IceCube Canada IPP Update

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7th June 2019

Very Eventful Year!

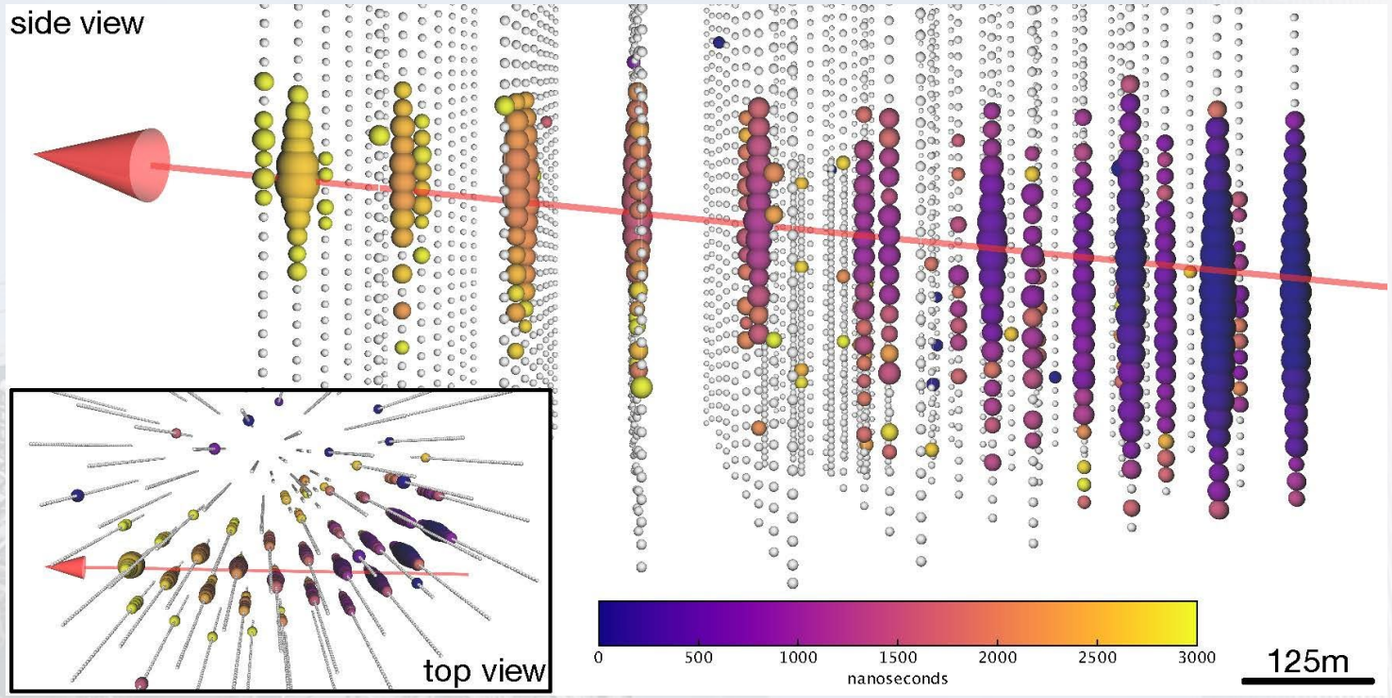
- Some great, Canadian-lead results
  - First evidence of high energy neutrinos from an extra-galactic source [10.1126/science.aat1378, 10.1126/science.aat2890]
  - Nu-tau appearance [PRD 99 (2019) 032007]
- Icecube upgrade approved by NSF in US
- Major new Canadian initiative:
  - Combining expertise of Icecube with Ocean Networks Canada with support from McDonald Institute: P-ONE
- People changes
  - Loss of two faculty in Alberta but one new faculty member at SFU is joining

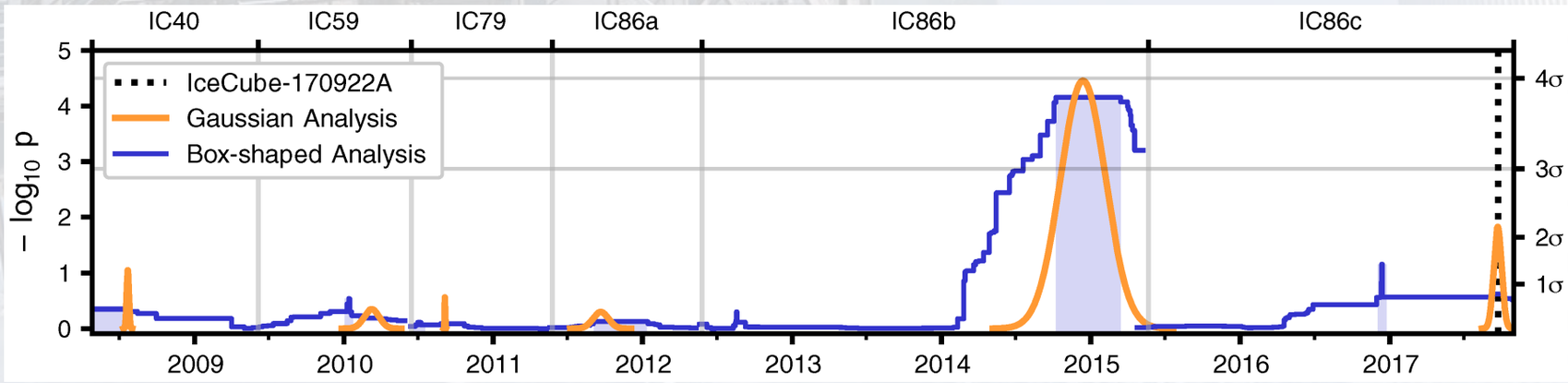
Icecube Canada

- Two institutes: Alberta and Queens
  - Four faculty (2.3 FTE)
  - Two postdocs
  - Three grad students
  - Plus seven undergrads over the past year
    - Combination of summer, USRA and co-op students
- Significant impact across the collaboration
  - Oscillations group convener (Juan Pablo)
  - Reconstruction and Systematics convener (Joshua)
  - Trigger-Filter Board (Roger)
  - Computing (Ken, Joshua and Jamie)
  - Particle phenomenology: atmospheric flux, high energy nu production (Anatoli)

