Progress on Single Crystal Simulations at UMD

Mekhala Paranjpe
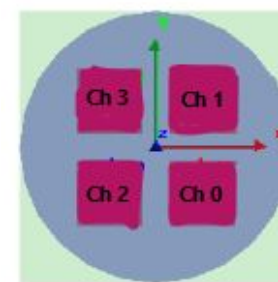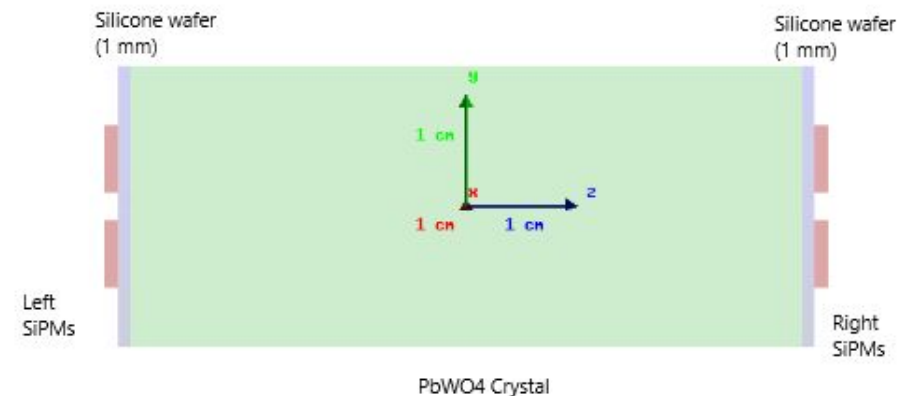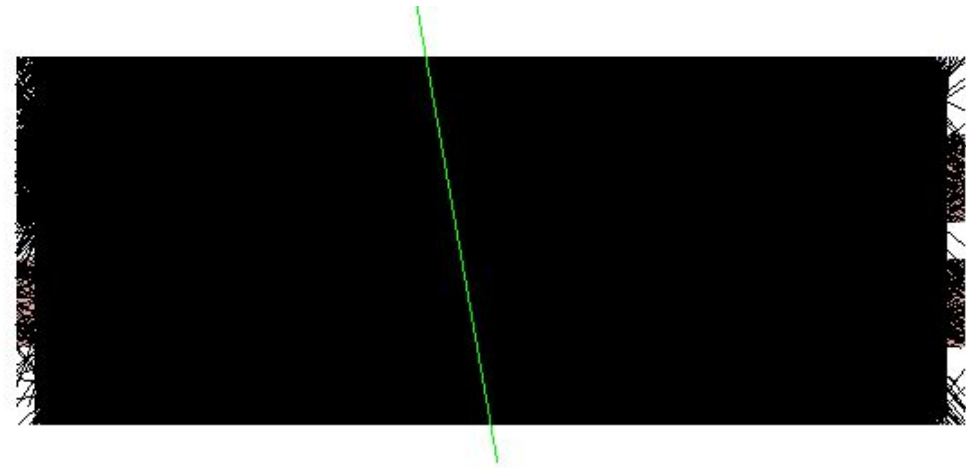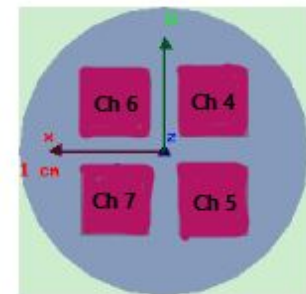09/14/2023

Recap

- Simulated a dual-readout crystal detector with GEANT4 + DD4hep
  - Reproduced the 2020 proposal plots (PbWO4)
  - Also simulated BGO and PbF2 crystals
- Currently simulating for 120 GeV protons with FNAL Test Beam setup (June)
  - Comparing MC plots of PbF2 and PbWO4 with the data
  - Agreement seen for PbF2 is not bad but for PbWO4, both ends with and without wavelength filter seem to be scintillation dominated

Recap - FNAL Test Beam (120 GeV protons) - setup

- Crystal dimensions are 2.5 cm ✕ 2.5 cm ✕ 6 cm for all the materials
- Four SiPM channels arranged in a 2 ✕ 2 array on each square face
- Median of the whole distribution of events is taken for comparison with data
- Proton passes through the center of the crystal
- Channels 1,3 and 4,6 (in the graphs) are the ones farther from the face on which the beam is incident, and channels 0,2 and 5,7 are the ones that are closer
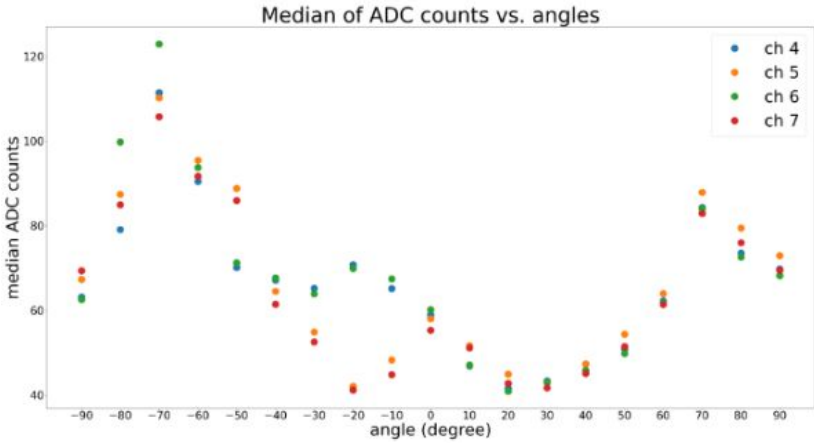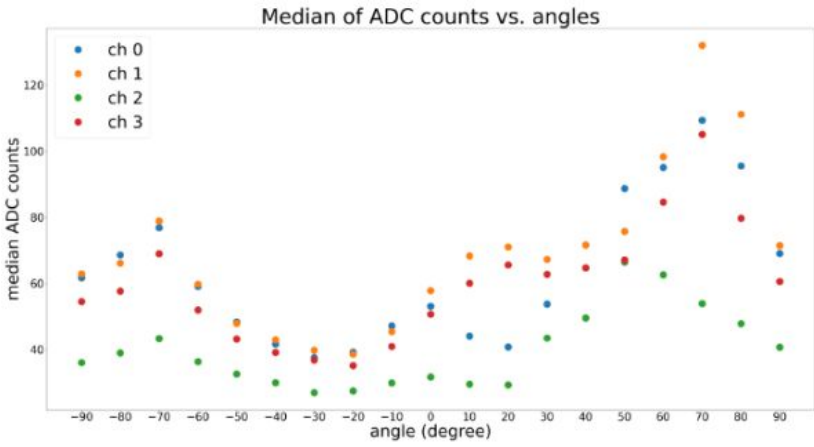

Silicone wafer (1 mm)   Silicone wafer (1 mm)

1 cm

1 cm   1 cm

Left SiPMs   Right SiPMs

PbWO4 Crystal

Ch 3   Ch 1   Ch 6   Ch 4

Ch 2   Ch 0   Ch 7   Ch 5
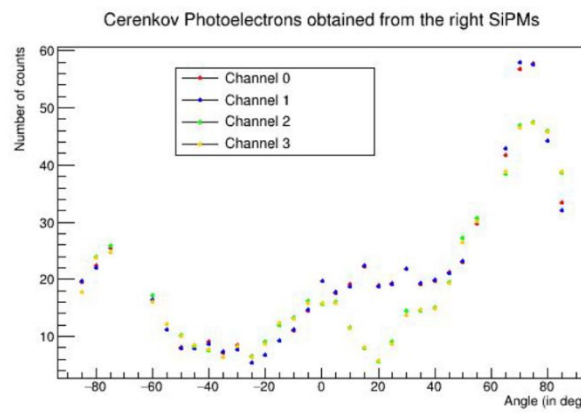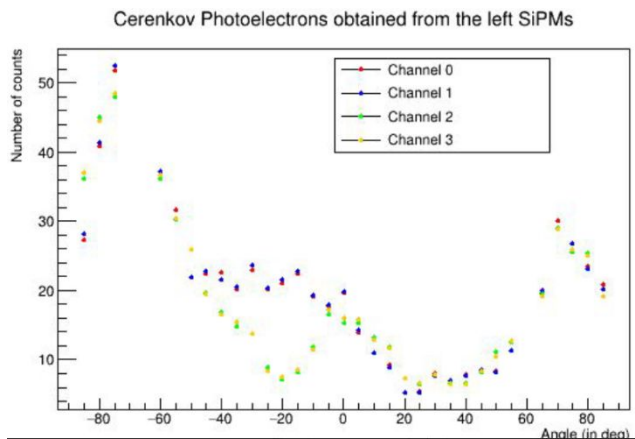
Viewed from the left side   Viewed from the right side

