The T2K Near Detector ND280 Upgrade Project

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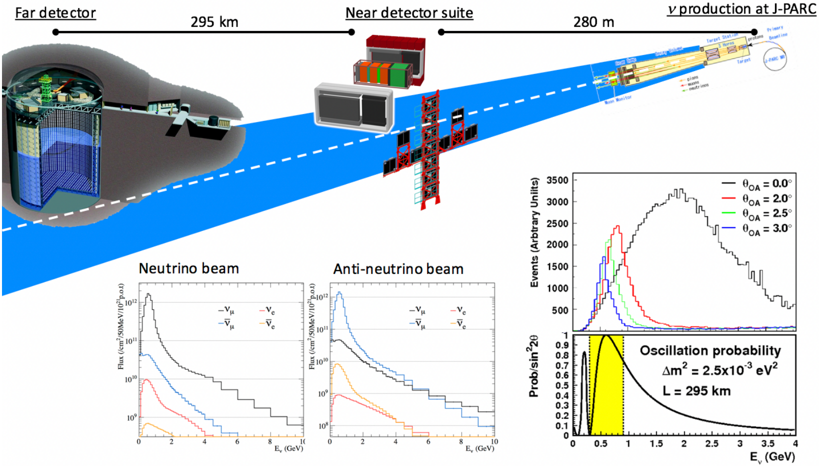
for the ND280 Upgrade WG

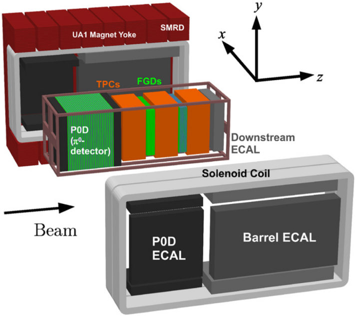
NNN18 Vancouver
November 1, 2018

T2K off-axis beam



ND280 Detectors

- "Basket" components:
  - Tracker: 3 TPCs and 2 FGDs.
  - π^0 detector (P0D).
  - ECAL (Upstream and downstream).
- Other components:
  - Barrel ECAL.
  - Muon detector (SMRD).
- Design driven by the physics goals of early 2000: measure θ_{13}
  NIM A 659 (2011) 106-135



ND280 Purpose

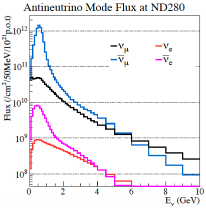
- Constraining of flux and cross-section measurements for T2K oscillation analyses.
- Neutrino cross-section measurements *PHYSICAL REVIEW D 96, 092006 (2017)*.

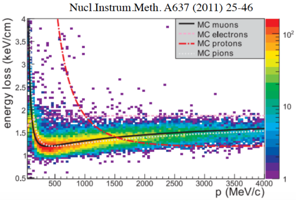
Systematics for FHC

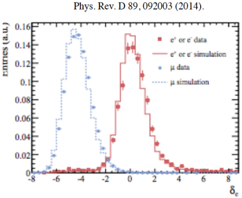
Source of uncertainty	ν_e CCQE-like $\delta N/N$	ν_μ $\delta N/N$	ν_e CC1π^+ $\delta N/N$
Flux (w/ ND280 constraint)	3.7%	3.6%	3.6%
Cross section (w/ ND280 constraint)	5.1%	4.0%	4.9%
Flux+cross section			
(w/o ND280 constraint)	11.3%	10.8%	16.4%
(w/ ND280 constraint)	4.2%	2.9%	5.0%
FSI + SI + PN at SK	2.5%	1.5%	10.5%
SK detector	2.4%	3.9%	9.3%
All			
(w/o ND280 constraint)	12.7%	12.0%	21.9%
(w/ ND280 constraint)	5.5%	5.1%	14.8%

Current ND280 configuration: advantages

- Magnetised detector: rejection of wrong sign beam component.
- Active target.
- TPCs: 3D reconstruction, charge, momentum and particle ID.
  - electron and muon separation at $> 4\sigma$

