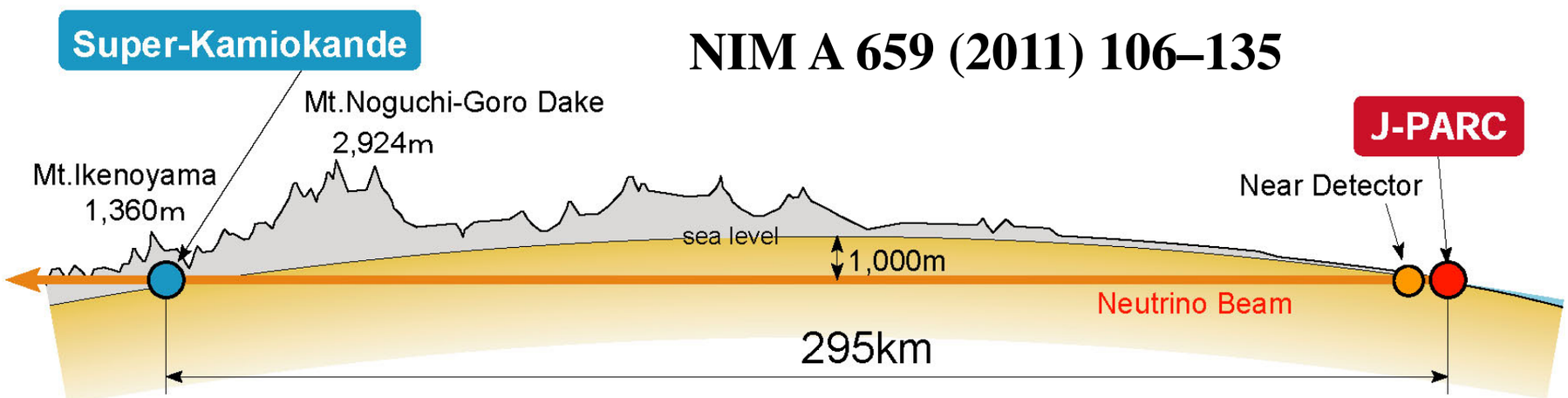
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

The upgrade project of the T2K near detector

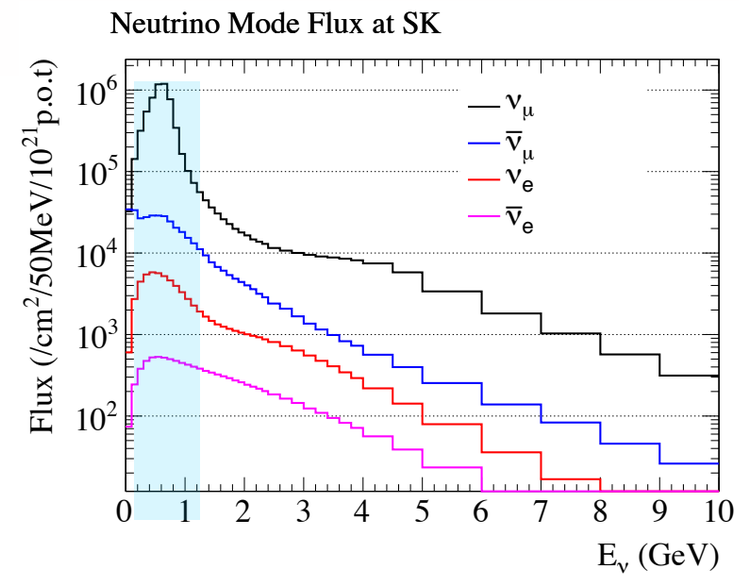
Davide Sgalaberna for the T2K collaboration,
University of Geneva,
EPS-HEP conference (Venice 8/7/17)

The T2K experiment

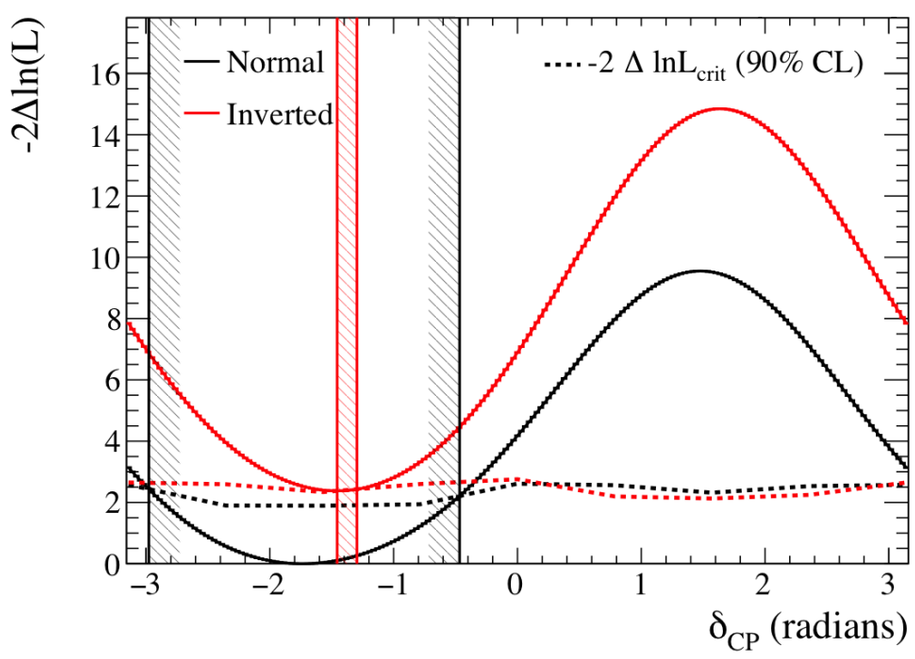
- Long-baseline neutrino oscillation experiment in Japan
- Precise measurement of neutrino oscillation parameters ($\sin^2\Theta_{23}$, Δm^2_{32}, $\sin^2\Theta_{13}$) and search for CP violation



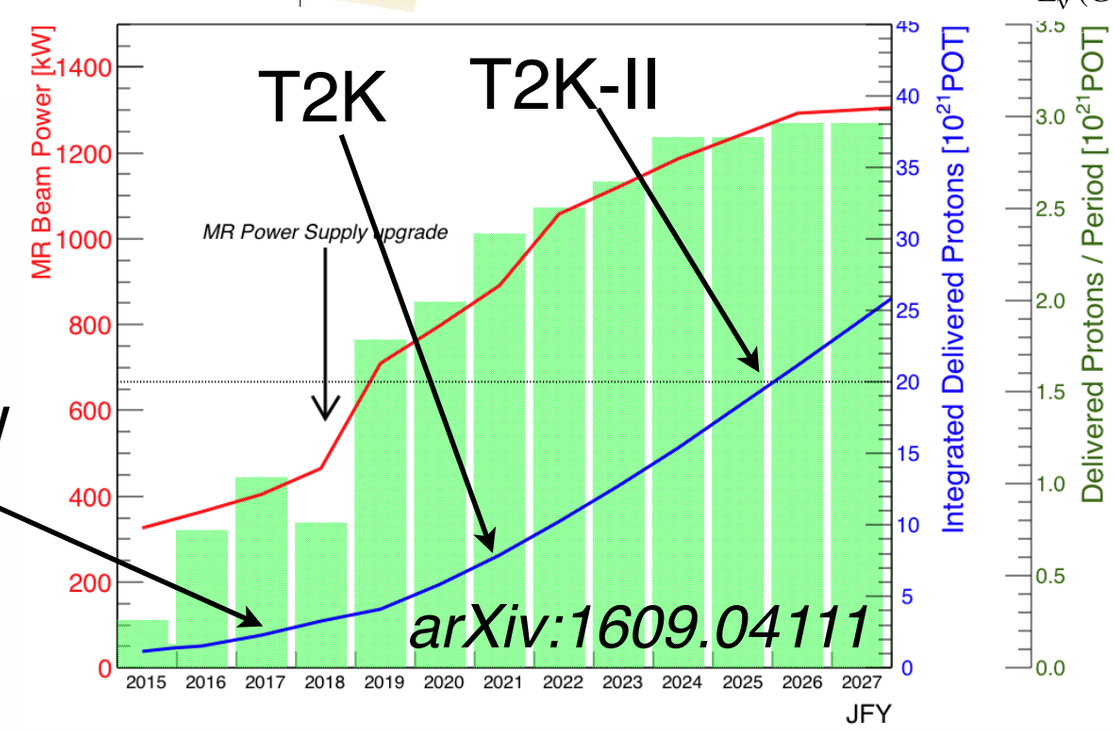
NIM A 659 (2011) 106–135



T2K Run 1-7

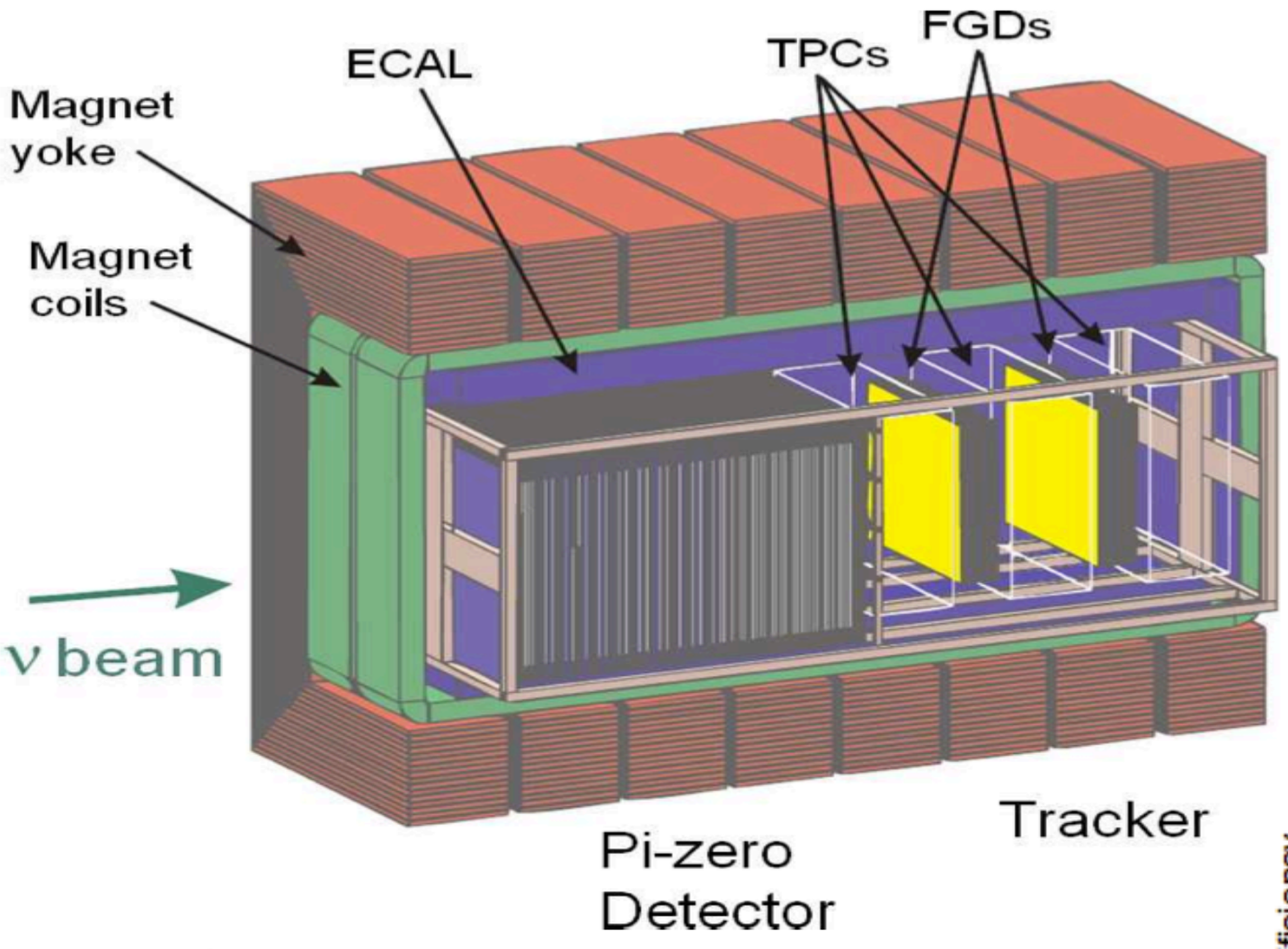


Now



- **T2K-II phase**: 20×10^{21} Protons On Target (POT) by 2025: ~x3 T2K approved
  - exclude CP conservation hypothesis at more than 3σ if $\delta_{CP} \sim -\pi/2$ and NH
- Need to reduce the systematic error and the cross-section model dependence

The T2K off-axis near detector: ND280



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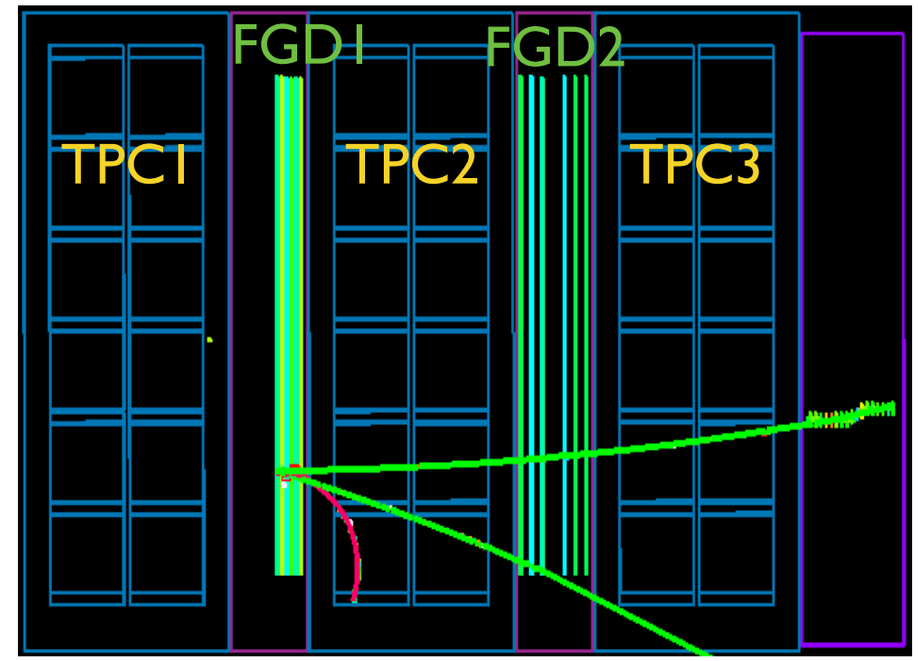
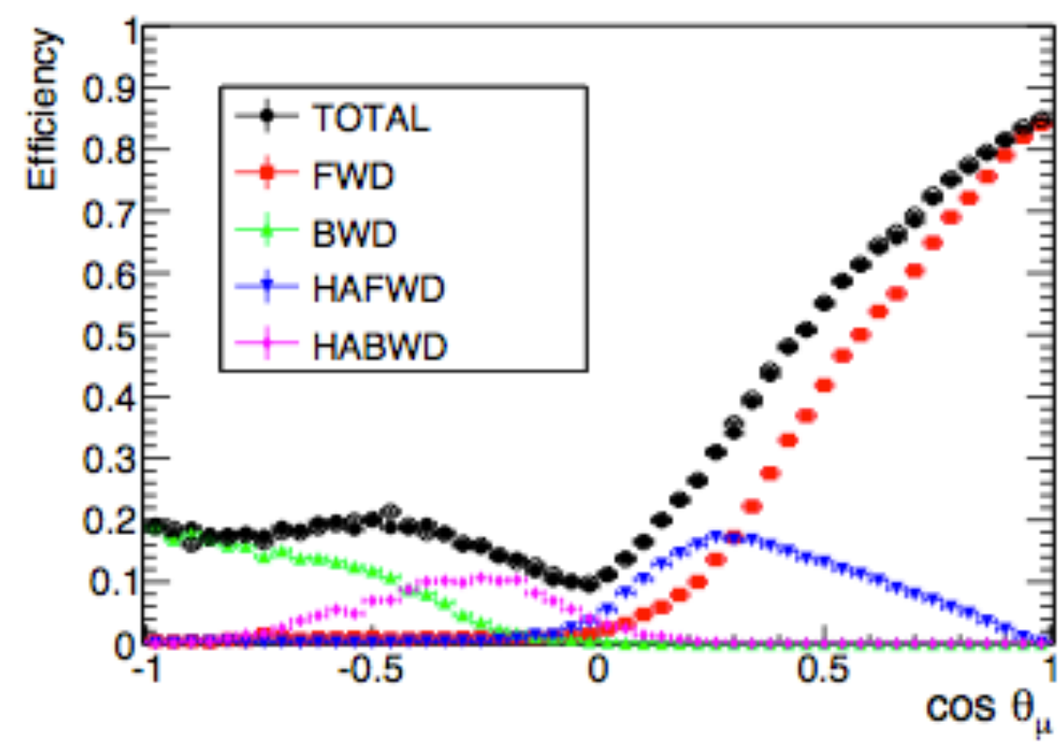


