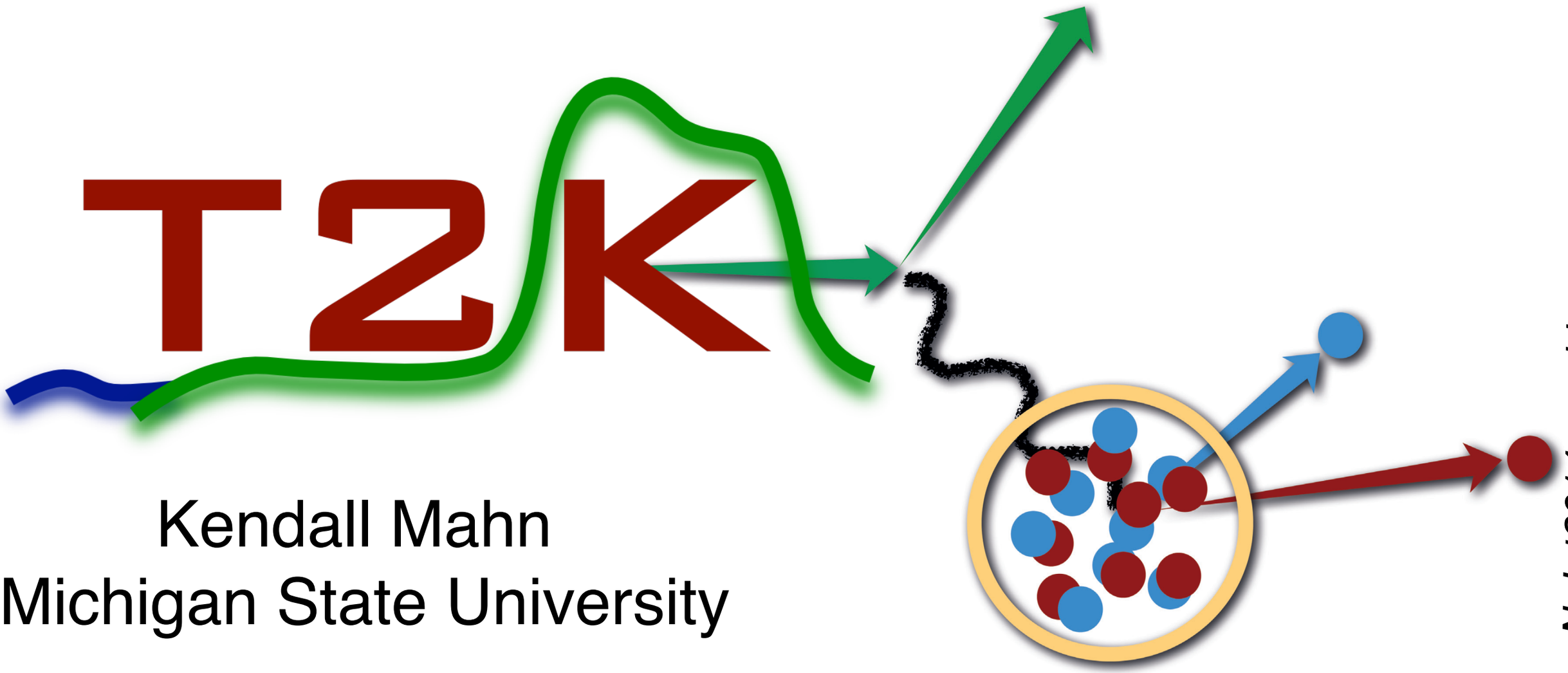
T2K: current status and initiatives



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NuSTEC
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Award DE-SC0015903

Office of Science
U.S. Department of Energy

Disclaimer

- This talk includes standard T2K information
- But, the conclusions are my own and are not T2K official
  - *Let's talk! T2K as a user*
  - *Let's talk! T2K as a measurement provider*
  - *Then, let's form a specific plan…*

Tokai-to-Kamioka is an accelerator-based neutrino experiment

- Broad physics program includes measurements of ν_μ ,$\bar{\nu}_\mu$ disappearance, ν_e, $\bar{\nu}_e$ appearance, exotica and neutrino interactions

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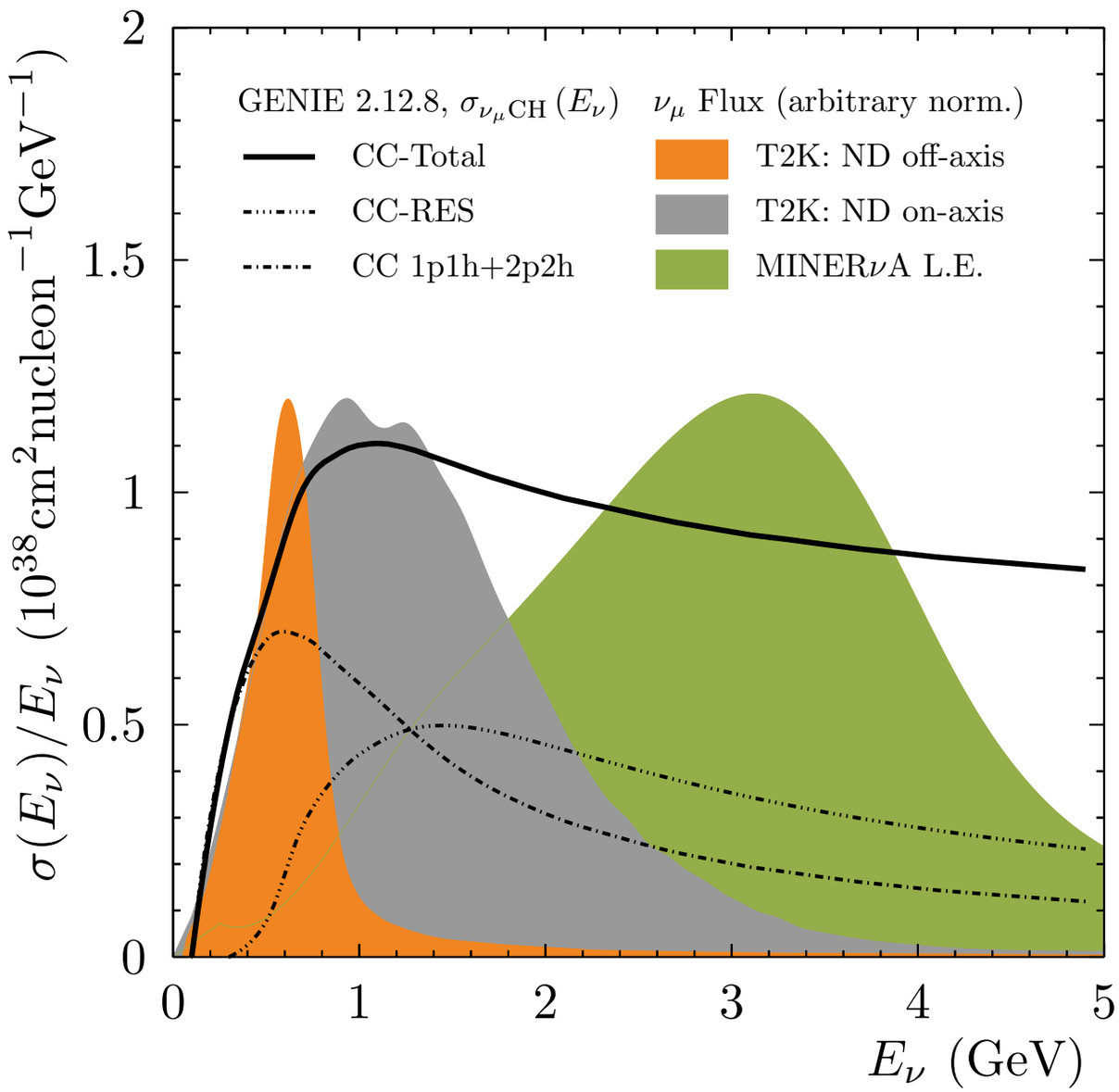

