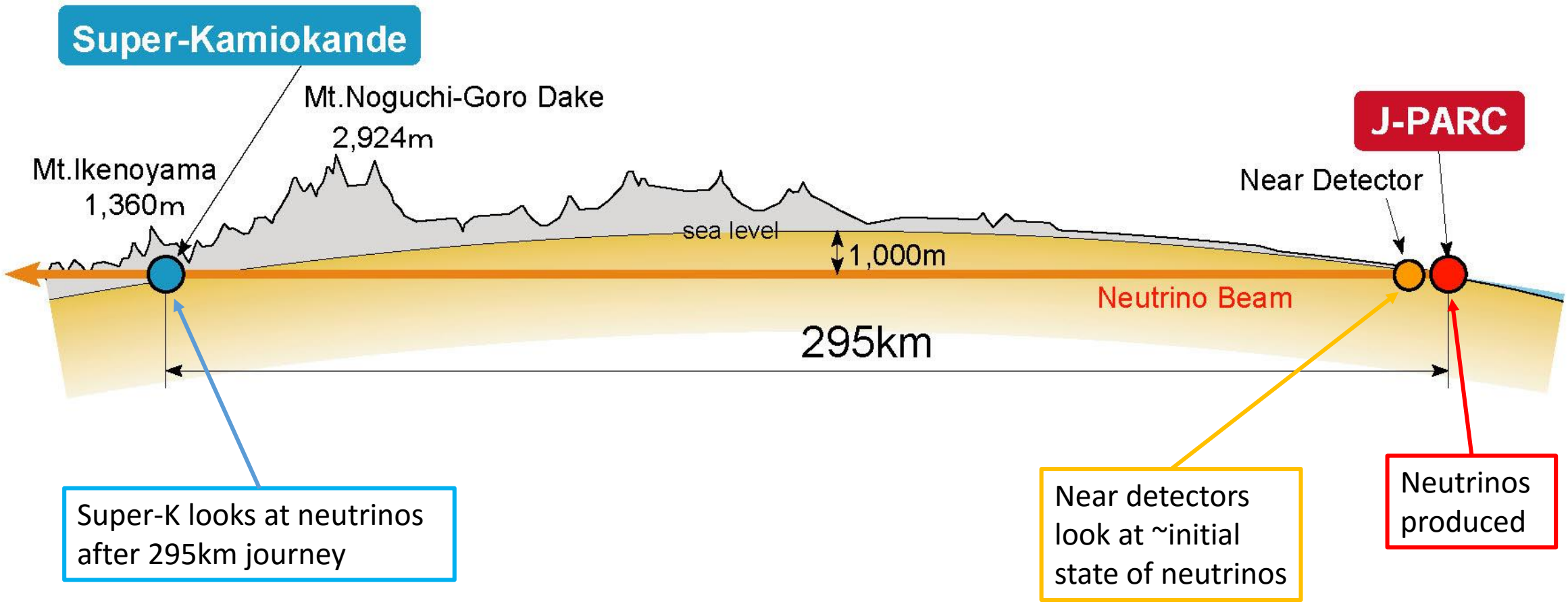
Neutrino Interaction Cross-Section Measurements from the T2K Collaboration

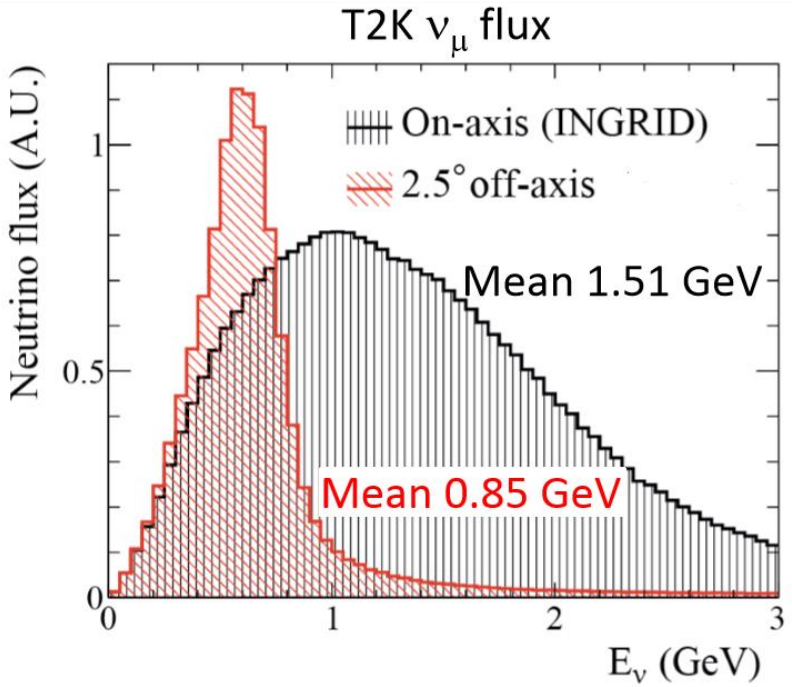
David Payne on behalf of the T2K Collaboration

