# PHYS 1441 – Section 002
# Lecture #9

*Wednesday, Sept. 30, 2020*

*Dr. Jaehoon Yu*

- CH23
  - Relationship between V and E
  - V due to Point Charges
  - Functional shape of V
  - V due to Charge Distributions
  - Equi-potential Lines and Surfaces

# Announcements

- Reading assignments: CH22 – 4 and CH23 – 9
- Online Quiz 2 on Quest
  - Beginning of class next Wednesday, Oct. 7
  - Covers: CH22.1 through what we finish Monday, Oct. 5
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
  - No derivations, word definitions or setups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
  - Must send me the photos of front and back of the formula sheet, including the blank, no later than 11am the day of the quiz
    - Once submitted, you cannot change, unless I ask you to delete some part of the sheet!

# Reminder: SP#3 – Civic Duty I: Voter Registration

- **Voter registration in Texas ends on Monday, Oct. 5, 2020**
  - Registration can be done: https://www.votetexas.gov/register/index.html
  - Check your registration: https://teamrv-mvp.sos.texas.gov/MVP/mvp.do
- For those who are legal to take part in the election
  - Your own registration to vote: 10 points
    - Include the screen shot your own voter registration check
  - You can have up to 3 more people who are not registered to register: 5 points each
    - Must include before and after the registration screen shots of the same person next to each other to show these are newly registered
- For those who are not legal to take part in the election
  - You can have up to 5 people who are not registered to register: 5 points each
    - Must include before and after the registration screen shots of the same person next to each other to show these are newly registered
- **Deadline: 1pm Wednesday, Oct. 7, 2020**
- Put all screen shots in one pdf file following the naming convention – SP3-LastName-FirstName-Fall20.pdf and upload to the CANVAS assignment

# SP#3 – Civic Duty I: Voter Registration – 2


**Voter Information**

Name: JAEHOON YU
[redacted]
Gender: MALE
Valid From: 01/01/2020
Effective Date of Registration: 05/20/2004
Voter Status: ACTIVE
County: TARRANT
Precinct: 2266
VUID: 1050748339

Change your Address

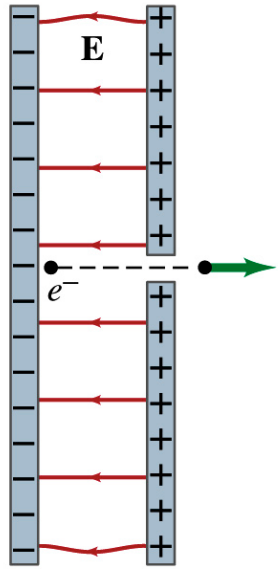
**Upcoming Elections (Select Election for available polling information)**

11/03/2020--2020 NOVEMBER 3RD GENERAL ELECTION

***Eligibility is determined by Effective Date of Registration (Must be on or before Election Day)

# Reminder: Special Project #4

- **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.




  - 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 the 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 the initial speed of 0.1% to 90% of the speed of light. You need to look up and write down the relevant constants, such as mass of the electron, charge of the electron and the speed of light. (5 points)
- Must be handwritten and not copied from anyone else!
  - Follow the SP naming convention: SP4-first-last-fall20.pdf which includes all pages in one file ➔ Be sure to write your name onto all pages of the project report!
- Due beginning of the class **Monday, Oct. 12**, submitted on CANVAS!

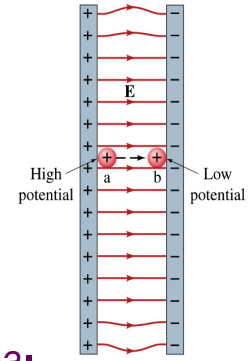
# Electric Potential and Potential Energy

- What is the definition of the electric potential?
  - The potential energy difference per unit charge

$$V_{ba} = \frac{U_b - U_a}{q}$$

- OK, then, how would you express the potential energy that a charge q would obtain when it is moved between point *a* and *b* with the potential difference $V_{ba}$?

$$U_b - U_a = q(V_b - V_a) = qV_{ba}$$




  - In other words, if an object with charge q moves through a potential difference $V_{ba}$, its potential energy changes by $qV_{ba}$.
- So based on this, how differently would you describe the electric potential in words?
  - A measure of how much kinetic energy an electric charge can acquire under the given field
  - A measure of how much work a given charge can do.

