Introduction and Status of the Water Cherenkov Test Experiment

Mark Hartz

WCTE Workshop, 2020/11/23

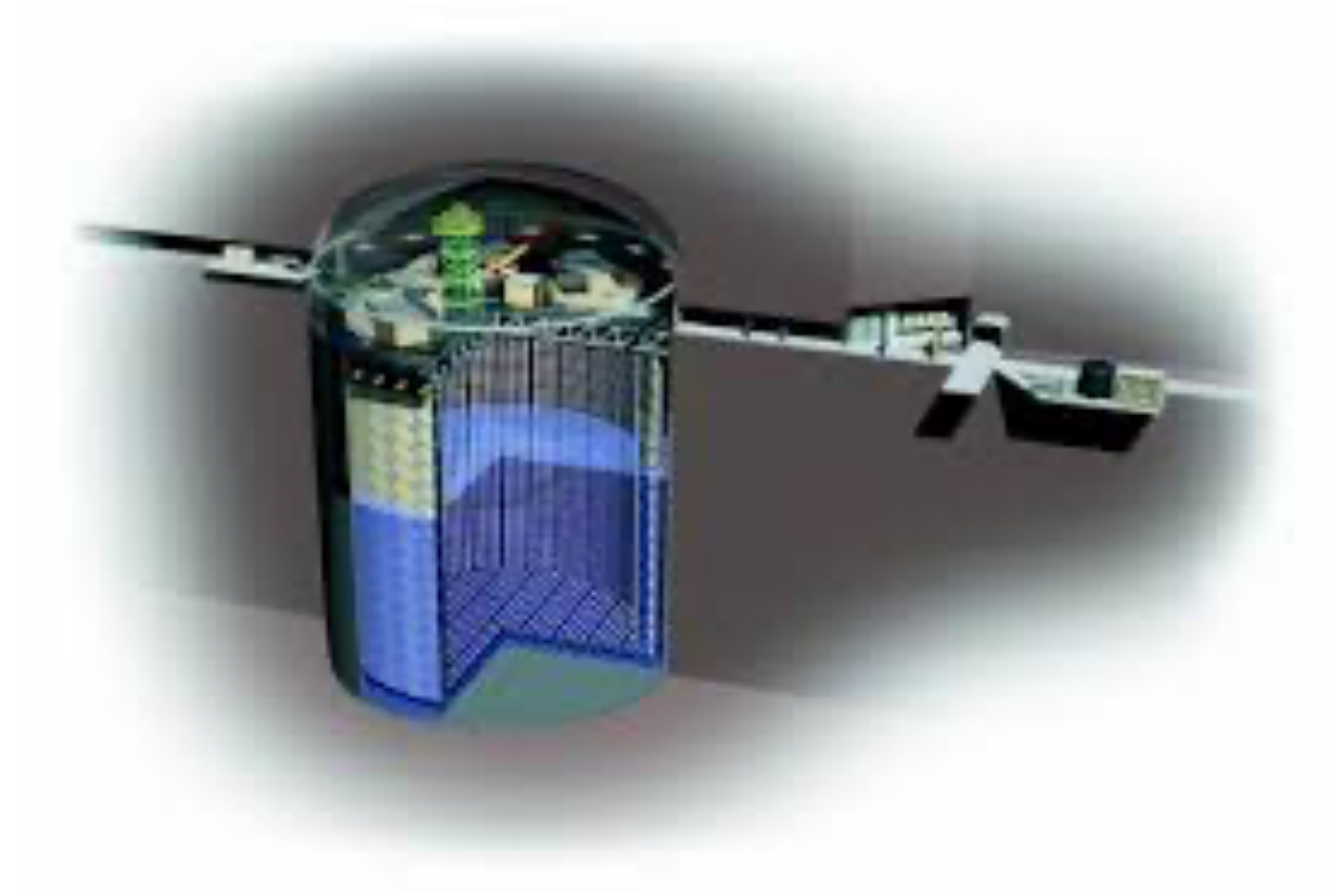
Outline

- Motivation of a water Cherenkov test beam experiment
- Proposed configurations of the WCTE
- Status of the WCTE
- Introduction to this workshop

Water Cherenkov Detector Technology - Present

- **The Super-K experiment:**
  - Study of atmospheric and solar neutrinos
  - Search for nucleon decay
  - Far detector for T2K accelerator neutrino studies
  - As announced at Neutrino 2020 loading with **$Gd_2(SO_4)_3$** is starting - allow high efficiency detection of neutrons
  - Uncertainties on detector modeling for T2K analyses range from **2.5%-13%** on predicted event rates
- Water/ice Cherenkov detectors as neutrino telescopes (**IceCube, KM3NeT**)

Super-Kamiokande



T2K, Neutrino 2020

Table 21: Uncertainty on the number of event in each SK sample broken by error source before the BANFF fit.

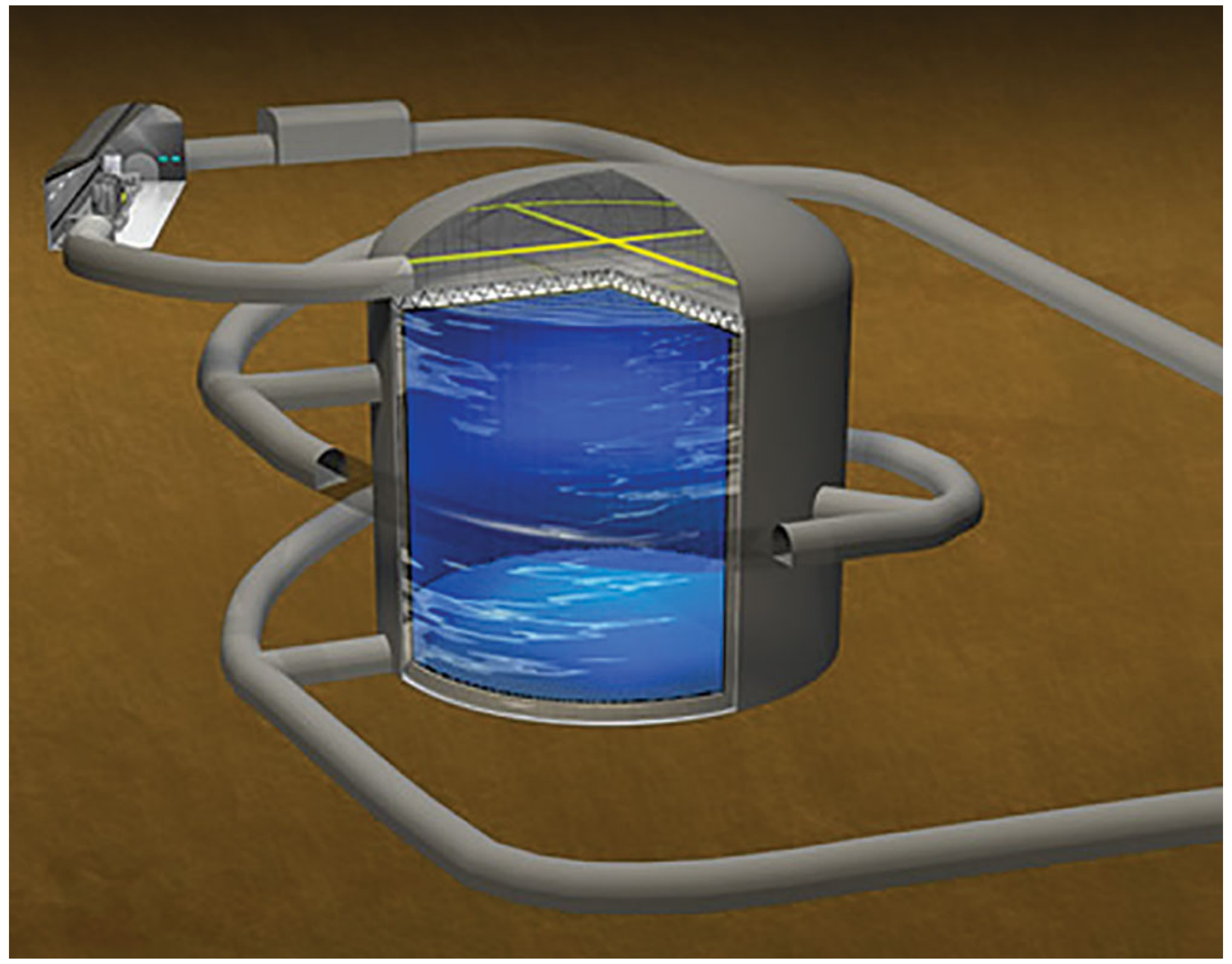
	1Rμ		1Re			
Error source	FHC	RHC	FHC	RHC	FHC CC1π^+	FHC/RHC
Flux	5.1%	4.7%	4.8%	4.7%	4.9%	2.7%
Cross-section (all)	10.1%	10.1%	11.9%	10.3%	12.0%	10.4%
SK+SI+PN	2.9%	2.5%	3.3%	4.4%	13.4%	1.4%
Total	11.1%	11.3%	13.0%	12.1%	18.7%	10.7%

KM3NeT **multi-PMT**
Digital Optical Module (DOM)

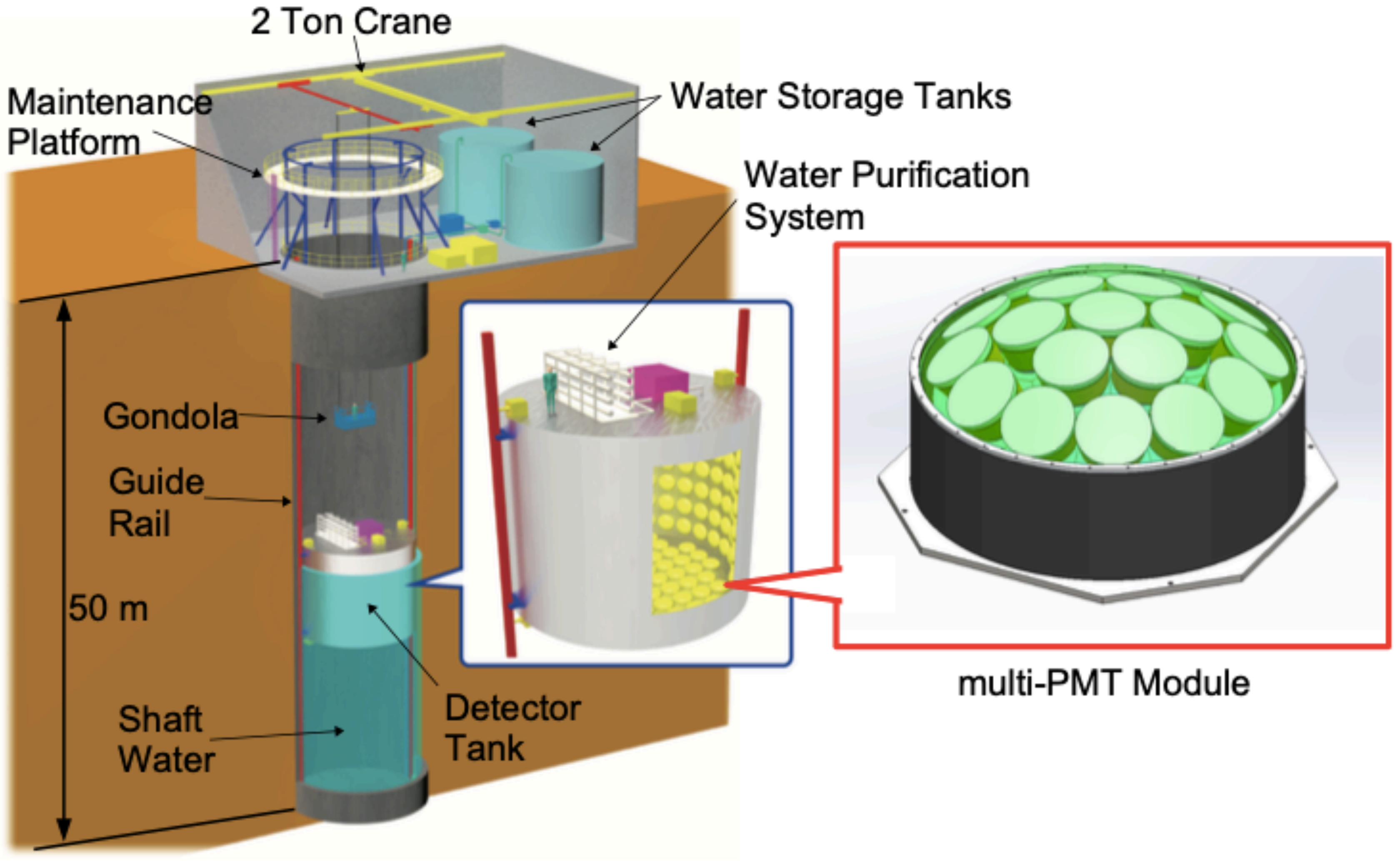
The Future, Hyper-Kamiokande

- Hyper-K is the next-generation successor of Super-K
  - **8x larger fiducial mass** than Super-K
  - **2.5x more intense beam** compared to current T2K
  - Neutrino oscillation measurements made with 1-3% statistical precision
  - Systematic error reduction is critical
    - Calibration of the detector response at the 1% level
    - Understanding of neutrino flux and interaction cross section systematic errors at the 1%-3% level
- Intermediate Water Cherenkov Detector (IWCD) is part of Hyper-K project
  - Measure neutrino interactions over a range of neutrino energies
  - Detector size is ~800 ton, 6 m tall x 8 m diameter inner detector
  - Requires calibration at the 1% level
  - Uses **multi-PMT** photon detectors

