PHYS 1441 – Section 001
Lecture #7

Wednesday, June 12, 2019

Dr. Jaehoon Yu

- Chapter 23
  – V due to Charge Distributions
  – Equi-potential Lines and Surfaces
  – Electric Potential Due to Electric Dipole
- Chapter 24 Capacitance etc..
  – Capacitors
  – Capacitors in Series or Parallel
  – Electric Energy Storage

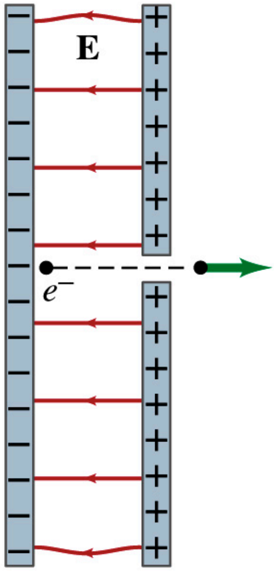
Today's homework is #5, due 11pm, Sunday, June 16!!

Announcements

- Quiz #2
  - At the beginning of the class tomorrow, Thursday, June 13
  - Covers up to what we've learned today
  - You can bring your calculator but it must not have any relevant formula pre-input
    - Cell phones or any types of computers cannot replaced a calculator!
  - BYOF: You may bring one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
  - No derivations, word definitions, setups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
- Term 1 result
  - Class average: 56.4/100
  - Top score: 97.5
- Reminder: Evaluation criteria
  - Homework: 25%
  - Final exam: 23%
  - Mid-term: 20%
  - One better of the two term exams:12%
  - Lab and quizzes: 10% each + 10% extra credit!!

Reminder: Special Project #3

- **Particle Accelerator**. A charged particle of mass **M** with charge **-Q** is accelerated in the uniform field **E** between two parallel charged plates whose separation is **D** as shown in the figure on the right. The charged particle is accelerated from an initial speed $\mathbf{v_0}$ near the negative plate and passes through a tiny hole in the positive plate as shown in the figure right.
  - Derive the formula for the electric field E to accelerate the charged particle to a fraction f of the speed of light c. Express E in terms of **M, Q, D,** f, **c** and $\mathbf{v_0}$.
  - (a) Using the Coulomb force and kinematic equations. (8 points)
  - (b) Using the work-kinetic energy theorem. (8 points)
  - (c) Using the formula above, evaluate the strength of the electric field E to accelerate an electron from 0.1% of the speed of light to 90% of the speed of light. You need to look up the relevant constants, such as mass of the electron, charge of the electron and the speed of light. (5 points)



- Please do NOT copy but have your own handwritten answer!
- Due beginning of the class Monday, June 17

Properties of the Electric Potential

- What are the differences between the electric potential and the electric field?
  - Electric potential

    $$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

    - Electric potential energy per unit charge
    - Inversely proportional to the distance
    - Simply add the potential by each of the source charges to obtain the total potential from multiple charges, since potential is a scalar quantity
  - Electric field

    $$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

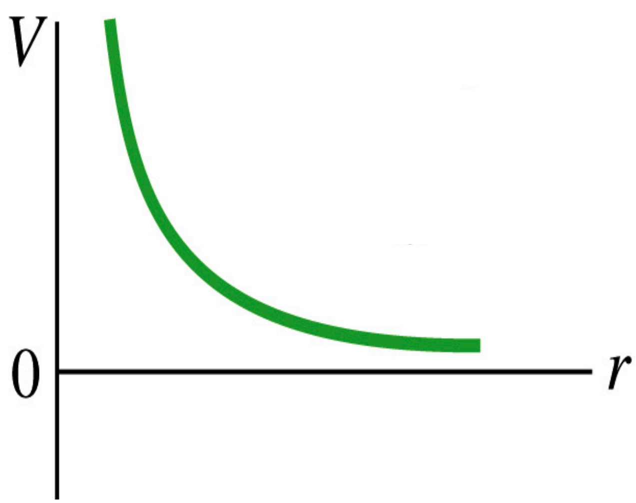
    - Electric force per unit charge
    - Inversely proportional to the **square** of the distance
    - Need vector sums to obtain the total field from multiple source charges
- Potential due to a positive charge is a large positive near the charge and decreases towards 0 at the large distance.
- Potential due to a negative charge is a large negative near the charge and increases towards 0 at a large distance.

Shape of the Electric Potential

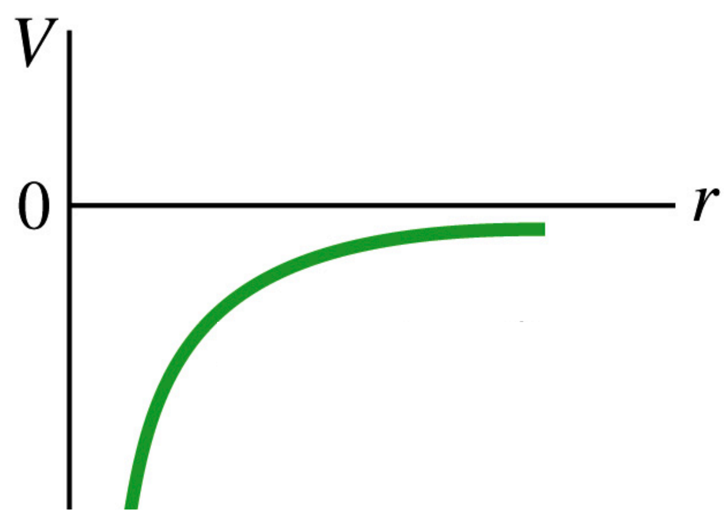
- So, how does the electric potential look like as a function of distance?
  - What is the formula for the potential by a single charge?

