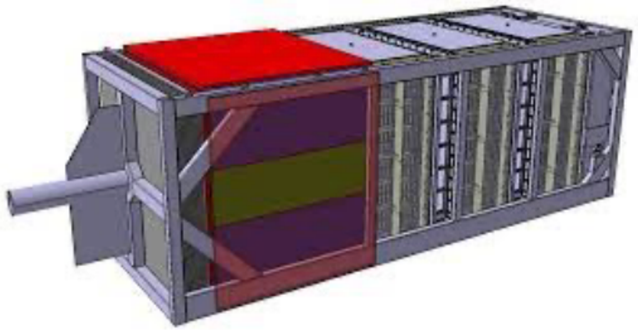
São Paulo, Brasil

T2K Near Detector Upgrade

NuInt 2024

14th Workshop on Neutrino-Nucleus Interactions

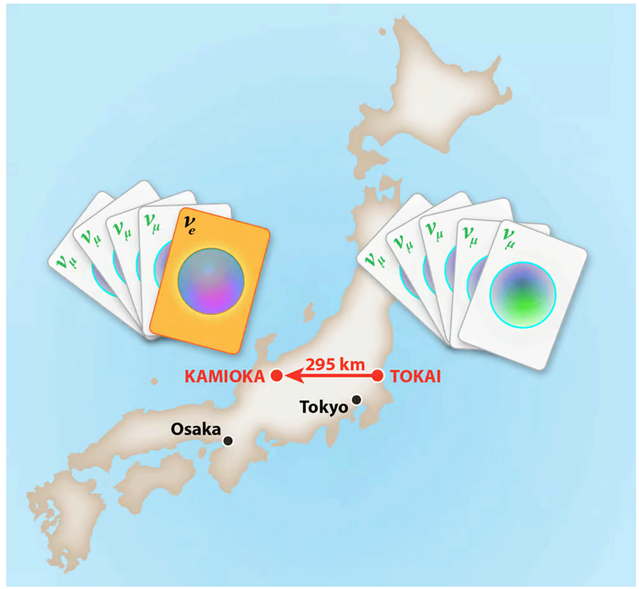
Uncertainties and Prospects for Future Improvements

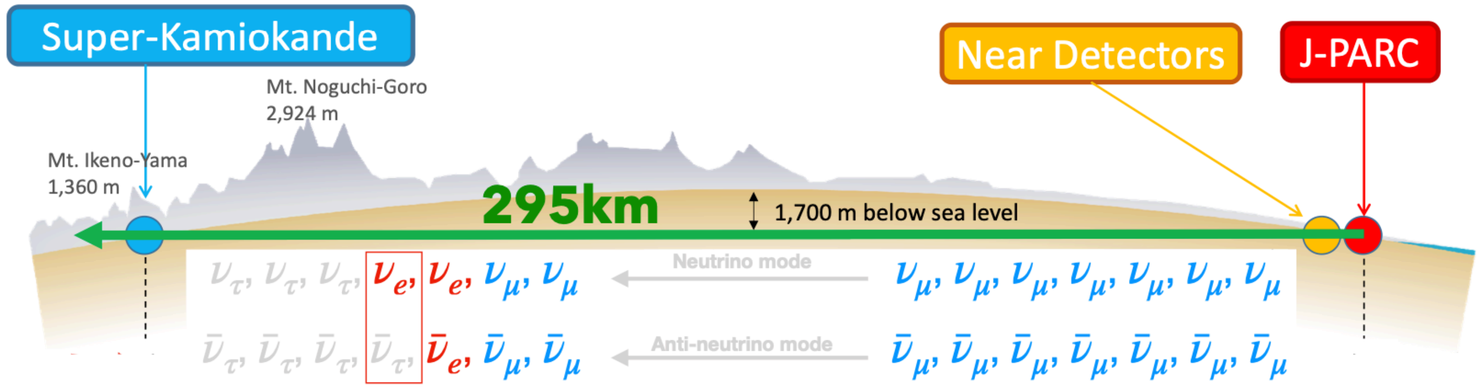


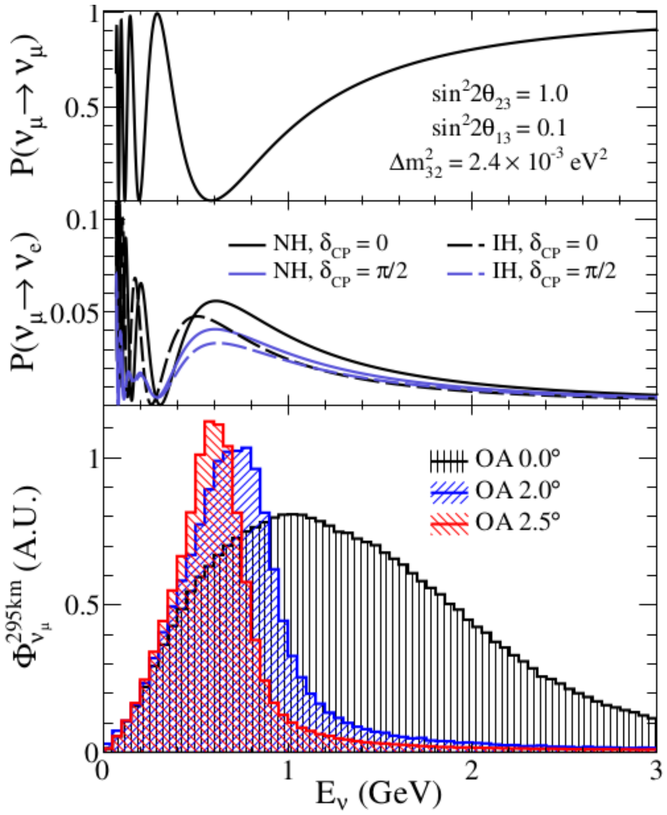
Ulysse VIRGINET, on behalf of the T2K Collaboration

Friday, April 19th 2024

The T2K experiment

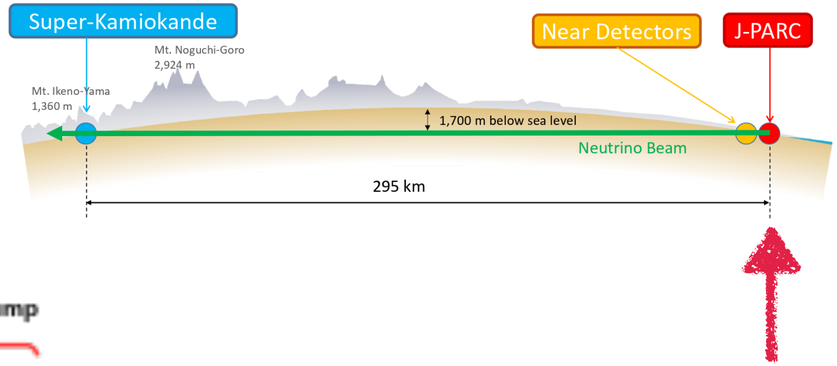


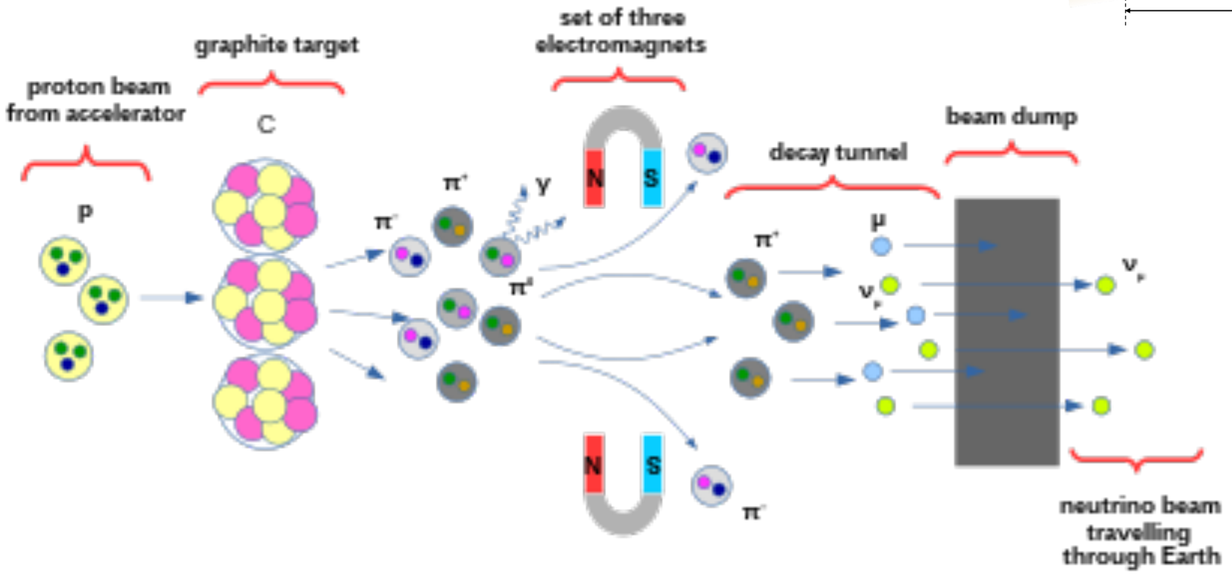


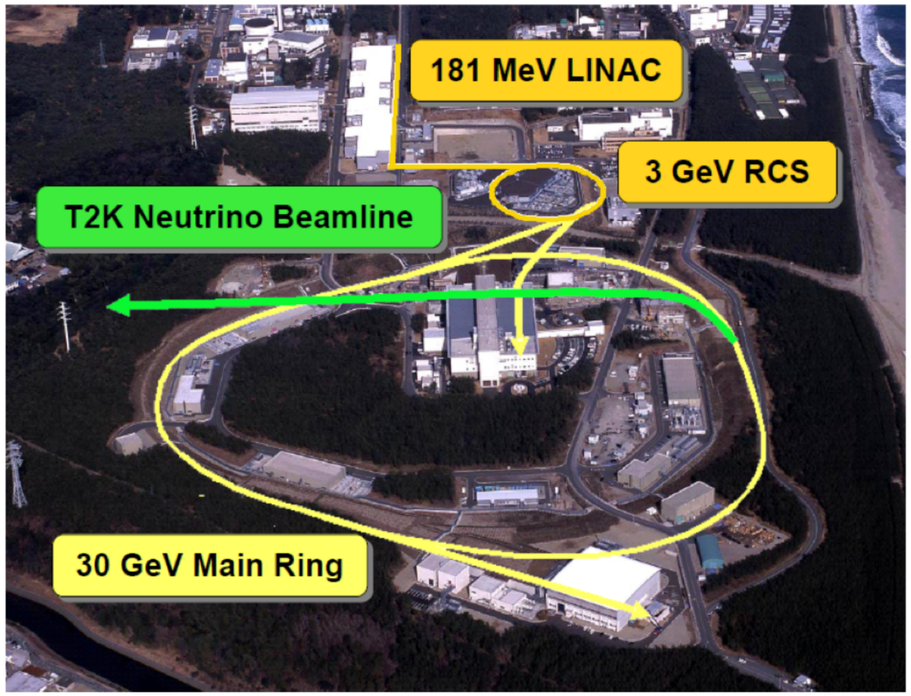


- Long-baseline neutrino oscillation experiment
- Has taken data in Japan since 2010
- 2.5° off-axis angle peaks ν_μ energy spectrum at ~600 MeV
- Measures $\nu_\mu(\bar{\nu}_\mu)$ disappearance and $\nu_e(\bar{\nu}_e)$ appearance in a $\nu_\mu(\bar{\nu}_\mu)$ beam, 295km away at Super-Kamiokande

