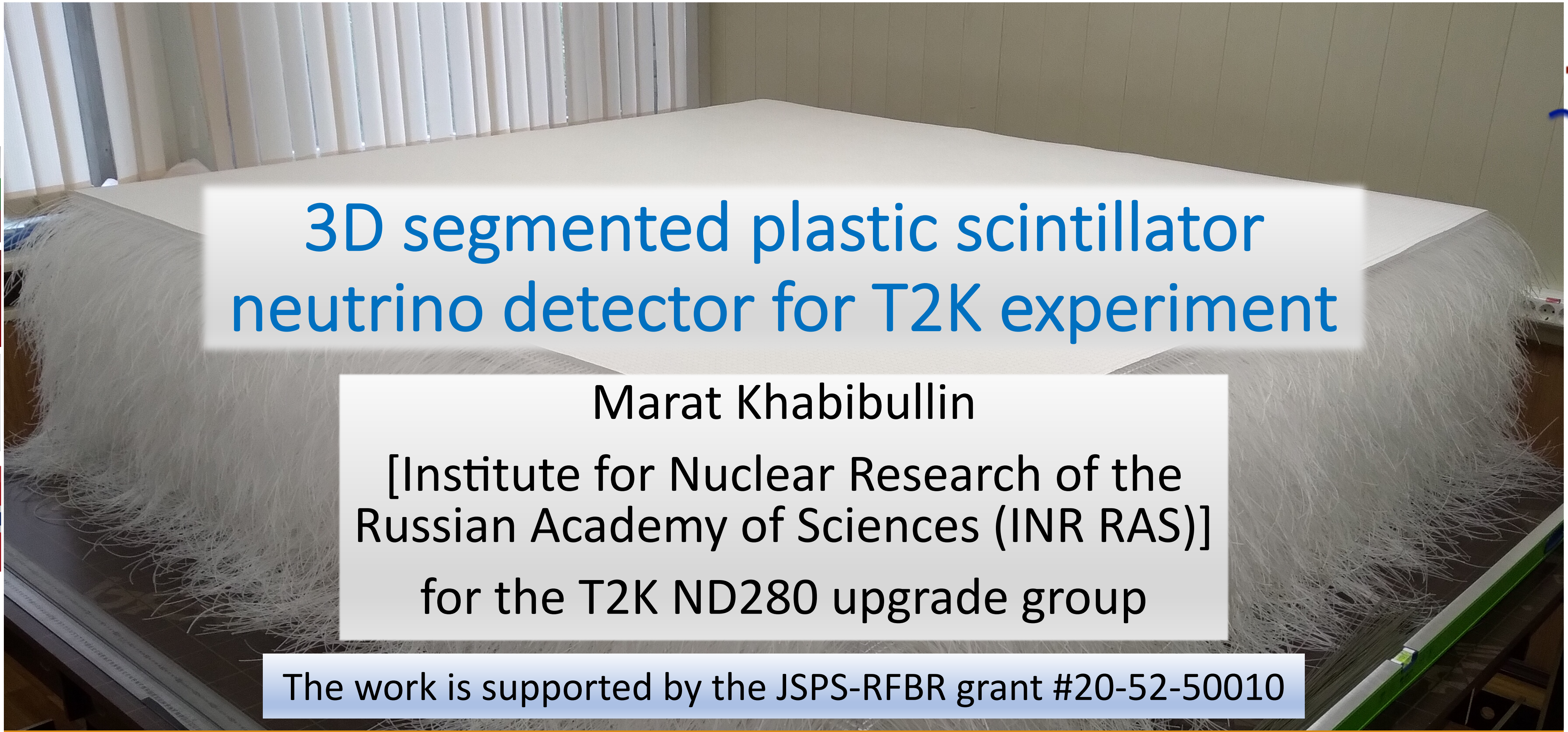


3D segmented plastic scintillator neutrino detector for T2K experiment

Marat Khabibullin

[Institute for Nuclear Research of the Russian Academy of Sciences (INR RAS)]

for the T2K ND280 upgrade group

The work is supported by the JSPS-RFBR grant #20-52-50010

XIX International Workshop on Neutrino Telescopes

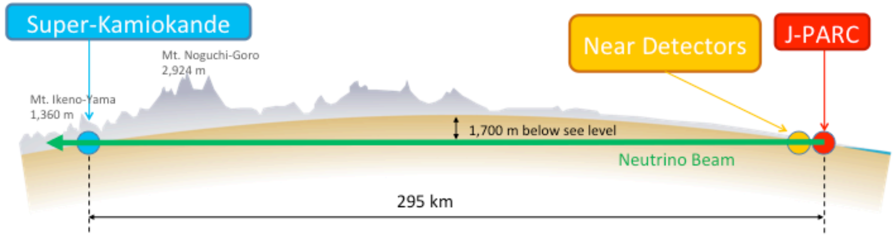
18-26 February 2021
Online

Joint Institute for Nuclear Research

CERN

T2K experiment

See Mathieu Guigue's talk today @ Plenary



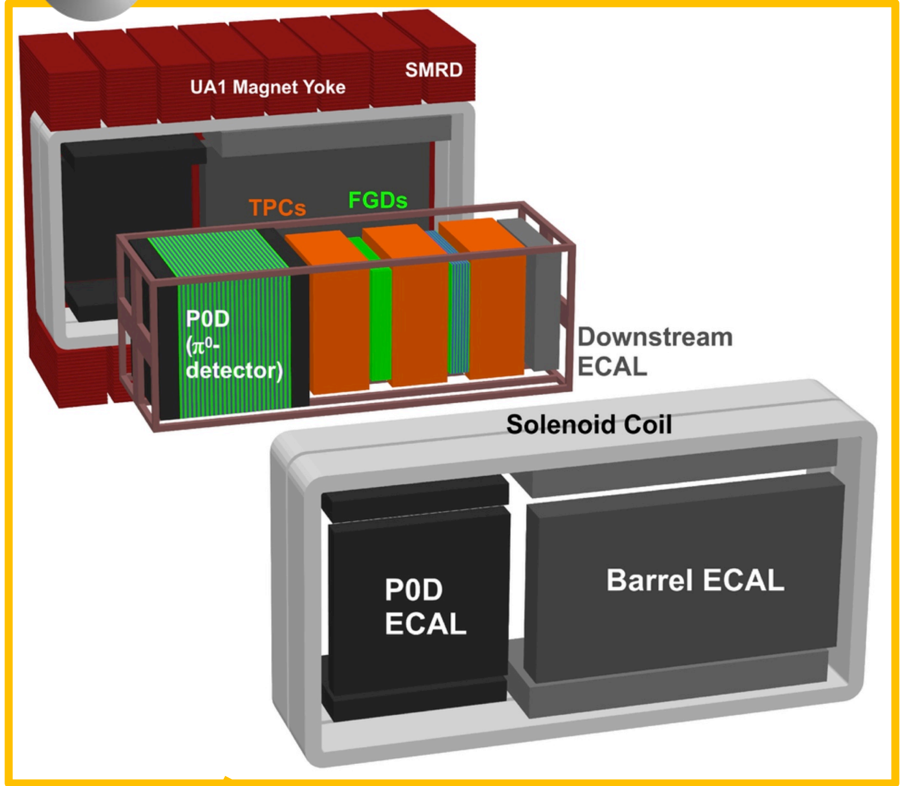
T2K is a long baseline accelerator neutrino experiment aiming to:

- Precise measurement of ν_μ and $\bar{\nu}_\mu$ *disappearance* → θ_{23} and Δm^2_{32}
- Observation of ν_e and $\bar{\nu}_e$ *appearance* → determine θ_{13} and δ_{CP}.

