T2K, Super-K, Hyper-K PPAP Community Meeting 2020

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State of Play

- Big news in 2020: Hyper-K is funded in Japan
- Gadolinium added to Super-K
  - Full members of Super-K since 2015
- Forward Momentum on ND280-Upgrade and Beam Power for T2K
  - Upgrades to all components of T2K

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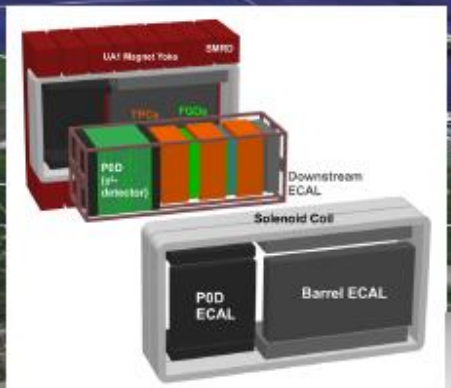
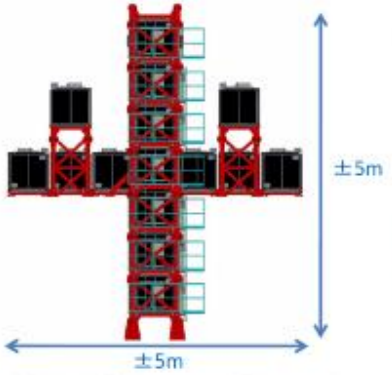
T2K

T2K Experiment

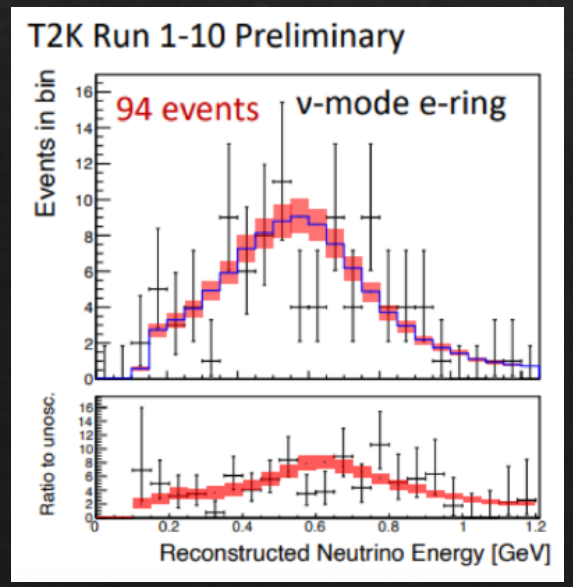
- Muon (anti) neutrino beam generated at J-PARC
- Beam travels 295 km to large SK far detector to be measured after oscillations
- Near detector complex, ND280 constrains beam flux and interaction cross-section before oscillation
- Important to constrain non-oscillation parts of model to avoid bias

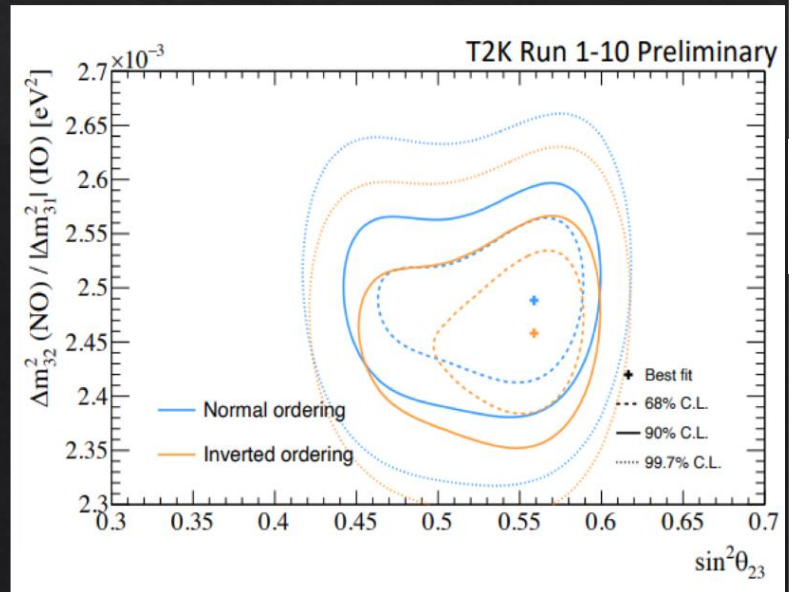


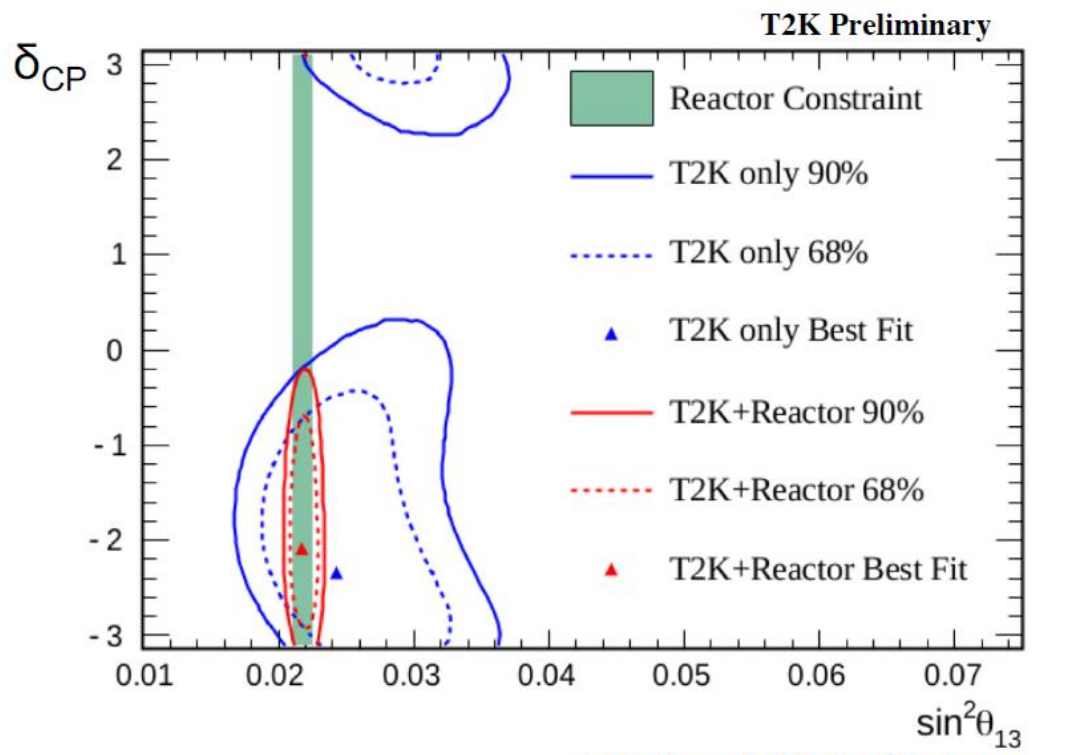


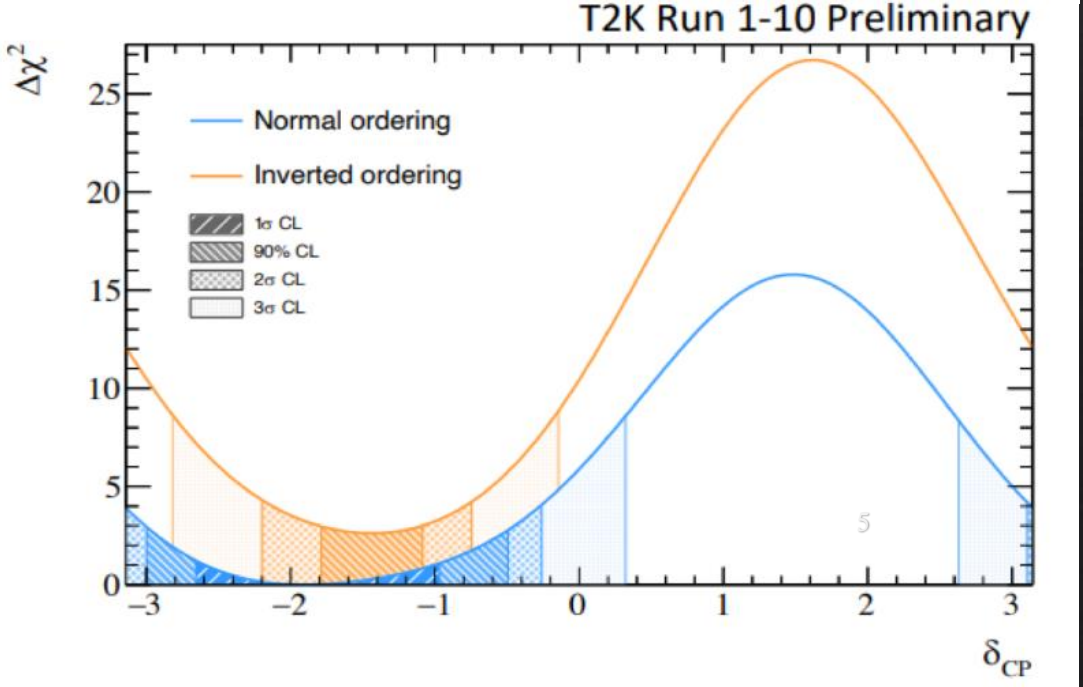
Latest Results

- Five channel simultaneous fit
  - υ mode – 1Rμ 1Re 1Re1me
  - $\bar{\upsilon}$ mode – 1Rμ, 1Re
- Near detector data constrains flux and cross section uncertainties
- υ mode 1.97x10^{21} pot, $\bar{\upsilon}$ mode 1.63x10^{21} pot