- **Processes of interest:**
- Charged current and neutral current
- Quasi-elastic (1p1h), multinucleon (2p2h), single pion production (SPP)

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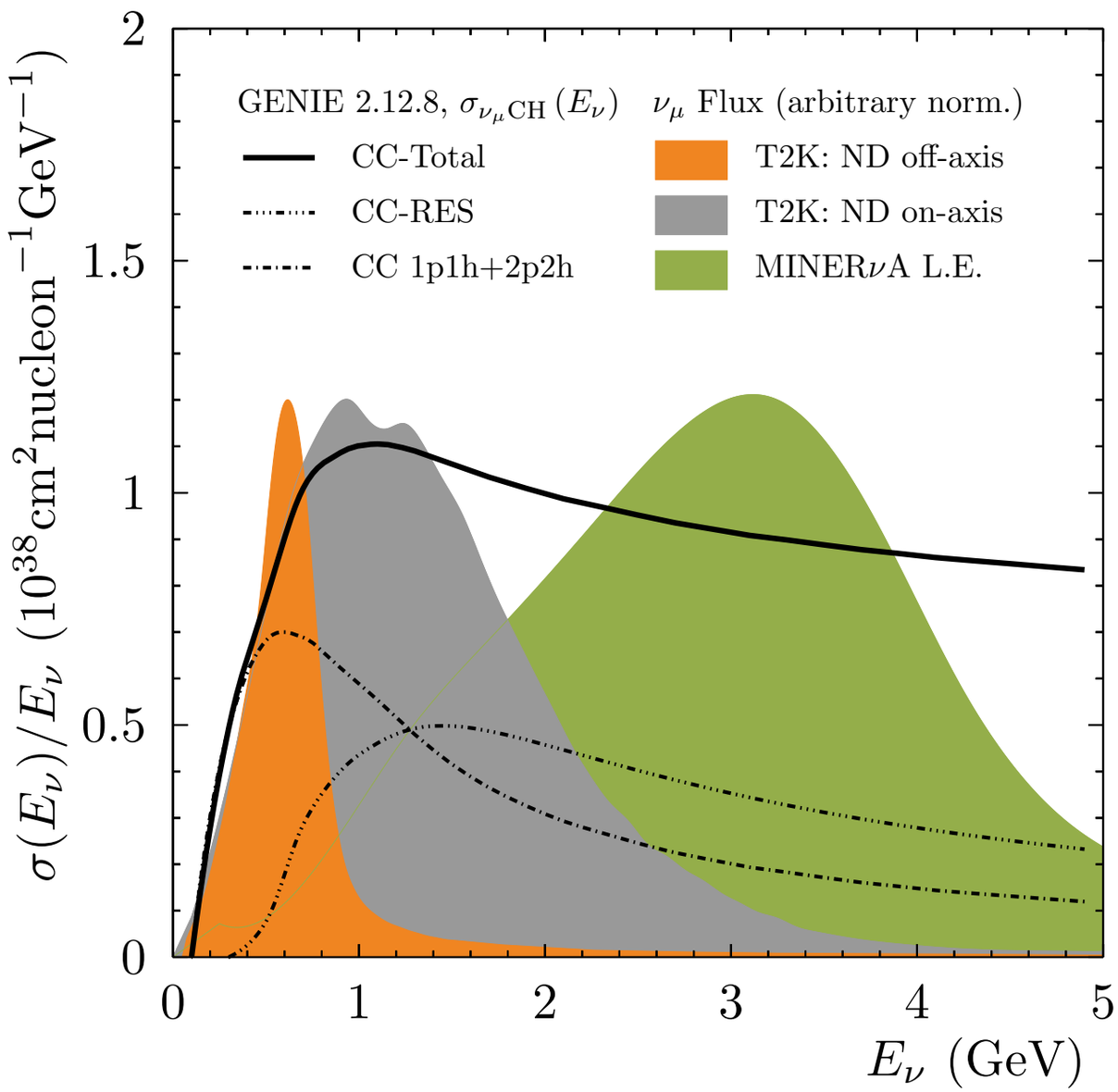
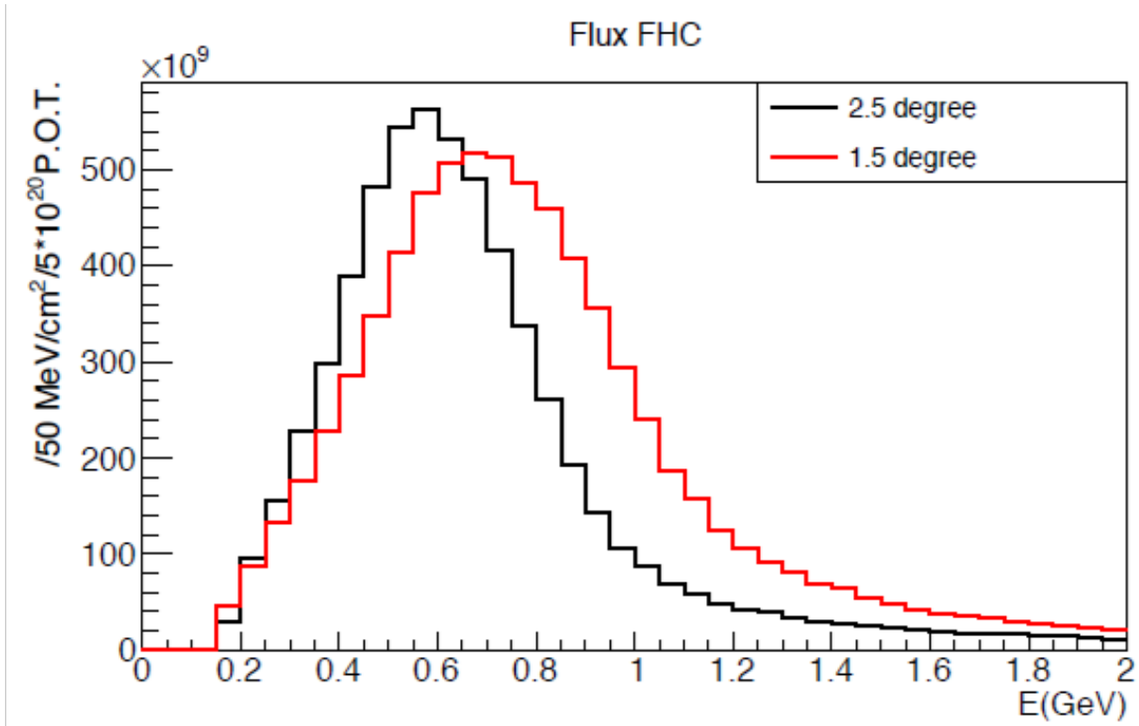


