Progress on Single Crystal Simulations at UMD

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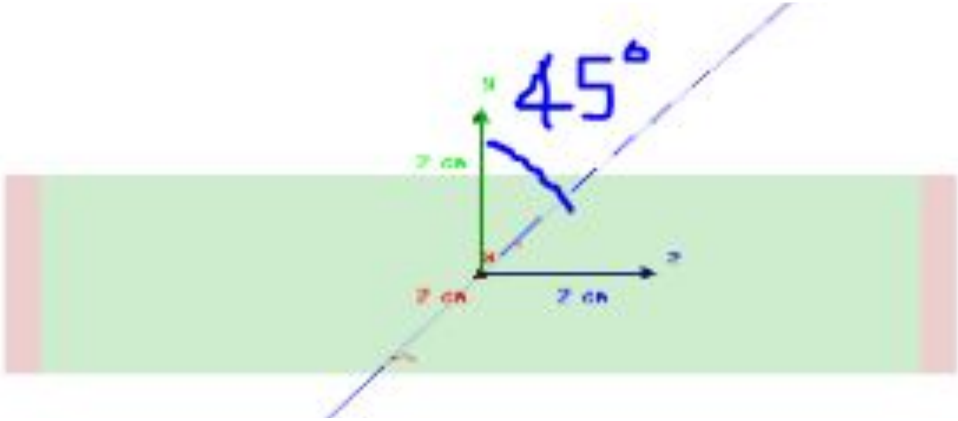
Outline

- Results of the reproduction of the 2020 proposal plot for Lead Tungstate (Single Crystal)
    - This is done to make accurate predictions
- Refinement of the geometry with filter elements and new dimensions (To do)
- Addition of a cosmic ray simulator to mimic experimental conditions (To do)
- Extending the predictions to crystals of other materials (eg. BGO, PbF2)

Geometry of the crystal and sample display

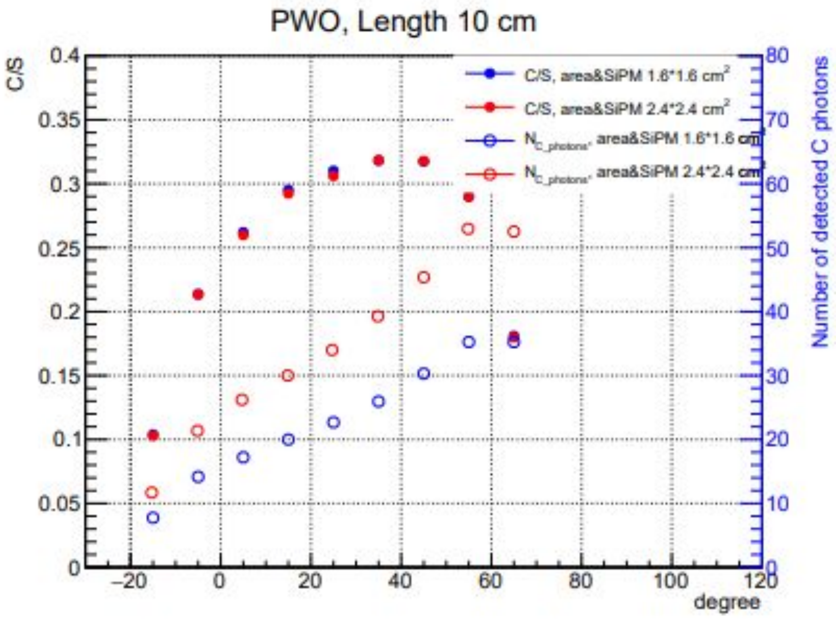
- We have a $PbWO_4$ crystal of 2.4cm ✕ 2.4cm ✕ 10cm flanked by silicone gaps (0.1 mm) on both square surfaces and that is attached to the SiPMs (one SiPM on either of the square faces)
  - The electronic response of the SiPMs has not been modelled in the simulations and the quantum efficiency of the SiPMs (as a function of photon wavelength) has simply been incorporated into the post processing file
- In all subsequent plots, the simulation has been done for a 1 GeV muon whose angle of incidence in the crystal has been measured from the normal to the longest side

