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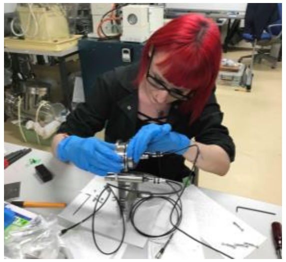
The Water Cherenkov Test Experiment @ CERN



NuFACT 2021

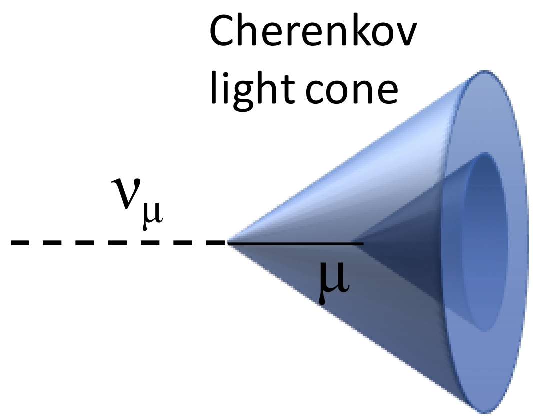
WG6 parallel 08/09/2021

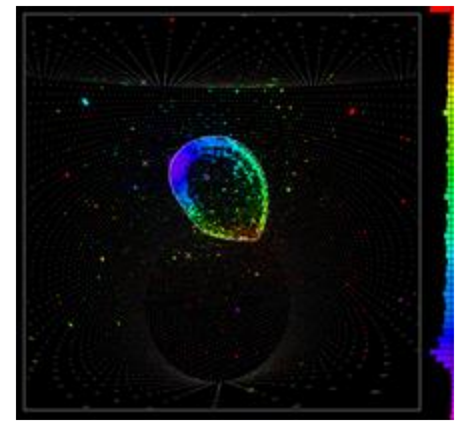
Lauren Anthony on behalf of the **WCTE** collaboration

l.anthony@imperial.ac.uk

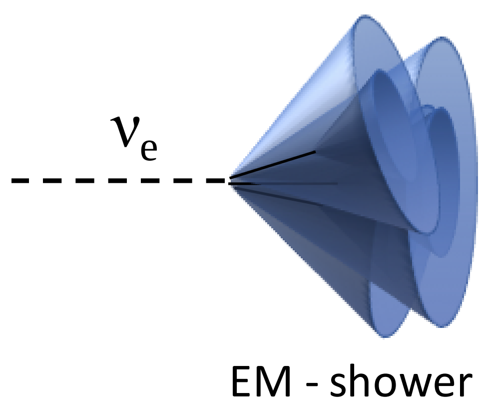
Water Cherenkov Detectors

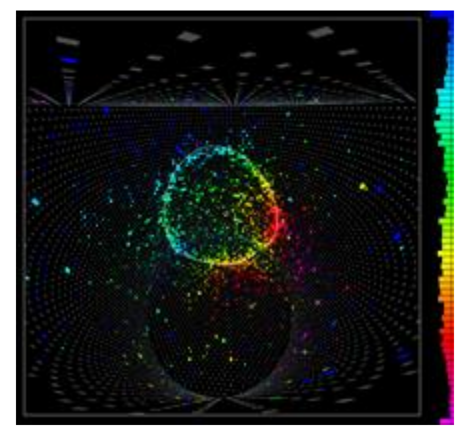
- Well understood technology
- Excellent performance
  - 99% μ/e separation
  - 2% momentum resolution
  - 1° direction resolution





- New technologies
  - Gadolinium (Super-Kamiokande)
  - Water-based liquid scintillator (THEIA)
  - Photo-detector modules (Hyper-Kamiokande/IWCD)





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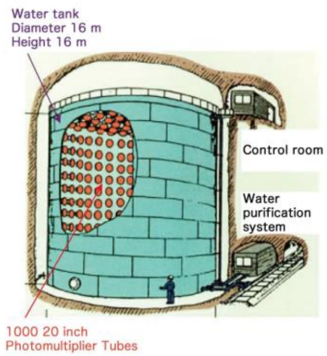
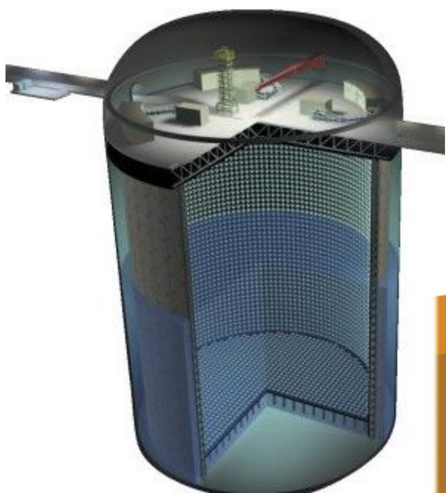
Water Cherenkov Detectors in Japan

- Several generations of detectors
  - Tested and well understood technologies

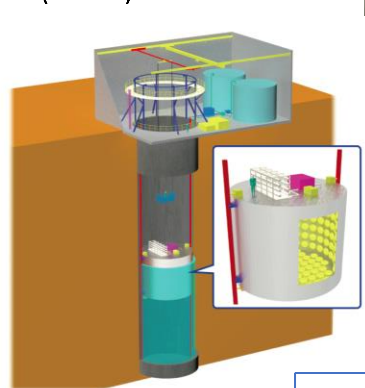
Kamiokande
0.7kt fiducial mass



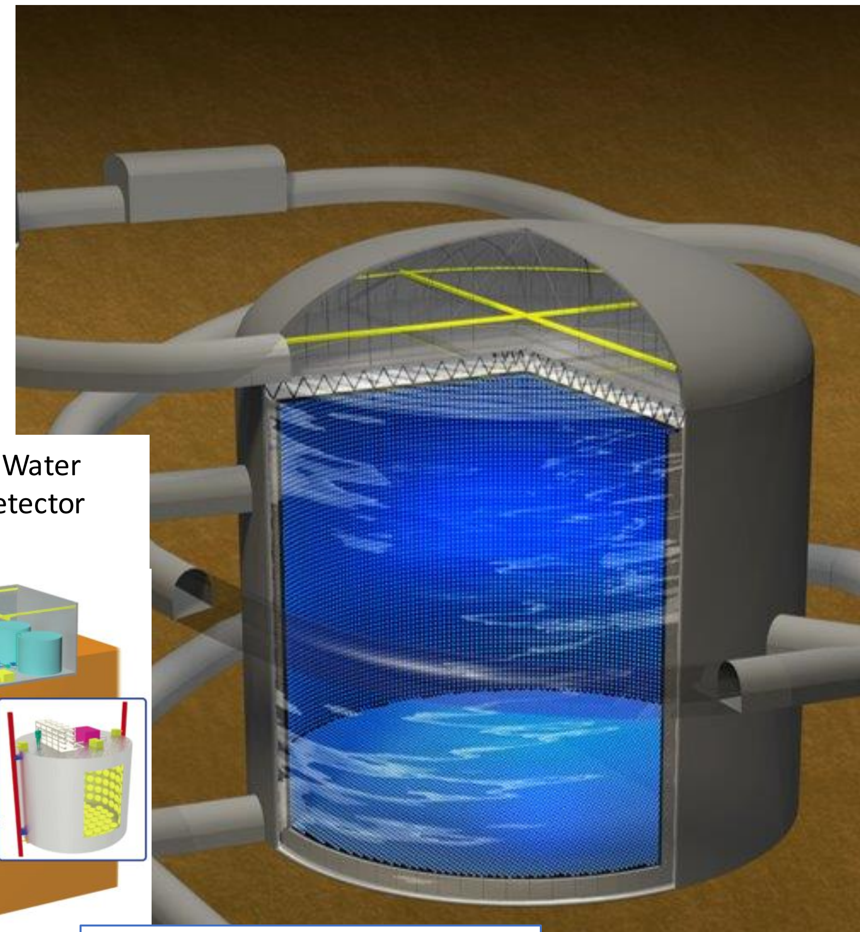
Super-Kamiokande
22.5kt fiducial mass



Intermediate Water Cherenkov Detector (IWCD)



Hyper-Kamiokande - 188kt fiducial mass



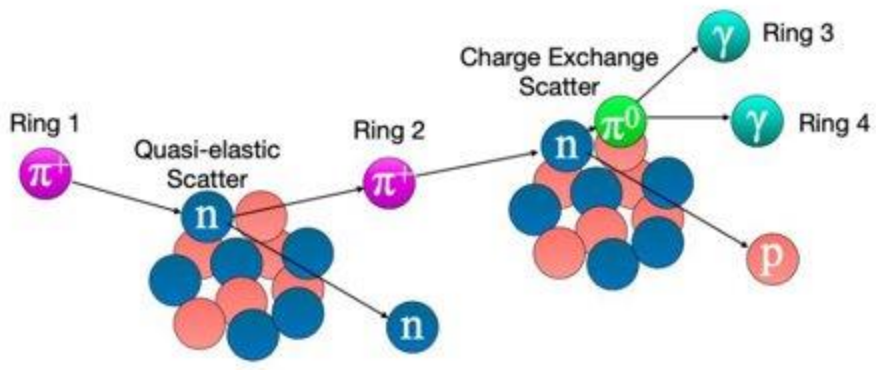
Super-Kamiokande talks/Posters @ NuFACT
M. Taani – 09/09 12:40 WG1
A. Goldsack – 09/09 13:00 WG6
L. Muchado - Poster

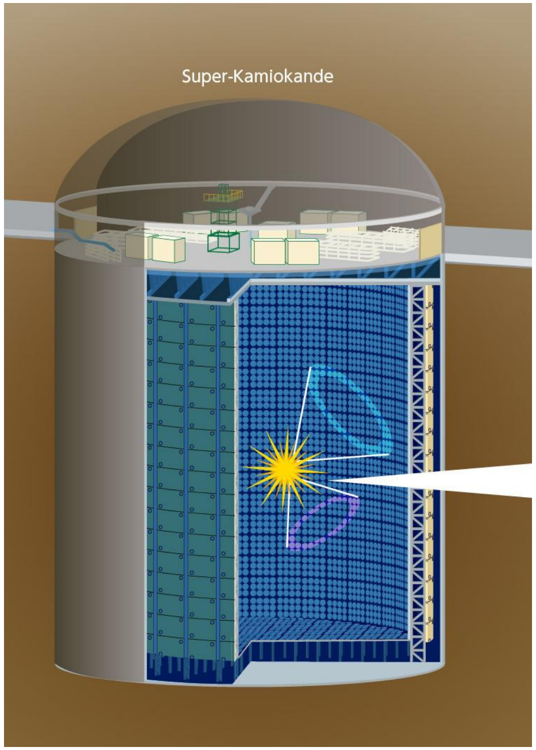
L. Anthony

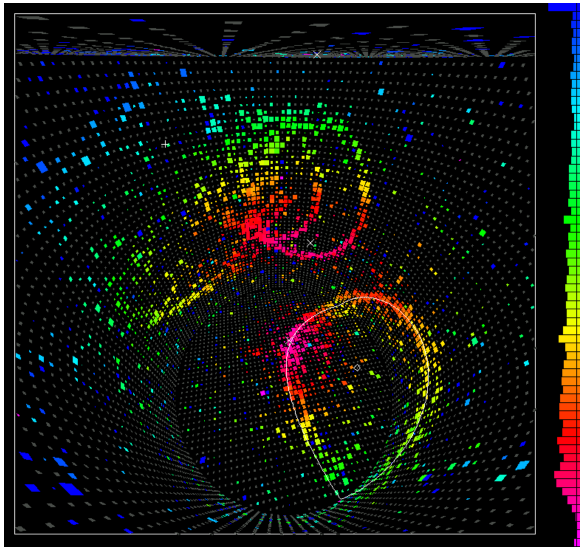
See talk by R.Akutsu 09/09 WG1, 16:45

Water Cherenkov Detector Limitations

- Super-K uncertainty includes detector effects and uncertainties in secondary interactions of pions and nucleons
  - Little data and very difficult to model

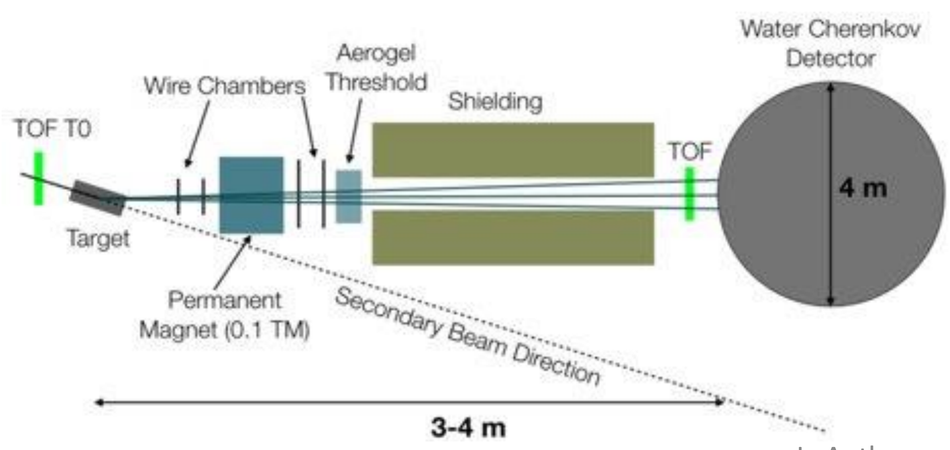


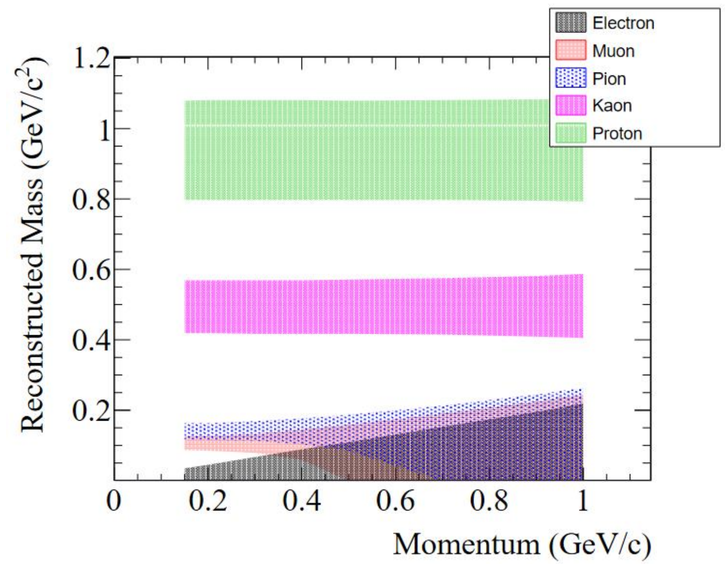




The Water Cherenkov Test Experiment (WCTE)

