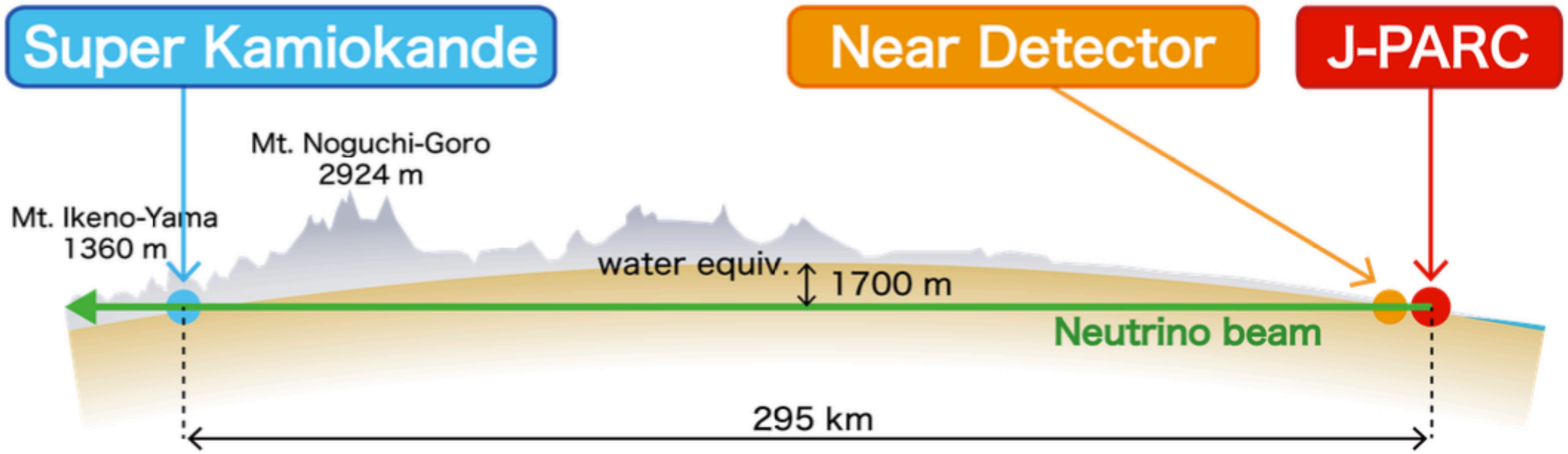
The T2K near detector upgrade

NGUYEN Quoc Viet
Laboratoire Leprince-Ringuet

30th Rencontres du Vietnam
Windows on the universe

Quy Nhon, 08/08/2023

T2K EXPERIMENT

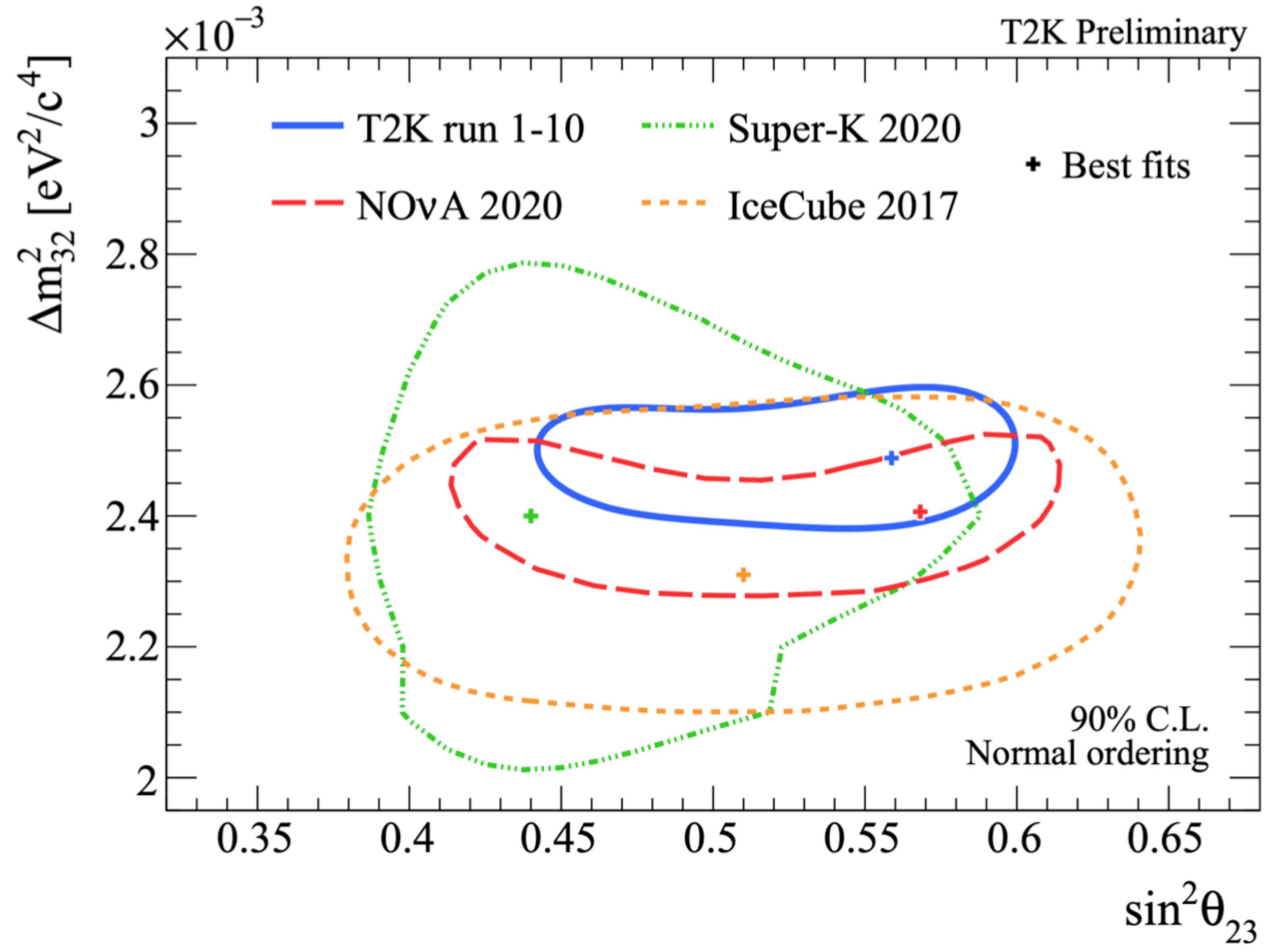


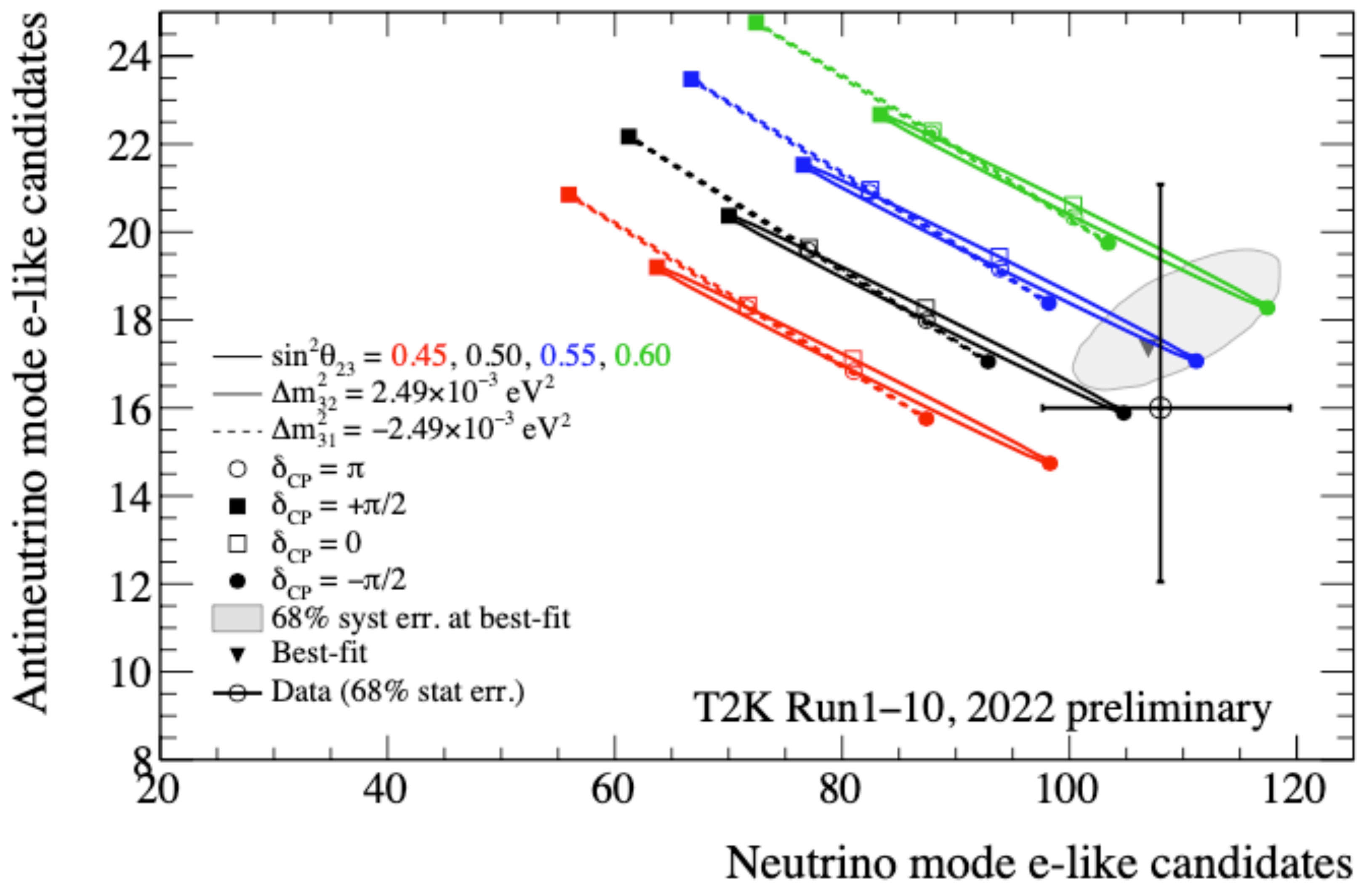
- T2K (Tokai to Kamioka) is a long-baseline neutrino experiment in Japan, and is studying neutrino oscillations.
- T2K is the first experiment to report evidence for the neutrino appearance oscillation ($\nu_\mu \rightarrow \nu_e$) in 2013 (Phys. Rev. Lett:12:061802, 2014.)
- The current goal of T2K is searching for the CP violation in the lepton sector by comparing the appearance probabilities of neutrino and antineutrinos. (T2K can produce either neutrino or anti-neutrino beam).
  => First hint of CP violation at 3sigma CL in 2020 (Nature 580, 339-344 (2020))

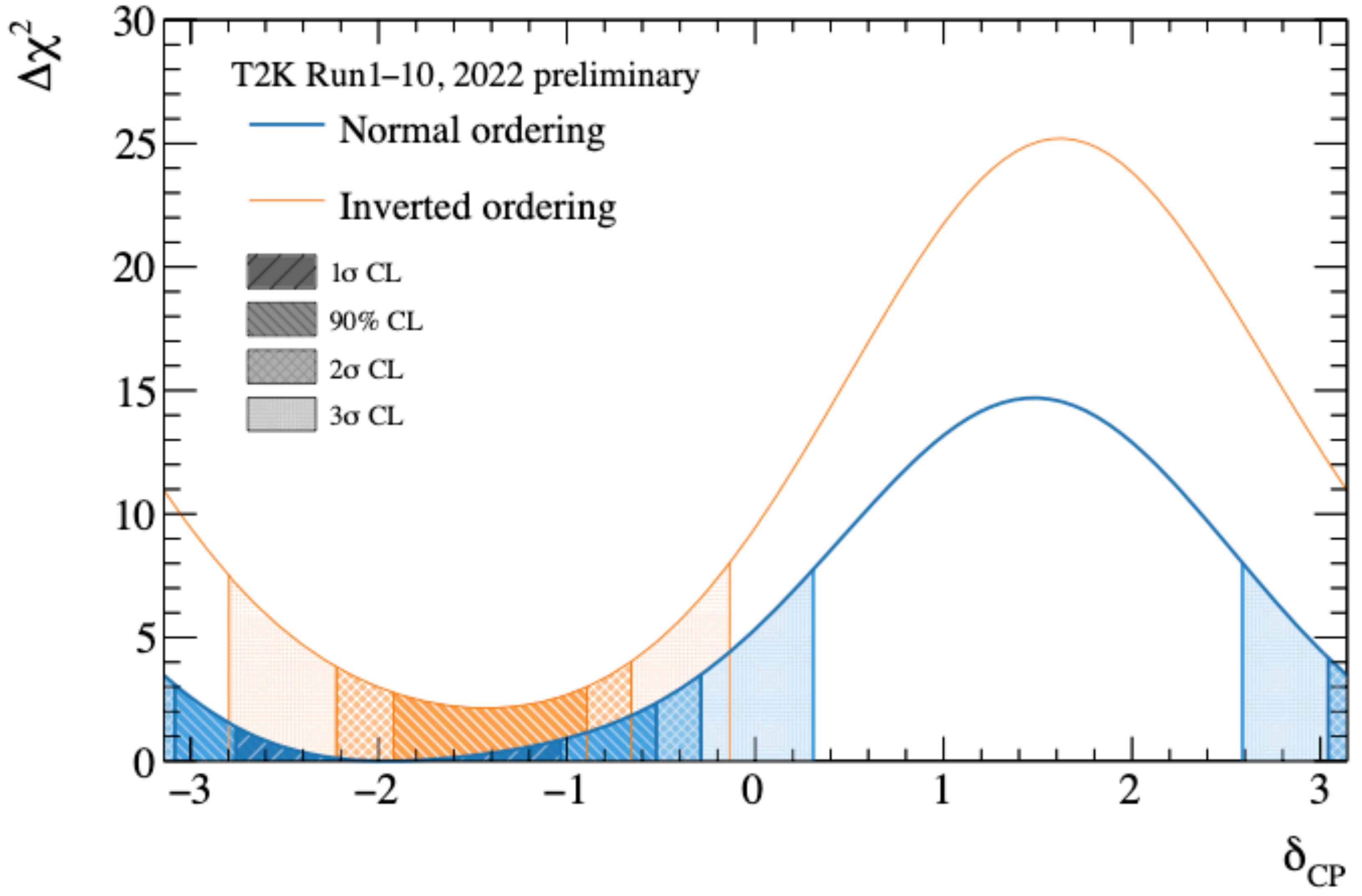
T2K EXPERIMENT

T2K EXPERIMENT: CURRENT RESULTS

- 4 main oscillation channels in T2K: $\nu_\mu \to \nu_\mu$ disappearance (dominated by θ_{23} and Δm^2_{23}) and $\nu_\mu \to \nu_e$ appearance (dominated by θ_{13}, θ_{23} and δ_{CP} and mass hierarchy) and similar two for anti-neutrino.



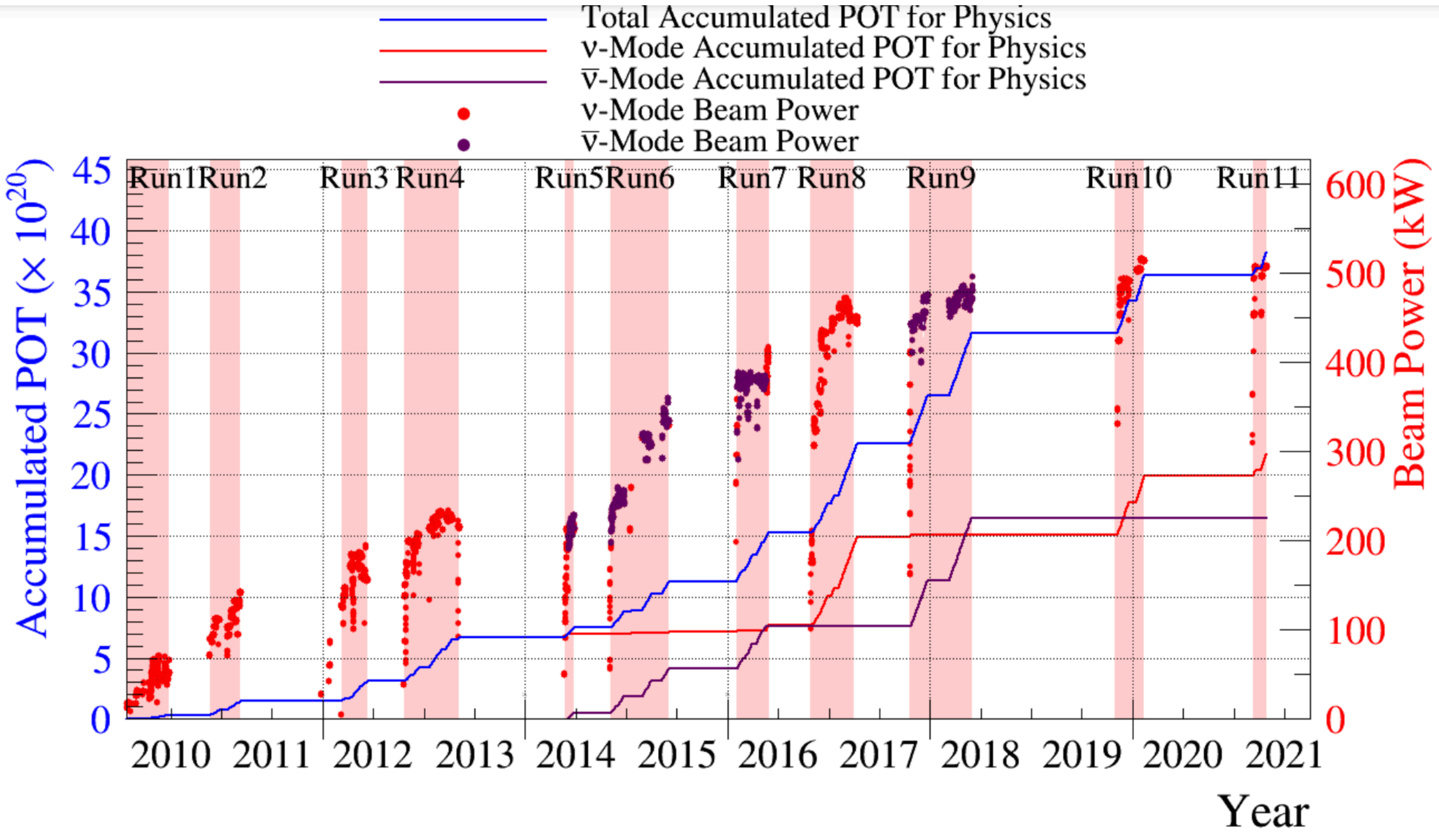




- Data point around the maximum CP-violating value of $-\pi/2$
- A wide region of δ_{CP} space is excluded at 3σ C.L.
- The constraints for $\nu_e/\bar{\nu}_e$ appearance are still dominated by the statistical uncertainty