The T2K experiment: J-PARC

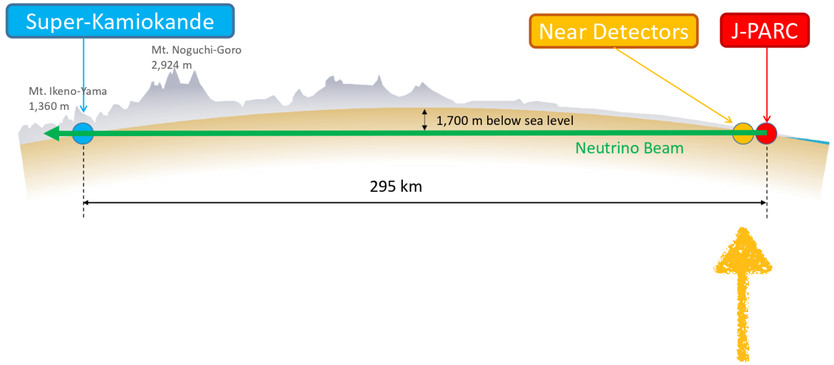




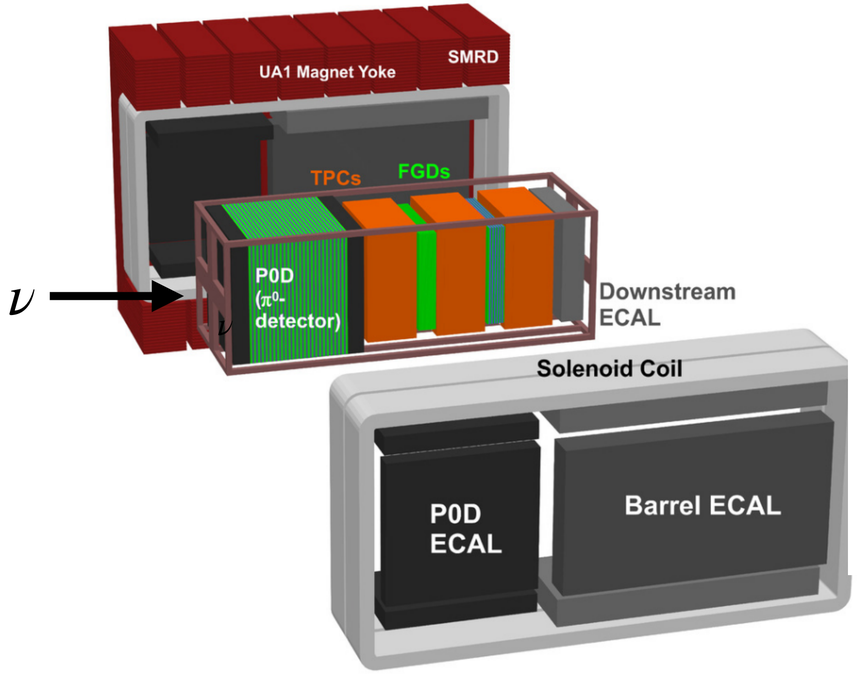


- Japan Proton Accelerator Research Complex: Acceleration of protons
- Collisions on a graphite target produce mainly mesons: $\pi^{\pm}, K^{\pm}$
- Thanks to magnetic horns, select:
  - Either π^{+}, K^{+} which decay mainly in $\mu^{+} + \nu_{\mu} \rightarrow \nu_{\mu}$ **beam**
  - Or π^{-}, K^{-} which decay mainly in $\mu^{-} + \bar{\nu}_{\mu} \rightarrow \bar{\nu}_{\mu}$ **beam**

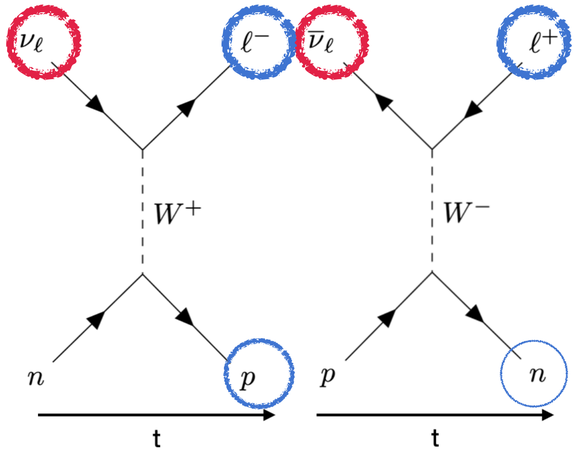
The T2K experiment: ND280



- Magnetized (thanks to **magnet yoke** coming from CERN UA1 experiment) series of detectors, located 280m downstream of the J-PARC graphite target
- **PoD** (π^0 detector): measurement of π^0 production ($\pi^0 \rightarrow \gamma + \gamma$ mimics ν_e interaction)
- **FGDs** (Fine Grain Detectors): plastic scintillator bars planes where (anti)neutrino interaction (most probably) takes place: target (+ tracker)
- **TPCs** (Time Projection Chambers): highly accurate reconstruction of particle's momentum: very precise tracker
- **ECAL** (Electromagnetic calorimeter): measures energy deposit

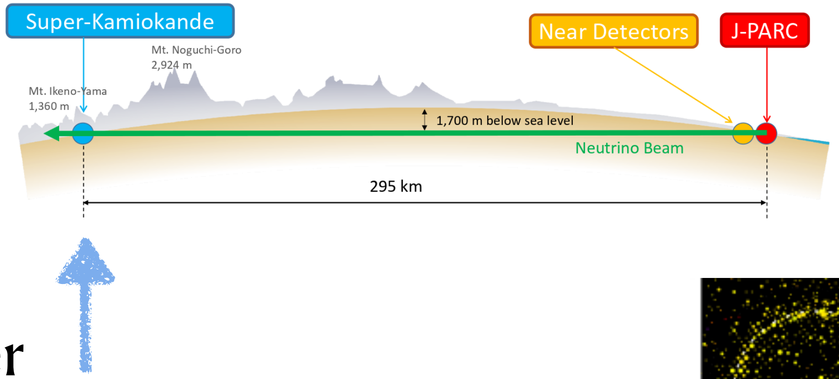


Schematic view of ND280 original configuration (2010-2022)

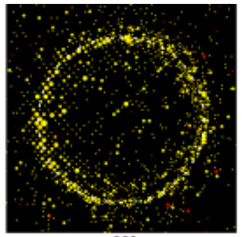


$\ell \in \{e, \mu, \tau\}$

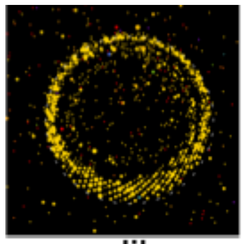
The T2K experiment: SK



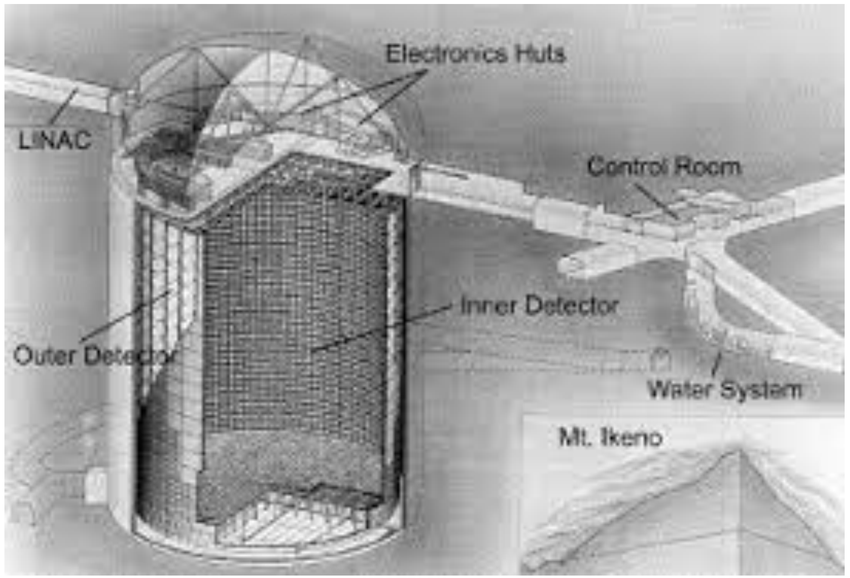
- 40m diameter × 40m height cylinder
- Filled with 50000 tons of ultra pure water
- More than 10000 PMT aim to detect Cherenkov light emitted by charged lepton coming from ν interaction

