T2K実験
(phase 1)

宇宙線研究所将来計画に向けた勉強会

宇宙ニュートリノ研究部門

2006/06/29

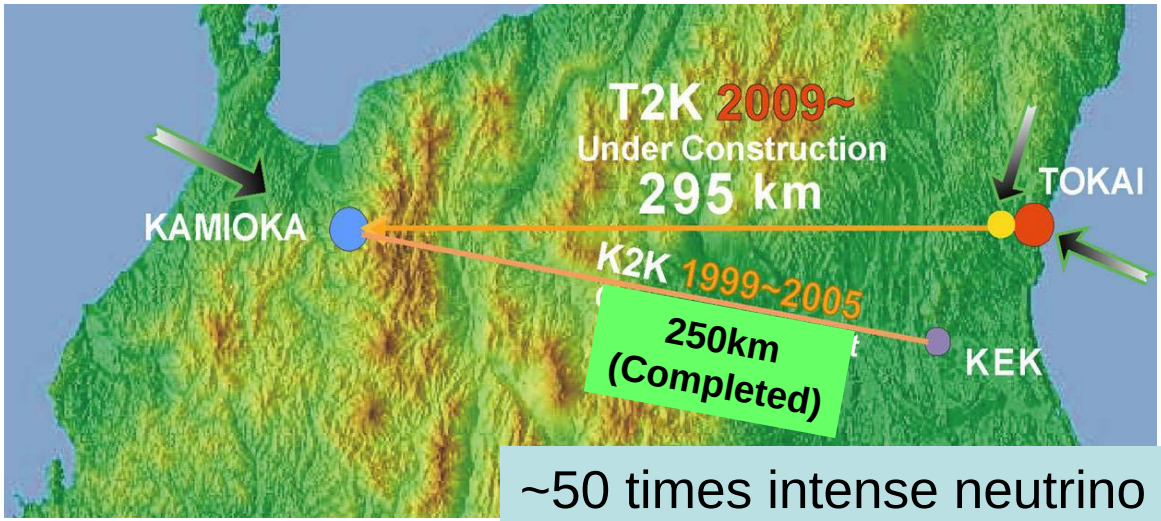
早戸　良成

T2K experiment

(Tokai to Kamioka long baseline neutrino oscillation experiment)

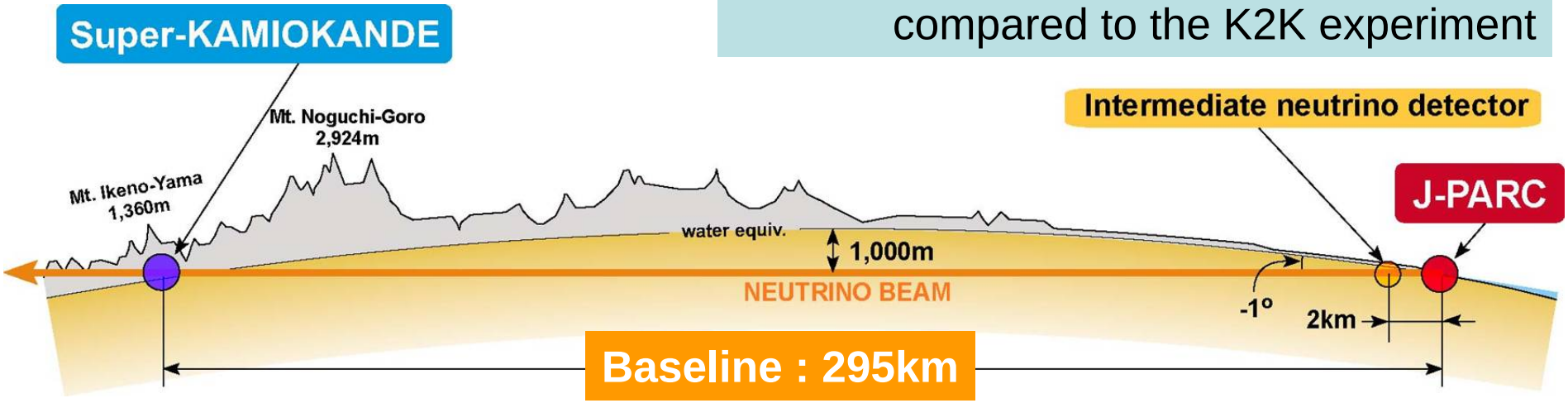
Use intense proton beam from J-PARC accelerator.

(0.75MW 50GeV PS , 30GeV @ T=0)



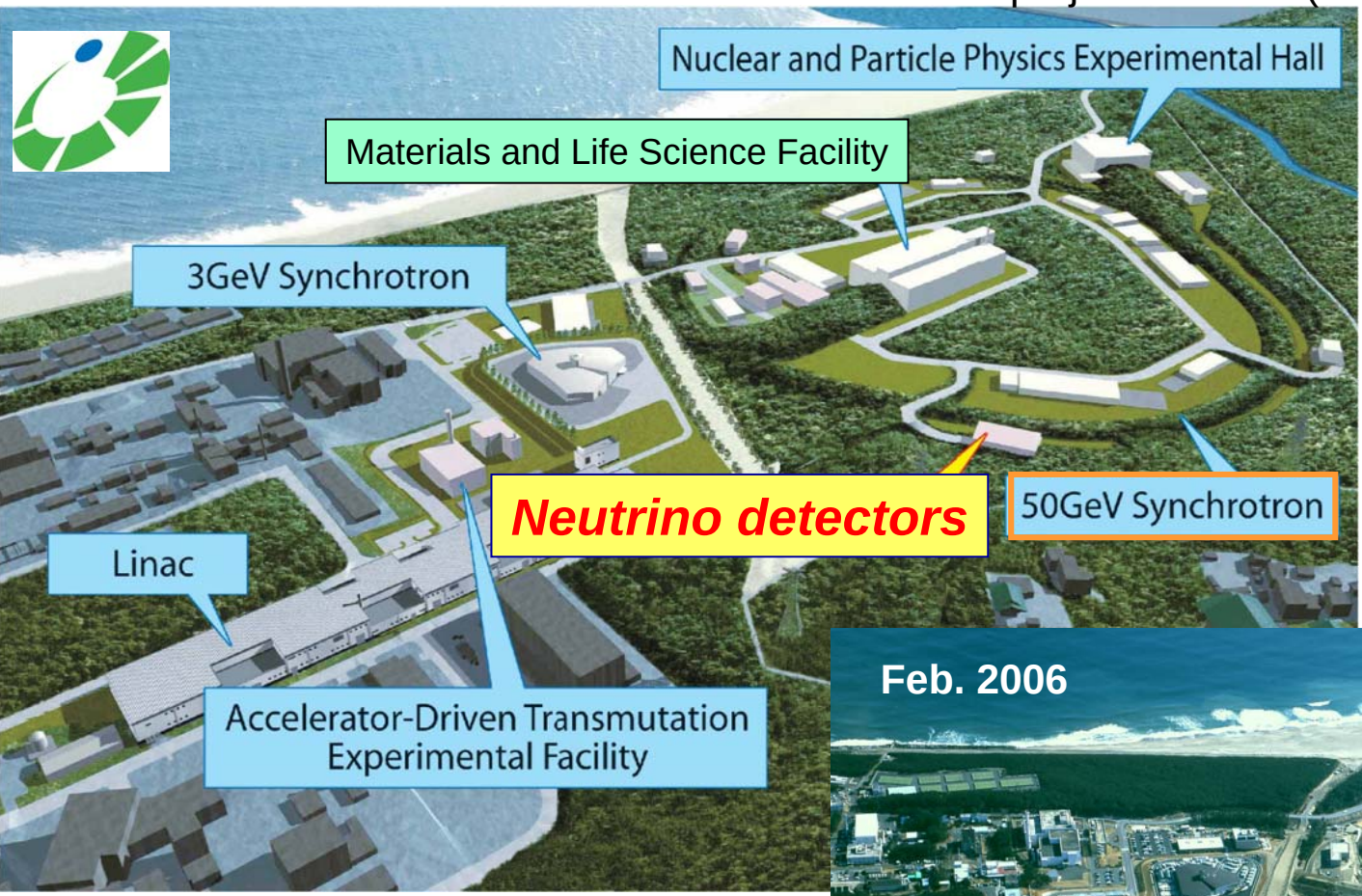
~50 times intense neutrino beam

compared to the K2K experiment



Japan Proton Accelerator Research Complex

Joint project of JAEA (former JAERI) and KEK



400MeV LINAC
(200MeV@T=0)

