T2K

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IPP Town Hall Meeting

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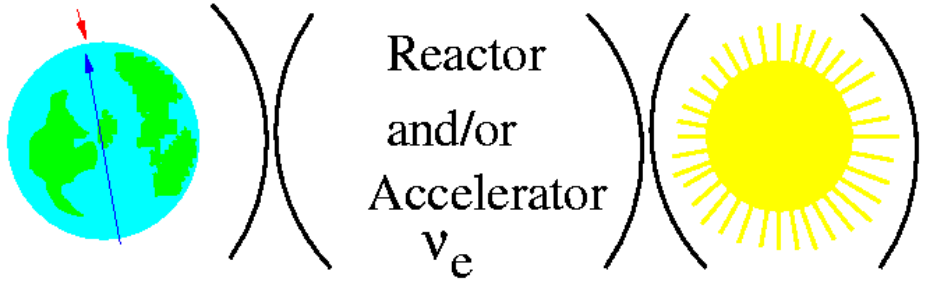
Neutrino Oscillations in one slide

Whole community's worth of talks to investigate the phenomenon that neutrinos have mass and change flavors as they propagate

- Standard picture: 3x3 mixing matrix between mass and flavor eigenstates, defined by 3 angles and a phase

Call them $\theta_{12}, \theta_{23}, \theta_{13}, \delta$ if $s_{ij} = \sin\theta_{ij}, c_{ij} = \cos\theta_{ij}$, then

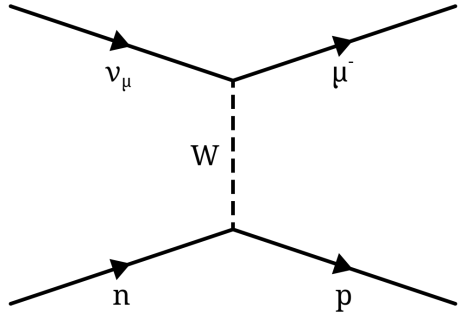
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

U= 

- Still much we don't know:
  - Do neutrinos violate CP?
  - Are neutrino masses ordered the way all the other fermions are ordered?
  - Is this all there is?
- Testing this model at higher and higher levels of precision, but it's not easy

- Answering these questions takes a world-wide effort

Making a Precise Oscillation Measurement



- Ingredients for high Statistics:
  - As intense a neutrino beam as you can stand
  - A near detector as similar to your far detector as you can afford
  - As large a far detector as you can afford
- Ingredients for low systematics:
  - Measurements of hadron production to have an accurate flux prediction
    - These come from a worldwide effort!
  - Measurements of Neutrino Interactions
    - These also come from a worldwide effort!
  - Models to translate from neutrino interaction measurements to the underlying physics of the nucleus!
  - Additional constraints on those models from a near detector

Fundamental Challenge:
Oscillations are f(E_ν)
Something Detectors ONLY measure approximately!