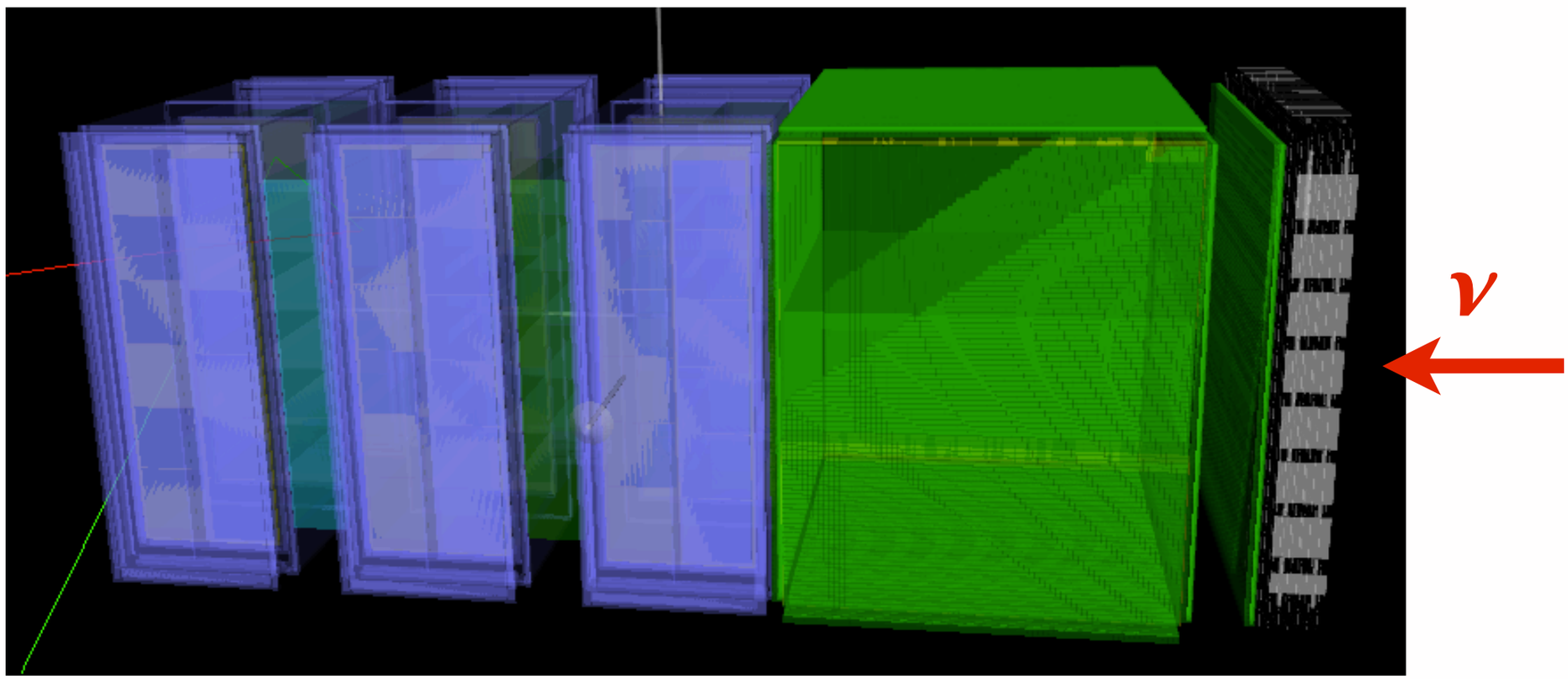


- 2.5º off the neutrino beam axis:
  - narrow beam at oscillation maximum
- 0.2 T dipole magnet
- 2 Fine-Grain-Detectors (FGD) as active target (XY):
  - FGD1: plastic scintillator
  - FGD2: water + plastic scintillator
- 3 vertical TPCs

Good acceptance only for forward tracks

ND280 upgrade detector configurations

- Keep the current tracker (2 FGDs + 3 vertical TPCs)
- Build new tracking detectors upstream
  - horizontal plastic scint. detector (1.8x0.6x2 m^3)
  - 2 horizontal TPCs



- Keep the electromagnetic calorimeter
- Time-of-Flight detector around new tracker
  - timing for track reconstruction and rejection of out-of-fiducial volume interactions
  - improve particle identification

	Current	Upgrade
Target Mass (tons)	2.2	4.3

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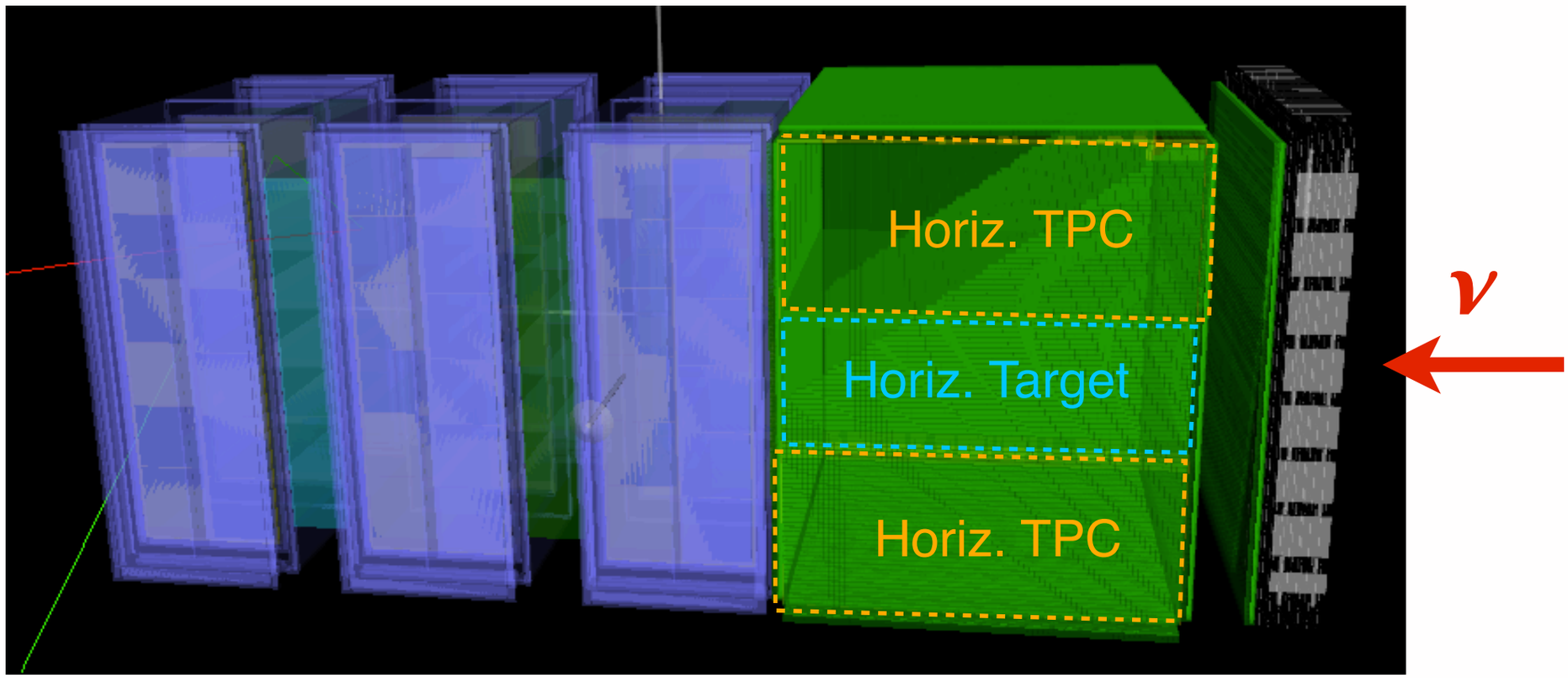

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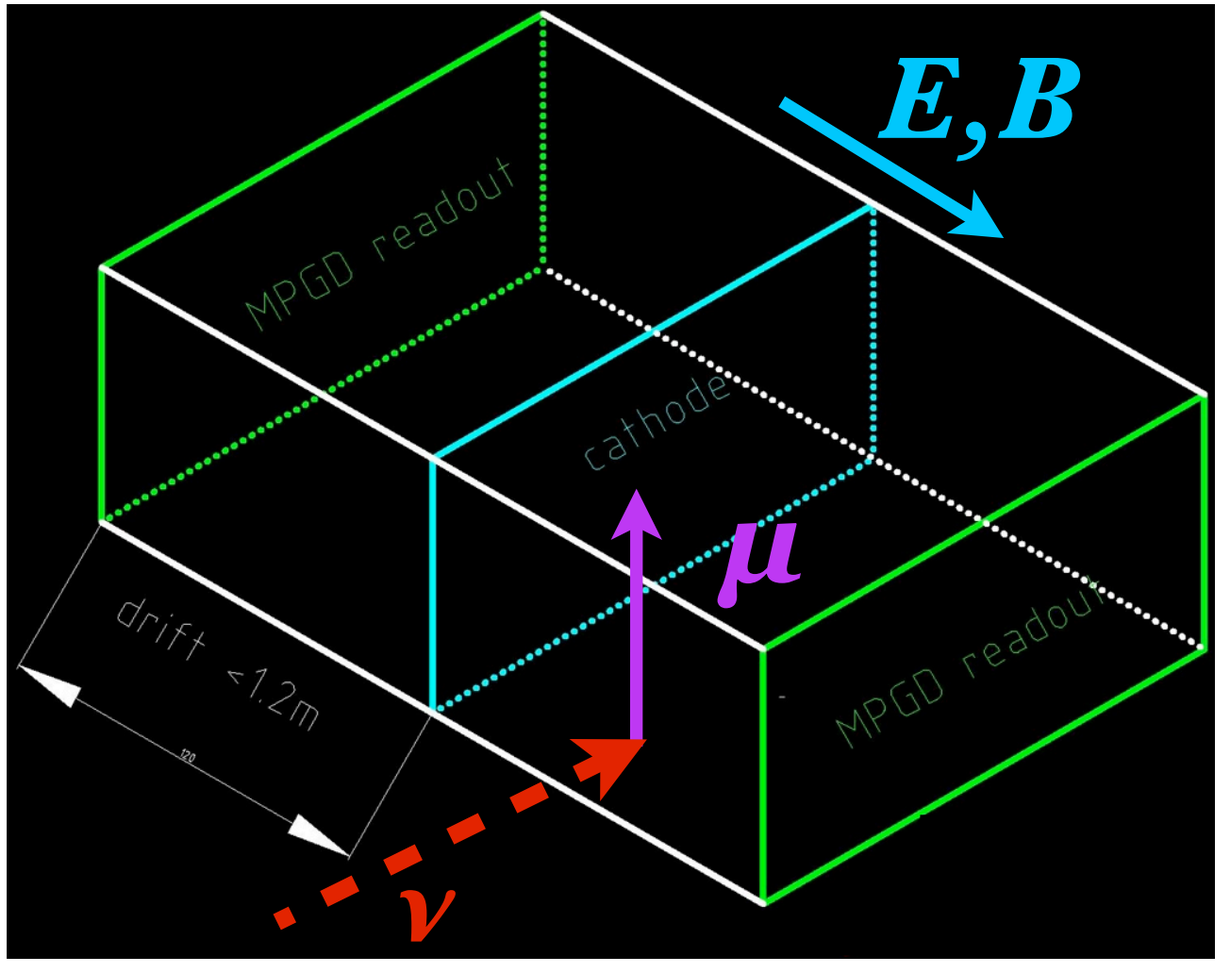
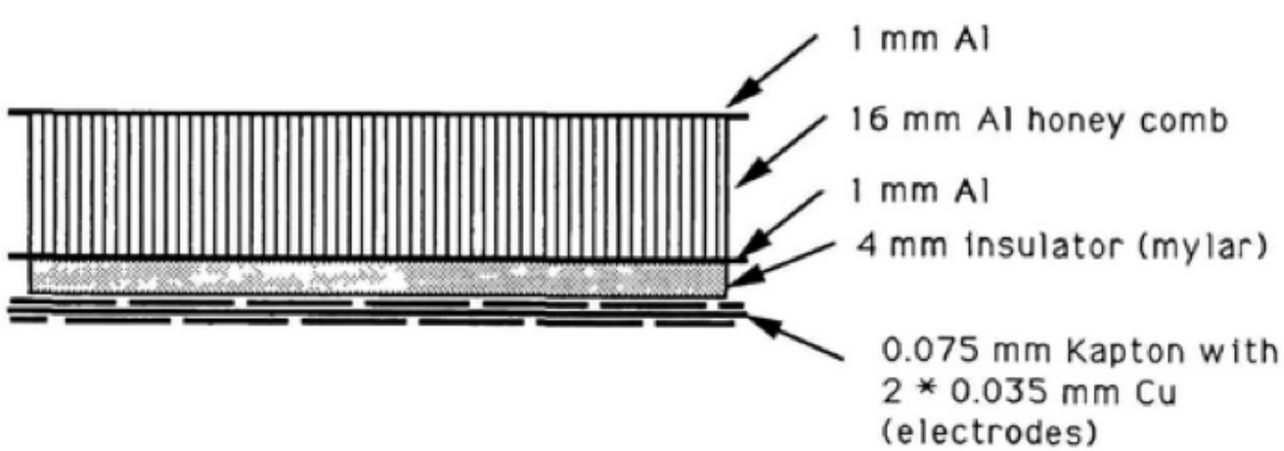
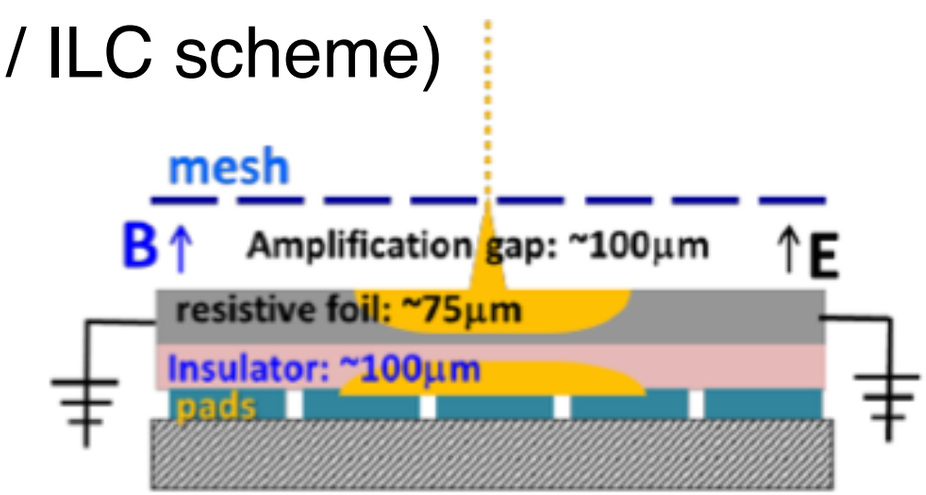
The New horizontal TPCs



Parameter	Value for 1 TPC
Dimension	1.8(x) x 0.8(y) x 2.0(z) m^3
Volume	2.9 m^3
Drift Length	90 cm
Pad area	~1 cm^2 (~2 cm^2 resistive MM)
Sensitive area	3.2 m^4
# MM	16 (50x50 cm^2 each MM)
# channels	3.2×10^4

