Physics and Performance of the Upgraded T2K's ND280

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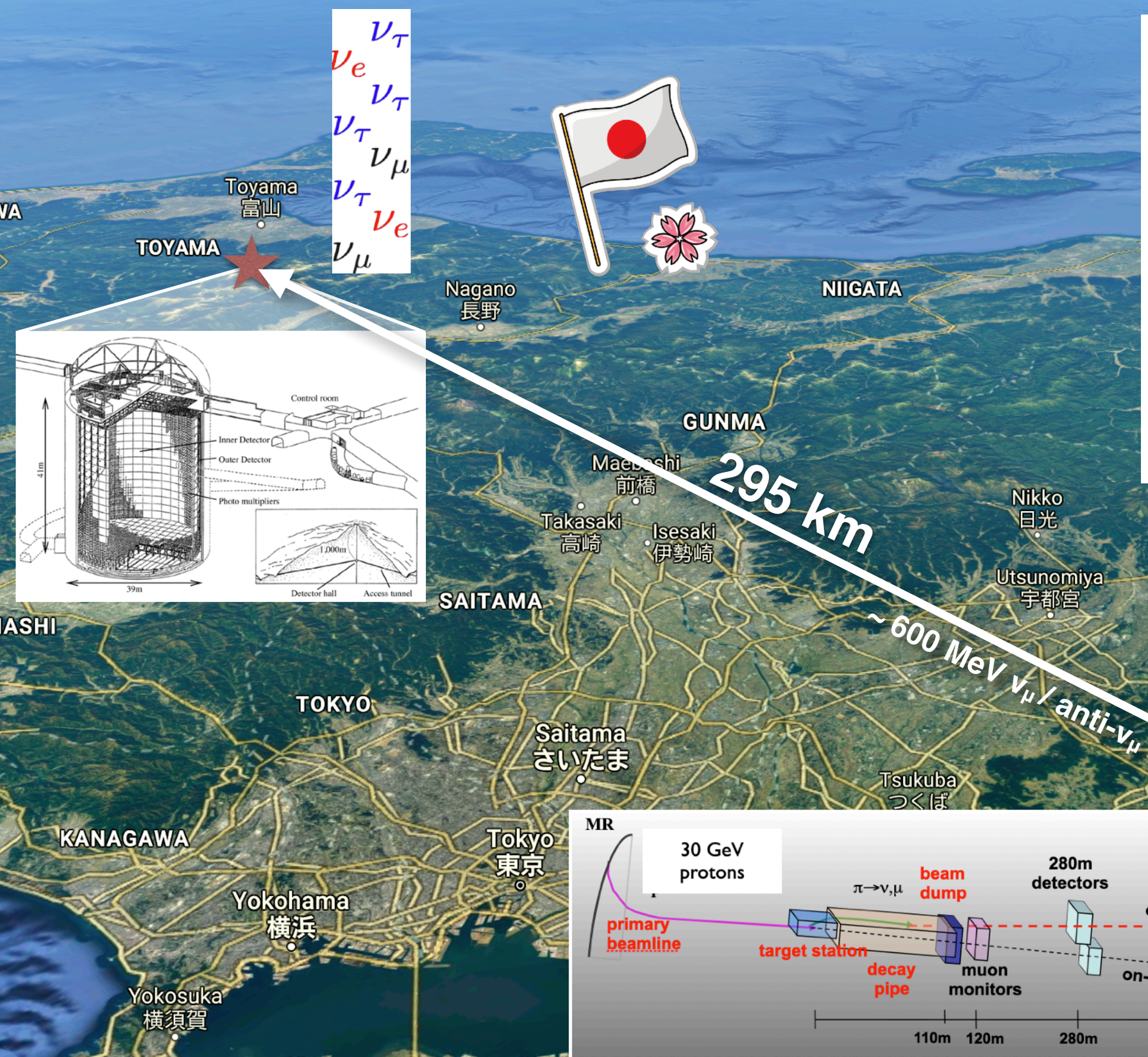
LPNHE - (Paris)

The 8th of October - 2020

Ikenoyama (Autumn)

The T2K Experiment



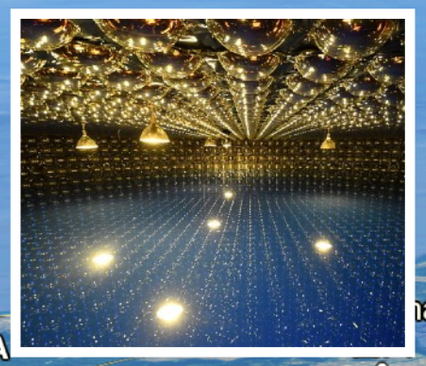
Physics Motivations

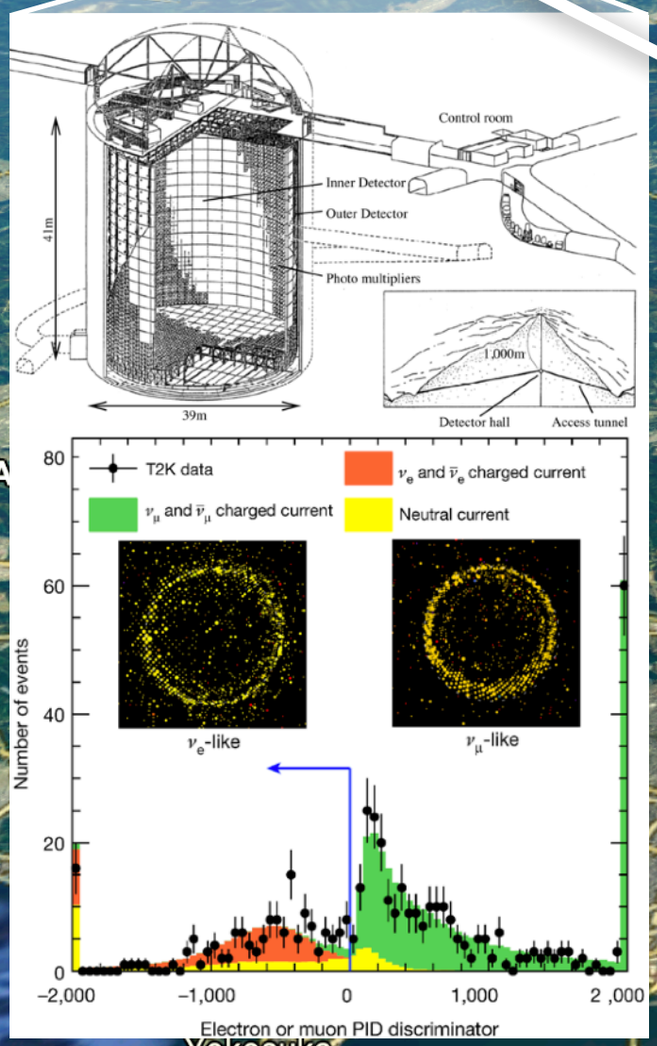
- Neutrino Oscillation Experiment
- **Precise measurement** of Δm^2_{23}, θ_{23}
- **Searching for the CP violation in the lepton sector (δ_{CP})**
- Neutrino mass hierarchy

Scientific Instruments

- J-PARC Neutrino Beam
- Super-Kamiokande
- **ND280**, INGRID, Wagasci, Baby MIND

T2K - Super-Kamiokande (SK)