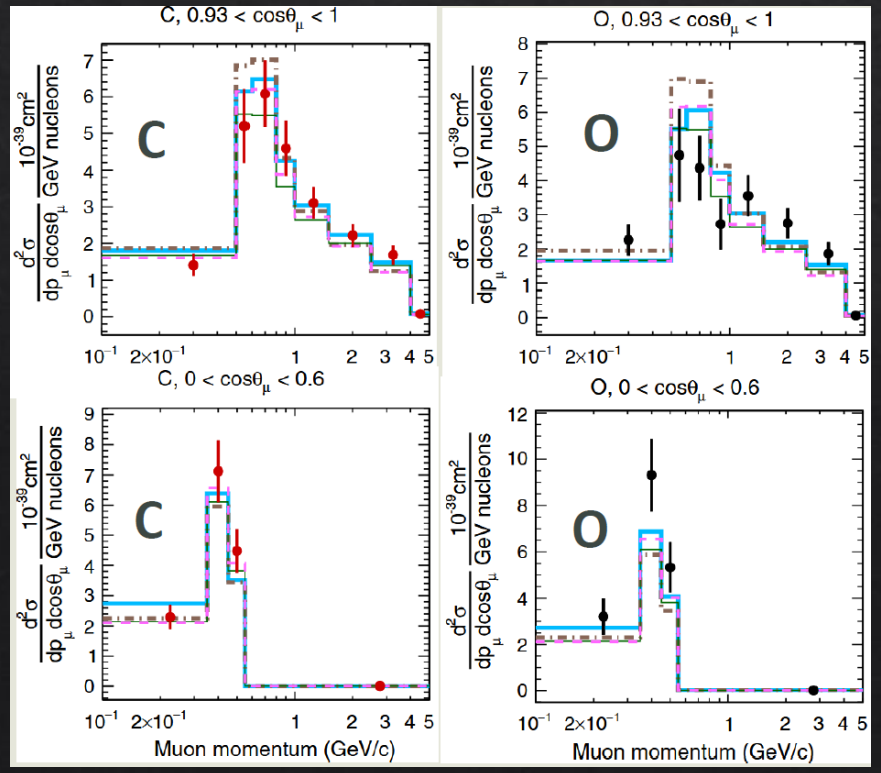




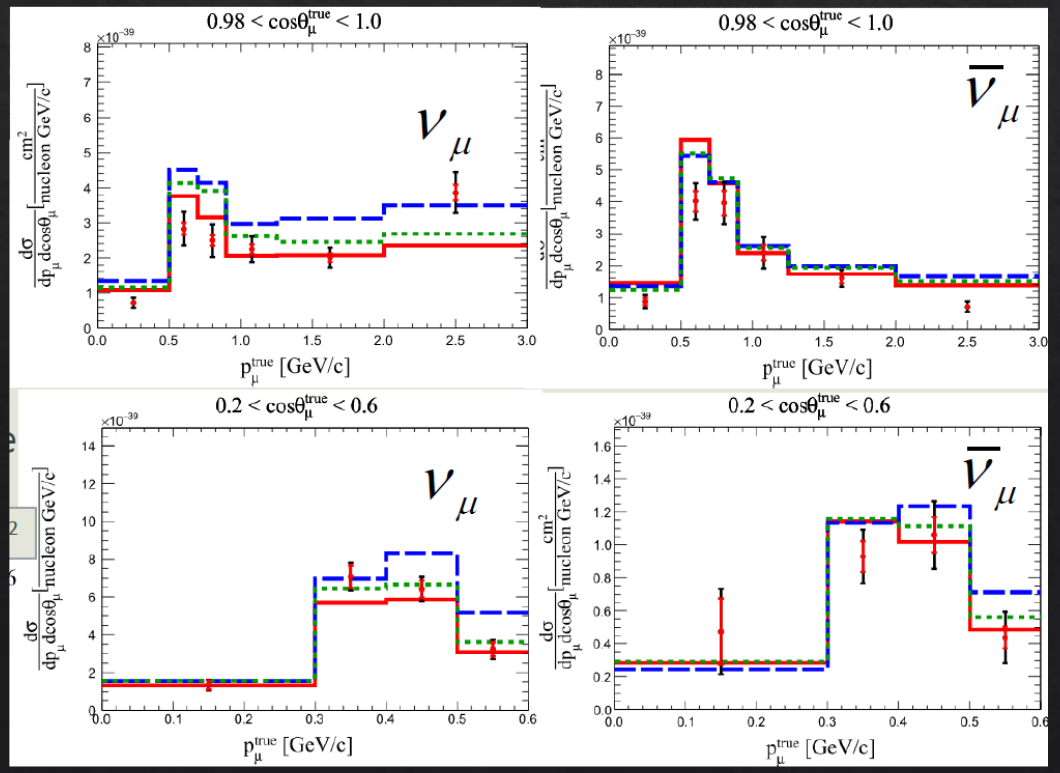
Cross Section Results

- Near Detector complex continues to produce more precise cross section measurements
- Data continue to challenge cross section models

