Neutrino activity at the PPE group

Lilia Drakopoulou for the neutrino group

The neutrino group :

Steve Playfer
Matthew Needham
Greig Cowan
Lilia Drakopoulou
Mahdi Taani

Last year Summer students:
Nicolas Angelides (TITUS software improvement)
Clare Park (Geant4 studies)
Neil McBlane (LAPPD tests in lab)

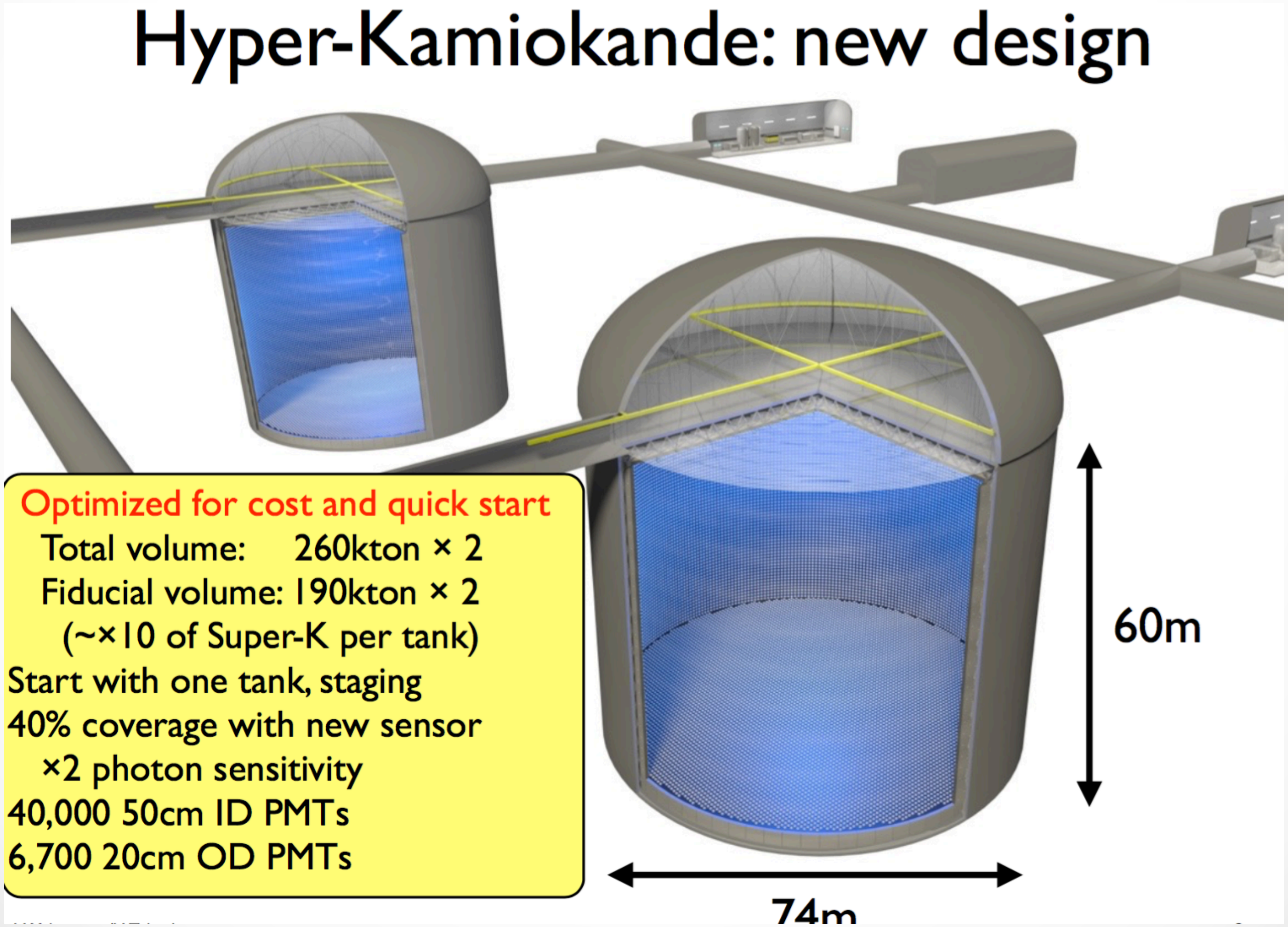
The PPE group has joined the following neutrino experiments :

- Hyper-Kamiokande (Hyper-K) in Japan
  TITUS intermediate detector (sub-group)

- Last October part of the group joined the ANNIE experiment in Fermilab.

