Upgrade of the T2K Near Detector ND280

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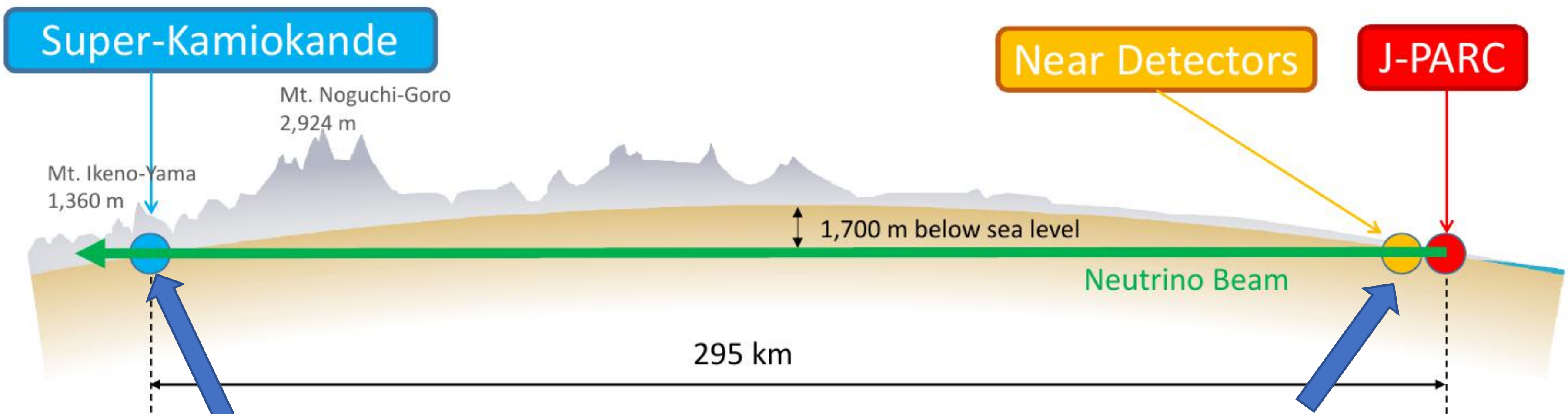
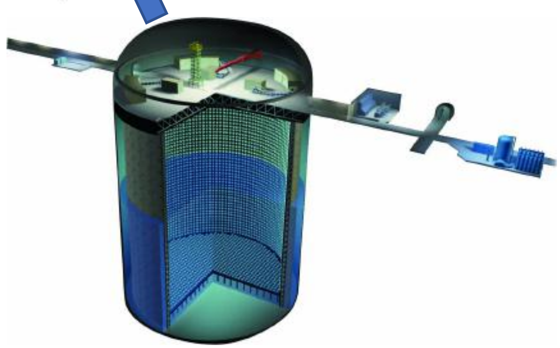
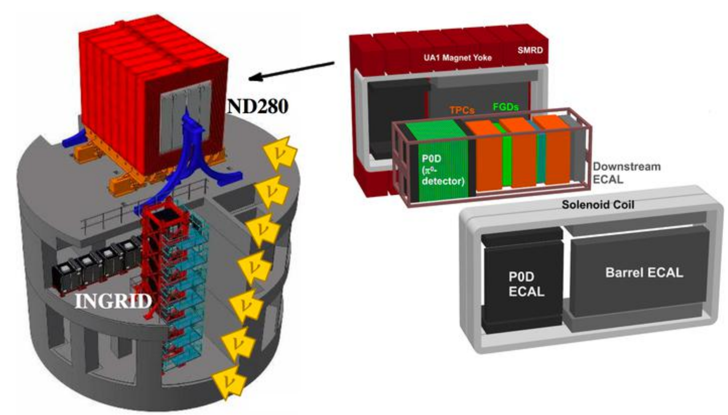
T2K Experiment

- T2K (Tokai To Kamioka) is a long-baseline neutrino oscillation experiment in Japan
- Precise measurement of neutrino oscillation parameters ($\sin^2\theta_{23}$, Δm^2_{32}, $\sin^2\theta_{13}$) and search for CP violation





Off-axis beam (2.5^0)
Neutrino flux peaks at 0.6 GeV

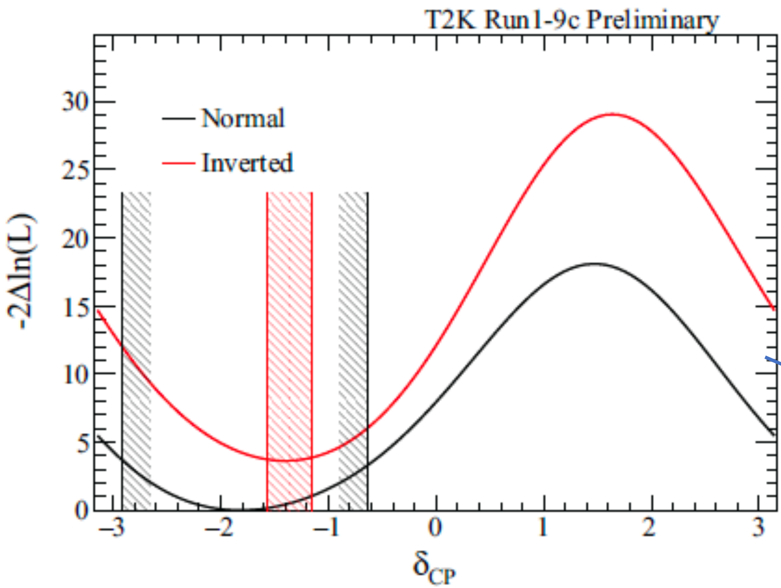


Super-Kamiokande (SK)
50 kt of water cherenkov detector

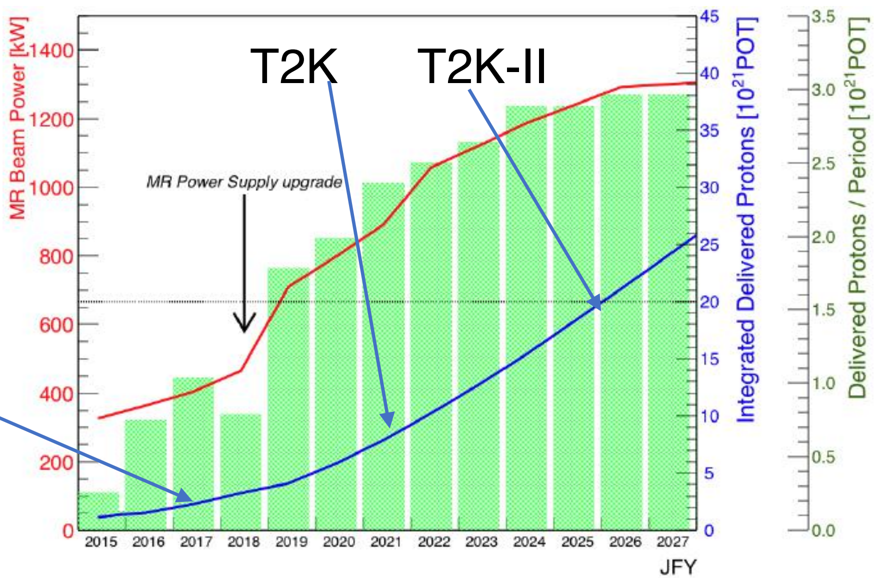
Prospects for the future: T2K-II

- J-PARC long term beam power increase plan: **0.47MW → 1.3MW**
- Plan to gradually increase the beam intensity up to ~1 MW in 2021
- T2K is expected to reach the approved statistics (**7.8 x 10^{21} POT**) around 2021
- T2K-II phase (2022-): proposed to extend T2K run to **20 x 10^{21} POT by 2025**

arXiv:1609.04111



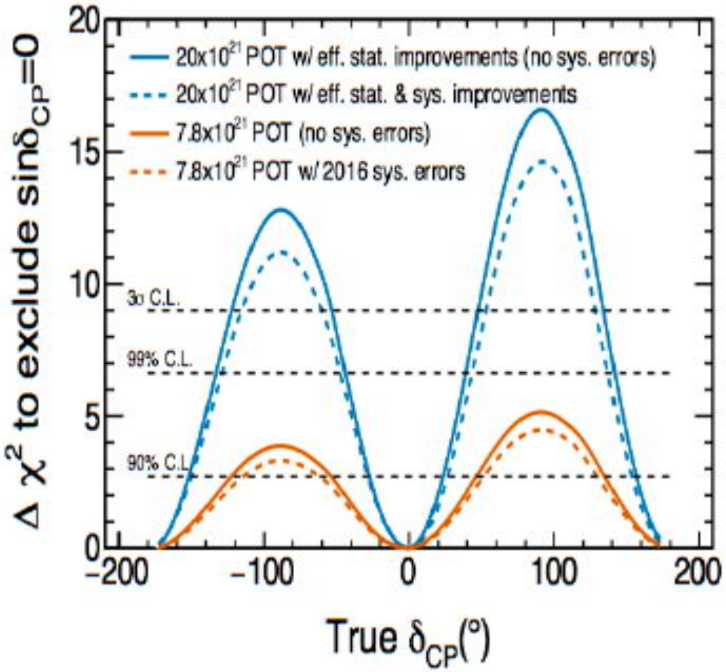
T2K: CP conservation excluded at >2σ confidence level