Comparison of angular dependence plots for PbF2

- Plots sent by Junjie (UMich from test beam data)

Median of ADC counts vs. angles

Median of ADC counts vs. angles

Plots from data

Cerenkov Photoelectrons obtained from the left SiPMs

Cerenkov Photoelectrons obtained from the right SiPMs

Plots from simulation

- Conversion factor - 1 p.e. Count -> 3 ADC counts - these are actually pulse amplitude counts and not integrated over the whole signal
- The agreement (shown in the next two slides) is not bad, but could be better - the maxima and minima in the MC are rather extreme compared to the data i.e. peaks are very high and minima are very low

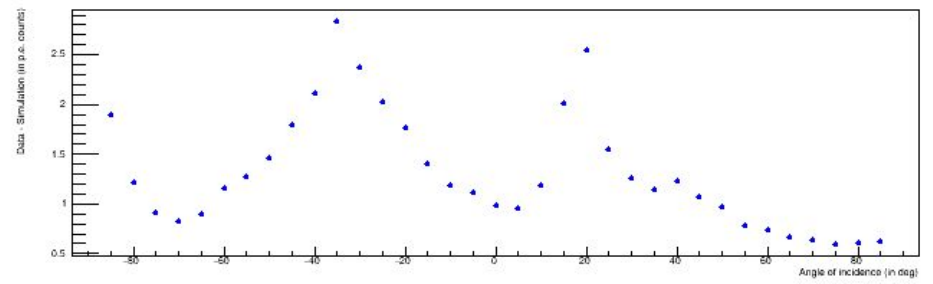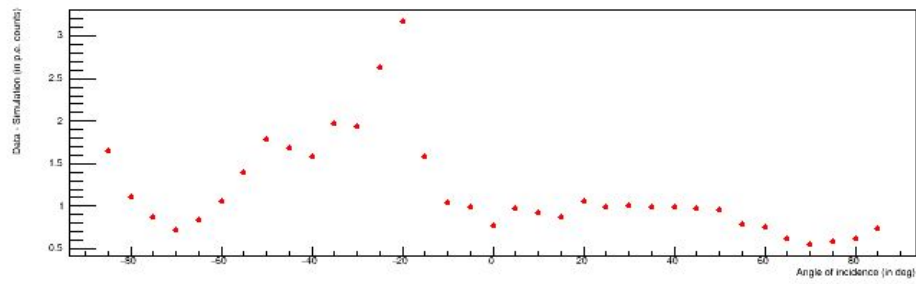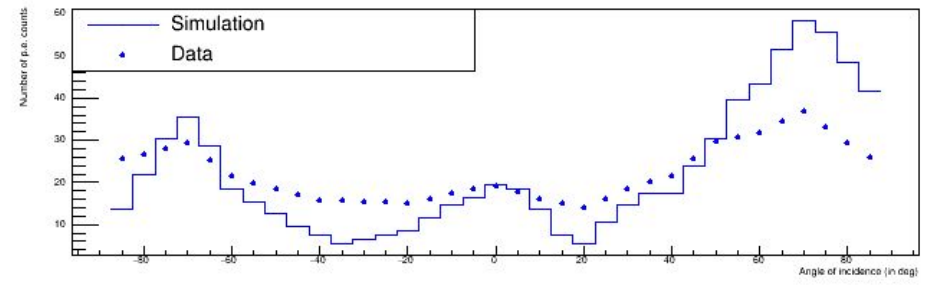Left side channels (Ch 0,1,2,3) for PbF2 - Cerenkov only