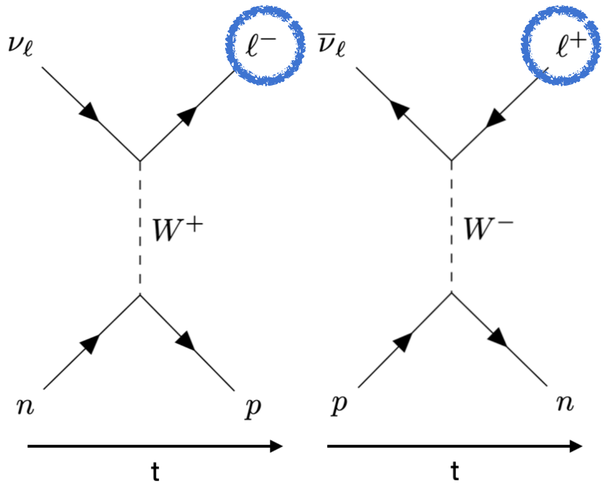


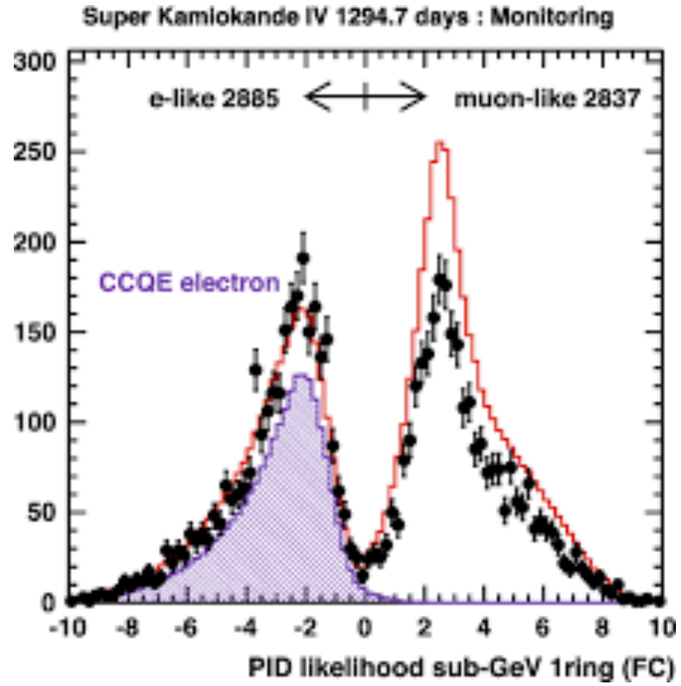
ν_e-like



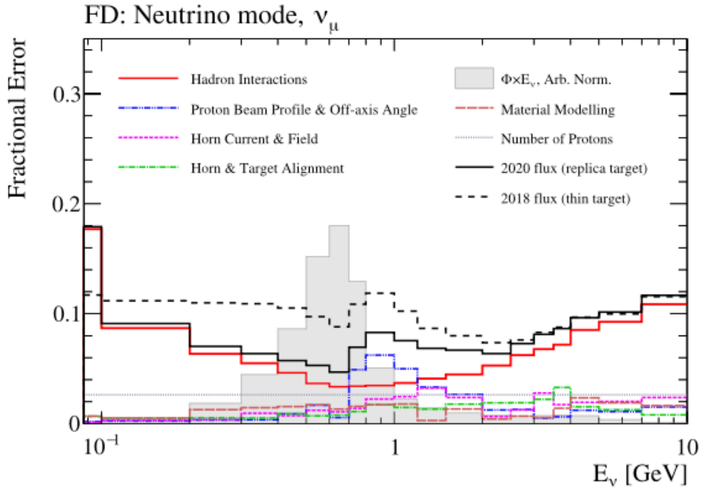
ν_μ-like

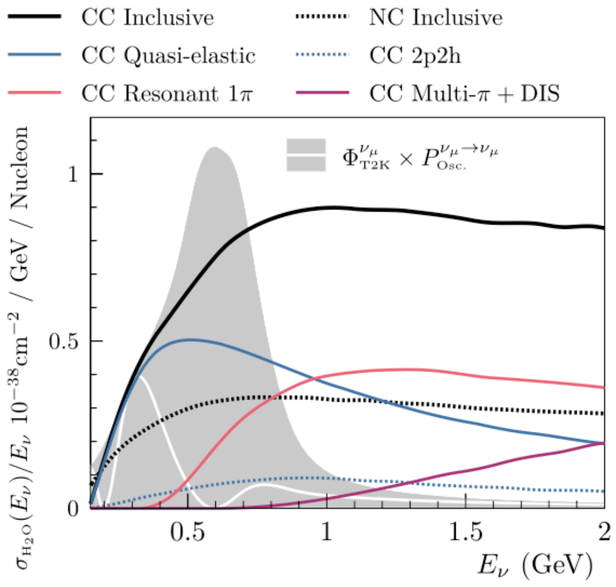






The T2K oscillation analysis





$$R_{\nu_\ell} = \mathscr{P}_{\nu_\mu \to \nu_\ell}(E_\nu) \times \sigma(E_\nu) \times \Phi(E_\nu) \times \epsilon(E_\nu)$$

Event rate — Oscillation probability — ν x-sec — ν flux — Detector efficiency

Flux prediction:
Proton beam measurement
Hadron production (NA61 2009 replica target data)

Neutrino interactions:
Cross-section models
External data

ND280 measurements:
ν_μ and $\bar{\nu}_\mu$ selections to constrain flux and cross-sections

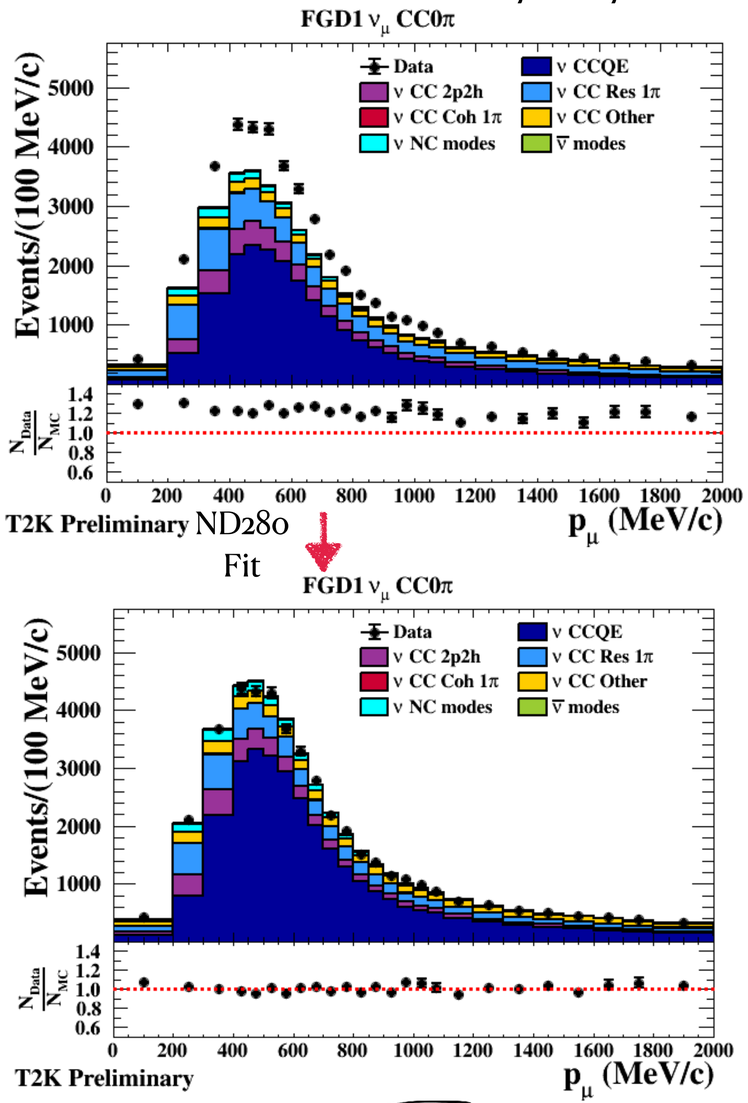
Prediction at the Far Detector:
Combine flux, cross section and ND280 to predict the expected events at SK

Extract oscillation parameters!

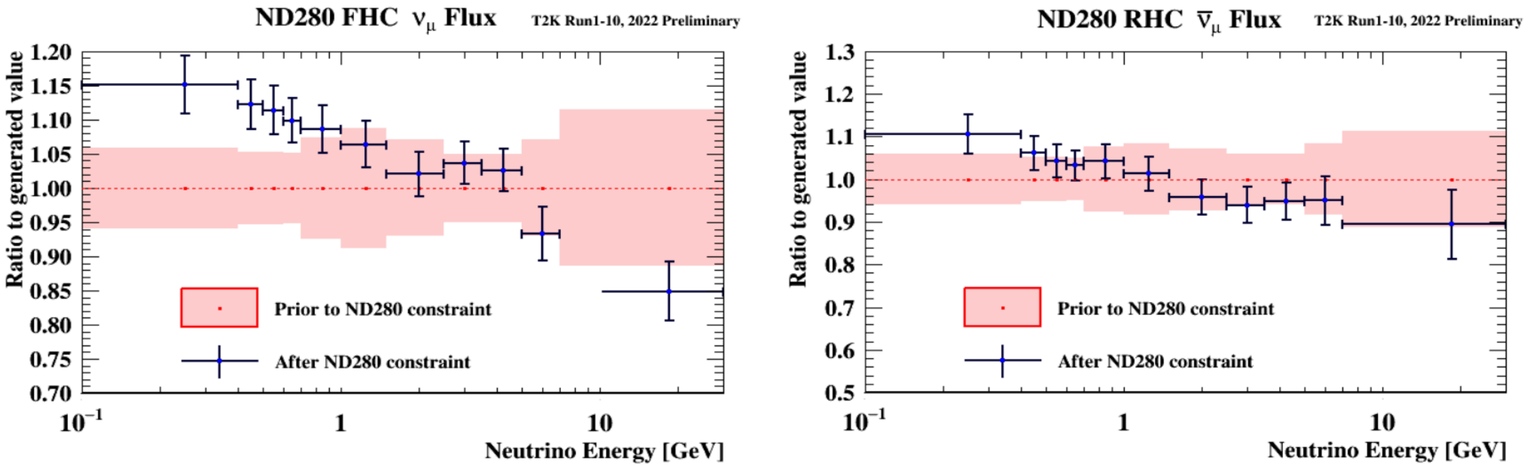
SK measurements:
Select CC ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$ candidates after the oscillations

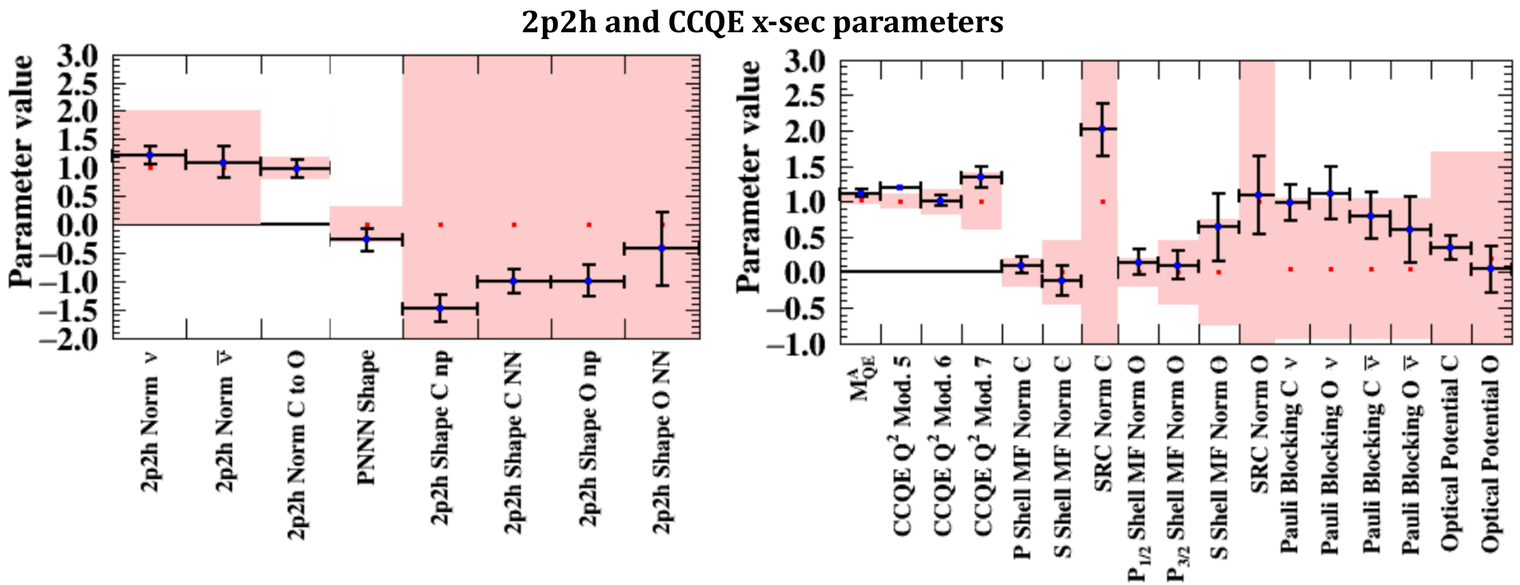
Reduction of flux and x-sec uncertainties at ND280

