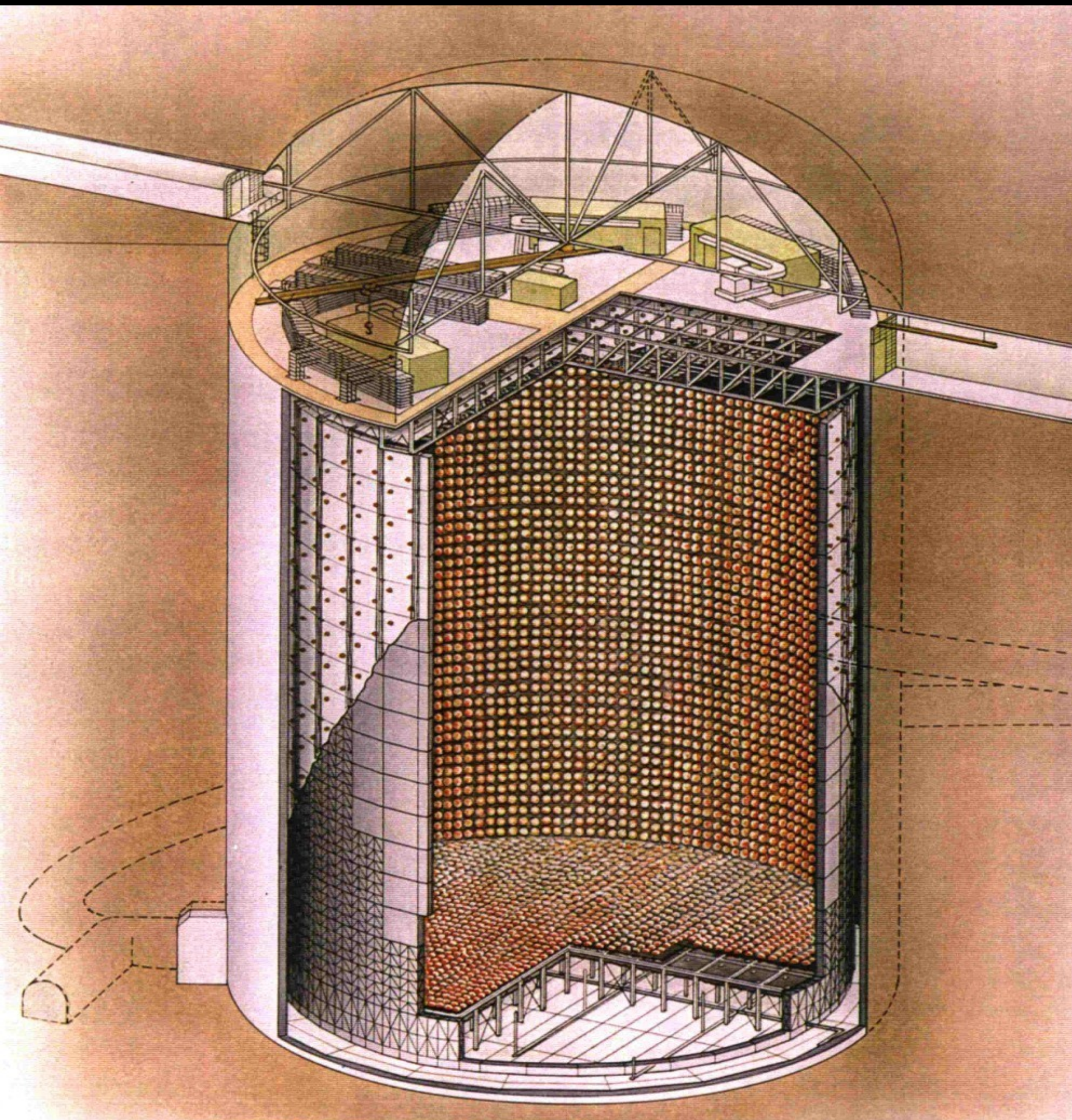
Recent T2K Oscillation Results



L. Ludovici
INFN/Roma

Jennifer Consortium
General Meeting
October 6th, 2017

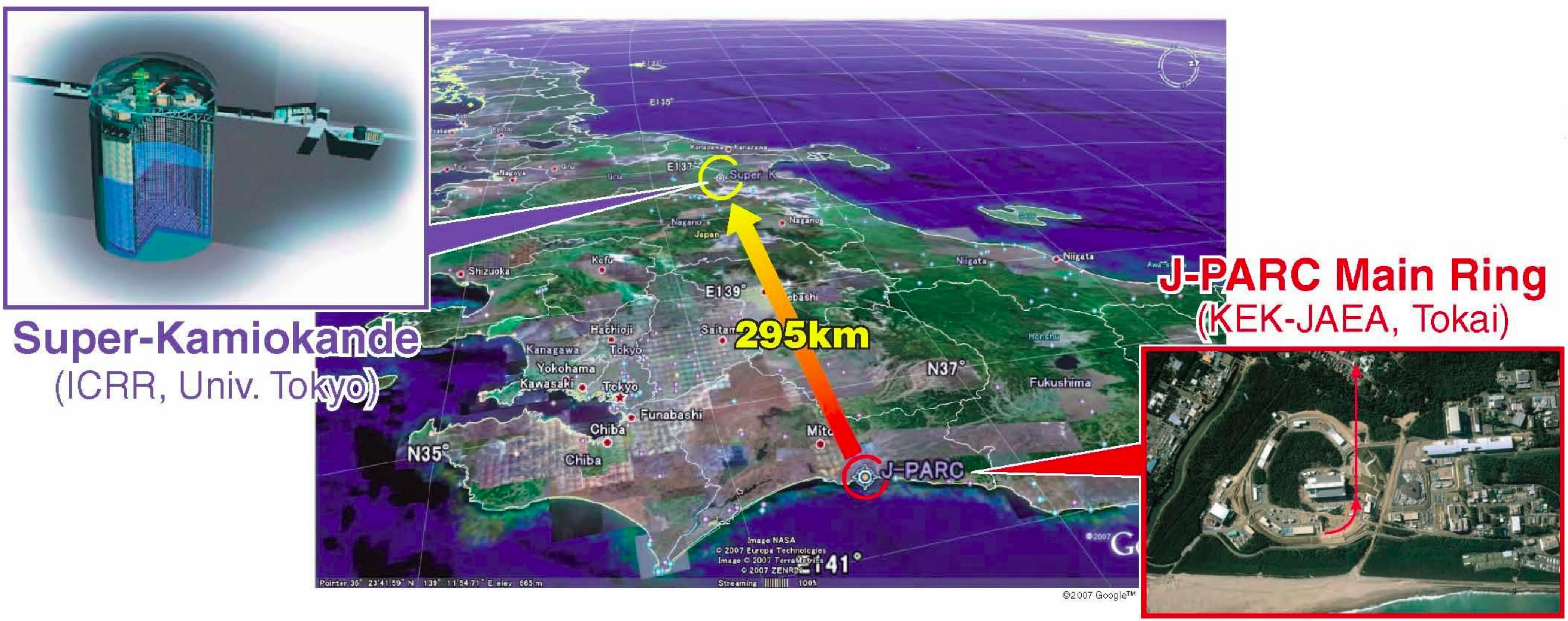
T2K experiment

Recent oscillation results

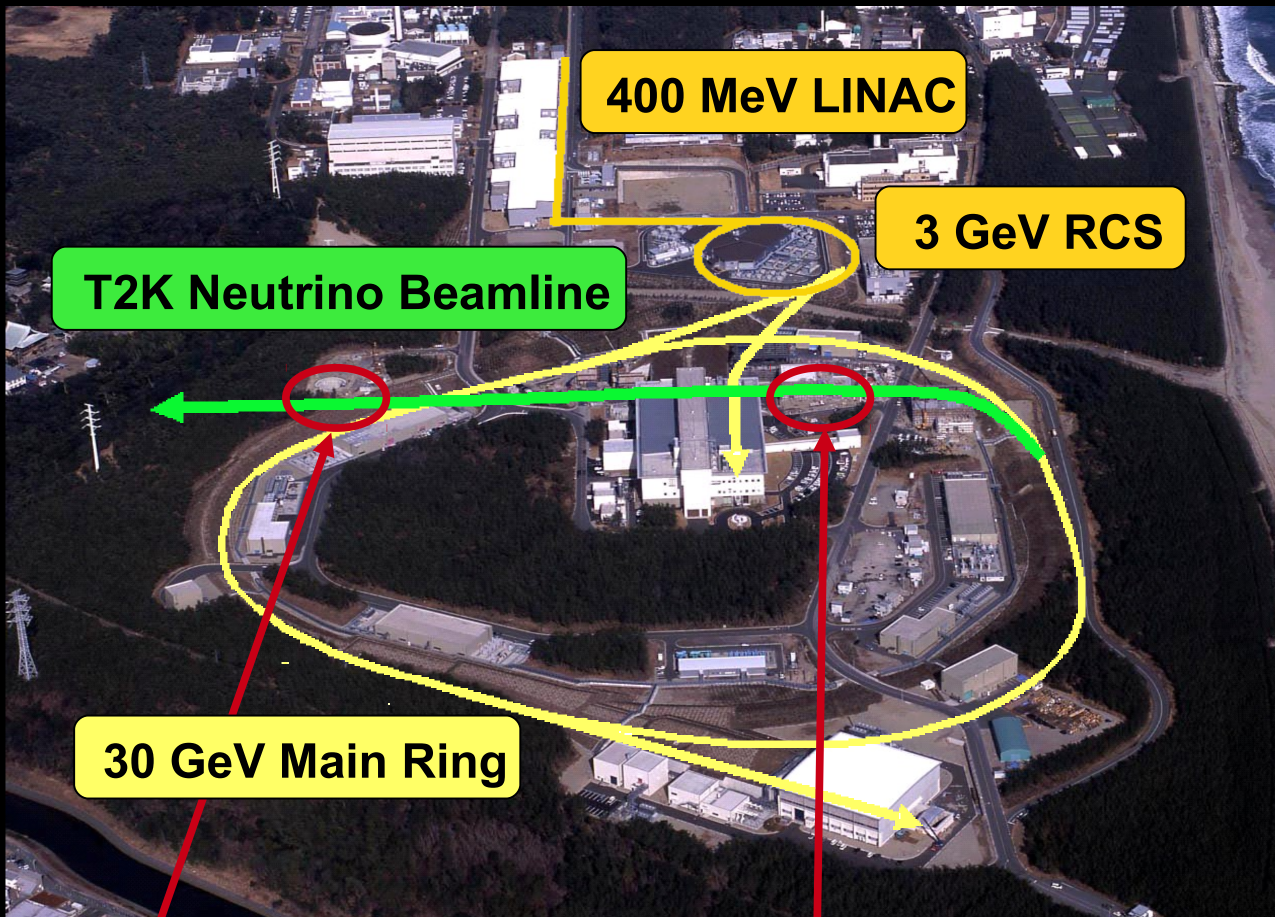
Conclusions & Outlook

London 22-23/9/2016
EU Grant n.644294

T2K (Tokai to Kamioka) experiment



JPARC Neutrino Beamline



ND280
On-axis and off-axis detectors at 280m

TARGET STATION
750KW carbon target (civil engineer designed for 4MW)

