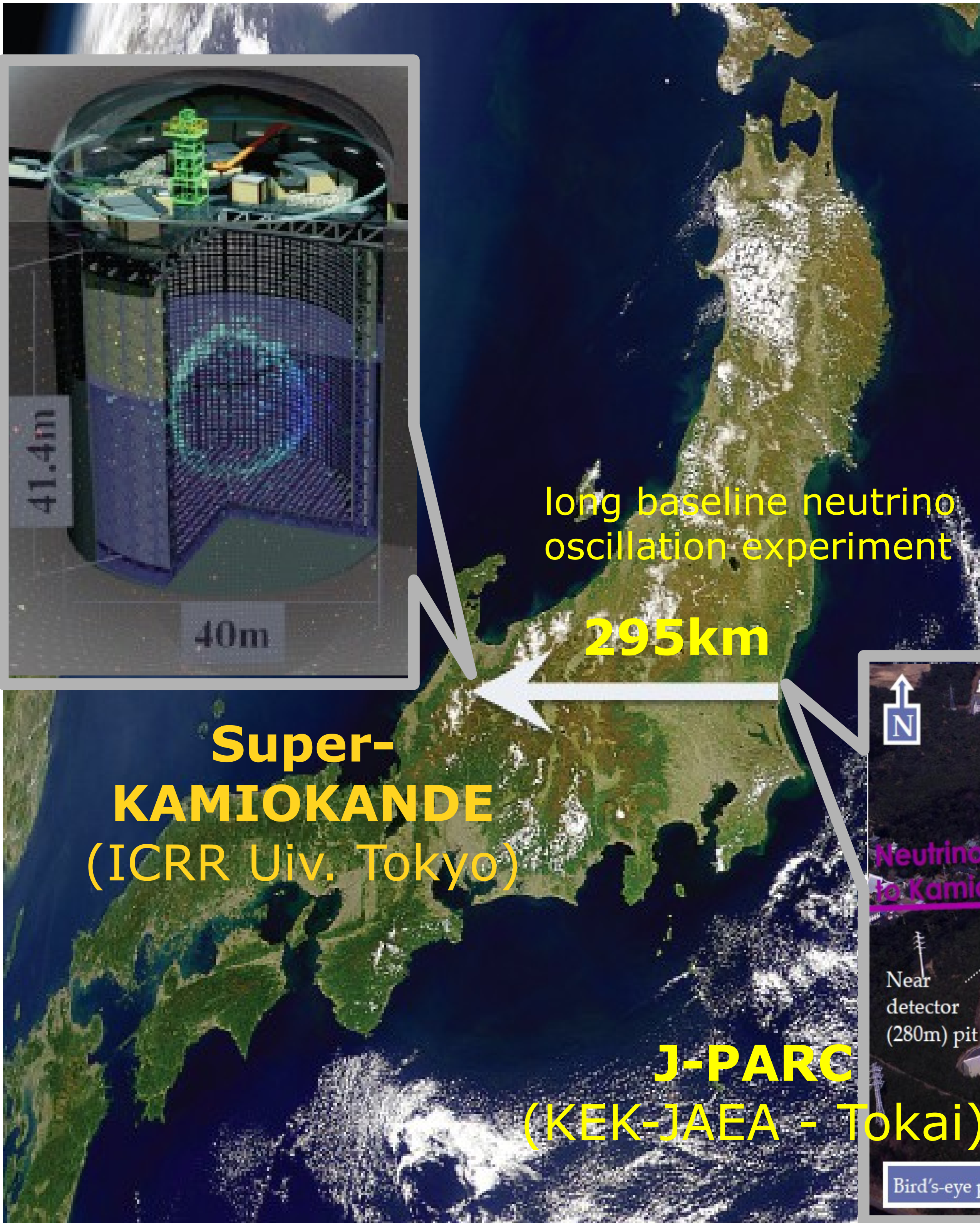
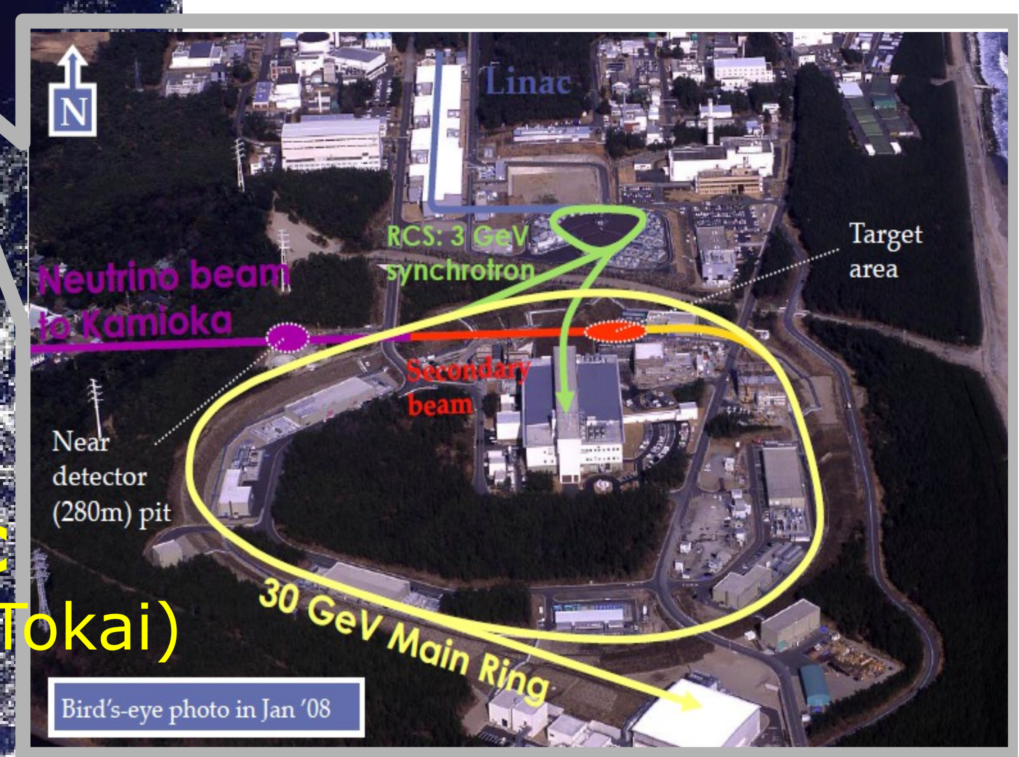
T2K

Collaborazione internazionale

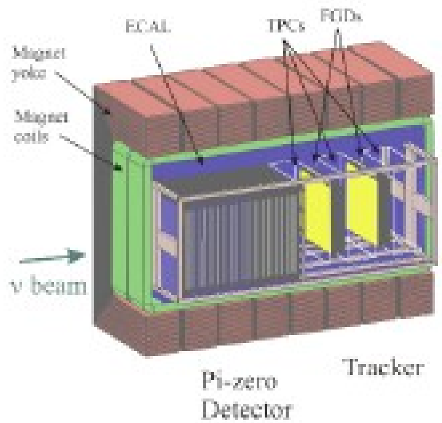
- 400 fisici, 59 istituzioni, 11 paesi
- 5 sezioni INFN (Ba, Na, LNF, Pd, Rm1)
- Pd: M.Mezzetto, M.Laveder, G.Collazuol

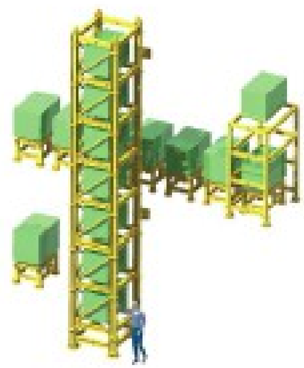




Esperimento T2K

Uses the **J-PARC accelerator** complex for the beam.





On and off-axis hybrid **near detectors** at 280m

- 3 gas TPCs
- 2 fine grained detectors con carbon/water targets
- Dipole magnet 0.2T

→ normalizzazione flusso ν
→ misure sez. urto ν

Use information from hadron production experiment NA61

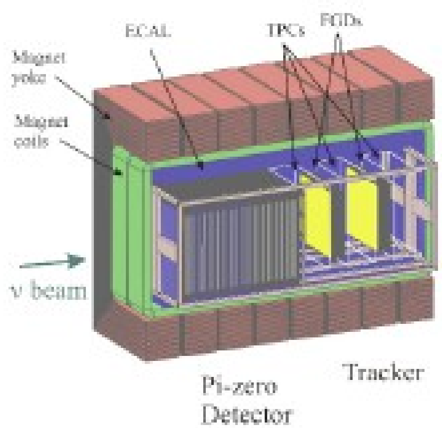
Far detector: Super-K at 295 km.

