INSTITUTE OF PARTICLE PHYSICS

H. A. TANAKA (UBC/IPP)

T2K AND HYPER-KAMIOKANDE

IPP Town Hall Meeting, June 2015
University of Alberta

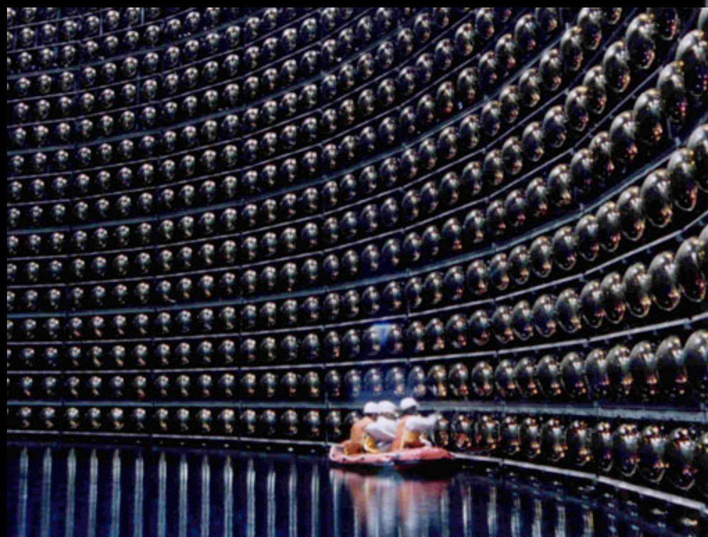
OVERVIEW:

ND280
"near" detector

~400 collaborators
from 11 nations

J-PARC

Super Kamiokande
"far" detector



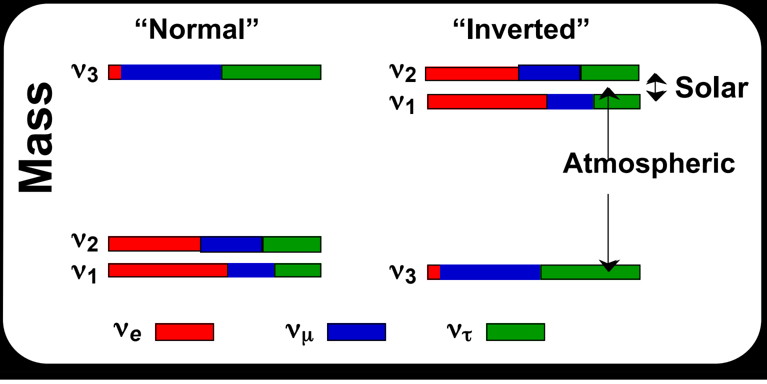
- T2K: Tokai-to-Kamioka neutrino oscillation:
  - Study neutrino oscillations with an intense $\nu_\mu/\bar{\nu}_\mu$ beam sent 295 km across Japan to the Super-Kamiokande (SK) detector. Near detector (ND) at 280 meters from target.
- Hyper-Kamiokande: a x25 upgrade to Super-Kamiokande
  - definitive observation and measurement of CPV in neutrinos
  - Test the unitarity of neutrino mixing
  - proton decay, detection of supernova neutrinos, neutrino observatory, etc.
- NuPRISM
  - unique detector concept to study fundamental properties of neutrino interactions
  - reduce systematics in neutrino oscillation searches, sterile neutrino searches

NEUTRINO OSCILLATION TALKS AT CAP

- **Session: T3-5 (Tuesday, 1545-1715) CAB 235. Chair: Z. Gesce**
  - **N. Hastings:**
    - "Status of Long Baseline Experiments" (1545-1615)
  - **F. Shaker:**
    - "Electron Neutrino Cross Section Measurements at the T2K Off-Axis Near Detector" (1615-1630)
  - **C. Nielsen:**
    - "Constraining Oscillation Analysis Inputs at the T2K Near Detector" (1630-1645)
  - **K. Clark:**
    - "Deep Core and PINGU - Studying Neutrinos in the Ice" (1645-1700)
  - **A. Konaka:**
    - "Experimental test of the unitarity of the leptonic mixing (PMNS) matrix" (1700-1715)

NEUTRINO OSCILLATIONS in the Standard Model

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}U_{e1} & U_{e2} & U_{e3}\\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3}\\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3}\end{pmatrix} \times \begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$



"Mass hierarchy problem"

↓

$c_{ij} = \cos\theta_{ij}$

$s_{ij} = \sin\theta_{ij}$

$$\begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix} \cdot \begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & c_{13}\end{pmatrix} \cdot \begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix} \cdot \begin{pmatrix}e^{i\alpha_1/2} & 0 & 0\\ 0 & e^{i\alpha_2/2} & 0\\ 0 & 0 & 1\end{pmatrix}$$

$$\begin{aligned} P(\nu_\mu \to \nu_e) \sim\ & \sin^2 2\theta_{13} \times \sin^2\theta_{23} \frac{\sin^2[(1-x)\Delta]}{(1-x)^2} && (\equiv P_0)\\ & -\alpha \sin 2\theta_{13} \times \sin\delta \sin 2\theta_{12} \sin 2\theta_{23} \sin\Delta \frac{\sin(x\Delta)}{x} \frac{\sin[(1-x)\Delta]}{(1-x)} && (\equiv P_1)\\ & +\alpha \sin 2\theta_{13} \times \cos\delta \sin 2\theta_{12} \sin 2\theta_{23} \cos\Delta \frac{\sin(x\Delta)}{x} \frac{\sin[(1-x)\Delta]}{(1-x)} && (\equiv P_2)\\ & +\alpha^2 \times \cos^2\theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(x\Delta)}{x^2} && (\equiv P_3) \end{aligned}$$

M. Freund, PRD64 (2001) 053003

$$\Delta \equiv \frac{\Delta m^2_{31} L}{4E} \qquad x \equiv \frac{2\sqrt{2} G_F N_e E}{\Delta m^2_{31}}$$

$$P(\nu_\mu \to \nu_\mu) = 1 - \left(\cos^4 2\theta_{13} \sin^2 2\theta_{23} + \sin^2 2\theta_{13} \sin^2\theta_{23}\right) \sin^2 \Delta m^2_{31} \frac{L}{4E}$$

- CP odd phase δ induces $\nu/\overline{\nu}$ asymmetries in oscillations (CP violation)
- x (matter effect) sensitive to mass ordering → mass hierarchy resolution
- θ_{23} ~ 45 degrees: possible unknown symmetry in the mixing?

HISTORY

- Founding members of the collaboration in 2001
  - introduced off-axis beam concept
- Construction: 2004-2009
- Data-taking from 2010

UA, UBC, Regina, UT, UVic, Winnipeg, York, TRIUMF

The JHF-Kamioka neutrino project

Y. Itow[1], T. Kajita[1], K. Kaneyuki[1], M. Shiozawa[1], Y. Totsuka[1], Y. Hayato[2], T. Ishida[2], T. Ishii[2], T. Kobayashi[2], T. Maruyama[2], K. Nakamura[2], Y. Obayashi[2], Y. Oyama[2], M. Sakuda[2], M. Yoshida[2], S. Aoki[3], T. Hara[3], A. Suzuki[3], A. Ichikawa[4], T. Nakaya[4], K. Nishikawa[4], T. Hasegawa[5], K. Ishihara[5], A. Suzuki[5], A. Konaka[6]

[1] Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan

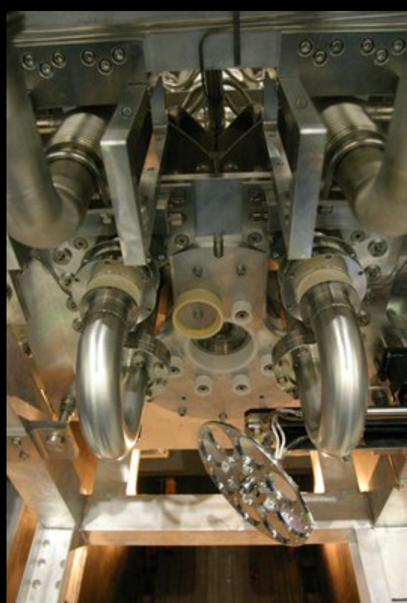
[2] Inst. of Particle and Nuclear Studies, High Energy Accelerator Research Org. (KEK), Tsukuba, Ibaraki 305-0801, Japan

[3] Department of Physics, Kobe University, Kobe, Hyogo 657-8501, Japan

[4] Department of Physics, Kyoto University, Kyoto 606-8502, Japan

[5] Department of Physics, Tohoku University, Sendai, Miyagi, 980-8578, Japan

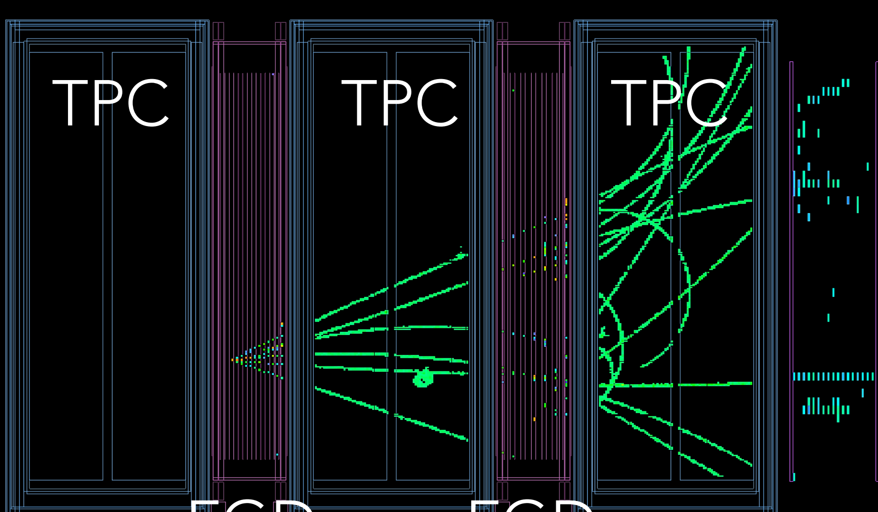
[6] TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada, V6T 2A3

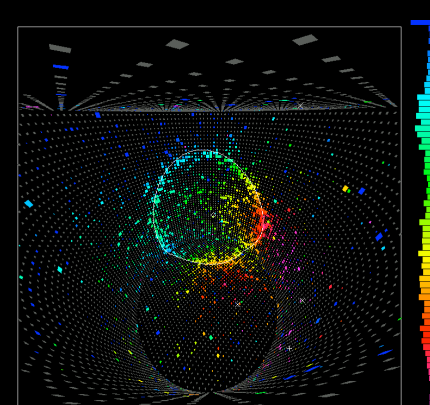


OTR

TPC

FGD





Canadian contributions:

- beam line: OTR monitor, remote handling
- Near detector tracker
  - fine-grained scintillating detectors (FGDs)
  - time projection chambers (TPCs)
  - slow control, network, services
- Analysis:
  - near/far extrapolation
  - ND: calibration, reconstruction
  - SK reconstruction algorithm
- Computing:
  - "Tier 1" storage, ~1/2 of computing
  - website, databases, repositories (TRIUMF)

PROGRESS

conveners:
A. Konaka (SK)
S. Oser (ND280 ν_μ)
H. A. Tanaka (ND280, SK)

- 2011: Indication of ν_e appearance
  - 6 ν_e candidates (1.5)

PRL107 (2011) 041801
Lepton-Photon 2011
H. A. Tanaka

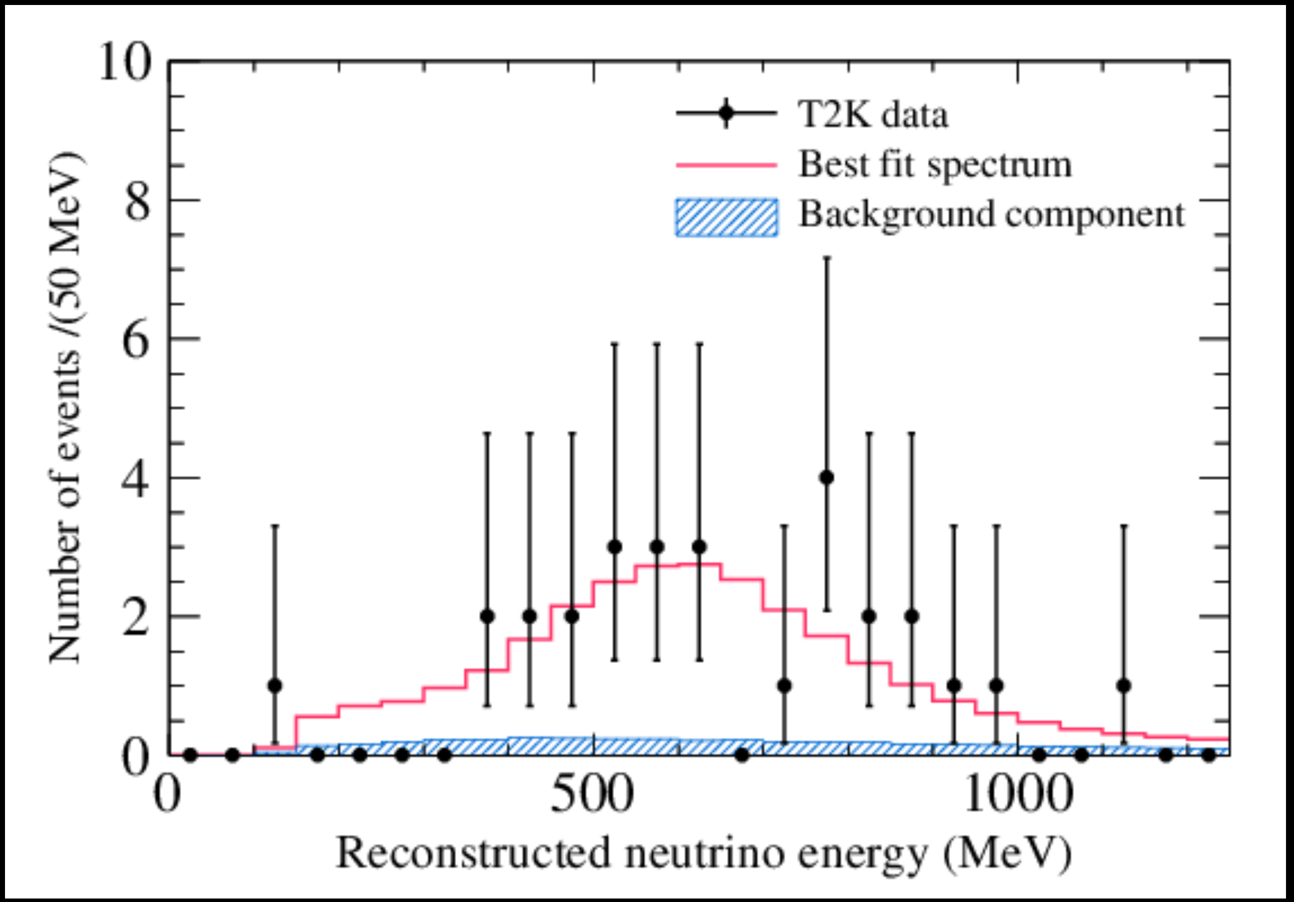
- 2012: Evidence of ν_e appearance
  - 11 ν_e candidates (3.3)

