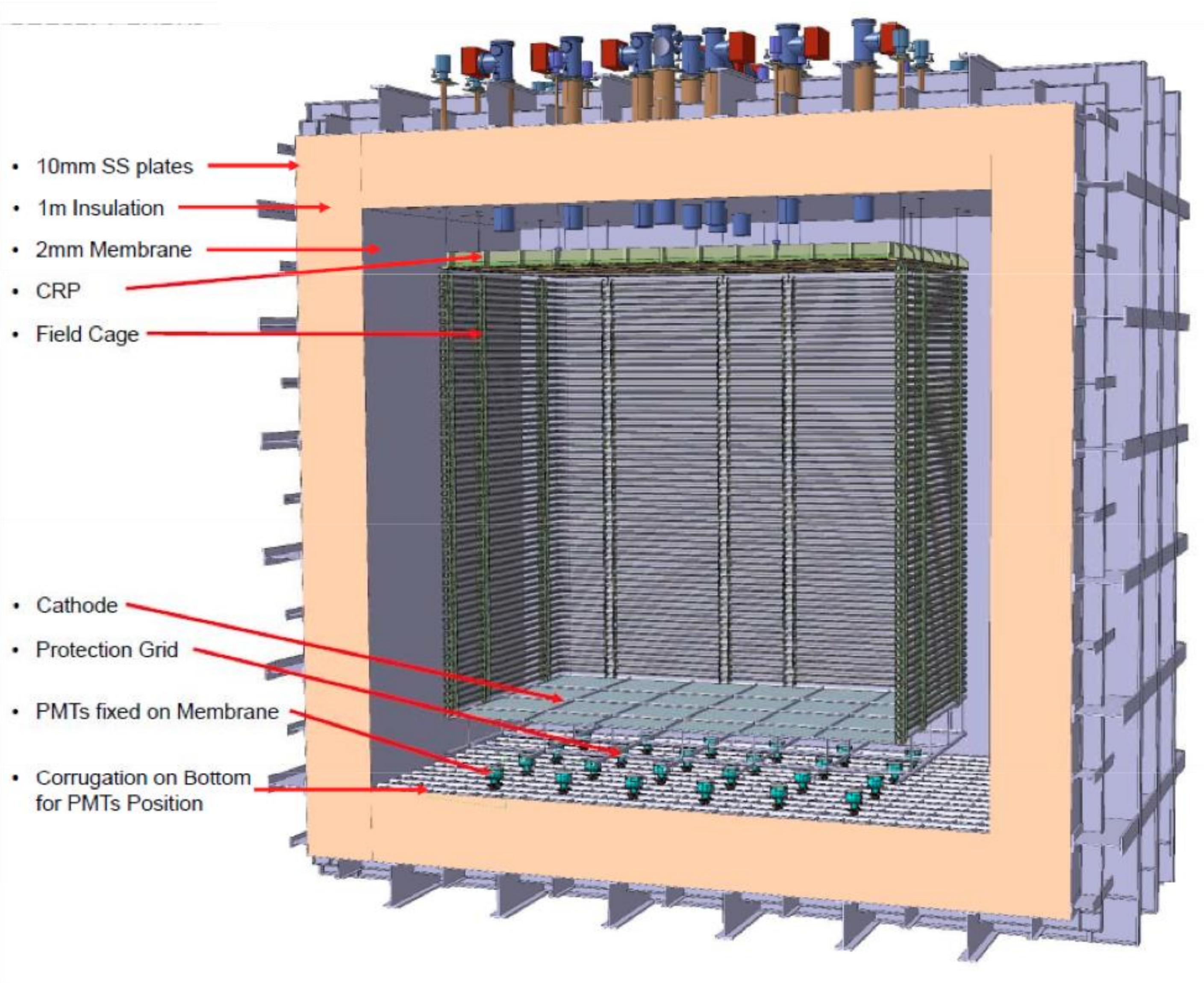
CATHODE DISCHARGE SIMULATION

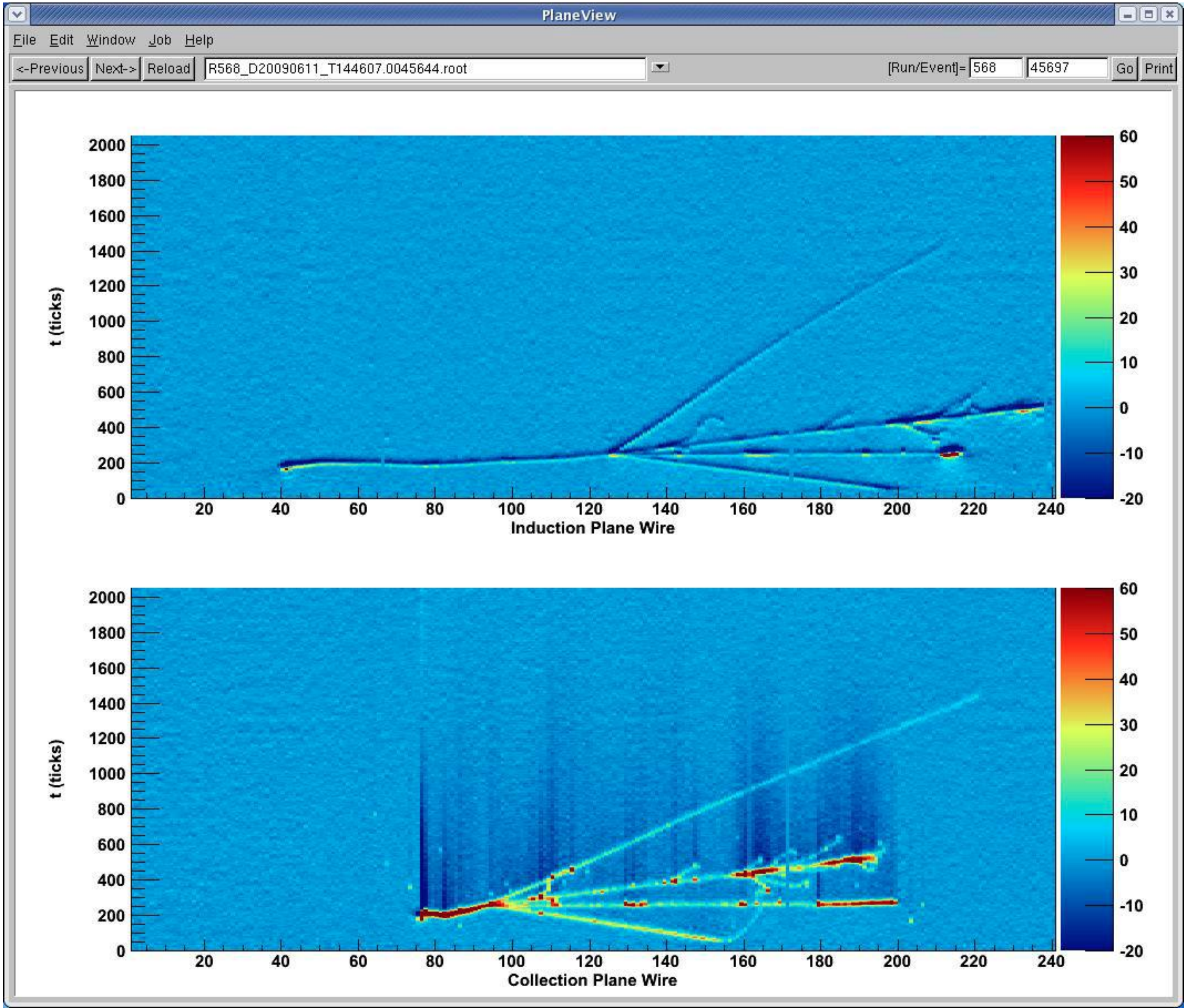
William Kyle
Dr. Glenn Horton-Smith

DUNE RECAP

It’s a Giant Capacitor

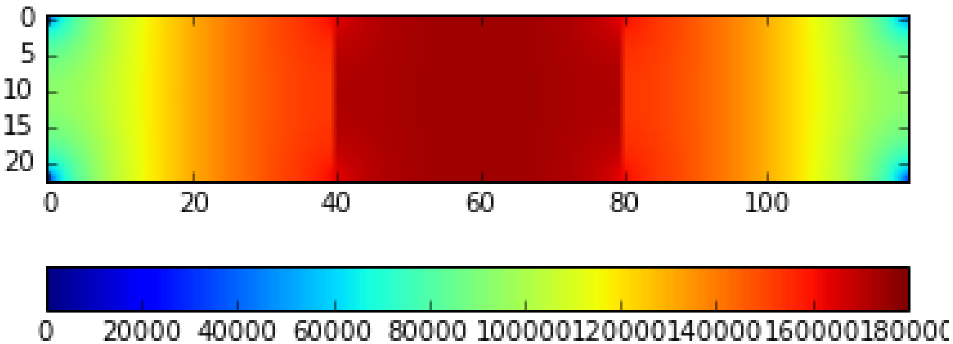


That Does Physics