Extra-galactic Neutrinos

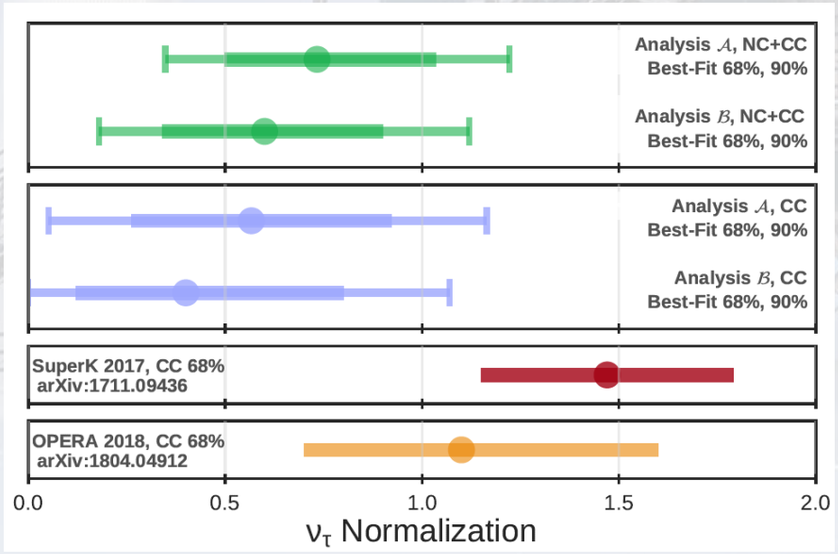
- Observation of ~290TeV neutrino from the direction of blazar TXS 0506+056 coincident with gamma-ray flares observed by Fermi-LAT and MAGIC
  - 3 sigma significance
- IceCube follow-up showed previous cluster of neutrinos between Sept 2014-March 2015
  - 3.5 sigma significance
- First evidence of an extra-galactic high energy neutrino source
- Analysis lead by Claudio, used Alberta GPU cluster