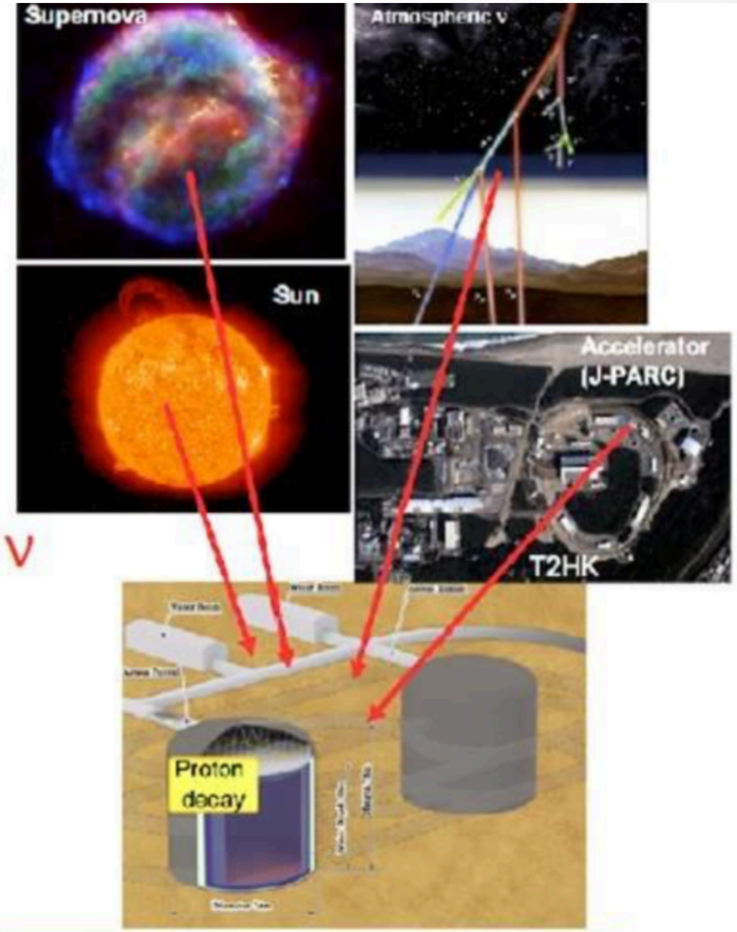
Hyper-Kamiokande (Hyper-K)

- Hyper-K is a WCh detector that will act as a far detector for the long baseline *ν* experiment using the *ν* beam from J-PARC in Japan.
- Physics goals of Hyper-K include the measurement of CP violation in the *ν* sector and mass hierarchy measurements.



Hyper-Kamiokande (Hyper-K)