T2K will run until 2026 with higher beam intensity, so to improve a sensitivity to δ_{CP} we need to **reduce systematic uncertainties**

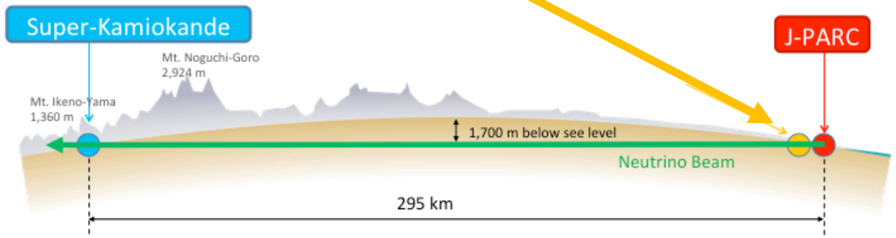
Neutrino source: J-PARC (Japan Proton Accelerator Research Complex)
Neutrino detectors: near (ND280 and INGRID) and far (Super-Kamiokande, or SK)

Near detector ND280 (current)



- **Current ND280** reduces the systematics in the predicted number of events at SK from 13-19% down to **5-14%** (for $\nu_e/\bar{\nu}_e$ *appearance*)
- However, some sources of systematics remain:
  - non-isotropic detection of leptons in ND280 (in contrast to SK) [see next slide]
  - high threshold of proton detection [see next slide]
  - neutrino cross-section models

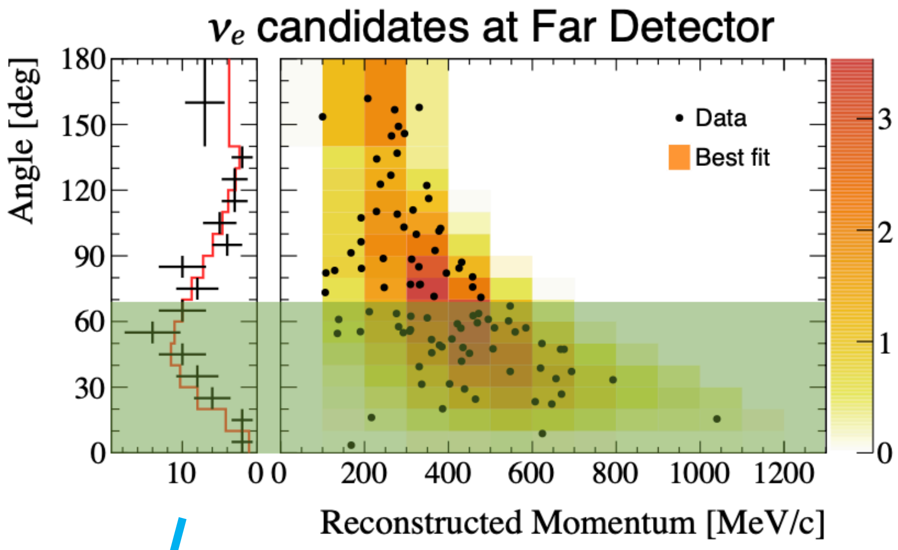
ND280: UA1 **Magnet** (0.2 T); **P0D**;
3 **TPC**s; 2 **FGD**s; **ECAL**; **SMRD**



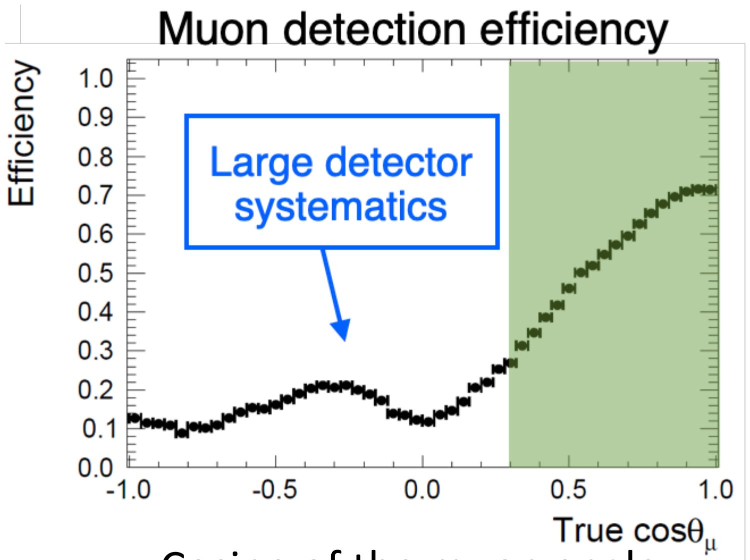
P0D = π^0-detector; **TPC** = Time Projection Chamber; **FGD** = Fine-Grained Detector; **ECAL** = E/m Calorimeter; **SMRD** = Side Muon Range Detector