chair: M. Hartz, K. Mahn
PRD 88 (2013) 3, 032002

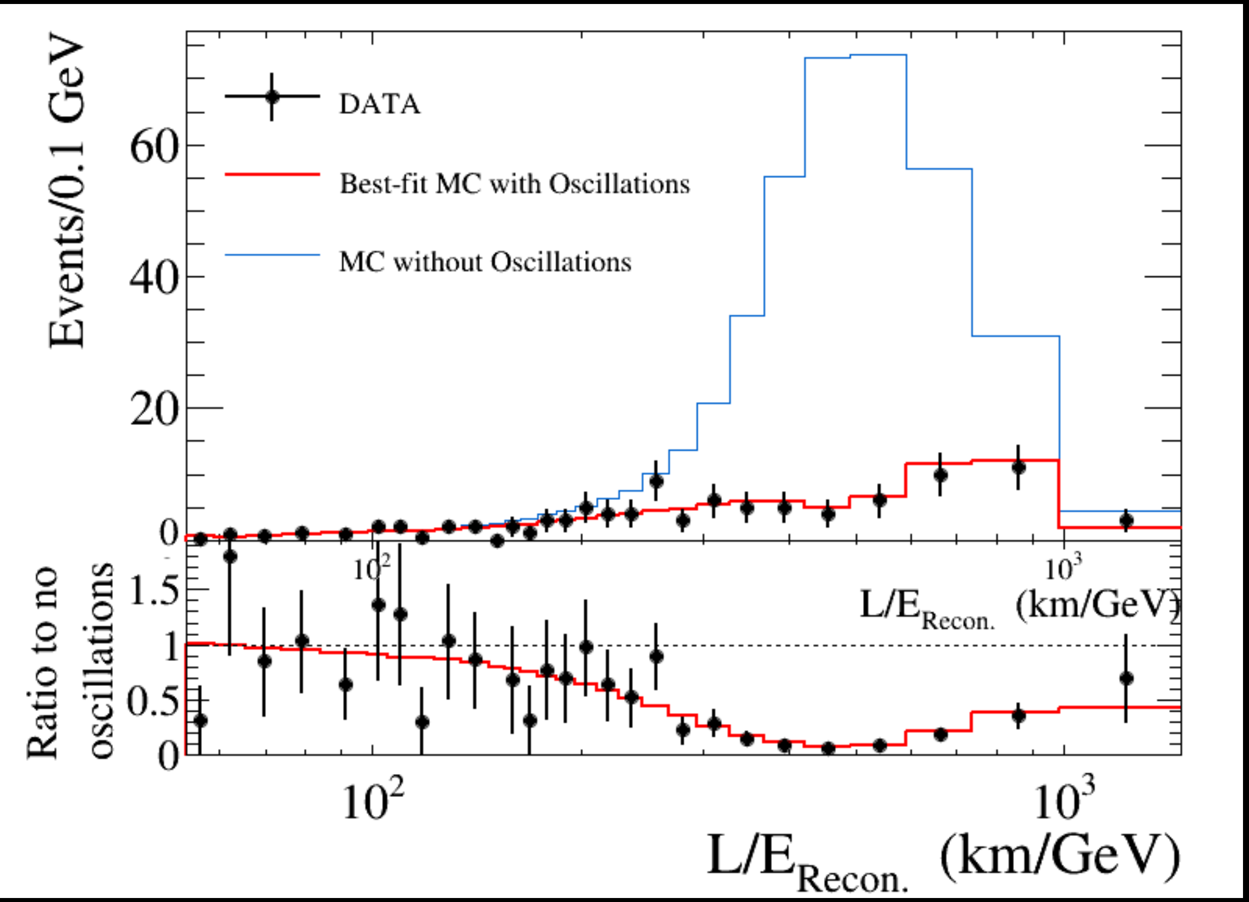
- 2013: Definitive observation
  - 28 ν_e candidates (4.9)

PRL 112 (2014) 061802

EPS-HEP 2013 M. Wilking (ND280 ν_μ, TRIUMF)



conveners: K. Mahn (TRIUMF), M. Hartz (York/Toronto),
A. Hillairet (UVic, ND280 ν_μ)
analysis coordinator: H. A. Tanaka



- 2014:

chair: S. Oser
PRL 112 (2014) 18, 181801

  - Most precise measurement of θ_{23} with ν_μ disappearance

chair: D. Karlen
PRD91 (2015) 7, 072010

  - First constraints on δ_{CP} with joint analysis of $\nu_\mu + \nu_e$ data

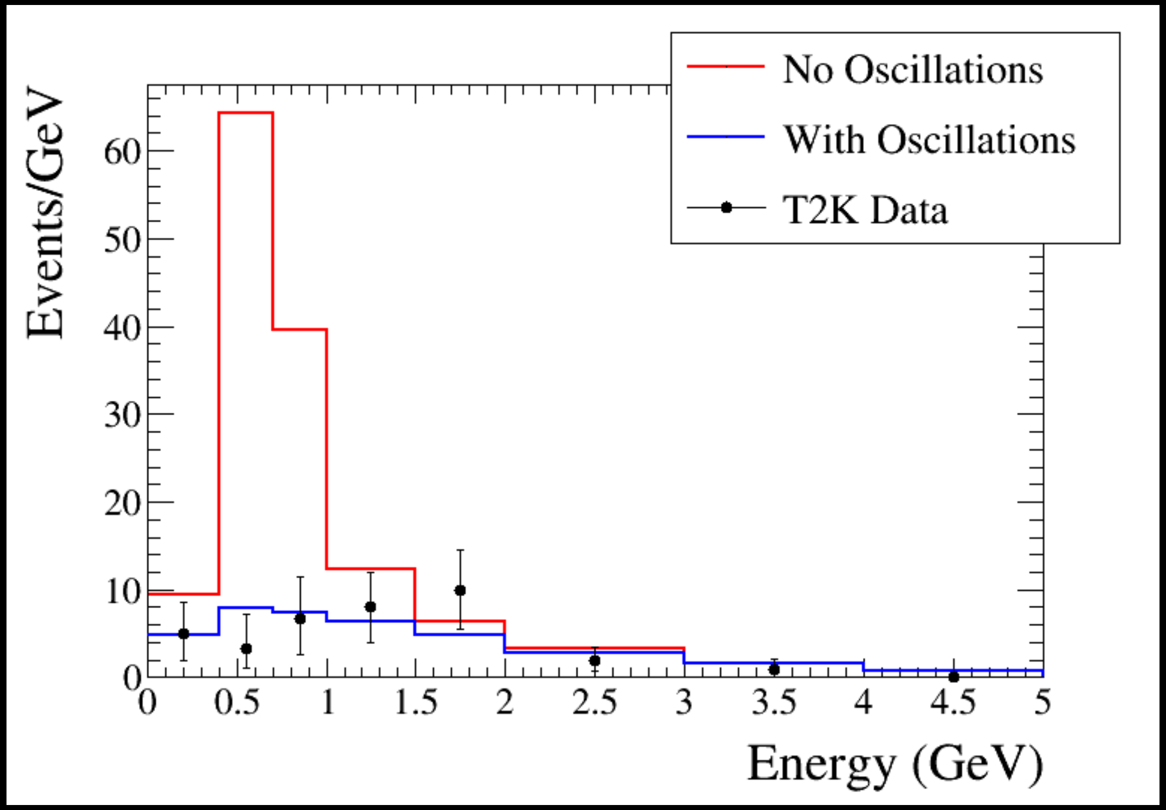
Moriond EW 2014
P. de Perio

    - large range disfavoured @90% CL

TODAY:

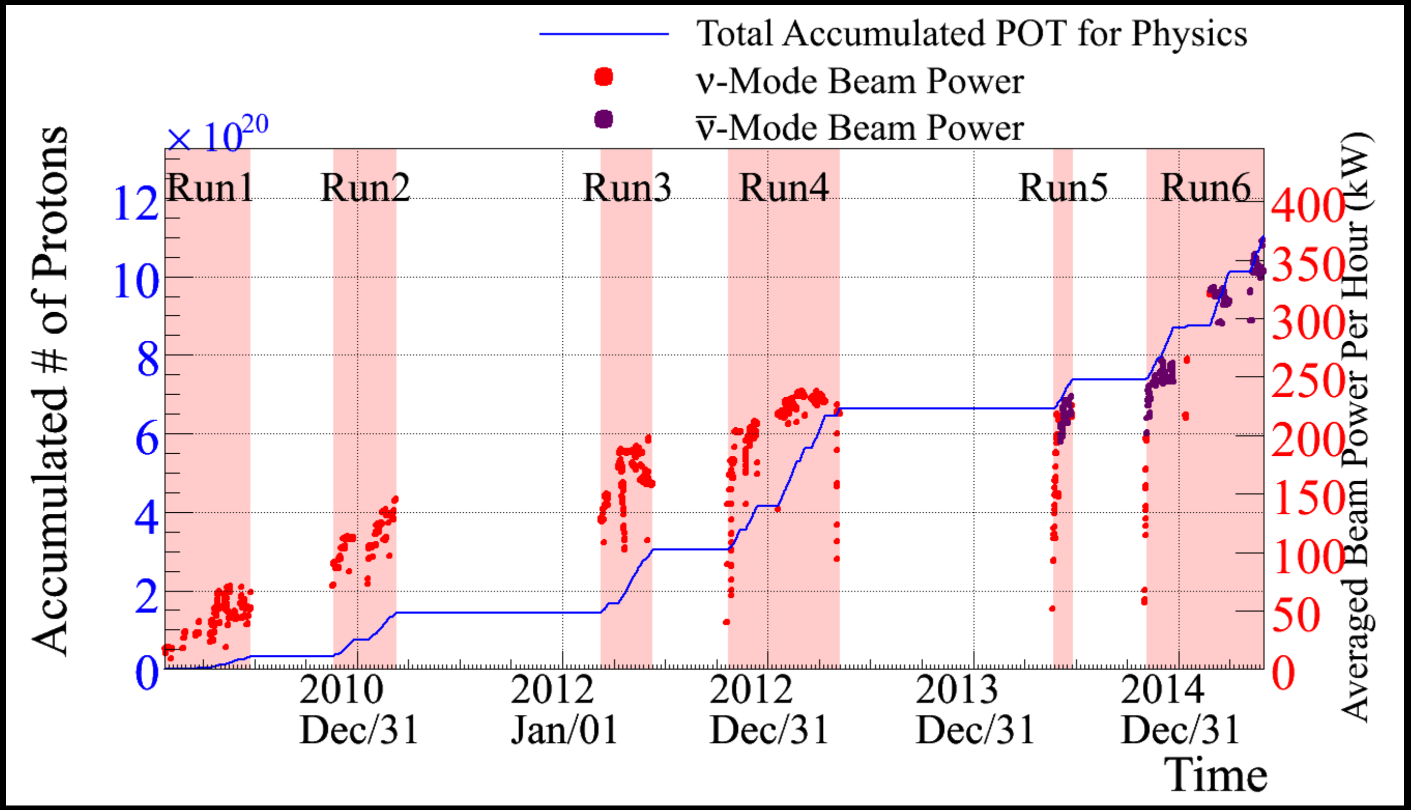
Conveners: M. Scott (TRIUMF), M. Hartz (TRIUMF/IPMU), A. Hillairet (UVic), B. Jamieson (Winnipeg), Y. Petrov (UBC)
Analysis Coordinator: H. A. Tanaka

B. Jamieson CIPANP 2015



- Antineutrino Running:
  - 1st antineutrino results with 2.3x10[20] POT
    - see talks by N. Hastings, C. Nielsen, F. Shaker
  - Update soon with 4.0x10[20] POT
    - new $\bar{\nu}_\mu$ disappearance
    - first $\bar{\nu}_e$ appearance
    - joint analysis

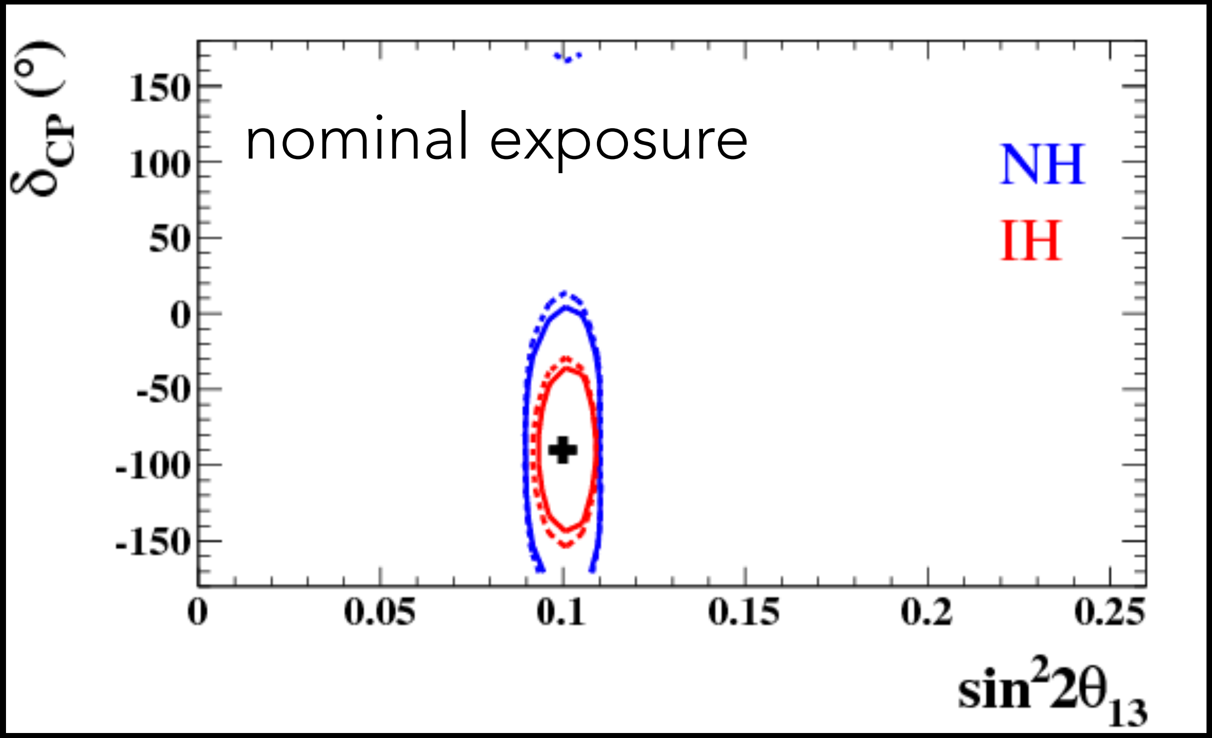
- Beam power
  - 1/2015: ~240 kW→320 kW
  - 3/2015: ~320 kW→350 kW
    - Maximum: ~375 kW
- >400 kW possible currently
- 750 kW (and beyond) possible following power supply upgrade