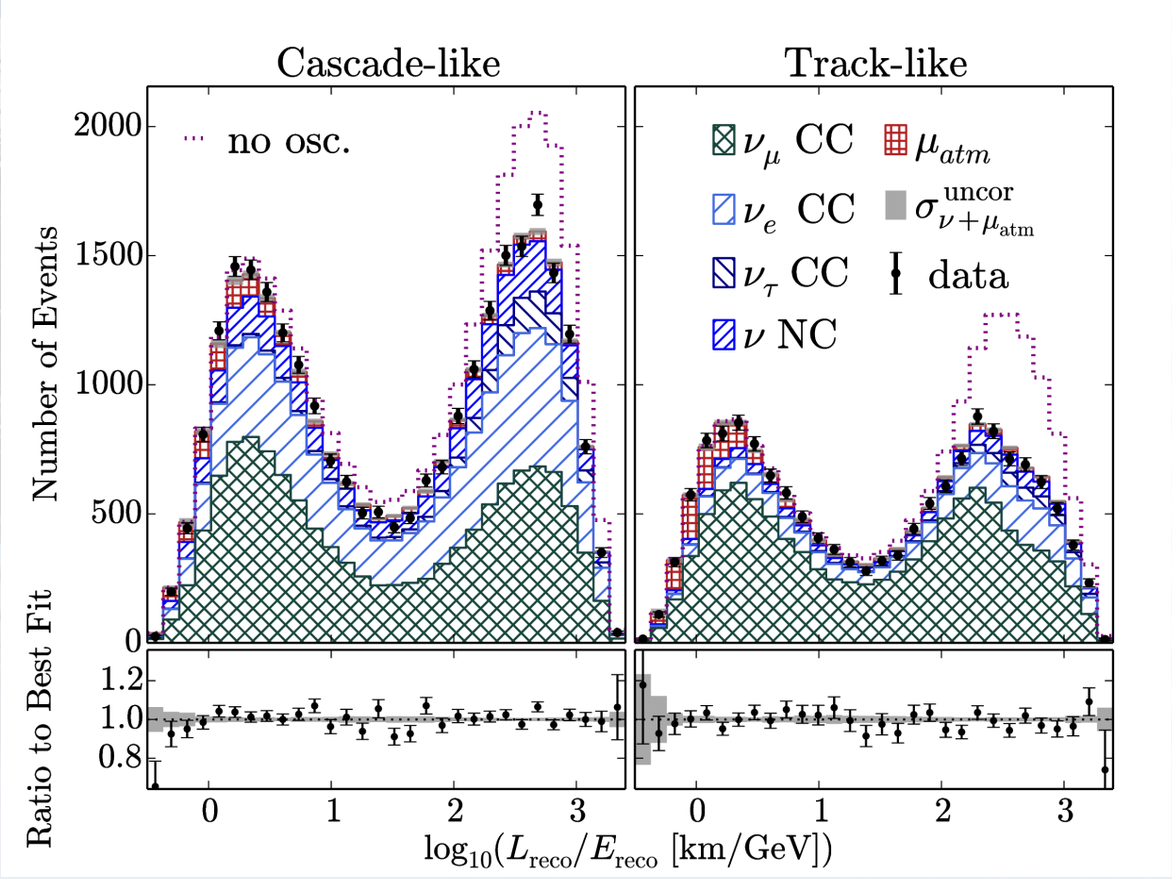




Nu-tau Appearance

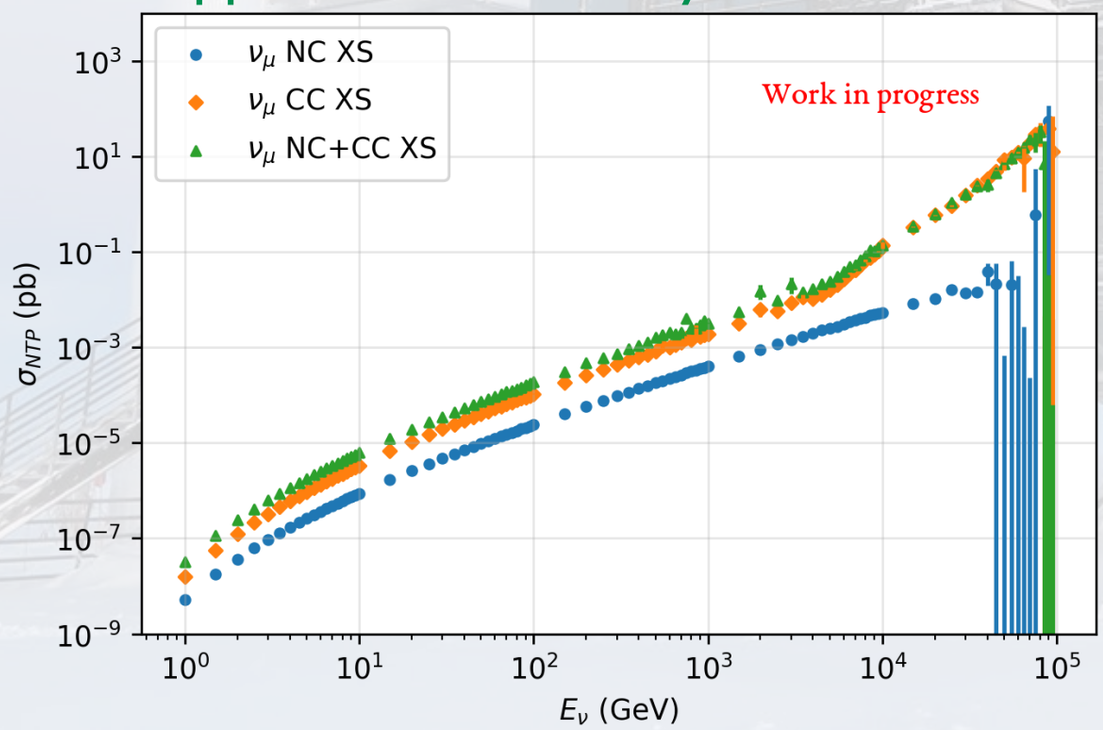
- Appearance of nu-tau from oscillations important for PMNS matrix unitarity checks [Juan Pablo, Joshua]
  - Only seen so far by OPERA and SuperK
  - Unitarity: $|U_{e3}|^2 + |U_{\mu 3}|^2 + |U_{\tau 3}|^2 = 1$, Exp: $|U_{e3}|^2 + |U_{\mu 3}|^2 \approx 0.5$
- Icecube analysis used Deepcore
  - DOMs closer (42m H, 7m V): energy threshold 5 GeV
- Vary oscillation parameters to fit data (fix solar params)
  - Relies on detailed modelling of atmospheric nu flux