Near detector ND280 (current): systematics

Leptons at SK almost isotropic
0-180 degrees wrt to the nu-beam

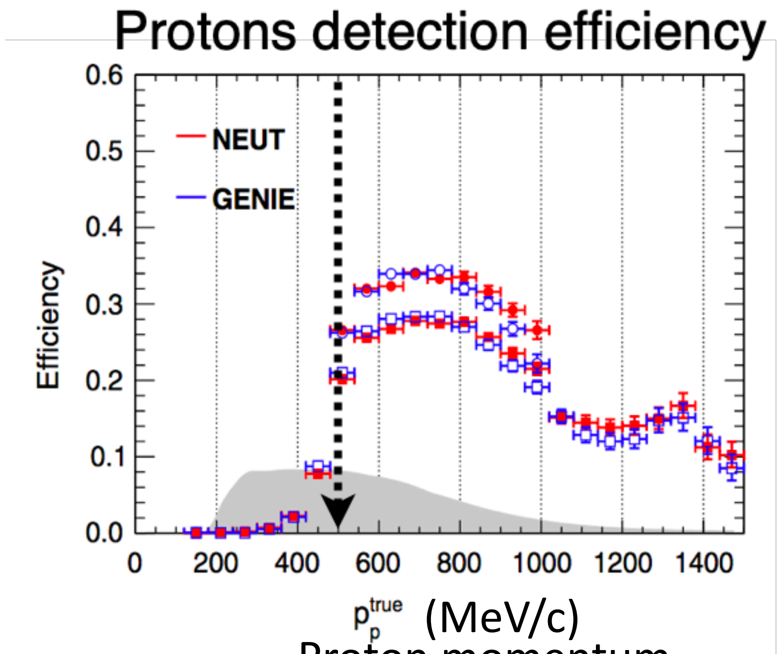


Leptons at ND280 mostly forward:
0-70 degrees wrt to the nu-beam

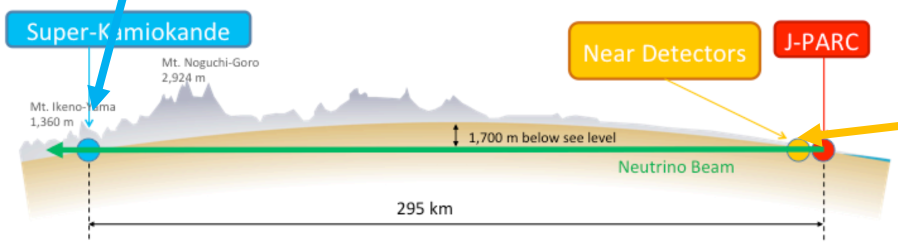


Cosine of the muon angle
wrt to the beam

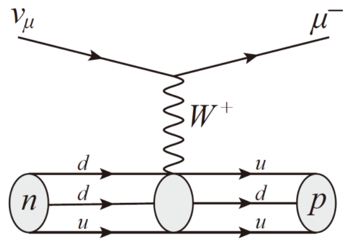
High threshold of proton detection

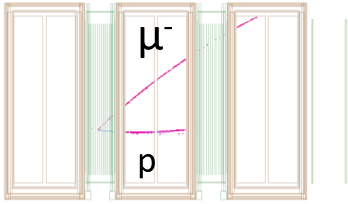


Proton momentum

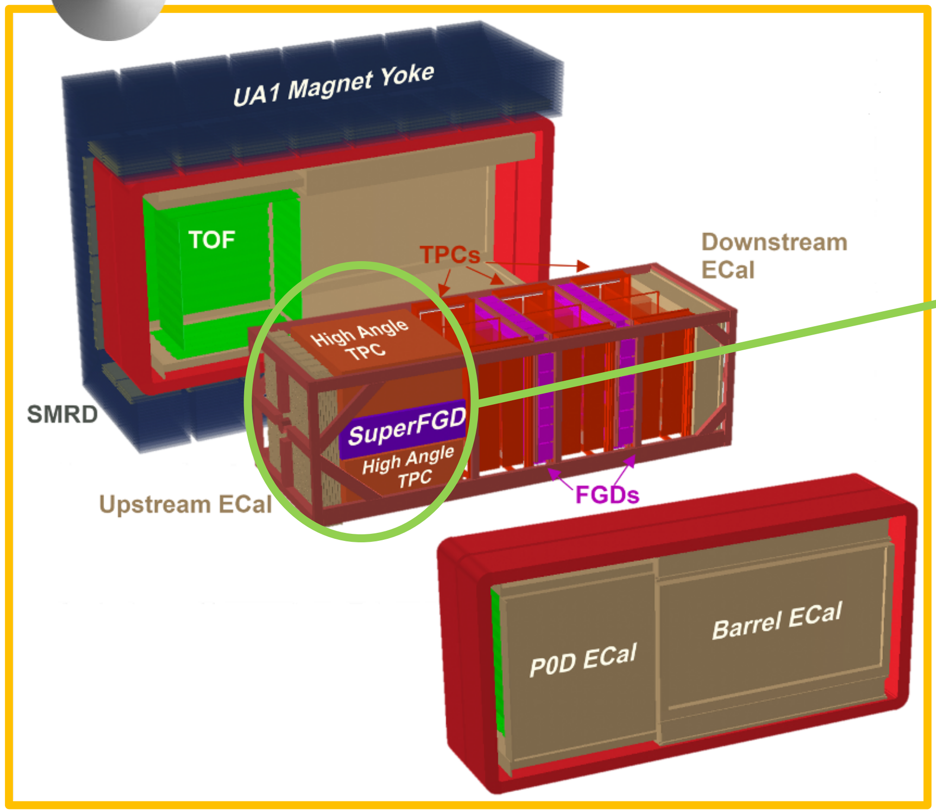


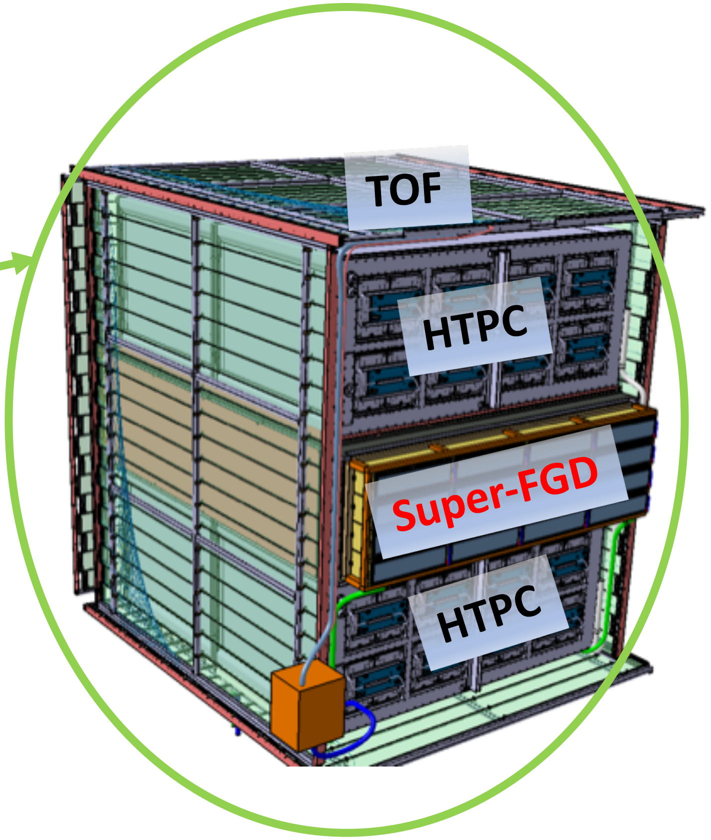
CCQE: $\nu_\mu + n \rightarrow \mu^- + p$





ND280 Upgrade (2022)

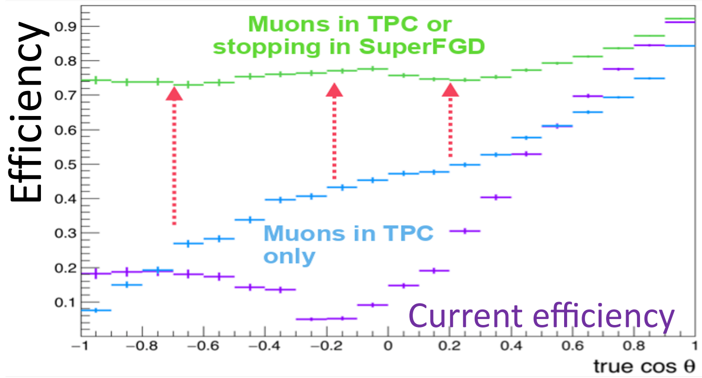




In the Upgraded ND280 the **P0D** is replaced :

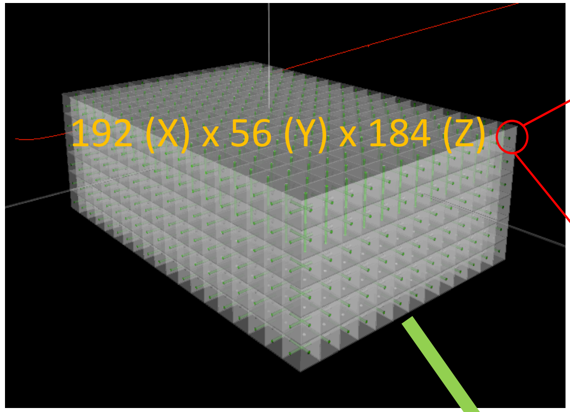
- by active 3D neutrino target (**Super-FGD**);
- two horizontal TPCs (**HTPC**)
- six time-of-flight panels (**TOF**)

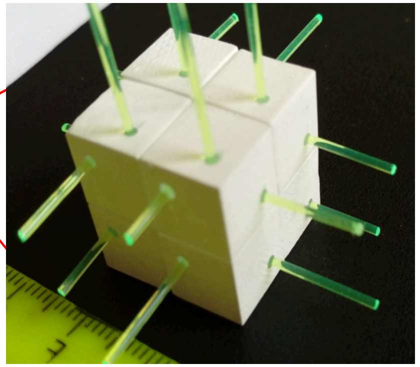
See Sergey Suvorov's talk on 25/Feb/2021

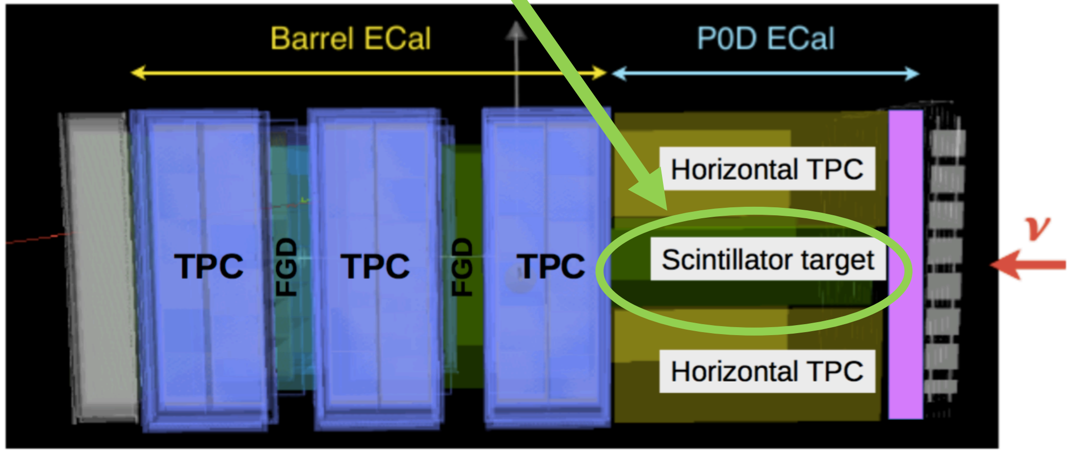


Goal: a) reduce systematics down to 3-4%;
b) 4π-acceptance for leptons from ν-interactions;
c) reduce proton detection threshold (to ~300 MeV/c);
d) neutron detection (for $\overline{\nu}$ detection).

Super Fine-Grained Detector (SFGD)





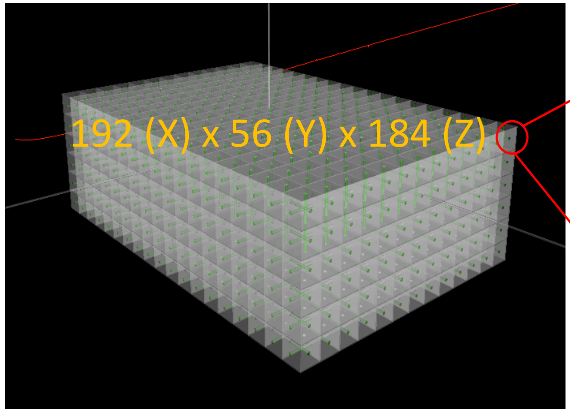


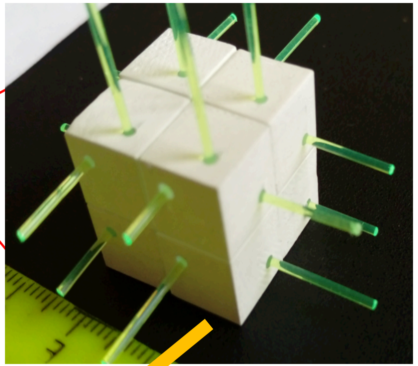
- **Active element**: scintillator **cube** 1 cm^3 with 3 orthogonal holes for WLS fibers
- **Full detector** (baseline design):

  184 (Z) x 192 (X) x 56 (Y) = **1,978,368** cubes
- **Weight** (cubes): **~2,000 kg**
- **WLS Fibers** (3 diff. lengths): **56,384** pcs
- **Light Readout**: **56,384** MPPCs
- **Electronics**: MPPC-PCBs and FEBs based on CITIROC
- **Calibration**: Light-Guide Plate (LGP) + LED
- **Mechanical box**: sandwich of CF and other materials

WLS = Wave-Length Shifting (fiber); **MPPC** = Multi-Pixel Photon Counter; **PCB** = Printed Circuit Board
CITIROC = Cherenkov Imaging Telescope Integrated Read Out Chip; **FEB** = Front-End Board; **CF** = Carbon Fiber

SuperFGD: cubes and readout





Active element: scintillator **cube** 1 cm^3 with 3 orthogonal holes for WLS fibers

