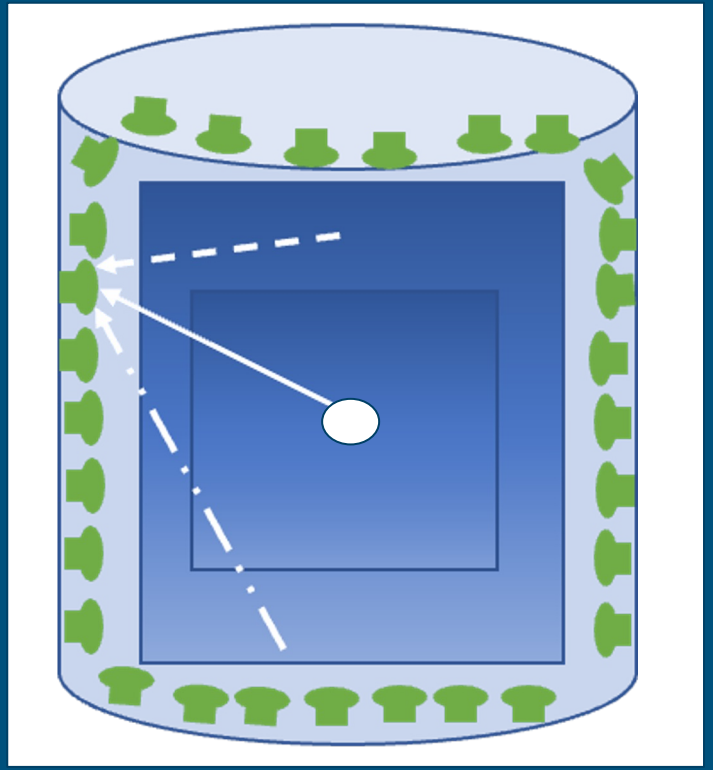
PMT pre-calibration plan

Vincent Gousy-Leblanc
WCTE CM meeting
July 22th

Why is pre-calibration needed (Nakajima-san)

- Why is in-situ calibration not enough ?
  - Lot's of degeneracy between the different detector response
    - Non uniform water transparency, scattering, reflections
    - Timing offset
    - PMT exact position
    - Angular response
    - etc
- Pre-calibration should help separate the different degeneracy



Making a pre-calibration plan

- Pre-calibration measurements plan
  - All PMT will be tested by the PMT manufacturer
    - Electronic supplier will test the assembled PMTs
  - 2% of PMT will be shipped to the PMT testing station
    - Validate measurements
  - HV and FEB board will be tested by electronics supplier
  - 0.5% will be characterized
  - Mechanical parts
    - 3D scanning of samples at assembly sites
  - Optical testing of acrylic dome sample will be tested during the construction phase
- For WCTE (still undefined)
  - mPMT pre-calibration
    - Basic set of tests will be applied to all mPMT (requirements needs to be defined ?)
  - Basic characterization at the mPMT test stand (TRIUMF) and Warsaw group
    - Test and characterize multiple mPMT
    - How many ?
  - Full characterization at PTF (~1-2 disassemble mPMT)
    - Underwater measurements of the full mPMT angular response and variations to wavelength, magnetic field and polarization)
    - Measure detection efficiency, transit time and gain
    - Precise characterization of sets of 3 inch PMT in air

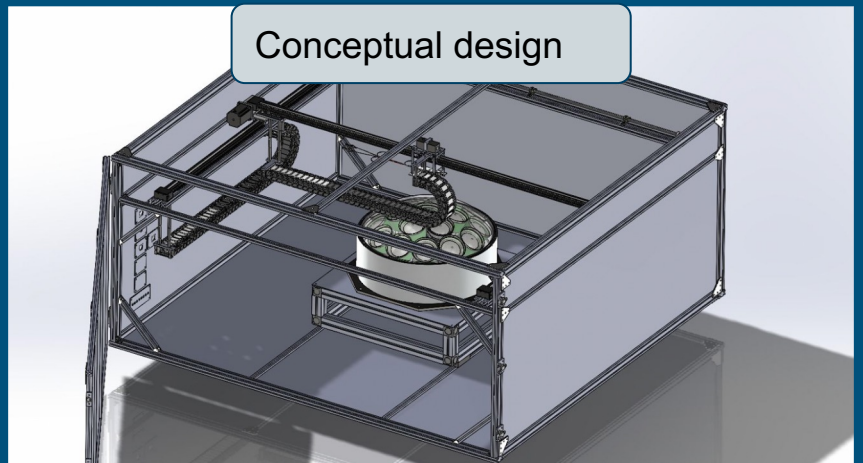
mPMT demo system

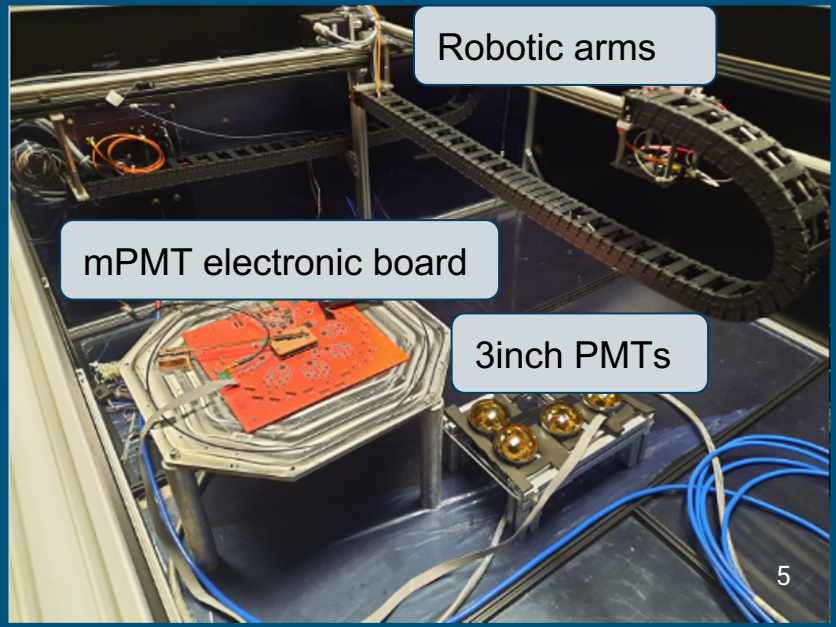
- Four boards (control,monitor HV)
- Can read 2 channel in real time