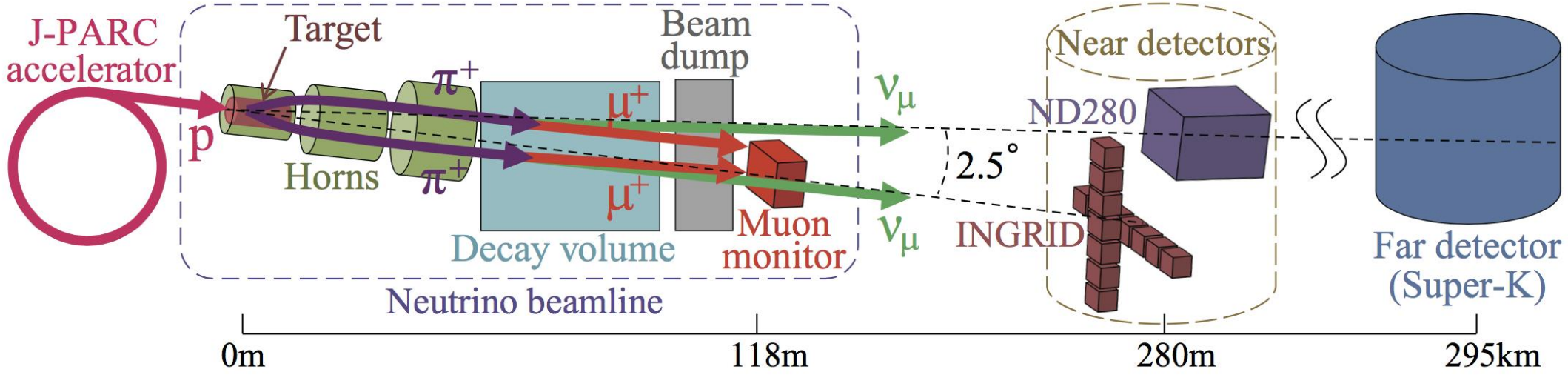
The T2K Experiment



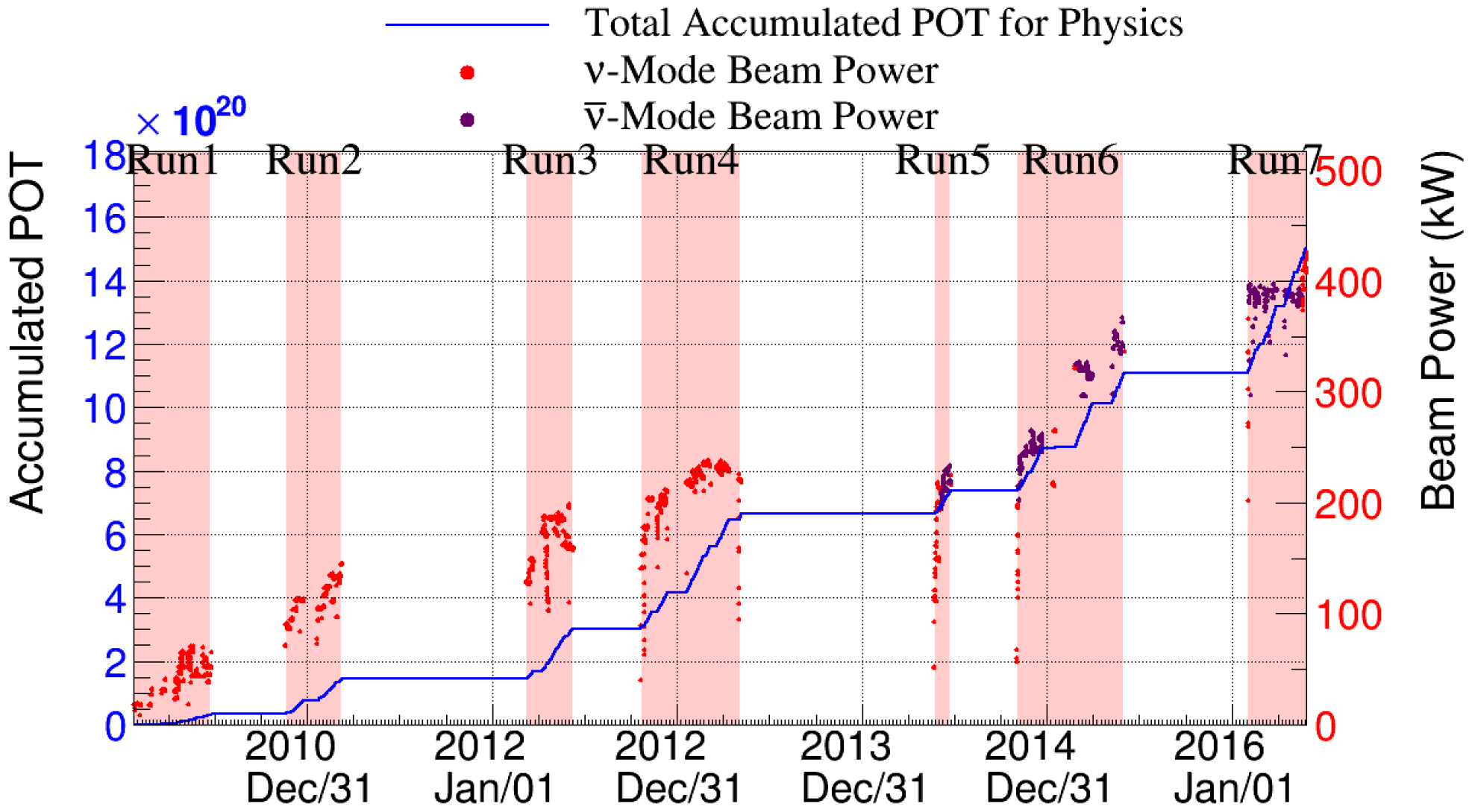
The Beam

- Off-axis beam
- Direction of horn current used to focus neutrinos or anti neutrinos

