Imperial College London

The Water Cherenkov Test Experiment @ CERN

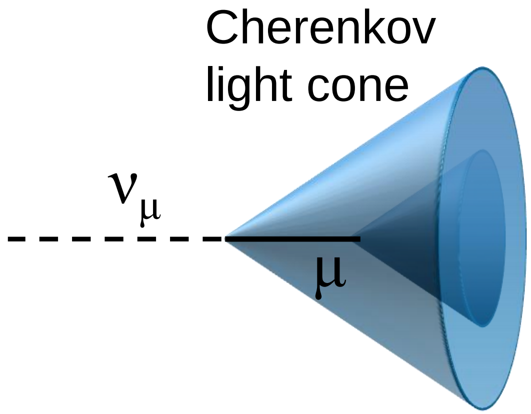
EPS-HEP 2021

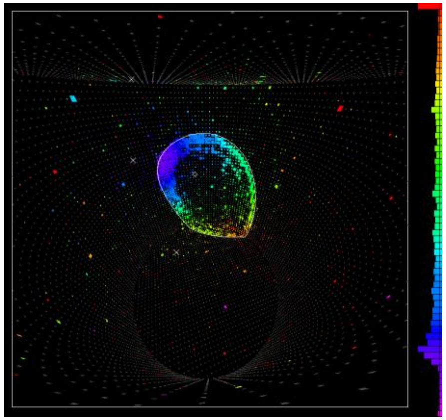
26th July

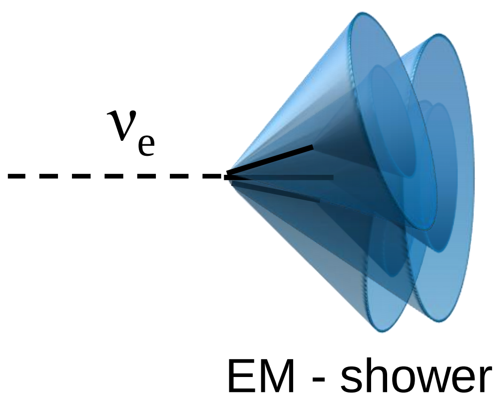
Mark Scott

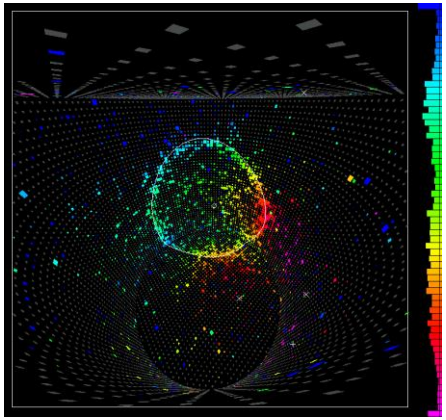
Water Cherenkov detectors for neutrino physics

- Excellent performance:
  - >99% μ/e separation
  - 2% momentum resolution
  - 1° direction resolution
- New technologies
  - Gadolinium
  - Water-based liquid scintillator
  - Photo-detector modules