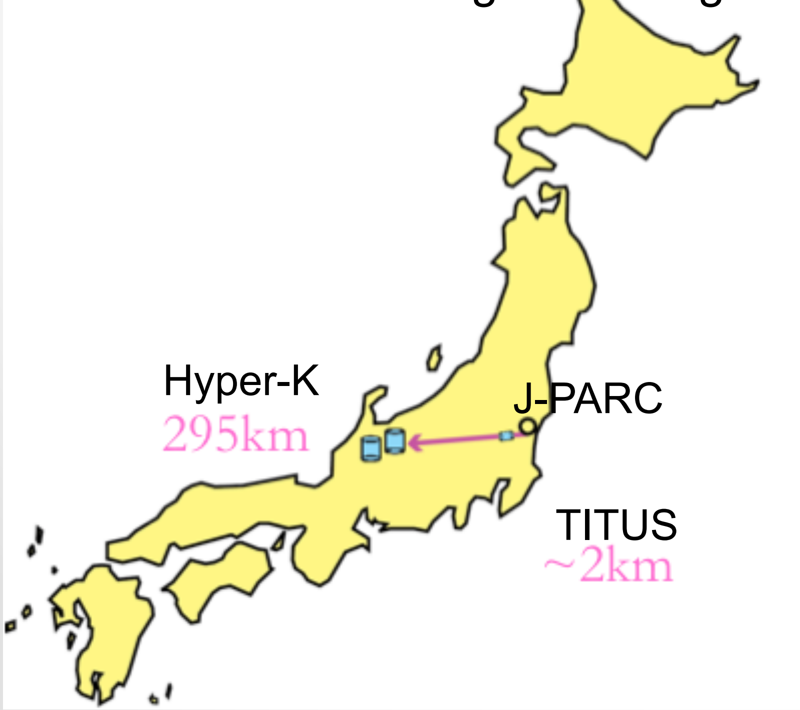
- Neutrino oscillation physics
  - Comprehensive study with beam and atmospheric neutrinos
- Search for nucleon decay
  - Possible discovery with ~×10 better sensitivity than Super-K
- Neutrino astrophysics
  - Precision measurements of solar ν
  - High statistics measurements of SN burst ν
  - Detection and study of relic SN neutrinos
- Geophysics (neutrinography of interior of the Earth)
- Maybe more (unexpected)

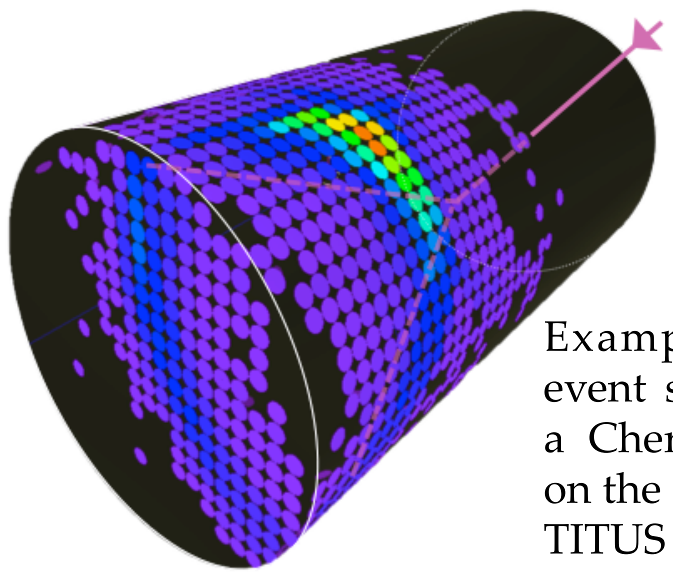


Extend highly successful program of Super-K

Hyper-Kamiokande (Hyper-K)

- Off-axis far detector for long baseline ν experiment using the J-PARC (Japan Proton Accelerator Research Complex) ν-beam
- 1.3 MW proton beam is used to generate 0.6 GeV ν-beam. Horn currents from +320 to -320 kA are employed to generate $\bar{\nu}_\mu/\nu_\mu$ enhanced beams.
- Hyper-K physics goals include ν CP-violation and mass hierarchy measurements.
- TITUS (Tokai Intermediate Tank for the Unoscillated Spectrum) is a WCh detector with a mass of 2.1 kton horizontally placed along the beam to act as an intermediate detector.
- Same off-axis angle and target material as the far detector reduces systematics.



