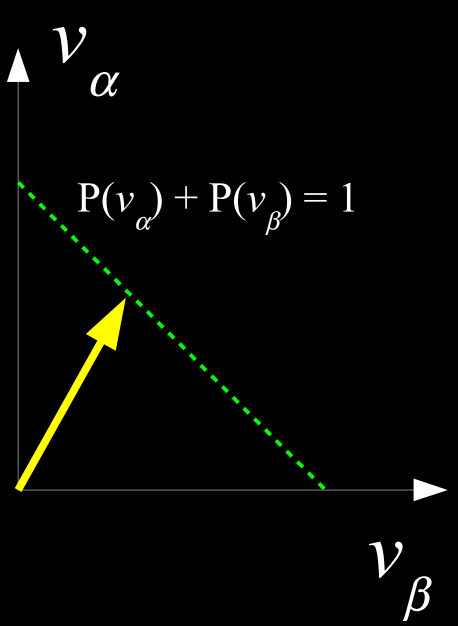
Recent Results from the T2K Near Detector

Xianguo LU/ 卢显国 University of Oxford
on behalf of the T2K Collaboration

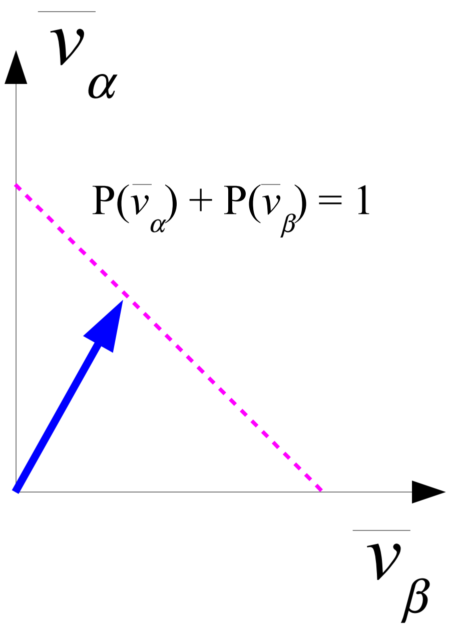
NuFACT 2018, Blacksburg, 15 August 2018

Neutrino

– Oscillation



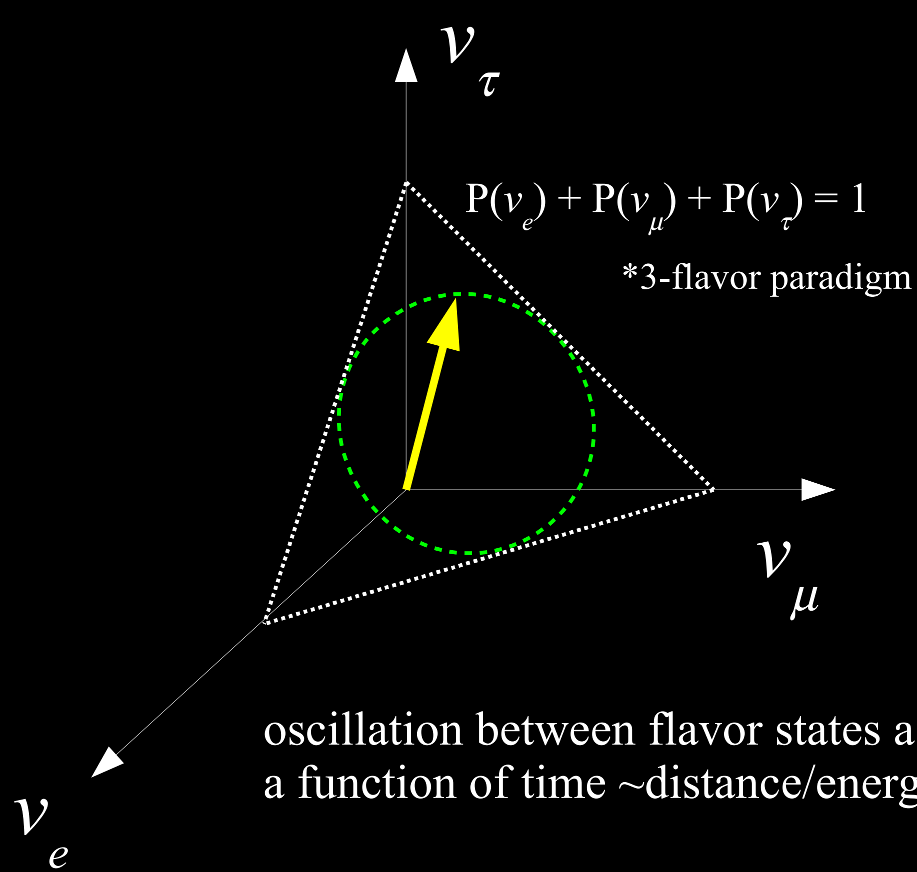
oscillation between flavor states as
a function of time ~distance/energy



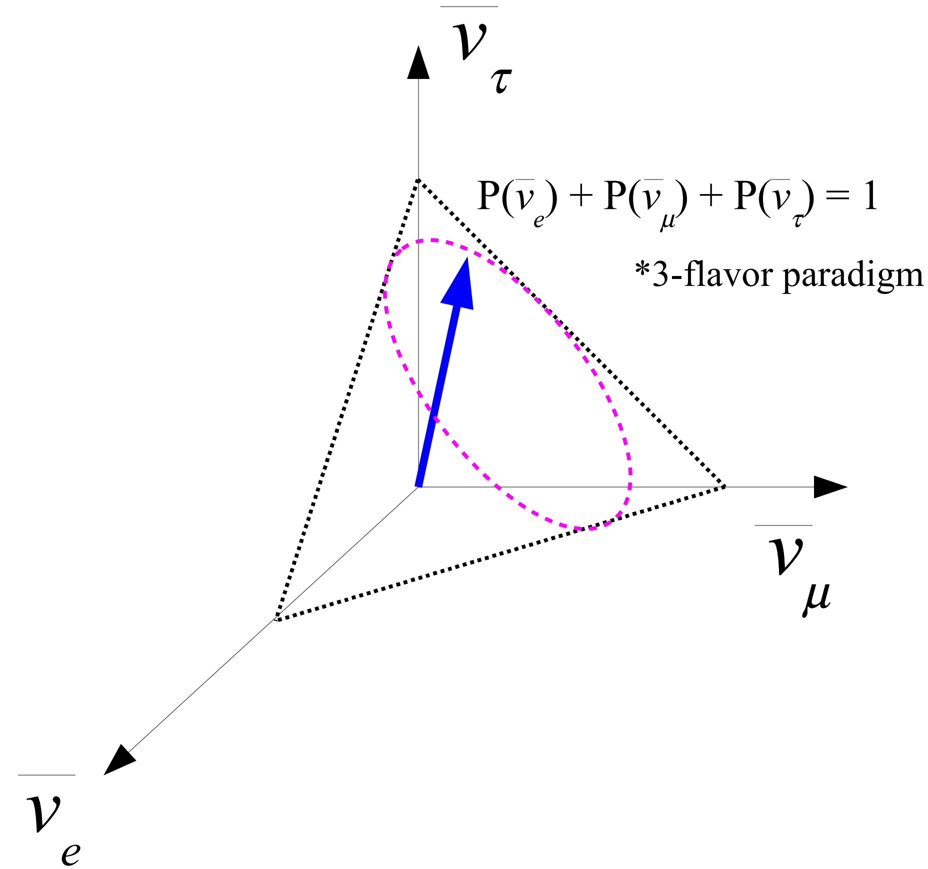
Only 2 flavors, same oscillation behavior

Neutrino

– CP violation

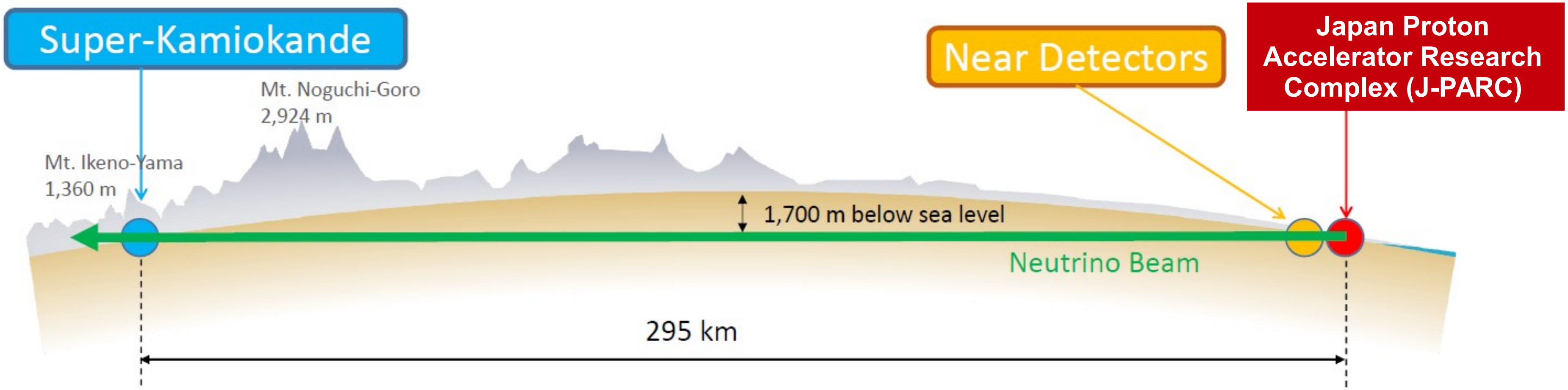


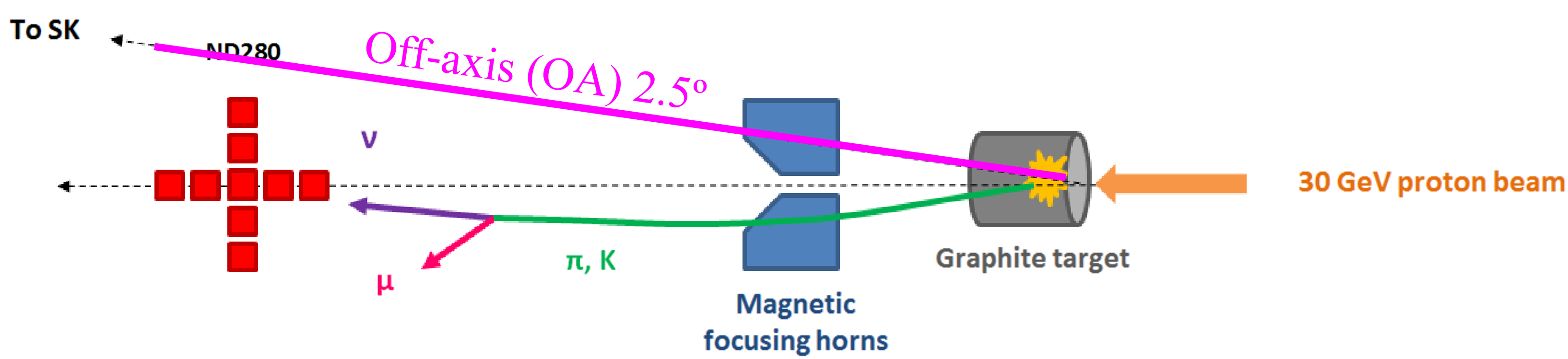
oscillation between flavor states as a function of time ~distance/energy