- Fit non-oscillated ν_μ ($\bar{\nu}_\mu$) spectrum



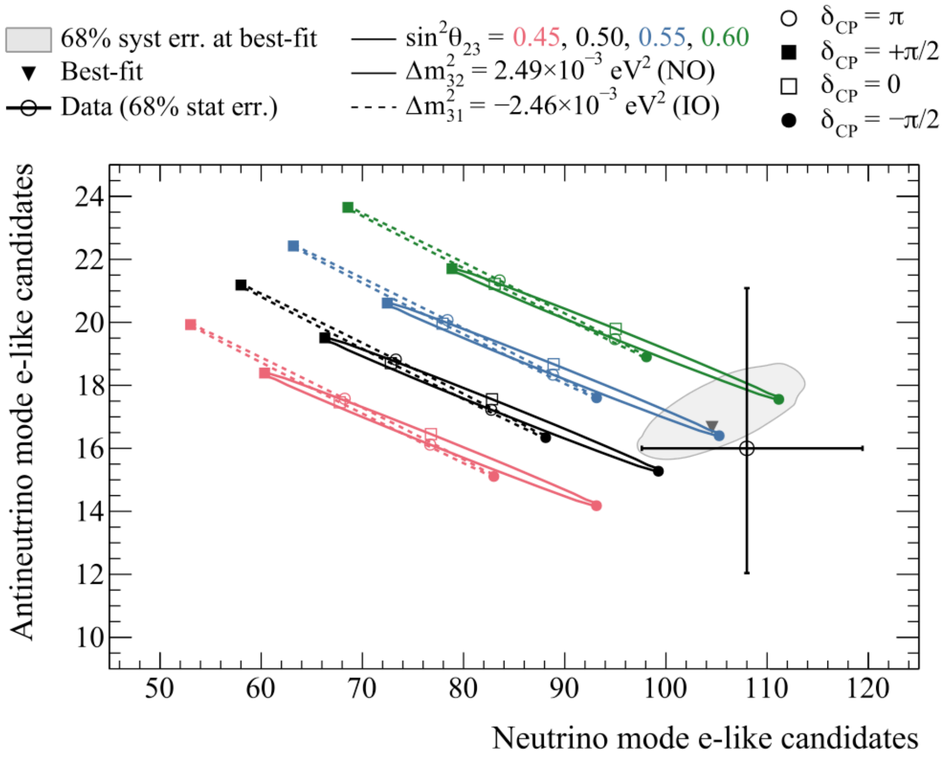
- Reduction of flux and cross-section systematic uncertainties

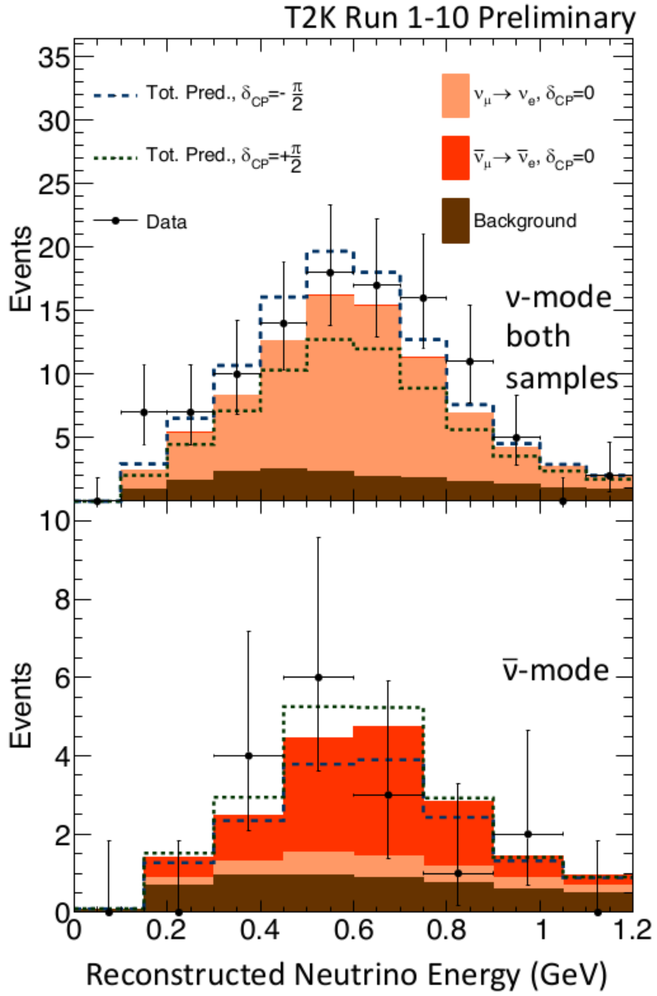




Promising results...

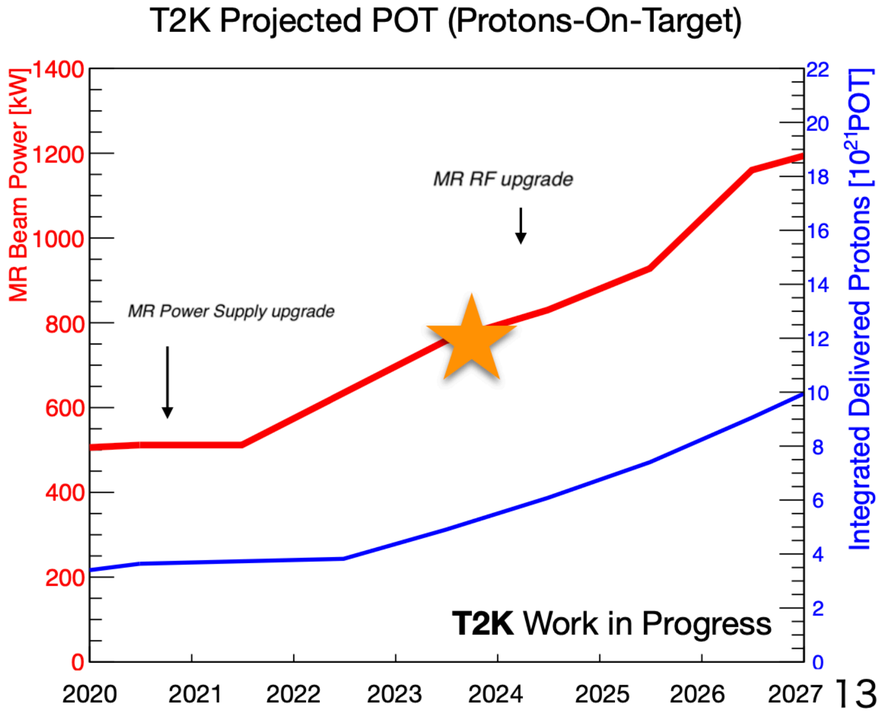
- 2 CP symmetry conserving points ruled out at the 2σ confidence level [https://www.nature.com/articles/s41586-020-2177-0]





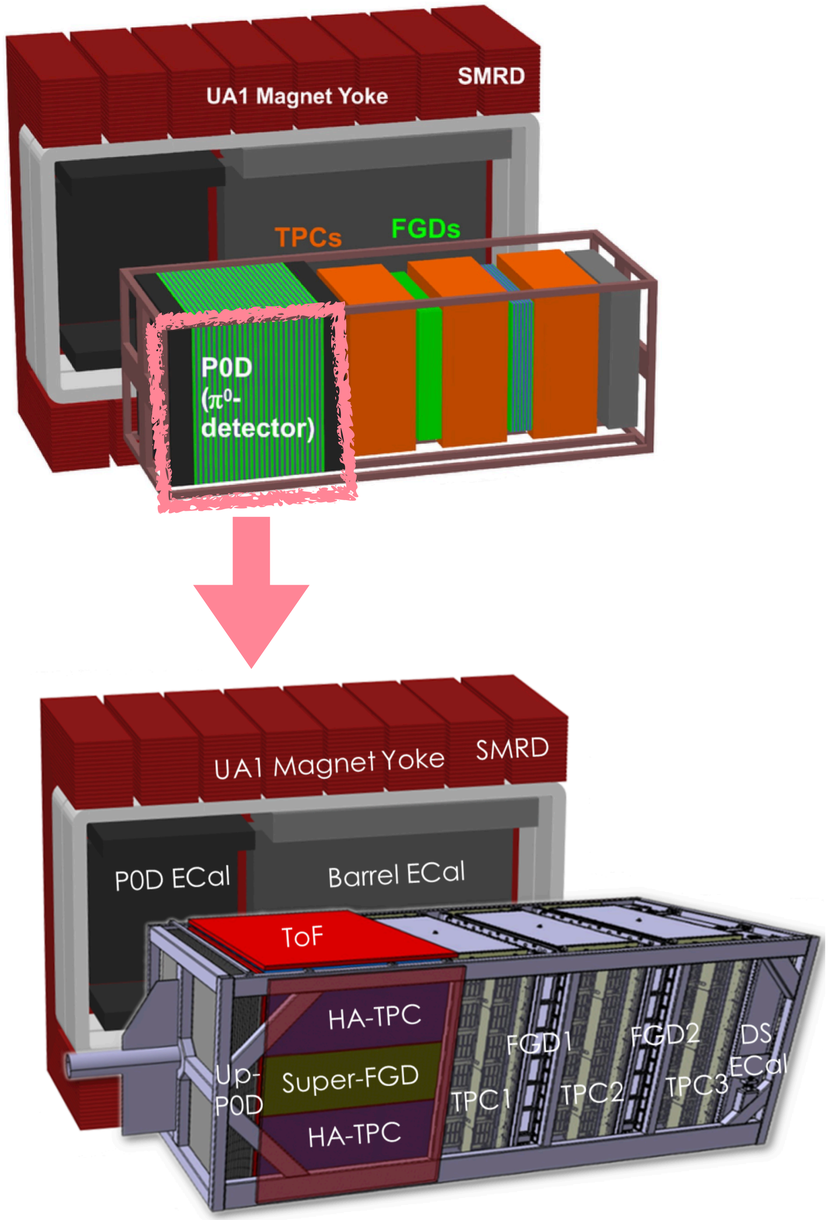
... but can do even better: T2K-II !

- Upgrade of J-PARC neutrino beam line: proton **beam power** gradually **increase** from $\simeq$ 500kW to 1.3MW (in 2027) thanks to faster cycle from 2.48s → 1.36s
- New electromagnetic horns → 320 kA instead of 250 kA → 10% increase in neutrino flux
- Goal: collect >10×10^{21} POT by 2027 → 3σ measurement of CP violation if $\delta_{CP} \simeq -\frac{\pi}{2}$
- Successfully achieved 710 kW stable operation with 320 kA horn current → continuous operations at 760 kW were also demonstrated

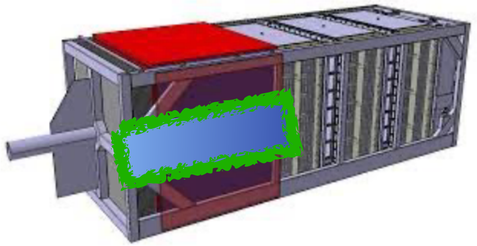


... but can do even better: T2K-II !

