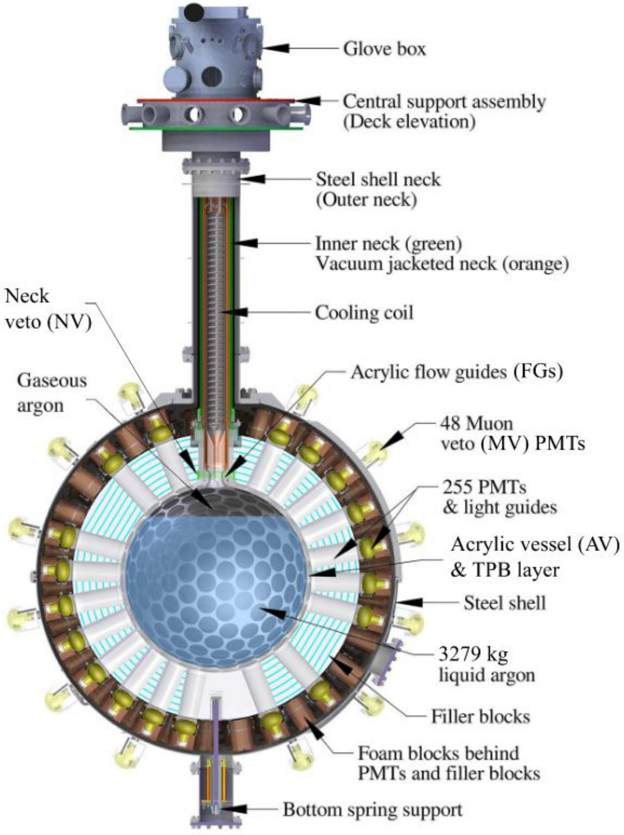
Investigating Improvements to Event Selection Cuts Against Neck Alpha Backgrounds for DEAP-3600

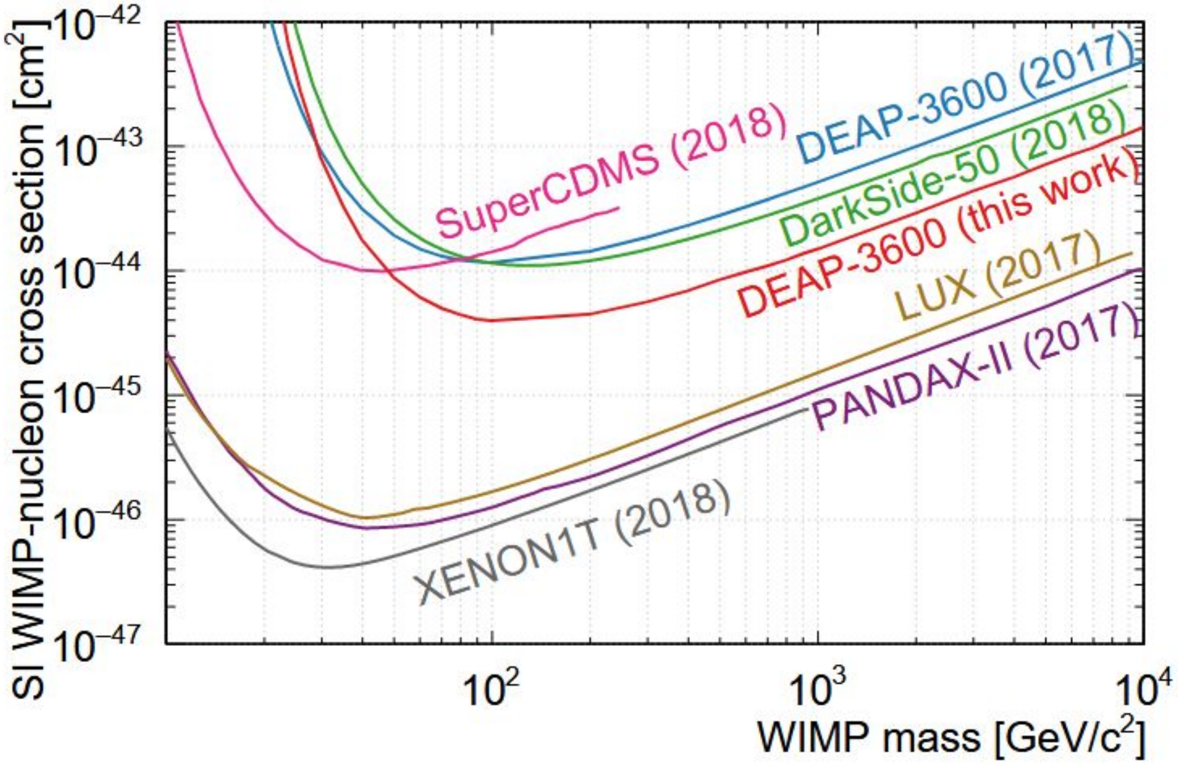
May Wittenberg - CASST 2022

What is DEAP-3600?

