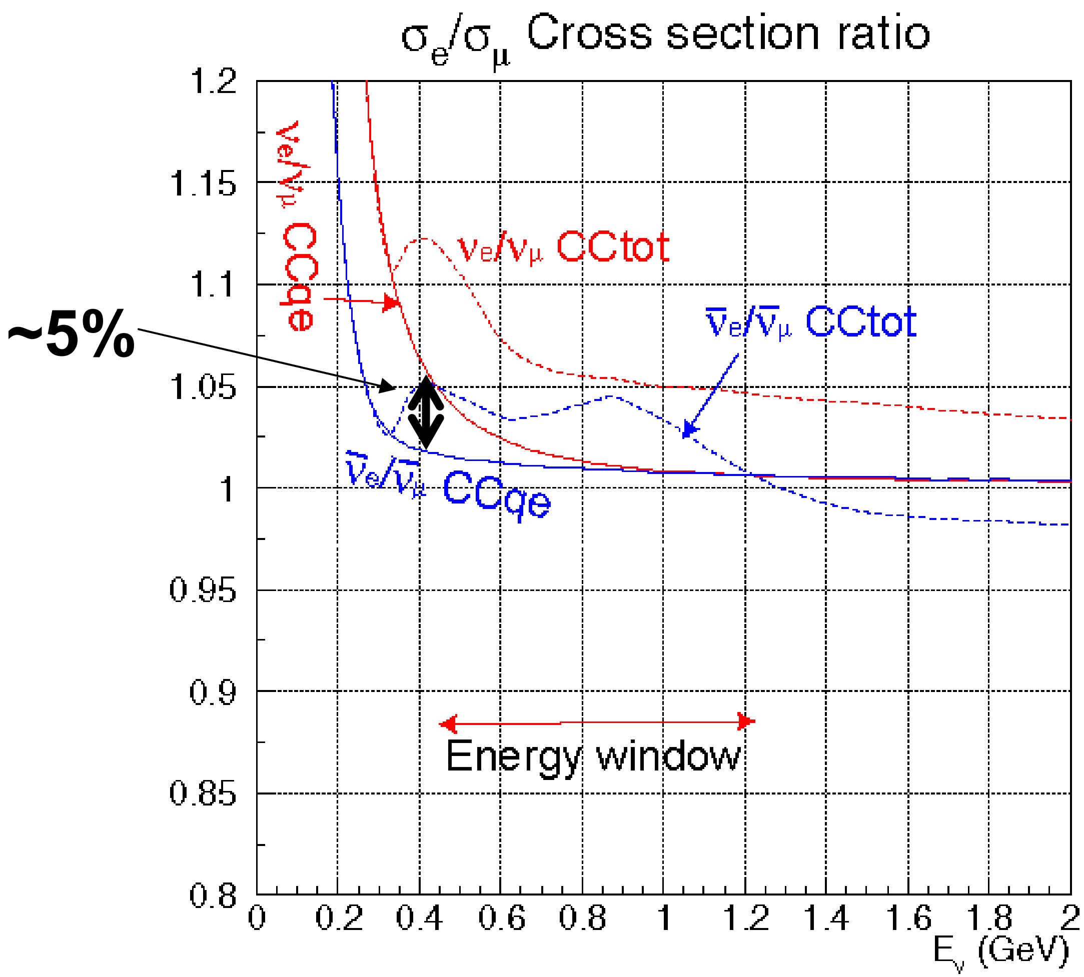
$$N_e(E_{true}) = \Phi_\mu(E_{true}) \cdot P_{\mu\to e}(E_{true}) \cdot \sigma_e(E_{true}) \cdot \varepsilon_e(E_{true})$$

Divide by exp'ed # of ν_μ events w/o oscillation

r_σ r_ε

$$P'_{\mu\to e}(E_{true}) \equiv \frac{N_e(E_{true})}{N_\mu^{\exp}(E_{true})} = \frac{N_e(E_{true})}{\Phi_\mu^{\exp} \cdot \sigma_\mu \cdot \varepsilon_\mu} = \frac{N_e(E_{true})}{\Phi_\mu^{\exp} \cdot \sigma_e \cdot \varepsilon_e} \times \frac{\sigma_e \cdot \varepsilon_e}{\sigma_\mu \cdot \varepsilon_\mu}$$
$$= P_{\mu\to e}(E_{true}) \cdot r_\sigma(E_{true}) \cdot r_\varepsilon(E_{true})$$

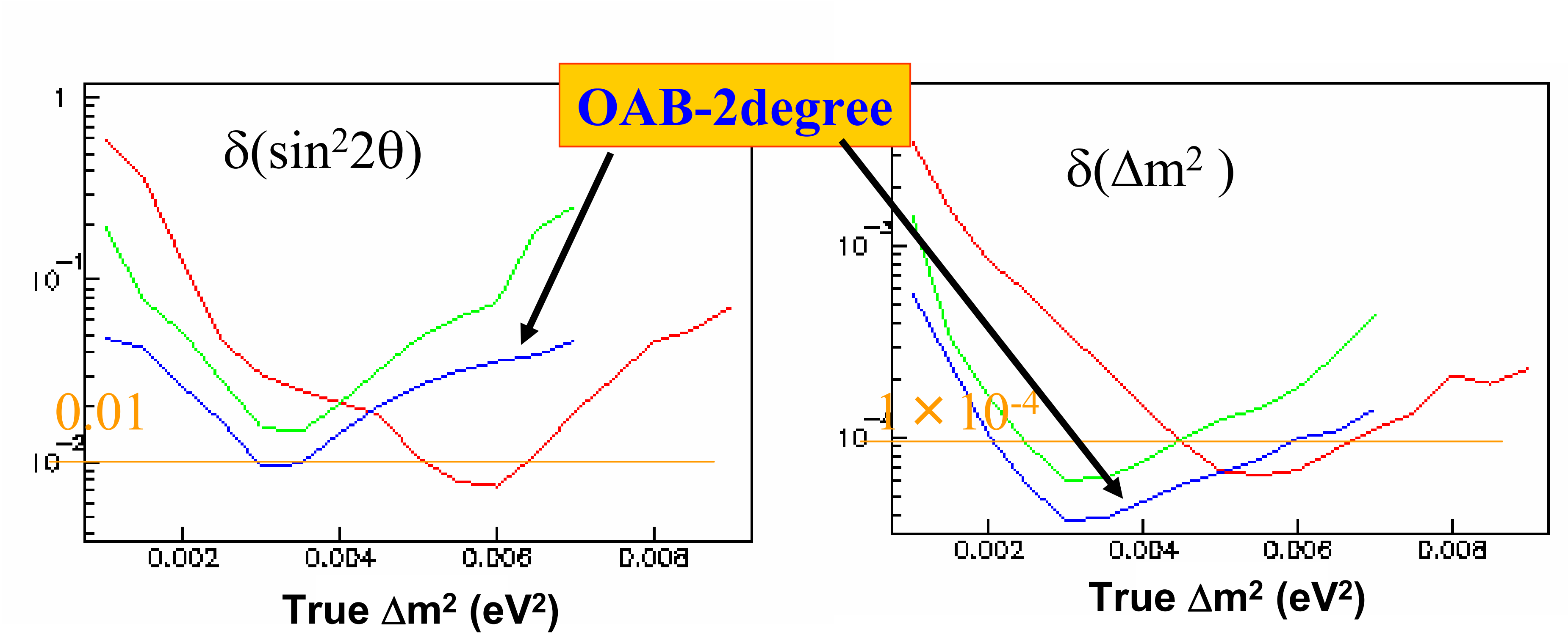
Cross section difference



CCqe ratio diff
1~5% @ energy window

Quick rise in low energy side → need detailed info.
→ cross section measurement? (νfact?)