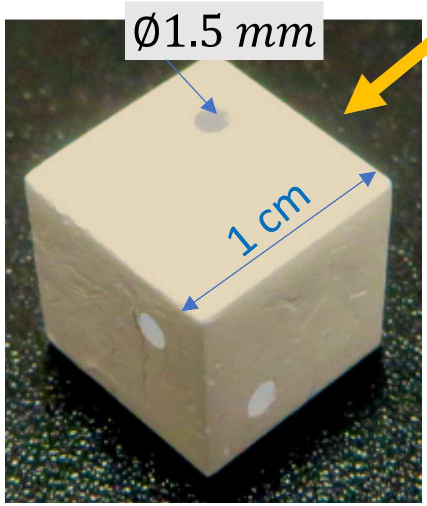
Cube material:

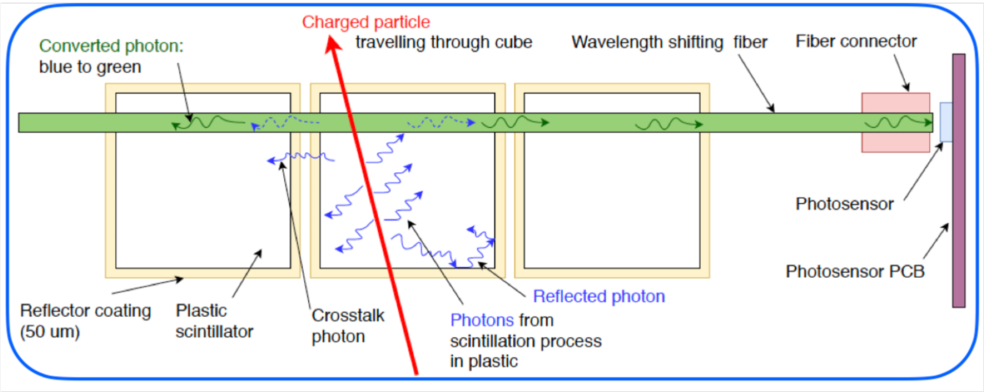
- polystyrene $[C_6H_5CHCH_2]_n$
- +1.5% of paratherphenyl (PTP)
- +0.01% of POPOP (1,4-bis benzene)

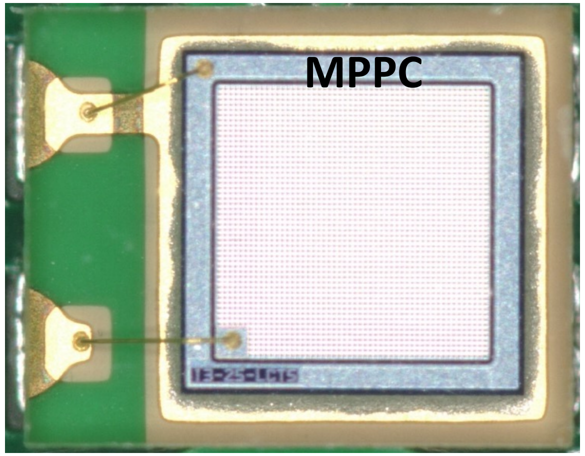
Chemical reflector (etching): ~50 μm

WLS fiber: Kuraray Y11, Ø1 mm, 2-clad

MPPC: Hamamatsu S13360-1325PE







Two sites of SuperFGD production in Russia *)

INR,
Troitsk, Moscow

- quality check
- layer assembly
- testing
- logistics
- financial support

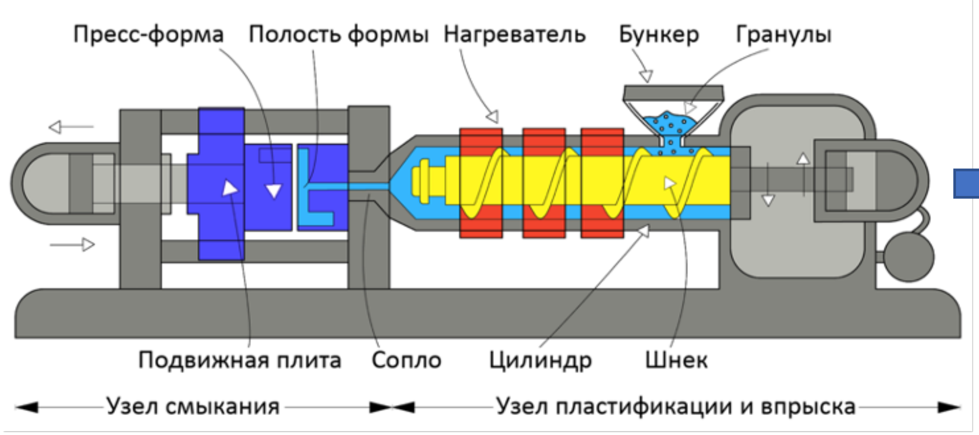
“**Uniplast**” factory,
Vladimir city
Cube production:

- injection molding
- etching
- hole drilling
- hole cleaning

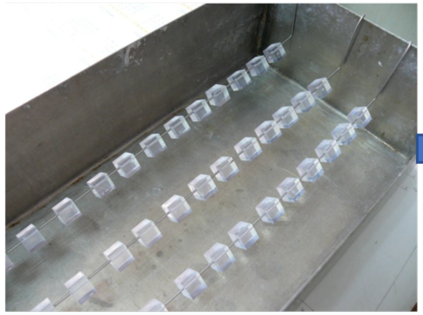
*) Part of the cubes were produced in collaboration with **Stony Brook University**, USA

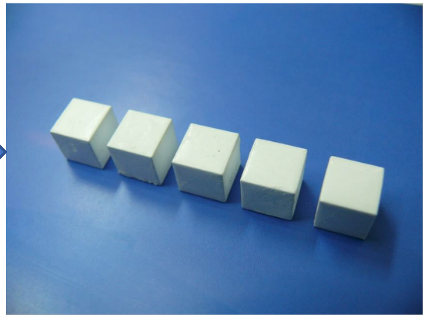
Uniplast Co. (Vladimir city): Cube production

