Upgrade of T2K Near Detector ND280

Yury Kudenko

INR, Moscow

For the T2K ND280 Upgrade Working Group

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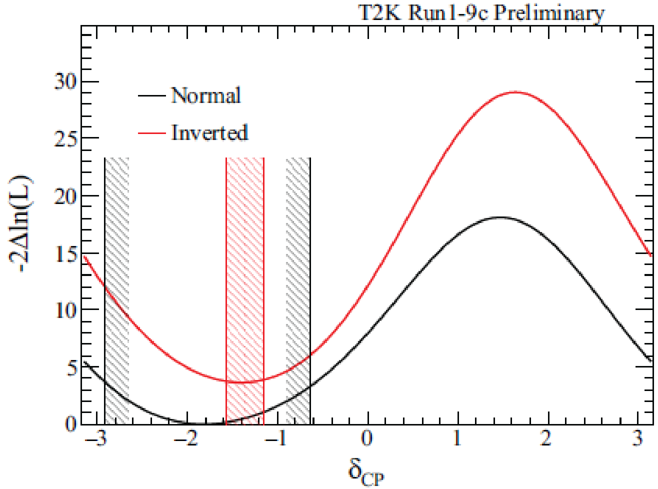
5 June 2019

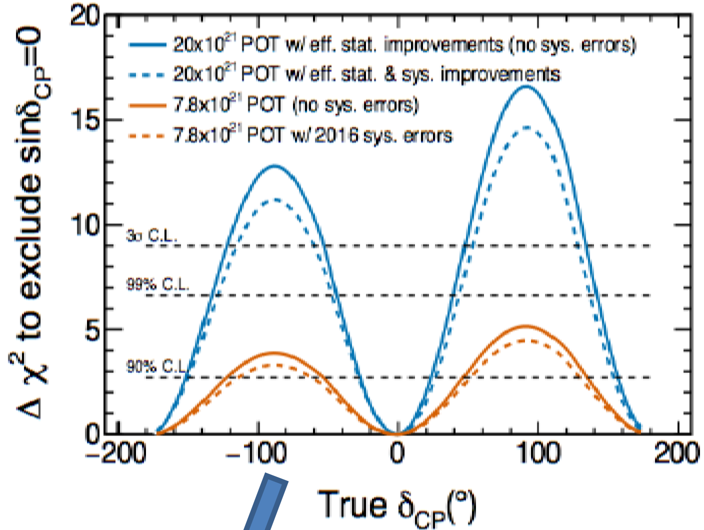
Search for CP violation

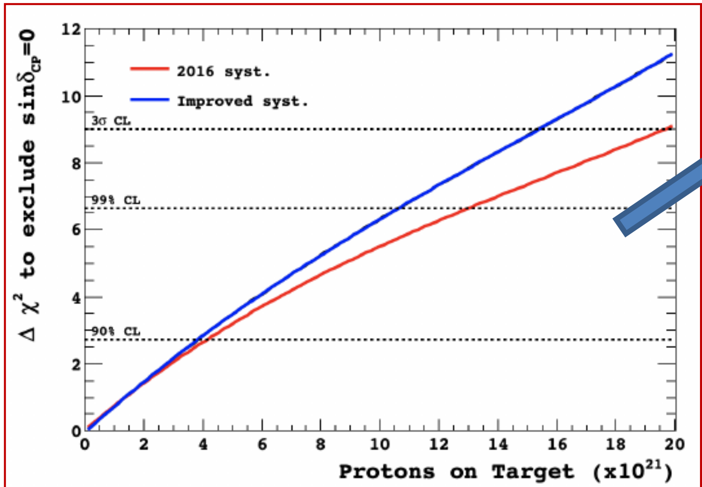
Main T2K goal: search for CP violation

T2K: CP conservation excluded at $>2\sigma$ confidence level



T2K-II: 20×10^{21} POT by 2025

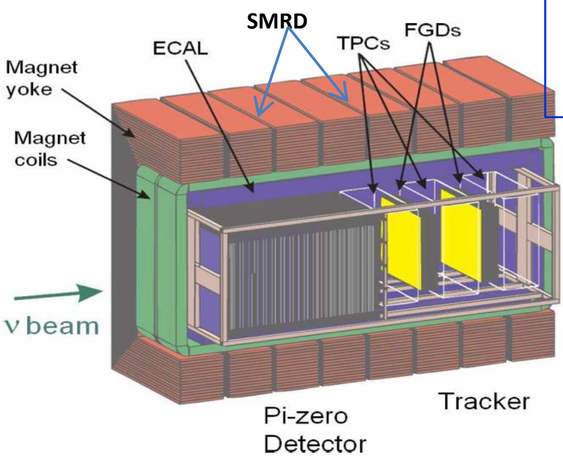




T2K-II will exclude CP conservation hypothesis at $3\boldsymbol{\sigma}$ for a wide range of δ_{CP} values

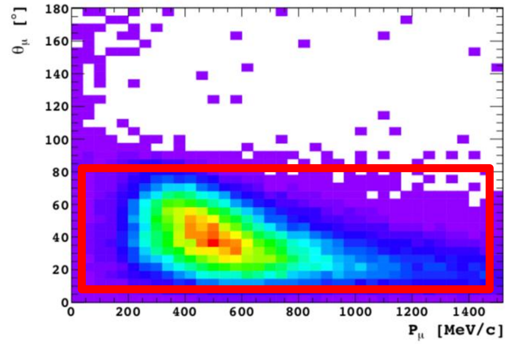
- To reach **T2K-II** goal the systematic uncertainties should be reduced from the current level of **6-7 %** to **≤ 4 %.**
- **Hyper-Kamiokande** requires much better understanding of neutrino-nucleus interactions

T2K ND280

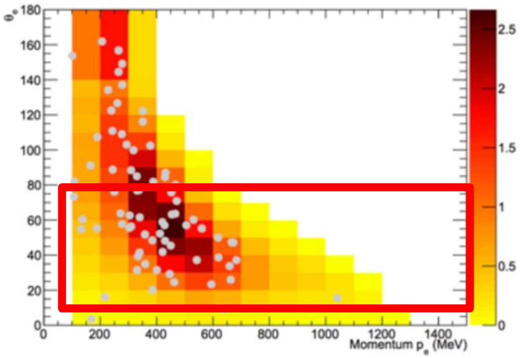


Measurement of neutrino energy based on reconstructed muon momentum and angle by ND280

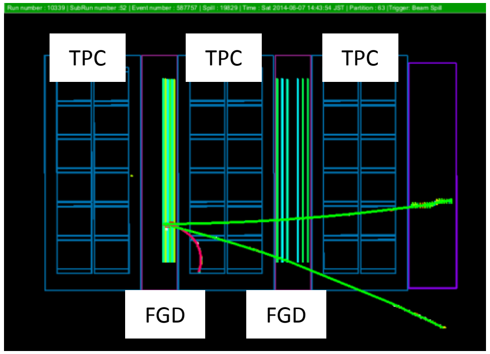
muons at ND280 forward direction

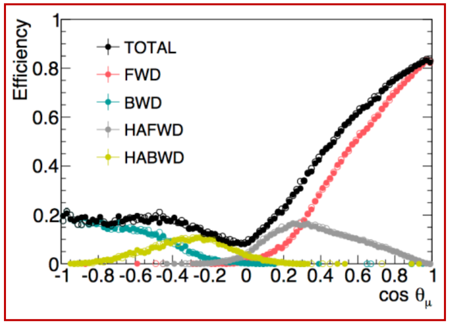


electrons at SuperK 4π acceptance



ν interaction in ND280





ND280

- Momentum threshold for protons 450 MeV/c (100 MeV kinetic energy)
- Non-CCQE interaction (2p2h, FSI) observed as CCQE
- Acceptance for tracks in forward direction, SuperK - 4π acceptance
- Larger systematic uncertainties due to tracks not measured by TPCs and bad track timing

Physics motivation

Present ND280

ND280 provides mainly acceptance for tracks in forward direction, while Super-Kamiokande has 4π acceptance

Neutrino nucleus interactions are not well known → model dependence

The near-to-far prediction in oscillation analysis relies on a cross-section model

Upgrade

- Important to measure neutrino interactions in all phase space
- Precisely detect particles produced at any angle
- Reduce detection threshold, measure protons with low threshold
- Measure neutrons in anti-ν_μ interactions
- Reduce background, obtain better track identification using TOF
- Provide electron/gamma separation