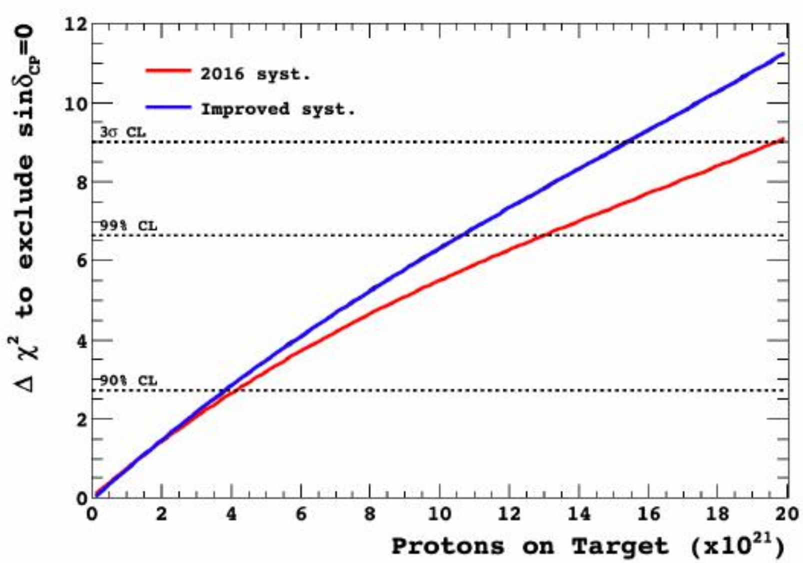
Anticipated MR beam power and POT accumulation plan by calendar year

Search for CP violation

T2K-II: 20 x 10^{21} POT by 2025



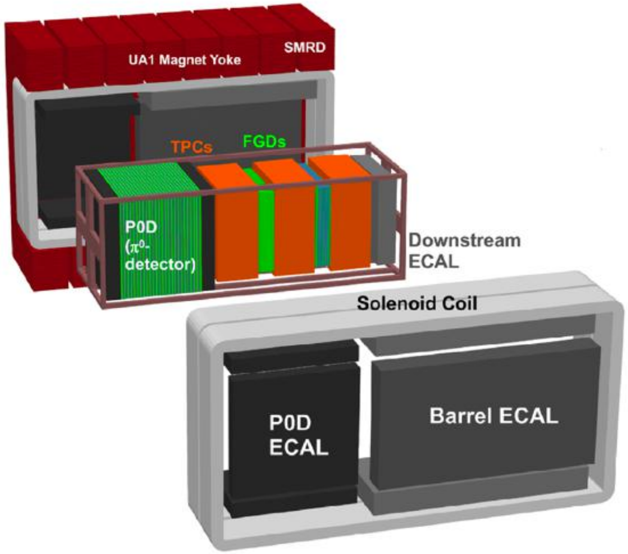
arXiv:1901.03750



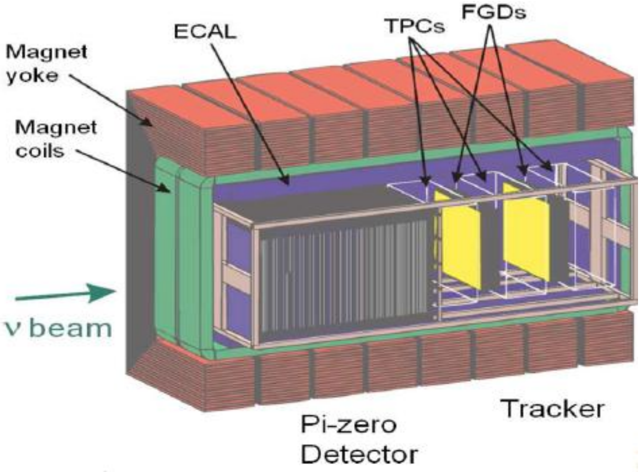
- With higher statistics at T2K-II, the physics reach will be enhanced by reducing systematic errors.
- T2K-II can exclude CP conservation hypothesis at $3\boldsymbol{\sigma}$ for a wide range of δ_{CP} values
- To reach T2K-II goal, the systematic uncertainties should be reduced from the current level of **6-7 %** to ~ **4 % - ND280 Upgrade is proposed**

T2K ND280

- Excellent performance - operated since 2010
- Providing critical input for oscillation measurements
    - Measure the neutrino interaction rates
    - Strongly constrain the expected rates at Super-Kamiokande for precision oscillation analyses
    - Measure neutrino nucleus cross-sections in several channels



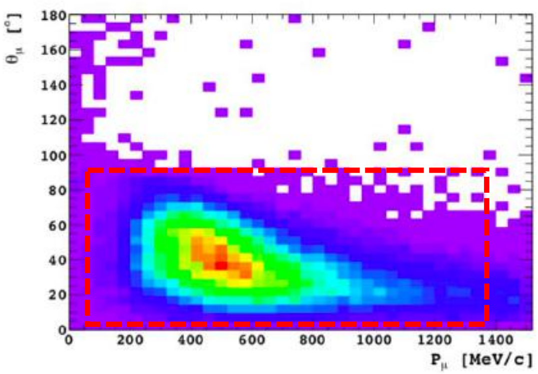
- Inside 0.2T magnet
- One Pi-zero detector (P0D)
- Two Fine-Grained detectors (FGD)
    - planes of scintillator bars along XY (perpendicular to neutrino beam)
- Three Time Projection Chambers (TPC)
- Electromagnetic Calorimeter (ECal)

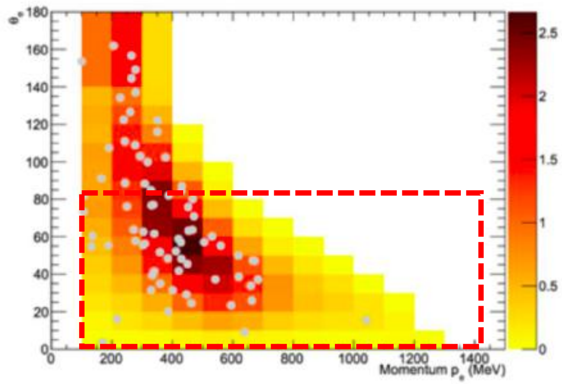


T2K ND280

The current ND280 design configuration has limitations

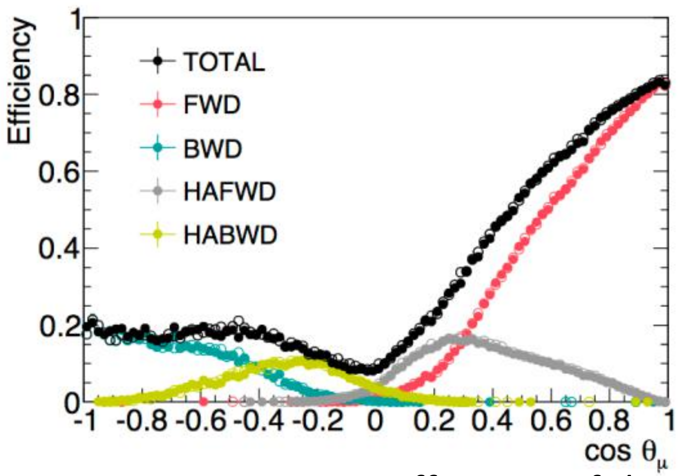
- ND280 - acceptance for tracks in forward direction, SuperK - 4π acceptance