- **Multiple detectors with a variety of detection capabilities**
- **Near:** ND280 (soon ND upgrade)
- **Far:** Super-Kamiokande
- Near: **INGRID**, **WAGASCI+BabyMIND**



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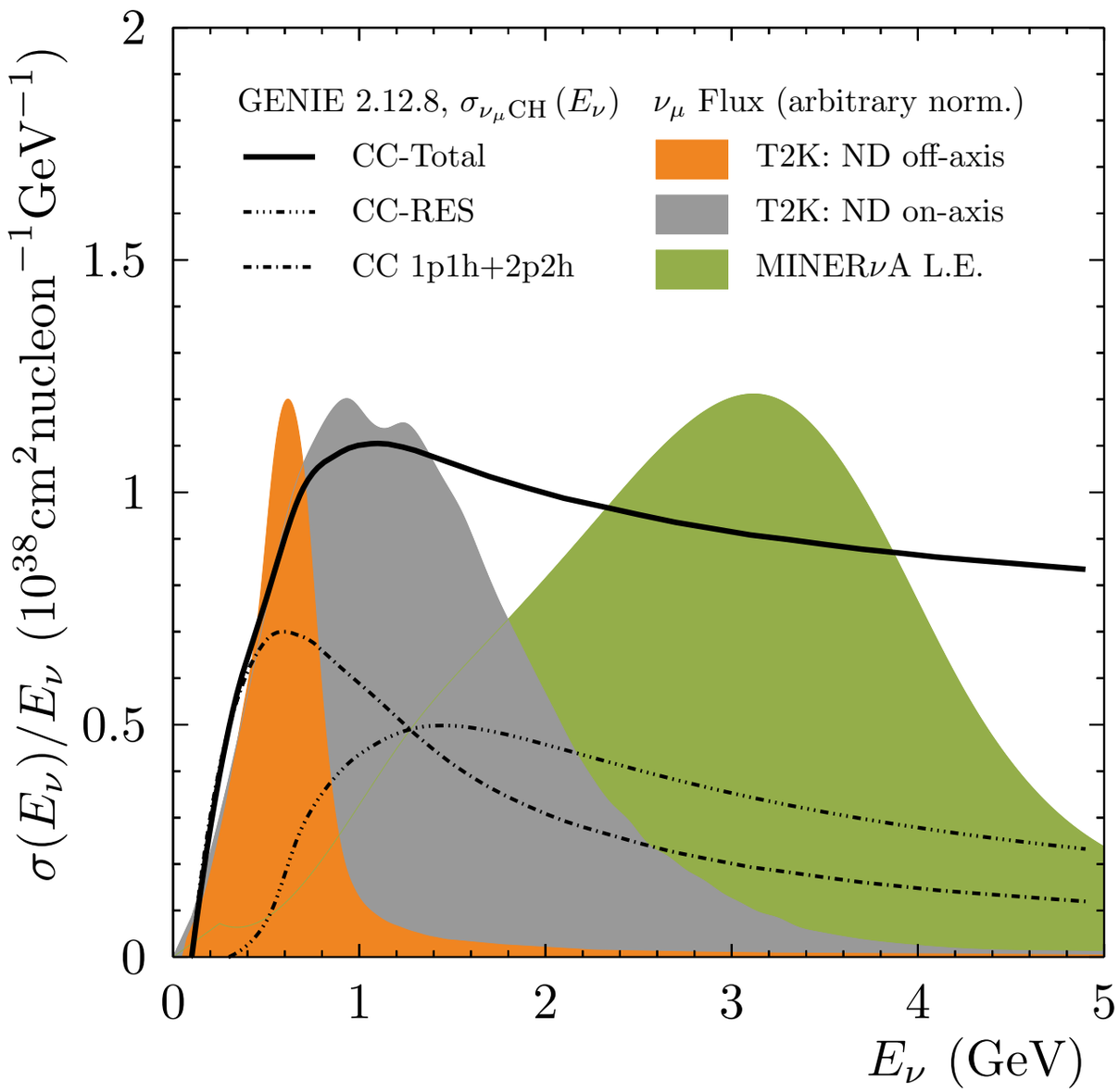
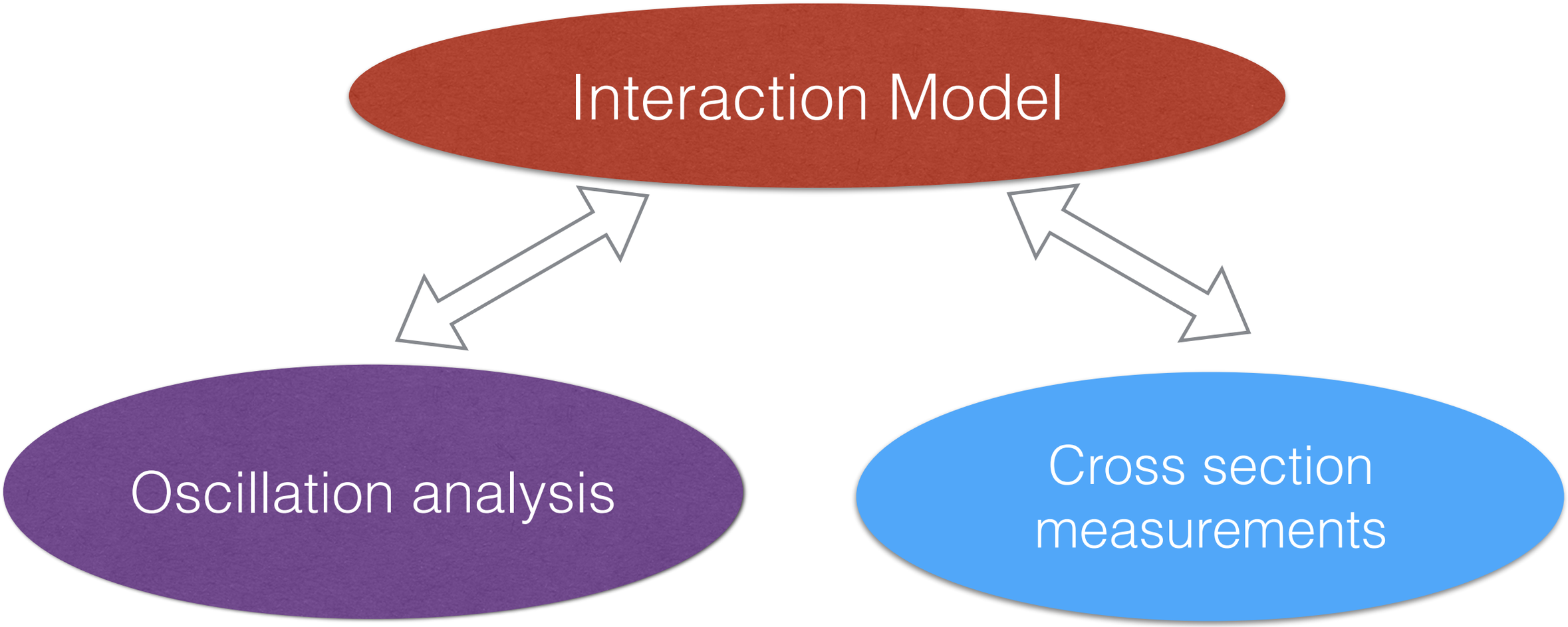


