Event Reconstruction For ARGO

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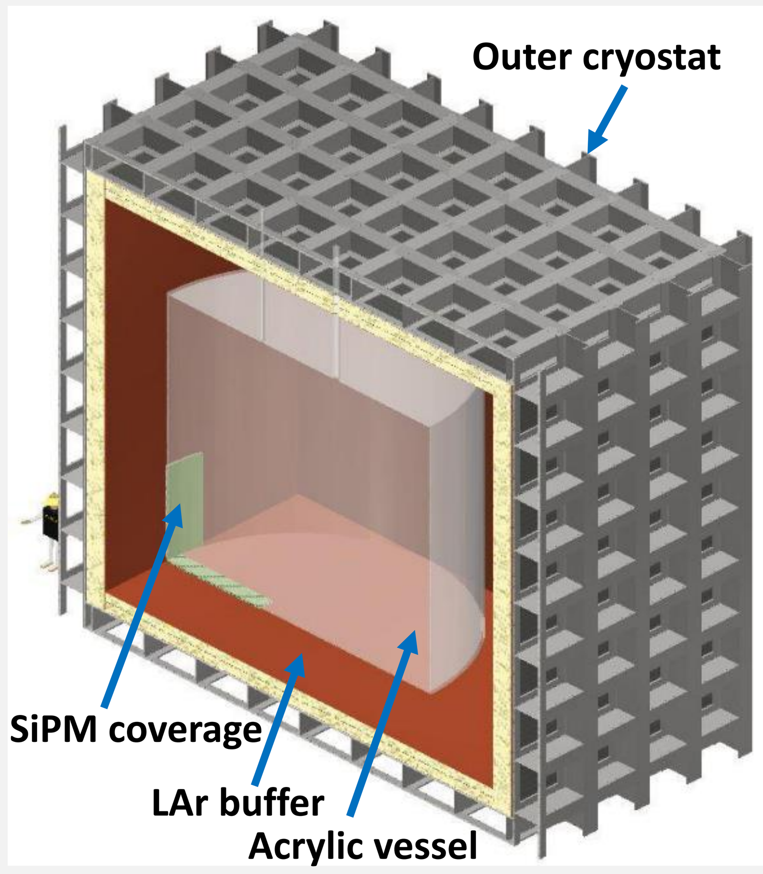
INTRODUCTION

ARGO is a liquid-argon scintillation detector aimed to directly observe elastic scattering of galactic WIMPs in the target. It is proposed to be deployed at SNOLAB, known for its low-background environment conducive to sensitive experiments. One possible design for ARGO is a single-phase detector housing 400 tonnes of low-radioactivity liquid argon within a cylindrical acrylic vessel measuring seven meters in height and diameter.

Conceptual design of the ARGO

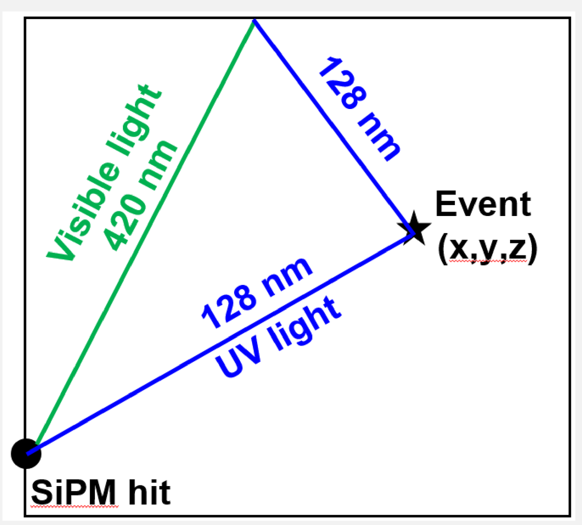


The primary objective of this study is to understand the requirements for efficient photon sensing, particularly in rejecting surface events such as alpha particles. This entails determining the optimal photon detectors needed and their required properties for effective operation.