400 MeV Linac

3GeV Rapid Cycling Synchrotron (25Hz,1MW)

30 GeV Main Ring

750KW design power

Normal+Superconducting proton extraction line

Beam position and CT

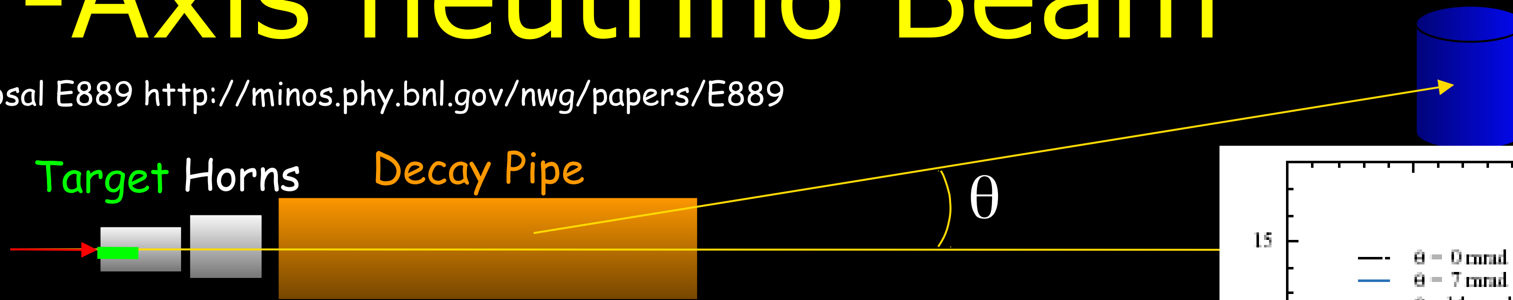
3 horns focusing system

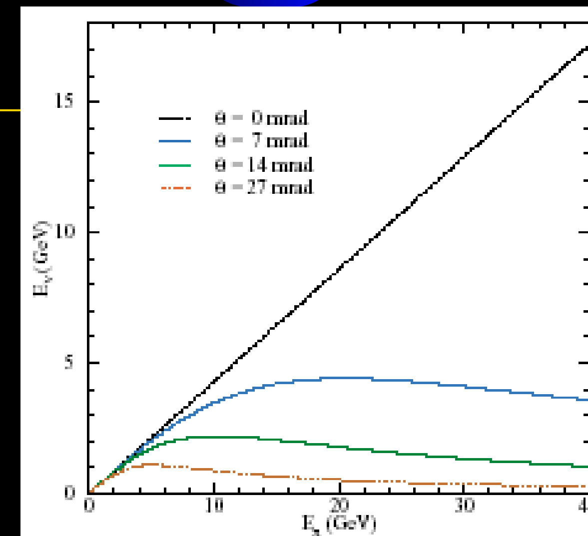
He filled decay volume

Muon monitor system

Off-Axis neutrino Beam

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

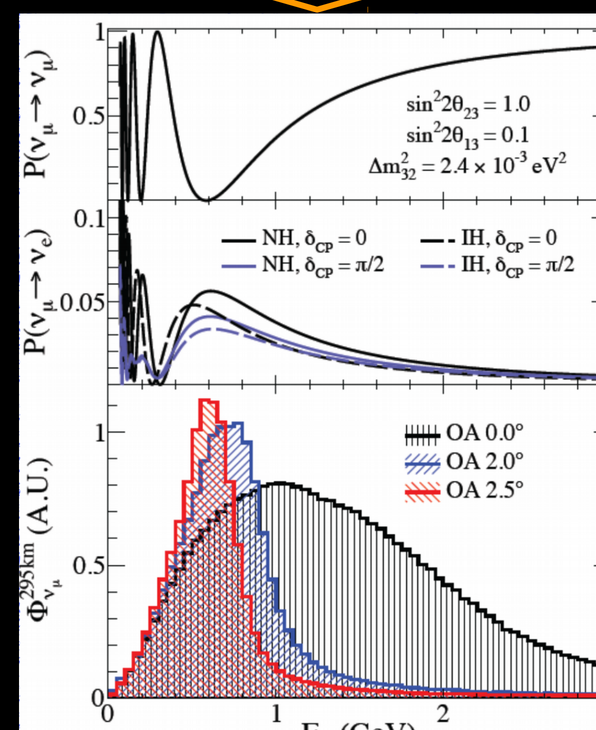




$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2\,(E_\pi - p_\pi \cos\theta)} \qquad \Phi_\nu = \frac{1}{4\pi L^2}\,\frac{m_\pi^2}{(E_\pi - p_\pi \cos\theta)^2}$$

$E_\pi \gg m_\pi$, 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 NCπ^0 bckg.

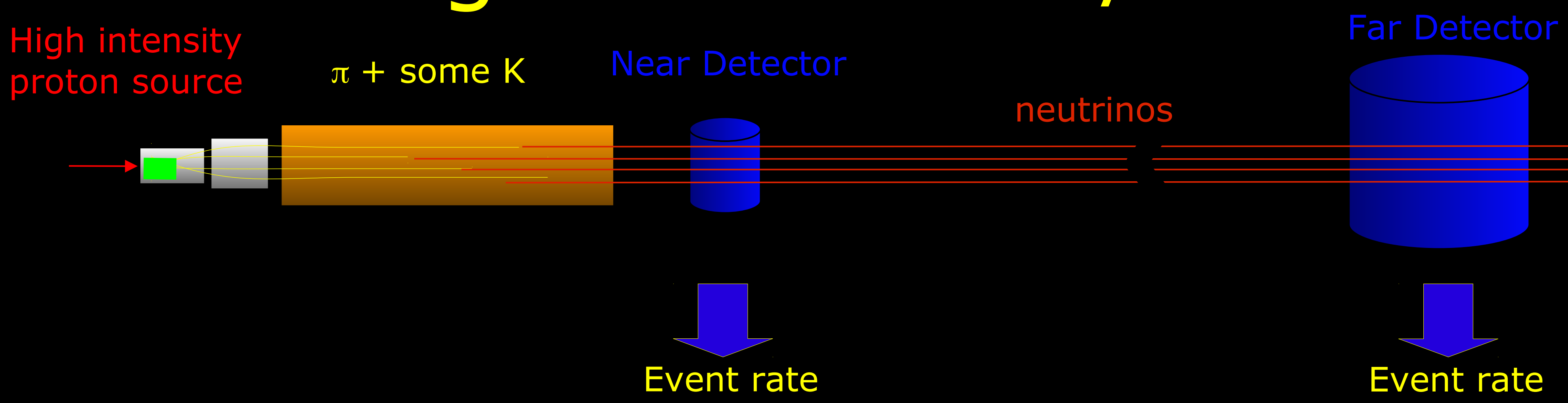
Reduced ν_e contamination

Tune energy to maximise sensitivity:

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

Beam energy almost fixed by geometry

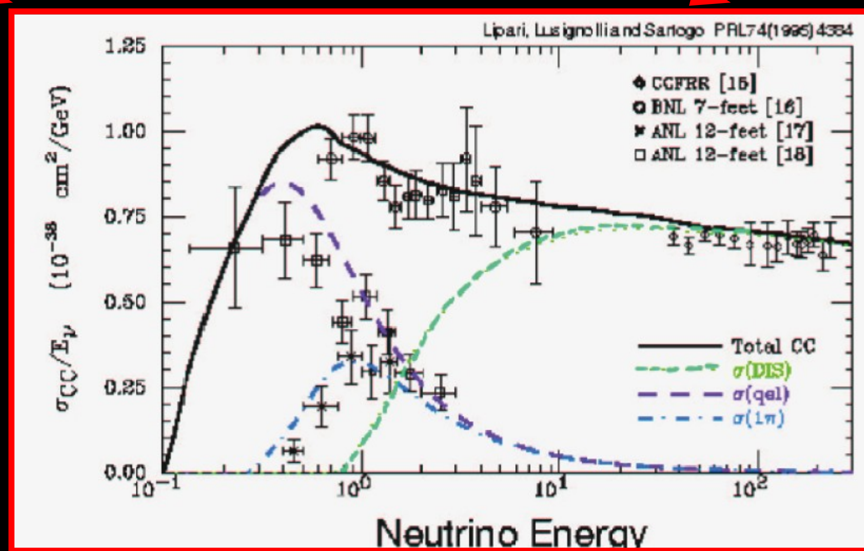
Long Baseline Far/Near



$\Phi_\nu^{near}(E)$

Beam monitoring
Beam simulation MC
Hadroproduction experiments

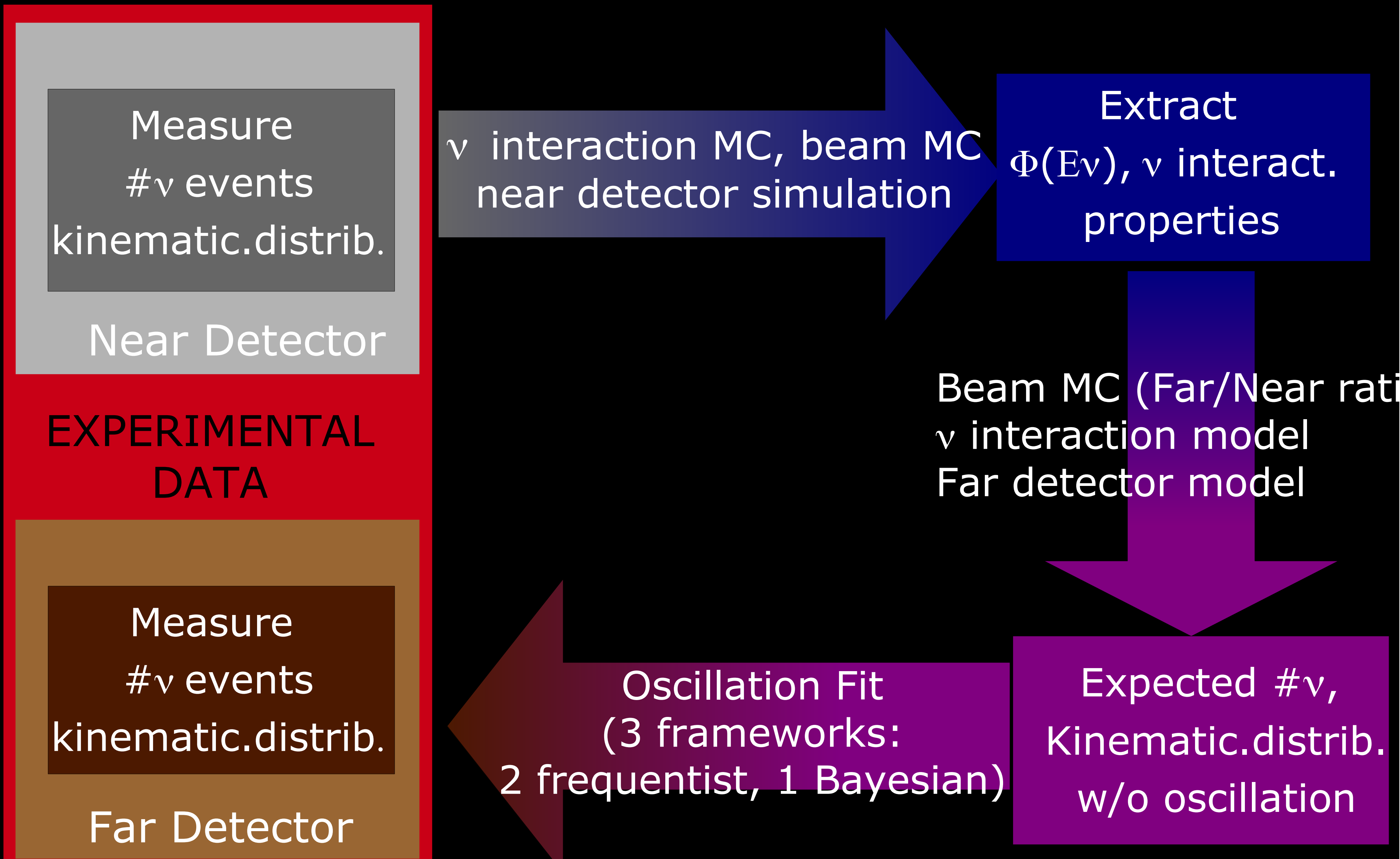
$\sigma(E) \times \Phi_\nu^{near}(E) \Leftrightarrow \sigma(E) \times \Phi_\nu^{far}(E)$