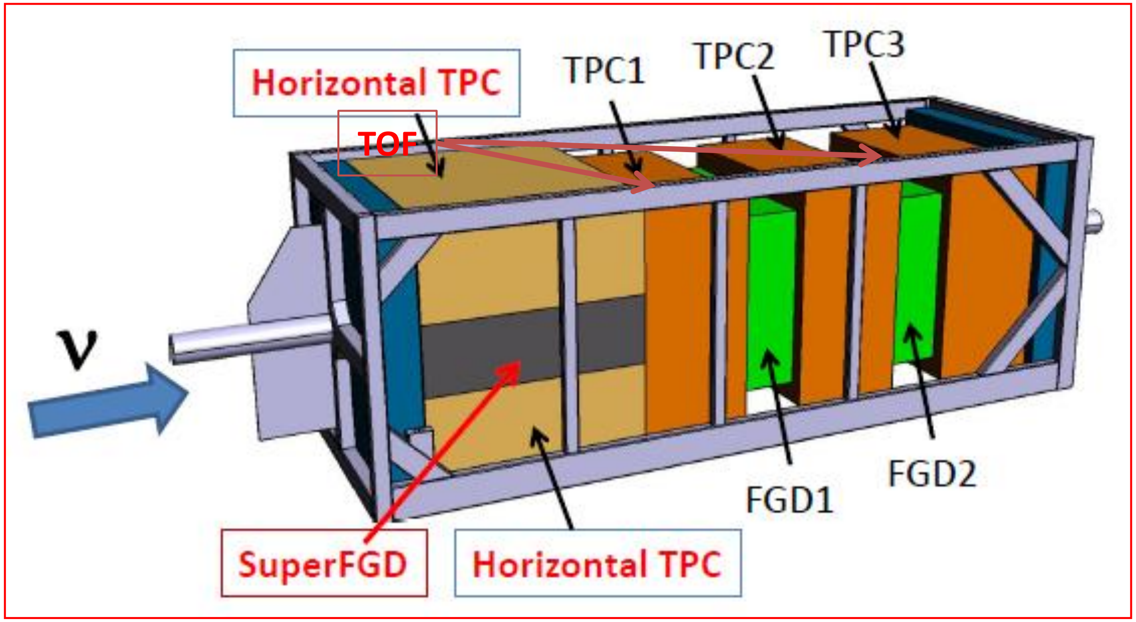
ND280 upgrade

Upgrade ND280 to reduce systematics to ≤4% level
Needed for T2K-II and Hyper-Kamiokande

arXiv:1901.03750

New upstream tracker:
- Two Horizontal TPCs
- One 3D fine-grained scintillator target SuperFGD
- TOF system around new tracker

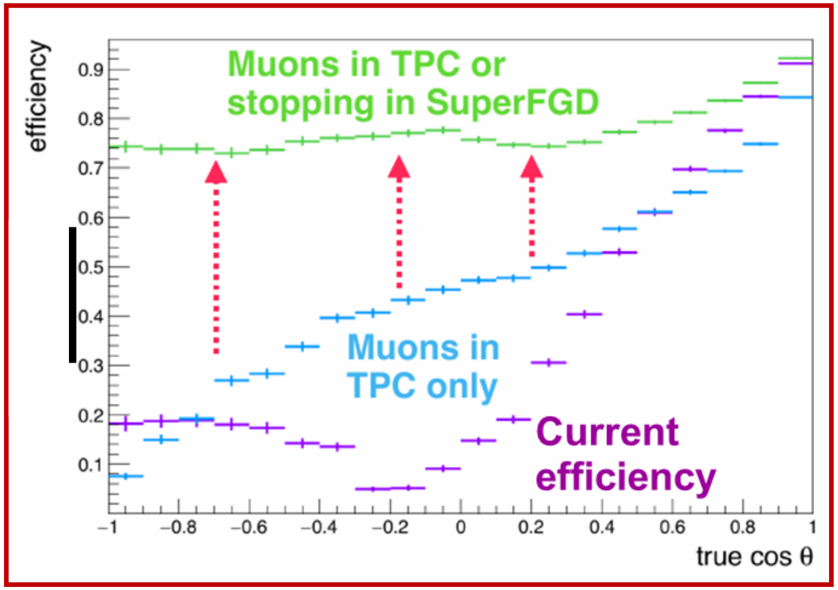
- Fully active detector
- 4π acceptance for charged particles
- Detection of low energy protons and pions
- Electron/gamma separation
- Electron neutrino studies
- Detection of neutrons



T2K upgrade group
~ 90 participants
from 10 countries

Extended Phase Space

4π acceptance for muons

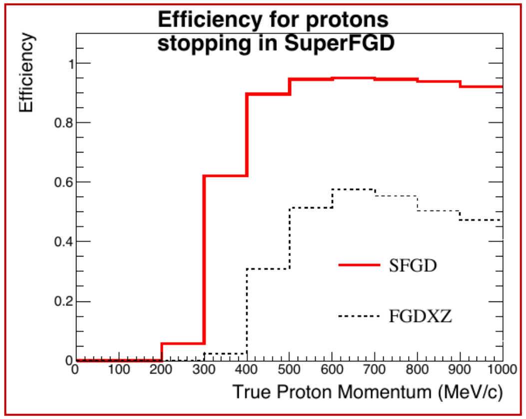


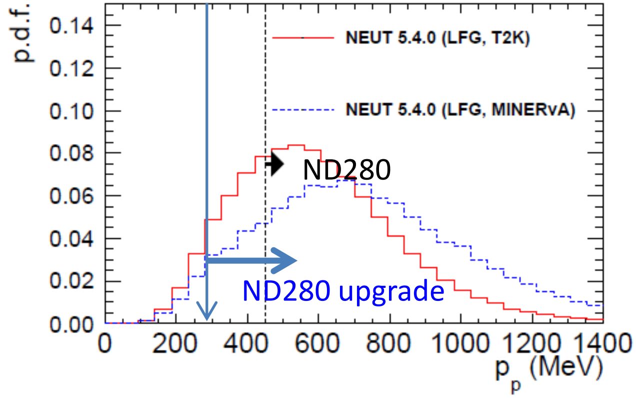
$$E_\nu = \frac{m_p^2 - (m_n - E_b)^2 - m_\mu^2 + 2(m_n - E_b)E_\mu}{2(m_n - E_b - E_\mu + p_\mu \cos\theta_\mu)}$$

Nuclear effects which impact the oscillation measurements :

- **Fermi motion**
- **2p2h**
- **FSI**

Detection of protons and neutrons in the final state will allow to test nuclear effects and to avoid biases in oscillation measurements

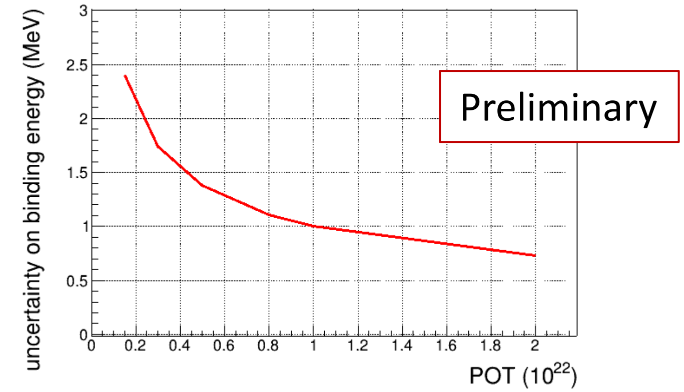




Measurement of nucleons

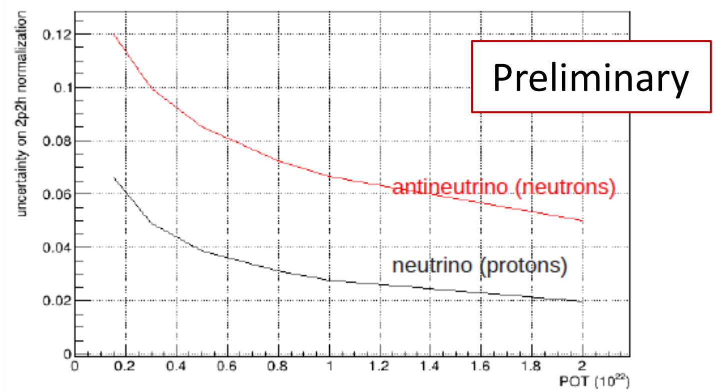
SuperFGD similiation
S.Bolognesi, S.Dolan, L.Muntenau