We developed time- and charge-based reconstruction algorithms to predict the origin coordinates of events within the ARGO detector, focusing specifically on surface events. These algorithms demonstrate a strong relationship between predicted and true coordinates.

Due to the large size of the detector, the contribution of Rayleigh scattering events is significant, posing a challenge for event reconstruction, especially for the time-based method. To mitigate this bias, we focused on the prompt part of the signal, as it provides the most reconstruction power.

TIME FITTER



Event diagram in ARGO

Time-of-flight corrected SiPM residual time

$$t_{res} = t_{hit} - t_{fit} - \frac{|\vec{r_{fit}} - \vec{r_{hit}}|}{V_g}$$

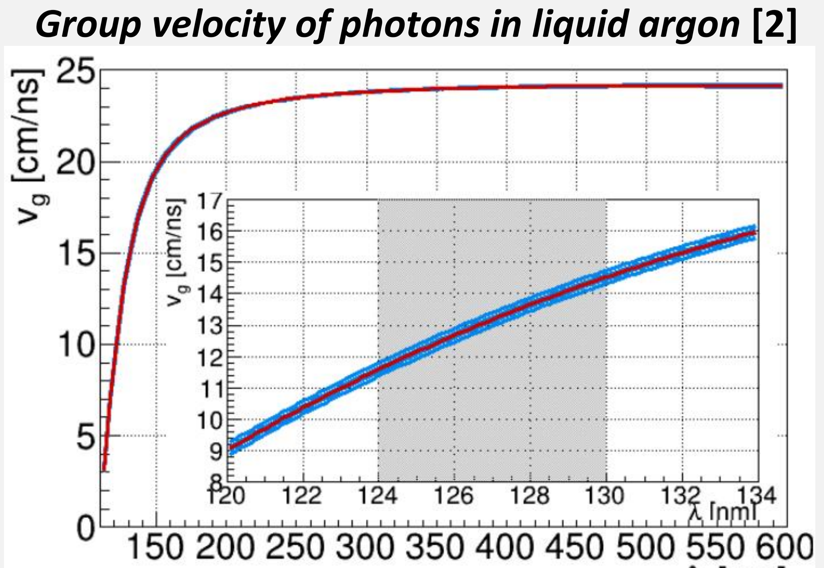
V_g - group velocity of UV photons

$$PDF_t = \mathrm{F}(r_{fit}, t_{fit}, r_{hit}, t_{hit}) \quad LL_t = \sum_i Log(PDF_t^i)$$

$\{t_{fit}, r_{fit}\}$ defined maximizing the likelihood function.

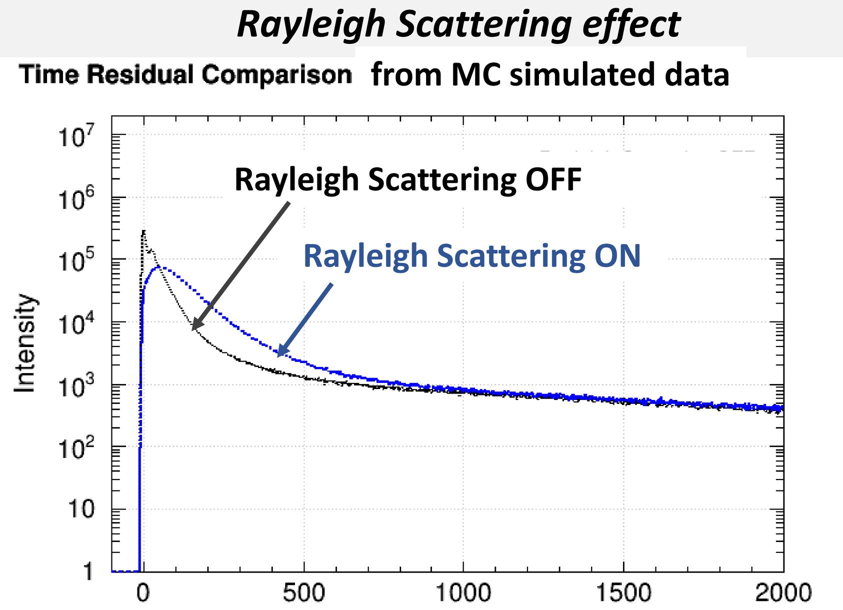
We used effective group velocity of visible light in liquid argon to avoid negative residual time distribution.