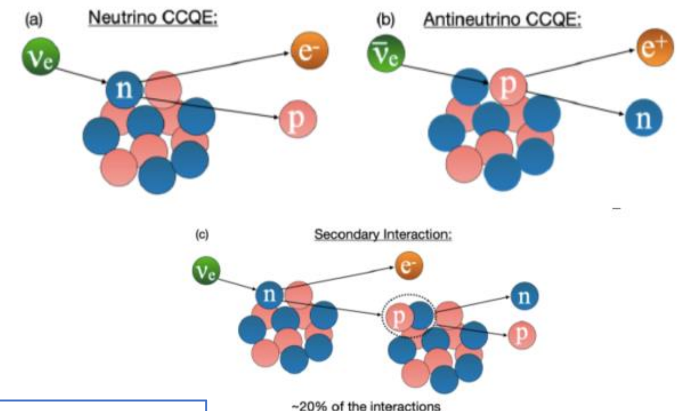
- Small scale Water Cherenkov detector to be commissioned at CERN in 2022/23
  - **Potential to become platform for neutrino measurements at CERN**
- Study detector systematics and response 200 MeV/c - 1000 MeV/c
- ~4m * 4m cylindrical detector
  - Proposal document can be found here: http://cds.cern.ch/record/2712416/files/?ln=en
- Gadolinium sulphate doped





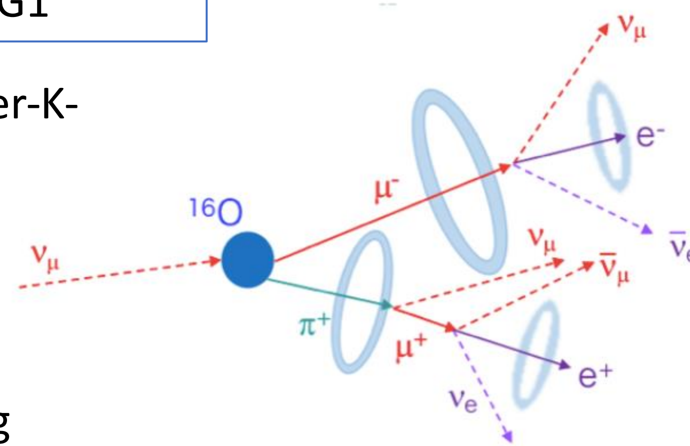
WCTE Physics Program

- **Studies of Cherenkov light production/processes**
  - EM models in GEANT4 differ
  - Difficult to study in large detectors
- **Energy scale calibration**
  - At Super-K the current systematic uncertainty on overall energy scale is 2%
    - Needs to reduce to 0.5% for Hyper-K



See talk by L. Muntenau
08/09 13:46 WG1

- **Secondary neutron production**
  - Used for neutrino/anti-neutrino tagging in Super-K-Gd and Hyper-K
- **Pion scattering**
  - Reconstruction of Pions in final state is challenging
    - Limited in modelling of hadronic scattering data on Oxygen



Experimental area @ CERN

- T9 beam line in the East Area - secondary particle beam with momenta ranging from ~400 MeV/c to ~1500 MeV/c

- 40m long secondary beamline
  - Lower energy Pions decay in flight
  - Need tertiary production target

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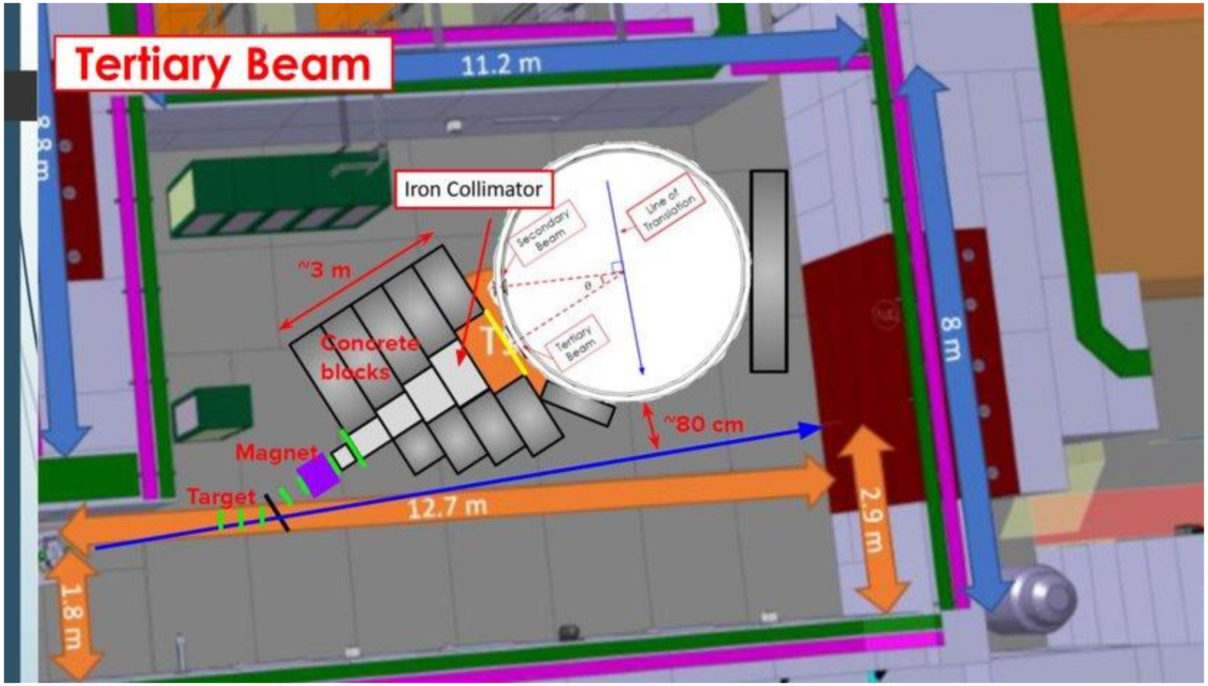
T9 Beamline @ CERN

Two beam configurations available in T9 area - Momentum range 300 – 1200 MeV

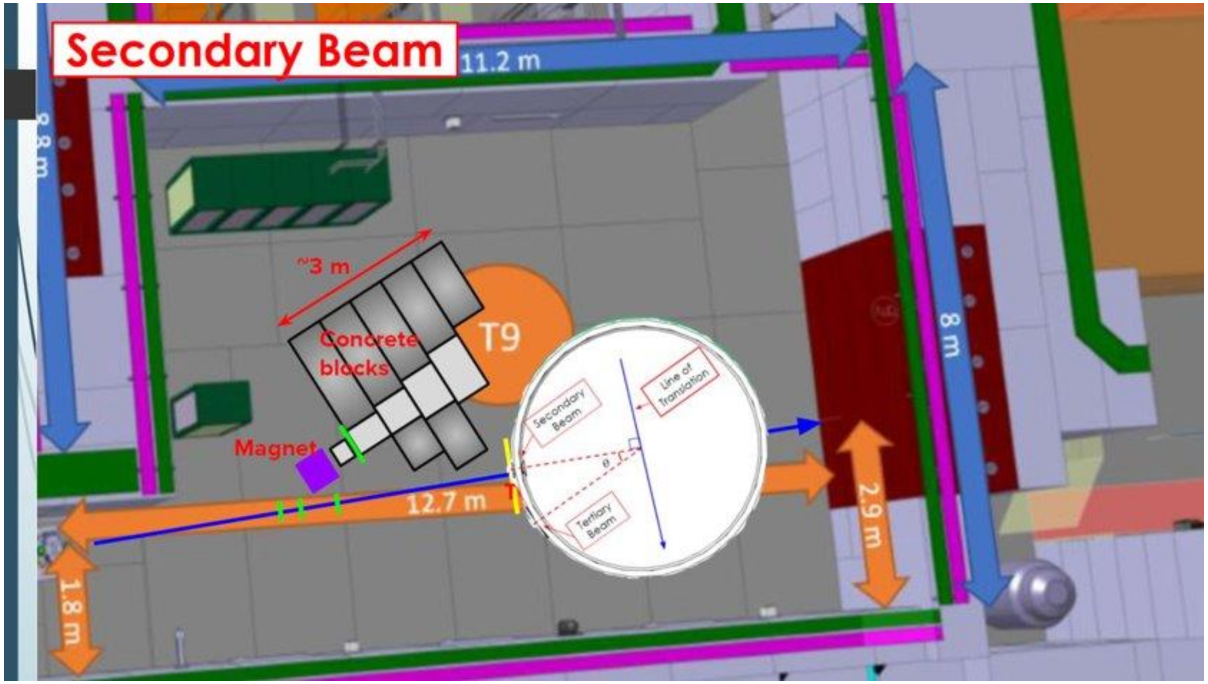
1. Tertiary beam position for low momentum pion and proton fluxes