Hyper-Kamiokande Detector

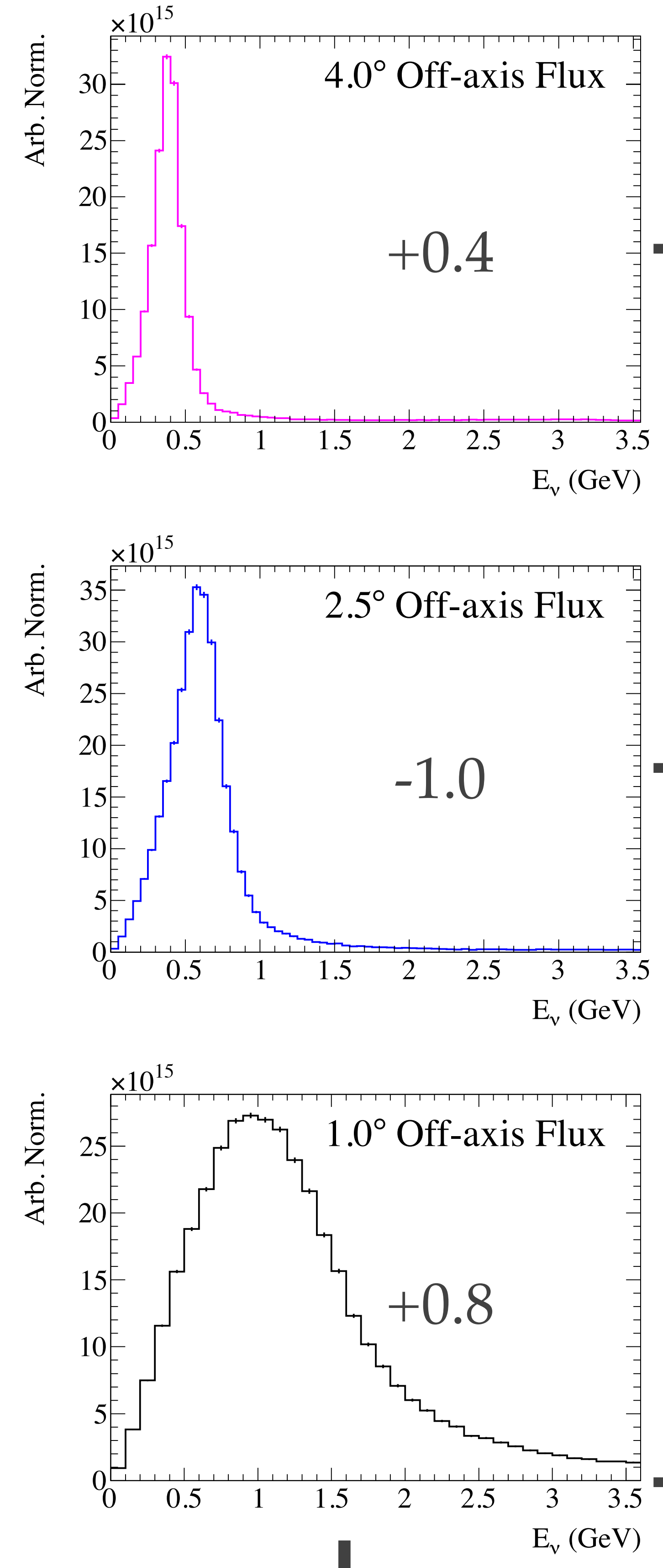


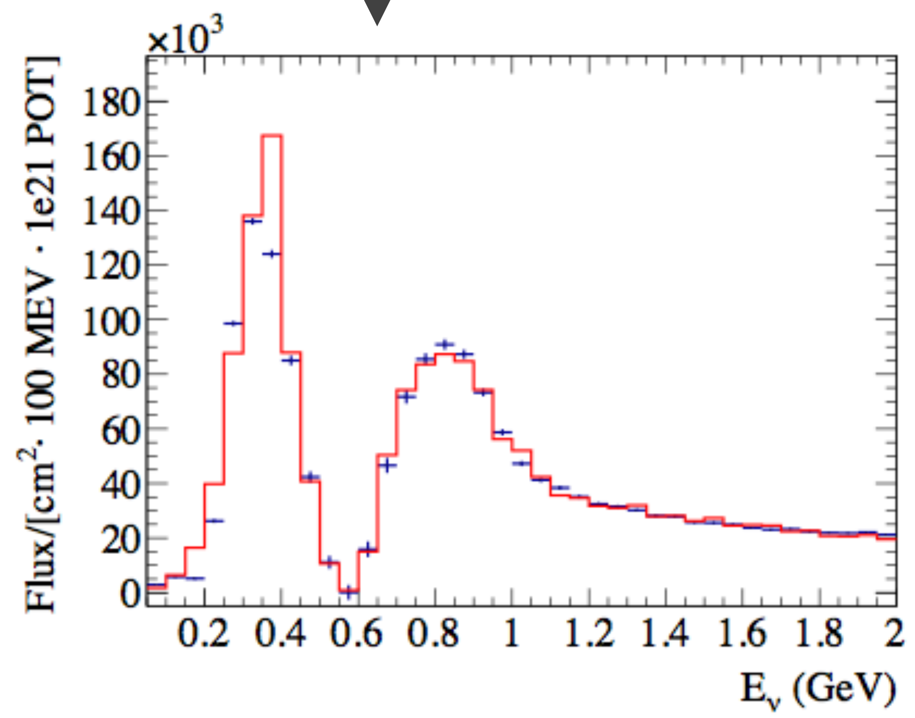
IWCD



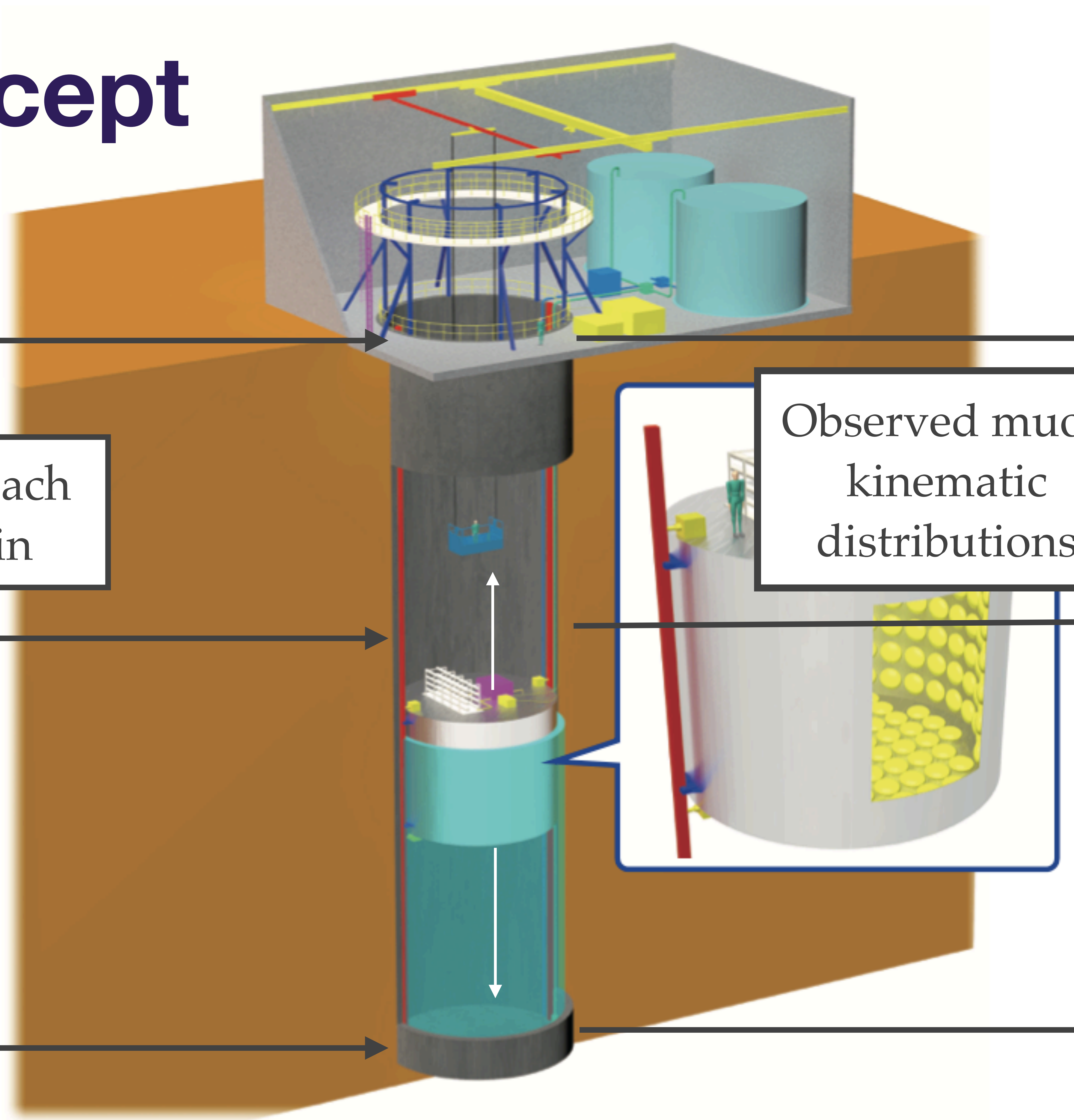
NuPRISM Concept

Hyper-Kamiokande

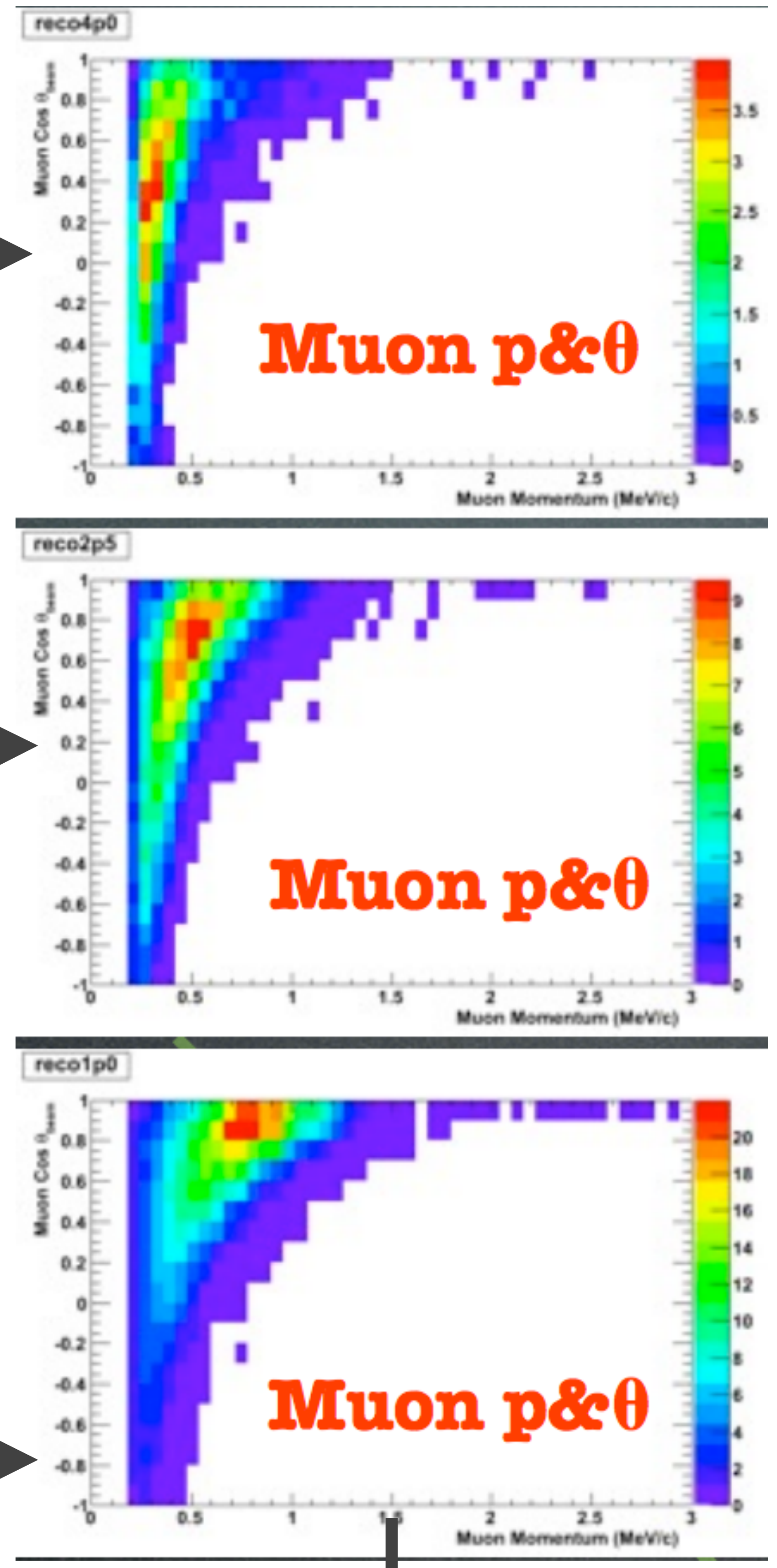


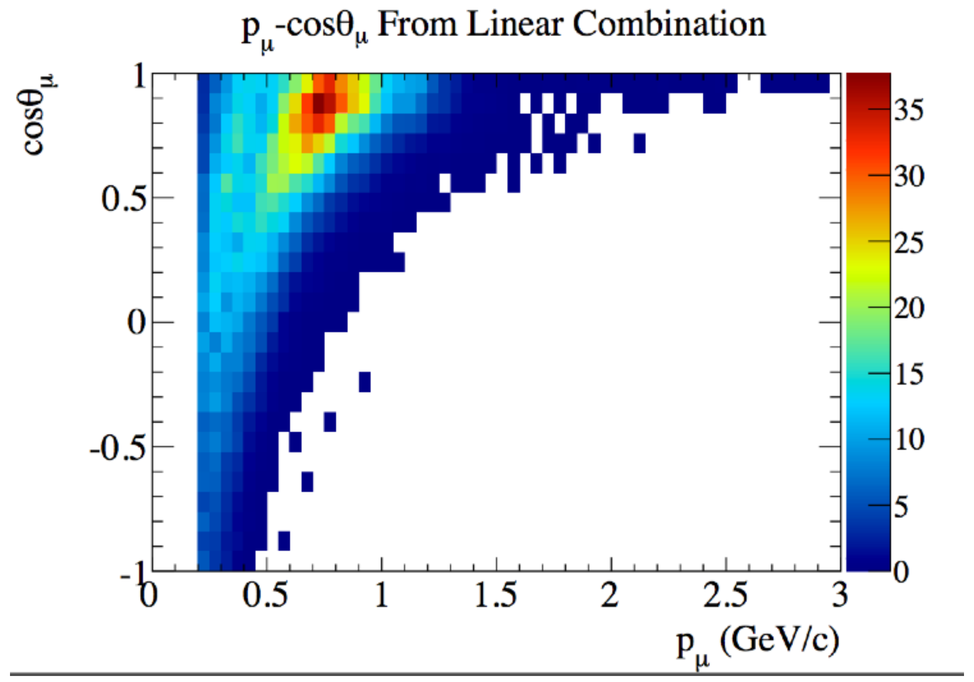


Spectra at each off-axis bin



Observed muon kinematic distributions





Linear combinations reproduce the oscillated flux, and predict muon kinematic distributions for the oscillated flux

Need precise detector calibration at each position!

The Future, Beyond Hyper-Kamiokande

- **ESSnuSB** neutrino oscillation experiment at second oscillation maximum
  - Neutrino source at European Spallation Source
    - Nearby water Cherenkov near detector
  - Megaton scale water Cherenkov far detector ~540 km from neutrino source
  - Similar requirements to Hyper-K
- **THEIA** experiment is another many kiloton scale detector
  - Use **water-based liquid scintillator (WbLS)** in detector to have both Cherenkov and scintillation light
    - New technology requires:
      - Intermediate timescale smaller detectors to develop WbLS technology
      - Development of photosensor technologies to take advantage of two types of light
    - **More in talk by M. Wilking on Wednesday**

