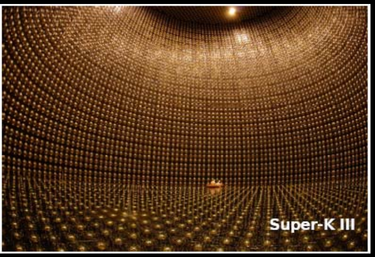
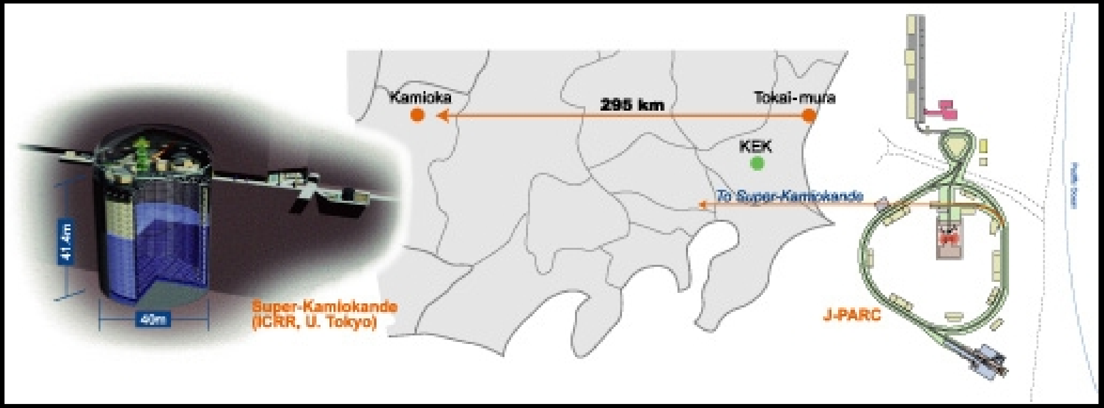
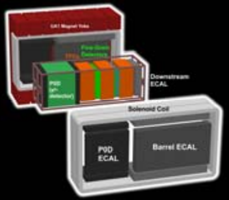
JPARC future and Large Detectors







Christos Touramanis

UNIVERSITY OF LIVERPOOL

IoP Large Detectors Meeting
Sheffield 15 Dec 2008

T2K UK

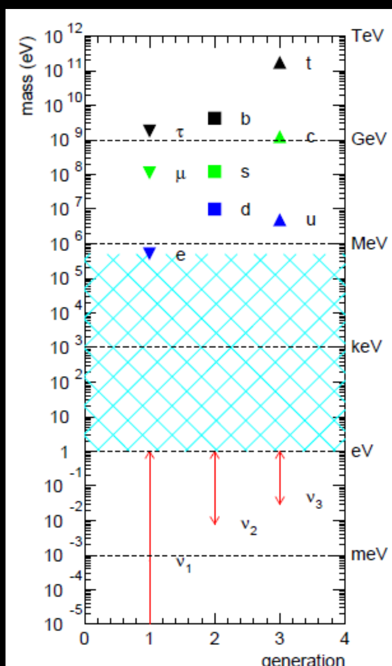
Outline

WHAT? Neutrino physics in long-baseline experiments with accelerator-made neutrinos

- WHY? The science case
- WHERE? JPARC
- CURRENT PROGRAMME
- FUTURE PROGRAMME
- LARGE DETECTOR

Motivation (experimentalist's view)

Empirical puzzles:
- Neutrino mass, mixing
- Baryon asymmetry



$$V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.001 \\ 0.2 & 1 & 0.01 \\ 0.001 & 0.01 & 1 \end{pmatrix}$$

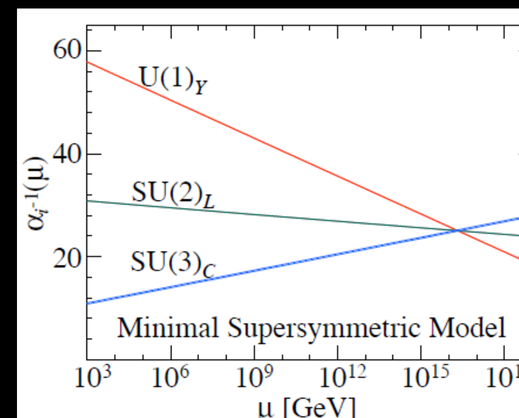
angles	*quarks*	*leptons*	*sum*
θ_{12}	12.8^0	33.9^0	46.7 ± 2.4^0
θ_{23}	2.3^0	41.6^0	$43.9^{+5.1}_{-3.6}$
θ_{13}	0.5^0	$< 8^0$	$< 8.5^0$

$$V_{MNS} \sim \begin{pmatrix} 0.8 & 0.5 & 0.2 \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

- Mass hierarchy
- Different mixing matrices

Is there a pattern?

Exciting coincidences:
- Unification
- Inflation



- Forces unify at ~10^{16}
- Inflation: spinless field ~10^{13}
- Seesaw: RH neutrino ~10^{14}

Is this accidental?

Baryon asymmetry

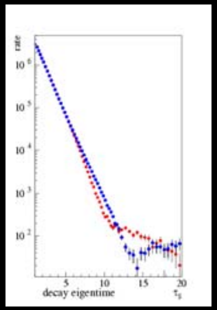
Baryon/photon ratio:

- 10^{-18} SM + Standard cosmology
- BBN – Deuterium: 10^{-10}
- CMB (WMAP): 10^{-10}

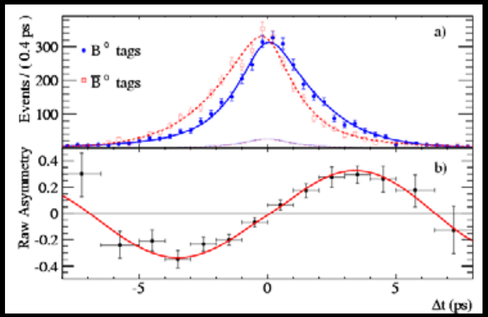
For every billion ordinary particles annihilating with antimatter in the early Universe, one extra was left "standing."

Quark flavour understood – CPV due to CKM phase

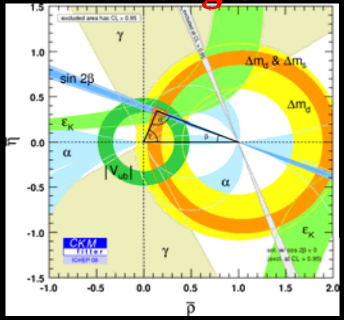
Kaons, CPLEAR



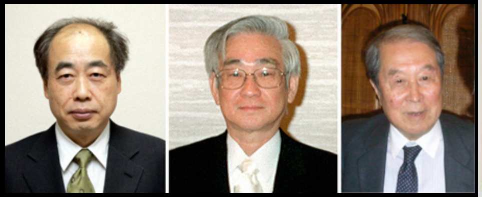
B mesons, BABAR

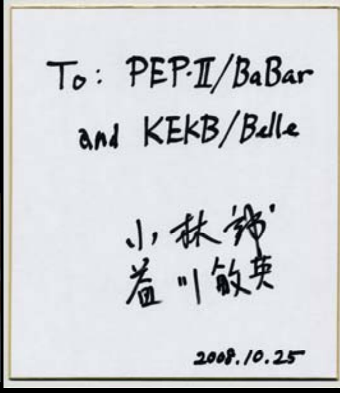


Unitarity Triangle



2008 Nobel Prize





Inflation would have wiped out any initial asymmetry

Matter dominance created at or after end of inflation

UNKNOWN MECHANISM: Leptogenesis?

Neutrino mixing

Flavor eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 3} & U_{\tau 3} \end{bmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass eigenstates

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\mathrm{CP}}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\mathrm{CP}}} & 0 & c_{13} \end{pmatrix} \cdot \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} e^{i\eta_1} & 0 & 0 \\ 0 & e^{i\eta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric
(+ ν_μ Long BL)

ν_μ Long BL
reactor Short BL

Solar
(+ reactor Long BL)

Majorana
??

$$c_{ij} = \cos(\theta_{ij})$$

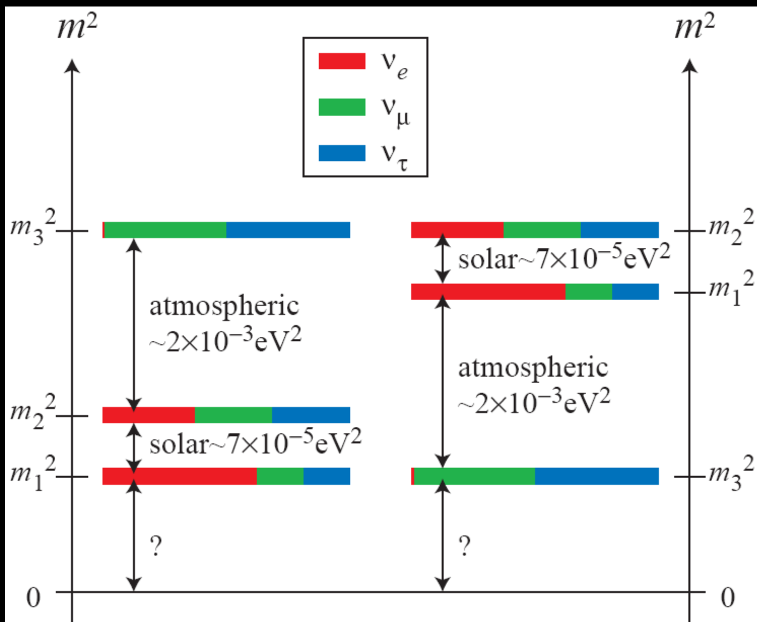
$$s_{ij} = \sin(\theta_{ij})$$

2-neutrino oscillation

$$P_{\alpha\beta} = \delta_{\alpha\beta} - \left(2\delta_{\alpha\beta} - 1\right)\sin^2(2\theta)\sin^2\left(1.27 \bullet \Delta m^2 \bullet \frac{L}{E}\right)$$