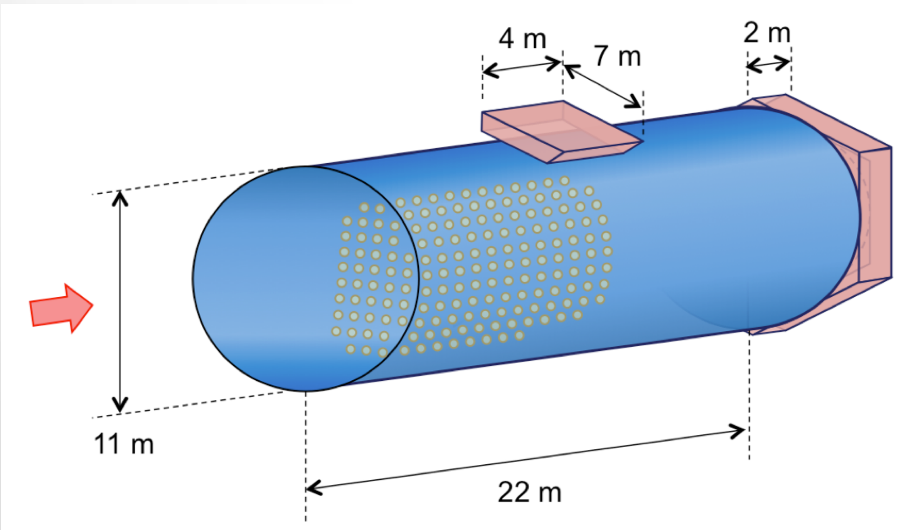


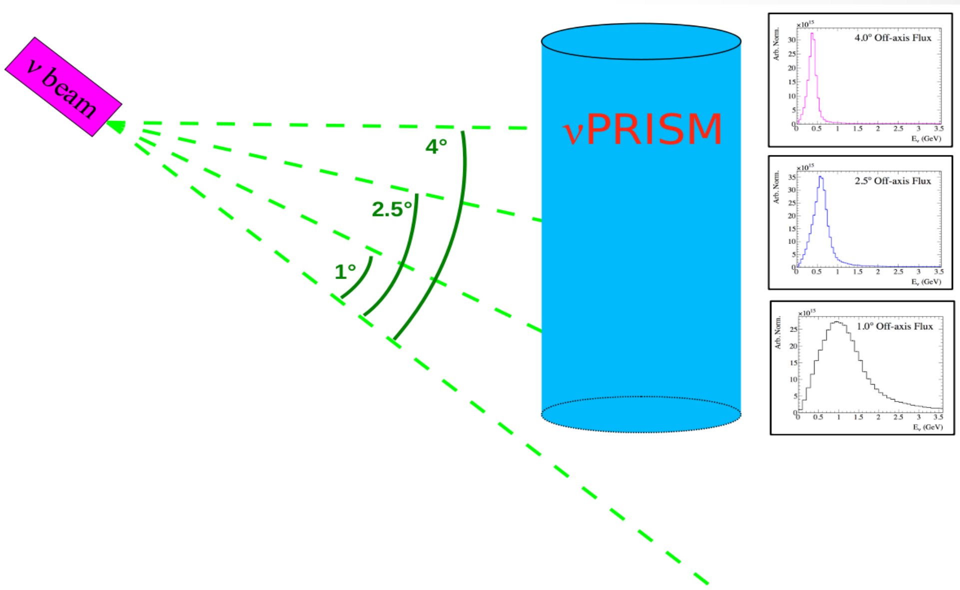
Example of the event signature of a Cherenkov ring on the PMTs of the TITUS detector.

Hyper-Kamiokande (Hyper-K)

Two intermediate WCh designs: **TITUS** and **NuPrism**

- **TITUS**: instrumented with PMTs. The design also features two magnetised muon range detectors (MRDs), one downstream of the tank and the other on the top edge. TITUS was designed to perform neutron tagging, so incorporates a 0.1% by mass gadolinium loading in the baseline design.
- **NuPRism**: WCh detector spanning 1°-4° from the neutrino beam axis. Instrumented movable cylinder (ID: 8m diameter, 10m tall). By measuring neutrino interactions across a range of off-axis angles NuPRISM would sample many different neutrino spectra, each of which peaks at a different energy.
- It can provide a direct measurement of the far detector lepton kinematics for any given set of oscillation parameters, which largely removes neutrino interaction modeling uncertainties.

