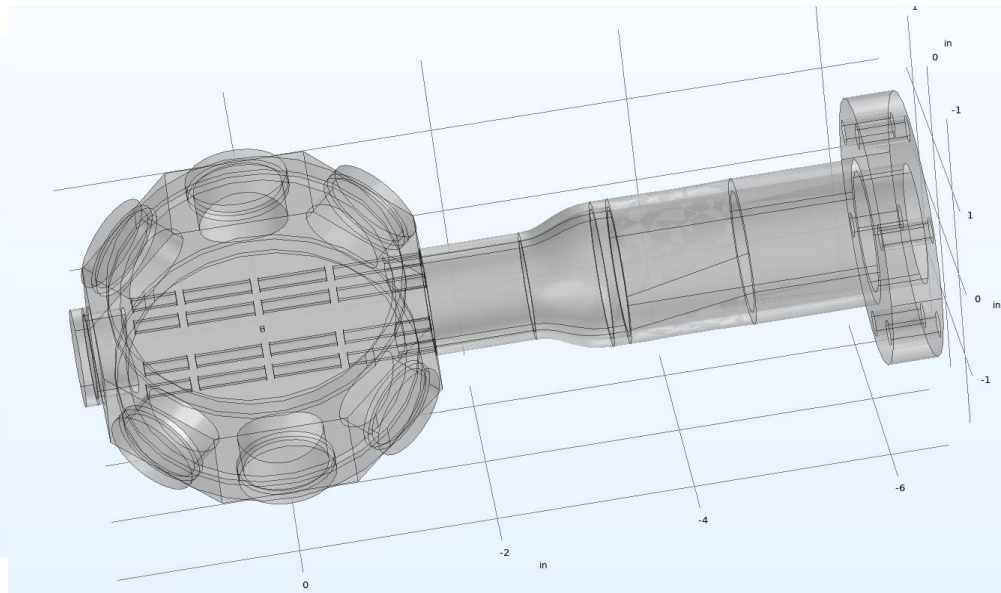
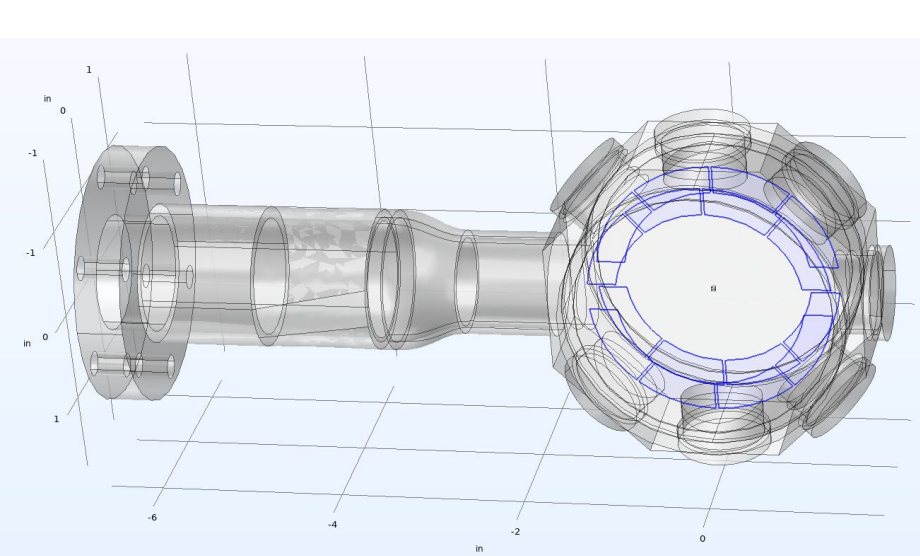
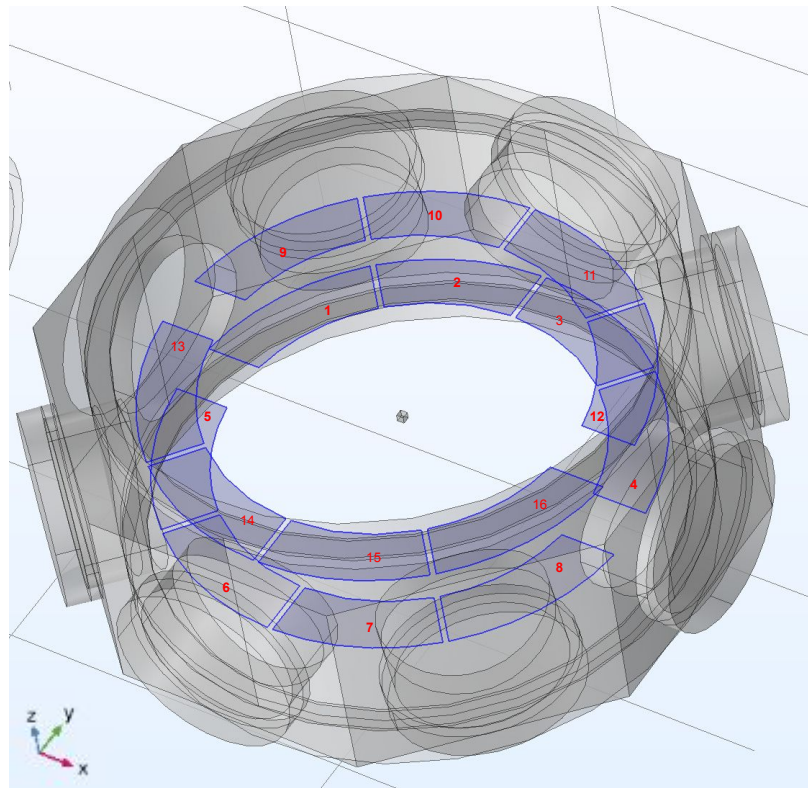
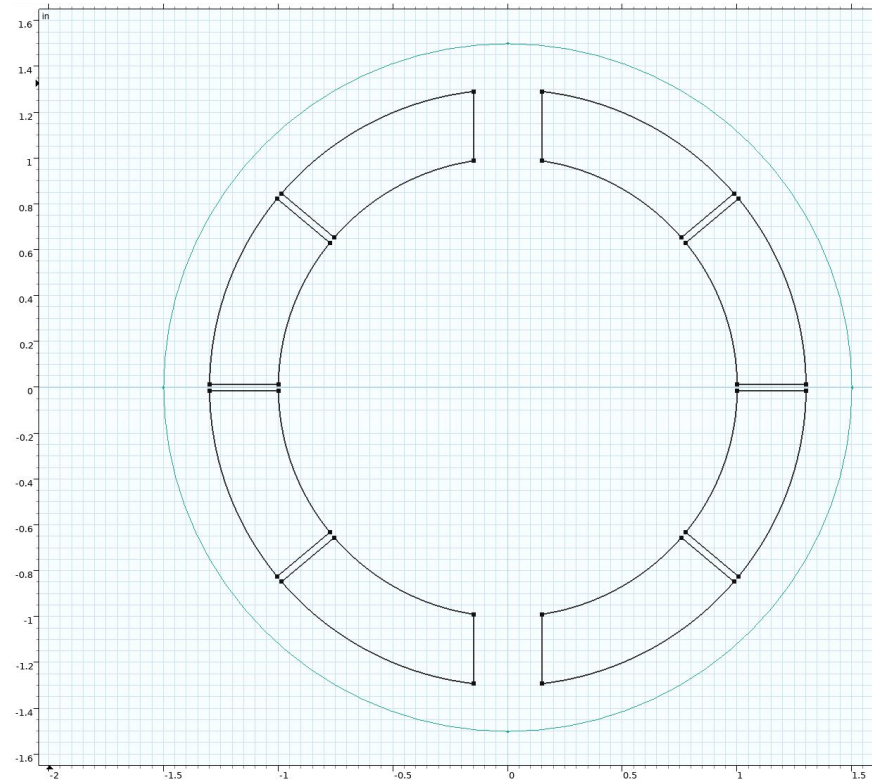