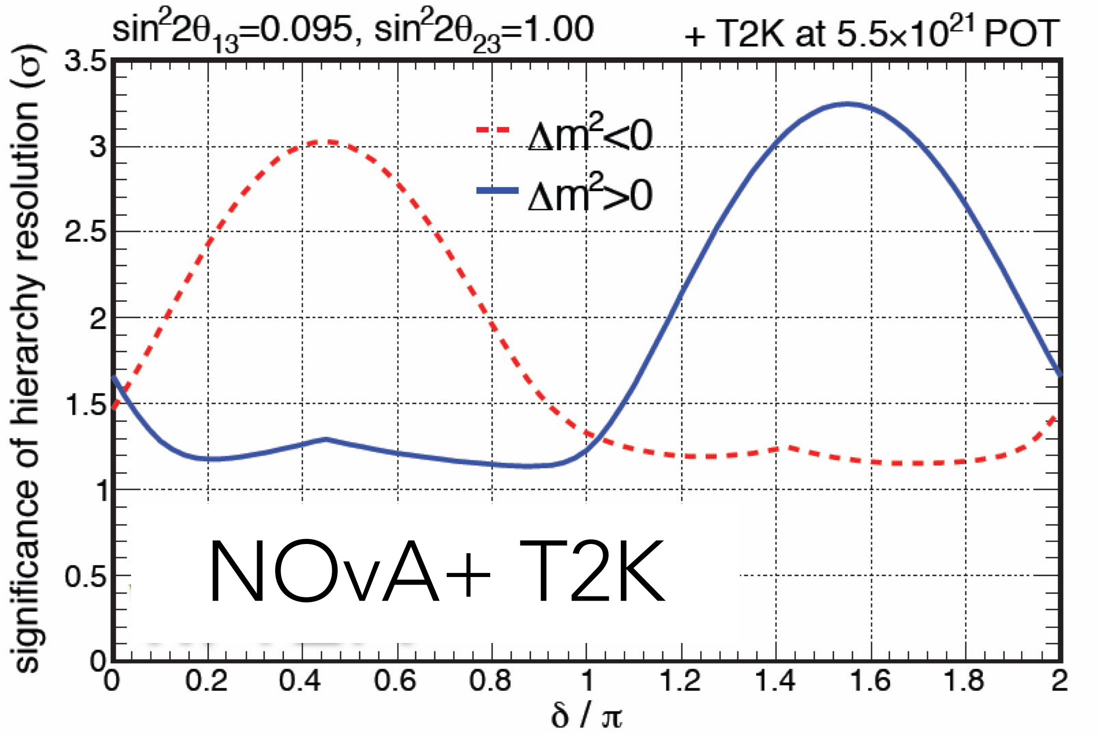


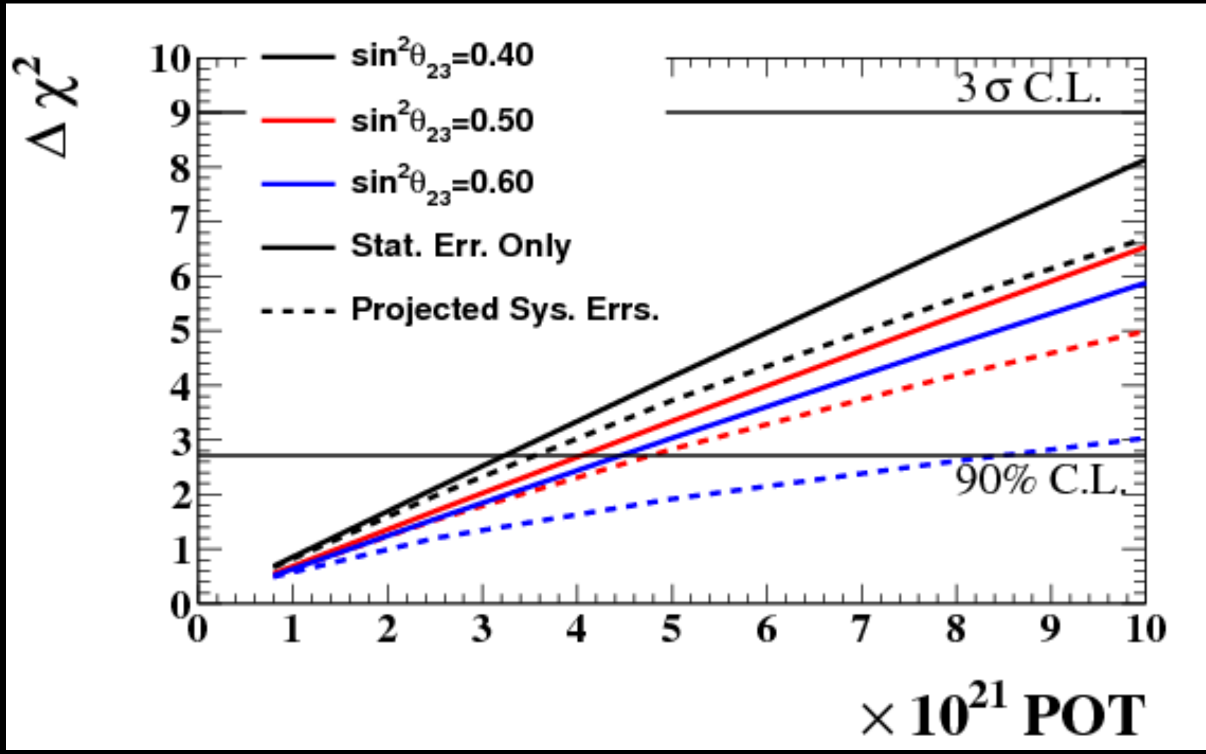
CANADIAN LEADERSHIP IN T2K/HK

	TIME ⟹		
T2K			
Executive	J-M. POUTISSOU	J. MARTIN	D. KARLEN
Run Coordination	D. KARLEN (CHAIR)	N. HASTINGS	N. HASTINGS
Beam		M. HARTZ	M. HARTZ
ND	H. A. TANAKA	S. M. OSER	
ND ν_{μ}	S. M. OSER	M. WILKING	A. HILLAIRET
ND ν_{e}			B. JAMIESON
ND Calibration	F. RETIERE		Y. PETROV
software/computing	T.LINDNER	T.LINDNER	T. LINDNER
Near/Far, Oscillation		M. HARTZ, K. MAHN	M. HARTZ, M. SCOTT
T2K-SK (Far det)	A. KONAKA	H. A. TANAKA	M. WILKING
Analysis			H. A. TANAKA
Publication	S. M. OSER (CHAIR)		
Speakers		S. BHADRA	M. BARBI, H. A. TANAKA
Election		S. BHADRA	S. BHADRA (CHAIR)
HK			
International Steering	J-M POUTISSOU		
Institutional Board	S. BHADRA, A. KONAKA		
Electronics/DAQ	T. LINDNER		

2017-21: T2K ν OSCILLATION:

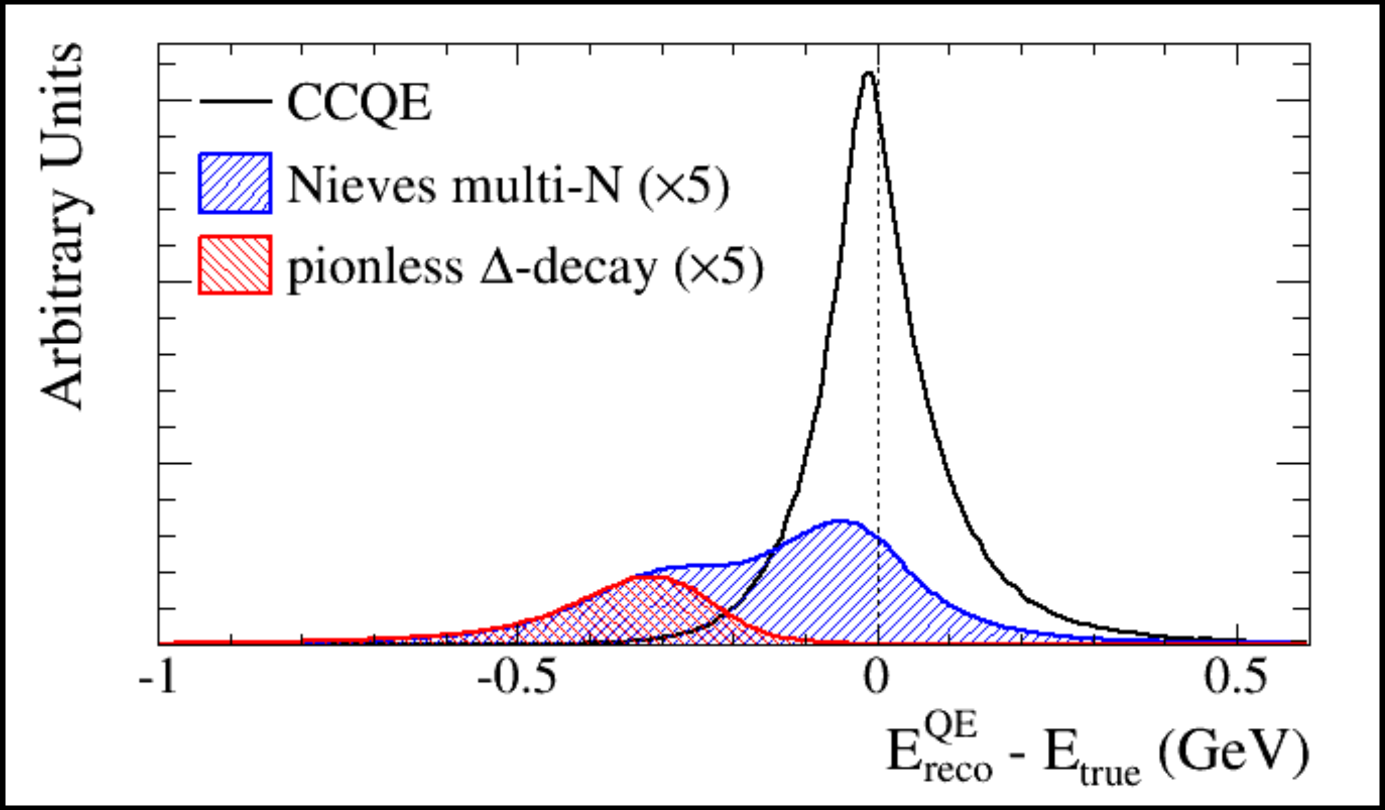


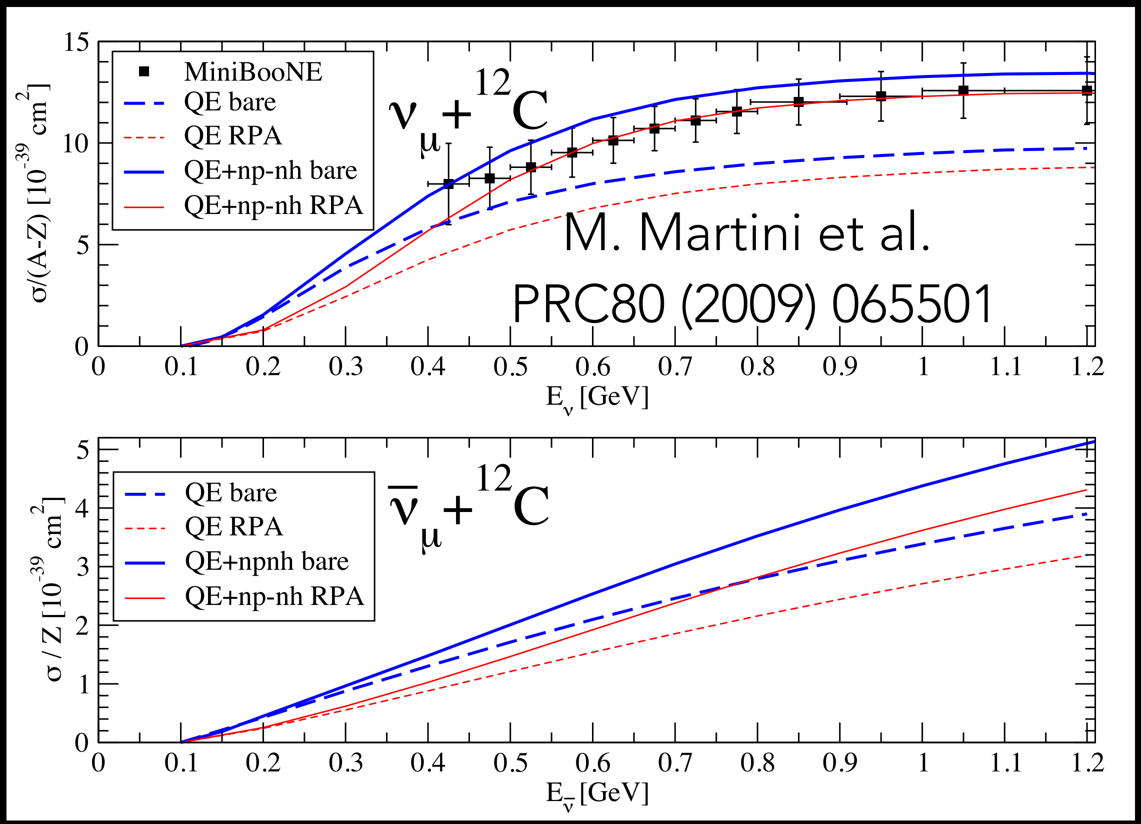




- Search for CP violation in neutrino oscillations
  - would be the second source of CP violation in particle physics!
- Precision measurement of θ_{23}
  - search for non-maximal θ_{23}
  - octant resolution
  - what is the structure of mixing in neutrinos?
- Resolution of neutrino mass hierarchy with other experiments.

NEUTRINO INTERACTIONS

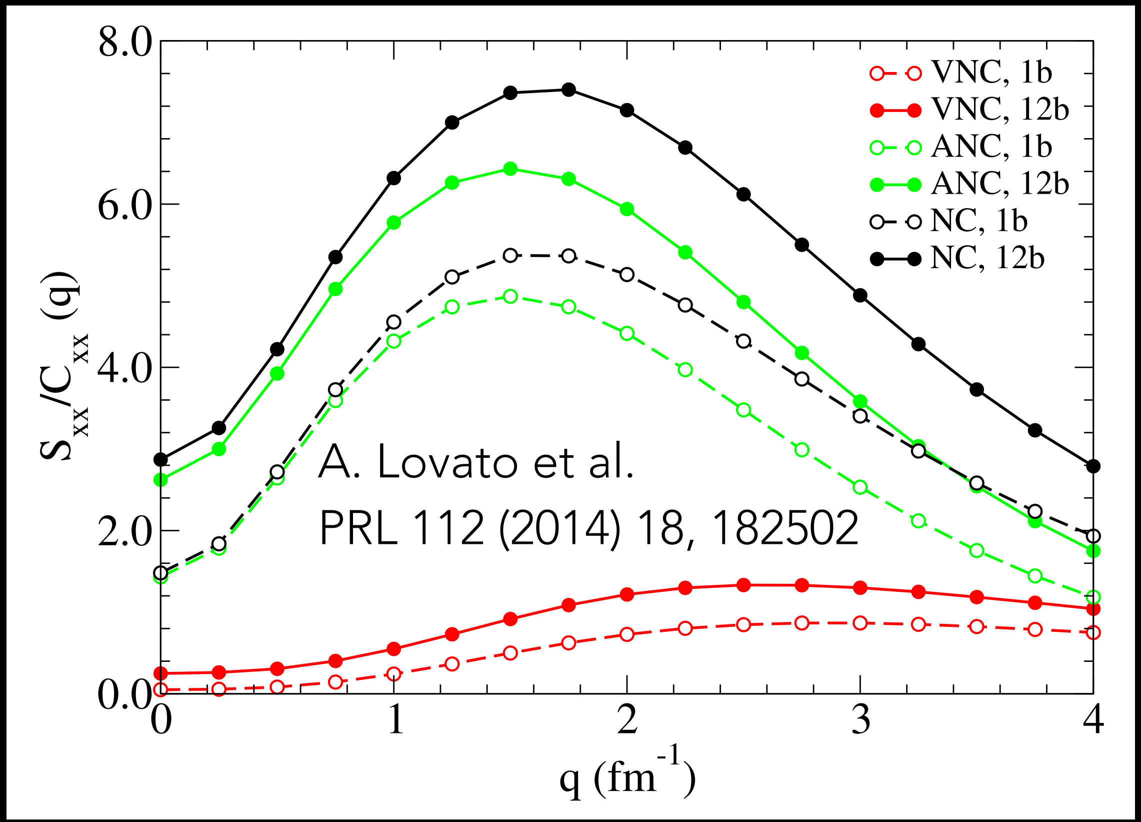




- neutrino energy reconstruction depends on assuming "underlying" mechanism, e.g.

$$\nu_\ell + n \to \ell + p$$

- Additional multi-nucleon mechanisms contribute to the cross section with the same effective final state
  - changes underlying kinematics relation between lepton kinematics and neutrino energy
- Critical to understand for ν-oscillation physics
  - very active area of nuclear theoretical work
  - probe fundamental nature of the electroweak interaction in nuclei



SENSITIVITY IMPROVEMENTS

current systematic errors

	ν_e	w/ ND	ν_μ	w/ ND
	%	%	%	%
SK detector	4.03		2.72	
Hadronic	2.98		2.44	
uncor. ν	5.00		4.69	
flux/corr ν	21.75	2.74	26.04	3.15
Total	23.45	7.65	26.80	6.75

- Increasing effective statistics
  - include π pion production channels in addition to "quasi-elastic" interactions in samples at SK by reconstructing multi-ring topologies