Oscillation property difference
→ CP violation

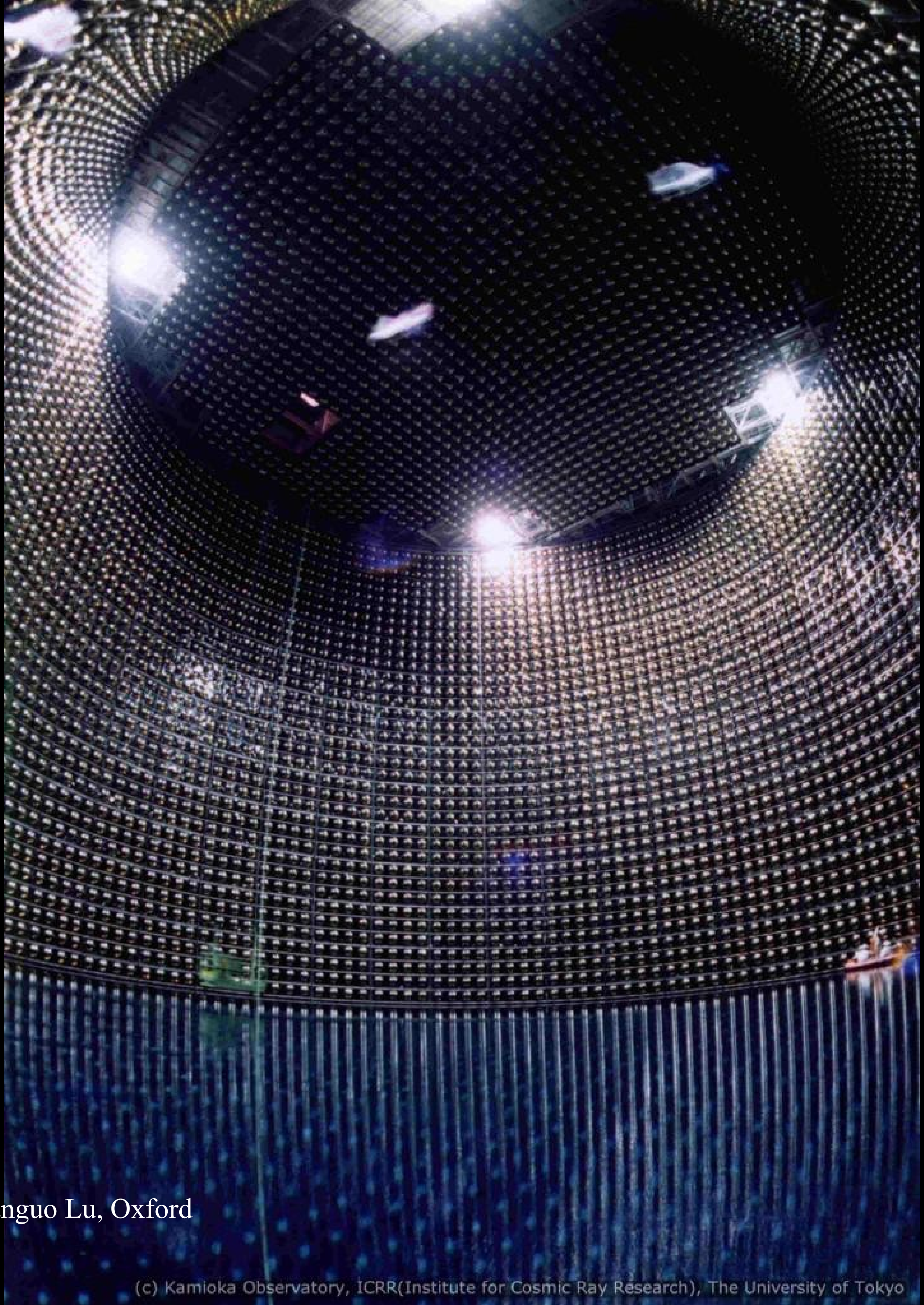
The T2K Experiment





Charge selection on neutrino parents

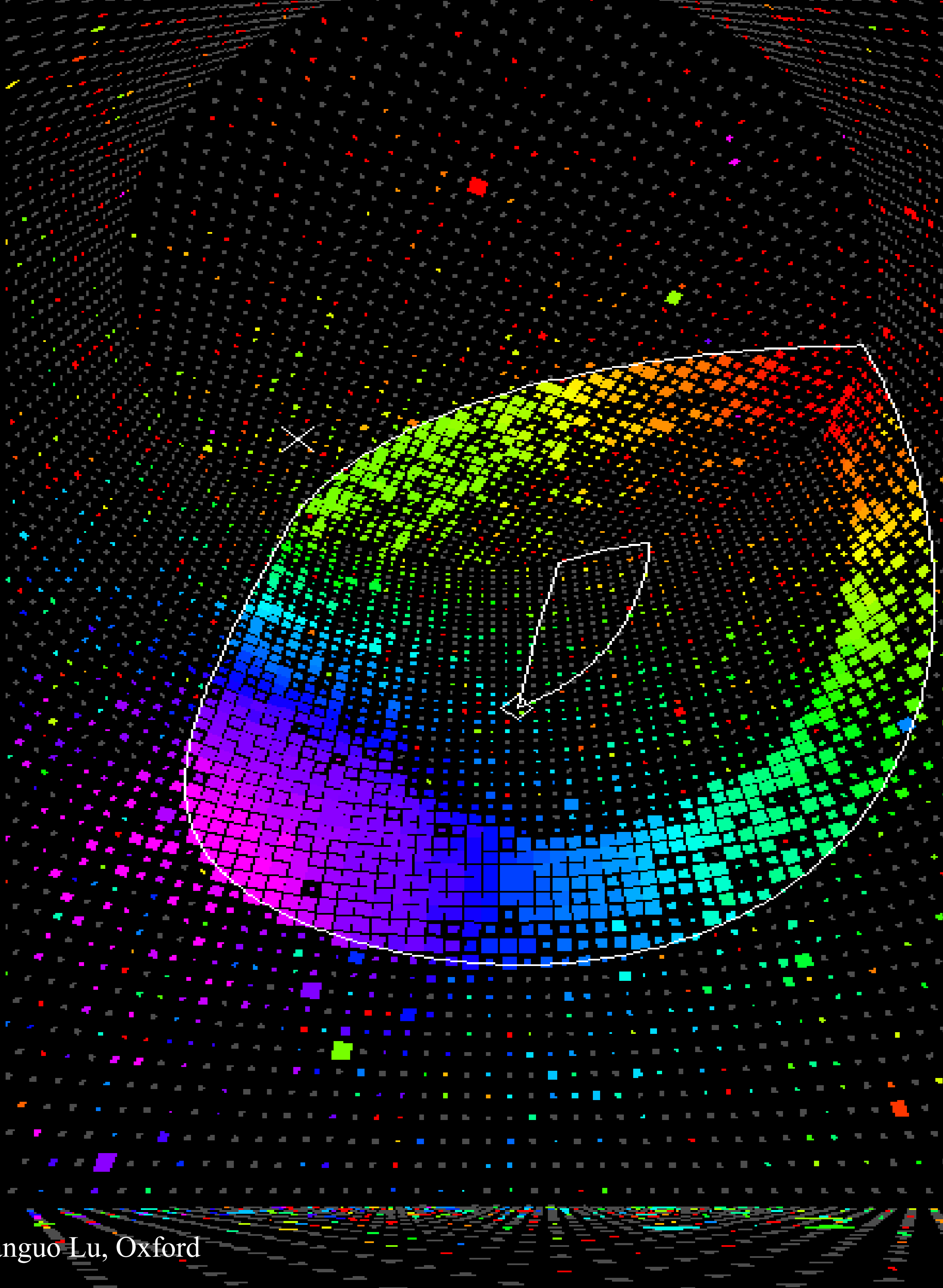
$\rightarrow \nu$ or $\bar{\nu}$ mode

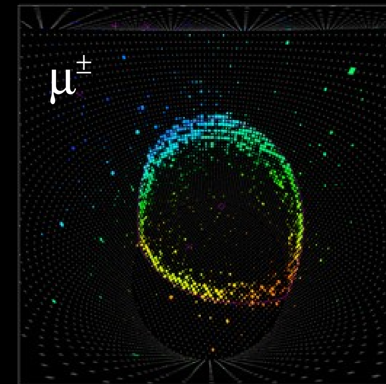


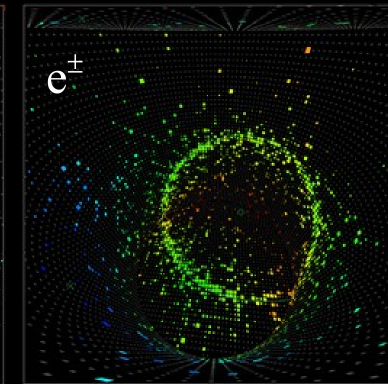
T2K far detector: Super-Kamiokande

- 50 kt water-Cherenkov
- 11129 20-inch PMTs in inner detector; 1885 8-inch PMTs in outer veto detector

Source: http://www-sk.icrr.u-tokyo.ac.jp/sk/detector/image-e.html







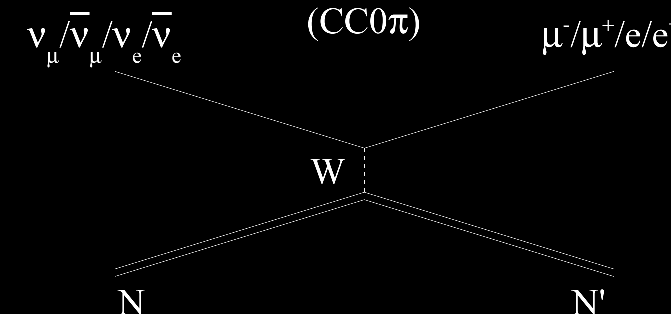
μ, e identification

→ detect propagated ν from J-PARC

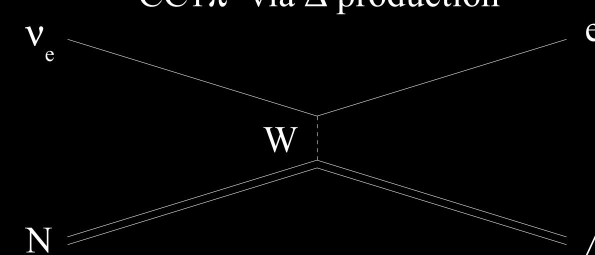
→ E_ν rec. from μ/e kinematics

Charged-Current Quasi-Elastic

(CC0π)



CC1π^+ via Δ production



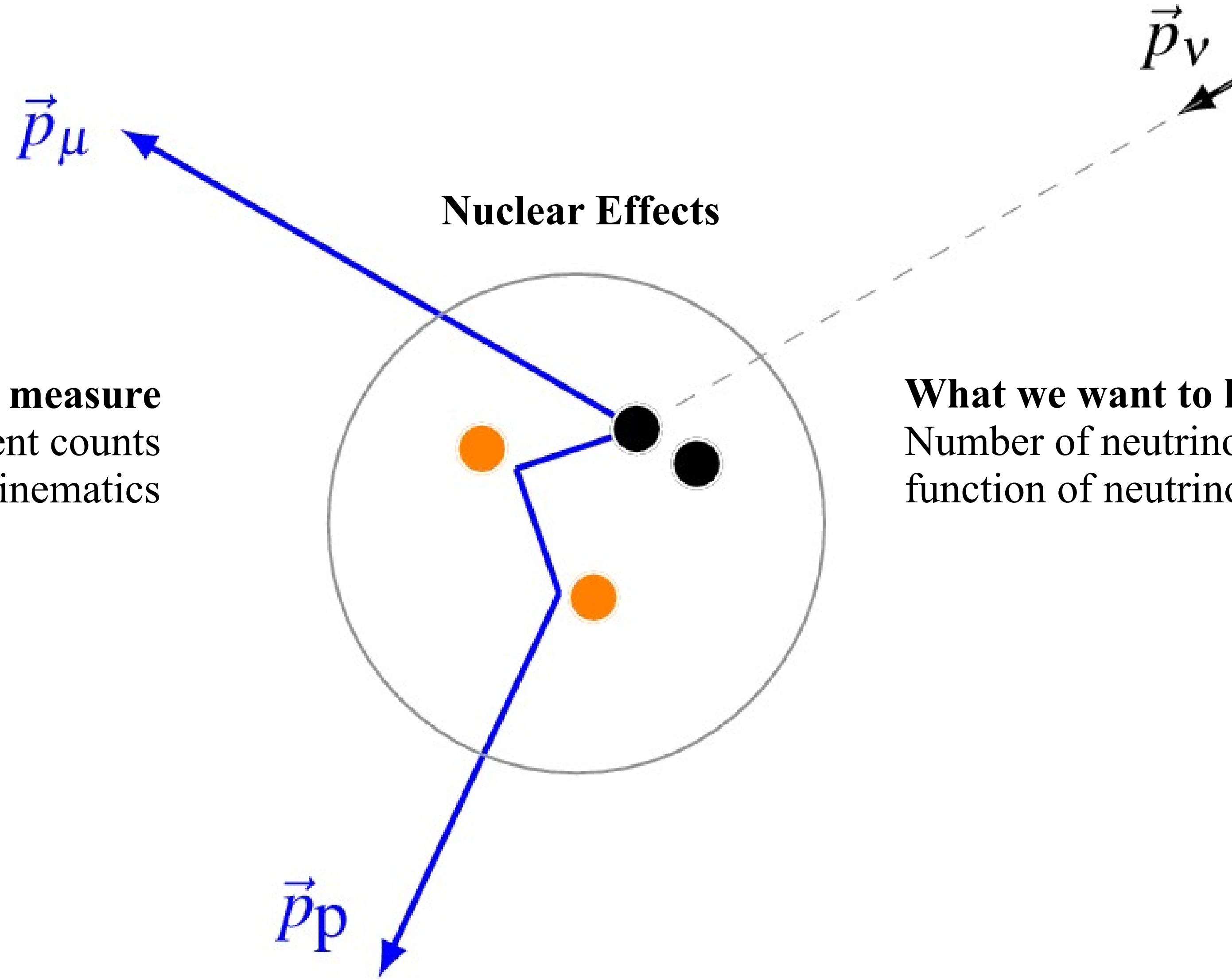
(No CC1π^- sample due to π^- absorption)

Xianguo Lu, Oxford

Source: http://www.ps.uci.edu/~tomba/sk/tscan/th

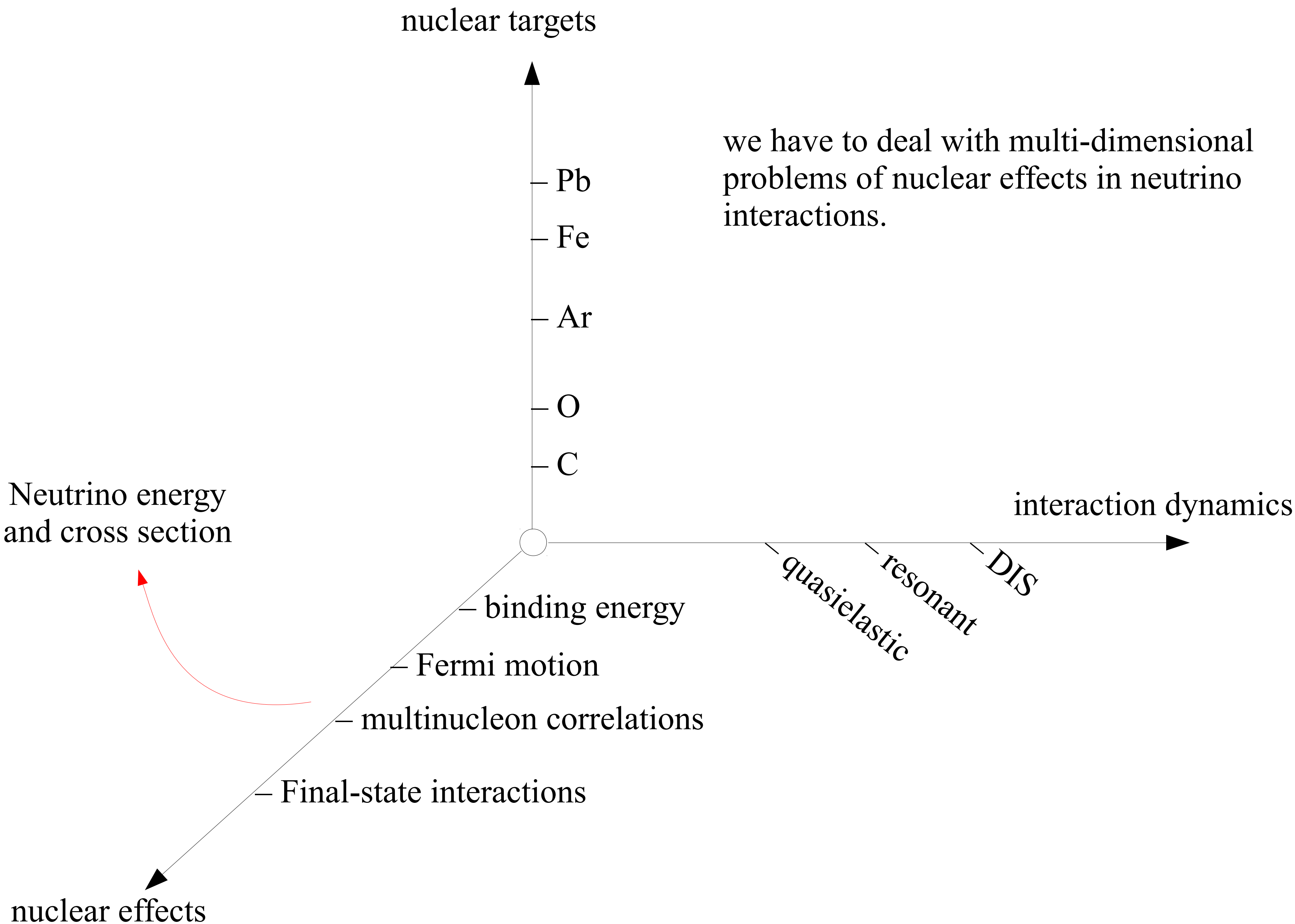
The big picture of neutrino detection in oscillation measurements

