The T2K Near Detector Upgrade

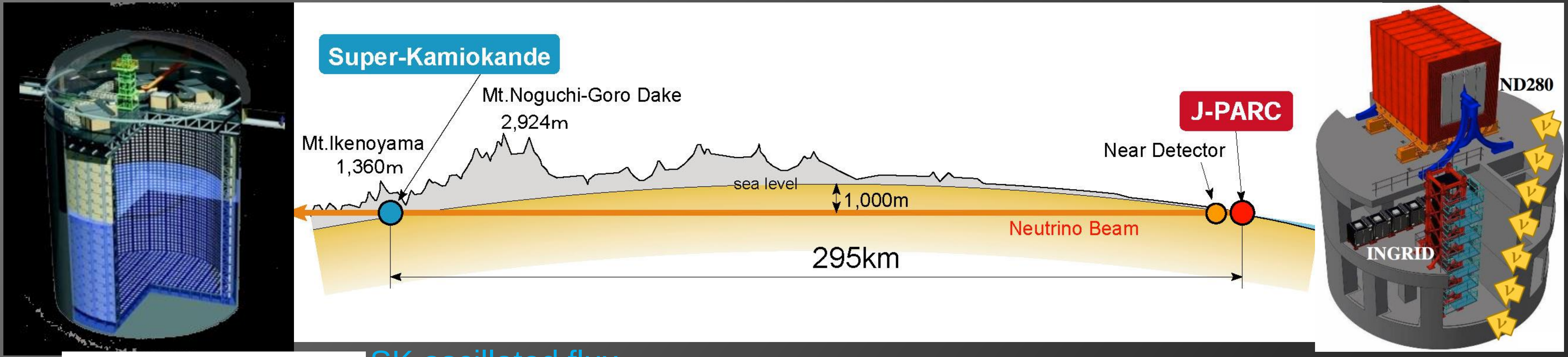
M. Tzanov, Louisiana State University

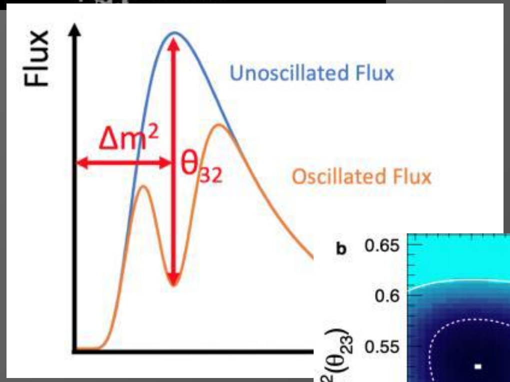
on behalf of the T2K Collaboration

NuFact 2021, Cagliari, Italy , September 2021

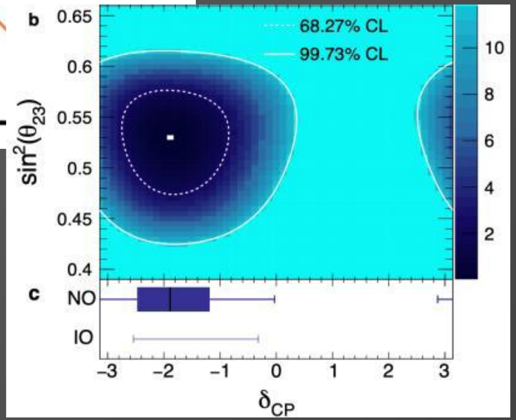
LSU

The T2K Experiment



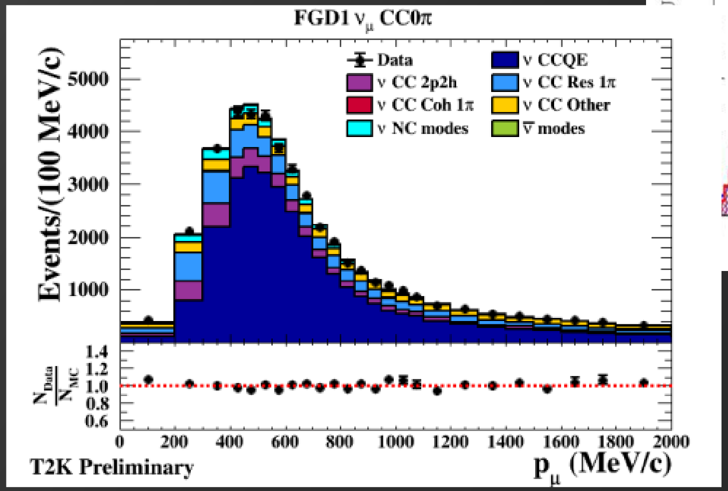


SK oscillated flux measurement

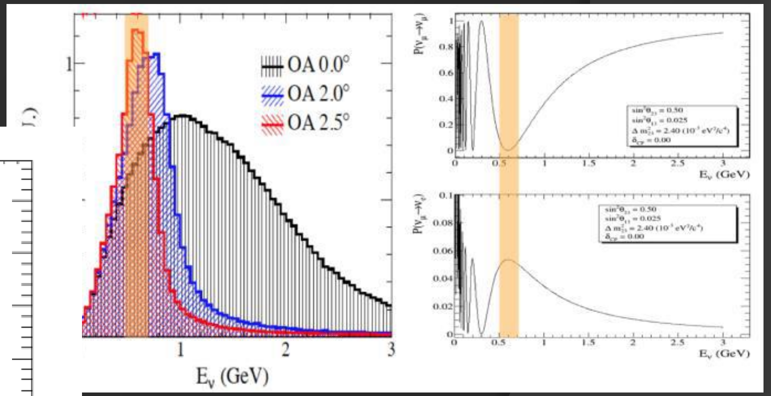


K. Abe et al., Nature 580, 339–344(2020)

ND280 rate measurement/constraint



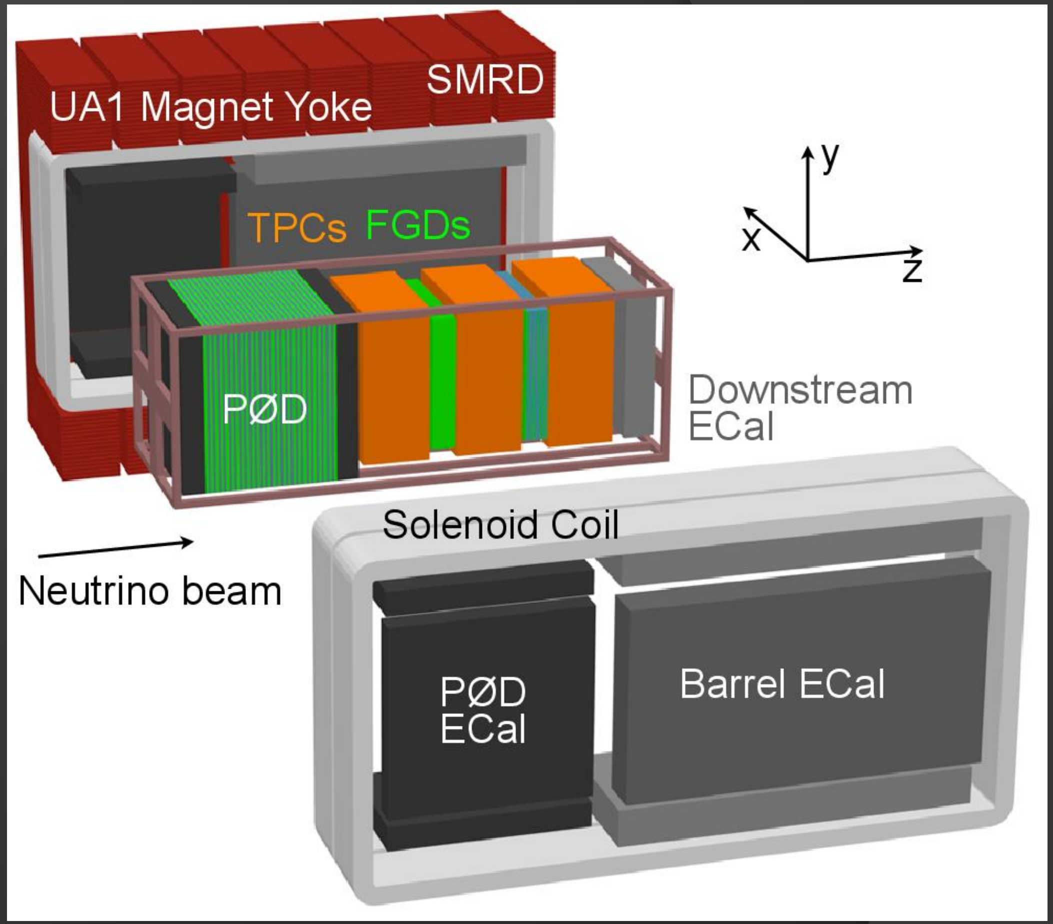
J-PARC Off-axis ν beam



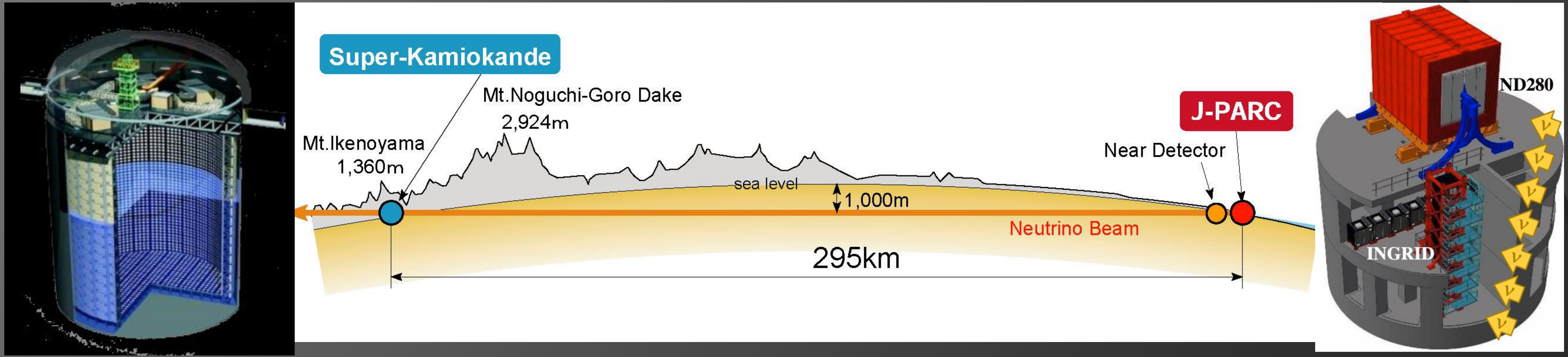
Off-Axis Near Detector Complex ND280

Refurbished UA1 magnet providing
0.2 T magnetic field surrounding

- ND280 Tracking detector :
  - Two Fine Grained Detectors (FGDs) – main neutrino targets. FGD1 consists of layers of 10x10 mm plastic scintillator bars instrumented with Multi-Pixel Photon Counters (MPPCs).
  - Three Time Projection Chambers (TPCs) filled mainly with Ar-based gas mixture provide particle ID based on dE/dx and momentum measurement.
- Side Muon Range Detector (SMRD)
- EM Calorimeters
- π^0 detector (P0D)