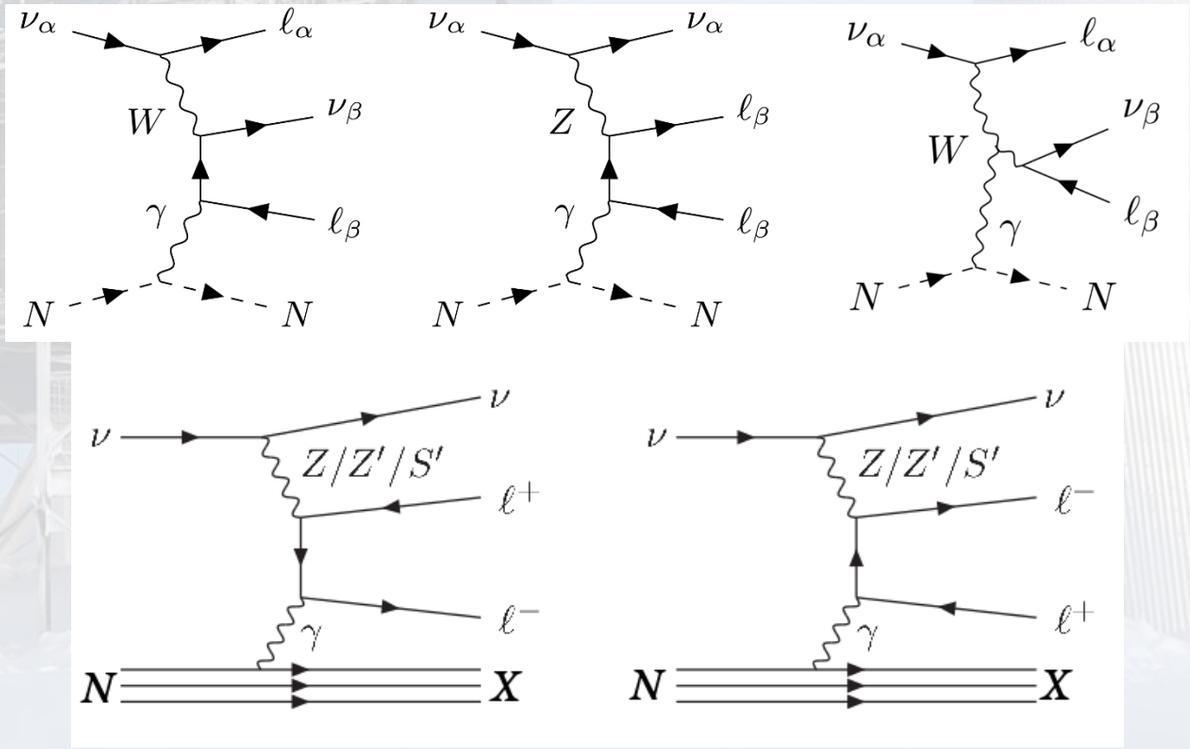




Future Physics Analyses

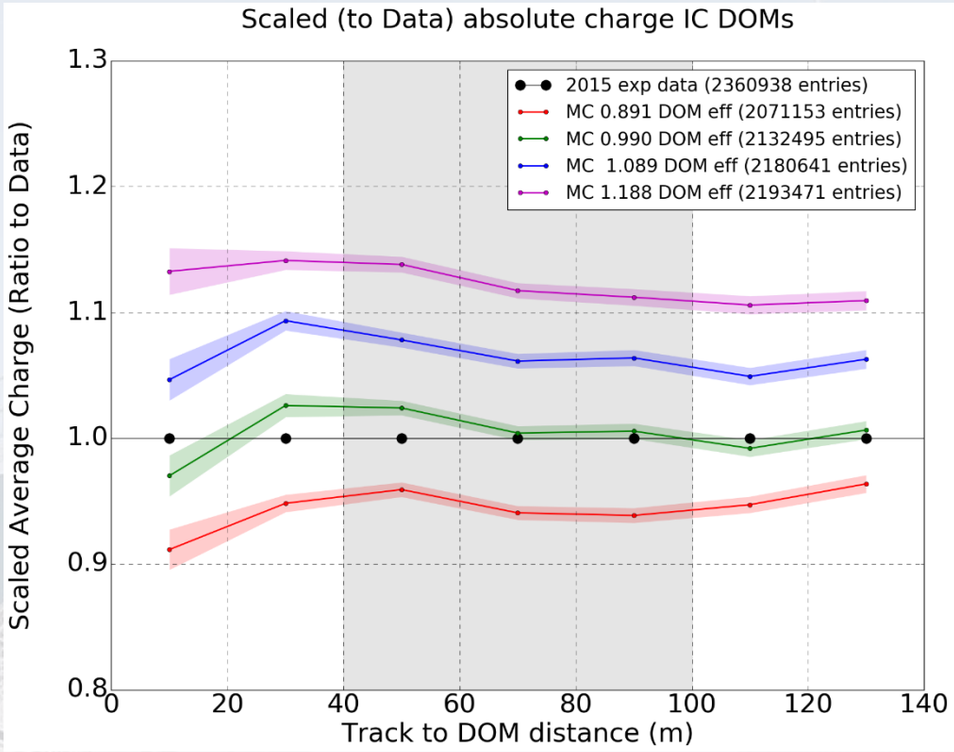
- Atmospheric neutrino flux analysis
  - Understand neutrino flux from cosmic ray showers
  - Critical for improving neutrino oscillation analyses
  - Improve understanding of hadronic physics
  - Initial analysis part of PhD thesis, now being significantly improved for a paper
- Neutrino Trident events [See Sourav's 1st Prize winning CAP poster!]
  - Second order, Weak+EM neutrino interaction producing two charged leptons: probe for BSM physics
  - Main challenge is to reconstruct two muon tracks…but if successful then applications exist beyond tridents

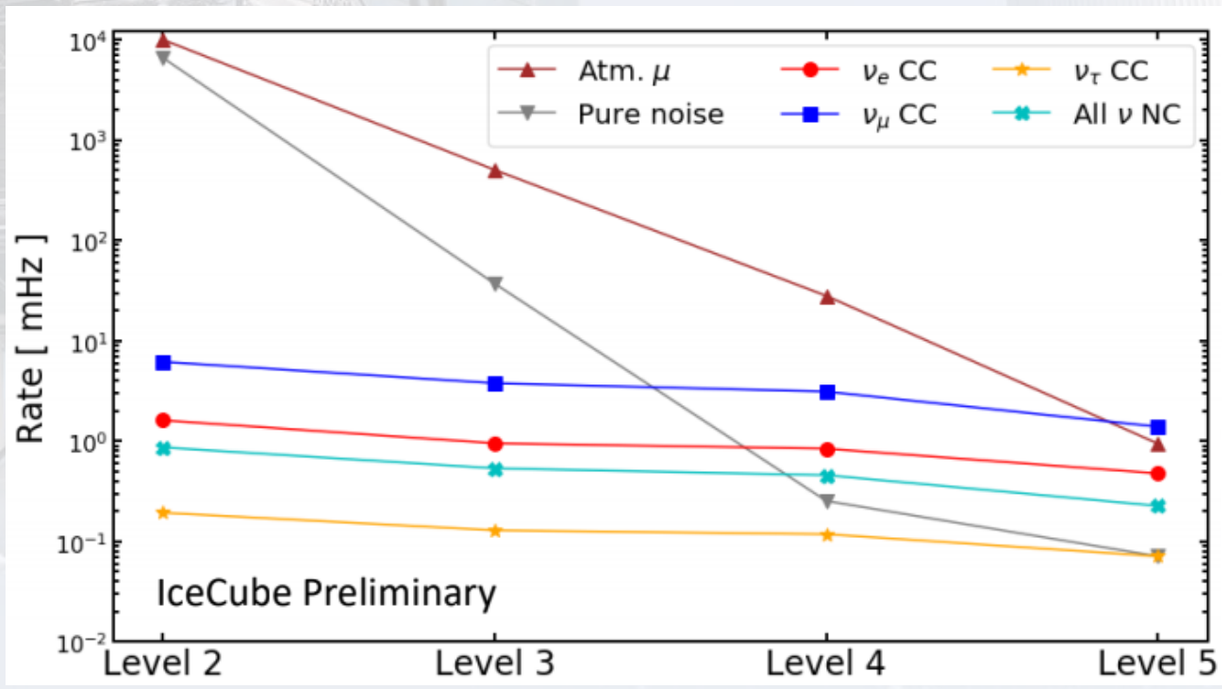




Further Canadian Work

- In-situ calibration of detector modules (DOMs) [See Nick's CAP poster!]
  - Use cosmic muons to calibrate MC detector response
- Development of new, low energy neutrino sample
  - Large scale effort to significantly improve the selection criteria for low energy neutrino analyses
    - Large gains in background rejection through multivariant and data driven methods
  - Combined with full 10-year dataset increase sample size from 50k to 500k neutrinos
  - Huge improvement for next oscillation analyses
    - Expect first results by end of the summer





