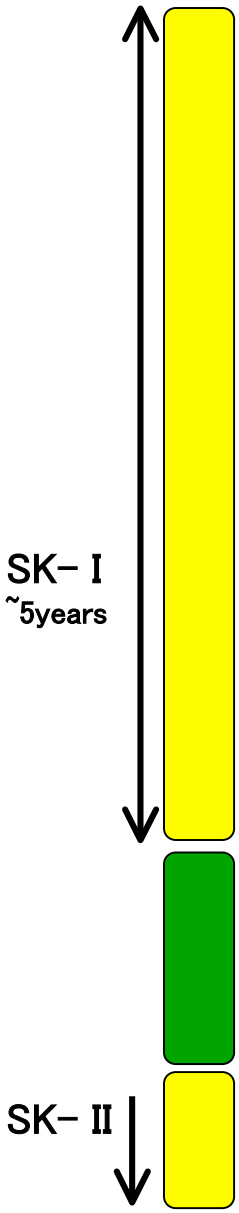
Neutrino Programs in Japan/Korea

Hiro Aihara
University of Tokyo

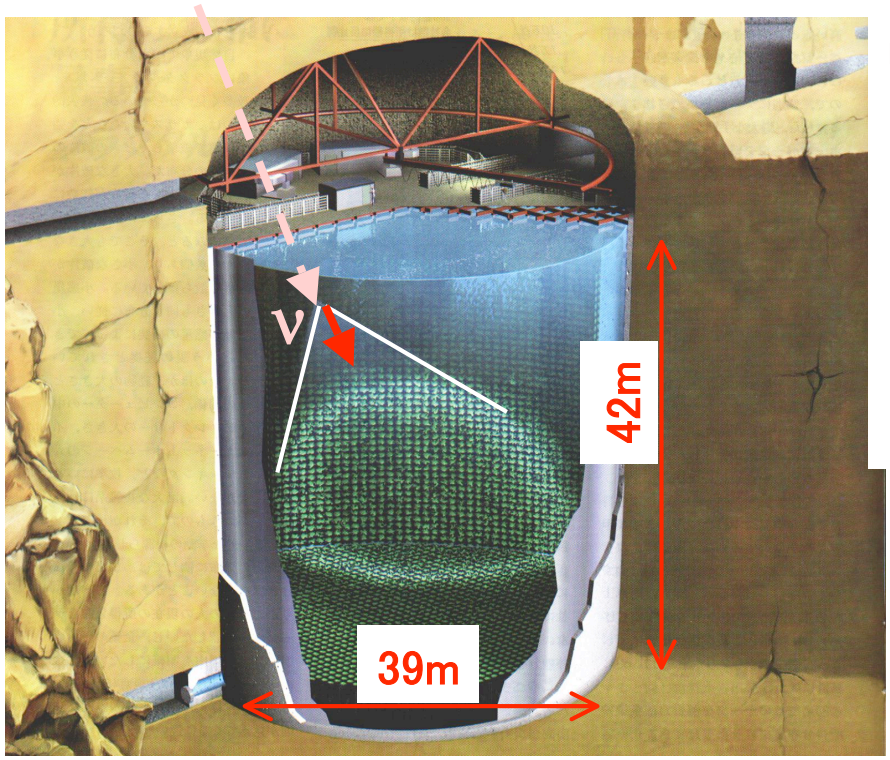
presented at P5 meeting at Fermilab on April 18, 2006

Super Kamiokande III

Water Cherenkov detector



- 1996.4 Start data taking (SK- I)



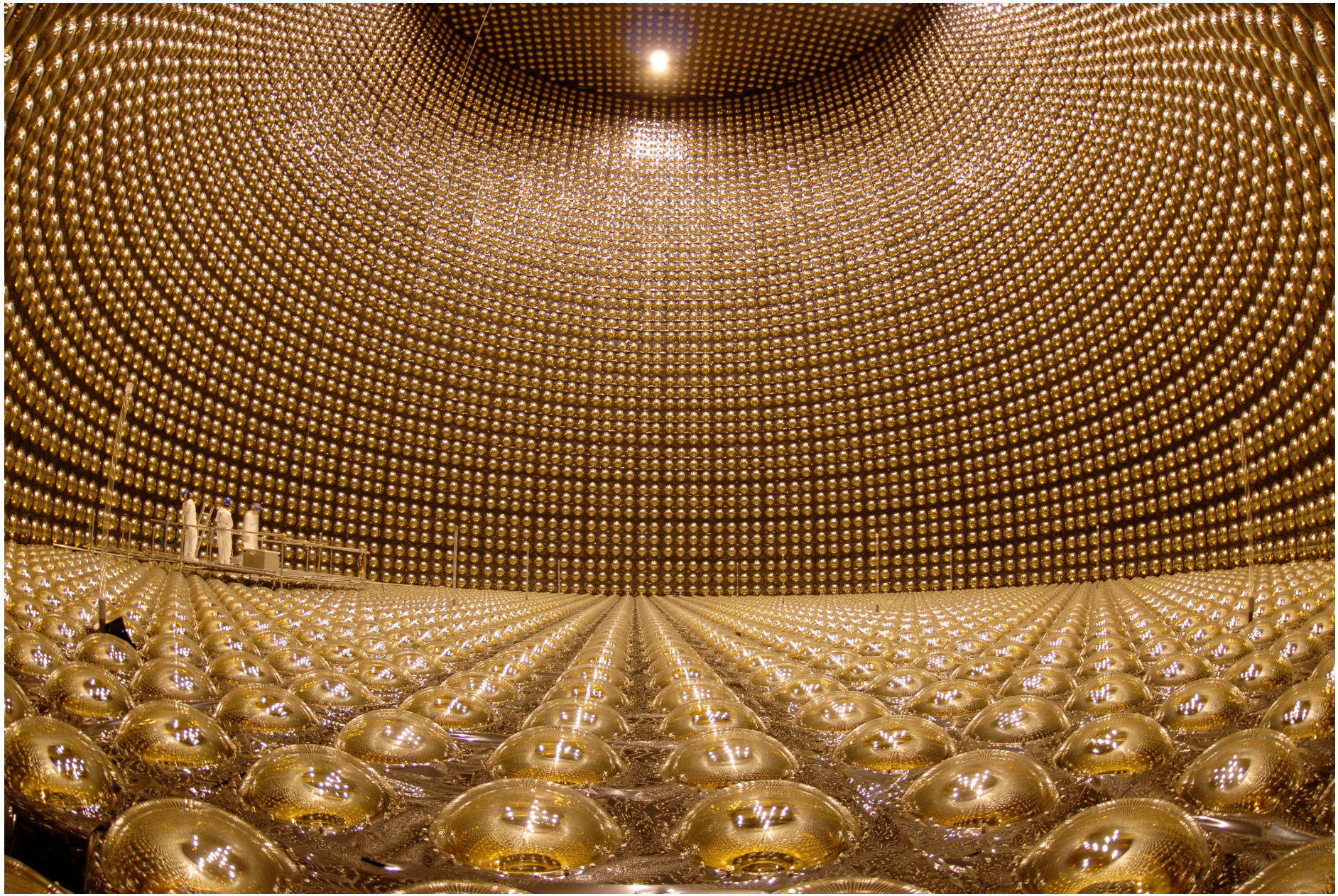
- 2700 w.e. overbuden
- 50,000 ton (22,500 ton fid.)
- 11,146 20 inch PMTs
- Photo cathode coverage: 40% of surface
- 1,885 anti-counter PMTs

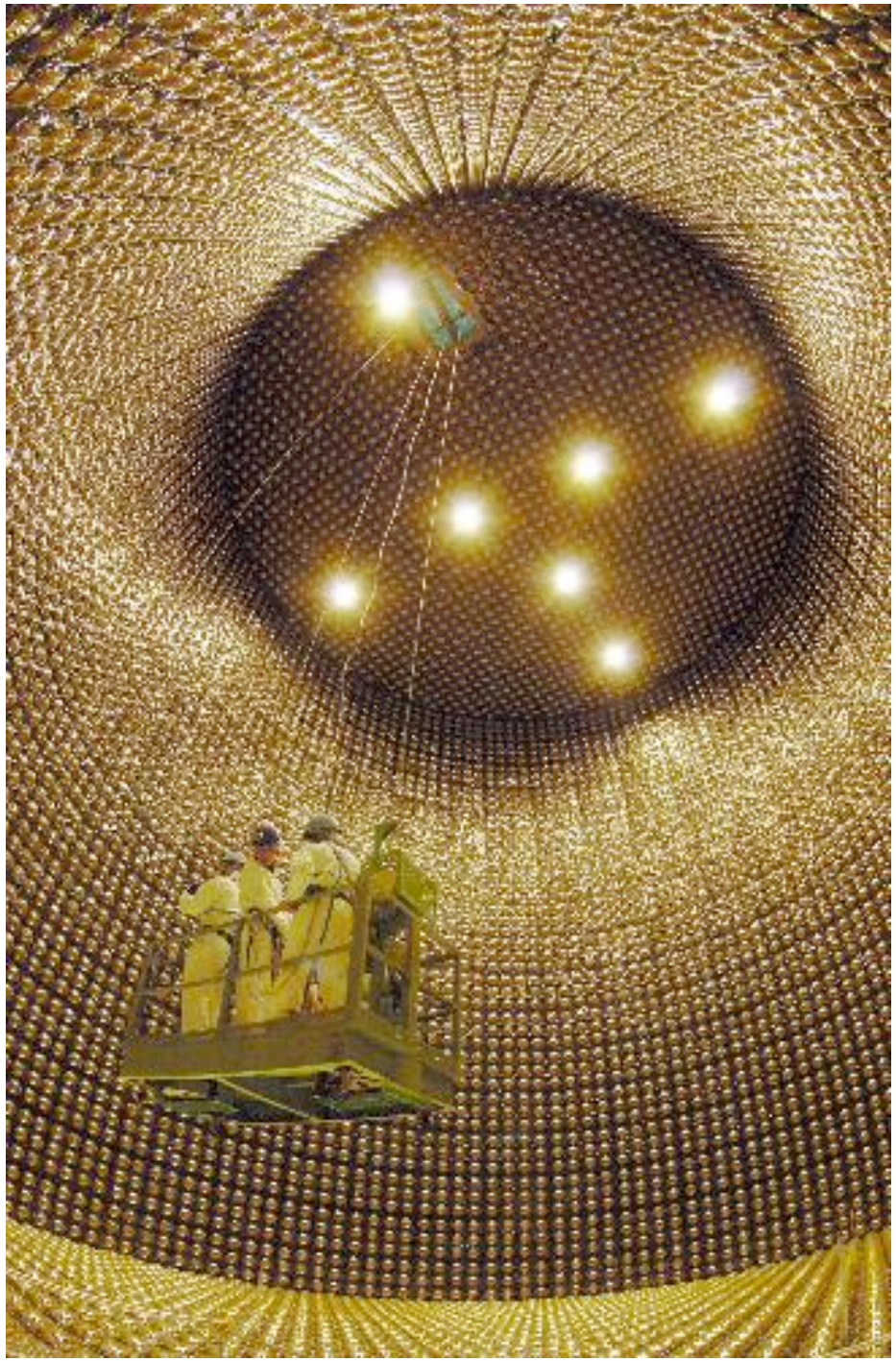
- 2001.7 Stop data taking for detector upgrade
- 2001.11 Accident (6777 inner PMTs, 1100 outer PMTs were destroyed)
  partial reconstruction of the detector

- 2002.10 Resume data taking (SK- II) mostly for K2K (photocathode coverage of 20%, 7MeV

- 2005.10 Start full recovery work

Acrylic + FRP vessel





SK is back to full sensitivity to continue on

- Solar neutrinos
  (Eth down to 4MeV)
- Atomospheric neutrinos
- Super Nova neutinos

Resume normal data taking in June.

US has been and will continue to be a partner in SK program.

Institute for Cosmic Ray Research (ICRR), The University of Tokyo
Boston University
Brookhaven National Laboratory
University of California, Irvine
Chonnam National University
California State University, Dominguez Hills
Duke University
Gifu University
University of Hawaii
High Energy Accelerator Research Organization (KEK)
Indiana University
Kobe University
University of Kyoto
Los Alamos National Laboratory
Louisiana State University
Minnesota University
Miyagi University of Education
State University of New York at Stony Brook
Nagoya University
Niigata University
Okayama University
Osaka University
Seoul National University
Sung Kyun Kwan University
Shizuoka University
Tohoku University
University of Tokyo
Tokai University
Tokyo Institute of Technology
Tsinghua University
University of Warsaw
University of Washington

Accelerator based

T2K-I

2009 -

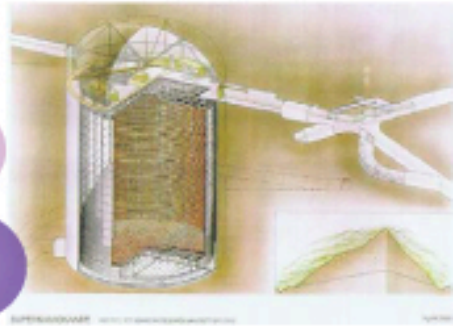
ν_e ν_μ ν_τ

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{MNS}\, V_M^{CP} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

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

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

ν_1 ν_2 ν_3



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

atmospheric **Cross Mixing** solar

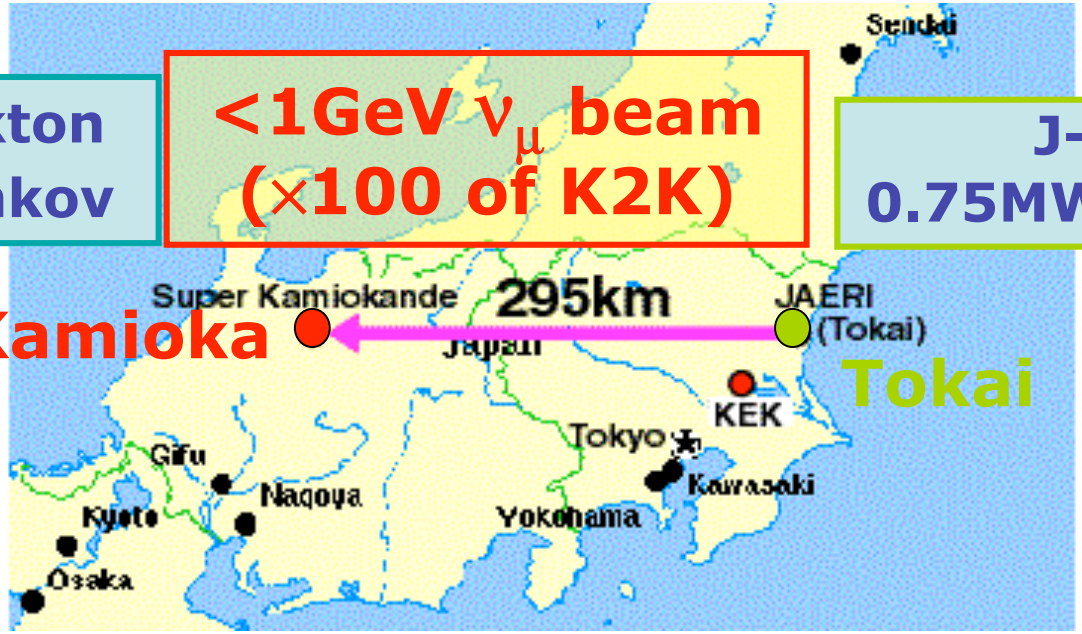
- Discover the last oscillation channel
  - θ_{13}
- CP violation in the lepton sector (ν, $\bar{\nu}$)
  - **δ (or a new source of CPV)**
- Mass hierarchy
  - The sign of Δm_{23}^2 ($m_3 > m_1$ or $m_3 < m_1$)
- Test of the standard ν oscillation scenario (U_{MNS})
  - Precise measurements of ν oscillations ($\pm\Delta m_{23}^2$, θ_{23})

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

Super-K: 50 kton Water Cherenkov

<1GeV ν_μ beam (×100 of K2K)

J-PARC 0.75MW 50GeV PS



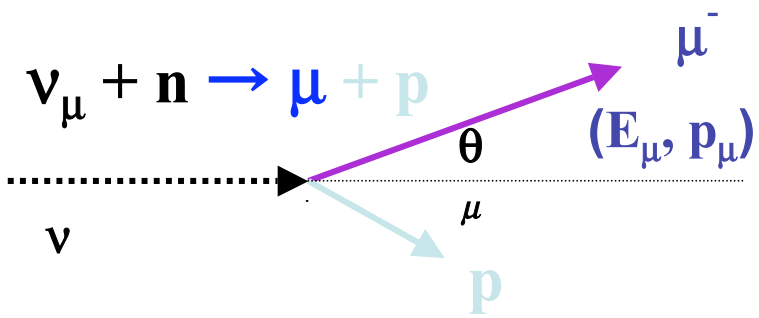
Physics goals

- Discovery of $\nu_\mu \rightarrow \nu_e$ appearance
- Precision measurement of disappearance $\nu_\mu \rightarrow \nu_x$

T2K Collaboration

- 11 Countries (No. of members)
  - Canada(24), France(8), Italy(11), Japan(46), Korea(9), Poland(1), Russia(8), Spain(12), Switzerland(3), UK(25), US(42)
  - 58 Institutes, 189 members.