The T2K Experiment



T2K is a long-baseline neutrino oscillation experiment:

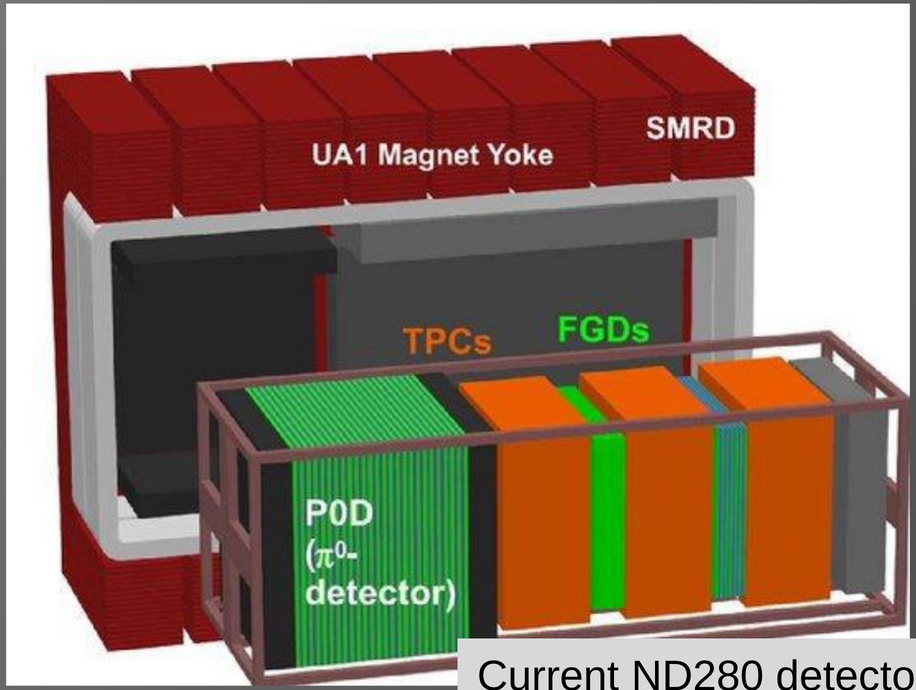
- First to observe ν_e appearance in a ν_μ beam.
  PRL 112, 061802 (2014)
- Constraint on CP violating phase
  Nature 580, 339–344(2020).
- Measure precisely $\nu_\mu \rightarrow \nu_\mu$ disappearance parameters
  PRD 103, 011101 (2021)

New cross section measurements

PRD 101, 112001 (2020)
PRD 101, 112004 (2020)
PRD 101, 012007 (2020)
PRD 102, 012007 (2020)
JHEP 10(2020)114 (2020)

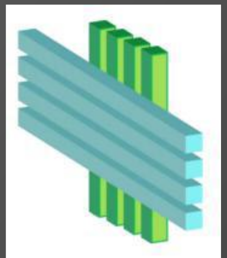
Measure neutrino cross sections in the near detector.

Limitations of the Current ND280 Detector



Current ND280 detector

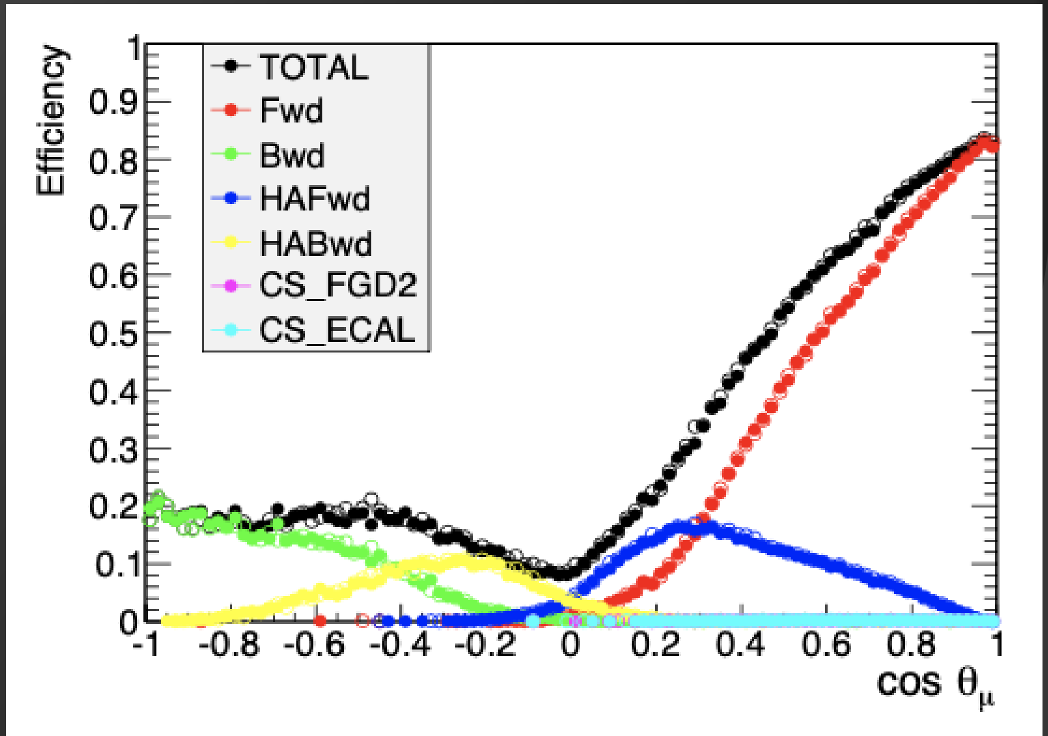
FGD



1cm x 1cm
Scintillation bars

Geometrical acceptance:
- Mostly forward acceptance
- Tracks w/o TPCs (high-angle)
- Tracks w/o TPCs (low-momentum)

Kinematic regions with low efficiency



Detector response:
- Limited timing information – no direction information
- No neutron info
- High detection threshold
- Poor electron/photon separation

T2K-II (2022-2026)

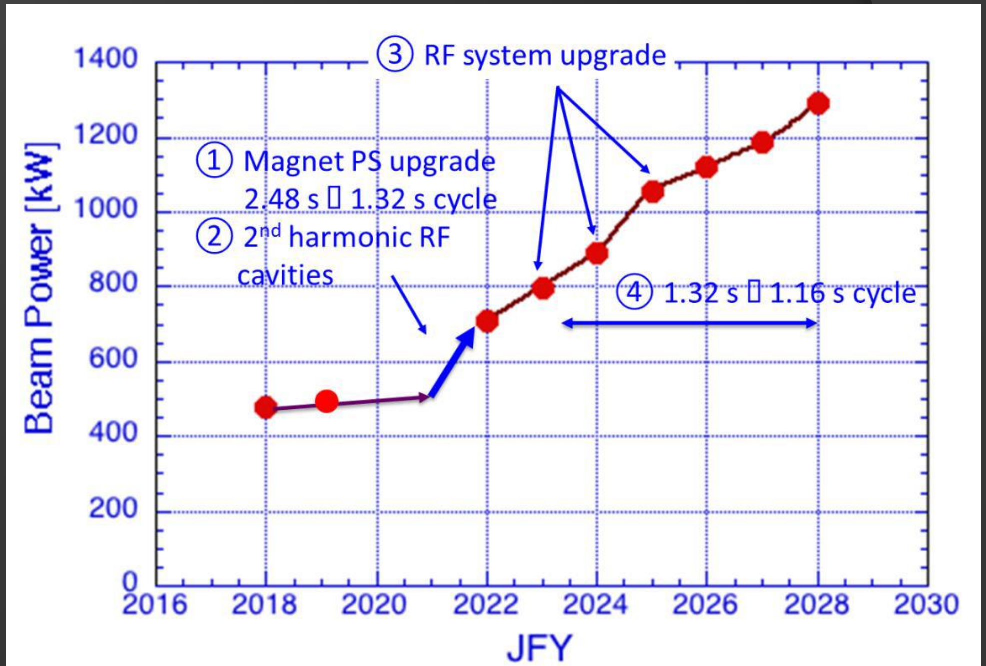
Improved measurements:

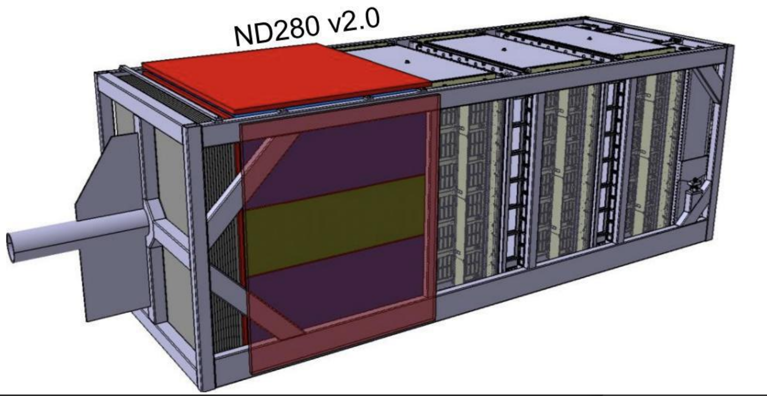
- CPV observation in the optimal scenario at 3σ
- Reduce systematic uncertainties from 5-6% down to 4%
- Constrain neutrino nucleus interactions

Planned upgrades:

