Study data from the Large Hadron Collider

Connect to schools around the world during the World Data Day and compare your results

Orientation Phase

The World Data day (W2D2) is an activity which has been developed by the quarknet team (https://quarknet.org/). It is an event which takes place once per year and schools from all over the world discuss and compare their results from analysis of data from the ATLAS and CMS experiments at CERN with their fellow students via a video connection. The relevant site where the teachers can register for the event is https://quarknet.org/content/lhc-world-wide-data-day-2018. In order to compensate for different time zones the video connection lasts 24 hours and schools from similar time zones get connected simultaneously. The event during the 24 hour duration is moderated by high energy researches located in different parts of the world. The event takes place only once a year but the analysis of the events can be done at any time, when the teacher wishes to spend 1-2 hours with his/her students doing so. Moreover a collaboration with other schools can be arranged.

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Orienting and Asking Questions

Provide Contact with the content and/or provoke curiosity

- Have you heard about the ultimate components of matter, the quarks and leptons?
- Have you heard about the most powerful accelerator in the world the LHC, which is built at CERN in order to study the components of matter?
- Have you heard about the Higgs boson discovery in 2012 and how it completed our model of the subatomic world?
- Have you heard about the cosmic rays?

Learn about CERN

CERN is one of the world's largest research centers located near Geneva. It is dedicated to basic research: looking for answers to questions like "what is the Universe made of?", "what are the forces governing the behavior of the smallest constituents?", "what is dark matter made of?".

Watch the video "CERN in 3 mins": https://www.youtube.com/watch?v=PHP13tTjidA

The LHC@CERN

The Large Hadron Collider (LHC) is a gigantic scientific instrument at CERN. LHC is a circular accelerator with a circumference of about 27Km. The LHC tunnel spans the border between Switzerland and France and is about 100m under the ground. It is a particle accelerator used by physicists to study the smallest known particles – the fundamental building blocks of all things.

View the video below for further information

https://www.youtube.com/watch?v=pQhbhpU9Wrg

Two beams of subatomic particles called 'hadrons' – either protons or heavy ions –travel in opposite directions inside the circular accelerator, gaining energy with every lap. Physicists 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 analyse the particles created in the collisions using special detectors in a number of experiments dedicated to the LHC.

Watch what happens when two heavy nuclei collide:

Heavy Ion Collision Event Animation

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

LHC houses two general-purpose detectors/experiments the ATLAS and the CMS experiment. Both experiment on the 4th July 2012 reported evidence for the long sought Higgs boson.

The ATLAS detector/experiment

The ATLAS detector (A Toroidal LHC ApparatuS), was designed to cover the widest possible range of investigations at the LHC. Its main objectives are/were to discover the Higgs boson, to test the theory of supersymmetry, to study matter and antimatter, the formation of dark matter and to search for extra dimensions and new phenomena.

Involved in the experiment are 3000 physicists from 180 universities and laboratories in 38 countries. The detector with 44m length and 25m height is the largest, in volume, detector ever built. Its size stems from the need for great accuracy in detecting the nature and trajectory of the particles resulting from the particle collisions.

For more information watch the video

https://www.youtube.com/watch?v=ckARmttkTS4

The CMS detector/experiment

The CMS detector (Compact Muon Solenoid) is the other general-purpose detector at the LHC. It has a broad physics programme ranging from studying the Standard Model (including the Higgs boson) to searching for extra dimensions and particles that could make up dark matter. Although it has the same scientific goals as the ATLAS experiment, it uses different technical solutions and a different magnet-system design. The CMS detector is built around a huge solenoid magnet. This takes the form of a cylindrical coil of superconducting cable that generates a field of 4 Tesla, about 100,000 times the magnetic field of the Earth. The field is confined by a steel "yoke" that forms the bulk of the detector's 14,000-tonne weight.

The CMS experiment is one of the largest international scientific collaborations in history, involving 4300 particle physicists, engineers, technicians, students and support staff from 182 institutes in 42 countries.

