Long Baseline Neutrino Experiment in Japan

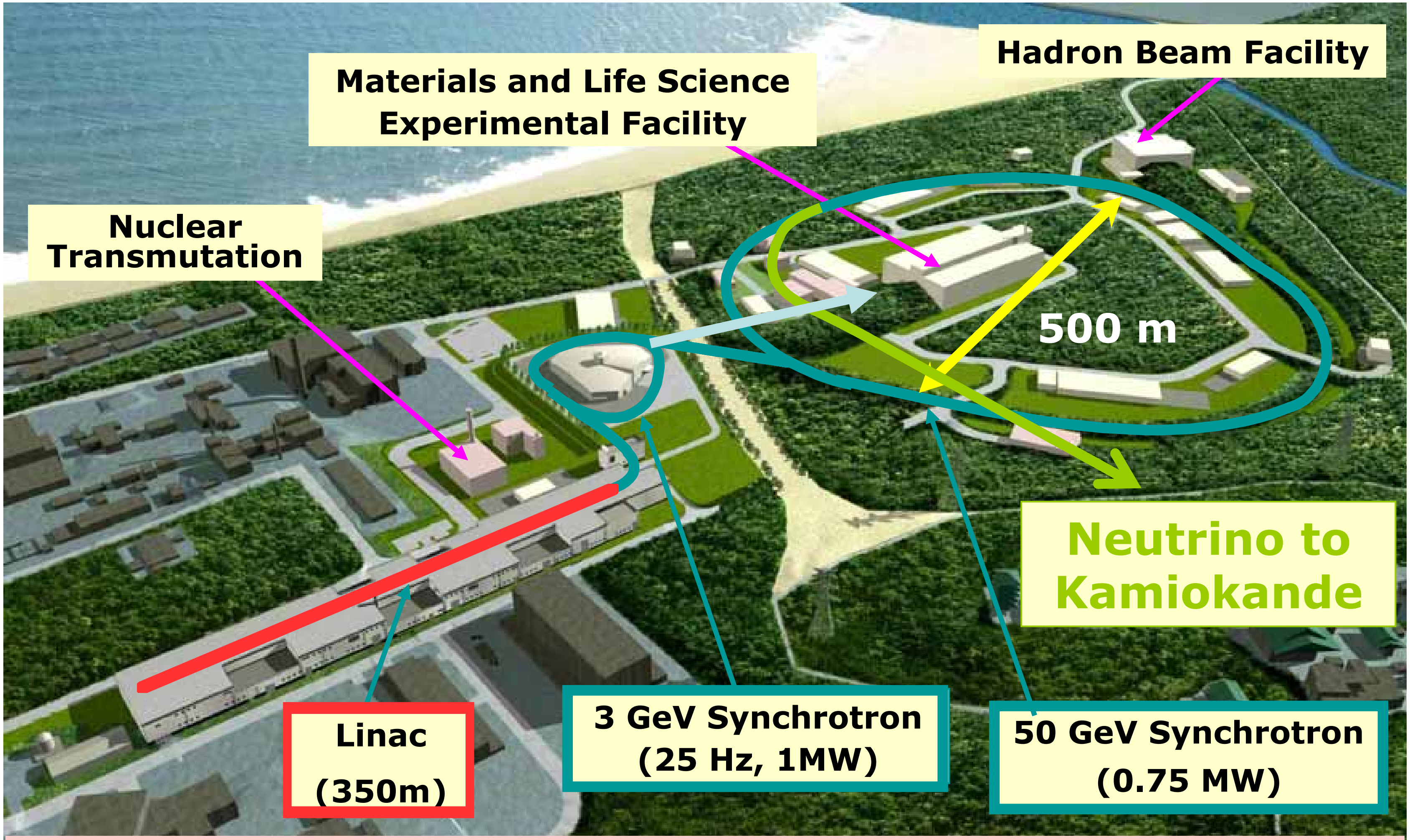
T2K (Tokai to Kamioka Neutrino Oscillation Experiment)
Neutrino facility becomes a reality in 3 years

III International Workshop on
"Neutrino Oscillations in Venice"

Koichiro Nishikawa
Kyoto University

February 8, 2006

J-PARC Facility



J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAERI

Non-zero mass of neutrinos !
What kind of neutrino facility needed for years to come?
Flavor Physics esp. history of neutrino studies show full of surprises ⇔ co op with unexpected
(Kamiokande for Kamioka Nucleon decay Experiment !)

Quantities: lepton ID and neutrino energy E_ν

Good E_ν determination

Precision measurement of θ_{23}
Precision measurement of oscillation pattern ⇒ oscillation **+ ?**

Lepton ID, NC-CC distinction

e -appearance Δm^2 ⇒ MNS 3gen. formulation like **CKM**
e-appearance exp. ⇒ **CPV** in leptonic process (leptogenesis?)

What is the best configuration for $\underline{E_\nu}$ and <u>PID</u>, given detector must be massive (simple) ?

Main features of T2K-1

The distance (295km) and Δm^2 ($\sim 2.5 \times 10^{-3}$ eV^2)

1. Oscillation max. at sub-GeV neutrino energy
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   - Small high energy tail
     - small BKG in νe search and $E\nu$ reconstruction

2. Proper coverage of near detector(s)
   - Cross section ambiguity

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   - Realistic systematic errors and how to improve

4. Accumulation of technologies on high power beam

Long baseline neutrino oscillation experiment from Tokai to Kamioka. (T2K)

Super-K: 50 kton Water Cherenkov

Phase2: Hyper-K

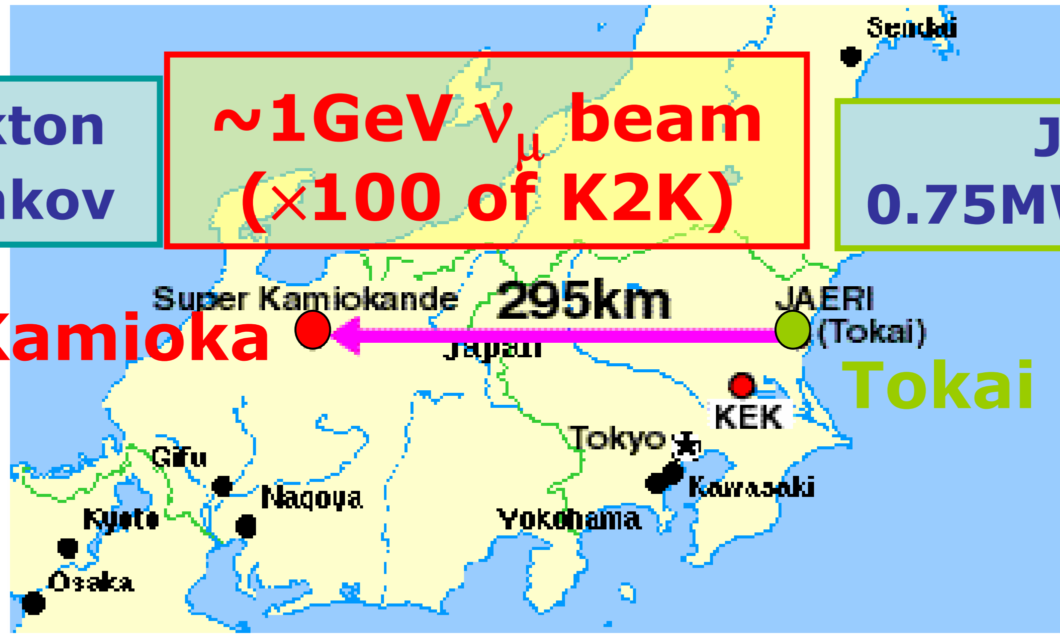
~1GeV ν_μ beam (×100 of K2K)

J-PARC 0.75MW 50GeV PS

Phase2: 3~4 MW

Kamioka

Tokai

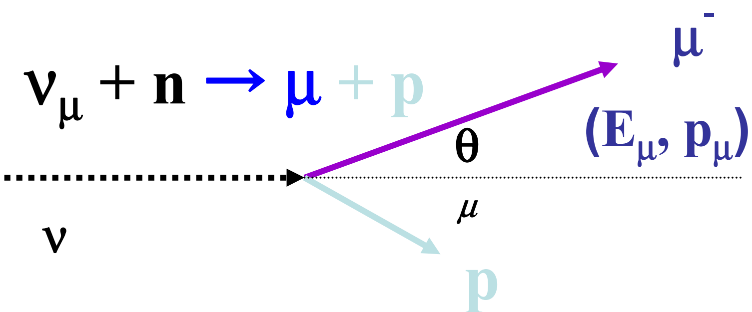


Physics goals

- Discovery of $\nu_\mu \rightarrow \nu_e$ appearance
- Precise meas. of disappearance $\nu_\mu \rightarrow \nu_x$
- Discovery of CP violation (Phase2)

