Electric Field Performance Evaluation of the nEXO Detector

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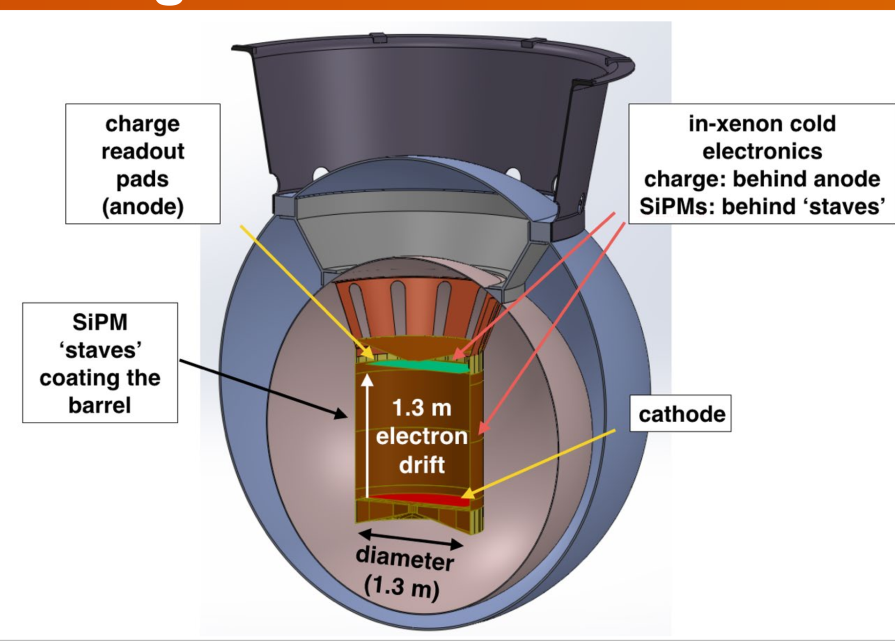
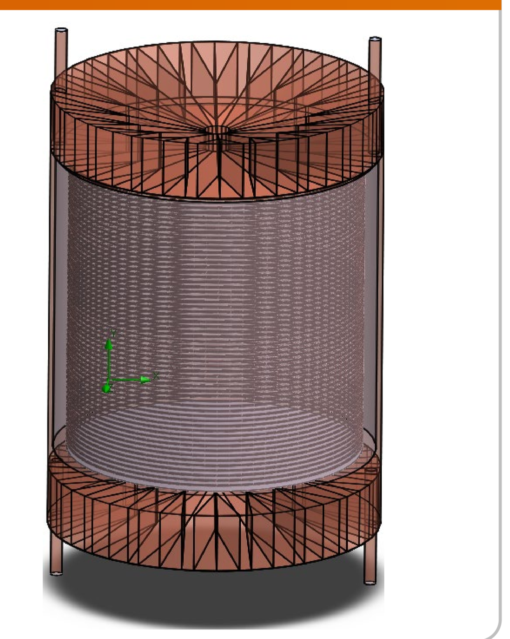
1. Motivation

- The next Enriched Xenon Observatory (nEXO) is a proposed experiment to search for the rare "neutrino-less double beta decay" (0vBB) process of Xenon-136.
- The observation of 0vBB decay would demonstrate lepton number violation and confirm that the neutrino is a Majorana fermion, where neutrino is its own antiparticle.
- This would impact our understanding of neutrino mass generation mechanisms and the origin of the matter-antimatter asymmetry in the universe.
- Since the event is so rare, the goal of this project is to analyze the characteristics and performance of the electric field within the TPC. The nEXO TPC is currently in the design phase and different TPC geometries will be studied and compared to optimize the electric field uniformity and charge collection efficiency to maximize the sensitivity of the experiment.

