# T2K recent results and plans

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for the T2K collaboration

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# Neutrino oscillations

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta_{CP}}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{i\delta_{CP}} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Atmospherics and LBL
$\theta_{23} \sim 45°$
$|\Delta m^2_{32}| \sim 2.5\times10^{-3}$ eV$^2$

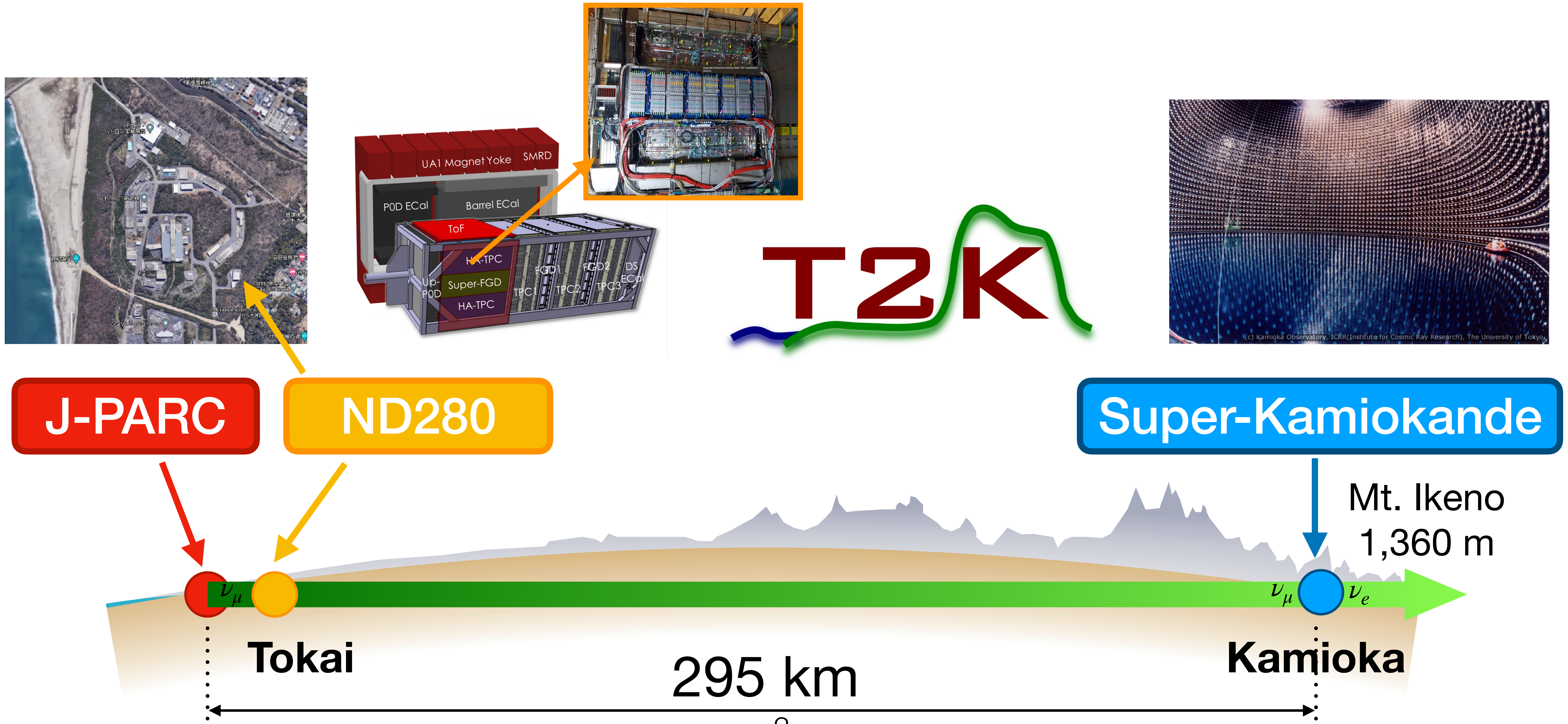
Reactors
$\theta_{13} \sim 10°$
LBL
$\theta_{13}$ and $\delta_{CP}$

Solar and reactors
$\theta_{12} \sim 35°$
$\Delta m^2_{21} \sim 7.5\times10^{-5}$ eV$^2$

- Long baseline (LBL) experiments sensitive to 5 of the PMNS parameters
  - $\theta_{23}$, $|\Delta m^2_{32}|$ → LBL provides the most precise measurements of these parameters
  - $\theta_{13}$ → dominated by reactor experiments
  - $\delta_{CP}$ and sign of $\Delta m^2_{32}$ (normal or inverted ordering) → still unknown and accessible to LBL

# T2K experiment

- High intensity ~600 MeV $\nu_\mu$ or $\bar{\nu}_\mu$ beam produced at J-PARC (Tokai)
- Neutrinos detected at the Near Detector (ND280) and at the Far Detector (Super-Kamiokande)
  - $\nu_e$ and $\bar{\nu}_e$ appearance → determine $\theta_{13}$ and $\delta_{CP}$
  - Precise measurement of $\nu_\mu$ disappearance → $\theta_{23}$ and $|\Delta m^2_{32}|$



# T2K collaboration

**~560 members, 74 institutes, 15 countries(incl. CERN)**

- Active collaboration involved in
  - Oscillation analysis and measurements of neutrino cross-sections (see dedicated talk and posters)
  - Joint analyses with SK and NOvA (discussed in the next talk)
  - Beamline and detector upgrades (ND280 Upgrade, SK-Gd)

**M. Buizza Avanzini, Overview on neutrino cross section measurements**

N. Latham, and K. Kowalik posters

# Have a look at 16 T2K posters

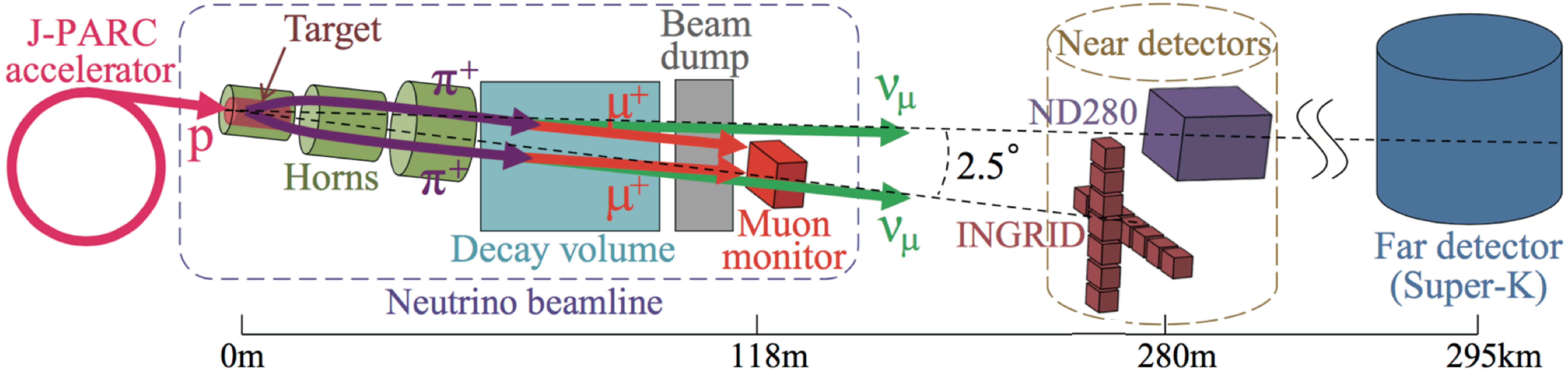
**8 posters on oscillation and cross-section analyses**

- A. Blanchet, GUNDAM: a pioneering universal tool for long-baseline neutrino oscillation experiments
- D. Carabadjac, Recent T2K oscillation analysis results and Hyper-Kamiokande sensitivity to accelerator neutrino oscillations
- K. Kowalik, Measurement of $K^+$ production in the charged-current neutrino interactions in the T2K experiment
- N. Latham, First Measurement of the Charged Current Electron Neutrino Pion Production Cross Section on a Carbon Target at T2K
- E. Miller, Fitting T2K Near Detector Data using a Markov Chain Monte Carlo
- L. Osu, Near detector constraints for the T2K Oscillation Analysis using the GUNDAM framework
- Z. Xie, L. Berns, First joint analysis of Super-Kamiokande atmospheric and T2K accelerator neutrino data
- C, Valls, The WAGASCI-BabyMIND detector of the upgraded T2K experiment

**8 posters on ND280 upgrade**

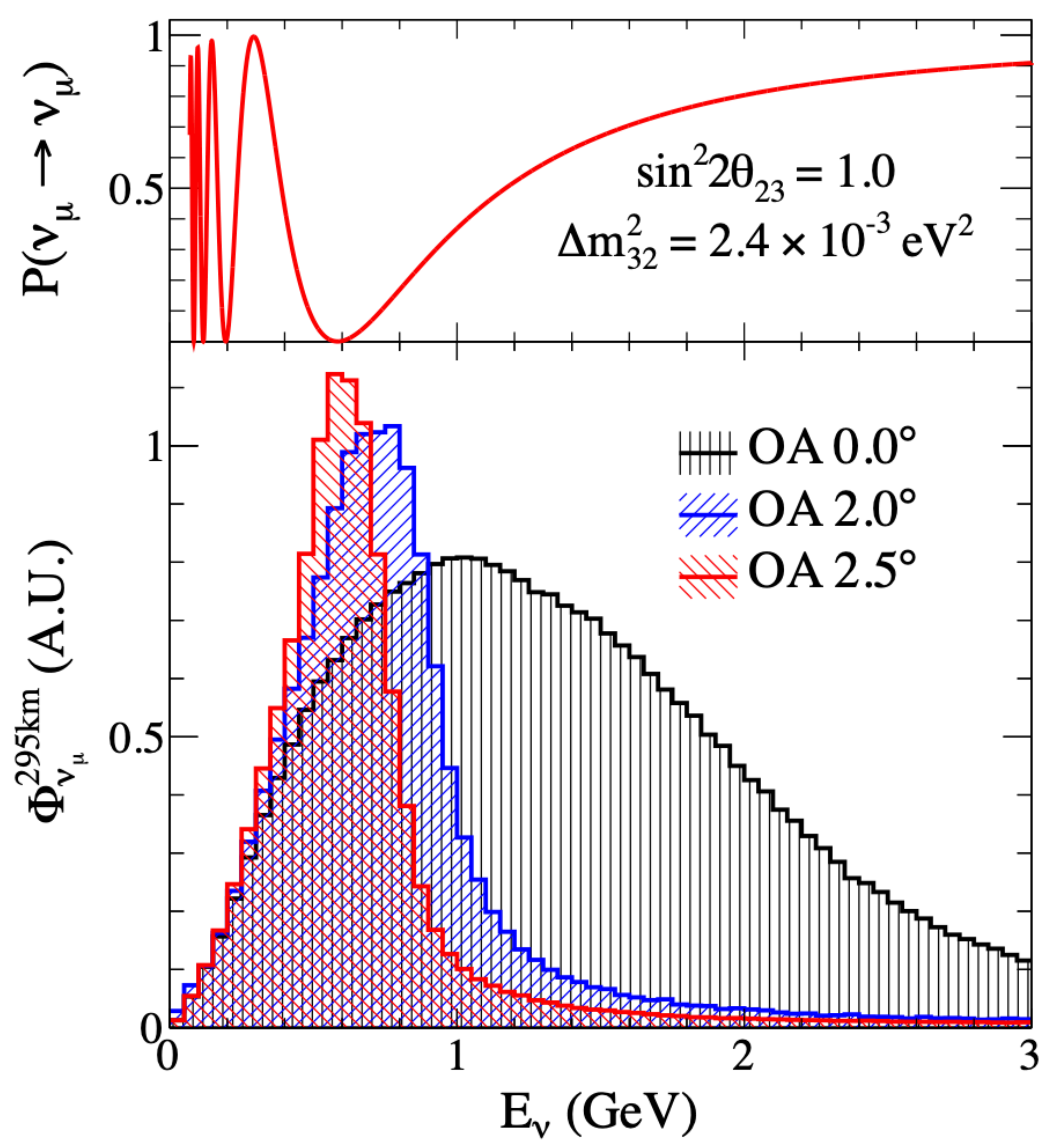
- T. Doyle, Characterising the Detector Response of the SuperFGD as part of the T2K Near Detector Upgrade
- M. Feltre, Commissioning of High Angle Time Projection Chambers for T2K ND Upgrade
- D. Ferlewicz, Commissioning and calibration of the Super-FGD in the T2K experiment near detector upgrade
- L. Kneale, Neutrons as probes of nuclear effects in muon neutrino CC0π at T2K's upgraded near detector
- K. Lachner, $\nu_\mu$ CC0π cross-section measurement with calorimetric information at the upgraded T2K near detector
- W. Li, Transverse Kinematic Imbalance Analysis and Pion Trackless Reconstruction at the Upgraded T2K Near Detector
- Q. V. Nguyen, An innovative detector Super-FGD for T2K near detector and its front-end readout architecture
- U. Virginet, Track reconstruction in the HA-TPC of the upgraded near detector of T2K

# T2K beamline




- 30 GeV proton beam from J-PARC Main Ring extracted onto a graphite target
- p+C interactions producing hadrons (mainly pions and kaons)
- Hadrons are focused and selected in charge by 3 electromagnetic horns
  - If $\pi^+$ are focused $\nu_\mu$ are produced by $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - Changing the horn current we can produce $\bar{\nu}_\mu$ from $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
- Off-axis technique → detectors intercept a narrow-band beam at the maximum of the oscillation probability

$\nu_\mu$ survival probability



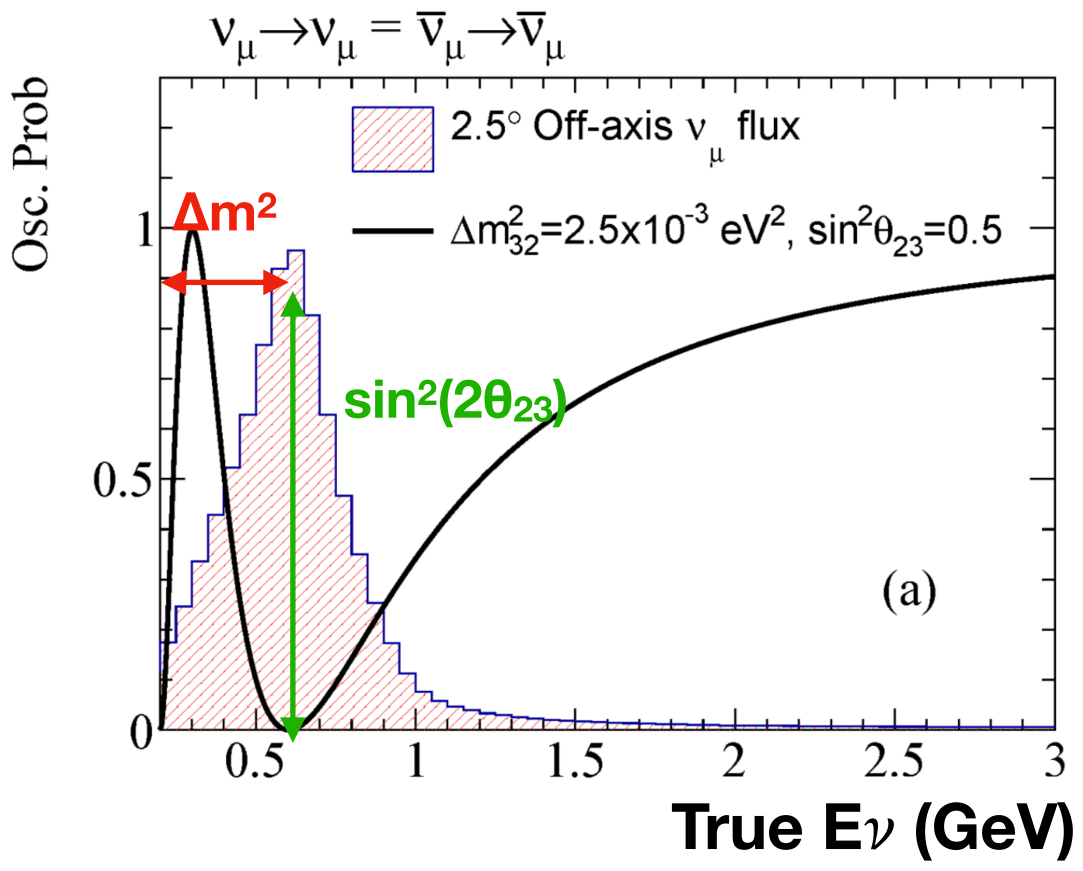
# Physics case

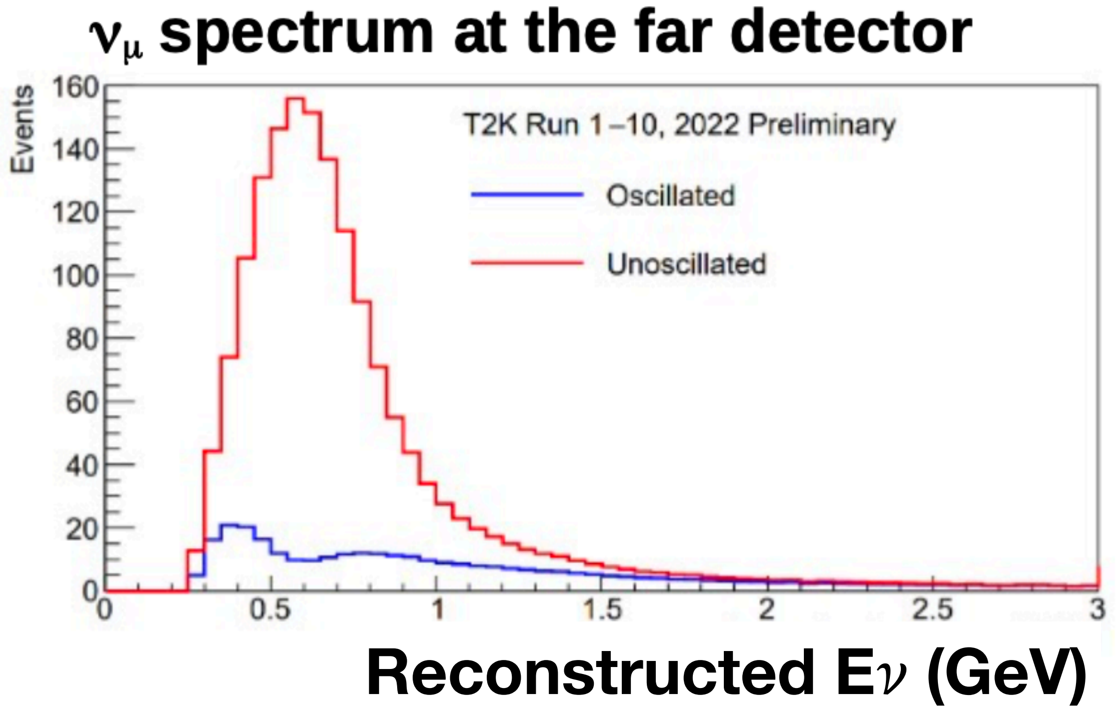
## $\nu_\mu$ and $\bar{\nu}_\mu$ disappearance

$$P(\nu_\mu \to \nu_\mu) = P(\bar{\nu}_\mu \to \bar{\nu}_\mu) = 1 - \sin^2(2\theta_{23})\sin^2\left(1.27\frac{\Delta m^2 L}{E}\right)$$

Same oscillation probability for $\nu$ and $\bar{\nu}$

Sensitive to $|\Delta m^2_{32}|$ and to $\sin^2(2\theta_{23})$ → no sensitivity to mass ordering and $\delta_{CP}$




## $\nu_e$ and $\bar{\nu}_e$ appearance

$$P(\overline{\nu_\mu} \to \overline{\nu_e}) \simeq \sin^2\theta_{23}\frac{\sin^2 2\theta_{13}}{(A-1)^2}\sin^2[(A-1)\Delta_{31}]$$

$$(\mp)\alpha\frac{J_0\sin\delta_{CP}}{A(1-A)}\sin\Delta_{31}\sin(A\Delta_{31})sin[(1-A)\Delta_{31}]$$

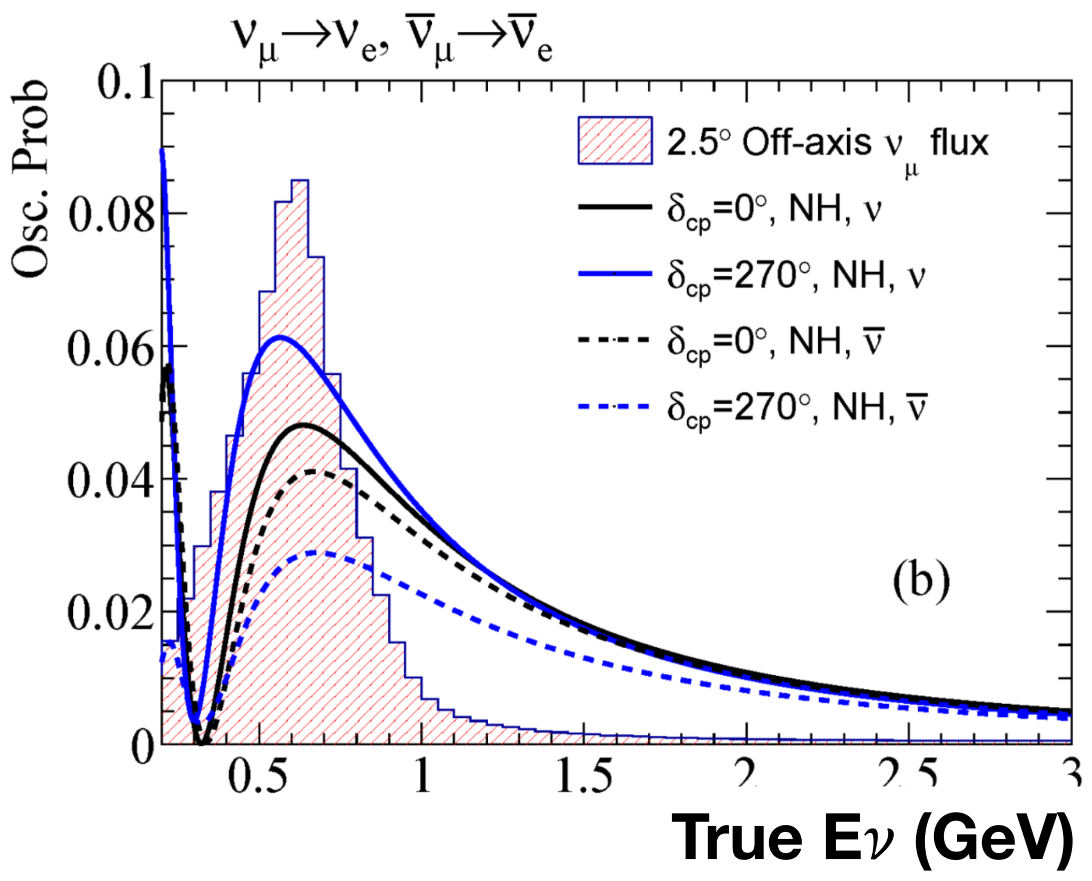
$$+\alpha\frac{J_0\cos\delta_{CP}}{A(1-A)}\cos\Delta_{31}\sin(A\Delta_{31})sin[(1-A)\Delta_{31}] + O(\alpha^2)$$

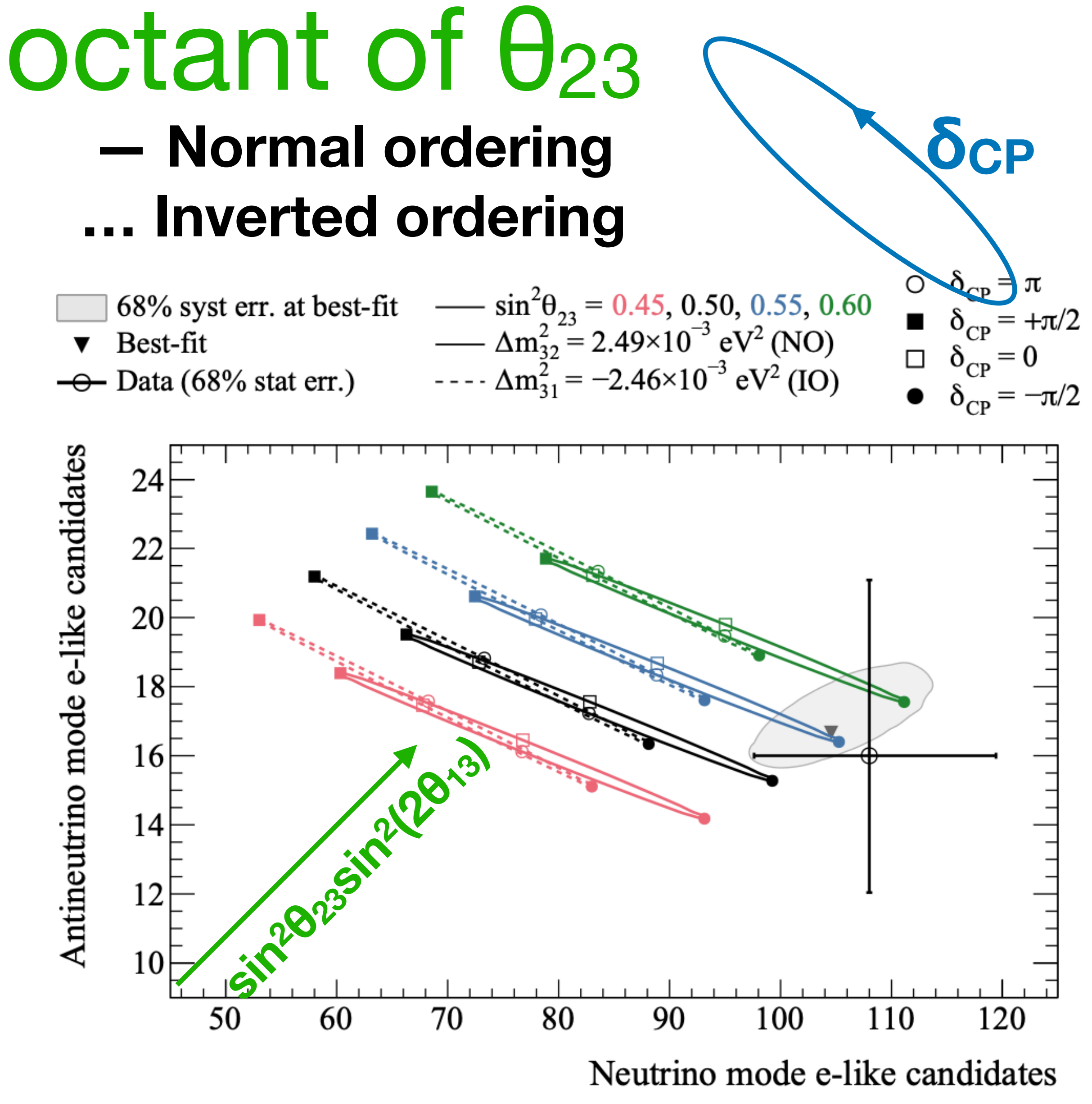
$\alpha = \Delta m^2_{21}/\Delta m^2_{31} \sim 1/30$

$J_0 = \sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}\cos\theta_{13}$

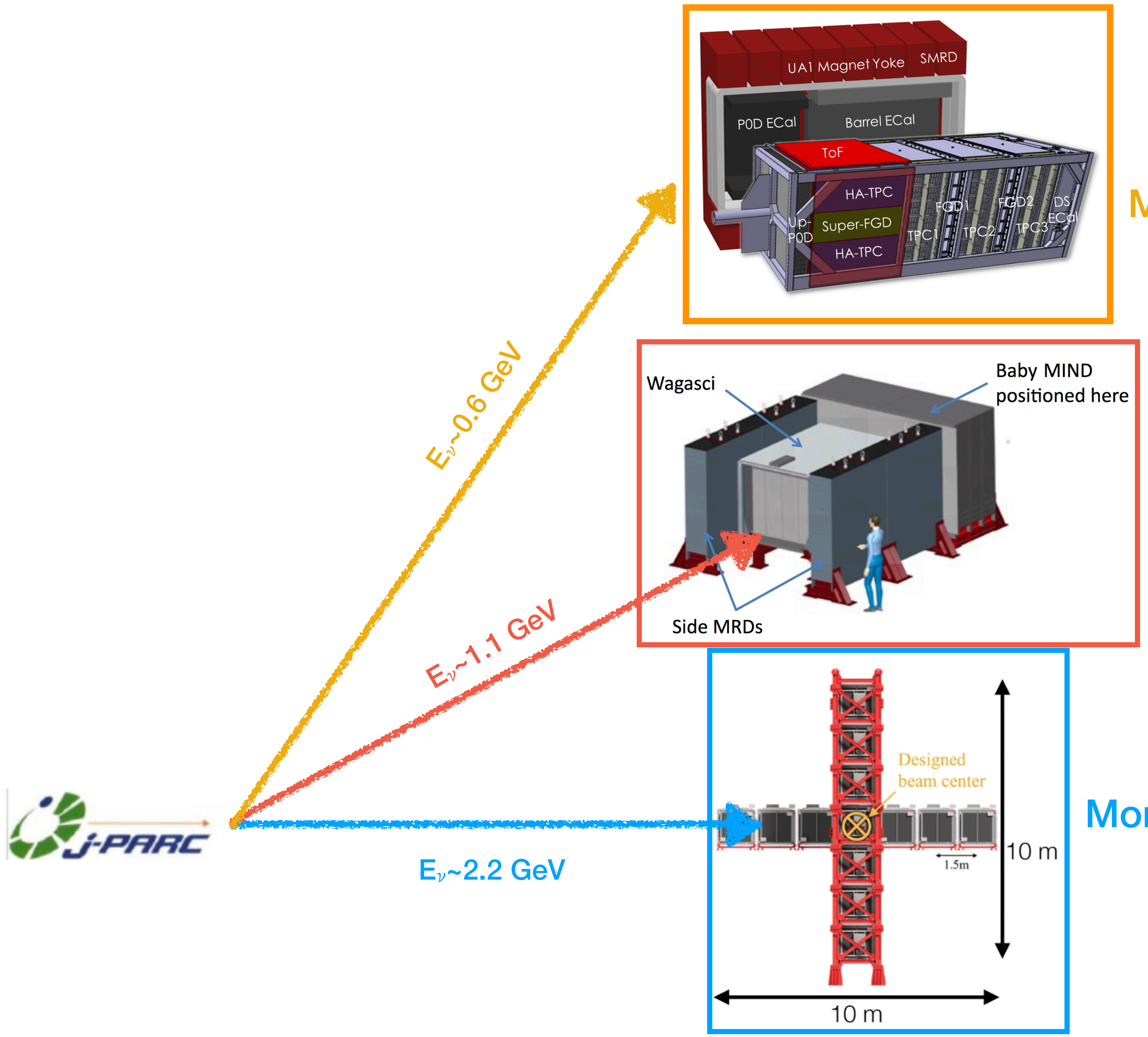
$A = (\mp)2\sqrt{2}G_F n_e E/\Delta m^2_{31}$

Sensitivity to $\delta_{CP}$, to the mass ordering and to the octant of $\theta_{23}$



# Near Detector complex




Off-Axis ND280
Constrain systematics in T2K oscillation analyses
Measure neutrino cross-sections
In operation since 2010 and upgraded in 2023

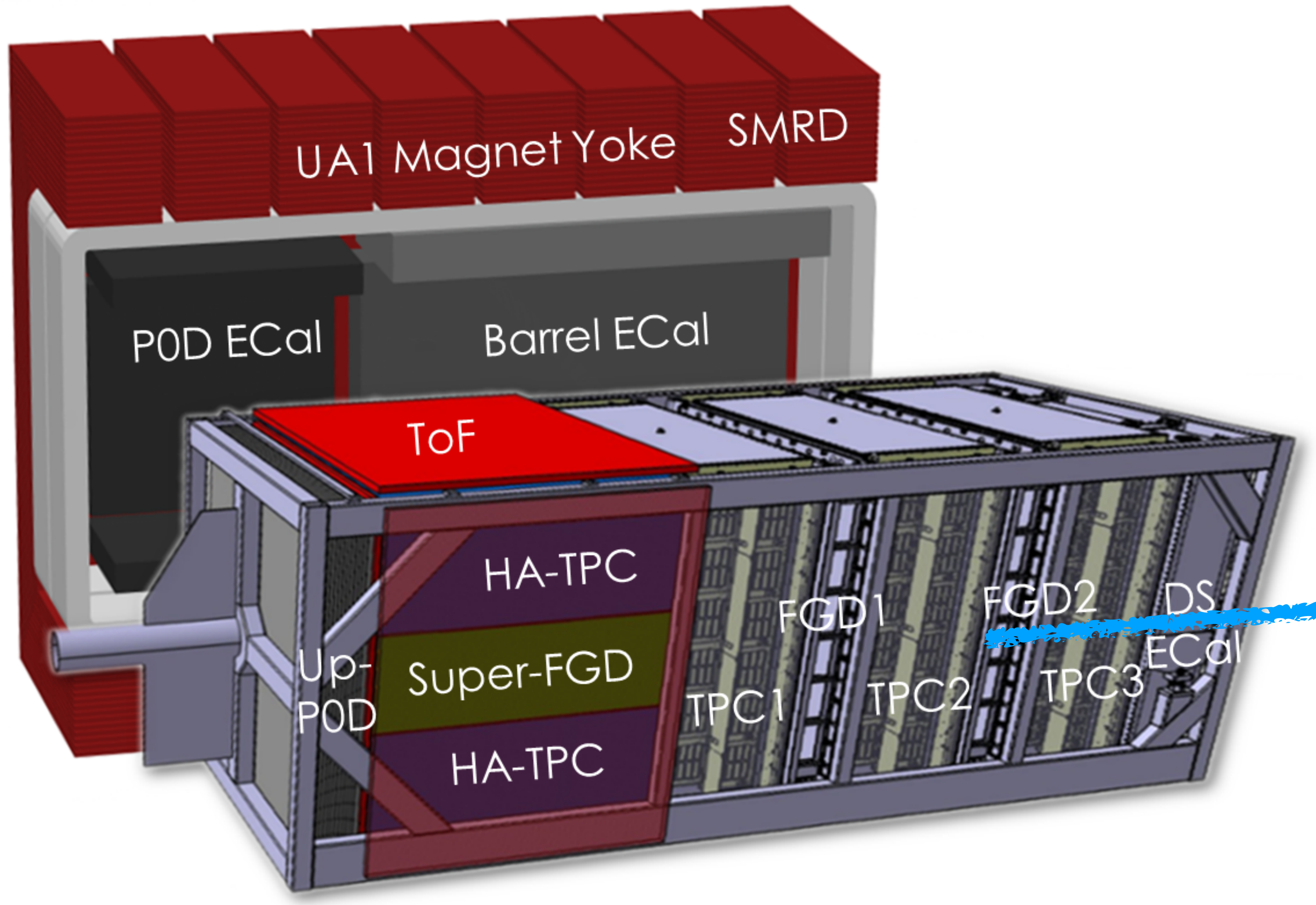
WAGASCI/BabyMIND
Installed in 2019
Cross-sections on water

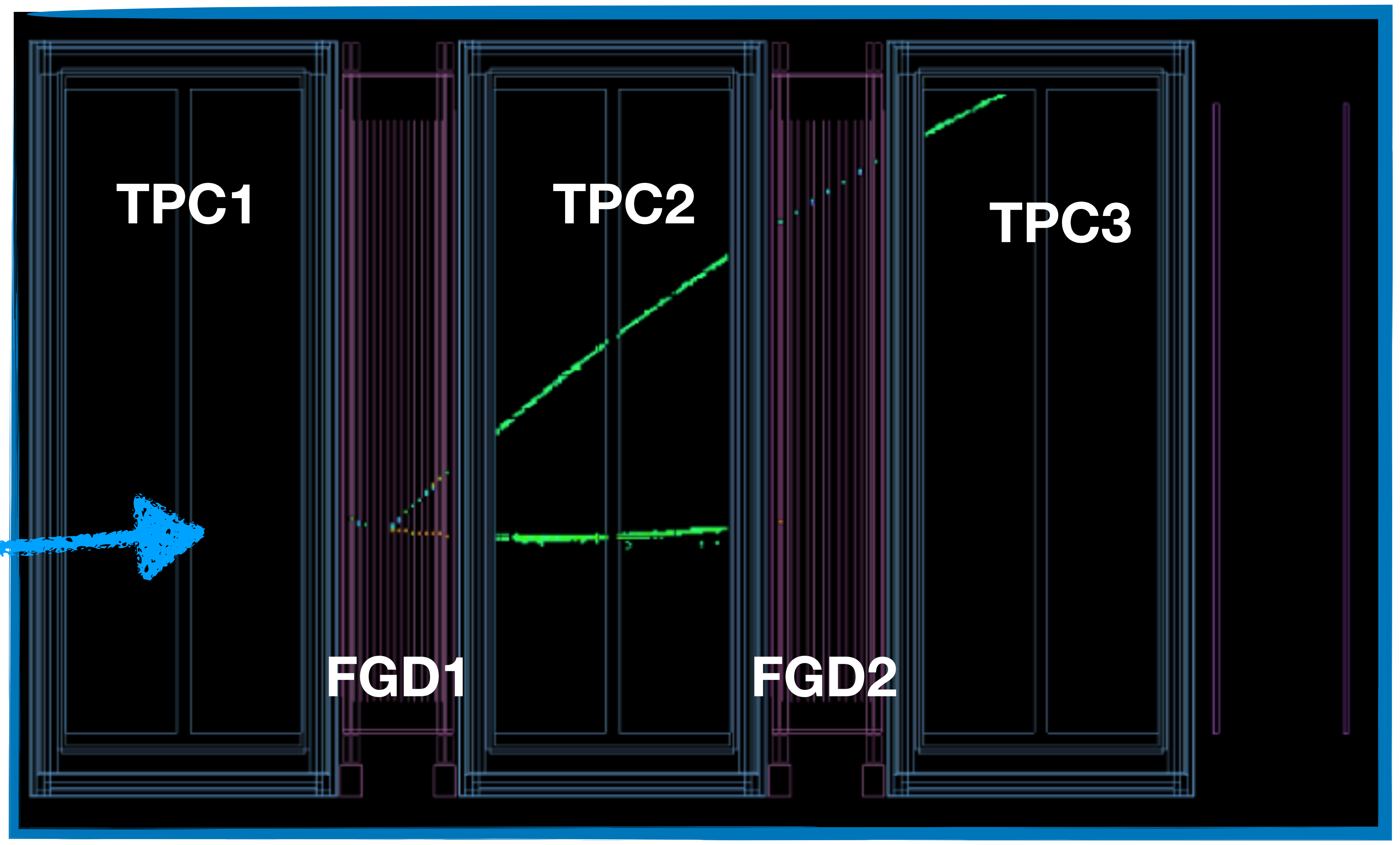
C. Valls poster

INGRID: on-axis detector
Monitoring $\nu$ beam profile day-by-day
Cross-section measurements
In operation since 2009

- Near Detector complex at 280 m from the target
- Several detectors installed to monitor the beam, reduce systematic uncertainties in oscillation analyses, and measure $\nu$ and $\bar{\nu}$ cross-sections

