WP2 Report

Work Package dedicated to T2K detector upgrade and Neutrino Physics

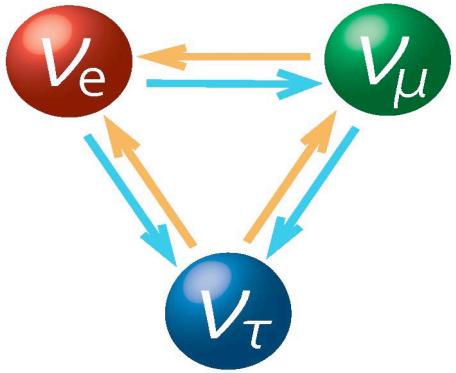
MG. Catanesi INFN Bari

Bruxelles , 12/12/2022

JENNIFER2
EU grant n.822070

Oscillating Neutrinos....

If neutrinos have masses, neutrinos change their flavor (type) from one flavor (type) to the other.



Theoretically predicted by;

S. Sakata, Z. Maki, M. Nakagawa

arXiv:0910.1657

B. Pontecorvo

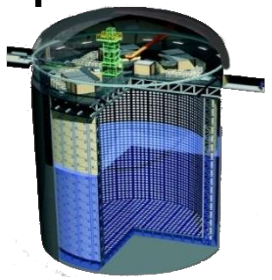
E (GeV) = neutrino energy
L (Km) = Distance from the source and the detector

If neutrino mass is small the oscillation length (L/E) gets longer. → L= 300Km or more

The Tokai-to-Kamioka (T2K) experiment

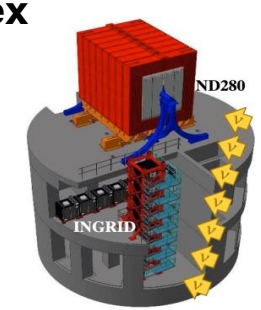
Far detector

Super Kamiokande



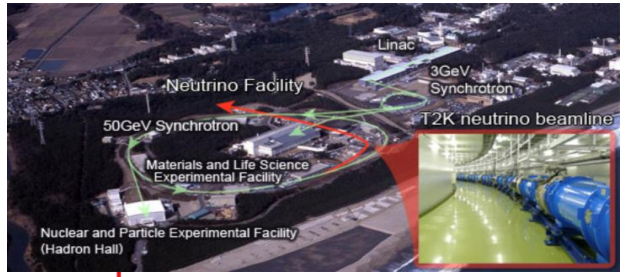
Near detector

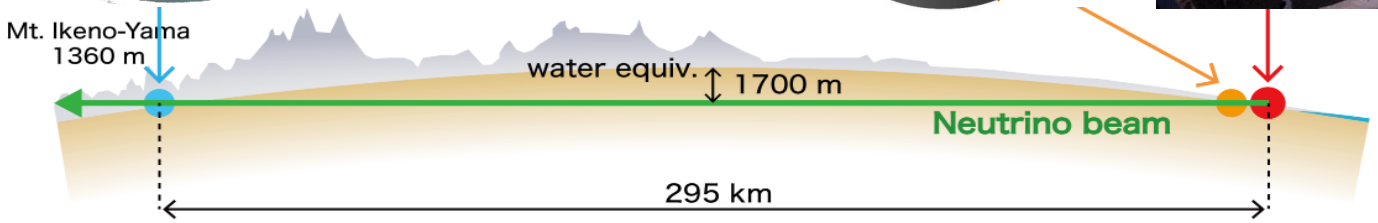
complex



J-Parc

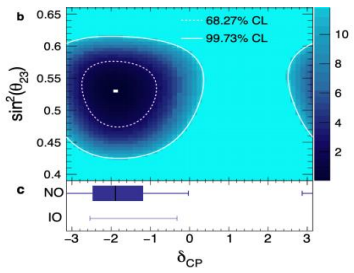
Neutrino Beam

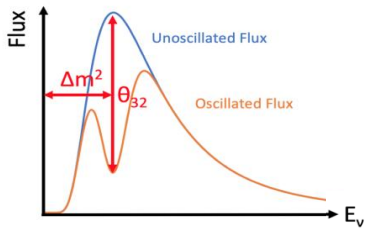




@SK

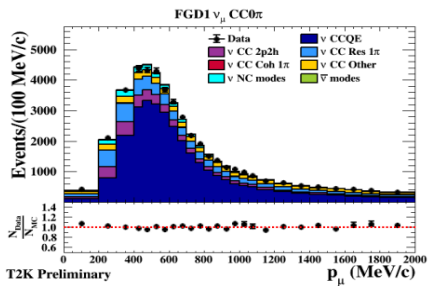
Measure oscillated beam





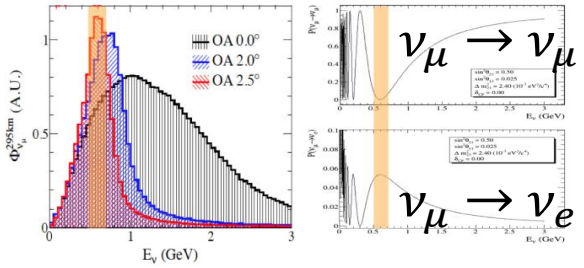
@ND280

Characterize beam and ν interactions



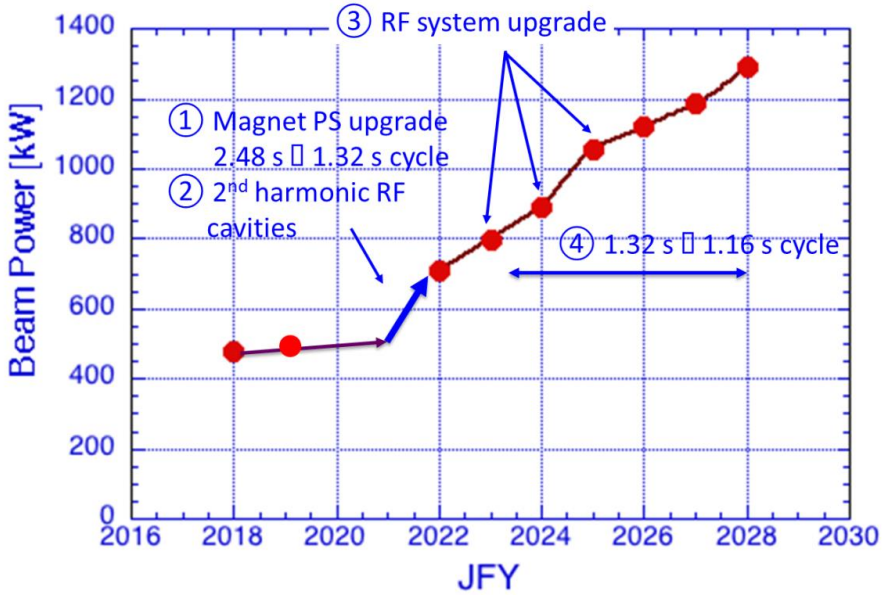
@J-PARC

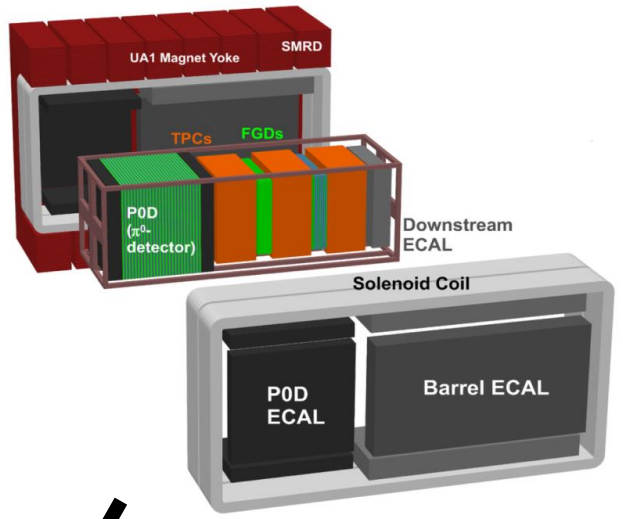
Create Neutrino's off-axis beam ν_μ or $\overline{\nu}_\mu$