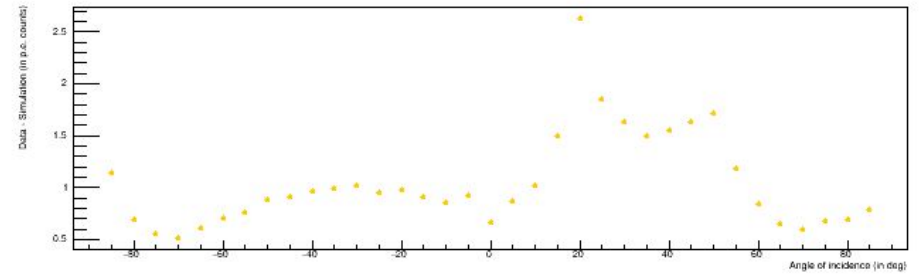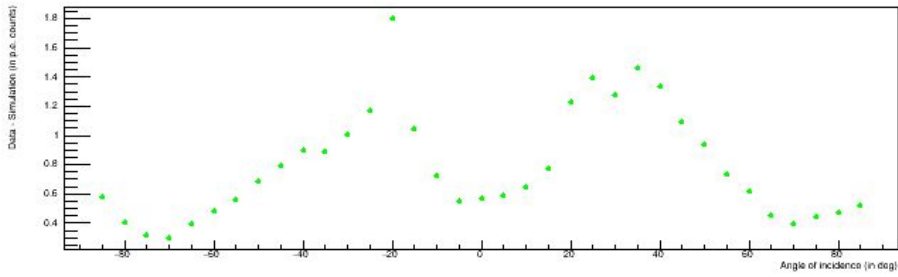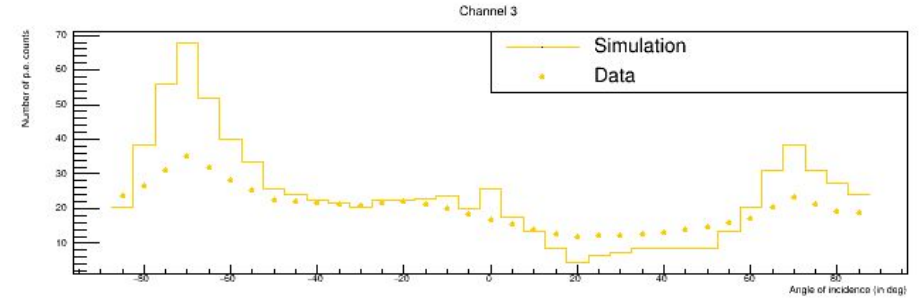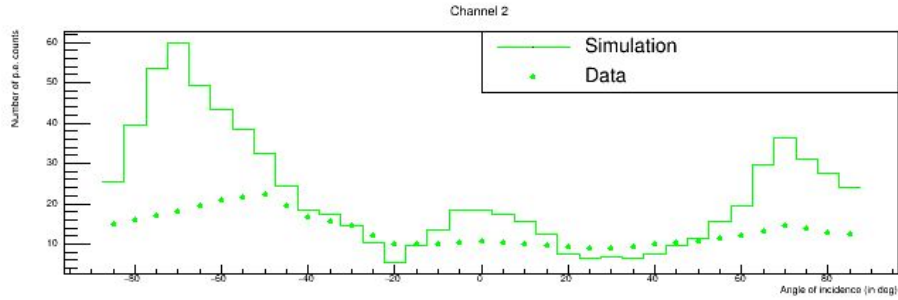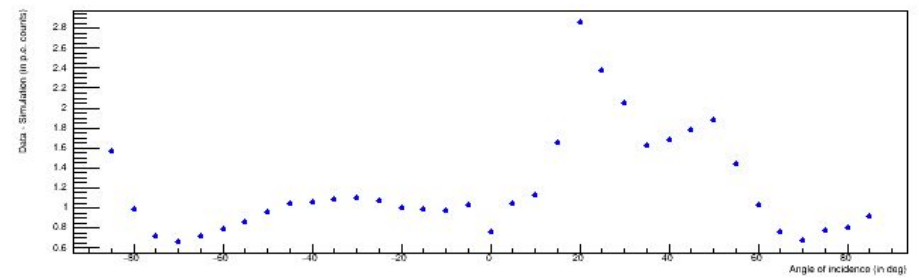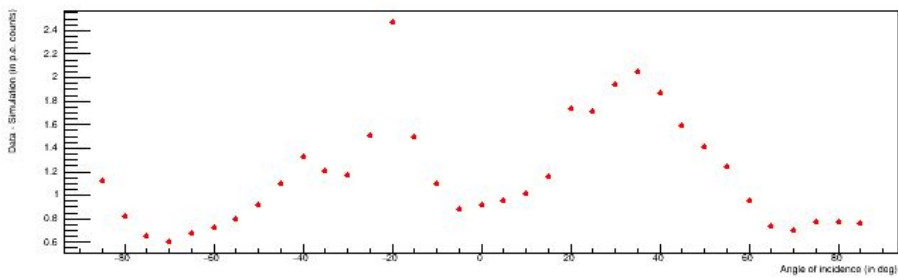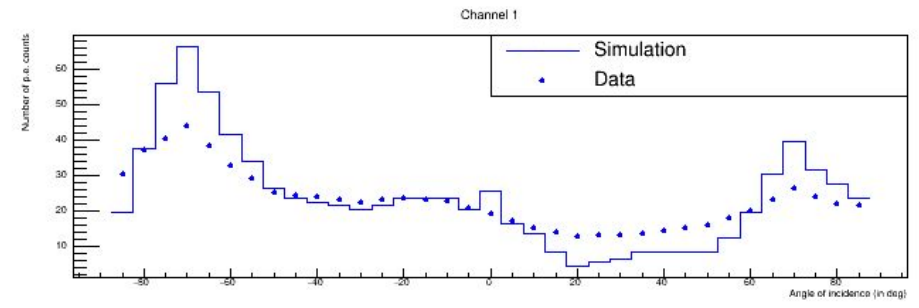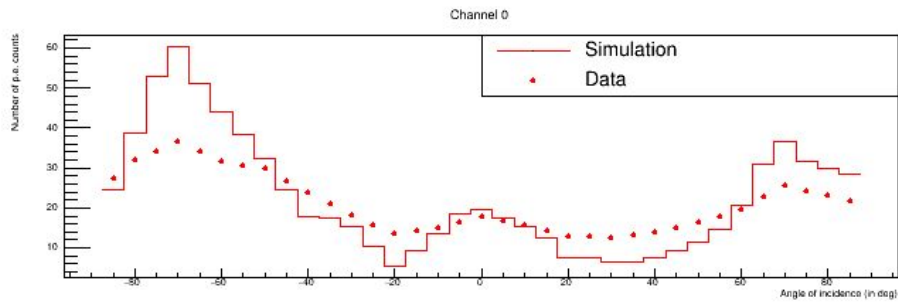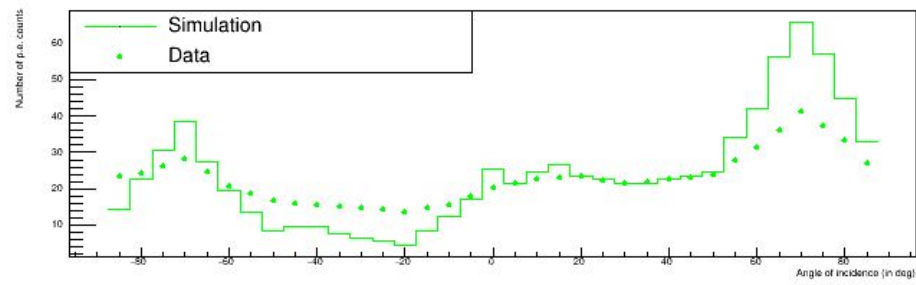
Right side channels (Ch 4,5,6,7) for PbF2 - Cerenkov only
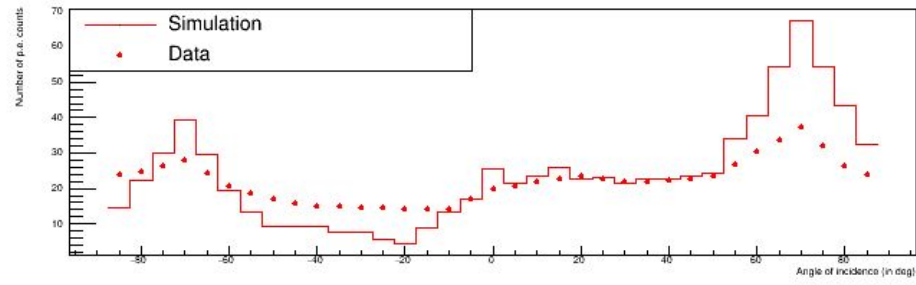
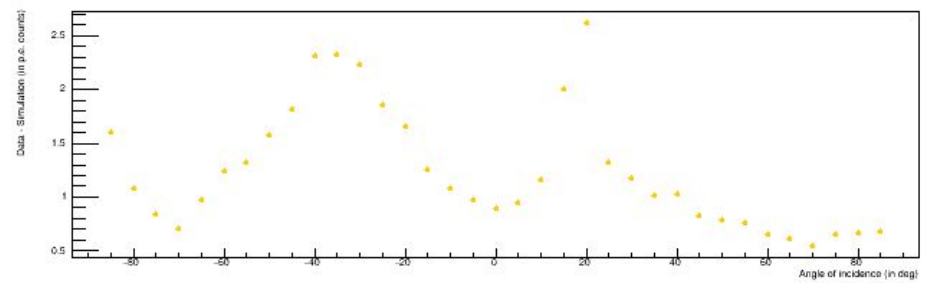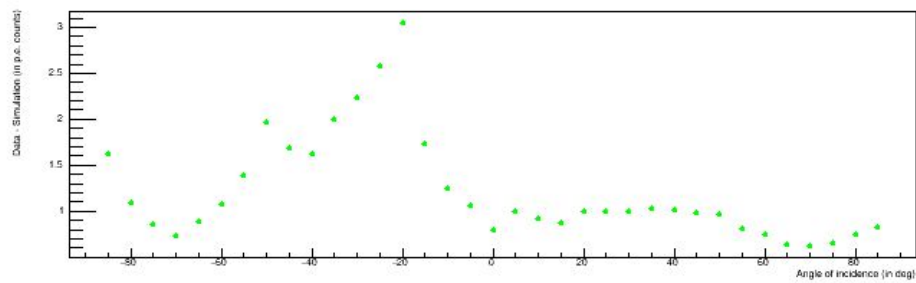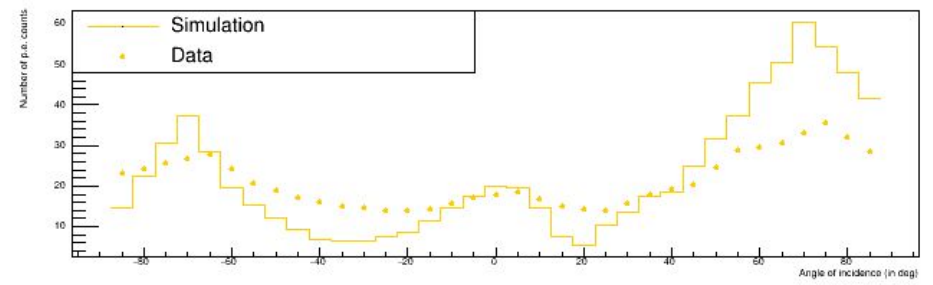# Comparison of angular dependence plots for PbWO4 (SiPMs without filter) - Ch 4 to 7