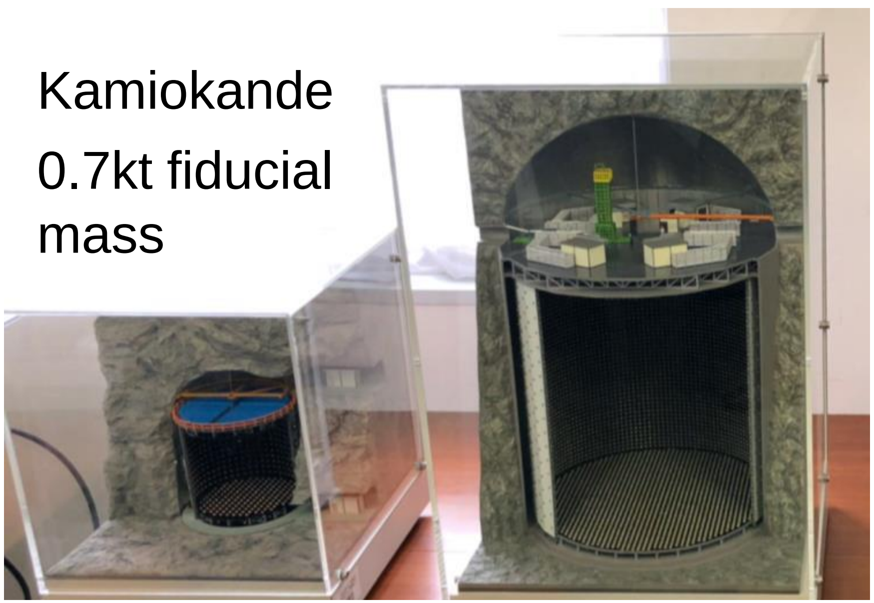




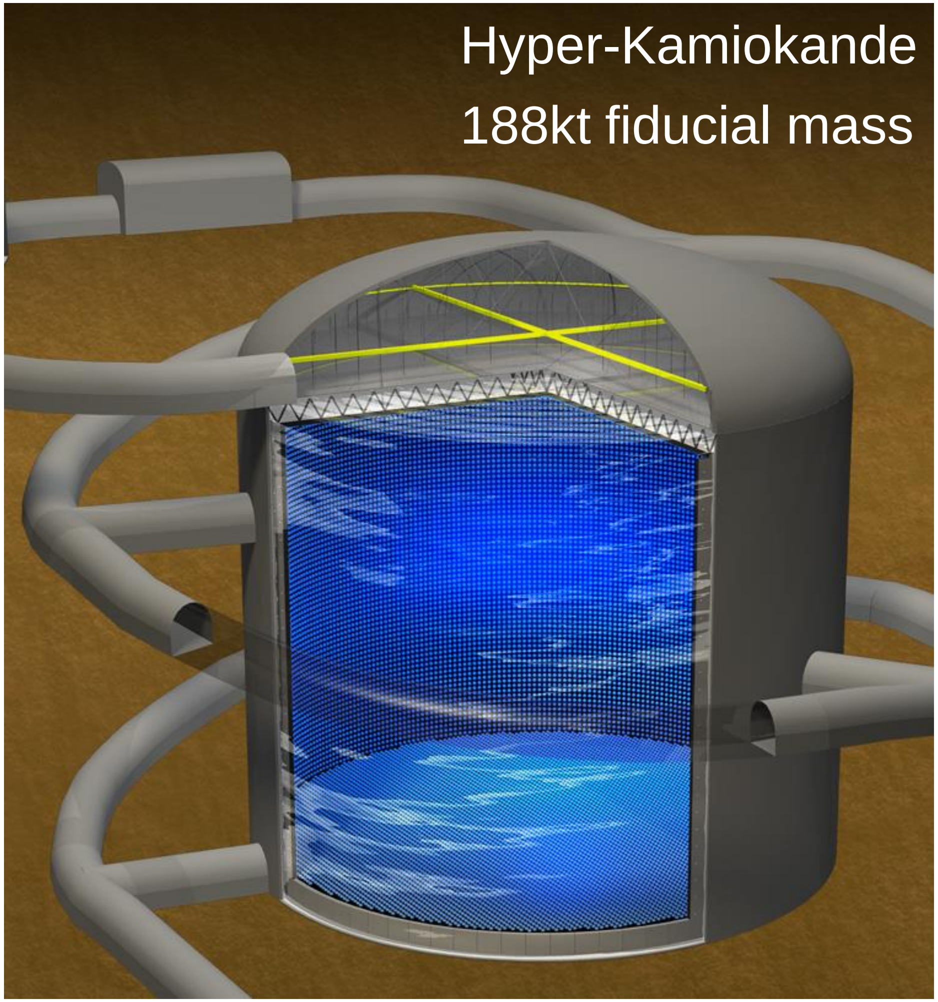
Water Cherenkov detectors in Kamioka

Kamiokande
0.7kt fiducial mass

Super-Kamiokande
22.5kt fiducial mass

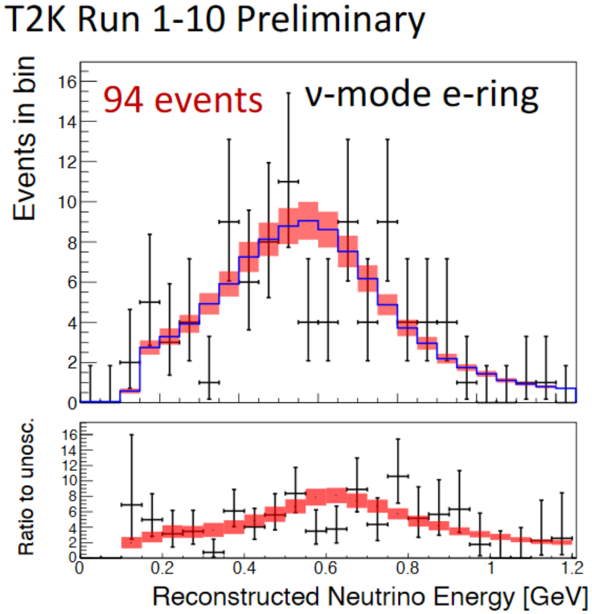


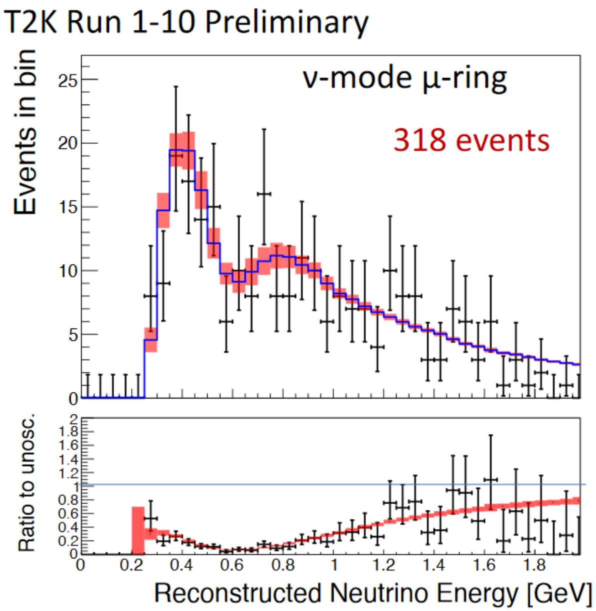
Hyper-Kamiokande
188kt fiducial mass



Neutrino oscillations at T2K

- Super-K has been in operation for 25 years
- T2K has collected data for >10 years
- Some of the most precise measurements of neutrino oscillations





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

Systematic uncertainties at T2K

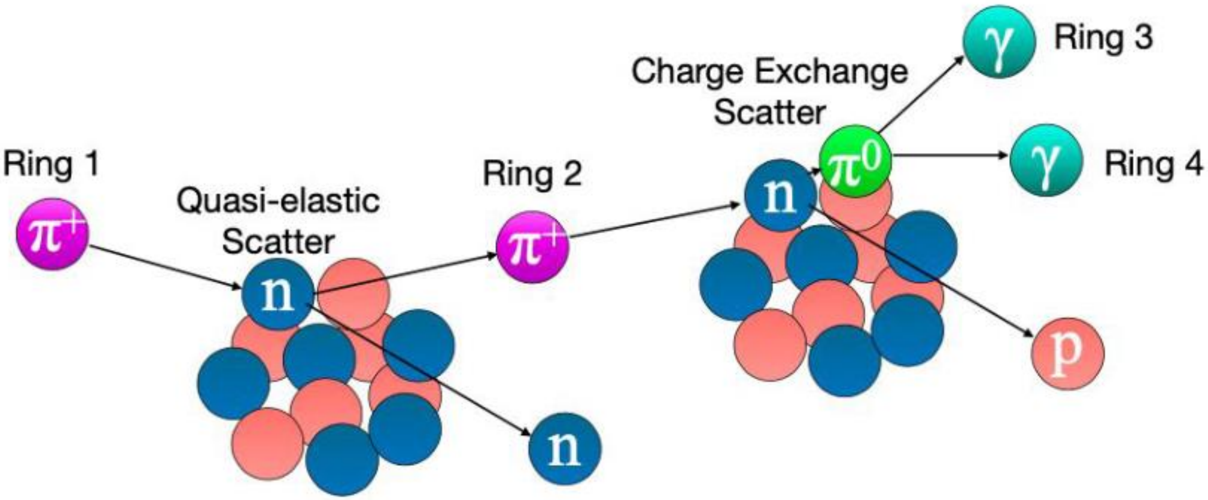
- T2K currently limited by statistical uncertainty, future neutrino experiments will be limited by systematic uncertainty
- SK detector largest uncertainty in electron-like event samples