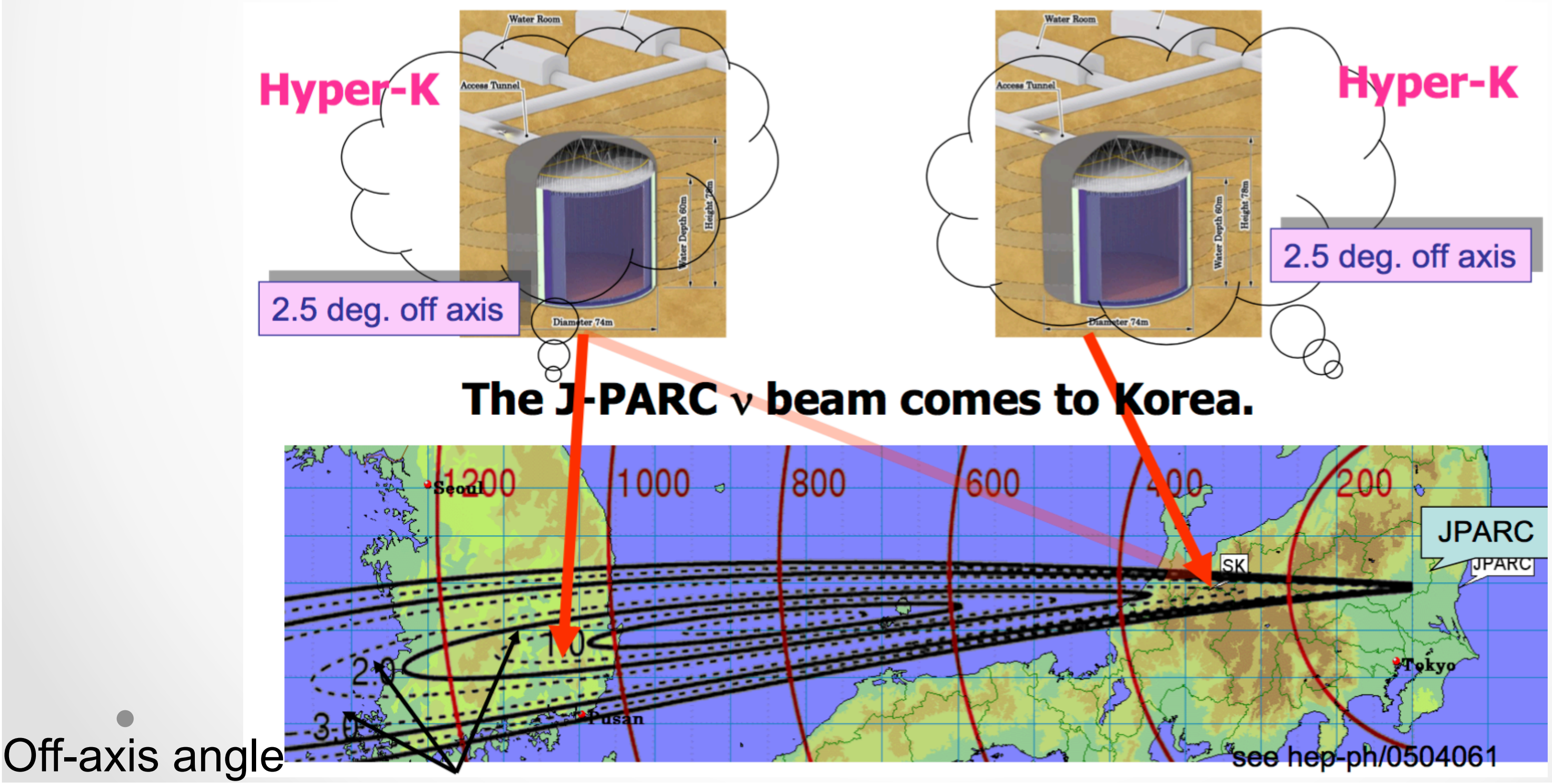




Hyper-K - 2nd HK detector in Korea

The physics reach of the long baseline Hyper-K experiment is enhanced by the 2nd detector in Korea (~1100km, 1.5~2.5°).

- The Korean detector covers the second oscillation maxima where the CP violation effect is 3 times larger than in the first oscillation maxima.
- The longer baseline leads to at a larger matter effect and improves the sensitivity to the mass ordering.
- The Korean detector may have smaller background due to its larger overburden (> 800 m) and interesting non-accelerator neutrino physics can be probed.