- Plan to build a thin (few cm) field cage (Aleph / ILC scheme)





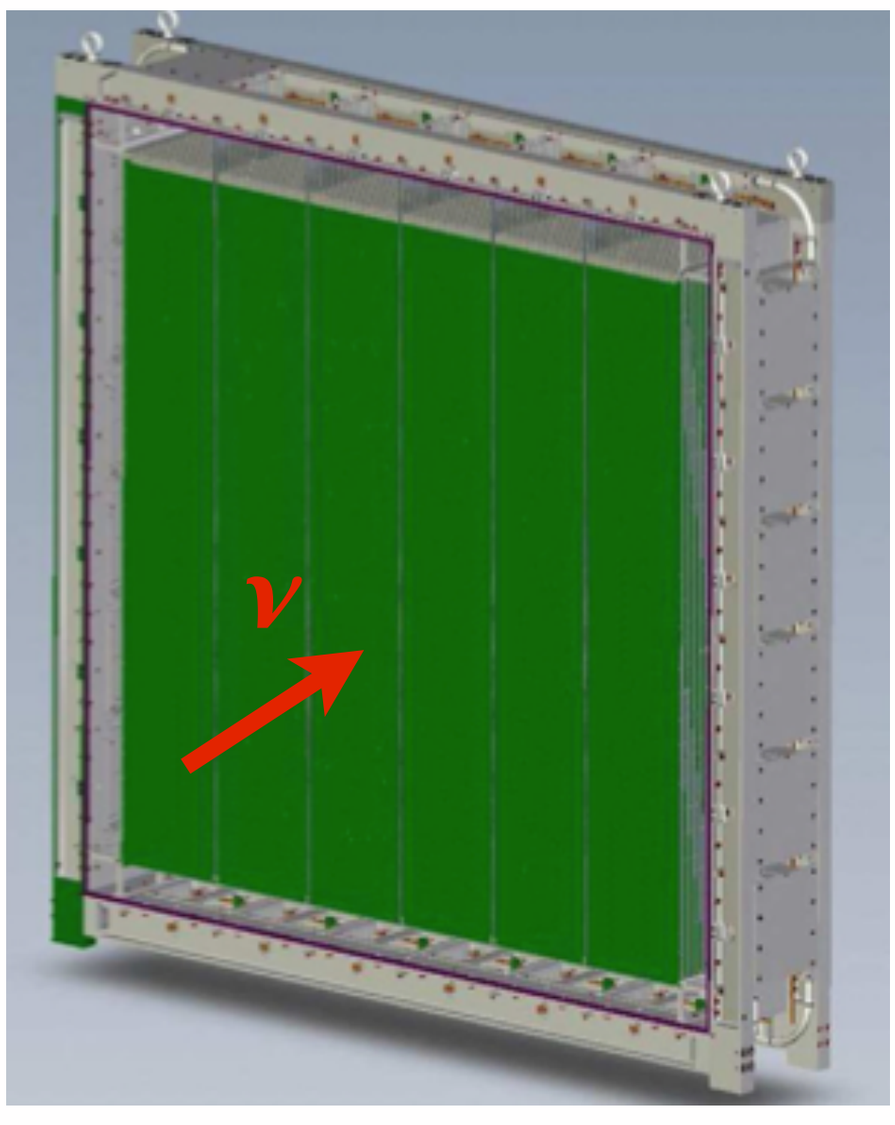
Resistive Bulk MicroMegas (charge spread, intrinsic spark protection)

The new scintillator-based target detector

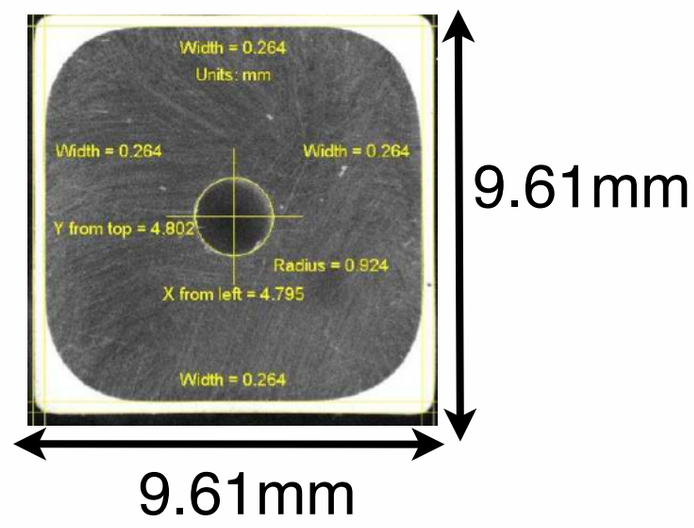
- We are considering several options
  - simulation studies are ongoing to choose the technology with best performance

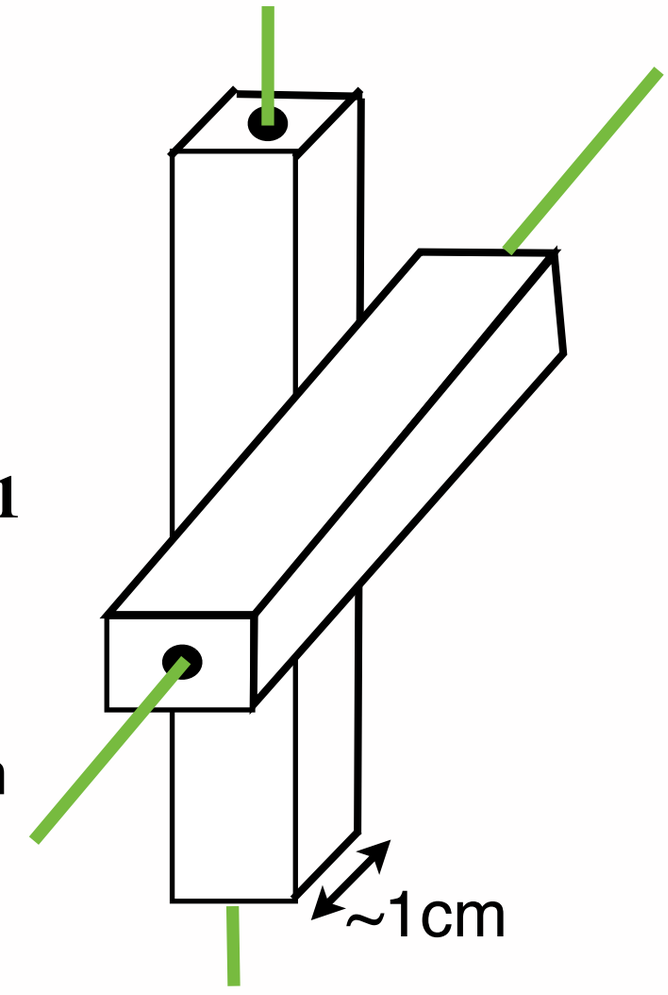
1) FGD-like detector: well known technology

- FGD XY rotated by 90°



NIM A 696 (2012) 1–31





- Extruded plastic scintillator bars coated with TiO_2
- MPPC (S10362-13-050C) 1.3x1.3 mm^2 (PDE@525nm 26-30%)
- ~30 photoelectrons per MIP crossing a bar
- FGD1 (scint. layers), FGD2 (scint.+water layers)

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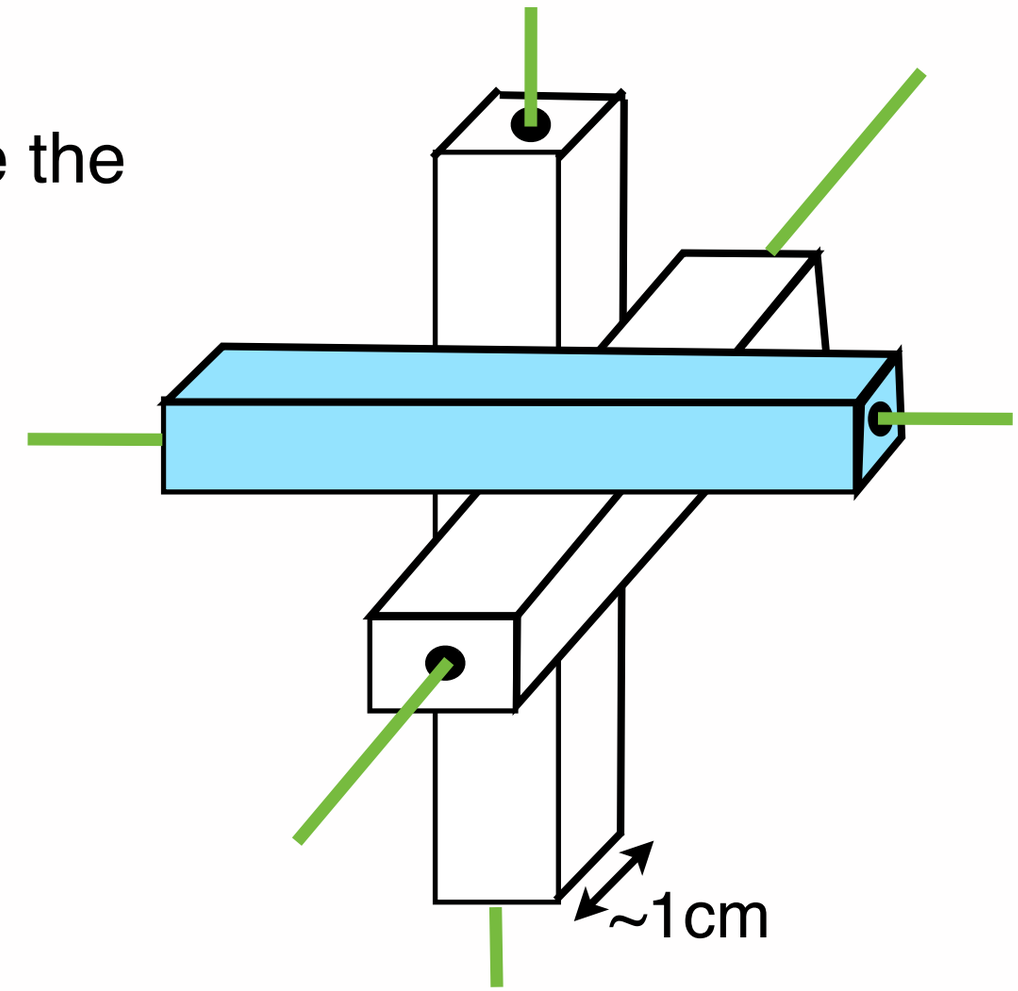
1) FGD-like detector: well known technology

- FGD XY rotated by 90°
- FGD3D: bars along XYZ direcitions
  - 3 views with 3 hits
  - 25% of volume is air
  - no water cross section measurement



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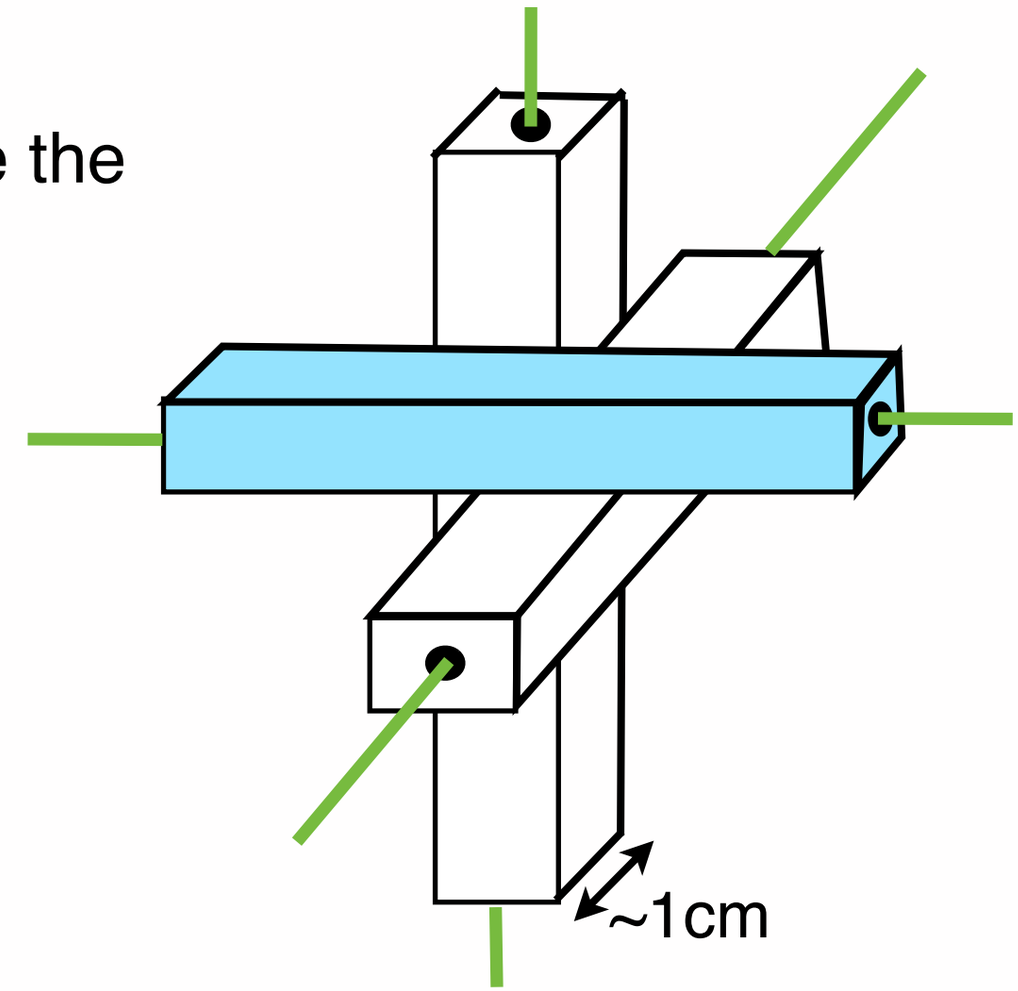
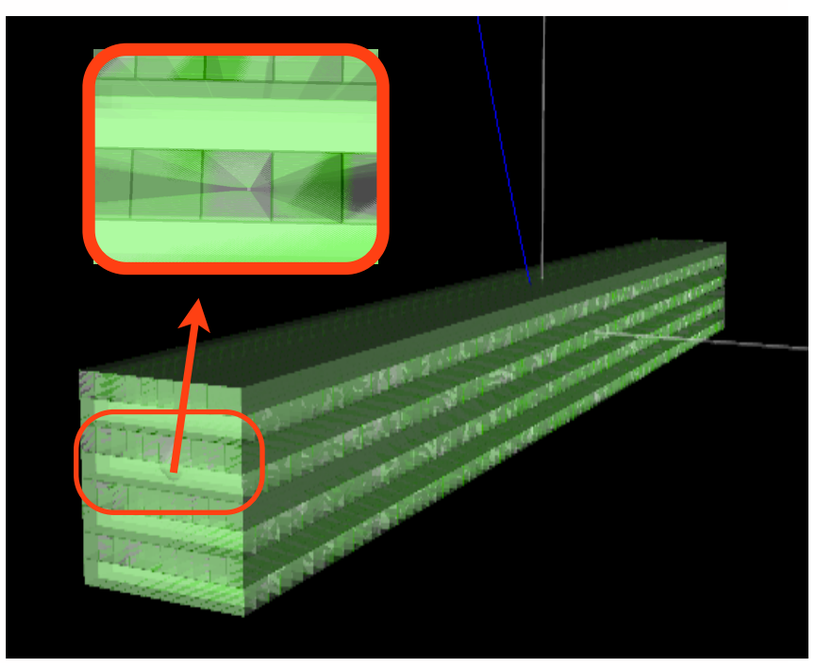
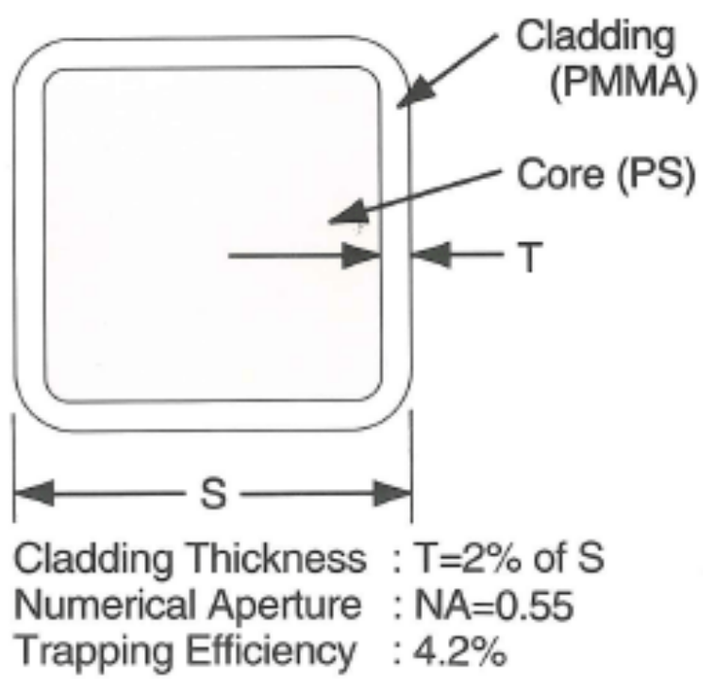