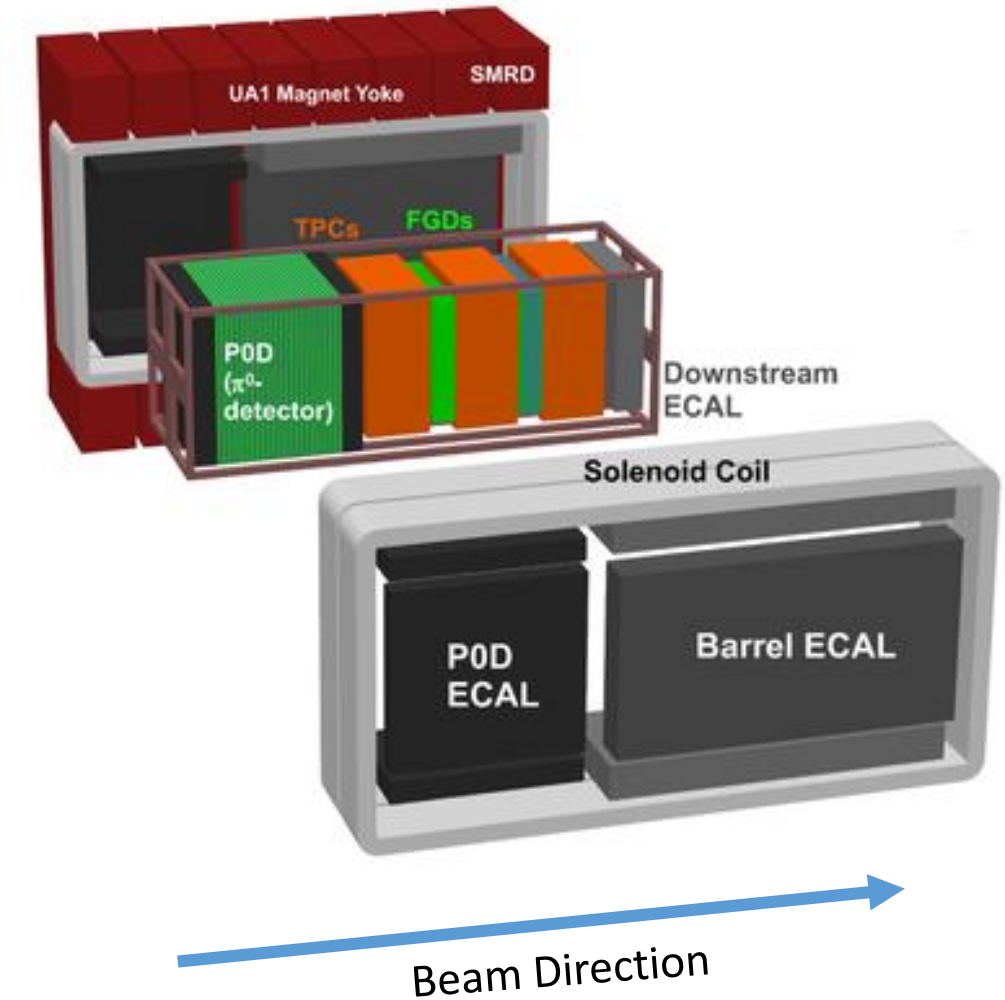


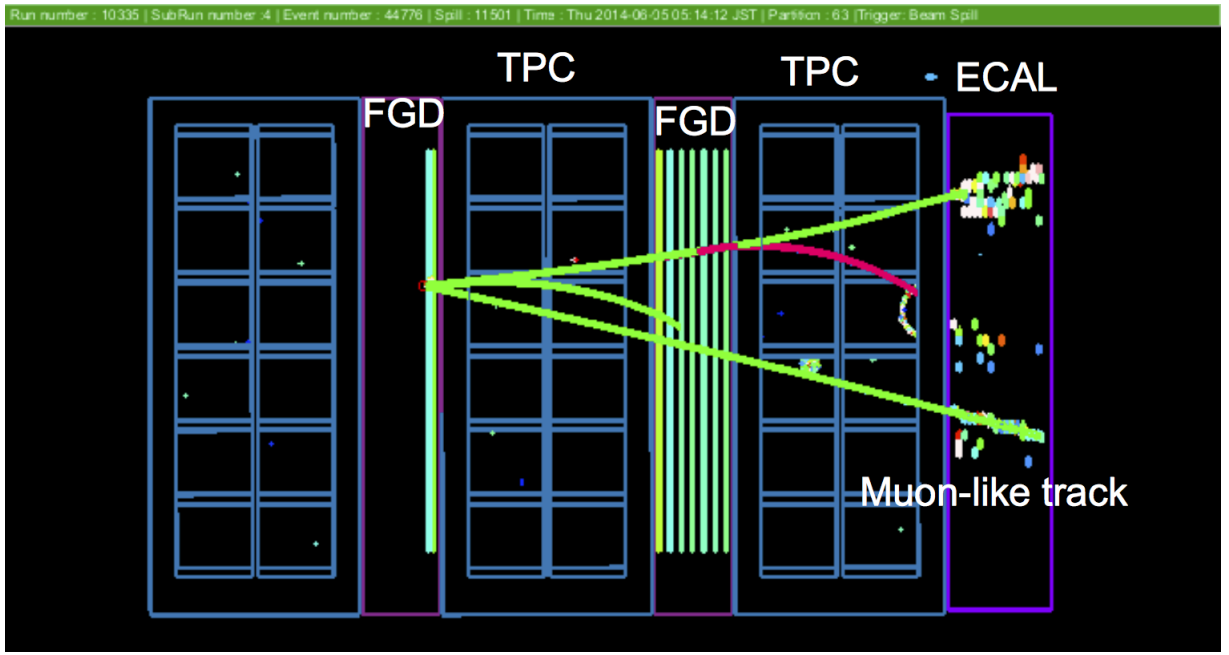


Protons On Target

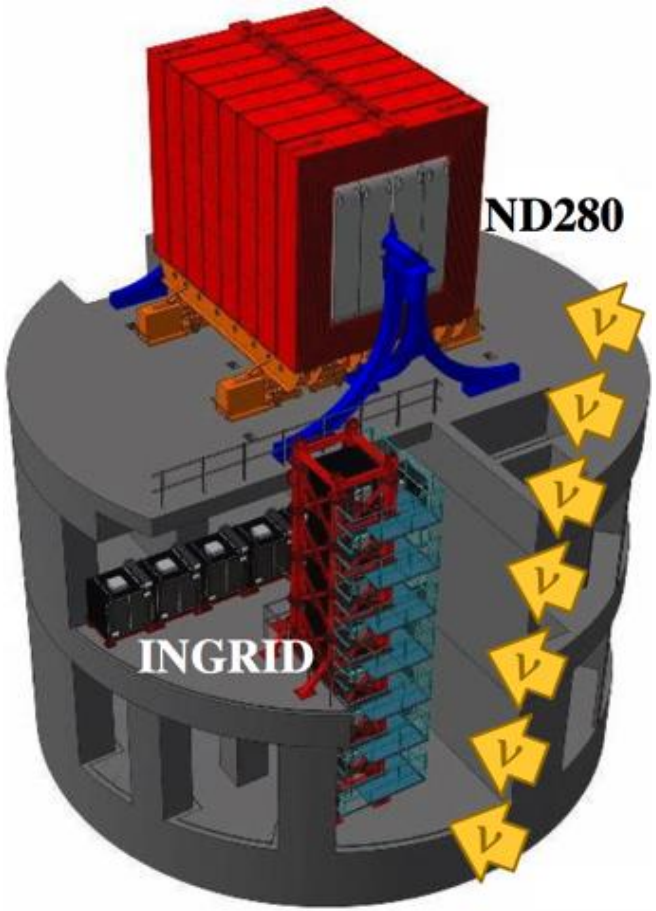


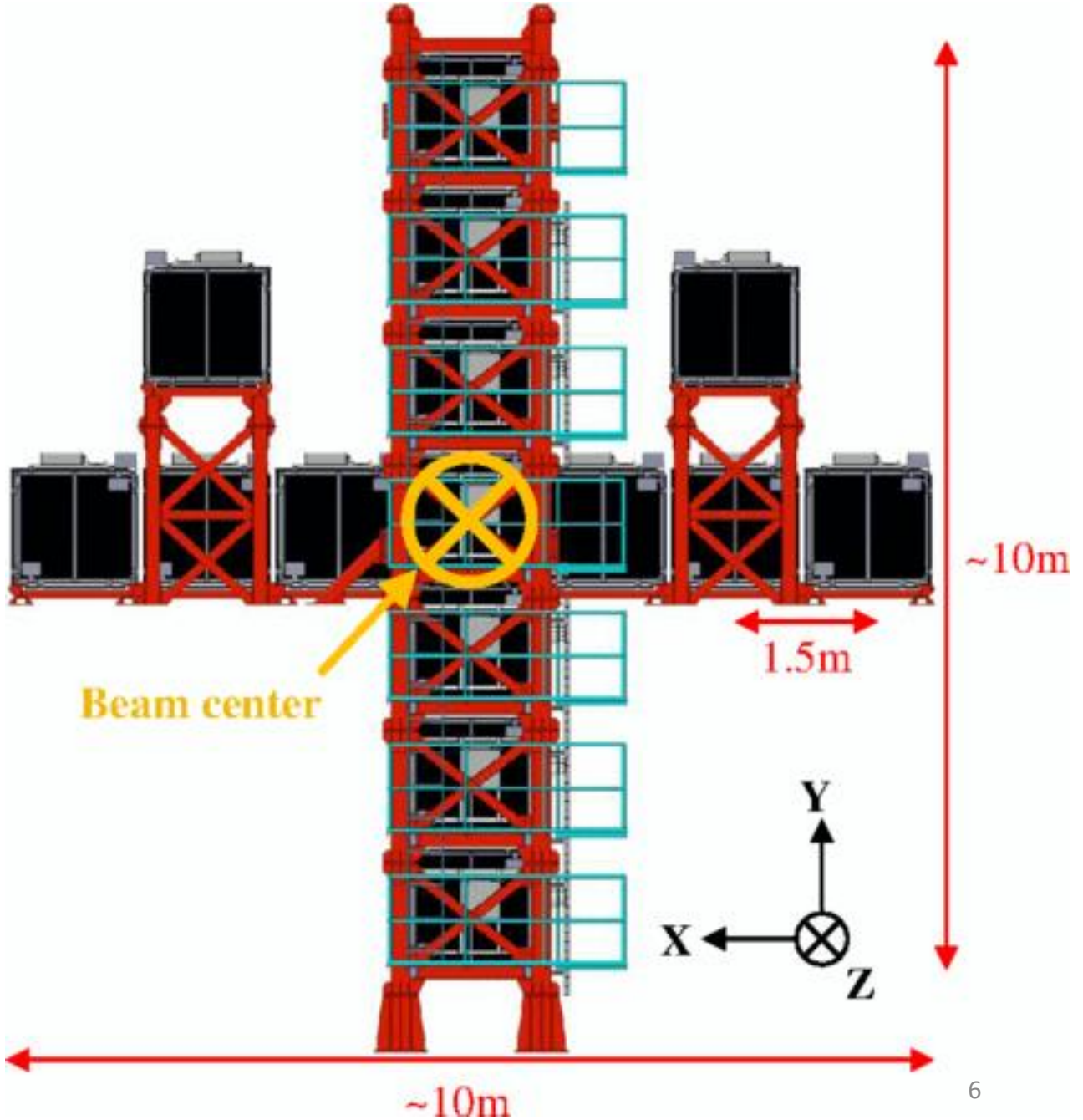
At 280m, off Axis: ND280



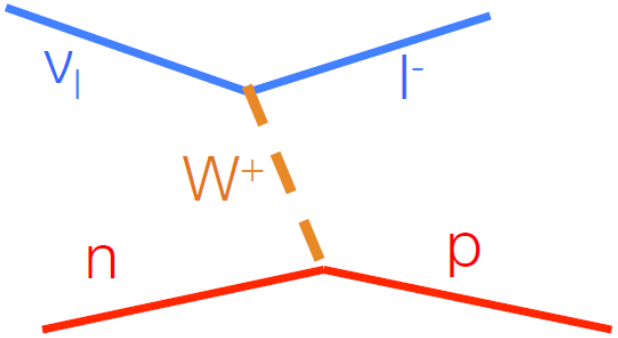


At 280 m, on Axis: INGRID

