THE T2K NEAR DETECTOR ND280 UPGRADE

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NuInt 18 - GSSI, L'Aquila

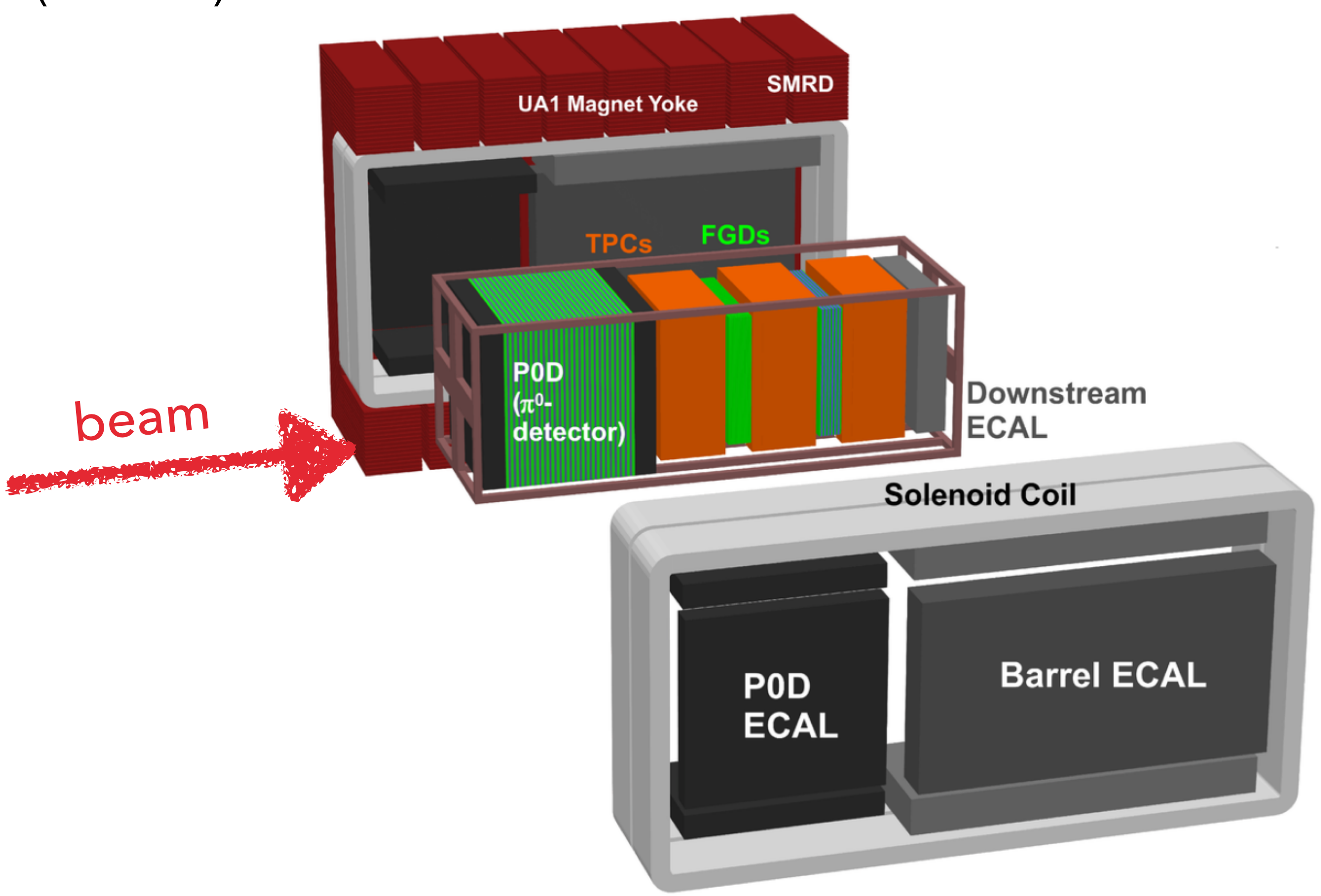
OVERVIEW

- The current ND280 detector : advantages and limitations
- The ND280 upgrade
- Expected performances of the upgraded detector and impact to the T2K oscillation analyses

THE CURRENT ND280 DETECTOR

- Tracker system : 2 active neutrino target (FGDs) + 3 TPCs
- π^0 detector (P0D)
- Electromagnetic calorimeter (ECAL)
- 0.2 T magnetic field (UA1 magnet)
- Muon detector (SMRD)

NIM A 659 (2011) 106–135



Design driven by the physics goal of early 2000: measure ϑ_{13}!

THE CURRENT ND280 DETECTOR

Current role:

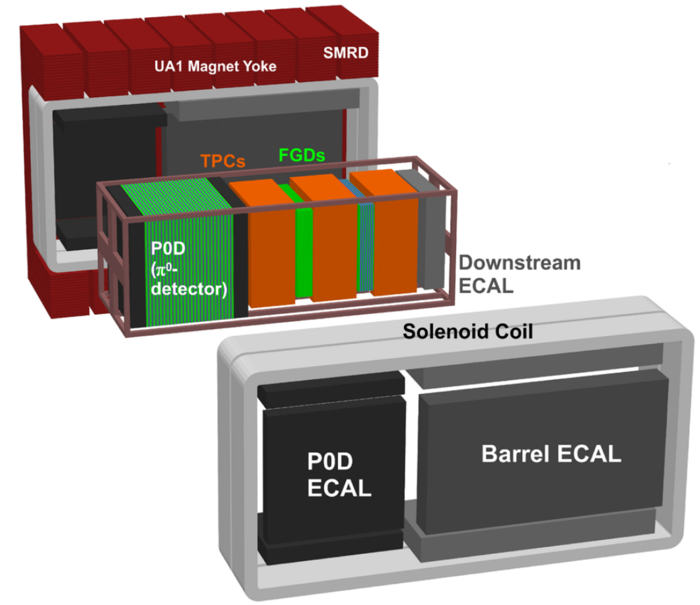
- Flux and cross section systematics constrain for T2K oscillation analyses
- Neutrino cross-section measurements (*see talks on Monday*)

Systematics for FHC

	ν_e CCQE-like	ν_μ	ν_e CC1π^+
Source of uncertainty	$\delta N/N$	$\delta N/N$	$\delta N/N$
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%

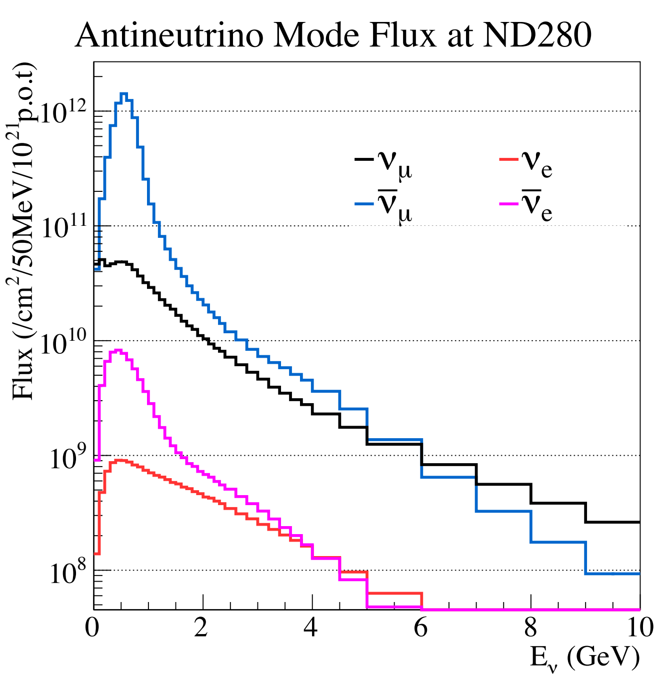
PHYSICAL REVIEW D 96, 092006 (2017)

THE CURRENT ND280 DETECTOR

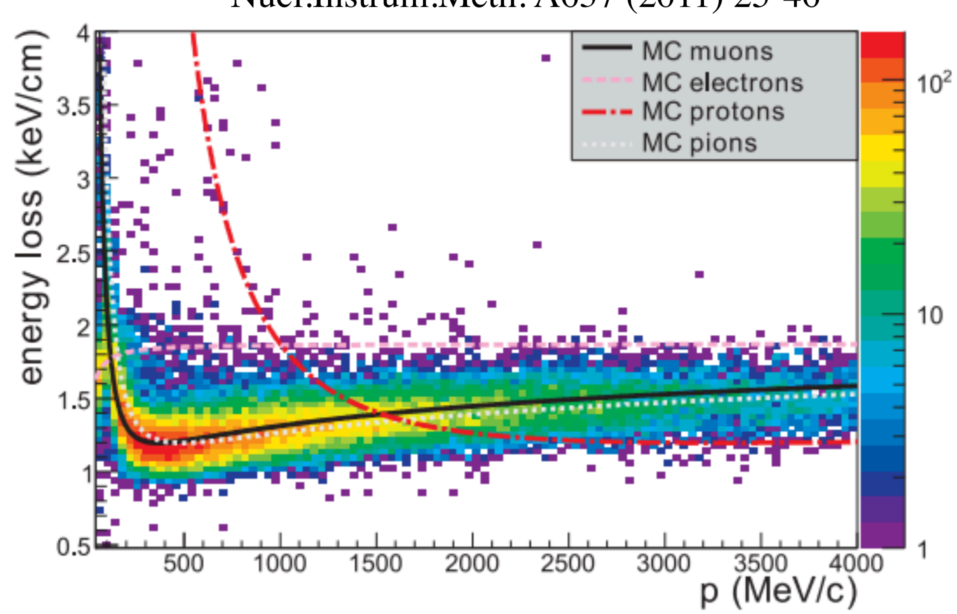


Advantages:

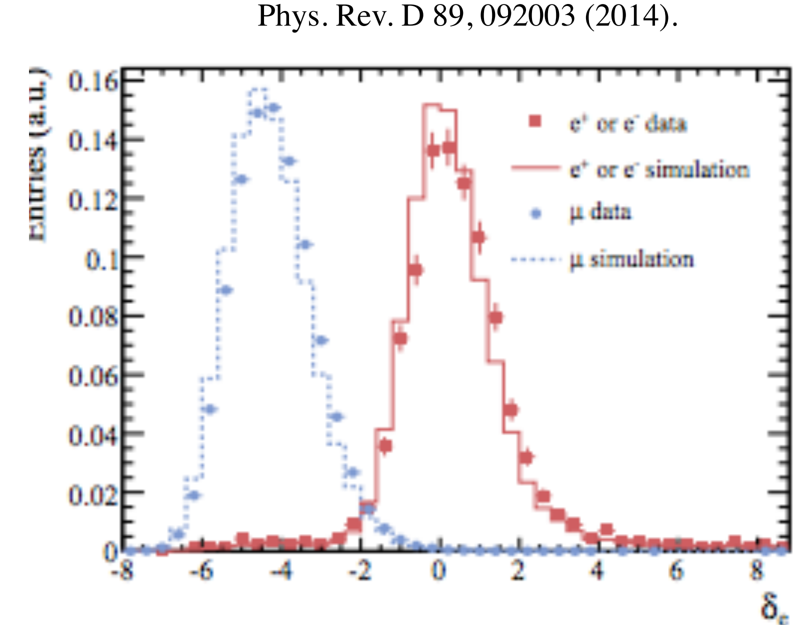
- Magnetised detector: discrimination of the wrong sign beam component
- Active target
- TPCs : 3D reconstruction, charge, momentum and Particle Identification
  - electron and muon separation at > 4σ

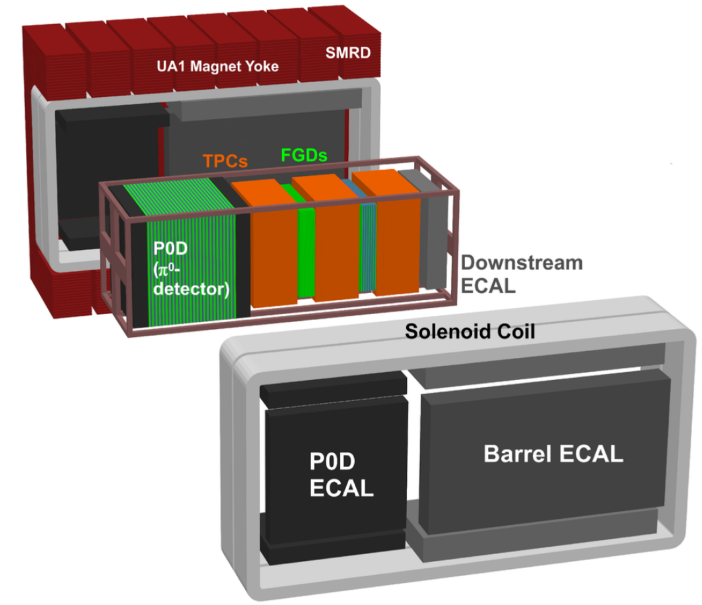


Nucl.Instrum.Meth. A637 (2011) 25-46



Phys. Rev. D 89, 092003 (2014).

