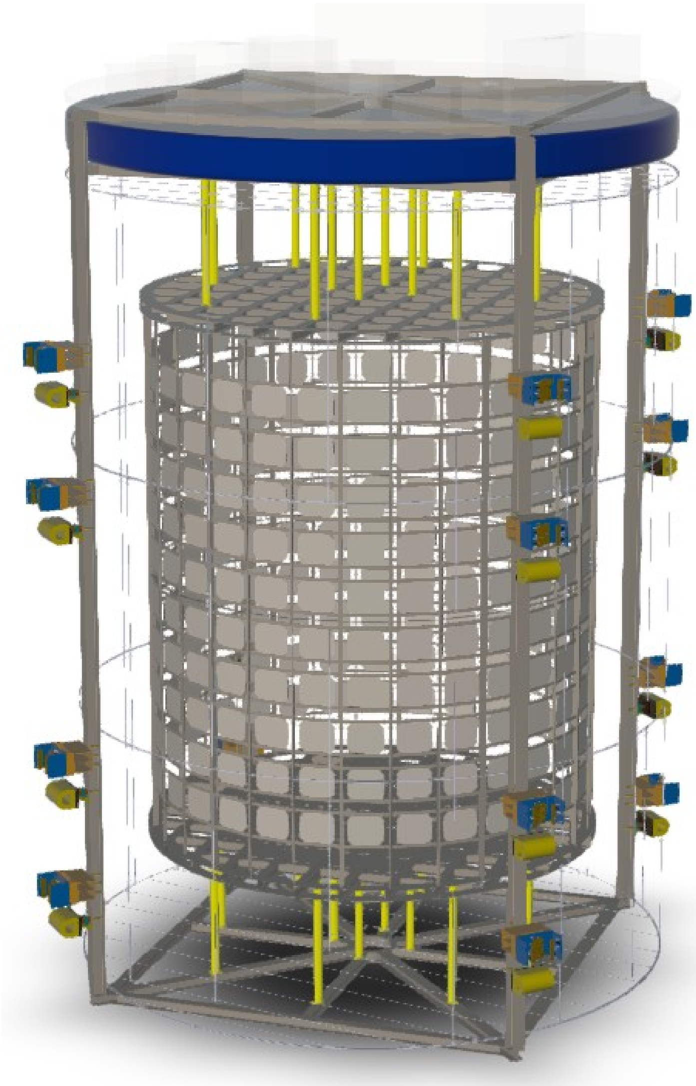
IWCD, the Intermediate Water Cherenkov Detector for HyperK

Pablo @ 2nd HK-ES meeting (IFAE) -- 2024/09/30



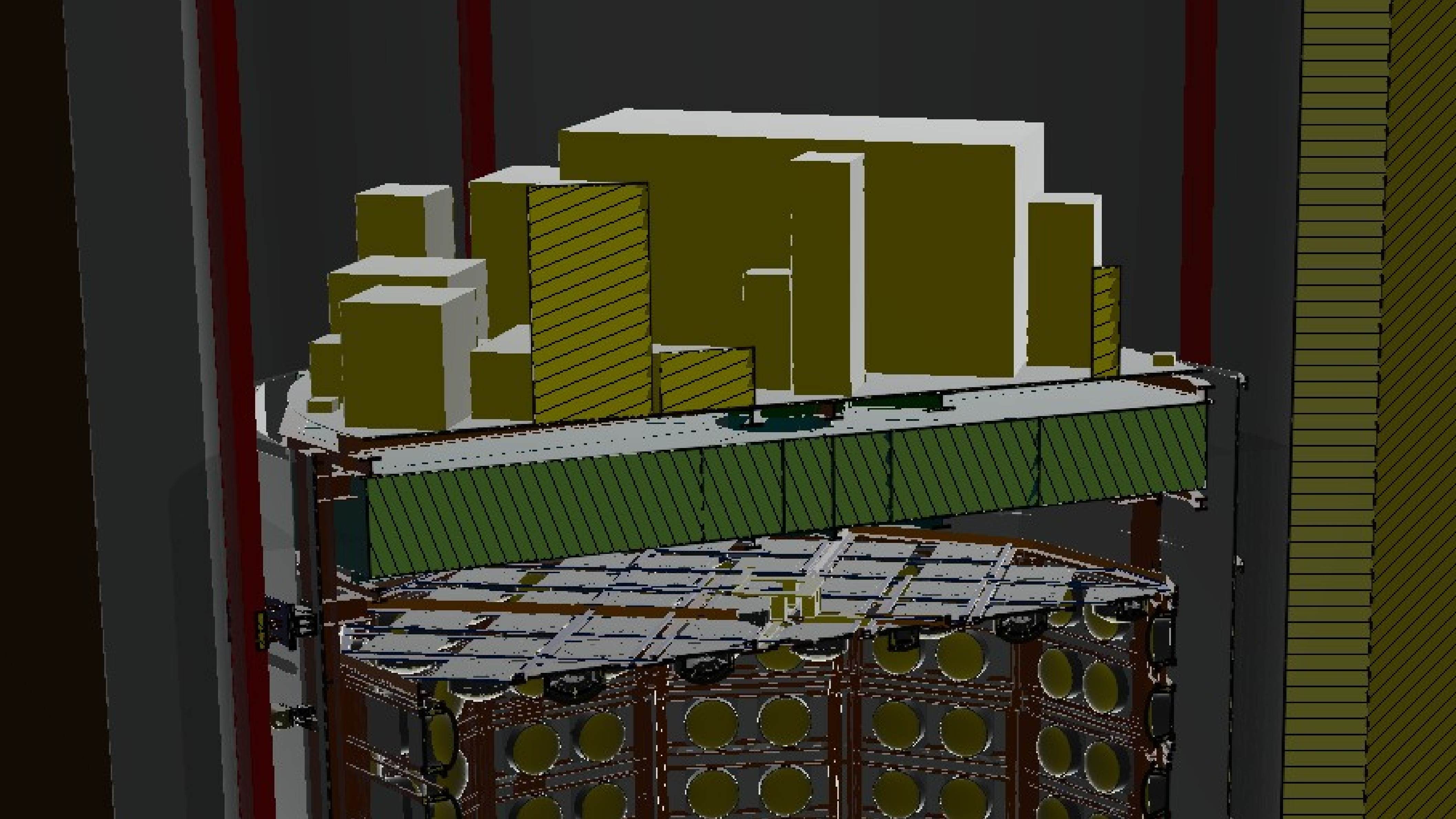
The IWCD is a new 600-ton (300 ton inner volume) intermediate detector for the HyperK project located ~850 m downstream of the J-PARC neutrino source