2. TPC Design

- The time projection chamber (TPC) is filled with 5kg of 90% enriched liquid Xenon (LXe), which serve as both the decay isotope and detection medium.
- The anode are segmented into an array of charge collection tiles at ground potential and a negative high voltage cathode is located at the bottom.
- An electric field shaping copper rings (58 rings) connected in a chain to forming a high voltage field cage between the anode and the cathode. The field cage purpose is to achieve a uniform drift field, so that the drift electron trajectories deviate as little as possible.
- However, there are distortions of the electric field, which prevent full charge collection for events happen near the field cage.
- An array of UV-sensitive silicon photomultipliers (SiPMs) are arrange right behind the field shaping copper rings . When an event happen, the SiPMs will detects the photons from scintillation light and the electrons traversing the cylindrical TPC are drifting along the path of the electric field drifts will be detect at the anode. To analyze the particle trajectory and interaction, the cylindrical coordinates need to be collected.





3. Neutrinoless Double Beta Decay

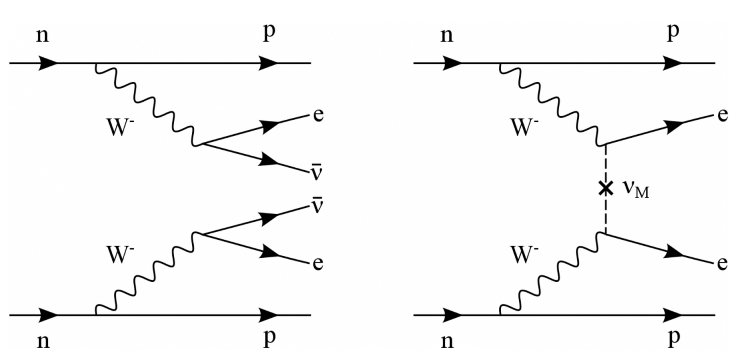
One of the most important open questions in neutrino physics is the question of whether neutrinos are Majorana or Dirac particles. For Dirac particles, which include most familiar kind, particles are distinct from anti-particles. For Majorana particles, on the other hand, particles and anti-particles are identical except for their helicities.

Attempts to detect the (possible) Majorana nature of neutrinos focus around the double beta decay process:

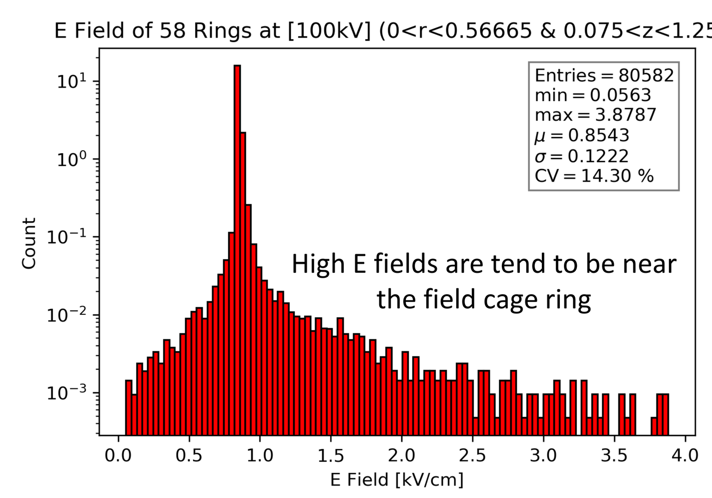
$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}e$$

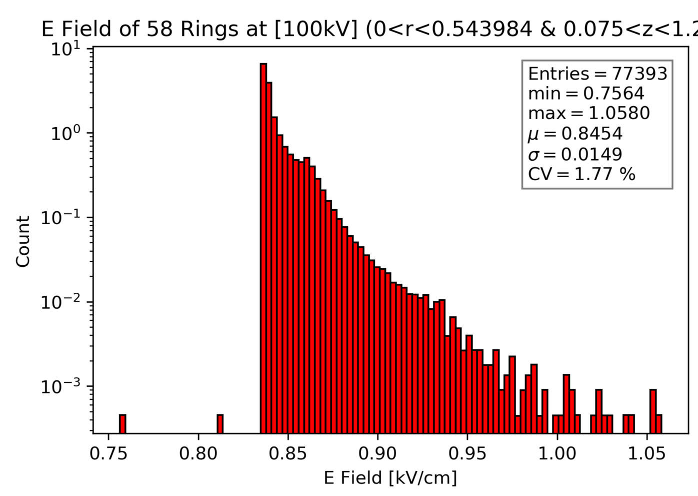
If neutrinos are Majorana particles, the anti-neutrino emitted by one of the neutrons can be absorbed as a neutrino by the other. The resulting process, in which no neutrinos are emitted, is neutrinoless double beta decay:

$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$



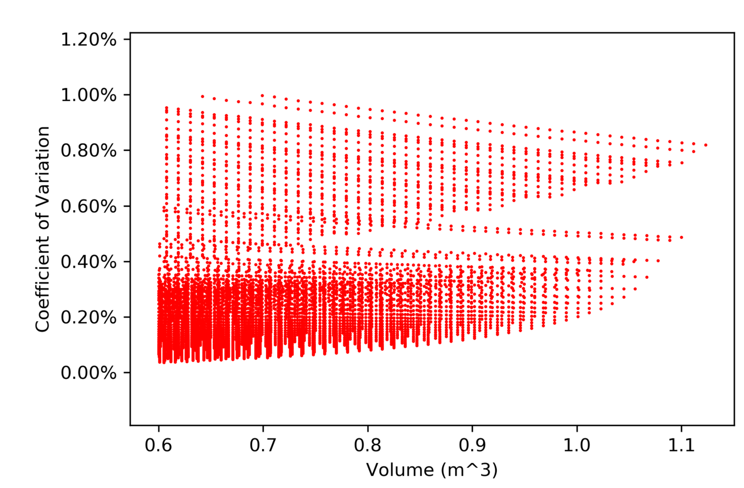
4. Electric Field Uniformity of the TPC





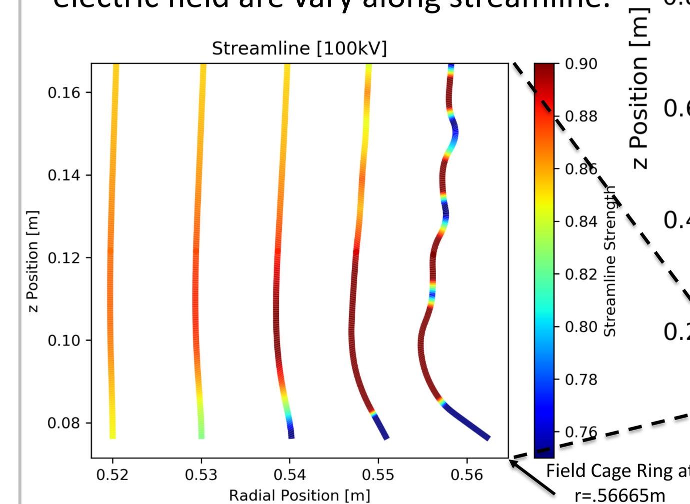
The electric fields uniformity improve moving toward the center of the TPC, where an ideal average E field is around 0.84531 kV/cm. To investigate what is the largest "fiducial" volume that will satisfy a given limit on the electric field uniformity, we generate more than 250,000 non-hollow cylinder within the TPC and calculate the coefficient of variation (CV).

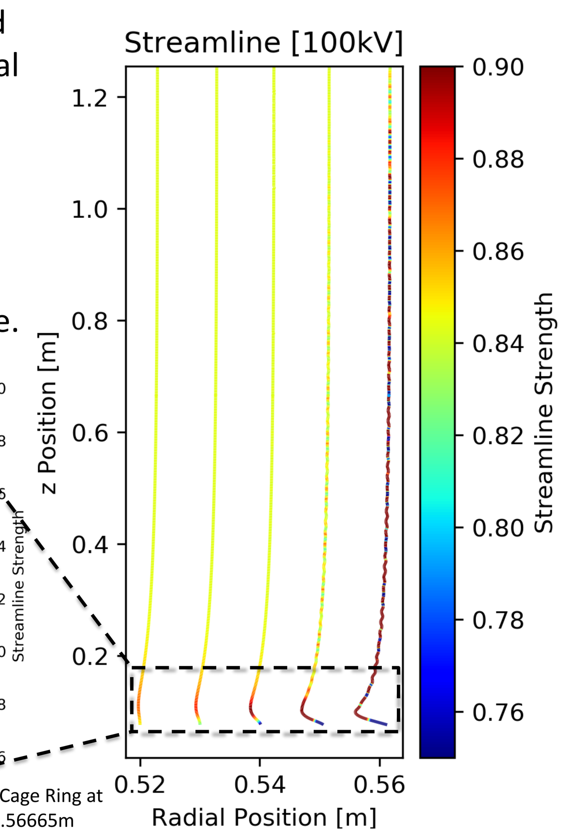
Desire CV	Volume(m^3)	CV	r_min(m)	r_max(m)	z_min(m)	z_max(m)
CV < 1%	1.12316	0.81 %	0	0.55531	0.09866	1.258
CV < .75%	1.09978	0.48 %	0	0.54398	0.075	1.258
CV < .5%	1.09978	0.48 %	0	0.54398	0.075	1.258
CV < .25%	1.03379	0.24 %	0	0.54398	0.14598	1.258