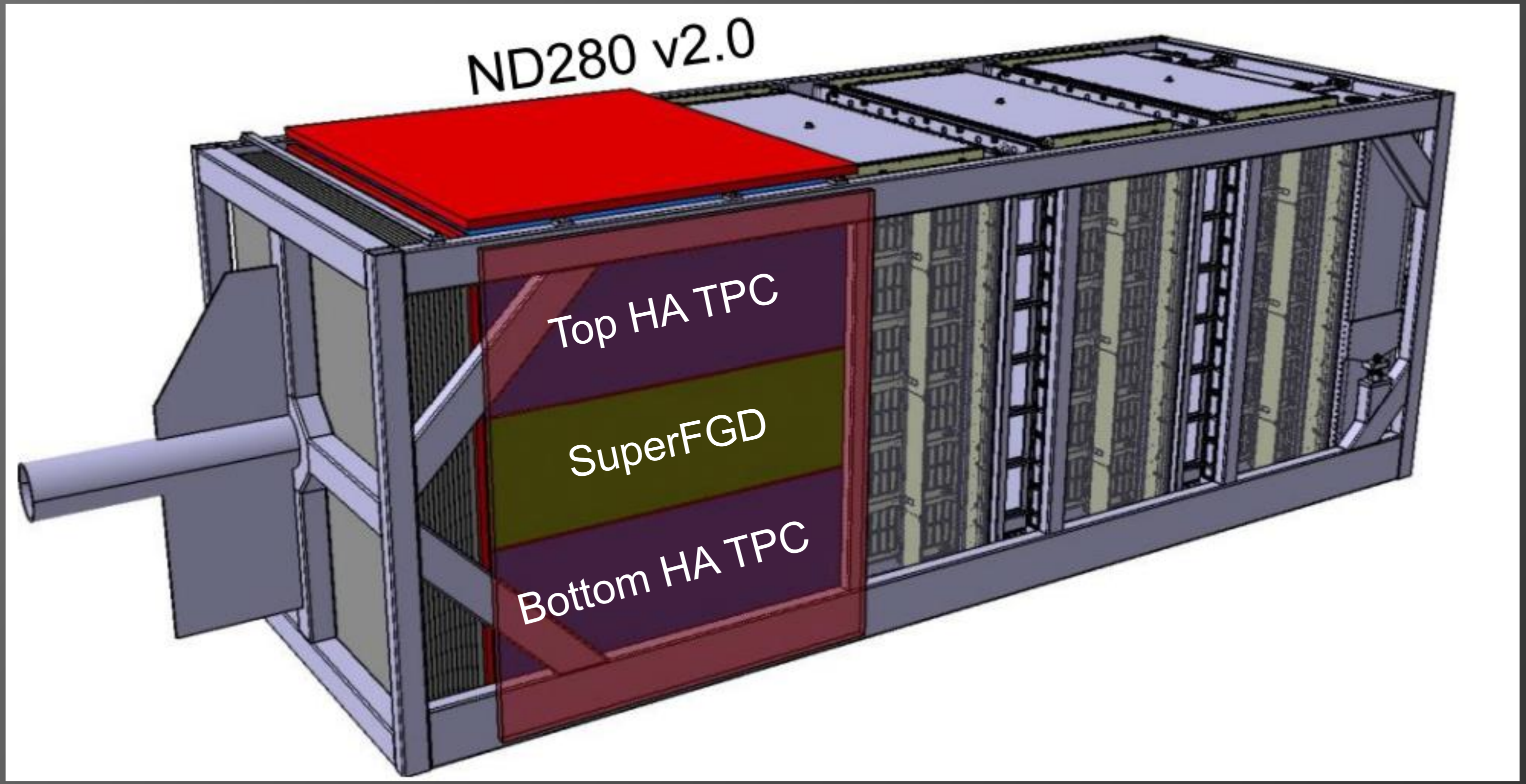
- Beam power upgrade:
  0.5 MW → 1.1 MW (→ 1.3 MW HyperK)
  ~ 8x the statistics

- Near detector upgrade:
  replace P0D with highly segmented detector
  with 4π acceptance



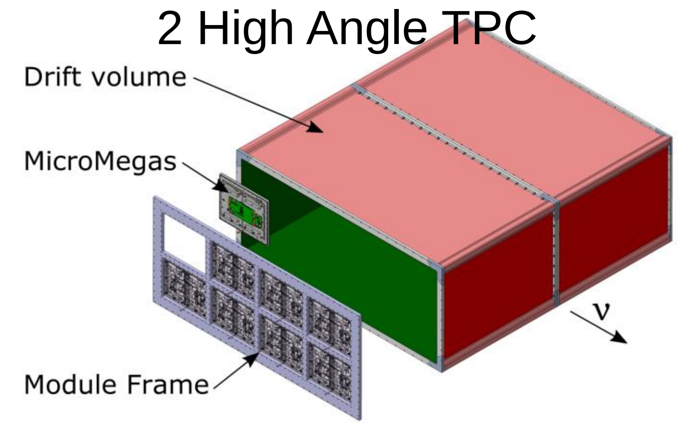


ND280 Detector Upgrade

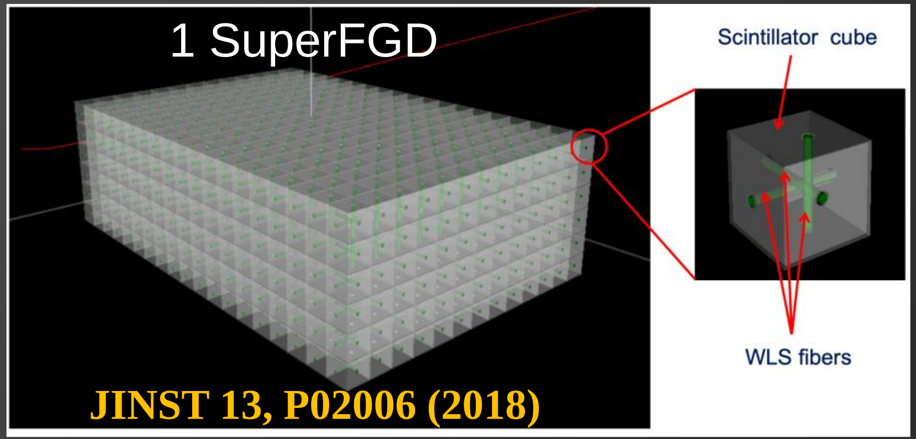


ND280 Upgrade TDR:
arXiv:1901.03750

Expected installation: 2022



NIM A 957, 163286 (2020)



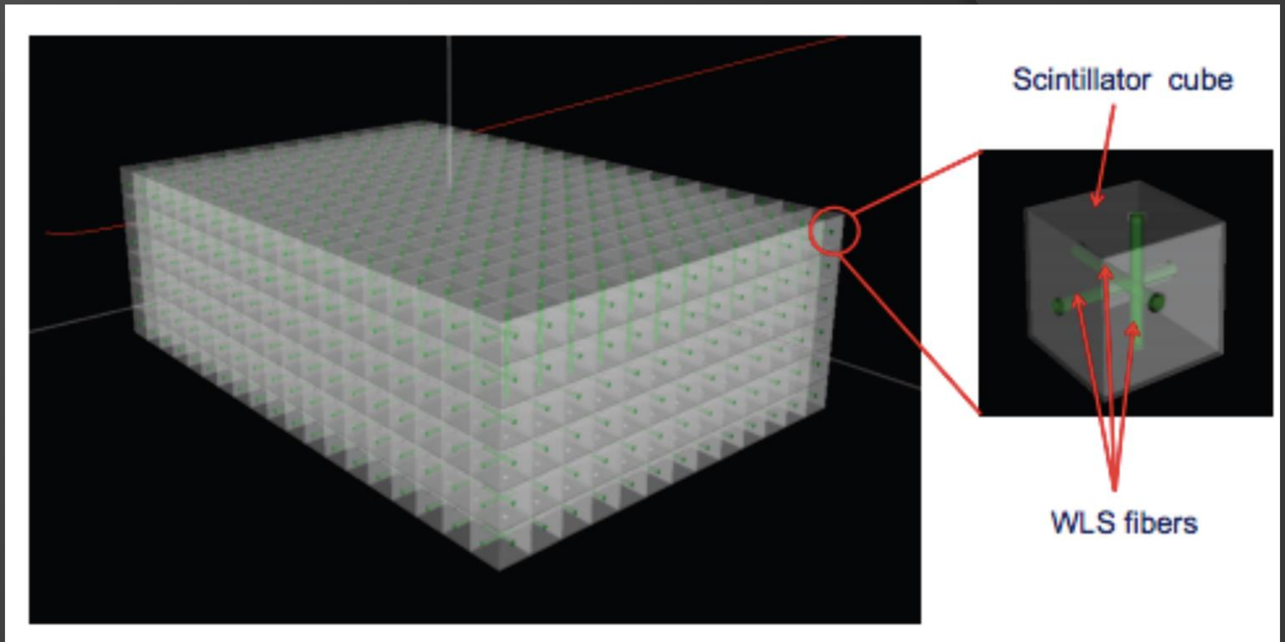
JINST 13, P02006 (2018)
JINST 15, P12003 (2020)

JPS Conf. Proc. 27, 011005 (2019)

Super Fine Grained Detector (SuperFGD) – Concept

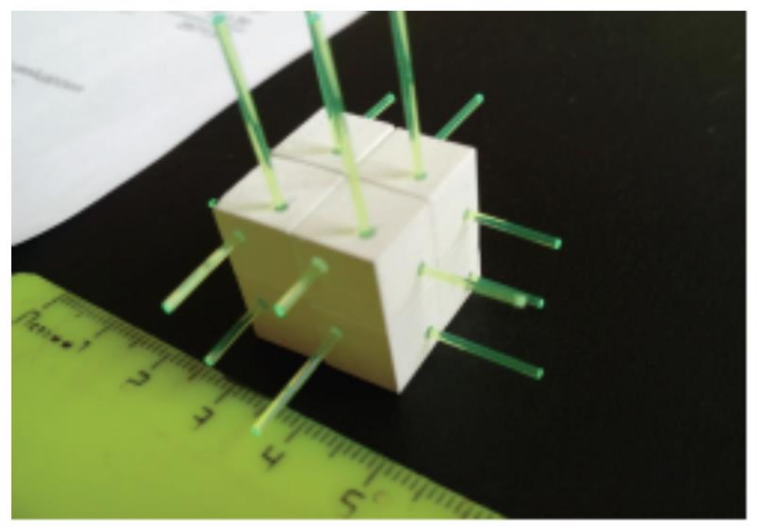
Novel 3D Scintillation Tracker:

- Granularity: 1cm scintillation cubes
- 1.92m (d) x 0.56m (h) x 1.82m (w) active volume
- $2x10^6$ cubes
- 3D WLS fiber readout
- 60k MPPC channels



Detector readout

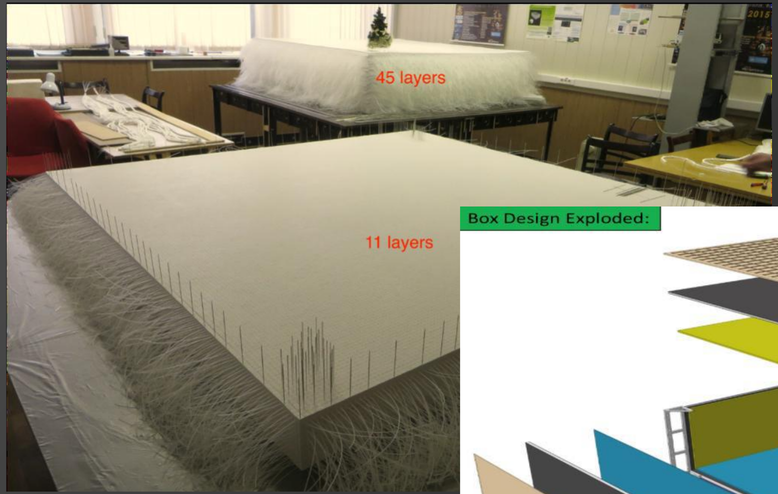
- 3D hits allow for a detailed 3D reconstruction
- 4π acceptance
- Electronics based on CITIROC chip

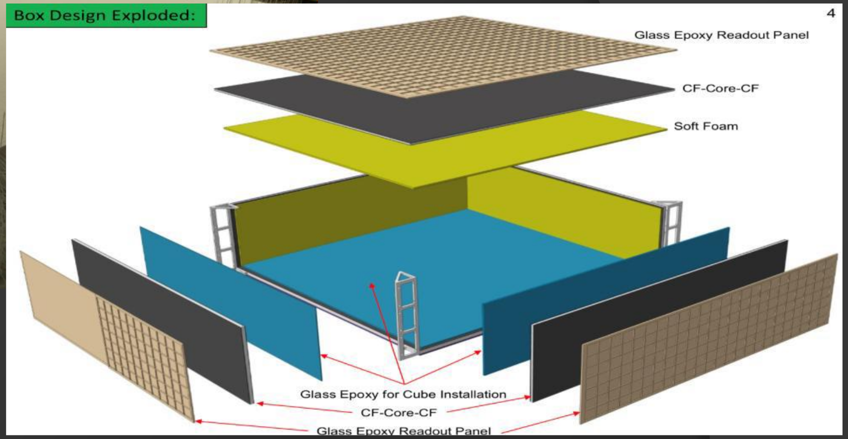


SuperFGD Detector – Design and Status

Cubes and Box:

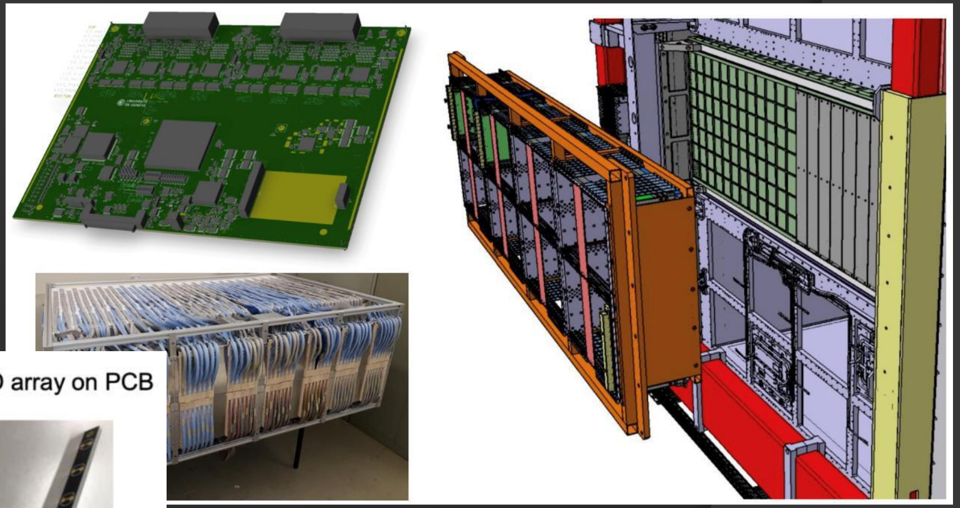
- All (~2.1 million) cubes have been produced
- 56 layers + 1 spare (182x192) assembled
- Box needs to withstand 2 tons weight and earthquakes (composite material)
- Box design has been validated with prototypes
- The box is currently in production

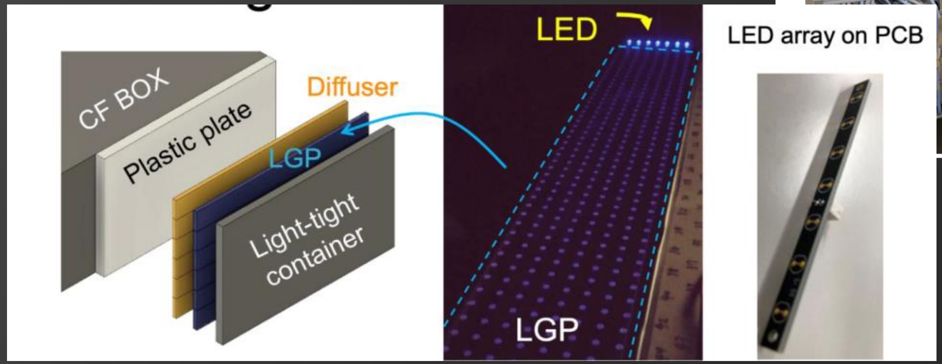




Electronics

- Design of the readout front-end is finished
- 400MHz sampling provides 2.5ns timing information
- Integrated calibration system: regular MPPC calibration



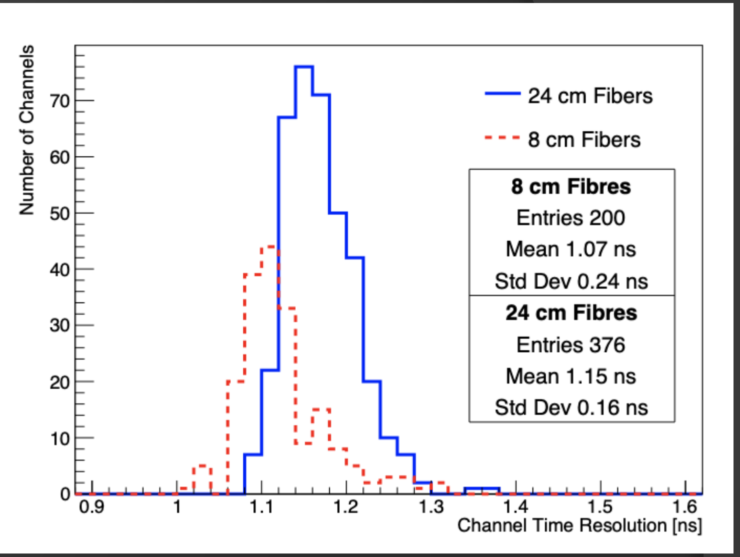


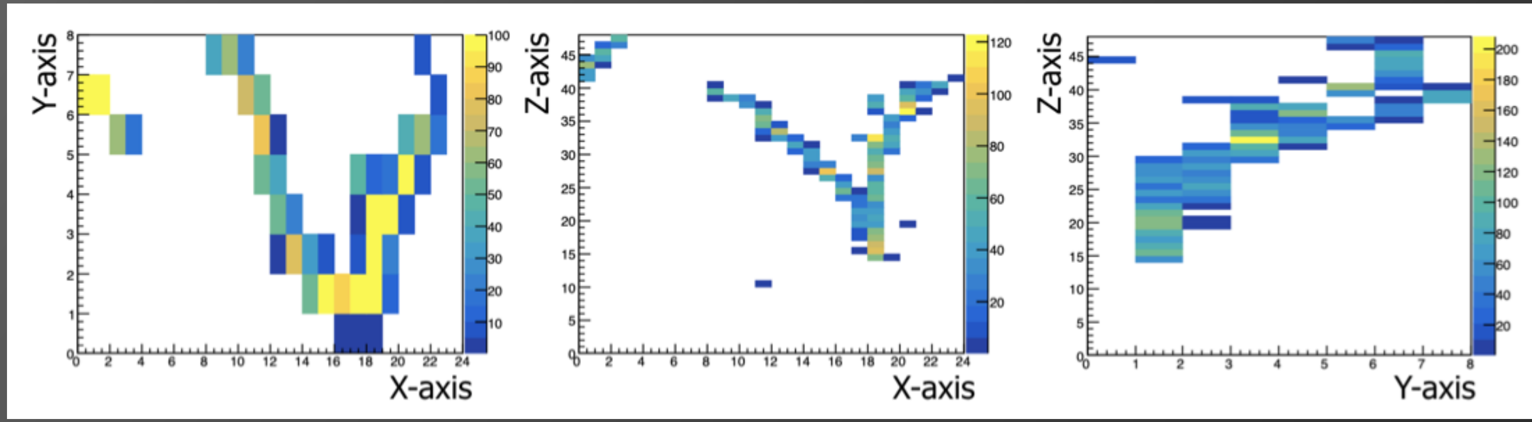
SuperFGD – Testbeam Performance

Prototypes with different sizes exposed to testbeams at CERN and LANL.

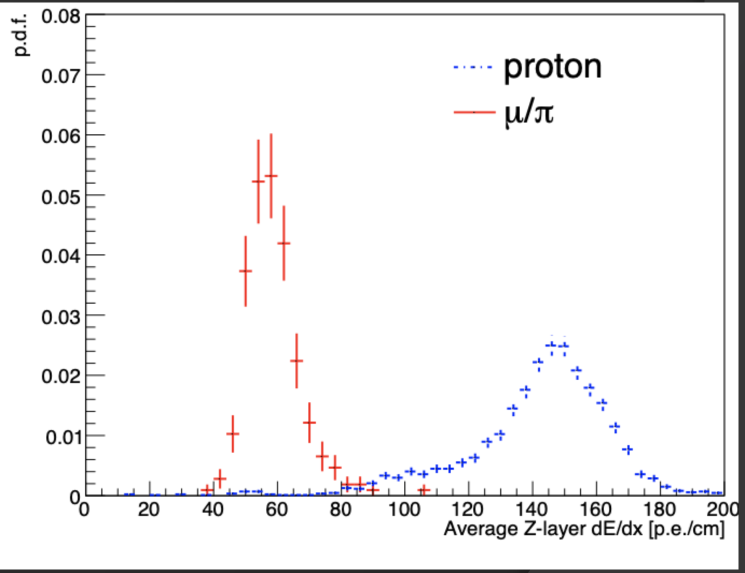
Charged particle testbeam at CERN, JINST 15 P12003 (2020)

- Stopping protons
- Gamma conversion
- Good time resolution
- Good μ/p discrimination using dE/dx