2) Scintillator fiber detector (XY fibers)



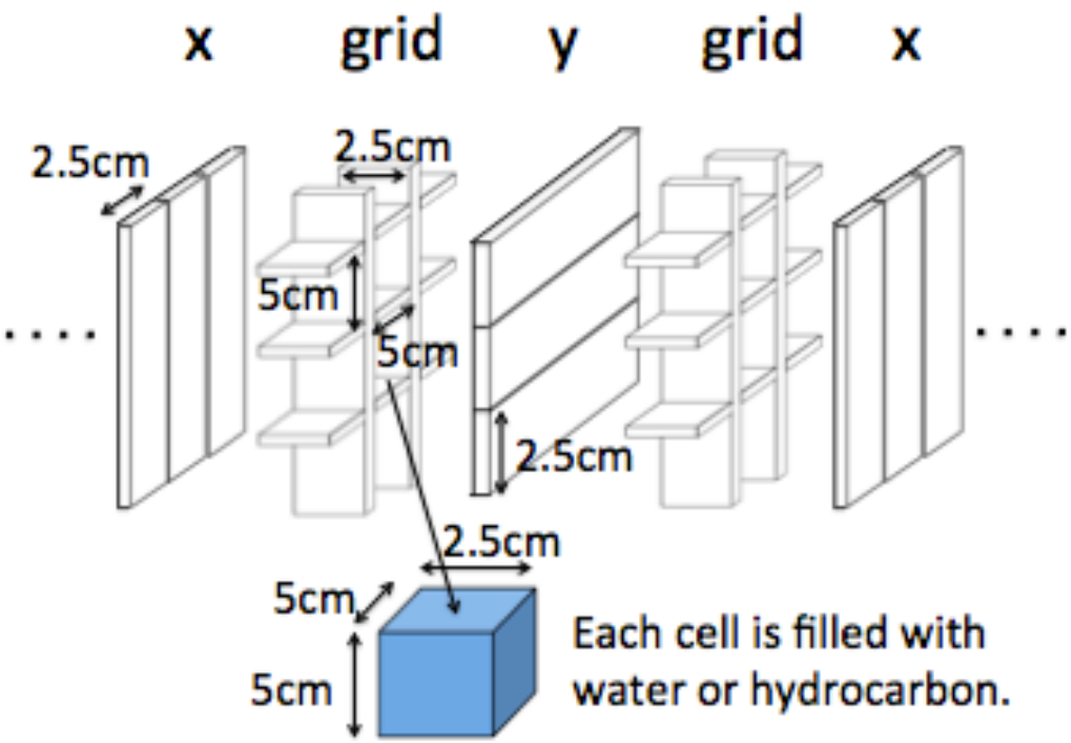


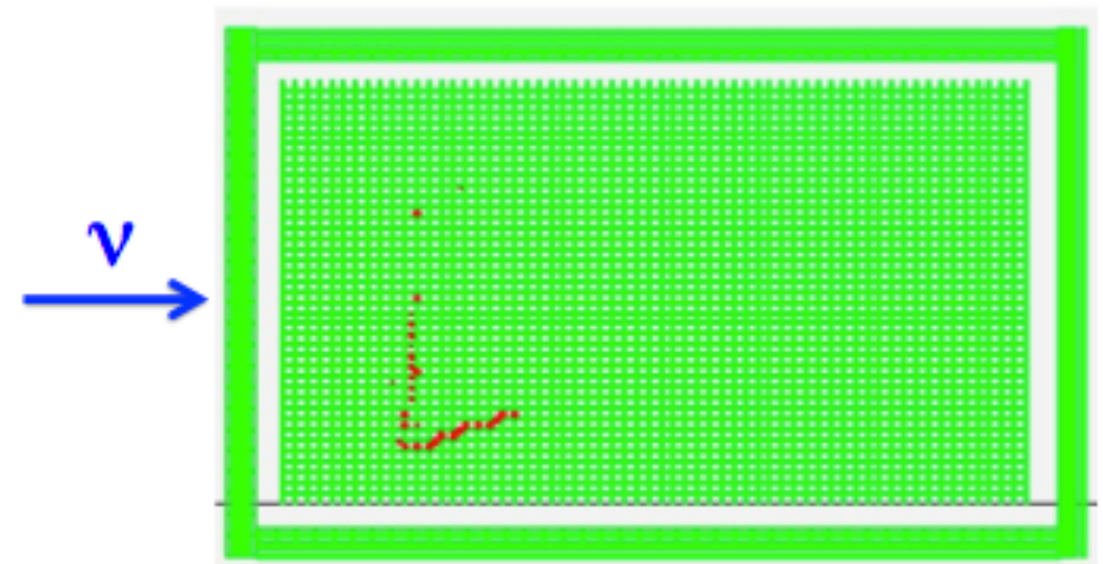
- Kuraray 2mm single-clad
- 23.7±0.1 p.e./mm @15cm (MIP)
- Expect very good performance but many channel (>300k)
- R&D by Neutrino group of Kyoto University at Research Center for ELectron PHoton Science (ELPH), Tohoku University

The new scintillator-based target detector

3) WAGASCI-like detector

- T59 experiment will run at J-PARC (**JPS Conf. Proc. 8, 023003 (2015)**)
- prototype running in front of the T2K On-Axis detector

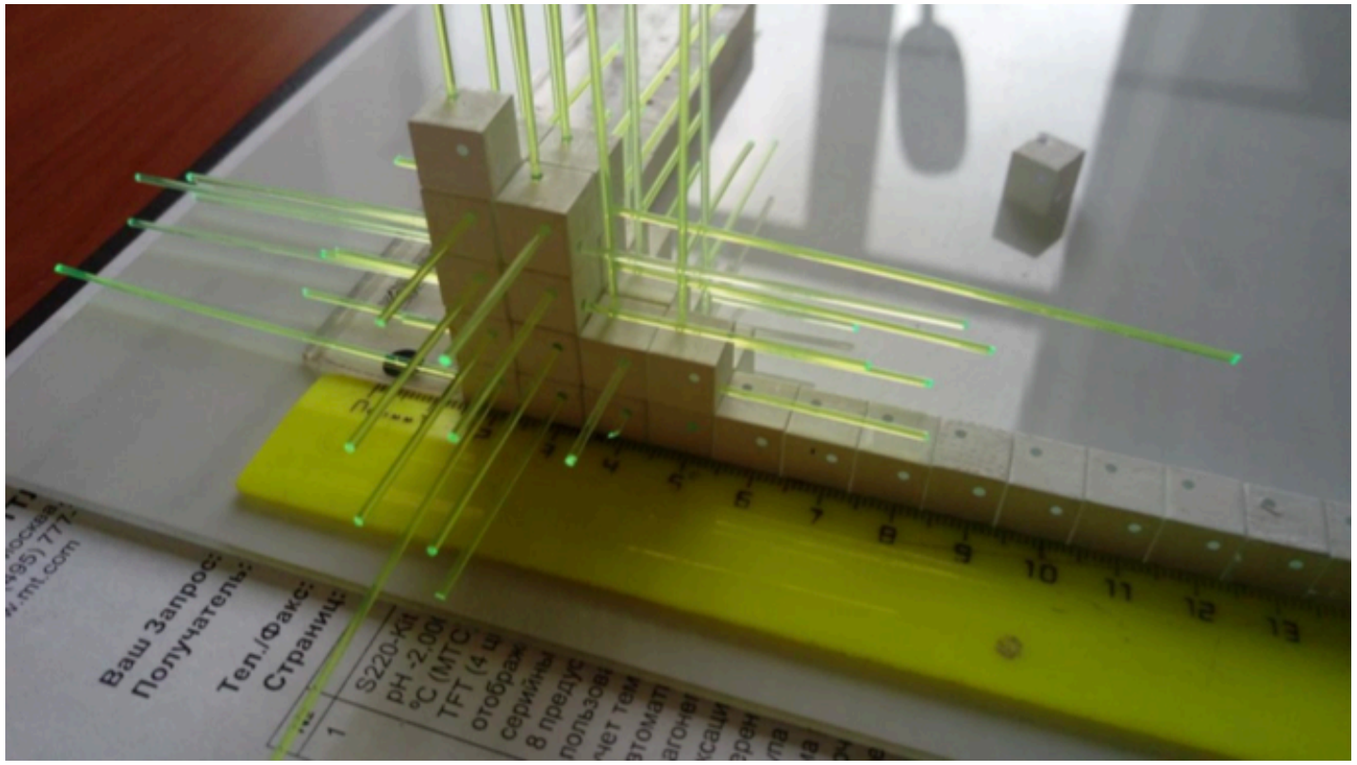


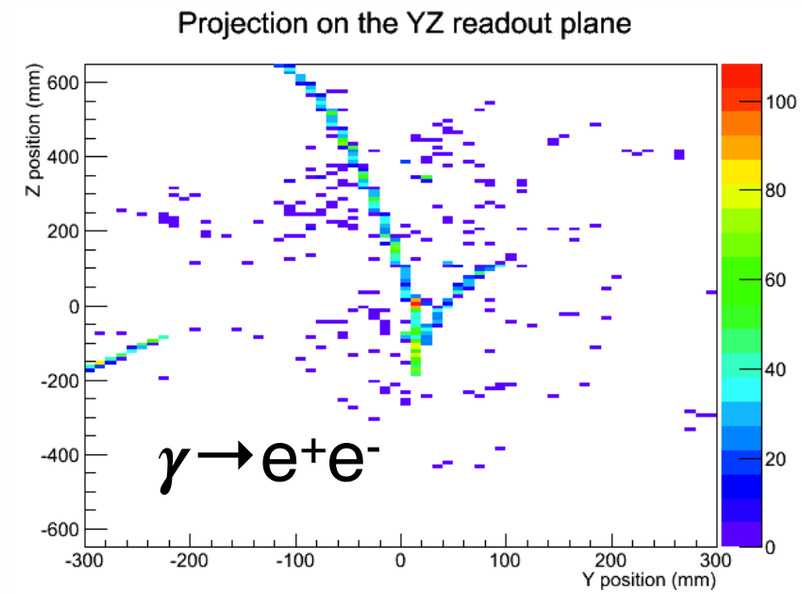


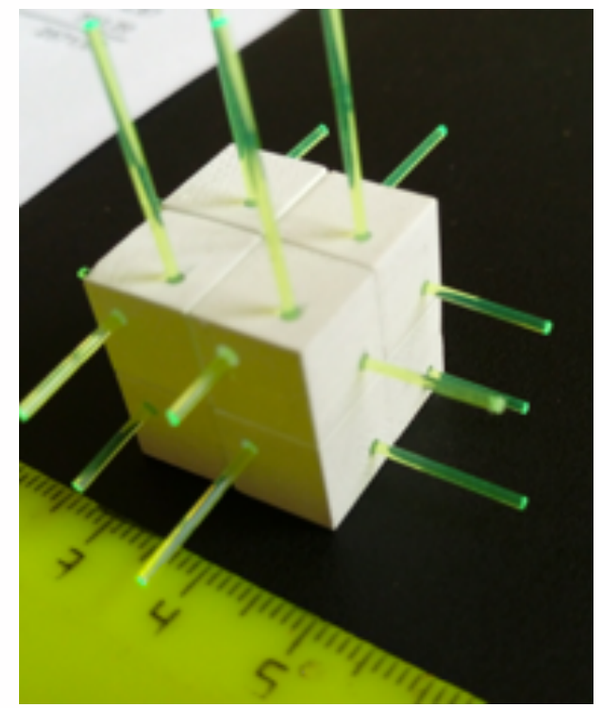
- Empty or filled with water: measurement of neutrino interactions in water
- Efficiency to select muons ≳90% over the full solid angle
- Empty module drastically reduces the momentum threshold (~300 MeV/c for protons) but 3 times less target mass

The new scintillator-based target detector

4) SuperFGD
- plastic scint. 1x1x1 cm^3 cubes coated
- all the volume is fully active
- 3 views per hit





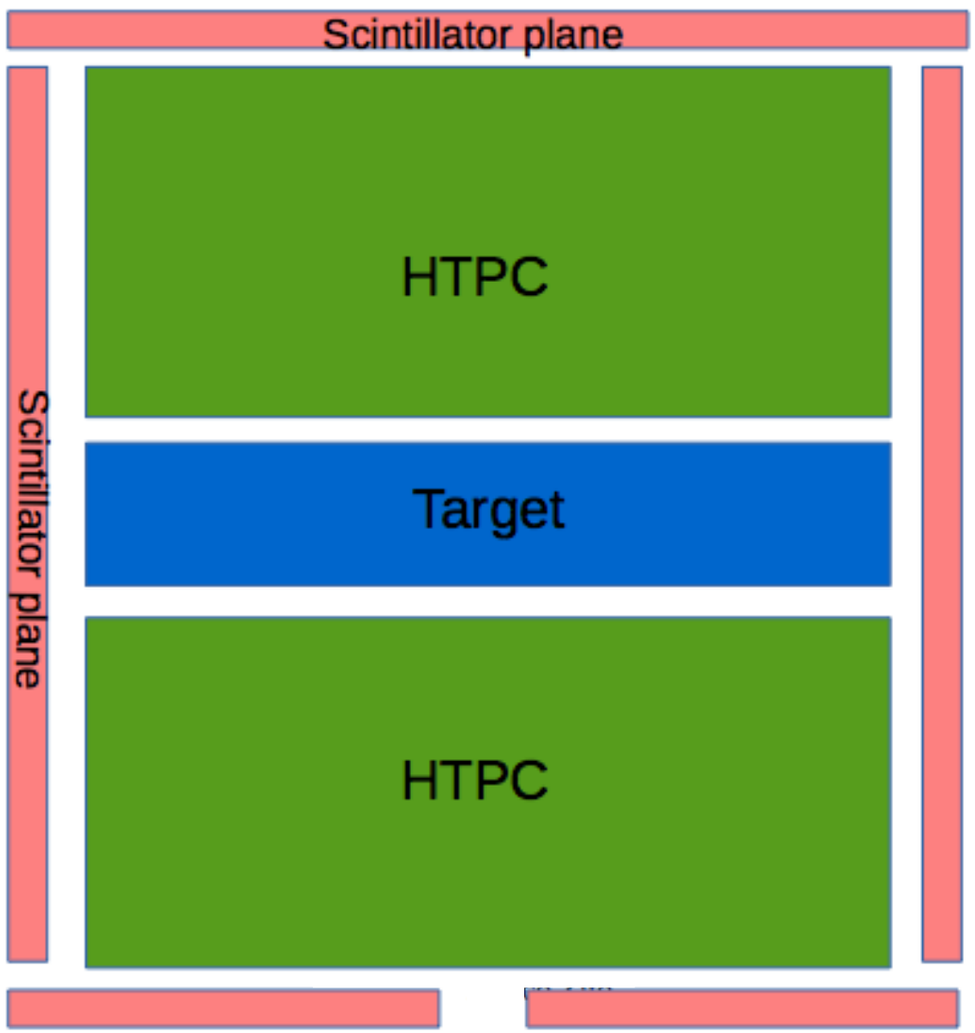


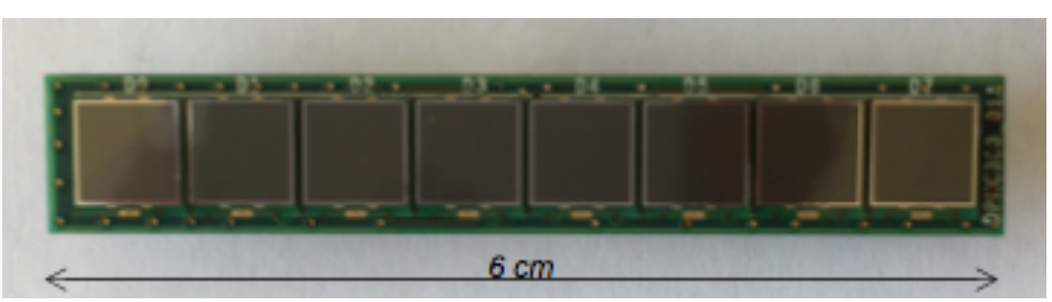
- Simulation studies and hardware R&D are ongoing
- 230 cubes manufactured by Uniplast chemical company (Russia)
  - light yield (cosmics): ~150 pe/MIP in total
  - prototype and test beam in Autumn