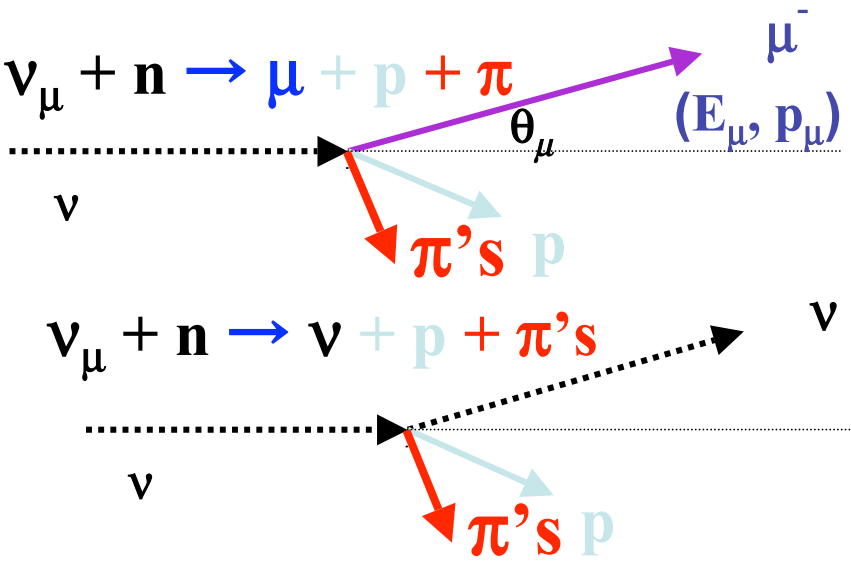
E_ν reconstruction at low energy



- CC QE
  - can reconstruct $E\nu \leftarrow (\theta_\mu, p_\mu)$

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

$\delta E \sim 60$ MeV $\delta E/E \sim 10\%$



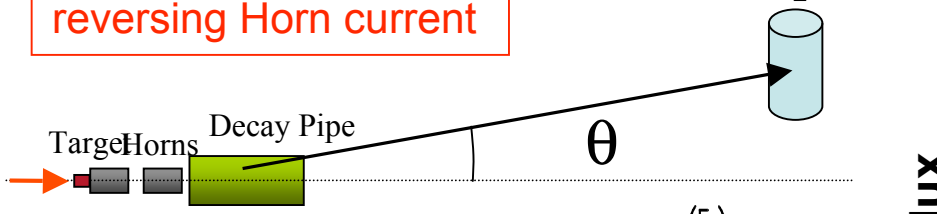
- bkg. for E_ν measurement

High energy part

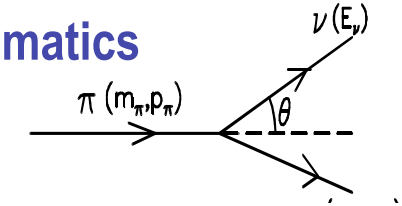
- bkg.for e-appearance

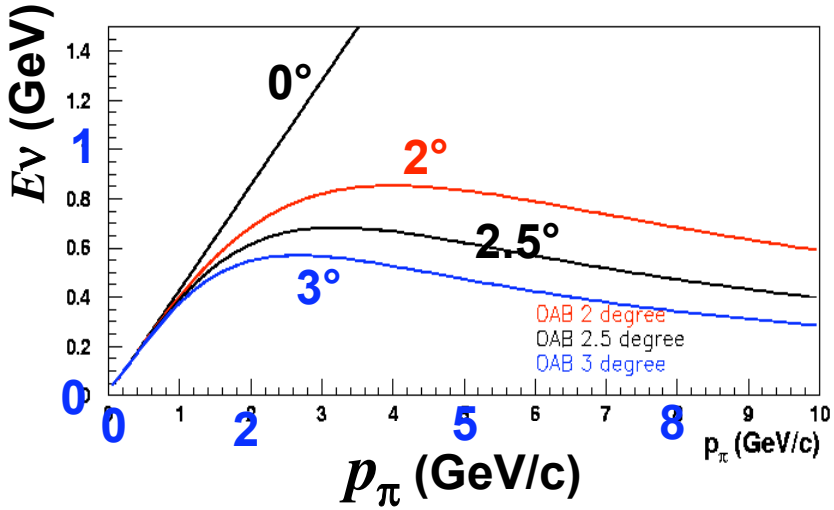
Narrow intense beam: Off-axis beam

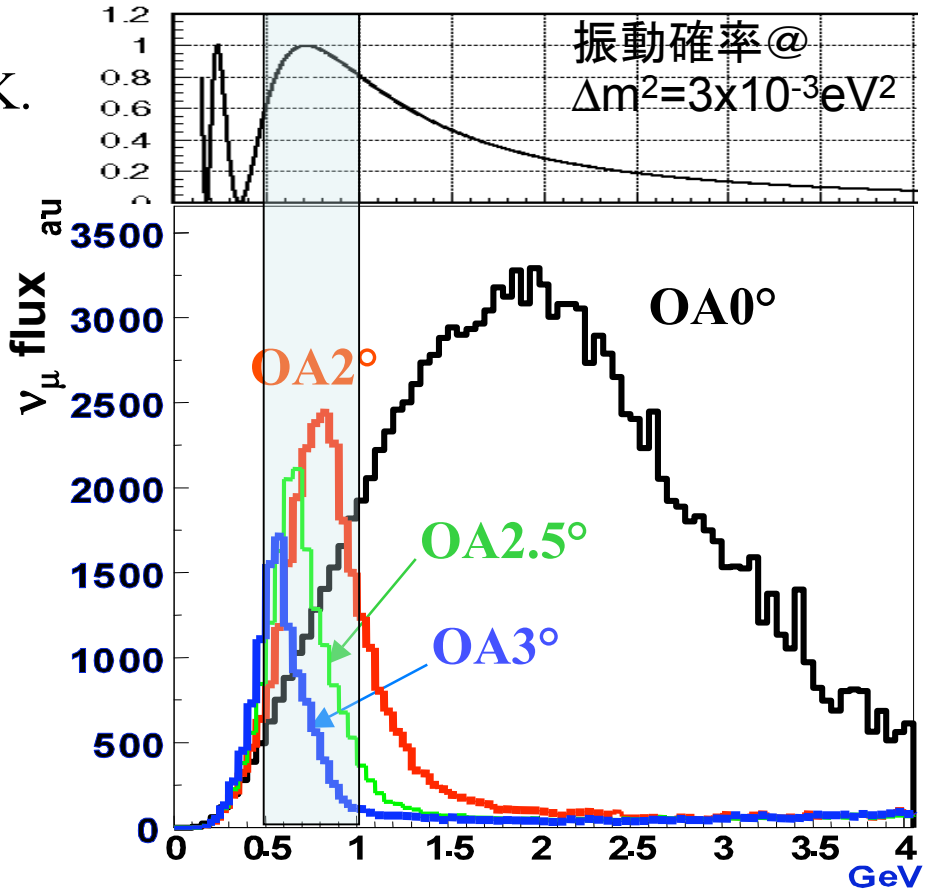
Anti-neutrinos by reversing Horn current



π decay Kinematics







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

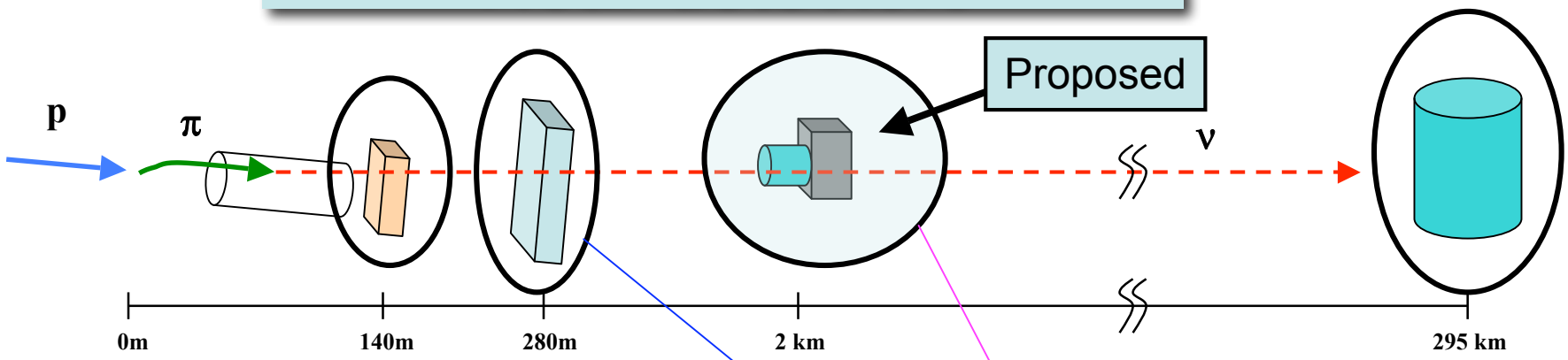
@SK (OAB 2.5 deg/1 yr, no-osci.)

~ 1030 ν_μ CC+NC single rings

~ 970 ν_μ CC single rings

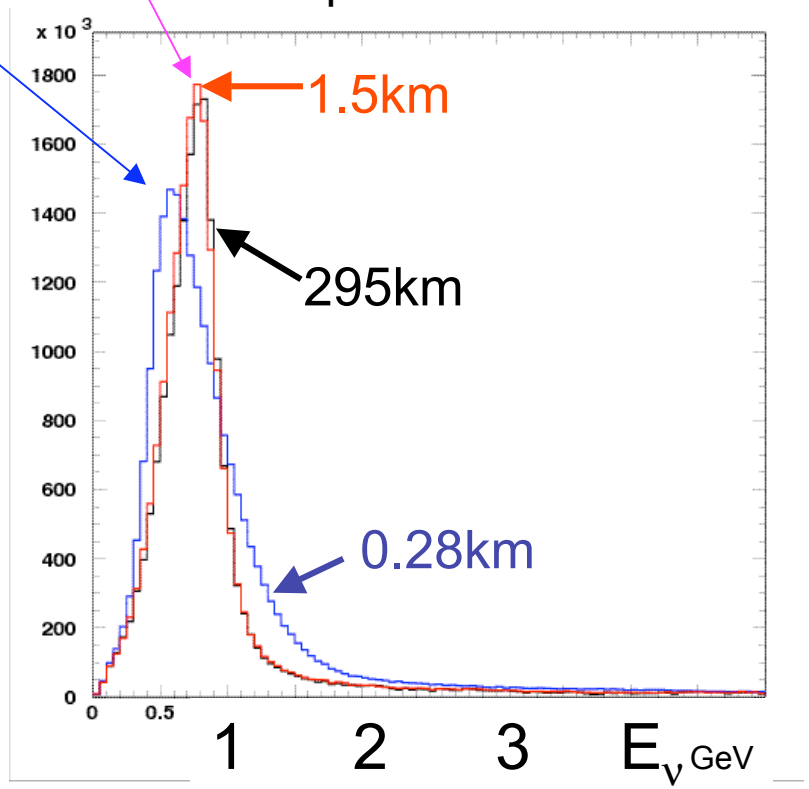
ν_e ~0.4% at ν_μ peak

Near detectors

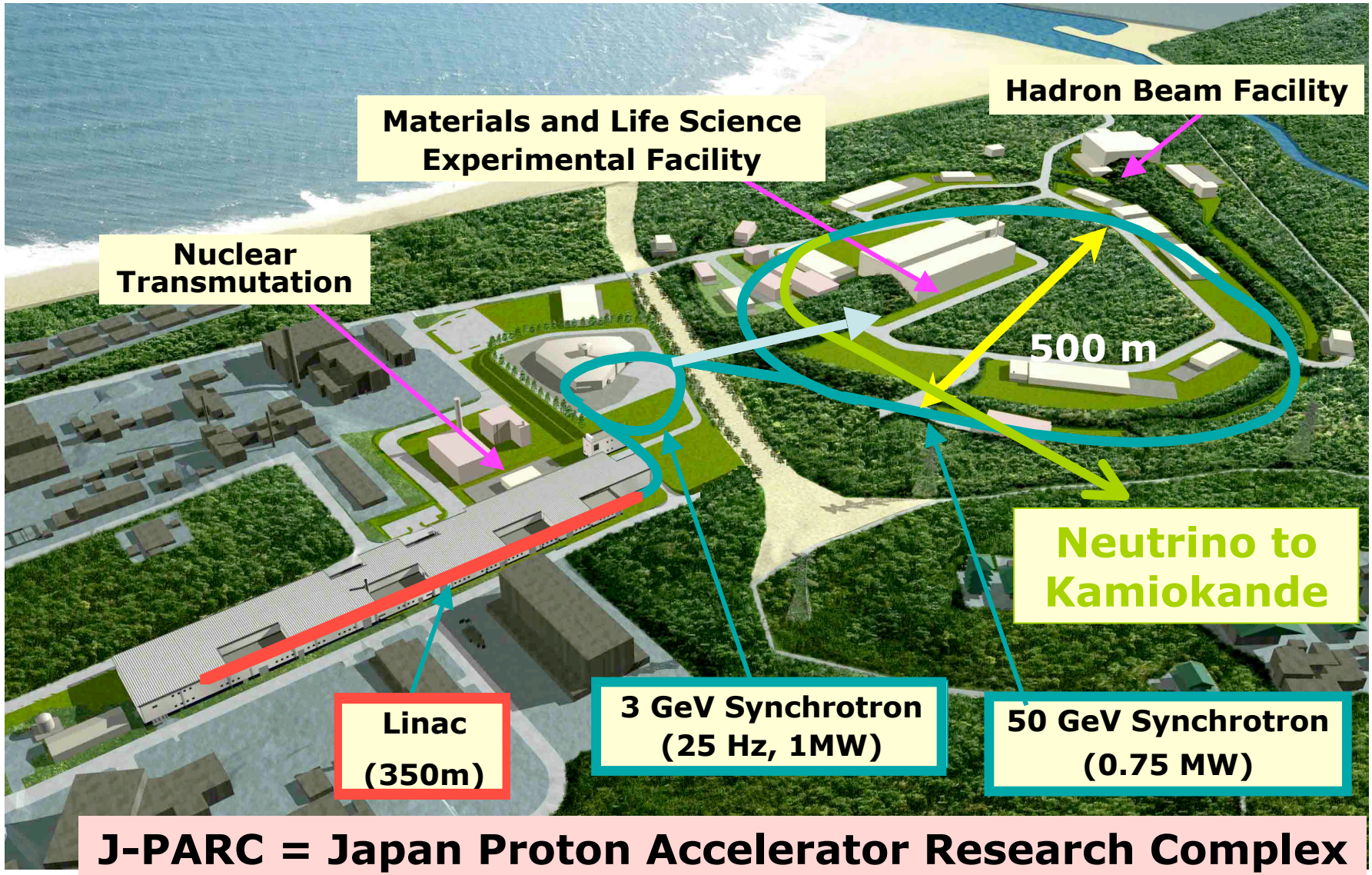


- **Muon monitors @ ~140m**
  - Fast (spill-by-spill) monitoring of beam direction/intensity ($\pi \rightarrow \mu \nu$)
- **First near detector @280m**
  - Flux/spectrum/νe - off-axis
  - intensity/direction - on-axis
- **Second near detector @ ~2km**
  - E_ν spectrum identical to that at SK
  - facility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