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

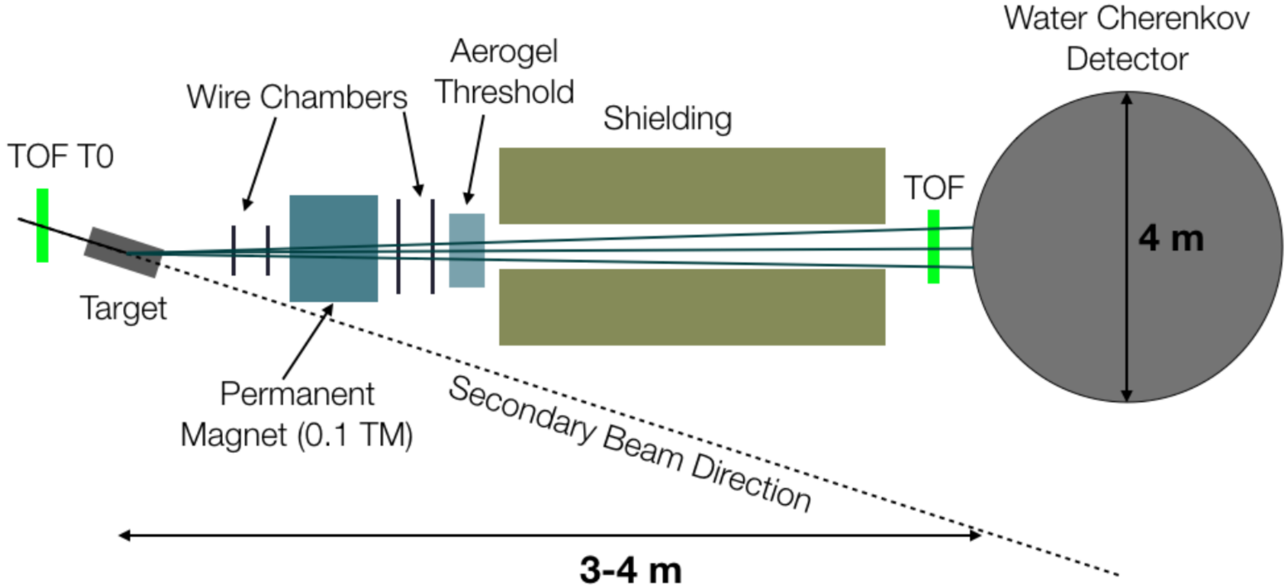
Secondary interactions

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



Water Cherenkov Test Experiment

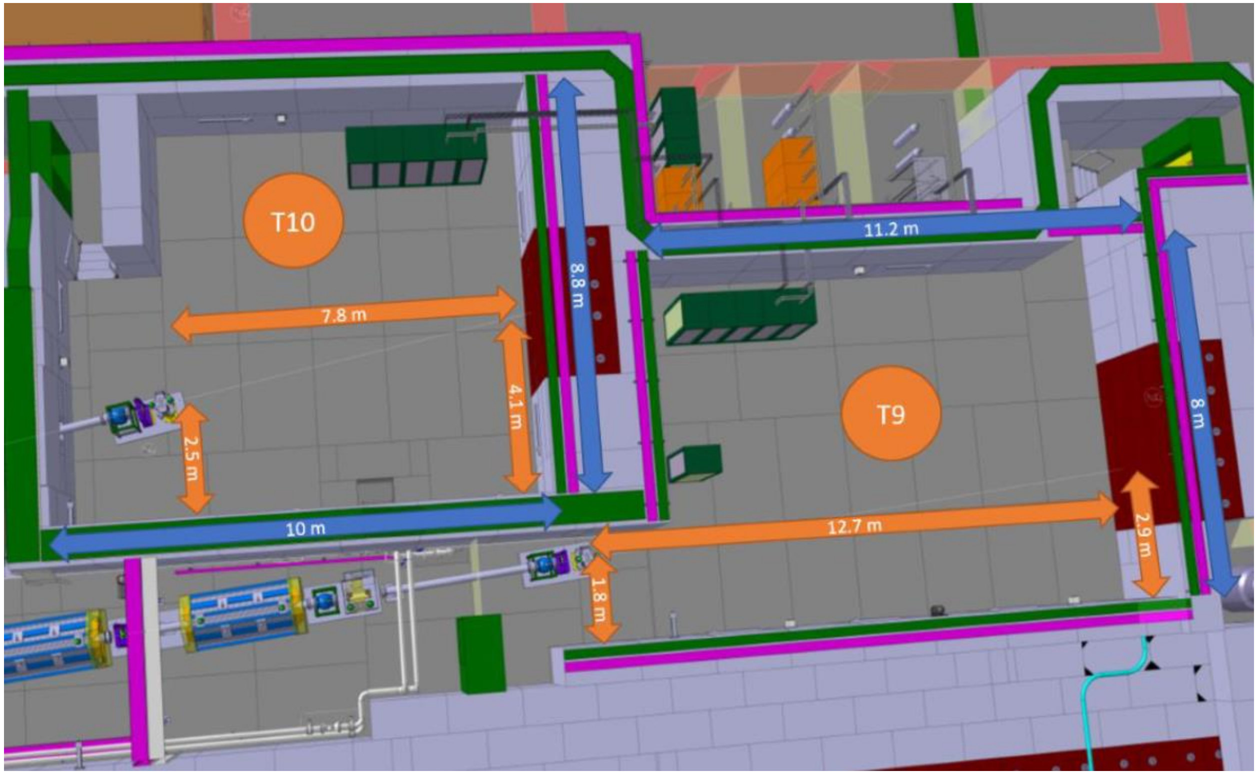
- Goal: study detector systems and detector response to pions, muons, electrons and protons from 200 MeV/c up to 1000 MeV/c
- ~4m diameter, ~4m high cylindrical water Cherenkov detector
  http://cds.cern.ch/record/2712416/files/?ln=en
- Gadolinium sulphate loading planned for neutron detection



Experimental area at CERN

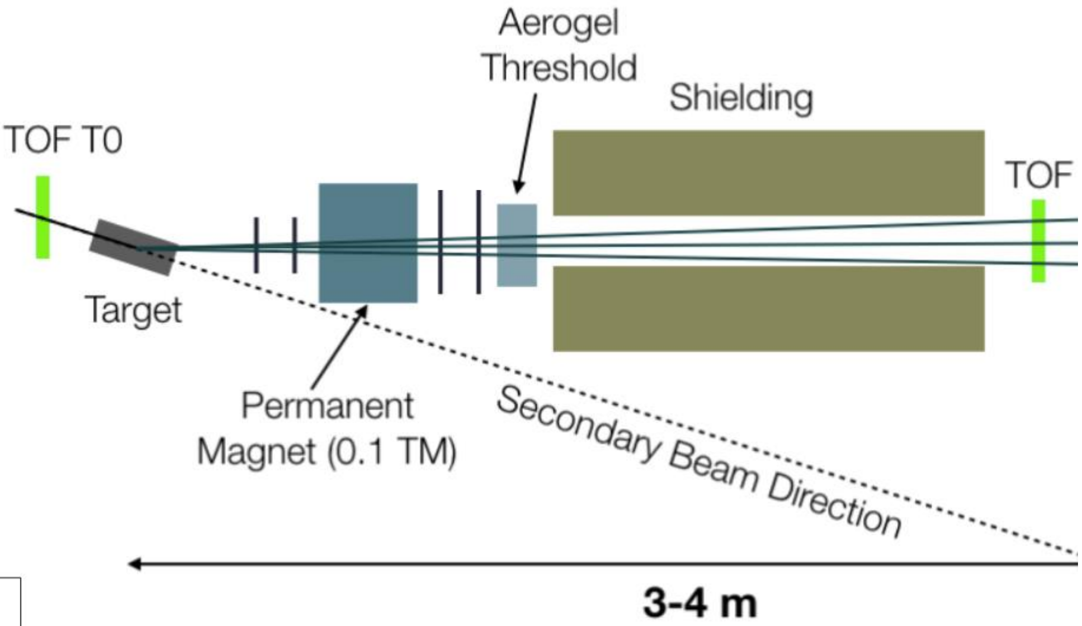
- T9 beam line in the East Area - secondary particle beam with momenta ranging from ~400 MeV/c to ~15 GeV/c

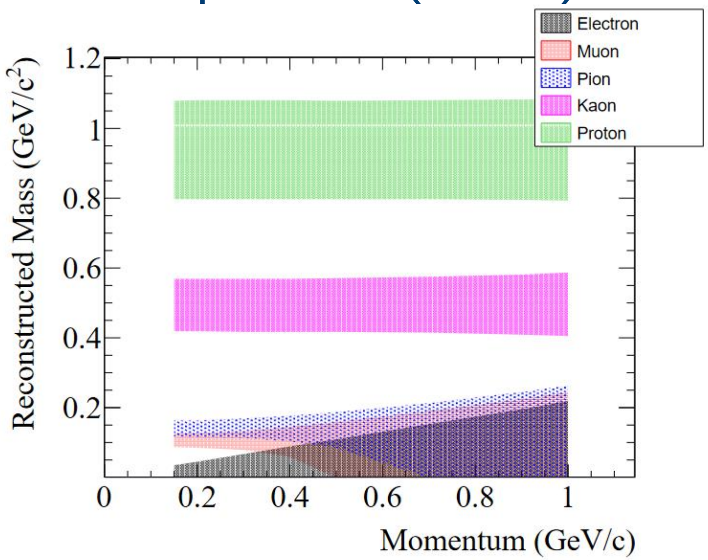
- 40m long secondary beamline
  - Pions decay in flight
  - Need tertiary production target