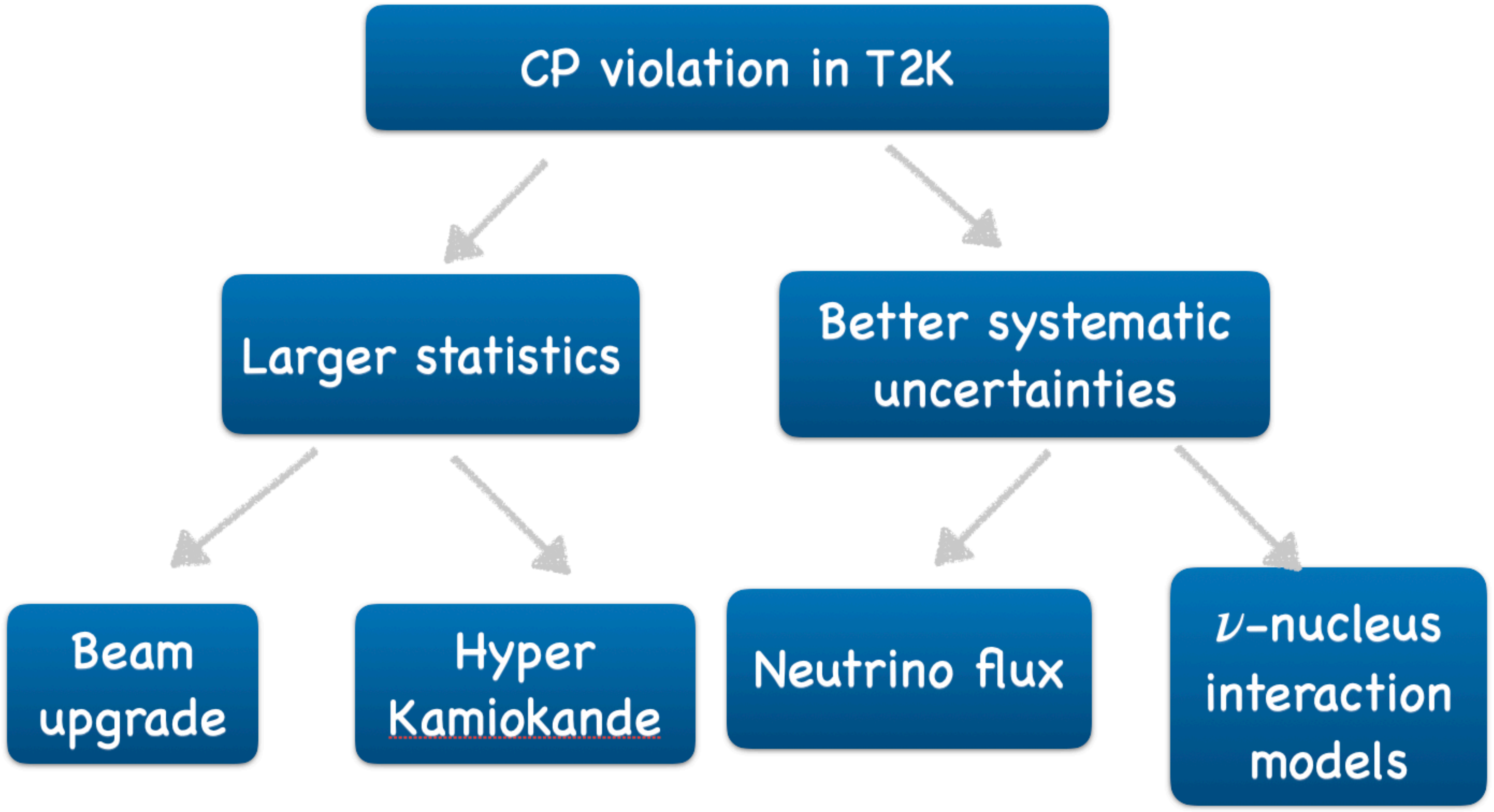
More on T2K plenary talk on Aug. 10th by Son Cao

T2K STATISTIC



23 Jan 2010 – 27 Apr 2021
POT Total: 3.82×10^{21}
(maximum power 522.6 kW)

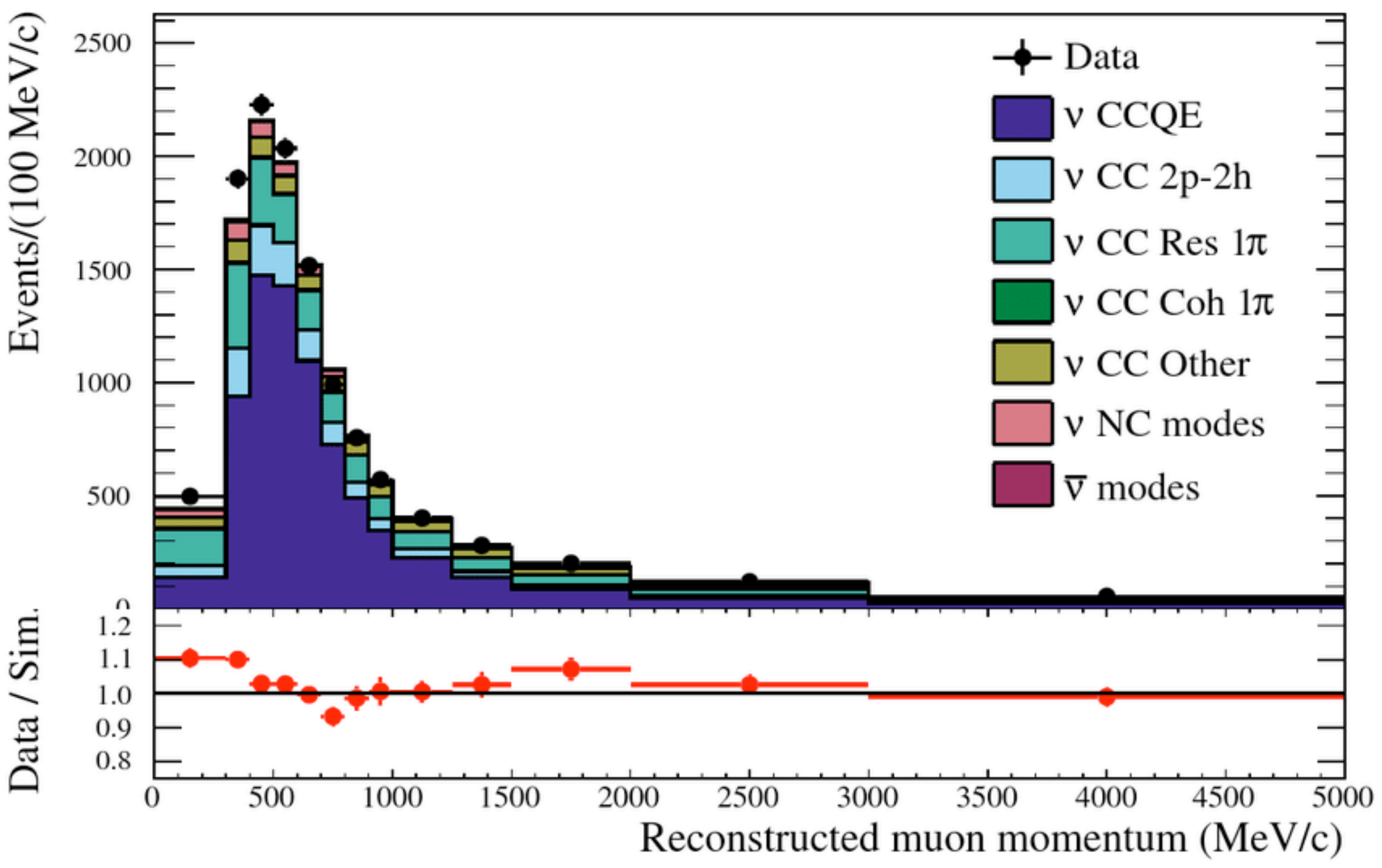
ν-mode: 2.17×10^{21} (56.8%)
$\bar{\nu}$-mode: 1.65×10^{21} (43.2%)

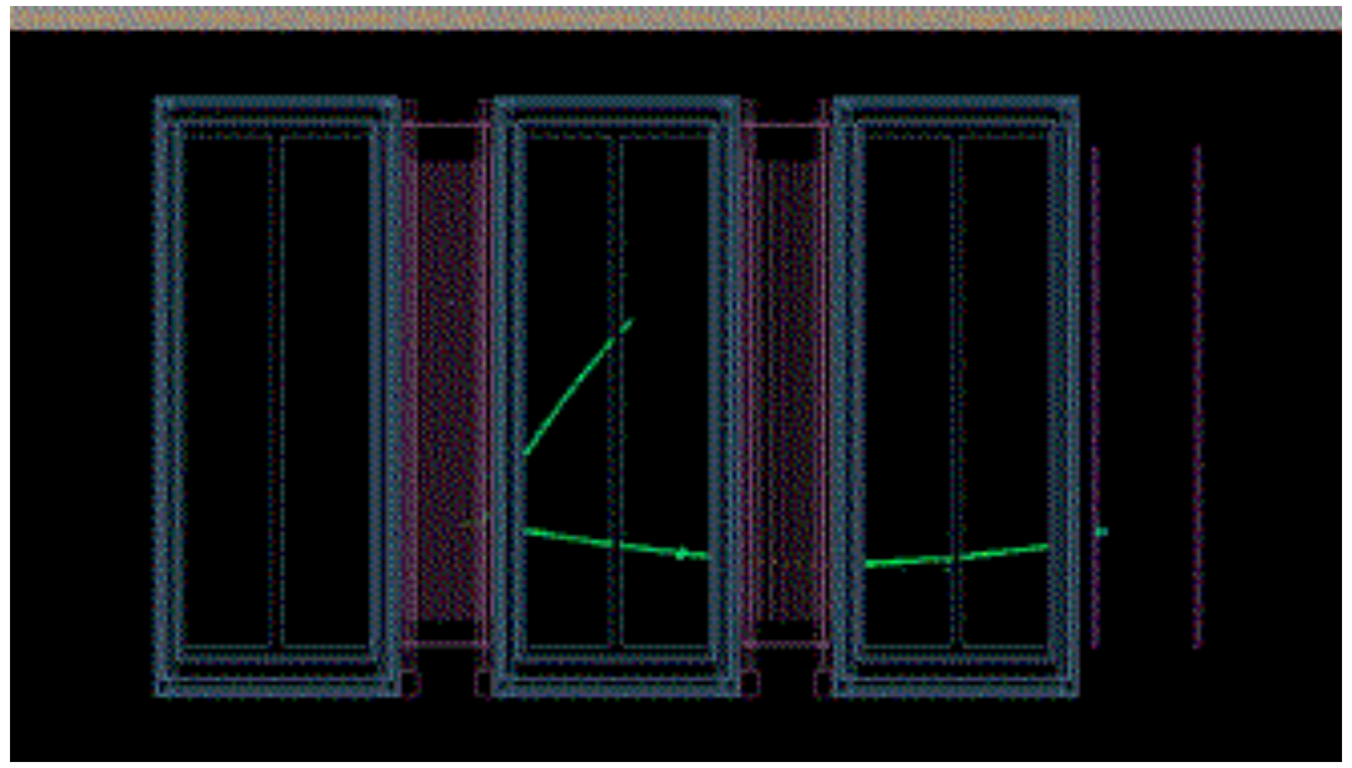


Need to better constrain ν-nucleus interactions models
=> ND280 upgrade project

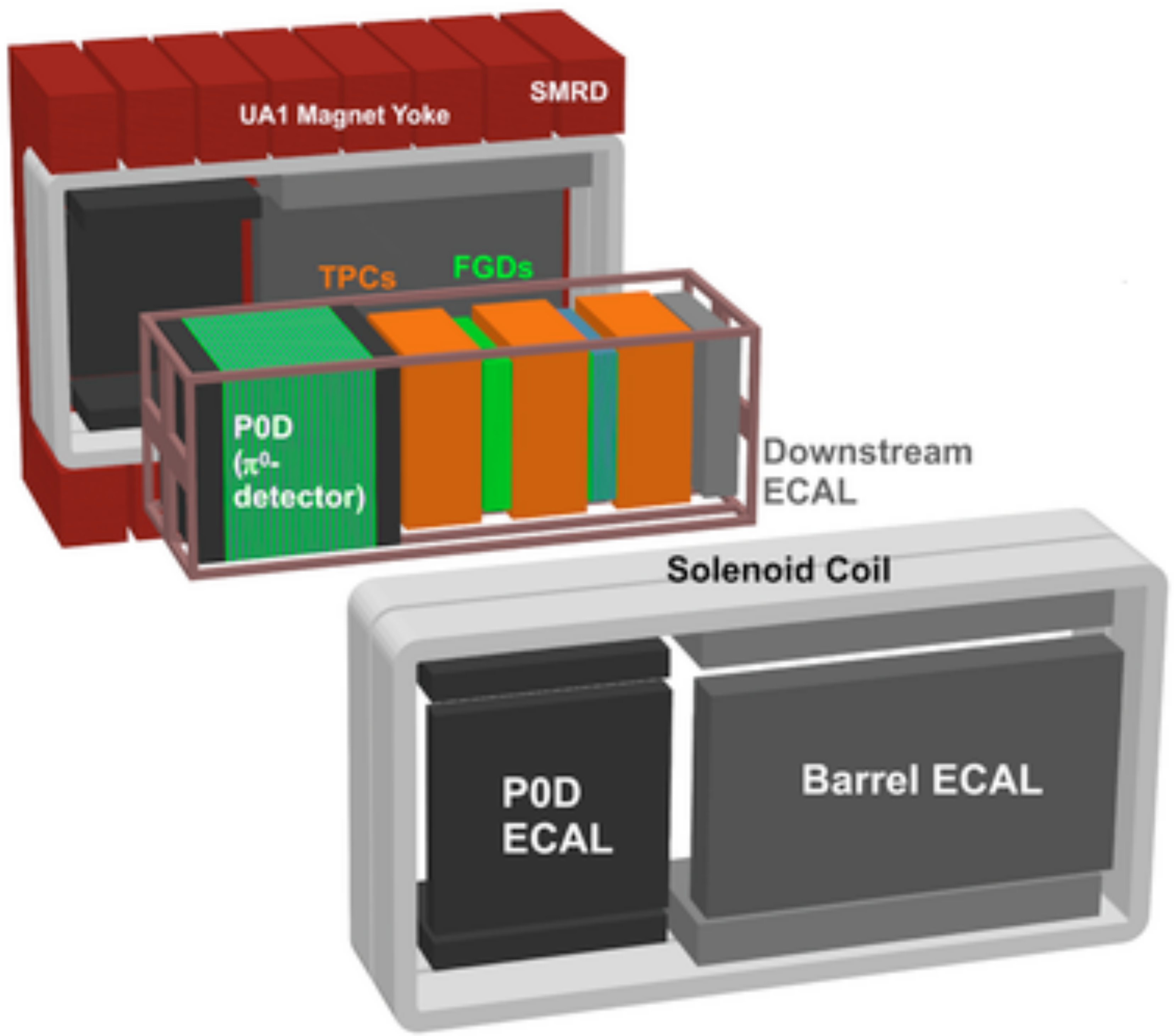
T2K EXPERIMENT: NEAR DETECTOR (ND280)

- Near detector ND280 is designed to constrain the neutrino flux⊗cross-section
- The tracker includes 2 Fine Grained Detectors (FGD) and 3 Time Projection Chambers (TPC)
  => measure the momentum of charged particles and particle identification.