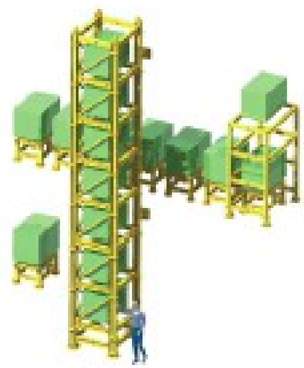
- 1km undergroud
- 50kt Water Cherenkov
  → 22.5 kt fiducial vol.
- 2m outer detector (veto)

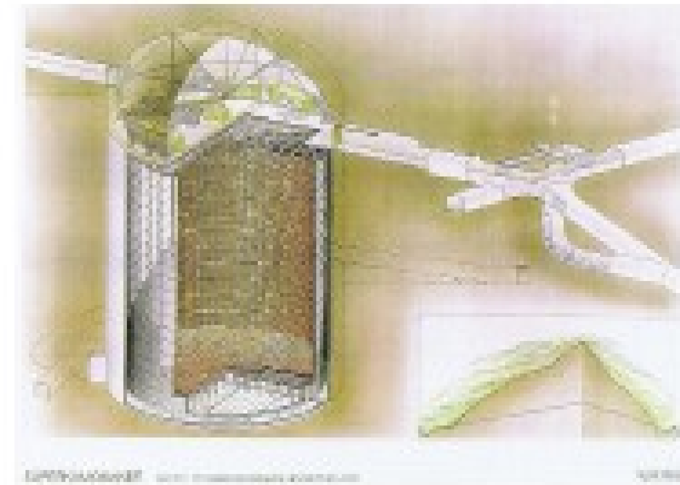
→ ~60% efficiency for ν_e
~95% π^o rejection

Esperimento T2K

Uses the **J-PARC accelerator** complex for the beam.



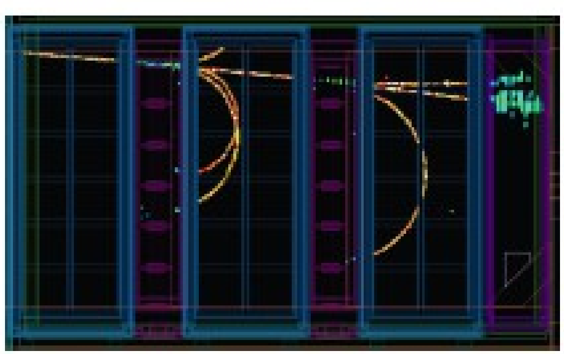




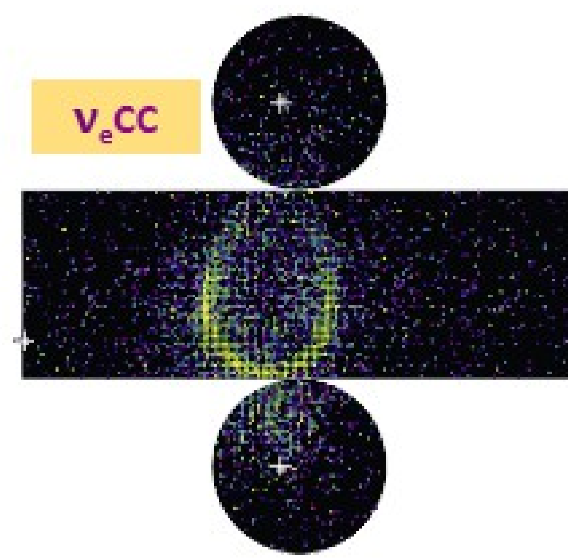
Far detector: Super-K at 295 km.

Use information from hadron production experiment NA61

On and off-axis hybrid **near detectors** at 280m



ν_eCC



Esperimento T2K

Motivazioni

- Ricerca di θ_{13} in appearance mode → ok: evidenza $\nu_\mu \rightarrow \nu_e$ in 2012
- Misura di precisione θ_{23} e Δm^2_{23} → in progress
- Indicazione δ_{CP} e gerarchia masse → in progress
- Misura sezioni d'urto @ 1GeV → in progress

Stato attuale

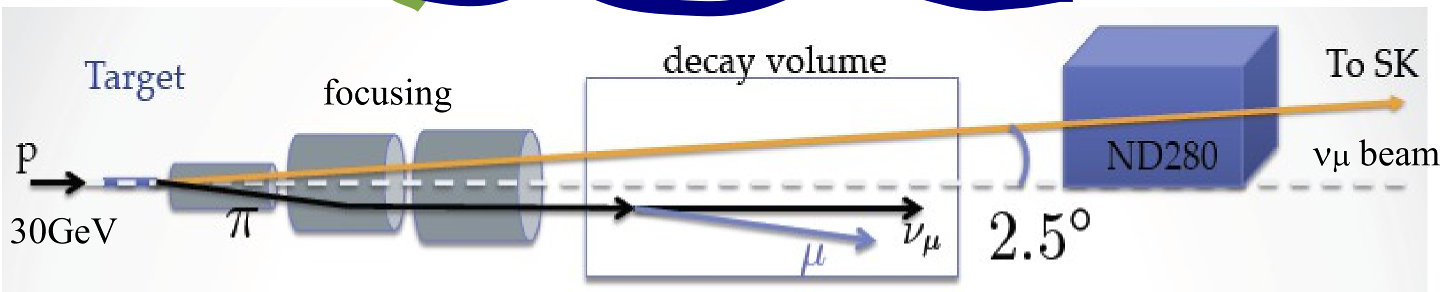
- Statistica finale attesa 7.8×10^{21} pot

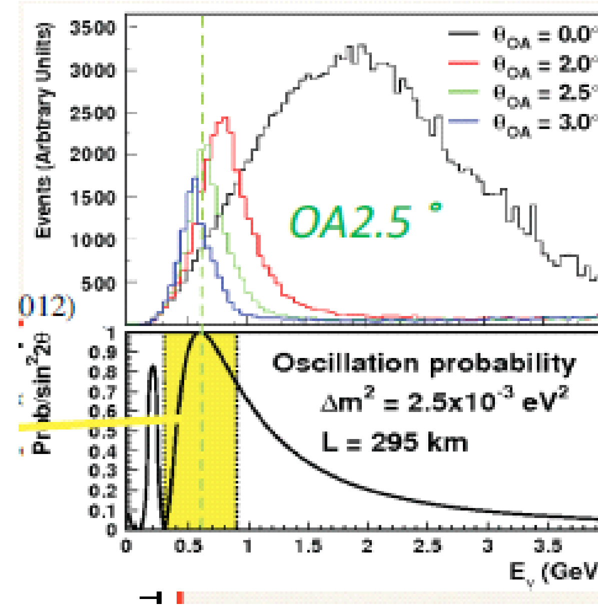
→ DATA TAKING APPROVATO @JPARC FINO A 2019

- Fino ad oggi 7.2×10^{20} pot (10%) di cui 0.4×10^{20} pot anti-ν_μ

→ graduale upgrade intensita` del fascio → fino 2017

Fascio off-axis



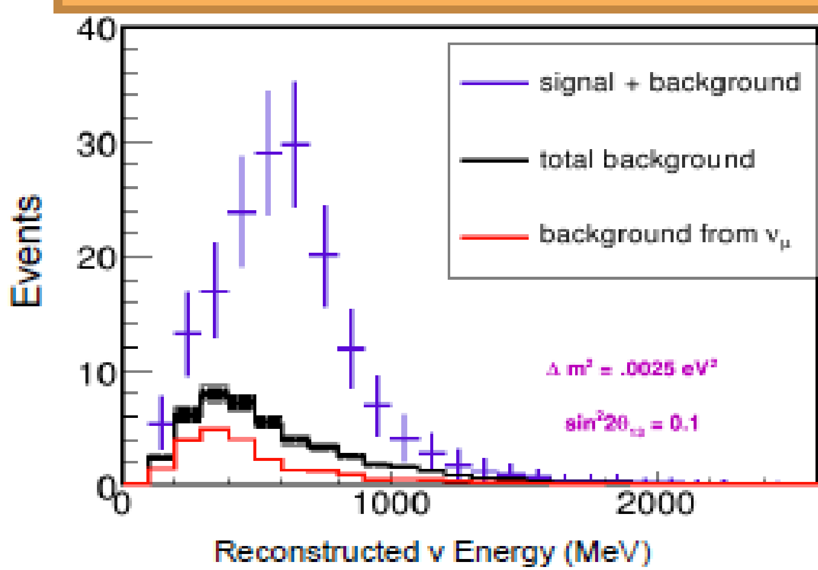


Arricchimento di neutrini mono-energetici ~0.6 GeV (al costo di riduzione intensita`)

T2K ottimizzato per ricerca oscillazioni sia in apparizione sia in scomparsa → narrow band beam su primo massimo oscillazione