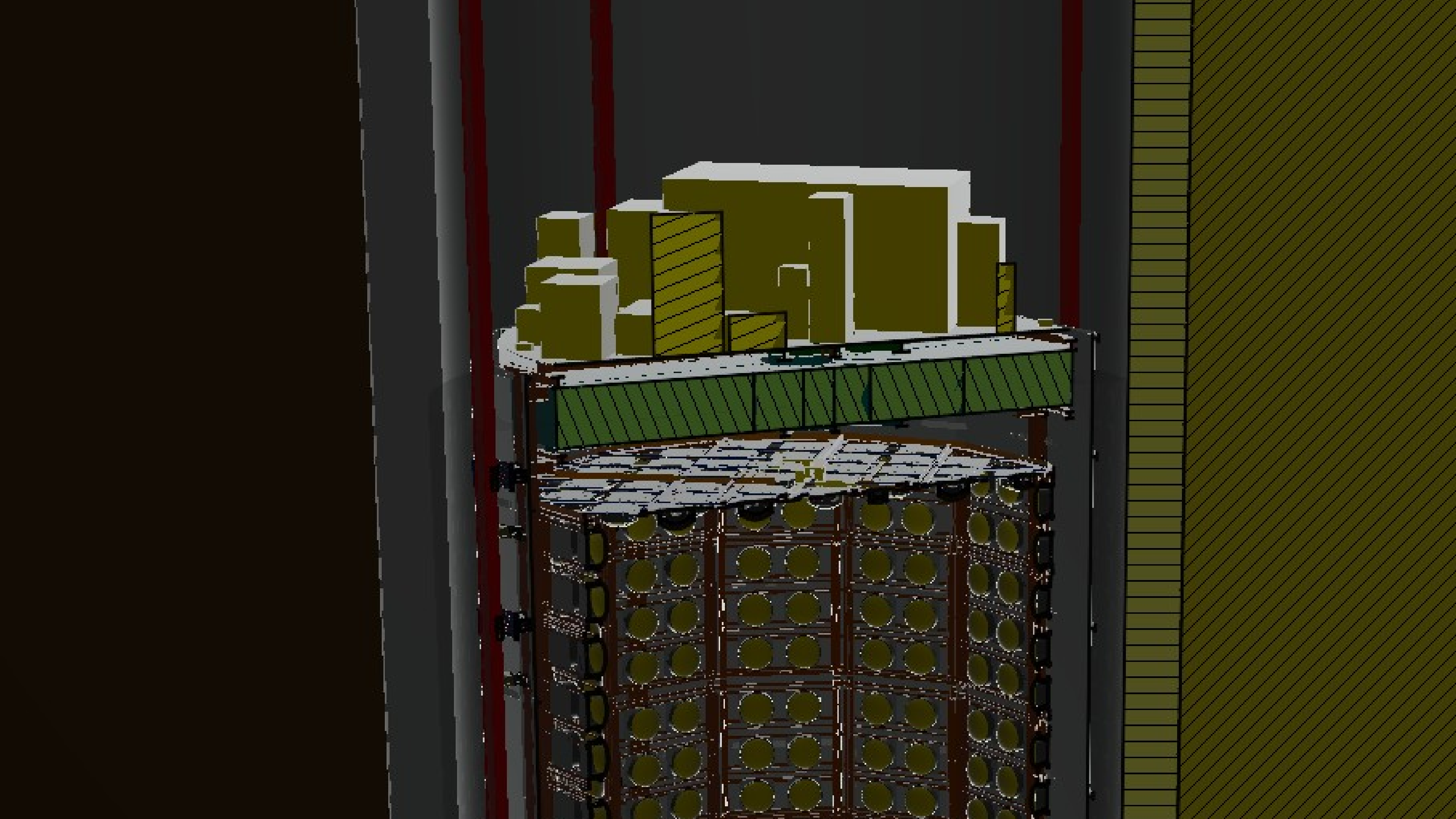
→ the main goal is to make measurements to control systematic errors for the long baseline (and atm) program

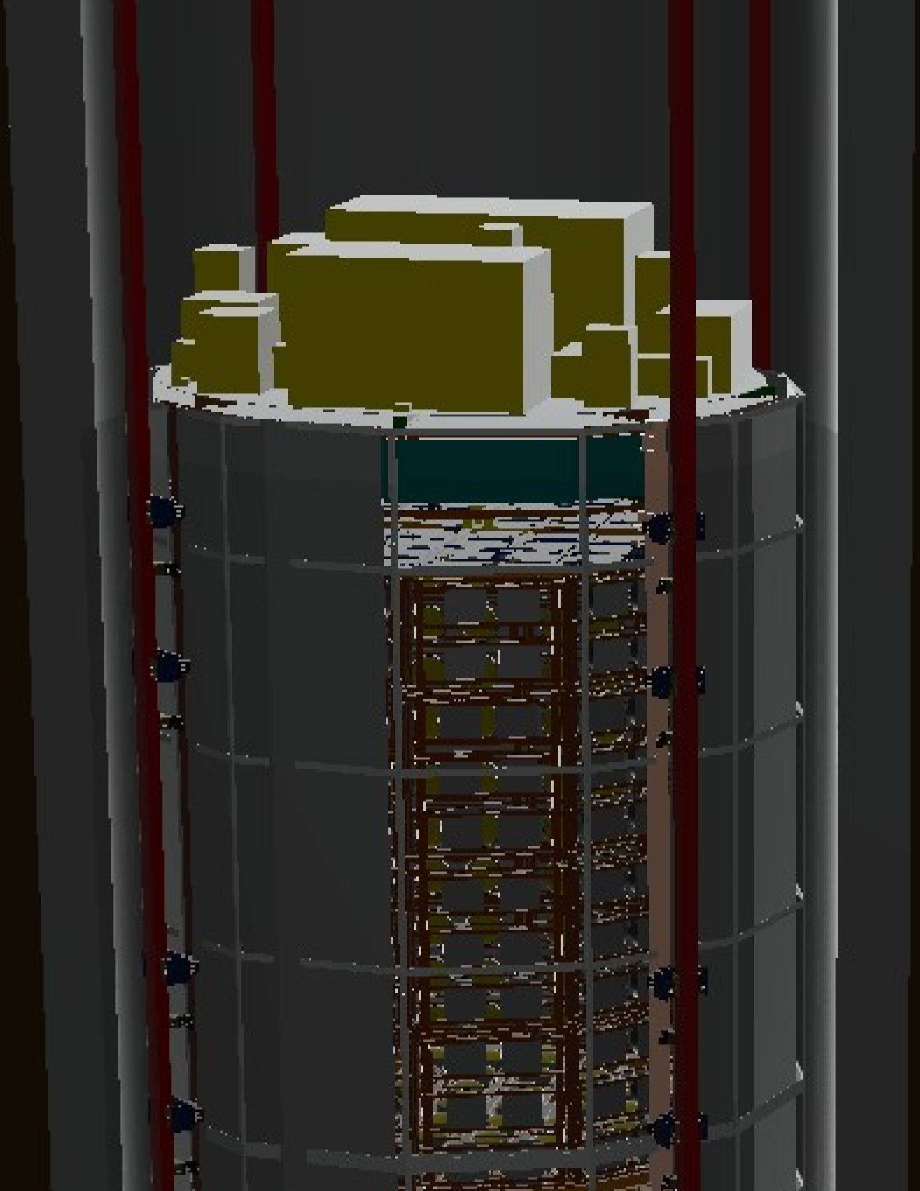
IWCD has unique capability to move vertically to probe different off-axis angles and thus neutrino energy spectra to study energy reconstruction, flux characterization and cross sections. Same target as HK-FD.