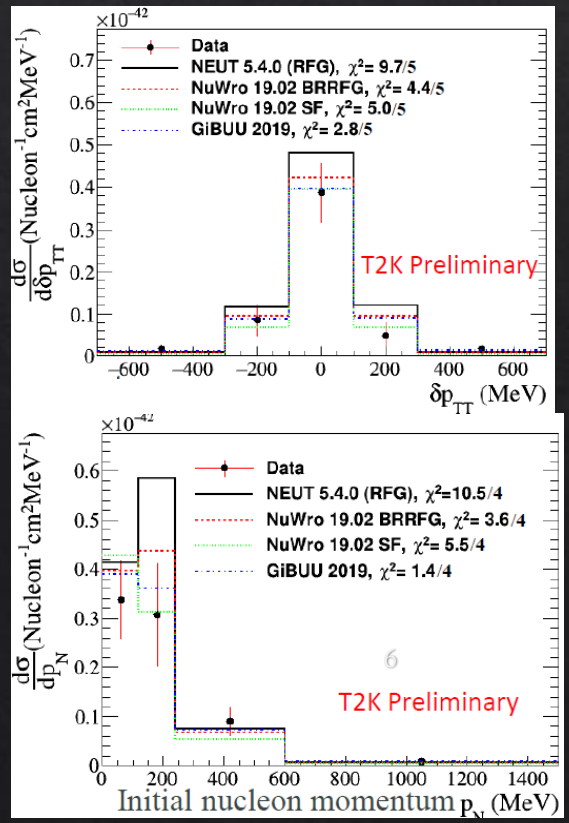
Joint C, O CC0π 58 Bins



Joint neutrino, antineutrino CC0π on C

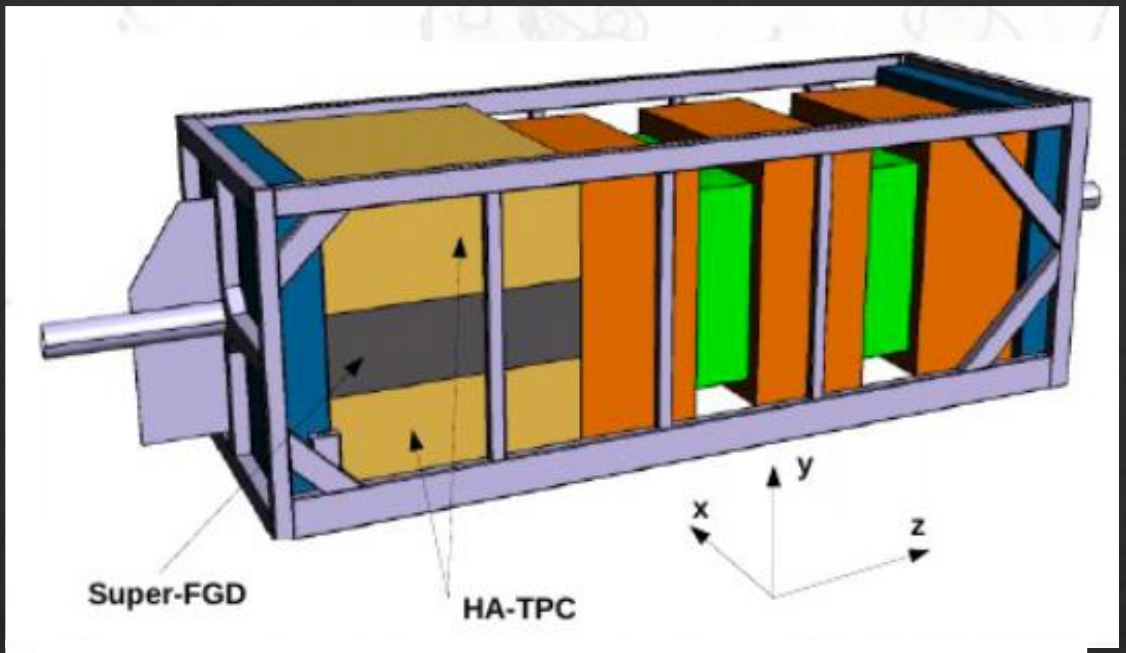


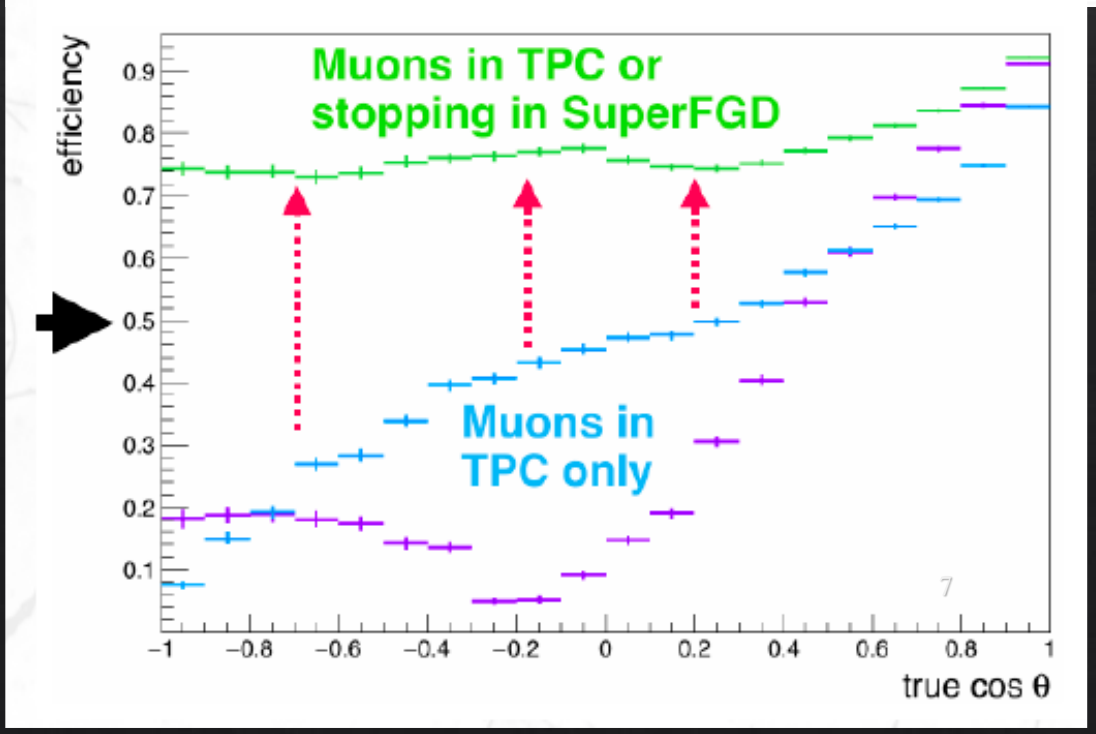
CC1π transverse kinematic imbalance



ND280 Upgrade

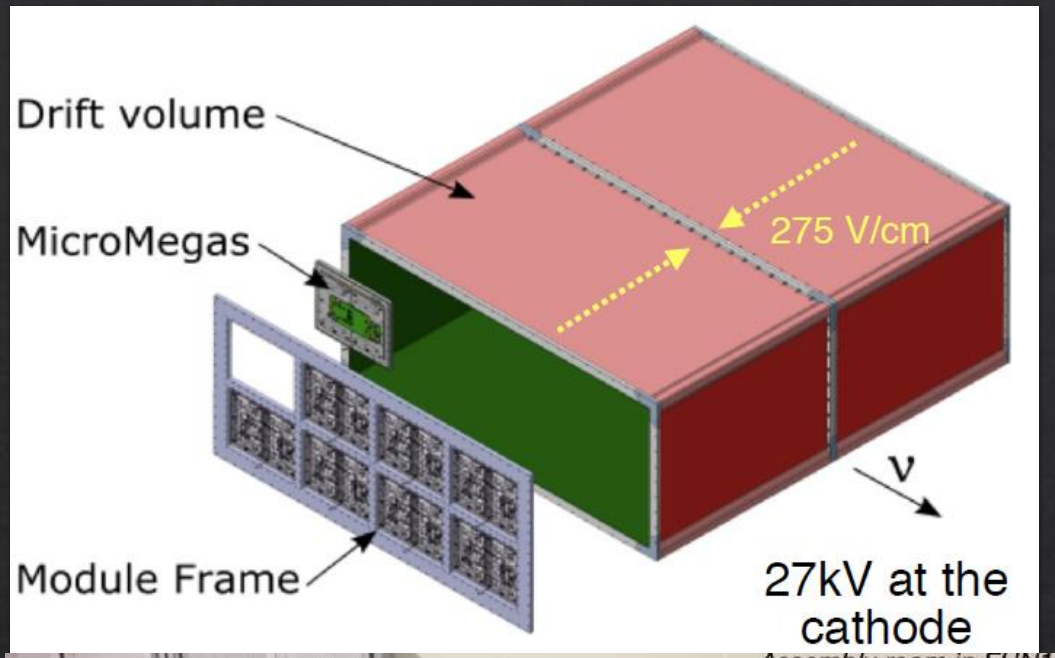
- Upgrade near detector to improve granularity, high angle and backwards tracking
- Scheduled for installation by Summer 2022
- UK Responsibilities/Leadership:
  - DAQ
  - Software
  - ECAL
  - TripT electronics
    - ECAL, INGRID, SMRD, POD
  - Analysis

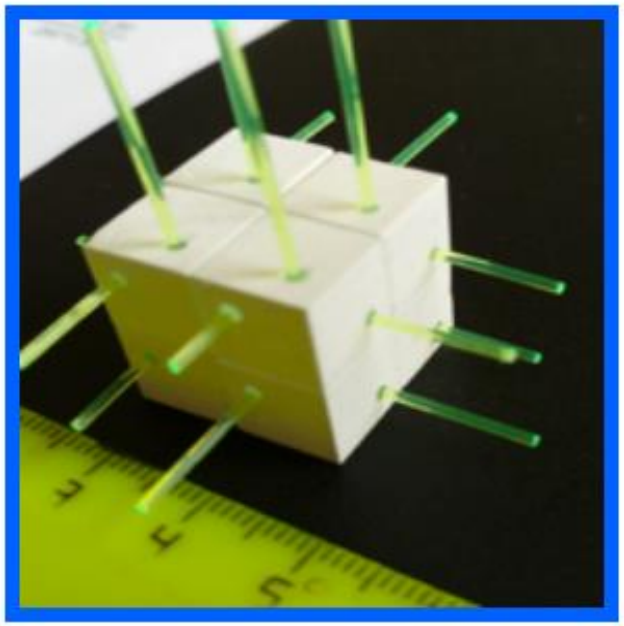




ND280 Upgrade

TPC





1x1x1 cm^3 cubes

Polystirene scintillator

1.5% paraterphenyl

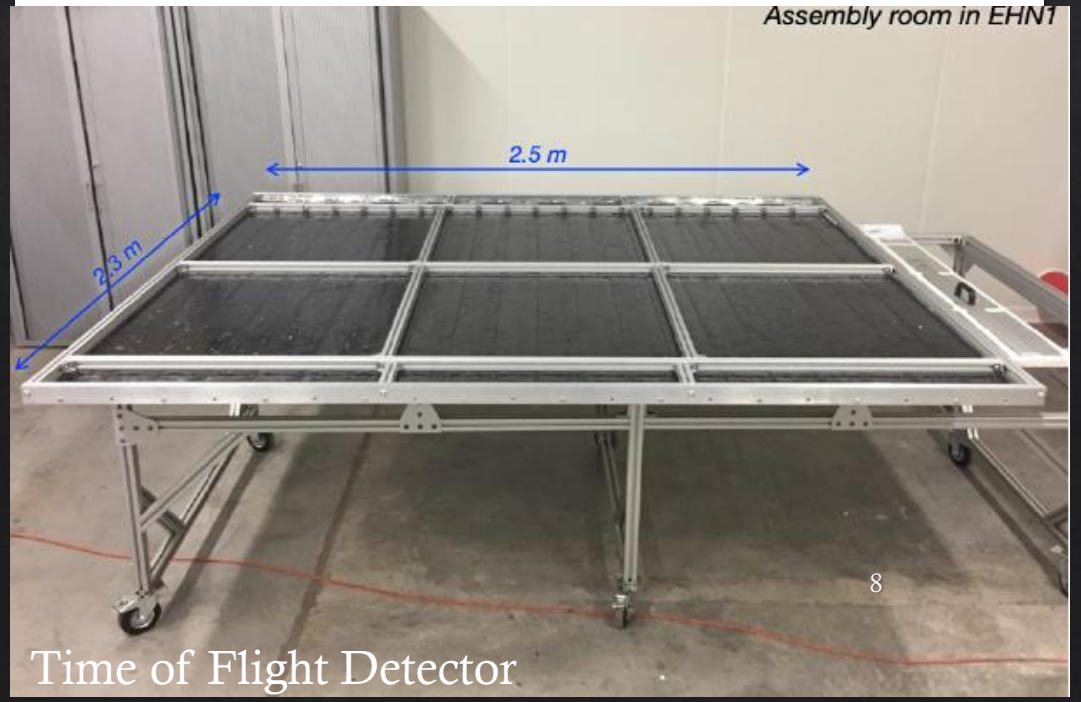
0.01% POPOP

Chemical etched reflector

WLS fiber Kuraray Y11 2-clad (⌀=1mm)

