MAKIN' IT ROUND THE BEND:
QUALITATIVE
STUDENT PAGES

DESCRIPTION
Have you ever wondered how the Large Hadron Collider (LHC) causes the protons to travel so fast? Have you ever wondered why the LHC is a large circle? This activity is designed to help you develop answers to these questions using a simulation of various parts of the LHC.

WHAT YOU MUST KNOW
You must be able to:
- Define the types of electrically charged particles as positive or negative.
- Define the types of magnetic poles as north and south.
- Apply the right-hand rule in situations described by vector cross products.

LEARNING OBJECTIVES
Qualitative Treatment:
As a result of this investigation, you will be able to:
- Describe the direction of motion of an electrically charged particle when interacting with an electric field.
- Describe the direction of motion of an electrically charged particle when interacting with a magnetic field.
- Describe the conditions needed for an electrically charged particle to travel through a region of crossed electric and magnetic fields with velocity unchanged.
- Describe the path traveled by an electrically charged particle entering a region of magnetic field.
- Describe how the right-hand rule can be used to predict the curvature of an electrically charged particle in a magnetic field.

RESOURCES/MATERIALS
The links below provide useful background material.
https://home.cern/about/how-accelerator-works
http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach/components/magnets.htm
http://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.magnetic_multipoles

IMPLEMENTATION
Each part below will use the *Makin' it Round the Bend* simulation:
https://quarknet.org/sites/default/files/MassSpec_moverq11Mar2018.html__0.zip.
(The folder must be decompressed. There is provision for this step in both Windows and Mac operating systems. Ask your teacher for help if you need it.)

Open the simulation and get acquainted with the features of the simulation. Along the bottom there are buttons for *Play, Pause, Step left (Step <<), Step right (Step >>),* and *Reset*. There is no *Stop* button so you must use *Pause* to stop the simulation. There are three tabs along the very bottom of the simulation. Each tab opens the simulation for that part.

1. *Accelerator*
   - Along the bottom locate values for t in x10^{-6} s, x in mm, and v_x in km/s. Below the parallel plates are sliders to select *Electric field* in N/C, and *mass/charge ratio*

in x10^{-9} kg/C.

2. *Velocity Selector*
    - Along the bottom are the values for *t* in x10^{-6} s. Just under the parallel plates are values for *x* in mm, *y* in mm, v_X in km/s and v_Y in km/s. Below the parallel plates there are sliders to select *Electric field* in N/C, *Magnetic field* in mT, Charge Attributes: *mass/charge ratio* in x10^{-9} kg/C, and *Initial* v_x in km/s.
3. *Mass Spectrometer*
    - Under the velocity selector plates are values for *t* in x10^{-6} s, the values for *x* in mm, *y* in mm, v_X in km/s, and v_Y in km/s. The sliders control each region of the mass spectrometer:
        - *Velocity Selector* Controls: *Electric field* in N/C, *Magnetic field* in mT
        - *Mass Deflector* Controls: *Magnetic field 2* in mT
        - *Charge Attributes*: *mass/charge ratio* in x10^{-9} kg/C
        - *Initial* v_x in km/s

In each section, the force vector resulting from the interaction between the electrically charged particle and the field is the same color as the field vector.

PART 1: PICKING UP SPEED

Select the tab *1. Accelerator* to begin this activity. Make sure that you know how to start and stop the simulation to collect data for change in velocity and change in time. You can use these data to determine the acceleration of the electrically charged particle for a chosen setting of the *Electric field* slider.

<u>Qualitative Treatment</u>:

You need to gather evidence to answer the following questions:

- Does the electrically charged particle change motion in the electric field? What evidence from the data supports your claim?
- Does the electrically charged particle speed up, slow down or have constant velocity? What evidence from the data supports your claim?
- What is the direction of motion of the electrically charged particle compared to the direction of the electric field vector? What evidence from the data supports your claim?
- If the electric field strength is increased, does the electrically charged particle speed up more, slow down more or continue to travel with the same velocity? What evidence from the data supports your claim?

Organize your notes and write claim, evidence, reasoning statements for each question.

PART 2: CHOOSE YOUR RACER

Select the tab *2. Velocity Selector* to begin this activity. Notice that the initial setting results in the electrically charged particle traveling straight through the region of crossed electric and magnetic fields.

<u>Qualitative Treatment</u>:

You need to gather evidence to answer the following questions:

- What is the test, using the meters just below the parallel plates, to determine if the electrically charged particle is traveling straight through the plates? What evidence from the data supports your claim?

- What is the relationship between the electric field vector and the magnetic field vector when the electrically charged particle passes straight through the crossed electric and magnetic fields? What evidence from the data supports your claim?
- If the initial velocity in the x direction is changed with no change to the electric field strength or the magnetic field strength, does the electrically charged particle continue to travel straight through? What evidence from the data supports your claim?
- Select a new initial velocity in the x direction. What adjustments must you make to the electric field strength and magnetic field strength to once again make the electrically charged particle travel straight through the crossed electric and magnetic fields? What evidence from the data supports your claim?

Organize your notes and write claim, evidence, reasoning statements for each question.

PART 3: MAKIN' IT ROUND THE BEND

Select the tab *3. Mass Spectrometer* to begin this activity. You can set the values for the Charge Attributes, mass/charge ratio and Initial v_x at the beginning of each run. Notice that the initial setting of v_x allows the electrically charged particle to travel straight through the *Velocity Selector* when the *Electric field 1* and *Magnetic field* sliders are set appropriately. The electrically charged particle then enters the Mass Deflector which is controlled by *Magnetic field 2*.

Qualitative Treatment:

Gather evidence to answer the following questions:

- What is the relationship between the magnetic field strength in the mass spectrometer and the radius of curvature of the particle path? What evidence from the data supports your claim?
- What is the relationship between the mass/charge ratio and the radius of curvature of the particle path? What evidence from the data supports your claim?
- What is the relationship between the velocity of the particle as it enters the mass spectrometer and the radius of curvature? What evidence from the data supports your claim?
- What mathematical model can be used to describe the radius of curvature of the particle path based on these relationships? What evidence from the data supports your claim?

Organize your notes and write claim, evidence, reasoning statements for each question.