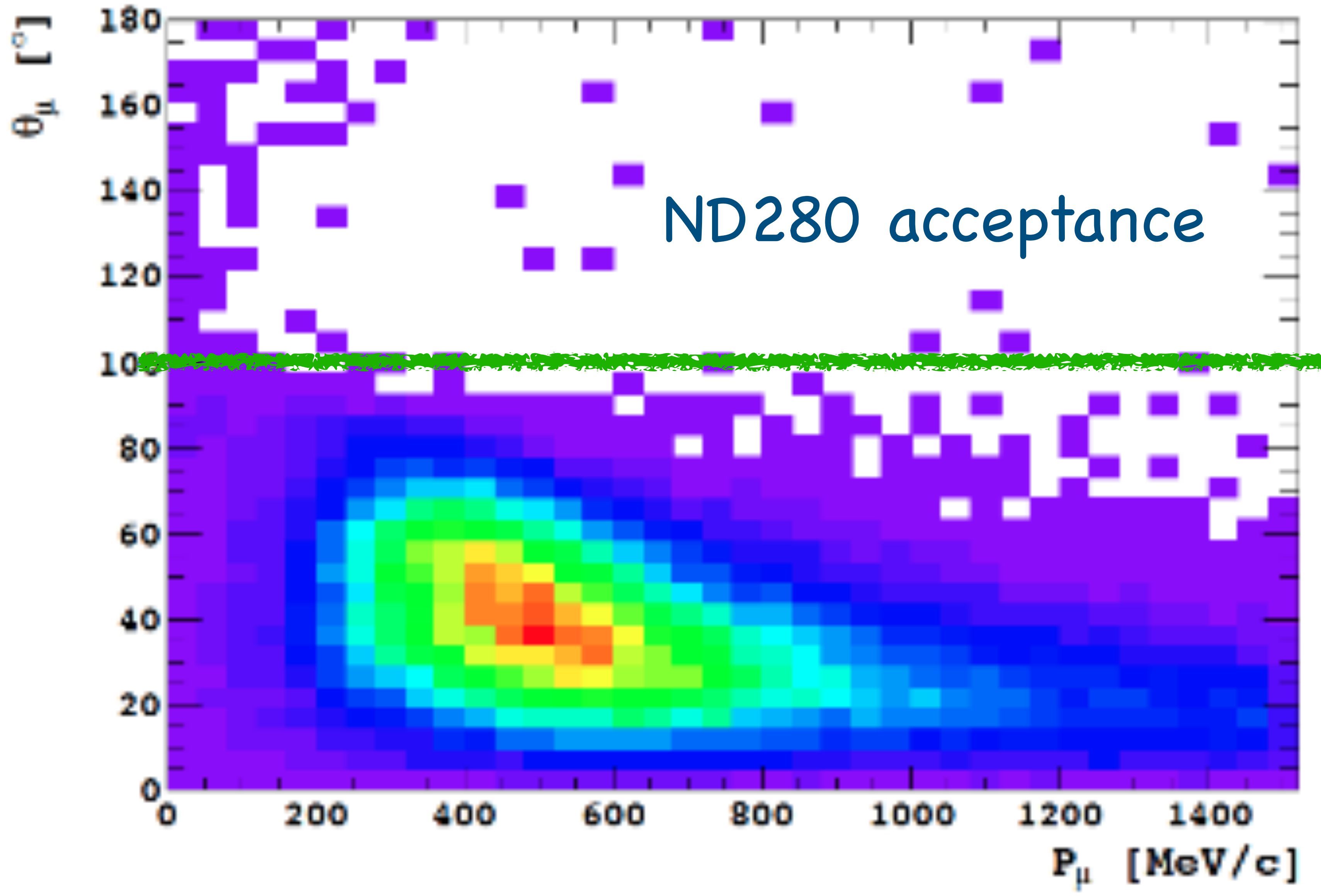


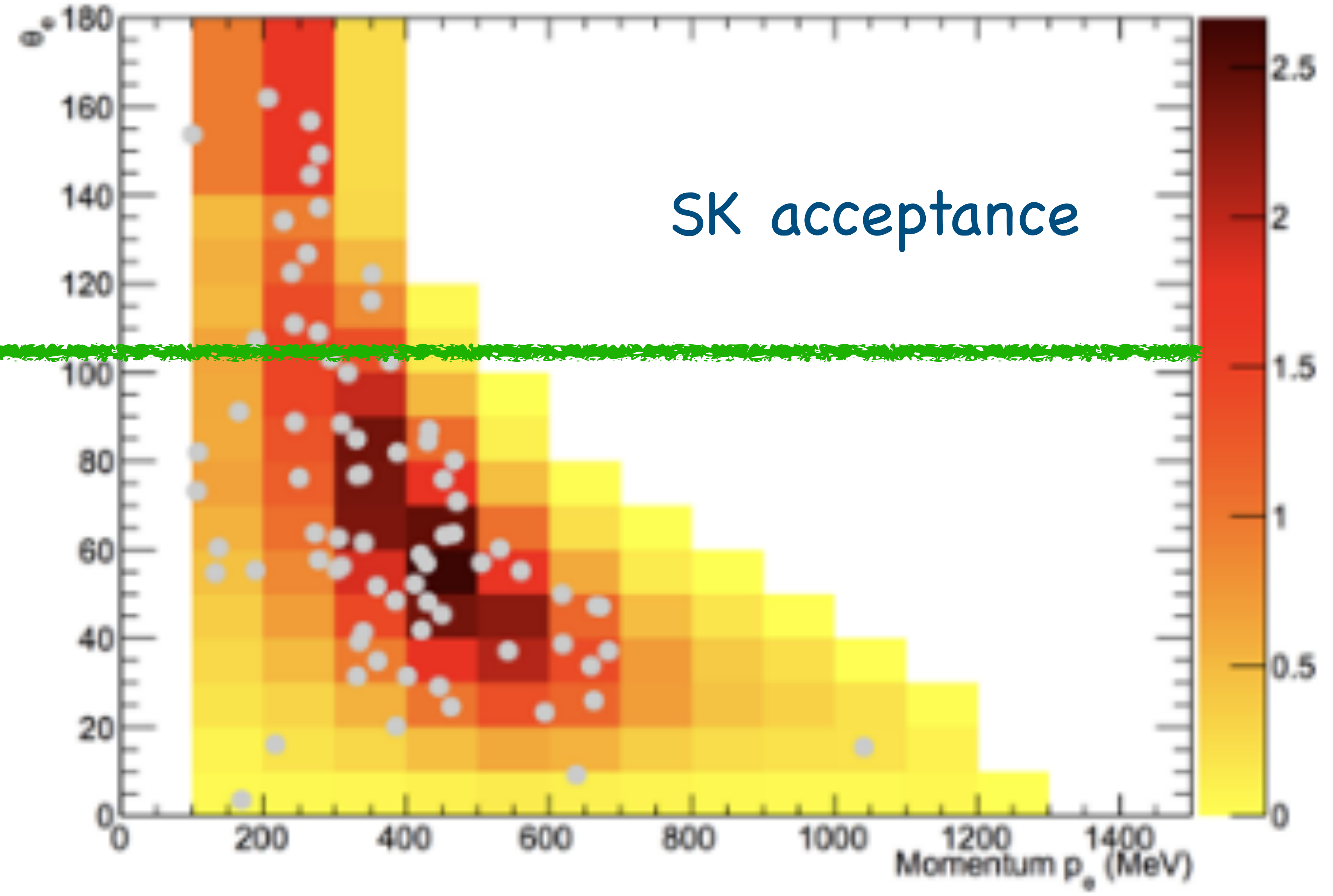
QE event at ND280



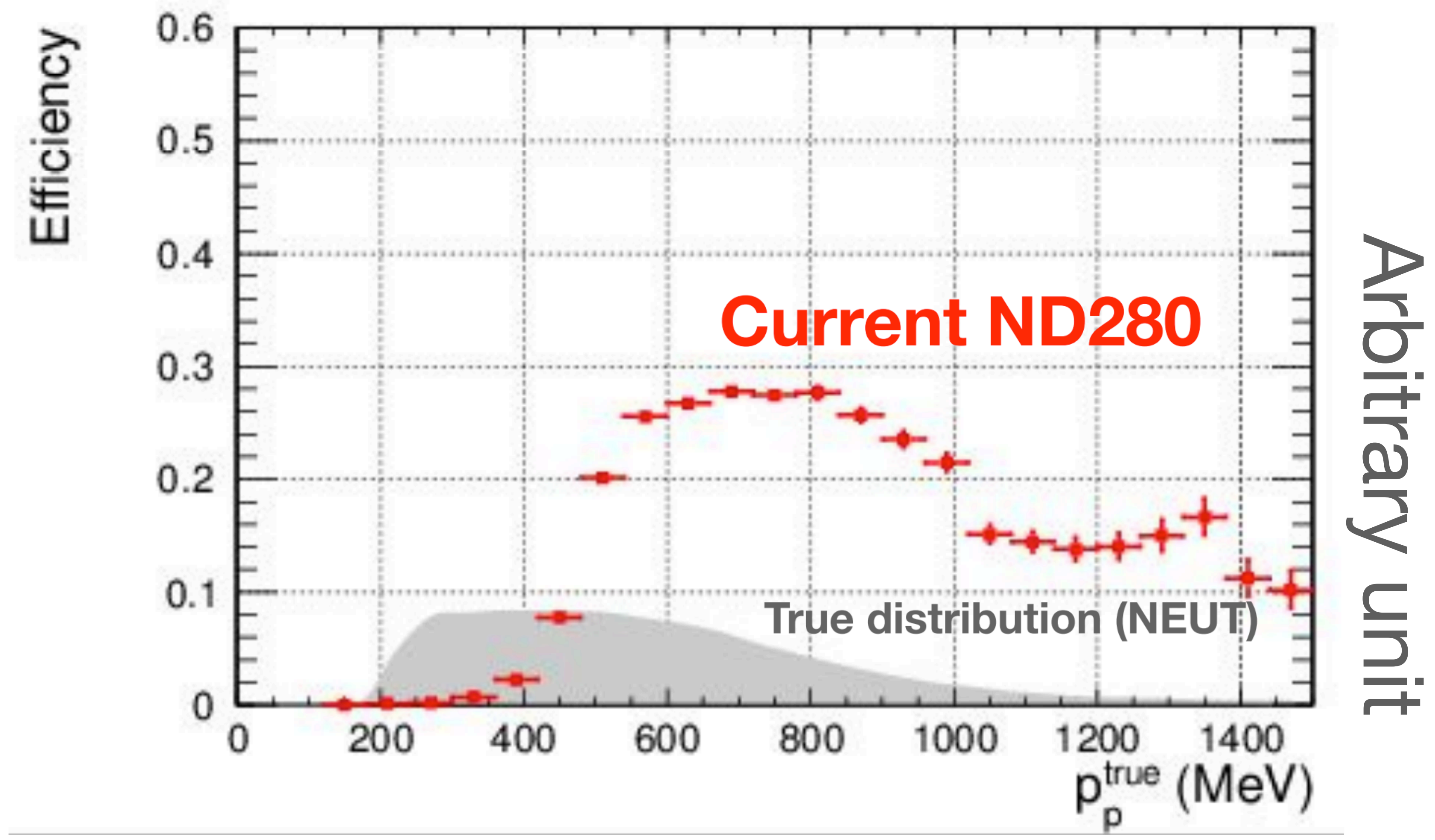
ND280 configuration

ND280 upgrade motivation



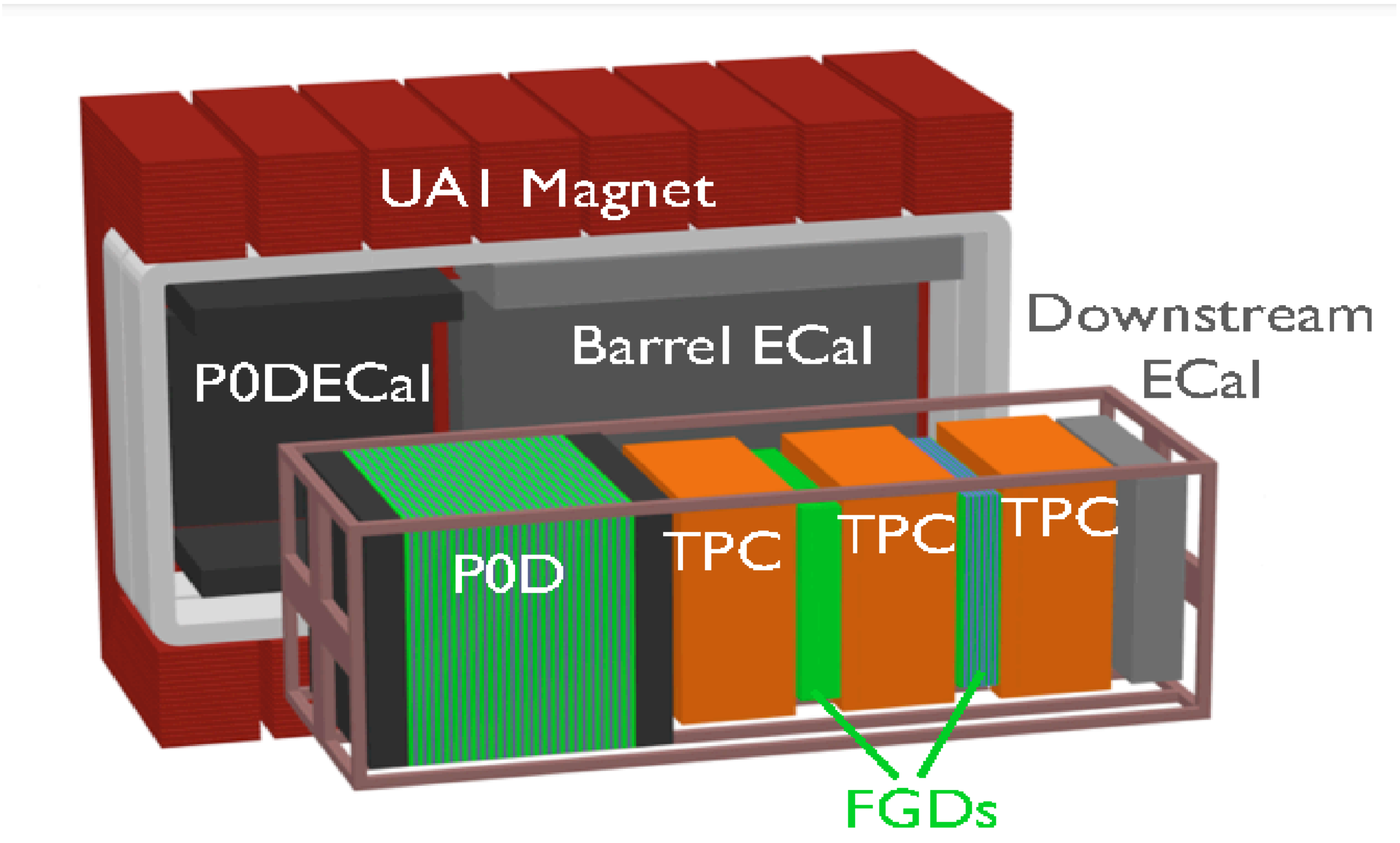


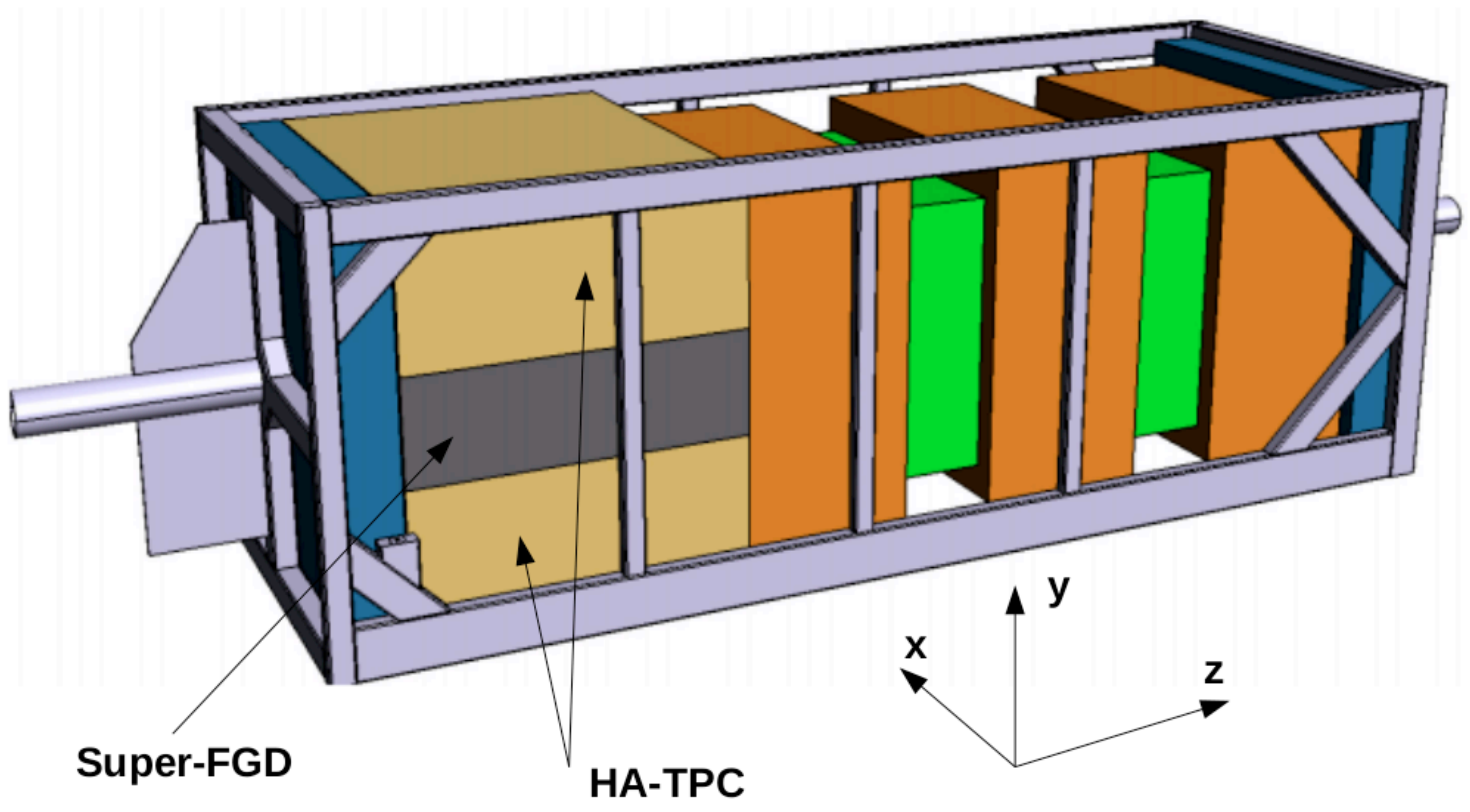
- The polar angle acceptances are not comparable between near and far detector
- The proton detection threshold is high
- Only muon kinematics are used to reconstruct neutrino energy