For more information take a virtual tour of the CMS experiment:

https://home.cern/science/experiments/cms

Some questions now:

- What happens during the particle collisions that take place in the LHC?
- What are the experiments performed at the LHC trying to achieve?

Teacher Guidelines:

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. Try to guide the discussion towards the introduction of the elementary particles.

You can find more information about accelerators and particle detectors in http://www.particleadventure.org/accelerators-and-detectors.html

Exploratory Phase

Question or Statement

Define Goals and/or questions from current knowledge

What do we currently know about the nature of subatomic particles and the forces that govern them?

Figure 1 shows (on the left with red and yellow) all the known elementary particles today. According to the most successful theoretical model, the Standard Model, all particles can be described on the basis of the six quarks and six leptons that are the fundamental building blocks. The forces that govern the interactions of particles are four and are transmitted via the force mediating particles (the right column of the figure).

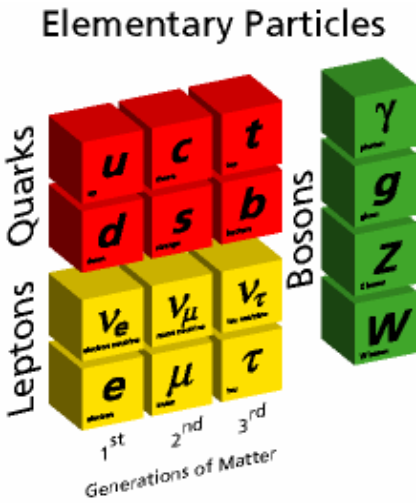


Figure 1 : Elementary particles and force carriers

The photon that has zero mass is the mediating particle of the electromagnetic force, the gluons (also massless) are the carriers of the strong interaction, the Z particles and W, are the mediating particles of weak interactions. Finally the graviton (not included in the figure above) for which we know very little, but is different from other mediating particles, is gravity's mediating particle.

Teacher Guidelines:

For more information you can visit the site:
http://www.particleadventure.org/standard-model.html

Generation of Hypotheses or Preliminary Explanations

Particle Collision Products

Some particles are very short-lived and decay almost immediately to more stable particles. In most proton collisions, the protons have gentle interactions, and the majority of the particles continue in the direction of the original particles (rather than perpendicular to the beam). However, rarely a few very massive particles are produced. If particles originate from the decay of a parent particle, their tracks should join together at the same origin point, called a "vertex".

Most massive particle's decays often give rise to several high-energy particles going out at large angles, more or less perpendicular to the original protons in the beam. For this reason we measure the momentum in a plane transverse to the bean plane, the so called transverse momentum (p_T), and we use it to pick up interesting events. By adding up the decay products which come from the same vertex we reconstruct the original "invisible" particle. In this demonstrator you will study the muons registered by the detectors which are the decay products of these “invisible” particles.

Teacher Guidelines

Scientists at CERN analyse the data they get from particle collisions done in the LHC in order to answer their questions. Your students will now be put in the shoes of scientists and will learn how to process the data and make “discoveries”. Their work will involve the study of some events recorded by the huge ATLAS detector. But first, they will have to be able to answer scientific questions, such as:

How are elementary particles classified?

When particles collide are new particles created or not?

Evidence

Plan Investigation

Before starting the data analysis you should

I. Learn how to distinguish the traces the muons in the ATLAS detector
II. In order to learn how different particles interact with different components of the ATLAS detector play with the applet given in http://atlas.physicsmasterclasses.org/videos/teilchenidentifikation.swf
III. Understand what the muons are and why the leave long traces in the detectors

Perform Investigation

You can use data from either the ATLAS or the CMS experiment or both to make the directional distributions of the muon tracks recorded in the detectors

In order to measure the direction of the tracks the axes and the respective angles have to be defined. Both experiments are of roughly cylindrical shape, their center being the collision point and the axis of the cylinder being the axis of the beams.

- Z-axis is the axis of the colliding beams
- Y-axis is vertical, perpendicular to the z-axis. +y axis is towards the zenith
- X-axis is horizontal and perpendicular to the z-axis. +x is directed towards the center of the accelerator ring.