IWCD will precisely measure the neutrino-nucleus cross section ratios with the most impact in the LBL analysis

$$\frac{\sigma_{\nu_e}(E_\nu)}{\sigma_{\nu_\mu}(E_\nu)}, \frac{\sigma_{\bar{\nu}_e}(E_{\bar{\nu}})}{\sigma_{\bar{\nu}_\mu}(E_{\bar{\nu}})}$$







The IWCD Design

IWCD is a simplified water-Cherenkov detector in the sense that it needs to be as buoyant (light) as possible. It will float in a floaded pit moving vertically according to the surrounding water level

A lot of work has been going on in the last year to optimize and make a feasible design:

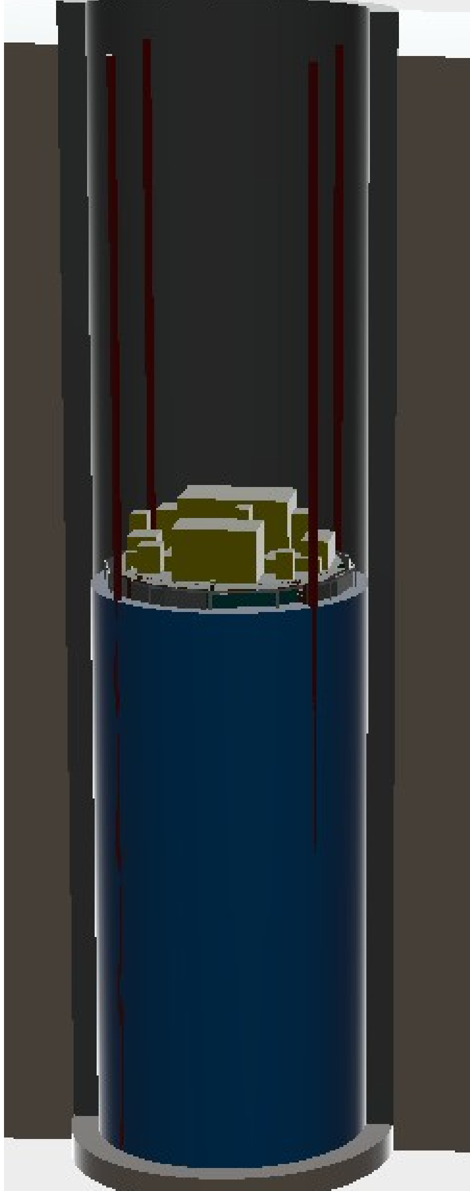
- Inner volume (ID): 7 m in diameter and 8 m in height
- Pit diameter will be 10.2 m
- To minimum off-axis angle of no more than 1.7º

Instrumented with 370 mPMTs in the ID, of which 100 are those ready for WCTE

The outer detector (OD) design is similar to Hyper-K OD with 3-inch PMT and wavelength shiPing plates (~370 for IWCD)

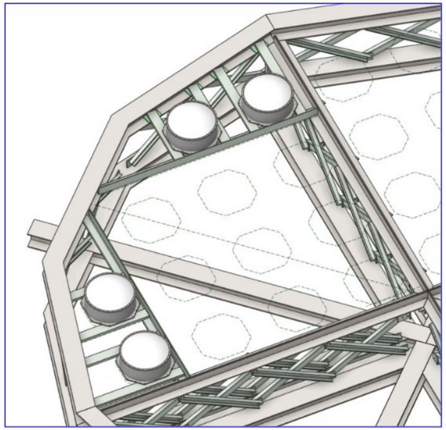
Tyvek sheets will separate ID from OD, and a geomembrane detector from the pit

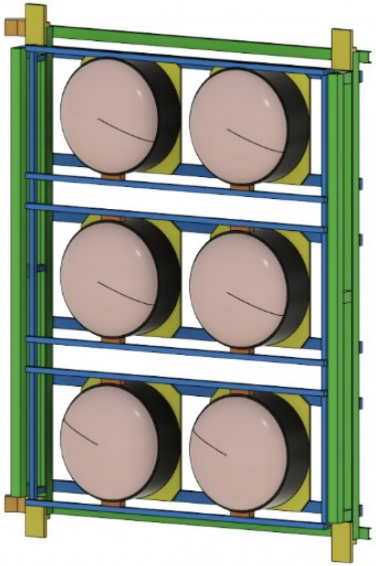
Most of the instrumentation (electronics, calibration, etc.) will be installed on top of the detector and move with it



12-gon stainless steel structure frame on which supermodules (SM) with ID mPMTs and OD PMTs are installed

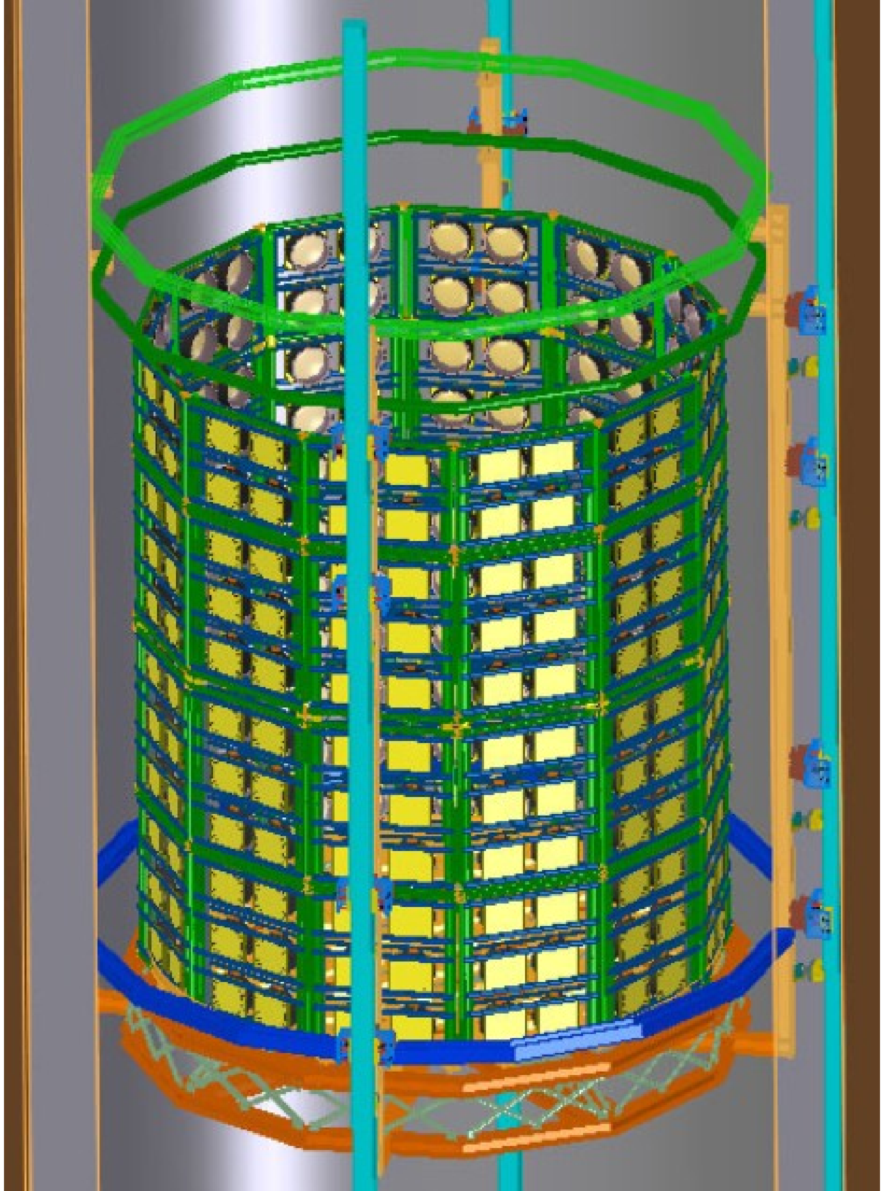
- 3x2 and 2x2 SMs for the barrel
- Larger SMs for the end caps