↓

1MW 3GeV RCS
(0.1MW @ T=0)

↓

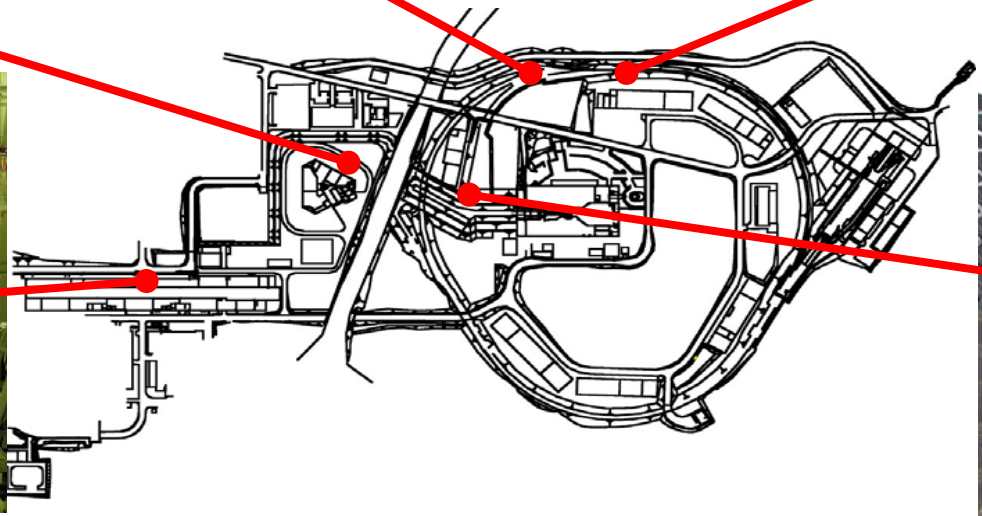
0.75MW 50GeV PS
(30GeV @ T=0)

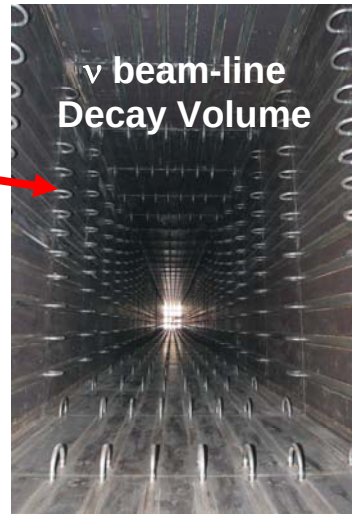
1×10^{21} protons/year

(130days/yr in 50GeV operation.)

c.f. K2K: ~1×10^{20} POT(6years)

Accelerator construction (Current status)

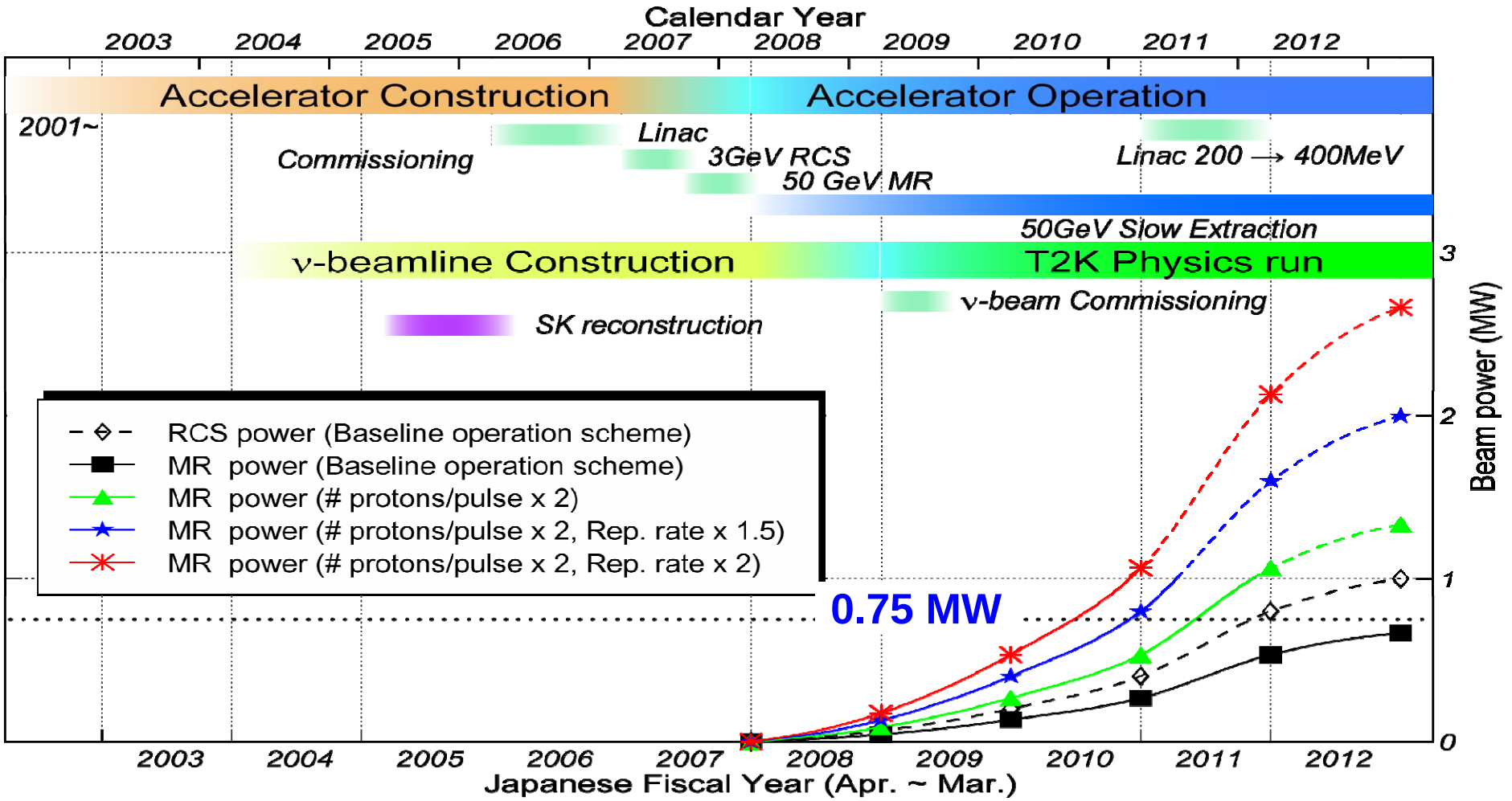




Commissioning of the neutrino beamline will start in 2009.