- Large liquid argon detector located at SNOLAB
- Searching for dark matter in the form of Weakly-Interacting Massive Particles (WIMPs) via direct detection
- Spherical acrylic vessel surrounded by PMTs
- 3.3 tons of LAr as target mass kept at roughly -180 degrees Celsius
- Sensitivity as low as 10^{-46} cm^2
- 255 8-inch-in-diameter Hamamatsu R5912 high quantum efficiency (HQE) PMTs



Cross Section of the DEAP-3600 Detector

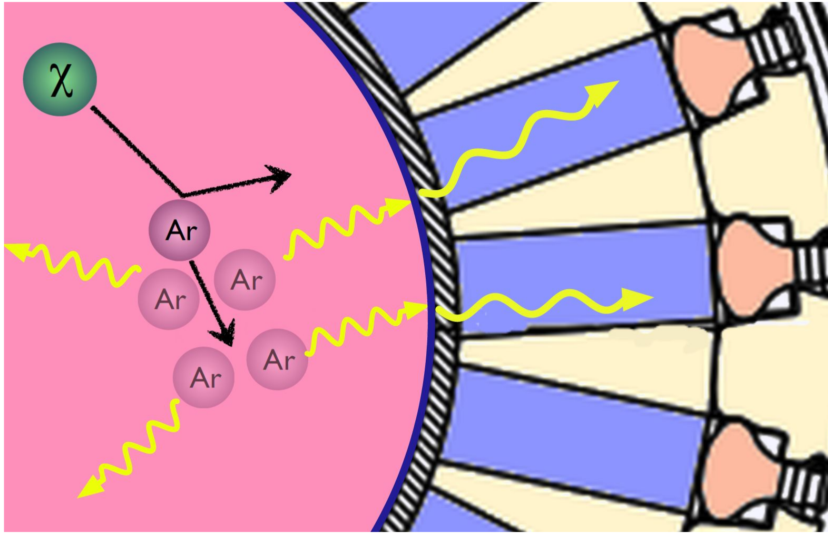


DEAP-3600 on the Exclusion Plot

90% confidence upper limit on the spin-independent WIMP-nucleon cross sections

A Standard Event

- Event begins with a nuclear recoil, excitation from an electromagnetic event, alpha particles, or heavy nuclei
- Argon scintillation occurs in UV spectrum at 128 nm
- Tetraphenyl butadiene (TPB) Coating shifts UV scintillation to visible spectrum
- Light is transmitted to the PMTs, and read out by waveform digitizers