Capability of the 2D mPMT test stand at TRIUMF

Development @TRIUMF of a 2D test stand (T.Lindner)

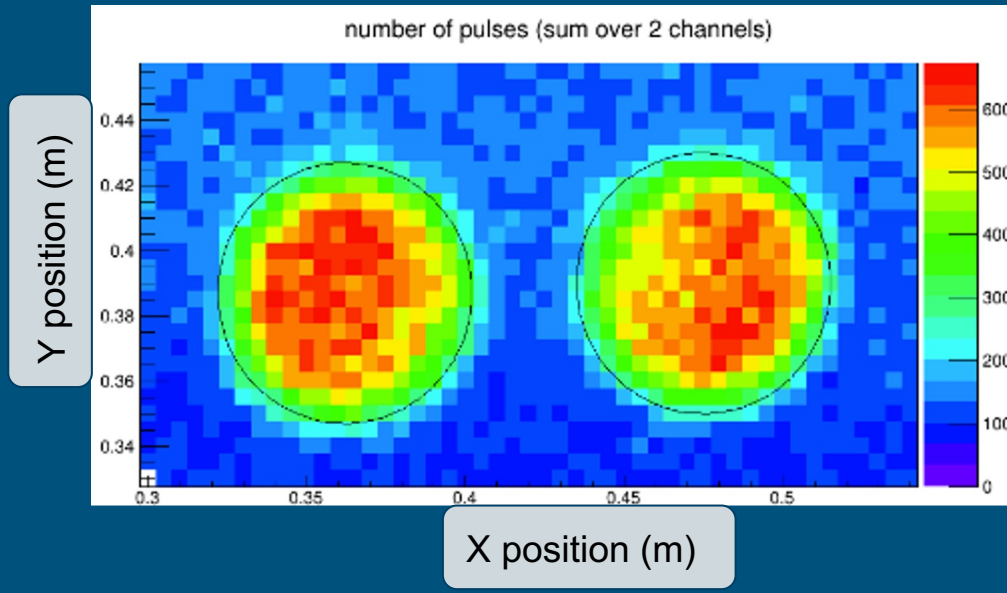
- Similar set up then for PTF (less complicated)
- Will allow characterization of single PMT and mPMT using pulsed LED and robotic arms
- Commissioning phase is now complete
  - Started testing mPMT (19 PMTs and 4 dummies)
    - Full analysis pipeline is tested for single PMT





Development @TRIUMF of a 2D test stand (T.Lindner) (2)

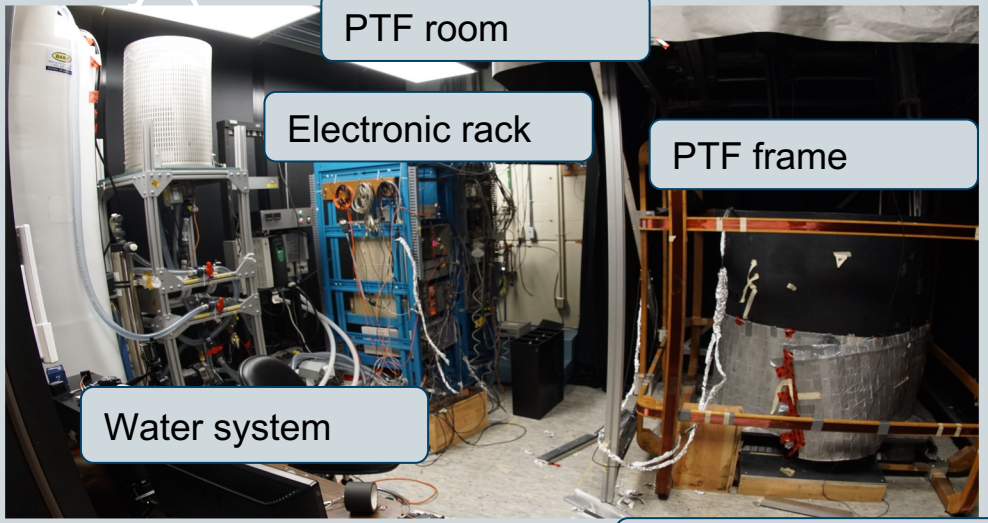
- Takes 5000 events at each scan point
- Can see distinctively the 2 PMT
- Few issues with the scan for now
  - Reproducibility
  - Too much data
- Currently :
  - Measure and confirm the timing resolution of PMT from Hamamatsu
  - Analyze the charge (to confirm)



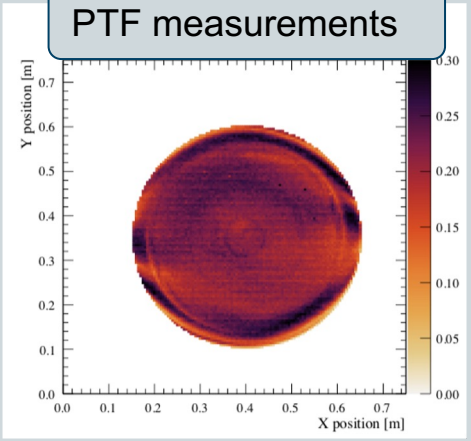
The photosensor test facility (PTF)

The Photosensor Test facility (PTF) at TRIUMF

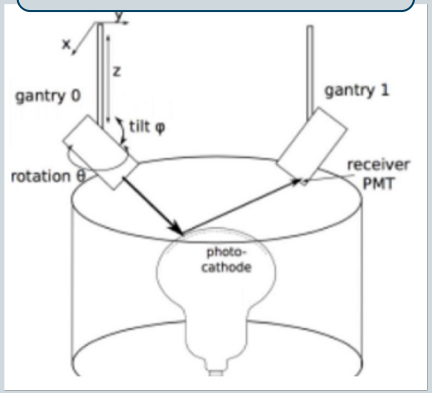
- 3 pairs of Helmholtz coils (one in each direction)
  - Can control magnetic field
- 2 optical box (laser, phidget included to measure tilt, rotation angle and magnetic field)
- DAQ to perform 2D characterization of PMT (transit time, detection efficiency, gain)
- Angular response and reflection measurements
  - Receiver PMT



