Position Reconstruction for DEAP-3600

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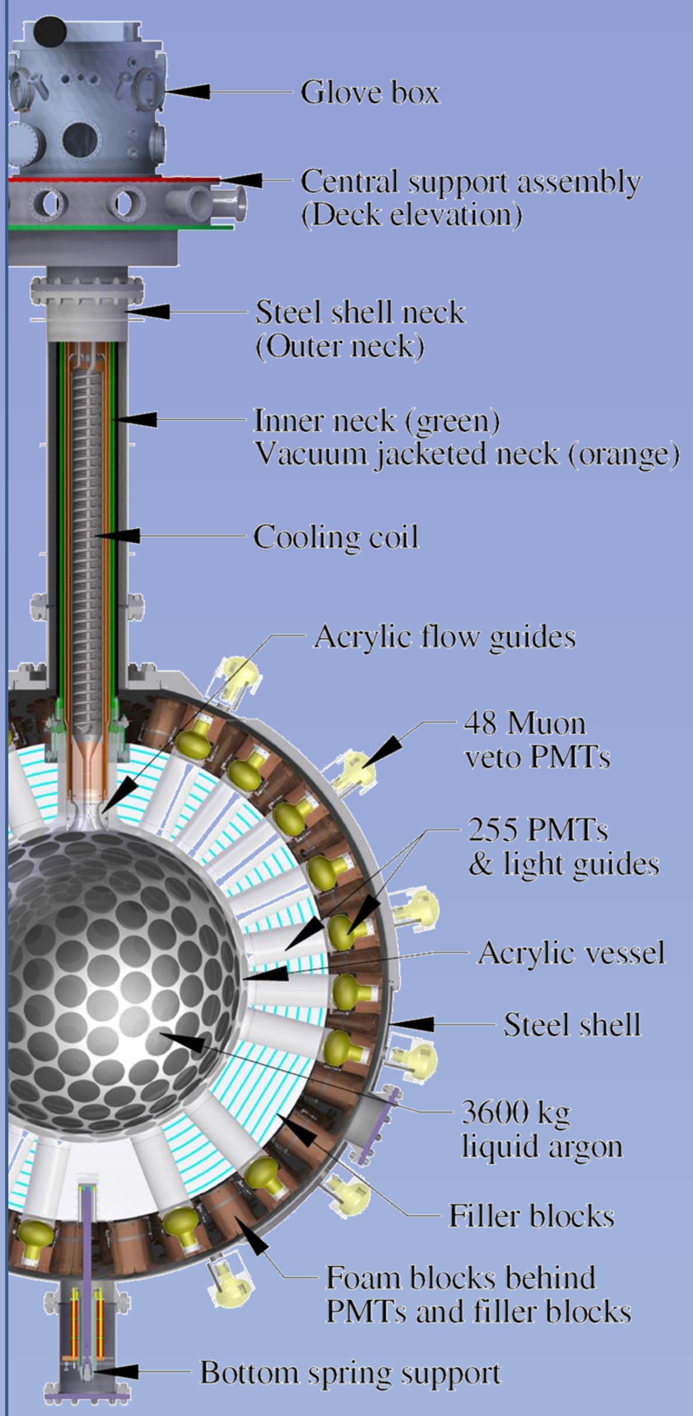
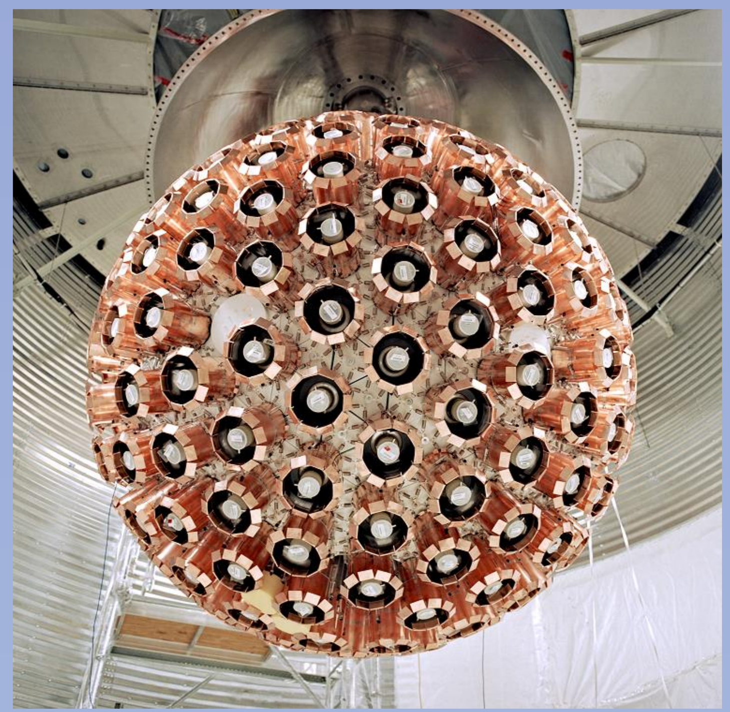
DEAP-3600