Reconstructed momentum and angle for μ selected at ND280 and e- selected at SK

Different acceptances contribute to systematic uncertainty



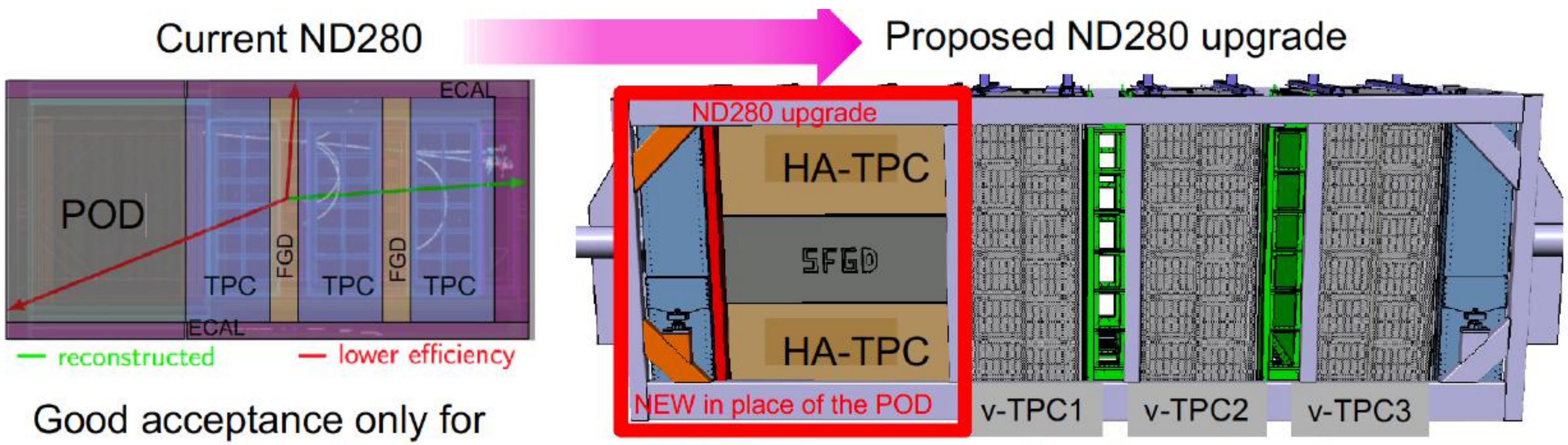
Reconstruction efficiency of the muon track

- Momentum threshold for protons 450 MeV/c (100 MeV kinetic energy) - neutrino interaction model dependence
- Larger systematic uncertainties due to tracks not measured by TPCs and bad track timing

Need for an Upgrade

ND280 Upgrade

- Important to measure neutrino interactions in all phase space
- Reduce detection threshold, measure protons with low threshold
- Reduce background, obtain better track identification using TOF
- Provide electron/gamma separation
- Measure neutrons in anti-ν_u interactions



Good acceptance only for forward tracks

+ 6 TOF planes surrounding the new tracker

Redesign of upstream part of detector

Project timeline:

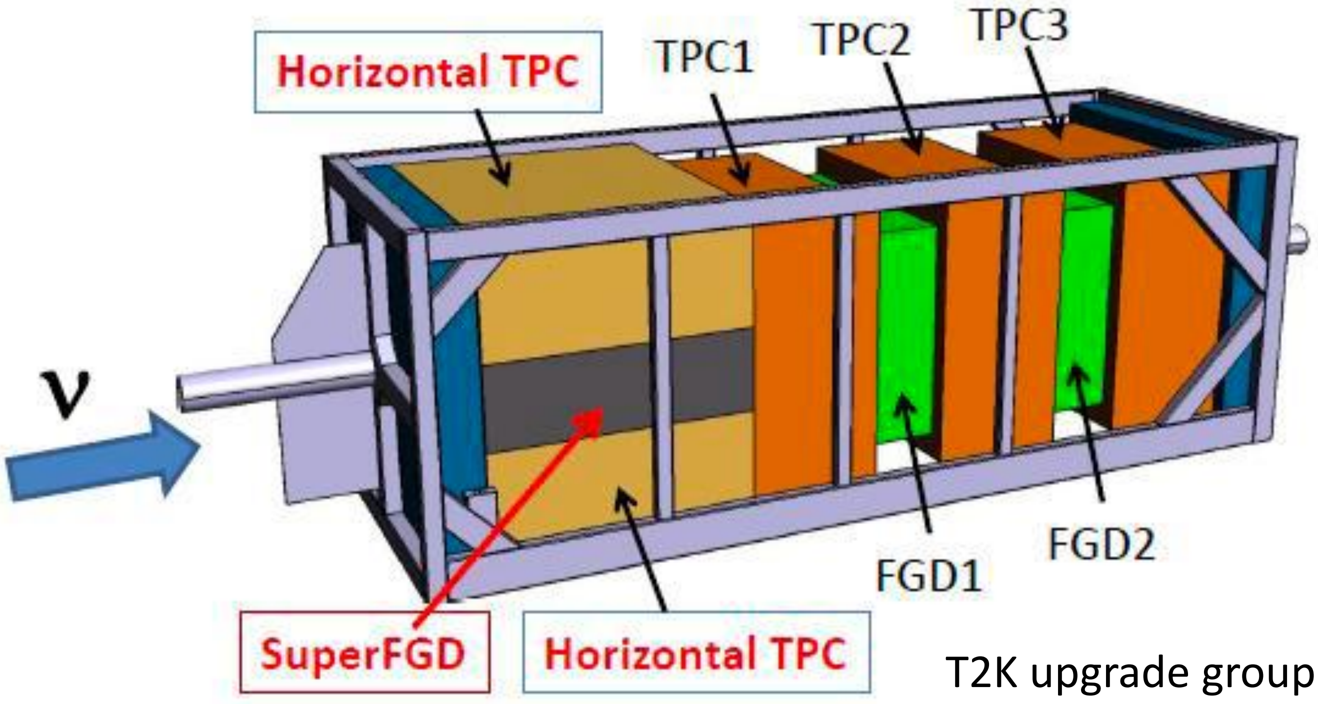
- Design and construction 2017-2021
- First data taking expected 2022

ND280 upgrade

arXiv:1901.03750

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

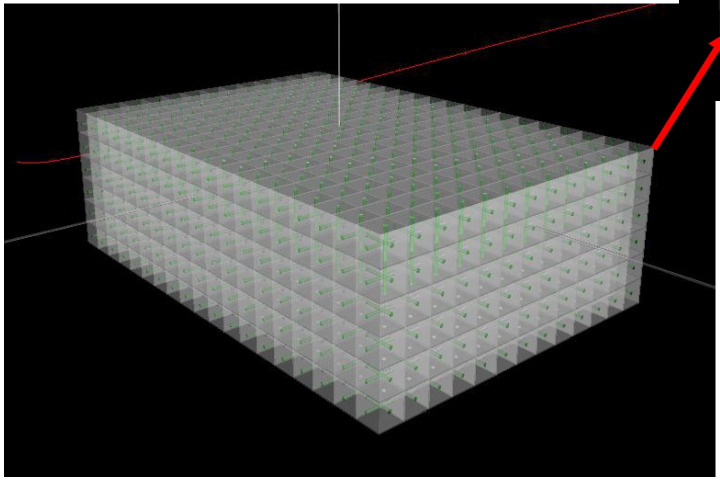
- Fully active detector
- Detection of low energy protons and pions
- Electron/gamma separation
- Electron neutrino studies
- Detection of neutrons

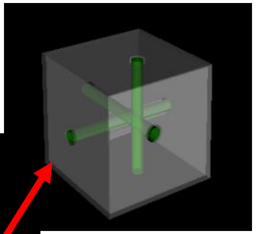


T2K upgrade group: ~ 90 participants from 10 countries

SuperFGD

- Novel design of a 3D fine grained scintillator detector
- Each cube (1 x 1 x 1 cm^3) has orthogonal 3 holes, diameter 1.5 mm
- 3D (x,y,z) WLS fiber readout, diameter 1.0 mm
- Volume ~200 x 200 x 60 cm^3
- **Highly Granular, ~2 x 10^6** scintillator cubes
- About 60000 readout WLS/MPPC channels
- Total active weight ~2 tons