ν_μ disappearance: 5 years precision

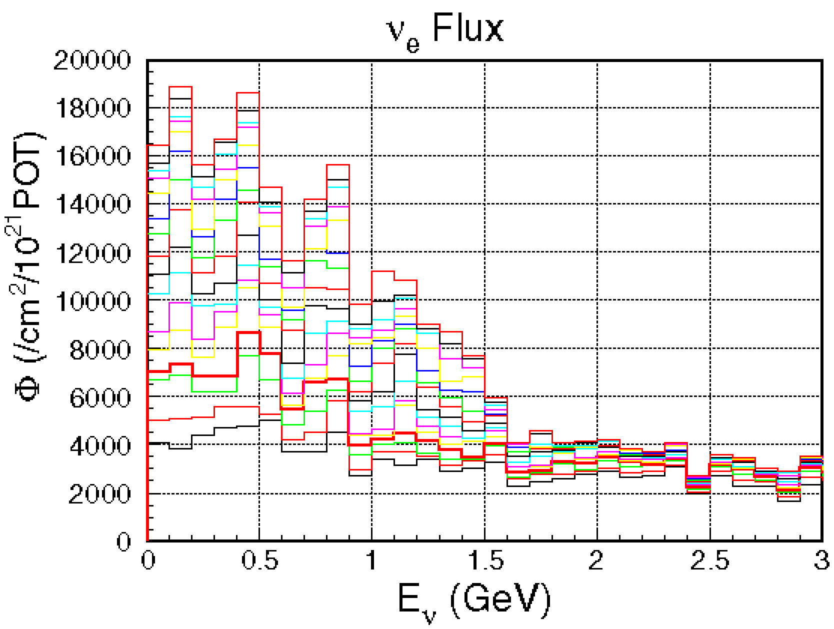


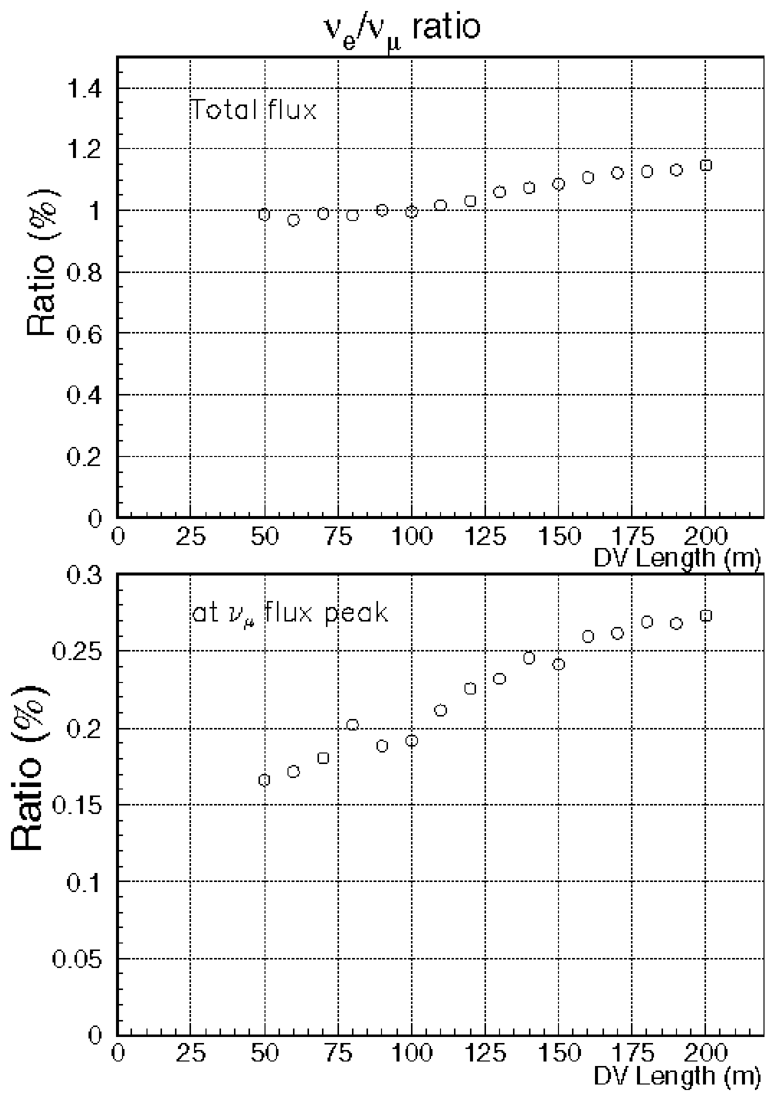
$\delta(\sin^2 2\theta)\sim 0.01$ in 5 years

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

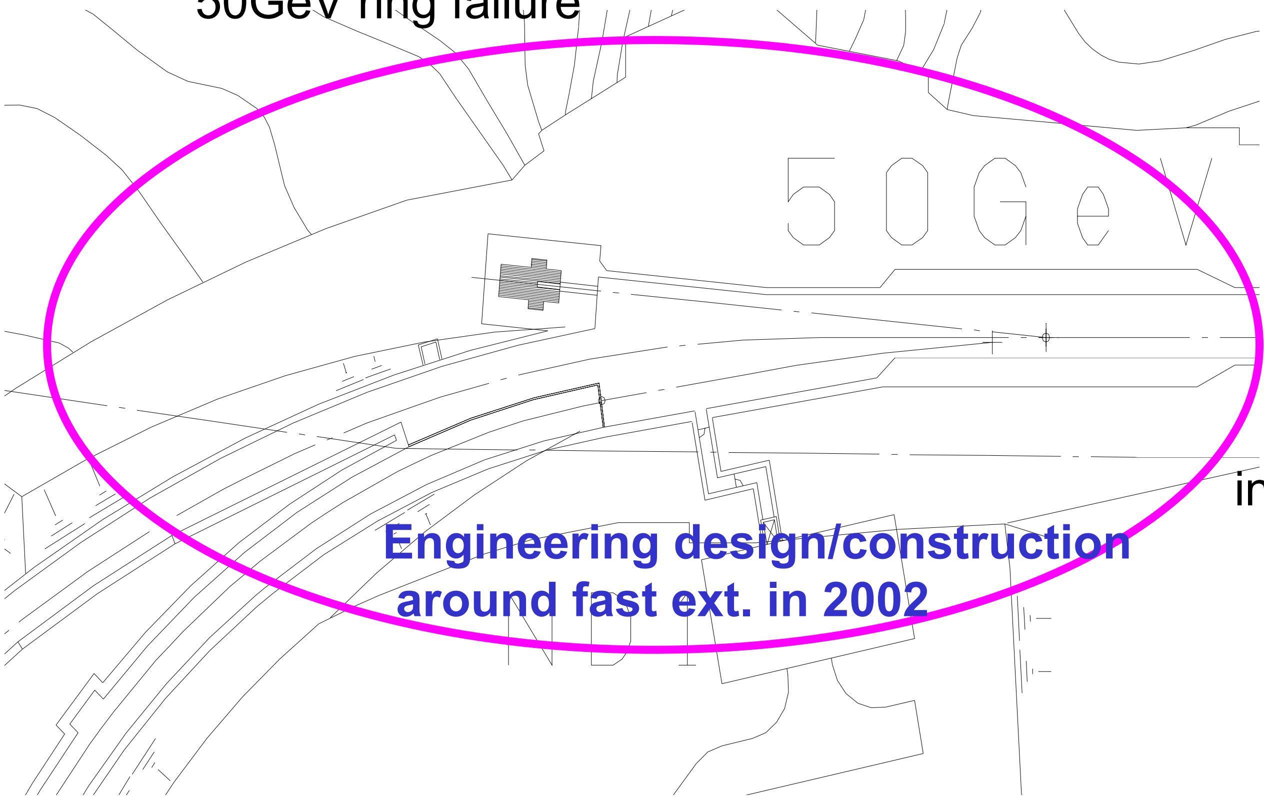
Decay pipe len 80m→130m

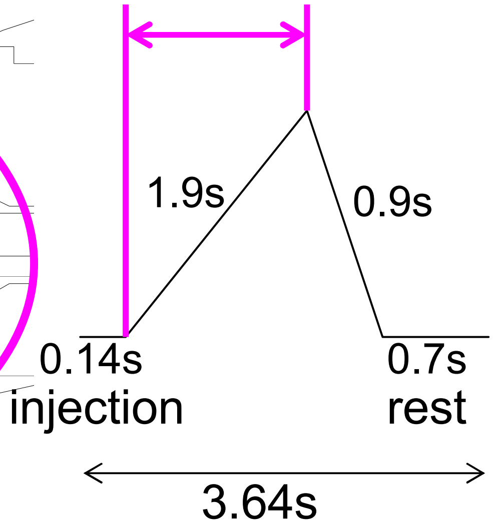
ν_e contamination





Beam (50GeV) abort (fast)





Position/scheme of beam abort not settled yet.