2018 *JINST* **13** P02006
NIM A936 (2019) 136-138

Super FGD

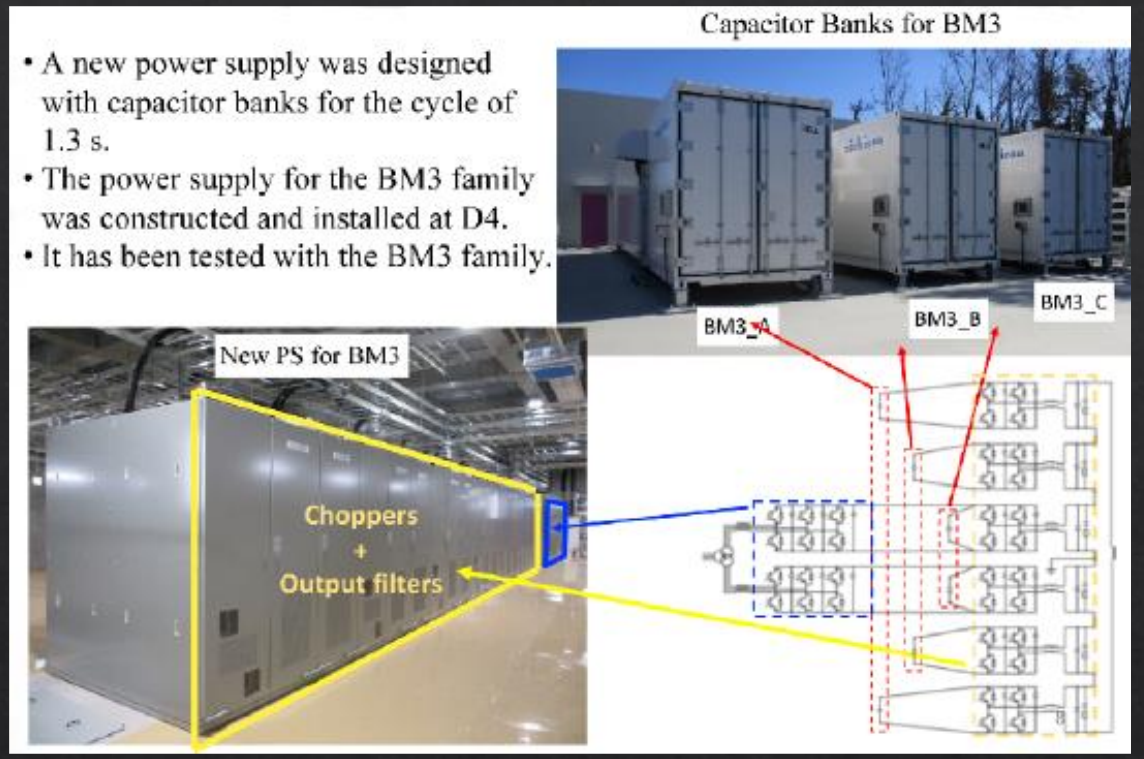


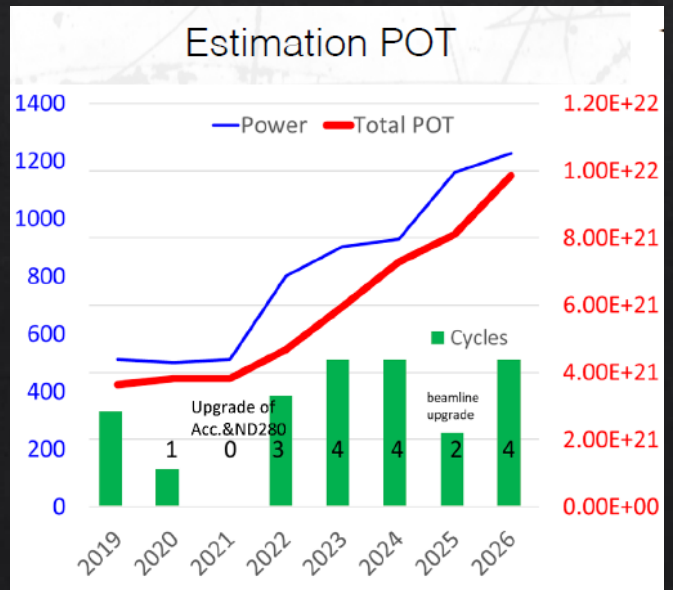
Time of Flight Detector

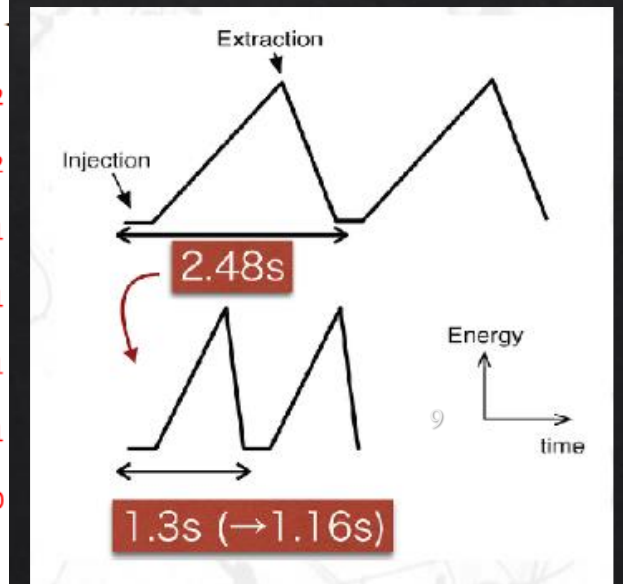
Beam Upgrade

- New power supplies designed for 1.3 s extraction cycle
- 515 kW stable operation in 2019/20
- Expect >800 kW by 2023
- > 1 MW by 2027

- Continued statistical improvement for oscillation and cross section measurements
- Good chance to reach 3σ CP if CP maximally violated







KEK's plan for future neutrino experiments at J-PARC

July 6, 2020

- The Hyper-Kamiokande (HK) project has been approved by the Japanese government and has officially started. It aims to begin operations in 2027. KEK will realize the upgrade of J-PARC for the HK project.

- KEK acknowledges the consensus of the community involved in the Japan-based neutrino experiments that states the need for T2K beam operations until at least 10×10^{21} POT in total.

- KEK recognizes the importance of T2K operation with the upgraded near detector (ND280) for further advancement of CPV measurements. This will also strengthen international collaboration on T2K and HK, contribute to the success of the neutrino program in Japan, and enhance the physics program of HK with an upgraded beam intensity from the start of its operation.

- In light of the above, KEK will make its best effort to provide approximately four months of T2K beam operations per year until the start of HK.

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Super Kamiokande

SK-GD

- Successfully added Gadolinium to detector in 2020
- Added 0.02% GdSO4
  - ~50% neutron capture on Gd
  - 8 MeV gamma cascade
  - High efficiency of nGd tag
- Neutron tagging for neutrino events

- Gadolinium cleanliness measured at BUGS facility at Boulby

Loading start !!

Gadolinium sulfate loading started on July 14th at 10:29

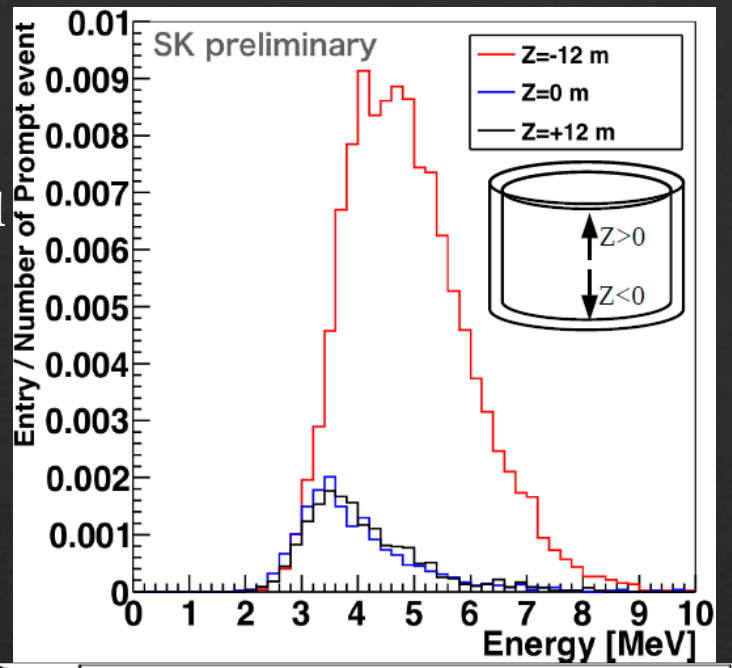
SK-V finished and SK-VI started

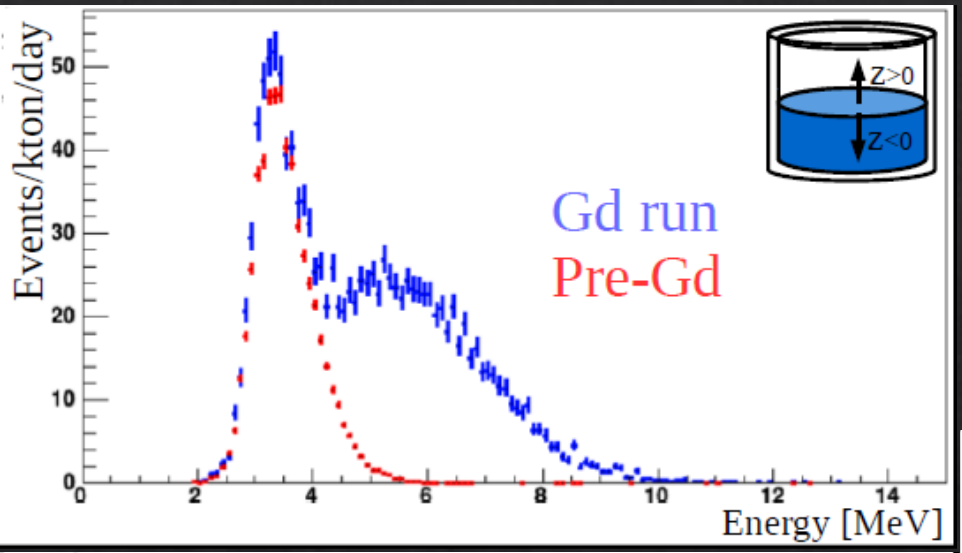
Gd-loading system started.