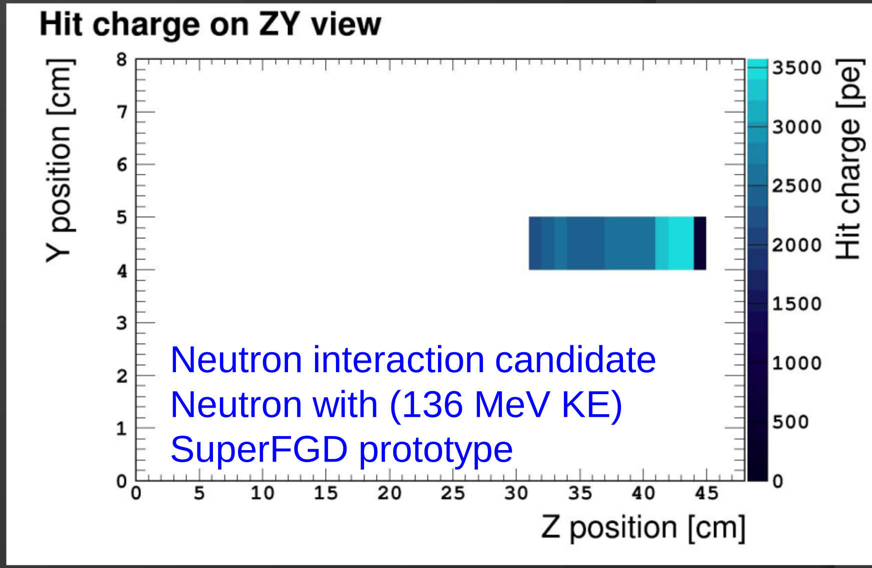
Gamma conversions in SuperFGD

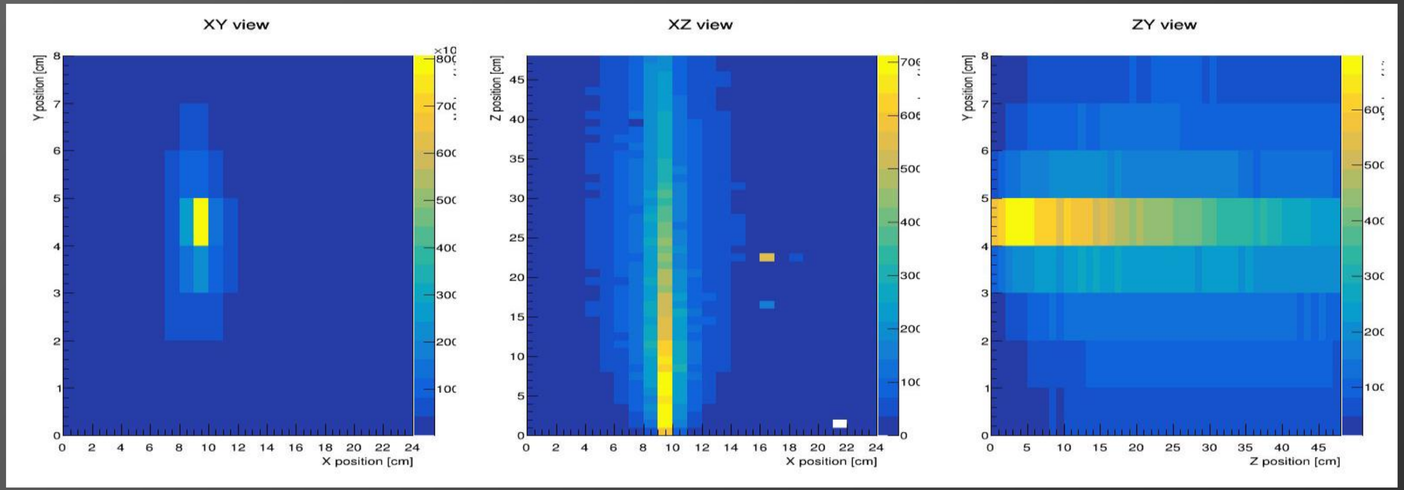


SuperFGD – Neutron Testbeam at LANL

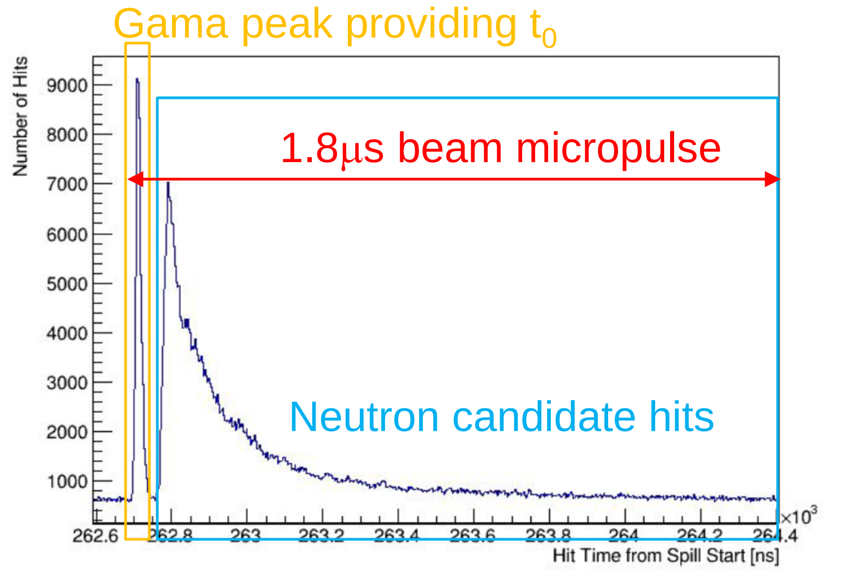
Neutron testbeam at LANL

- neutron beam from 0 – 800 MeV relevant for neutrons produced in neutrino interactions
- neutron energy measured from time-of-flight
- sufficient and high-quality data has been collected during 2019 and 2020 runs.
- beam collimation of 8mm and 1mm (2020)
- See Guang Yang's talk on Monday





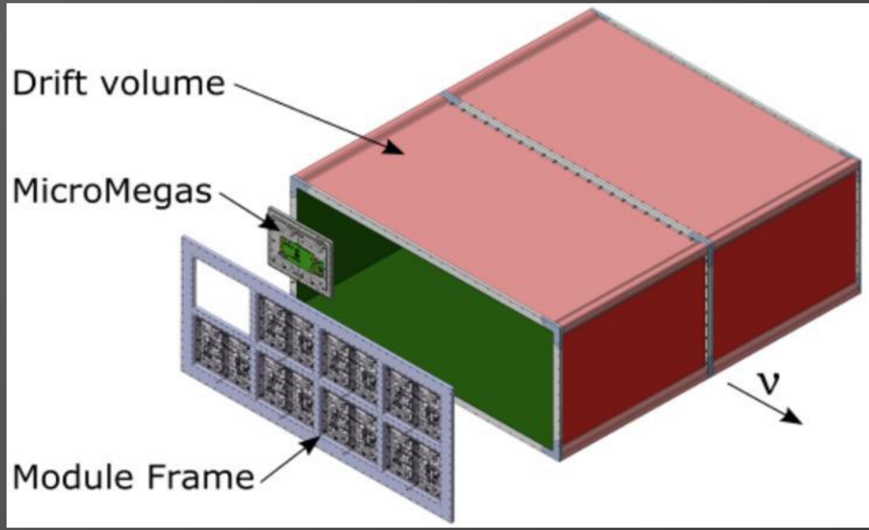
Neutron beam candidate hits

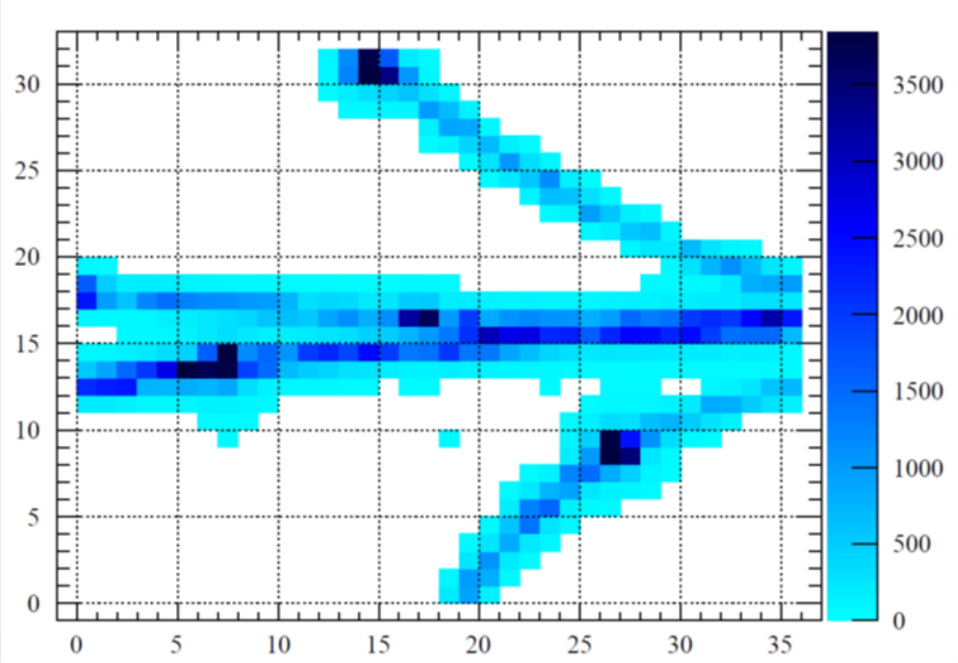


High-Angle TPC – Design and Status

Two new TPCs produced

- Provides tracking and particle ID
- Dimensions: 1.865 x 2.0 x 0. 82 m^3
- Composite material for the field cage
- Novel readout: 8 resistive Micromegas (ERAM) per side
- 1152 readout channels with 10.09x11.18 mm^2 pads per ERAM
- Same T2K gas (95%Ar, 2% CF4, 2% iC4H10)

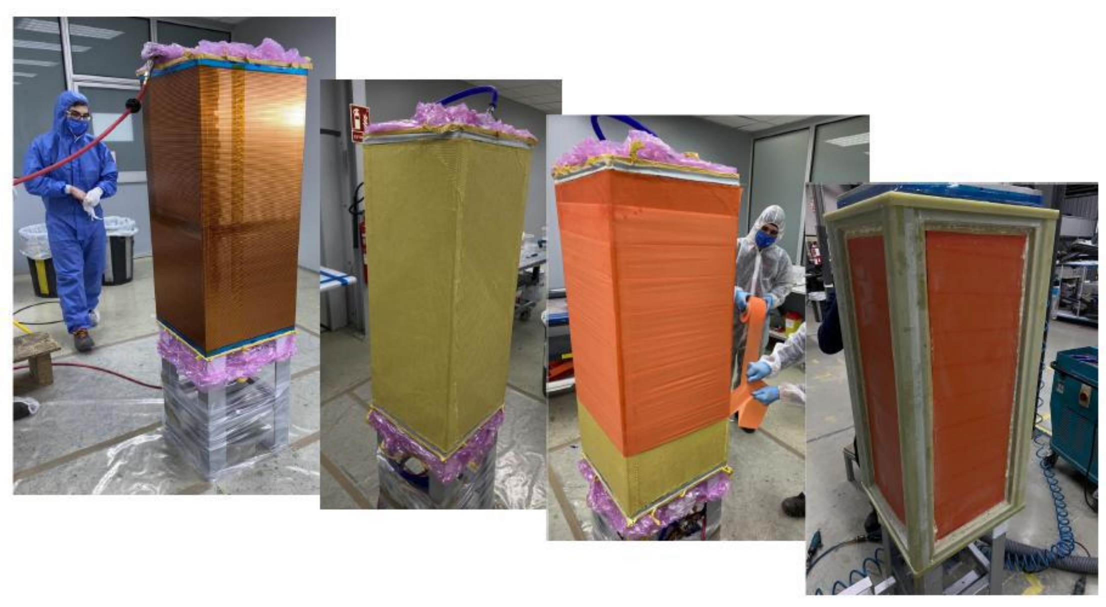




High-Angle TPC – Design and Status

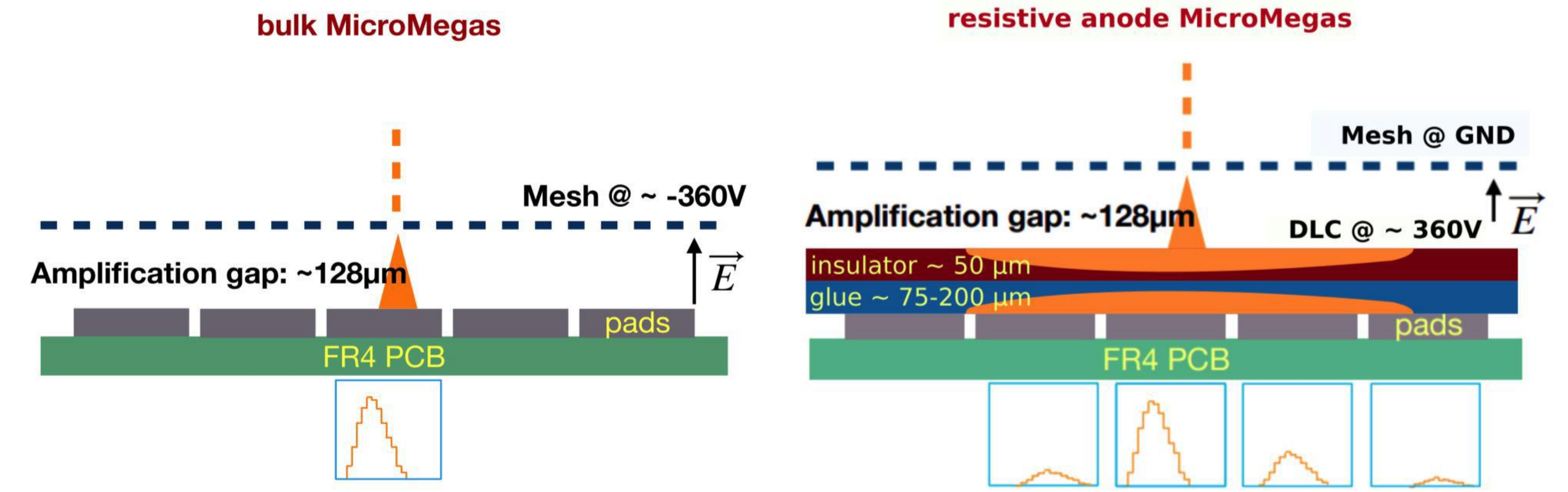
HA-TPC Field Cage

- TPC consists of 2 halves and separate cathode
- Production based on layers wrapped around mould
- 2 full length prototypes for 1MM produced and successfully tested.