- **Multiple detectors with a variety of detection capabilities**
- Near: ND280 (soon ND upgrade)
- Far: Super-Kamiokande
- Near: INGRID, WAGASCI+BabyMind
- **Well-understood beam:** recently improved flux uncertainties (esp. data from NA61 and soon EMPHATIC)
- neutrino and antineutrino-modes
- **Multiple targets:** C, H2O, Fe and Ar, Pb

T2K: Tackling the challenge of interactions



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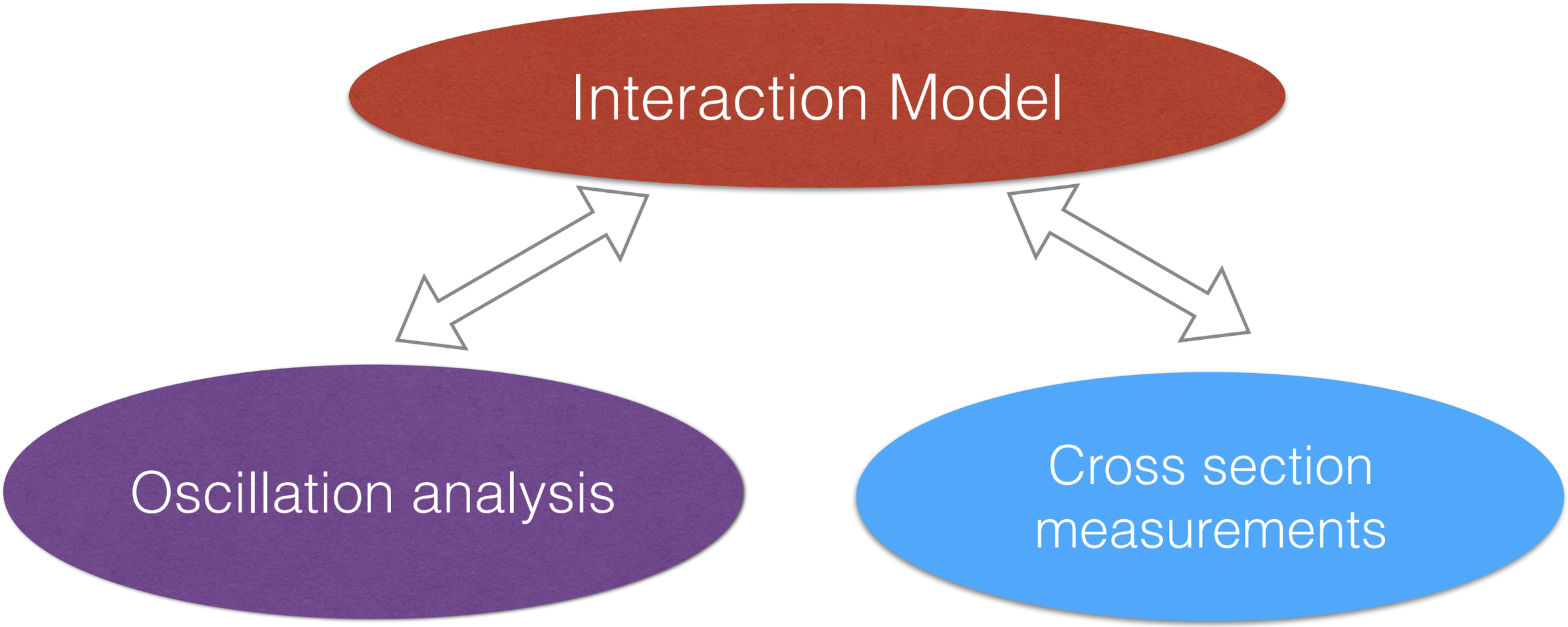
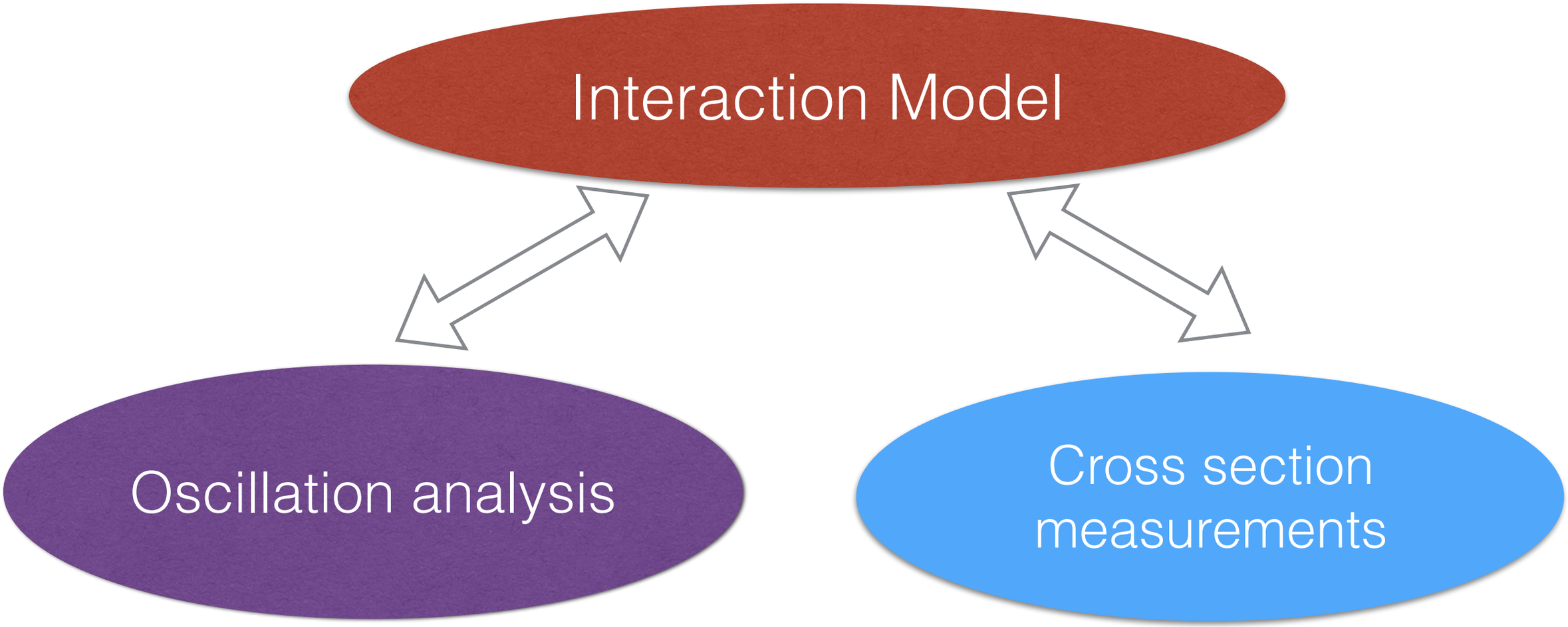