You will be measuring the polar angles θ and ϕ to determine the direction of the muon tracks. The following screenshots will show you the way to measure the angles (using a protractor)

A. Using ATLAS data

Step 1: Getting familiar with the HYPATIA analysis tool

Before we get started with our research let's have a look at the event display tool we are going to use. The tool 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.

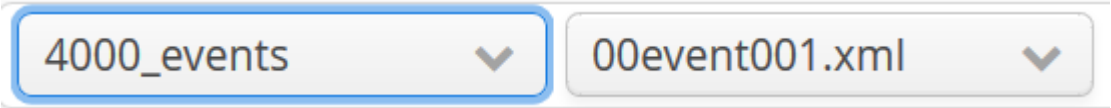
- You can access HYPATIA at : hypatia.iasa.gr/w2d2

Step 2: Identify the events of interest and measure angles

Each group of two students analyses a group of 50 events from the following google spreadsheet:

https://docs.google.com/spreadsheets/d/1r47xv8S7BJ_E-LG5IW_fY0ufOCgQ0esQeyNHelWwulk/edit#gid=0

Choose a group of events from column D, preferably different for each group of students. Open the HYPATIA event file tab to the right



and insert the group number (first two numbers correspond to the group and last three correspond to the event number).

Now the real work starts: You should search for events which have TWO long tracks which reach the blue muon chambers in at least one view. Ignore any other kind of events. When you find events of interest measure the ϕ angle (in the xy view) and the θ angle (in the yz view) for EACH muon as described in the screenshot below using a protractor as shown in Figures 3 and 4. Make a tick mark in the tally sheet for each angle measured using the closest value displayed. The tally sheets can be found in:

https://quarknet.org/sites/default/files/w2d2tally_0.pdf

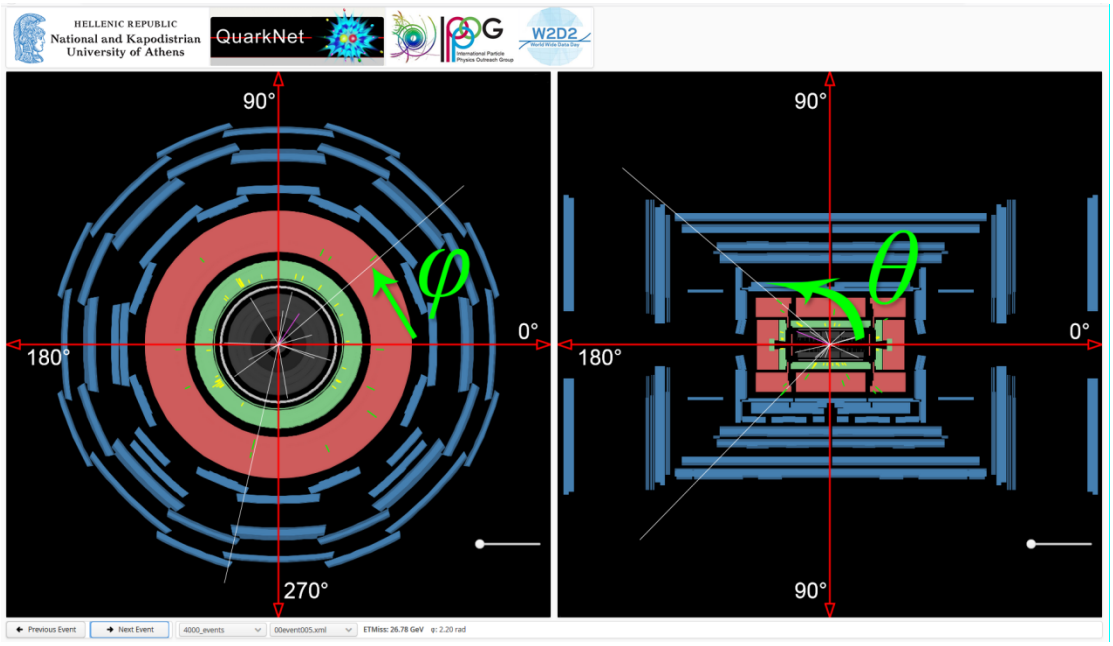


Figure 2: the xy and the yz endview of the ATLAS data using the HYPATIA tool, indicating how the φ and ϑ angles should be measured