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

If Q is Positive



If Q is Negative



Uniformly charged sphere would have the potential the same as a single point charge.

What does this mean? **Uniformly charged sphere behaves like all the charge is on the single point in the center.**

Example 23 – 6

Work to bring two positive charges close together: What is minimum work required by an external force to bring the charge q=+3.00μC from a great distance away (r=∞) to a point 0.500m from a charge Q=+20.0 μC?

What is the work done by the electric field in terms of potential energy and potential?

$$W = -qV_{ba} = -\frac{q}{4\pi\varepsilon_0}\left(\frac{Q}{r_b} - \frac{Q}{r_a}\right)$$

Since $r_b = 0.500m, r_a = \infty$ we obtain

$$W = -\frac{q}{4\pi\varepsilon_0}\left(\frac{Q}{r_b} - 0\right) = -\frac{q}{4\pi\varepsilon_0}\frac{Q}{r_b} = -\frac{\left(8.99\times10^{9}\, N\cdot m^2/C^2\right)\cdot\left(3.00\times10^{-6}C\right)\left(20.00\times10^{-6}C\right)}{0.500m} = -1.08J$$

Electric force does negative work. In other words, the external force must work +1.08J to bring the charge 3.00μC from infinity to 0.500m to the charge 20.0μC.

Electric Potential by Charge Distributions

- Let's consider the case of n individual point charges in a given space and V=0 at r=∞.
- Then the potential V_{ia} due to the charge Q_i at point a, at a distance r_{ia} from Q_i is

$$V_{ia} = \frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}$$

- Thus the total potential V_a by all n point charges is

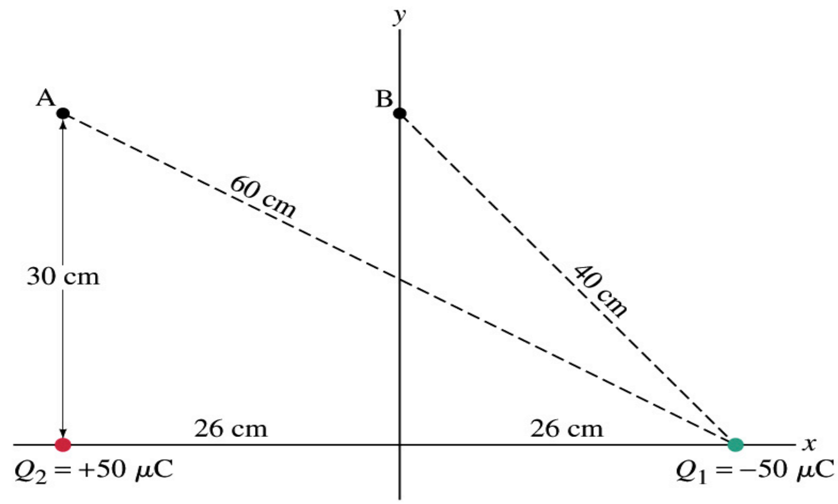
$$V_a = \sum_{i=1}^{n} V_{ia} = \sum_{i=1}^{n} \frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}$$

- For a continuous charge distribution, we obtain

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$$

Example

- **Potential due to two charges**: Calculate the electric potential (a) at point A in the figure due to the two charges shown, and (b) at point B.



- Potential is a scalar quantity, so one adds the potential by each of the source charge, as if they are numbers.

(a) potential at A is $V_A = V_{1A} + V_{2A} = \sum \frac{Q_i}{4\pi\varepsilon_0} \frac{1}{r_{iA}} =$

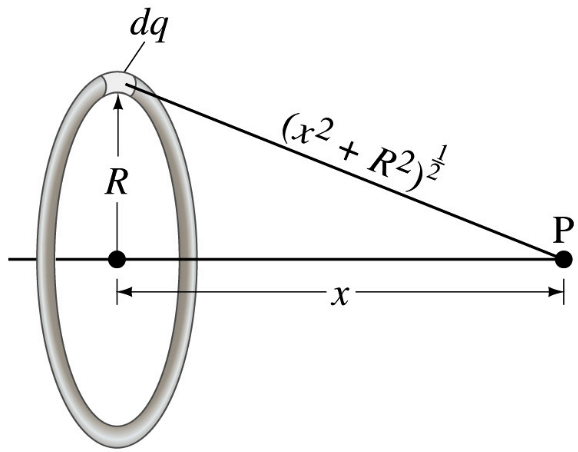
$$= \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{r_{1A}} + \frac{1}{4\pi\varepsilon_0} \frac{Q_2}{r_{2A}} = \frac{1}{4\pi\varepsilon_0} \left(\frac{Q_1}{r_{1A}} + \frac{Q_2}{r_{2A}} \right)$$

$$= 9.0 \times 10^9 \left(\frac{-50 \times 10^{-6}}{0.60} + \frac{50 \times 10^{-6}}{0.30} \right) = 7.5 \times 10^5 V$$

(b) How about potential at B?

Example 23 – 8

- **Potential due to a ring of charge**: A thin circular ring of radius R carries a uniformly distributed charge Q. Determine the electric potential at a point P on the axis of the ring a distance x from its center.