PTF measurements



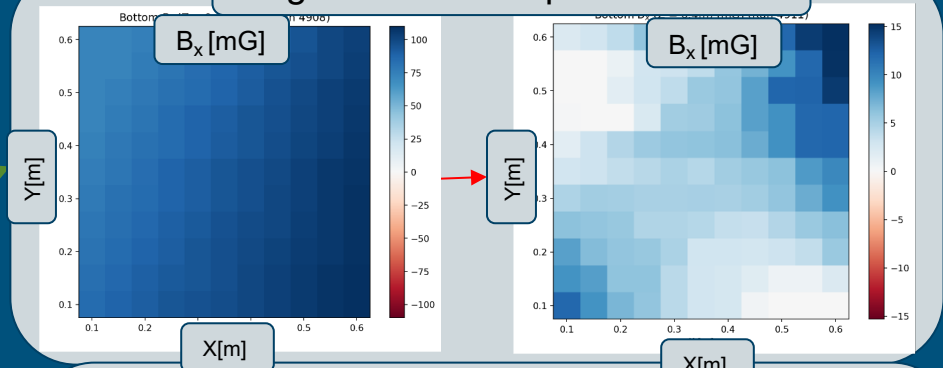
PTF Geometry



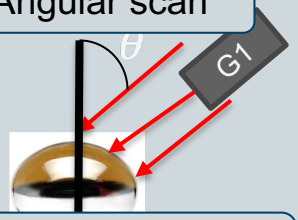
PTF capability

- PTF will be able to measure and separate more external variables
  - Magnetic field
  - Angular dependance
  - Polarization dependance
  - Wavelength dependance

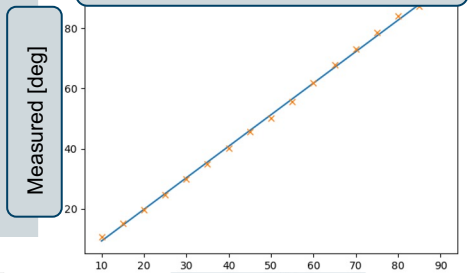
Magnetic field compensation



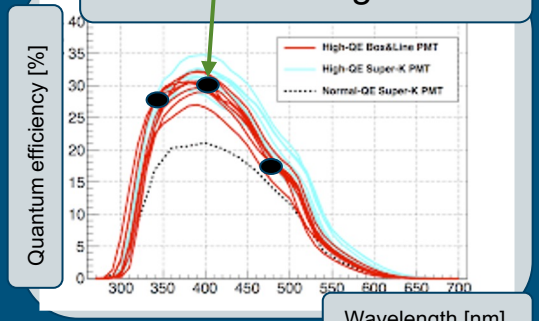
Angular scan



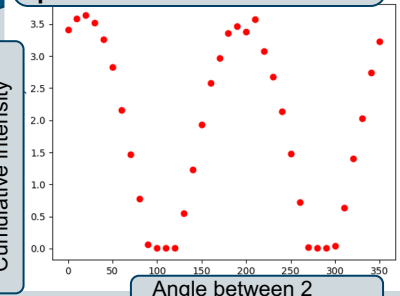
Calibration of the tilt



QE vs wavelenght



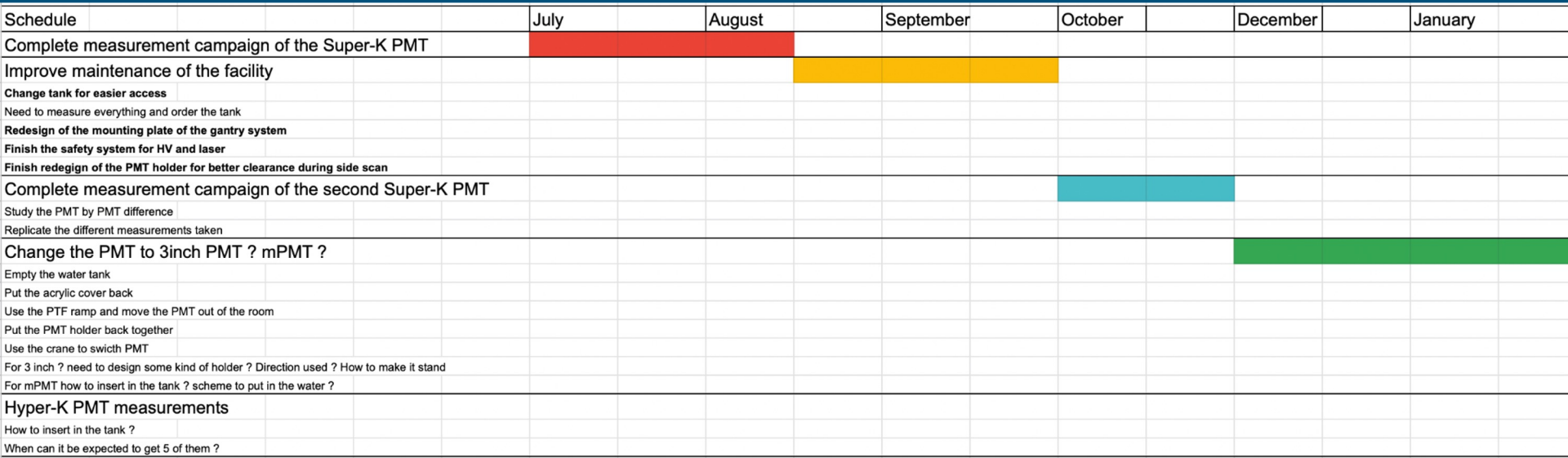
Calibration of the polarizer



Rotator mount

Schedule (future)