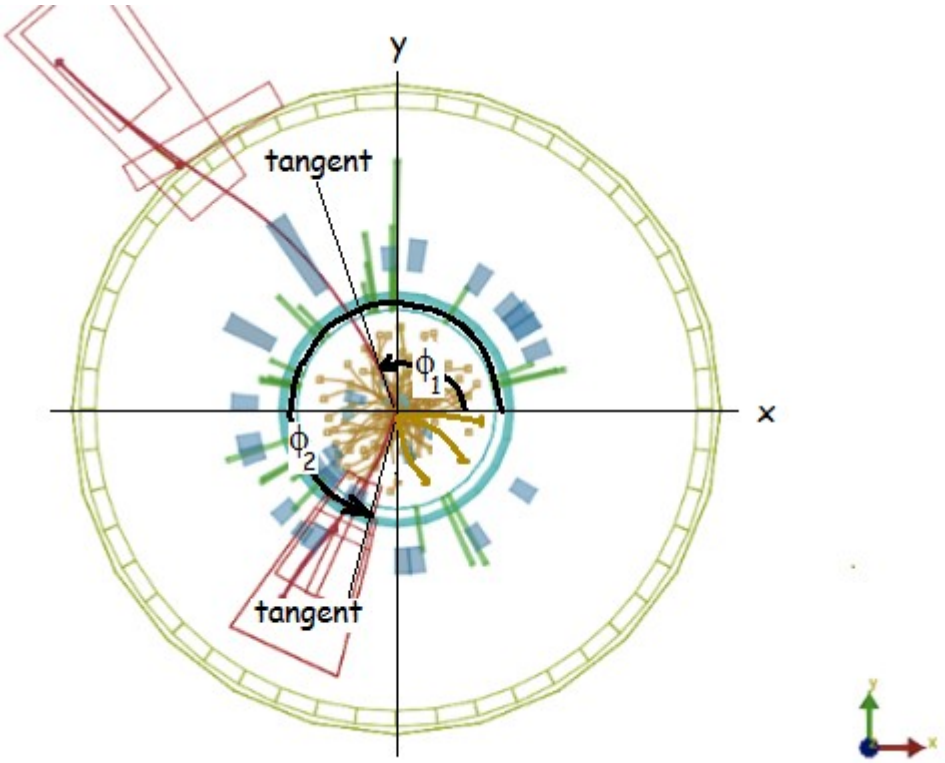
Step 3: Distributions

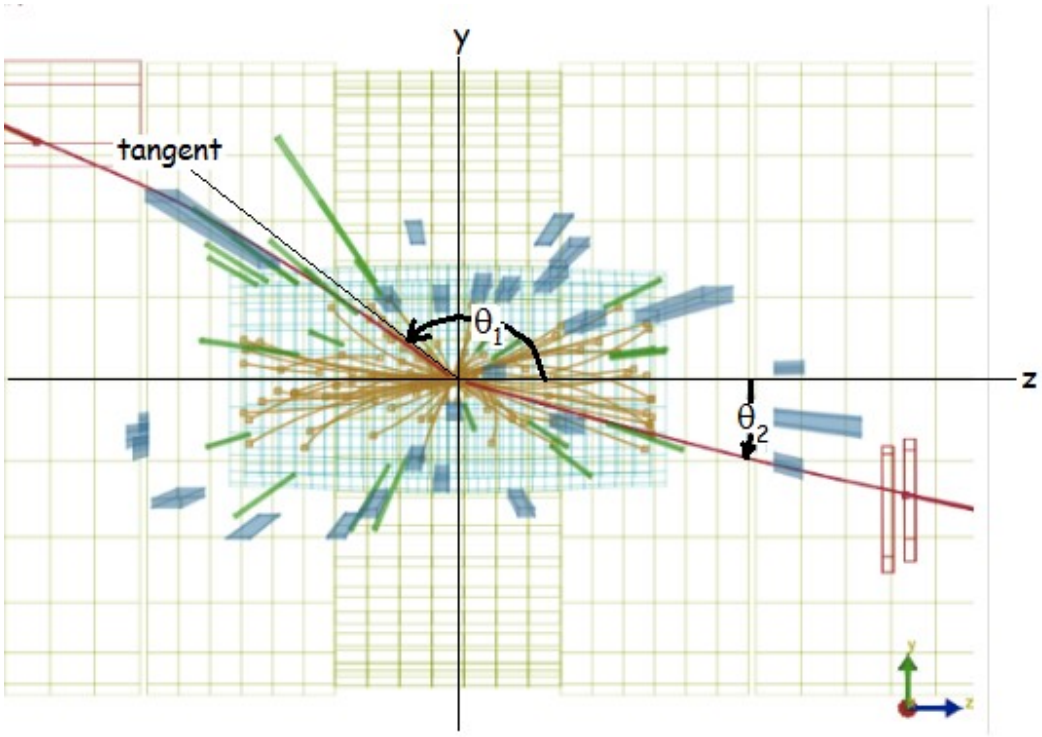
After all groups have finished analyzing their event group make a histrogram for each of the angles combining the measurement of all the class. Angle θ should be between 0 and 180 degrees whereas angle ϕ should be between 0 and 360 degrees.

B.Using CMS data

Step1: Get familiar with the ispy tool

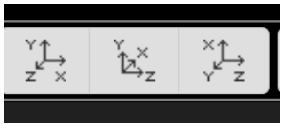
Open the CMS event analysis tool (ispy) http://ispy-webgl-w2d2.web.cern.ch/ this will give you a general view of the CMS detector. Use the left upper hand side tab to select the masterclass files and upload a file from the web. Below you see the event display of an event in both views.





Step 2: Identify the events of interest and measure angles

Each group of two students analyses a group of 100 events from the google speadsheet https://docs.google.com/spreadsheets/d/1r47xv8S7BJ_E-LG5IW_fY0ufOCgQ0esQeyNHelWwulk/edit#gid=994558702. Choose a group of events from column D and upload it from the masterclass file tab.

Now real work starts: You should search for events which have TWO long tracks in at least one view reaching the muon chambers. Ignore any other kind of events. When you find events of interest measure the ϕ angle (in the xy view) and the θ angle (in the yz view) for EACH muon. You can use the tab on top of the page  to change views. Measure the angles as described in the screenshots below (Fig 3 and 4) using a protractor and make a tick mark in the tally sheet for each angle measured using the closest value displayed. The tally sheets can be found in: https://quarknet.org/sites/default/files/w2d2tally_0.pdf