Loading $Gd_2(SO_4)_3 \cdot 8H_2O$ powder

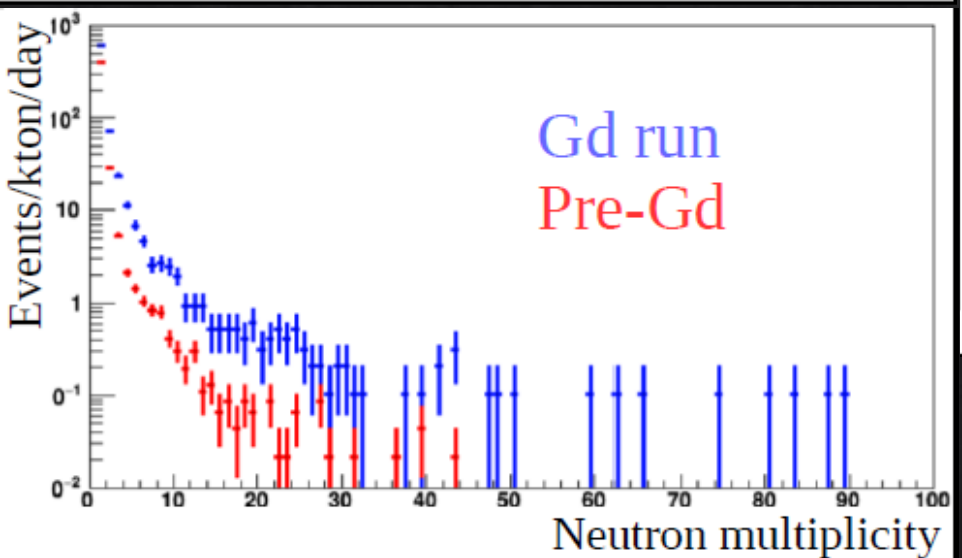
Neutrons in SK-GD

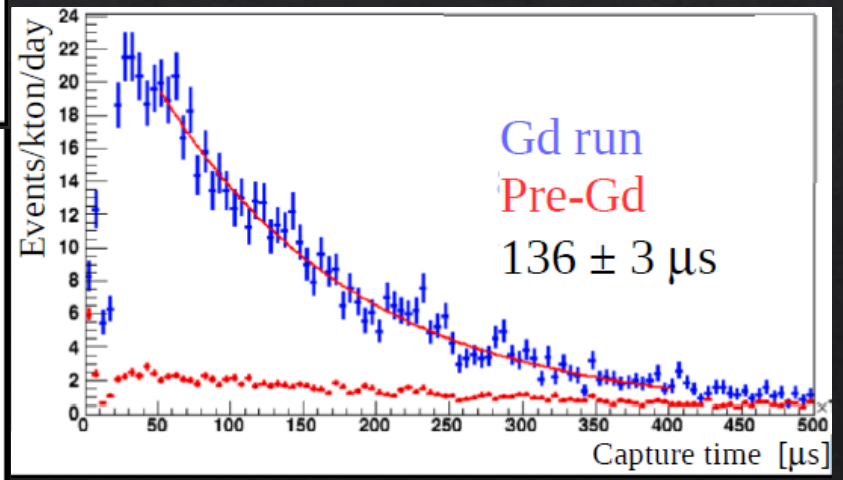
AmBe source during fill



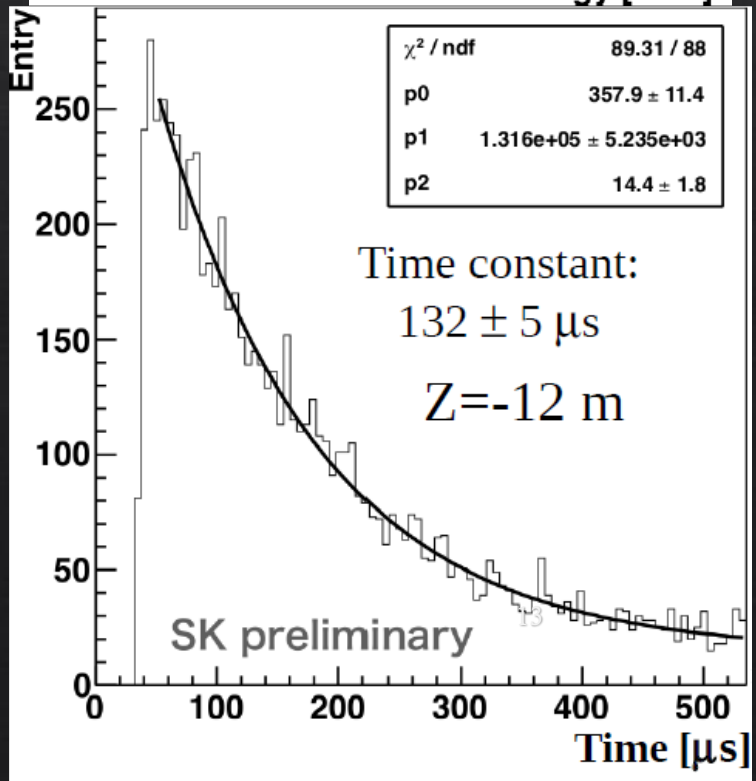


- Neutrons clearly visible in SK as Gd is loaded





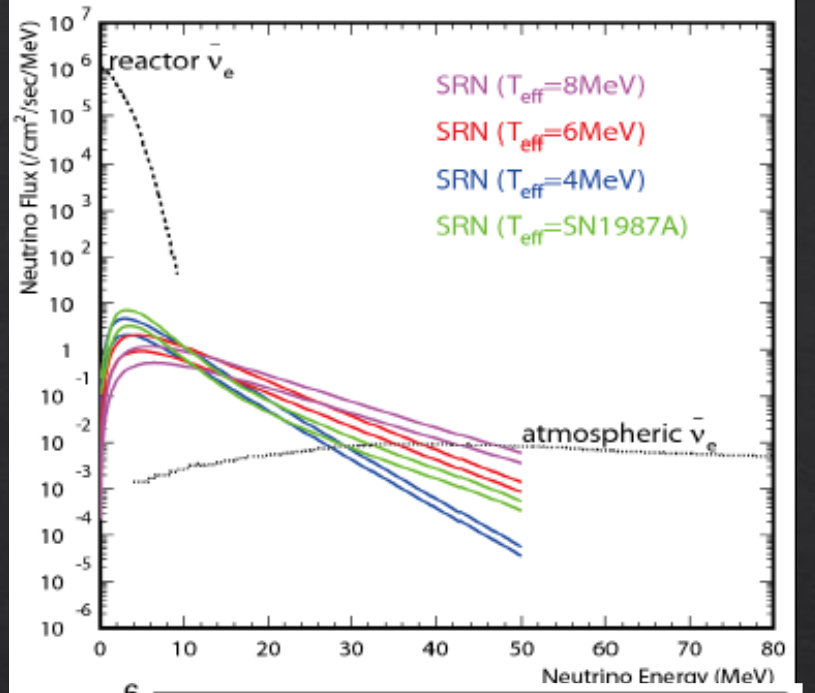
Spallation Neutrons

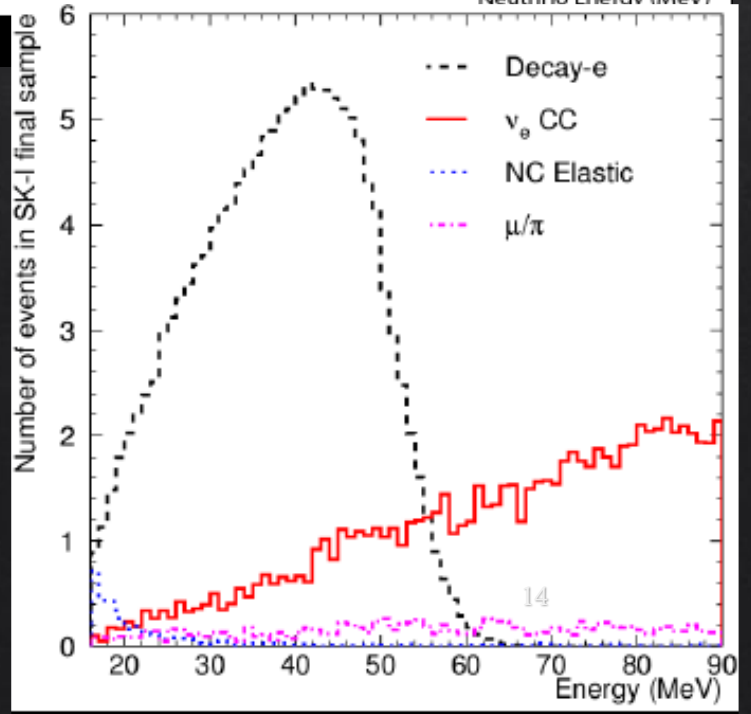


SK-GD Physics

- Diffuser supernova neutrino background
  - Use neutron tagging to select antineutrinos and supress background
  - Potential to discover in SK-Gd
- Many other applications of Gd
  - T2K: analysis – sensitivity to wrong sign backgrounds
  - T2K: neutron sensitivity in NC-γ events
  - SK Atmospheric: Some neutrino-antineutrino sensitivity
  - Supernova burst physics
- Continuation of SK physics programme

- Development of SNEWS2.0



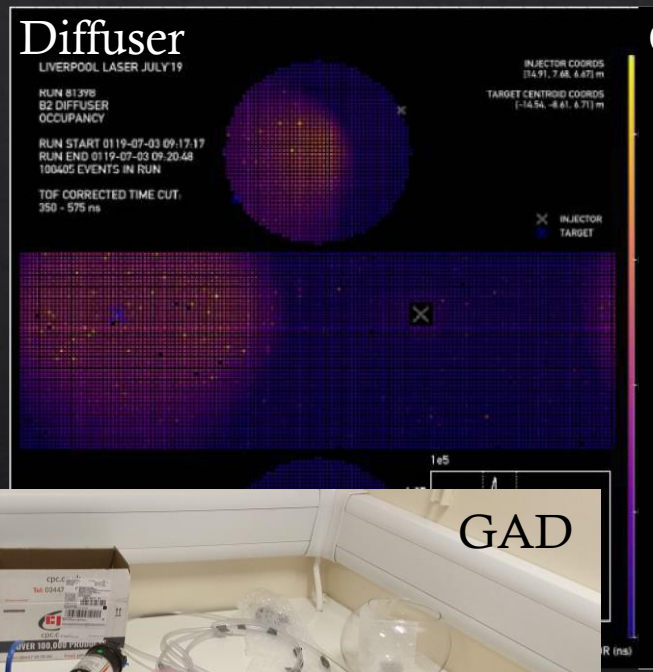


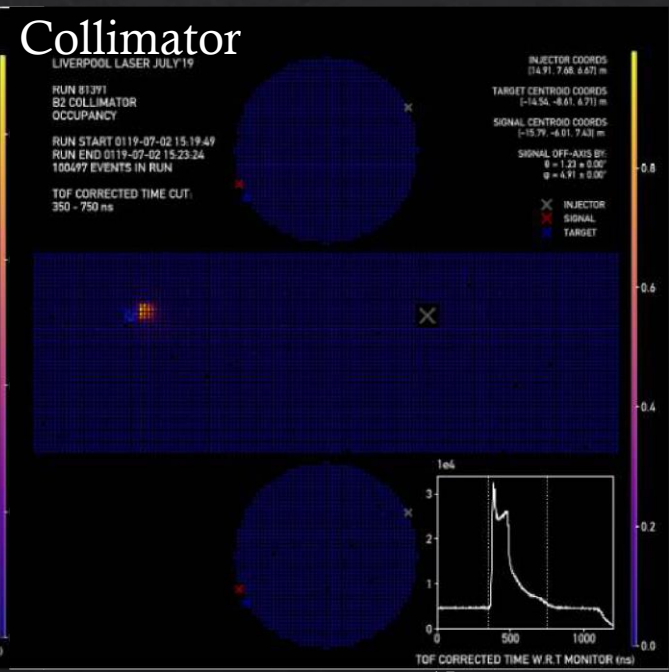
Phys.Rev. D85 (2012) 052007

Calibration

- Light Injection System
  - Deployed during refurbishment in 2018
  - Used to monitor $GdSO_4$ loading
    - Passage of GD front clearly visible in the data
  - Monitoring and measurement of water quality
- Analysis of Outer Detector Light Injection System
- GAD
  - Gadolinium Monitor
  - Will deploy to EGADS then SK

LED Pulser System





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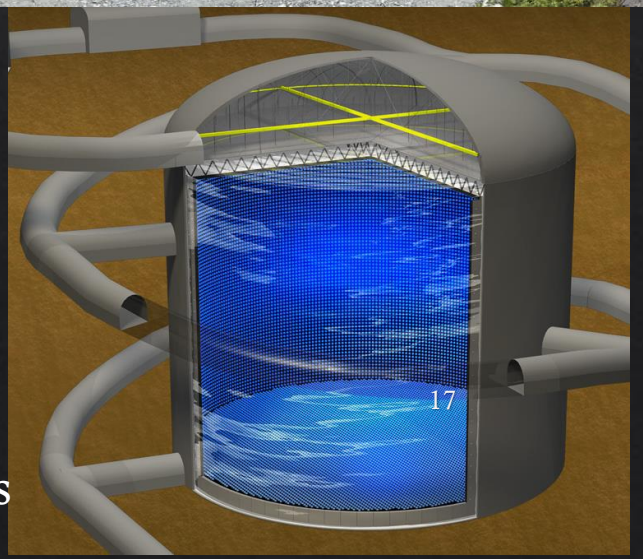
Hyper-K

Hyper Kamiokande

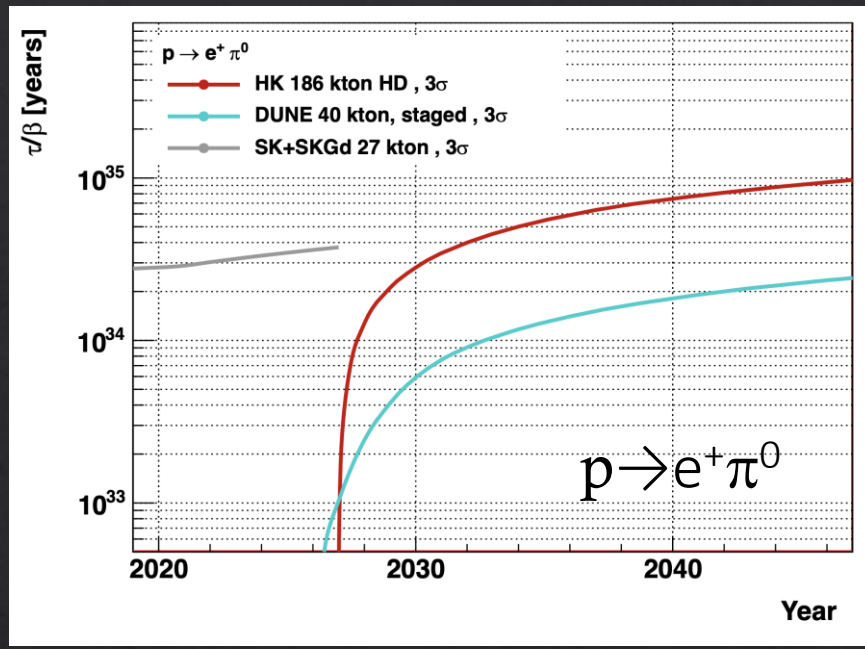
- Hyper Kamiokande was approved in Japan starting construction in April.
  - Currently early site work has started
  - Preparing PMT order
  - Expected to commence operation in 2027
- Upgrade JPARC beam to 1.3MW
- New Detector in Tokai: IWCD