Neutrino oscillations today

Mass hierarchy



normal **inverted**

$$\Delta m^2_{21} = 7.67\,^{+0.22}_{-0.21}\,\left(^{+0.67}_{-0.61}\right) \times 10^{-5}\ \mathrm{eV}^2\,,$$

$$\Delta m^2_{31} = \begin{cases} -2.37 \pm 0.15\ \left(^{+0.43}_{-0.46}\right) \times 10^{-3}\ \mathrm{eV}^2 \\ +2.46 \pm 0.15\ \left(^{+0.47}_{-0.42}\right) \times 10^{-3}\ \mathrm{eV}^2 \end{cases}$$

$$\theta_{12} = 34.5 \pm 1.4\ \left(^{+4.8}_{-4.0}\right)\,,$$

$$\theta_{23} = 42.3\,^{+5.1}_{-3.3}\,\left(^{+11.3}_{-7.7}\right)\,,$$

$$\theta_{13} = 0.0\,^{+7.9}_{-0.0}\,\left(^{+12.9}_{-0.0}\right)\,,$$

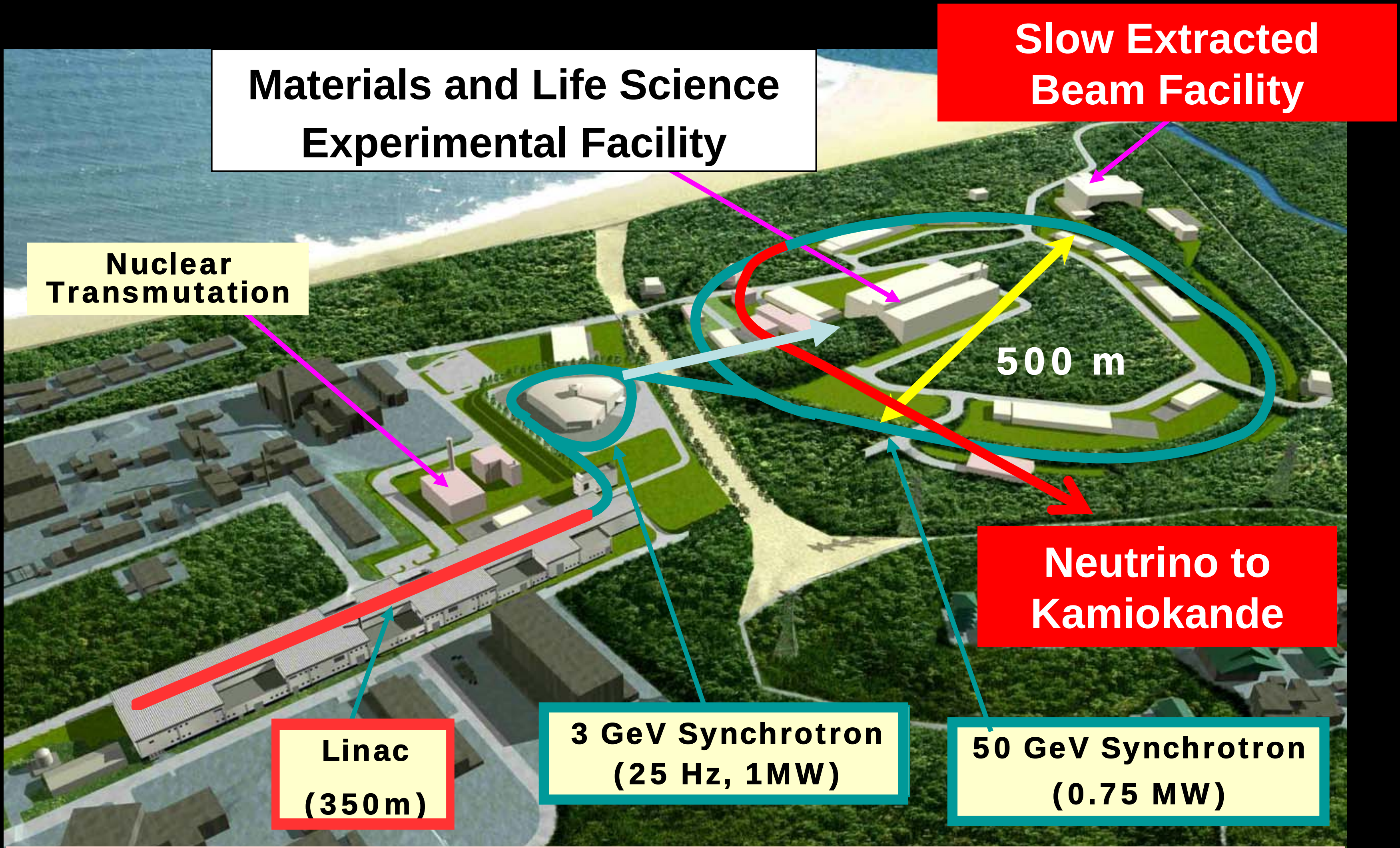
$$\delta_{\mathrm{CP}} \in [0,\ 360]\,.$$

hep-ph 0704.1800v2 16 Oct 2007

Errors:
1σ (3σ)

- Is θ_{13} non-zero?
- CP violation?
- Is θ_{23} 45^0?
- Which hierarchy?

J-PARC: a brand new $2bn facility



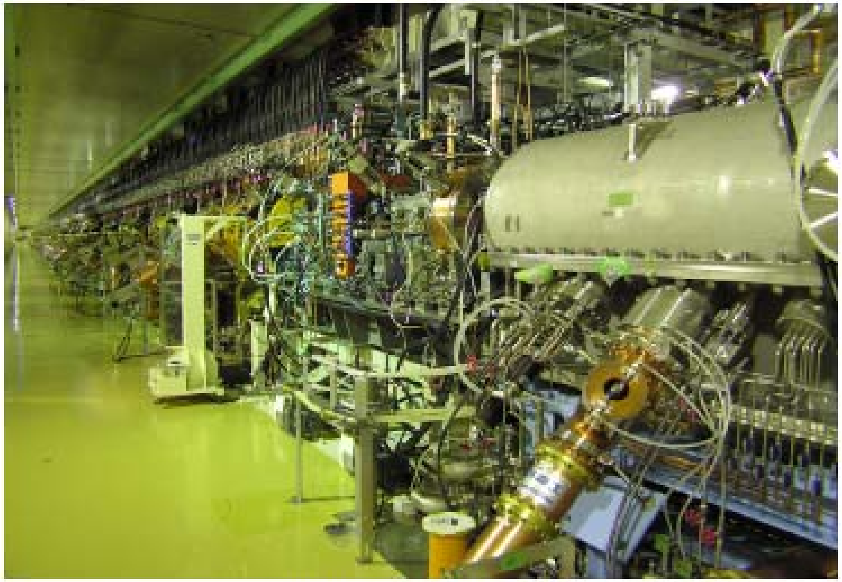
J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA

J-PARC construction since 2001

First funds for neutrino project approved in December 2003!

J-PARC: 28 January 2008

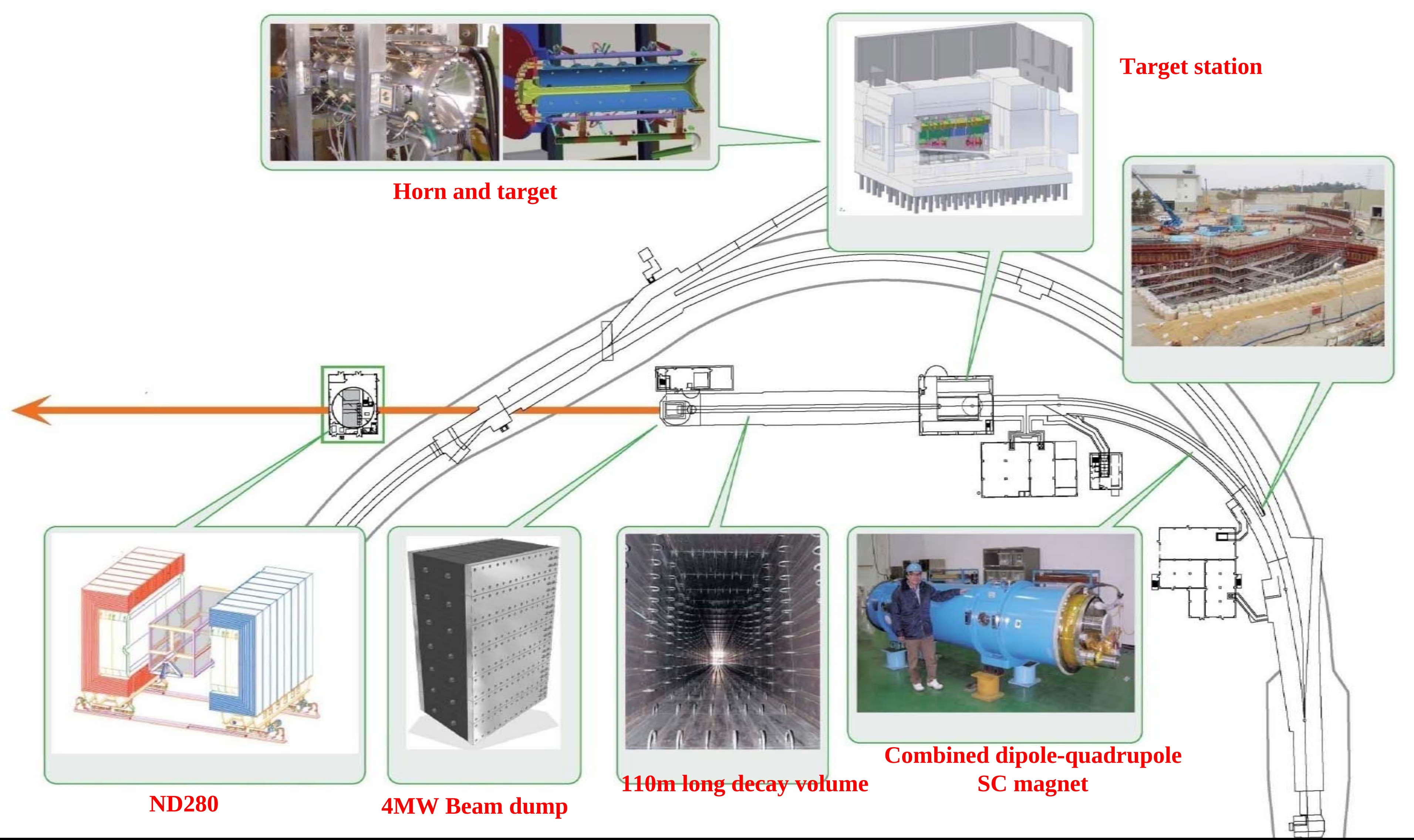

Linac (330 m)