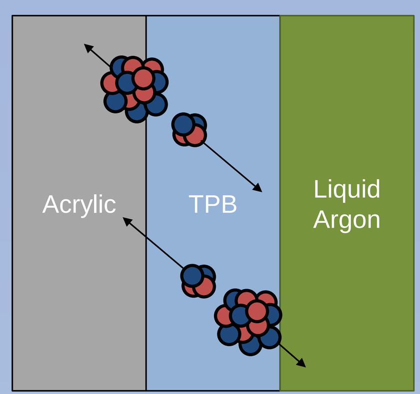


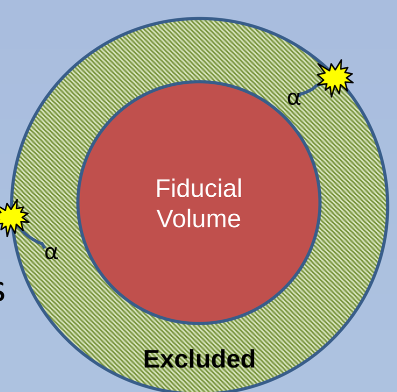
- DEAP-3600 is a dark matter search experiment located 2km underground at SNOLAB in Sudbury, ON
- It uses ultrapure liquid argon as a target mass
- The liquid argon is enclosed in a spherical acrylic vessel 851 mm in radius
- A TPB coating on the acrylic shifts the wavelengths of scintillation photons
- Light guides transport scintillation photons to 255 Photo-Multiplier Tubes (PMTs) that surround the acrylic vessel

