# “Conservation of momentum” Lesson plan

## About the lesson plan

Please provide some general information about your lesson plan.

**Title:** Conservation of momentum

**Brief Description:** Students will determine the total momentum from all particles tracked after a particle collision and they will calculate the missing momentum(magnitude & direction).

**Subject Domain:** Accelerators & beams, Calorimeters, Particle beam parameters, Particle detectors, Angular velocity, Collision, Conservation of momentum

**Keywords:** mass, velocity, acceleration, energy, momentum, collision, conservation of momentum, radians, degrees, vector

**Language:** English

**Age Range:** 15 – 18

**Didactical Hours:** 3 didactic hours

**Educational Objectives (Types of knowledge):**
Factual: Learn about the conservation of momentum.
Conceptual: Get acquainted with particle physics research
Procedural: Learn how to add vectors, Measure vector angles and convert radians to degrees of angle
Meta-cognitive: Learn how to process real scientific data from the ATLAS experiment

## Orientation

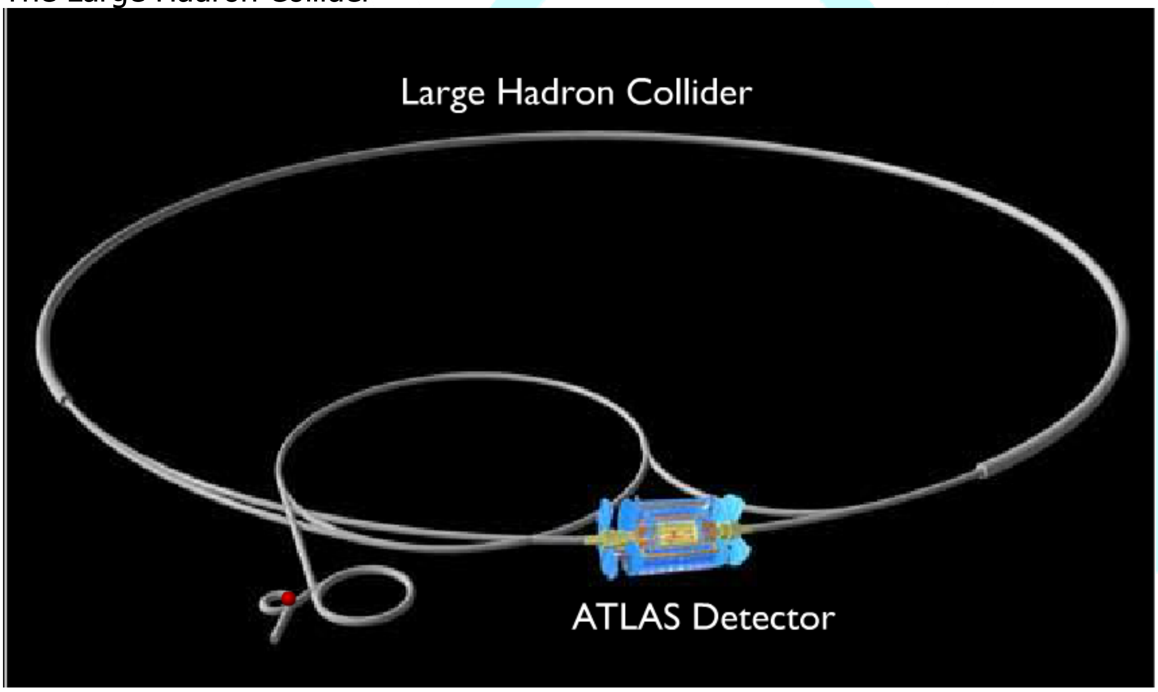
a. The LHC@CERN

The Large Hadron Collider (LHC) is a gigantic scientific instrument near Geneva, where it spans the border between Switzerland and France about 100m underground. It is a particle accelerator used by physicists to study the smallest known particles – the fundamental building blocks of all things

CERN in 3 minutes

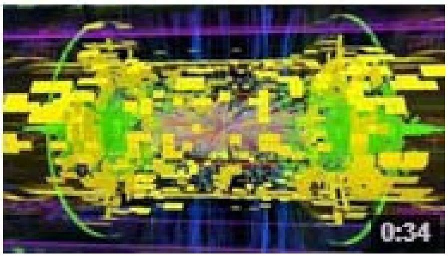

Two beams of subatomic particles called 'hadrons' – either protons or lead ions – will travel in opposite directions inside the circular accelerator, gaining energy with every lap. Physicists will use the LHC to recreate the conditions just after the Big Bang, by colliding the two beams head-on at very high energy. Teams of physicists from around the world will analyse the particles created in the collisions using special detectors in a number of experiments dedicated to the LHC.

The Large Hadron Collider




http://hands-on-cern.physto.se/ani/acc_lhc_atlas/lhc_atlas.swf

Heavy Ion Collision Event Animation




http://www.youtube.com/watch?v=k64s4Ho-8-I

- What do you know about the work done at CERN?
- What are the experiments performed trying to achieve?
- What happens during the particle collisions that take place in the LHC?