What we measure
Event counts
Final-state kinematics



What we want to know about
Number of neutrinos as a function of neutrino energy

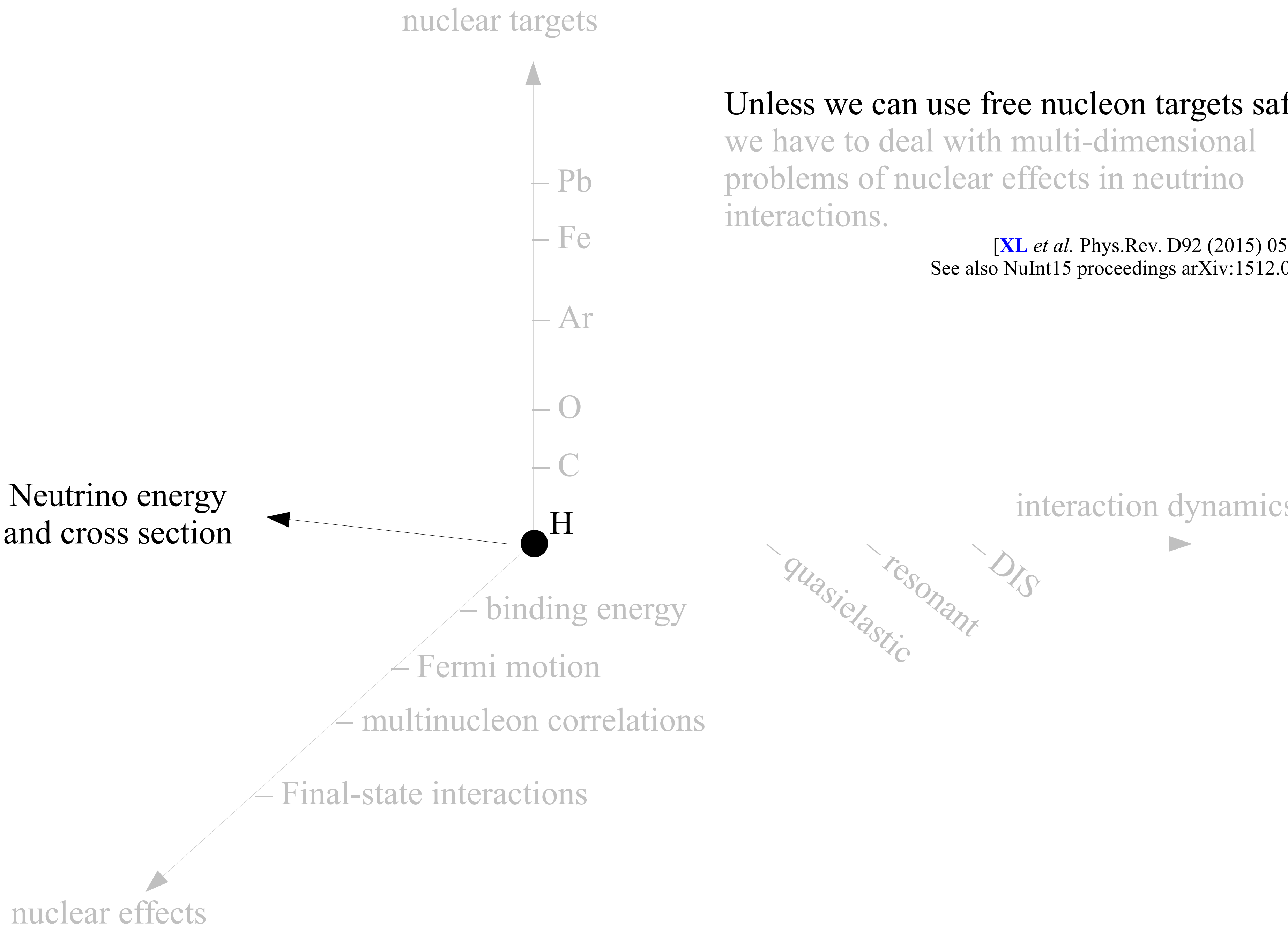
we have to deal with multi-dimensional problems of nuclear effects in neutrino interactions.



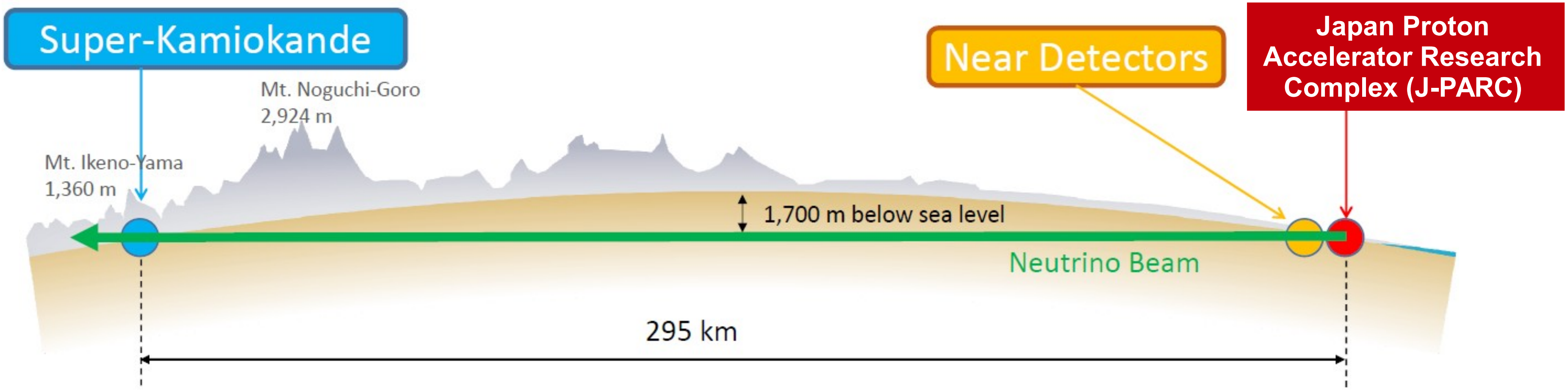
Unless we can use free nucleon targets safely,

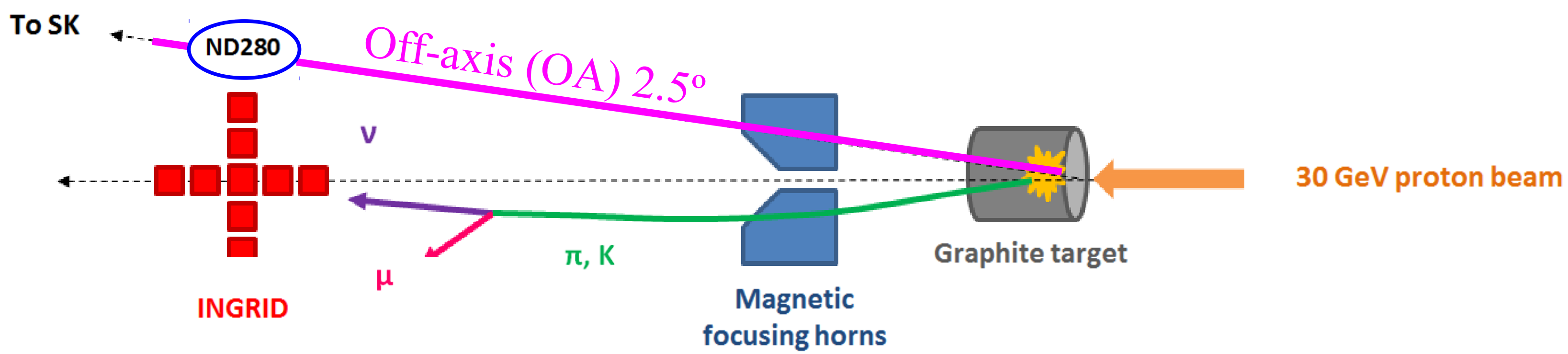
we have to deal with multi-dimensional problems of nuclear effects in neutrino interactions.

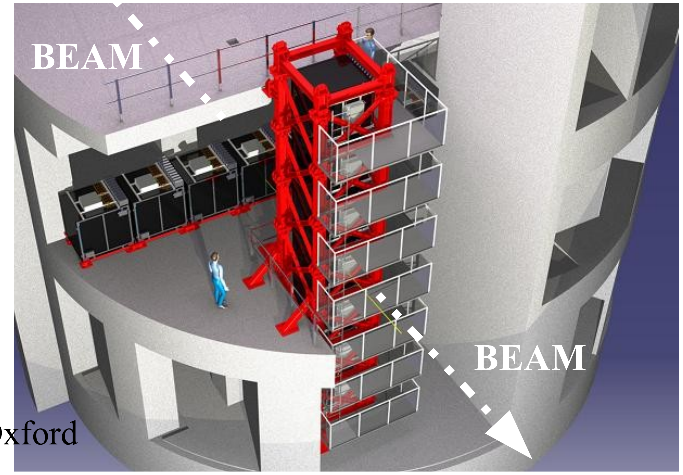
[**XL** *et al.* Phys.Rev. D92 (2015) 051302, See also NuInt15 proceedings arXiv:1512.09042]



The T2K Experiment



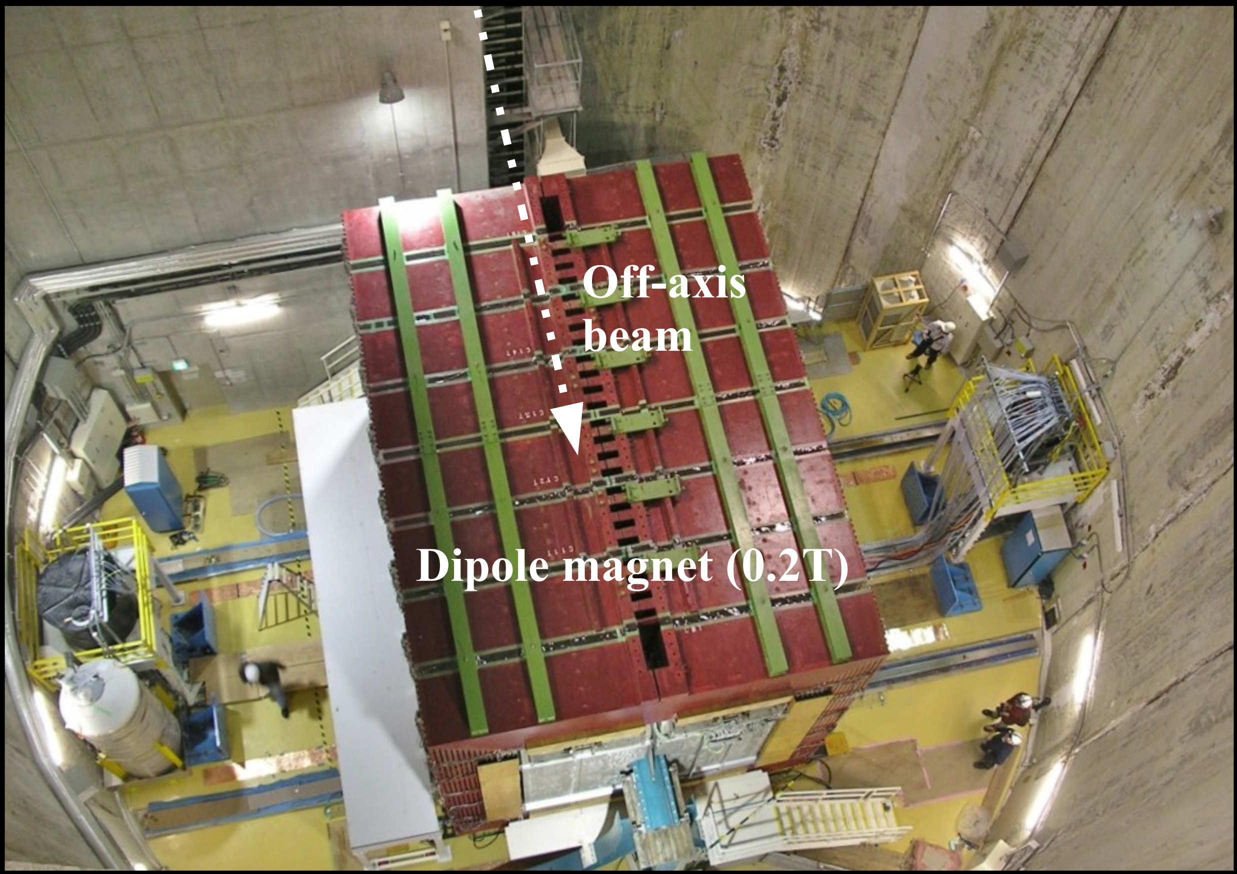




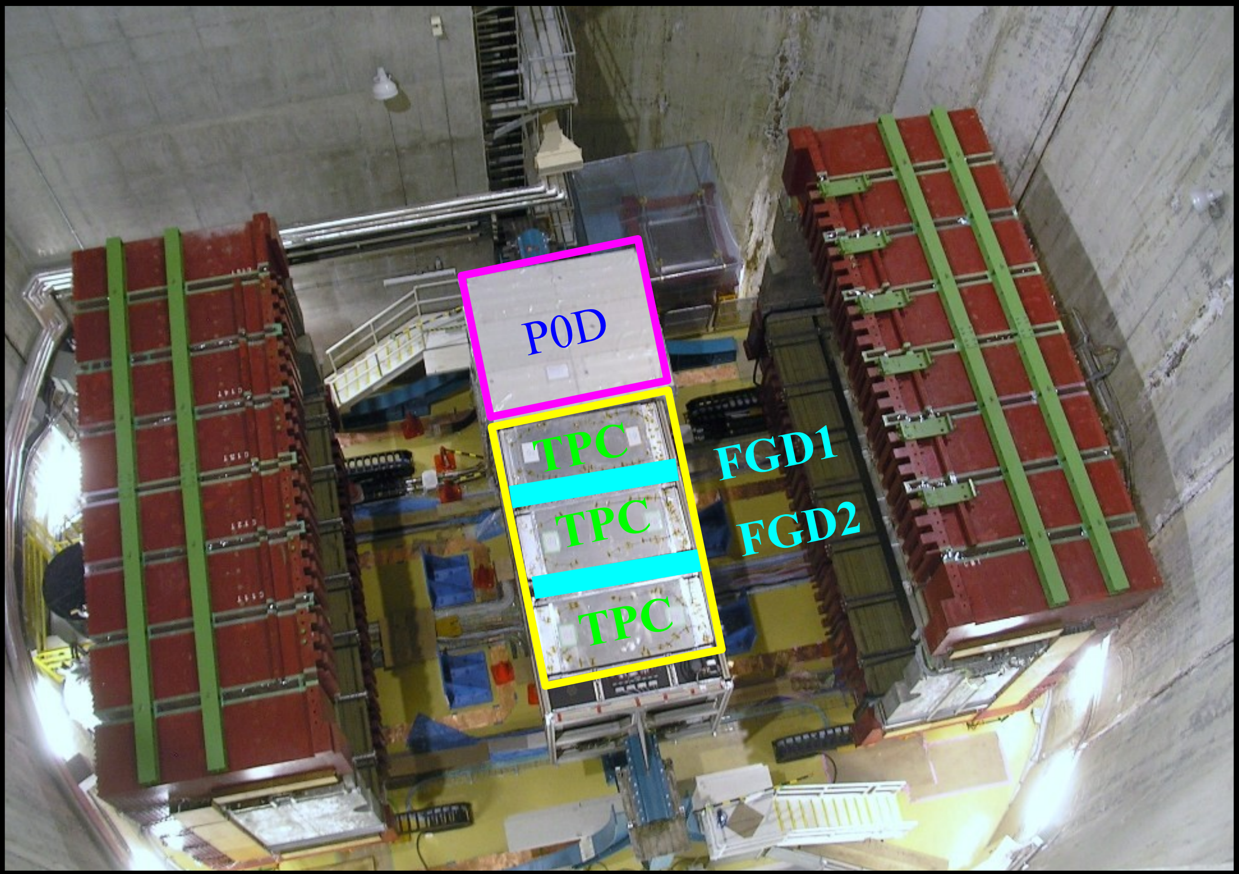
Crossed arrays of 9-ton iron-scintillator detectors

