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WCTE Analysis Overview

WCTE Collaboration Meeting 22/07/22

Lauren Anthony

l.anthony@imperial.ac.uk

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Contents

- Simulation overview
  - Updates to WCSim
  - Upcoming WCSim tasks
- FiTQun reconstruction
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- WCTE analysis framework
  - Alternative PID with machine learning
  - WCTE event selection
  - Studies required based on July beam test
- Beam window studies
- PMT timing and water attenuation length analysis

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This Session

1. PMT timing and water attenuation length analysis - Alie Craplet
2. Beam window studies - Yassine Alj Hakim
3. Alternative PID with machine learning - Tanima Mondal, Sunanda, Arnab Saker

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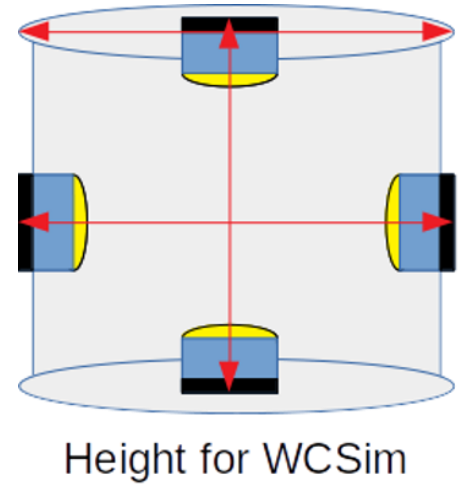
WCTE Geometry Options

- Original: 18 column 5 row (~130mPMT)
- Reduced diameter #1: 18 column 5 row
- Reduced diameter #2: 16 column 5 row
- Reduced height and diameter: 16 column 4 row (~104 mPMT)



Config	Columns	Rows	Height (mm)	Diameter (mm)	ID height (mm)	ID diameter (mm)	Photocoverage
Original	18	5	4320	4022	3539	3621	19%
Reduced diam 1	18	5	4200	3800	3539	3439	20%
Reduced diam 2 (16c-5r)	16	5	4200	3800	3539	3427	17%
Reduced height and diam (16c-4r)	16	4	3400	3800	2739	3427	19%

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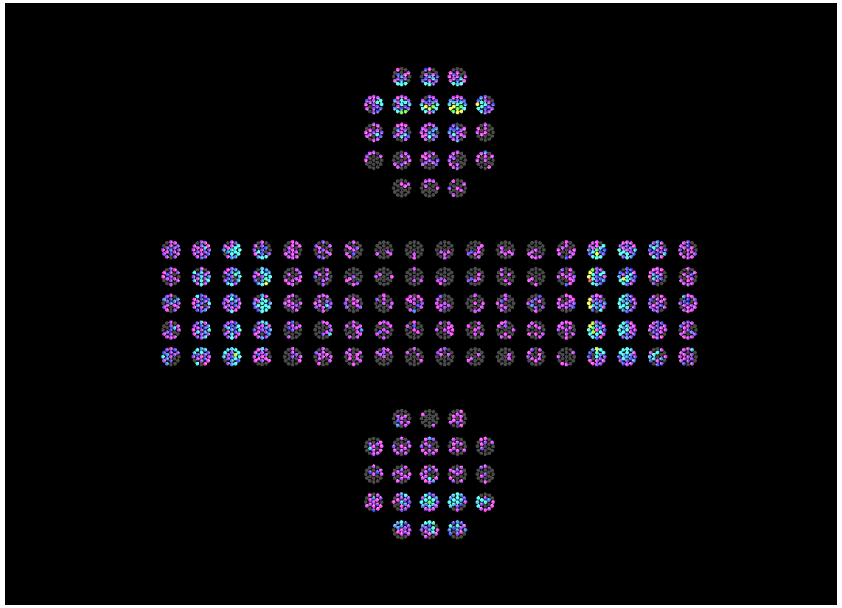
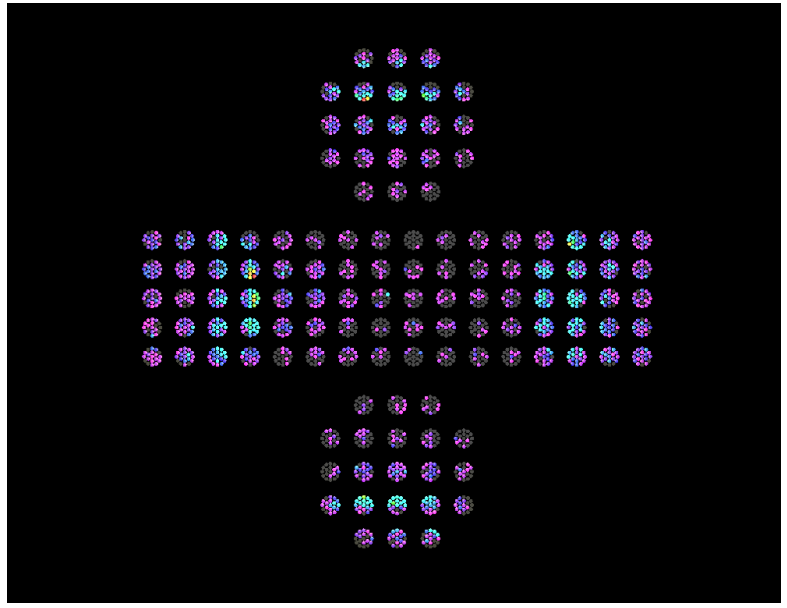
WCTE Geometry Options

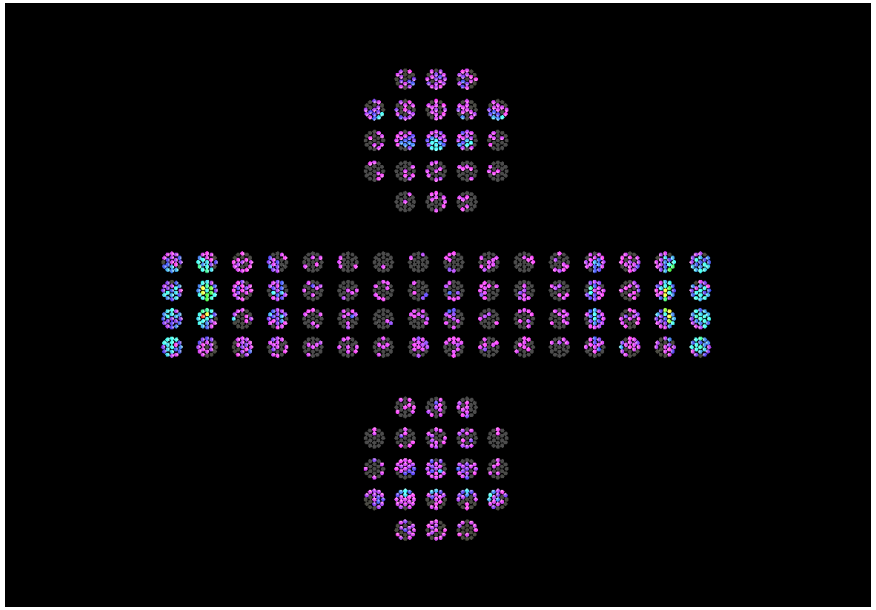
Original 18 column, 5 row



16 column, 5 row



16 column, 4 row



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Simulation and Reconstruction Overview

1. Simulations done using WCSim
   - https://github.com/WCSim/WCSim (official)
   - https://github.com/laurenanthony2/WCSim (options to change WCTE geometry)

2. Apply the fiTQun reconstruction algorithm
   - https://iopscience.iop.org/article/10.1088/1742-6596/888/1/012066
   - For geometries with significant changes I.e. different number of mPMTs this must be retuned
   - To use fiTQun you must be added to the github repo