12 countries
~60 institutions
~180 collaborators

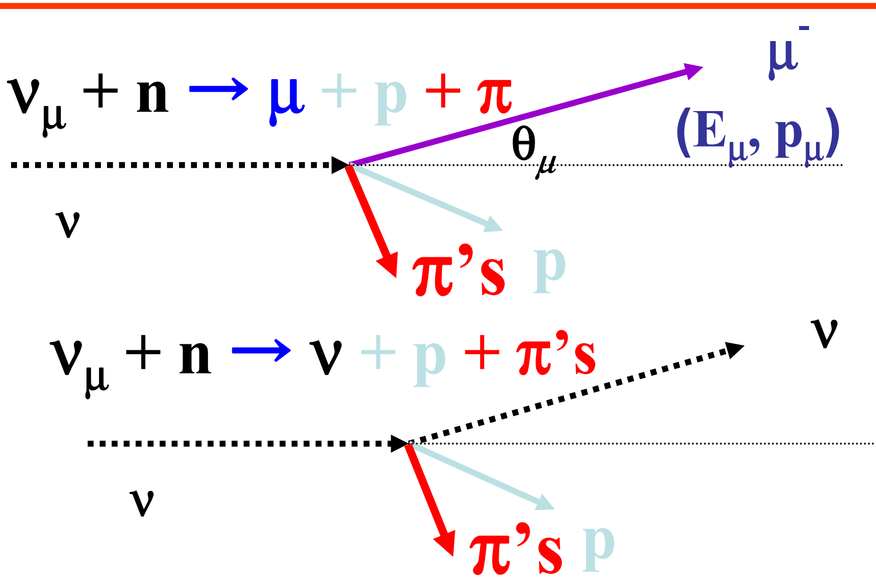
E_ν reconstruction at low energy



- ✧ **CC QE**
  - ✧ **can reconstruct Eν ←(θ_μ,p_μ)**

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

δE ~ 60 MeV δE/E ~ 10%



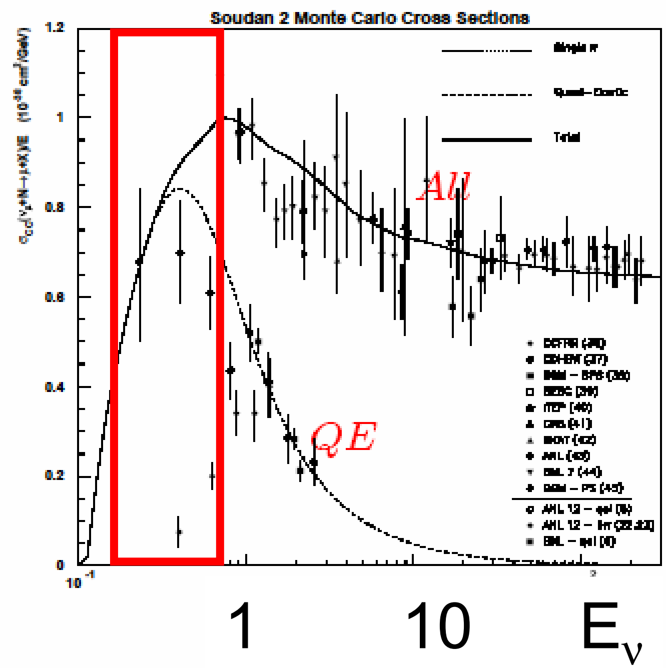
- ✧ **bkg. for E_ν measurement**

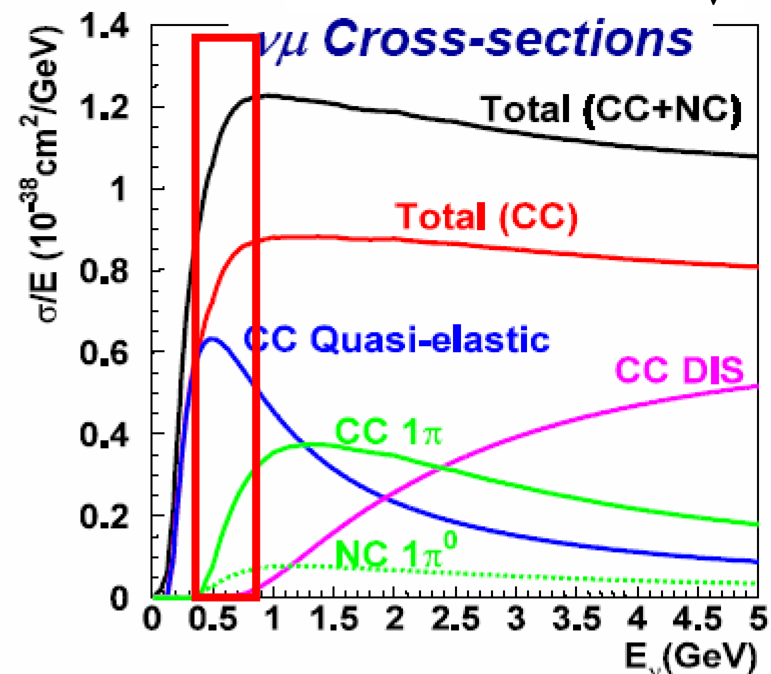
High energy part

- ✧ **bkg.for e-appearance**

1. Beam energy

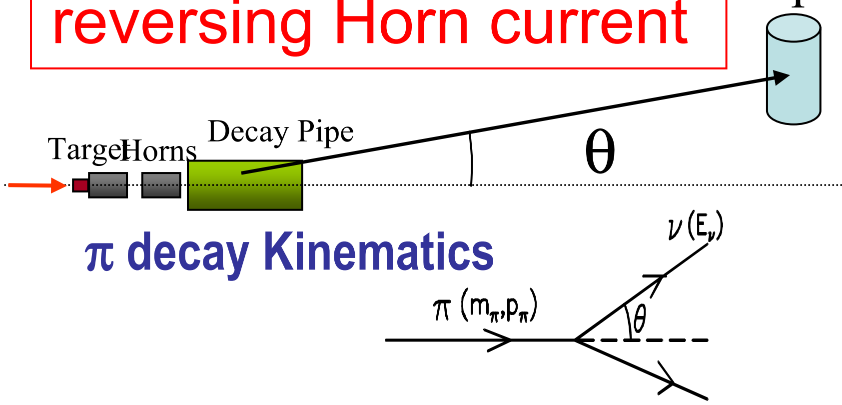
- Only the product
  F(E) x σ(E) is observable
  νμ spectrum changes by oscil.
  - Sub-GeV small HE tail
  - CCQE dominates (1 process)
- Even QE absolute cross section is known only with 20-30% precision
  - measurements at ν production with similar spectrum are critical
- Intermediate energy ν flux should be kept to minimum
  - Many processes contribute (QE, 1π, 2π, DIS)
  - Spectrum changes causes mixture of processes changes

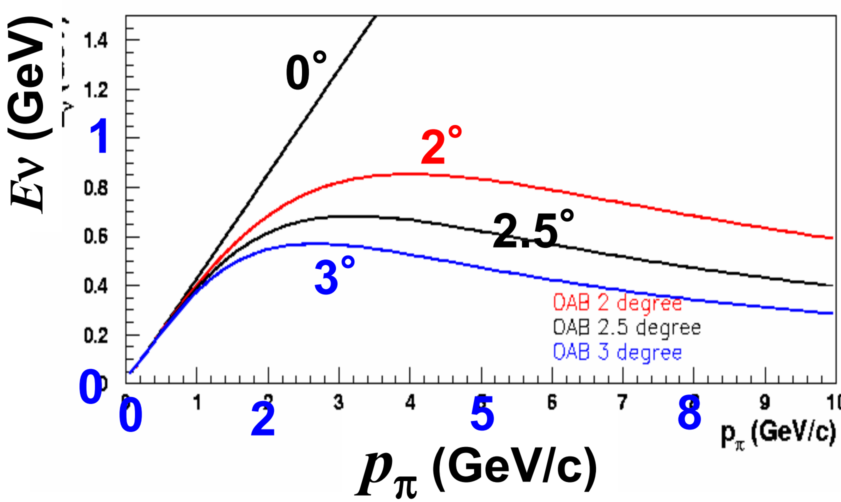


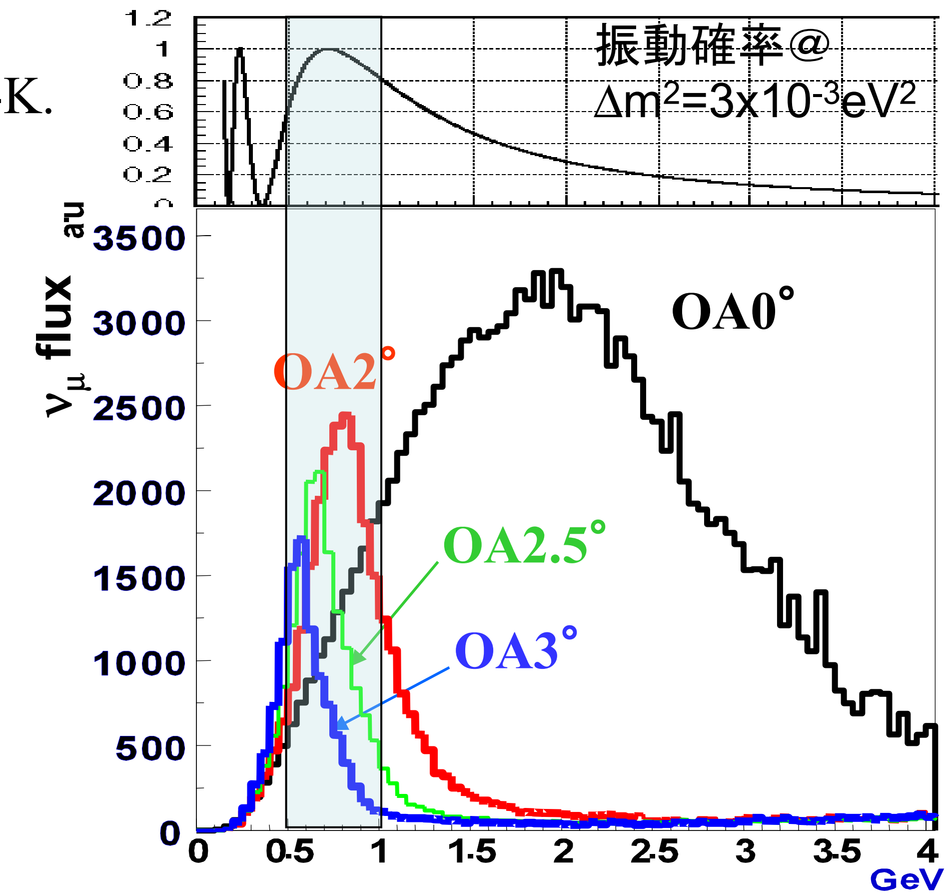


Narrow intense beam: Off-axis beam

Anti-neutrinos by reversing Horn current







- **Quasi Monochromatic Beam**
- **x 2~3 intense than NBB**
- **Tuned at oscillation maximum**

Statistics at SK

(OAB 2.5 deg, 1 yr, 22.5 kt)