Group velocity of photons in liquid argon [2]

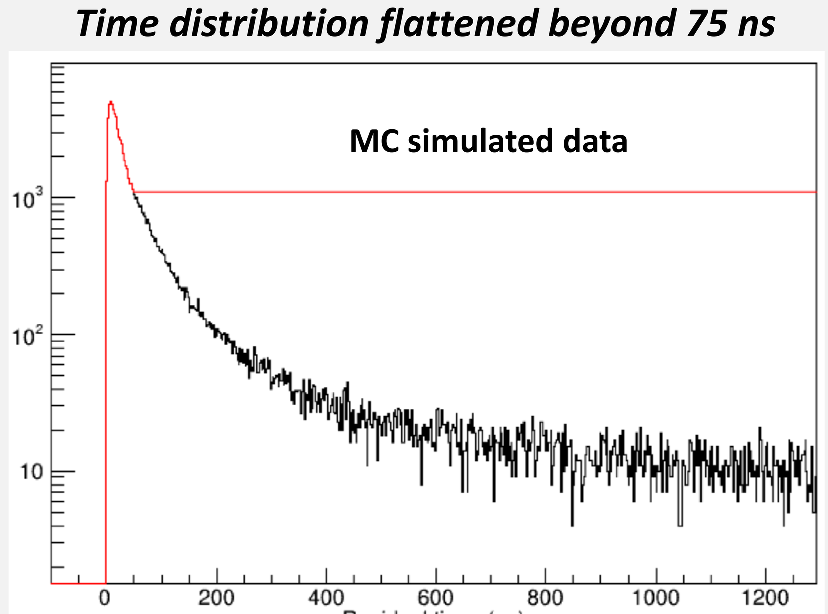


The presence of Rayleigh scattered light causes the residual time distribution to widen after the prompt light peak and become thicker in the later part. To address this issue, we flattened the distribution after the 75 ns mark to prevent likelihood misbehaving.

Rayleigh Scattering effect



Time distribution flattened beyond 75 ns



CHARGE FITTER

The charge-based method relies on the pattern of charges measured by the Silicon Photo-Multipliers (SiPM) positioned across the surface of the liquid argon vessel in the ARGO detector. The X and Y coordinates are determined by maximizing a likelihood function constructed using a probability distribution defined as a function of X and Y coordinates from Monte Carlo simulated events, while the Z coordinate is inferred from the measured charge distribution along the Z axis.