Science Chamber Electrode Simulation

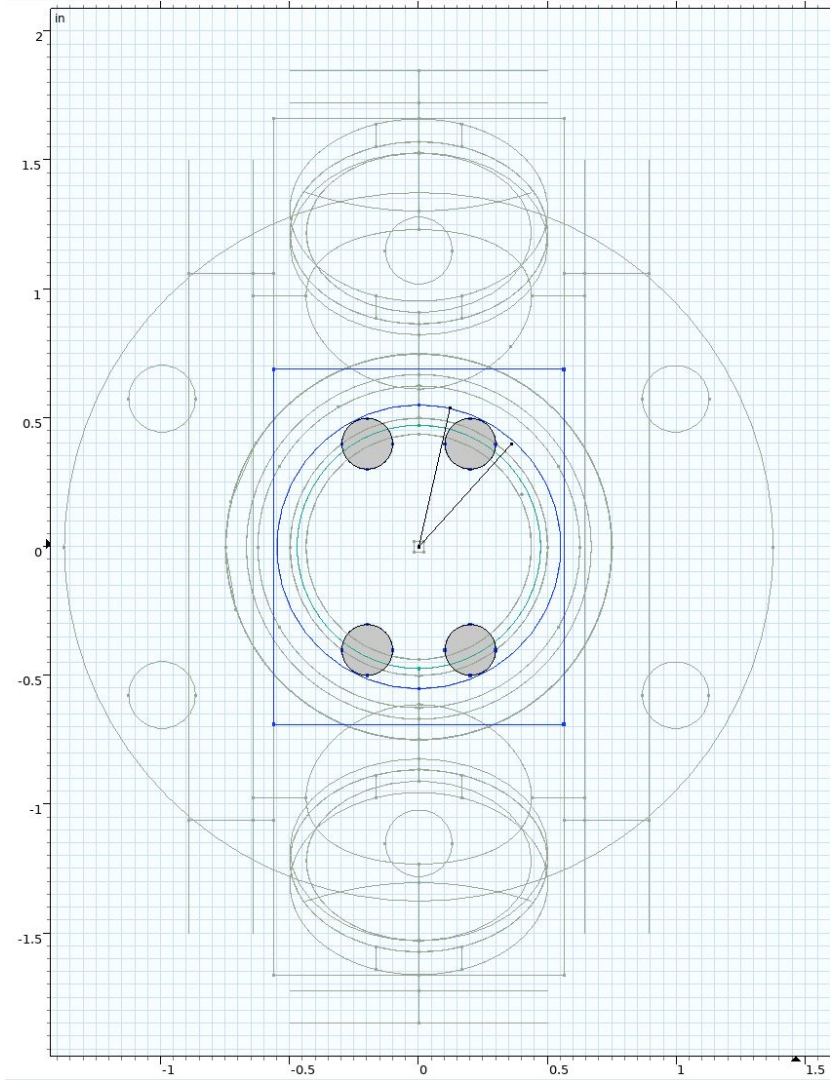
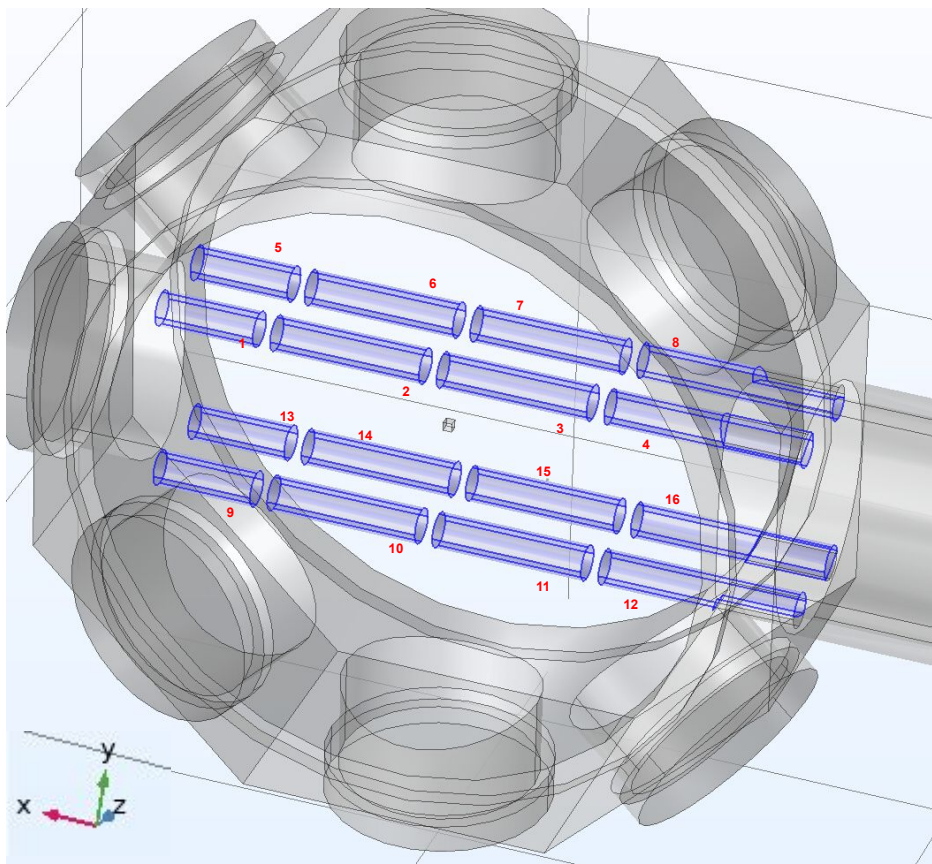
Cell designs



Disc design

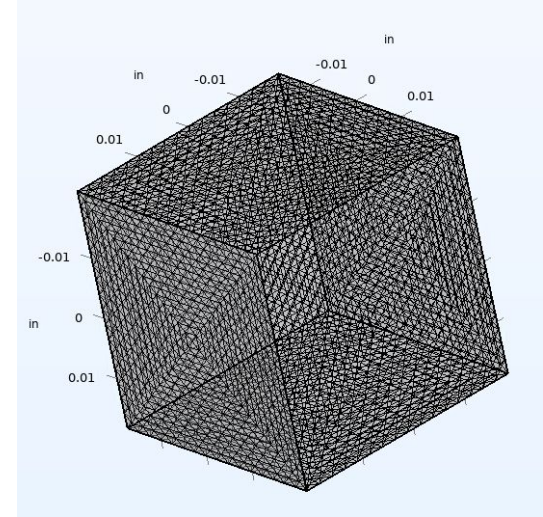


Cylinder design

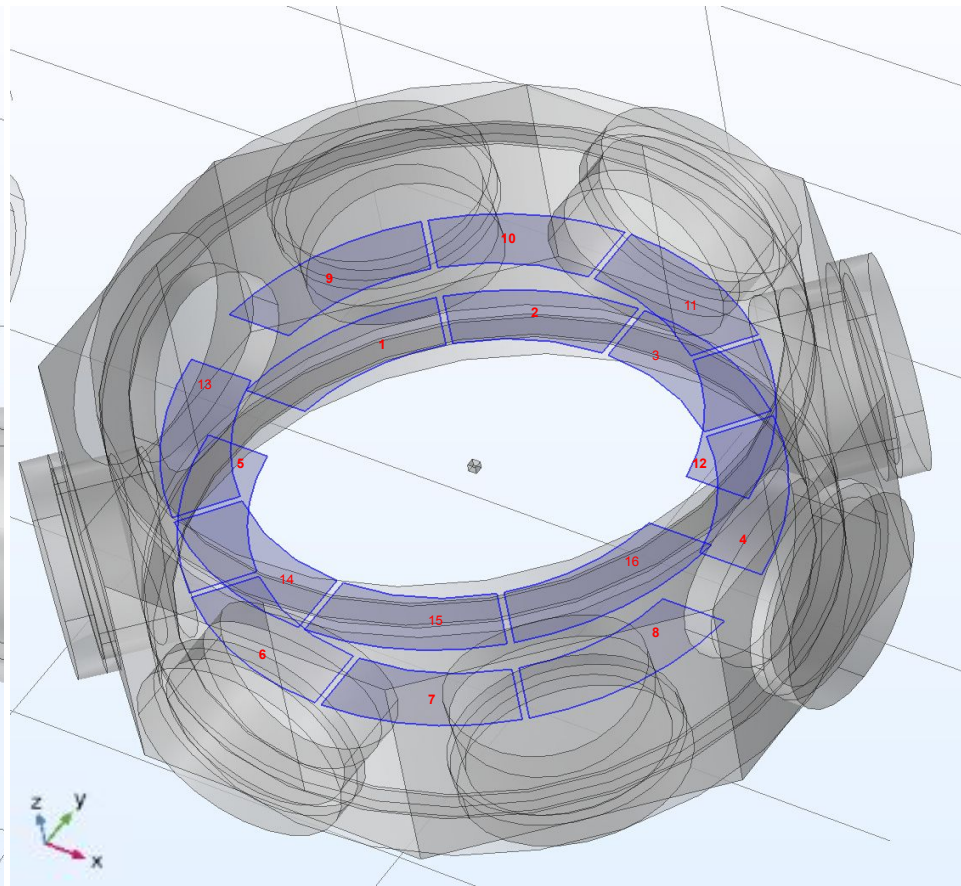
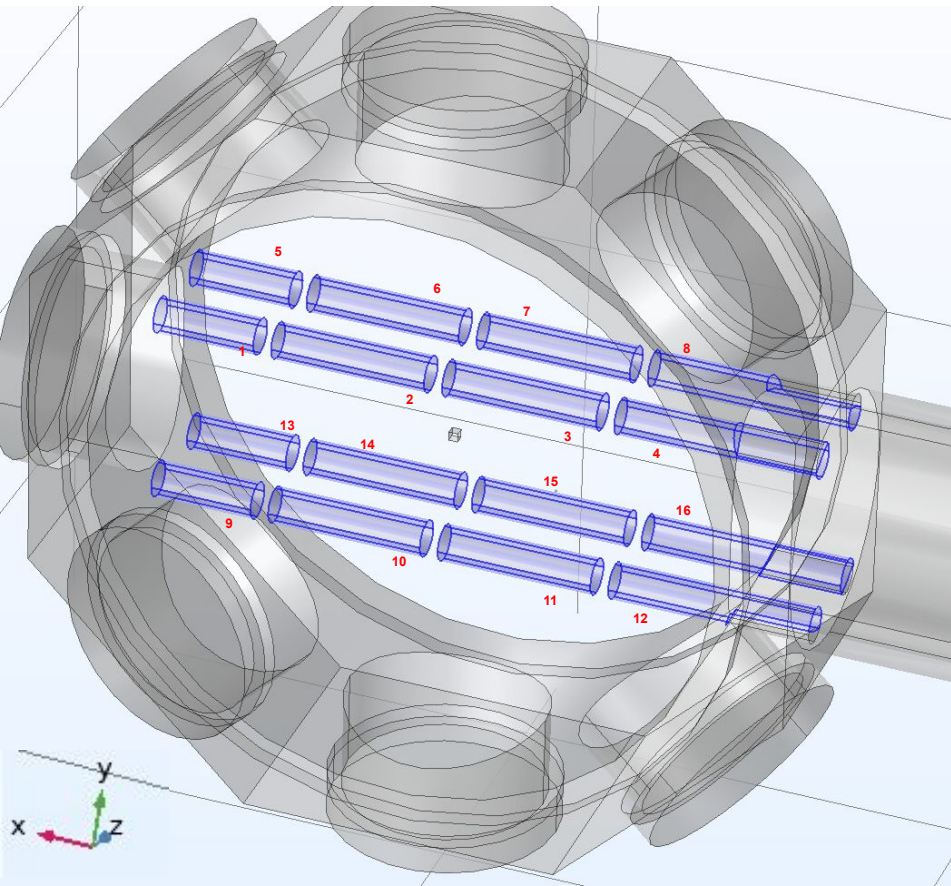