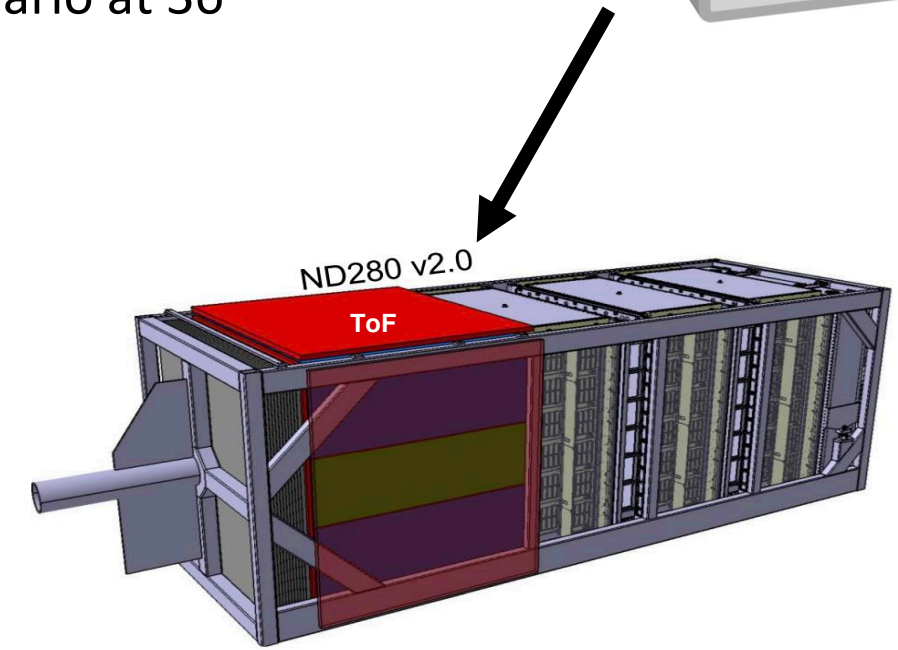


T2K-II (2022-2026)

- New subdetectors for ND280
- beam power upgrade: 0.5 MW → 1.1 MW (→ 1.3 MW HyperK)
- statistics: 3E21 POT (2018) → 12E21 POT (2026)
- aim: systematics from 5-6% to 4%
- Aim for CPV observation in optimal scenario at 3σ







WP2 main objectives

- Design, build, test and commission the upgrades for the T2K near detector (ND280), consisting of two TPCs and a scintillator based 3D Fine Grained Detector (Super-FGD).
- Perfect the measurements of neutrino cross-sections, in particular to pin down nuclear effects and improve modelling.
- Perform oscillation measurements with neutrinos and anti-neutrinos, both in appearance and disappearance, to maximize the sensitivity to leptonic CP violation.

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Tasks

WP2 is organized in 4 tasks, 2 related to T2K upgrades, and 2 to analysis

- Task 2.1: Construction and commissioning of the ND280 TPC [with participating institutes: **INFN,CNRS,CEA,NCBJ,IFJ-PAN,IFAE,KEK**]
- Task 2.2: Construction and commissioning of the Super FGD [**UGE,KEK,U- Tokyo**]
- Task 2.3: Neutrinos cross section measurement
- Task 2.4: Neutrino oscillation analysis [**INFN,CNRS,CEA,NCBJ,IFJ-PAN,IFAE,UGE,QMUL,KEK,U-Tokyo**]

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Deliverables & Milestones

Task 2.1 and 2.2

Deliverable: Technical Design Report of the upgraded ND280; EMD: 12
Milestone: Production and test of first prototypes with front-end electronics; EMD: 24

Deliverable: report paper on the new detectors; EMD: 48

Task 2.3

Milestones: improved selection acceptance for cross-section measurements, EMD 24; neutrino energy reconstruction using detectors at different off-axis angles, EMD 36

Deliverables: report on cross-sections on C and O and reduction of uncertainties, EMD 48; report on electron neutrino cross-section and reduction of uncertainties, EMD 48

Task 2.4

Milestone: inclusion of multi-ring topologies in the event selection; EMD: 24
Deliverable:reportondCPsensitivity;EMD:48

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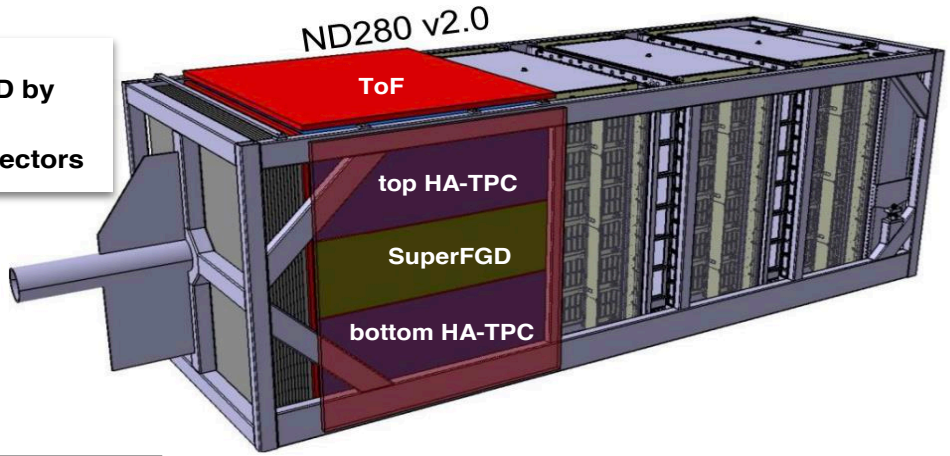
Tasks 2.1 & 2.2

The upgraded ND280 detector

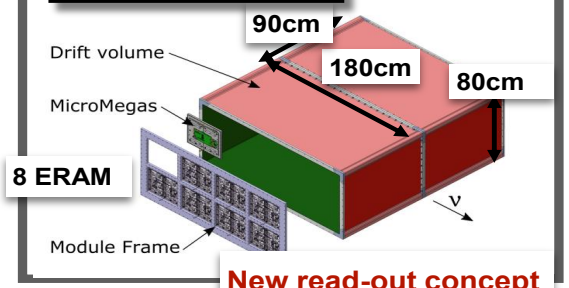
Replace P0D by new subdetectors



Milestones

- 2018 → TDR arXiv:1901.03750
- 2021/22 final modules
- 2022 installation

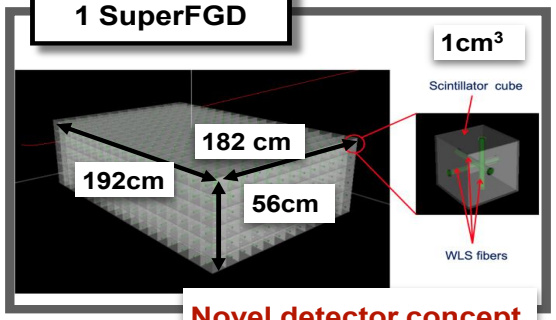
2 High Angle TPCs



New read-out concept

NIM A 957 163286 (2020)

1 SuperFGD



Novel detector concept

JINST 13, P02006 (2018)
JINST 15 P12003 (2020)