3. Retune fiTQun with new dimensions and produce MC using WCSim
   - Done using the fiTQun Utilities package

4. Apply new version of fiTQun

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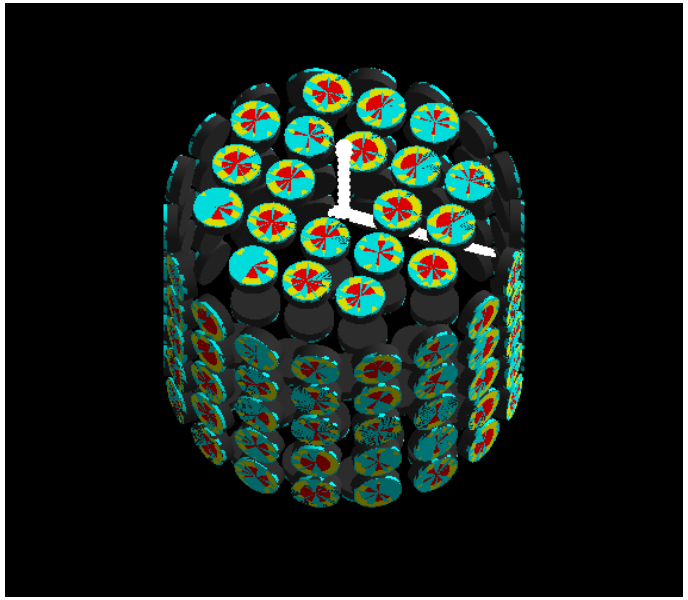
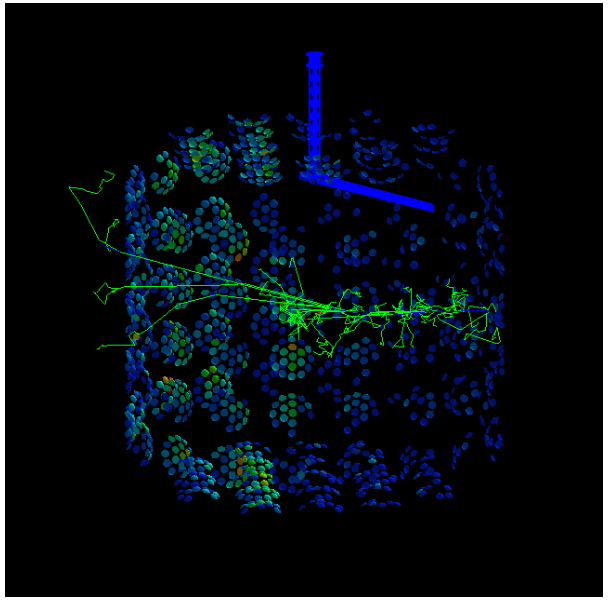
CAD Model Integration with WCSim

- CAD models have been successfully imported into WCSim (not implemented yet in official repo)
- Method uses "CADMesh" software (open source)
  - https://github.com/christopherpoole/CADMesh
- Working in PR for this function and for geometry options
- Pablo is working on importing CAD models of mounted cameras





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WCSim Tasks

- Potentially "The Great Merge" is approaching...
  - Merge HK and nuPRISM branches of WCSim
- Currently working on PR for all recent change from laurenanthony2/WCSim -> WCTE/WCSim:
  - Geometry updates
  - CAD interface
  - mPMT removal on top cap
- Process:
  - Line up WCTE/WCSim, nuPRISM/WCSim, WCSim/WCSim and keep them synced
    - Tom Dealtry merges the great merge into WCSim/WCSim
    - We merge WCTE PR into WCTE/WCSim
    - We PR from WCTE/WCSim into WCSim/WCSim
  - We will need some validation at various stages -> requires some more analyzers

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FiTQun Tuning Program: Current status (same as last meeting)

- Tuning for 18c5r was completed by Shinoki-san some time ago
  - These tuning files are available to download through fiTQun scripts
- Tuning for 16c5r is complete
  - Some bugs to iron out (see following slides)
- Tuning for 16c4r is ongoing
  - Found some bugs in the scattering table and PMT timing response and only reran for 16c5r
    - Angular response is complete
- Bugs mainly include a momentum bias (still investigating but is ok for some studies to look at relative differences in reconstruction)

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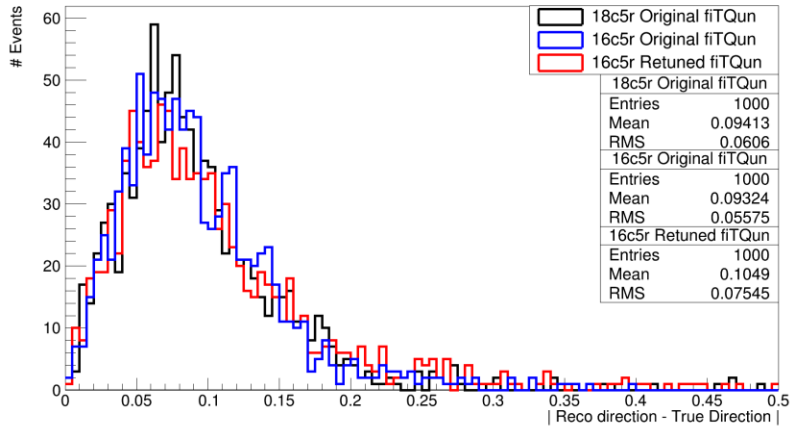
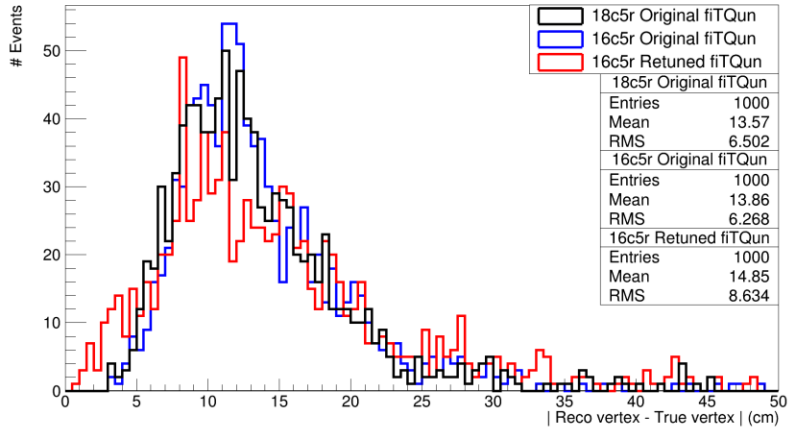
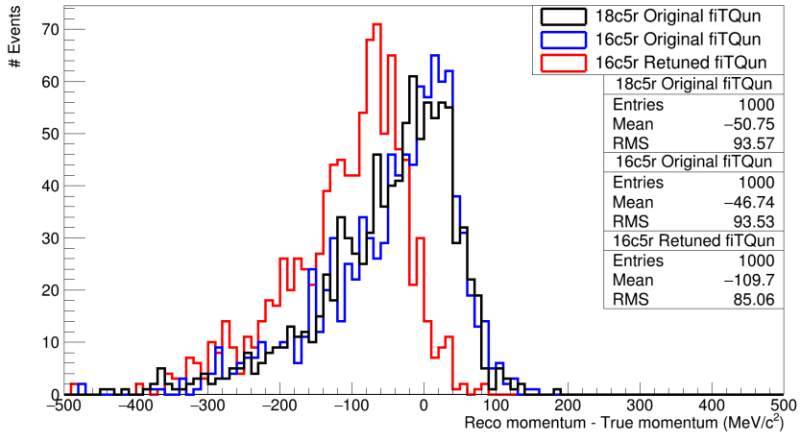
FiTQun reconstruction comparison: 500MeV e-



- **500MeV e- from centre of detector**
- Reconstruction seems worse after tuning
- RMS of momentum resolution reduced after tuning however there is a clear momentum bias
  - Requires some tuning of QE parameters in fiTQun override file





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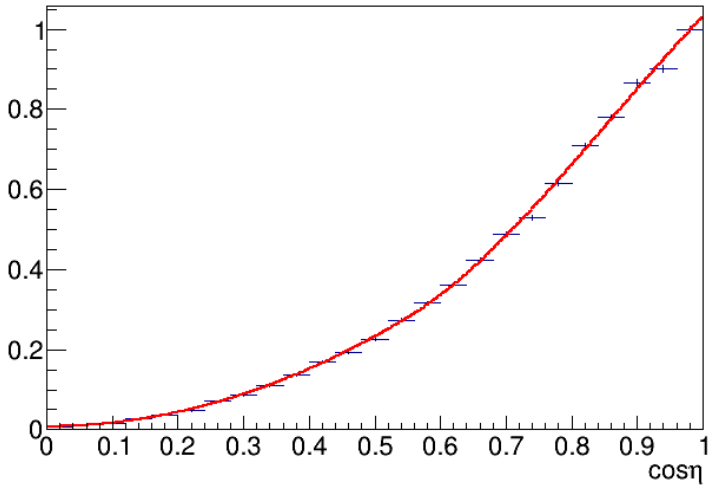
Initial look at outputs from angular response stage