Hyper-Kamiokande (Hyper-K)

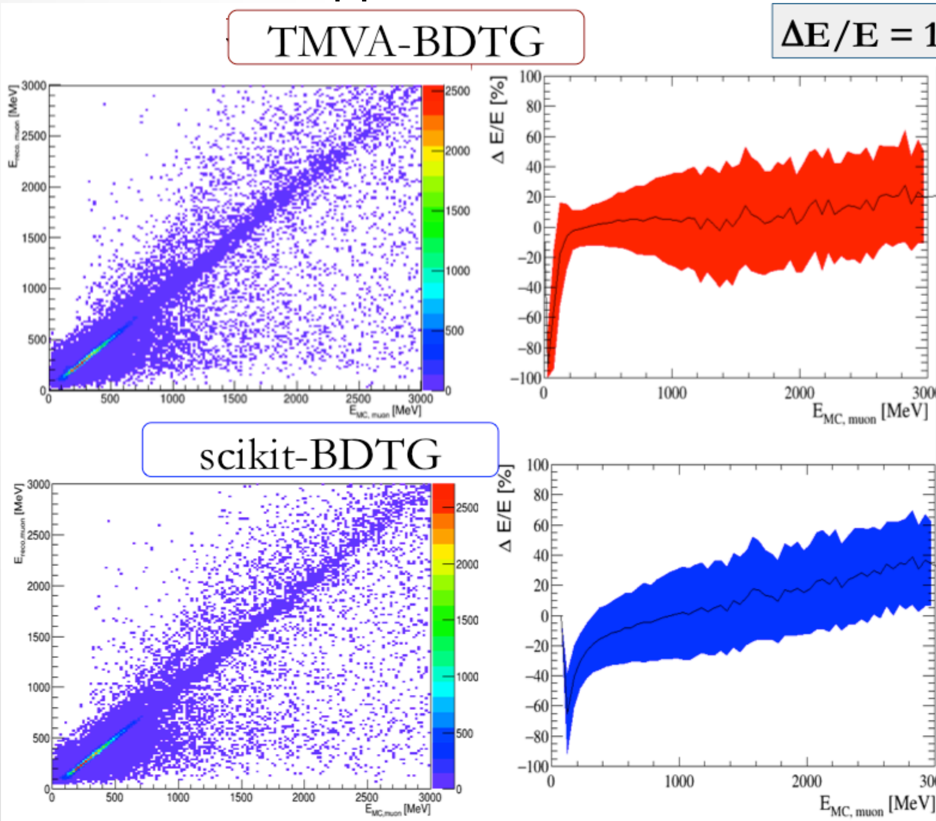
Our contribution to Hyper-K and scpecifically to the TITUS detector so far:

- We performed several comparisons for different PMT photocoverage of TITUS (poster presented at Invisibles16).
- Significantly speed up the TITUS reconstruction.
- Proposed a new method for the energy reconstruction for WCh detectors based on Machine Learning Techniques (poster presented at NuPhys16).
  - * We perform a regression analysis using a Boosted Decision Tree with Gradient Boost (BDTG) to reconstruct the muon energy for $\nu\mu$ events crossing the detector volume.

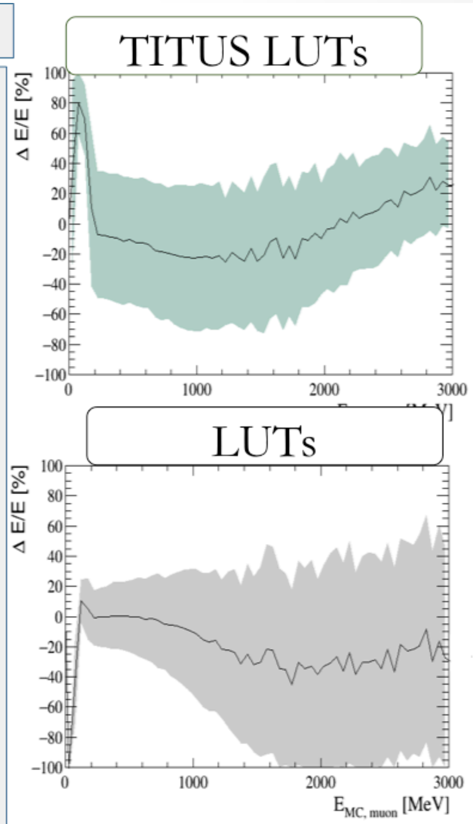
Hyper-Kamiokande (Hyper-K)