- Challenging schedule to follow due to hardware troubleshooting
  - Need second Super-K PMT
- Will need to develop hardware for mPMT testing (next slide)



Measurements of mPMT in PTF

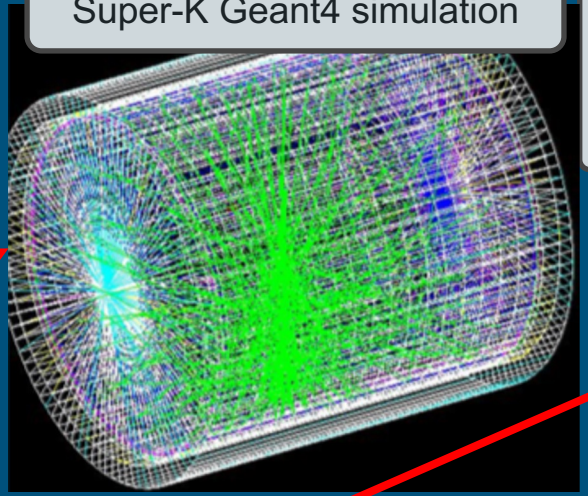
- Repurpose the PTF facility to do underwater measurements for the mPMT
  - Need to recompensate the magnetic field (dynode is at a different location)
  - Need to develop a procedure to insert 3 inch PMT and mPMT in the water tank
    - Need to develop a stand for mPMT
    - Need to design a holder for the 3 inch PMT (3D printed ?)
  - Modify the collision avoidance code (avoid collision with the gantry and the system)
- Pre-calibration measurement
  - Measure the transit time, gain and detection efficiency for the 13 individual PMT
    - Replicate the measurement with mPMT
  - Comparing the 2 detector response will give hopefully hints of the relationship between the individual PMT response vs the mPMT response

Potential integration of measurements into simulations

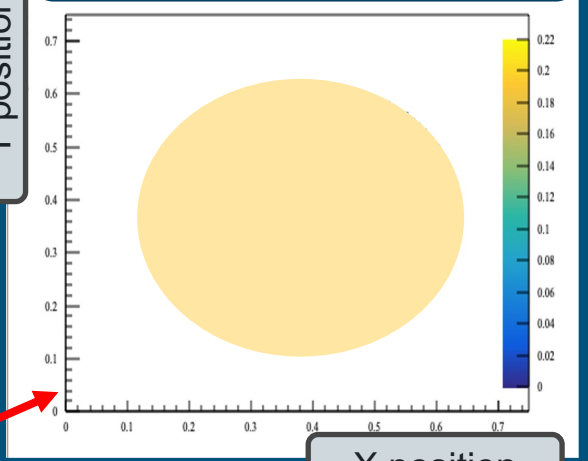
Simulation pipeline for Super-K

- Simplest implementation :
  - Replace Uniform DE by position dependant DE

Super-K Geant4 simulation



Uniform DE implemented

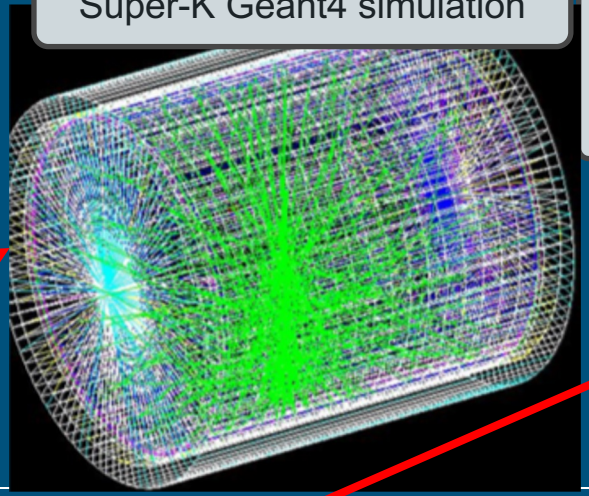


SKG4

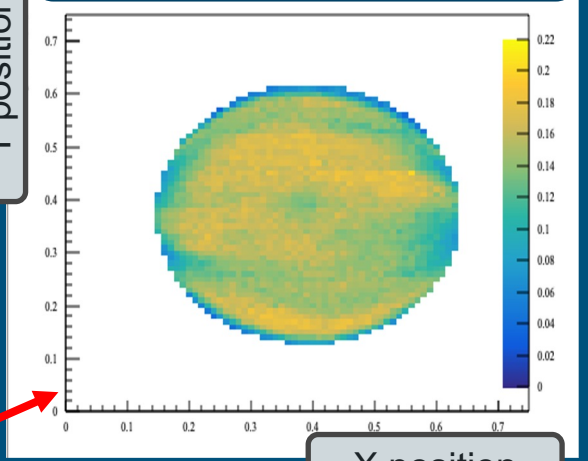
Simulation pipeline

- Simplest implementation :
  - Replace Uniform DE by position dependant DE

Super-K Geant4 simulation

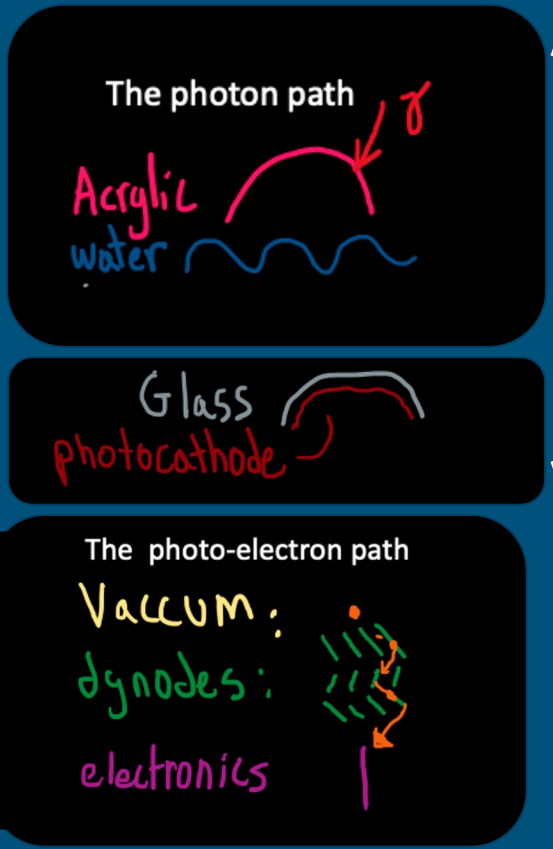


PMT measurements done in 2020 (in water, 0mG, no acrylic)