- Each point on the ring is at the same distance from the point P. What is the distance?

$$r = \sqrt{R^2 + x^2}$$

- So the potential at P is

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r} = \frac{1}{4\pi\varepsilon_0 r}\int dq = \frac{1}{4\pi\varepsilon_0\sqrt{x^2+R^2}}\int dq = \frac{Q}{4\pi\varepsilon_0\sqrt{x^2+R^2}}$$

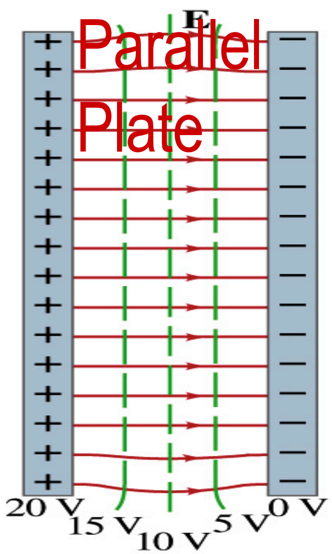
What's this?

Equi-potential Surfaces

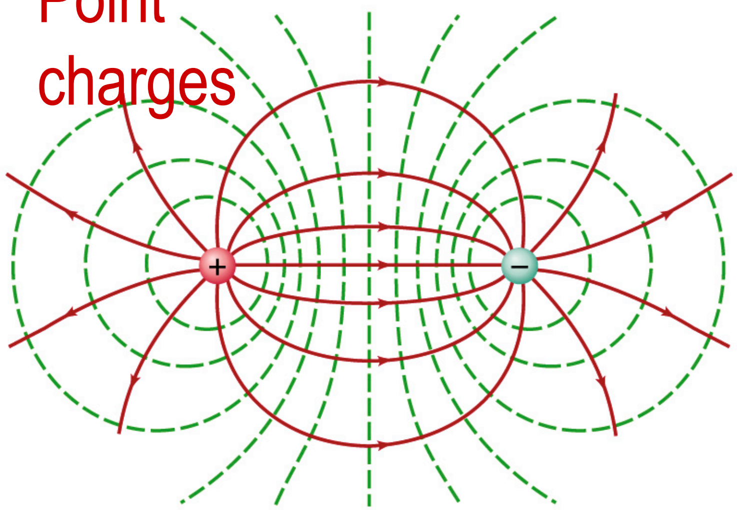
- Electric potential can be graphically shown using the equipotential lines in 2-D or the equipotential surfaces in 3-D
- Any two points on the equipotential surfaces (lines) are at the same potential
- What does this mean in terms of the potential difference?
  - The potential difference between any two points on an equipotential surface is 0.
- How about the potential energy difference?
  - Also 0.
- What does this mean in terms of the work to move a charge along the surface between these two points?
  - No work is necessary to move a charge between these two points.

Equi-potential Surfaces

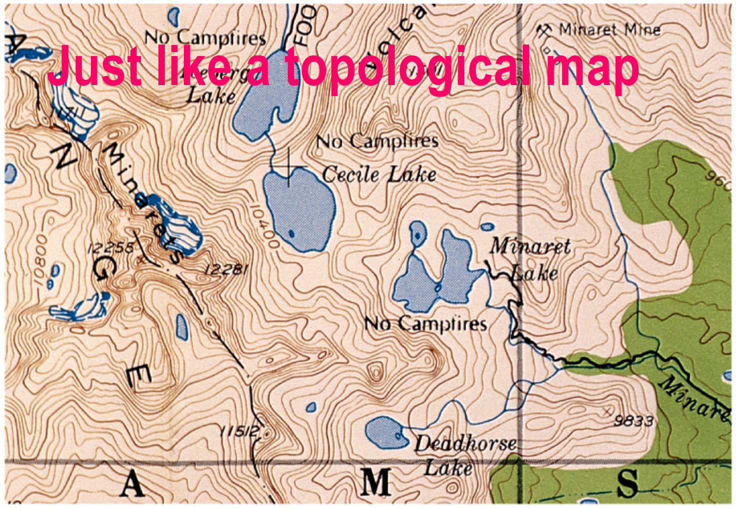
- An equipotential surface (line) must be perpendicular to the electric field. Why?
  - If there are any parallel components to the electric field, it would require work to move a charge along the surface.
- Since the equipotential surface (line) is perpendicular to the electric field, we can draw these surfaces or lines easily.
- Since there can be no electric field within a conductor in a static case, the entire volume of a conductor must be at the same potential.
- So the electric field must be perpendicular to the conductor surface.