(Poll11 – V & PE)

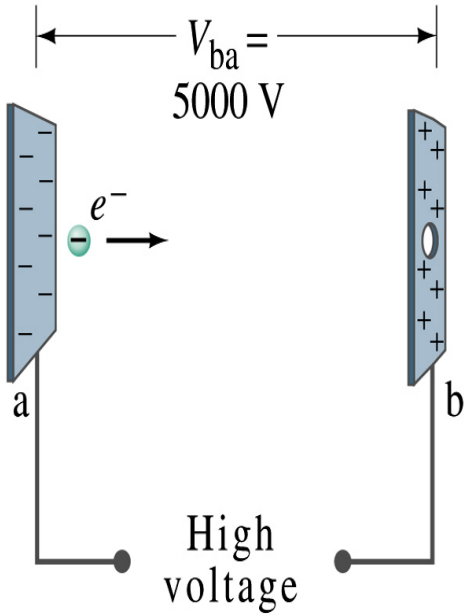
# Some Typical Potential Differences

| Sources | Approximate Voltage |
|---|---|
| Thundercloud to ground (~5km) | $10^8$ V |
| High-Voltage Power Lines | $10^6$ V |
| Power supply for TV tube | $10^4$ V |
| Automobile ignition | $10^4$ V |
| Household outlet | $10^2$ V |
| Automobile battery | 12 V |
| Flashlight battery | 1.5 V |
| Resting potential across nerve membrane | $10^{-1}$ V |
| Potential changes on skin (EKG and EEG) | $10^{-4}$ V |

In a typical lightning strike, 15C of electrons are released in 500μs. What is the total kinetic energy of these electrons when they strike the ground? What is the power released during this strike? What do you think will happen to a tree hit by this lightning?

# Example 23 – 2

**Electrons in TV tube:** Suppose an electron in the picture tube of a television set is accelerated from rest through a potential difference $V_{ba}$=+5000V. (a) What is the change in potential energy of the electron? (b) What is the speed of the electron (m=9.1x10$^{-31}$kg) as a result of this acceleration? (c) Repeat for a proton (m=1.67x10$^{-27}$kg) that accelerates through a potential difference of $V_{ba}$=-5000V.




- (a) What is the charge of an electron?
  - $e = -1.6 \times 10^{-19} C$
- So what is the change of its potential energy?

$$\Delta U = qV_{ba} = eV_{ba} = \left(-1.6 \times 10^{-19} C\right)\left(+5000V\right) = -8.0 \times 10^{-16} J$$

# Example 23 – 2

- (b) Speed of the electron?
  - The entire potential energy of the electron turns to its kinetic energy. Thus the equation is

$$\Delta K = \frac{1}{2} m_e v_e^2 - 0 = W = -\Delta U = -eV_{ba} =$$
$$= -\left(-1.6\times10^{-19}\,C\right)5000V = 8.0\times10^{-16}\,J$$

$$v_e = \sqrt{\frac{2\times eV_{ba}}{m_e}} = \sqrt{\frac{2\times 8.0\times10^{-16}}{9.1\times10^{-31}}} = 4.2\times10^{7}\,m/s$$

- (C) Speed of the proton?

$$\Delta K = \frac{1}{2} m_p v_p^2 - 0 = W = -\Delta U = -\left\{\left(-e\right)\left(-V_{ba}\right)\right\} = -eV_{ba} = 8.0\times10^{-16}\,J$$

$$v_p = \sqrt{\frac{2\times eV_{ba}}{m_p}} = \sqrt{\frac{2\times 8.0\times10^{-16}}{1.67\times10^{-27}}} = 9.8\times10^{5}\,m/s$$

# Electric Potential and Electric Field

- The effect of a charge distribution can be described in terms of electric field or electric potential.
  - What kind of quantities are the electric field and the electric potential?
    - Electric Field (poll 2): Vector
    - Electric Potential (poll 2): Scalar
  - Since electric potential is a scalar quantity, it is often easier to handle.
- Well other than the above, how are these two quantities related?