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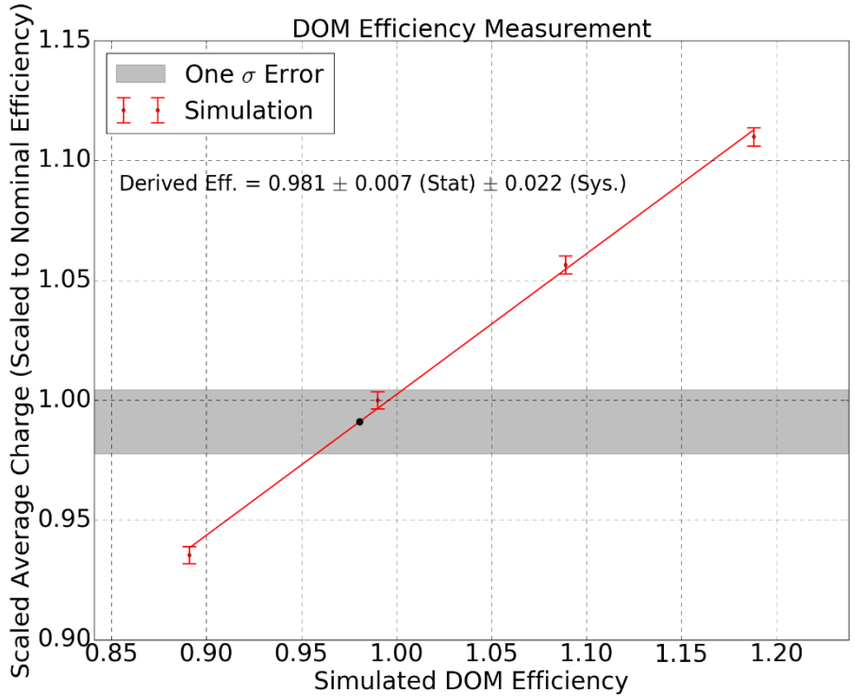
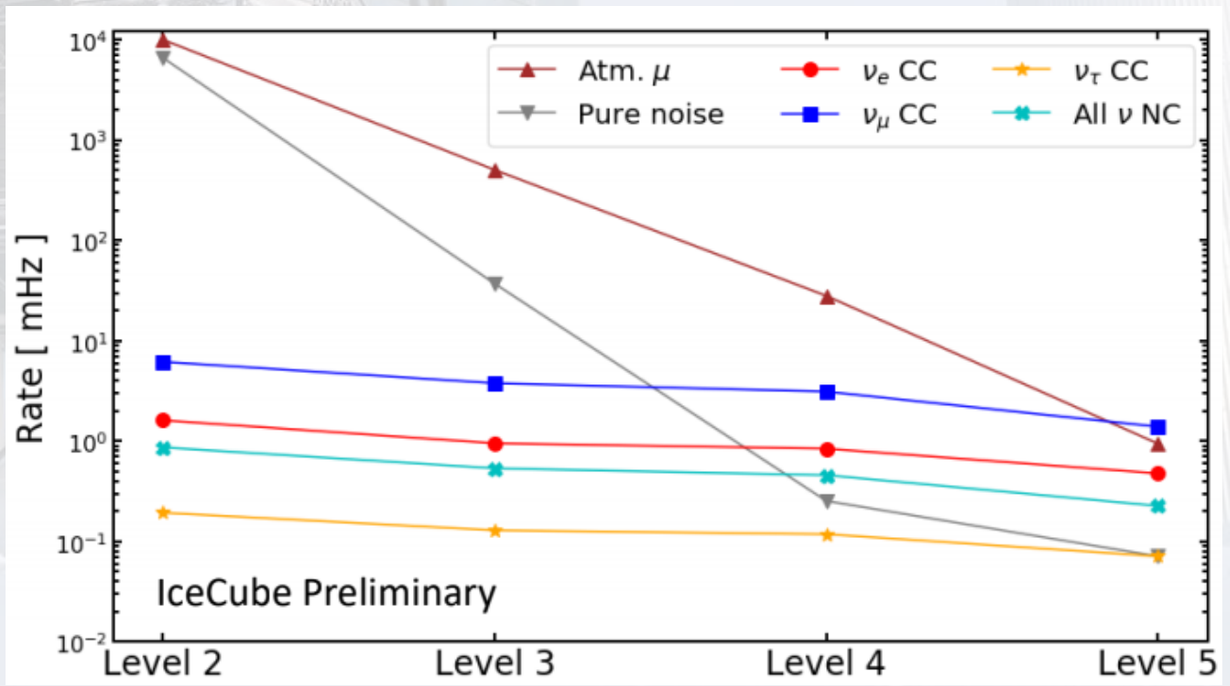
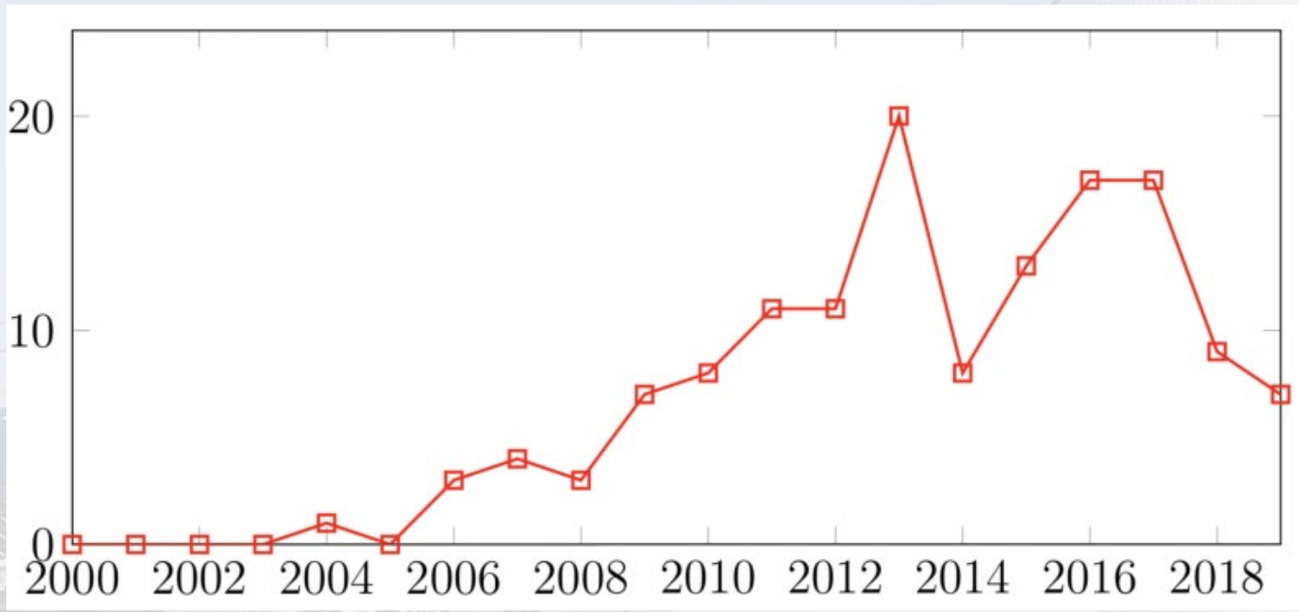