T9 Beamline @ CERN

Two beam positions available in T9 area

1. Secondary beam position for electron, muon and proton fluxes



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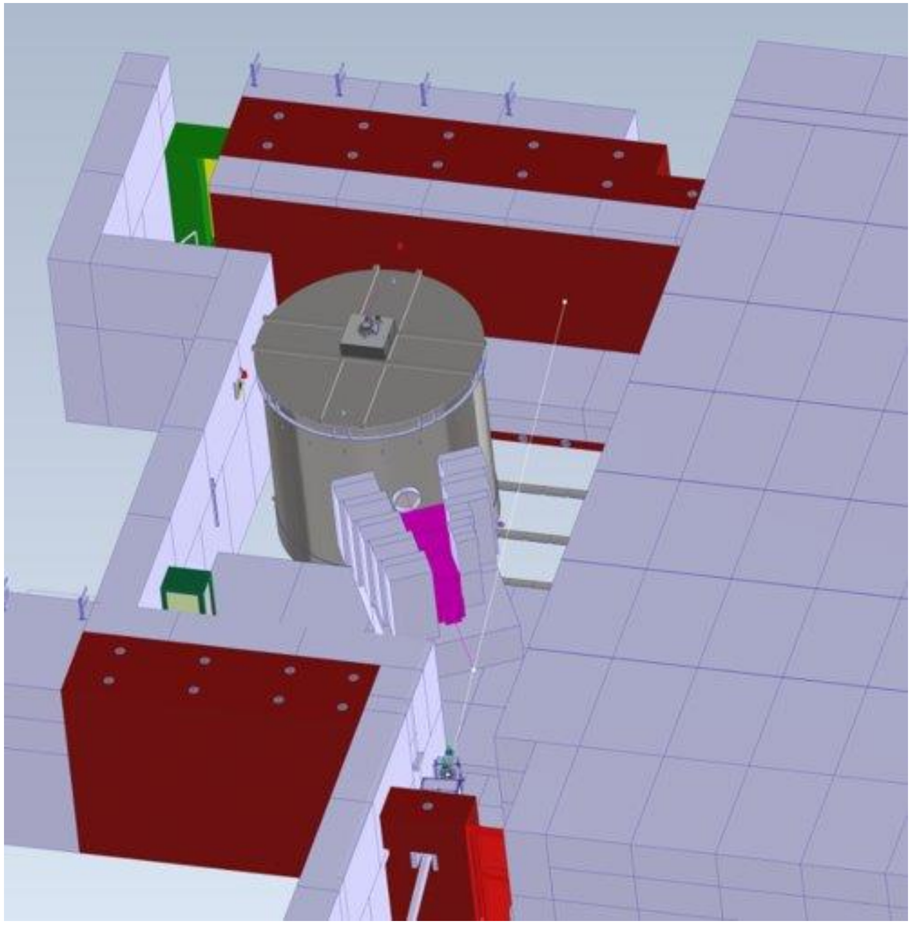
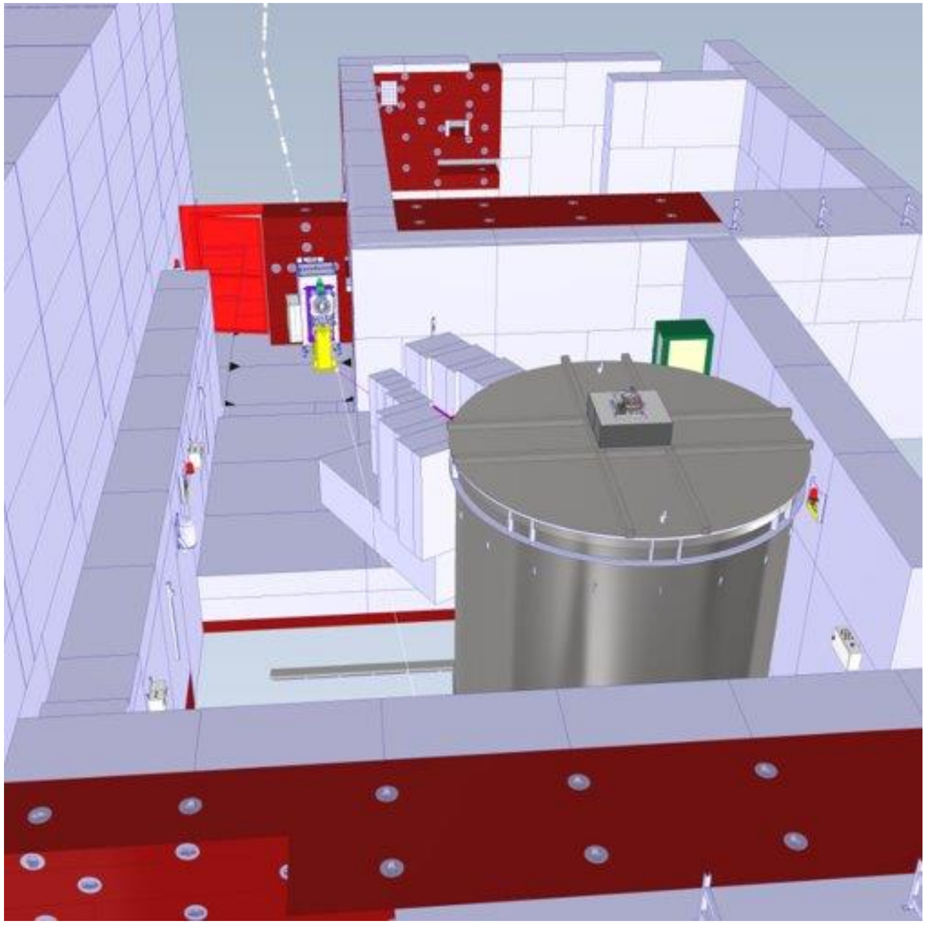
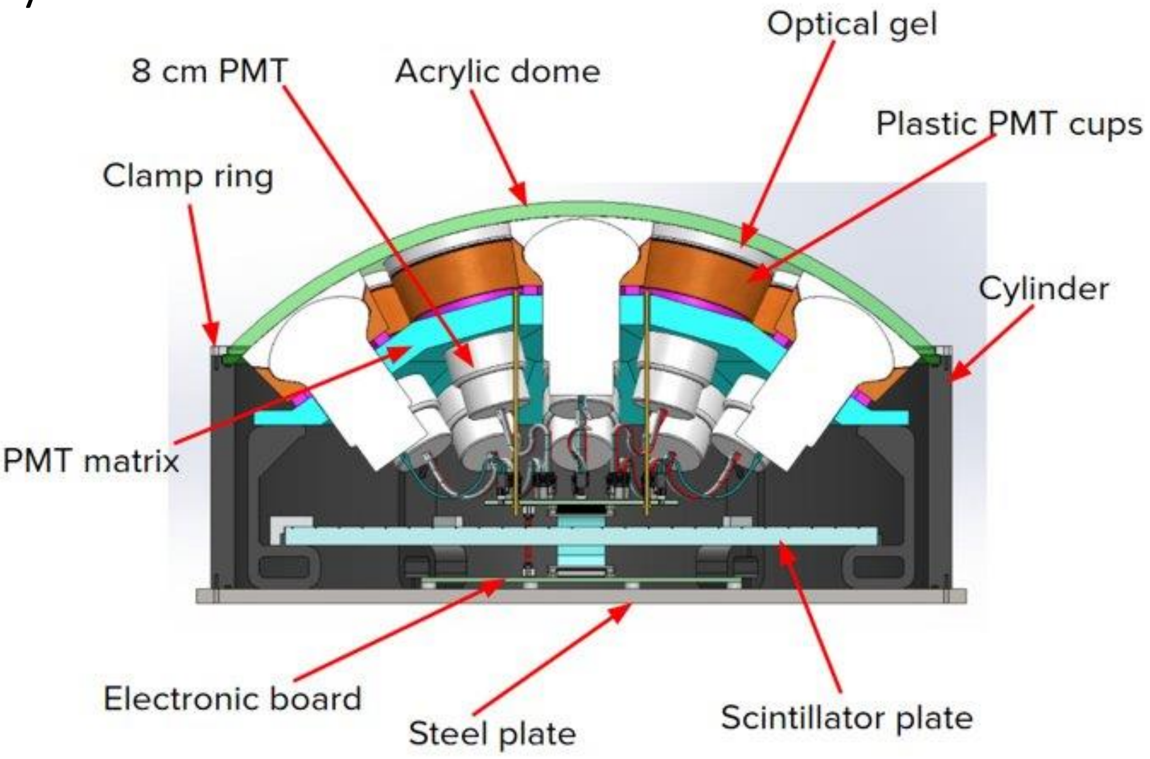
WCTE @ CERN T9 Beamline





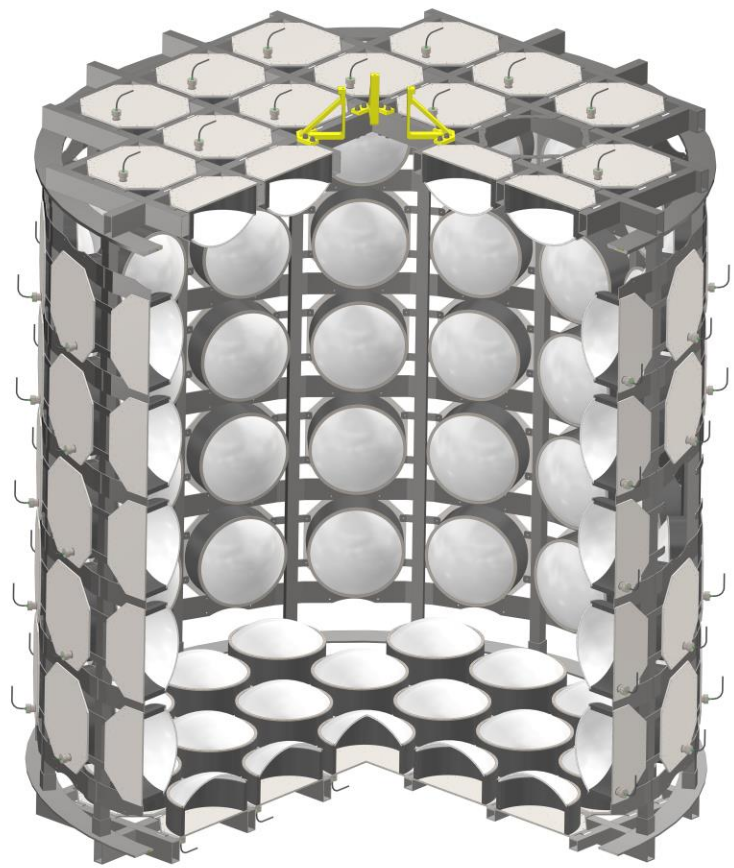
WCTE Detector Instrumentation

- Nineteen 8cm diameter PMTs (Hamamatsu R14374) - multi-PMT modules (mPMT)
- Improved granularity and timing compared to larger PMTs
- Integrated LED calibration system within mPMT module



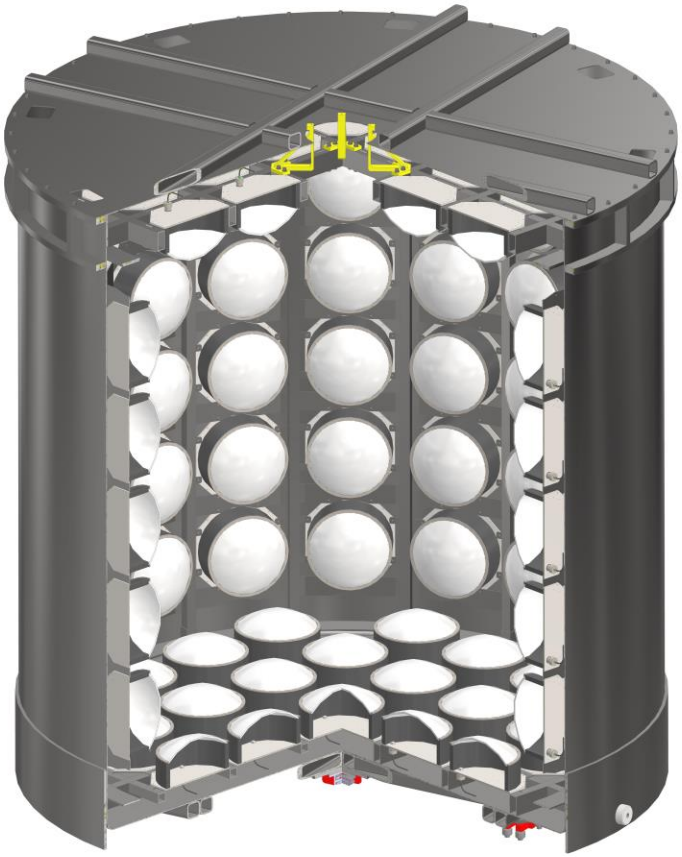
WCTE Detector Design

- Internal cylindrical support structure fabricated from stainless steel
- Houses ~130 multi-PMT modules



WCTE Detector Design

- Internal cylindrical support structure fabricated from stainless steel
- Houses ~130 multi-PMT modules
- Housed inside a cylindrical water tank
- Base of tank has rails for attachment to moving system
- Brackets mounted on lid for calibration system support



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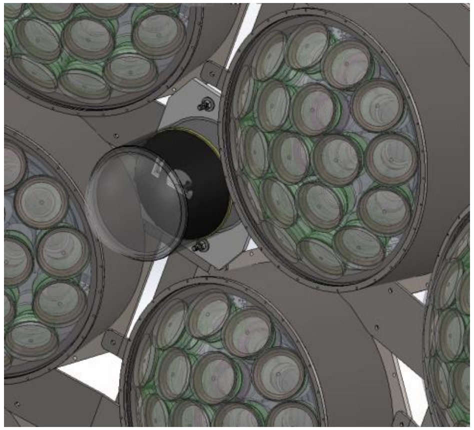
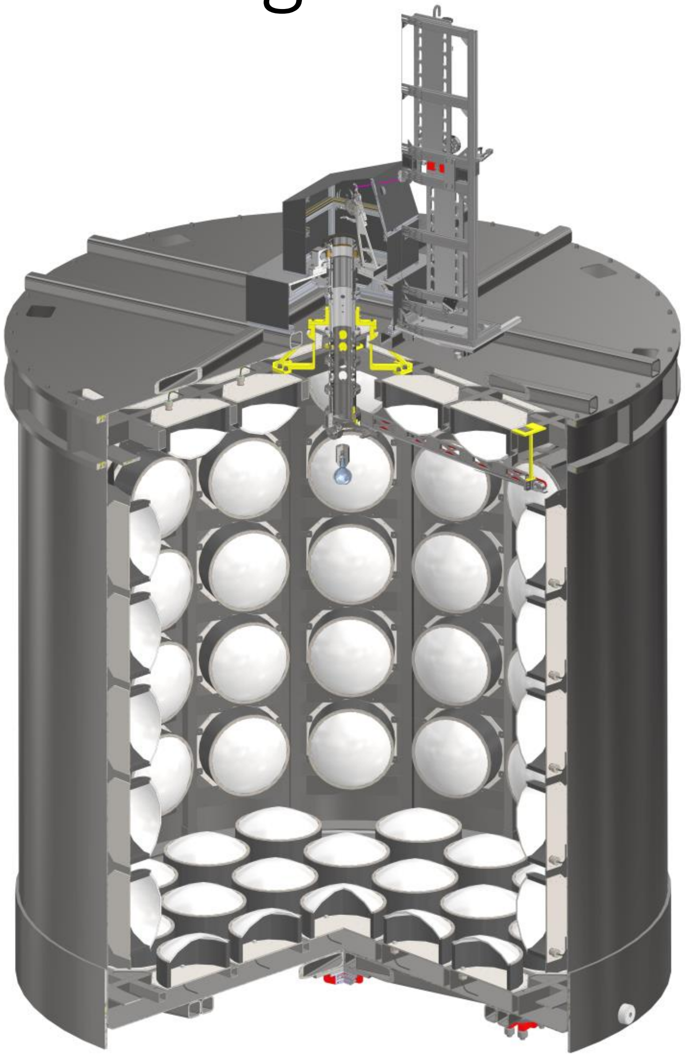
WCTE Detector Design

- Calibration systems mounted on support structure and lid
- Permenently deployed inside detector