Modeling

- for each of 16 electrodes, put 1V and zero the rest
- record field distribution for $N=545$ points
- z-plane with (x, y) in $[-0.5, 0.5]$ mm
- Matrix $A[3, N, 16]$
 - $E_{\text{induced_x}} = A[0] V_{\text{electrodes}}$
 - $E_{\text{induced_y}} = A[1] V_{\text{electrodes}}$
 - $E_{\text{induced_z}} = A[2] V_{\text{electrodes}}$
- calculate target field based on noise model
- Least squares to obtain best fit
- minimizes electric field norm-squared averaged over each point
- Disclaimer: rounding error can lead to symmetry-breaking



Electrode labeling



Noise modeling

- Point charge on chamber boundary
- Chamber: radius 1.5in, height 1.25 in
 - $r=38.1\text{mm}$, $h=30.16\text{mm}$

```
# (x, y, z): coordinate to calculate field for (in mm)
# (tx, ty, tz): absolute position of the test charge, in millimeters
# returns: 3d field vector in V / m
def custom_field_function(x, y, z, tx, ty, tz):
    # Field strength is inversely proportional to the distance squared
    rsq = ((x - tx)**2 + (y - ty)**2 + (z - tz) ** 2)
    # Distance in meters
    r = rsq ** .5 * 1e-3
    # Field strength = 1 / (4\pi \epsilon_0 r) * q
    # Here q is in 1 pCoulomb
    strength = 1e-12 / (4 * np.pi * 8.854e-12 * r)
    return np.array([x - tx, y - ty, z - tz]) /rsq * strength
```



You

What are realistic charges for stray static charge which may build on the wall of an atomic experiment's chamber?



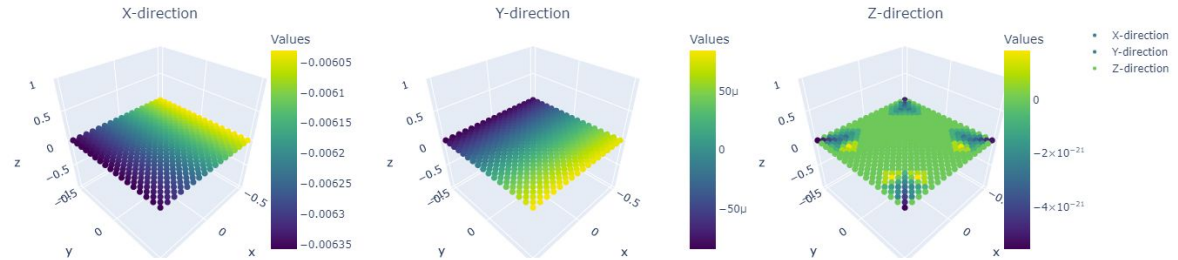
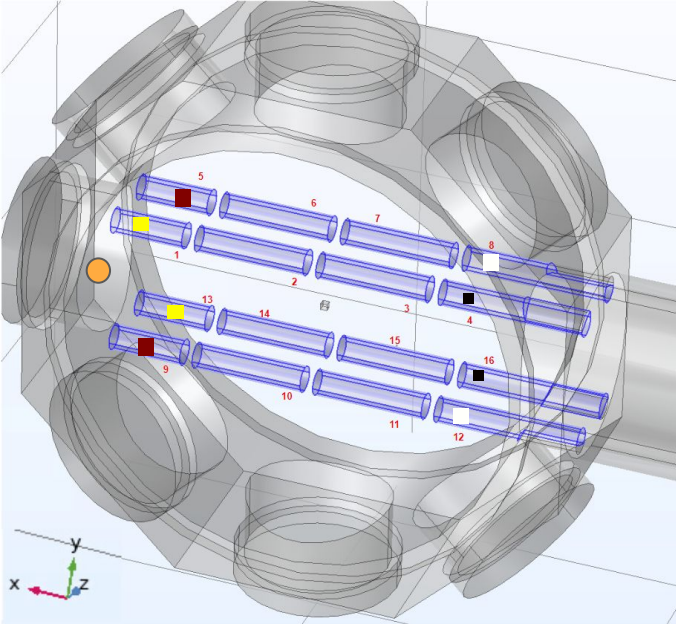
ChatGPT

In atomic physics experiments, especially those conducted in ultra-high vacuum conditions, the amount of stray static charge that can build up on the walls of a chamber is typically very small, often in the range of picocoulombs (pC) or even less. The exact amount can vary based on a number of factors, including the materials used, the level of insulation, environmental conditions, and the procedures followed during the experiment.

Static charges in such sensitive environments can be influenced by:

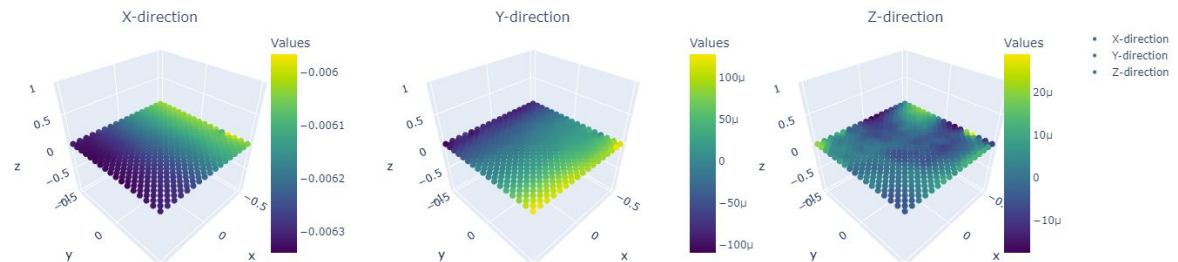
- **Contact electrification:** When different materials come into contact, they may exchange electrons, leading to a build-up of static charge.
- **Ionizing radiation:** This can cause the ionization of air molecules or materials in the chamber, leading to the accumulation of charge.
- **Triboelectric effects:** Movement of particles or gases within or across surfaces of the chamber can lead to charge generation.

Given the precision required in atomic experiments, even small charges like these can affect experimental results, which is why such environments are typically designed to minimize static charge accumulation through grounding, the use of conductive or antistatic materials, and controlling the humidity levels. The control of static electricity is also crucial to avoid any possible interference with the sensitive measurements or to prevent damage to the equipment.