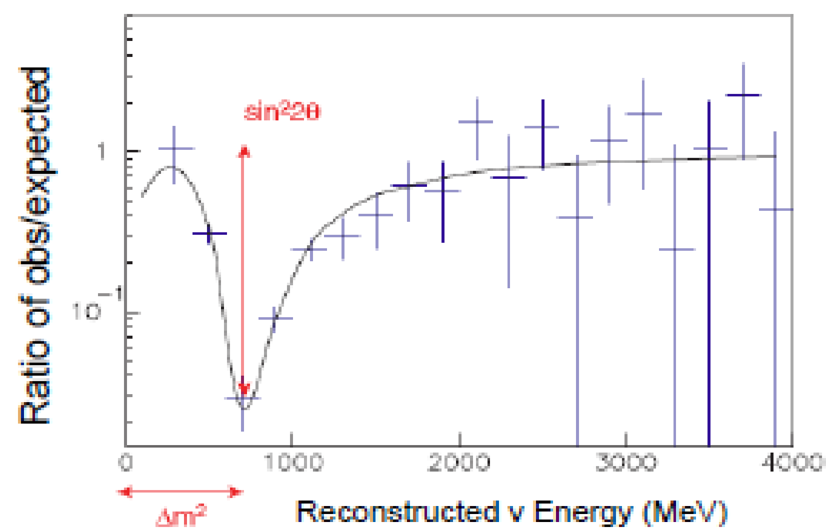
Appearance

ν_e appearance: determine θ_{13} constrain δ_{CP}

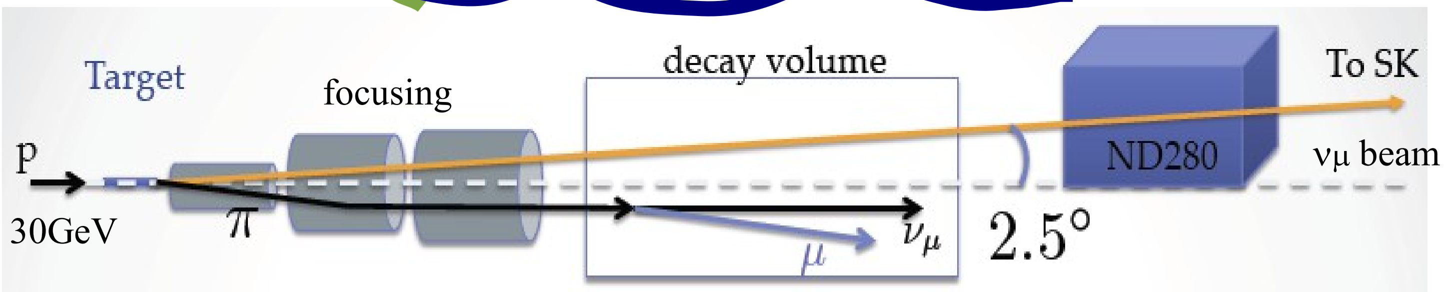


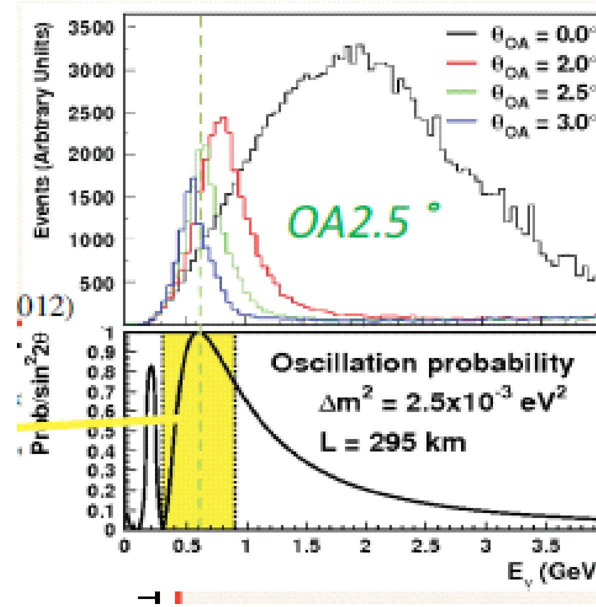
Disappearance:

ν_μ disappearance: determine θ_{23} and Δm^2_{32}



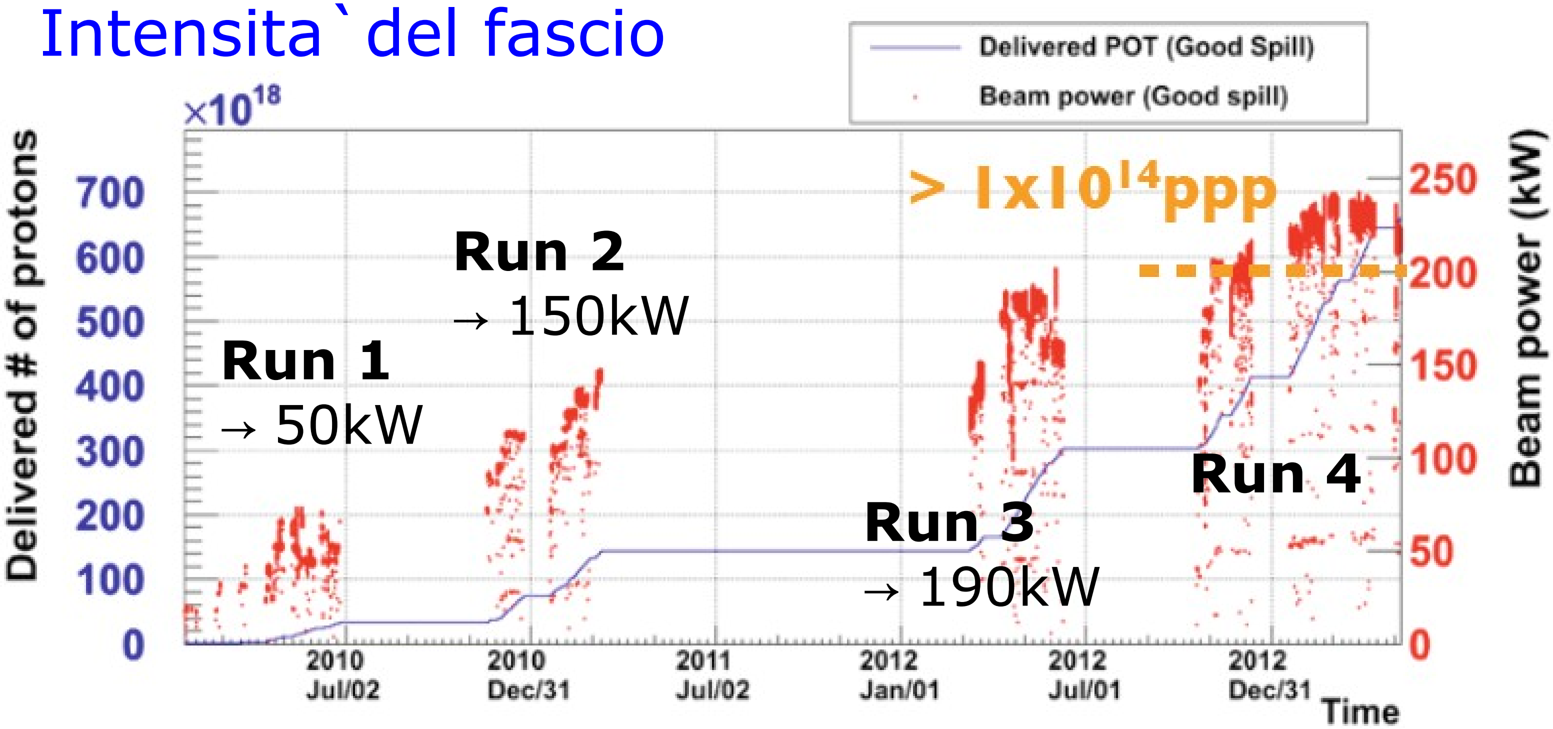
Fascio off-axis





Arricchimento di neutrini mono-energetici ~0.6 GeV (al costo di riduzione intensita`)