Calibration deployment system

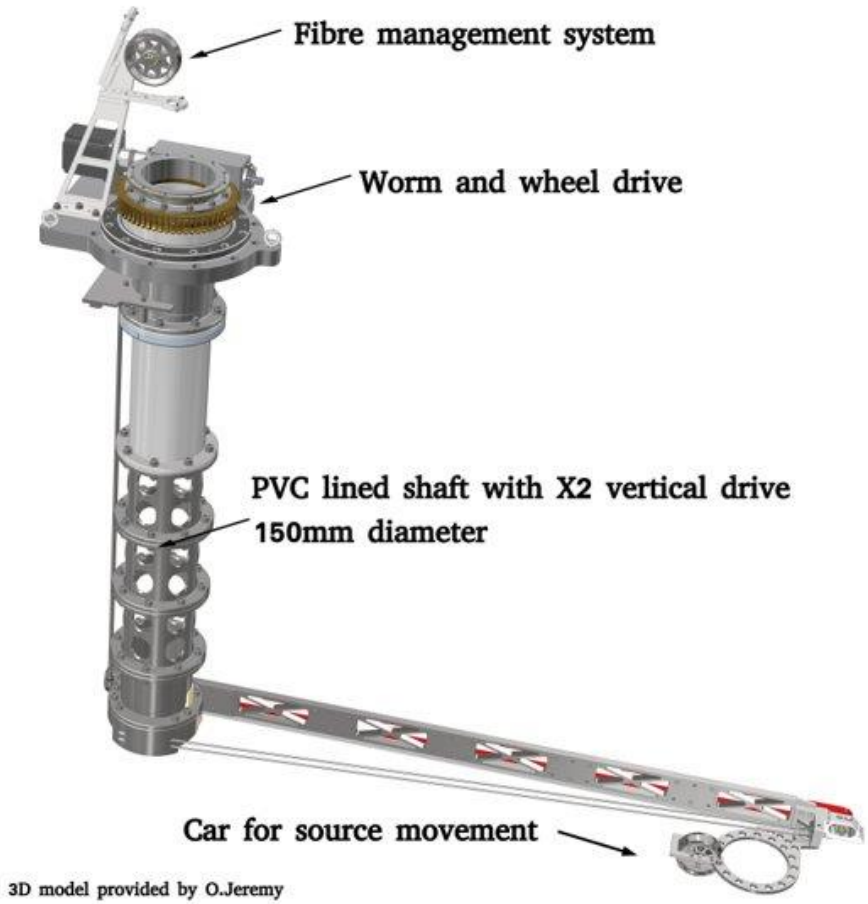


Mounted cameras

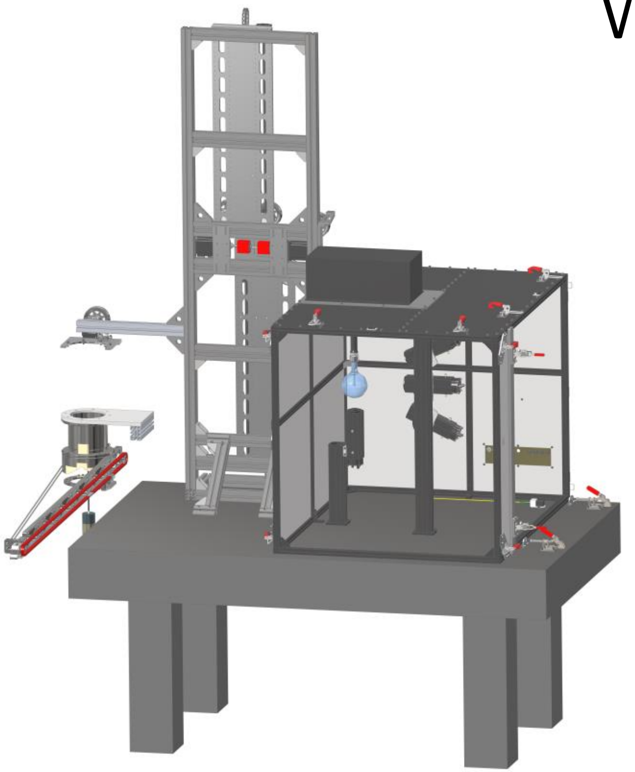


WCTE Calibration

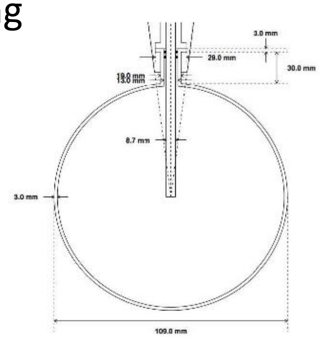
- Developing multi-axis system to deploy various calibration sources into the detector
- Movement in 3 axes
- Deploy sources at user defined calibration points
- Sources
  - Isotropic light source
  - Camera for photogrammetry
  - Radioactive source
- Other fixed source include mounted cameras and LED system (see slide 11)



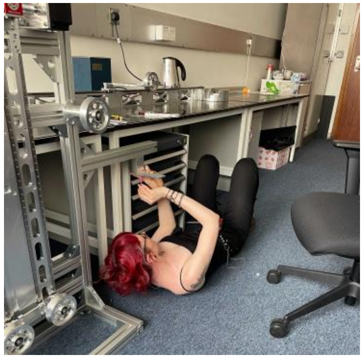
WCTE Calibration



- Imperial group is designing/fabricating a laser diffuser ball and associated deployment system for HK/IWCD/WCTE to measure:
  - Geometry
  - Water
  - Reflections
  - PMT response
  - Timing

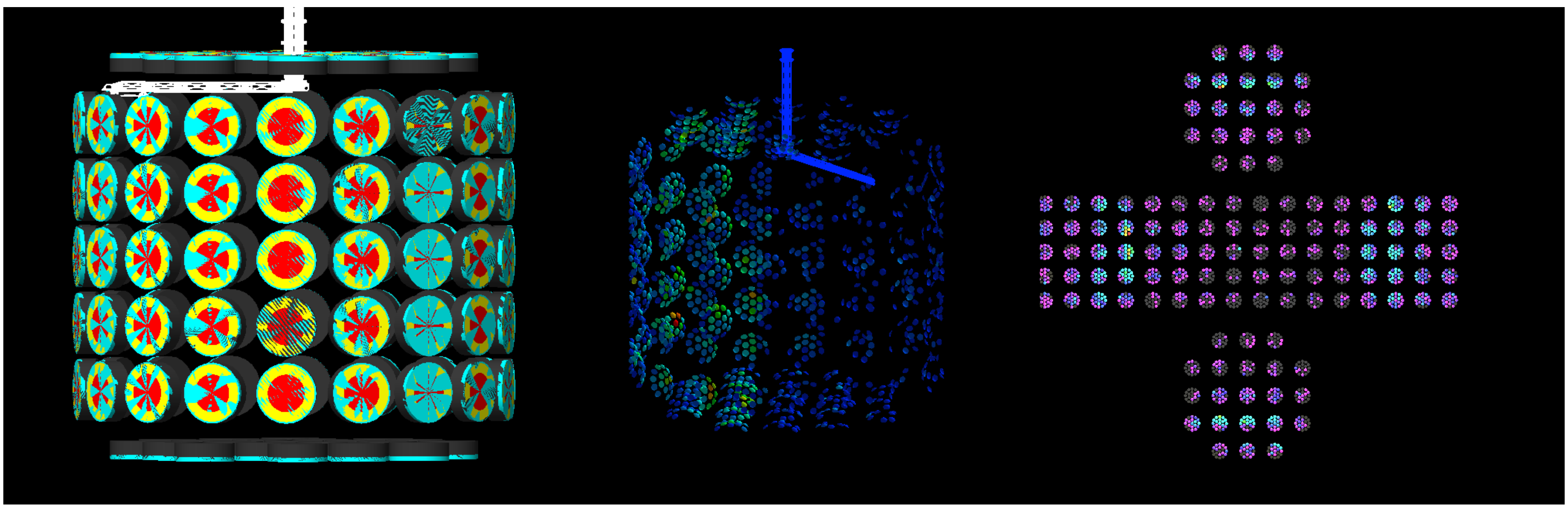


- Build on SNO/SNO+/DEAP3600 design
  - Quartz flask
  - Suspended glass spheres
  - Optical gel



WCTE Simulation

- Using Water Cherenkov Simulation (WCSim) software to produce detector simulations
  - Open source GEANT4 based software developed for simulating large water Cherenkov detectors: https://github.com/WCSim/WCSim
  - Included mPMT modules and calibration system
    - Calibration system included by importing CAD model into GEANT4 using open source CADMesh software: https://github.com/christopherpoole/CADMesh



Summary

- WCTE able to perform several key studies
  - Test new technologies
  - Measure secondary particle interactions
  - Demonstrate 1% level detector calibration
- Crucial measurements for future water Cherenkov detectors
  - Hyper-K, THEIA, ESSvSB

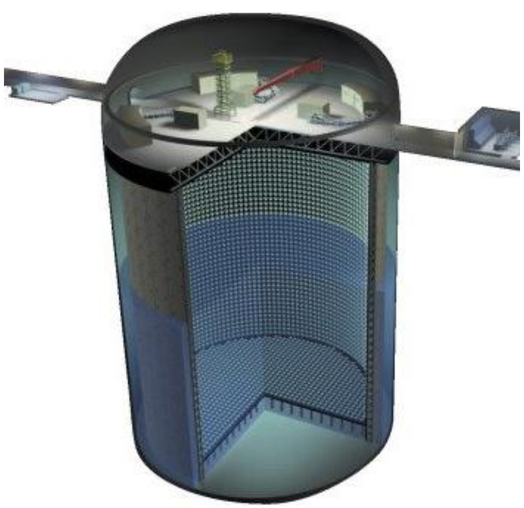
See ESSvSB workshop
07/09, 09:00

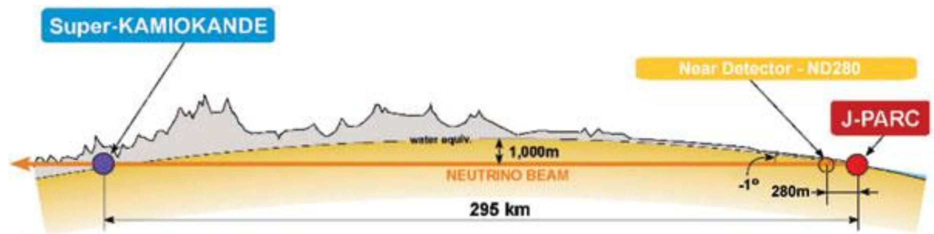
- Ongoing studies of detector response and event reconstruction
- Recommended by SPSC for beam time in 2023 – new collaborators welcome!
  - Spokesperson: M.Hartz, mhartz@triumf.ca

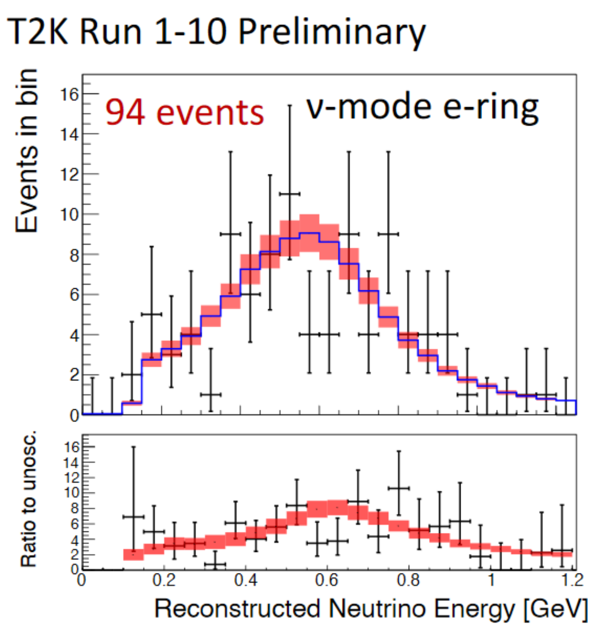
Backup

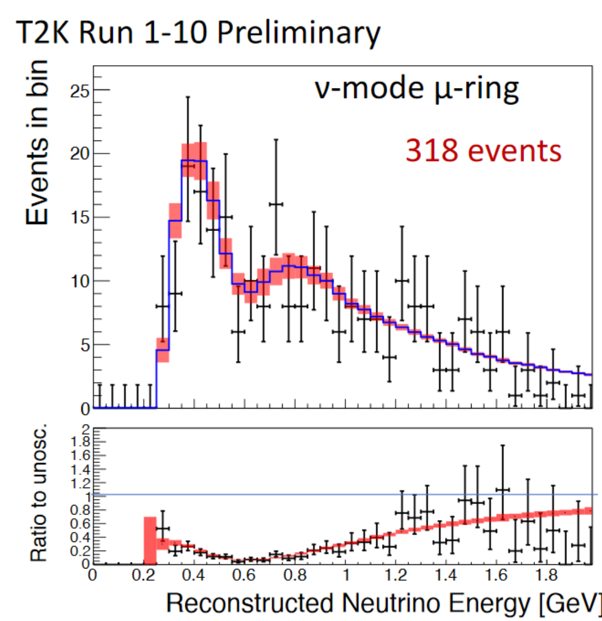
Neutrino Oscillation at T2K

- Super-Kamiokande has been in operation for ~25 years
- T2K has been taking data for ~10 years
- Made some of the most precise measurements of neutrino oscillations





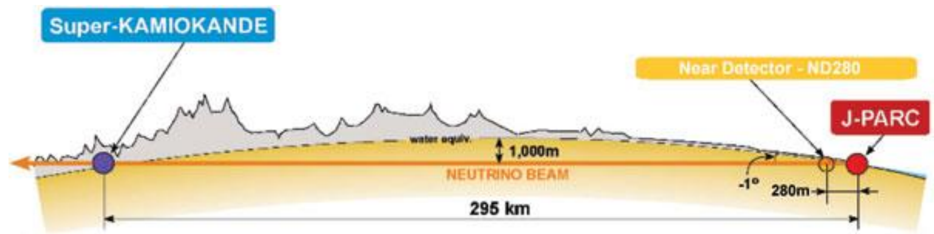




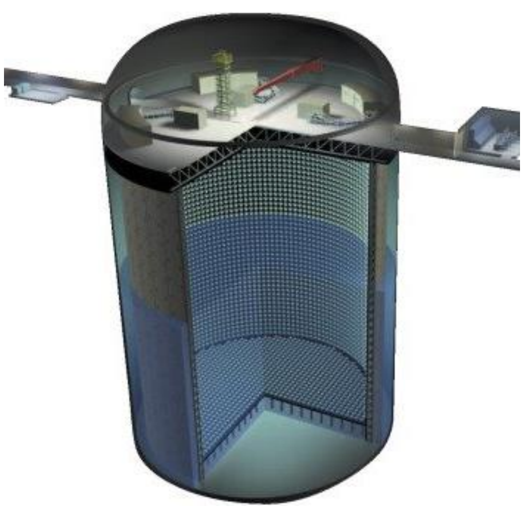
P. Dunne, Neutrino 2020, https://zenodo.org/record/4154355

Systematic Uncertainty at T2K

- T2K currently limited by statistical uncertainty
- Future experiments will be systematics limited
- Largest uncertainty on electron like samples is SK detector uncertainty