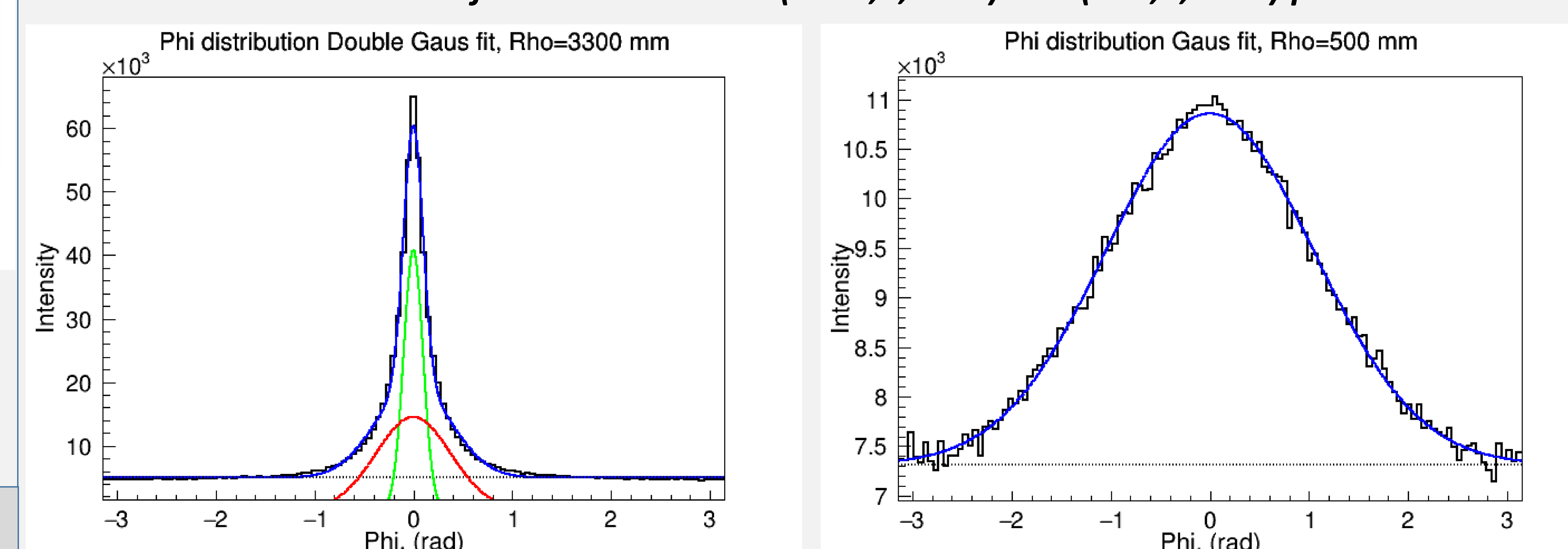
Probability distribution function for charge-based method

$$PDF_c = \mathrm{F}(\varphi_{fit}, \rho_{fit}, \varphi_{hit}, \rho_{hit}) \qquad LL_c = \sum_i Log(PDF_c^i)$$

$\{\varphi_{fit}, \rho_{fit}\}$ defined maximizing the likelihood function.

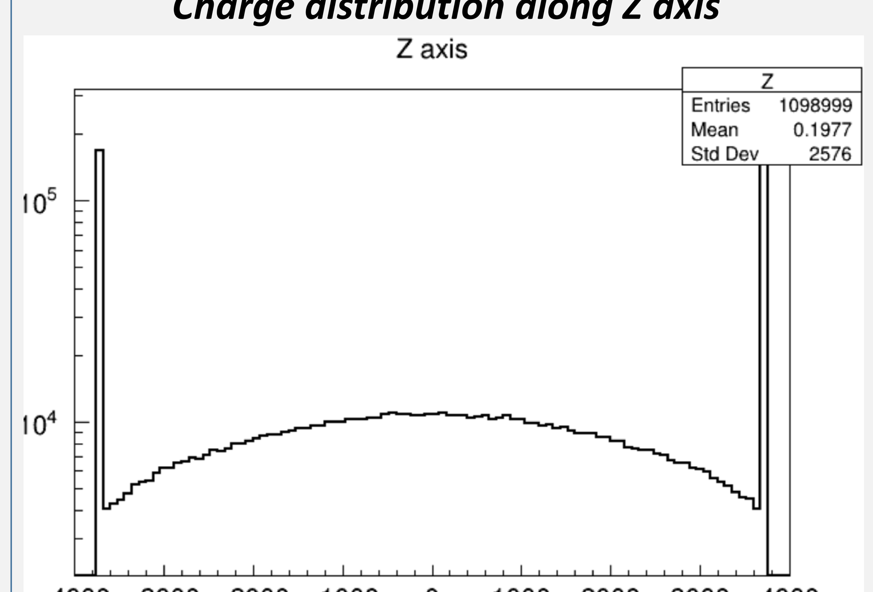
The probability of detecting photons by a SiPM is a highly non-linear function of the event's coordinates and changes rapidly as the interaction point comes closer to the SiPM. We used double Gaussian functions for fitting Phi distribution.