J-PARC construction & operation schedule

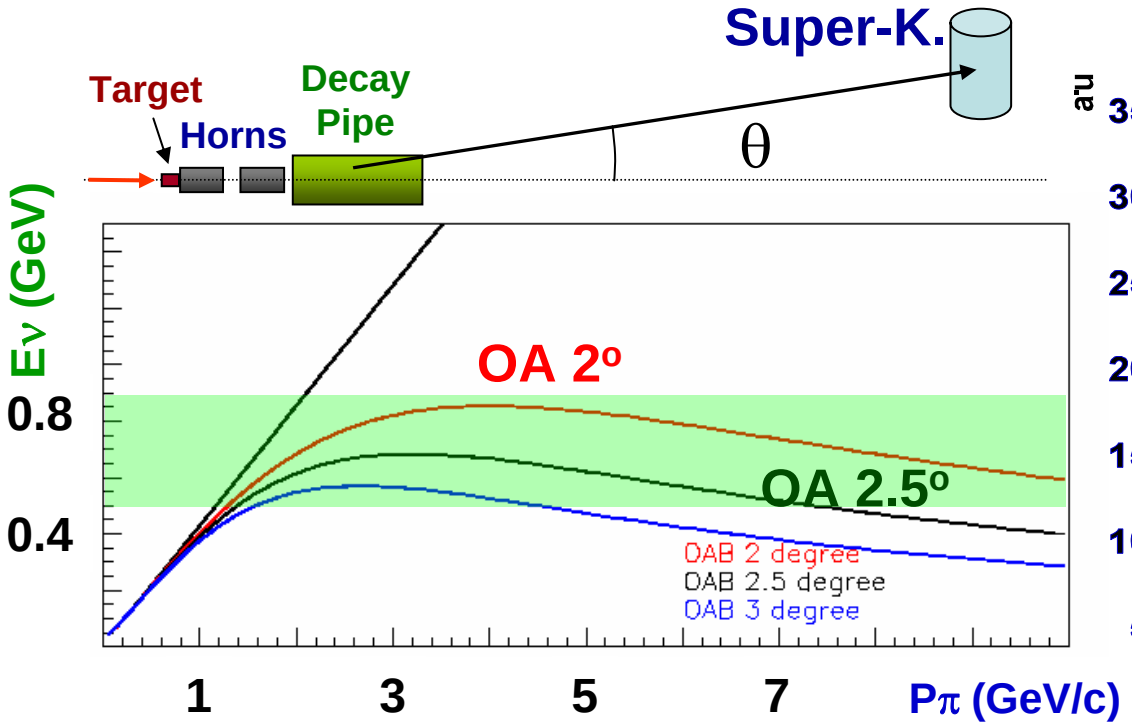
Beam power estimation

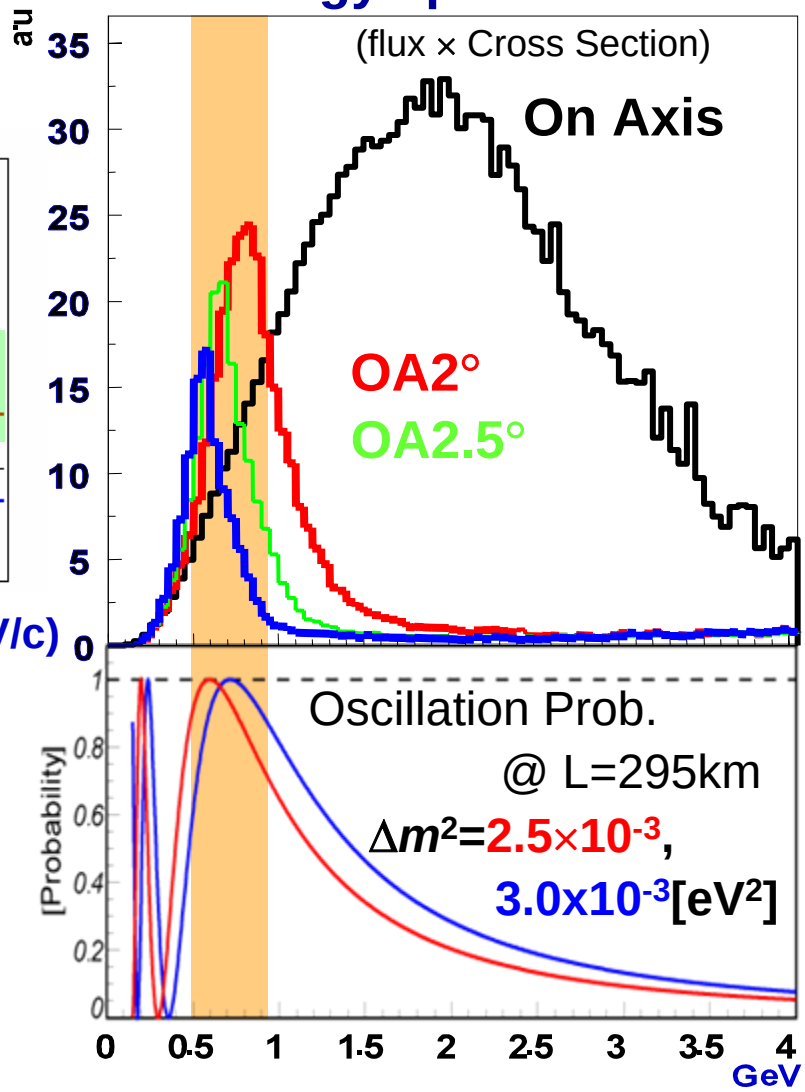


Off axis beam

Method to generate quasi-monochromatic neutrino beam

(ref.: BNL-E889 proposal)



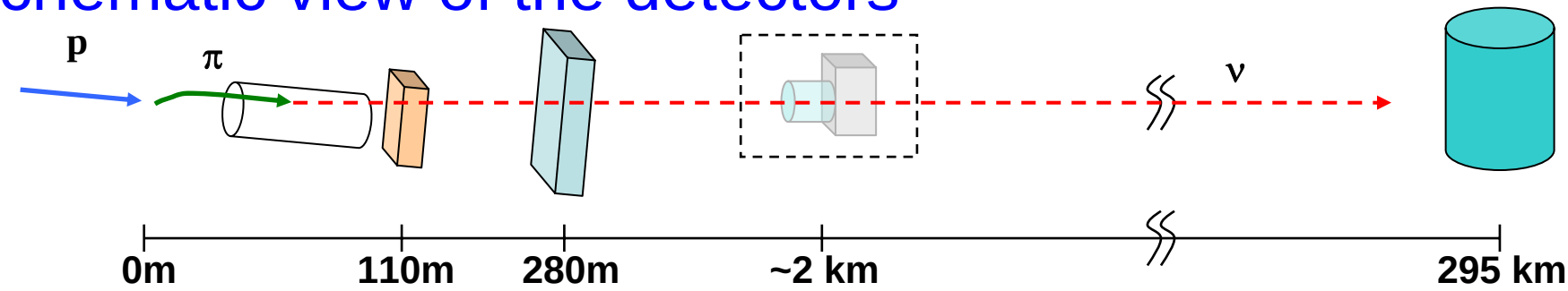


ν beam energy can be optimized by changing the off-axis angle.

↓

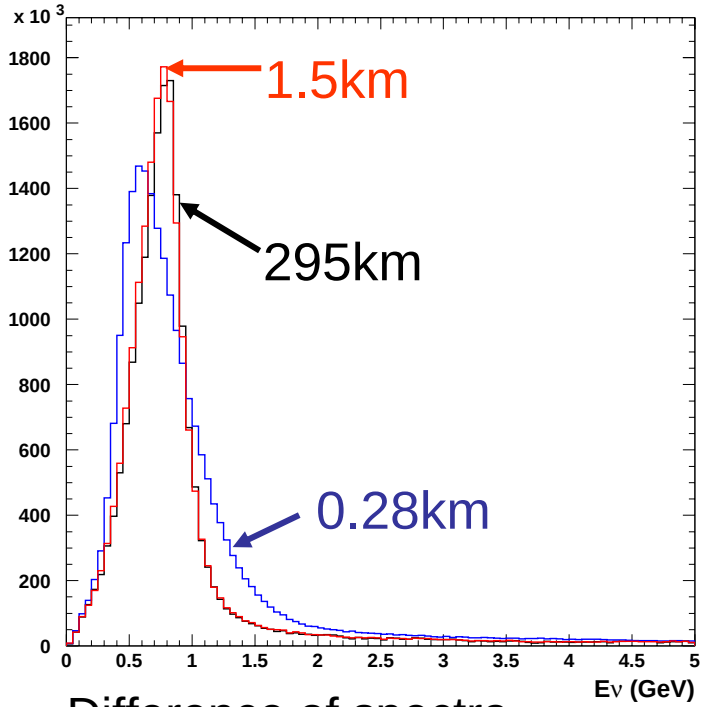
Maximize physics sensitivity.