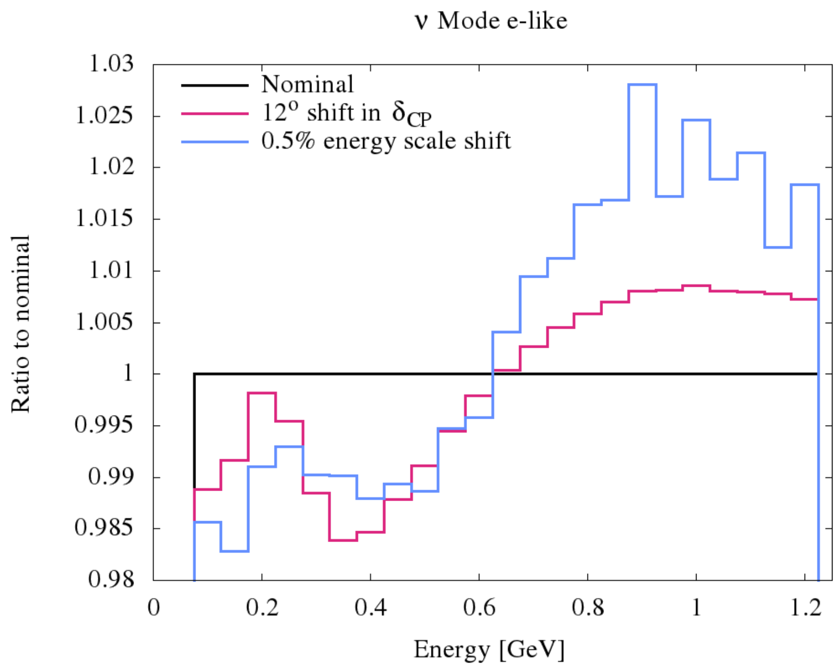
Error source	1Rμ FHC	1Rμ RHC	1Re FHC	1Re RHC	1Re FHC CC1π^+	1Re FHC/RHC
Flux	2.9	2.8	2.8	2.9	2.8	1.4
Xsec (ND constr)	3.1	3.0	3.2	3.1	4.2	1.5
Flux+Xsec (ND constr)	2.1	2.3	2.0	2.3	4.1	1.7
2p2h Edep	0.4	0.4	0.2	0.2	0.0	0.2
BG_A^{RES} low-p_π	0.4	2.5	0.1	2.2	0.1	2.1
$\sigma(\nu_e)$, $\sigma(\bar{\nu}_e)$	0.0	0.0	2.6	1.5	2.7	3.0
NC γ	0.0	0.0	1.4	2.4	0.0	1.0
NC Other	0.2	0.2	0.2	0.4	0.8	0.2
SK	2.1	1.9	3.1	3.9	13.4	1.2
Total	3.0	4.0	4.7	5.9	14.3	4.3

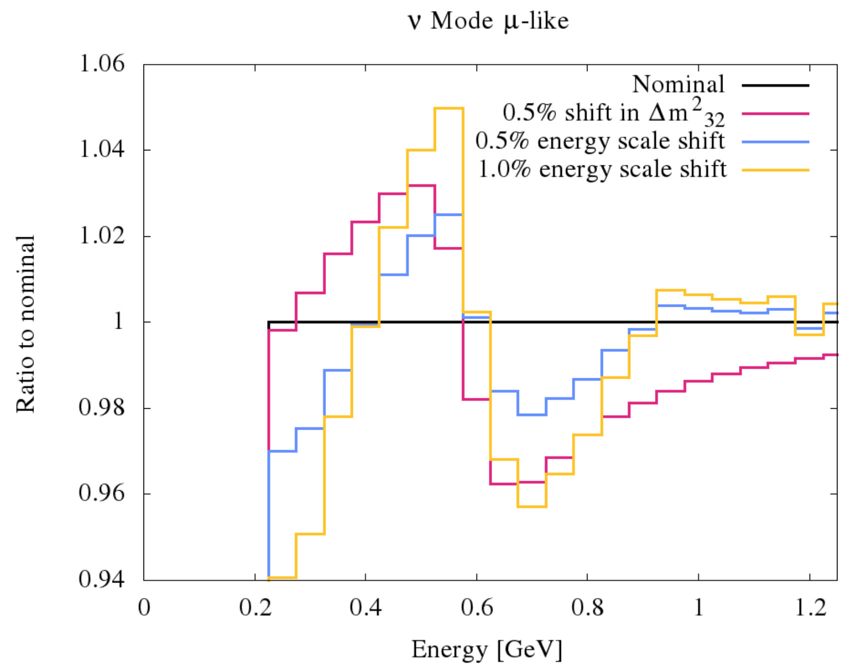


P. Dunne, Neutrino 2020, https://zenodo.org/record/4154355

Energy Scale

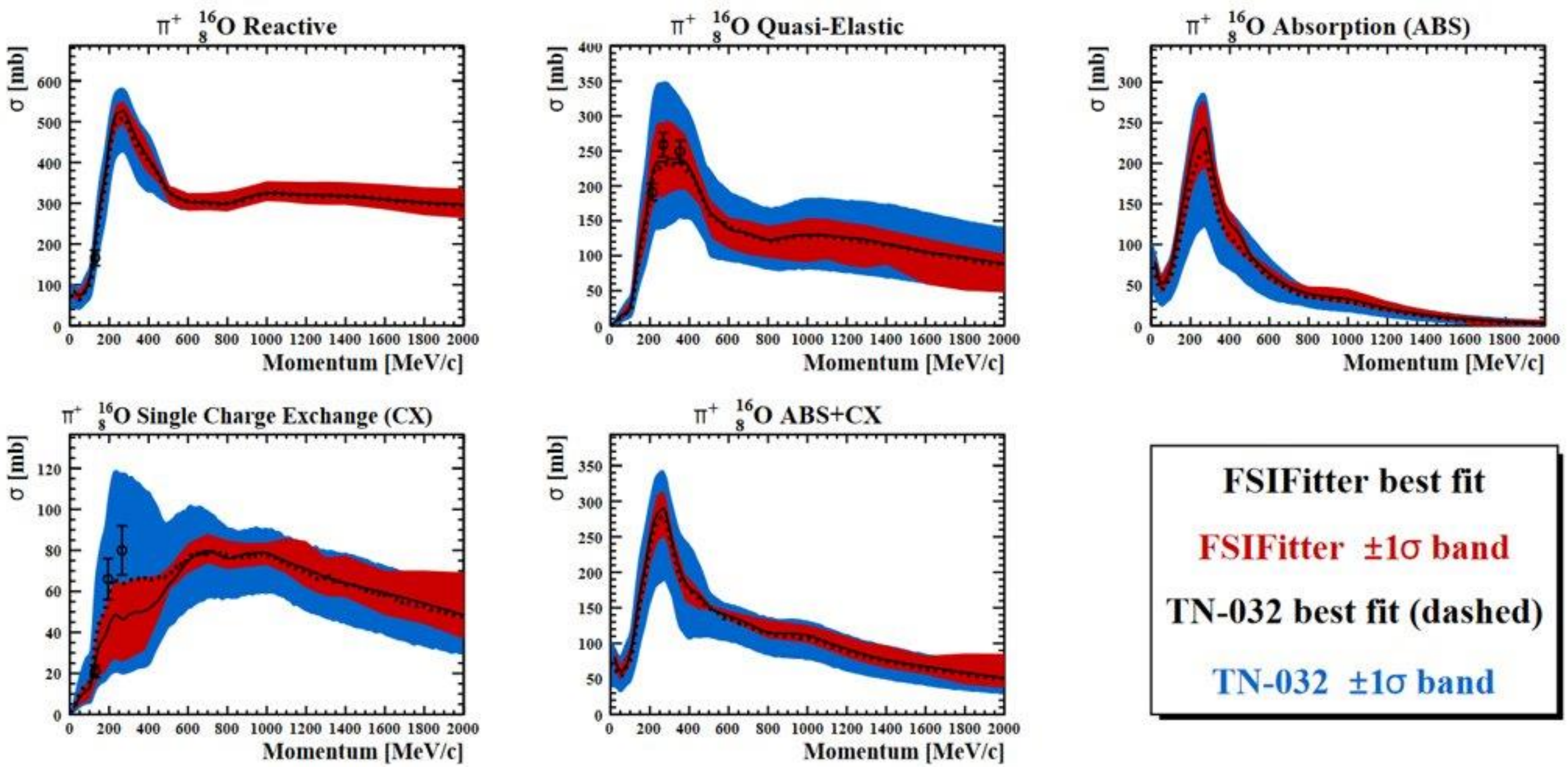
- Detector energy scale uncertainty impacts oscillation analysis
  - Systematic errors present degeneracies in oscillation parameters
- Degenerate with δCP in e-like samples and with Δm2_32 in μ-like samples
- Develop calibration program to reduce uncertainty on energy scale as much as possible





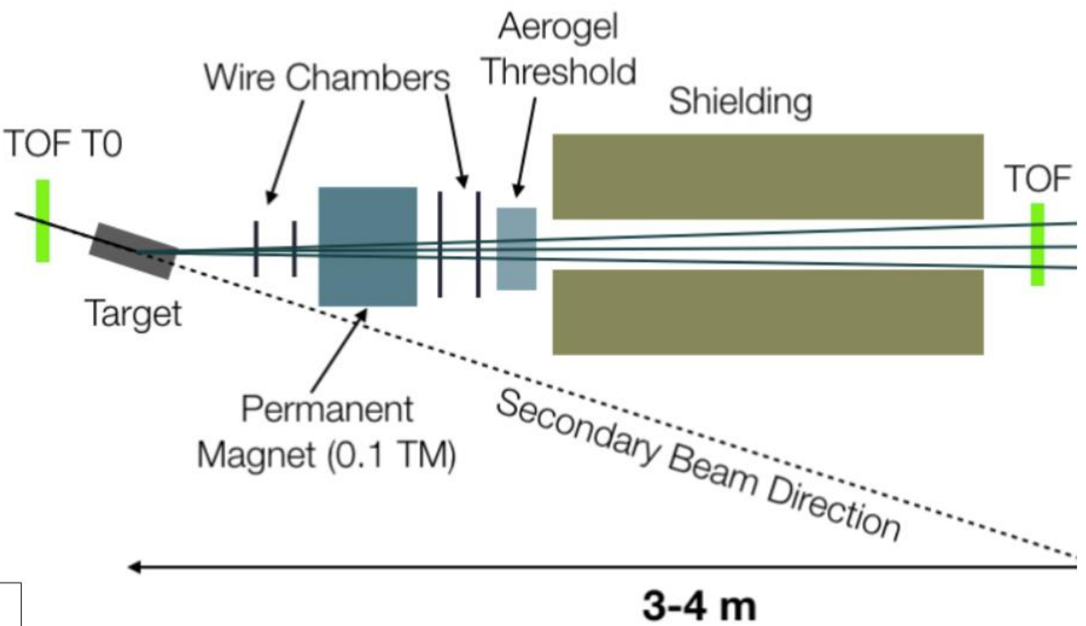
Pion scattering on Oxygen

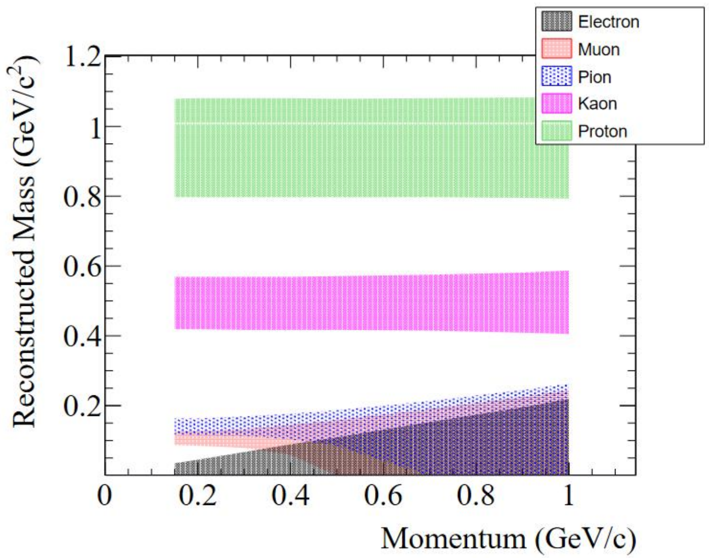
From E. S. P. Guerra, Measurement of Pion-Carbon Cross Sections at DUET and Measurement of Neutrino Oscillation Parameters at the T2K Experiment. PhD thesis, York University, 2018.