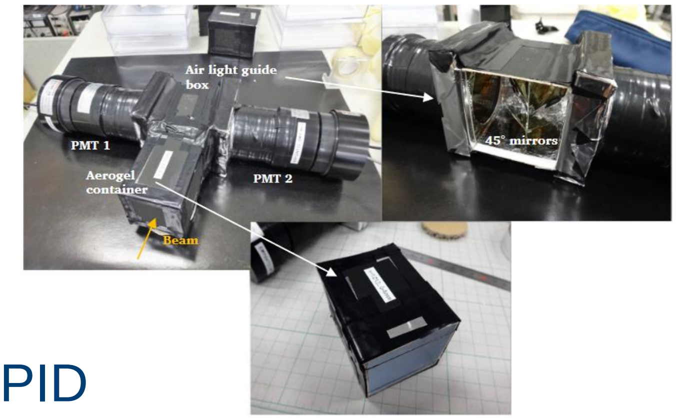
Tertiary beamline

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



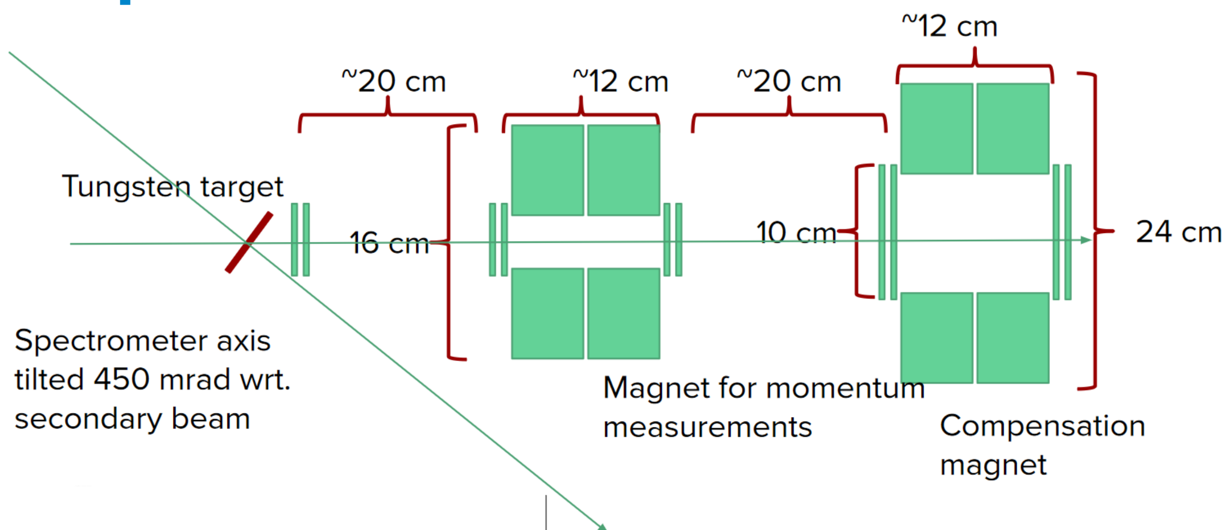


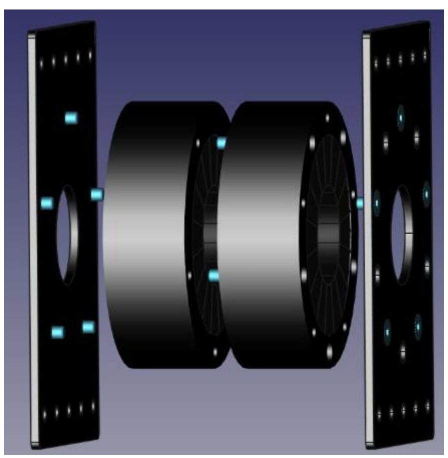
- Gas and aerogel Cherenkov detectors for higher momentum PID