$\sigma(E)$

Interaction models
Past experiments constraints

T2K Analysis Strategy



T2K Analysis Strategy

Measure
#ν events
kinematic.distrib.

Near Detector

EXPERIMENTAL DATA

Measure
#ν events
kinematic.distrib.

Far Detector

ν interaction MC, beam MC
near detector simulation

Extract
Φ(Eν), ν interact.
properties

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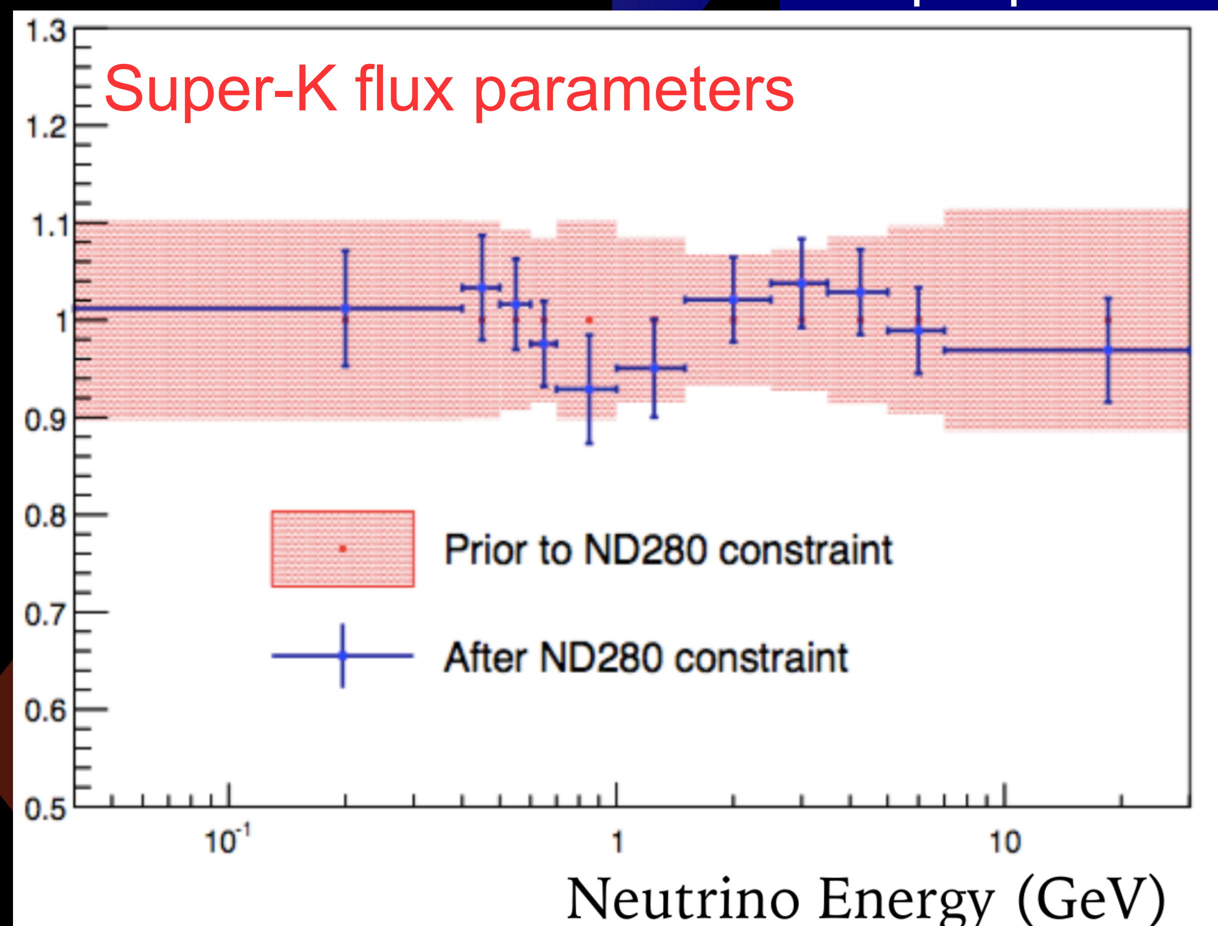
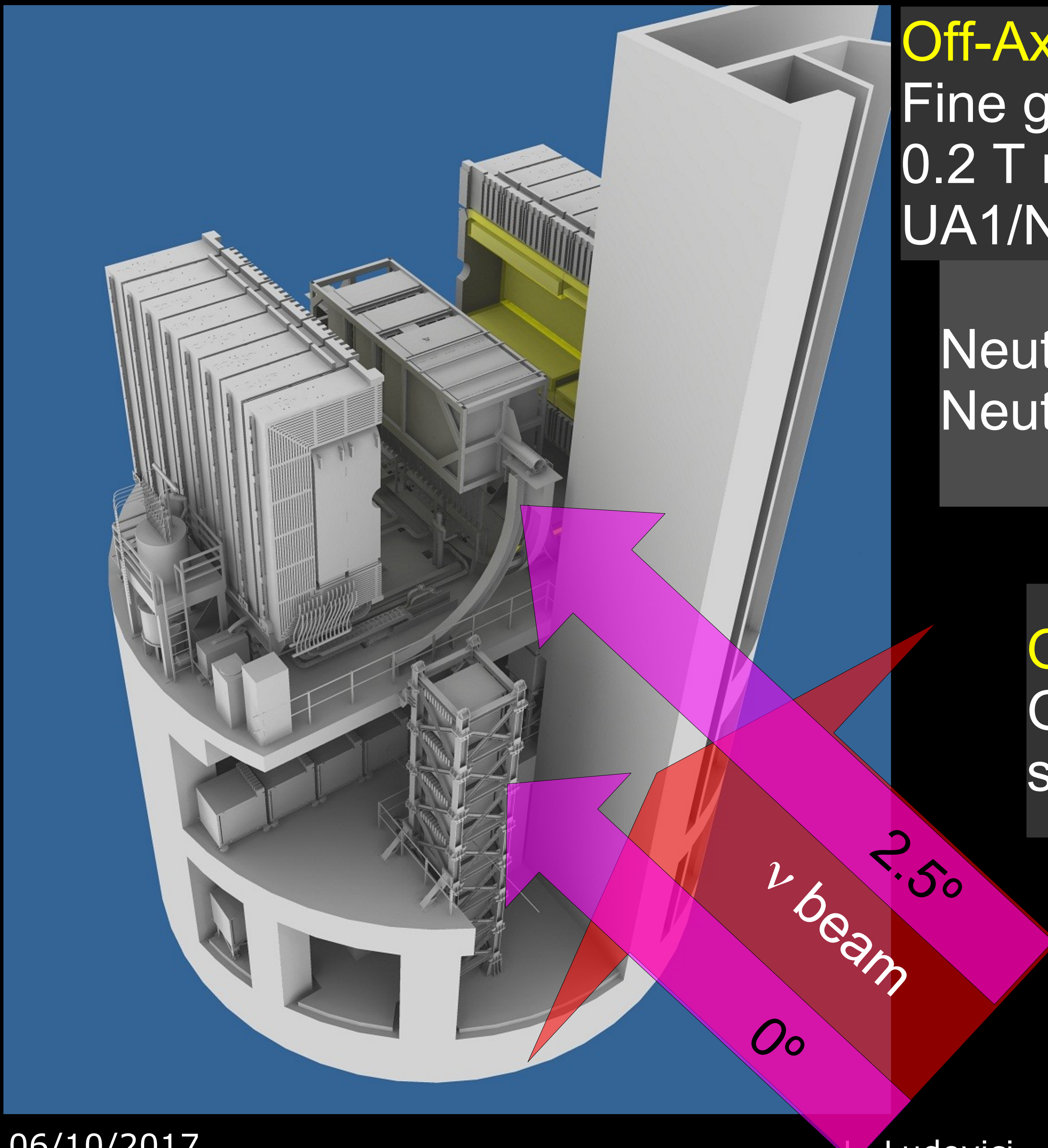


T2K Near Detector



Off-Axis detector (ND280)
Fine grain detectors+TPC trackers
0.2 T magnetic field (refurbished UA1/NOMAD magnet)

Neutrino flux
Neutrino interaction model

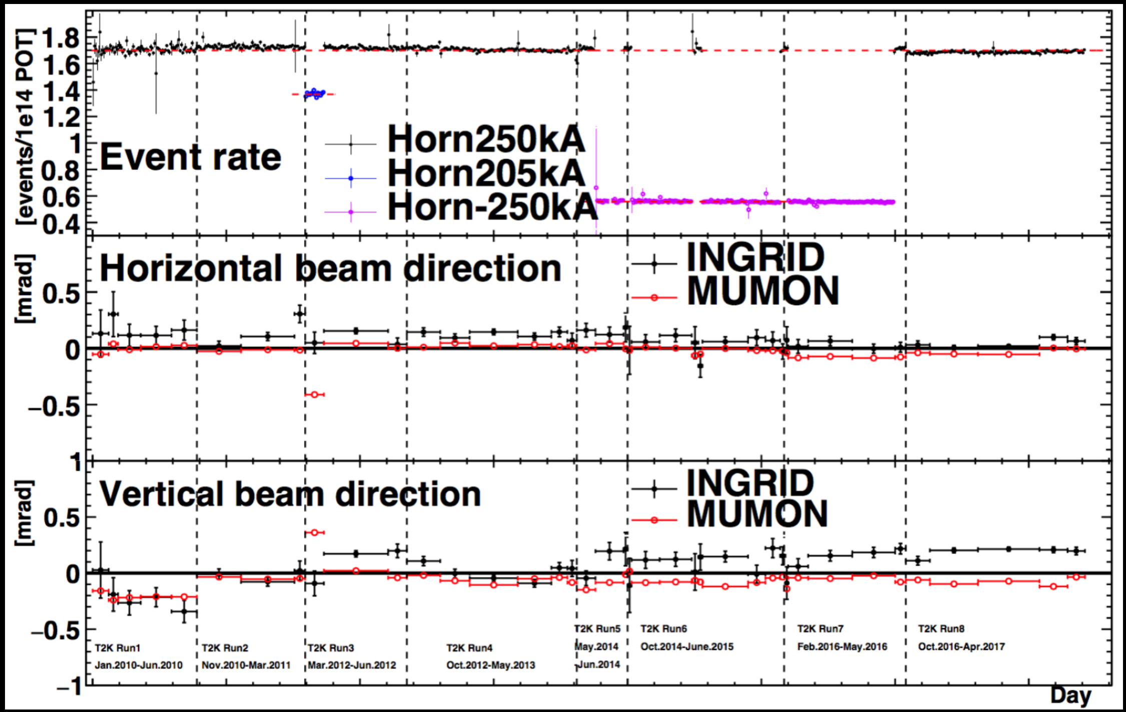
On-Axis detector (INGRID)
Grid of Scintillator/Iron sandwich blocks