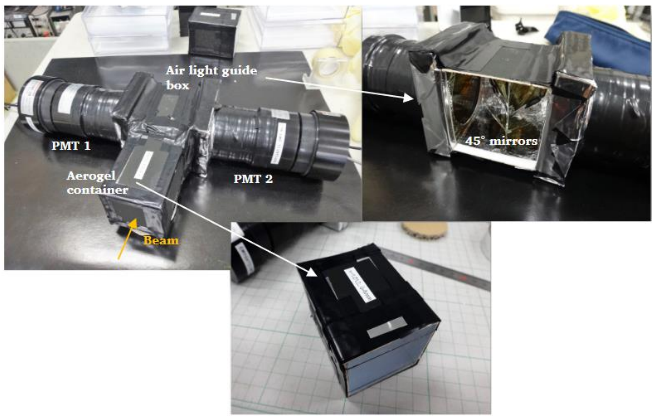
Tertiary beamline

- TOF detector with 100ps resolution RPCs
- Very good mass separation (below)



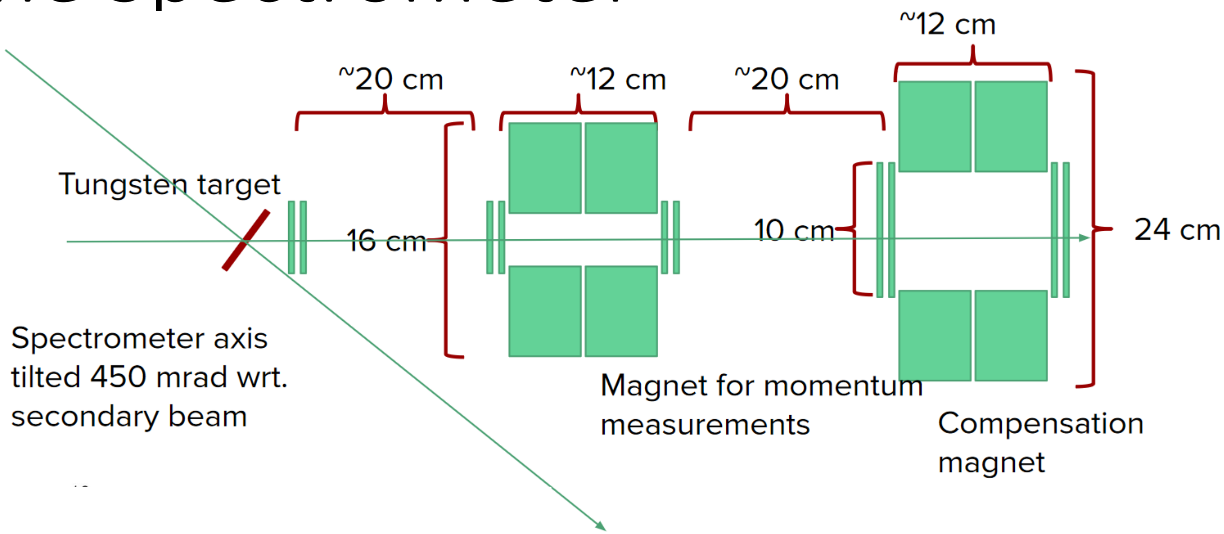


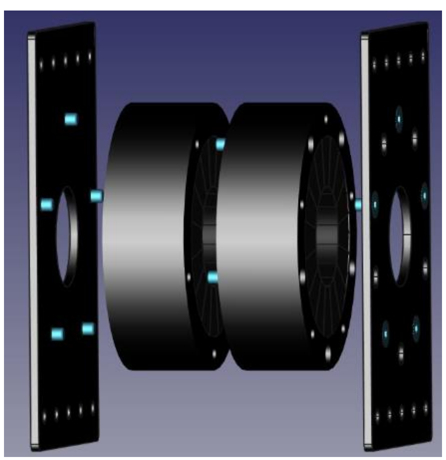
- Gas and aerogel Cherenkov detectors for higher momentum PID

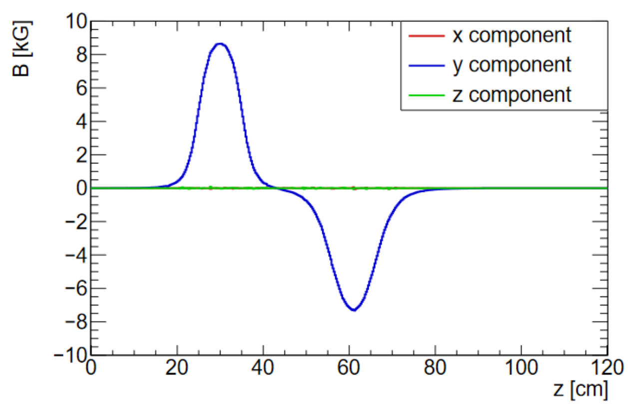


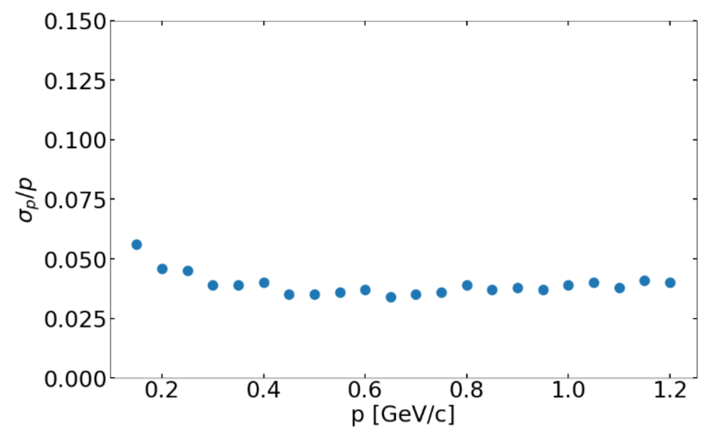
Tertiary Beamline Spectrometer

- Halbach array permanent magnets
- Silicon tracking planes (ATLAS SCTs)



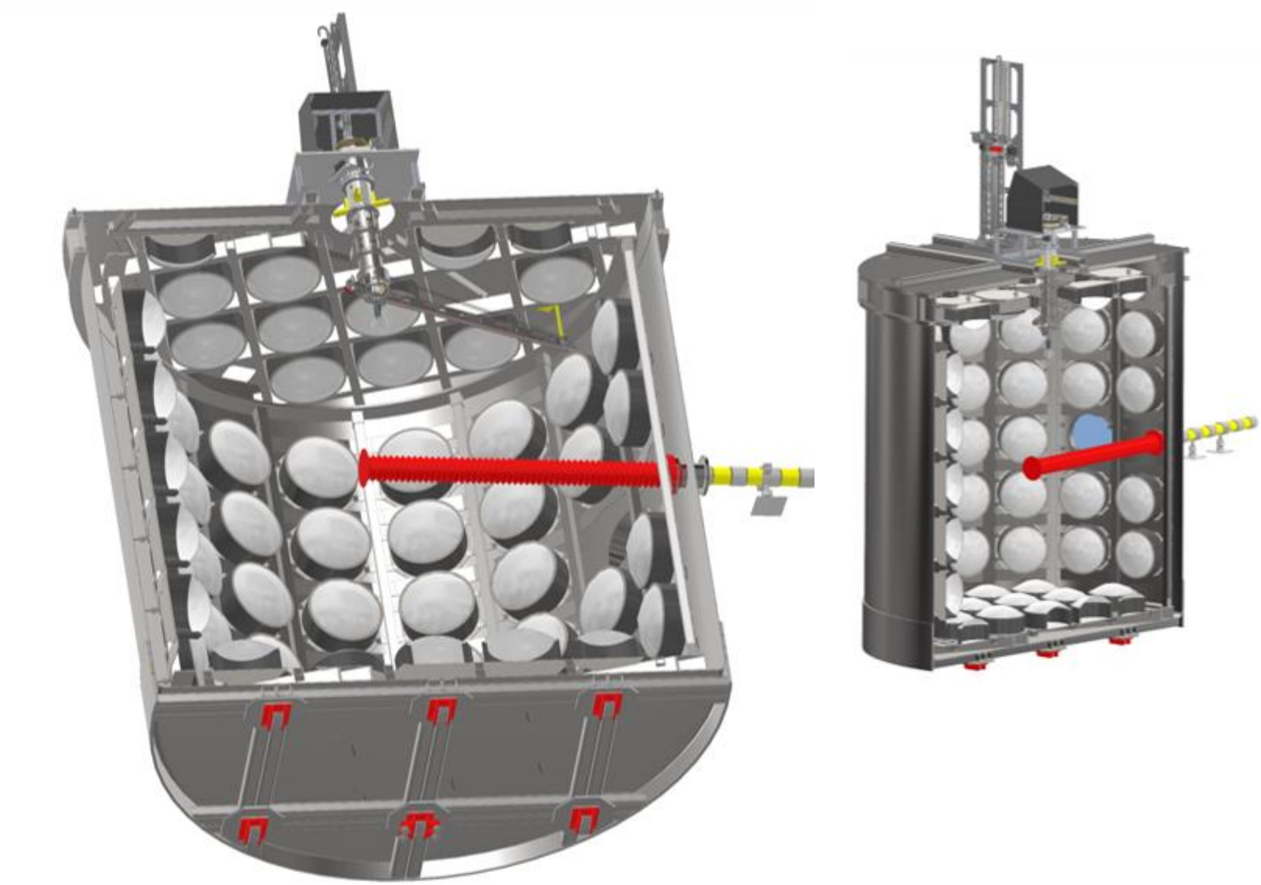




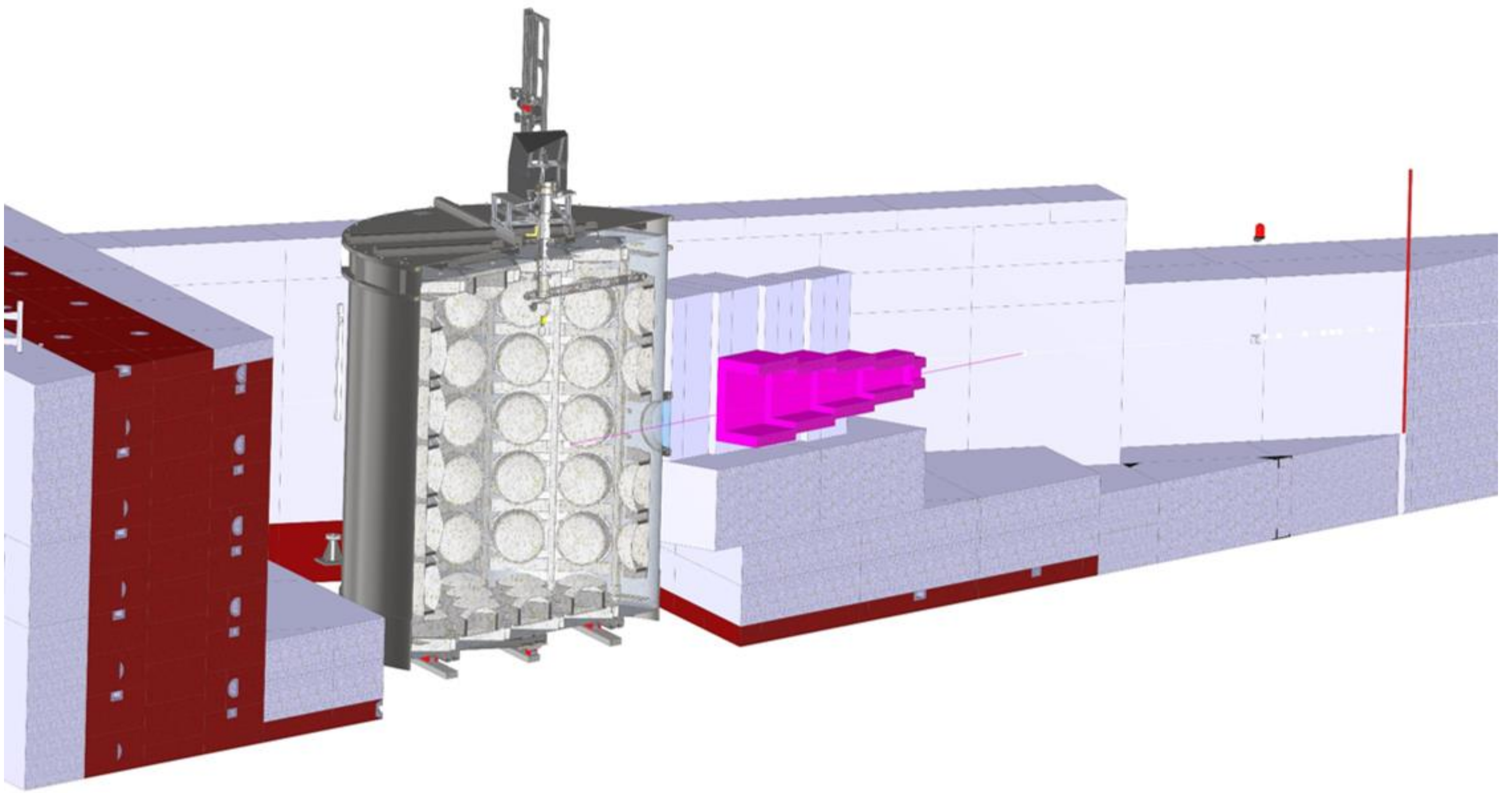


WCTE Detector Design

Detector:	Mass Kg
Vessel (inc movement sys)	4,700
mPMT Support Structure - populated	7,000 (each mPMT @ 41Kg)
Lid	1400
Water	42,000
CDS (total CDS)	200
Total Approx.	55,250