Proton detection efficiency

UPGRADED NEAR DETECTOR ND280: CONFIGURATION



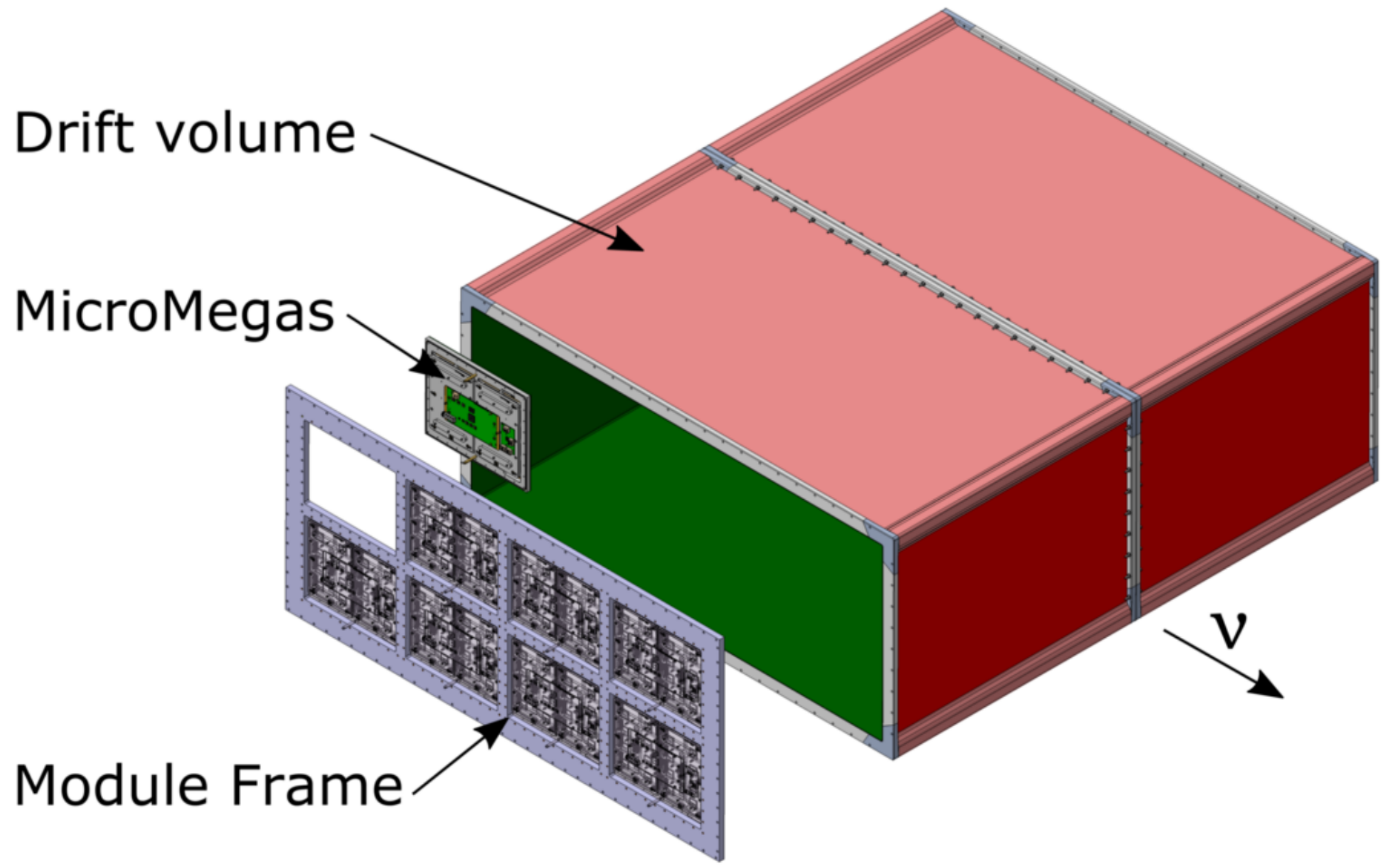


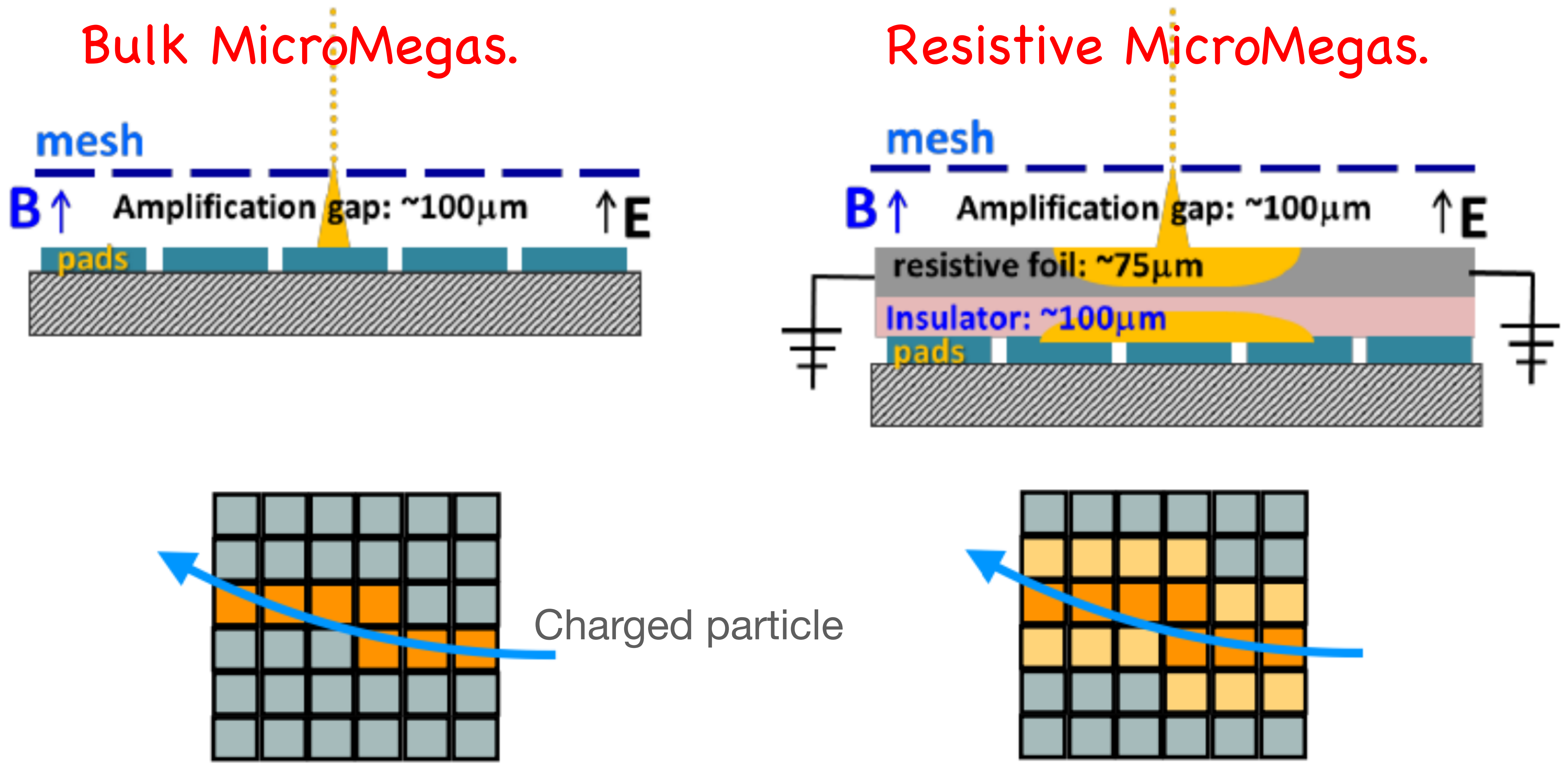
- 2 new High Angle TPC (HA-TPC)
- 1 Super-FGD in between 2 HA-TPC
- New Time Of Flight detector (TOF)

High Angle Time Projection Chamber (HA-TPC)

- Two new HA-TPCs
  - Dimensions: 1.865 x 2.0 x 0.82 m^3
  - Track reconstruction in 3D, PID by measuring momentum and deposited charge

- Main differences with current ND280 TPC
  - High-Angle TPC contains a new type of detector which is the Resistive MicroMegas (ERAM modules) with better spatial resolution.

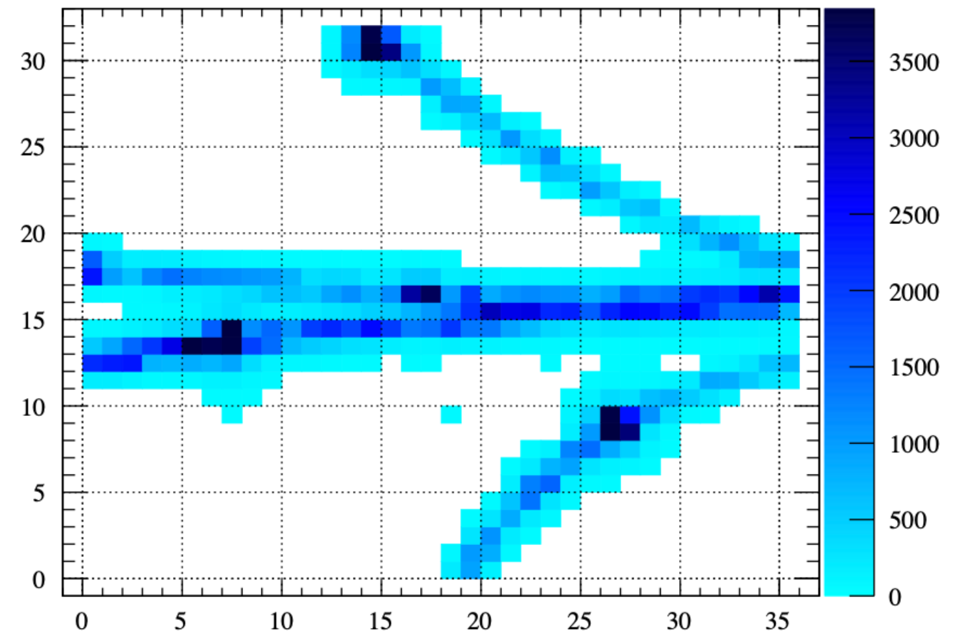


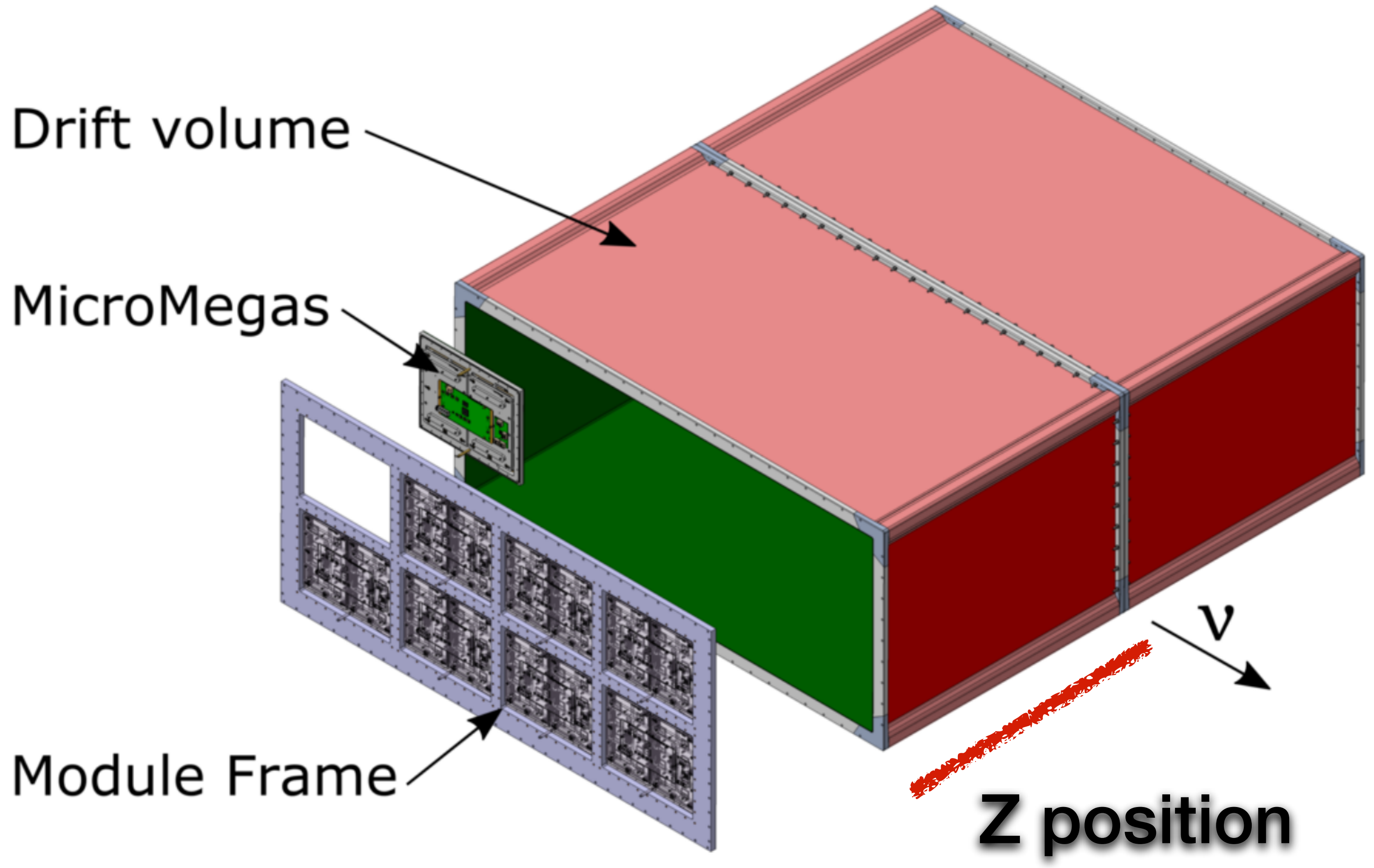


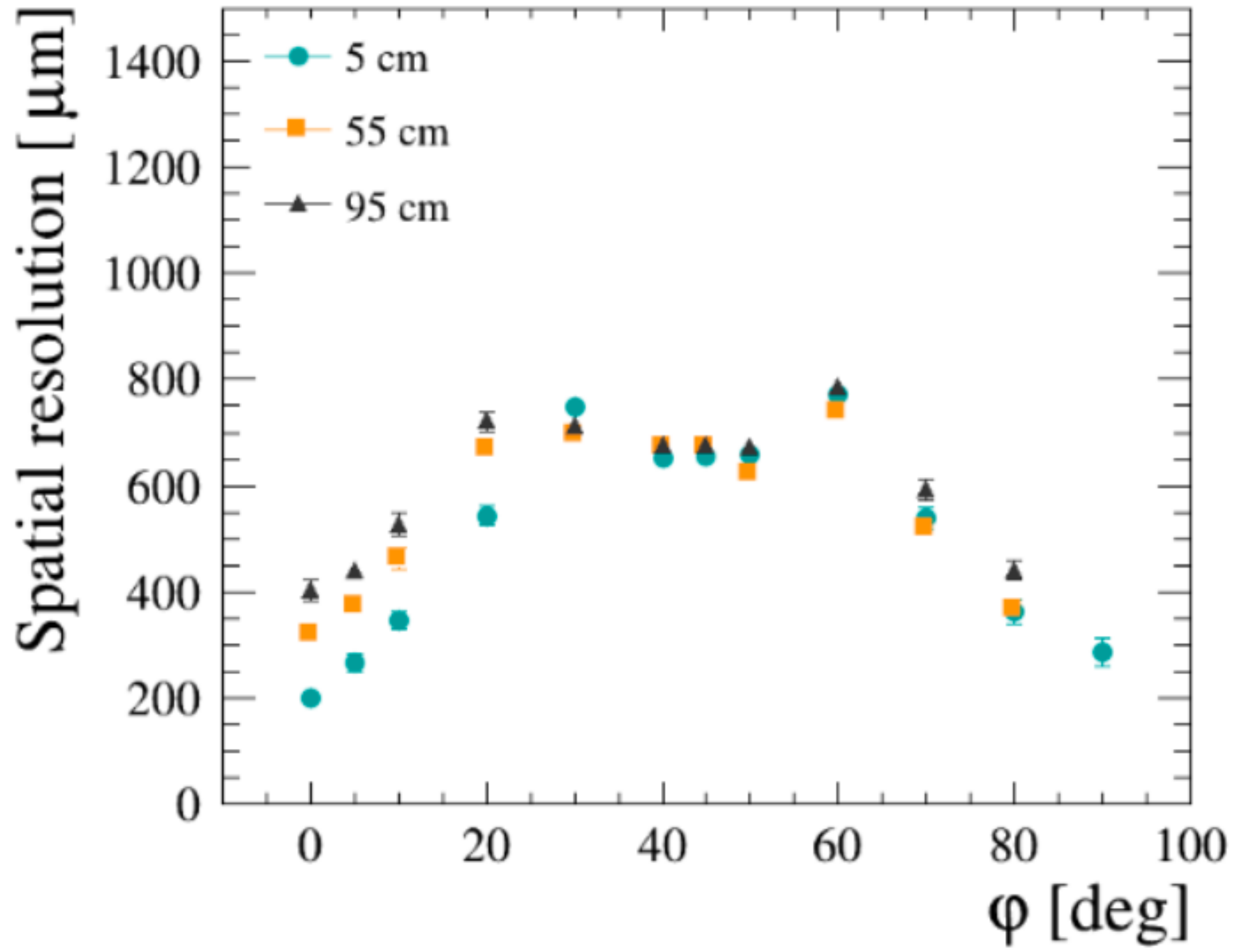
HA-TPC PERFORMANCE WITH TEST BEAM MEASUREMENT