Intensita` del fascio

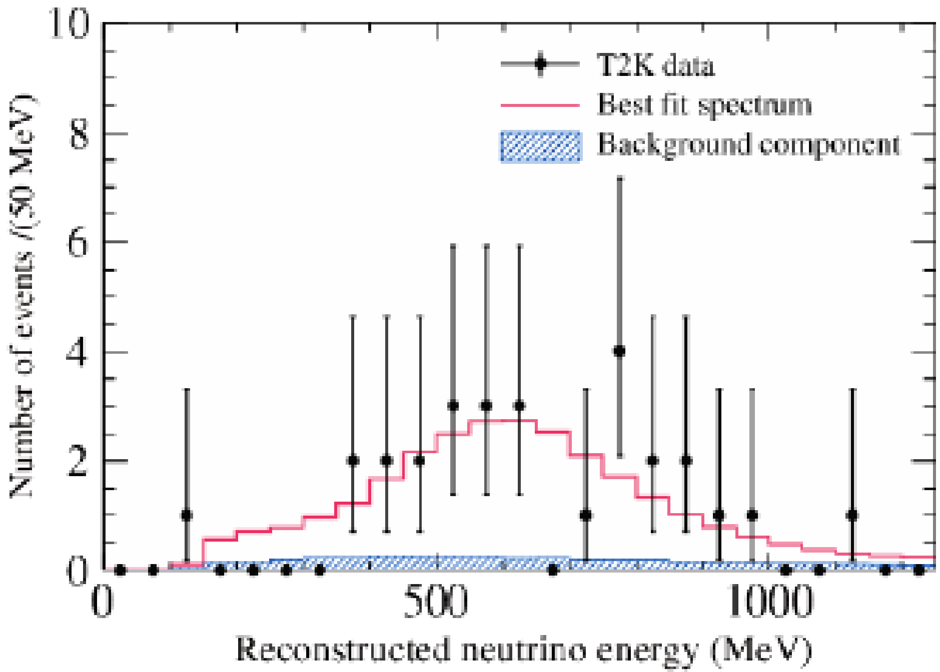


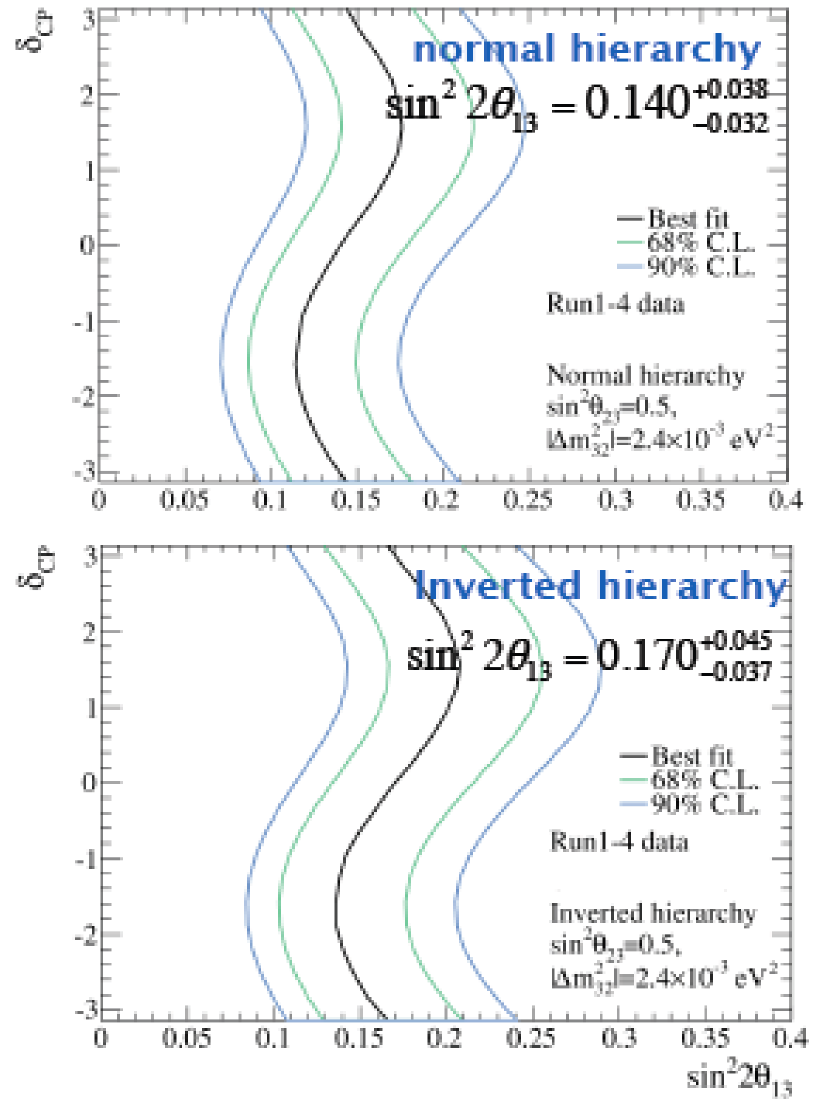
Run 4
200kW → 240kW
operazione stabile
→ fine luglio 2013..

..fine maggio 2013
stop per incidente
@ Hadron hall

Apparizione ν_e

Phys. Rev. Lett. 112, 061802 (2014)





4.92 ± 0.55 events expected background

28 events observed

21.6 events expected @ $\sin^2 2\theta_{13}$= 0.1

δ_{CP}= 0, $\sin^2\theta_{23}$= 0.5

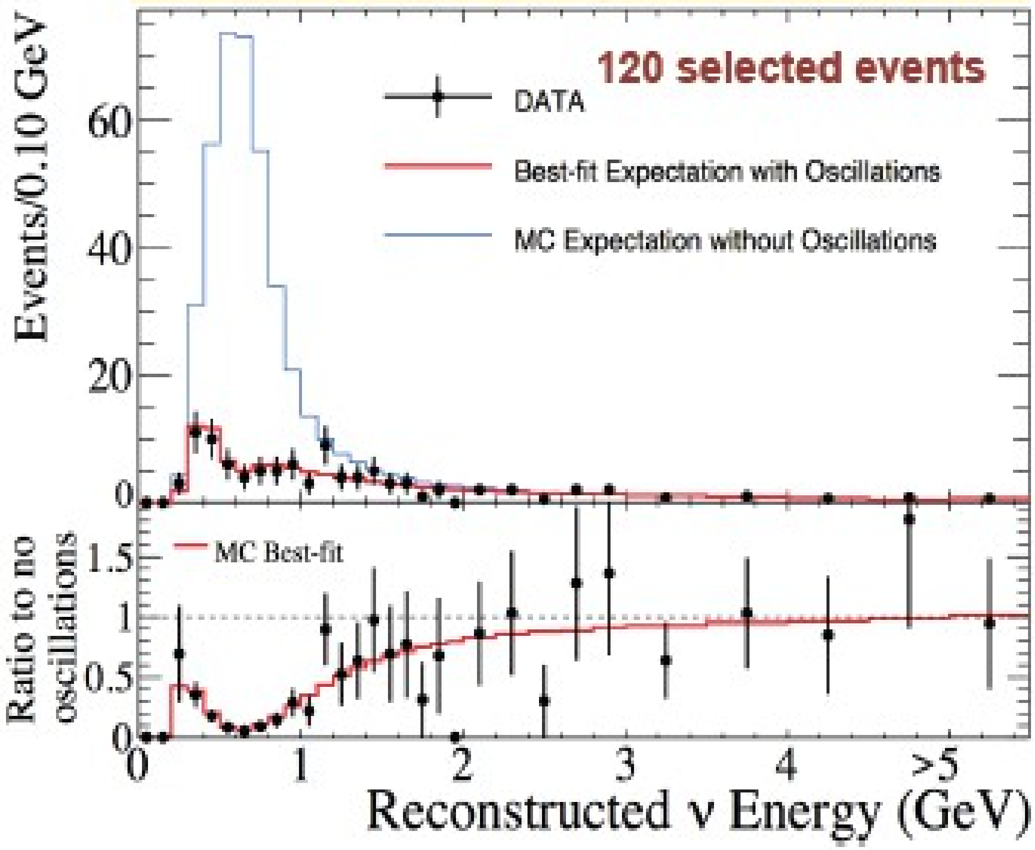
7.3 σ significance for non-zero θ_{13}

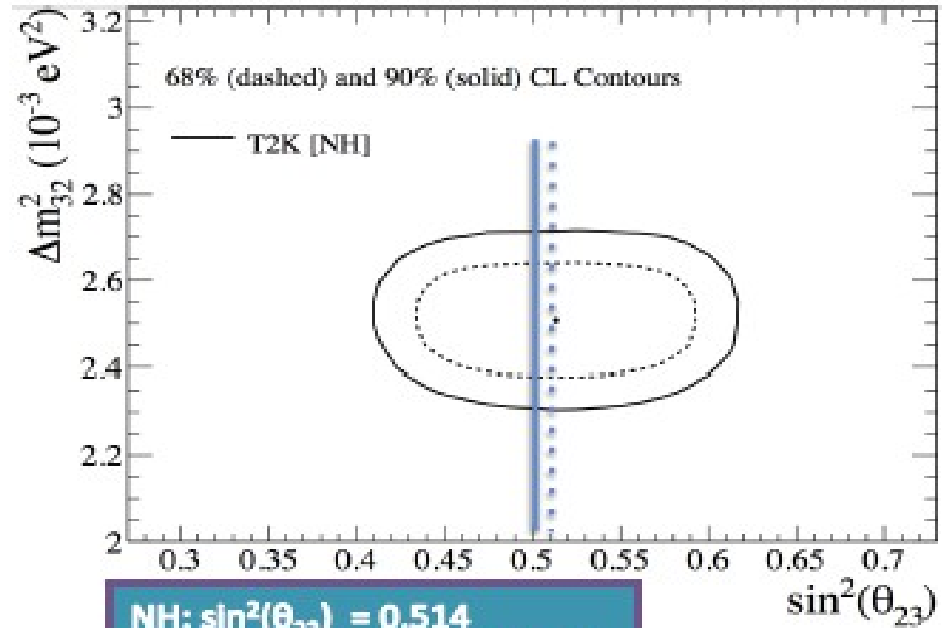
First ever observation (>5σ) of an explicit ν appearance channel