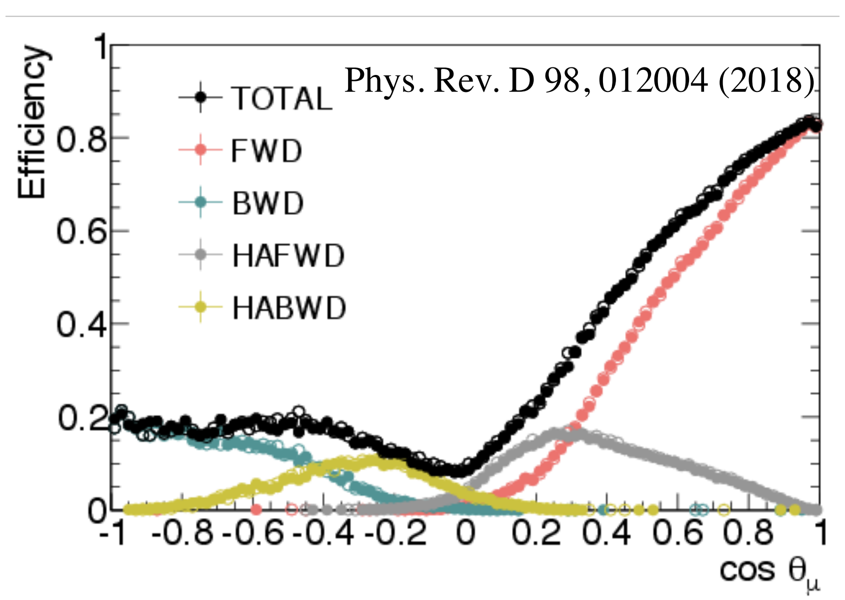


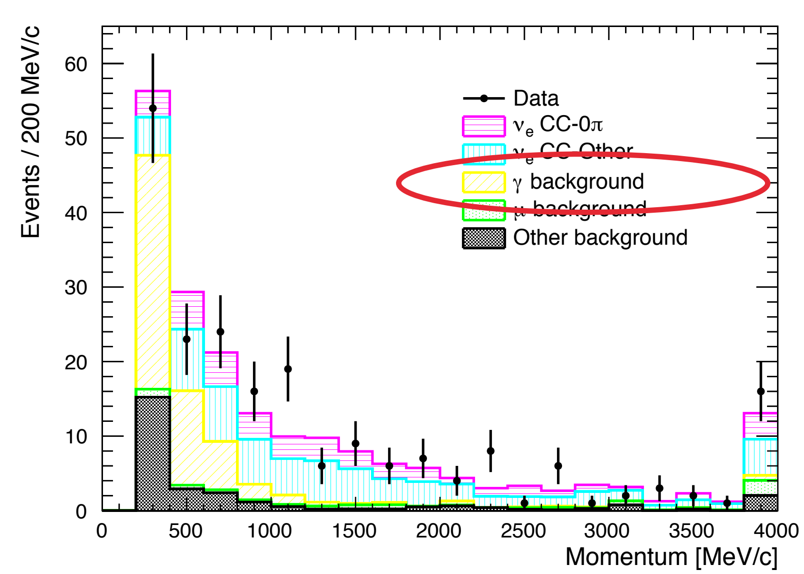


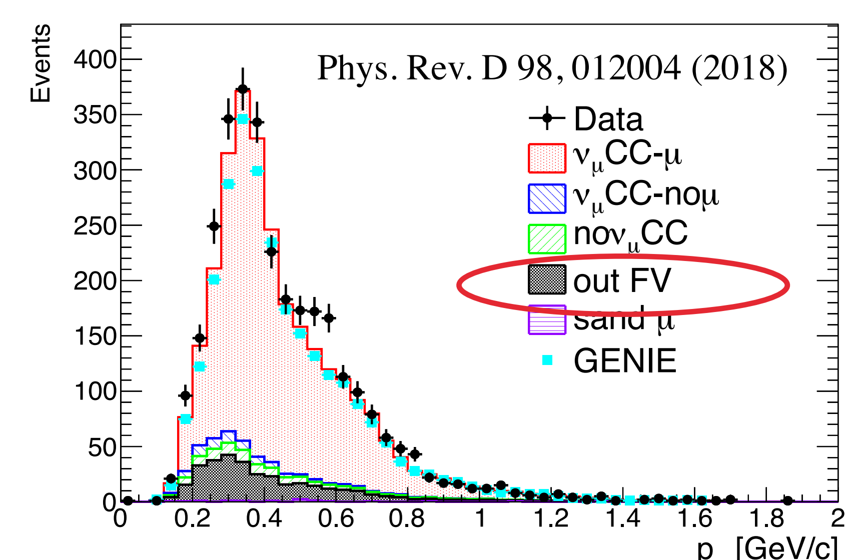
THE CURRENT ND280 DETECTOR

Limitations:

- Limited angular acceptance for high-angle and backward —> different from SK
- Poor detection and identification efficiency for ν_e < 1GeV (γ-conversion contamination)
- limited detection efficiency for low energy particles stopping in the target (2D view)
- Limited efficiency for the direction determination: Out-Of-Fiducial Volume (Out FV) background

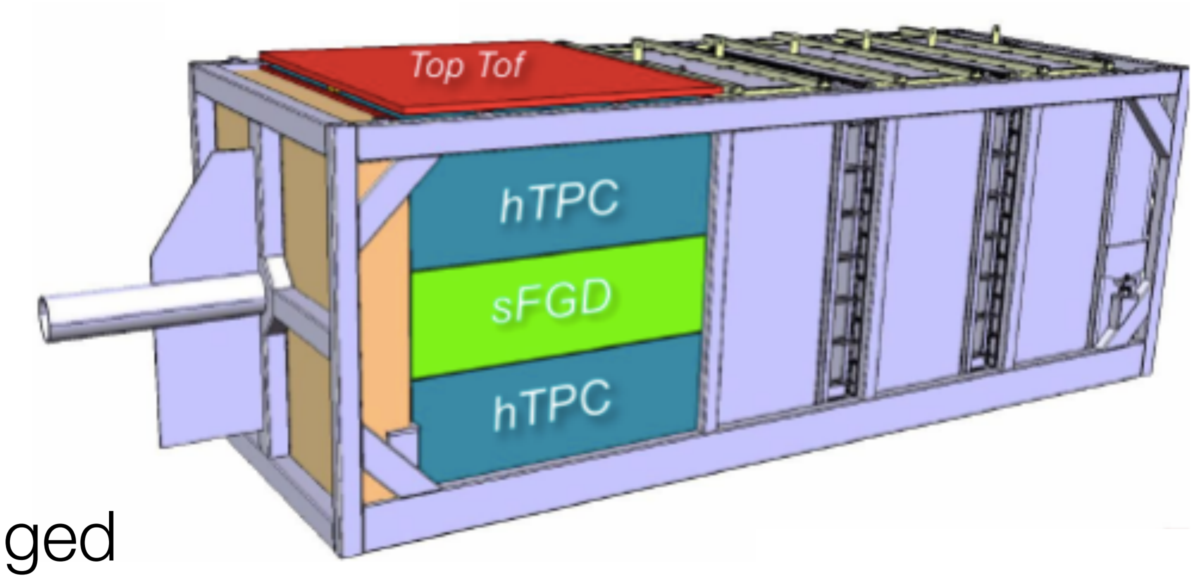




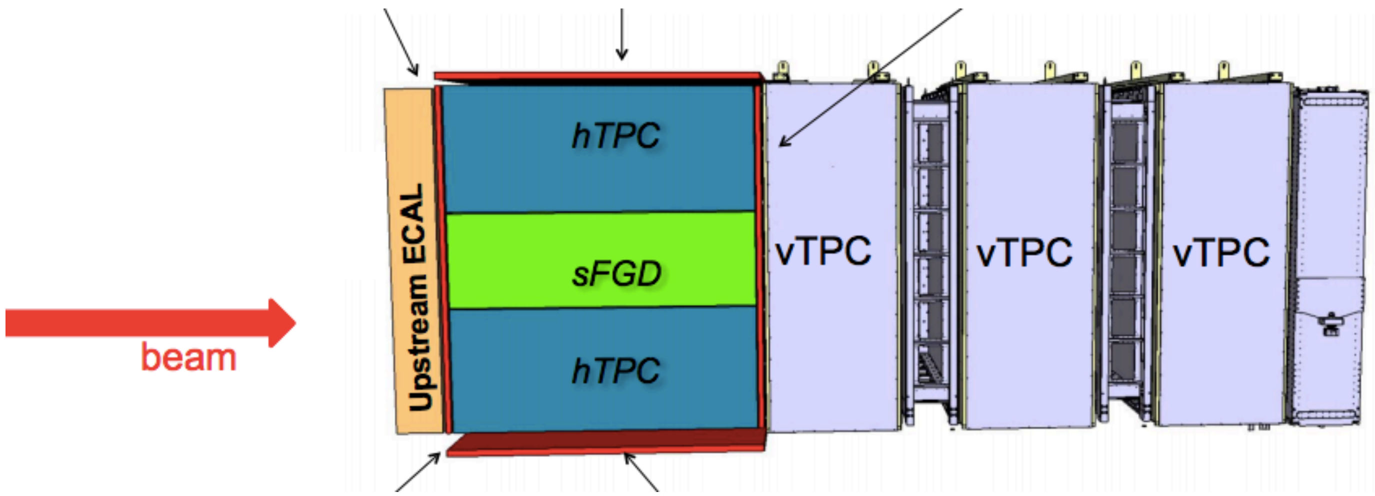


THE ND280 UPGRADE

CERN-SPSC-P357



- Re-design of the upstream part of ND280
- Down-stream tracker (FGD+TPCs) unchanged
  - 2 tons plastic scintillator target : super-FGD (sFGD)
  - two horizontal TPC (hTPC)
  - Time-of-Flight (ToF) all around



Design of the sub-detectors being finalised.

Installation foreseen for Summer 2021. First data-taking expected in 2022.

The new design will strengthen the physics potential of T2K during the phase-II

THE ND280 UPGRADE

- Proposal for the ND280 upgrade submitted last January
- Involvements of many Institutes (e.g. France, Italy, Spain, Germany, Russia, Japan, USA, CERN) including T2K groups and new groups
- TDR in preparation, expected for early 2019

http://cds.cern.ch/record/2299599/files/SPSC-P-357.pdf

The T2K-ND280 upgrade proposal

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CERN-SPSC-2018-001 / SPSC-P-357
09/01/2018

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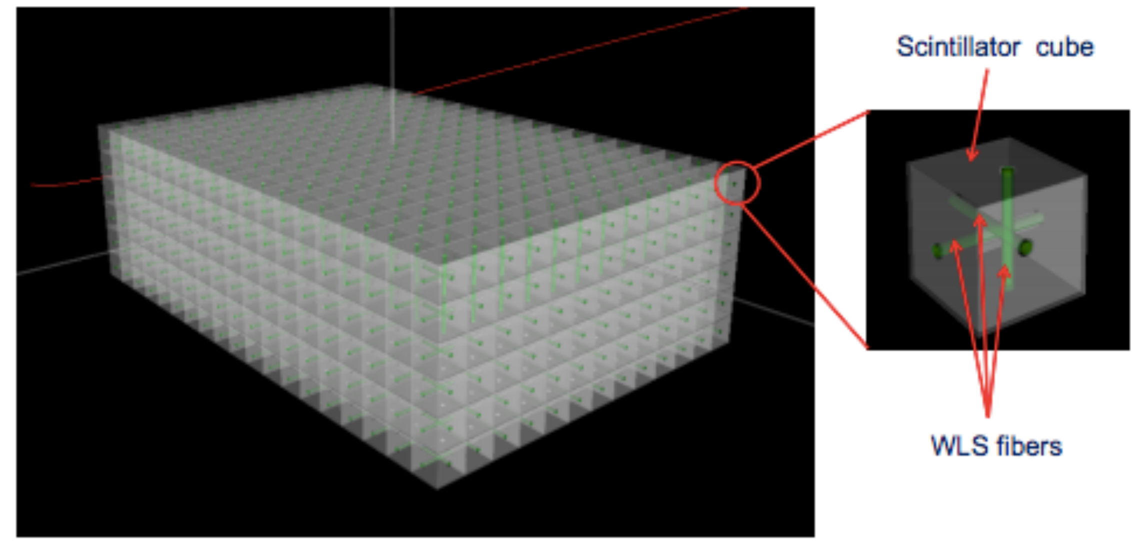
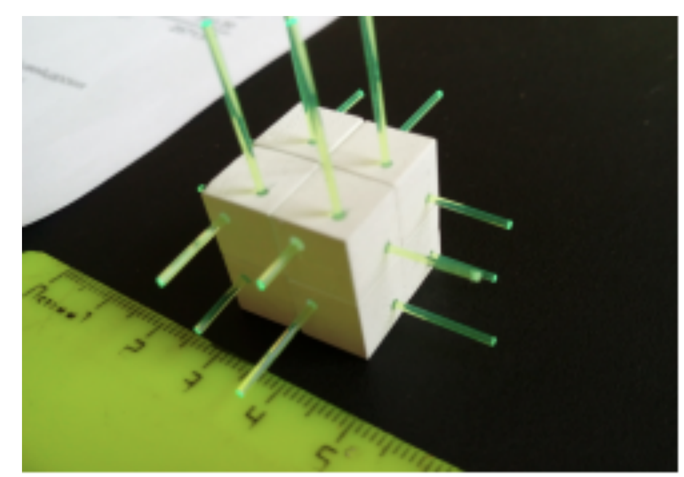
THE SUPER-FGD