# Electric Potential and Electric Field

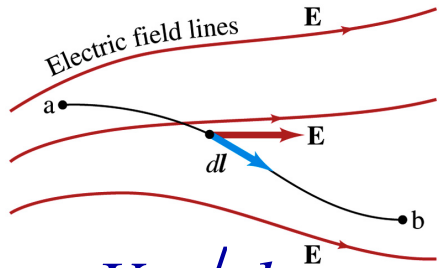
- **Potential energy** change is expressed in terms of a conservative force (point ***a*** at a higher potential)

$$U_b - U_a = -\vec{F}\cdot\vec{D} = -W_C$$

- For the electrical case, we are more interested in the **potential** difference:

$$V_{ba} = V_b - V_a = \frac{U_b - U_a}{q} = -\frac{\vec{F}}{q}\cdot\vec{D} = -\vec{E}\cdot\vec{D} = -ED\cos\theta$$

  - This formula can be used to determine $V_{ba}$ when the electric field is given.




- When the field is uniform

$$V_b - V_a = -\vec{E}\cdot\vec{D} = -ED\cos\theta = -Ed \quad \text{so} \quad E = -V_{ba}/d$$

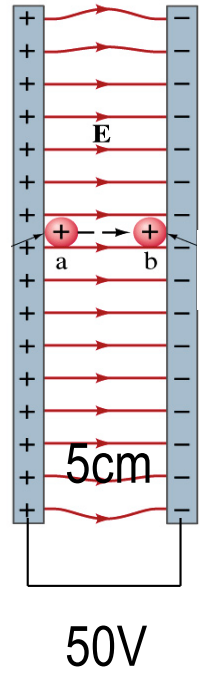
What does "-" sign mean? The direction of E is along that of decreasing potential.

Unit of the electric field in terms of potential? (poll 3) V/m Can you derive this from N/C?

# Example

**Uniform electric field obtained from voltage:**

Two parallel plates are charged to a voltage of 50V. If the separation between the plates is 5.0cm, calculate the magnitude of the electric field between them, ignoring any fringe effect.




What are the max PE and speed of a proton and an electron can obtain?

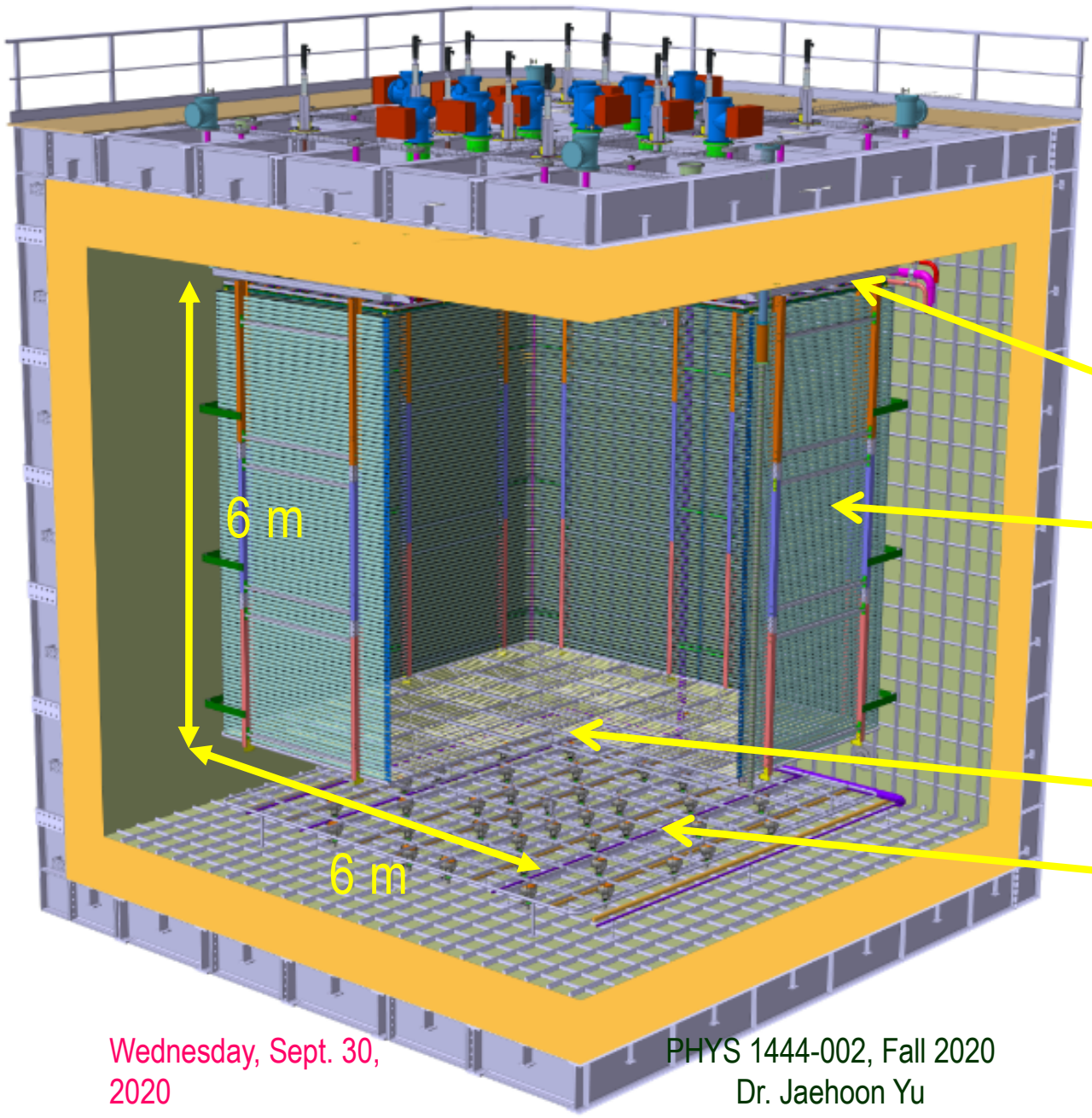
What is the relationship between electric field and the potential for a uniform field? $V = Ed$