SKG4

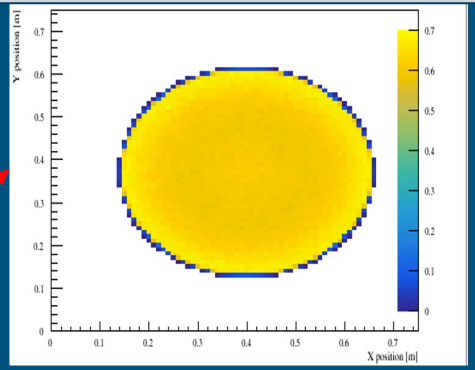
In detail: PMT Modelling



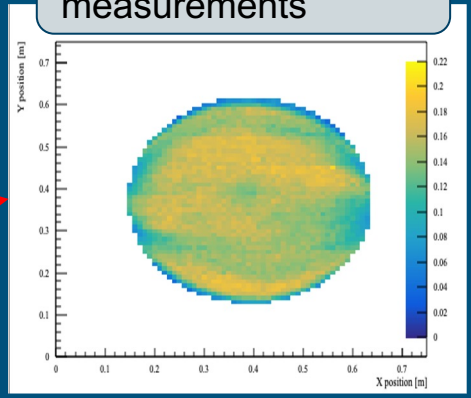
Simulation

PTF data

Step 1: Optical simulation assuming uniform DE in SKG4



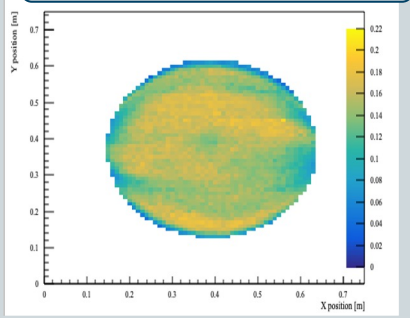
Step 2: Input PTF measurements



Modelling the experiment

Step 3: Build empirical model

DE measurements



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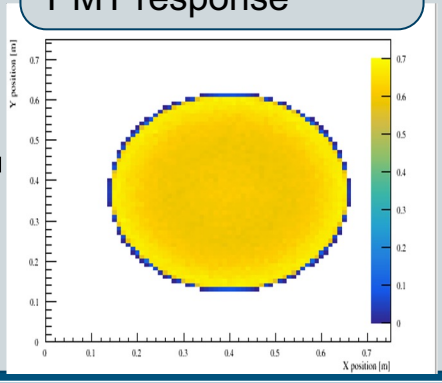
Simulation output, assuming uniform PMT response



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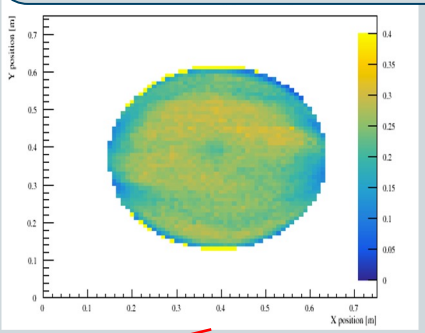
Empirical model of DE (corrected for known effects) for input to sim



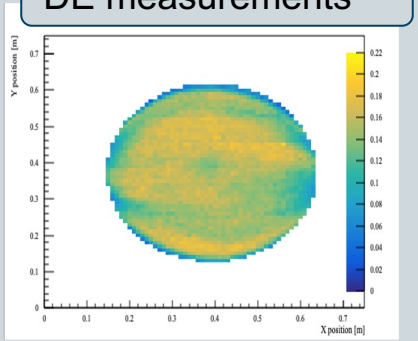
PTF implementation in (SKG4)

True hits → PTF position dependant DE → Digitize hits → Analysis (energy reconstruction, vertex position etc)

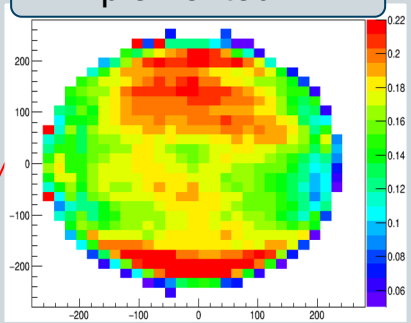
Integration of data into simulation

Step 4: Test empirical model (first cross check seems to be good)

DE measurements



Implemented DE



PTF implementation in (SKG4)

True hits → PTF position dependant DE → Digitize hits → Analysis (energy reconstruction, vertex position etc)

Integrating into WCSIM simulation

- Same idea could potentially be applied to WCSIM ?
  - Using mPMT measurements, it is be possible to extract each PMT direction and response
    - Could implement full mPMT response into the simulation
  - Estimate the impact of these measurements by doing a MC-MC comparaison ?
    - Compare the reconstruction effect on fiTQun
    - Compare mPMT vs 20inch PMT to understand their impact on reconstruction ?