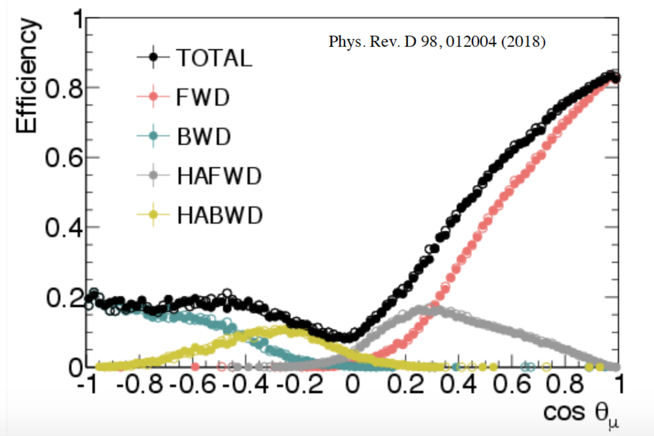






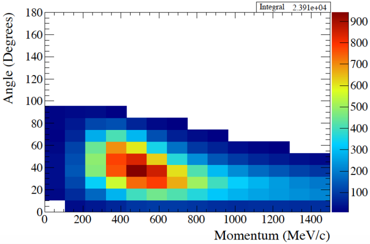
Current ND280 configuration: limitations

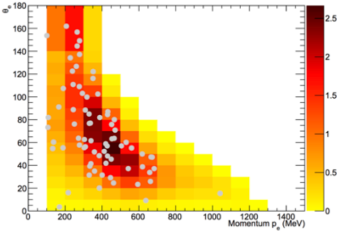
- Limited angular acceptance for high-angle and backward tracks.



Current ND280 configuration: limitations

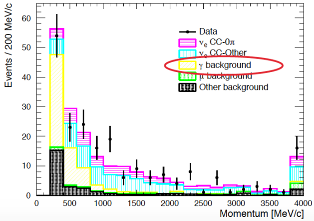
- Limited angular acceptance for high-angle and backward tracks.
- Angular acceptance different to SK (4π).

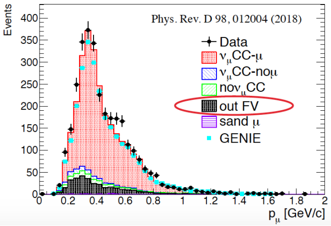




Current ND280 configuration: limitations

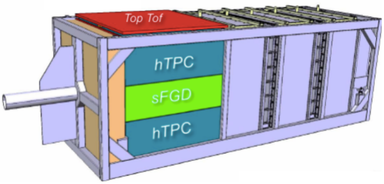
- Limited angular acceptance for high-angle and backward tracks.
- Angular acceptance different to SK (4π).
- Poor detection and identification efficiency for $e < 1$ GeV (γ conversion contamination).
- No track direction determination: large Out-Of-Fiducial Volume (Out FV) background.

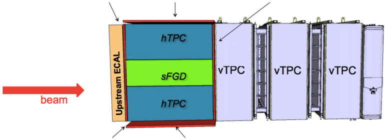




ND280 upgrade configuration

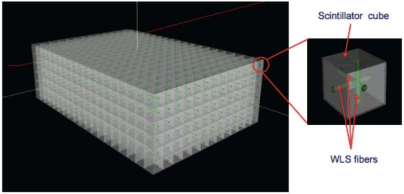
- Redesign of upstream part of "Basket" components:
  - Novel SuperFGD: two tons 3D fine grained plastic scintillator target.
  - Two new horizontal "high-angle" TPCs (hTPC).
  - TOF planes all around.
- Current downstream tracker FGDs + TPCs unchanged
- Project timeline:
  - Design and construction 2017-2021.
  - Installation 2021.
  - First data taking expected 2022.

