The T2K experiment

Latest results

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on behalf of the T2K INFN Group

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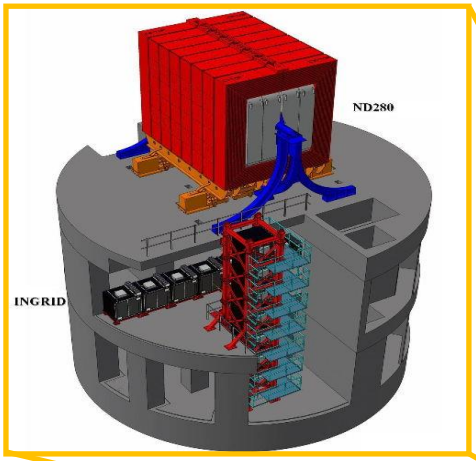
101° SIF Meeting

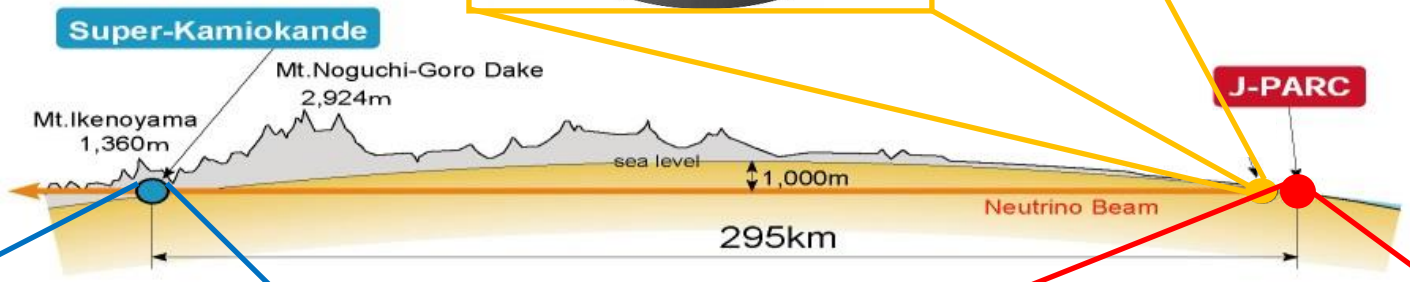
Rome, September 24th 2015

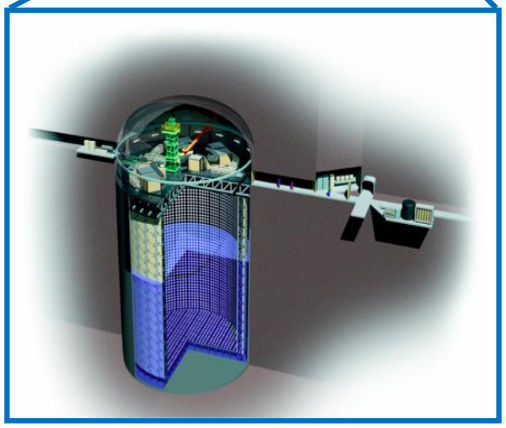
Long-baseline neutrino oscillation experiment installed in Japan. Data taking started in 2009.