Parallel Plate



Point charges



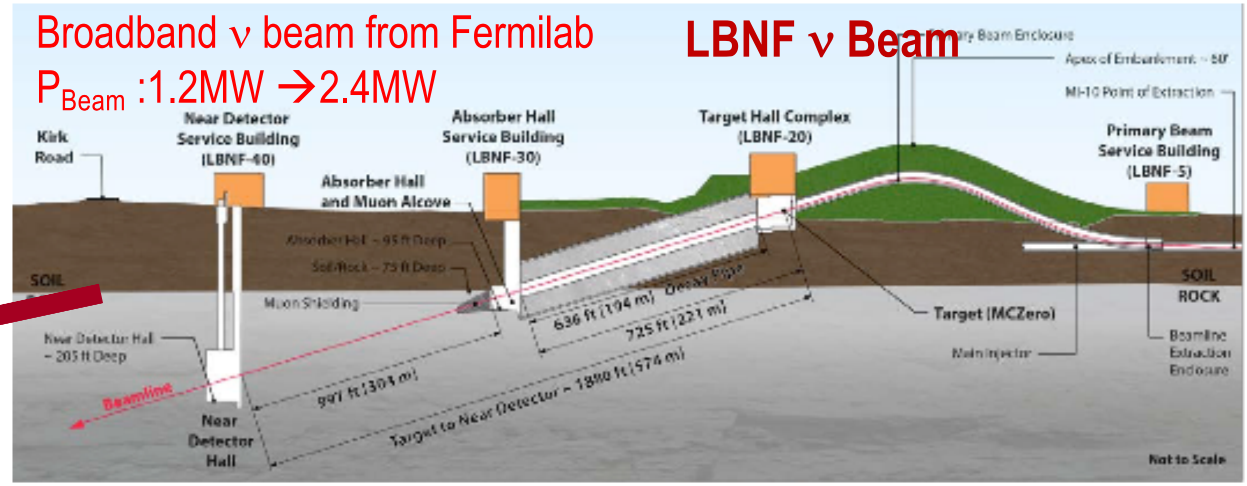
Just like a topological map

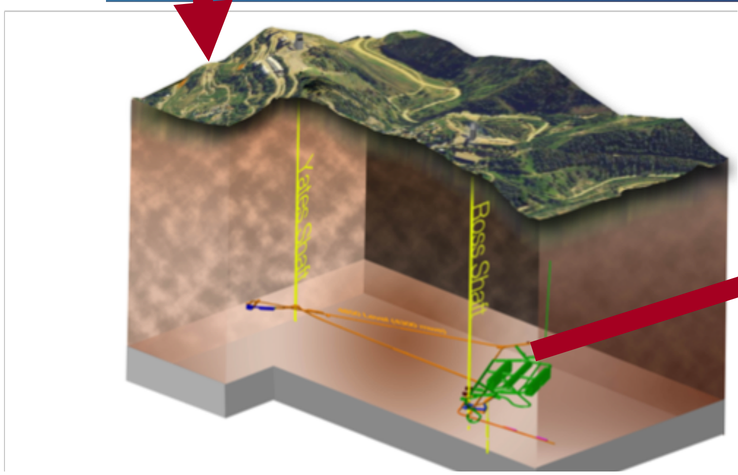
DUNE Experiment

Broadband ν beam from Fermilab

P_{Beam} :1.2MW → 2.4MW

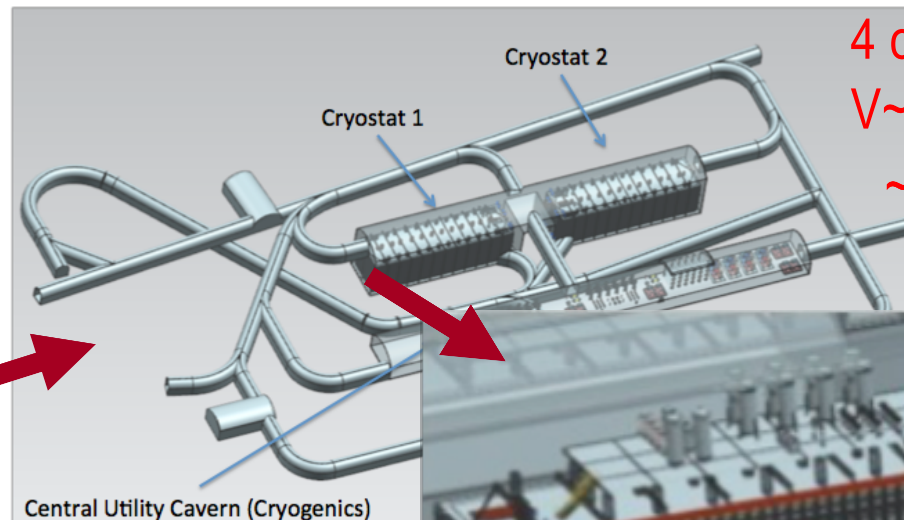