Measurement of beam direction and profile
Beam stability monitor

On-Axis (INGRID)

Grid of Fe/Scintillator sandwich detectors spanning across the neutrino beam center

Day by day monitor of neutrino event rates and beam profile stability



1 mrad → 2% beam energy shift

Off-Axis detector

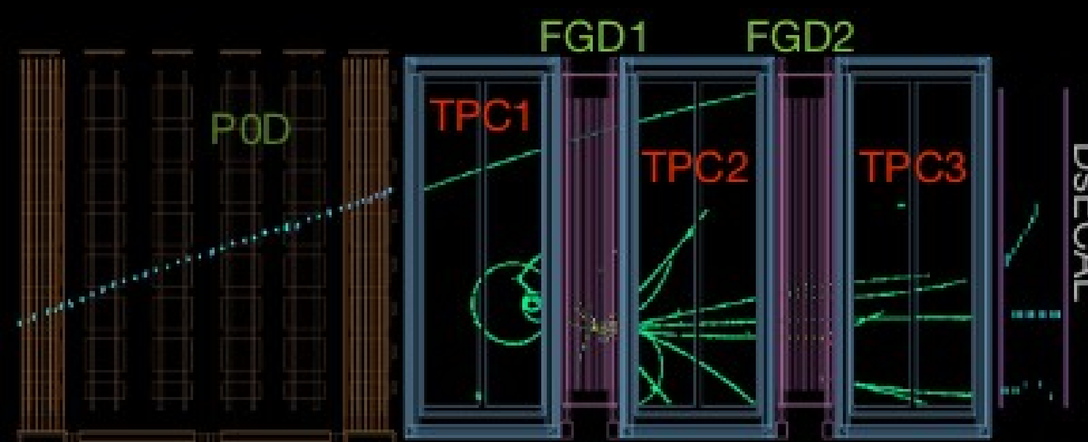
MAGNET
0.2 T (former UA1/NOMAD magnet)

SMRD (side muon range detector)
Scintillator planes in the magnet yoke

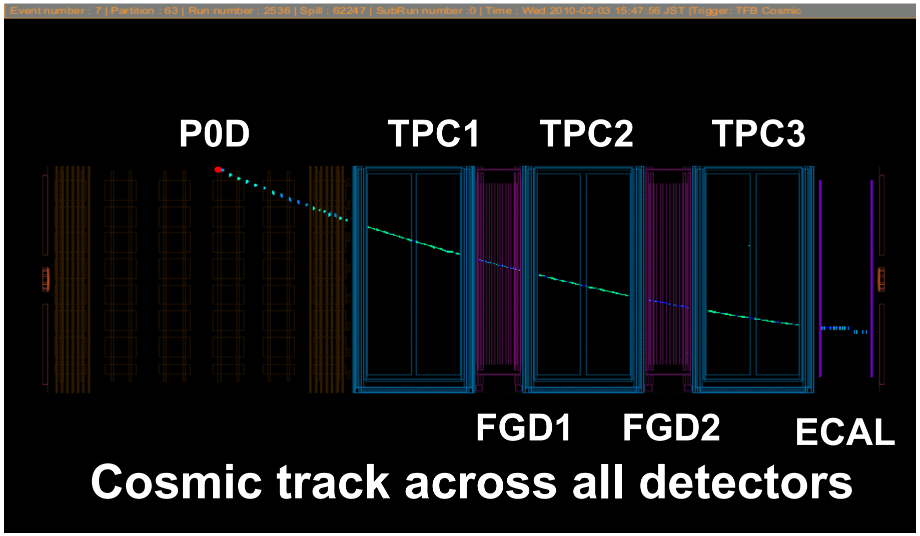
TRACKER: 2 FGD + 3 TPC
FGD (scintillating bars ~1x1cm): fully active neutrino target
TPC: tracking, momentum, e/μ PID (dE/dx ~10^3 muon rejection)

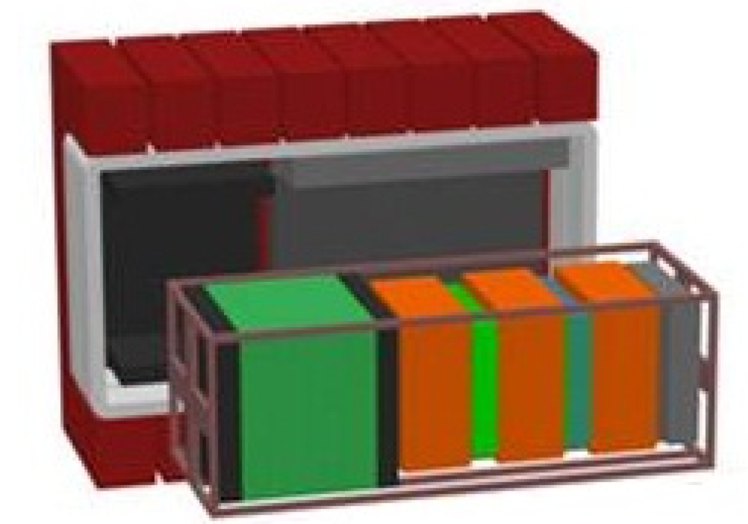
P0D (π° detector)
Scintillator/(brass/Pb), optimised for photon conversion and reconstruction

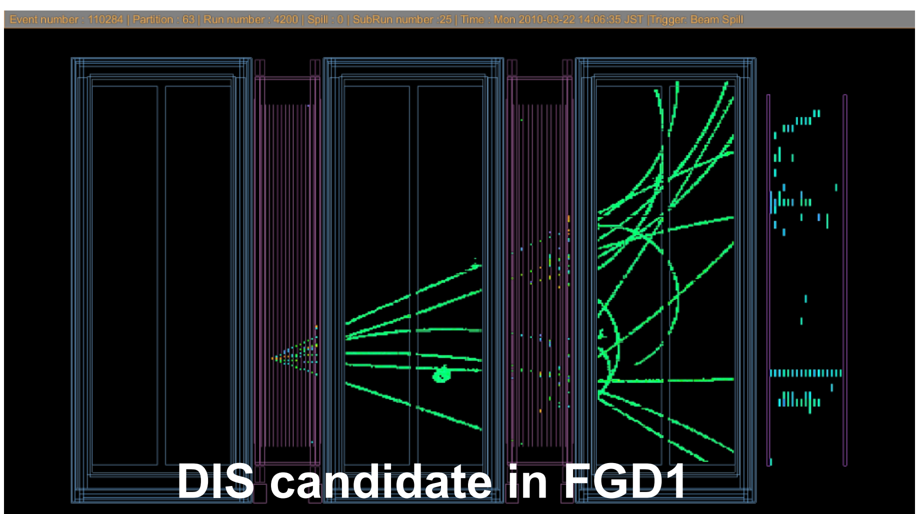
ECAL
Pb/Scintillator tracking calorimeter (e,γ energy flow and e/μ/π PID)