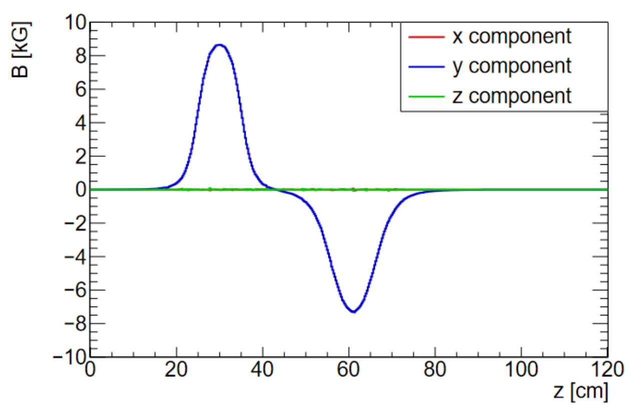


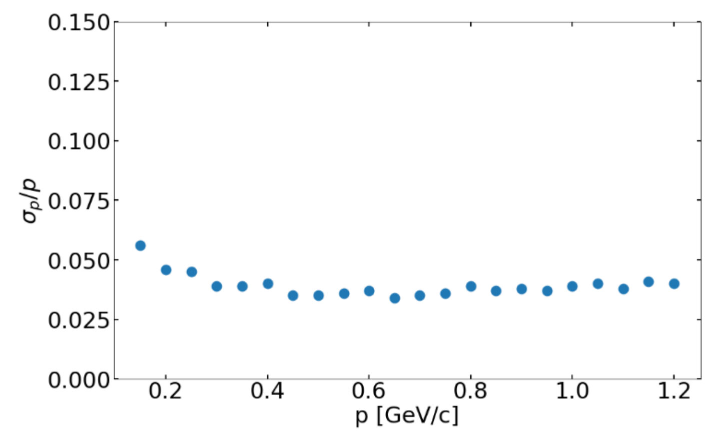
Tertiary beamline spectrometer

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



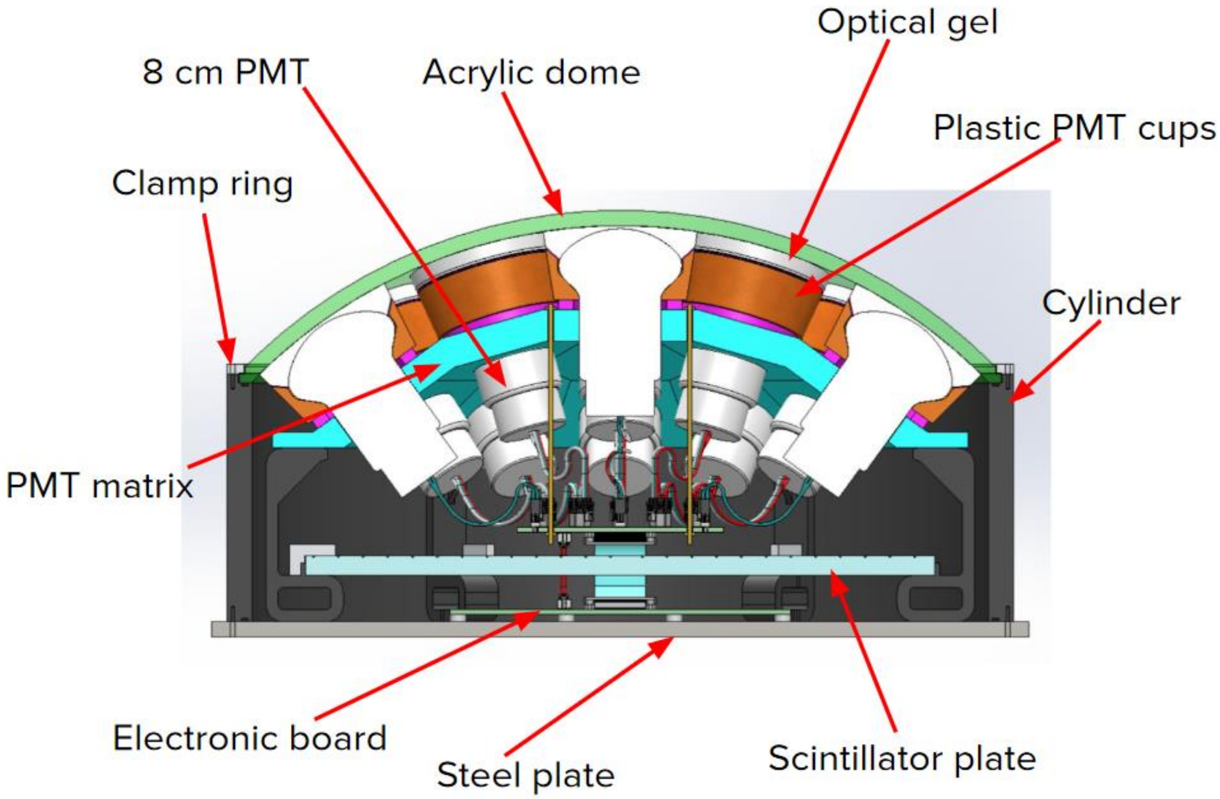






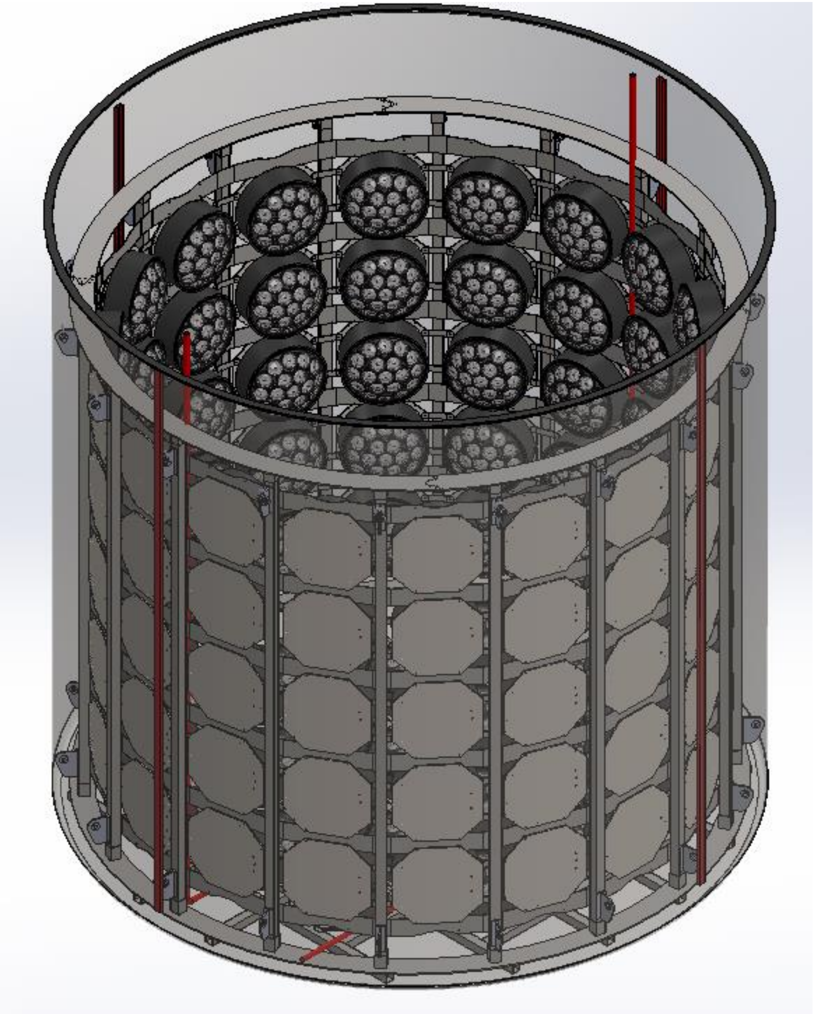
Multi-PMT photosensors

- Nineteen 8cm diameter PMTs (Hamamatsu R14374)
- Improved granularity and timing compared to larger PMTs



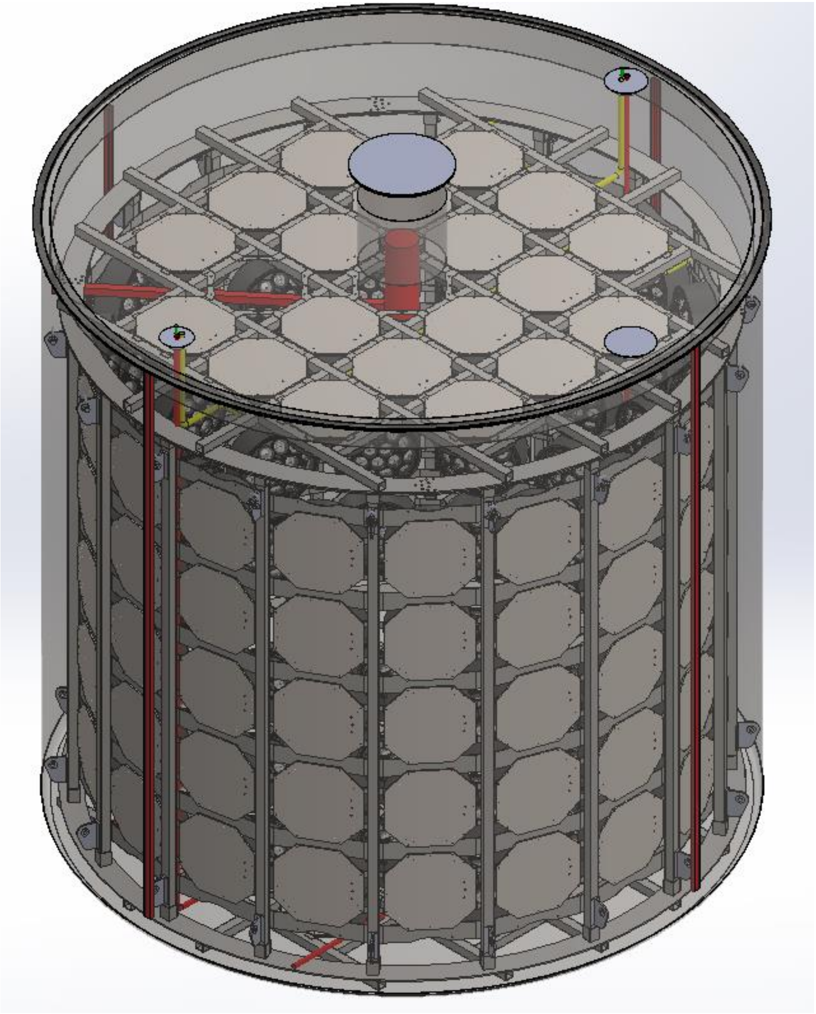
Detector design

- Internal cylinder composed of rectangular ‘scaffold’
- Holds ~130 multi-PMT modules
- Sits inside cylindrical water tank



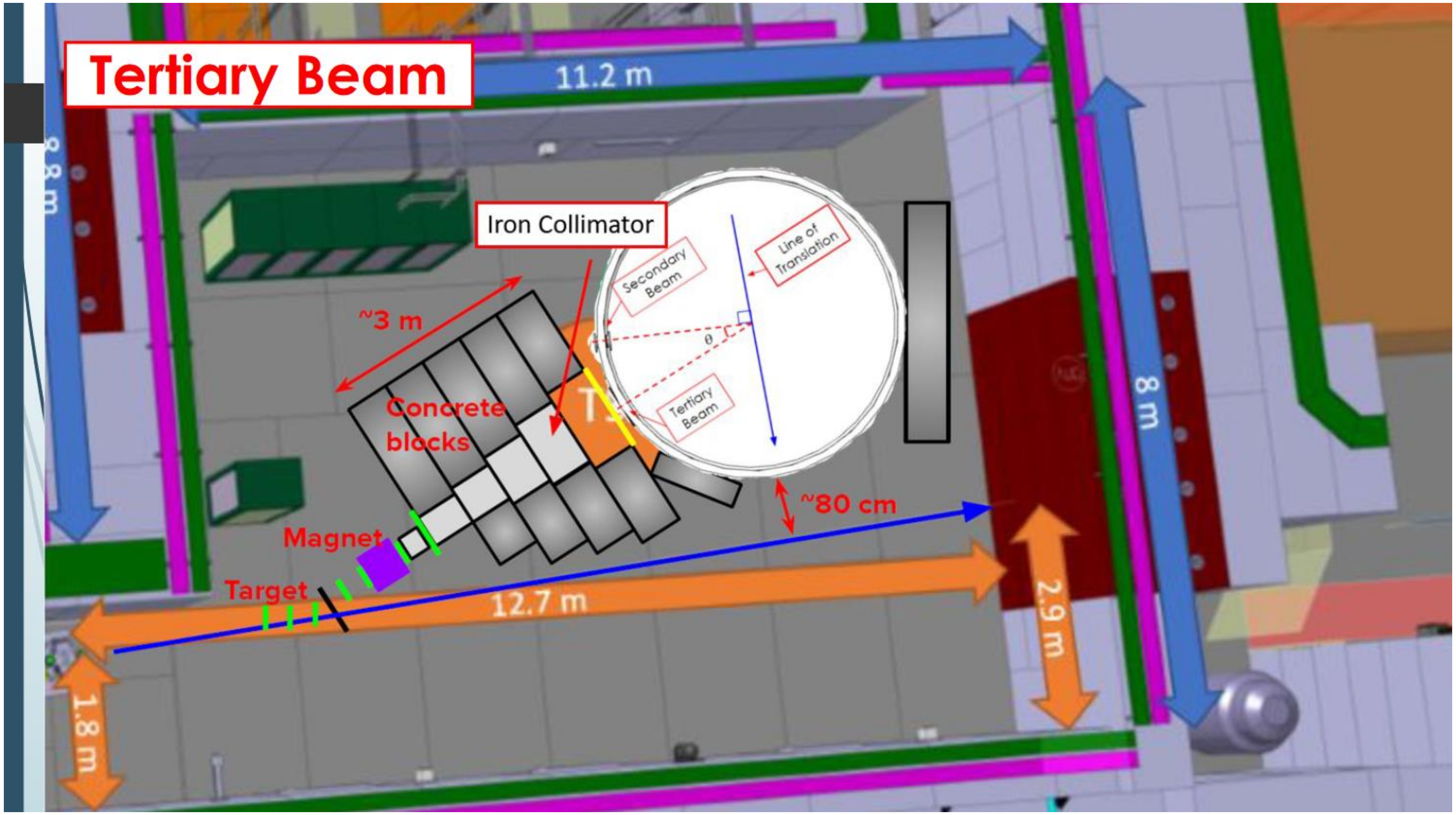
Detector design

- Internal cylinder composed of rectangular ‘scaffold’
- Holds ~130 multi-PMT modules
- Sits inside cylindrical water tank
- Lid provides access, services and calibration ports