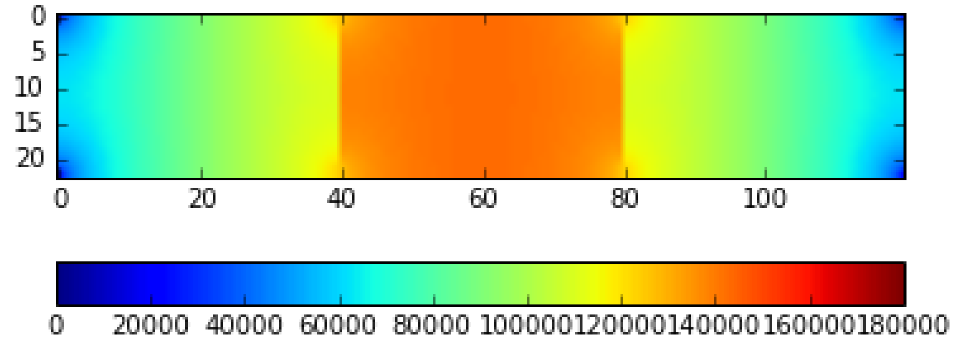


REVIEW OF CPA RESULTS

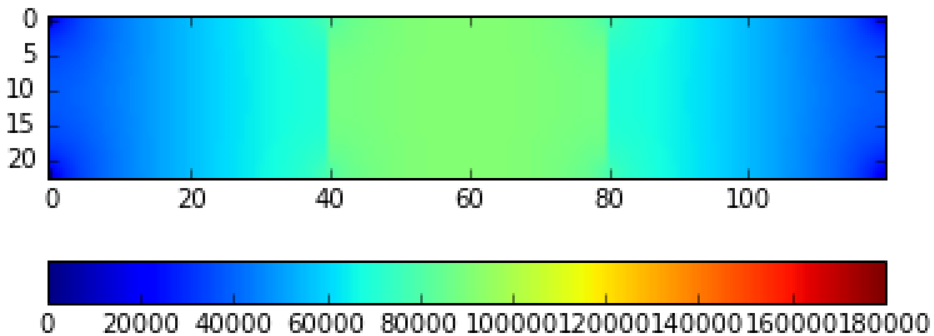
T = 40 us



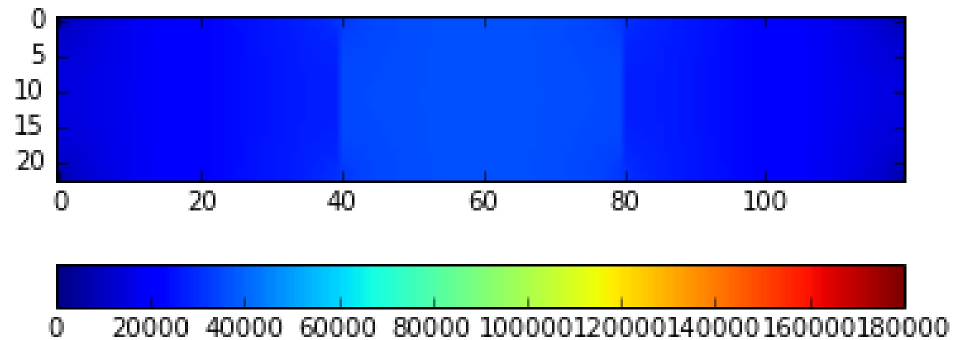
T = 100 us



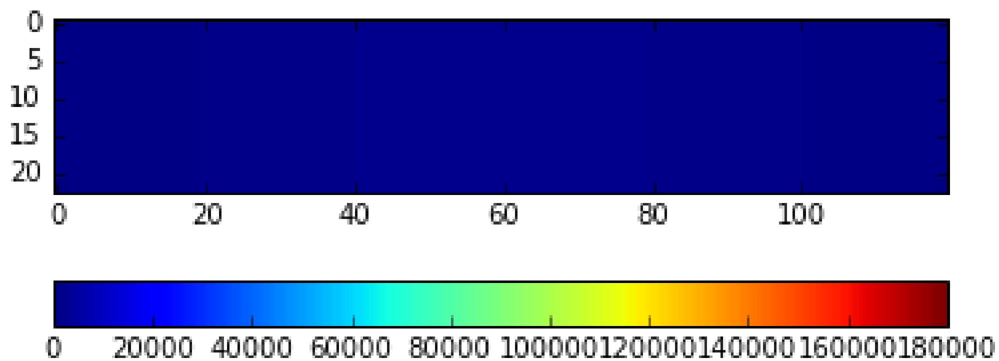
T = 200 us



T = 400 us