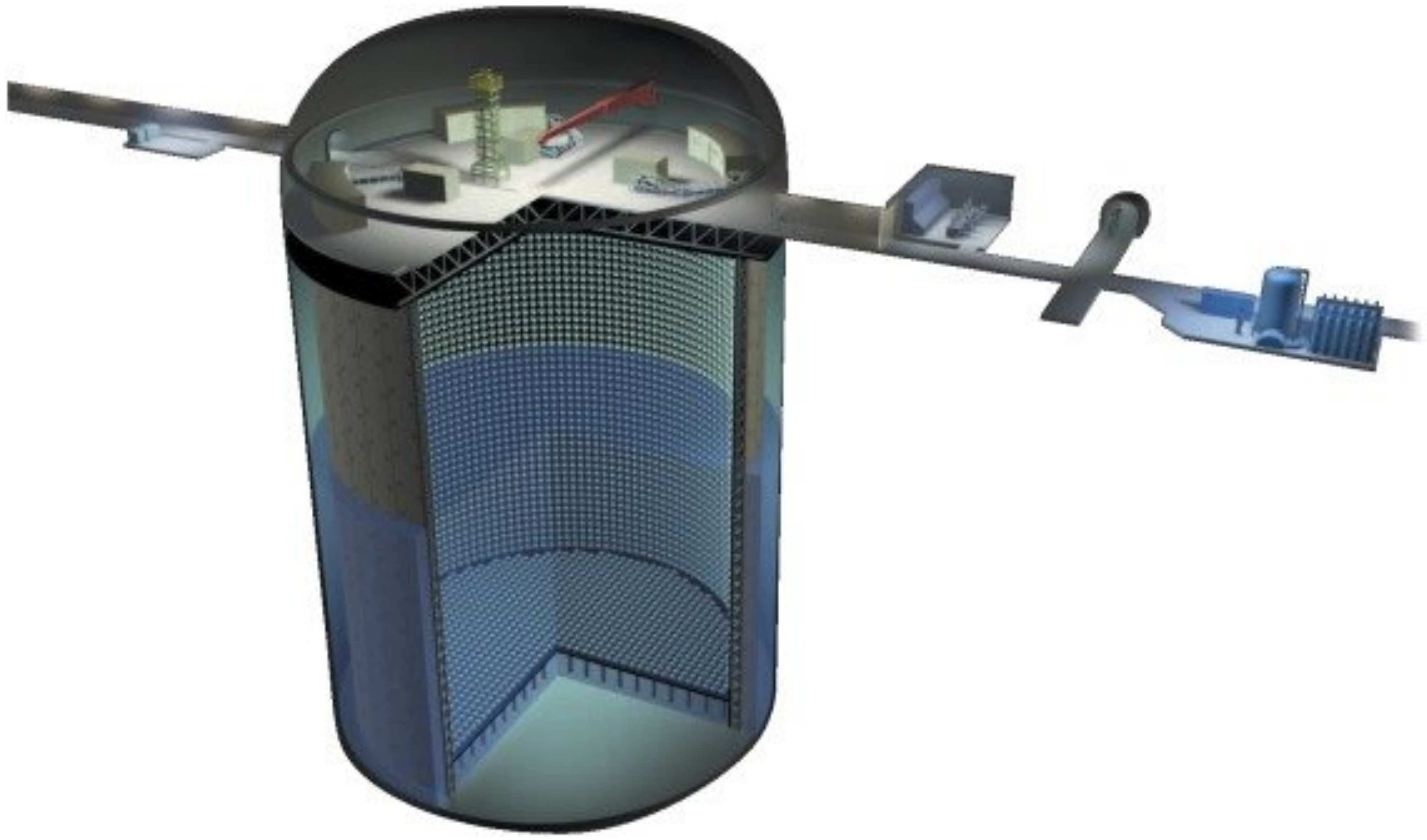
# Off-axis ND280



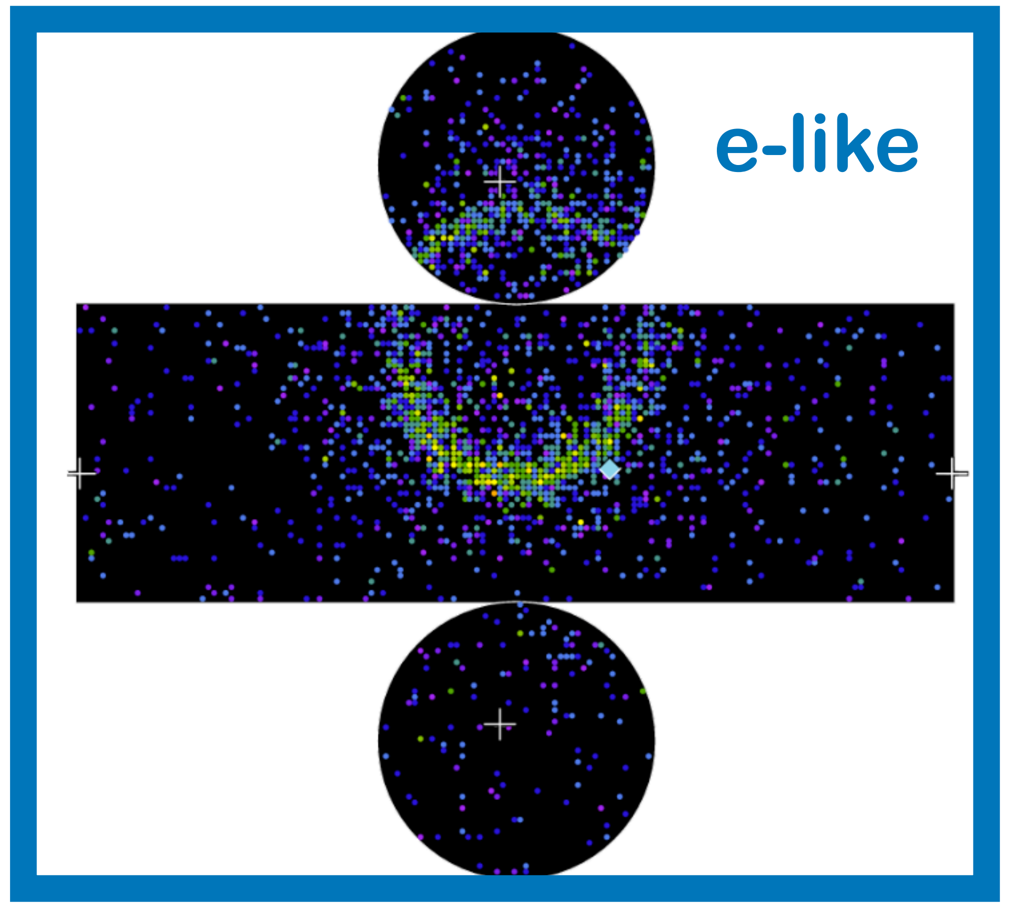



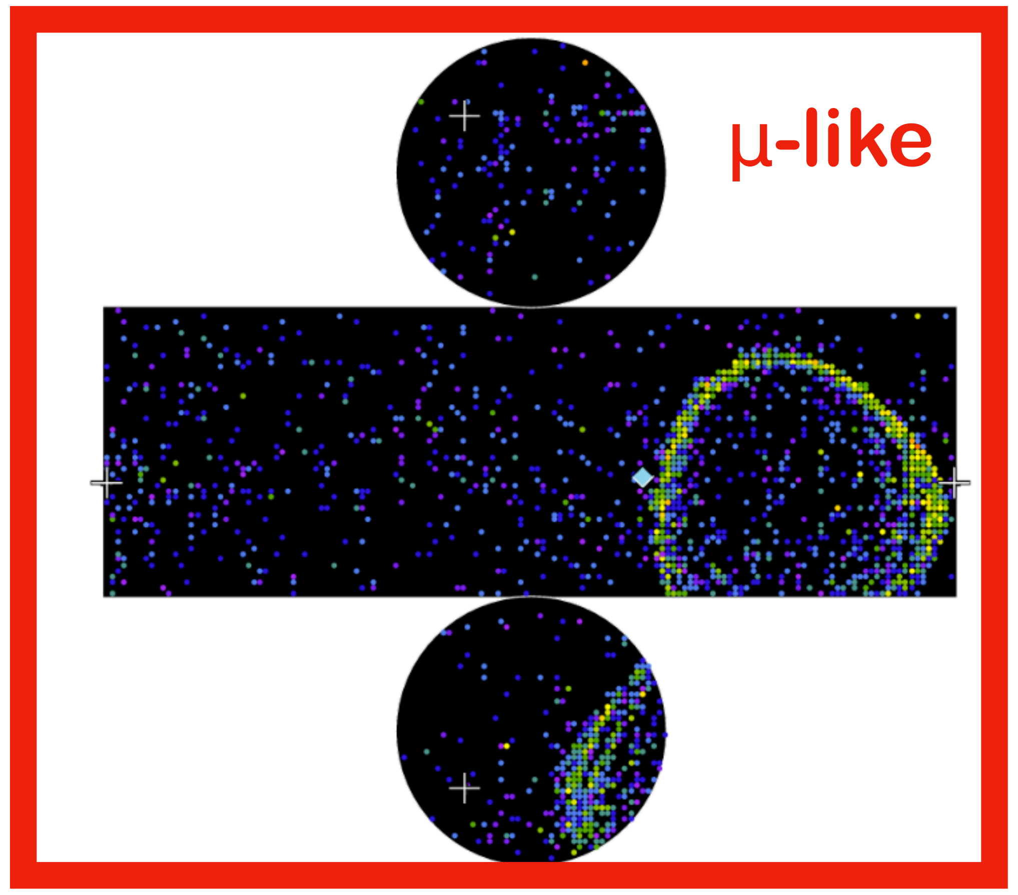

- Measure beam spectrum and flavor composition before the oscillations
- Detector installed inside the UA1/NOMAD magnet (0.2 T)
- An electromagnetic calorimeter to distinguish tracks from showers
- Upgraded in 2023 but for the analyses shown here the original tracker system is used:
  - 2 Fine Grained Detectors (target for $\nu$ interactions). FGD1 is pure scintillator, FGD2 has water layers interleaved with scintillator
  - 3 Time Projection Chambers: reconstruct momentum and charge of particles, PID based on measurement of ionization

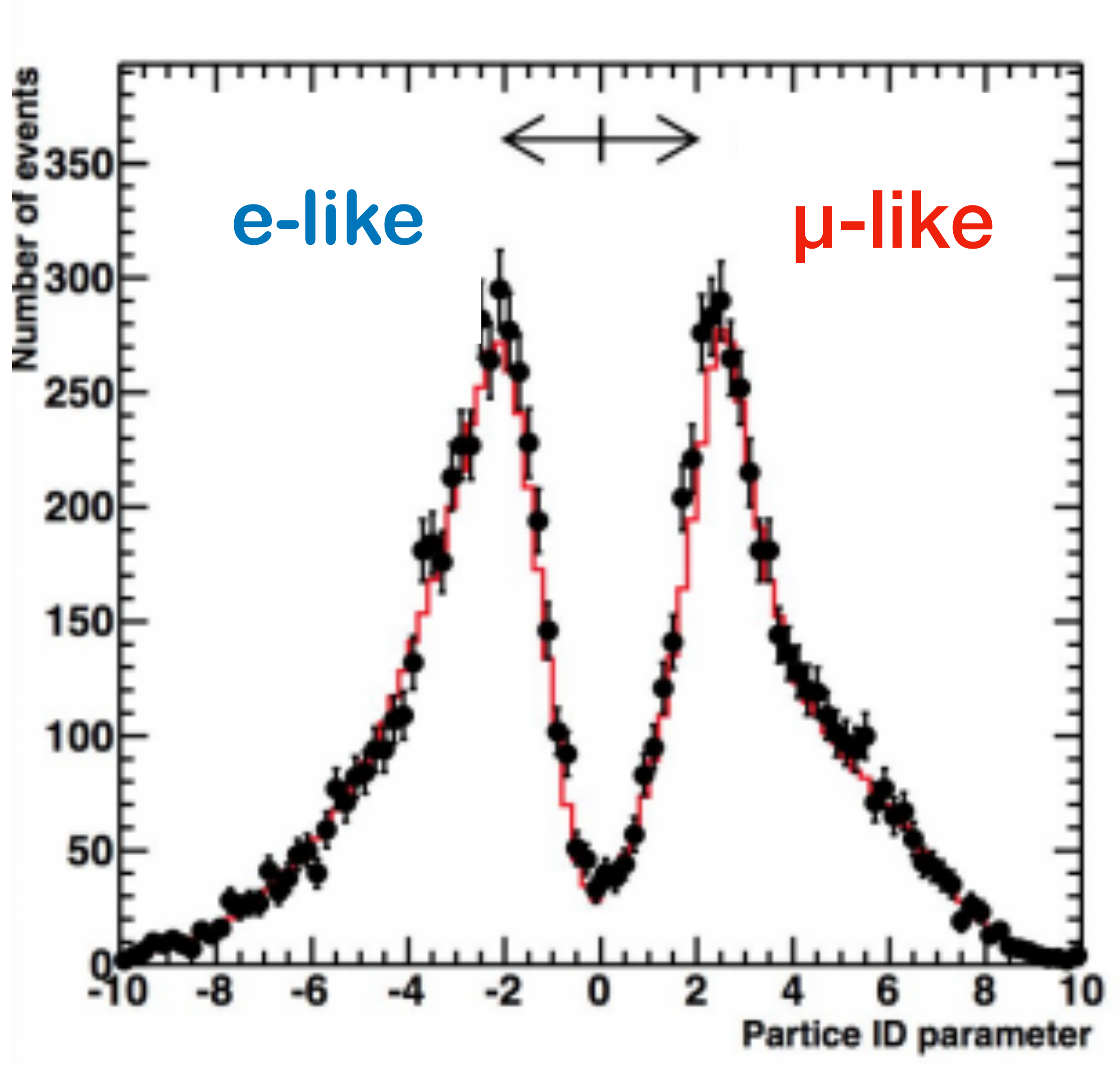
# Super-Kamiokande



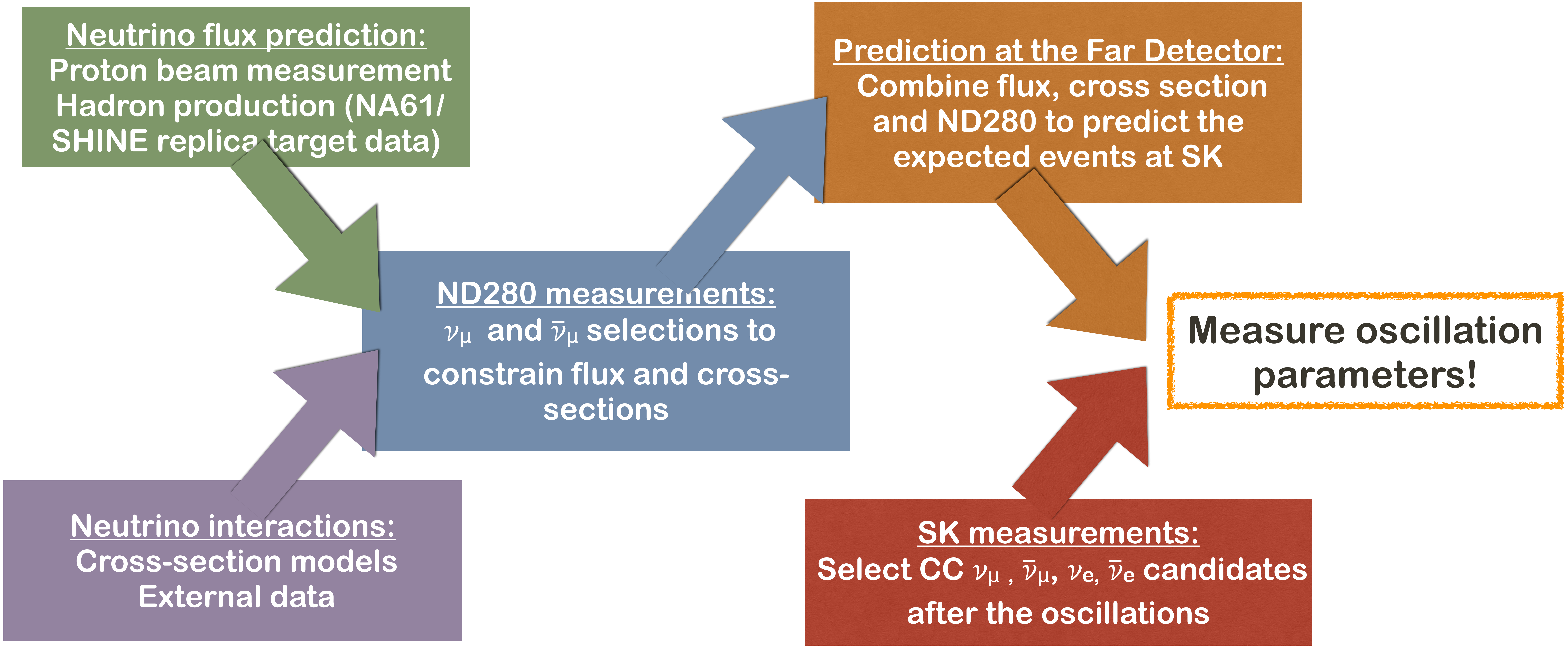
- 50 kton water Cherenkov detector
  - ~11k 20” PMTs for the inner detector, ~2000 8” PMTs for the outer detector, used as veto
- ~1000 meters underground in Kamioka, operated since 1996
- Different shape of Cherenkov ring → distinguish e/μ
- Added 0.03% Gd in 2022 → improve neutron tagging efficiency



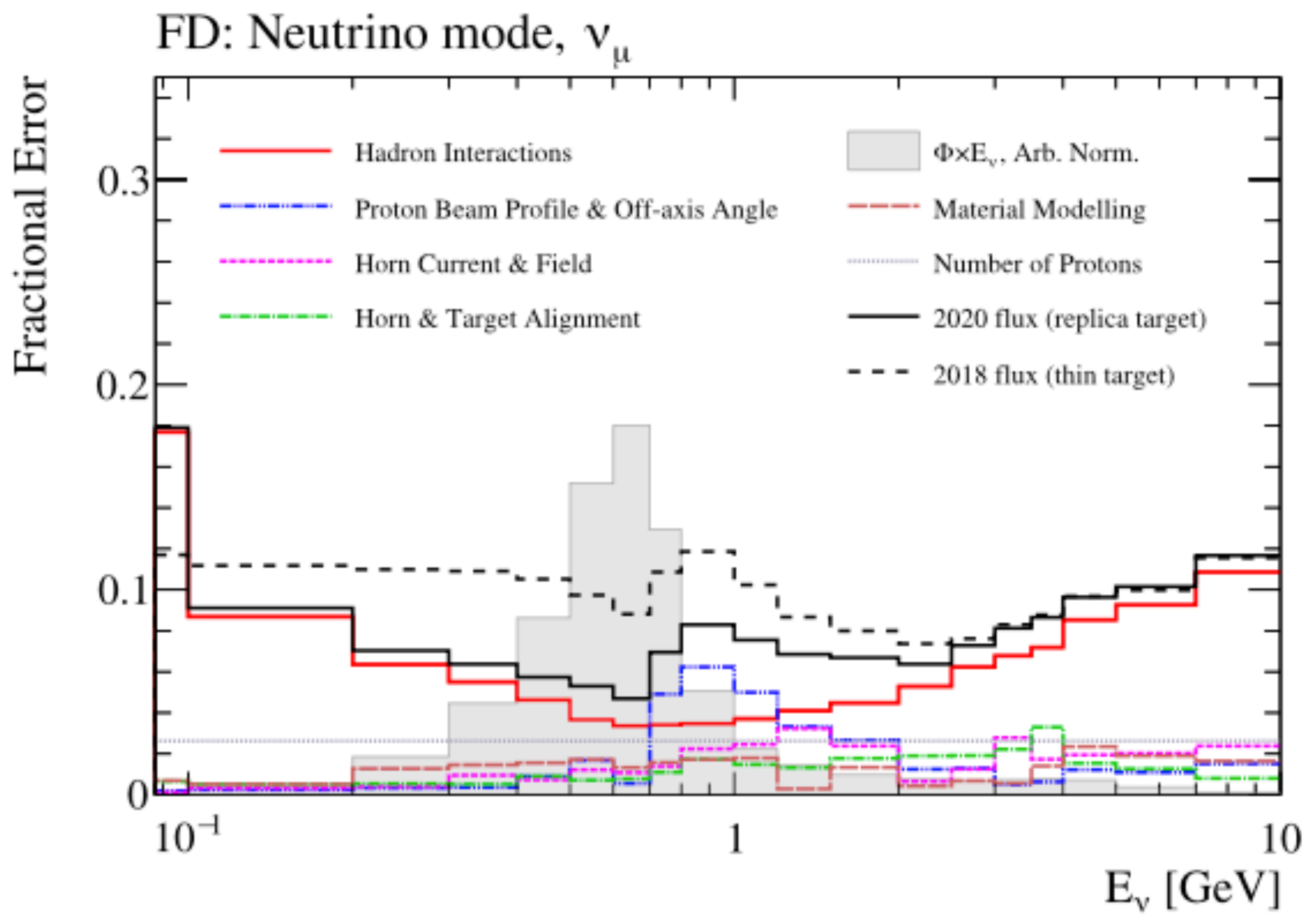
# T2K oscillation analysis



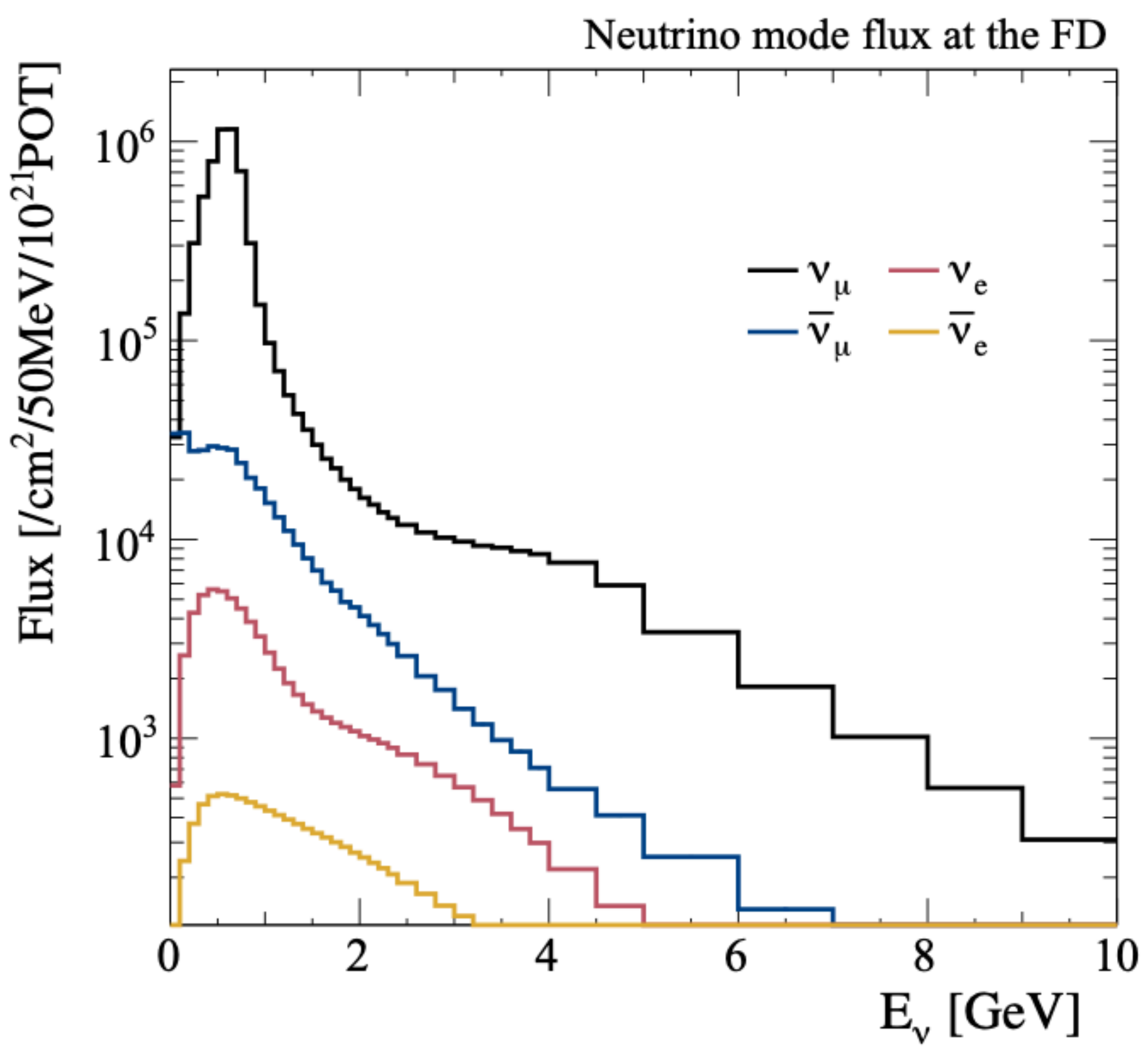

**Near and Far detector data are fitted either sequentially or simultaneously depending on the analysis considered**

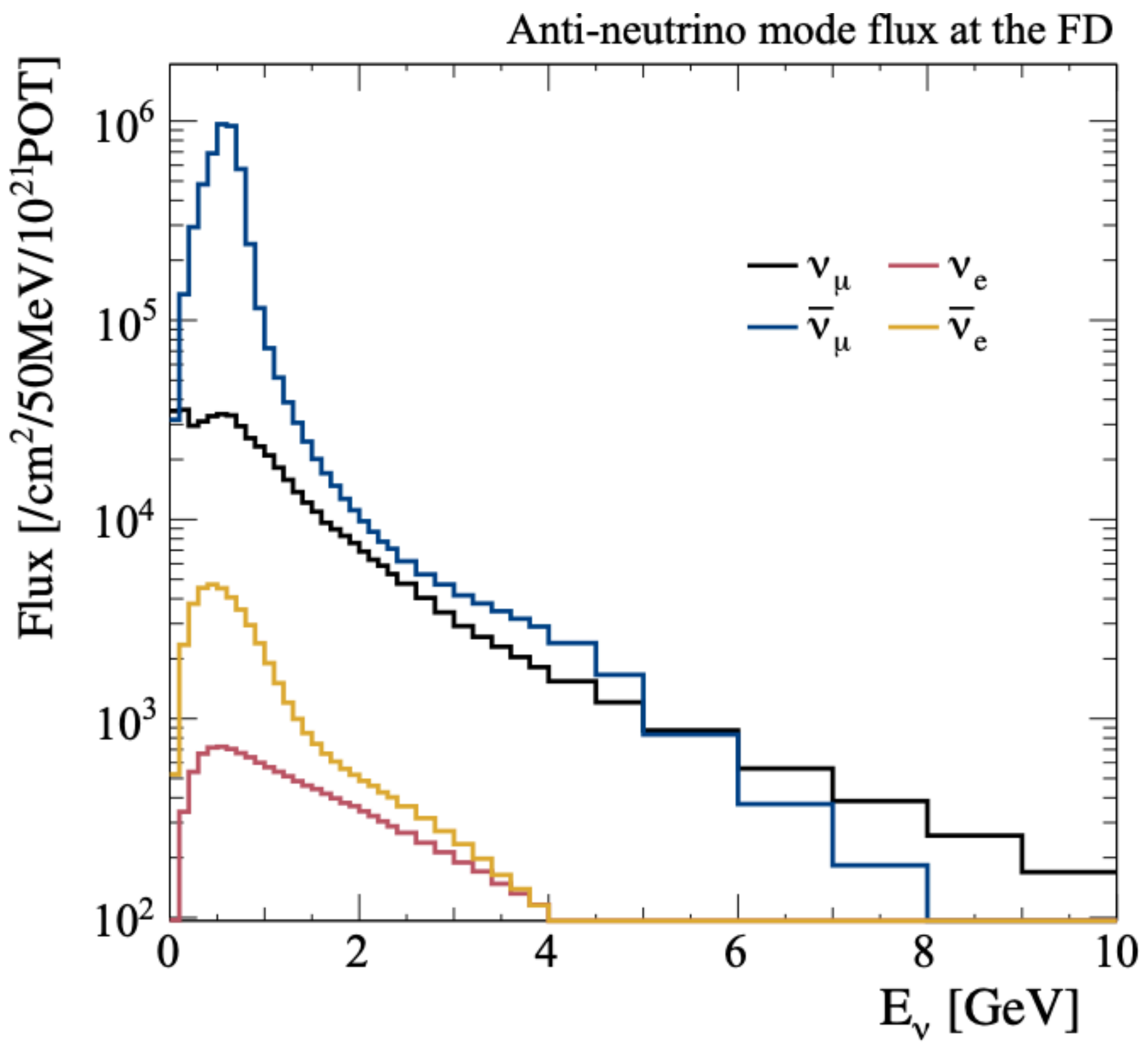
# Neutrino flux predictions

- Systematics on $\nu$ and $\bar{\nu}$ fluxes dominated by hadron-production cross-sections uncertainties in p-C collisions
- Reduced to ~5% thanks to the data from NA61/SHINE



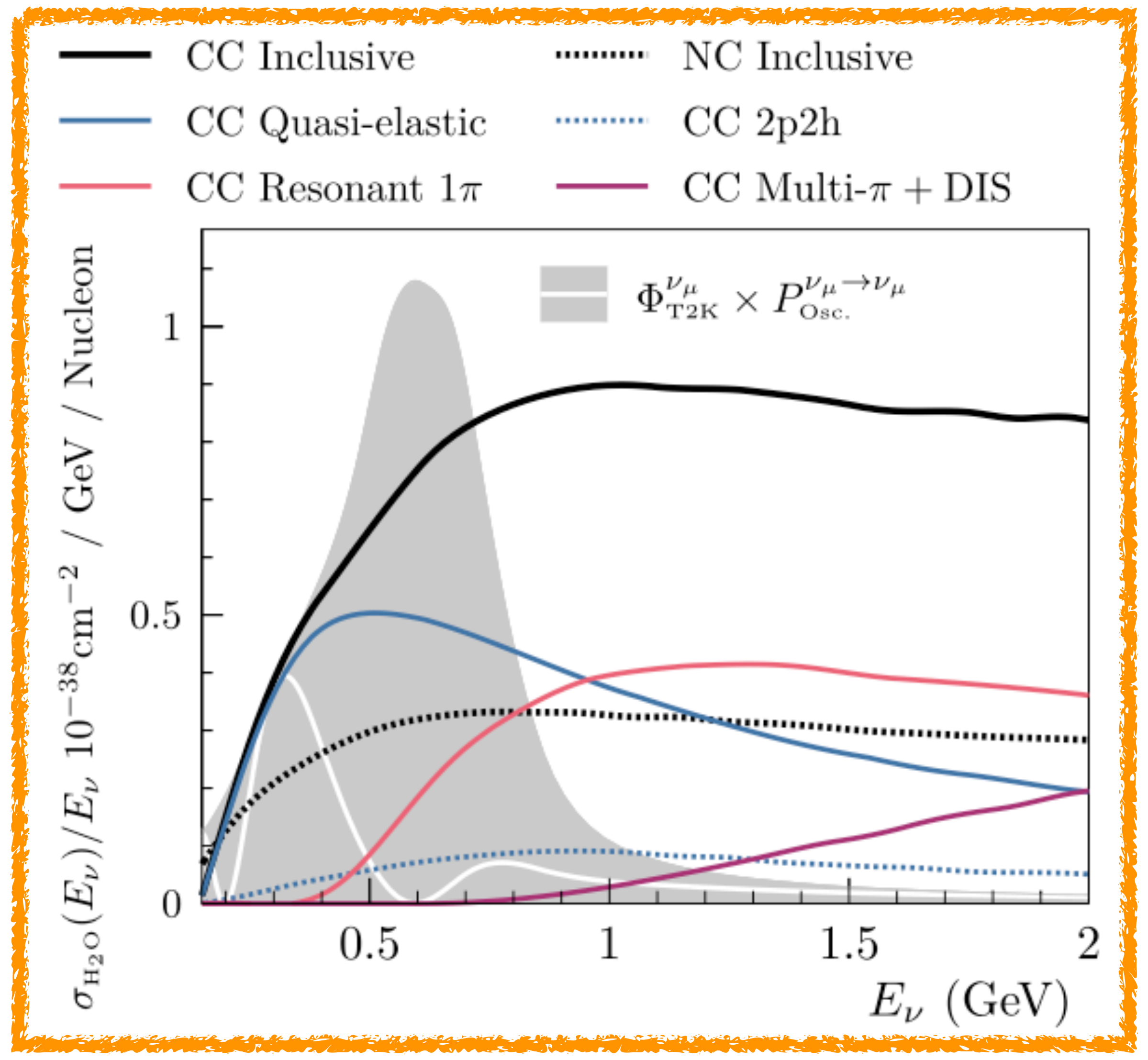

*Eur.Phys.J.C* 76 (2016) 11, 617
*Eur.Phys.J.C 76 (2016) 2, 84*



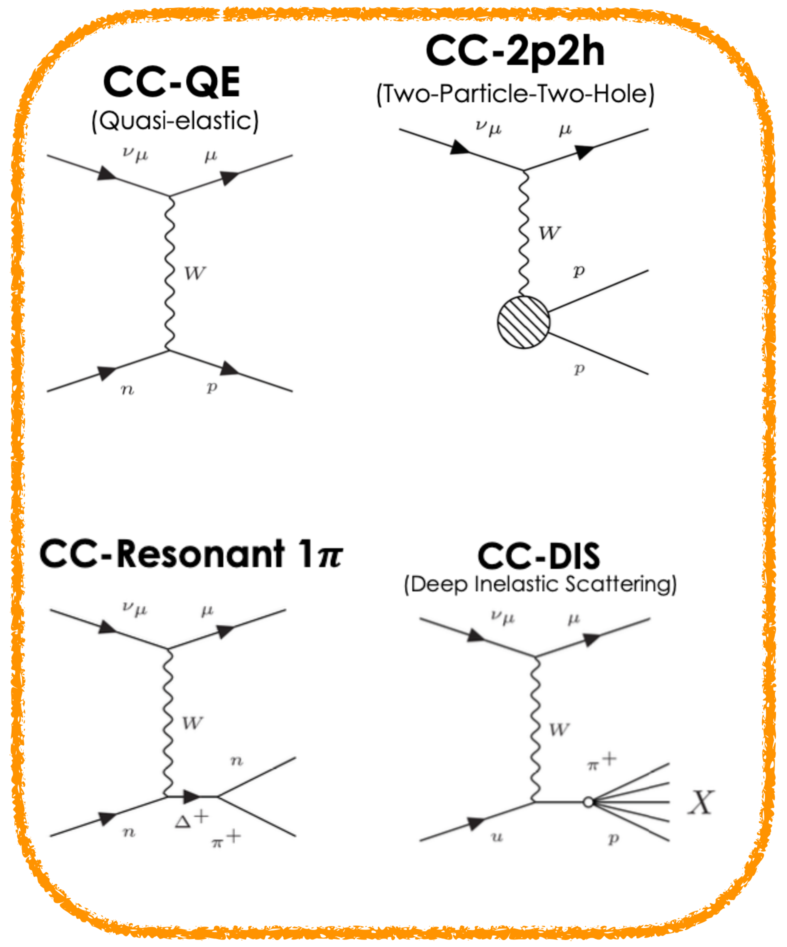

**Y. Nagai, Hadron Production Measurements for Determination of Neutrino Flux**

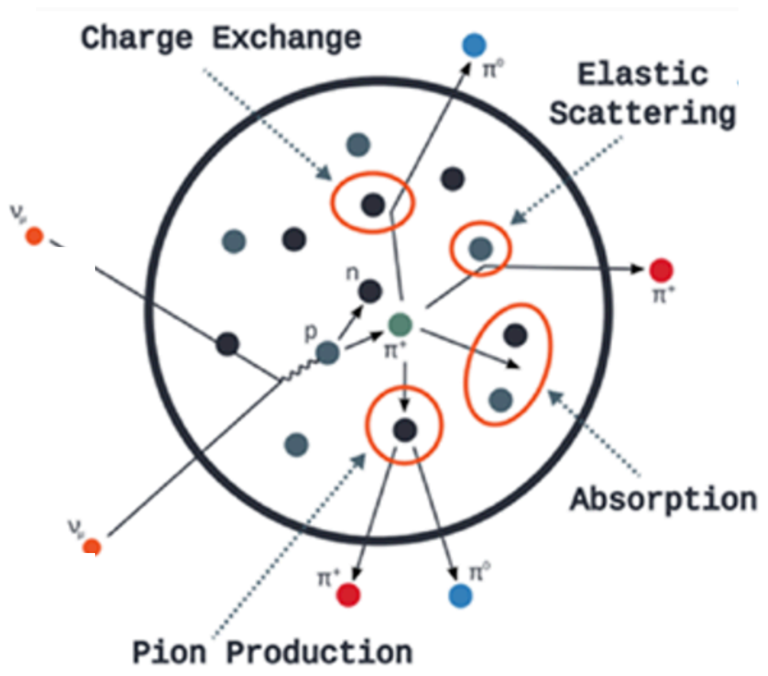
# $\nu$ cross-section model



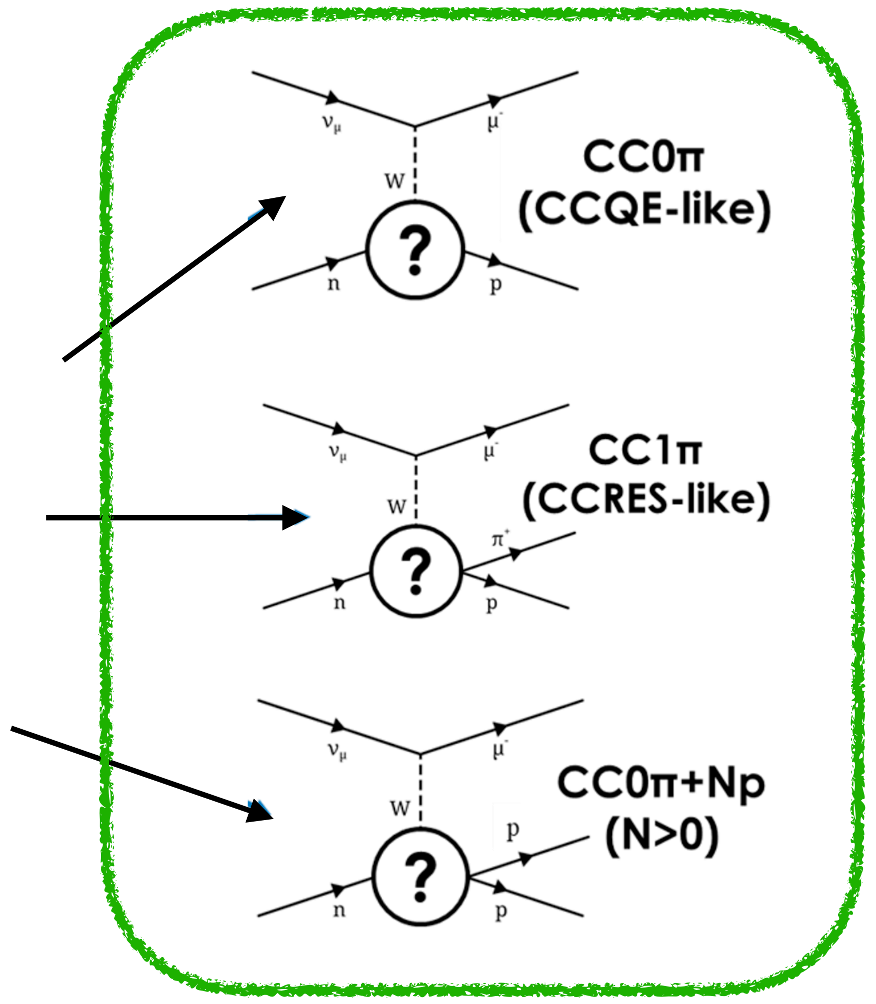

- At T2K energies dominated by CCQE channel
- Significant 2p2h and resonant contributions
- Mis-modeling of these contribution might bias the neutrino energy reconstruction → important to have a correct model with Near detector data