- We trained and tested two different BDTGs (from ROOT-TMVA and scikit-learn) with appropriate input variables.
- The results were compared with a TITUS method using look up tables (LUTs) with analogous variables and with a method using LUTs based only on the number of photoelectrons in rings.
- These methods will be further optimised in the future along with testing different approaches.

$\Delta E/E = 100*(E_{MC,\mu}-E_{reco,\mu}/E_{MC,\mu})$



- The mean and standard deviation of the resolution distribution in bins of energy is plotted.
- No cuts are applied.
- BDTGs perform better than LUTs.
- Results in energy reconstruction are better than the ones reported at the TITUS note [arXiv: 1606.08114 [physics.ins-det]]



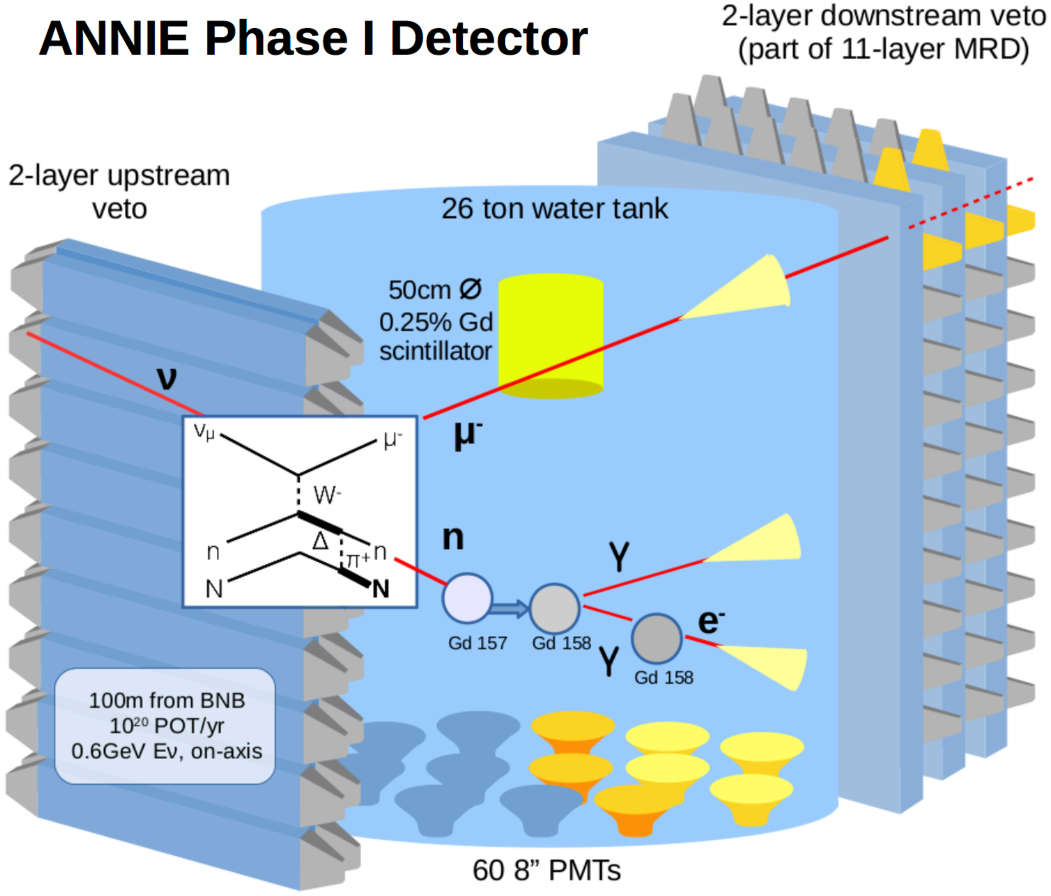
Accelerator Neutrino Neutron Interaction Experiment (ANNIE)

ANNIE is a water Cherenkov detector that uses neutron capture on Gd to detect neutrons. The goal is to measure the neutron multiplicity as a function of kinematic variables.