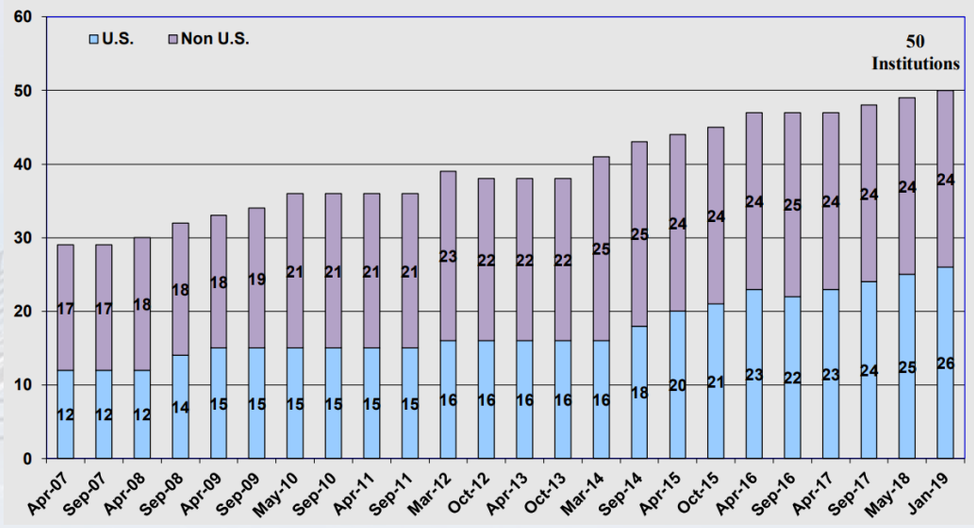


Icecube Publications

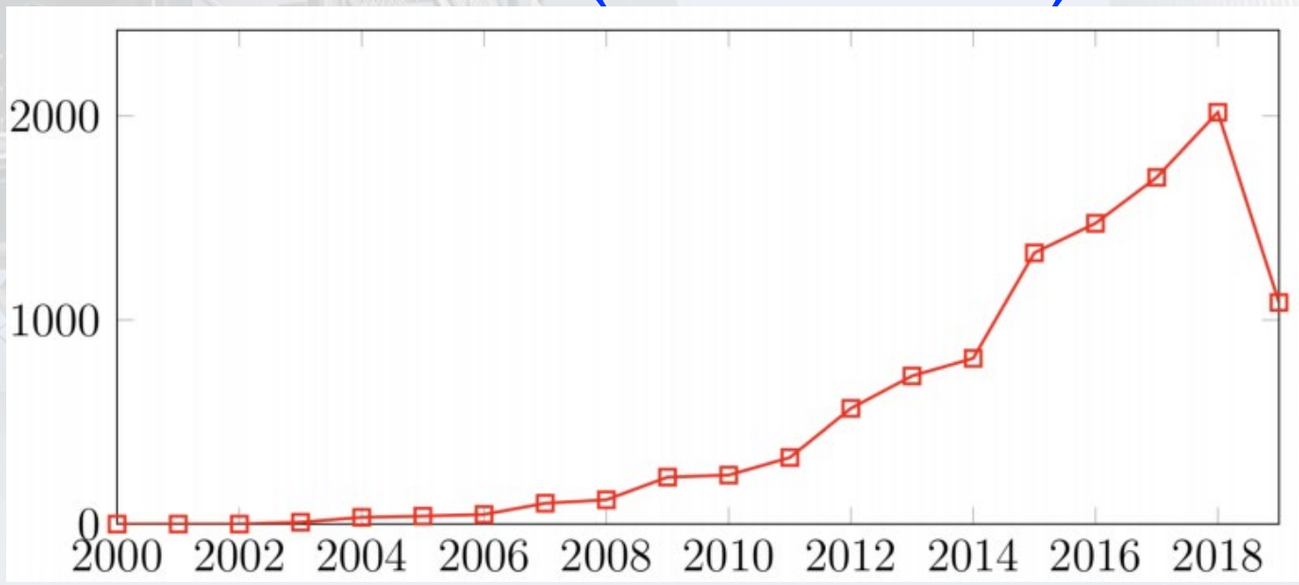
- Publication rate now flat
  - 10-20 papers/year
- Citations growing exponentially!
  - Data up to April 2019
- Collaboration still growing
  - Even split between US and non-US institutes