Phi distributions of events created at (3300,0,2500) and (500,0,3500) positions

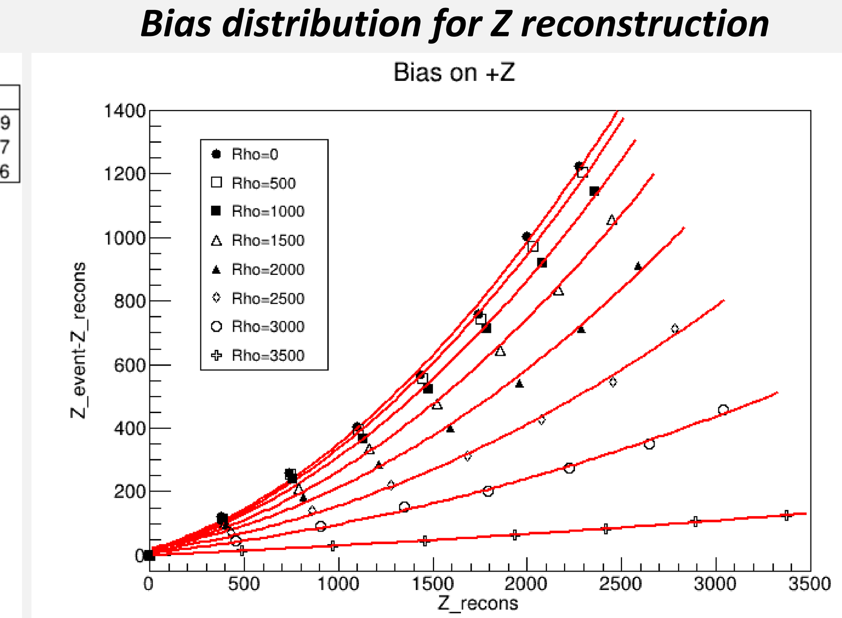


The Z coordinate was determined by identifying the location where the amount of charge dropped to half in the charge distribution along the Z axis. Initial simulations showed bias on Z-reconstruction and we corrected as shown below.