- Monitor neutrino beam stability and beam spatial profile
- estimate beam flux uncertainty
- stand-alone cross-section measurements

T2K off-axis near detector (ND280)



T2K off-axis near detector (ND280)



P0D: π^0 Detector
Scintillator-based ECal
CH w/ and w/o H_2O

Tracker:
- FGD: Fine-Grained Detector
  1. CH target
  2. CH + H_2O target
- Time Projection Chamber (TPC)

- constrain beam flux and cross section for oscillation analysis
- stand-alone neutrino interaction measurements

Cross-section measurements from T2K

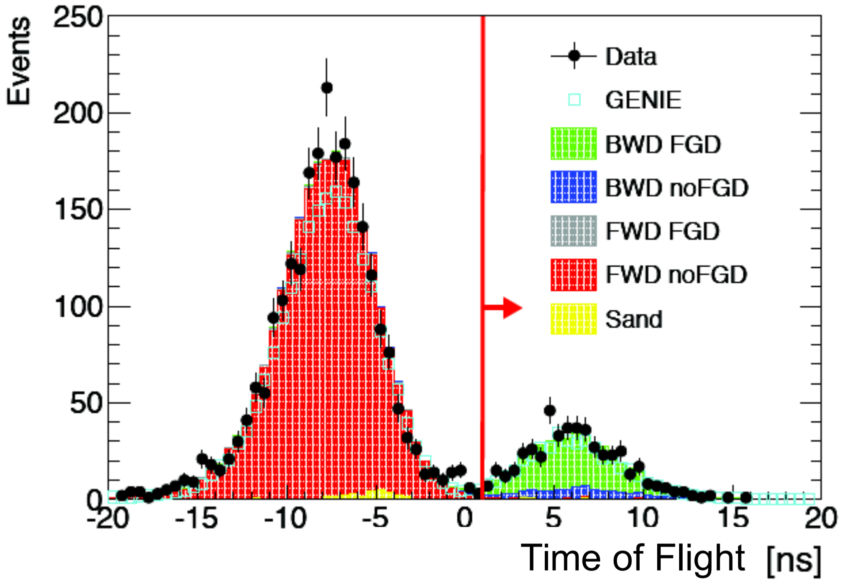
	CC inclusive	CC QE(-like)	CC π
H_2O	[$\bar{\nu}_\mu/\nu_\mu$:1706.04257] ν_e:1503.08815	ν_μ:1708.06771	ν_μ:1605.07964
CH	ν_μ:1801.05148 $\bar{\nu}_\mu/\nu_\mu$:1706.04257 ν_e:1407.7389 ν_μ:1407.4256 ν_μ:1302.4908	ν_μ:1802.05078 ν_μ:1602.03652 ν_μ:1503.07452 ν_μ:1411.6264	ν_μ:1604.04406
Fe	ν_μ:1509.06940 [ν_μ:1407.4256]		

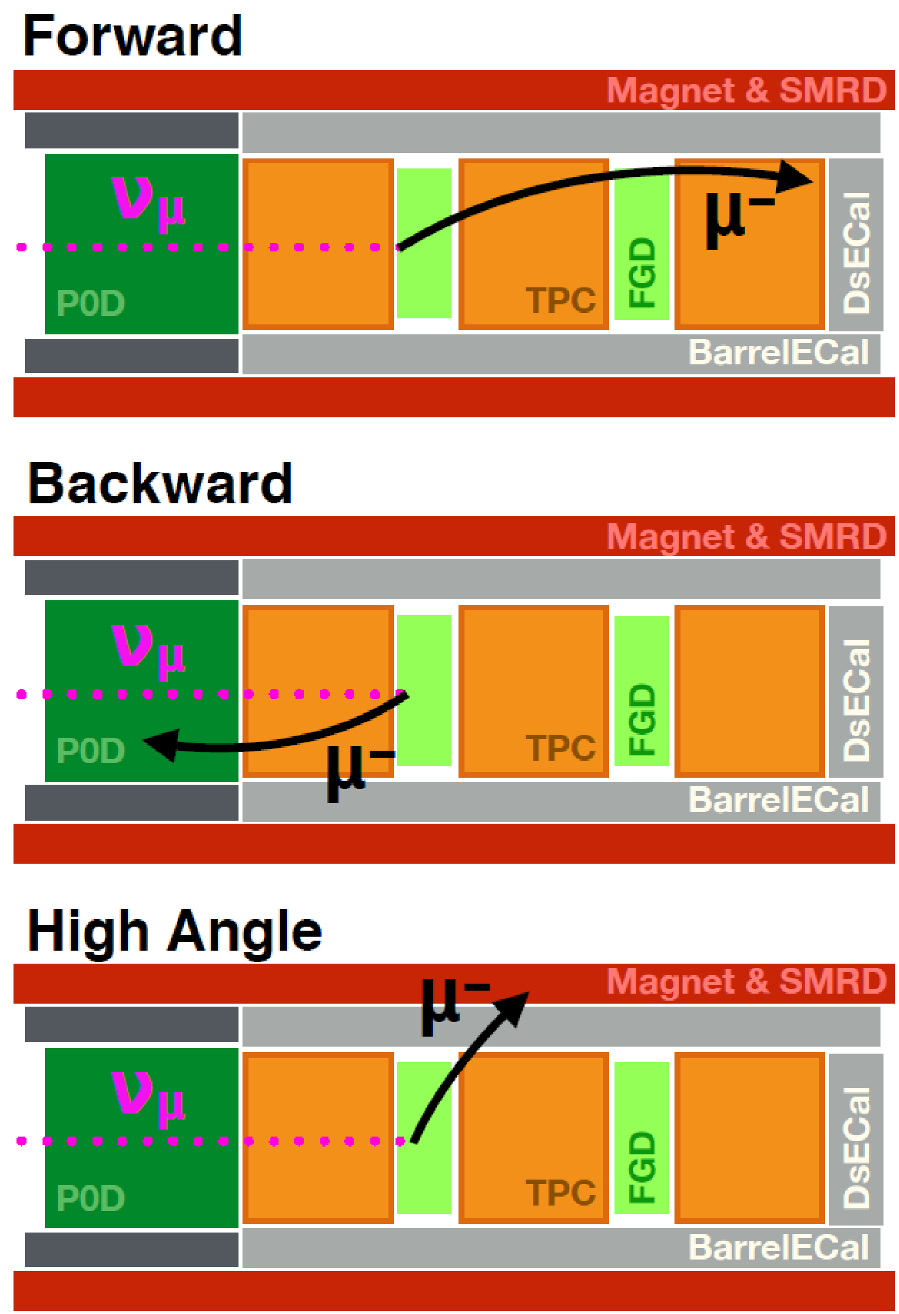
	NC Elastic	NC π
H_2O	ν_μ:1403.3140	ν_μ:1704.07467

CC: Charged Current
NC: Neutral Current

(A) T2K measurement of ν_μ CC inclusive cross section on CH

- Signal event: 1 μ^-, **4π phase space** [arXiv:1801.05148 to appear in PRD]





Better resemblance to SK acceptance

(A) T2K measurement of ν_μ CC inclusive cross section on CH

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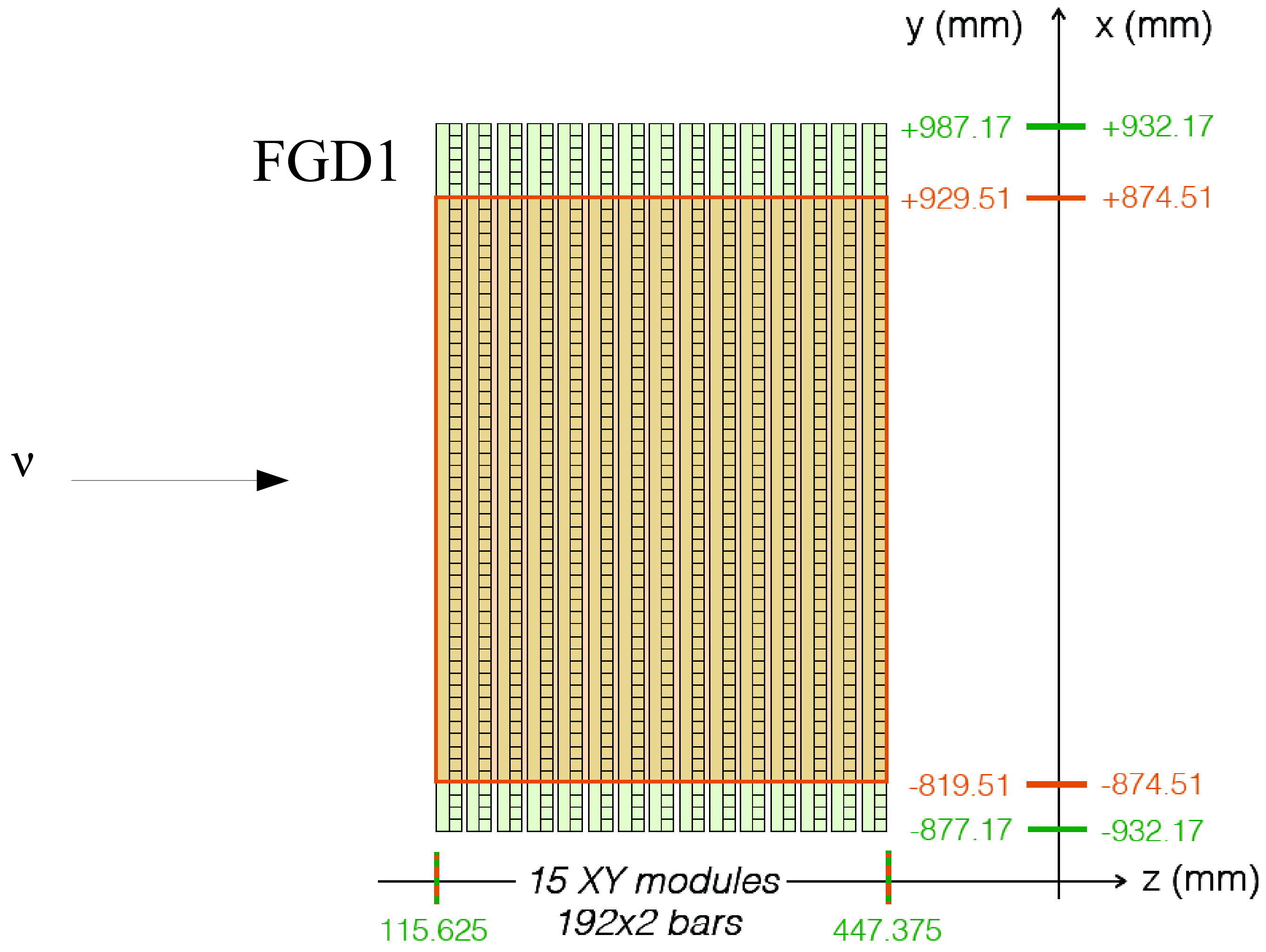

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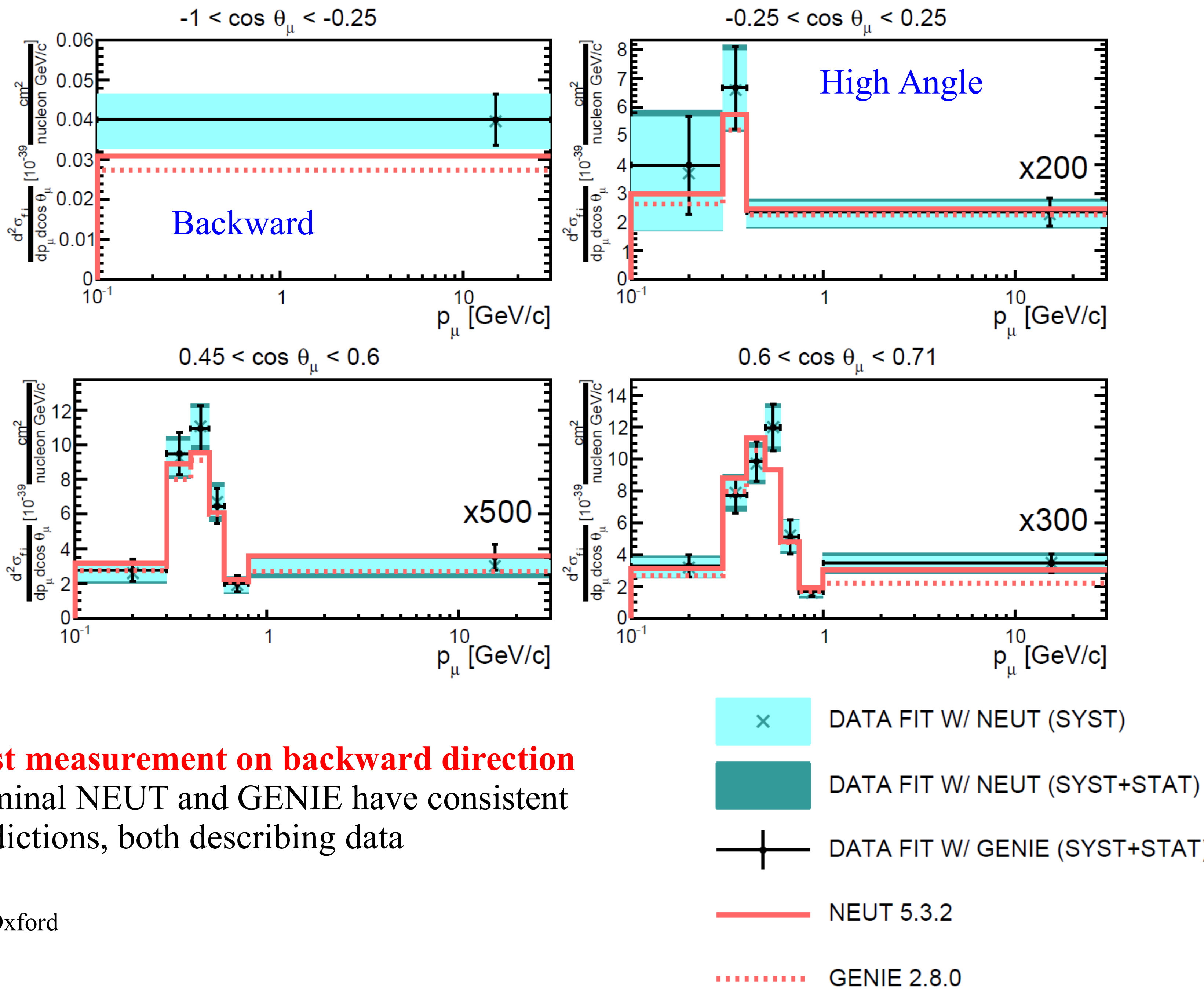