11 countries
60 institutions
~400 people



Near detector Complex

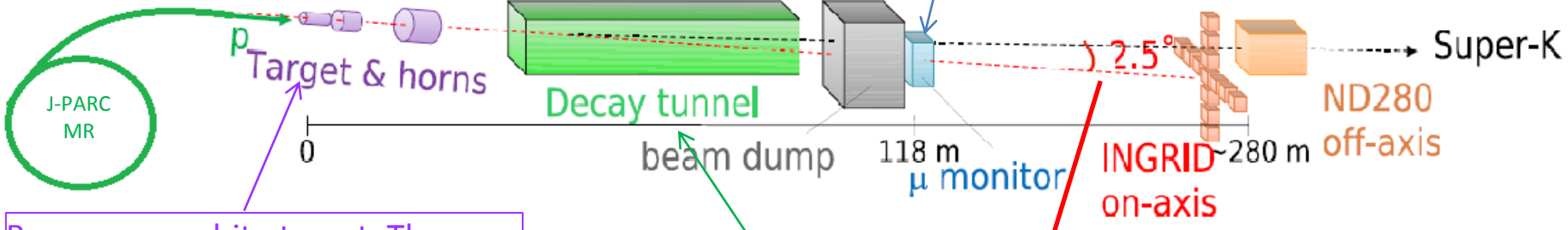




Beam production

30 GeV proton beam from J-PARC

μ monitor measures muons from pion decay



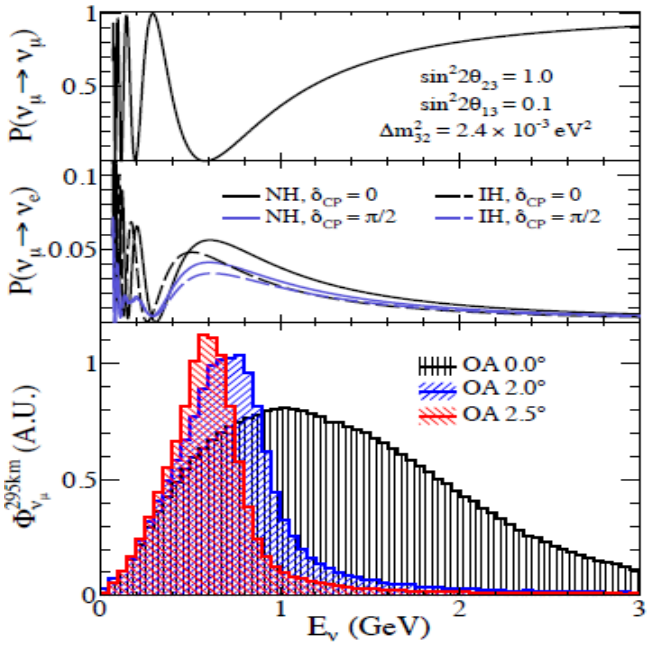
Beam on graphite target. Three magnetic horns focus charged hadrons

Pions, kaons, muons decay in 96 m decay volume.

Near Detector Complex

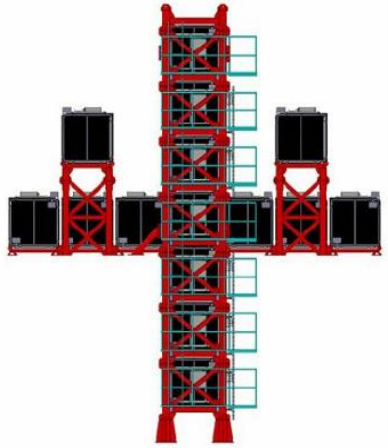
Off-axis (OA) neutrino beam

- ✓ High intensity narrow band beam
- ✓ Increase statistics @ osc. max. (0.6GeV)
- ✓ Decrease background from High Energy tail
- ✓ Dominated by CCQE
- ✓ Low ν_e background (three body decay disfavoured)



Near Detector Complex: INGRID & ND280

✓ INGRID (Interactive Neutrino GRID) is centered on the neutrino beam axis. Its purpose is to monitor the neutrino beam direction and stability.

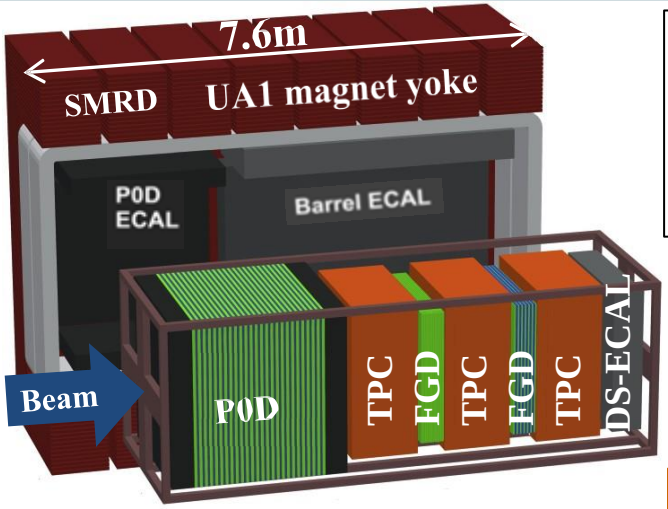


Main goals of **ND280**, located off axis (2.5°) and at 280 m from the target, are:

- ✓ Provide constraints for long-baseline oscillation analysis
- ✓ Reduce the systematic uncertainties
- ✓ Measurement of intrinsic wrong sign and flavour contaminations in the beam
- ✓ Cross section measurement below 1 GeV

A Large Dipole Magnet (UA1): 0.2T magnetic field to allow measurement of momenta and charges

Side Muon Range Detectors (SMRD): plastic scintillators instrumenting magnet iron slices



Pi0Detector (P0D): water layers and lead layers interleaved with scintillator-based tracking modules

ECals: sampling detector (scintillator and lead) to improve the identification of μ and π