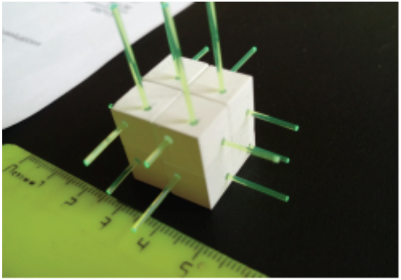




The SuperFGD

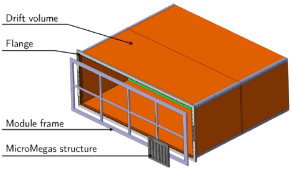
- Novel design of a 3D fine grained scintillator detector
  - Active tracking volume from 1 cm-sized plastic scintillator cubes
  - 2 tons from 1.92 (w) $\times$ 0.56 (h) $\times$ 1.92 (drift) m^3.
  - 2×10^6 cubes.
  - 6×10^4 channels (MPPC readout).
  - WLS fibers in 3 directions.
- Detector readout:
  - 3D view provides detailed 3D reconstruction.
  - 4π acceptance.
  - Tracking for particles entering the TPCs.
  - Detection of activity around vertex.

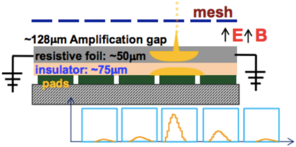




High angle TPCs

- Design based on successful operation of T2K TPCs
  - 2 volumes of 1.8 (w) $\times$ 0.7 (h) $\times$ 1 (drift) m^3.
  - 8 MM per volume.
  - Same T2K voltage and gas.
  - 2% material budget.
  - Momentum resolution of 10% at 1 GeV.
- Two main changes w.r.t existing TPCs:
  - **Field cage:** reduced dead space and maximised tracking volume, single wall box for gas containment and electrical insulation.
  - **Resistive MicroMegas:** charge spread on pads, good detection performance also for short drift distances: similar point resolution with larger pads: fewer electronics channels: protection of FE electronics from sparks no longer needed so more compact electronics maximises acceptance.

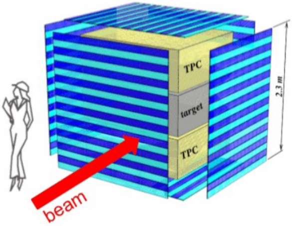




$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

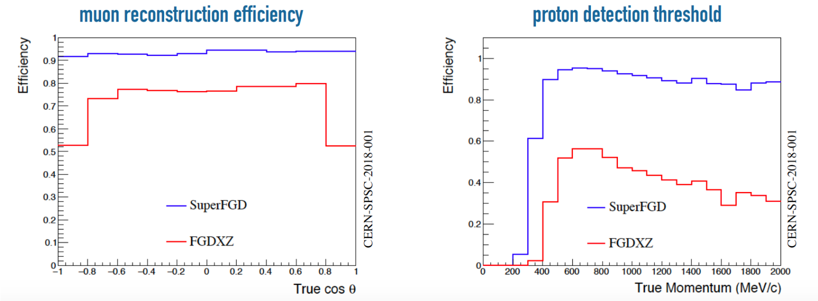
TOF system

- TOF planes surround new tracker (sFGD + hTPCs).
- Purpose: determination of particle direction for better rejection of incoming background.
- TOF structure.
  - Panels of cast scintillator bars of 230 (l) $\times$ 12 (h) $\times$ 1 (w) cm^3.
  - Arrays of 8 6 $\times$ 6 mm^2 SiPMs.
  - 2 sides readout.
  - 150 ps resolution.



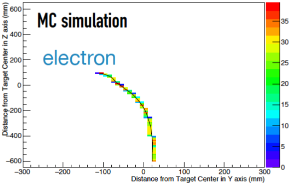
Upgrade: expected performances from simulations

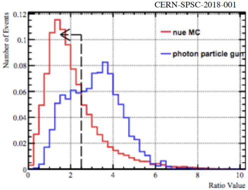
- Optimal design defined from simulations: 3D view is key:
  - sFGD: high reconstruction efficiency in all directions (∼90% for muons).
  - sFGD: lower detection thresholds for protons (∼ 300 MeV).