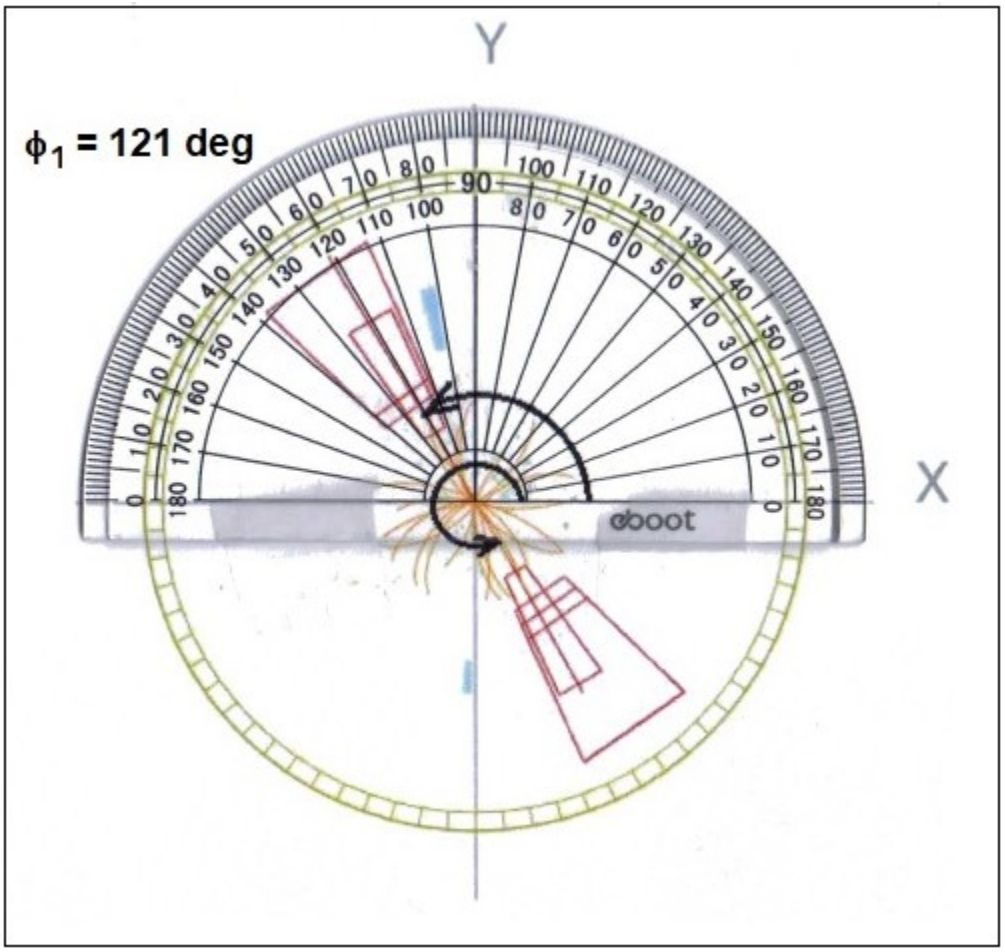


Figure 3: the xy endview of the CMS data using the ispy tool, indicating how the φ angles should be measured using a protractor

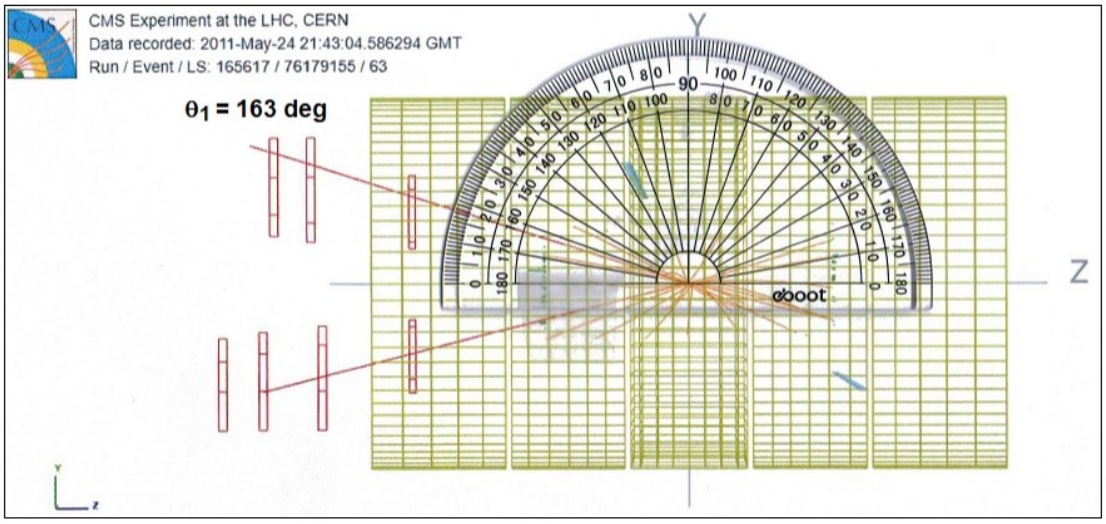


Figure 4: the yz endview of the CMS data using the ispy tool, indicating how the ϑ angles should be measured using a protractor

Step 3: *Distributions*

After all groups have finished analyzing their event group make a histrogram for each of the angles combining the measurement of all the class. Angle θ should be between 0 and 180 degrees whereas angle ϕ should be between 0 and 360 degrees.