~ 2200 ν_μ tot

~ 1600 ν_μ CC

ν_e ~0.4% at ν_μ peak

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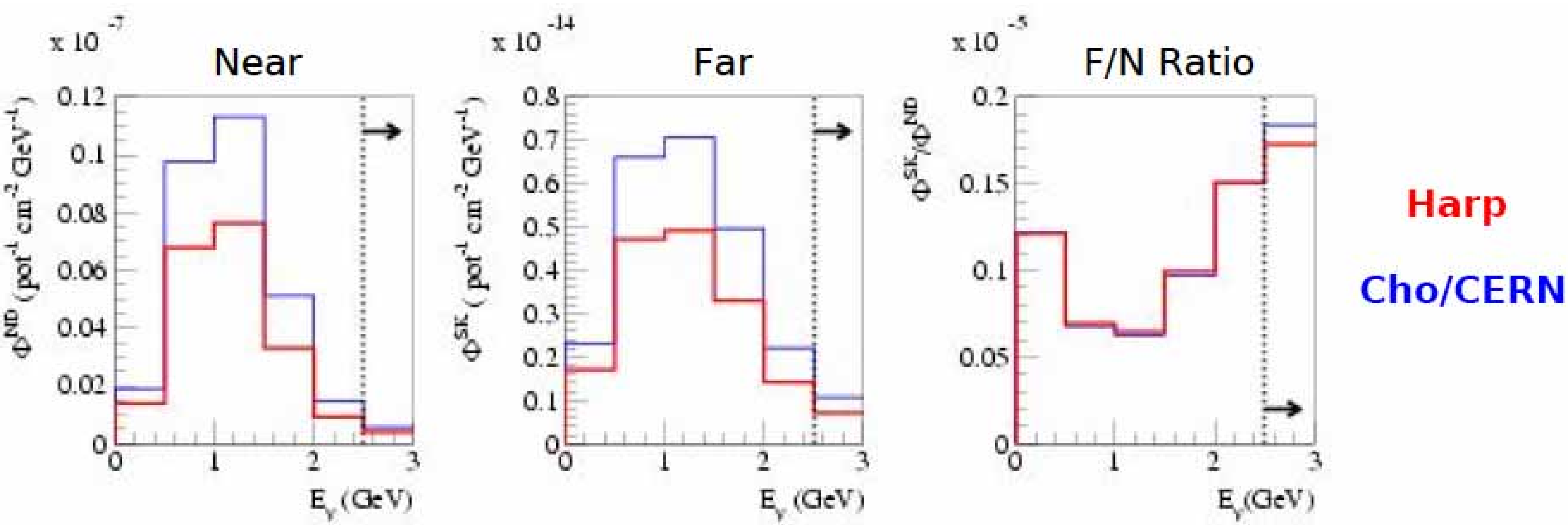
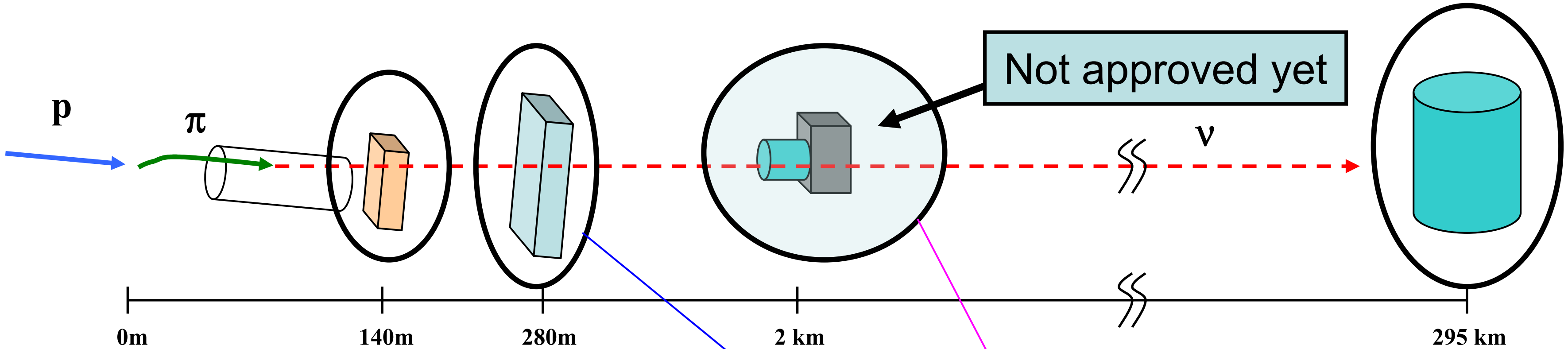
Experiences in K2K with Harp measurement

- Neutrino cross section cannot be trusted above GeV and below deep inelastic region –
- Proper near detectors to measure rate and Far/Near ratio should be used

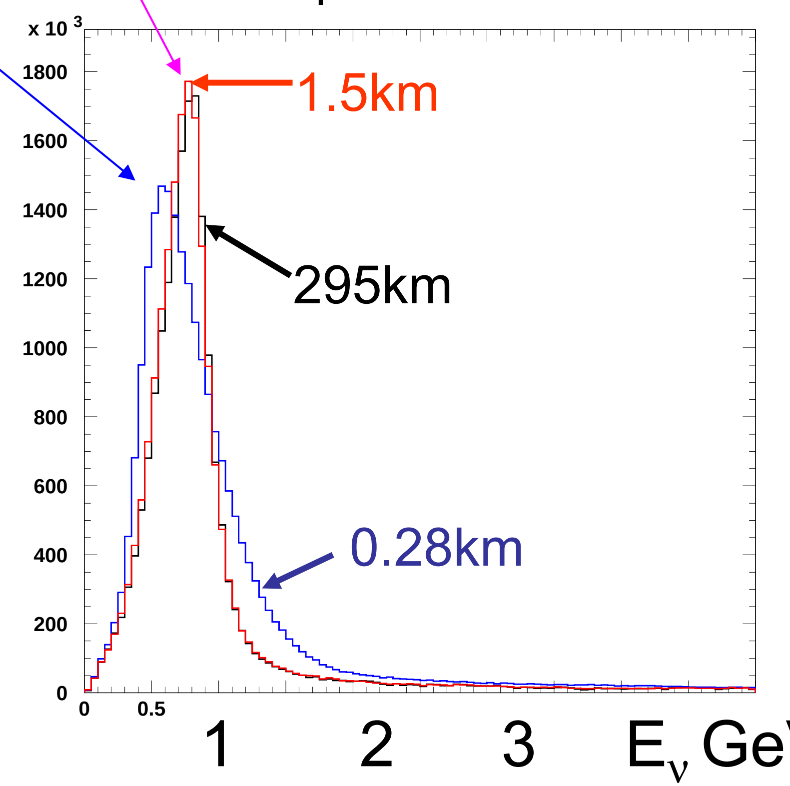


2. Near detector complex

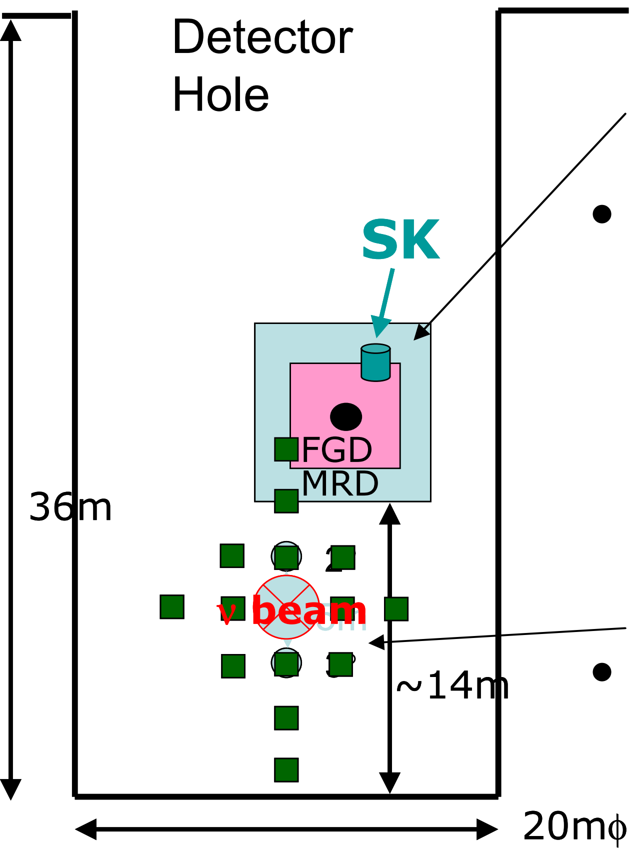


- **Muon monitors @ ~140m**
  - Fast (spill-by-spill) monitoring of beam direction/intensity ($\pi \rightarrow \mu\ \nu$)
- **First near detector @280m**
  - Flux/spectrum/νe - off-axis
  - intensity/direction - on-axis
- **Second near detector @ ~2km**
  - Almost same E_ν spectrum as for SK
  - facility request after commissioning of beam line
- **Far detector @ 295km**
  - **Super-Kamiokande (50kt)**

Neutrino spectra at diff. dist



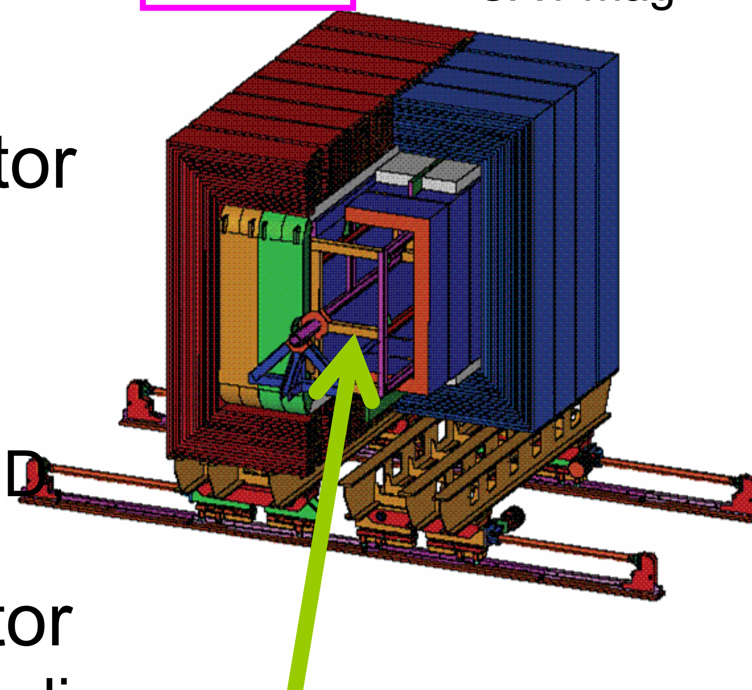
Conceptual Design of Near Detector @ 280m

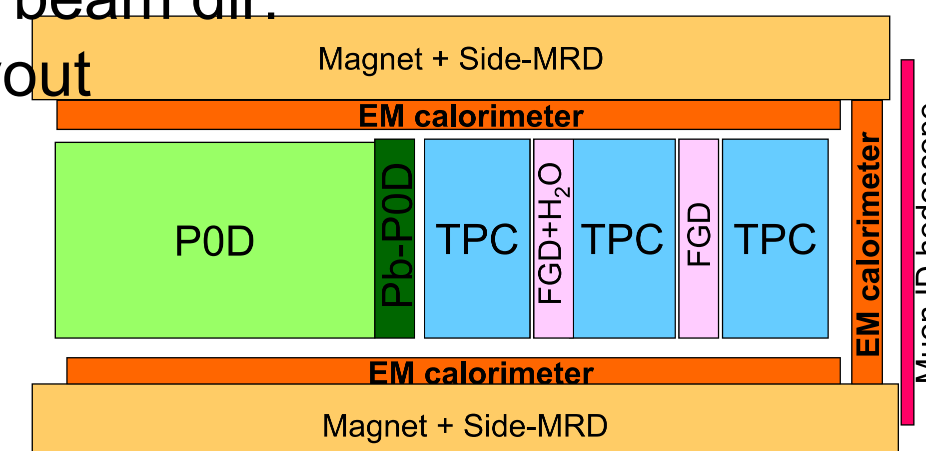


- Off-axis detector
  - ν spectrum
  - Cross sect.
  - ν_e contami.
  - UA1 mag, FGD, TPC, Ecal,..
- On axis detector
  - Monitor beam dir.
  - Grid layout