LBNF ν Beam





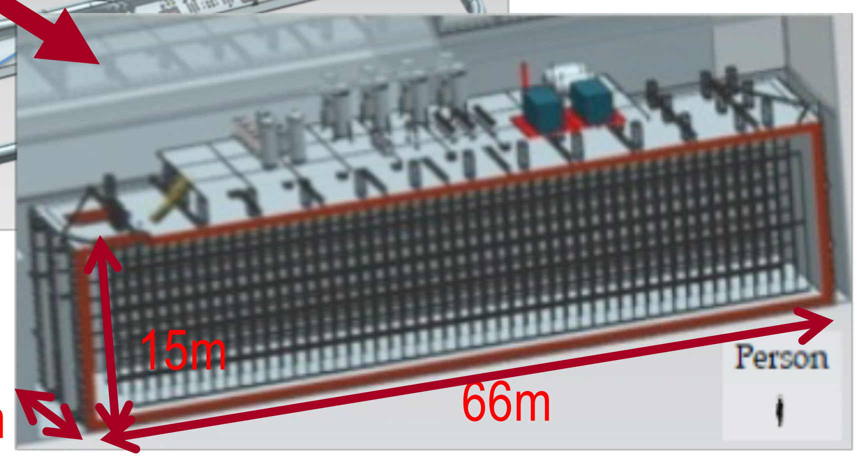
LBNF Far Detector Site, SURF

1500m underground



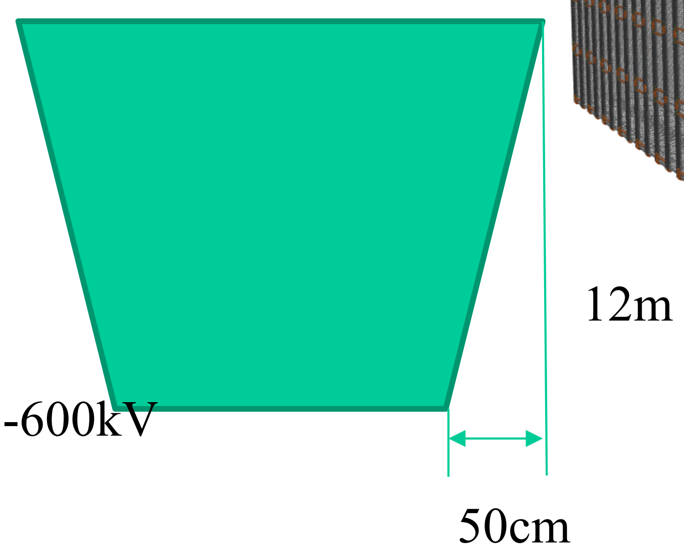
4 caverns w/ active V~10kt LAr each

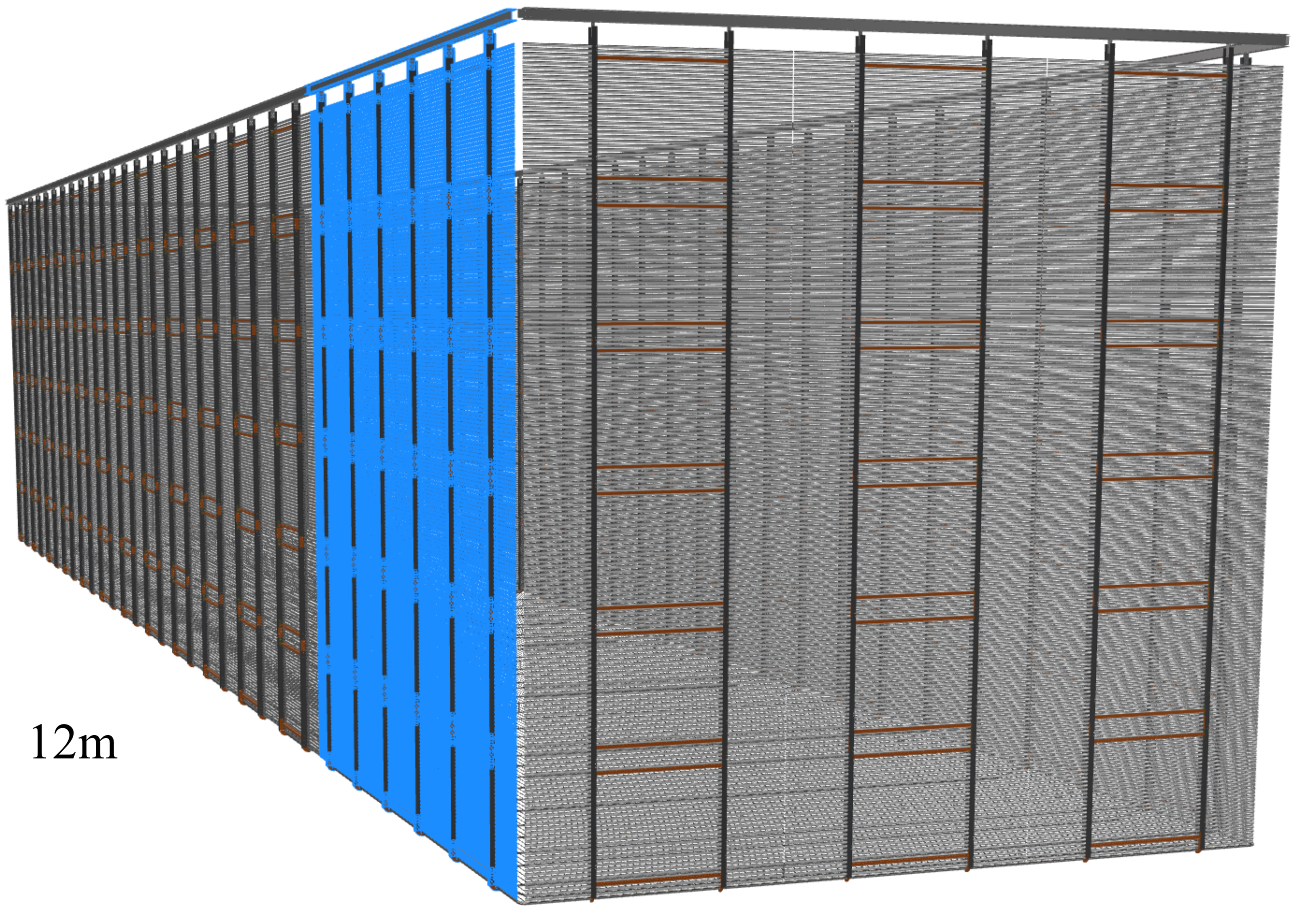
~30xICARUS



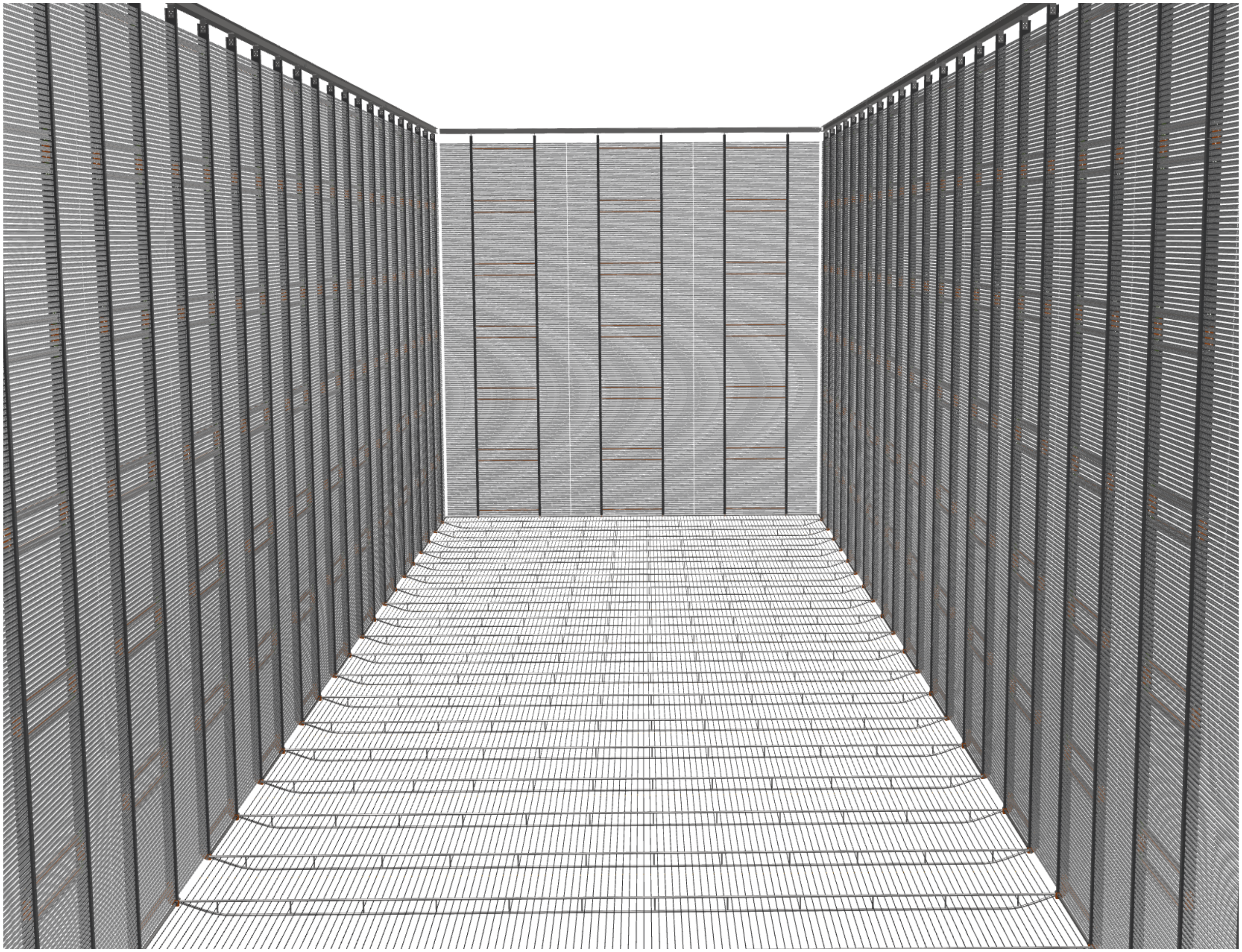