Scomparsa ν_μ

Phys. Rev. Lett. 112, 181801 (2014)

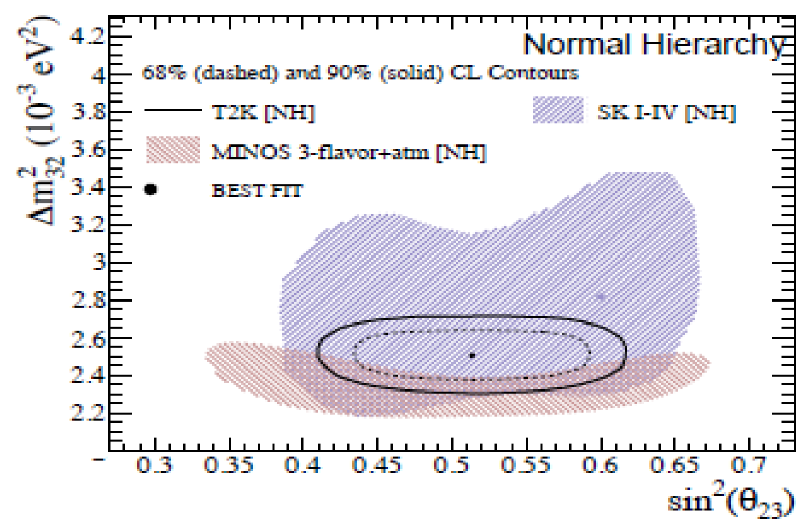
Shows the power of the off-axis technique!





NH: $\sin^2(\theta_{23})$ = 0.514
NH: Δm^2_{32} = 2.51×10^{-3} eV^2

For θ_{13} given by reactor experiments



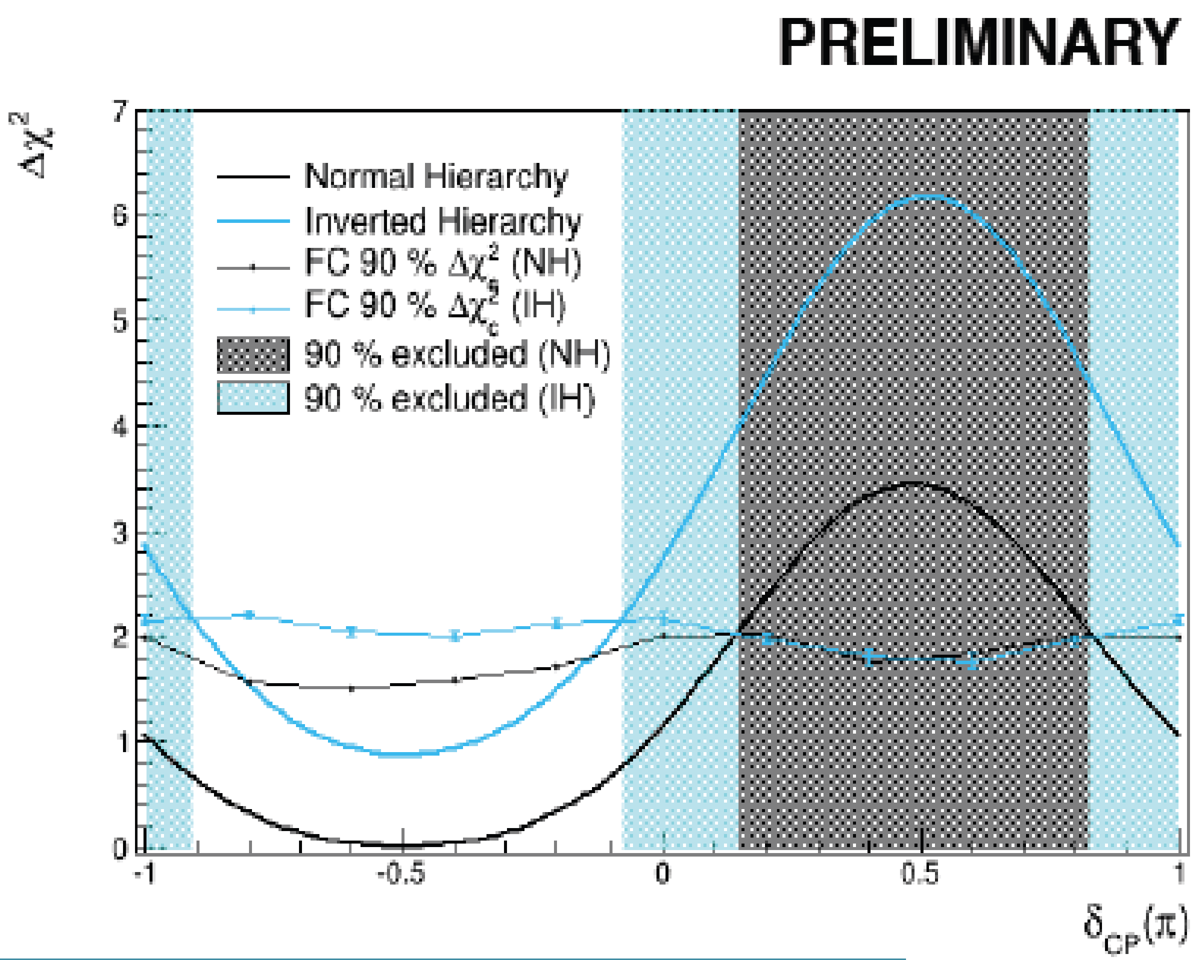
Per la prima volta l'angolo di mxing e\` misurato meglio da esperimento ad acceleratore che con gli atmosferici

Analisi congiunta $\nu_e + \nu_\mu$

Likelihood ratio fit to both $\nu_\mu + \nu_e$ event samples

Plot includes constraint from reactor experiments as given by PDG 2013.

T2K has a slight hint for the normal hierarchy with a value of δ_{CP} of $-\pi/2$

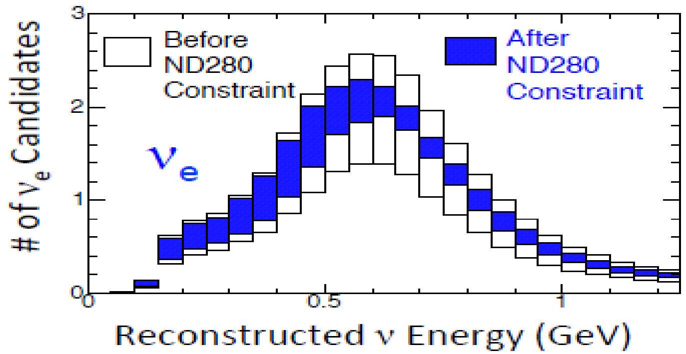


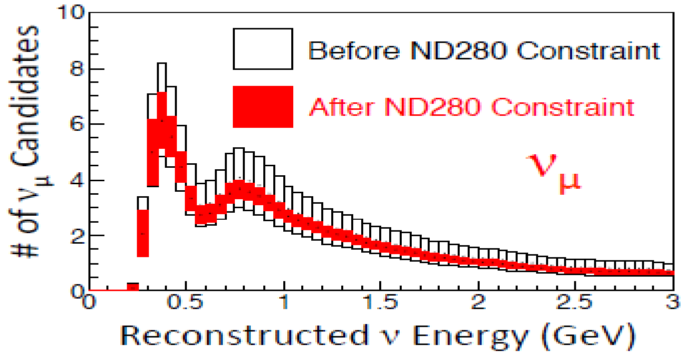
T2K studies indicate our best sensitivity will be for 50% ν/50% anti-ν running. Anti-nu running also opens a large new physics program.