Measurement of protons helps to reduce E_b uncertainty

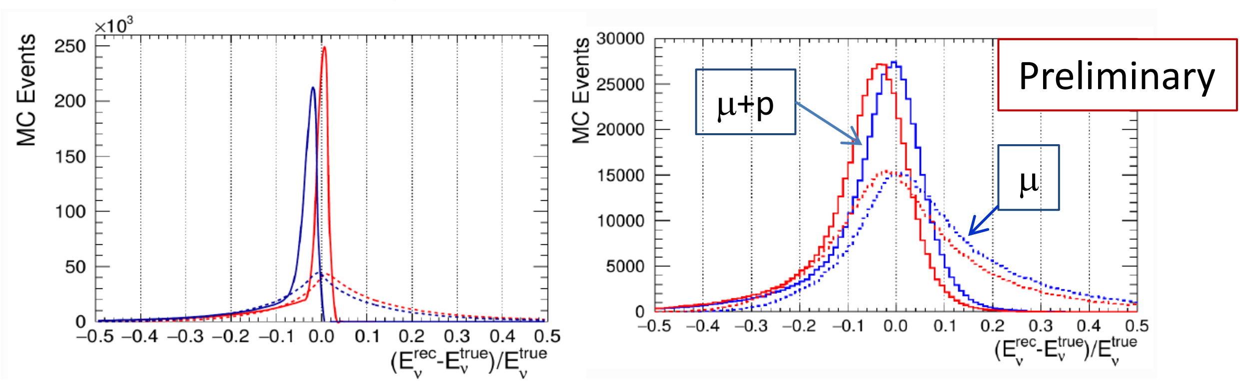


Neutron detection:
- 60% efficiency
- neutron path >50 cm
- energy resolution 15-30%

helps to reduce uncertainty on 2p2h contribution



Eν reconstruction based on muon kinematics and Ep + Eμ

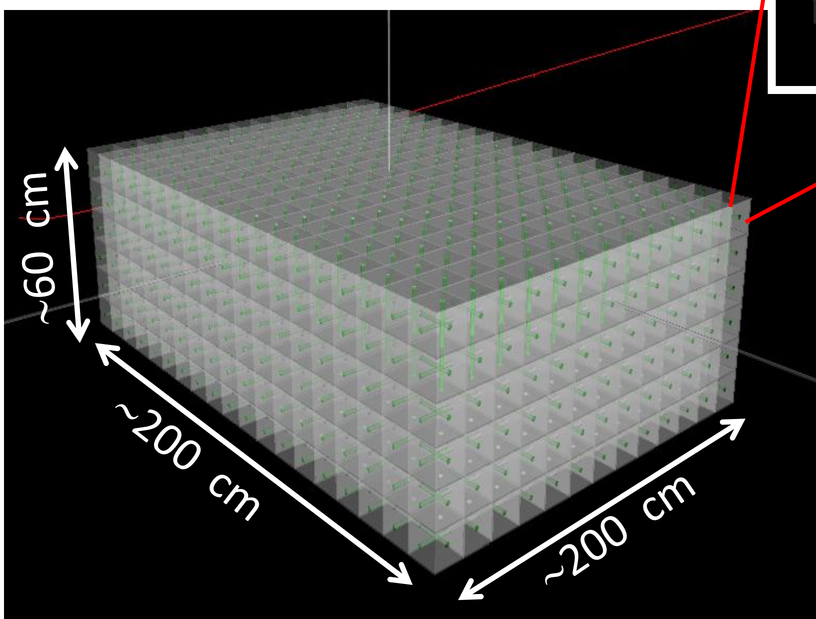


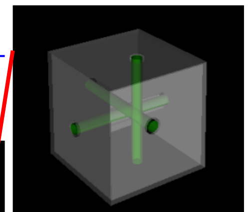
SuperFGD

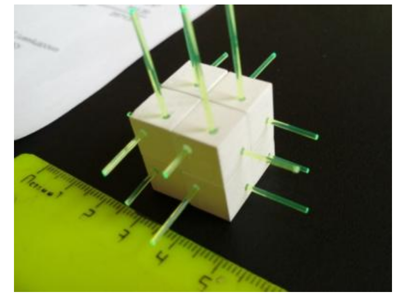
JINST 13 (2018) 02006

- Volume ~200 x 200 x 60 cm^3
- **~2 x 10^6** scintillator cubes , each 1 x 1 x 1 cm^3
- Each cube has orthogonal 3 holes, diameter 1.5 mm
- 3D (x,y,z) WLS readout
- About **60000** readout WLS/MPPC channels
- Total active weight about **2 t**

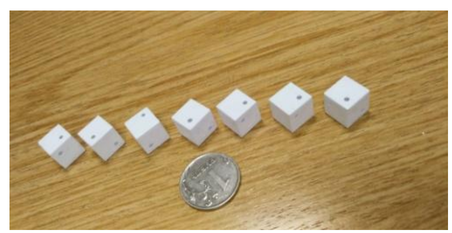
Fully active, highly granular, 4π scintillator neutrino detector with 3D WLS/MPPC readout

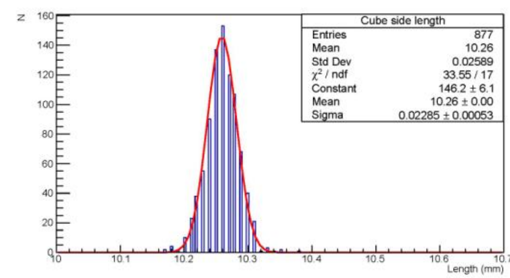






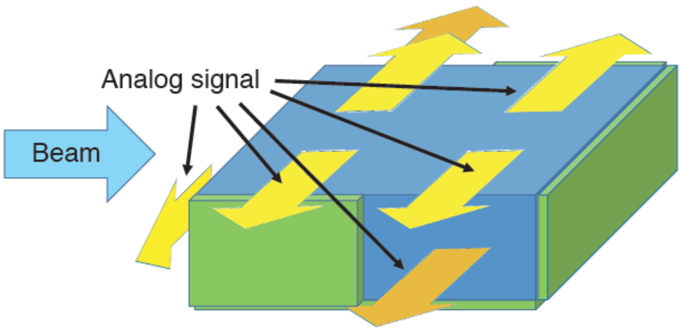
Cubes produced by injection molding
Covered by chemical reflector
Tolerance (each side) about 30 microns

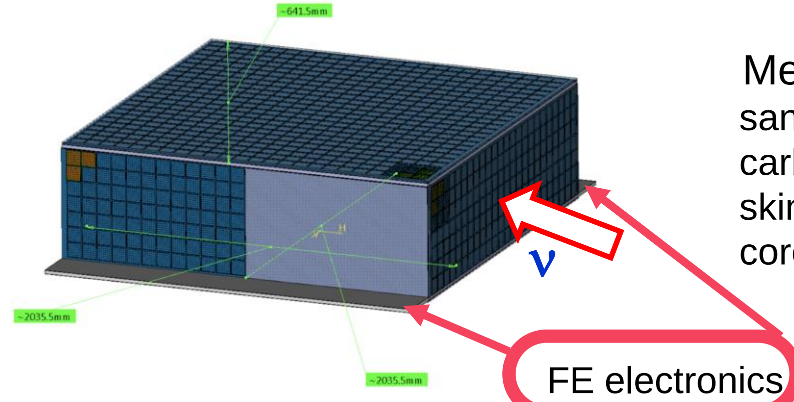




3 holes in each cube drilled
with the tolerance of 50-70 microns

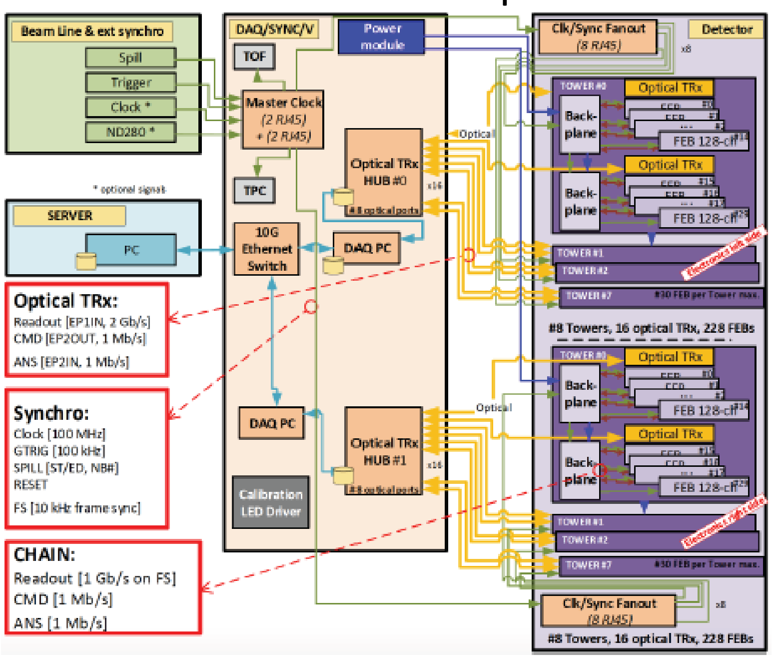
SFGD Readout/Electronics





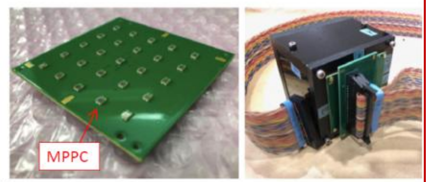
Mechanical box:
sandwich of 2 mm carbon-fiber (CF) skins and AIREX core (0.06 g/cm^3)

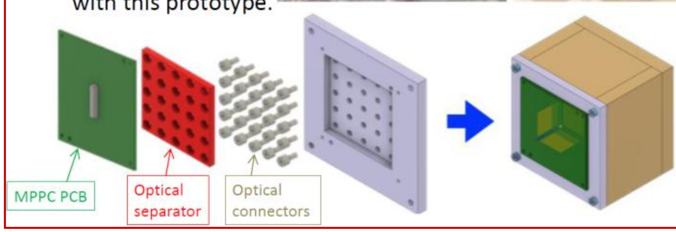
Electronics readout scheme based on CITIROC chips



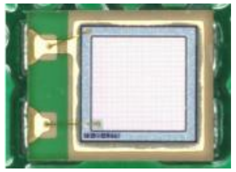
Prototype of optical interface

- Readout of 5× 5 MPPC channels.
- Including 5× 5 × 5 cubes.
- Tests were done with this prototype.