Neutrino spectra at diff. dist

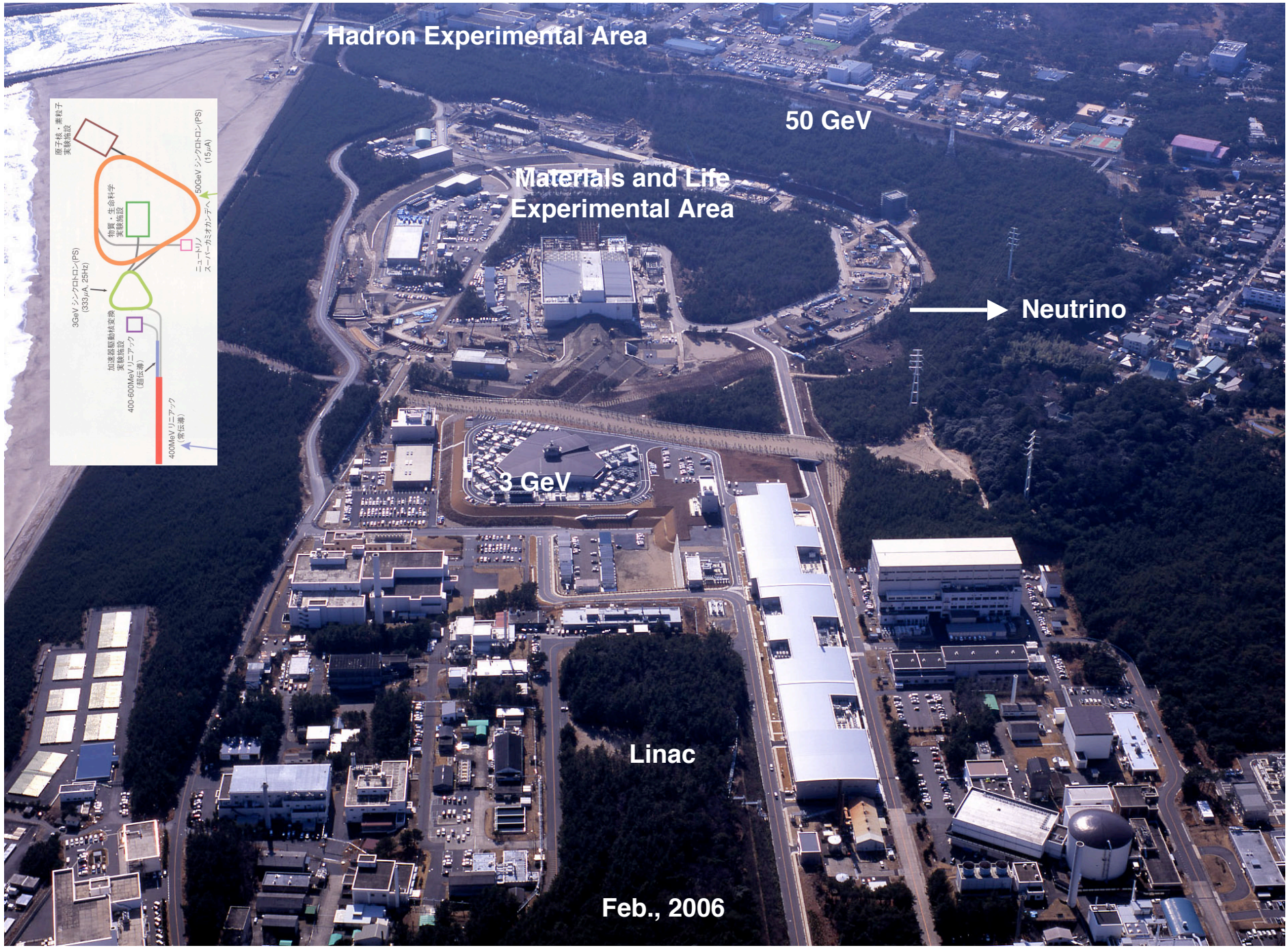


J-PARC



J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAERI


Hadron Experimental Area
50 GeV
Materials and Life
Experimental Area
Neutrino
3 GeV
Linac
Feb., 2006
原子核・素粒子
実験施設
物質・生命科学
実験施設
50GeV シンクロトロン(PS)
(15μA)
ニュートリノ
スーパーカミオカンデへ
3GeV シンクロトロン(PS)
(333μA, 25Hz)
加速器駆動核変換
実験施設
400-600MeV リニアック
(超伝導)
400MeV リニアック
(常伝導)

Neutrino Beam Line for T2K Experiment

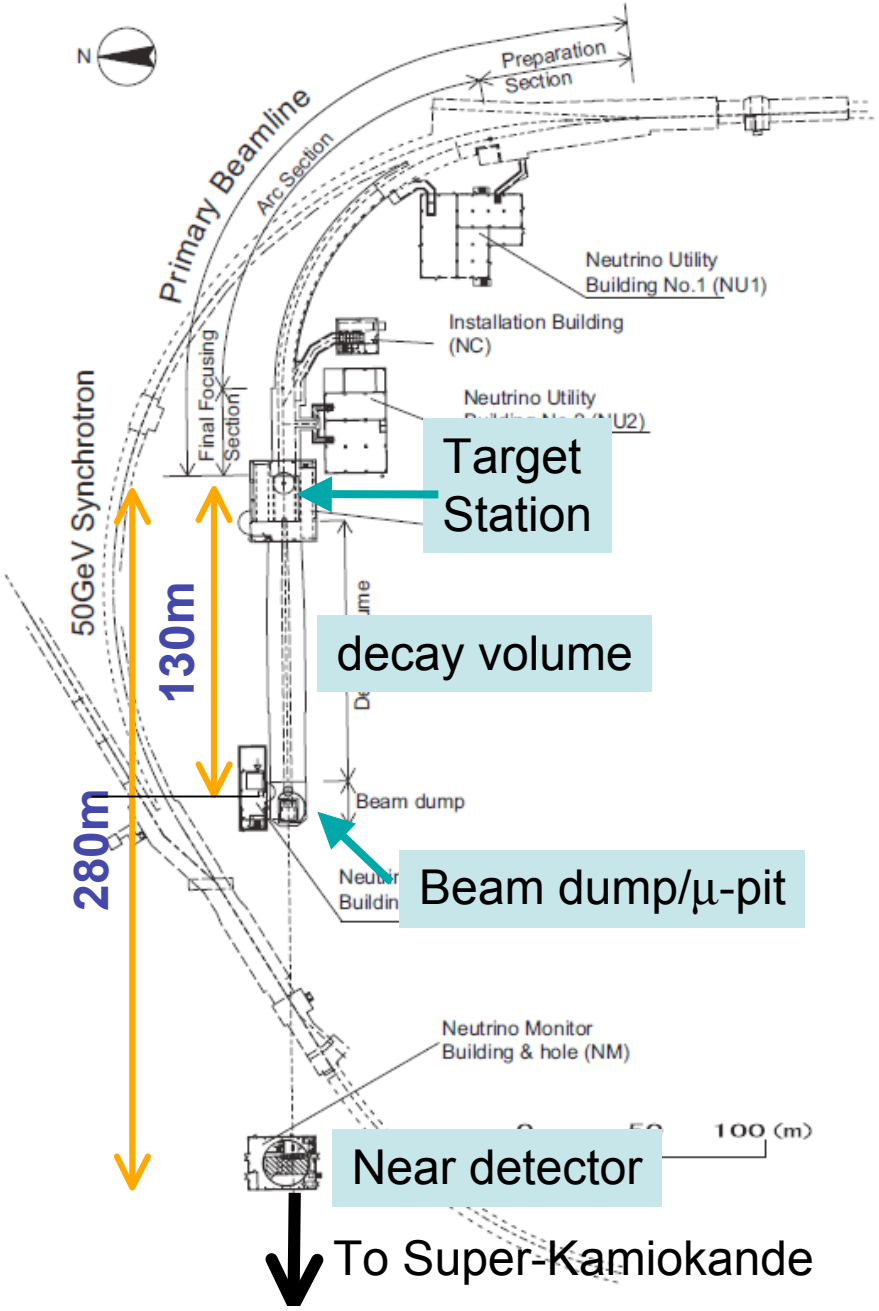
Special Features

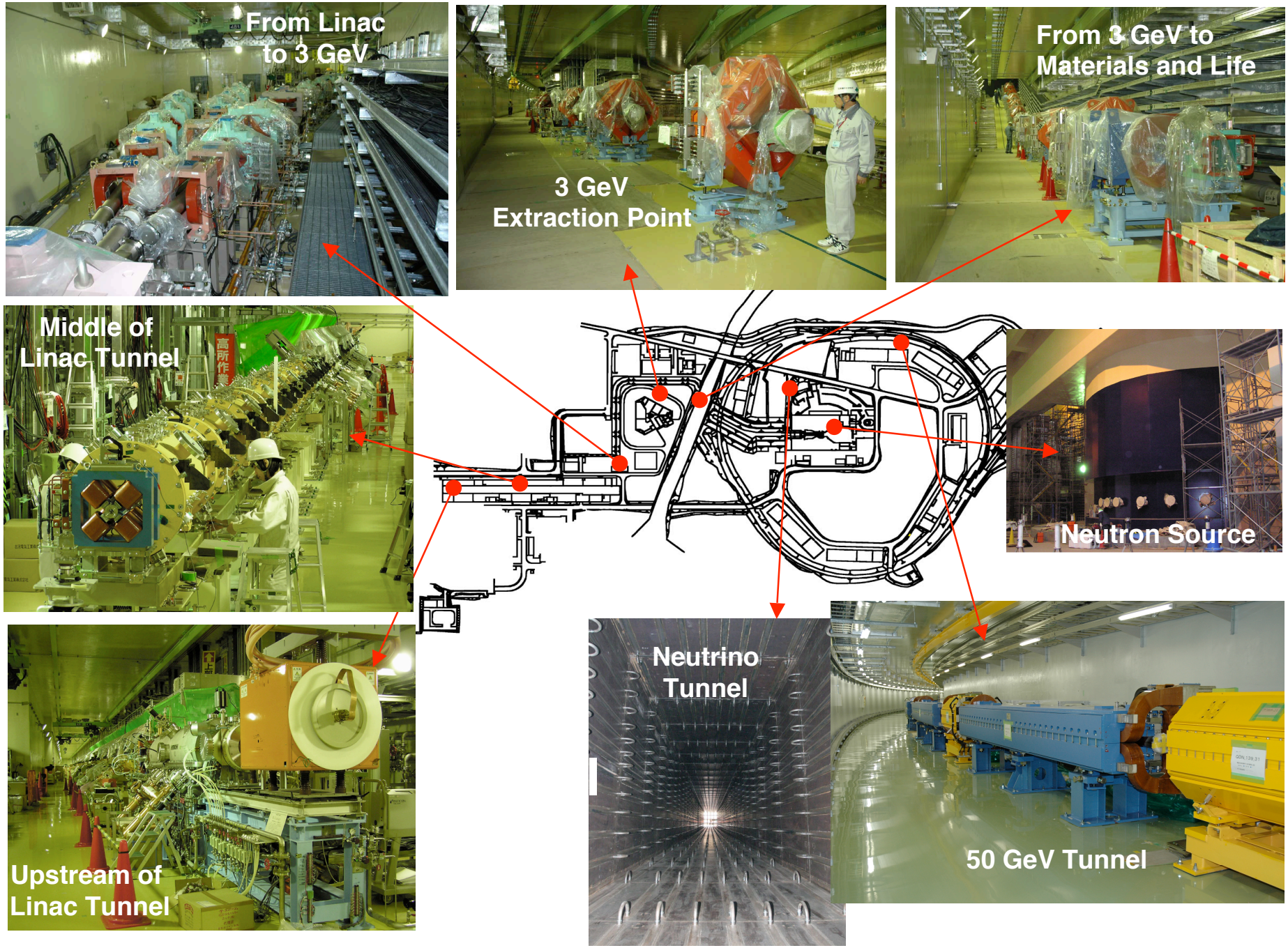
- **Superconducting combined function magnets**
- **Off-axis beam**

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

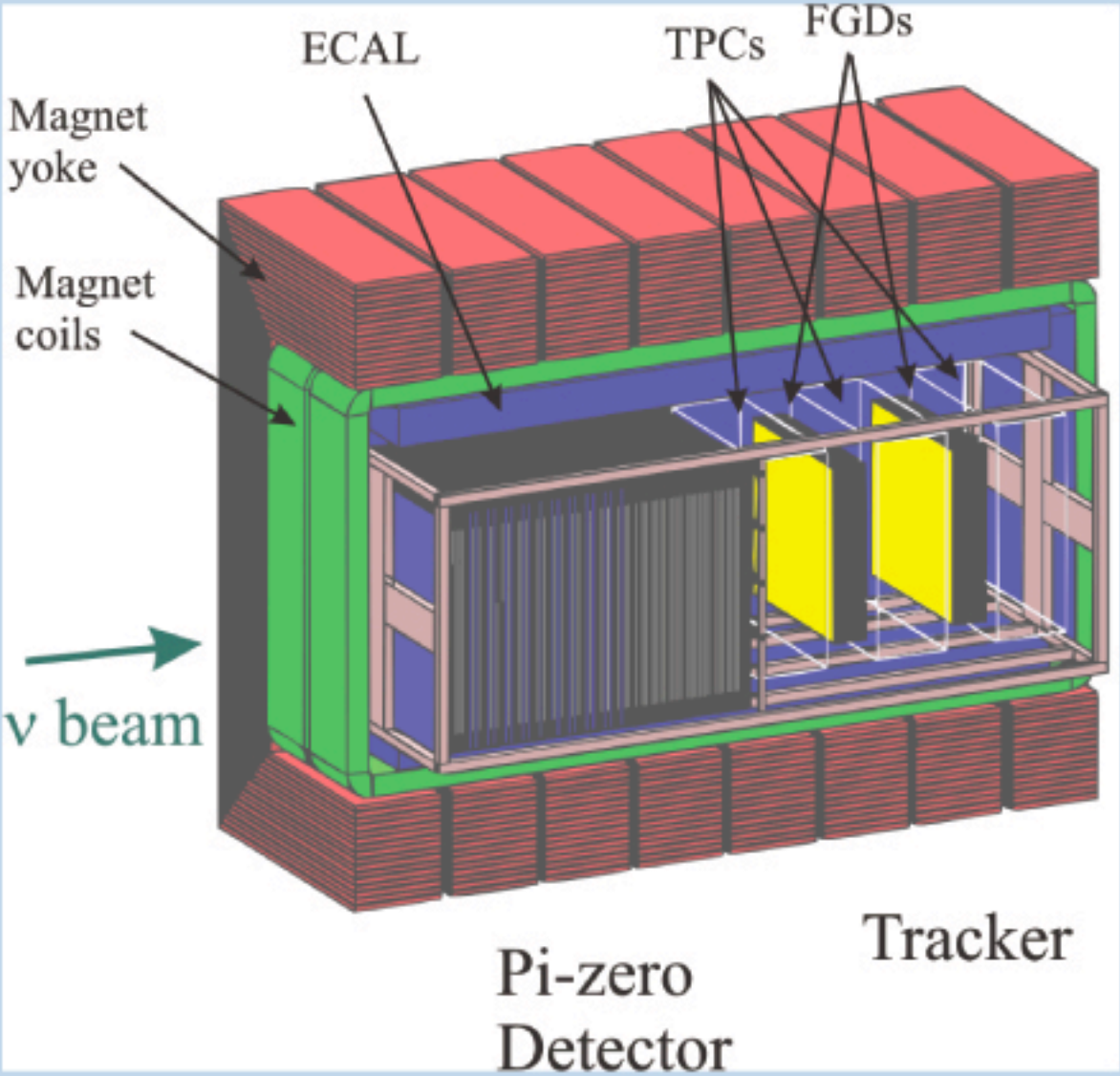
Construction: JFY2004~2008




From Linac
to 3 GeV
3 GeV
Extraction Point
From 3 GeV to
Materials and Life
Middle of
Linac Tunnel
Neutron Source
Upstream of
Linac Tunnel
Neutrino
Tunnel
50 GeV Tunnel

ND280 off axis detector: overview

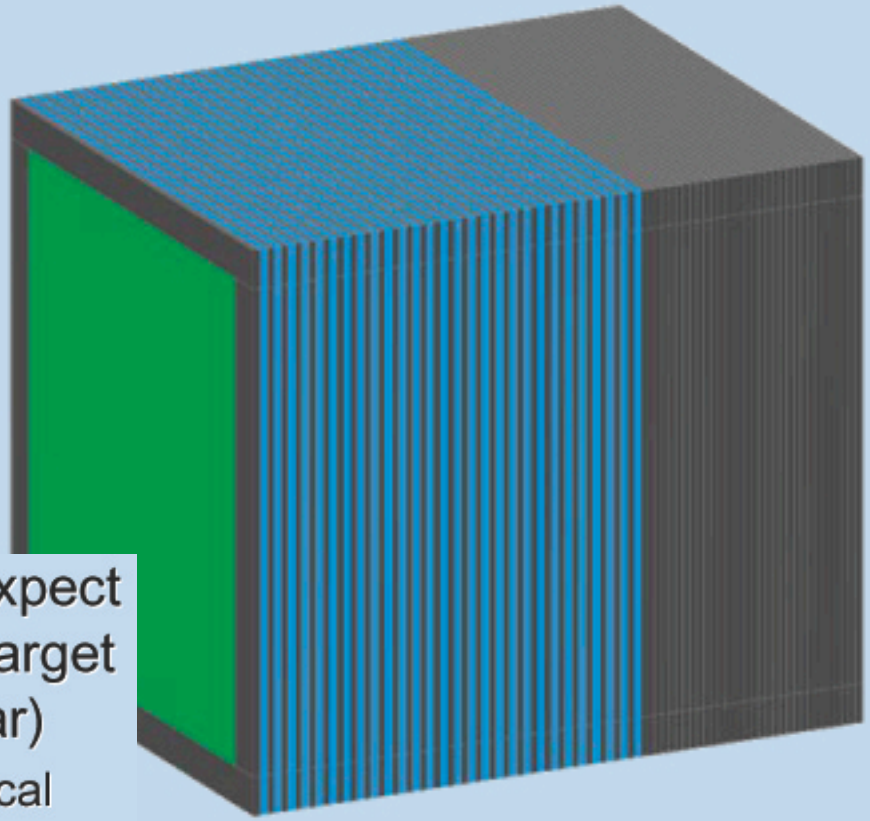
- UA1 magnet provides 0.2 T B field
- inner volume: $3.5 \times 3.6 \times 7.0\ m^3$
- front optimized for π^0 from NC
- rear optimized for CC studies
- surrounded by ECAL and muon detector



Pi-zero detector

designed to make high statistics measurements of ν interactions with electromagnetically showering particles

- scintillating bar tracking planes
- front section interleaved with passive water layers (blue)