$$N_\mu(E_\nu) = \sigma(E_\nu)\Phi_\nu(E_\nu)\epsilon(E_\nu)$$

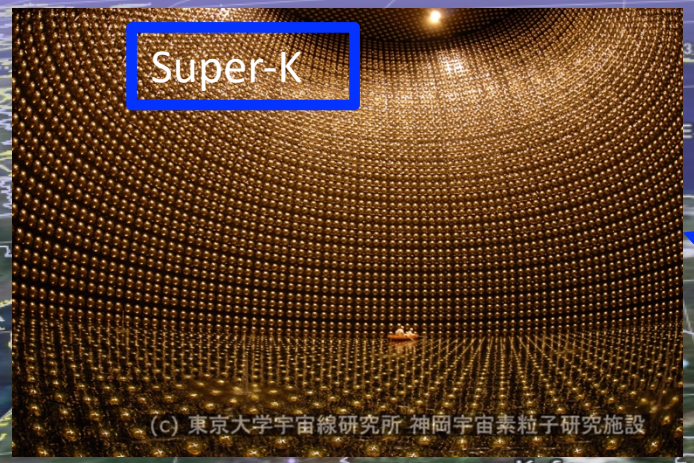
Interaction cross section

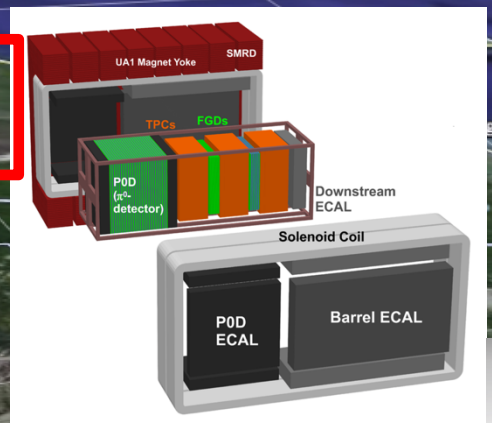
Neutrino flux

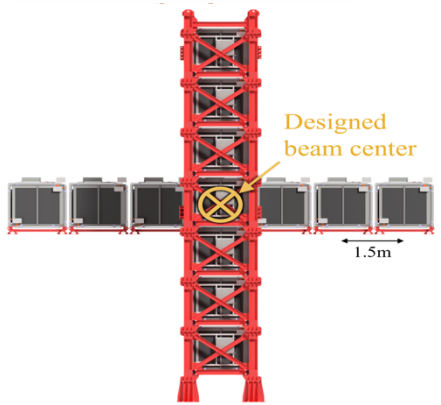
Detector effects

The T2K Experiment

- Muon (anti) neutrino beam generated at J-PARC
- Beam travels 295 km to large SK far detector to be measured after oscillations
- Near detector complex constrains beam flux and interaction cross-section before oscillation
- Important to constrain non-oscillation parts of model to avoid bias