3 GeV Synchrotron (350 m)


50GeV Synchrotron (1600 m)

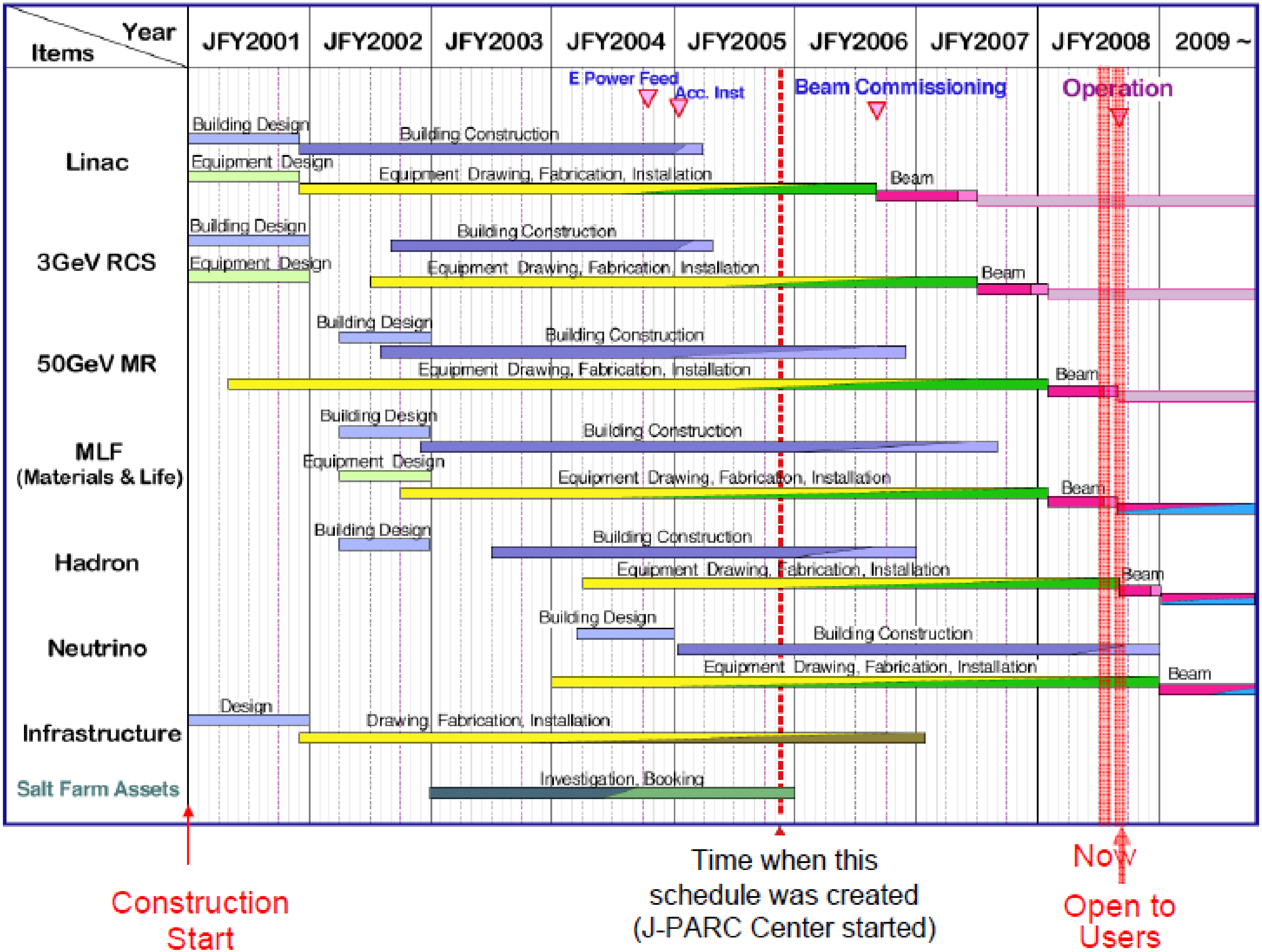

Superconducting magnets for the neutrino beamline

Neutrino Facility ($180m)



J-PARC Construction Schedule

Feb. 27 2006



Accelerator milestones

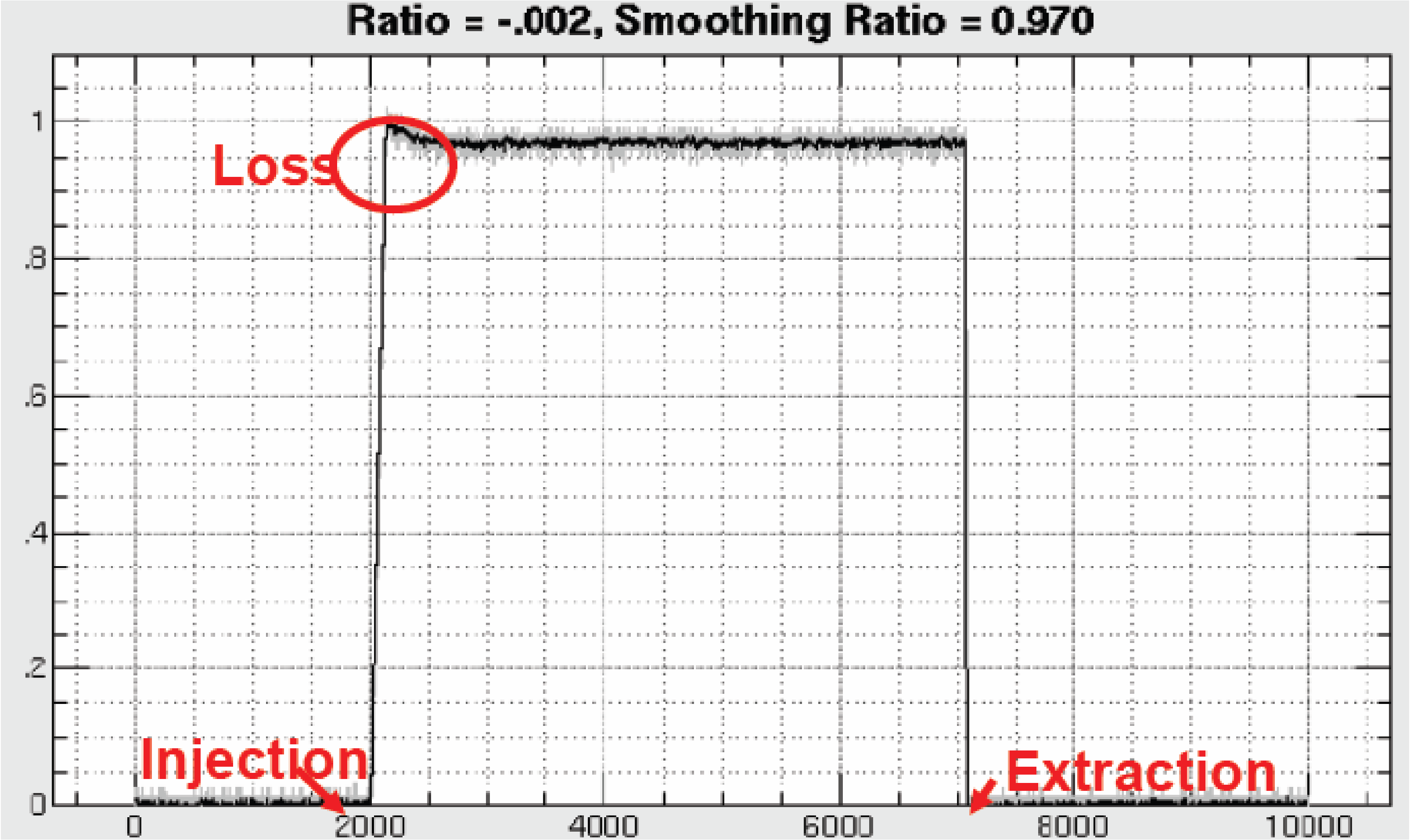
- LINAC, 23 Jan 07: 181MeV H^- beam
- RCS, 31 Oct 07: protons accelerated to 3GeV
- MR, 22 May 08: protons circulated at 3GeV
- RCS, 19 Sept 08: 210kW for 70 sec, 315kW-equivalent in single-bunch mode

- MR, Dec 08: acceleration to 30GeV
- Neutrino Beam Line, April 09: first neutrinos