Super-Kamiokande

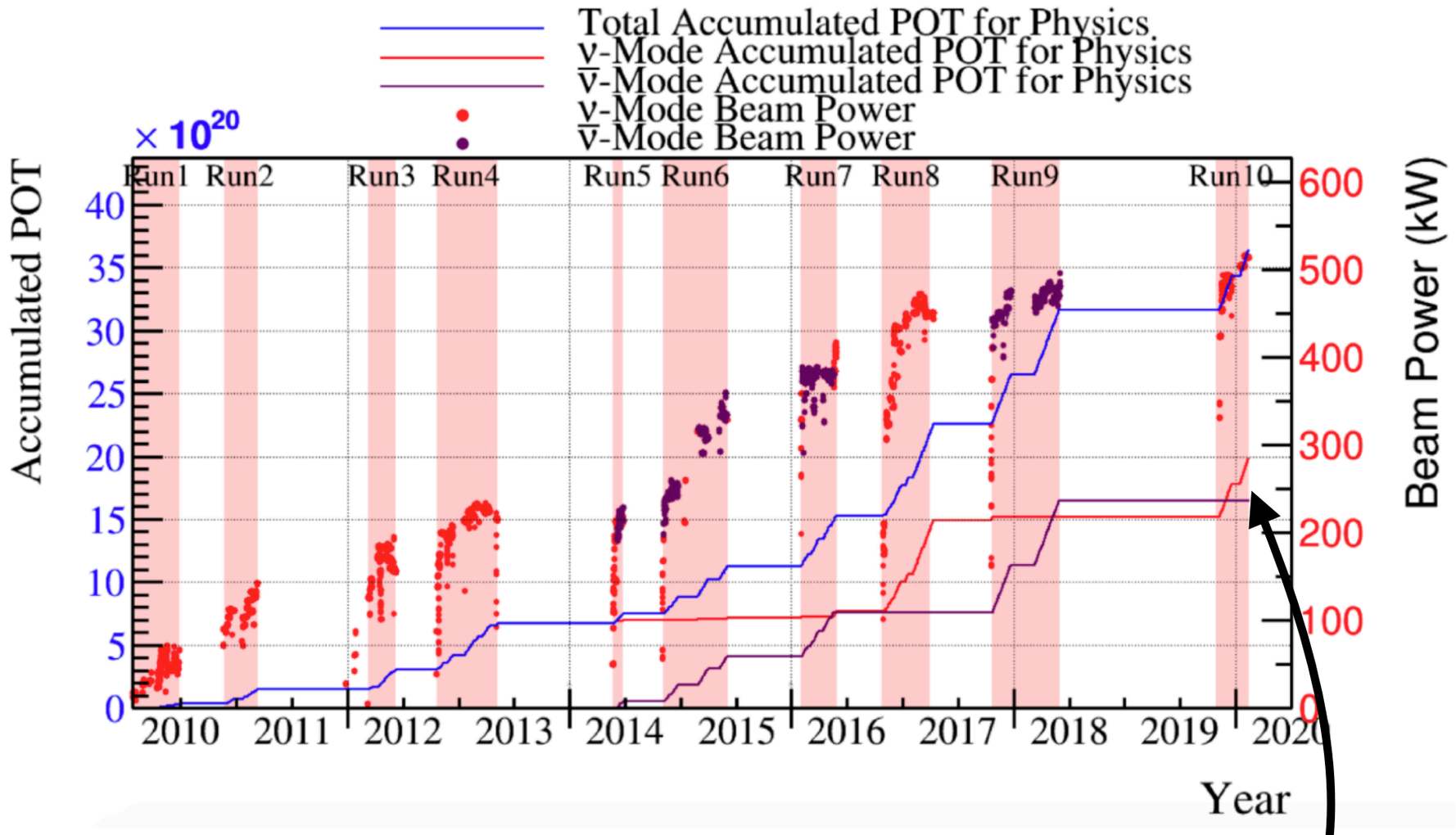
A water Cherenkov detector.

- Excellent particle identification
- Excellent momentum reconstruction (through range)
- Interaction vertex reconstruction
- Track Multiplicity
- Particle range

Main Challenges

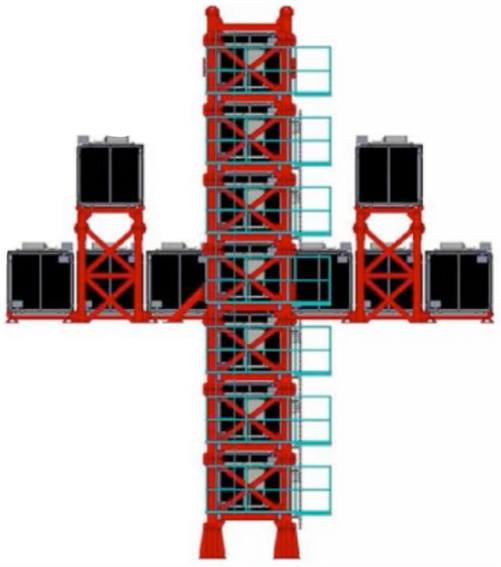
- Accumulation of statistics
- Good understanding of systematics
  - *vμ/anti-vμ flux*
  - *Neutrino-Nucleus Int. Models*
  - *Near and far detectors*

T2K - Accumulated Statistics

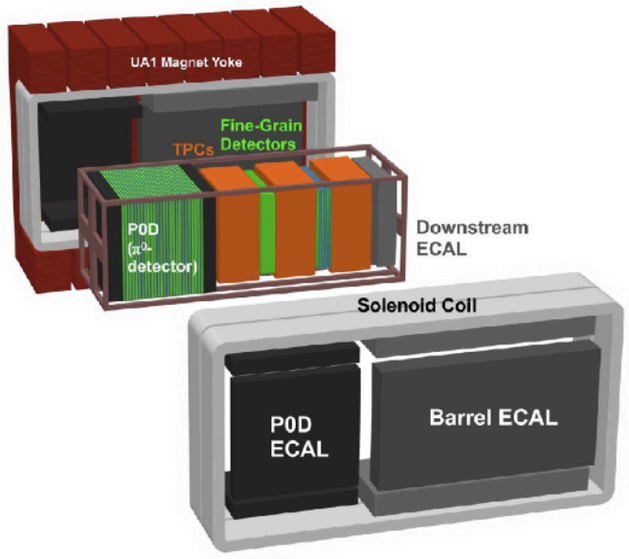


- Last publication shown the results with 3.1×10^{21} POT
- Approx. 50% neutrino - 50% anti-neutrino
- 515 kW stable operation in 2019
  - *+ 33% of ν-mode for next analysis*