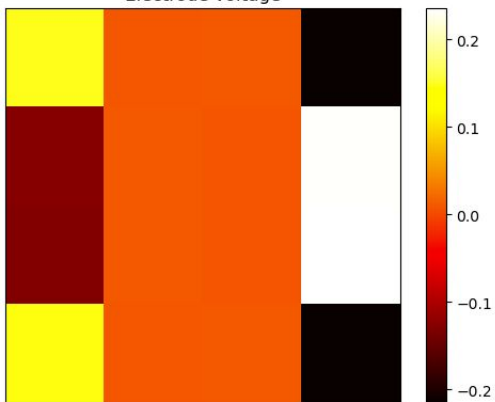


$(x, y, z) = (38.1, 0, 0)$

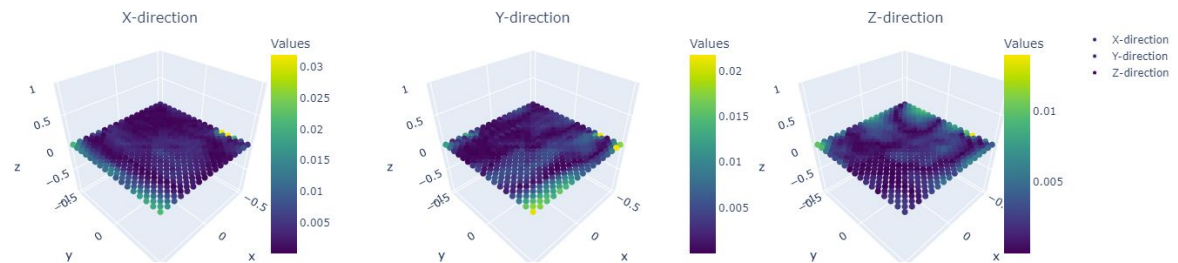
Field fit

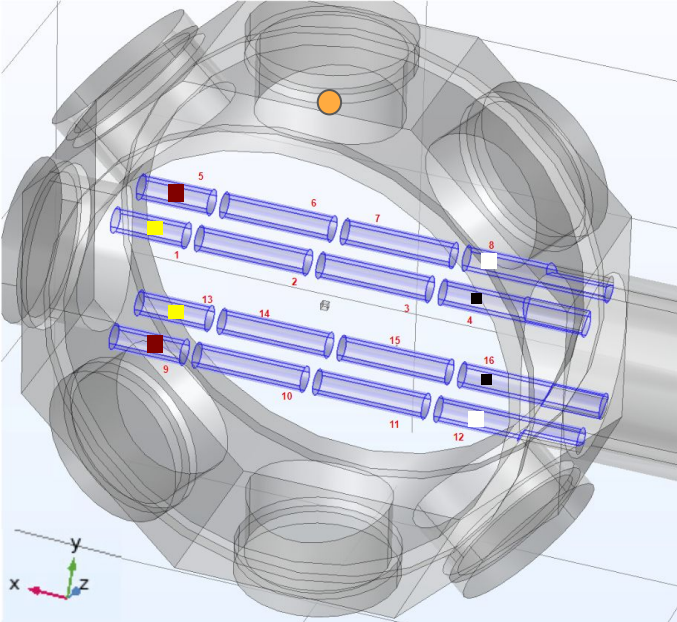


Electrode voltage

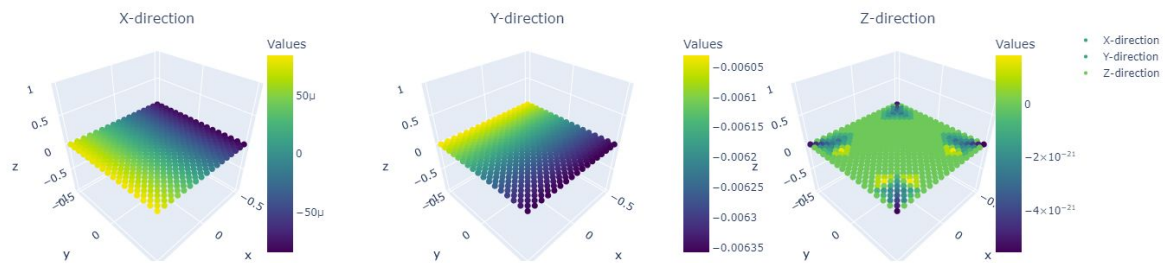
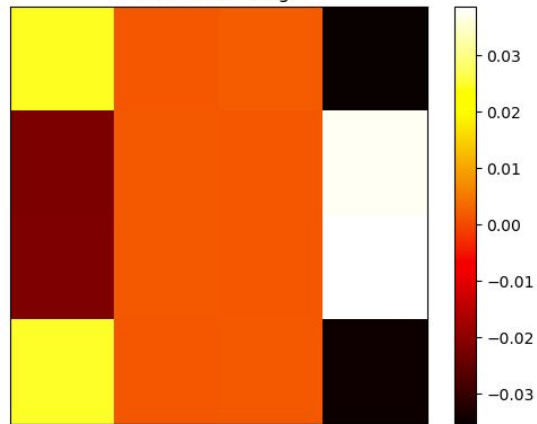


Absolute error



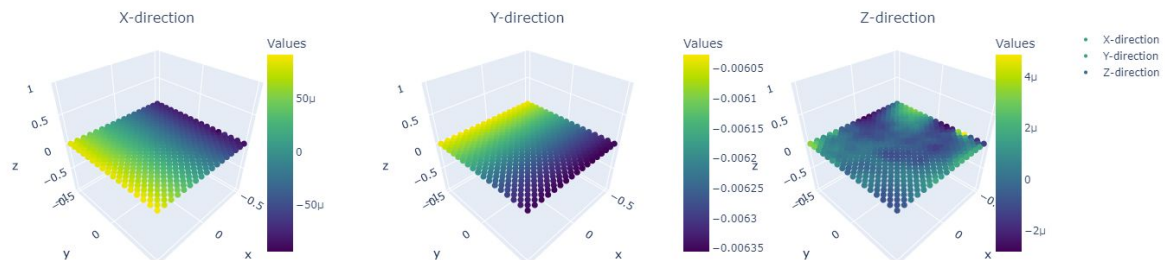


Electrode voltage

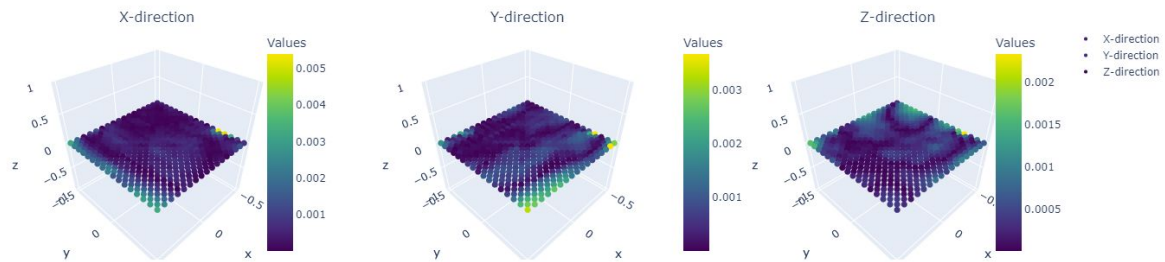


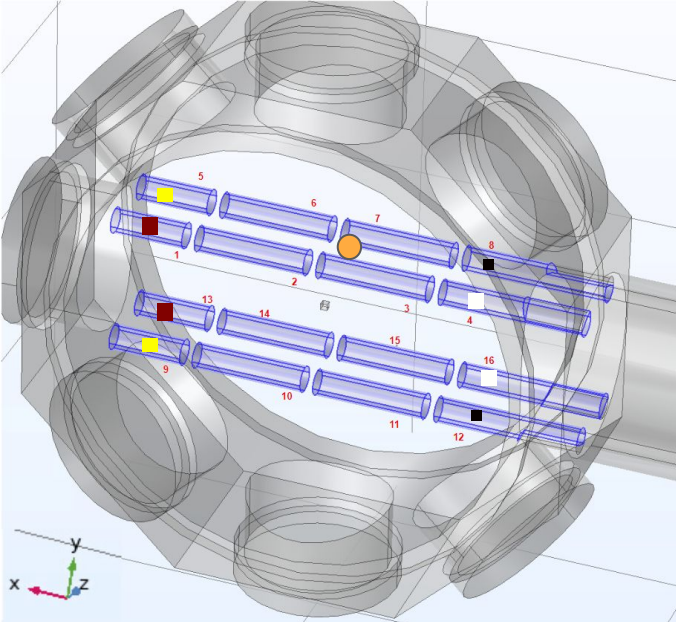
$$(x, y, z) = (0, 38.1, 0)$$

Field fit

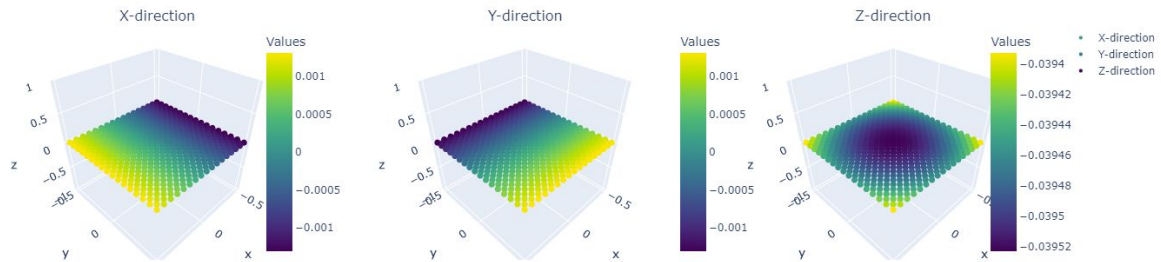
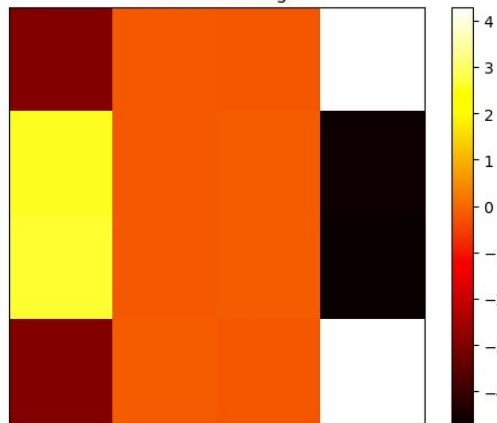