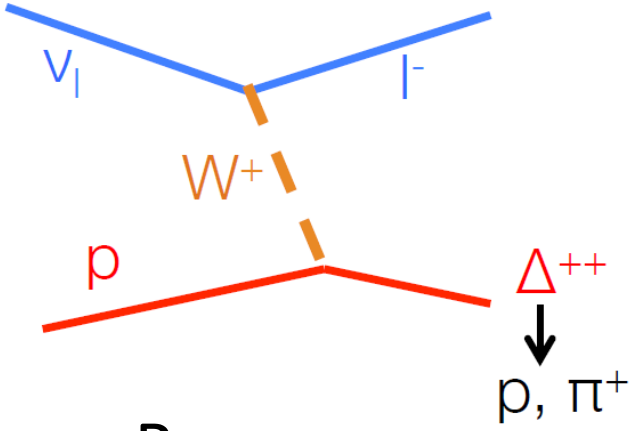




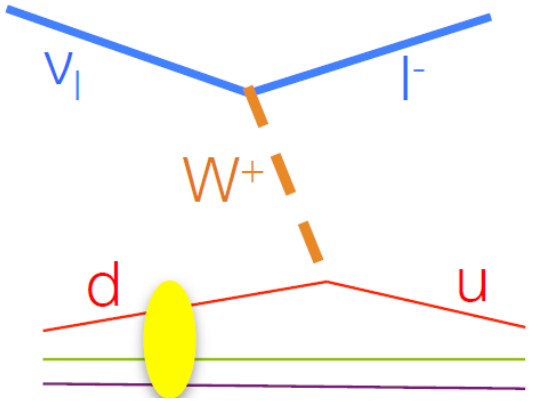
Neutrino interactions



Quasi-elastic (CCQE)

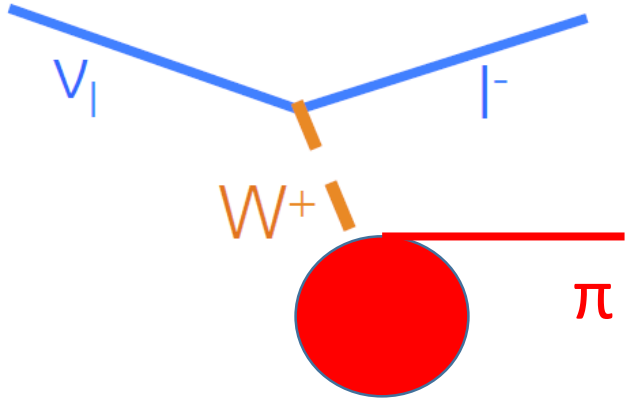


Resonance

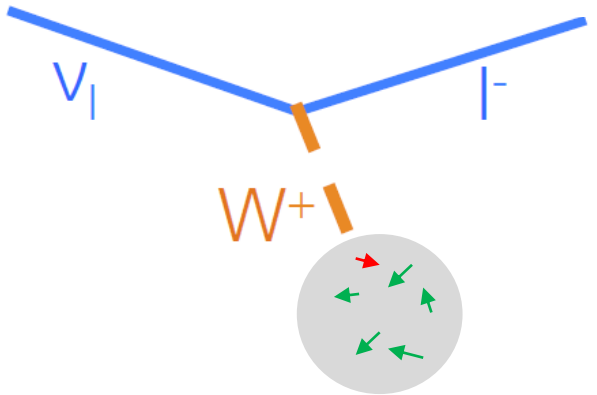


Deep Inelastic Scattering (DIS)