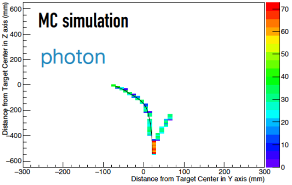


sFGD pattern recognition

- sFGD high granularity allows for excellent pattern recognition.
- Disentangling one/two tracks looking at the light yields in first cubes.
  - disentangling electrons from photon conversion (ν_e background.)

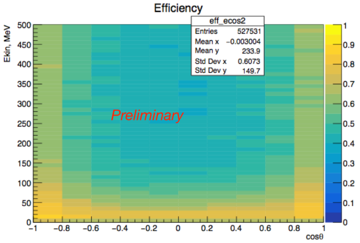






Upgrade: expected performances from simulations

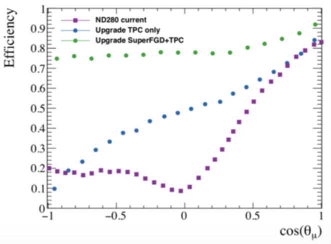
- Neutron detection would be of great interest for neutrino interaction models studies.
  - Preliminary studies of SuperFGD detection efficiency look very promising.
  - Further developments are ongoing (energy/angular resolution, gamma background discrimination).



Using MC particle guns with energy 0 - 500 MeV uniform in angle

Upgrade: expected performances from simulations

- Larger angular acceptance from new TPCs and TOF.
  - Reconstruction efficiency expected to drastically improve.
  - ... especially for high-angle and backward going tracks.
- Approx. $\times 2$ more events expected for a given exposure thanks to larger target mass.
- Further reduction in the OOFV background thanks to the TOF.



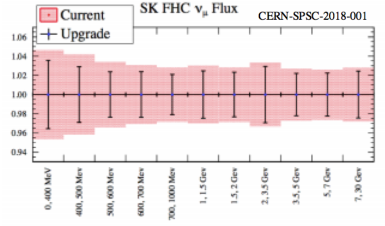
CERN-SPSC-2018-001

Selection	Current-like	Upgrade-like
ν_μ (ν beam)	93,401	194,654
$\bar{\nu}_\mu$ ($\bar{\nu}$ beam)	33,437	63,687
ν_μ ($\bar{\nu}$ beam)	17,998	33,773

expected numbers for 1×10^{21} POT

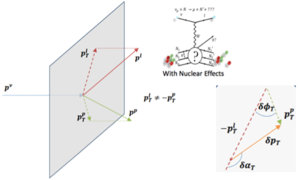
Upgrade: expected performances from simulations

- ND280 upgrade estimated impact on T2K oscillation analyses.
- Low momentum thresholds and full angle coverage will contribute better samples to study nuclear effects.
- Work in progress to demonstrate the capability of the new detector configuration to disentangle possible wrong/incomplete cross-section models.

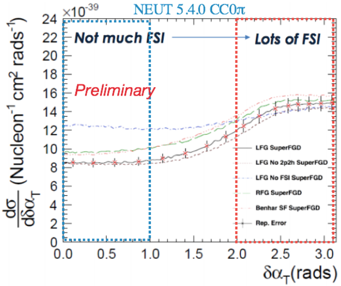


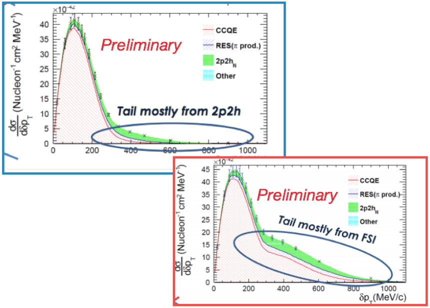
Parameters	Reduction of the uncertainty
Flux	20 %
σ_ν (CCQE/2p2h)	20% - 40%
FSI	45 %
σ_ν (Q^2 dependent)	25 %