Absolute error



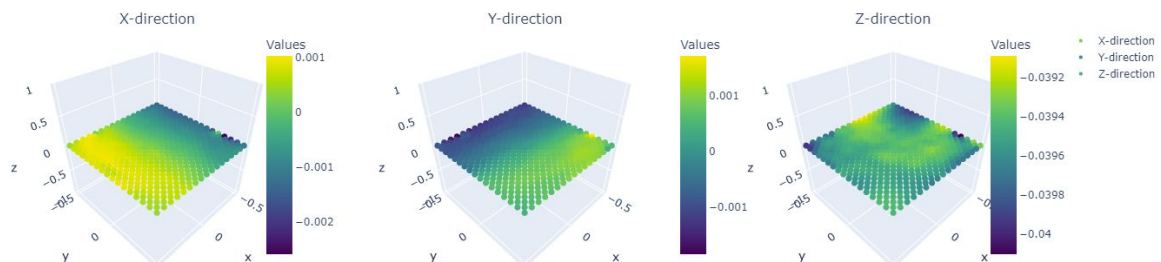


Electrode voltage

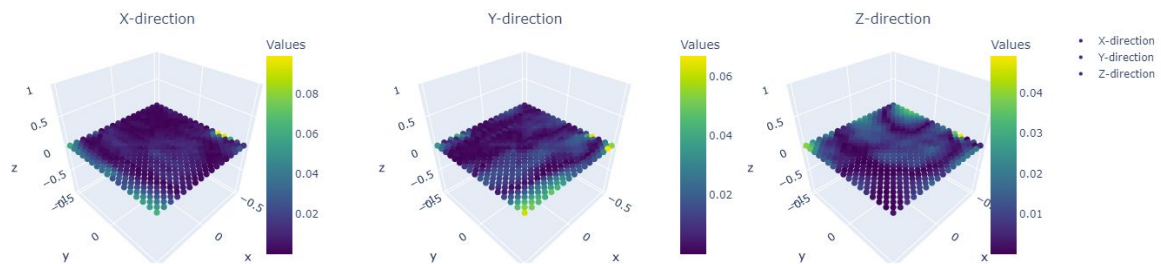


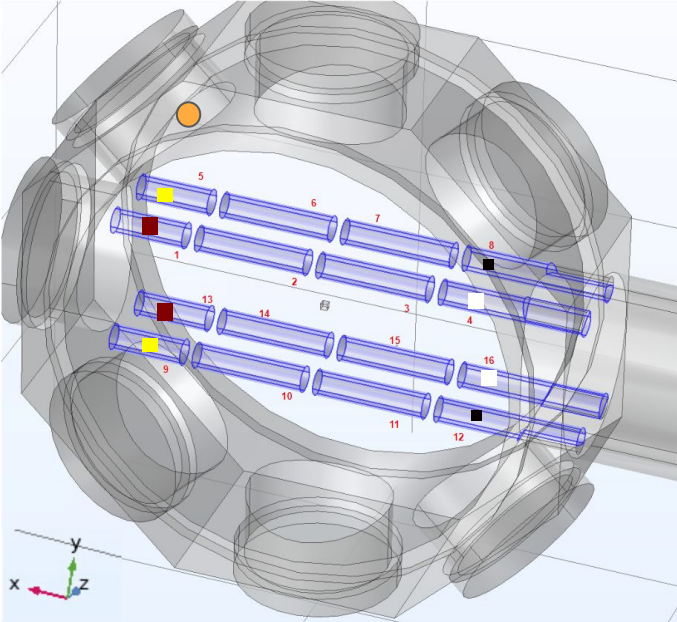
$(x, y, z) = (0, 0, 15.08)$

Field fit

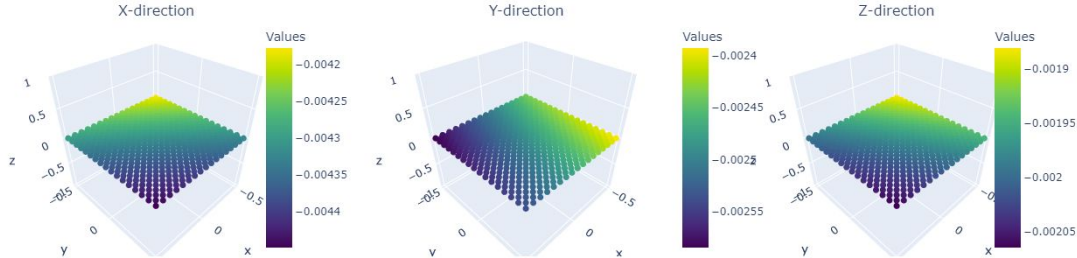
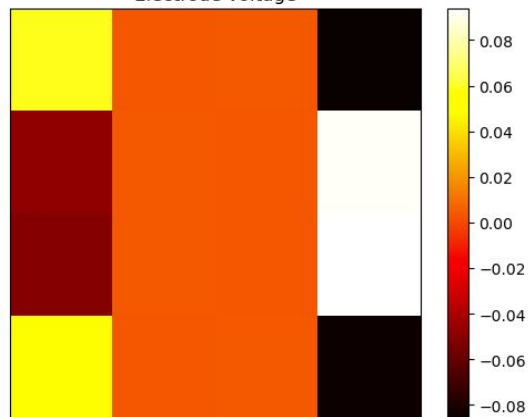