2 Fine Grain Detectors (FGDs) ν targets plastic scintillator

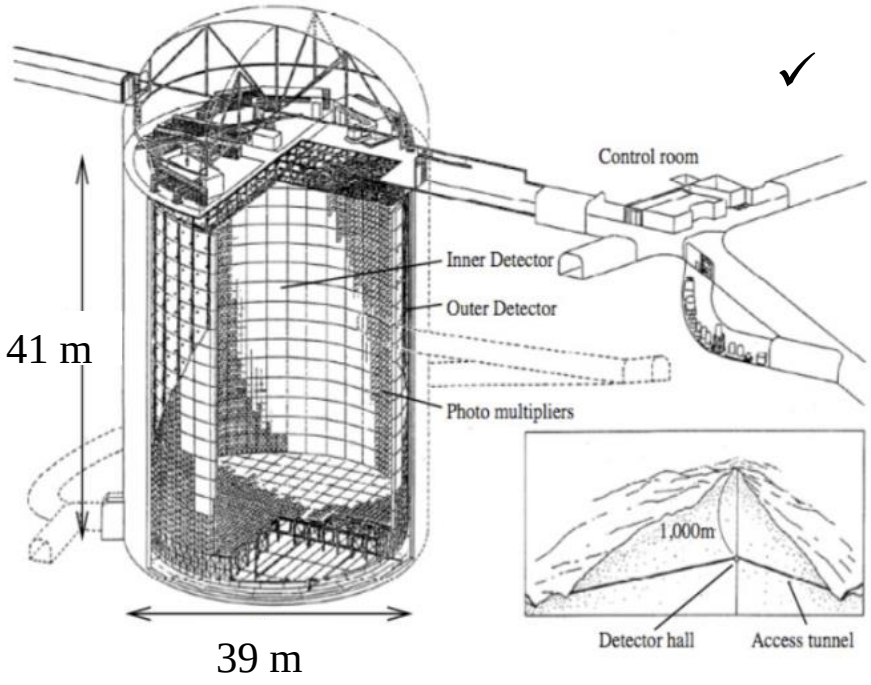
3 TPCs:

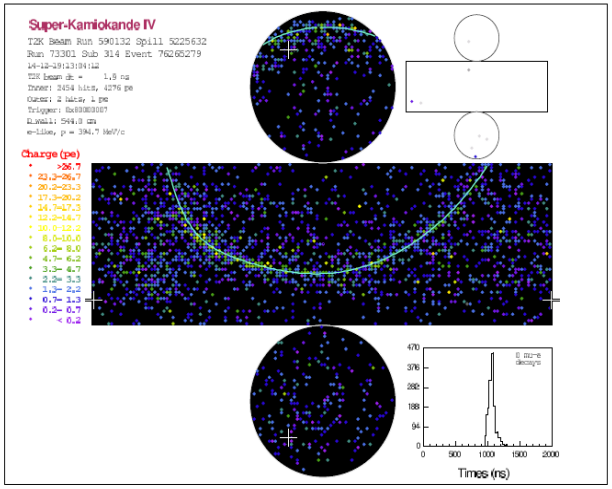
- ✓ Particle tracking
- ✓ Momentum and charge measurement
- ✓ Particle identification

SuperKamiokande (SK)

- ✓ SK is a water Cherenkov detector built 1 km deep in a cave of Mt. Ikenoyama operational since 1996 and at 295 km from the beam source at Tokai.

- ✓ Cylindrical tank filled with 50 kton (Fiducial mass for T2K analysis is 22.5kton) of ultra pure water divided in:
  - ✓ Inner Detector(ID) watched by 11,129 photomultiplier tubes (PMTs)
  - ✓ The outer detector (OD), around its inner walls there are 1,885 PMTs





$\overline{\nu}_e$ event candidate

Physics goals

Results achieved in neutrino mode (6.6×10^{20} POT)

- ✓ Discovery of $\nu_\mu \rightarrow \nu_e$ and precise θ_{13} measurement
- ✓ Precise measurement of $\nu_\mu \rightarrow \nu_\mu$ and thus of θ_{23}, Δm^2_{23}
- ✓ Neutrino X-sections below 1GeV @ND280
- ✓ ν_e disappearance in a sterile neutrino ($\nu_e \rightarrow \nu_s$)

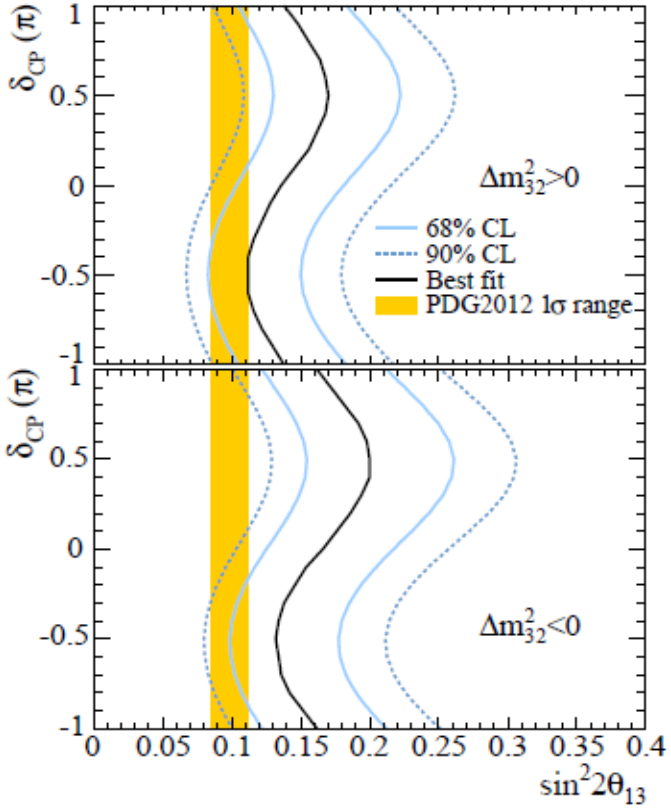
Future goals (50% $\bar{\nu}$ – 50% ν of 7.8×10^{21} POT)