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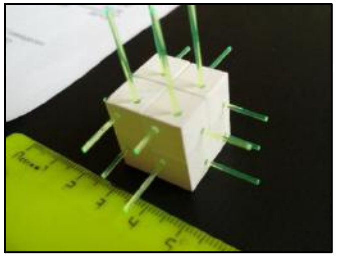
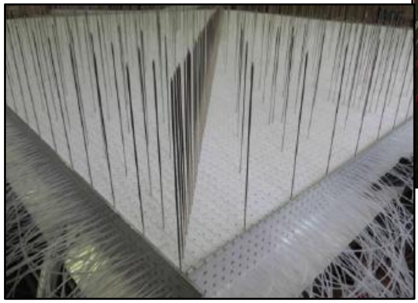
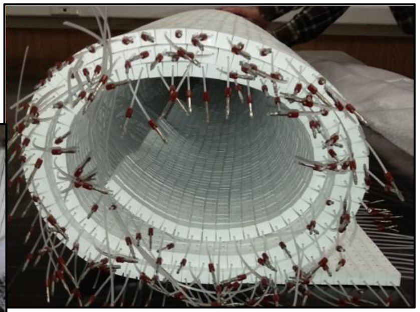


- Cubes produced by injection molding
- Covered by chemical reflector (50-80 **μ**m)





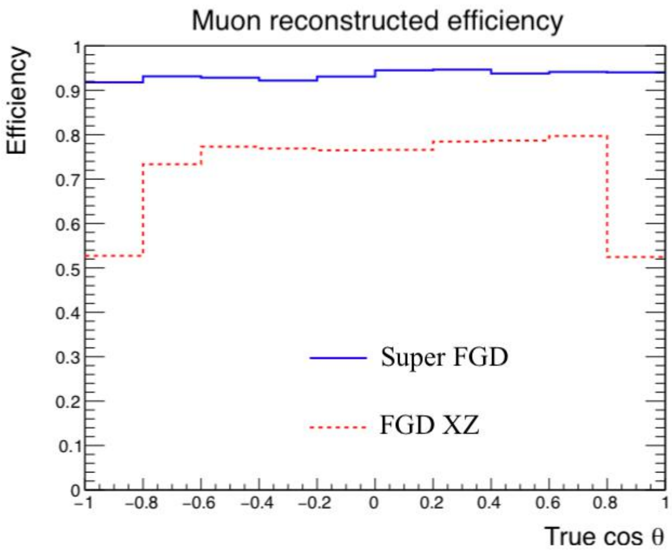
Swiss roll made of a plane of cubes

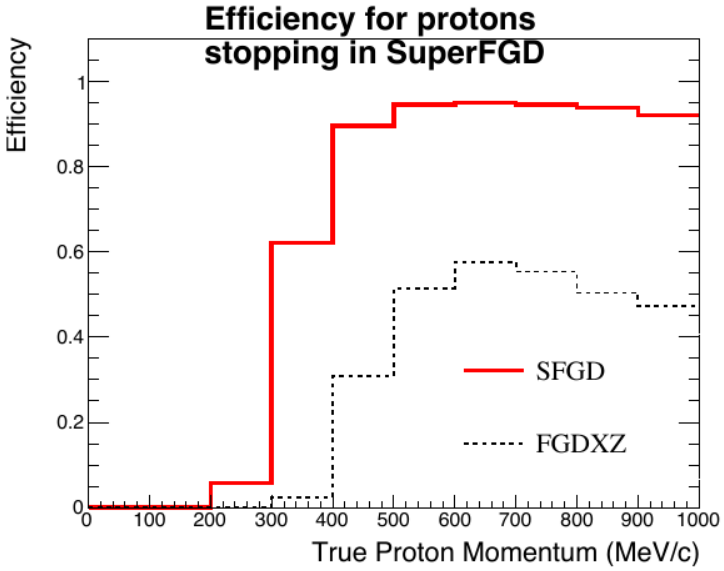
Extended Phase Space

Optimal design defined from simulations : SuperFGD 3D view is key

arXiv:1707.01785

- High reconstruction efficiency for whole angular range (~90% for muons)
- Lower detection thresholds for protons (~ 300 MeV from current 450 MeV)





- Possible to improve the reconstruction of the neutrino energy by measuring low energy protons and pions

Beam tests at CERN

Charged particle beam test at CERN : muons, pions, protons, positrons, electrons 0.5 – 5.0 GeV

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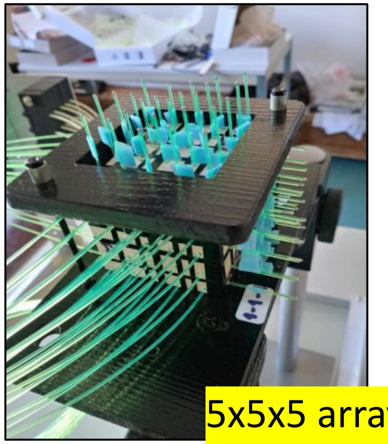
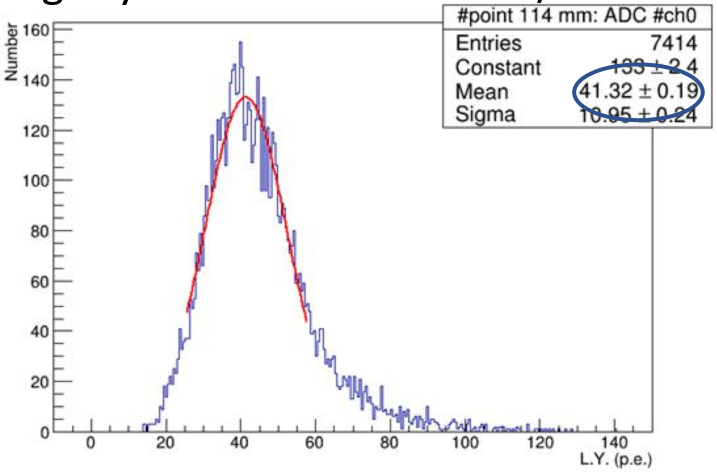


5x5x5 array with 75 fibers

Small prototype (2017)

- **5 cm x 5cm x 5cm -** 125 cubes
- **75** readout channels WLS fibers + MPPC's

Light yield of a MIP: 1 cube/1 fiber

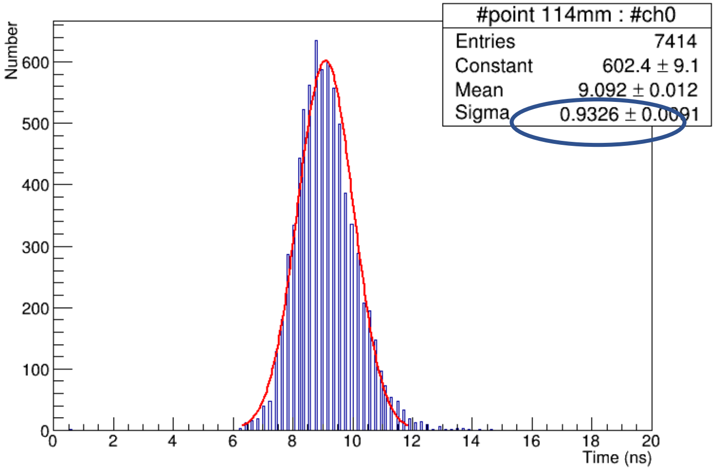


Measurements of :

- Light yield: ~ **40 pe/fiber**
- Timing res. : σ_t ~ **0.9 ns/fiber** and **0.7 ns/2** fibers
- Cube to cube light propagation (<4%)

Large light yield : Unambiguous proton identification, Low hit threshold

Detection of neutrons (see G. Yang's talk later)