HA-TPC ERAM module

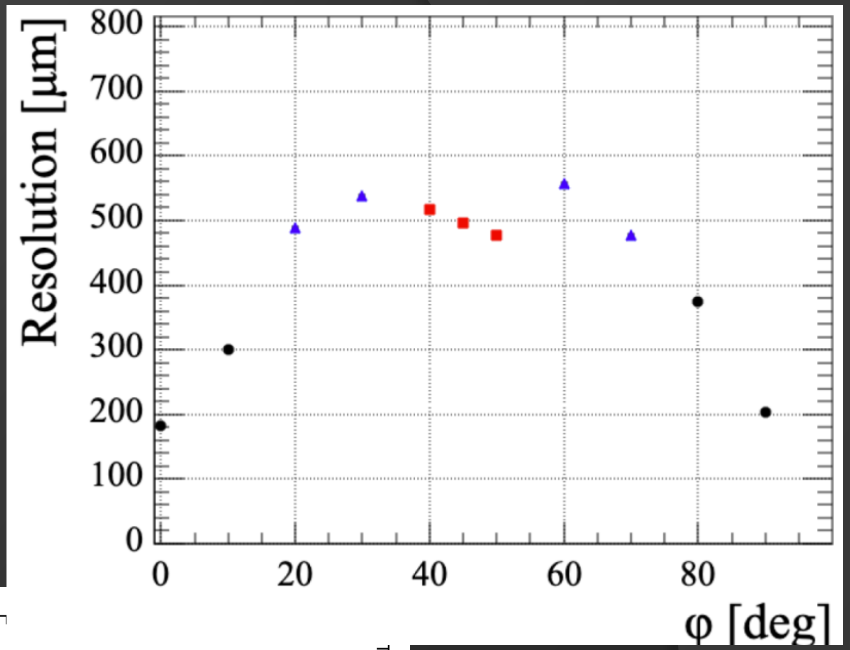
- Novel resistive MM readout
- Charge over several pads => better point resolution
- 32 ERAM modules
- Tested prototypes with various various RC parameters
- Pre-production of 8 modules at CERN

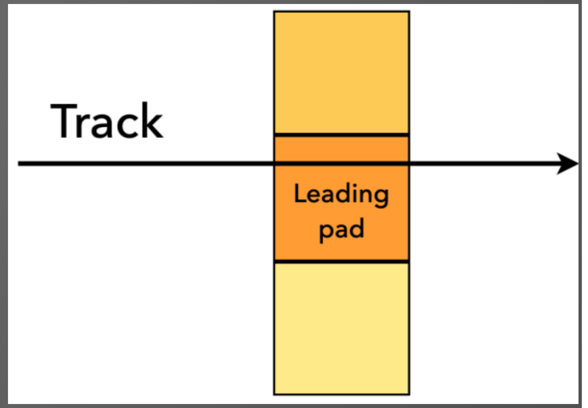


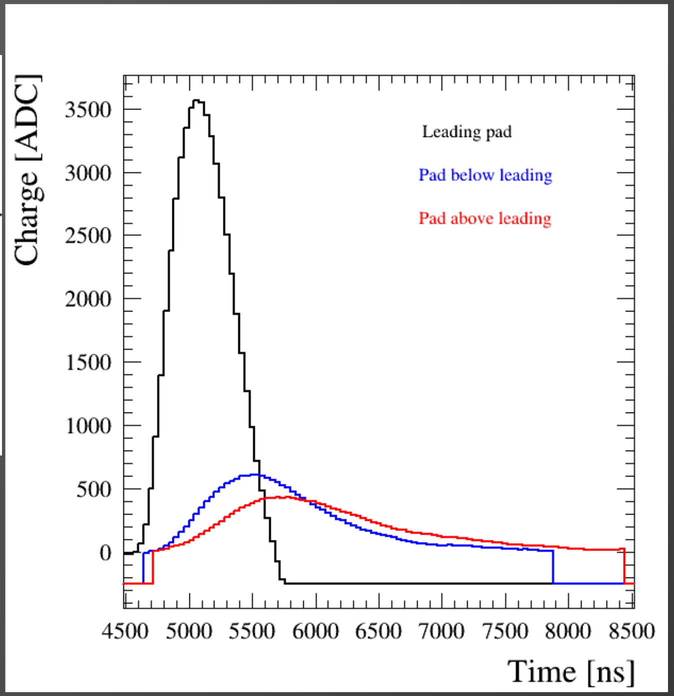
High-Angle TPC Prototypes – Testbeam Performance

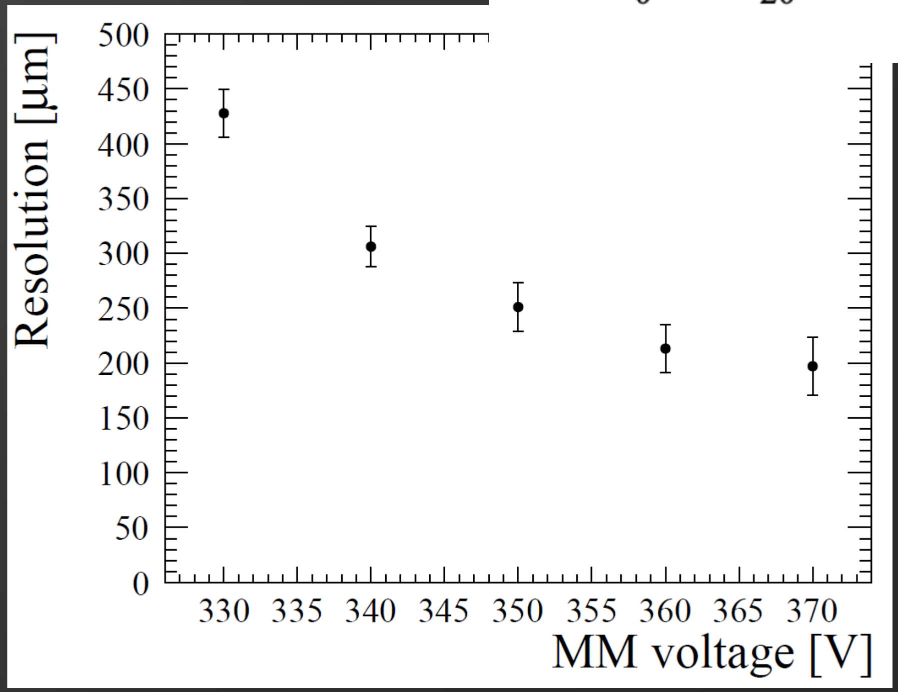
Prototypes tested in testbeams at DESY/CERN and cosmics at Saclay

- Different beam settings e, μ, π, p (0.5 to 2 GeV/c)
- New reconstruction algorithm based on testbeam data
- Spatial resolution better than 600μm for all angles
- For first 15cm is below 300μm





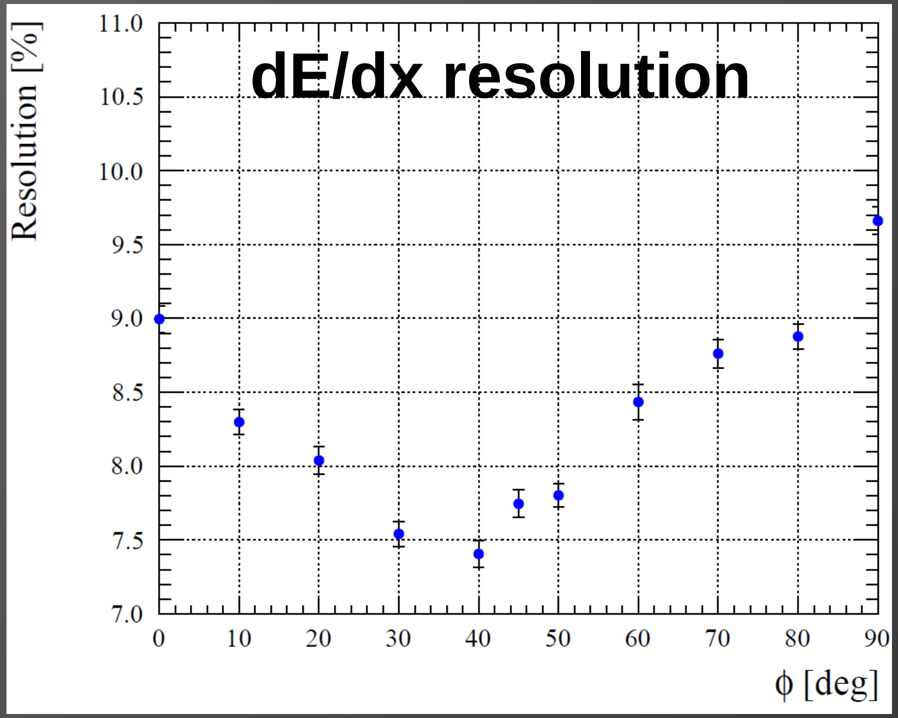


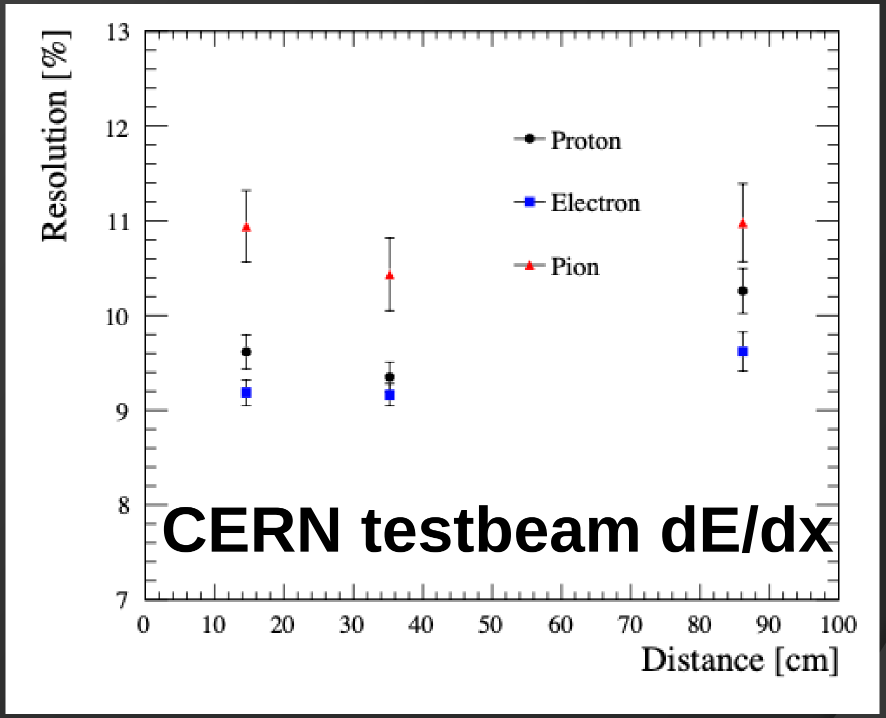


High-Angle TPC Prototypes – Testbeam Performance

Prototypes tested in testbeams at DESY/CERN and cosmics at Saclay

- Very good dE/dx resolution for all angles
- dE/dx resolution below 10%
- 2x better than current T2K TPC
- The testbeam performance study has been submitted to NIM https://arxiv.org/abs/2106.12634





