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Napoli, 4 Ottobre 2004

T2K: la nuova finestra sulle oscillazioni di neutrini

Scenario Attuale

Θ_{13} e $\nu_\mu \rightarrow \nu_e$

La Fisica di T2K

Partecipazione Italiana

500+ Cited papers 1986-Now

1. EVIDENCE FOR OSCILLATION OF ATMOSPHERIC NEUTRINOS — 2178
Super-Kamiokande Collaboration (Y. Fukuda *et al.*) Phys.Rev.Lett.81:1562 (1998) hep-ex/9807003

2. A MEASUREMENT OF THE SPIN ASYMMETRY AND DETERMINATION OF THE STRUCTURE FUNCTION G(1) IN DEEP INELASTIC MUON-PROTON SCATTERING — 1215
European Muon Collaboration (J. Ashman *et al.*) Phys.Lett. B206:364 (1988)

3. OBSERVATION OF TOP QUARK PRODUCTION IN $\bar{p}p$ COLLISIONS — 1099
CDF Collaboration (F. Abe *et al.*) Phys.Rev.Lett.74:2626 (1995) hep-ex/9503002

4. OBSERVATION OF THE TOP QUARK. — 1052
D0 Collaboration (S. Abachi *et al.*) Phys.Rev.Lett.74:2632 (1995) hep-ex/9503003

5. MEASUREMENT OF THE RATE OF $\nu_e + d \rightarrow p + p + e-$ INTERACTIONS PRODUCED BY B^8 SOLAR NEUTRINOS AT THE SUDBURY NEUTRINO OBSERVATORY. — 932
SNO Collaboration (Q.R. Ahmad *et al.*) Phys.Rev.Lett.87:071301 (2001) nucl-ex/0106015

6. LIMITS ON NEUTRINO OSCILLATIONS FROM THE CHOOZ EXPERIMENT — 911
CHOOZ Collaboration (M. Apollonio *et al.*) Phys.Lett.B466:415 (1999) hep-ex/9907037

7. MEASUREMENT OF THE SOLAR ELECTRON NEUTRINO FLUX WITH THE HOMESTAKE CHLORINE DETECTOR — 848
Bruce T. Cleveland et al. Astrophys.J.496:505 (1998)

8. ATMOSPHERIC ν_μ / ν_e RATIO IN THE MULTIGEV ENERGY RANGE — 829
Kamiokande Collaboration (Y. Fukuda *et al.*) Phys.Lett.B335:237 (1994)

9. DIRECT EVIDENCE FOR NEUTRINO FLAVOR TRANSFORMATION FROM NEUTRAL CURRENT INTERACTIONS IN THE SUDBURY NEUTRINO OBSERVATORY — 792
SNO Collaboration (Q.R. Ahmad *et al.*) Phys.Rev.Lett.89:011301 (2002) nucl-ex/0204008

10. INITIAL RESULTS FROM THE CHOOZ LONG BASELINE REACTOR NEUTRINO OSCILLATION EXPERIMEN — 771
CHOOZ Collaboration (M. Apollonio *et al.*) Phys.Lett.B420:397 (1998) hep-ex/9711002

11. FIRST MEASUREMENT OF THE RATE FOR THE INCLUSIVE RADIATIVE PENGUIN DECAY $b \rightarrow s \gamma$ — 681
CLEO Collaboration (M.S. Alam *et al.*) Phys.Rev.Lett.74:2885 (1995)

12. OBSERVATION OF A SMALL ATMOSPHERIC ν_μ / ν_e RATIO IN KAMIOKANDE — 678
Kamiokande-II Collaboration (K.S. Hirata *et al.*) Phys.Lett.B280:146 (1992)

13. EXPERIMENTAL STUDIES ON MULTI-JET PRODUCTION IN e+e- ANNIHILATION AT PETRA ENERGIES — 666
JADE Collaboration (W. Bartel *et al.*) Z.Phys.C33:23 (1986)

14. FIRST RESULTS FROM KAMLAND: EVIDENCE FOR REACTOR ANTI-NEUTRINO DISAPPEARANCE — 656
Kamland Collaboration (K. Eguchi *et al.*) Phys.Rev.Lett.90:021802 (2003)

15. MEASUREMENT OF A SMALL ATMOSPHERIC MUON-NEUTRINO / ELECTRON-NEUTRINO RATIO — 641
Super-Kamiokande Collaboration (Y. Fukuda *et al.*) Phys.Lett.B433:9 (1998) hep-ex/9803006

16. GALLEX SOLAR NEUTRINO OBSERVATIONS: RESULTS FROM GALLEX IV 631
GALLEX Collaboration (W. Hampel *et al.*) Phys.Lett.B447:127 (1998)

17. EVIDENCE FOR TOP QUARK PRODUCTION IN $\bar{p}$ p COLLISIONS AT $S^{1/2}$ = 1.8 TeV 627
CDF Collaboration (F. Abe *et al.*) Phys.Rev.D50:2966 (1994)

18. EVIDENCE FOR $\bar{\nu}_\mu \to \bar{\nu}_e$ OSCILLATIONS FROM THE LSND EXPERIMENT AT LAMPF 626
LSND Collaboration (C. Athanassopoulos *et al.*) Phys.Rev.Lett.77:3082 (1996) nucl-ex/9605003

19. SOLAR NEUTRINO DATA COVERING SOLAR CYCLE 22 623
Kamiokande Collaboration (Y. Fukuda *et al.*) Phys.Rev.Lett.77:1683 (1996)

20. OBSERVATION OF A NEUTRINO BURST FROM THE SUPERNOVA SN1987A 622
Kamiokande-II Collaboration (K. Hirata *et al.*) Phys.Rev.Lett.58:1490 (1987)

21. STUDY OF THE ATMOSPHERIC NEUTRINO FLUX IN THE MULTI-GEV ENERGY RANGE. 620
Super-Kamiokande Collaboration (Y. Fukuda *et al.*) Phys.Lett.B436:33 (1998) hep-ex/9805006

22. SOLAR B^8 AND HEP NEUTRINO MEASUREMENTS FROM 1258 DAYS OF SUPER-KAMIOKANDE DATA 598
Super-Kamiokande Collaboration (S. Fukuda *et al.*) Phys..Rev.Lett.86:5651 (2001) hep-ex/0103032

23. THE ν_e AND ν_μ CONTENT OF THE ATMOSPHERIC FLUX 591
IMB Collaboration (R. Becker-Szendy *et al.*) Phys.Rev.D46:3720 (1992)

24. EVIDENCE FOR $\nu_\mu \to \nu_e$ NEUTRINO OSCILLATIONS FROM LSND 580
LSND Collaboration (C. Athanassopoulos *et al.*) Phys.Rev.Lett.81:1774 (1998) nucl-ex/9709006

25. OBSERVATION OF A NEUTRINO BURST IN COINCIDENCE WITH SUPERNOVA SN1987A IN THE LARGE MAGELLANIC CLOUD 559
IMB Collaboration (R.M. Bionta *et al.*) Phys.Rev.Lett.58:1494 (1987)

26. MEASUREMENT OF DAY AND NIGHT NEUTRINO ENERGY SPECTRA AT SNO AND CONSTRAINTS ON NEUTRINO MIXING PARAMETERS 542
SNO Collaboration (Q.R. Ahmad *et al.*) Phys.Rev.Lett.89:011302 (2002) nucl-ex/0204009

27. MEASUREMENT OF THE SPIN DEPENDENT STRUCTURE FUNCTION G1(x) OF THE DEUTERON 529
Spin Muon Collaboration (B.Adeva *et al.*) Phys.Lett. B302:533 (1993)

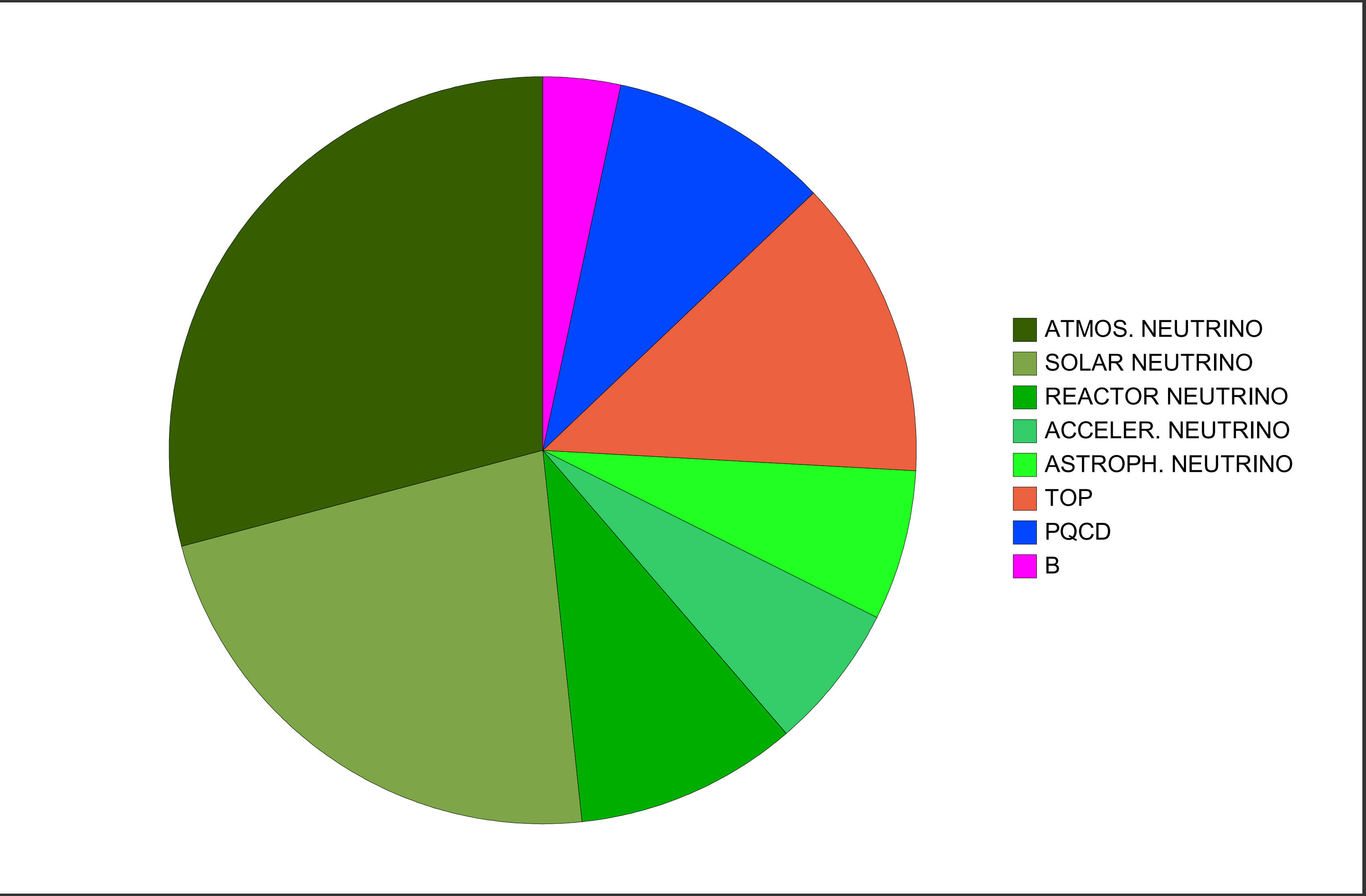
28. EVIDENCE FOR TOP QUARK PRODUCTION IN $\bar{p}$ p COLLISIONS AT $S^{1/2}$ = 1.8 TeV 524
CDF Collaboration (F. Abe *et al.*) Phys.Rev.Lett.73:225 (1994) hep-ex/9405005

29. EXPERIMENTAL STUDY OF THE ATMOSPHERIC NEUTRINO FLUX 519
Kamiokande-II Collaboration (K.S. Hirata *et al.*) Phys.Lett.B205:416 (1988)

30. TAU NEUTRINOS FAVORED OVER STERILE IN ATMOSPHERIC MUON-NEUTRINO OSCILLATIONS 503
Super-Kamiokande Collaboration (S. Fukuda *et al.*) Phys..Rev.Lett.85:3999 (2000) hep-ex/0009001

31. MEASUREMENT OF THE FLUX AND ZENITH ANGLE DISTRIBUTION OF UPWARD THROUGH MUONS BY SUPER-KAMIOKANDE 500
Super-Kamiokande Collaboration (Y. Fukuda *et al.*) Phys..Rev.Lett.82:2644 (1999) hep-ex/9812014

500+ Cited papers 1986-Now



Present evidences of neutrino mass and mixing

$\nu_e \rightarrow \nu_\mu, \nu_\tau$ with $\Delta m^2 \approx 10^{-4}$ eV^2, almost (not fully) maximal mixing.

1. ν_μ and/or ν_τ NC appearance from the Sun in SNO.
2. "Lab Test": reactor ν_e disappearance at L≈200Km in Kamland (4.6σ)

$\nu_\mu \rightarrow \nu_\tau$ with $\Delta m^2 = (1.8 \div 3.6) \cdot 10^{-3}$ eV^2, $\sin^2 2\theta > 0.92$ at 90%CL

1. Super-K upward-going atmospheric ν_μ disappearance.
2. Most likely $\nu_\mu \rightarrow \nu_\tau$ from π^o and matter effects in Super-K (2÷3σ)
3. "Lab Test": ν_μ disappearance in accelerator from K2K (4σ)

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ with $\Delta m^2 \sim 0.1$ eV^2

1. LSND claimed evidence of neutrino oscillation.
2. Unseen by KARMEN with marginal sensitivity
3. Controversy to be solved by Mini-BooNE (results in 2005 ?)