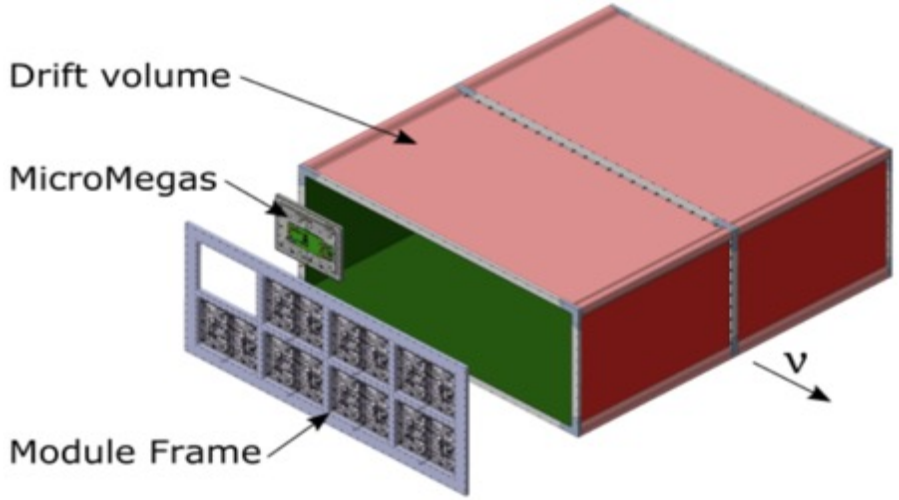
6 ToF panels

150 ps time resolution resolution

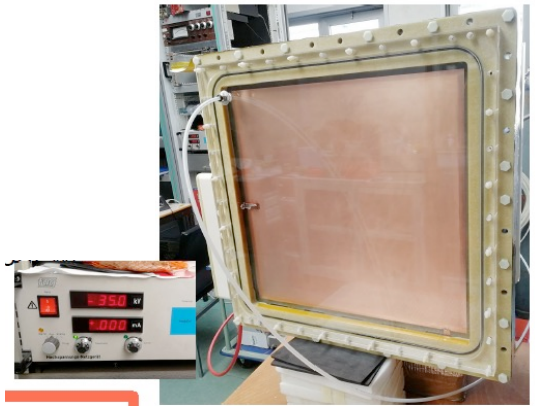
JPS Conf. Proc. 27, 011005 (2019)

High Angle-TPCs: Task 2.1

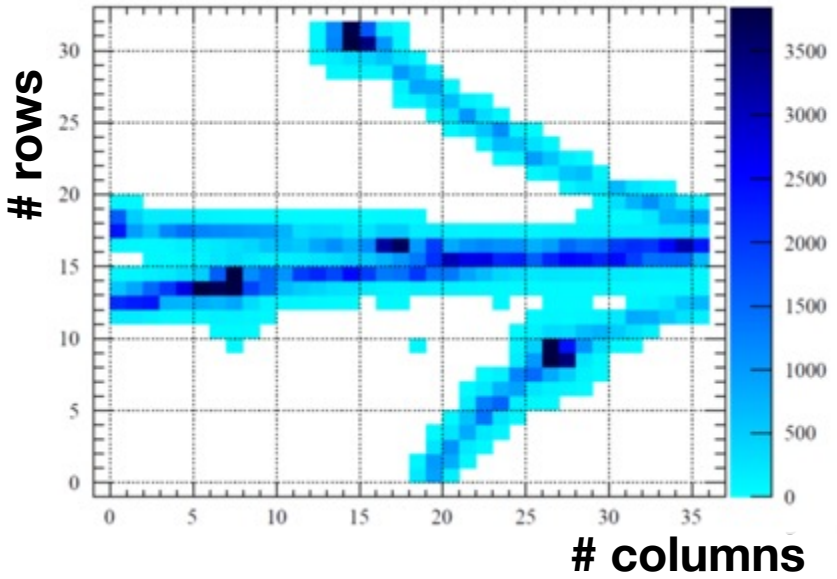
- 2 new TPCs consisting of 4 field cage halves being produced
- Dimensions: 1865x2000x820 mm3
- Composite materials for field cage
- Readout by 32 resistive Micromegas (ERAM) (novel technology)
- 1152 readout channels with 10.09x11.18 mm2 pads per ERAM
- **Providing tracking and particle identification**



- Various ERAM prototypes with different RC parameters produced and tested
- 2 full length Field Cage prototypes for 1 MM + several mock-ups produced and tested