- **2 tons** of 1cm size cube WLS fibres in the 3 directions
- 1.8x0.6x2 m^3: ~2M cubes and 60k channels
- Readout done using MPPC
- Full active plastic scintillator target :
    - 3D view and very detailed 3D reconstruction
    - 4π acceptance
    - tracking for particles entering the TPCs
    - detection of activity around the vertex





General details of the design: JINST 13 P02006 (2018)

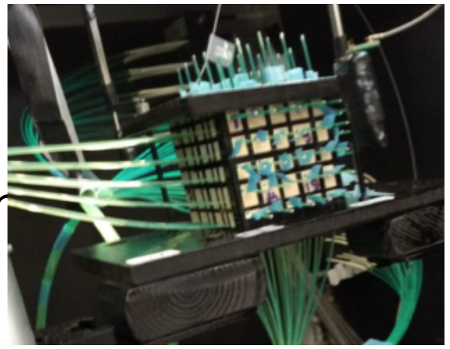
Extruded plastic scint. 1x1x1 cm^3 cube

Chemical etching as reflector (~50-100 μm thick)

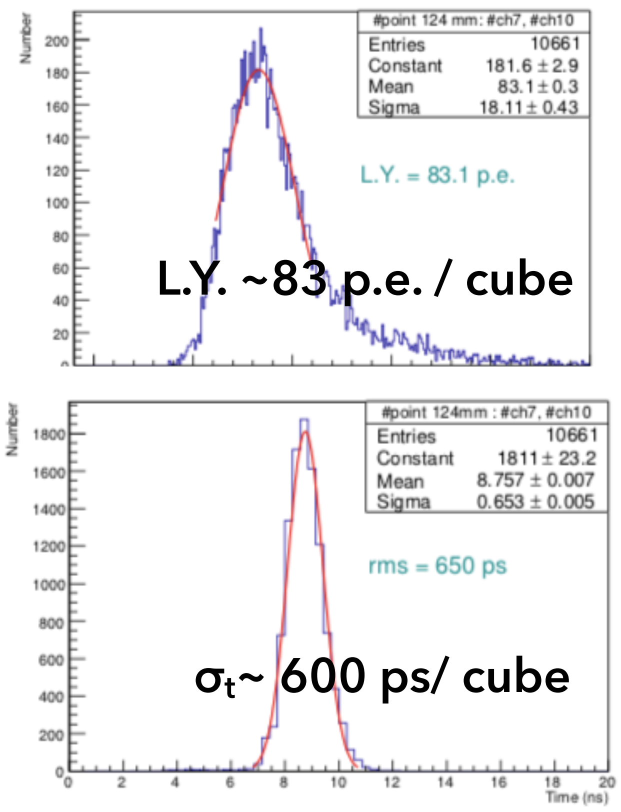
3 WLS fibers (Kuraray Y11, 2-clad, 1mm) along XYZ

TEST BEAM @ CERN : SFGD

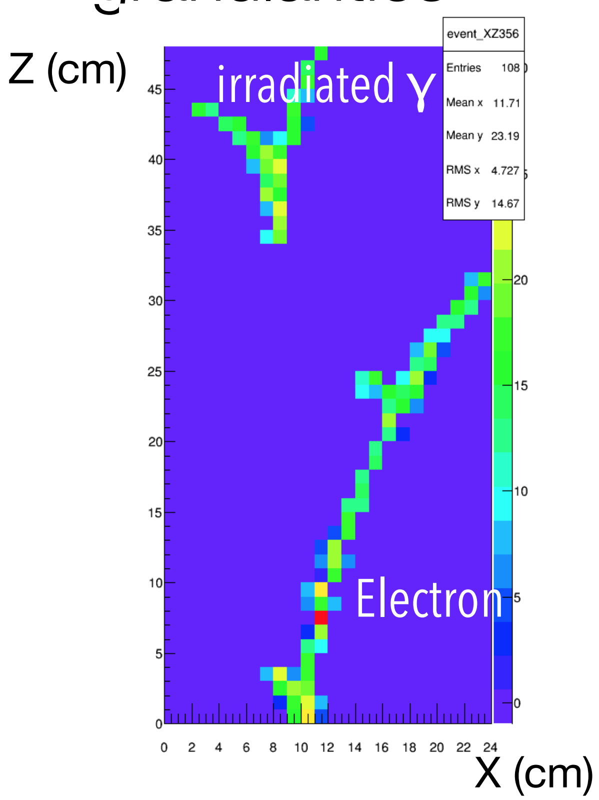
- October 2017: 5x5x5 cm³ prototype
  - light yield in WLS fibres transverse to the beam

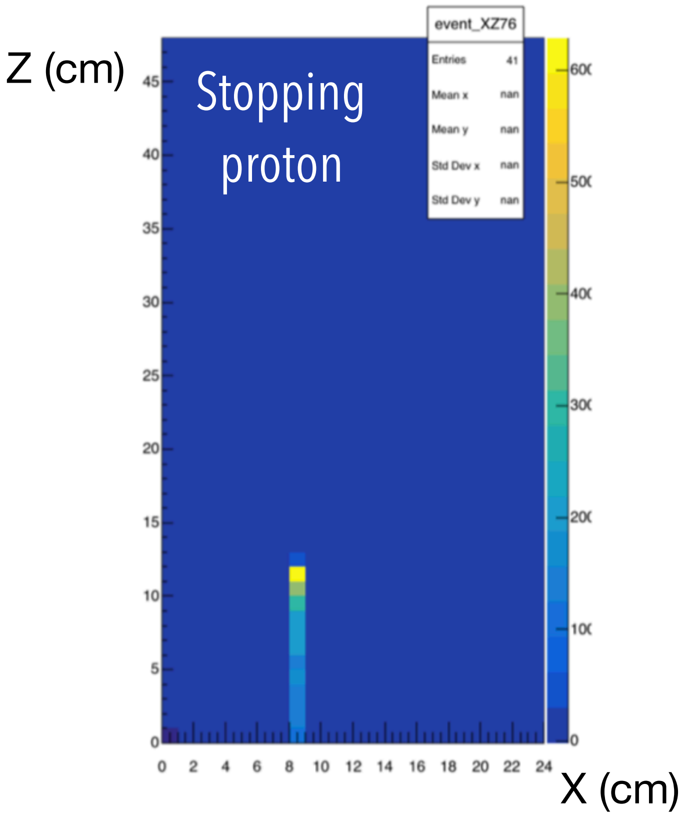


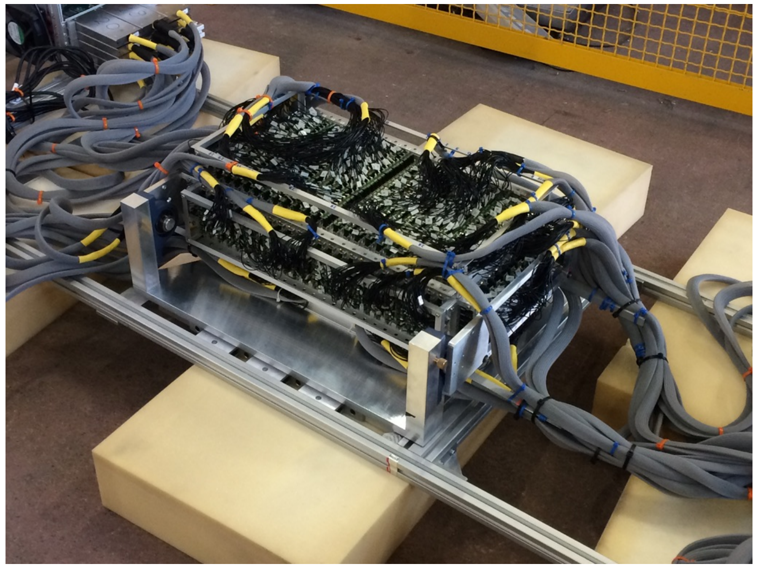
arXiv:1808.08829



- Summer 2018: 24x8x48 cm³ prototype in B field
  - test of the technology with a larger detector : electronics response, tracking capability, pixel granularities





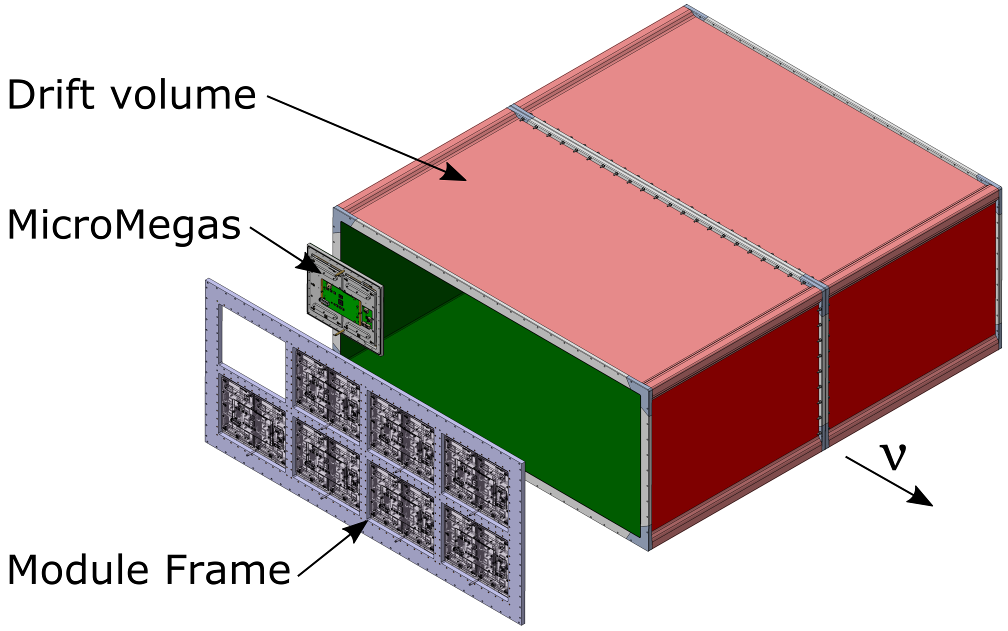


THE HIGH-ANGLE TPCS

Design based on the successful operation of the existing TPCs

Two new horizontal TPCs with :

- 2 volumes of 2.0 (w) x 0.8 (h) x 2(drift) m^3
- 8 MMs per volume
- cathode voltage at 25kV (E field of 275 V/cm)
- T2K gas : 95% Ar, 3% CF4, 2% Isobutane
- ~ 4% X_0 material budget
- momentum resolution better than 10% at 1 GeV



THE HIGH-ANGLE TPCS

Two main changes with respect to the existing TPCs :

Field cage

Design derived by the goal of reducing dead space and maximise the tracking volume

- Single wall box guaranteeing gas containment and electrical insulation
- Layers of solid insulator mounted on a composite material (G10-clad honeycomb)
- Field cage strips in the inner side