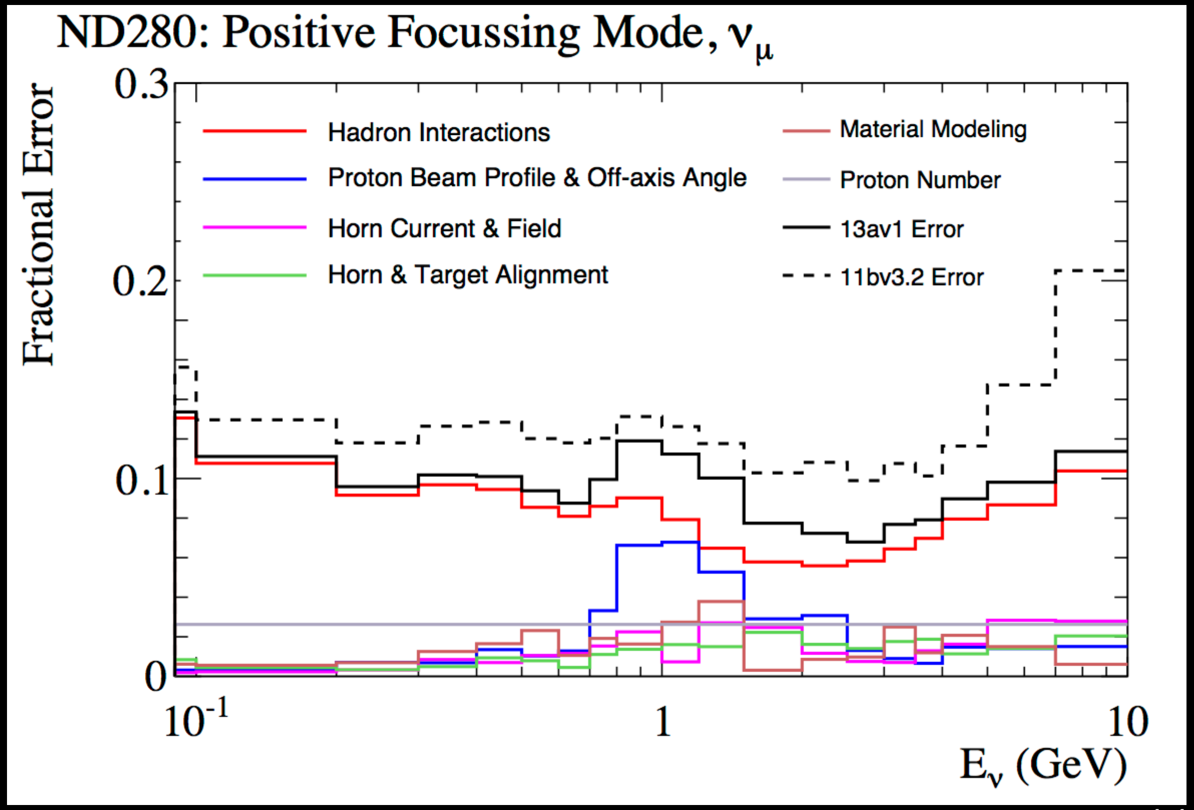
$$\nu_\ell + n \rightarrow \ell + p$$
$$\nu_\ell + (n/p) \rightarrow \ell + \pi + (n/p)$$

  - increase fiducial volume

Canadian leadership in all the above

- Continuous effort to reduce systematics
  - neutrino flux prediction
  - ν-interaction model improvements
  - near/far extrapolation with near detector samples
    - water target in FGD2
  - reduction of SK errors, backgrounds

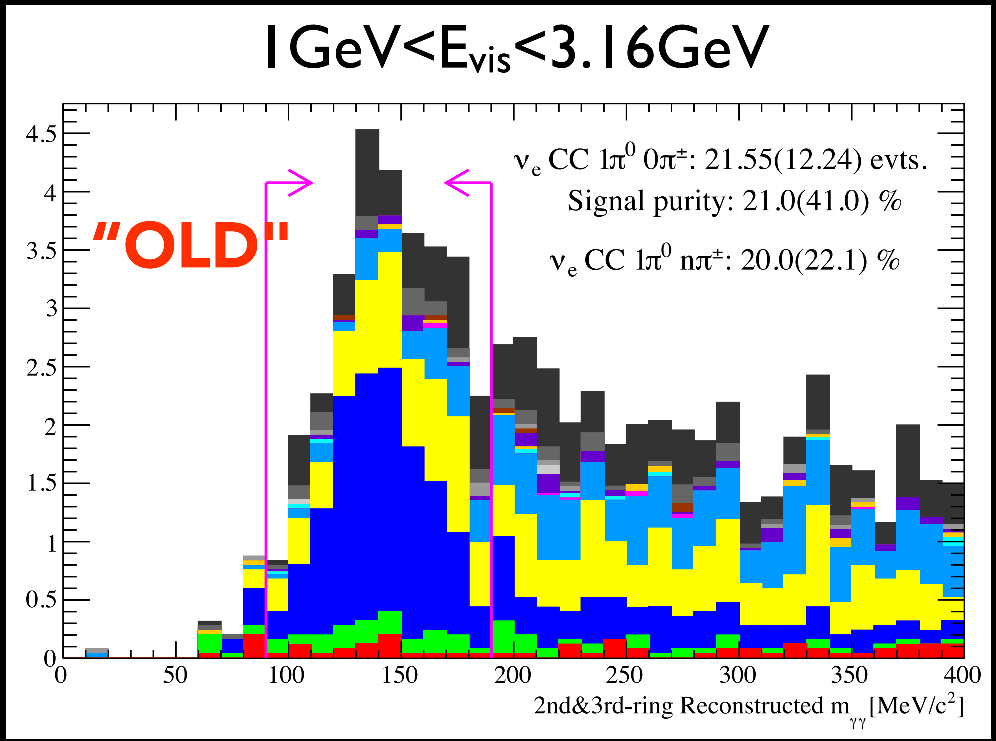
see talks by C. Nielsen, F. Shaker

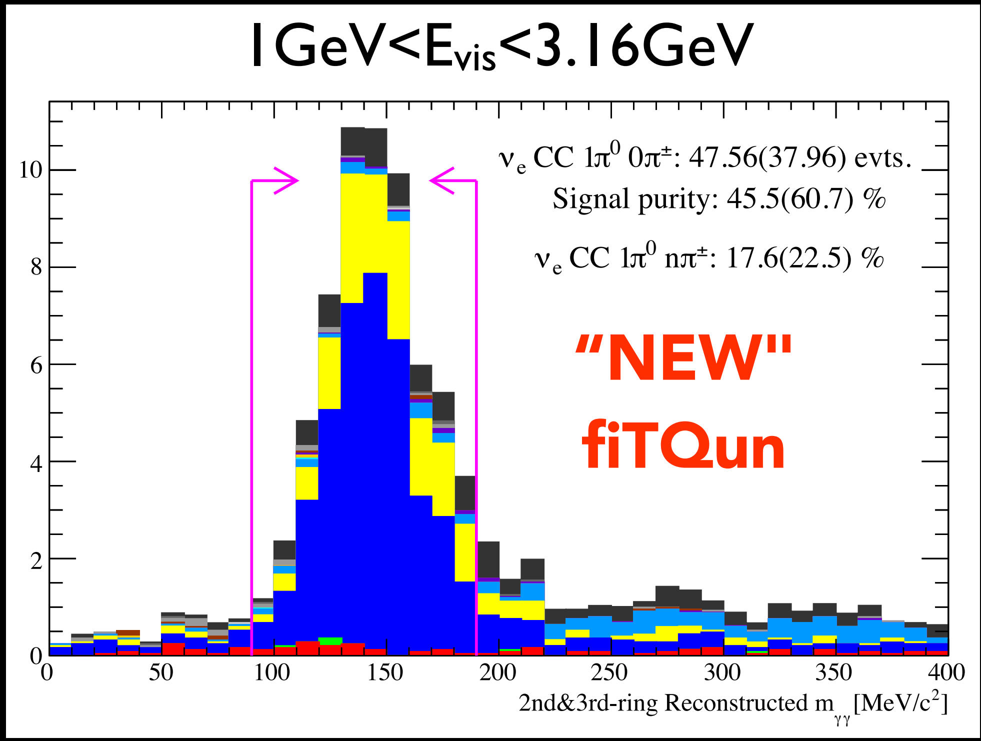


ATMOSPHERIC NEUTRINOS

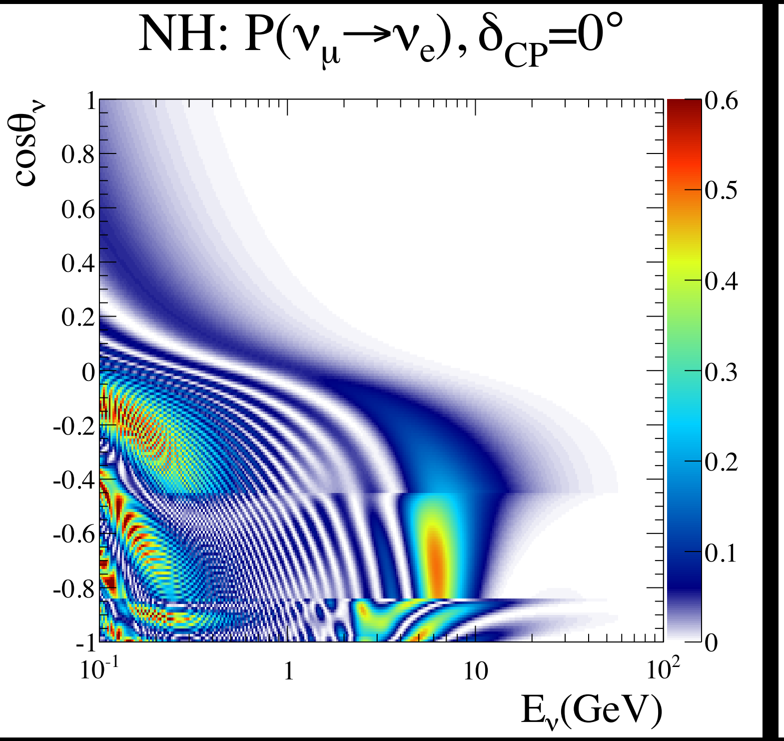
- T2K has minimal sensitivity to matter effects
- Atmospheric neutrinos in SK:
  - "complementary" sample with large matter effects to probe mass hierarchy.
  - reconstruction of multi-GeV neutrinos critical for sensitivity→ multi-ring topologies
- New reconstruction algorithm increases efficiency by >x3 in key channels with large improvement in purity.
  - Aim to make SK atmospheric sample competitive for near term mass hierarchy determination.