arXiv:1707.01785

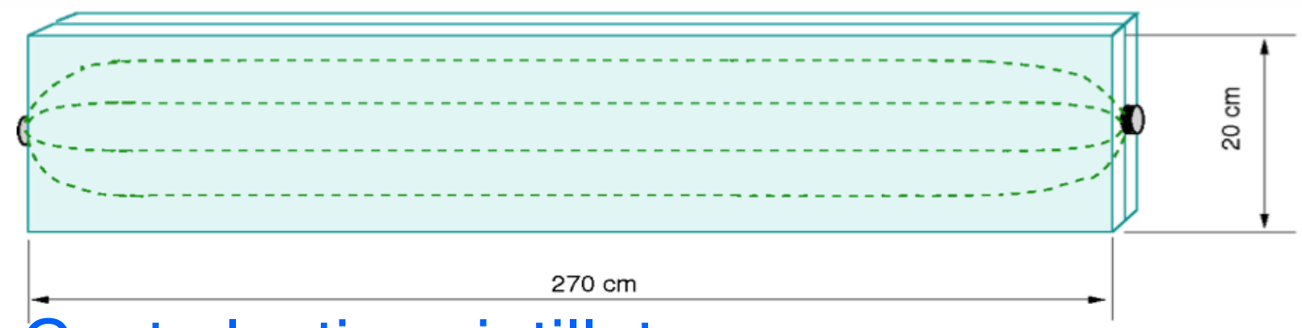
Time of Flight detector

- Determine the sense of the tracks
- Improve particle Identification, e^+ / protons and electrons / muons

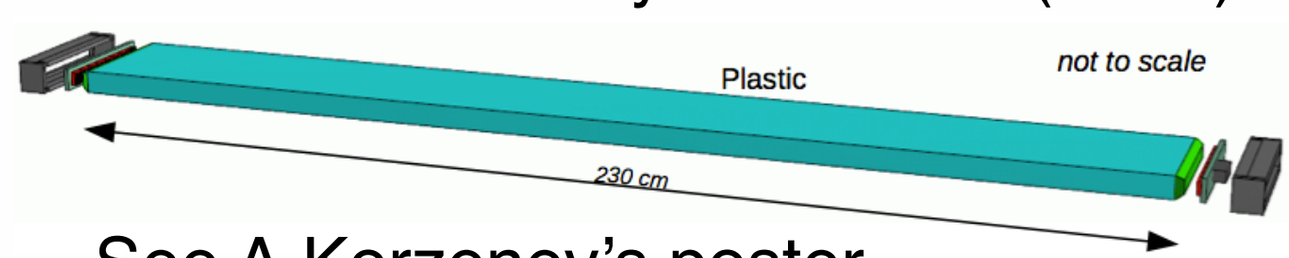




- Extruded plastic scintillator
  - 2 extruded plastic scintillators bars
  - 4 WLS Kuraray 1mm fibers (glued), single connector, 3x3mm^2 MPPC, double-end
  - Time resolution is 630-650 ps
  - R&D studies at INR (Moscow)



- Cast plastic scintillator
  - about 4m attenuation length
  - 8 sensors of 6x6 mm^2
  - Time resolution is 120-140 ps
  - R&D at University of Geneva (SHiP)

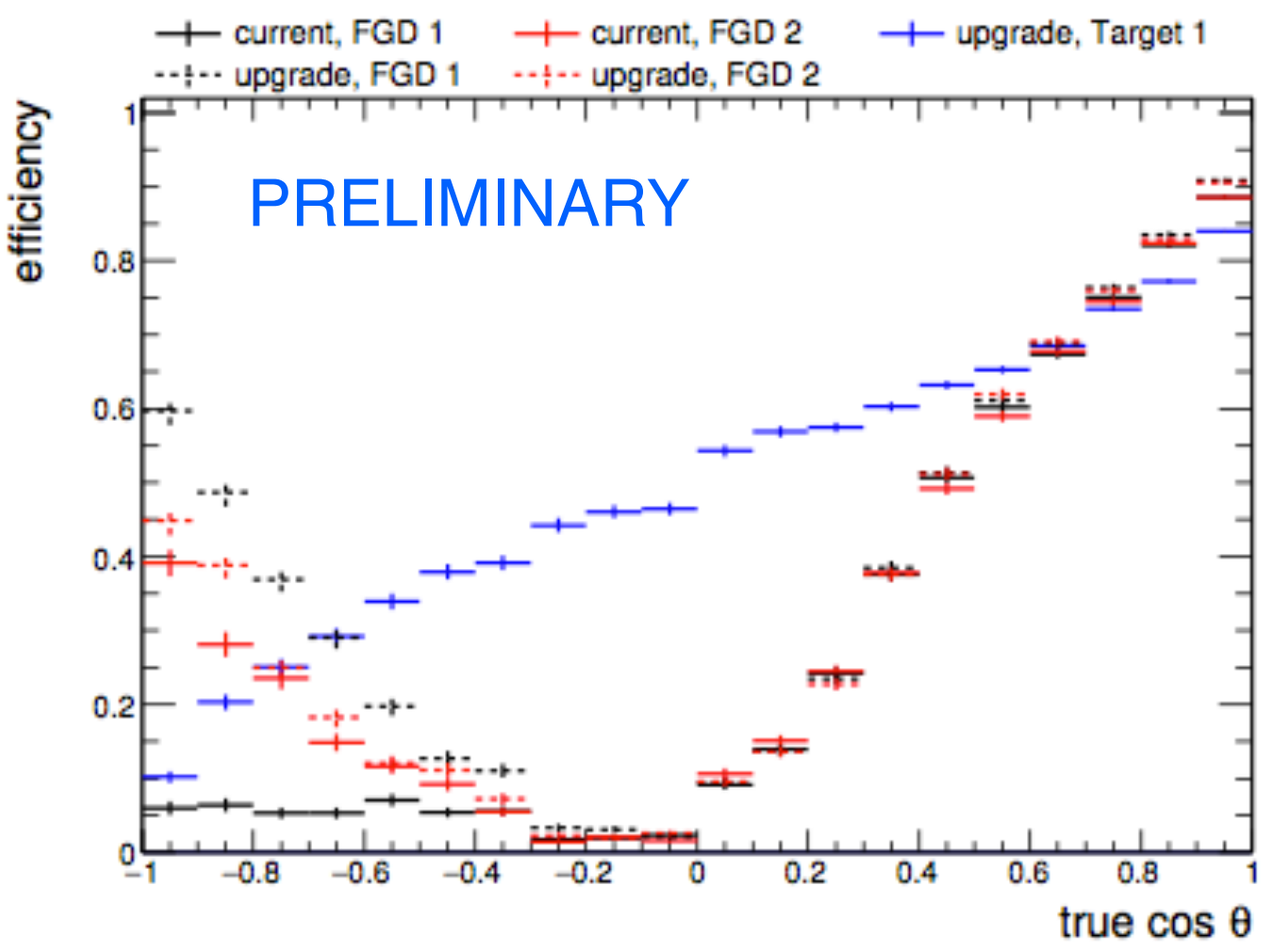


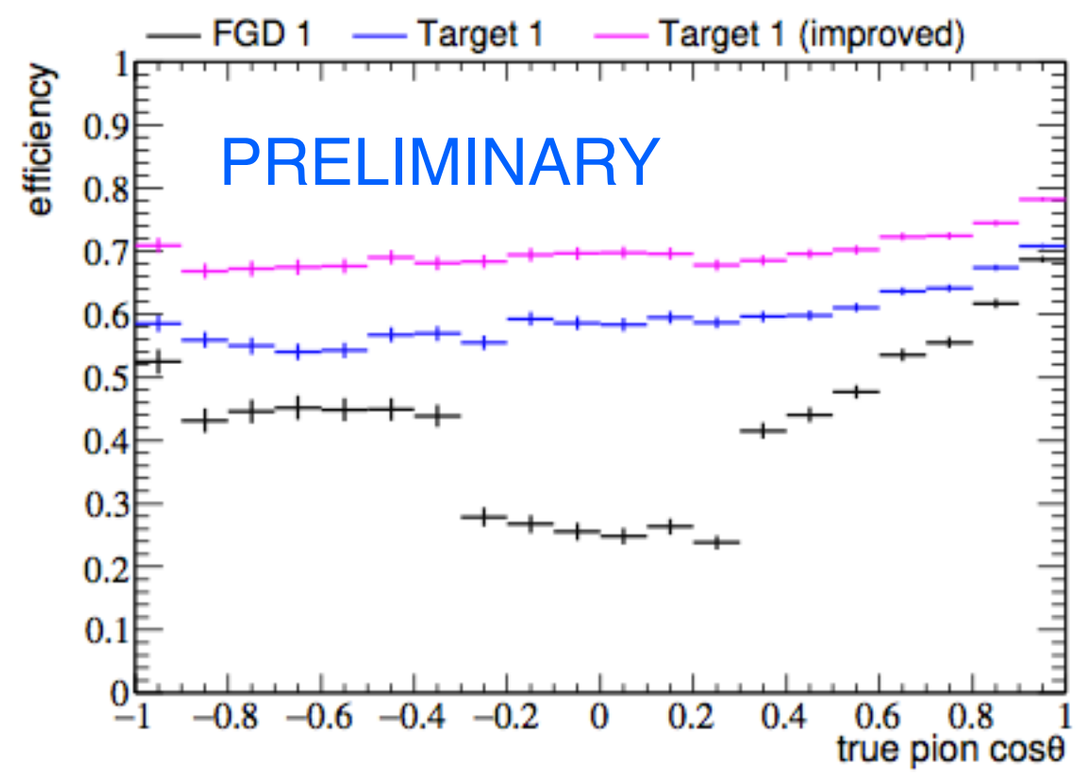
See A.Korzenev's poster

Simulation studies

- Simulated with GEANT4 both ND280 upgrade and current-like detectors
- Select ν_μ ($\bar{\nu}_\mu$) Charged-Current (CC) events:
  - muon track reconstructed in either TPC or ECal
- Use ToF informations for track reconstruction

Expected # of selected events		
10^{21} POT	Current-like	Upgrade
ν_μ	95860	199775
$\bar{\nu}_\mu$	27443	54249





- Reduce systematic uncertainties by 20-40% more than ND280 current
- Work is ongoing on ν_e ($\bar{\nu}_e$) interaction studies

Conclusions

- T2K Near Detector upgrade launched as official T2K project
  - improvement of Near Detector toward T2K-II (and Hyper-K)
  - Expression of Interest in January 2017: CERN SPSC-EOI-015
  - signed by ~190 physicists (aims to be part of the CERN neutrino platform)
- Plan for the T2K near detector upgrade
  - end of 2017: technical design and submit the proposal to SPSC
  - 2017-2018: prototypes of TPCs, scint. detectors in testbeam
  - 2019-2020: production, integration at CERN, system test
  - 2021: shipment to Japan, installation, commissioning
- R&D of a High Pressure TPC as a detector to explore the details of neutrino interactions
- Already 3 open workshops since November 2016

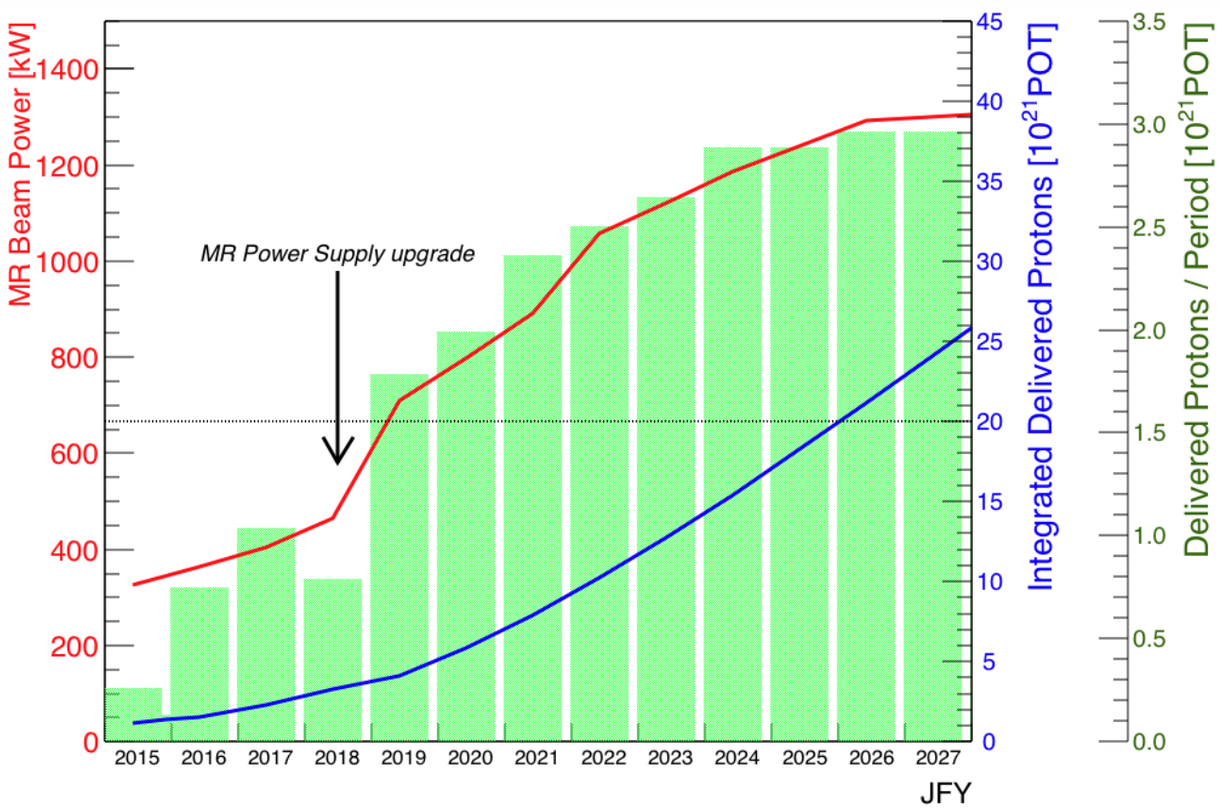
  https://indico.cern.ch/event/568177/ https://indico.cern.ch/event/613107/ https://indico.cern.ch/event/633840/
- Next open workshop at CERN Aug. 1-2: https://indico.cern.ch/event/644360/