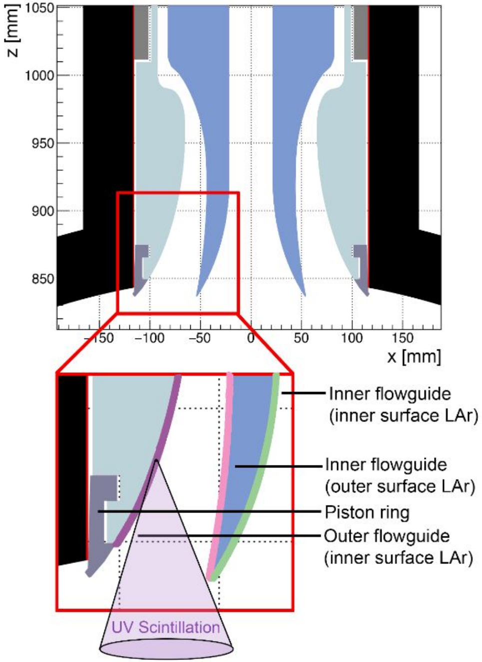


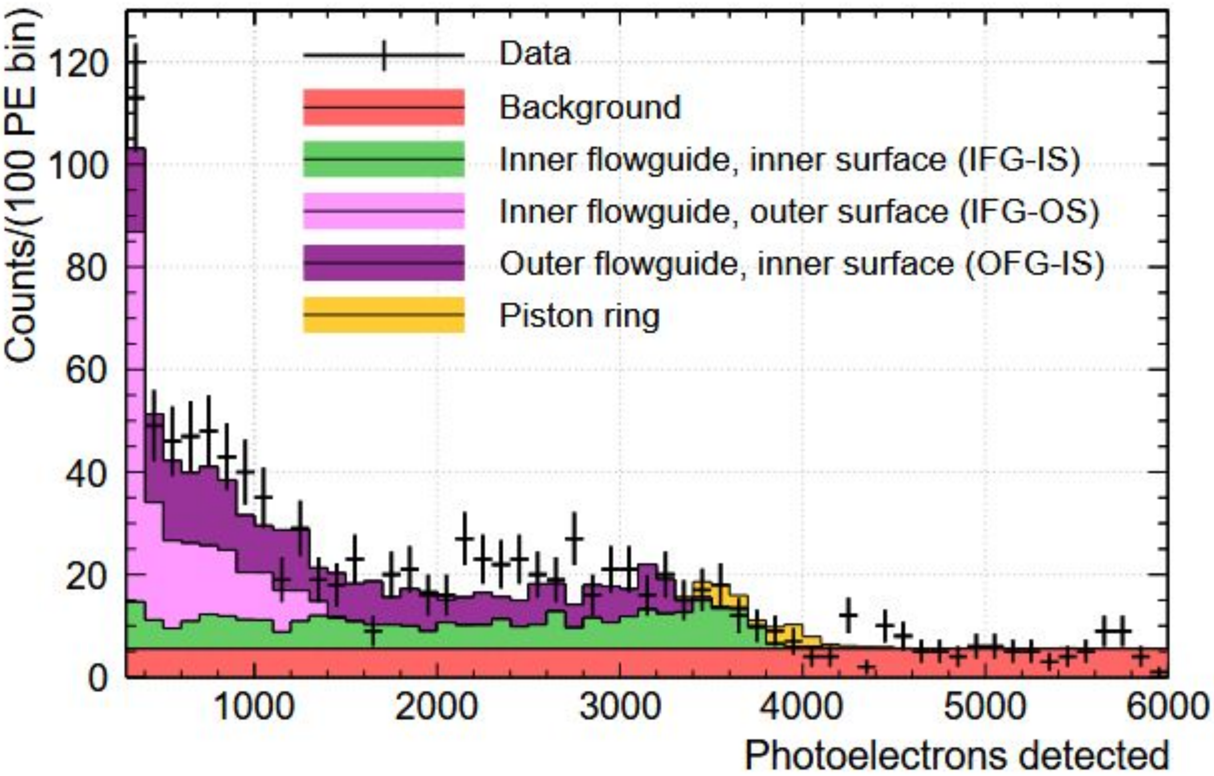
Standard DEAP-3600 Recoil Event

Backgrounds Means Cuts

- To make sure we're detecting dark matter, we need to make sure we're accounting for everything else
- Two cuts were investigated related to Neck Alpha backgrounds
    - Alpha particles occurring around the neck region of the detector
- Wanted to see if we could improve the signal efficiency of a cut, or reduce its background leakage, or both

- Signal
    - Ar40 nuclear recoils
- Backgrounds (Neck Alphas)
  - Dust Alphas
    - Po210 alpha decays on dust particulates of varying radii, no TPB
    - 1 μm, 5 μm, 10 μm, 17 μm, 25 μm
  - Flowguide Alphas
    - Po210 alpha decays on neck surfaces
    - Inner flowguide, Inner surface
    - Inner flowguide, Outer surface
    - Outer flowguide, Inner surface