π, K, p …



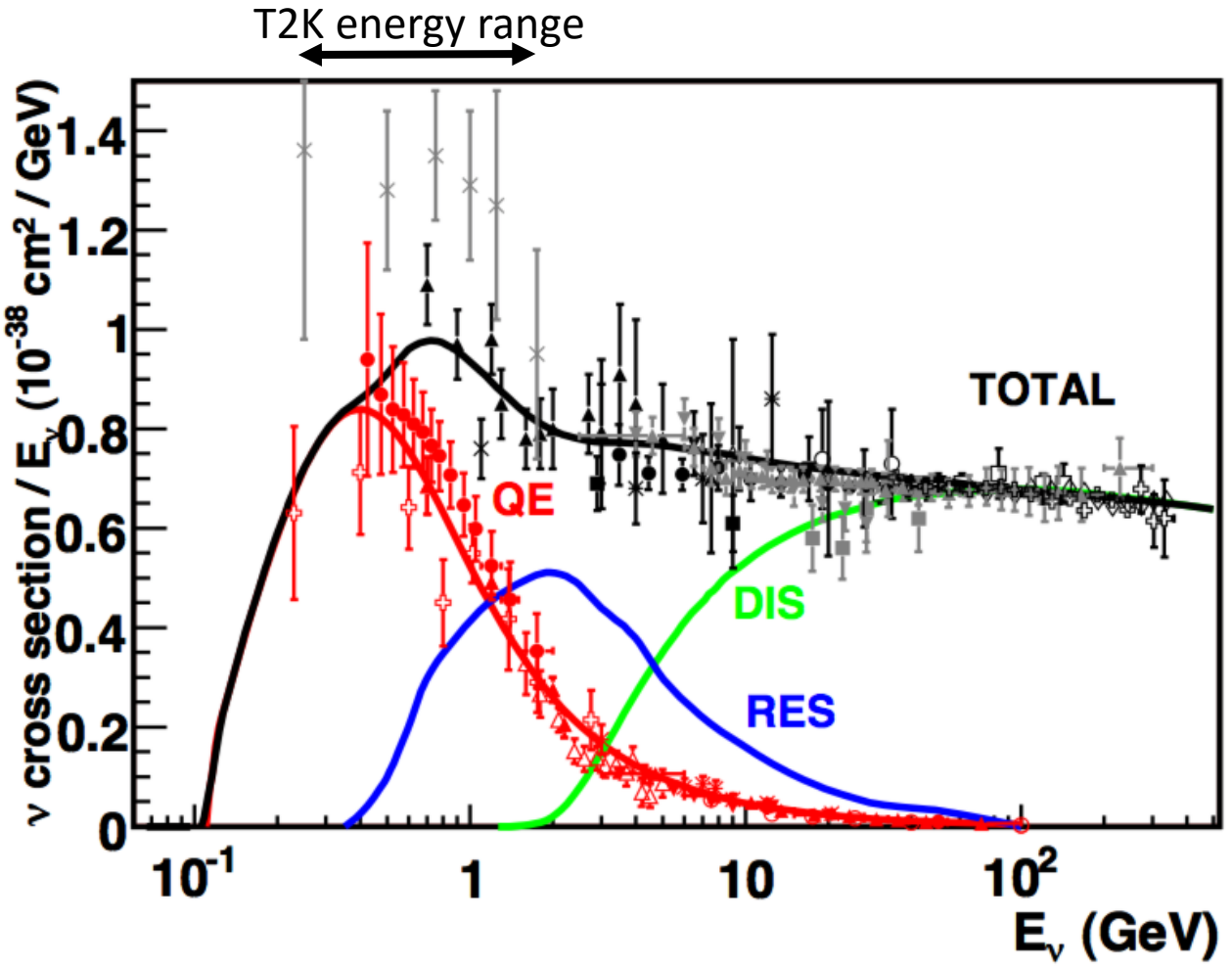
Coherent π Production



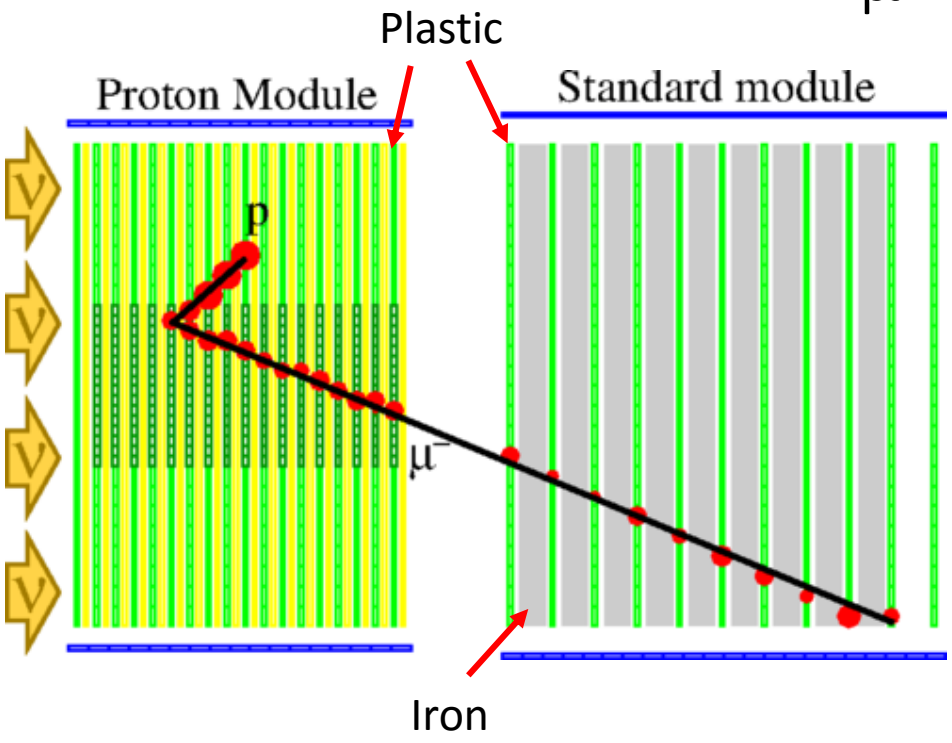
Intra-nuclear Effects

Neutrino Interactions

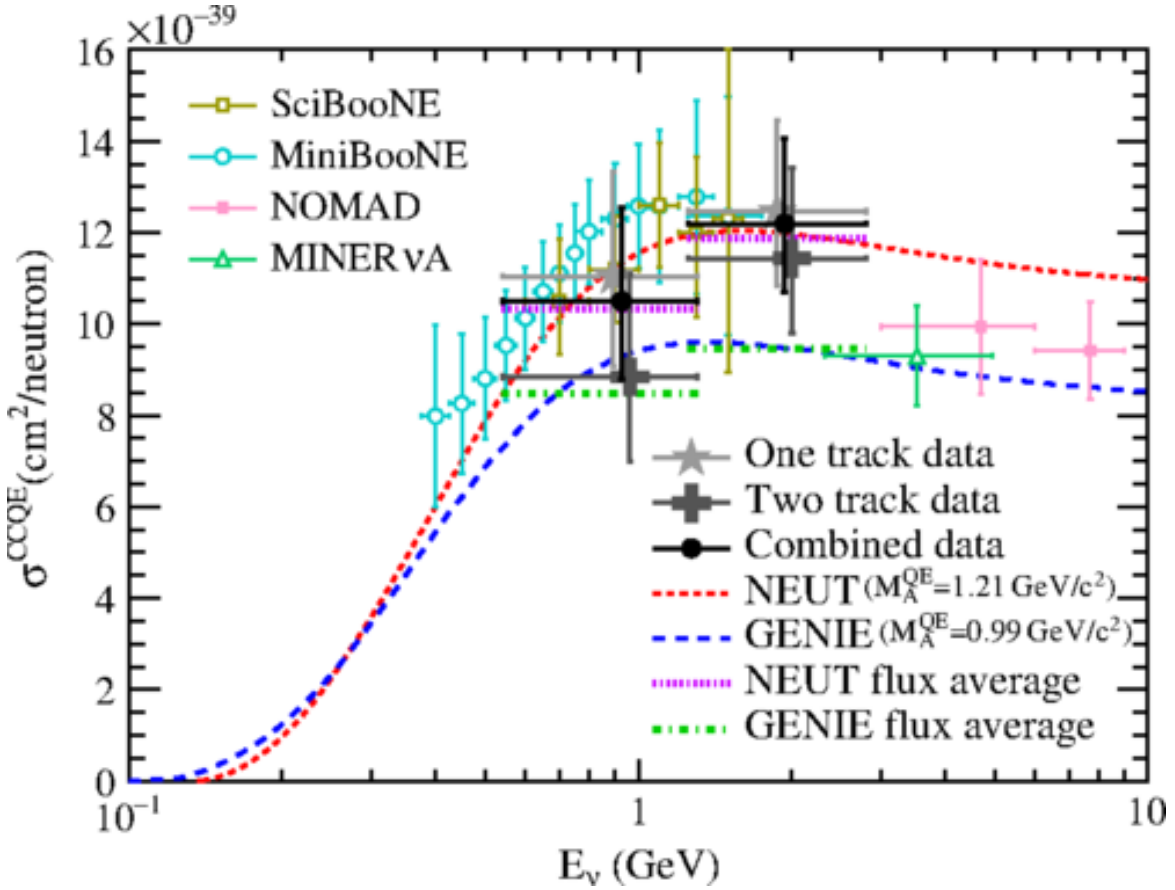
- Low energy: nucleus interaction
- High energy: nucleon interaction
- Intermediate energy: “a complex combination of quasi-elastic (QE) scattering, resonance production, and deep inelastic scattering processes, each of which has its own model and associated uncertainties”
  - SNOWMASS (arXiv:1310.4340v1 [hep-ex])



Cross Section of ν_μ CCQE on Carbon at INGRID



- (CCQE – Charged Current Quasi Elastic)
- Uses special proton module as target
- Events split into low energy (<1.5GeV) and high energy (>1 GeV) by penetration of muon