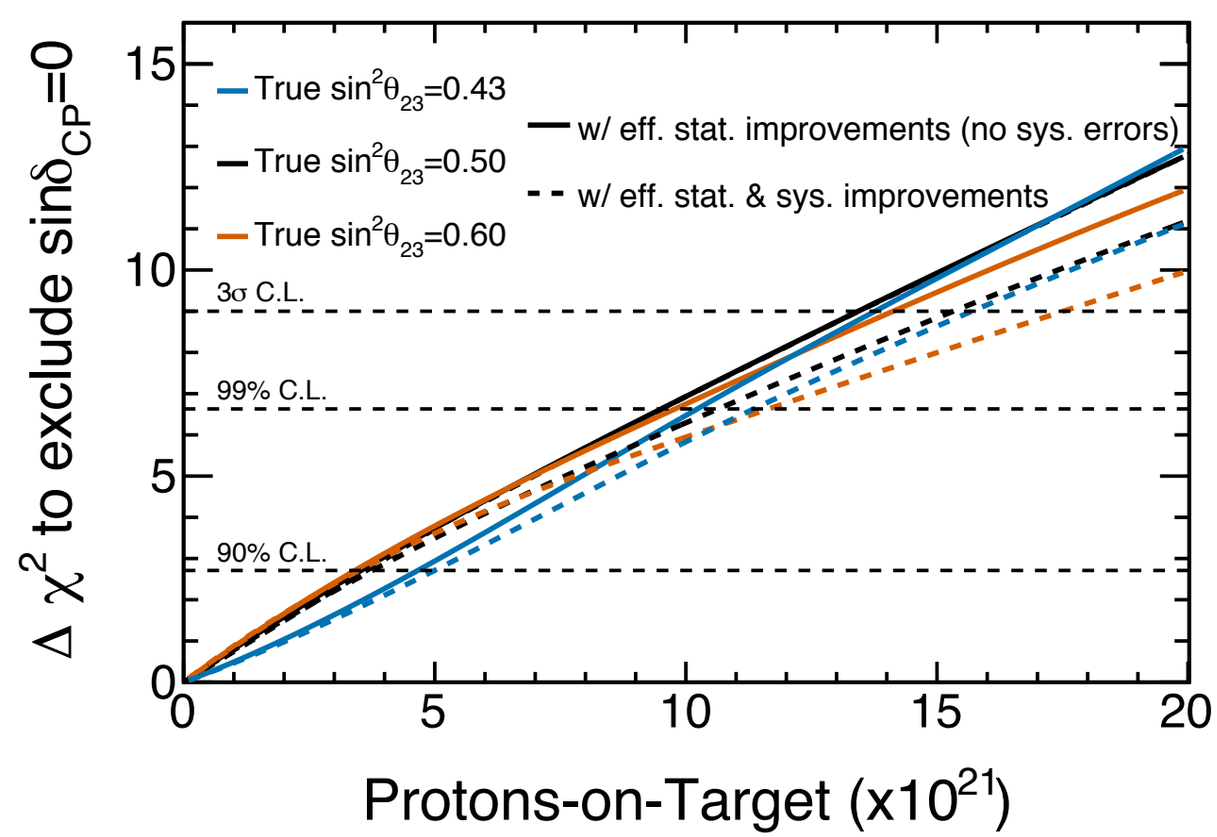
New members are already joining and more are welcome

BACKUP

Prospects for the future: T2K-II

- Expect to reach the approved T2K statistics (7.8×10^{21} POT) around 2021
- **T2K-II phase**: proposed to extend T2K run to 20×10^{21} POT by 2025 (Stage-I status at summer 2016 JPARC PAC)
- Plan to gradually increase the beam intensity up to ~1 MW in 2021
- Demonstrated 3.41×10^{13} protons per beam operation → 1MW equivalent

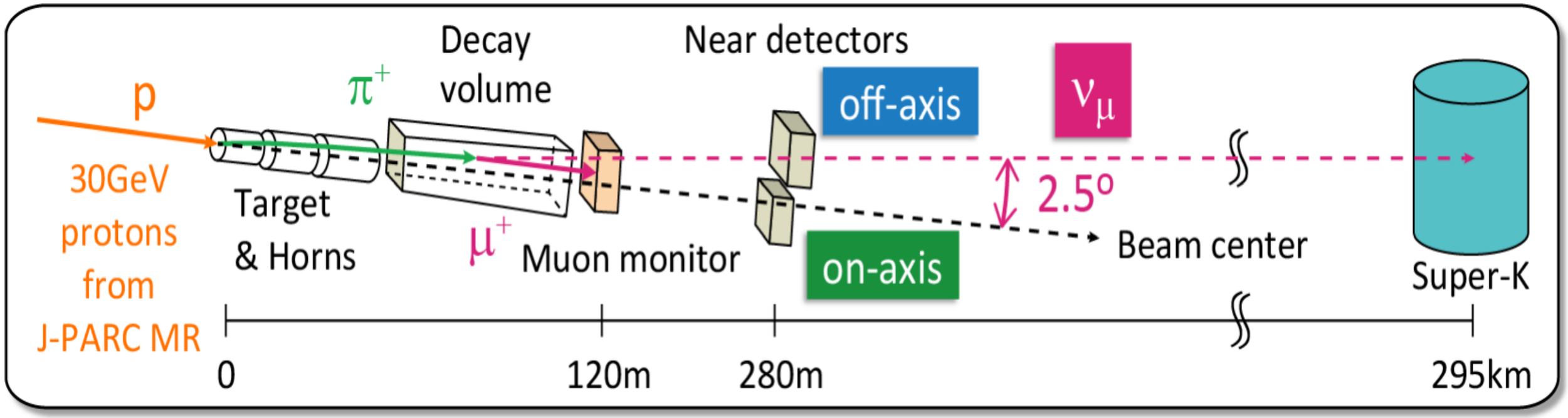




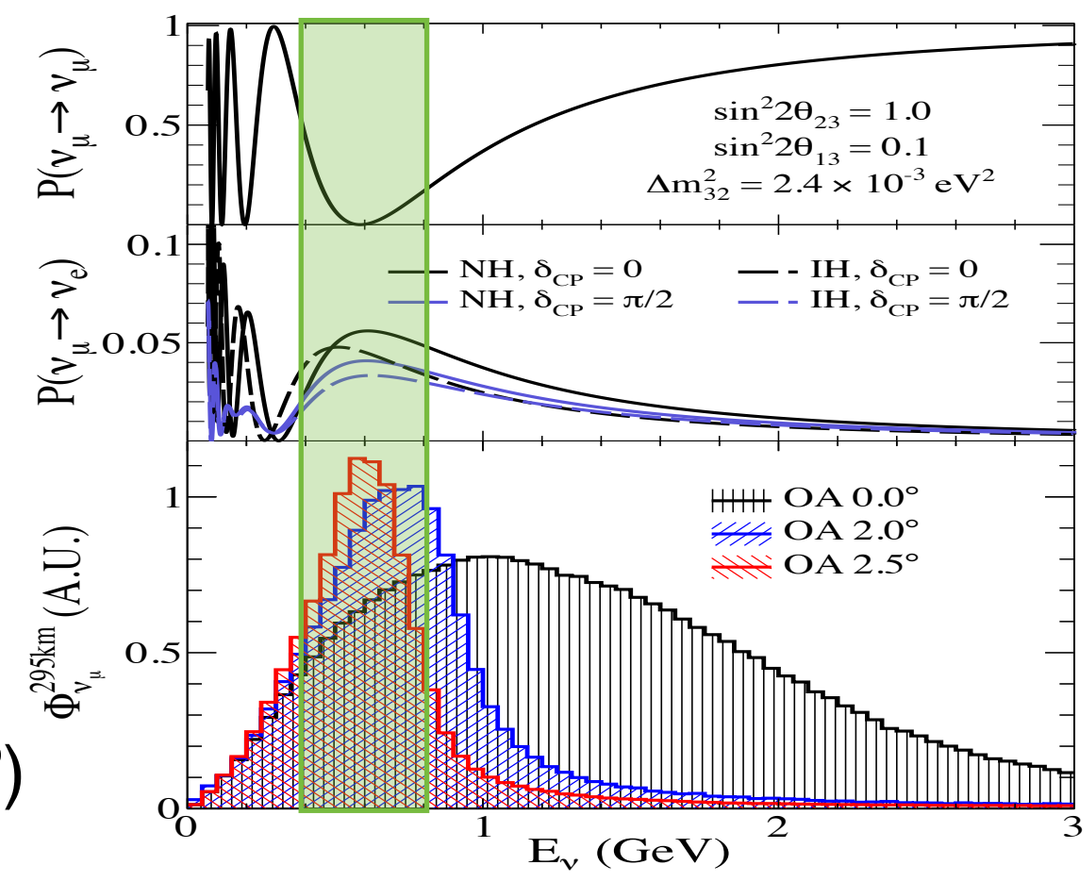
- Exclude CP conservation hypothesis at more than 3σ if $\delta_{CP} \sim -\pi/2$ and NH

We need to reduce the systematic uncertainties

Design principle: the off-axis angle



- 30 GeV proton beam on 90 cm long graphite target
- ν_μ and $\bar{\nu}_\mu$ produced by pion and kaon decay:
  - $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
- Invert magnet polarity to produce a $\bar{\nu}_\mu$ beam
- First off-axis neutrino beam experiment (2.5°)
  - narrow spectrum peaked at 0.6 GeV, on the expected oscillation maximum



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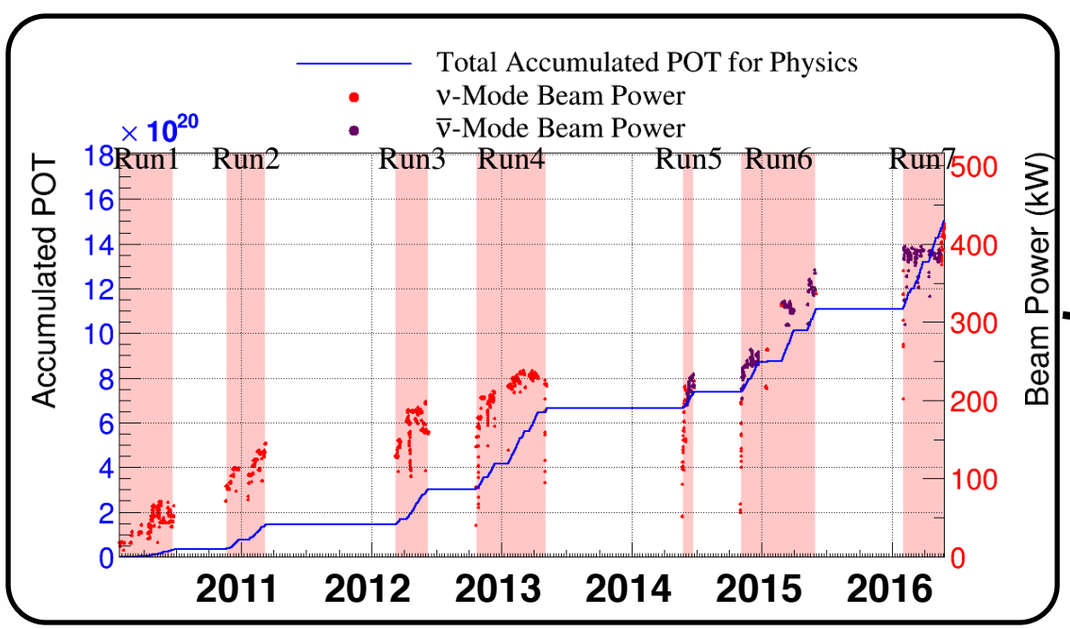
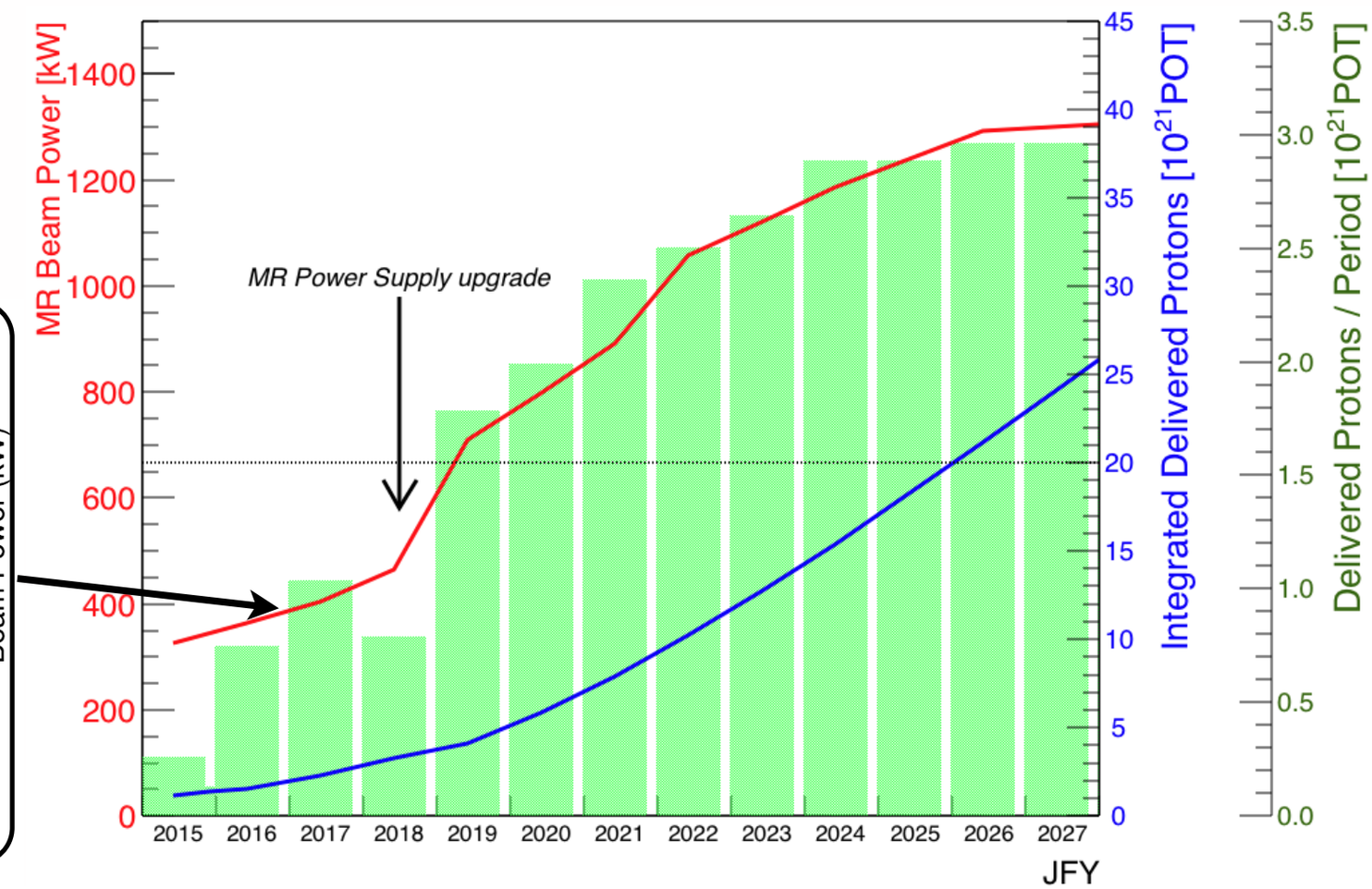
- **T2K-II phase**: proposed to extend T2K run to 20×10^{21} POT by 2025 (Stage-I status at summer JPARC PAC)
- Plan to gradually increase the beam intensity up to ~1 MW in 2021
- Aiming for >1 MW intensity for 2021 and 1.3 MW in ~2026: accelerator and beam-line upgrade is needed
- Demonstrated 3.41×10^{13} protons per beam operation → 1MW equivalent