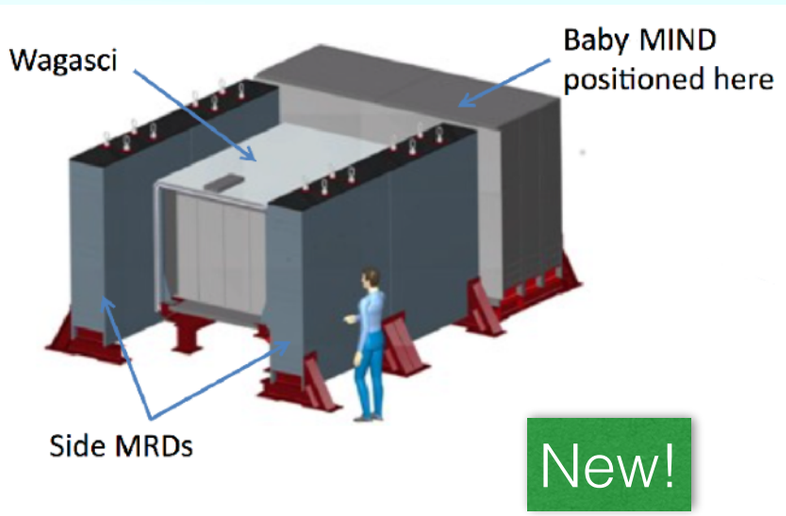
T2K - The Near Detectors



INGRID: On-axis

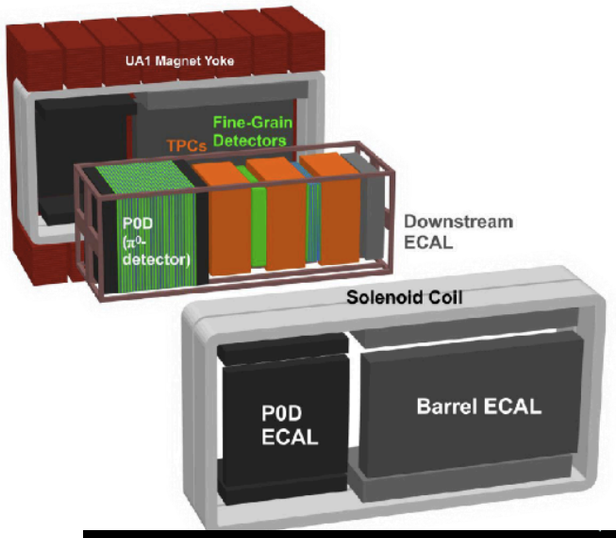


ND280: Off-axis

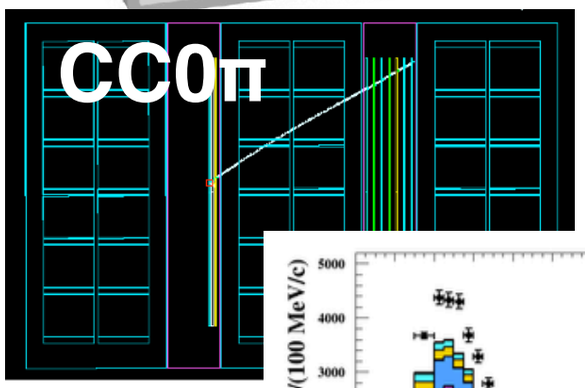


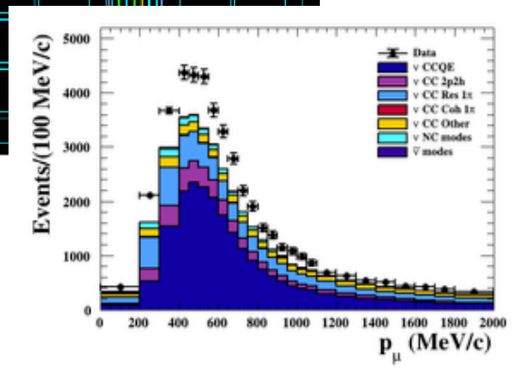
Wagasci/Baby MIND: Off-axis

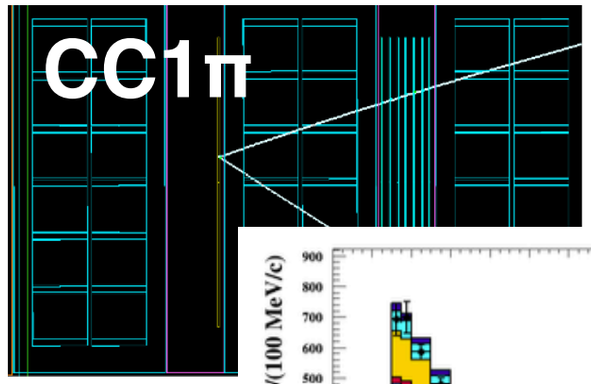
T2K - Off-axis ND280

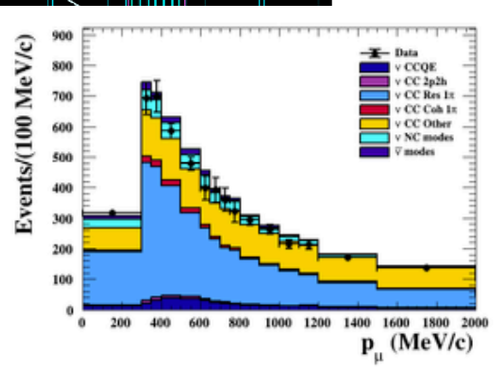


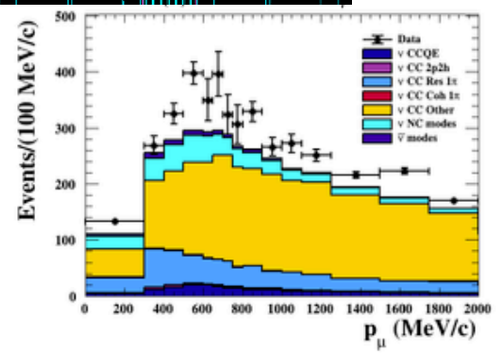
- ND280 detector provide
  - *2 neutrino interaction targets: one with Carbon, one with Water (like SK)*
  - *3 TPCs for particle tracking*
  - *1 surrounding magnet which provide particle charge identification*
- ND280's role in T2K is to provide stringent constrains on the systematic parameters
  - *Events are gathered in samples by their topologies*
  - *Neutrino/Anti-Neutrino data are fitted with prior uncertainties*