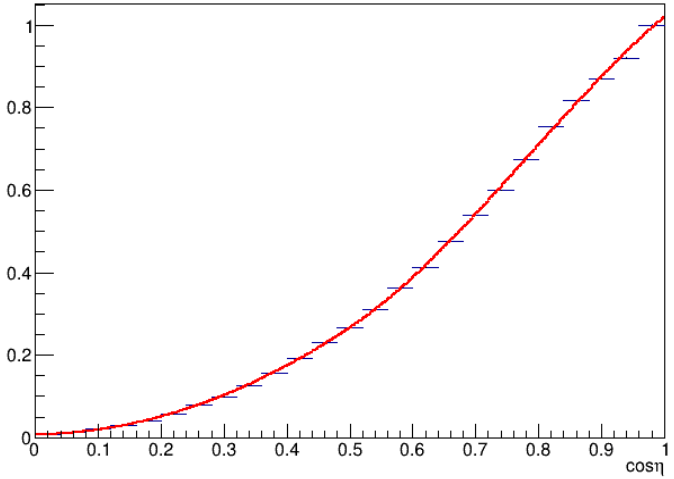
Angular Response Comparison

Angular response shape for 16c 4r has been verified in Alie's analysis using WCSim only

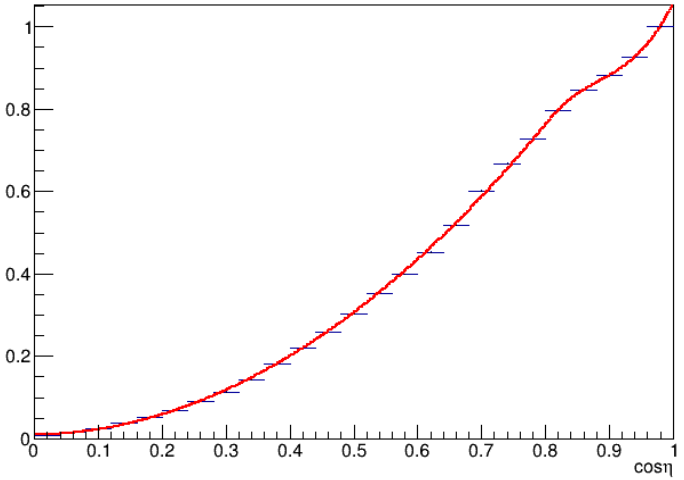
18c5r

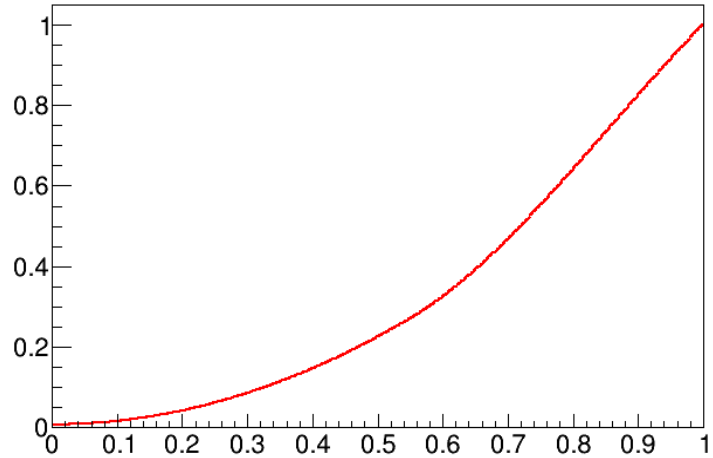


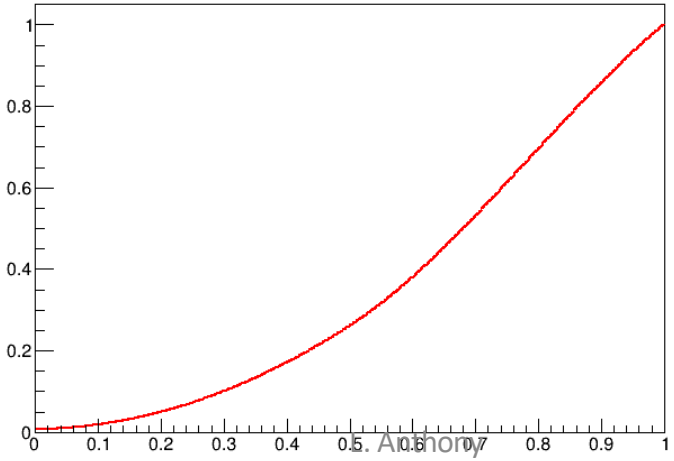
16c5r

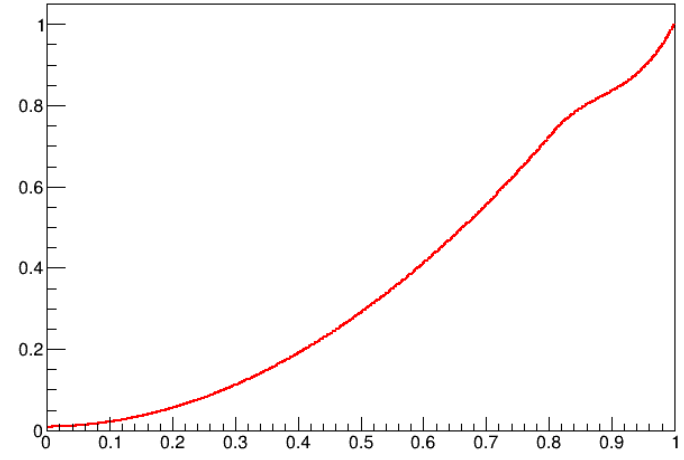


16c4r









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WCTE Analysis: Defining Analysis Cuts

- Seen from the reconstructed momentum plots that there are momentum regions where we do not reconstruct so well
  - Many particles pass through the detector
  - Some below Cherenkov threshold
  - Low visible energy events

- Need to calculate:
  - "towall" and "dwall" - distances of vertex to detector wall
    - Based on calculations used for SK and IWCD
  - Visible energy cut
  - PID cuts based on likelihood

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Study of Beam/statistics requirements

- Need to study the requirements necessary for the beam

- Important to study electron contamination in muon sample
  - Ideally want 99% purity in muon sample
  - Need to study mis-PID

- Pion studies
  - Pions mostly use to study scattering
  - Expect ~ 1k pion events/day WCTE
  - 200 MeV pions are below Cherenkov threshold when entering the detector (with nominal beam window design)
  - Impacts beam window design
  - WCSim is difficult to remove individual mPMTs in the current configuration

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Tanima Mondal, Arnab Saker, Sunanda

Machine Learning Application

(Alternative PID method)

- **Motivation from Results obtained for Machine Learning applications in IWCD.**
- **Idea is to apply Machine Learning Techniques for PID & Event Reconstruction.**

- WCSim Simulation of 1 million e- and μ- events using (4R,16C) geometry class.