Time-of-Flight System

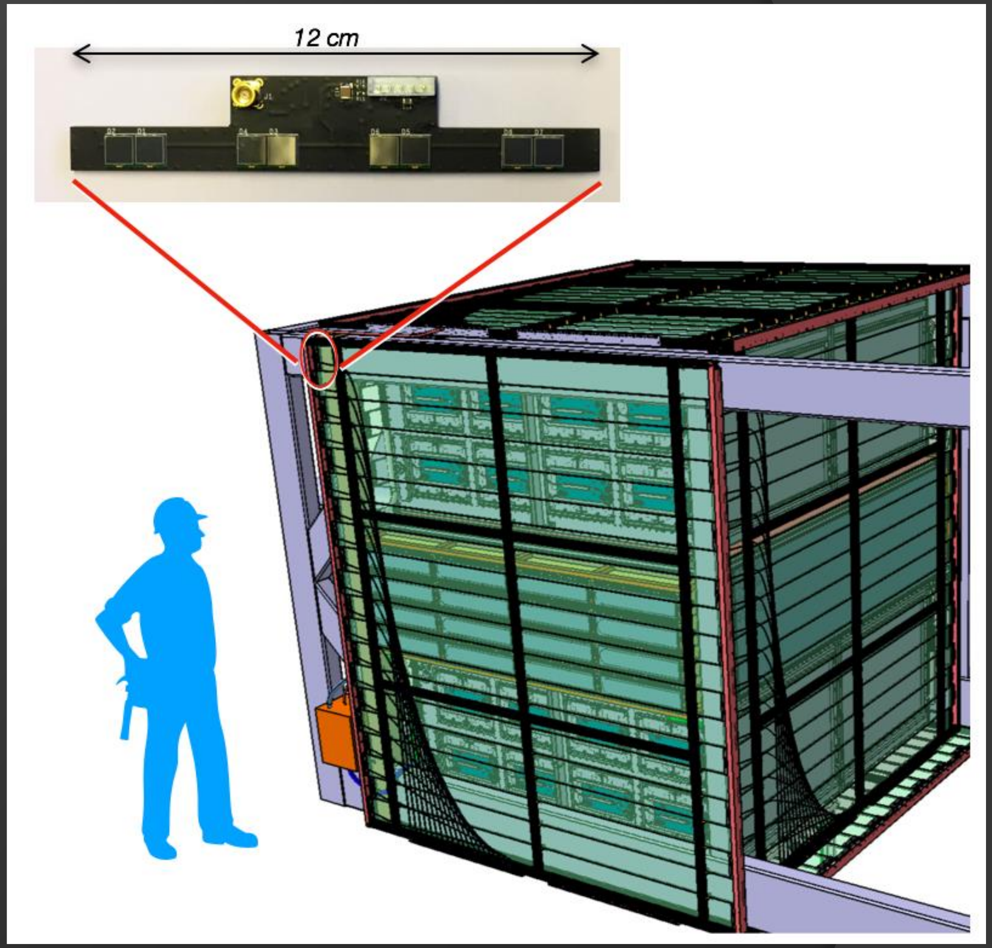
Six TOF planes surround SuperFGD and HA-TPC

- Provide particle direction for background rejection
- Serves as cosmic trigger
- Time calibration for SuperFGD

Based on a concept of the SHiP timing detector project

- 6 (2.3m x 2.5m) modules made from 2.3m x 0.12m x 0.01m scintillation bars
- Double sided readout with 8 6x6 mm^2 SiPMs per side
- SAMPIC waveform digitizer

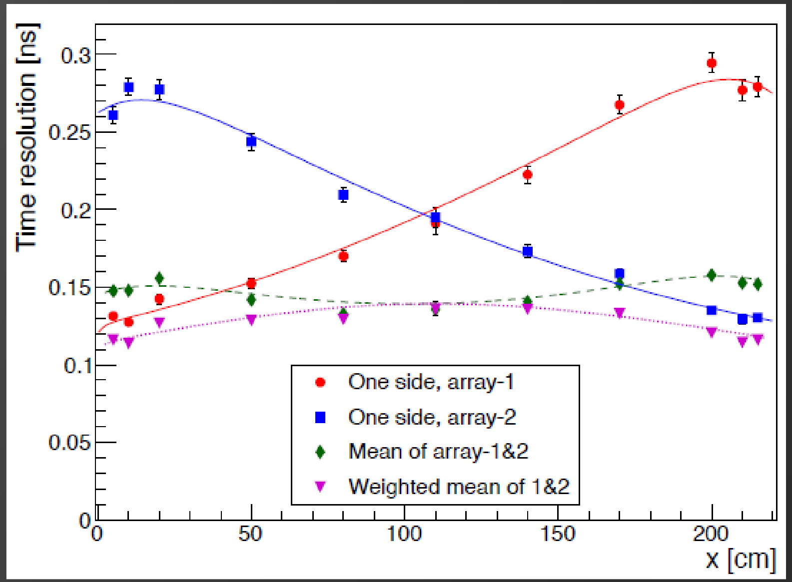
Currently quality control of all modules with cosmics



Time-of-Flight System Prototype – Cosmic Ray Tests

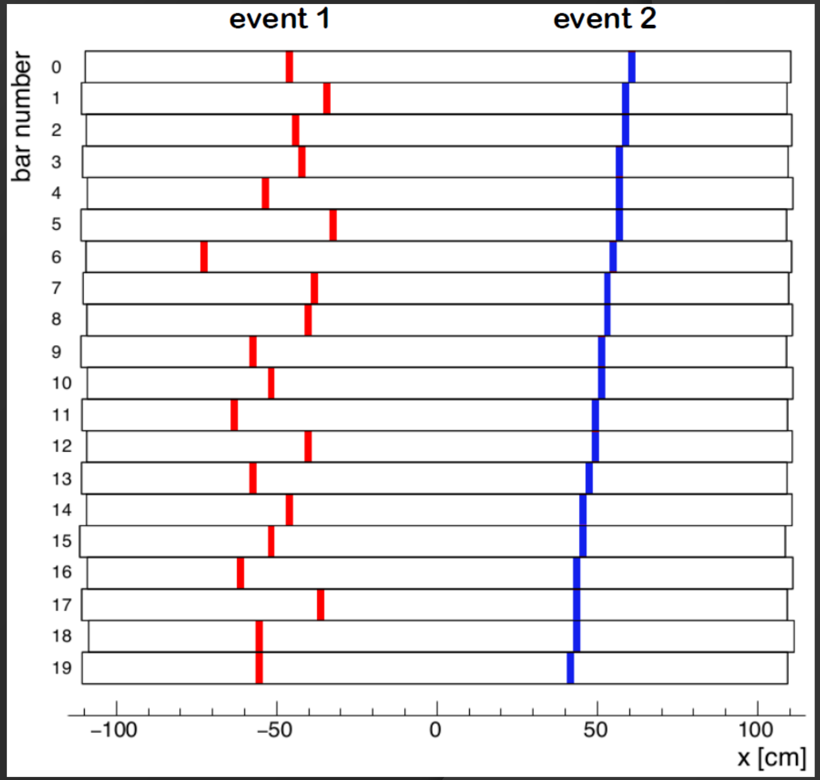
- Several tests with cosmic rays
- Achieved 150ps time resolution
- Results in https://arxiv.org/abs/2109.03078

Single bar using cosmic rays – 1 vs 2 sided time resolution.