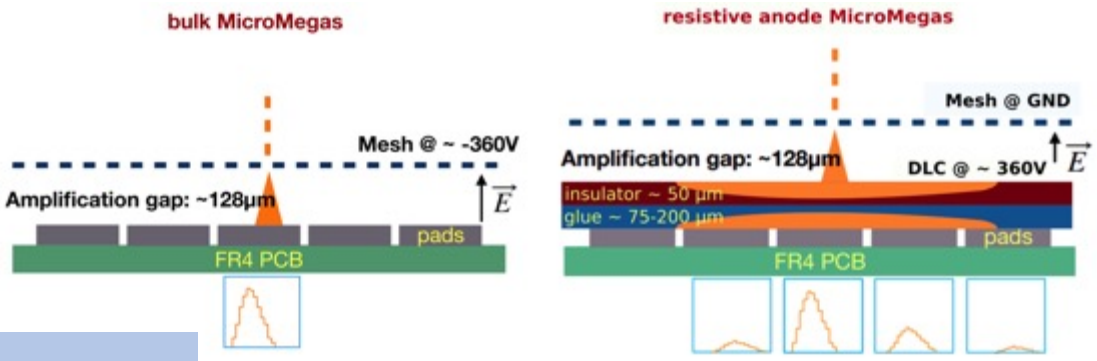


Testbeam event

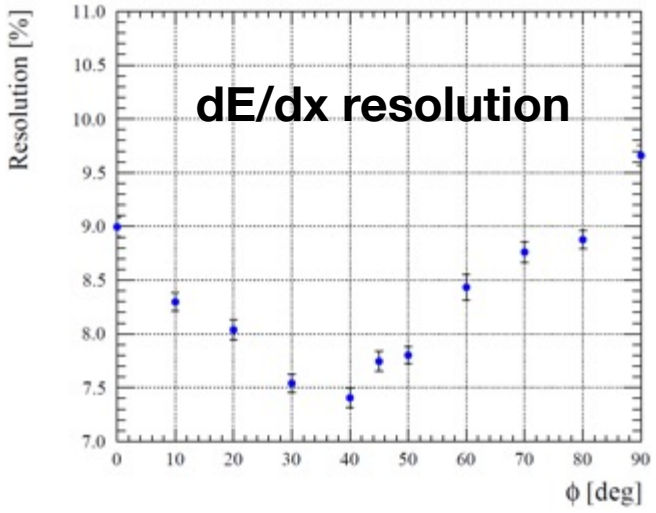


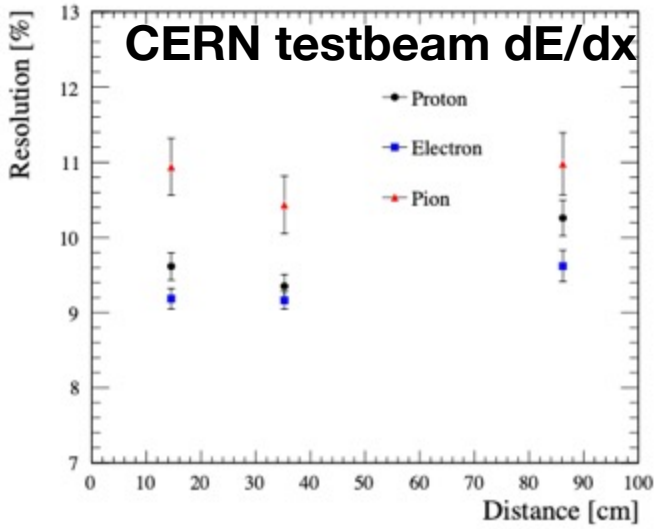
HA-TPC ERAM Modules

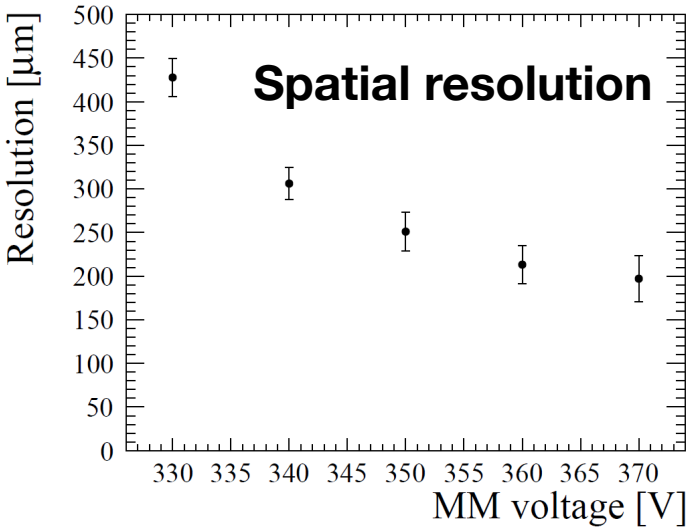
- Novel resistive MM readout
- Charge over several pads => better point resolution
- 32 ERAM modules needed + 8 spares
- Pre-production of 8 modules ongoing at CERN MPGD workshop



- ➢ Very good dE/dx and point resolution performance
- ➢ For all angles better than 600 um (for first 15 cm values below 300 um)
- ➢ dE/dx resolution below 10% for final detector







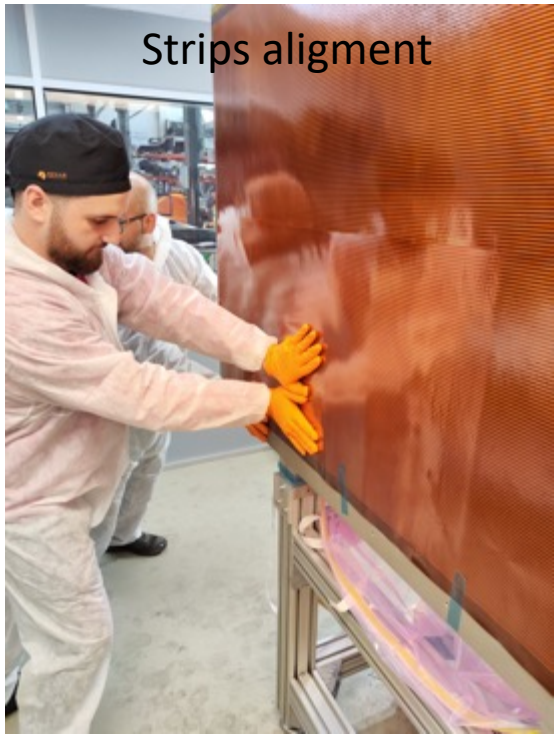
HA-TPC Field Cage

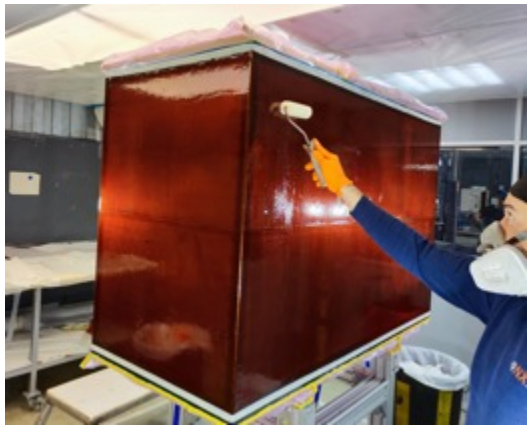
- TPC consists of 2 halves and separate cathode
- Production based on layers wrapped around mould (new !)
- Successfully tested:
  - Metrology
  - HV stability in air and argon up to 35 kV
  - Gas tightness

Mould Assembly at the INFN Bari Workshop

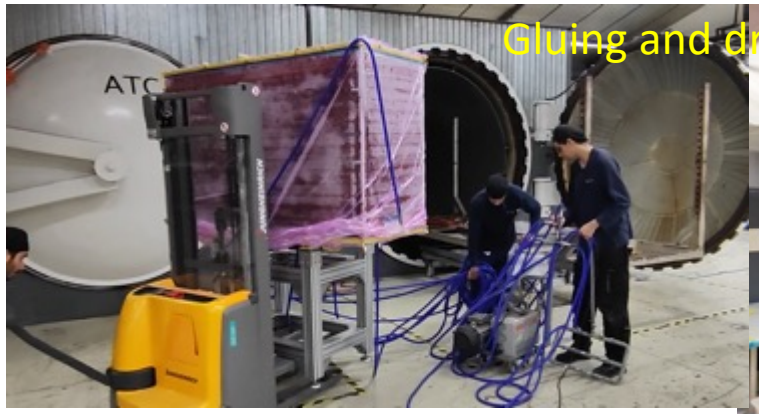
- Production of final field cages (FC) started beginning of 2022
- A first half field cage (FC0) was build (pre-production).
  FC0 was used to test and improve quality control and optimize production procedures
- Production of FC1 started in October and progress very well until now