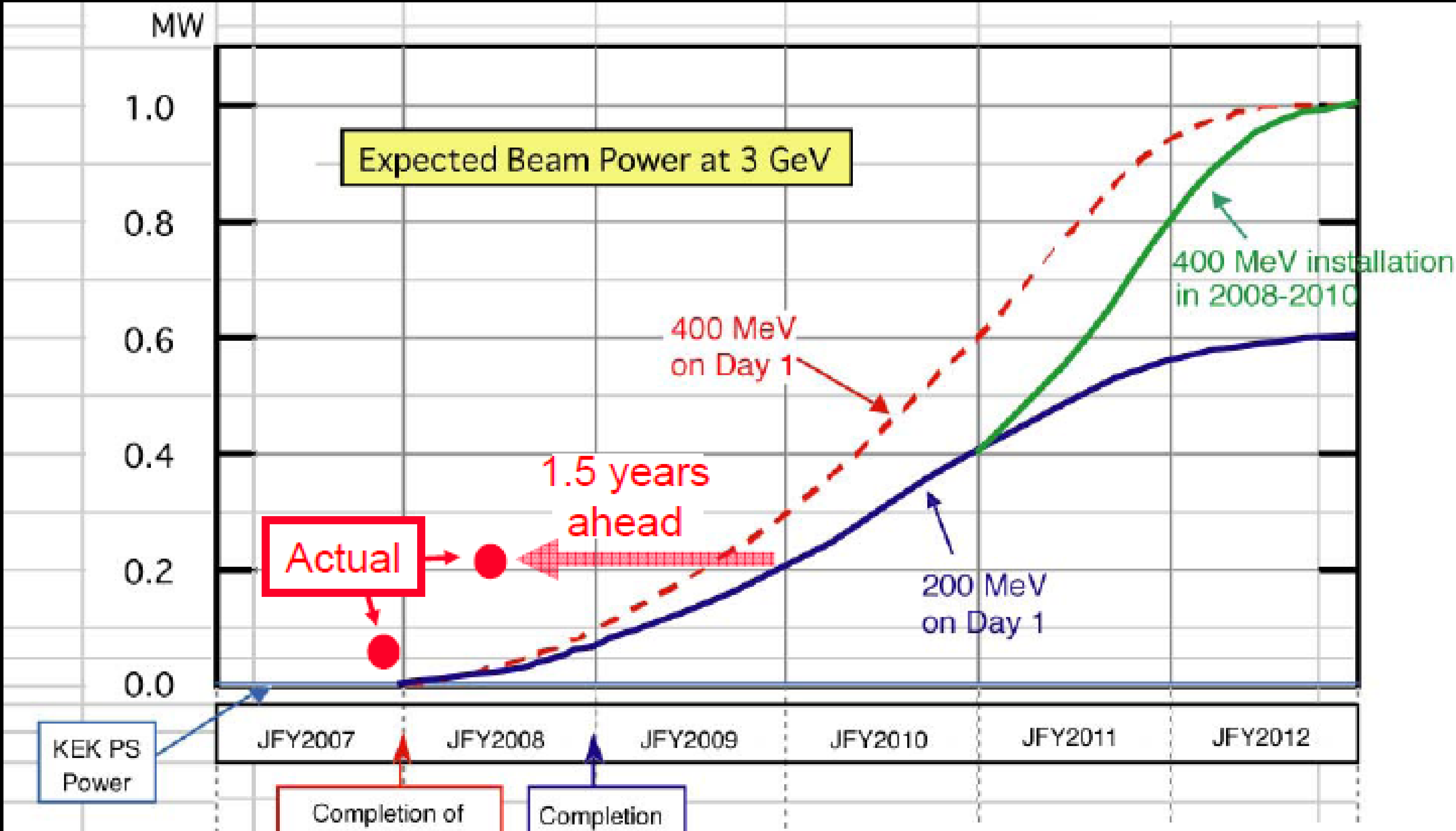
3GeV RCS at 210kW

2008/09/18 11:00

1.772x10^{13} ppp : 210kW @ 25Hz Operation. , Loss:~3%

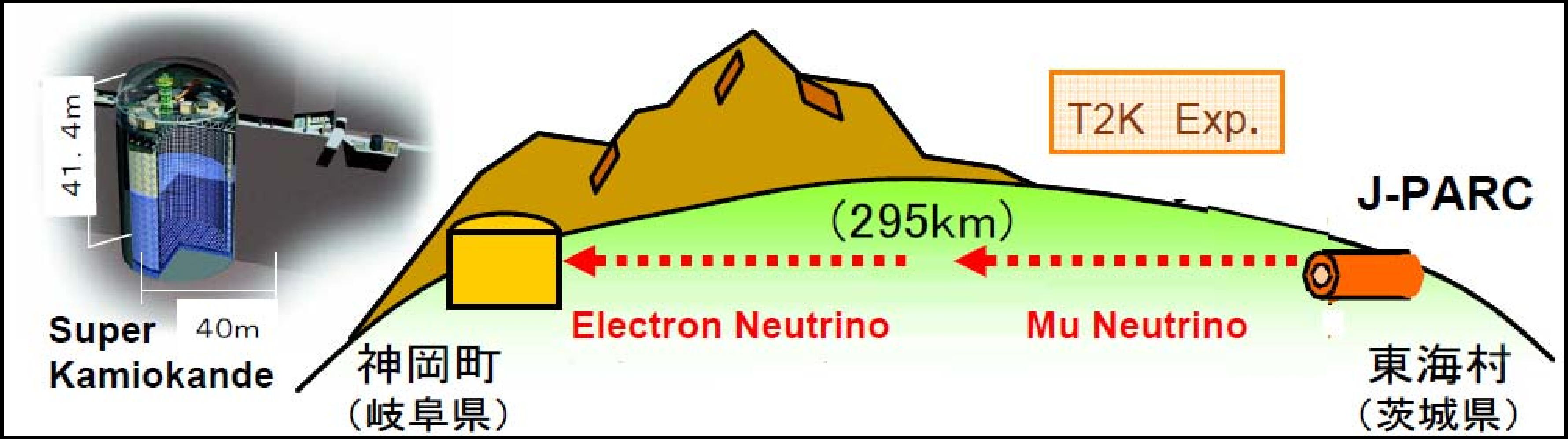


Beam Power Plan

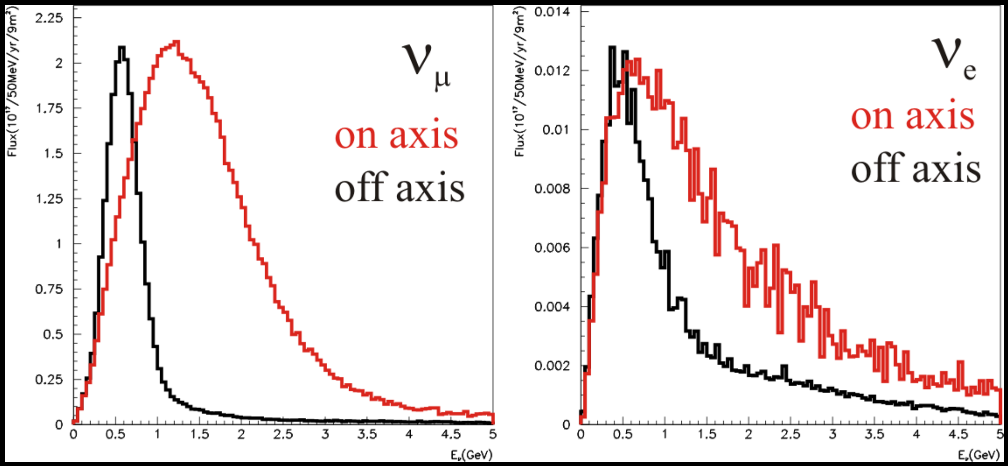


Power at KEK-Booster = 3 kW

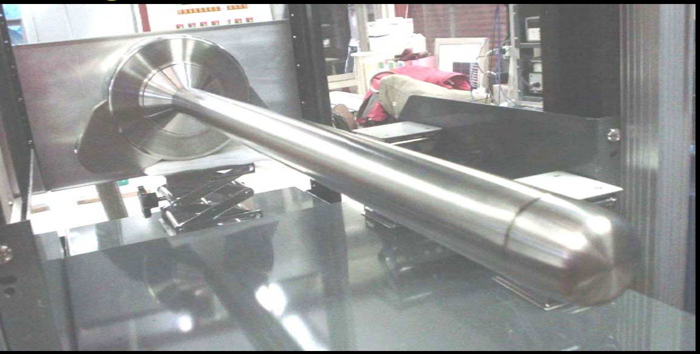
T2K



- Off-axis beam
- 0.75MW x 15000h
- Search for θ_{13}
- Precision: θ_{23}, Δm^2_{23}
- Near Detector: Neutrino interactions