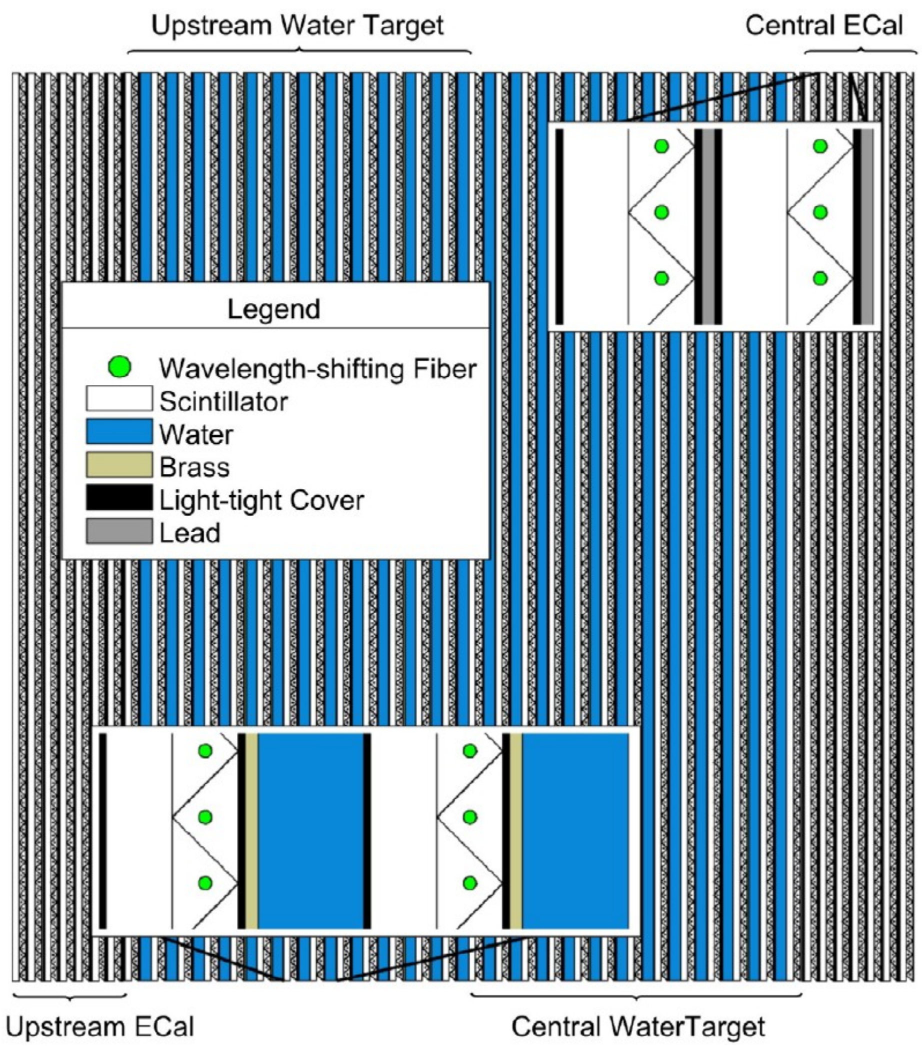
- **First measurement on backward direction**
- Nominal NEUT and GENIE have consistent predictions, both describing data

(B) T2K measurement of ν_μ CC0π cross section on water

- Signal event: 1 μ^-, **0 π,** no other mesons, restricted phase space [Phys.Rev. D97 (2018) 012001, on CH: Phys.Rev. D93 (2016) 112012]

P0D

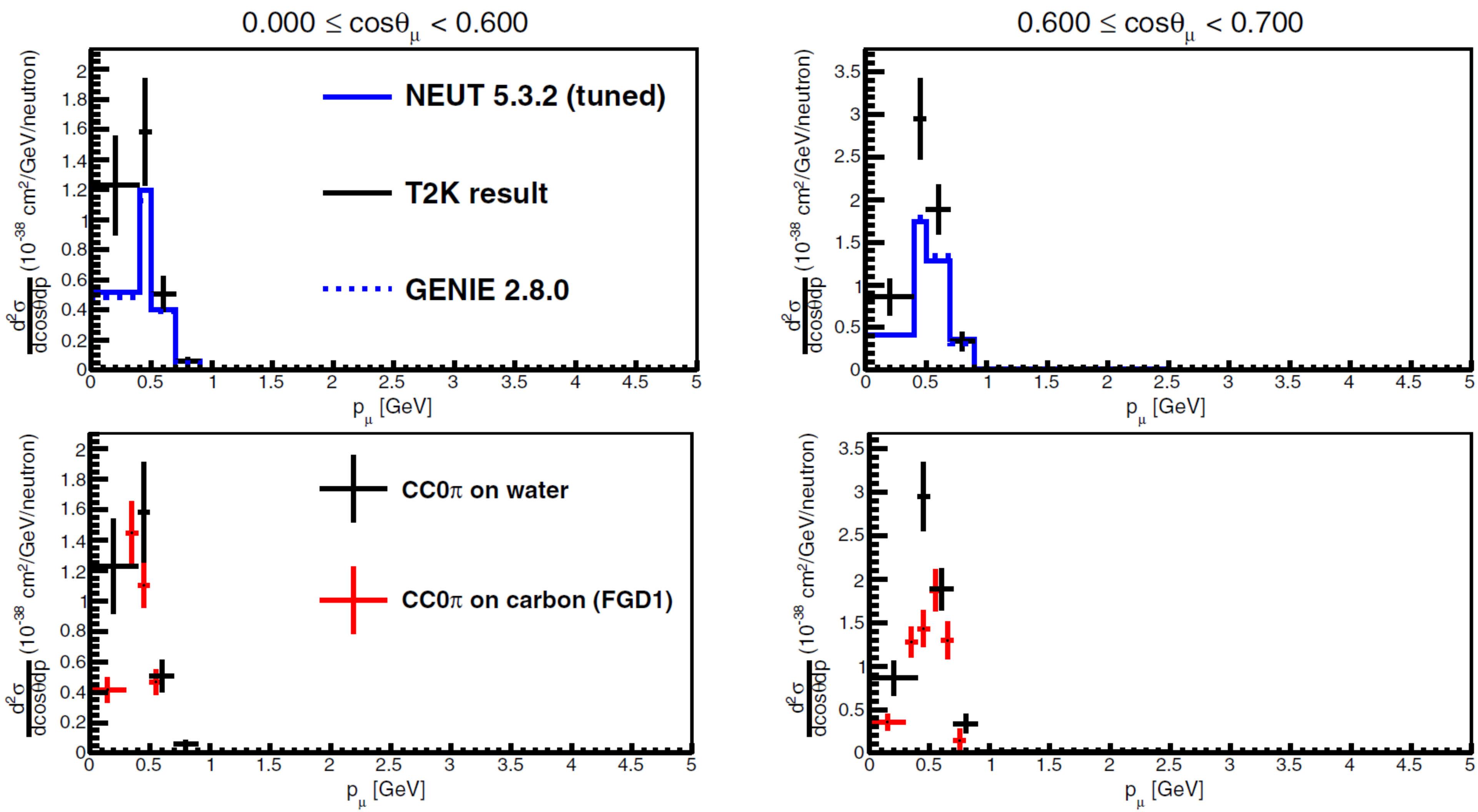
ν



Cross section on water obtained by subtraction:
$H_2O = (CH+H_2O) - CH$ = WaterIn – WaterOut

(B) T2K measurement of ν_μ CC0π cross section on water

- Signal event: 1 μ^-, **0 π,** no other mesons, restricted phase space [Phys.Rev. D97 (2018) 012001, on CH: Phys.Rev. D93 (2016) 112012]

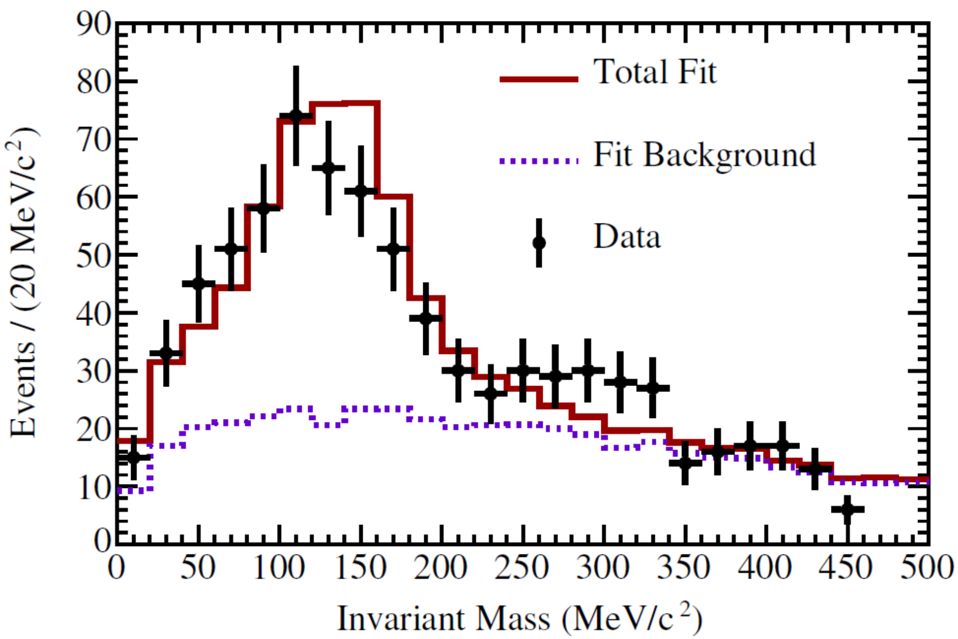


- Dominant signal channel in SK, important systematics in C/O difference.
- **Model deficit at high-angle region**
- **C/O difference mainly at high angle**

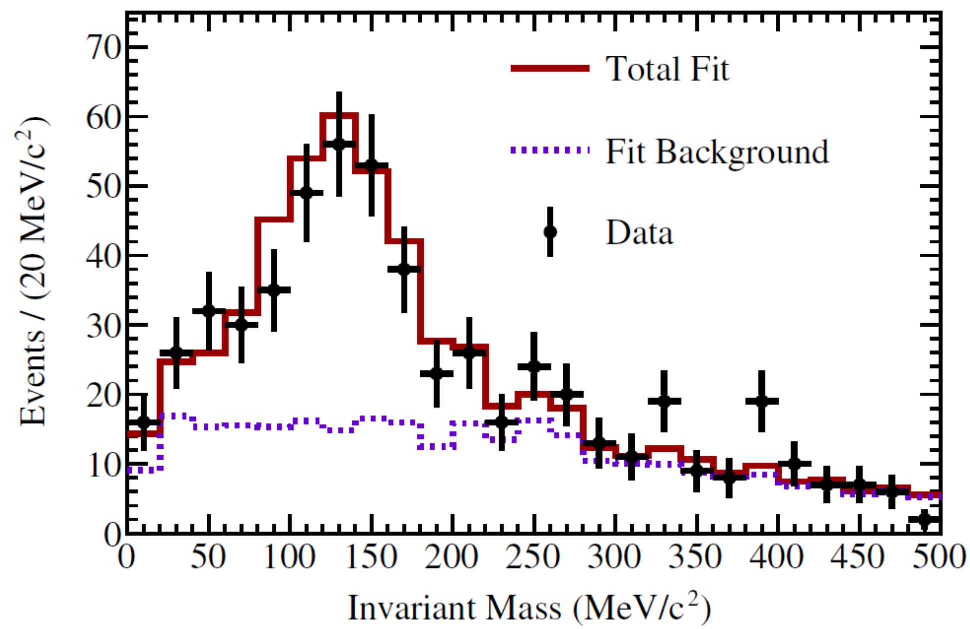
(C) T2K measurement of ν_μ NC1π^0 cross section on water

- Signal event: 0 μ^-, **1 π^0**, no other mesons, restricted ph [Phys.Rev. D97 (2018) 032002]

P0D as target, same subtraction scheme



Water-**in** configuration



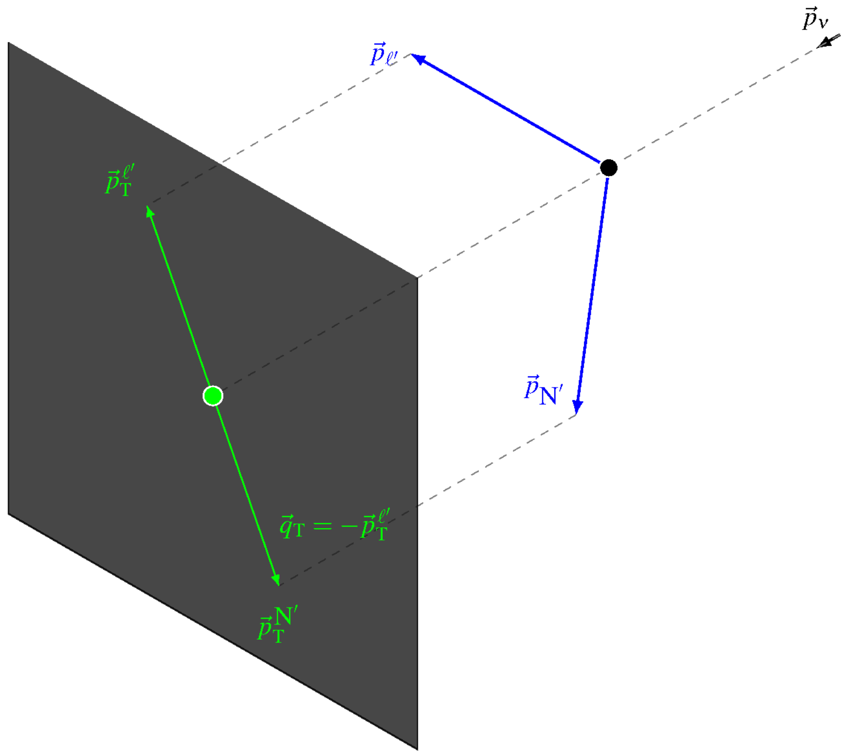
Water-**out** configuration

- One of the largest background sources for ν_e appearance in SK
- π^0 on water by subtraction 106 ± 41 (stat) ± 69 (sys) events
- Measured/NEUT = 0.68 ± 0.26 (stat) ± 0.44 (sys) ± 0.12 (flux) → consistent within errors

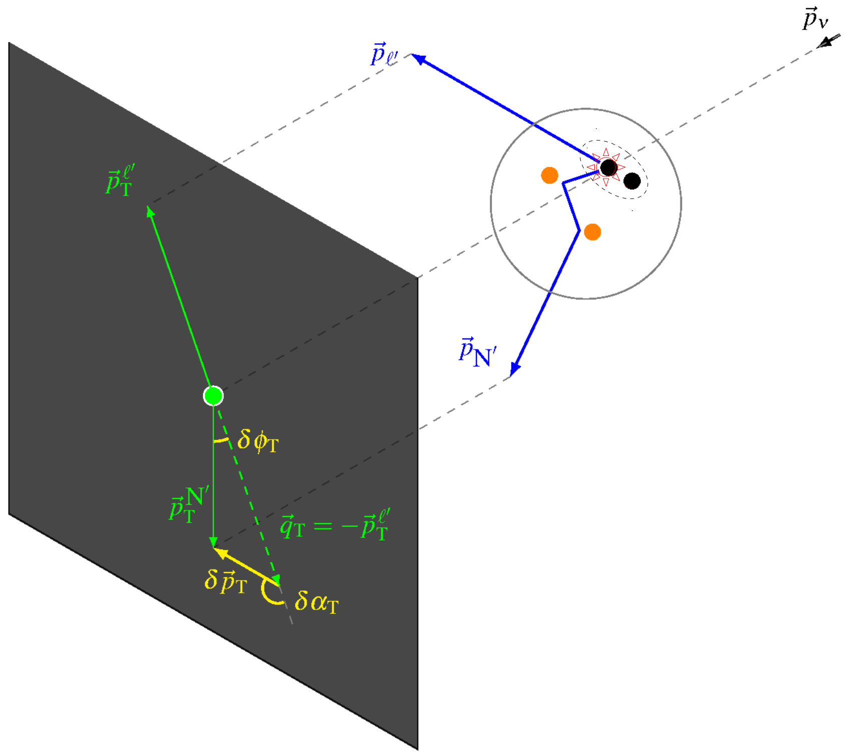
Transverse kinematic imbalances

$$\delta\vec{p}_{\mathrm{T}} = \vec{p}_{\mathrm{T}}^{\mathrm{N}} - \Delta\vec{p}_{\mathrm{T}}$$

Convolution of Fermi motion and **Intra-nuclear Momentum Transfer** (**IMT**) due to FSI, resonance production, 2p2h etc.