Absolute error



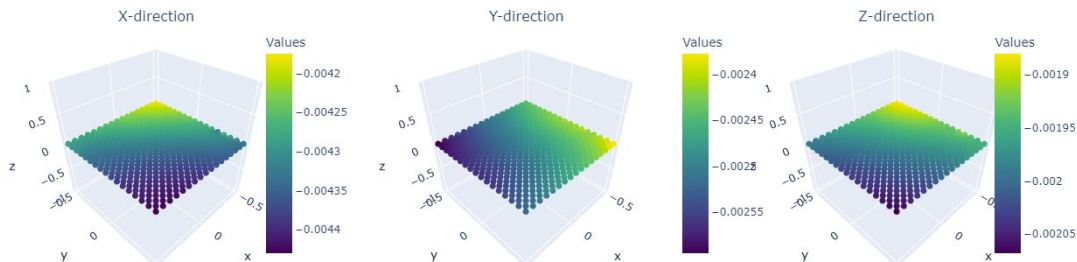


Electrode voltage

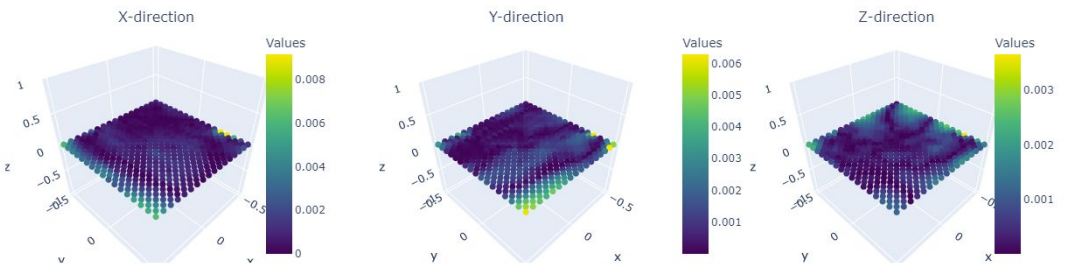


$(x, y, z) = (33, 19.05, 15.08)$ 30-degrees

Field fit

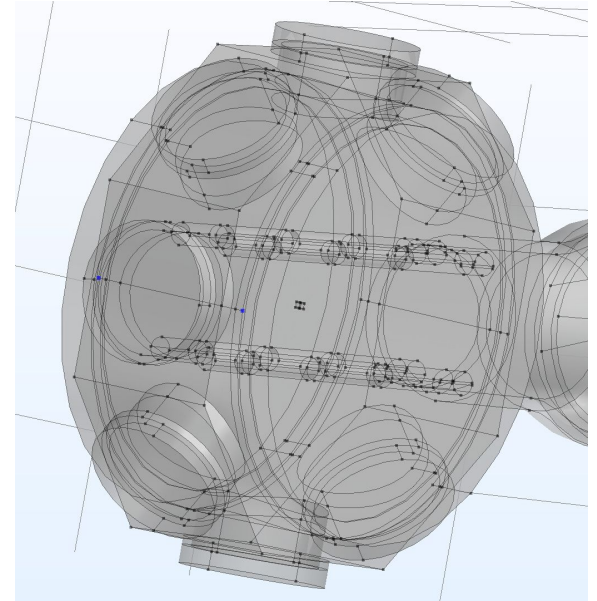


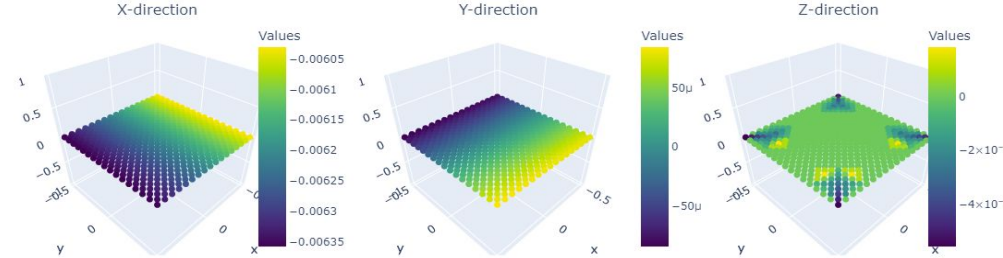
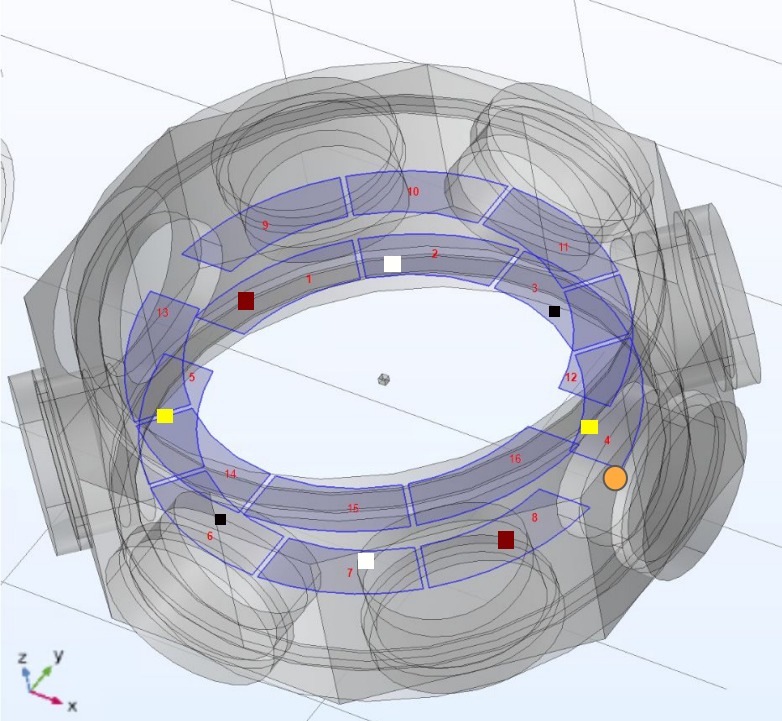
Absolute error



Cylinder takeaways

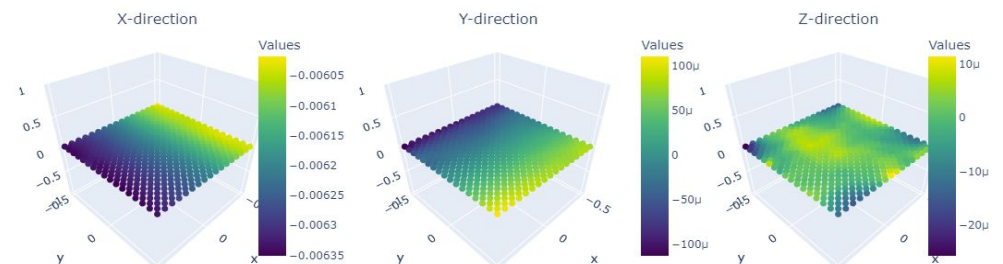
- Middle 8 electrodes are barely activated
 - Octupole configuration minimizes field deviation
- Voltage requirement: $z > x > y$



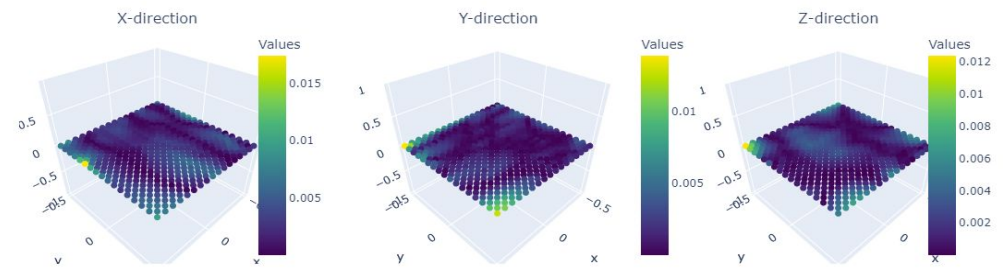


$(x, y, z) = (38.1, 0, 0)$

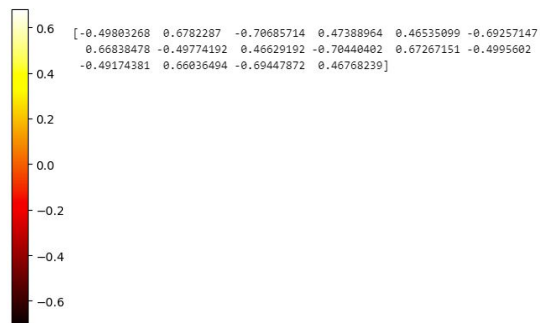
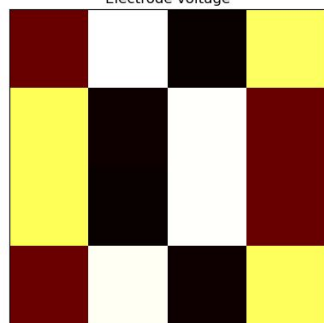
Field fit

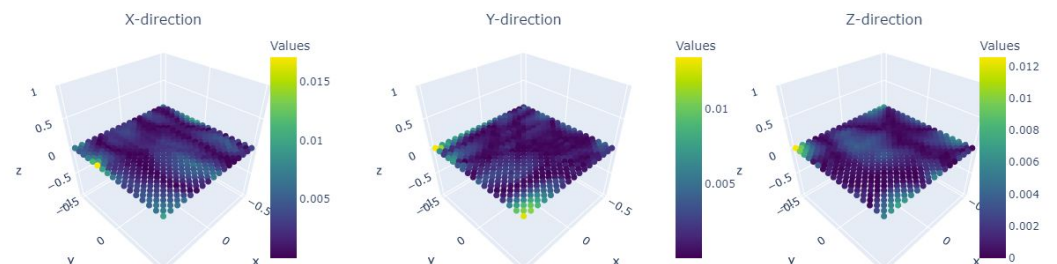
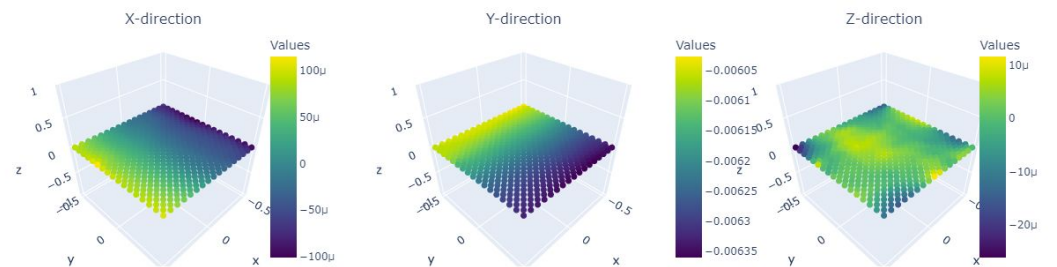
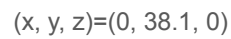
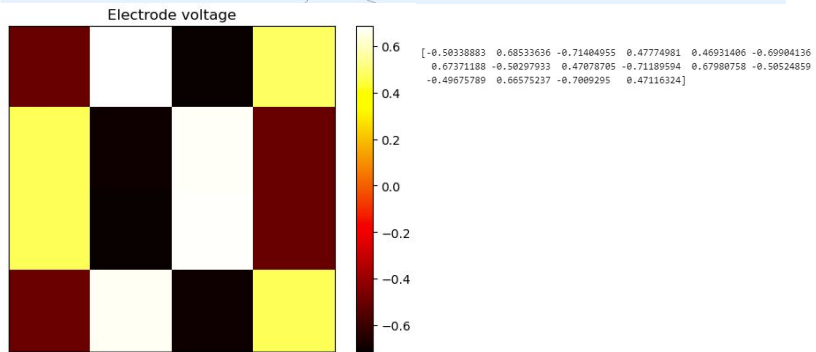