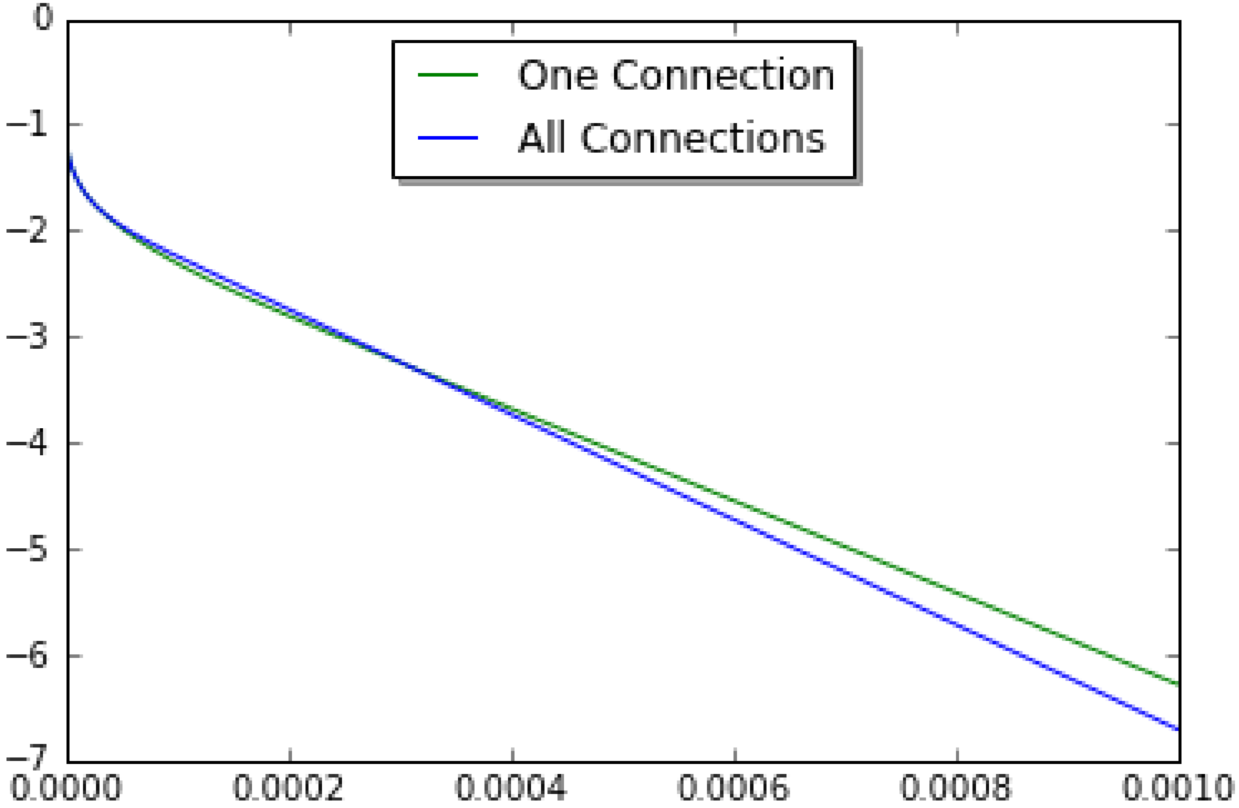


T = 1 ms

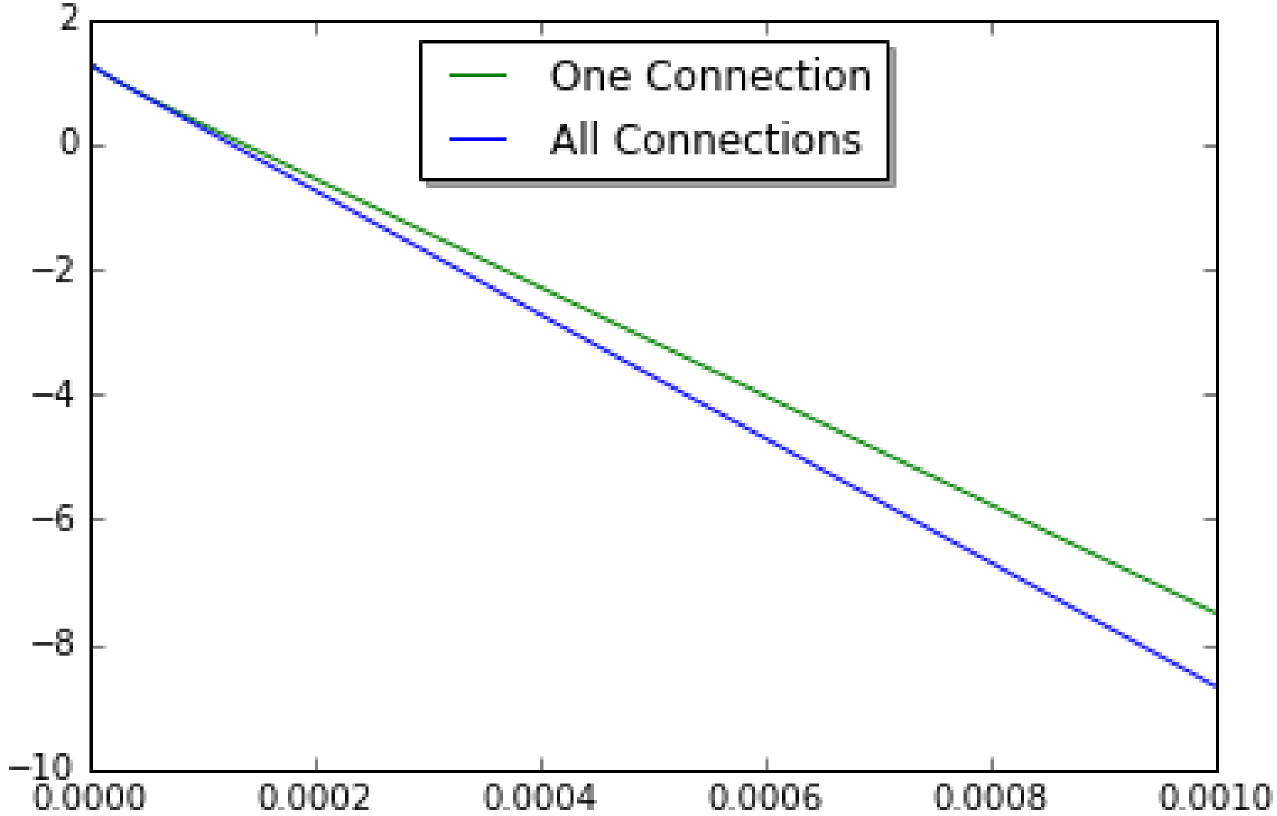


What's the Difference

Log Plot of Current (A) vs Time (s)



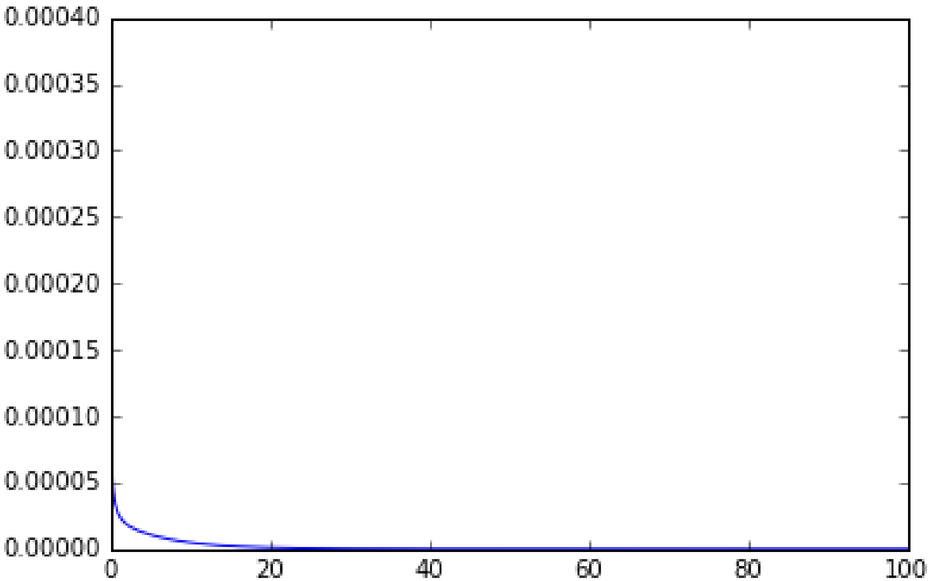
Log Plot of Energy (J) vs Time (s)



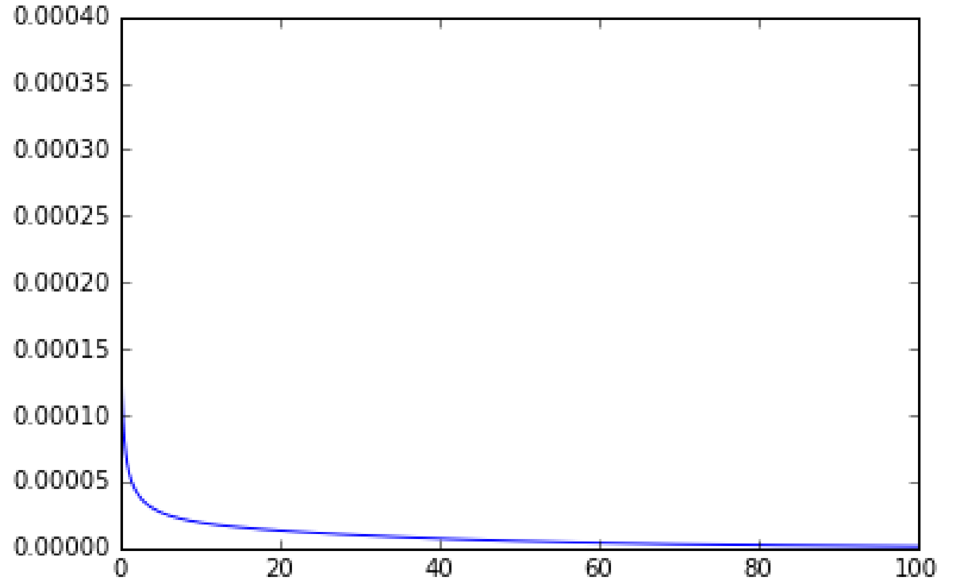
Adding the Field Cage

- After presenting this to the DUNE HV group, I was then asked if I could adding in a simulation of the field cage discharging as they are fed by the same HV cable. So I did that for both of the side lengths of the field cage.