EXPECTED PERFORMANCES



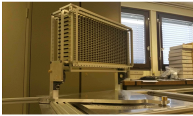
- Low momentum threshold and full angle coverage will grant better samples to study nuclear effects
- **Single Transverse Variable analyses** with the upgrade geometry seems to be very powerful to disentangle nuclear effects



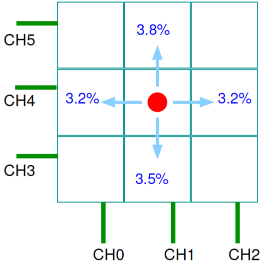


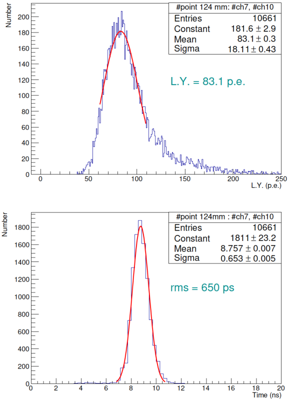
SuperFGD prototypes

- Extruded scintillator bars cut to cubes:
  - Polysterene based, 1.5 % PTP, 0.01% POPOP.
  - Reflective coating 30 to 100 μm from chemical etching of surface.
  - ... NIM A469 (2001) 340.
  - Kuraray WLS fiber (S-type, dia 1.0 mm).
  - Eljen EJ-500 optical cement.
  - Custom optical connector.
- $5 \times 5 \times 5$ proto tested at CERN Oct. 2017
  - Light yield
  - Optical crosstalk
  - Time resolution
- $48 \times 24 \times 8$ proto tested at CERN summer 2018
  - Tested in 0.2 T magnet.
  - Readout electronics optimisation and calibration.
  - Track and pattern recognition.
  - Stopping protons.
  - Photon conversion.

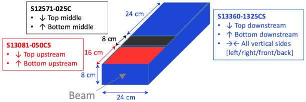


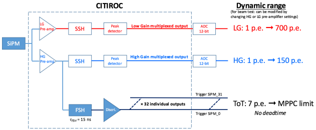
- $5 \times 5 \times 5$ prototype.
  - Charge and time spectra for a single cube, two fibers.
  - Time resolution for a cube with two fibers is $\sigma_t = 0.65 - 0.71$ ns .
  - Crosstalk average value is 3.7 % per side of cube.

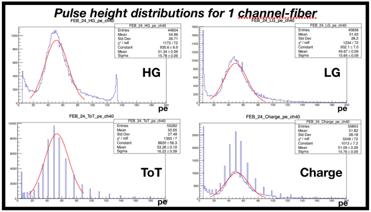


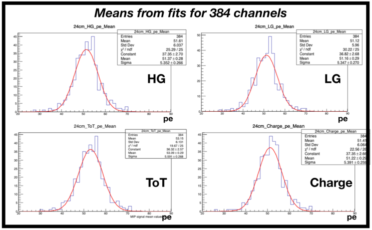


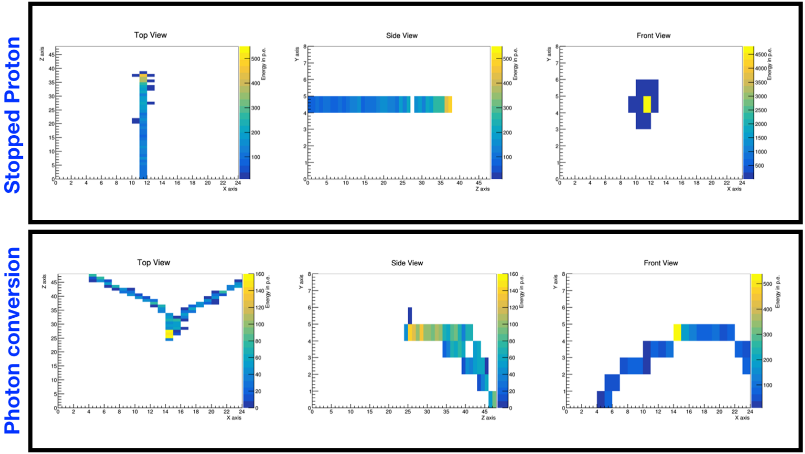
- $48 \times 24 \times 8$ prototype.
  - 1728 MPPCs: 3 types.
- Baby MIND electronics
- Calibration for beam tests:
  - Use LED at low p.e.
  - Use beam particles at higher p.e.