Section of Tertiary Beam into Detector



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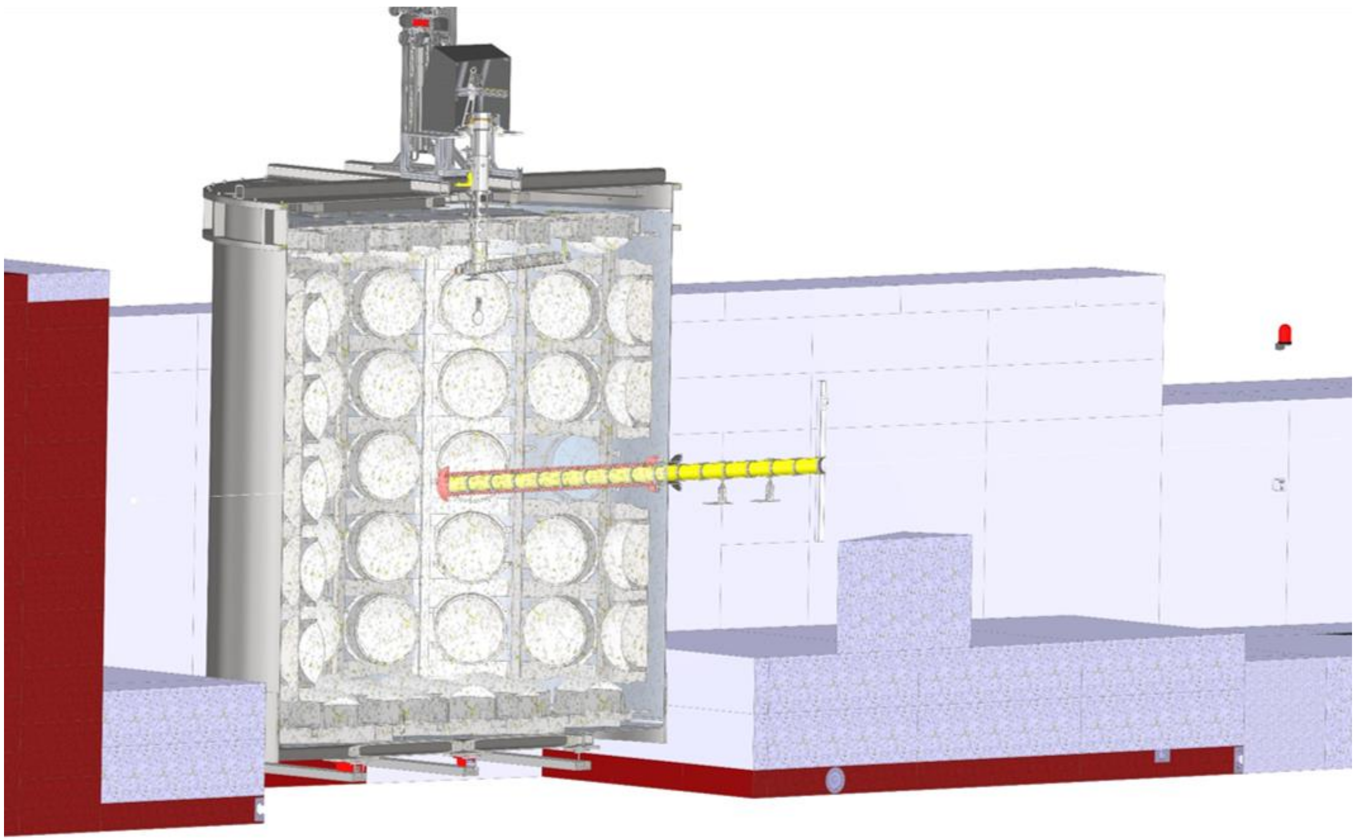
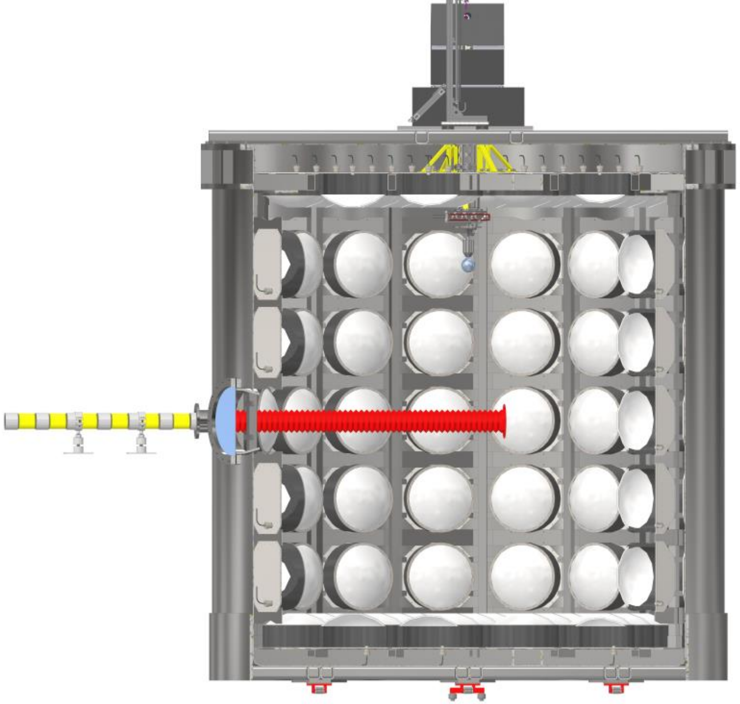
Section of Secondary Beam into Detector

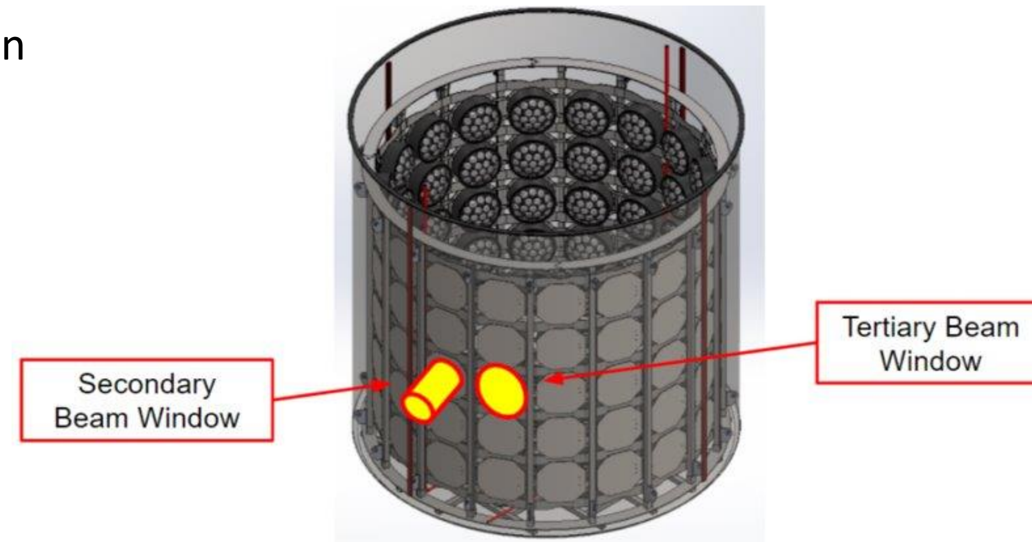


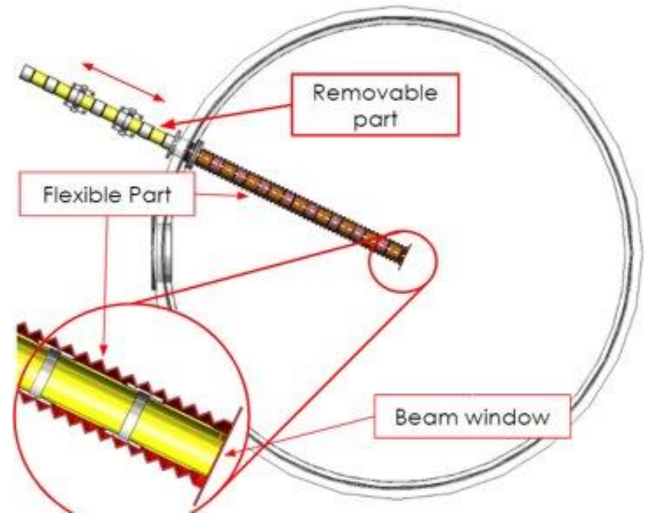
WCTE Detector Design

- Extendible beam window mounted on detector wall for use in secondary beam configuraiton

- Position particle entry point at detector centre







WCTE Detector Design

Detector	Dimension mm
Diameter of Vessel OD	3800
Outermost Diameter	3960
Height*	4180

*Height from top of lid to the rollers

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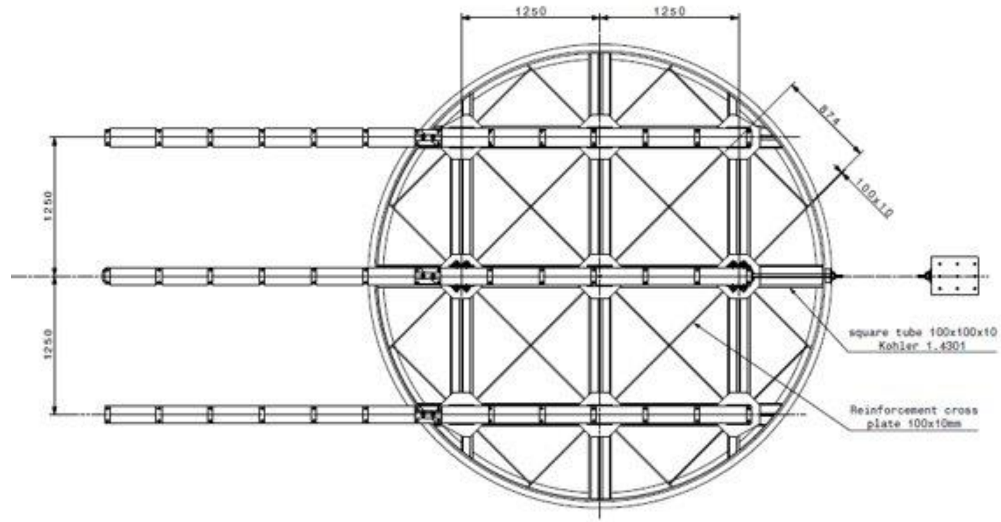
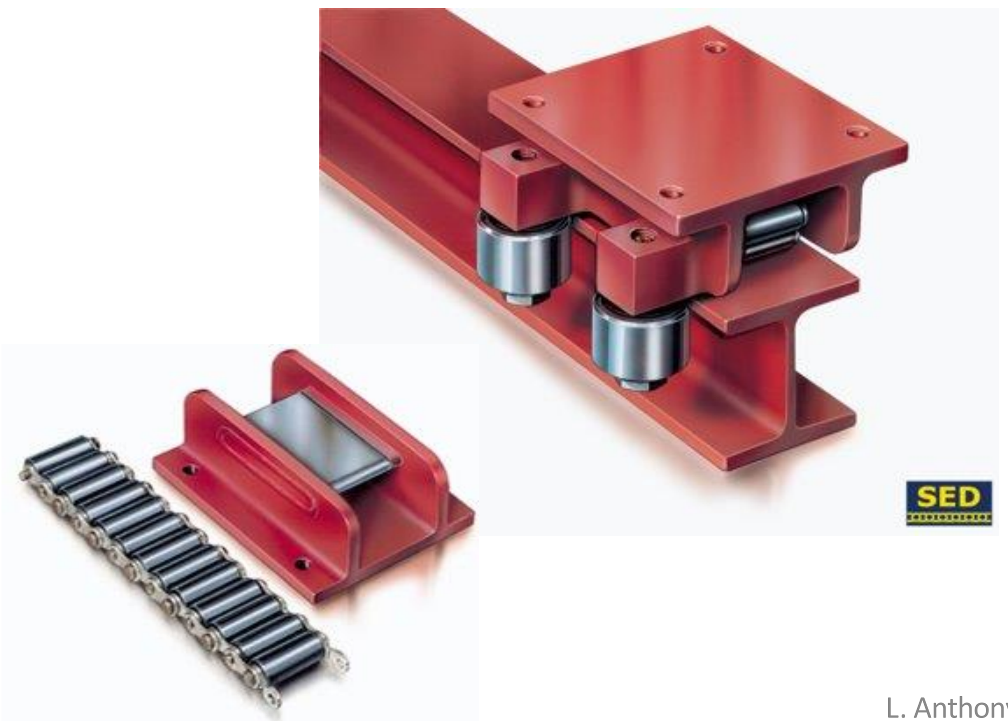
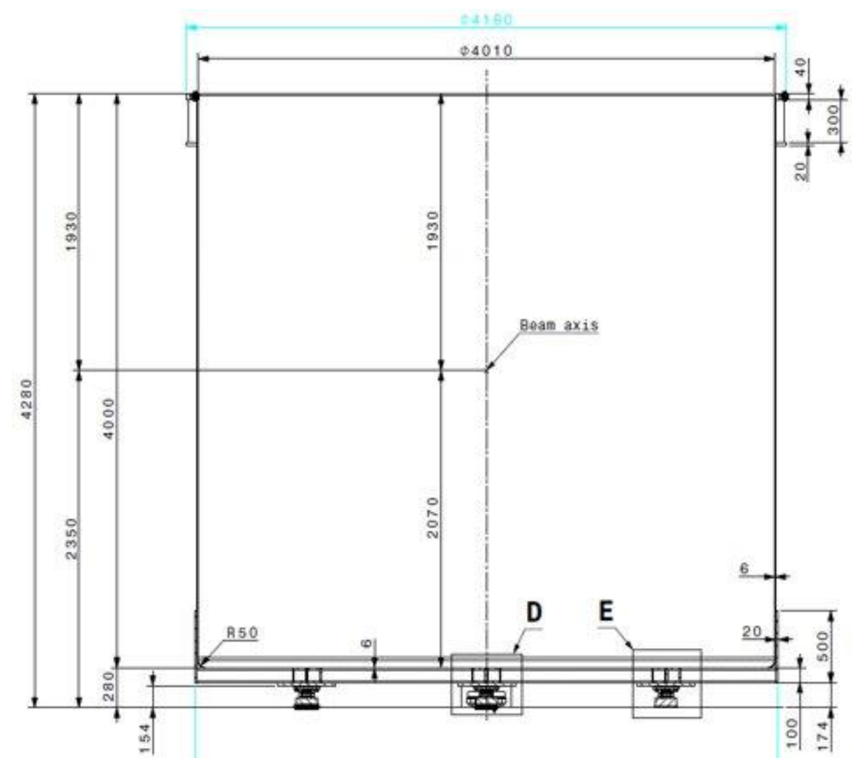
Movement System