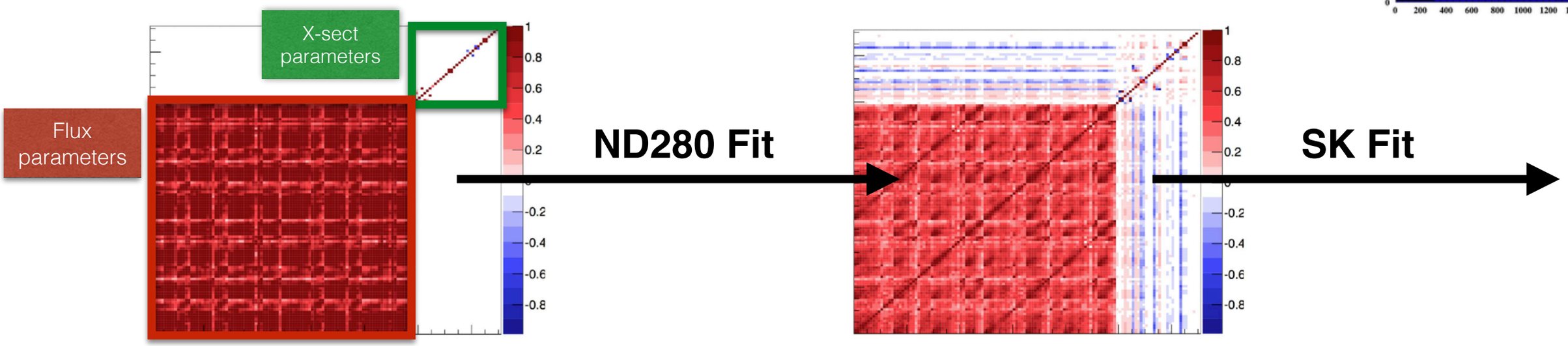




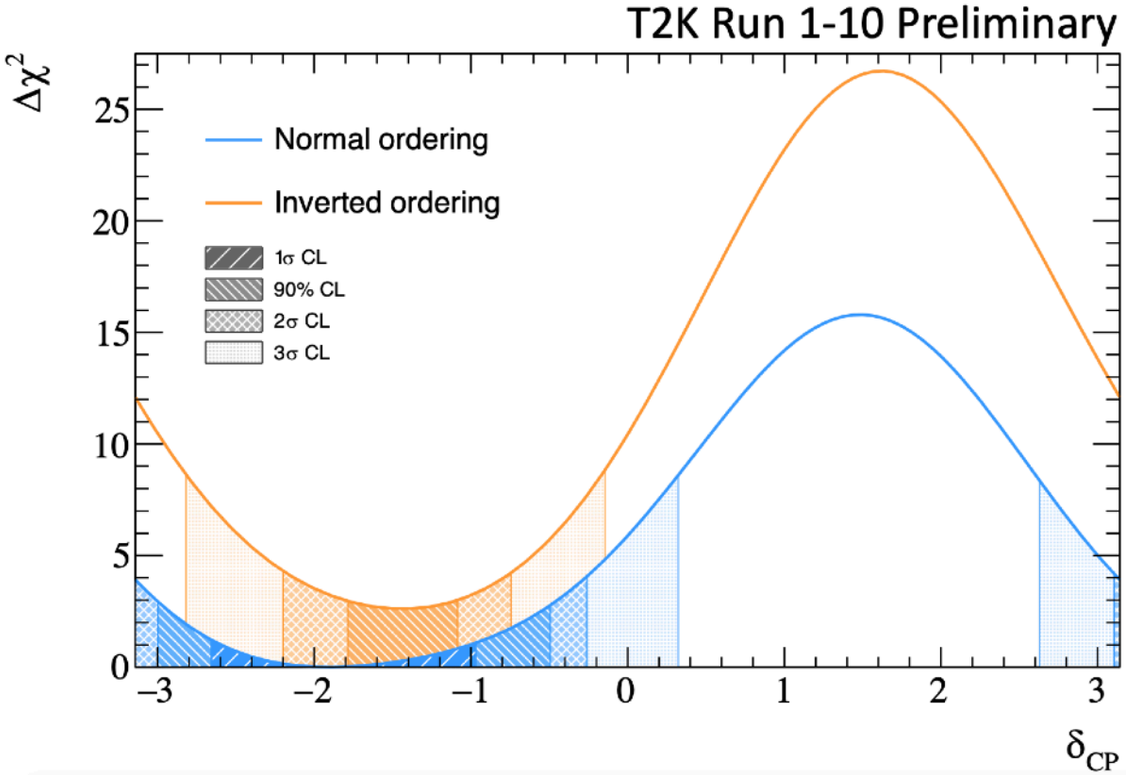


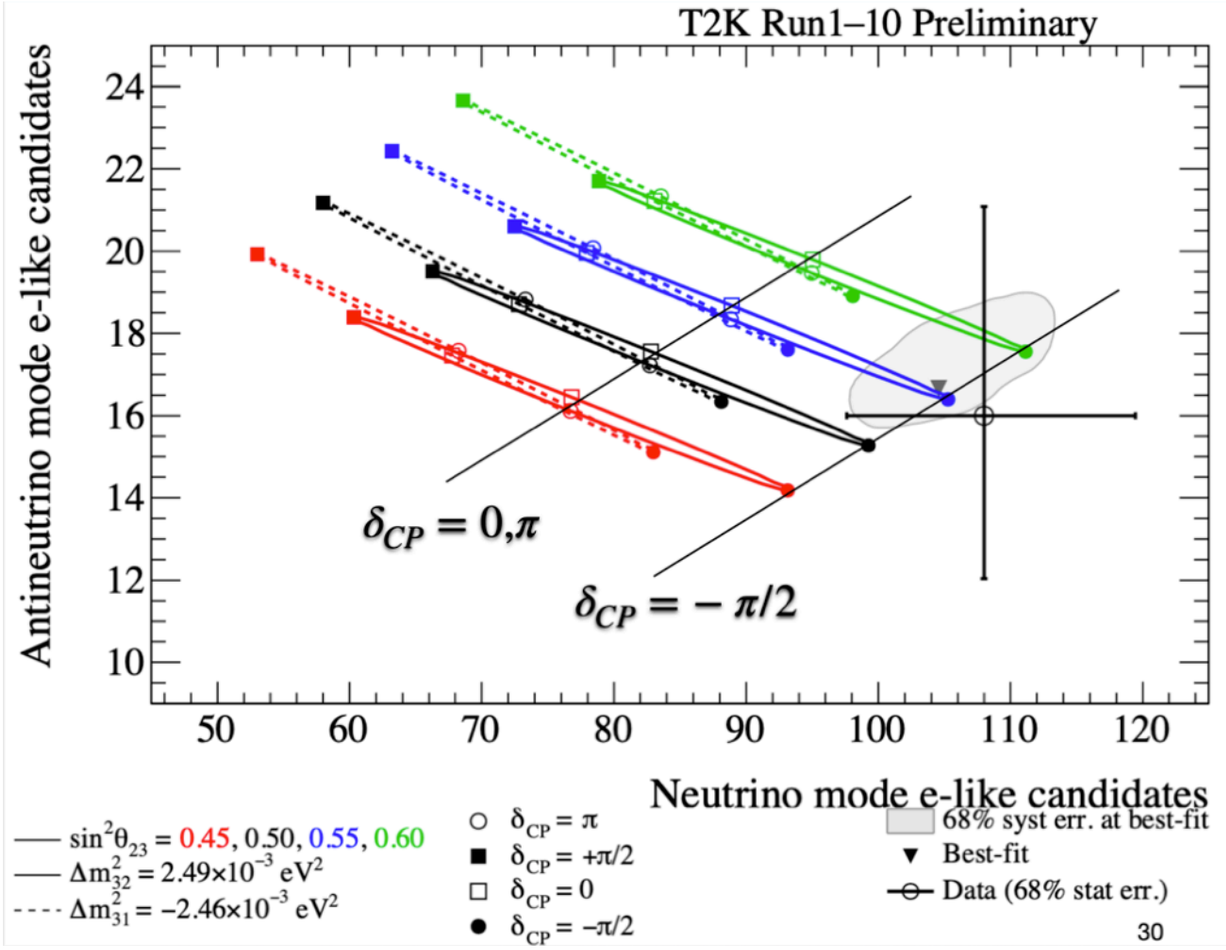






T2K - Latest Results

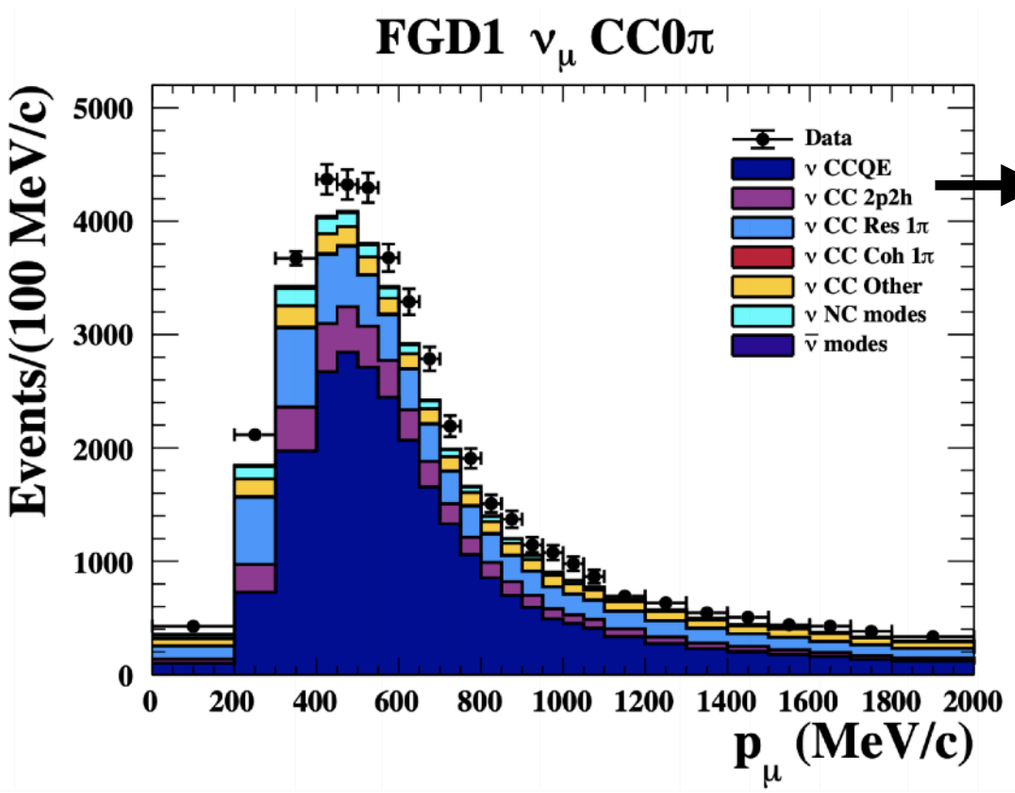




- **δ_{CP} measurement has been published** by the T2K collaboration on the 15th of April
  - "No CP violation" scenario excluded at C.L. ~ 2σ
  - Including reaction constrains (θ_{13})
- **The next generation of experiments is willing to push the constrains further on δ_{CP}**

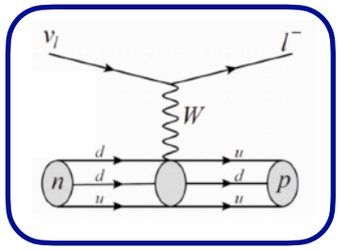
Improving ν-Nucleus Interaction Models

- Main source of systematic uncertainties
  - Binding Energy (E_b)
  - Final State Interaction (with π absorption)
  - ν_μ 2p2h normalisation

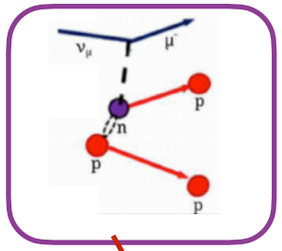


T2K Run 1-10 Preliminary

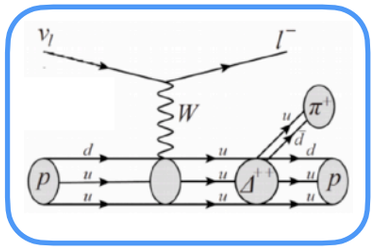
CCQE



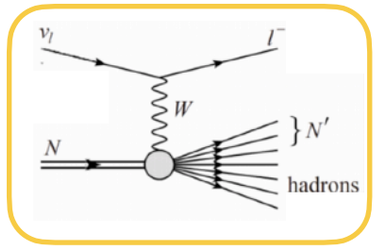
2p2h

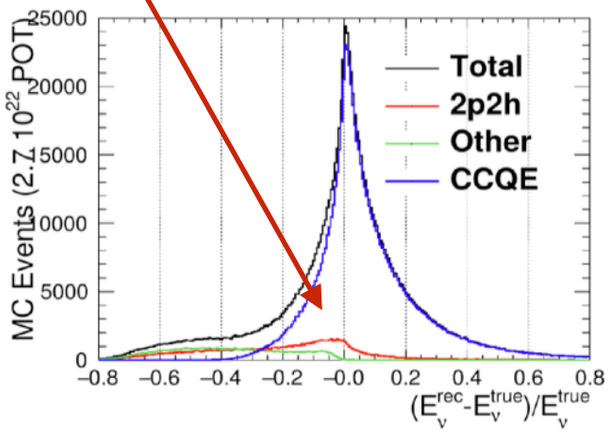


RES (abs. π)