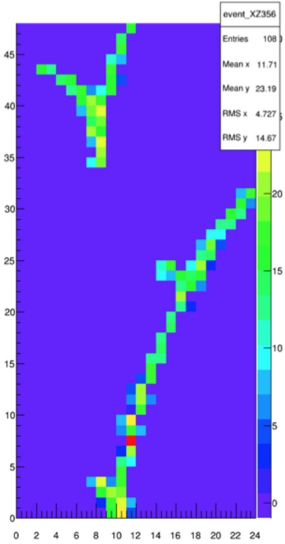




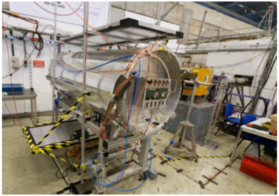


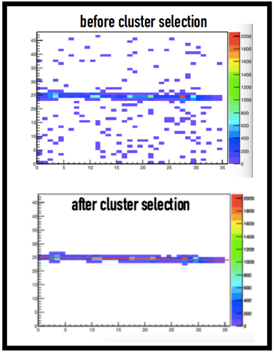



Stopped Proton
Photon conversion
Top View
Side View
Front View
X axis
Z axis
Y axis
Energy in p.e.

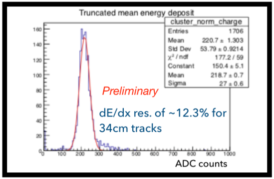

event_XZ356
Entries 108
Mean x 11.71
Mean y 23.19
RMS x 4.727
RMS y 14.67
45
40
35
30
25
20
15
10
5
0
0 2 4 6 8 10 12 14 16 18 20 22 24
20
15
10
5
0

- TPC test beam at CERN this summer 2018.
- Using HARP TPC field cage with one resistive MM.
- Different beam settings, cosmic and radioactive source data collected to study the resistive MM performances.
- Data being analysed, but preliminary results look promising.



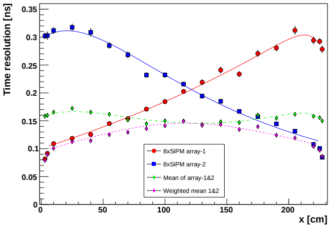


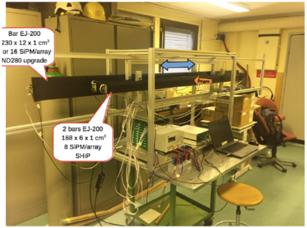
Muon track



Muon dE/dx

- Several tests of TOF prototypes at CERN.
  - Autumn 2017: $\sim$ 70 ps time res. for 1.5 m bars.
  - Summer 2018: panels prototypes with $168 \times 6 \times 1$ cm^3 bars tested.
  - Autumn 2018: beam test with ND280 upgrade bars.





- The **ND280** detectors play a significant role in the reduction of flux and cross-section systematics in T2K oscillation analyses.
- Since **2009** they have performed very well. However the current design configuration does have **Limitations**.
- An **upgrade** of the detector suite is underway to strengthen T2K physics potential.
  - *Detectors tested this summer at CERN-PS*
    ... including a novel 3D fine grained scintillator detector
  - *Installation of final detectors foreseen at J-PARC for summer 2021.*