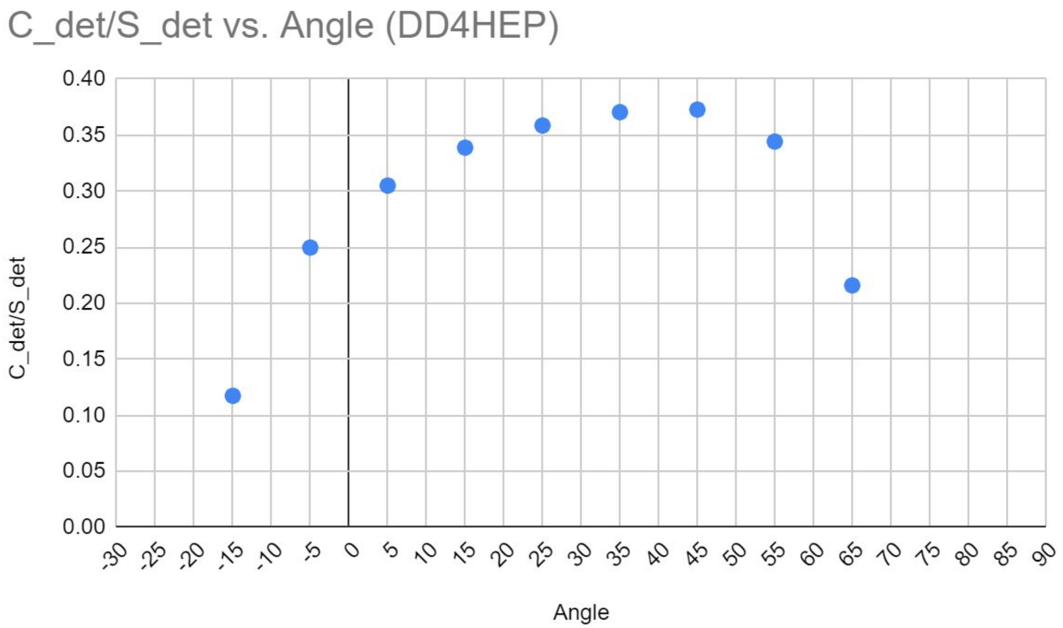
- The latest version of the code can be found here: https://github.com/Mekhpar/SingleDualCrystal



Comparison of angular dependence plots

- Reproduced the plot from the 2020 proposal (to the left below) for a PbWO4 crystal of 2.4cm ✕ 2.4cm ✕ 10cm using Sarah's SingleDualCrystal code in GEANT4 + DD4HEP