Nuova fase → Run in modalita` antineutrino

Nuova fase presa dati → fascio anti-ν

- Cosa implica θ_{13} grande:
  - Possibilita' di ricerca di CPV nel settore leptonico e di nuova fisica (misure di precisione di θ_{23} e le informazioni di θ_{13} da esperimenti ai reattori saranno rilevanti in questo campo)
  - Conferma della misura di θ_{13} in anti-neutrino mode
- Di cosa ha bisogno T2K per nuova fase:
  - Presa dati con fascio in polarita' inversa (anti-ν_μ)
  - Migliorare le performances dell'ND280 per misure di sezione d'urto ad alta precisione (errore sistematico dominante)





Systematic Source	Relative Uncertainty in # of ν_e Candidates (%)	Relative Uncertainty in # of ν_μ Candidates (%)
Flux + cross section (ND280 constrained)	2.9	2.7
Cross section (ND280-independent)	4.7	4.9
π Hadronic Interactions	2.3	3.5
SK Detector	2.6	4.4
Total	**6.8**	**8.1**

Goal finale 5%

PAC proposal approved may 2014

Proposal:

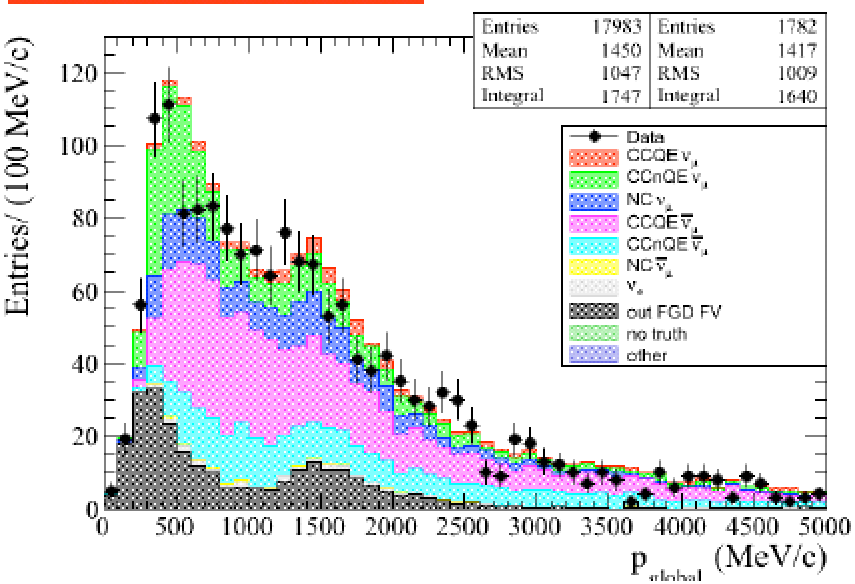
- Following a "pilot run" in June 2014 to operate the T2K beam line for the first time in antineutrino-mode, we propose to accumulate ***a significant exposure of antineutrino-mode running at T2K.***
- We expect 1×10^{20} POT to be accumulated in the pilot run
- ***We request 4×10^{20} POT following the summer shutdown to accumulate a total of 5×10^{20} POT of antineutrino mode exposure***
- Goals:
  - World-leading measurement of $\bar{\nu}_\mu$ disappearance parameters
  - Start of $\bar{\nu}_e$ appearance program
    - expect 5 total $\bar{\nu}_e$ candidates, including 2 background events.
    - ~equal exposure of neutrino/antineutrino exposure is optimum for θ_{23} octant, δ_{CP} sensitivity
  - Start an extensive and timely program of antineutrino interaction studies at ND280.

Analisi $\bar{\nu}_{\mu}$ in near detector – I –

Analisi italiana coordinata da G.Catanesi

Misura della contaminazione di anti-ν nel fascio di ν @ND280 (entra in stima errore sistematico oscillazione)

$\langle data/MC \rangle_{0<p<5GeV} = 0.95$



Spettro $p_{\mu+}$

numu CCQE	5,5%
numu CCnQE	17%
numu NC	11,4%
anti-numu CCQE	33,2%
anti-numu CCnQE	17%
OOFV	14,4%

Purezza CC inclusiva ~50%

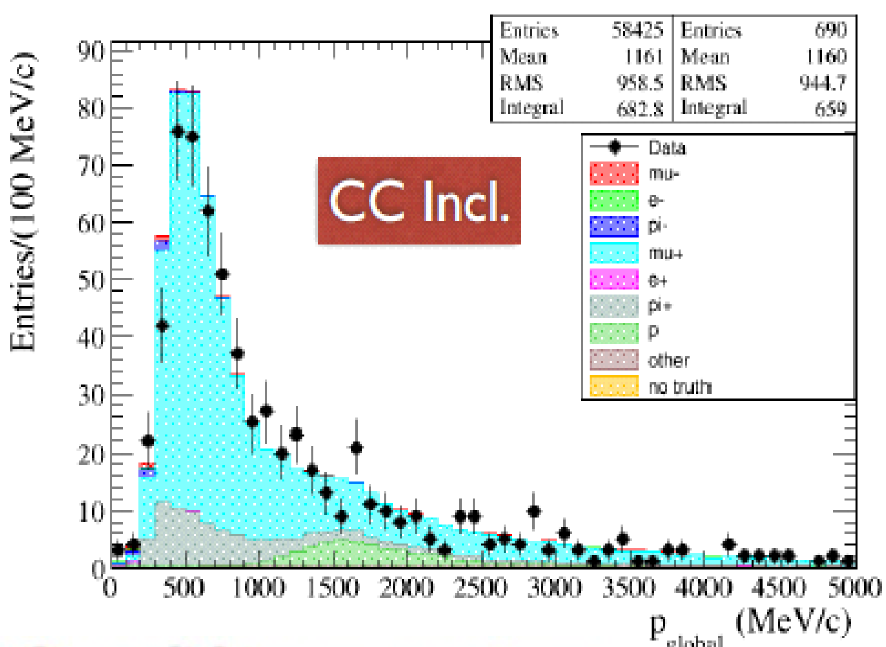
- Riduzione fino al 9% su tutto lo spettro di energia dell'incertezza sistematica sulla componente di flusso di ν_μ
- Riduzione dal 40% al 13% dell'incertezza ~~si~~stematica sul rapporto $\sigma_{\bar{\nu}}/\sigma_{\nu}$

Analisi $\overline{\nu}_\mu$ in near detector – II –

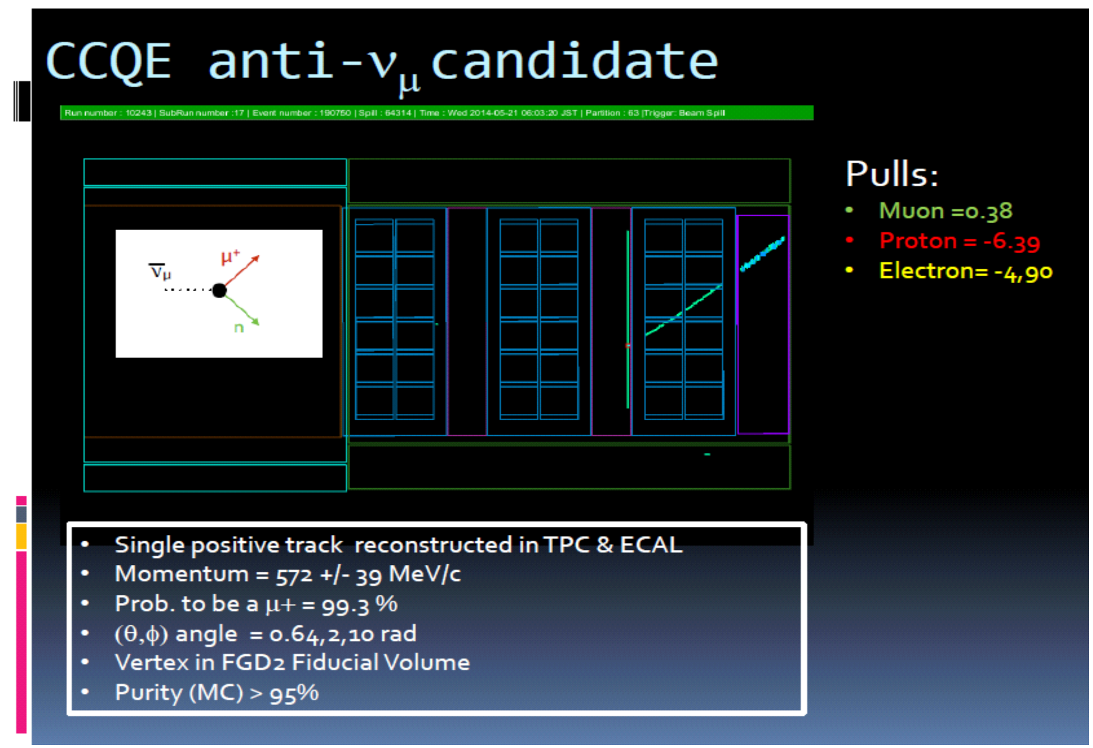
Analisi italiana coordinata da G.Catanesi

1) misura di anti-ν nel fascio di anti-ν @ND280
→ estrapolazione del flusso a SK
Nota: x-sec. non conosciute a bassa energia

2) misura di contaminuazione ν nel fascio di anti-ν @ND280
→ errori sistematici a SK