Solving for E

$$E = \frac{V}{d} = \frac{50V}{5.0cm} = \frac{50V}{5\times10^{-2}m} = 1000V/m$$

Which direction is the field? Direction of decreasing potential!

# E Field in ProtoDUNE DP



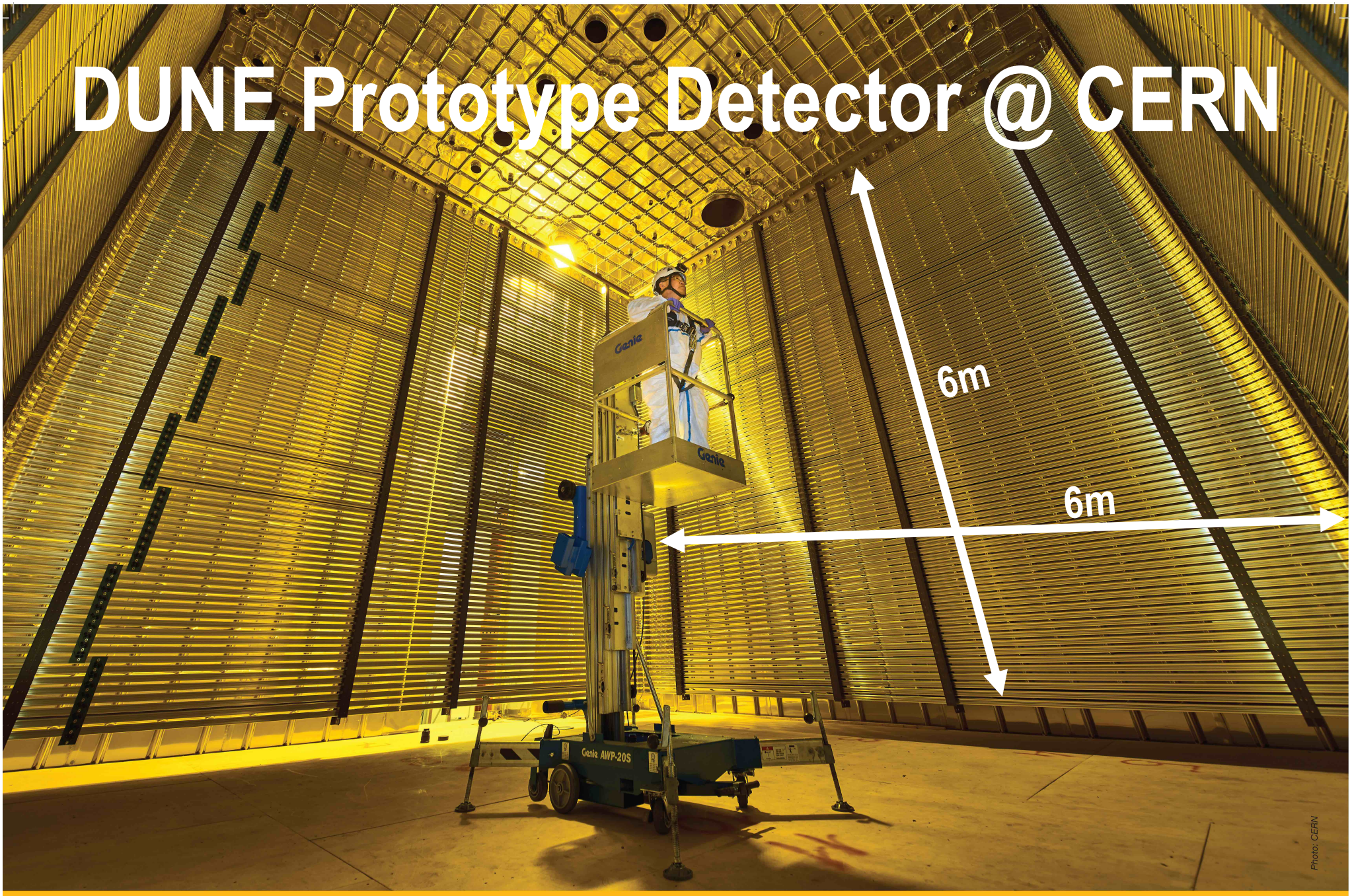

- What is the electric field between the cathode and the ground grid?
- What do you need to know?
  - $V_{cathode}$= - 300kV
  - d= 70cm