Schematic view of the detectors



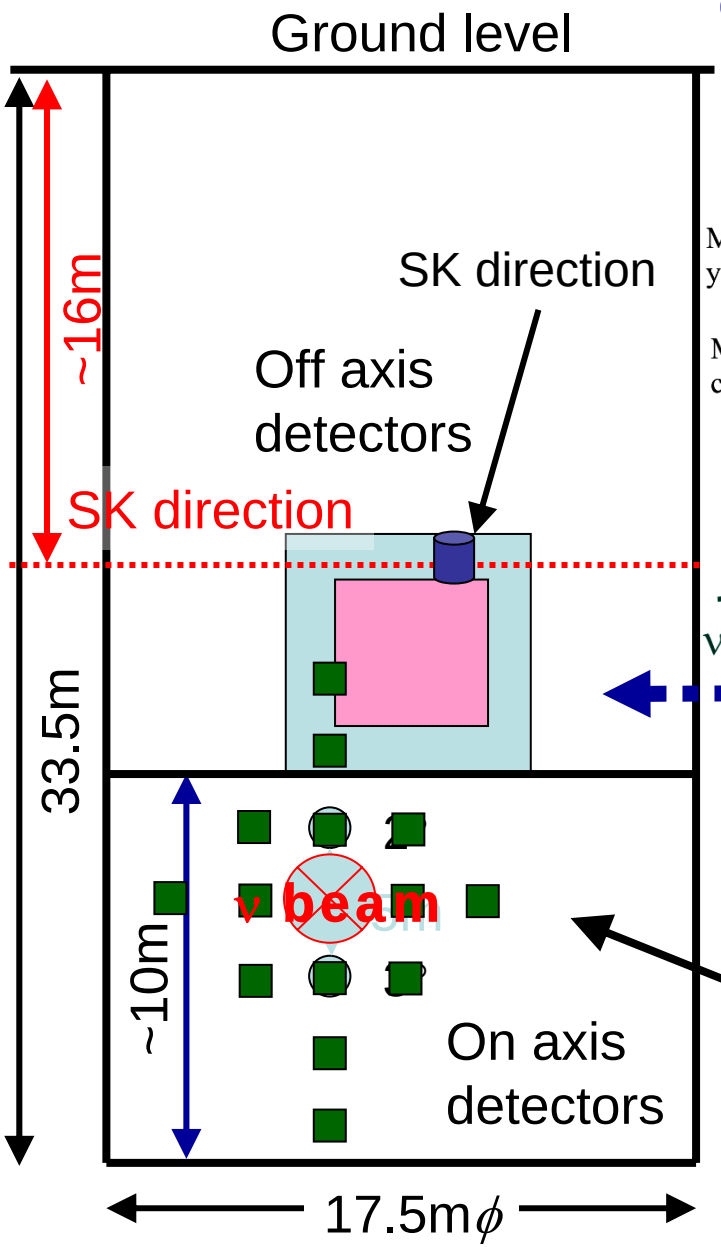
- **1st phase**
  - **Muon monitors @ ~110m**
    Fast (spill-by-spill) monitoring of beam direction & intensity
  - **Front detector @280m**
    Neutrino energy spectrum, intensity and direction
  - **Far detector @ 295km**
    Super-Kamiokande(50kt)
- **Future upgrade**
  Second Front Detector @ ~2km
  Almost same E_ν spectrum as SK
  Hyper Kamiokande

Neutrino spectra at different distance



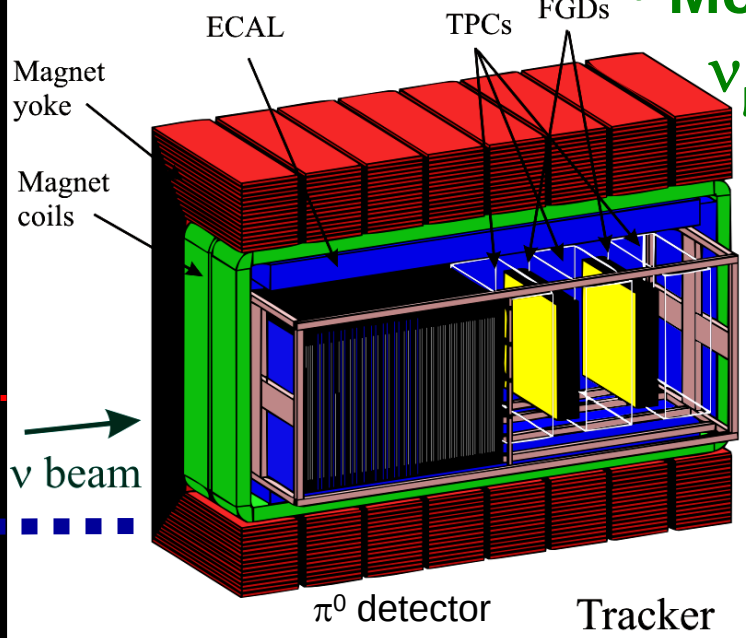
Difference of spectra
->Dominant systematic error in K2K

The 280m near neutrino detectors



Off-axis detector (B=0.2T)

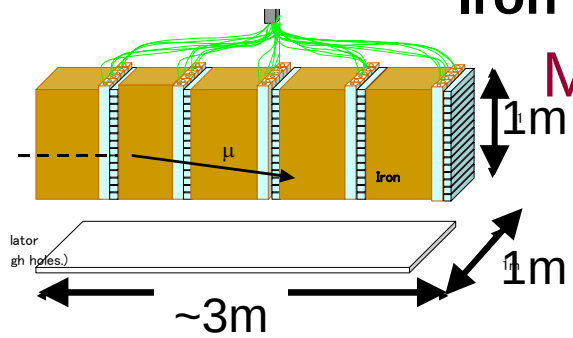
TPC & scintillator detectors



- **Measure ν_μ and ν_e fluxes and spectra**
- **Study ν interactions** (CC-QE, non-QE and π production)

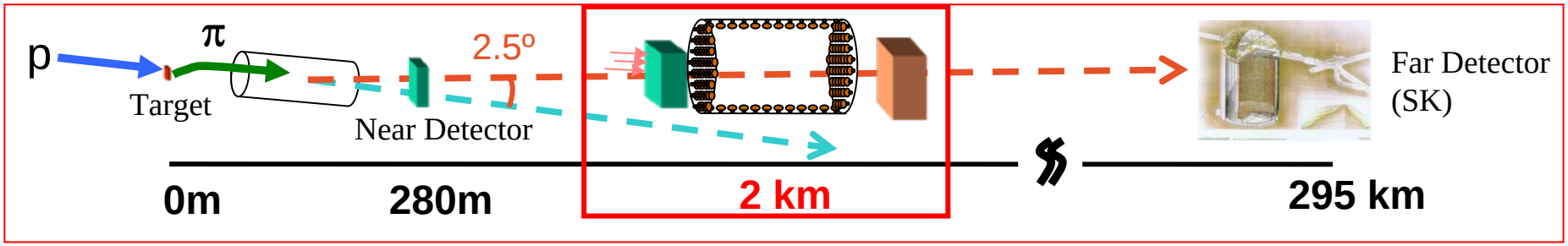
On-axis (0°)

Iron + scintillator



Measure beam direction and beam stability

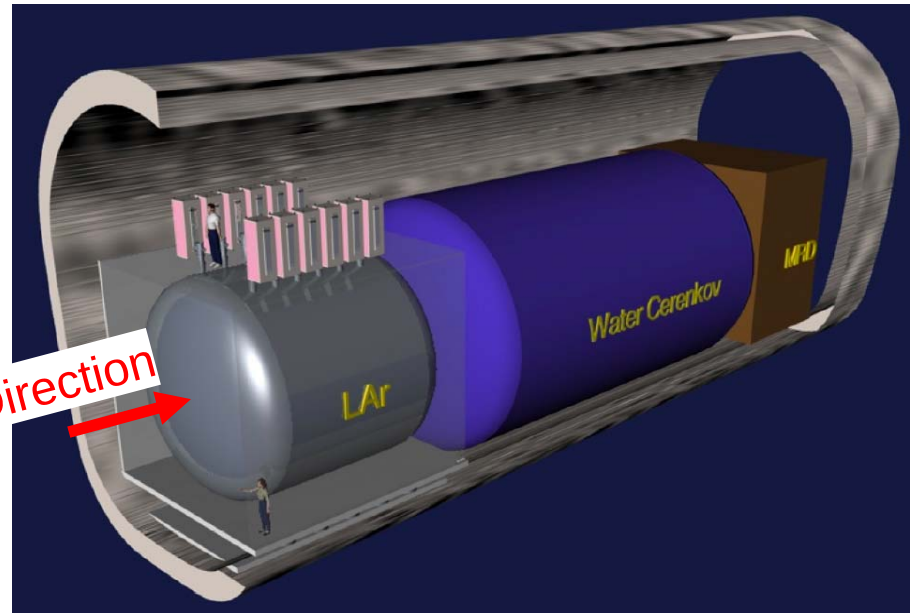
Possible intermediate detector @ 2km



- E_ν spectrum @ 2km
  ~ E_ν spectrum @ SK w/o oscillation

→ Possible to reduce uncertainties from Far/Near ratio.