Neutrino Mixing Handbook

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} & U_{\alpha i} & \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

pure flavour eigenstate → each mass eigenstate takes a different phase → back to flavour eigenstates

$$U = U_A \cdot U_{13} \cdot U_S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & C_{23} & S_{23} \\ 0 & -S_{23} & C_{23} \end{pmatrix} \begin{pmatrix} C_{13} & 0 & S_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -S_{13}e^{-i\delta} & 0 & C_{13} \end{pmatrix} \begin{pmatrix} C_{12} & S_{12} & 0 \\ -S_{12} & C_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmospheric ?? solar

3 neutrinos → 2 mass differences, 3 angles and 1 *CP* phase

Δm^2_{12} Δm^2_{23} θ_{12} θ_{23} θ_{13} δ

$$P(\overset{(-)}{\nu}_\alpha \rightarrow \overset{(-)}{\nu}_\beta) = \delta_{\alpha\beta} - 4 \sum_{k>j} \mathrm{Re}[W^{jk}_{\alpha\beta}] \sin^2 \Delta_{jk} \underbrace{(\pm) 2 \sum_{k>j} \mathrm{Im}[W^{jk}_{\alpha\beta}] \sin 2\Delta_{jk}}_{\text{CP odd}}$$

$\Delta_{jk} = 1.27 \Delta m^2_{jk}(\mathrm{eV}^2) L(\mathrm{Km})/E_\nu (\mathrm{GeV})$, $W^{jk}_{\alpha\beta} = U_{\alpha j} U^*_{\beta j} U^*_{\alpha k} U_{\beta k}$

Mixing Parameters Knowledge

$$U = \begin{pmatrix} -C_{13}C_{12} & C_{13}S_{12} & S_{13}e^{-i\delta} \\ S_{12}C_{23}+C_{12}S_{23}S_{13}e^{i\delta} & C_{12}C_{23}+S_{12}S_{23}S_{13}e^{i\delta} & S_{23}C_{13} \\ S_{12}S_{23}-C_{12}C_{23}S_{13}e^{i\delta} & C_{12}S_{23}+S_{12}C_{23}S_{13}e^{i\delta} & -C_{23}C_{13} \end{pmatrix}$$

$$|U| = \begin{pmatrix} 0.72\text{-}0.88 & 0.46\text{-}0.68 & <0.22 \\ 0.25\text{-}0.65 & 0.27\text{-}0.73 & 0.55\text{-}0.84 \\ 0.10\text{-}0.57 & 0.41\text{-}0.80 & 0.52\text{-}0.83 \end{pmatrix}$$

Bahcall et al.
hep-ex/0212147

$\Delta m^2_{23} = \Delta m^2_{atm} \sim 2.5 \cdot 10^{-3}$ eV^2

$\Delta m^2_{12} = \Delta m^2_{sun} \sim 7 \cdot 10^{-5}$ eV^2

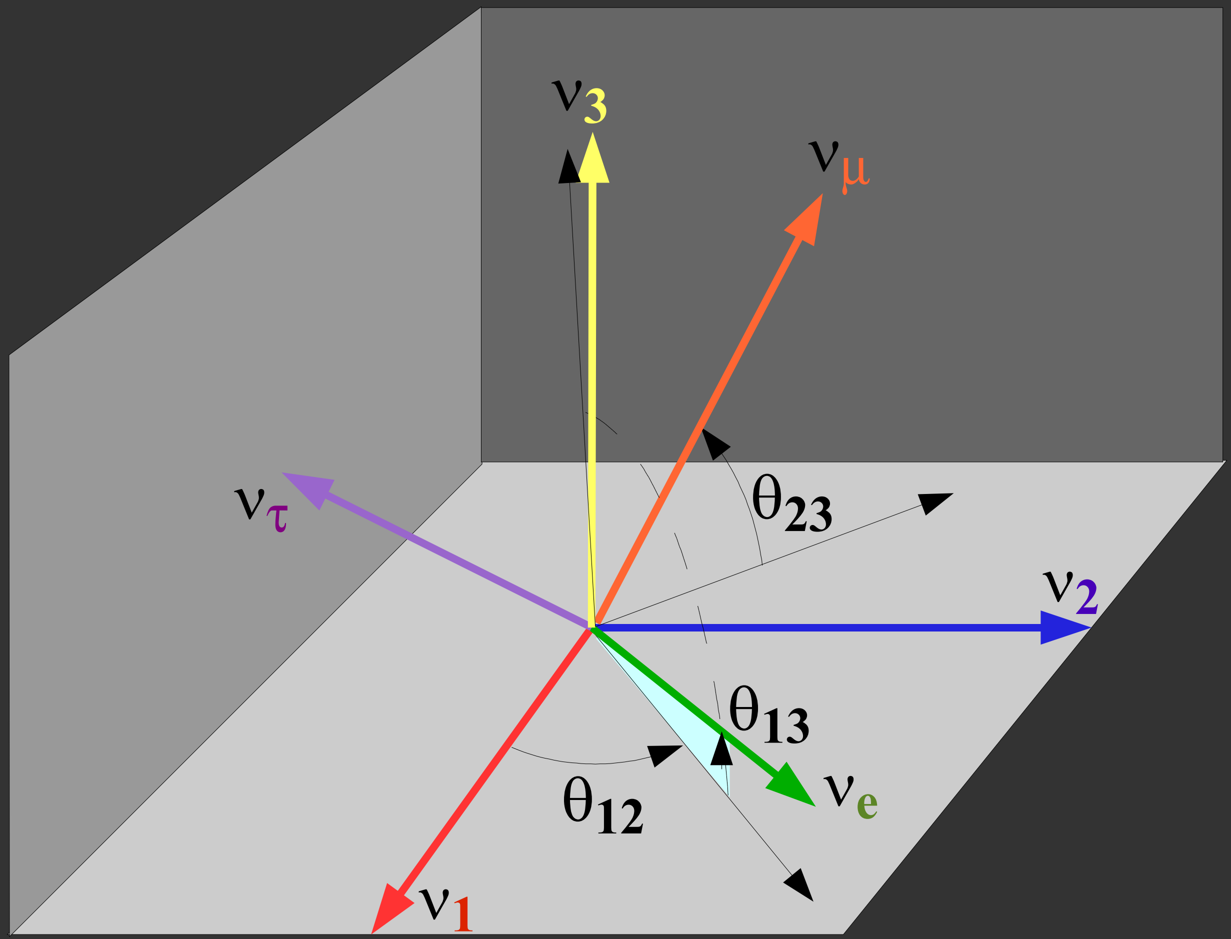
$\theta_{23} \sim 45^o$ "atmospheric"

$\theta_{12} \lesssim 45^o$ "solar"

$\theta_{13} < 13^o$

δ No idea.

The mixing angles



$$U = U_A \cdot U_{13} \cdot U_S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & C_{23} & S_{23} \\ 0 & -S_{23} & C_{23} \end{pmatrix} \begin{pmatrix} C_{13} & 0 & S_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -S_{13}e^{-i\delta} & 0 & C_{13} \end{pmatrix} \begin{pmatrix} C_{12} & S_{12} & 0 \\ -S_{12} & C_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Effective Mixing Angles

$$P(\overset{(-)}{\nu}_\alpha \to \overset{(-)}{\nu}_\beta) = \delta_{\alpha\beta} - 4 \sum_{k>j} \mathbf{Re}[W^{jk}_{\alpha\beta}] \sin^2 \Delta_{jk} (\pm) 2 \sum_{k>j} \mathbf{Im}[W^{jk}_{\alpha\beta}] \sin \mathbf{2}\Delta_{jk}$$

$$\Delta_{jk} = k\, \Delta m^2_{jk}(eV^2) L(Km)/E_\nu (GeV) \,, \quad W^{jk}_{\alpha\beta} = U_{\alpha j} U^*_{\beta j} U^*_{\alpha k} U_{\beta k}$$

Experiments at terrestrial baselines, with $\Delta_{12} << 1$, are described by 3 parameters only: θ_{23}, Δm_{23}, θ_{13}, and 2-flavors-like formulae:

$$P(\nu_e \to \nu_\mu) \cong \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2 \Delta_{23} = \sin^2 2\theta_{\mu e} \sin^2 \Delta_{23}$$

$$P(\nu_\mu \to \nu_\tau) \cong \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2 \Delta_{23} = \sin^2 2\theta_{\mu\tau} \sin^2 \Delta_{23}$$

$$P(\nu_e \to \nu_\tau) \cong \cos^2\theta_{23} \sin^2 2\theta_{13} \sin^2 \Delta_{23} = \sin^2 2\theta_{e\tau} \sin^2 \Delta_{23}$$

$$P(\nu_\mu \to \nu_\mu) \cong \quad = 1 - (\sin^2 2\theta_{\mu\tau} + \sin^2 2\theta_{\mu e}) \sin^2 \Delta_{23}$$

$$P(\nu_e \to \nu_e) \cong 1 - \sin^2 2\theta_{13} \sin^2 \Delta_{23}$$

Effective mixing angles:

$$\sin^2 2\theta_{\mu e} = \sin^2\theta_{23} \sin^2 2\theta_{13} \cong 0.5 \sin^2 2\theta_{13}$$

$$\sin^2 2\theta_{\mu\tau} = \cos^4\theta_{13} \sin^2 2\theta_{23} \cong \sin^2 2\theta_{23}$$

$$\sin^2 2\theta_{\mu e} = \cos^2\theta_{23} \sin^2 2\theta_{13} \cong 0.5 \sin^2 2\theta_{13}$$

LCP Asymmetry

Being θ_{13} small, and Δm^2_{12} is only ~30 times smaller than Δm^2_{23} (LMA):

$$P(\overset{(-)}{\nu}_e \rightarrow \overset{(-)}{\nu}_\mu) \simeq \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\Delta_{13} + \quad \text{“atmospheric”}$$

$$+ \cos^2\theta_{23}\sin^2 2\theta_{12}\sin^2\Delta_{12} + \quad \text{“solar”}$$

$$+ \; J\,\Delta_{12}\sin\Delta_{13}\cos(^{(\pm)}\delta - \Delta_{13}) \quad \text{“interference”} \propto \text{J determinant}$$

$$J = \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13}$$

large   large   large   ??

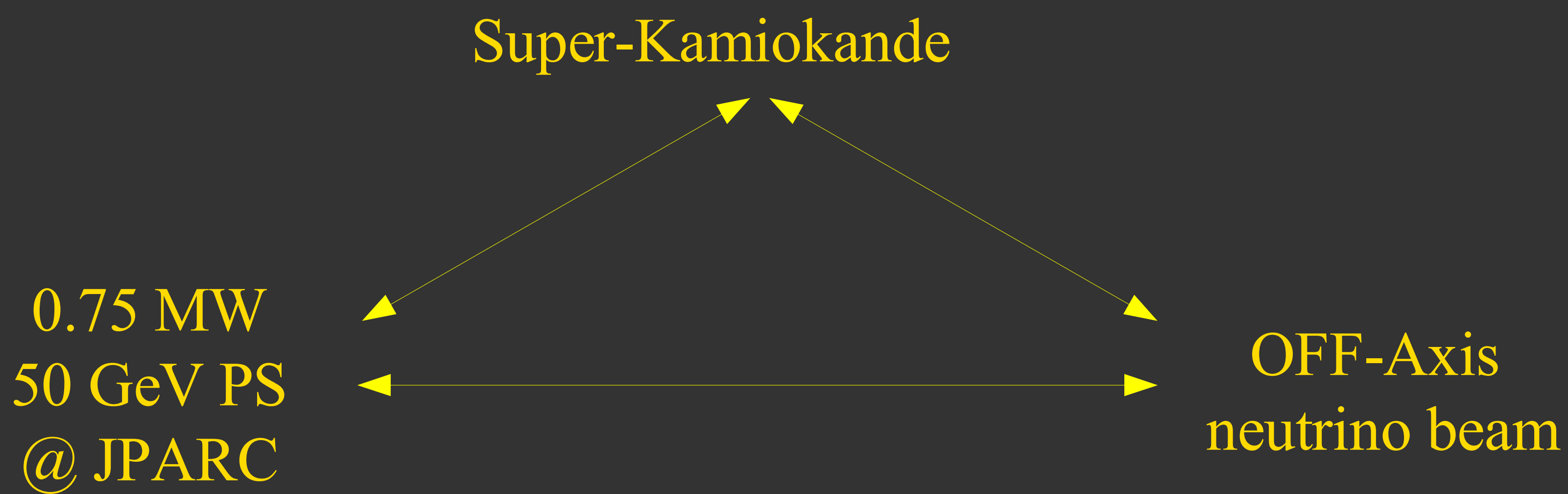
$\nu_e \leftrightarrow \nu_\mu$ gives the best opportunity for LCPV due to the suppression of the leading CP conserving contributions

LCP violating term vanishes for small θ_{13}

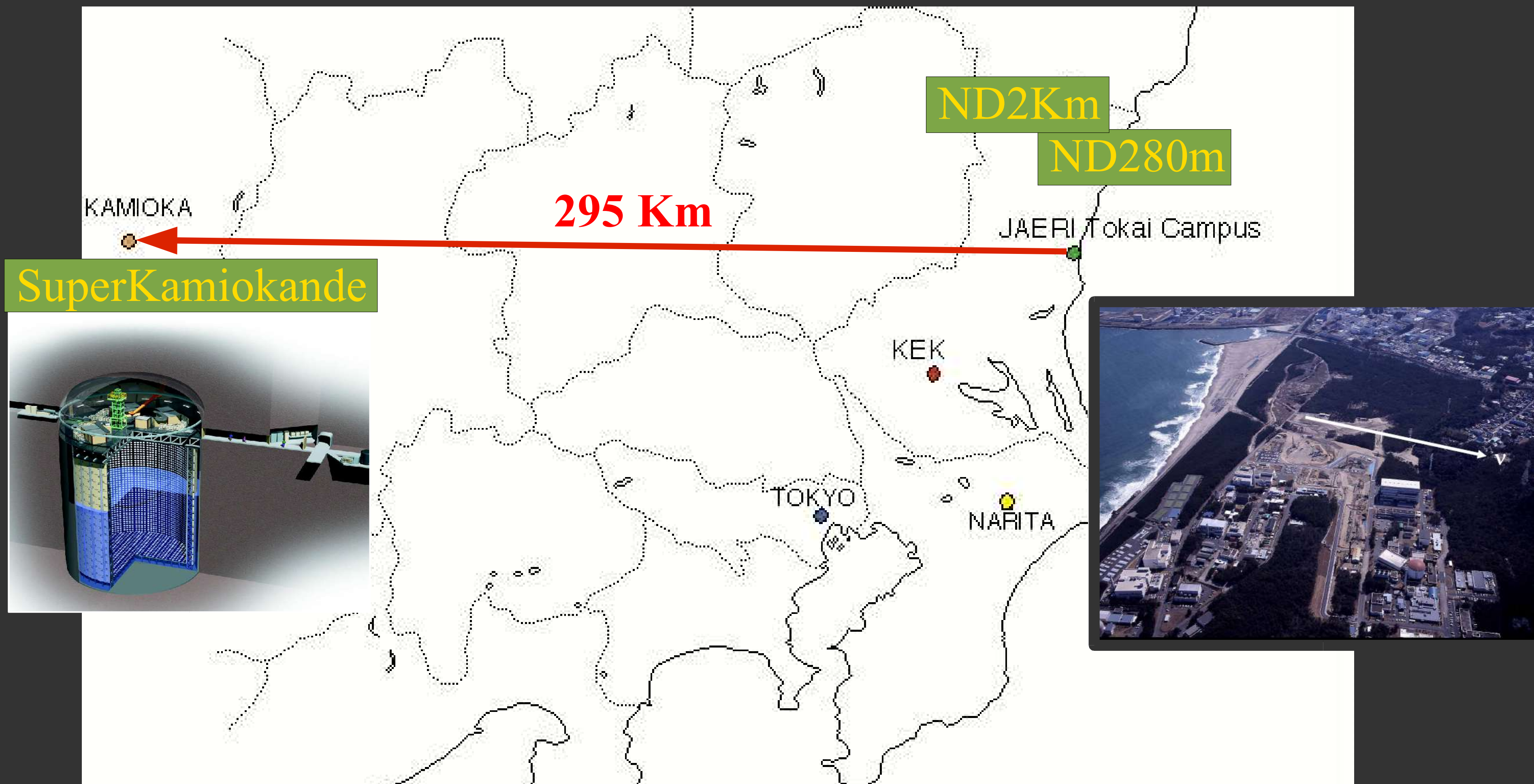
Discovery of non-zero θ_{13} is a pre-requisite of any sensible experimental strategy to attack the difficult problem of LCPV

T2K Experimental Strategy

- High intensity ν beam $\rightarrow$ high statistic
- Sub-GeV beam, well suited for water Cherenkov. Cross-section largely QE: ν_μ n $\rightarrow$ μ^- p. Eν reconstruction.
- E/L tuned to (first) oscillation maximum.
- Narrow band beam to reduce NC background.