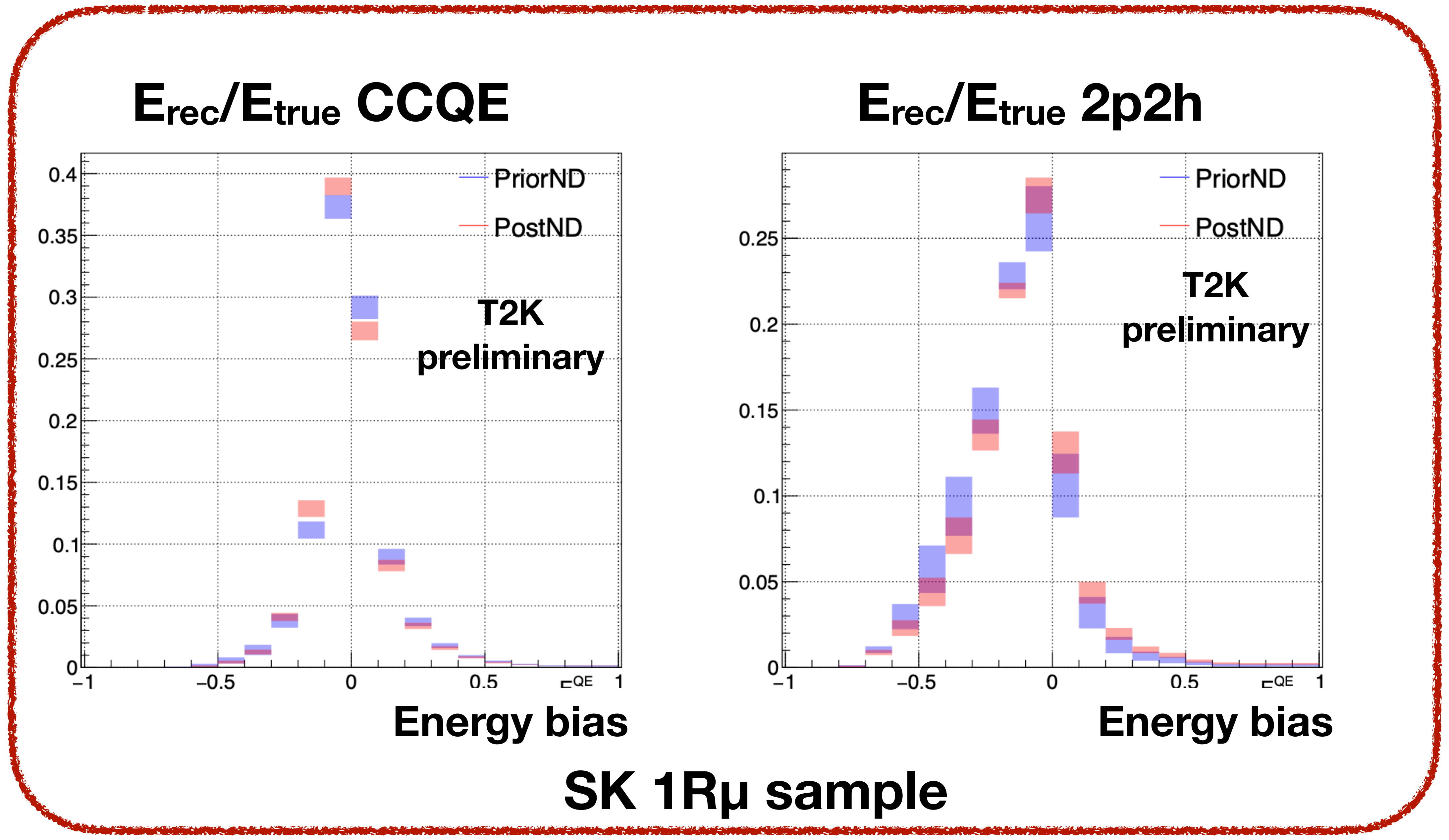
Generator



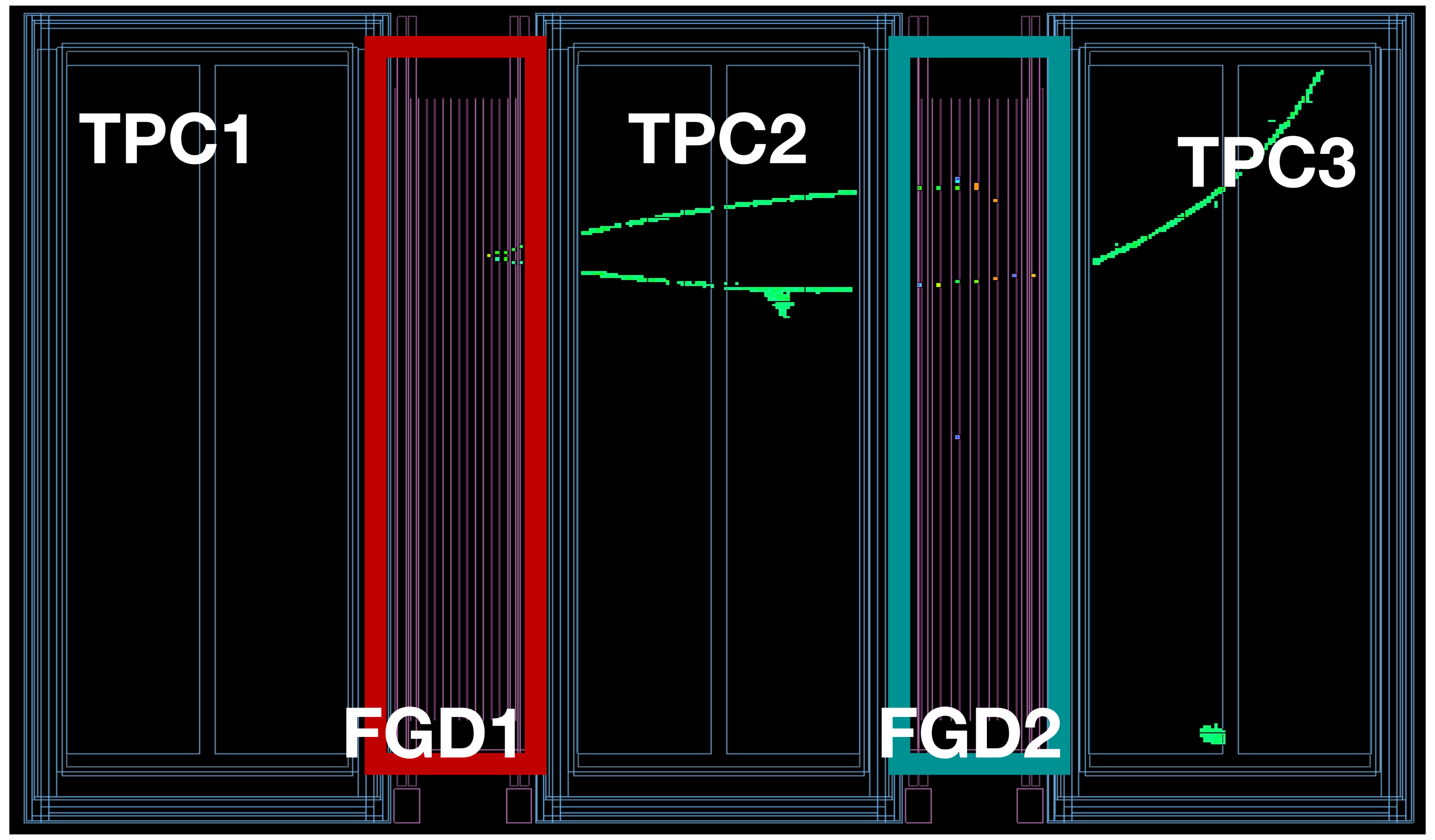




Observables

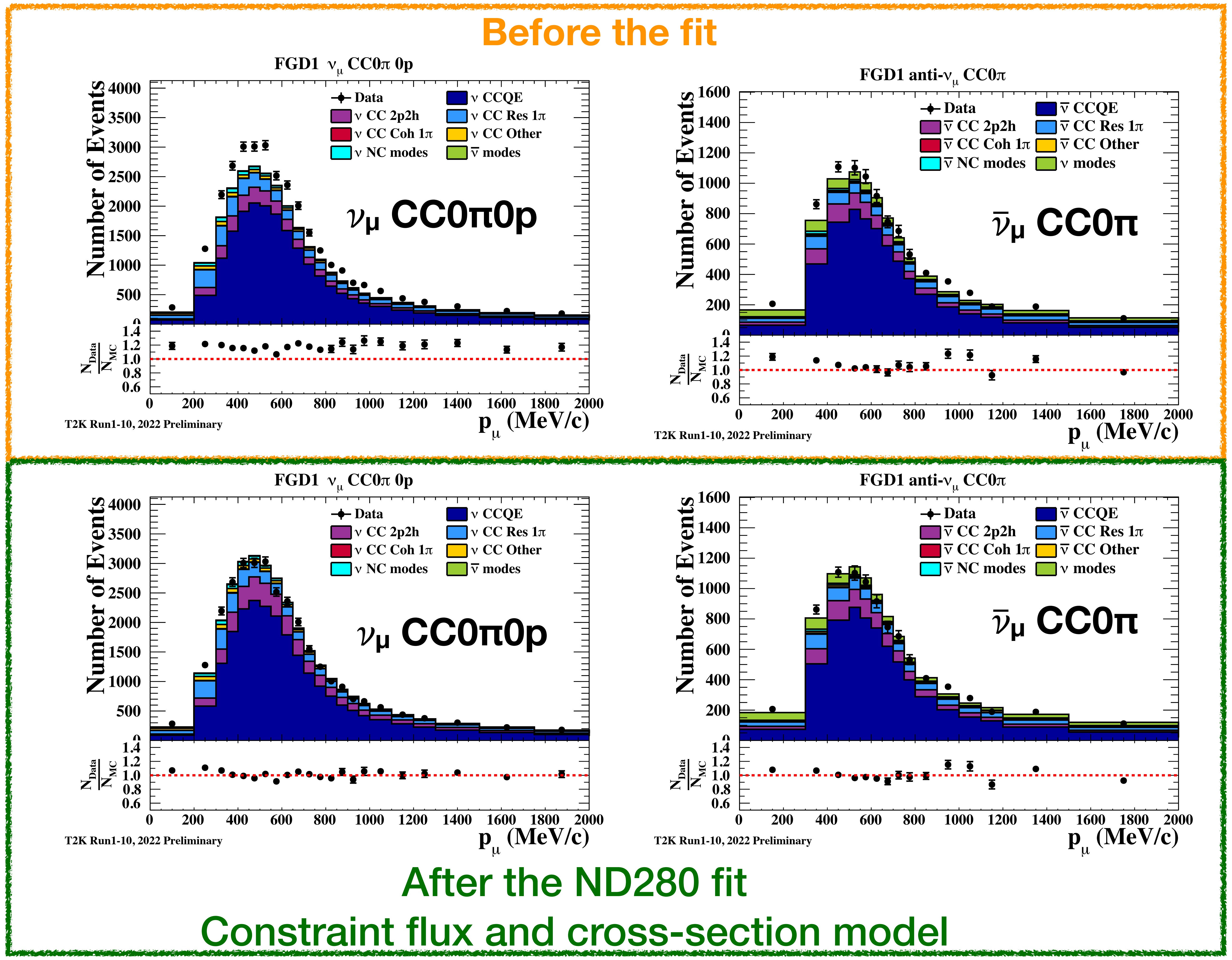


# ND280 selections



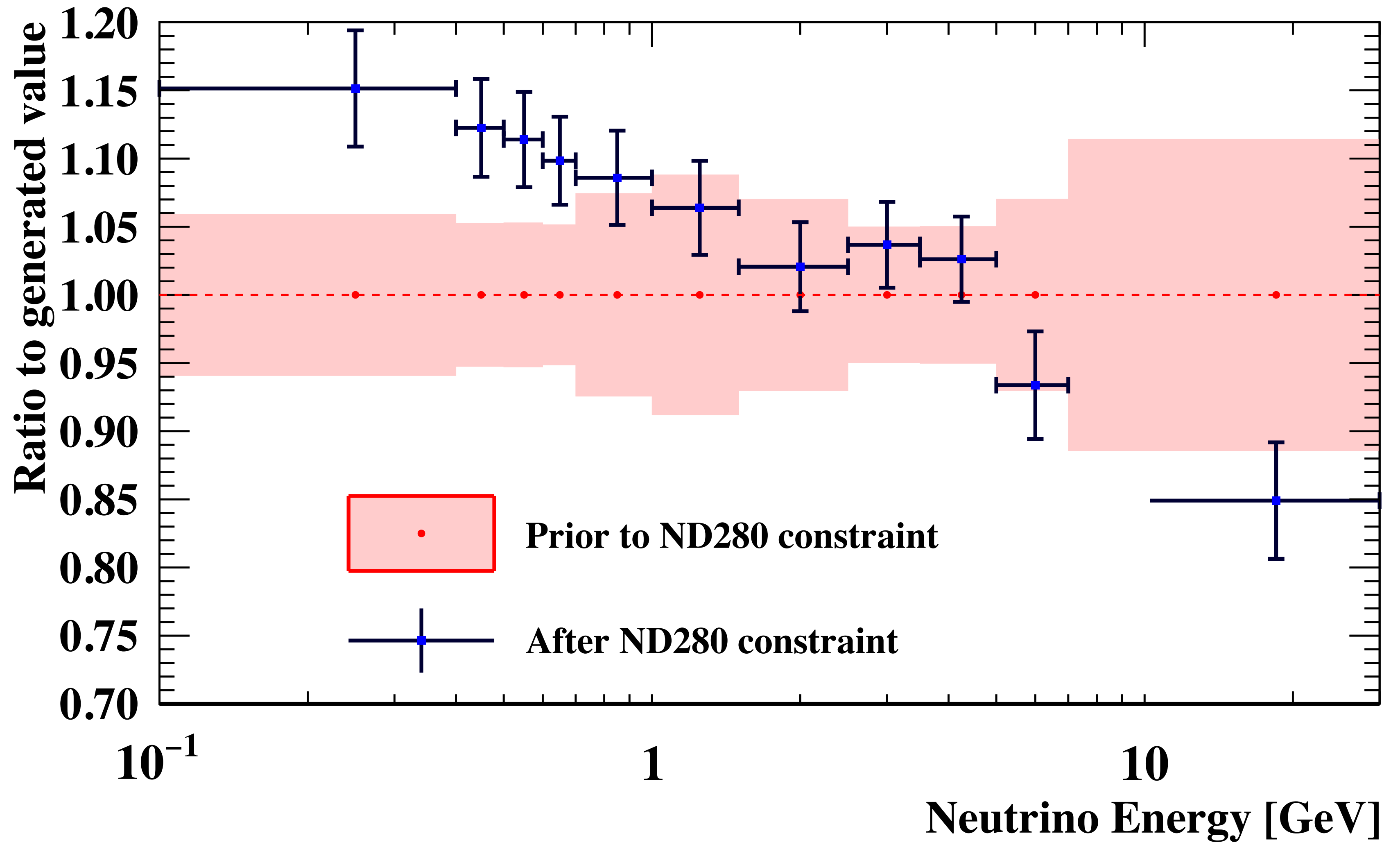

- ND280 magnetized detector
- Select interactions on CH (FGD1) and CH/Water (FGD2)
- Precise measurement of $P_\mu$ and $\theta_\mu$ with the TPCs
- Distinguish $\nu$ from $\bar{\nu}$ interactions thanks to the reconstruction of the charge of the lepton
- Separate samples based on number of reconstructed pions (CC0π, CC1π, CCNπ), protons, photons, etc → 22 samples in total are used in the fit



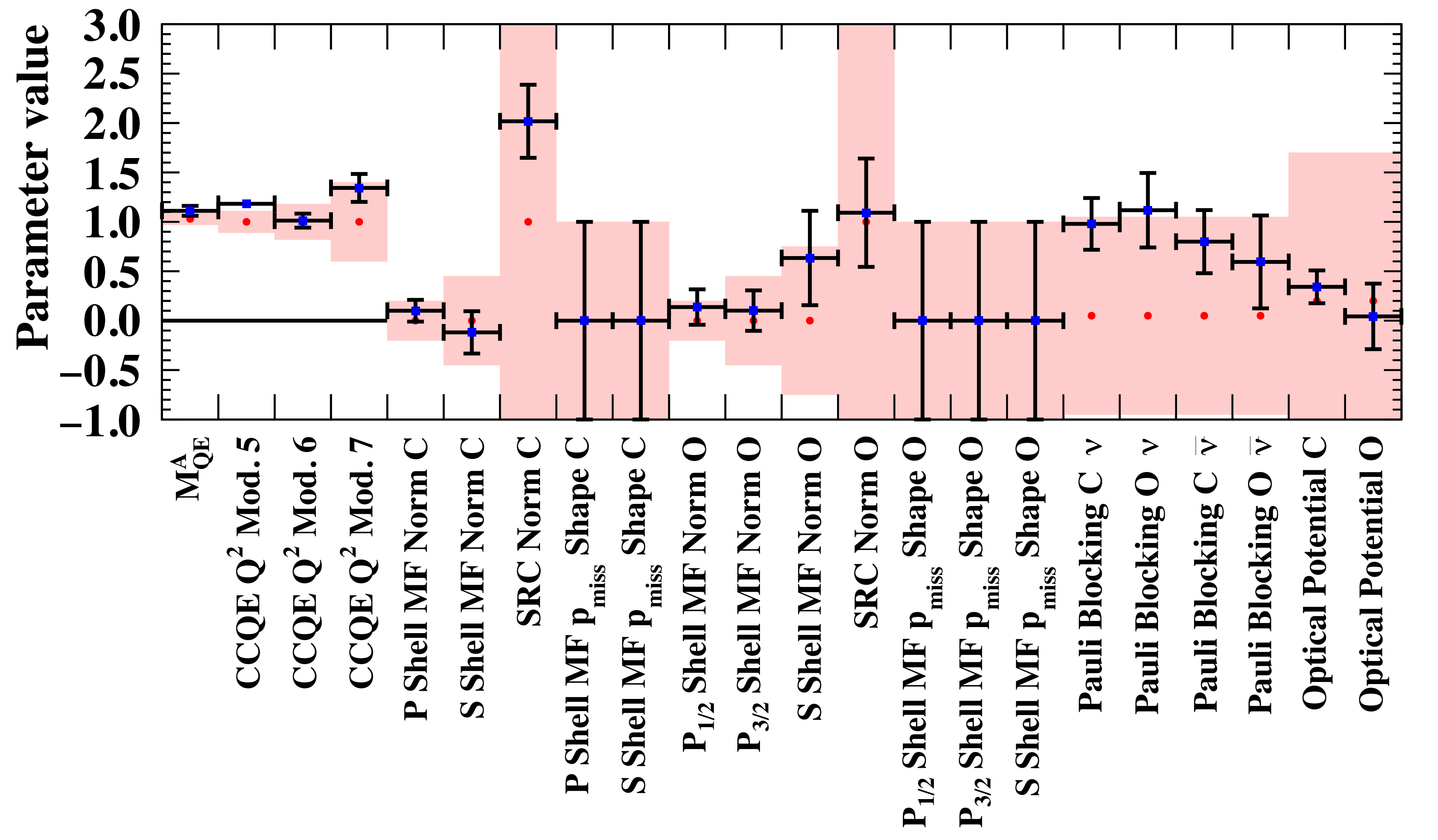
# ND280 fit

E. Miller, L. Osu, and A. Blanchet posters

**ND280 $\nu$-mode flux parameters**



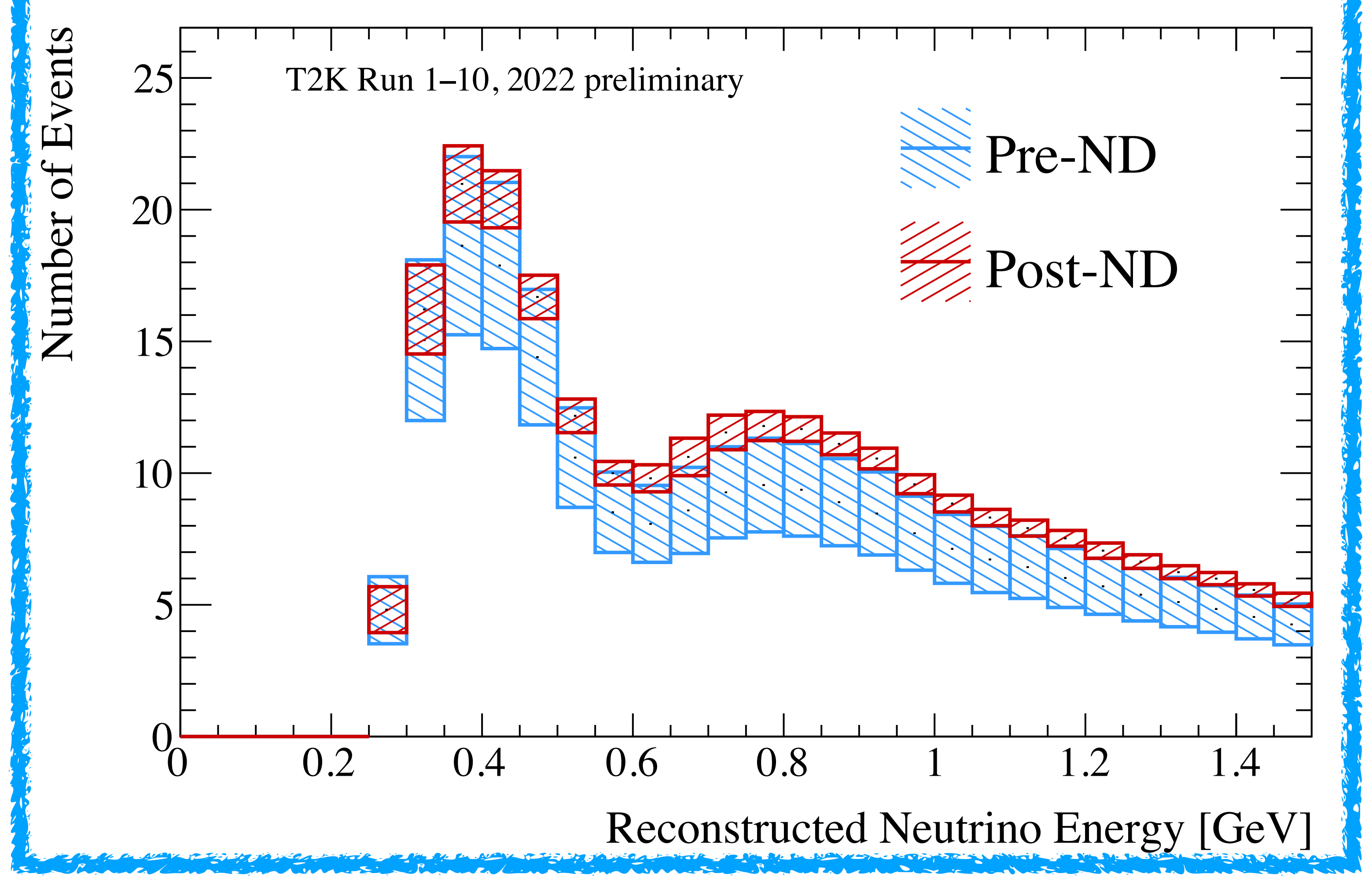

**CCQE x-sec parameters**



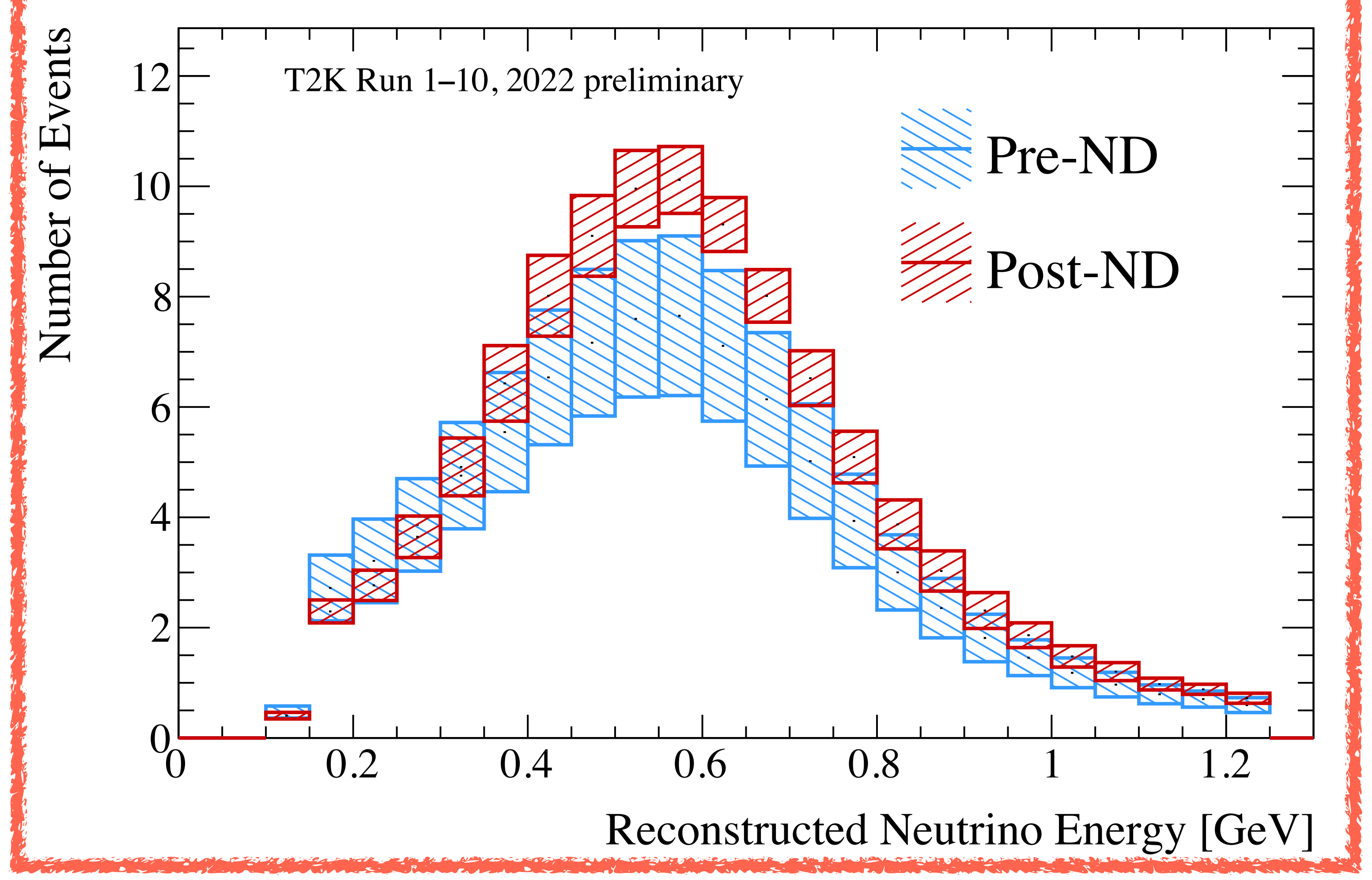

- Tune and reduce uncertainties from flux and cross-section systematics
- Correlate flux and cross-section to predict expected spectra at the Far Detector

| Sample | Pre-ND fit | Post-ND fit |
|---|---|---|
| $\nu$-mode 1Rμ | 16.7% | 3.4% |
| $\nu$-mode 1Re | 17.3% | 5.2% |
| $\nu$-mode MR | 12.5% | 4.9% |
| $\nu$-mode 1Re+d.e. | 20.9% | 14.3% |
| $\bar{\nu}$-mode 1Rμ | 14.6% | 3.9% |
| $\bar{\nu}$-mode 1Re | 14.4% | 5.8% |

**SK Single ring μ-like sample**

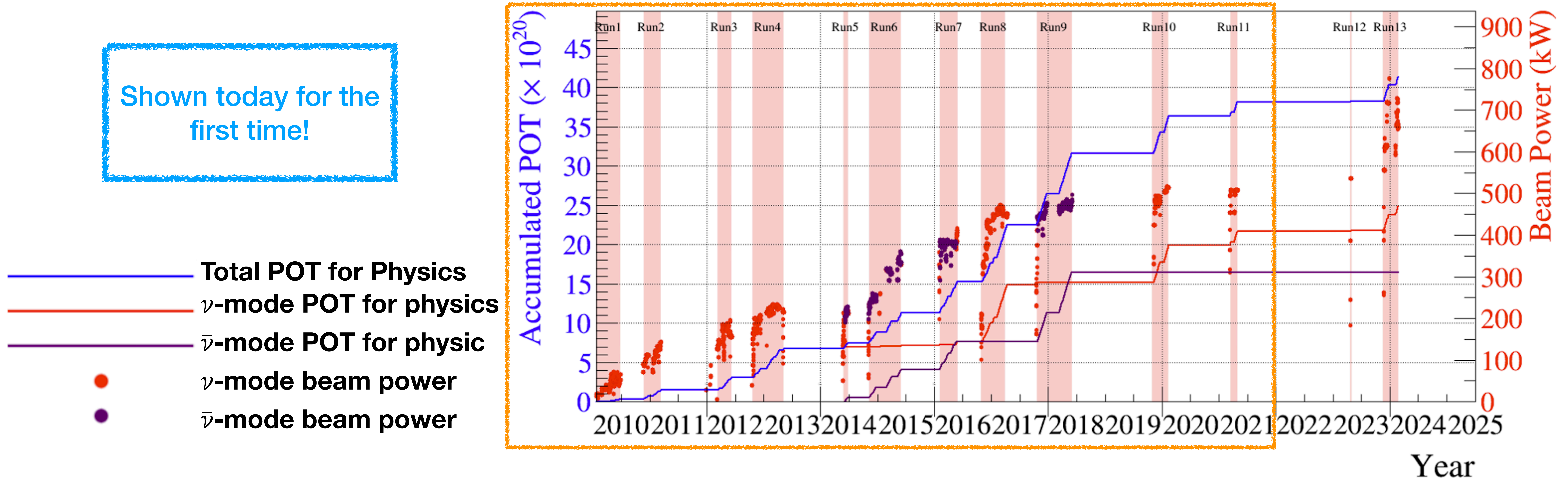



**SK single ring e-like sample**



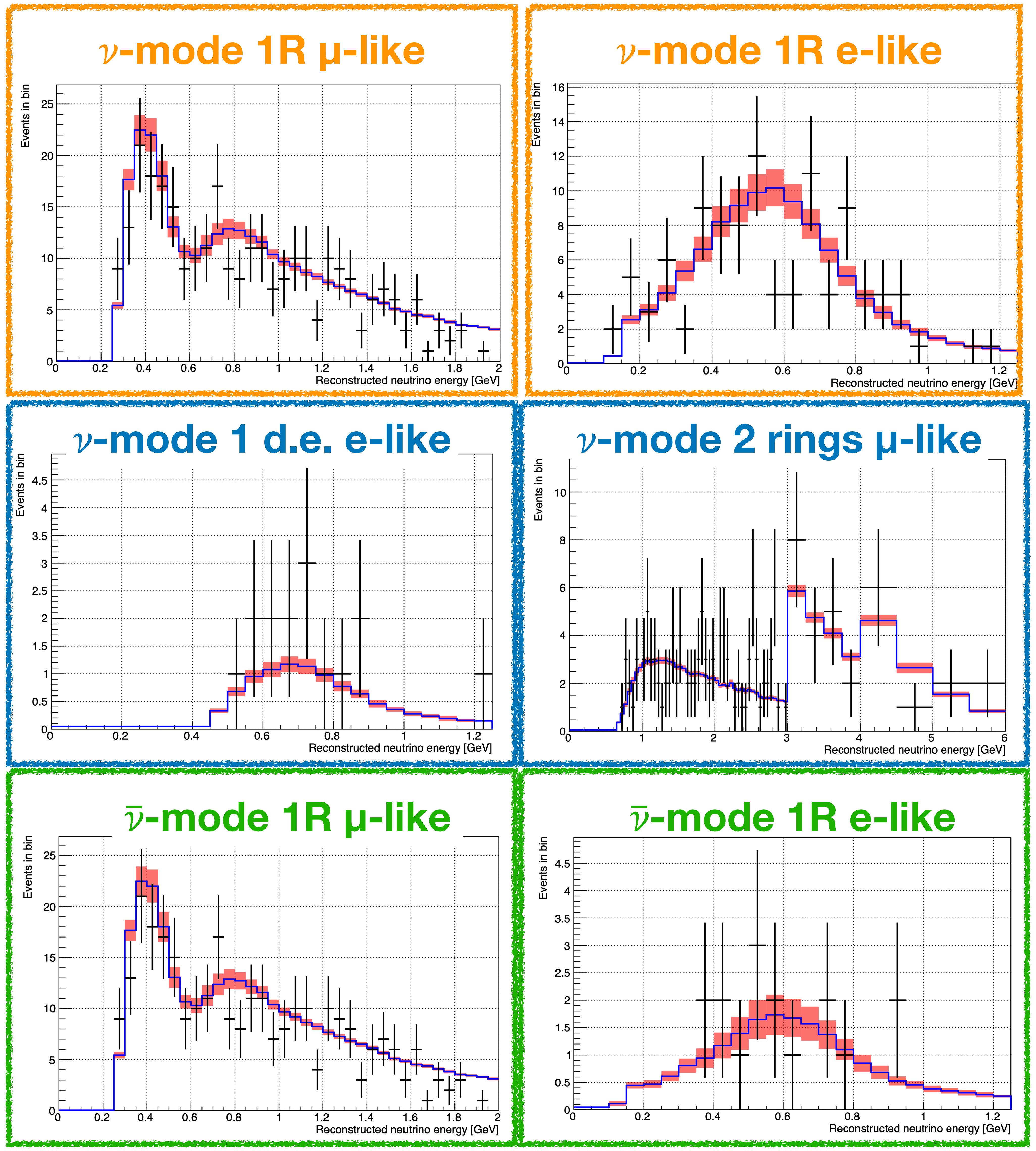
# New T2K oscillation results

Shown today for the first time!



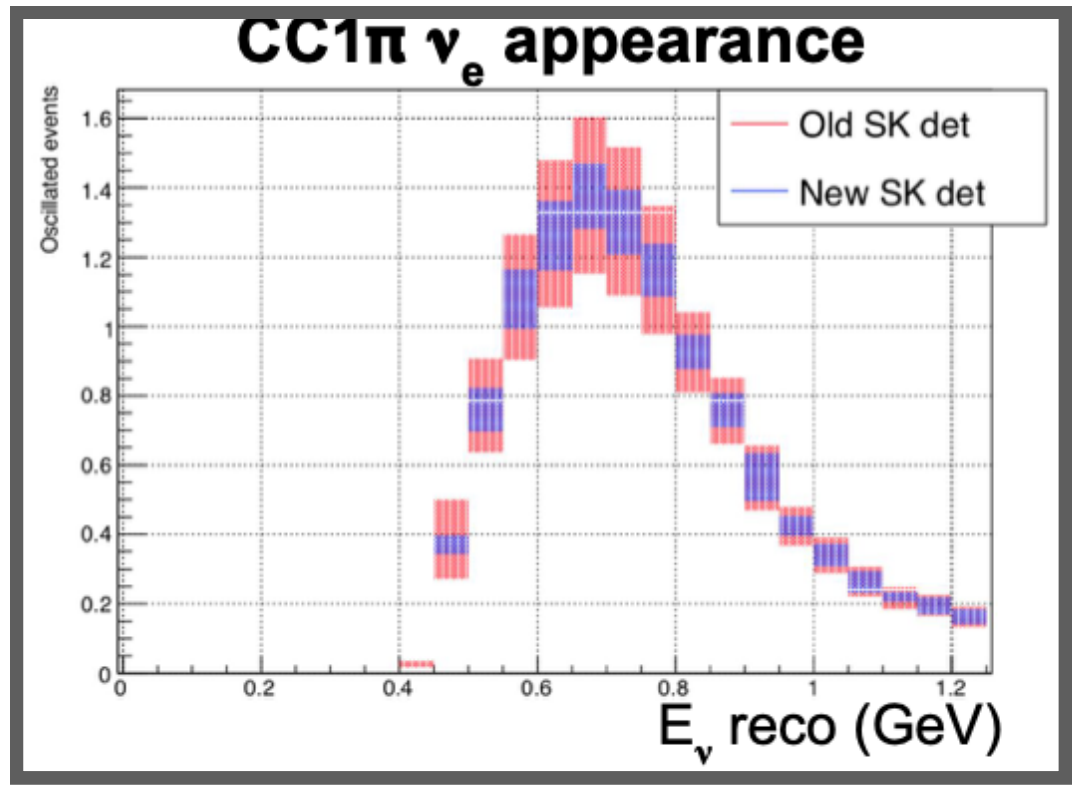

- Add Run 11 (10% of statistics in $\nu$-mode) → first T2K data with SK-Gd
- Same ND280 analysis and neutrino interaction model as Neutrino2022 results
- Reduction of SK detector systematics

# Super-K selections



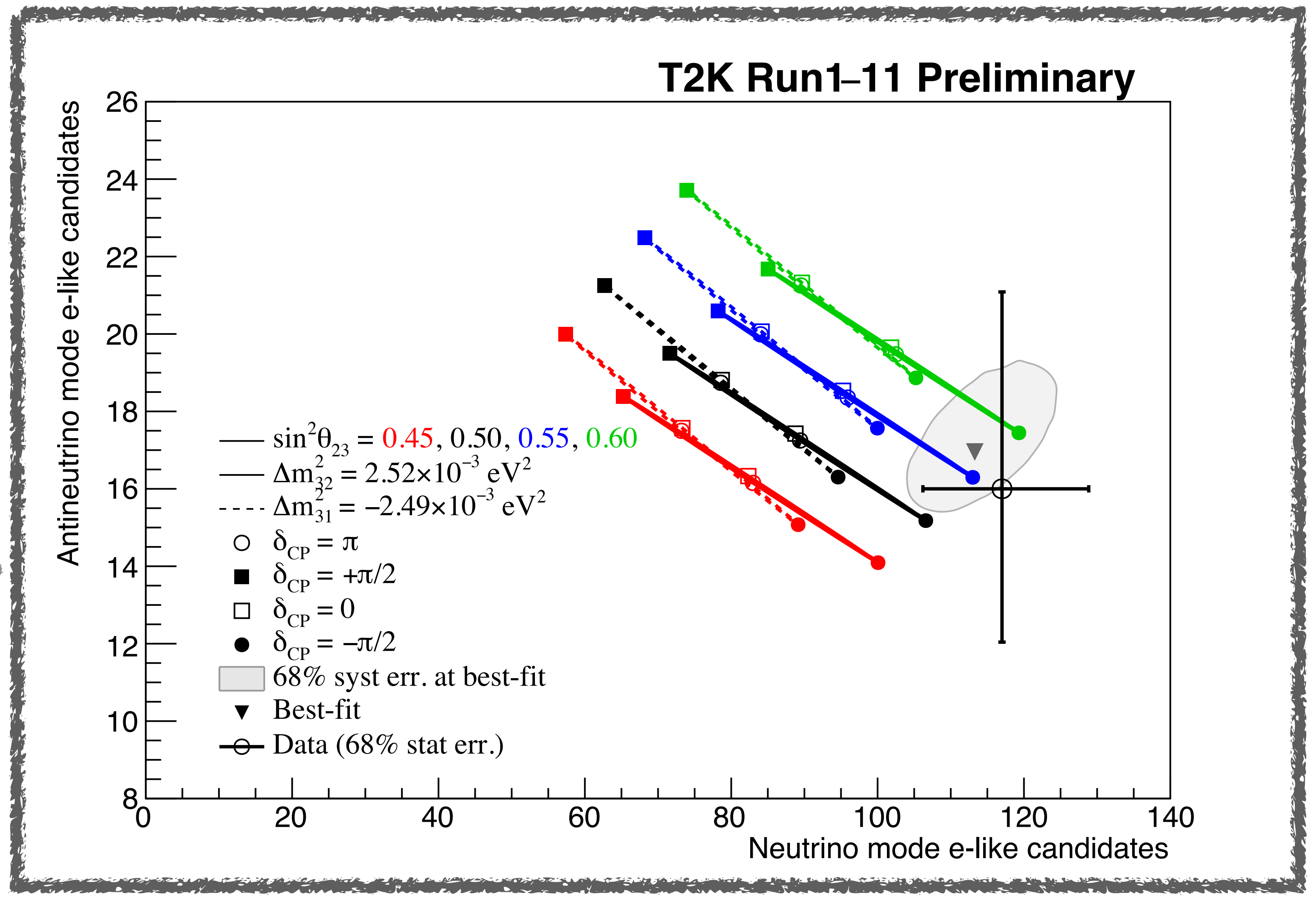

- 6 samples are selected at SK
  - 2 samples 1R μ-like/e-like in ν-mode → CCQE enhanced
  - 2 samples CC1π enhanced (2 rings or with an additional decay electrons)
  - 2 samples 1R μ-like/e-like in ν̄-mode → CCQE enhanced
- New detector covariance matrix at SK → significantly reduce systematics in the 1 Re+d.e. sample

| Sample | OA22 | New results |
|---|---|---|
| ν-mode 1Rμ | 3.4% | 3.2% |
| ν-mode 1Re | 5.2% | 4.9% |
| ν-mode MR | 4.9% | 3.9% |
| ν-mode 1Re+d.e. | 14.3% | 6.3% |
| ν̄-mode 1Rμ | 3.9% | 5.0% |
| ν̄-mode 1Re | 5.8% | 6.7% |



# Oscillation analysis results

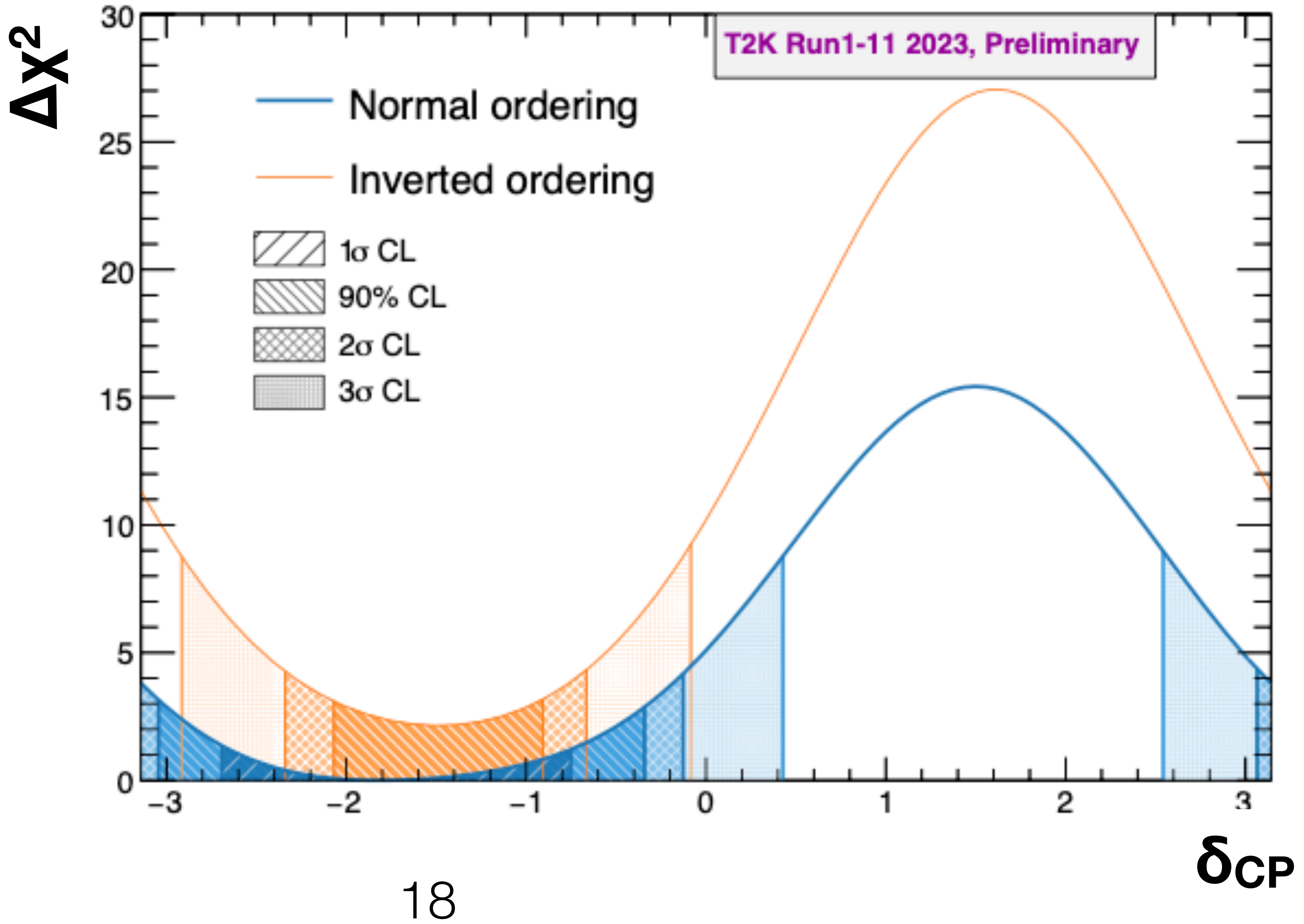
| Sample | $\delta_{CP}$=-π/2 | $\delta_{CP}$=0 | $\delta_{CP}$=π/2 | $\delta_{CP}$=π | Data |
|---|---|---|---|---|---|
| $\nu$-mode 1Rμ | 417.2 | 416.3 | 417.1 | 418.2 | 357 |
| $\nu$-mode MR | 123.9 | 123.3 | 123.9 | 124.4 | 140 |
| $\bar{\nu}$-mode 1Rμ | 146.6 | 146.3 | 146.6 | 147.0 | 137 |
| $\nu$-mode 1Re | 113.2 | 95.5 | 78.3 | 96.0 | 102 |
| $\bar{\nu}$-mode 1Re+d.e. | 10.0 | 8.8 | 7.2 | 8.4 | 15 |
| $\bar{\nu}$-mode 1Re | 17.6 | 20.0 | 22.2 | 19.7 | 16 |