DIS



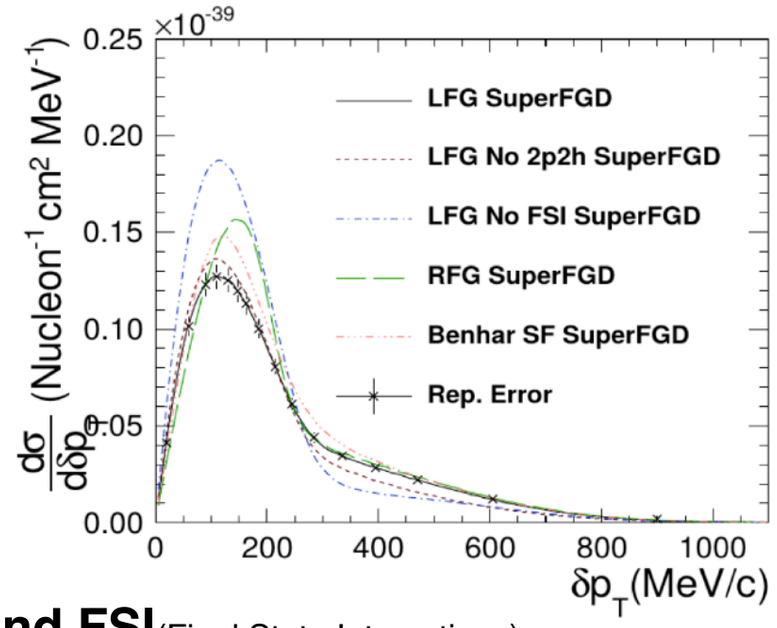


- CCQE formulae for energy reconstruction of the neutrino does not work well for other components
- 2p2h component is not very well known : **2p2h/CCQE = 10%-20% ?**
- We need to study with better precision the kinematics of outgoing particles in order to better constrain 2p2h in the fit

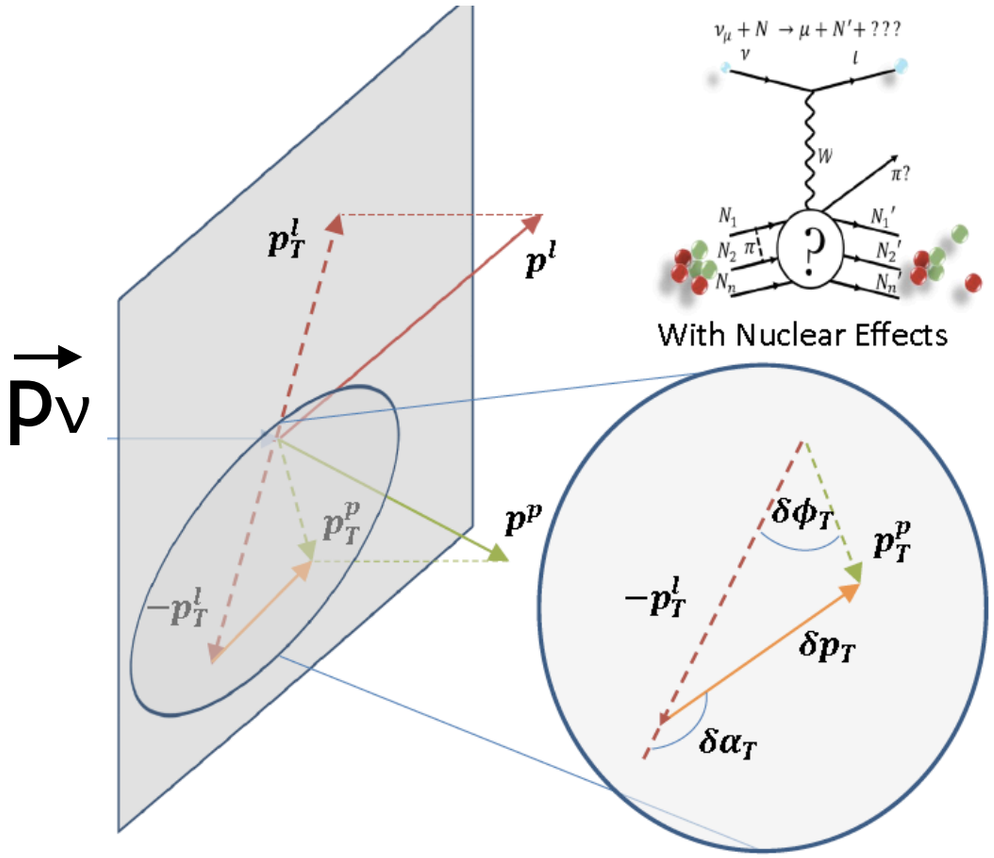
Transverse Momentum Imbalance

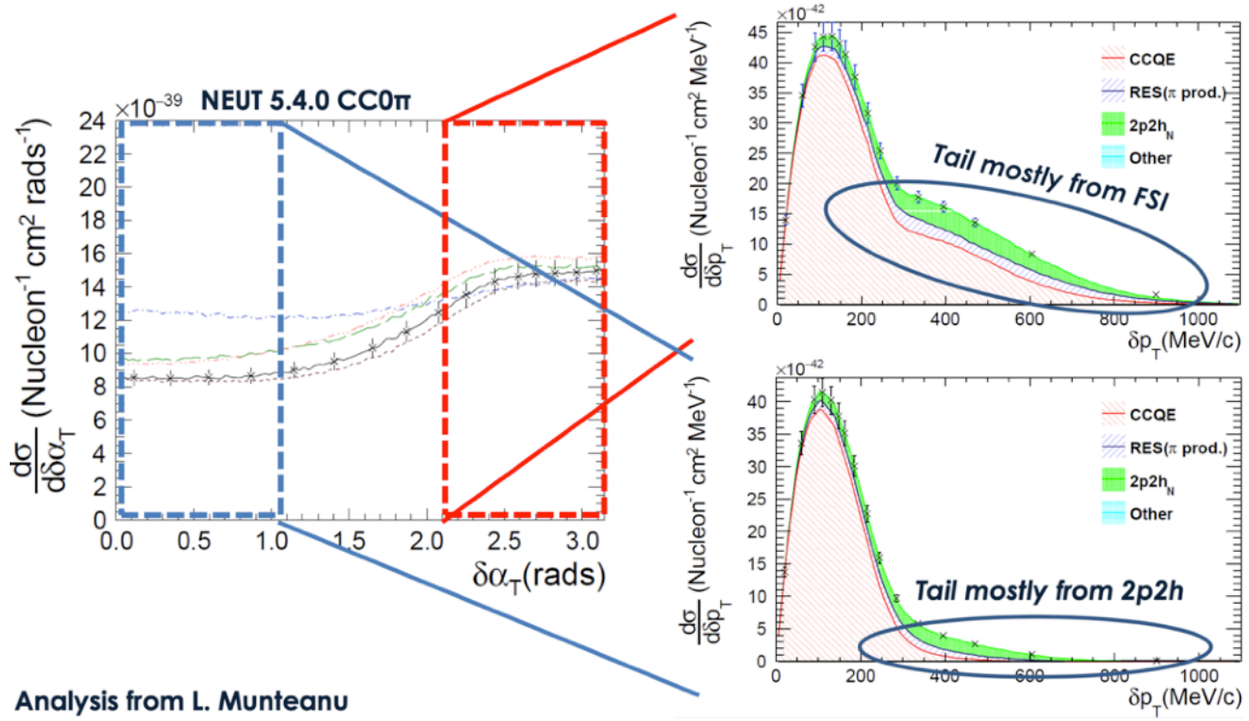
Low energy recoil protons allow us to measure transverse momentum imbalance to access nuclear effects: Fermi momentum and re-interactions.

$$(p_\mu, \cos\theta_\mu) \rightarrow (\delta p_T, \delta\alpha_T, p_n \ldots)$$



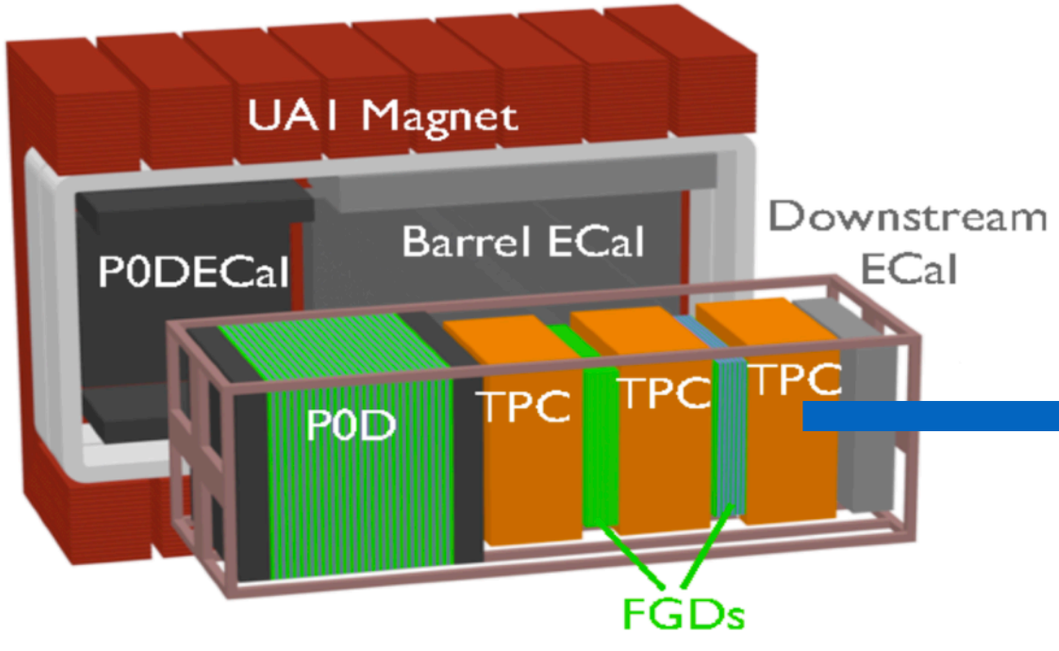
- δp_T is almost a direct measurement of the **Fermi momentum**
- Measuring δp_T in bins of $\delta\alpha_T$ may allow **excellent separation of 2p2h and FSI** (Final State Interactions)