Stationary nucleon target

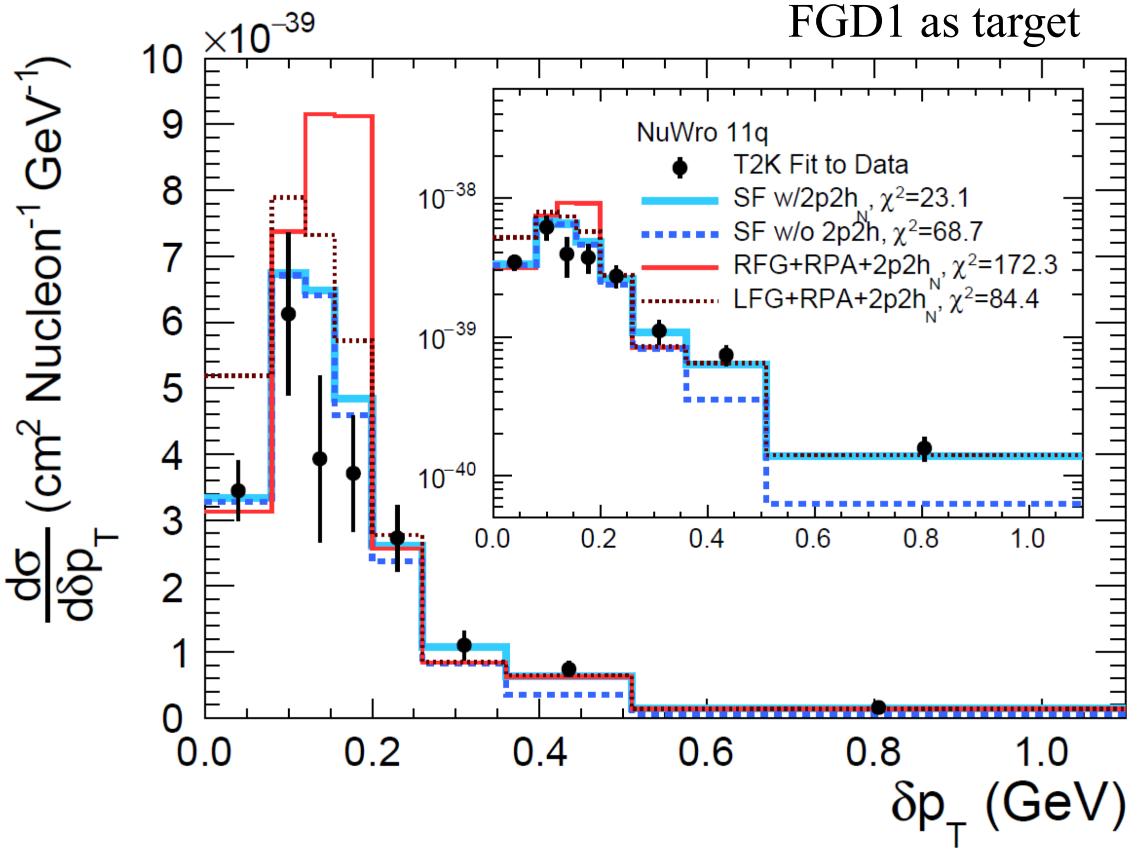


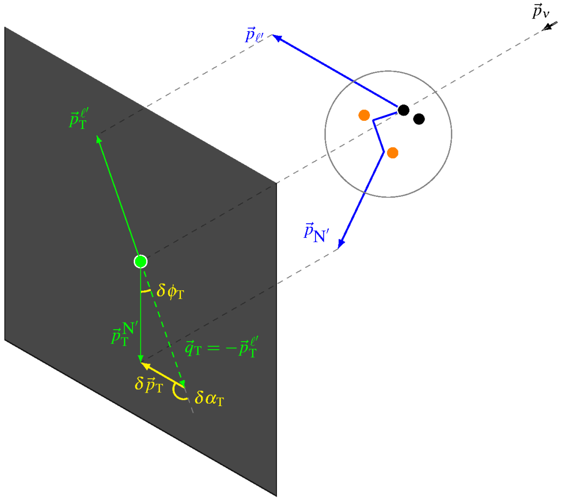
Nuclear target

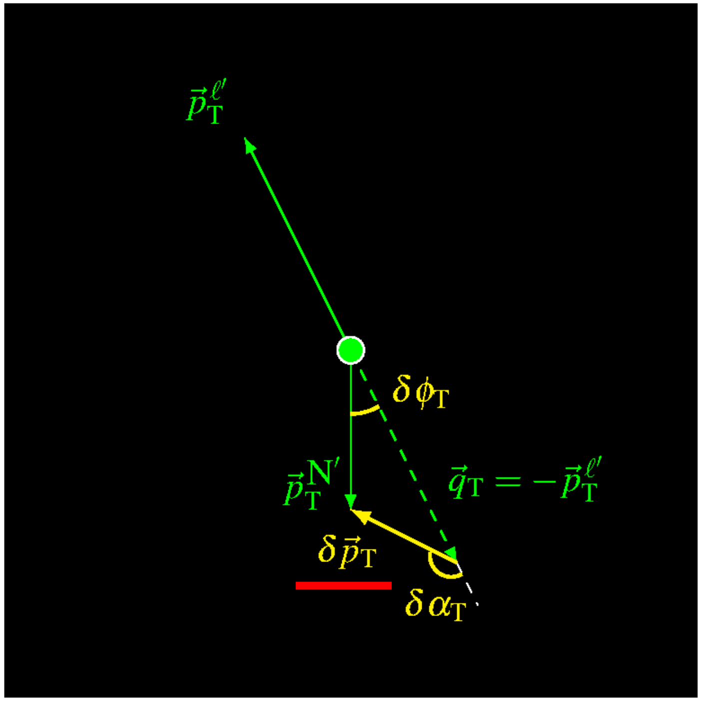
[**XL** *et al.* Phys.Rev. C94 (2016) 015503]

(D) T2K measurement of single-transverse kinematic imbalances (ν_μ CCNp0π CH)

- Signal event: 1 μ^-, **0 π**, at least 1 p, restricted ph [arXiv:1802.05078 to appear in PRD]







Separation of nuclear effects:

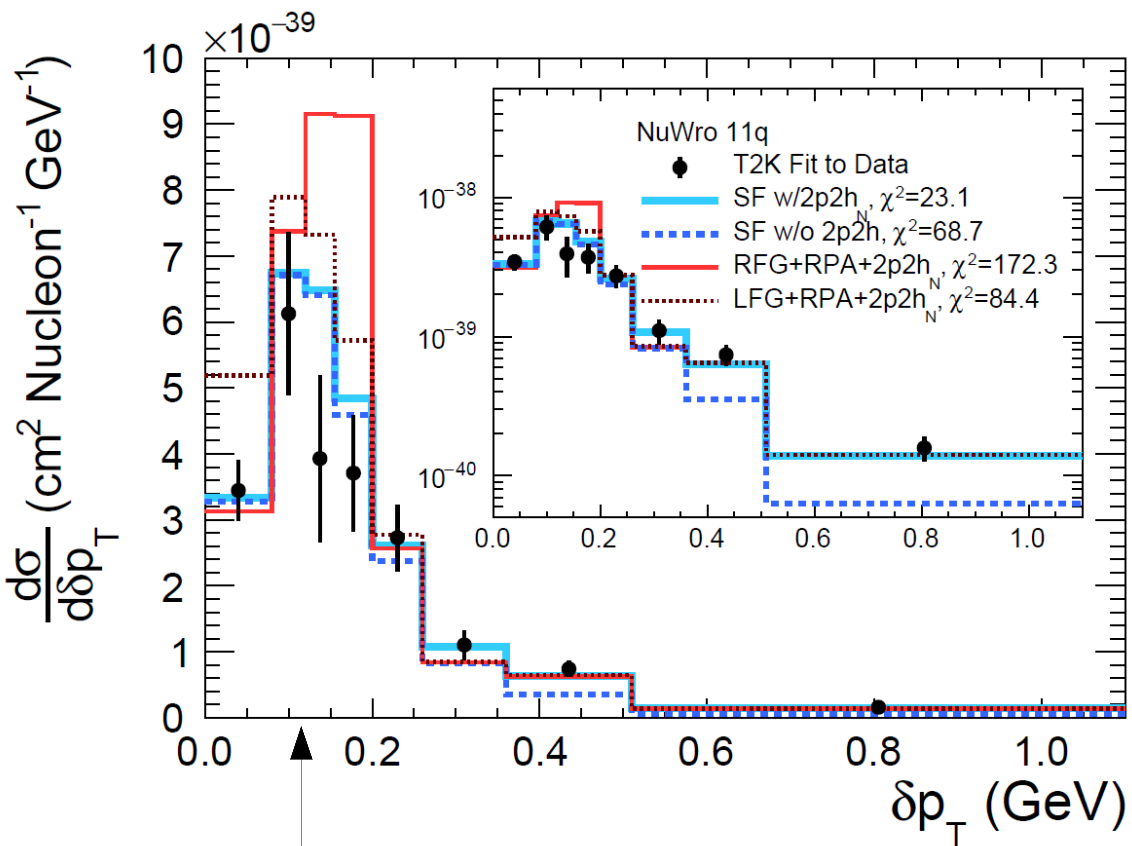
$$\delta\vec{p}_{\mathrm{T}} = \vec{p}_{\mathrm{T}}^{\,\mathrm{N}} - \Delta\vec{p}_{\mathrm{T}}$$

Fermi motion

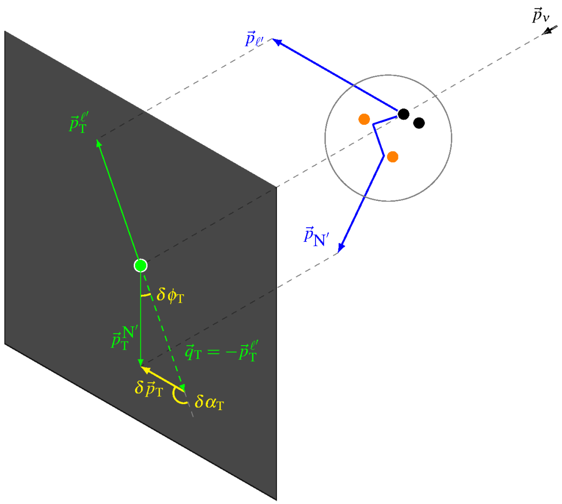
Intra-nuclear momentum transfer (IMT) in resonance production, 2p2h and FSI

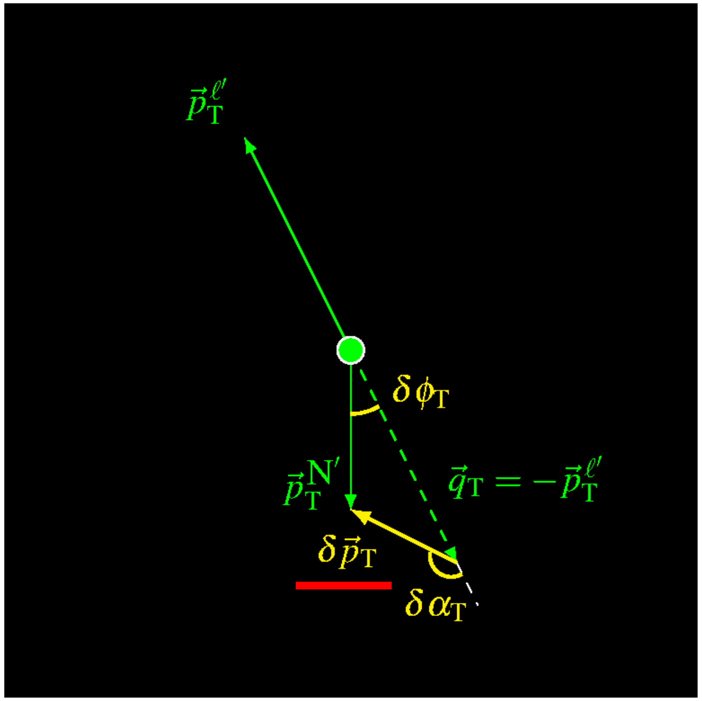
(D) T2K measurement of single-transverse kinematic imbalances (ν_μ CCNp0π CH)

- Signal event: 1 μ^-, **0 π**, at least 1 p, restricted ph [arXiv:1802.05078 to appear in PRD]



Fermi motion: Spectral Function (SF) is preferred





(D) T2K measurement of single-transverse kinematic imbalances (ν_μ CCNp0π CH)