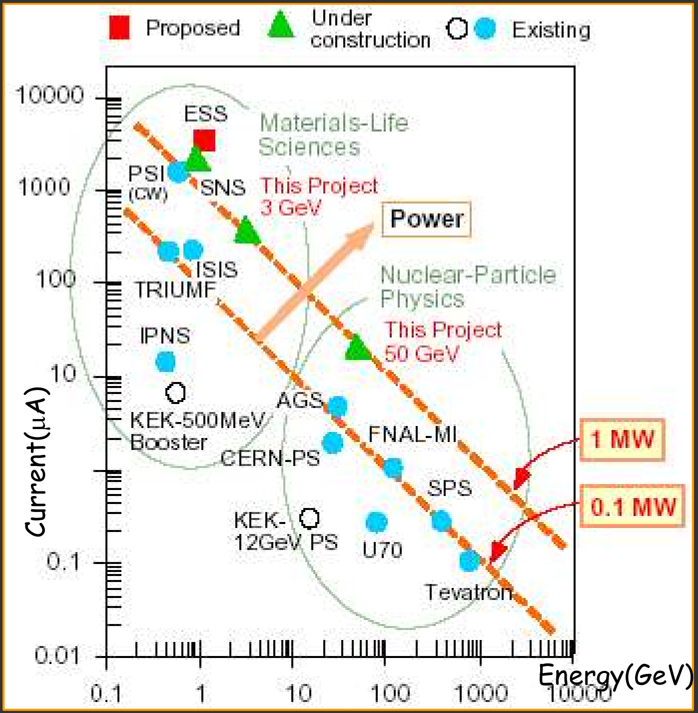


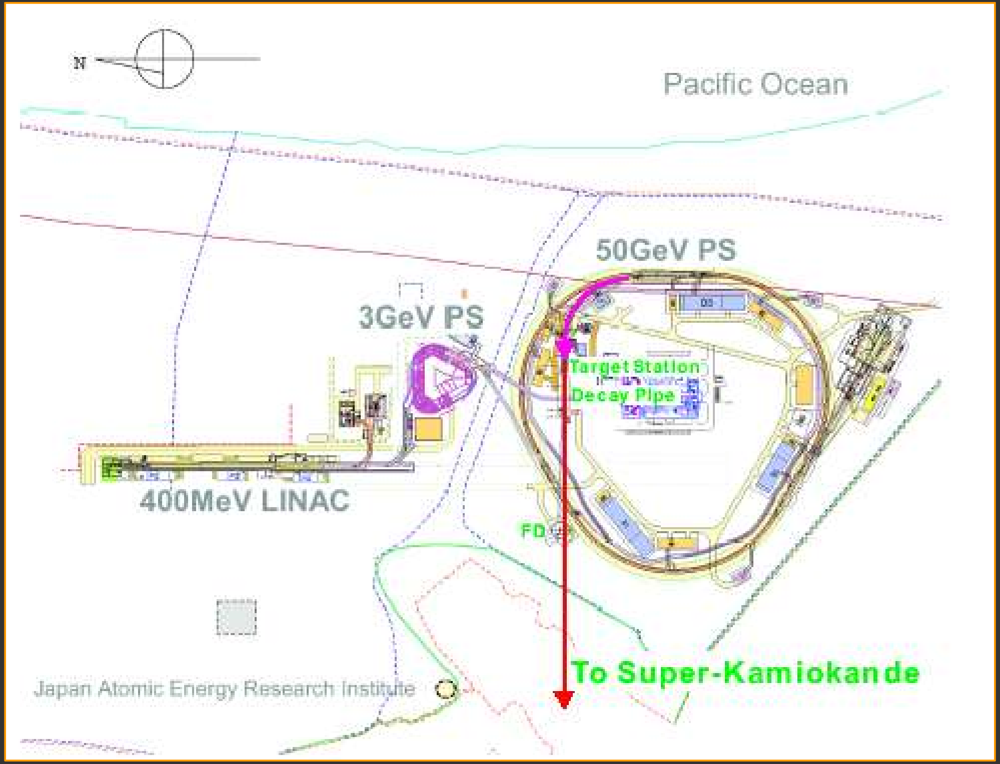
T2K Baseline and Layout



JPARC facility

KEK-JAERI joint project
JAERI@Tokai-mura, 295 Km from
Super-K (60Km NE of KEK)
Construction 2001-2007
Cost: 1335(1890) Oku¥ (1 Oku¥ ~1M$)





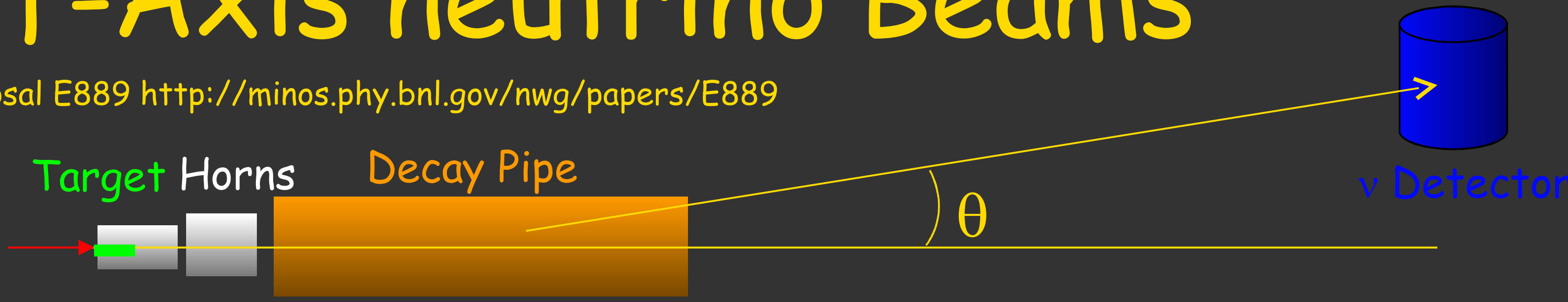
	JPARC	K2K	NuMI	CNGS
E(GeV)	50	12	120	400
Intensity (10^{12}ppp)	330	6	40	48
Rate (Hz)	0.29	0.45	0.53	~0.10
Power (MW)	0.75	0.0052	0.41	0.3

Linac Area

50 GeV PS (11.1.2004)

Off-Axis neutrino Beams

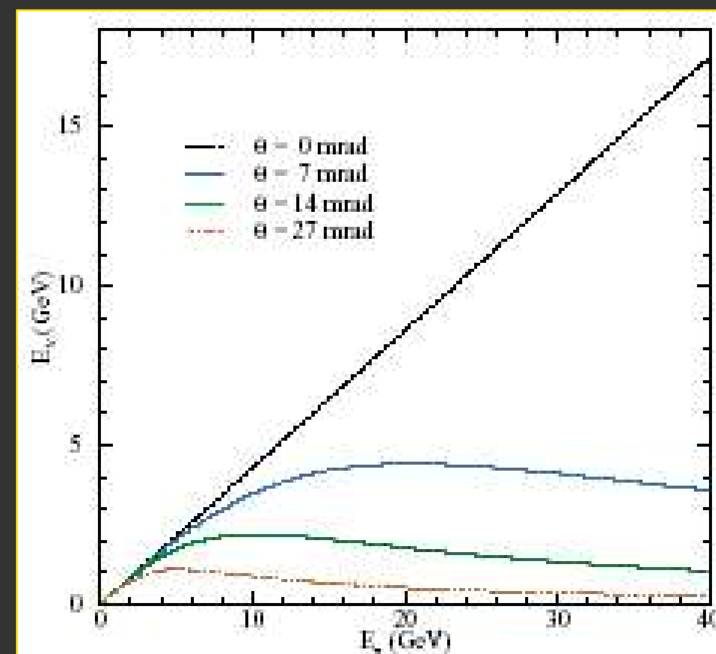
BNL proposal E889 http://minos.phy.bnl.gov/nwg/papers/E889



$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2\,(E_\pi - p_\pi \cos\theta)} \qquad \Phi_\nu = \frac{1}{4\pi L^2}\,\frac{m_\pi^2}{(E_\pi - p_\pi\cos\theta)^2}$$

$E_\pi \gg m_\pi$, and $\theta \ll 1$

$$\frac{m_\pi^2 - m_\mu^2}{m_\pi^2\,(1 + \gamma_\pi^2\theta^2)}\,E_\pi \qquad \frac{1}{\pi L^2}\left(\frac{E_\pi}{m_\pi}\right)^2 \frac{1}{(1 + \gamma_\pi^2\theta^2)^2}$$



Much higher flux than old-style NBB.
Strong cut-off of HE tail.

Reduced ν_e contamination.

Tune energy to maximise sensitivity

$$\Delta = 1.27 \cdot \Delta m^2(eV^2) \cdot L(Km) \,/\, E(GeV)$$

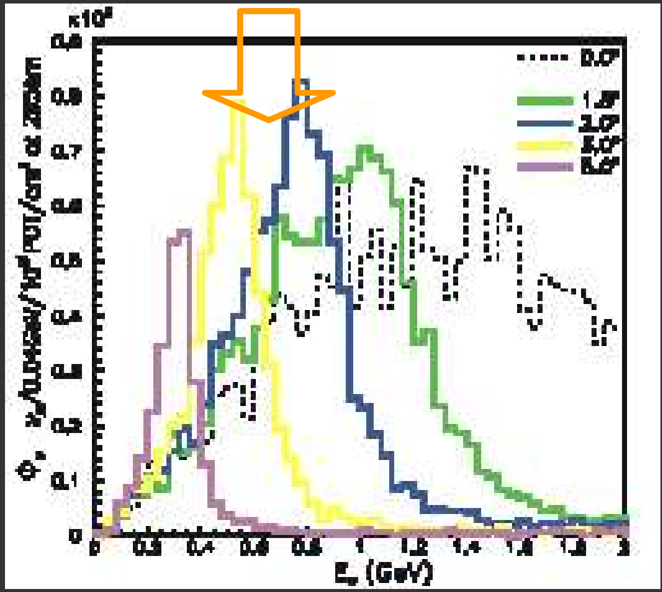
Beam energy almost fixed by geometry

T2K Beam

- $3.3 \cdot 10^{14}$ ppp at 0.285 Hz (0.75 MW, 2.64 MJ/pulse)
- 10^{21} pot/yr in 130 days/yr
- SC proton transport line
- Graphite target
- Secondary pions focused by horns
- Decay pipe 130m length from target
- Near detector at 280m from target
- Intermediate detector at 2Km
- Super-K at 295 Km. (22.5 kt fiducial)

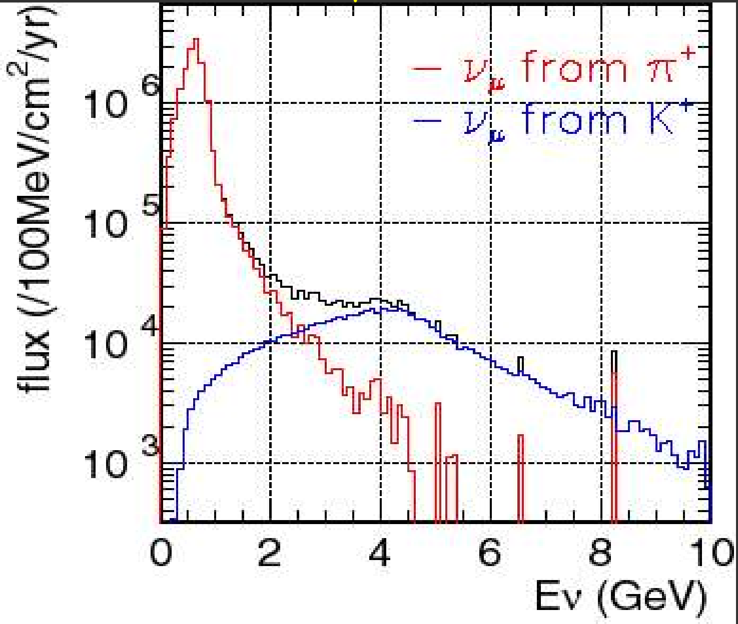
- Beam steering angle $2.5^{o} \pm 0.5^{o}$.
- Tune energy between 0.4 and 1 GeV
- Best tuning to $\Delta m^2 = (1.6 \div 4) \cdot 10^{-3}$ eV^2

Beam	E_{peak}	Flux (10^6/cm^2/yr)		ν_e/ν_μ (%)		All, CC events (events/22.5kt/yr)	
		ν_μ	ν_e	total	@peak	ν_μ	ν_e
OA2^o	0.7	19.2	0.19	1.00	0.21	3100 2200	60 45
OA3^o	0.55	10.6	0.13	1.21	0.20	1100 800	29 22