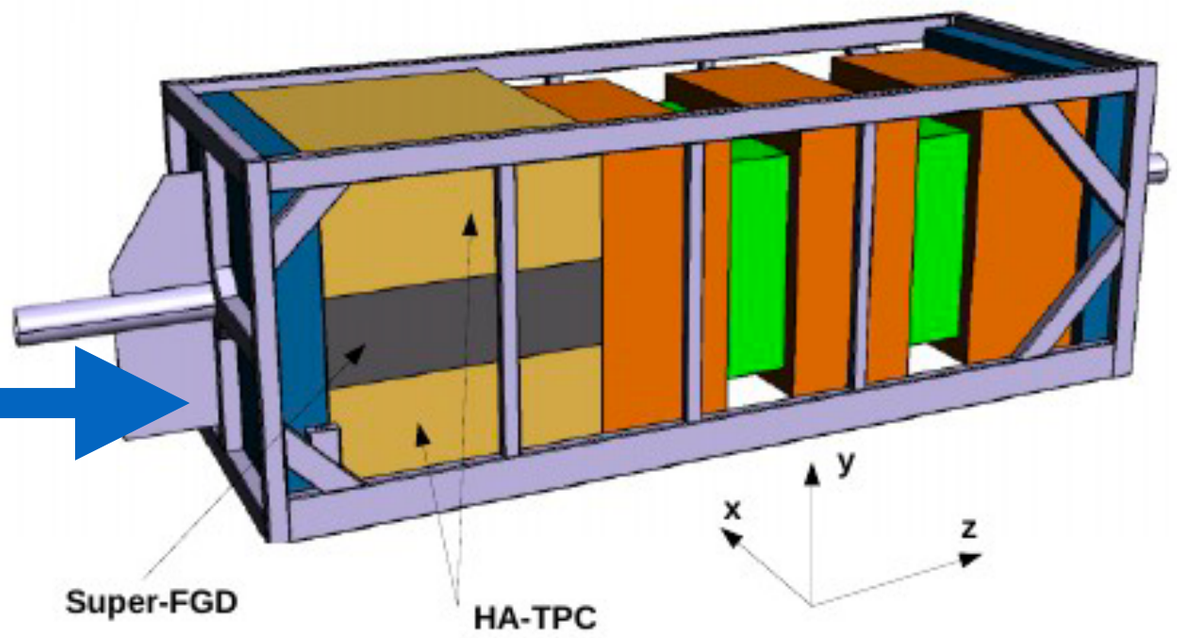


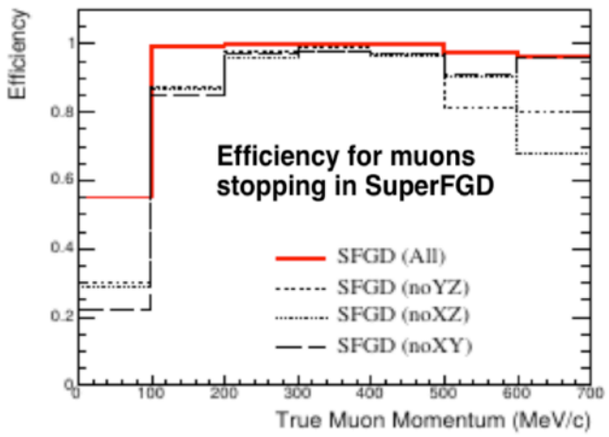


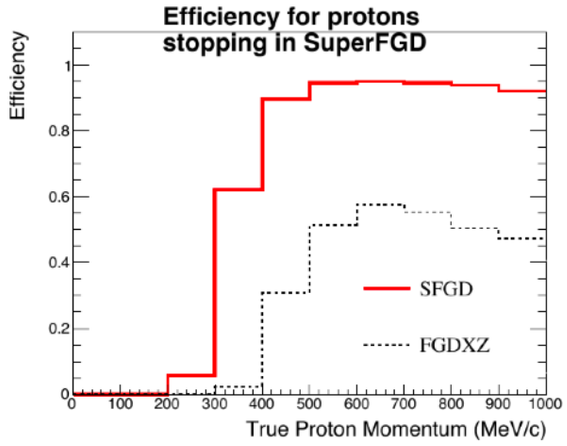
Analysis from L. Munteanu

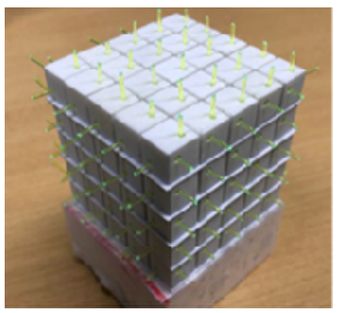
The Upgrades of ND280: Super-FGD

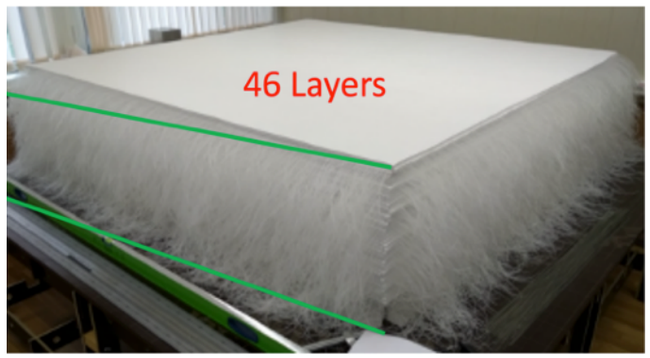






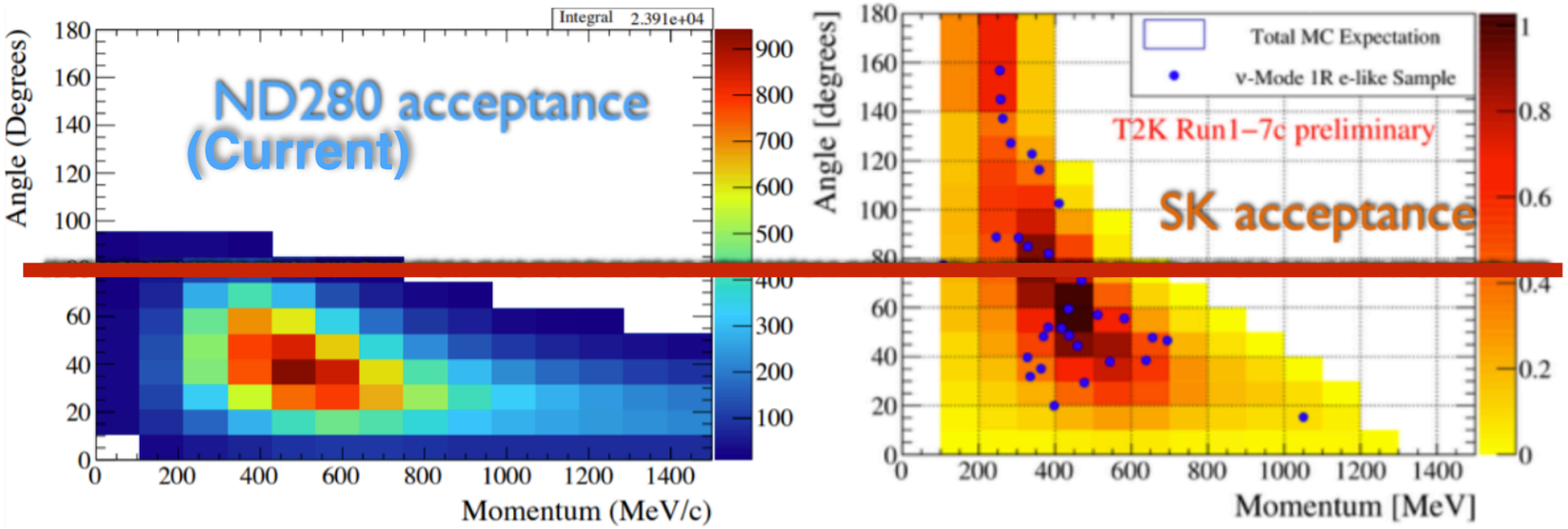


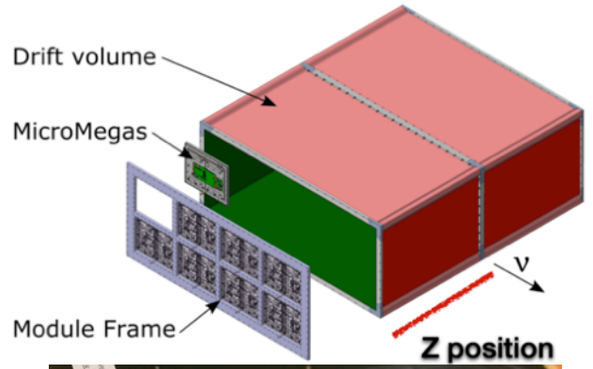


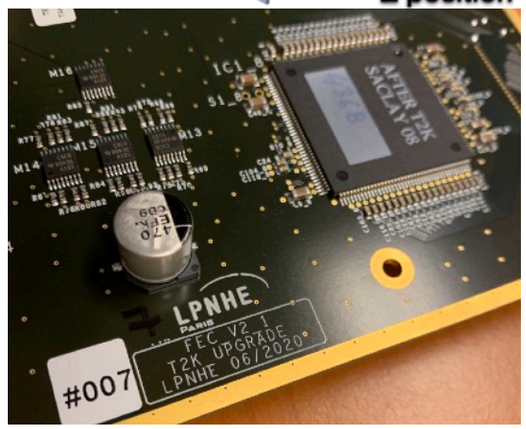


- x2 in statistics for equal POT