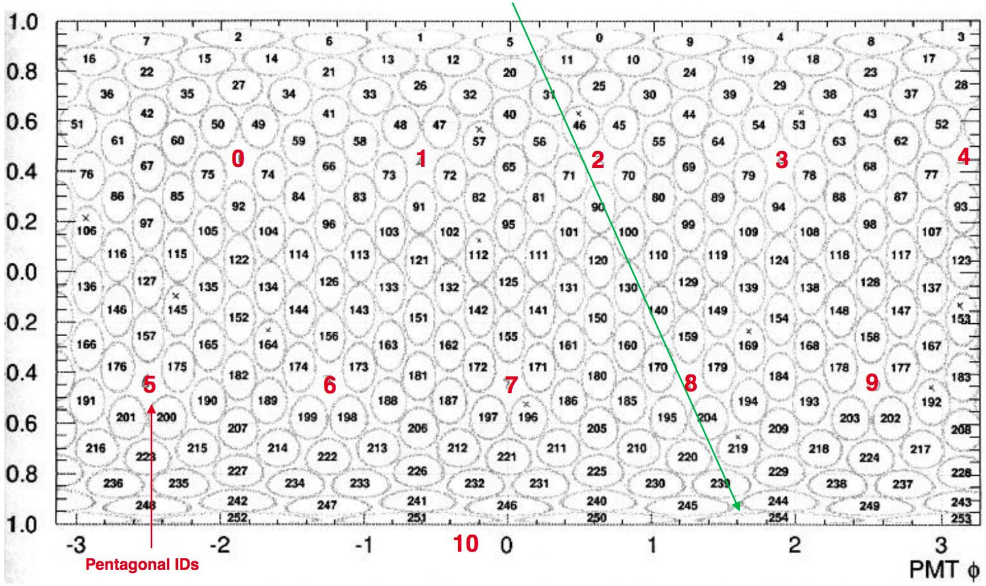


DEAP-3600 Data with Neck Alpha Contributions

1D-projection of the observed PE spectra (black points) and expected distributions from the background model components, normalized to the best-fit rates.

Cut 1: Charge Fraction Top N Rings

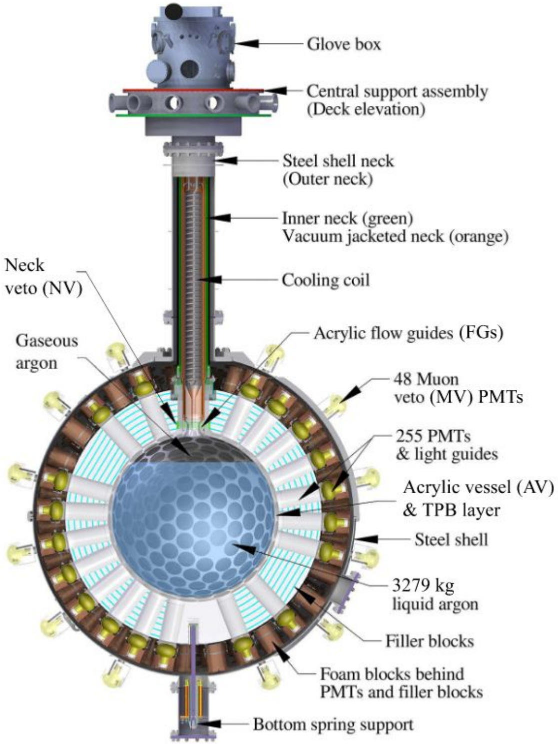
- The PMT geometry can be represented by a series of rings
- The current cut eliminates events with high charge fraction in the top two rings
- Goal: a larger selection of Top N Rings, with a new conditional value




```
if ( (chargetopring+chargesecondring)/qPE >= 0.04 ) continue; // High charge cut in positive z-axis
```

Cut 2: Pulse Index First GAr

- The LAr in the vessel does not completely fill it, the rest of it contains GAr
- Scintillation events above the fill line can reflect off the GAr/LAr interface, and register on PMTs above that region before the PMTs further down do so
- Goal: a smaller ring selection for last_gar_pmt_id, and a new conditional value