- ✓ Discovery of $\bar{\nu}_\mu$ disappearance and $\bar{\nu}_e$ appearance up to 3σ
- ✓ Preliminary measurement of leptonic δ_{CP} violation up to 2.5σ
- ✓ Antineutrino X-sections below 1GeV @ND280
- ✓ Sterile neutrino searches

Preliminary result from first 4×10^{20} POT anti-nu sample here

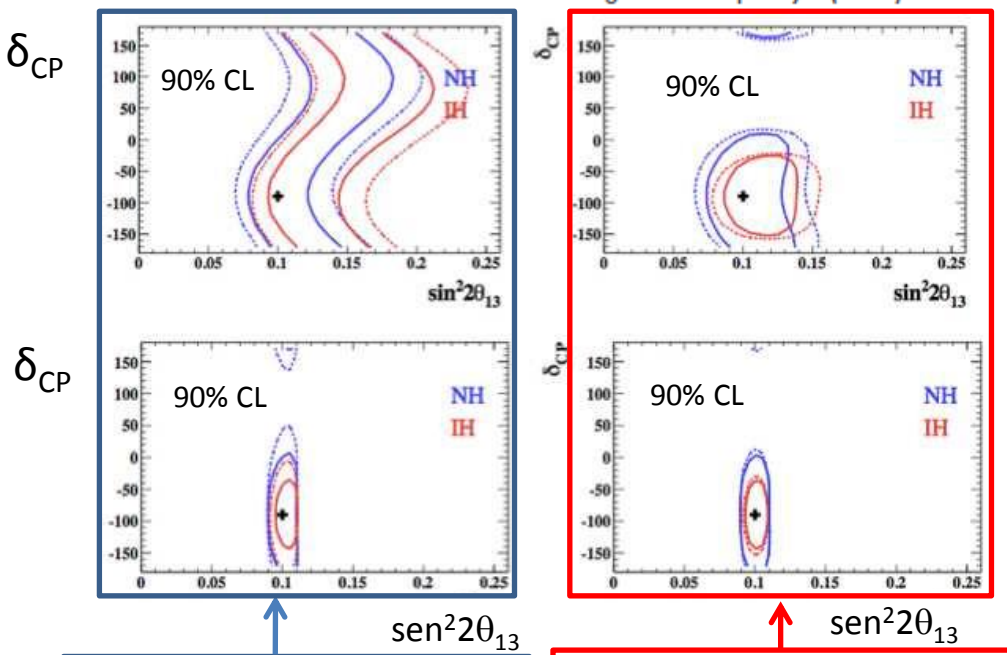
Why anti-neutrino?

- ✓ θ_{13} is big enough to allow the mesurement of the leptonic CP phase δ_{CP} detecting difference in the oscillation probability for ν and $\bar{\nu}$