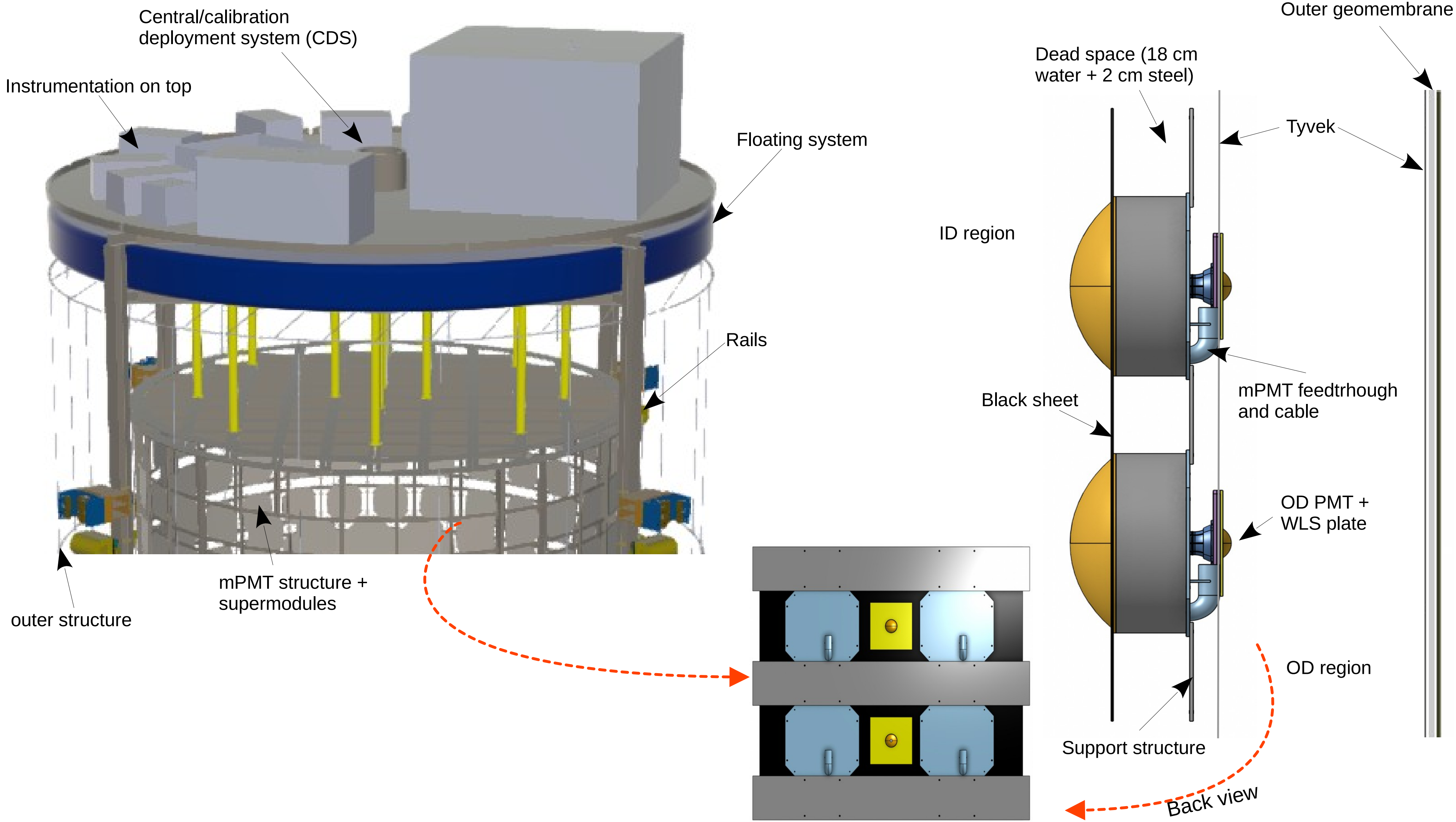




Sparser and lighter outer structure surrounding the PMT structure on which the geomembrane is attached and which defines the OD

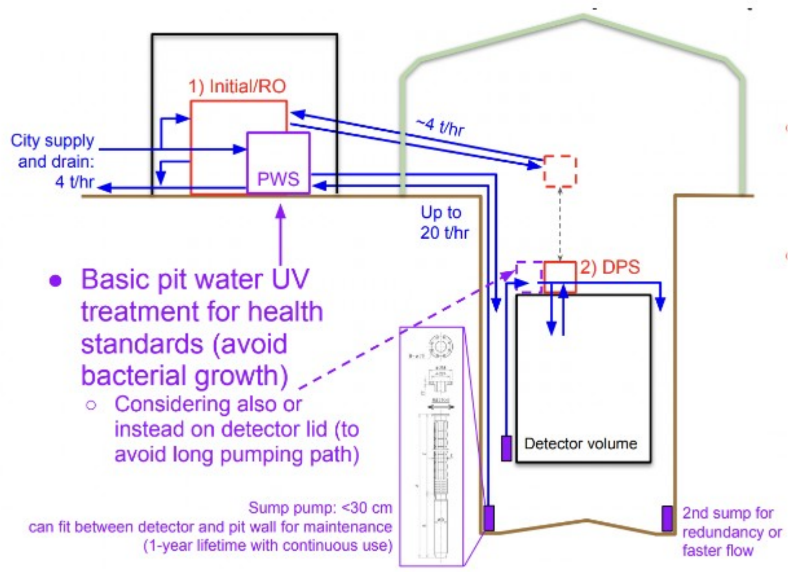
Vertical rails and a floating system on top allow and guide the vertical movement