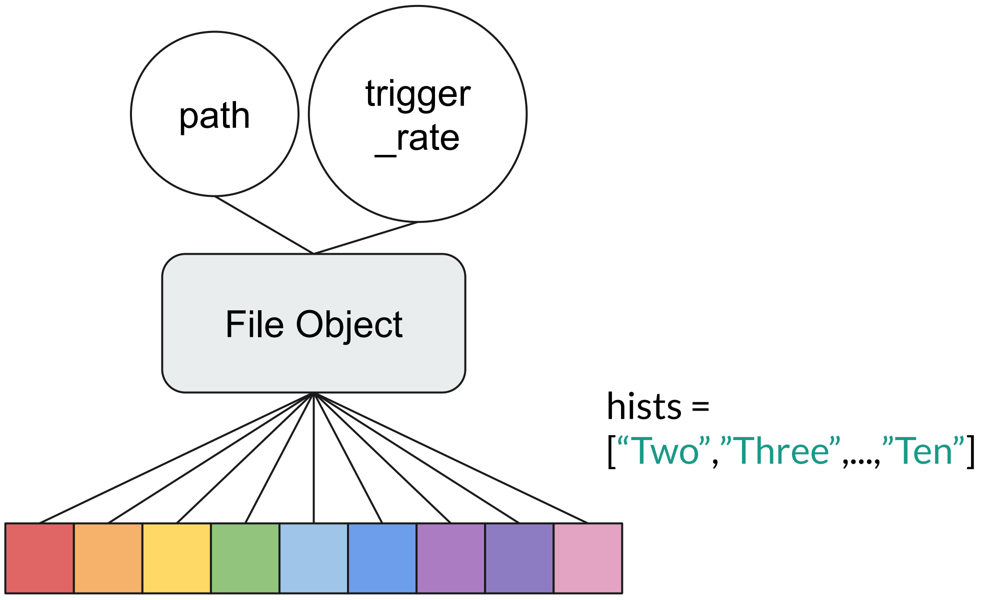



```
if ( pulseindexfirstgar <= 2 ) continue; // PMT ID of first three pulses must not be looking at gas phase

/rat/proc pmtfirstpulse
/rat/procset time_window_start -150.
/rat/procset time_window_end 150.
/rat/procset last_gar_pmt_id 64
```

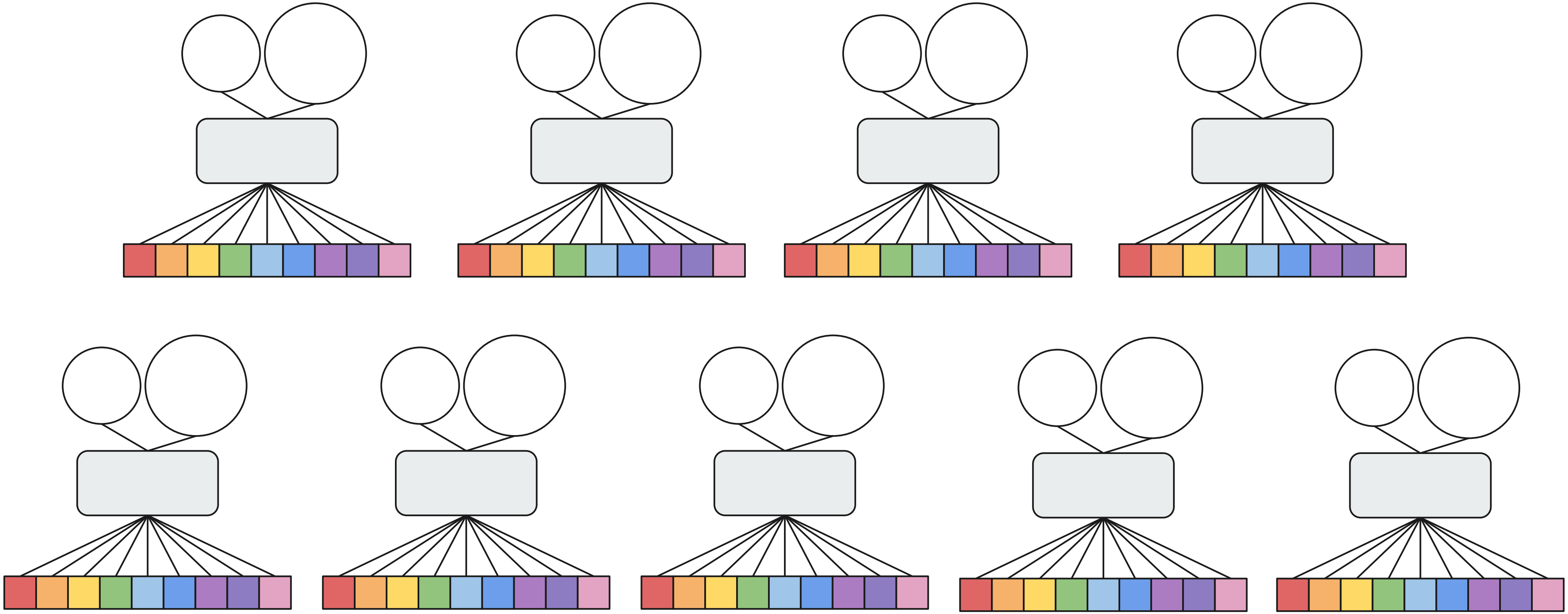
Method

- Using simulation files for the signal and selected backgrounds, histograms could be generated
- Both variables involved PMT rings, so much of the code for both followed the same structure
- Data would need to be analyzed for the desired selection of rings
- Ring Charge processor only supported calculating ring charges for the top two rings
    - Wanted to look at the data for the top ten rings, so these would need to be calculated manually
- Pulse Index First GAr processor supported any rings from the first to the ninth, so no manual calculations were necessary
- Coding was split into two python files, one to generate histograms, and another to display them