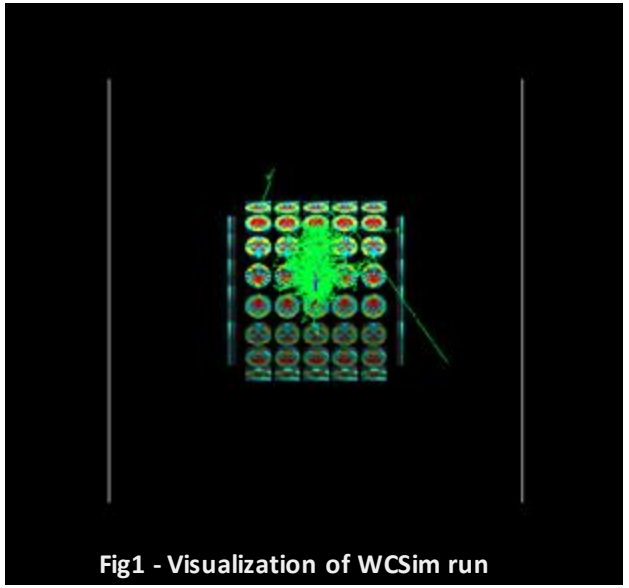
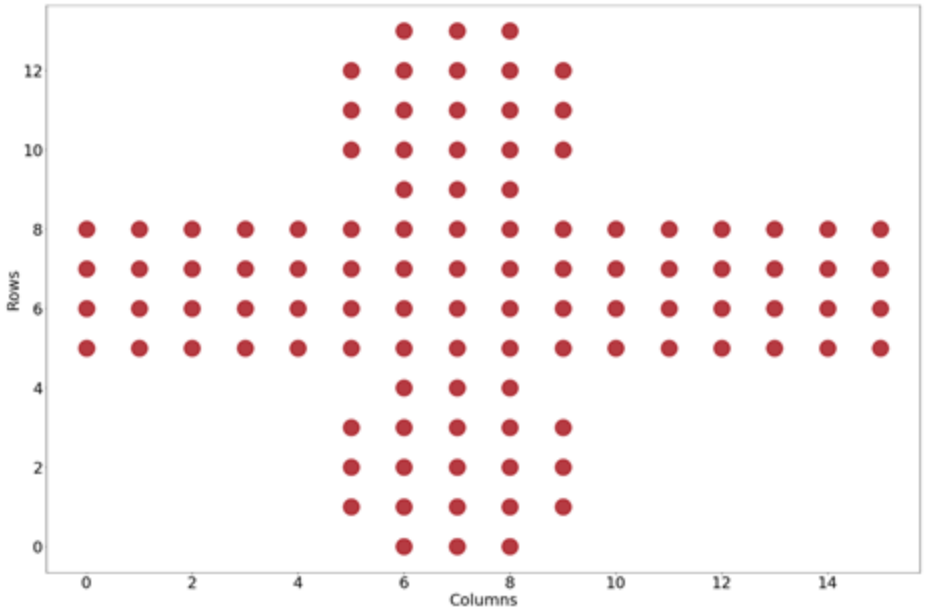


Fig1 - Visualization of WCSim run

- **Current Work:**

  Development of ML Data Pipeline (Faster implementation of ML model)
  - Conversion of .root files -> .h5 file for ML training
  - Data Exploration and Preprocessing of the Simulated event data
  - 3D mapping of WCTE detector to 2D Image.

- **Future Work:**
  - **Initiate ML training with generated event data.**
  - **Apply Machine Learning Algorithms**
    - For Event Reconstruction.
    - Particle Identification Analysis.



2D mapping of mPMT's

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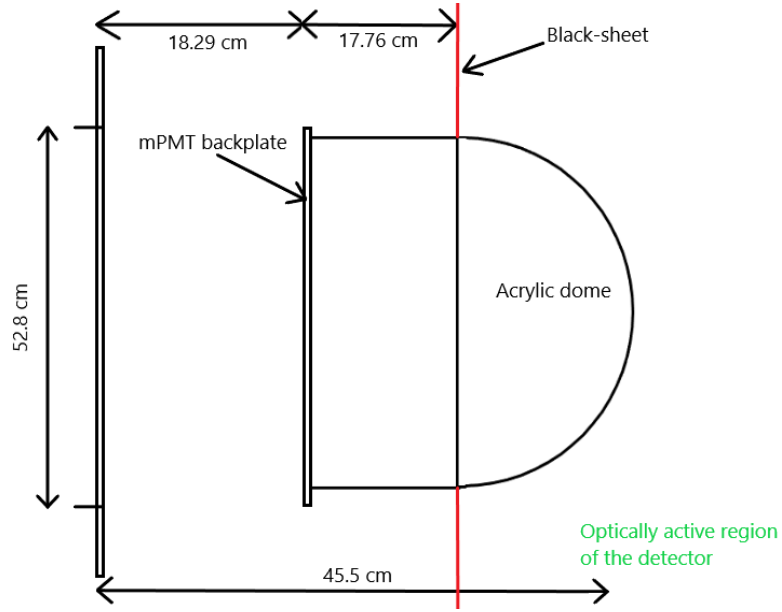
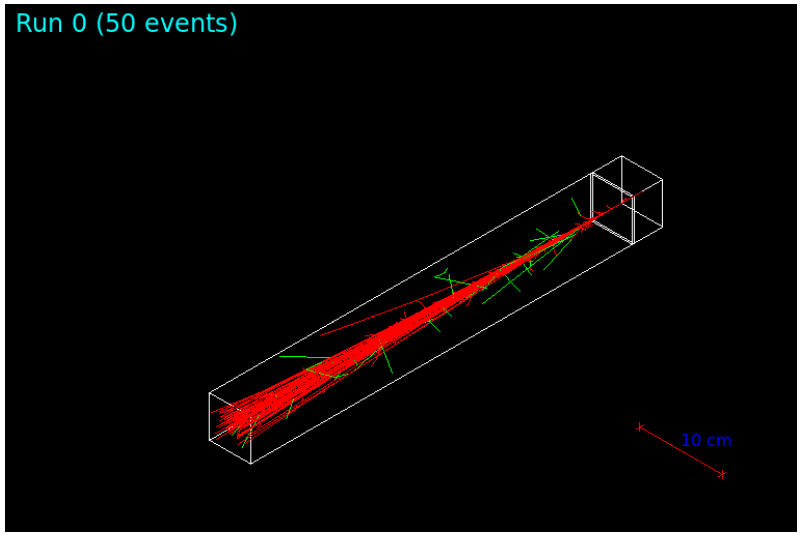
Y. Alj Hakim

Beam Window Studies



- Beam window simulation
  - Using Geant4 v4.10.01.p03
  - Using detector dimensions, material characteristics from WCSim
  - Physics lists:
    - FTFP_BERT, G4EmStandardPhysics, G4OpticalPhysics
  - Compared different beam window configurations
    - Using 200, 300, 2150 MeV/c electron, muon, pion and proton beam
    - 2500 events simulated
    - Looked at beam divergence and beam energy resolution at the black sheet position



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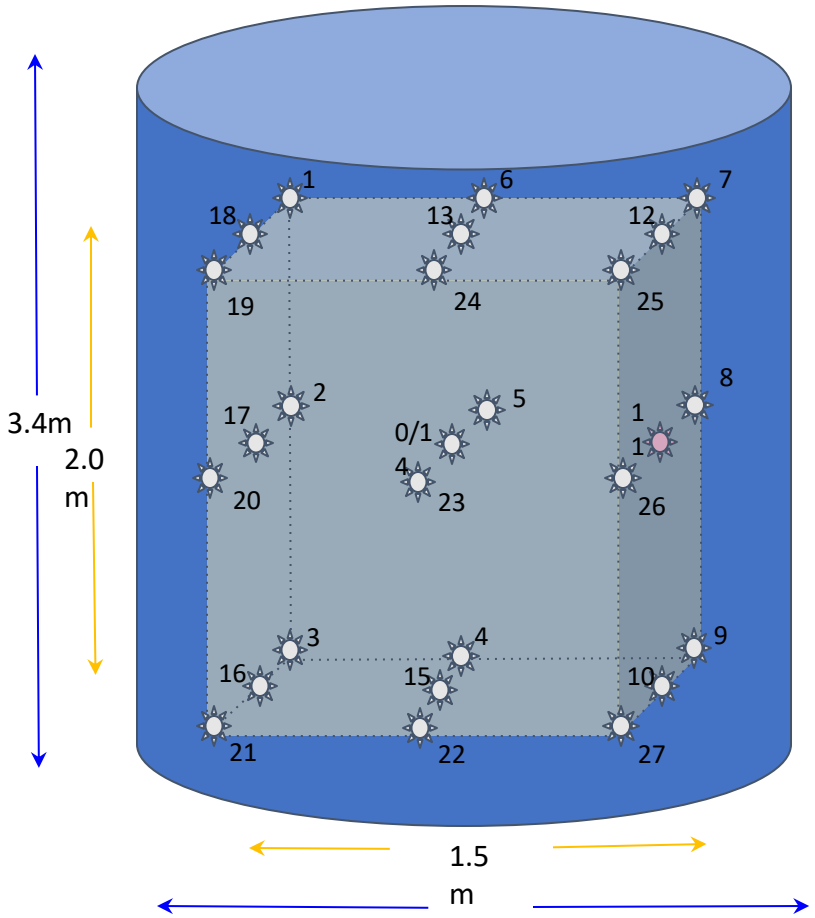
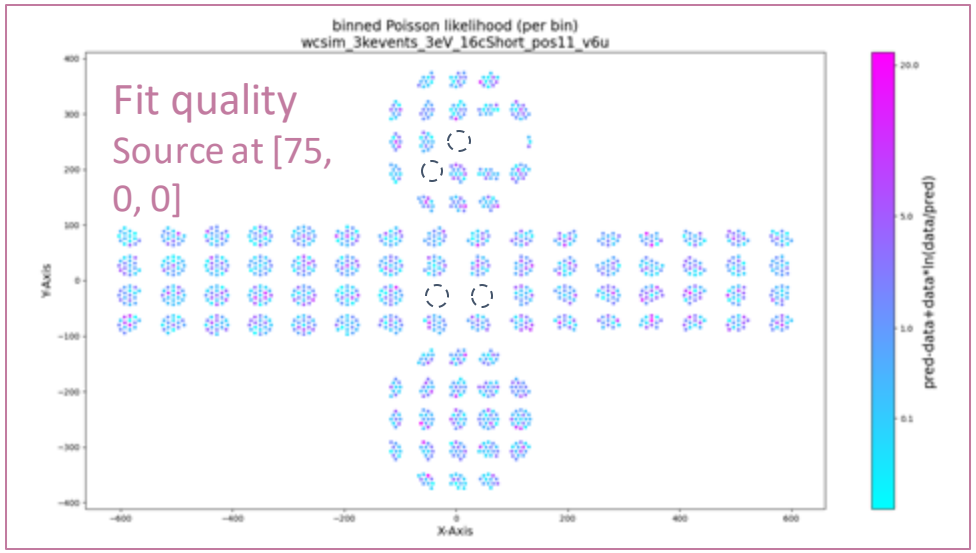
A. Craplet