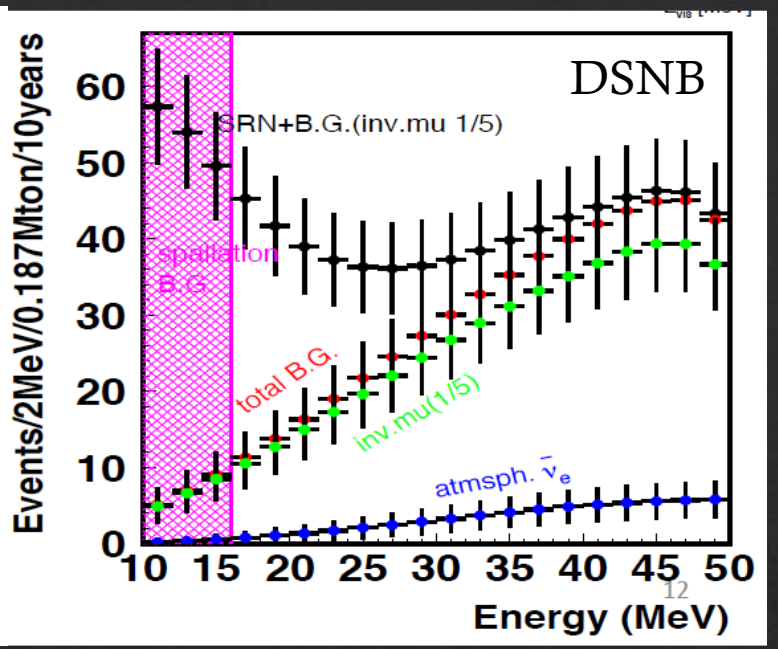


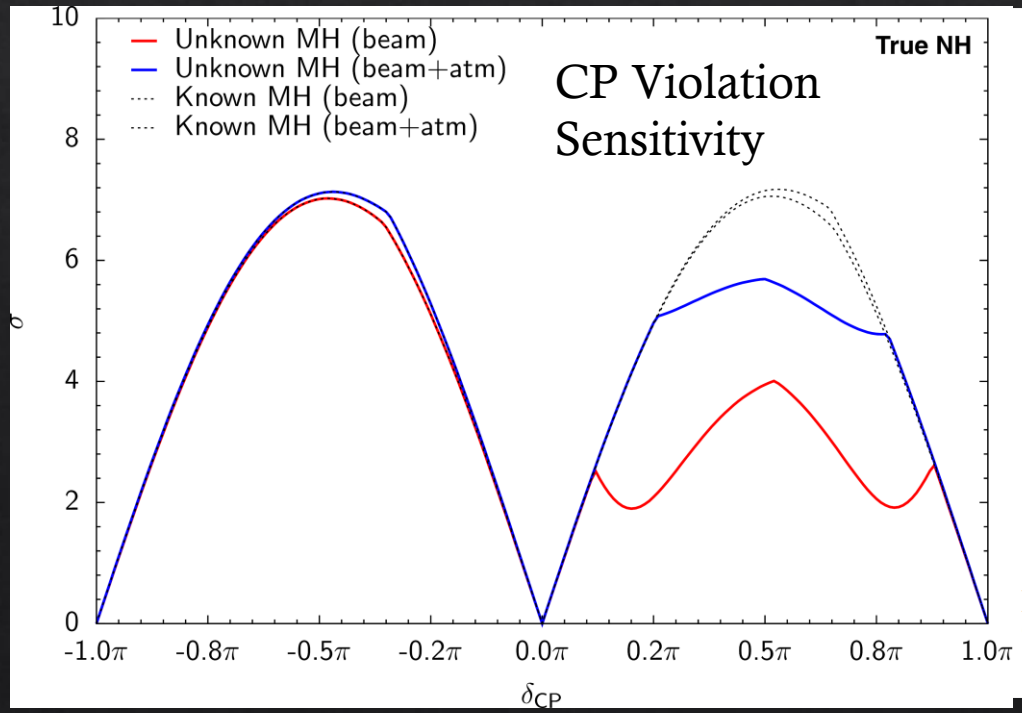
188 kton Fiducial Mass

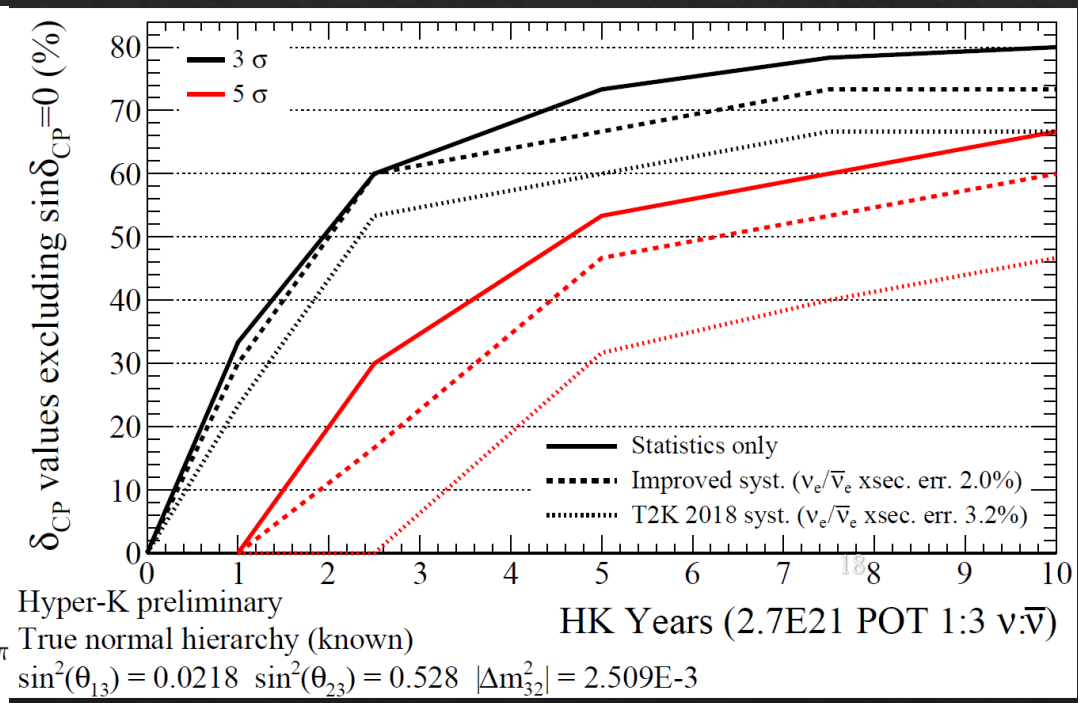
Physics

- High Statistics Measurements for Oscillation Signatures
  - Systematics Limited
- Nucleon Decay to unprecedented sensitivity
  - Multiple channels
- Supernovae
- Solar
  - Upturn
  - Day-night
- Follow Up Observations