This may give significant modification on ν facility design depending on solution

Urgent task

Expected Signal & BG

4MW, 1Mt, ν_μ2yr, ν_μ6.8yr, $\sin^2 2\theta_{13}$=0.1(Chooz)

ν_μ beam	Signal	BG				
		Total	νμ	νμbar	νe	νebar
Gen'ed in FV	40k		878k	99k	28k	4.7k
Selected	8893	1691	686	122	834	49
			41%	7%	49%	3%
Efficiency	22%		0.08%	0.12%	3.00%	1.04%
QE	8404	w/π0	613	96	33	3.4
from En>1.2GeV			355	115	196	20

νμ BG: 88%π^0, 58%HE

wrong sign cont. small

$\bar{\nu}_\mu$ beam	Signal	BG				
		Total	νμ	νμbar	νe	νebar
Gen'ed in FV	40k		1079k	830k	44k	30k
Selected	9272	3572	799	1316	594	862
			22%	37%	17%	24%
Efficiency	23%		0.07%	0.16%	1.35%	2.89%
QE	8228	w/π0	714	1112	50	28

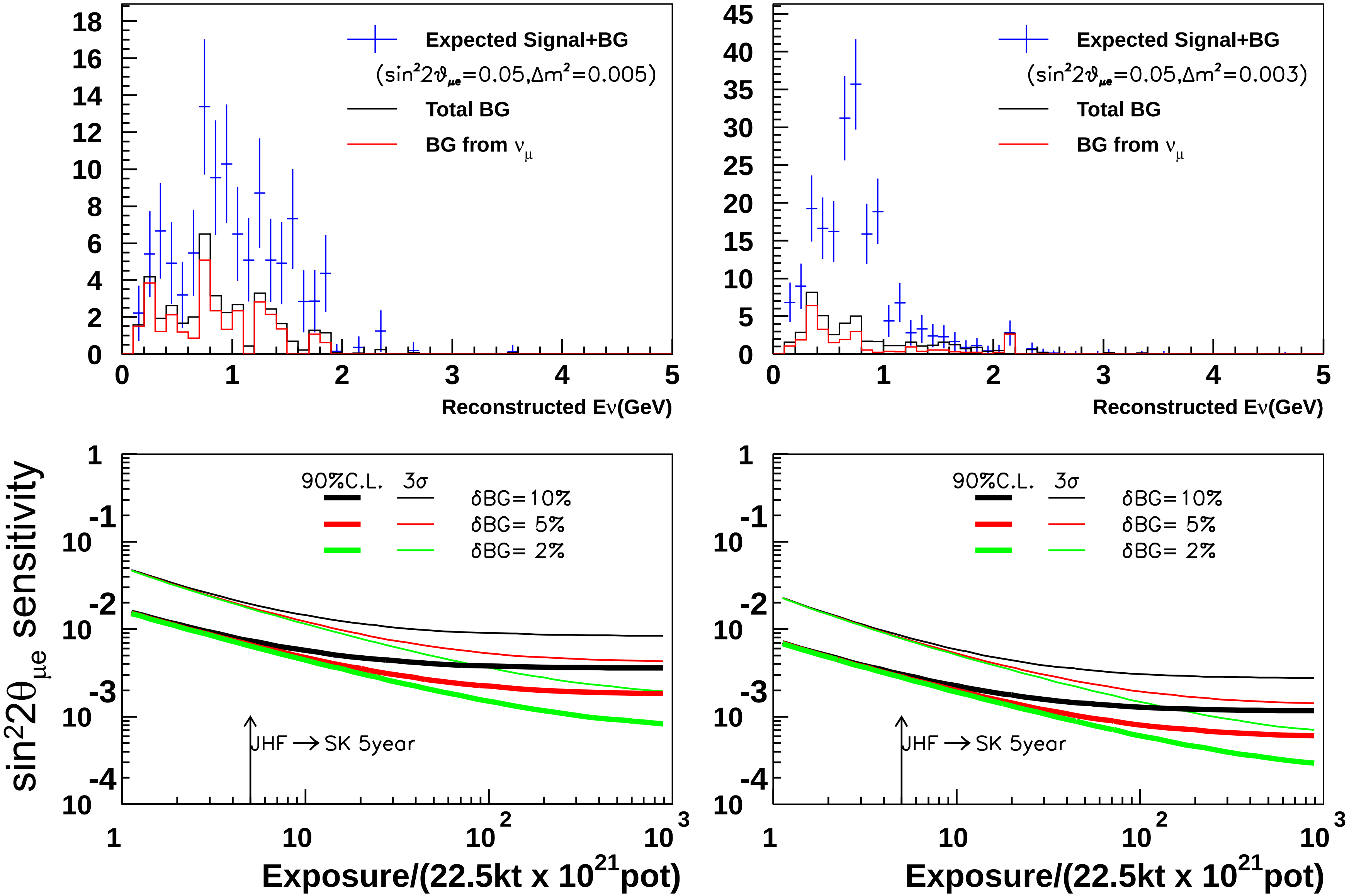
All src. compara.

νμ BG: 86%π^0, 67%HE

Signal: ~90% CCQE

Sensitivity for Mixing Angle

WBB 5year | **Off Axis (2°) 5year**



1. Target

Simulation of the energy deposit

Material	Carbon
Size of the target	3cmϕ x 80cm
	(2 interaction length)
Beam	50GeV, 2.64MJ/pulse
	$(\sigma_x = \sigma_y = 5mm)$
Simulator	GEANT + GCALOR

→ 60.8kJ/pulse (2.3%) in total

Simulation of the heat generation at the target

Simulator

ANSYS

Material properties of Carbon

Density

2.27 g/cm^3

Specific heat

1.612 J/cm^3/K

Thermal conductivity

19.6 W/cm/deg

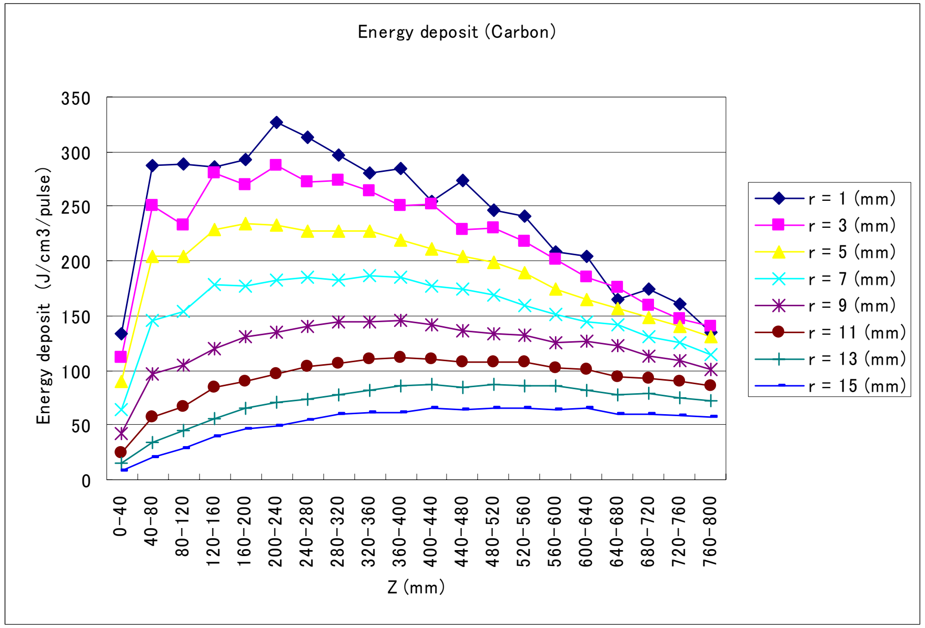
Thermal convection coeff.