PMT timing and water attenuation length analysis



- Study PMT timing – how well can we calibrate out differences in PMT response/properties
- Calculation of water attenuation length through developing the HK "hybrid attenuation fitter"



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Summary

- Some updates and merges necessary for WCSim to move on
  - Require some person power for validations of merged versions of WCSim
- Retuning of the reconstruction algorithm is ongoing
  - Shown some degradation in momentum, direction and vertex resolution compared to larger detector
  - Need to study direct and indirect light MC in more detail
- Working on more comprehensive analysis and selection cuts for WCTE
  - Necessary for studying WCTE beam requirements
  - Studies of muon sample purity
  - Low momentum pion reconstruction
- Beam window studies suggest a beam window entering the detector within the support structure is favourable
- Ongoing studies in
  - PID with machine learning
  - Calibration analyses for PMT timing and water attenuation length

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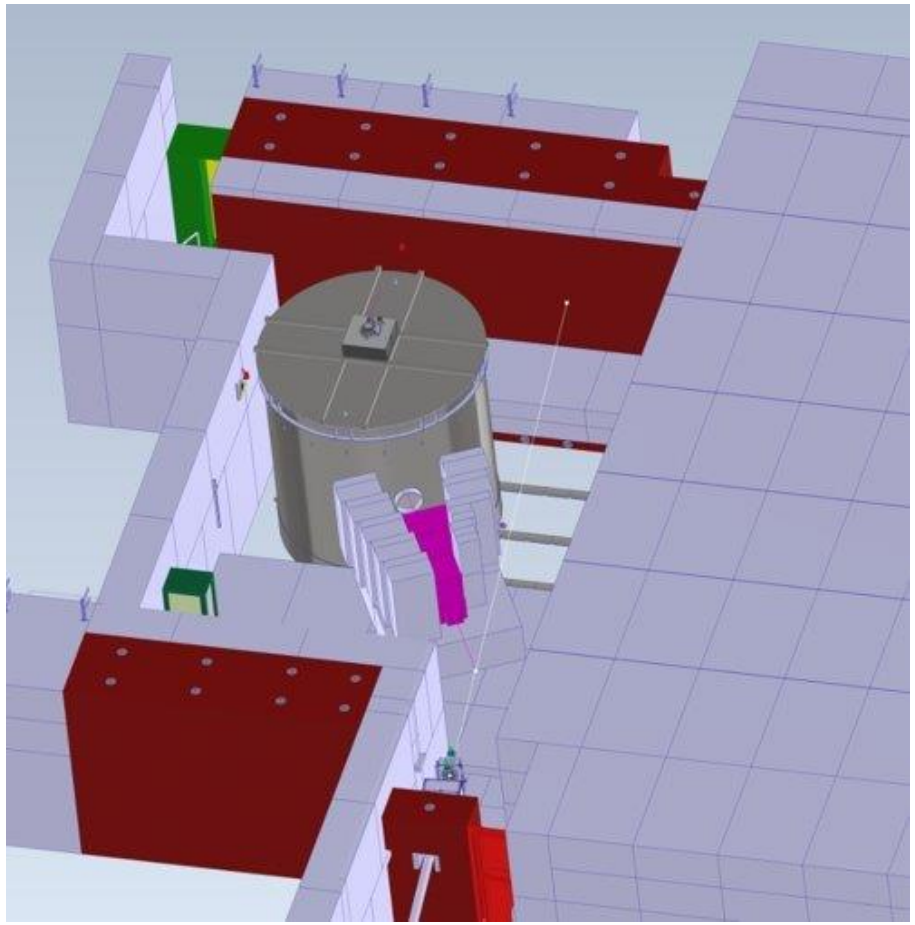
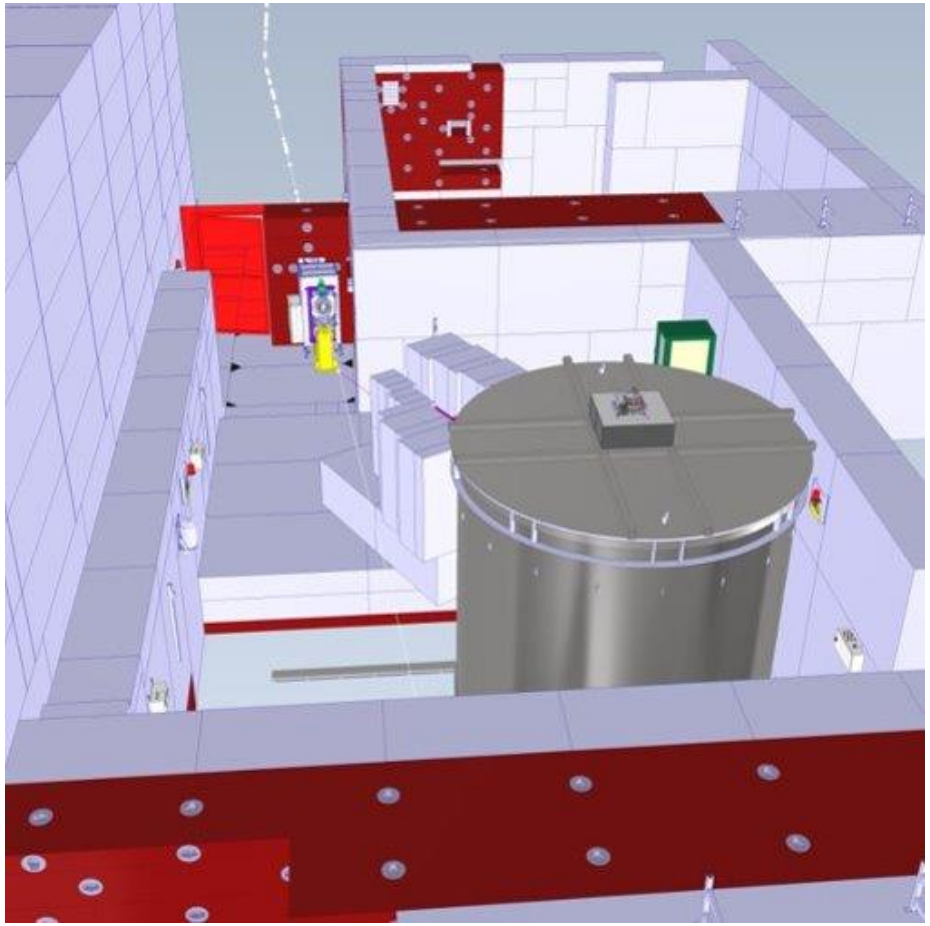
WCTE in T9