Central/calibration deployment system (CDS)
Instrumentation on top
Floating system
Rails
outer structure
mPMT structure + supermodules
Outer geomembrane
Dead space (18 cm water + 2 cm steel)
Tyvek
ID region
mPMT feedtrhough and cable
Black sheet
OD PMT + WLS plate
OD region
Support structure
Back view

Water system

• Reverse osmosis system at ground level for initial filling
• Recirculation system located on top of the detector to maintain water quality
• Ion exchange resins, filter and UV organic removal
• Water system for the pit is also necessary, but much simpler

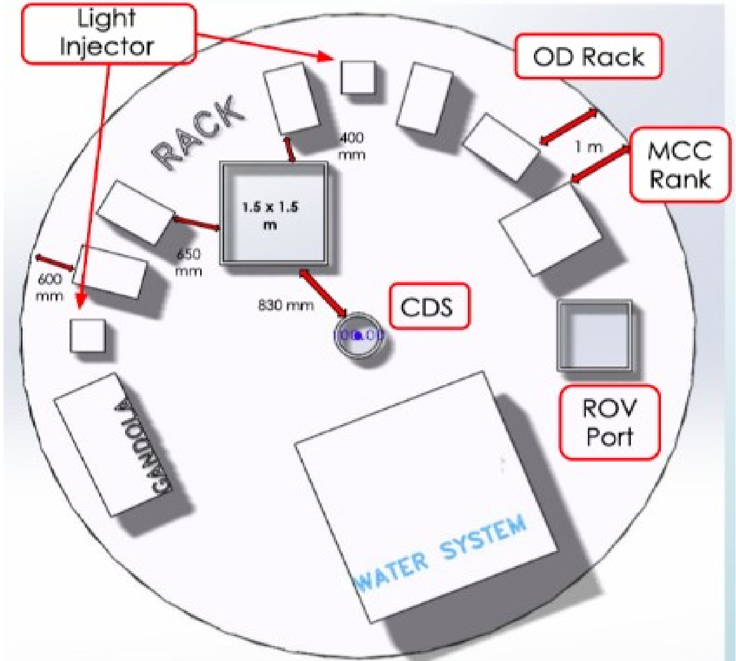


Calibration

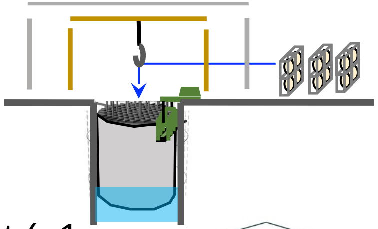
• Deployed through the CDS:
  - Radioactive sources (Ni-Cf, Am-Be)
  - Xe lamp + diffusser ball

• Lights and cameras for photogrammetry

• Light injectors at different locations of the detector



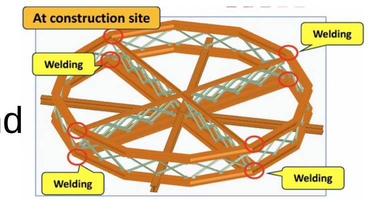
After Facility Tent Building Complete



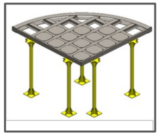
Assembly

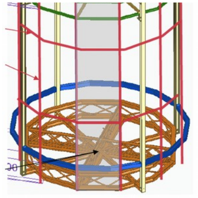
Surface Work

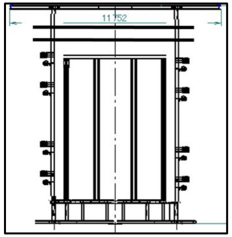
1)Assemble bottom frame with membrane & OD Tyvek, pillars and bottom sparse frame (10 days)



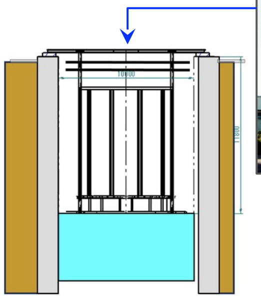
2)Install vertical frame with moving system, barrel outer OD Tyvek and membrane, top frame and lifting jig (1 month + 8 days)







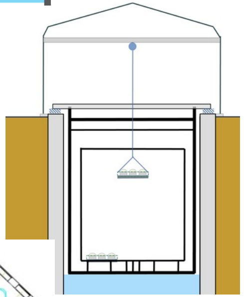
3)Crane into pit and attach to guide rails and hang by lifting jig (3 days)



Total: 2 months

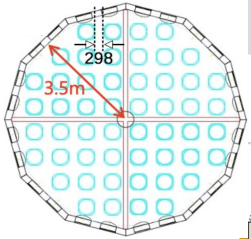
In-pit Work

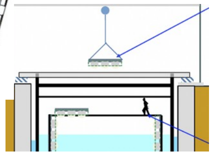
4)Install bottom and barrel SMs, calibration, cabling, and blacksheet (~1 days/SM → 2 months)



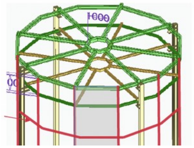
5)Install top sparse structure (2 days)

6)Install top Sms, OD Tyvek and CDS arm (1 day/SM → 1 week)

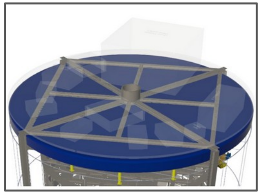




7)Install top outer structure with yellow pillars, OD Tyvek, and membrane (1 week)