- **Super-FGD**
  - Quasi-3D imaging
    - *Improved tracking*
    - *Lower proton detection threshold*
    - *Neutron measurement capabilities*
  - Time of Flight for background reduction

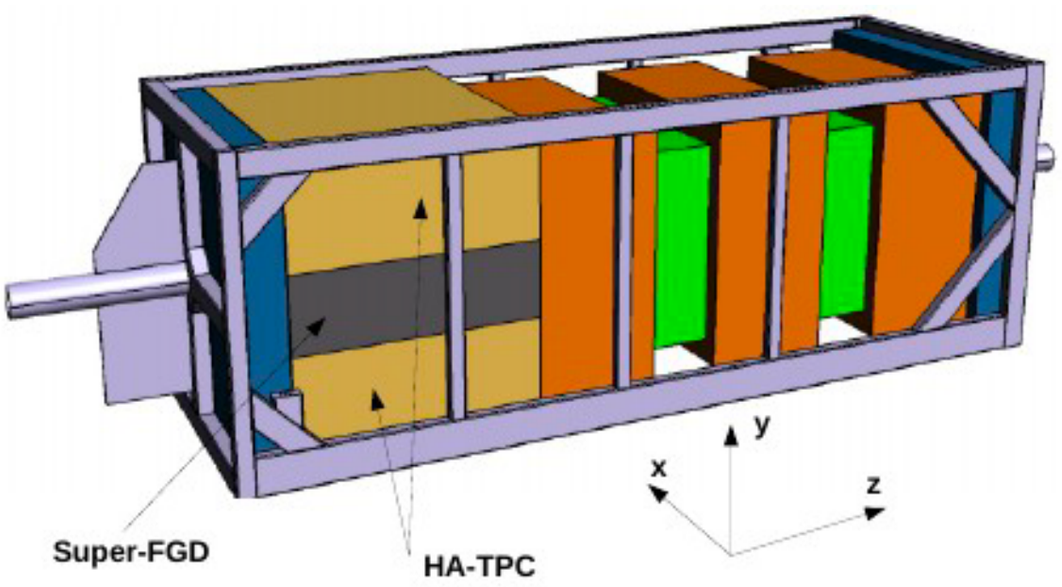
The Upgrades of ND280: HA-TPCs

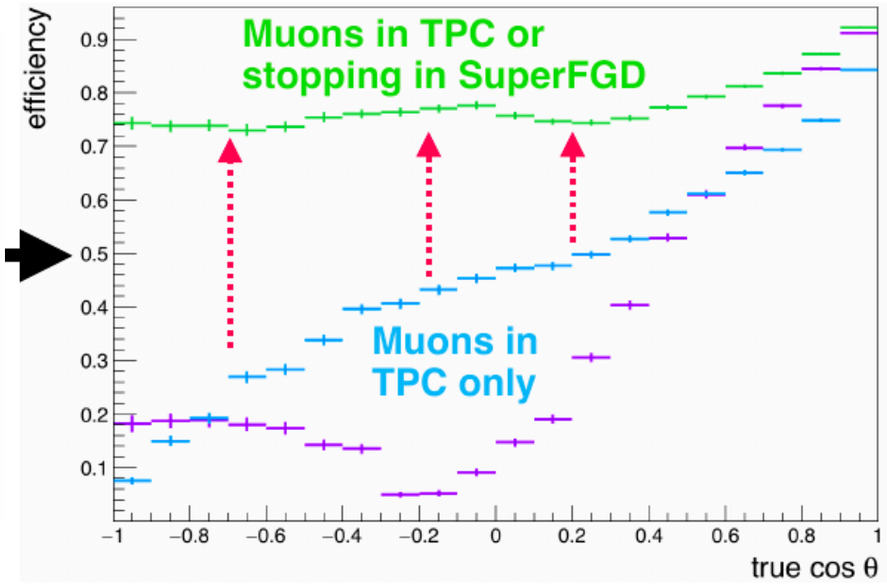






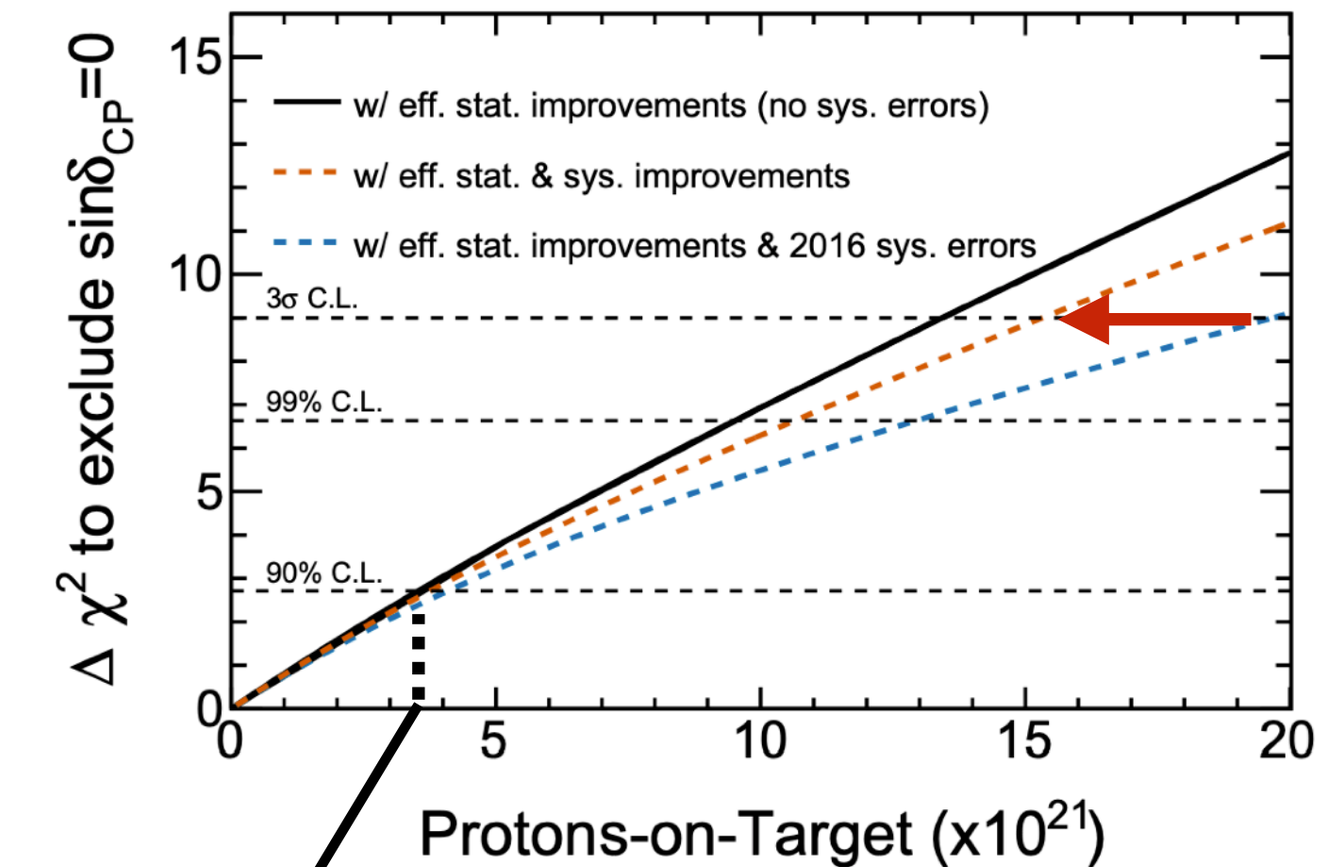
- **High Angle TPCs**
  - Improved high angle acceptance
  - Better tracking capabilities