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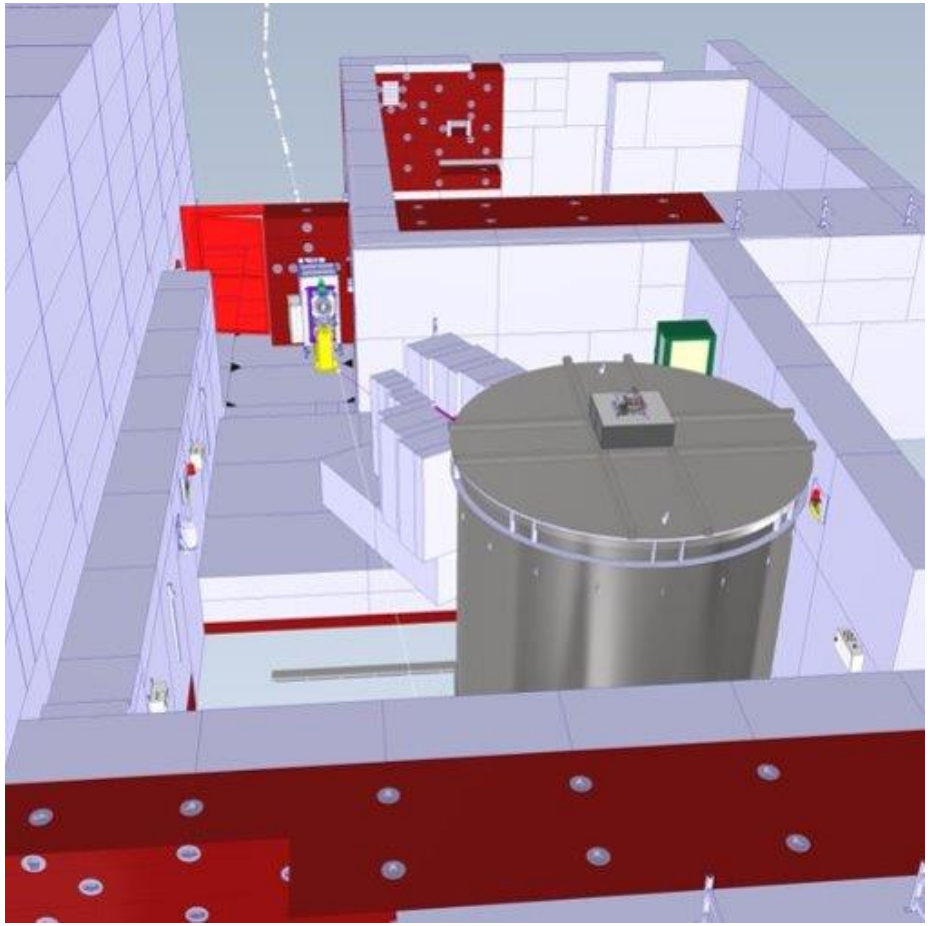
WCTE in T9: Diameter Restriction

- Original 18 mPMT column, 5 mPMT row detector was a tight fit into T9
  - Space for movement system
    - Little space to walk around
    - Little space for crank
- Tank diameter was also larger than could easily be transported
  - > 4m diameter required road closure
- Smaller diameter also reduces price
- Studied a reduction in diameter by
  - Keeping same number of mPMTs
  - Removing 2 columns



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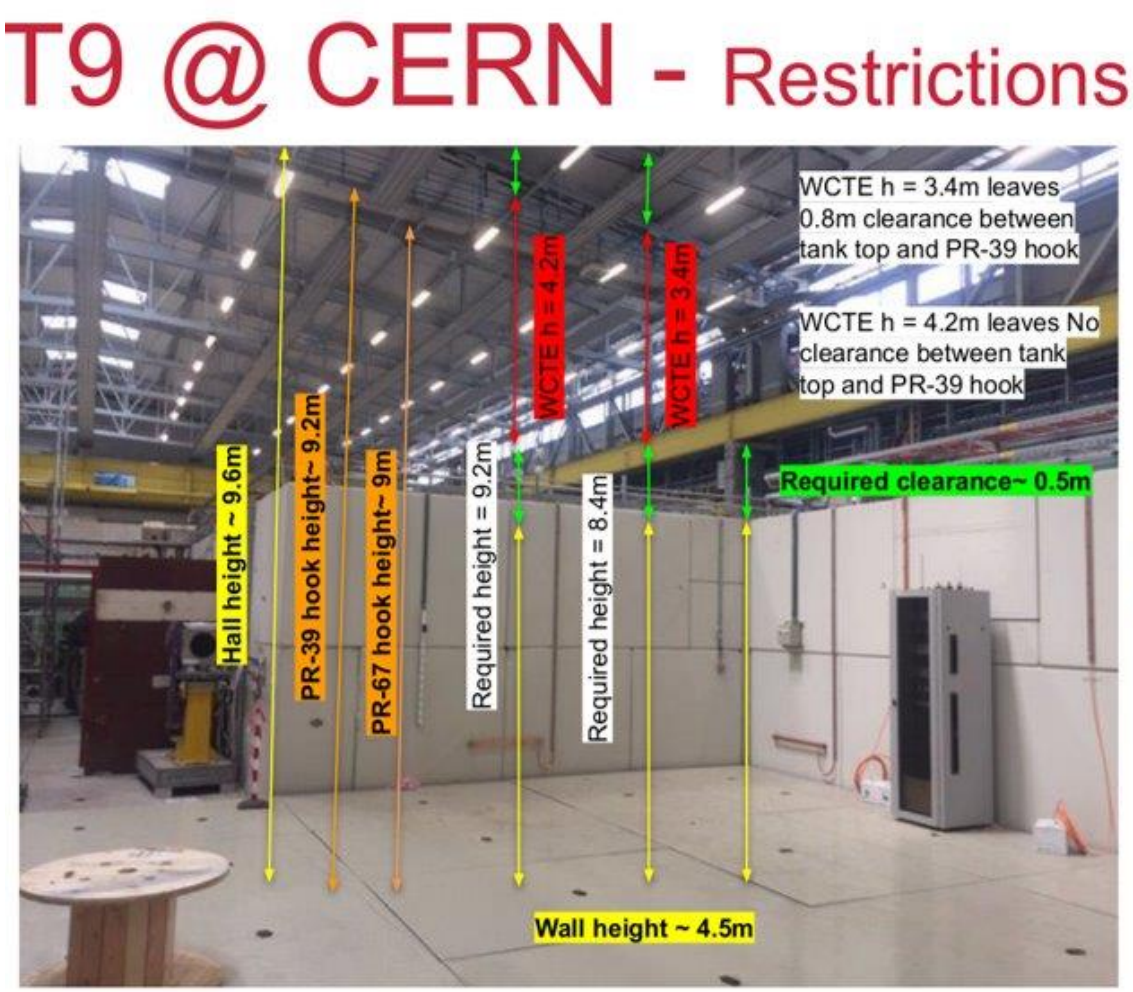
WCTE in T9: Height Restrictions