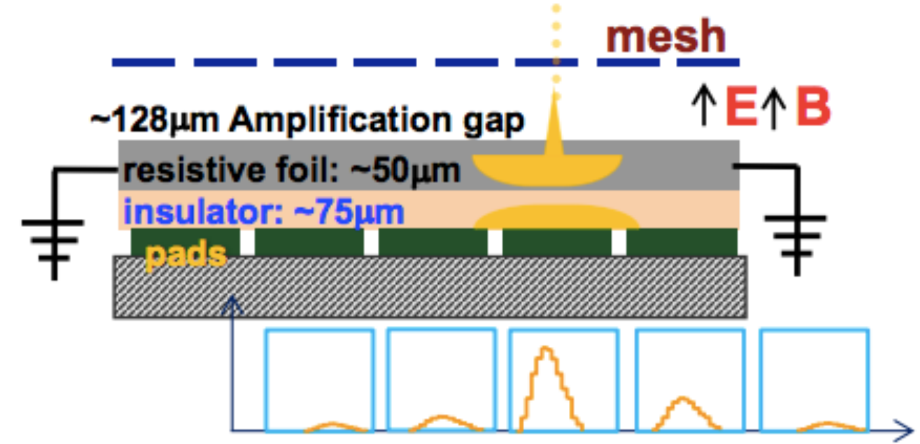
Aramide Fiber fabric based layer stack

outer layer

Material	Thickss (mm)
Copper coated polymide film	~ 0.15
Aramid Fiber Fabric (Kevlar)	2.00
Aramide HoneyComb panel	25.00
Aramid Fiber Fabric (Kevlar)	2.00
Polymide film (insulation)	~ 0.10
Strips (double later) on Kapton foil	~ 0.15
TOTAL RADIATION LENGHT ~ 4% X_0	~ 29.40

inner layer

THE HIGH-ANGLE TPCS



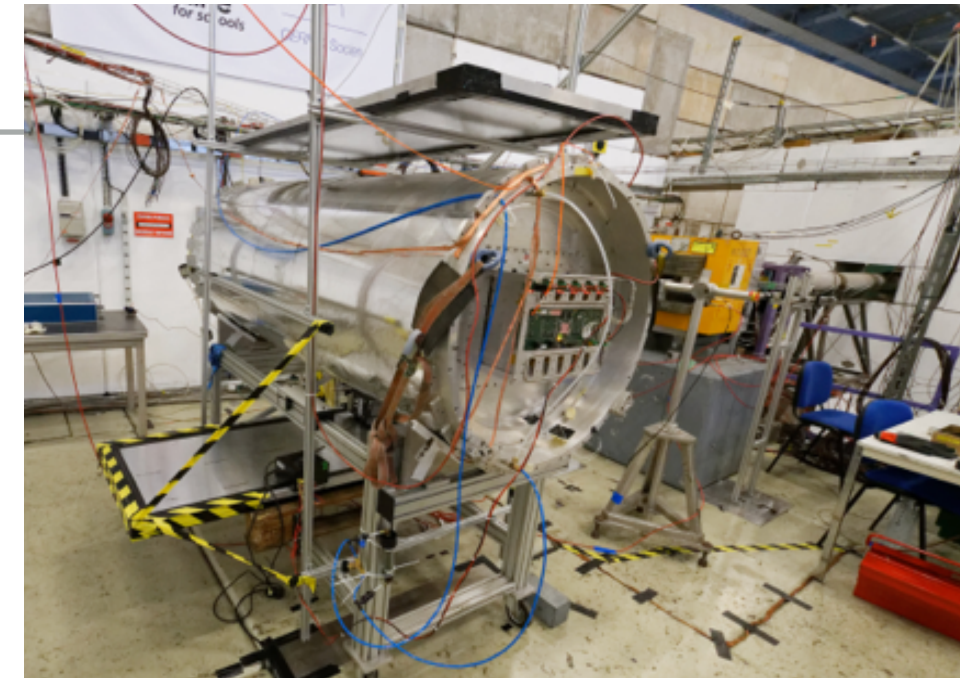
$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

Two main changes with respect to the existing TPCs:

MicroMegas

- Use of **resistive MMs** developed for the ILC TPC
  - charge spread on the pads with time with a Gaussian behaviour
  - good detection performances also for short drift distances
  - similar or better space point resolution but with larger pads → less electronics channels
  - protection of FE electronics from possible spark no more needed → more compact electronics and maximise the acceptance

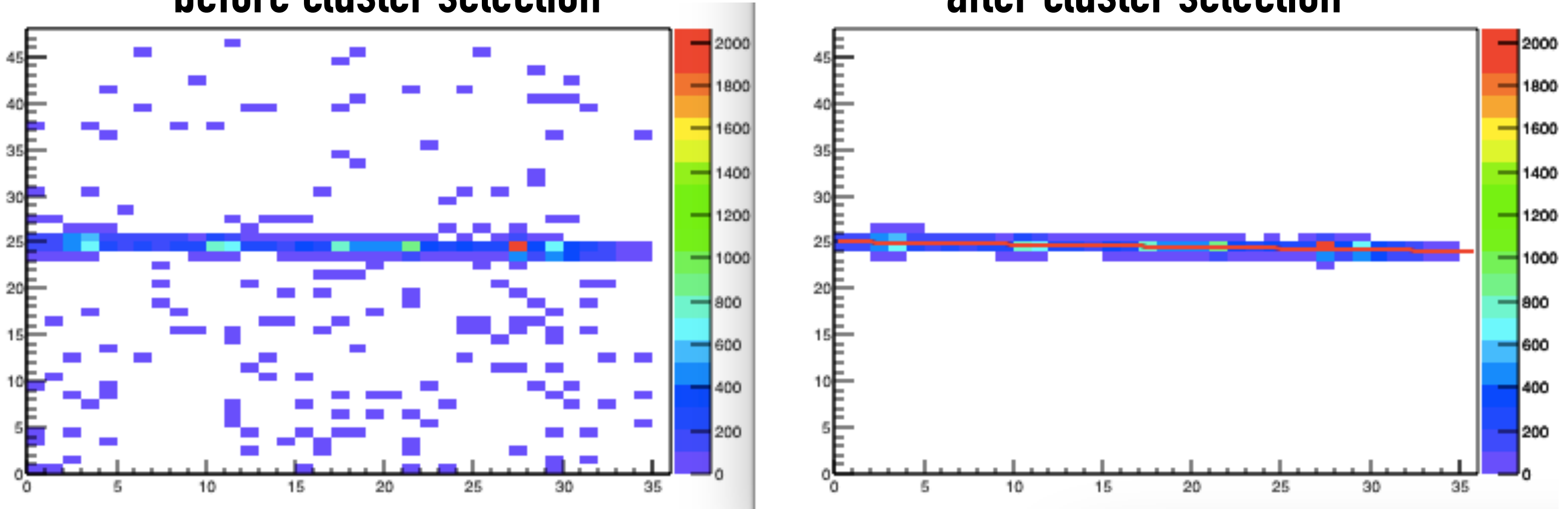
TEST BEAM @ CERN : HA-TPC



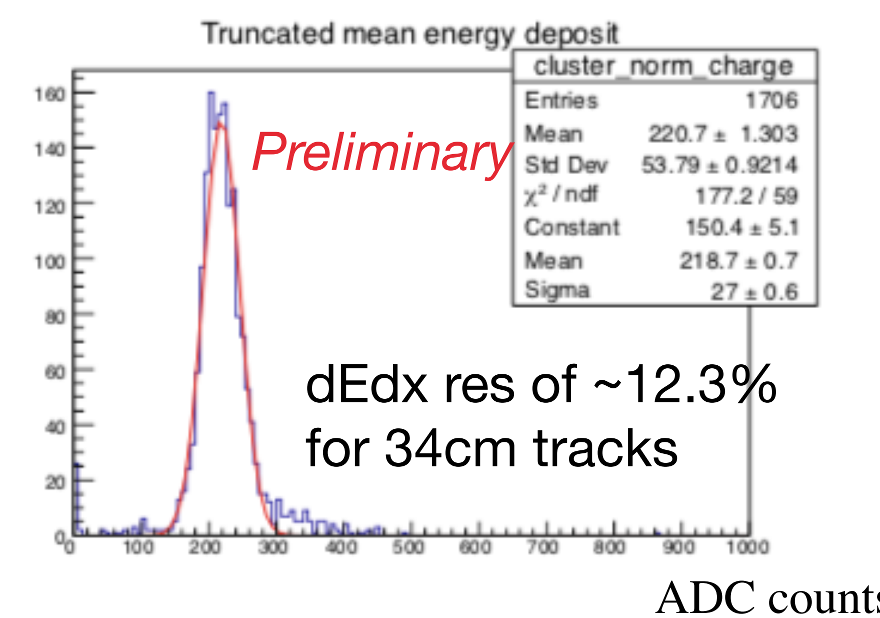
- Test beam at CERN this summer (august 2018)
- Using HARP TPC field cage with one resistive MM
- Different beam settings, cosmic and radioactive source data collected to study the resistive MM performances
- Data being analysed but the preliminary results are very promising

Muon track

before cluster selection | after cluster selection

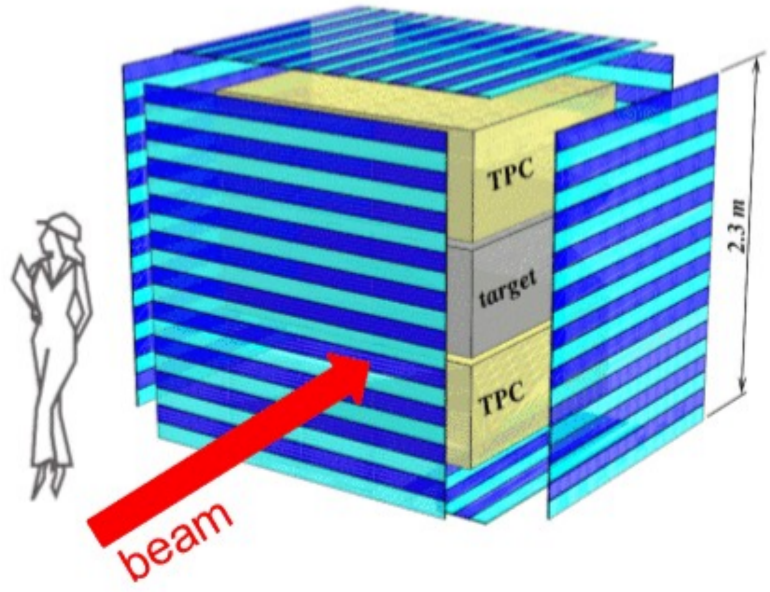


Muons dEdx



THE TIME-OF-FLIGHT

- Time-of Flight detector surrounding the new tracker (sFGD + HA-TPC)
- Goal: particle directions determination allowing for a better rejection of incoming background
  - panels of cast scintillator bars of 230 (l) x 12 (h) x 1(w) cm^3
  - Arrays of 8 or 6 SiPM of 6x6mm
  - 2 sides readout
  - 80 ps resolution



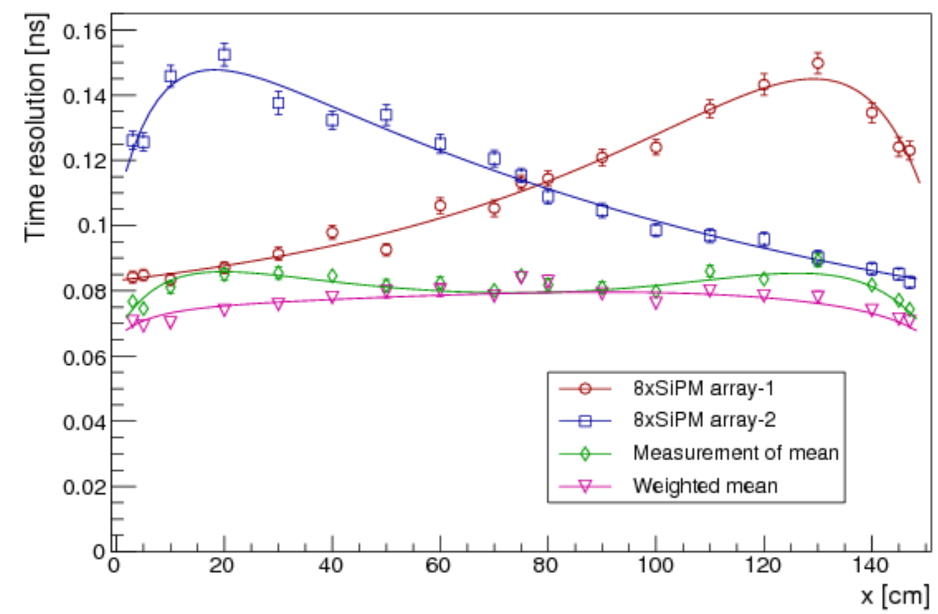
Test bench developed at UniGe.

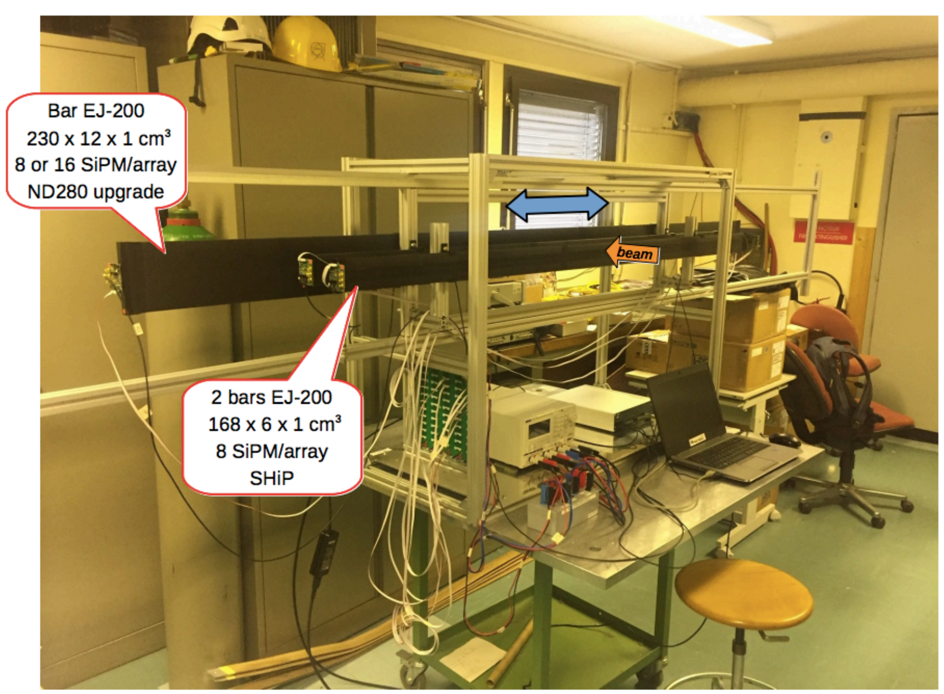
Prototype for timing detector for SHIP and ToF detector for the ND280upgrade