arXiv:1609.04111

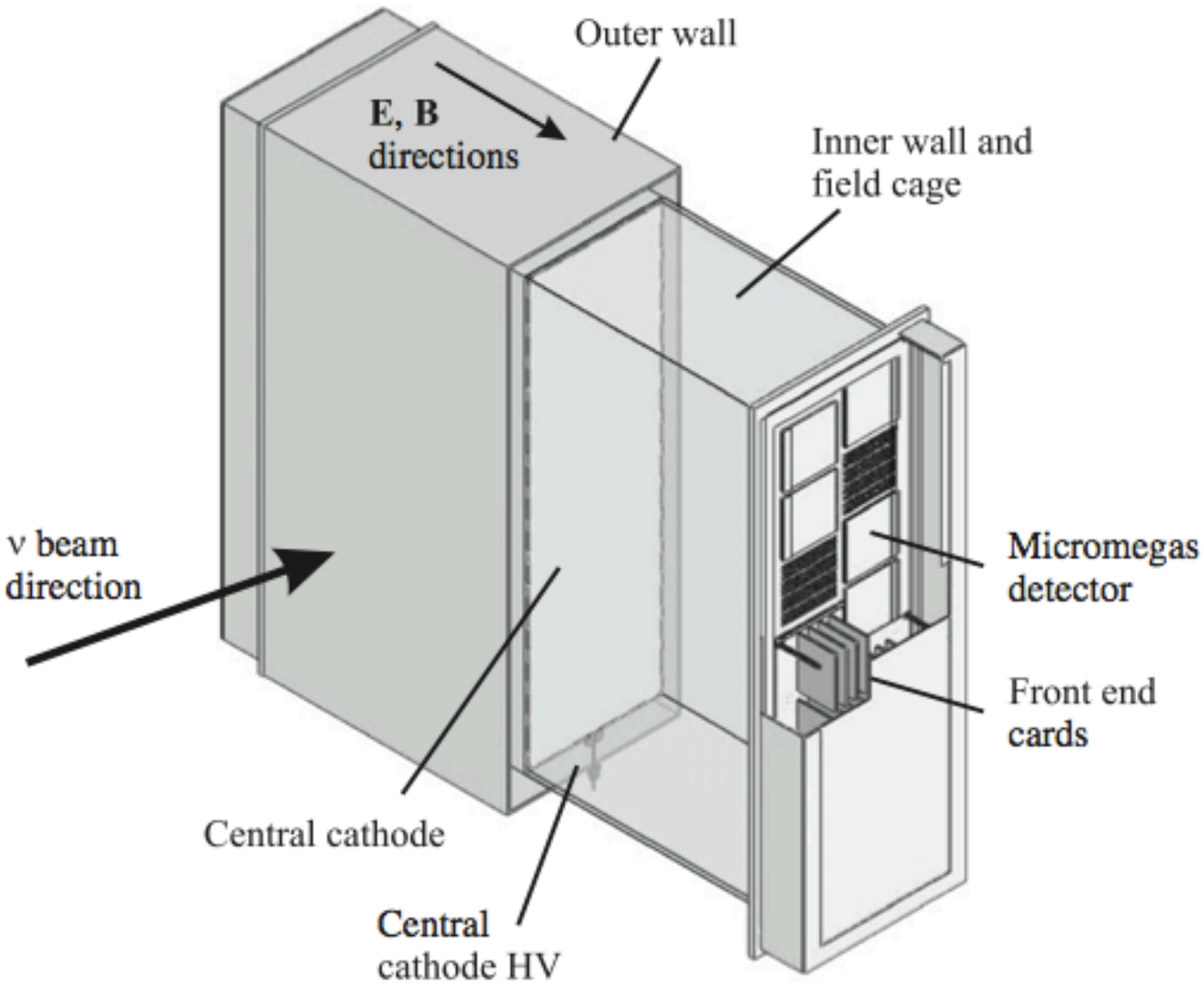
TODAY



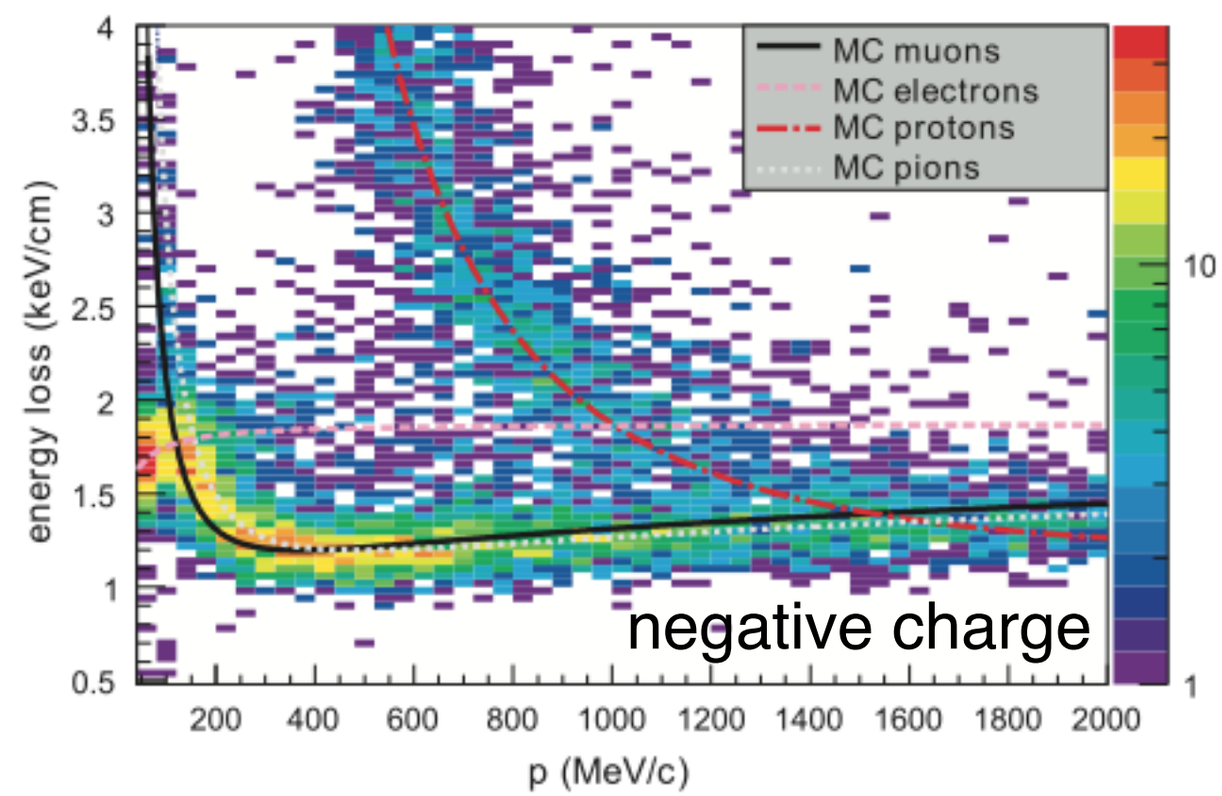


The ND280 TPCs

ADD REFERENCE

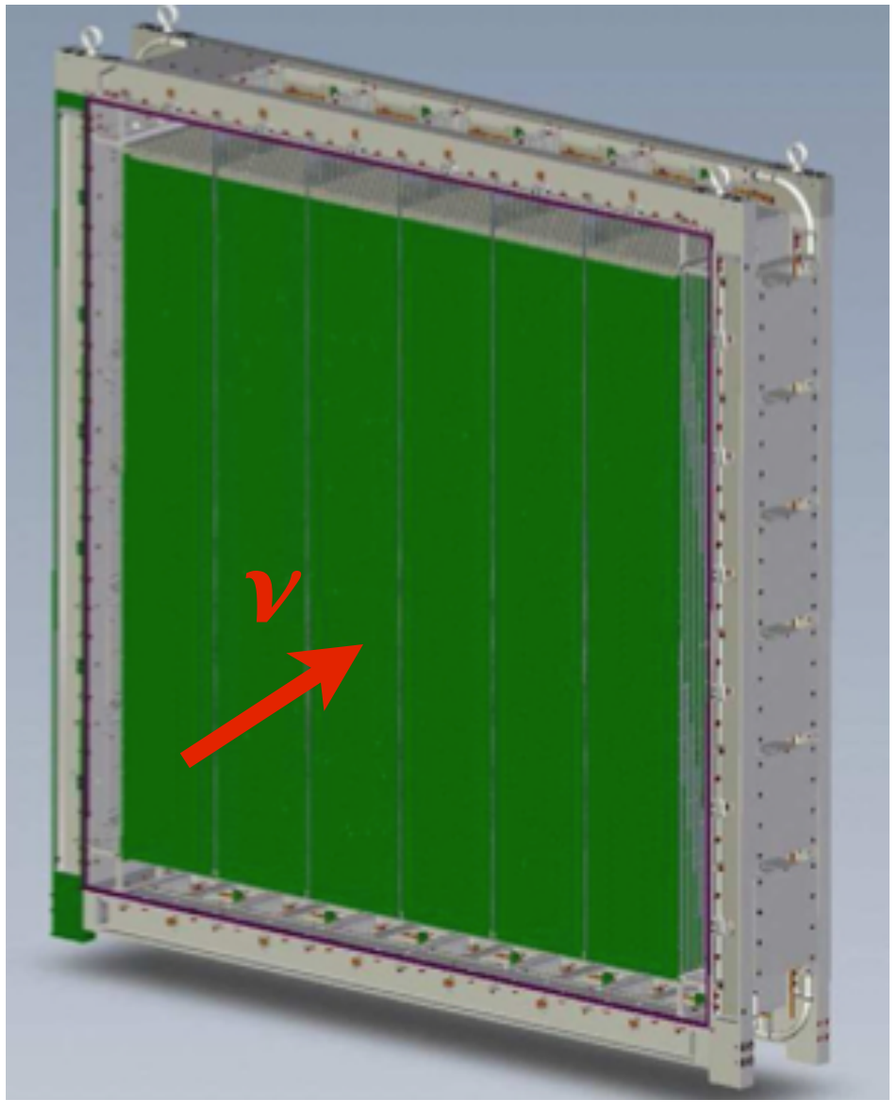


- Gas mixture is $Ar:CF_4:iC_4H_{10}$ (95:3:2)
- Two gas volumes: CO_2 as insulator
- 12 Micromegas modules:
  - $9m^2$ surface covered
  - $70mm^2$ pad segmentation



- Performances:
  - 0.7mm space resolution
  - 9% momentum resolution @1GeV
  - 7.8% resolution in dEdx (MIP)
- Key role in the study of the neutrino interactions: charge, momentum, PID

The ND280 Fine Grain Detector (FGD)



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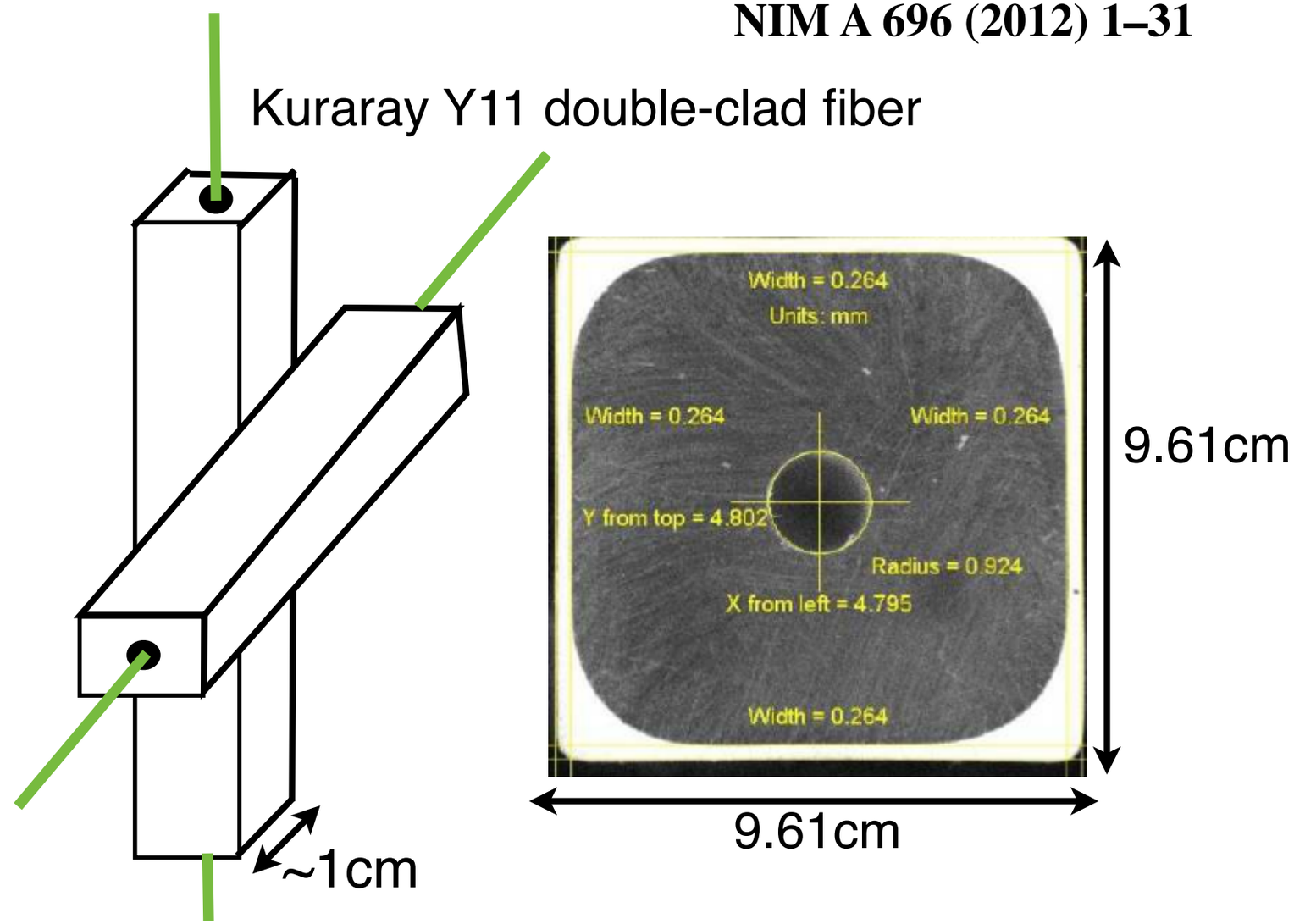
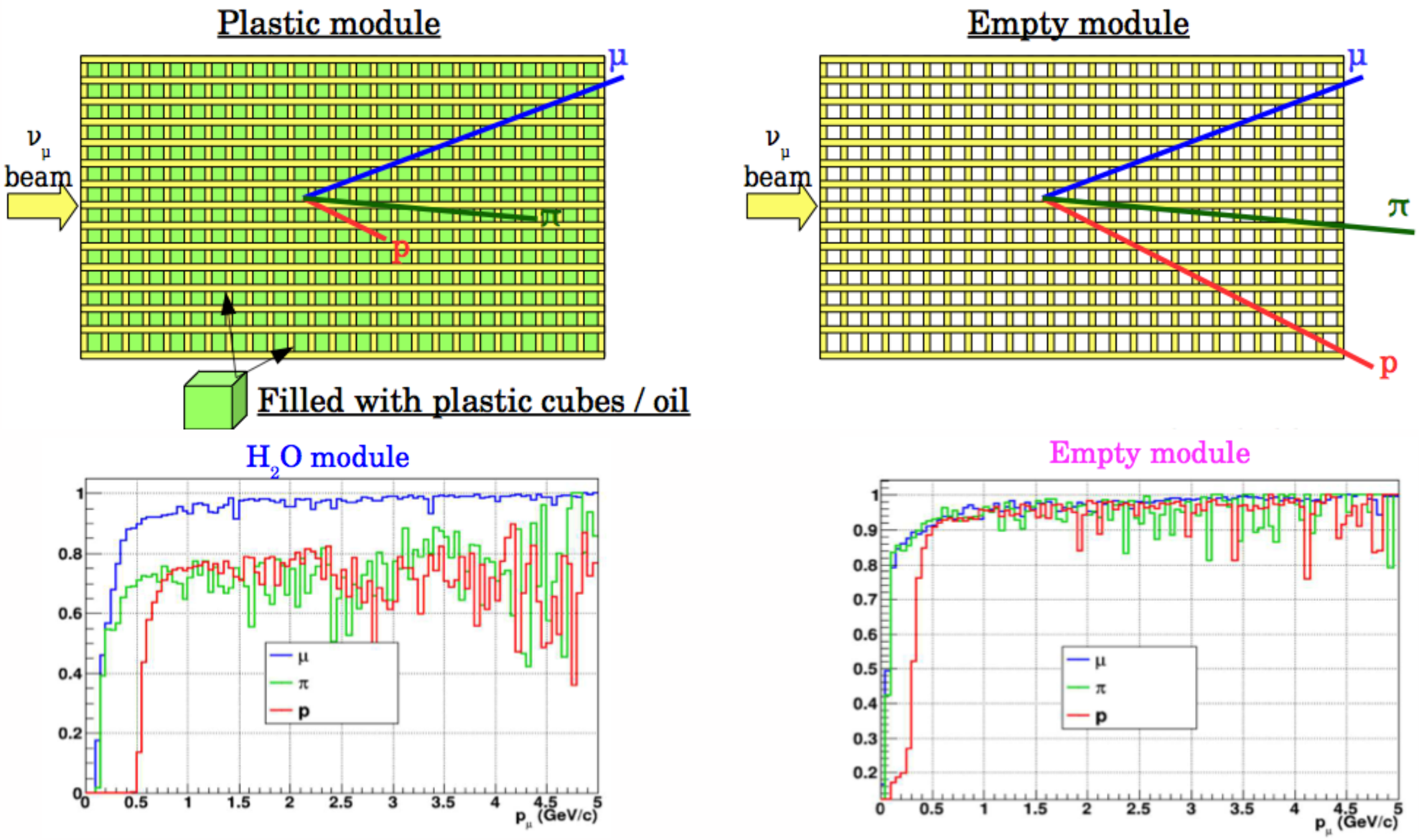