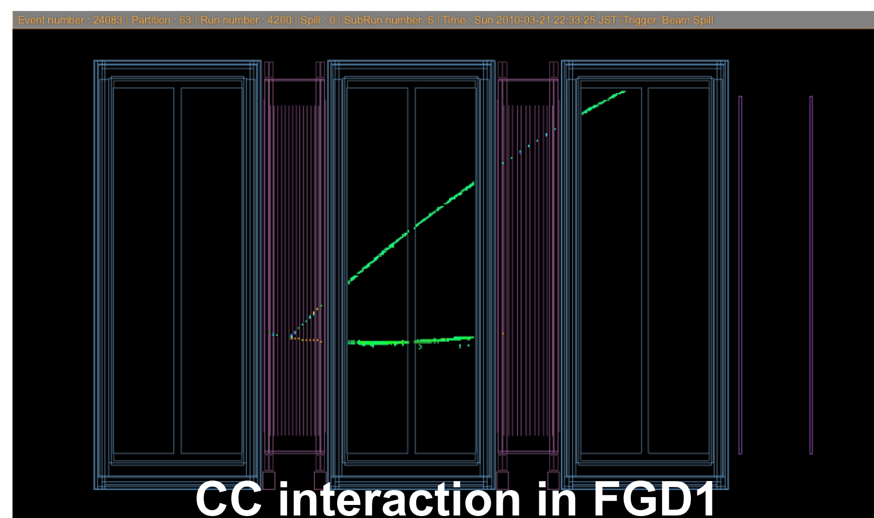


ND280 events

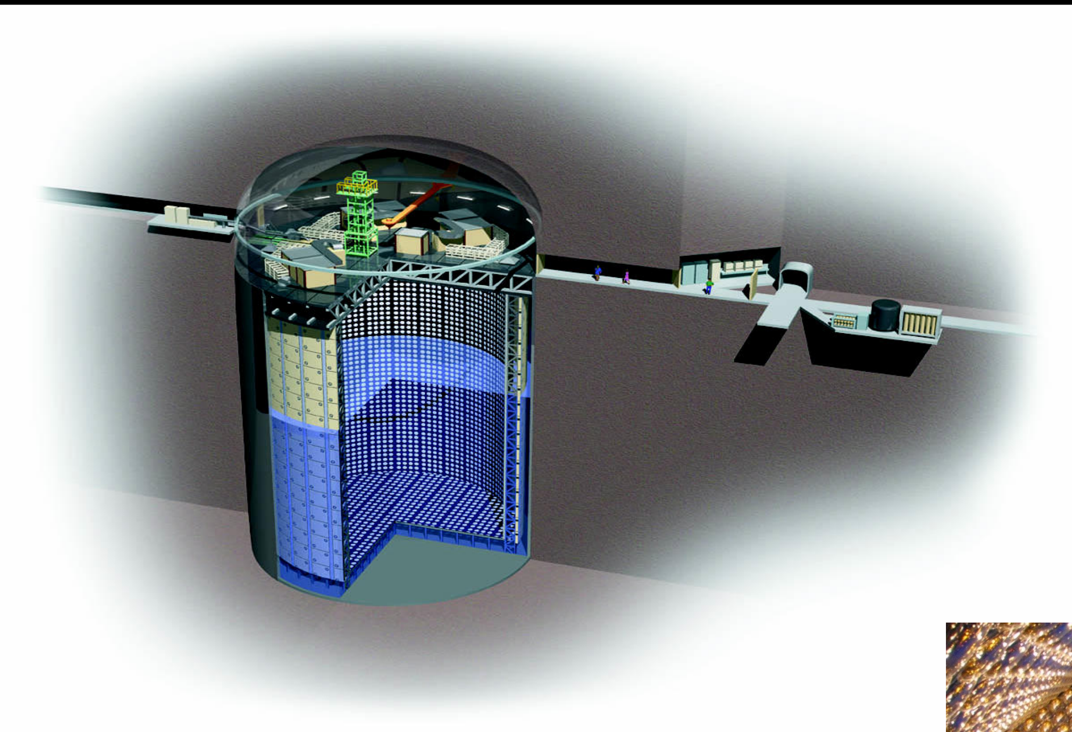








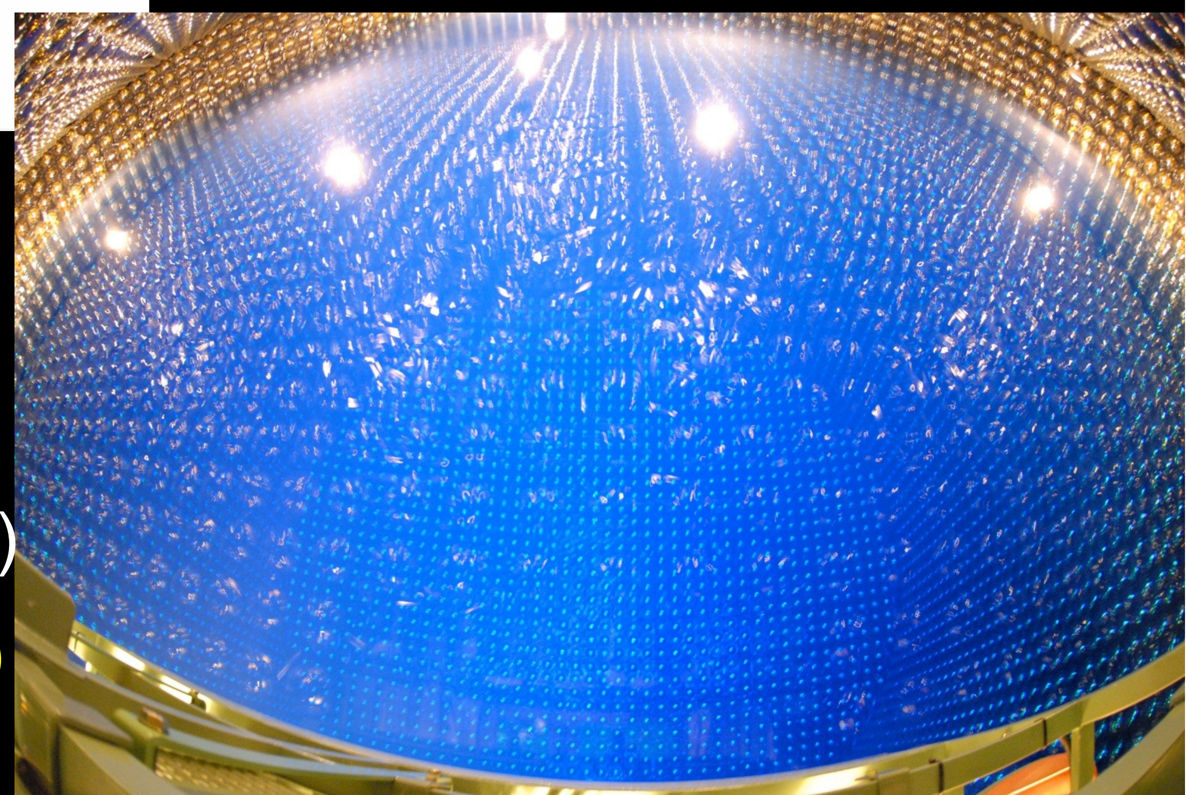
Super-Kamiokande



50 kt water Cherenkov

Inner Detector:
11,129 20" PMTs, 40% coverage

Outer Detector:
~2000 8" PMTs



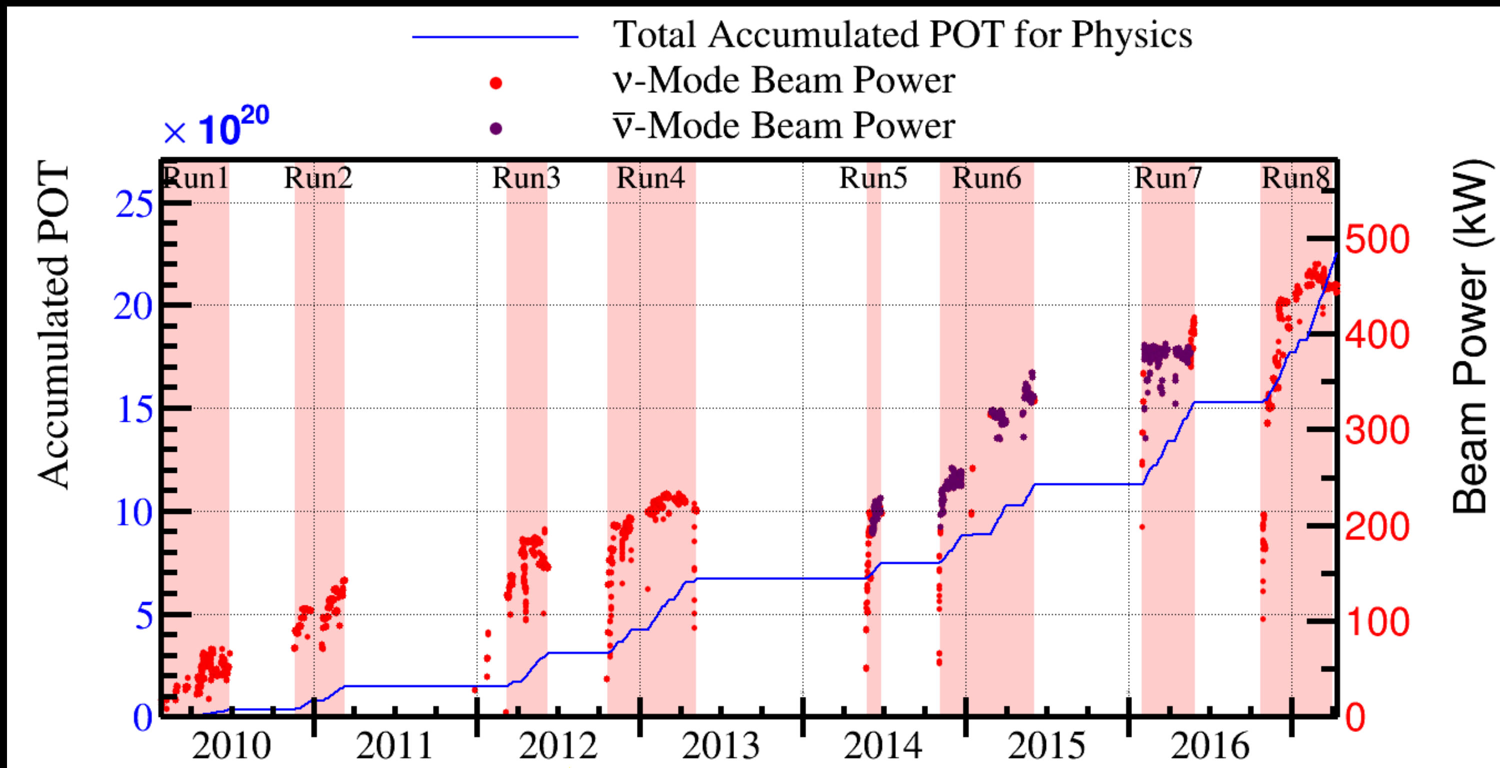
Operational since 1996 (SK I)

After 2001 accident running with 20% coverage (SK II)

Reconstructed in 2006 (SK III)

DAQ upgrade in 2008 (SK IV)

T2K Data Collection



1^st^ ν_e appear. 2.5σ
1^st^ ν_μ disapp.

ν_e appear.
3.1σ

ν_e appear. 7.3σ
1^st^ δ_{CP} constraint

Summer 2016 published
PRL 118(2017) 15801

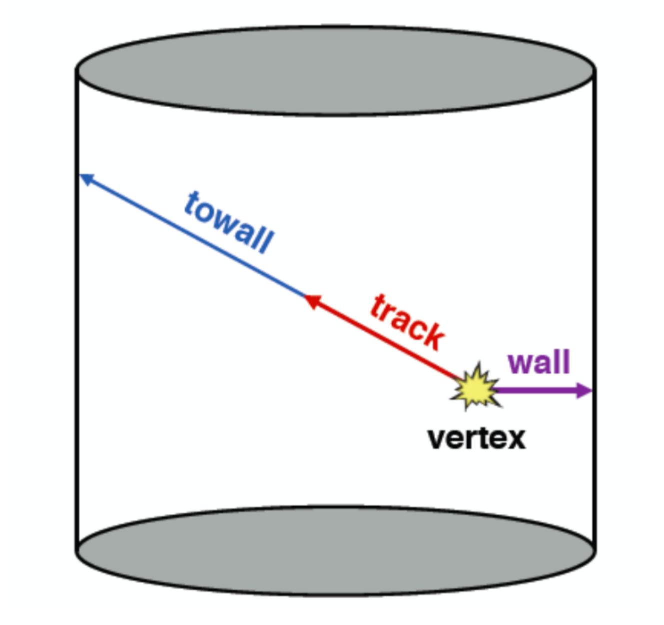
14.7 (7.6) x10^{20} PoT in neutrino(antineutrino) mode, 29% of approved T2K PoT
Stable operations at 470 kW last year → doubled run1-4 neutrino statistics

2017 Analysis Improvements

Super-K event reconstruction:

- new algorithm (fitQun) applied to all samples
- optimisation of fiducial volume cuts