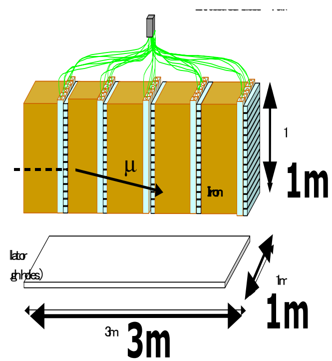
Off-axis

UA1 mag

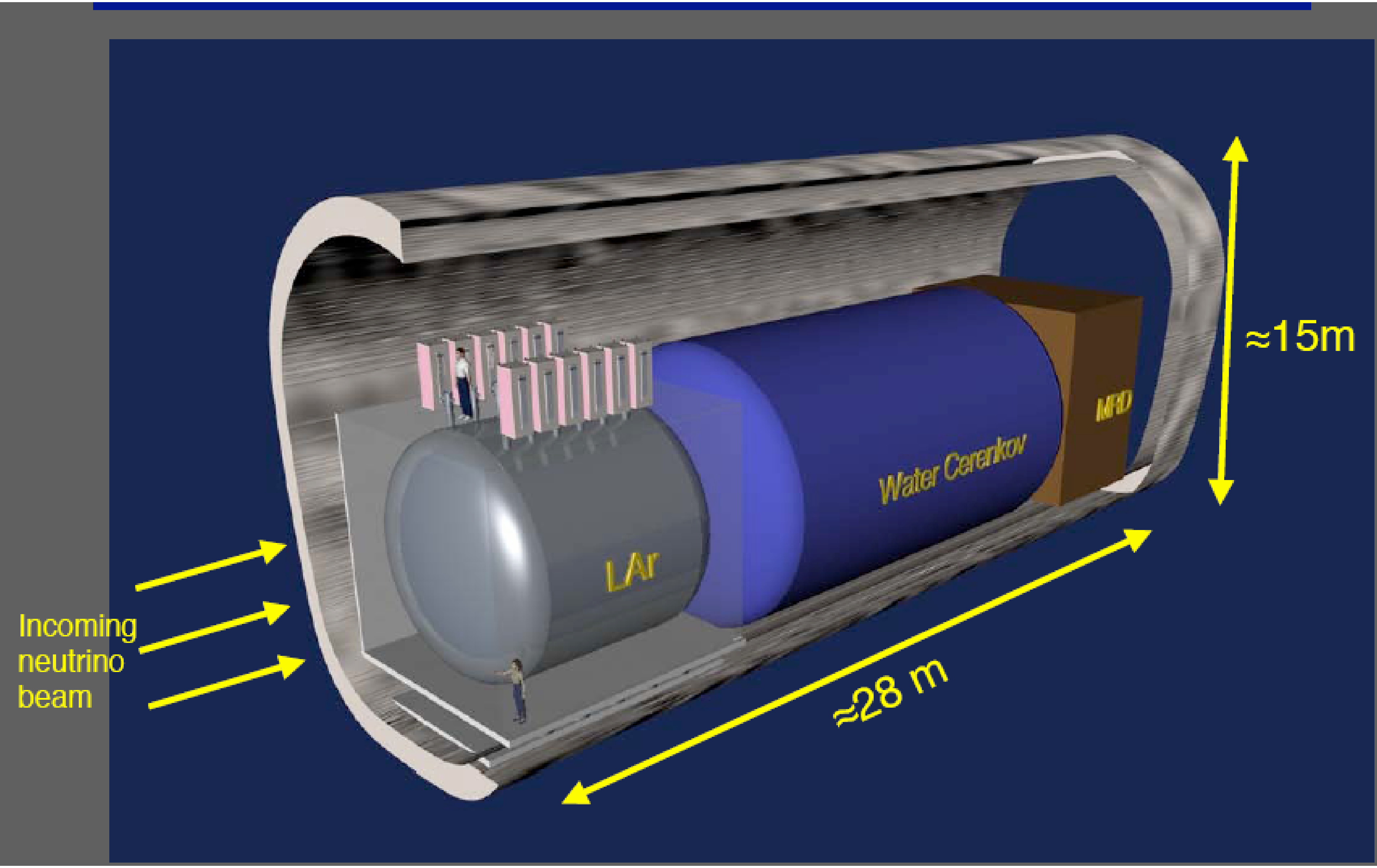




On-axis



Possible 2km detectors



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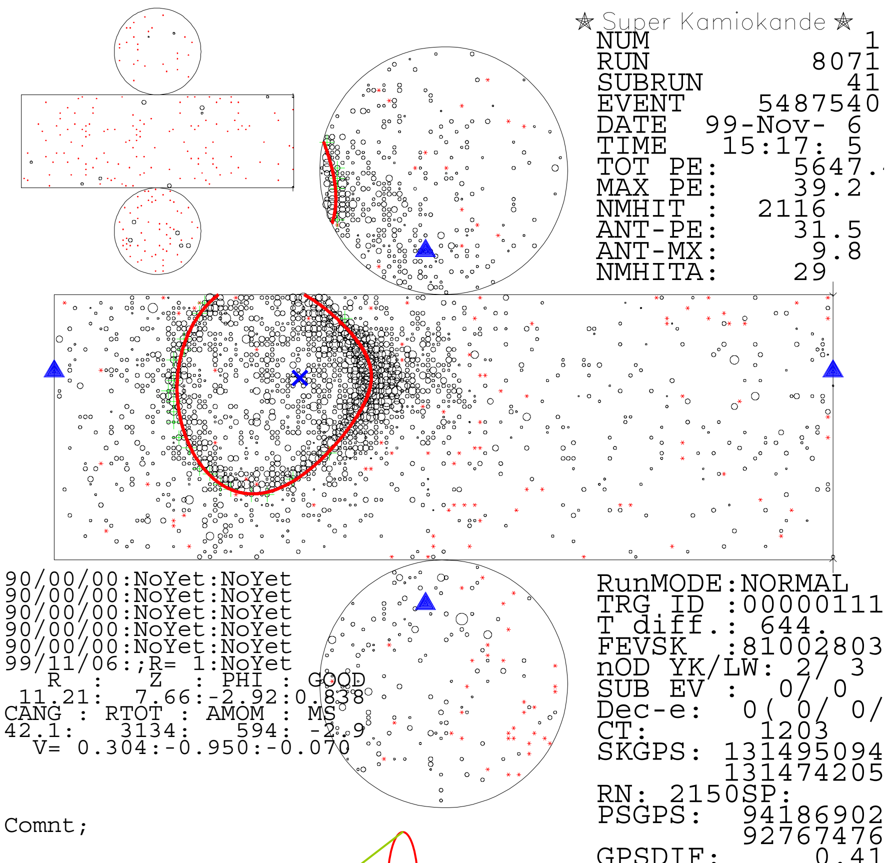
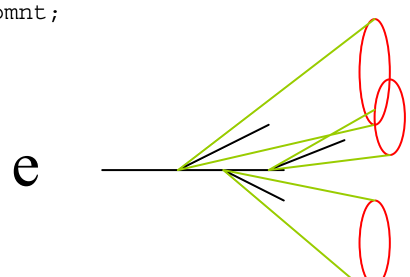
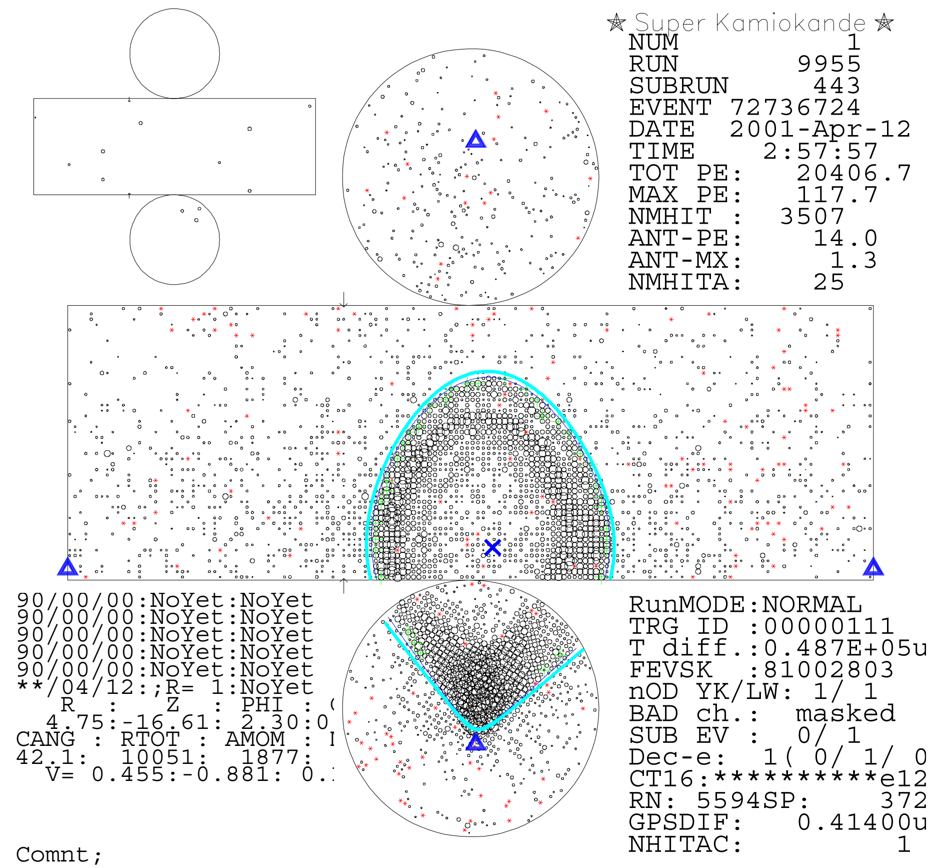
3. PID in SK