Model Development: Reduced systematic uncertainty through external data, theory

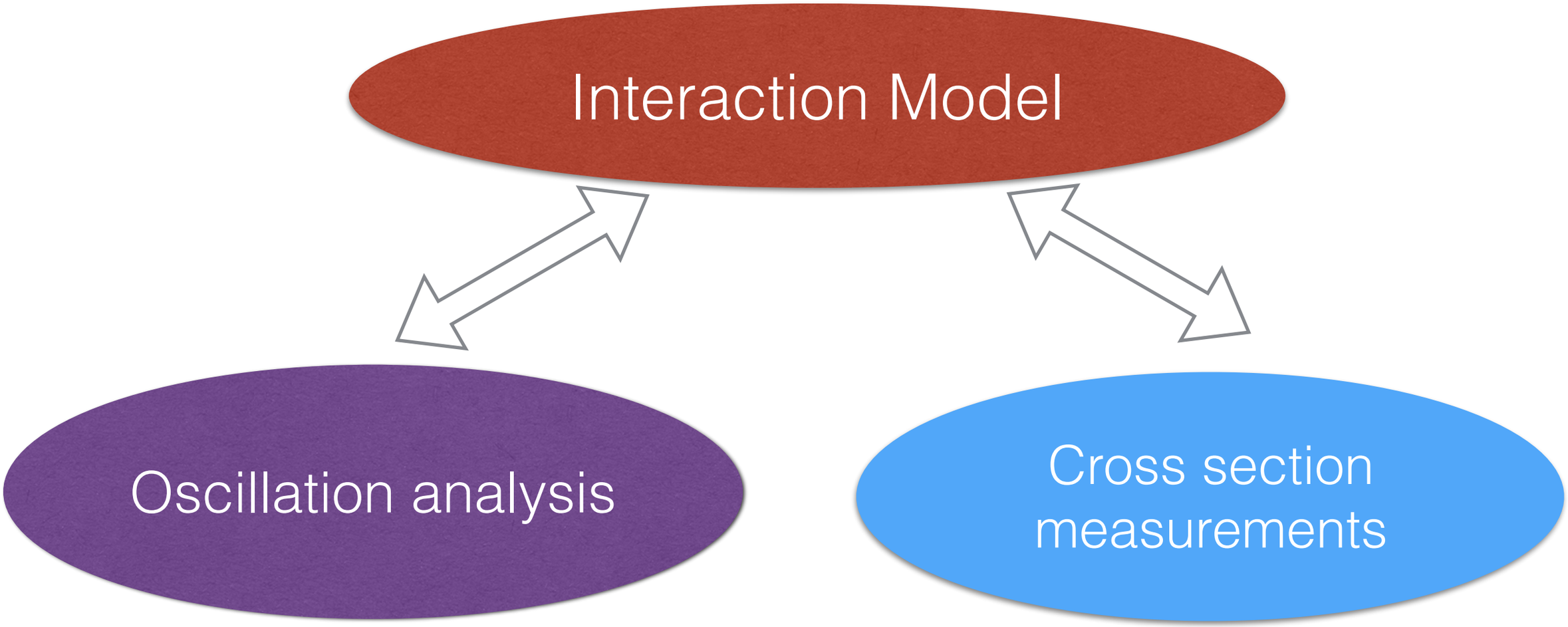
T2K: Tackling the challenge of interactions