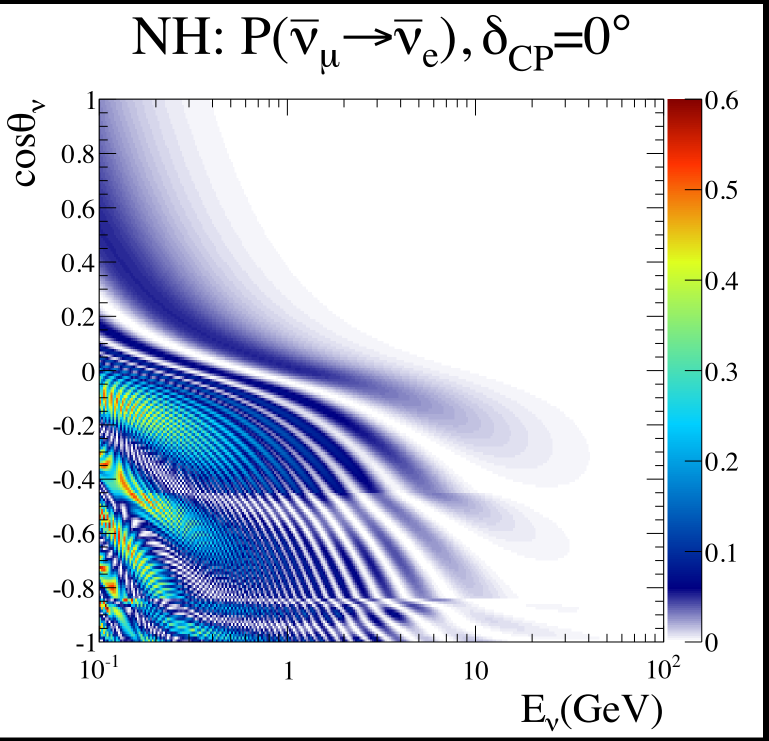
ν_e CC π^0 reconstruction



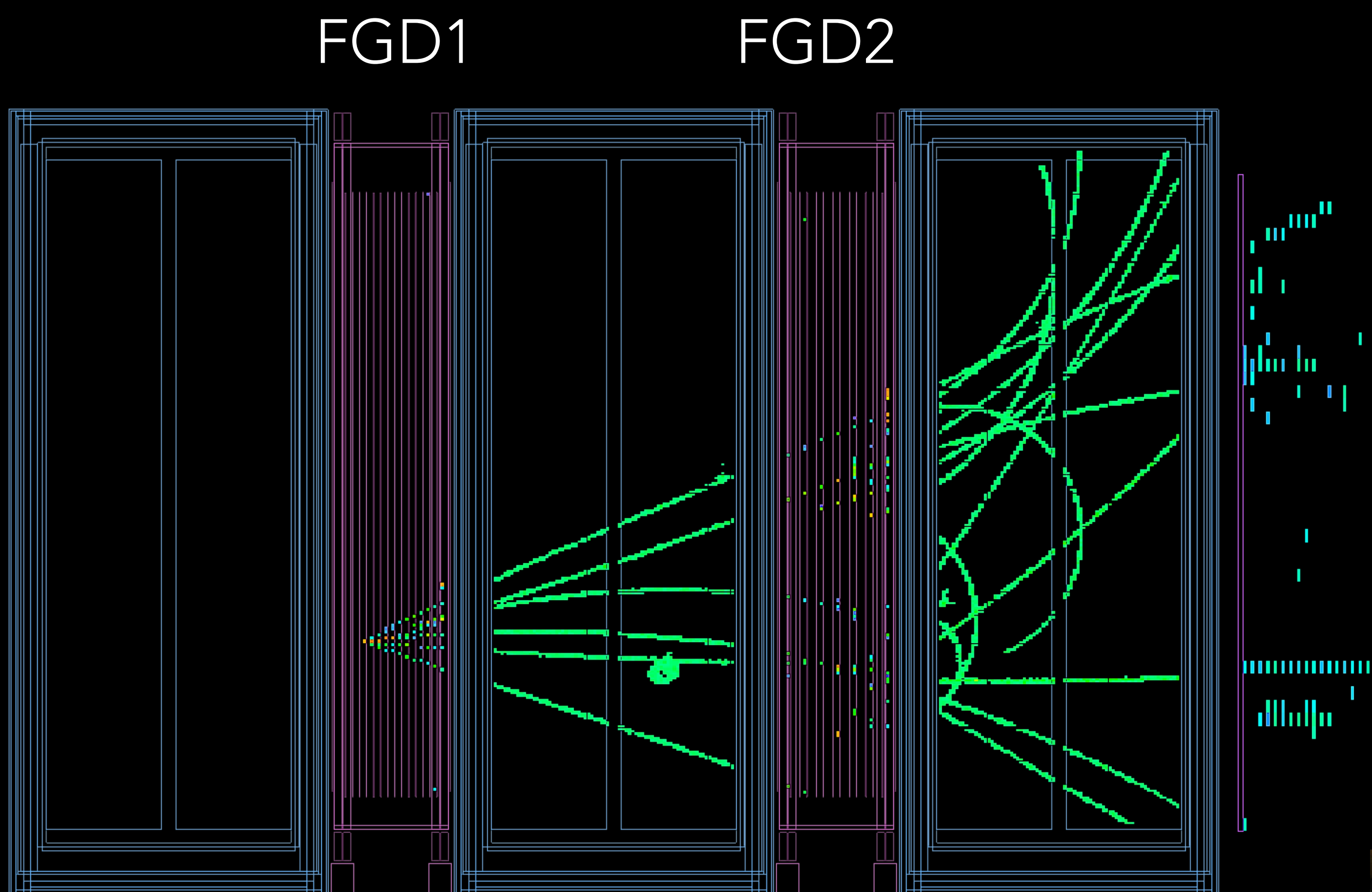


Potential to significantly improve proton decay searches



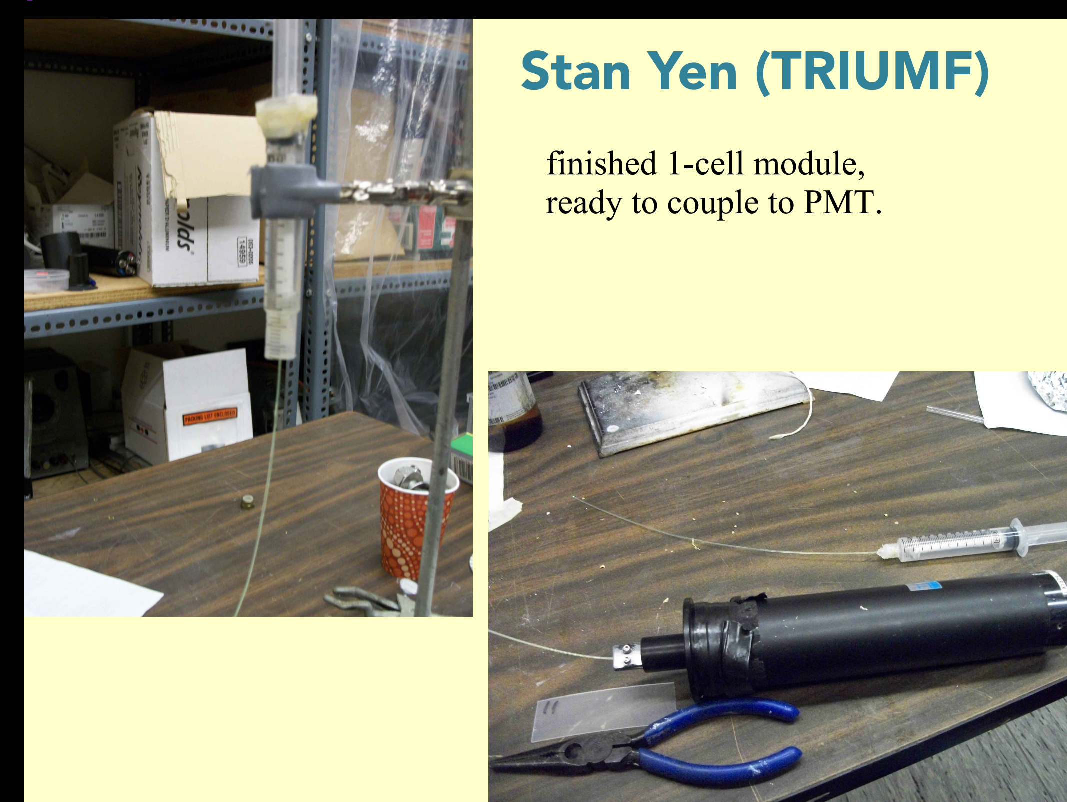


WATER-BASED SCINTILLATOR



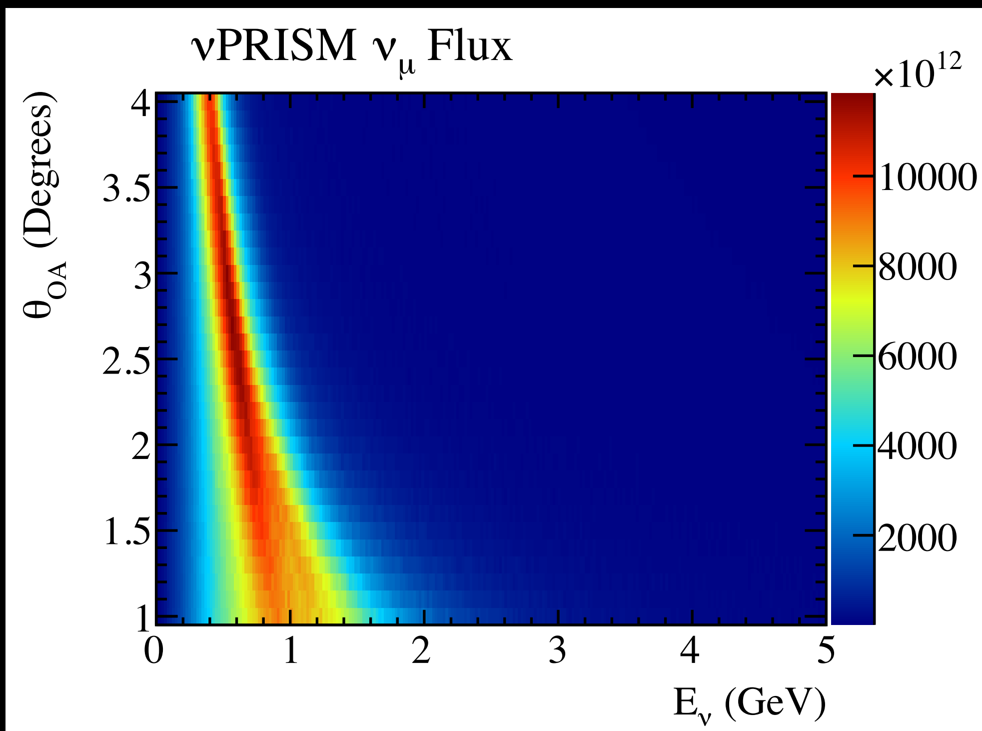
- Current FGD system includes passive water modules in one detector (FGD2)
- Subtraction analysis with FGD1 yields
- First results soon!

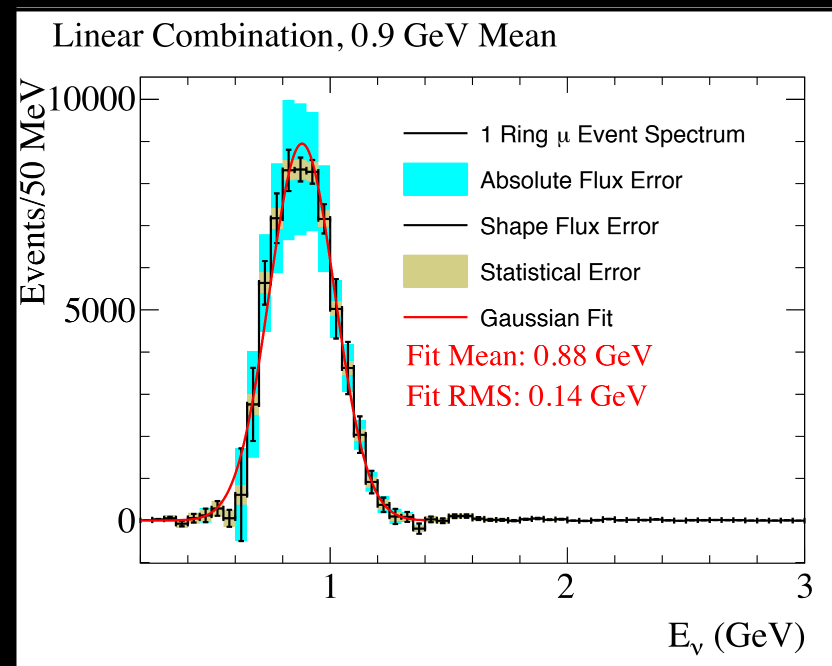
See talk by C. Nielsen

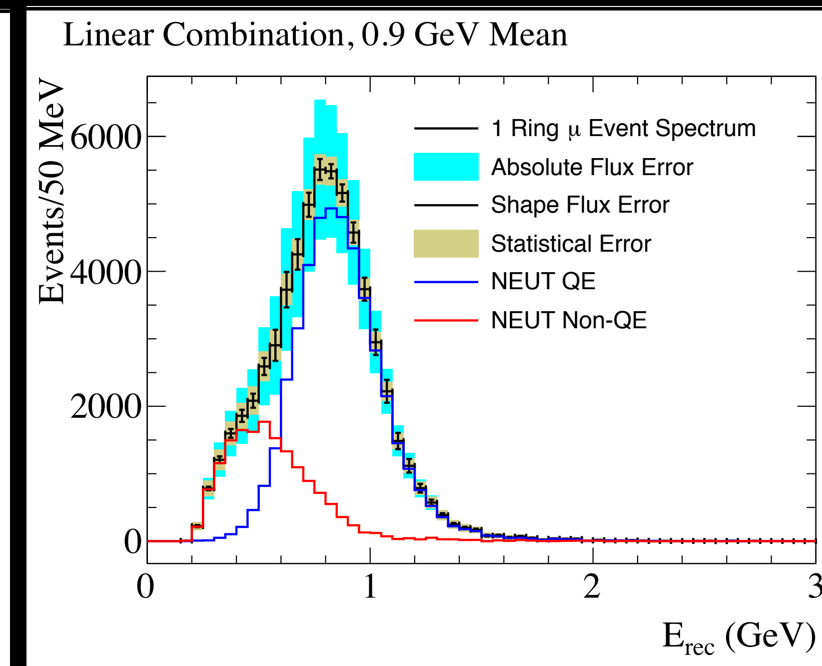


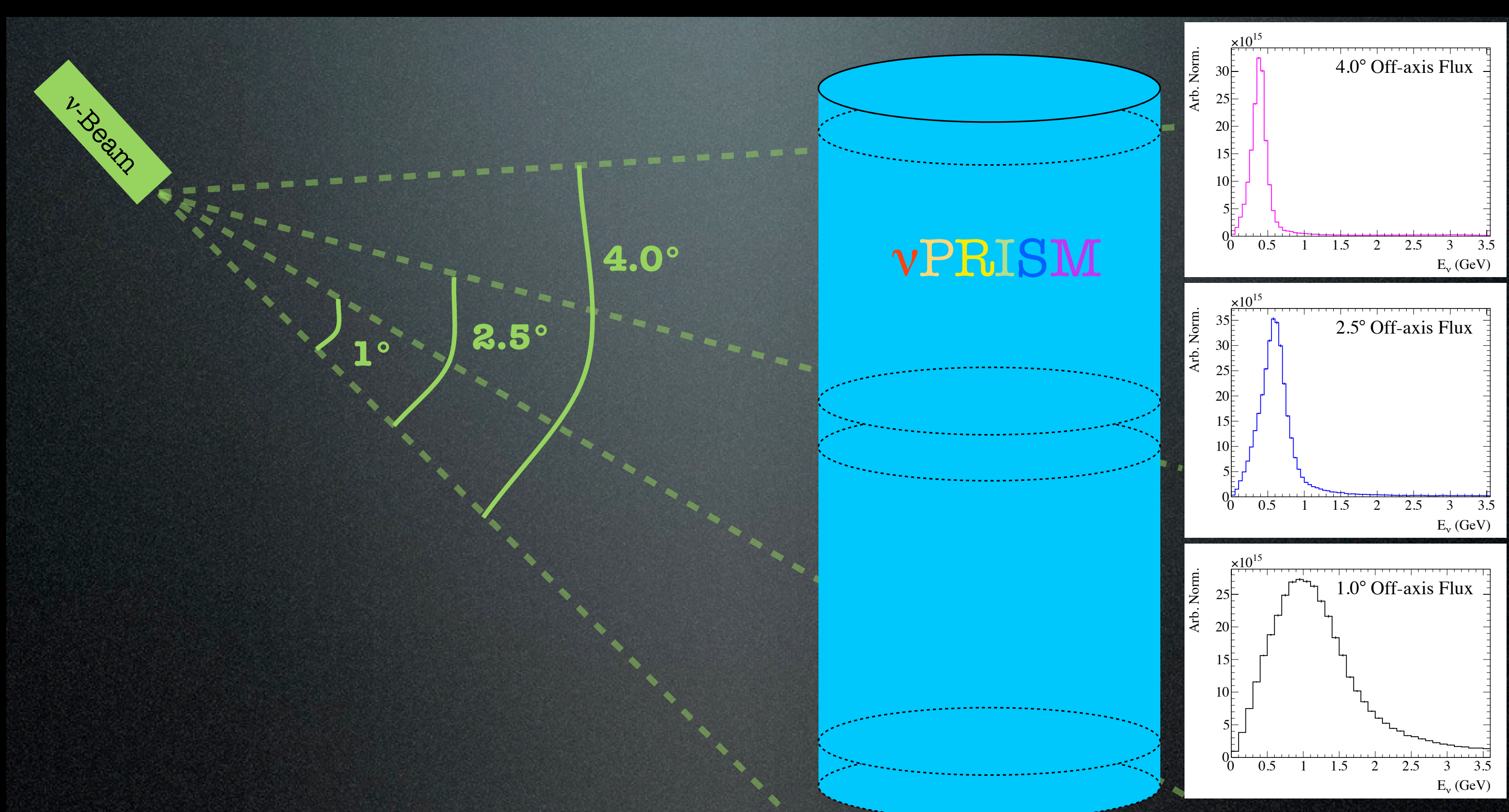
- Tracking is very important for event identification
  - fully active detector desired
  - possibly finer granularity
- New WbLS developed by BNL
- Single cell prototype under study with TRIUMF M11 beam line