These upgrades are being constructed and will be installed at J-PARC in 2022

Physics And Performances



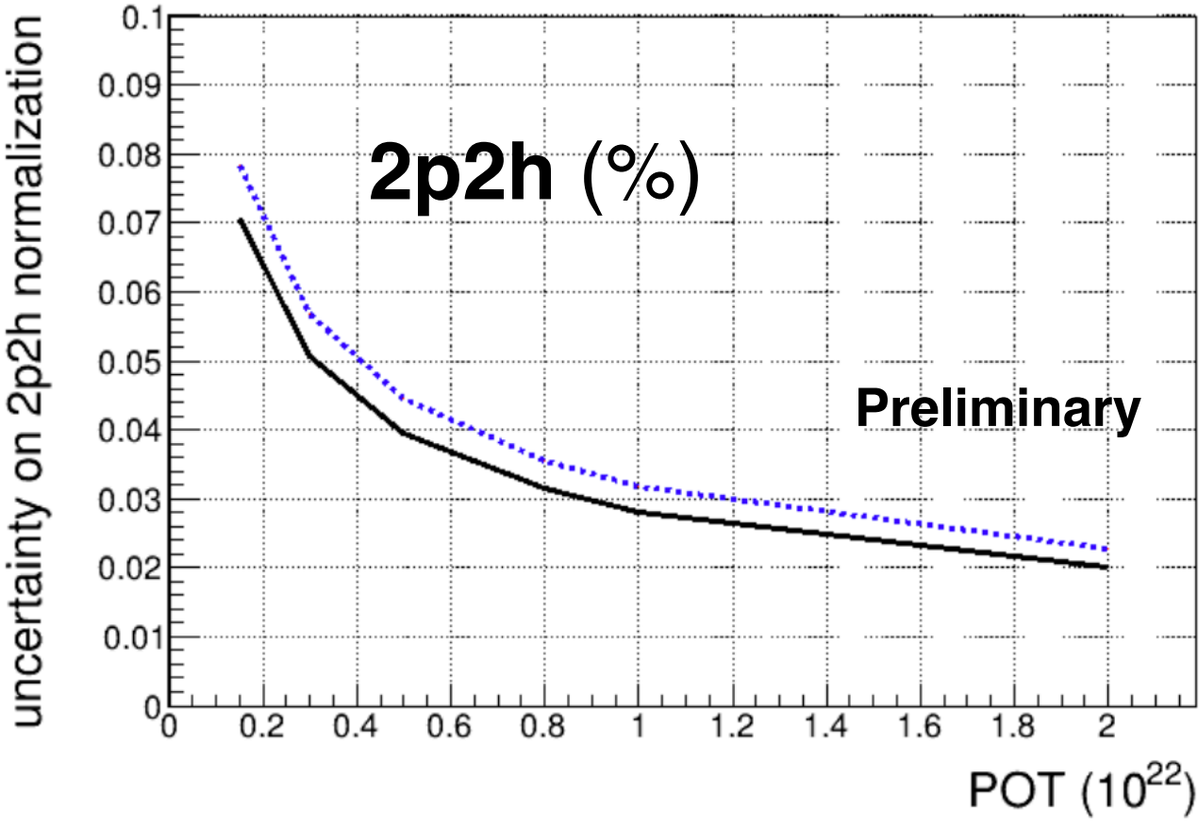
Current POT of T2K

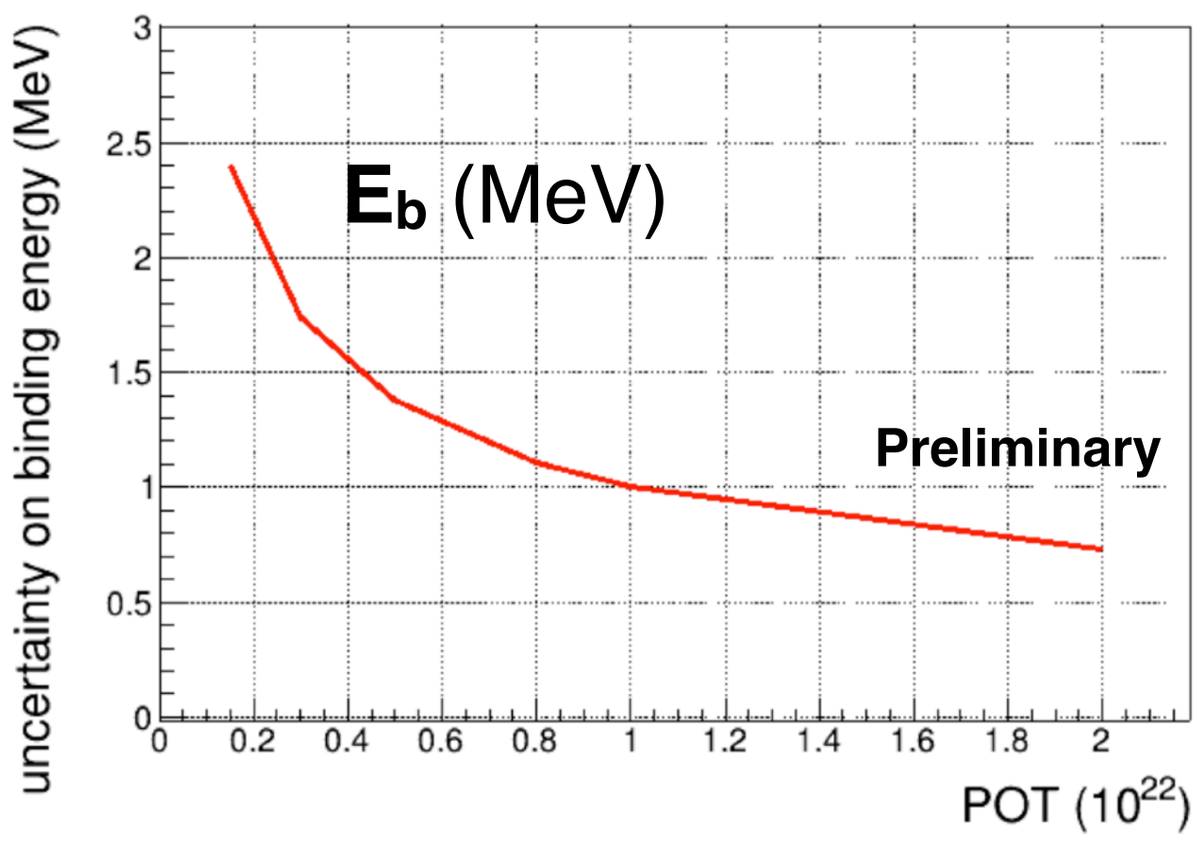
arXiv:1609.04111

Physics And Performances

- Very promising results:
  - 2p2h will be constrained **to less than 5%** (prior uncertainty is currently at 100%)
  - Binding Energy (E_b) parameter could be constrained at **better than 1 MeV**

- Next step is to include more systematics
  - Adding them to the simple fitter
  - Or using a more robust framework to imitate the fit





Conclusion

- We are now closing the measurement of the PMNS matrix.
  - Atmospheric angle close to maximal.
  - Rejected **CP conservation** ($\sin(\delta_{CP}) = 0$) @ **2σ C.L.**
  - Mild preference for normal hierarchy.

- Today's state of the art
  - Main systematics are from the beam modelling (improved with the NA61/SHINE hadron production experiment) and x-section modelling.
  - T2K made a great job to reduce x-sec uncertainties to ~3%.
  - To reduce even further the x-sec uncertainties an upgrade is being constructed.
  - T2K measurements are important for **HK, DUNE, NOvA and atmospheric neutrino oscillations**.

- **Heading toward 3σ sensitivity on δ_{CP}**
  - Several key-instruments are being upgraded: beam/far-detector/near-detectors
  - ND280 will provide a major role for understanding **neutrino-nucleus models uncertainties**
  - Especially thanks to 2 new integrated detectors: **HA-TPC** and **Super-FGD**
  - Will be able to measure **hadrons kinematic along with the outgoing lepton**
  - It will allow to take advantage of the **transverse kinematic imbalance** to provide new stringent constrains on each systematic parameters and models

- Upgraded ND280 will be an essential part of the Hyper-Kamiokande Near Detector complex

Questions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