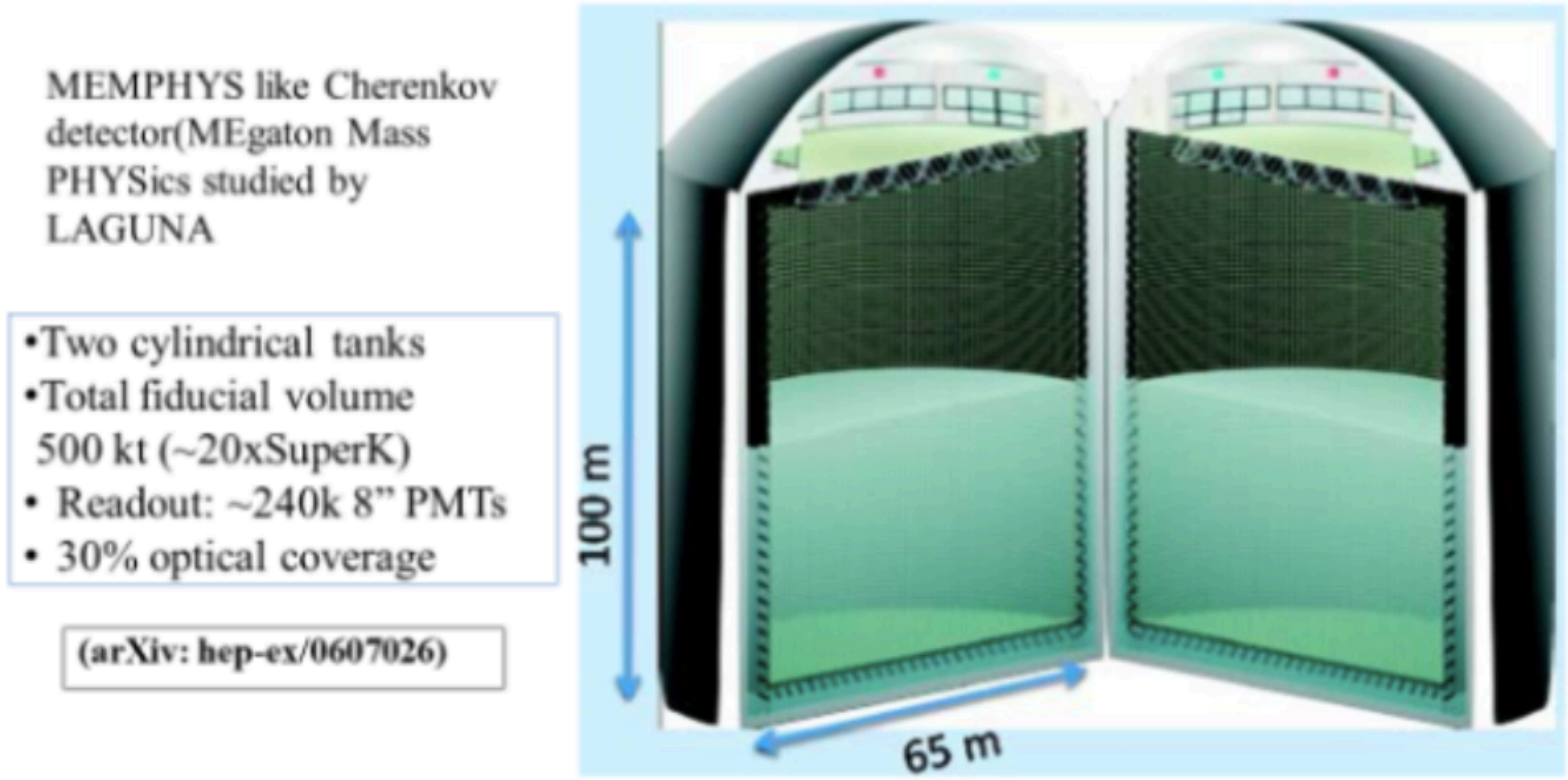


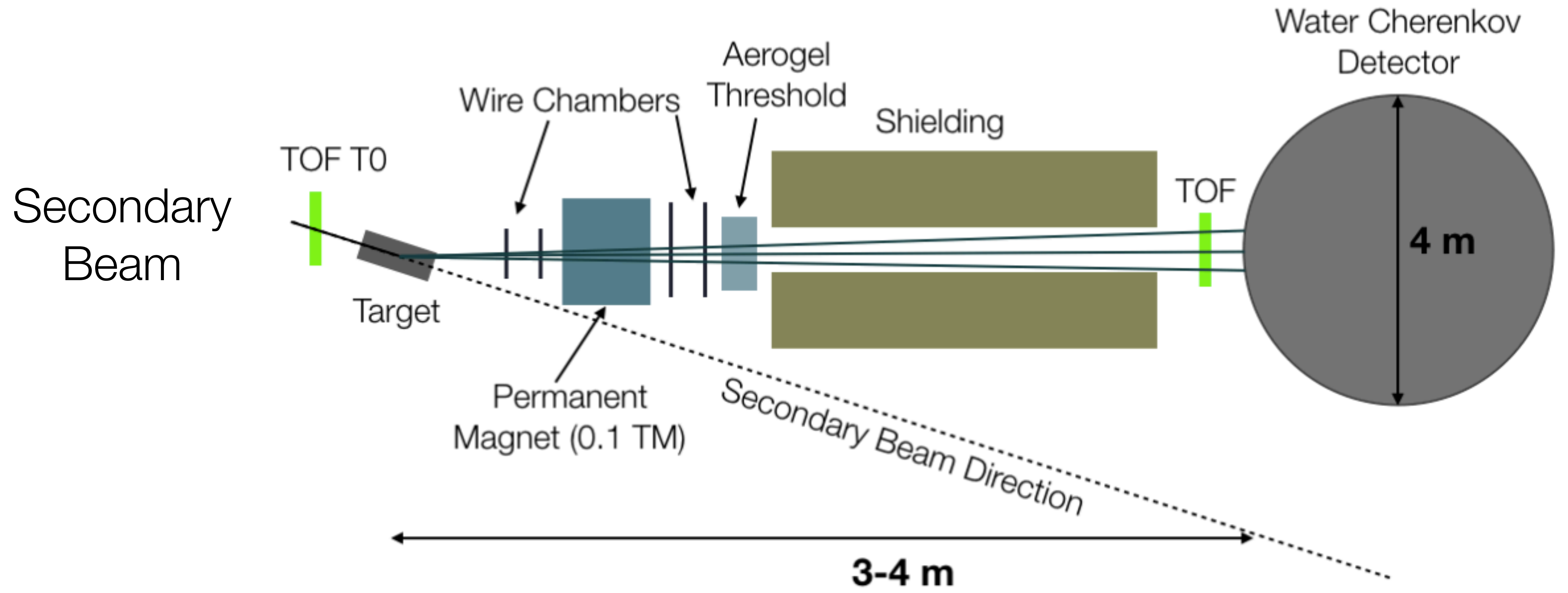
FIG. 3. Drawing of the MEMPHYS water Cherenkov detector design.

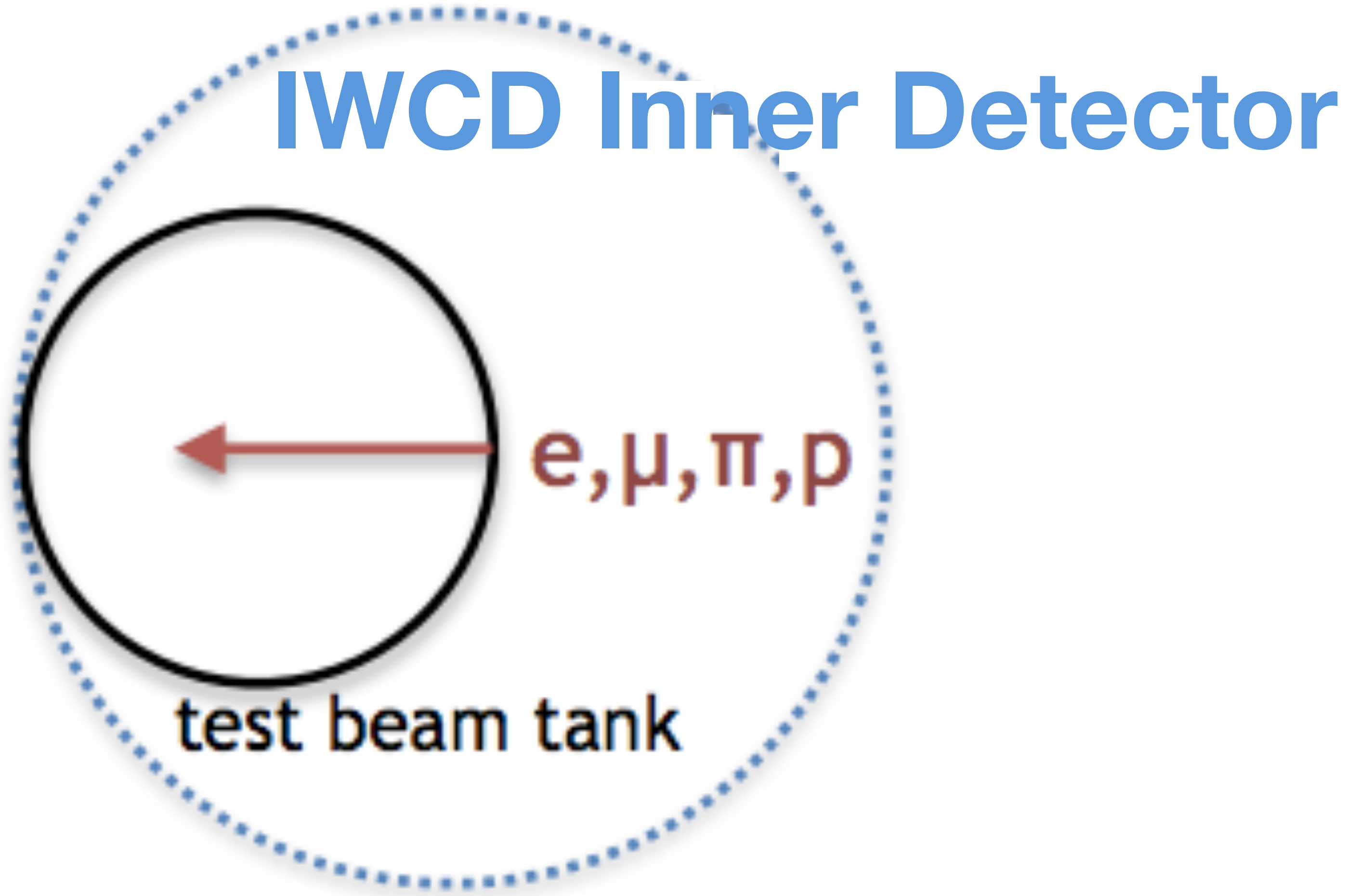
THEIA physics program includes:

Neutrinoless double beta decay
Long baseline neutrinos
Solar neutrinos
Nucleon decay
Supernova neutrinos
Geoneutrinos

Proposed Water Cherenkov Test Experiment (WCTE)

- Platform to:
  - Test new new technologies for water Cherenkov/optical detectors, e.g. multi-PMTs, WbLS, etc.
  - Apply calibration techniques with known particle fluxes to validate 1% level calibration at GeV scale
  - Measure important physics processes such as Cherenkov light production and hadron scattering necessary detector modeling
- We propose a test experiment that is **~4 m diameter x 4 m tall**
- Tertiary or secondary **particle fluxes of $\pi^{\pm}$, p, μ, e in the 200 MeV/c-1200 MeV/c range**

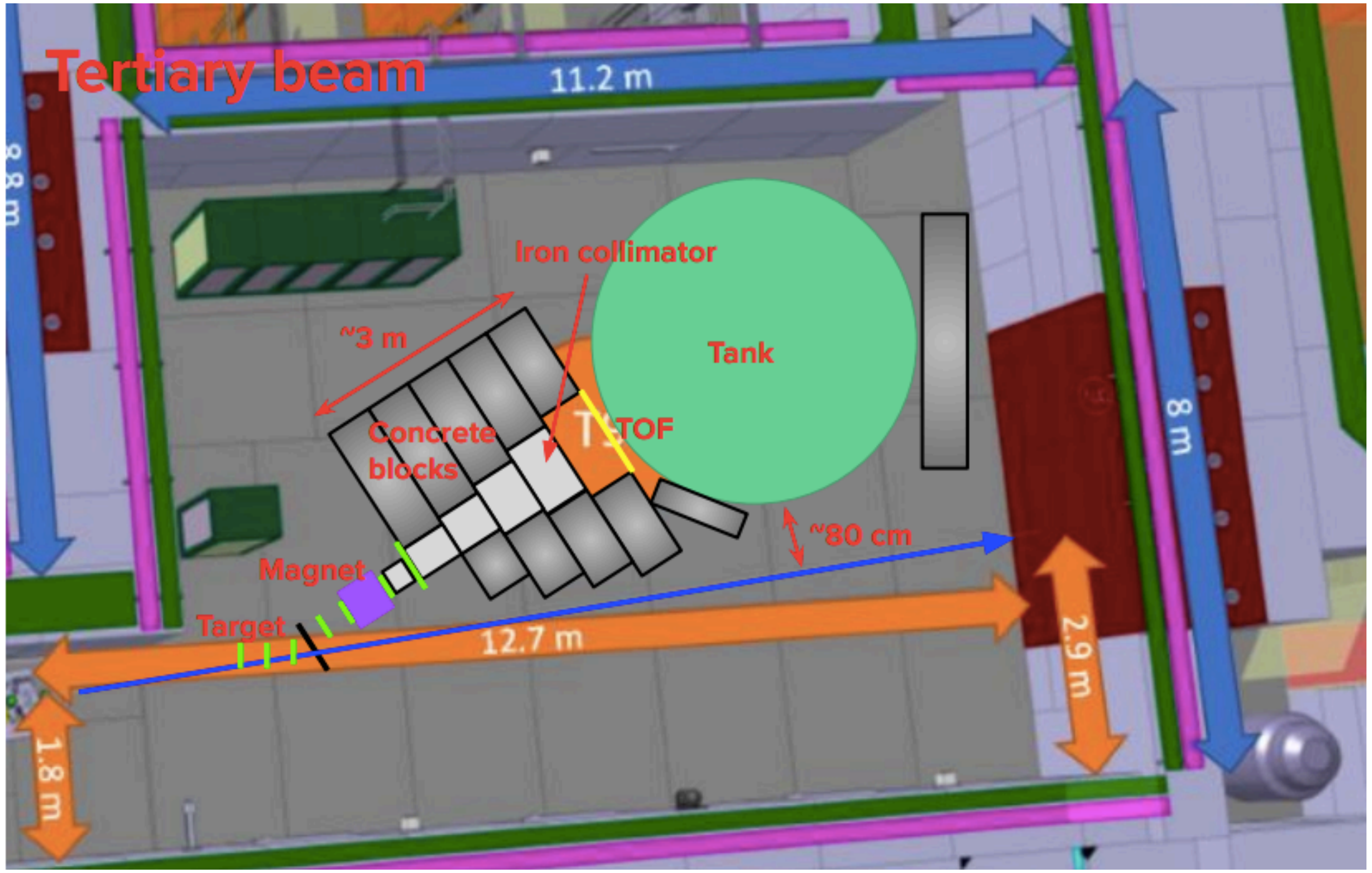




Where to Operate the WCTE

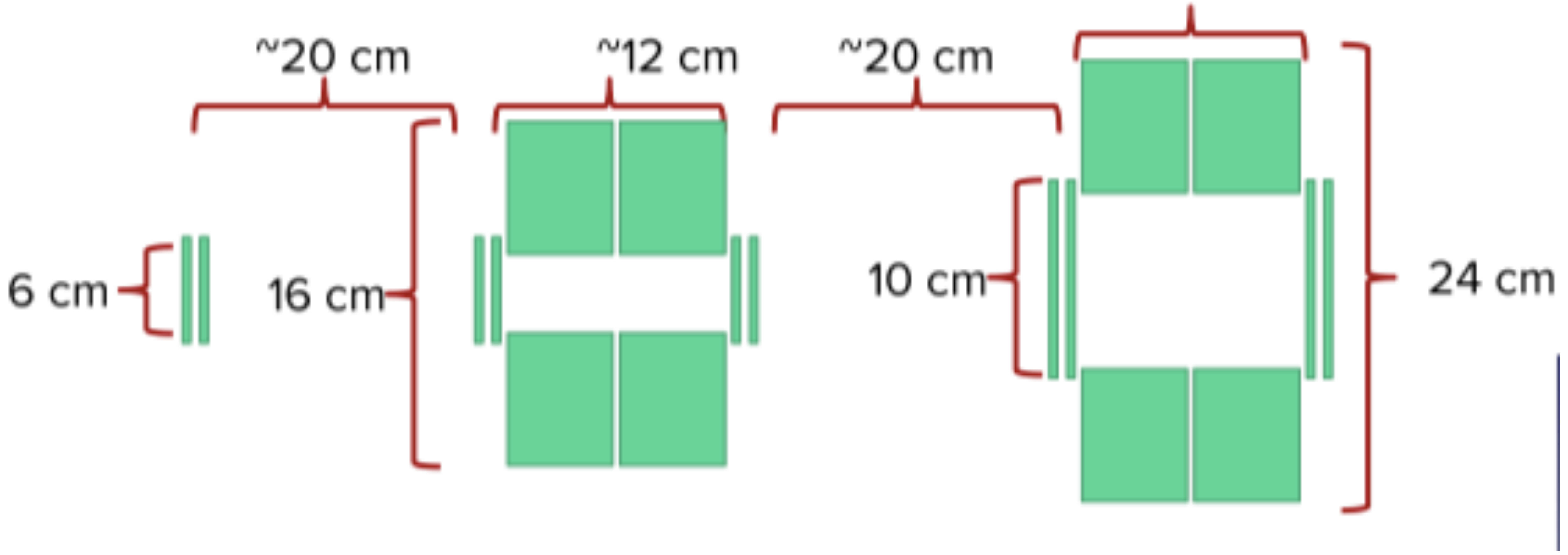
- Require experimental hall large enough to house detector
- Need secondary particle beam with momenta ranging from ~400 MeV/c to ~15 GeV/c

- Propose to use the **T9 secondary beam line** (fed by PS) in the **CERN East Area**
- Secondary particle rates of up to **5e6 per spill**
- Secondary beam line is ~40 m long
  - Low momentum pions decay-in-flight
  - Need tertiary production target close to the detector for pions
- Propose configuration with tertiary production target and spectrometer as shown to left