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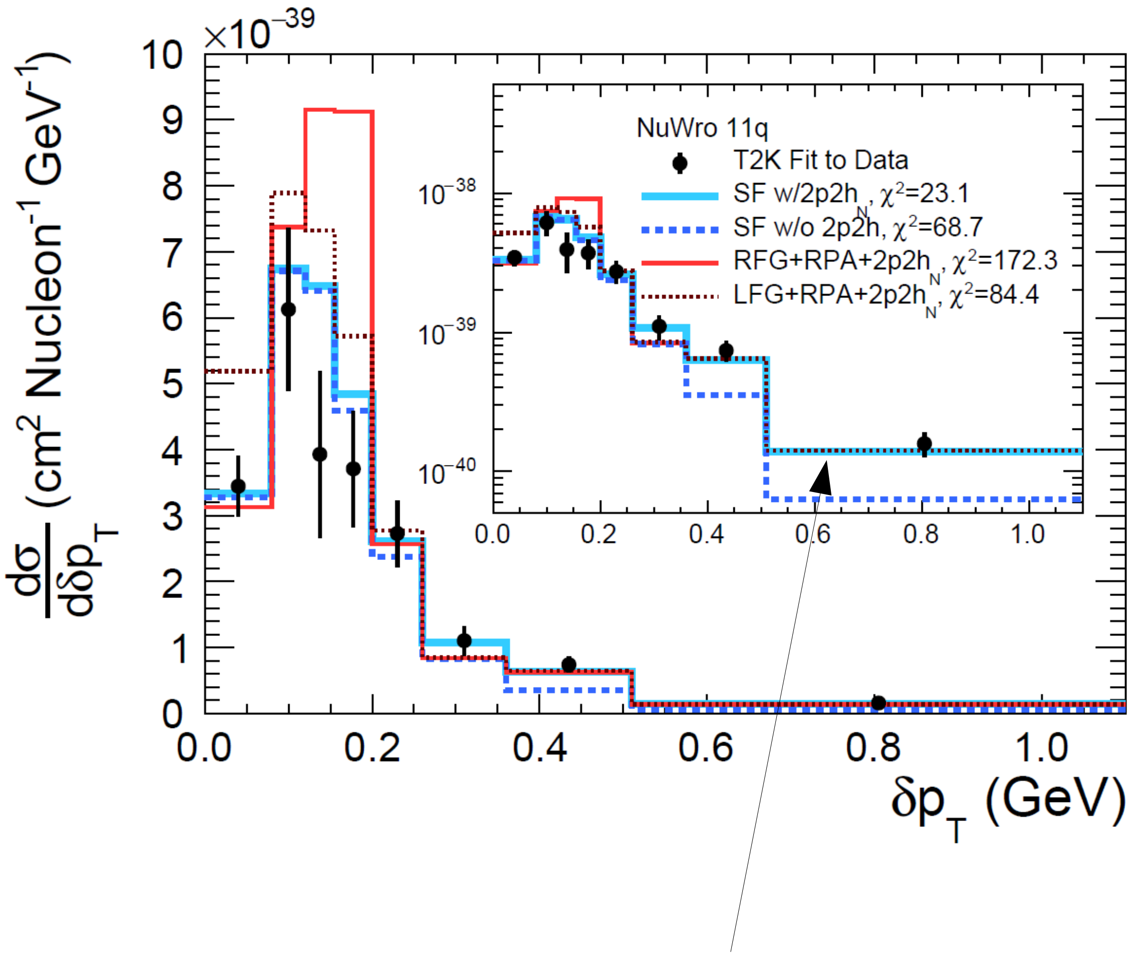
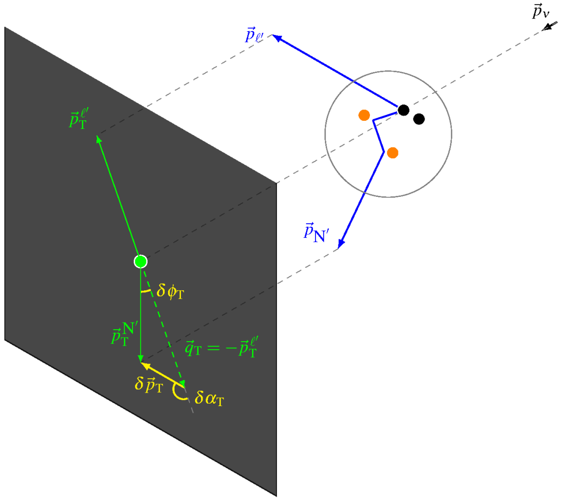
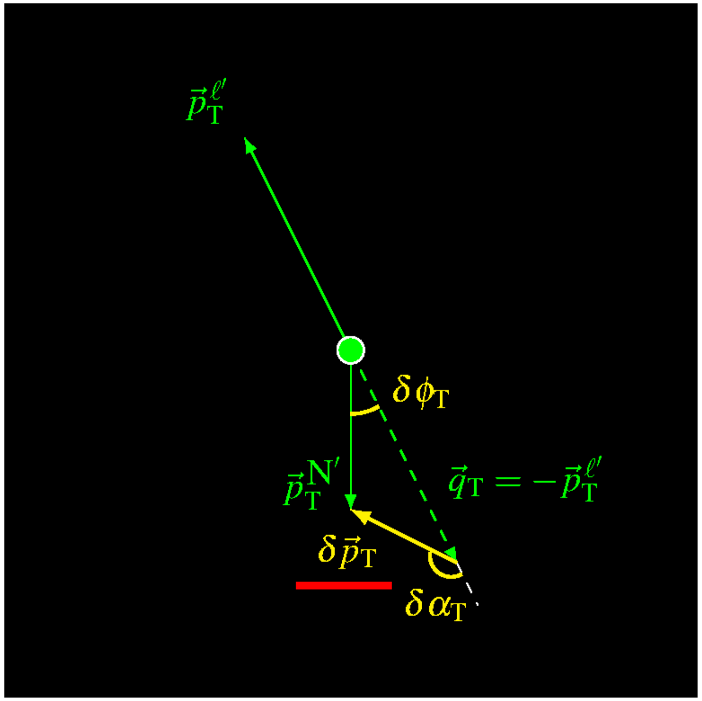


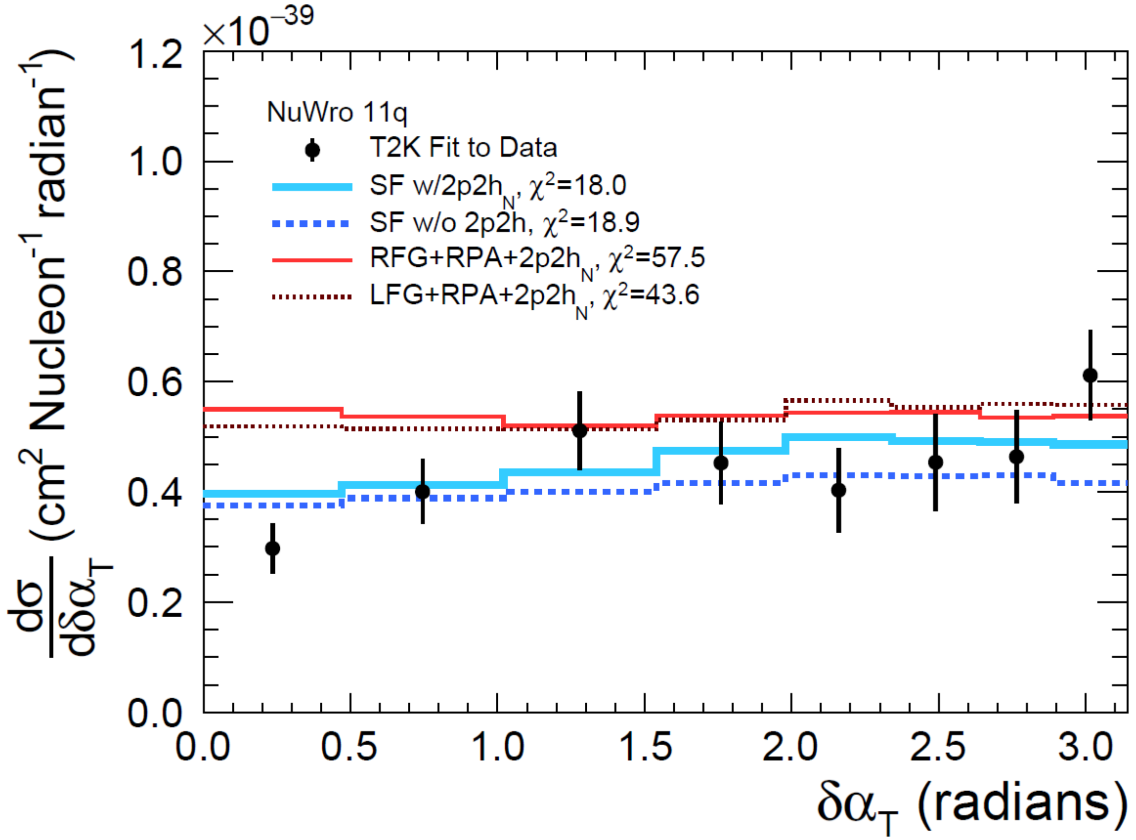
IMT: 2p2h on top of SF is needed

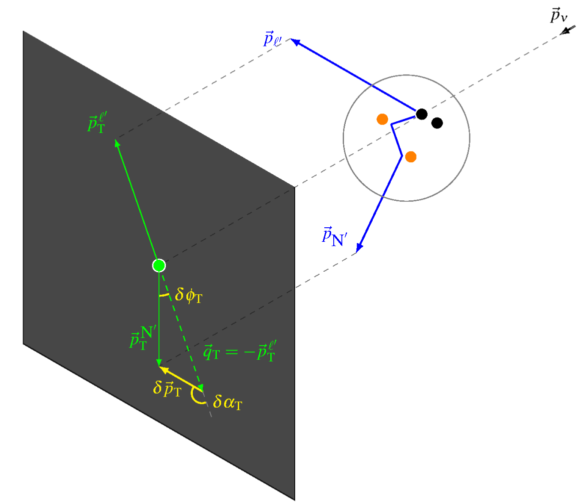


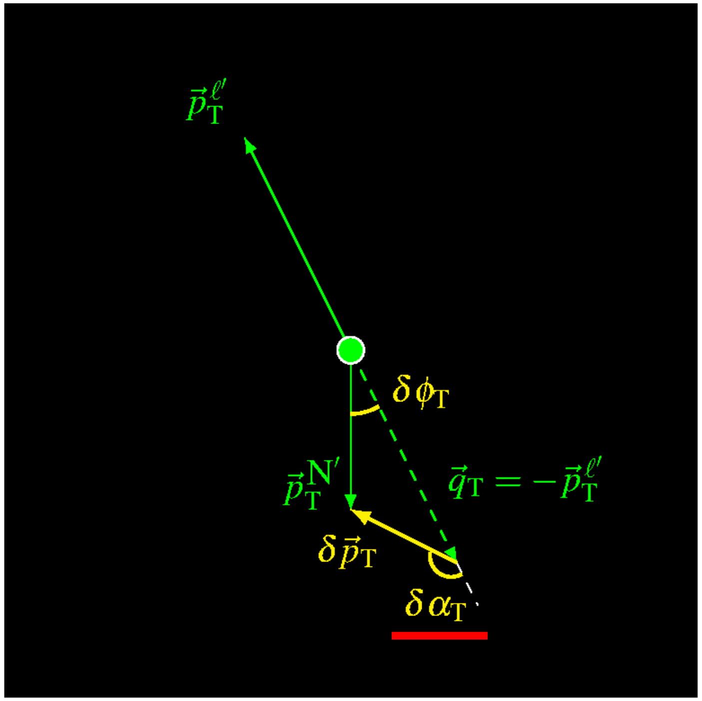


(D) T2K measurement of single-transverse kinematic imbalances (ν_μ CCNp0π CH)

- Signal event: 1 μ^-, **0 π**, at least 1 p, restricted ph [arXiv:1802.05078 to appear in PRD]



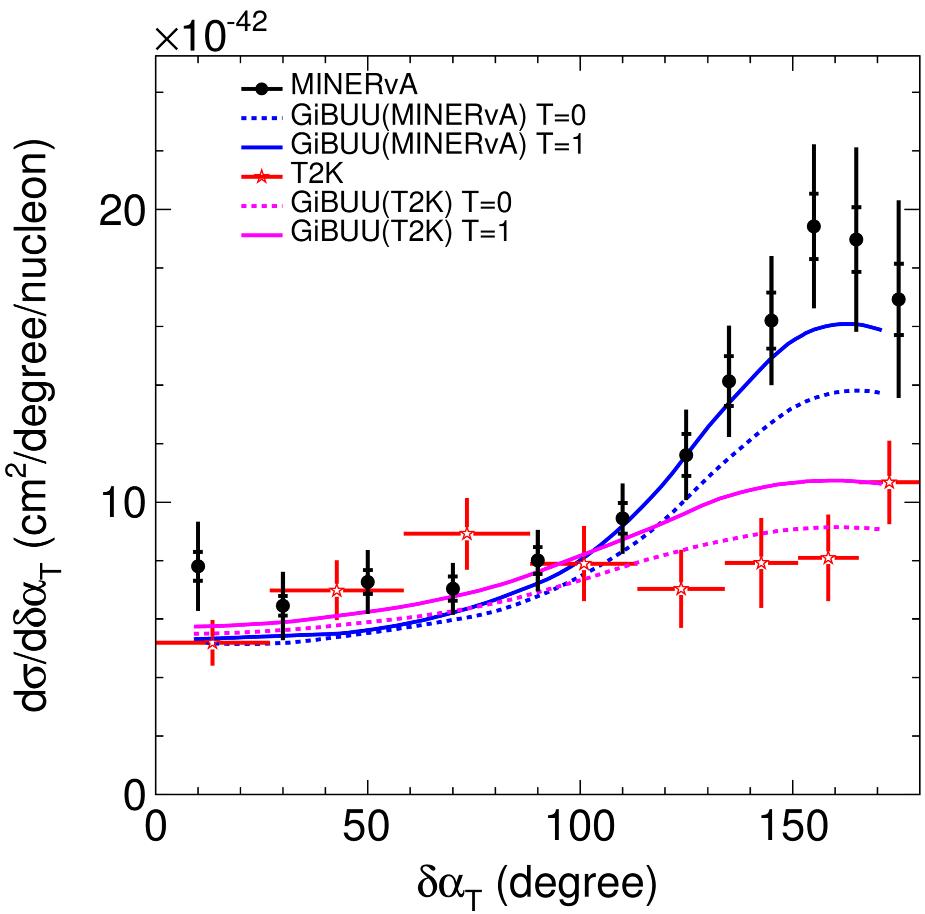


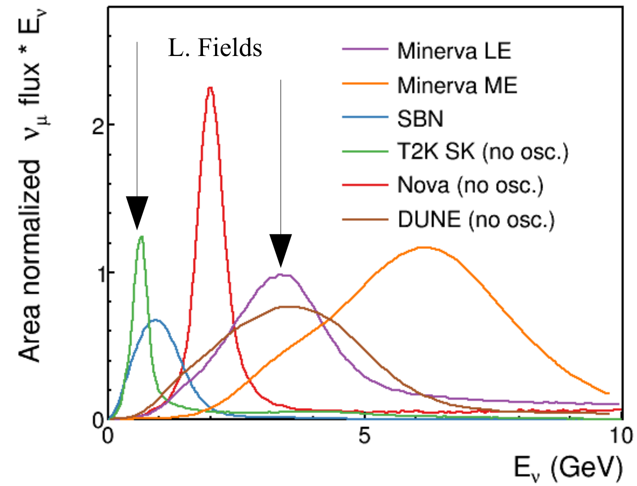


Transverse boosting angle – non-flatness indicates strength of IMT:
Mild strength of IMT at T2K energy

Nuclear Effect Diagnostics

- Initial state
- Final state
- Non-exclusive dynamics
- Energy dependence





1) T2K measured $\delta\alpha_T$ at $\langle E_\nu \rangle$ = 0.6 GeV on same target with slightly different signal phase space definitions
2) Difference in upper quadrant indicates different IMT strength.
3) Sensitivity to isospin assignment (T=0, 1) in GiBUU 2p2h model.

- T2K data: arXiv:1802.05078
  to appear in PRD, see also my T2K talk tomorrow
- GiBUU: Phys.Rept. 512 (2012) 1-124
  see also arXiv:1804.09488 for T2K-GiBUU comparison

74. MINERvA Cross Section Results
Xianguo Lu
14/08/2018, 14:00
WG1+WG2

Summary

- Neutrino-nuclear cross section measurements important for oscillation analysis.