NUPRISM





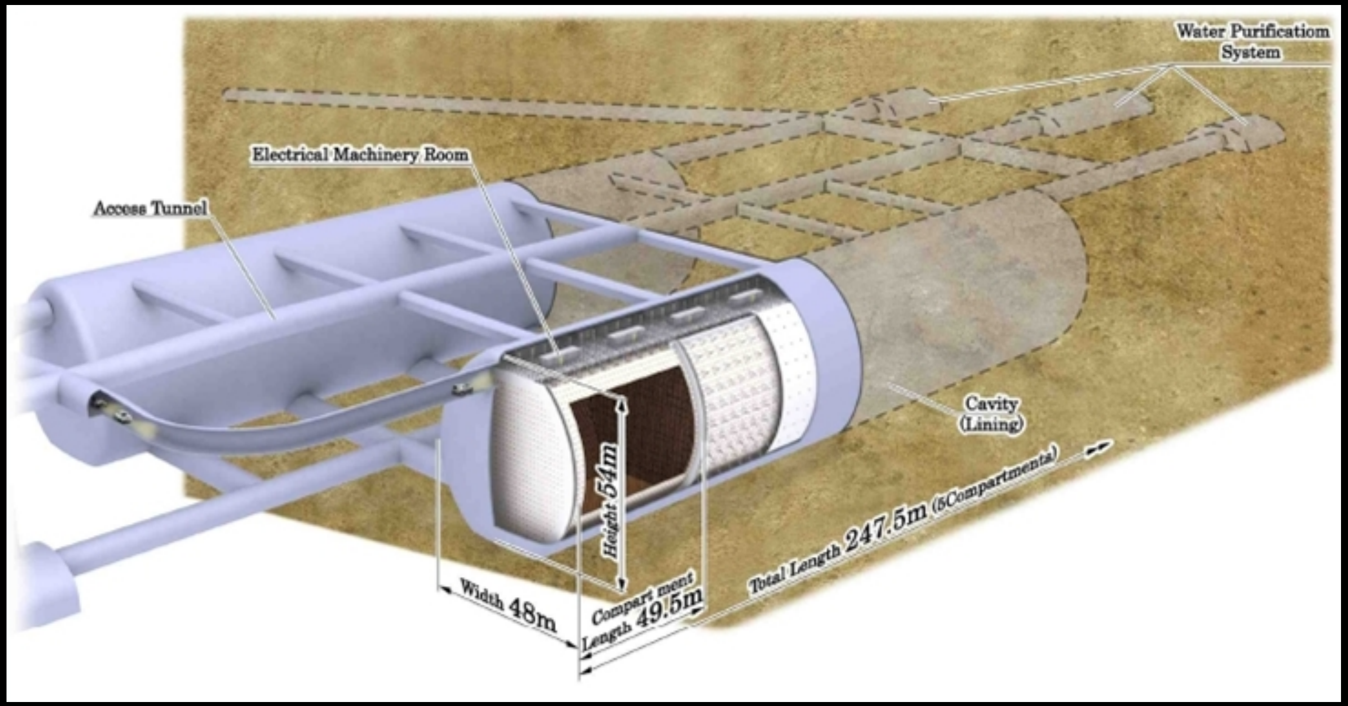


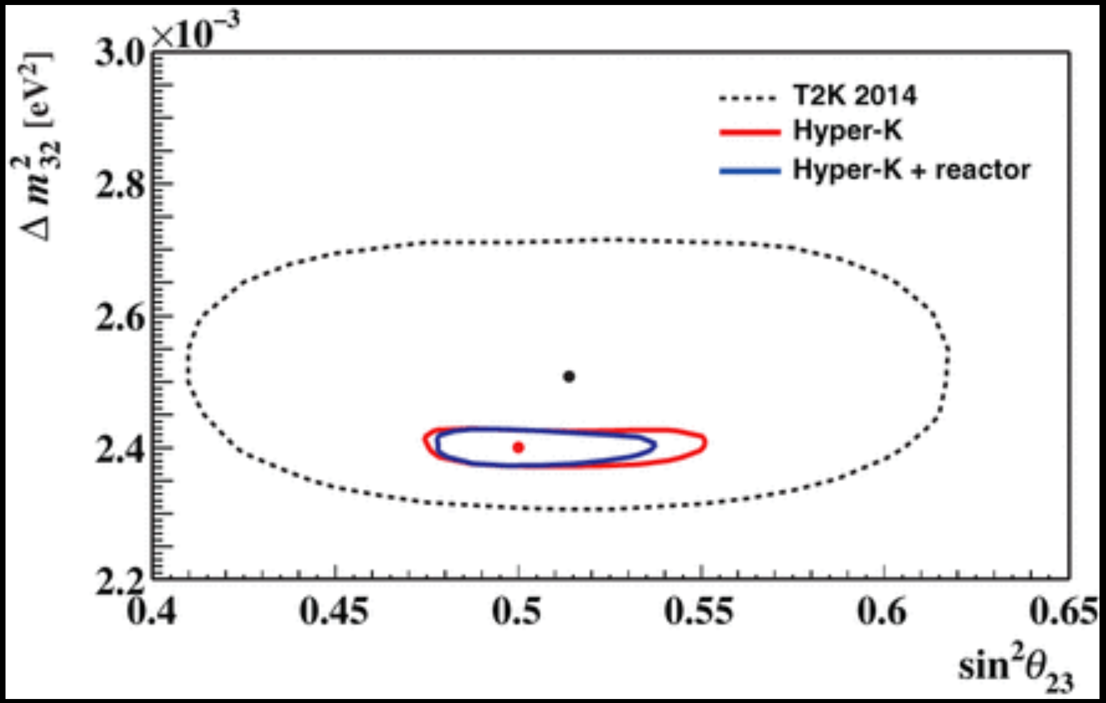


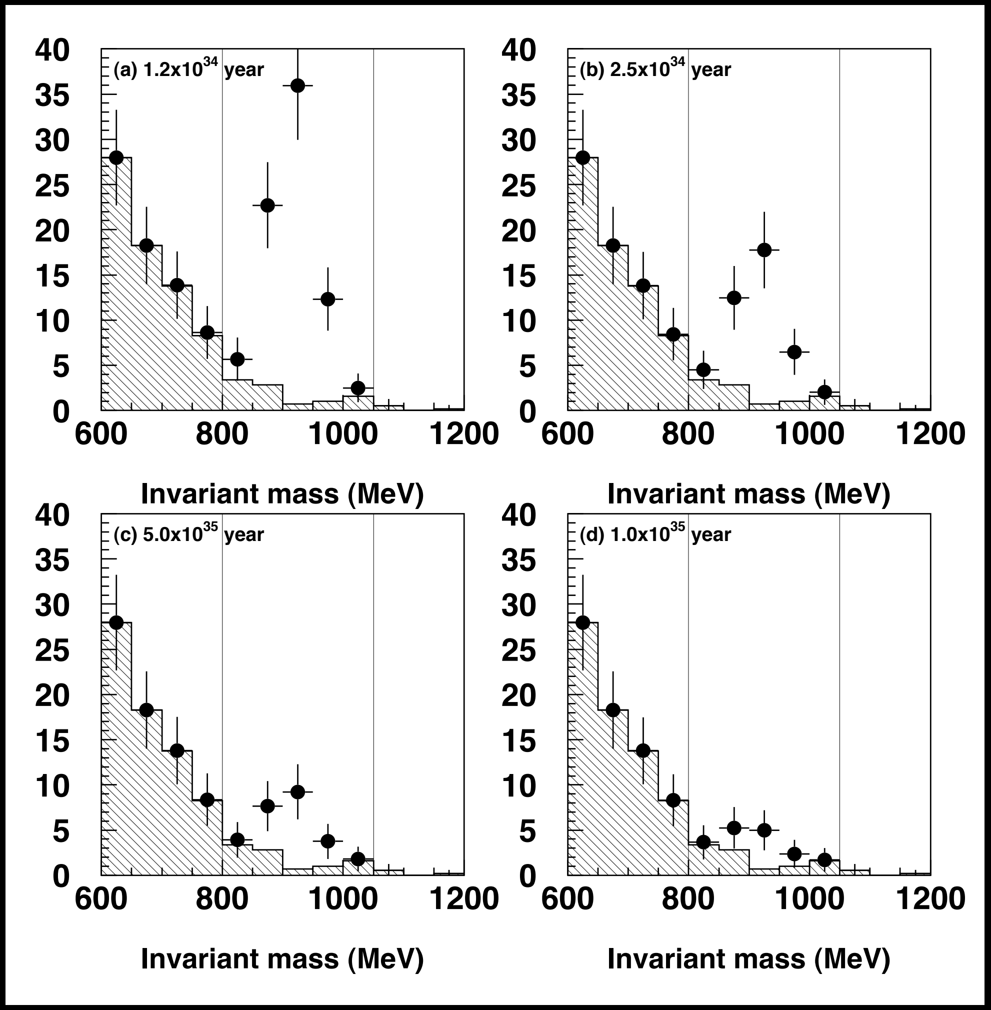
large WČ detector ~1 km from target

- Variation of E_ν vs. angle to beam axis
  - "off-axis effect"
  - requires well-known flux
- Simulate detector response (e.g. lepton kinematics) from narrow band of E_ν
- Greatly reduce uncertainties from modelling uncertainties of neutrino interactions
- Proposal to be presented to J-PARC PAC in July.

HYPER-KAMIOKANDE







- 20x upgrade to SK:
  - 50 (22.5) kT→990 (560) kT, 99K 20” PMT
- >3 (5) σ CPV for 76(58)% δ_{CP} values
- Combination of beam and atmospheric data may allow test of neutrino mixing unitarity

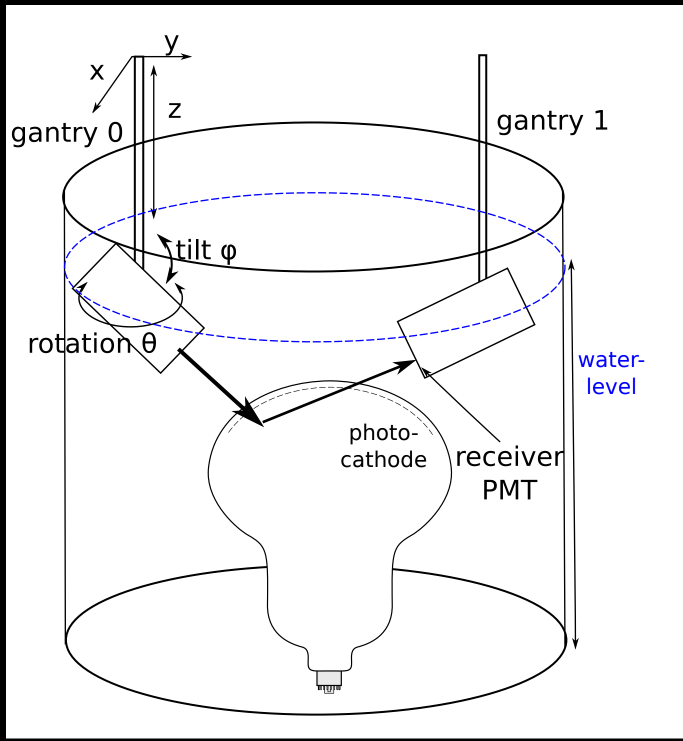
see talk by A. Konaka

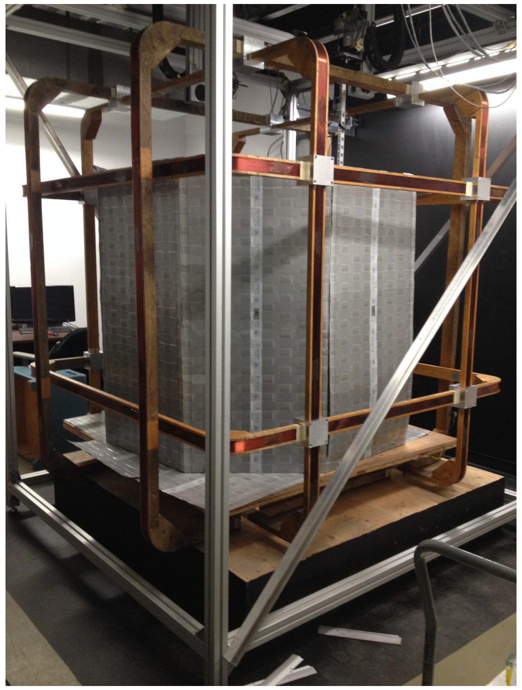
  - Mass hierarchy, Lorentz Violation, sterile neutrinos, etc.
- Extend proton decay limits by an order of magnitude
- Detect supernova burst neutrinos to >1 Mpc
- Observatory for neutrino astrophysics
  - indirect dark matter searches, etc.

HK STATUS

- Endorsed by Japanese particle and cosmic ray communities as one of two highest priority future projects.
- One of 27 (/192) projects selected by the Science Council of Japan's 2014 Master Plan for Large-scale Research Projects in all fields of science.
- Not included in 2014 MEXT roadmap:
  - Strong support for science program
  - further clarification of international organization/participation requested
- KEK-IPNS/ICRR MOU for cooperation on HK (1/2015)
  - Directors review of project ~end of 2015
    - Baseline design with 20" PMTs (SK experience) and alternatives
  - Formation of proto-collaboration
- Aiming for inclusion in MEXT roadmap in 2017

HK R&D IN CANADA

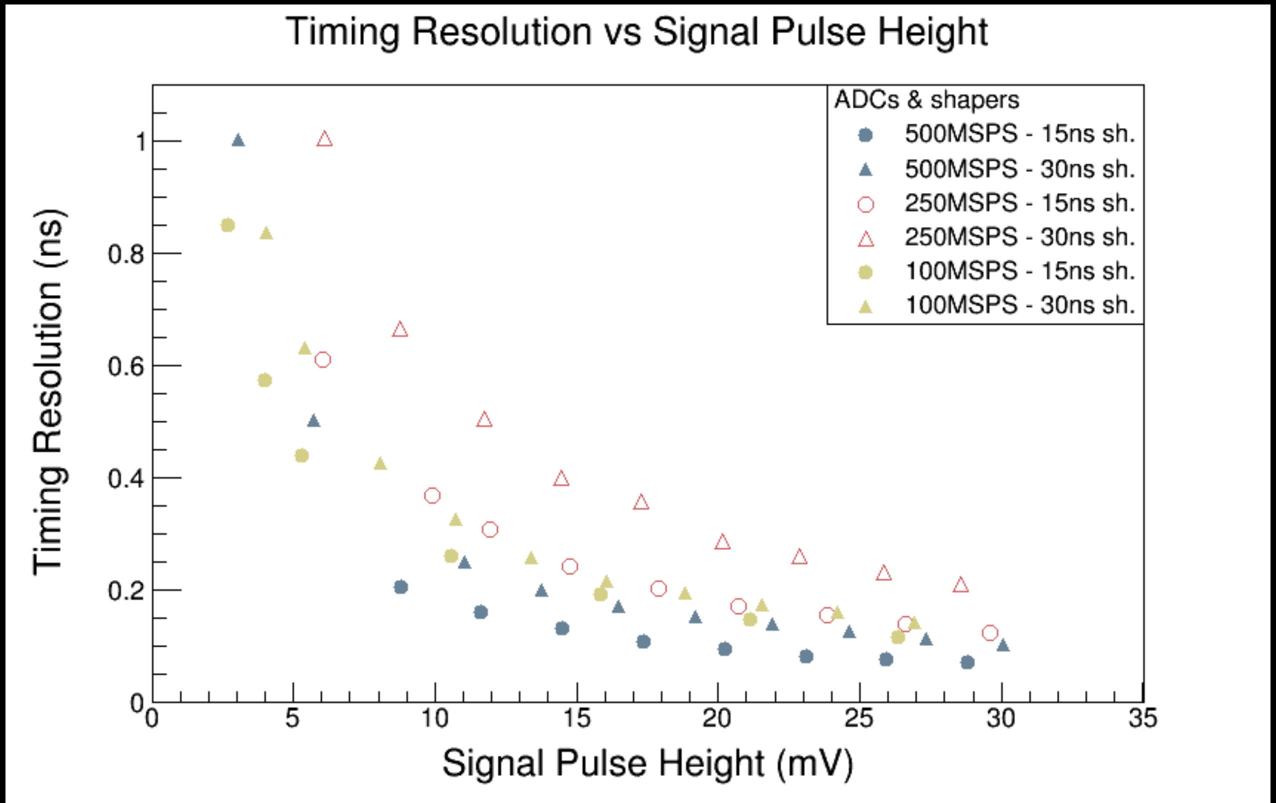




L: 20″ SK PMT at TRIUMF
R: papier mâché mockup

CFI funded

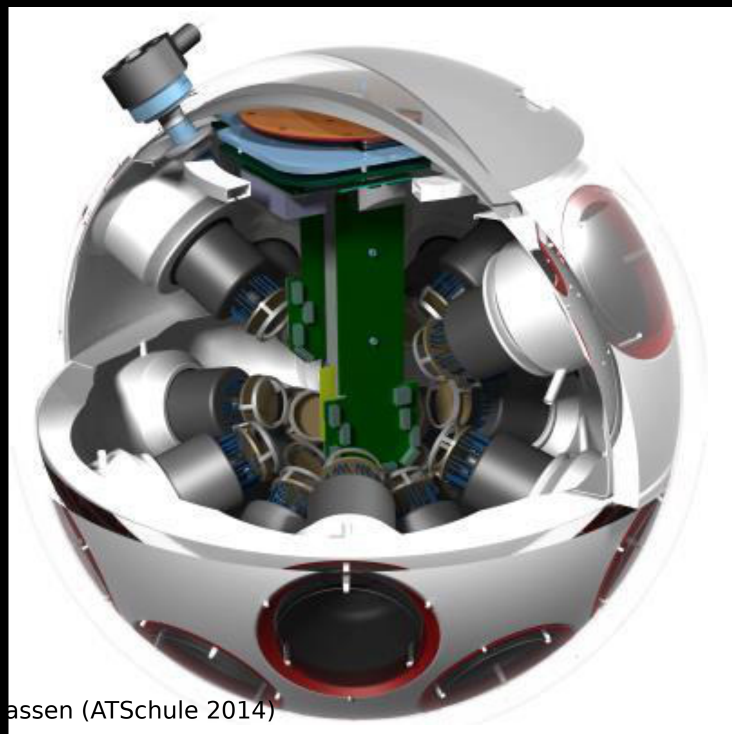
- TRIUMF photosensor test facility
  - detailed measurement/characterization of large area photosensors in water
  - Measurements of SK 20″ PMT, new 20″ High QE PMT, and 8″ hybrid-PMT in progress

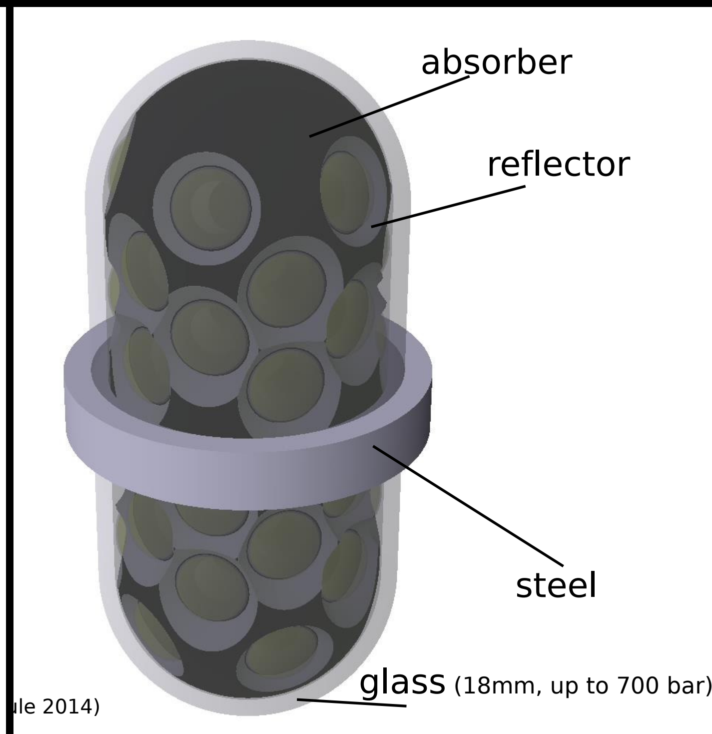


- Readout electronics
  - full waveform digitization of shaped PMT pulse
  - optimization/study of:
    - shaping time
    - sampling rate
    - long cable propagation (65/150 m)
- Data transfer/acquisition
  - RapidIO redundant routing protocol