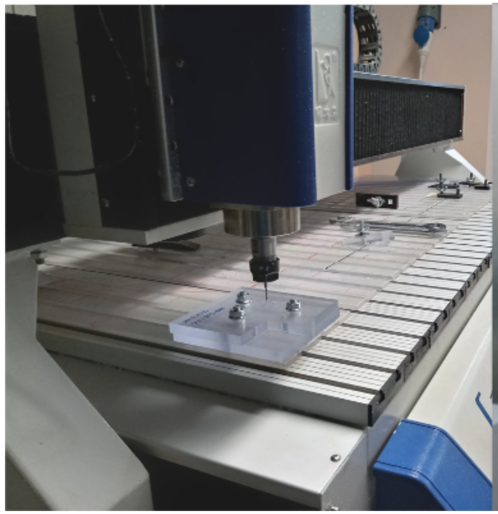
Injection molding



Chemical reflector

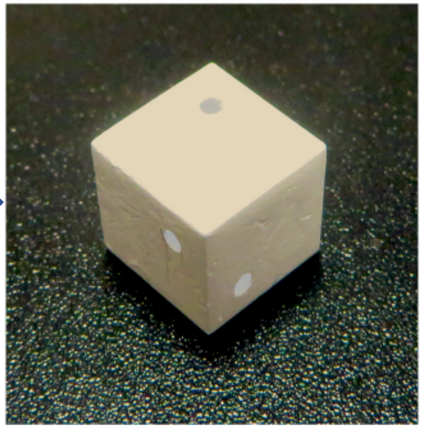






Hole drilling

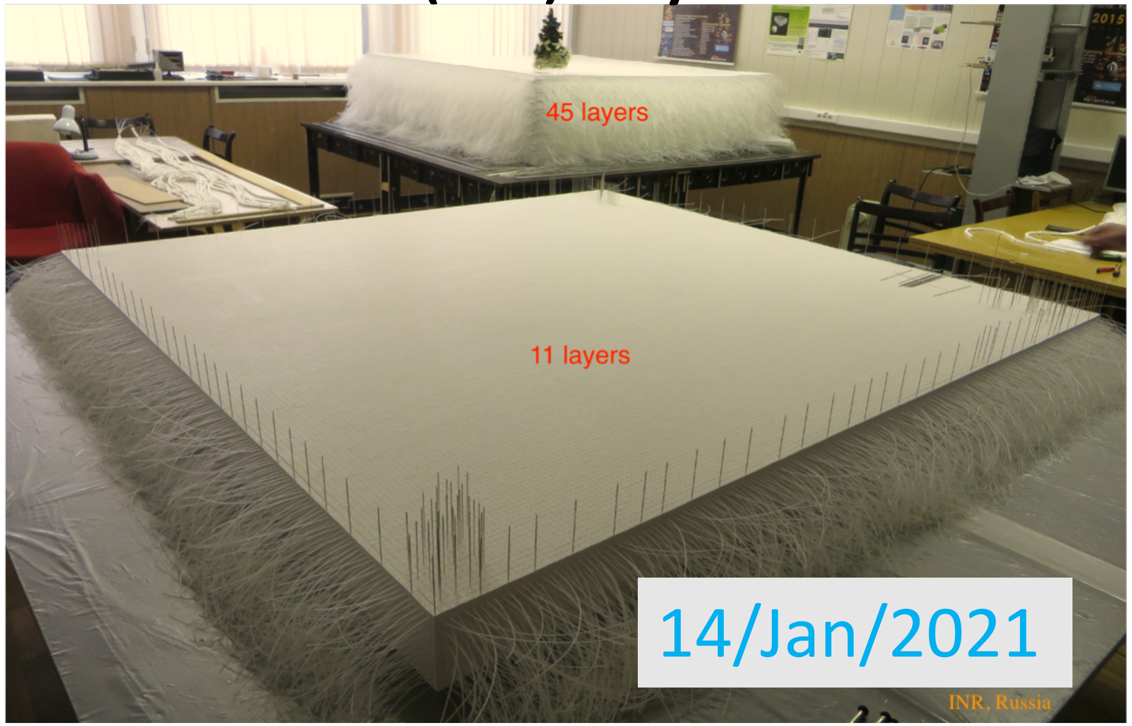
Hole cleaning



INR (Troitsk, Moscow): Layer assembly

First layers

All (56) layers



The cube layers are assembled with fishing lines (to be replaced by WLS fibers)

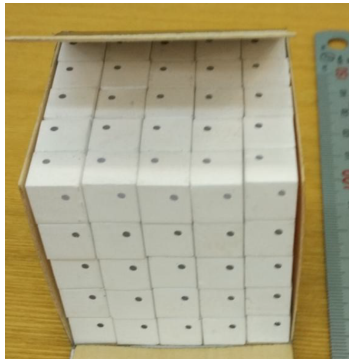
1 Layer = 184 x 192 cubes (baseline design)

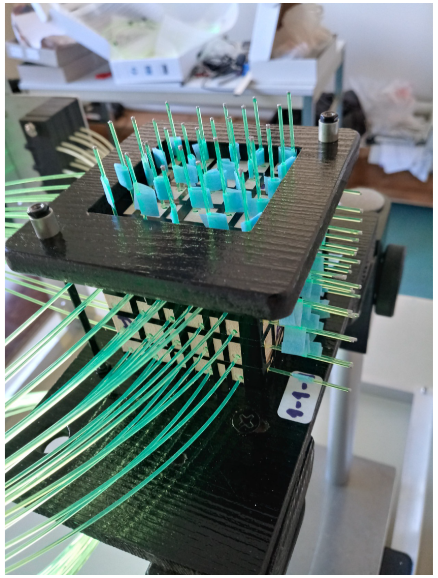
Status of the SuperFGD

- All 1-cm^3 cubes (~2 mln.) are produced and all layers are assembled with *fishing lines* (56 layers of 192 x 184 cubes)
- All other systems (mechanical box; read-out; electronics & cables; calibration; assembly platform) are in preparation
- Software and algorithms for reconstruction and DAQ are under development
- In order to check the performance of the SFGD several prototypes were produced and tested at CERN and LANL (see next slides)

Prototypes of the SuperFGD for tests

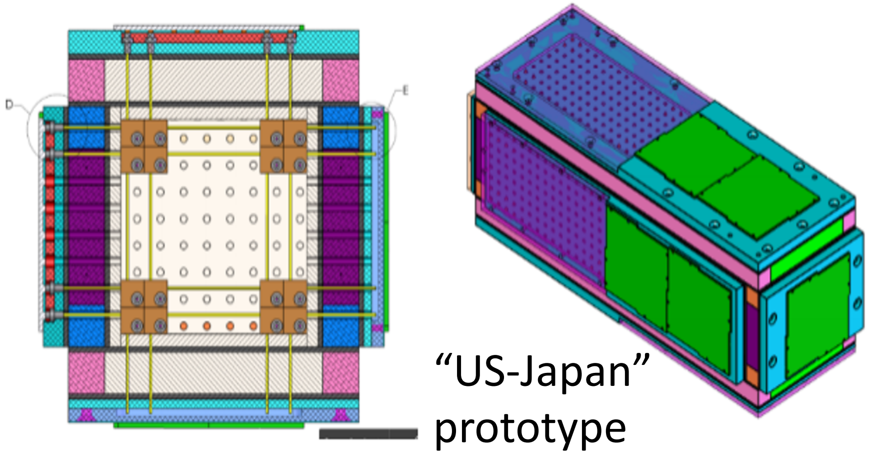
5 × 5 × 5
(125) cubes



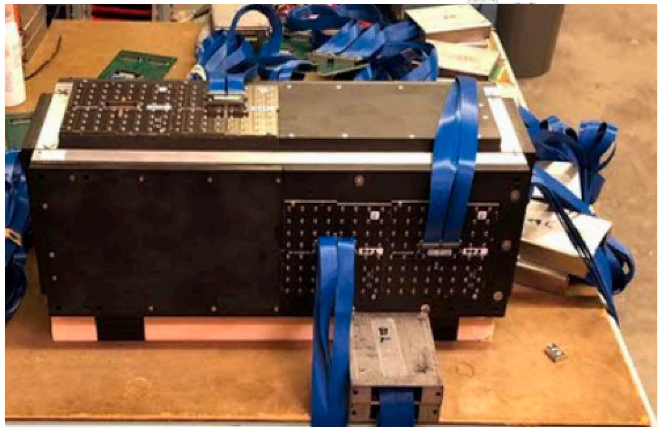


X × Y × Z
24 × 8 × 48
(9216) cubes

X × Y × Z
8 × 8 × 32
(2048) cubes



“US-Japan” prototype



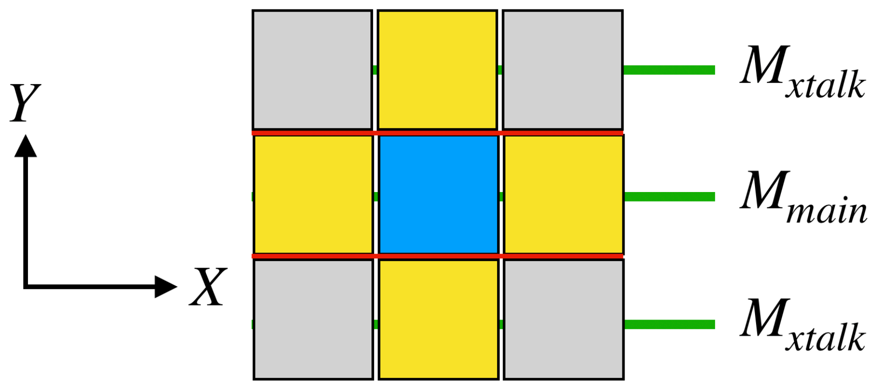
Beam tests: charged particles @ CERN PS

2017-2018: beam tests of the 5x5x5 and 24x8x48 prototypes at CERN PS/T9 with (0.4-8.0) GeV/c protons, muons (±), pions (±), electrons/positrons

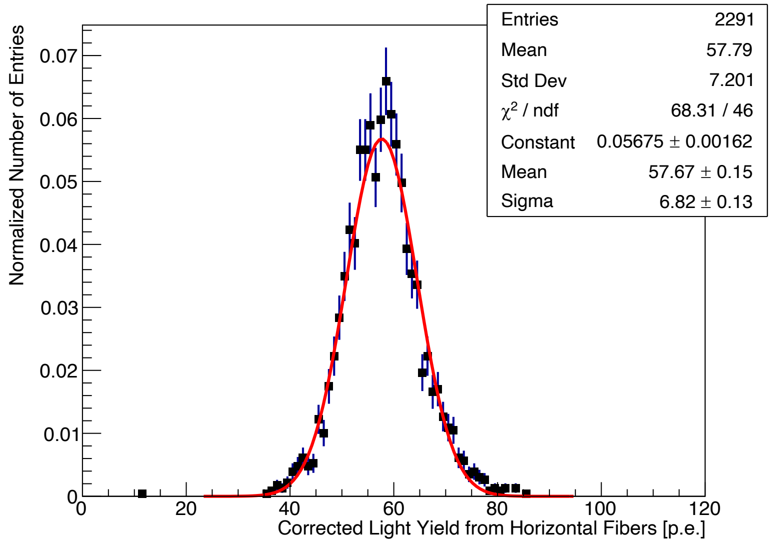
Nucl.Instrum.Meth. A923 (2019) 134-138
Nucl.Instrum.Meth. A936 (2019) 136-138