Teacher Guidelines:

A great help for using the CMS ispy tool is provided by the following webcast: https://www.screencast.com/t/mPwIbd44

Special notes on recording data in Google sheet:
Please assign data to students to examine. In the interests of speed and to avoid too much data overlap, please try to assign 50 events to each group of two students working together and try to assign data that has not been entered so far. You can find data used listed by other teachers in the google spreadsheet under Dataset in column D. Note that each dataset for CMS has 100 events and each dataset for ATLAS has 50 events, so please plan accordingly.

It was suggested in the screencasts that students look in column D for data that has not been entered in at least the past 20 lines. Students will not have to worry about that if you assign them the data.
Each class *(not each student or pairs of students) should enter total data on* one *line. In the Dataset cell in column D, summarize the datasets used, e.g. "7, 9-14". If you make a histogram of class results for ϑ and another for φ (useful for discussion below), this should be easy to do.*

Analysis and Explanation

Analysis: Analyze evidence to discover a possible answer

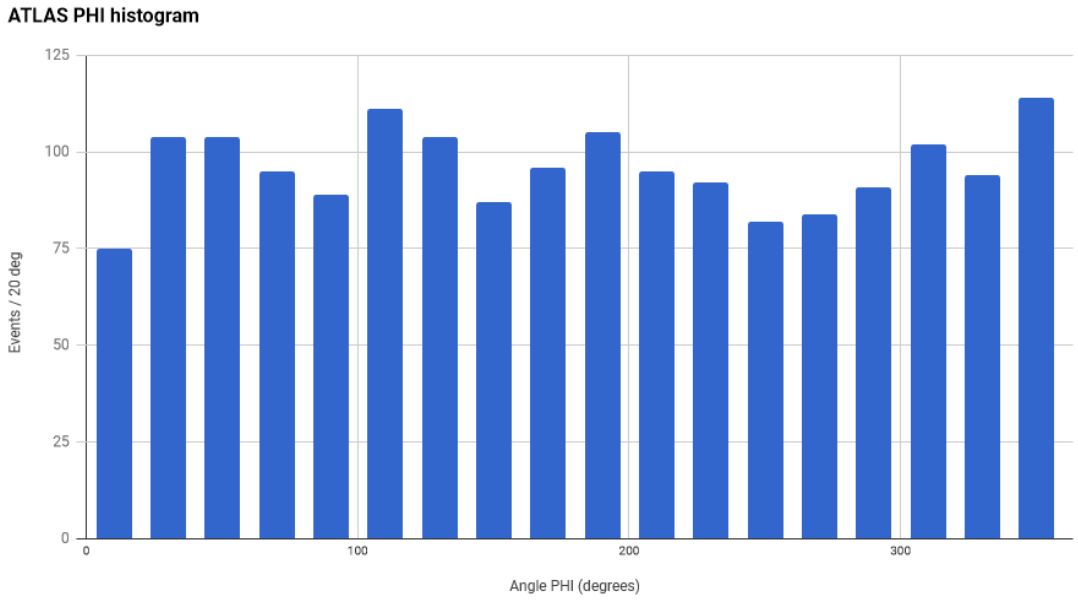
Look at the ϕ and θ angle distributions produced by combining the measurements of all the class.