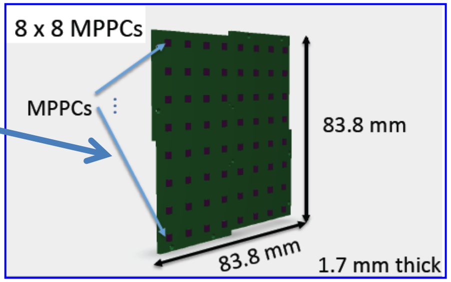




Photosensor:
surface mount
MPPC S13360-1325PE

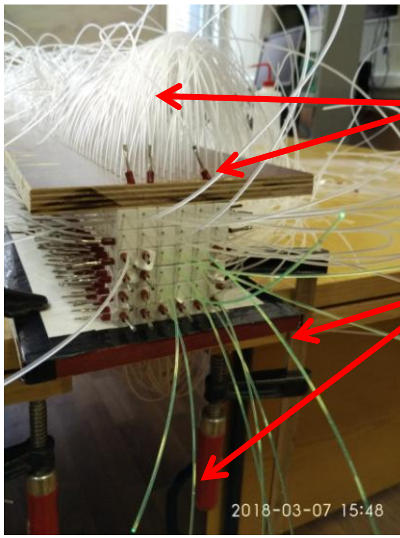


8 x 8 MPPC PCB
for SuperFGD



Assembly procedure

Baseline method: 1- assembly of planes and whole detector using fishing lines
2 - replacement of fishing lines by WLS fibers



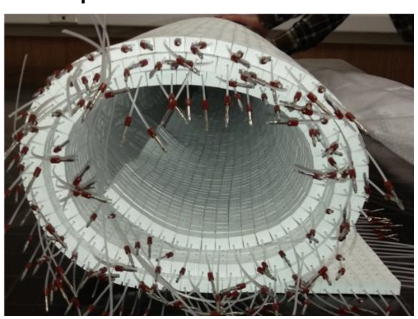
Fishing lines

Y11 WLS fibers

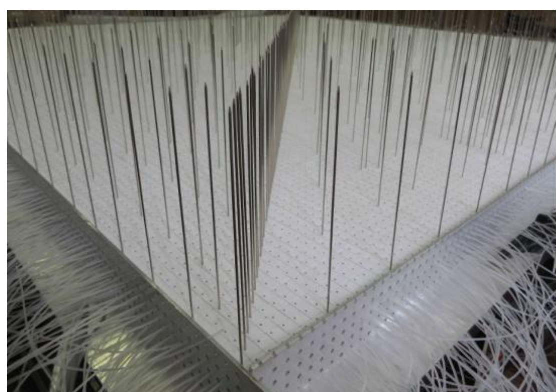
Method was tested with small prototypes

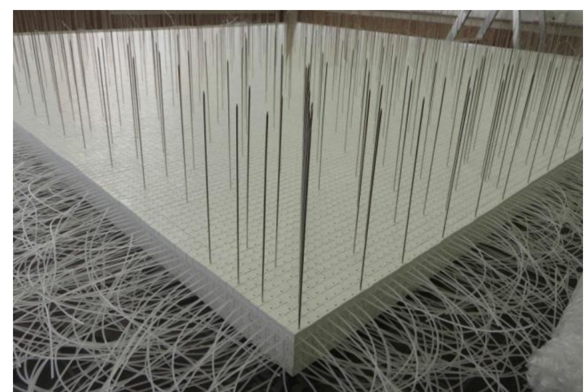
SFGD planes under assembly

Swiss roll made of a plane of cubes



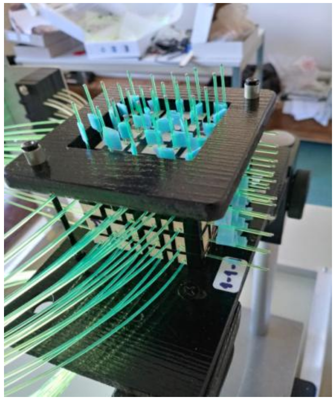
Four panes assembled with fishing lines and stainless steel needles





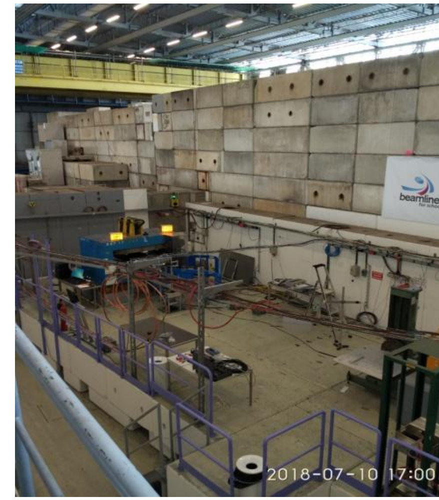
Beam tests at CERN

T9 channel at CERN: muons, pions, protons, electrons 0.5 – 5.0 GeV

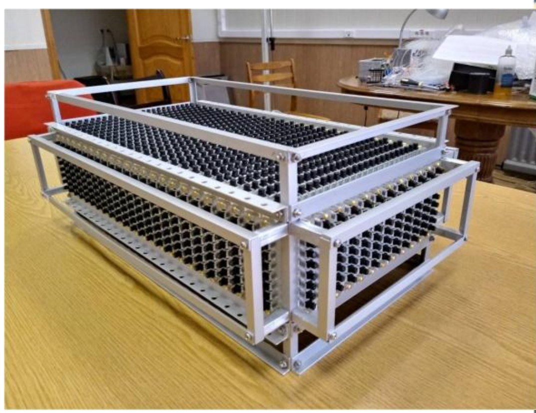


Small prototype
125 cubes
75 readout channels
WLS fibers + MPPC's

2017-2018



Large prototype

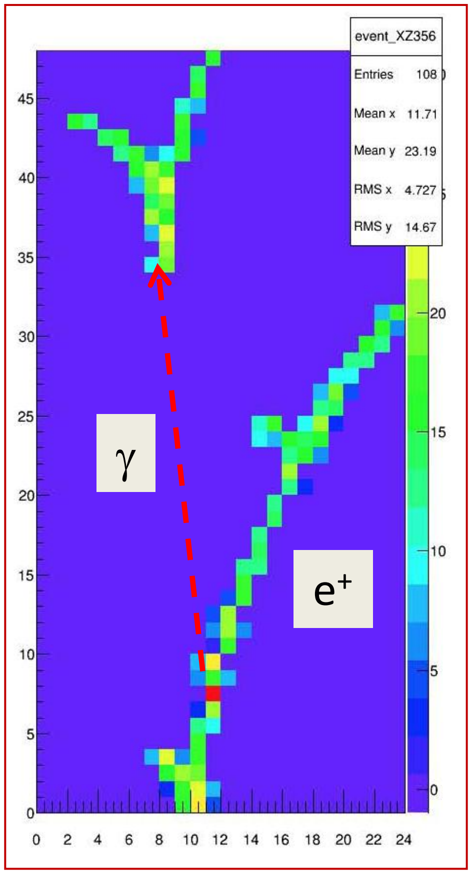


Large prototype
Length 48 cm
Width 24 cm
Height 8 cm
9216 cubes
Readout:
1728 Y11 WLS fibers and MPPC's