7.887 kW/m^2/K

Melting point

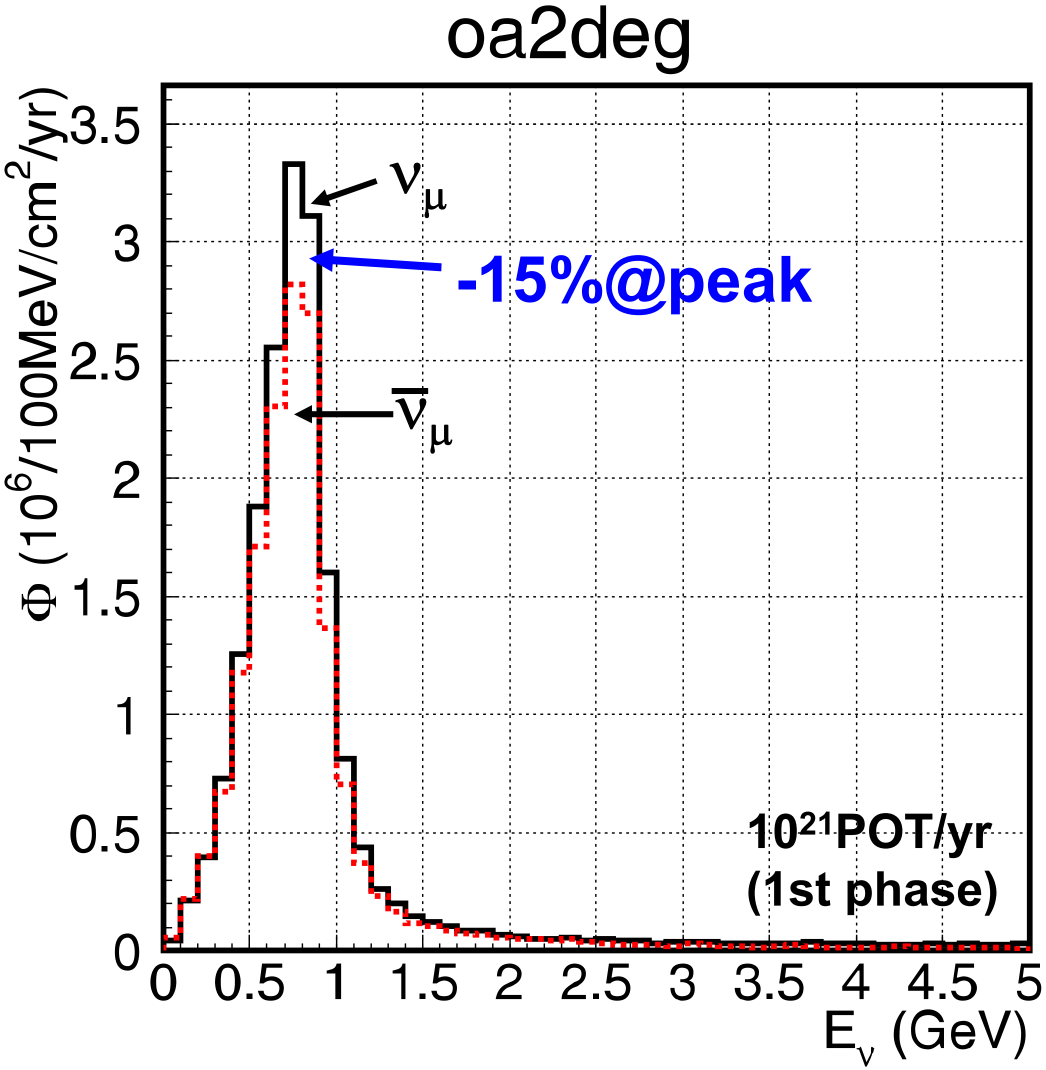
3550 ℃

Energy deposit (from GEANT)

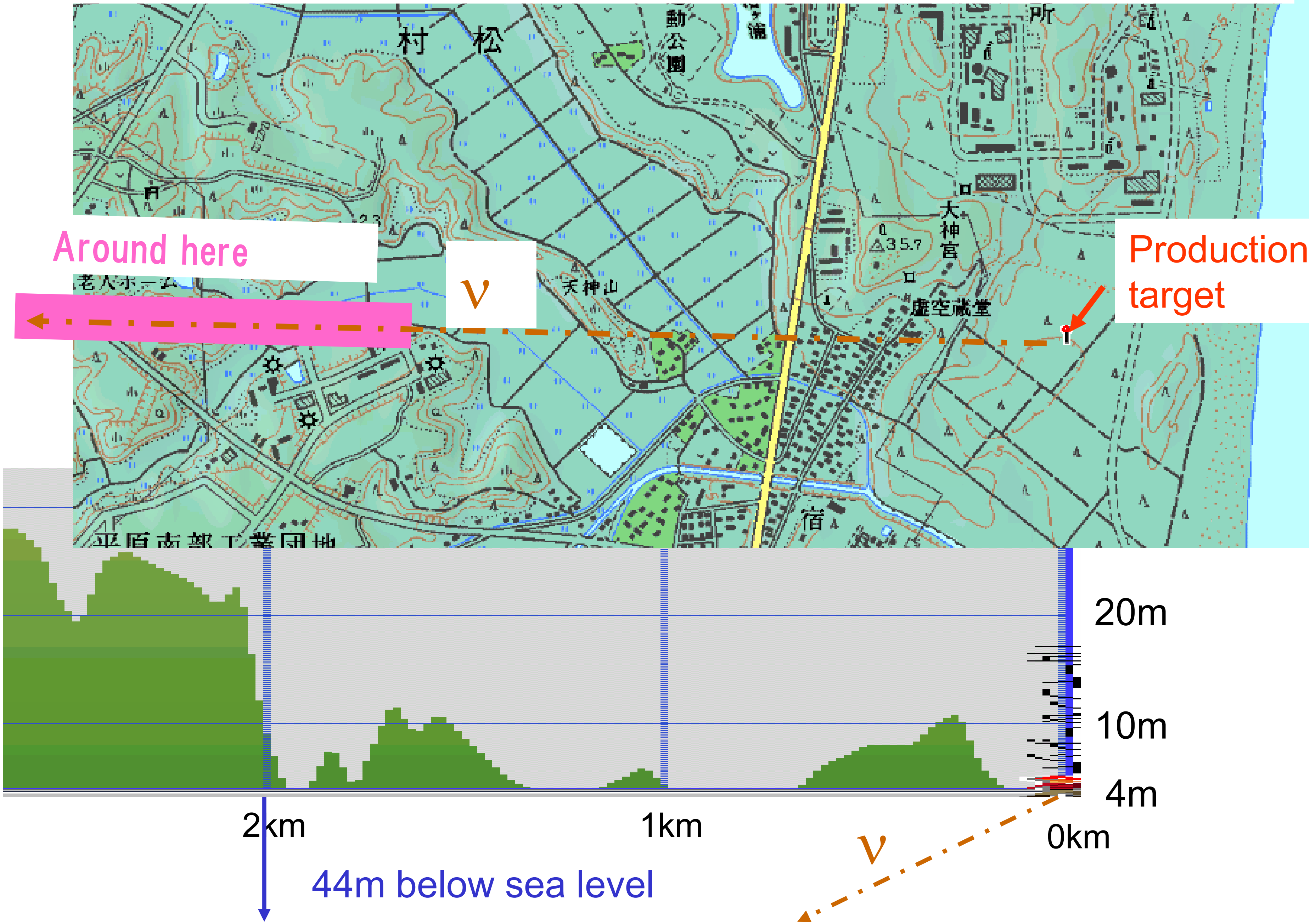


$\nu_\mu / \overline{\nu_\mu}$ flux for CPV meas.