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**Notes for the teacher:**
You may begin your lesson with a brief presentation of CERN and the Large Hadron Collider using videos or numerous pictures. Trigger a small conversation with your class by asking your students the questions mentioned above and others like them. You may find additional information on LHC in the "The LHC brief description" document. Try to guide the discussion towards the introduction of the elementary particles.

## Conceptualization

### Sub-phase: Hypothesis

Let's see what we already know about particle collisions!

**Step 1:**

1. Does the momentum depend on the direction of the velocity?
2. What is an isolated system?
3. What does "conservation of momentum" really mean?
4. Does the kinetic energy need to be conserved in collisions?
5. How are elementary particles classified?
6. When particles collide are new particles created or not?

Create a map which includes all the concepts that are relative to particle collision in the LHC. Use arrows to connect the different concepts.

**Step 2:**
Scientists at CERN analyse the data they get from particle collisions done in the LHC in order to answer their scientific questions. We will now put ourselves in the shoes of scientists and we will learn how they process their data. Our work will involve the studying of some events from the ATLAS detector. But first, we will have to set our own scientific questions. Read the

questions below and make your hypotheses. Make sure to write down your hypotheses in a notebook because our research will be based on them.

- Does the conservation of momentum also apply to the plane perpendicular to the beams' direction (x-y plane) during particle collisions?

- How can we measure the total momentum in such collisions in the x-y plane?

- If we measured the total momentum on the x-y plane after a collision what to you expect to find?

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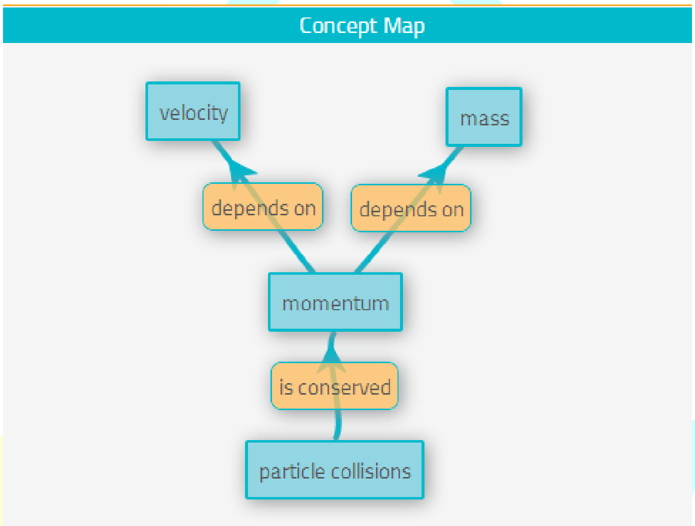
**Notes for the teacher:**

**Step 1:**

During your discussion with students on the issues mentioned above make sure to ask scientifically oriented questions like the ones mentioned above to further engage them. Thus, the related theory will mainly be presented by students and the teacher only adds information when needed. In the "Related theory" document you may find additional information on the theory involved in this activity.

An example concept map could be the following:




**Step 2:**

You may inform your students about what they will do during this exercise:

- Learn about the conservation of momentum
- Learn how to process the data provided by the ATLAS experiment.

Do not point out any mistakes students might make. Students are supposed to discover these mistakes themselves and correct them. Alternatively, you may note them down and bring them back to their attention at a later stage.

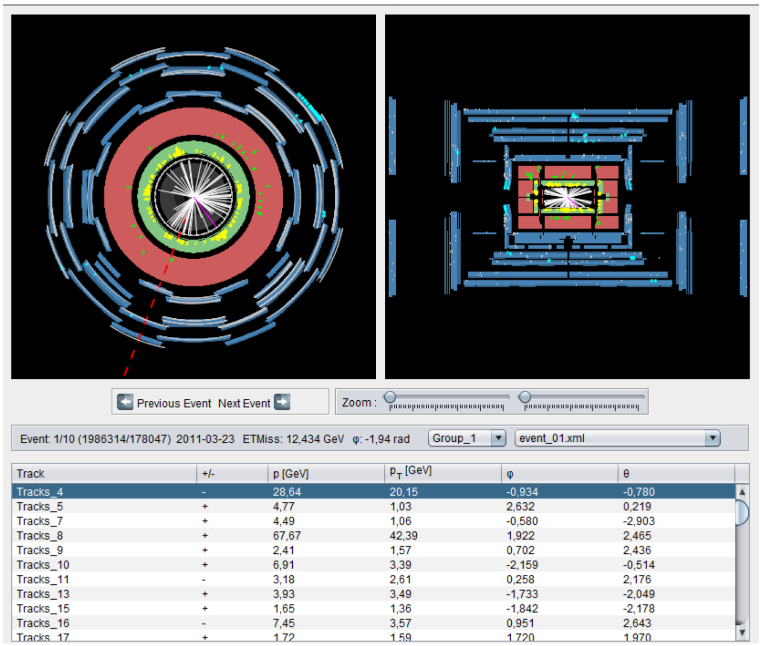
## Investigation

You can divide your students into groups of four students.