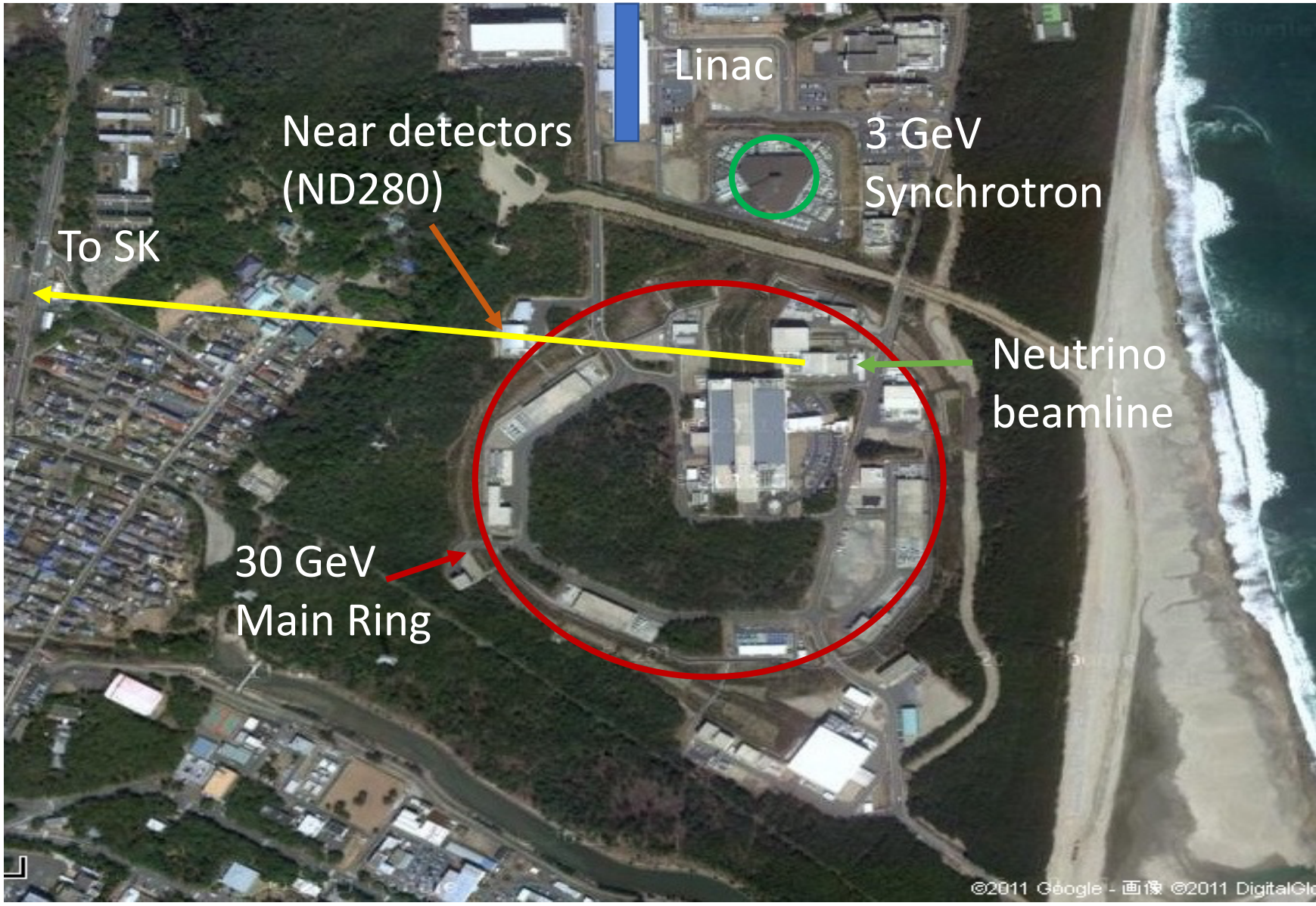






J-PARC and the T2K Beamline

- T2K beamline uses fast extraction from J-PARC main ring with a beam pulse every 2.5 seconds
- Main ring power supply upgrade next year will allow for higher beam power
- 1-year shutdown in 2021
- Canadian researchers provide instrumentation for this beamline!