Latest T2K δ_{CP} vs $\sin^2 2\theta_{13}$ result in neutrino beam mode

Prog. Theor. Exp. Phys. (2015) 043C01

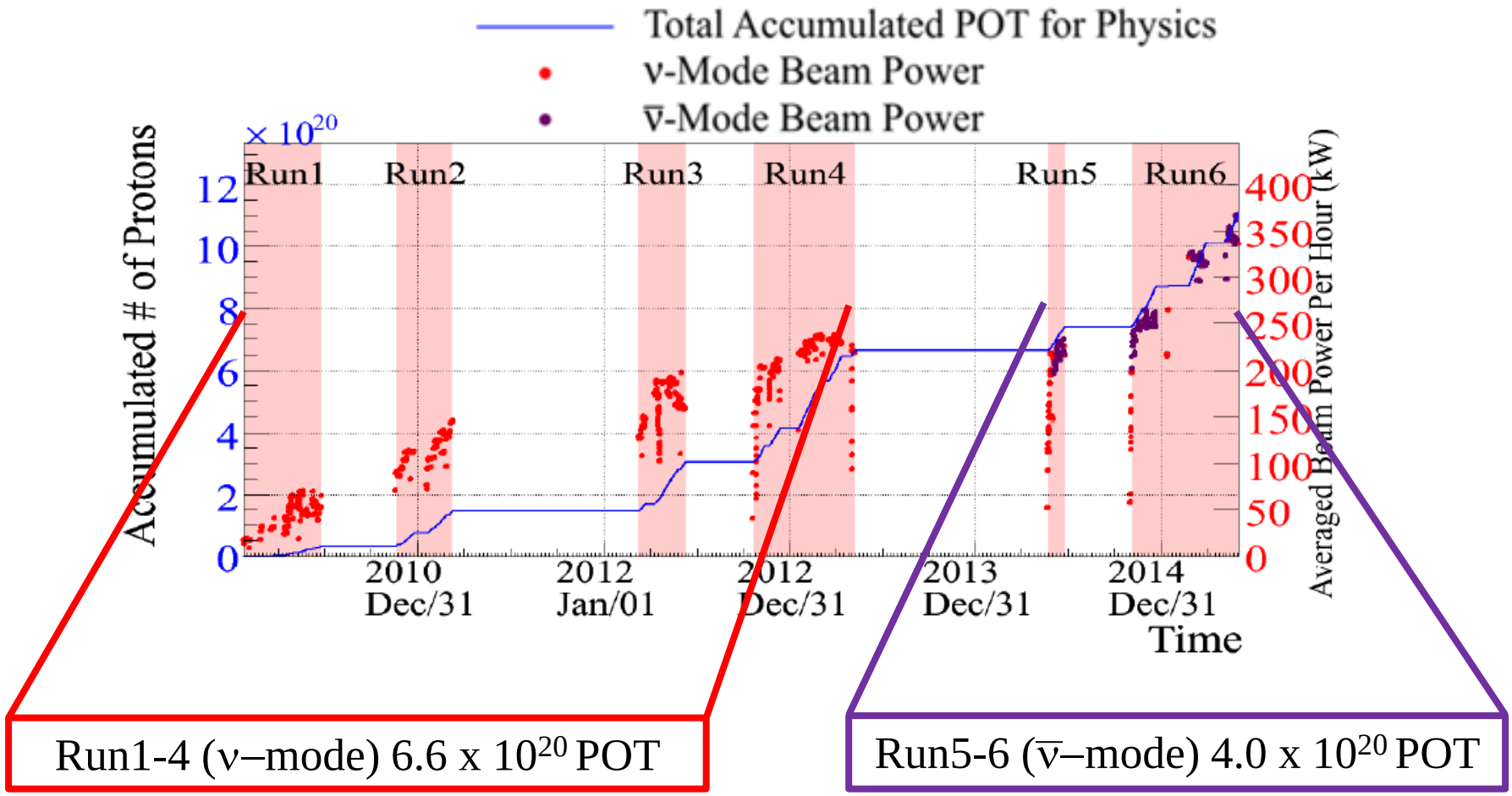


100% ν - running mode, without (top) and with (bottom) ultimate reactor constraint*.

50% ν - 50% $\bar{\nu}$- running mode, without (top) and with (bottom) ultimate reactor constraint*.

*Contour are plotter for the case true δ_{CP} = -90°, $\text{sen}^2 2\theta_{13}$ = 0.1 and NH. Solid contour: statistical error only. Dashed contour: stat+syst.