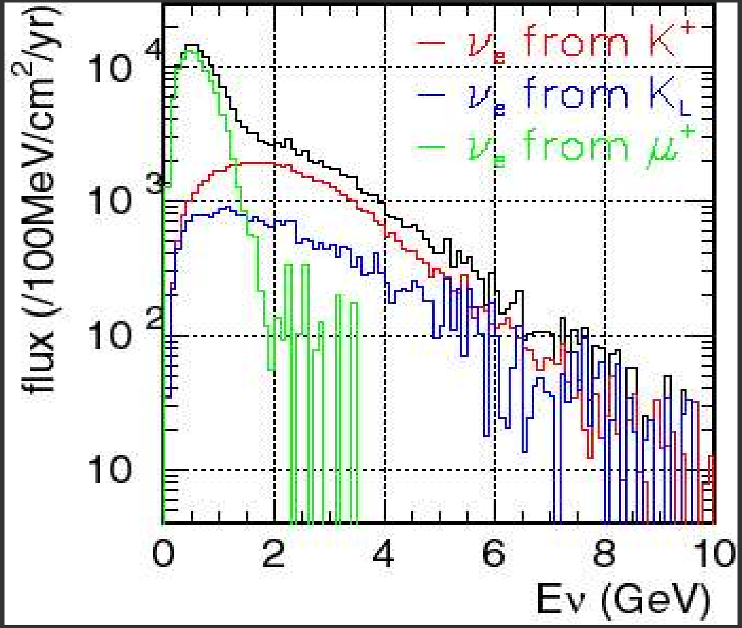


Neutrino Sources

ν_μ flux at SK



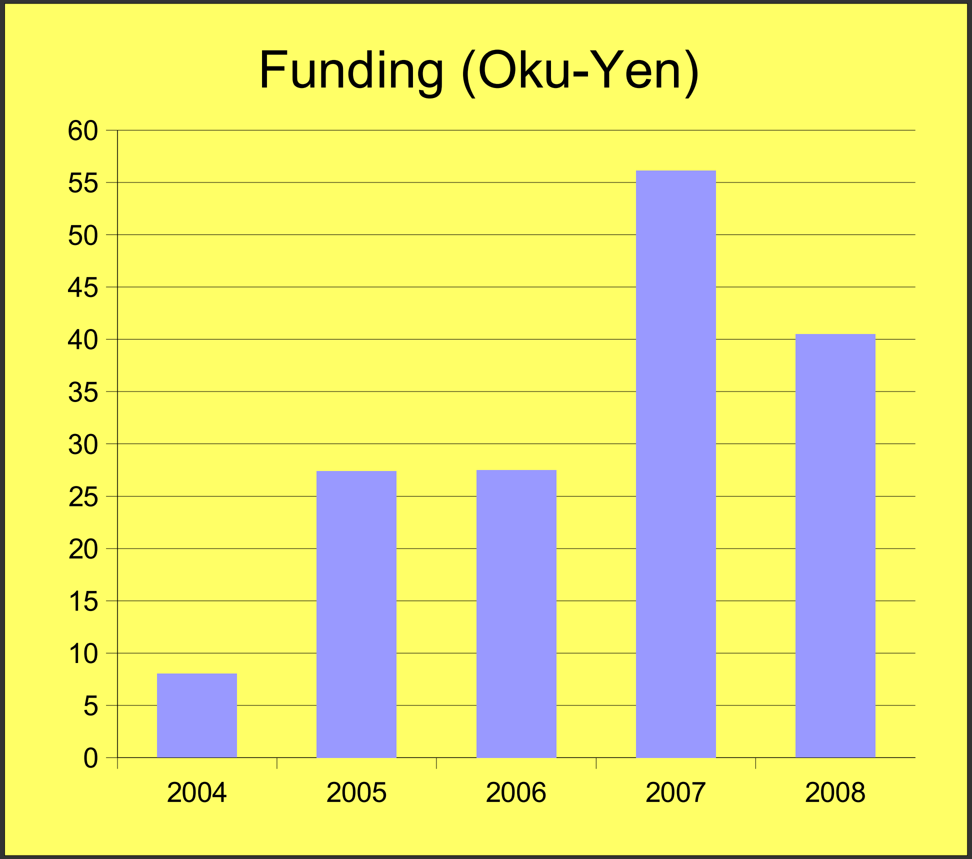
ν_e flux at SK



$K / \pi = 0.052$ @SK
$= 0.047$ @ND

$K^+ / K_L / \mu^+ = 32\% / 14\% / 54\%$ @SK
$= 29\% / 13\% / 59\%$ @ND

Neutrino Beam approved

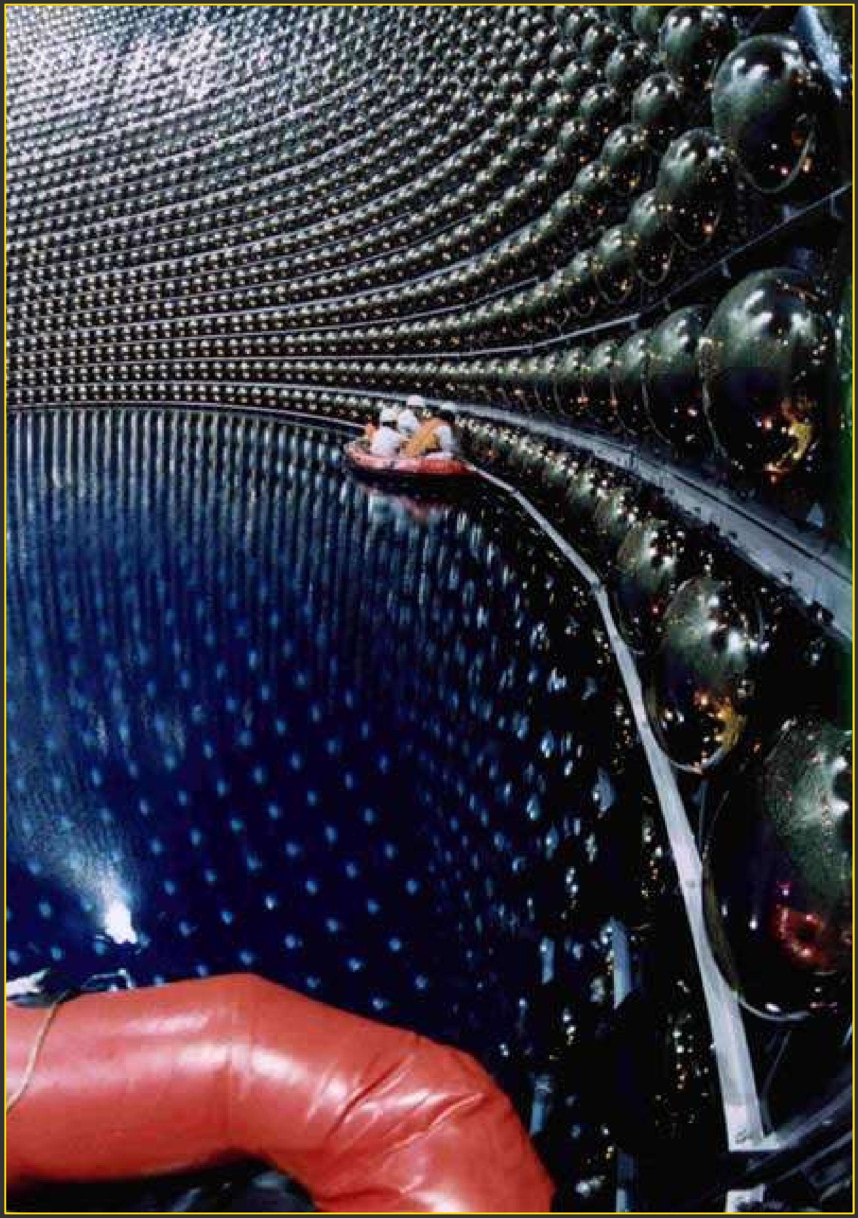


Last December the neutrino facility, originally staged to JPARC phase II, advanced to phase I.

159.6 Oku-yen (10^8 yen) in 5 fiscal years 2004-2008.

2Km hall and detectors not included yet. Funds will have to be secured later: no guarantee now.

Far detector



Super-Kamiokande.

50 kt total mass, 22.5 kt fiducial.

Original coverage 40%.

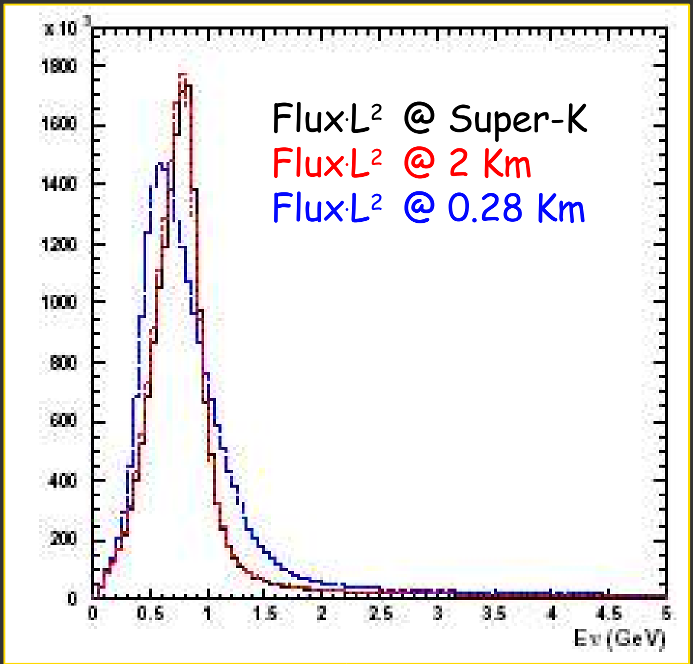
After 2001 accident half PMTs reinstalled (19% coverage) with individual acrilic vessels.

Full rebuild planned after K2K run in summer 2005.

It will be ready for T2K..

From 2008 on, T2K will be the major user of Super-Kamiokande.

T2K Near Detectors



Near detector at 280 m

- Covers both on-axis and off-axis.
- Monitor beam stability and flux.
- High rate: 60 events/kt/spill.
- Study ν_μ and ν_e interactions: CCQE, CC, NC.
- Non point-like ν source, different target, different detector technology: flux extrapolation to Super-K problem.

Intermediate detector at 2 Km
Ultimate systematic. Not in the baseline design

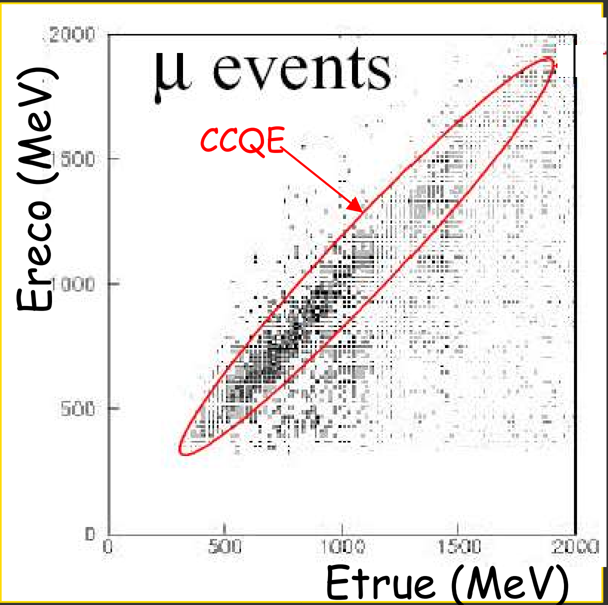
- Off-Axis as Super-K
- Water-Cherenkov (100t fiducial mass) to cancel detector systematic.
- Spectrum differences < 10% $\rightarrow$ better than 2% systematic on ν_e background subtraction.

T2K Physics Programme

1. Discovery of θ_{13} down to $\sin^2 2\theta_{13}$=0.006
2. Precise measurement of $\sin^2 2\theta_{23}$ (±0.01), Δm^2_{23} (±10^{-4} eV^2)
3. Discovery/constraint sterile components through NC

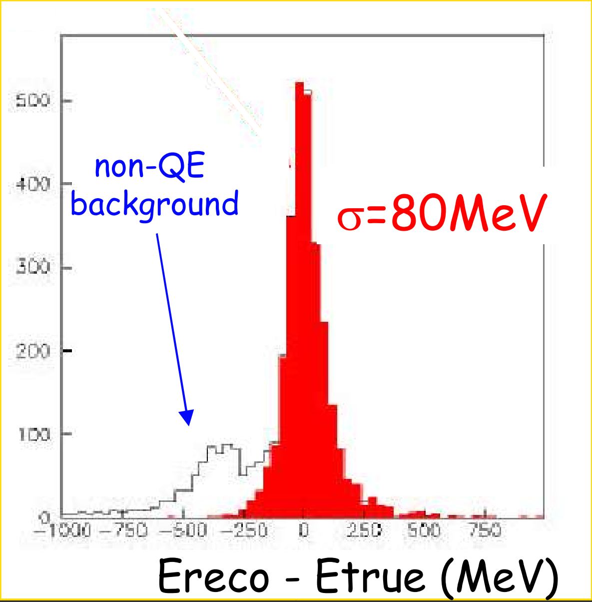
1. How small is the mixing between the 1st and 3rd generation ?
2. How close to maximal is the 2nd and 3rd generation mixing ?
3. Are sterile neutrino there ?
4. Is there anything new or unexpected ?

Neutrino Energy Measure



Almost exact (Fermi motion) for QE interactions: $\nu_l\ n \rightarrow l\ p$

$$E_\nu^{rec} = \frac{m_n E_l - m_l^2/2}{m_n - E_l + P_l \cos\theta_l}$$



non-QE CC interactions of higher energy neutrinos → background for ν_μ disappearance

Coherent π^o production from NC interactions of higher energy neutrinos is a background for ν_e appearance

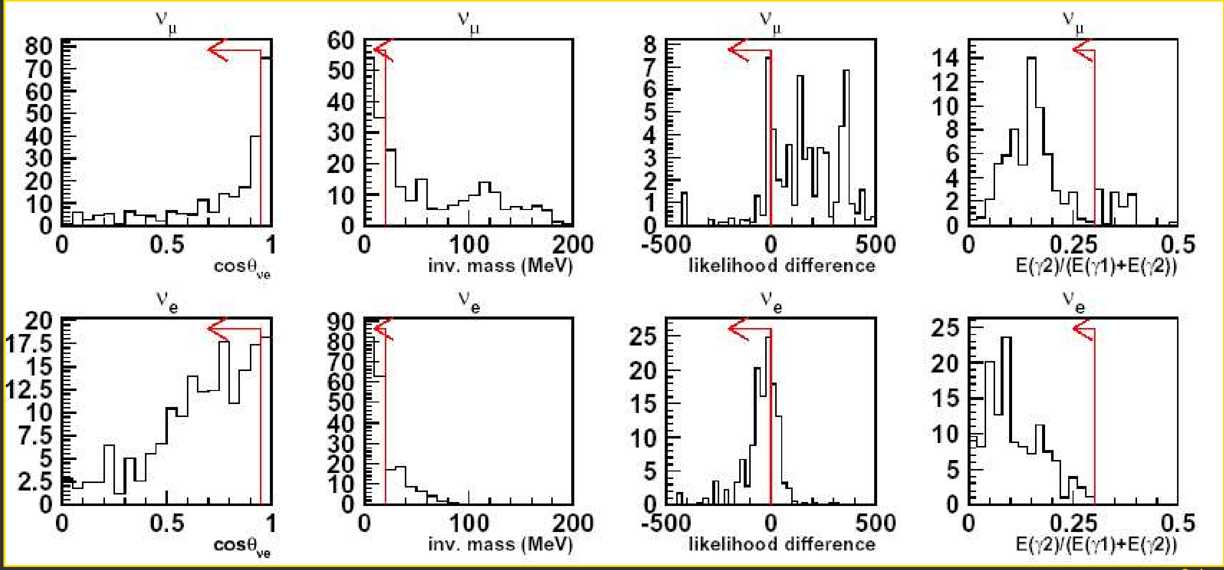
Θ_{13} (ν_e appearance)