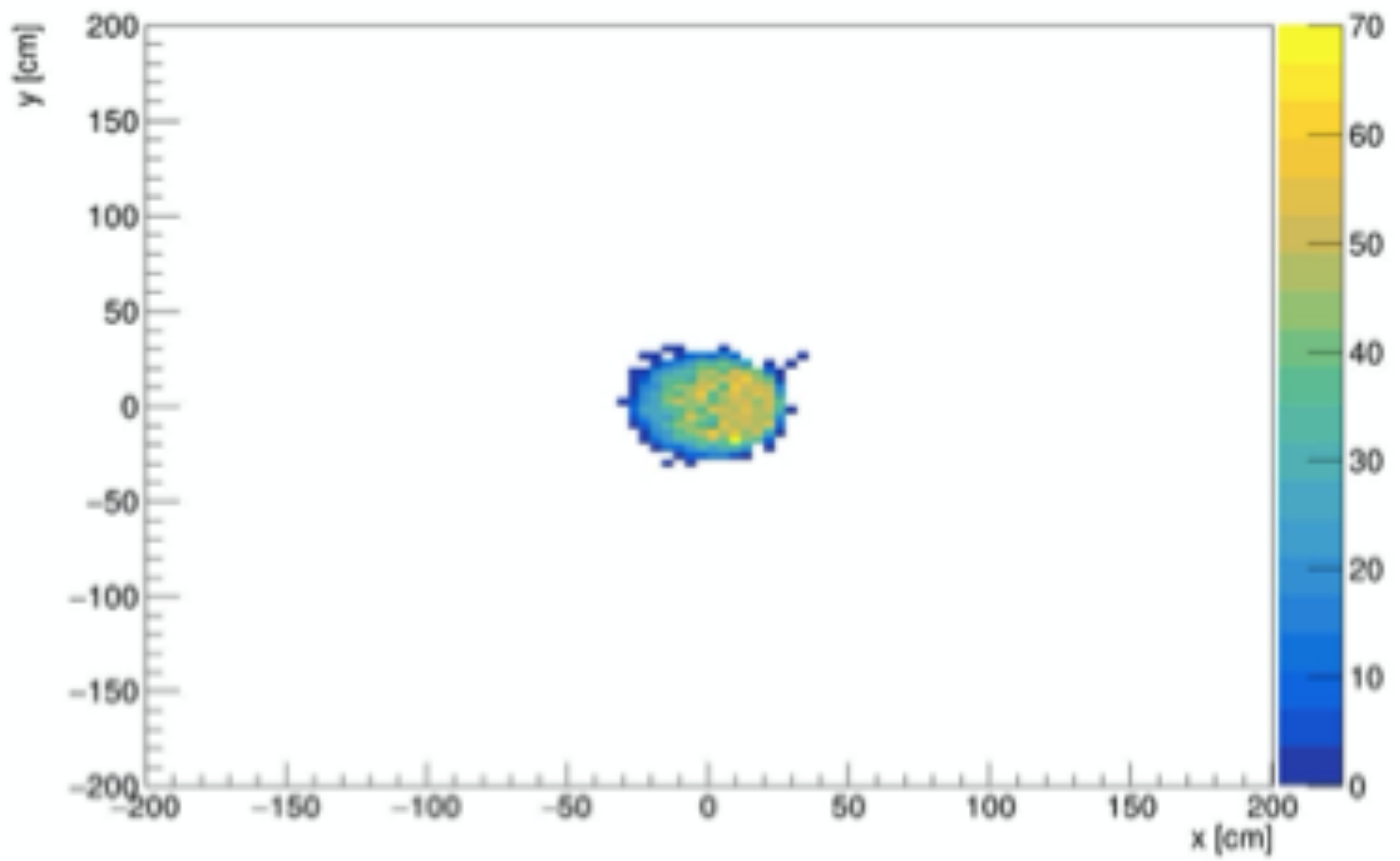


More in today's talks by M. Pavin

WCTE Spectrometer



Transverse distribution of tertiary particles

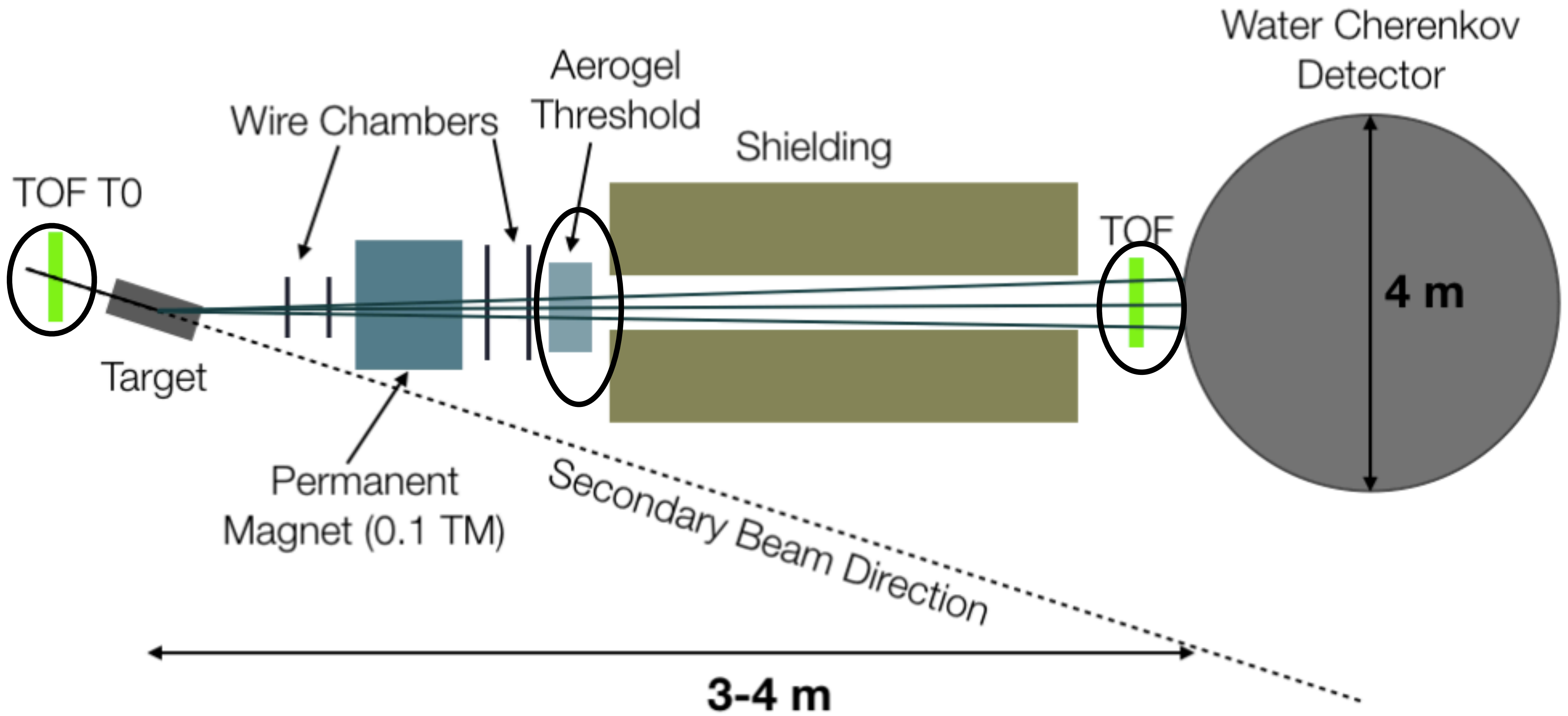


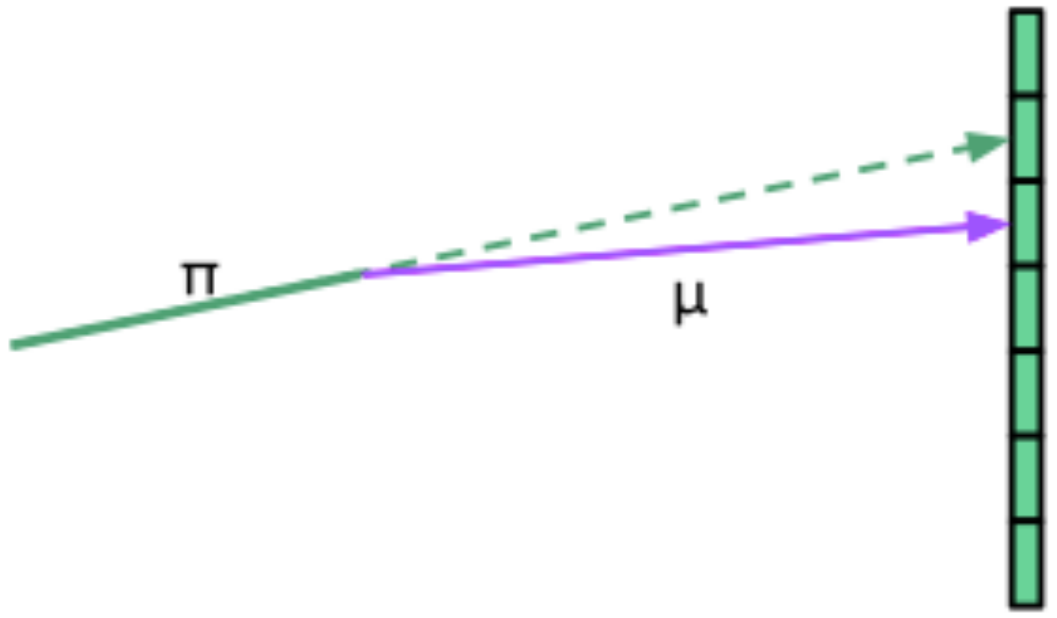
- Spectrometer based on Halbach array permanent magnets with dipole fields
  - Field strengths of ~1T achievable
- Silicon strip detectors for tracking layers
- Can achieve momentum resolution of 5% or better
- Second compensation magnet keeps the beam spot relatively small (important for beam window design)

More in today's talks by M. Pavin and P. Sarin

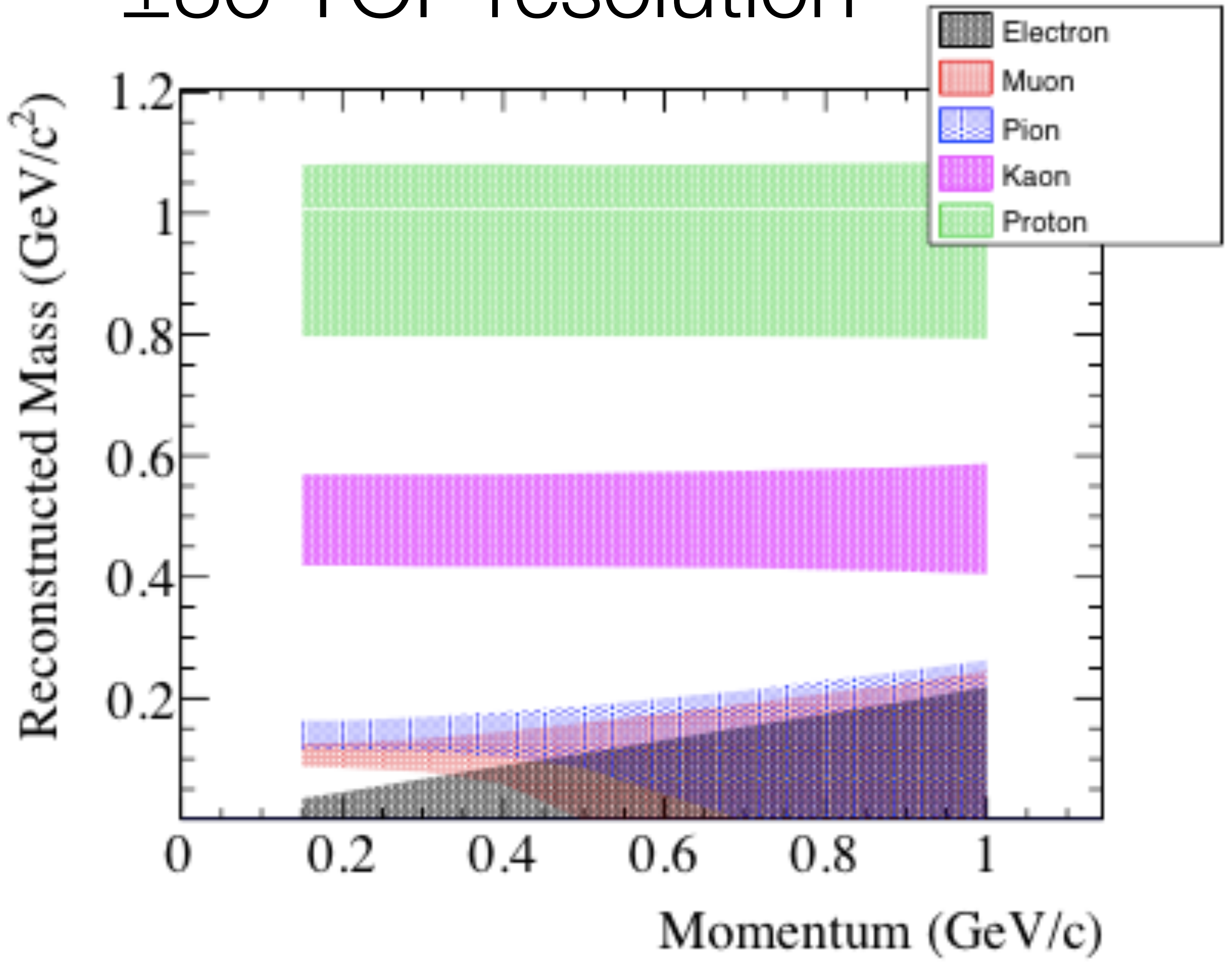
Particle Identification

- TOF detector with 100 ps resolution
  - Can use **resistive plate chambers (RPC)**
  - Sufficient resolution to separate pion, kaon and proton (lower right)
- For high-momentum pion/electron separation, we can use an aerogel Cherenkov threshold detector
- To separate muons from pion decay-in-flight, the TOF detector is segmented





