MAKIN' IT ROUND THE BEND:
QUANTITATIVE
STUDENT PAGES

DESCRIPTION
Have you ever wondered how the Large Hadron Collider (LHC) can cause 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.

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. Open the simulation and introduce yourself to its features. *Link to 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, are the values for t in $x10^{-6}$ s, x in mm, and v_x in km/s. Below the parallel plates there are sliders to select *Electric field* in N/C, and *mass/charge ratio* in $x10^{-9}$ kg/C.
2. *Velocity Selector*
   - Along the bottom, is the value for t in $x10^{-6}$ s. Just under the parallel plates, are the 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 the 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 m T
     - *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 charge particle and the field is the same color as the field vector.

PART 1: PICKING UP SPEED
Select Tab *1. Accelerator* to begin this activity.

Practice starting and stopping the simulation to collect data for change in velocity and change in time. You can use these data can to determine the acceleration of the electrically charged particle for a chosen setting of the *Electric field* slider. Organize your data into a data table. A suggested arrangement is shown:

t_1 (10^{-6}s)	v_{x1} (km/s)	t_2 (10^{-6}s)	v_{x2} (km/s)	a (km/s^2)	E (N/C)

Collect data for at least five values of *Electric field* strength. You will need more rows in your data table.

Construct a graph of *Electric field* vs. *acceleration*. Use the checklist to complete the data analysis for this part:
- Plot graph of E vs a including linear scale, units on axes, correctly plotted points, best fit line.
- Find the slope of the best fit line not just two data points.
- Correctly determine the SI units of the slope.
- Use the slope units to determine the physical meaning of the slope.
- Write the equation of this graph.
- Relate this result to theoretical equations.
- Write a paragraph providing claim, evidence and reasoning to justify the mathematical model suggested by the value and units of the slope of the linear graph.

PART 2: CHOOSE YOUR RACER
Select 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.

Select a new initial velocity in the x direction and a new *mass/charge* ratio.
Select a value for *Electric field* .
Adjust the *Magnetic field* value until the electrically charged particle continues straight through the *Velocity Selector*.
Change the *Electric field* value.
Collect data for at least five values of *Electric field* strength.
Organize your data into a data table. You will need to add more rows to the data table. See a suggested arrangement:

Mass/charge _____(kg/C)   *Initial v_x* _____km/s

E (N/C)	B (mT)

Construct a graph of E vs B. Use the checklist to complete the data analysis for this part:
- Plot graph of E vs B including linear scale, units on axes, correctly plotted points, best fit line.

- Find the slope of the best fit line not just two data points.
- Correctly determine the SI units of the slope.
- Use the slope units to determine the physical meaning of the slope.
- Write the equation of this graph.
- Relate this result to theoretical equations.
- Write a paragraph providing claim, evidence and reasoning to justify the mathematical model suggested by the value and units of the slope of the linear graph.

PART 3: MAKIN' IT ROUND THE BEND

Select Tab *3. Mass Spectrometer* to begin this activity. The values for the Charge Attributes, mass/charge ratio and Initial v_x can be set 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*.

Set the *Initial v_x* value as the electrically charged particle enters the *Velocity Selector*.
Adjust the *Electric field 1* and the *Magnetic field* in the *Velocity Selector* to be sure the electrically charged particle passes into the *Mass Spectrometer*. The magnetic field in the *Mass Deflector* is controlled by *Magnetic field 2*.
Let the simulation run and press *Pause* while the particle is still in the *Mass Deflector*.
Record the necessary data.
Collect data for at least five values of *Magnetic field* strength. You will need to add rows to your data table. The radius value (*r*) is found using ½ Δy.
Organize your data into a data table. A suggested arrangement is shown:

mass/charge ratio _____(x 10^{-9} kg/C) *Initial v_x* _____(km/s)
Magnetic Field 2 _____mT

Mass Deflector			
Δx (mm)	*Δy* (mm)	*r = ½ Δy* (mm)	*B* (mT)

Construct a graph of *r* vs *B*. Use the checklist to complete the data analysis for this part:
- Plot graph of *r* vs *B* including linear scale, units on axes, correctly plotted points, best fit line.
- Correctly linearize the data by plotting *r* vs *1/B*
- Find the slope of the best fit line not just two data points.
- Correctly determine the SI units of the slope.
- Use the slope units to determine the physical meaning of the slope.
- Write the equation of this graph.
- Relate this result to theoretical equations.
- Write a paragraph providing claim, evidence and reasoning to justify the mathematical model suggested by the value and units of the slope of the linear graph.