DUNE Field Cage Outside View

- End walls will be angled



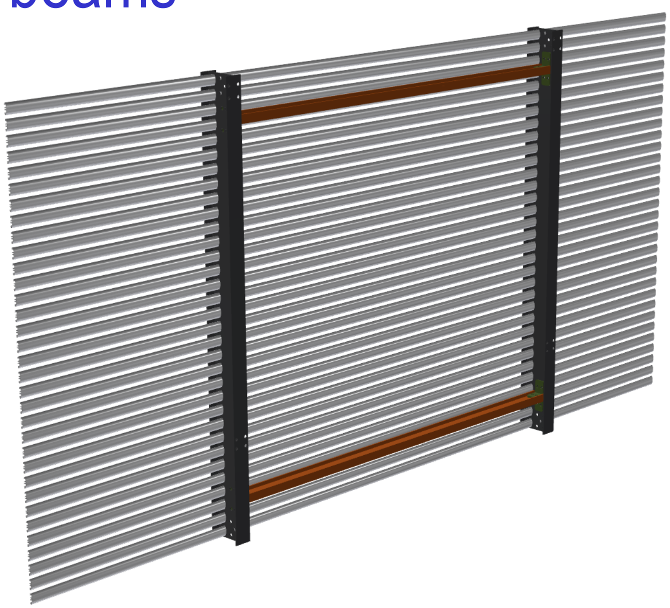


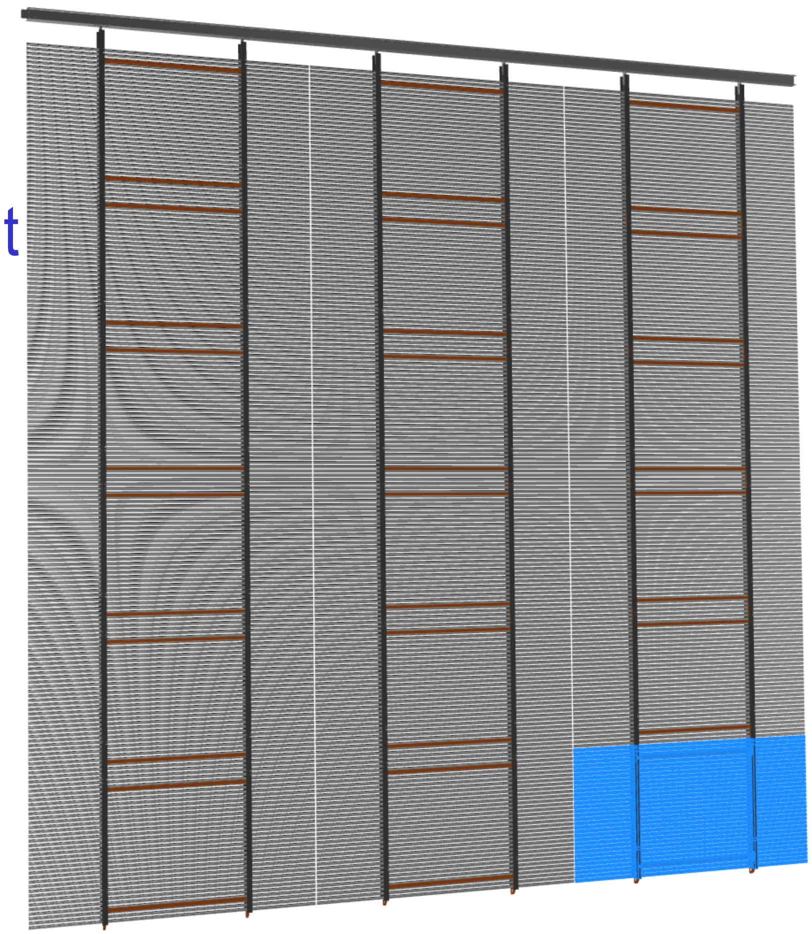
DUNE Field Cage Inside View

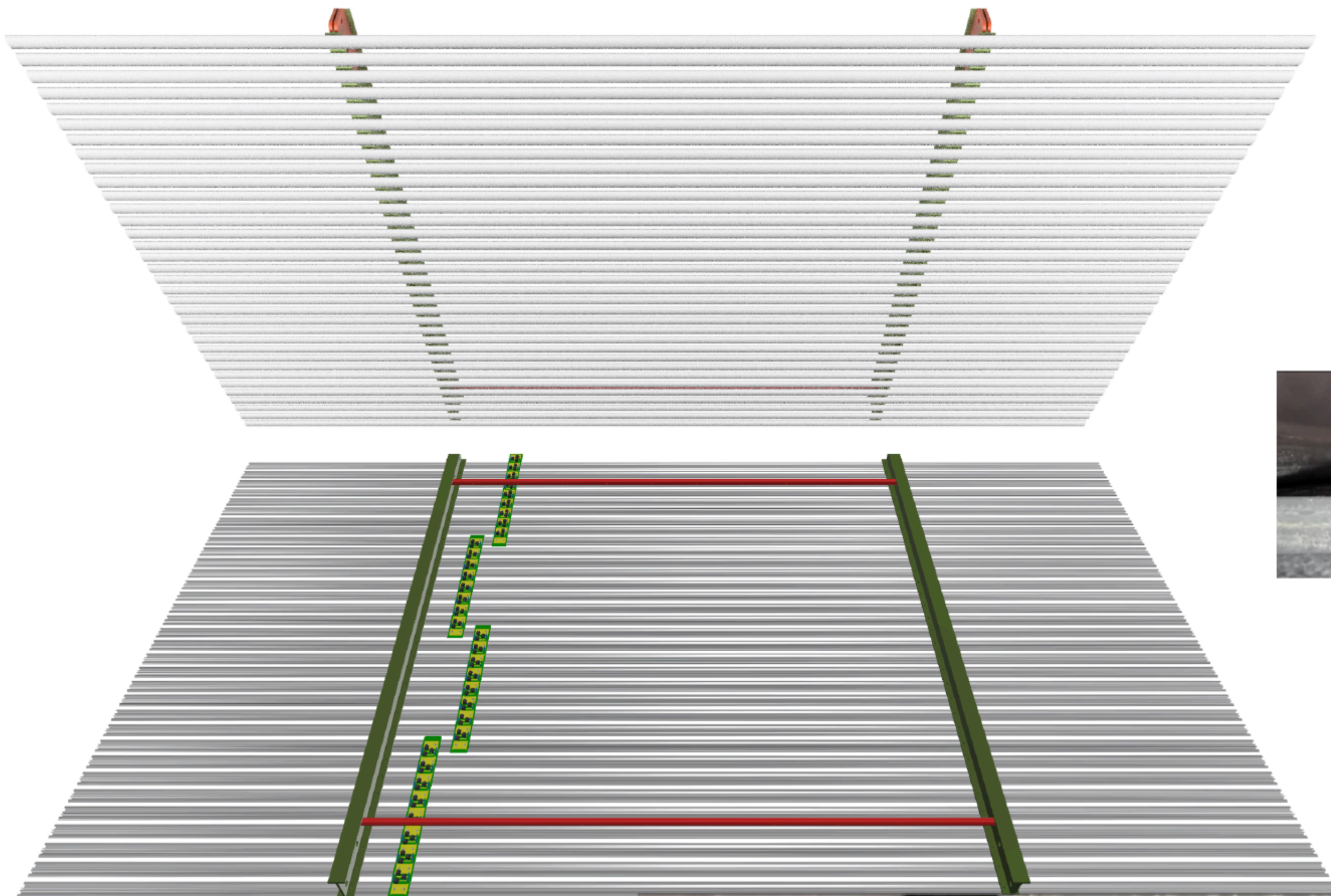


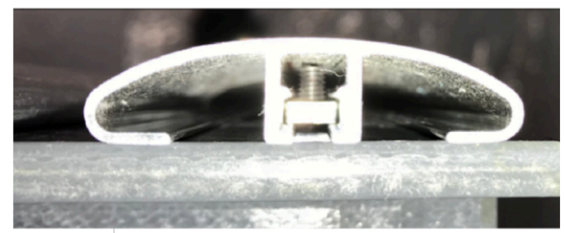