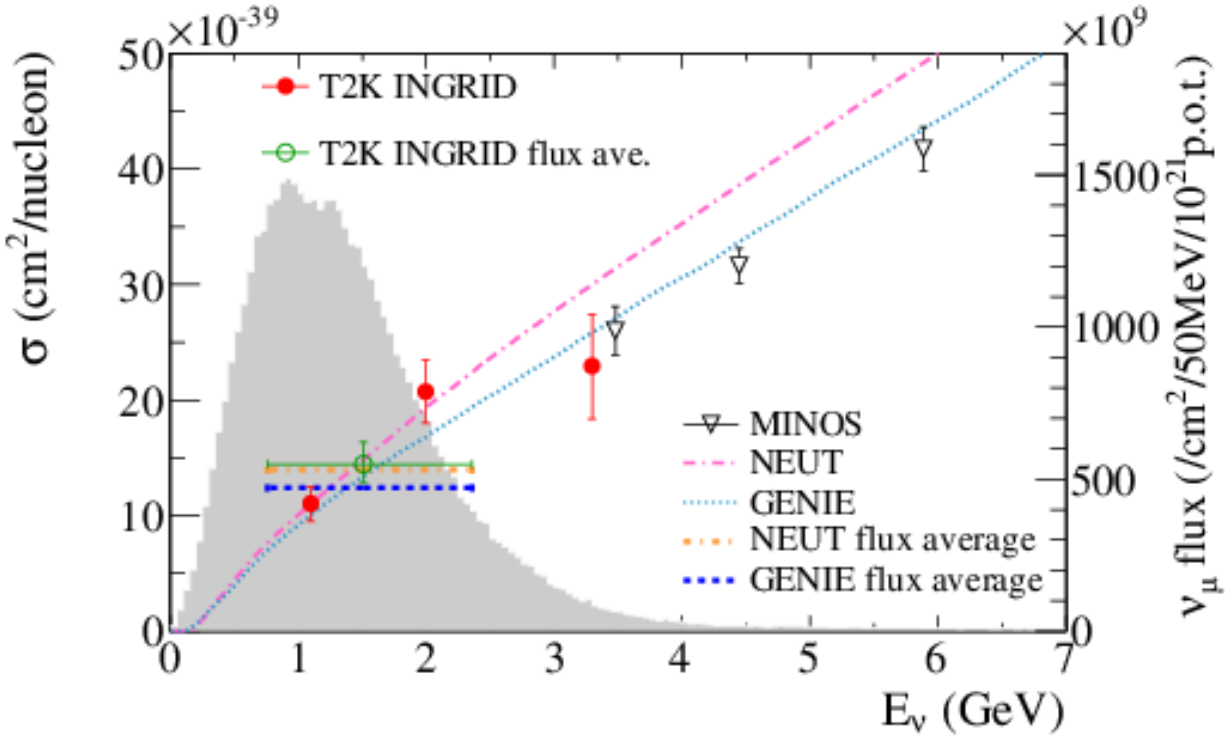
$\sigma^{CCQE}(1.94GeV)=11.95\pm0.19^{+1.82}_{-1.47}$ (10^{-39} cm^2/neutron)

$\sigma^{CCQE}(0.93GeV)=10.64\pm0.37^{+2.03}_{-1.65}$ (10^{-39} cm^2/neutron)

Phys. Rev. D 91,112002

Measurement of ν_μ CC-Inclusive Cross Section on Iron at INGRID

- Doesn't use proton module
- Events split into energy categories by predicted energy profile of module and contained/non-contained event
- Phys. Rev. D 93, 072002 (2016)
- arXiv:1509.06940v1[hep-ex]

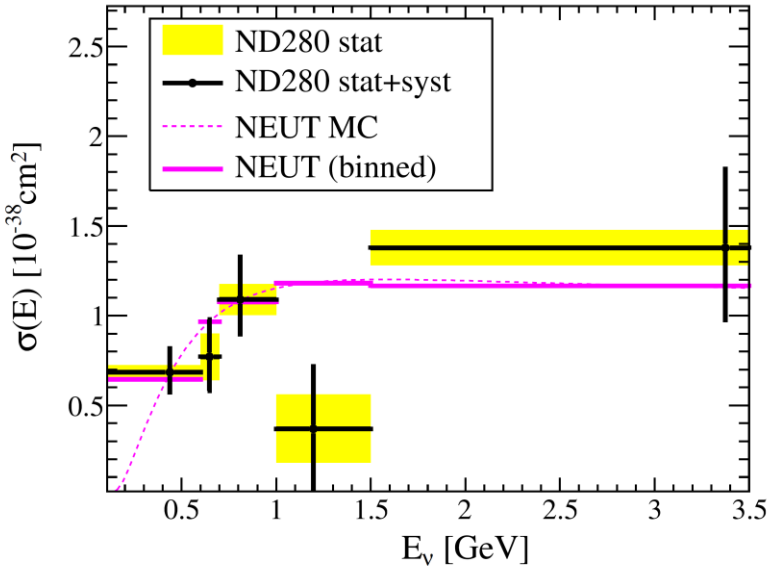


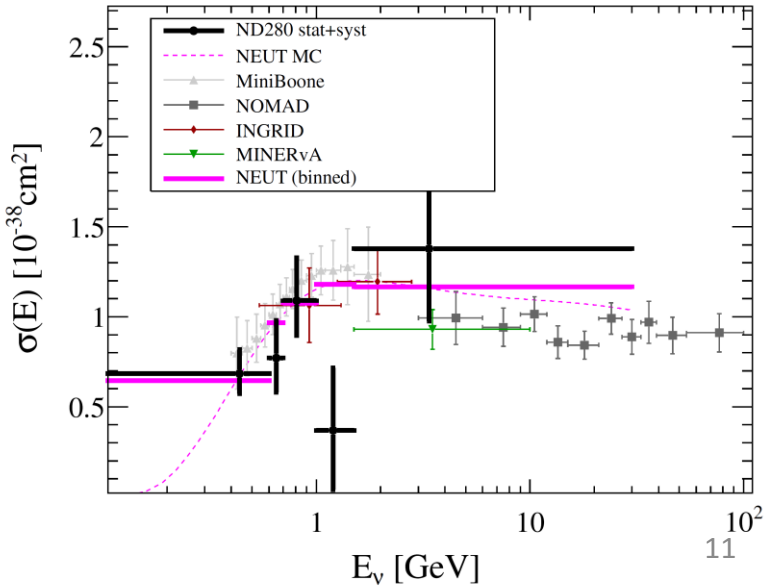
σ^{CC}(1.1 GeV) = 1.10±0.15 (10^{-38} cm^2/nucleon)
σ^{CC}(2.0 GeV) = 2.07±0.27 (10^{-38} cm^2/nucleon)
σ^{CC}(3.3 GeV) = 2.29±0.45 (10^{-38} cm^2/nucleon)

Measurement of ν_μ CCQE Cross Section on Carbon at ND280

- ND280 lets us measure energy, direction
- $\sigma^{CCQE}(FI) = 0.83 \pm 0.12\ 10^{-38}\ cm^2$
- Axial mass M^{QE}_A parameter was measured* to be $1.26^{+0.21}_{-0.18}$ GeV/c^2
  - (Shape only $1.43^{+0.28}_{-0.22}$ GeV/c^2)