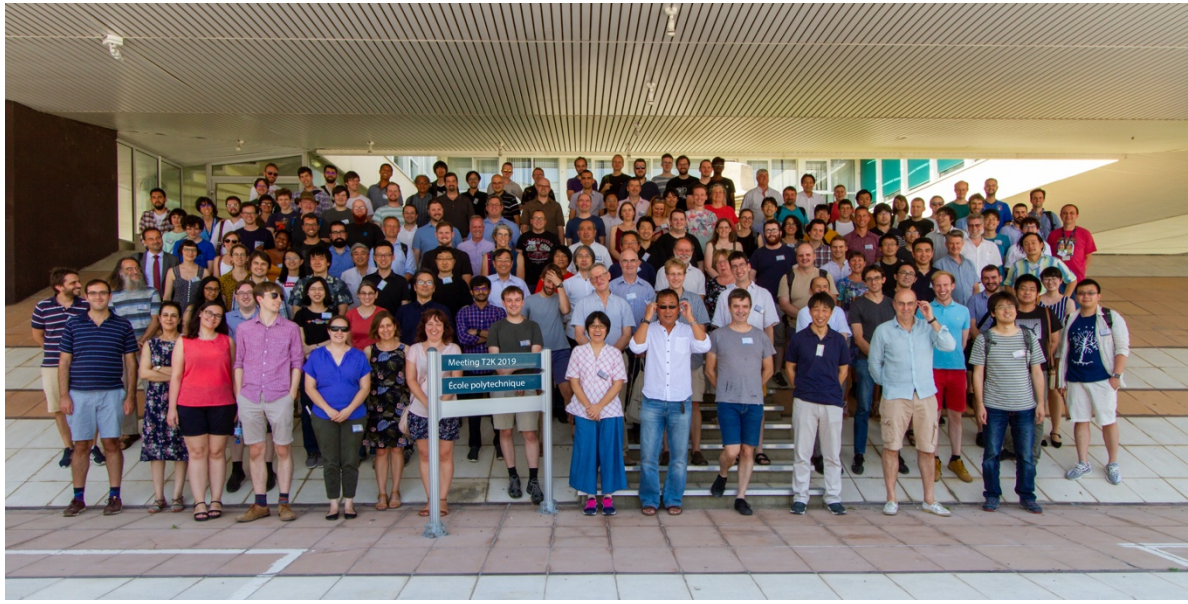
T2K Collaboration

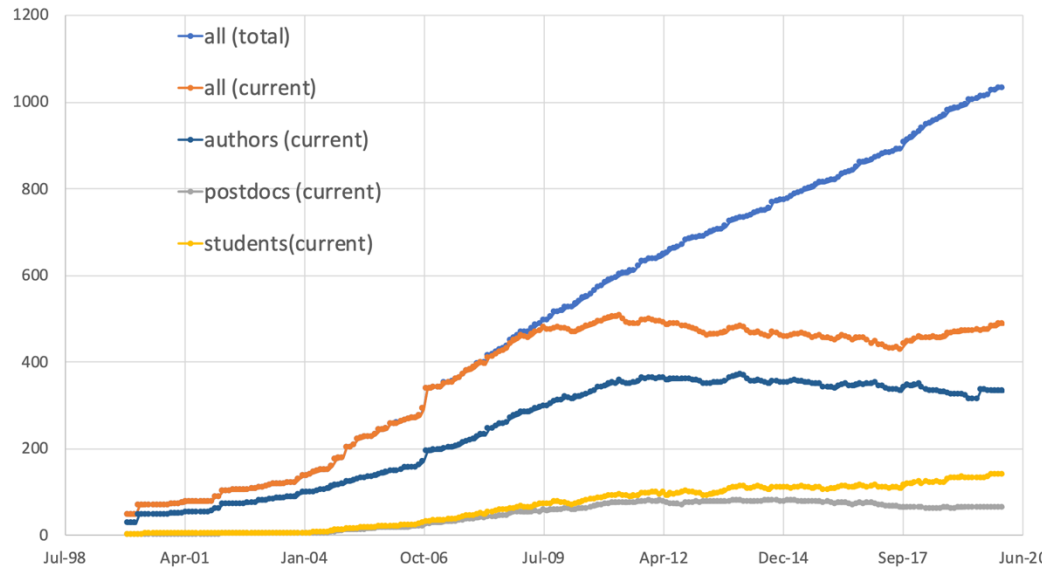
~500 members, 69 institutes, 12 countries