Data taking summary

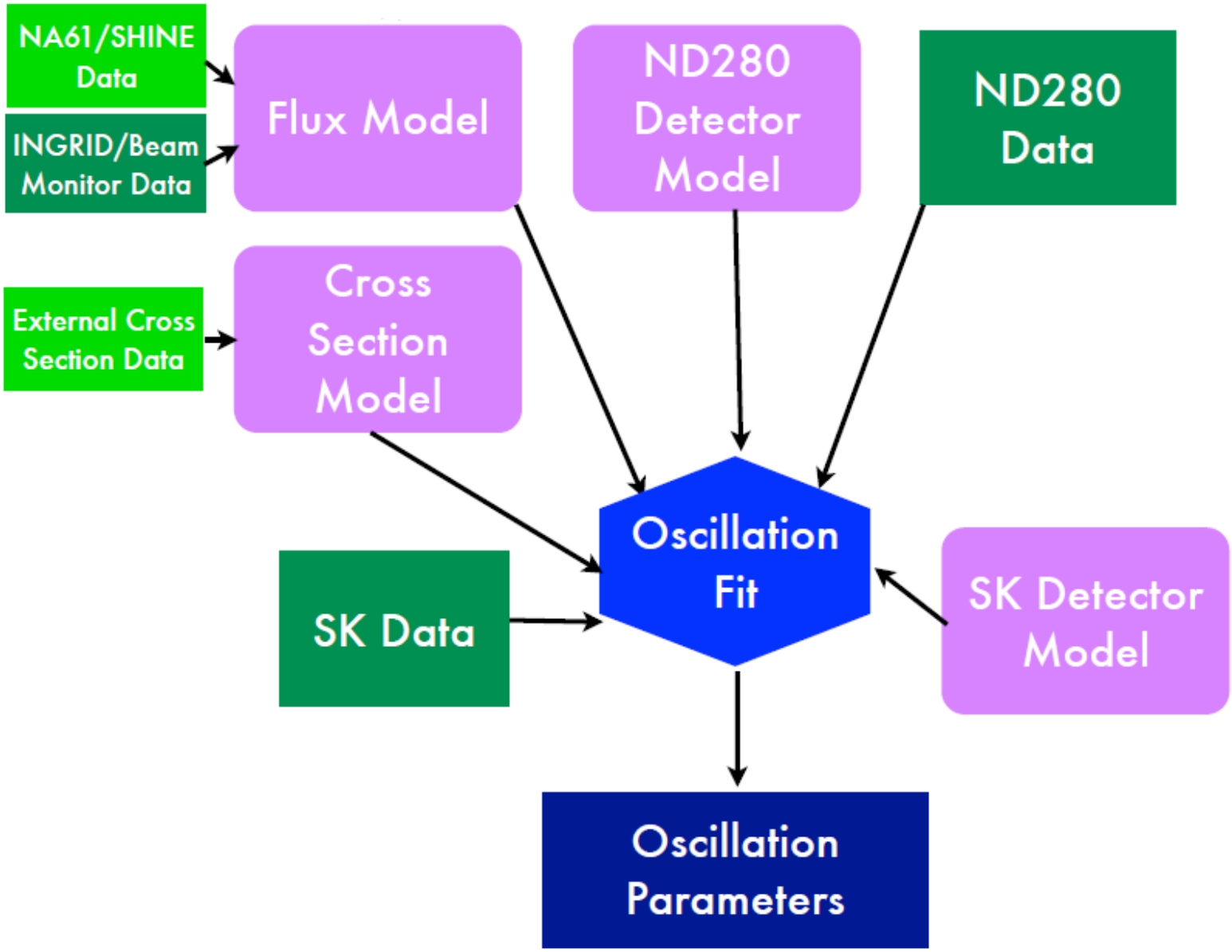


Run1-4 (ν–mode) 6.6 x 10^{20} POT

Run5-6 ($\bar{\nu}$–mode) 4.0 x 10^{20} POT

Total 1.06x10^{21} POT

Analysis Strategy

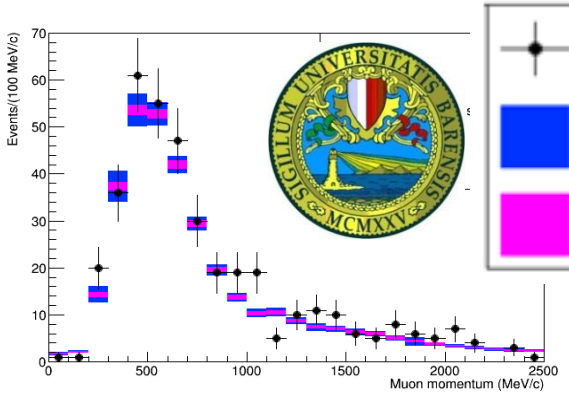


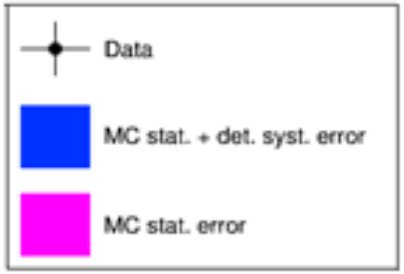
ND Event Samples

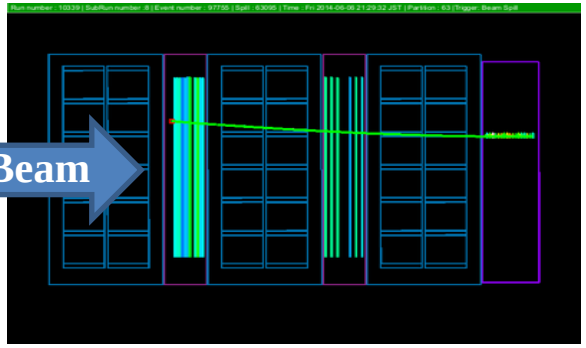
Select CC $\bar{\nu}_\mu$ candidates based on interactions with μ^+