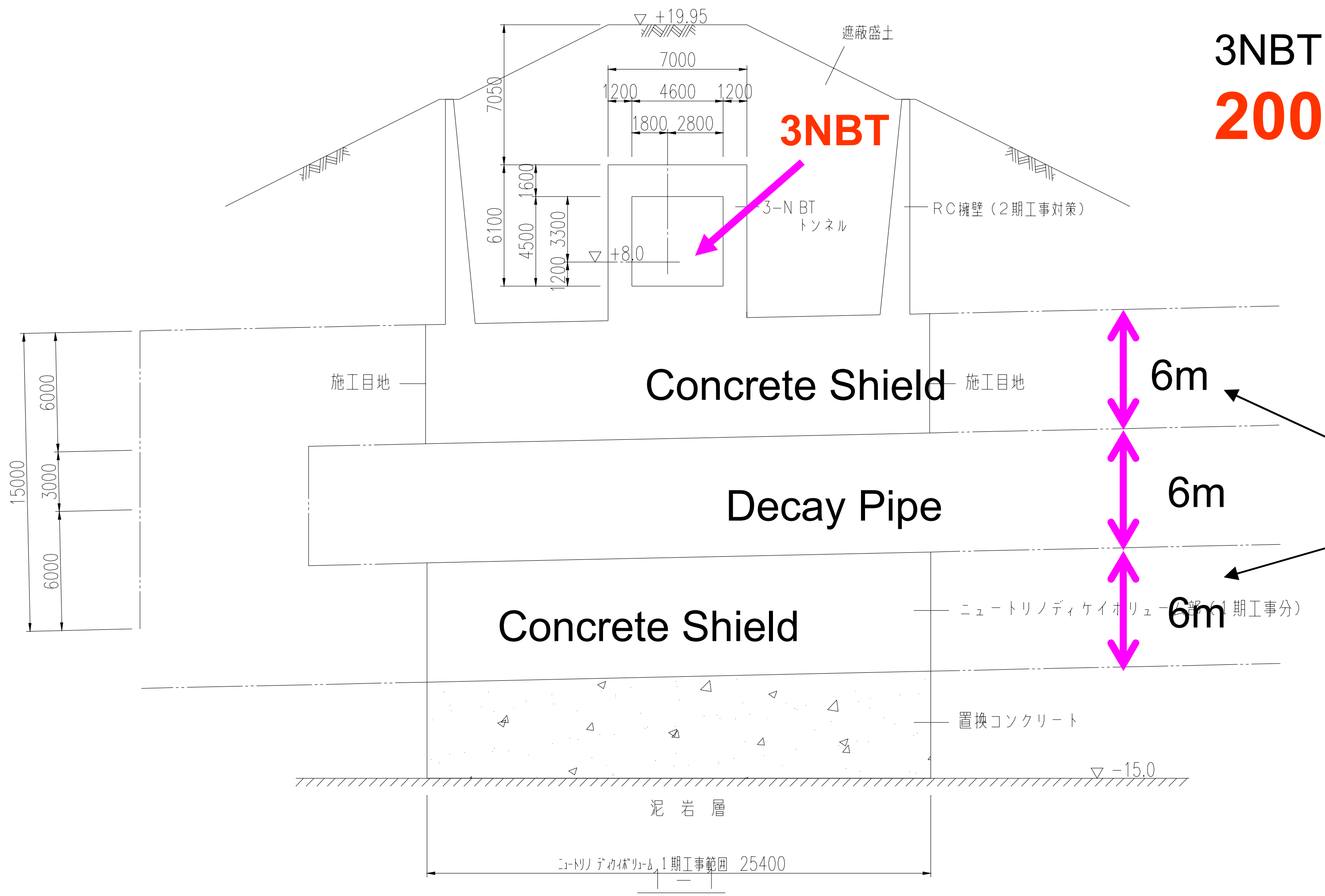
Sign flip by just changing horn polarity



Candidate sites for 2km front detector



Decay pipe (3NBT cross)