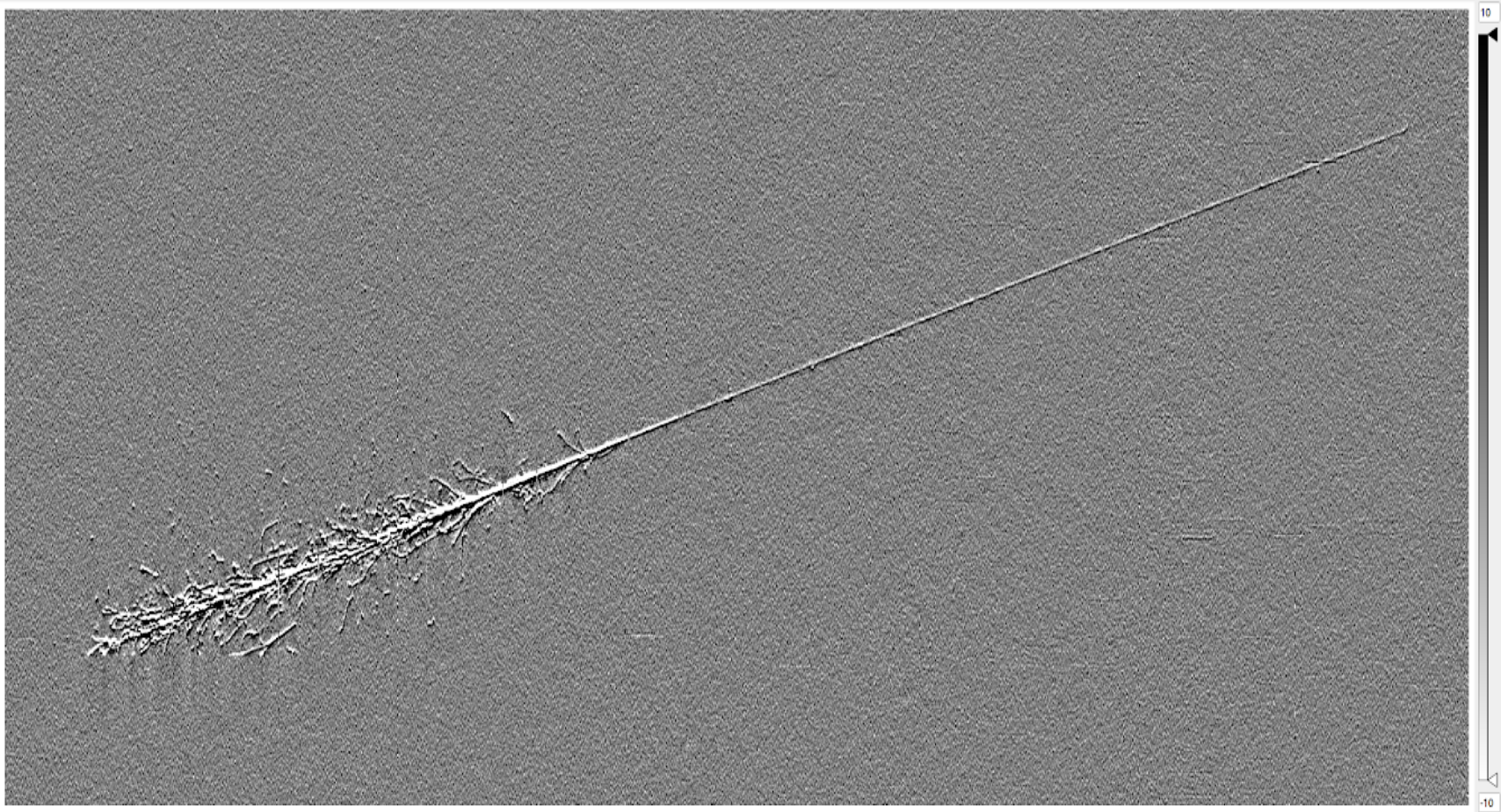
Charge Readout Planes

Field Cage (common structural elements with SP)

Cathode

Ground Grid


DUNE Prototype Detector @ CERN
6m
6m
Genie
Genie
Genie AWP-20S
Photo: CERN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Event: 1300
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Max Range
Clear Points
Eval. Points
Grayscale
AutoRange
Lock A.R.
Wire Drawing
Subtract Pedestal
Draw anode/cathode
Scale Bar
Use cm
Draw Logo
Draw Options
None
Wire
Select
Raw Digit
Select
OpDetWaveform
Hit:
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Cluster:
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Shower:
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Track:
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Mctrack:
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Endpoint 2
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--None--
Sps:
--None--
Opflash:
--None--
All Views
View H
Cryo 0
Cryo 1
View U
Cryo 0
Cryo 1
View V
Cryo 0
Cryo 1
Optical
View U, Cryo 1
Quit
W: 3711, T: 79
Message Bar
Capture Screen

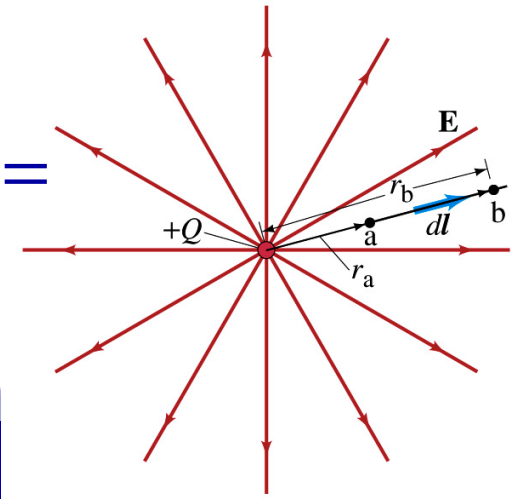
# Electric Potential due to Point Charges

- What is the electric field by a single point charge Q at a distance r?