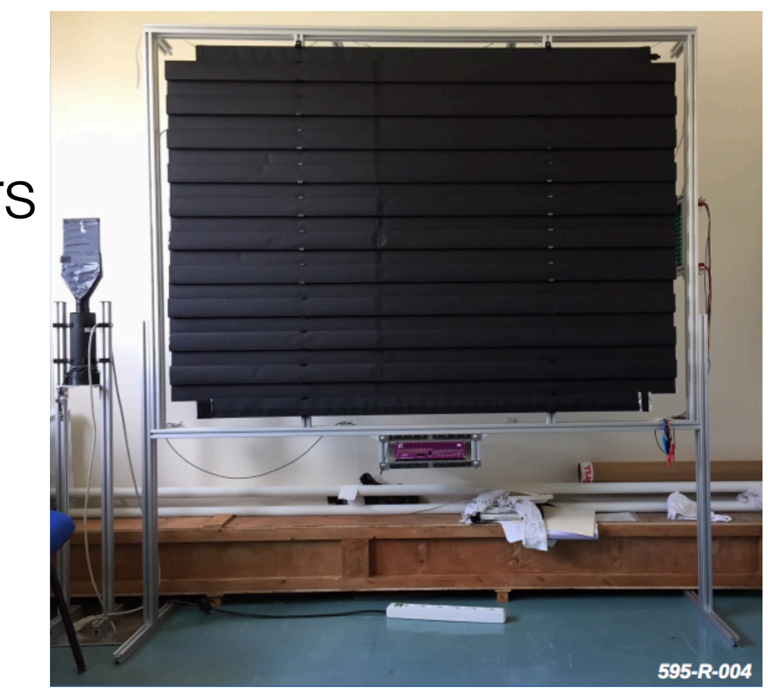
JINST 12 (2017) no.11, P11023 (arXiv:1709.08972)

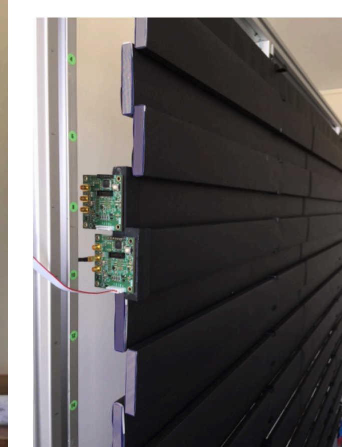
TEST BEAM @ CERN : TOF

- Several test beam at CERN
  - ~70 ps time resolution achieved for 1.5m bars (Autums 2017 tests)
  - Summer 2018 : panels prototypes with 168x6x1 cm^3 bars tested
  - currently : test beam with ND280upgrade bars









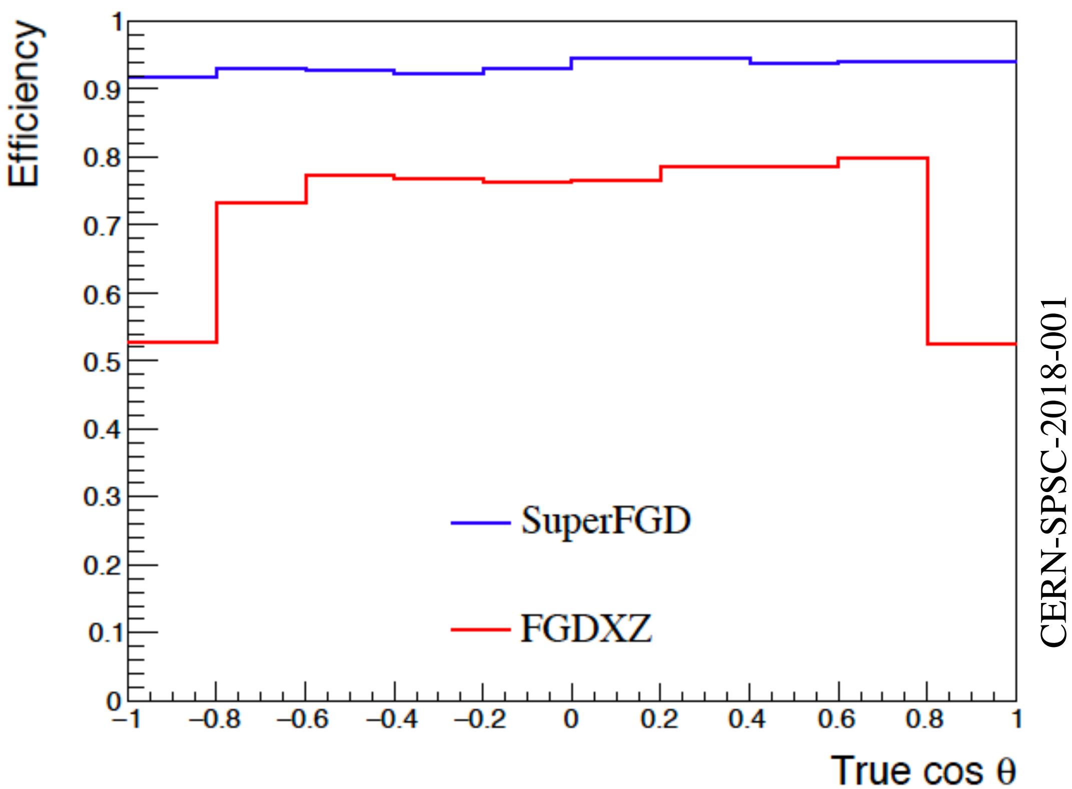
EXPECTED PERFORMANCES

SUPER-FGD

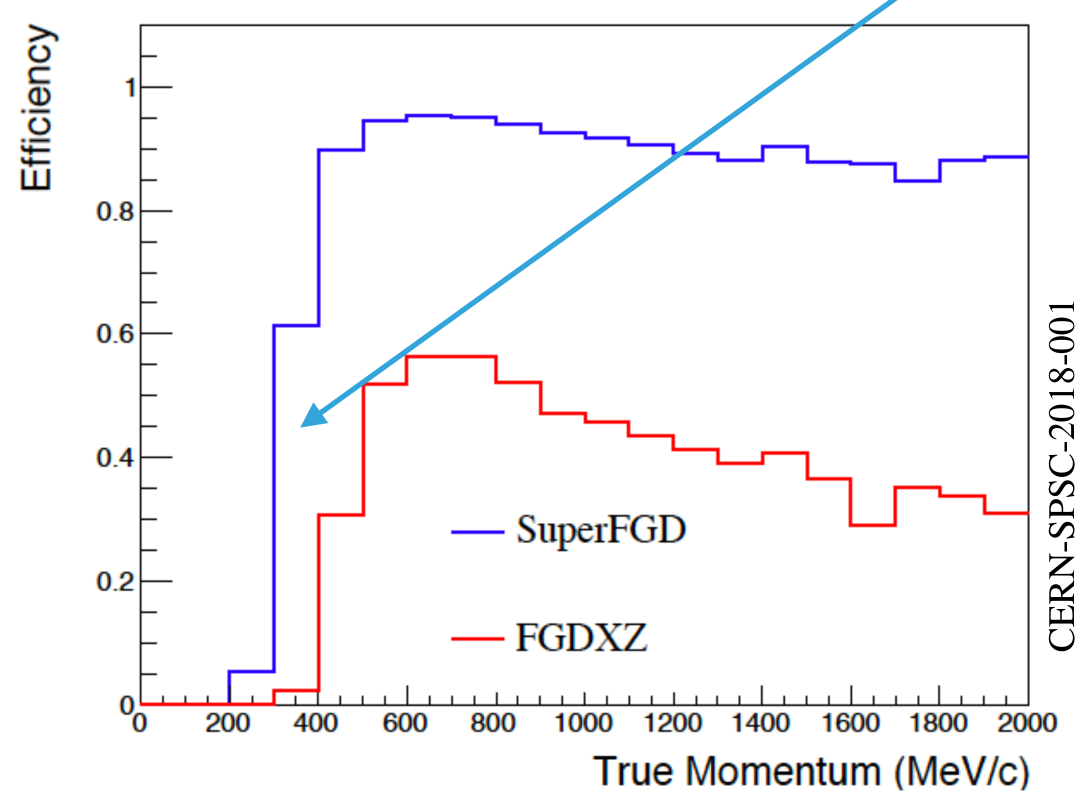
- Simulation studies have been performed to define the optimal design: the 3D view is key
  - sFGD: high reconstruction efficiency in all direction (~90% for muons)
  - sFGD: lower detection threshold for protons: ~300 MeV

very important to dig nuclear effects (e.g. STV analyses)