Asia	117
Japan	114
Vietnam	3

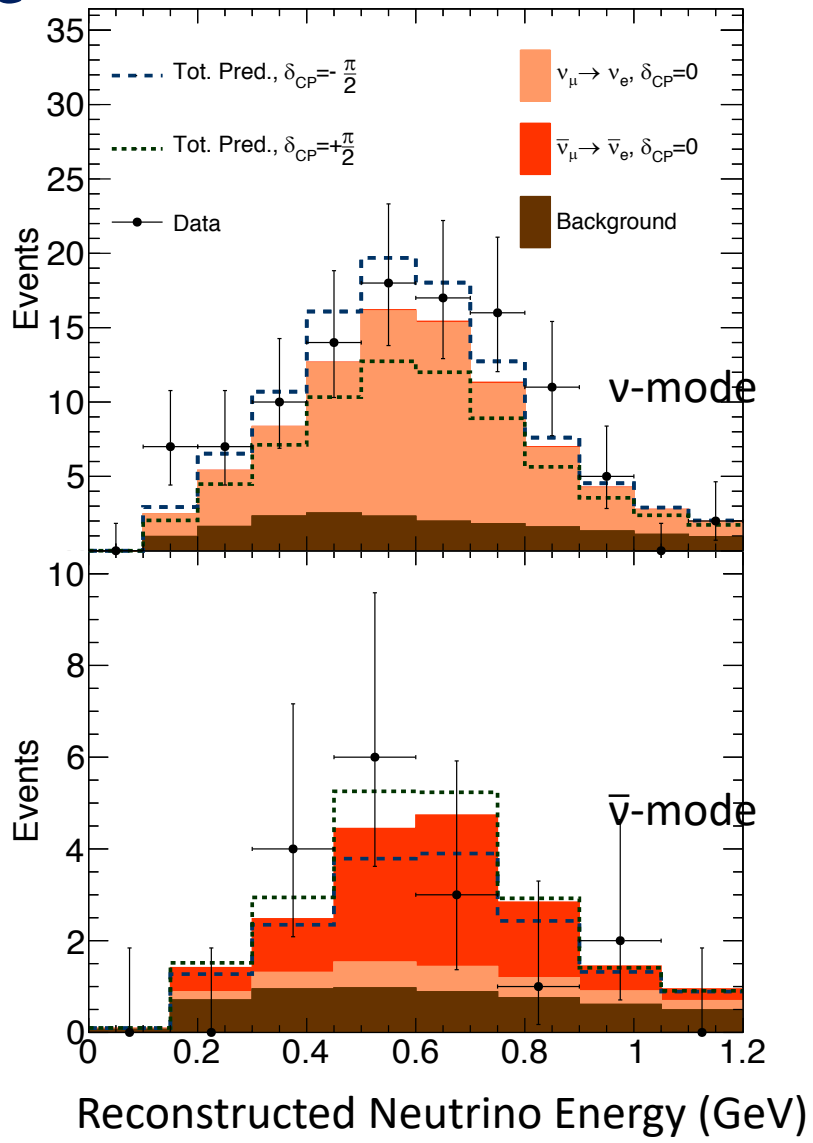
Americas	96
Canada	26
USA	70

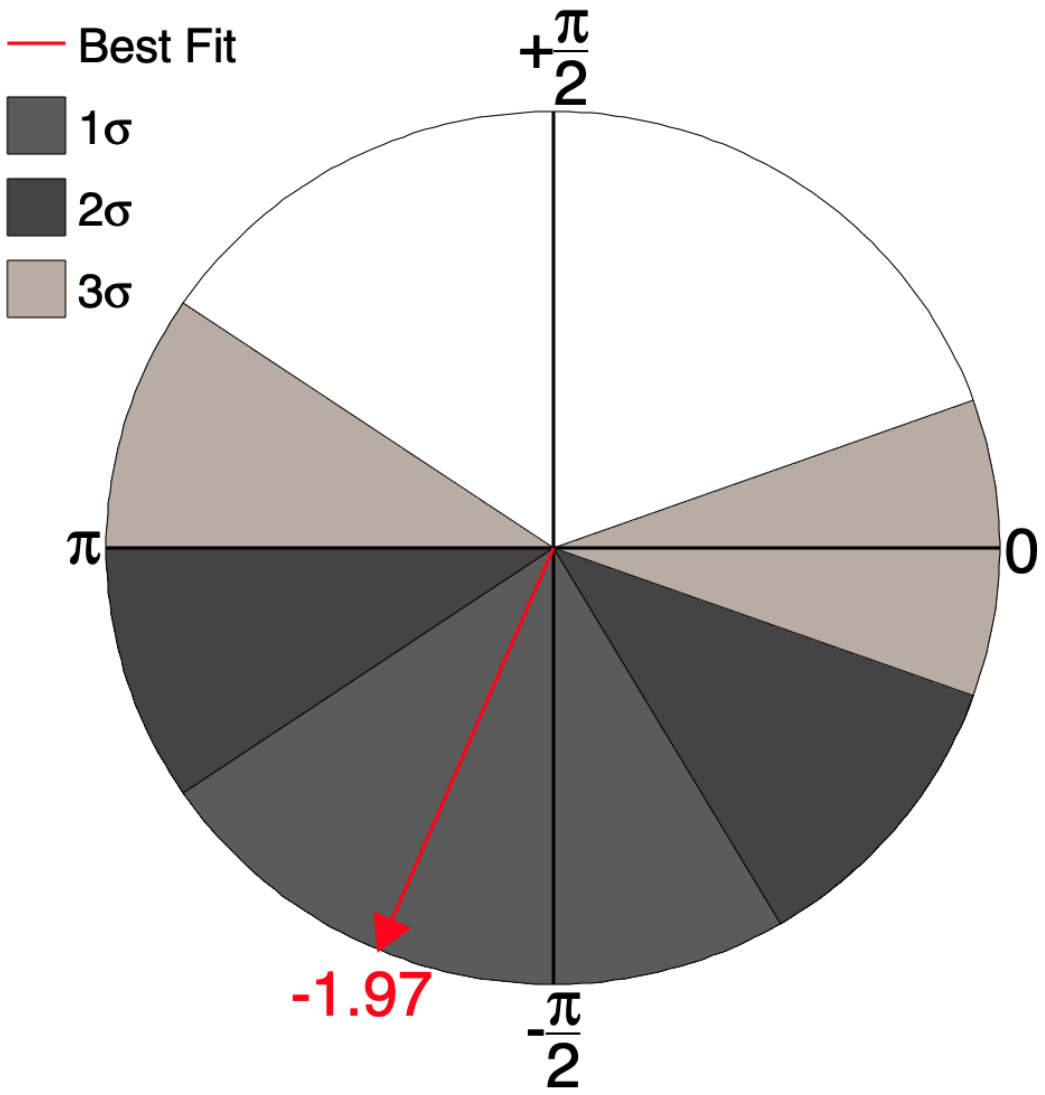
Europe	262
France	40
Germany	5
Italy	24
Poland	27
Russia	19
Spain	14
Switzerland	34
UK	99





ν_e appearance events at T2K (since Nature paper)





Future Running of T2K Beamline

- Balance between future and current programs
- Recent statement by the KEK directorate: recognition that T2K running between now and Hyper-K is important to the community
- “Will make best efforts to run 4 cycles per year” between now and the start of Hyper-Kamiokande (cycle = ~1 month)
- This means a lot of new data with the Near Detector, and with SK doped with Gd [better neutron detection, see later]
- This means that T2K remains an **active collaboration** and an **excellent training ground** for the leaders of the next generation(s) of oscillation experiments