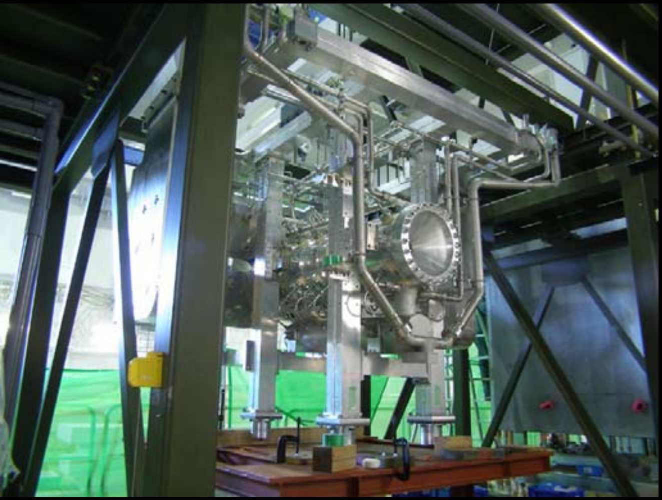


Target

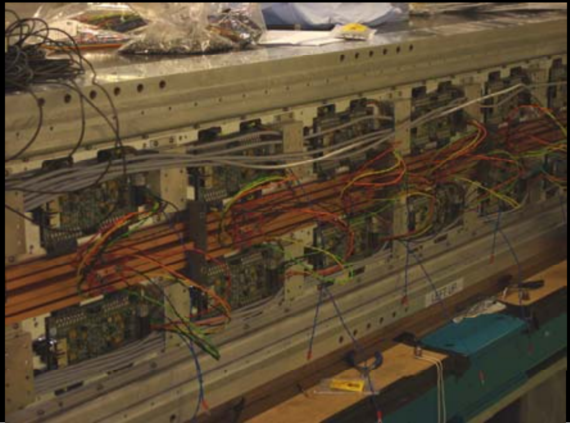


ND280 (UA1) Magnet in pit

1st Horn

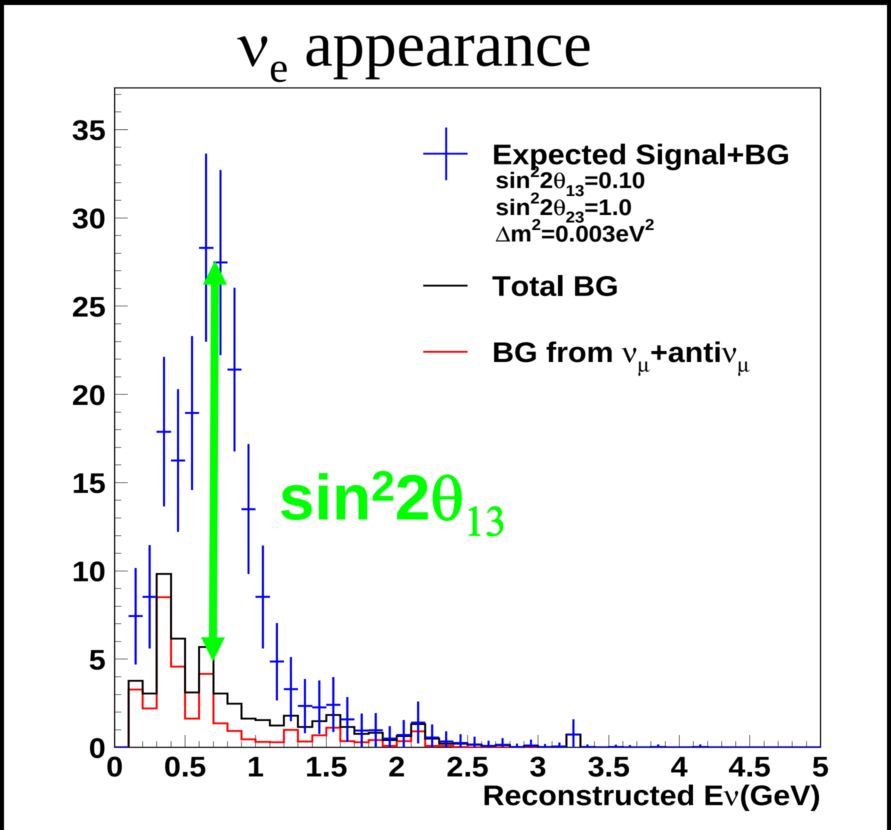


DS ECAL

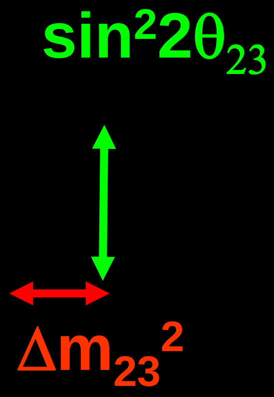


Fast Extraction Kicker Magnets

Main T2K measurements



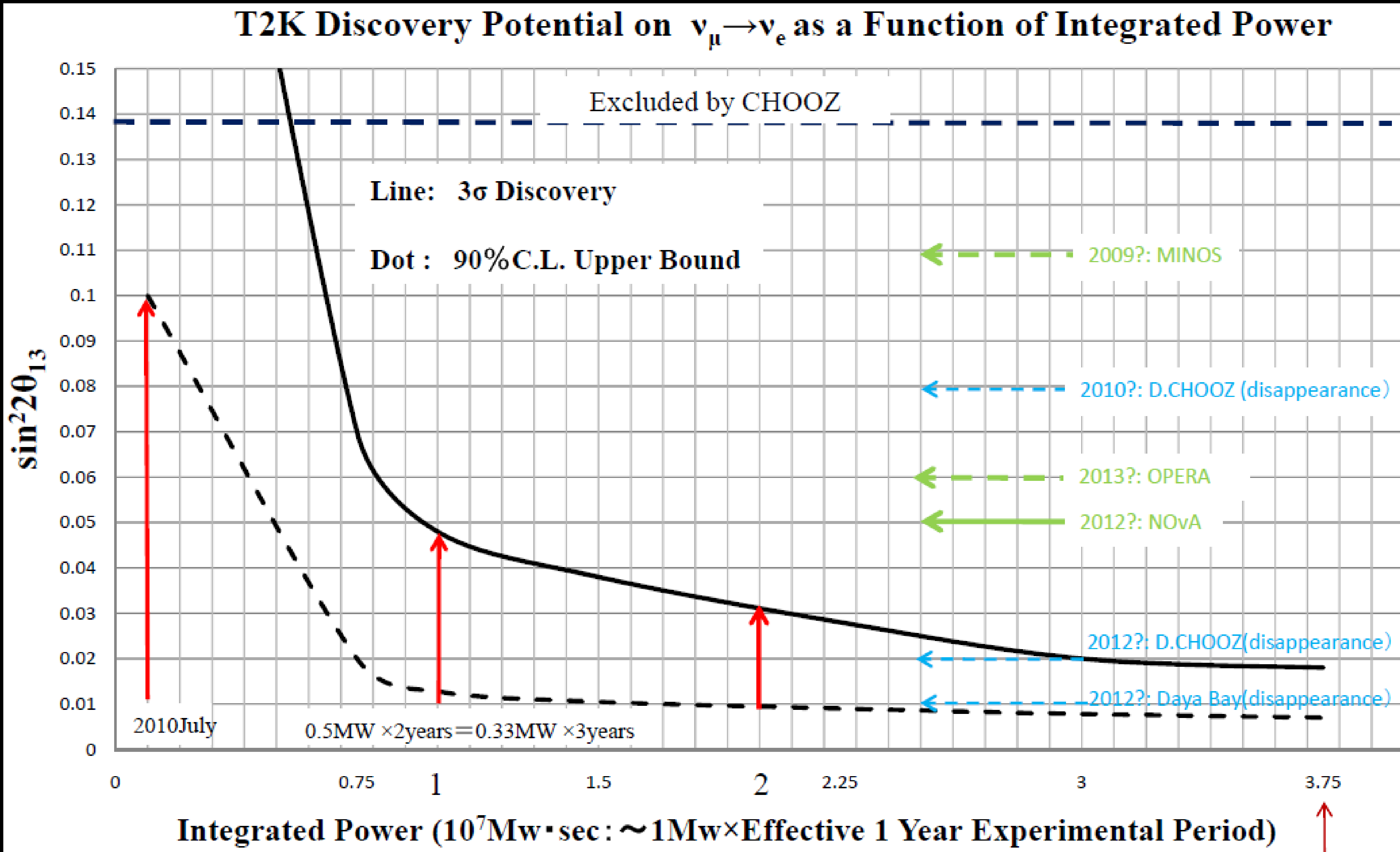
ν_μ disappearance



The challenges:

- Knowledge of initial beam content and kinematics
- Knowledge of backgrounds

θ_{13} reach



Future JPARC Neutrino Programme

Higher Beam Power

Very Large Far Detector

$\Rightarrow$CP Violation search
Precision in θ_{13}
Mass hierarchy

Beam Upgrade

- Number of bunches in MR
  - Fast Extraction Kicker Magnet
- Repetition Rate
  - RF and Magnet Power Supplies
- RCS h (RF improvements)
  - h=2: 2bunch x 4cycle MR injection
  - h=1: single bunch, double number of protons, 8cycle injection
- LINAC energy (181MeV to 400MeV)

- Beam upgrades to be funded from FY2009

Power Upgrade of Neutrino Beam (8 bunches/pulse)

MR 30 GeV

LINAC 181MeV

Cycle time 3.52 sec

4 10^{13} P/bunch

0.27MW

LINAC 400MeV

0.45MW

5%

(MR usage of RCS)

MR RF Upgrade

Cycle time=1.76

0.55MW

0.91MW

8%

RCS h=1 Operation

Cycle time 1.92

8.3 10^{13} P/bunch

1MW

MR 30 GeV

LINAC 400MeV

Cycle time 1.92sec

8.3 10^{13} P/bunch

1.66MW

17%

Future Far Detector

- Where: baseline, off-axis angle
- Technology: Water or LAr?
- Size: the bigger the better?
- Related: beam energy

Aims:

- Sensitivity to CP (δ)
- Resolve ambiguities
- Determine mass hierarchy

Considerations

- Signal reconstruction
- Background rejection
- Neutrino energy determination

Locations

Super-K	295km	2.5^0 O.A. angle
Okinoshima	658km	0.8^0 O.A. angle
Korea	~1050km	$(1\text{-}2)^0$ O.A. angle

Eight-fold parameter degeneracy

Intrinsic degeneracy: $(\theta_{13}, \delta_{CP}) \to (\theta'_{13}, \delta'_{CP})$

Sign degeneracy: $\Delta m^2_{31} \to -\Delta m^2_{31}$

Octant degeneracy: $\theta_{23} \to \pi/2 - \theta_{23}$ (if not maximal)