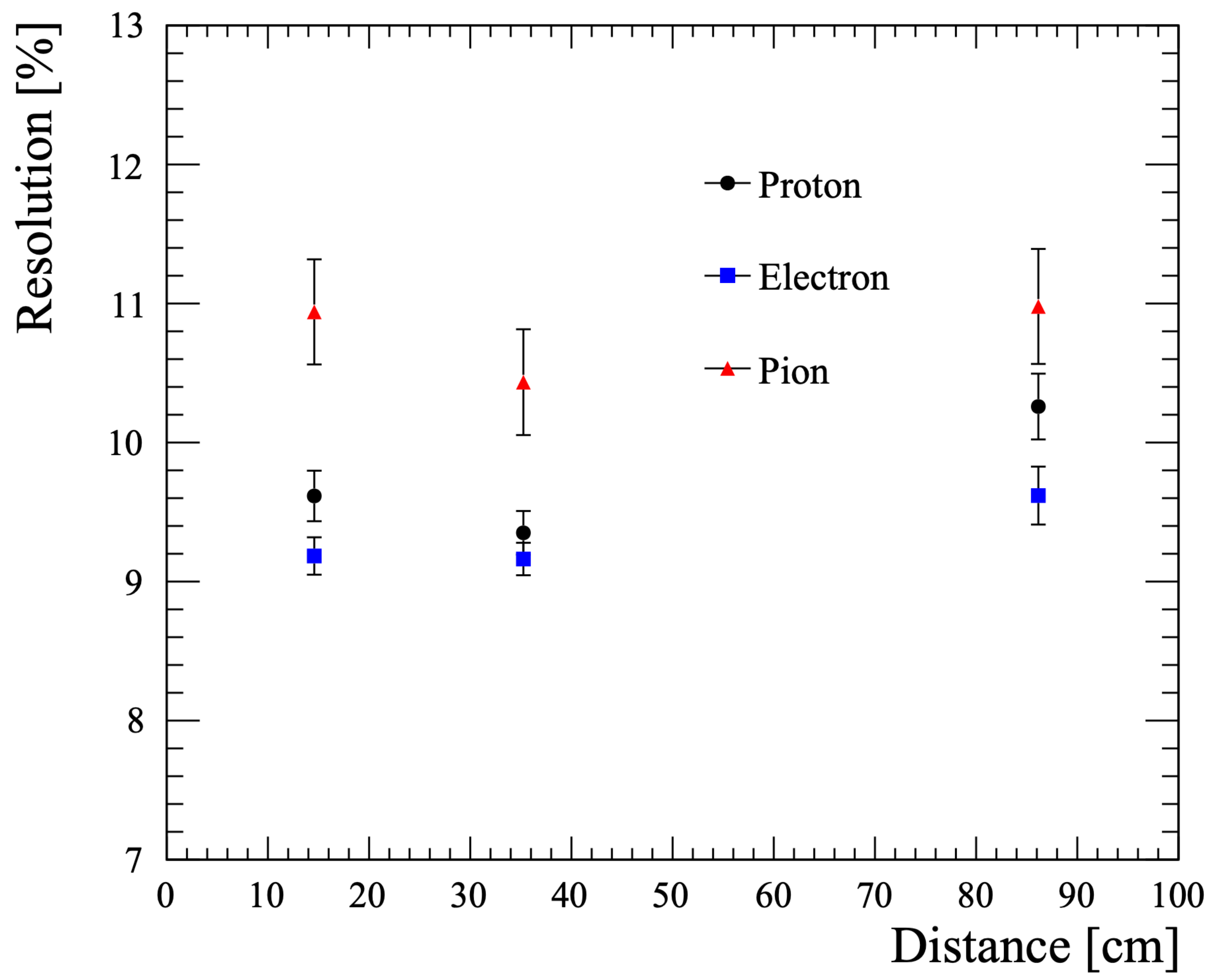
Many test beam were performed at CERN and DESY to validate the concept and design of the HA-TPC
arXiv:1907.07060 arXiv:2106.12634 arXiv:2212.06541 arXiv:2303.04481

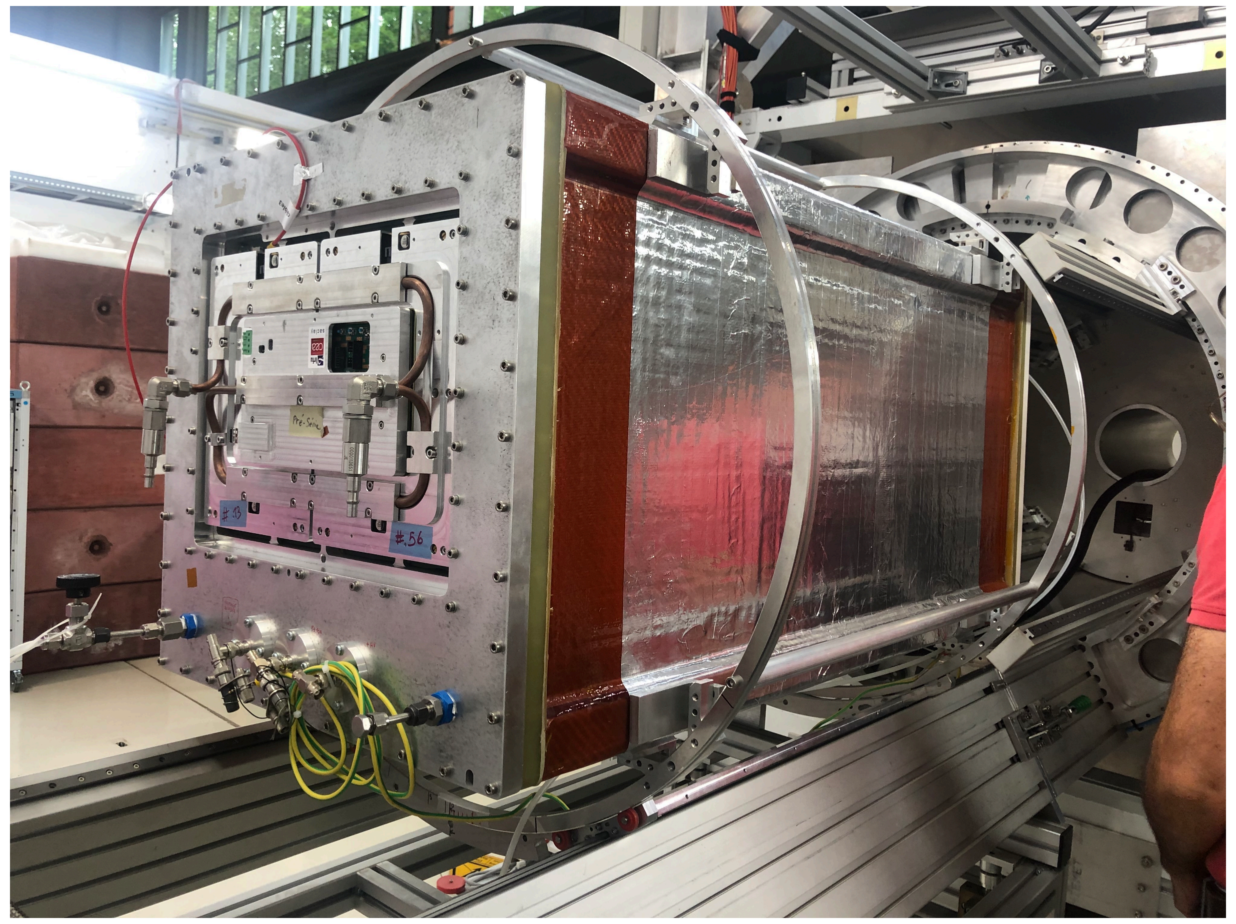
- dE/dx resolution is <10% => good discrimination between electron and muon
- Spatial resolution between 200 and 600 μm (depending on angle and drift distance)