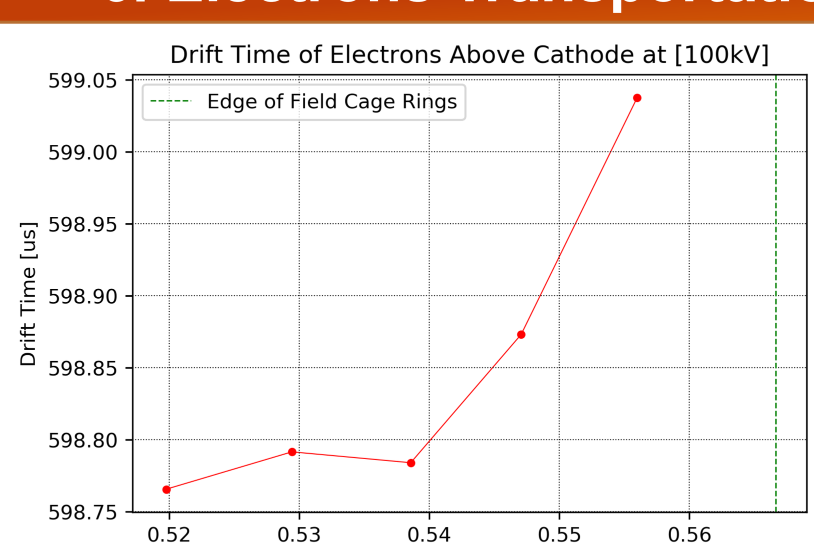
5. Streamline of Electric Field

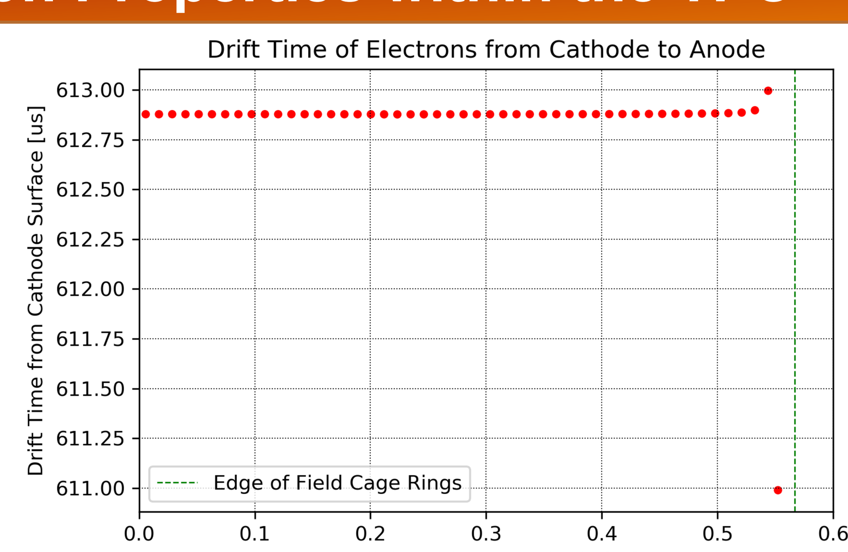
Electric field streamlines are distorted near the field cage rings, causing radial displacements at the anode and variations in drift time. The length of the last streamline are longer comparing to other streamline. Furthermore, the magnitude of the electric field are vary along streamline.