Short Side I

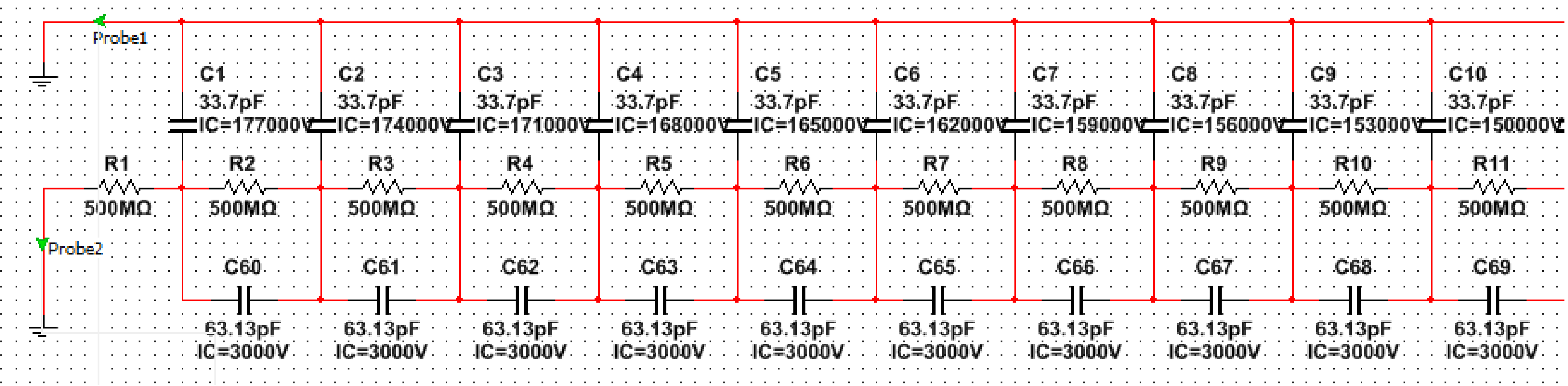


Long Side I



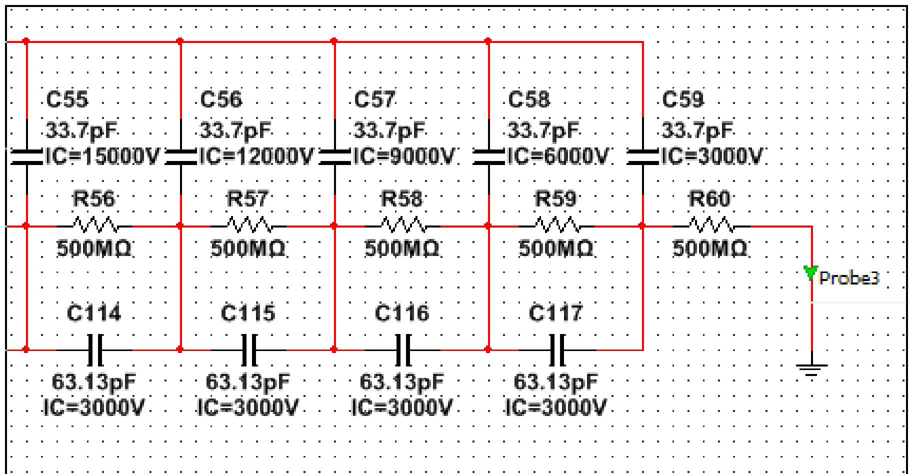
Comparison

- Then, I made a SPICE circuit simulation of the field cage discharge to compare with my results