→ 30% increase in “effective” statistics



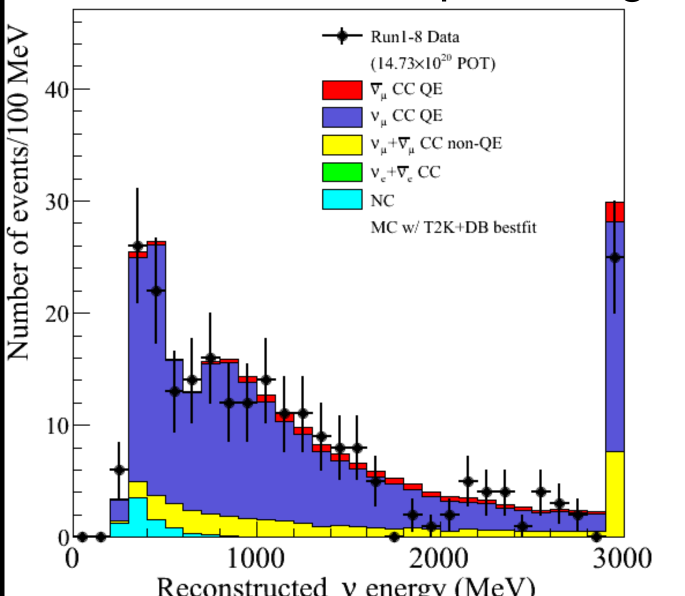
Interaction model in our MC neutrino interaction generator (NEUT):

- inclusion of a model (Valencia 2p-2h model) for multi-nucleon processes
- inclusion of long range correlation effects in the nucleus (random phase approximation, RPA)

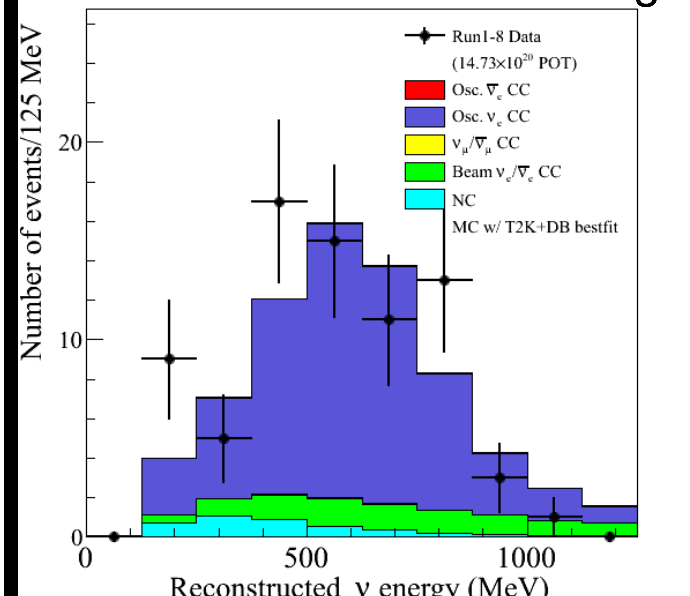
New parametrisation of uncertainties, still under systematic checks for robustness → effect is small for δ_{CP} but larger for “atmospheric parameters”

Far detector samples

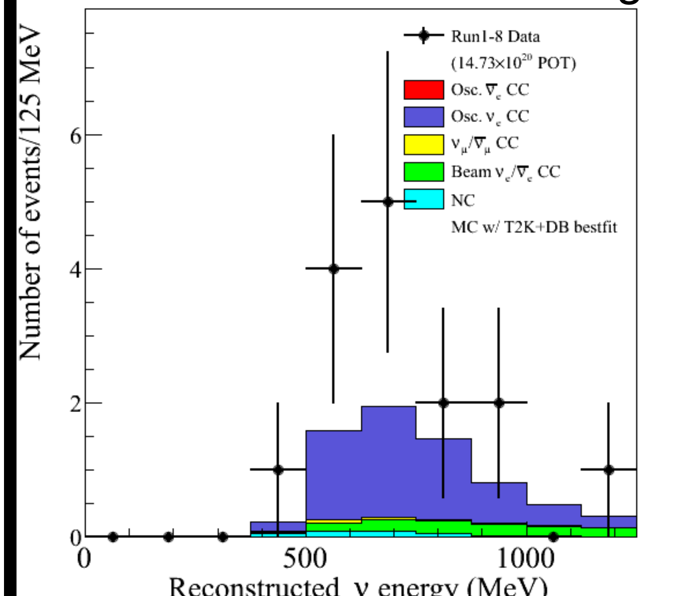
Neutrino CCQE 1μ-like ring



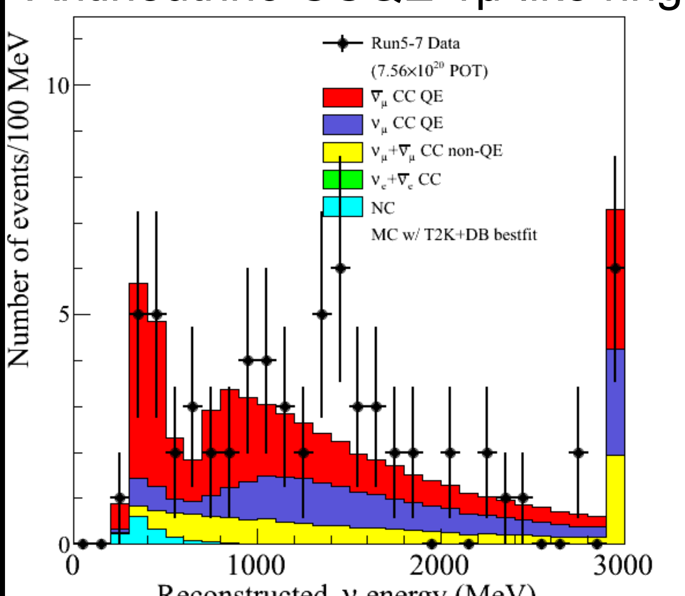
Neutrino CCQE 1e-like ring



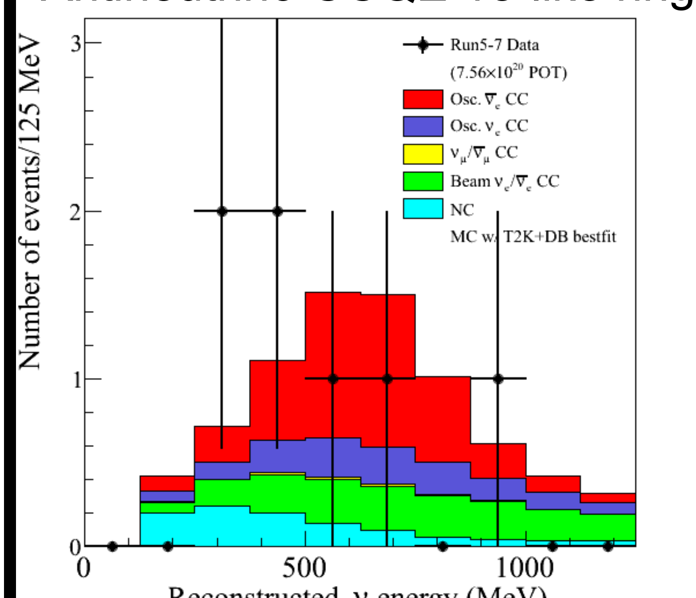
Neutrino CC1π 1e-like ring



Antineutrino CCQE 1μ-like ring

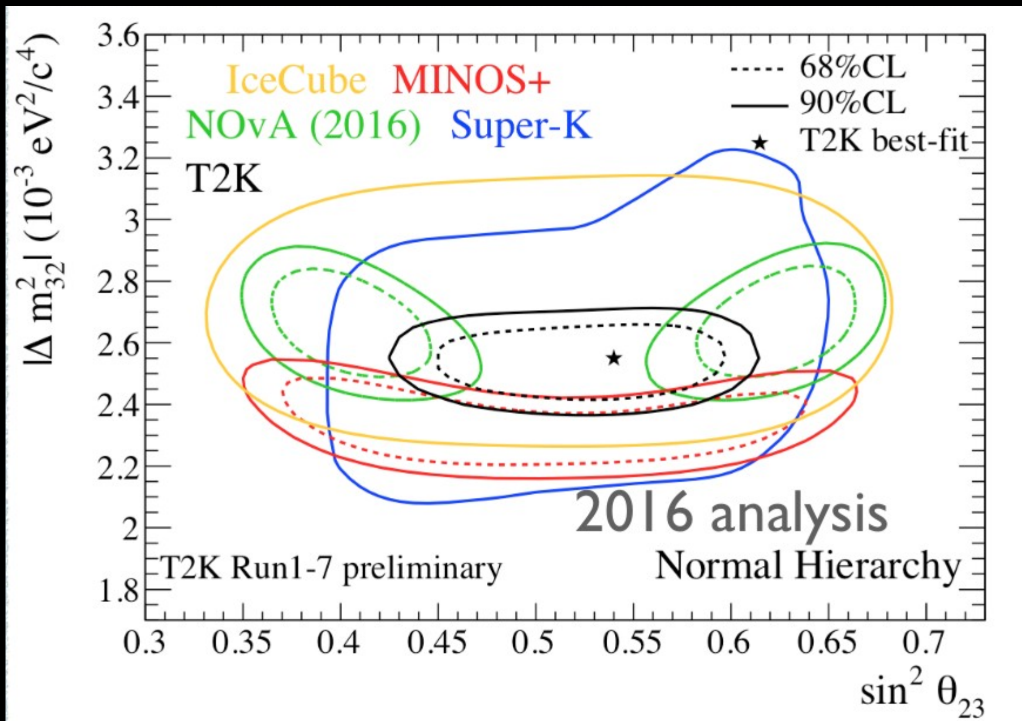


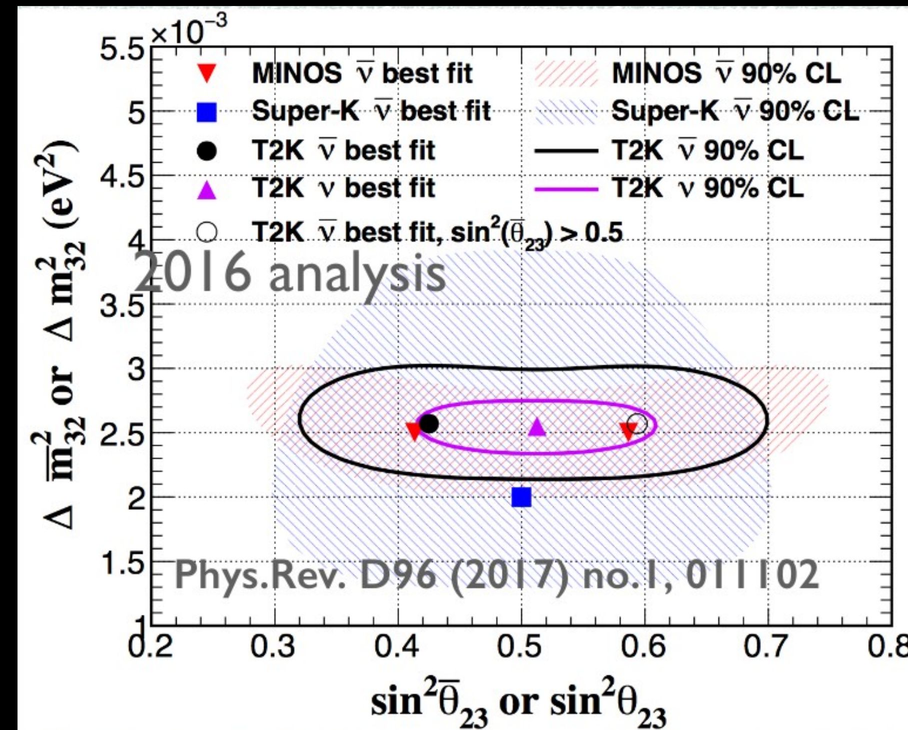
Antineutrino CCQE 1e-like ring



T2K Preliminary

Atmospheric parameters (2016)