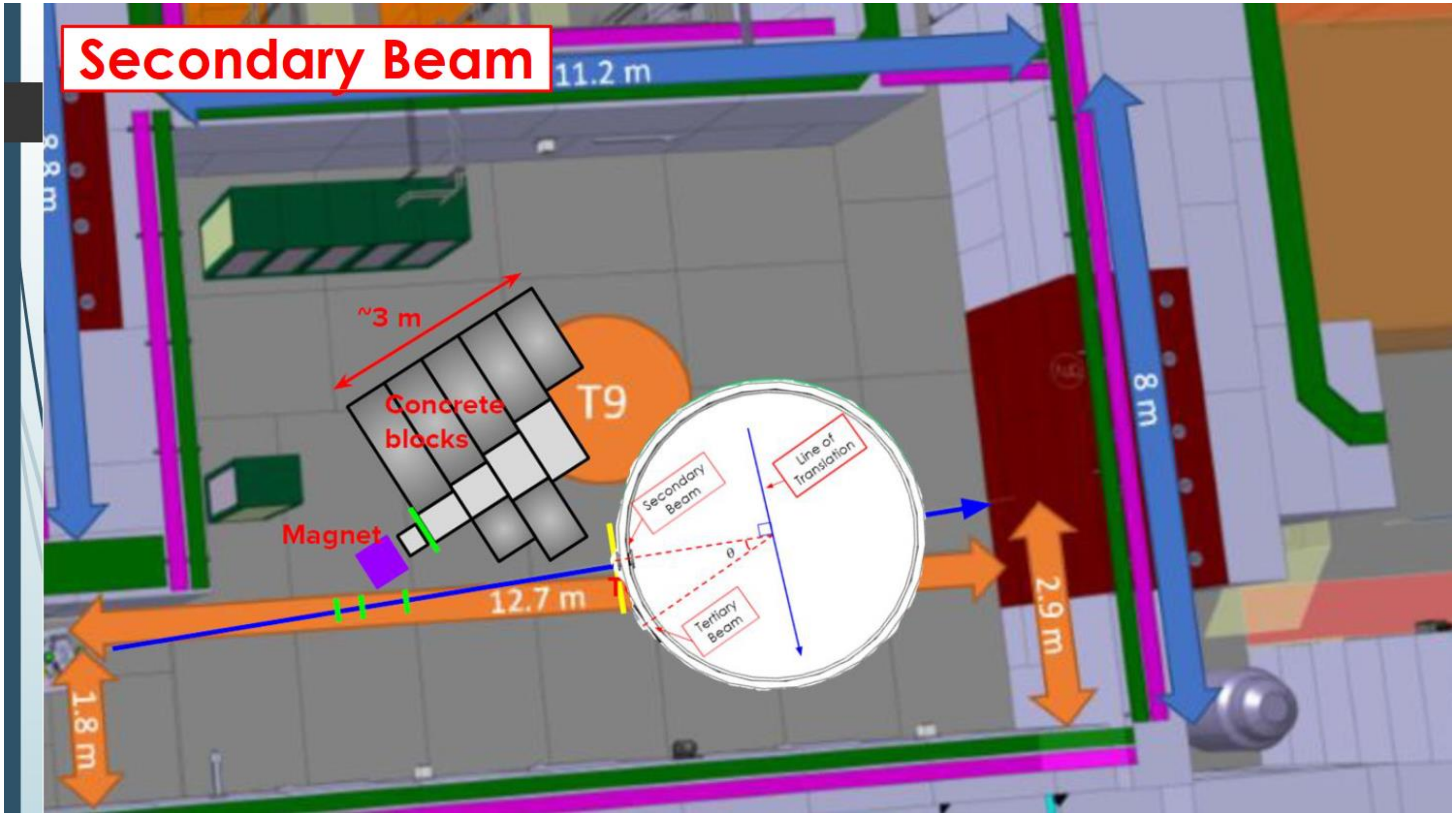
Translation in T9

- Tertiary beam configuration



Translation in T9

- Secondary beam configuration



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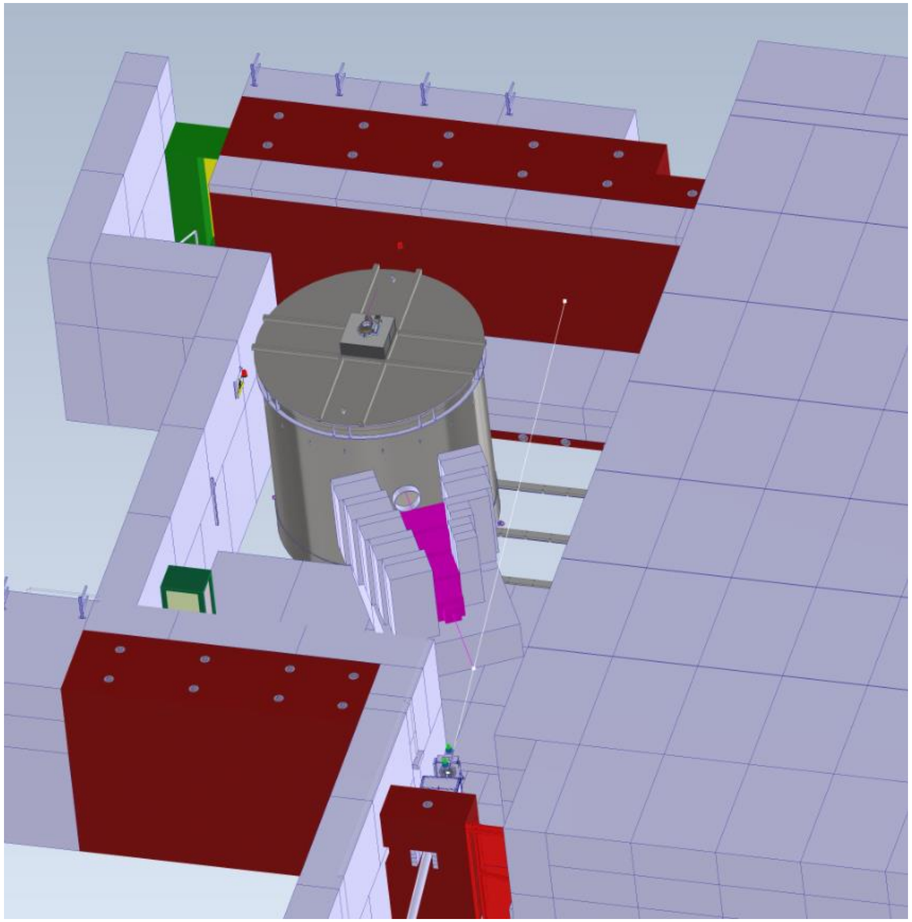
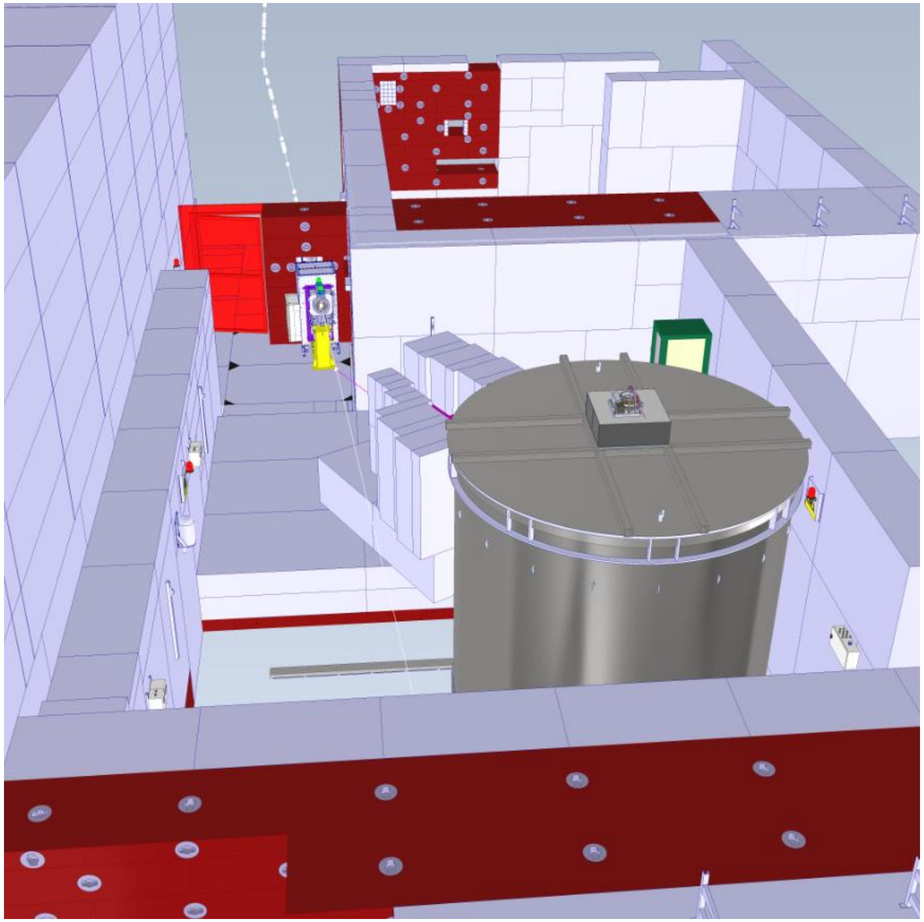
WCTE at CERN T9 beamline