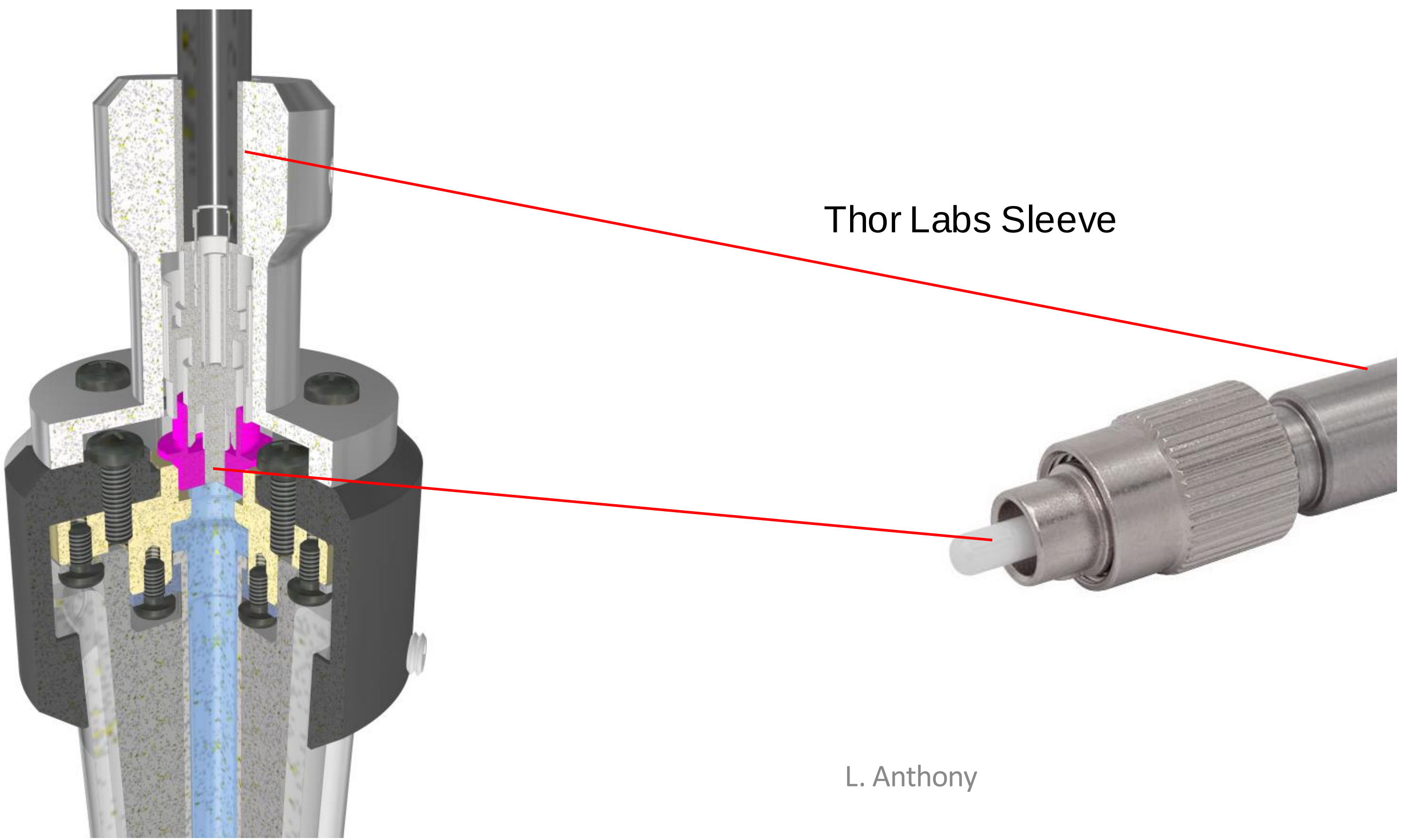


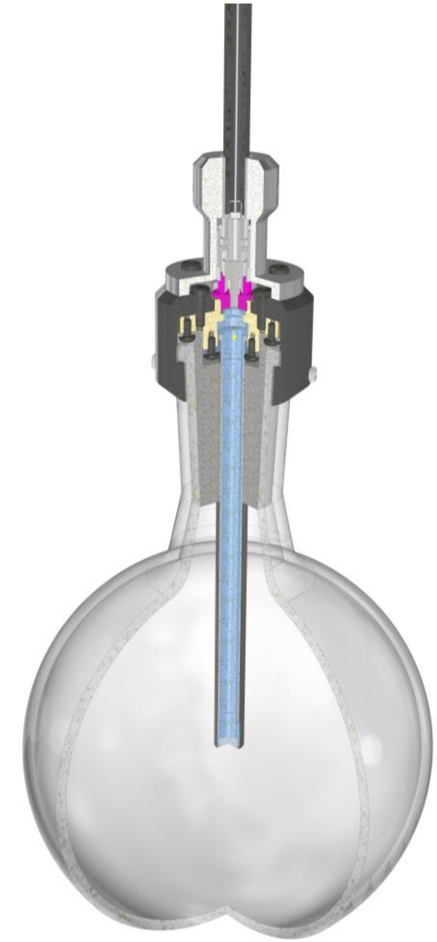




Isotropic Light Source

- Umbilical Termination
  - Uses ThorLabs bulkhead HAFC connector to mate fibre with quartz rod
  - Sealed connection with optical gel to remove any air gap
  - Parts being fabricated at Imperial for prototype
- Weight will also be mounted around clamp and will use fluid seal to ensure is water tight



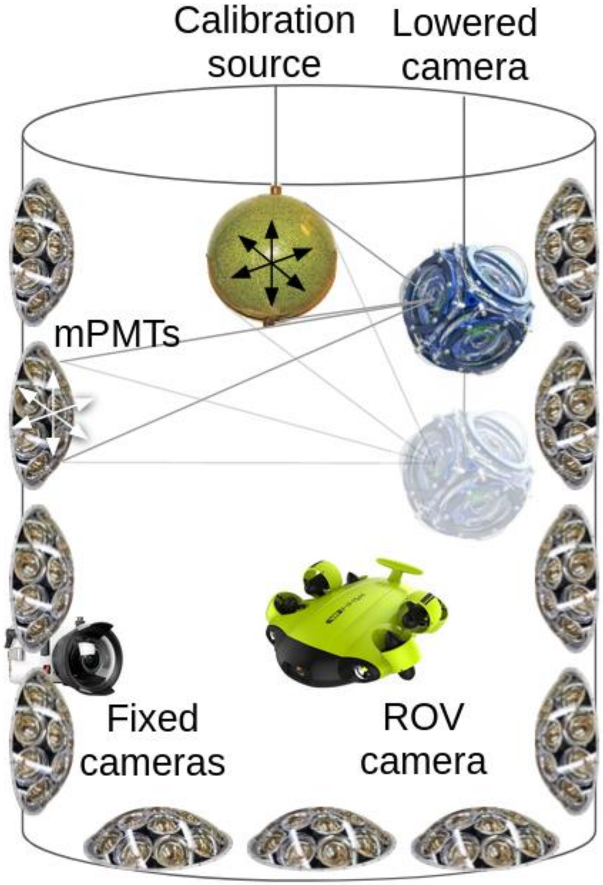


Photogrammetry

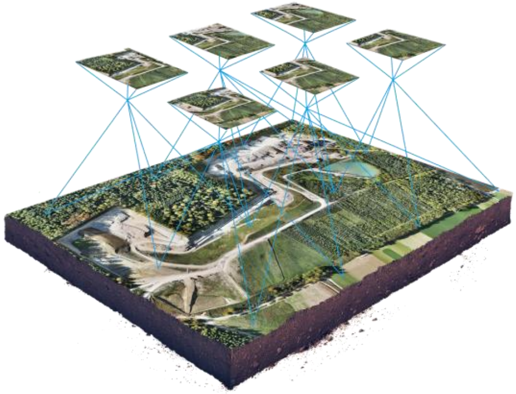
P. de Perio, N Prouse

- Detector geometry and source position measurements using stereoscopic reconstruction with photographs

- Mitigate uncertainties due to:
  - Construction tolerances / imperfections
  - Stretching / twisting of support structure due to PMT buoyancy
  - Source deployment positioning

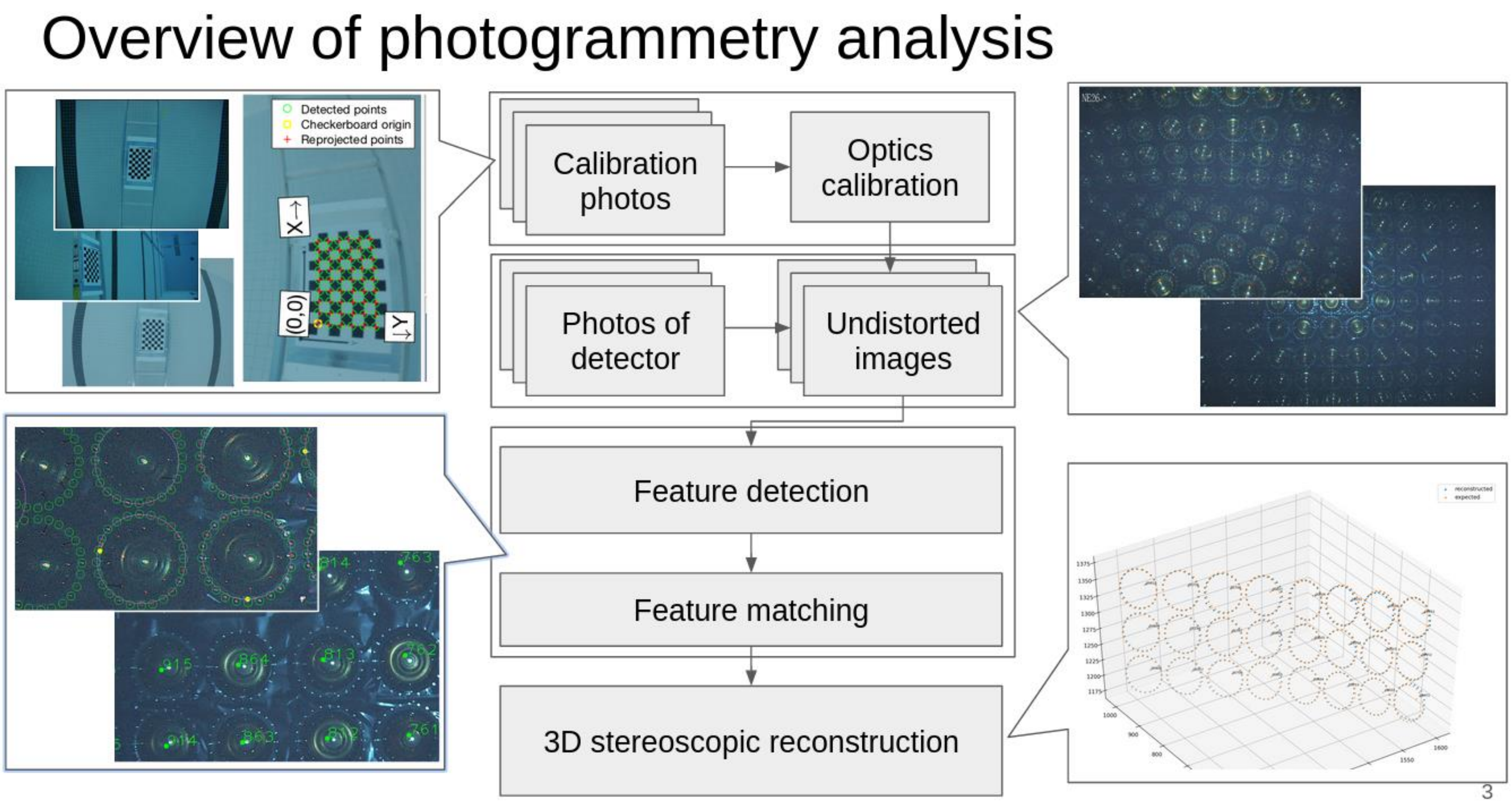


Similar to aerial topographical surveying



Photogrammetry

P. de Perio, N Prouse

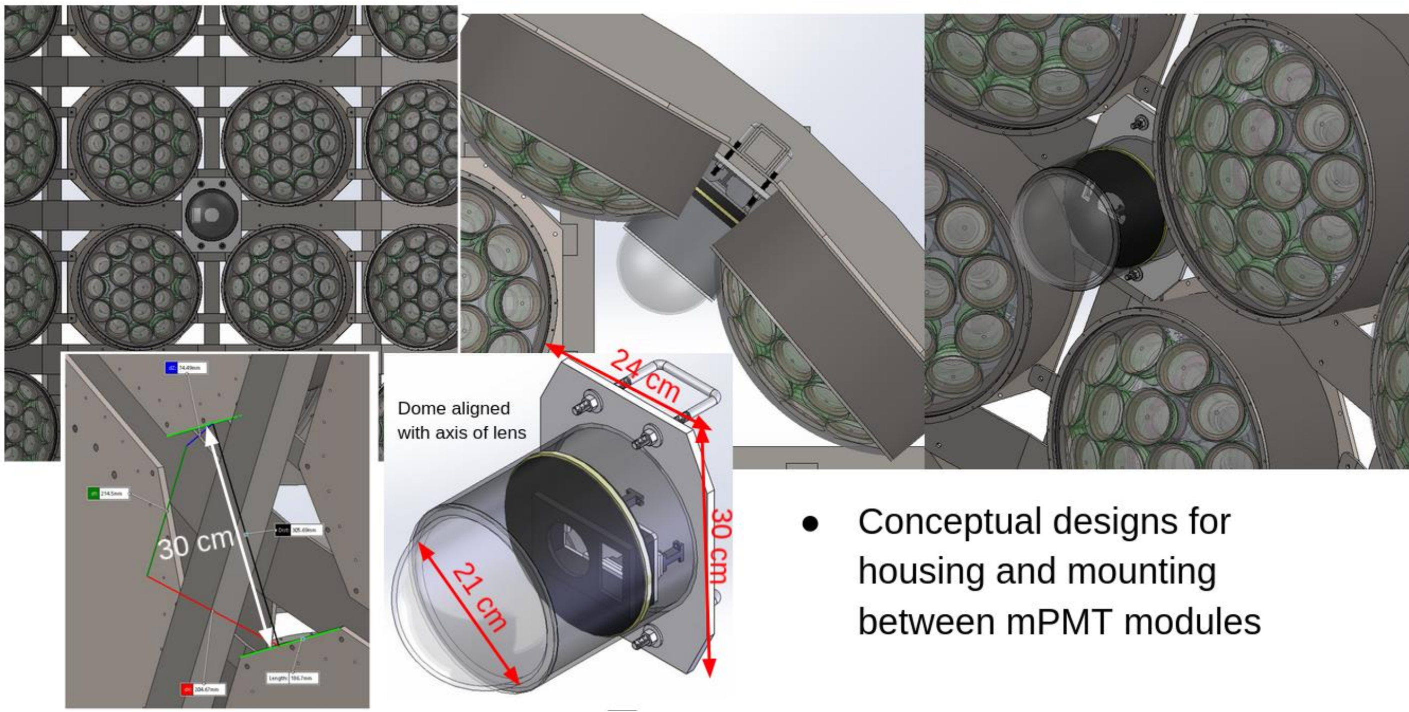


Photogrammetry

P. de Perio, N Prouse

Camera Mounting

Shubham Garode (TRIUMF)



- Conceptual designs for housing and mounting between mPMT modules

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