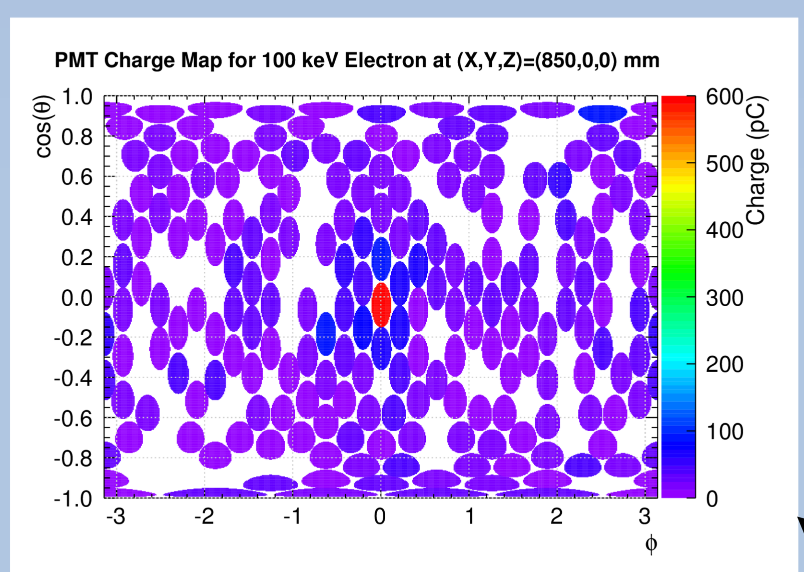


Position Reconstruction – Motivation

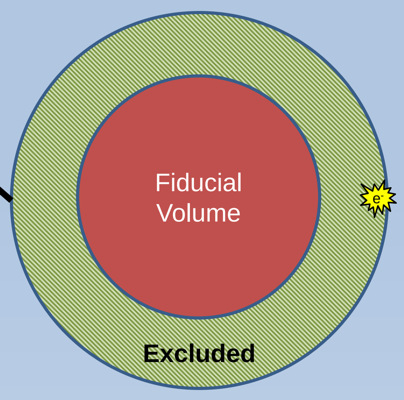
- Pulse-shape discrimination:
  - Liquid argon has a long-lived triplet (1600 ns) and short lived singlet (6.7 ns) excited state
  - Ratio of triplet to singlet states depends on particle ID
  - Used to exclude most backgrounds, but can't discriminate some alpha decays
- Alpha-decaying isotopes exist in small quantities in the acrylic and TPB
- Scintillation in TPB can cause alphas to mimic dark matter signals
- These tend to not penetrate very deep into the argon
- Position reconstruction can therefore exclude these events based on distance from surface