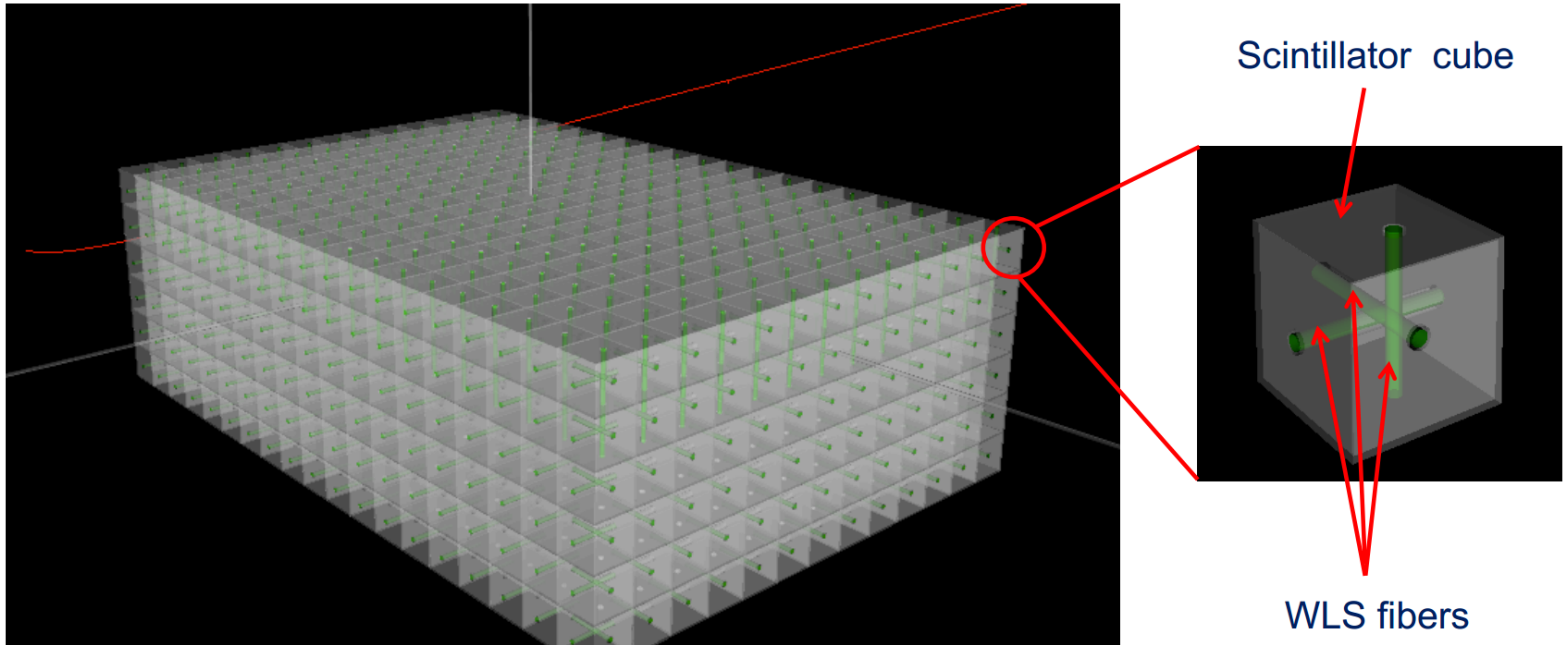


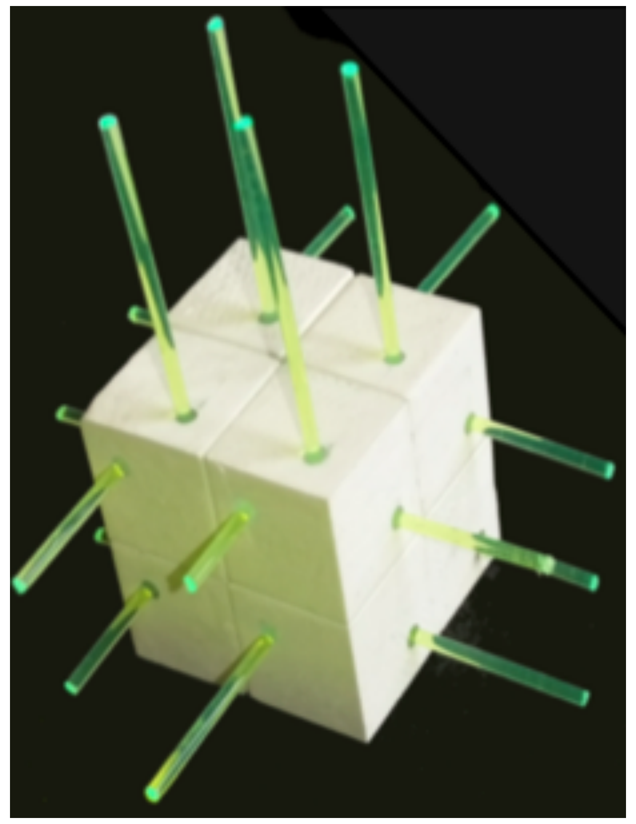


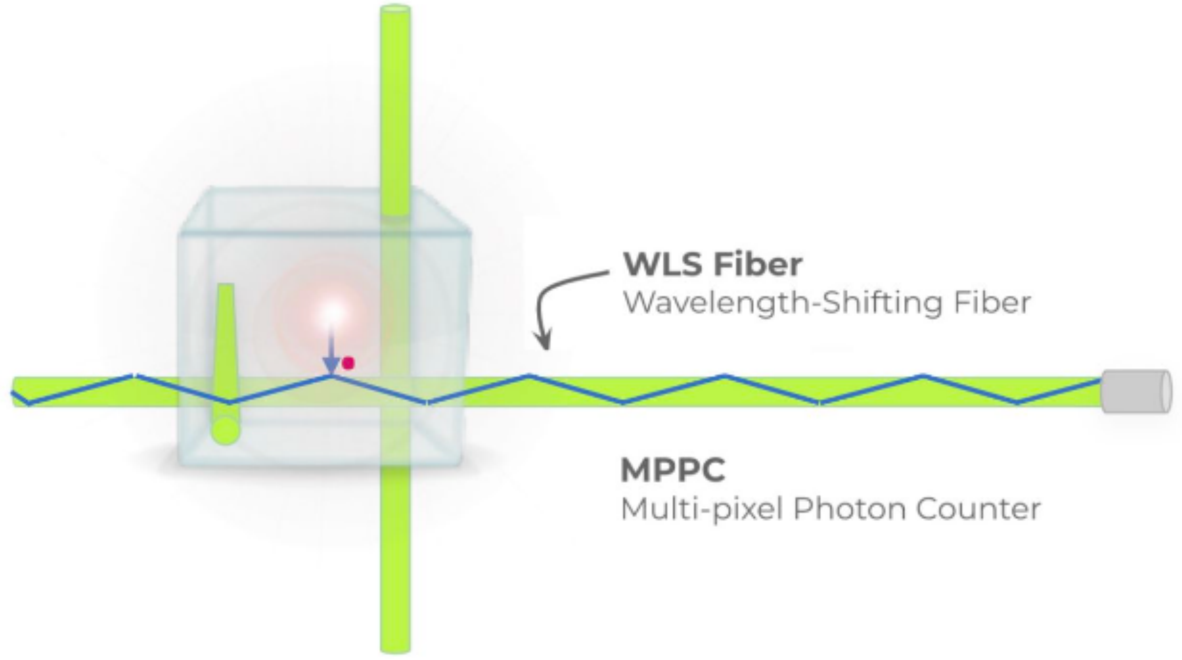


A prototype at Desy test beam 2021

SUPER FGD DETECTOR





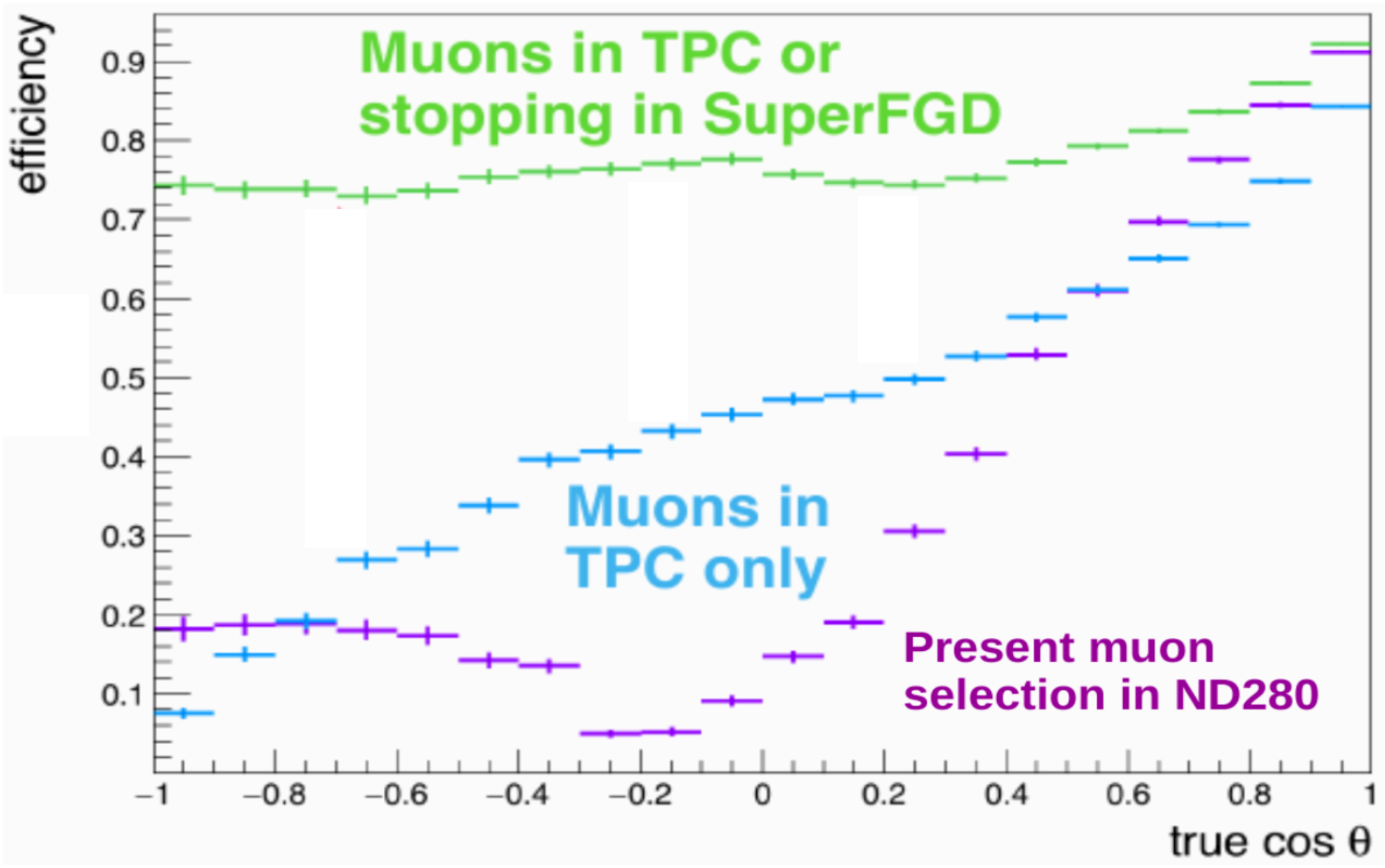


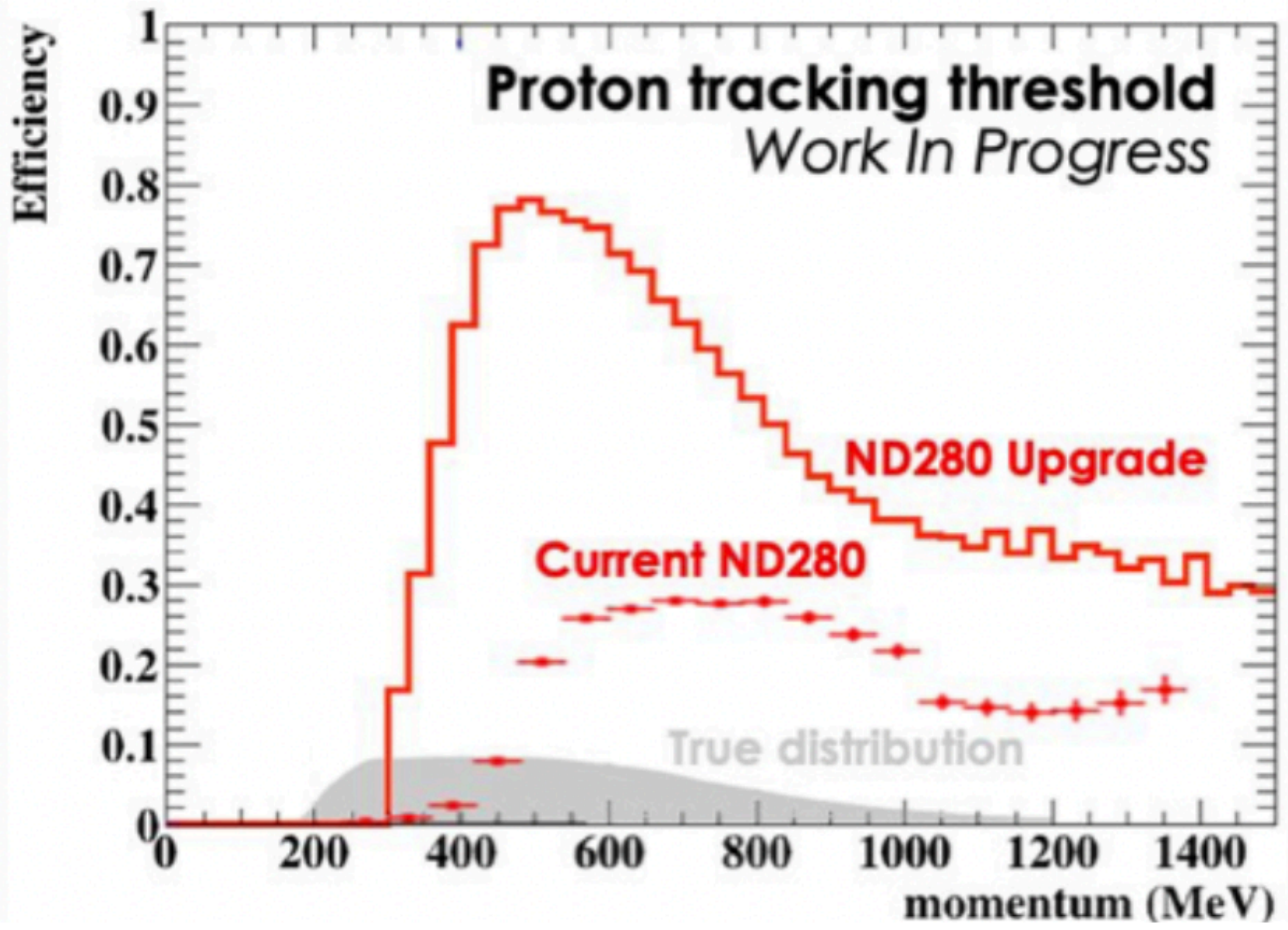
- Super-FGD: 192 × 192 × 56 scintillator cubes (2 million) with 3D readout => 2 tons of fully active target

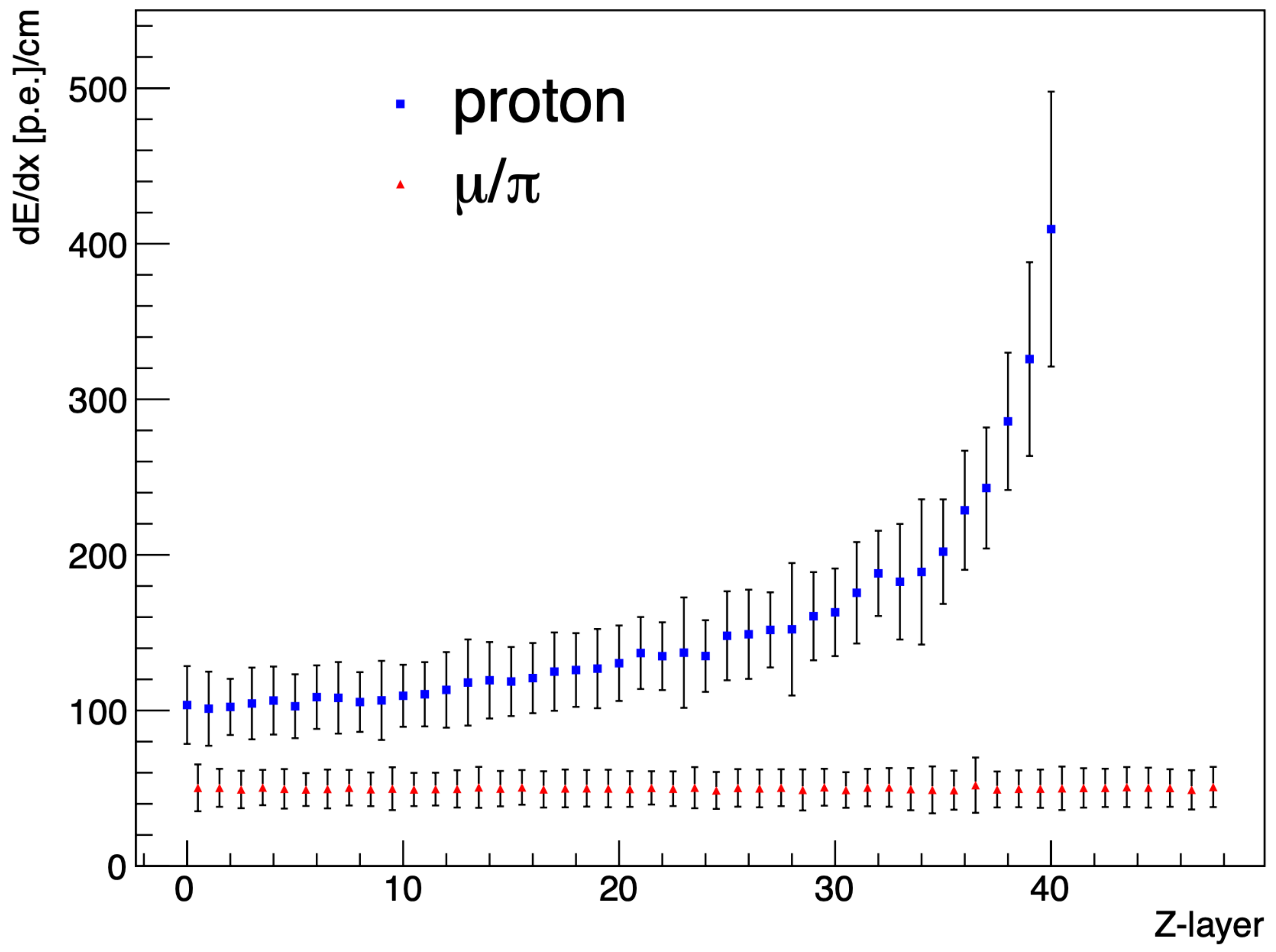
- Wavelength shifting (WLS) fibers are used to collect light from scintillator cubes. (70 km of WLS fiber in total)

- One end of the fibers is connected to a Multi-Pixel Photon Counter (MPPC) the other end is mirrored.
  => around 60.000 channels.

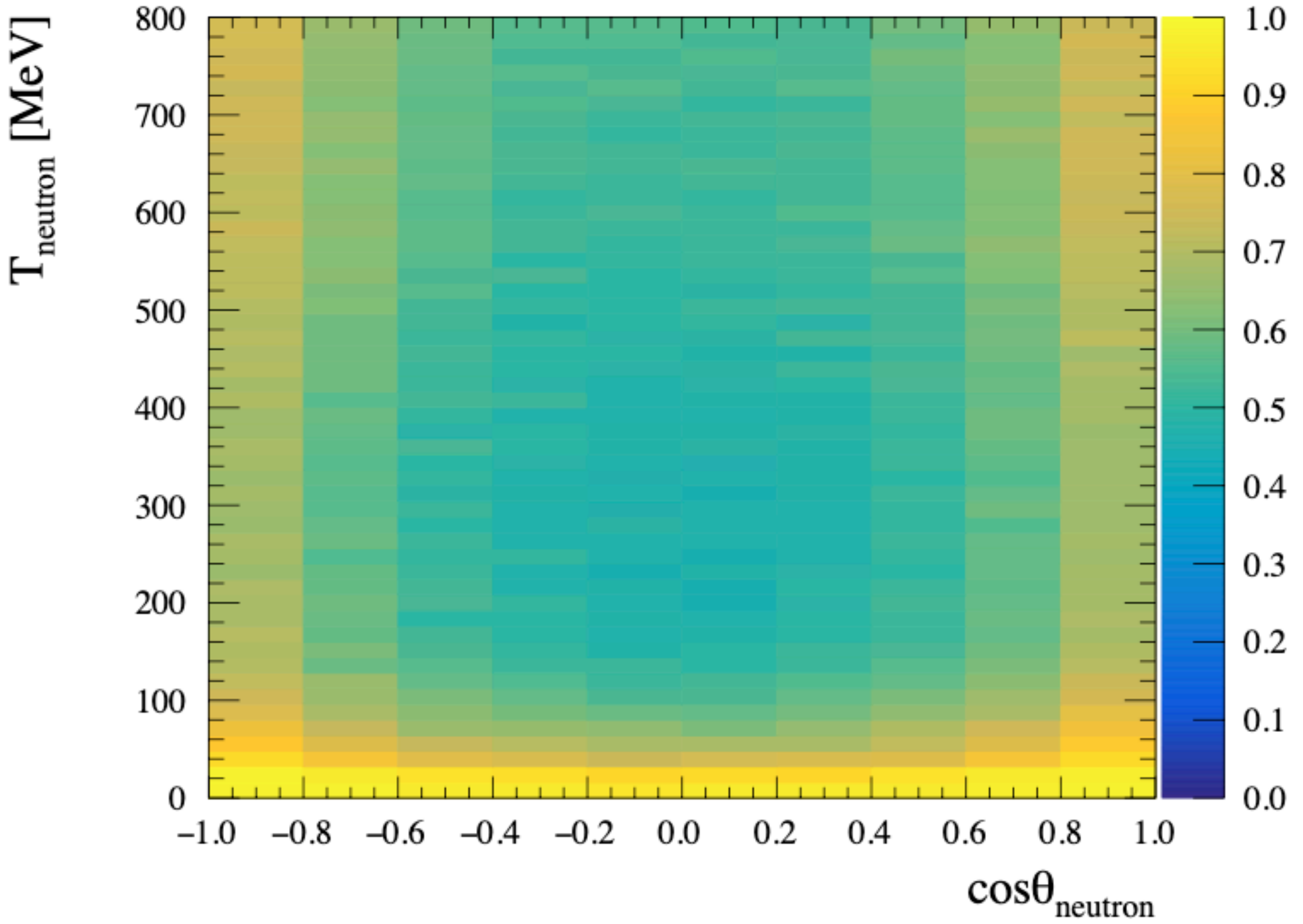
SUPER FGD PERFORMANCE

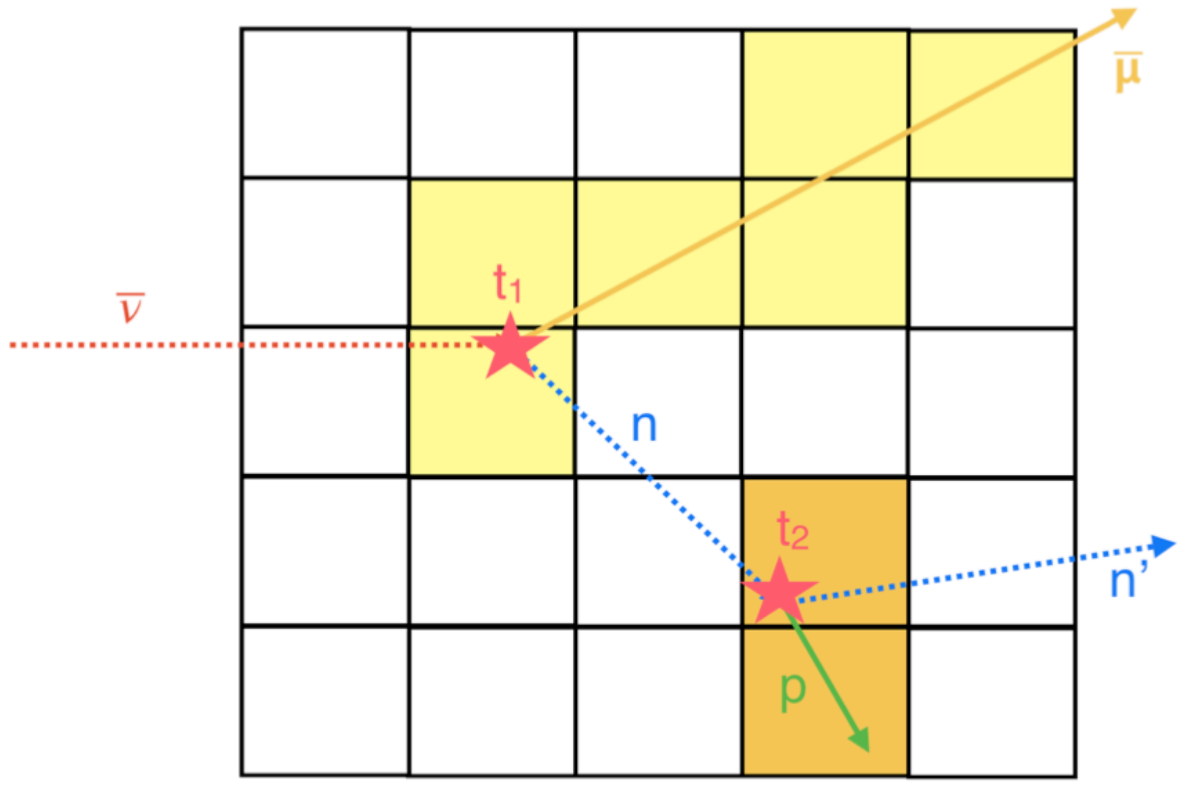






- 4π coverage (isotropic)
- Lower proton momentum threshold (300MeV/c)
- Neutron kinematics reconstruction by time of flight technique (0.6 ns time resolution)
- Very enhanced PID