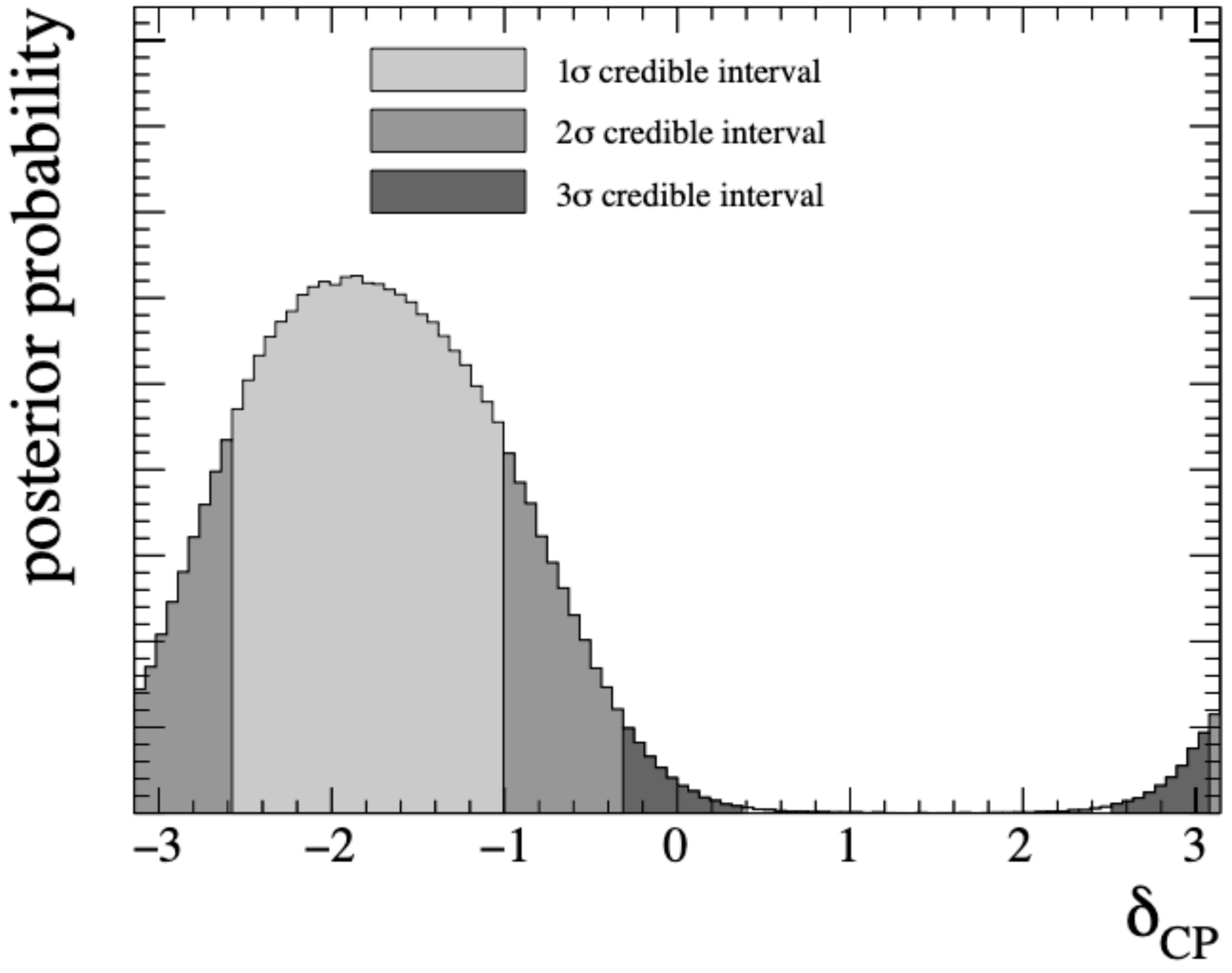



Credible intervals marginalized over both hierarchies

- Preference for $\delta_{CP}$~-π/2 but CP conserving values are within the 2σ interval

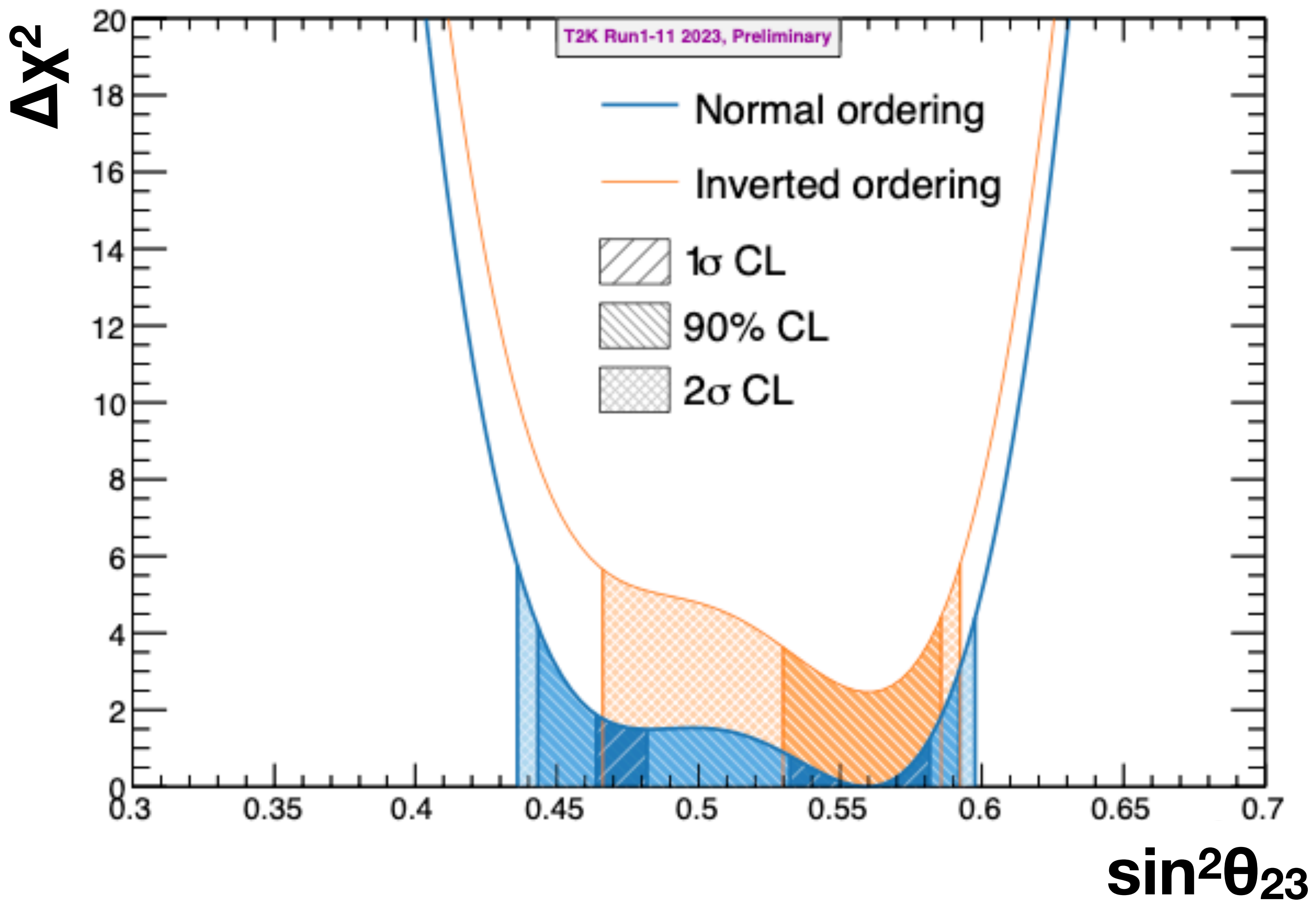
D. Carabadjac poster



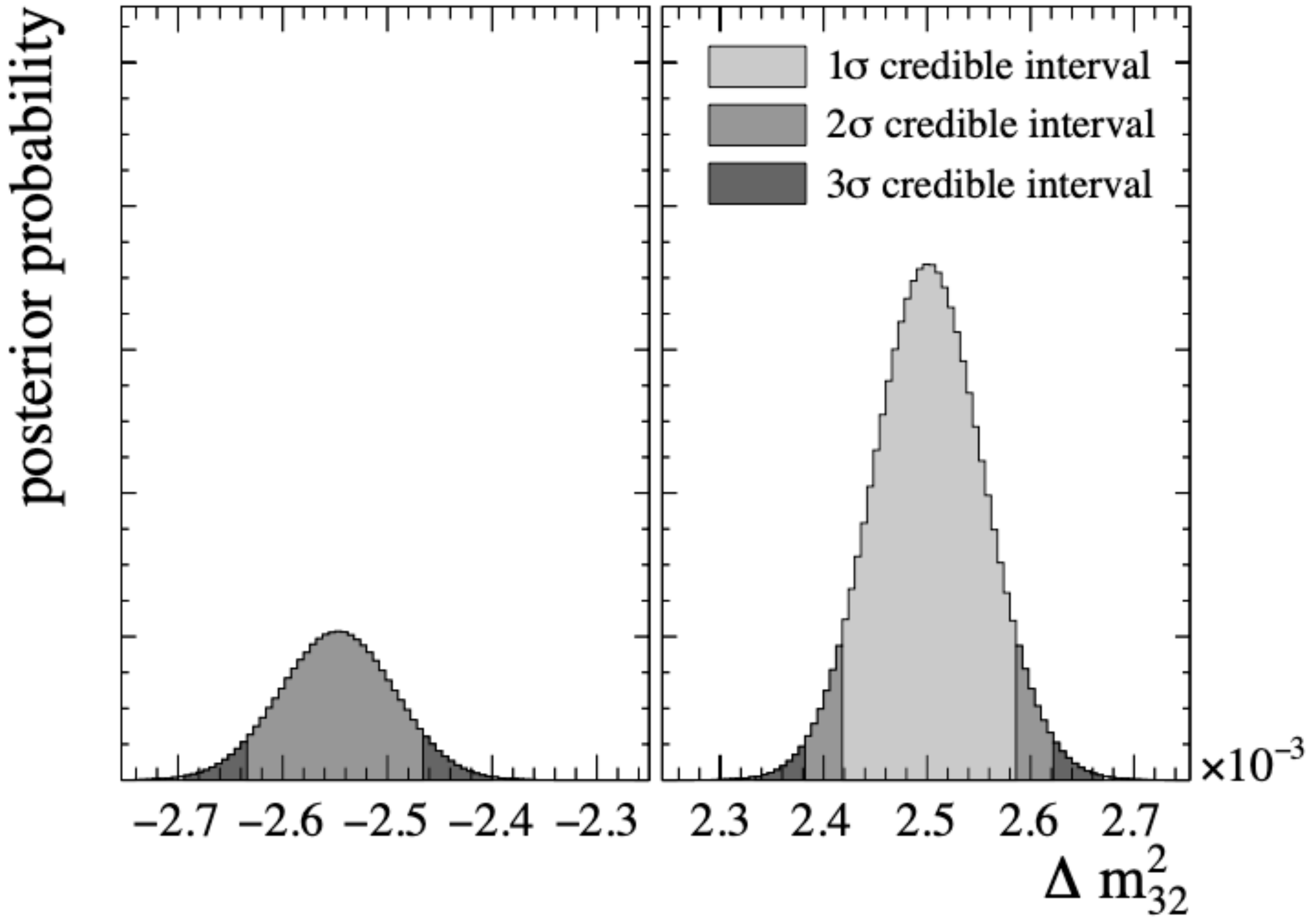



# Mass ordering and $\theta_{23}$ octant

- Slight preference for normal ordering and upper octant but none of them is significant
  - Bayes factor NO/IO = 3.3
  - Bayes factor ($\theta_{23}$>0.5)/($\theta_{23}$<0.5) = 2.6

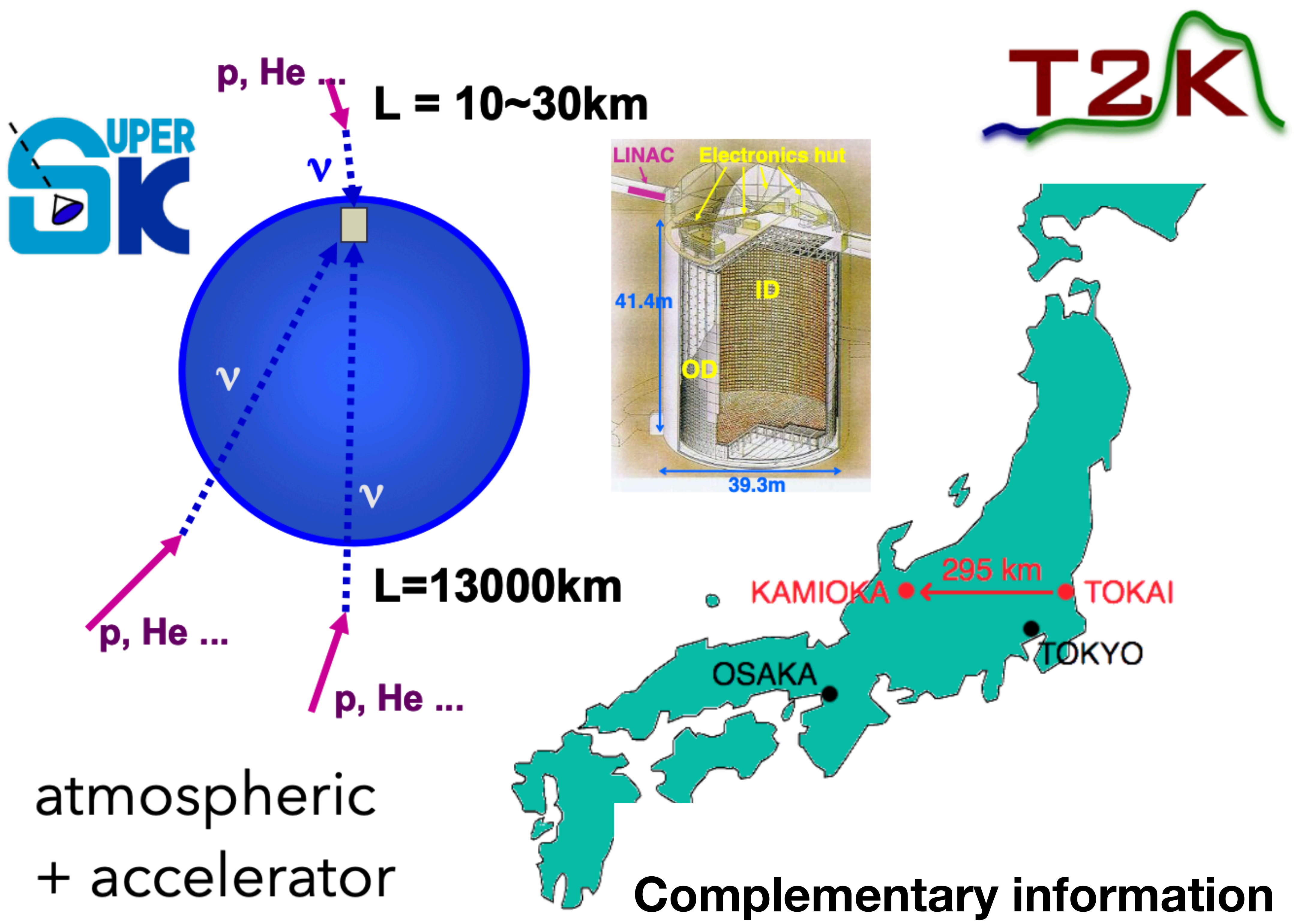



| | $\sin^2\theta_{23} < 0.5$ | $\sin^2\theta_{23} > 0.5$ | Sum |
|---|---|---|---|
| NH ($\Delta m^2_{32} > 0$) | 0.23 | 0.54 | 0.77 |
| IH ($\Delta m^2_{32} < 0$) | 0.05 | 0.18 | 0.23 |
| Sum | 0.28 | 0.72 | 1.00 |



# Joint analyses

- In 2023 we released two joint analyses
- T2K+NOvA combination → will be presented in the next talk
- T2K+SK combination

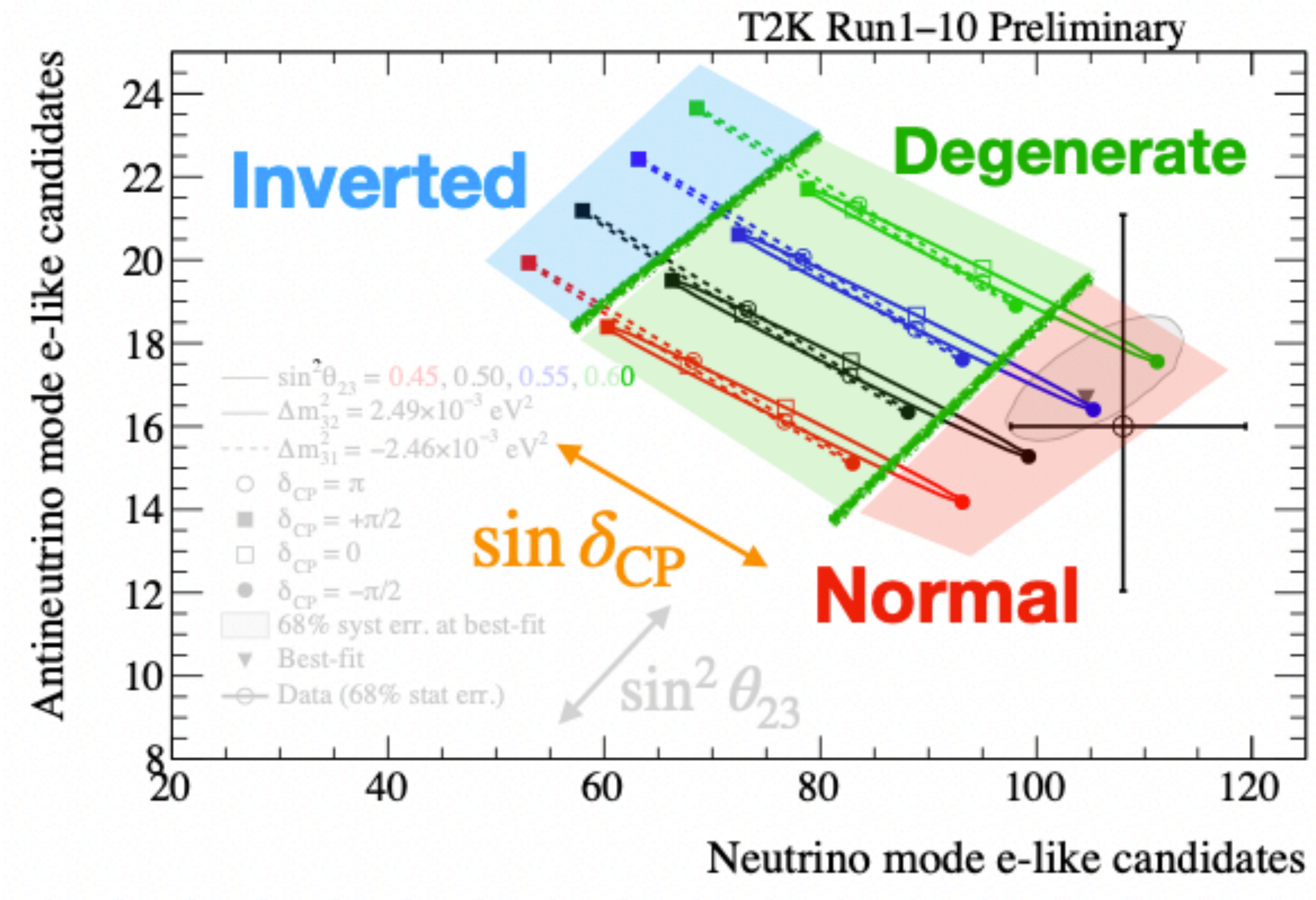


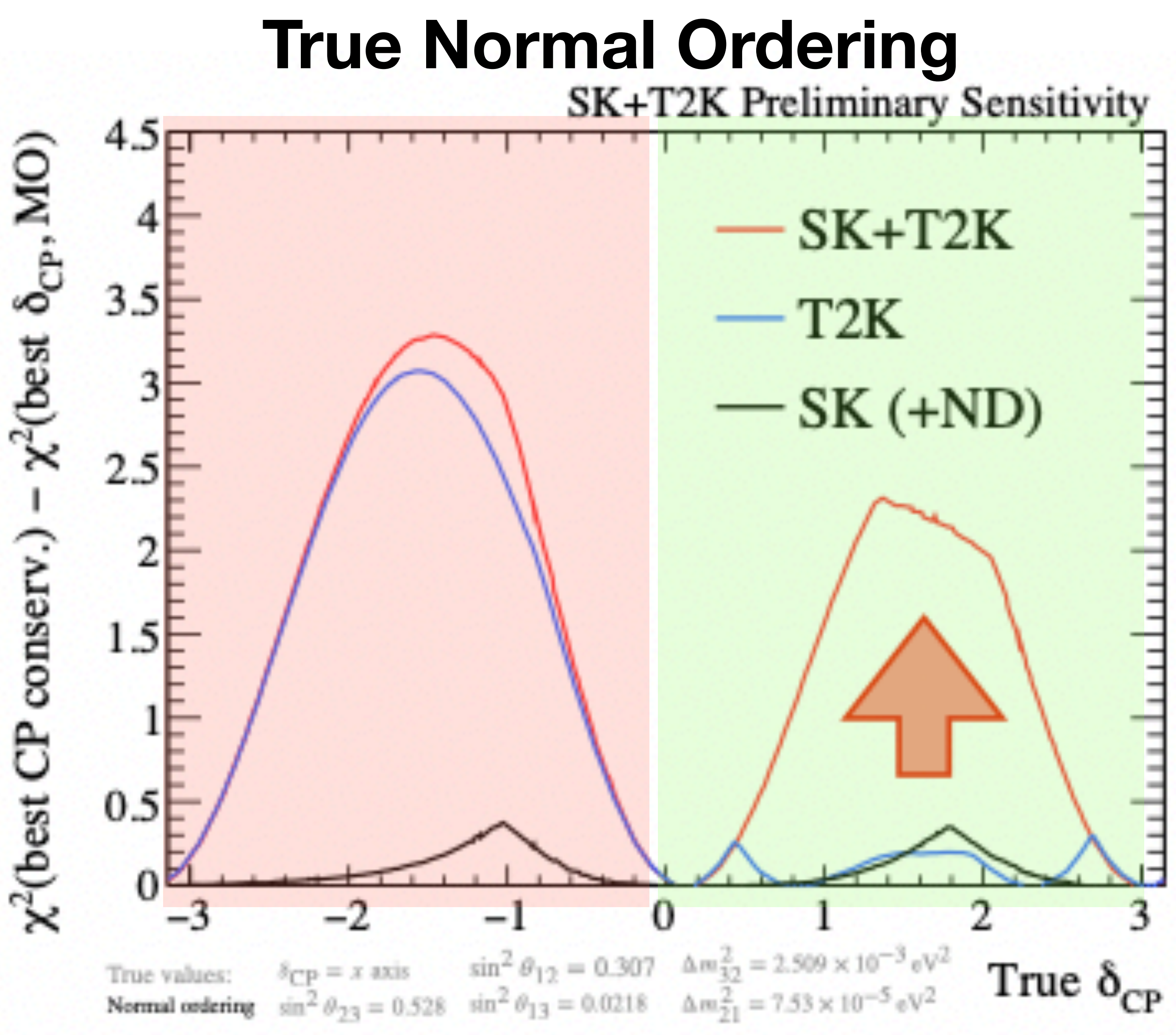

T2K data as in [Phys.Rev.D 108 (2023) 7, 072011] - (5 samples) POT: 3.6 x $10^{21}$

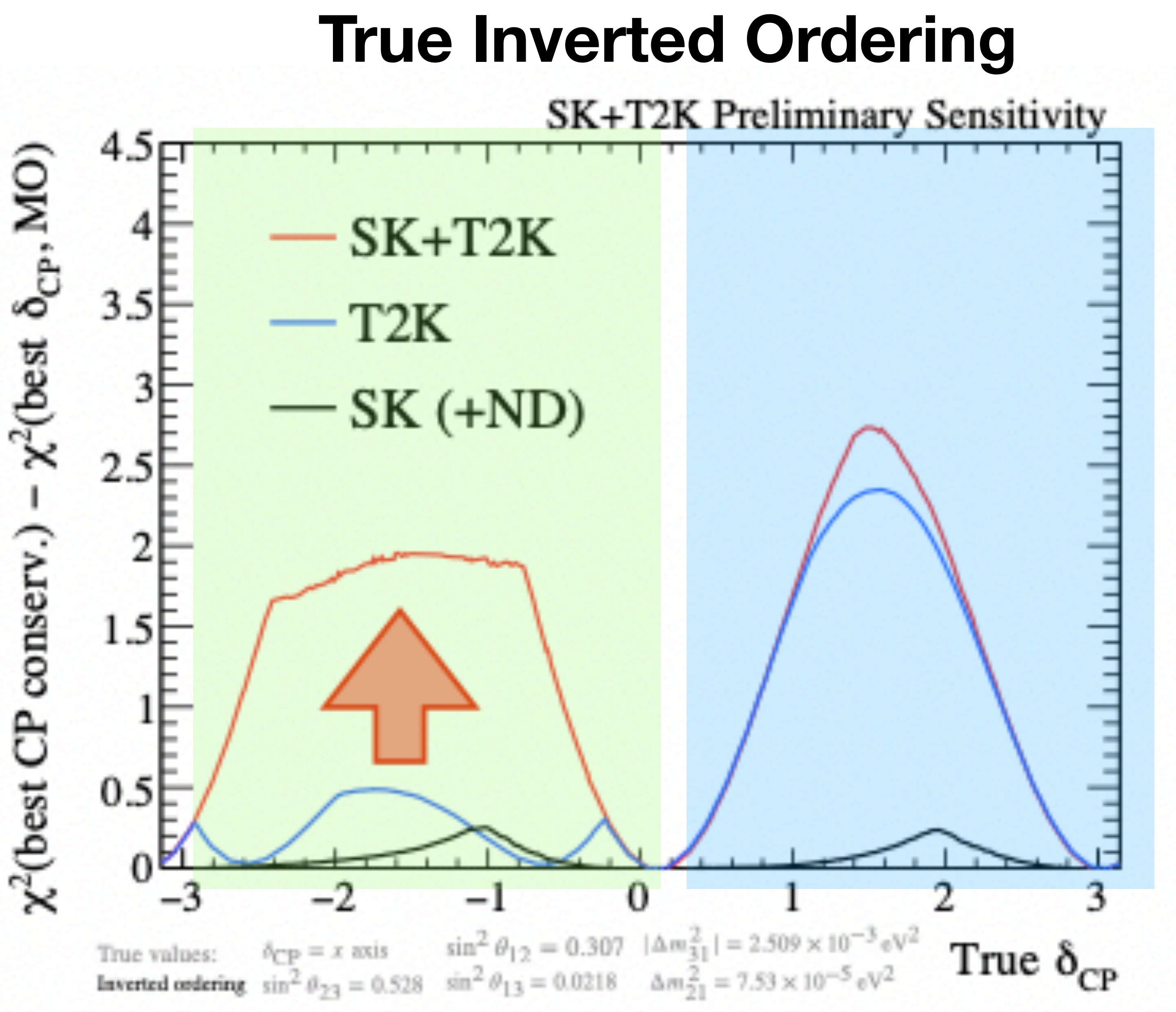
SK-IV data (18 samples) before Gd doping [PTEP 2019 (2019) 5, 053F01] - 3244 days (2008-2018)

# T2K+SK joint analysis

- T2K has good sensitivity to $\delta_{CP}$ but mild sensitivity to mass ordering
- SK has good constraint on mass ordering but not on $\delta_{CP}$
- Adding SK atmospheric sample allows to break the degeneracies between the CP violation parameter $\delta_{CP}$ and the mass ordering → boost sensitivity to CP



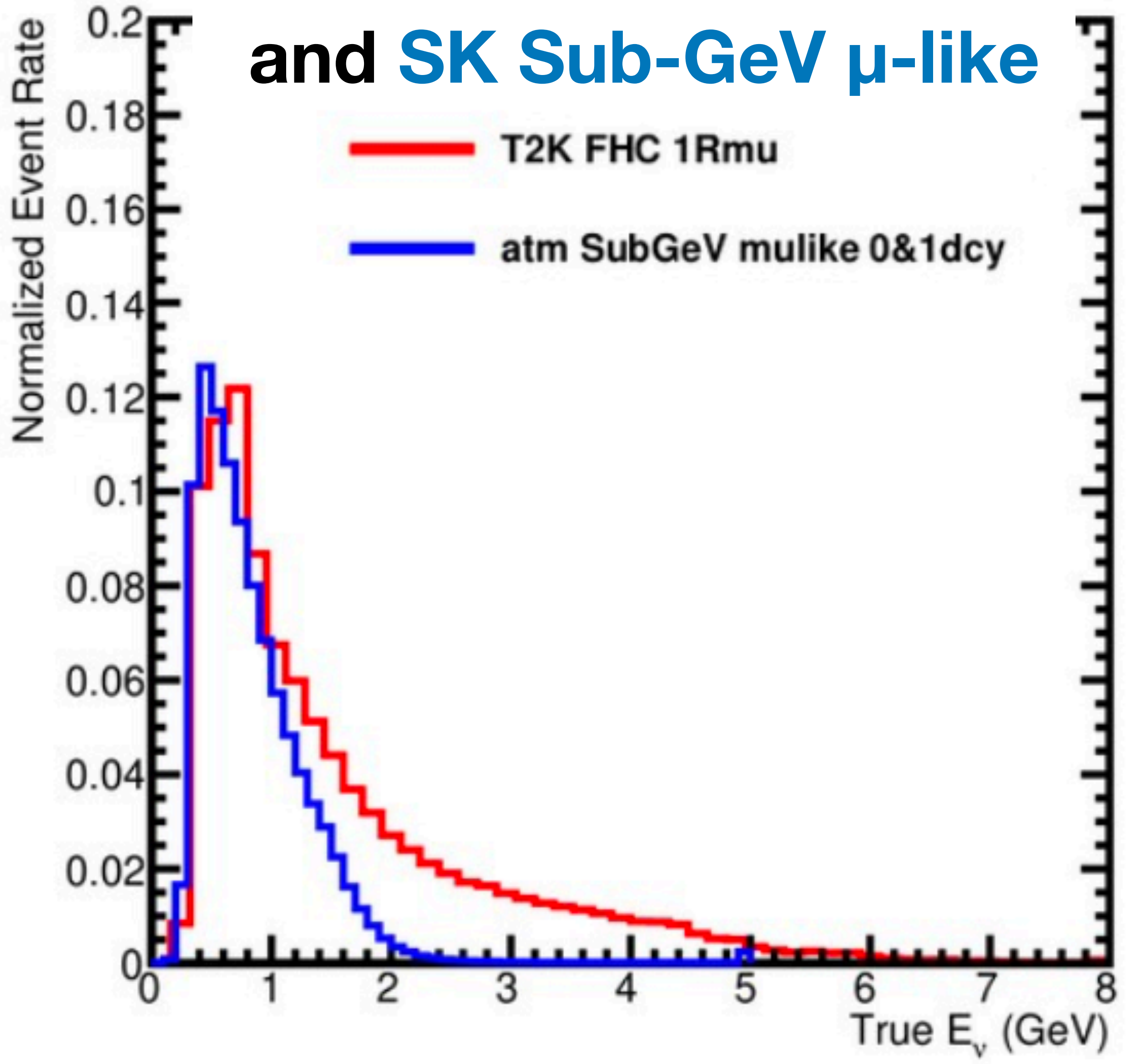
# T2K+SK model

- Same far detector → unify model and systematic uncertainties when necessary
  - Evaluate correlations in detector systematics between the T2K beam and SK atmospheric samples
  - Develop unified interaction model for T2K beam and SK low-energy samples covering similar energy region

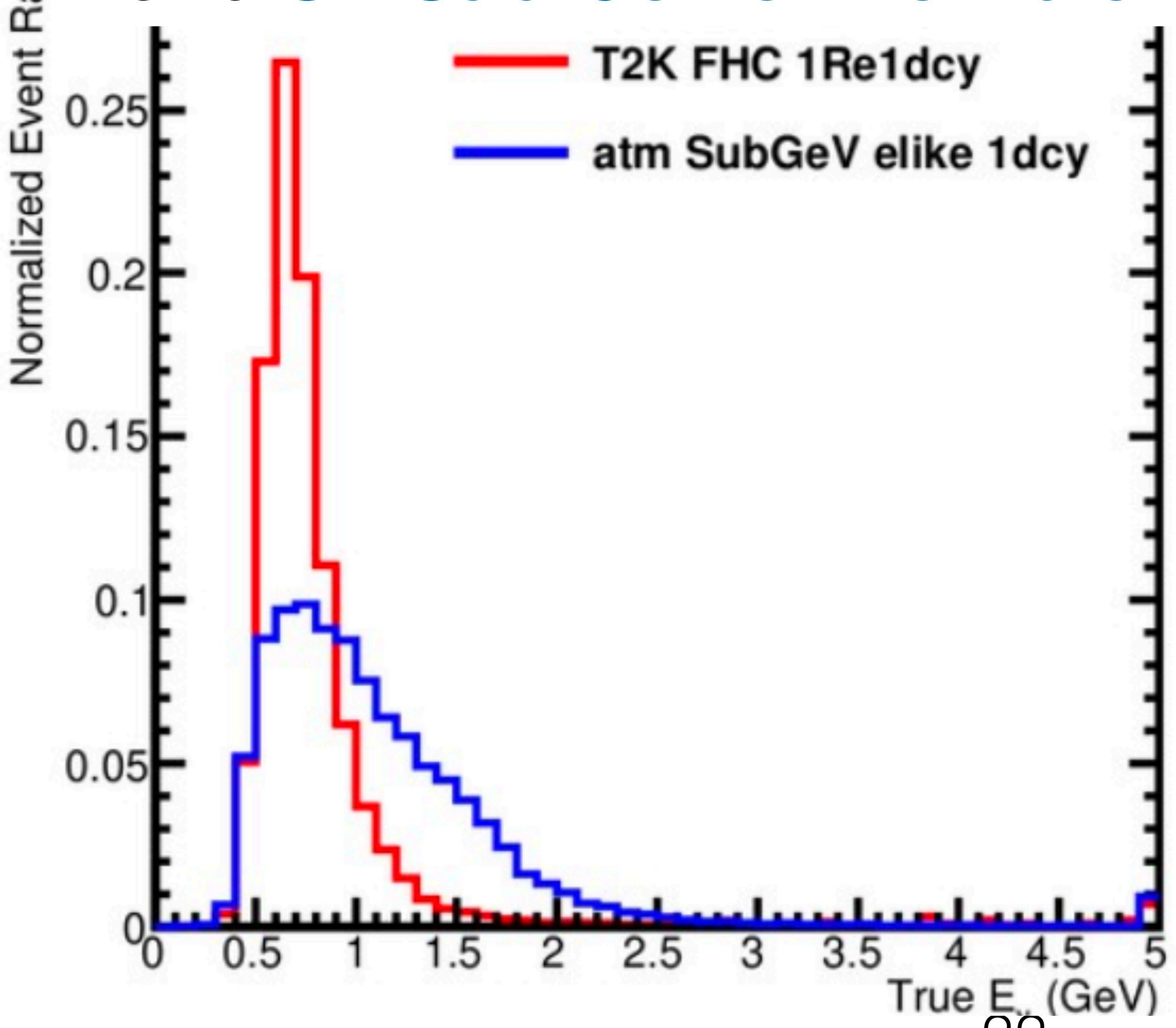
**ND280 data used to constraint the cross-section model for SK low-energy samples**

| | **Low-energy** sub-GeV atm + beam | **High-energy** multi-GeV atm |
|---|---|---|
| **CCQE** | T2K model with ND280 constraint, correlated in low-E/highE (except for high-$Q^2$) | |
| | high-$Q^2$ params w/ND280 | high-$Q^2$ params w/o ND |
| | add $\nu_e/\nu_\mu$ ratio unc. (CRPA) | |
| **2p2h** | T2K model w/ND280 | SK model (100% error) + T2K-style shape |
| **Resonant** | T2K model w/ND280 + new pion momentum dial + NC1π0 uncertainties | SK model for 3 dials common with T2K, use more recent larger T2K priors |
| **DIS** | T2K model w/ND280 | SK model |
| $\nu_\tau$ | SK model (25% norm on top of other syst) for other systematics checked that we have no numerically unstable values | |
| **FSI** | T2K model w/ND280 | T2K model w/o ND280 should be mostly same as SK model |
| **SI** | T2K model, correlated in low-E/high-E only applied to FC and PC for atm, PN not applied to atm | |