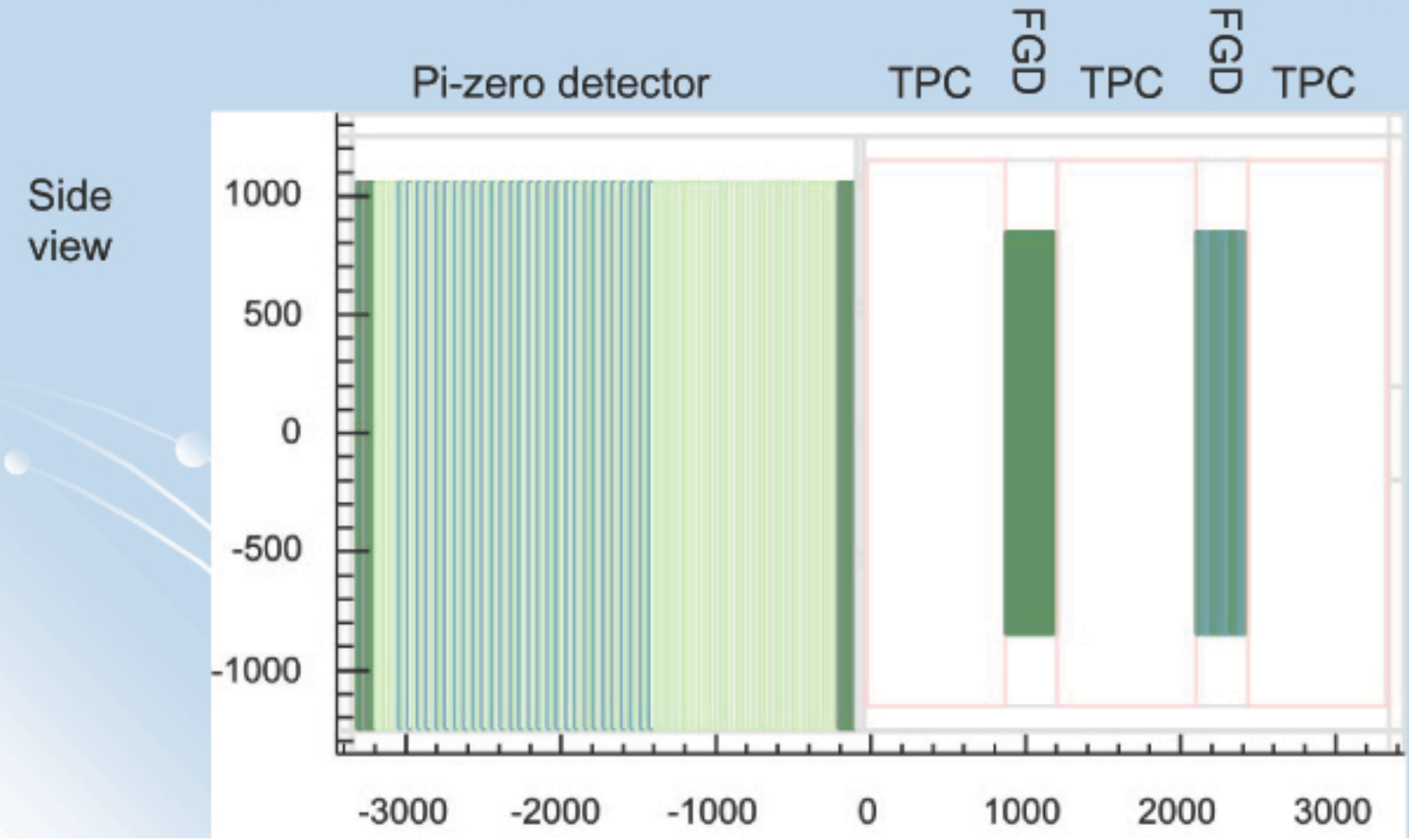


With a fiducial mass of 1.7 tons of water, expect ~17×10^3 NC single π^0 events in the water target for 10^{21} protons on target (one nominal year)

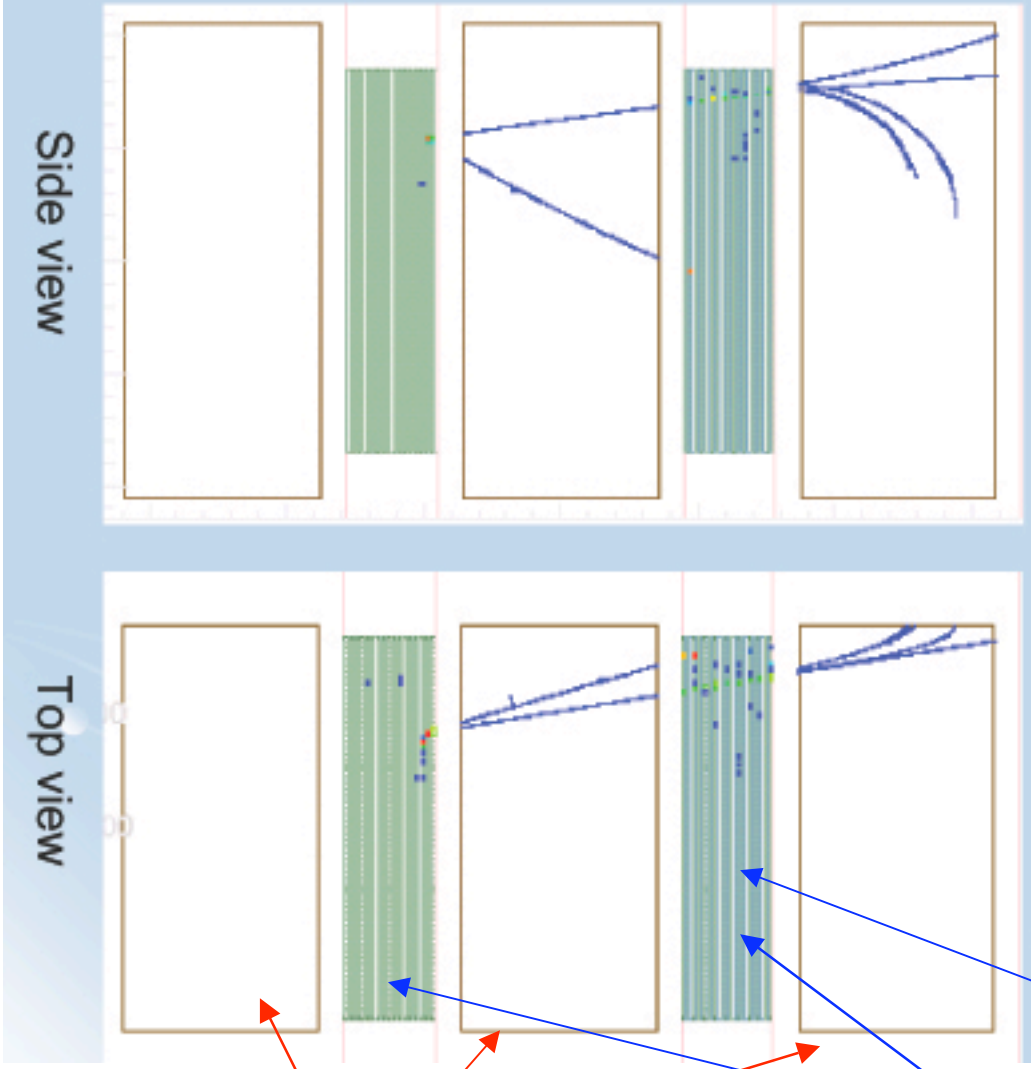
- must determine water cross sections by statistical subtraction (from total of ~60×10^3 such events)
- eff. for π^0 reconstruction, p > 200 MeV/c: 50-60%

Tracker

- consists of solid active target modules (FGD) and gas time projection chamber modules (TPC)



Tracker – ν_e CC event



Event No.: 13 Reaction code: 1 Position in File: 13

Primary Vertex [mm]: (423, 543, 985)

Located in

Basket_0/TRK_0/Active_1/ScintX1_145/bar_39527

Informational particles

ν_e (12)	Trk -1,	KE= 2893 MeV
n (2112)	Trk -1,	KE= 0 MeV

Primary particles

e^- (11)	Trk 1,	KE= 2578 MeV
n (2112)	Trk 2,	KE= 46 MeV
p (2212)	Trk 3,	KE= 15 MeV
p (2212)	Trk 4,	KE= 117 MeV
p (2212)	Trk 5,	KE= 86 MeV
p (2212)	Trk 6,	KE= 14 MeV
γ (22)	Trk 7,	KE= 4 MeV

This one contains water.

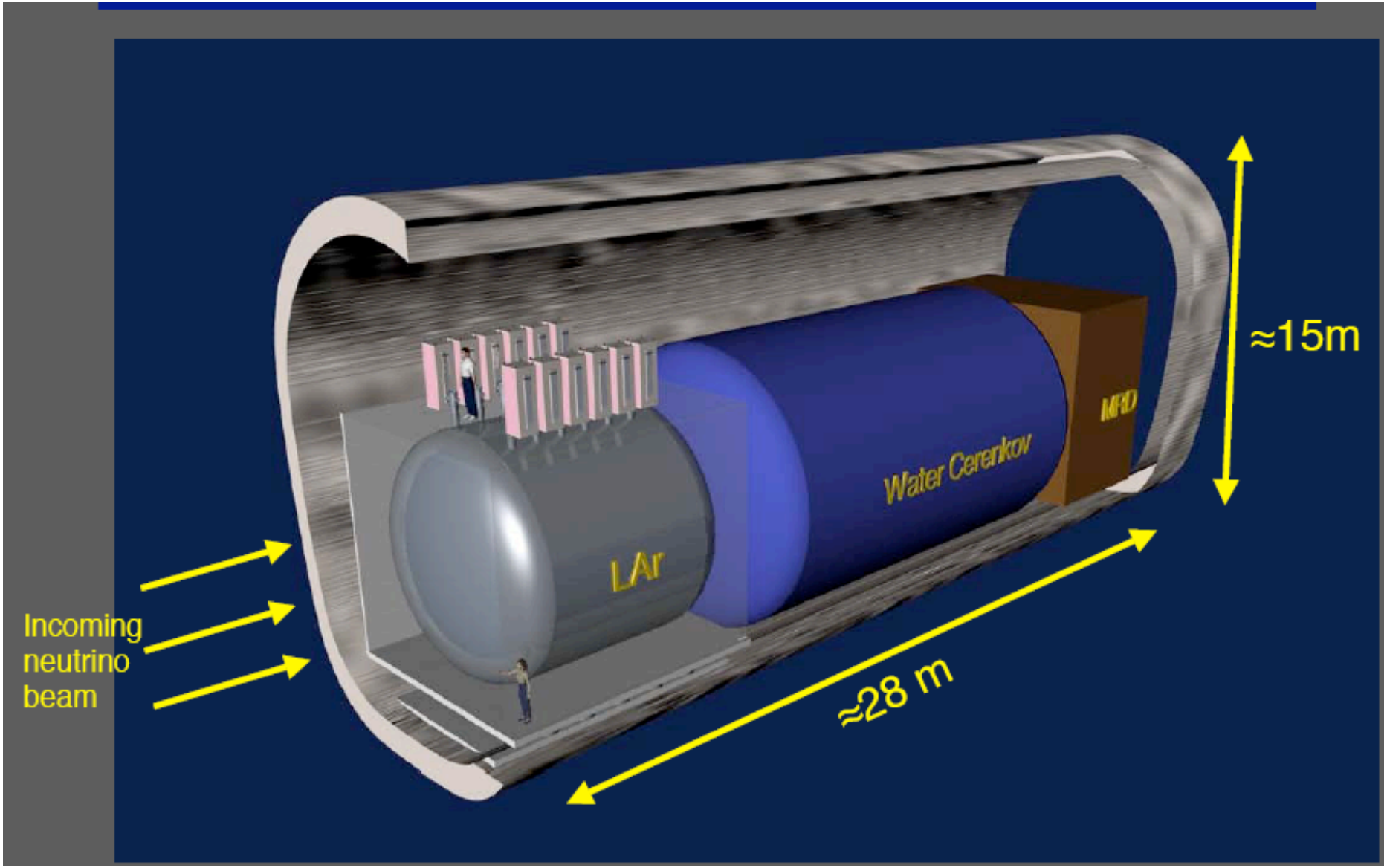
TPC

FGD (Sci-bar)

Tracker

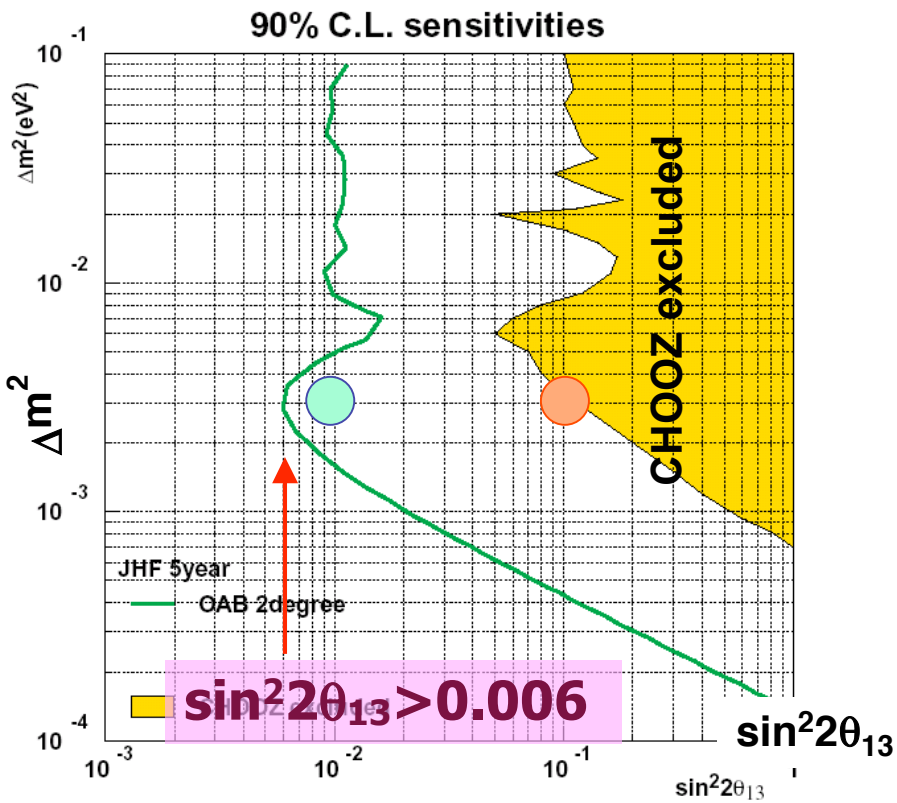
- With ~ 1.2 ton total mass in each FGD module, expect ~ 4×10^5 neutrino interactions in the tracker in a nominal year (10^{21} POT)
  - fiducial cuts, efficiency reduce this, but ample statistics for tuning MC simulations
- Note that combined, the TPC inner volumes hold ~ 16 kg gas, resulting in ~ 2×10^3 neutrino interactions in a nominal year

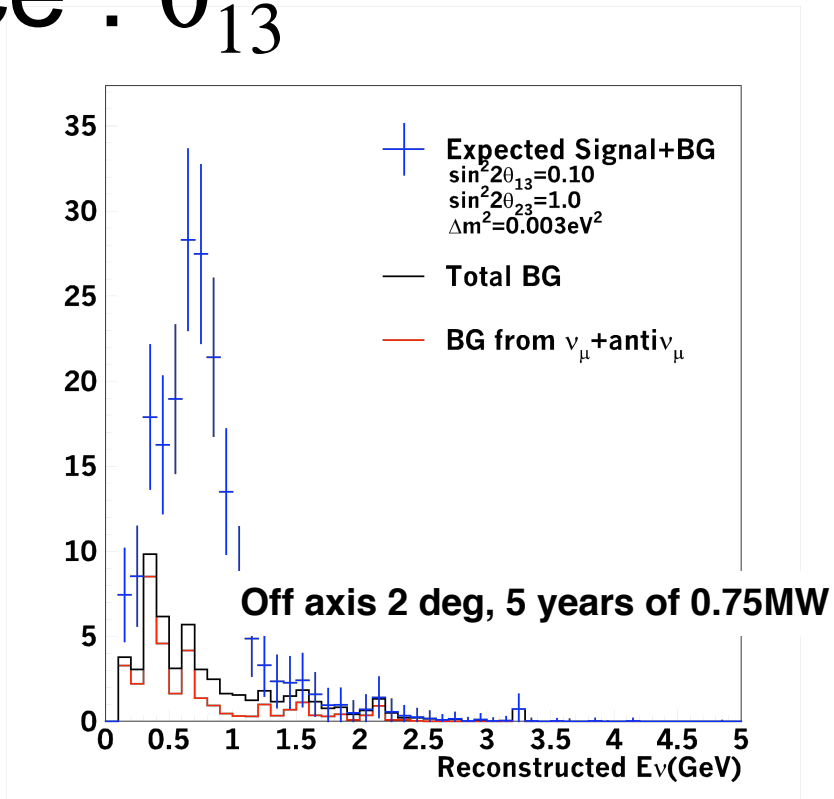
Proposed detectors at 2km



Goal : improve systematics from ~10% to ~5%

ν_e appearance : θ_{13}



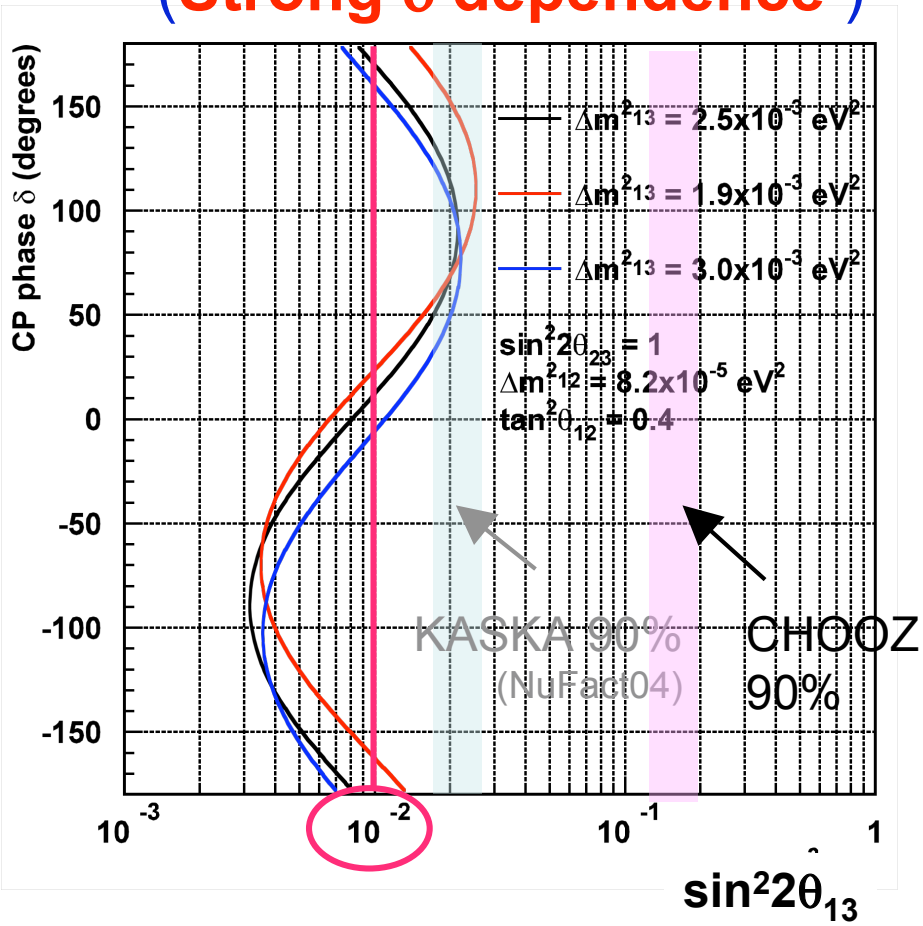


$\sin^2 2\theta_{13}$	Estimated background in Super-K					Signal (~40% eff.)	Signal + BG
	ν_μ (NC π^0)	ν_e beam	$\bar{\nu}_\mu$	$\bar{\nu}_e$	total		
0.1	12.0	10.7	1.7	0.5	24.9	114.6	139.5
0.01	12.0	10.7	1.7	0.5	24.9	11.5	36.4