JINST (2020) 15 P12003

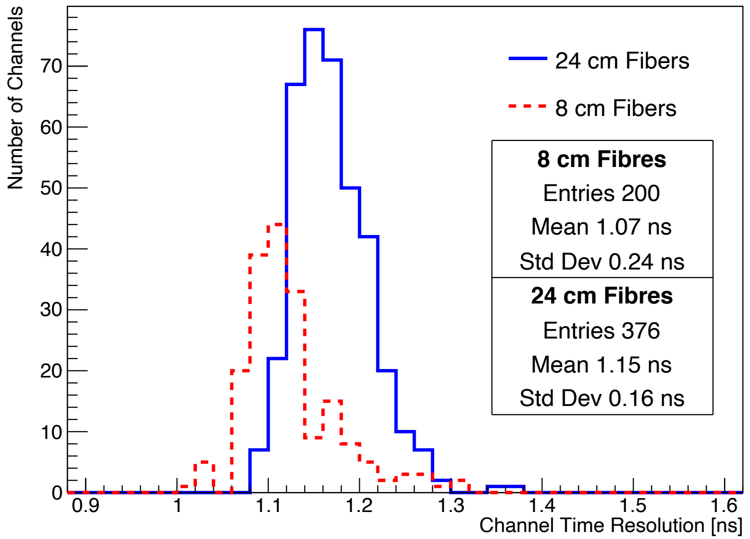
Optical crosstalk: ~3%



Light yield of one cube /MIP (corrected): **~58 p.e.**



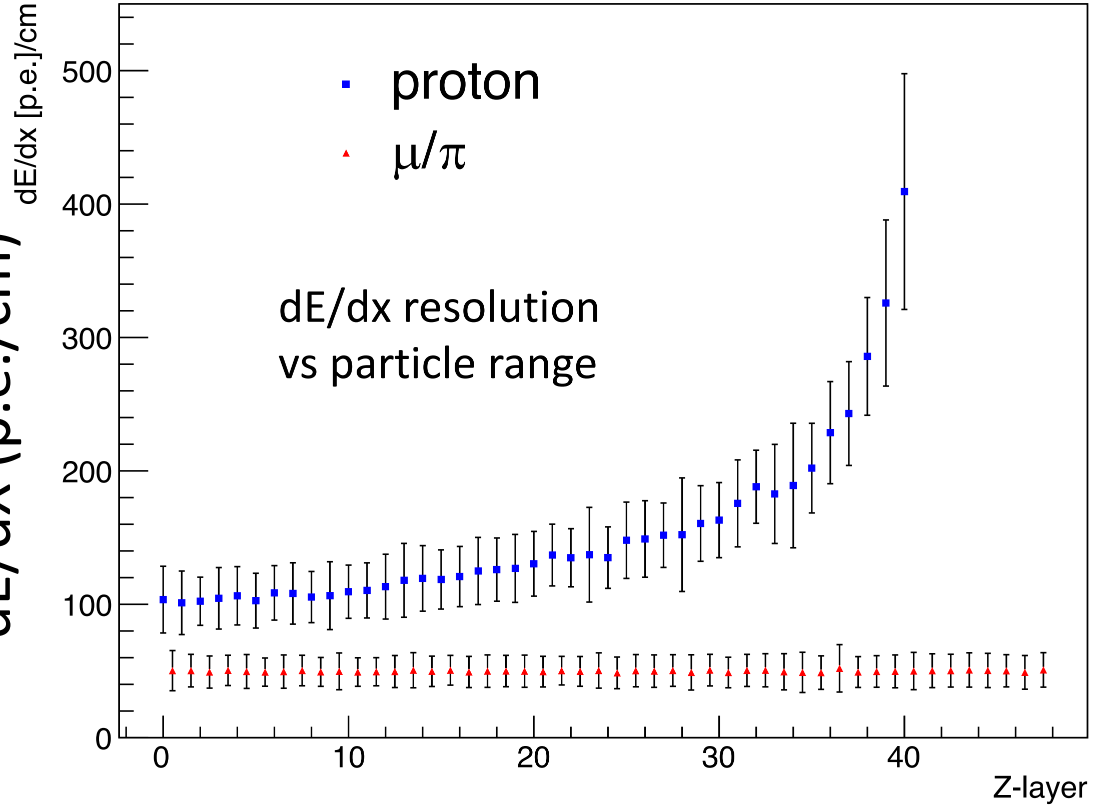
Time resolution: **~1.1 ns**



Beam tests: charged particles @ CERN PS

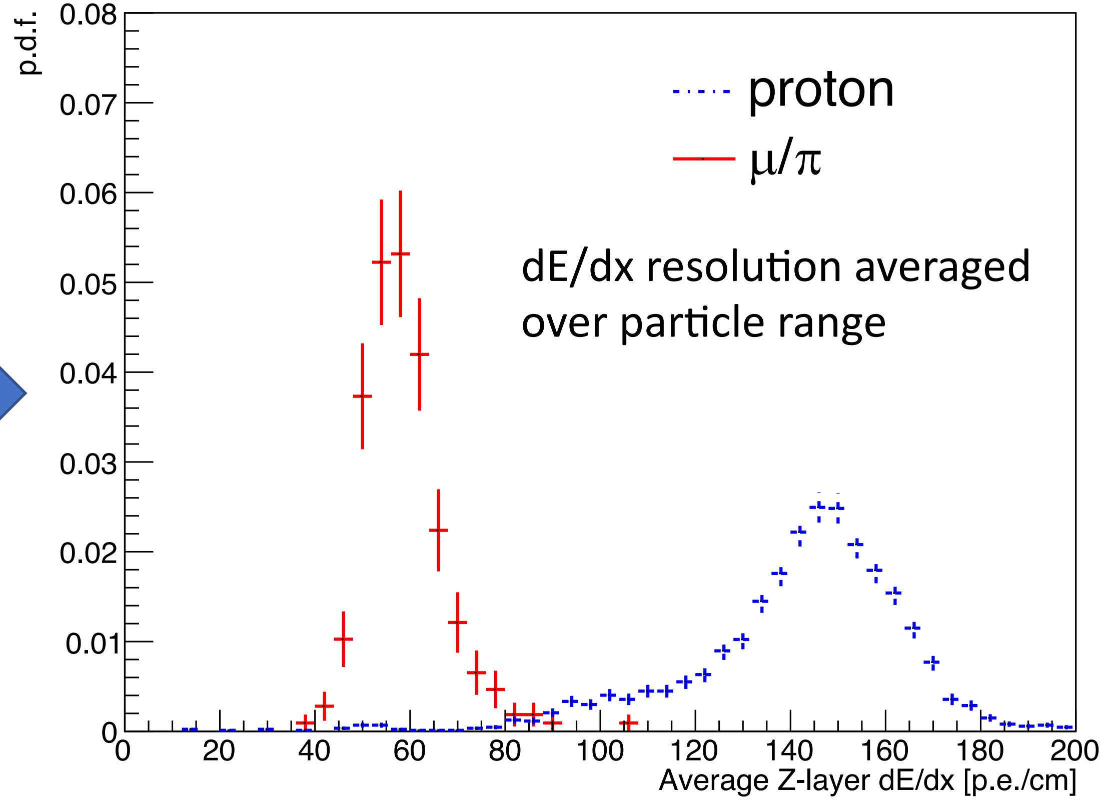
JINST (2020) 15 P12003

Particle identification with dE/dx + range



dE/dX (p.e./cm)

Range (cm)

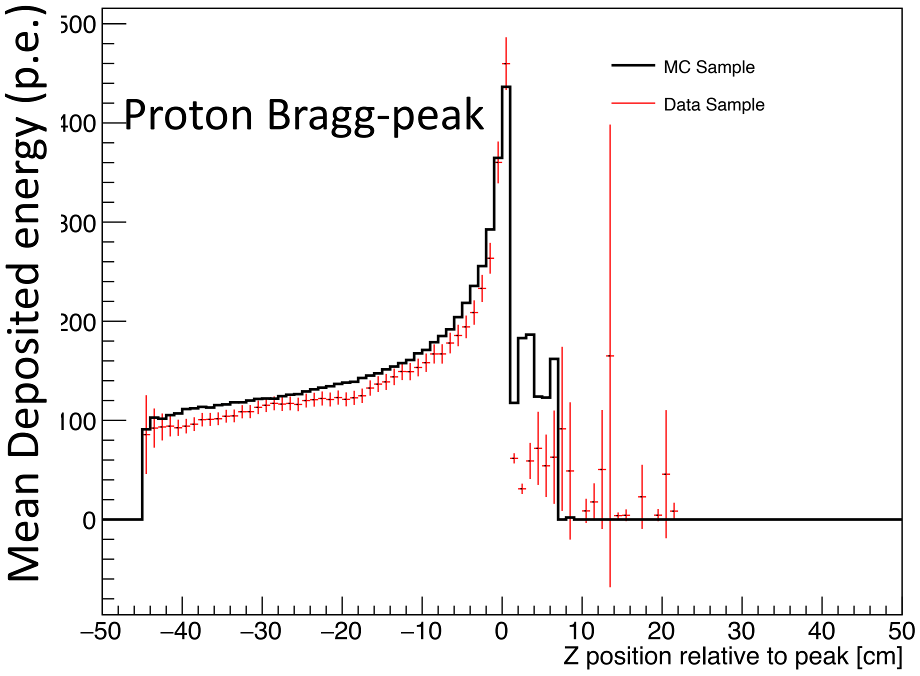


dE/dX (p.e./cm)