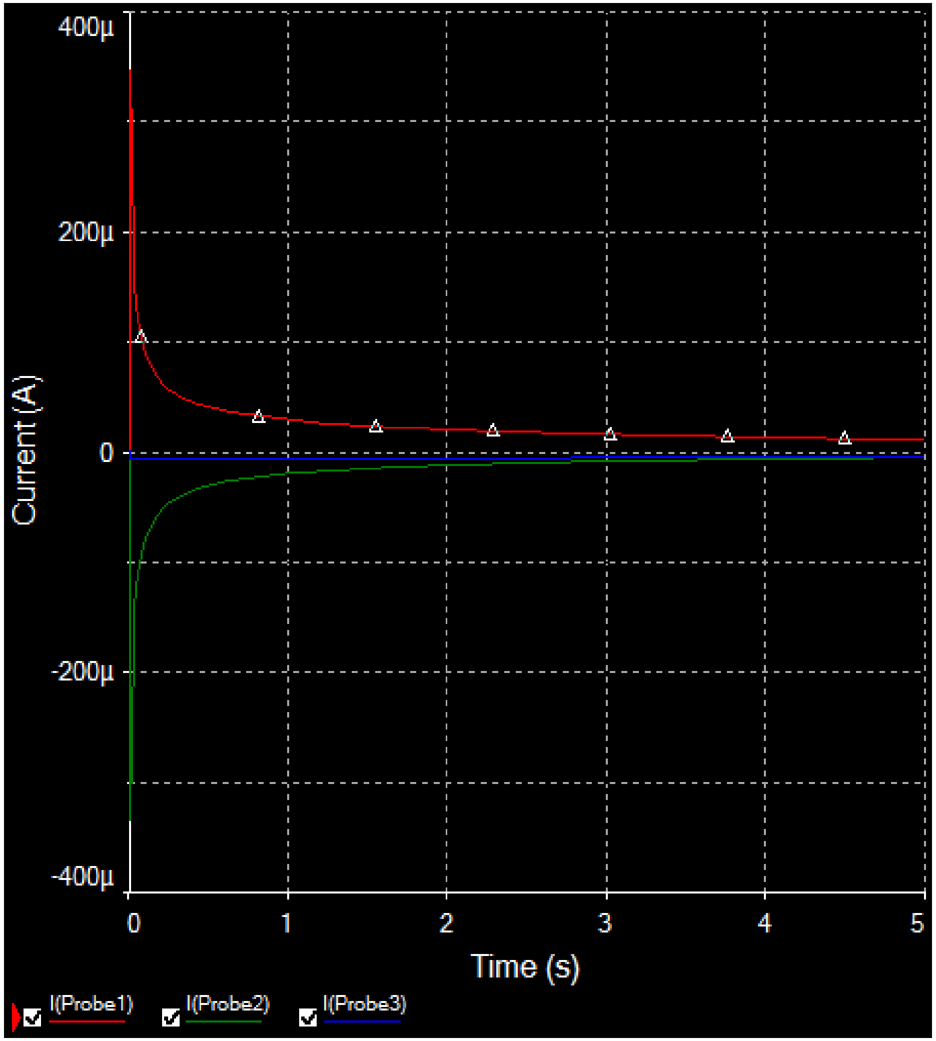
. . .

. . .

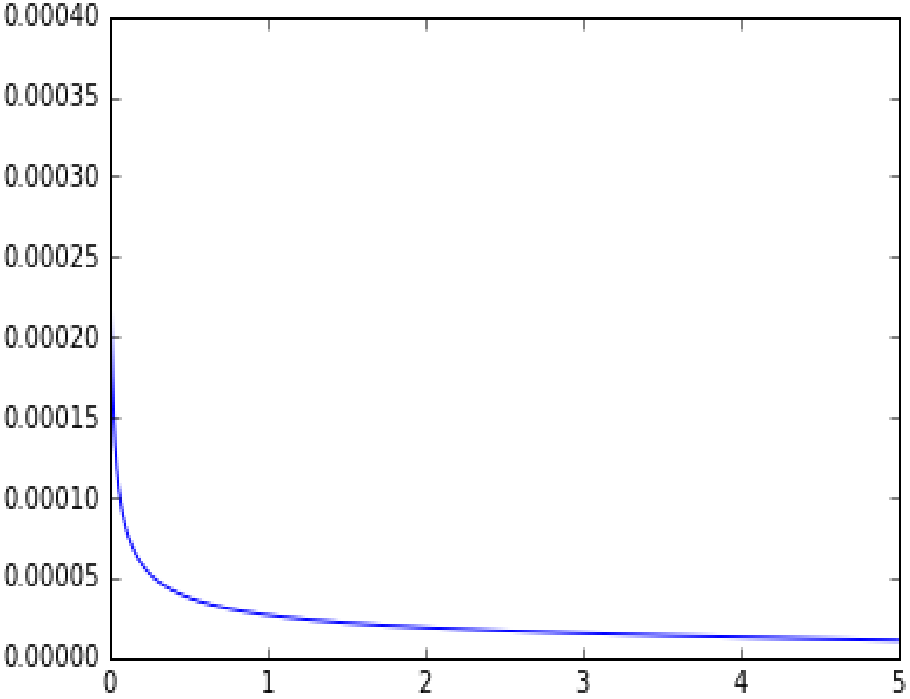


Comparing Results

SPICE

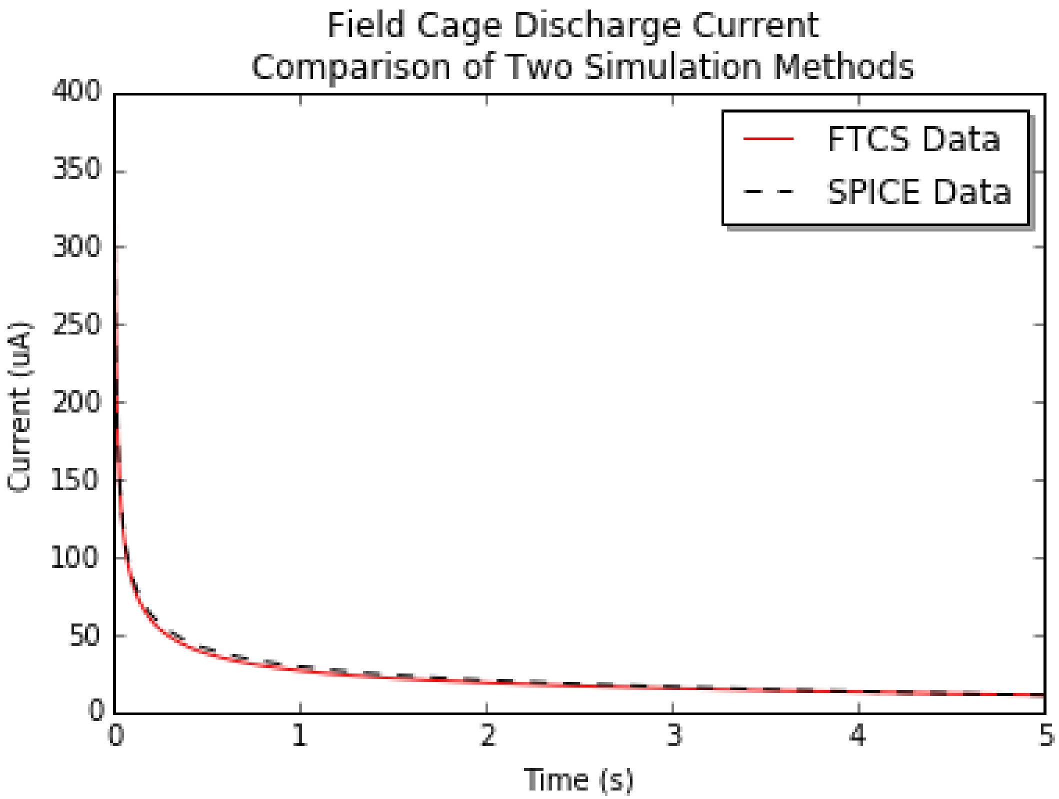


PYTHON



Direct Comparison of FTCS and SPICE

- Shown data is for one complete side of the field cage on the shorter dimension of CPA / LArTPC of 1.15 m (vs long side of 6.0 m)