T2K Physics Sensitivity without 2km detectors

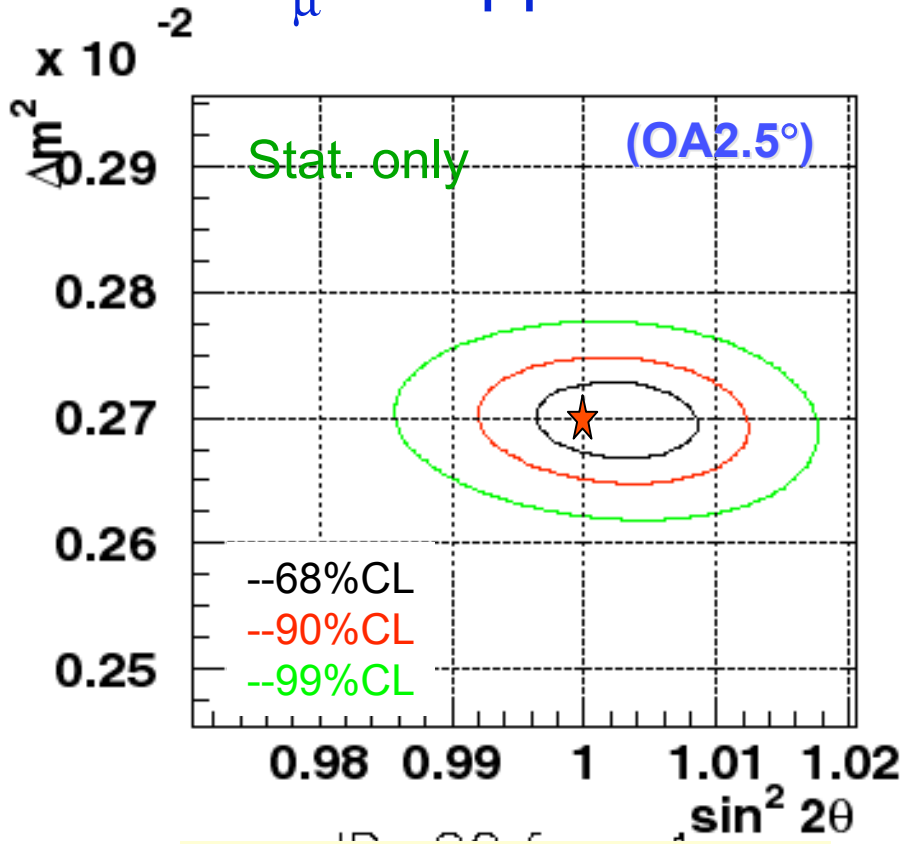
ν_e appearance

(Strong δ dependence)



a factor of >10 improvement over CHOOZ

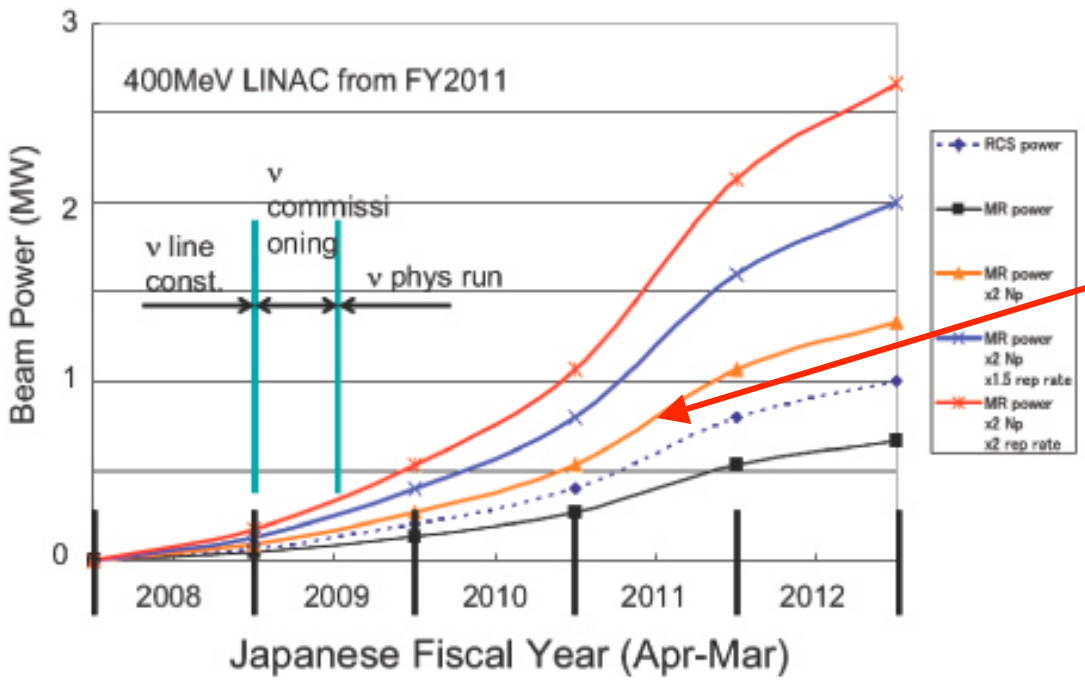
ν_μ disappearance



Goal

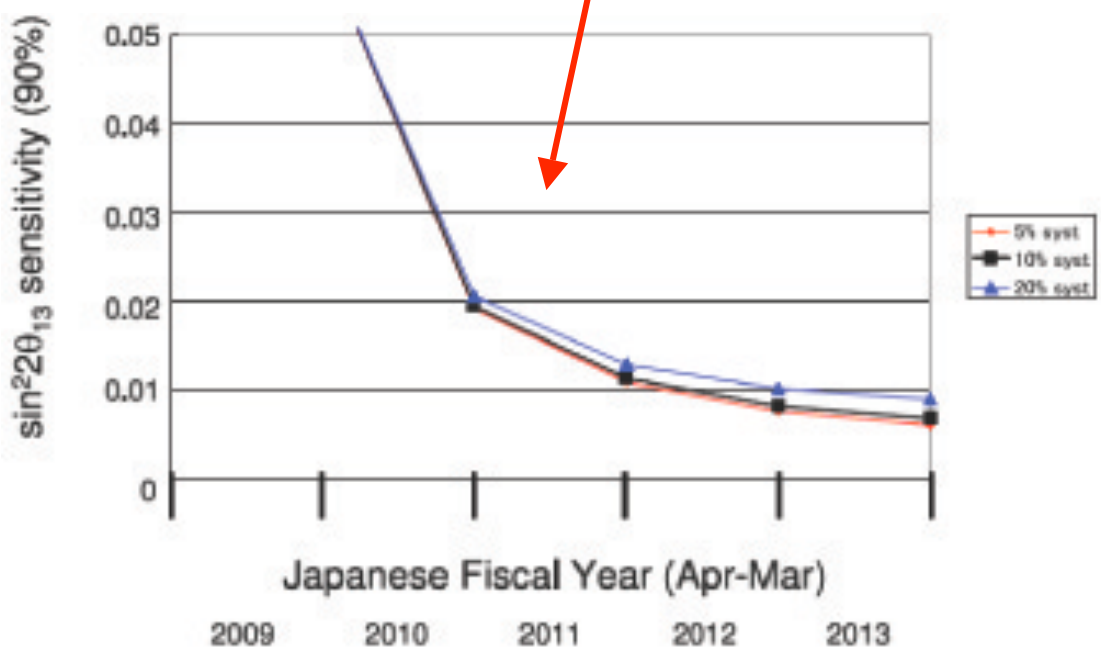
$\delta(\sin^2 2\theta_{23}) \sim 0.01$

$\delta(\Delta m_{23}^2) \sim < 1 \times 10^{-4}$



T2K-I

Most likely scenario



Options beyond T2K-I

T2K- II

Super-K: 50 kton Water Cherenkov

Phase2: Hyper-K

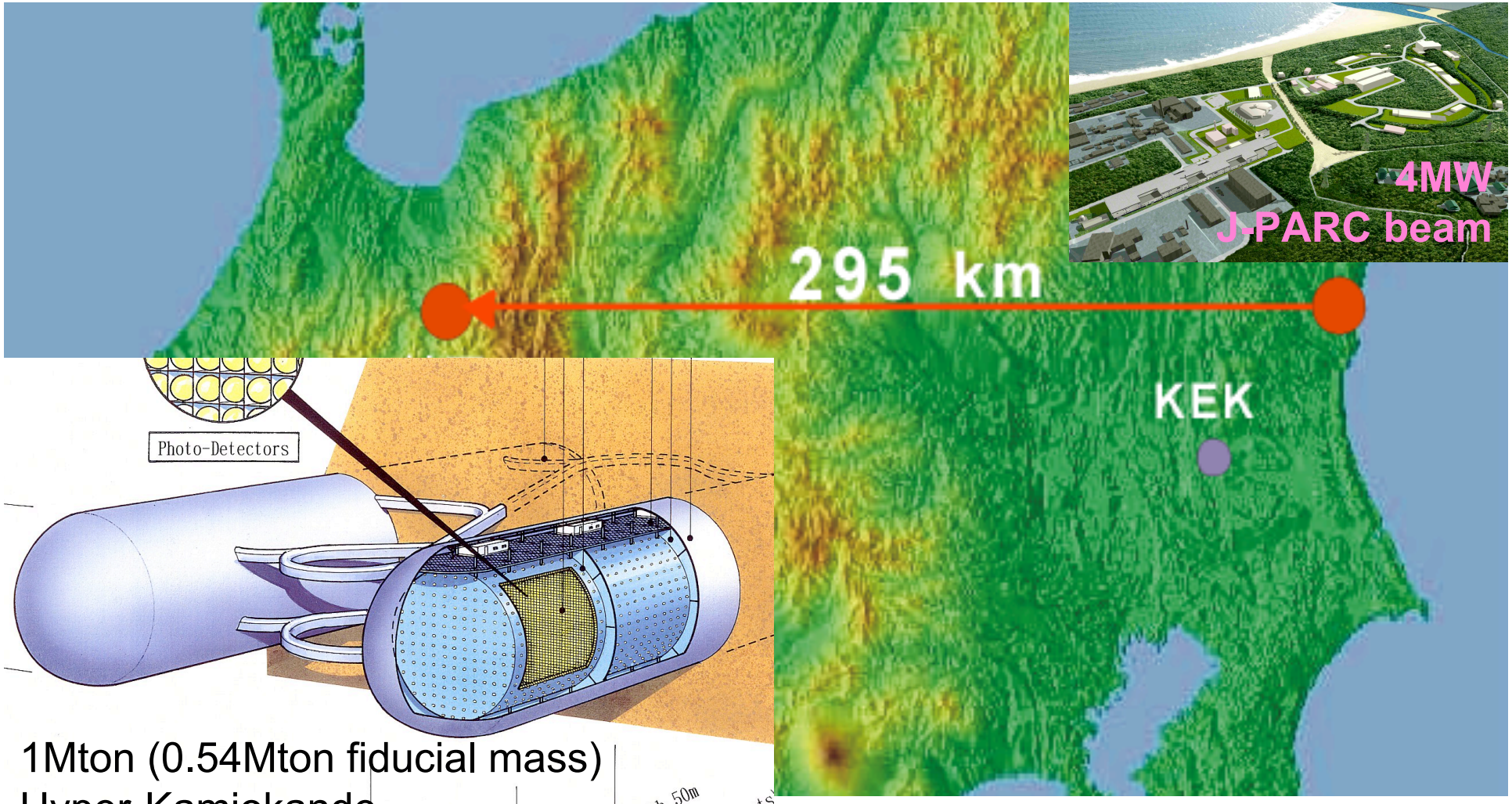
<1GeV ν_μ beam

J-PARC 0.75MW 50GeV PS

Phase2: 3~4 MW

CP violation in lepton sector

T2K -II (baseline design)



1Mton (0.54Mton fiducial mass)
Hyper-Kamiokande

2years of ν run + 6 years of anti-ν run ➔
O(0.5·10^6) events for both runs

Candidate site

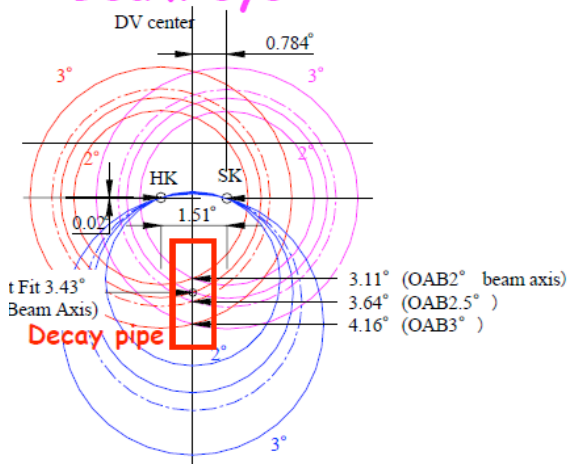
Super-K (Depth:2700mwe)

295 km

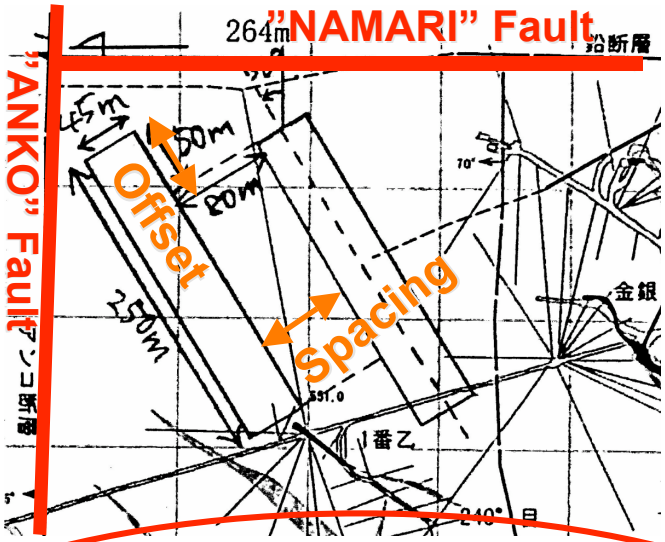
J-PARC

Hyper-K (Depth: 1400 - 1900mwe, not decided yet)
(Tochibora-mine of the Kamioka mining company)

Beam eye

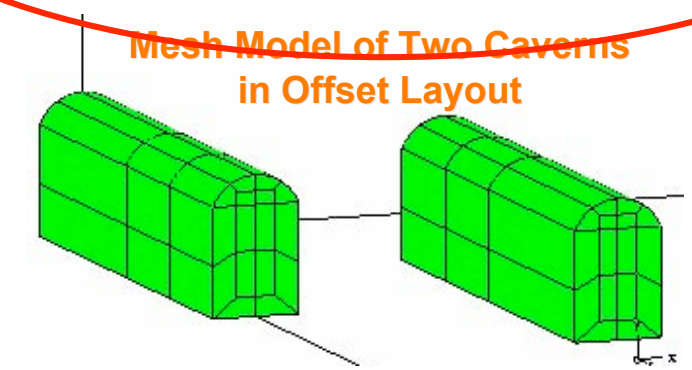


Safety Factor Diagram around Hyper-K Two Parallel Cavern Model for Analyzing Optimum Offset Layout at TOCHIBORA Mine

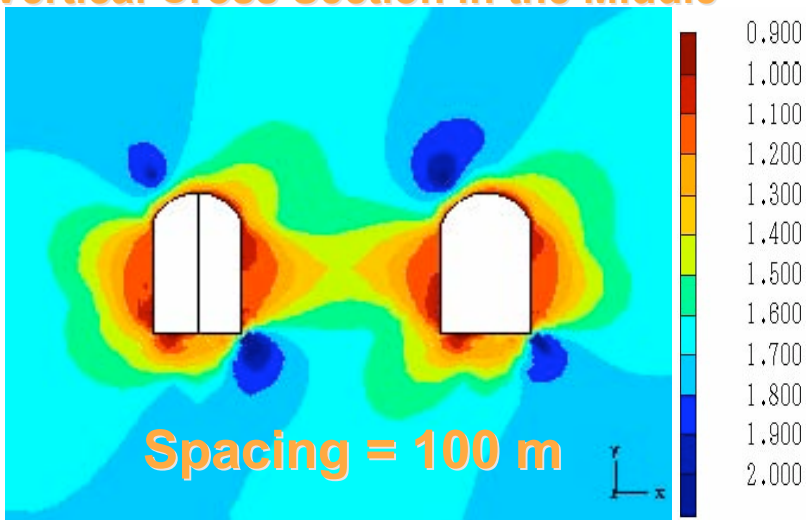


Layout with 100m Spacing and 100m Offset is the most preferable. However, considering the adjacent Faults, Layout with 80m Spacing and 50m Offset could be the best available.