Here’s what a File Object looks like

samples = [“Ar40”,”DustR10”,”DustR17”,”DustR1”,”DustR25”,”DustR5”,”IFIS”,”IFOS”,”OFIS”]



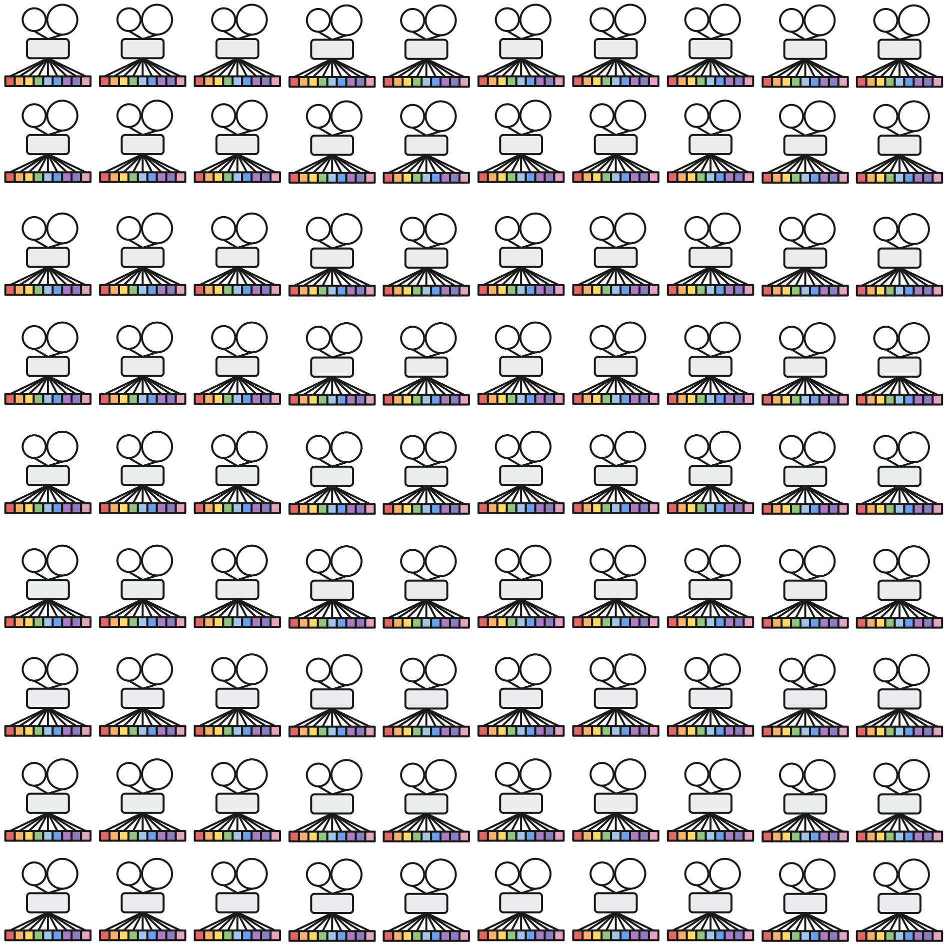
Each File looks at a certain Sample

For each sample, we look at Ten Files

Let's do the math!

9 Histograms per File * 10 Files per Sample * 9 Samples = **810 Histograms**

Where would we be without "for loops"?