**True E$\nu$ T2K 1 Rμ sample and SK Sub-GeV μ-like**




**True E$\nu$ T2K 1 Re+d.e. sample and SK Sub-GeV e-like 1 d.e.**

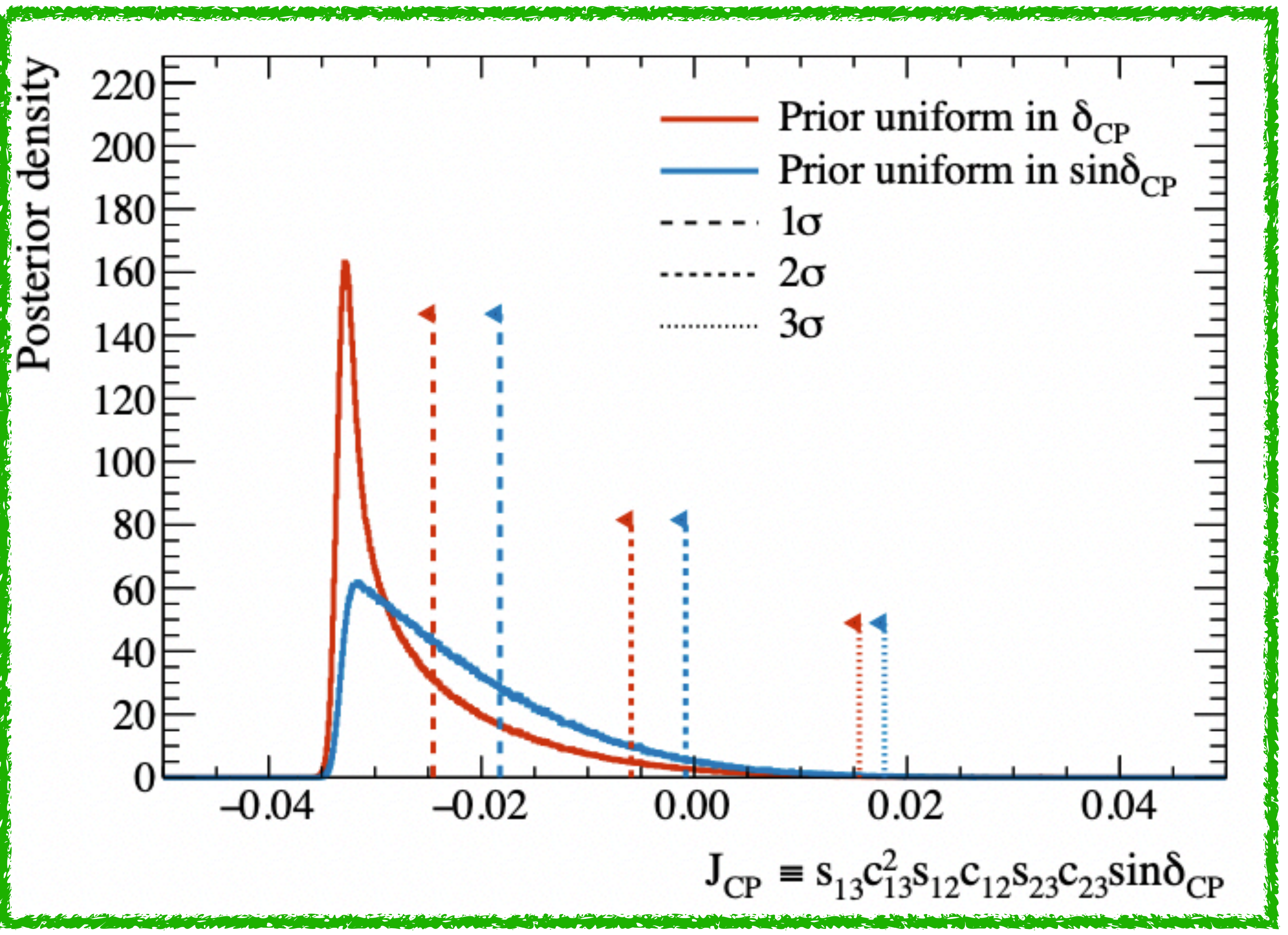


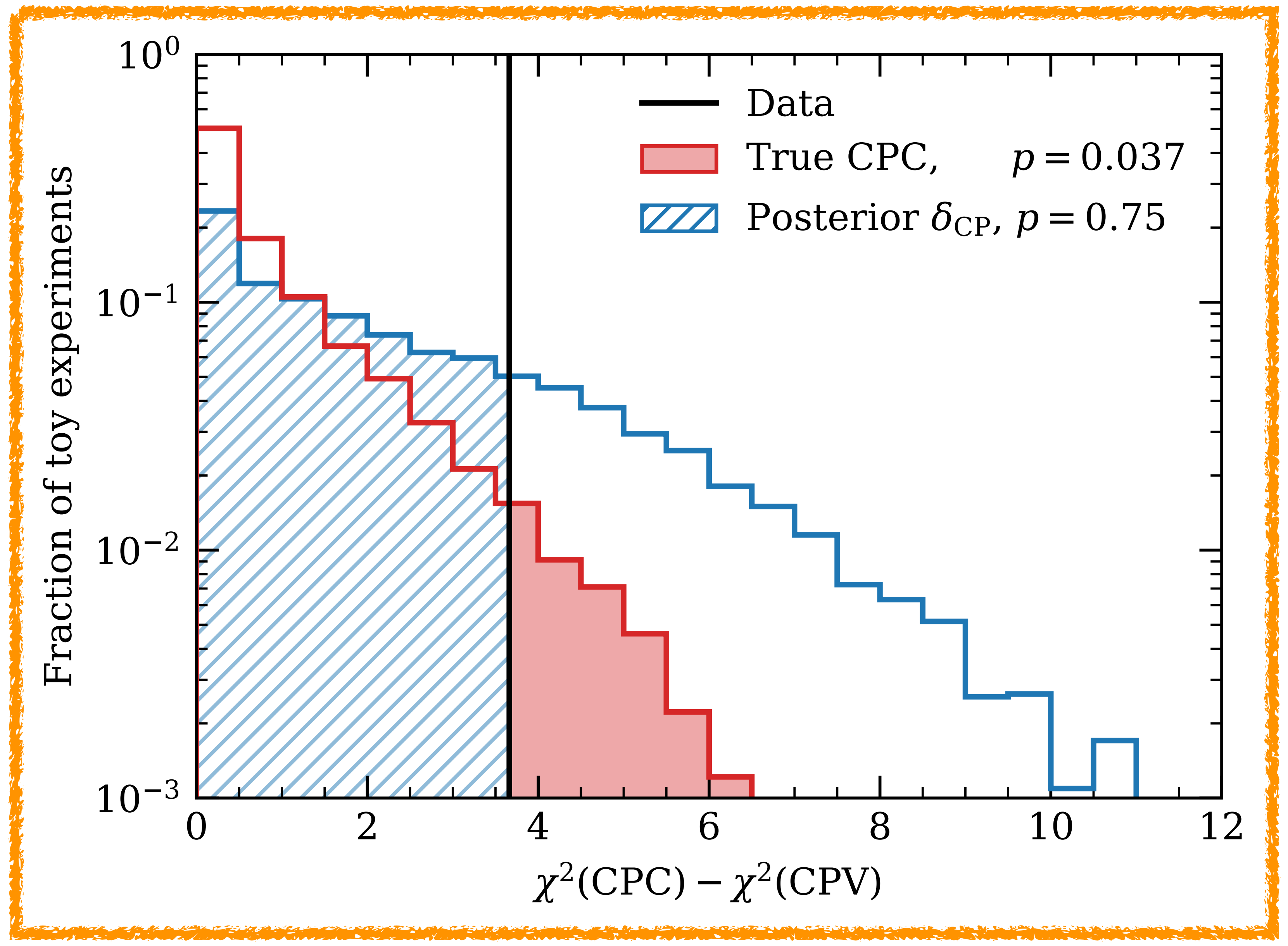
Z. Xie, L. Berns poster

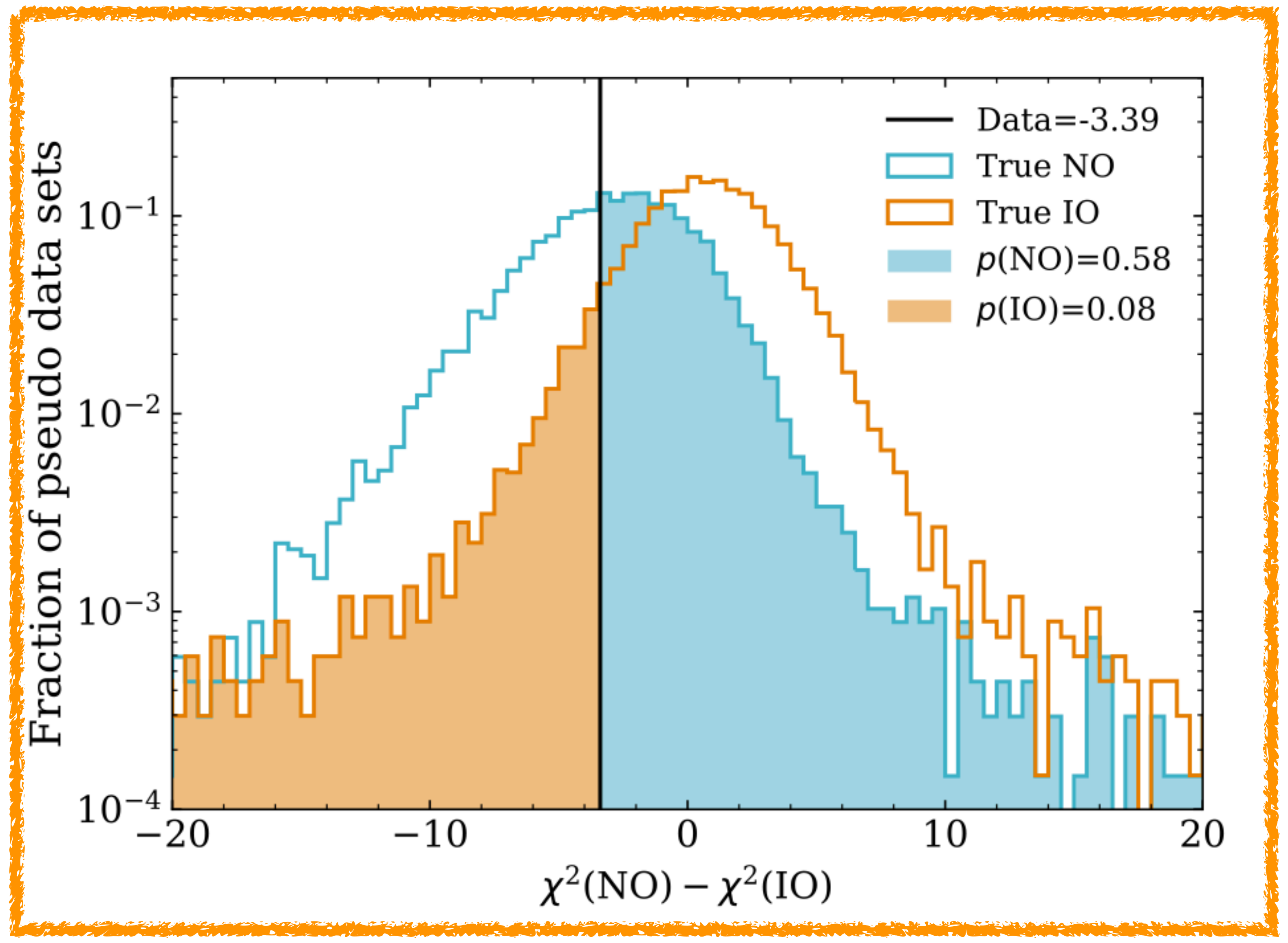
arXiv:2405.12488

# Results

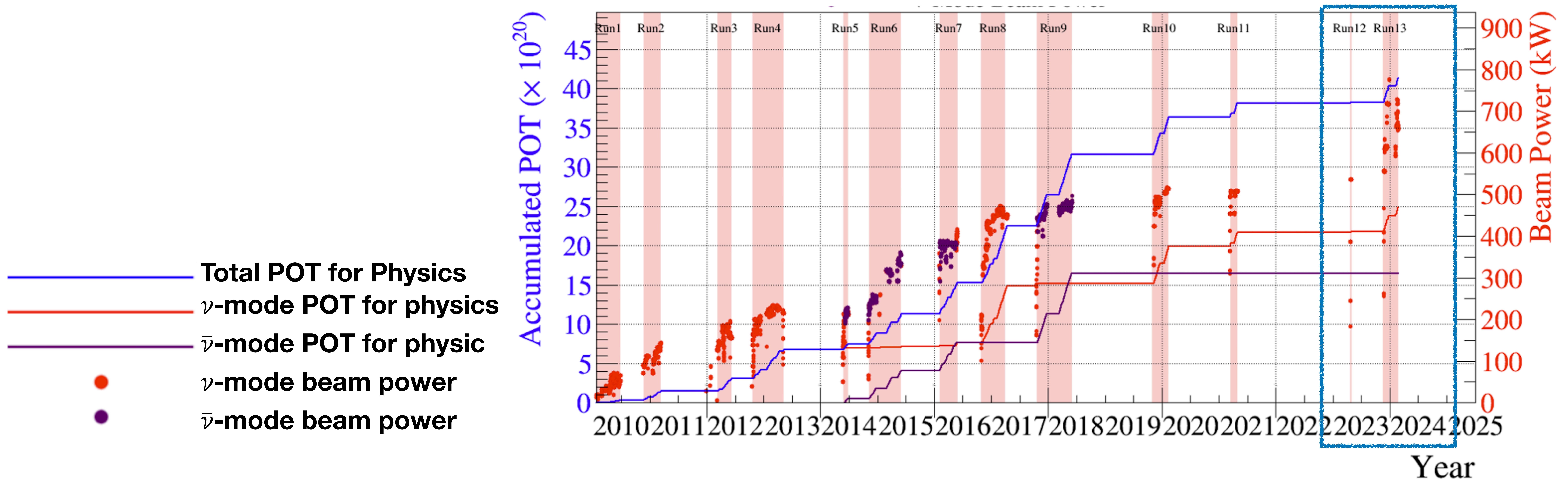
- Both experiments individually prefer normal ordering and $\delta_{CP}$~-π/2, T2K prefers upper octant, SK prefer lower octant
- We performed Bayesian and Frequentist analyses → frequentist analyses shown today
- The CP-conserving value of the Jarlskog invariant is excluded with a significance between 1.9 and 2 σ
- In the frequentist analysis, p-value for CPC is 0.037 but increase to 0.05 when potential biases due to cross-section mis-modeling are included
- Normal ordering is preferred, p-value for IO 0.08



# T2K what’s next?



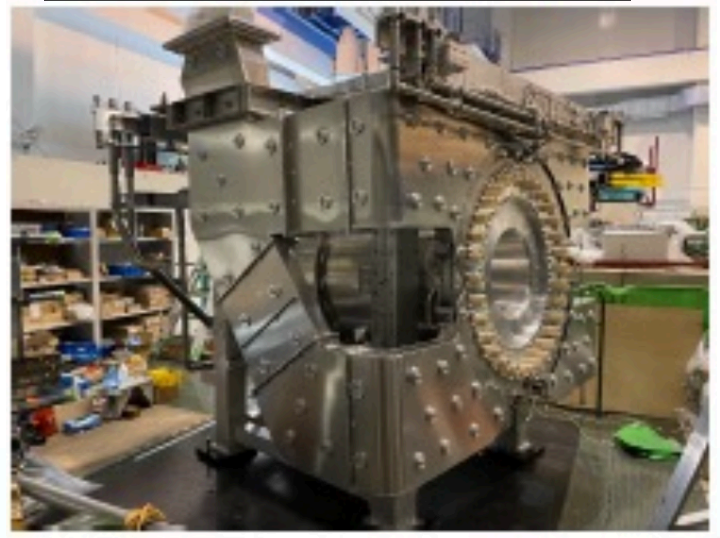

- Run 13 in December/February 2024, currently taking beam data
- Upgrades on the beamline → 750 kW reached in December 2023
- ND280 upgrade installed

# Neutrino beamline upgrades

- Replacement of Main Ring power supplies to allow for higher repetition rate from 2.48s to 1.36s
- Several upgrades done on the neutrino beamline to cope with higher beam power
- Horn being operated at 320 kA instead of 250 kA → ~10% increase in the $\nu$ flux

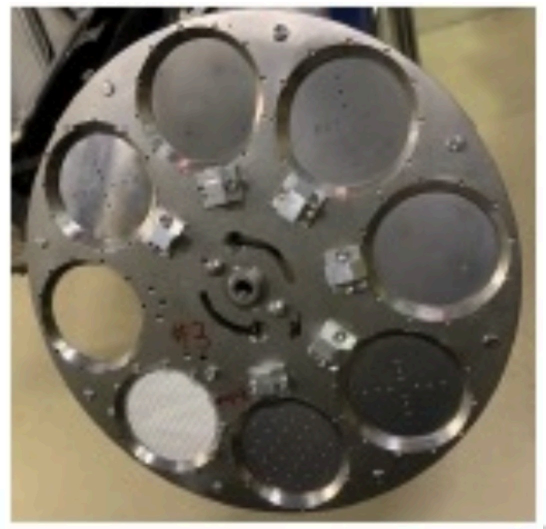
New horn PS for 320 kA/1Hz operation

New horns 1 and 2



Increasing cooling capability for the heat generated by beam

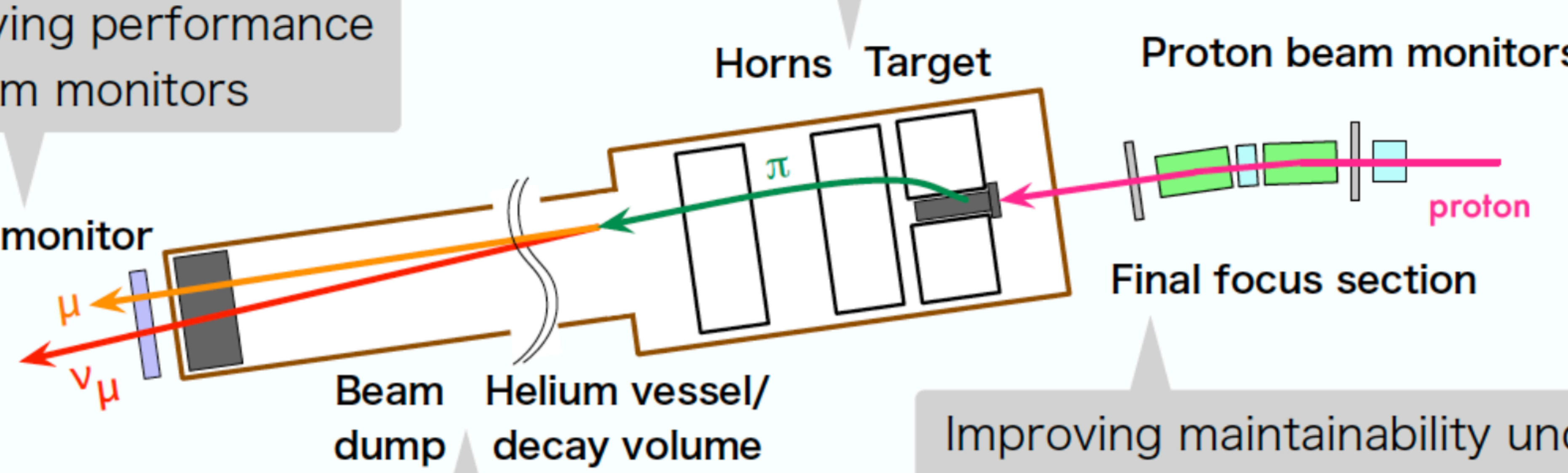
New OTR



Improving performance of beam monitors

New FVD2 magnet


Improving performance of beam monitors



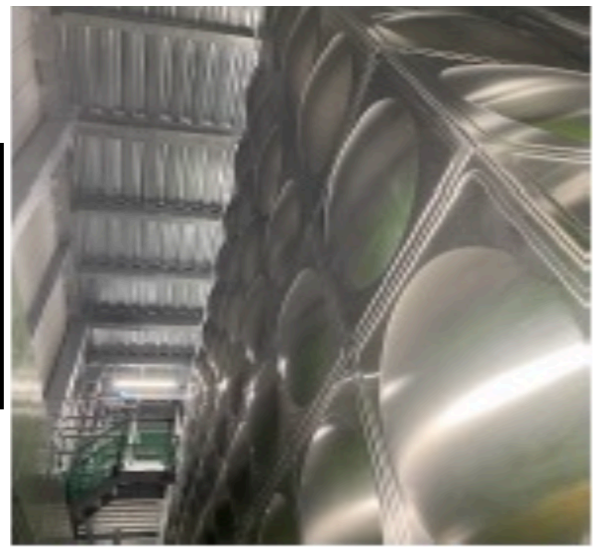

Improving maintainability under higher radio-active environment

Increasing capability of radio-active waste handling

New target

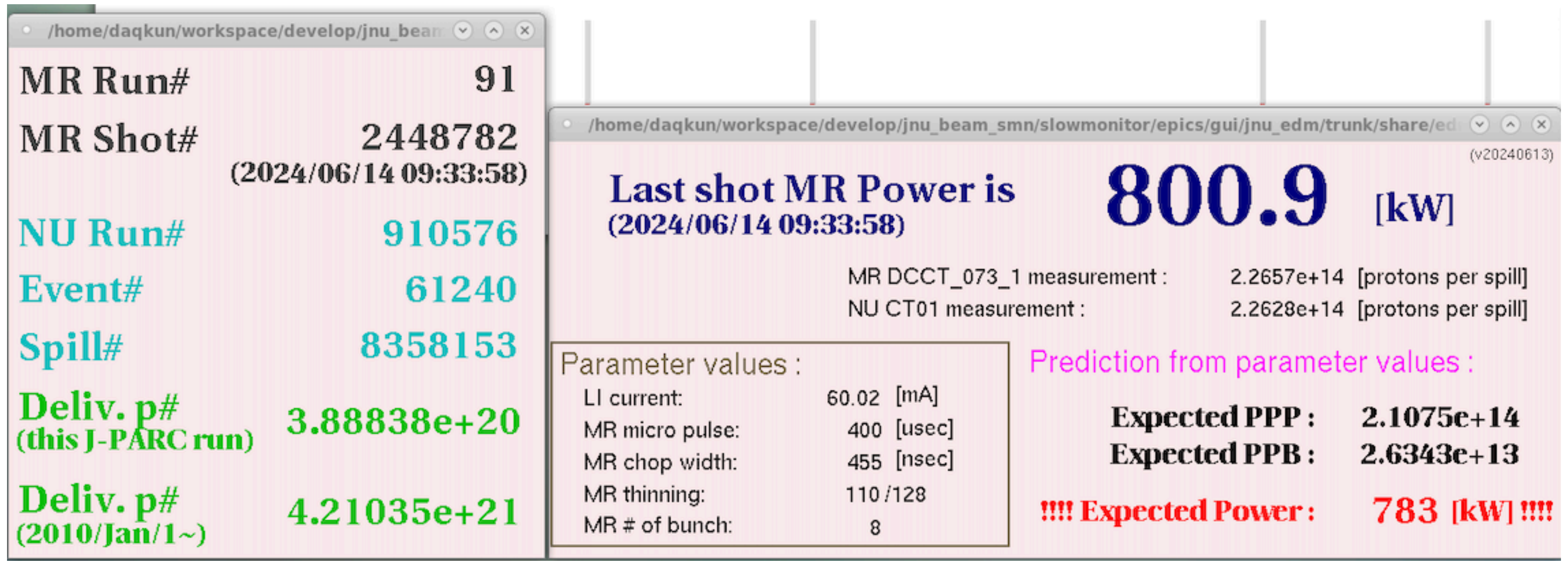
New MUMON Si (Half sensors)

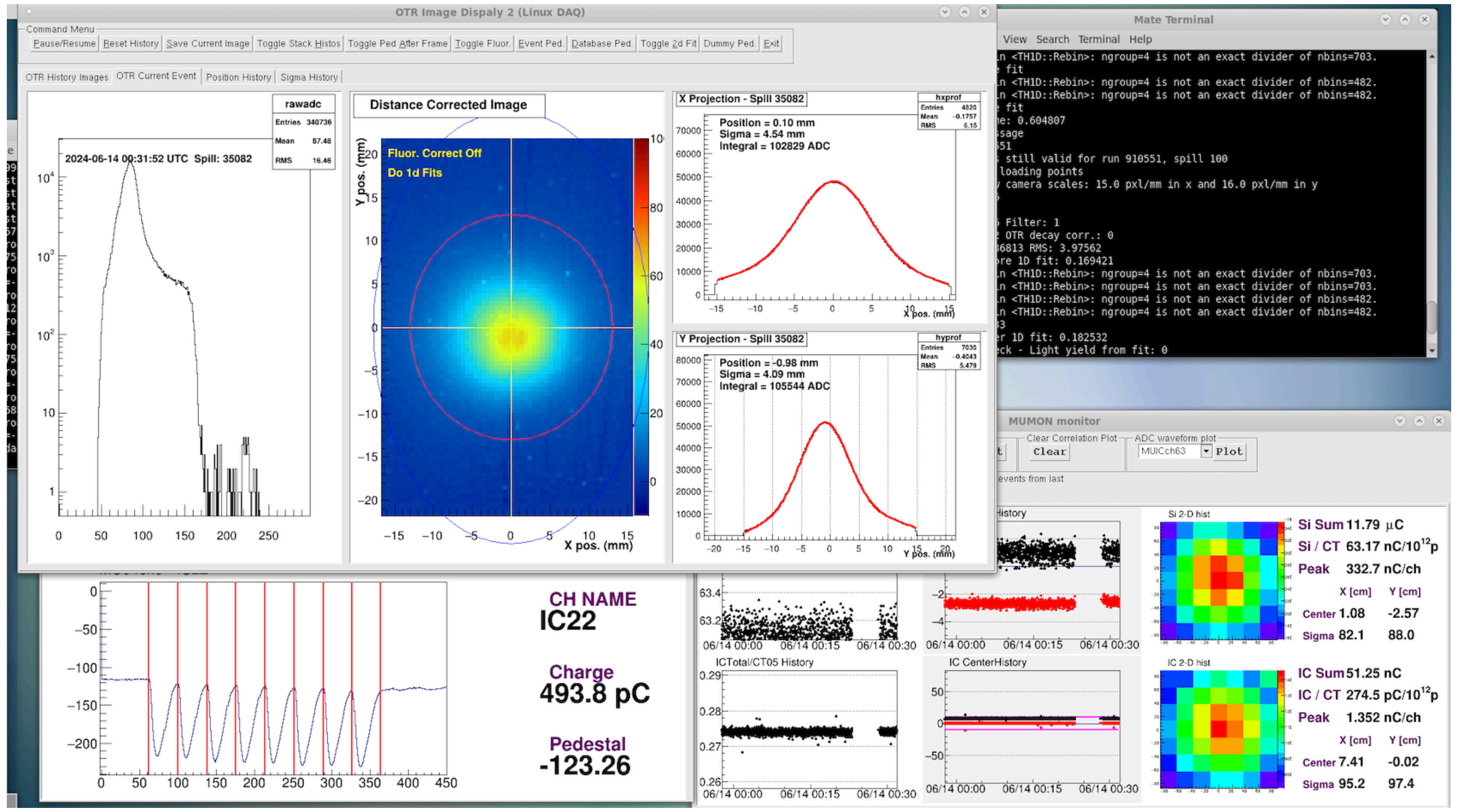
New water tank for radioactive water disposal



New target cooling system

# Towards higher beam power

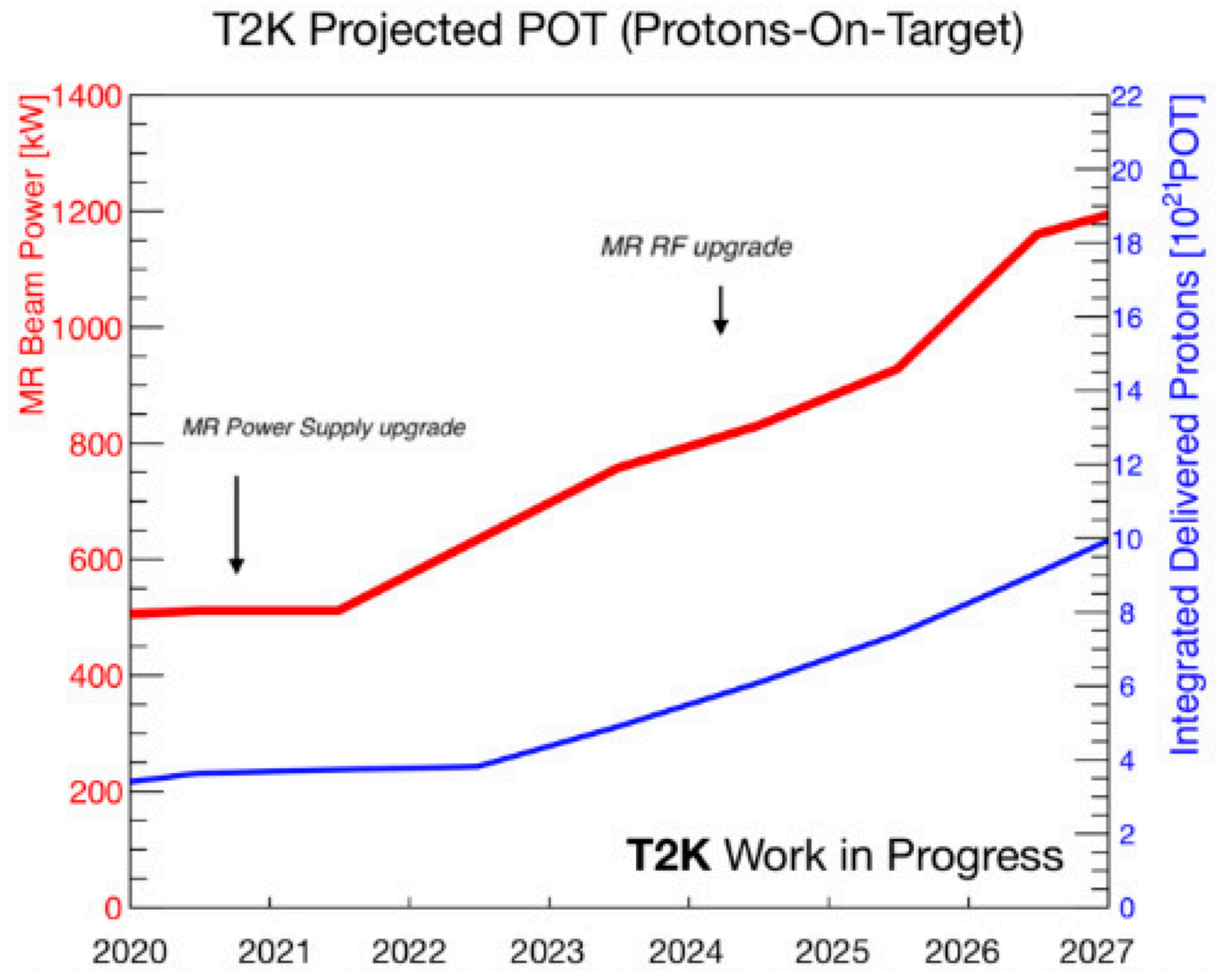


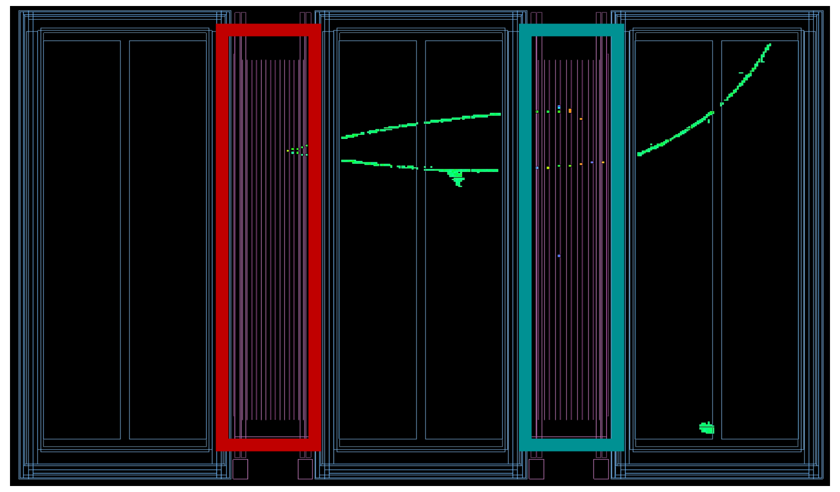

- June 2024 → Beam power increased to 800 kW since last week! (~500 kW before upgrades)

- Steady improvements to reach 1.3 MW by 2027 → increase T2K statistics by a factor of 3 by 2027

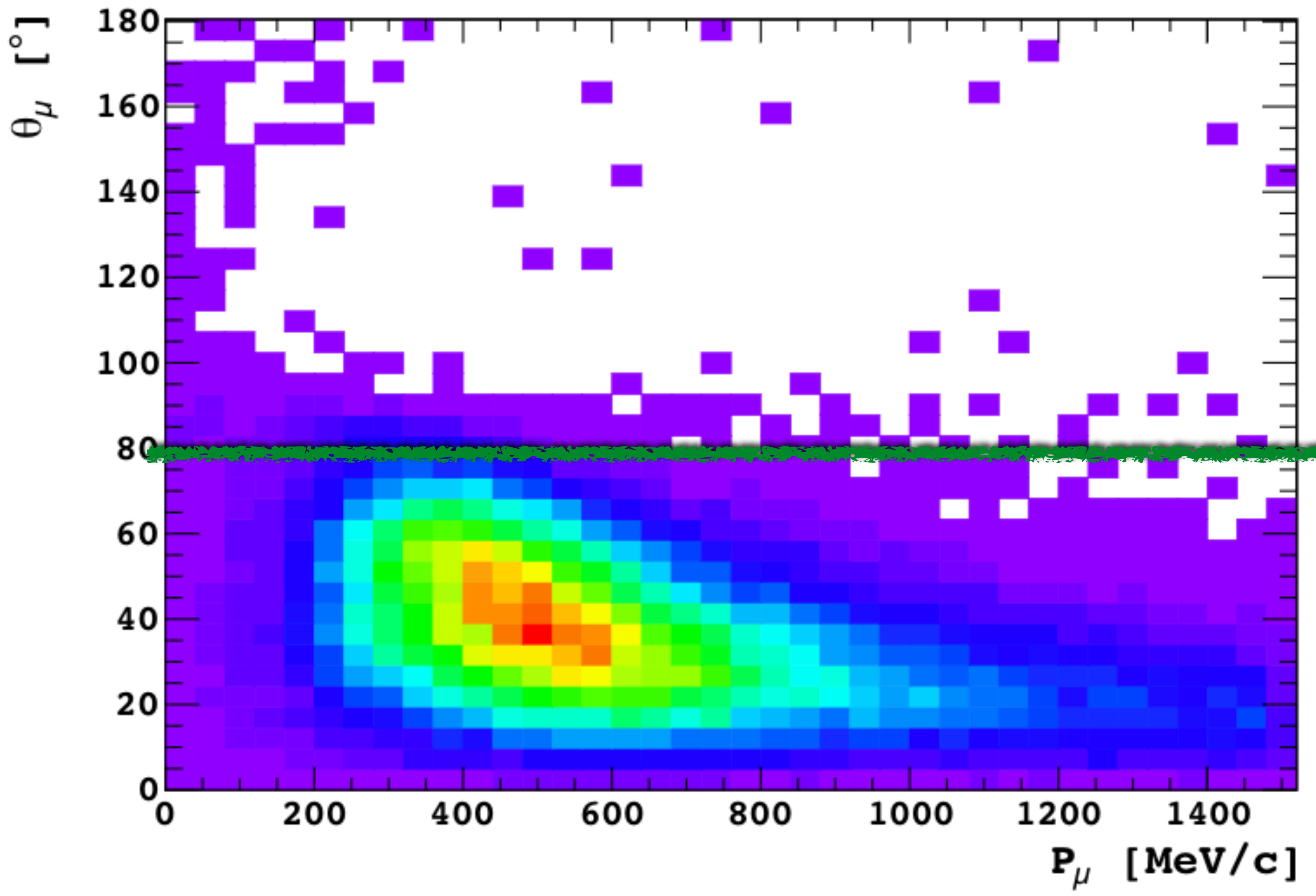
- Larger statistics → need to reduce systematic uncertainties → ND280 upgrade



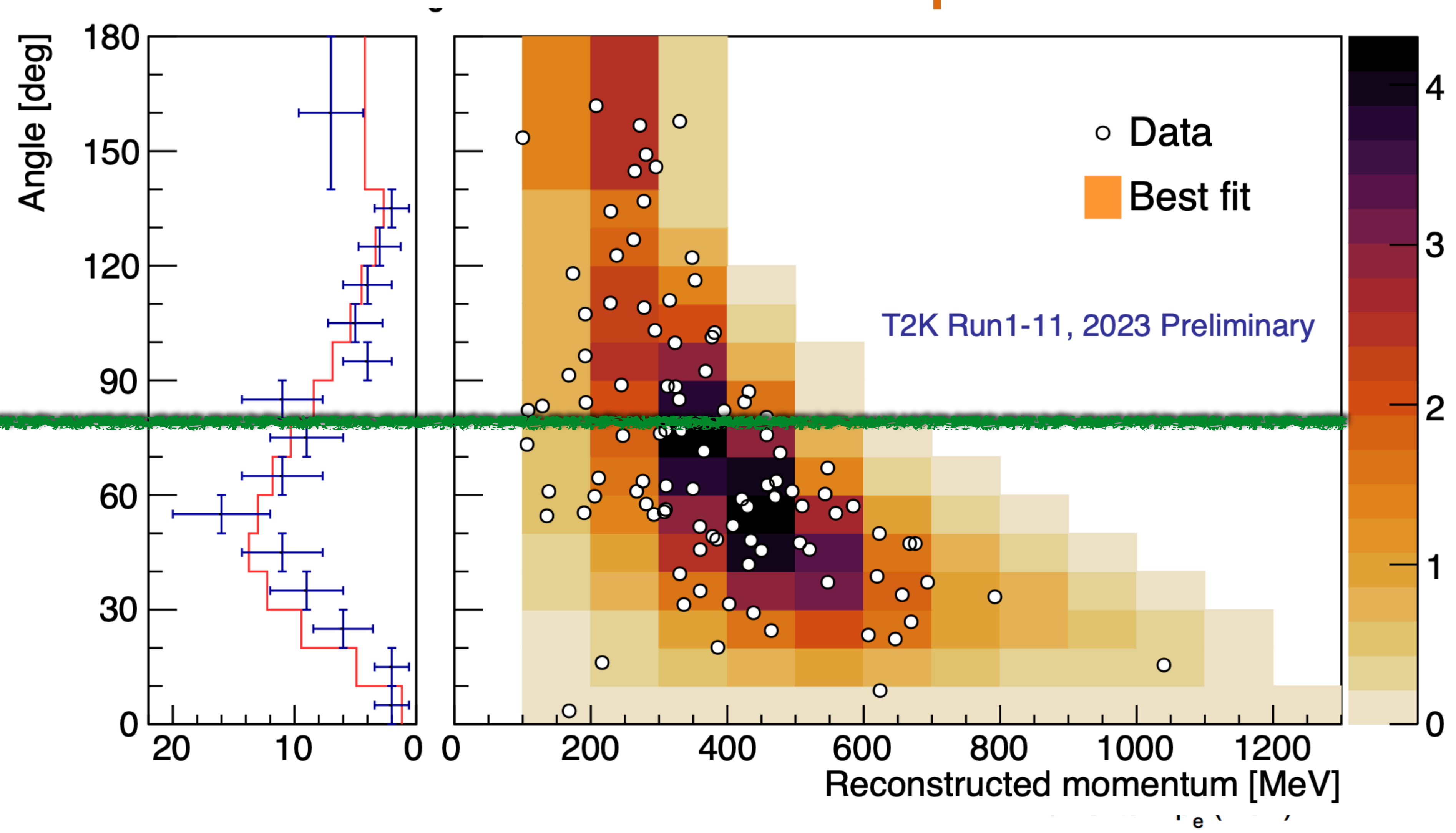
# ND280 limitations



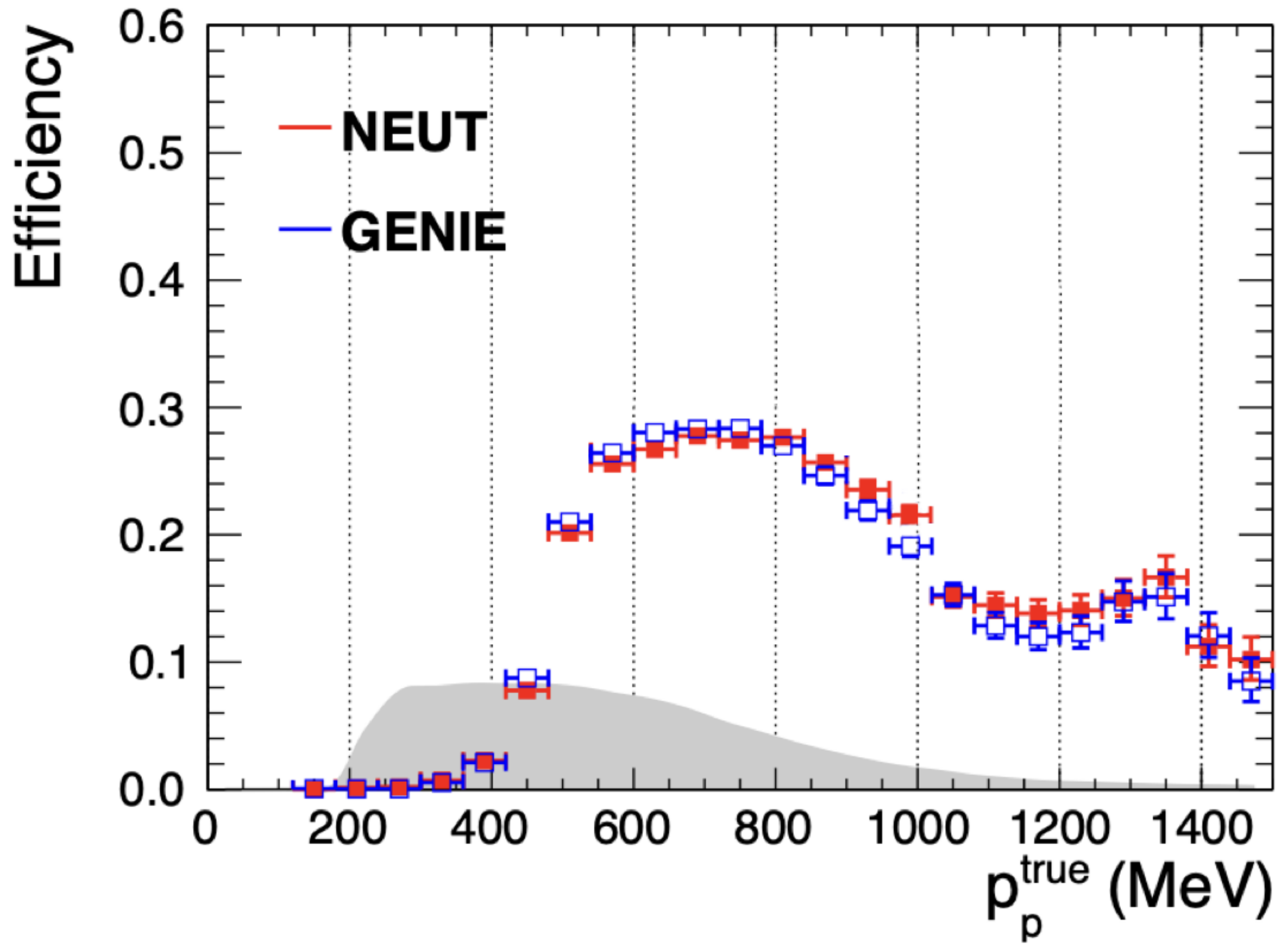
ND280 acceptance




SK acceptance

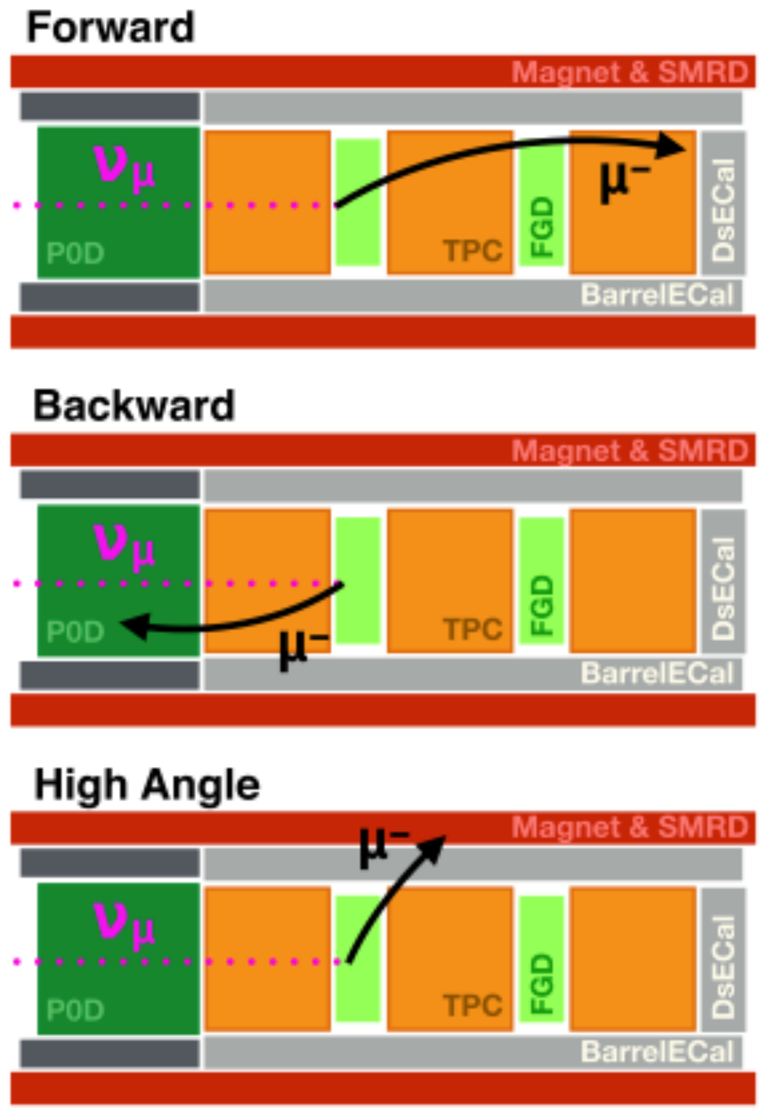


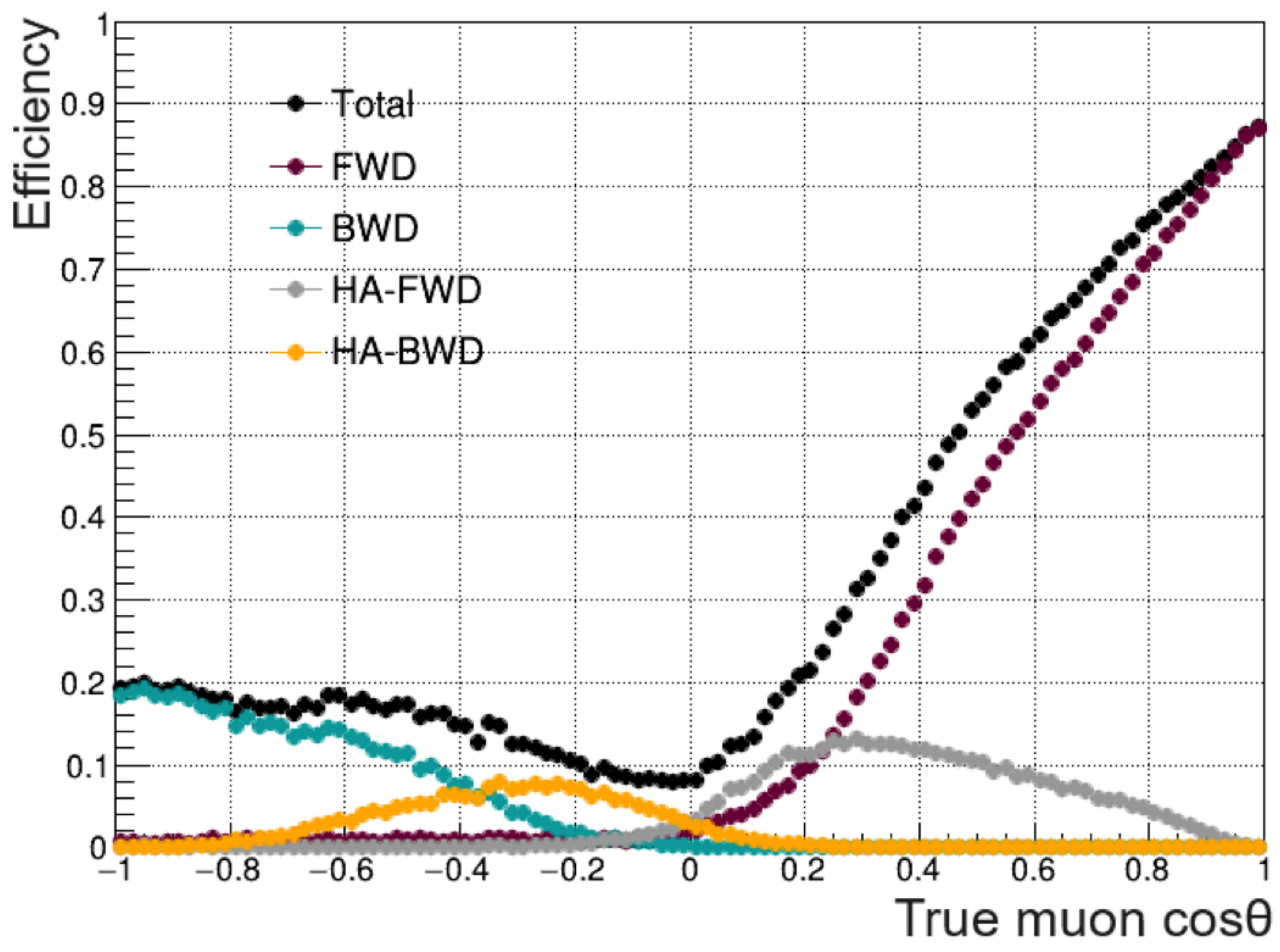

**ND280 Proton reconstruction efficiency**




- Reduced angular acceptance $\nu$ → mostly reconstruct forward going tracks entering the TPCs
- Low efficiency to reconstruct low momentum protons