Beam events

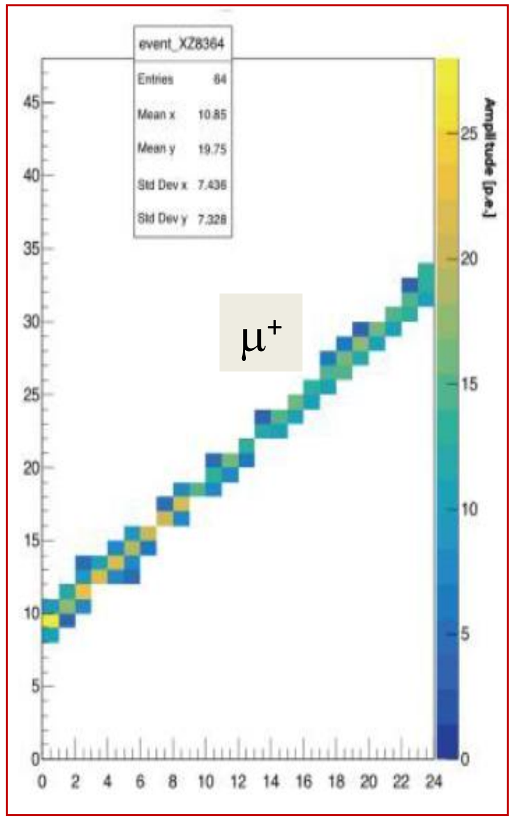
Positron, 1 GeV, B = 0.2 T

Top view



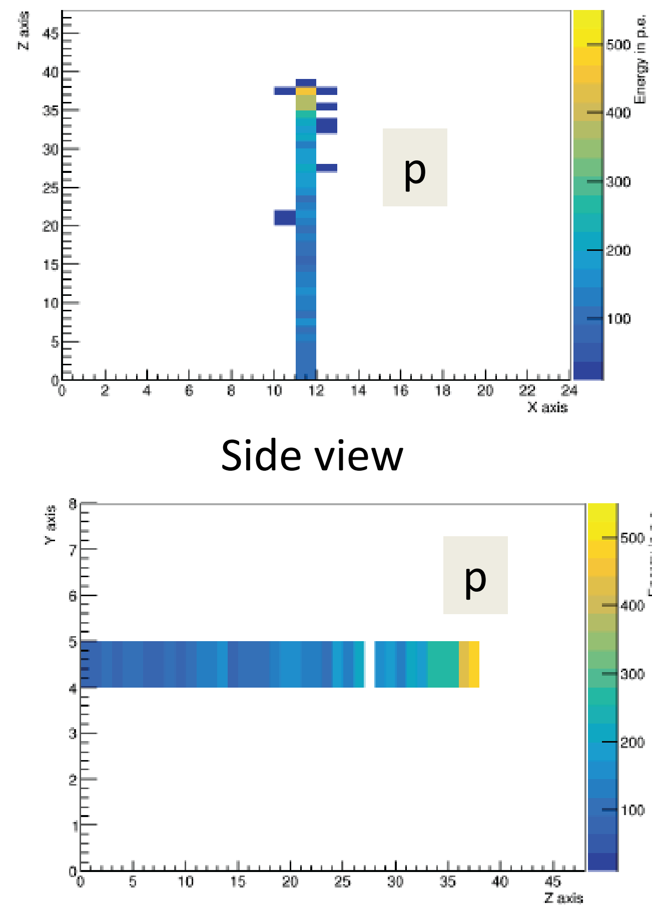
Muon, 5 GeV, 45 deg

Top view



Stopped proton, 0.8 GeV

Top view

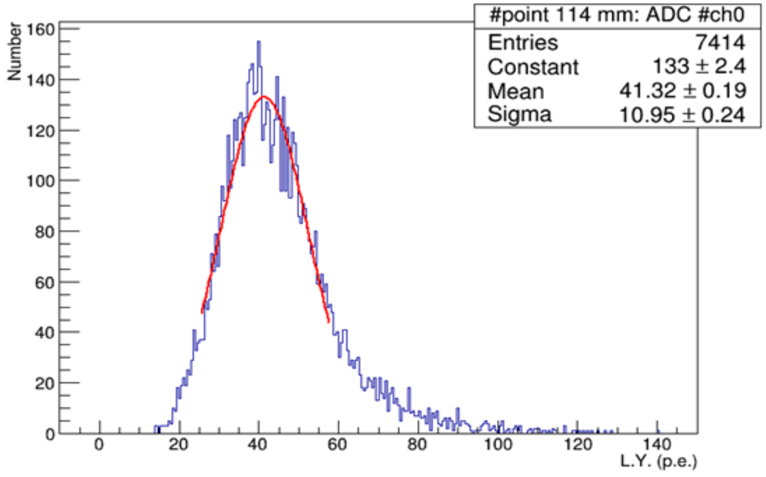


Parameters of cubes

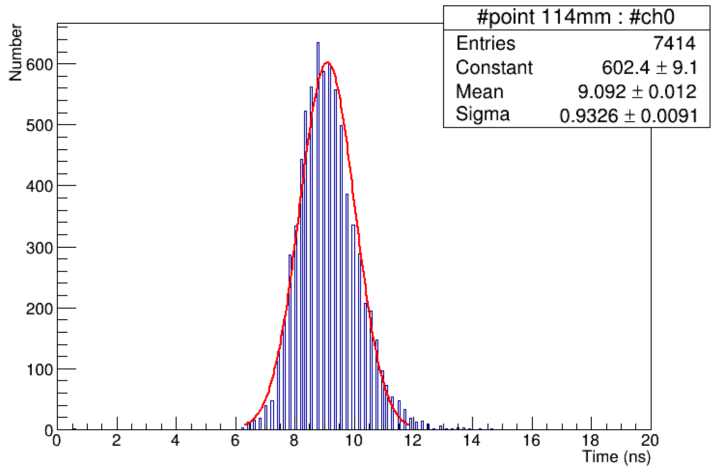
Light yield of a MIP: 1 cube/1 WLS fiber

Fiber length = 1.3 m

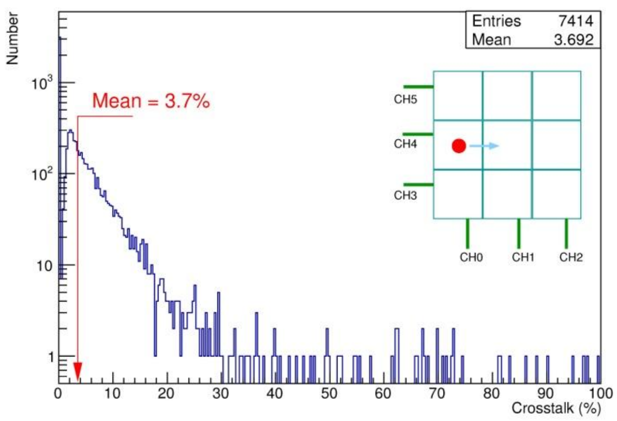
NIM A923 (2019) 134



Time resolution of a MIP: 1 cube/1 fiber



Cross talk about 3 %



Light yield of 1 cube/1 fiber	**~ 40 p.e./MIP**
Light yield of 1 cube/2 fibers	**~ 80 p.e./MIP**
Time resolution **(σ)**	
1 fiber:	**0.92 ns**
1 cube/2 fibers:	**0.68 ns**
2 cubes/4 fibers:	**0.48 ns**
3 cubes/6 fibers:	**0.39 ns**

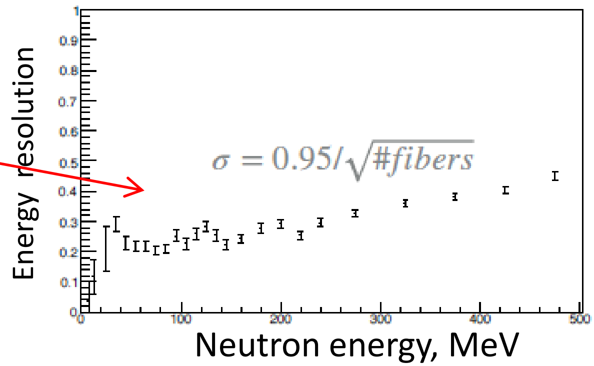
Detection of neutrons

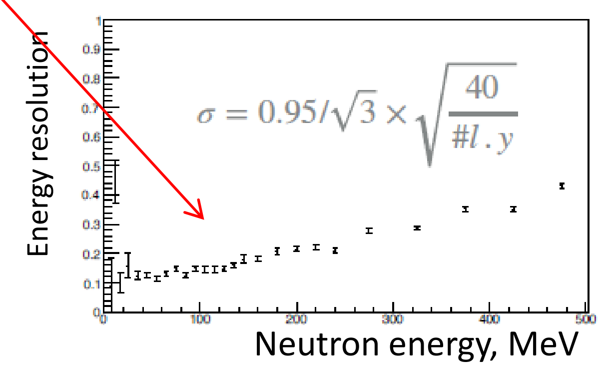
SuperFGD:
fully active detector
made of polystyrene (CH),
3D granularity, good time resolution,
good neutron detection efficiency