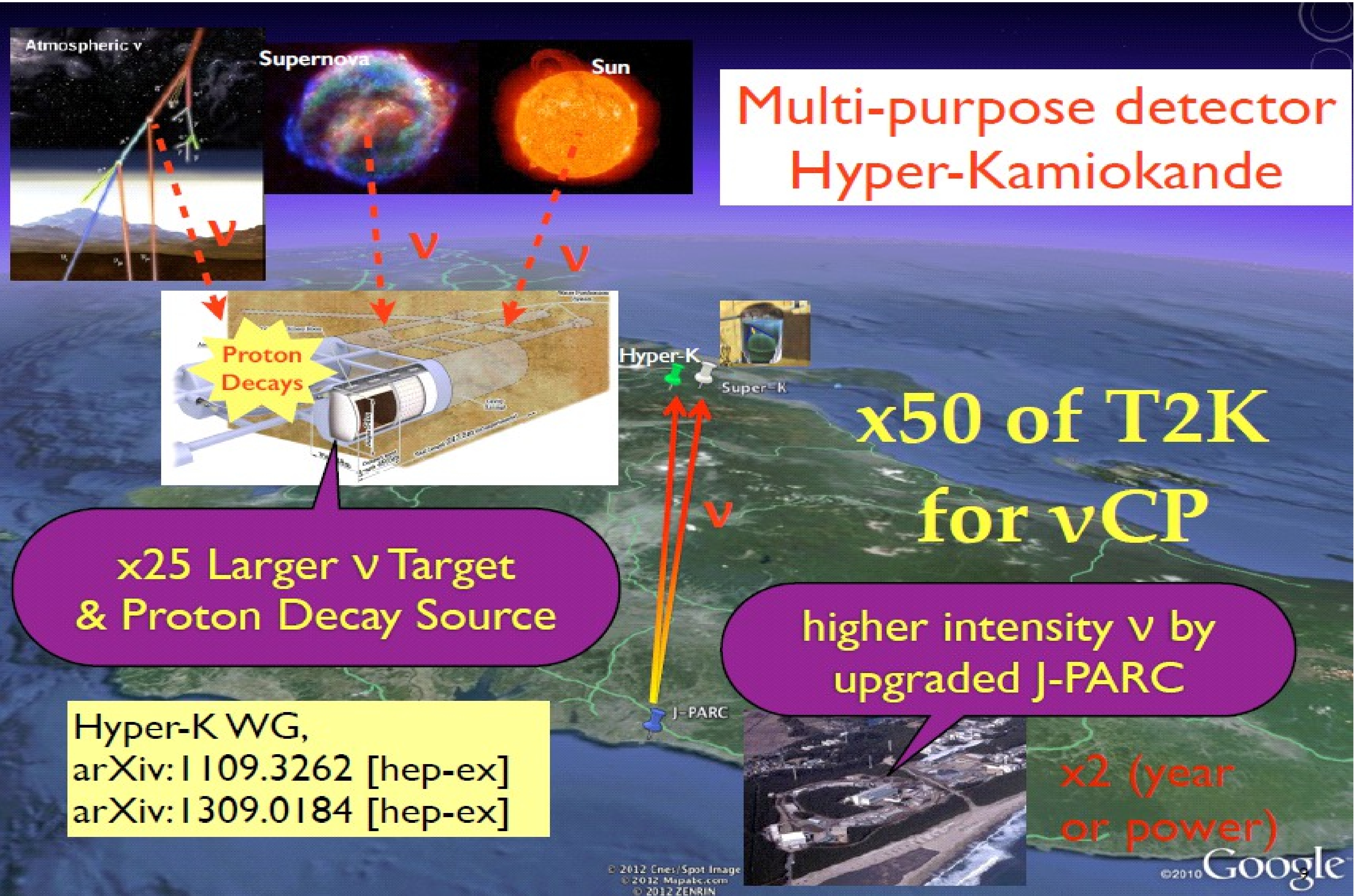


μ+ candidate momentum



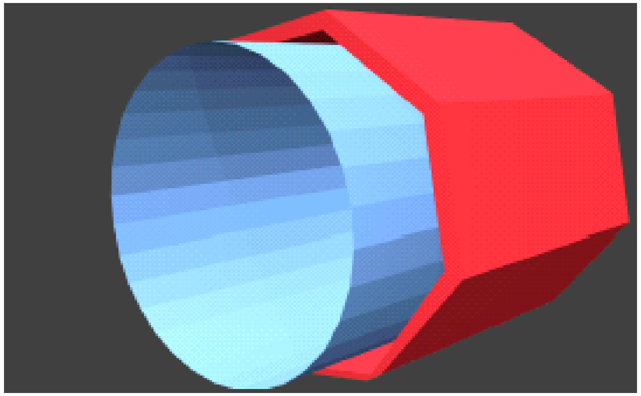
Neutrino 2014: primo evento di anti-nu

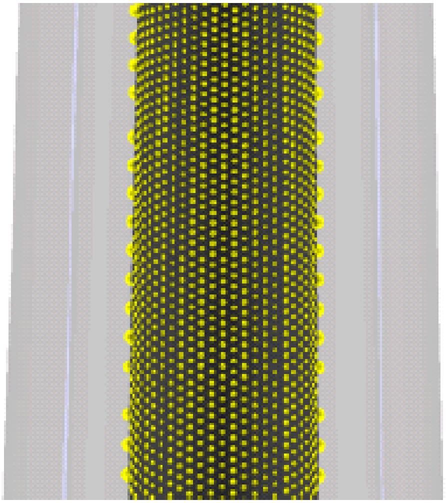
HYPERK Project (LOI April 2014)



Study of new near detectors

- Possible new near detectors under study
  - Aim for further reducing systematics
- Upgrade of T2K ND280 detectors
- New water Cherenkov detector at ~1-2km distance
  - The same technology as the far detector
  - Flux almost the same as HK, less event pileup
  - Water Cherenkov + muon range detector (TITUS)
  - Utilize off-axis dependence of spectrum (nuPRISM)





T2K Padova

Gruppo
M.Mezzetto (75%), G.Collazuol (60%), M.Laveder (60%)
→ 2.0FTE

Attivita` (presenti e future)
- presa dati a JPARC
- operazioni e shift TPC (JPARC)
- attivita` di servizio (tasks): produzioni MC
- analisi anti-ν_μ e studi di sensitivita` CP

Richieste finanziarie 2015
- si prevedono 7 mesi di Run
  → richieste in preparazione, simili a 2014

Non ci sono richieste per i **servizi di Sezione**

Additional material

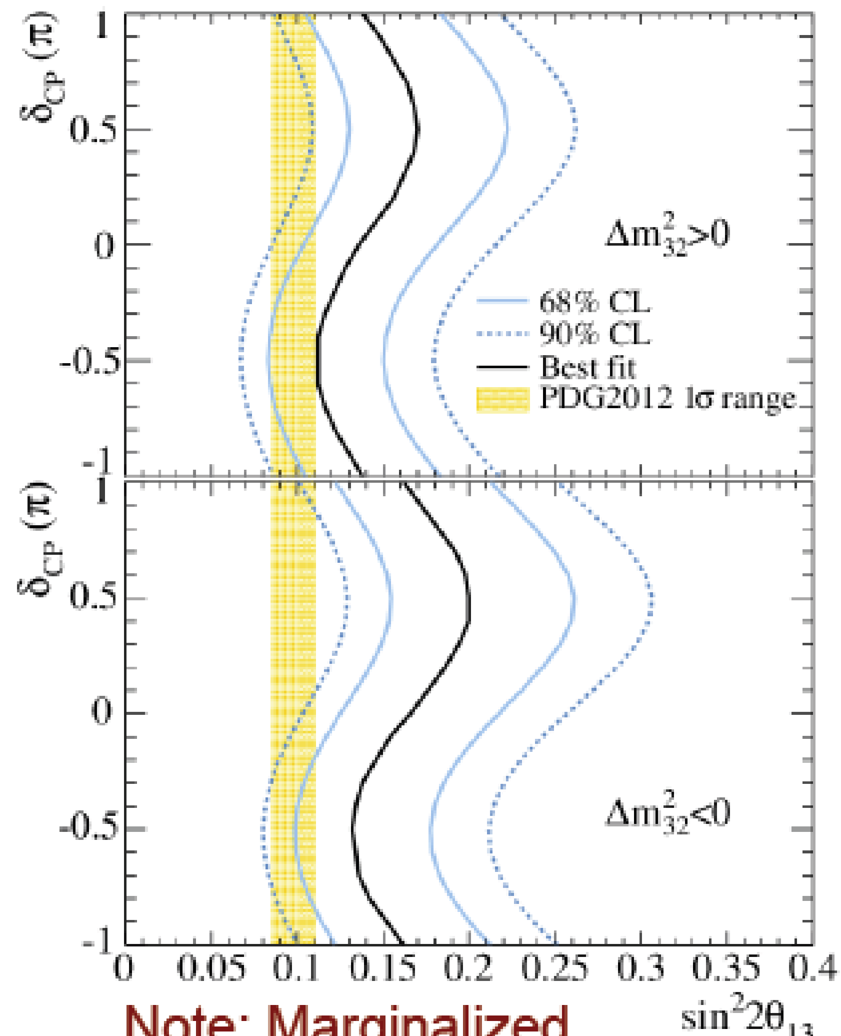
Upgrade fascio

JFY	2011	2012	2013	2014	2015	2016	2017
			Linac Upgrade (180 → 400MeV)				
FX power [kW] **SX power : User op. (study) [kW]**	**150** **3 (10)**	**200** **10 (50)**	**~ 300** **<50**	**400** **50 (100)**	→		**750** **100**
Cycle time of main magnet PS **New magnet PS for high rep.**	3.04 s	2.56–2.48 s R&D	2.48–2.40 s		Manufacture installation/test		1.3 s
Present RF system **New high gradient rf system**	Install. #7,8	Install. #9 R&D		Manufacture installation/test			
Ring collimators	Additional shields	Add. shields & collimators (2kW)	Add. shields & collimators (3.5kW)				
Injection system **FX system**	New injection kicker	Kicker PS improvement、Septum1 manufacture /test LF septum, PS for HF septa manufacture /test					

→ Previsti +4 10^{20} pot in 2014 e +6 10^{20} pot in 2015

CP phase and hierarchy

- Comparing with the external reactor constraint the best overlap is for the normal hierarchy with $\delta_{cp}=-\pi/2$.
- This is a **lucky point**!
- You also need to increase the θ_{23} mixing angle to account for the number of observed events.



