Hyper-K simulation

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Task 1.5 Hyper-Kamiokande simulation

- Deliverable due March 2026
  - *simulation data analysis with the final photosensor configuration*

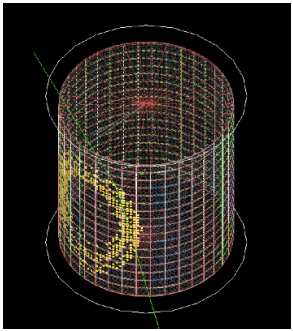
Have 3 pieces of software to do this

1. Geant-4 physics, PMT & electronics simulation
   1. WCSim is the current package
   2. GHOST is the new package
2. Triggering using TriggerApp

Outline

WCSim

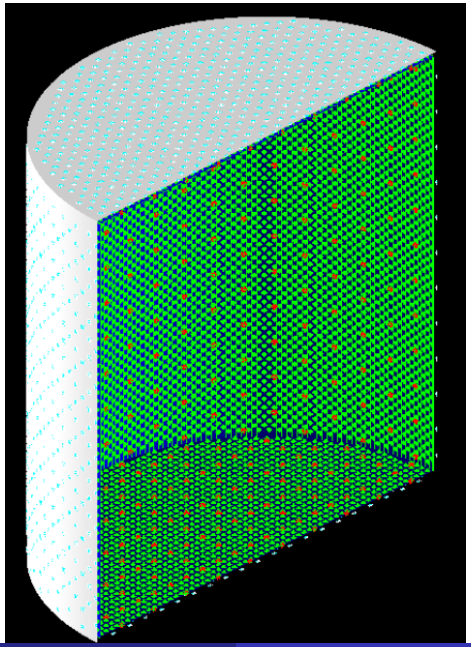
- An open-sourced, Geant4-based simulation code for water Cherenkov detectors
- User can define a detector configuration by choosing:
  - Detector geometry
    - ⋆ SK, Hyper-K far detector, IWCD, WCTE, ...
  - PMT type
    - ⋆ SK 20", HK 20", mPMT 3", OD 3", ...
  - Electronics
    - ⋆ SKI
  - Simple triggers
    - ⋆ NHits, pass all
- Run particles in your detector using either:
  - Input from neutrino interaction generators
  - or using Geant4 particle generation



New far detector geometry

Realistic implementation based on integration drawings

- PMTs placed in realistic positions
  - 20”
  - mPMTs
  - OD

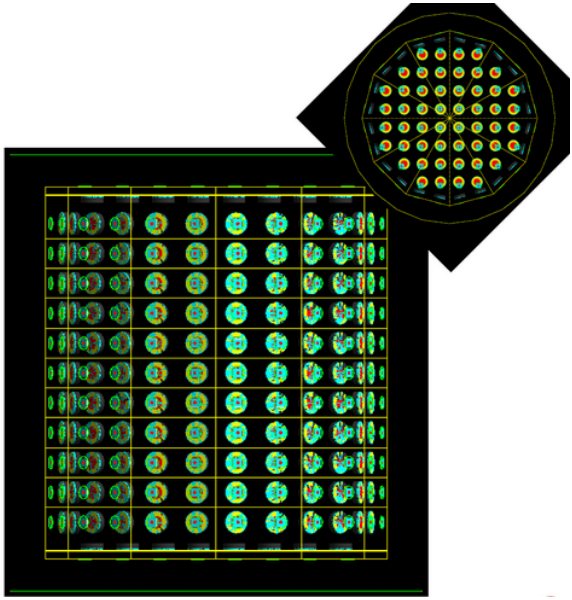


New IWCD geometry

UTokyo

Realistic implementation based on integration drawings

- New tank size
- New number of mPMTs
- New number of OD PMTs
- New OD water thickness



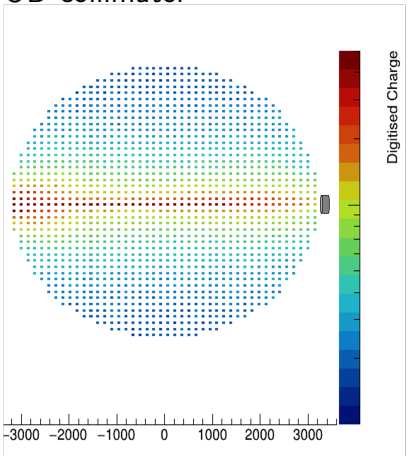
Calibration source generator

Sheffield

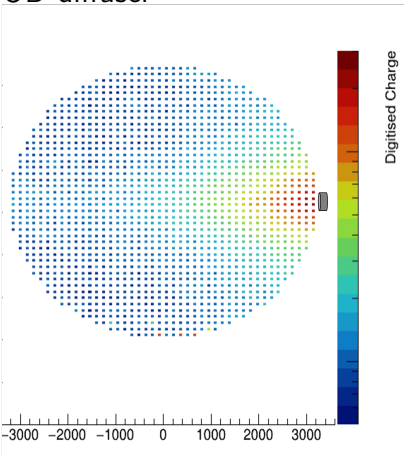
Implemented event generator to simulate photon emission from light injectors

- Specify parameters for each LI source in JSON file
  - Position
  - Direction
  - Emission profile
  - Wavelength
  - ...