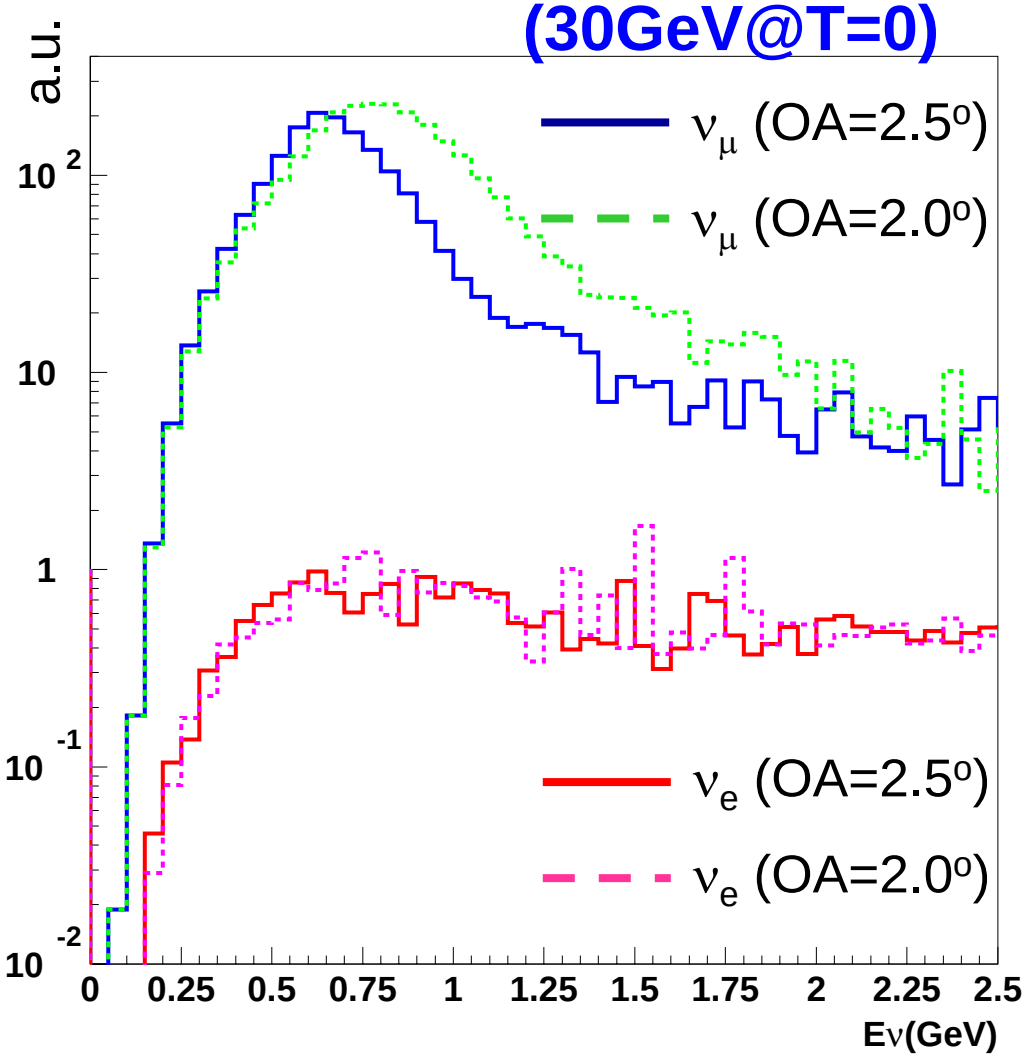
- Detectors
  - –Liquid Ar TPC
  - –Water Cherenkov
    - Very similar ν detection to SK
  - –Muon Range Detector



To be requested in Japan after the commissioning of J-PARC facilities.

Expected flux and number of interactions @ SK

ν flux x cross-section @SK (30GeV@T=0)



Expected event rate in 1yr
(22.5kt, full intensity)

OA 2.5°

ν_μ { total : ~ 2330
CC : ~ 1660

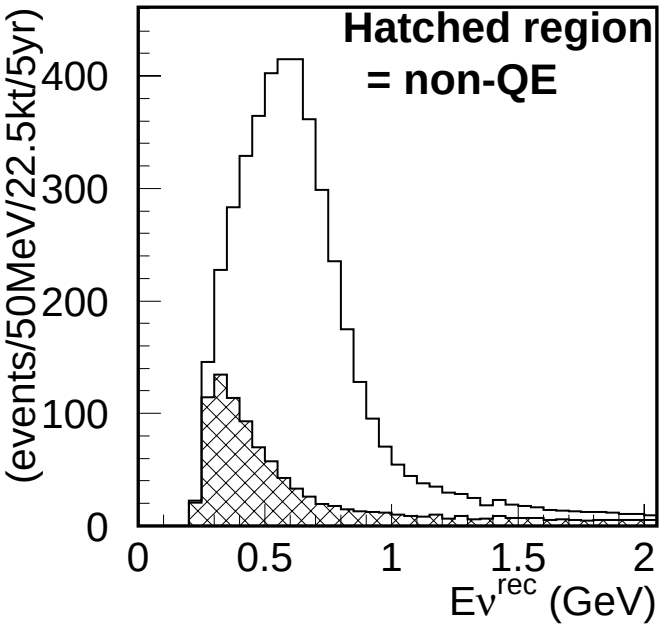
ν_e { total : ~ 45
(0.4~0.5%@ peak)

ν oscillation study (1) ν_μ disappearance

$P(\nu_\mu \rightarrow \nu_\mu) \sim 1 - \sin^2\theta_{23}\sin^2(1.27\,\Delta m^2_{23}L/E)$

Use 1-ring μ-like events and reconstruct energy of ν.

No oscillation



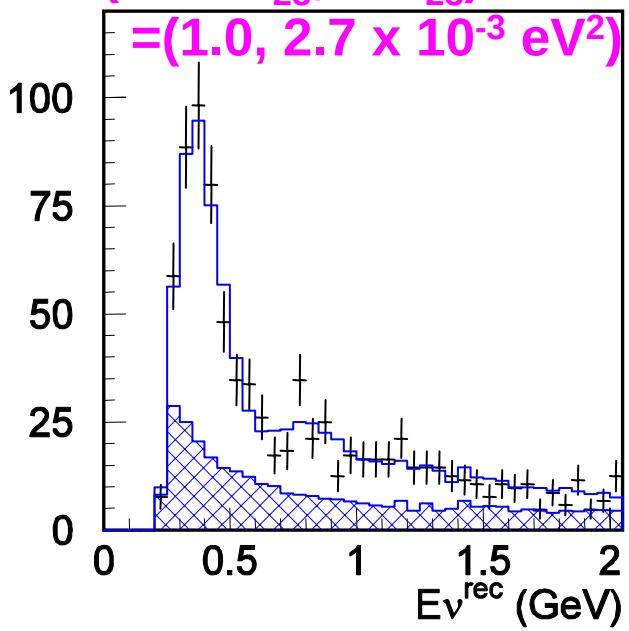
no oscillation

~4800 events/5yr

With oscillation

$(\sin^2 2\theta_{23}, \Delta m^2_{23})$

$=(1.0,\ 2.7 \times 10^{-3}\ eV^2)$



$\Delta m^2_{23} = 2.7 \times 10^{-3}\ eV^2$

~1200 events/5yr

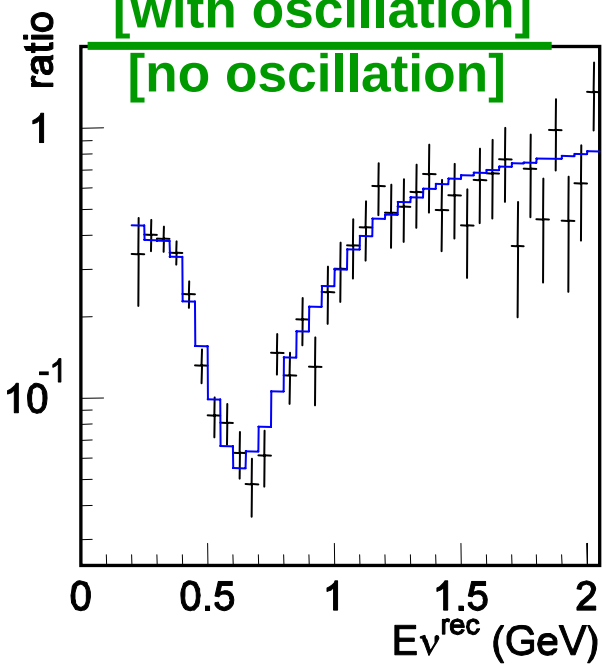
$\Delta m^2_{23} = 2.0 \times 10^{-3}\ eV^2$