Model Development: Reduced systematic uncertainty through external data, theory

Completeness: tests of impact of modeling with bias studies

T2K: Tackling the challenge of interactions

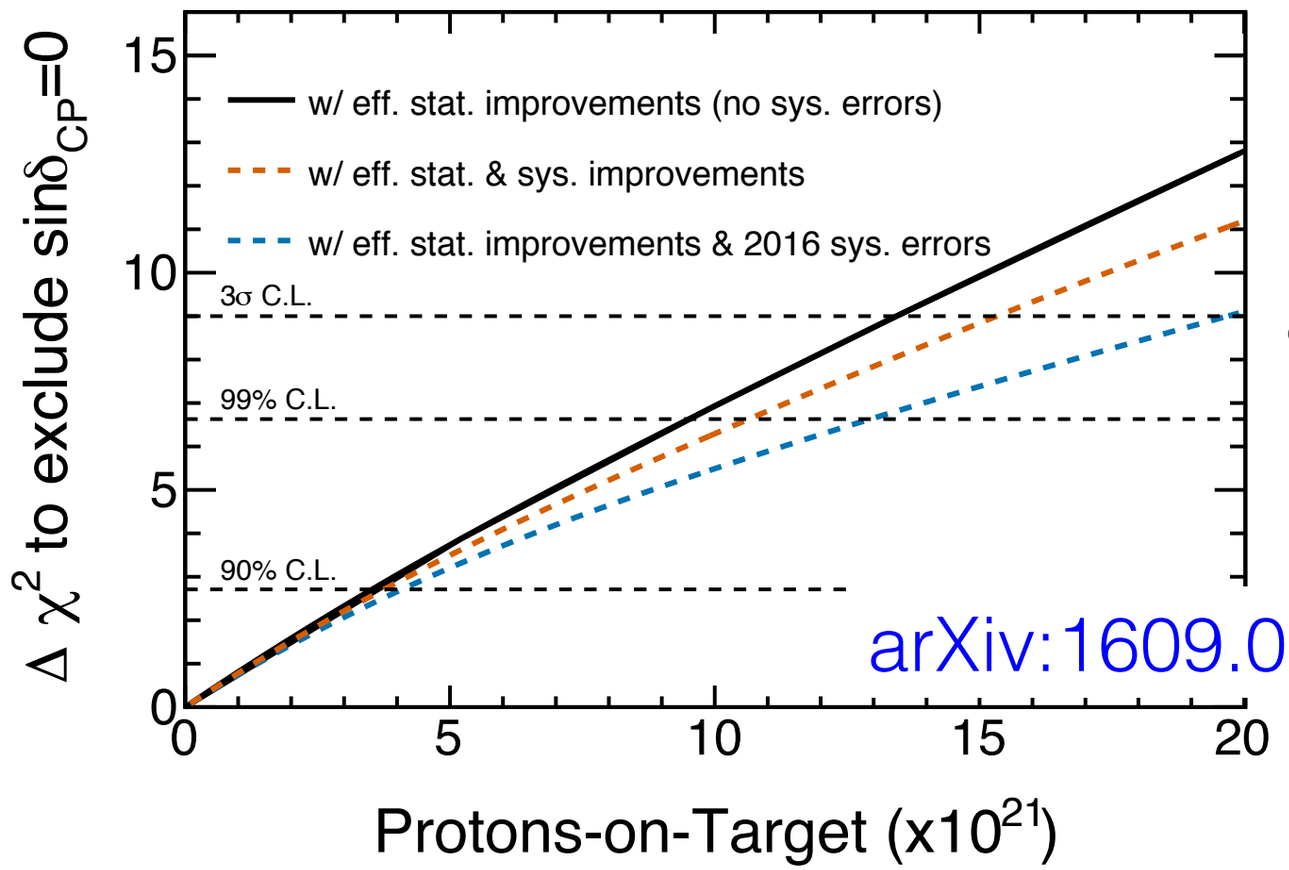


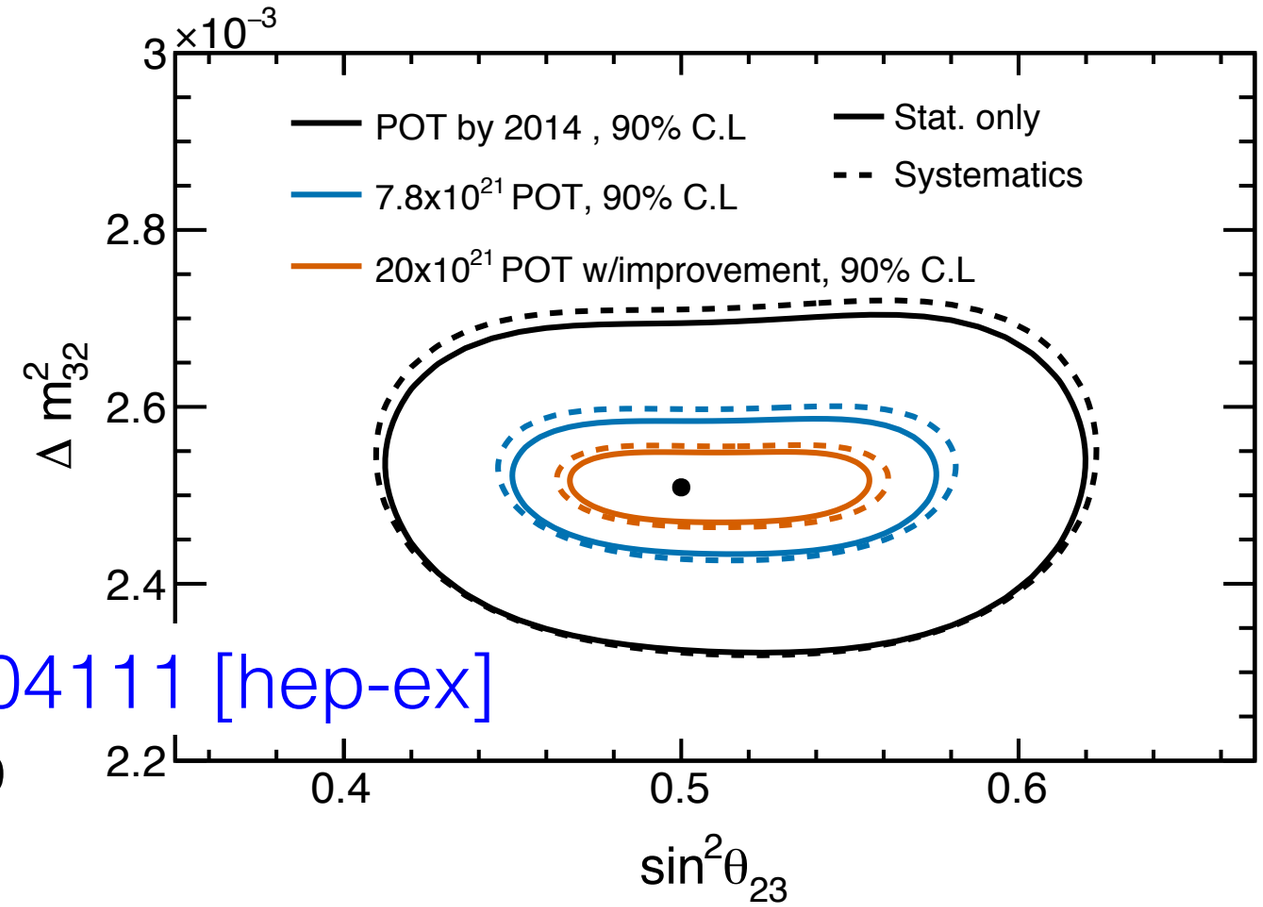
Model Development: Reduced systematic uncertainty through external data, theory