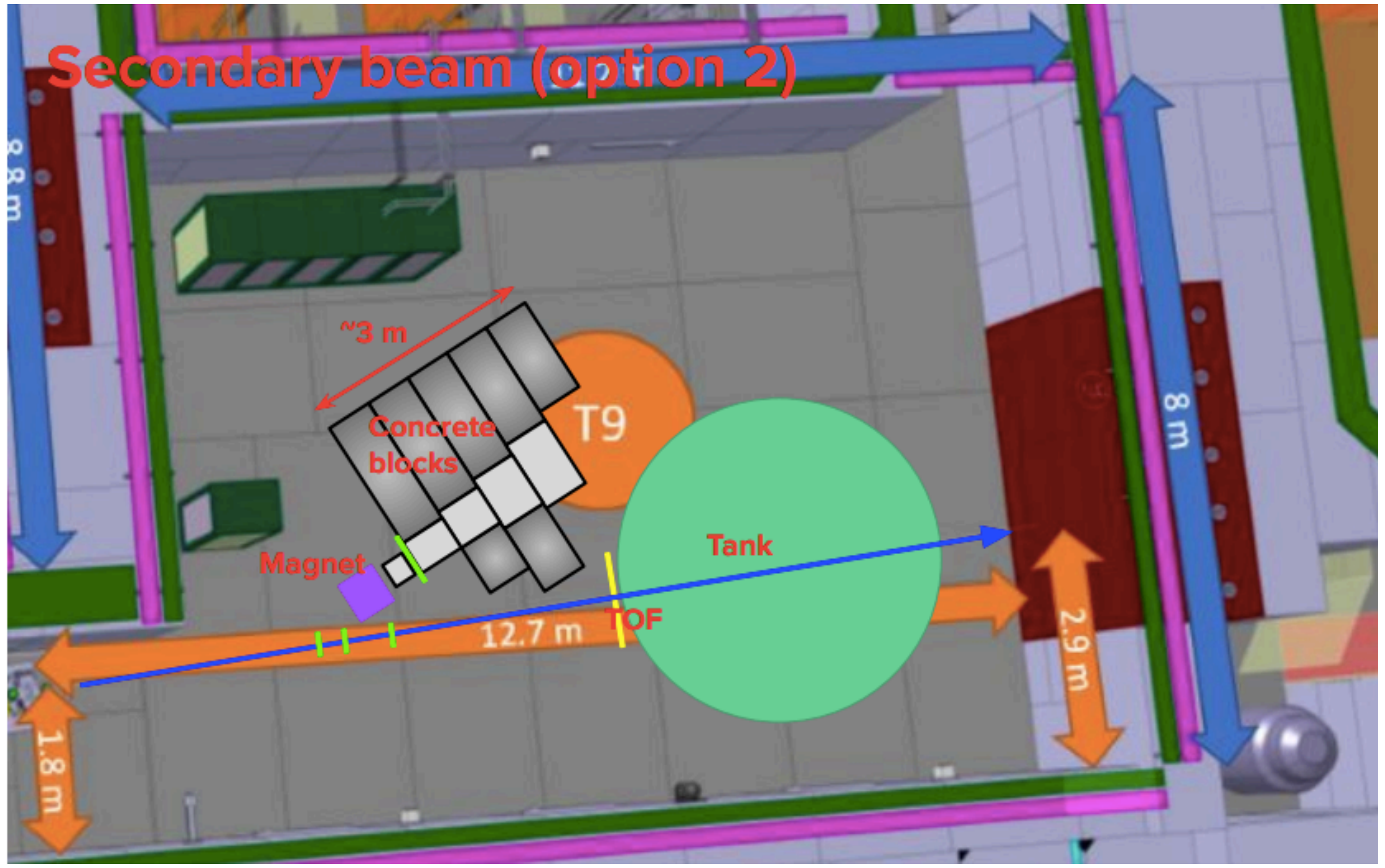
±3σ TOF resolution

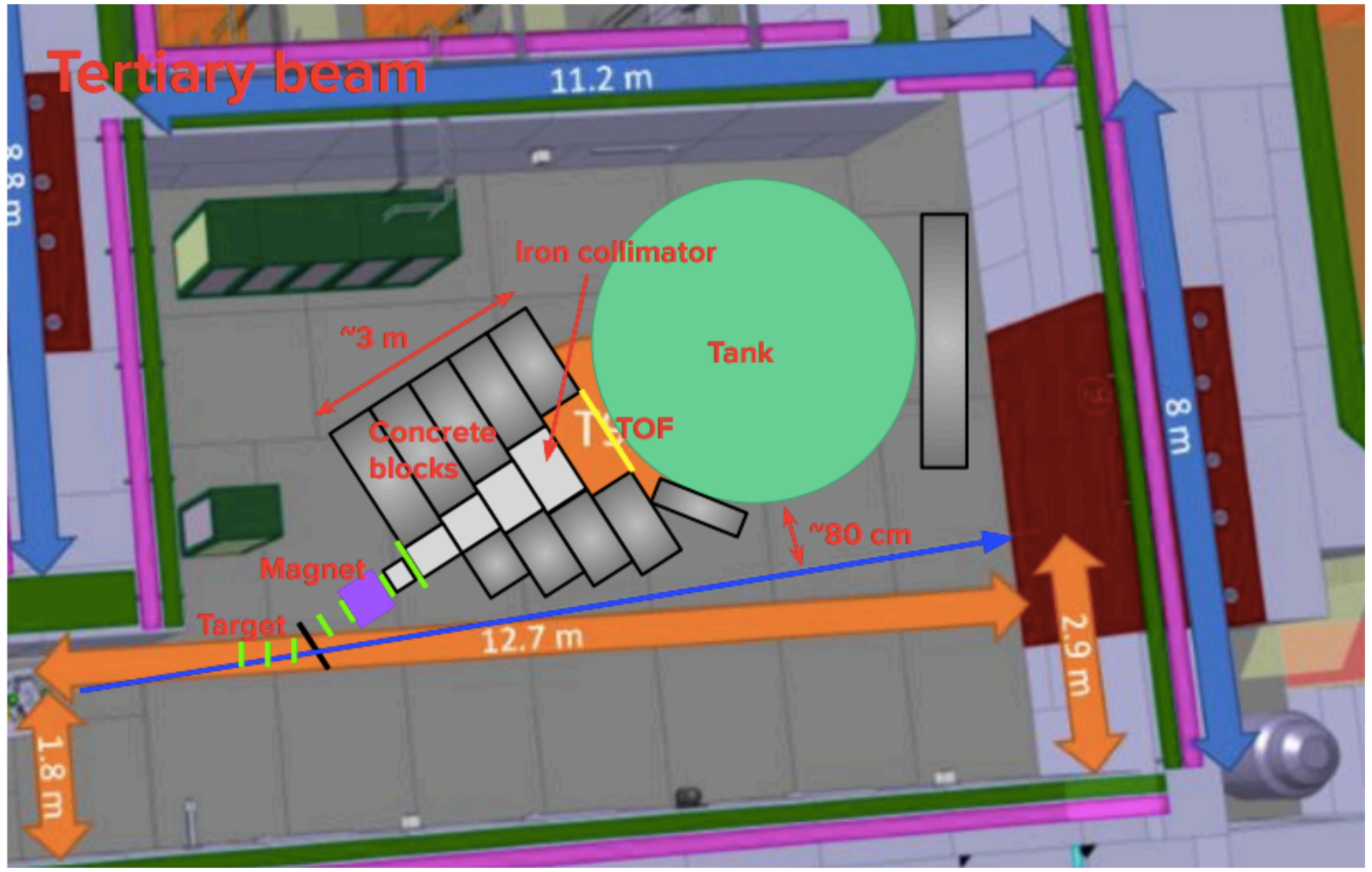


WCTE Beam Configurations

More on moving detector in talk by O. Jeremy tomorrow

- We expect to run in two different beam configurations:



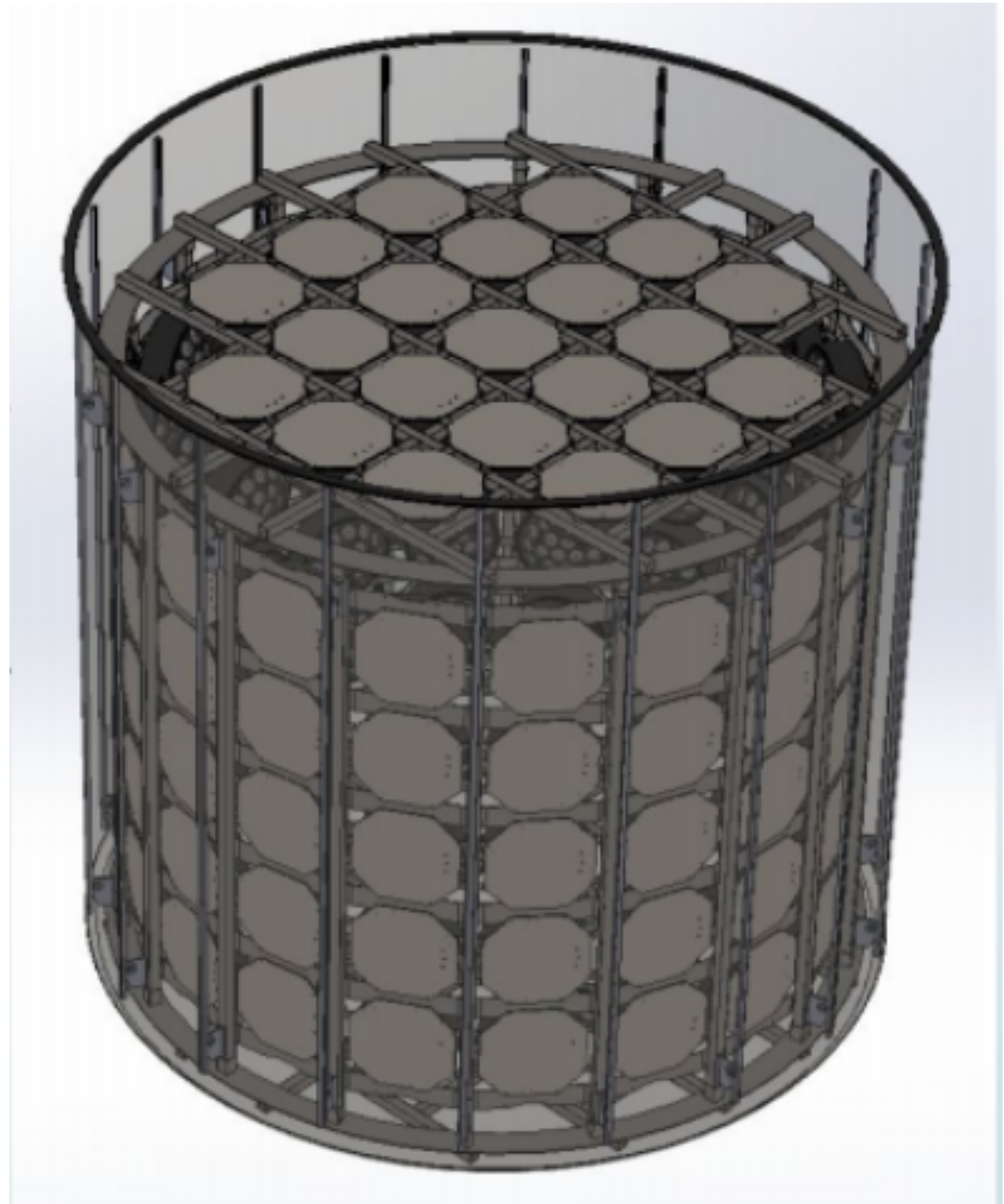


- Secondary beam for electron and muon fluxes
- Target is ~40 m upstream
  - Most low momentum pions decay-in-flight before detector

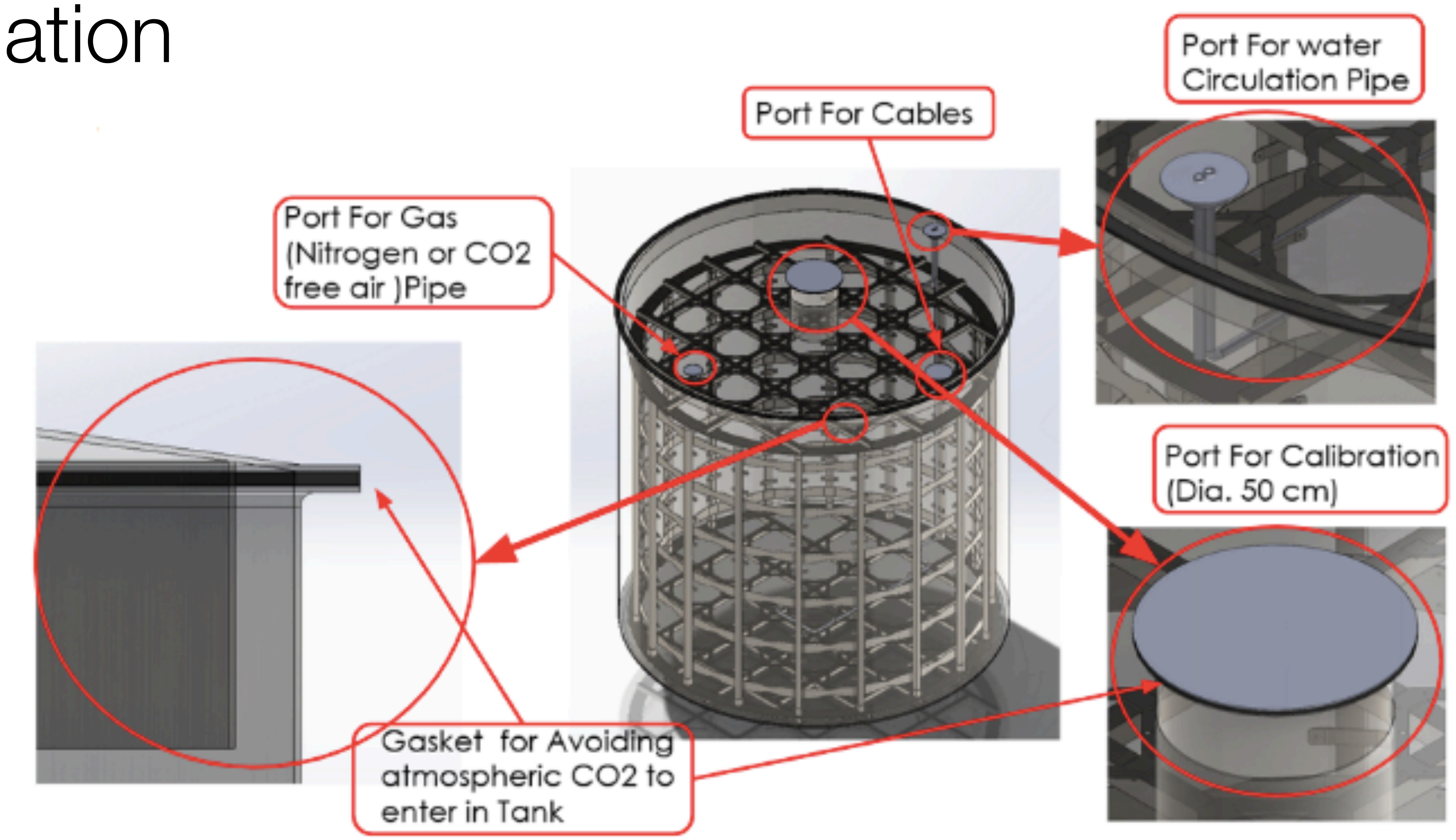
- Tertiary beam configuration places target close to the detector
- Compact spectrometer just downstream of target
- Low momentum pion fluxes possible

The Detector

- The detector is installed in a stainless steal 304 tank with ~6 mm thick walls
- A support structure to hold the photosensors in installed inside the tank
- Maximum number of photosensors is 128
- The tank lid will have ports for cabling, water circulation pipes, calibration source deployment