~1630 events/5yr

Ratio of E_ν^{rec}

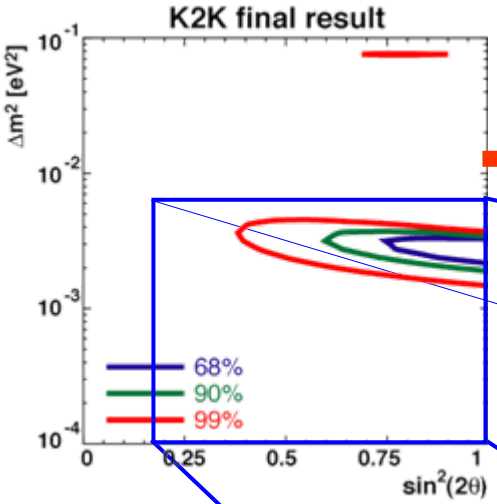
[with oscillation]

[no oscillation]

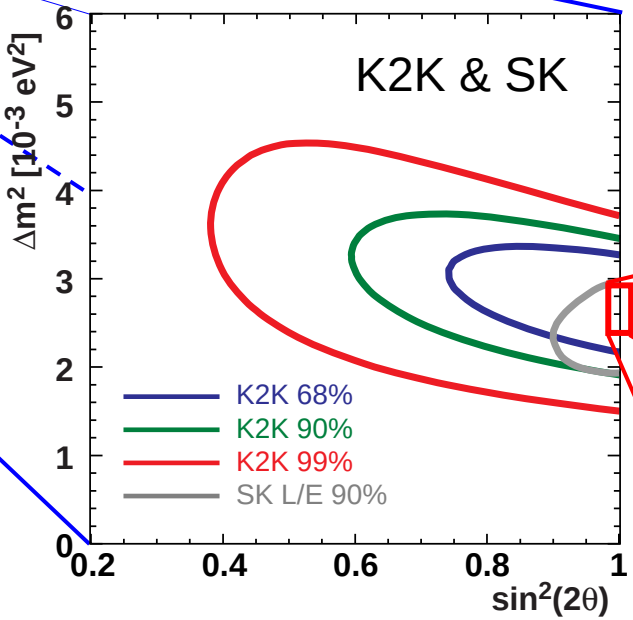


ν oscillation study (1) ν_μ disappearance

Expected sensitivity

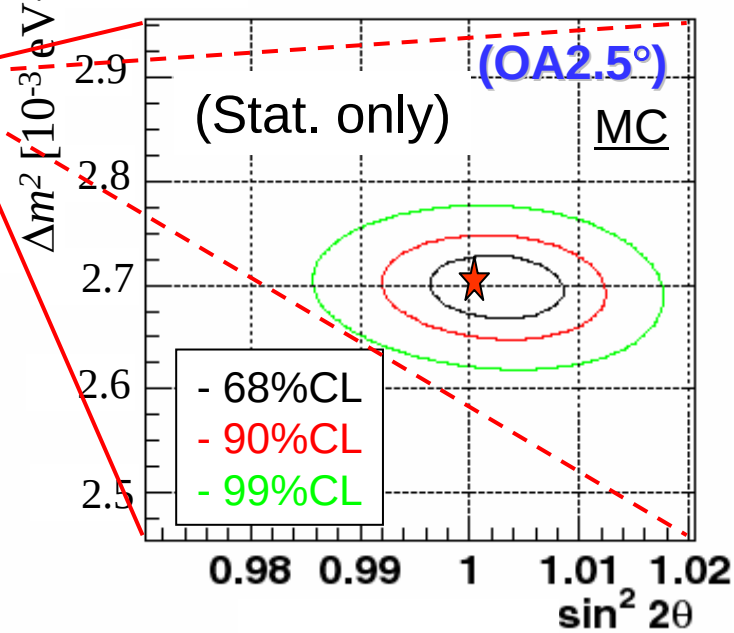


Statistics : 50 x K2K



T2K

~ 5years @ full Intensity



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

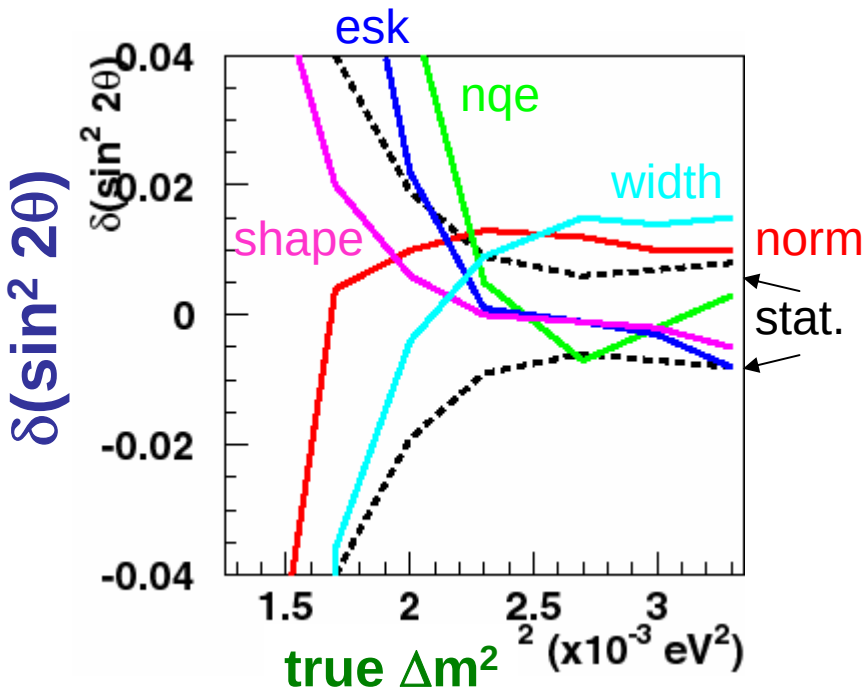
$\delta(\Delta m^2_{23}) < 1 \times 10^{-4}$ [eV²]

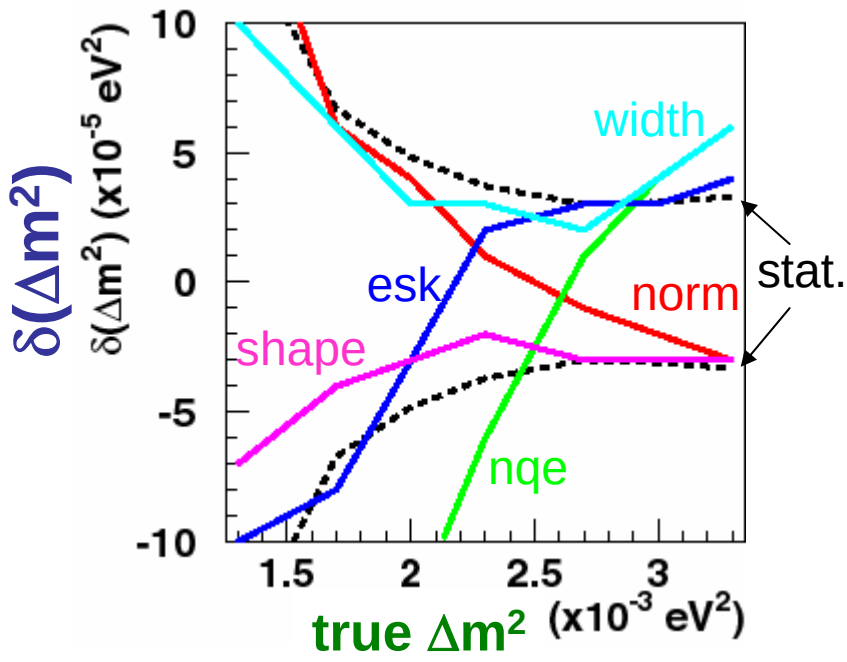
ν oscillation study (1) ν_μ disappearance

To reduce systematic errors comparable or smaller than statistical errors,

- Flux normalization < 10%
- Non-QE ratio < 20%
- Energy scale < 4%
- Spectrum shape [Confirm two models: FLUKA/MARS]
- Spectrum width < 10%

It is possible to achieve at this level
with the near detector measurements
and external information, p/K production experiments.