# 4π selection at ND280

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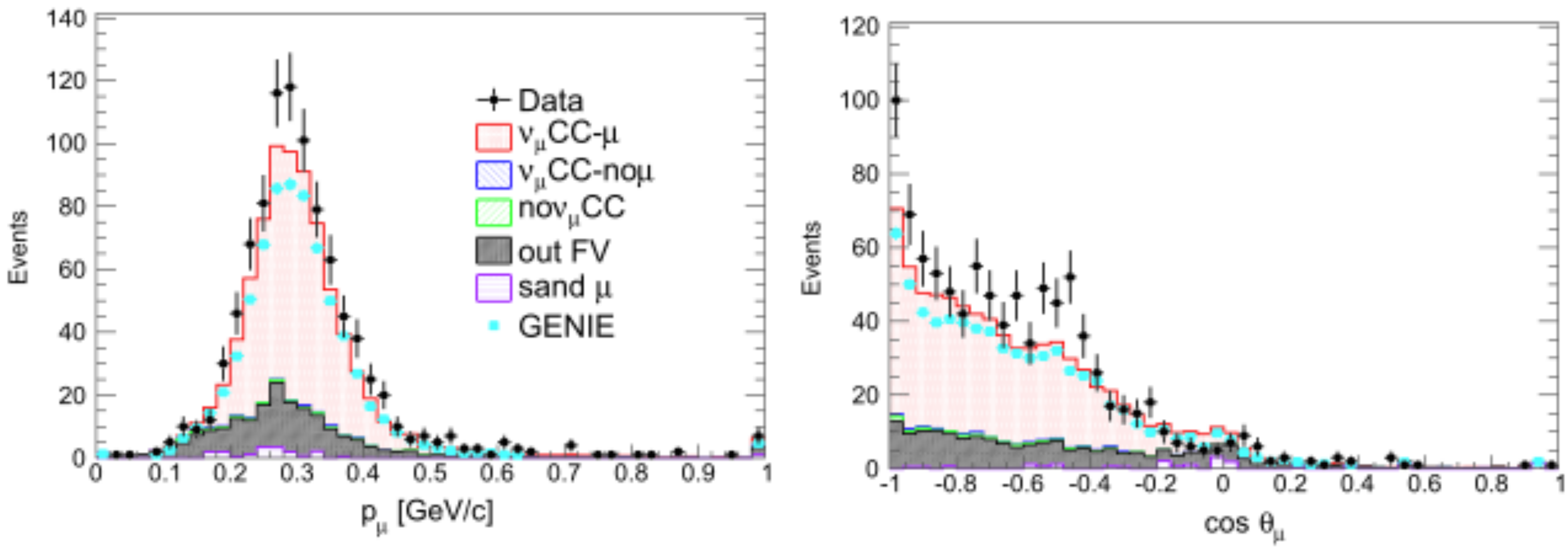
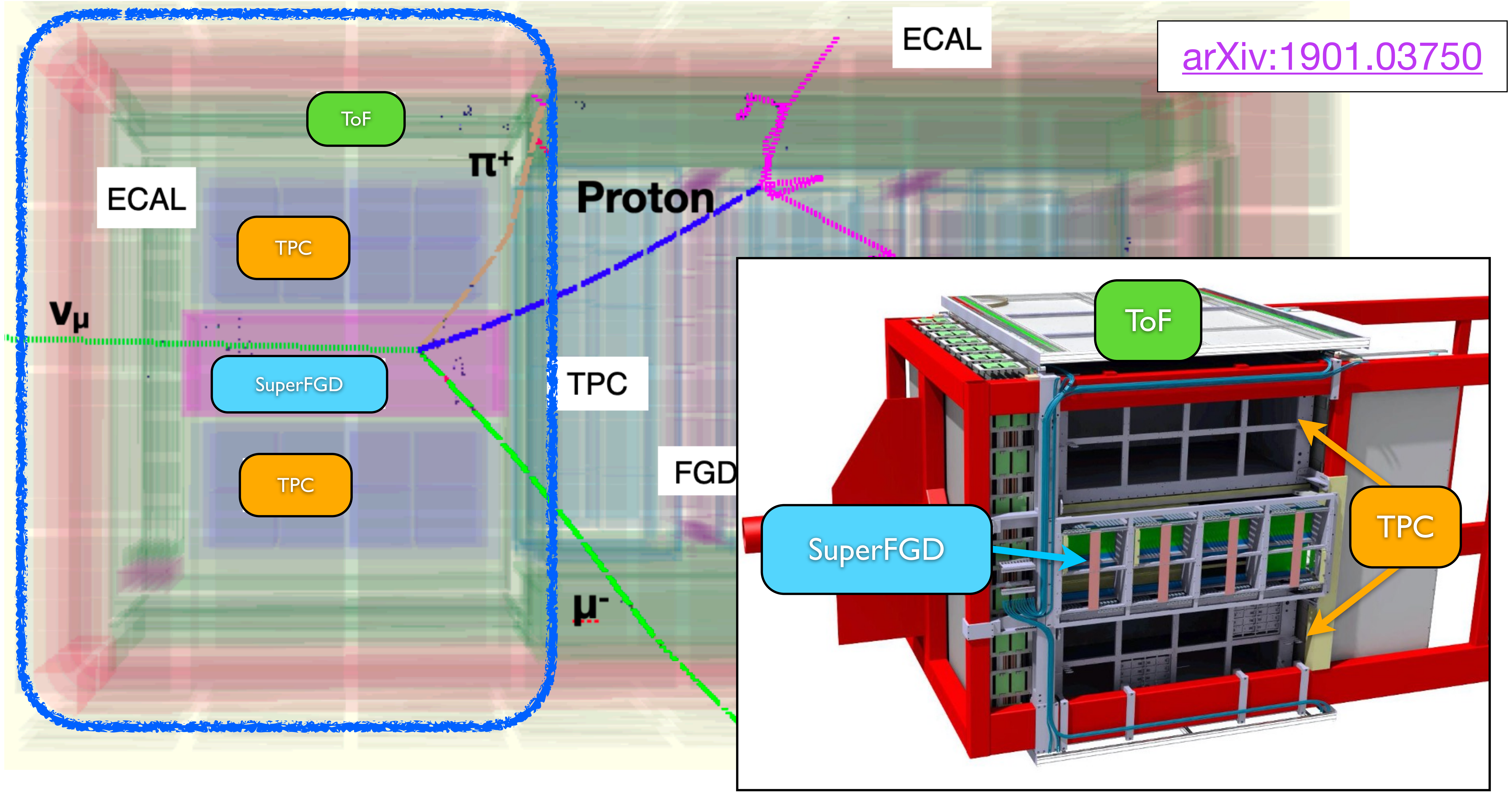



- Working on new cross-section model with more freedom and higher cross-section uncertainties
- Addition of high angle and backward going tracks in ND280 to match SK acceptance
- Limited efficiency ~ 20% due to the absence of TPCs in the high angle region → upgrade of ND280

**Preliminary Asimov fit → similar systematics**

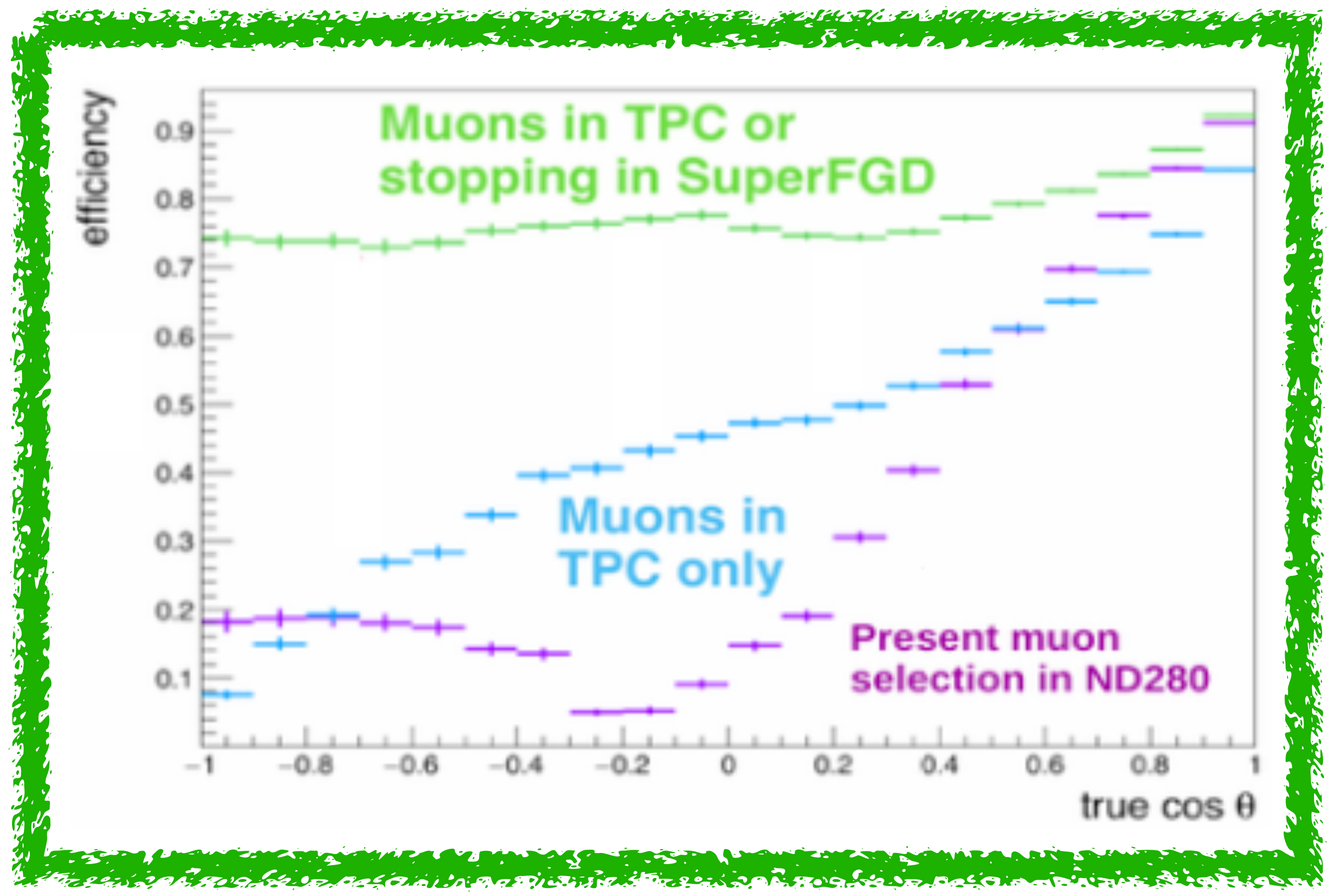
| Sample | Pre-ND fit | Post-ND fit | Previous x-sec model - no 4π |
|---|---|---|---|
| $\nu$-mode 1Rμ | 15.8% | 2.6% | 2.5% |
| $\nu$-mode 1Re | 20.8% | 4.0% | 3.8% |
| $\nu$-mode MR | 12.1% | 2.8% | 2.1% |
| $\nu$-mode 1Re+d.e. | 13.8% | 4.7% | 4.2% |
| $\bar{\nu}$-mode 1Rμ | 15.3% | 2.7% | 2.4% |
| $\bar{\nu}$-mode 1Re | 15.5% | 3.5% | 3.5% |

# The Near Detector upgrade

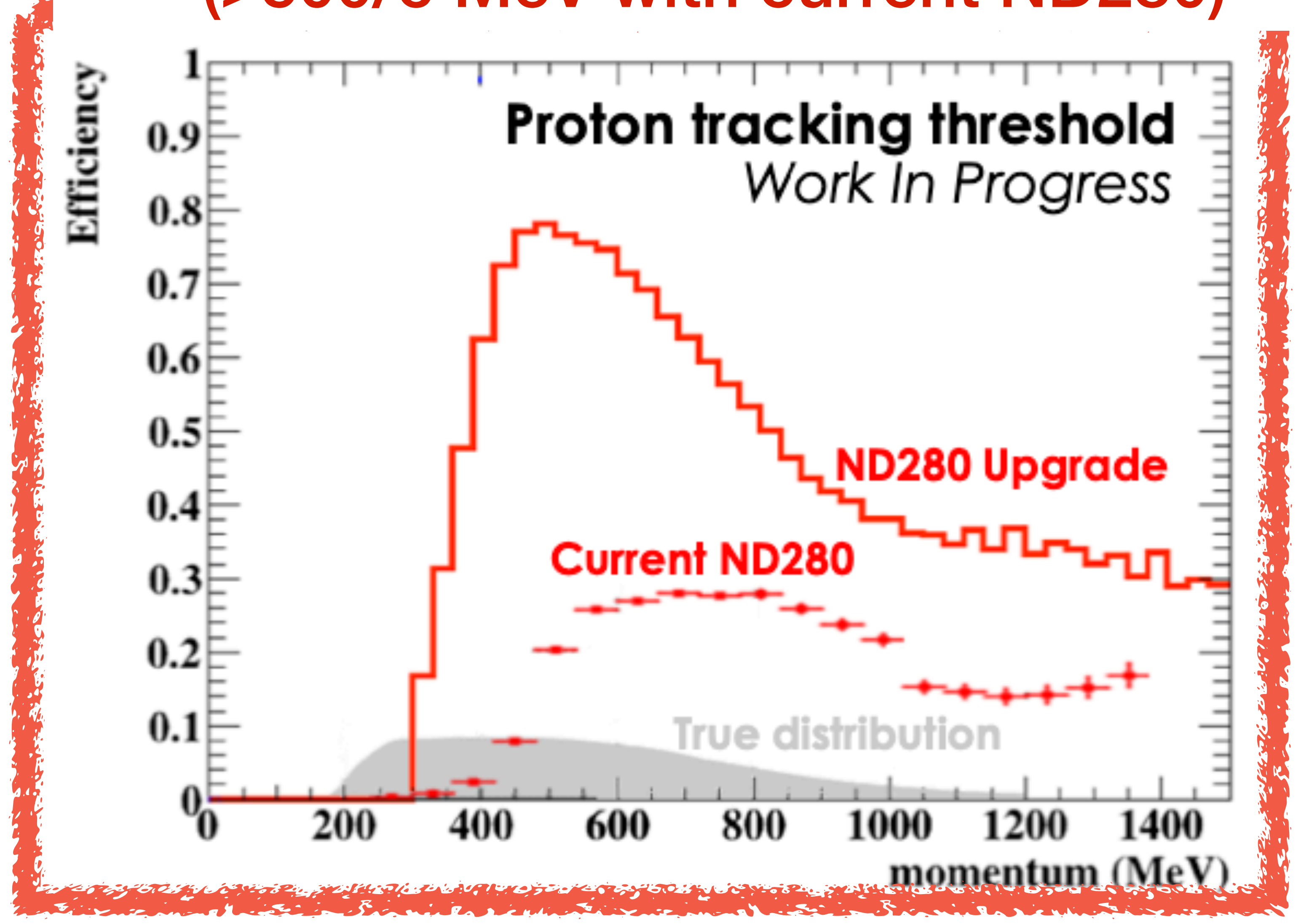



Replace part of the P0D detector (measured NC $\pi^0$ production) with a new scintillator target (SuperFGD), two High-Angle TPCs and six ToF planes

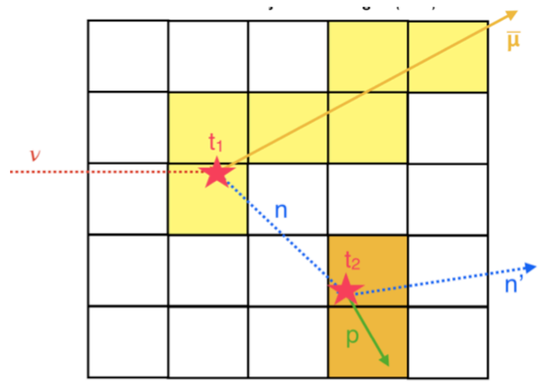
# ND280 Upgrade improvements



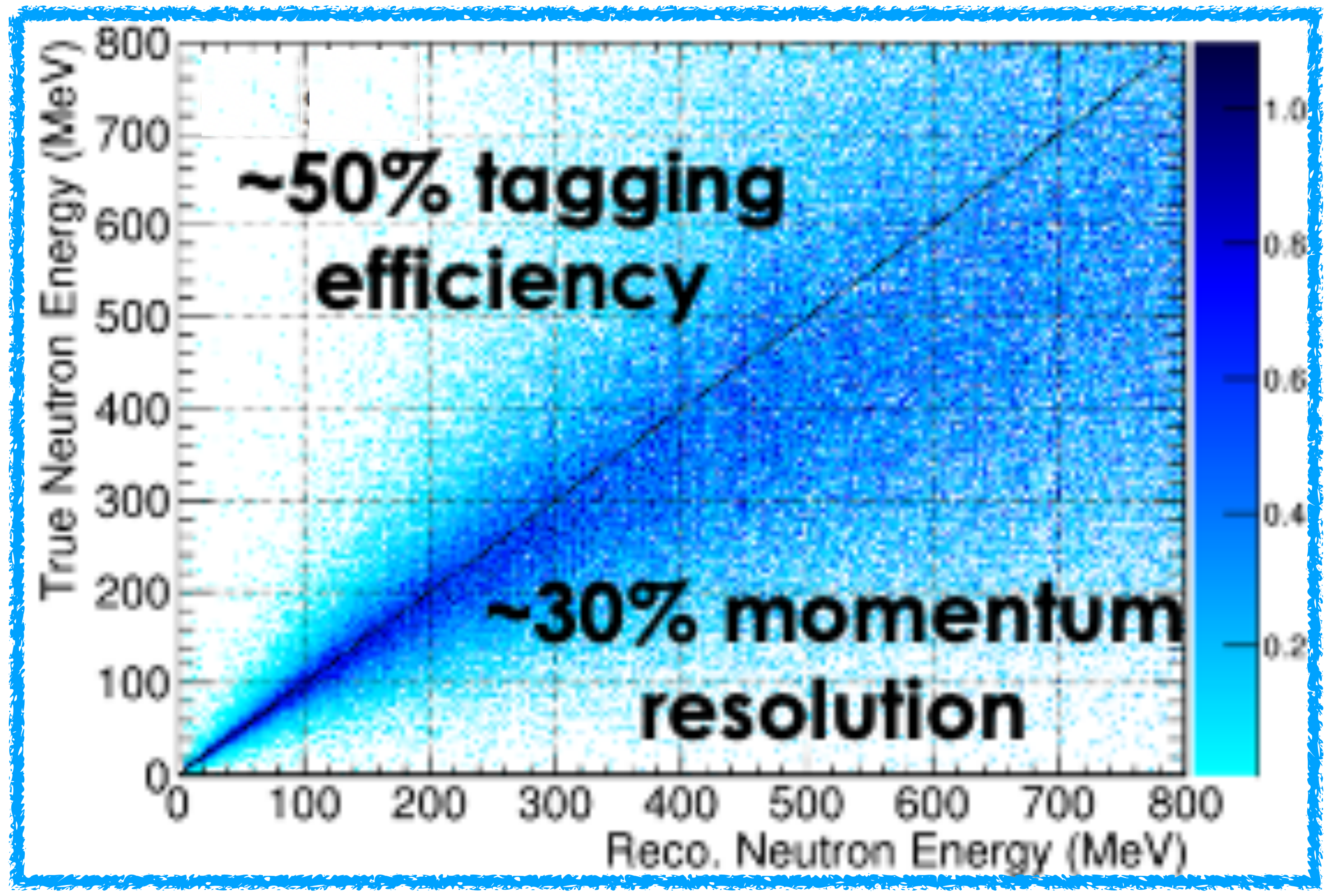

Protons → threshold down to 300 MeV/c (>500/c MeV with current ND280)




- High-Angle TPCs allow to reconstruct muons at any angle with respect to beam
- Super-FGD allow to fully reconstruct in 3D the tracks issued by $\nu$ interactions → lower threshold and excellent resolution to reconstruct protons at any angle
  - Improved PID performances thanks to the high granularity and light yield
- Neutrons will also be reconstructed by using time of flight between vertex of $\bar{\nu}$ interaction and the neutron re-interaction in the detector



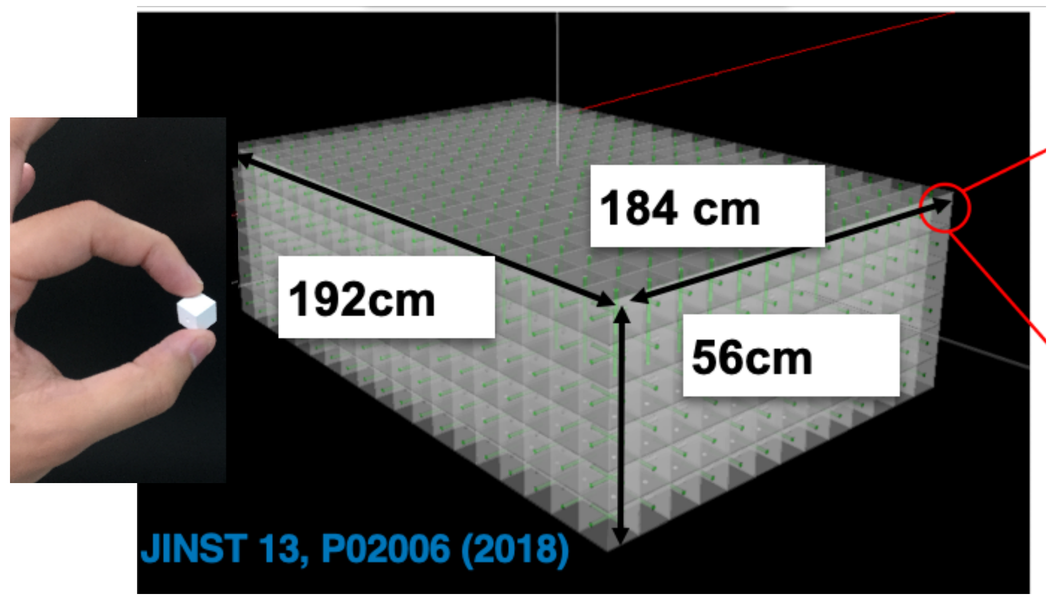
$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$

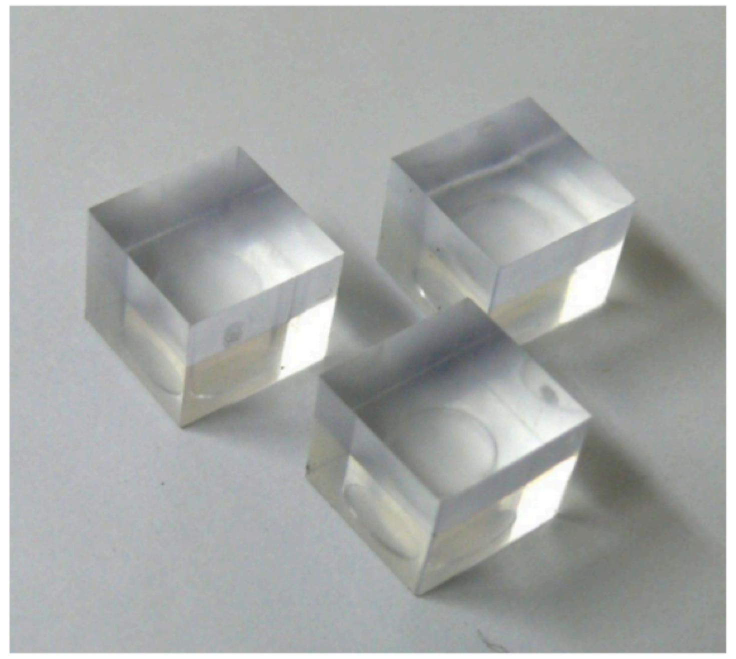


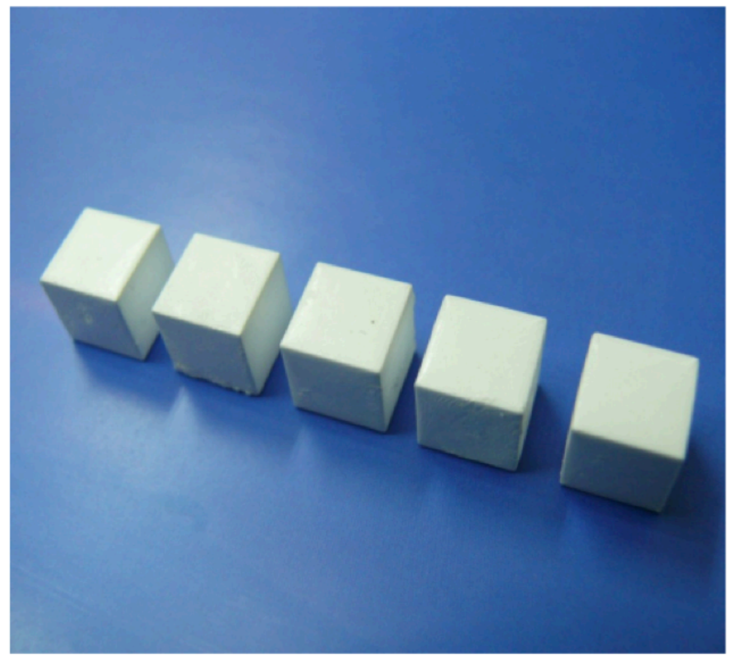

Phys.Rev.D 101 (2020) 9, 092003

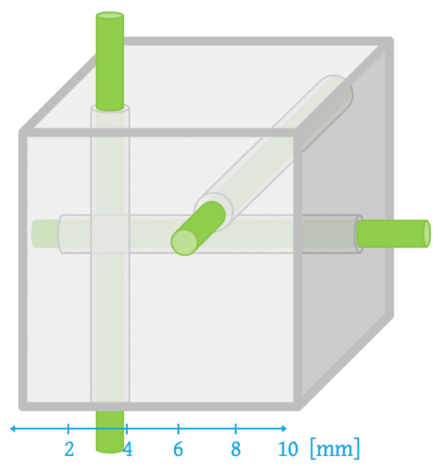
T. Doyle, D. Ferlewicz, and Q.V. Nguyen posters

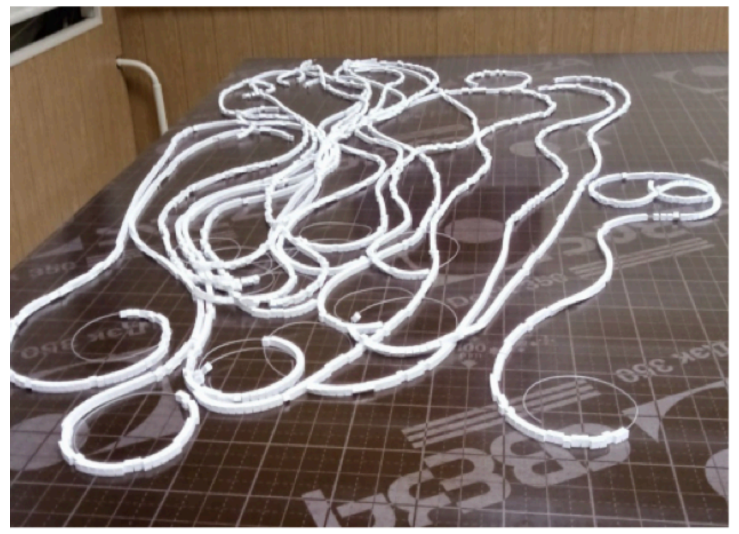
# Super-FGD

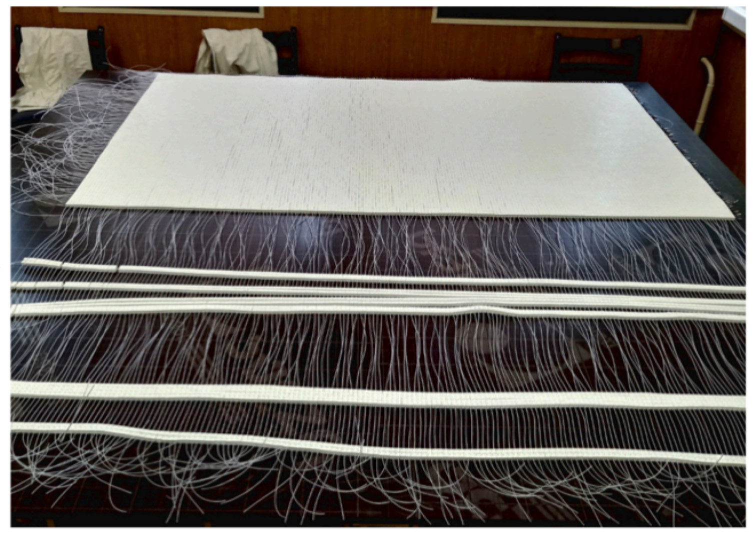


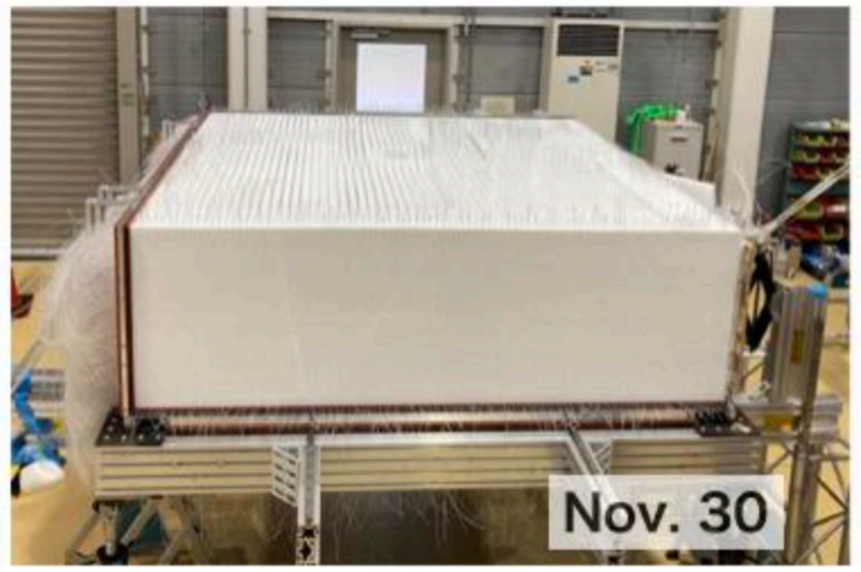





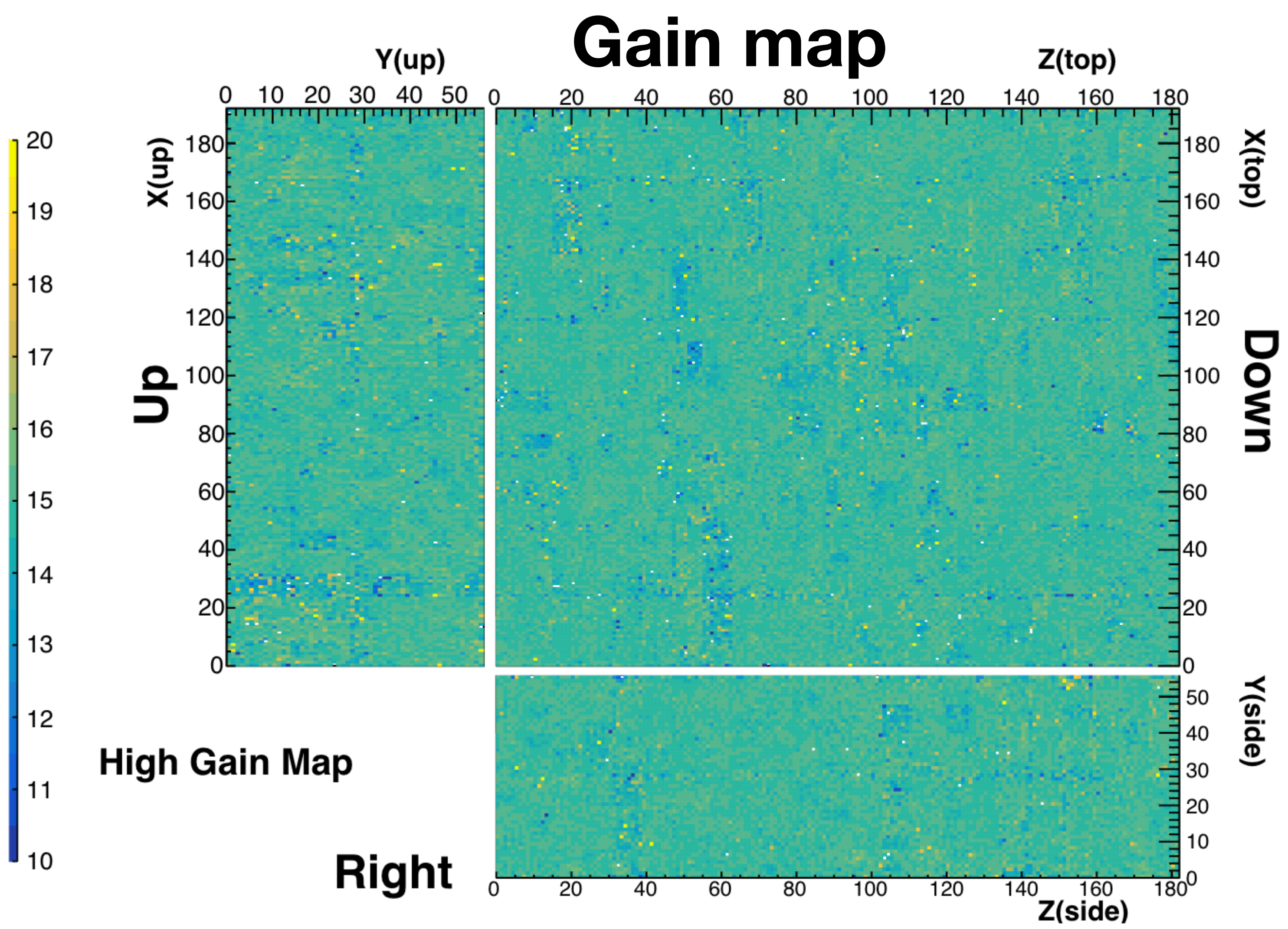


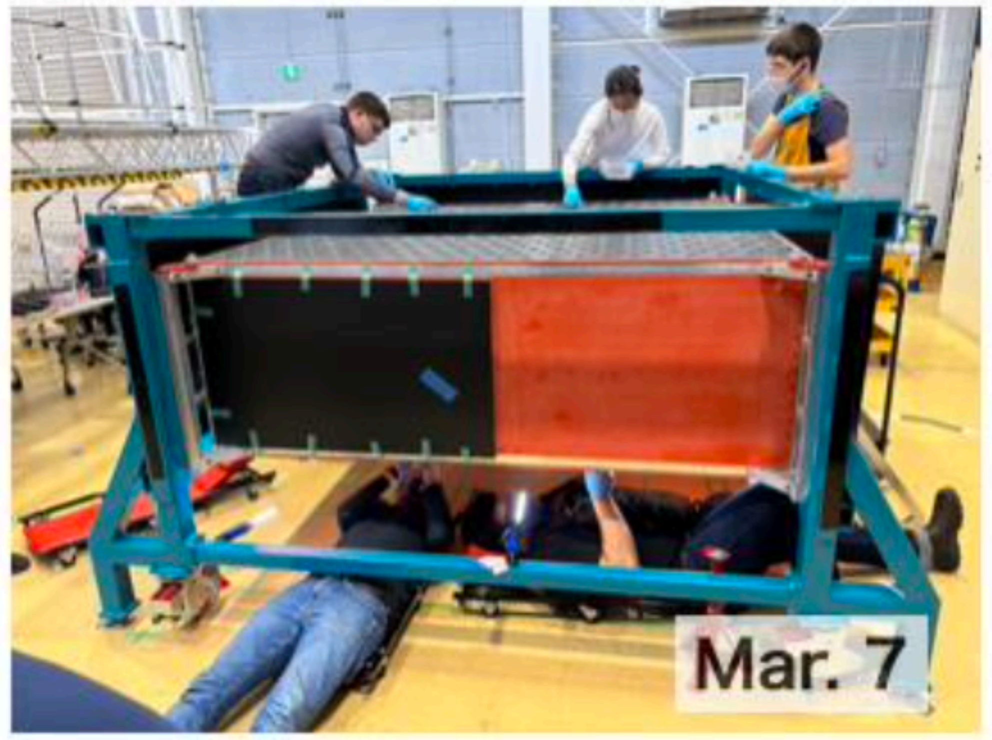



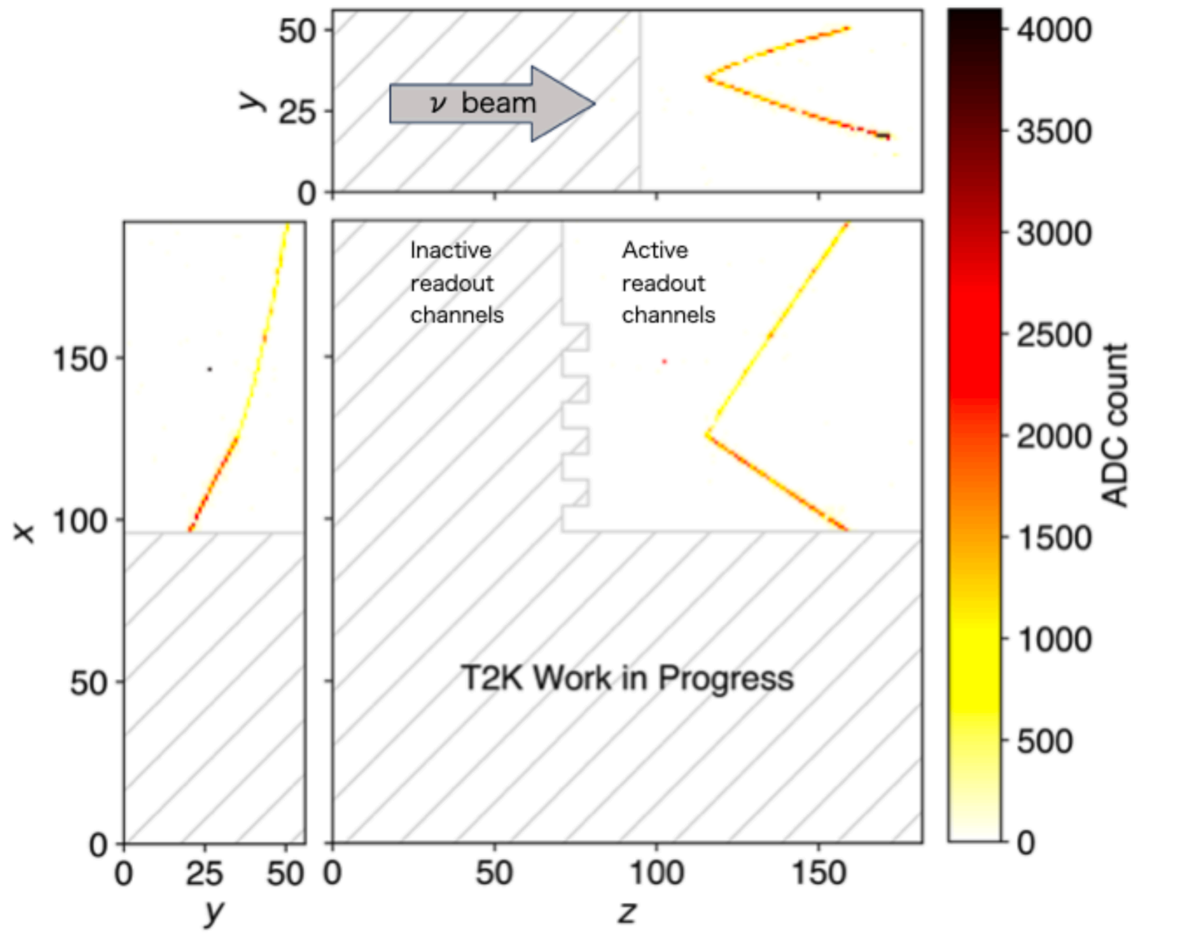





- 2 millions of optically insulated plastic scintillator cubes in a carbon fiber mechanical box
- 3 WLS fibres in each cube → 3D readout
- ~56k channels with SiPM → ns resolution for MIPs
- High granularity → lower threshold to reconstruct hadrons