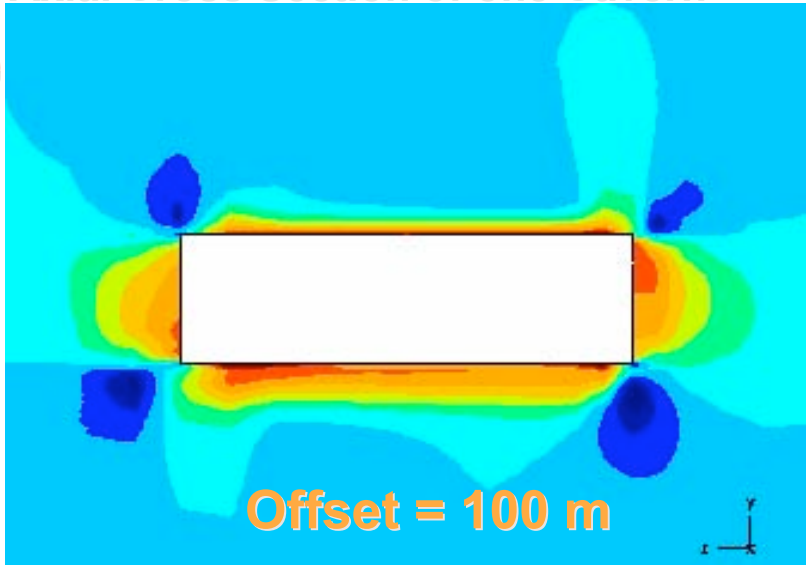
Mesh Model of Two Caverns in Offset Layout



Vertical Cross Section in the Middle



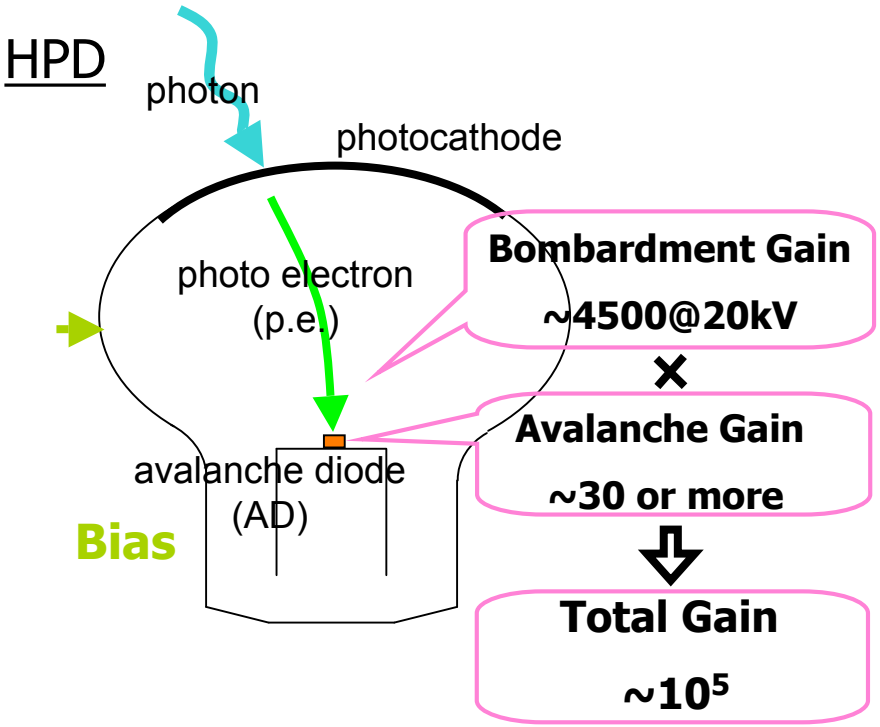
Axial Cross Section of one Cavern



R&D for a new photosensor

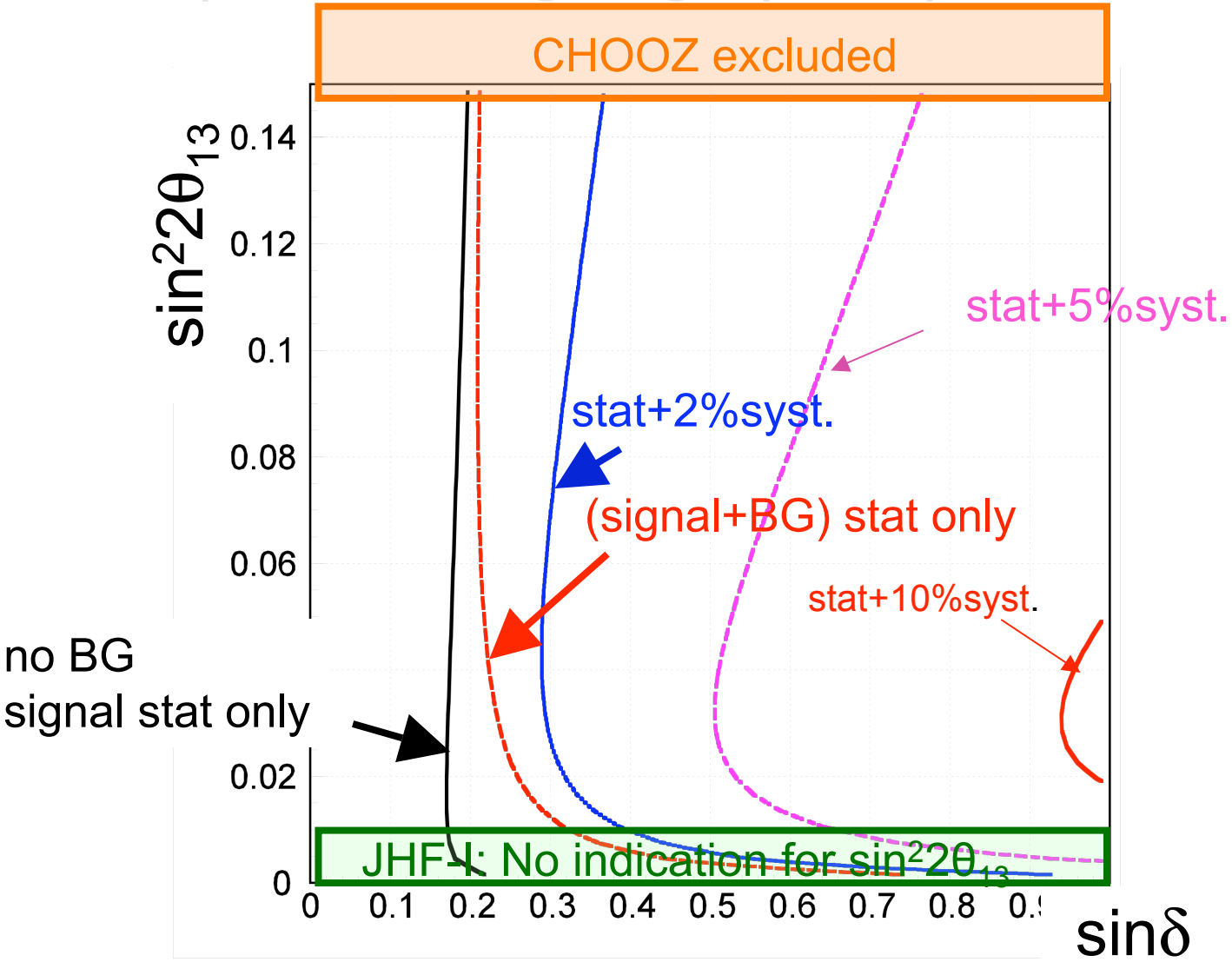
40% surface coverage by photocathode at HK
=> 200,000 20inch PMTs => prohibitive cost

Six year R&D program by Hamamatsu, Tokyo & KEK for a large format hybrid photodector started last year. Aim for cost reduction by 4.



13inch HPD prototype by HPK

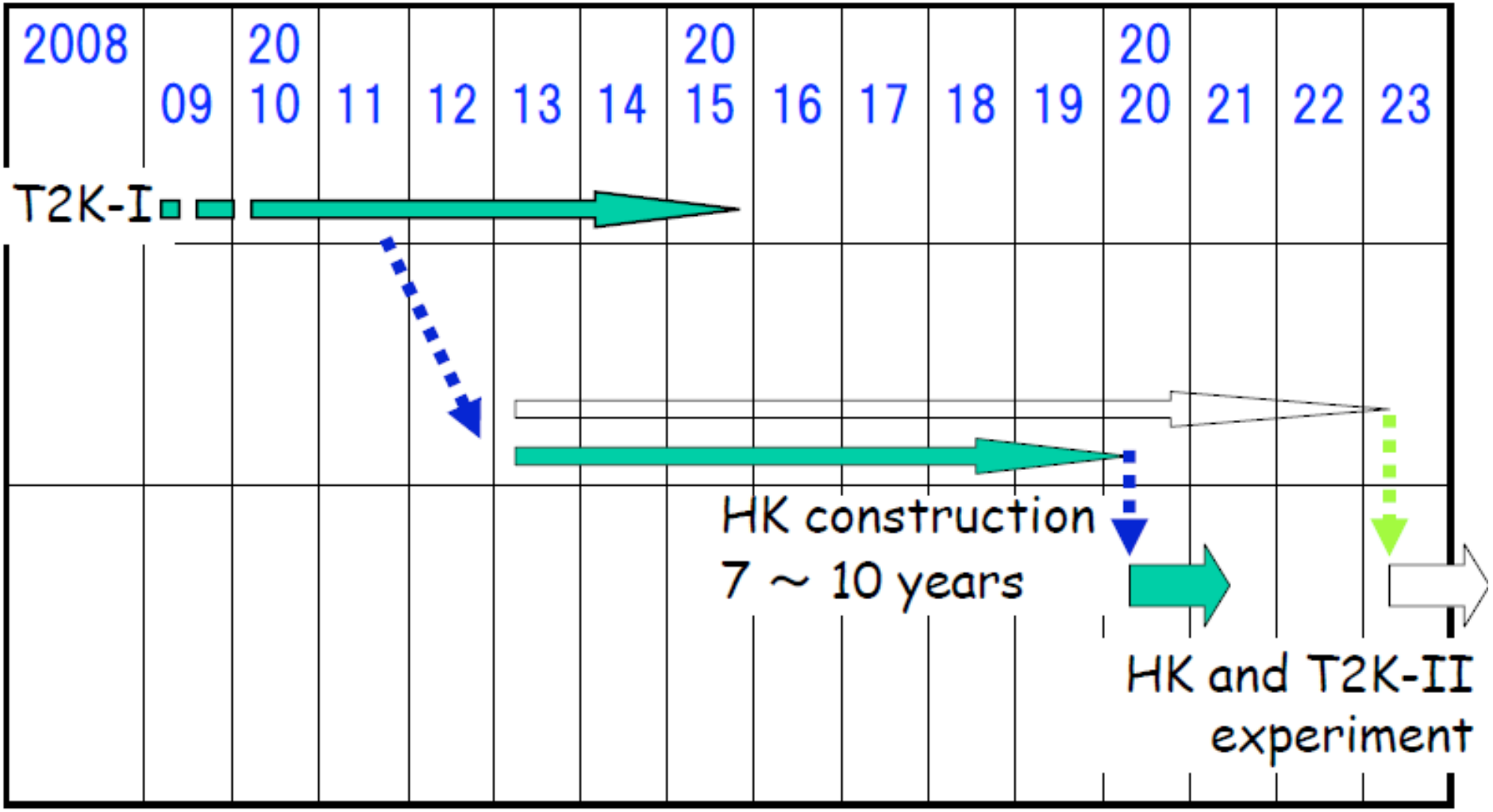
3σ CP sensitivity (assuming sign(Δm^2) is known)



Simple analysis based on rates only.

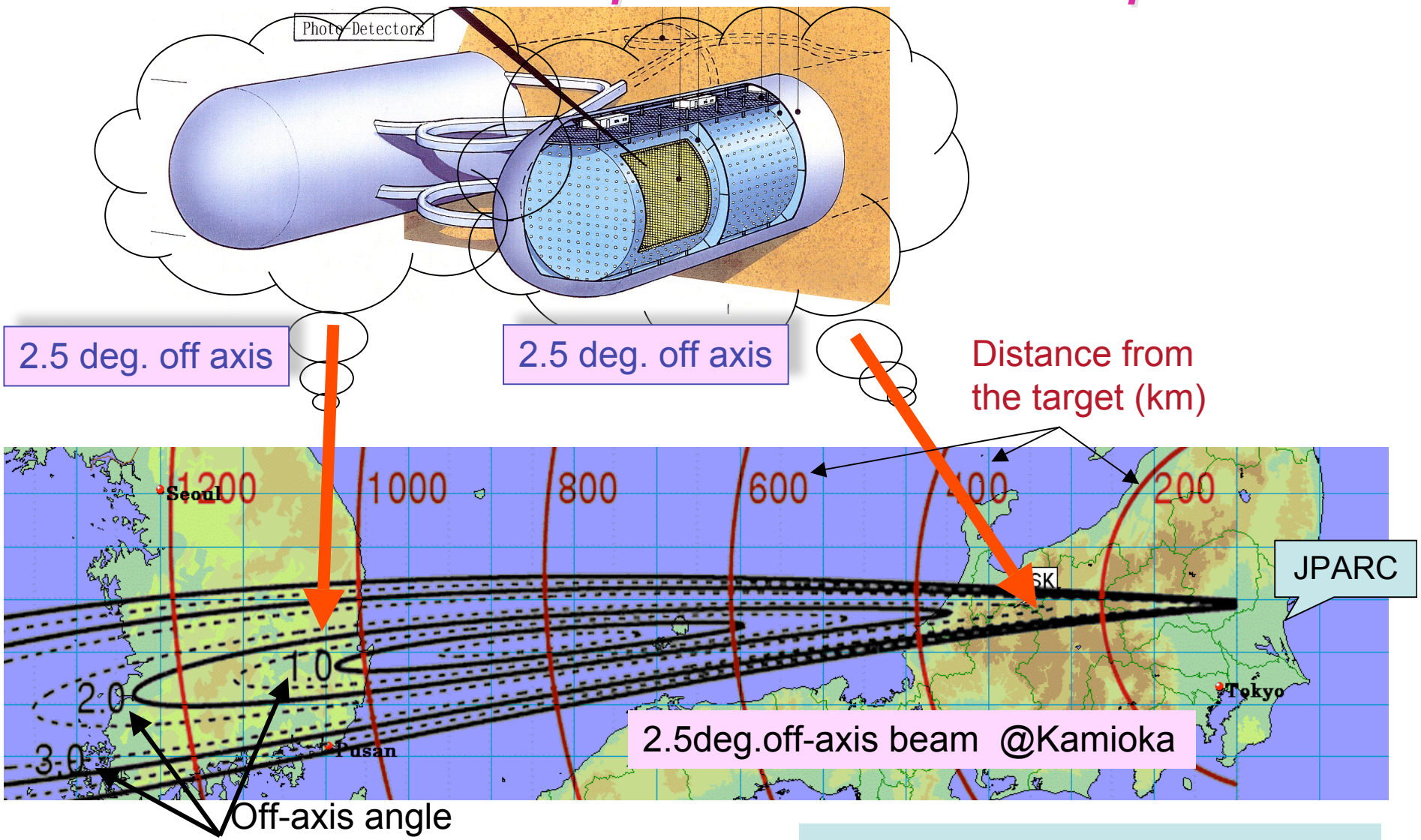
3σ CP sensitivity : $|\delta|>20^o$ for $\sin^2 2\theta_{13}>0.01$ with 2% syst.