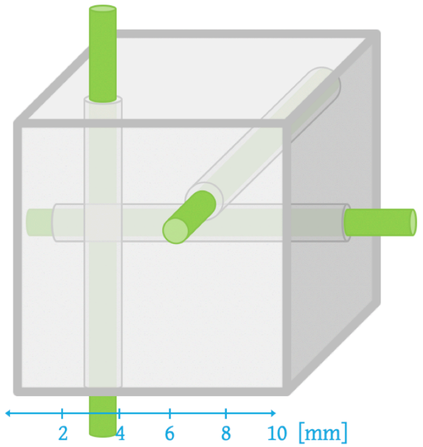
- Upgrade of the ND280: replacement of PoD by:
  - **SFGD** (Super Fine Grain Detector): 2 millions of 1cm^3 plastic scintillator cubes
  - **2 HA-TPC** (High-Angle TPC): TPCs at the top and the bottom of the SFGD, equipped with the new Resistive Micromegas technology
  - 6 **TOF** planes surrounding this structure

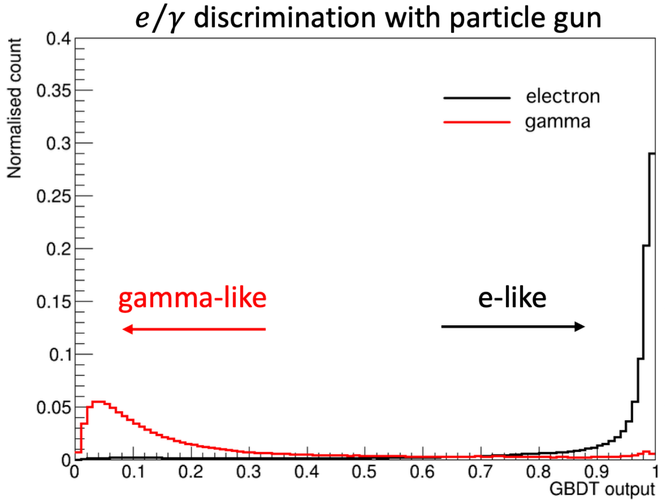


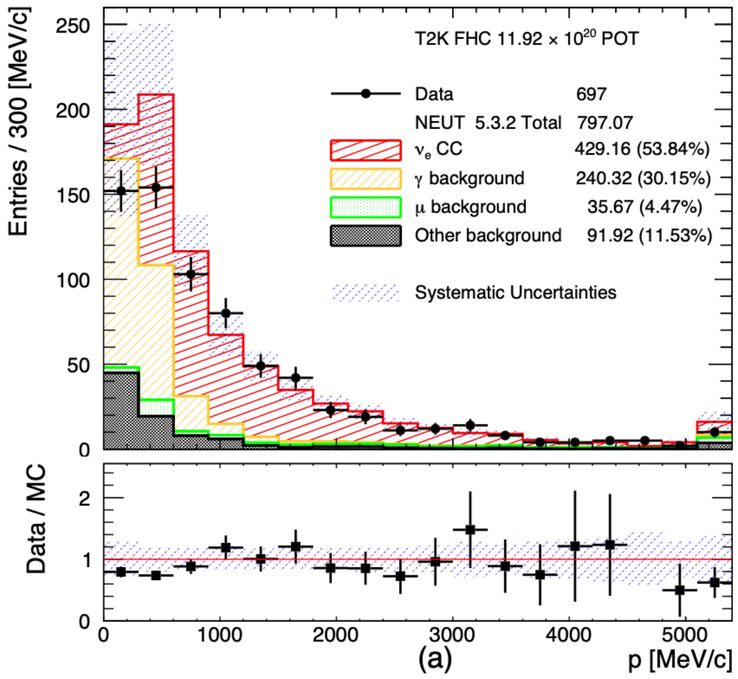
SFGD

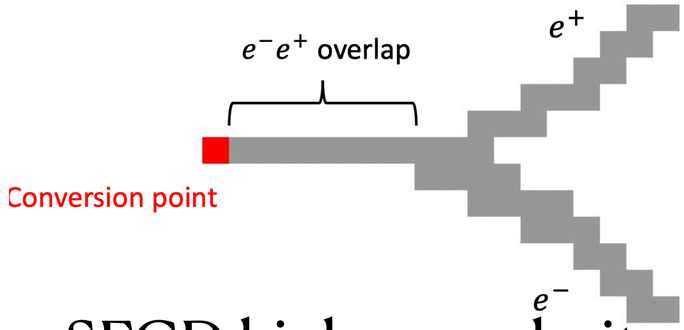


- 2 millions optically independent plastic scintillator cubes made of polystyrene and doped with 1.5% of paraterphenyl (PTP) and 0.01% of POPOP.



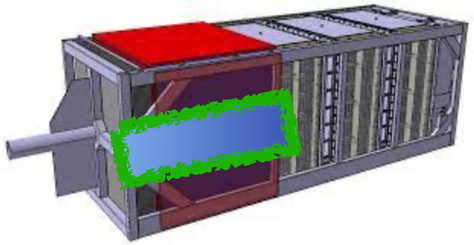




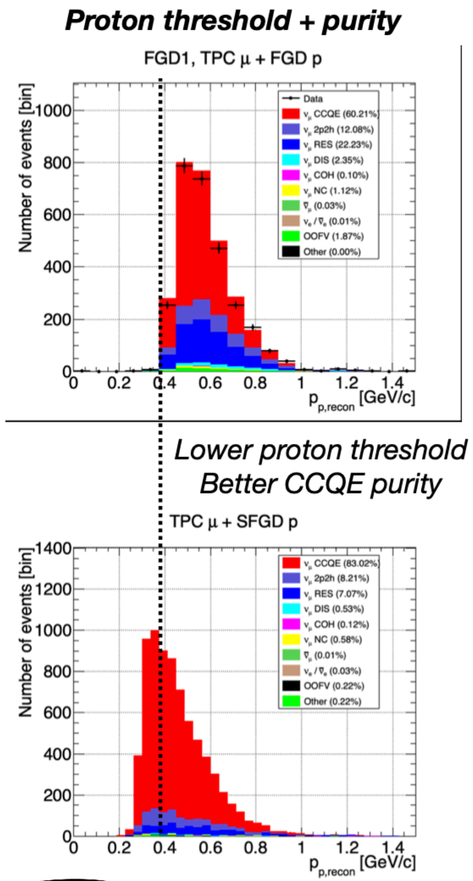


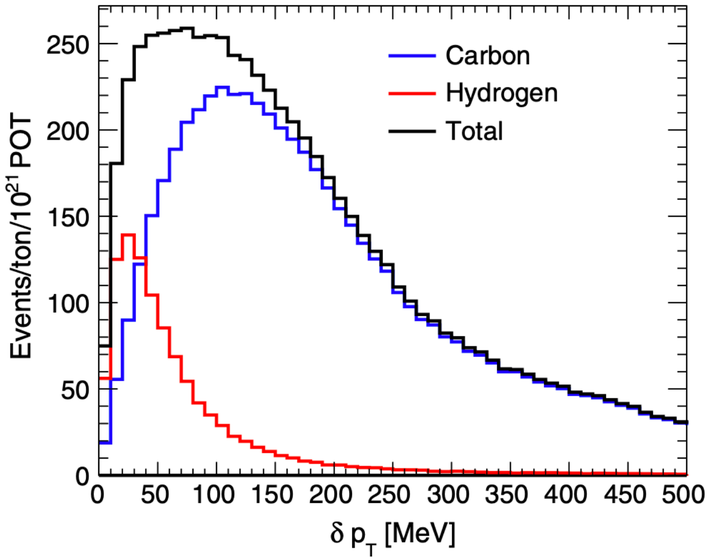
- SFGD high-granularity means better separation of e^- coming from ν_e interactions and the ones coming from $\gamma \rightarrow e^+e^-$ conversions
- Expect a clear sample of low energy ν_e

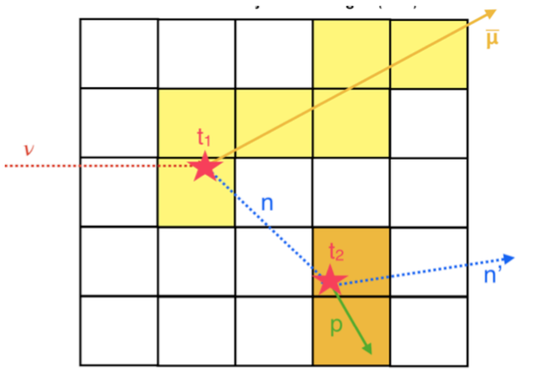
SFGD



- Better efficiency to reconstruct proton at low energy

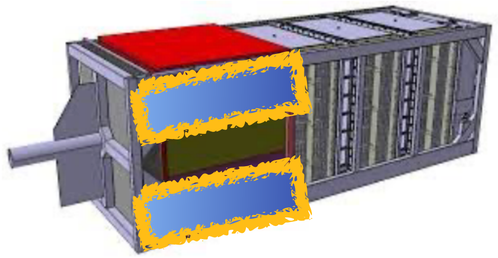




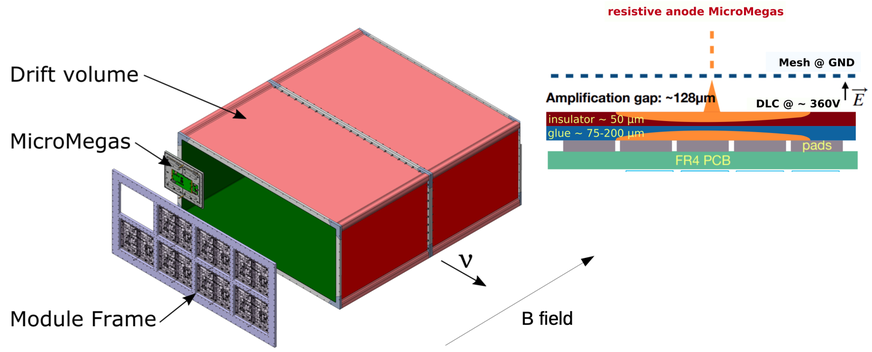


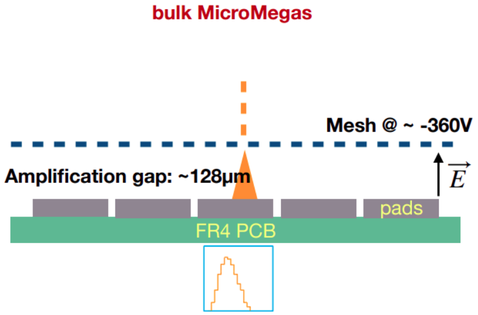
- Reconstruction of neutron kinematics thanks to their pre-thermalization scattering on protons
- Exclusive selection of $\mu^+ + n$ samples of $\overline{\nu}_\mu$ interaction similar to what is done with $\mu^- + p$ in ν_μ case
- Sample used to measure $\overline{\nu}_\mu$ interactions on H, no nuclear effect so accurate measurement of neutrino flux !