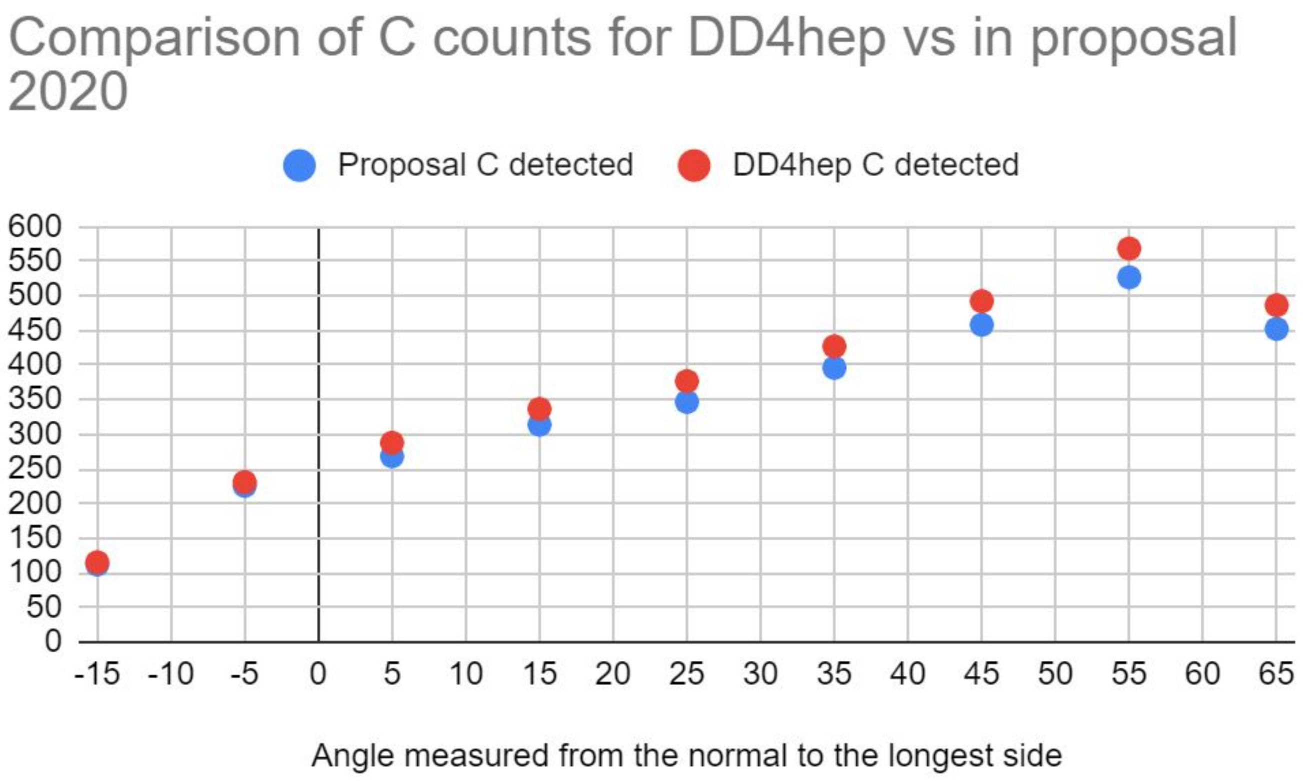




This was done to understand the geometry and benchmark it so that it can be used to predict the results of the actual tests being done at UMich