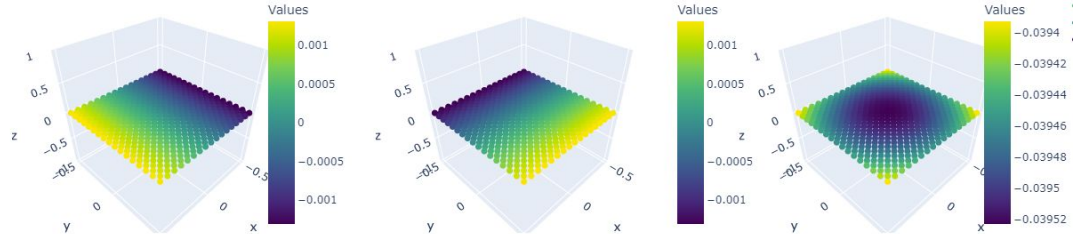
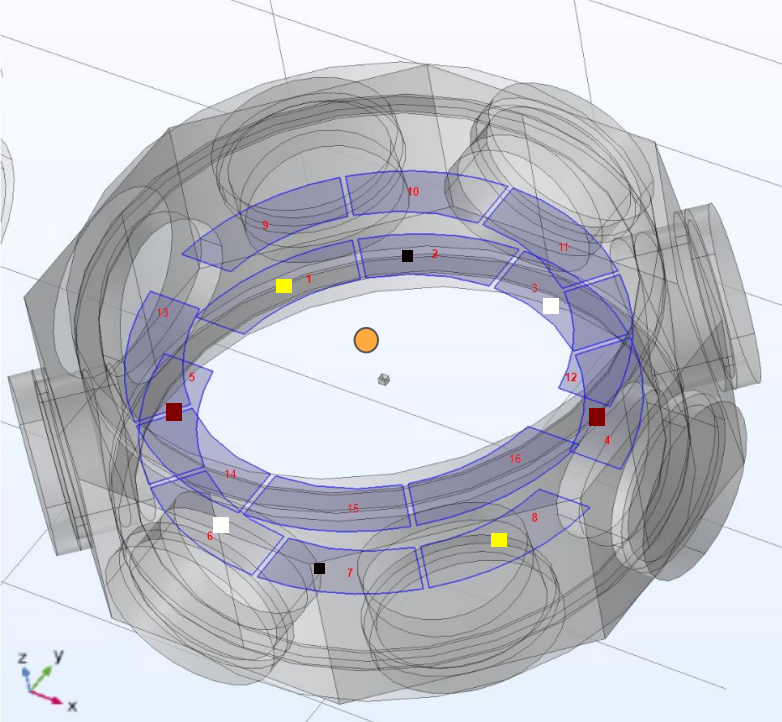
Absolute error



Electrode voltage

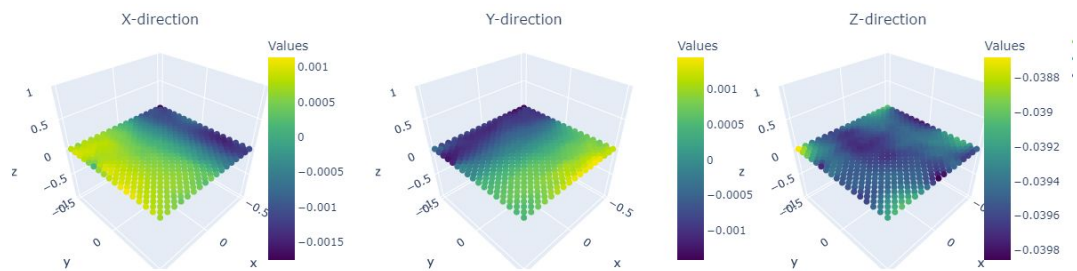




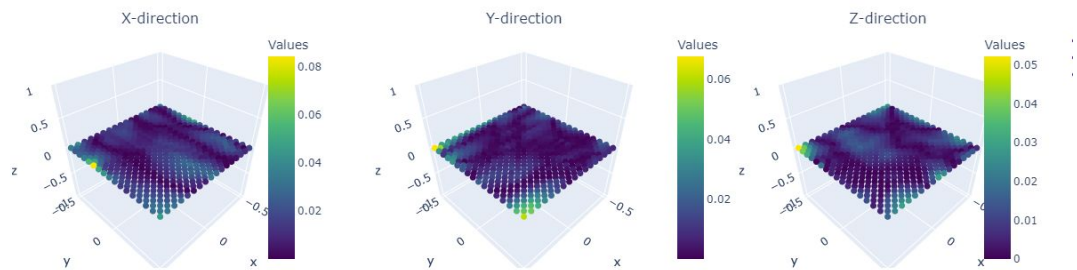


$(x, y, z) = (0, 38.1, 0)$

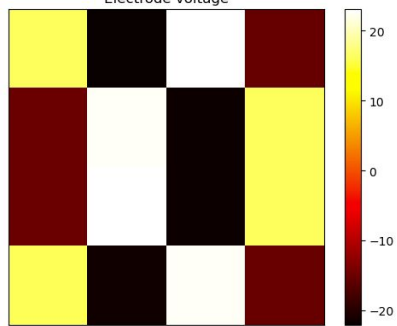
Field fit

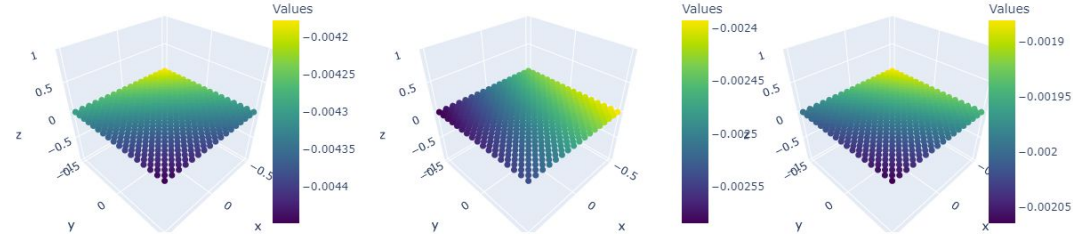
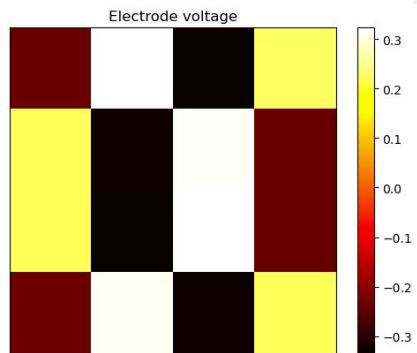
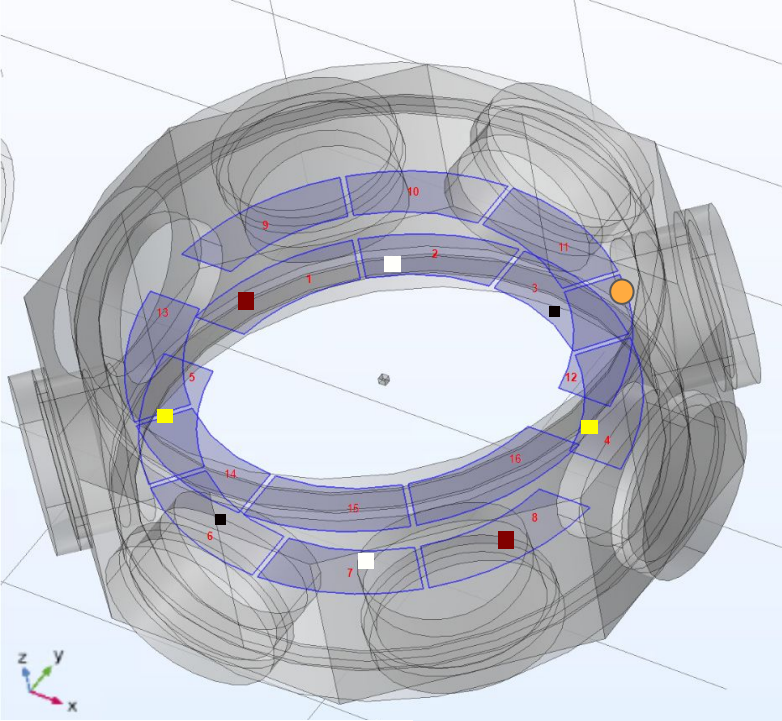