Strips aligment



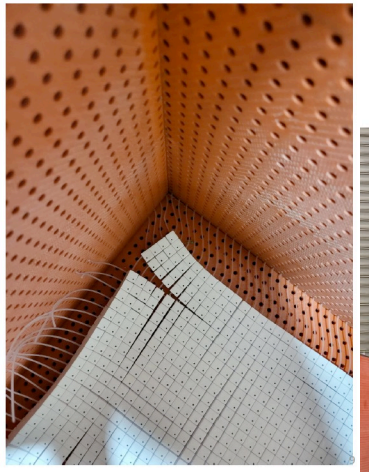


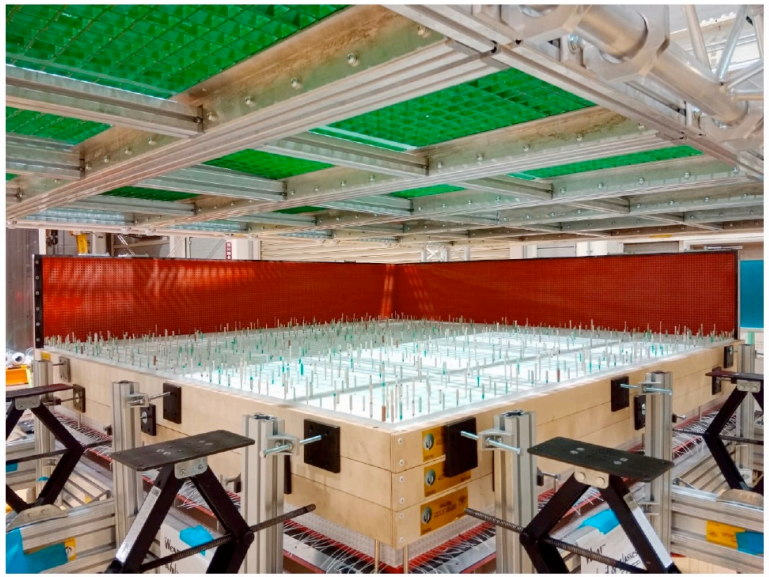
Gluing and drying layers at Nexus



SuperFGD Status : Task 2.2

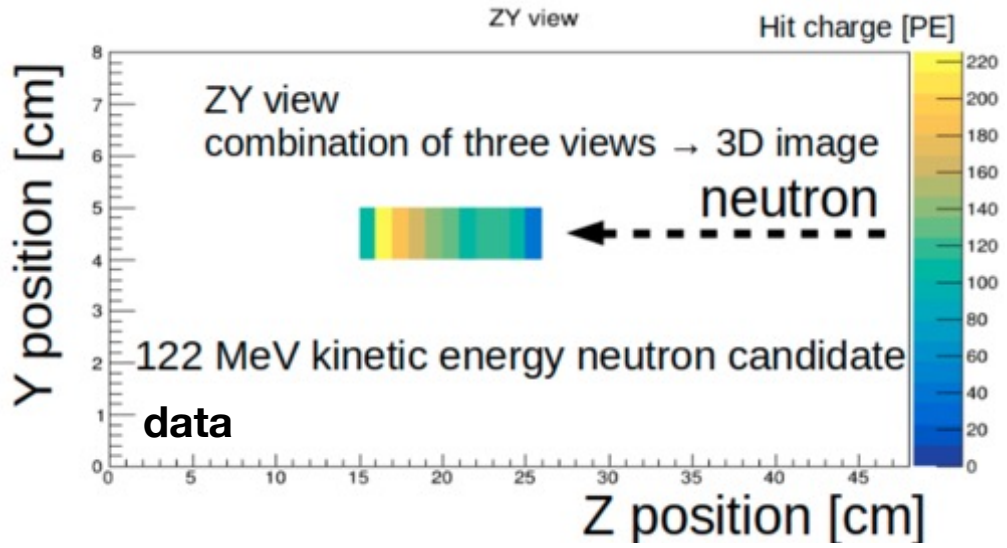
- Cubes were successfully shipped to J-PARC in June
- Assembly structure arrived in September at J-PARC
- All box panels arrived at CERN in August
- Quality control including 3.5 t load test performed successfully at CERN
- Box arrived at J-PARC 24th of October 2022
- Cube layer assembly in box started and is progressing very well
- This stage expected to be completed by 21st of November
- Foam necessary to close box expected to arrive mid of December

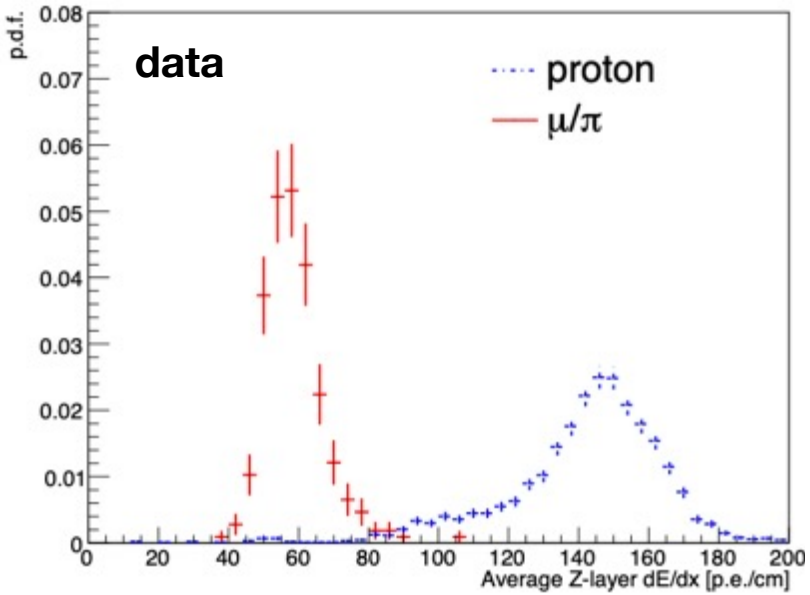


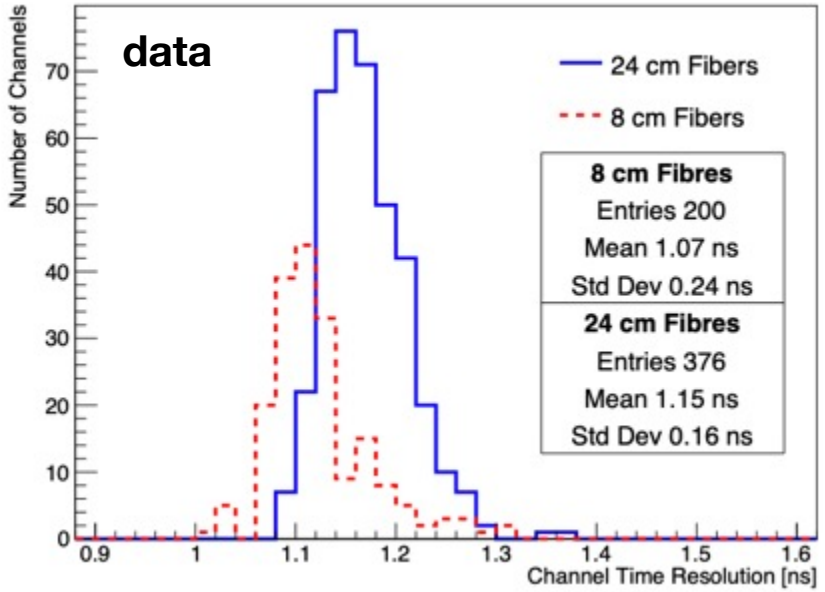


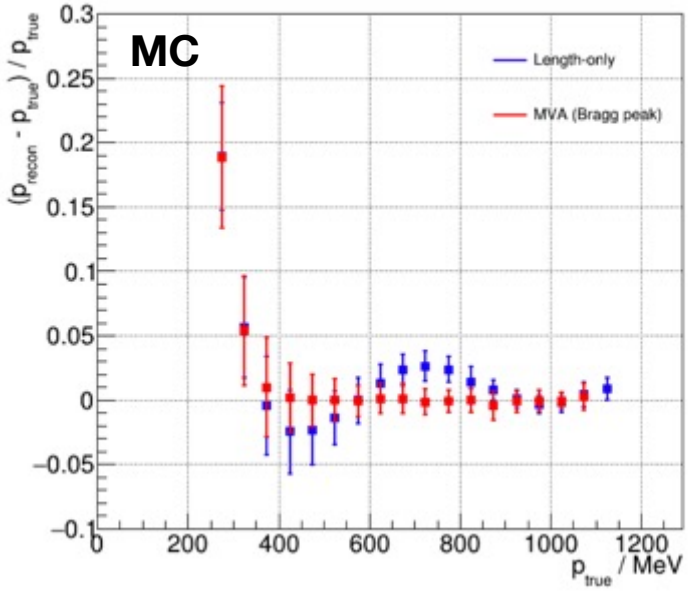
SuperFGD Testbeam and MC Performance

- Various prototypes were exposed to testbeams at CERN (charged particles) and Los Alamos (neutrons)
- Charged particle analysis indicates good dE/dx and timing **(published Dec. 2020, 2020 JINST 15 P12003)**
- Neutron data analysis ongoing
- Used to tune MC
- Promising results for stopping particles









ND280 Upgrade Schedule

- Ongoing until summer 2023:
  - SFGD assembly and commissioning at J-PARC
  - New TPC Gas System installation and commissioning
- Spring 2023: neutrino beam with existing ND280
- Installation of new detectors:
  - July 2023: bottom HA-TPC
  - August/September: SuperFGD
  - November 2023: top HA-TPC
  - December 2023: last TOF panels
- Depending on neutrino beam availability the installation of top HA-TPC might be postponed to beginning 2024
- Commissioning of the new ND280 (2023-2024)
- Data taking (4 months/year) (2023 -> 2026)

Status of deliverables and milestones:

Deliverable: TDR => done

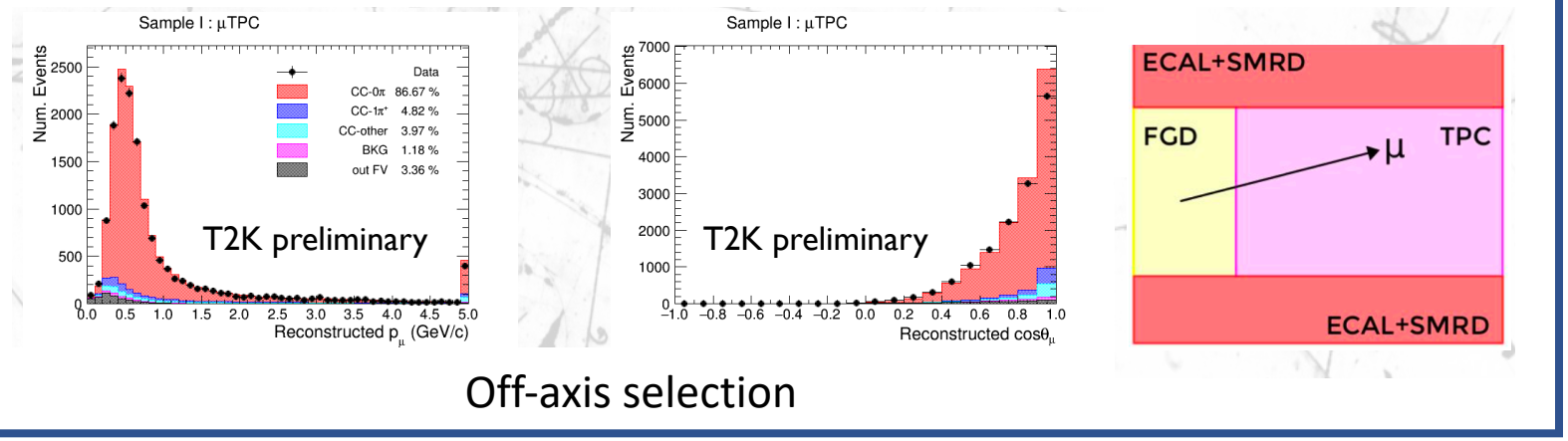
Milestones: Prototypes and their testing => done

Final deliverable: Article about new subdetectors => after installation

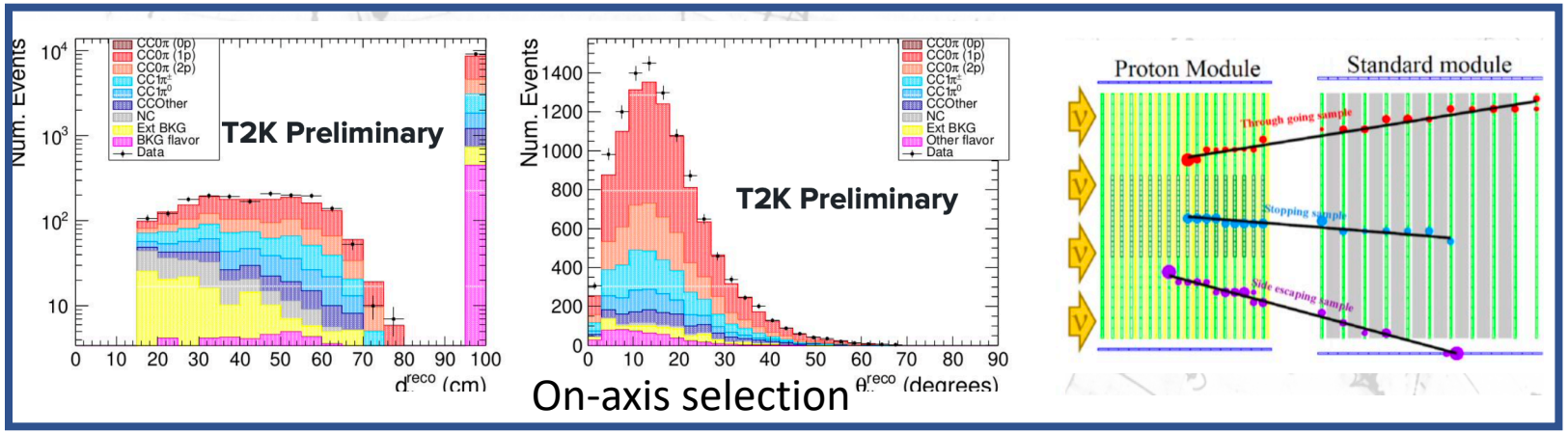
Significant number of secondments will be needed!

Task 2.3: Neutrinos cross section measurements

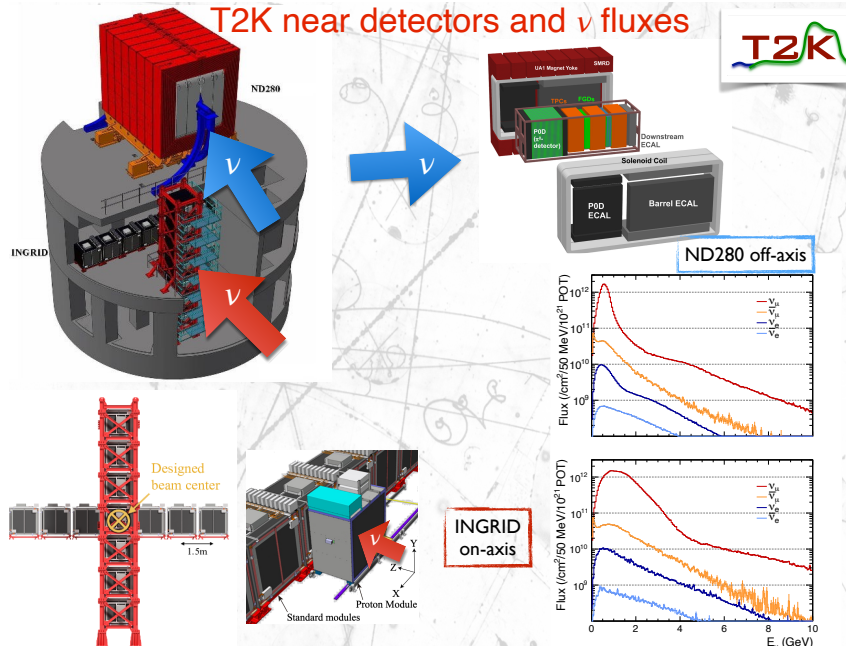
Milestones: improved selection acceptance for cross-section measurements, EMD 24; neutrino energy reconstruction using detectors at different off-axis angles, EMD 36