Calibration

- Goal to understand detector response at 1% level
- System to deploy sources to any position within detector
  - Laser diffuser ball
  - NiCf source
  - Neutron source
  - Camera (photogrammetry)
- Ex-situ calibration of multi-PMTs

Summary

- WCTE will study the response of a water Cherenkov detector to charged particles
  - Measure secondary particle interactions
  - Testbed for new technology
  - Demonstrate 1%-level detector calibration
- Crucial measurements for future water Cherenkov detectors
  - Hyper-K, THEIA, ESSvSB
- Recommended by SPSC for beam time in 2023 – new collaborators welcome!

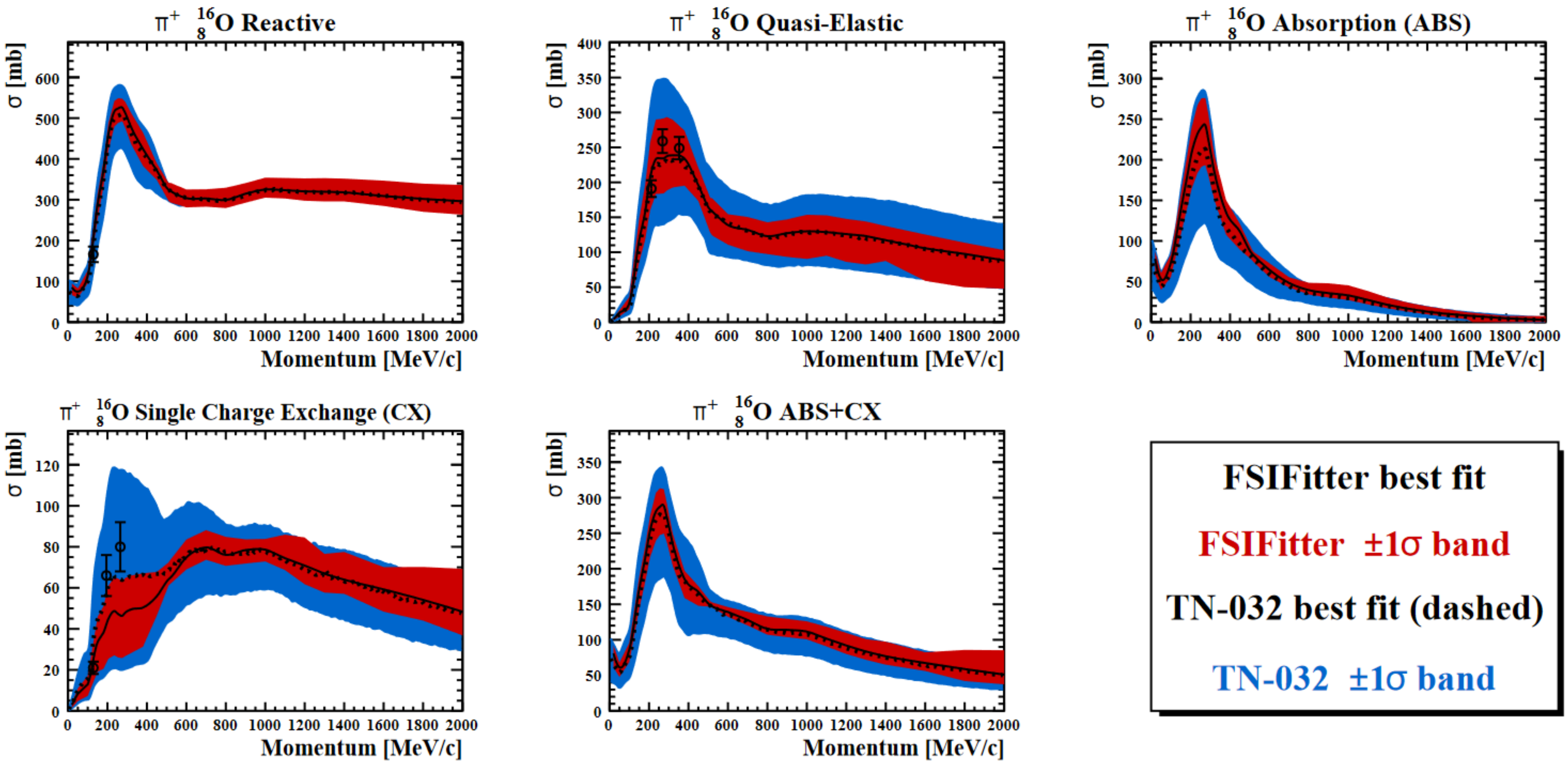
Back-up slides

WCTE data-taking

- Four data taking periods
  - Pure water run
    - Secondary beam
    - Tertiary beam
  - Gadolinium loaded run
    - Tertiary beam
    - Secondary beam
- Gadolinium removed with resin prior after final data taking run