$\Delta m^2 = 3 \cdot 10^{-3}$
$\sin^2\theta_{13} = 0.1$

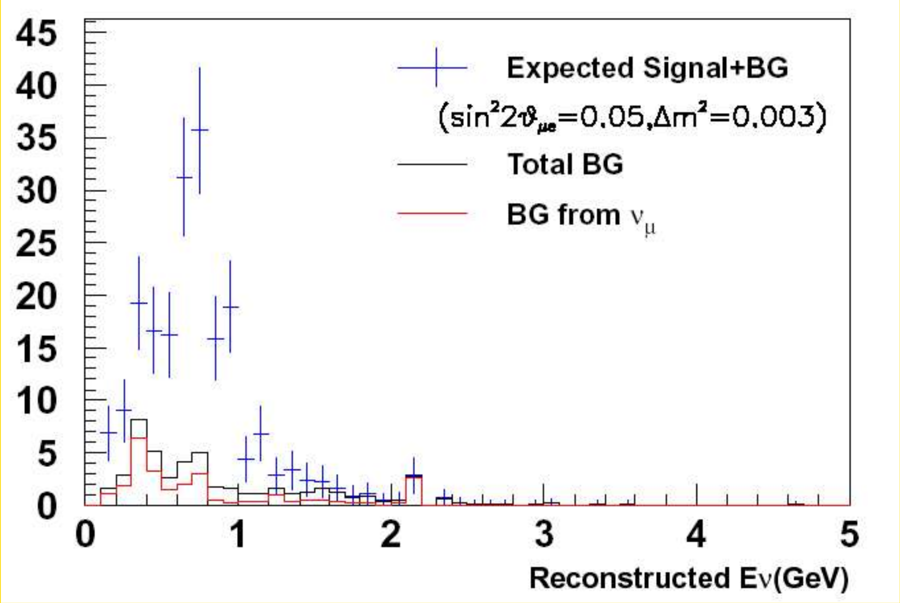
	ν_μ CC	ν_μ NC	Beam ν_e	Oscillated ν_e
Events in FV	10713.6	4080.3	292.1	301.6
1Ring e-like	14.3	247.1	68.4	203.7
e/π^o separation	3.5	23.0	21.9	152.2
0.4GeV<E<1.2GeV	1.8	9.3	11.1	123.2

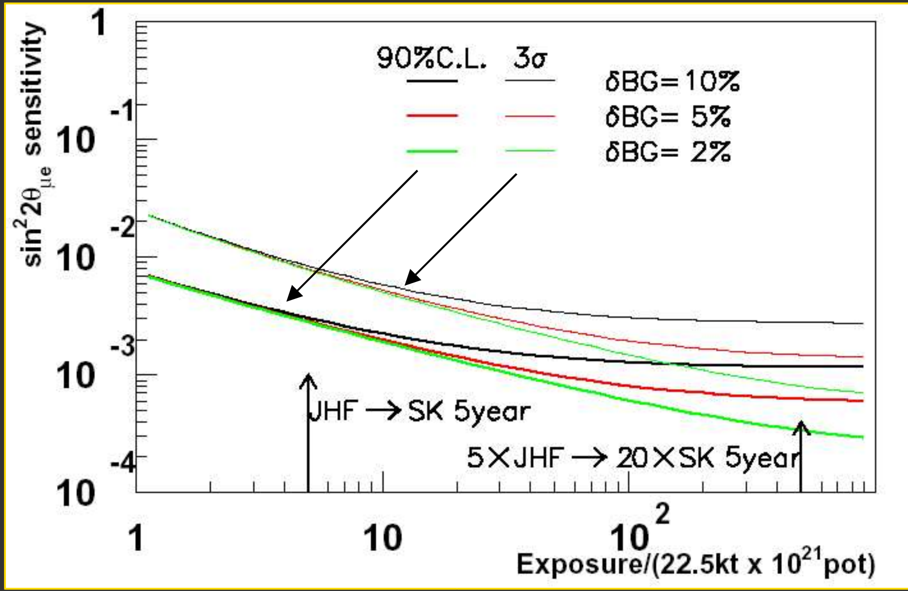
e/π^o separation

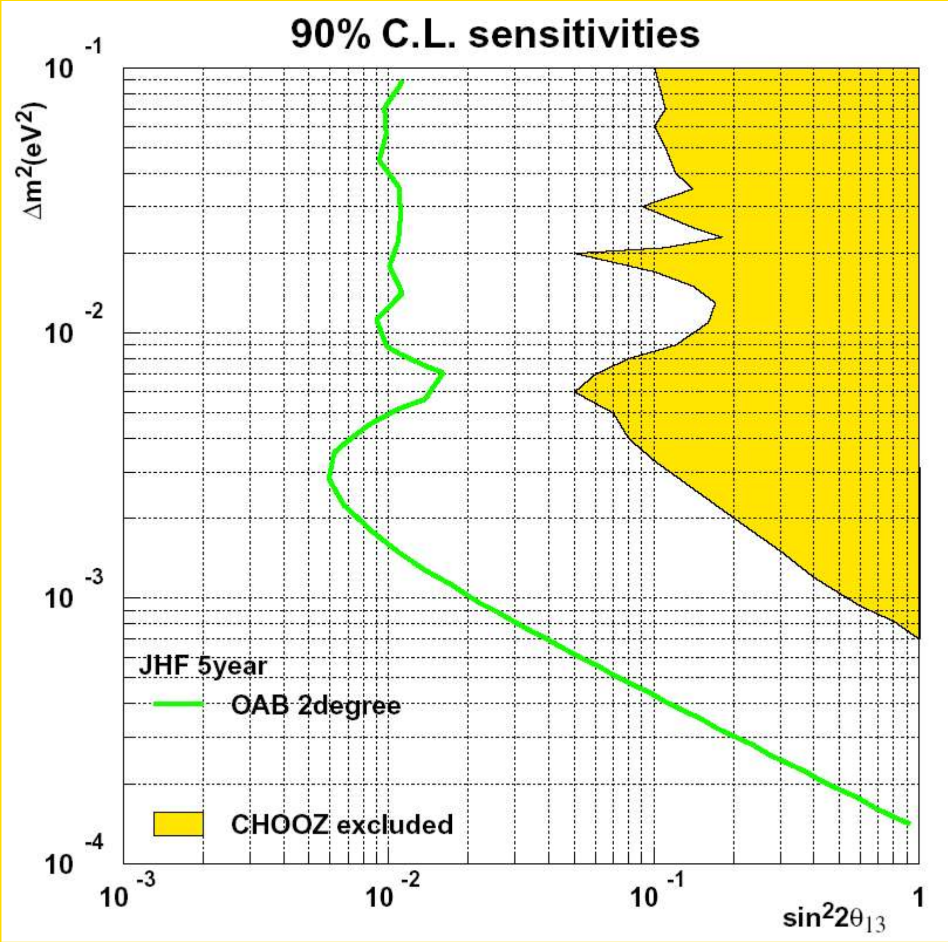
1. Forward cut
2. high inv.mass cut
3. 1-2 rings likelihood cut
4. Ring balance cut



Θ_{13} sensitivity

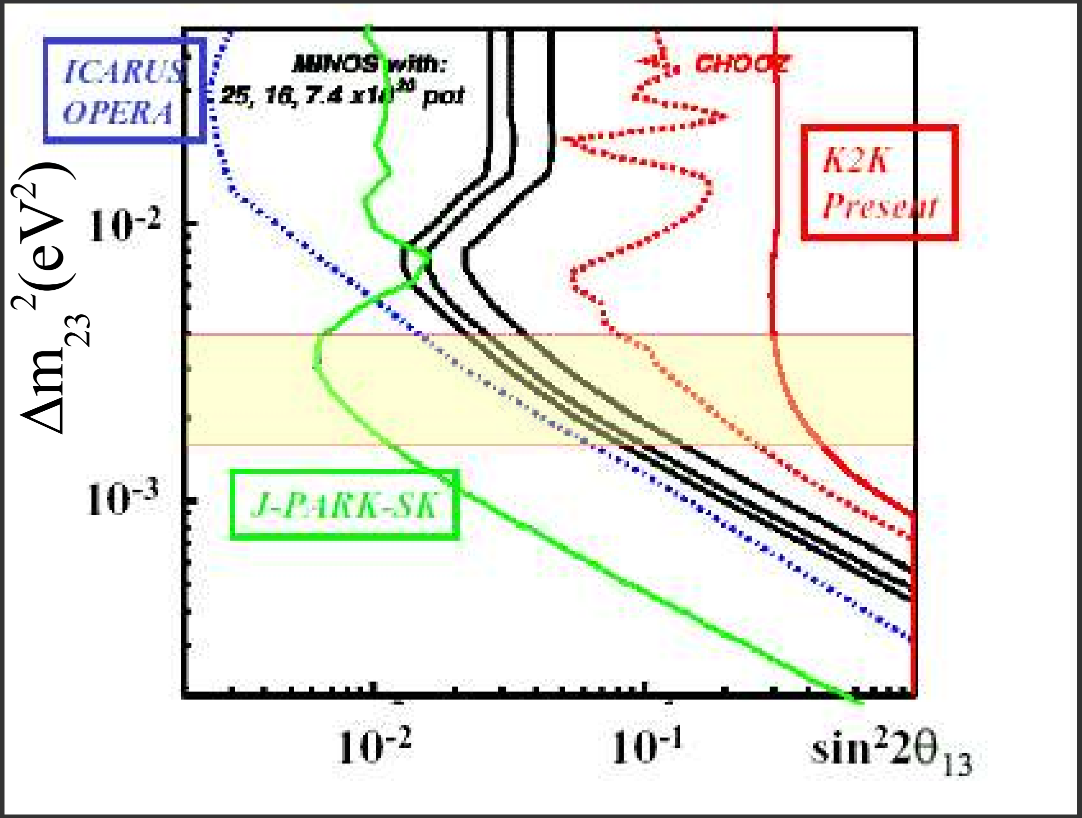






Expected θ_{13} Reach

90% CL Sensitivity



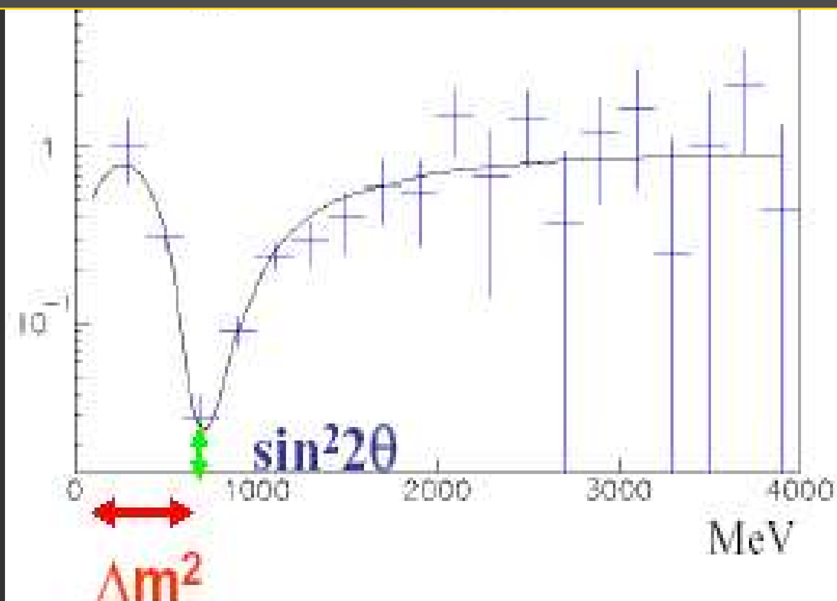
Δm_{23}, θ_{23} (ν_μ disappearance)

Survival probability

Meas./No-Oscill. (22.5kt x 5 year)

Fit with:

$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{23} \cos^4\theta_{13} \sin^2 \Delta_{23}$



O(1%) measurement

"atmospheric" parameters

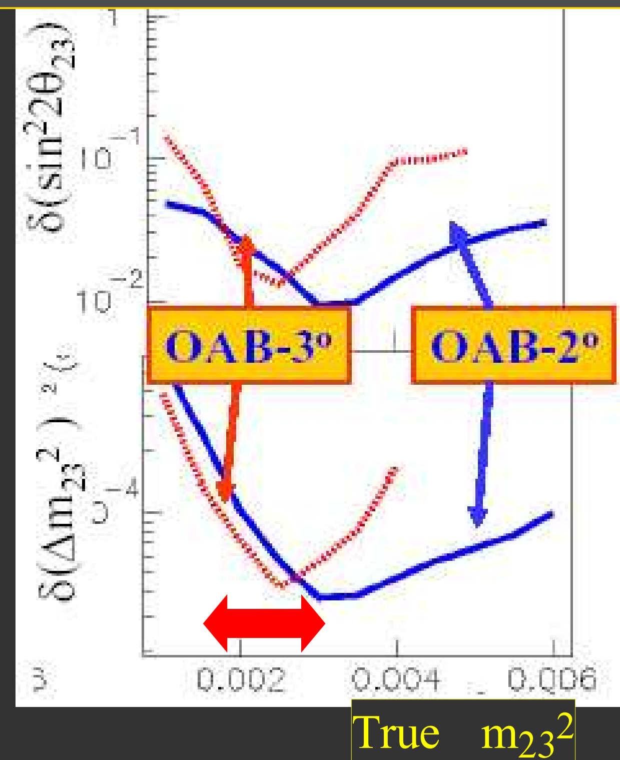
$\delta \sin^2 2\theta_{23} = 0.01$, $\delta\, \Delta m^2_{23} = 4 \cdot 10^{-5}\ eV^2$