Charge distribution along Z axis



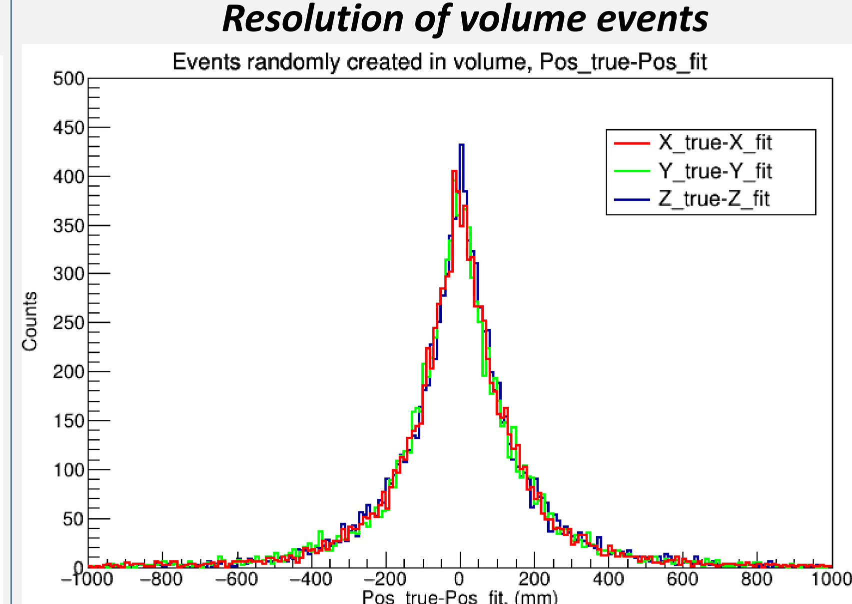
Bias distribution for Z reconstruction



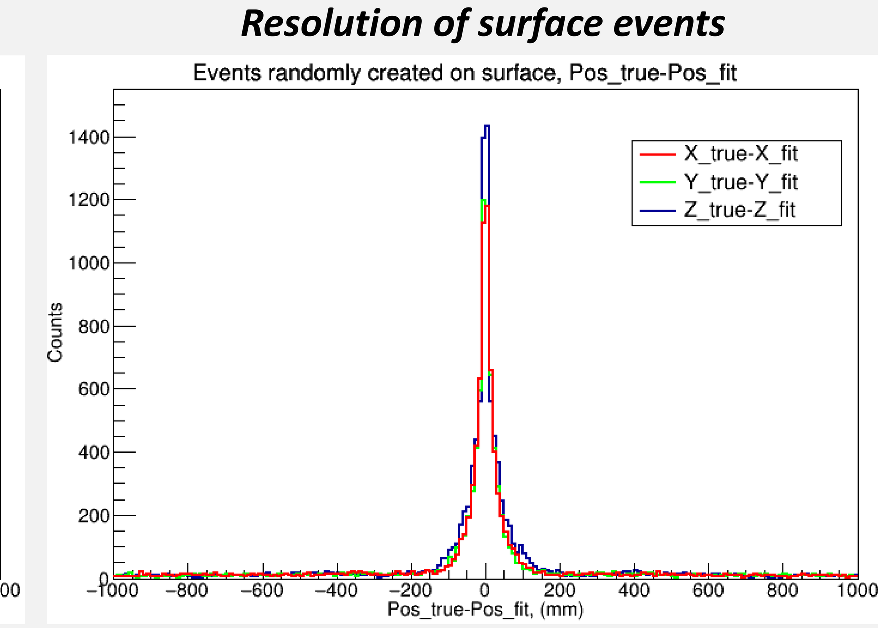
RECONSTRUCTION RESOLUTION (CHARGE FITTER)

We reconstructed Monte Carlo (MC) simulated surface and volume events using the algorithm based on charge fitting. The following figures display resolution of 10000 reconstructed events created by MC simulations of 100 keV alphas within the entire volume (left) and on the surface (right) of the ARGO detector.