T. Lindner: HK electronics/DAQ convener

NEW CONCEPT: MPMT/MDOM



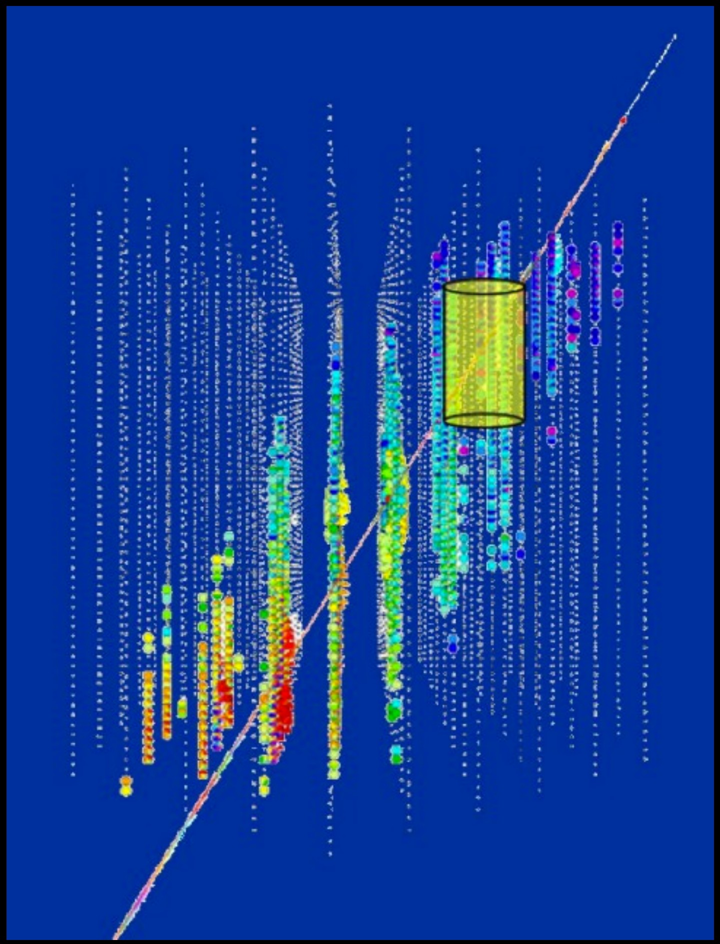


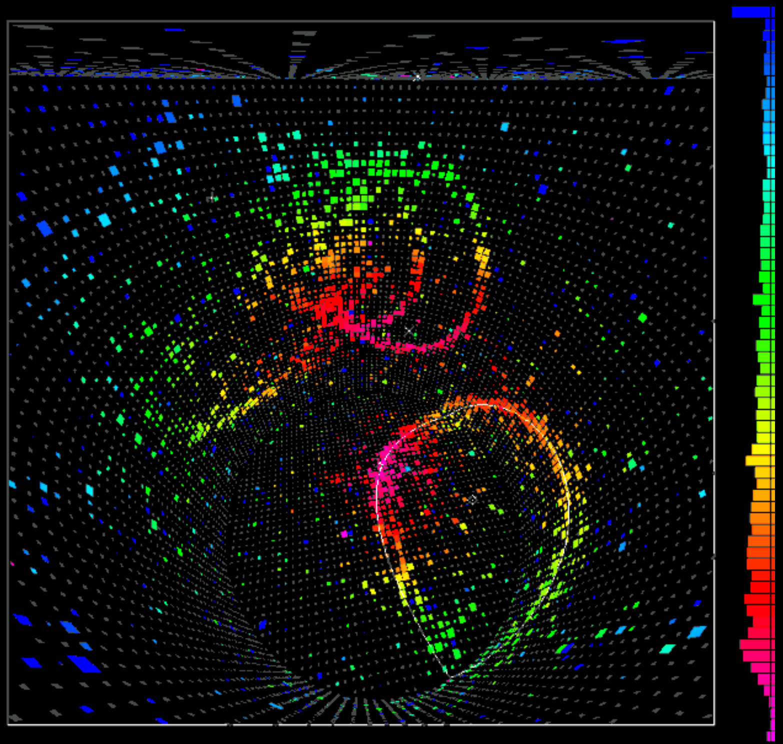
- Investigating potential physics performance vs. "traditional" large (8"-20" PMT) configurations
- Consider simultaneously with cost to see which is optimal (best physics/$)

- Exploring new concepts from PINGU, KM3NET:
  - pressure vessel containing array of 3" PMTs with readout electronics embedded
  - light collection using WLS, dichroic mirrors to increase effective area.
- Provides existing technical solution for:
  - pressure/implosion risk at high pressures
  - in-water electronics, calibration devices
- Potential cost reduction:
  - ~no need for magnetic shielding (μ-metal, compensation coils)
  - deployment via strings rather than free-standing frame
  - more useable fiducial volume relative to total volume?

ICECUBE/PINGU

**see talks by D. Grant
K. Clark@CAP**





- Recent HK/PINGU-Canada workshop to investigate potential collaboration
- Both experiments require:
  - large array of photosensors deployed deep in water/ice
  - photosensor readout electronics
  - calibration devices to measure optical properties of the bulk media (water/ice)
  - reconstruction using space/time pattern of Č light
- Large area of overlap in concepts and needs:
  - mDOM/PMT photosensor configuration
  - full waveform readout of photosensor output
    - time/charge resolution, power, cost requirements
  - calibration, reconstruction methods
- Working towards collaborative R&D effort in anticipation of potential approval of either project
  - Potential RTI and future CFI request.

2017-21: EXPECTED HQP

	FY2015
FACULTY	14 (8 FTE)
POSTDOC	6
STUDENTS	11

UA, UBC, Regina, UT, UVic, Winnipeg, York, TRIUMF

- Also 4-5 undergraduate students/year (USRA, Co-op, MITACS, Honours thesis)

- Expect to maintain ~constant effort for 2017-2020
- Bare minimum needed to maintain
  - ongoing operation of T2K OTR, FGD, TPC
  - continuing analysis of ND280 and SK data
    - improve sensitivity and reduce systematics towards CPV
    - develop new analysis of atmospheric data towards MH
  - take leading role in NuPRISM and HK R&D
    - photosensor and electronics development
    - simulation and detector design optimization
- NuPRISM will be proposed to J-PARC PAC in July
- Formal approval of HK expected in 2017, possible ramp up.

POSTDOCS: CURRENT ACTIVITIES

- **T. Feusels (UBC)**
  - neutrino interaction modeling, multi-nucleon studies in ND, FGD operations
  - photosensor development and mDOM/mPMT development for HK
- **A. Fiorentini (York)**
  - beam analysis, ND quasi-elastic studies
  - OTR operations and analysis
- **N. Hastings (Regina)**
  - ND run coordination
  - ND data quality convener
- **A. Hillairet (UVic)**
  - ND ν_μ convener
  - TPC operations
- **Y. Petrov (UBC)**
  - ND calibration convener, reconstruction development
  - TPC operations
- **M. Scott (TRIUMF)**
  - ND near/far convener, ND analysis development
  - FGD operations

- Recent postdocs → faculty/staff
  - A. Marino (CU Boulder)
  - B. Jamieson (Winnipeg)
  - T. Lindner (TRIUMF)
  - M. Hartz (IPMU/TRIUMF)
  - M. Wilking (Stony Brook)
  - K. Mahn (MSU)

All continue on T2K with leading roles

2017-21: EQUIPMENT NEEDS

- Continued maintenance of T2K detectors
  - T2K ND280 FGDs, TPCs
  - OTR beam monitor
  - Network, slow control, services for ND280
  - (computing)
- Photosensor and electronics R&D for NuPRISM and HK (2015-2017)
  - further refinement of requirements and concept
  - prototyping and test setups
  - equipment needs are expected to be modest
    - but need engineering support for design
  - RTI request coordinated with IceCube/PINGU
- Approval of NuPRISM/HK → proposal for construction funds (2017-)
  - we hope to make major contributions to the readout electronics and photosensors in collaboration with other collaborating nations/groups
  - almost certainly a CFI request

2017-21: COMPUTING

- T2K computing requirements summarized in the IPP/CINP white paper
  - ComputeCanada/TRIUMF and EU-GRID are the two primary sources of computing resources for the T2K collaboration
  - databases, repositories, website (t2k.org) supported by TRIUMF
  - critical for our participation and leadership in T2K, HK, NuPRISM.
- CPU:
  - currently using 610 core-years of computing on Westgrid and Scinet
  - we expect to grow modestly (10-20%) each year as
    - T2K statistics increases, MC samples increase accordingly
    - additional simulation studies for NuPRISM and HK
    - large fraction is SK control samples which will not increase substantially
- Storage:
  - 610 TB currently stored on Tier 1 server at TRIUMF   CFI funded
    - expect this to grow significantly (~40%/year) with statistics
  - Additional ~100 TB maintained online on ComputeCanada resources
  - Long term strategy is under discussion

2017-21: SUPPORT FROM TRIUMF

- TRIUMF has always provided a strong foundation for our activities
  - detector design/construction/operation/maintenance
  - beam tests, pion scattering studies, work areas for development
  - user computing, office space, Tier 1 storage
  - visiting scientists, workshops.
- Ongoing and continuing activities:
  - Detector facility support for ND280 repairs/maintenance
  - Photosensor Test Facility at TRIUMF
  - Beam tests at M11
- Will look to TRIUMF and MRS for:
  - engineering, machining, and design support for HK/NuPRISM photosensor and electronics R&D effort
  - mechanical design concepts for overall HK/NuPRISM detector

RELATIONSHIPS

- Canada has a vibrant neutrino program:
  - SNO+: “low” energy solar and $0\nu2\beta$
  - (n)EXO: $0\nu2\beta$
  - HALO: supernova burst neutrinos (ν_e)
  - IceCube/PINGU: ultra-high energy neutrino astrophysics, “medium” to“high” energy atmospheric.
  - T2K/HK: accelerator-based neutrino oscillation studies, “low” to “medium” energy atmospheric neutrinos, astrophysics, SN neutrinos (burst/relic), proton decay.
- Overall program is highly complementary with small overlaps
- Related issues in photosensor/electronics may allow coordinated R&D for future development
- International:
  - T2K and HK are highly international collaborations (11-12 nations) hosted by ICRR and KEK/J-PARC in Japan
    - TRIUMF is a “hub” for international collaboration on analysis and R&D
  - NuPRISM has gathered support in Canada, US, and EU, but needs funding and Japanese support for new facility.
  - NOvA (now) and DUNE (future) are complementary efforts to probe the same physics with different detector technologies.

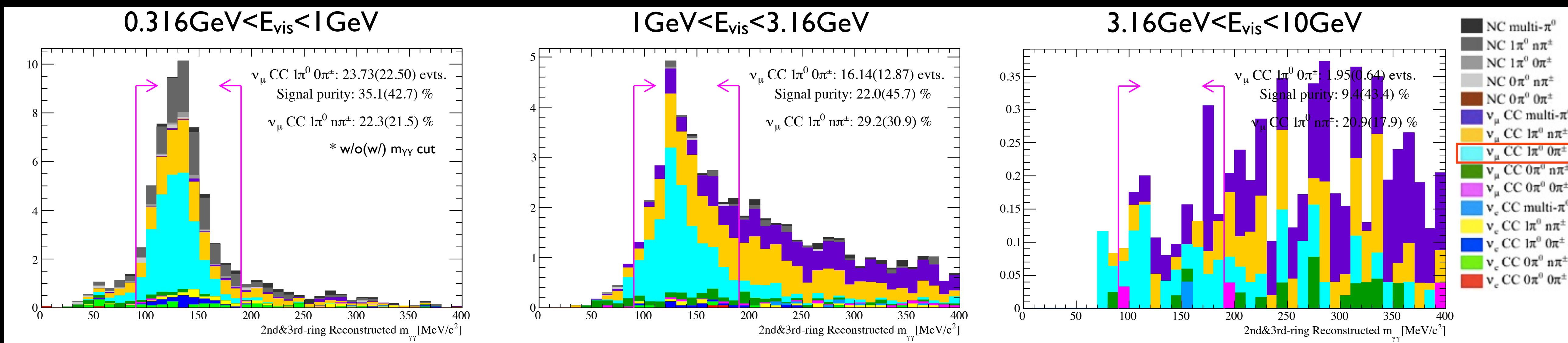
CONCLUSIONS

- T2K (and Canadian effort) has been a great success
  - major discoveries/advances in neutrino oscillations with strong contributions from Canada (hardware, analysis, leadership)
  - large recent gains in accelerator performance
  - accelerator upgrade to increase rep. rate by ~x2.
- Next goal: towards initial indications of CPV with ultimate exposure of T2K
  - First antineutrino data and results
  - Canadian-led analysis improvements to enhance sensitivity
  - Mass hierarchy determination in SK atmospheric data and with other experiments
  - Continue a world leading program into the 2020's!
- Actively planning future program through NuPRISM and HK
  - new concept for directly measuring relevant properties of neutrino interactions and reducing important systematics (NuPRISM)
  - new overall design concepts for HK experiment
  - identifying and exploiting synergies with IceCube/PINGU
- Continued support from CFI, IPP, NSERC, TRIUMF is critical to continued success
  - new collaborators always welcome!

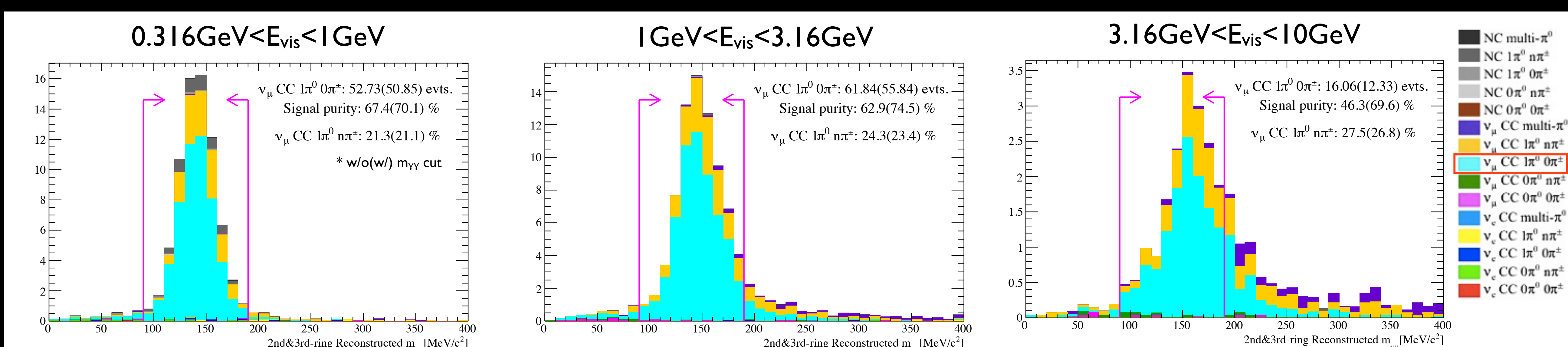
BACKUP SLIDES

ν_μ CCπ^0

old algorithm

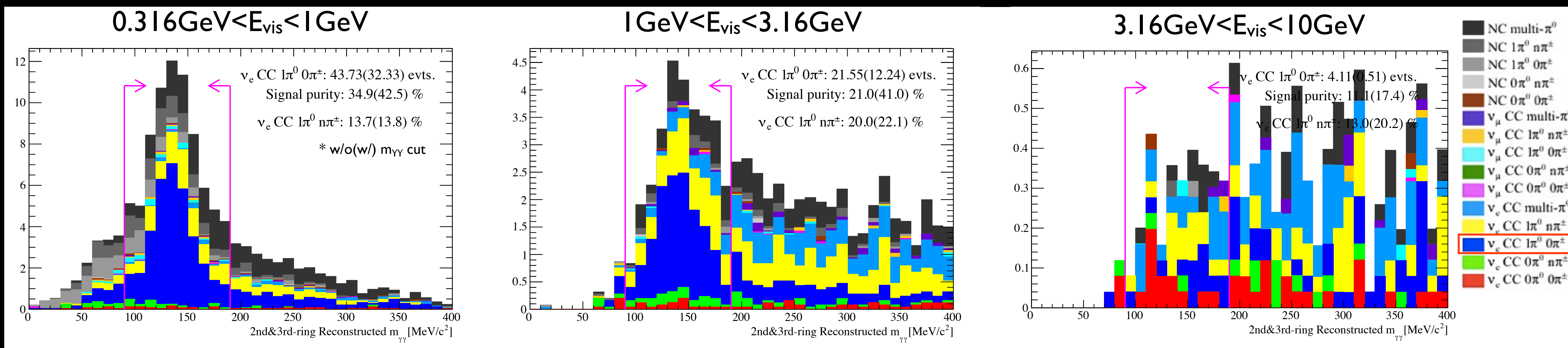


new algorithm ("fiTQun")