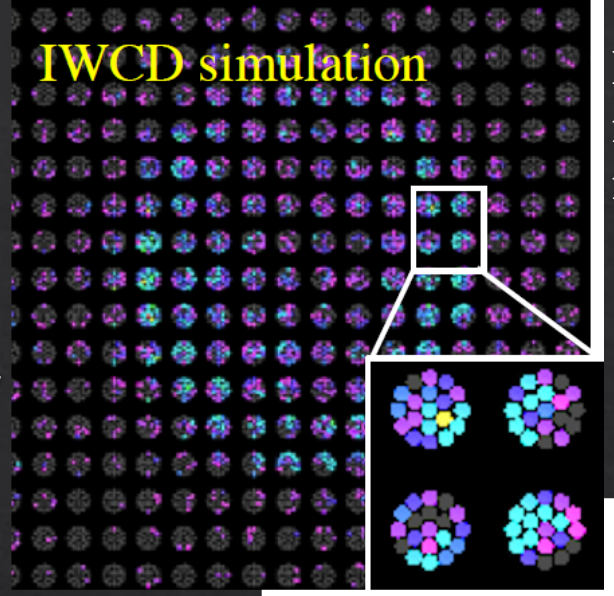


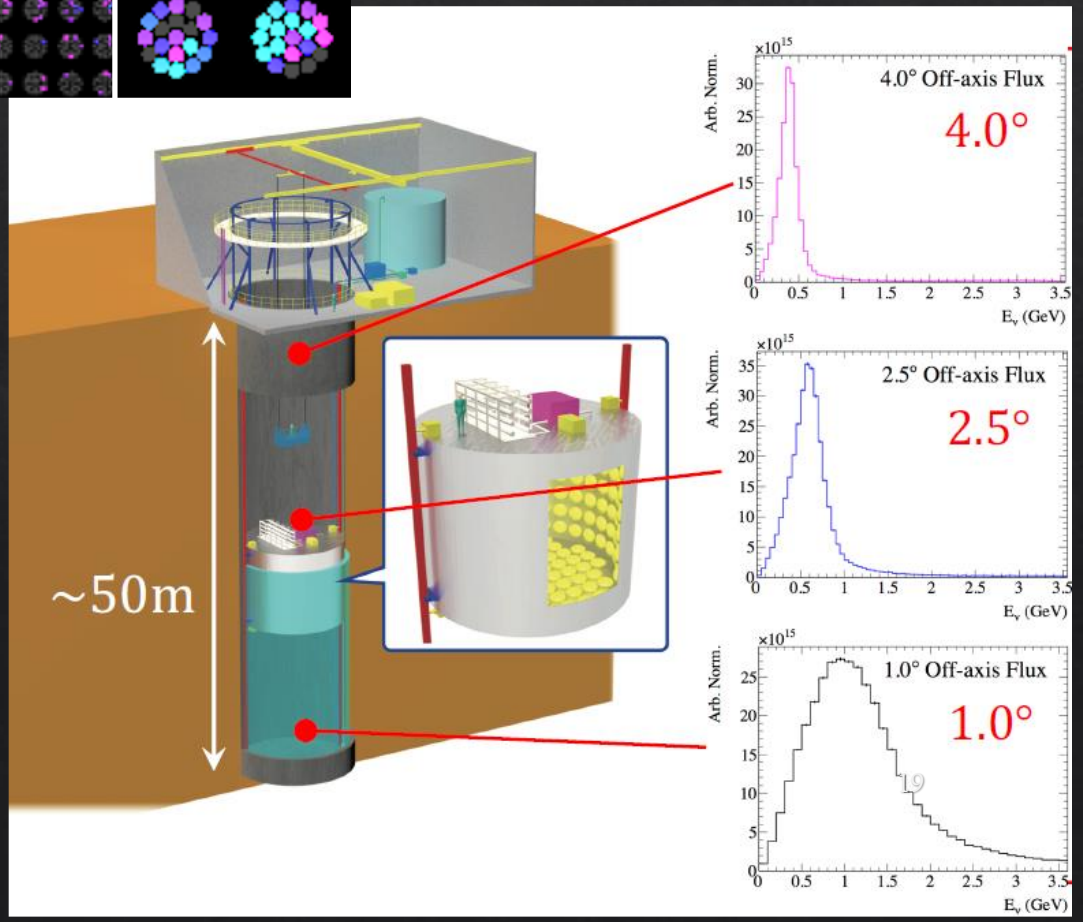




Near Detectors

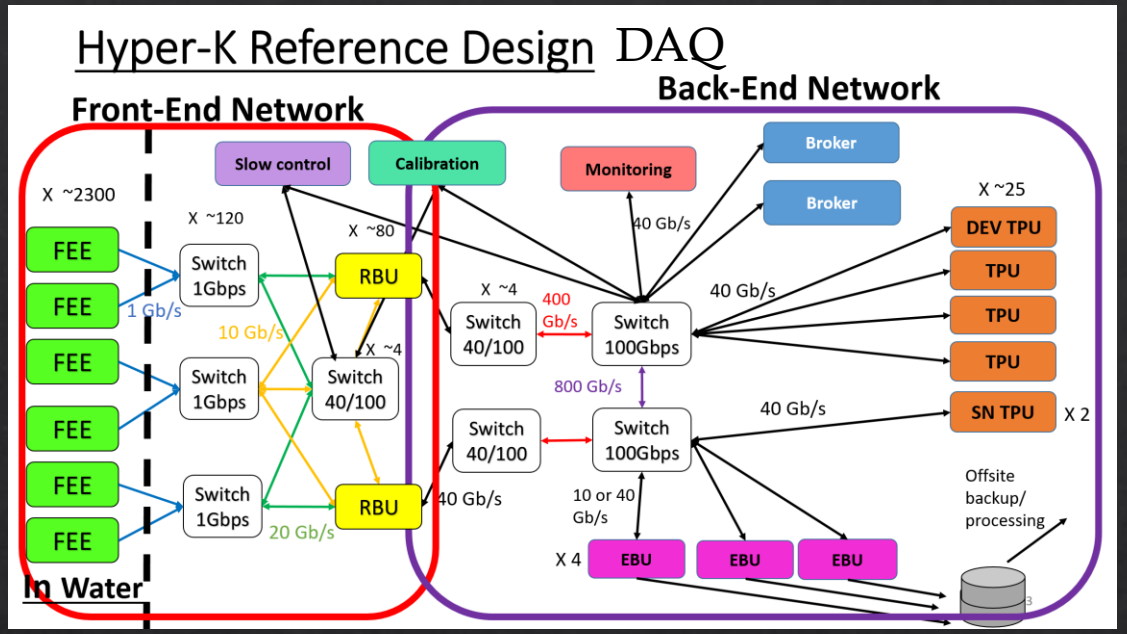
- Continued support of ND280 DAQ + ECAL
- IWCD
  - Intermediate water Cherenkov detector
    - 1 kton
    - ~1 km baseline
  - Move through different off axis angles to change neutrino spectrum
  - Allow improved measurements of cross sections and lepton kinematics as a function of neutrino energy
  - Significantly improve measurement of ν_e cross section
    - ~3-5% Uncertainty
  - Use mPMTs

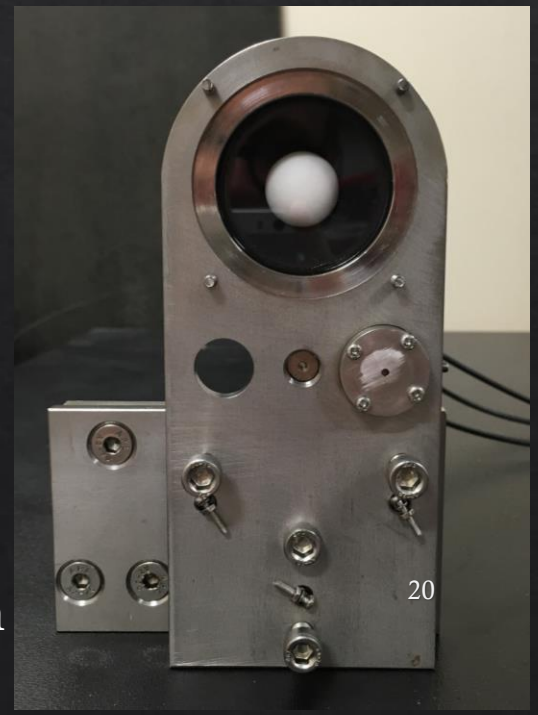




DAQ + Calibration

- The UK will provide the DAQ and light injection systems building from previous work in T2K and SK
- Delivery of full DAQ system including trigger, electronics interface and slow control
  - Robust to nearby supernova ensuring all data collected
- Calibration light injection system with diffusers and collimators to measure and monitor
  - Water Quality
  - PMT Properties
  - Required to reduce detector systematics to meet Hyper-K goals
- Both systems also provided for IWCD



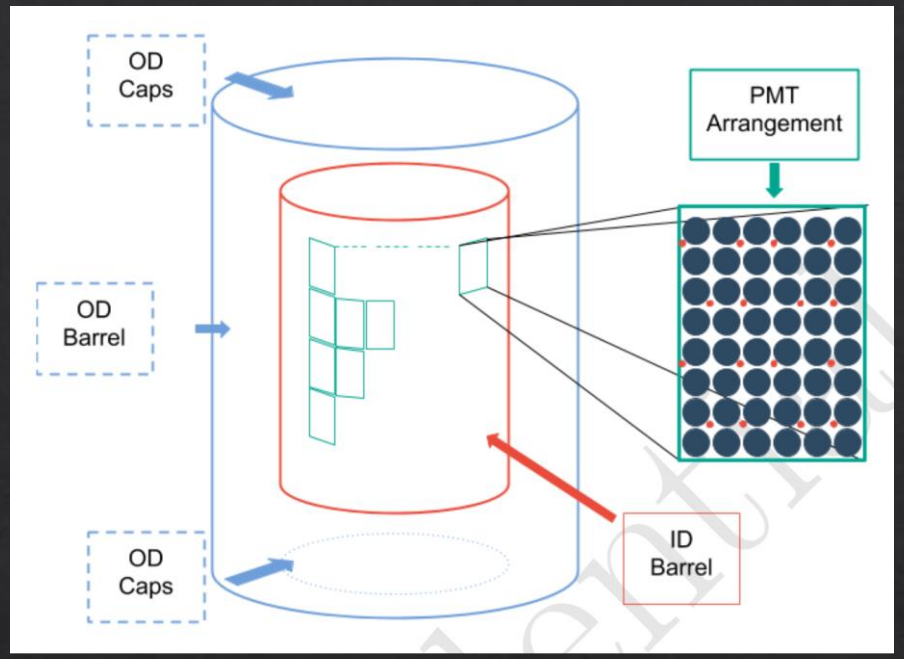


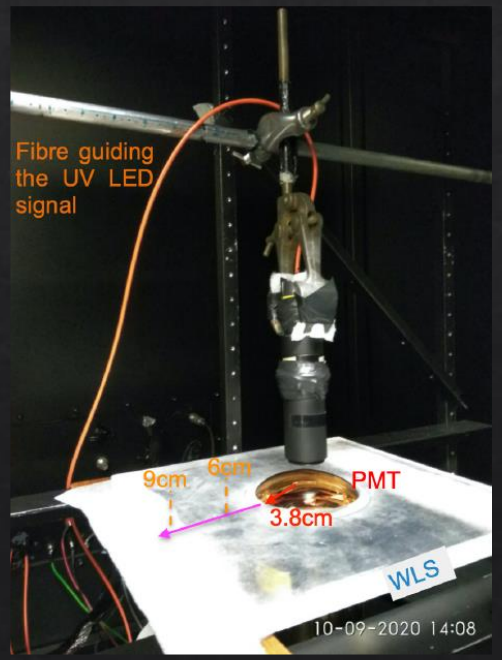
Light Injection Optical Plate

Outer Detector

- We aim to supply the Outer Detector for Hyper-K
- 10k 8 cm PMTs with wavelength shifting plates
  - 0.2% coverage
  - Currently evaluating performance to select PMT and WLSPlate
- Readout electronics
  - See next slide
- Light injection calibration system
  - 122 Diffusers
  - 12 Collimators
  - Measure OD optical response