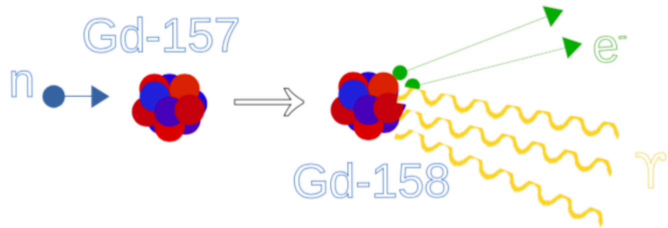
- The ANNIE detector is a 26-ton water tank, currently containing sixty 8” PMTs for 'phase I' background measurement
- Physics runs will use approximately 200 PMTs
- These will be augmented with LAPPDs as they become available
- An upstream scintillating veto rejects events with muons

identifying a upstream rock interaction

- A downstream MRD measures outgoing muon energy an dangle

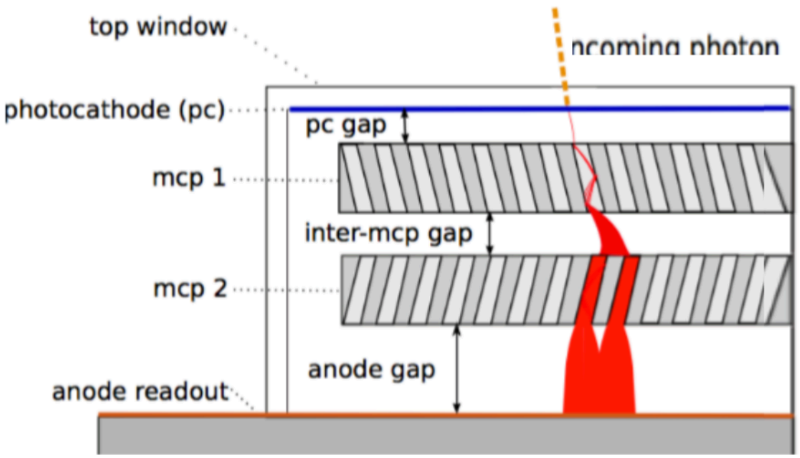


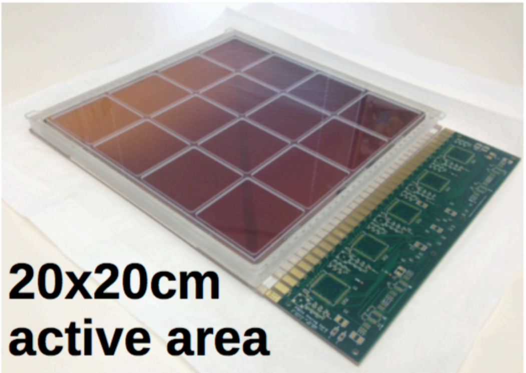
Accelerator Neutrino Neutron Interaction Experiment (ANNIE)



With 0.2% $Gd_2(SO_4)_3$ loading, 90% of final state neutrons capture on Gd, releasing 8MeV total energy

- To reconstruct events, ANNIE will implement 'Large Area Picosecond Photodetectors' (LAPPDS)





Accelerator Neutrino Neutron Interaction Experiment (ANNIE)

Our contribution to ANNIE:

- short-term visit in ANNIE site at Fermilab funded by SUPA: contribution to neutron calibration measurements and to the detector maintenance
- A stand-alone LAPPD code was incorporated in WCSim simulation package and will be used for Physics Run I simulations (full PMT coverage and partial LAPPD coverage)
- fiTQun reconstruction code is tuned for ANNIE – *Work in progress*
- Shifts to the ANNIE detector (remotely)

Thank you!