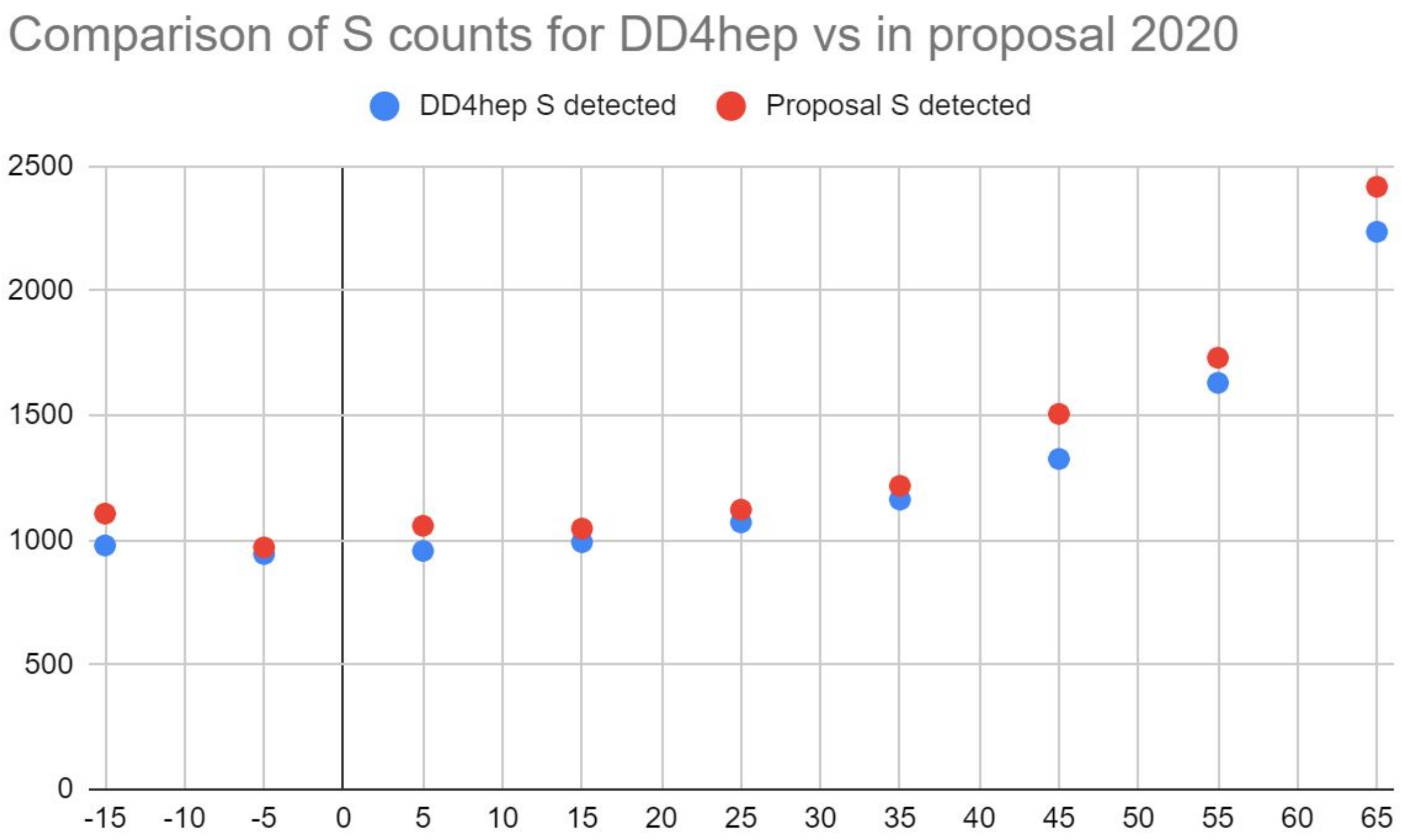
C (Cerenkov) counts

- The C counts match the proposal plot well
  - Just the photon counts reaching the SiPM and not including the filter and/or quantum efficiency of the SiPM
- The C photons are counted at the end which has more counts (muon angle > 0 degrees); the scintillation (S) photons are counted at the opposite end
  - This is relevant because the C photons are directional and have a cone of emission, and S photons are fairly isotropic



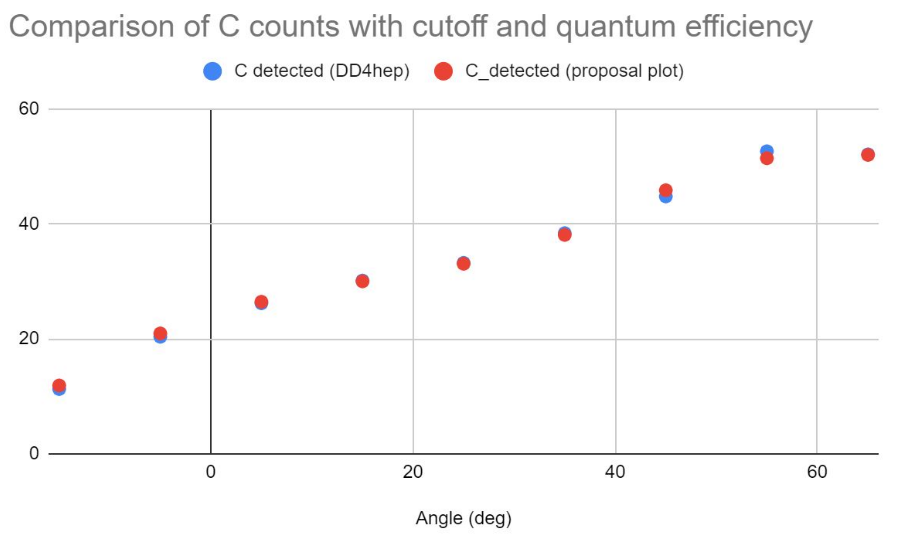
S (Scintillation) counts

- S counts on the end opposite to where the C counts are measured also match with the proposal plot
  - Again these are the photon counts reaching the SiPM and not including the filter and/or quantum efficiency of the SiPM
  - The scintillation spectrum used for PbWO4 is shown later