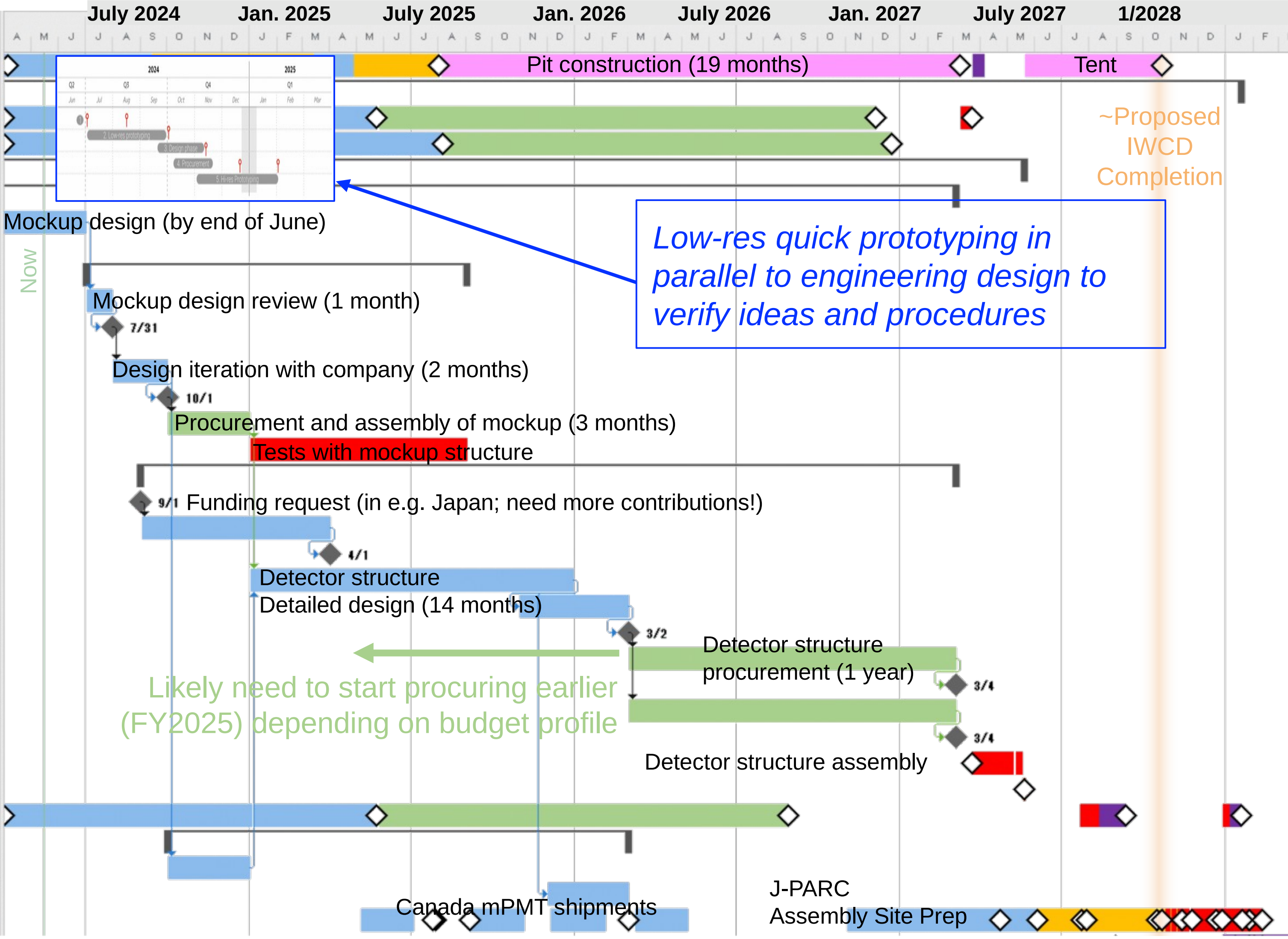


8)Install float and lid (2 weeks)



Total: 2.2 months

Name	Duration	Start
IWCD Site/Facility	1193days?	Sat 4/1/23
IWCD Detector	1320days?	Tue 1/3/23
Moving System	1082days?	Thu 2/2/23
Outer Membrane	714days	Mon 4/1/24
Support Structures	1083days	Sat 4/1/23
Design and Procurement	1028days	Sat 4/1/23
Basic Design	328days	Sat 4/1/23
Initial design for facility input	0days	Mon 9/4/23
Prototype (Mockup) Structure	305days	Tue 7/2/24
Prototype Design Review	22days	Tue 7/2/24
Complete Prototype design for company consultation	0days	Wed 7/31/24
Prototype design iteration with com	44days	Thu 8/1/24
Start prototype procurement	0days	Tue 10/1/24
Prototype procurement and assemt	66days	Wed 10/2/24
Prototype tests	173days	Thu 1/2/25
Full Structure	656days	Sun 9/1/24
Funding Request	0days	Sun 9/1/24
Funding Review	152days	Mon 9/2/24
Funding Available	0days	Tue 4/1/25
Detailed Design	260days	Thu 1/2/25
Detailed Design Review	88days	Fri 10/31/25
Start Support Structures Procureme	0days	Mon 3/2/26
Inner Support Structure Procuremer	264days	Tue 3/3/26
Deliver SM Structures	0days	Thu 3/4/27
Outer structure procurement	264days	Tue 3/3/26
Deliver Outer structure	0days	Thu 3/4/27
Assembly of outer structure	40days	Mon 3/22/27
Installation of outer structure	3days	Tue 5/18/27
Water Systems	1320days?	Tue 1/3/23
All-Systems Reviews	370days	Wed 10/2/24
All-Systems Review 1	66days	Wed 10/2/24
All-Systems Review 2	66days	Mon 12/1/25
IWCD Integration	334days	Mon 11/2/26



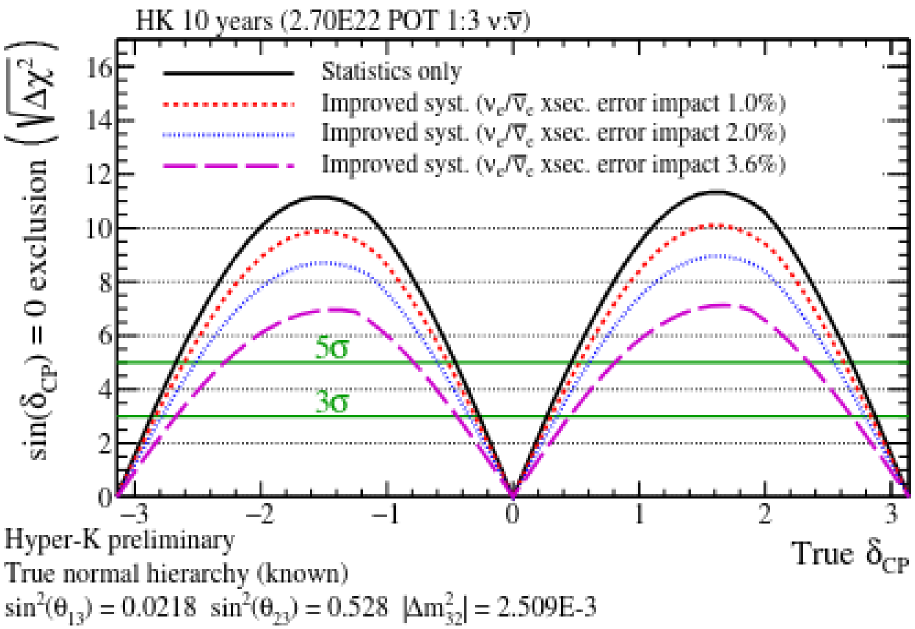
Importance of IWCD physics measurements

CP violation

The e over μ, neutrino antineutrino double ratio is one of the most limiting uncertainties in the sensitivity of HK to CPV

Currently the uncertainty on this quantity is estimated from theory, of 4.9%.

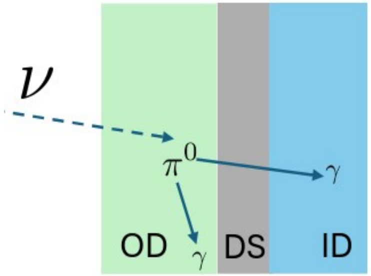
IWCD can constrain this uncertainty to 3.6% (preliminary)



This measurement largely relies on IWCD's capability to reconstruct pure samples of electron (anti)neutrinos

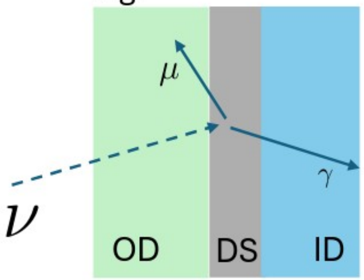
→ *Intrinsic electron-like background*

Sister Gamma e.g.