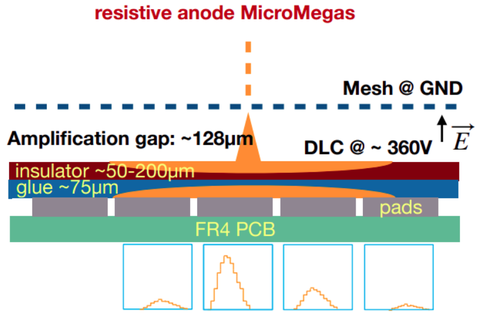
HA-TPC

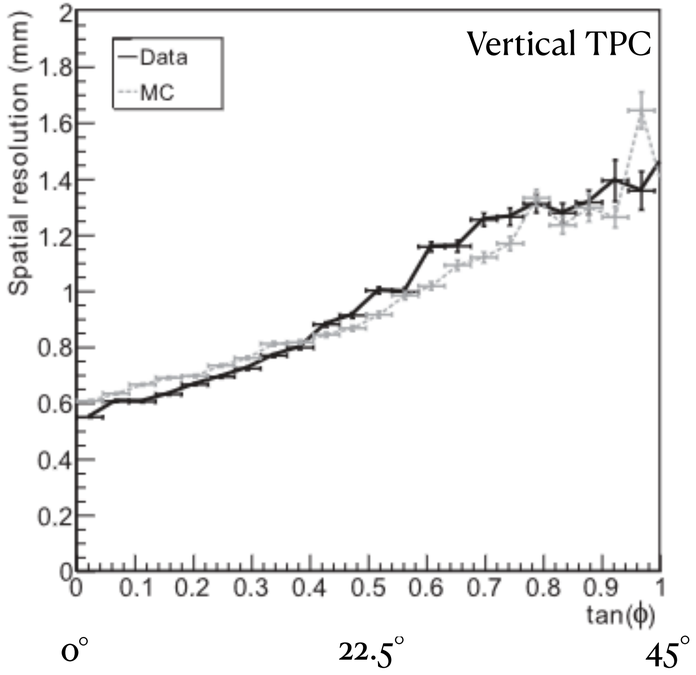


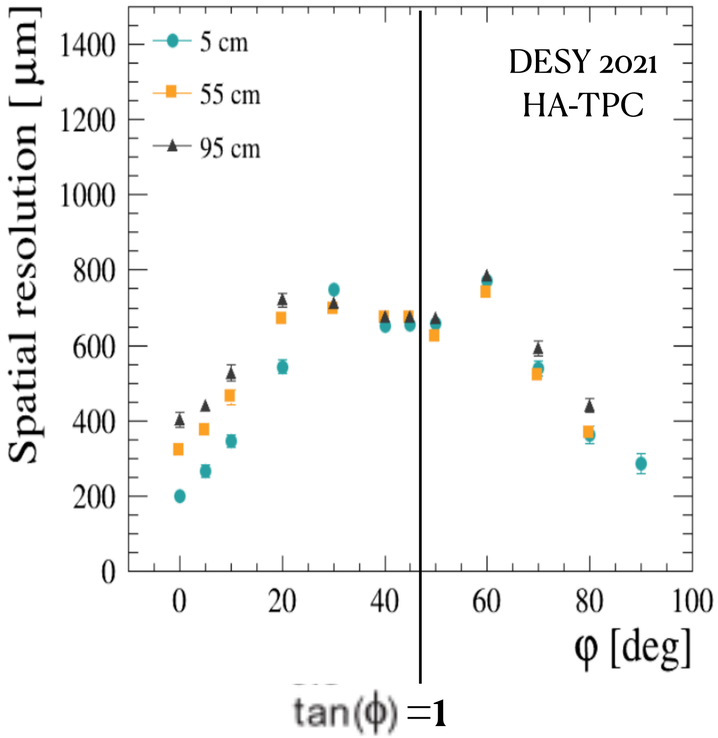
- New TPCs equipped with the resistive anode MicroMegas (ERAM) technology
- Compared to the bulk MicroMegas which equip the vertical TPC, ERAM spatial resolution is much better thanks to Gaussian charge spreading











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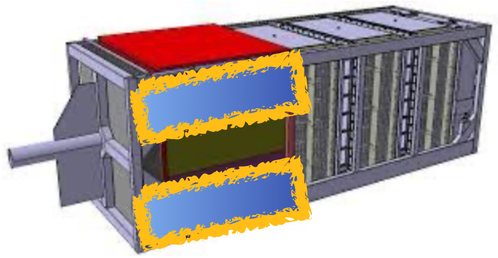
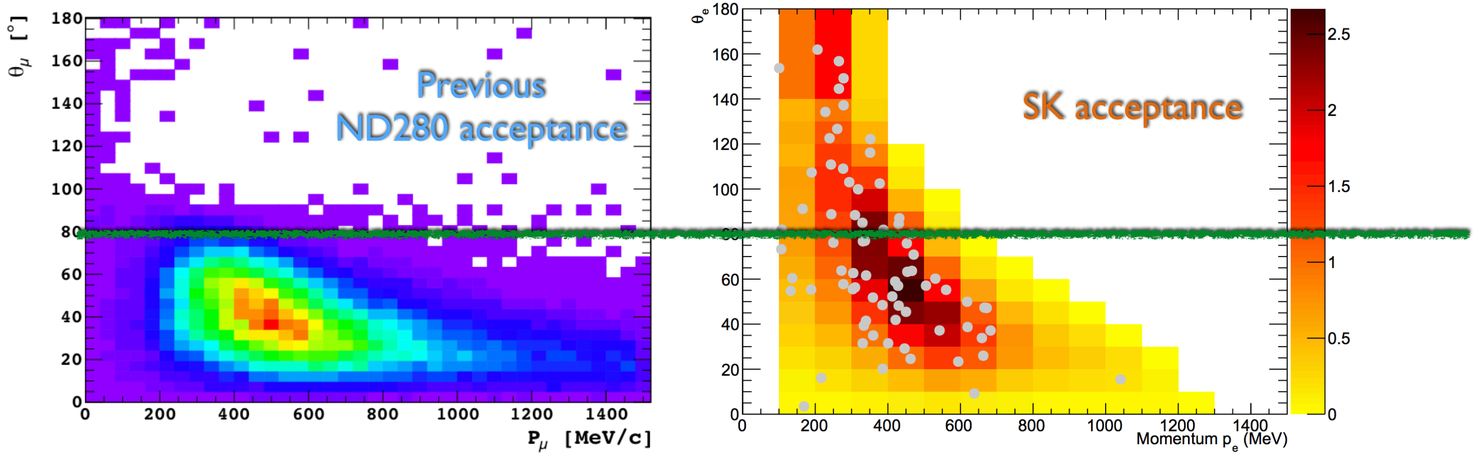
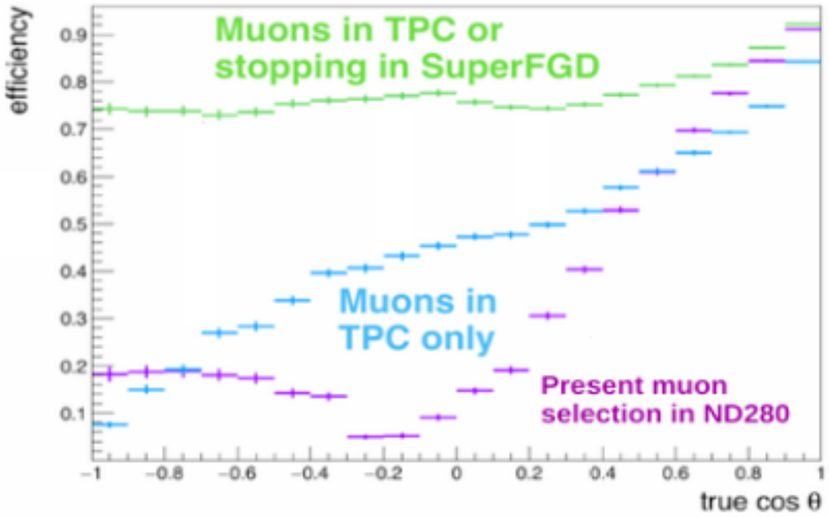
HA-TPC



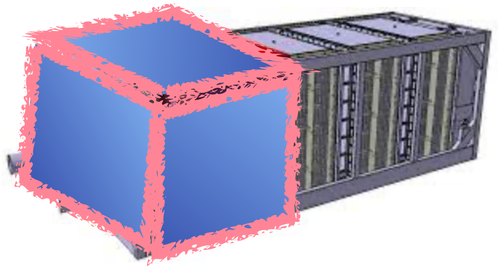
- Previous ND280 limitation: acceptance didn't match SK's one:



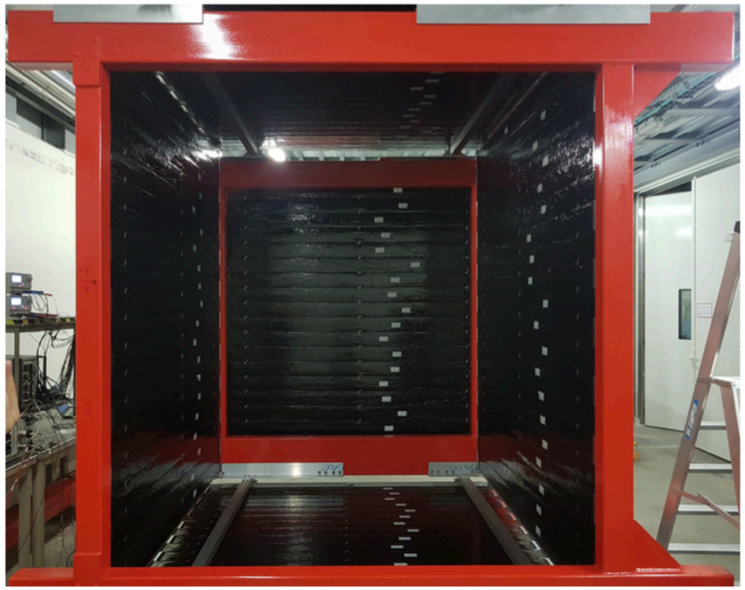


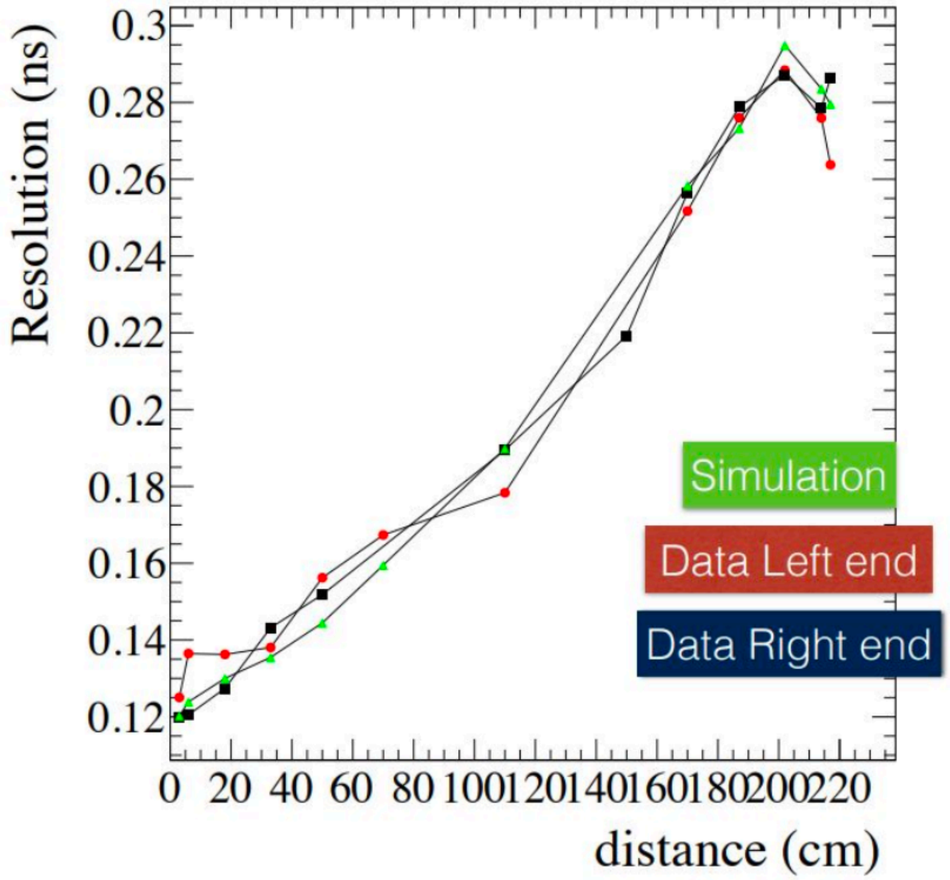
- This issue is now fixed with the addition of the two HA-TPCs on top and bottom of SFGD
- Efficiency reaches more than 70% for all incoming track angles!