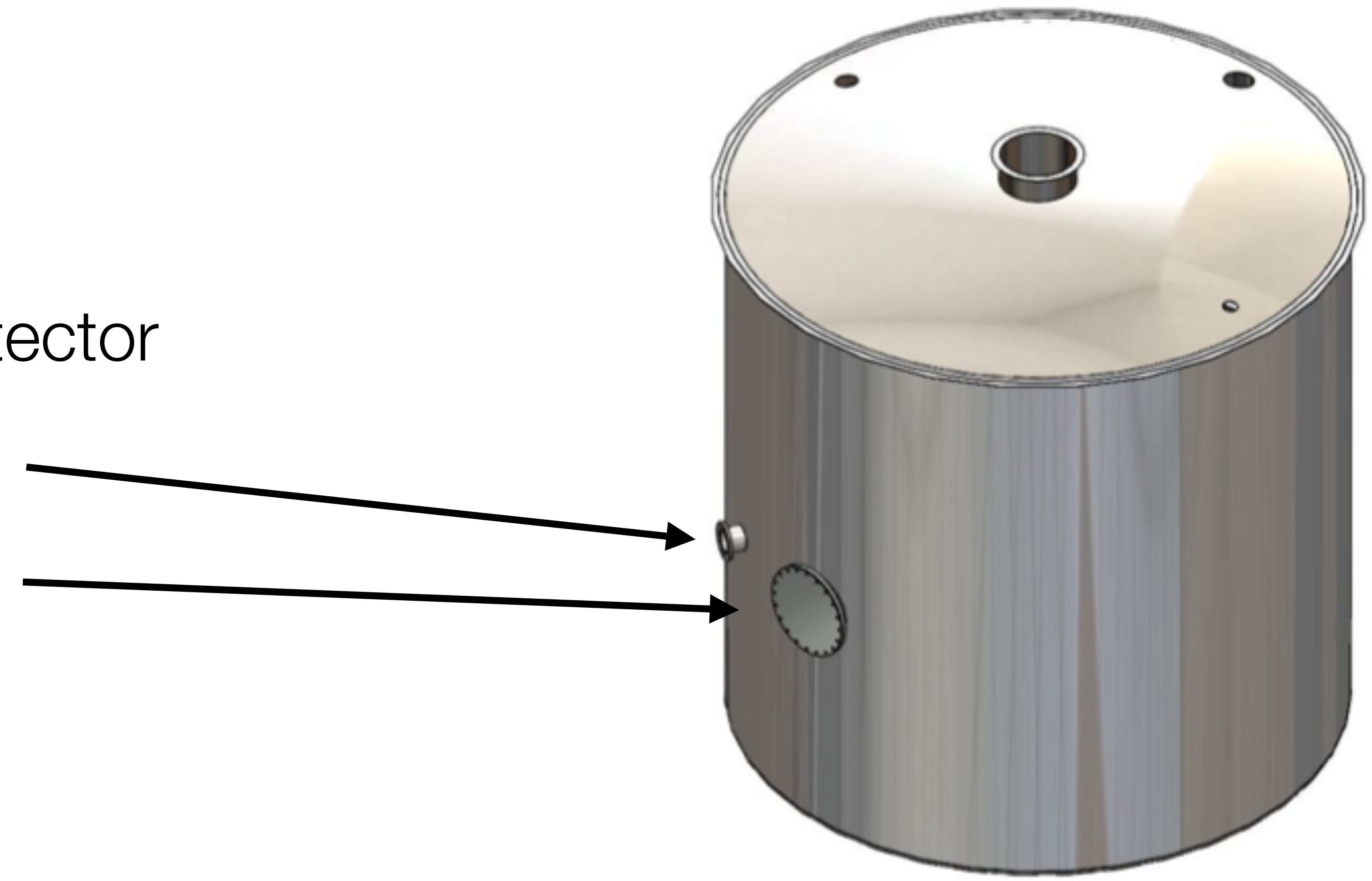


More detail in talks by A. Konaka, S. Garode and S. Joshi tomorrow

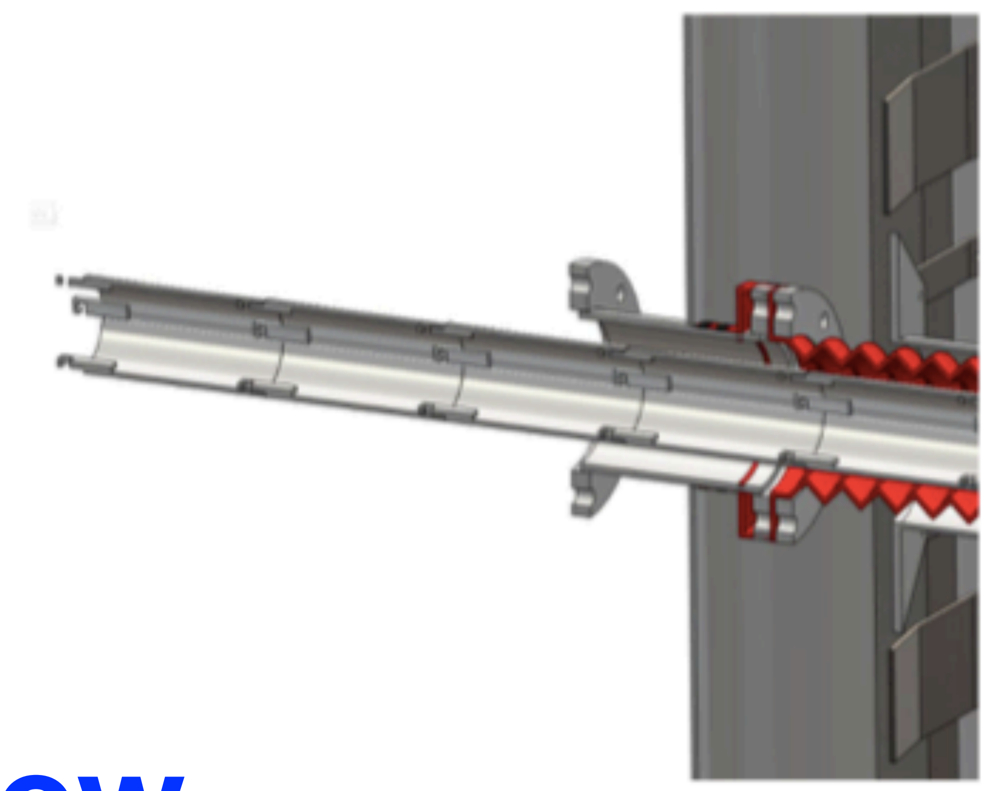


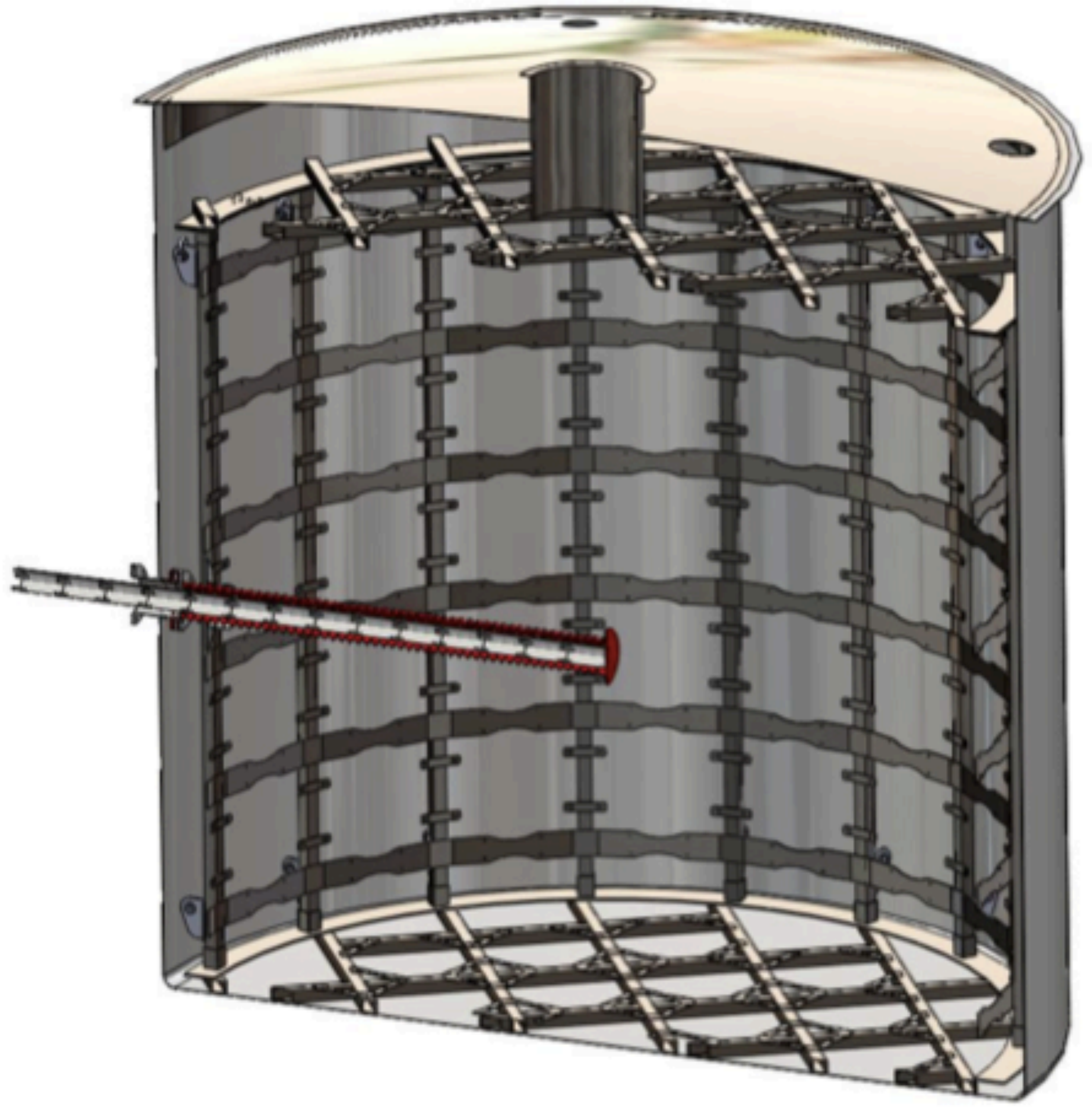
Beam Windows/Pipes

- Aim to minimize material where beam enters detector
  - Beam pipe for secondary beam configuration
  - Beam window for tertiary beam configuration



- Developing design of extendable beam pipe to vary injection point in detector
  - Segmented pipe that can be moved into and our of detector provides structural support
  - Surrounded by flexible water-tight material



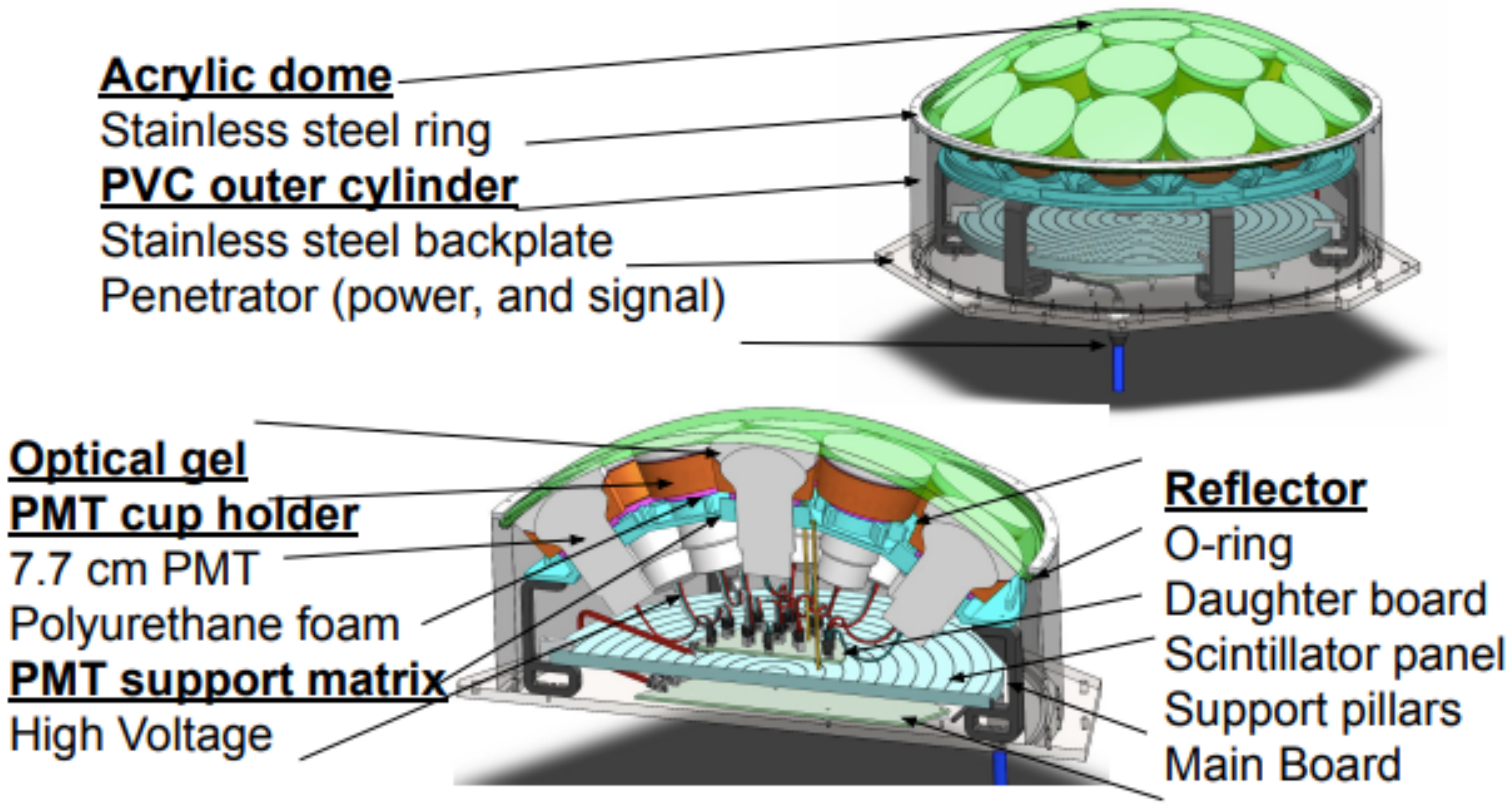


More in talk by S. Garode tomorrow

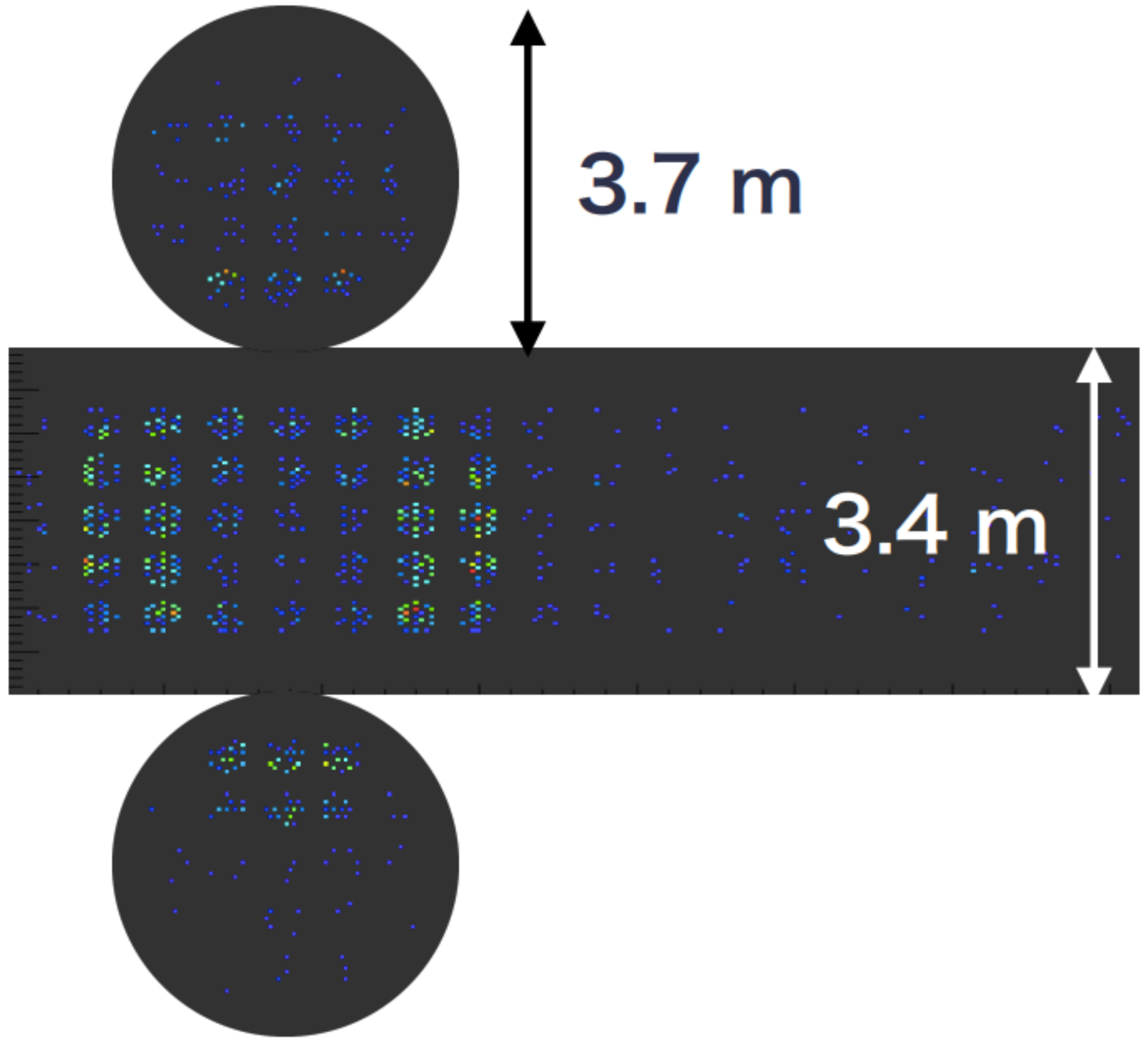
Photosensors & Reconstruction

More in talks by T. Linder and M. Ziembicki tomorrow

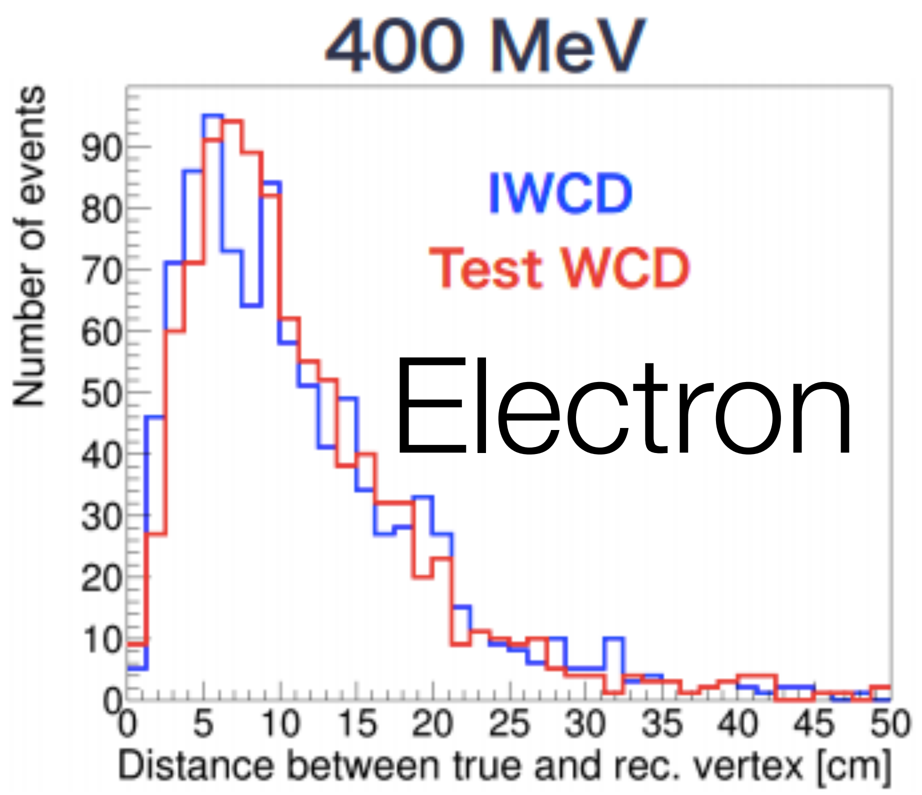
- We will use multi-PMT photo detectors in IWCD
- Very good timing resolution (1.6 ns FWHM) 3-inch diameter PMTs
- In water-tight module with FADC based readout electronics
- Power and communication to to mPMT with single cable using PoE

