CMS WZH–PATH MASTERCLASS
TEACHER NOTES

<u>NOTE</u>: This activity is designed to help teachers and their students participate in a masterclass held at a university or lab, in partnership with a particle physicist.

DESCRIPTION

Each year about 13,000 high school students in 50 countries come to one of about 200 nearby universities or research centers for one day in order to unravel mysteries of particle physics. Lectures from active scientists give insight in topics and methods of basic research on matter and forces at the fundamental level, enabling the students to perform measurements on authentic data from particle physics experiments. At the end of each day, as in an international research collaboration, the participants join in a videoconference for discussion and combination of their results.

STANDARDS ADDRESSED

Next Generation Science Standards

Science and Engineering Practices

1. Asking questions
2. Developing and using models
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Disciplinary Core Ideas – Physical Science

PS1.A: Structure and Properties of Matter
PS2.B: Types of Interactions
PS2.C: Stability and Instability in Physical Systems
PS3.B: Conservation of Energy and Energy Transfer
PS3.C: Relationship between Energy and Forces

Crosscutting Concepts

1. Patterns
2. Cause and Effect: Mechanism and Explanation
3. Scale, Proportion, and Quantity
4. Systems and System Models
7. Stability and Change

Common Core Literacy Standards

Reading

9-12.4 Determine the meaning of symbols, key terms . . .
9-12.7 Translate quantitative or technical information . . .

Common Core Mathematics Standards

MP2. Reason abstractly and quantitatively.
MP6. Attend to precision.

IB Physics Standard 1: Measurement and Uncertainty

1.2.6 Describe and give examples of random and systematic errors.
1.2.8 Explain how the effects of random errors may be reduced.
1.2.11 Determine the uncertainties in results.

IB Physics Standard 7: The Structure of Matter

Aim 4: Particle physics involves the analysis and evaluation of very large amounts of data.
Standard 7.3.4: Apply the Einstein mass-energy equivalence relationship.

ENDURING UNDERSTANDINGS

- Claims are made based on data that comprise the evidence for the claim. These data provide indirect evidence to study phenomena that cannot be directly observed.
- Particle physicists use conservation laws to discover characteristics, such as mass and charge, of

fundamental particles that cannot be observed directly.

Learning Objectives

Students will be able to:

1. Describe the particle properties that are detected by each major component of the CMS detector.
2. Apply pattern recognition and conservation laws to identify particles and their charges, given a set of CMS events.
3. Build a mass histogram and determine the mass of each particle identified on this histogram.
4. Describe how the shape of a peak on the histogram gives an indication of the uncertainty in the reported mass for each particle identified.

Prior Knowledge

Students must be able to:

- Describe a claim and indirect evidence based on an activity such as *Rolling with Rutherford* found in the Data Portfolio.
- Identify the peak in a histogram and explain what it means based on an experiment such as *Dice, Histograms and Probability* found in the Data Portfolio.
- Describe how quarks combine to form mesons and baryons based on an activity such as *Quark Workbench* found in the Data Portfolio.
- Apply conservation rules to measurements to provide evidence for unobserved particles based on an activity such as *Calculate the Top Quark Mass* or *Calculate the Z Mass* found in the Data Portfolio.

In order to address this prior knowledge before the masterclass day, you may use the classroom preparation resources found in the QuarkNet Masterclass Library; go online to https://quarknet.org, then select MASTERCLASSES from the top menu bar and then select LHC PROJECT MAP.

Background Material

- The LHC from *CERN in 3 minutes:* https://www.youtube.com/watch?v=PHP13tTjidA
- Information on the CMS experiment at CERN: https://home.cern/about/experiments/cms
- Additional background information can be found in the QuarkNet Masterclass Library; see above.

Resources

CMS Masterclass website: https://web.quarknet.org/mc/cms/

- Additional resources can be found in the QuarkNet Masterclass Library; see above.

Implementation

We encourage you to partner with a particle physicist (mentor) at a university or lab in order to conduct a masterclass for your students. The masterclass institute itself is usually one day in length and often takes place at the university or lab where the mentor is based. The most successful masterclasses involve advanced planning among the teachers and mentors involved, and include an orientation in which teachers and mentors become familiar with the masterclass process, structures, data analysis, and classroom preparation expectations that allow students to maximize their masterclass experience.

Implementation details can be found in the QuarkNet Masterclass Library; see above. We encourage you to use the Classroom Preparation and CMS sections of the Library. CMS Masterclass Documentation is included in the CMS section of the Library and helps you understand the mechanics of the CMS masterclass.

Assessment

Upon completion of the masterclass experience, you may have students provide answers to each of the following through discussion, and/or video, and/or written responses on paper.

1. Describe the particle properties determined by each major component of the CMS detector.
2. Apply pattern recognition and conservation laws to identify particles and their charges, given a set of CMS events.
3. Build and interpret a mass histogram.
4. Explain how the shape of the peak can give information about the uncertainty in your claim about the mass of the particle represented by that peak.