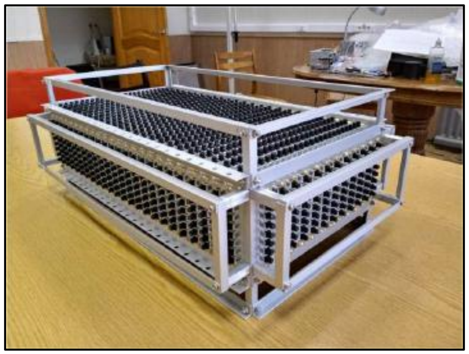
Time resolution of a MIP: 1 cube/1 fiber

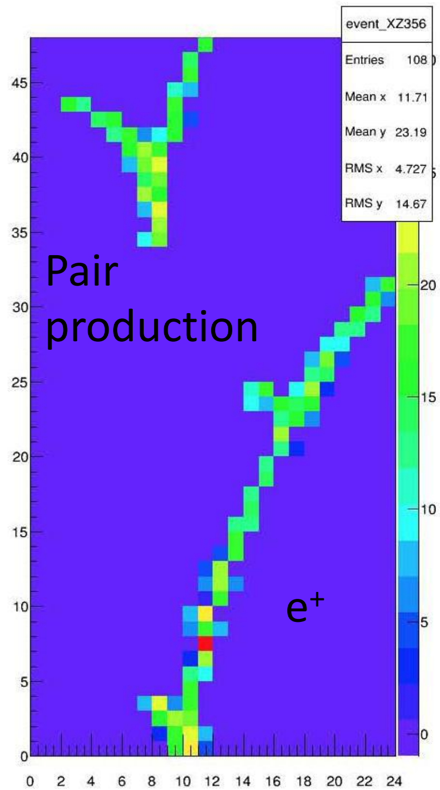
Beam tests at CERN

Charged particle beam test at CERN : muons, pions, protons, positrons, electrons 0.5 – 5.0 GeV

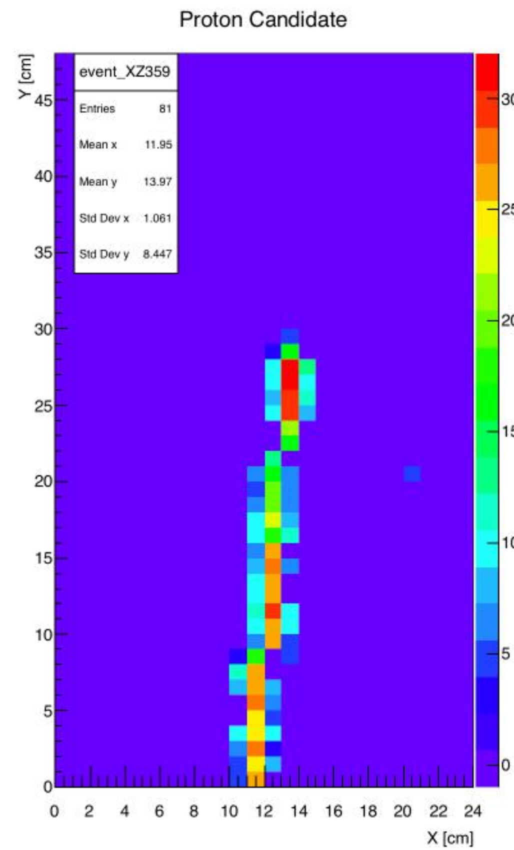
Large prototype (2018)

- **48 cm x 24 cm x 8 cm** - 9216 cubes, **1728** readout channels WLS fibers + MPPC's
- Inside a magnet (0.2 T) - Tracking capability, analysis is ongoing



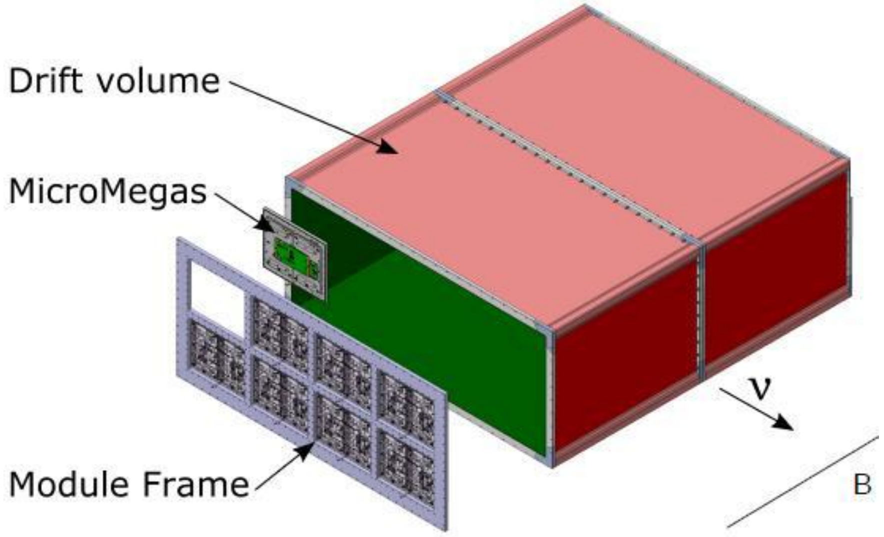


Positron, 1 GeV, B = 0.2 T



Stopped proton

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

Readout -> Micromegas (MM) detector

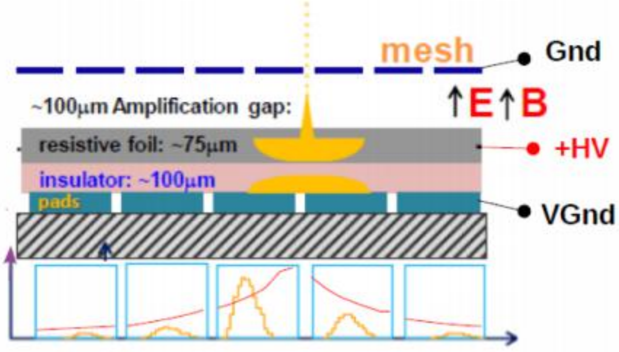
new "resistive bulk" technique

→ charge sharing: lower pad density

→ no sparks: no need of protecting diodes at FE input

Field Cage : thin, light-weight and low Z walls

→ minimize dead space + maximize tracking volume

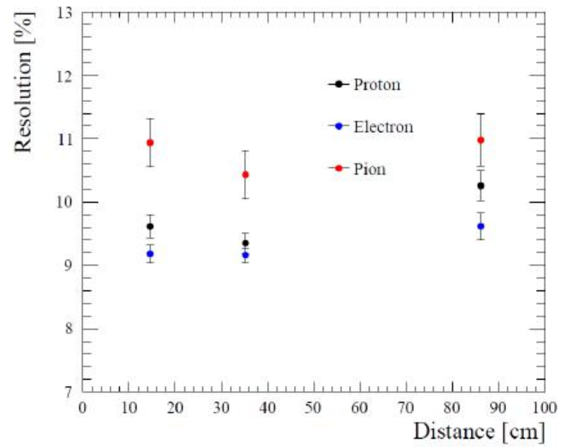


Resistive micromegas

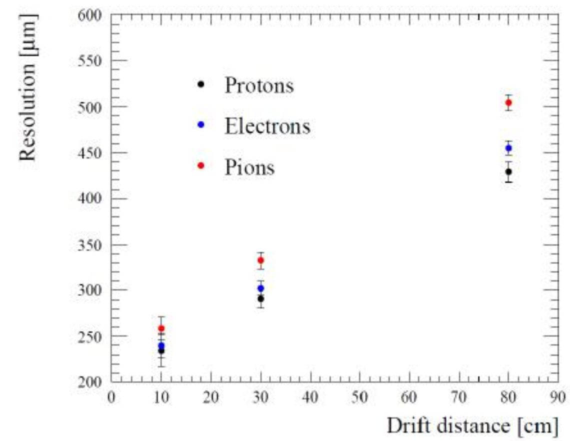
Test of HATPC

Beam test at CERN in Aug. - Sept., 2018 with muons, pions, electrons, protons
Momentum: 0.5, 0.8, 1, 2 GeV/c

arXiv:1907.07060



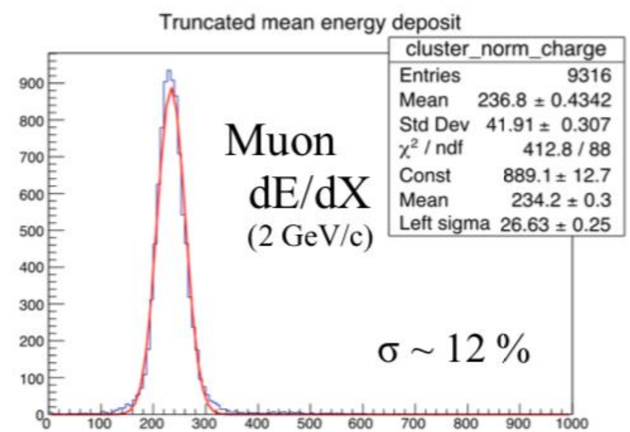
dE/dx resolution



Spatial resolution

Excellent results with Resistive type bulk RMM :