3NBT construction

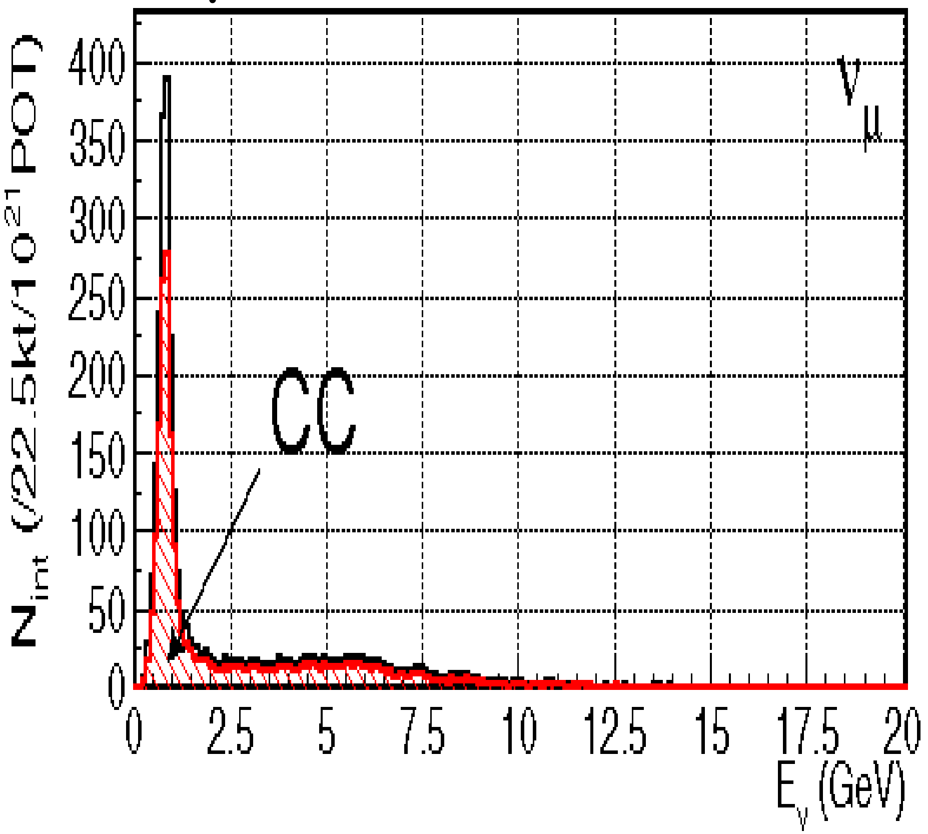
2003~

need to be minimized

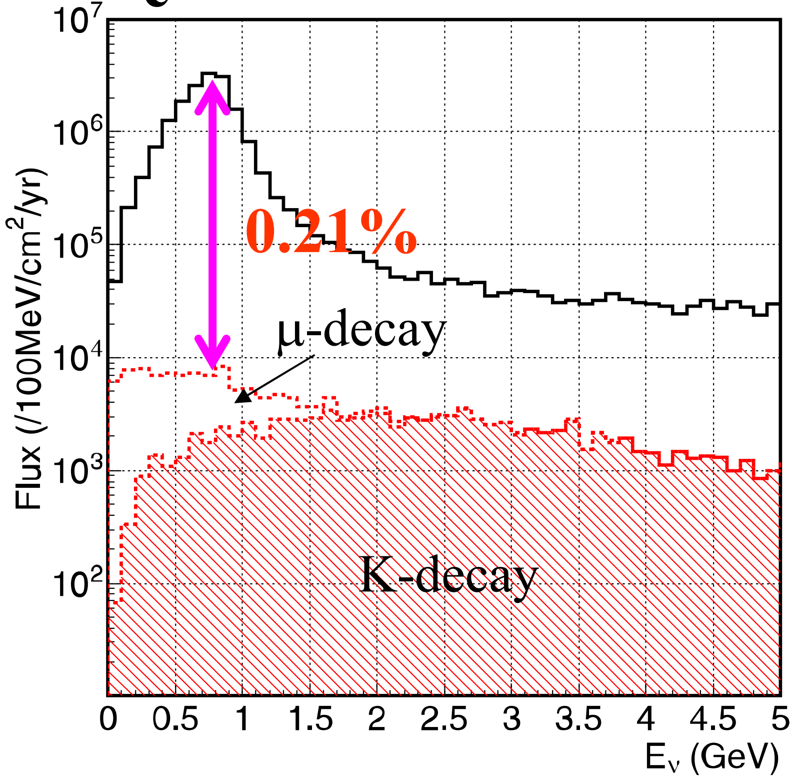
Expected spectrum

OAB2°

ν_μ



ν_e contamination



~3100 tot int/22.5kt/yr

~2200 CC int/22.5kt/yr

Very small ν_e/ν_μ @ ν_μ peak

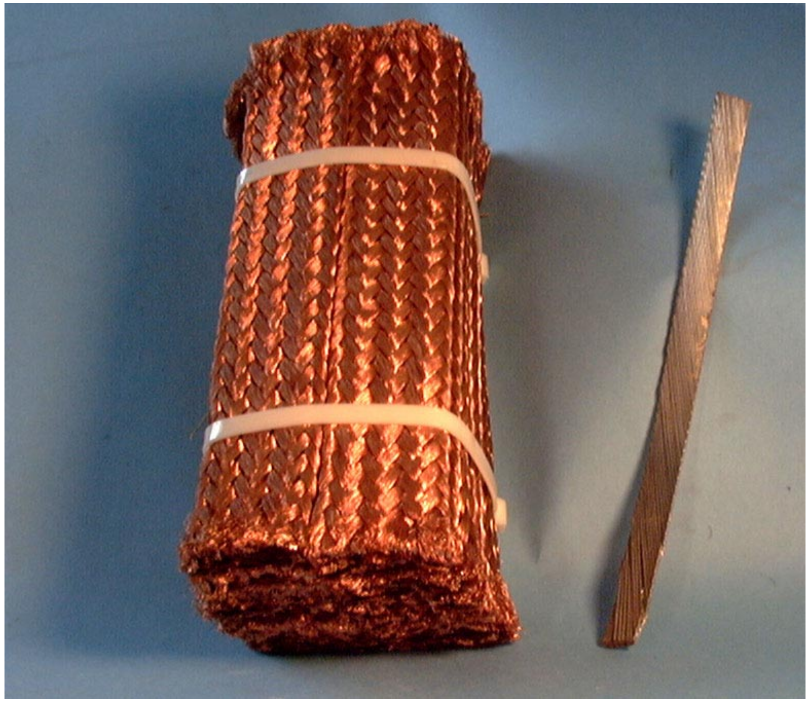
(still for 80m pipe len)

Super conducting magnet design (cont'd)

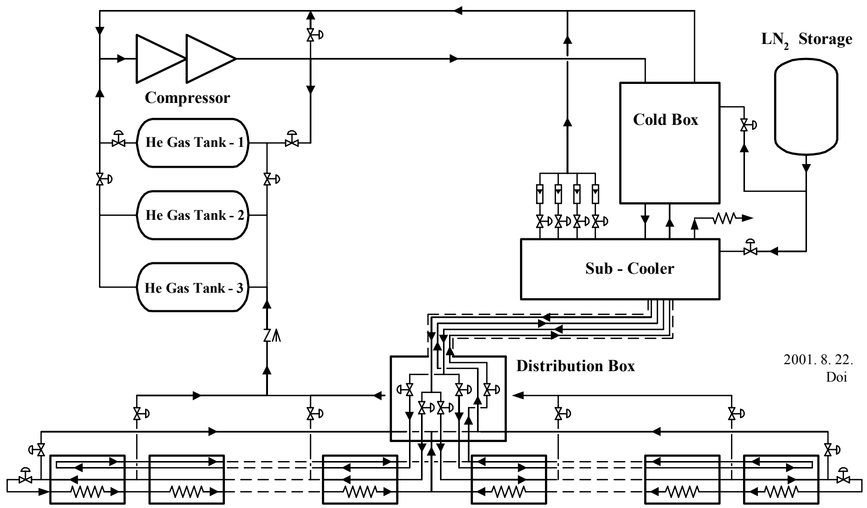
- Superconducting Cables

  : Insulated by Polyimide Film

		D=220mm LHC-Dipole-Inner Cable	D=180 mm LHC-Dipole-Outer Cable
Strand	Diameter [mm]	1.065±0.0025	0.825±0.0025
	Copper to super ratio	1.6~1.7±0.03	1.9~2.0±0.03
	Filament size [□m]	7±0.1	6±0.1
	Filament spacing [□m]	>1	>1
	Number of filaments	8700~8900±20	6300~6550±20
	RRR	>70	>70
	Twist pitch [mm]	18±1.5	15±1.5
	Critical current, 1.9K [A]	>515 @10T	>380 @9T
	n value at 7 T, 4.2 K	>30	>30
	Thickness of coating [□m]	1	1
Cable	Number of strands	28	36
	Thickness [mm]		
	Thin	1.900±0.006	1.480±0.006
	Center	1.736±0.006	1.362±0.006
	Thick	2.064±0.006	1.598±0.006
	Width [mm]	15.1±0.02	15.1±0.02
	Cable twist pitch [mm]	115±5	100±5
	Keystone angle [deg.]	1.25±0.05	0.90±0.05
	Critical current, 1.9K [A]	>13750@10T	>12960@10T
	Cross-contact resistance [□□]	~15	~40