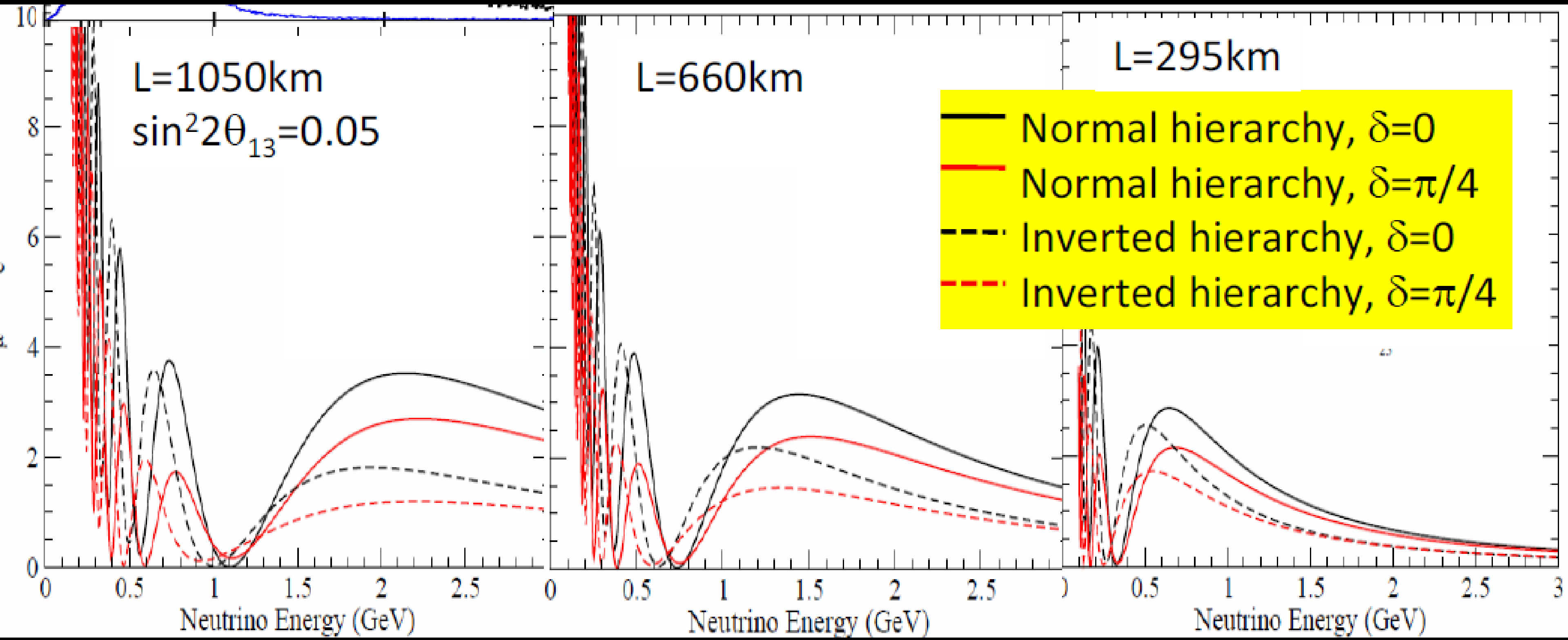
- Beam energy: CP effect large at low E
  - BUT higher E favours hierarchy resolution
    - And increases high-E to low-E backgrounds
- CP violation sensitivity compromised by wrong-sign, CP-even solutions: longer baseline allows to disentangle hierarchies (strong matter effects)
- For small θ_{13} CP sensitivity driven by statistics: short baseline advantage

Options

- Sample multiple L/E points:
  - Detectors at multiple baselines (T2KK: Kamioka and Korea, Water Čerenkov, 0.27Mton fiducial volume each)
    - Identical detectors most important for mass hierarchy
  - E_ν spectrum at single far detector:
    - Wide beam energy (small O.A. angle)
    - Good resolution far detector
- Water Čerenkov: known technology BUT only CCQE
- LAr TPC:
  - Increased statistics through use of all CC events
  - Less NC feed-down: allows small O.A. angles
    - Lower backgrounds: robustness against systematics
    - Small OA angle: higher statistics; less sensitive to Δm_{13}
  - Superior E_ν resolution

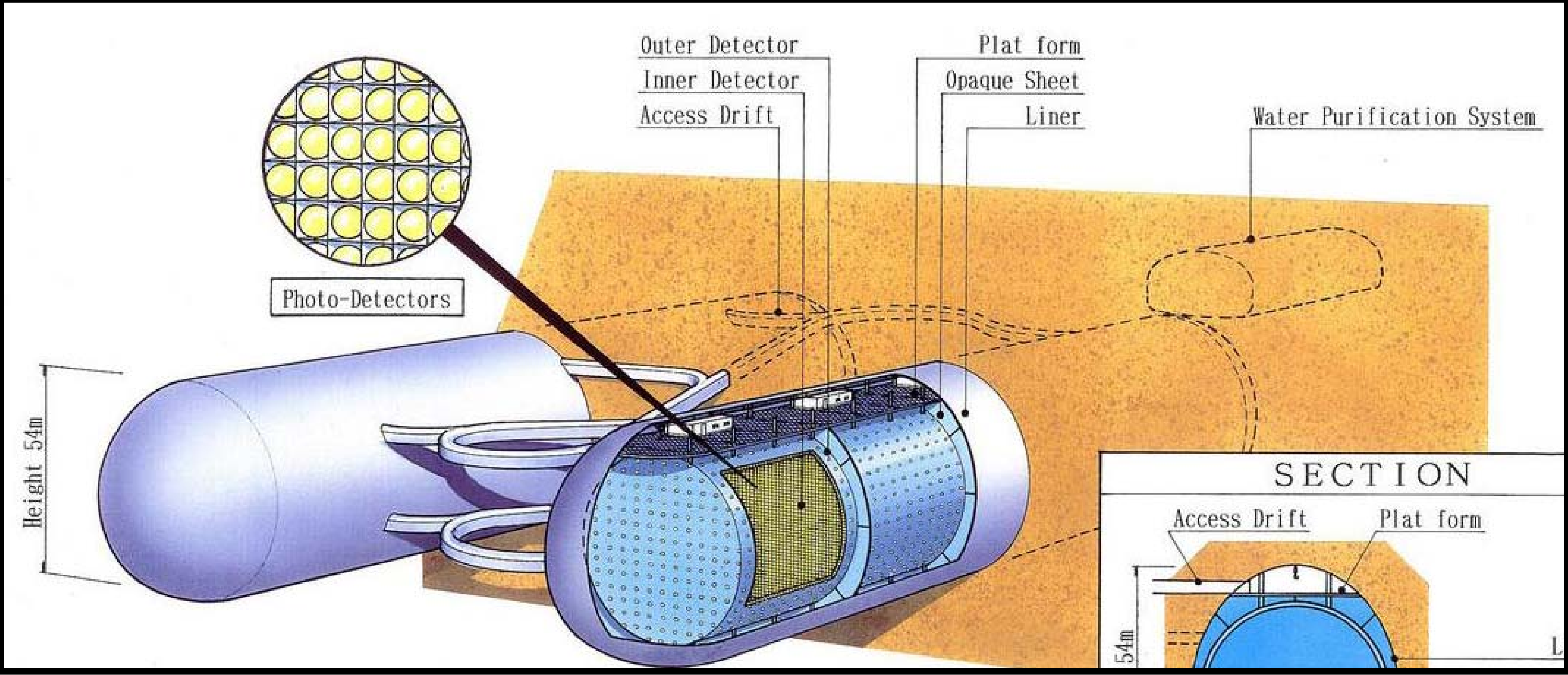
Neutrino energy, oscillation maxima

All plots: $\nu_\mu \rightarrow \nu_e$ probability

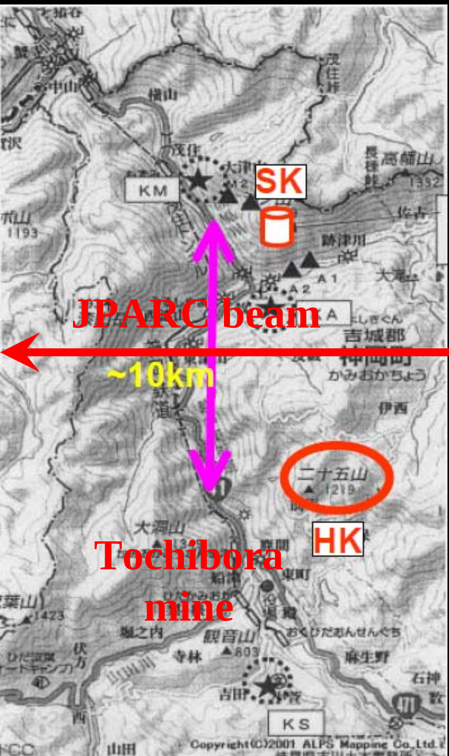


Hyper-K

- 1Mt water (total), 540kt fiducial
- Known technology, ~1 order of magnitude scale-up from Super-K
- Only 1st maximum; off-axis 2^0
- Overburden: 600m of rock