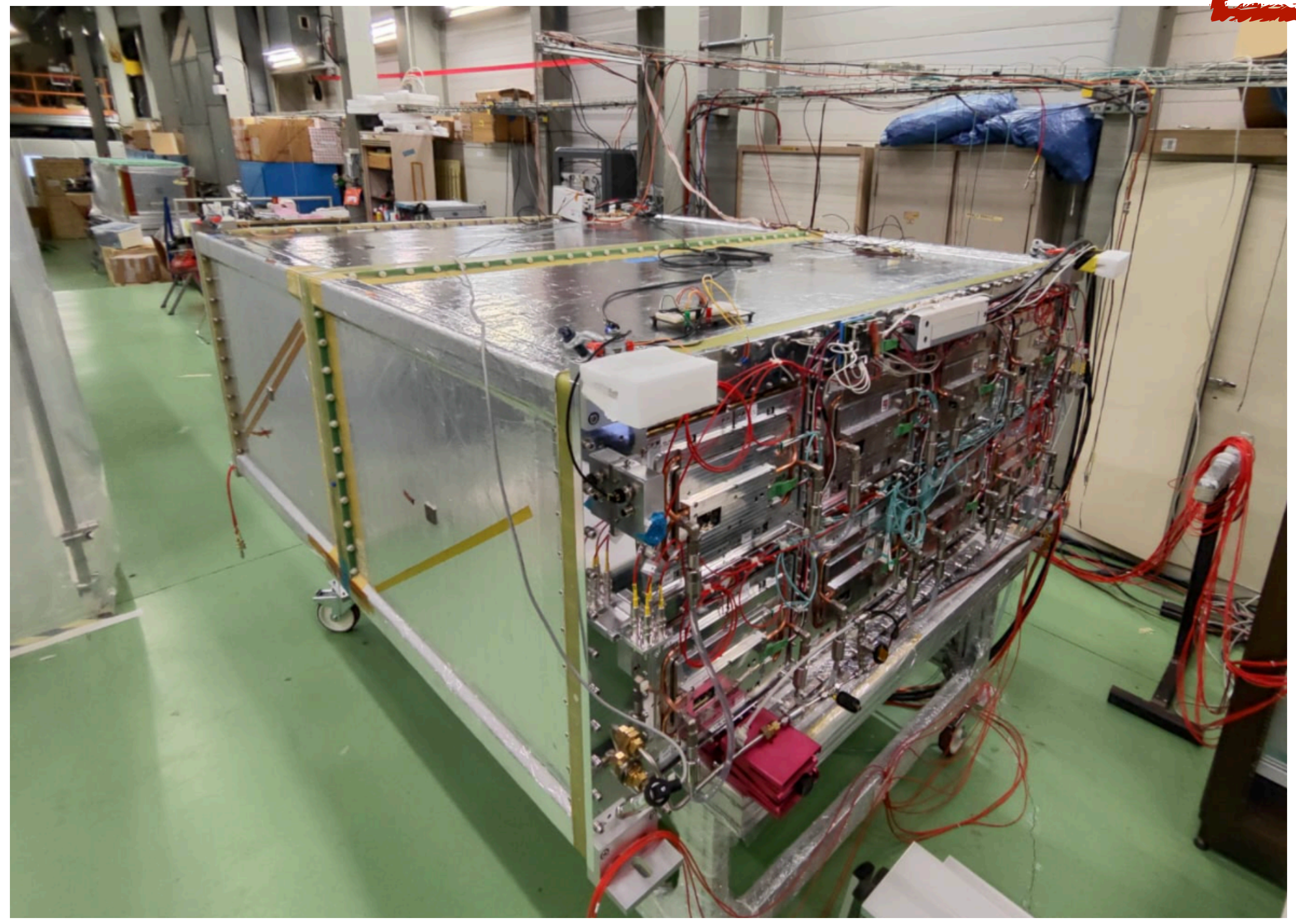


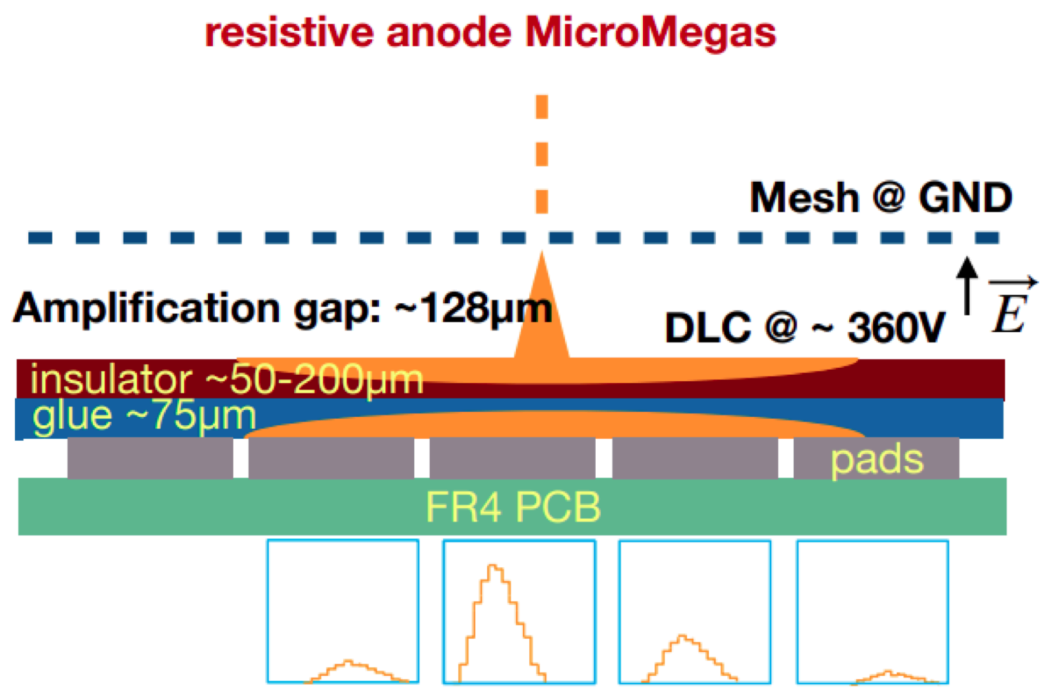



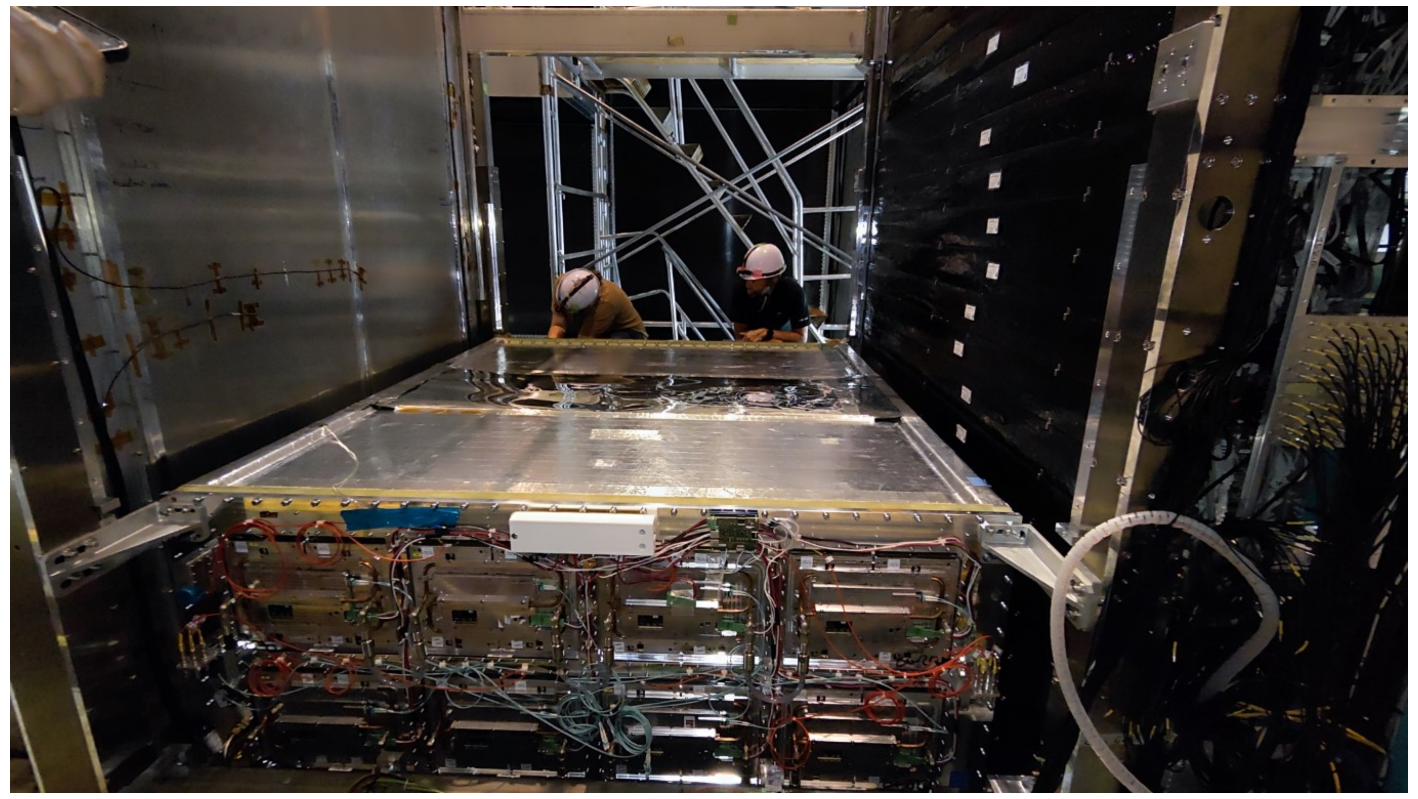
# High-Angle TPCs

M. Feltre and U. Virginet posters

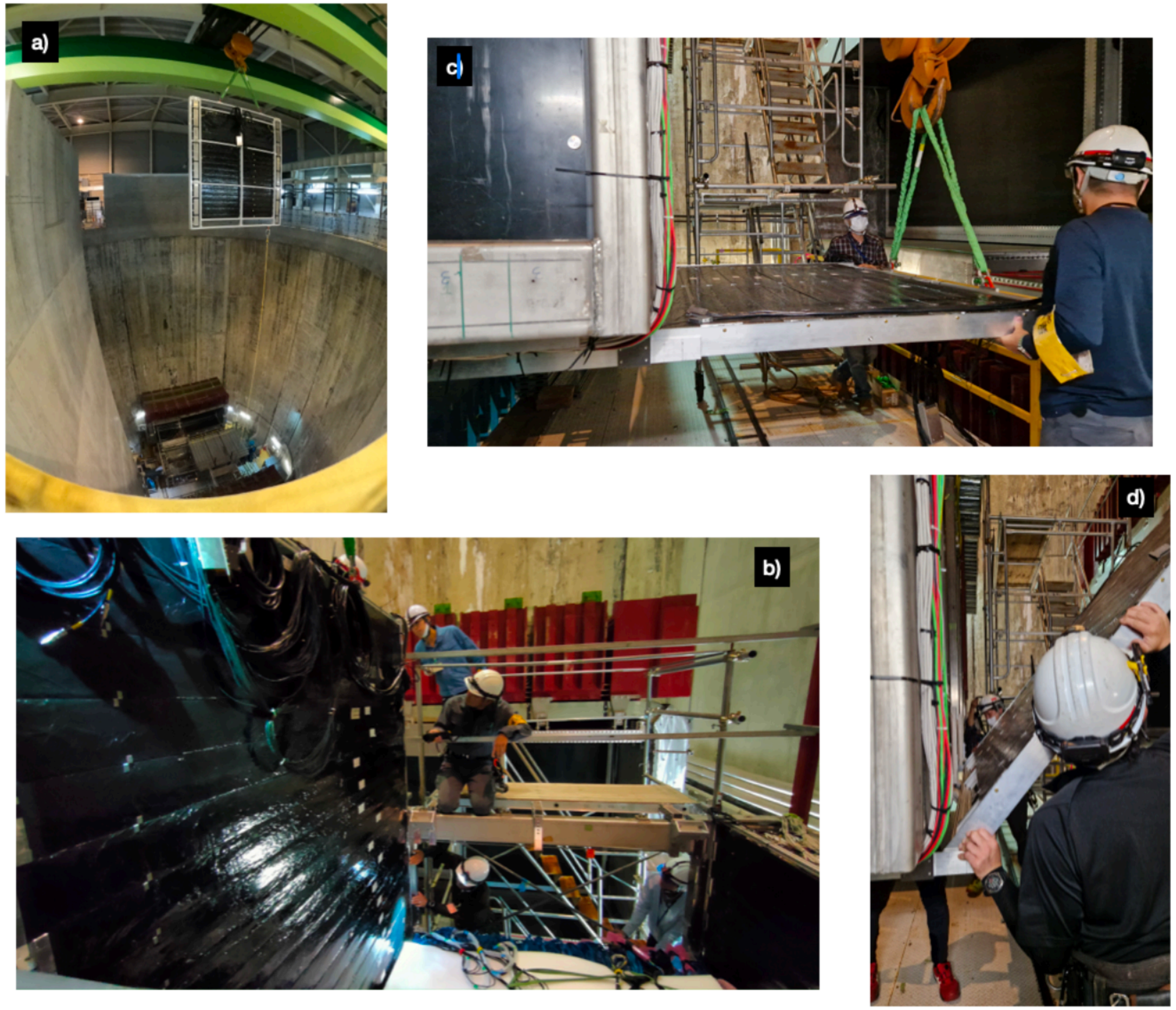




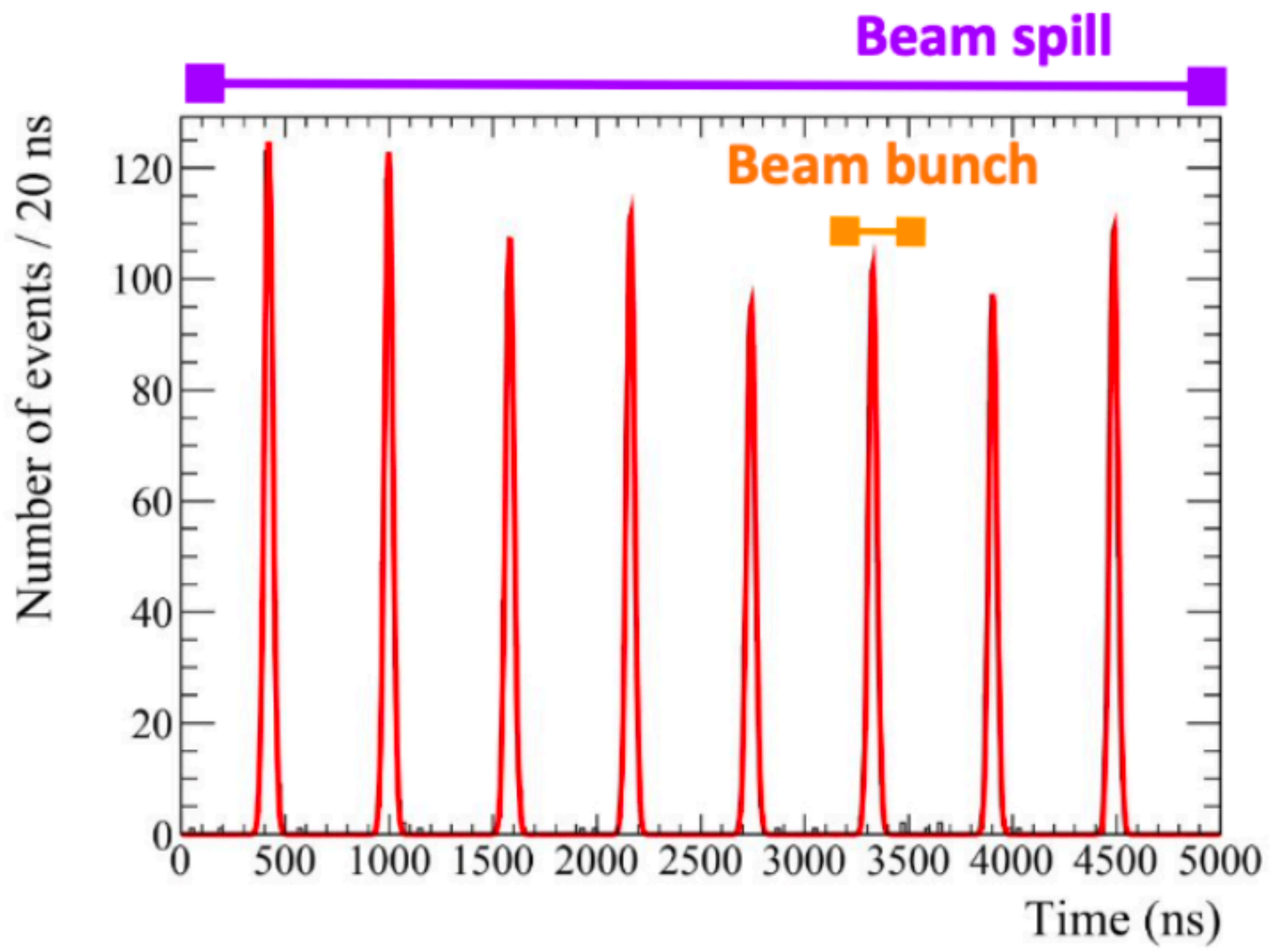

- Reconstruct leptons emitted at high angle with respect to the beam
- TPC instrumented with resistive MicroMegas modules
- Chambers have been assembled and tested at CERN before shipment



# Time-Of-Flight

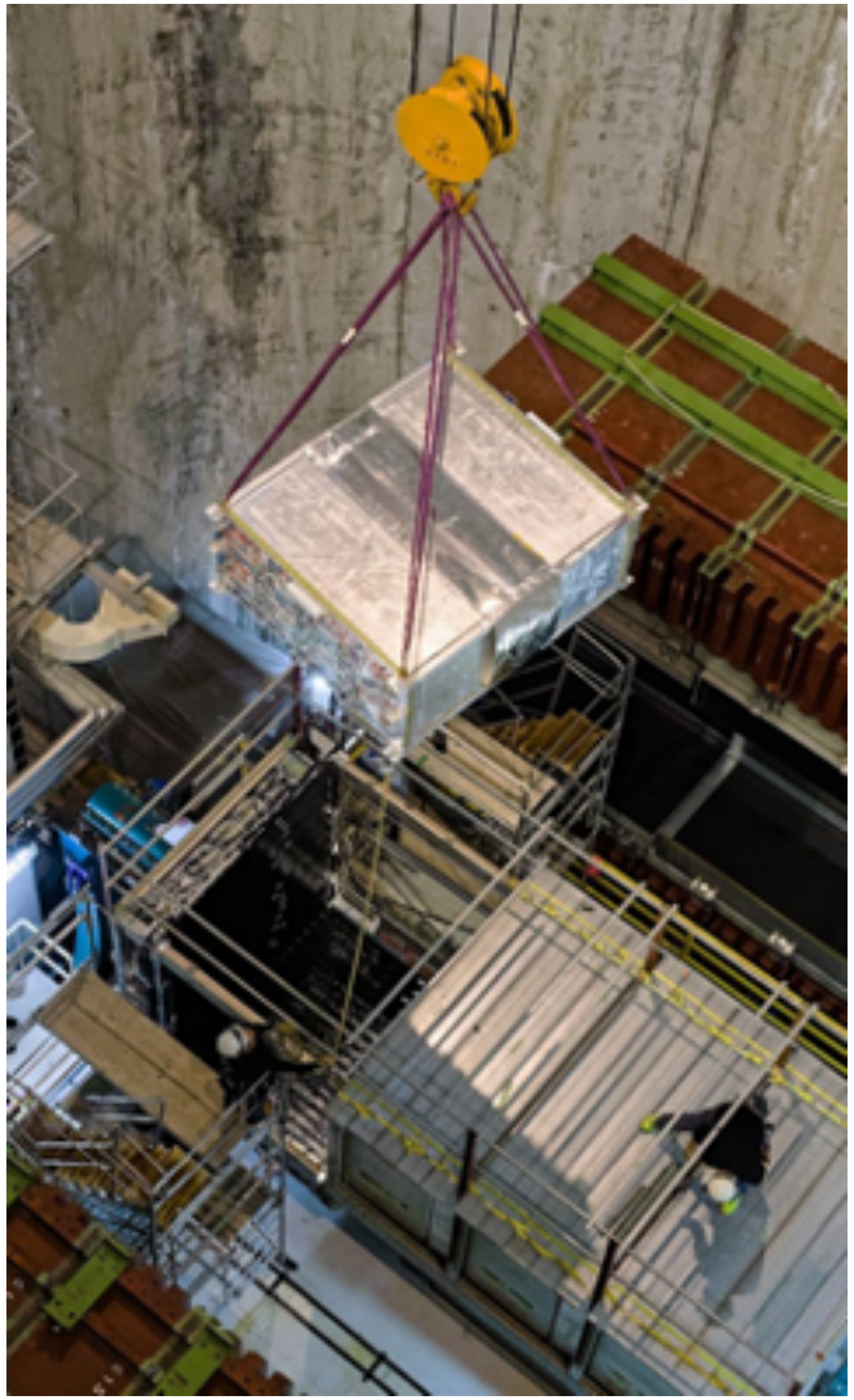


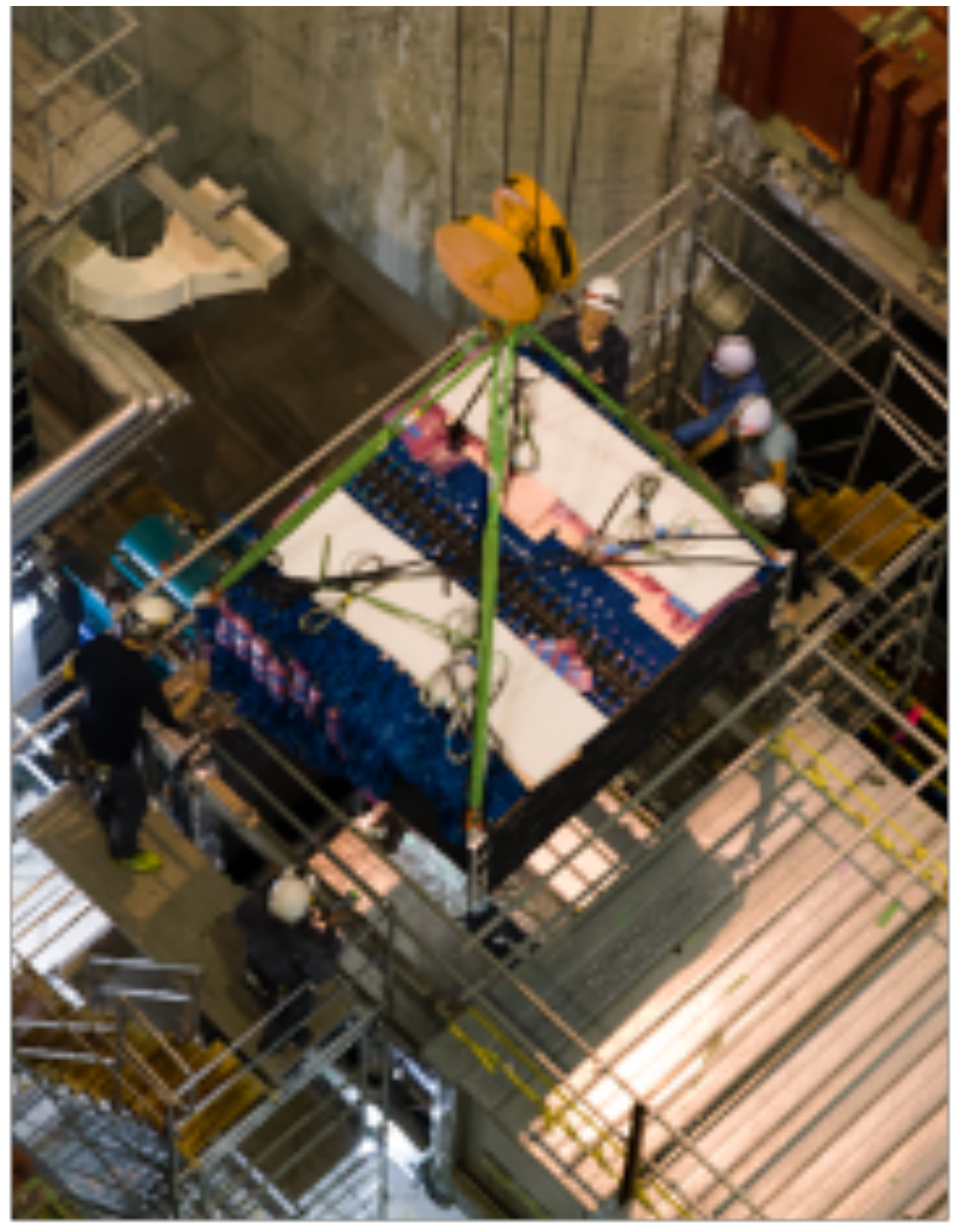

- Reconstruct track direction to reject tracks entering the new tracker region
- All 6 TOF modules assembled and tested at CERN and shipped to J-PARC
- Time resolution ~ 150 ps observed during tests at CERN
- 8 bunches neutrino beam structure clearly visible