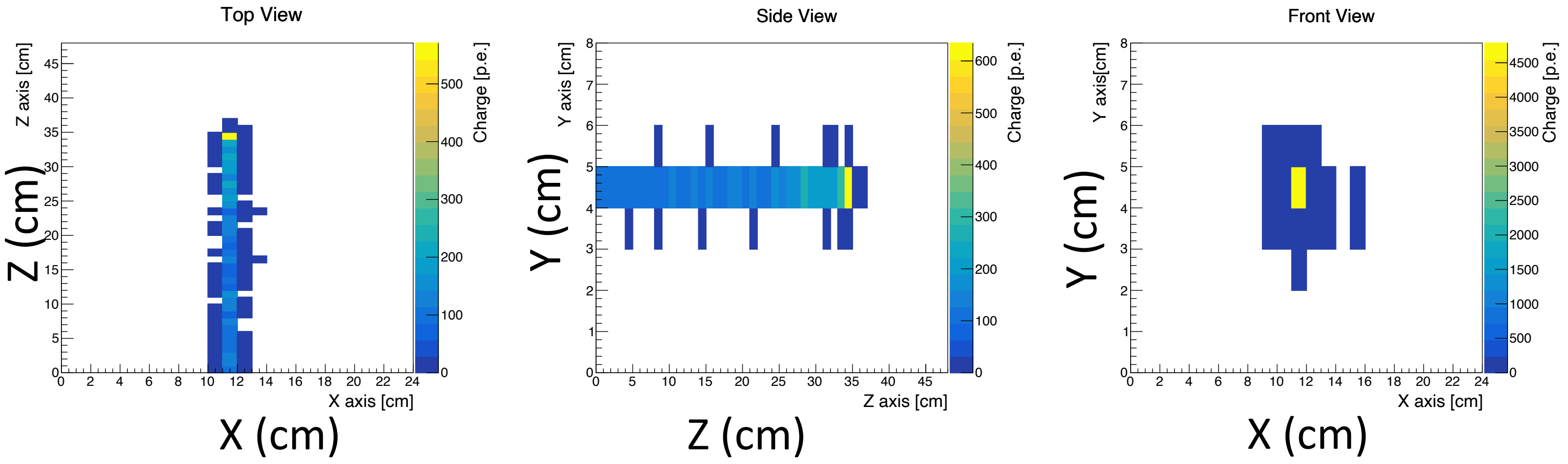
Beam tests: charged particles @ CERN PS

JINST (2020) 15 P12003

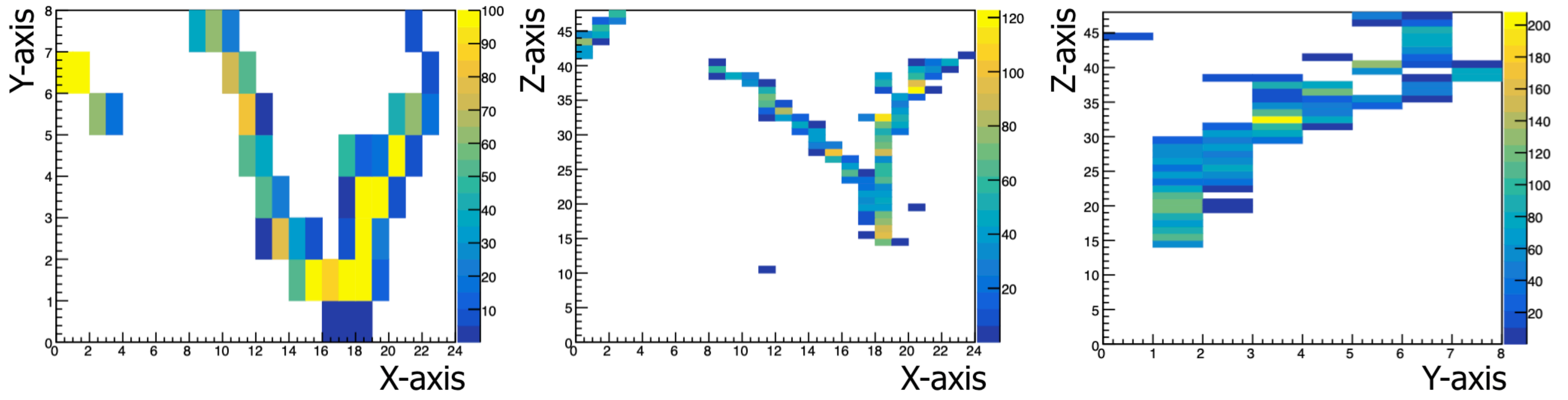
Stopped proton (~800 MeV/c)



Z position (cm)

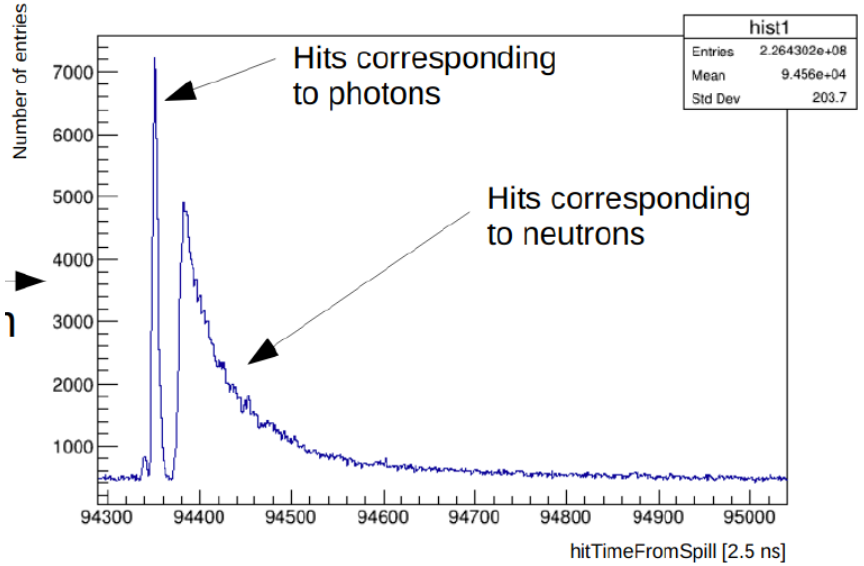


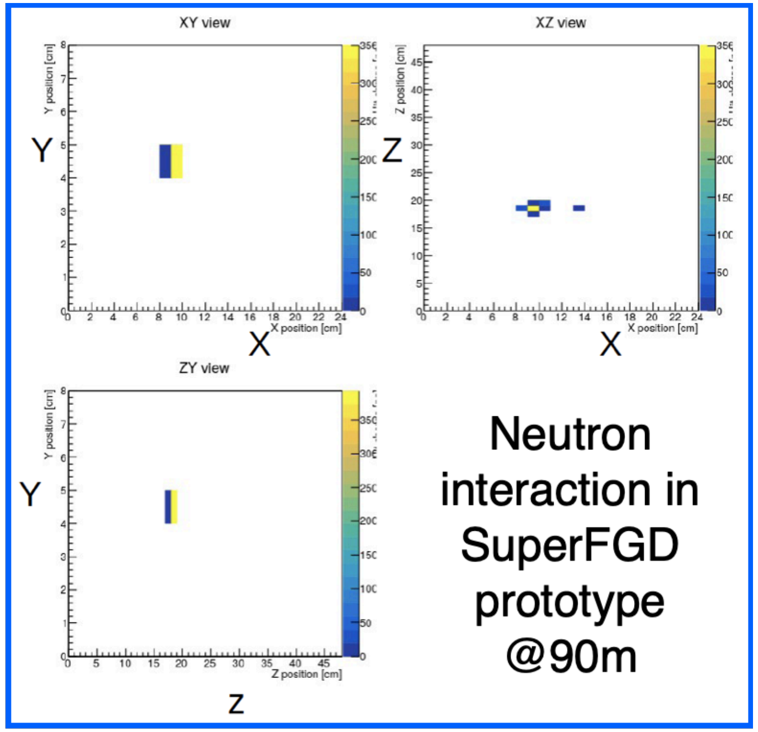
γ –conversion event

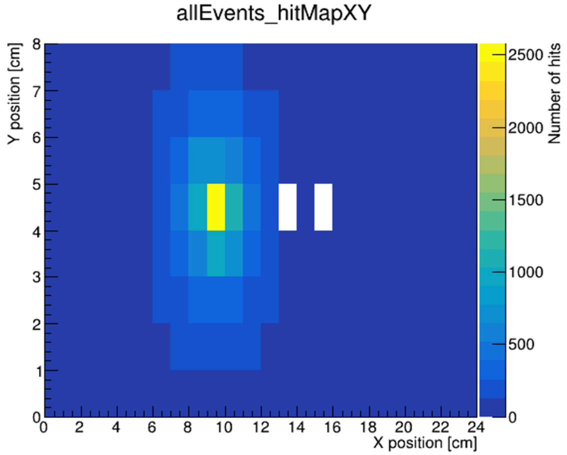


Neutron beam tests at LANL

Dec/2019 and Dec/2020: beam tests of the 8x8x32 and 24x8x48 prototypes at LANL with neutrons (0 - 800 MeV). Analysis is ongoing