Resolution of volume events



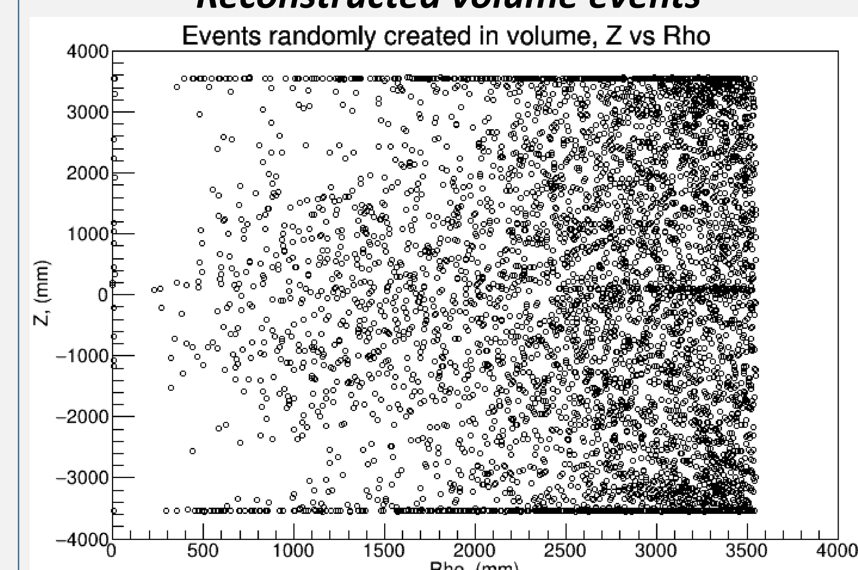
Resolution of surface events



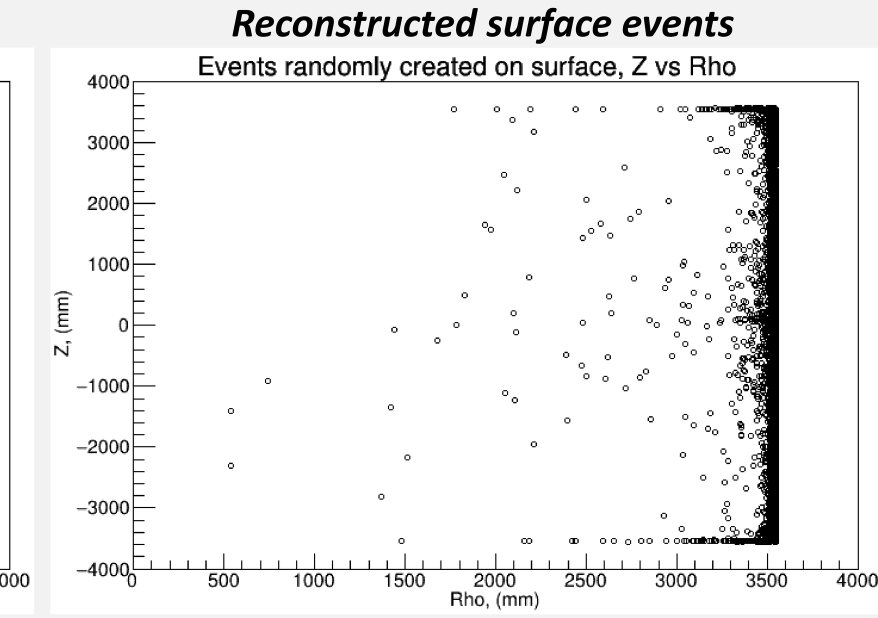
RECONSTRUCTED EVENTS (TIME FITTER)

The following figures display 10000 reconstructed events created by MC simulations of 100 keV alphas within the entire volume (left) and on the surface (right) of the ARGO detector.