Plotting It Together: Charge Fraction Top N Rings

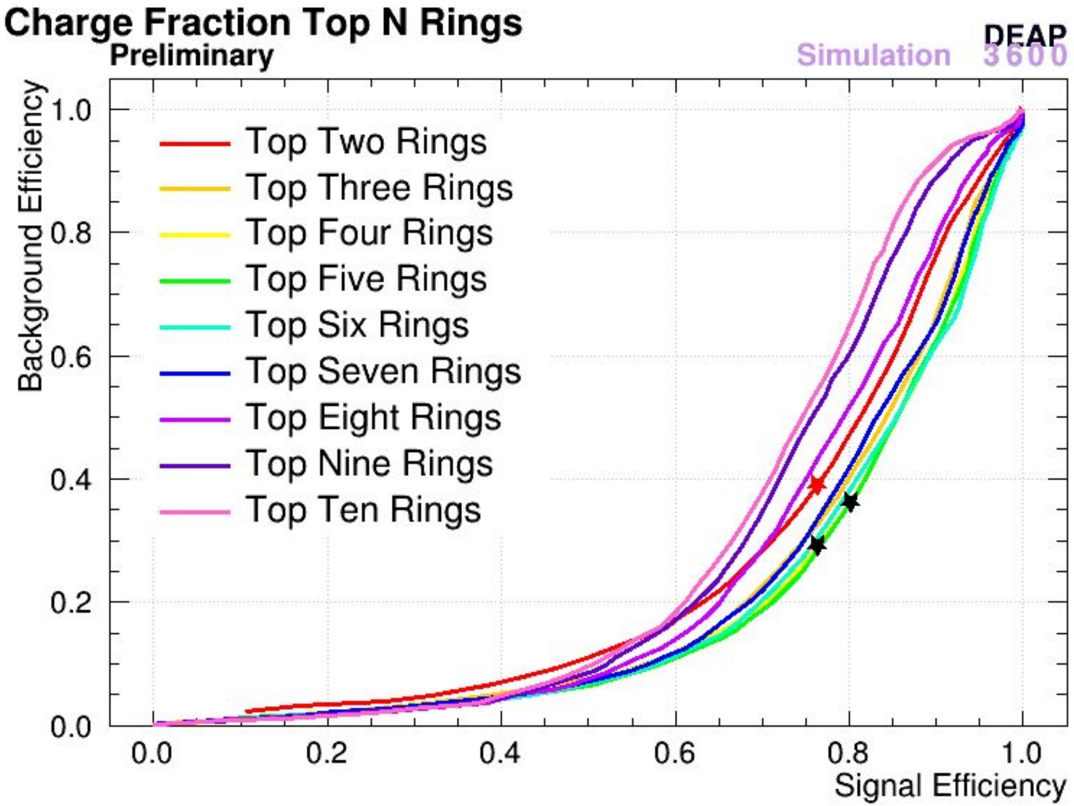
- Histograms were scaled to their sample's trigger rate (Hz)
- Each had 100 bins from 0 to 0.5 (each bin represented a charge fraction increase of 0.005%)

ROC Curves

- Histograms don't tell us nearly as much as ROC Curves do
- Compare Signal Efficiency to Background Efficiency (Leakage)
- Made for three selected backgrounds (Dust Alphas were determined to be largely negligible in the Neck Alpha Control Region)

Results

- (chargetopring + chargesecondring + chargethirdring + chargefourthring) / qPE >= Lower point: 0.09, Higher point: 0.095
- Top Four, Five and Six Rings showed consistent improvement versus the original top two ring cut
- 0.09 maintains a similar signal efficiency (0.75) while reducing background leakage (0.4 -> 0.3)