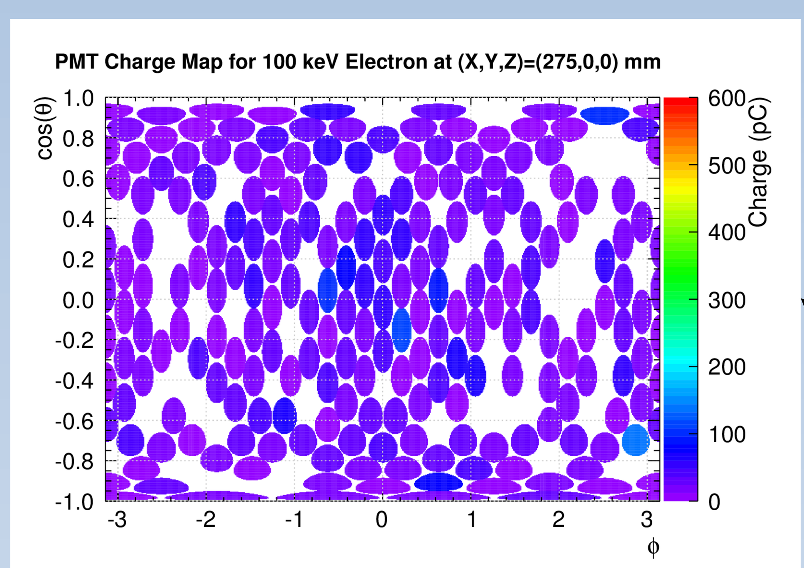




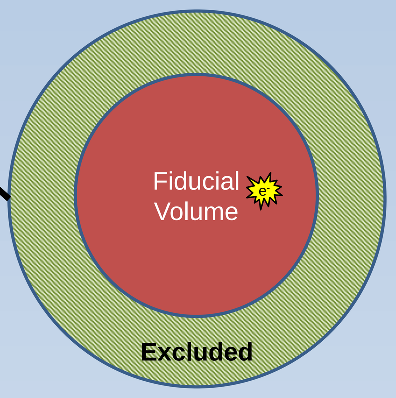


Event close to acrylic surface





Event close to centre



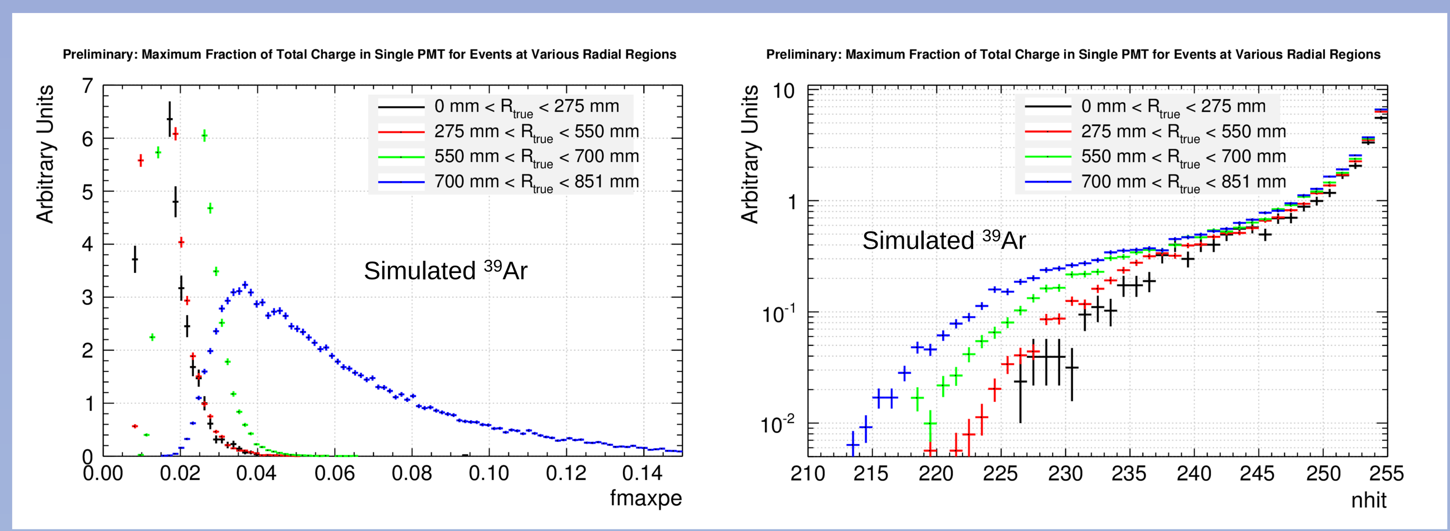
- Sample PMT charge distributions for events close to surface (top) and close to centre (bottom)
- 1 photo-electron ≈ 10 pC
- Afterpulsing can cause lone, bright PMTs

Plot Parameters

- fmaxpe and nhit characterize the PMT charge distribution (defined below)
- R_{recon} = Reconstructed event distance from centre
- R_{true} = True event distance from centre
- R_0 = Acrylic vessel radius
- X is the distance from the centre of the acrylic vessel along a horizontal axis, with Y=Z=0
- MBFit, Centroid, and ShellFit are the position reconstruction algorithms
- Polar Coordinates: $X=R_0\cos(\theta)\sin(\phi)$, $Y=R_0\sin(\theta)\sin(\phi)$, and $Z=\cos(\phi)$

Position Reconstruction – Variables

- The DEAP analysis uses several variables that characterize the PMT charge distribution
- These variables are sensitive to event positions
- This poster mentions two of these variables as examples:



"fmaxpe" - The fraction of light detected by the PMT that detects the largest amount of charge