L > 50 cm
Light yield = 40 p.e./(MIP x fiber)

$$\sigma_t = 0.95ns / \sqrt{\# \ fibers}$$

$$\sigma_t = \frac{0.95ns}{\sqrt{3}} \sqrt{\frac{40}{l.y.}}$$

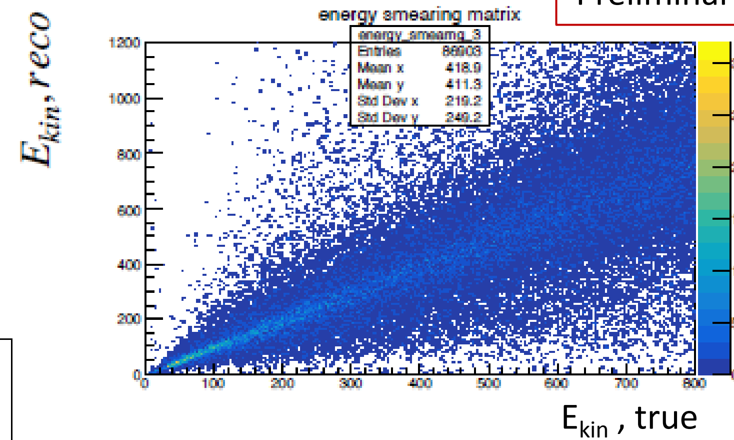




External backgrounds
from the pit walls and
the magnet - under study

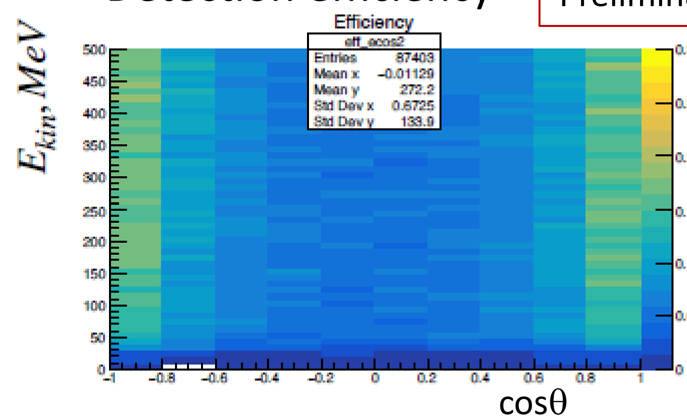
Monte Carlo study

Preliminary

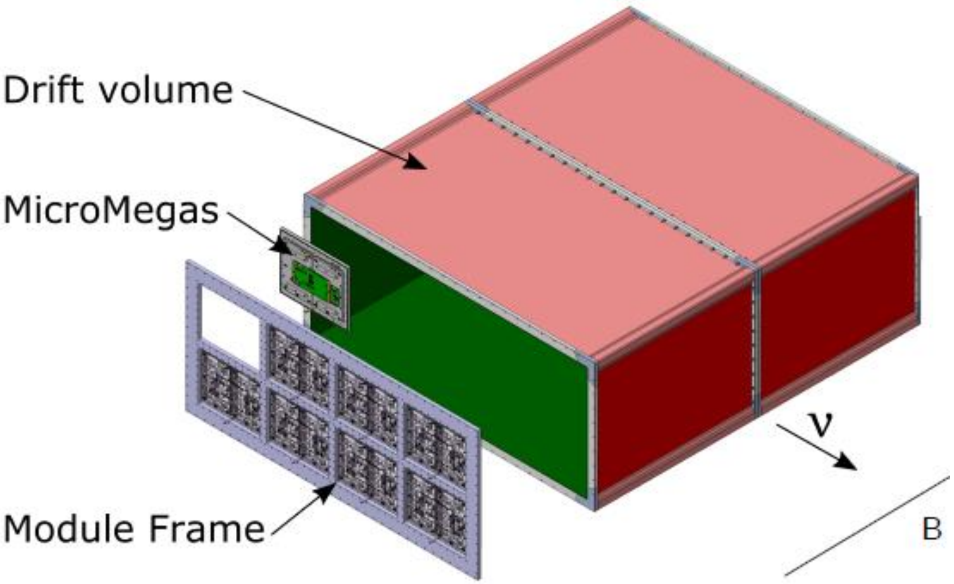


Detection efficiency

Preliminary



High Angle TPC

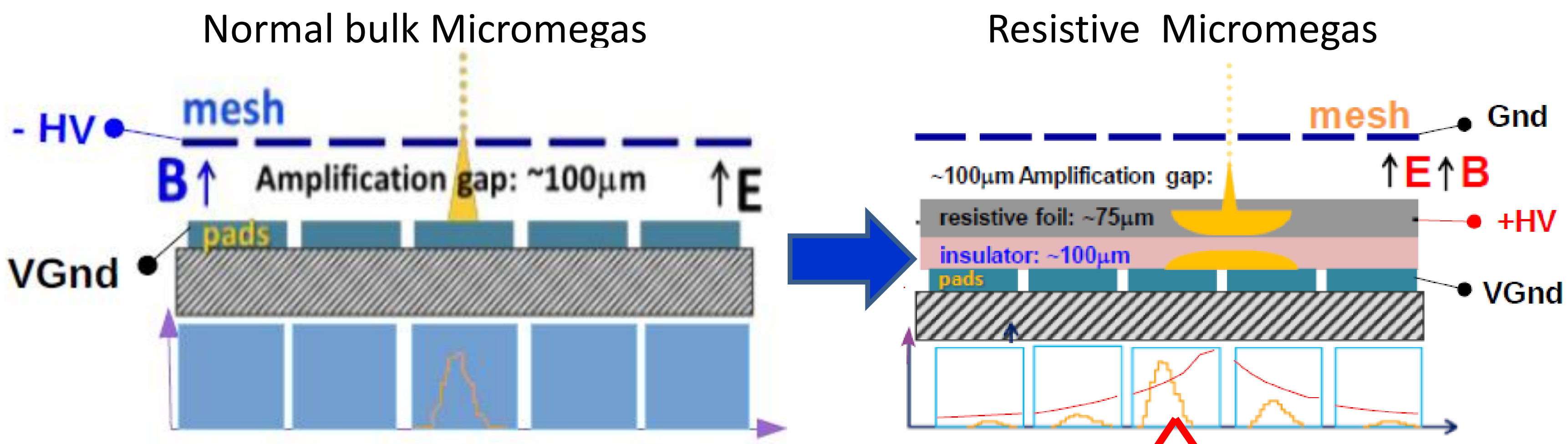


Parameter	Value
Overall x × y × z (m)	2.0 × 0.8 × 1.8
Drift distance (cm)	90
Magnetic Field (T)	0.2
Electric field (V/cm)	275
Gas Ar-CF_4-iC_4H_{10} (%)	95 - 3 - 2
Drift Velocity $cm/\mu s$	7.8
Transverse diffusion ($\mu m/\sqrt{cm}$)	265
Micromegas gain	1000
Micromegas dim. z×y (mm)	340 × 410
Pad z × y (mm)	10 × 11
N pads	36864
el. noise (ENC)	800
S/N	100
Sampling frequency (MHz)	25
N time samples	511

Micromegas detector: new “resistive bulk” technique
→ charge sharing: same spatial resolution with lower pad density
→ no sparks: no need of protecting diodes at FE input
Field Cage: thin, light-weight and low Z walls
→ thin walls made of solid insulator walls (composite material)
→ minimize dead space + maximize tracking volume

Resistive Micromegas

New Micromegas configuration:
Encapsulated resistive anode with grounded mesh



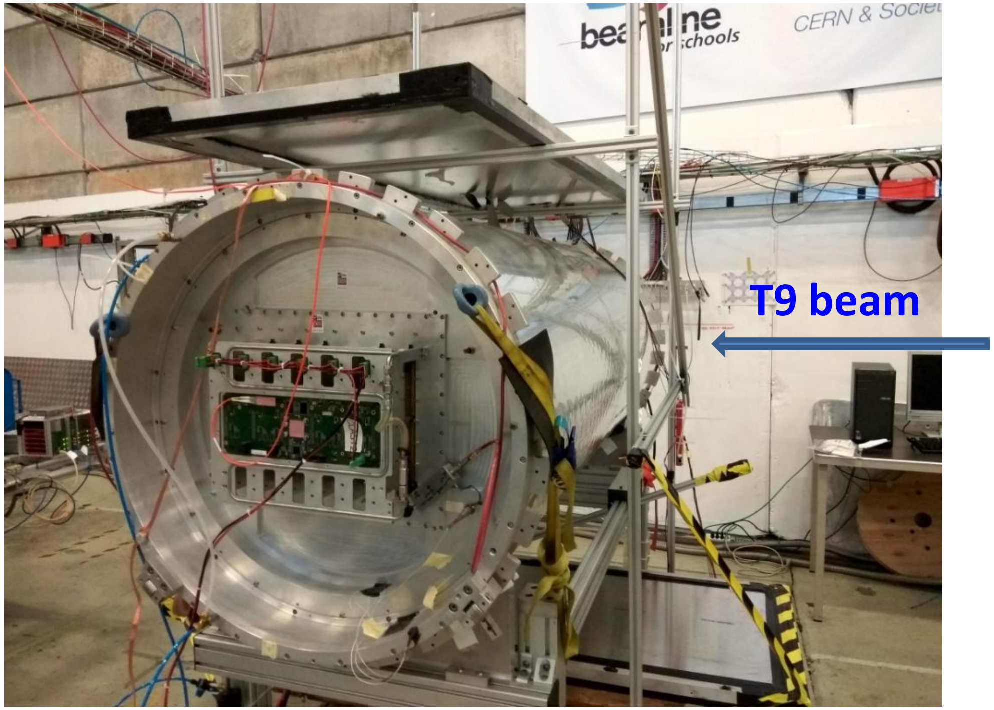
Charge detected over several pads

- **Better spatial resolution**
- **A smaller number of channels**
- **Resistive layer prevents sparks → operation at higher gain**
- **Potentially better field homogeneity**
- **Less sensitive to electric noise**

dE/dx ?