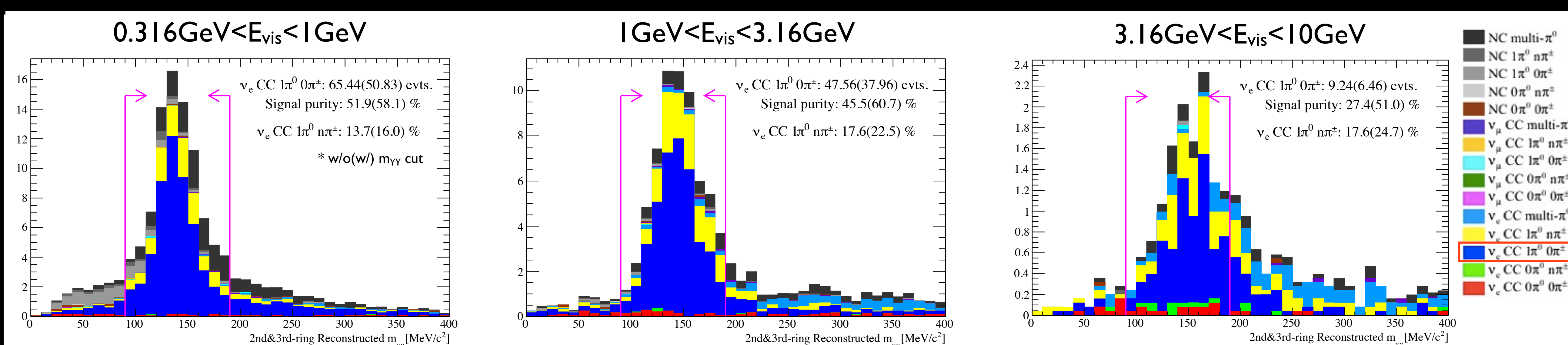


ν_e CCπ^0

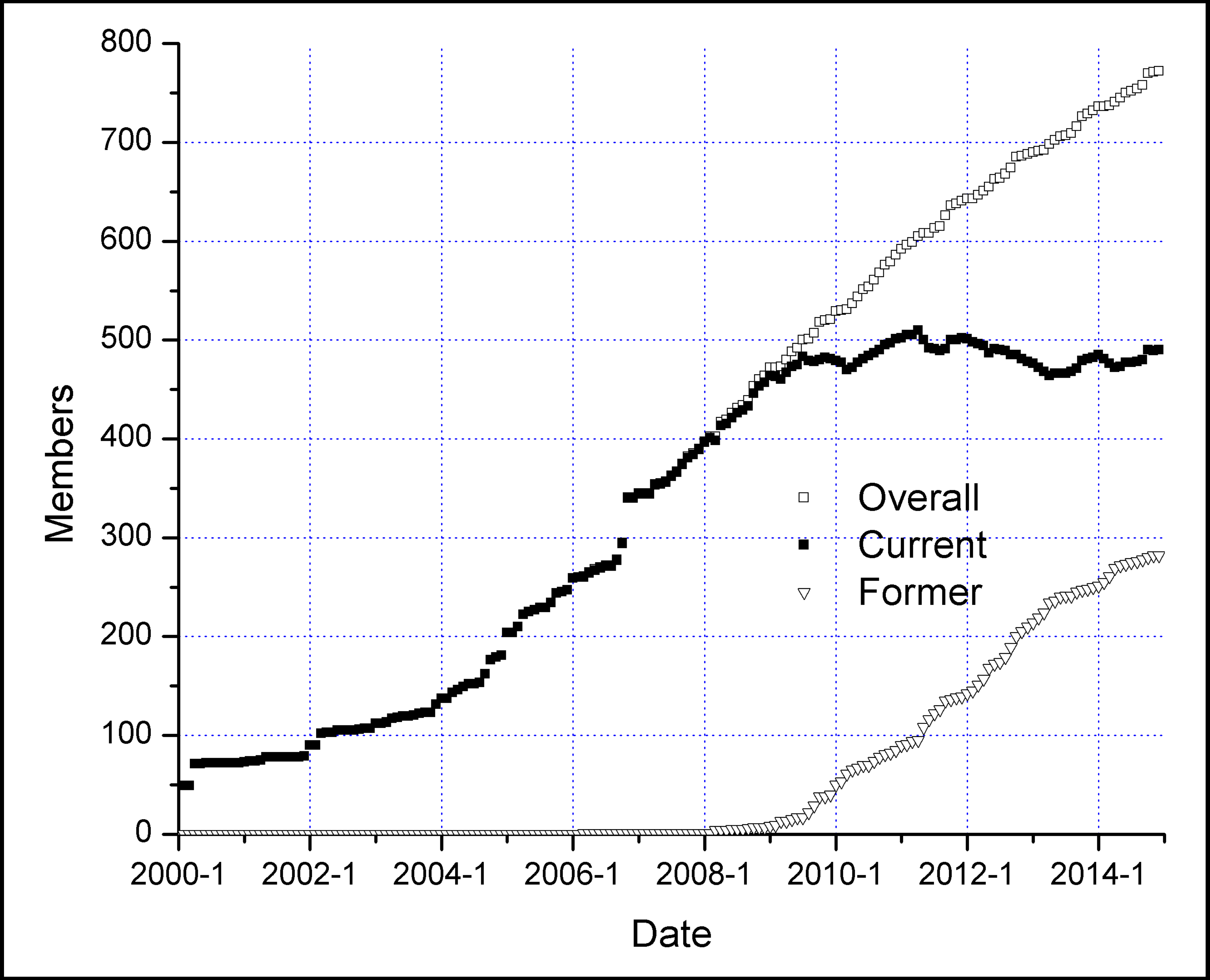
old algorithm



new algorithm (“fiTQun”)



T2K COLLABORATION MEMBERSHIP



- More or less constant since 2009
- New members join as existing collaborators move on (students, postdocs, etc.)

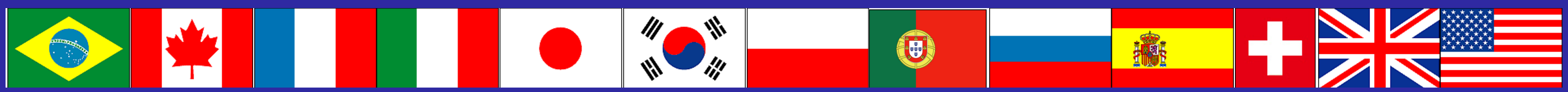
Power upgrade plan of MR

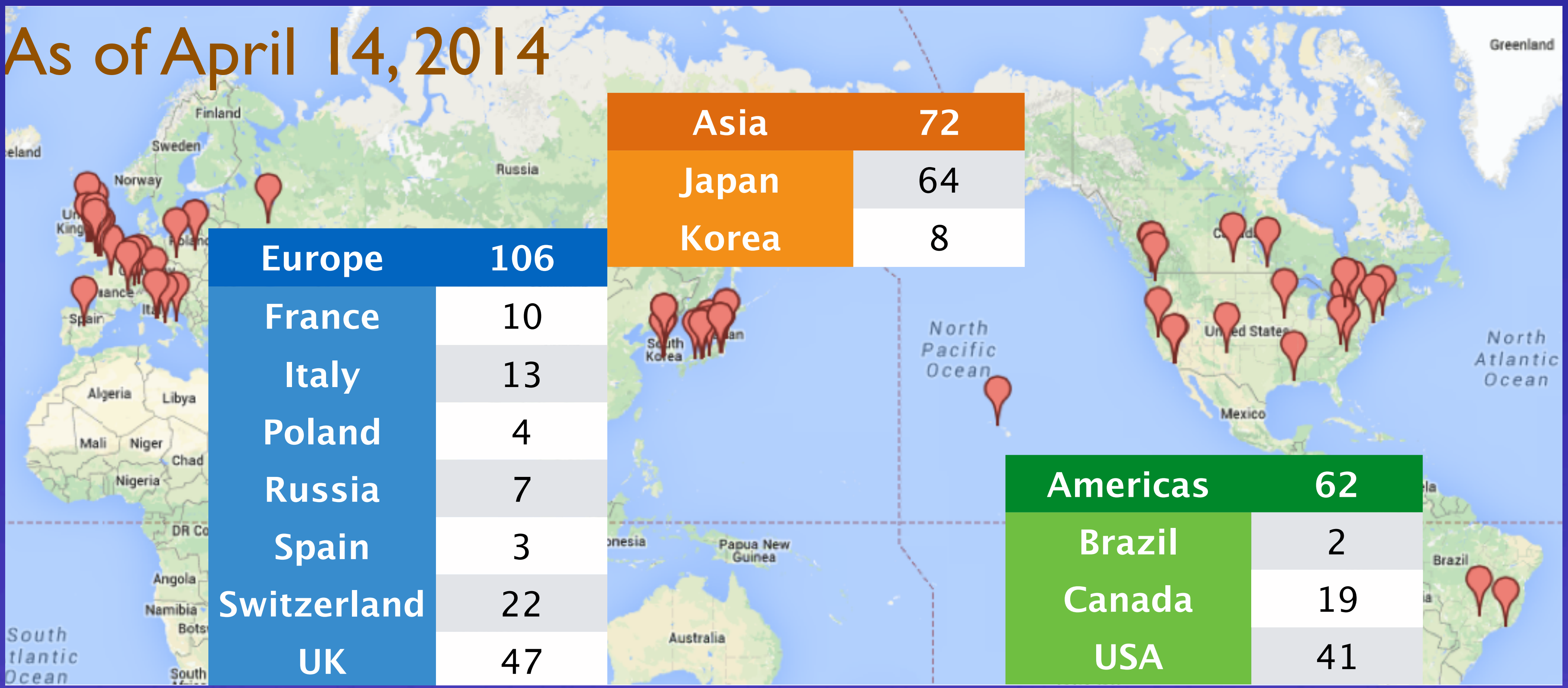
FX: The high rep. rate scheme is adopted to achieve the design beam intensity, 750 kW.
Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities.
SX: After replacement of stainless steel ducts to titanium ducts to reduce residual radiation dose, 50 kW operation for users will be started. Beam power will be gradually increased toward 100 kW carefully watching the residual activity. Local shields will also be installed if necessary.

JFY	2014	2015	2016	2017	2018	2019
Event	Li. current 30 -> 50 mA		New PS Buildings →			
FX [kW] (study/trial) SX [kW] (study/trial)	240-320 -	>320 24~50	~400 >50	>400 50~100	~750 ~100	>750 100
Period of magnet PS New magnet PS	2.48 s R&D →	Low cost R&D →		Mass production →	1.3 s	
Present RF system High gradient rf system	Manufacture, installation & test →					
Ring collimators	Back to JFY2012 (2kW)	Add. colli. C,D	Add. colli. E,F			
Injection system FX system	Kicker PS improvement, Septa manufacture /test → Kicker PS improvement, LF & HF septa manufacture /test →					
SX collimator / Local shields			Local shields →			
Ti ducts and SX devices with Ti chamber	Beam ducts	ESS				

FY	POWER (KW)	FX MONTHS	POT (10^{20})	TOTAL (10^{20})
2015	350	3	3.5	13.5
2016	400	5	6.7	20.2
2017	400	5	6.7	27.0
2018	400	5	6.7	33.7

Hyper-K Collaboration





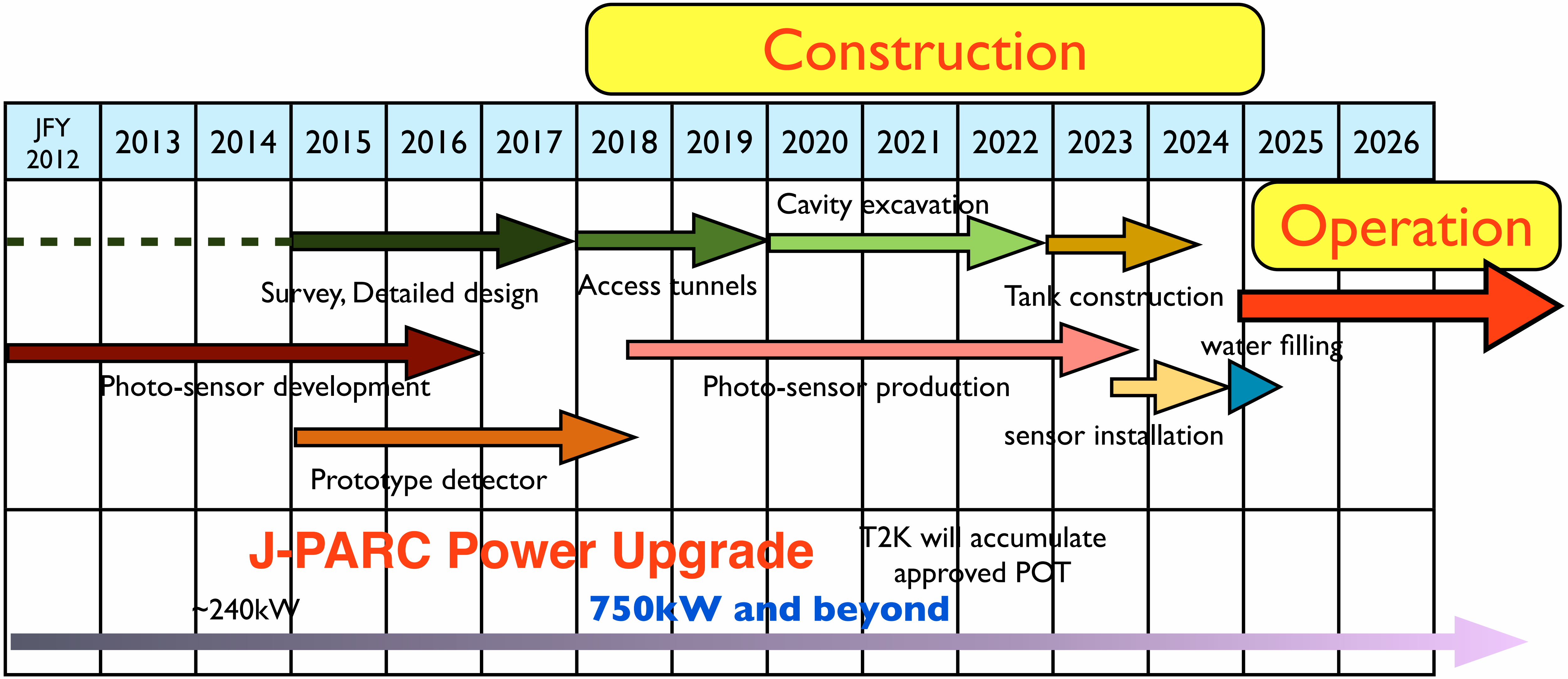
As of April 14, 2014

Europe	106
France	10
Italy	13
Poland	4
Russia	7
Spain	3
Switzerland	22
UK	47

Asia	72
Japan	64
Korea	8

Americas	62
Brazil	2
Canada	19
USA	41

Target Schedule



- -2018 Construction starts
- -2025 Data taking start
  - -2028 Discovery of Neutrino CP violation ?
  - -2030 Discovery of Proton Decay ?
  - -20xx Detection of supernova neutrinos
  - -20xx Discovery of new phenomena