INDUCED CURRENT AT APA

What's the Goal Here

- We have plenty of knowledge/understanding of what sort of behavior we should see from Voltage/E field in LArTPC/at APA in steady state of detector operation.
- However, the fields resultant of the CPA during a discharge are vastly more complicated, due to the non uniformities and wide ranges of voltages of different elements across the Cathode.
- Therefore, finding any sort of exact solutions to even the quasi-static approximations of the electric fields all but impossible, and completely impractical for our needs.
- So, I instead decided that I could get a close enough approximation to provide meaningful outputs using just the monopole term of a multipole expansion to get Voltages res. from cathode, at z=3.6m=dist. btw the APA and the CPA.

Method Used for Monopole Approx.

- However, what I did wasn't a monopole approximation of the CPA as a whole. Rather, I realized that our FTCS method was already breaking up the CPA into many sections of CPA at set V's, and with defined sizes and relative locations.
- So, I decided to do a monopole term approx. separately for each individual CPA section, (in this case: 5 cm x 5 cm sections)
- I.e. Since the CPA has a know Capacitance/m^2 , I could find a C for each.05x.05 m section: C = (Capacitance/m^2)*($.05^2$). Hence, as Q=C/V, and our simulation give a V of each section at every time-step, we also know a total charge, (the monopole moment), of each section.

Monopole Method Cont'd

- We know the equations describing a point charge to be:

$$V(r) = \frac{1}{4\pi\epsilon}\frac{Q}{r} \quad \overset{s.t.}{\rightarrow} \quad \vec{E}(r) = \frac{1}{4\pi\epsilon}\frac{Q}{r^2}\hat{r}$$

- And from our previously assumed geometry of CPA and APA as a finite parallel plate capacitor:

$$C_{\|\, plates} = \frac{\epsilon\, A}{d} = \frac{\epsilon\,(0.05m)^2}{3.6m} \quad \therefore \quad C_{\|\, plates} = \epsilon\left(\frac{1}{1440}m\right)$$

- Hence:

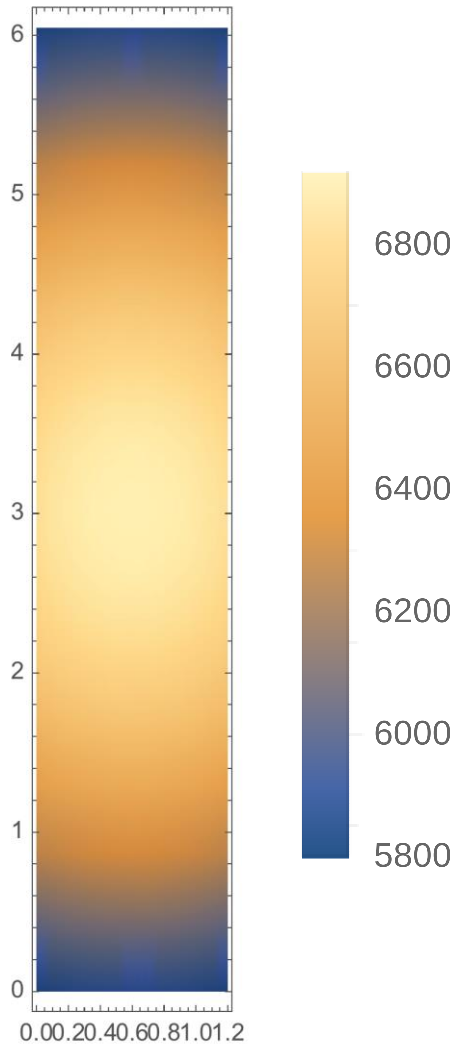
$$V(r) = \frac{V_{element}}{5760\pi\, r}$$

where $r = \sqrt{(x - xc)^2 + (y - yc)^2 + (3.6m)^2}$

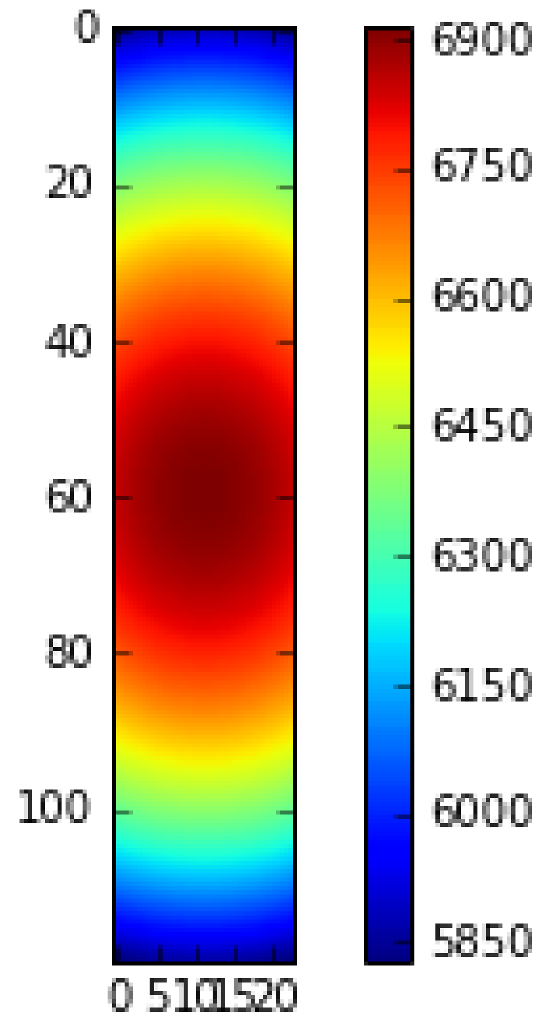
and $(xc, yc) = center\; of\; CPA\; element$

What Results Do We Get From This?