Reconstructed volume events



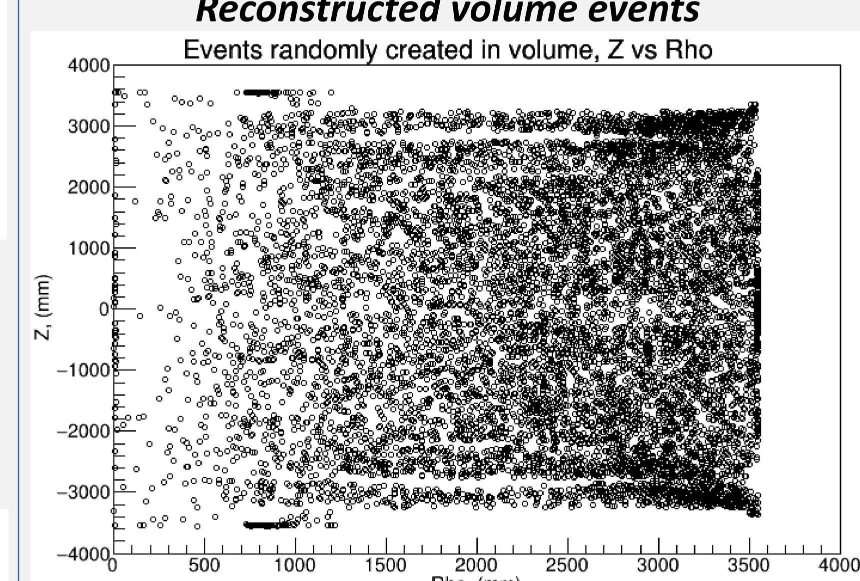
Reconstructed surface events



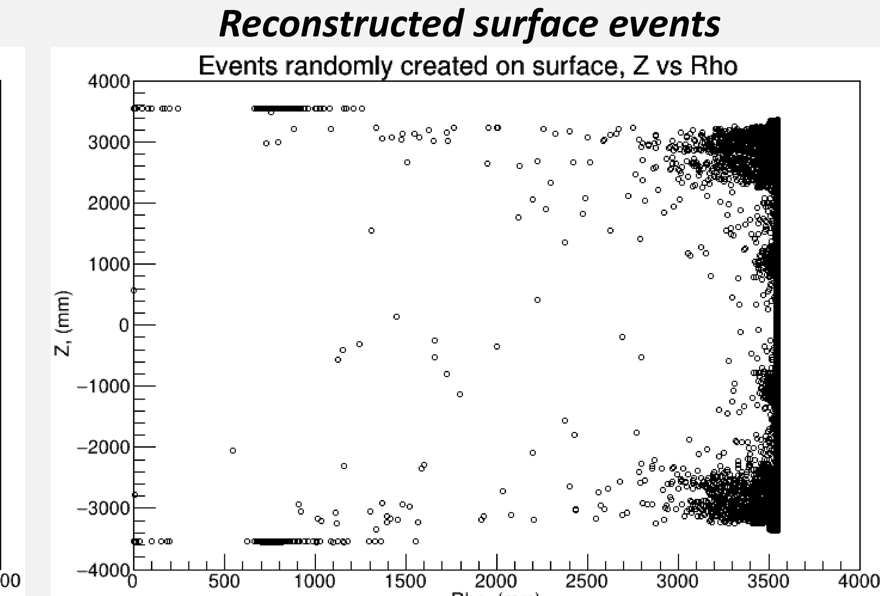
The time fitter needs some improvement due to observed misconstructions. Specifically, there are fewer events reconstructed in the middle of the detector compared to the surface, despite the events being uniformly created throughout the volume. Additionally, there are extra events reconstructed at the center while the events being created on the surface, indicating inaccuracies in the time fit.

RECONSTRUCTED EVENTS (CHARGE FITTER)

Reconstructed volume events



Reconstructed surface events



The charge fitter demonstrates reasonable reconstruction accuracy for events uniformly distributed within the volume, as opposed to the time fitter. However, there is a small area where no events are reconstructed. The charge fitter's performance is less optimal in reconstructing surface events compared to the time fitter. Specifically, fewer events are reconstructed at the top and bottom of the detector compared to the barrel surface, despite the uniform creation of events across the surface.

SUMMARY AND FURTHER WORK

Through MC simulations and utilizing time and charge fitting algorithms, we have reconstructed both surface and volume events in the ARGO detector. This work significantly contributes to ongoing efforts aimed at understanding the critical requirements for photon sensing and surface event rejection within the detector, which are crucial for detecting WIMPs. While our results demonstrate successful reconstructions, we have also observed some misconstructions with both the time and charge fitters. Moving forward, our focus will be on enhancing the accuracy of the reconstruction algorithms, particularly for surface events. We plan to incorporate machine learning techniques to further refine our reconstruction capabilities and to cross-check different algorithms, ensuring robustness in the reconstruction process. Additionally, our MC simulations will include more detailed modeling of Silicon Photomultiplier (SiPM) effects, such as external cross-talk.

REFERENCES

1. S. Cebrián, Review on dark matter searches, J. Phys. Conf. Ser. 2502 (2023) 012004.
2. S. Westerdale (on behalf of the DEAP and NEST collaborations), The DEAP-3600 liquid argon optical model and NEST updates (2023), arXiv:2312.07712