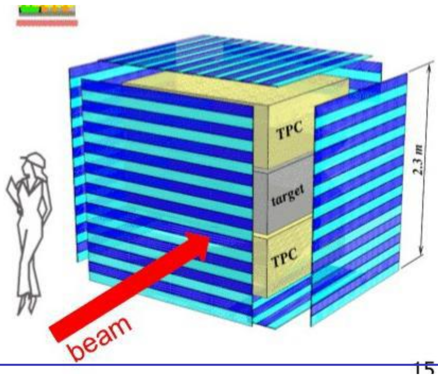
- about 10% dE/dx resolution
- 300 μm spatial resolution –> x2 better wrt bulk MM
- stable working conditions -> no sparks



TOF system

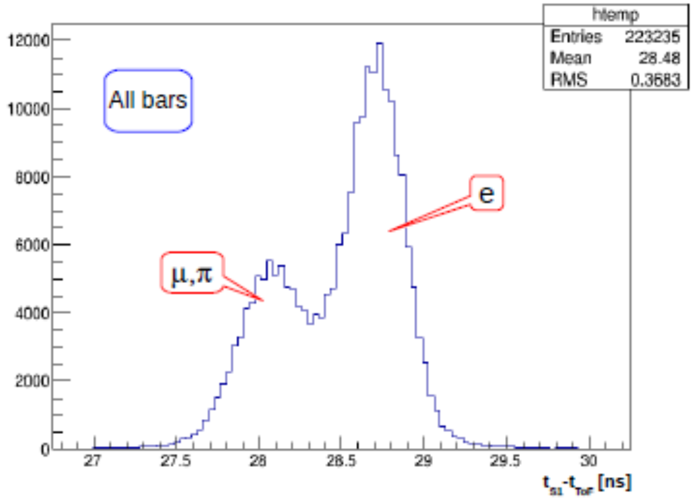
Time-of-Flight detector surrounds the new tracker (SuperFGD + Horizontal TPCs)

- Better rejection of incoming background
- Charged track direction unambiguously determined (in combination with the SuperFGD)
- Improved PID capabilities



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

P = 0.8 GeV/c, L = 10 m

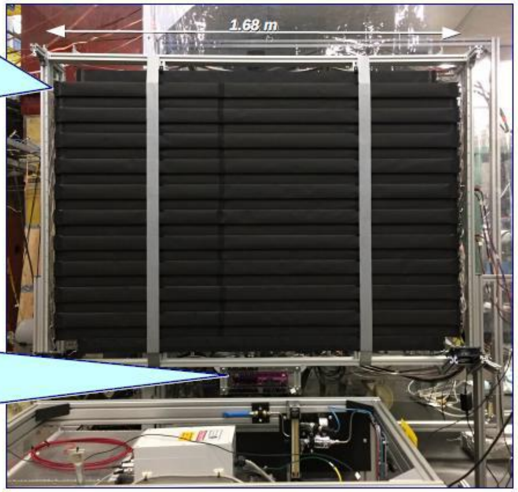


Achieved time resolution ~ 70 ps

Readout by SiPM-arrays

64ch SAMPIC module

Testbeam Aug 15 – Sep 19, East hall T10 of CERN PS



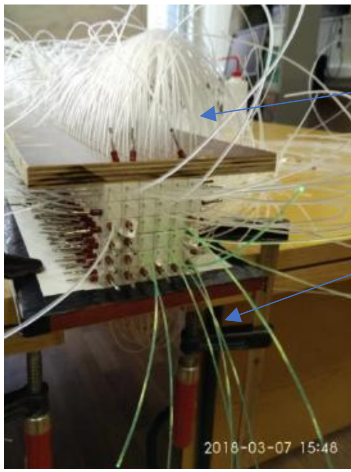
Summary

- Since 2009 the ND280 detector have performed very well. However the current design configuration has limitations.
- Better understanding of neutrino interactions and reduction of systematics are needed to fully exploit T2K-II
- Upgrade of the T2K near detector ND280 is in progress
  - Approved by CERN as the Neutrino Platform NP07 project
- Beam tests at CERN - good performance of TPC and SuperFGD
- TOF Innovative technology works well
- Further tests planned (e.g. LANL, DESY) in 2019
- Production of all detector components: 2019-2020
- Assembly, installation and commissioning at J-PARC - 2021

Assembly procedure

Baseline method:

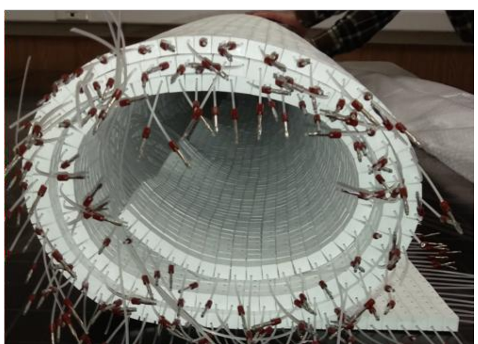
1. assembly of planes and whole detector using fishing lines
2. replacement of fishing lines by WLS fibers