Systematics

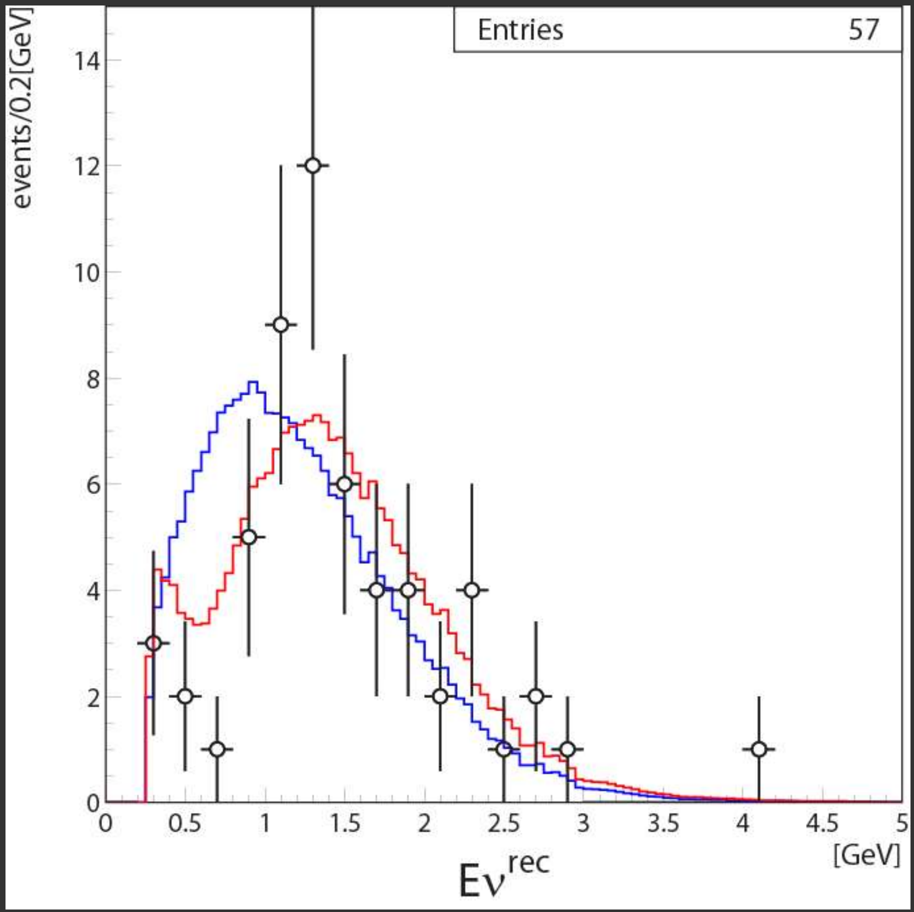
Energy scale

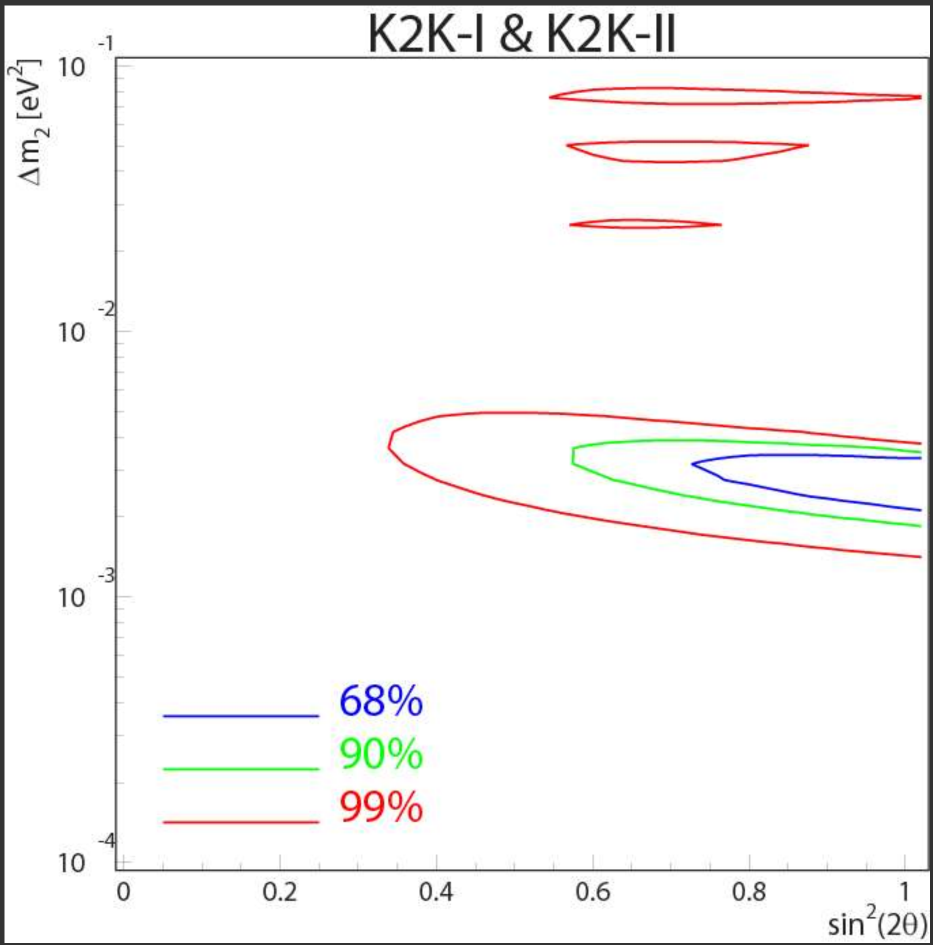
Subtraction of non-QE backg.

Near-Far extrapolation



$\nu_\mu \rightarrow \nu_\mu$ in K2K (T2K/100)





Δm^2 @ $\sin^2 2\theta = 1$:

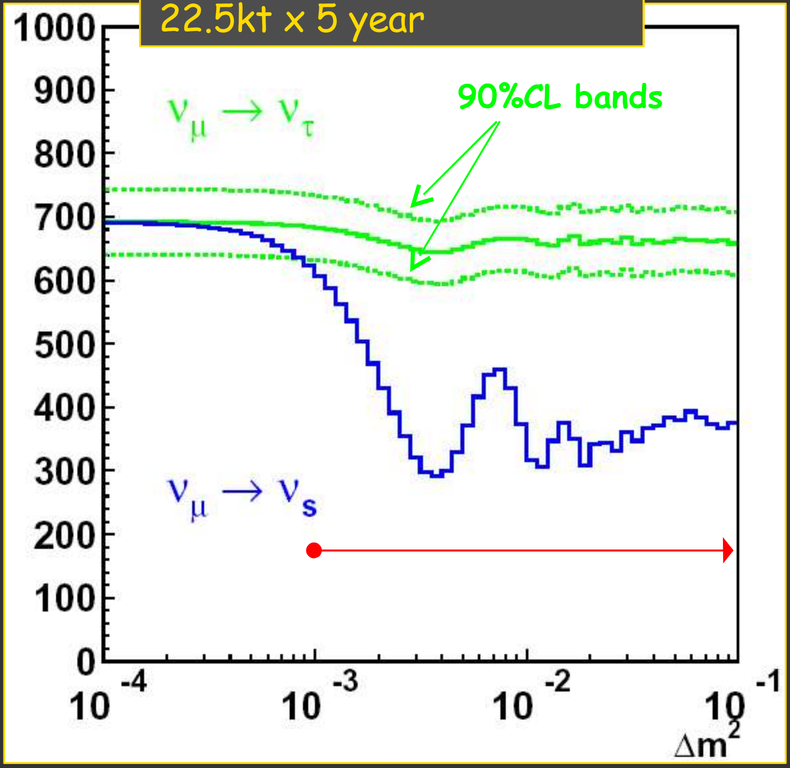
$2.14 < \Delta m^2 < 3.37$ [eV]$\times 10^3$ @68%

$1.87 < \Delta m^2 < 3.58$ [eV]$\times 10^3$ @90%

Search for sterile neutrinos

NC interactions sensitive to all active neutrinos. Together with $\nu_\mu \to \nu_\mu$ and $\nu_\mu \to \nu_e$, NC provide a measurement of $\nu_\mu \to \nu_\tau$ and $\nu_\mu \to \nu_s$.

Expected single π^o events
22.5kt x 5 year



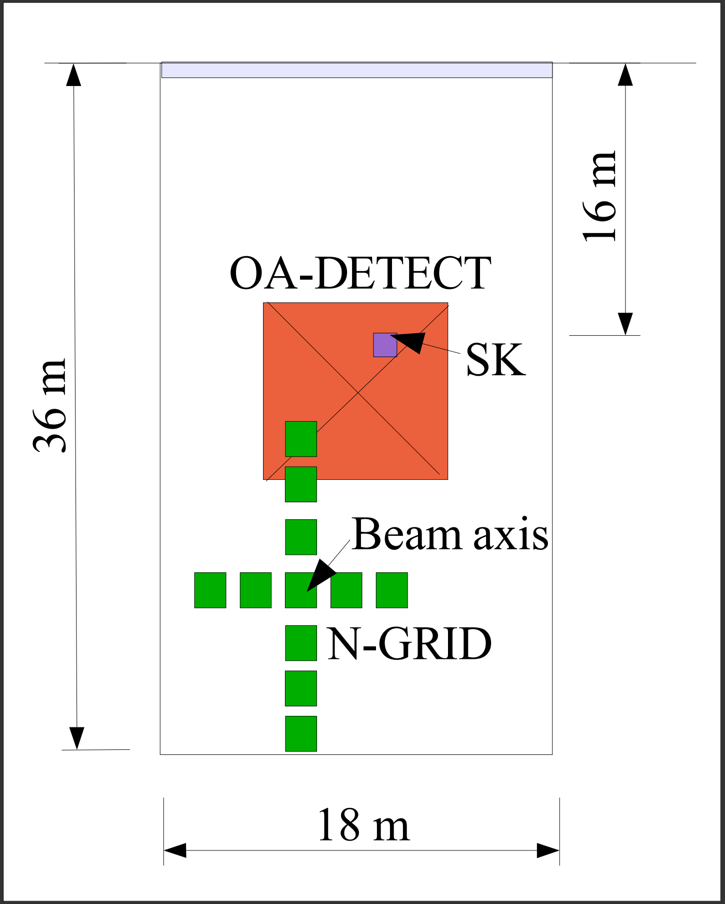
NC selection of single π^o, lepton-less events: ν N$\to\nu$ N π^o (Smirnov-Vissani tag)

π^o production cross-section accurately measured (better than 5%) in the near detectors.

No way to reconstruct the neutrino energy. Off-Axis, narrow band neutrino beam essential.

Goal of ND280m

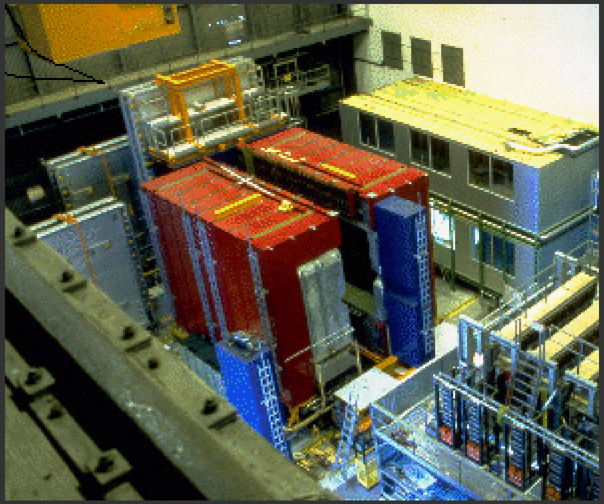
- Measure and $_e$ flux minimising syst. in the near/far extrapolation.
- Measure ^{0} cross section, bgr. to appearance of $_e$ and sterile (via NC tag).
- Measure nQE/QE ratio, major syst. uncertainty in E reconstruction.
- Monitor the neutrino beam stability.

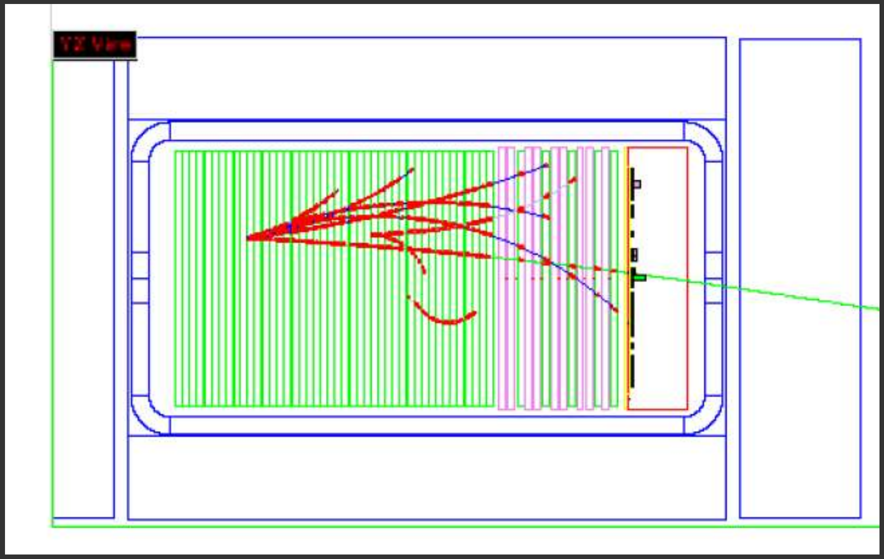


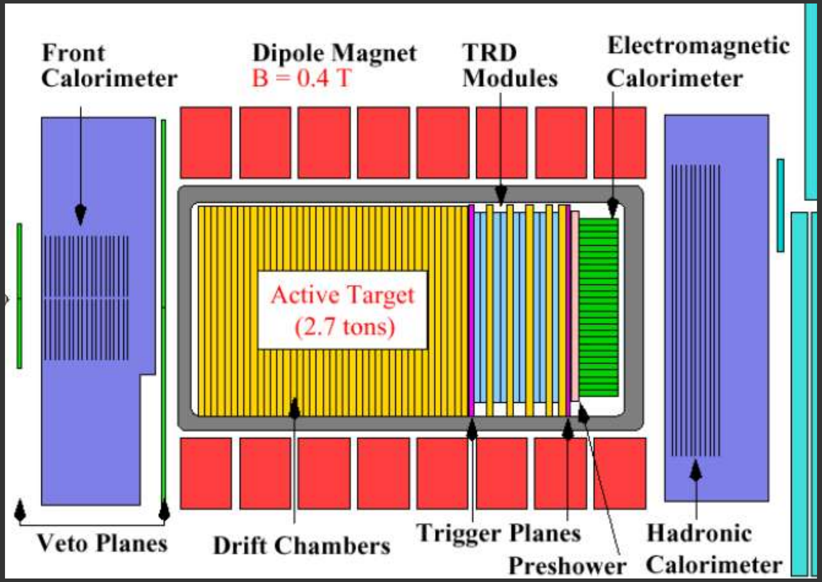
UA1/Nomad Magnet

7.64(L)× 6.116(H)× 5.596(W)
B=0.67T (UA1), 0.4T(NOMAD)
B=0.2T for T2K (Power<0.6MW)