Multilayer Tyvek



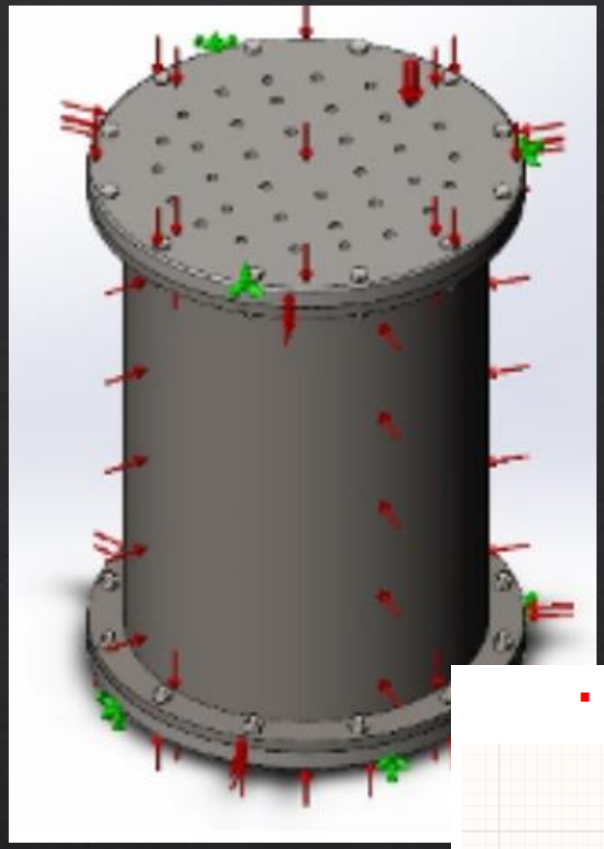


WLS Plate Measurements

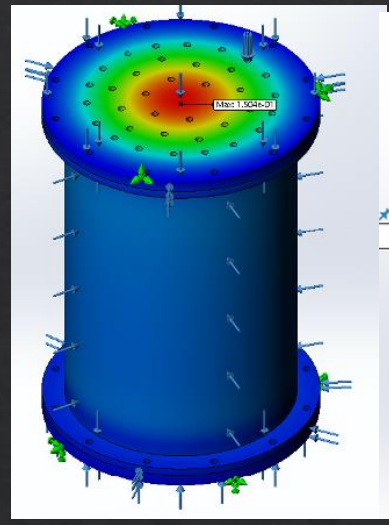
PMT Options

OD electronics

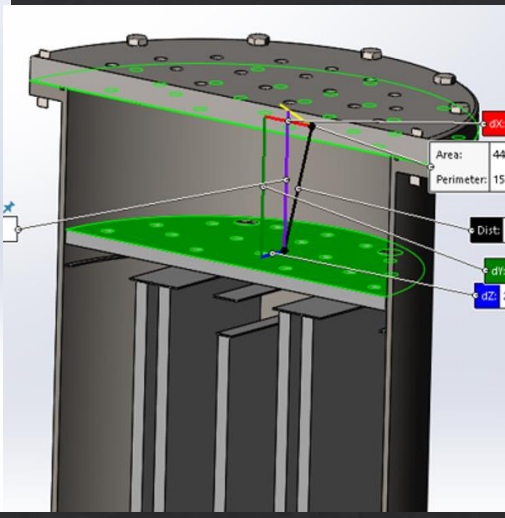
- Will also produce OD underwater electronics and water tight vessels
- Electronics:
  - HV Supply
  - Readout
    - Increase number of channels for each FEB in OD to simplify overall design
- Water Tight Case
  - Must withstand 1MPa water pressure
  - Cable Feedthroughs in lid of case.



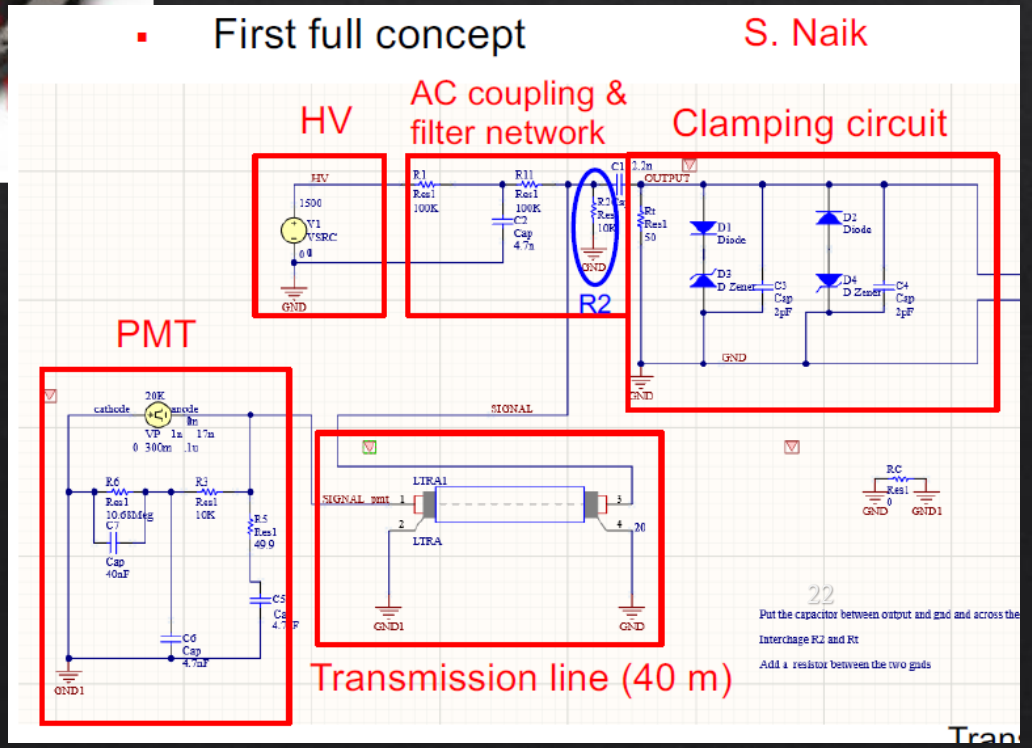
Water Tight Vessel



Pressure Simulations



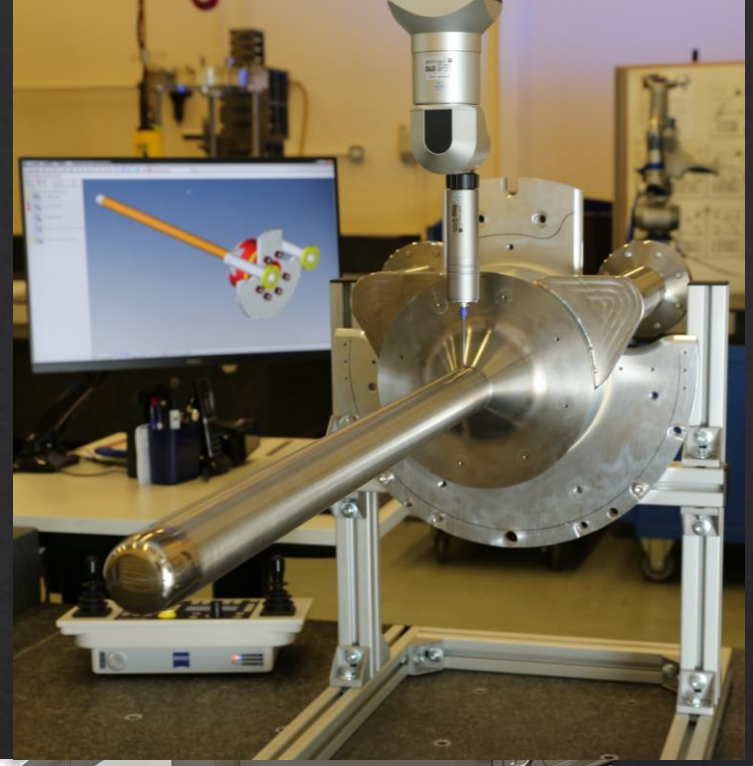
Internal Layout



Electronics Concept

Neutrino Beam

- Continue to support neutrino beam through T2K into Hyper-K era
- Upgrade target and beam window for 1.3 MW operation
  - Optimise target for physics design
- Tune up and abort dump also require upgrade for 1.3 MW
- Aim to improve beamline model



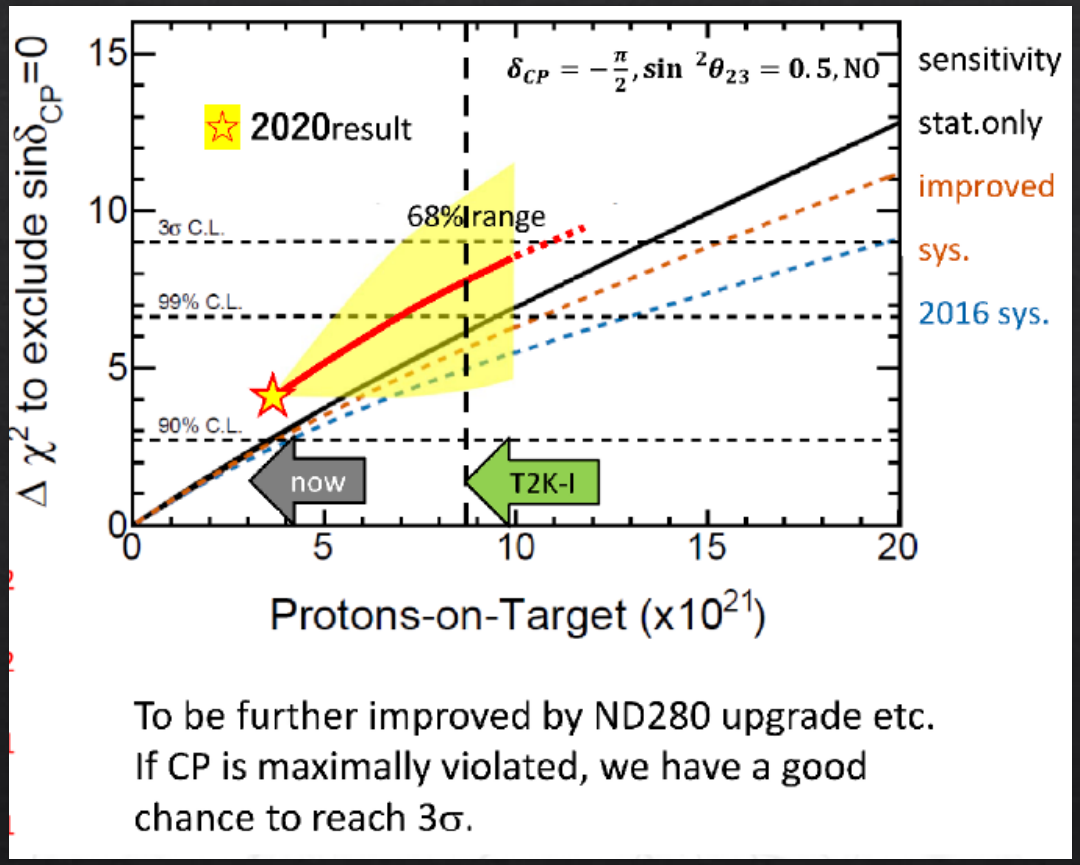
Conclusion

- Hyper-K is funded in Japan and will start in 2027
- The UK is making important contributions and is providing leadership within the collaboration

- Both T2K and SK are upgrading in the near future/now
  - ND280 Upgrade
  - JPARC Beam Upgrade
  - SK-GD
- Expect exciting results from these upgrades in the run up to Hyper-K

Backup

Expected T2K Sensitivity



To be further improved by ND280 upgrade etc.
If CP is maximally violated, we have a good chance to reach 3σ.

WAGASCI/BabyMIND

- While ND280 Upgrade is ongoing we have already added to the near detector systems
- Baby MIND magnetic spectrometer for WAGASCI
  - Glasgow joined T2K
- Measurement neutrino cross-sections in water and scintillator at 1.5° off-axis angle (800 MeV) to reduce oscillation systematic errors
- First full data-taking during Run 10 with neutrinos: Nov 2019 – Feb 2020