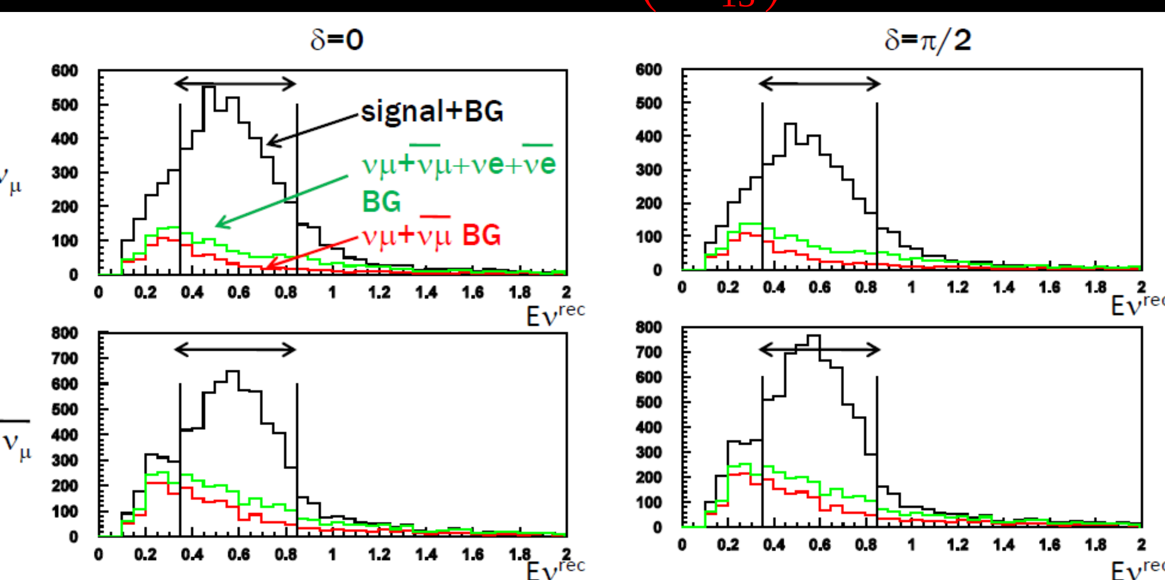


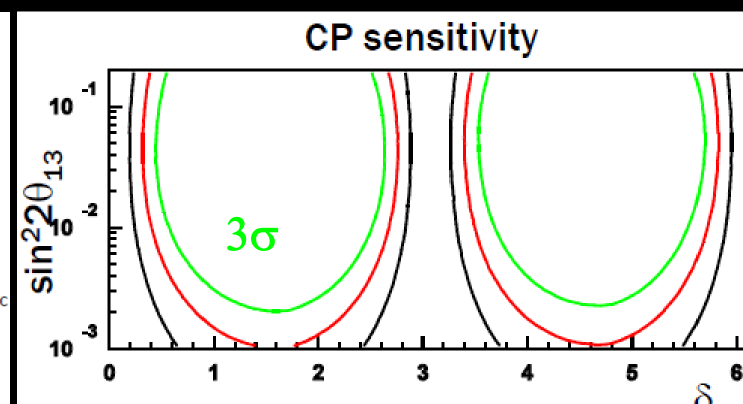
Hyper-K



- Cost: 1/3 cavern, 2/3 photosensors
- Coverage: 20% (100,000 20-inch PMTs) or 40% (200,000)?
- Dead-time-free electronics (as in SK-IV (?))
- Assume neutrino (2.2y) and antineutrino (7.8y) running

$$\sin^2(2\theta_{13}) = 0.1$$



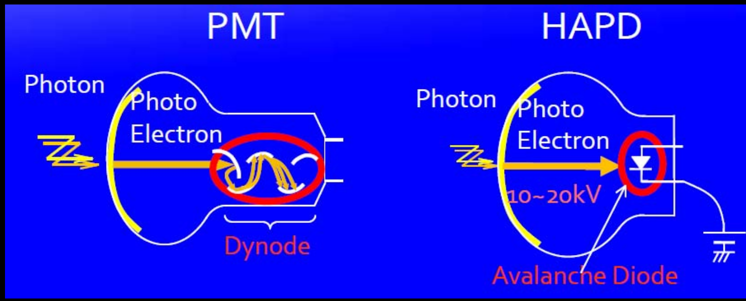


(Kaneyuki, NP08)

Photosensors for Hyper-K

- 20inch PMT (Super-K)
- PMm^2 (multiple smaller PMTs, Photonis-FR-JP project)
- HAPD (Hamamatsu, JP project)
  - Also develop low-power readout (fast sampling, slow ADC)

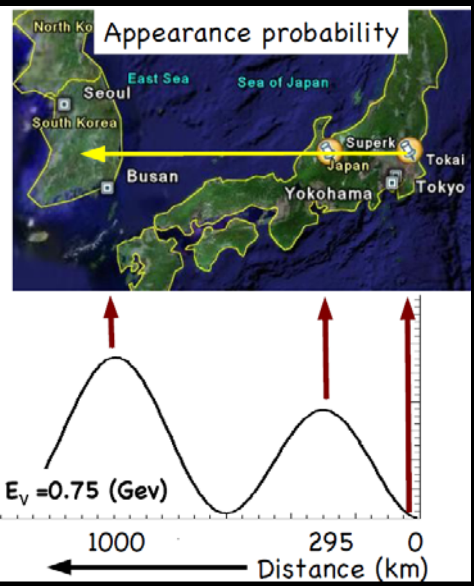
Parameters*		13inch HAPD	13inch PMT (R8055)	20inch PMT (for SK)
Single Photon Time Resolution (s)		190ps	1400ps	2300ps
Single Photon Energy Resolution		24%	70%	150%
Pulse Response	Rise Time	1ns	6ns	10ns
	Pulse Width	2.2ns	10ns	20ns
Transient Time		12ns	100ns	95ns
Dynamic Range (Signal Intensity in p.e.)		3000 p.e.	2000 p.e.	1000 p.e.
Order of Gain		10^5	10^7	10^7

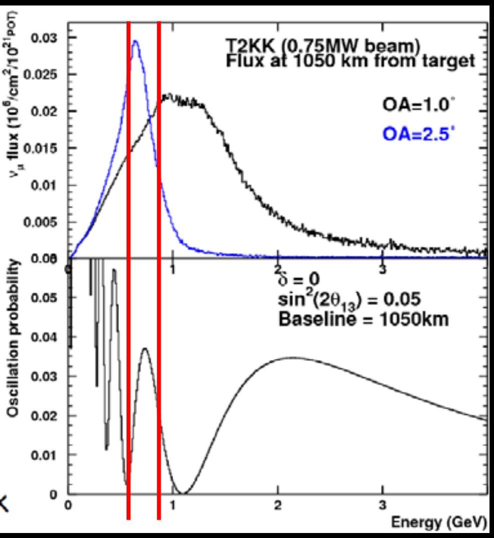


(Abe at NP08)

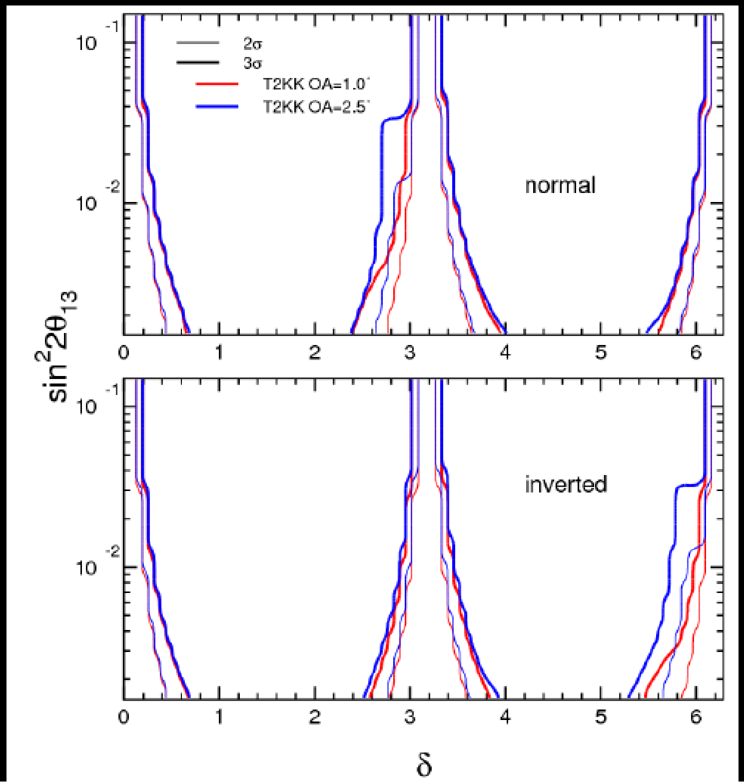
T2KK

- Move one of two Hyper-K modules to Korea: sampling at two oscillation maxima
- Same detector, similar costs
- 5y neutrino, 5y antineutrino



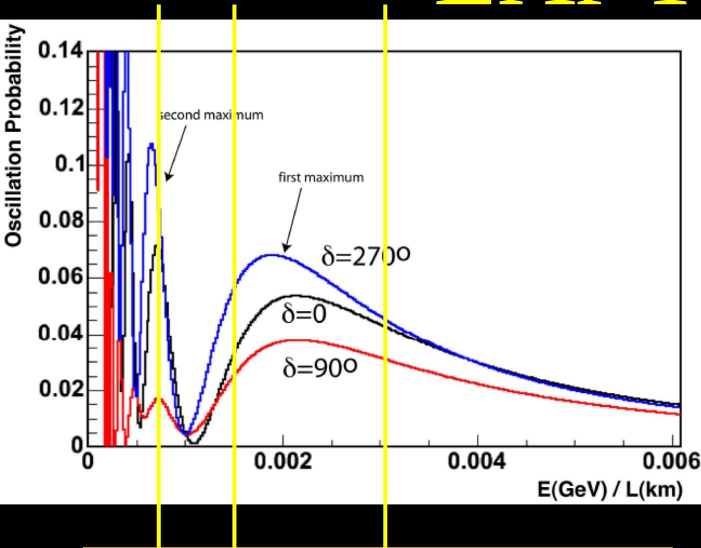


(Dufour NP08)