TOF



- 6 Plastic scintillator planes forming a cube that surround SFGD and HAT
- Reconstruction of track direction with a time resolution between 100 and 300 ps



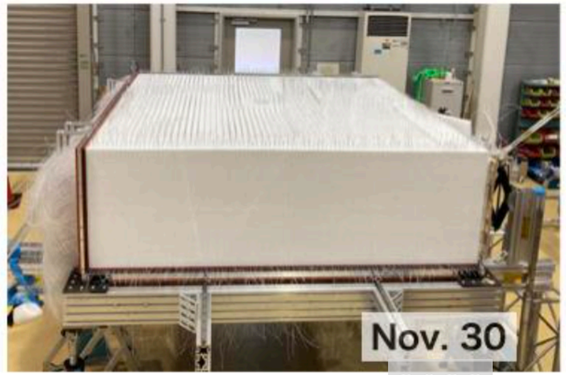


Super-FGD and HA-TPC assemblies

- SFGD assembly at J-PARC

First cube layer assembly

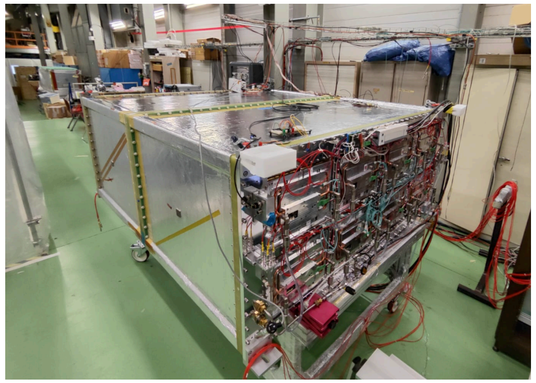
Stop panels removed



Box closure

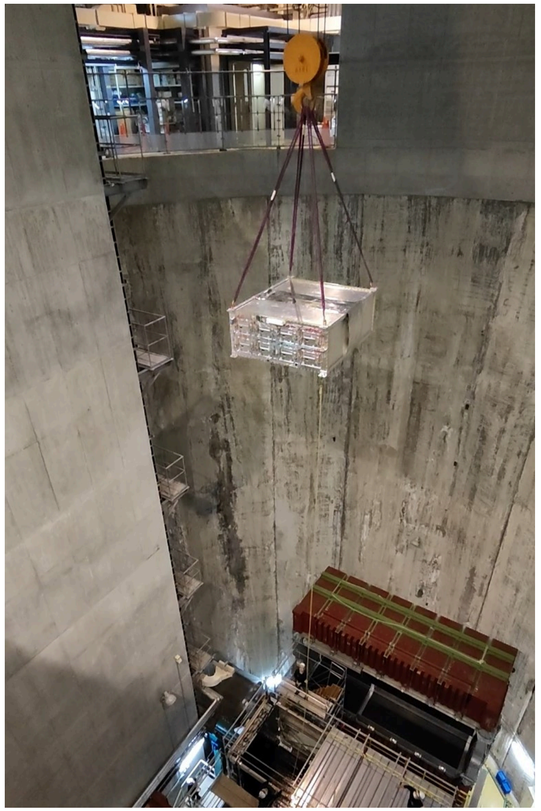
Light barrier/cables asse

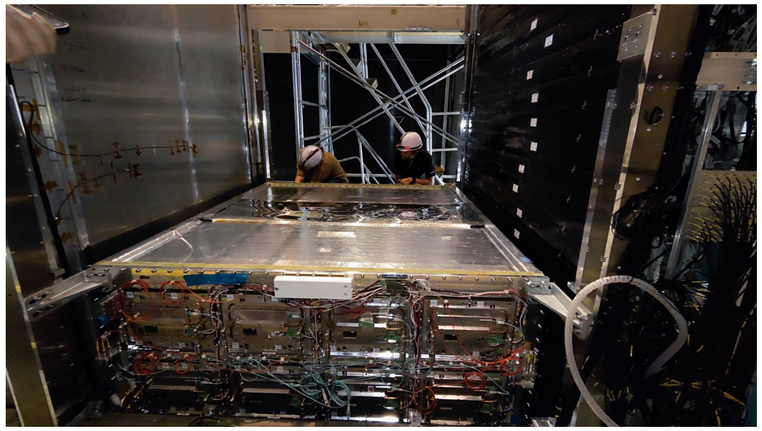
- HA-TPC assembly and commisionning at CERN, arrived fully instrumented at J-PARC!

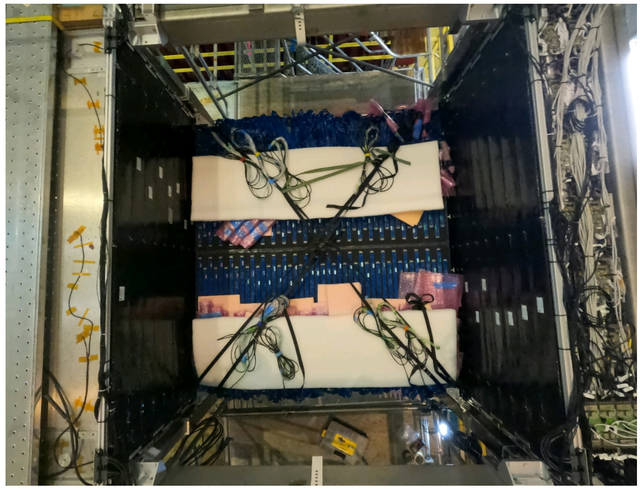


HA-TPC delivered at J-PARC

ND280 Upgrade's installation

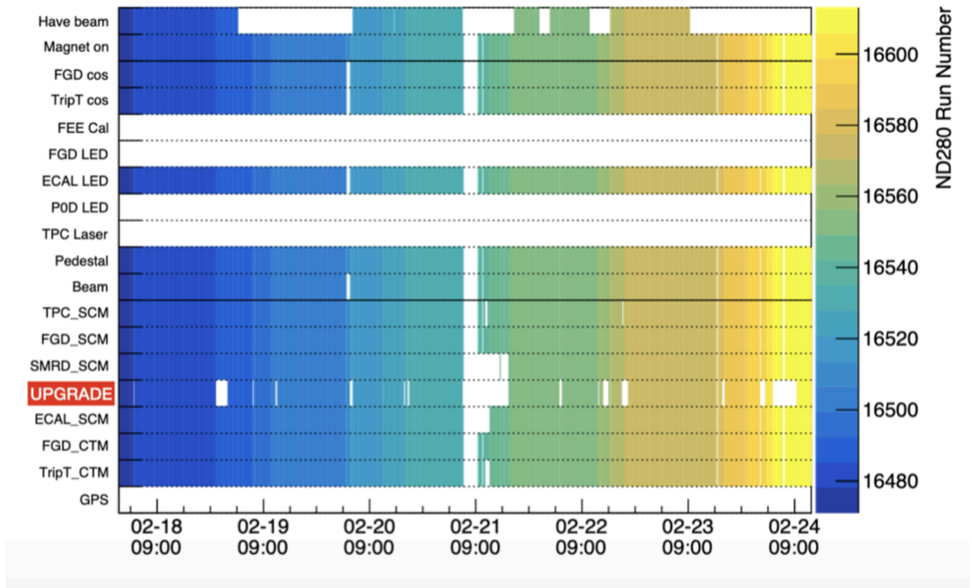


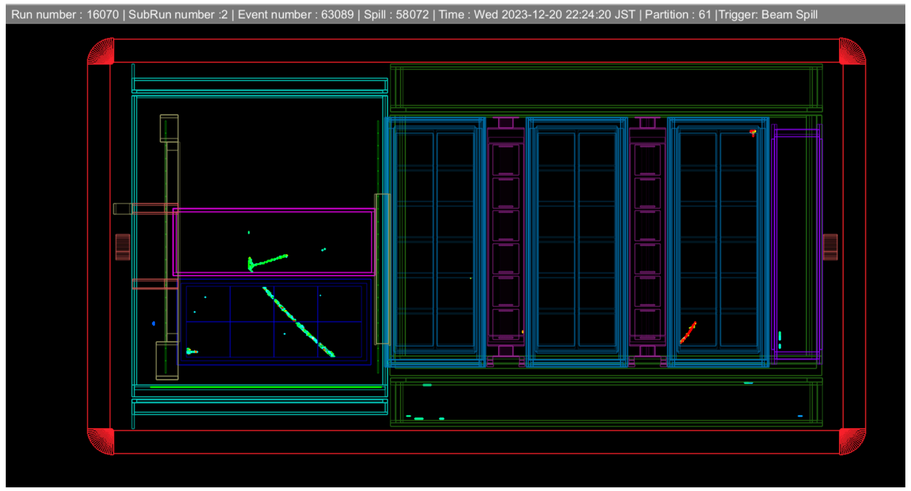


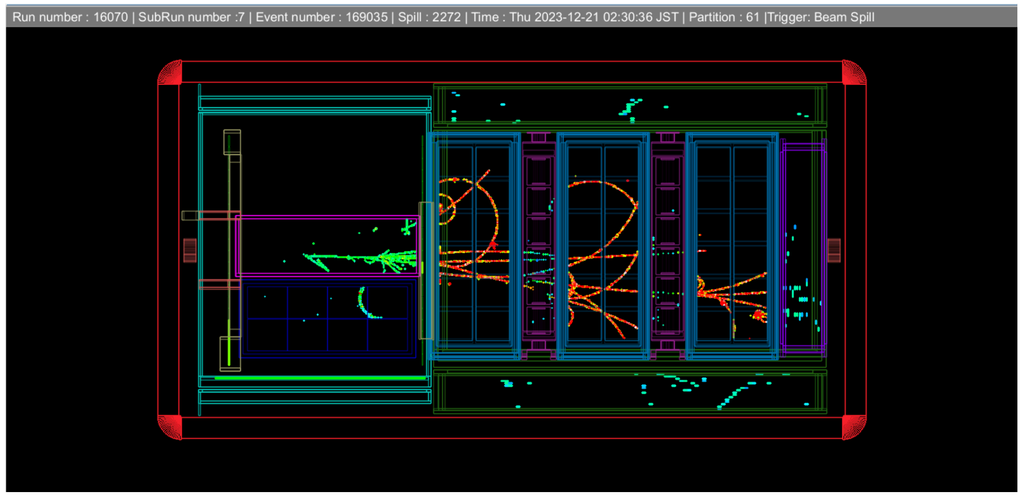


T2K-II is truly happening !