- Scintillation yield - 200 ph/MeV, and the data is scaled down by a factor of 145.07
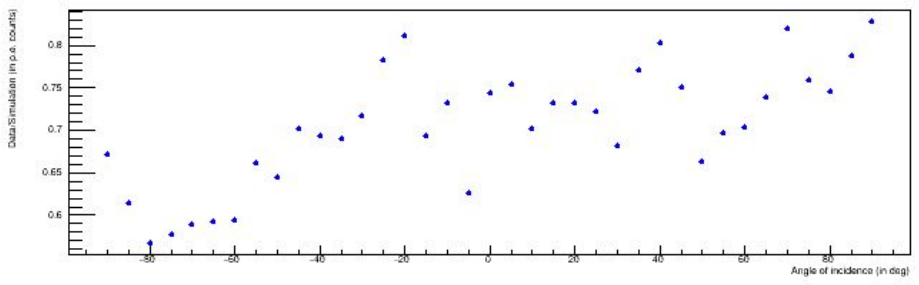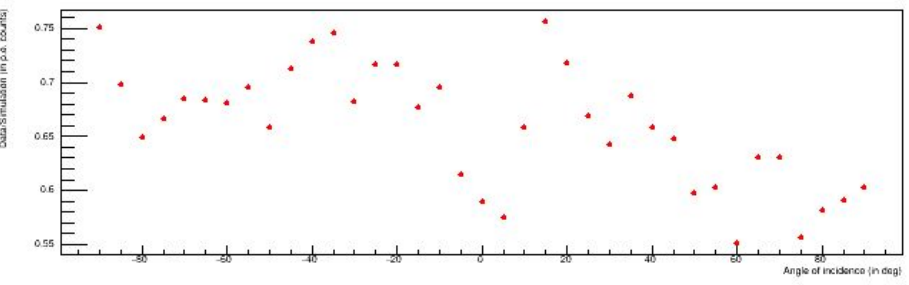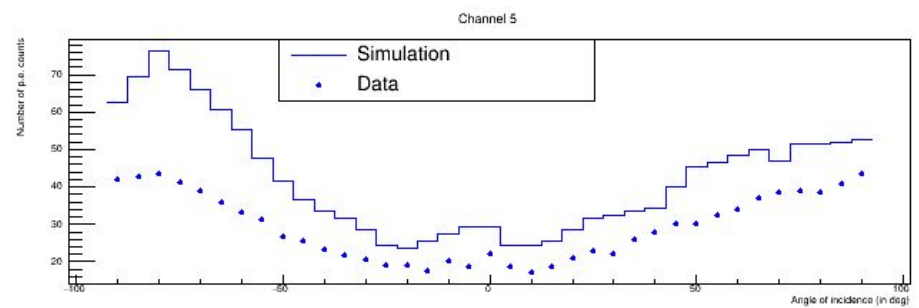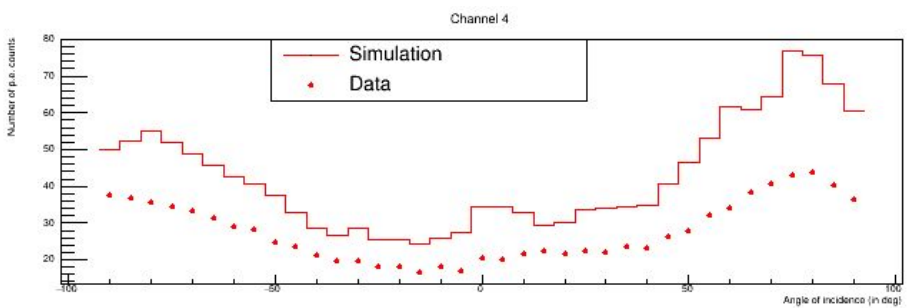- The trends are similar for the various angles, but overall the MC predicts 1.5 to 2 times the counts from the data
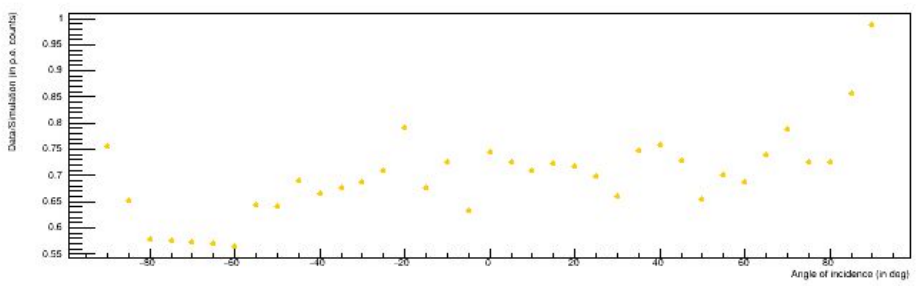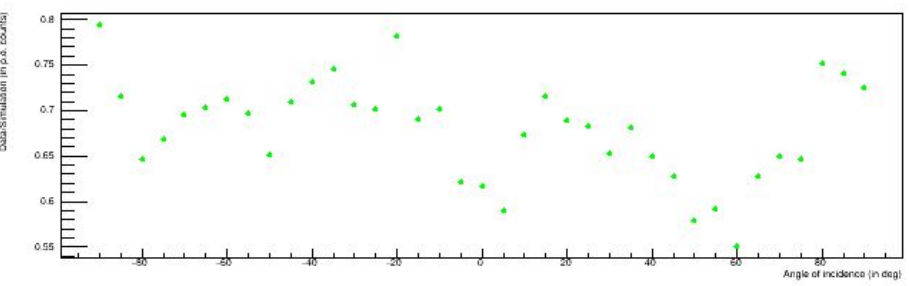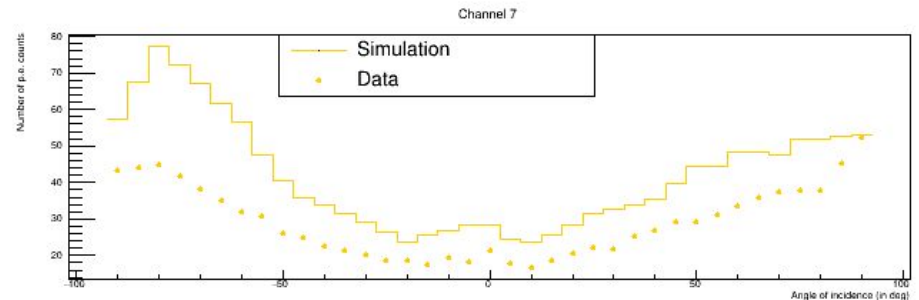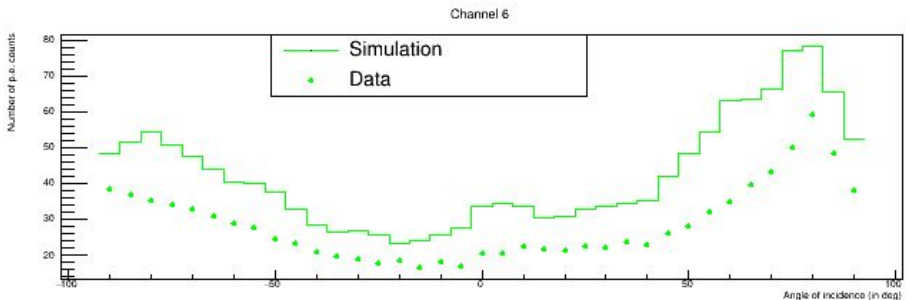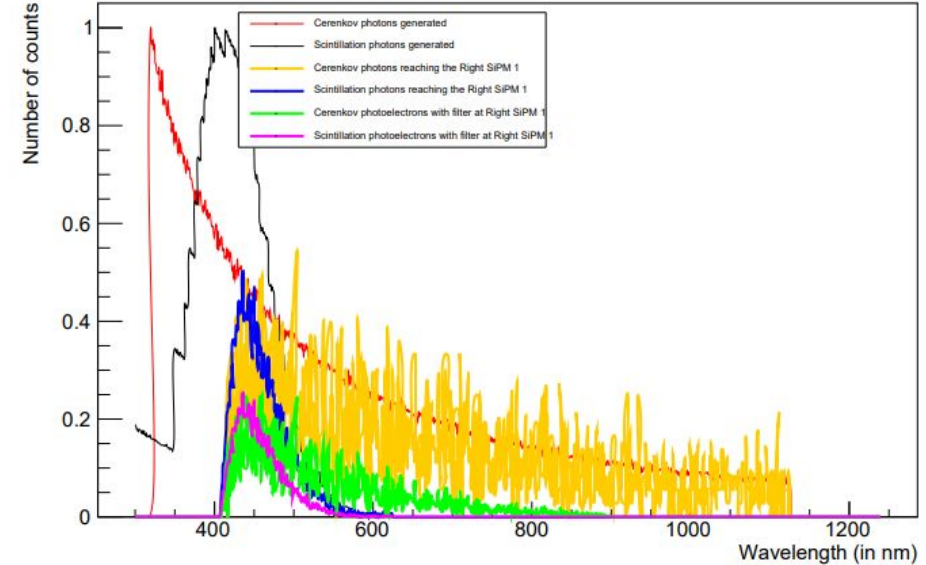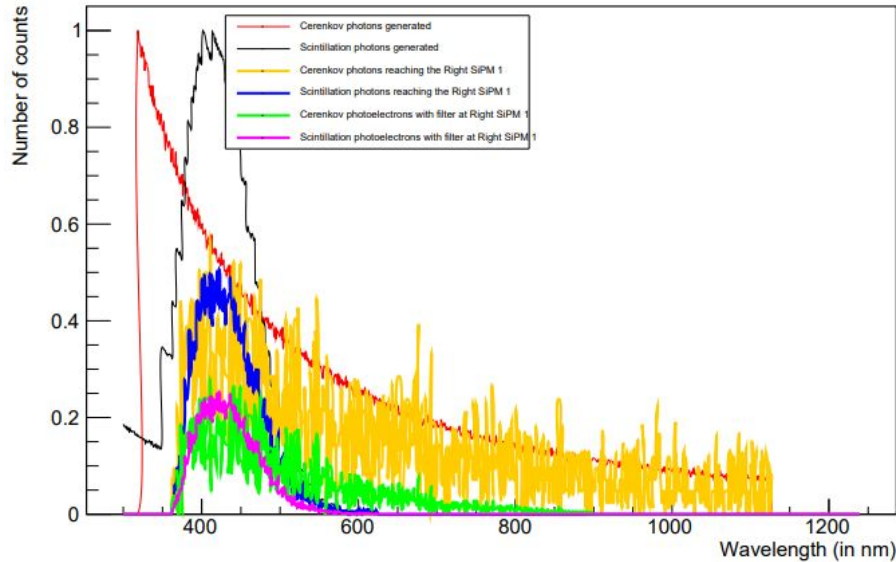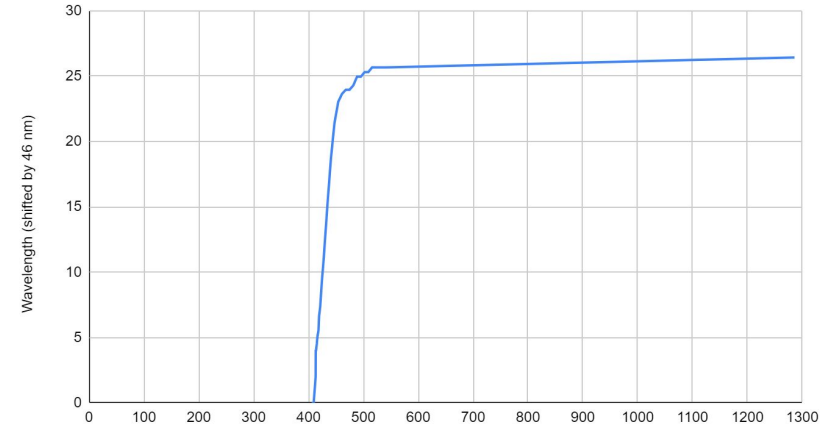
Comparison of angular dependence plots for PbWO4 (SiPMs without filter) - Ch 4 to 7