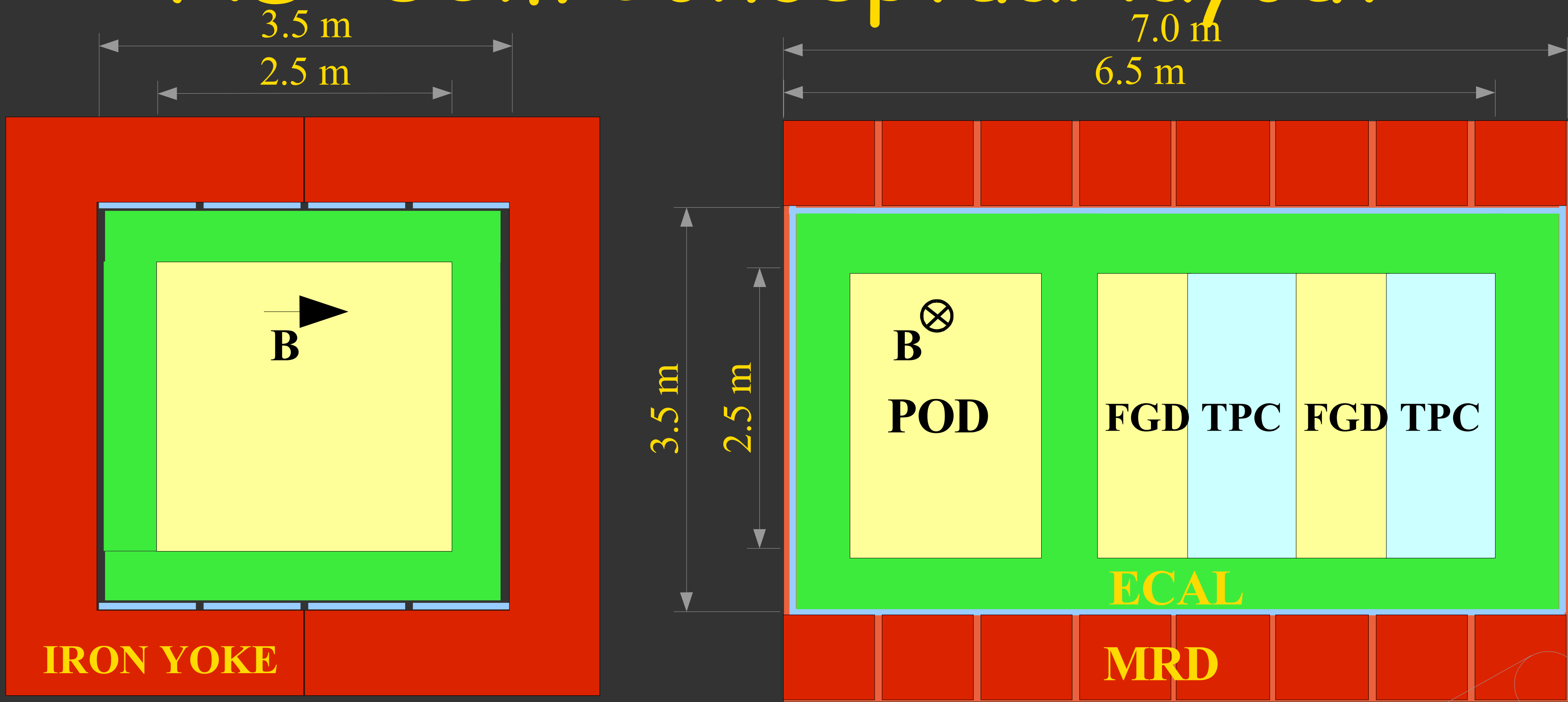
Magnet+Tracker was our main contribution to the conceptual design brainstorming.

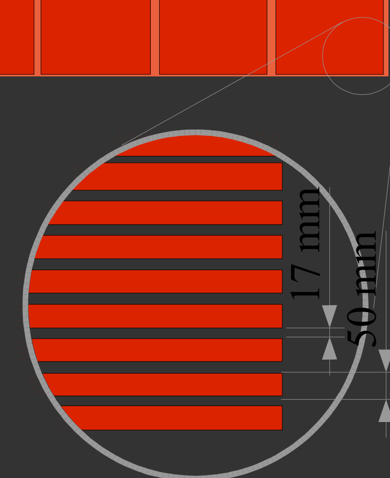






ND280m Conceptual layout





POD: ν target, specialised FGD for measurement

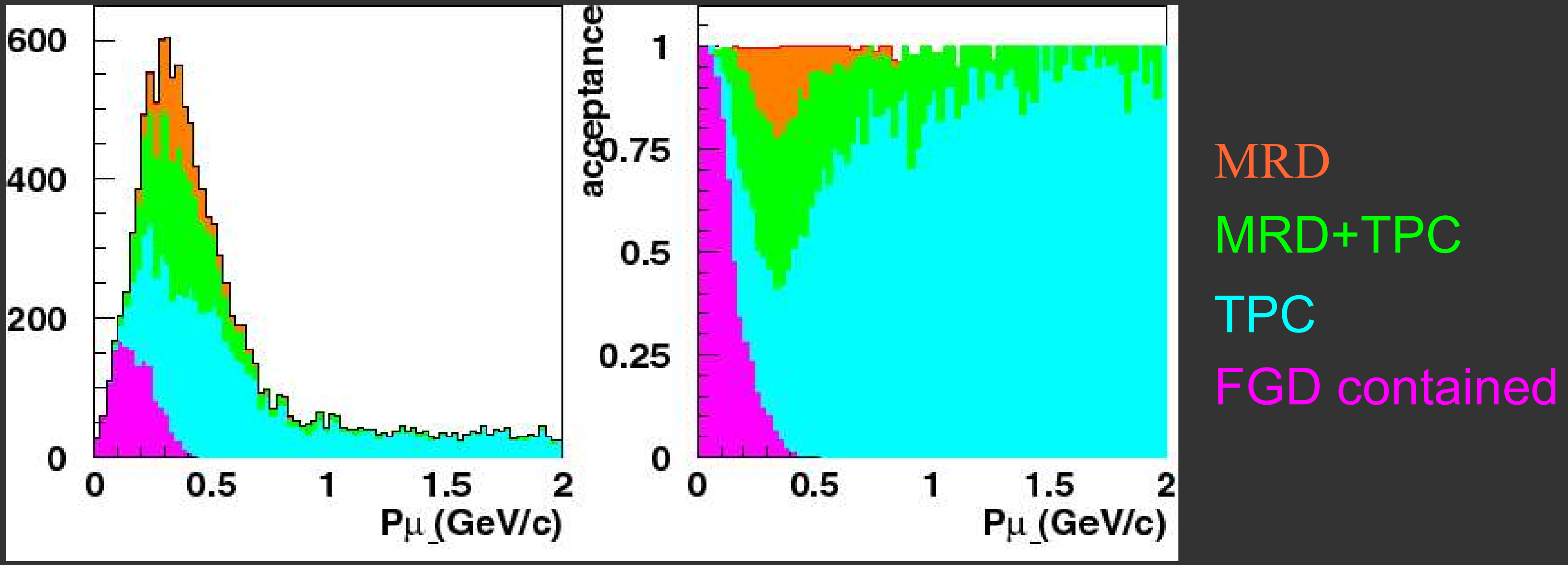
ECAL: containement, converter

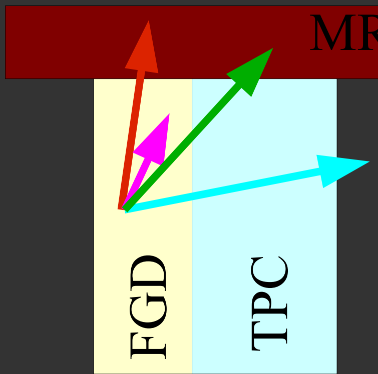
FGD: ν target, dE/dx, PID

TPC: momentum, charge, dE/dx, PID

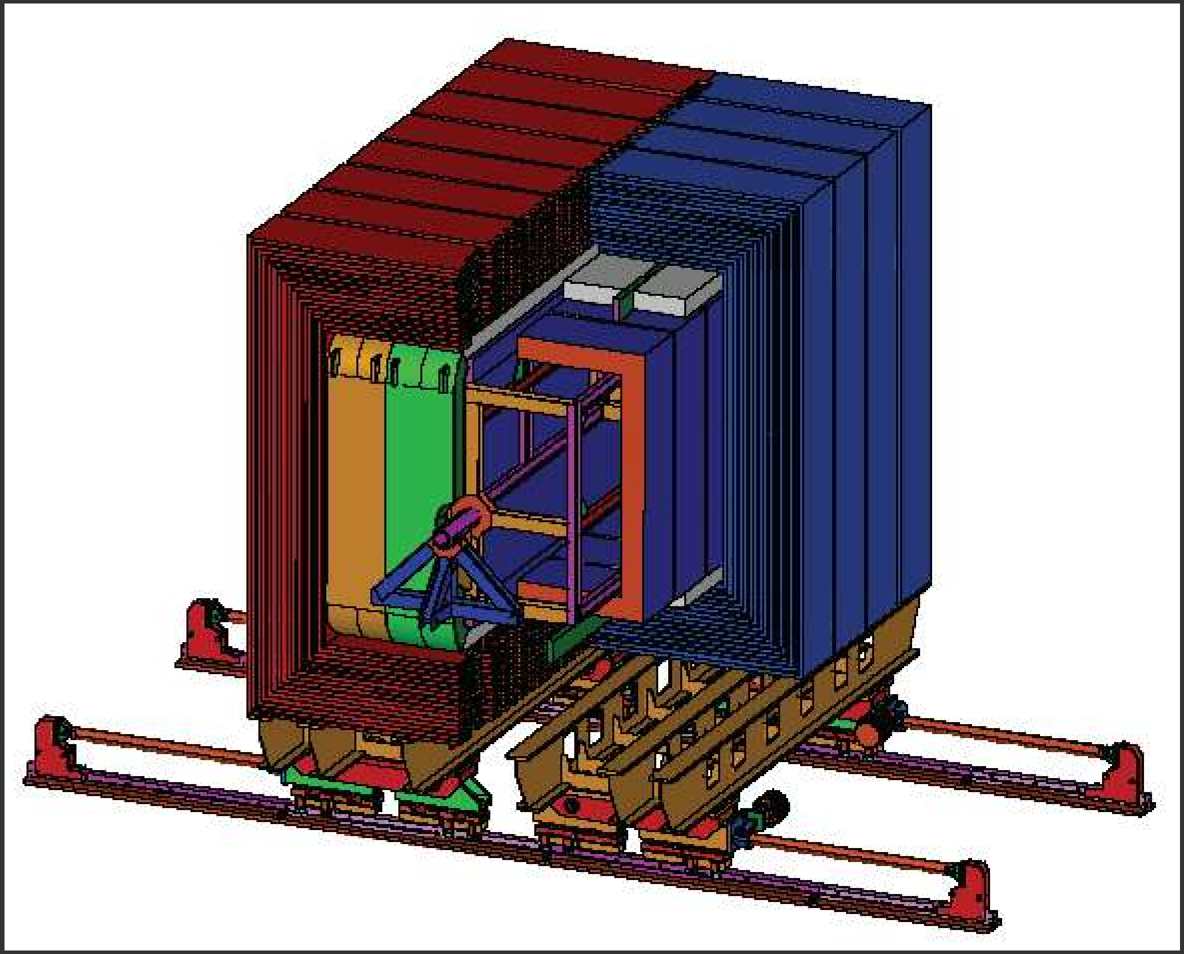
MRD: range, large angle, additional / ID

Muon Acceptance





Magnet and Detector Support



C.Gargiulo – Servizio Progettazione Meccanica INFN/Roma

Magnet Cost

300 k€ Shipping.

Based on company inquiries for half the magnet yoke, extrapolated to the full magnet yoke plus coils.

<200 k€ Power supply.

Conservative estimation based on inquiry to a single company (80 k€ for 3600A,110V, 0.4MW from OCEM). Depends on requirement to be specified (inductance, stability, ecc).

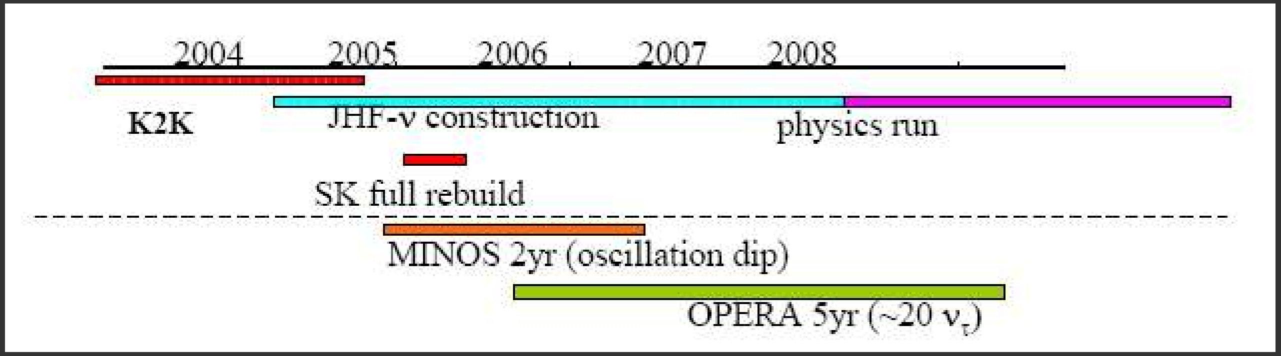
100-200 k€ Infrastructures.

Educated guess for motors, controllers, rails, inner detector basket.