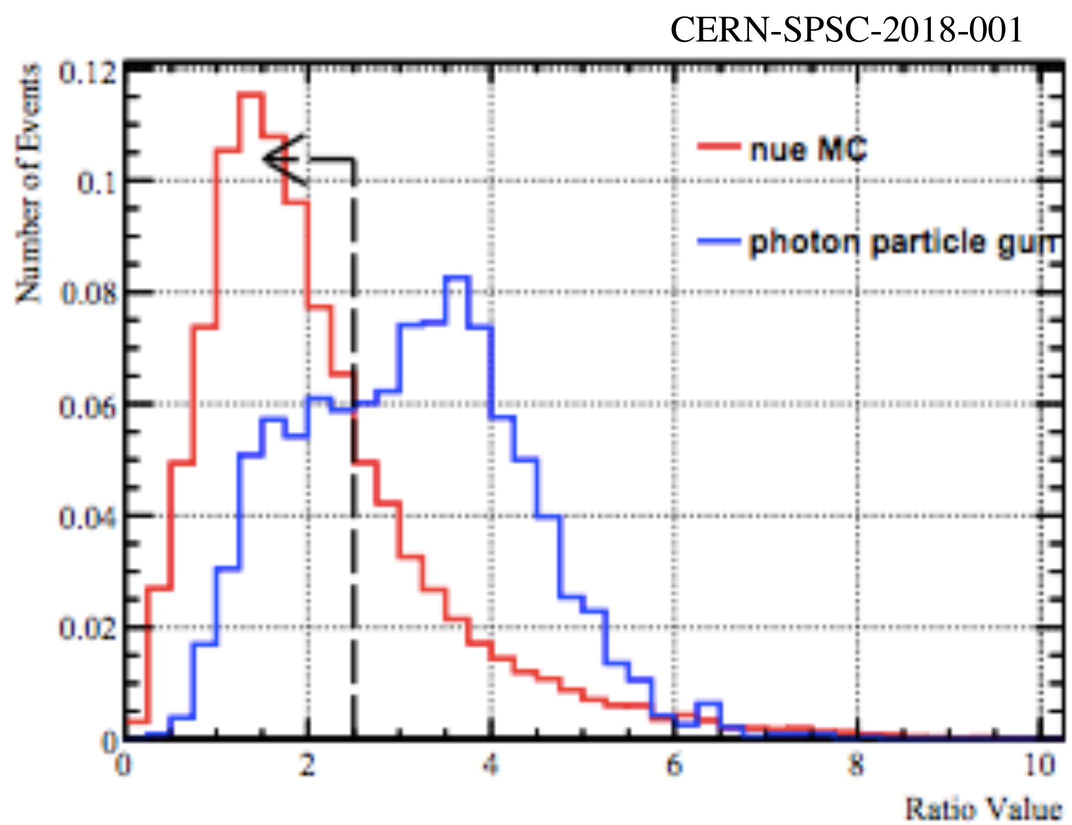
muon reconstruction efficiency

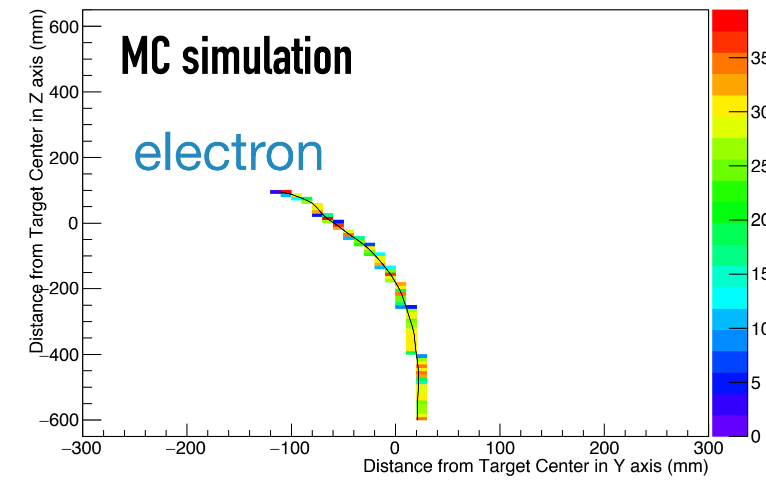


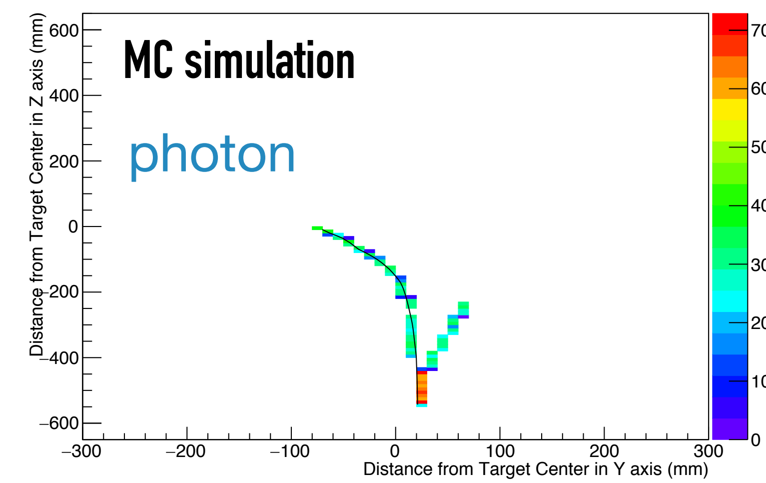
proton detection threshold



SUPER-FGD



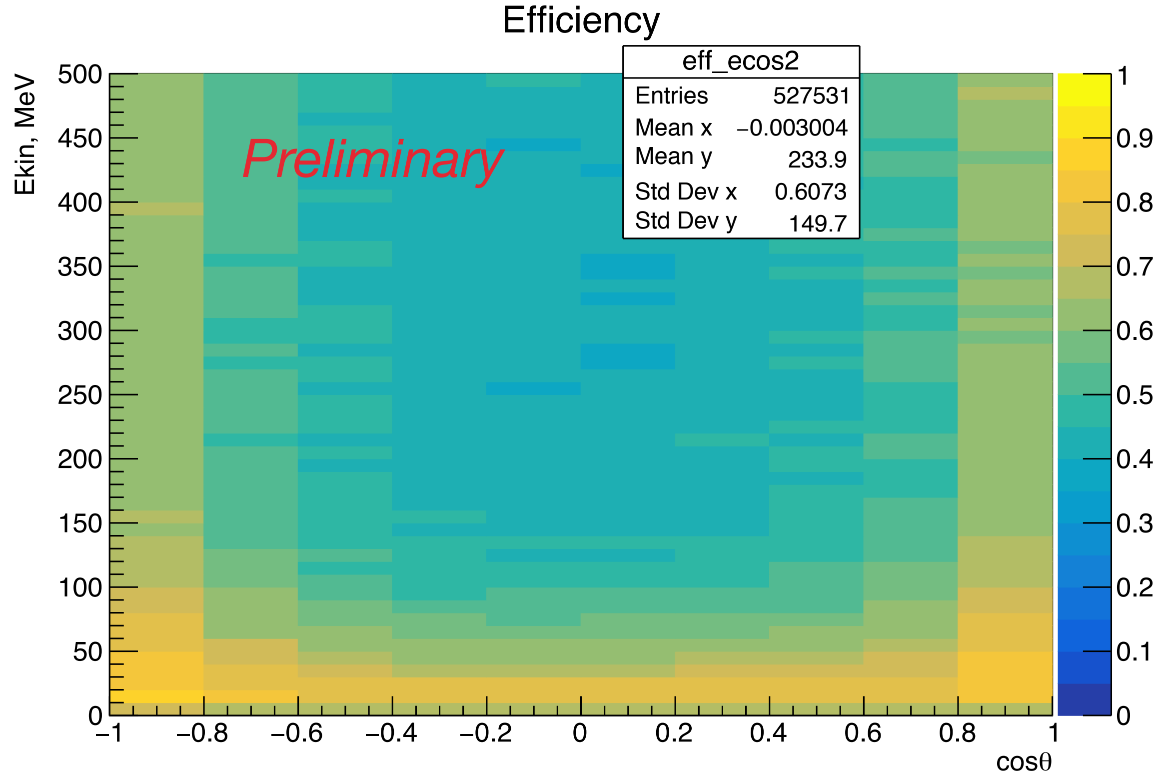




- Super-FGD high granularity allows for an excellent pattern recognition
- Possibility to disentangle one/two tracks looking at the light yields in the first cubes
  - key handle to disentangle electrons from photo-conversion (ν_e background)

SUPER-FGD

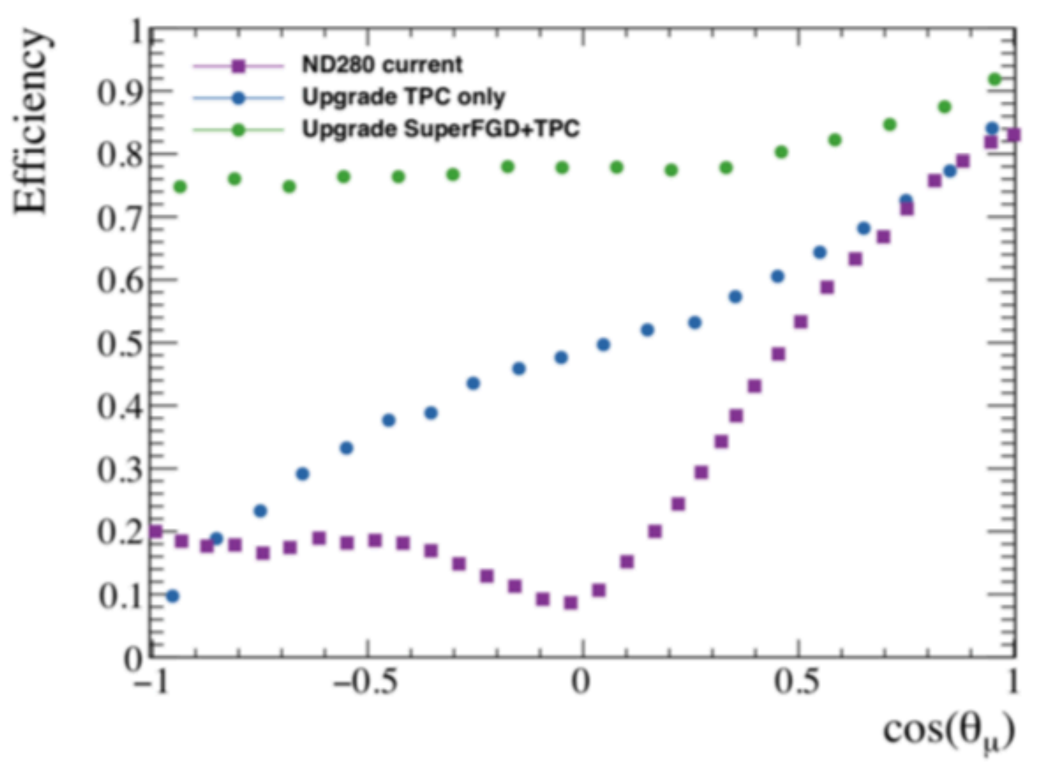
- A possible detection of neutrons would be of deep interest to study neutrino interaction models
- Preliminary studies of the detection efficiency by the super-FGD very promising
  - simulating neutrons in the sFGD, selected by looking at hits away from the vertex activity
- Further developments (energy resolution, gamma background discrimination) are on-going



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

EXPECTED PERFORMANCES

- Larger detector angular acceptance thanks to the new TPCs and ToF allowing for high-angle and backward going tracks reconstruction
  - Reconstruction efficiency expected to drastically improve
- About 2x events expected for a given exposure thanks to the larger target mass
- Further reduction of the OOFV background thanks to the ToF



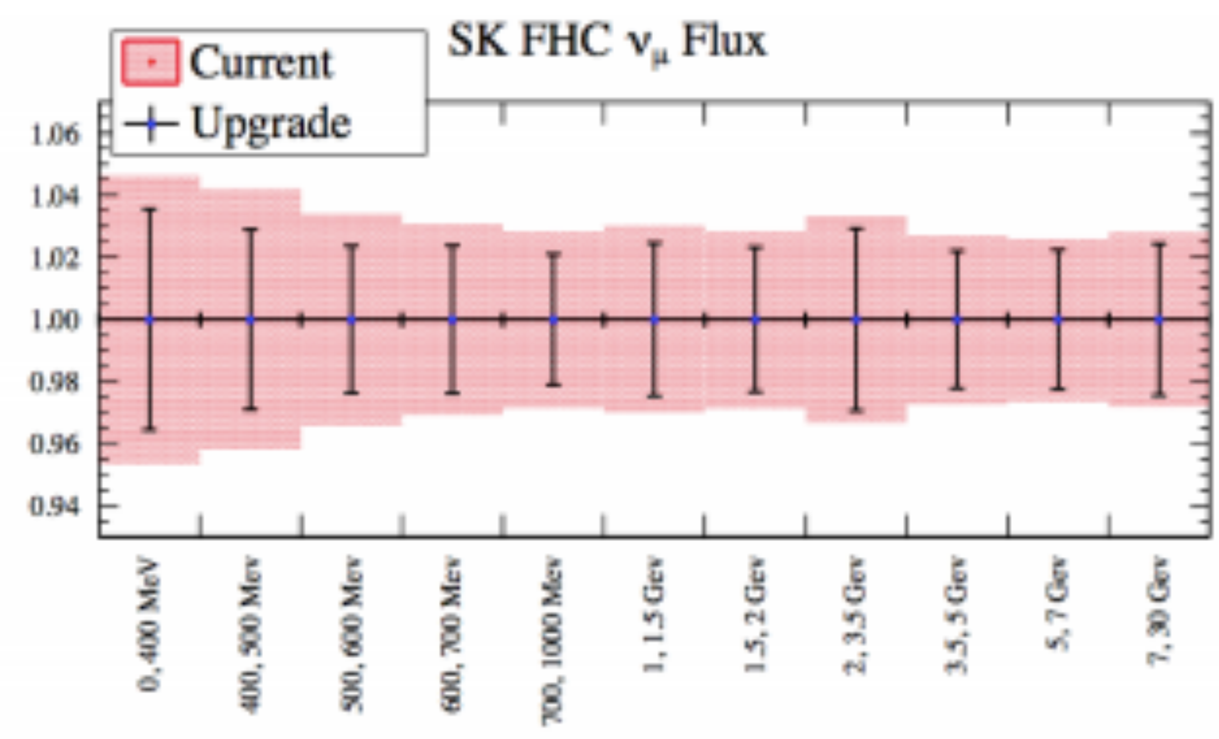
expected numbers for 1×10^{21} POT

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

CERN-SPSC-2018-001

EXPECTED PERFORMANCES

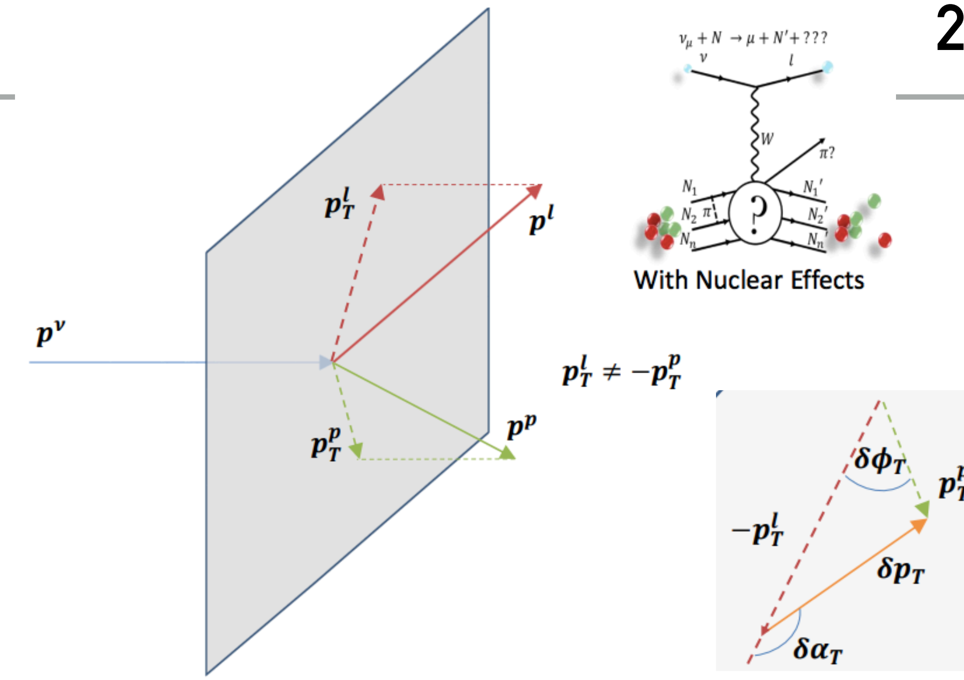
- Estimation of the impact of the ND upgrade on the T2K oscillation analyses
- Work in progress to demonstrate the capability of the new detector configuration to disentangle possible wrong/incomplete cross-section models