Test of HATPC

Micromegas RMM0 (DLC-bulk MM)
mounted on ex-HARP field cage at T9 beam line at CERN



Gas volume HARP TPC
Drift distance 1.5 m/25 kV
25 l/h Ar(95%)/CF4(3%)/isobutane(2%)

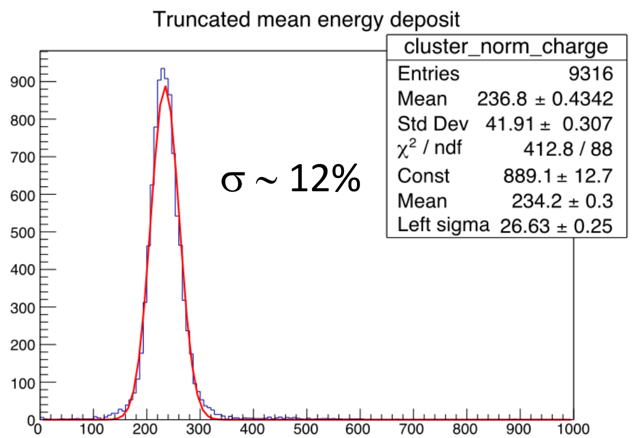
Detector MM0 module
MM with resistive foil
Horizontal x Vertical = 36 x 48 pads
1728 pads in total
Each pad 0.98 x 0.7 cm2
Nominal MM voltage 340 V
Sampling time 80 ns
Nominal peaking time 600 ns

Beam test at CERN in August-September 2018
Beam: muons, pions, electrons, protons
momentum 0.5, +-0.8, 1, 2 GeV/c

TPC performance (I)

Beam events

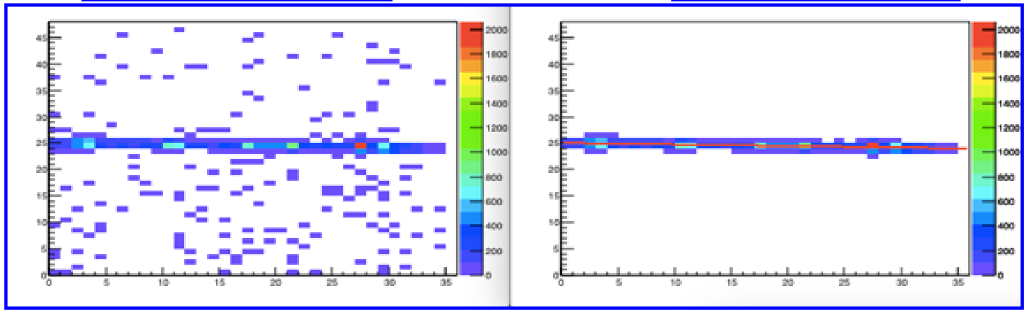
dE/dx, 2 GeV/c muons



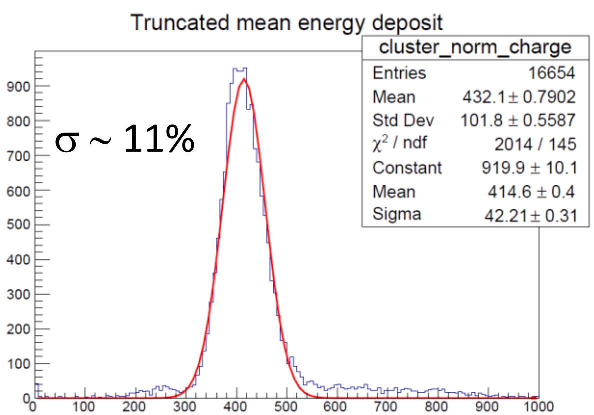
before cluster selection

Muon track

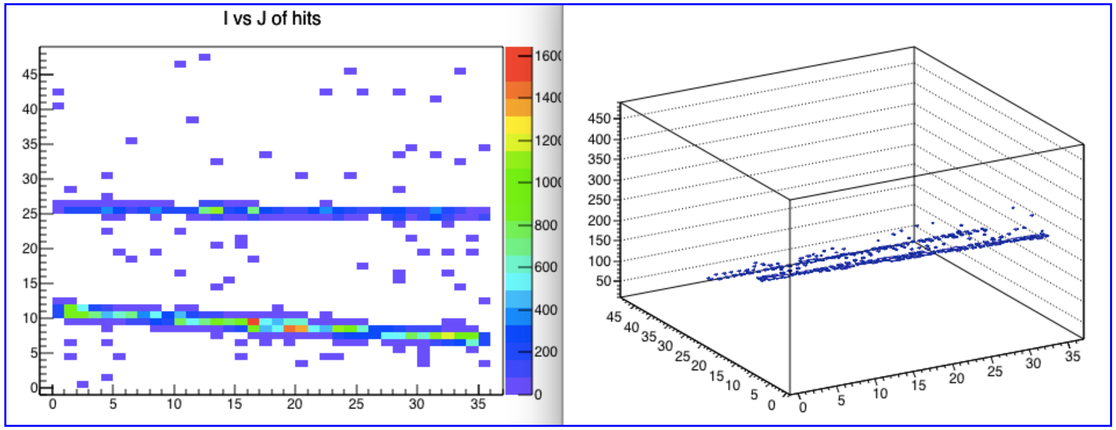
after cluster selection



dE/dx, electrons

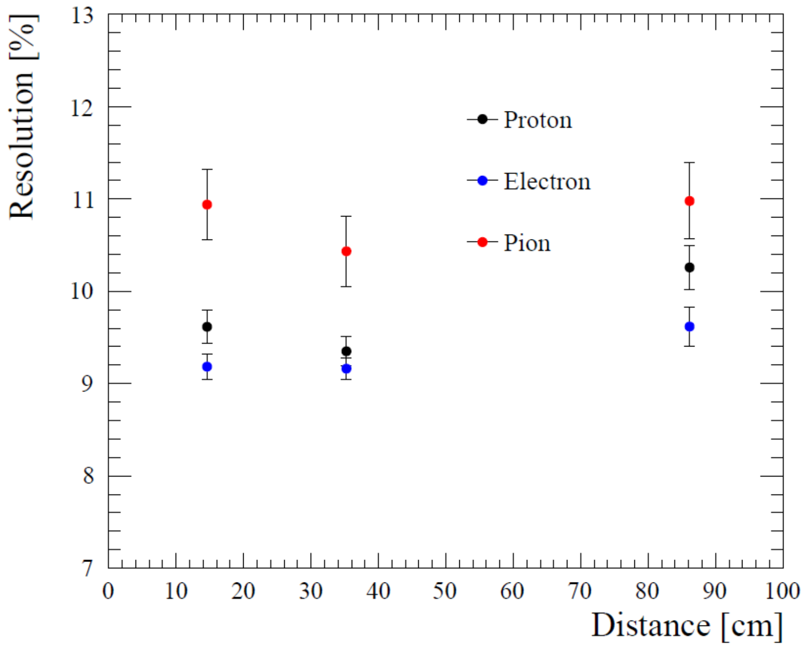


2 tracks detected

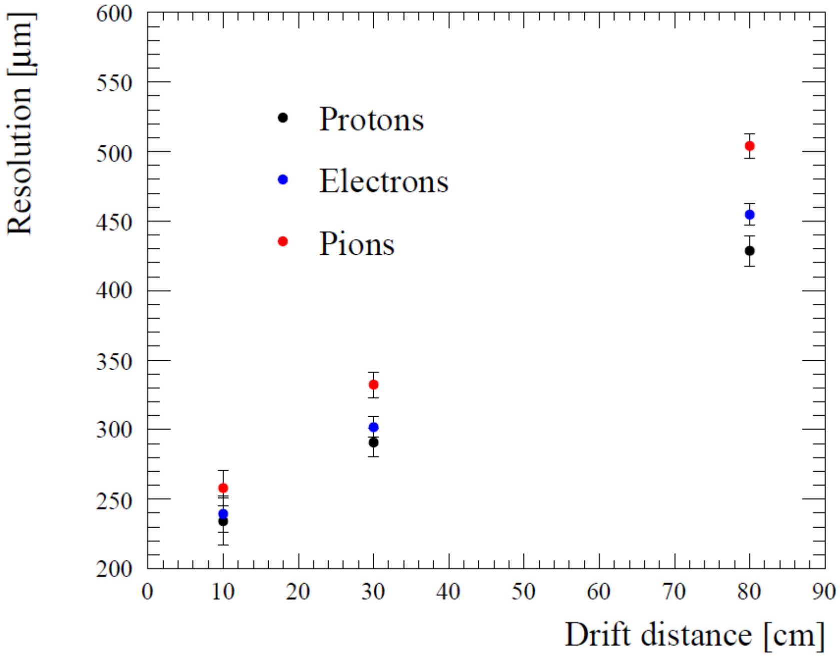


TPC performance (II)