- ✓ highest momentum track, positive charge, and PID consistent with muon
- ✓ Two sub-samples based on track multiplicity: CC-1Track, CC>1 Track
- ✓ Complementary selection of neutrino candidates in antineutrino mode

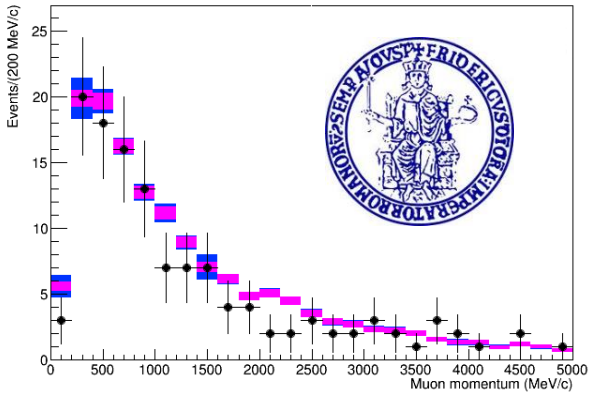
CC-1Track
antineutrino selection, anti-nu mode

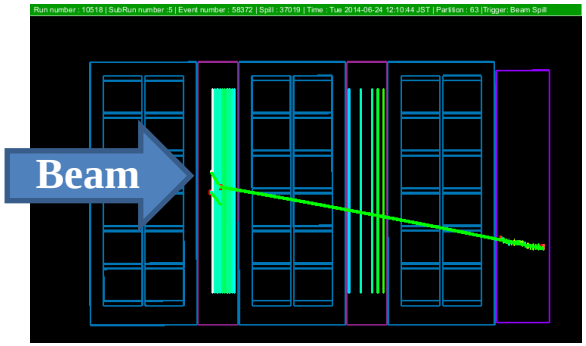






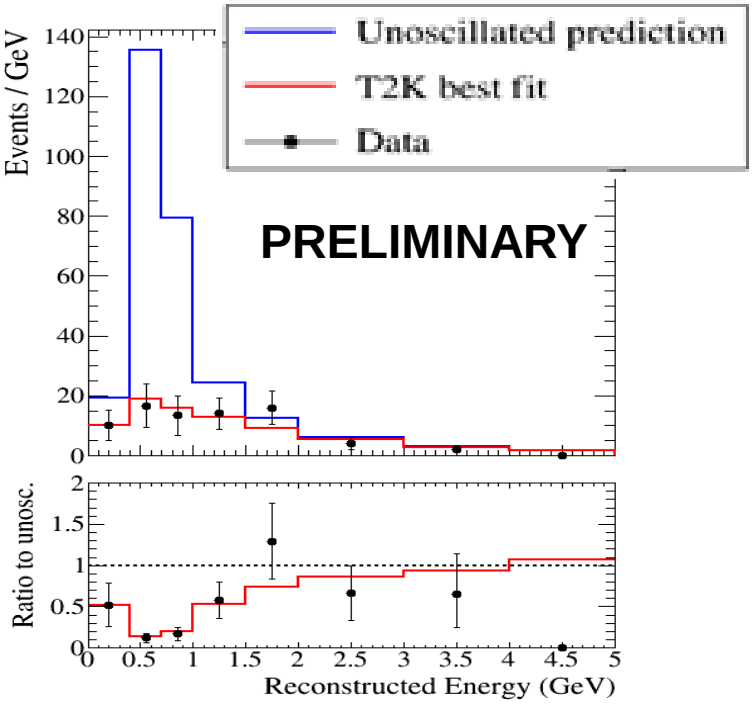
CC-1Track
neutrino selection, anti-nu mode

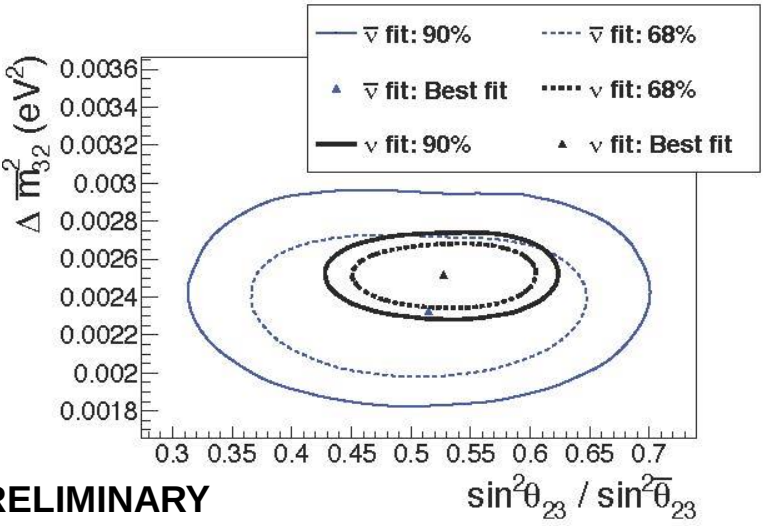




$\bar{\nu}_\mu$ disappearance

- ✓ $\bar{\nu}_\mu$ disappearance is examined using 4.0×10^{20} POT anti-neutrino run. 34 events are found where 104 events are expected for no oscillations.
- ✓ The best-fit oscillation parameters are calculated to be for normal hierarchy.
- ✓ Oscillation parameters for anti-neutrinos well agree with the parameters for neutrinos within statistical errors.