- In an attempt to fix the simulation peak in Chs 4 and 6 which is appearing due to the Cerenkov component (in the 0-20 deg region) the lower wavelength part was excluded i.e. the transmission spectrum was begun at ~400 nm instead of at ~360 nm

Old spectrum (cutoff at ~360 nm)
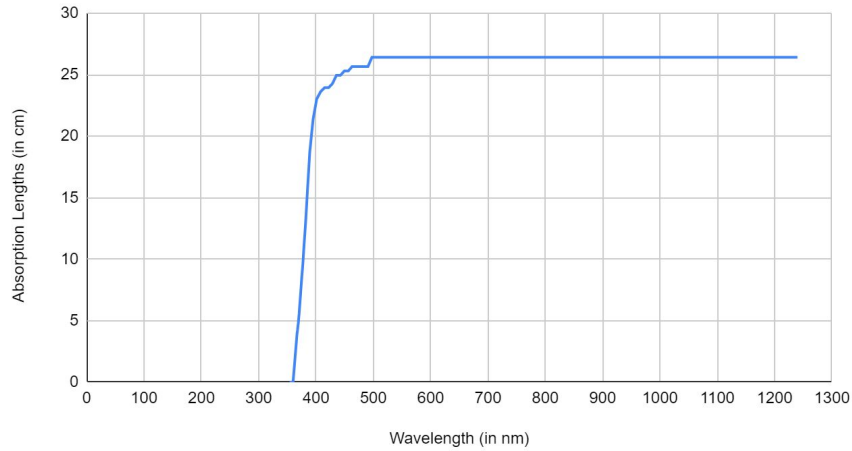
New spectrum (cutoff at ~400 nm)

- Other possibilities - scale factor for data might be smaller than what is currently applied, absorption lengths for the data might be smaller than the MC lengths

Comparison of angular dependence plots for PbWO4 (SiPMs without filter) - Ch 4 to 7
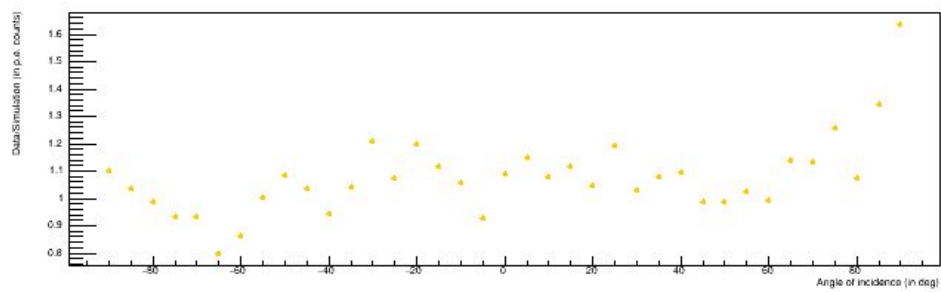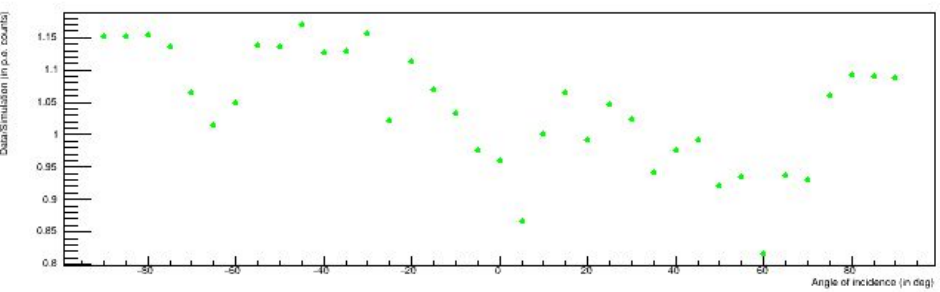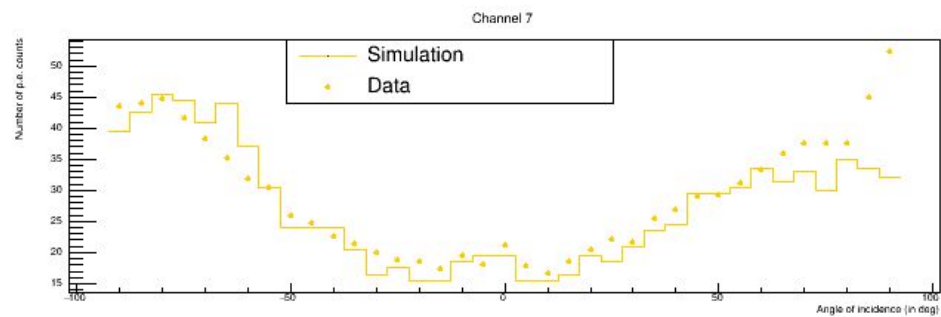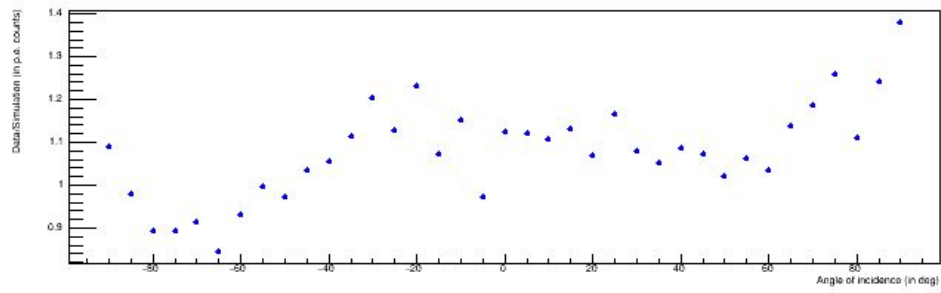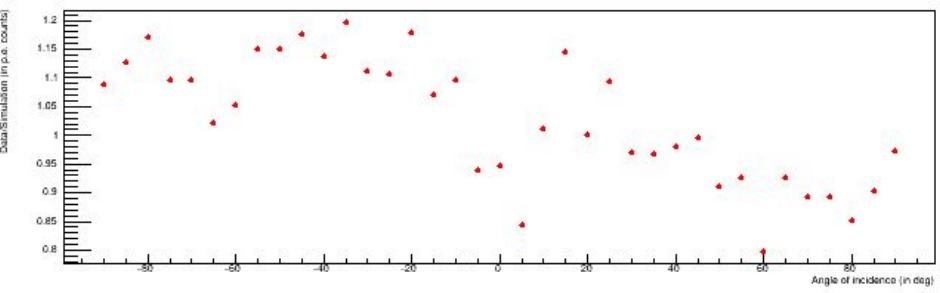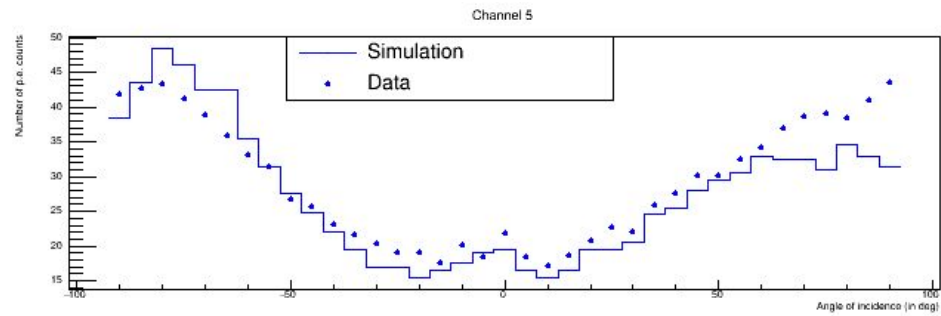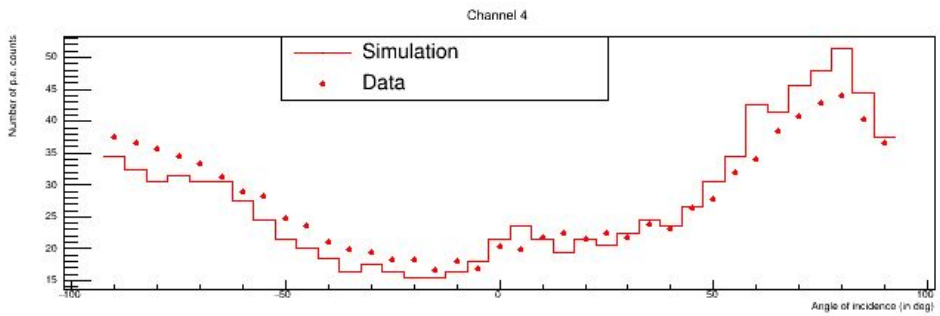
With shifted transmission cutoff