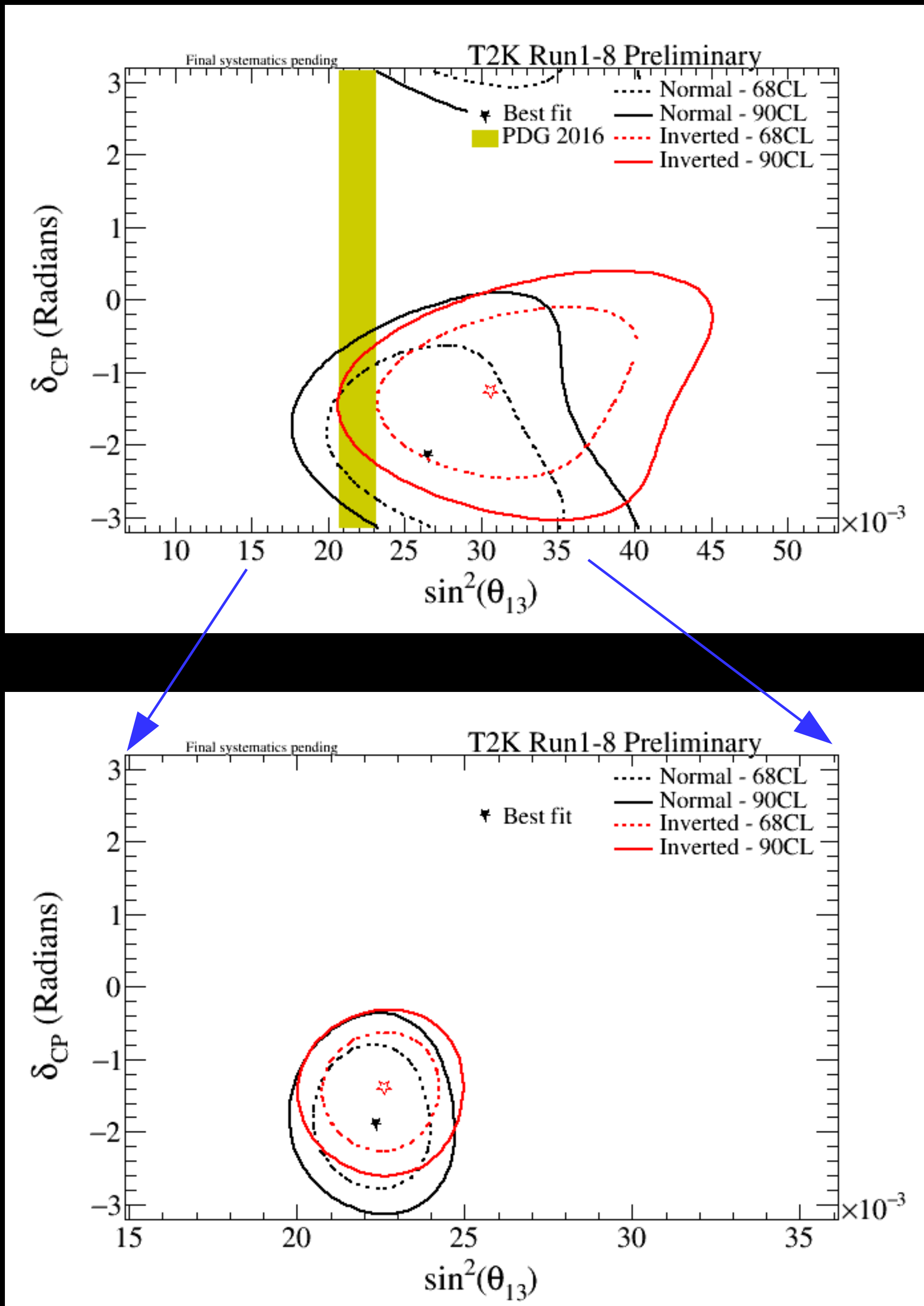




2016 analysis (5 samples joint fit with θ_{13} reactor constraint)
Compatibles with other experiments. Highest octant and NH “slightly” favoured
CPT conserved: $P(\nu_\mu\rightarrow\nu_\mu)$ consistent with $P(\bar{\nu}_\mu\rightarrow\bar{\nu}_\mu)$

2017 analysis: on-going work to assess systematic uncertainties from neutrino interactions models

Θ_{13} and δ_{CP}



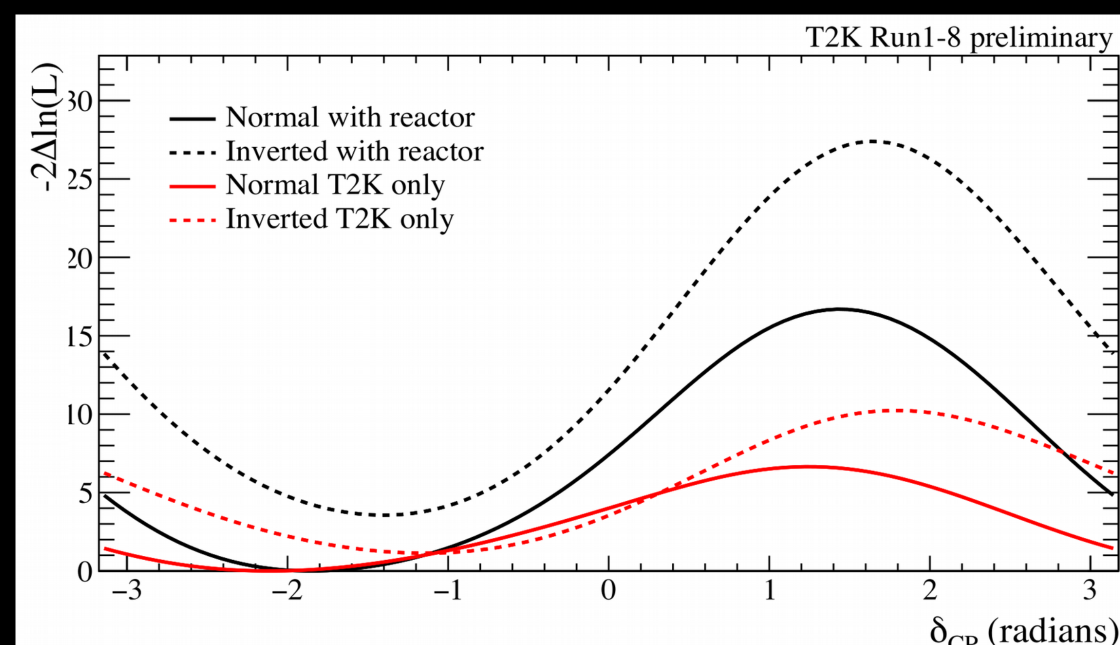
Closed 90%CL contours even w/o reactors

Best fit (NH) $\sin^2\theta_{13}=0.0277\ ^{+0.0054}_{-0.0047}$

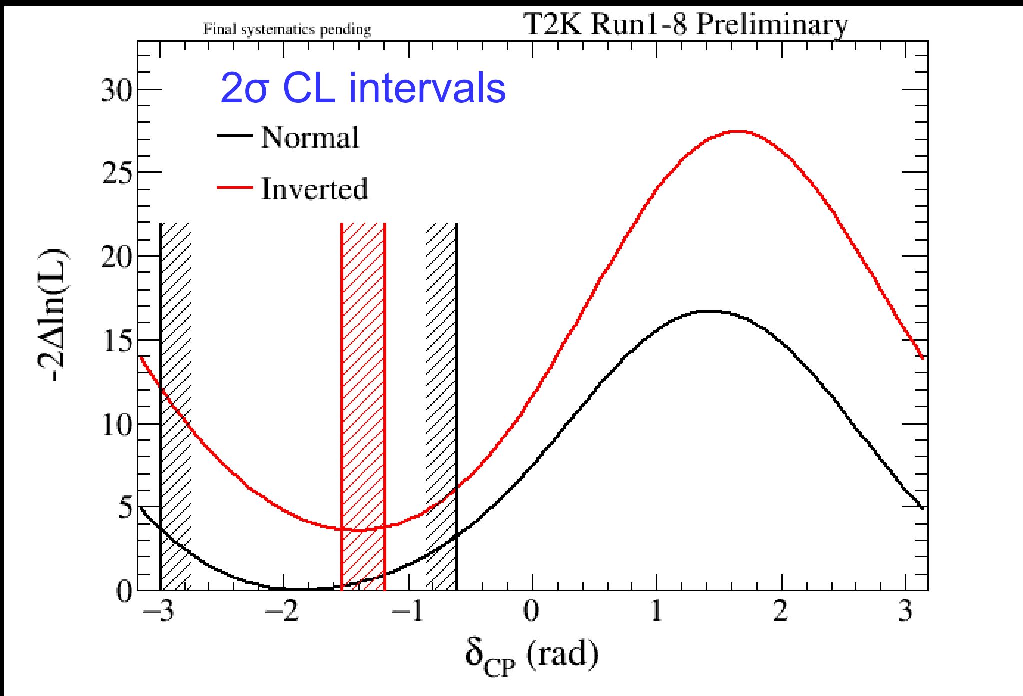
PDG 2016: $\sin^2\theta_{13}=0.0210\pm0.0011$

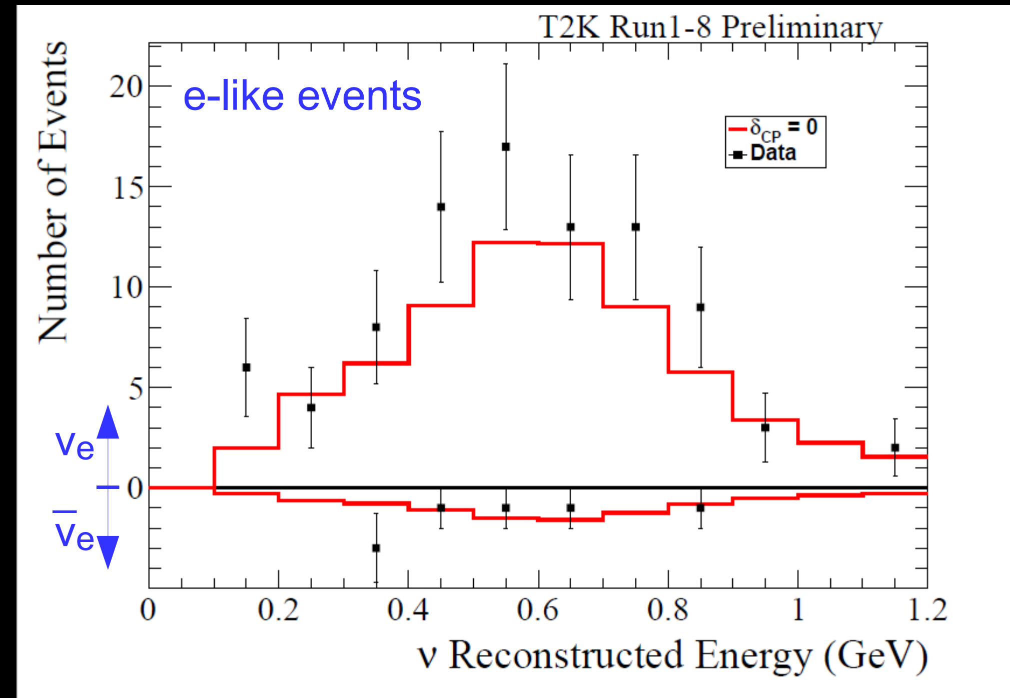
Large CPV favoured

δ_{CP} sensitivity improves with reactors



Results: δ_{CP}





CP conserving values (0,π) fall outside 2σ CL intervals

Observed events favour large CPV ($\delta_{CP}=-1.83^{+0.604}_{-0.654}$ radians for NH) and normal mass hierarchy