Mathematica Test of Initial Cond.



Python IC Result



Getting Induced Charge on APA from Voltage

- Assumed a conducting plane at 0V and used boundary conditions equation of

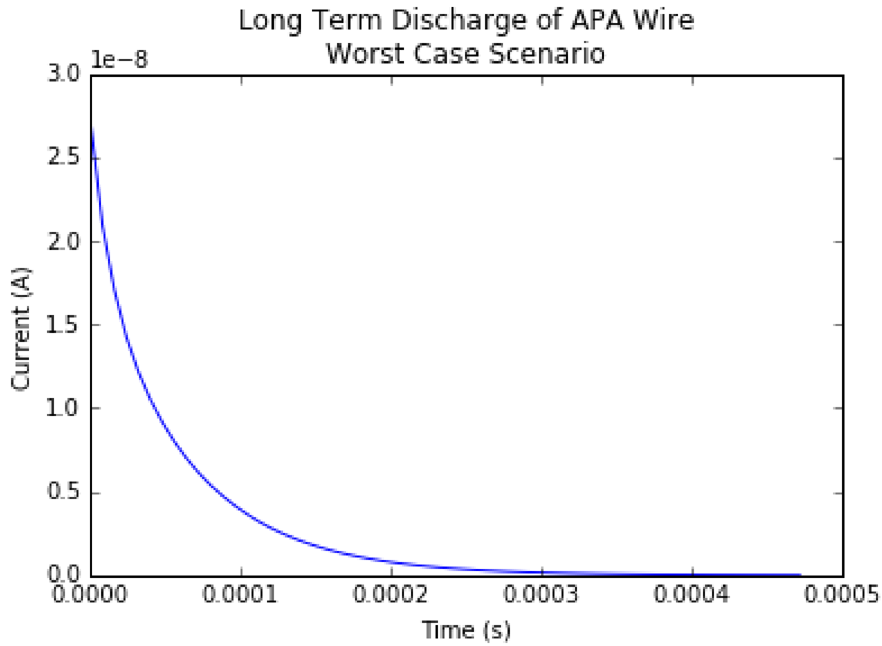
$$\frac{\partial V_{above}}{\partial n} - \frac{\partial V_{below}}{\partial n} = -\frac{\sigma}{\epsilon}$$

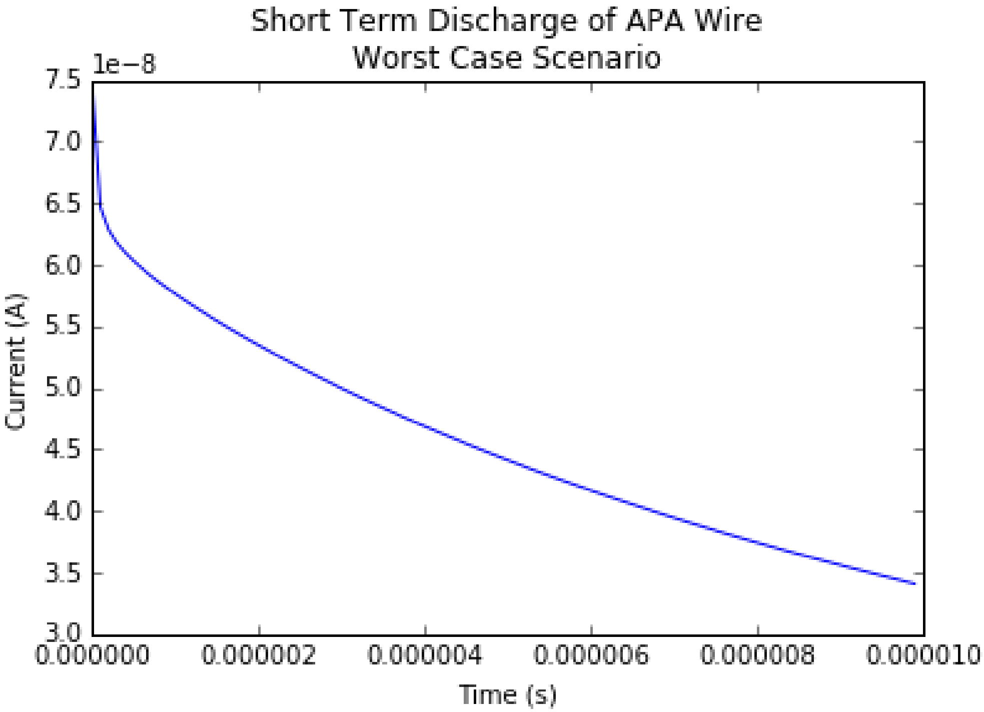
- This gives us a surface charge (sigma) for each element at each time step.

$$I = \sum_i \left(\frac{\Delta \sigma_i \, A}{\Delta t} \right)$$

- We wanted worst case scenario so we summed over the 6m length of the anode plane

Results


Long Term Discharge of APA Wire
Worst Case Scenario
1e−8
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Current (A)
0.0000
0.0001
0.0002
0.0003
0.0004
0.0005
Time (s)


Short Term Discharge of APA Wire
Worst Case Scenario
1e−8
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
Current (A)
0.000000
0.000002
0.000004
0.000006
0.000008
0.000010
Time (s)