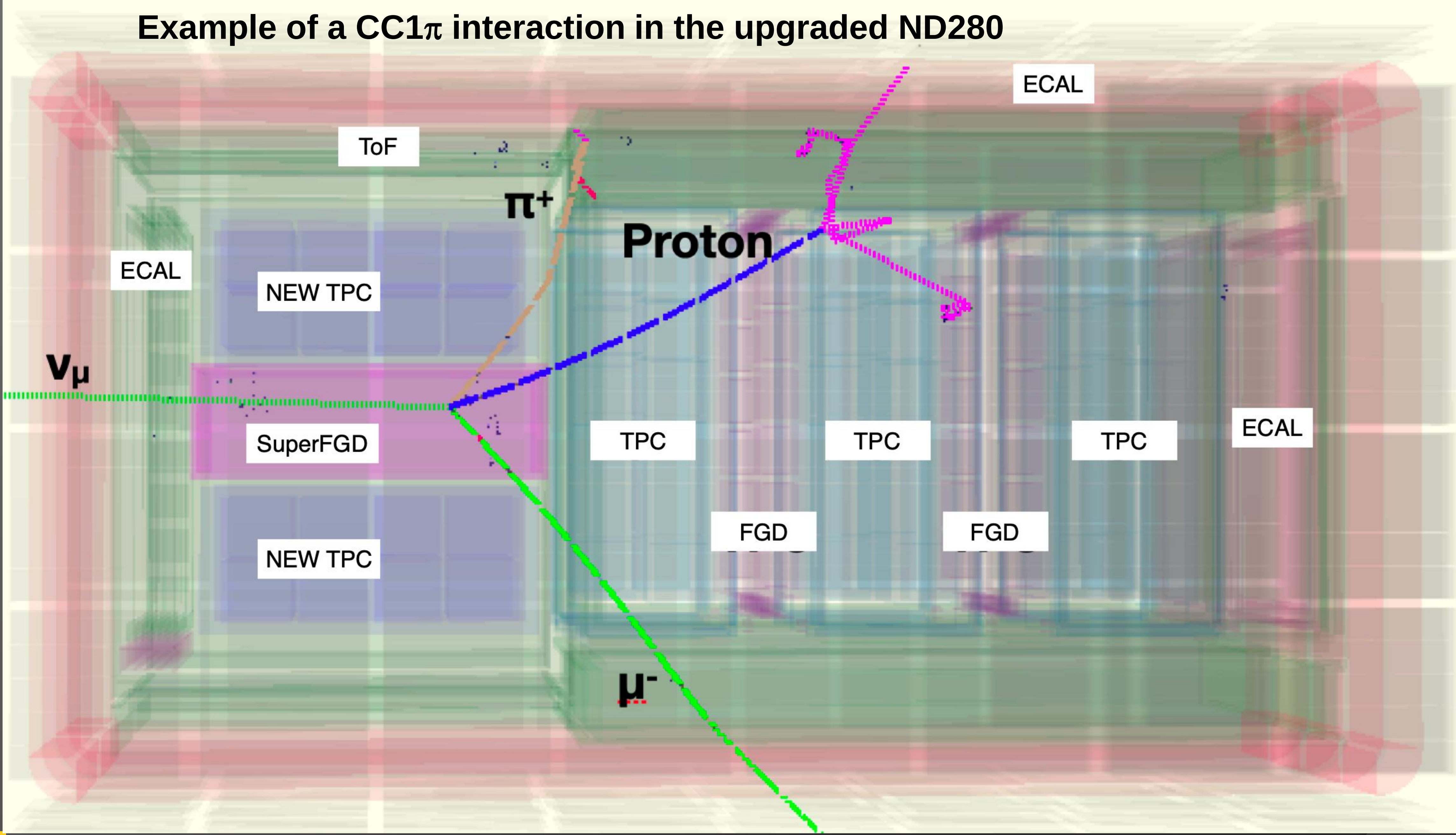


bar length

Cosmic ray shower and track in a fully assembled module



ND280 Upgrade – Expected Performance



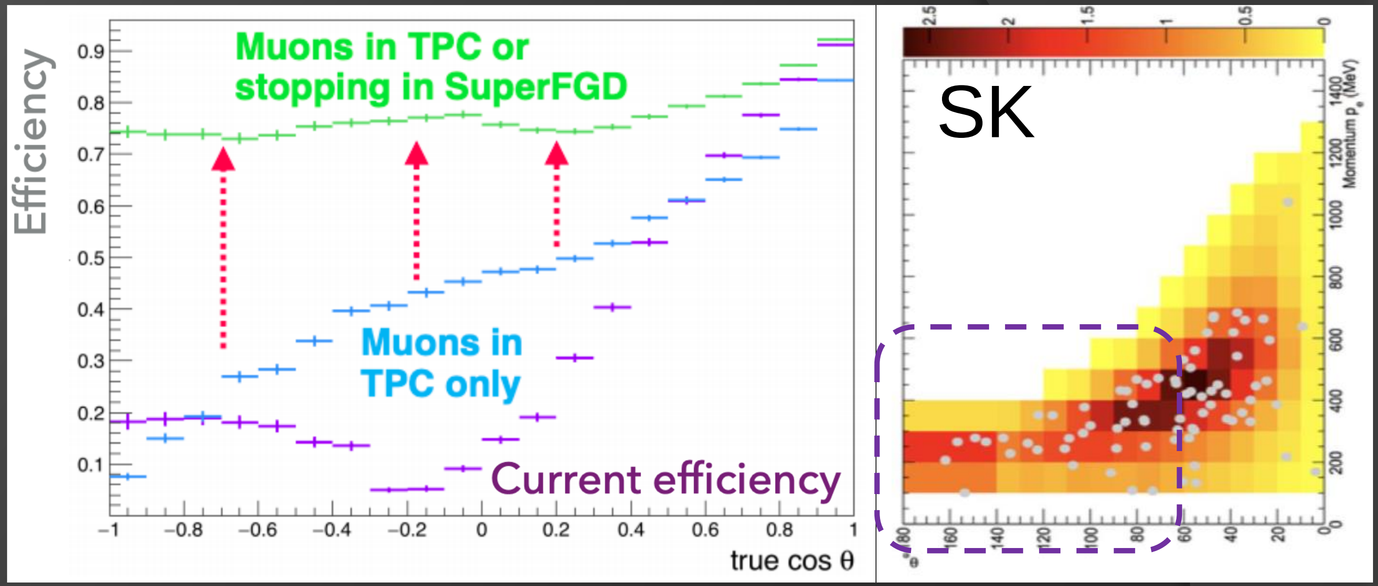
ND280 Upgrade – Expected Performance

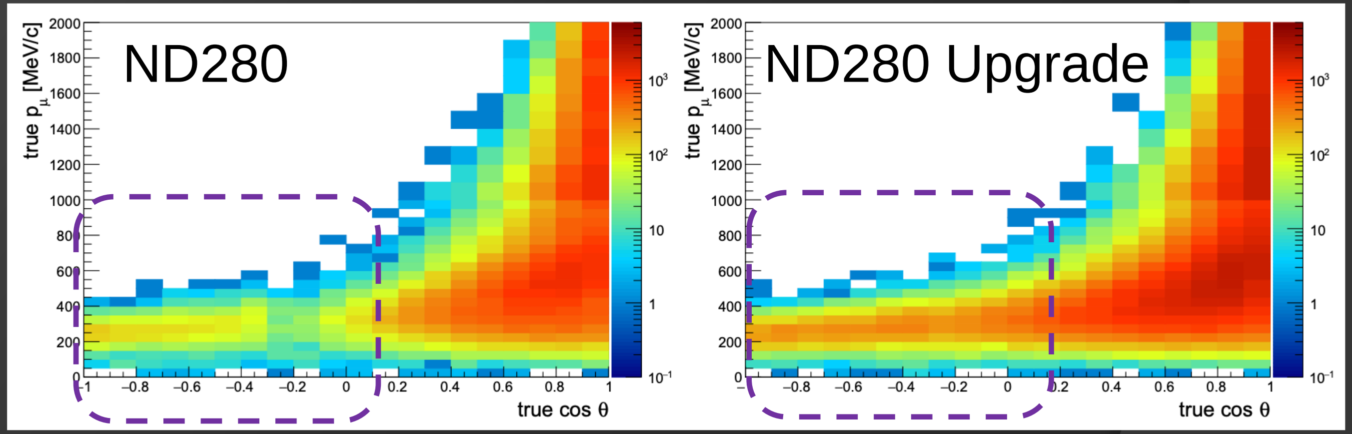
Improved kinematic range

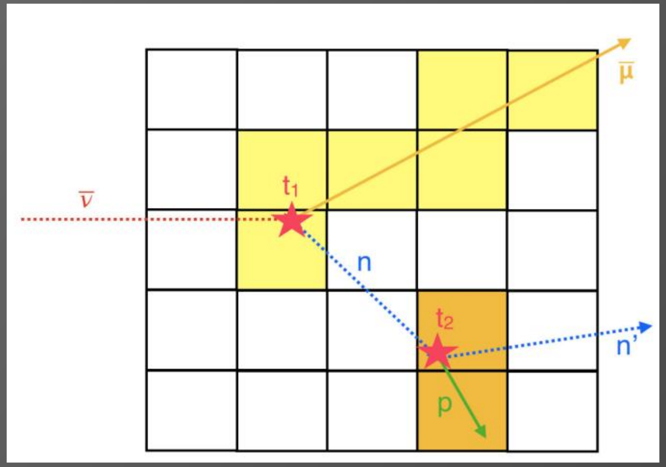
- Better efficiency for all angles
- Coverage similar to SK
- Isotropically finely segmented
- 3D hadronic tracking
- Good for transverse variable reconstruction

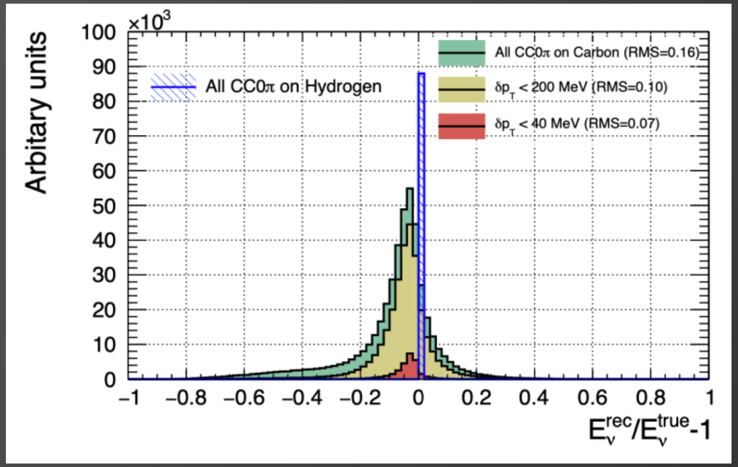
Neutron reconstruction from TOF

- Reduce neutrino energy bias
- Shown in Phys. Rev. D 101, 092003









Conclusions and Status

T2K's ND280 is instrumental in the measurements of the oscillation parameters.

- Constraint on the far detector rate
- Reduction of systematic uncertainties
- Limitations in current design

The ND280 upgrade will address some of these limitations

- Novel technologies tested extensively with testbeams
- Important for both T2K-II and HyperK
- Detector construction is progressing well for start in 2022

In addition, beamline upgrade will allow for ~8x the current statistics.

Details on the expected physics performance are detailed in the following:
https://arxiv.org/abs/2108.11779
Also discussed in poster by Viet: https://indico.cern.ch/event/855372/contributions/4480664/

Exciting time for the T2K collaboration in expectation of the new ND280 upgrade data.

More T2K Talks and Posters

121. Results from T2K
Dr Ciro Riccio (Stony Brook University (US)), 9/6/21, 12:40 PM Plenary

274. Latest results from T2K
Justyna Lagoda (National Centre for Nuclear Research (PL)) , 9/8/21, 1:02 PM, WG 1

103. Neutrino interaction modelling and uncertainties for T2K analyses
Dr Clarence Wret (University of Rochester) , 9/8/21, 4:00 PM, WG1+WG2 (WG1 zoom)

174. Is T2K missing energy? Searching the electron-scattering data archives for robust removal energy uncertainties
Mr Jordan McElwee (University of Sheffield) 9/8/21, 4:36 PM WG1+WG2 (WG1 zoom)

104. Combined neutrino and antineutrino charged current cross section measurement on carbon with zero final state pions in the T2K near detector complex
Caspar Maria Schloesser (ETH Zurich (CH)), 9/9/21, 12:58 PM WG 2

170. An improved muon neutrino charged-current single positive pion cross section on water using michel electron reconstruction in the T2K near detector
Sam Jenkins (University of Sheffield), 9/9/21, 1:16 PM WG 2

335. Charged current interactions on carbon with a single positively charged pion in the final state at the T2K off-axis near detector with 4π solid angle acceptance
Danaisis Vargas (Universitat Autonoma de Barcelona (ES)), Poster session NB: do not use Safari; use Firefox, Chrome or Edge

169. Expanding T2K near detector fit by adding proton information
Kamil Janusz Skwarczynski (National Centre for Nuclear Research (PL)), Poster session NB: do not use Safari; use Firefox, Chrome or Edge

92. Physics studies for ND280 upgrade in T2K experiment
Viet Nguyen (LPNHE Paris (IN2P3/CNRS)), Poster session NB: do not use Safari; use Firefox, Chrome or Edge