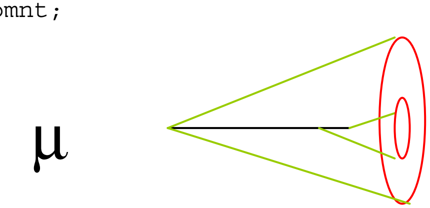
e-like





μ-like

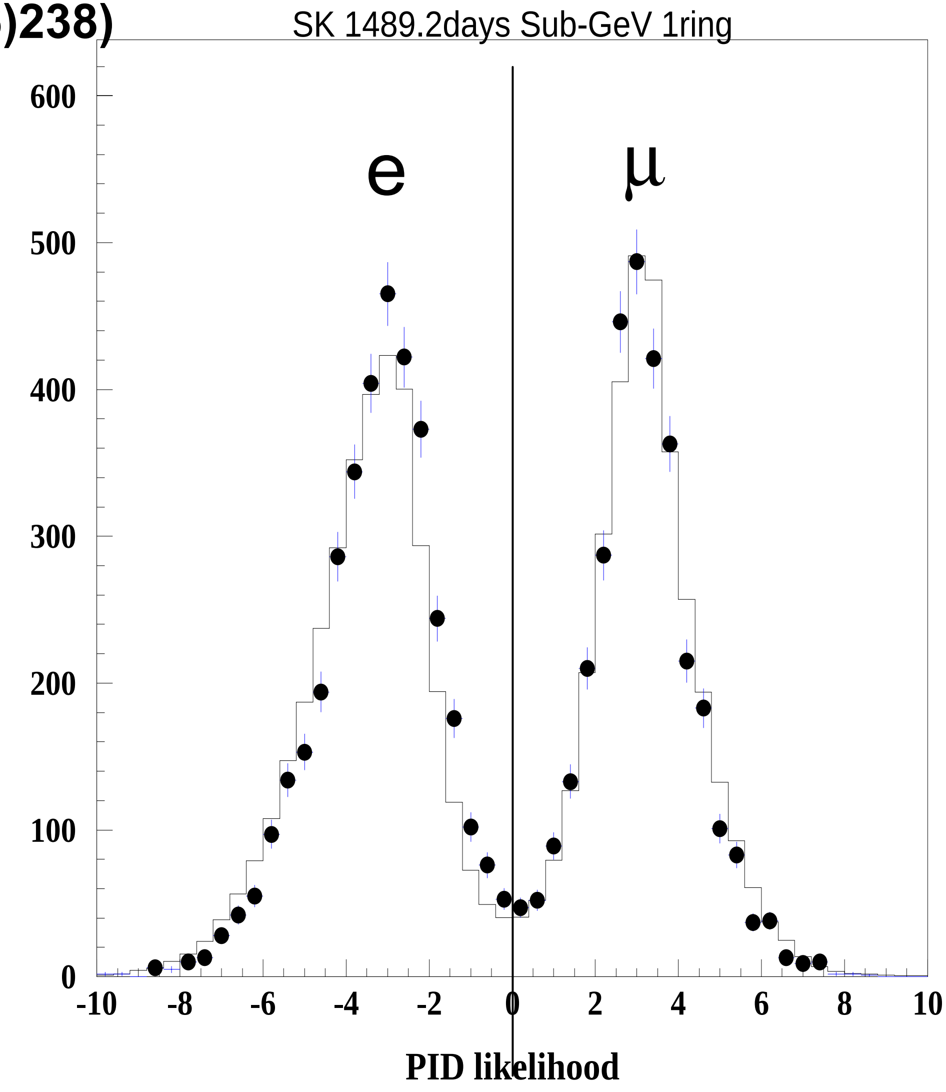




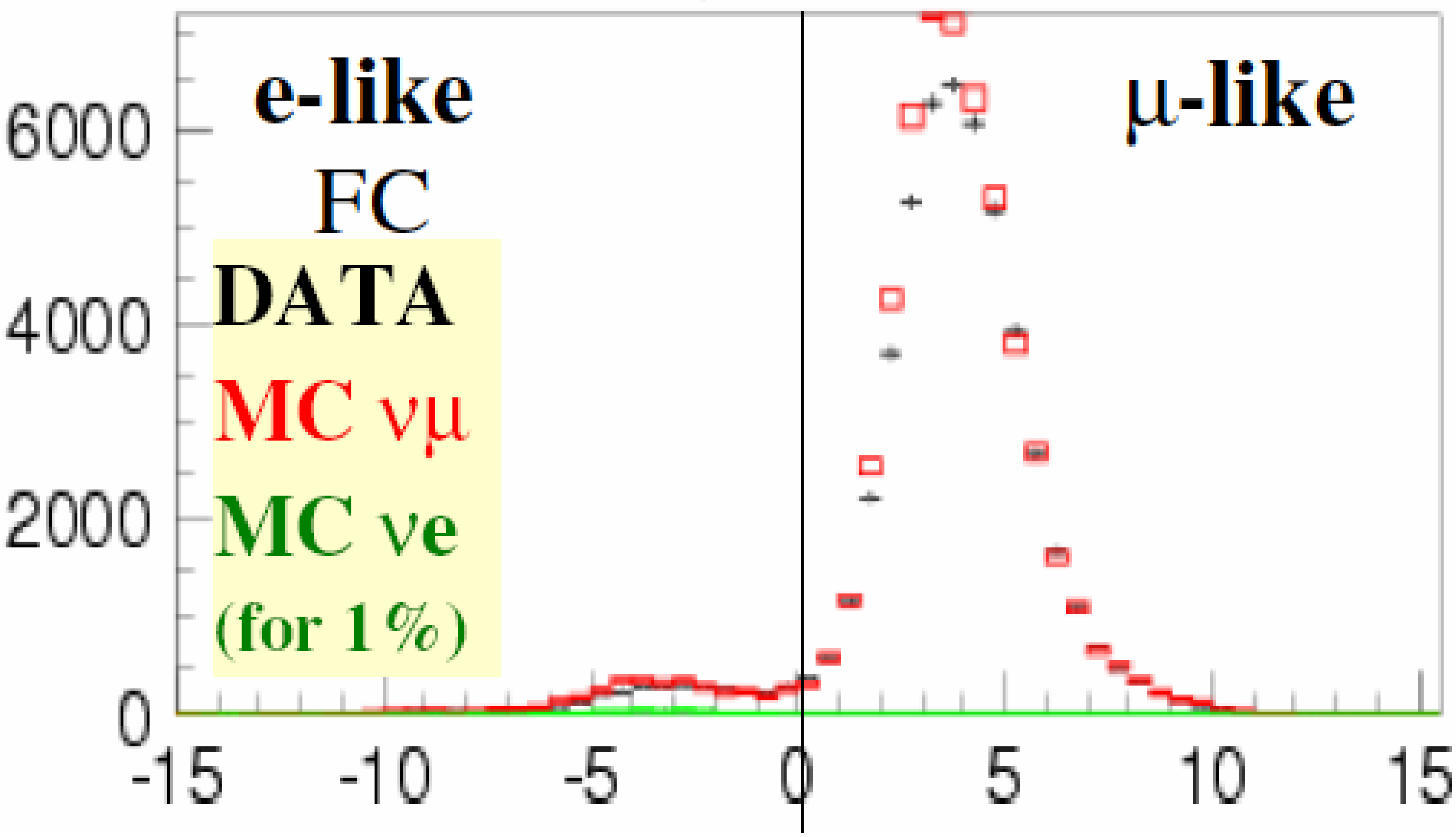
Particle ID (e & μ) (in single ring events)

- **An experiment with test beams confirmed the particle ID capability (PL B374(1996)238)**

Super-Kamiokande
Atmosphric data



K2K 1KT data and MC reproducibility



SK data reduction in K2K real data:

—K2K-1—	νμ MC	beam νe	Data
FCFV	79.7*1	0.80	55
Single ring	49.97	0.46	33
Electron like*2	2.62	0.40	3
Evis > 100 MeV	2.43	0.39	2
No decay-e	1.88	0.34	1
Pi0 cut	0.57	0.17	0
—K2K-2—	**νμ MC**	**beam νe**	**Data**
FCFV	76.2*1	0.85	57
Single ring	48.52	0.51	34
Electron like*2	3.17	0.44	5
Evis > 100 MeV	2.89	0.44	5
No decay-e	2.14	0.38	4
Pi0 cut	0.73	0.21	1

In total,
#expected BG = 1.68
#observed = 1

νμ (NC π0)BKG
1.3 events

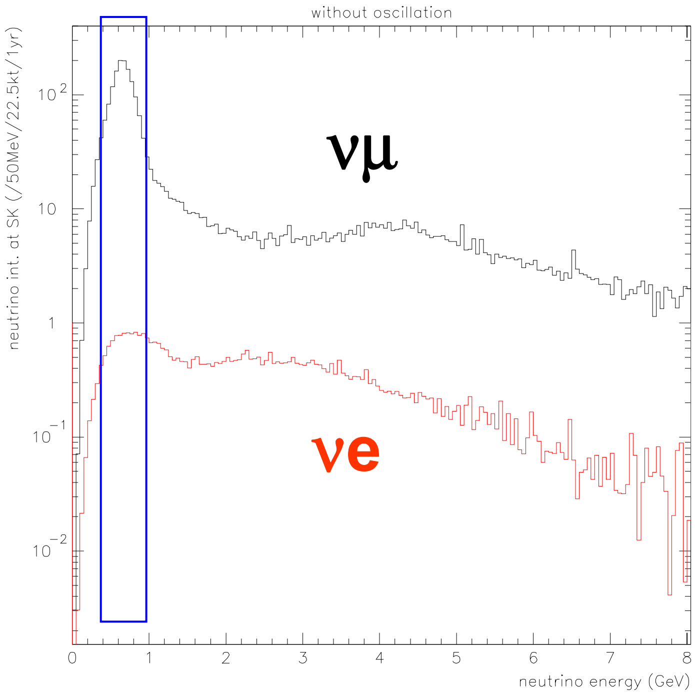
*1 Normalized by Nsk
*2 different from std. PID
(opening angle & ring pattern)

Search for $\nu_\mu \rightarrow \nu_e$ oscillation in K2K has achieved necessary $\pi 0$ rejection

•K2K real data with background rejection algorithm

As a result,

# of expected BG	1.68 events
	(1.3 from ν_μ & 0.38 from beam ν_e)
# of observed events	1 event



T2K low energy beam, small tail

1/3 by HE tail – NC $\pi 0$
1/3 by E rec

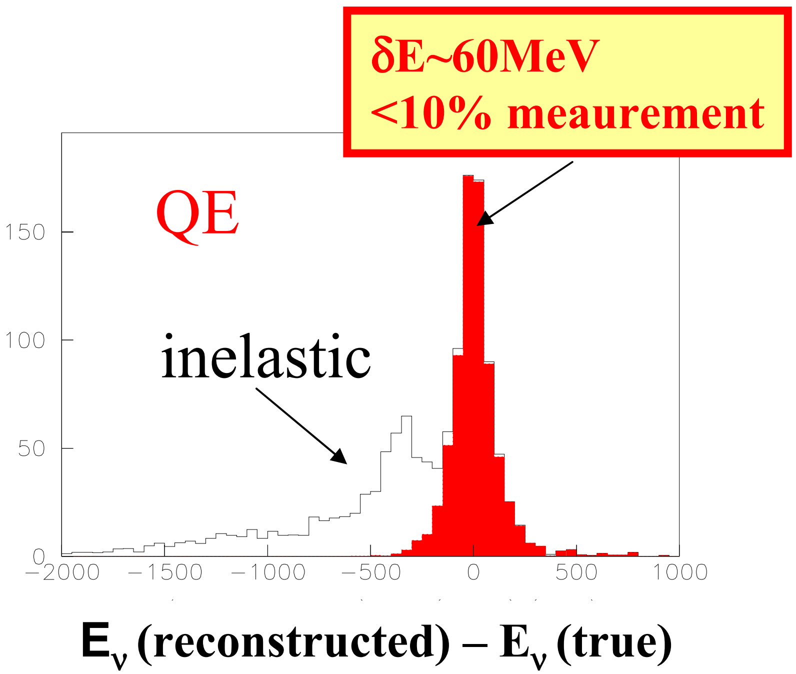
Rough extrapolation to T2K
x~100 νμ 10,000 νμ without osc.
Shown by real data