Completeness: tests of impact of modeling with bias studies

Unique, new or improved, measurements for theory and current, future experimental program

Goals for T2K oscillation analysis





arXiv:1609.04111 [hep-ex]

- Precision measurements of mixing parameters; searches for new physics (δ_{CP}?)
- New features: beamline upgrade, neutron tagging in SK, new near detectors
- New samples (tagged pions), use of hadronic state at ND

Uncertainties in oscillation analysis

- Interaction model is a significant source of uncertainty. **Issues**:
  - Our parameterizations and models may have unphysical features
  - We see data/data and data/MC disagreements
  - Analysis is always changing

Uncertainties in oscillation analysis

- Interaction model is a significant source of uncertainty. **Approaches**:
  - Our parameterizations and models may have unphysical features -> ***work with theory groups***
  - We see data/data and data/MC disagreements -> ***Test the models against external results; consider how extrapolation is impacted***
  - Analysis is always changing -> ***iterate each year on what needs refinement/update; develop new samples***

Specific needs

- Continual refinement of CCQE (dominant process) +2p2h (highly uncertain)
  - Especially lepton/hadronic state correlations; Neutrons (Gd doping at SK)
- Pion production
  - nucleon -> nuclear side (low Q2 discrepancies? Multi-nucleon?)
  - Iteration on new reduced uncertainties in FSI model from external scattering
- Both: Relationship between neutrino and antineutrino: scrutiny and freedoms
- Usual: theoretically driven uncertainties
  - nue/nuebar uncertainties; NC1gamma

Specific measurements

In service of our oscillation analysis//model development:

- New measurements with three different fluxes
- ND upgrade will have improved acceptance, photon separation
  - New measurements of leptonic/hadronic final state correlations (QE+2p2h, pion production); neutrons?
  - Discussing nue measurements (with current and future data)

And, other unique measurements we can make:

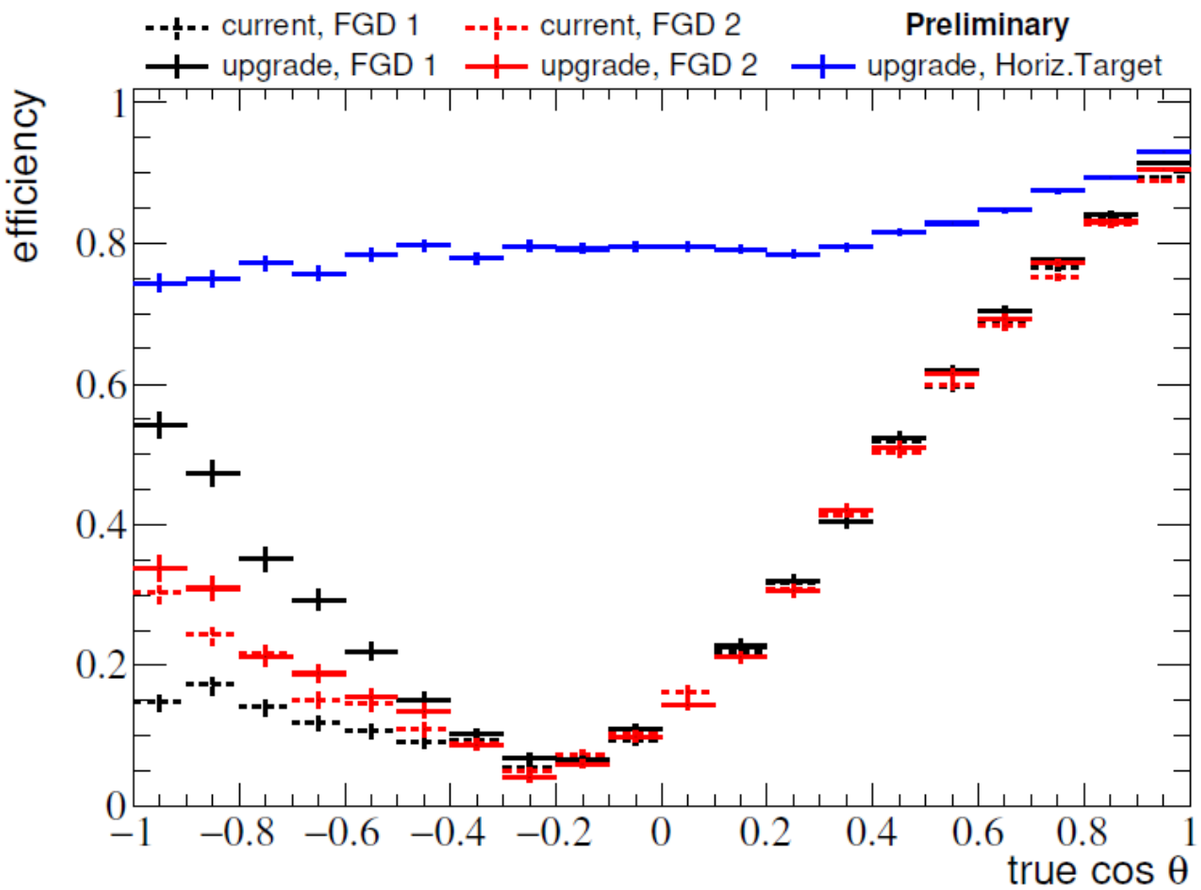
- Recent result of NCQE-like interactions for relic SN backgrounds