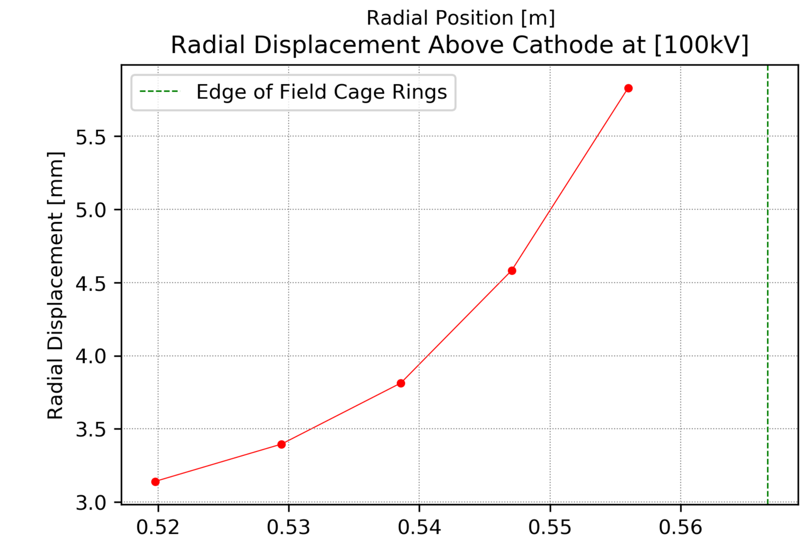


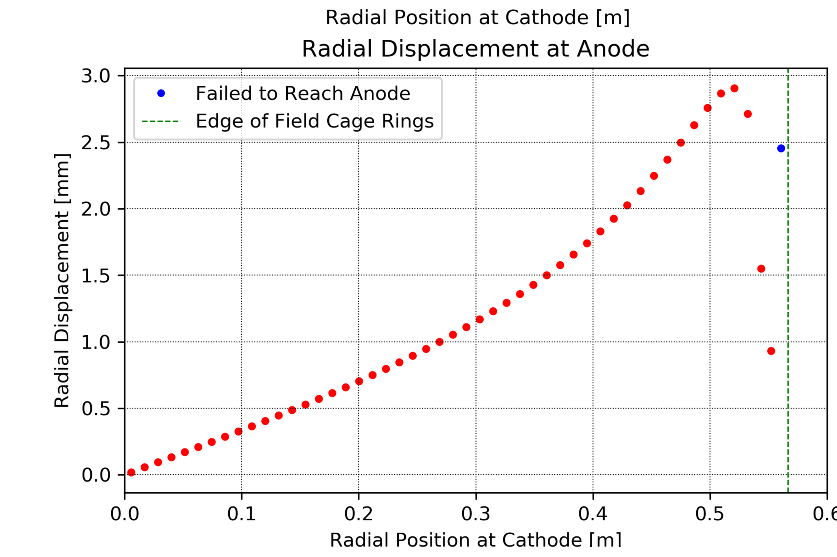


6. Electrons Transportation Properties within the TPC





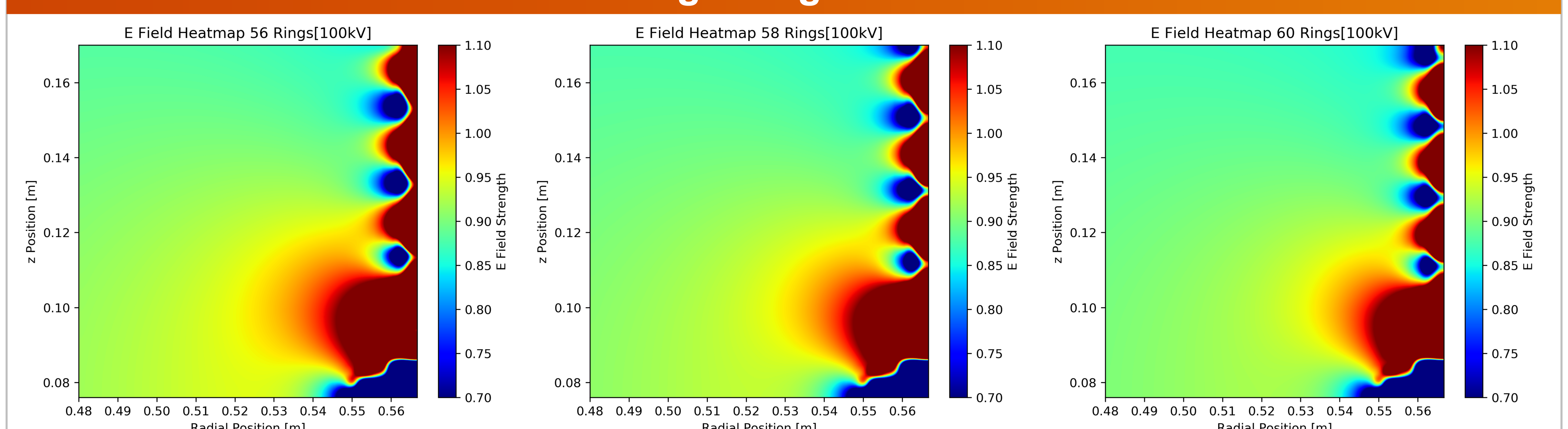


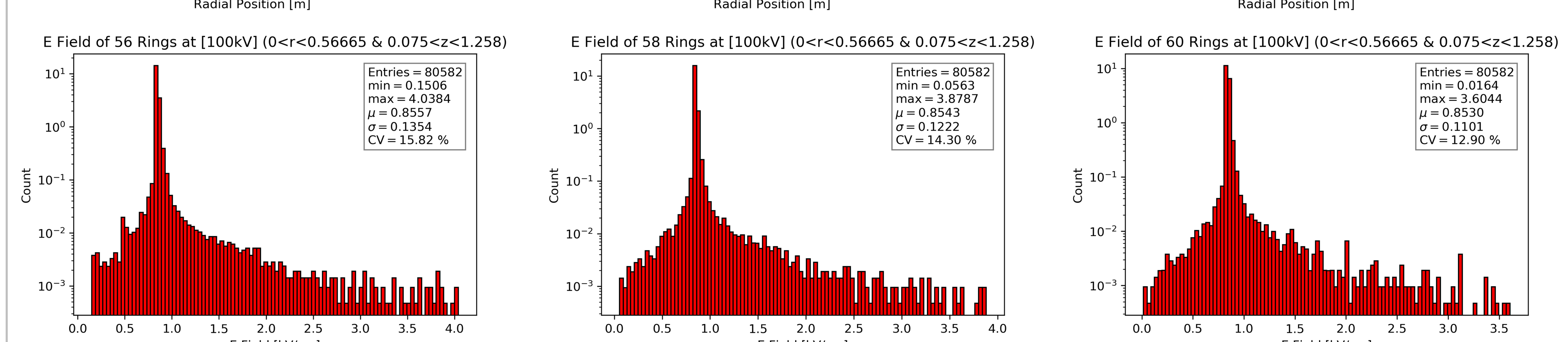


Since there are distortions of the electric field near the field cage, the wiggle and longer length causes a longer drift time to reach the anode.

The distortions of the electric field near the field cage also cause the electron paths at the anode to be radially displaced from their original starting position.

7. Field Cage Rings Modification





By analyzing the effect of adding or removing field rings on electric field uniformity, the coefficient of variation decreases as expected. However, the high number of rings would limit the efficiency of light collection by the UV-sensitive silicon photomultipliers (SiPMs) arrange right behind the field shaping copper rings. .

8. Conclusions

We quantitative studied different detector geometries and configurations, electron and ion drift patterns, and regions of poor charge collection. Our next step would be study of optimal number of field rings, including tracking maximum electric field values outside the active volume. Study the effect of surface charge build up on insulating reflective layers as part of Electric Field task force. Also, compare performance of 24-edge silicon field rings vs the original round copper rings

9. Acknowledgements

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