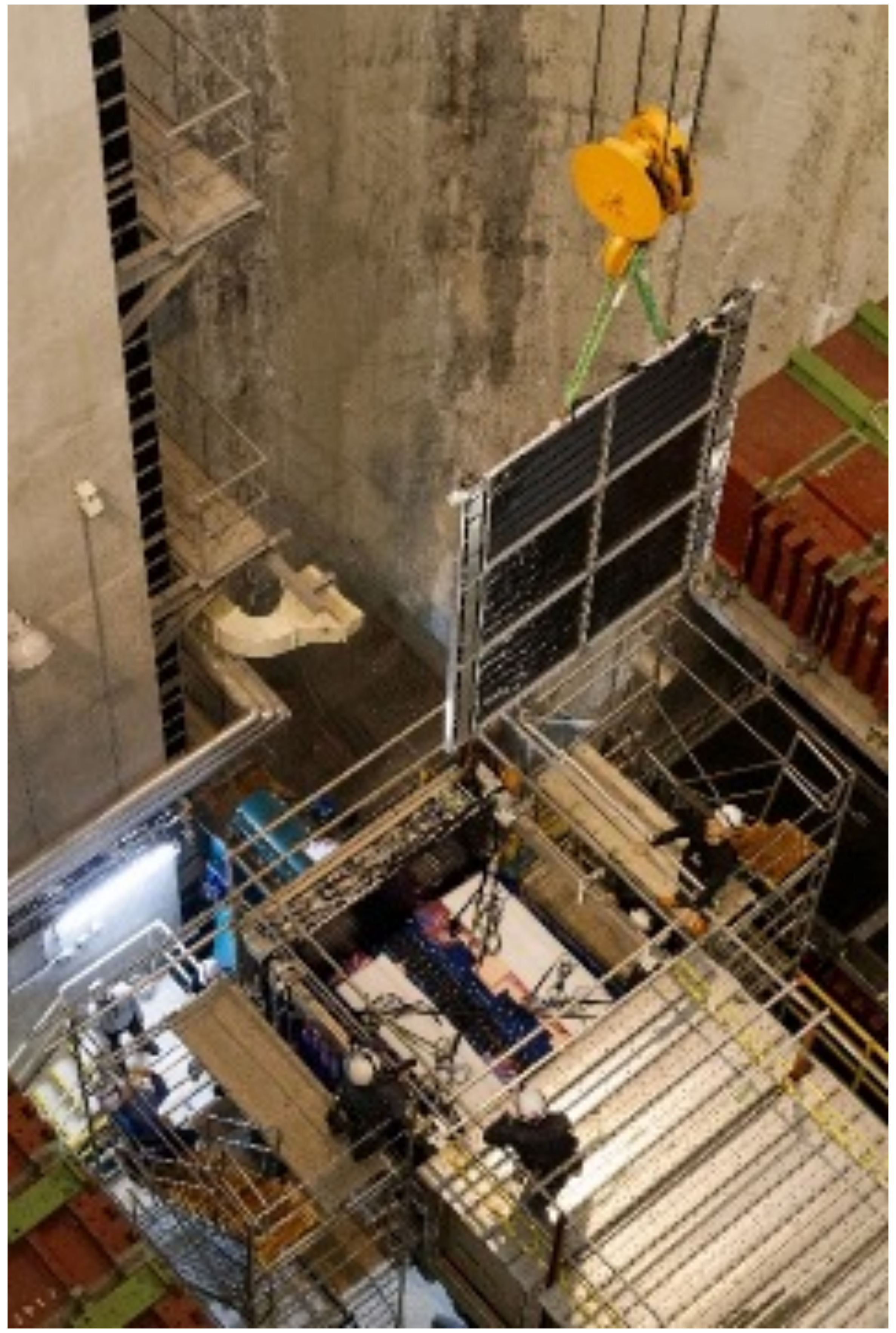


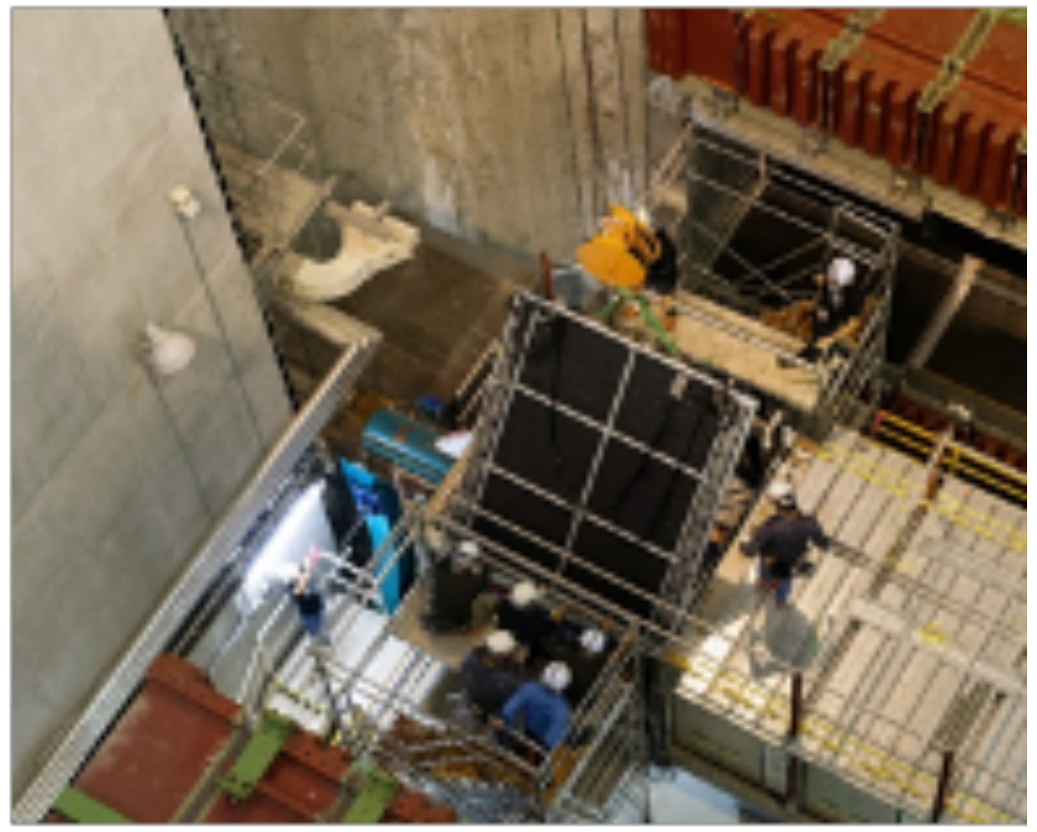
T2K

# Installation at J-PARC



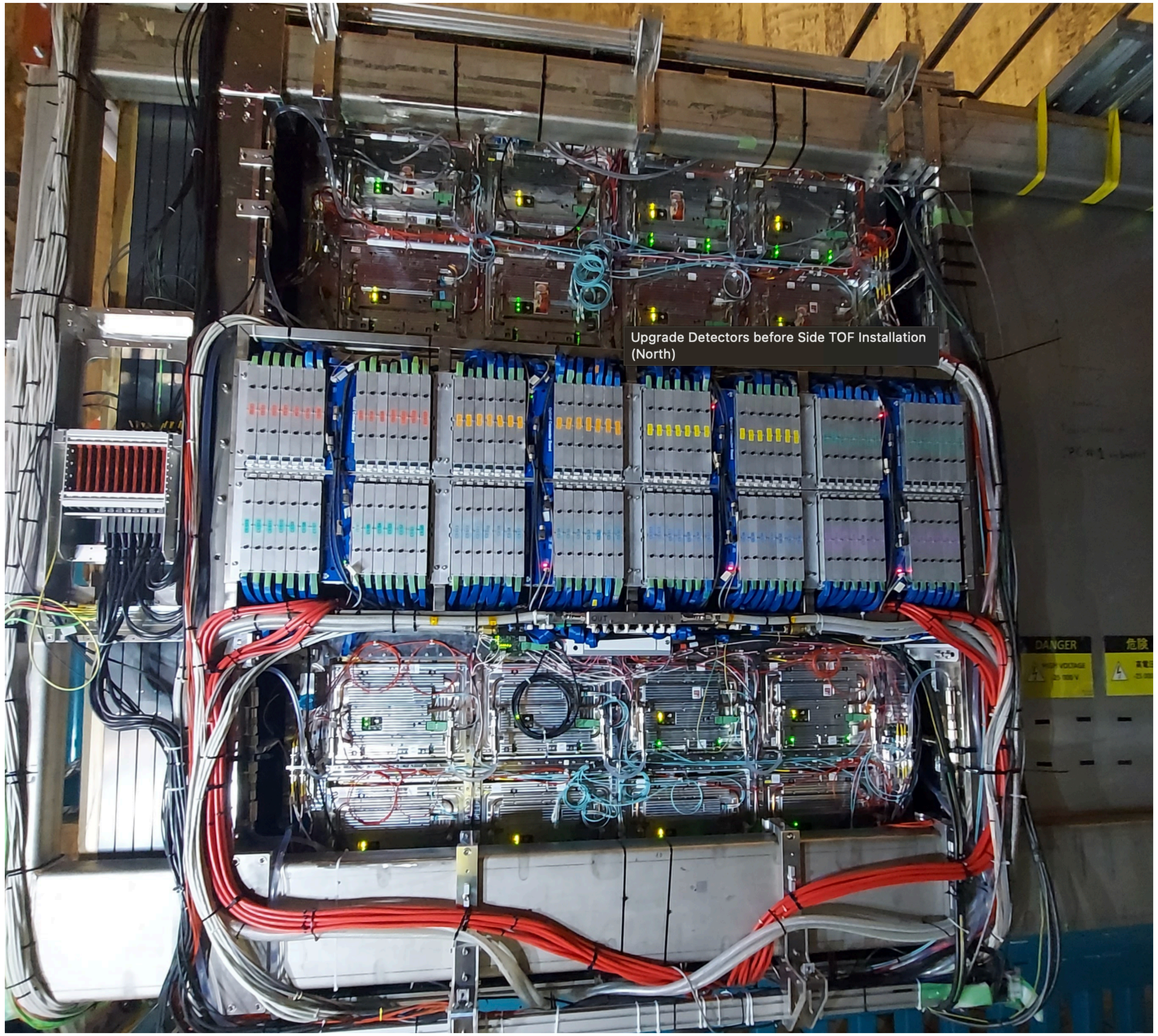


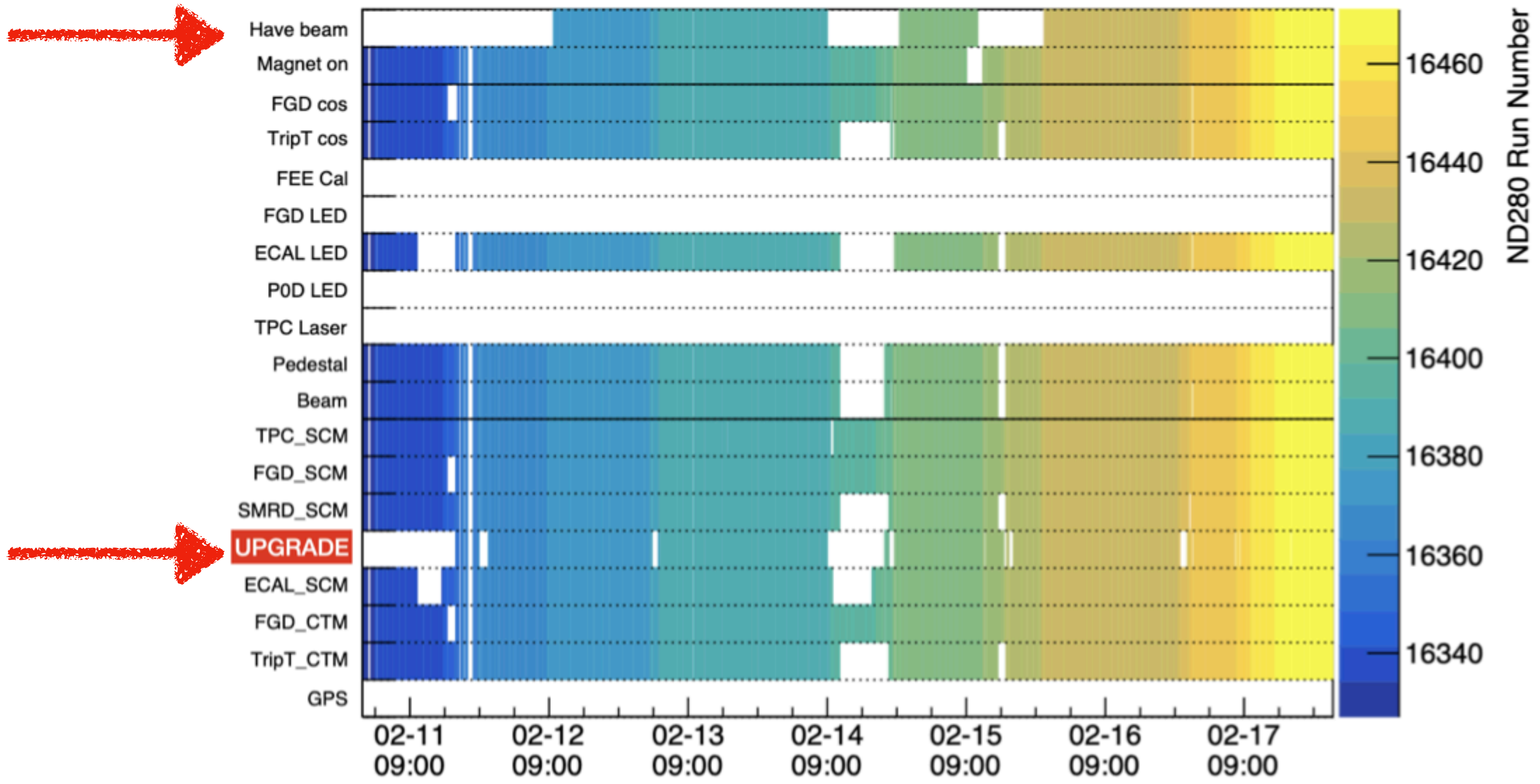




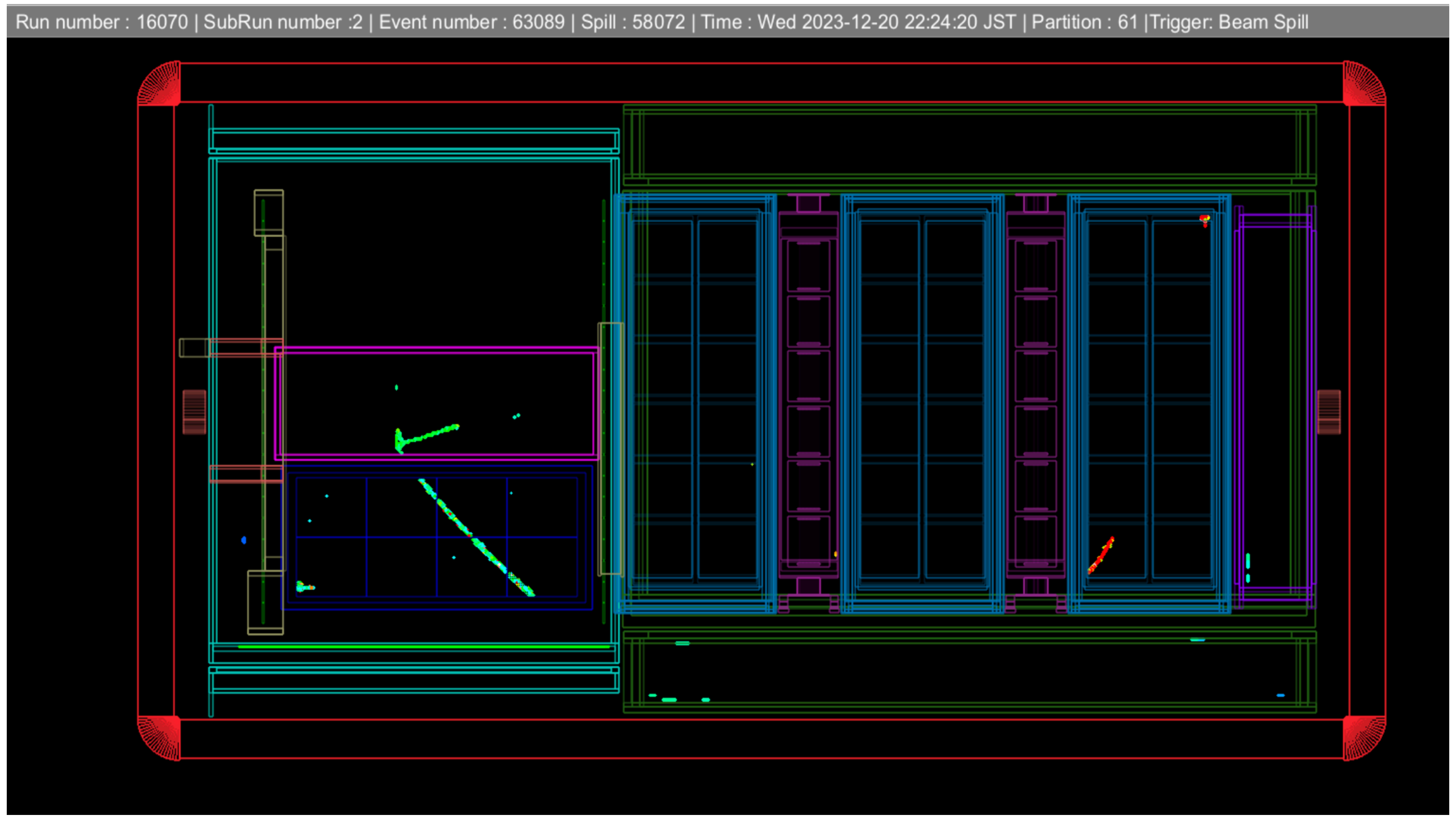
# Detectors installed and taking data

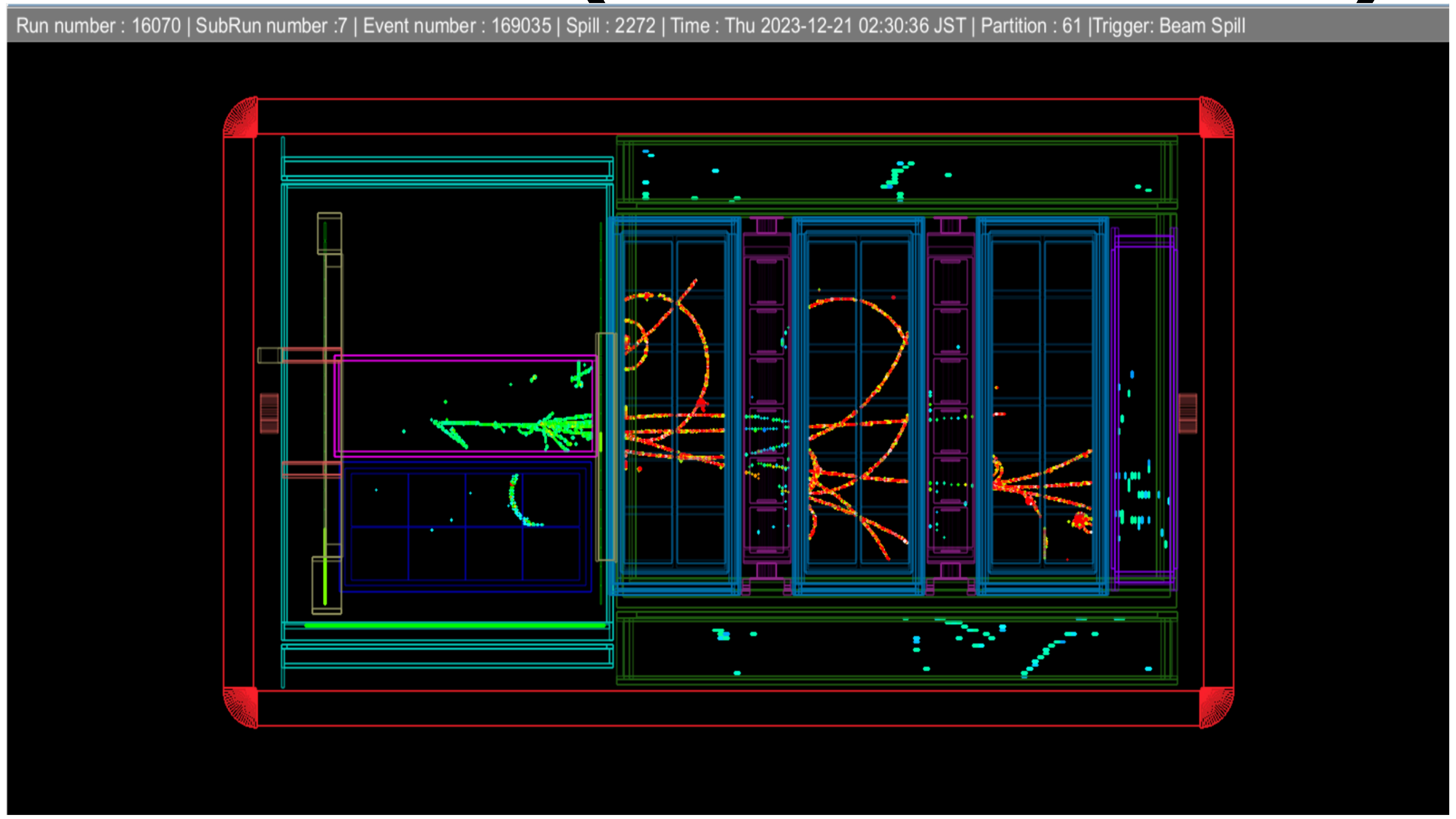
April 2024

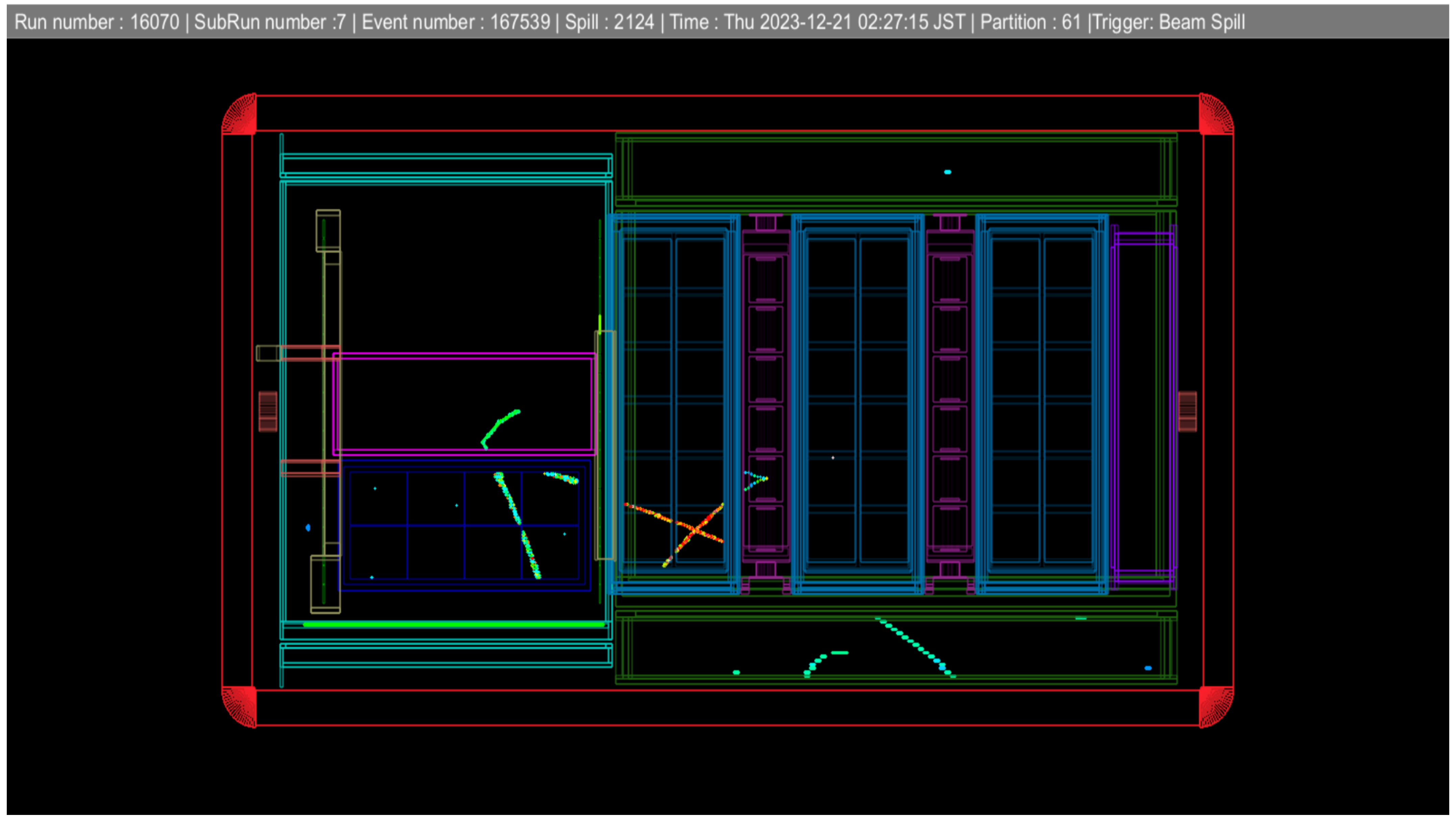


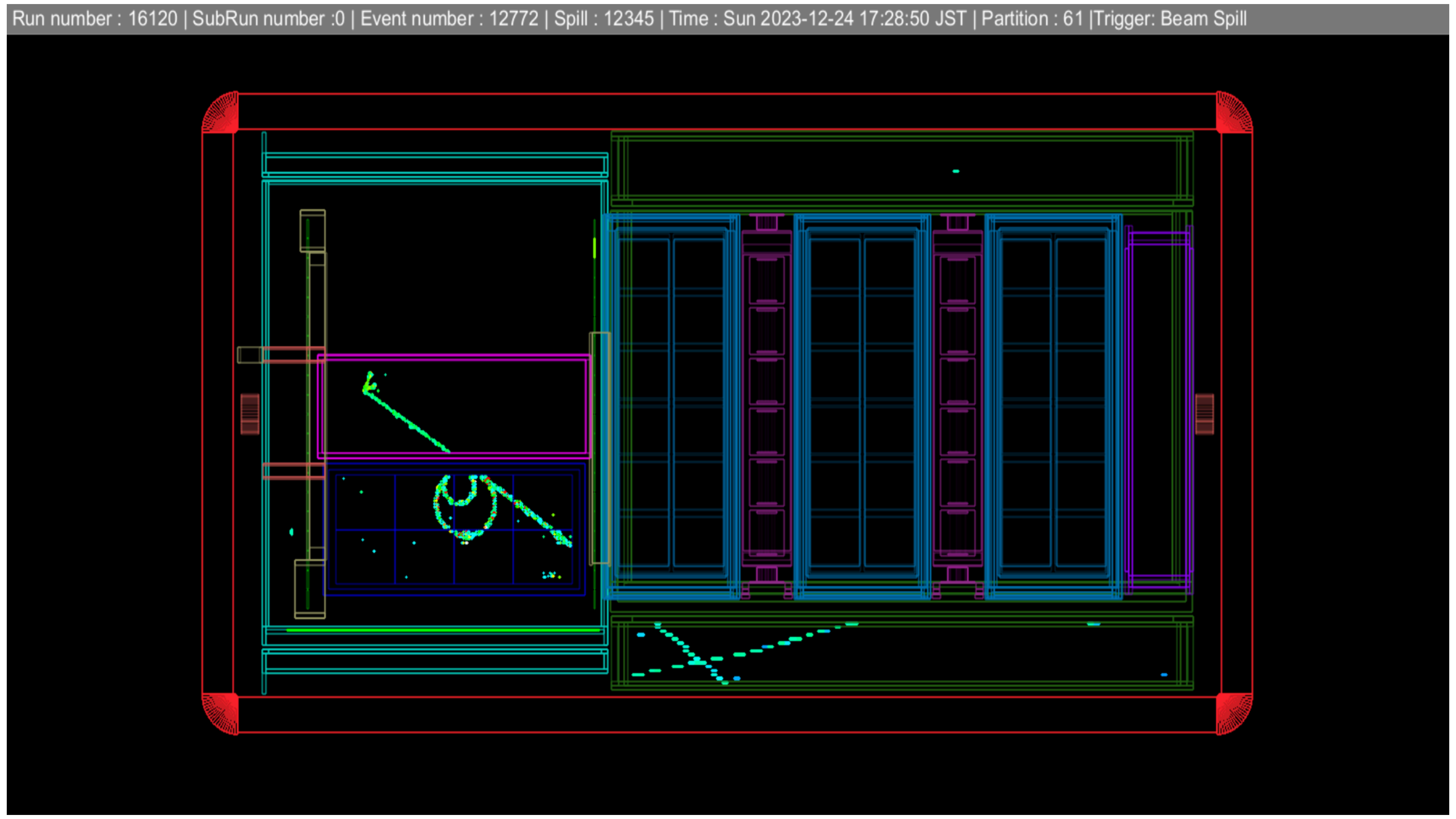



# First neutrino interactions (Dec 2023)

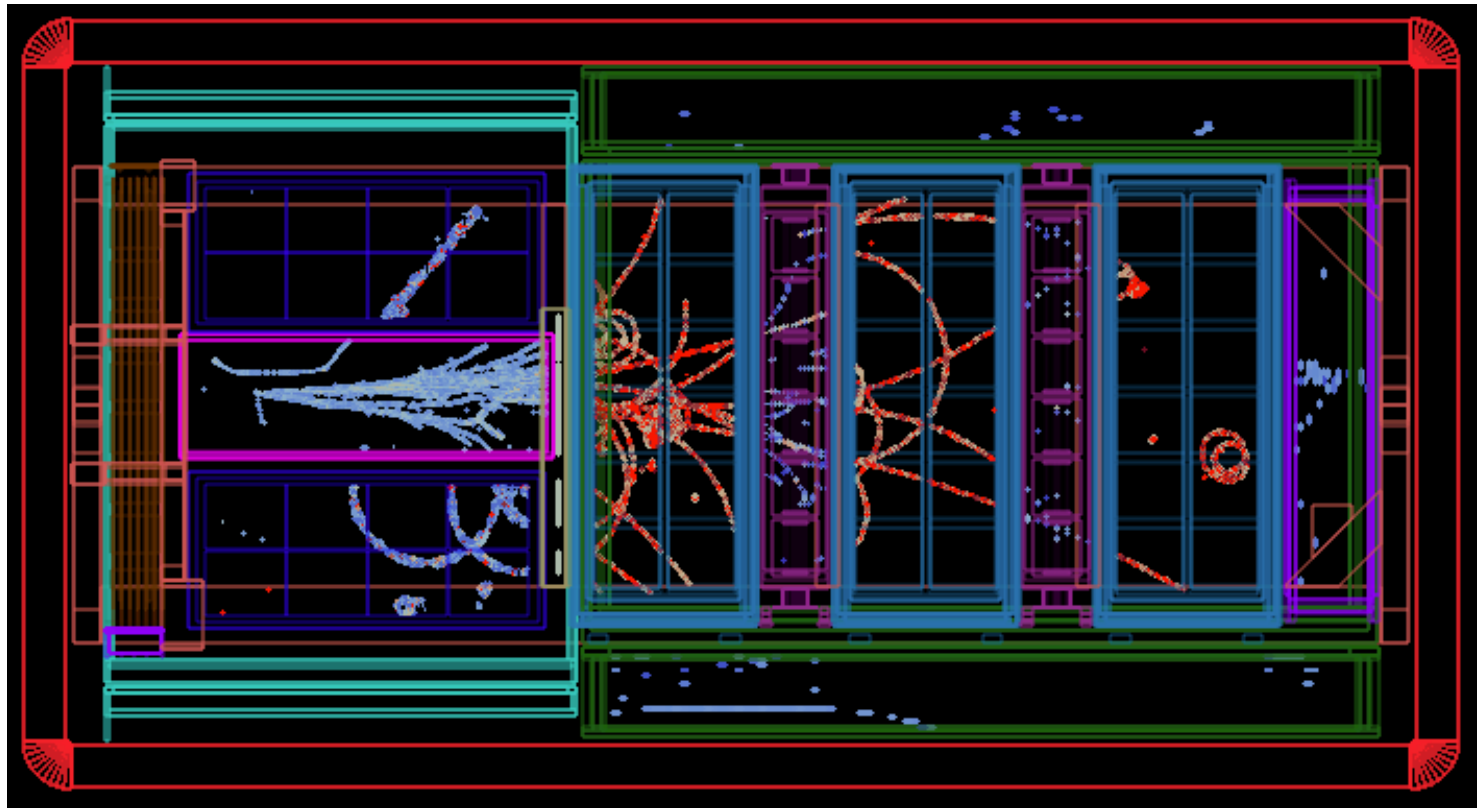


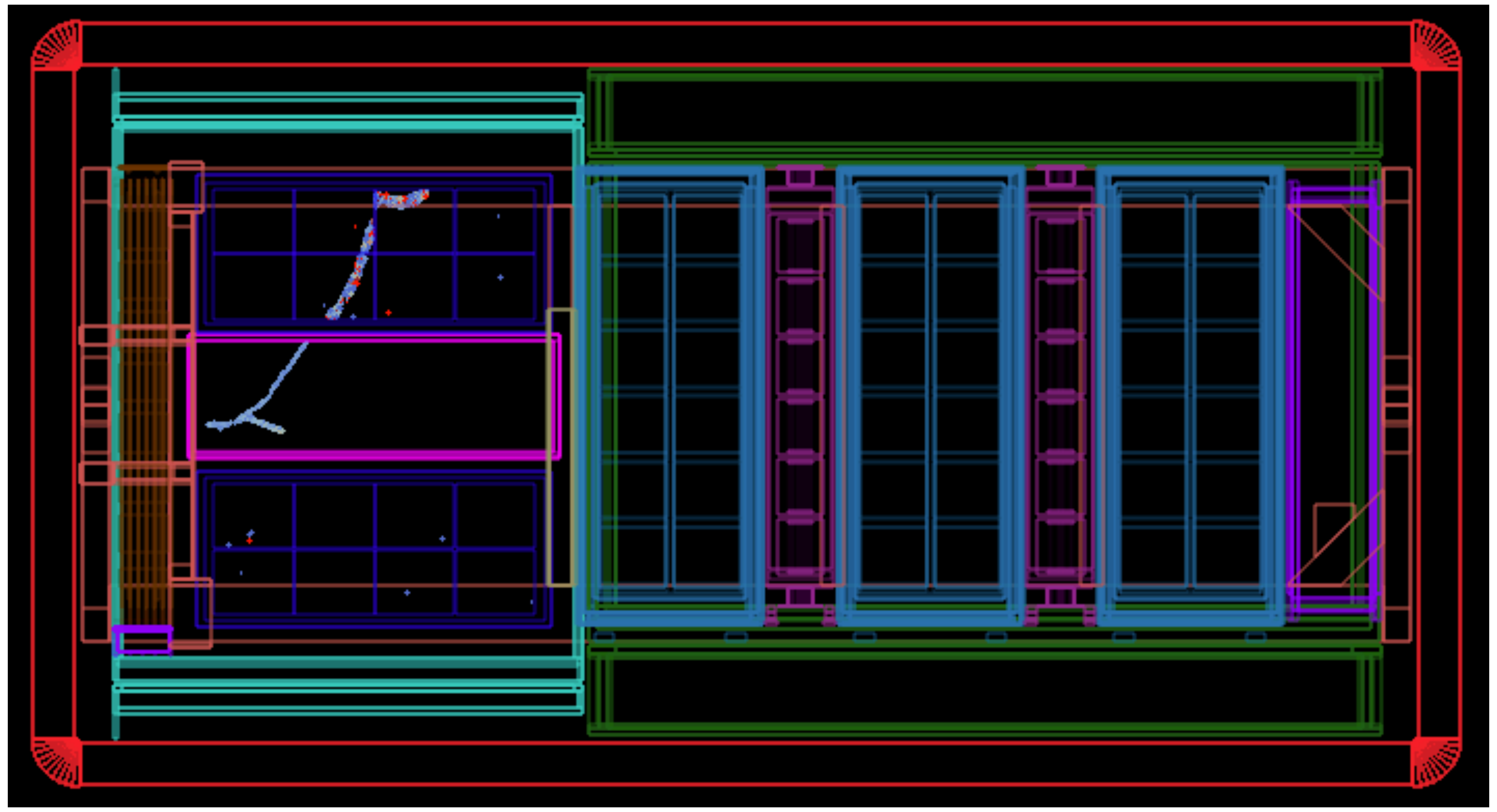



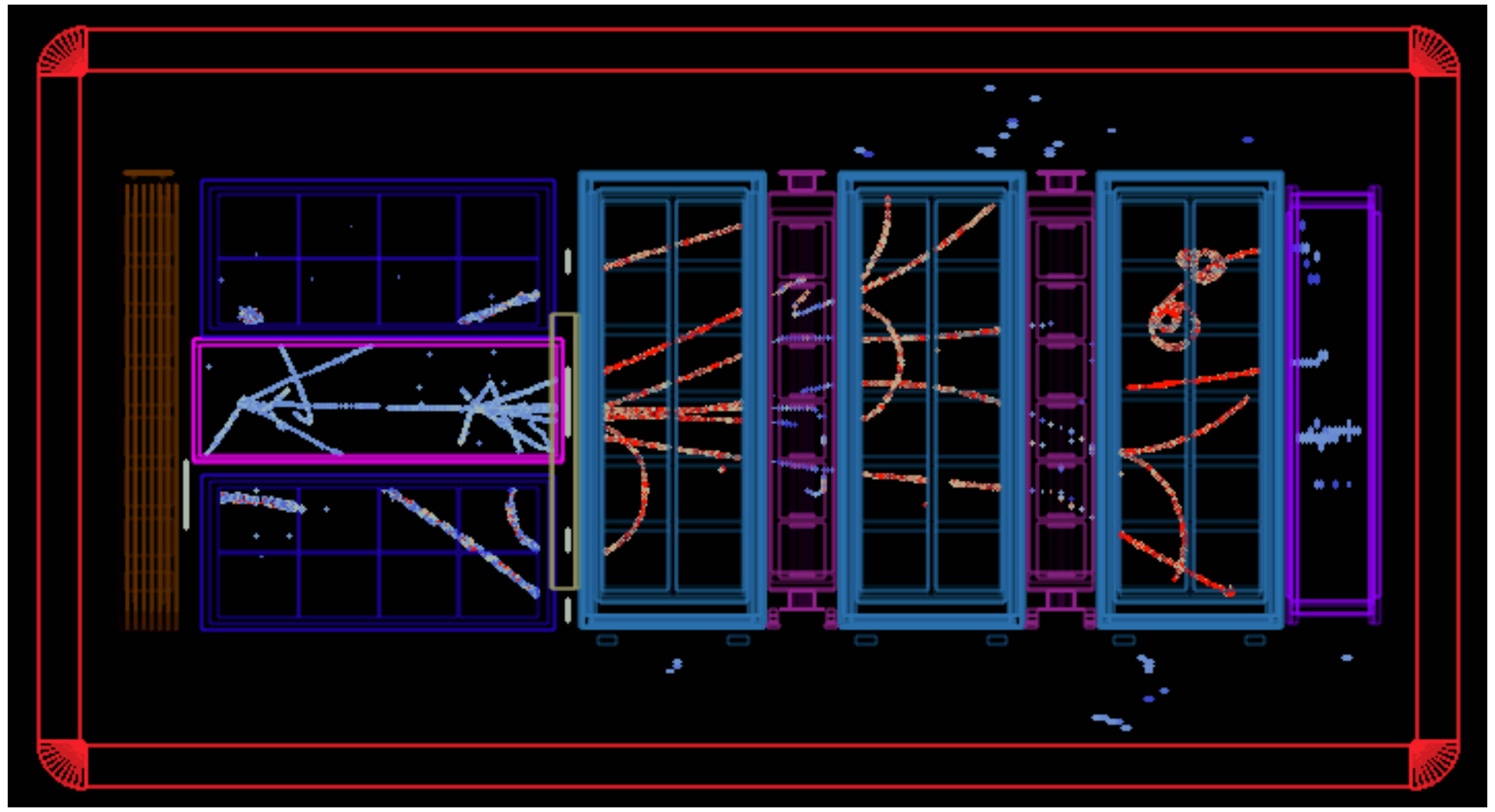



# June 2024: Full upgrade



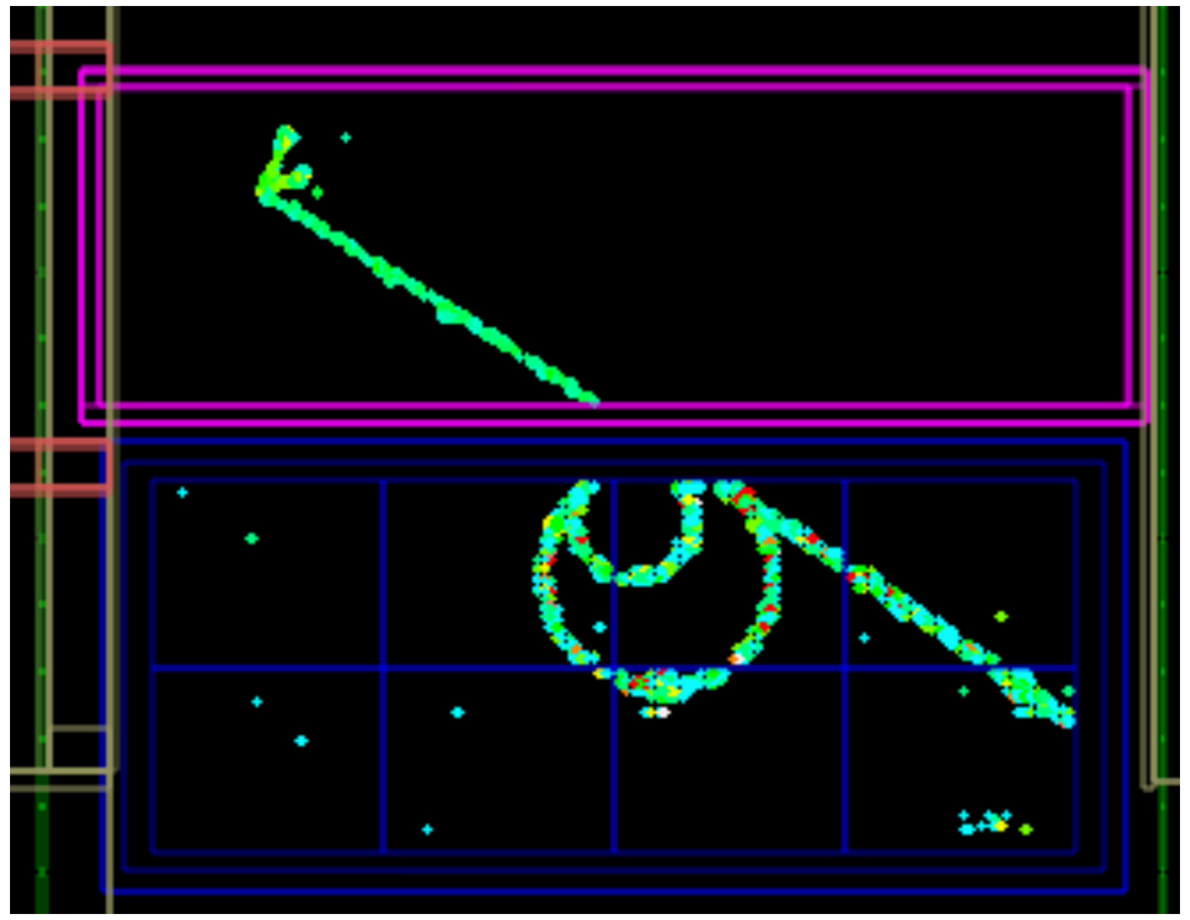




L. Kneale, K. Lachner, and W. Li posters

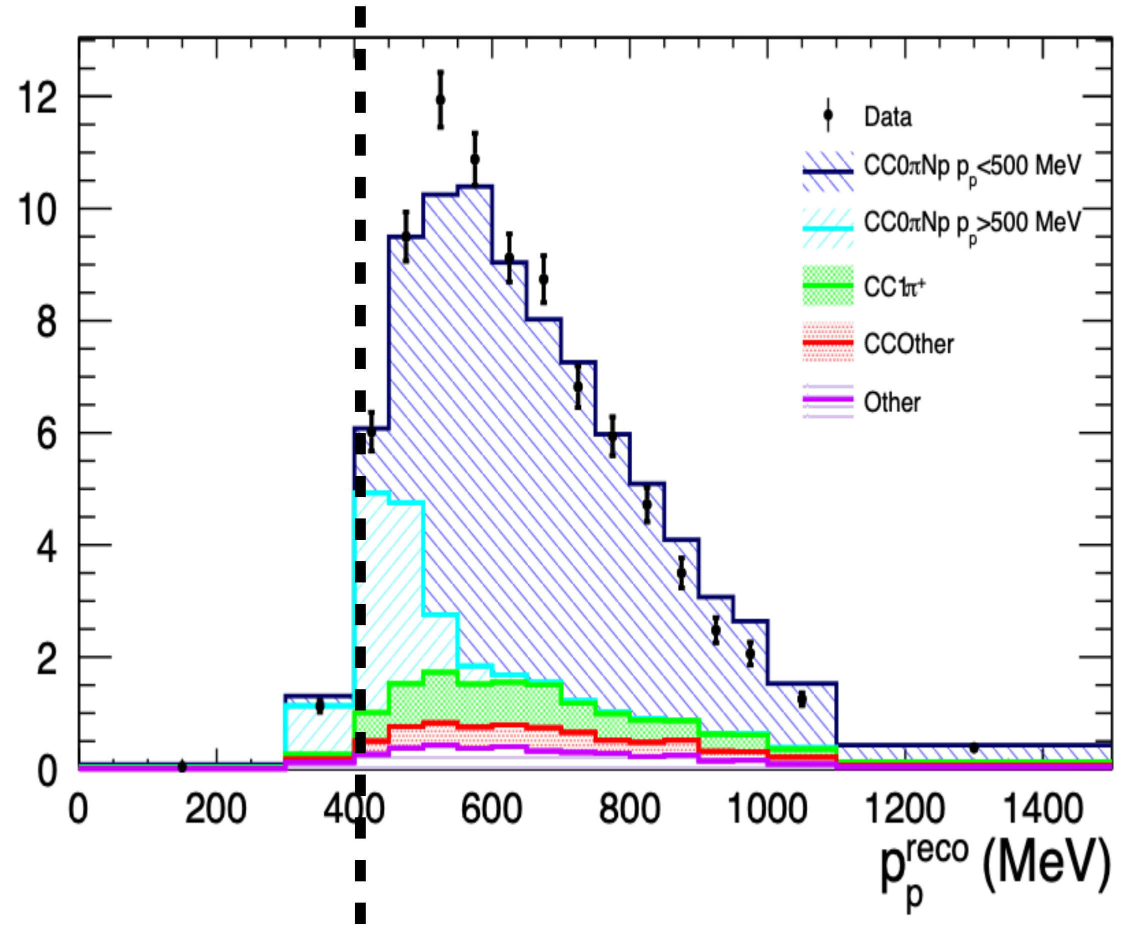
# Expected results

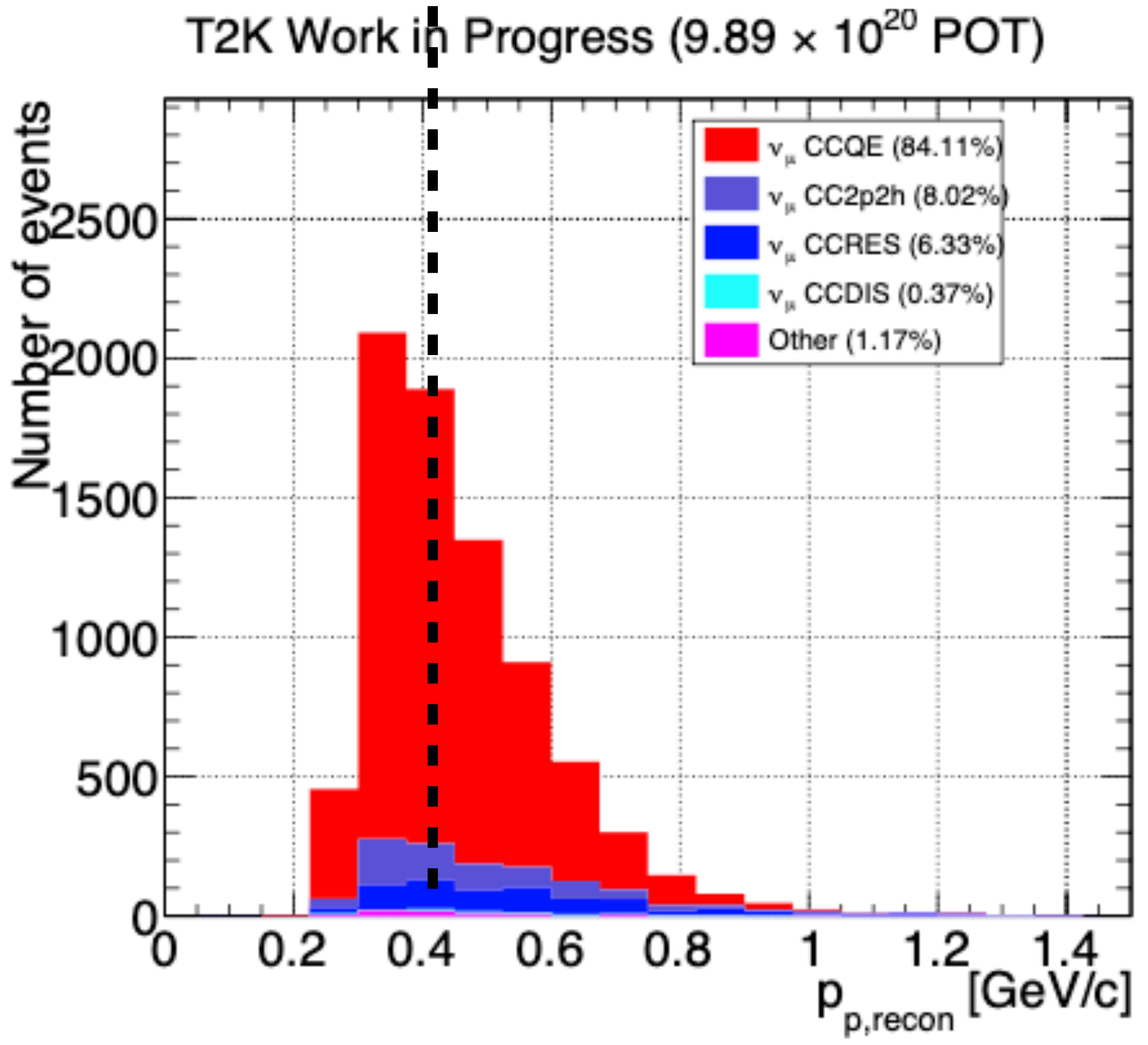
- First physics run with full upgrade currently on-going
- Expect to select 20k $\nu_\mu$ CC0π interactions in the super-FGD for 1 month of beam
- ~ half of them with a reconstructed proton



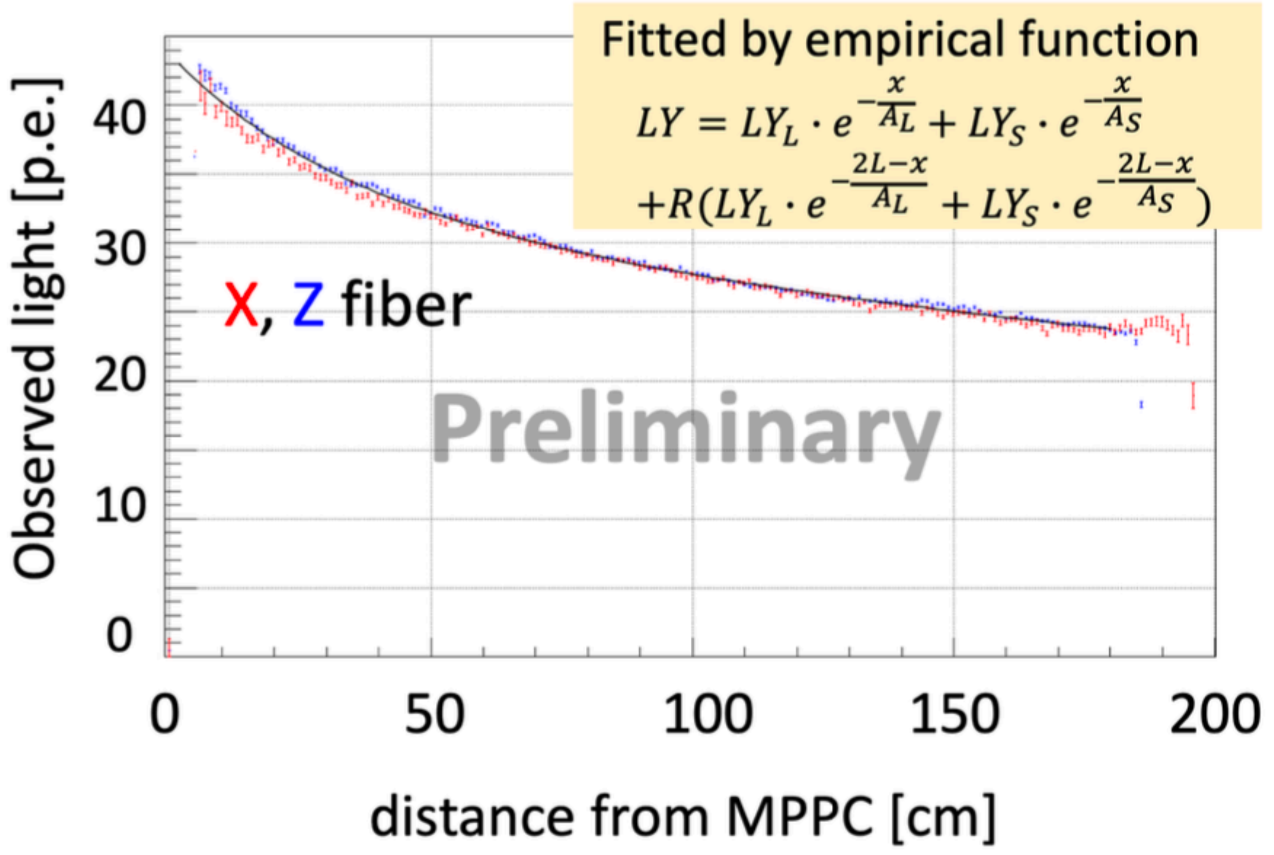
FGD

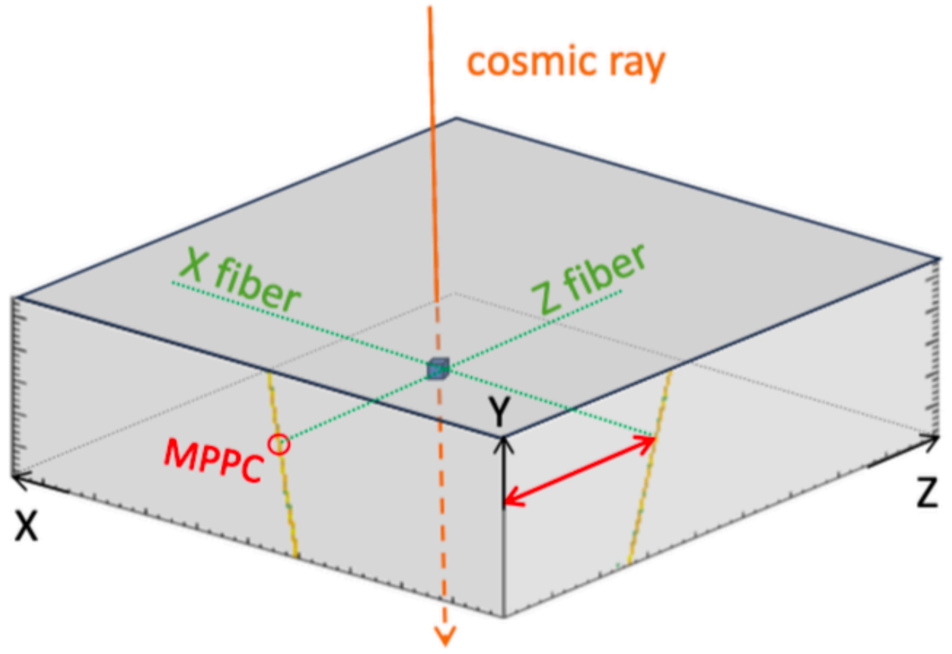
sFGD



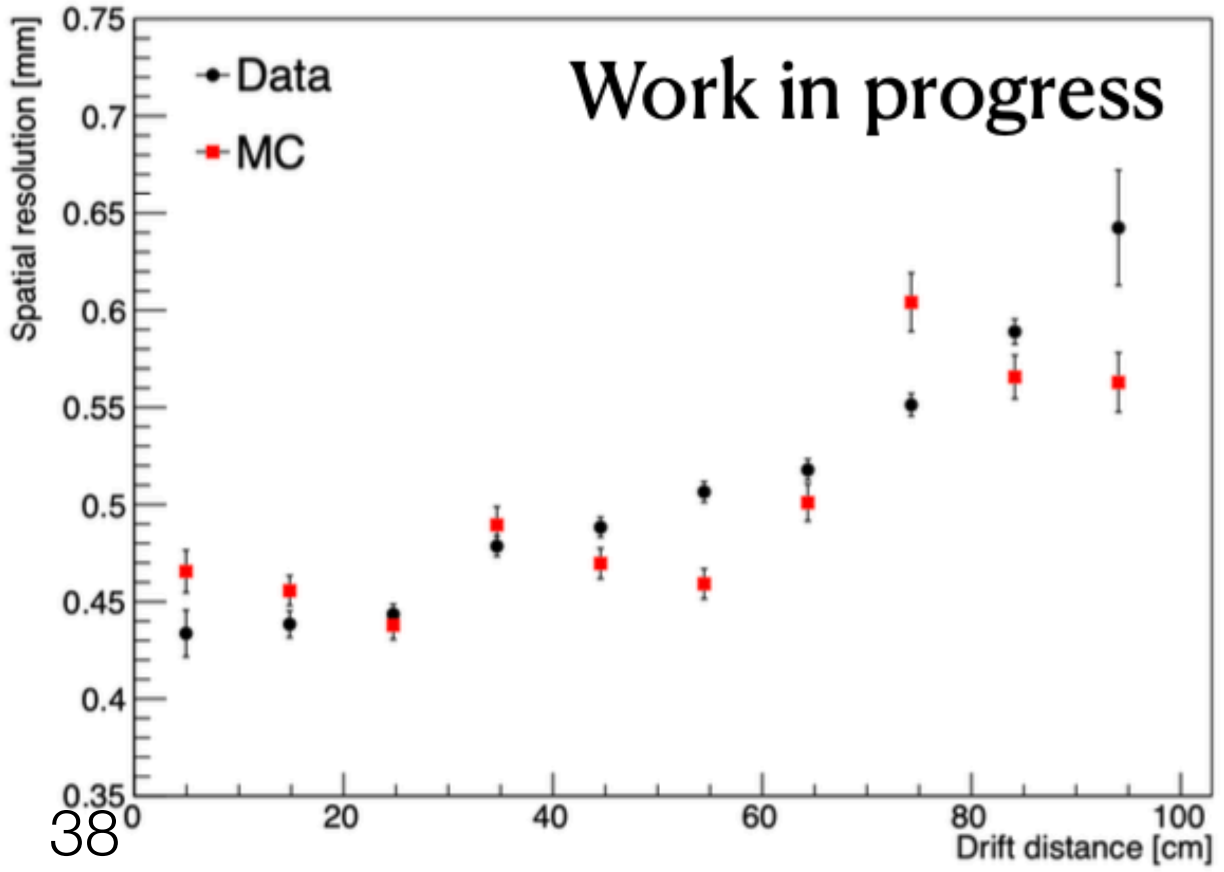




**sFGD L.Y. vs distance from MPPC**




**HA-TPC spatial resolution**



# Conclusions

- T2K is a long baseline experiment aiming at precise measurement of $\theta_{23}$, $\Delta m^2_{32}$ and looking for neutrino mass ordering and CP violation
- Upgrades on the beamline, near detector and far detector have been completed
  - Neutrino beam running stably at 800 kW
  - ND280 upgrade installation completed and seeing neutrino interactions!
- New oscillation results have also been released with 10% additional statistics at far detector
  - CP symmetry excluded at 90% CL
  - Mild preference for normal ordering and upper octant for $\theta_{23}$
- Joint analyses with SK and NOvA (see next talk) have also been released
  - CP symmetry excluded at $2\sigma$ from T2K+SK
- Stay tuned for future results with high power beam and near detector upgrade!