dE/dx resolution



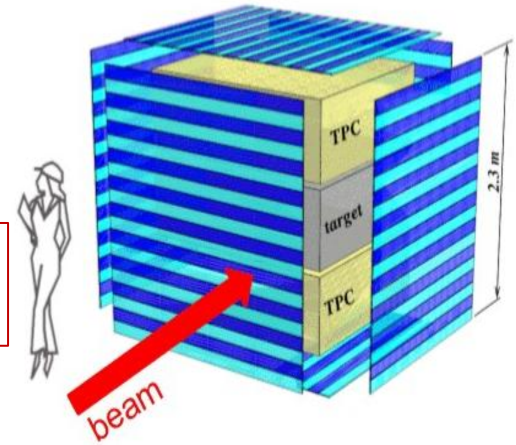
Spatial resolution



Excellent results with Resistive type bulk RMM:
- **about 10% dE/dx resolution**
- **300 μm spatial resolution – factor 2 better wrt bulk MM**
- **stable working conditions – no sparks**

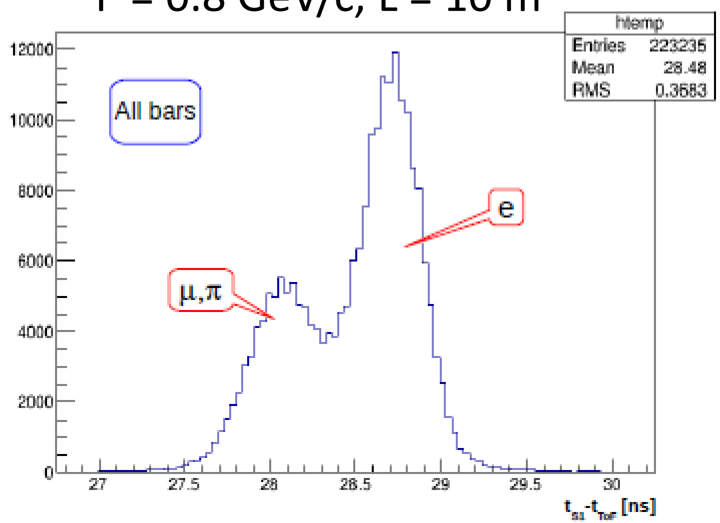
TOF system

Time-of-Flight detector surrounds the new tracker (Super FGD + High Angle TPCs) for better rejection of incoming background

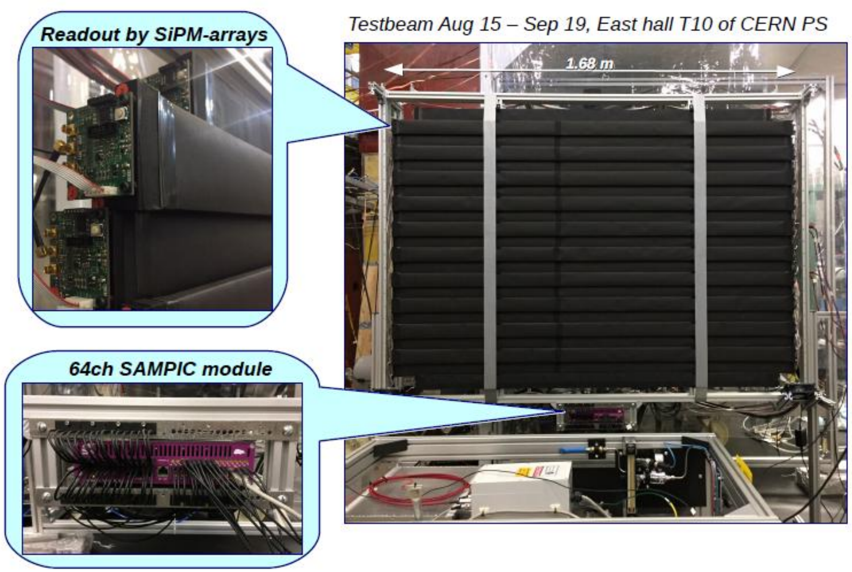


TOF bar: cast scintillator EJ-200, 1.68 m x 6 cm 1 cm
readout by 8 arrays of 6x6 mm^2 Hamamatsu MPPC's

P = 0.8 GeV/c, L = 10 m

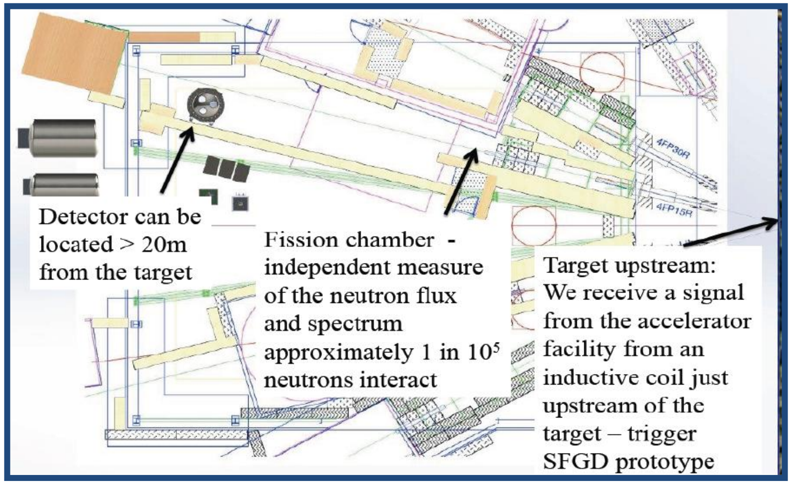


Achieved time resolution σ~70 ps

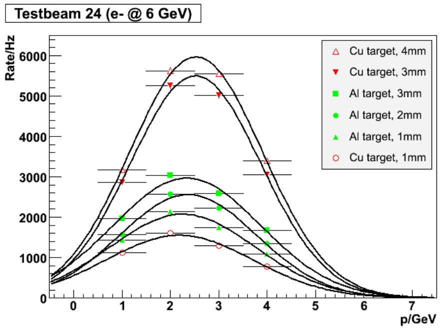


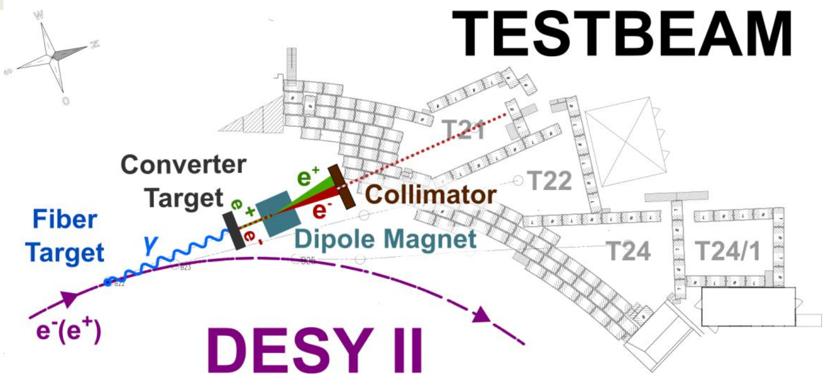
In-Beam Tests in 2019

Test of the SFGD prototype (~12000 cubes) with neutrons with energies up to 800 MeV at LANL



Test of the final type of RMM at DESY
Electron beam with energies up to 6 GeV





Conclusion

Better understanding of neutrino interactions and reduction of systematics are needed to make full use of the capabilities Of T2K and Hyper-Kamiokande to search for CP violation

Upgrade of the T2K near detector ND280 in progress

ND280 upgrade approved by CERN as the Neutrino Platform NP07 project

Beam tests at CERN → good performance of SuperFGD, HATPC, TOF

Innovative technology works well

Production all detector components: 2019-2020

Assembly, installation and commissioning at J-PARC - 2021