- Small O.A. angle (1^0):
  - Reduced feed-down NC bgr
  - Only second maximum
- Large O.A. angle (2.5^0):
  - 2 appearance peaks
  - Higher backgrounds
- Both positions similar for CP violation
- 1^0 more sensitive to mass hierarchy

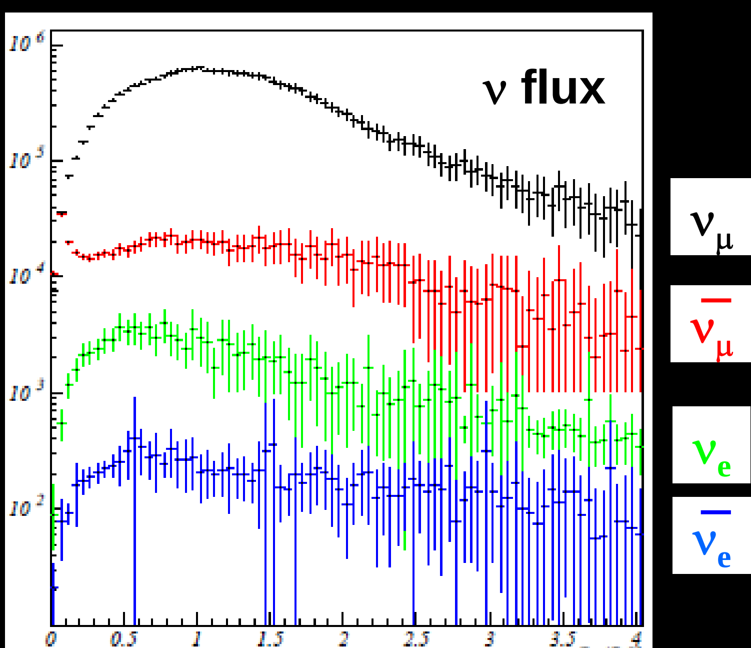
LAr TPC in Okinoshima

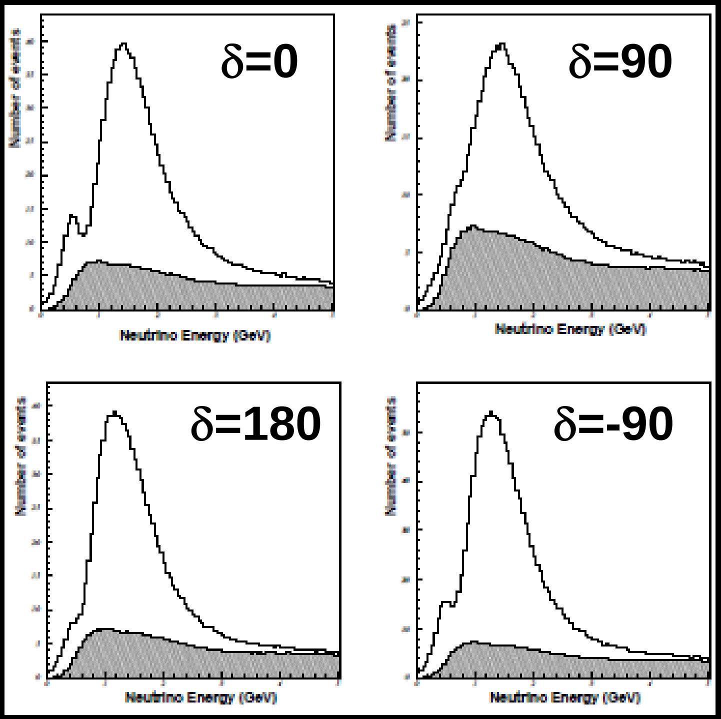


.5 1. 2.

E(GeV) at Okinishima (658km)

- 100kt LAr detector
- Near-surface possible
- Access to all CC events
- Access to two maxima
- Neutrino-only run
- Exploit superior resolution
- Details in A. Rubbia's talk

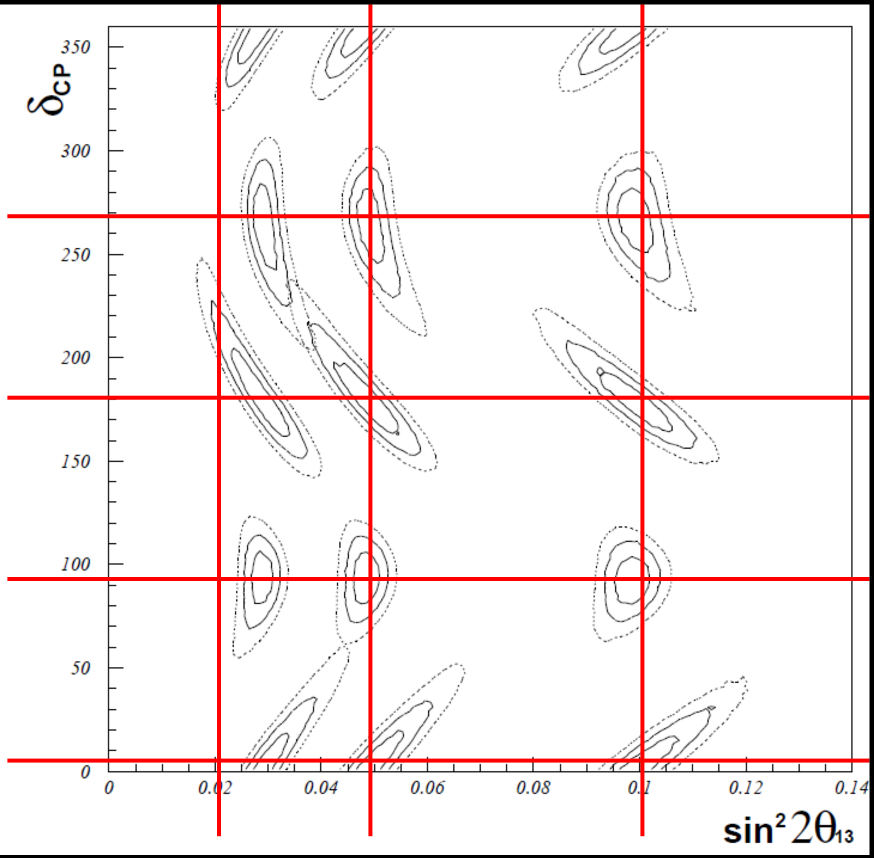




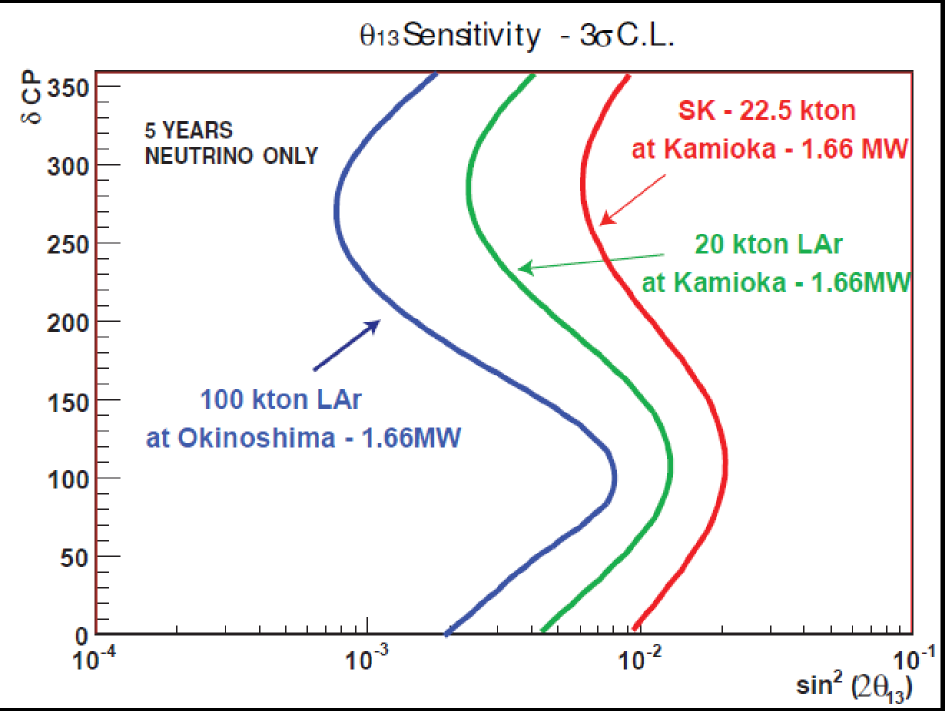
Reconstructed neutrino energy for 100MeV/c resolution

Plots from [hep-ph] 0804.2111

Sensitivity of LAr@Okinoshima option



Fit results for (3x4) cases of true values and 100MeV/c resolution



Plots from [hep-ph] 0804.2111

Summary of different options

	Scinario 1 Okinoshima	Scenario 2 Kamioka	Scenario 3 Korea
Baseline(km)	660	295	295 & 1000
Off-Axis Angle(°)	0.8(almost on-axis)	2.5	2.5 1
Method	ν_e Spectrum Shape	Ratio between ν_e $\bar{\nu}_e$	ν_e Spectrum Shape
Beam	5Years ν_{μ}, then Decide Next	2.2 Years ν_{μ}, 7.8 Years $\bar{\nu}_{\mu}$,	5 Years ν_{μ}, 5 Years $\bar{\nu}_{\mu}$,
Detector Tech.	Liq. Ar TPC	Water Cherenkov	Water Cherenkov
Detector Mass (kt)	100	2×270	270+270

- JPARC neutrino facility offers a realistic basis for a 15y neutrino programme aimed at CP violation
- Detector technologies of varying maturity and expected performance exist, R&D programmes are ongoing
- Great discovery potential!