*Assumptions: Smith-Moniz CCQE model with a relativistic Fermi gas nuclear model

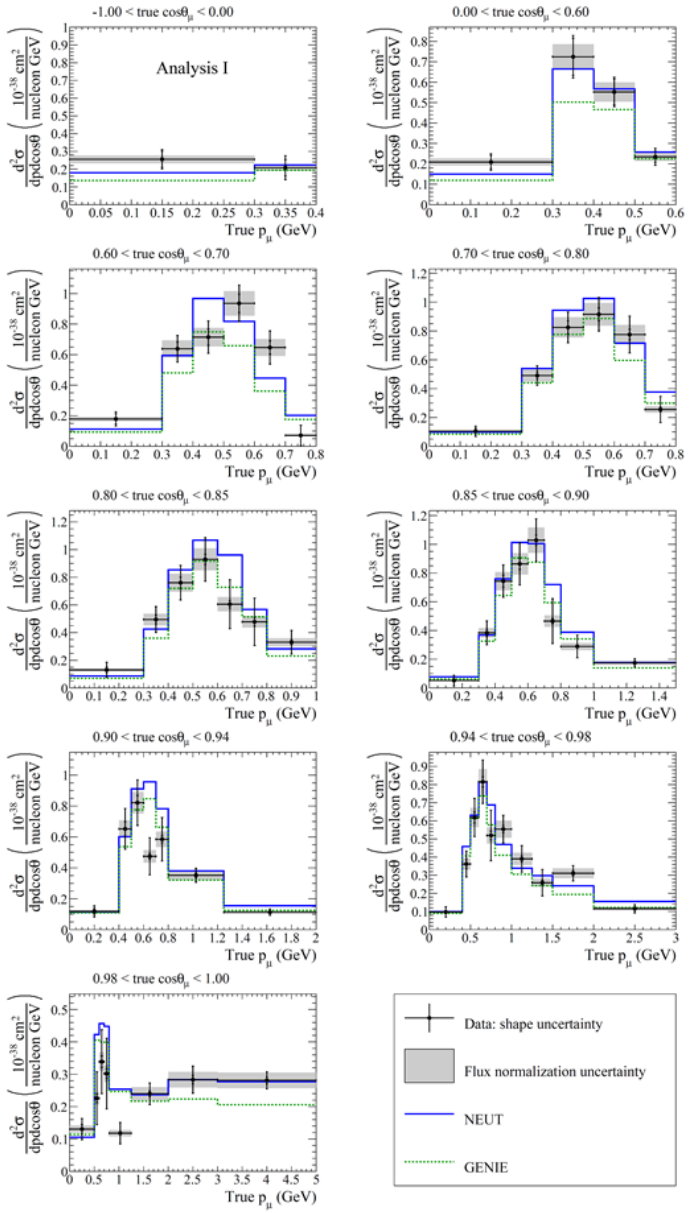




Phys. Rev. D 92, 112003

ν_μ Charged Current Interactions on Carbon; Double Differential Cross Section

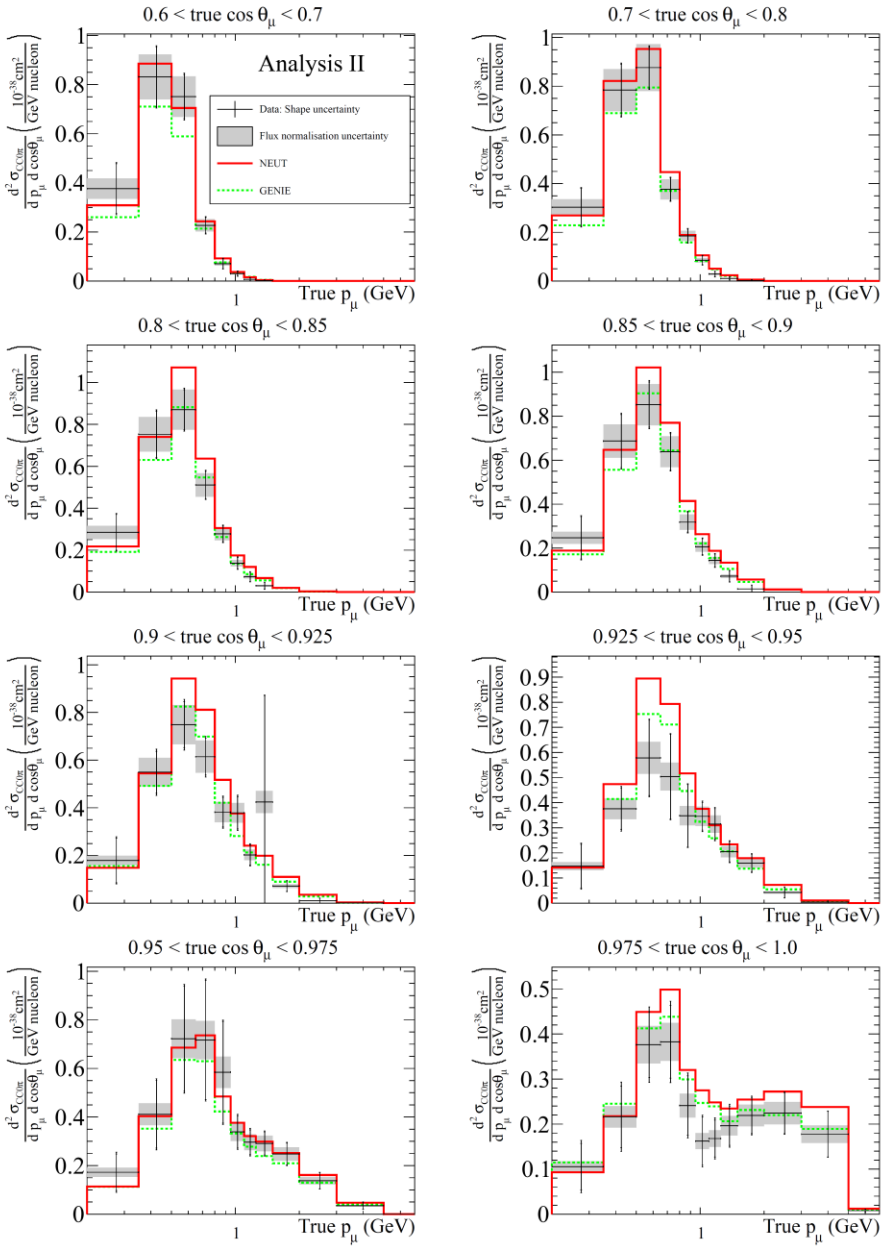
- Flux-integrated cross section in terms of ($Cos\theta_\mu$,p_μ) of outgoing μ for model independence
- Two separate analyses with different selections, backgrounds and cross section extraction methods used to demonstrate robustness of result
- Analysis 1: Binned likelihood fit
- Analysis 2: Bayesian unfolding



Double Differential Cross Section continued

- Good agreement between methods
- Compares favourably with recent models (nucleon-nucleon correlations)
- Cannot distinguish between models with current precision
- Good agreement with MC tuned to external data to describe nuclear effects

σ^{CCQE}(Full phase space)=0.417±0.047±0.005 (10^{-38}cm^2/nucleon)
σ^{CCQE}(Best S/B)=0.202±0.036±0.003 (10^{-38}cm^2/nucleon)