T2K Phase I → II Time Line



Detector in Korea ?

Possible experimental set-up



2nd oscillation max in Korea

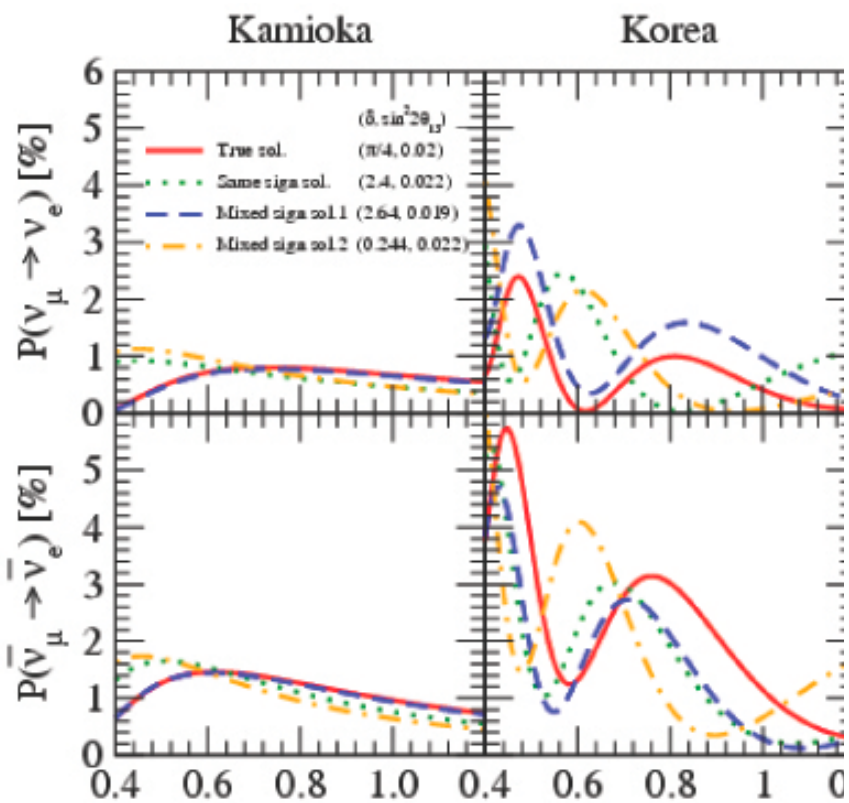
(Matter effect small due to low Eν)

First oscillation max at SK

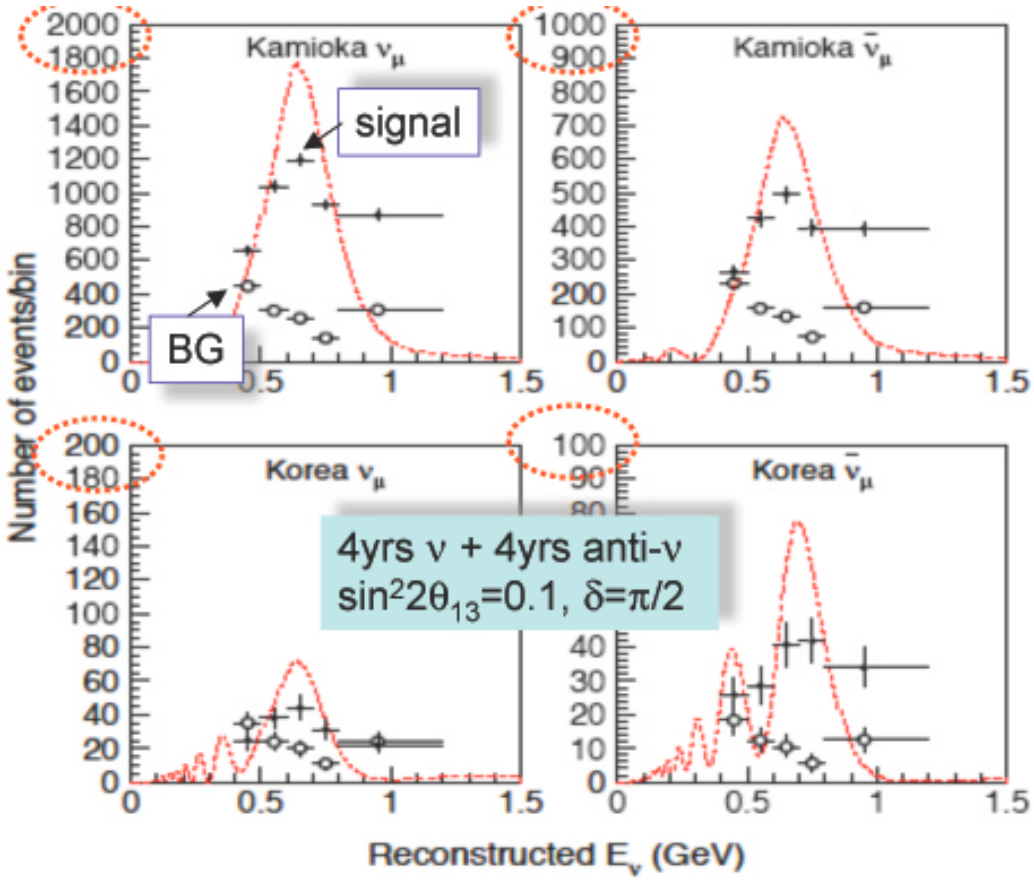
Same off-axis angle in Kamioka and Korea

(2.5 deg. in this study)

hep-ph/0504026
PR D72(2005)033003



Reconstructed E_ν (GeV)



A simultaneous fit to 4 spectra gives $\sin^2 2\theta_{13}$, δ and the mass hierarchy.

Expected sensitivity

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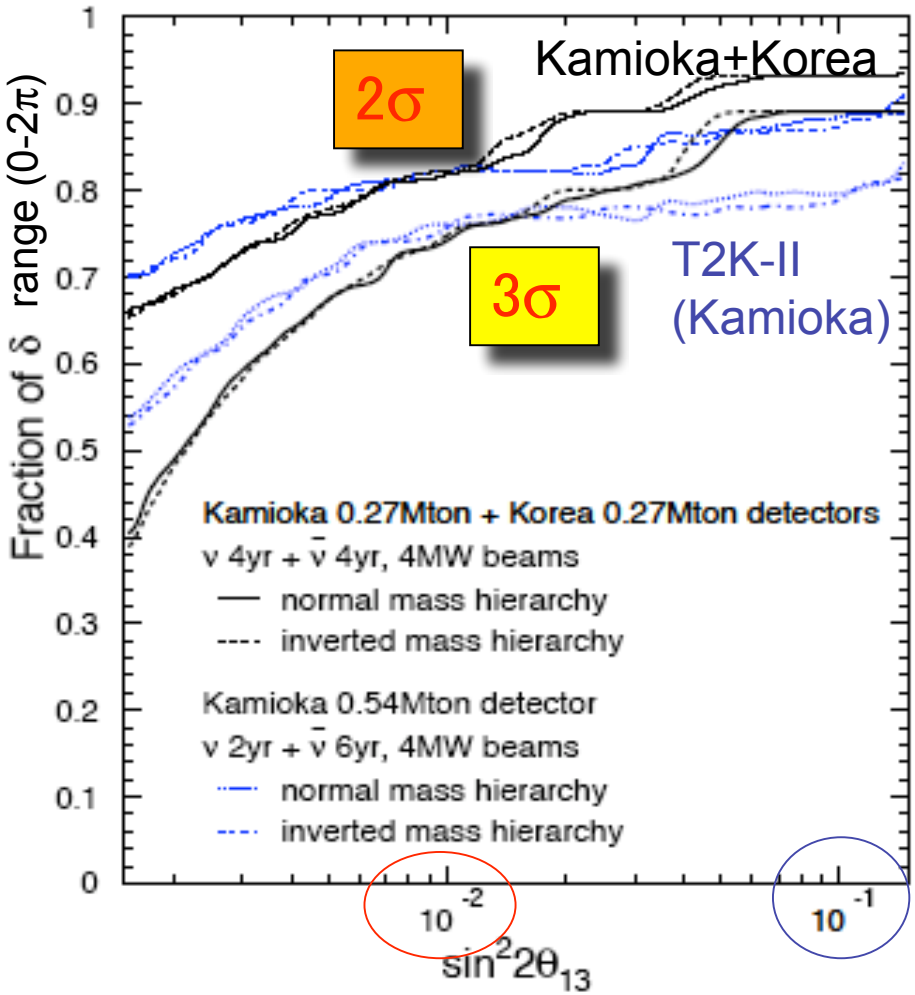
PR D72(2005)033003

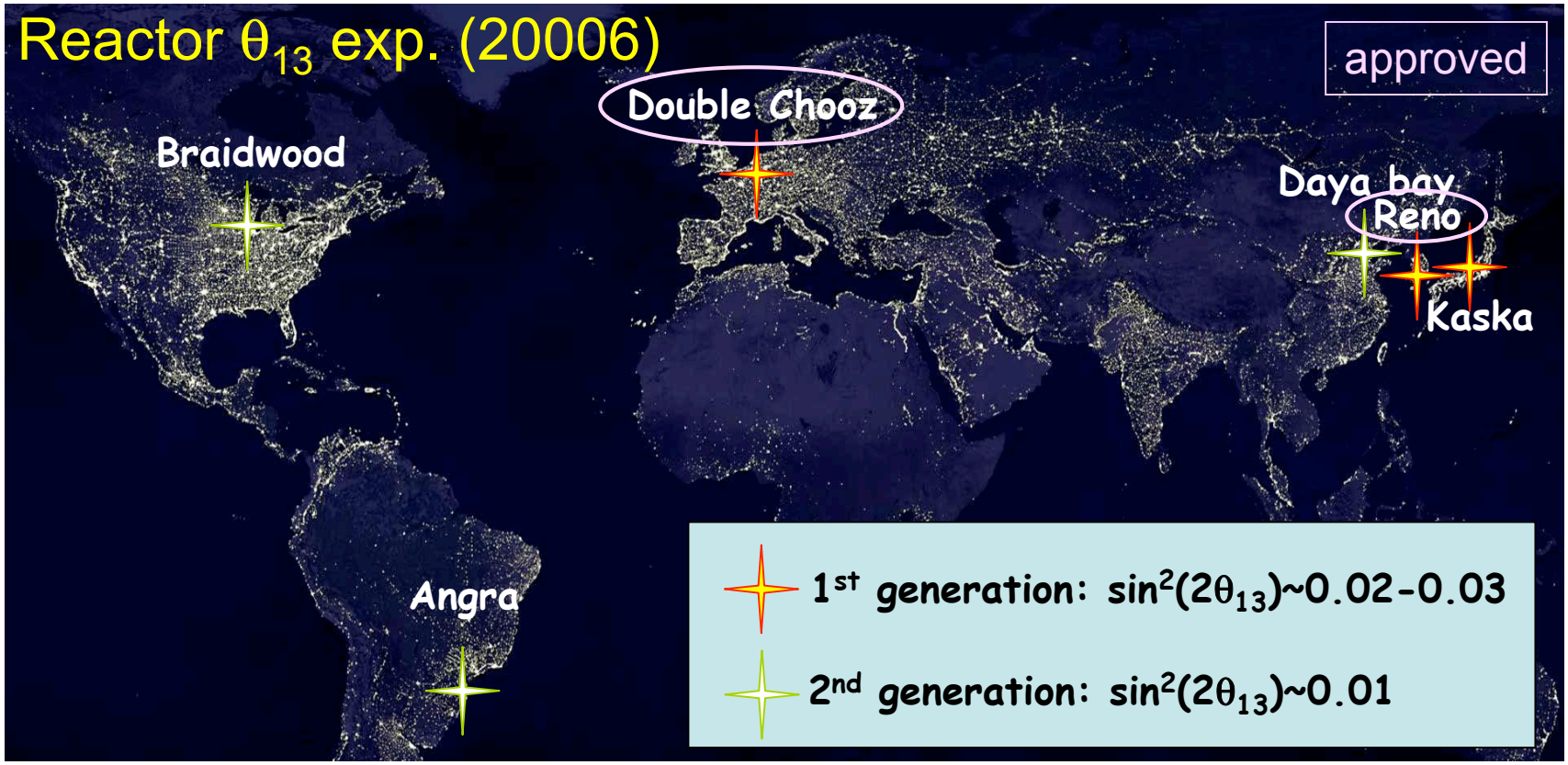
Neutrino + anti-neutrino runs = 8 years

Sensitivity to CP($\sin\delta \neq 0$)



Reactor based

Reactor θ_{13} exp.



- T2K and Reactor θ_{13} exp. are **complementary**.
  - Appearance signal versus Disappearance signal.
  - Statistics Limited versus Systematic Limited (may say statistics…)
  - Large CPV effect versus Pure θ_{13} effect. $P(\bar{\nu} \rightarrow \bar{\nu}) = 1 - \sin^2 2\theta_{13}$ @max
  - Similar Time scale (~2010)

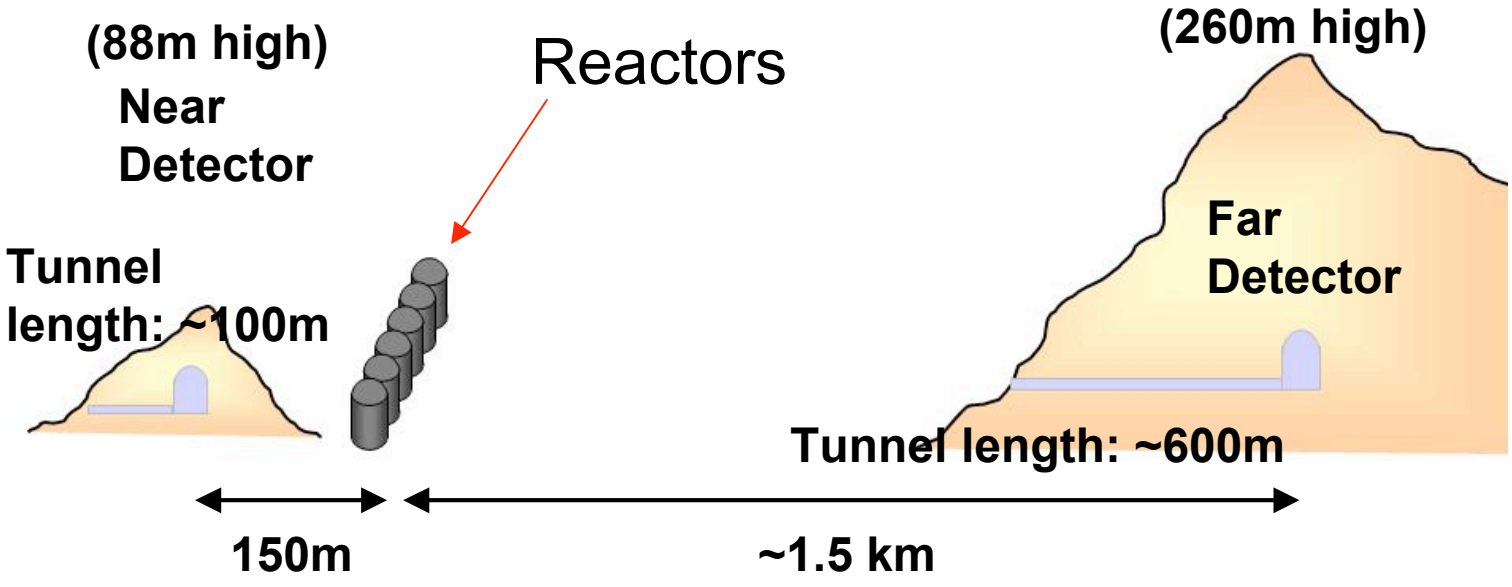
RENO

Reactor Experiment for Neutrino Oscillations at YoungGwang in Korea

Soo-Bong Kim (SNU)

YoungGwang Nuclear Power Plant

Schematic Setup of RENO at YoungGwang



θ_{13} Measurement Using YoungGwang Reactor

- 20tons (fid. vol.) of liquid scintillator detectors (US$10M):
  Near detector (~150m) + Far detector (~1.5km)
  (88m high Mt.) (260m high Mt.)