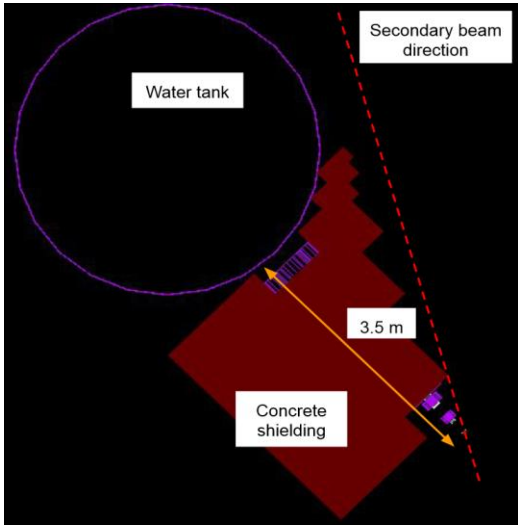
Pion scattering on Oxygen

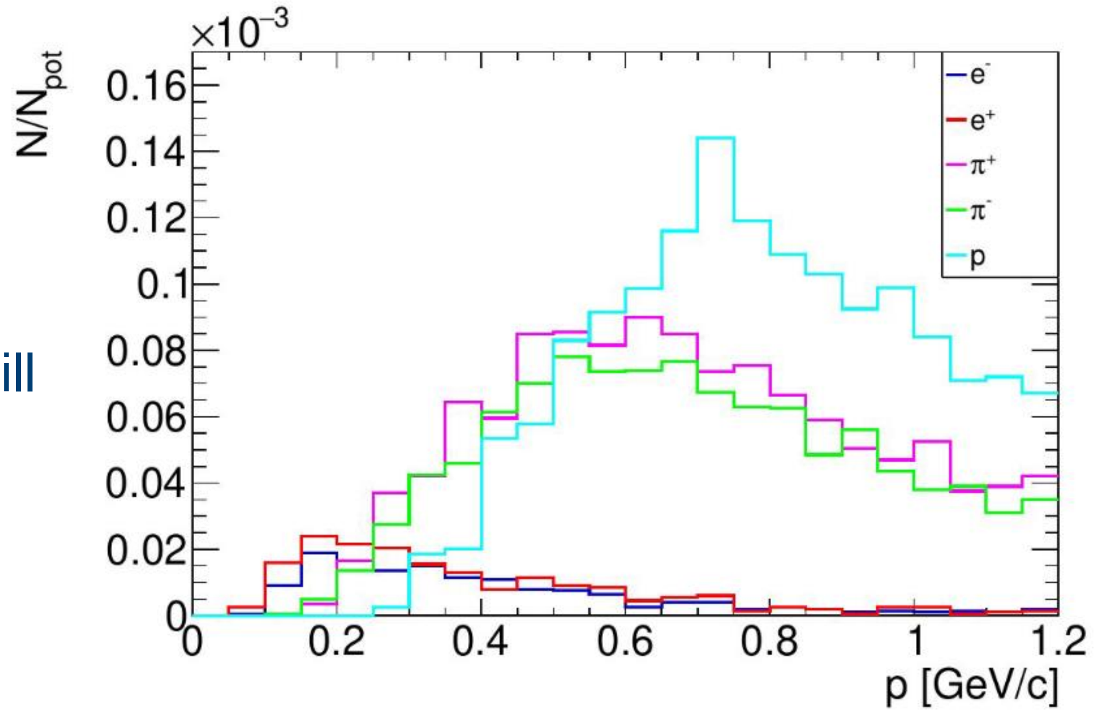
- From E. S. P. Guerra, Measurement of Pion-Carbon Cross Sections at DUET and Measurement of Neutrino Oscillation Parameters at the T2K Experiment. PhD thesis, York University, 2018.



Tertiary particle rates

- Realistic beamline simulation
- $5{\times}10^6$ particles per spill
- Table shows particles entering detector per spill





e-	e+	π-	π+	p
715	905	5265	5965	7510

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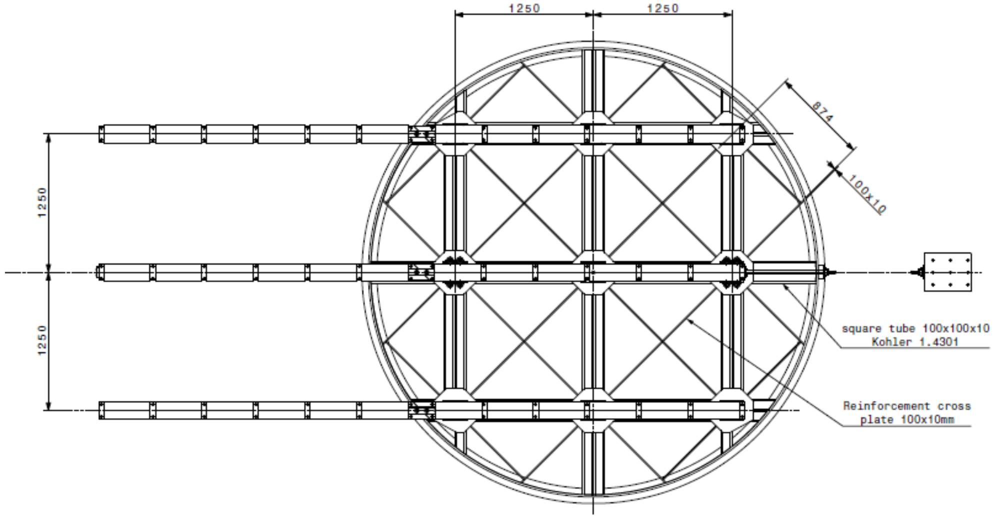
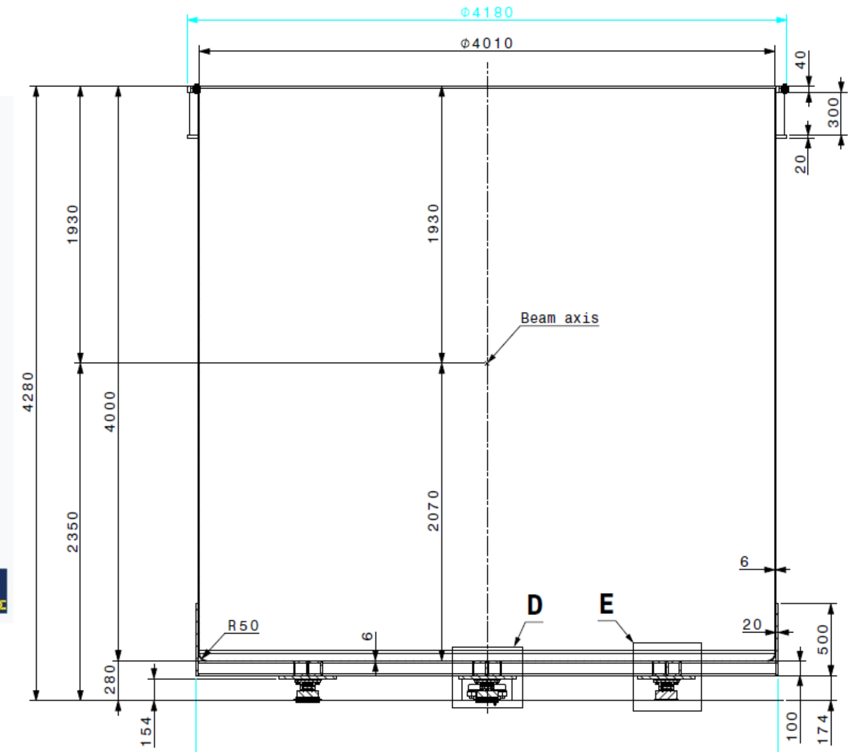
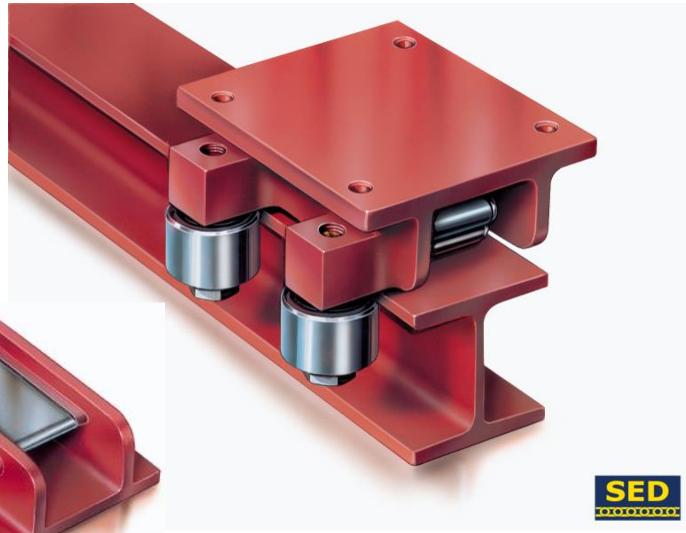
Movement System

- Tank filled weight of ~60 tons
- Rail + rollers, move with mechanical winch







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Beam windows

- Tertiary and secondary beam windows
- Secondary window has extendable pipe – inject particles into bulk of detector