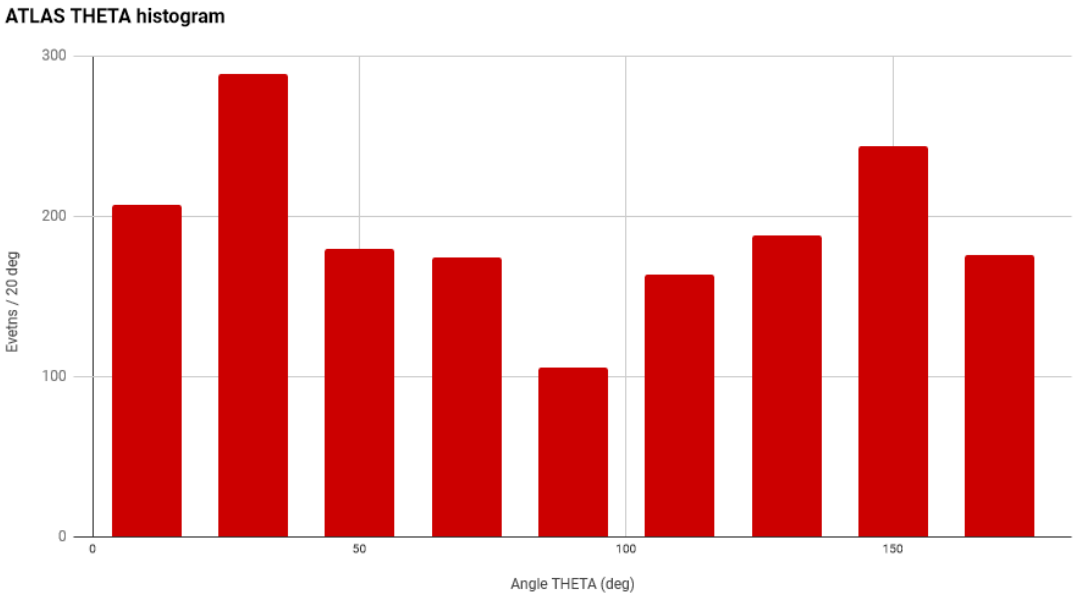
- Are the distributions uniform? If not can you think of reasons for not being so?
- The cosmic rays are mainly composed of muons. Do you think that you have observed any cosmic rays? Justify your answer
- Discuss with your teacher what could be the "virtual" particles which decayed in the two muons which you measured.
- Take a closer look at the ATLAS and CMS detectors to decide if they are symmetrical in the xy and yz views.

Explanation: Formulate an explanation based on the analysis of your evidence

Below you see the ϕ and θ distributions obtained by combining measurements of several schools

- What do you observe?
- How different are they from your measurements?
- Comment on possible bias on the measurements





What are advantages of looking at everyone's combined data on one plot?

You may wish to watch the following short video:
https://www.youtube.com/watch?v=73JeQ2RZnwc

To understand when the physicists claim "evidence" for a new result and when they claim "discovery"

Teacher Guidelines:

You may wish to carry further the statistics argument by performing some simple experiments with dices filling histograms :

https://quarknet.org/data-portfolio/activity/dice-histograms-probability

or teach students about the Gaussian distribution with a simple rolling balls experiment:

https://quarknet.org/data-portfolio/activity/rolling-rutherford

Consolidation Phase

Connect

Connect explanation with current scientific knowledge

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

1. What is the best way to combine the results from different groups of students? Should you do that?
2. Can you combine results from the two different experiments (ATLAS and CMS)?
3. What is of the statistical error in each angle bin? Different mass measurements?

Teacher Guidelines:

If you have noted any mistakes that the students made during the previous phases make sure to bring them up and discuss them with your students so they may understand what their mistakes was.

It is useful to point out to the students, that these are real sets of data, but the events have undergone a certain selection. Most events recorded from the collisions DO NOT contain dimuons

Communicate

Communicate and justify your explanation

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 make a small video out of it, a prezi, a PowerPoint presentation or a poster like those presented by scientists during conferences.
You can communicate with other schools around the world on W2D2. In November 2019 about 70 schools where connected and presented their results. The following map shows the location of the schools

Reflect

Reflect on what you have learned from the learning process

Compare the results of your team with those of other teams.

Could there be particles which escape the detector “unseen”?

Teacher Guidelines:

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.

If you register for the World Data Day then you and your students can enter in a video conference to discuss the results with other schools at approximately the same time zone. In order to connect you have to follow the steps described in the W2D2 webpage (http://tiny.cc/w2d2-18). You will need:

- A computer with a good FIXED internet connection and a microphone, camera, and speakers.
- Download the vidyo system which CERN scientists use to communicate with each other
- This can be done from https://cloud.vidyo.com/signup