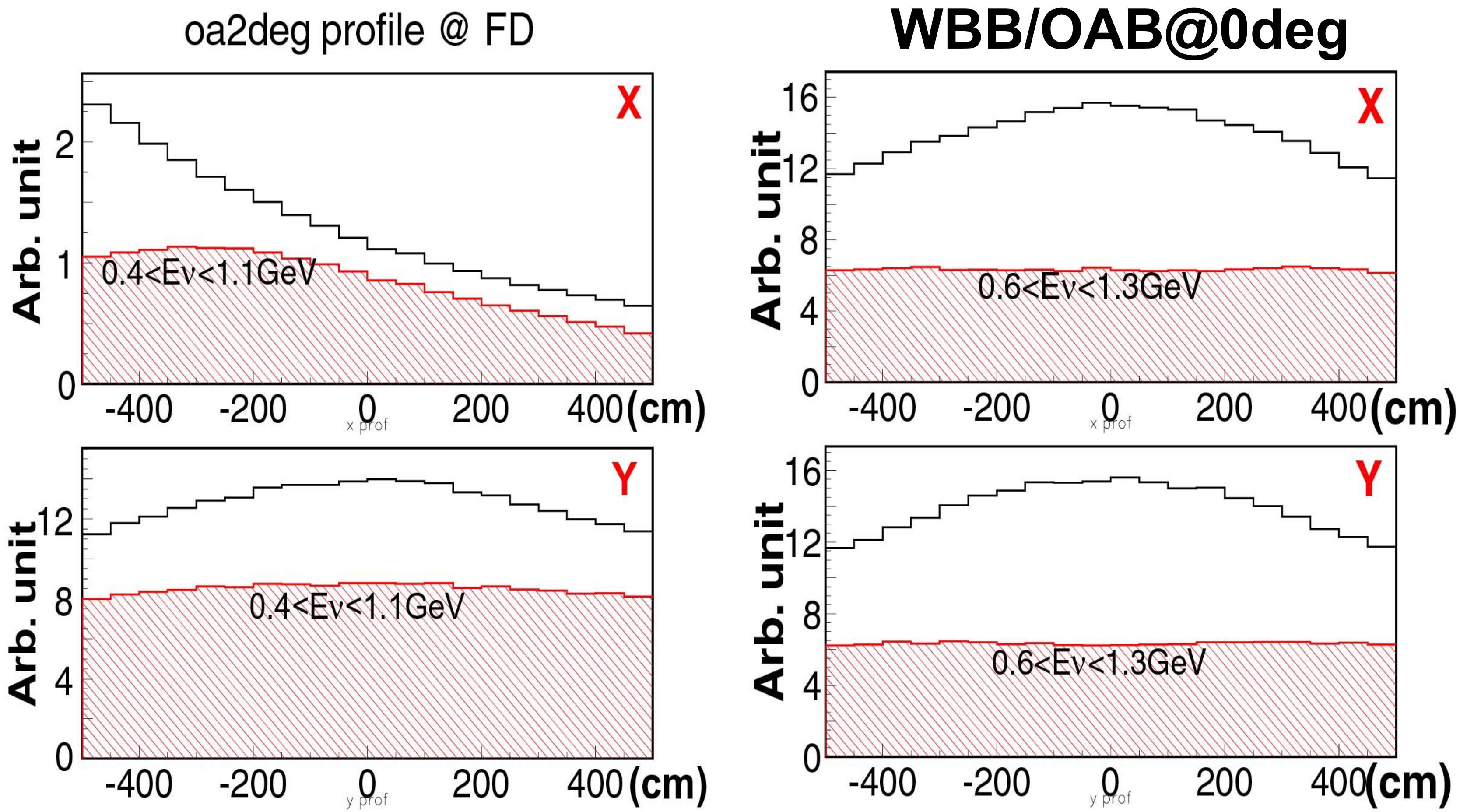
Low T facility



A candidate design

Y.Doi

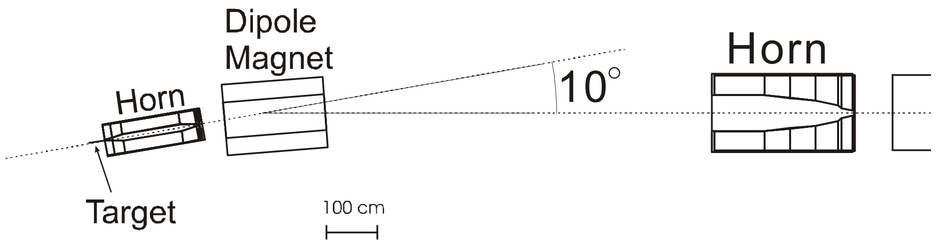
Neutrino profile @ FD

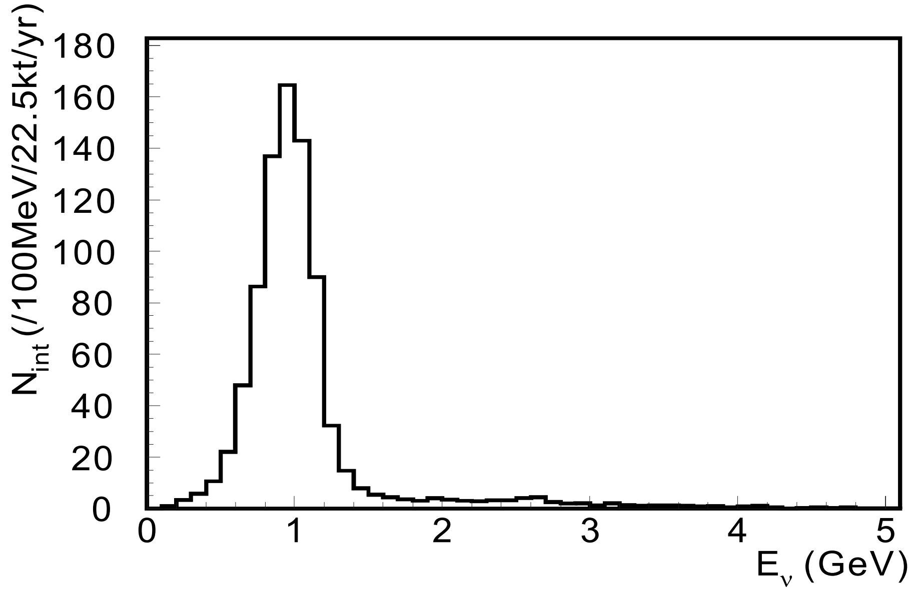


OAB direction can be monitored w/ beam profile on beam axis.

Low energy component has very wide spread.→ may need another method

Narrow Band Beam for ν int study @ near

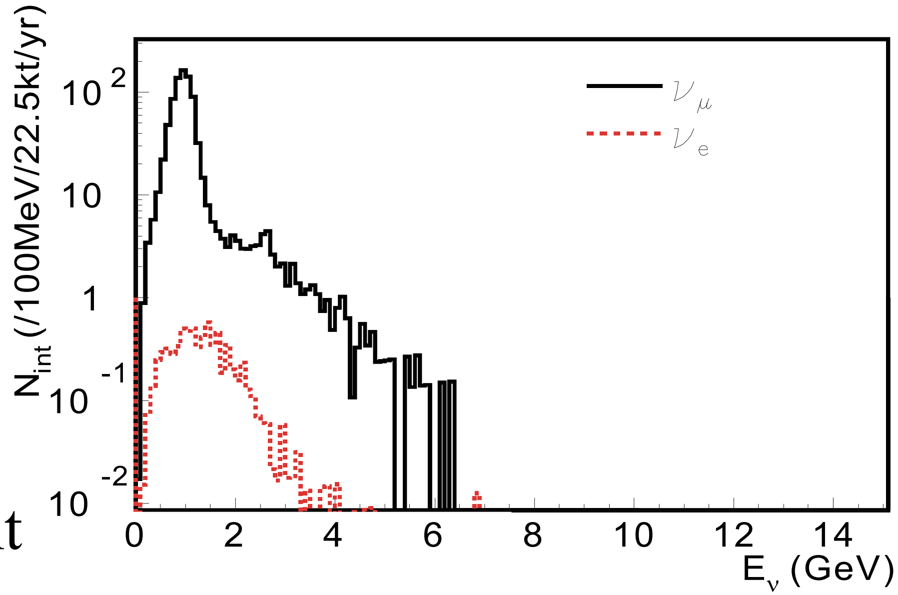




~2 int./100t/spill

ν_e:0.8%(0.3% @ peak)

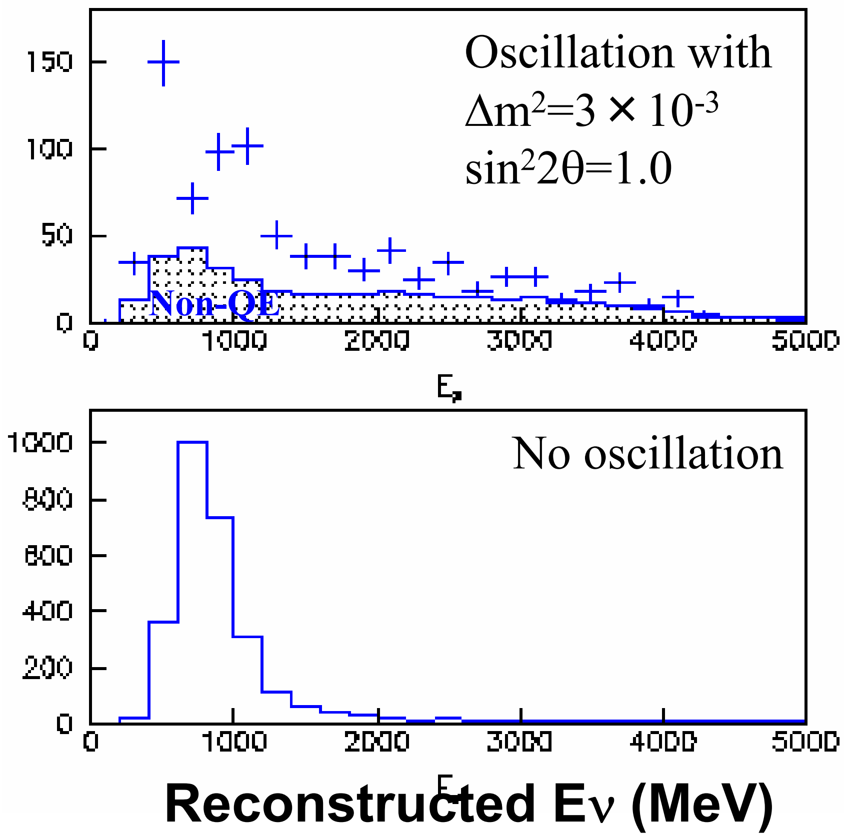
- **Easy to tune E_ν**
- Less HE tail
- Less sys err from spectrum