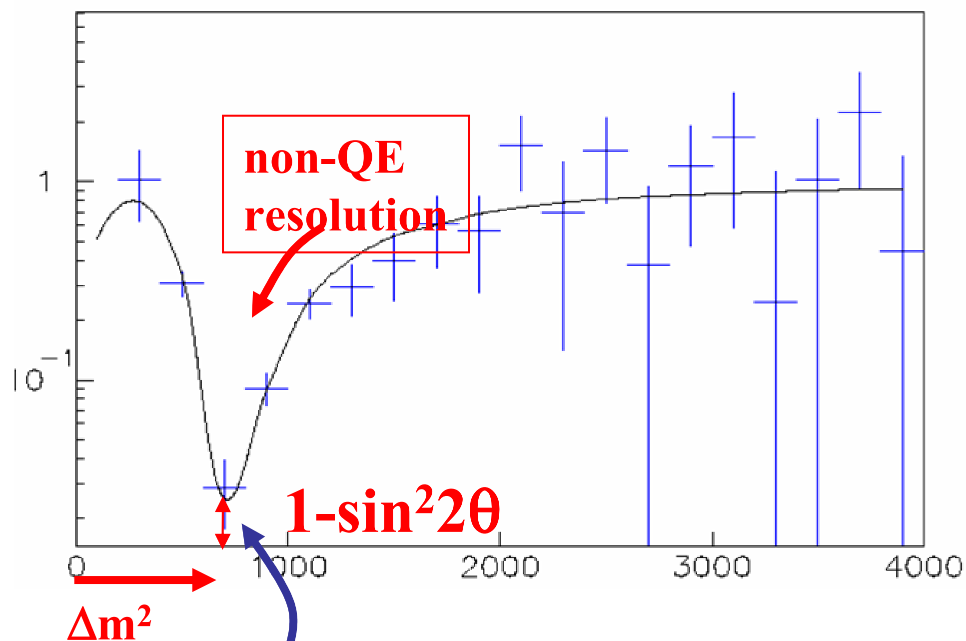
BKG ~1.3x100/9~15 for 5 years T2K

Sensitivities, precision in T2K phase-1

Disappearance
E_ν reconstruction resolution

- Large QE fraction for <1 GeV
- Knowledge of QE cross sections
- Beam with small high energy tail





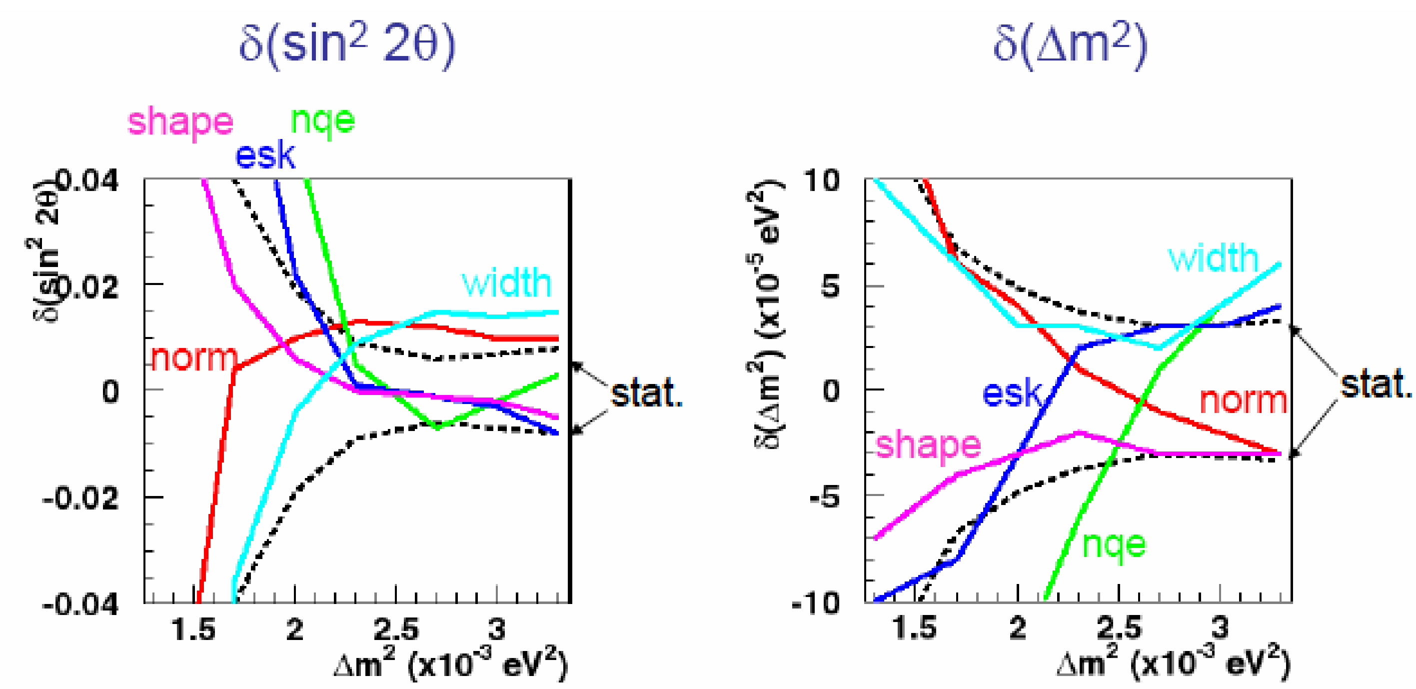
± 10% bin
High resolution : less sensitive to systematics

Precision measurement of θ_{23} , Δm^2_{23} possible systematic errors and phase-1 stat.

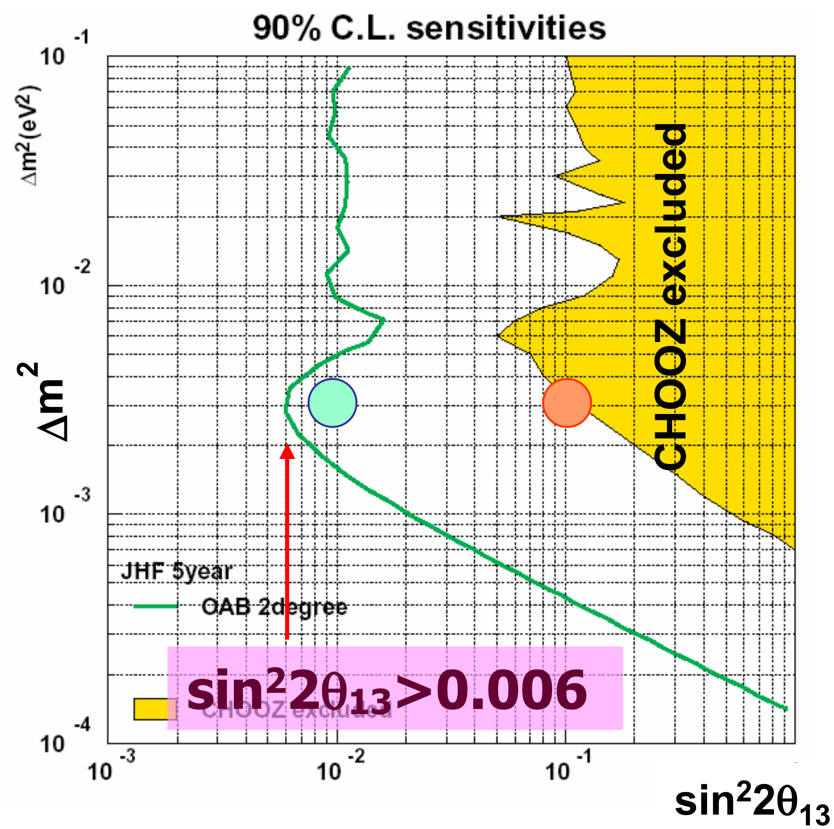
- Systematic errors
  - **normalization (10% (→5%(K2K))**
  - **non-qe/qe ratio (20% (to be measured))**
  - **E scale (4% (K2K 2%))**
  - **Spectrum shape (Fluka/MARS →(Near D.))**
  - **Spectrum width (10%)**

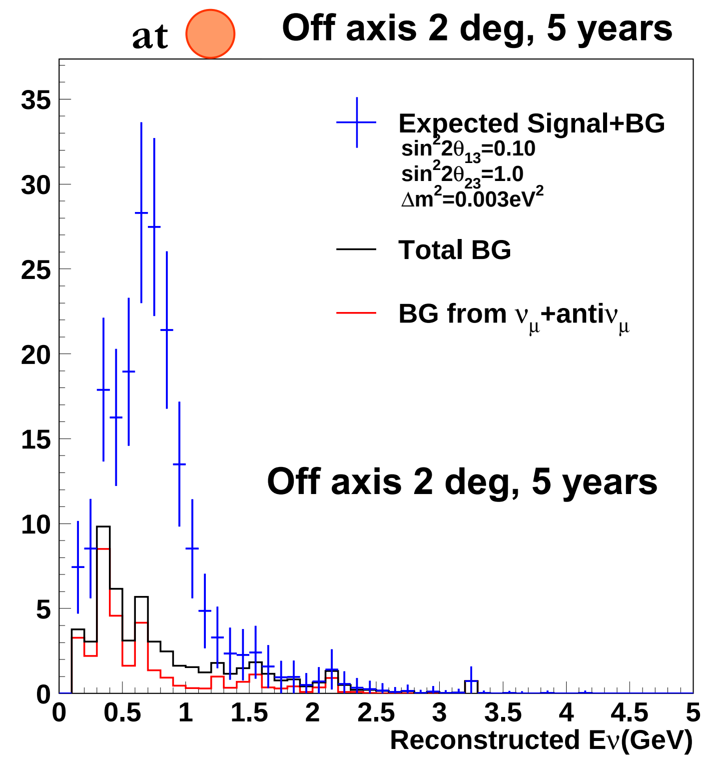
OA2.5°

$\delta(\sin^2 2\theta_{23}) \sim 0.01$
$\delta(\Delta m^2_{23}) < 1 \times 10^{-4}\ eV^2$