### Sub-phase: Experimentation

**Step 1:**

Before we get started with our research let's have a look at the lab we are going to use. The lab that will help us perform our research is called HYPATIA and it is an analysis tool designed to analyse real data obtained from the ATLAS experiment carried out on the LHC at CERN. Visit the "Equipment manual" document to read about the lab.




**Step 2:**

**1.** Select event file 'event_14.xml' (use buttons "Previous Event" and "Next Event") from the "Higgs" group of data to view the data from the collision under investigation.

**2.** Look at the data in the table below the detector. Try to understand to which track depicted in the detector each line of data belongs to.

**3.** In order to calculate the total momentum of the collision you will need to draw the vector of each particle. To do that, we must first identify the magnitude and the angle of each vector.

For each particle, the angle of the vector is the angle (φ) which is depicted in radians.
The magnitude of the each vector is the value in column P[GeV]). Use the table below to keep note of your data.

| Track Name | Particle Identity | Angle in degrees | Normalized magnitude |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

Before you draw your vectors you must make sure you are using the correct values. To this end pay attention to the 2 tips mentioned below*.

a. The angle is depicted in radians. In order to draw the vector you must first convert the angles in degrees.

b. In order to be able to draw the vectors they must all be drawn to scale. In order to do this you must normalize your values. Divide all measurement for the momentum with the lowest value and fill in the respective column of your table.

**4.** Based on your calculations above draw the respective vectors.

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**Notes for the teacher:**

The main idea of the exercise is for students to discover a missing particle based on the conservation of momentum using the HYPATIA analysis tool. In any particle collision like those under investigation the final total momentum on the x-y plane (the plane perpendicular to the direction of the two beams) is expected to be zero. Students will be asked to measure this total momentum after a collision and verify this fact. However the total momentum which they will calculate will not be zero which must lead them to the conclusion that an extra particle was created during the collision, whose track could not be detected by the instruments. In order for the momentum to be conserved this missing particle (which is a neutrino) must have momentum equal to the total momentum calculated by the students and of opposite direction.

You may choose to divide the class into groups in order to do the experimentation.

Students also have the tendency to change variables in a uncoordinated way. Guide them so as to make their investigation as systematic as possible by changing only one variable at a time and by keeping notes not only for their data but also about the process itself.

*You may choose not to provide the students upfront with the two tips mentioned above, and mention them only after they have faced the problem of how to draw the vectors.

**Tip:** Make sure students understand the connection between the investigation and the hypotheses they have made. In other words make sure they understand why they are doing every single step.

## Sub-phase: Data interpretation

Now use the data you have collected to make some further investigation.

1. Study the tracks and note down in your table what kind of particle you believe each track belongs to. Explain why you made each choice.

2. Based on the vector analysis you did calculate the amount of total momentum and its respective angle. Make sure to use the original values and not the normalized ones. Is the total momentum you calculated zero? If not, why is it not zero?

3. Draw the vector for the total momentum according to your estimation and the respective missing momentum vector. (Not exact solution)

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**Notes for the teacher:**
You may find the answers of the questions in the "Teacher answer key" document.

## Conclusion

Based on the experiment you conducted, answer the following questions. Note down your answers in order to produce your report.

1. Is the total momentum (the x-y plane) you calculated zero? If not, why is it not zero?

2. Does the conservation of momentum apply or not? If yes why is the total momentum you calculated non zero?

3. Does the vector for the missing momentum you drew match the vector presented in the detector?

4. What sources of error are there?

Now look back to your original hypotheses and compare them to your conclusions. Do your results agree with your conclusions? Identify any mistakes you might have made while making your hypothesis.

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**Notes for the teacher:**
If you have noted any mistakes that the students made during the previous phases make sure to bring them up and discuss them with their students so they may understand what their mistakes was.
It is useful to point out to the students, that the real set of data for this event (and all other events) included thousands of tracks which are very very small. Scientists, in order to make the same calculations for the vectors (just like the students did) they use extensive computational programmes.

**Editor: Tsourlidaki Eleftheria**

## Discussion

### Sub-phase 1: Communication

Make a brief report of your work so you can present your work to your fellow-students. In order to attract their attention try to be as creative as possible. You can do a small video out of it, a prezi, a PowerPoint presentation or a poster like those presented by scientists during conferences.

### Sub-phase 2: Reflection

Compare your results of your team used with those of other teams. Have you calculated the same total momentum?

Is there a possibility that other particles that have not been tracked might have been produced? Can you give examples?

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**Notes for the teacher:**
Comment on your students results. Point out which are the strong parts of their work and which are the weak ones.

Finally ask your students to comment on the accuracy of the method followed.

You may also discuss with them about the Higgs boson, and how scientist are able to track it through data like the ones they used in this activity. For more information check here.