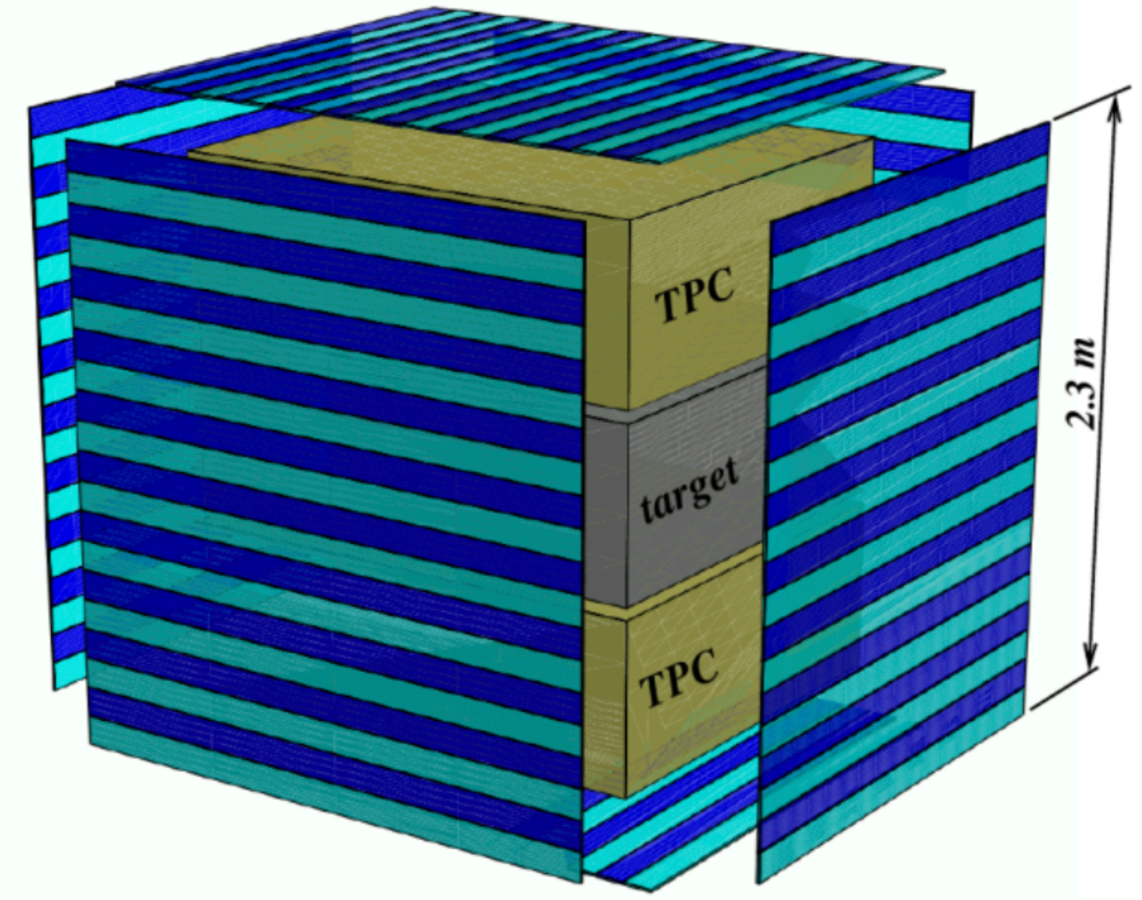


Neutron detection through time of flight technique

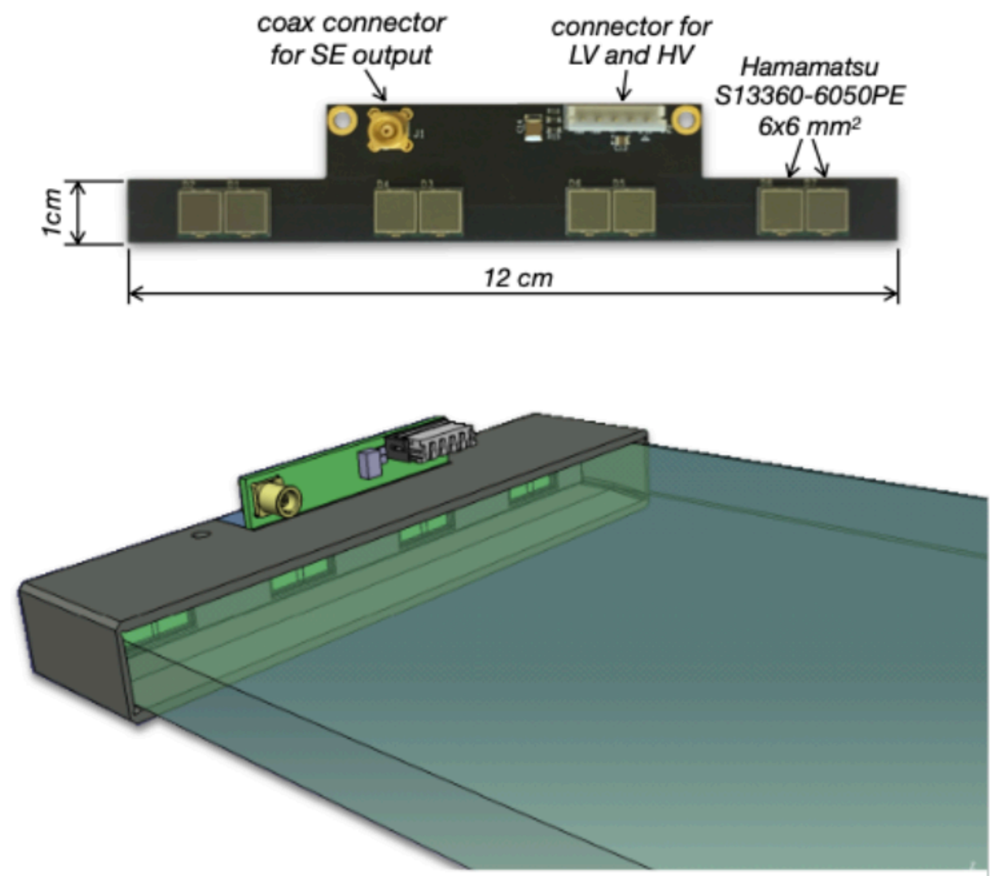
TIME OF FLIGHT DETECTOR (TOF)

- Six TOF planes will cover 2 HA-TPCs and SuperFGD.
- Each plane of 2.2×2.4 m^2 consists of 20 scintillator bars.
- Both ends readout by 8 MPPCs on each end of each bar.

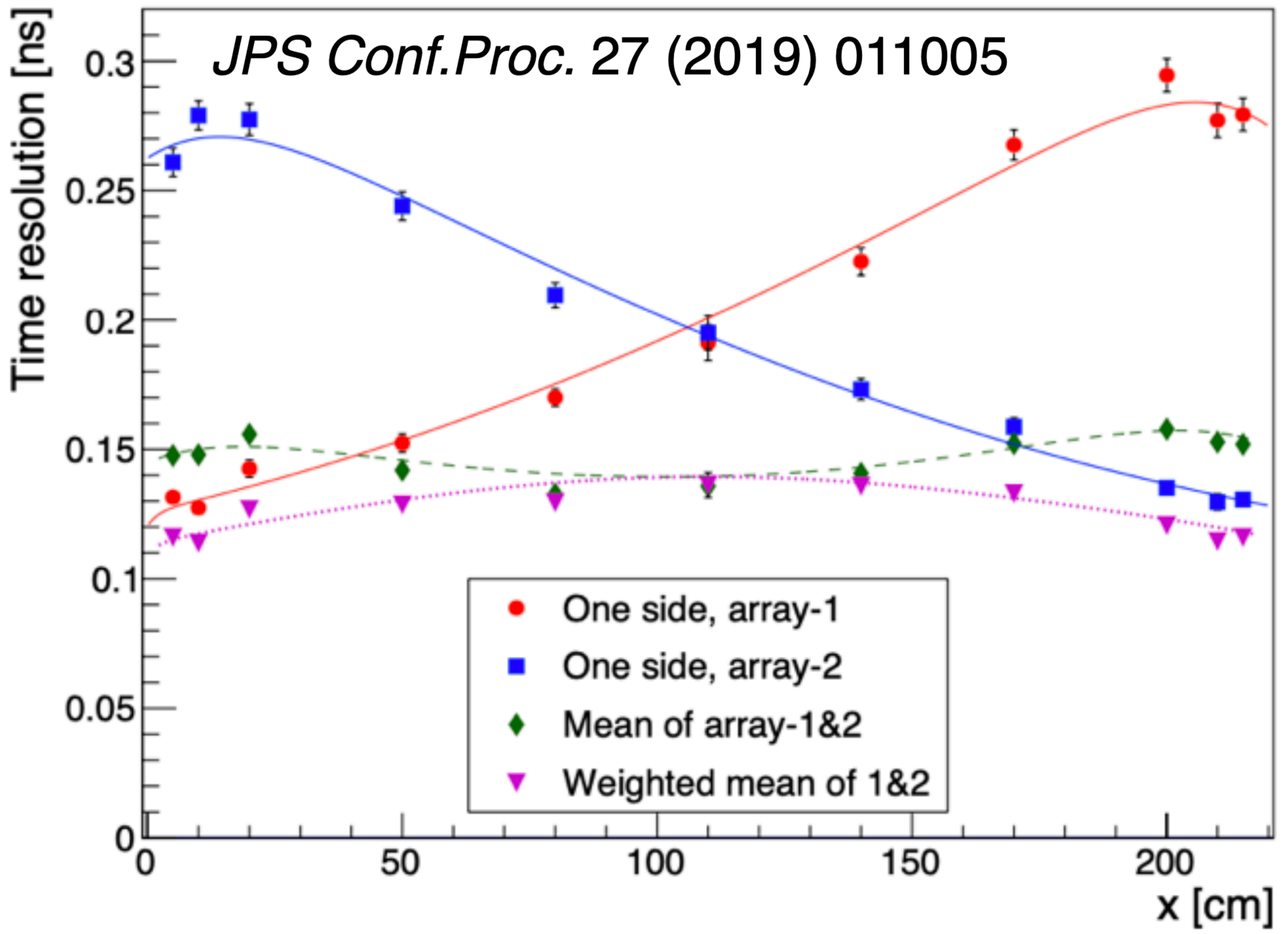
- Precise timing measurement for particles as they traverse the TOF modules (resolution of 150 ps during commissioning at CERN).
- Determine the track direction and minimise background
- It is used as the cosmic trigger to calibrate SuperFGD and HA-TPCs



TOF schematic view



Scintillator bar and end-cap



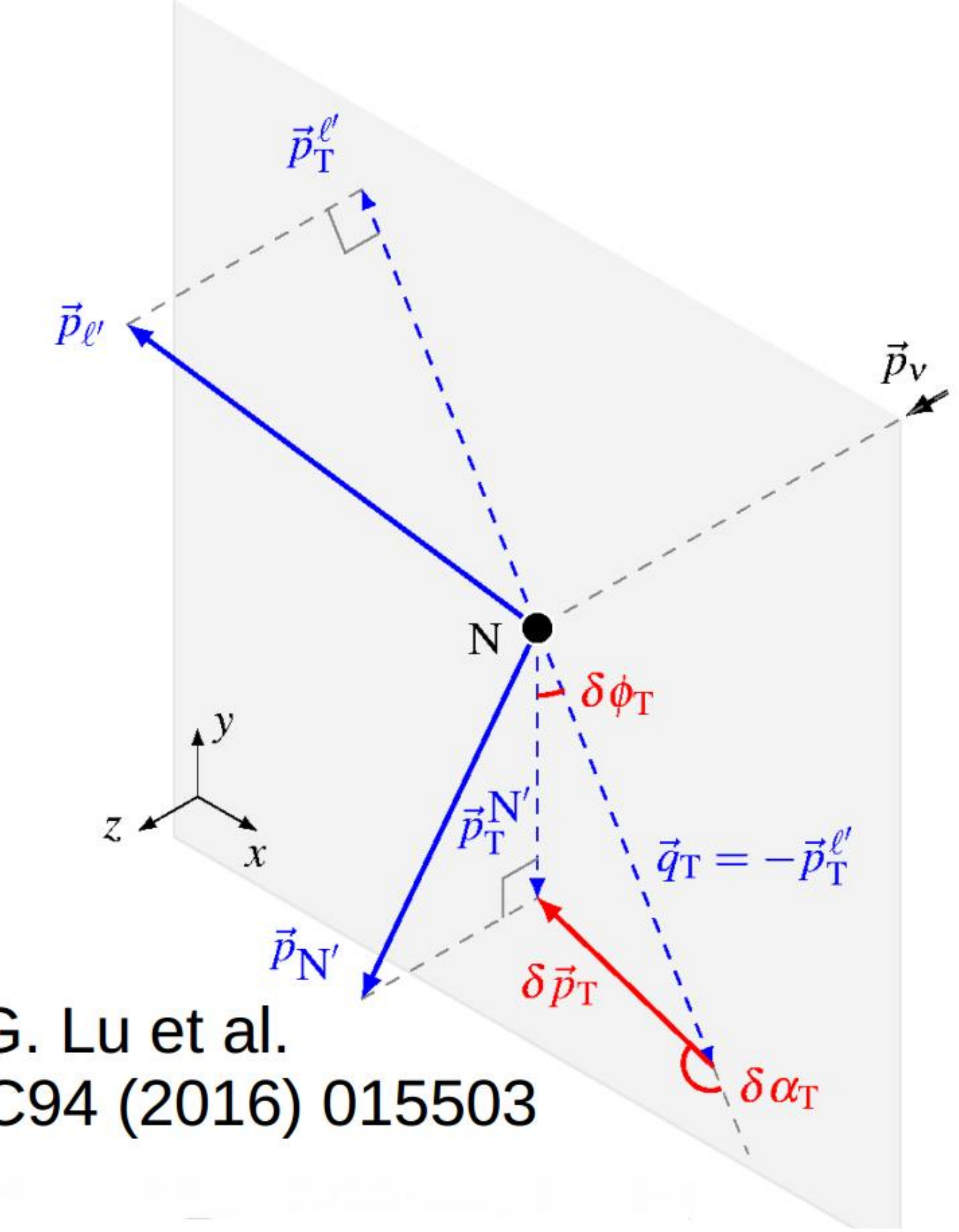
UPGRADED NEAR DETECTOR ND280: PERFORMANCE

Neutrino energy reconstruction is based on the Charge Current Quasi-Elastic (CCQE) kinematics

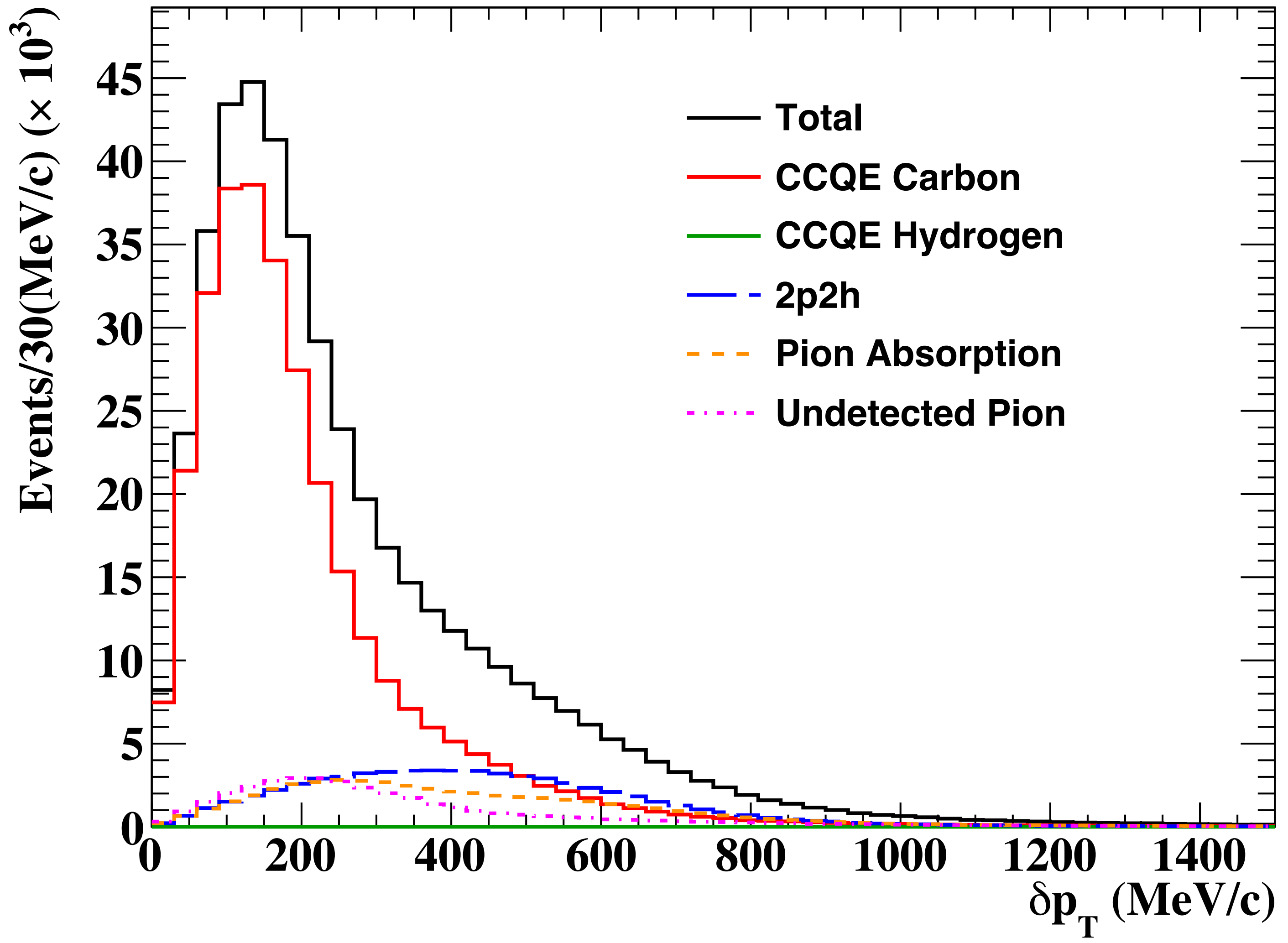
$$E_{QE} = \frac{m_p^2 - m_\mu^2 - (m_n - E_{rmv})^2 + 2E_\mu(m_n - E_{rmv})}{2(m_n - E_{rmv} - E_\mu + p_\mu^z)}$$

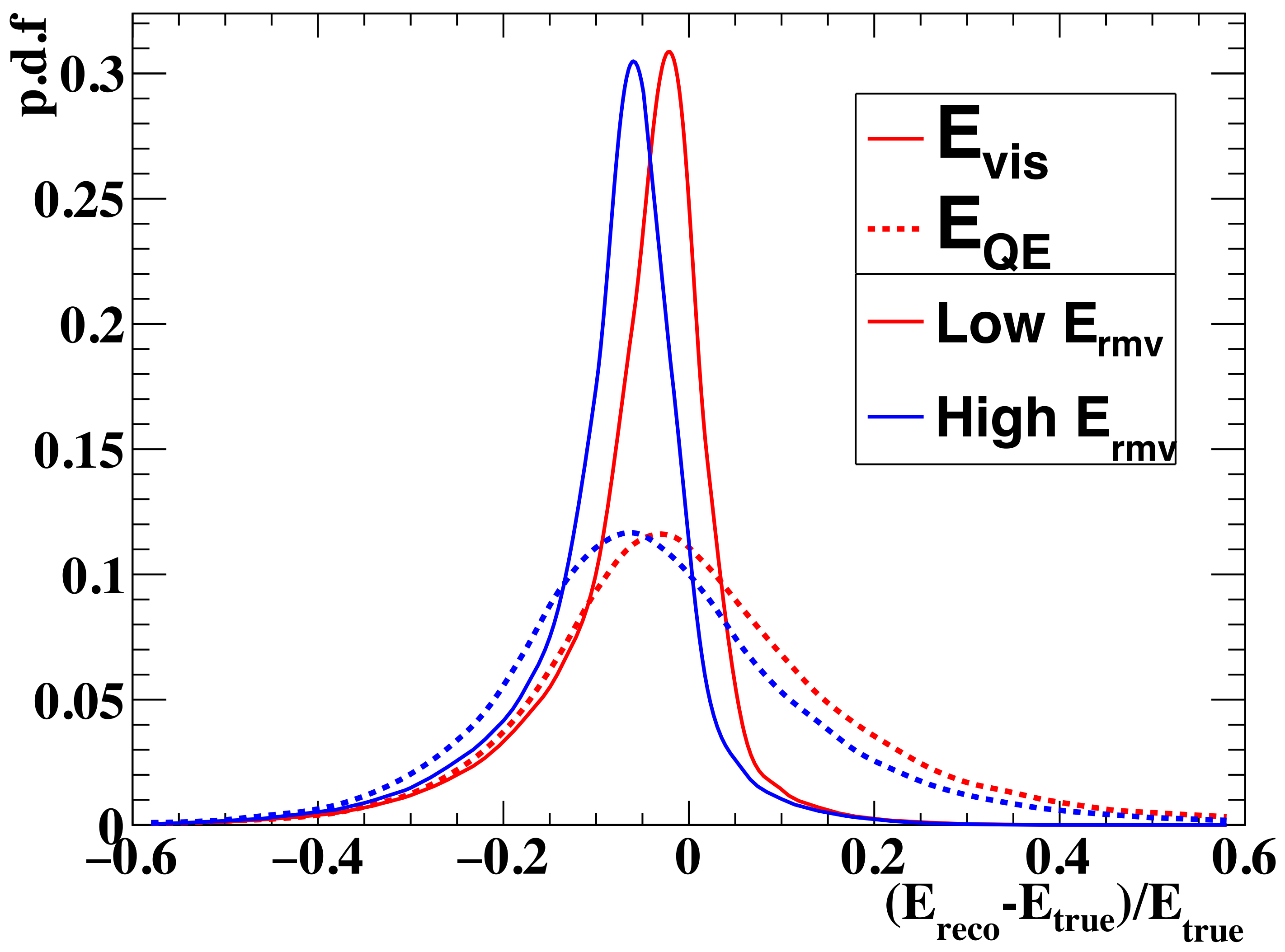
=> only lepton kinematics in current analysis