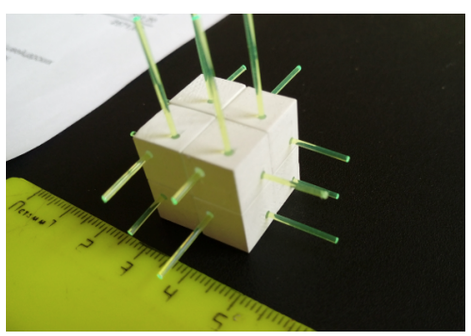
T2K and the community

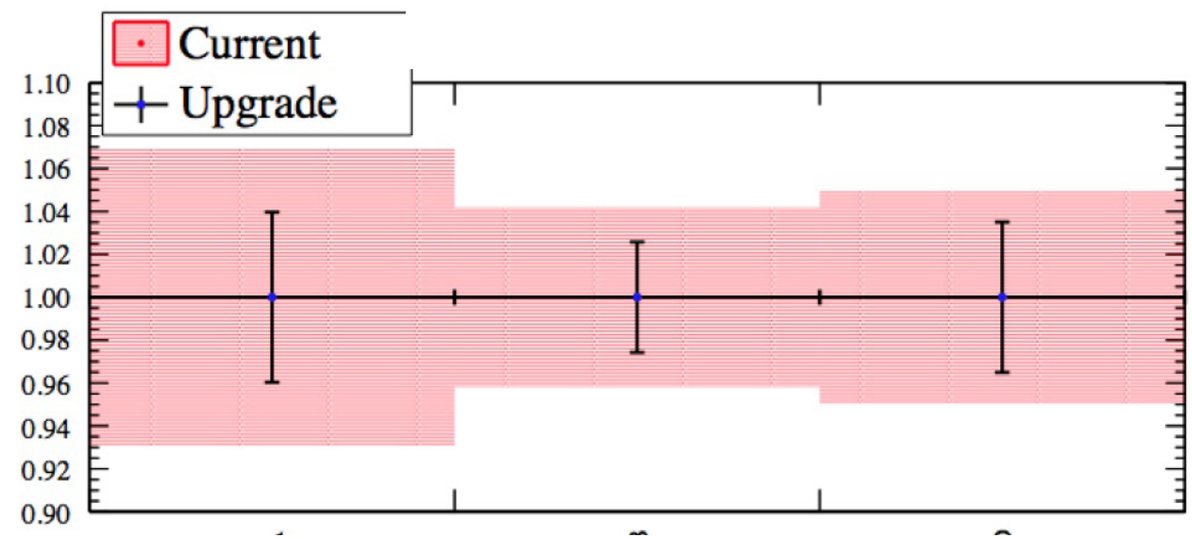
- Let's work together!
  - Discuss possible specific work projects and how they fit in
  - Various fellowships to support work in Japan or with T2K groups
- How we make measurements is important - *see D. Cherdack talk*
- And, connecting our results to theory and/or users is also important
  - What measurements do you need from us?
  - Ease of use? Interpretation?

Backup

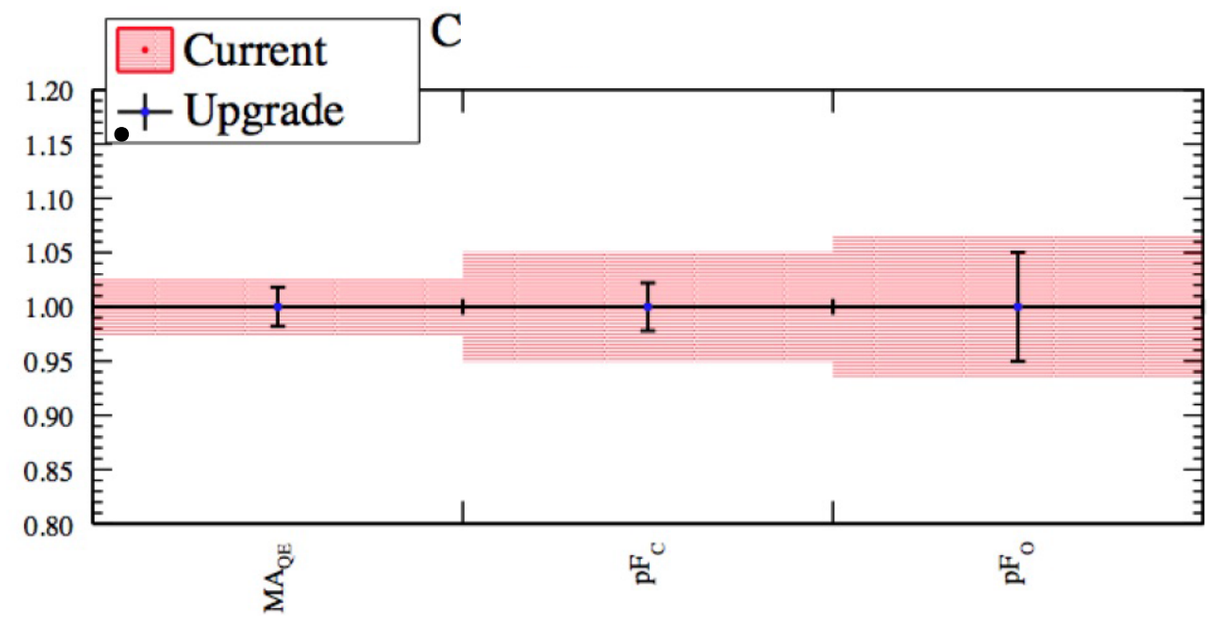
Future of T2K: ND upgrade







CCQE model parameters



- ND upgrade will have improved acceptance compared to ND280
- Improved constraint of cross section models within oscillation analysis; improved statistics at high angle for cross section measurements

Model Progress on T2K
Table circa Summer 2018

Dominant uncertainty in oscillation analysis from neutrino interaction (cross section) model

Error source	1-ring e-like		
	ν-mode	$\bar{\nu}$-mode	$\nu_e/\bar{\nu}_e$
SK Detector	2.83	3.79	1.47
SK FSI+SI+PN	3.02	2.31	1.58
Flux + Xsec constrained	3.02	2.86	2.31
E_b	7.26	3.66	3.74
$\sigma(\nu_e)/\sigma(\nu_\mu)$	2.63	1.46	3.03
NC1γ	1.07	2.58	1.49
NC Other	0.14	0.33	0.18
All Systematics	8.81	7.03	5.87

From Nu-Print workshop: https://indico.fnal.gov/event/15849/timetable/#20180312

- What are the uncertainties needed for the 2p2h?
  - Large uncertainties on leptonic side (across q0-q3?). Differences between nu and nubar in overall strength.
  - What should be the hadronic final state association? And how much energy into (which) outgoing particles?
- Insufficiency of current resonance model to describe pion kinematics, low Q2 discrepancies.
  - Is 2p2h-like processes in resonance production?
  - Need NC for significant backgrounds (or exotic signals)
- Transition region! Incomplete experimental and theoretical footing
- Need heavier targets (Ar!) model efforts
- Nue/numu uncertainties
- *Kendall adds: NC diffractive processes not explicitly assessed*