Off-axis selection

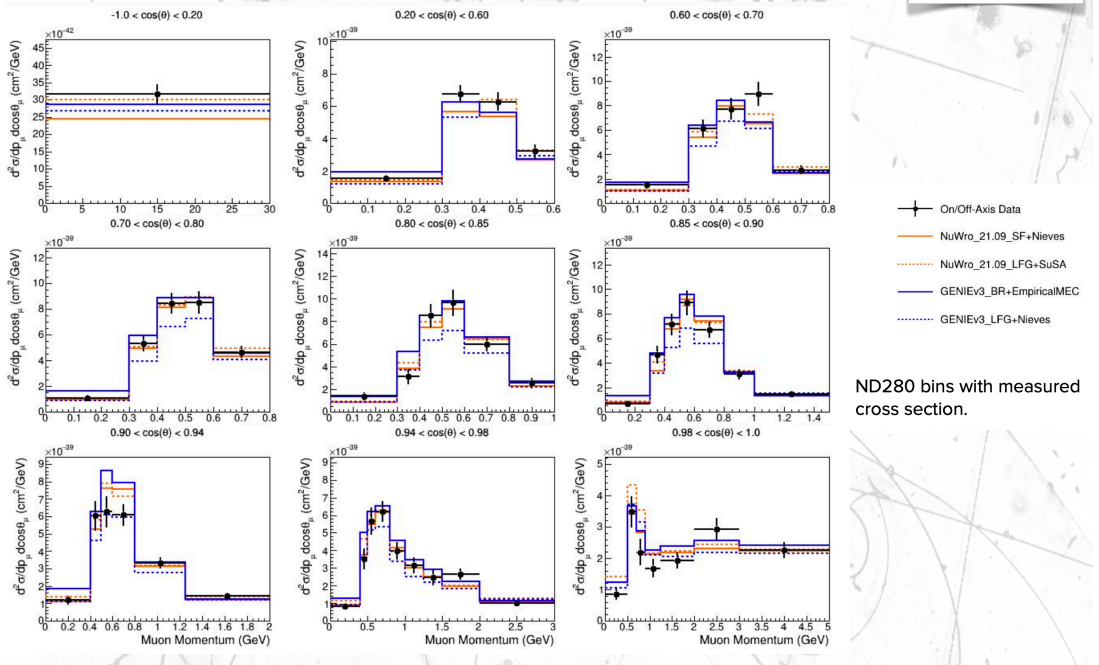


On-axis selection



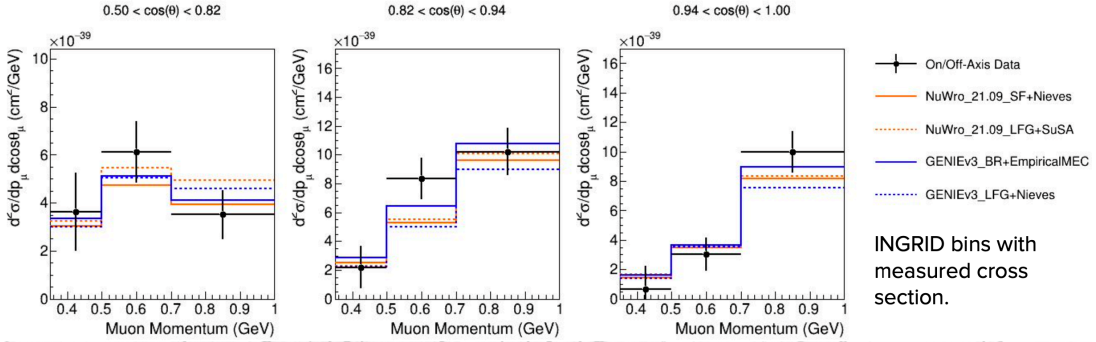
Paper in preparation! Target journal: PRD

Off-Axis results



ND280 bins with measured cross section.

On-Axis results



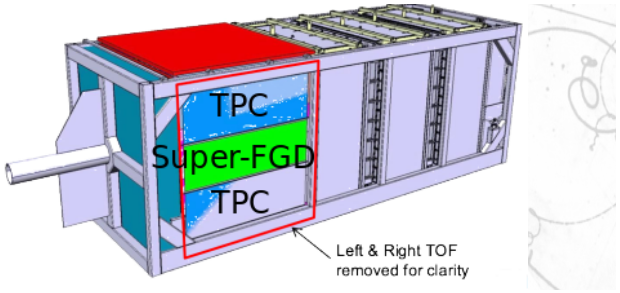
INGRID bins with measured cross section.

Advanced Analysis

1. *anti-**νμ** CC1**π**- analysis in FGD1*
2. **νμ** CC1**π**+ analysis in FGD1/FGD2
3. *NC1**π**+ analysis* (C. Jesus Valls)
4. **νμ** *CC0**π** analysis in WAGASCI/BM*
5. Joint CC0**π** **νμ**/anti-**νμ** on/off-axis
6. *Kaon production analysis*
7. 4**π** **νμ** CC1**π**+ analysis
8. *anti-**νμ** CC1**π**- analysis in FGD1*/FGD2
9. ***νe** CC1**π**+ analysis in FGD1*
10. *NC**π**0 in the P0D*

This task is an excellent playground for a broad community of theoreticians and experimentalists, mixing different skills and backgrounds. It is also a valuable environment for students, where they can enrich the foundations of their career. Cross-section of the different neutrino types on different targets (C, O, Fe) will be published open access and will be accompanied by public data releases in order to allow a broader community to interpret and study them

(Task 2.3 Coordinator : F. Sanchez)

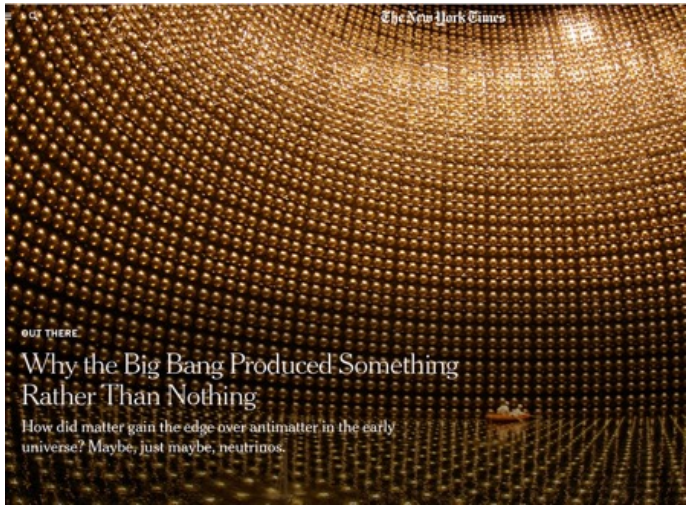


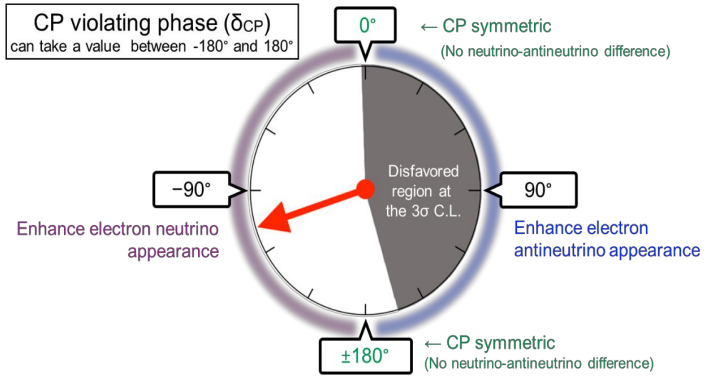
Many analyses would be redone with the new (more performing) detector !

Task 2.4: Neutrino oscillation analysis

Using beams of muon neutrinos and muon antineutrinos, T2K has studied how these particles and antiparticles transmute into electron neutrinos and electron antineutrinos, respectively. T2K observed that the number of muons anti-neutrinos that oscillate is lower respect muon neutrinos (April 2020)

The effect can be sufficiently large to explain the matter-antimatter asymmetry





the most probable value is -90 degrees

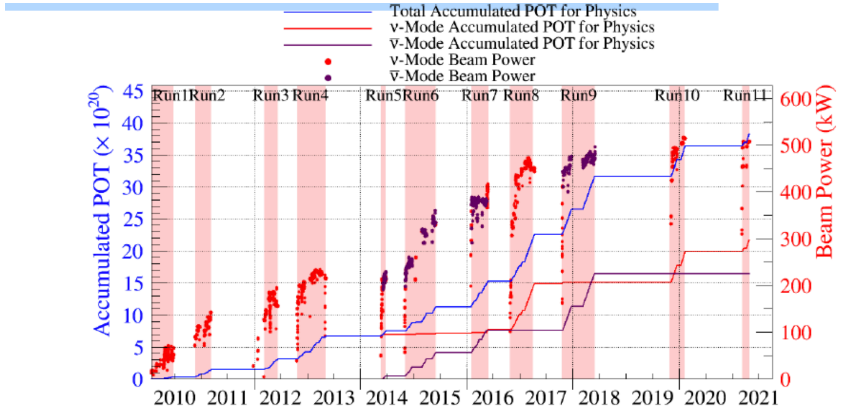
Not only a great scientific achievement but also unique opportunity to disseminate scientific information to a large audience:

- Articles on important newspapers around the world (> 100)
- Interviews on internation and regional media (TV, YTube ..)
- Public seminars
- etc. etc.

Task 2.4: Neutrino oscillation analysis

What's new in 2022 analysis?