DUNE Field Cage Construction

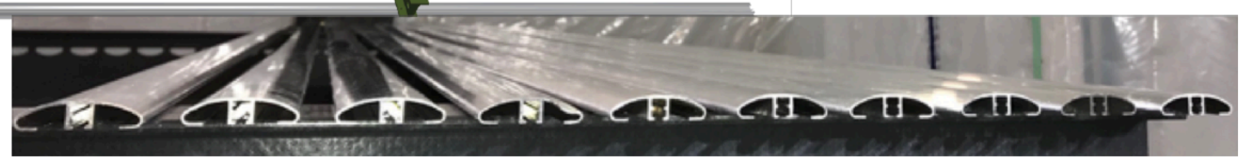
- FC Module (FCM): 4m wide x 2m tall
- FC Super Module (FCSM): 12m x 12m (3x6 FCM)
  - Each FCSM is supported by one 12m long SS beam.
  - The I-beam is hang from 2 cables to the roof
- Entire FC: 12 FC Super Modules
- The sub-modules will have profiles face out
- Use 4" I-beams



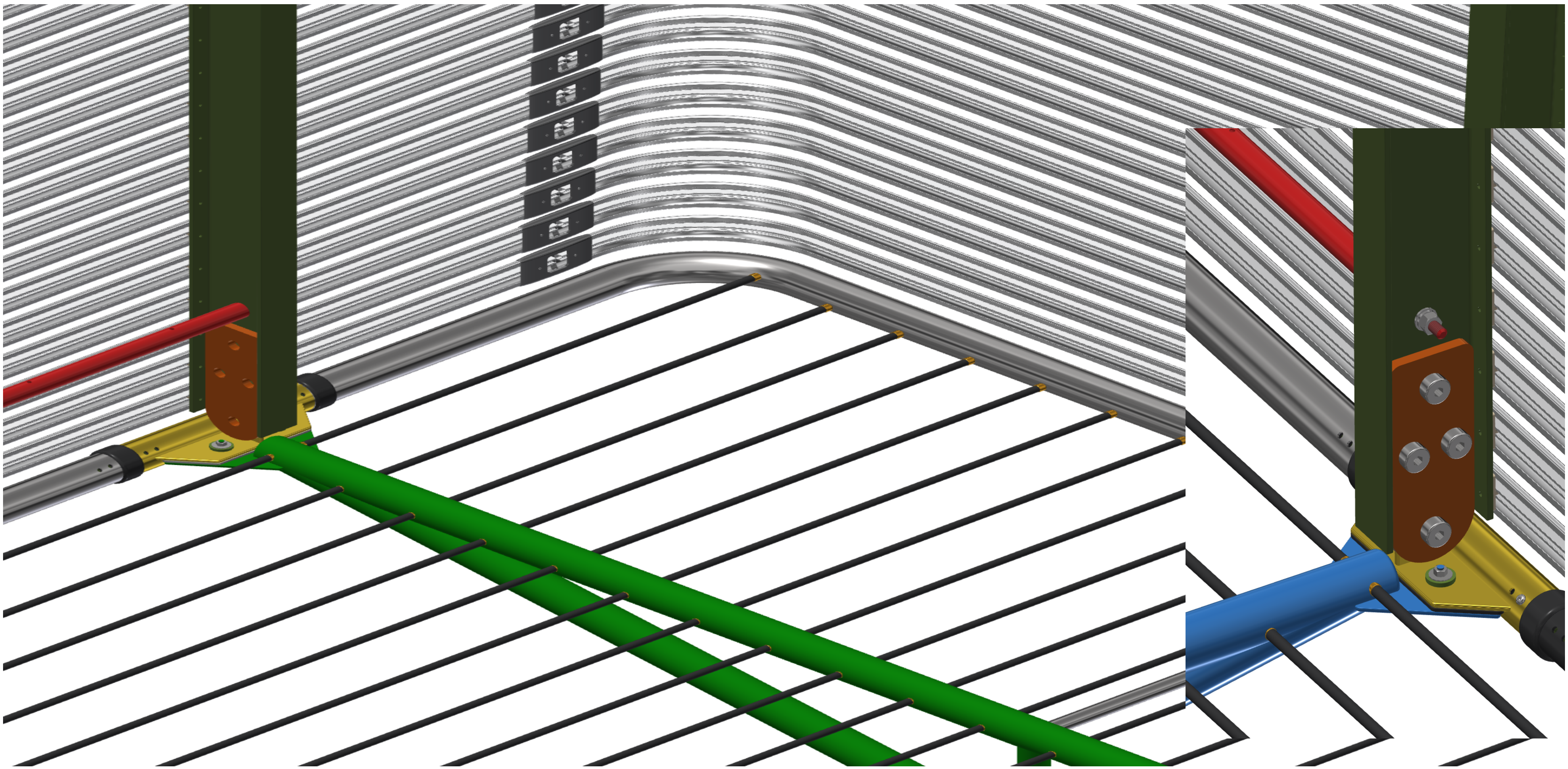








Cathode and Field Cage Connection at the Corner



Field Simulations

- 2D simulatior
- Equipotential lines