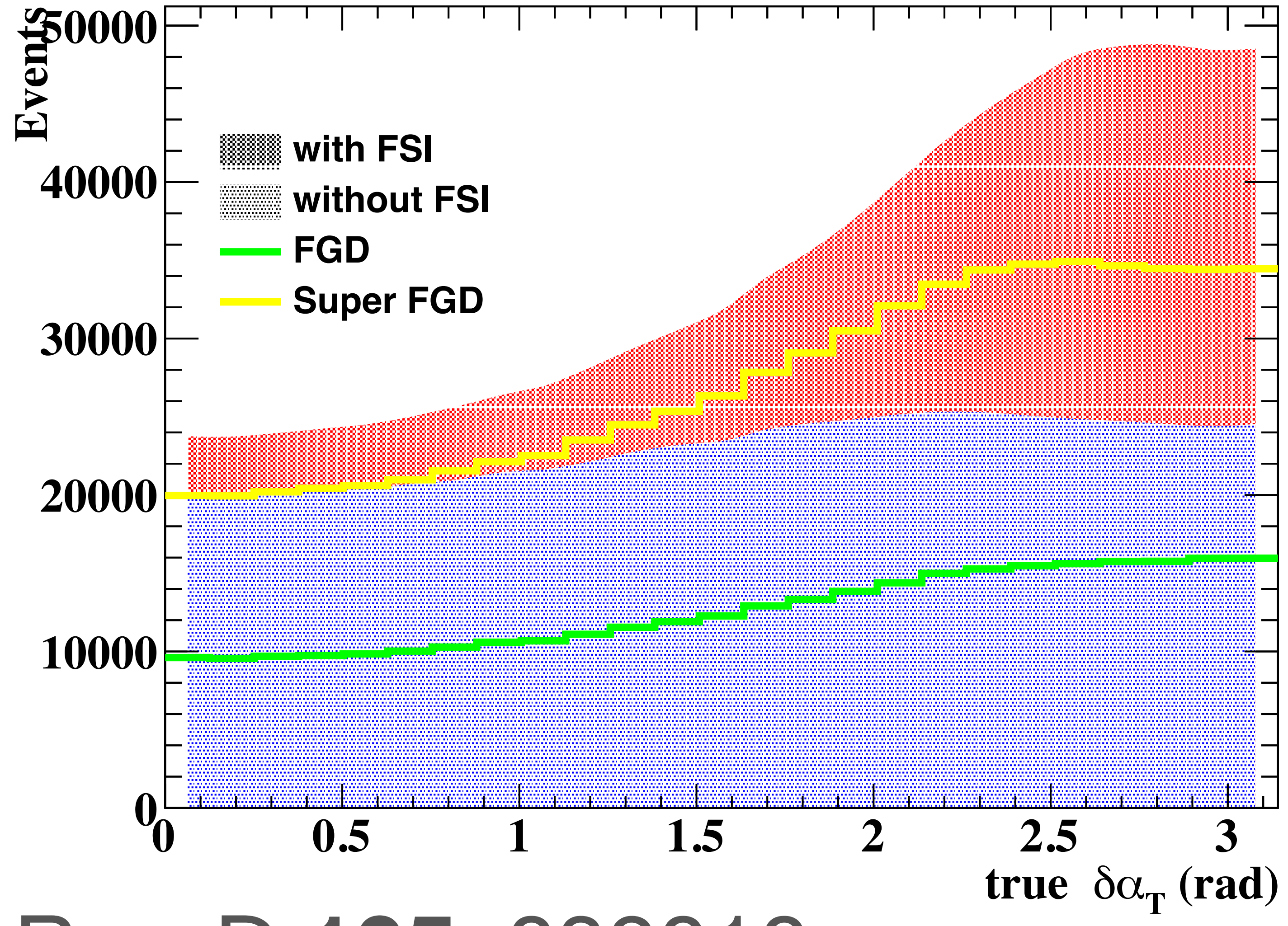
- Thanks to upgraded ND280, we can access to hadron kinematic. - measure kinematic imbalance-transverse variables



X -G. Lu et al.
PRC94 (2016) 015503





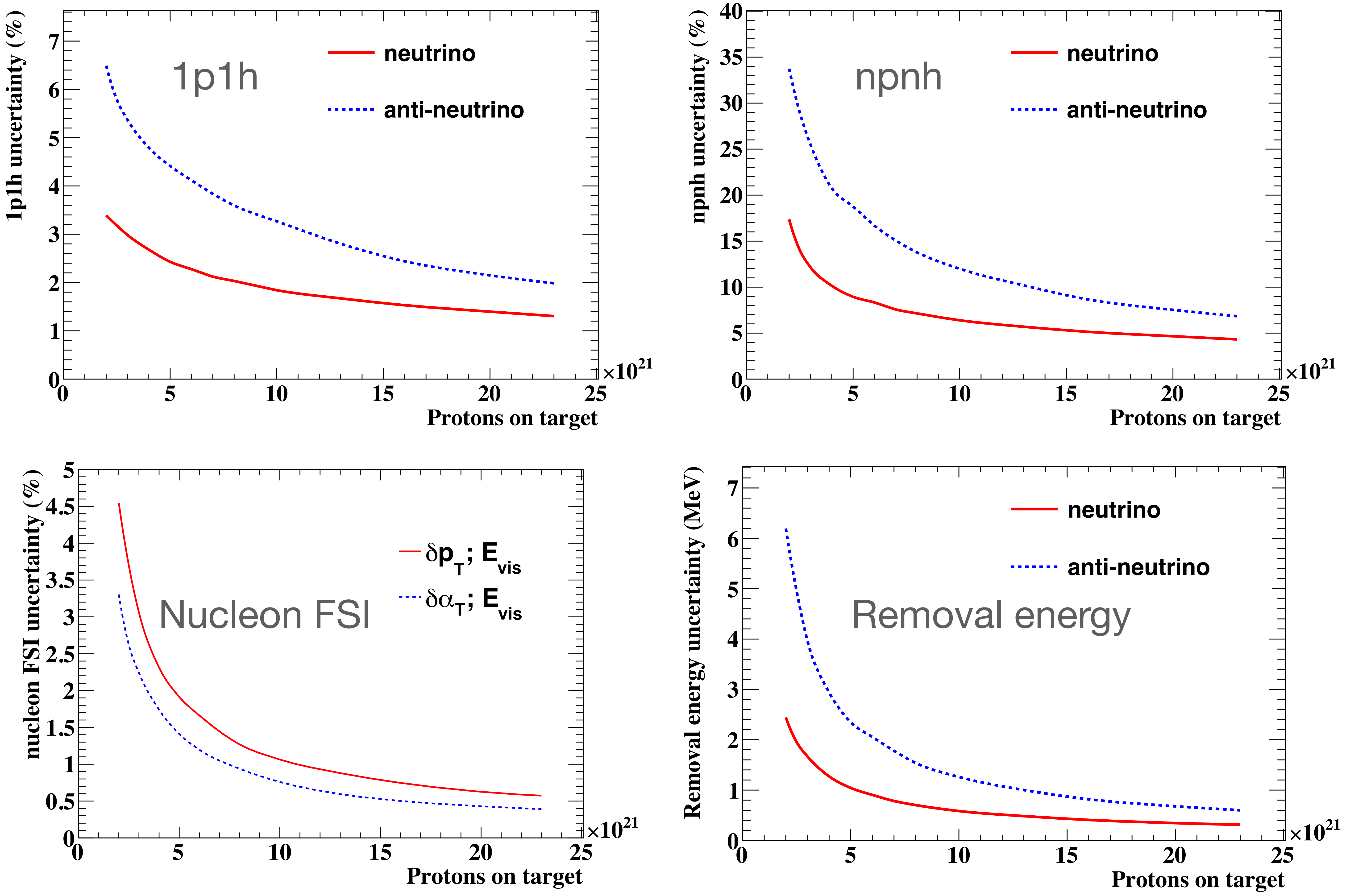


Phys. Rev. D **105**, 032010

UPGRADED NEAR DETECTOR ND280: PERFORMANCE

At 20×10^{21} POT

- E_{rmv} uncertainty is below 1MeV.
- 1p1h and 2p2h uncertainties are below 3% and 10% respectively.
- Nucleon final state interaction (FSI) is constraint to below 1.5% uncertainty.



See also the talk of Joachim Kopp yesterday for the neutrino-nucleus interaction

Phys. Rev. D 105, 032010

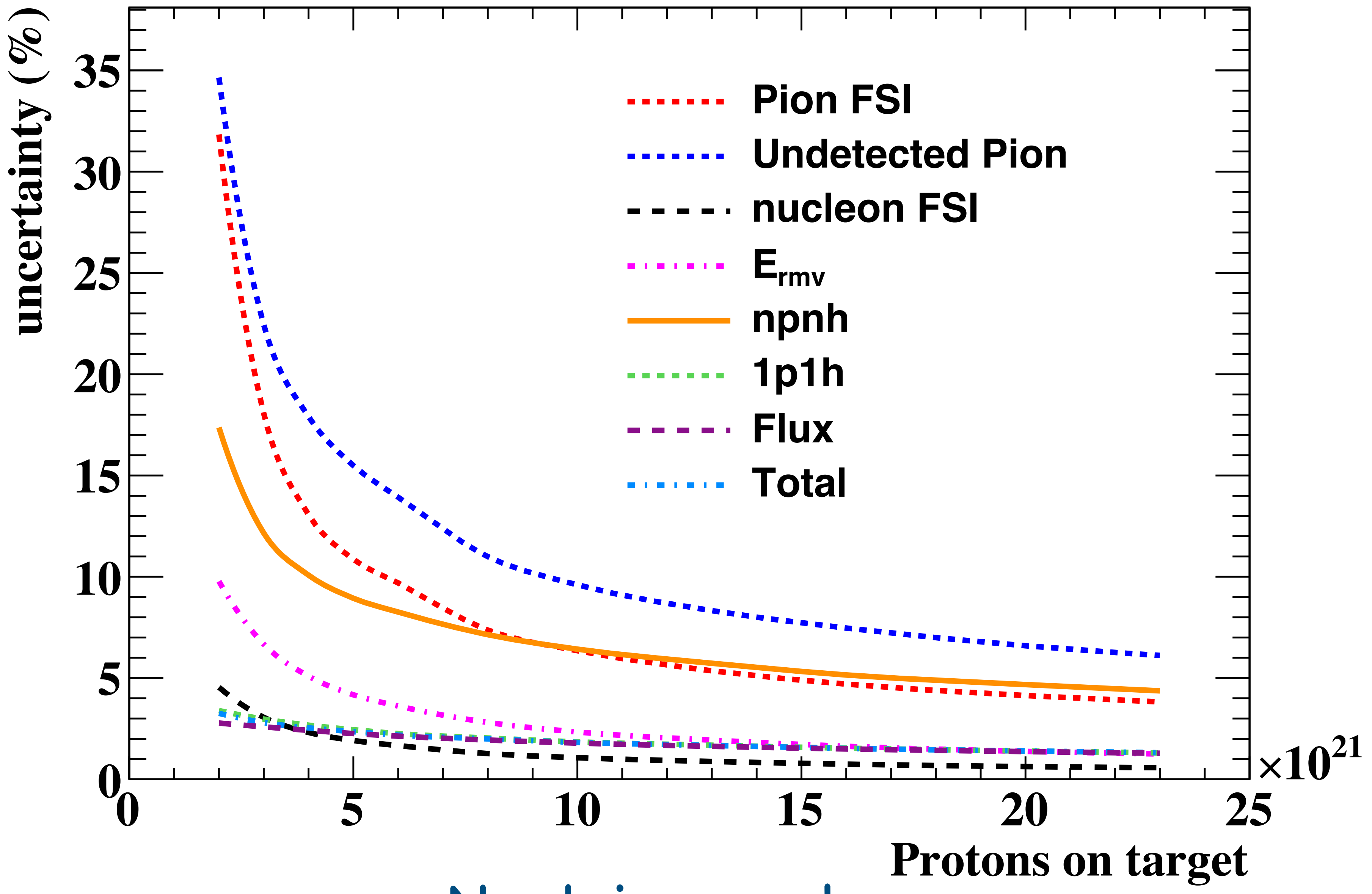
SUMMARY

To be ready for the Hyper-K period, where the statistical uncertainty is reduced and the systematic uncertainty becomes dominant, ND280 Upgrade helps significantly with improving systematic uncertainties.

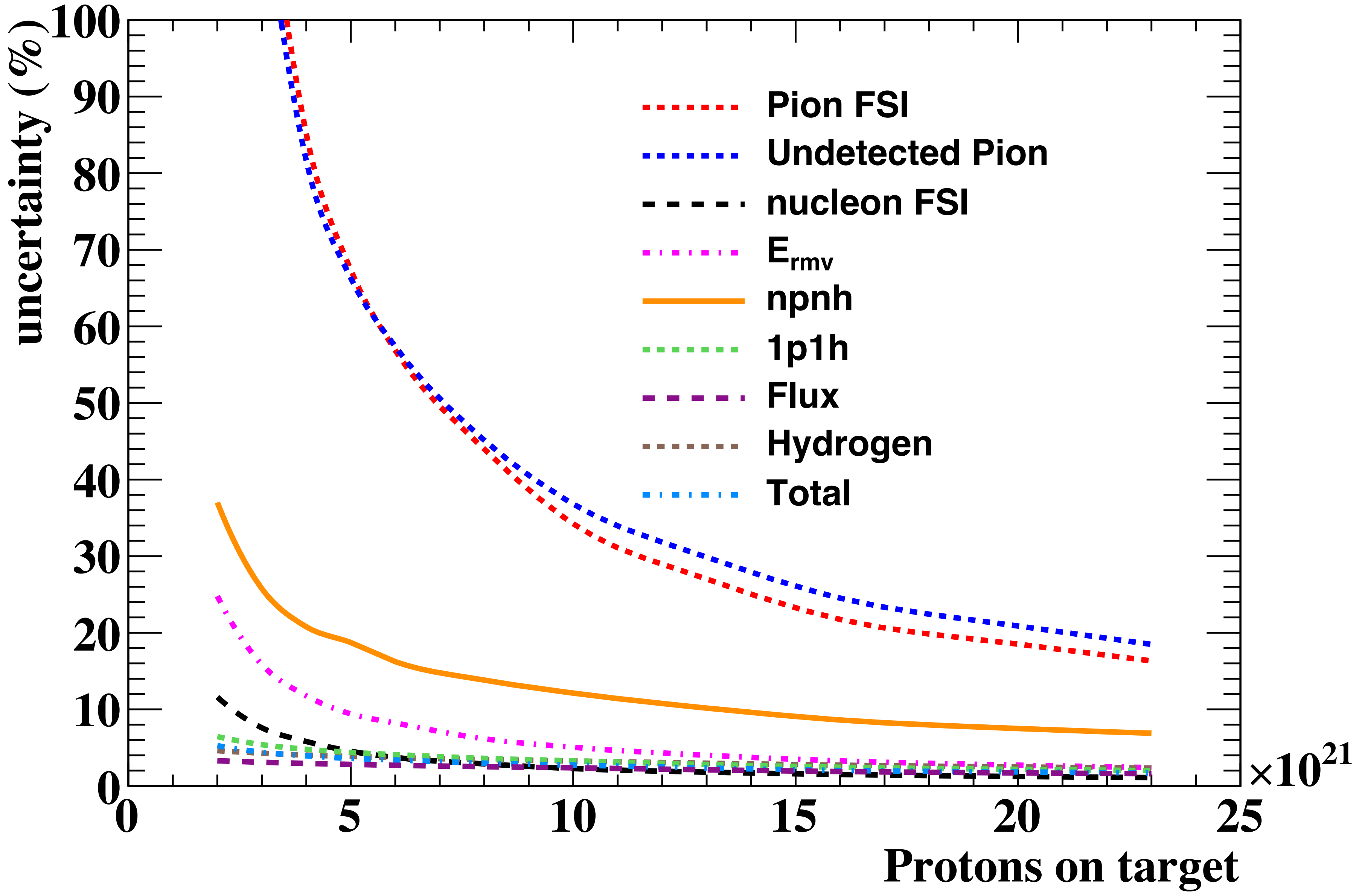
Upgraded ND280 is actively under installation and near to completion. Commissioning is on-going in Japan and the delay is in week scale.

Many new tools related to simulation and reconstruction are actively under development for the new detector.

First beam with new configuration of ND280 is scheduled at the end of 2023 => Stay Tuned!!



Neutrino mode



Phys. Rev. D **105**, 032010

Anti-Neutrino mode