Canadian Efforts on T2K: Pre-2022

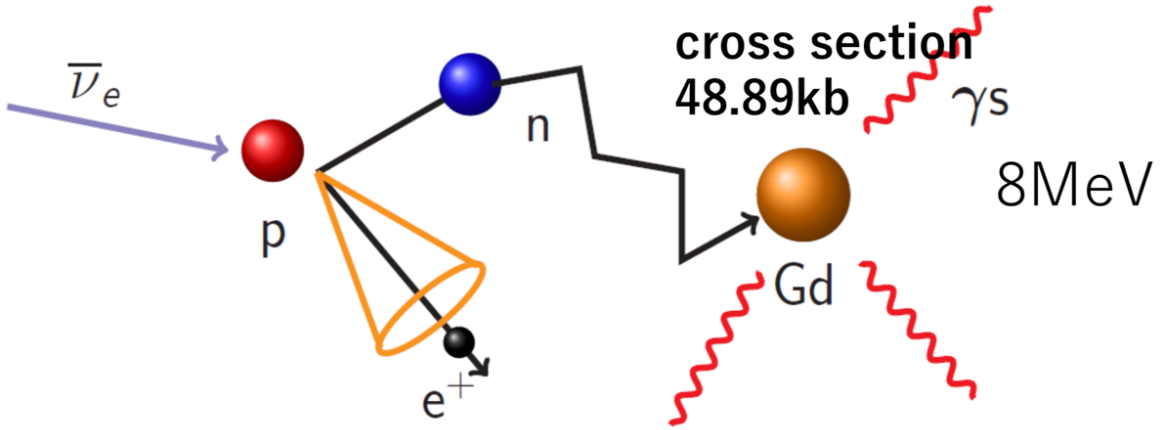
- Canadian institutions were among the founding institutions on T2K
- Provided key Near Detector components
  - Time Projection Chambers, Fine Grained Detector
- Provided Proton Beam Instrumentation: Optical Transition Radiation Monitor, plus development of Beam Induced Fluorescence Monitor
- Compute Canada plays essential role on the experiment, responsible for getting latest results to Neutrino 2020!
- Mark Hartz currently Analysis Coordinator of T2K, corresponding author for Nature Paper
- Hiro Tanaka was previous analysis coordinator, Kendall Mahn, former postdoc in Canada is also current analysis coordinator
- Constant Canadian presence on Executive Committee

Canadian Efforts on T2K: 2022-2026

- Focus is on making the most of the statistics that T2K has collected and will continue to collect—we are in the precision era!
- Need to improve on all fronts: Flux uncertainties, cross section modeling, and exploring the possibility of new channels (with identified pions in the final state, or with identified neutrons in the final state from Gd loading)
- 5 T2K groups with ~8 faculty collaborators (split across other efforts), including TRIUMF
- Current Support of T2K through Compute Canada, Beamline Instrumentation (OTR, BIF R&D), student and postdoc support
- Also involved in improving T2K neutron efficiency with Gd loading

How could you possibly improve on Super-K?

- Make it a better neutron detector!
- Key to getting low energy anti-neutrino interactions
  - From supernovae, diffuse and otherwise, and reactors
- Adding Gd to Super-K will improves neutron detectior efficiency
- Detector refurbished in 2018 to improve water handling system
- 14 tonnes of Gd ready to dissolve in SuperK: loading 0.02%Gd water **STARTED YESTERDAY**!
- Expect significant improvement even at 0.02%, final goal is 0.2%
- May also be useful for T2K because of special role that neutrons play in antineutrino/neutrino discrimination



Y. Nakajima, Neutrino 2020

2022-2026 Timeline for T2K-Canada

- This is a period of transition
  - Current grant is through 2023
  - Expect the next grant to be at a modest level to make sure the students and postdocs finish the projects they have started
  - No new hardware projects for T2K past current grant which has OTR upgrade support
  - Lessons learned during this era will be key to long term success of DUNE and HK
  - Beam Induced fluorescence device hardware funded through Japanese funding sources, but leadership is here (Mark Hartz, TRIUMF)!
- Many ramping from T2K to next generation experiments (DUNE see N. Ilic, HK, see M. Hartz)
- Focus of Analysis Effort:
  - Super-K and Gd reconstruction
  - Near Detector Analyses to improve cross section uncertainties in Oscillation Measurements at T2K and beyond