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2} = k\frac{Q}{r^2}$$

- Electric potential due to the field E for moving from point $r_a$ to $r_b$ in the radial direction away from the charge Q is

$$V_b - V_a = -\int_{r_a}^{r_b} \vec{E}\cdot d\vec{l} = -\frac{Q}{4\pi\varepsilon_0}\int_{r_a}^{r_b}\frac{\hat{r}}{r^2}\cdot\hat{r}\,dr =$$

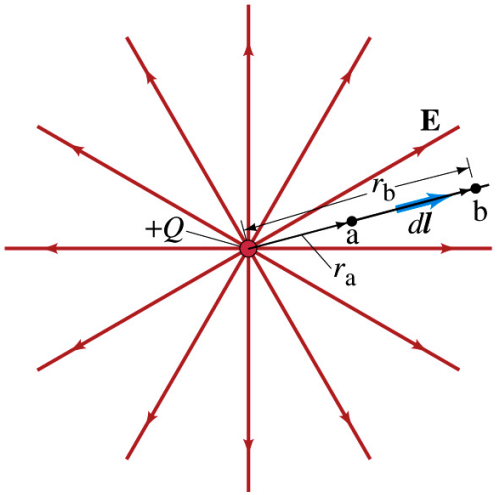



$$= -\frac{Q}{4\pi\varepsilon_0}\int_{r_a}^{r_b}\frac{1}{r^2}dr = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_b} - \frac{1}{r_a}\right)$$

# Electric Potential due to Point Charges

- Since only the differences in potential have physical meaning, we can choose $V_b = 0$ at $r_b = \infty$.
- The electrical potential V at a distance r from a single point charge Q is

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




- So the absolute potential by a single point charge can be thought of **the potential difference by a single point charge between r and infinity**

# Properties of the Electric Potential

- What are the differences between the electric potential and the electric field?
  - Electric potential (poll 2)

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

    - 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 (poll 2)

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

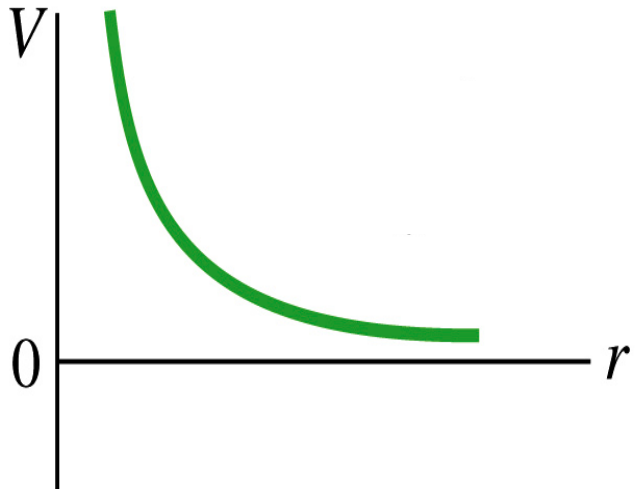
    - Electric force per unit charge
    - Inversely proportional to the **square** of the distance
    - Need vector sums to obtain the total field from multiple source charges
- Potential due to a positive charge is a large positive near the charge and decreases towards 0 at the large distance.
- Potential due to a negative charge is a large negative near the charge and increases towards 0 at a large distance. (Poll12)

# Shape of the Electric Potential

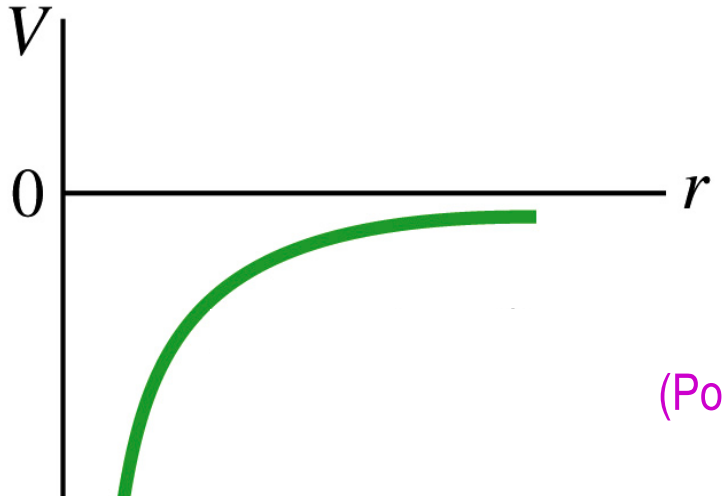
- So, how does the electric potential look like as a function of distance?
  - What is the formula for the potential by a single charge?

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

If Q is Positive




If Q is Negative




(Poll12)

**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.**