- Updated flux prediction based on analysis of the NA61/Shine 2010 replica target data for hadron production
- Updated neutrino interaction model – improved uncertainties for spectral function model and additional uncertainties for resonant and multi-pion events as well as FSI
- New proton and photon tagging selection for the near detector ND280
- In far detector analysis introduce **new m-like CC1p sample** selection

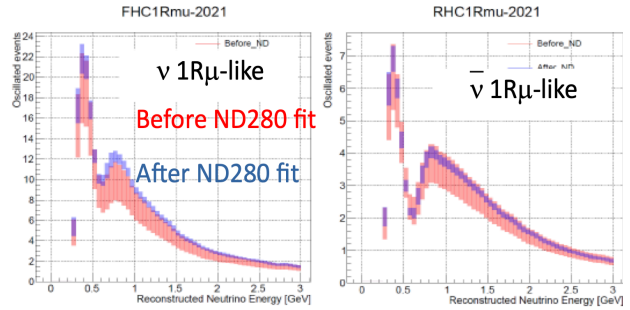


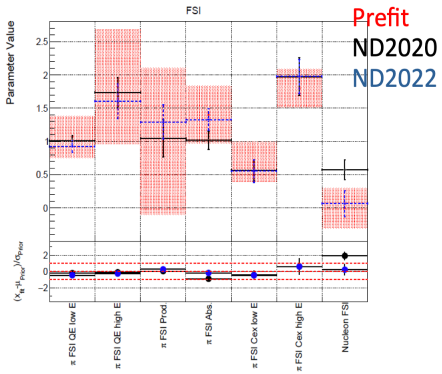
Used here:

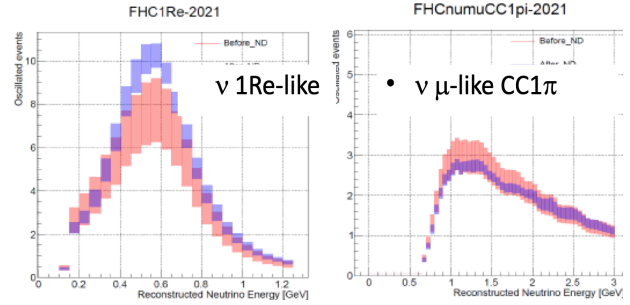
Near detectors	Far detector
ν-mode: 1.3905 x 10^{21} POT	ν-mode: 1.9664 x 10^{21} POT
ν̄-mode: 0.6307 x 10^{21} POT	ν̄-mode: 1.6346 x 10^{21} POT

Near Detector fit results

- Constraint neutrino flux and provides prediction of flux for Far Detector including CC1π sample
- Constrain interaction parameters and their uncertainties







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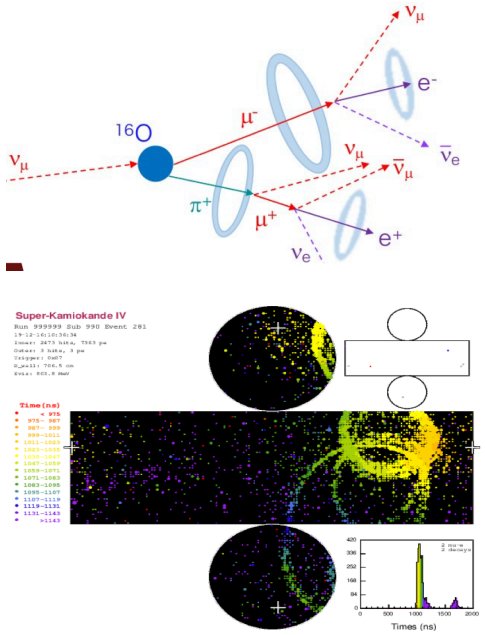
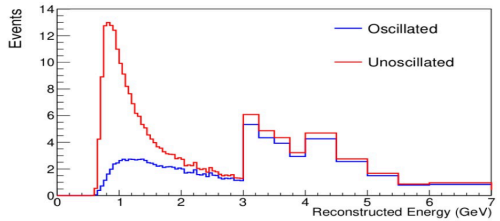
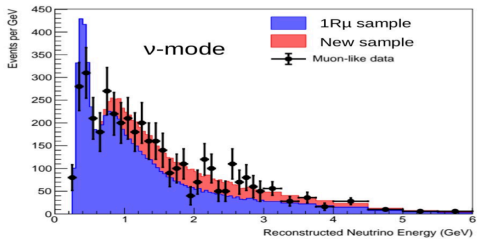
Milestone: inclusion of multi-ring topologies in the event selection



- New! Included from T2K Run 1-10 ν-mode data for the first time in T2K oscillation analysis
- Parent $E_\nu \sim$ 1.2 GeV → oscillation effect still present



- ~30% increase of total ν_μ-like events: Sensitive to θ_{23} & $|\Delta^2_{32}|$.



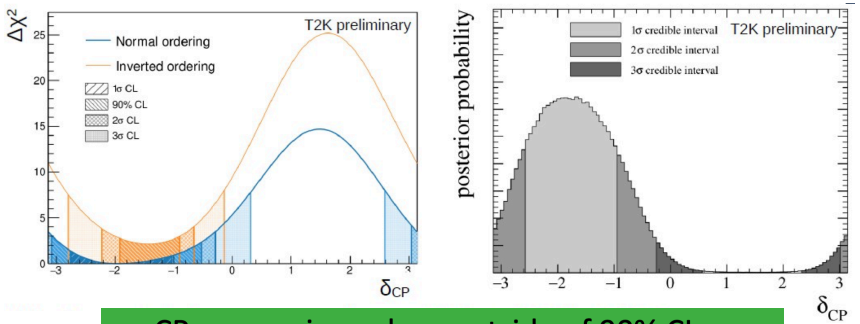
Paper in preparation

Mode	Sample	δ=-π/2 MC	δ=0 MC	δ=π/2 MC	δ=π MC	Data
ν	1Re	102.7	86.7	71.1	87.1	**94**
	1Re CC1π⁺	10.0	8.7	7.1	8.4	**14**
	1Rμ	379.1	378.3	379.1	380.0	**318**
	MRμ CC1π⁺	116.5	116.0	116.5	117.0	**134**
$\bar{\nu}$	1Re	17.3	19.7	21.8	19.4	**16**
	1Rμ	144.9	144.5	144.9	145.3	**137**

Results on δ_{CP} phase

Frequentist approach (Feldman-Cousin method)

Bayesian approach (Marginalized over MO)



CP conserving values outside of 90% CL
Best fit close to maximal CP violation near -π/2

Status of secondments

Institution	WP2 done (months)	WP2 planned	WP2 % done
INFN	6,9	49,0	14,1%
DESY		0,0	
OEAW-HEPHY		0,0	
IFJ-PAN	0,7	7,0	10,5%
UKP		0,0	
JSI		0,0	
METU		0,0	
TAU		0,0	
LAL-CNRS	1,2	9,0	13,7%
CEA	2,4	16,0	15,0%
IFAE	1,0	12,0	8,1%
UNIGE	1,6	18,0	9,1%
NCBJ	2,8	17,0	16,3%
KCL (Qmul)	0,0	3,0	0,0%
UKRI	0,7	6,0	12,2%
CAEN		0,0	
FBK		0,0	
Total	17,4	137,0	12,7%

Comments:

- WP2 secondments stopped ~ Feb 2020, less than one year after the start of the project
- Average usage of secondments was ~ 13% at the Jennifer2 suspension date, approx uniform across beneficiaries
- **After a 2-year stop, it is expected that secondments for T2K upgrades will now ramp up quite rapidly during the next > 2 years**
- We are now approaching the installation and commissioning phase
- 5 people in secondment per year seems a reasonable estimation during this phase .
- Milestones and deliverables foreseen at his phase of the project are met