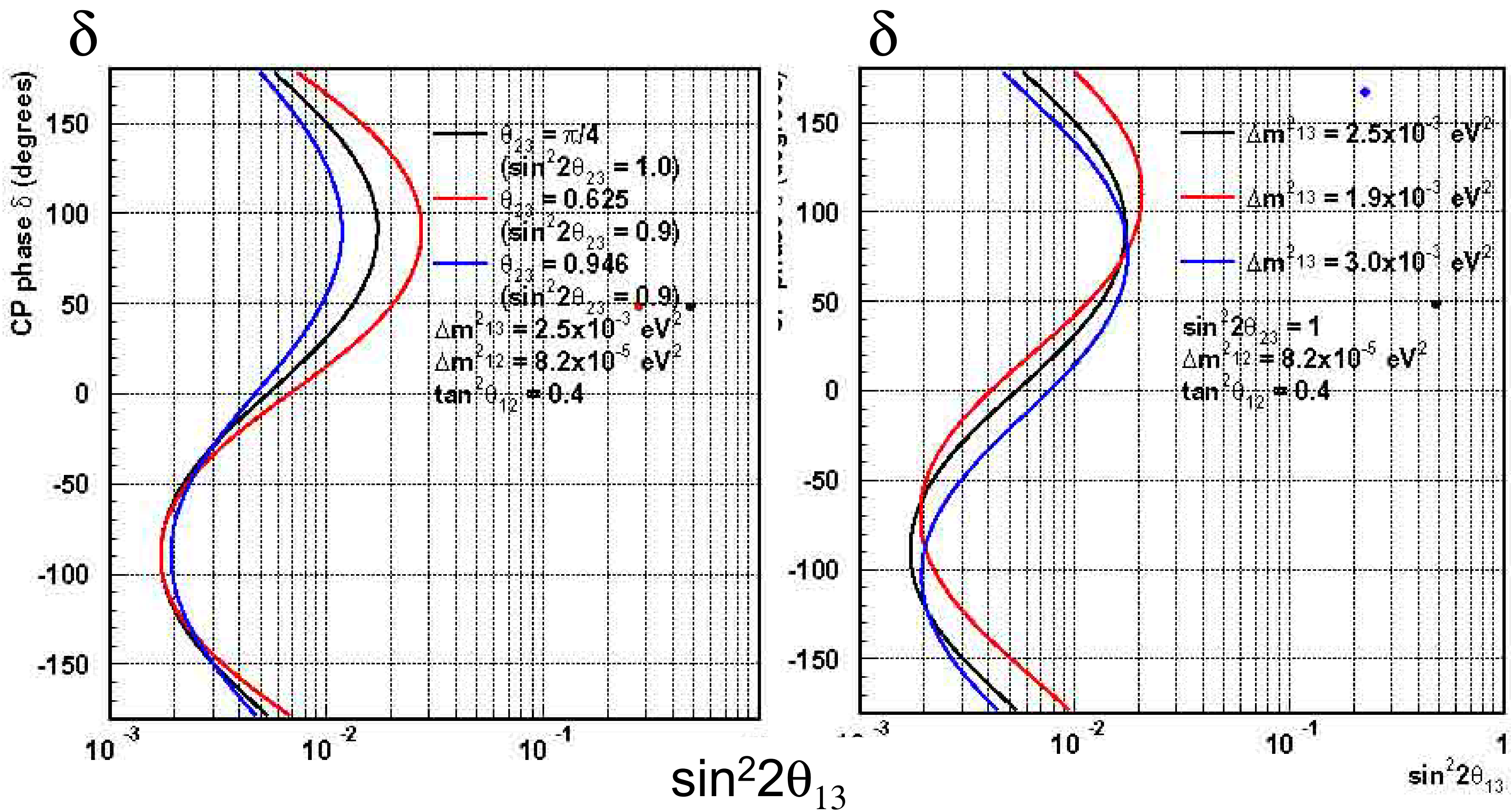
ν_e appearance : θ_{13}





$\sin^2 2\theta_{13}$	Estimated background in Super-K					Signal (~40% eff.)	Signal + BG
	ν_μ (NC π^0)	ν_e beam	$\bar{\nu}_\mu$	$\bar{\nu}_e$	total		
0.1	12.0	10.7	1.7	0.5	24.9	114.6	139.5
0.01	12.0	10.7	1.7	0.5	24.9	11.5	36.4

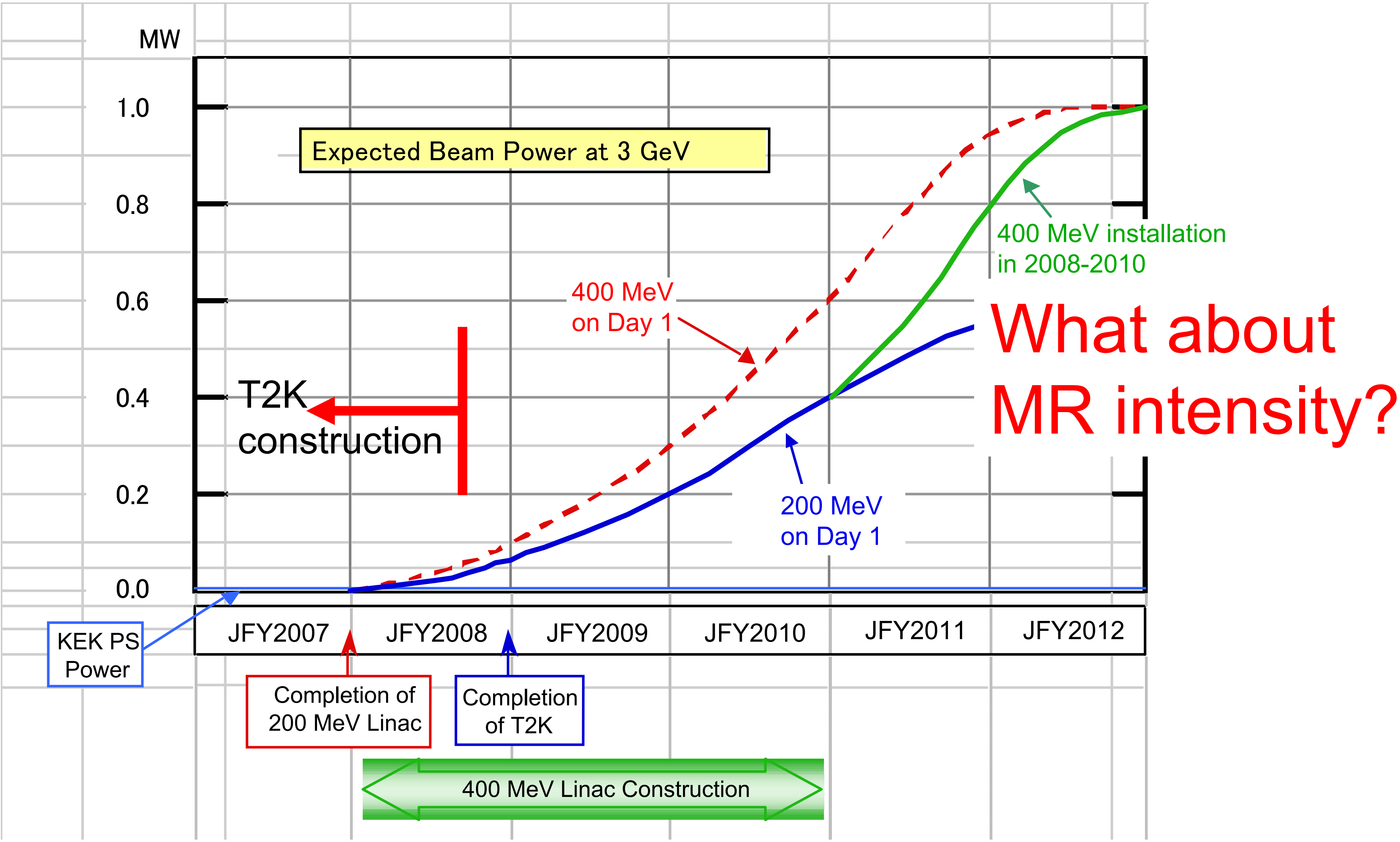
Sensitivity to θ_{13} as a fuction of CP-phase δ



$\delta \rightarrow -\delta$ for $\nu \rightarrow$ anti-ν

Status of JPARC

3 GeV RCS commissioning plan



Intensity of MR

- J-PARC start with 180 MeV LINAC

Currently, following realistic scenarios have been studied

- Intensity in 3 GeV Booster limited by space charge effect
  - increase number of bunches in MR by RF freq. increase in MR (injection time)
  - larger bucket in Booster to increase no. of protons/bunches
  - More RF power to increase rep. (with money)
- Every possible effort to increase MR intensity faster than 3GeV booster

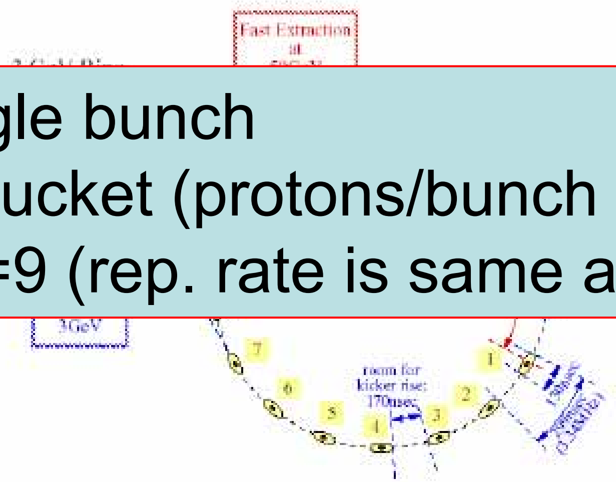
- Badget request will be submitted to restore 400 MeV LINAC (2008,9,10 ?)

- Eventually more than MW beam

Injection Scheme to the 50 GeV MR

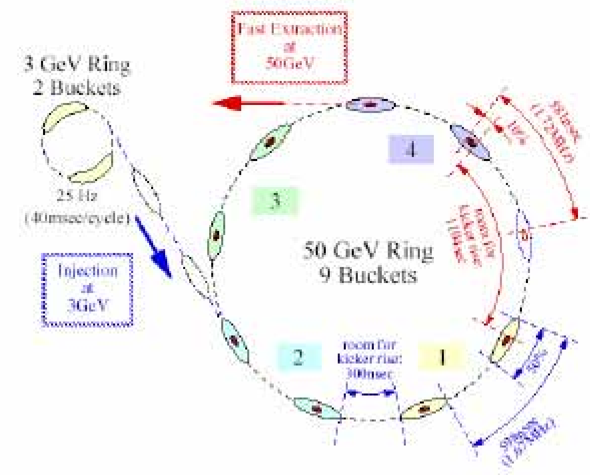
h = 18 (181-MeV injection)

Injection/Fast Extraction Scheme for the 50 GeV Ring



h = 9 (400-MeV injection)

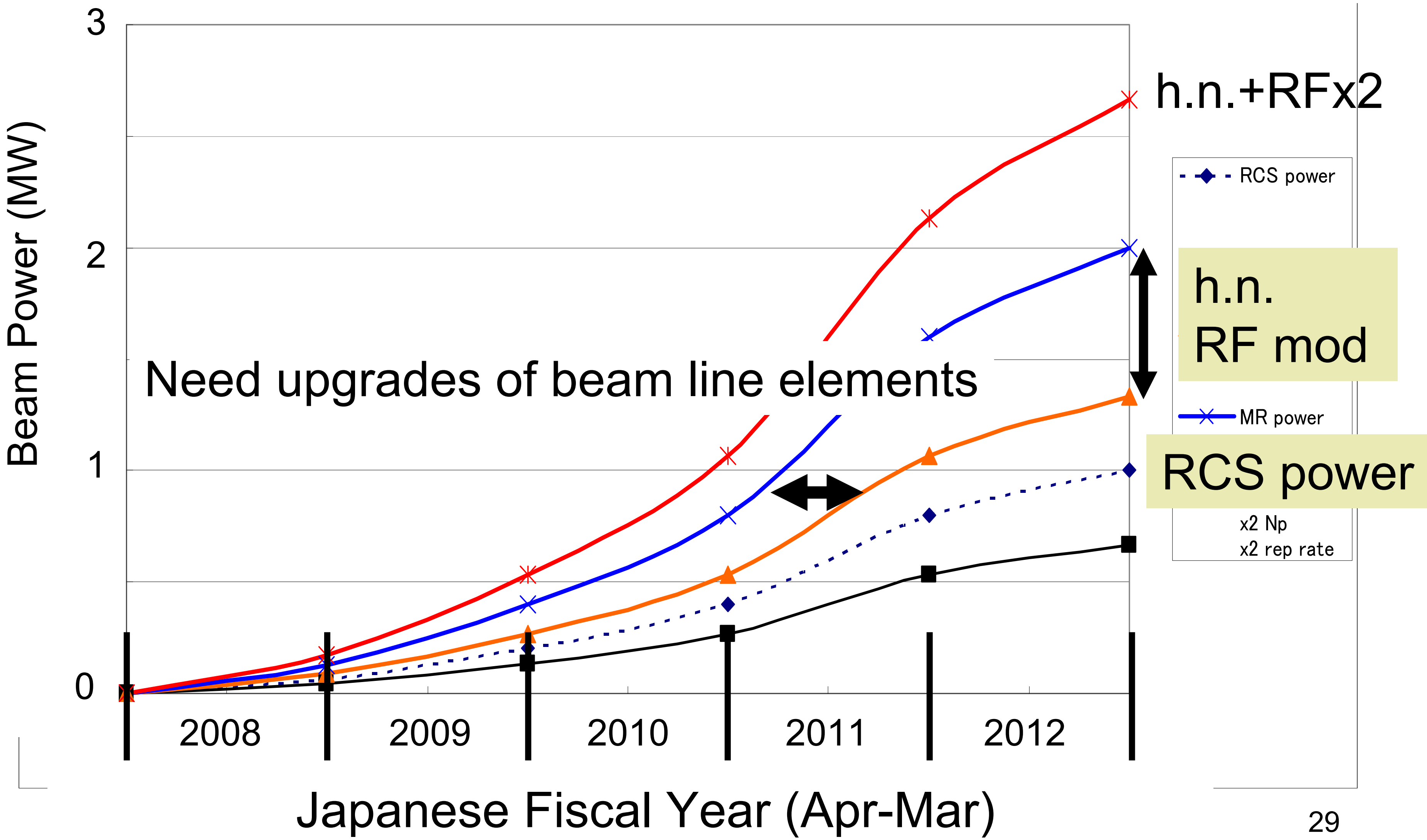
Injection/Fast Extraction Scheme for the 50 GeV Ring