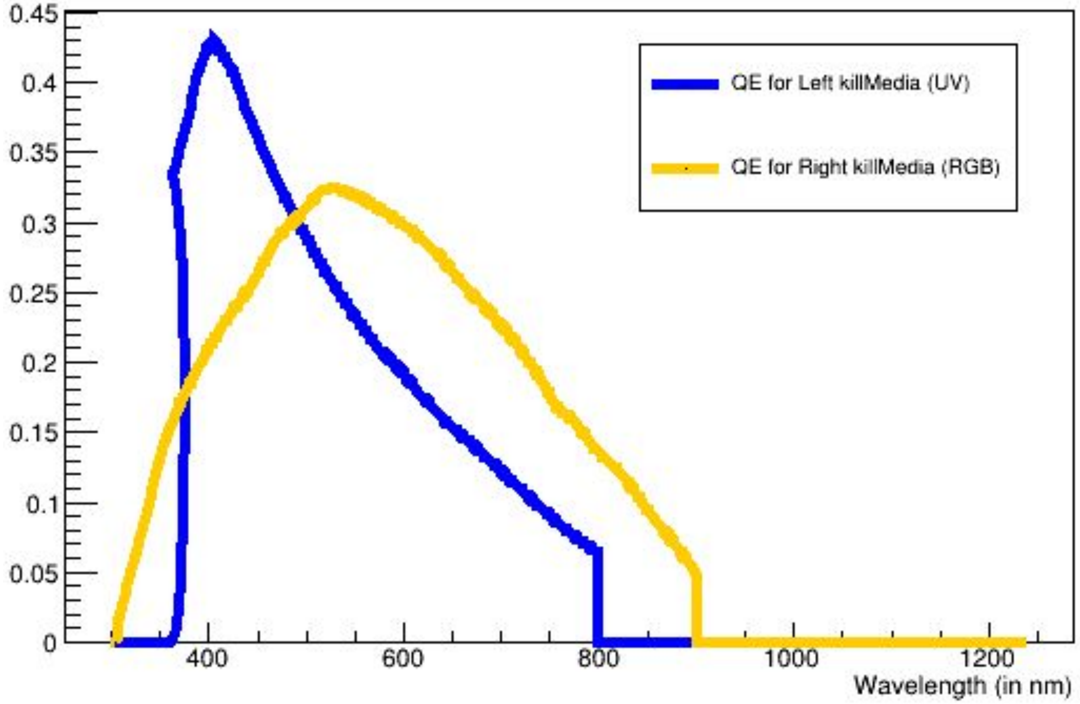


C counts (with cutoff)

- Also with a hard lower cutoff of 550 nm for the Cerenkov end (this is with the cutoff as well as the quantum efficiency of the SiPMs) the plots show good agreement
    - This was originally chosen is because the scintillation counts are negligible above 550 nm