600-700 k€ Total

1€ ~ 1.2$ ~ 130¥

Design of 280m detectors in progress.   Proposal in Spring 2005



T2K Upgrade (Phase II)

Phase I

High intensity ν beam (100xK2K) from JPARC (0.75 MW) to SK (50kt)

1. Precision measurement of $\sin^2 2\theta_{23}$ and Δm^2_{23} (factor 10 improvement)
2. Discovery of θ_{13} down to $\sin^2 2\theta_{13} > 0.006$ (factor 20 improvement)
3. Search for sterile components through NC interactions

Phase II

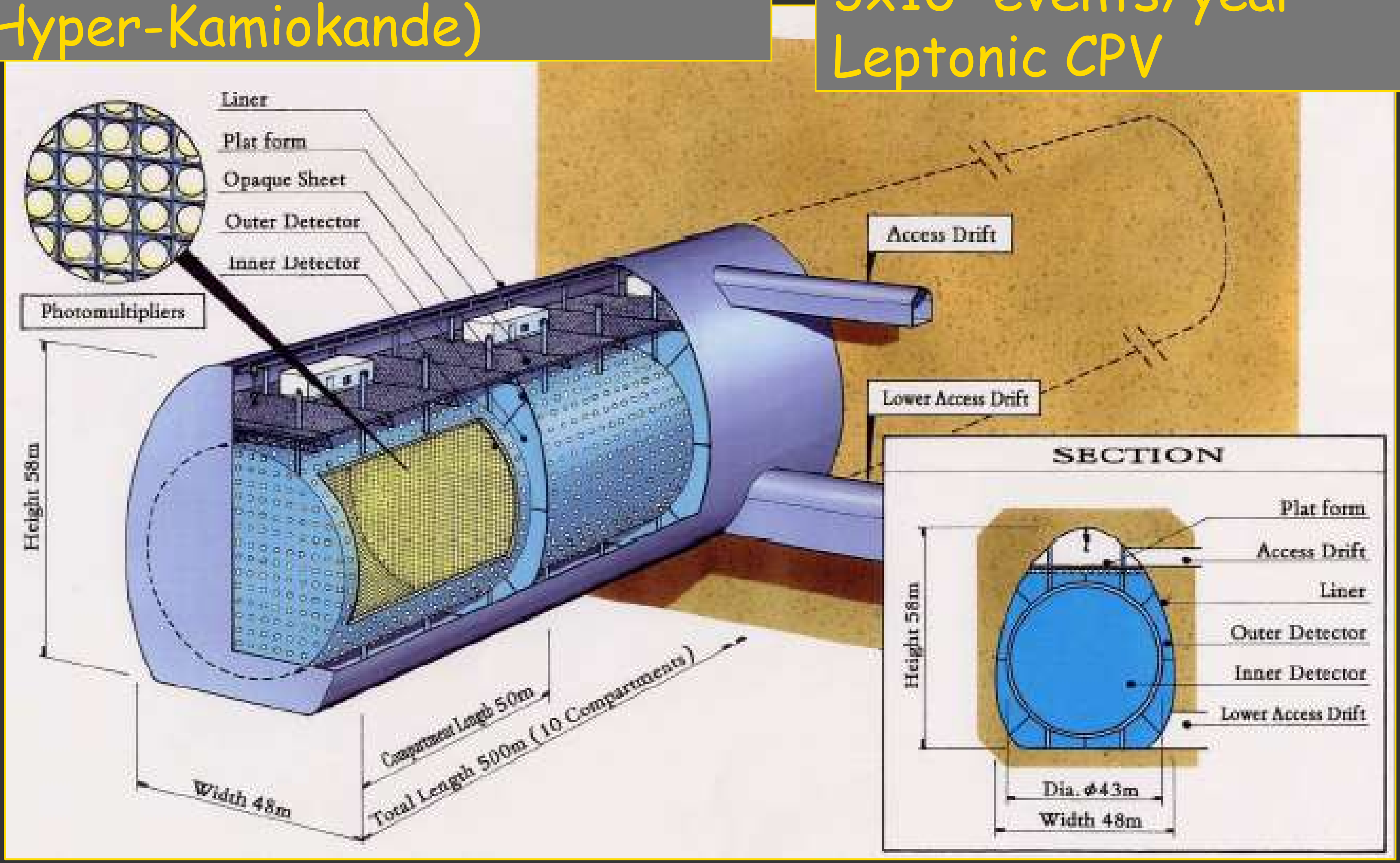
JPARC upgrade to 4 MW power and Hyper-Kamiokande (1Mt) (100xPhase I)

1. Discovery of θ_{13} down to $\sin^2 2\theta_{13} > 0.001$
2. Leptonic CP violation. δ down to 10-20 degrees if $\sin^2 2\theta_{13} > 0.01$

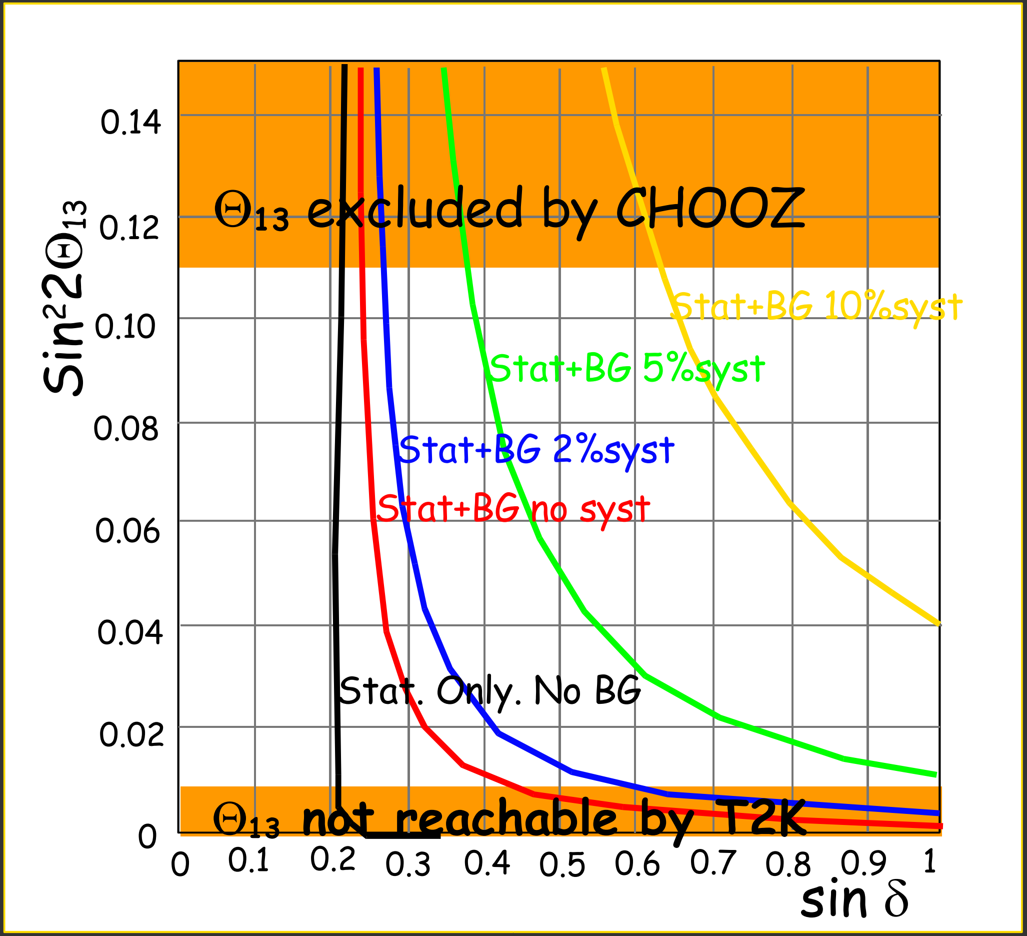
T2K Phase-II (20??)

0.75 → 4MW beam power
50 kt → 1 Mt water Cherenkov
(Hyper-Kamiokande)

3×10^5 events/year
Leptonic CPV



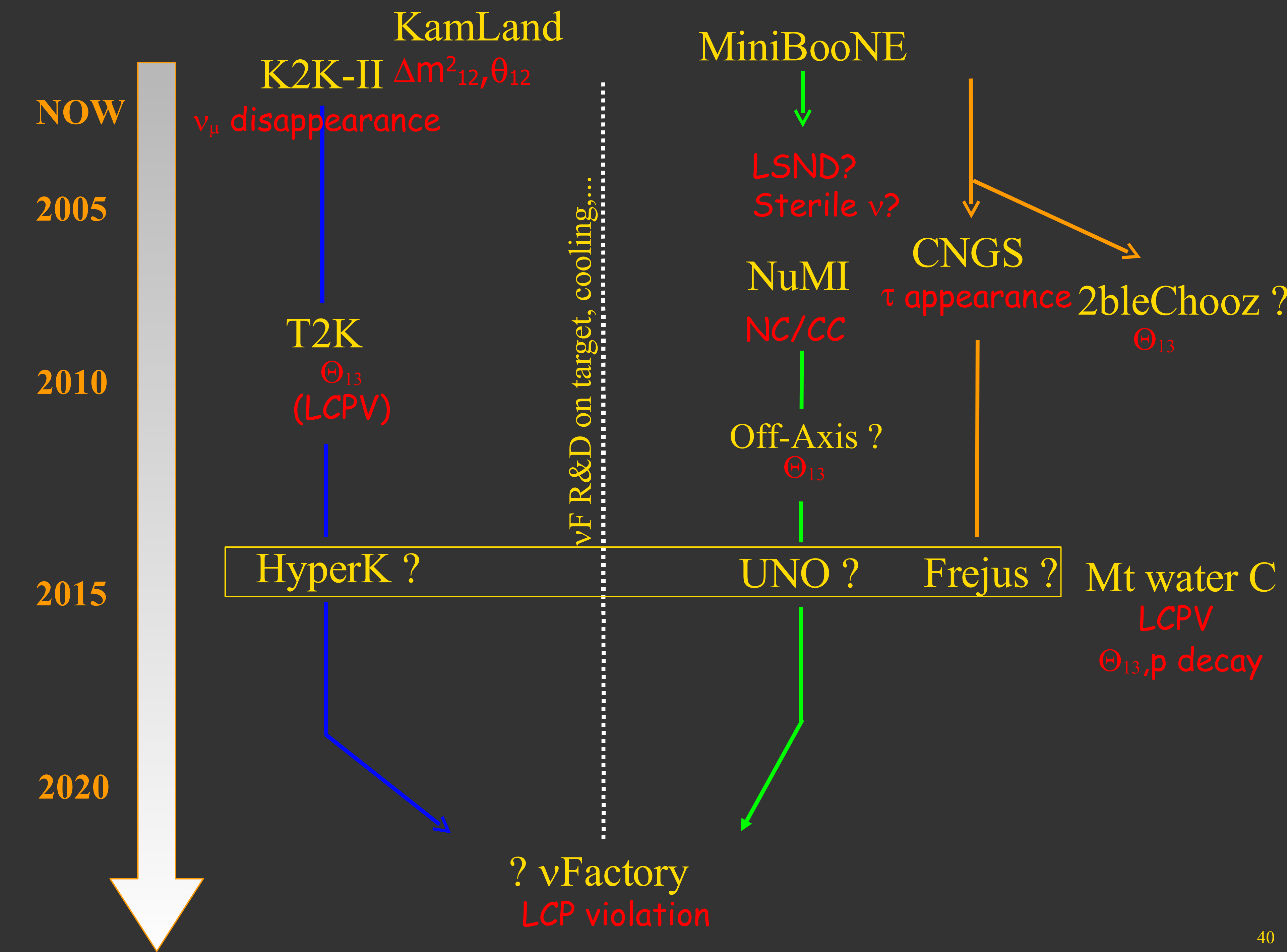
Phase-II CPV Sensitivity



If T2K discovers non-zero θ_{13}, than JPARC-II will be sensitive to LCPV down to δ=10-20 degrees.

$$A^{CP}_{e\mu} = \frac{P(\nu_e \rightarrow \nu_\mu) - P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)}{P(\nu_e \rightarrow \nu_\mu) + P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)} = \frac{\Delta m^2_{12} L}{4 E_\nu} \cdot \frac{\sin^2 2\theta_{12}}{\sin \theta_{13}} \cdot \sin \delta$$

(without matter effects)



NOW
2005
2010
2015
2020
KamLand
K2K-II
$\Delta m^2_{12}, \theta_{12}$
ν_μ disappearance
MiniBooNE
LSND?
Sterile ν?
CNGS
τ appearance
2bleChooz ?
Θ_{13}
NuMI
NC/CC
T2K
Θ_{13}
(LCPV)
νF R&D on target, cooling,...
Off-Axis ?
Θ_{13}
HyperK ?
UNO ?
Frejus ?
Mt water C
LCPV
Θ_{13},p decay
? νFactory
LCP violation

Stato di T2K

- La costruzione di JPARC è iniziata nel 2001 e il primo fascio è atteso nel 2008.
- La fase-I (0.75MW) è approvata e finanziata (oltre 1M€).
- Il programma di neutrini è una delle principali motivazioni per la costruzione della facility.
- L'approvazione della neutrino beam-line in Giappone (MEXT) è stata decisa decisa nel dicembre 2003 e finanziata su cinque anni, 2004-2008.
- Proto-collaborazione T2K con Giappone, Canada, Francia, Italia, Corea, Russia, Spagna, UK e USA.
- Working groups internazionali per il disegno del rivelatore.
- Una LoI è stata inviata nel gennaio 2003, firmata da istituti in Giappone, Canada, Francia, Italia (Bari,Napoli,Padova,Roma I), Corea, Polonia, Russia, Spagna, Svizzera, UK and USA.
- Proposal nella primavera del 2005. Inizio presa dati alla fine del 2008.

T2K è il progetto più interessante nel futuro prossimo delle oscillazioni, per scala dei tempi, strategia sperimentale, flessibilità e ricchezza del programma scientifico.

Partecipazione italiana

- Gli italiani sono coinvolti e presenti a vario livello nel disegno del rivelatore.
- L'opzione magnete+tracking è una proposta (P.F.Loverre) e una riconosciuta responsabilità italiana.
- Meccanica della movimentazione, cooling, implicazioni del magnete sull'ingegnerizzazione dell'intero rivelatore (C.Gargiulo, Roma).
- L'opzione TPC per il tracking è una proposta italiana (E.Radicioni) che ha raccolto l'immediato interesse di gruppi canadesi e EoI di altri gruppi europei.
- La TPC è un progetto complesso con elementi diversi (mechanics, field cage, gas system, gem/micromegas amplification, readout pad, readout electronics) da realizzare con pochissimo tempo per R&D.
- I gruppi italiani coinvolti stanno attivamente cercando di allargare la propria partecipazione.

Conclusioni

Ora

- La fisica delle oscillazioni di neutrini vive anni di importanti risultati.
- I neutrini solari oscillano. Evidenza di neutrini attivi non-ν_e dal sole. Conferma da una sorgente artificiale.
- Forte indicazione di sparizione dei ν_μ atmosferici. Conferma da una sorgente artificiale.

Next (qualche anno)

- K2K-II: Conferma sparizione ν_μ. Pattern di oscillazione.
- MiniBooNE: LSND?
- NuMi: NC/CC, sterili/tau
- CNGS: apparizione diretta di tau

Next^2 T2K (presa dati fine 2008)

- Ricerca di θ_{13}.
- Misura di precisione dei parametri (GUT test, mass models,...)

Next^3 (..??..)

- Leptonic CP violation. Gerarchia delle masse.
- Test del triangolo di unitarietà

Questions

What physics is behind neutrino masses and mixing ?
How many neutrino species are there ?
Is there any sterile neutrino ?
What is the neutrino mass pattern (hierarchy) ?
What is the absolute scale of neutrino mass ?
Are neutrino Maiorana particles ?
What is the leptonic mixing matrix ?
Is there CP violation in neutrino interactions ?
Is LCPV responsible for the baryon asymmetry ?

How big is Θ_{13} ? -> experimental study of LCPV and hyerarchy depends on the answer!