OR single bunch
larger bucket (protons/bunch larger)
keep h=9 (rep. rate is same as original

	h = 18	h = 9
Injection time	560ms	120ms
RF frequency	3.34-3.44	1.67-1.72 MHz
Injection kicker flat top	130ns	900ns : PFN cable length
Pulse bending magnet flat top	600ms	120ms
Injection kicker rise time	170ns	300ns

Accelerator commissioning plan



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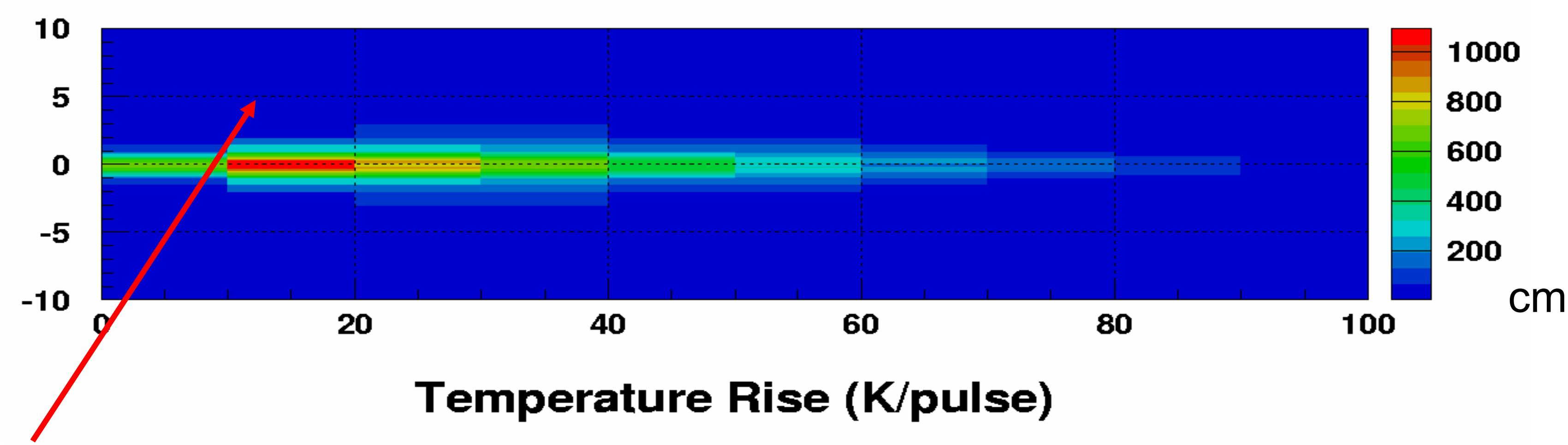
First high enrgy MW fast-ext'ed beam !

3.3E14 ppp w/ 5μs pulse

cm When this beam hits an iron block,

Residual radiation

> 1000Sv/h



1100°

(cf. melting point 1536°)

✓ Material heavier than iron would melt.

✓ Thermal shock stress $\approx E\alpha\Delta T \approx 3GPa$

(max stress ~300 MPa)

Material heavier than Ti might be destroyed.

Neutrino Beam Line for T2K Experiment

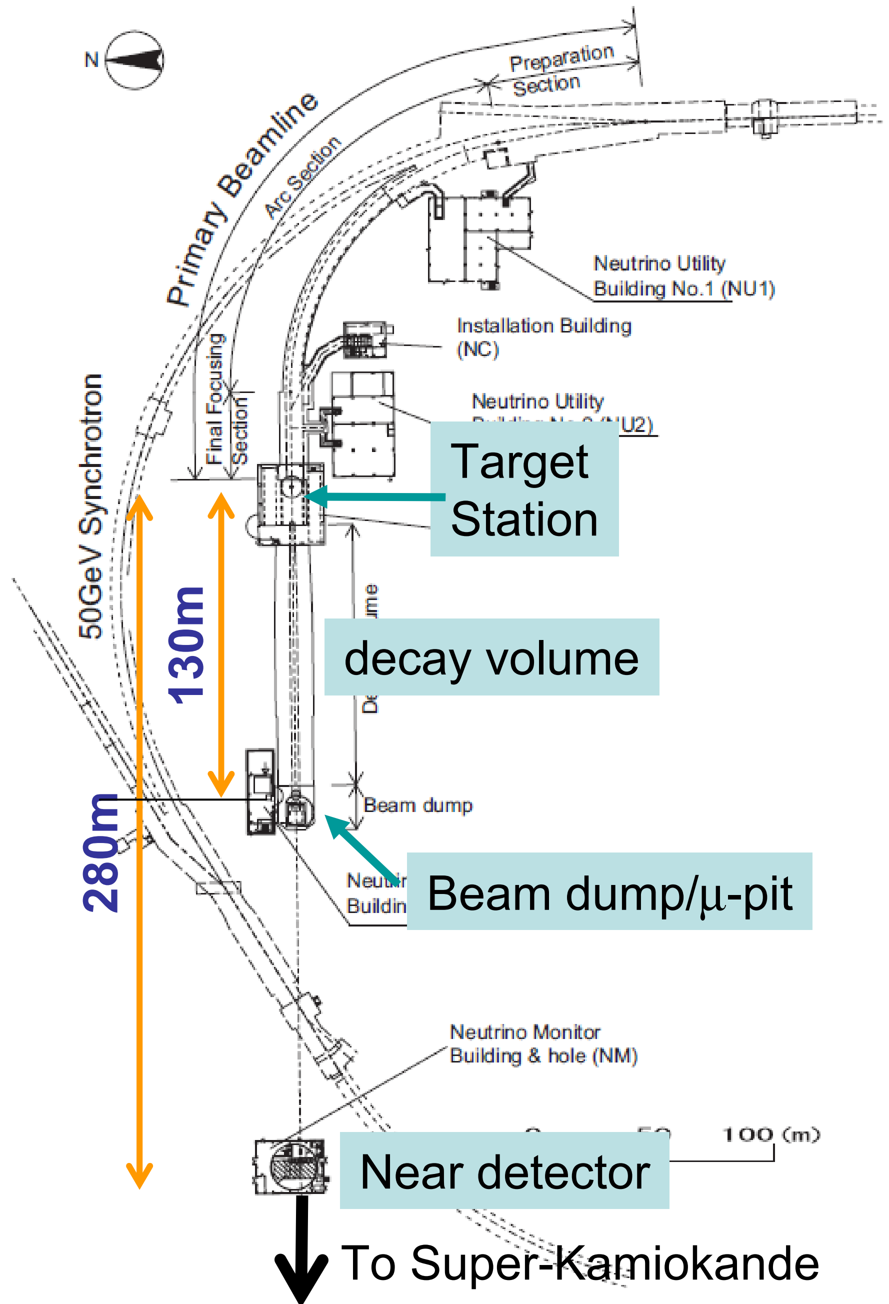
Special Features

- Superconducting combined function magnets
- Off-axis beam

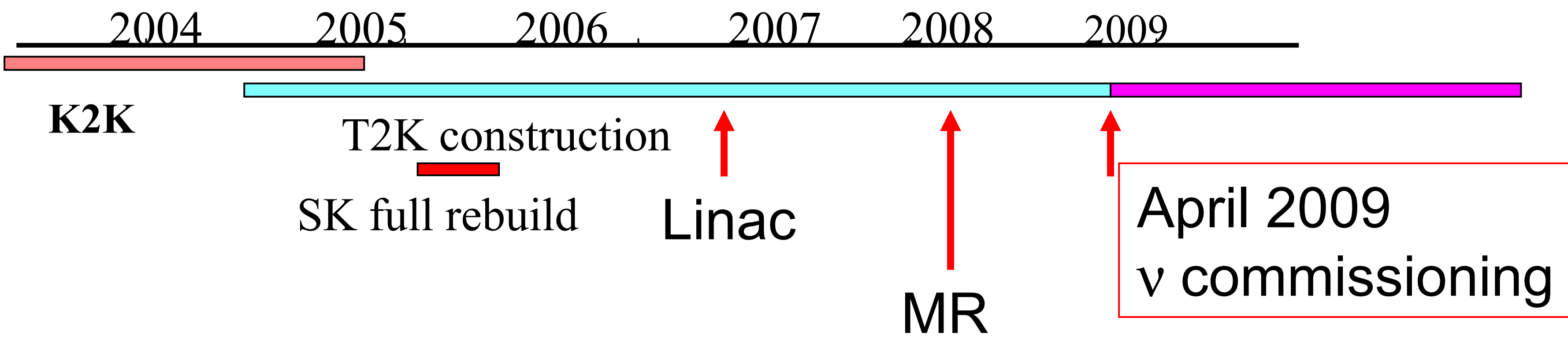
Components

- Primary proton beam line
  - Normal conducting magnets
  - Superconducting arc
  - Proton beam monitors
- Target/Horn system
- Decay pipe (130m)
  - Cover OA angle 2~3 deg.
- Beam dump
- muon monitors
- Near neutrino detector

Construction: JFY2004~2008



Schedule of T2K



- Possible upgrade in future →Next speaker
  - 4MW Super-J-PARC + Hyper-K (1Mt water Cherenkov)
  - CP violation in lepton sector
  - Proton Decay

Many new concepts emerged from studies of neutrinos.

LH world
Quark as physical constituent
Number of generations
Wide variety mass of elementary particles
…….

Tradition will continue and
New results in 2010