Plotting It Together: Pulse Index First GAr

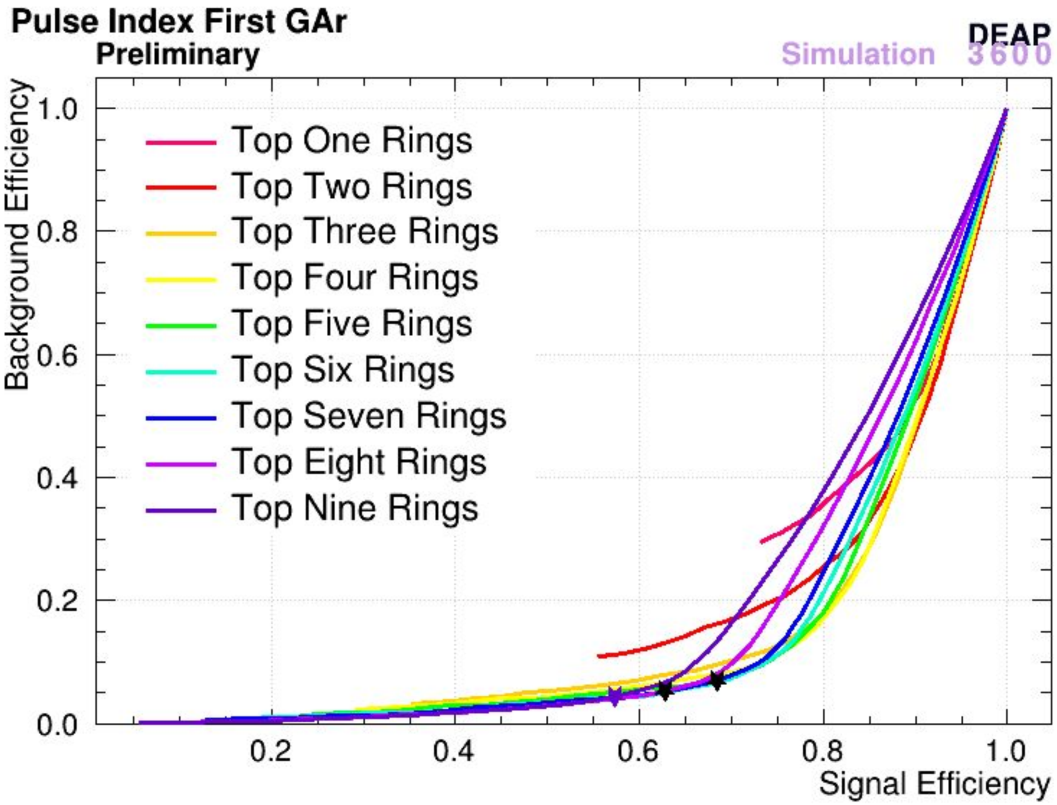
- Histograms were scaled to their sample's trigger rate (Hz)
- Each had 20 bins from 0 to 20 (only integer values)

ROC Curves

- Histograms don't tell us nearly as much as ROC Curves do
- Compare Signal Efficiency to Background Efficiency (Leakage)
- Made for three selected backgrounds (Dust Alphas were determined to be largely negligible in the Neck Alpha Control Region)

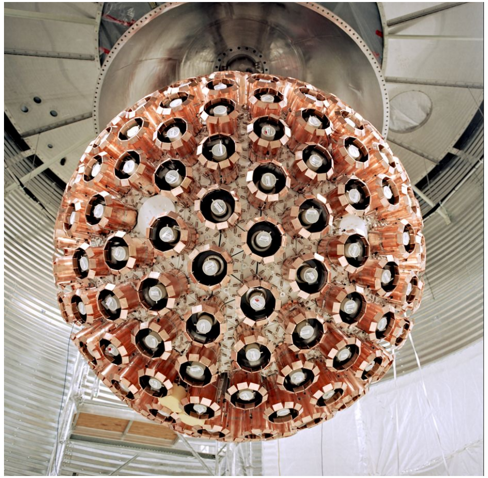
Results

- pulseindexfirstgar <= 2, last_gar_pmt_id 54 (Ring Eight) / last_gar_pmt_id 44 (Ring Seven)
- ROC curves included any overflow data (entries past an integer value of 20)
- The eighth ring curve (light purple) had an extremely minimal background leakage difference (0.05), with a slight signal efficiency increase (0.575 -> 0.625)
- The seventh ring curve (dark blue) had a slight background leakage increase (0.05 -> 0.06) with a more significant signal efficiency increase (0.575 -> 0.675)

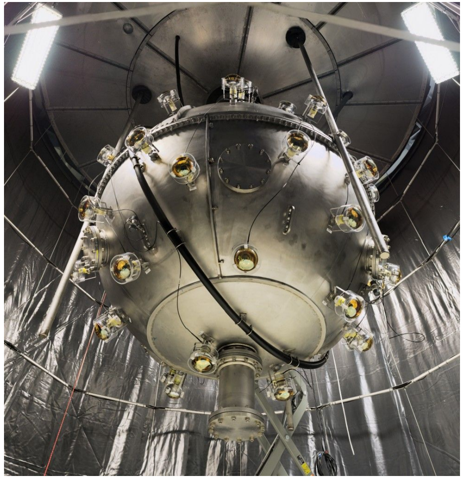


Next Steps

- Found two ways to optimize the DEAP-3600 WIMP search event selection
- The Ring Charge processor still lacks the ability to calculate the required ring charges for the new cut
- Once the new cuts are decided on and implemented, new simulations will need to be run



Acrylic Vessel With Copper Thermal Shorts



Steel Shell with Veto PMTs

Thank You!