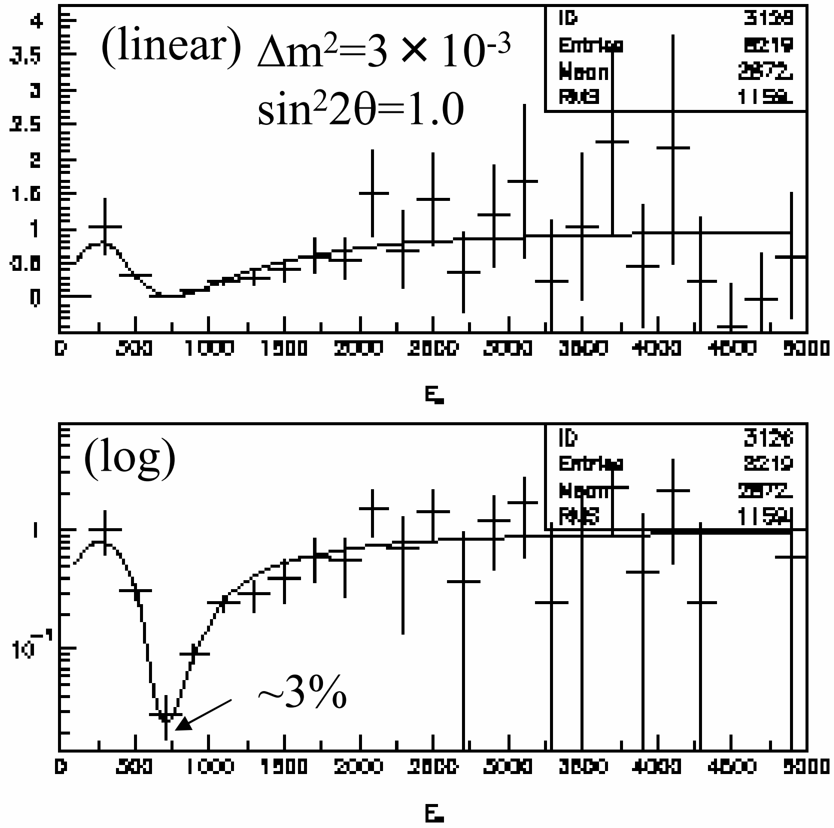
Reduce syst err in SK measurement

ν_μ disappearance

1ring FC μ-like



Ratio after BG subtraction



Clear oscillation patter can be observed.

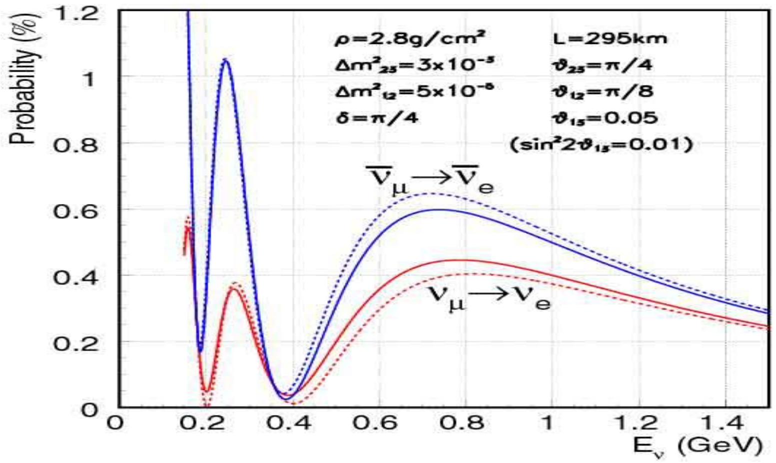
Fit with $1-\sin^2 2\theta \cdot \sin^2(1.27\Delta m^2 L/E)$

CPV

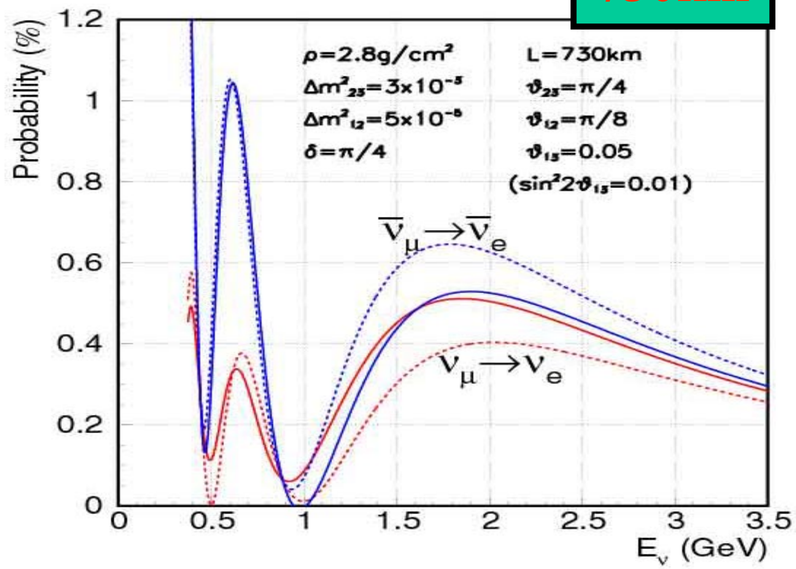
$\nu_\mu \rightarrow \nu_e$ osc. probability w/ CPV/matter

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

295km



730km

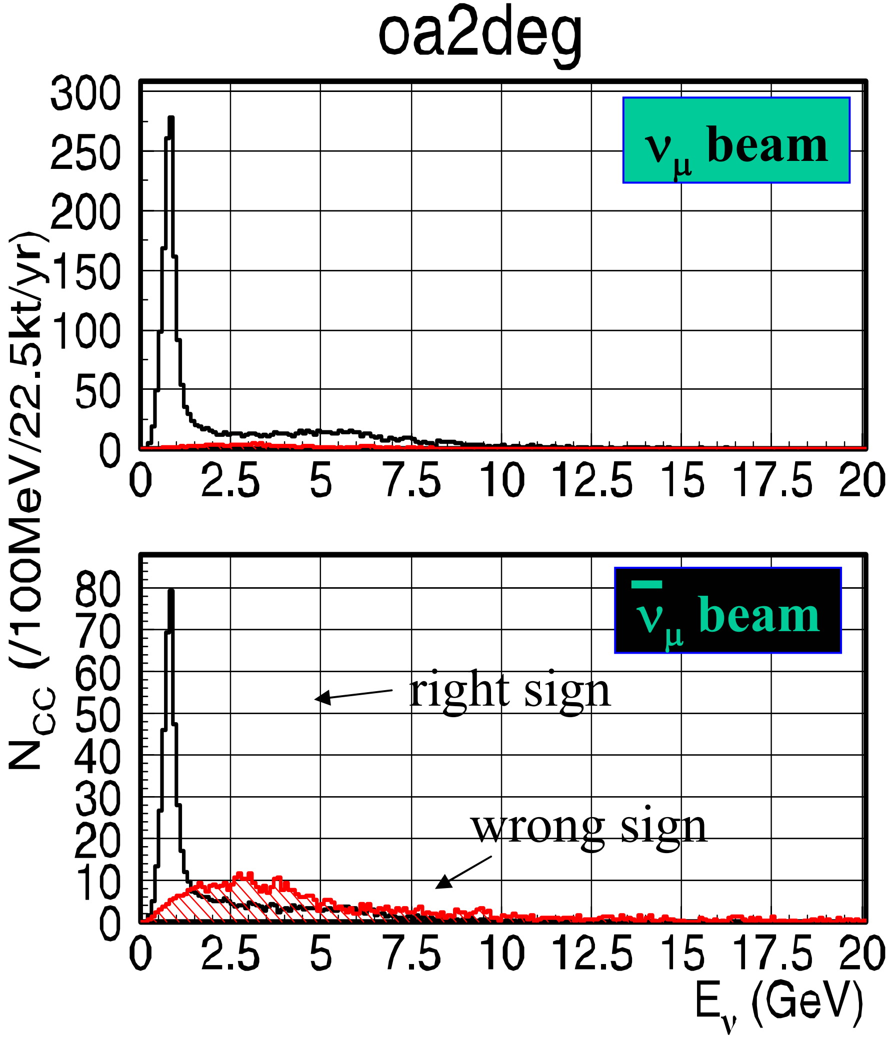


CP Asymmetry

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

Small fake asymmetry by matter effect at low energy

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

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