Published Papers



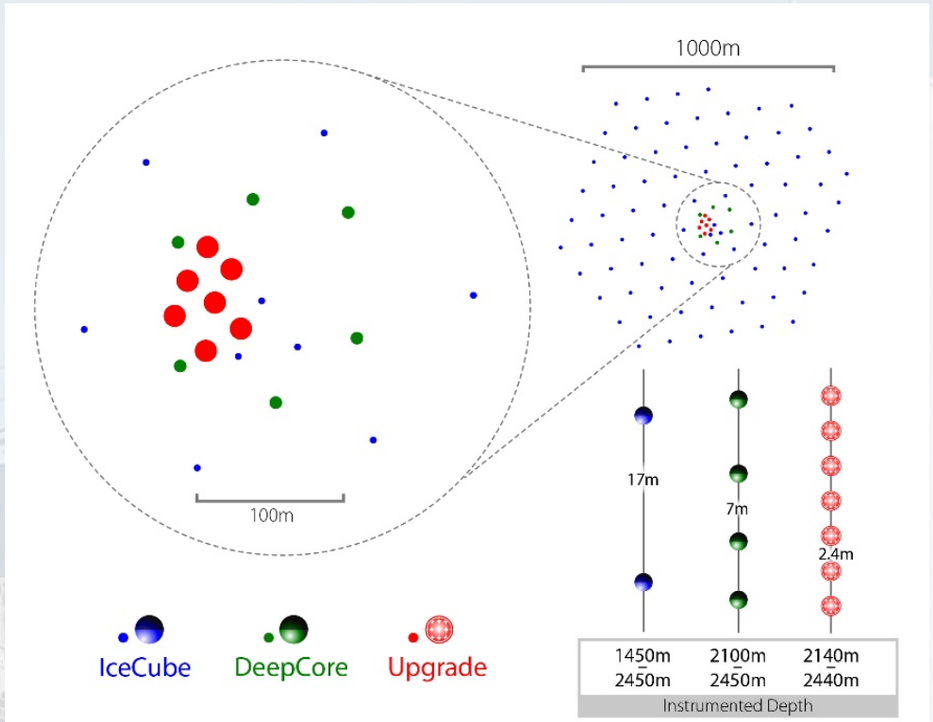


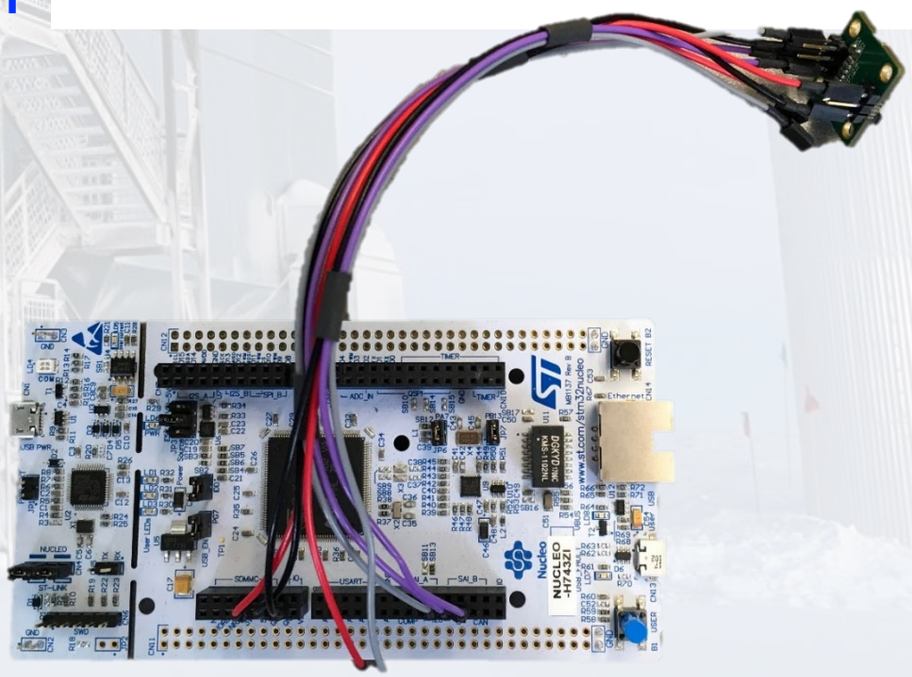
Citations (no self cites)



Icecube Upgrade

- NSF has approved a 7-string upgrade
  - Primary aim is to improve detector calibration and knowledge of the ice before Icecube Gen 2
  - …but significant opportunity for low energy physics
- Major funding: US, Japan, Germany
  - CFI timescale precluded significant Canadian contribution
- Strings will be deployed with a variety of closely spaced modules
  - 2m vertical, 15m horizontal
- Canadian involvement:
  - Developing DOM software
    - ARM MCU on DOM mainboard controls all aspects of each DOM: DAQ (via FPGA), calibration and sensors
  - Flasher calibration





Computing

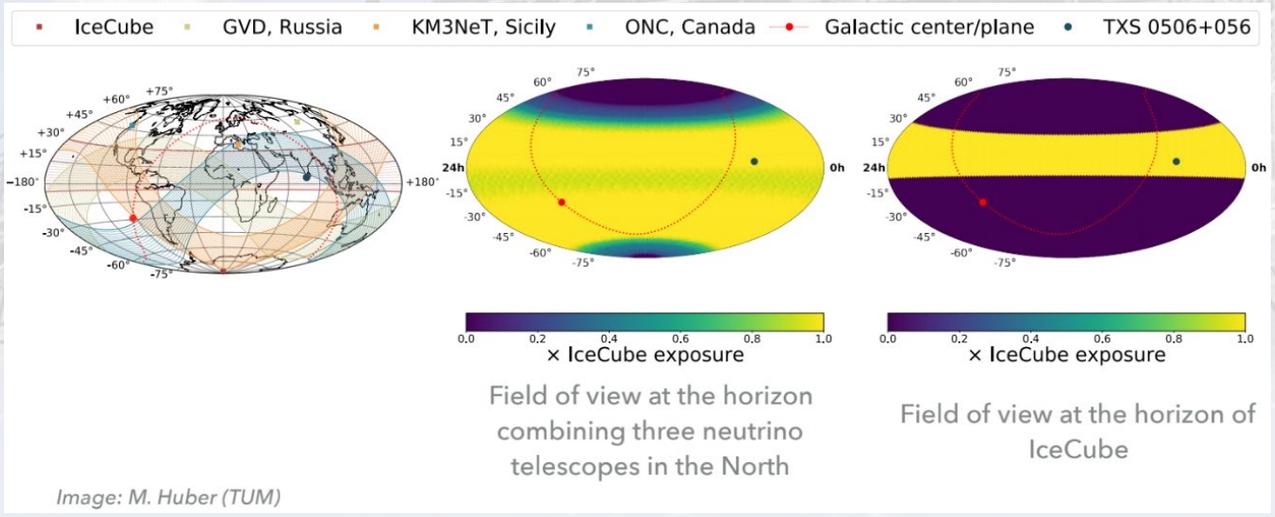
- Two components to Canadian Icecube computing
  - Compute Canada allocation on Cedar
    - Removed from Graham due to lack of network access
  - Local, virtual GPU cluster "Illume" in Alberta as part of Faculty-wide OpenStack cluster managed with Compute Canada (USherbrooke team)
- Generation of low energy MC (up to 10 TeV) on Cedar
  - Job submission still manual but working on glide-ins for Condor
    - Glide-ins need to run a container…inside the existing container
- Cedar still has some issues remaining
  - Major problem due to use of non-standard CentOS 7
    - Now solved via singularity which re-implements standard CentOS 7 libraries and environment
  - LusterFS still having periodic issues and backups have proven unreliable
- Now hired local computing support (shared with SNO+) to free up postdoc time for physics

Illume and Cirrus

- Cirrus is an OpenStack cluster run by Faculty of Science in Alberta (~Tier 3 in ATLAS model)
  - Managed by CC admins under contract but switching to shared management with local research IT team
  - Same environment as CC clouds (run by same team!)
- Researchers purchase resources (CPU, disk etc.) which they own for the lifetime of the hardware
  - Replaces separate local clusters with one, centrally managed cluster
  - Advantages of VMs coupled with centrally managed bulk RAID-Z3 disk
    - provides snapshots and replication if needed; $125 per usable TB
- Developed OpenStack patch to allow use of retail NVIDIA GPUs within VMs (via PCI pass-through)
  - ~x10 cheaper than enterprise GPUs but single precision only which is exactly what our code is optimised for
- Available for local users or Icecube generally via glide-ins