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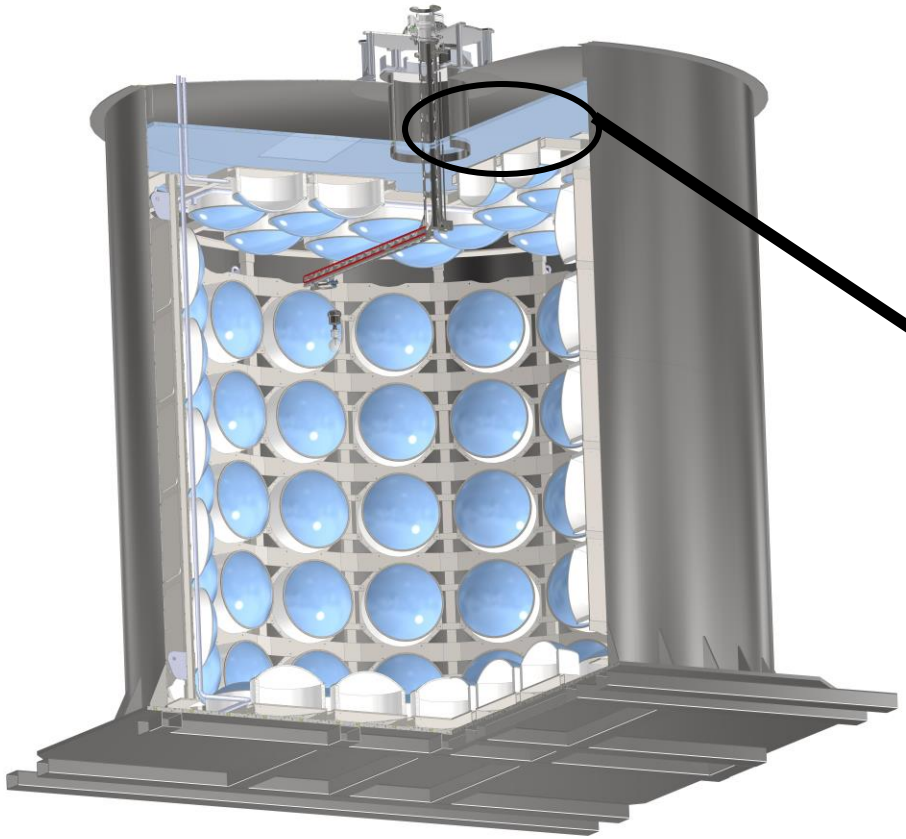
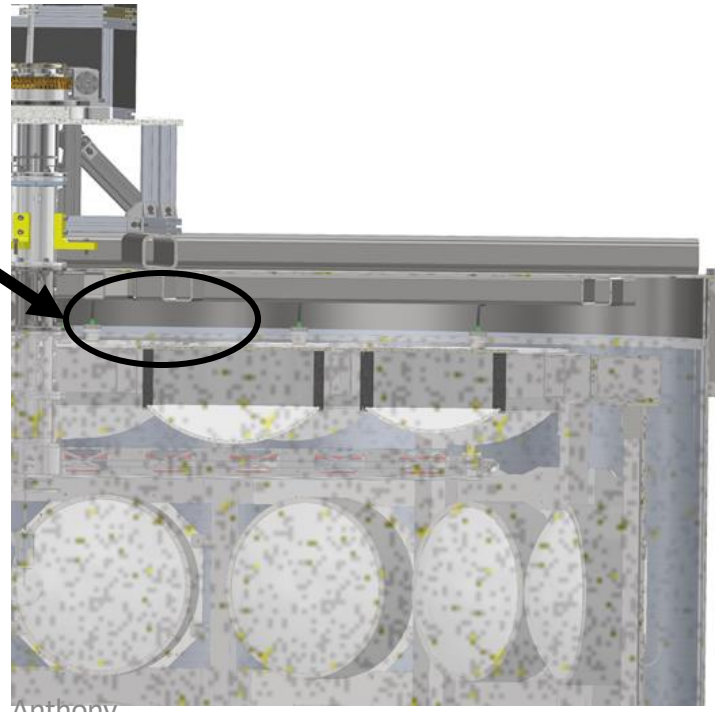
Reminder: Height Restrictions



- With original design, it was not possible to lift WCTE into T9 with either crane
- Investigated:
  - Removing some space between support structure and lid
  - Remove one row of mPMTs



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FiTQun Tuning Program

1. Create indirect light tables (scattered and reflected light)
   - Simulate "electron bomb" ~1bn events (MC used for this step and angular response)

2. PMT tunings
   - PMT charge response (doesn't need to be changed if using same PMTs)
   - PMT angular response (detector dependent)
   - PMT timing response (detector dependent)

3. Scalar parameters
   - Don't know so much about

4. Cherenkov profiles (independent of detector, but varies with simulation package)
   - Shouldn’t need to be redone for new geometries

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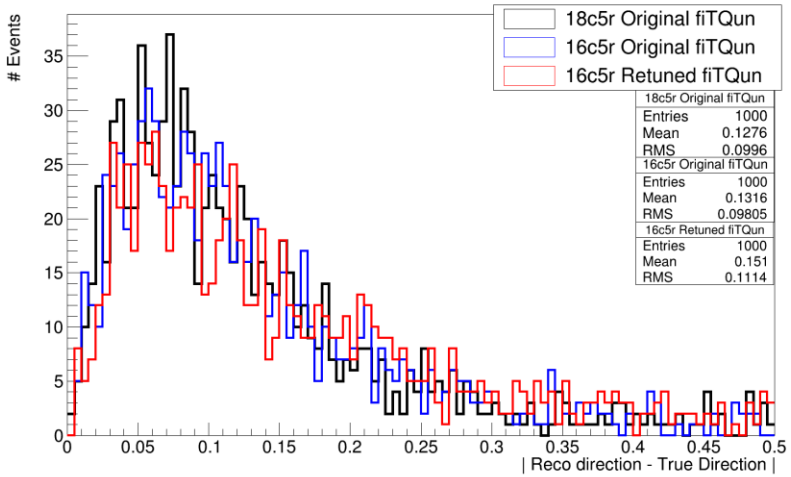
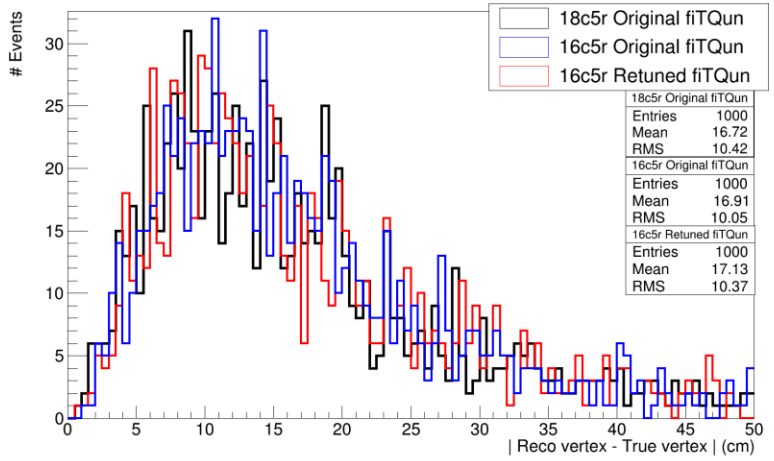
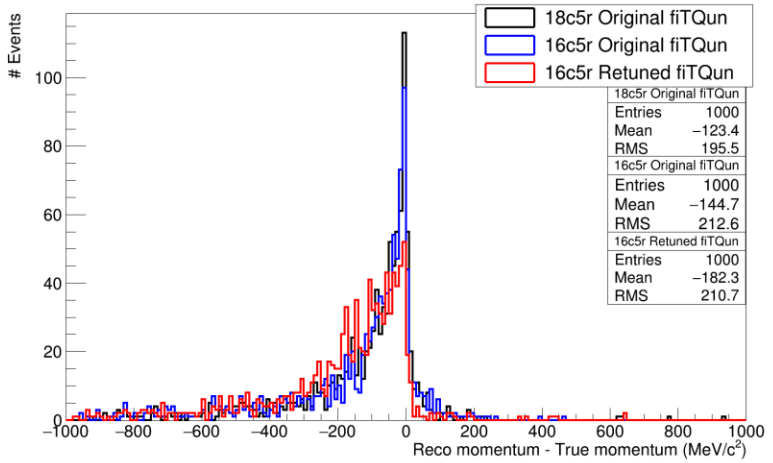
FiTQun reconstruction comparison: 1000MeV e-



- **0 - 1000MeV e- uniformly distributed**
- Resolution much worse for after tuning