Absolute error



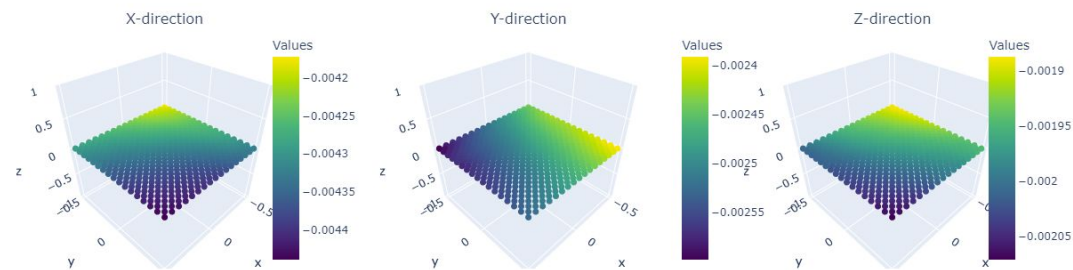
Electrode voltage



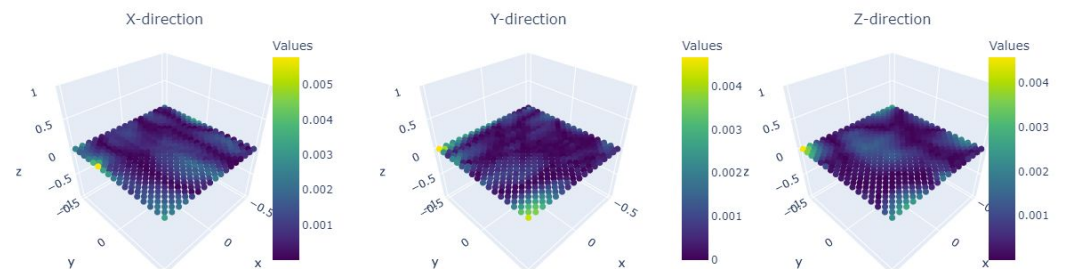


$(x, y, z)=(0, 38.1, 0)$ $(x, y, z)=(33, 19.05, 15.08)$ 30-degrees

Field fit



Absolute error

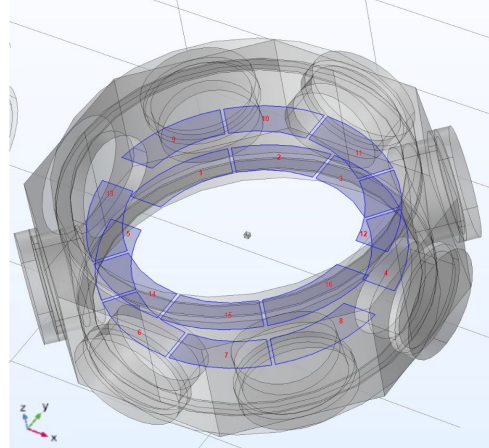


Disc takeaways

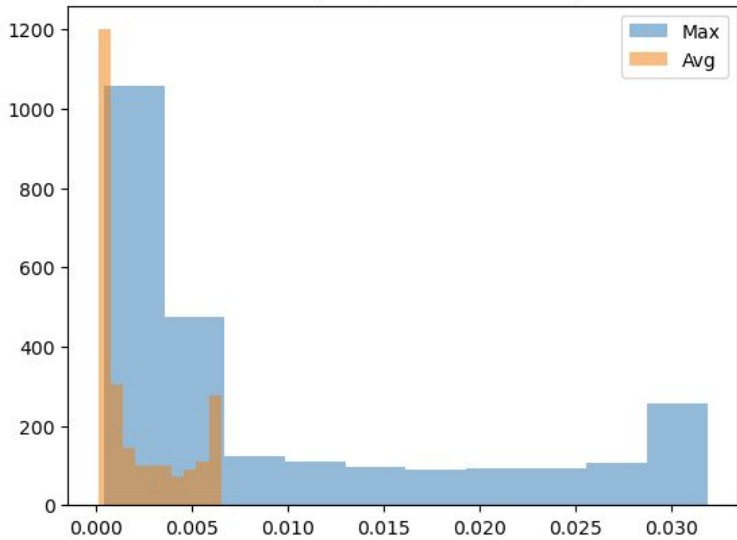
- 16 electrodes evenly activated
 - 16-pole configuration minimizes field deviation
- Voltage requirement: $z \gg x = y$
- More symmetry $x \sim y$, but larger voltage for z

Quantitative analysis

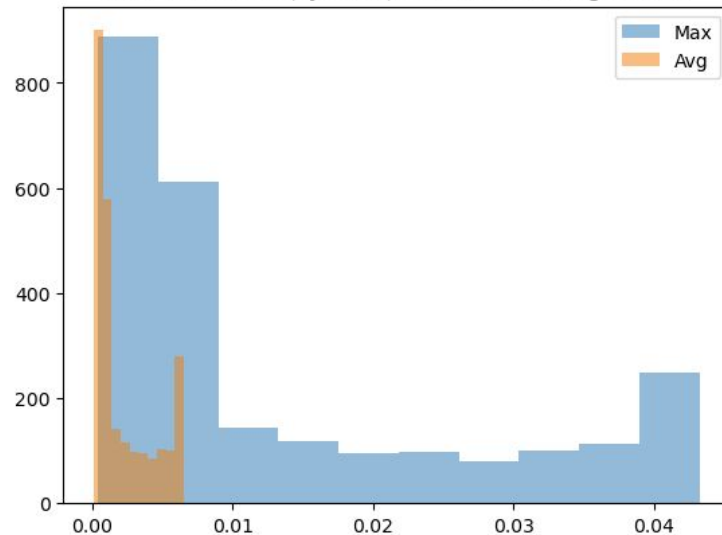
- Quarter-circle on chamber surface
- $|E_{\text{target}} - E_{\text{fit}}| / |E_{\text{target}}|. \text{mean}()$
- High-error cases are concentrated at $x=y=0$



Field norm ratio (disc): error / mean target norm

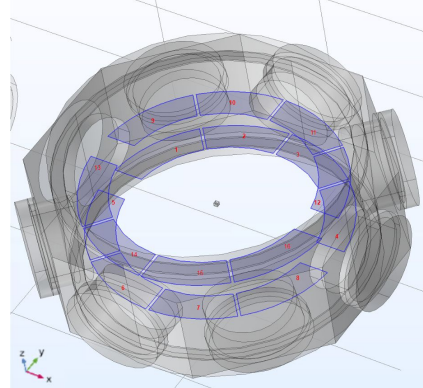


Field norm ratio (cylinder): error / mean target norm

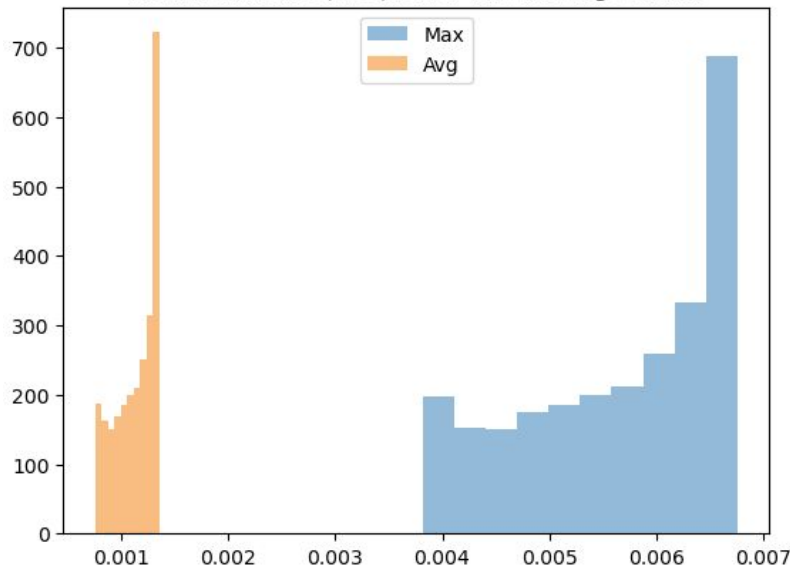


Quantitative analysis

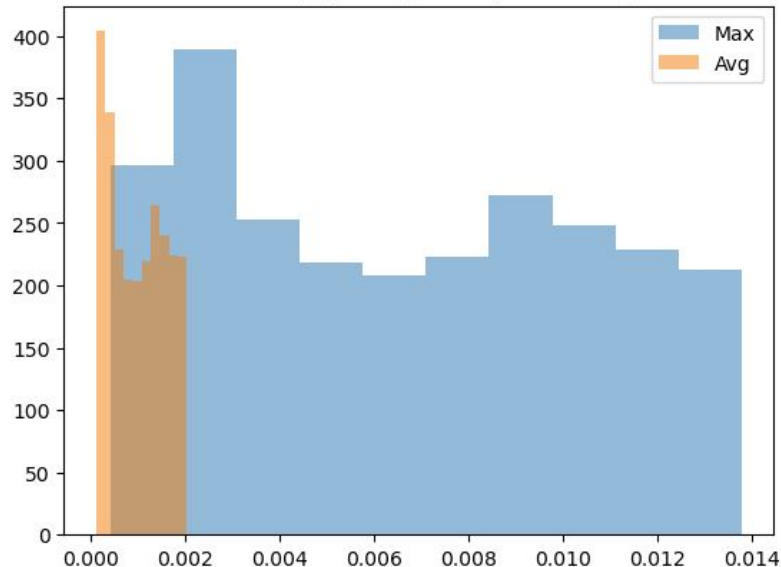
- Quarter-circle on side surface
- More uniform distribution of error
- Greater height, lower error (cylinder: ~perfect compensation for large theta)



Field norm ratio (disc): error / mean target norm



Field norm ratio (cylinder): error / mean target norm



Verdict?

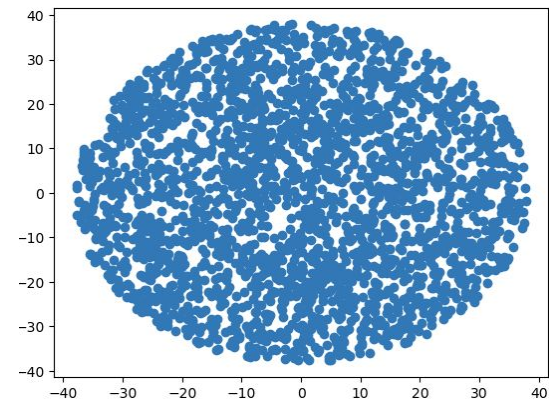
- Disc performs quantitatively better than cylinder
 - How much do we care about the margin?
- Disc > 16-cylinder \geq 8-cylinder

Electrode Simulation updates

11.12.23

New quantitative analysis

- Stray charge on the cylinder cap only
 - the other error region <10% error
- Avg of max: how the worst charge affects the plane
- Max of max: how the worst charge affects the worst position



Field (V/m) per 1 pC	Disc	16-rod	8-rod
Avg of avg	1.96e-5	1.99e-5	8.17e-5
Max of avg	2.54e-4	2.54e-4	9.86e-4
Avg of max	9.73e-5	1.32e-4	1.91e-4
Max of max	1.24e-3	1.70e-3	1.81e-3