Possible studies for pre-calibration

- Study needs to be done to determine the pre-calibration requirements
  - Study the effect on mPMT response of
    - angular response
    - Position dependance (normalization shift)
    - PMT detection efficiency
    - PMT dark noise and after-pulse
    - PMT timing response (random fluctuation)
- How much pre-calibration measurements can be used and related to the detector operation
  - Relationship between pre-calibration and in detector measurements
- Validation of mPMT performance
  - Confirm specs and expectations for dark noise, transit time and gain measurements

Conclusion

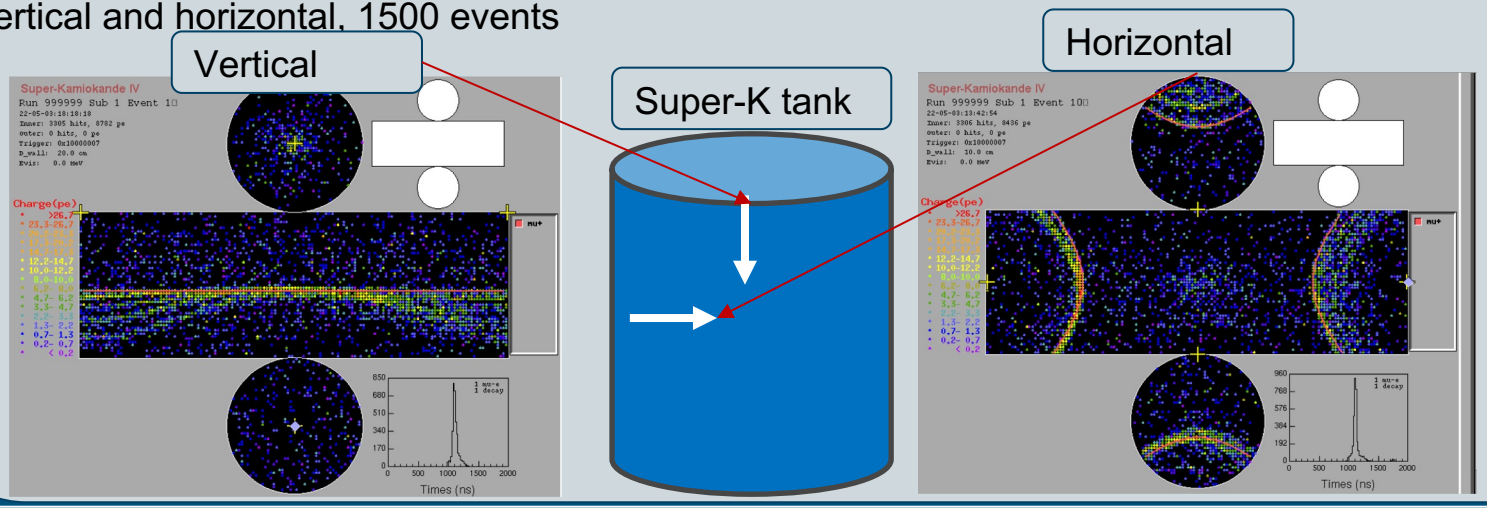
- Pre-calibration plan and requirements needs to be established for WCTE
  - PTF is able to do a full characterization of the PMT
    - Still have some time before doing actual measurements
  - mPMT test stand can measure basic PMT properties
    - Started establishing the analysis pipeline to test it
    - Will valide mPMT specifications
    - More results to come soon
  - Pipeline was created to integrate measurement into the simulations for Super-K, will need to be adapted

Thank you

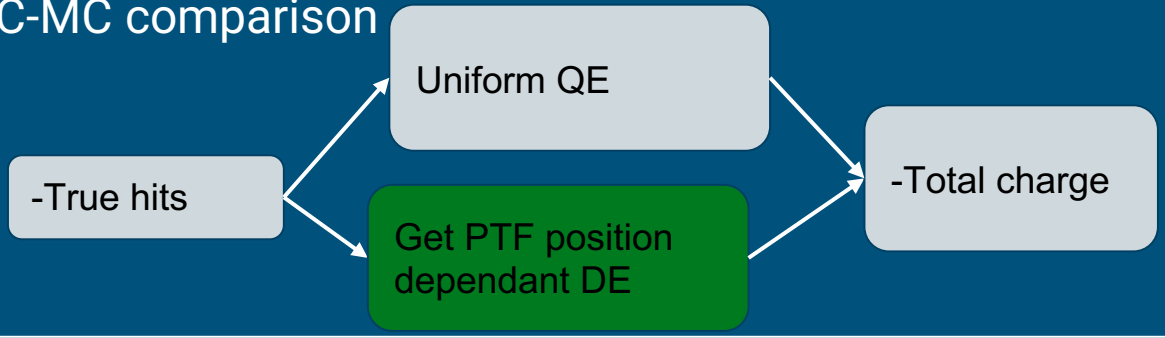
Back up

Integration of data into simulations (2)

Step 5: Apply empirical model on simple study : particle gun μ^+ ,E=1 GeV, dir= (0,0,-1;-1,0,0) vertical and horizontal, 1500 events



MC-MC comparison



Total charge horizontal vs vertical case

- Muon
  - Nominal
    - Mean ratio : 0.97
  - PTF
    - Mean ratio: 0.95

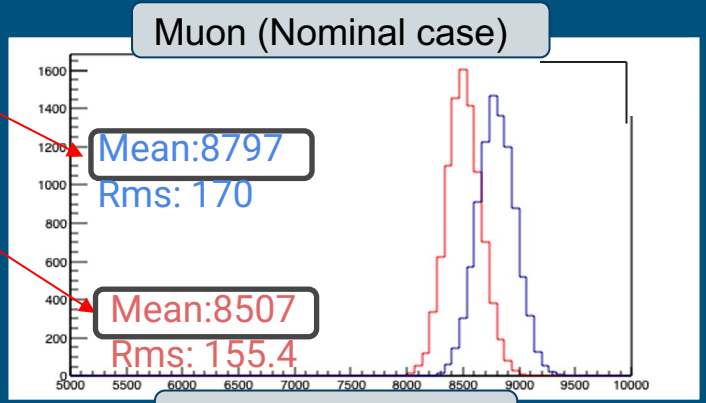
Mean ratio

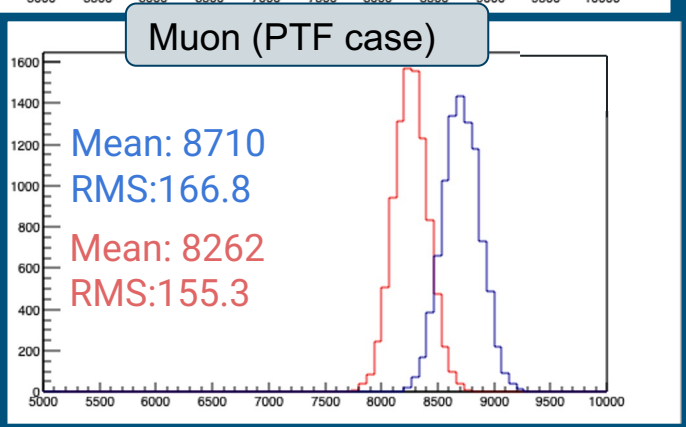
$$\frac{\text{Mean Vertical}}{\text{Mean Horizontal}}$$