ν oscillation study (2) ν_e appearance

$$
\begin{aligned}
P(\nu_\mu \to \nu_e) \approx & \sin^2 2\theta_{13} \sin^2 \theta_{23} \sin^2 \Delta \\
& \pm \alpha \sin 2\theta_{13} \sin\delta \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \sin^3 \Delta \\
& - \alpha \sin 2\theta_{13} \cos\delta \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \cos\Delta \sin 2\Delta \\
& + \alpha^2 \cos^2\theta_{23} \sin^2 2\theta_{12} \sin^2 \Delta
\end{aligned}
$$

$$
\alpha \equiv \Delta m^2_{21}/\Delta m^2_{31}
$$

$$
\Delta = \Delta m^2_{31} L/4E.
$$

$\tan^2\theta_{12}$~0.45
$\sin^2 2\theta_{13}$<0.2
α~0.03

→ $\alpha \sin 2\theta_{13}$<0.015
$\cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23}$ ~1

Around the oscillation maximum energy (E_ν ~ 0.6GeV)

→ Oscillation probability ~ $\sin^2 2\theta_{13} \sin^2\Delta \pm 0.015 \sin\delta \sin^3\Delta$

ν oscillation study (2) ν_e appearance

Search for the electrons from ν_e quasi-elastic scattering

Expected number of events

(5yrs of running @ full intensity)

$\nu_e + n \rightarrow e^- + p$

Event selection criteria	ν_μ CC BG	ν_μ NC BG	Beam ν_e BG	ν_e signal
Fully contained, E_{vis}>100MeV	2215	847	184	243
1ring e-like events, No decay electron	12	156	71	187
Reconstructed E_ν 0.35 ~ 0.85 GeV	1.8	47	21	146
π^0 rejection cuts Search for the "additional" ring Reject π^0 like events (using PMT hit pattern) Reconstructed π^0 mass < 100MeV/c^2 Reject events with "forward going" electron like particle (cosθ > 0.9)	0.7	9	13	**103**
	total ~ 23			

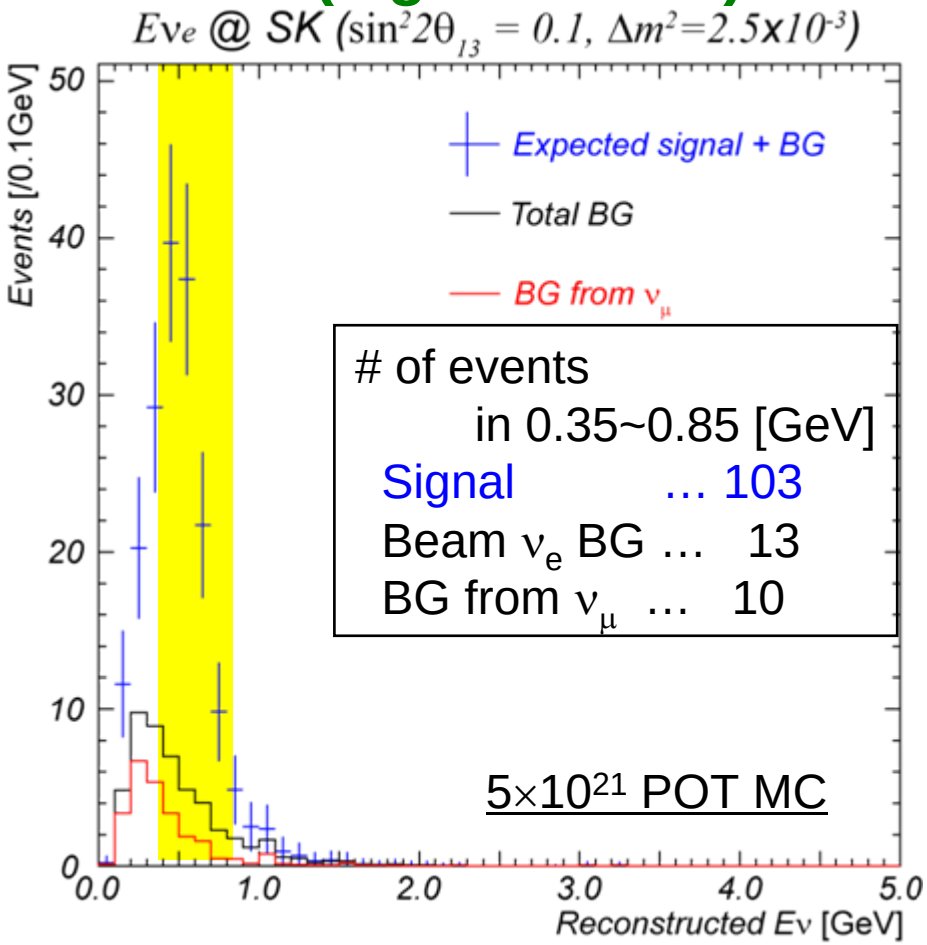
Oscillation prob. : Leading term only.

Assuming $\Delta m^2 = 2.5 \times 10^{-3} eV^2$, **$\sin^2 2\theta_{13} = 0.1$**

ν oscillation study (2) ν_e appearance

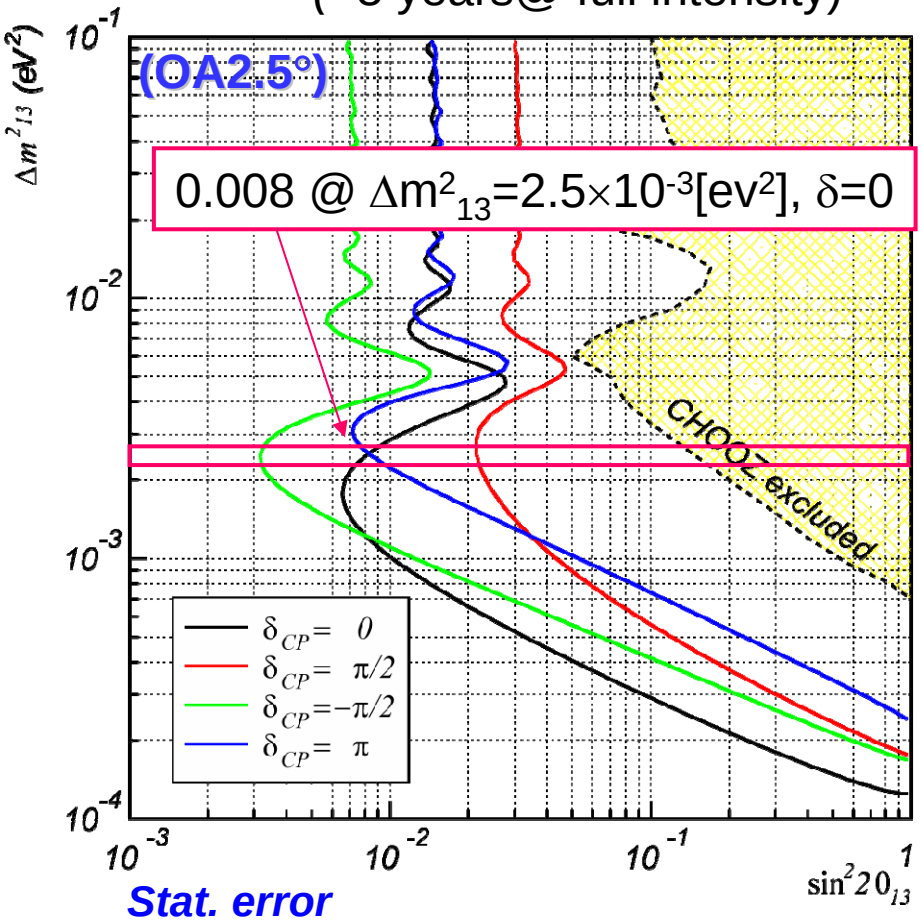
Expected energy spectrum and sensitivity

Energy spectrum (signal + B.G.)