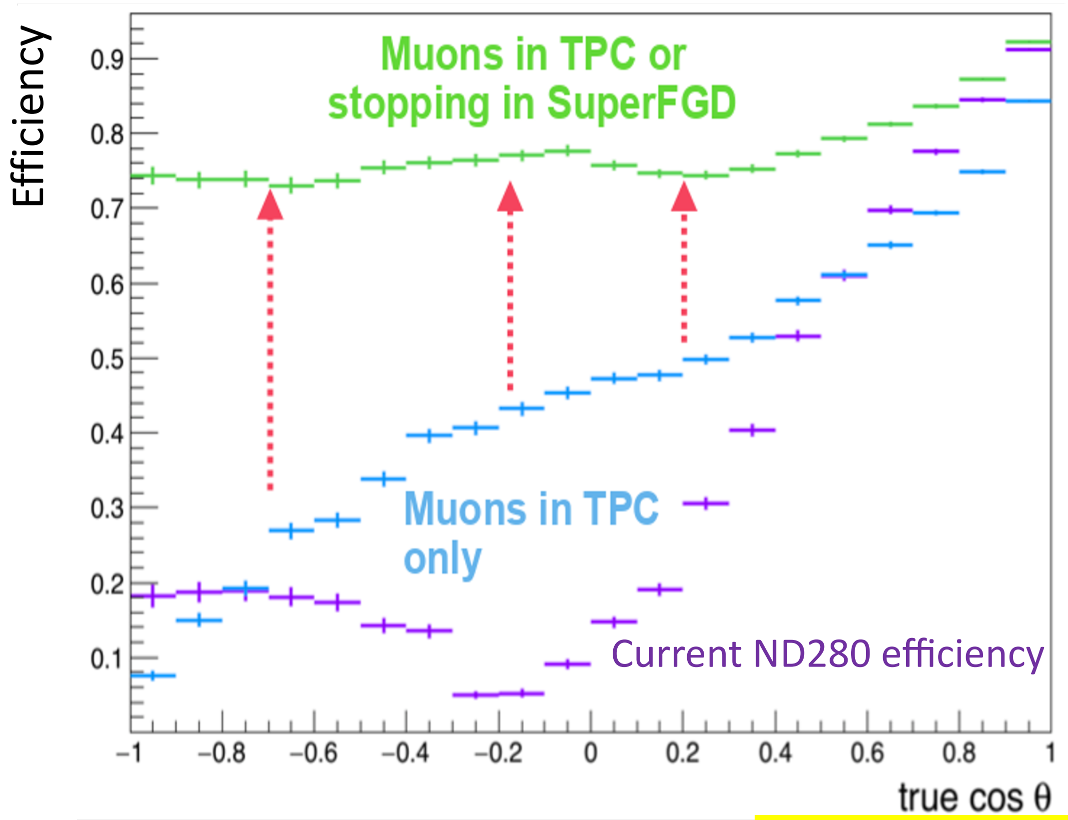


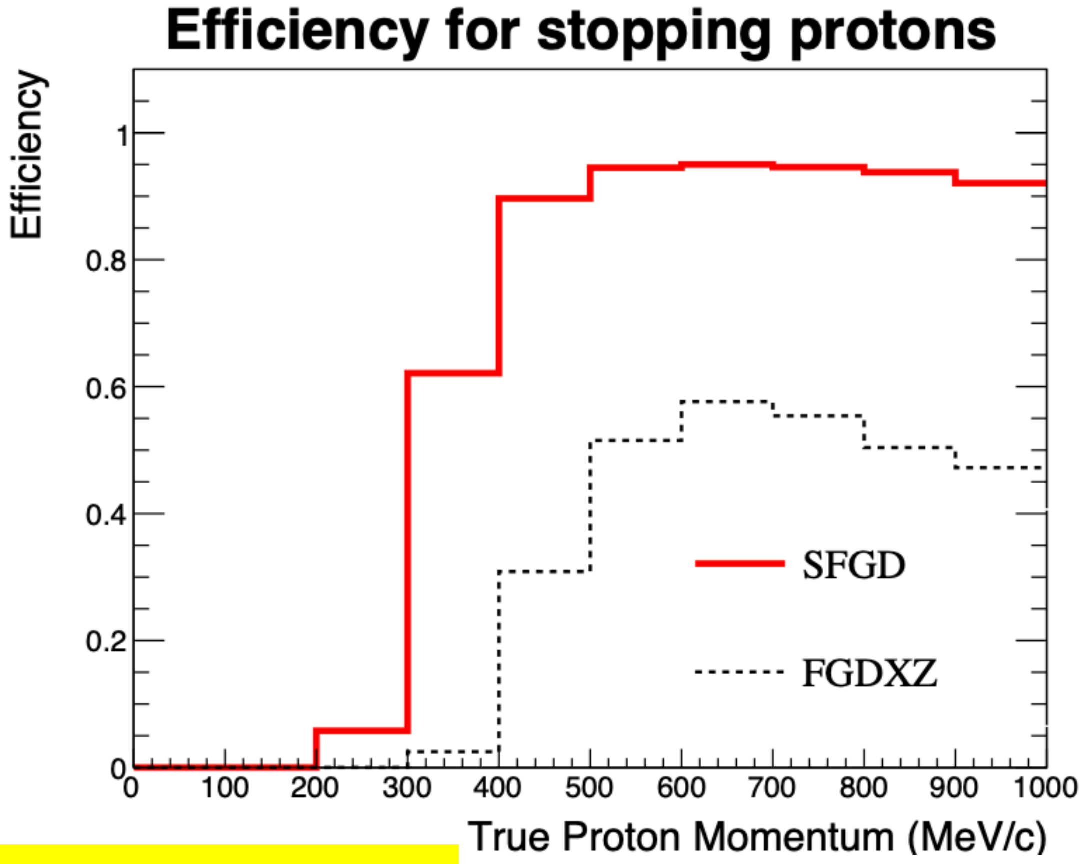




Neutron Beam

Expected efficiency of the ND280 Upgrade





For physics with the upgraded ND280
See Cesar Jesús-Valls'
talk on 24/Feb/2021

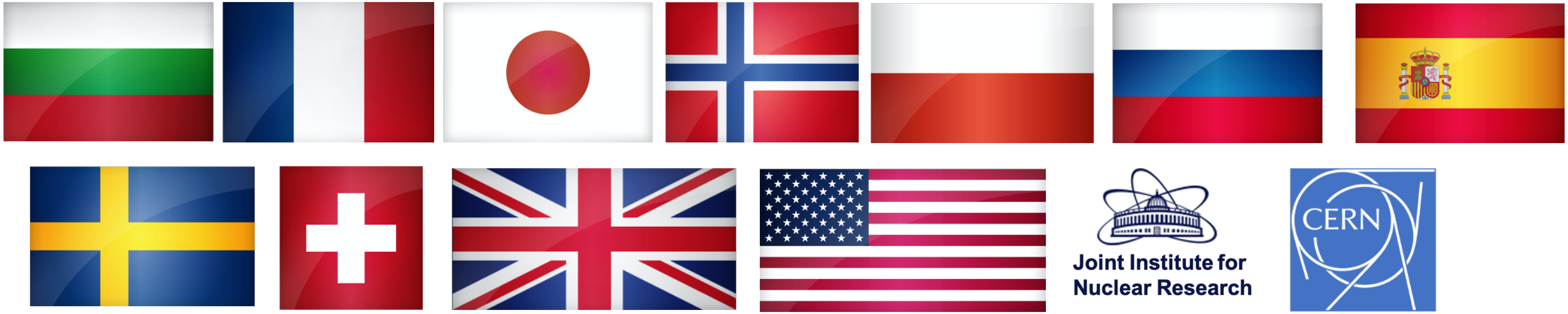
Summary

- The ND280 Upgrade is necessary to reduce systematics of the T2K and improve its sensitivity to δ_{CP}
- The 3D active plastic neutrino scintillator detector SuperFGD is a part of the ND280 Upgrade in T2K
- More than 2 million scintillator cubes of 1-cm^3 are manufactured for SuperFGD
- All 56 layers (192 x 184 cubes) of the SuperFGD detector are assembled with *fishing lines*
- Charged-particle and neutron beam tests of the SuperFGD prototypes at CERN and LANL demonstrated a good performance of the SuperFGD

Backup slides

SuperFGD as an International Collaboration

SuperFGD (with all components) is the result of activities of many groups and individual members of institutions from different countries, as well as JINR and CERN



The work is supported by the JSPS-RFBR grant #20-52-50010