Angular dependence plots for PbWO4 (SiPMs without filter) - Ch 0 to 3

- The shape of the graph of data counts looks nothing like the one predicted by MC
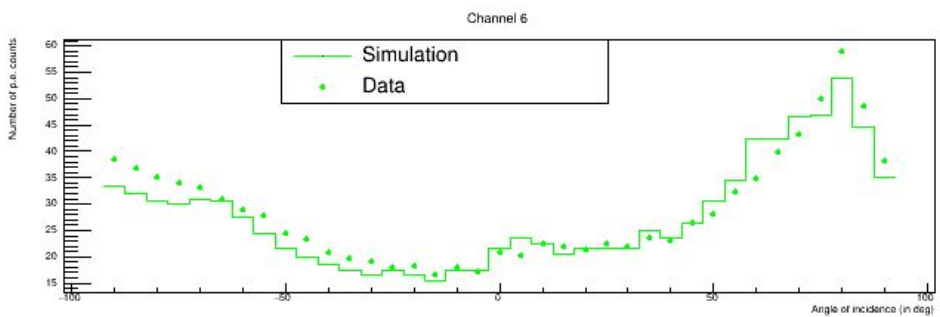- Some part of scintillation below the 600 nm filter cutoff is leaking through?

Number of Photoelectrons at the Left side SiPMs (Ch 0 to 3) - MC
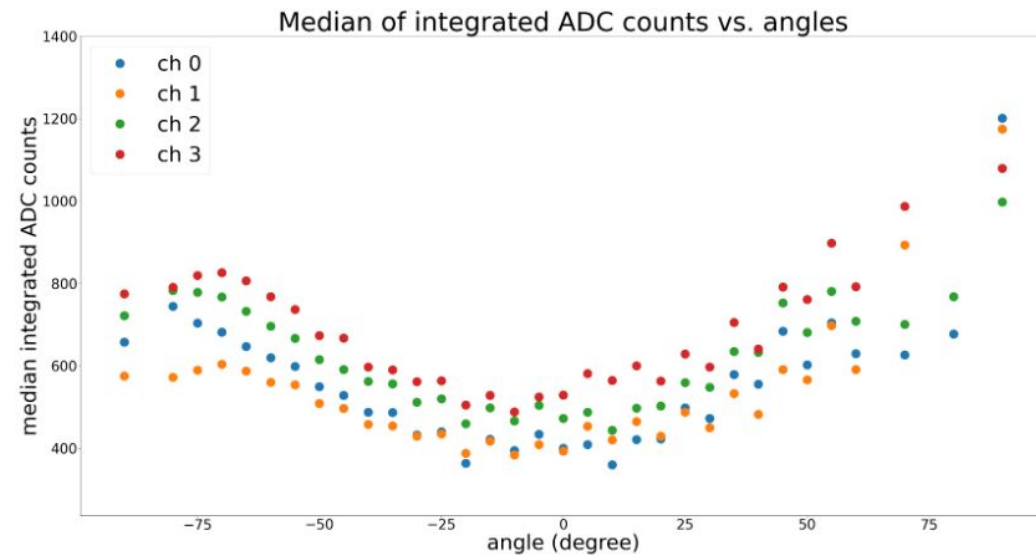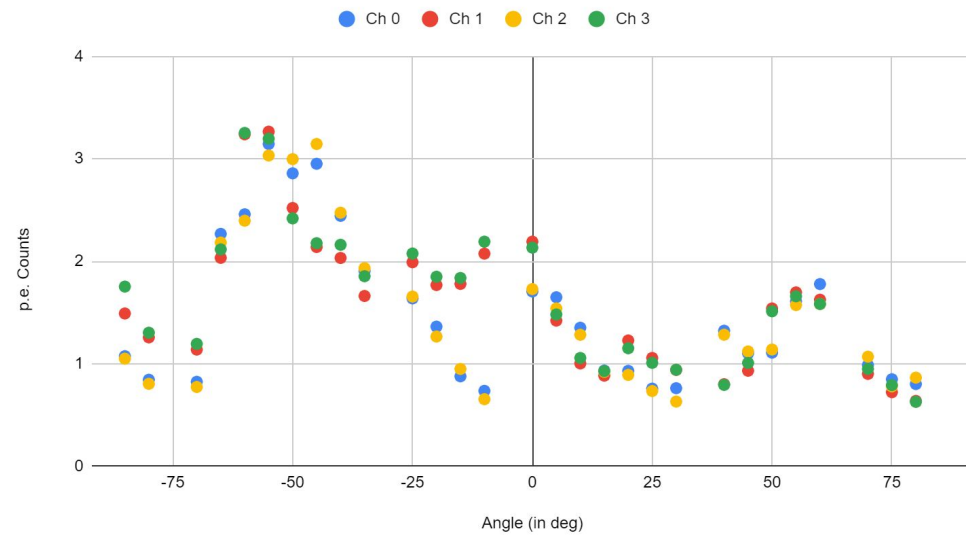
Backup

- Factor of 145.07 obtained from comparison of pulse amplitude and integrated counts for PbF2 (Ch 6)
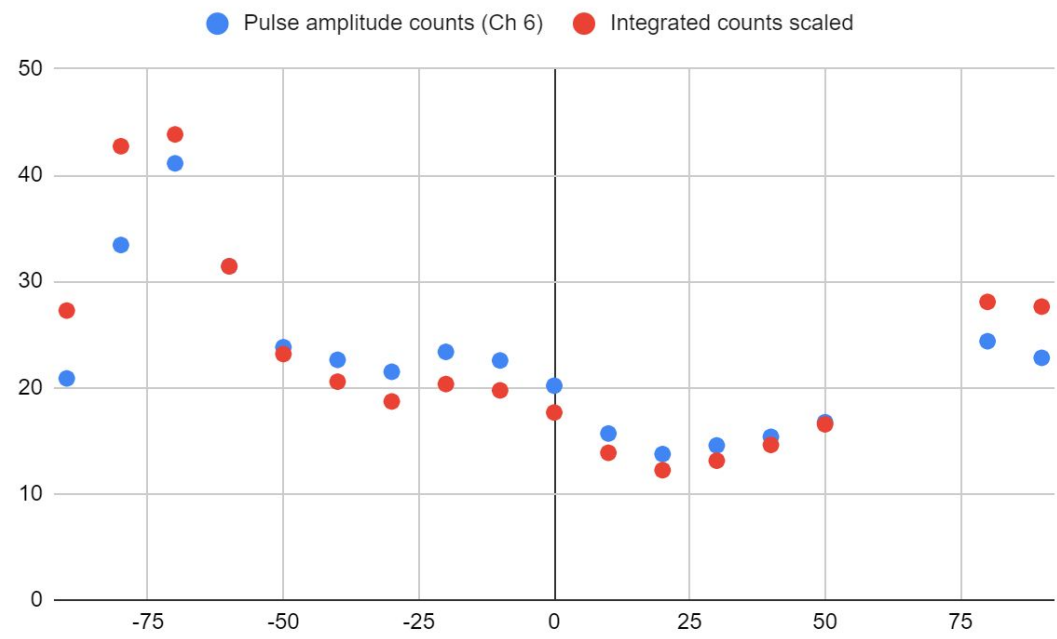
- Angular distribution of all photons (generated and transmitted) wrt the beam direction