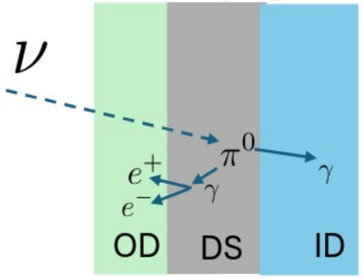
Sister gamma from pi-0 decay deposits energy in OD

Muon e.g.



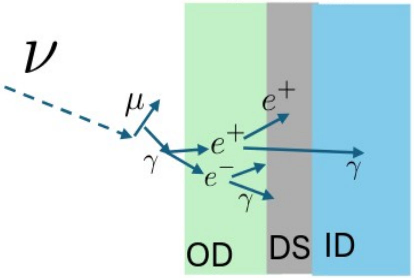
Muon from neutrino interaction deposits energy in the OD

EM Shower (gamma from pi-0) e.g.

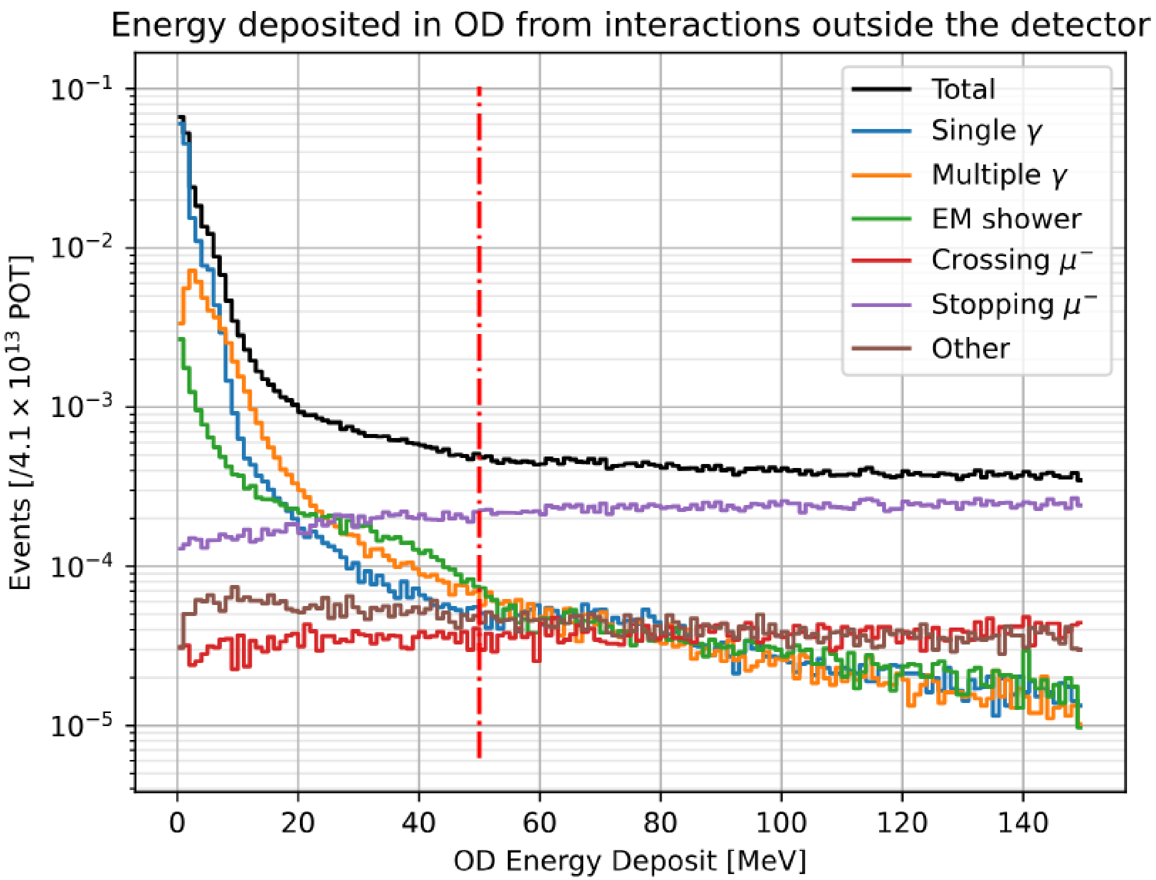


Sister gamma from pi-0 decay undergoes EM shower and that shower is detected in the OD

EM Shower (gamma not from pi-0) e.g.



Background gamma is a bremsstrahlung gamma and the rest of the shower detected in the OD



Importance of IWCD physics measurements

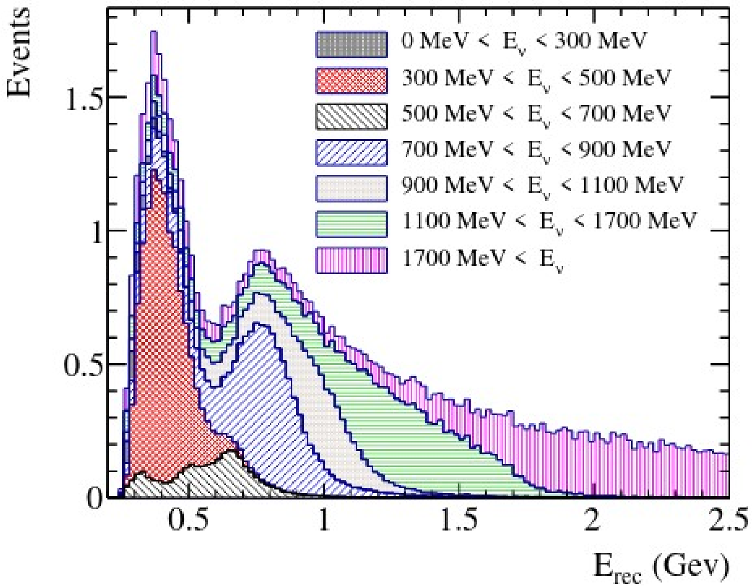
Feed-down and true neutrino energy

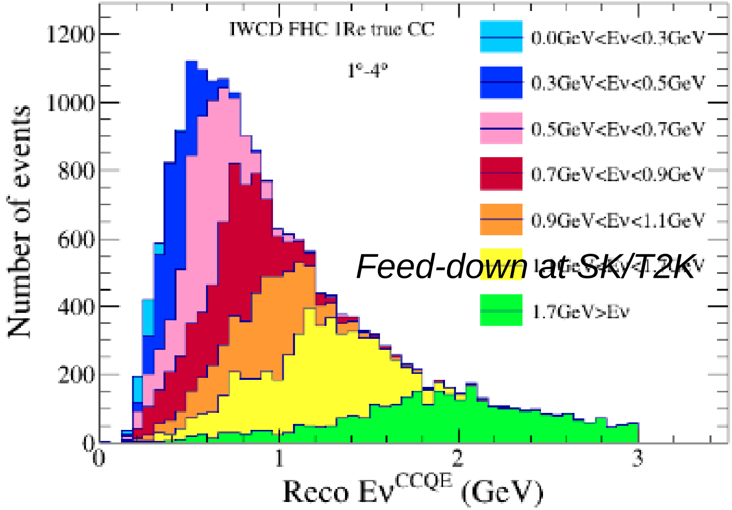
The energy scale of HK-FD is determined through calibration and the reconstructed energy inferred from CCQE kinematics