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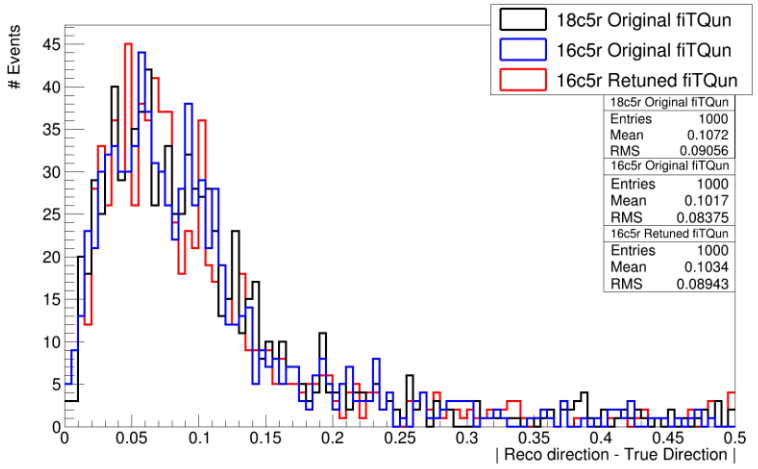
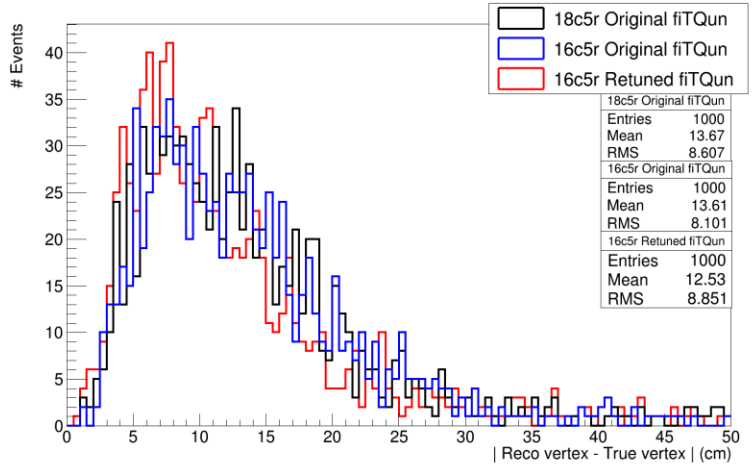
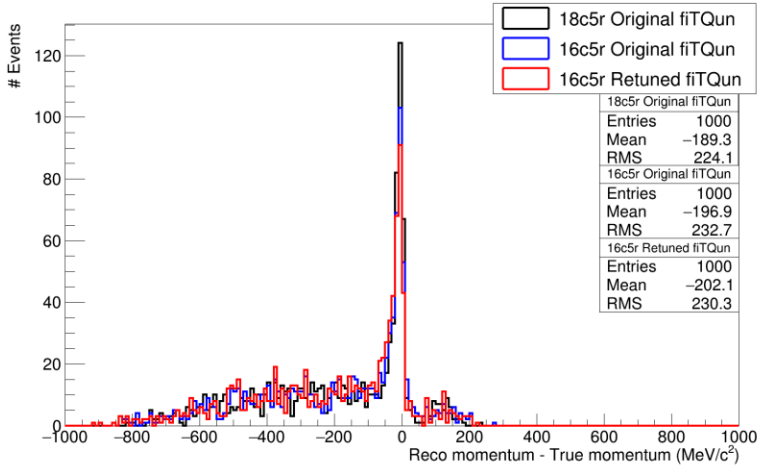
FiTQun reconstruction comparison: 1000MeV mu-



- **0 - 1000MeV mu- uniformly distributed**
- Smaller difference in mean and RMS values for uniformly distributed muons
- Resolution for muon like events seems better than for electrons after tuning
  - RMS of momentum resolution better after tuning





IWCD

- **Motivation is to apply Machine Learning Techniques to the IWCD event selection.**
- **Rebaseline of IWCD detector,** and **modification of IWCD geometry** to achieve neutrino interaction rates at higher precision.
- The performance of ML ResNet Model is analysed using IWCD short tank geometry data, to compare with fiTQun performance.

- **Current Work:**
  - **Analysing fiTQun PID performance for IWCD short tank geometry** to study ν_e event samples
  - ν_e interactions enriched samples are selected, where CC0$\pi\nu_e$ is signal event, NCπ^0 & entering **γ** are background events.
  - **Reconstruction algorithm fiTQun is applied with e-mu & π^0-e cut to separate signal from background.**
  - IWCD short tank geometry is analysed through **generating ROC curves and confusion matrix for PID.**

- **Future Work:**
  - Analyse fiTQun PID over IWCD latest production **with higher statistics and retune the cut line**.
  - Eventually **apply ML PID techniques to select IWCD events.**

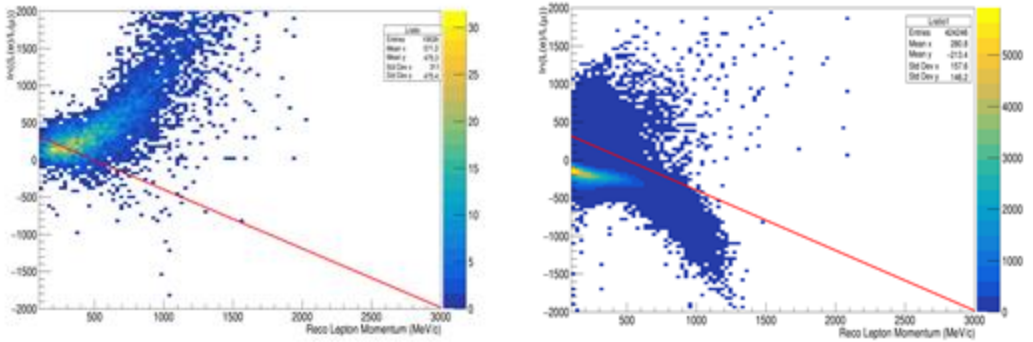


Figure: Distribution of events in reconstructed electron-muon likelihood ratio vs reconstructed lepton Momentum

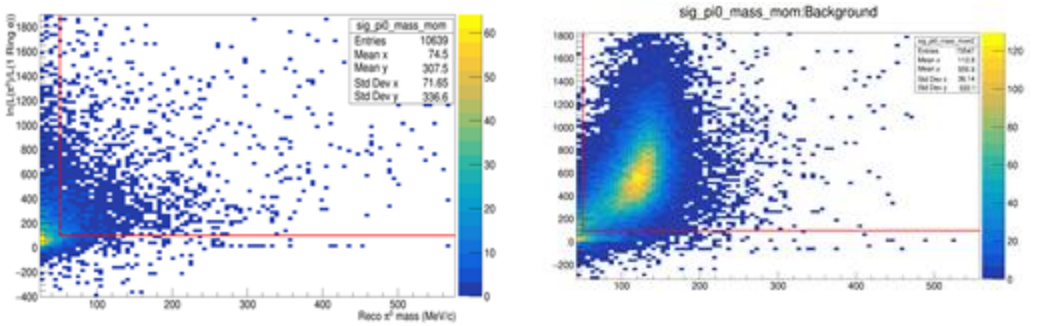


Figure: Distribution of events in reconstructed π^0-1 ring electron likelihood ratio Vs reconstructed π^0 mass

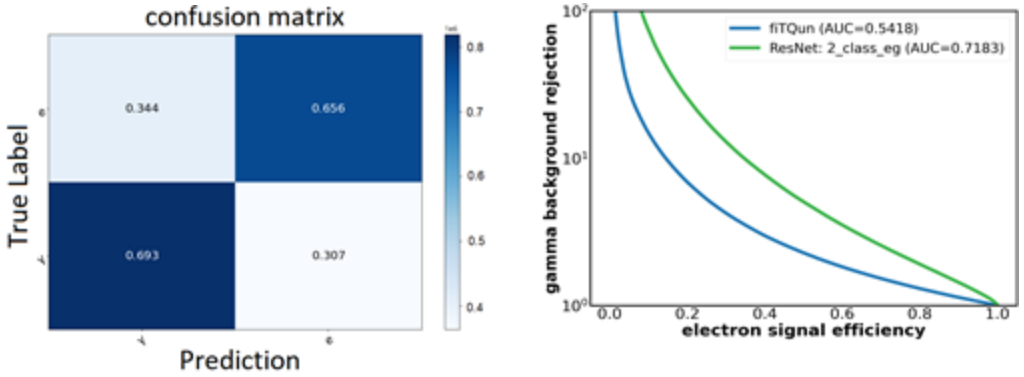


Figure: Confusion Matrix and ROC curve for e/γ identification