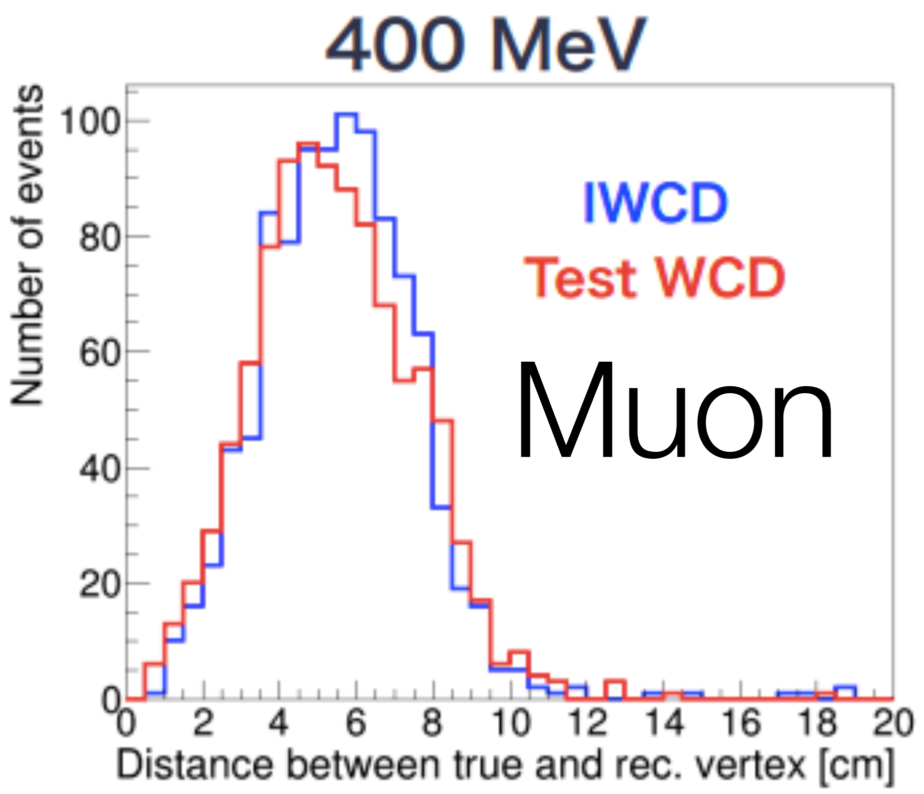


Example of simulated 400 MeV/c muon



Similar reconstruction performance to IWCD





More in talk by M. Ishitsuka today

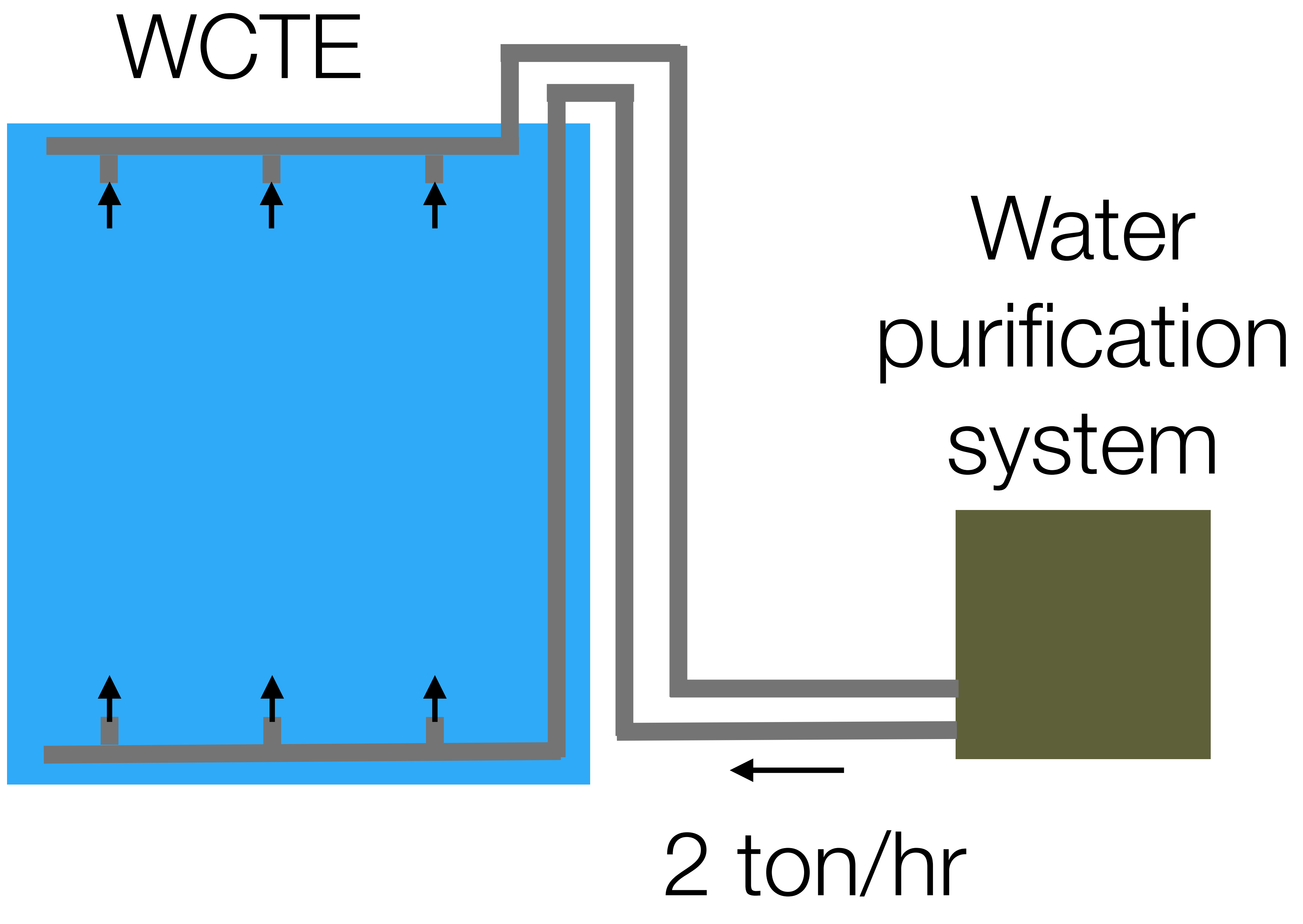
Other WCTE Systems

- Water purification system:
  - UV light to break down biologicals
  - Micro/nano-filters
  - Ion exchange resin
  - Chiller (~2 kW of cooling)
  - Capability for $Gd_2(SO_4)_3$ loading
- DAQ system will be based on IWCD/Hyper-K system
  - Need to handle beam triggers and monitor DAQ
  - **See talk by B. Richards on Tuesday**
- Calibration systems:

Calibration System	Super-Kamiokande	WCTE and IWCD	Hyper-Kamiokande
Light Injectors	✓	✓	✓
Diffuser Ball	(✓)	✓	(✓)
Nickel Source	✓	✓	✓
Neutron Source	✓	(✓)	✓
Photogrammetry	✓	(✓)	✓
mPMT LEDs		✓	✓
Muon tracker		✓	

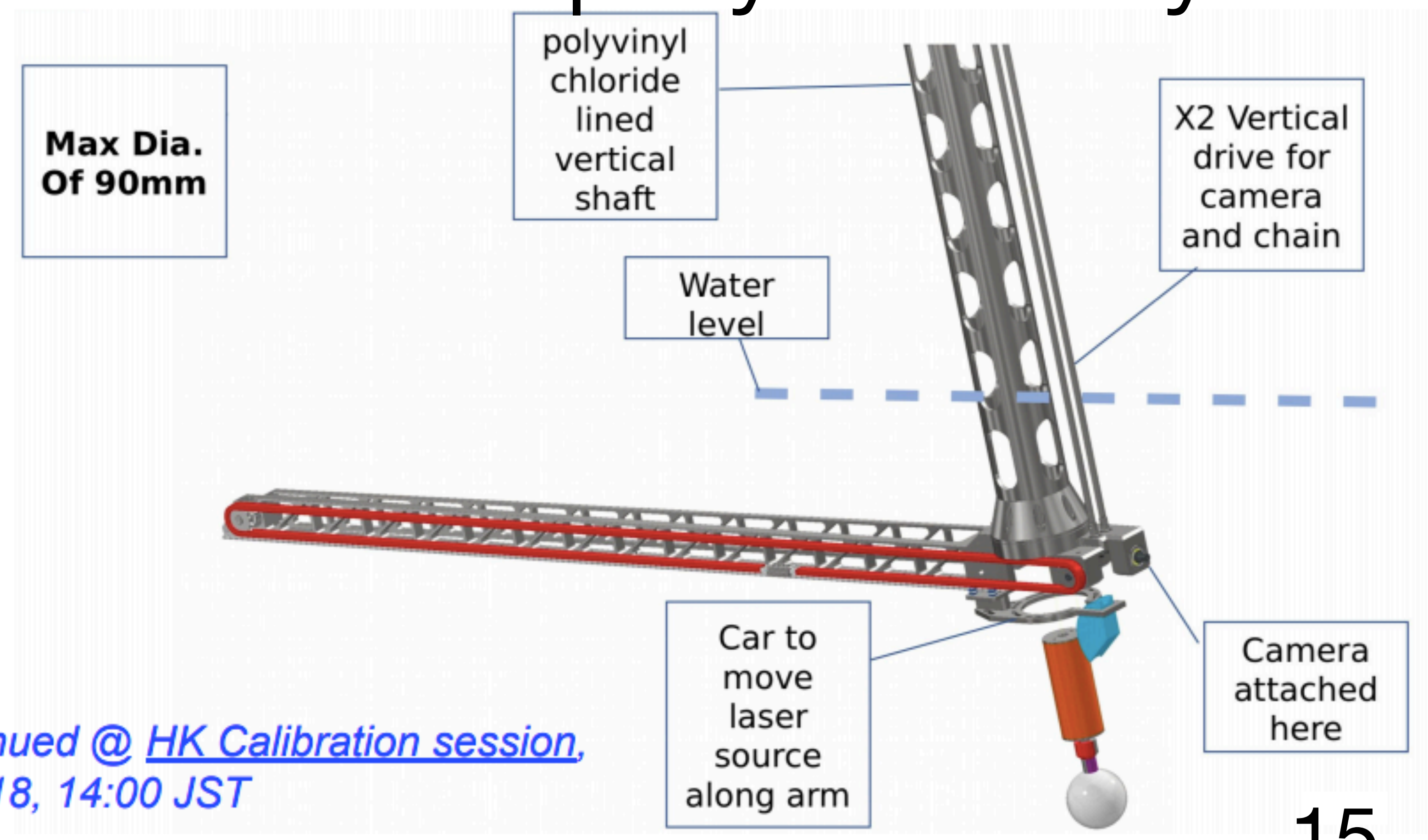
See talk by P. de Perio on Wed.

See talk by A. Konaka on Tuesday



See talk by L. Anthony on Wed.

Central Deployment System



Continued @ HK Calibration session, Sep. 18, 14:00 JST

Status of the WCTE

- The WCTE collaboration was formed after a meeting at CERN in July 2019: **https://indico.cern.ch/e/814739**
- Proposal for the WCTE was prepared and submitted to the CERN SPSC in March 2020: **CERN-SPSC-2020-005 ; SPSC-P-365**
  - >100 researchers signed proposal
  - Working with reviewers towards approval
- In this proposal, we propose operating in two phases: pure water and Gd loaded water
  - We suggest that and additional phase with WbLS may be proposed in the future
- We **aim for the start of operation of the experiment in 2023**
  - WCTE steering committee formed in August 2020
  - Steering committee is working to develop detailed schedule and help/organize funding requests
  - There are still many areas where contributions can be made

This Workshop

- This workshop provides an opportunity for:
  - Collaborators/groups focussing on WCTE to share the status of the project
  - Potential new collaborators to learn about the project and share their interests
  - Existing collaborators to see the status of the project and areas where efforts need to be directed
- We have left plenty of time in the agenda for discussion
  - Encourage attendees to ask questions and share interests/expertise
  - There is also a slack channel for discussion which can be joined at: https://join.slack.com/t/watercherenko-afv1279/shared_invite/zt-j9w16avk-XwUBgitkLfPqYzLYFPDdjA

Workshop Agenda - Monday

Monday, 23 November

14:30 → 15:00 Introduction Session

- 14:30 **WCTE Introduction and Status** — 20m
  Speaker: Dr Mark Hartz (TRIUMF & Kavli IPMU, University of Tokyo)

15:00 → 16:15 Physics and Analysis (Chair: M. Scott)

- 15:00 **WCTE Physics and Analysis Overview** — 25m
  Speaker: Masaki Ishitsuka (Tokyo University of Science)
- 15:25 **Cherenkov Angle Study** — 15m
  Speaker: Mo Jia (Stonybrook University)
- 15:40 **WCTE Measurements for T2K & Super-K** — 20m
  Speaker: Dr Mark Hartz (TRIUMF & Kavli IPMU, University of Tokyo)

16:15 → 17:30 Beam Line (Chair: A. Konaka)

- 16:15 **Beam Design and Simulation** — 30m
  Speaker: Dr Matej Pavin (TRIUMF)
- 16:45 **Spectrometer and TOF Hardware** — 20m
  Speaker: Prof. Pradeep Sarin (IIT Bombay)

Workshop Agenda - Tuesday

Tuesday, 24 November

14:30 → 15:45 **Tank and Support Structure (Chair: T. Ekelöf)**

- 14:30 **WCTE mechanical design overview** — 20m
  Speaker: Akira Konaka (TRIUMF)
- 14:50 **Beam pipe and window** — 15m
  Speaker: Shubham Garode
- 15:05 **Structural simulation** — 15m
  Speaker: Shardul Joshi (Vishwakarma Institute of Information Technology)
- 15:20 **Detector Moving System** — 15m
  Speaker: Oliver Jeremy (Imperial College London)

15:45 → 16:15 **Water System (Chair: M. Hartz)**

- 15:45 **WCTE Water System** — 20m
  Speaker: Akira Konaka (TRIUMF)

16:15 → 17:30 **Photosensors, DAQ, Trigger (Chair: M. Wilking)**

- 16:15 **DAQ, Trigger, Slow Control** — 20m
  Speaker: Benjamin Richards (Queen Mary University London)
- 16:35 **Multi-PMT Status** — 25m
  Speaker: Thomas Hermann Lindner (TRIUMF (CA))
- 17:00 **Multi-PMT Electronics** — 20m
  Speaker: Marcin Ziembicki (Warsaw University of Technology (PL))

Workshop Agenda - Wednesday

Wednesday, 25 November

14:30 → 15:45 Calibration (Chair: M. Ziembicki)

- 14:30 **Overview of WCTE Calibration** (30m)
  Speaker: Patrick de Perio (TRIUMF)
- 15:00 **Calibration Central Deployment System** (25m)
  Speaker: Dr Lauren Anthony (Imperial College London)

15:45 → 17:00 New Contributions, Ideas, Future Applications (Chair: M. Hartz)

- 15:45 **Multi-PMT Collaboration in Mexico** (20m)
  Speaker: Dr Saul Cuen-Rochin (TRIUMF)
- 16:05 **WbLS and Novel Photosensors in WCTE** (30m)
  Speaker: Prof. Michael Wilking (Stony Brook University)

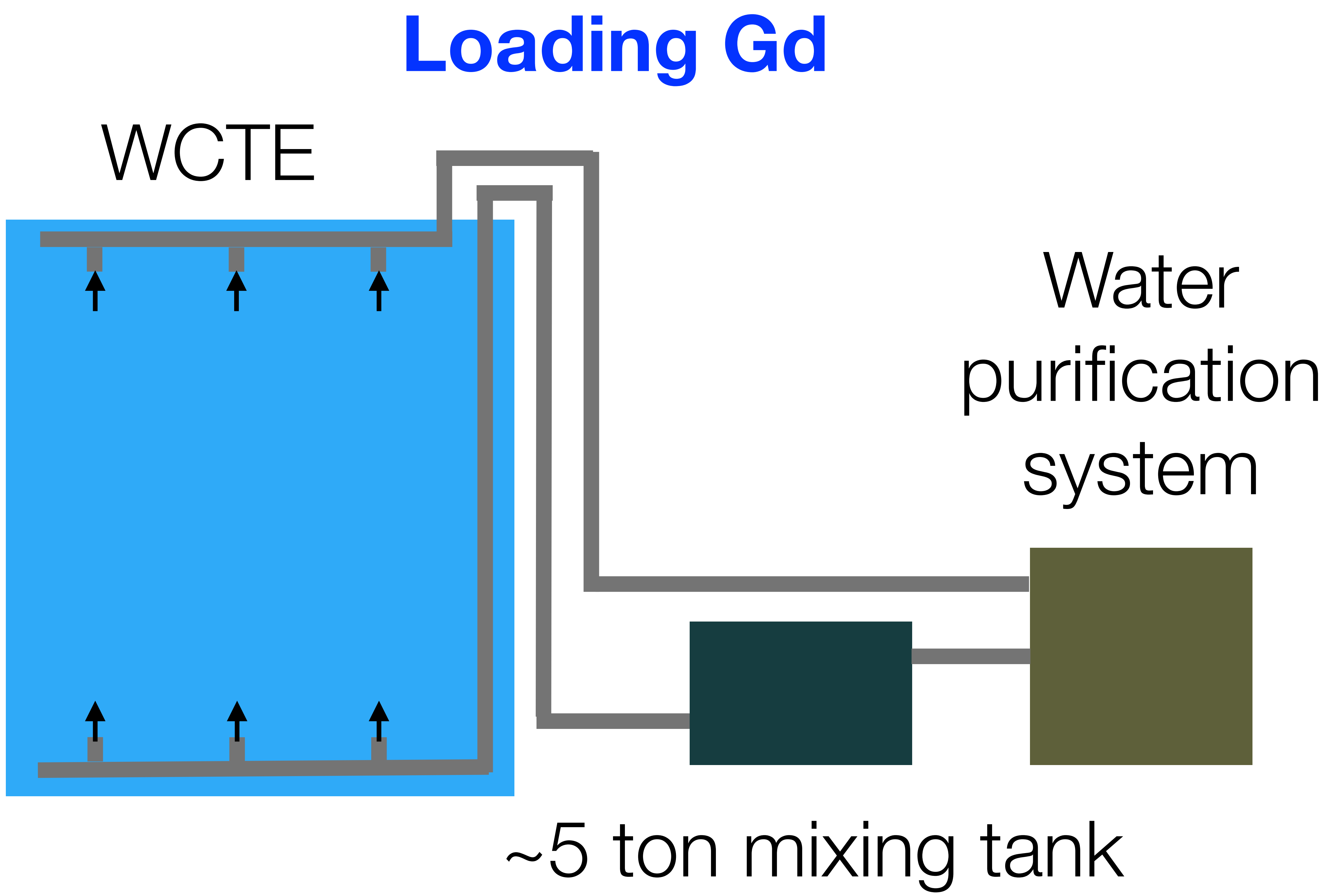
17:00 → 17:30 Proposal Status and Discussion