-20 deg

-10 deg

12

Comparison of angular dependence plots for PbF2

- The agreement is not bad, but could be better - the maxima and minima in the MC are rather extreme compared to the data i.e. peaks are very high and minima are very low
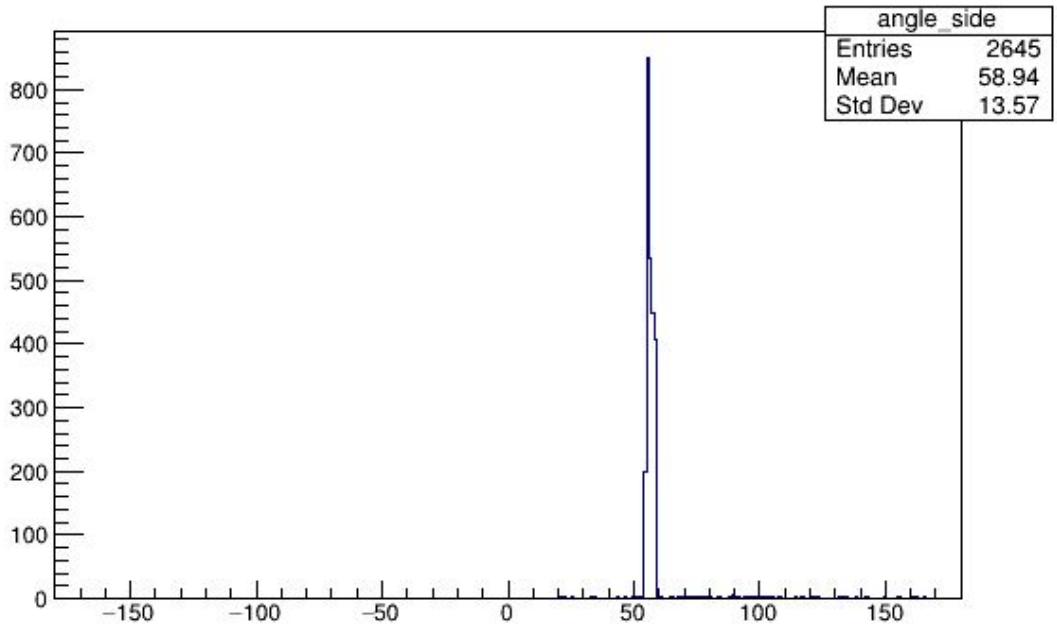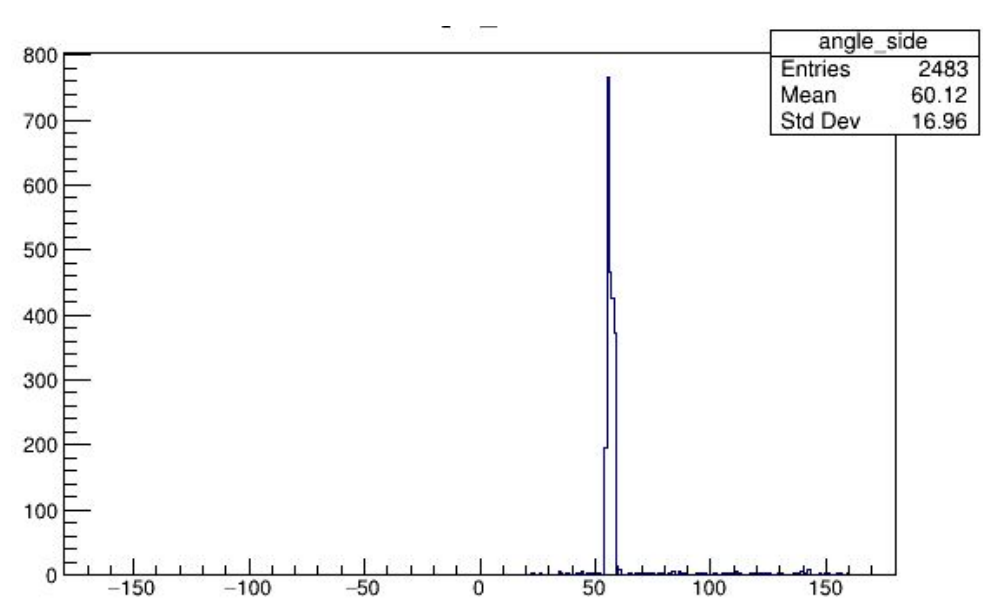- So in an attempt to investigate that, and especially in the -20 deg and 20 deg regions, where the photon counts reaching the near side SiPMs are very low, plotted the display with some filters from the output txt files obtained from the simulation
  - This was not done directly in the GEANT4 display
- The cuts on the tracks are:
  1) Photons hitting the top surface at their first reflection (these are the ones that are included in the emission cone and in the display profile)
  2) Cut 1) and hitting the left face of the crystal ($z = -30$ mm) in the region containing the near side SiPMs ($y=-1.25$ mm to $y=-7.25$ mm) at some stage in their trajectory
  3) Cut 1) and hitting the grease ($z = -31$ mm) and $y=-1.25$ mm to $y=-7.25$ mm) at some stage in their trajectory
- Also the distributions of the angles of the first steps of the tracks wrt the normal to the top face (+y direction) - the ones going to the right side have a -ve value, and a +ve value assigned for the ones going to the left side
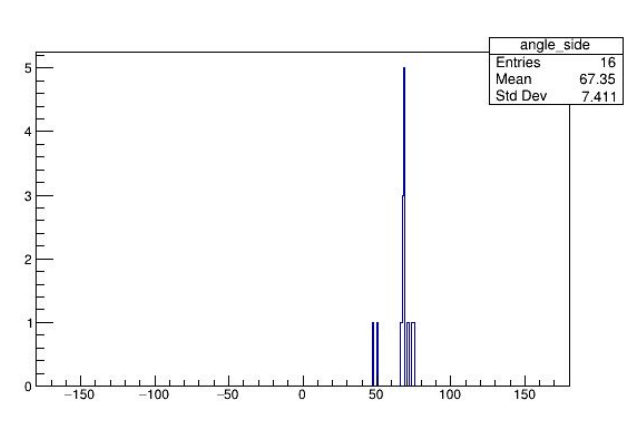
- 1 event for -20 deg and 1 event for -10 deg for comparison (the generated photon counts are such that they are slightly less than the median value, and do not belong to the Landau tail)
- Shown below are the various cuts for the -20 deg case, and the -10 deg case are on the next slide
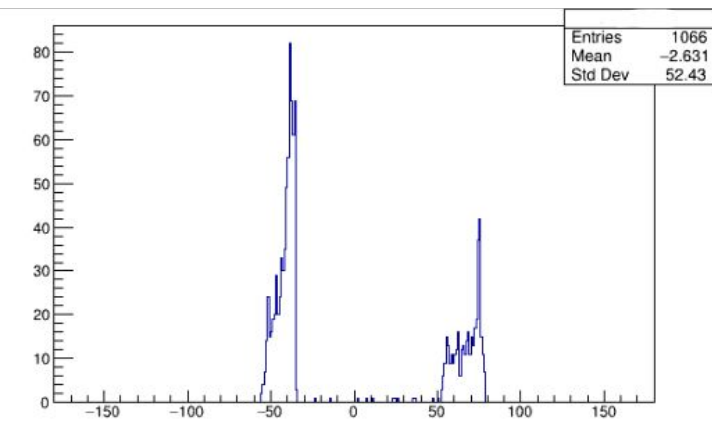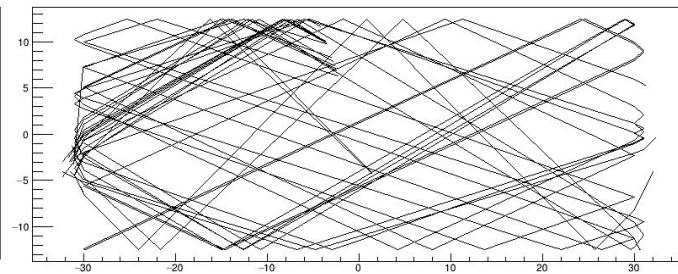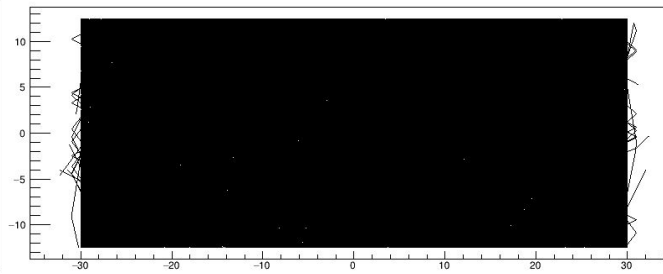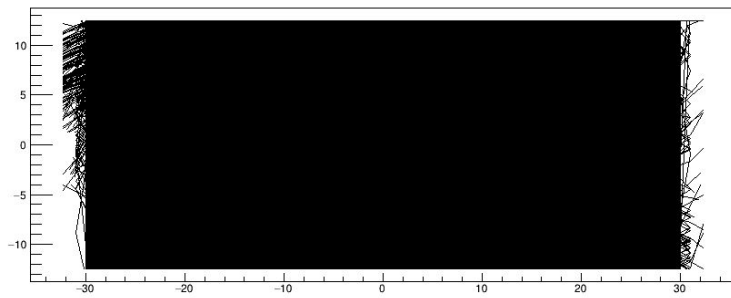

