PLOTTING A CONSENSUS
TEACHER NOTES

DESCRIPTION
Scientists set about determining the characteristics of particles using multiple experiments. This activity allows students to determine the mass of the Z Boson and the uncertainty in that mass. The experiments produce varying values with varying uncertainty. The purpose of this activity is to come to a consensus for the "best" value for the mass of the Z Boson.

STANDARDS ADDRESSED
Next Generation Science Standards

Science and Engineering Practices

4. Analyzing and interpreting data
5. Using mathematics and computational thinking

Crosscutting Concepts

3. Scale, proportion, and quantity

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.

AP Physic 1: Algebra-Based and AP Physics 2: Algebra-Based Science Practices

Science Practice 4

The student can plan and implement data collection strategies in relation to a particular scientific question.

Science Practice 5

The student can perform data analysis and evaluation of evidence.

IB Physics

Topic 1: Measurement and Uncertainties

1.2.6 Describe and give examples of random and systematic errors.

1.2.7 Distinguish between precision and accuracy.

1.2.8 Explain how the effects of random errors may be reduced.

1.2.11 Determine the uncertainties in results.

ENDURING UNDERSTANDINGS
- Scientists must account for uncertainty in measurements when reporting results.

LEARNING OBJECTIVES
Students will know and be able to:
- Describe how to interpret a mass plot to determine the most likely mass of the Z boson.
- Describe how to interpret a mass plot to determine the uncertainty in the mass of the Z boson measurement.
- Compare multiple results and uncertainties using a "dot and whisker" plot. Share their team results and provide the evidence for their claim.
- Determine if there are any outliers in the data. What evidence supports their claim?

Prior Knowledge

For a given histogram, students should be able to:

- Determine the best value to represent the data.
- Determine the uncertainty in the best value to represent the data.

Note to teacher: Students can develop these skills by completing the portfolio activity *Histograms: Uncertainty.*

Resources/Materials

- Link to the plots: https://quarknet.org/sites/default/files/strange.pdf

Background Material

Prerequisite for this activity is *Histogram: Uncertainty.* Link

Implementation

Divide your students into pairs. Give each pair one of the six pre-printed mass plots to analyze. Print enough mass plots so that each group has a plot to analyze. Each plot may be analyzed by more than one group.

Each pair of students examines their plot to find the peak and the uncertainty. The uncertainty can be estimated using the Full Width Half Maximum statistical rule described below.

The width tells us the range of values for a given number of events. In Figure 1 on the right, the width at 20 Events/2 GeV is 100 GeV – 55 GeV = 45 GeV. The x-axis value of the peak represents the experimental value of the mass of the Z boson. The width is a measure of the statistical uncertainty in that value.

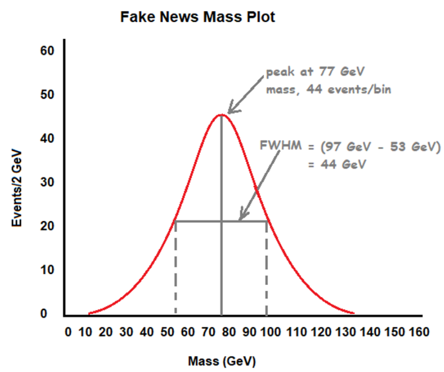

Figure 1

Each pair needs to team up with the other pairs who evaluated the same experimental result. The first task is to determine if the pairs results agree. If not, they should discuss and decide on a consensus value for the mass and a consensus value for uncertainty. Then, they report these two numbers to you.

You need to use a white board, large poster, or equivalent to prepare a blank graph with the axes labeled.

Each team needs to record their results on a *Fictional Z mass results* graph as shown in Figure 2 on the right. Note: This type of plot in Figure 2 is called a "dot and whisker" plot. Your students will be analyzing real data from real experiments. The version for your students will be blank. A student from each team plots the team result including an estimate for uncertainty. Instruct your students to place a dot to indicate the best estimate for the mass of the Z boson for their team experiment. The uncertainty is represented by a horizontal bar centered on the dot.

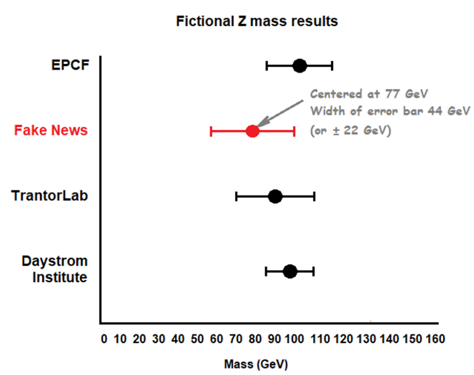

Figure 2

Lead a class discussion on what the community consensus on the mass of the Z boson based on the available results. There is one "outlier" planted in the assigned plots (New Linear Collider – not a real measurement). Dealing with the outlier should be part of the discussion, as should the reliability of the consensus. The technique can be generalized for finding properties of other particles.

ASSESSMENT

There are many possible conclusions supported by evidence. Use these questions as a guide.

- Describe how to interpret a mass plot to determine the most likely mass of the Z boson.
  - *The mostly mass of the Z boson is found by finding the peak in the data and reading the value of the peak on the horizontal axis.*
- Describe how to interpret a mass plot to determine the uncertainty in the mass of the Z boson measurement.
  - *The standard deviation in the Gaussian distribution is approximated by finding the width of the Gaussian when the frequency is half of the maximum value and dividing by 2 (Full-Width Half-Maximum over 2, or FWHM/2).*

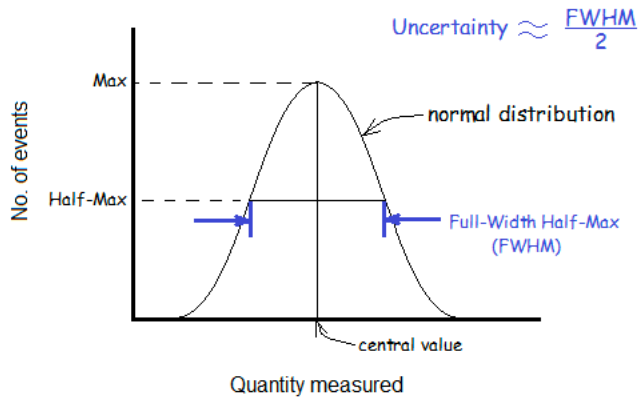

Figure 3: Defining uncertainty for a Gaussian distribution.

- Compare multiple results and uncertainties using a "dot and whisker" plot. Share your team results and provide the evidence for your claim.
  - *See Figure 2, a sample made using practice data.*
- Determine if there are any outliers in the data. What evidence supports your claim?
  - *Data is in agreement if the error bars overlap. An outlier falls completely outside the error bars of other data points. Using these data, the outlier is the data from* ***the New Linear Collider*** *mass plot.*

<u>Answer Key</u>*:*

The table lists typical results using the plots included in this activity. Your students' results will vary but they should agree within uncertainty with the values in the table.

CDF	91 ± 3 GeV/c^2
ATLAS	90 ± 4 GeV/c^2
New Linear Collider	**78 ± 4 GeV/c^2**
QN CMS e-Lab Z-> ee	90 ± 2.5 GeV/c^2
QN CMS e-Lab Z -> mu mu	92 ± 2.5 GeV/c^2
Masterclass	91 ± 3 GeV/c^2