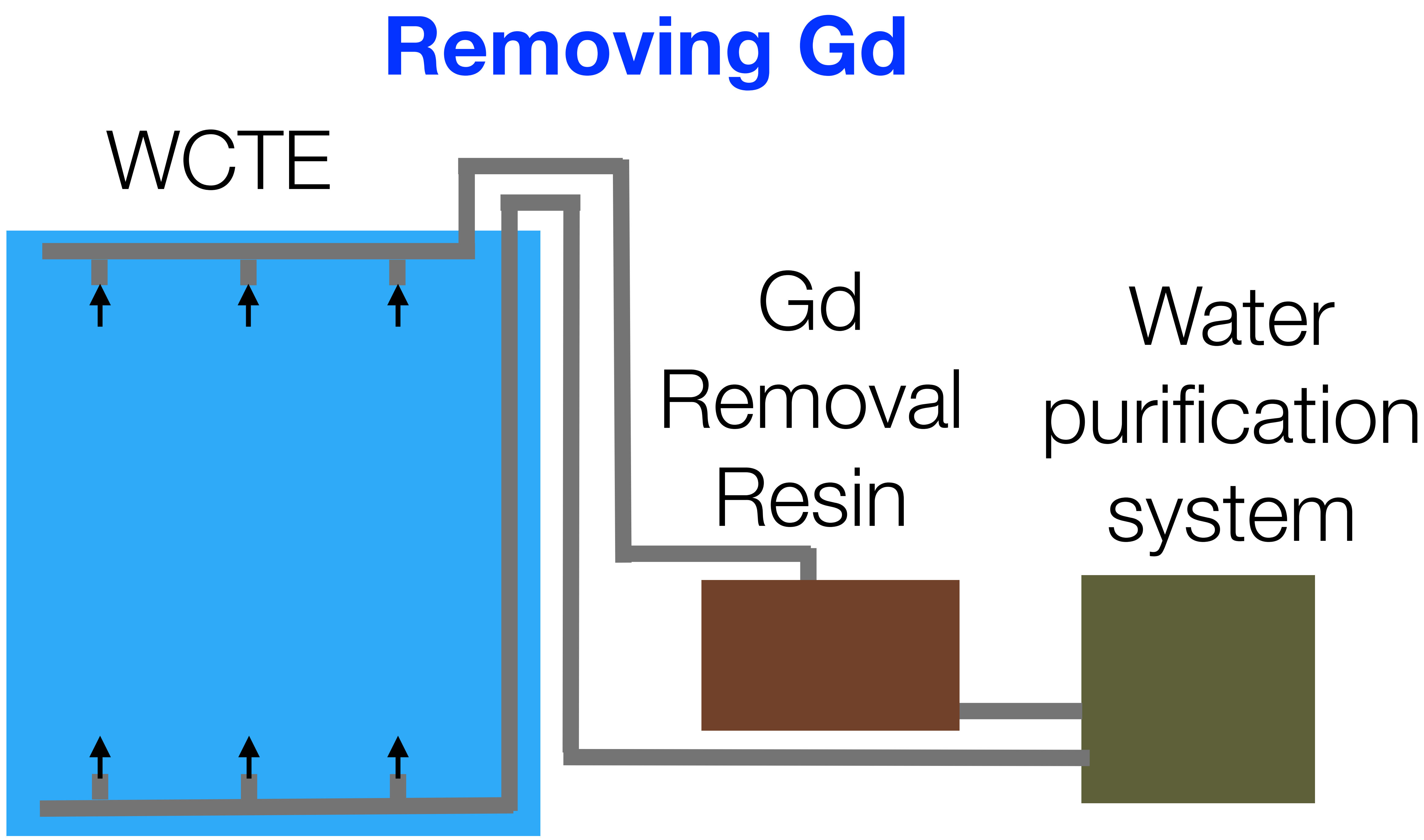
- 17:00 **Proposal Status and Discussion** (20m)
  Speaker: Mark Hartz (TRIUMF & Kavli IPMU, University of Tokyo)

Thank you

WCTE Water System - Gd Loading Phase

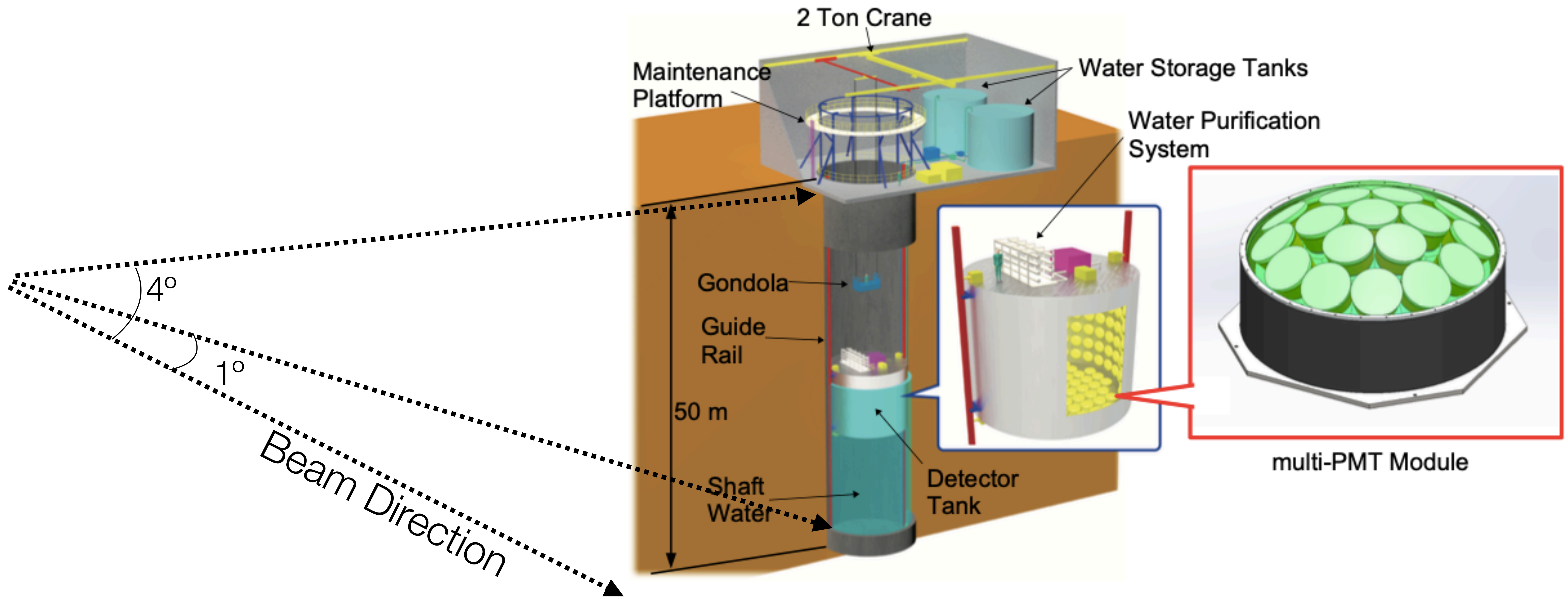
- Will add ~100 kg of $Gd_2(SO_4)_3$ to the water
  - During loading phase, mixing tank is added to dissolve $Gd_2(SO_4)_3$
- Ion exchange resin in water system will be removed or replaced with special resin
- Resin is used to remove $Gd_2(SO_4)_3$ when Gd loading phase is complete
  - Gd concentration measurement system will be used to monitor Gd level





WCTE Motivation

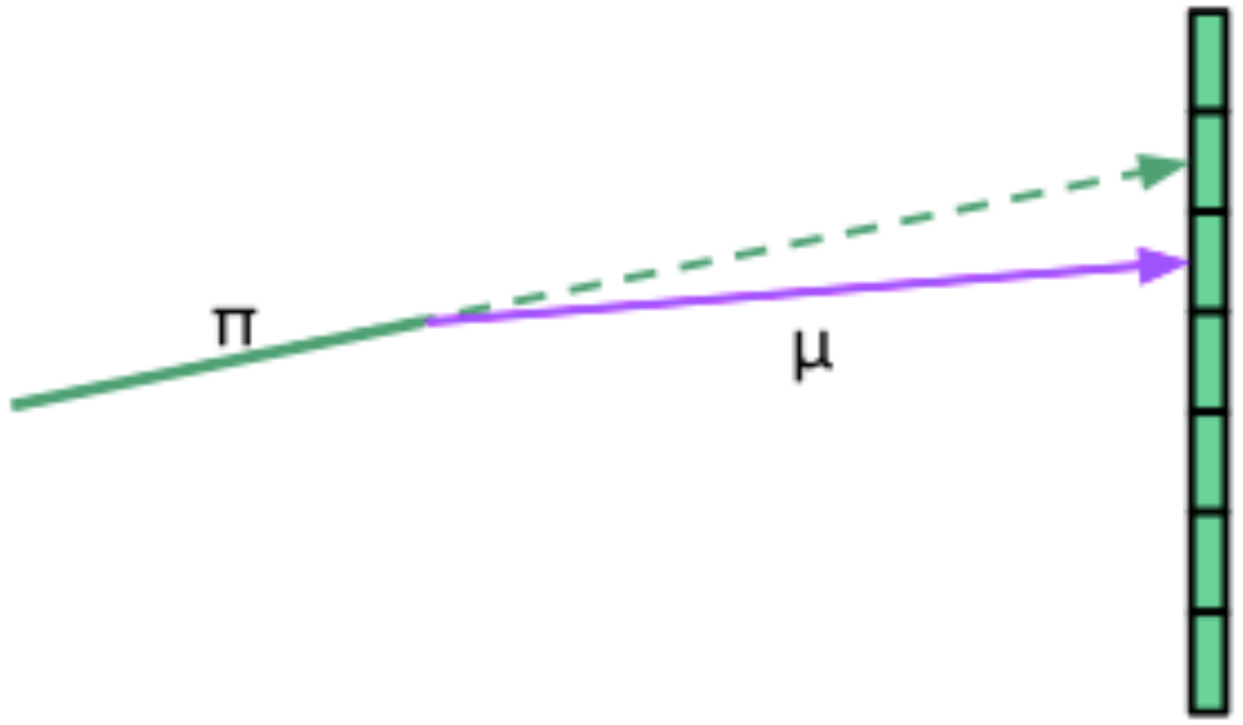
- Original motivation for water Cherenkov test experiment driven by planned Intermediate Water Cherenkov Detector (IWCD) for Hyper-K



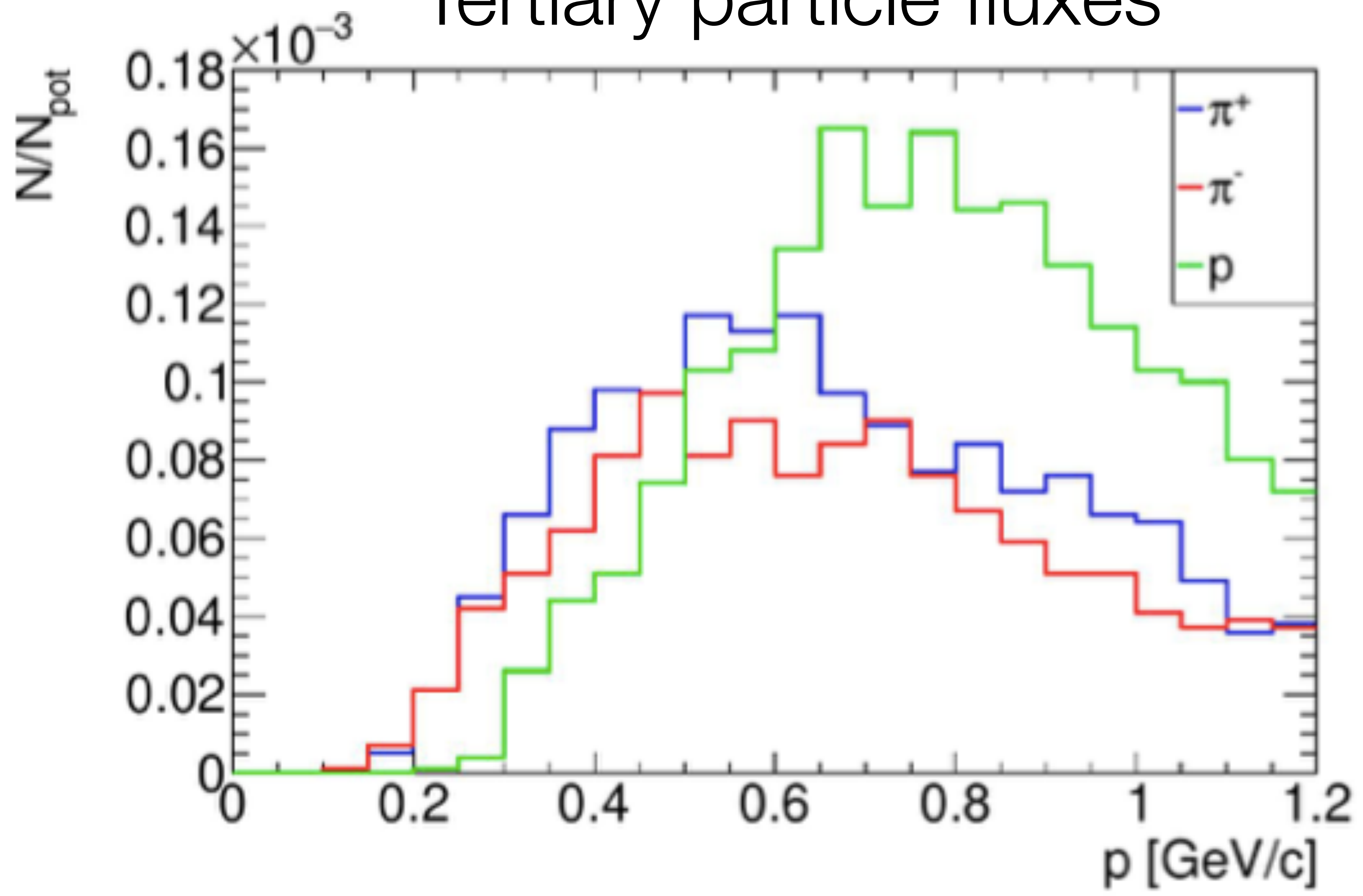
- Kilo-ton scale water Cherenkov detector
- Requires 1% level calibration
- Implement new technologies, such as the multi-PMT photosensors

Particle Fluxes and PID for Tertiary beam

- Per 50 MeV/c bin, producing ~1e-4 particles of interest per protons on target
  - Per-spill POT can be as high as 5e6
- Significant pion fluxes down to ~200 MeV/c can be achieved
- Proton fluxes down to ~300 MeV/c
- Segmented TOF detector serves two purposes
  - Particle identification
  - Measures kinks in tracks from spectrometer to identify pion decay-in-flight



Tertiary particle fluxes



Displacement at TOF due to decay-in-flight