Normal Hierarchy

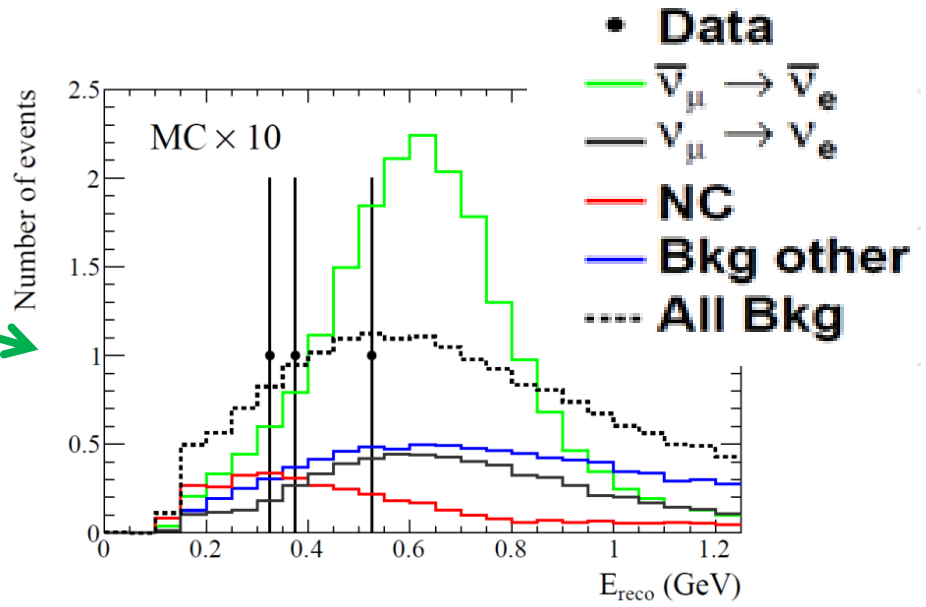
$$\Delta\bar{m}^2_{32} = (2.50^{+0.3}_{-0.2}) \times 10^{-3} \text{eV}^2$$

$$\sin^2\bar{\theta}_{23} = 0.46^{+0.14}_{-0.06}$$

$\bar{\nu}_e$ appearance

3 events observed!

PRELIMINARY



Normal Hierarchy

	$\delta_{CP} = -\pi/2$	$\delta_{CP} = 0$	$\delta_{CP} = +\pi/2$
Sig $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	1.961	2.636	3.288
Bkg $\nu_\mu \rightarrow \nu_e$	0.592	0.505	0.389
Bkg NC	0.349	0.349	0.349
Bkg other	0.826	0.826	0.826
Total	3.729	4.315	4.851

Inverted Hierarchy

	$\delta_{CP} = -\pi/2$	$\delta_{CP} = 0$	$\delta_{CP} = +\pi/2$
Sig $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.481	3.254	3.939
Bkg $\nu_\mu \rightarrow \nu_e$	0.531	0.423	0.341
Bkg NC	0.349	0.349	0.349
Bkg other	0.821	0.821	0.821
Total	4.181	4.848	5.450

T2K Cross Sections

Cross section measurements	Target	Reported in	Detector
$\bar{\nu}_\mu$ CC inclusive	**CH**	**Publication in progress**	**ND280, Tracker**
ν_μ CC inclusive	CH	PRD 87, 092003 (2013)	ND280, Tracker
ν_μ CCQE	CH	Accepted by PRD	ND280, Tracker
ν_e CC inclusive	CH	PRL 113, 241803 (2014)	ND280, Tracker
ν_μ NC π^0	CH/Water	Publication in progress	ND280, P0D
ν_μ NC elastic	Water	PRD 90, 072012 (2014)	SK
ν_μ CC inclusive	CH/Fe	PRD 90, 052010 (2014)	INGRID
ν_μ CCQE	CH	PRD 91, 112002 (2015)	INGRID
ν_μ CC coherent	CH	Publication in progress	INGRID
ν_μ CC coherent	CH	Publication in progress	ND280, Tracker
ν_μ CCπ^+	Water	Publication in progress	ND280, Tracker
ν_μ CC0π	CH	Publication in progress	ND280, Tracker

Thank you for your attention!