However reconstruction and intrinsic neutrino interaction processes (non-QE) tend to make the reconstructed energy of a neutrino lower than its true energy (feed-down)

A similar effect is seen due to the uncertainty in the direction of the beam and its relation with the neutrino spectrum

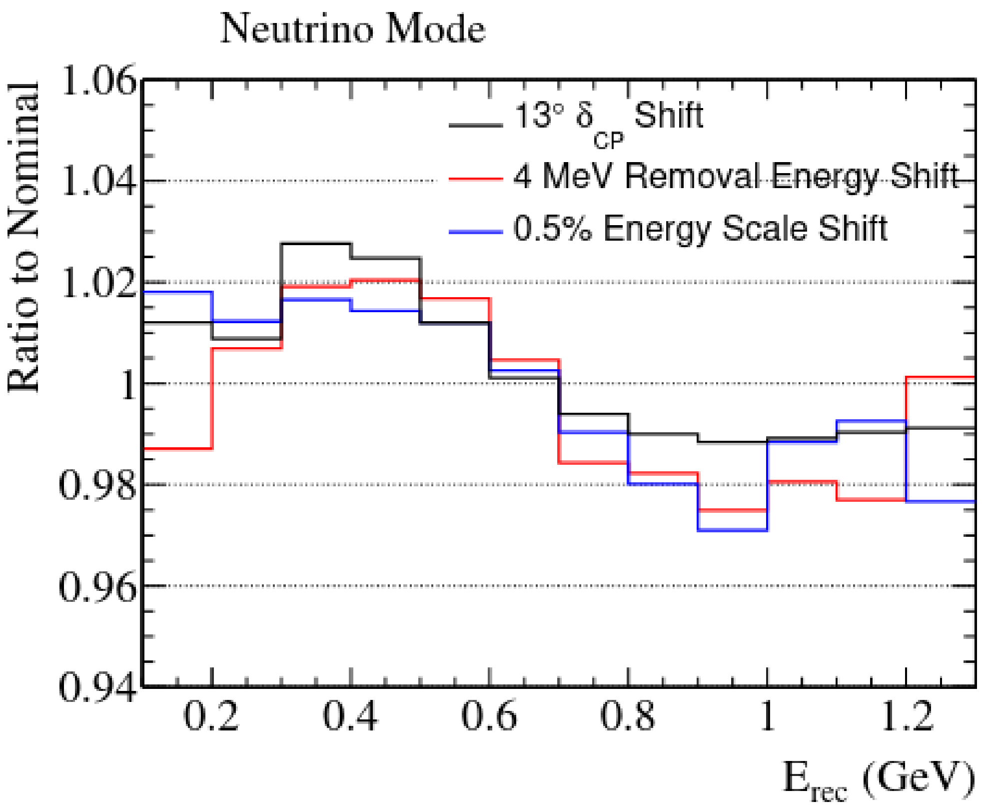
This alters and diffuses the shape of oscillation probabilities loosing sensitivity about the oscillation parameters

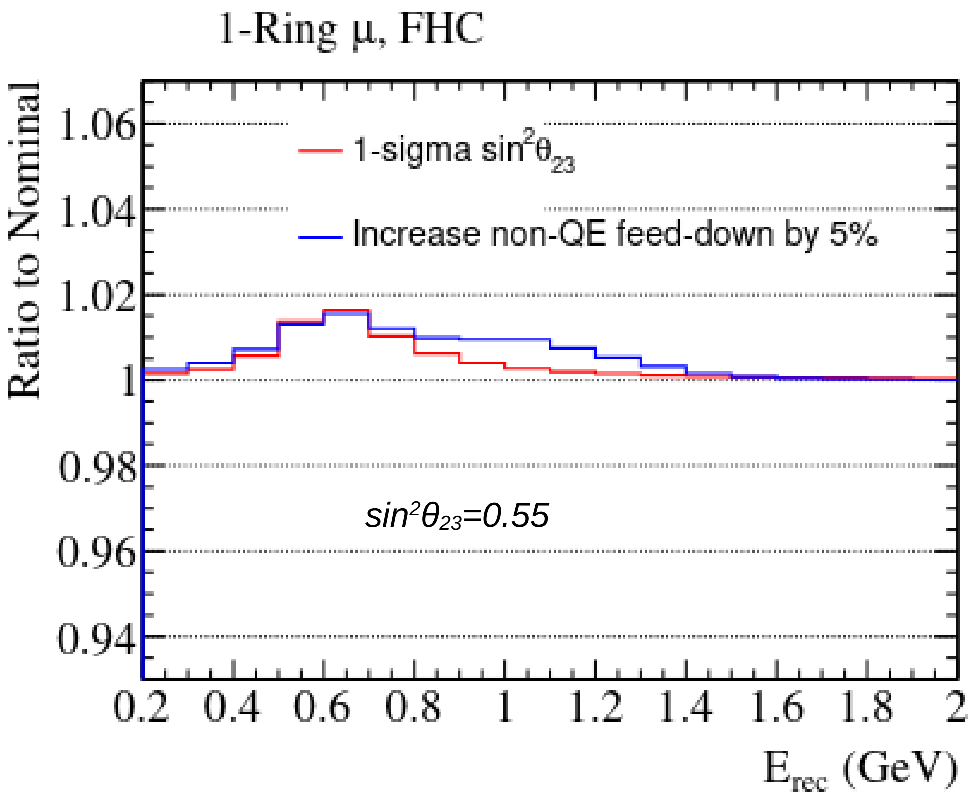




Importance of IWCD physics measurements

→ *Impact on CPV and θ_{23}*





Summary

- Challenging detector R&D profitting from WCTE and past WC detectors

- Very limited resources and tight schedule but important for the CP-discovery focused HK program

- Capable of significantly reducing sensitivity-dragging systematic uncertainties in LBL

- Other gains not treated here:
  - Improved BSM searches (e.g. steriles, neutrino decay) by combining ND280 and IWCD data
  - Reducing systematics for sub-GeV atmospheric neutrinos and, to a lesser extent, proton decay
  - Neutrino beam flux characterization
  - ND280 – IWCD cross-validation (e.g. $\sigma_\nu(O)/\sigma_\nu(C)$)