(1)
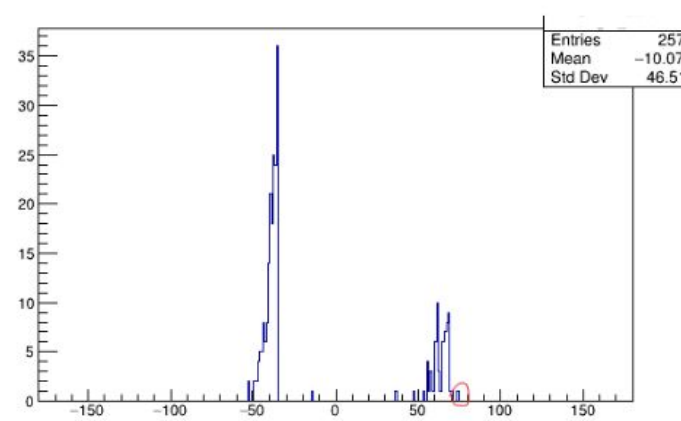
(2)

(3)

Most of the ~76 deg peak reduced, which is expected if we consider direct y reflections

The right side (-ve angles) peak filtered, due to the TIR at the grease - crystal interface (~36 and ~54 deg is the critical angle)
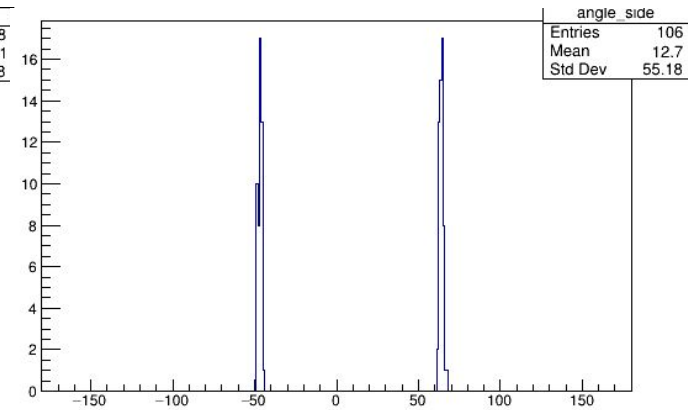
- -10 deg case - 66 deg with mainly y reflections should also not reach the bottom left region (y=-1.25 mm to y=-7.25 mm) so probably more contribution from the x reflections
- But even with a simple geometrical calculation (first order reflections from the top surface) we do have counts from 63 deg reaching there so it is possible
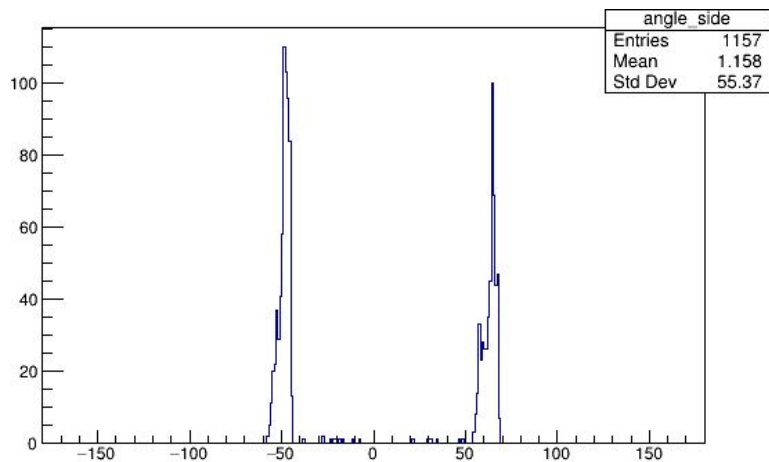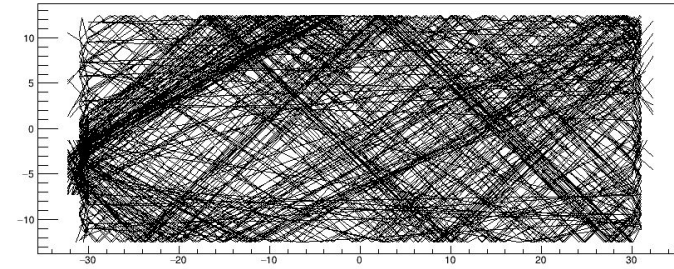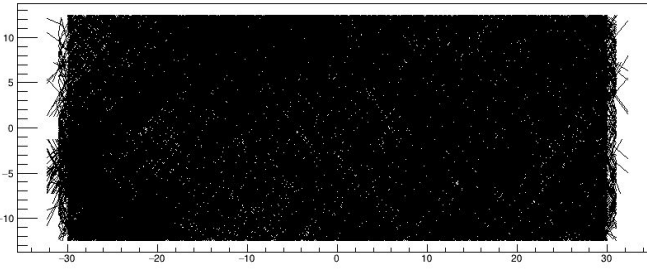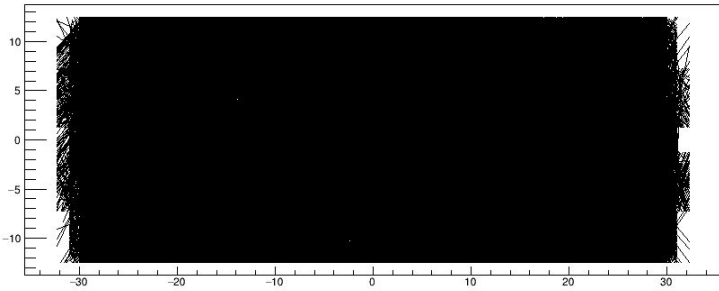
(1)
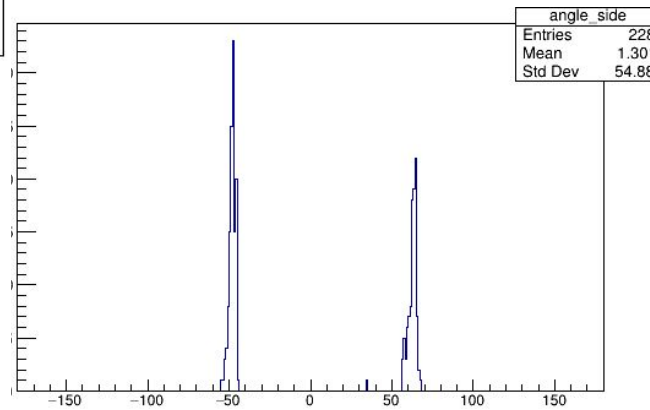
(2)

(3)

- First reflection at the faces perpendicular to the plane of the page