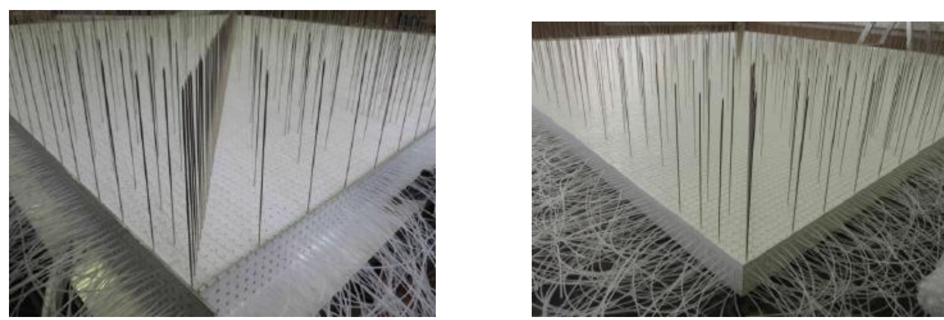
Fishing lines

Y11 WLS fibers

SuperFGD plane under assembly



Swiss roll made of a plane of cubes



Four planes assembled with fishing lines and stainless steel needles

Parameters of cubes

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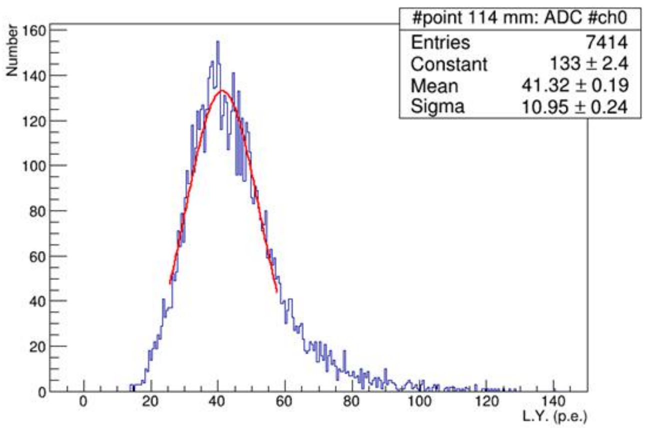
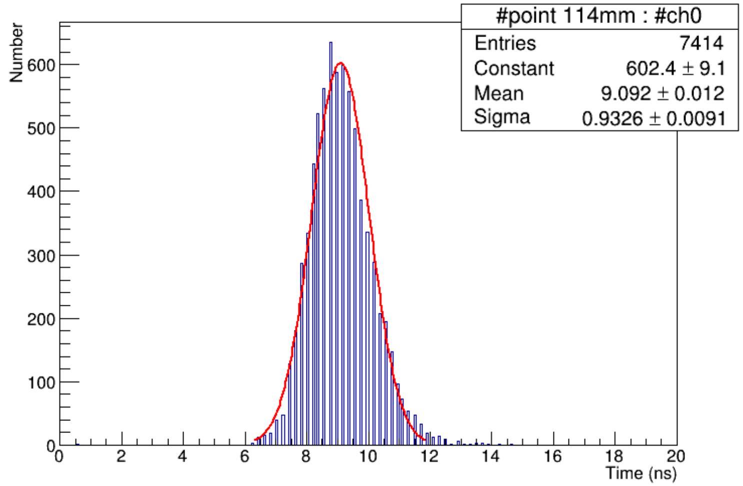
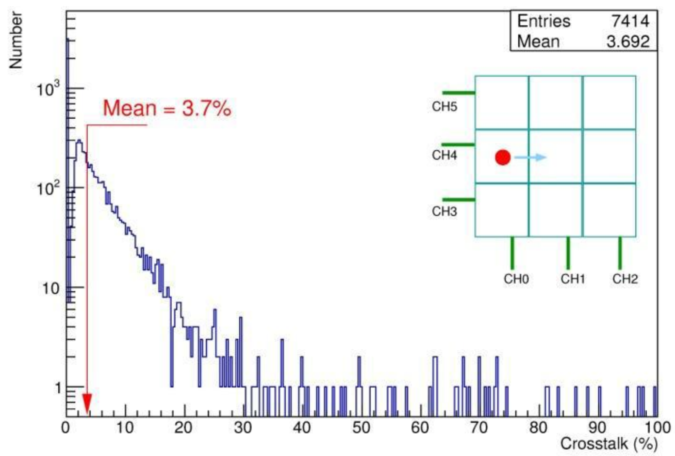
Light yield of a MIP: 1 cube/1 fiber



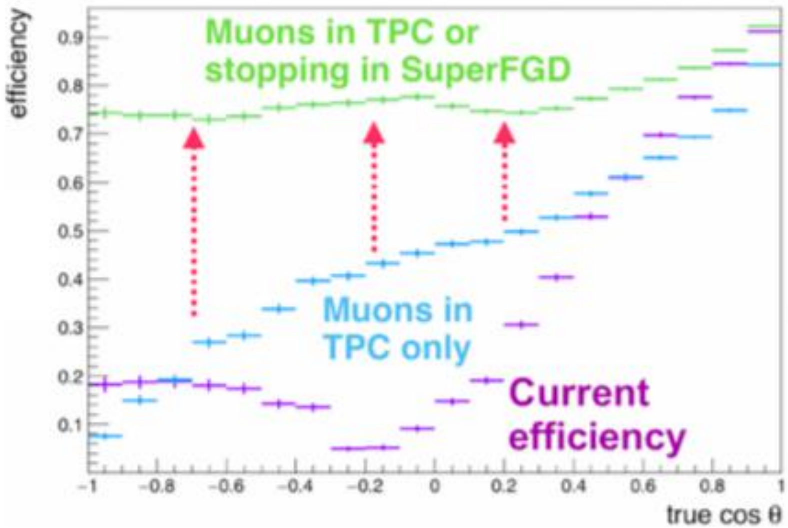
Time resolution of a MIP: 1 cube/1 fiber



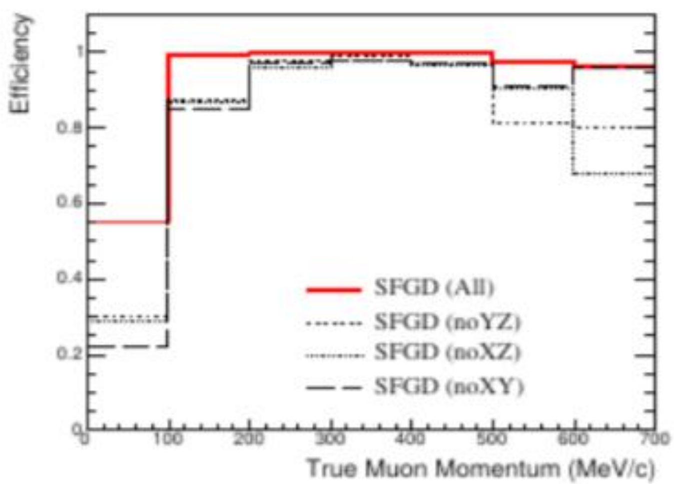
Cross talk about 4 %

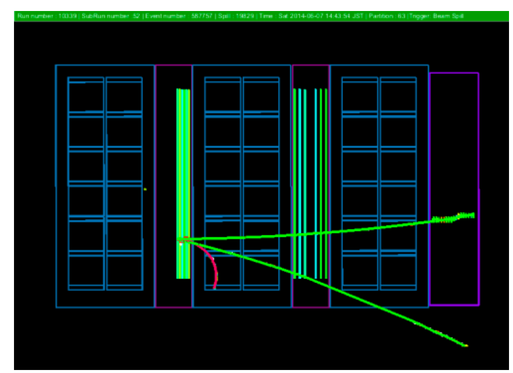


Light yield of 1 cube/1 fiber ~**40 p.e./MIP**
Light yield of 1 cube/2 fibers ~**80 p.e./MIP**
Time resolution **(σ)**
1 fiber: **0.92 ns**
1 cube/2 fibers: **0.68 ns**
2 cubes/4 fibers: **0.48 ns**
3 cubes/6 fibers: **0.39 ns**



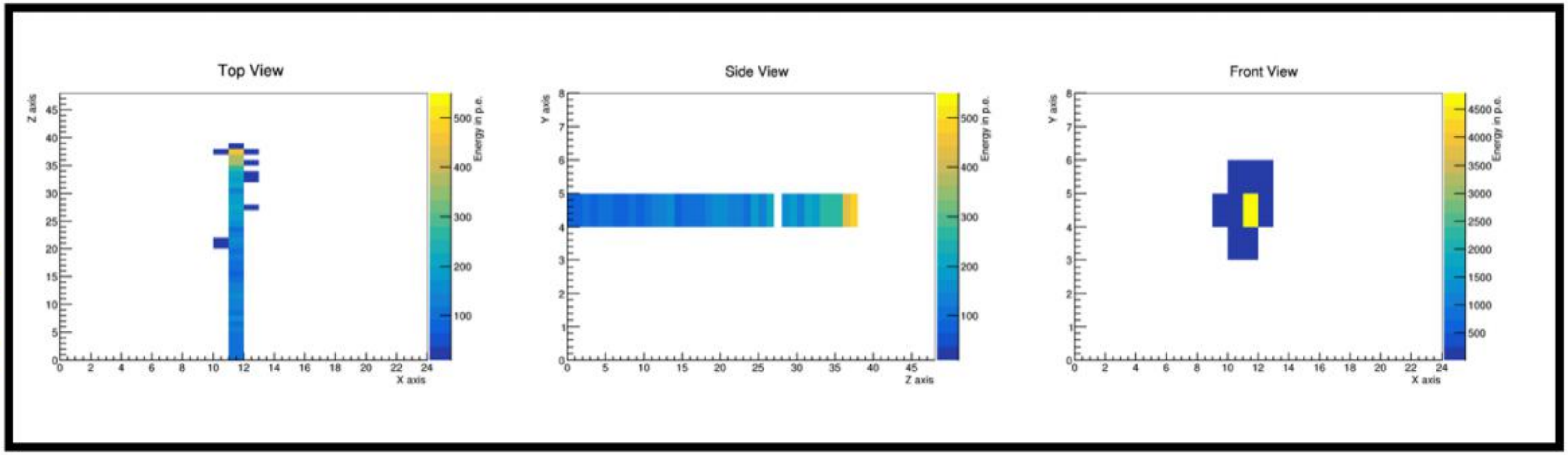
Parameter	Current ND280 (%)	Upgrade ND280 (%)
SK flux normalisation	3.1	2.4
$(0.6 < E_\nu < 0.7$ GeV)		
MA_{QE} (GeV/c^2)	2.6	1.8
ν_μ 2p2h normalisation	9.5	5.9
2p2h shape on Carbon	15.6	9.4
MA_{RES} (GeV/c^2)	1.8	1.2
Final State Interaction (π absorption)	6.5	3.4