P-ONE

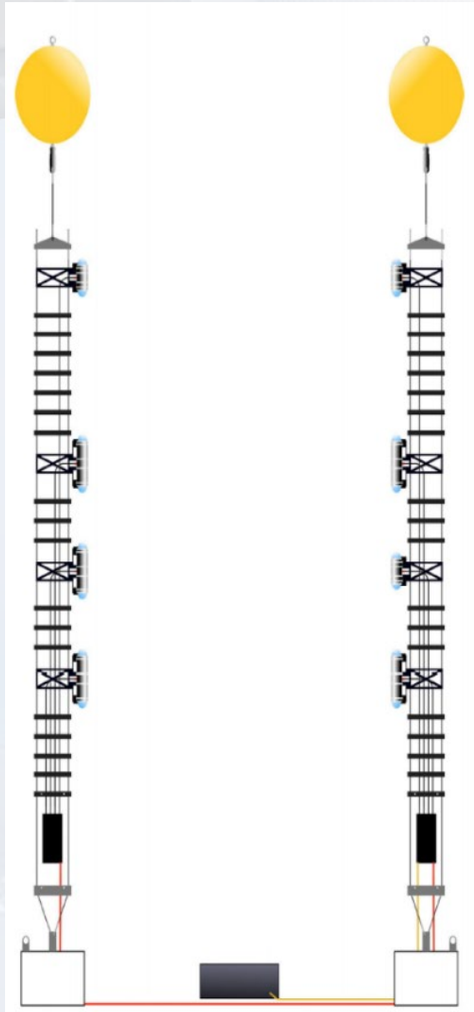
- Pacific Ocean Neutrino Explorer
  - Institutes: UAlberta, Queens, SFU, TUMunich, Michigan State, Ocean Networks Canada and McDonald Institute
- Build and deploy neutrino detector off the BC coast
  - Combine Icecube detector, ONC underwater operations and Canadian neutrino expertise
- Unprecedented capability to quickly deploy sparse detector to give excellent high energy neutrino coverage
  - Strong astrophysics case: increases sky coverage significantly
  - Studying e-tau separation: important for nu-oscillation analyses and water better than ice due to longer scattering length
- Already deployed and operating two proto-strings
  - Measuring water properties using Icecube calibration modules designed for upgrade
  - Plan to add third test string early in the 2020 season



Field of view at the horizon combining three neutrino telescopes in the North

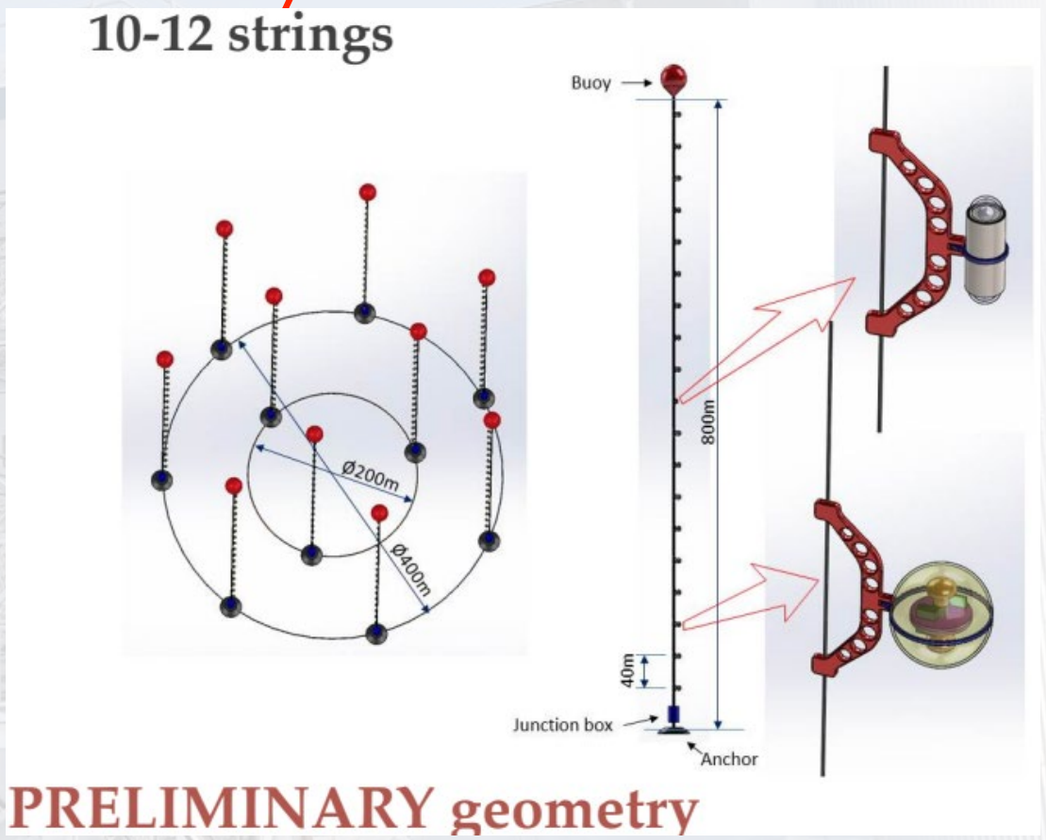
Field of view at the horizon of IceCube

Image: M. Huber (TUM)



P-ONE

- Working on some unique design features/opportunities
  - Possible to change geometry and/or service the detector
    - Cluster for low energy physics then separate for high energy
  - Interdisciplinary research
    - Discussing collaboration with biologists to study bioluminescence
- Analysis of existing string data and simulation of detector geometries conducted by co-op students with McDonald Institute support
  - Now hiring postdoc split between P-ONE/Icecube
- TUM already has EU funding secured, CFI application for initial 10-string detector this year
  - Focus on detecting tau neutrinos, gain experience for full scale, high energy detector
- Significant opportunities for anyone interested in joining!



Future Plans

- Concentrate on Icecube for the immediate future
  - Rich, established physics program continuing to yield significant results
    - Nu oscillations, BSM searches, cosmic rays, astrophysics
  - Great opportunity for more with upgrade
  - Gain experience with upgrade hardware: mDOMs
- Continue strong push on development of P-ONE
  - Apply Icecube detector and analysis expertise to detector design and development
- Grow P-ONE collaboration inside and outside Canada
  - Matthias Danninger, SFU will join @25% in April 2021
- Interested? Talk to Carsten, Juan Pablo, Ken or me!
  - P-ONE meeting at UAlberta 22-24th July: all welcome!