- New measurements of neutrino interactions
  - Inclusive

    (A) 1 μ^-, 4π phase space, CH
  - Semi-inclusive

    (B) 1 μ^-, 0 π, restricted phase space, H_2O
    (C) 0 μ^-, 1 π^0, restricted ph, H_2O
    (D) 1 μ^- , 0 π, at least 1 p, restricted ph., CH
  - (previous results on exclusive measurement: coherent pion production [Phys.Rev.Lett. 117 (2016) 192501])

- More cross section results:

  135. T2K Cross Section Model / Oscillation Needs
  Clarence Wret (University of Rochest...)
  17/08/2018, 14:30
  WG2

- Extensive program at ND280 to improve SK measurements
  - Phase space
  - Signal/background channels

- New measurement of single-transverse kinematic imbalances
  - Surgical diagnostics of nuclear effects
  - More on final-state correlations:

    74. MINERvA Cross Section Results
    Xianguo Lu
    14/08/2018, 14:00
    WG1+WG2

- Near Detector Upgrade see next talk:

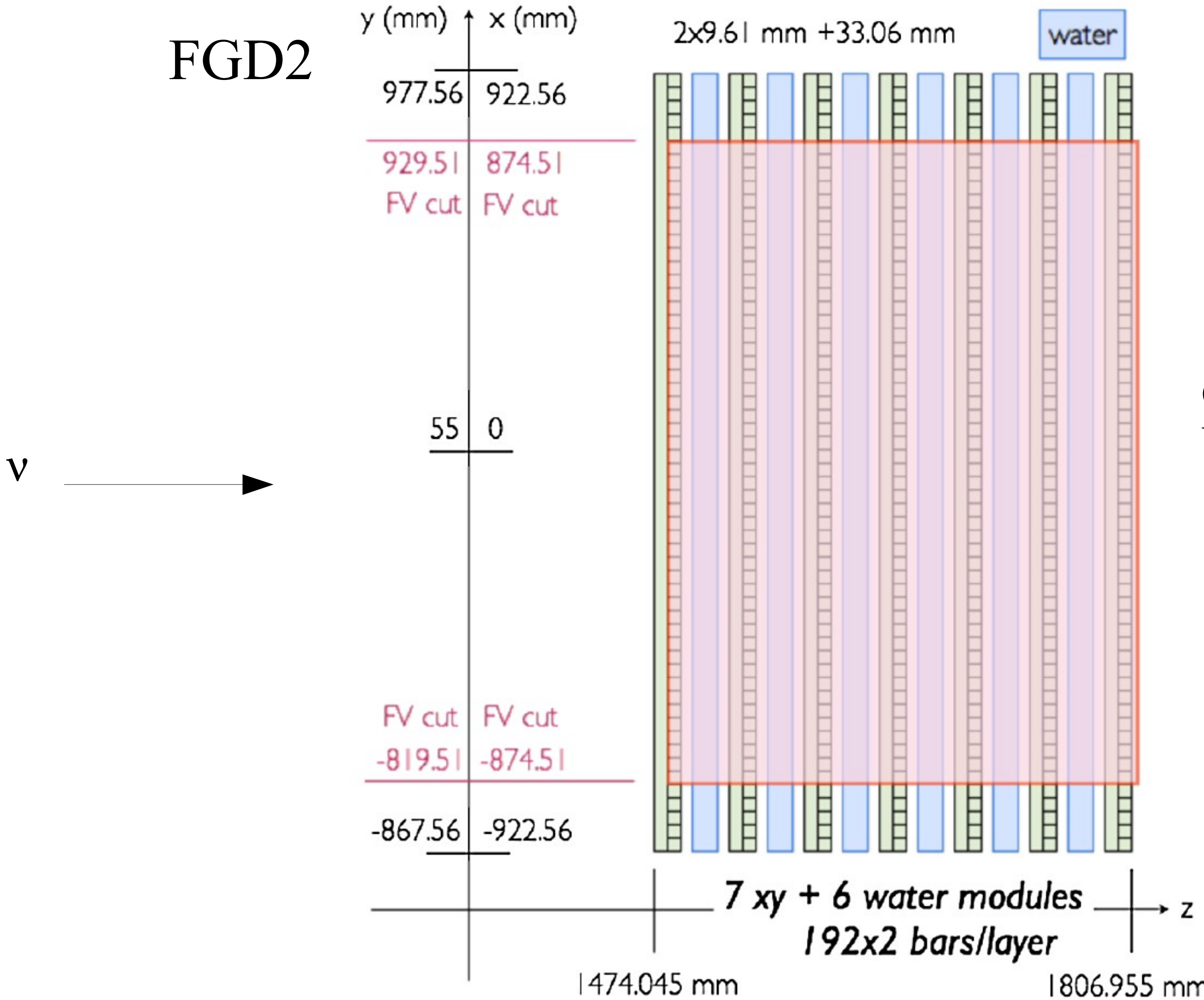
  28. T2K Near Detector Upgrades and Plans for T2HK
  Thorsten Lux
  15/08/2018, 10:20
  Plenary VI

BACKUP

(D) T2K measurement of ν_μ CC1π^+ cross section on water

- Signal event: 1 μ^-, **1 π^+**, no other mesons, restricted ph [Phys.Rev. D95 (2017) 012010]

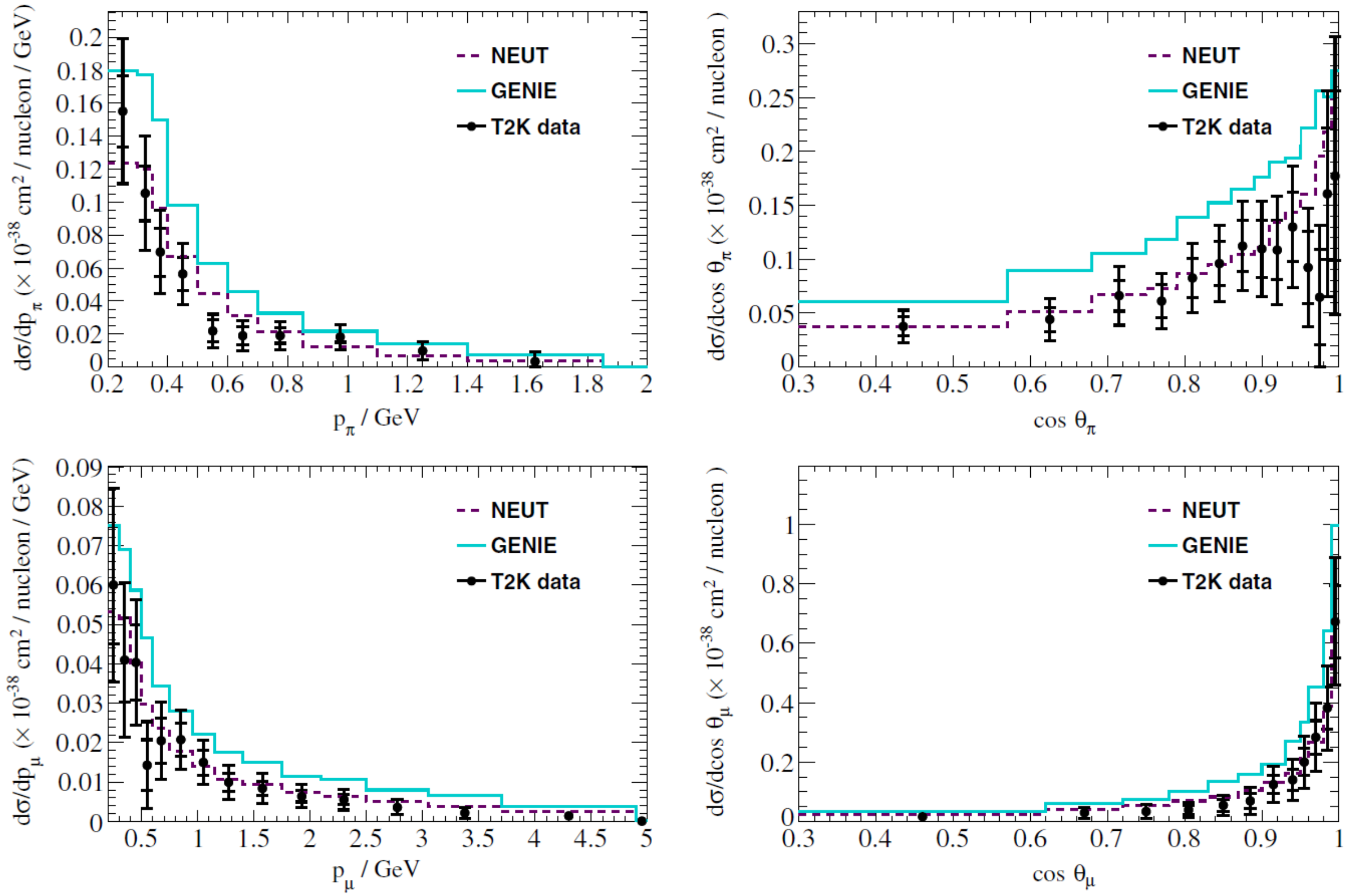
FGD2



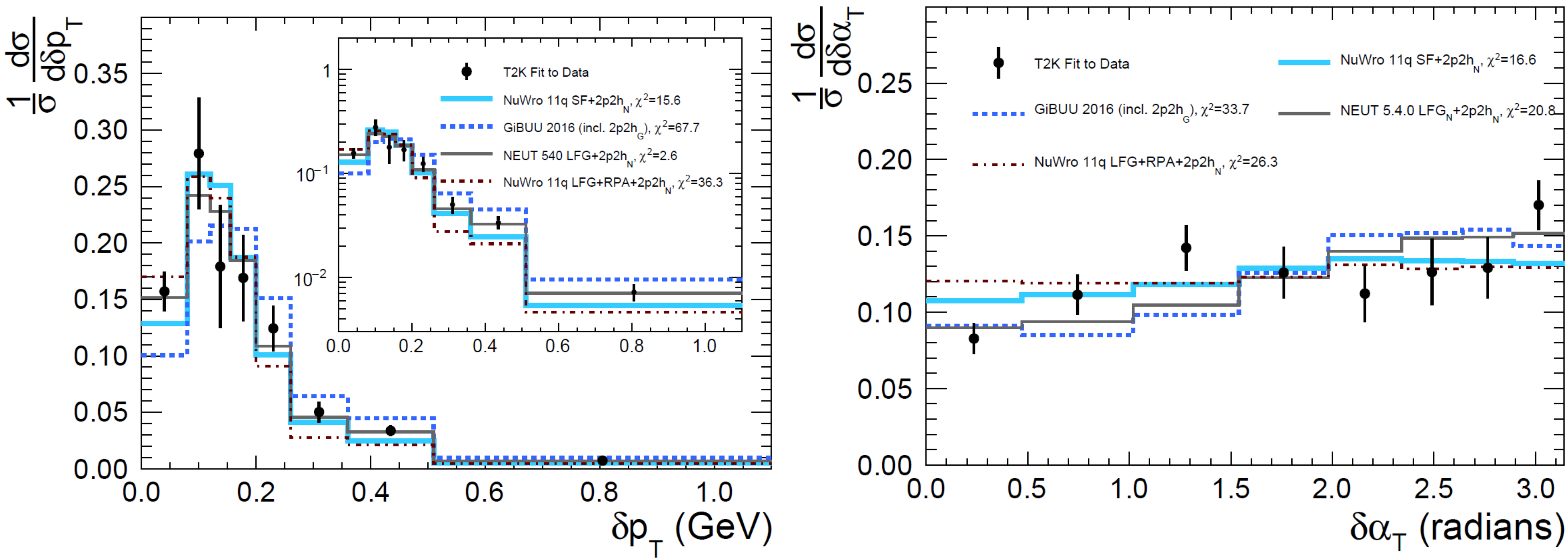
Cross section on water via Vertex restriction

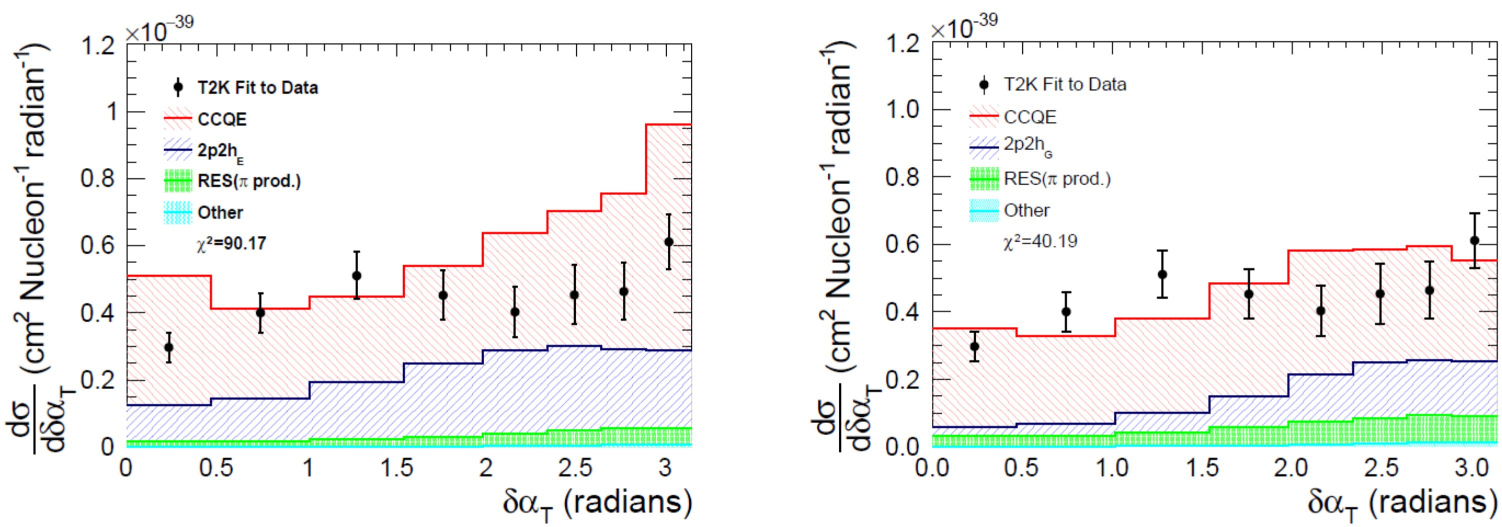
(D) T2K measurement of ν_μ CC1π^+ cross section on water

- Signal event: 1 μ^-, **1 π^+**, no other mesons, restricted ph [Phys.Rev. D95 (2017) 012010]



- One of signal channels in oscillation analyses
- NEUT agrees with data; GENIE over data by 2σ in normalization





arXiv:1802.05078

to appear in PRD

FIG. 17. The extracted differential cross section as a function of the single transverse variables compared to: the GENIE 2.12.4 simulation (**left**) and the GiBUU 2016 simulation (**right**). GENIE uses the Bodek and Richie RFG initial state model and this prediction also includes GENIE's empirical 2p2h prediction (2p2h$_E$). This GENIE prediction is similar that used as a starting point for the NOνA experiment's oscillation analyses. More details of these models can be found in Sec. IV A. The inlays on the plots show a close-up of the tail regions of δp_T and $\delta\phi_T$.

END