Allowed regions at 2σ CL

- for normal mass hierarchy: δ_{CP} = [-2.98, -0.6] radians
- for inverted δ_{CP} = [-1.54, -1.19] radians

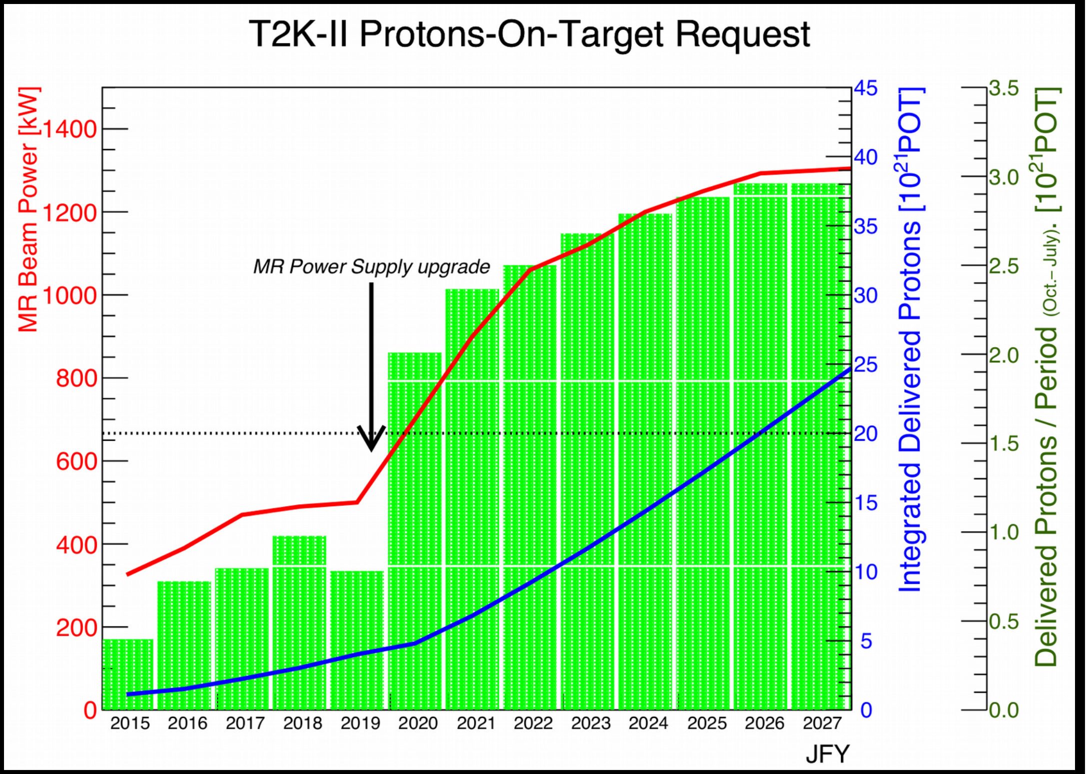
Future: T2K-II

Already approved 7.8x10^{21} PoT (by ~2021)

T2K-II proposal to operate until 2026 with 20x10^{21} PoT

Upgrade Main Ring power supplies to achieve 1 Hz repetition (1.3 MW ultimate beam power)

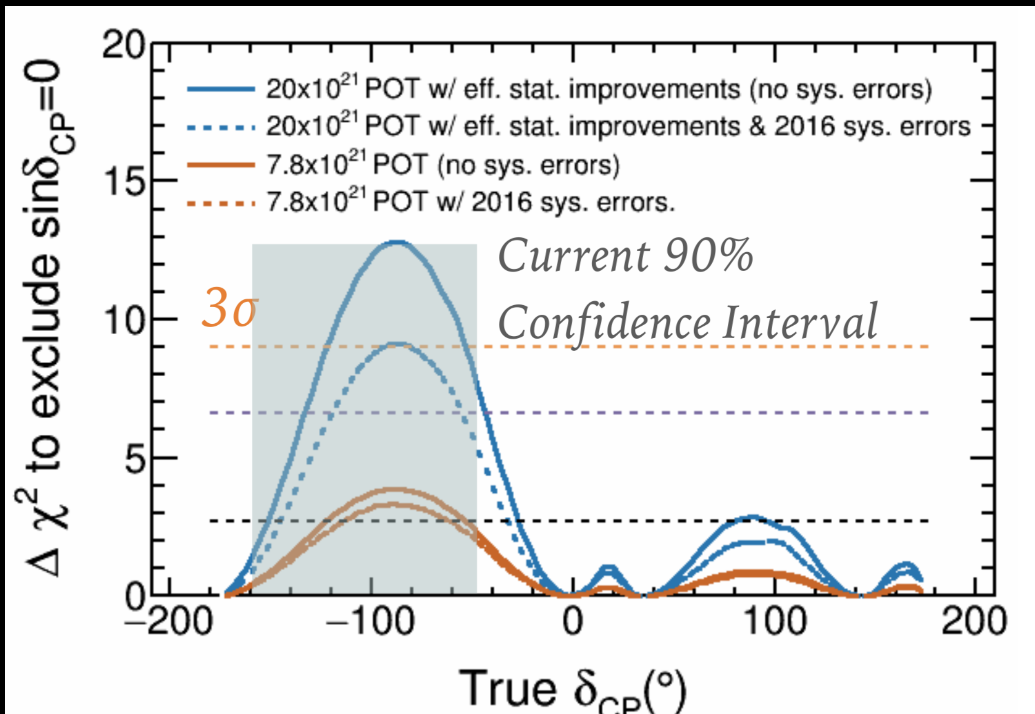
ND280 upgrade

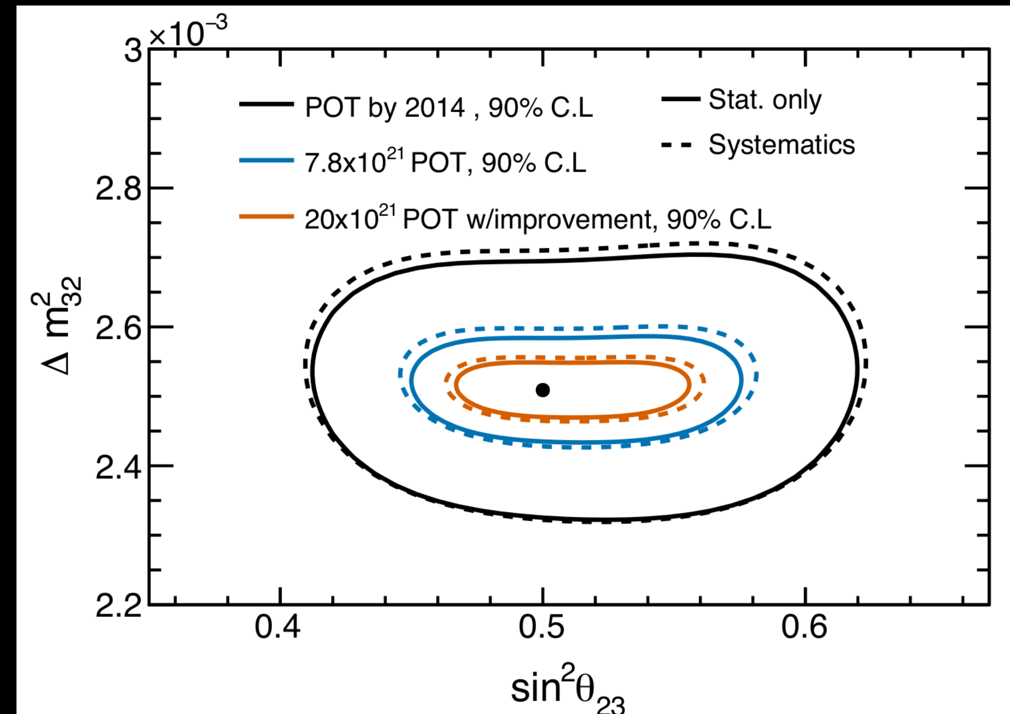


Analysis improvements:

- new ND280 samples to reduce neutrino interaction model systematics
- new Super-K samples to gain effective statistics (already ~30% with new Super-K reconstruction)

T2K-II Sensitivity





Potential for 3σ discovery of CPV if δ_{CP} is near the current best fit

Systematic errors are important → expected improvements in T2K-II

Significant improvements also on $\sin^2\theta_{23}$ and Δm_{32}

Conclusion and Outlook

T2K has doubled neutrino mode statistics since Summer 2016

Oscillation analysis updated to 22.5×10^{20} PoT (30% of expected PoT):

- improvement in neutrino interaction model
- new SK reconstruction and selection: +30% in effective statistics

→ CP conserving values of δ_{CP} falls outside 2σ CL intervals

T2K is working to:

- take data with beam power increasing toward 750 kW
- add new samples to improve systematics and increase statistics

Proposal to extend the run to 20×10^{21} PoT aiming at 3σ CPV discovery for favorable true δ_{CP} values (ie. if nature is kind to us!)

Stay tuned, there will be fun !

Thank you

WP3 status report (September 2017)

Vincenzo Berardi
INFN – Sezione di Bari (ITALY)

EU Grant n.644294

WP3 - Summary 1/2

- Asses the contribution of neutrino interaction in the sand and rock surrounding the near detector;
- Study of neutrino-nuclei and Meson Exchange Current interactions;
- Study of anti-neutrino interactions;
- Share the analysis techniques among the project participants and provide opportunities for the ESR to increase the interaction with KEK scientists.

WP3 - Summary 2/2

- Task 3.1 - Neutrino interactions and cross sections: [CEA, IFAE, INFN, NCBJ, QMUL, RAL]
- Task 3.2 – External background studies: [NCBJ,QMUL,RAL]
- Task 3.3 – Exotic Physics: [IFAE,QMUL,RAL]

WP3 – Milestones

- report on anti neutrino analysis; EMD:24 (April 2017) (delivered as scheduled)
- report on the methods of MEC searches; EMD: 48 (april 2019)
- combined muon and electron neutrino oscillation analysis report; EMD: 48 (april 2019)

JENNIFER
EU Grant n.644294