"nhit" - The number of PMTs that record pulses during an event

Position Reconstruction – Fitters

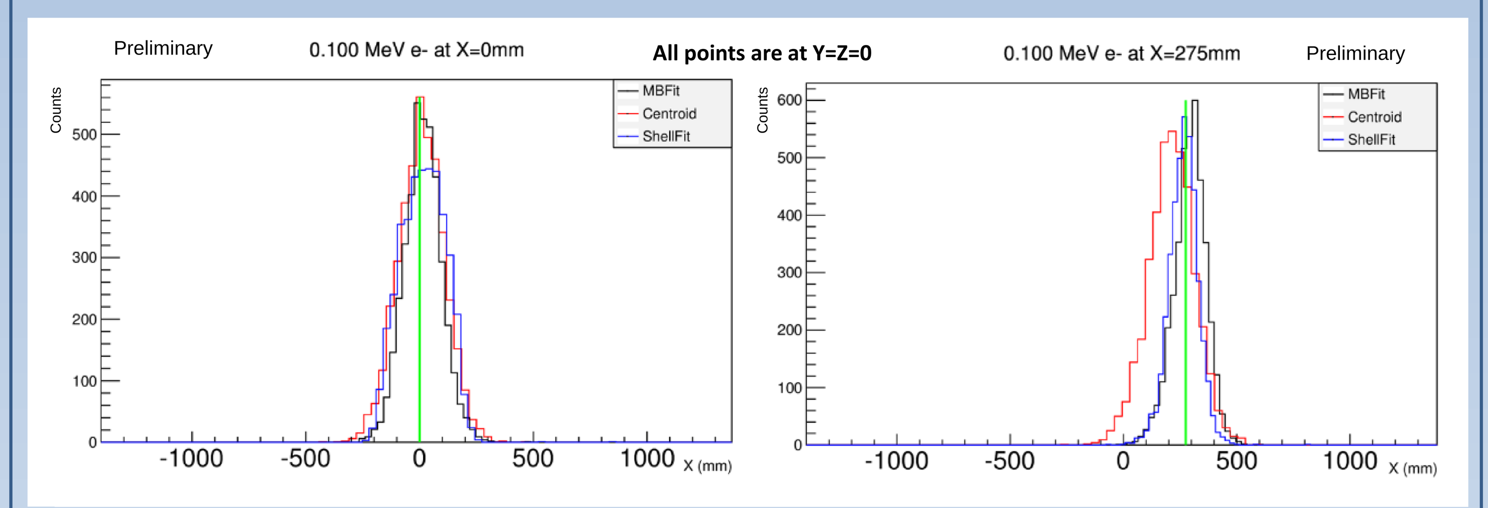
- Three preliminary position reconstruction algorithms that are under evaluation:
  - "Centroid" – Simple algorithm:

$$C = \frac{\sum_{i=1}^{nPMT} \boldsymbol{P_i} * Q_i^f}{\sum_{i=1}^{nPMT} Q_i^f}$$

  where $\boldsymbol{C}$ = position returned by Centroid, $\boldsymbol{P_i}$ = position of PMT, and Q_i^f = PMT charge scaled by tuning factor f ($f = 3$ in this poster).
  - "MBLikelihood" or "MBFit" - a negative log likelihood fit of the charge distribution. A Monte Carlo based tuning algorithm creates the likelihood function that is used by this fitter. This function depends on the state of the Monte Carlo model at the time of tuning, so it is necessary that the Monte Carlo be calibrated as well as possible.
  - "ShellFit" - ShellFit performs Monte Carlo simulations on an event-by-event basis to determine the position of events within the detector. It uses Centroid to get a position estimate for an event, and then performs a series of "mini-sims" in that region. A negative log likelihood minimization is used to converge on the most likely position of an event.

Fitter Characteristics

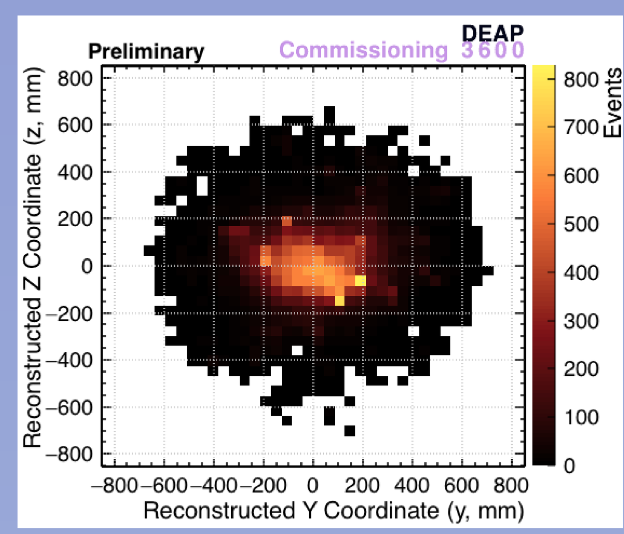
- Reconstructed positions for Monte Carlo electron events generated at fixed points along horizontal X-axis
- These fitters are preliminary, and under development and evaluation