Second ratio

$$\frac{\text{Ratio\_nominal}}{\text{Ratio\_PTF}}$$

Difference → 1.91%



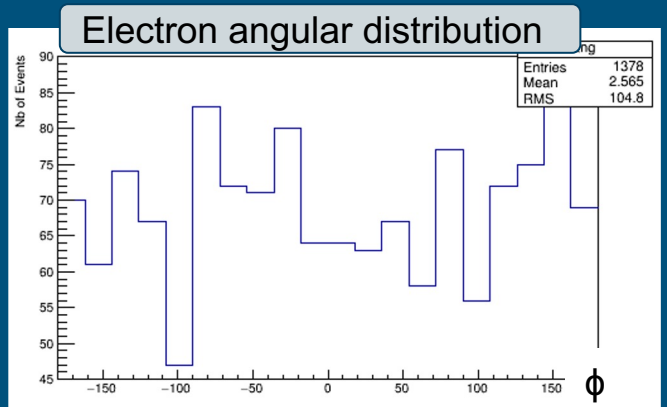


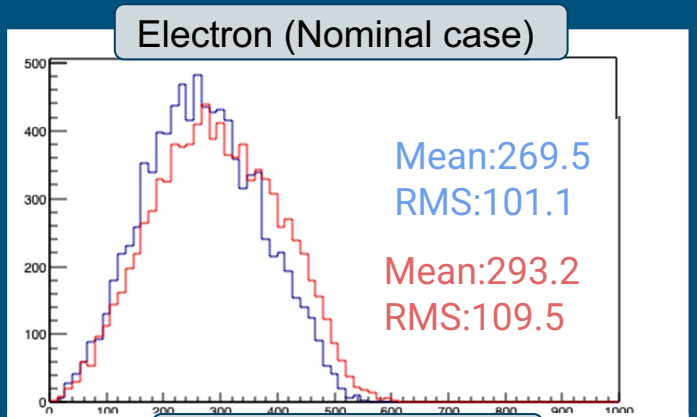
Total charge horizontal vs vertical case (2)

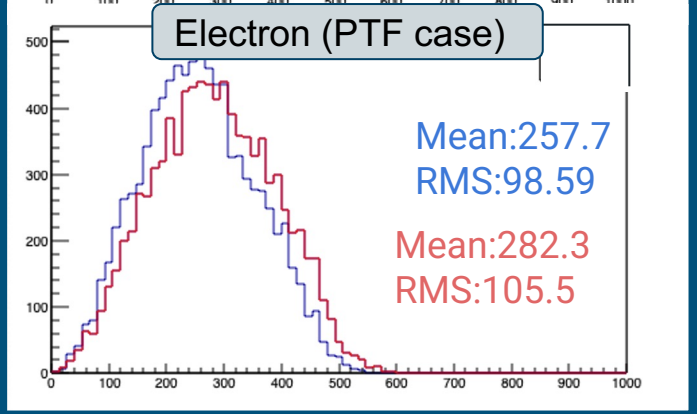
- Decay electron
  - Nominal
    - Mean ratio :0.92
  - PTF
    - Mean ratio: 0.91