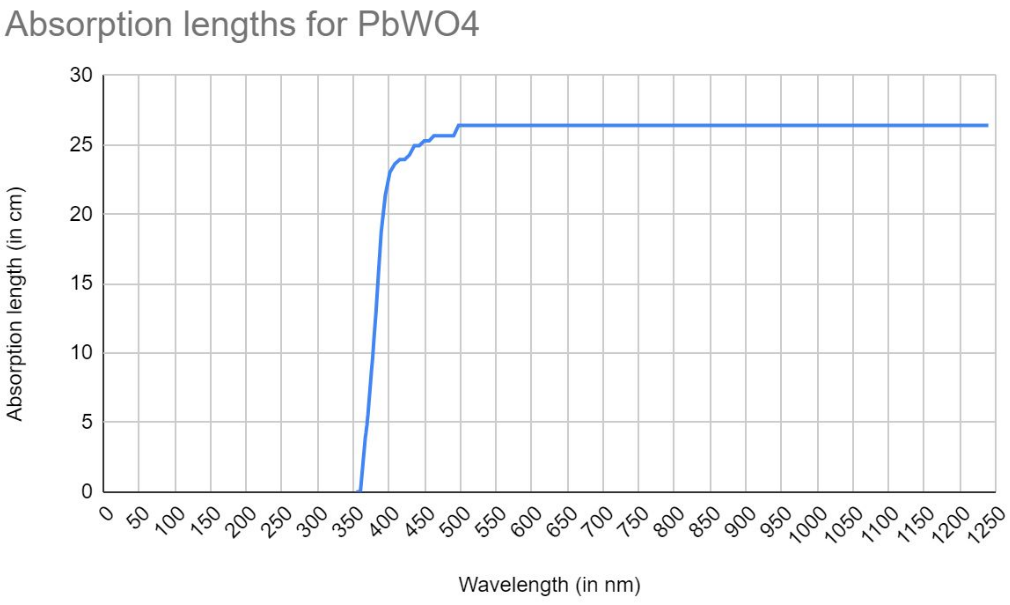


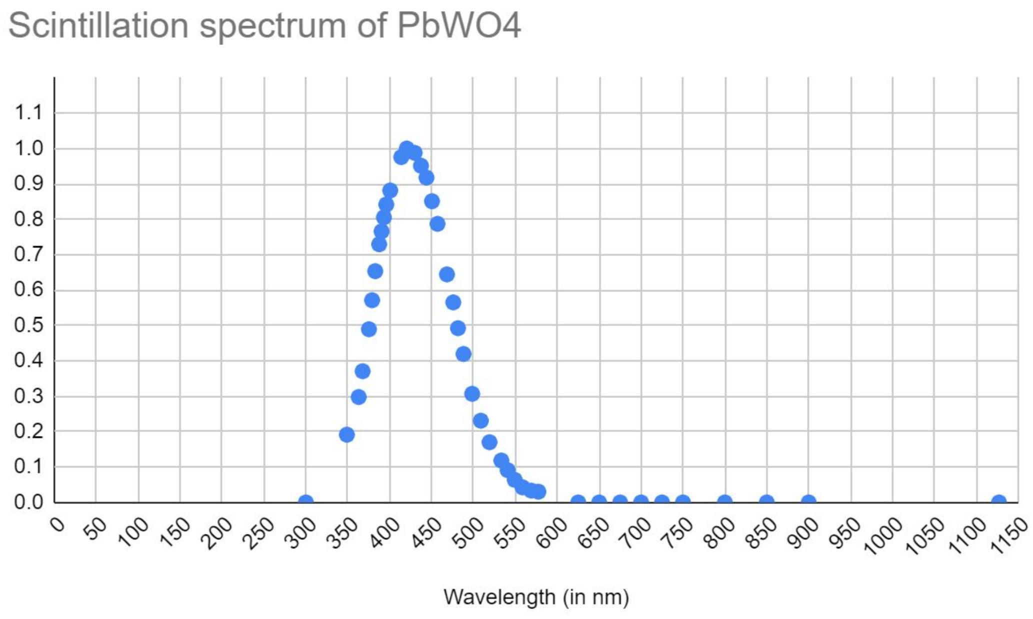
- Plots of the quantum efficiency for both SiPMs as a function of photon wavelength are shown to the right



Material Properties for PbWO4

- Shown below are plots of the attenuation length as a function of wavelength, and the scintillation spectrum for PbWO4