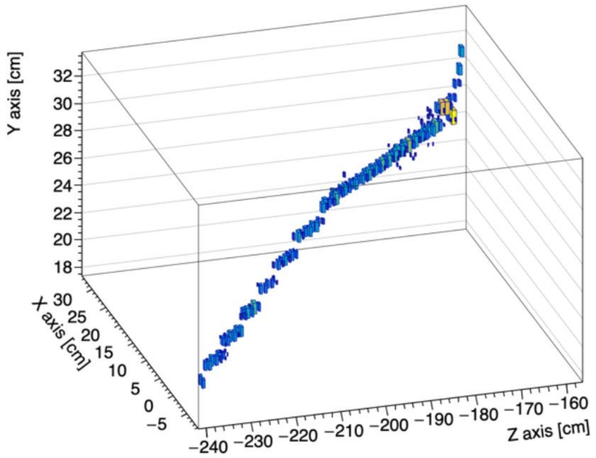
- The Bottom HAT, SFGD and 4/6 TOF planes were installed in the ND280 pit in end of 2023 and have started to take data
- The Top HAT will be installed together with the 2 last TOF panels by end of April 2024 and should be ready for May-June runs!

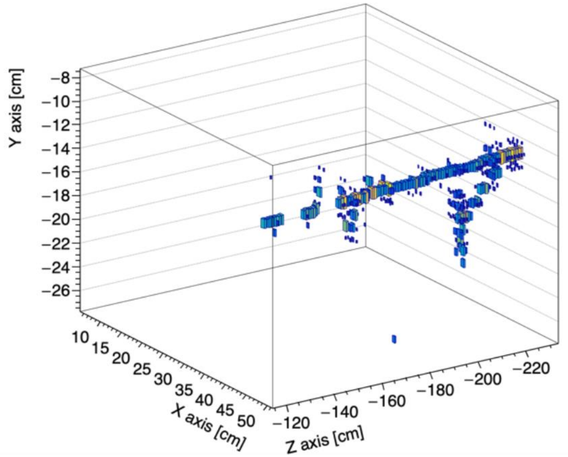


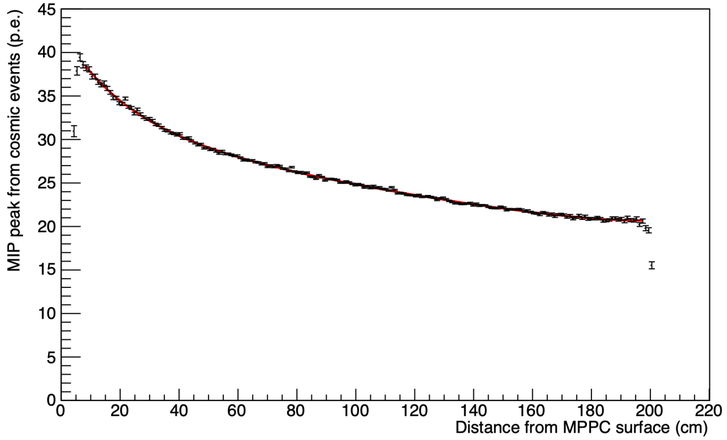




ND280 Upgrade: SFGD Preliminary results

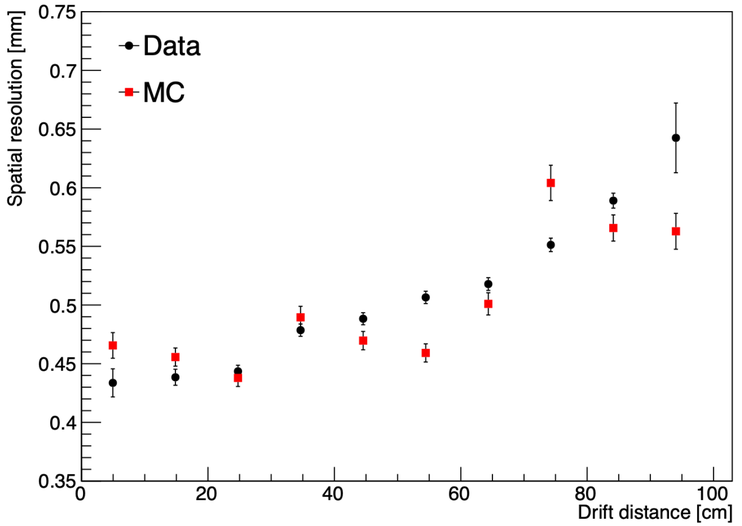


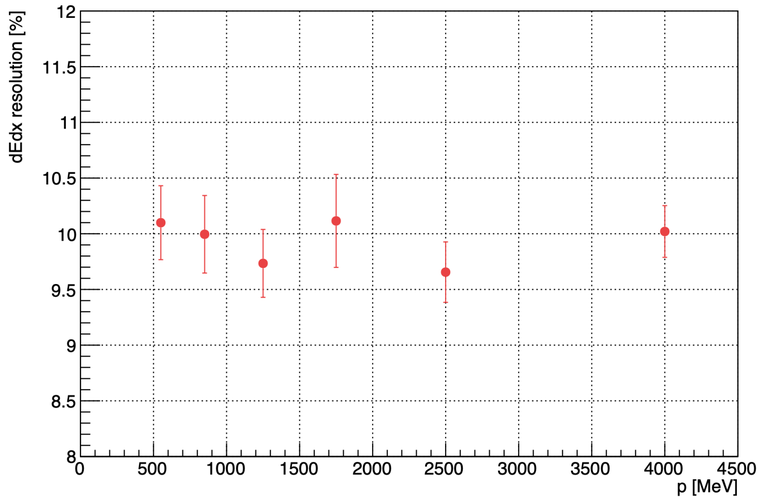




ND280 Upgrade: HA-TPC Preliminary results

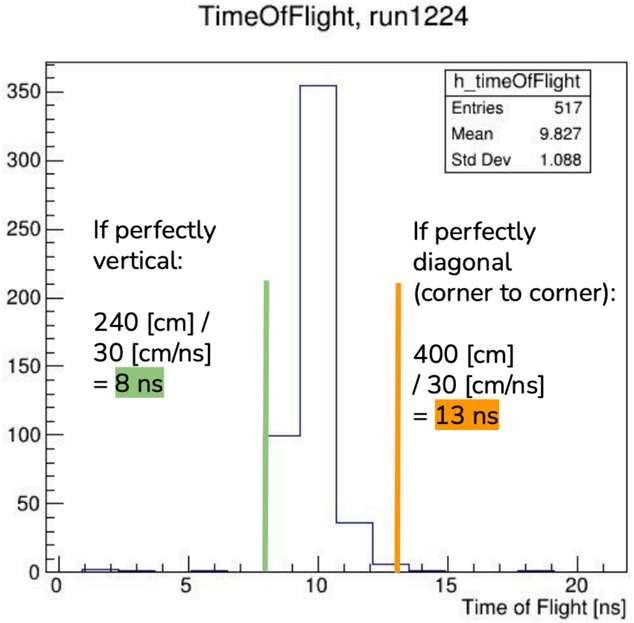
- Thanks to the cosmics data taken at J-PARC in end of 2023 a spatial resolution of the order of 550 μm, in agreement between data and MC, has been observed
- Moreover, dEdx resolution of the order of 10% has been measured in a wide range of momenta

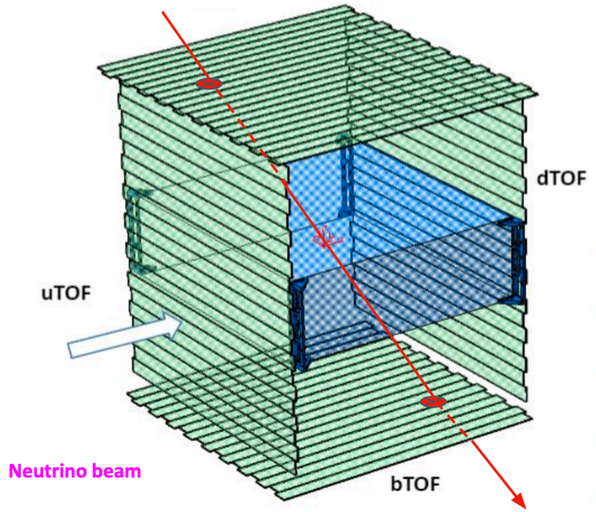




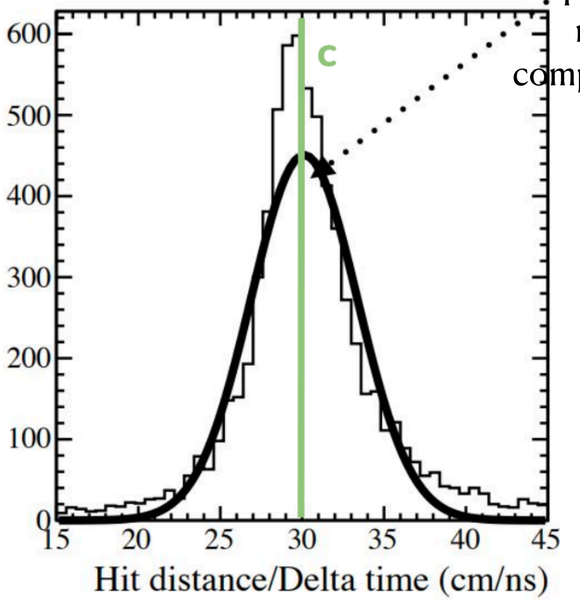
ND280 Upgrade: TOF Preliminary results

- Cosmics data taking

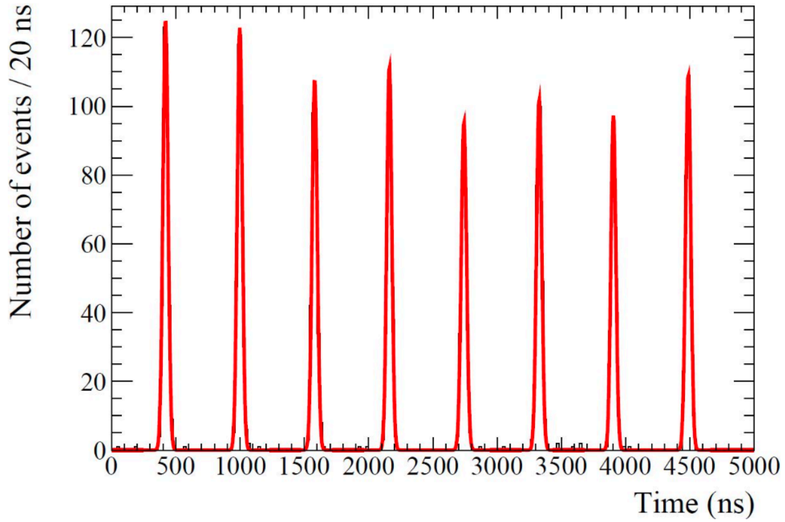




Cosmic crossing Top and Bottom



Speed of light measured compatible with c!



- Beam data taking
- TOF clearly distinguish the eight beam pulses structure!

Summary and perspectives

Thank you for your attention!