OD collimator



OD diffuser



Outline

GHOST

- WCSim is
  - Not very modular = hard to develop
  - Uses old C++11 standard
  - Uses old Geant4 v10.3.3 [October 2017]
  - Single threaded = inefficient
  - New features have been added in inconsistent ways
    - ⋆ e.g. with addition of multiple PMT types, can set dark rate options per PMT type, but not digitiser options
  - Not tuned to data (or other MC) for a few years
- Enter GHOST
  - Geant4 H_2O Simulation Tool

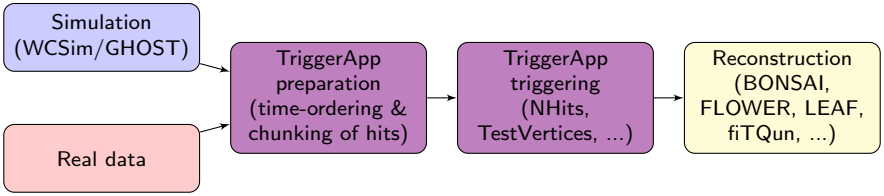
GHOST v1

Lancaster, Glasgow

- Through many meetings, we wrote a code design document to plan the GHOST structure
- v1 = WCSim restructured
  - Implementation ongoing
  - Setting up CI to automatically compare results with WCSim
  - Aim to release v1 in 2024
- v2 = simulation improved
  - Improve many aspects of the simulation
    - Geometry
    - Update PMT/electronics simulation
  - Add new features
    - More calibration sources
    - Allow PMT properties to be set per PMT
    - Read calibration database to simulate detector as it was at time t
  - Validate against / tune to SKG4 MC & WCTE data

Outline

TriggerApp



- TriggerApp designed & developed in UK
- TriggerApp can act on both data & MC
  - Easier to maintain & validate just one version of the algorithms
  - Limits chance of using inconsistent triggering in data & MC

TriggerApp v1 → v2

- MC-ready, and been a good test bed for novel triggers
  - → MC- & data-ready
- Single-threaded; can't use the full power of the multi-core online triggering machines
  - → Multi-threaded tools
- ROOT dependence in online tools → memory leaks
  - → only use ROOT for MC I/O
- Some things are inherently slow
  - → Implement improved algorithms

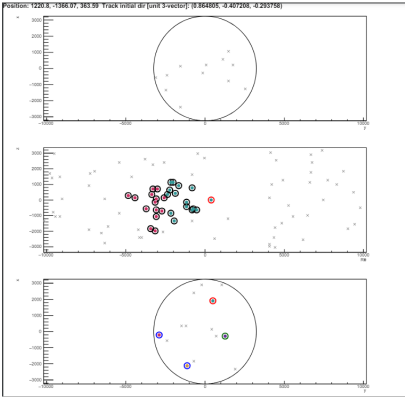
TriggerApp v2 status

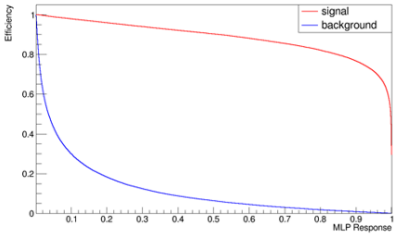
Lancaster, Warwick

- Automatic multi-threading & load-balancing design implemented
- MC I/O implemented
  - WCSim file format I/O tools complete
  - Simplified output file format tool being polished
- Trigger pipeline outlined
  - Simple test sort/trigger/trigger merging tools implemented
  - Efficient sorting, & NHits trigger algorithms being input now
  - Other trigger algorithms will be added soon

Trigger development: Multi-Layered Perceptron

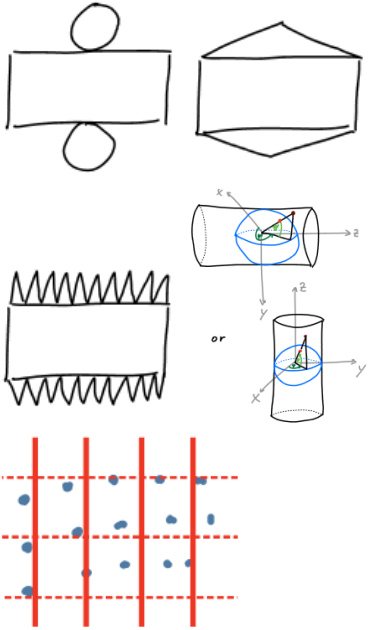
- Take basic hit information: time, position, (charge)
- Construct simple variables from this information
  - Many variables implemented
  - More ideas to be implemented...
- Train a TMVA on multiple mono-energetic low-energy electron particle guns
  - MLP has performed best so far
- Under development. Initial results promising





Trigger development: Convolutional Neural Network

- Take basic hit information: time, position, (charge)
- Construct a 2D image based on hits in ∼400 ns
- Convert image into a tensor
  - CNN requires *pixels* to be regularly spaced
- Train a CNN / sparse CNN on the 2D image
- Under development. Initial results promising



Summary

- Using same software for HK's far detector & IWCD
  - More efficient coding by just doing it once
  - Allows consistent models, systematics, etc.
- WCSim development ongoing
  - New IWCD & far detector geometries
  - New calibration source generator
- GHOST is being developed as the replacement for WCSim
  - v1 with better structure for future developments ongoing
  - v2 will bring many simulation improvements
- TriggerApp development ongoing
  - v2 with multi-threading structure implemented
  - Trigger algorithms being ported into v2
  - MLP & CNN triggers are promising, but work ongoing