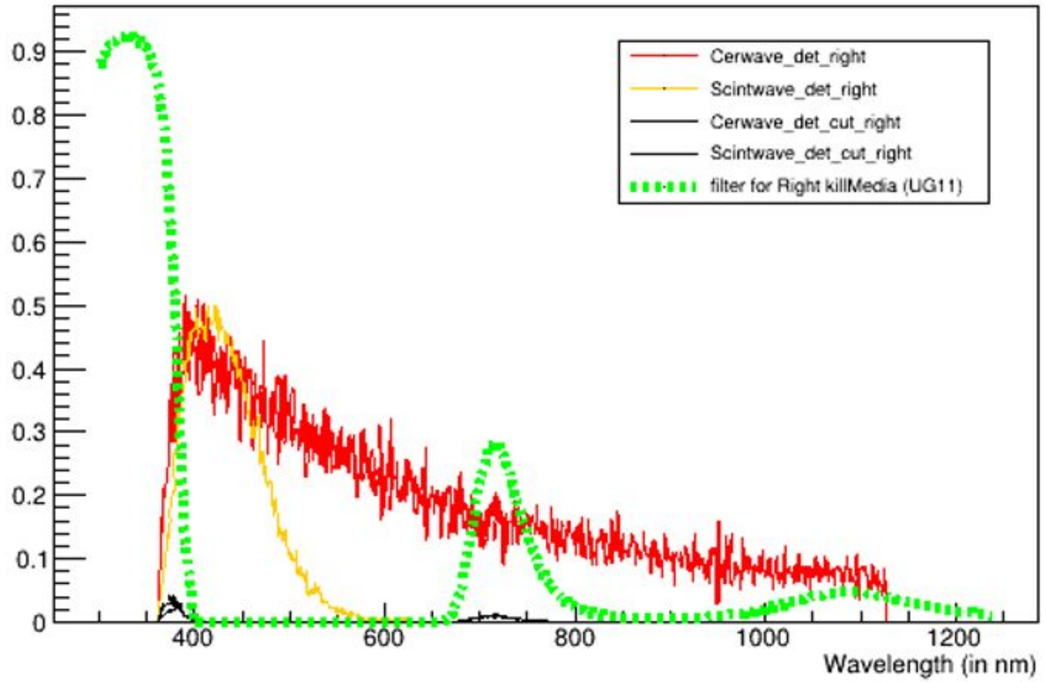


Refining the geometry

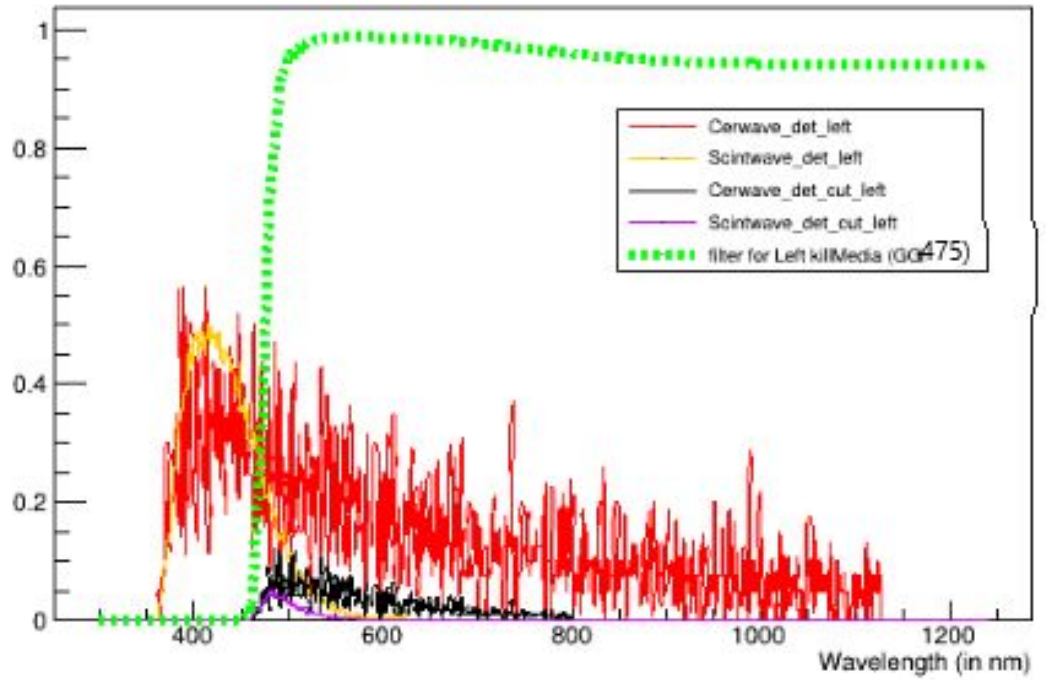
- Added filter efficiencies as given by Junjie (UG11 and GG475)
- For the filters, the transmission efficiencies as a function of the wavelength are at present added only to the post processing file
  - Filter material is not added as a physical object yet to the actual simulations
- The UG11 filter is used for the Cerenkov end and the GG475 filter is used for the scintillation end
- The UG11 has a window at around 700 nm where it exclusively picks up C photons, and a peak earlier at < 400 nm, but the scintillation spectrum overlaps completely with the Cerenkov part in that region
- The GG475 looks approximately like a step function in the range of interest (step at ~ 460 nm) which picks up C photons in addition to the intended S photons in the whole region
- Also tested the CRY (cosmic ray library) standalone (from http://nuclear.llnl.gov/simulation), and have to integrate it with DD4hep

Filter profiles

- Filter for C end (UG11)



- Filter for S (opposite) end (GG475)



Summary

- Simulated a dual-readout crystal detector with GEANT4 + DD4hep
  - Reproduced the 2020 proposal plots ($PbWO_4$)
- Worked on inclusion of additional effects
  - Tested filters
- Next steps: improve details of model
  - E.g., replace filter with actual object for the simulations, import CRY library