Name
Deborah Harris
Mark Hartz
Akira Konaka
Sampa Bhadra
John Martin
Blair Jamieson
Mauricio Barbi
Thomas Lindner

Relationship to other Canadian Efforts

- Not only strong ties between T2K and HyperK but also with DUNE
  - T2K's neutrino interaction model and measurements being adopted by DUNE
  - DUNE is borrowing many Near Detector strategies from T2K, since like T2K they cannot deploy a "functionally identical" near detector (See talk by N. Ilic)
  - EMPHATIC Hadron Production measurements benefit T2K & DUNE (see M. Hartz)
- Complementarity with ICECUBE/PINGU
  - Part of testing the framework is seeing oscillations across many energies and baselines, and seeing if we can break the new "standard neutrino model"
- Beamline at T2K is THE test bench for instrumentation that Hyper-K will need (Optical Transition Monitor, Beam Induced Fluorescence monitor)
- Gd-Doped Accelerator-beam measurements can help SK atmospheric analyses and possibly HK measurements

Equity, Diversity, Inclusion on T2K

- T2K as an experiment has instituted a Code of Conduct to set "expectations for professional conduct for members of the T2K collaboration"
- T2K meeting weeks include "Diversity Lunch" to discuss workplace environment issues: NOT only attended by women and minorities!
- T2K-Canada recognizes that we are far from representing the diversity of Canada but are trying to improve that to assemble the most effective teams to do science

Training Highly Qualified Professionals

- T2K has historically offered fantastic training opportunities
- Important to give students and postdocs real data to analyze, ideally data they helped to collect
- Two recent CAP Thesis Prizes awarded to T2K students (so far):
  - Patrick de Perio, University of Toronto
  - Elder Pinzon, York University
- Many leaders in tomorrow's long-baseline oscillation program, both here and abroad, came out of this program

Name	Institution	Year
Caio Licciardi	Regina PhD	2012
Daniel Roberge	UBC PhD	2012
Vyacheslav Galymov	York PhD	2012
Brian Kirby	UBC PhD	2012
Casey Bojechko	UVic PhD	2013
Patrick de Perio	Toronto PhD	2014
Anezka Kolaceke	Regina MSc	2014
Mark McCarthy	UBC MSc	2014
Shimpei Tobayama	UBC PhD	2016
Jordan Myslik	UVic PhD	2016
Christine Nielsen	UBC PhD	2017
Khalid Gameil	UBC MSc	2018
Fady Shaker	Winnipeg PhD	2018
Jiae Kim	UBC PhD	2018
Sophie Berkman	UBC PhD	2018
Elder Pinzon	York PhD	2018
Mitchell Yu	York PhD	2020
Trevor Towstego	Toronto PhD	2020
Shahin Ahmadi	Manitoba MSc	2020
Jashanjot Brar	Winnipeg MSc	2020

Name	Institution	Year
Thomas Lindner	UBC postdoc	2006-2011
Blair Jamieson	UBC postdoc	2008-2013
Kenji Hamano	TRIUMF postdoc	2008-2011
Mark Hartz	Toronto/York postdoc	2009-2013
Michael Wilking	TRIUMF postdoc	2008-2014
Kendall Mahn	TRIUMF postdoc	2009-2014
Anthony Hillairet	UVic postdoc	2010-2015
Sujeewa Kumaratunga	TRIUMF postdoc	2011-2013
Yevgeniy Petrov	UBC postdoc	2012-2017
Tom Feusels	UBC postdoc	2013-2018
Mark Scott	TRIUMF postdoc	2013-2018
Arturo Fiorentini	York postdoc	2013-2019
Nick Hastings	Regina postdoc	2010-2019
Saul Cuen-Rochin	TRIUMF postdoc	2019-2020

Broader Societal Impact

https://www.theonion.com/physicists-hail-major-breakthrough-after-discovering-ne-1844363984

- Neutrinos have captured the public's imagination
- T2K-Canada members give public talks on neutrinos
- "Young T2K" put out blog for Nature Paper release: 700 views!
- T2K won Breakthrough Prize in 2016
- T2K Nature Paper statistics:
  - 59 news articles, 508 tweets and 24 blogs