CERN-SPSC-2018-001

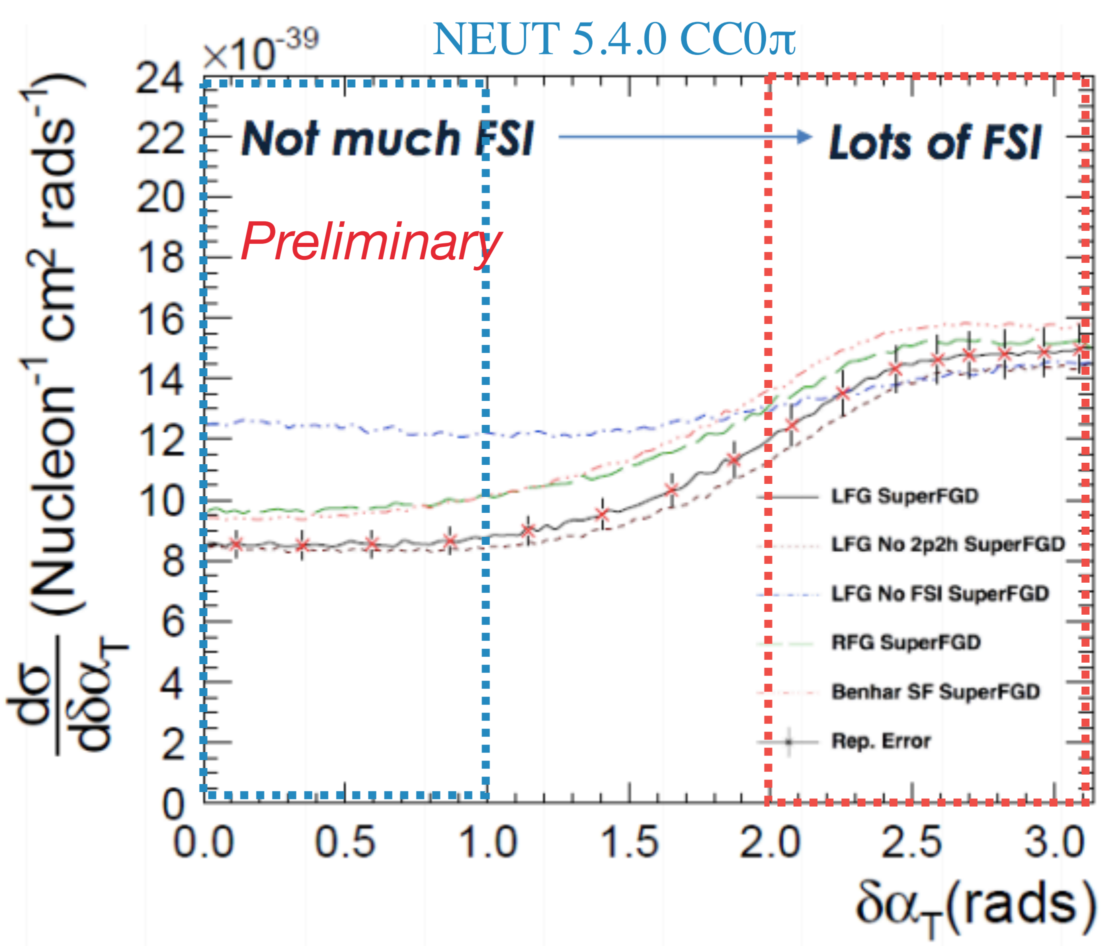
Parameters	Reduction of the uncertainty
Flux	20 %
σ_ν (CCQE/2p2h)	20% - 40%
FSI	45 %
σ_ν (Q^2 dependent)	25 %

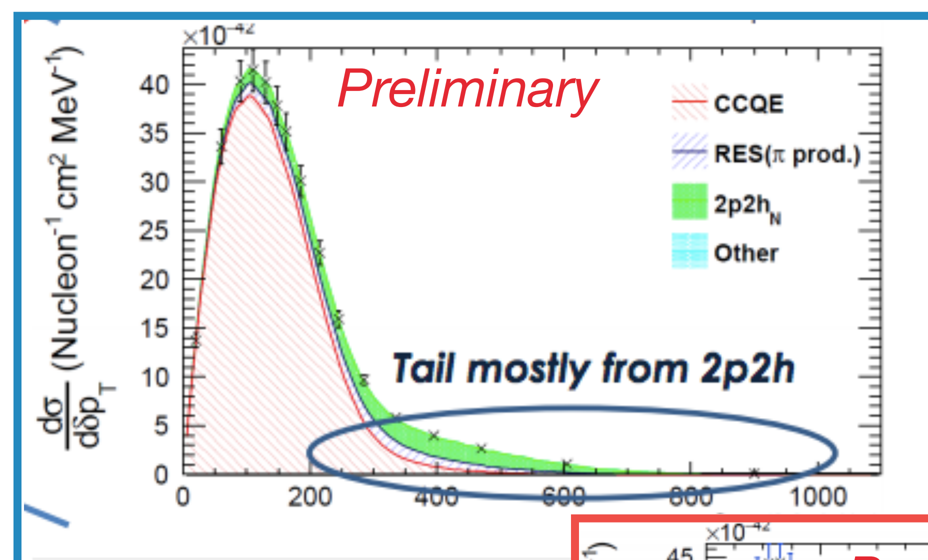
Phys.Rev. D98 (2018) no.3, 032003

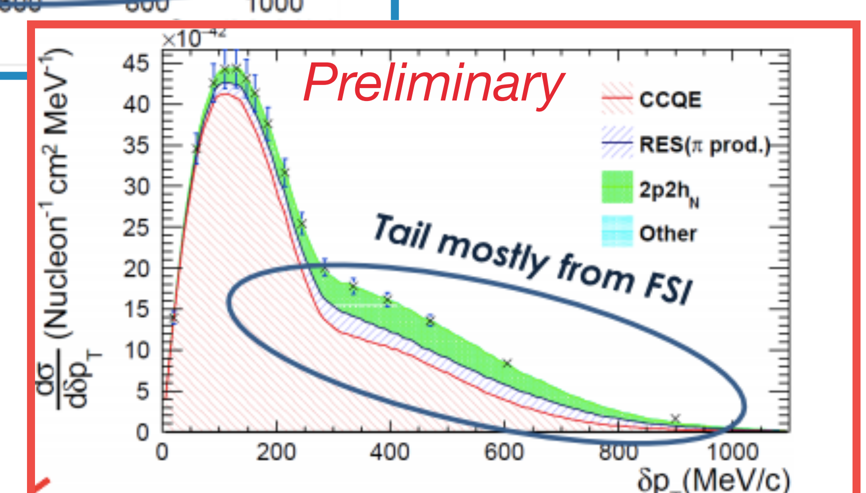


EXPECTED PERFORMANCES

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







CONCLUSIONS AND OUTLOOK

- The ND280 detector plays a key role in the reduction of flux and cross-cross-section systematics for the T2K oscillation analyses.

- Very well performing since 2009. However the current design present some limitations wrt the current physics program.

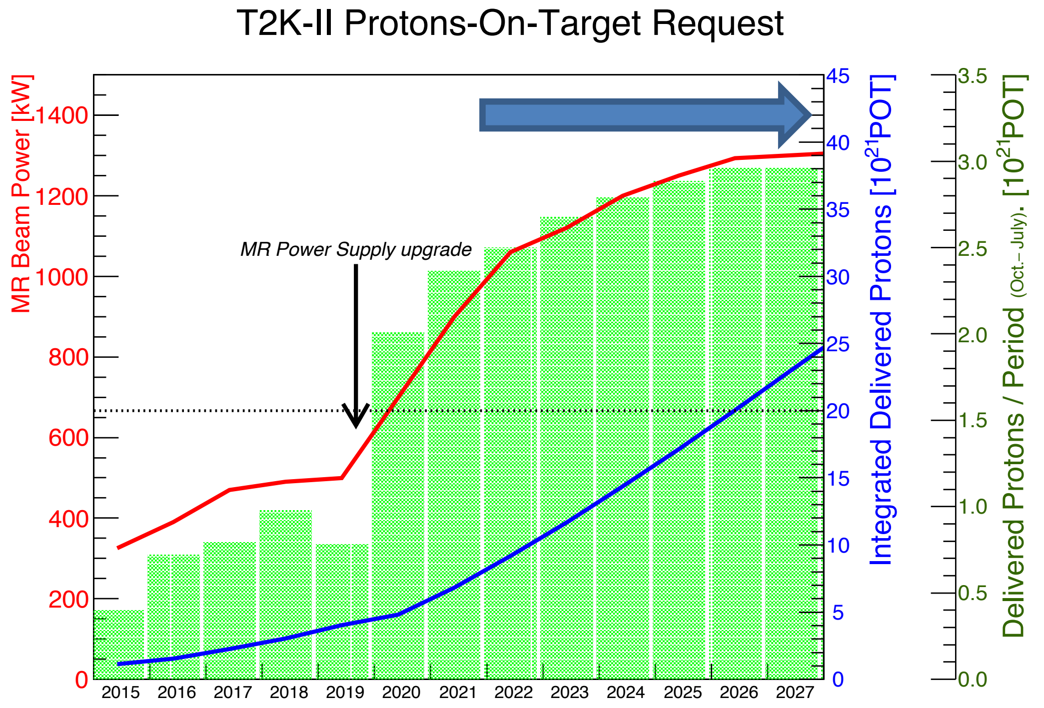
- A upgrade of the detector is being design to strengthen T2K physics potential.
  - Detector prototypes tested this summer with test beam.
  - Installation of the final detectors foreseen for Summer 2021.

Stay tuned!

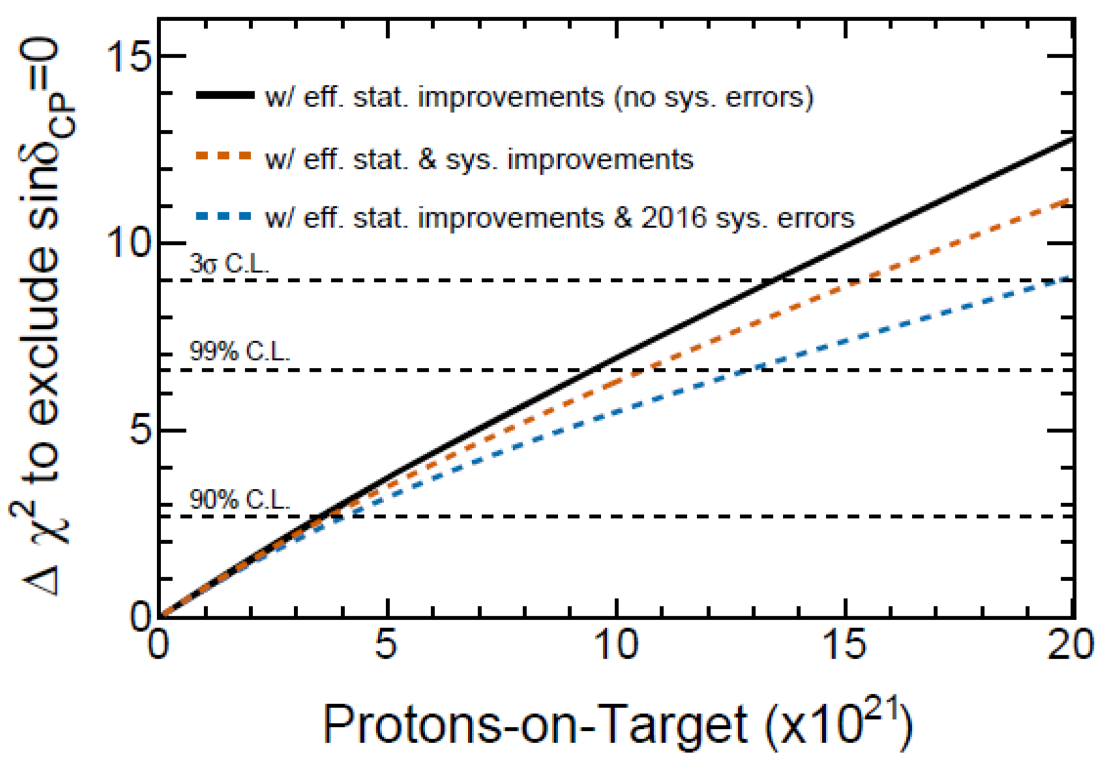
SUPPLEMENTARY

T2K – II

- beam power upgrade : 485kW to 1.3 MW
- requested extension of the T2K data taking. Approved statistics: 7X1021 POT with T2K-II will reach 20x1021 POT
- Aim for systematics reduction to ~4% and >3sigma sensitivity for CP violation if maximal