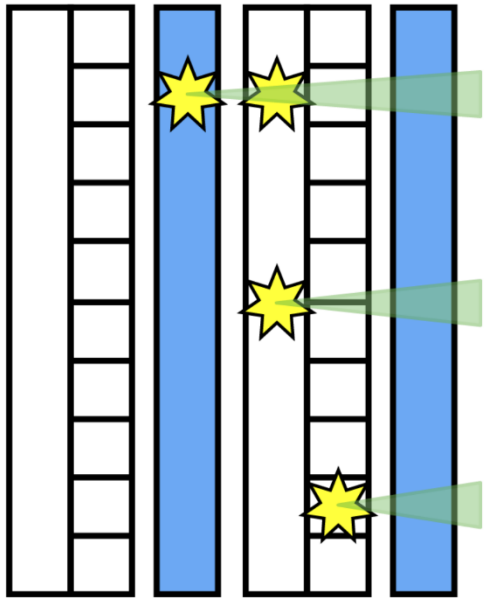


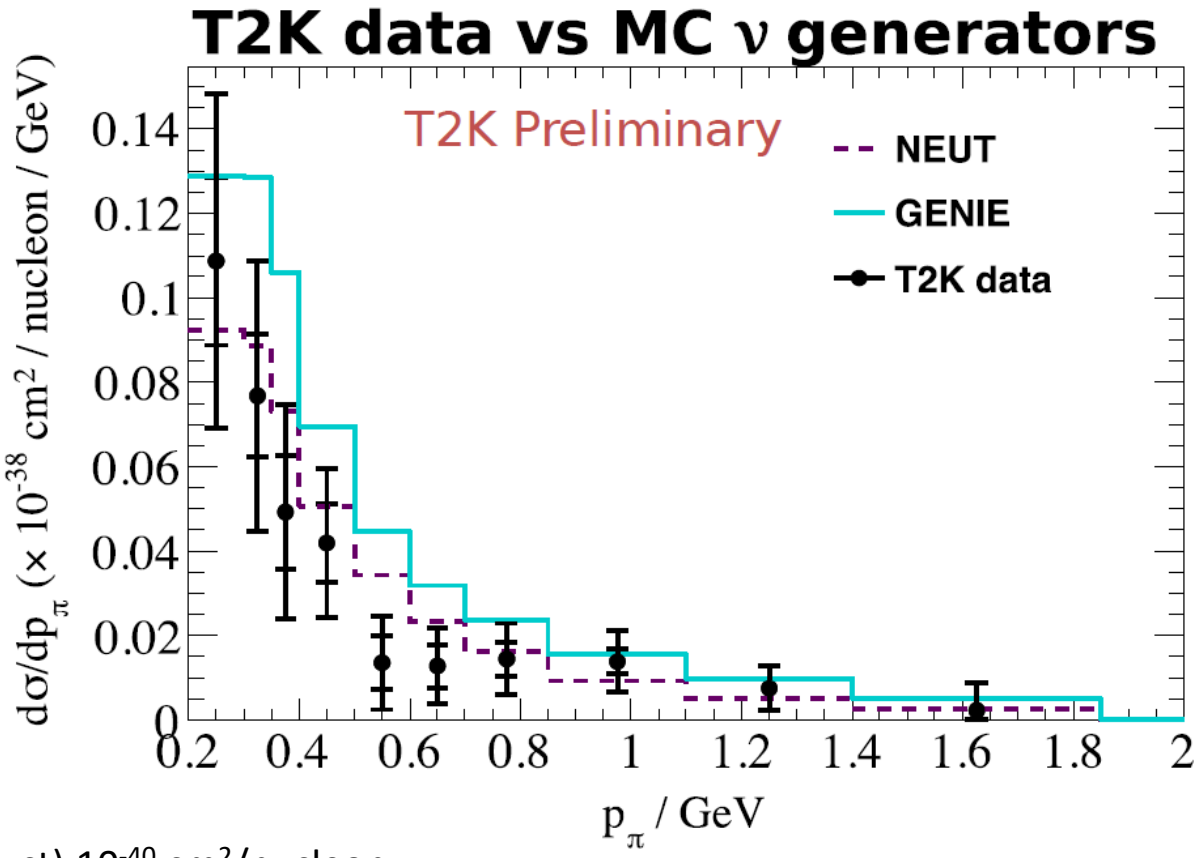
Summary of Published Results

Result	Beam	Target	Published	Summary
CCQE	On Axis	Carbon	Phys. Rev. D 91,112002	$\sigma^{CCQE}(1.94GeV)=11.95\pm0.19^{+1.82}_{-1.47}$ (10^{-39} cm^2/neutron) $\sigma^{CCQE}(0.93GeV)=10.64\pm0.37^{+2.03}_{-1.65}$ (10^{-39} cm2/neutron)
Inclusive CC	On Axis	Iron	Phys. Rev. D 93, 072002	σ^{CC}(1.1 GeV) = 1.10±0.15 (10^{-38} cm^2/nucleon) σ^{CC}(2.0 GeV) = 2.07±0.27 (10^{-38} cm^2/nucleon) σ^{CC}(3.3 GeV) = 2.29±0.45 (10^{-38} cm^2/nucleon)
CCQE	Off Axis	Carbon	Phys. Rev. D 92, 112003	σCCQE(FI)= 0.83±0.12 10^{-38} cm^2 $MAQE=1.26^{+0.21}_{-0.18}$ GeV/c^2 (Absolute) $MAQE=1.43^{+0.28}_{-0.22}$ GeV/c^2 (Shape)
CCQE double differential	Off Axis	Carbon	Accepted by PRD	σ^{CCQE}(Full phase space)=0.417±0.047±0.005 ($10^{-38}$$cm^2$/nucleon) σ^{CCQE}(Best S/B)=0.202±0.036±0.003 ($10^{-38}$$cm^2$/nucleon)

ND280 CC1π+ Cross Section on Water (preliminary)

- Selects for events interacting in water.





$\langle\sigma\rangle_{\phi}$= 4.25±0:48(stat)±1.56(syst) 10^{-40} cm^2/nucleon

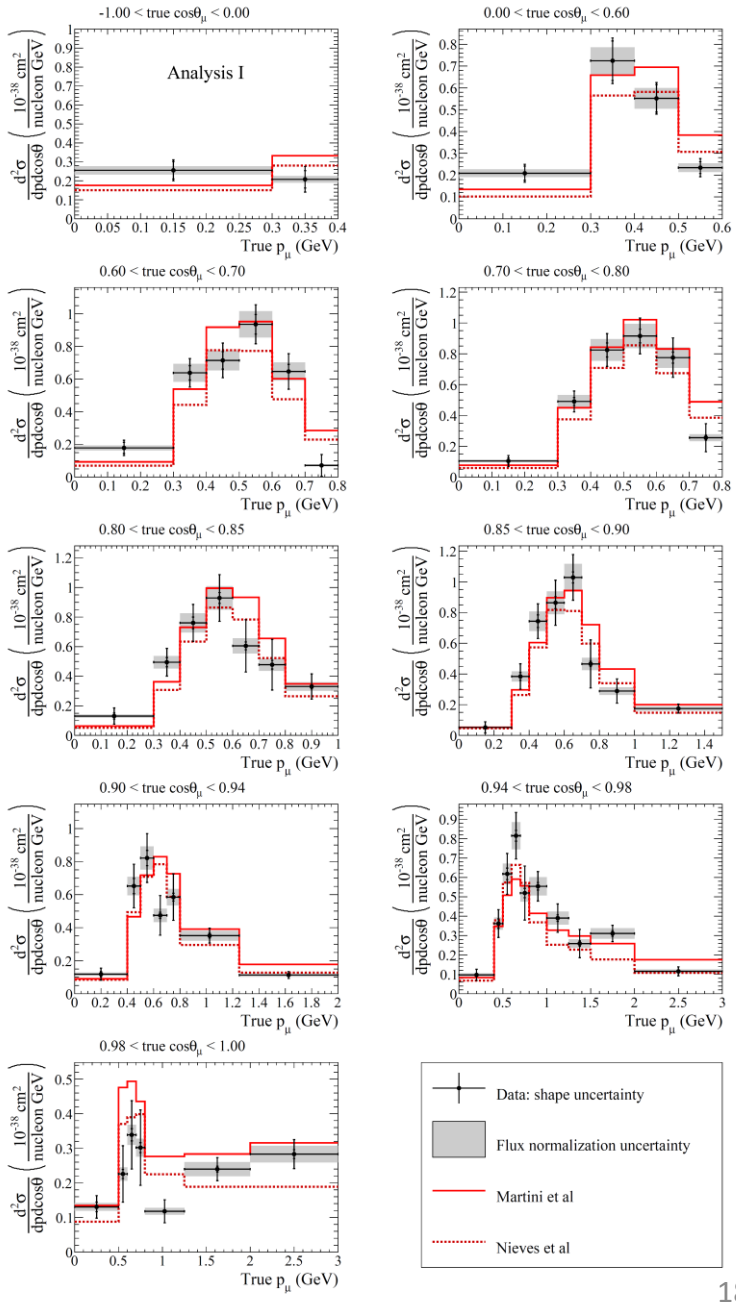
In Conclusion

- Cross-section results vital for understanding neutrino interactions
  - Vital for all other neutrino results
- T2K has many cross-section results already published
- And many on the way
  - Bigger datasets
  - Anti-neutrinos
  - Multivariate technique for ν_μ charged-current coherent pion production
  - Double-differential CCQE-like on water (unfolding and subtraction)
- Thanks!

The T2K Collaboration

Backup Slide: Double Differential vs models

- Martini et al. Phys. Rev. C 80, 065501(2008)
- Martini et al. Phys. Rev. C 81, 045502(2010)
- Nieves et al. Phys. Lett. B 707, 72(2012)
- Nieves et al. Phys. Rev. D 85, 113008(2012)



Backup Slide: Double Differential vs models – with and without correlations