- XY extruded plastic scintillator bars coated with TiO_2 (0.25mm thickness)
- MPPC (S10362-13-050C) 1.3x1.3 mm^2 (PDE@525nm 26-30%)
- About 30 photoelectrons per MIP crossing a bar
- FGD1 (15 XY scintillator layers) - FGD2 (7 XY scintillator + 6 water layers)
  - measure neutrino interactions both in water and plastic (~1.1 ton each)
- Limit: bad acceptance high-angle tracks

The neutrino target detector

- Plastic scintillator structure: 4π acceptance

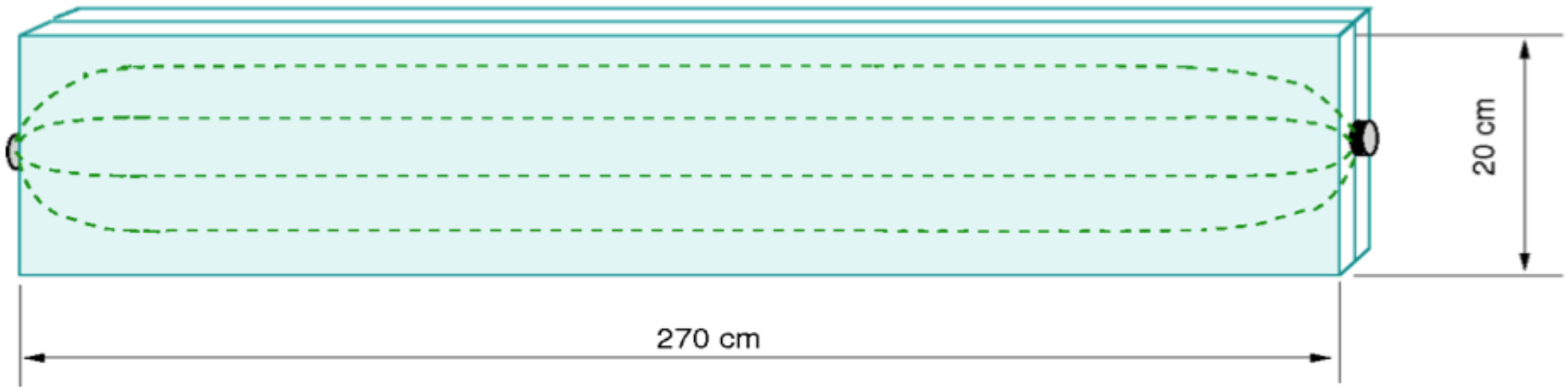


- Empty module drastically reduces the momentum threshold but ~30% mass
- Protons threshold down to ~300 MeV/c (close to Fermi momentum)
- Efficiency >90% over the full solid angle

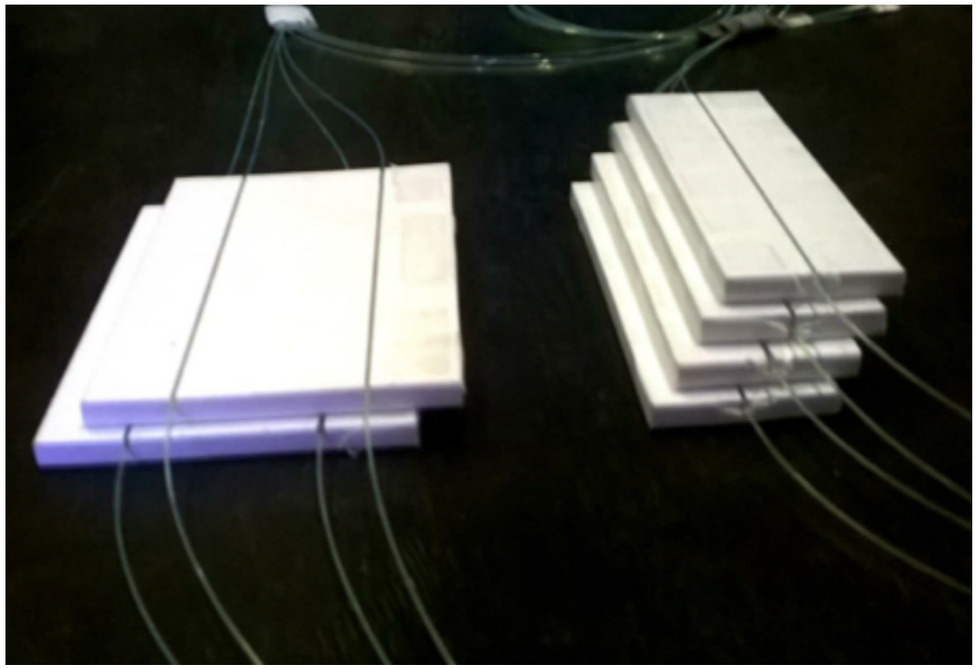
Time of Flight detector

- Provide timing for good track reconstruction
- Improve particle Identification, e.g. separate e^+ from ~1GeV protons

Extruded plastic scintillator



- 2 extruded plastic scintillators (20x0.7x270 cm^3)
- 4 WLS Kurakay 1mm fibers glued in each slab
- 8 WLS fibers connected to the connector at each side
- Connector mounted directly on the scintillator
- Single 3x3mm^2 MPPC at each end
- Expected time resolution is ~630-650 ps

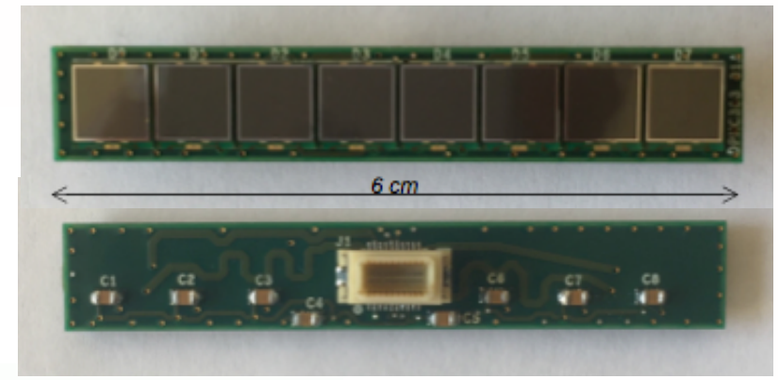


Several tests made at INR

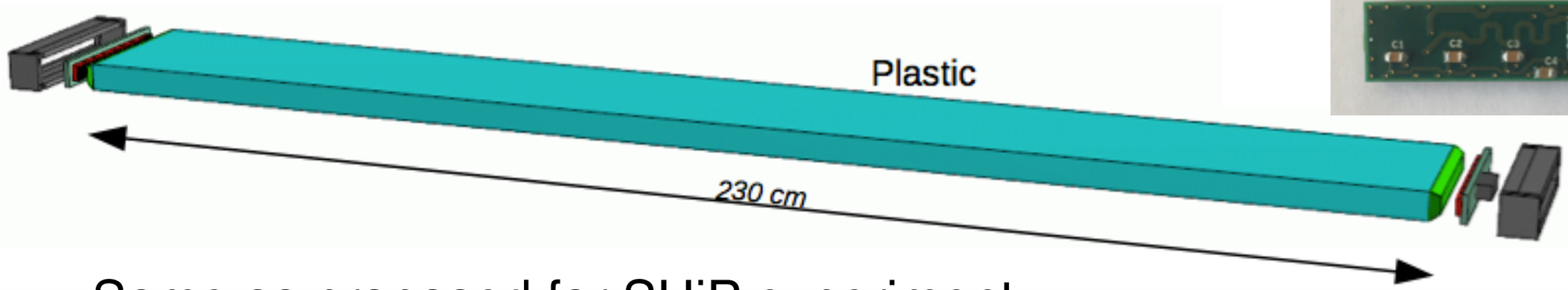
Time of Flight detector

- Provide timing for good track reconstruction
- Improve particle Identification, e.g. separate e^+ from ~1GeV protons

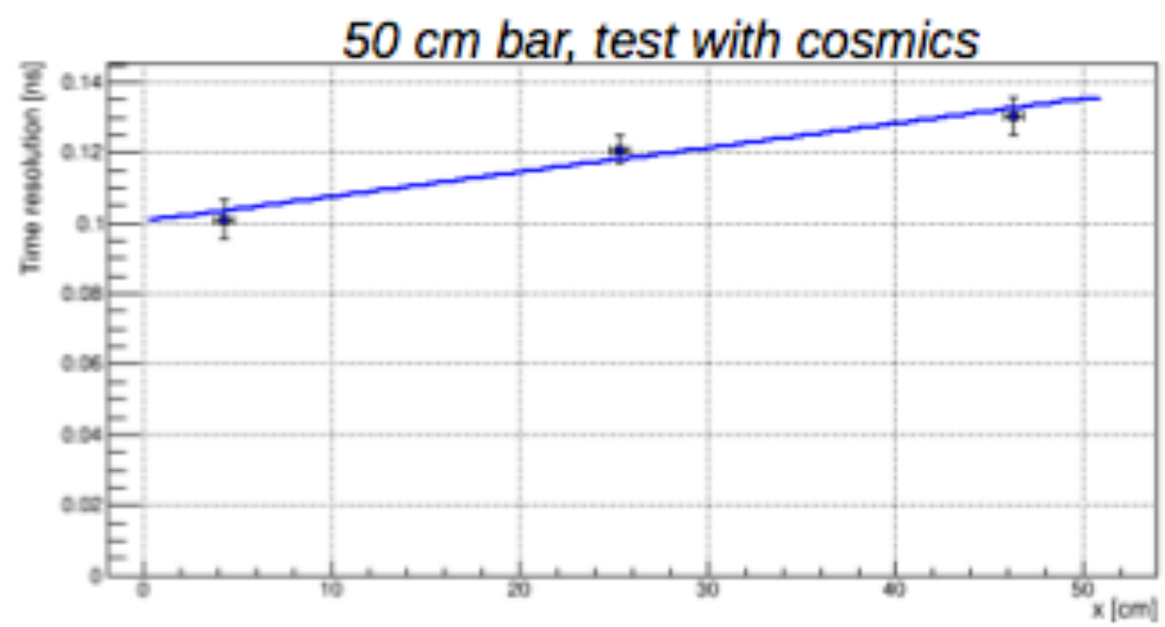
Cast plastic scintillator



Bar size: 6x1x270 cm^3



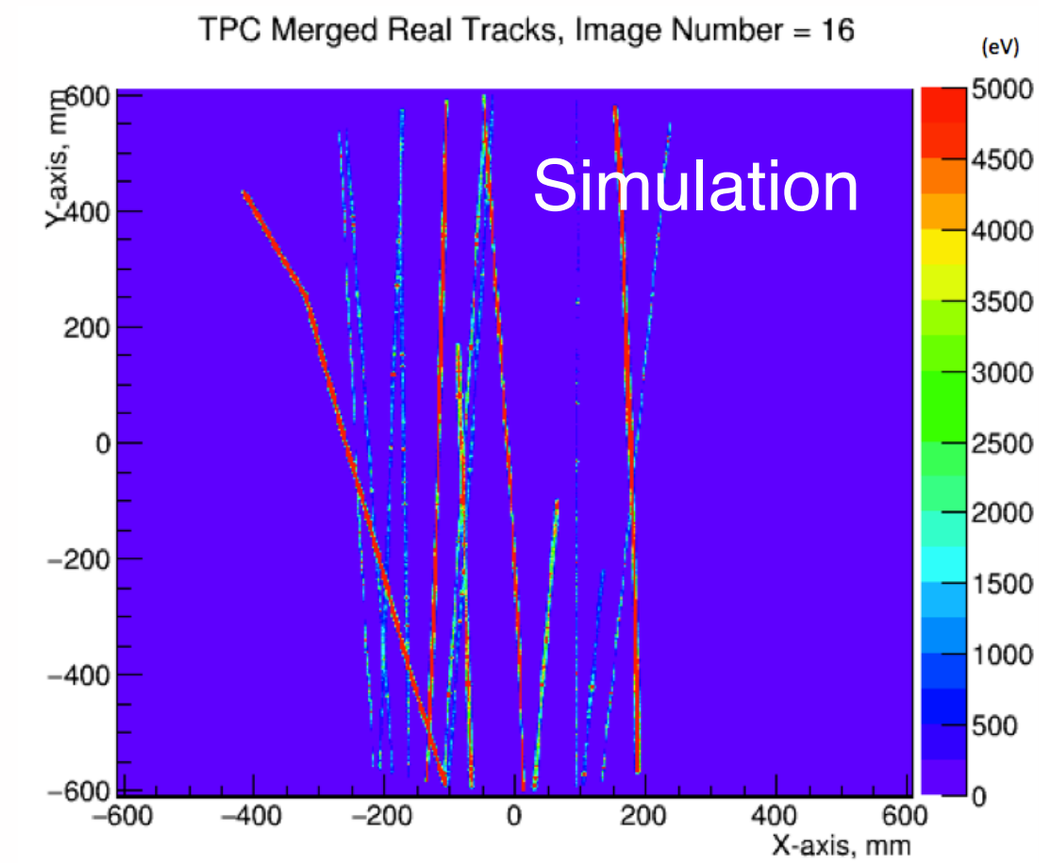
- Same as proposed for SHiP experiment
- Plastic material: EJ200(BC408) or EJ208(BC412)
  - Attenuation length ~4m
  - 1.42 kg/bar
- 8 sensors of 6x6 mm^2



- σ_t @50cm is ~140ps. With 1m long and double-end readout σ_t~100ps
- Better time resolution but more expensive than extruded plastic scintillator

R&D for a High Pressure TPC

- High pressure gas filled with time projection chamber:
  - use the gas as neutrino interaction target
- Complementary to plastic scintillator detectors:
  - much less target mass but detect most of the particles



Optical CCD + charge readout

- Beam test: prototype of 1 m^3 at 5 bar (CF_4, Ar, Ne, CH_4)
- Target is 2018 at CERN
- Measure proton-nucleus and pion-nucleus cross section

Preliminary EOI-15 Work Packages and Contact persons

Management: MZ and Masashi Yokoyama,
Contact with CERN: Alain Blondel

- WP1 Mechanical design and integration (Marcela Batkiewicz, Davide Sgalaberna)
- WP2 TPC field cage and gas vessel (Gabriella Catanesi, Emilio Radicioni)
- WP3 TPC Readout technology (Alain Delbart, CERN)
- WP4 TPC electronics and DAQ (Denis Calvet, Andrzej Rychter)
- WP5 Scintillator-based trackers (Japan+LLR)
- WP6 TOF system (Yury Kudenko)
- WP7 Gas system and calibration (Blair Jamieson, CERN)
- WP8 Test beam measurements (Federico Sanchez, Stefania Bordoni)
- WP9 High Pressure TPC (Asher Kaboth, Morgan Wascko)
- WP9 Simulation and optimization studies (Davide Sgalaberna)
- WP10 Physics studies (Sara Bolognesi, Claudio Giganti)
- WP11 DAQ (Giles Barr)
- WP12 Software (Yoshi Uchida)