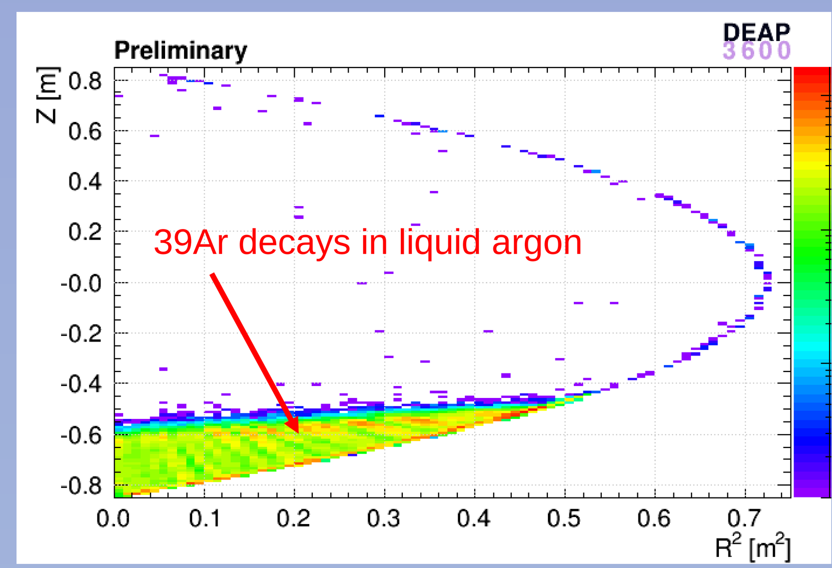
Note that X=0 is the centre of the detector, and X=851 mm is the edge

Fitters Tested with Laserball Data

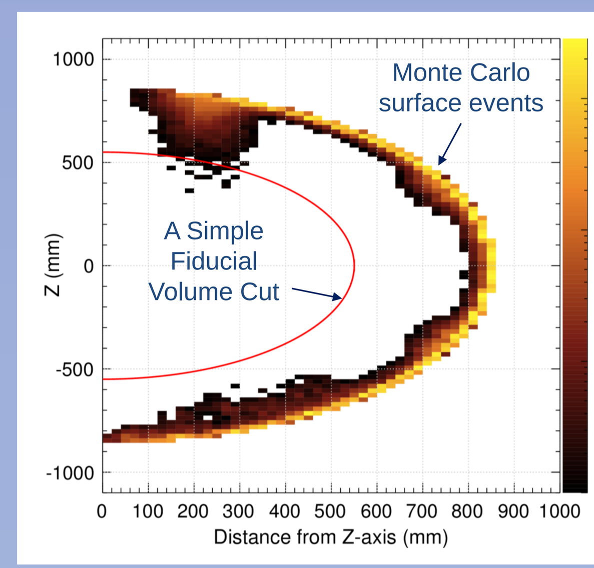
- Laserball was placed in centre of detector
- ShellFit was tested with laserball data