Note: Marginalized over θ_{23} and Δm^2_{32}

HK Status

status in Japan

Budget for the R&D was approved

1) Grant-in-Aid for Scientific Research on Innovative Area.
(5 years from 2013 to 2017)
Includes both Hyper-K R&D and T2K/J-PARC improvements.

Build a test (small) detector
to test the new equipment and components
to be used in the HK detector
and to confirm the detector stably works as a `system'.

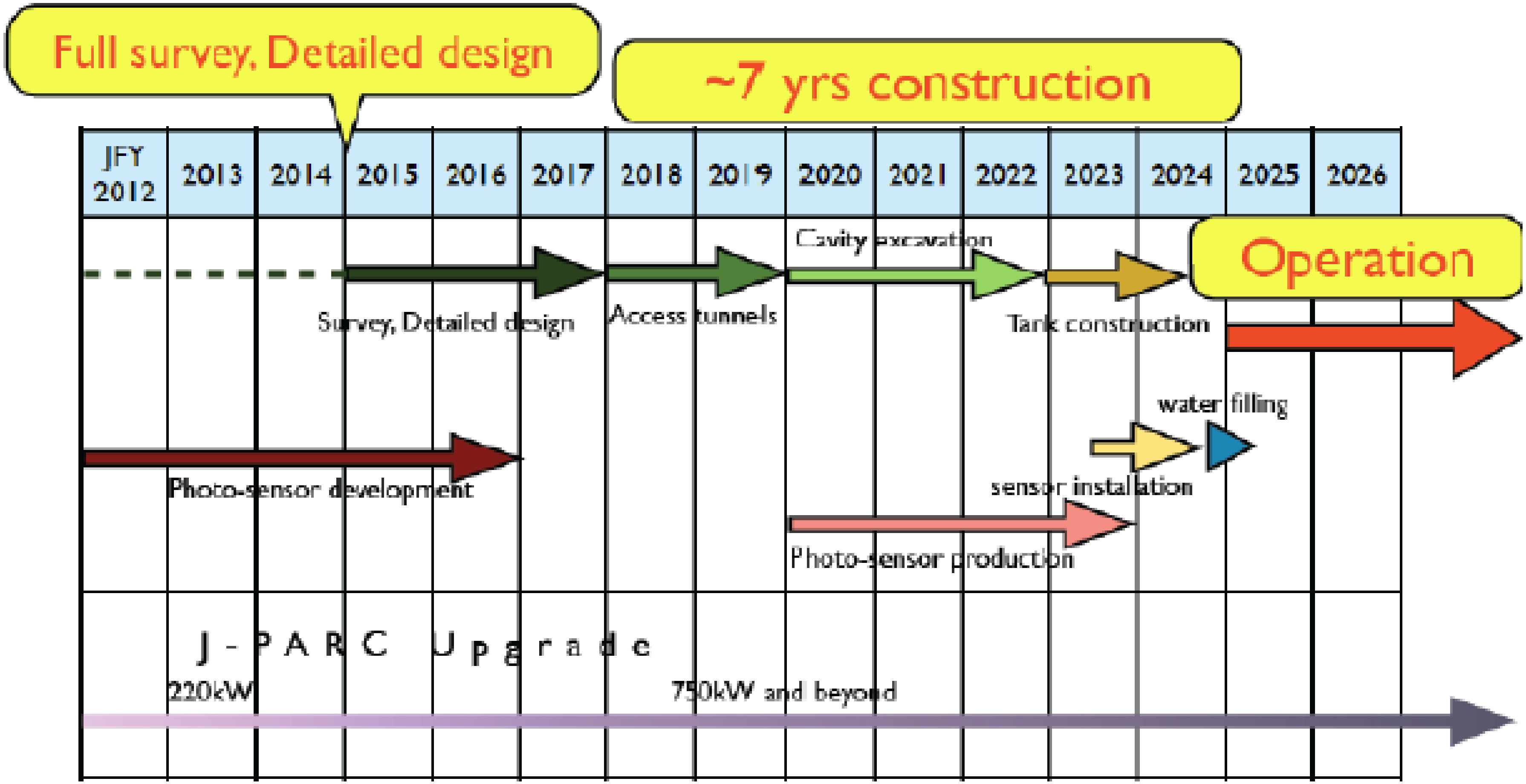
Budget for the R&D was approved

2) Japan/US Cooperation Program
in the Field of High Energy Physics.

For various R&D for the new neutrino detectors
(both near and far detectors)
and J-PARC accelerator / T2K beamline improvements.

Example : R&D of the FPGA-based TDC for
QTC-TDC based front-end electronics
is (just) started as a project in 2014.

HK Timeline



–2015 Full survey, Detailed design (3 years)
–2018 Excavation start (7 years)
–2025 Start operation

HK possibili contributi INFN

ND280 Upgrade (TPC)

Minor upgrades (electronics + space reorganisation)

Major Upgrade (HP TPC)

WC Detector: TiTUS (2Km) + HYPER-K

New photo detectors

Elettronica/DAQ

SW and Analysis (Anti-neutrino) + MC prod.

Neutrino Mixing

Neutrino flavor states are not mass eigenstates: $|\nu_i\rangle = \sum U_{\alpha i} |\nu_\alpha\rangle$

Matrix U contains 3 angles ($\theta_{12}, \theta_{23}, \theta_{13}$) and one phase (δ)

A useful decomposition:

$c_{ij} = cos(\theta_{ij}),\ s_{ij} = sin(\theta_{ij})$

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

Atmospheric: $38^\circ < \theta_{23} < 52^\circ$ **Super-K, MINOS**

CP sector: $\theta_{13} = (9 \pm 0.9)^\circ$ **Daya Bay, Reno, T2K**

Solar: $\theta_{12} = (34 \pm 1)^\circ$ **SNO, KamLAND**

Neutrino Mixing

Mass states interfere during neutrino propagation. Probability of observing flavor ν_β after making ν_α depends on :

- L : The distance the neutrino has traveled (in km)
- E : The energy of the neutrino (in GeV)
- Δm_{ij}^2 : The mass splitting between the i and j mass eigenstates (in eV^2)

NuMu Disappearance:

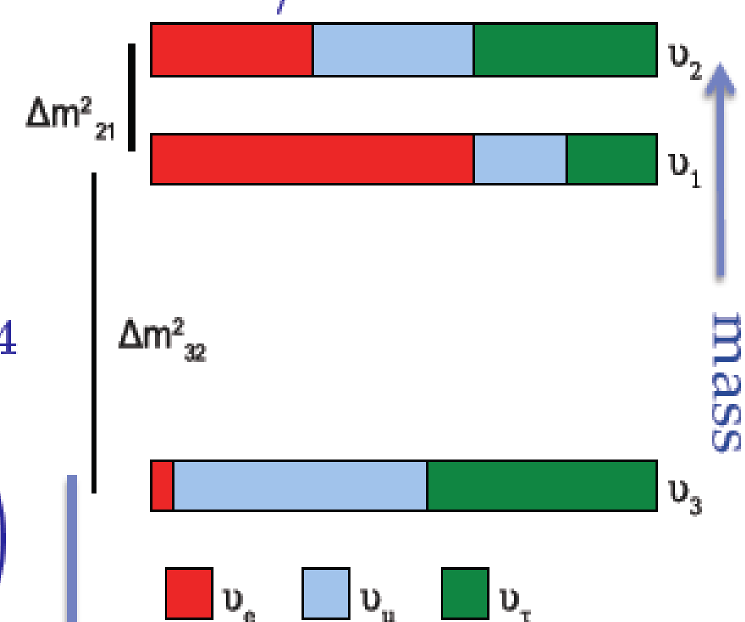
$$\approx 2.43 \times 10^{-3} \mathrm{eV}^2/c^4$$

$$P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \sin^2 2\theta_{23} \sin^2 \left(1.27 \frac{\Delta m_{32}^2 L}{E} \right)$$

Nue Appearance:

$$\approx 2.43 \times 10^{-3} \mathrm{eV}^2/c^4$$

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 \theta_{23} \sin^2 2\theta_{13} \sin^2 \left(1.27 \frac{\Delta m_{31}^2 L}{E} \right)$$



$$\approx 7.6 \times 10^{-5} \mathrm{eV}^2/c^4$$