T2K 90%CL sensitivity

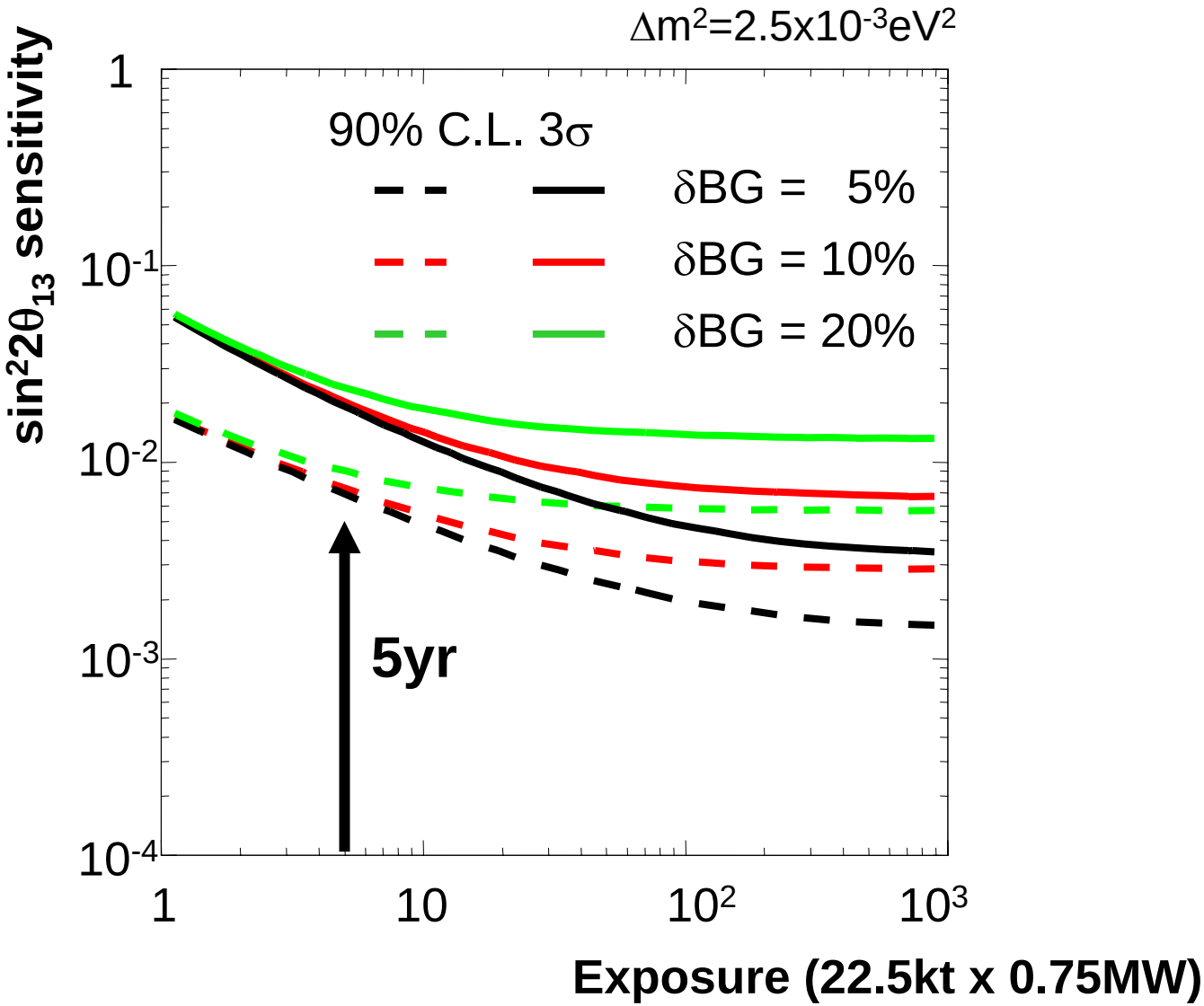
$\sin^2 2\theta_{23}$ = 1.0 is assumed.
(~5 years@ full intensity)



Stat. error
+ Syst. error for BG subtraction (10%)

ν oscillation study (2) ν_e appearance

Expected sensitivity v.s. time



ν oscillation study (2) ν_e appearance

Systematic errors

K2K での ν_e appearance search での error (ν_μ background)

ν flux & spectrum	~6%	→ Will be improved by data from near detectors and π/K production exp.
Detector calibrations (Water parameter etc.)	~6%	→ More study/understanding of the SK detector
Electron ID and π^0 rejection	~21%	→ Will be improved by new π^0 rejection
ν interactions	~11%	→ Will be improved by measurements of the near detectors and the other experiments.

Total systematic error ~10% is achievable.

Summary

- Commissioning of the J-PARC neutrino beam-line
  is expected to be started in 2009 as scheduled.
- The physics sensitivity will be maximized
  by using the “off axis” beam configuration.
- With the designed intensity of the proton beam,

  ν_μ **~ 2330 events / year (CC ~ 1660)**

  ν_e **~45 events / year (0.4~0.5%@ peak)**
- Expected sensitivity

  ν_μ disappearance

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

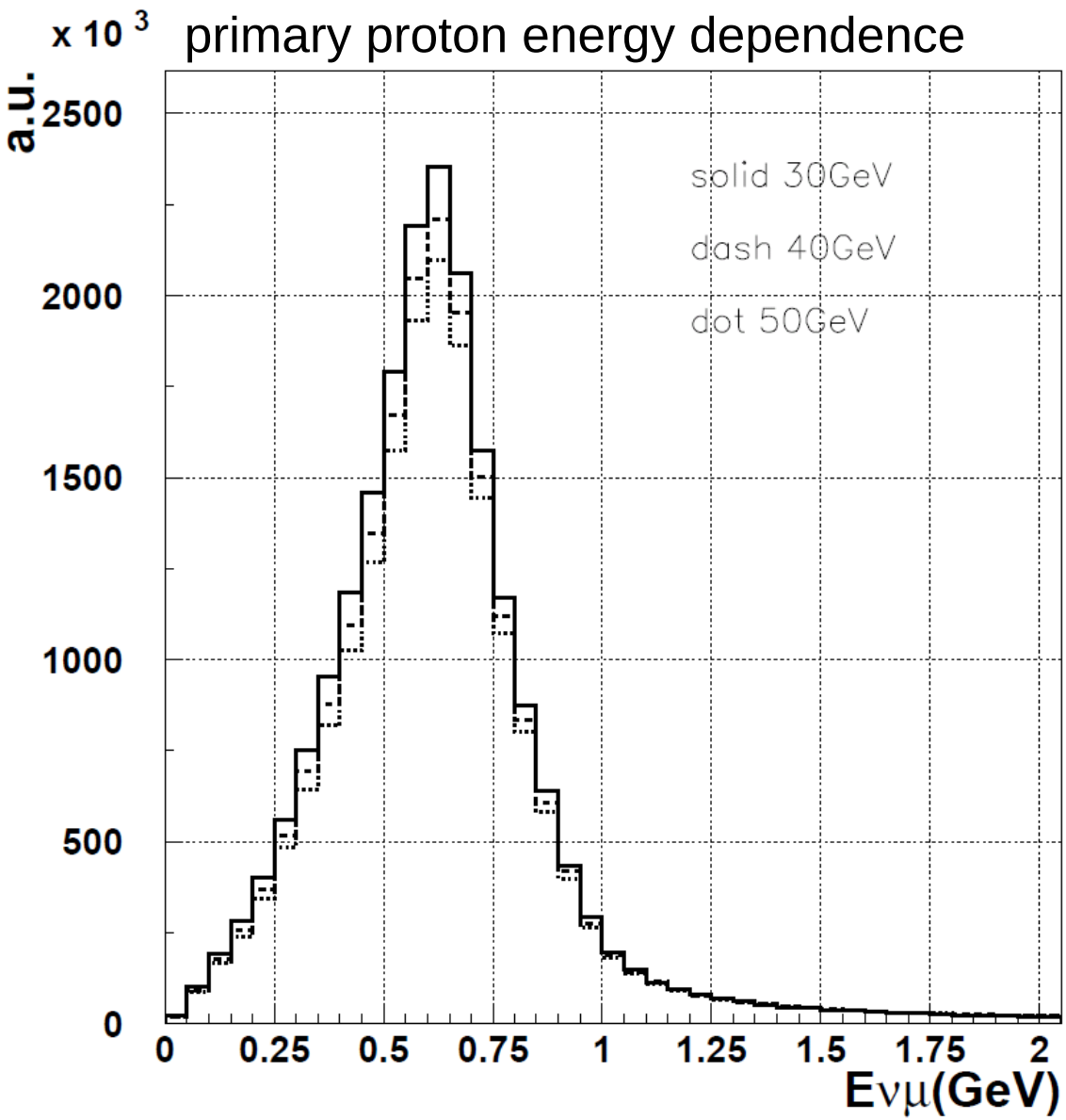
  $\delta(\Delta m^2_{23}) < 1 \times 10^{-4}$ [eV^2]

  ν_e appearance

  $\sin^2 2\theta_{13} \sim 0.008$ @ $\Delta m^2_{13} = 2.5 \times 10^{-3}$[ev^2], $\delta = 0$

fin.

Energy spectrum



Contribution from π & K