Some Fitter Applications



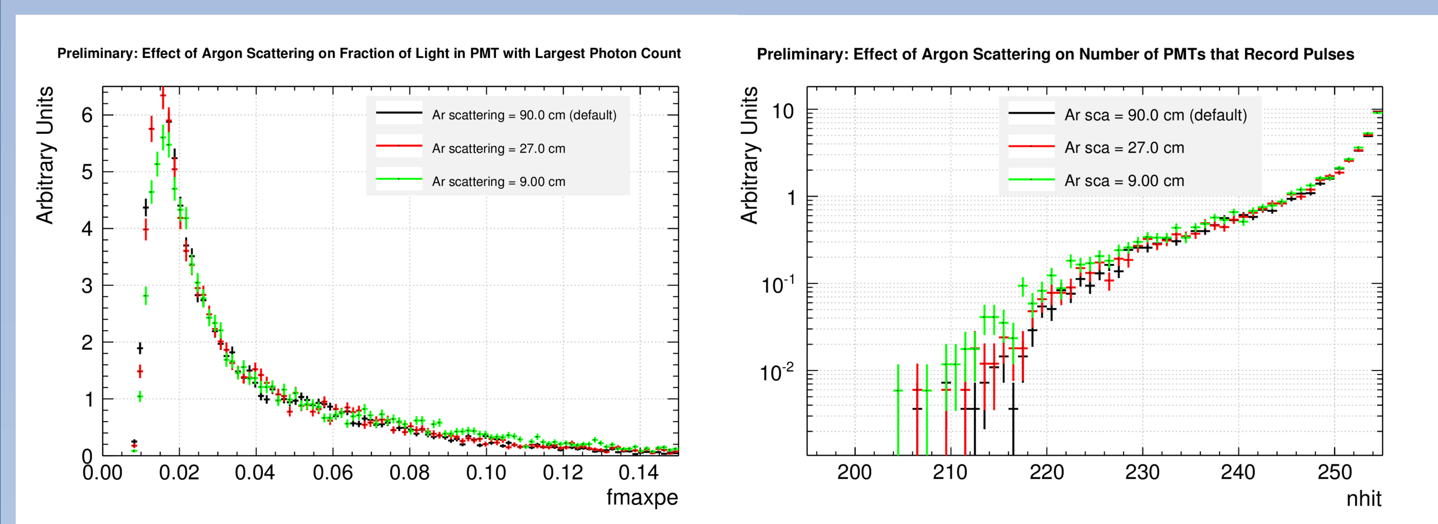
Could "see" liquid argon level during filling



Reconstructed positions of some simulated ^{214}Po surface events

Position Reconstruction – Calibration

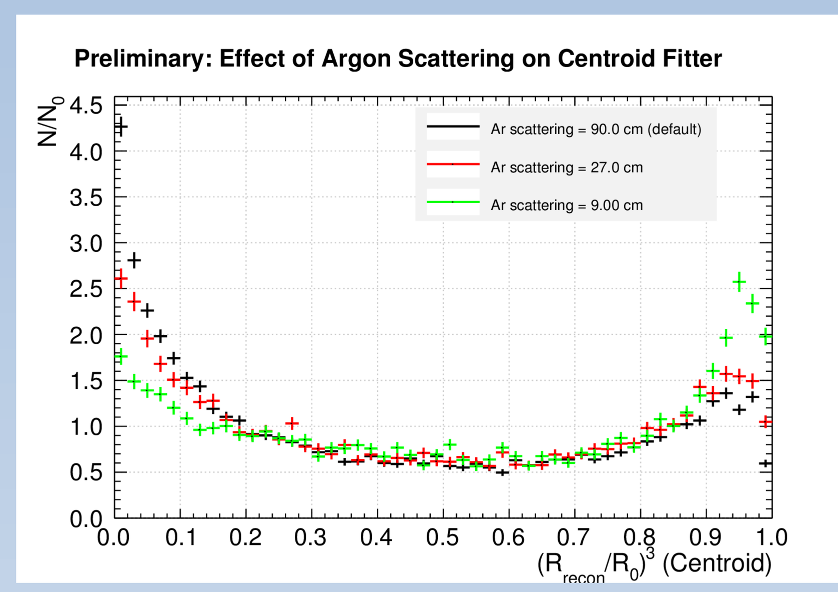
- Monte Carlo based fitters require well-calibrated Monte Carlo
- ^{39}Ar decays are a good calibration source, as it is distributed uniformly throughout the detector and has a very high rate
- Laserball, AARFs (light through a fibre), AmBe and ^{22}Na are other calibration tools
- ^{39}Ar events simulated uniformly throughout the detector in the following plots



Scattering length affect on the maximum fraction of light detected by a single PMT

Scattering length affect on the total number of PMTs hit

- In an actual calibration, the scattering length could be tuned along with other parameters in order to match the ^{39}Ar spectrum seen in data
- This is an example of how the Monte Carlo can be calibrated based on observed ^{39}Ar events



- Example of how the scattering length affects the reconstructed positions for Centroid.