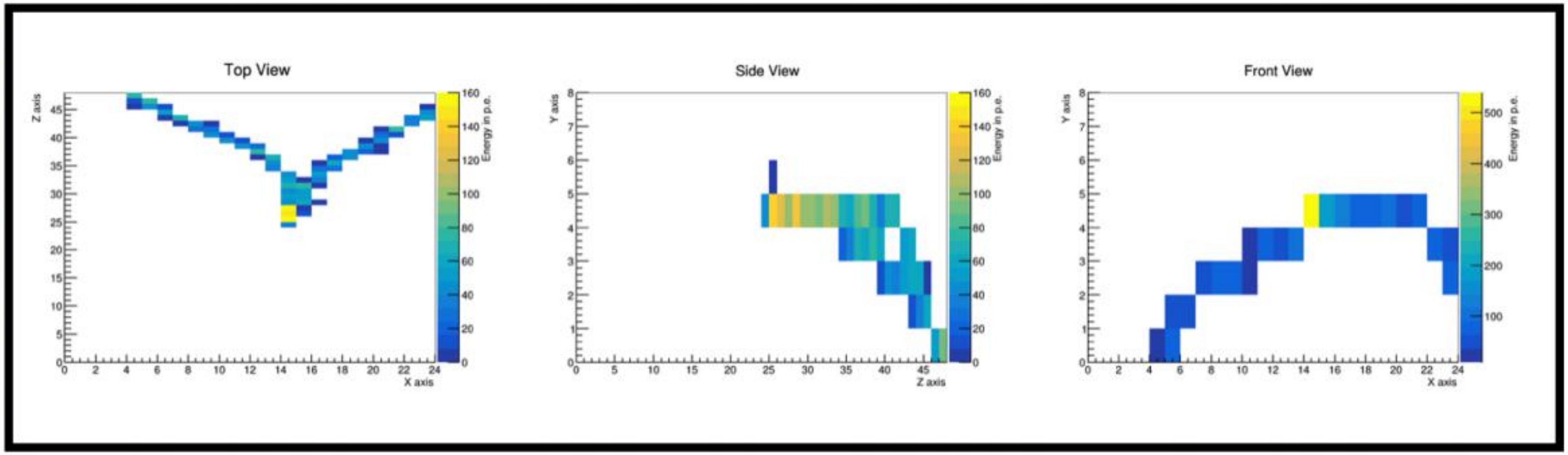


Beam Events

Stopped Proton

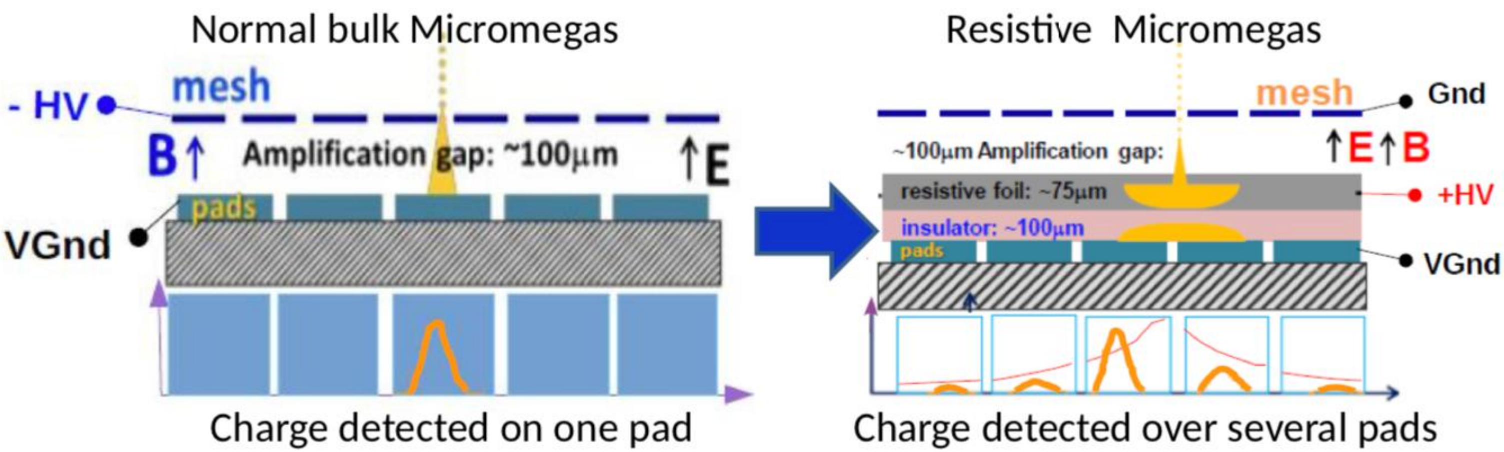


Photon conversion

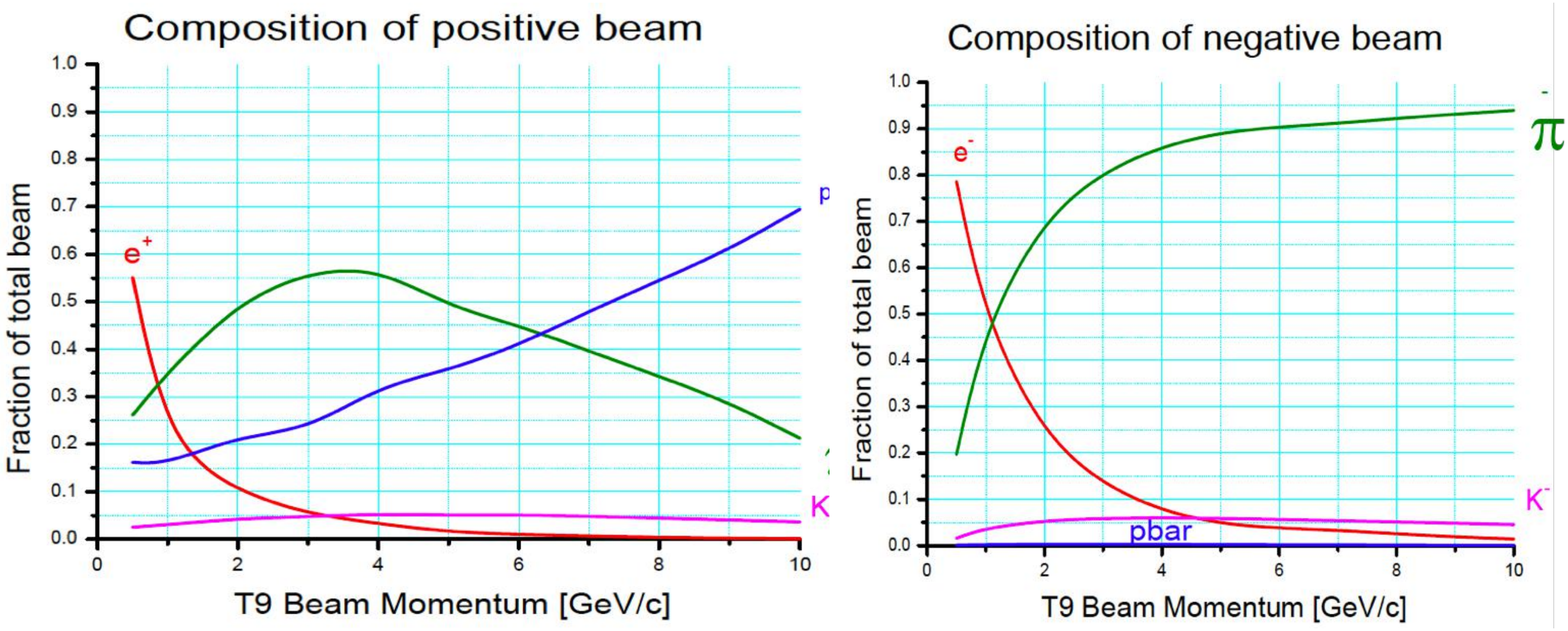


Resistive Micromegas

(Encapsulated resistive anode with grounded mesh)



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



Breakdown of the beam composition as a function of the momentum for hadron enriched beams at the T9 area at CERN.