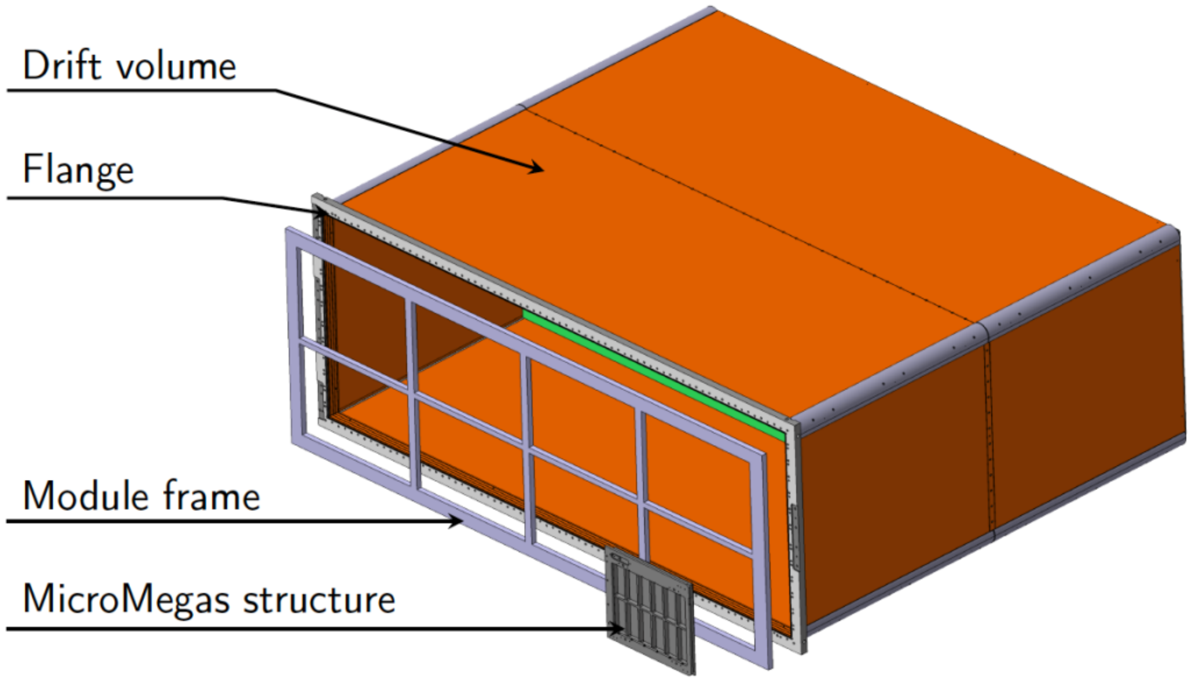


arXiv:1609.04111



HA-TPC

Parameter	Value
Overall x - y - z (m)	2.3 - 0.8 - 2.0
Drift distance (cm)	90
Magnetic Field (T)	0.2
Electric field (V/cm)	275
Gas AR-CF_4-iC_4H_{10} (%)	95 - 3 - 2
Drift Velocity $cm/\mu s$	7.8
Transverse diffusion ($\mu m/\sqrt{cm}$)	265
Micromegas gain	1000
Micromegas dim. z-y (mm)	340 - 410
Pad z - y (mm)	11 - 11
N pads	36864
el. noise (ENC)	800
S/N	100
Sampling frequency (MHz)	25
N time samples	511



SYSTEMATICS FOR RHC

TABLE XX. Effect of 1σ variation of the systematic uncertainties on the predicted event rates of the $\bar{\nu}$-mode samples.

	$\bar{\nu}_e$ CCQE-like	$\bar{\nu}_\mu$
Source of uncertainty	$\delta N/N$	$\delta N/N$
Flux (w/ ND280 constraint)	3.8%	3.8%
Cross section (w/ ND280 constraint)	5.5%	4.2%
Flux+cross section		
(w/o ND280 constraint)	12.9%	11.3%
(w/ ND280 constraint)	4.7%	3.5%
FSI + SI + PN at SK	3.0%	2.1%
SK detector	2.5%	3.4%
All		
(w/o ND280 constraint)	14.5%	12.5%
(w/ ND280 constraint)	6.5%	5.3%

SIGLE TRANSVERSE VARIABLE (STV) ANALYSES

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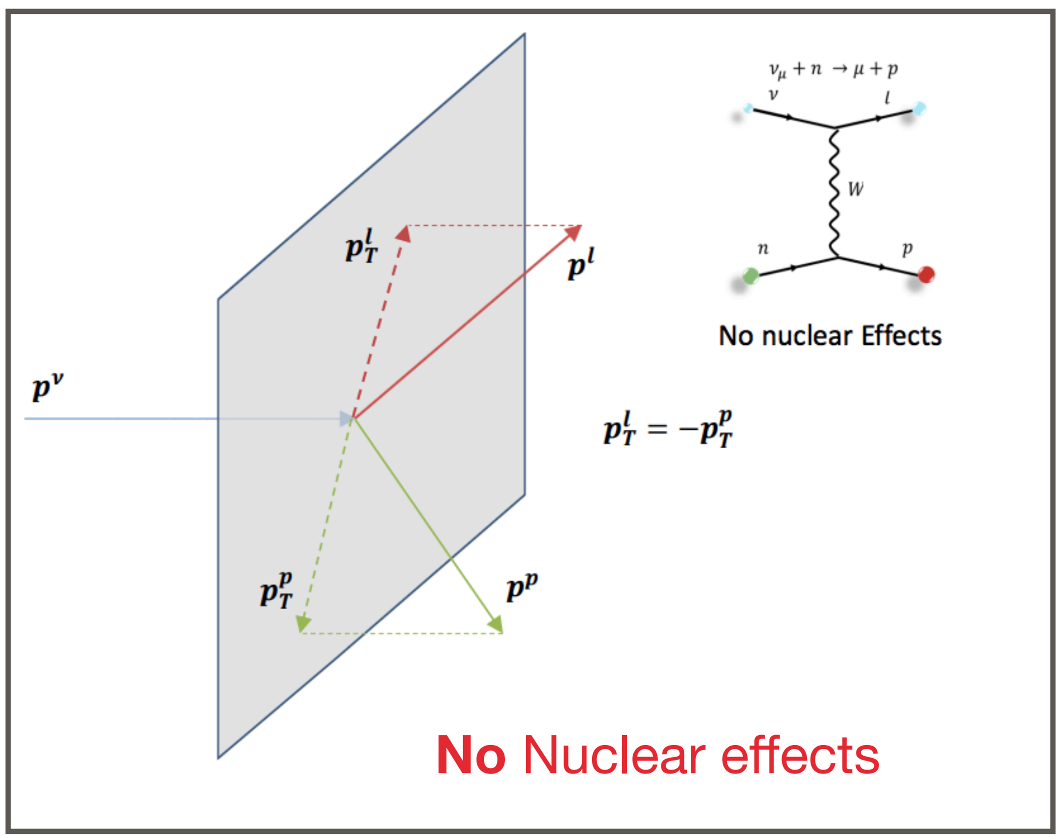

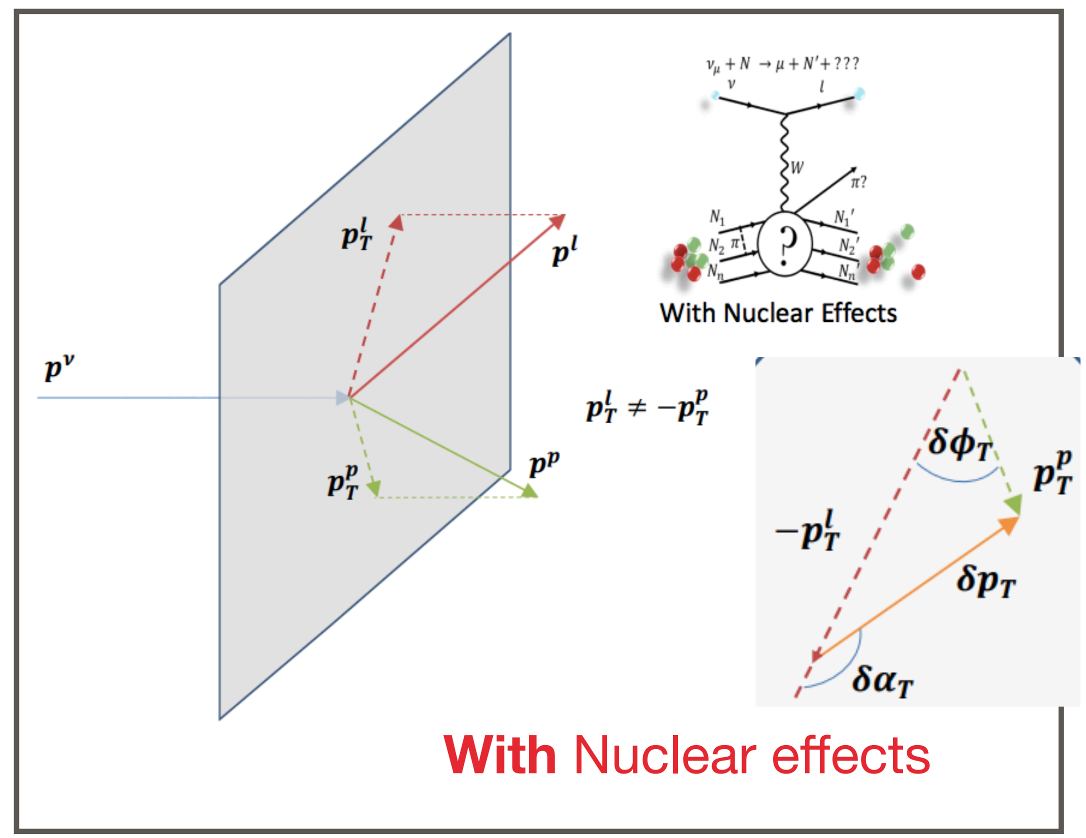

If we replaced the SuperFGD with a big FGD 1, could we still have such a probe of nuclear effects?

- No:

Large shape difference between FSI and no FSI lines for SuperFGD

Only small shape difference for an FGDXY

- SuperFGD sensitivity to low momentum protons is essential

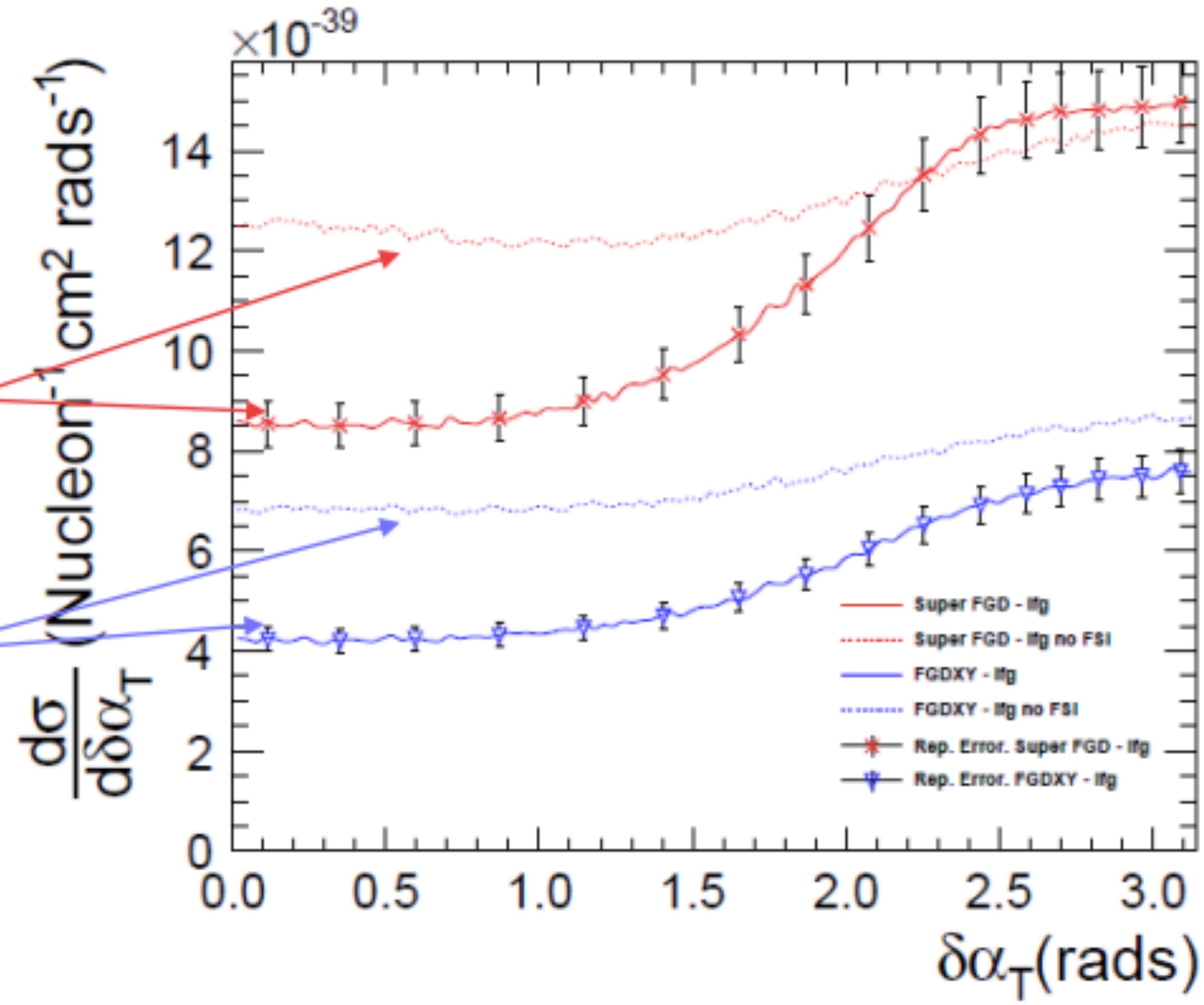

Figure 5: Comparison of the sensitivity to FSI effects through a measure of $\delta\alpha_T$ for the SuperFGD and an FGDXY. The y-axis reports the CCQE-like cross section within the phase space accessible by the relevant detector. Detector smearing and acceptance effects are applied as described in Sec. 0.1.2.