- 3 nearest detectors of 200~300kg scintillators

- Expected Number of Antineutrinos
  - Near detector : ~500/day (uncertainty less than 0.1%)
  - Far detector : ~50/day (18,000/year)
    (uncertainty less than 0.5%)

- Experimental systematic error : ~1%

- θ_{13} sensitivity : $\mathbf{\sin^2(2\theta_{13}) > 0.03}$

Status of RENO at YoungGwang

- ❑ Studied experimental feasibility (**$\sin^2(2\theta_{13}) > 0.03$)**
- ❑ Submitted a proposal of requesting US $9M to MOST (Ministry of Science and Technology) in April 2005
- ❑ MOST has chosen the RENO project and included in the list of government budget request for 2006
- ❑ The Ministry of Finance has approved the RENO budget in Dec. 2005 after Congress review
- ❑ RENO has started since March 1 of 2006
- ❑ Contacted the power plant and its local government → Promised their best cooperation if the project is approved
- ❑ A prototype with 40 liters of Gd liquid scintillator is being built
- ❑ International collaborators are being invited

A proposed Japanese reactor experiment

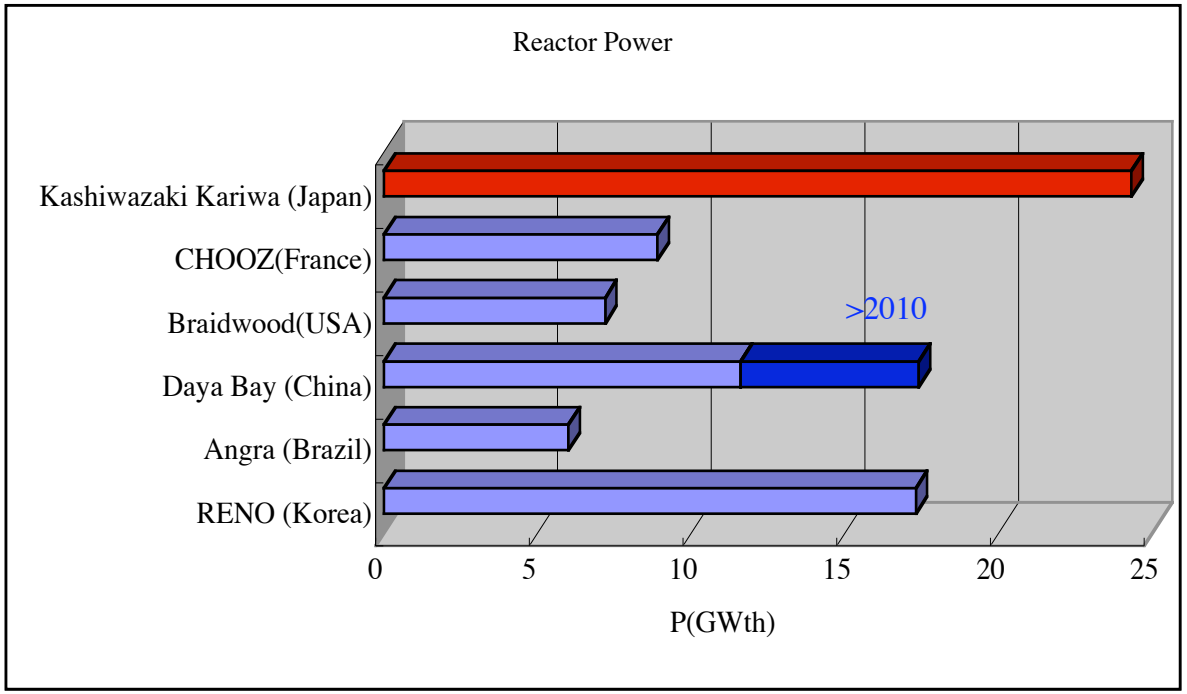
Kashiwazaki-Kariwa power plant

7 powerful reactors cluster into two group. (5BWR+2ABWR)

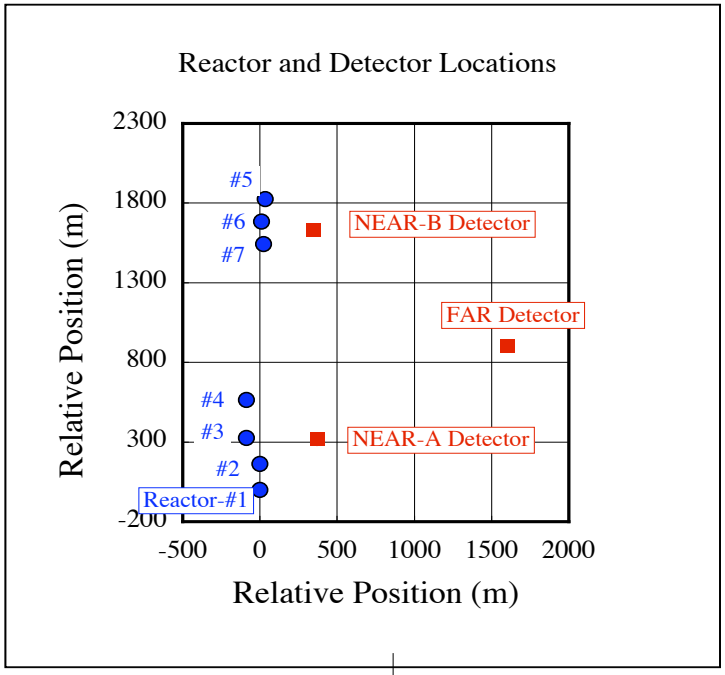
World's Largest Power

P=24.3GWth

Highest ν luminosity

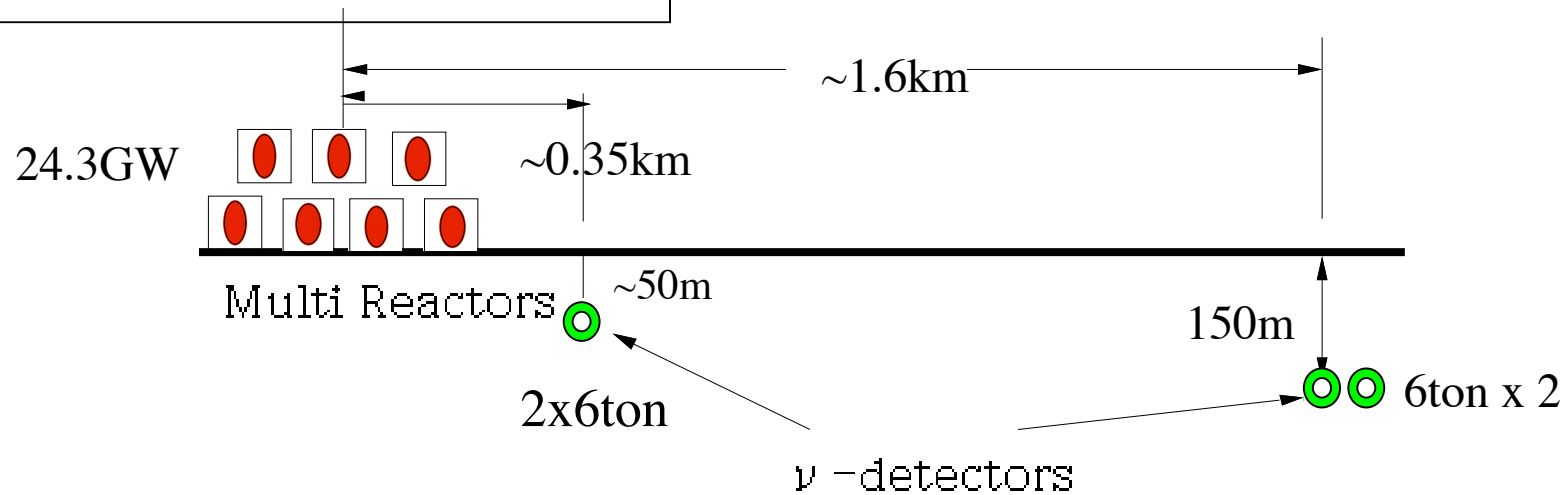


KASKA-θ_{13} Geometry

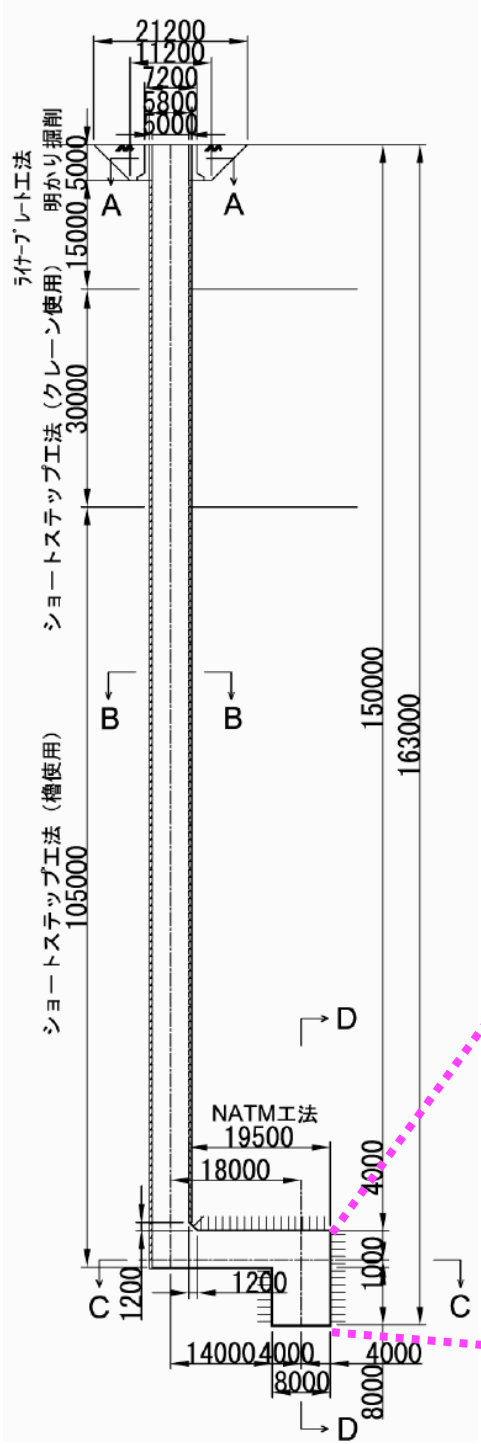


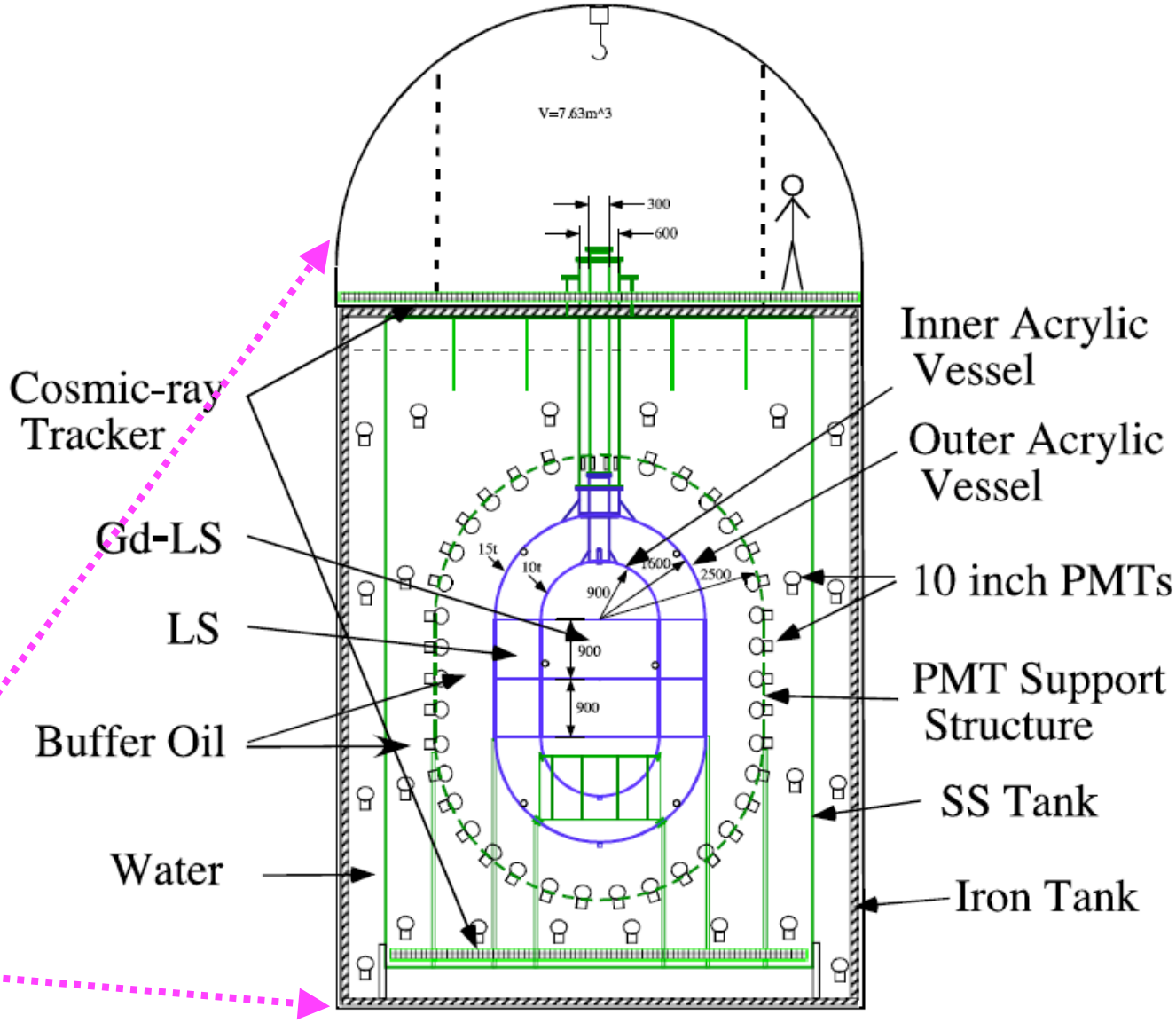
Identical detectors =>
Near/Far systematic cancellation

Shaft holes =>
Optimum baseline &
Optimum depth

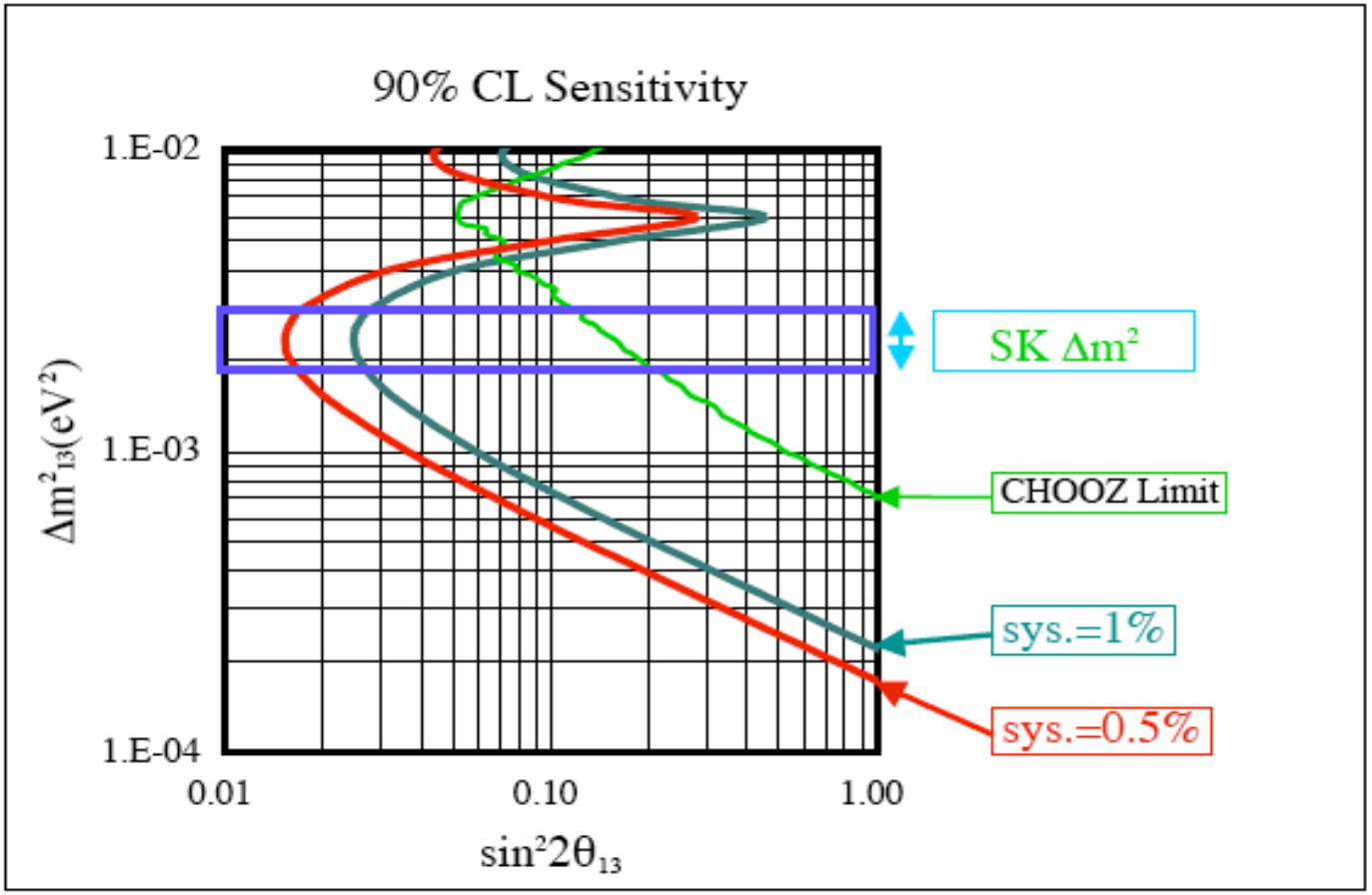


Detector & Shaft Hole





Expected Sensitivity



10x better sensitivity than current CHOOZ limit

Ongoing

- SK-III
- T2K-I (SK+ND280m+ND2km+0.75MW)
- KamLAND (Eth: 5MeV to 300KeV, ^{7}Be)

Planned

- T2K-II (HK+4MW)
- T2KK (0.5Mt x2 + 4MW)

Reactor

- RENO : in Korea/ approved
- KASKA : proposed

Our neutrino programs build on and around SK.

J-PARC/T2K

is

Japan's flagship project for the next 10 years.

End