Difference 0.69%

- Angular distribution

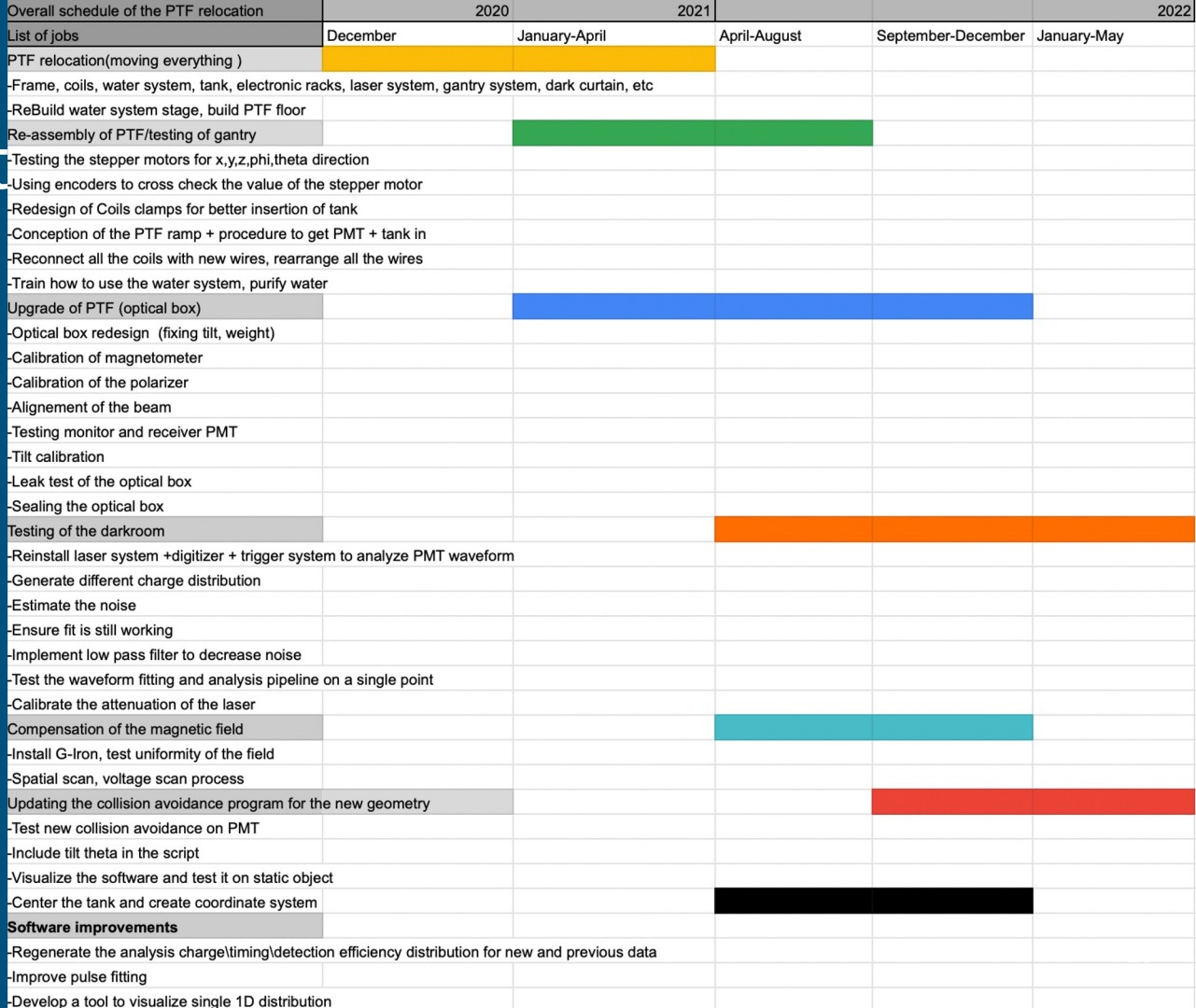






Schedule (past

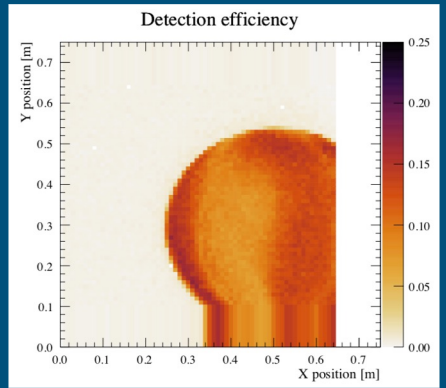
- Since last collaboration meeting
- Much more hardware issues than expected
  - Improvements needed a lot of troubleshoot
  - Different issues coming from the improvements
    - (still not completely resolve)
- Required a lot of work

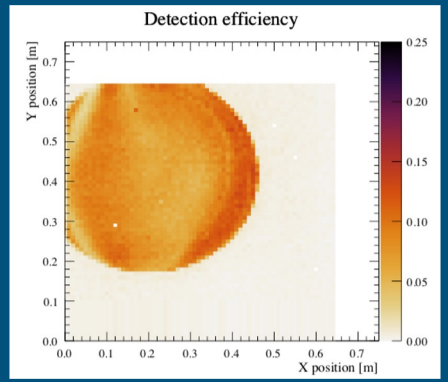


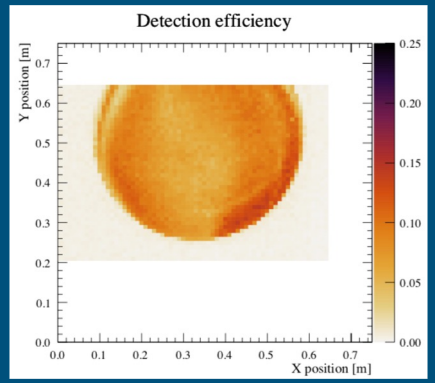
Overall schedule of the PTF relocation	2020	2021			2022
List of jobs	December	January-April	April-August	September-December	January-May
PTF relocation(moving everything)					
-Frame, coils, water system, tank, electronic racks, laser system, gantry system, dark curtain, etc					
-ReBuild water system stage, build PTF floor					
Re-assembly of PTF/testing of gantry					
-Testing the stepper motors for x,y,z,phi,theta direction					
-Using encoders to cross check the value of the stepper motor					
-Redesign of Coils clamps for better insertion of tank					
-Conception of the PTF ramp + procedure to get PMT + tank in					
-Reconnect all the coils with new wires, rearrange all the wires					
-Train how to use the water system, purify water					
Upgrade of PTF (optical box)					
-Optical box redesign (fixing tilt, weight)					
-Calibration of magnetometer					
-Calibration of the polarizer					
-Alignement of the beam					
-Testing monitor and receiver PMT					
-Tilt calibration					
-Leak test of the optical box					
-Sealing the optical box					
Testing of the darkroom					
-Reinstall laser system +digitizer + trigger system to analyze PMT waveform					
-Generate different charge distribution					
-Estimate the noise					
-Ensure fit is still working					
-Implement low pass filter to decrease noise					
-Test the waveform fitting and analysis pipeline on a single point					
-Calibrate the attenuation of the laser					
Compensation of the magnetic field					
-Install G-Iron, test uniformity of the field					
-Spatial scan, voltage scan process					
Updating the collision avoidance program for the new geometry					
-Test new collision avoidance on PMT					
-Include tilt theta in the script					
-Visualize the software and test it on static object					
-Center the tank and create coordinate system					
Software improvements					
-Regenerate the analysis charge\timing\detection efficiency distribution for new and previous data					
-Improve pulse fitting					
-Develop a tool to visualize single 1D distribution					

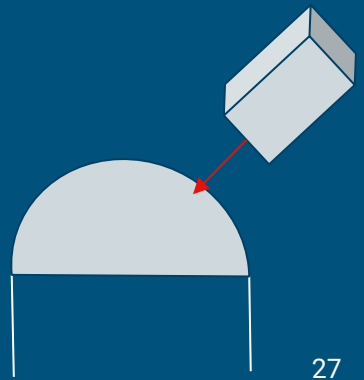
Measurements of mPMT in PTF

- Repurpose the PTF facility to do underwater measurements for the mPMT
  - Need to recompensate the magnetic field
  - Need to develop a procedure to insert 3 inch PMT and mPMT in the water tank
    - Need to develop a stand for the new PMT









How to control and understand the detector uncertainty (Nakajima-san)

- Study needs to established
  - How much pre-calibration is needed for the detector
  - How much pre-calibration measurements can be used and related to the detector operation