Pre-Lab Questions:

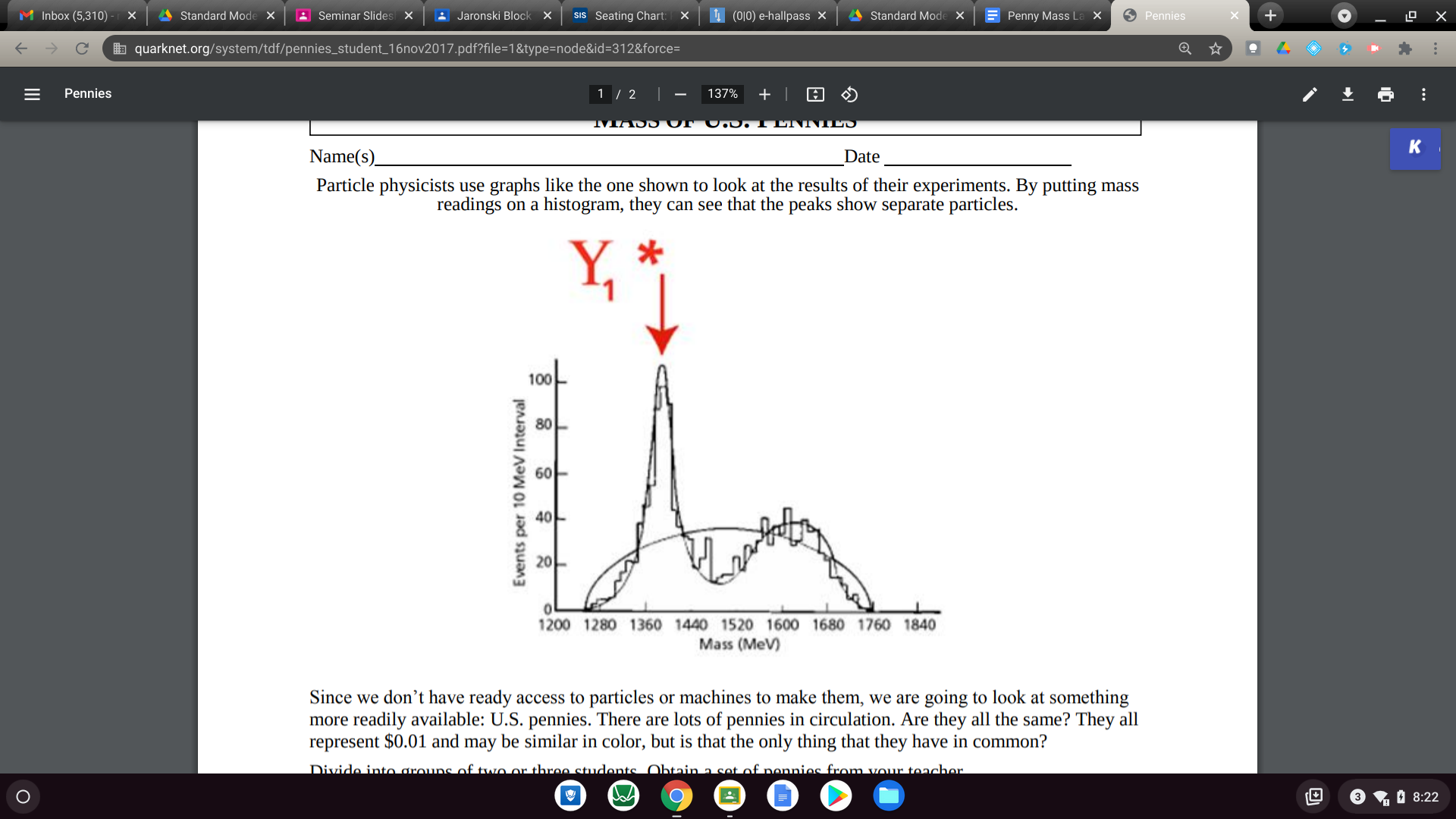
1. Are all coins the same mass?
2. If you pick up 3 pennies, or 3 dimes, are they all exactly the same?

Enduring Understandings: Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large data sets.

Objectives: In this activity, students will know and be able to:

1. Make a histogram to determine the mass of all U.S. pennies within experimental uncertainty.
2. Explain how this method of determining the change in U.S. penny composition relates to the experimental detection and analysis of fundamental particles.

Background:



Materials: Coins, Digital Mass Scale, Google Sheets/Data Analysis Software

Procedure:

1. Open your copy of the Google Sheet for taking your data.
2. Use the scale to find the mass, to the hundredth of a gram, of each coin.
3. Record in your data table the mass, the year the coin was minted, and also the condition of the coin (this last is a more subjective measure, of course). Use 1= Good, 2= Fair, 3= Poor for Coin Quality.
4. Once you have recorded the mass of all the coins, you can begin data analysis!

Data Analysis:

1. Use Google Sheets to calculate the mean mass of all the coins you measured. Record your answer here:

| Mean Coin Mass: |  |
| --- | --- |

1. Use Google Sheets to calculate the mean age of the coins. Record here:

| Mean Date Minted: |  |
| --- | --- |

1. Use Google Sheets to calculate the mean quality of the coins. Record here:

| Mean Quality (Scale of 1-3) |  |
| --- | --- |

1. Use Google Sheets to create a histogram of the Coin Mass Data. Insert the resulting histogram here:
2. Use Google Sheets to create a scatter plot of coin mass versus date minted. Insert the resulting plot here:
3. Use Google Sheets to create a scatter plot of coin mass versus quality. Insert the resulting plot here:
4. Copy and Paste your Coin Mass Data into the Class Data Google Sheet.

Conclusion:

1. Look at your histogram. What mass values show ‘peaks’, and what coins do you think caused each peak?
2. What information can you learn from the histogram that is hidden by calculating the mean of the data?
3. What conclusions can you draw from your scatter plot of mass versus year?
4. What conclusions can you draw from your scatter plot of mass versus quality?
5. How does your data compare to the class data?
6. Which is likely a more accurate data set, yours or the whole class? Why?
7. If your data peaks weren’t very tall, what would you need to do in order to be certain your histogram isn’t showing random results?
8. Using all the data analysis, what is your best answer for the mass of a modern US Penny?
9. Look up the accepted penny mass.

| Accepted Penny Mass Value: |  |
| --- | --- |

1. What is your percent error?
2. When particle physics experiments detect particles, the suspected mass is often included in a histogram much like what you have created. Why is the histogram a powerful tool for analyzing particle data?
3. The histogram shown below is taken from CMS data at the LHC, CERN. These mass events are the result of the collision of protons at near lightspeed. New particles were created, which then (in this data) decayed into a muon, and an anti-muon. The muons were measured by the CMS detector, and this plot was created.
   1. From the plot, what is the mass of the Z particle, in GeV?
   2. From the plot, what is the mass of the Y particle, in GeV?
   3. From the plot, what is the mass of the ɸ particle, in GeV?
   4. How can you tell the particles apart, even though they decayed into the same muon/antimuon pair?
   5. The gray area on the plot represents ‘noise’, or background. This could be uninteresting events, events that were partially not detected, or caused by things like cosmic rays, as well as imperfections with the equipment.
      1. How many events, above background, were required to create a distinct peak that shows the presence of a particle? *Make your best estimate.*

Image shown below is a histogram from CMS data of muon/antimuon decays.

*Image Credit: QuarkNet BAMC (Big Analysis of Muons) Lecture, Spring 2020.*

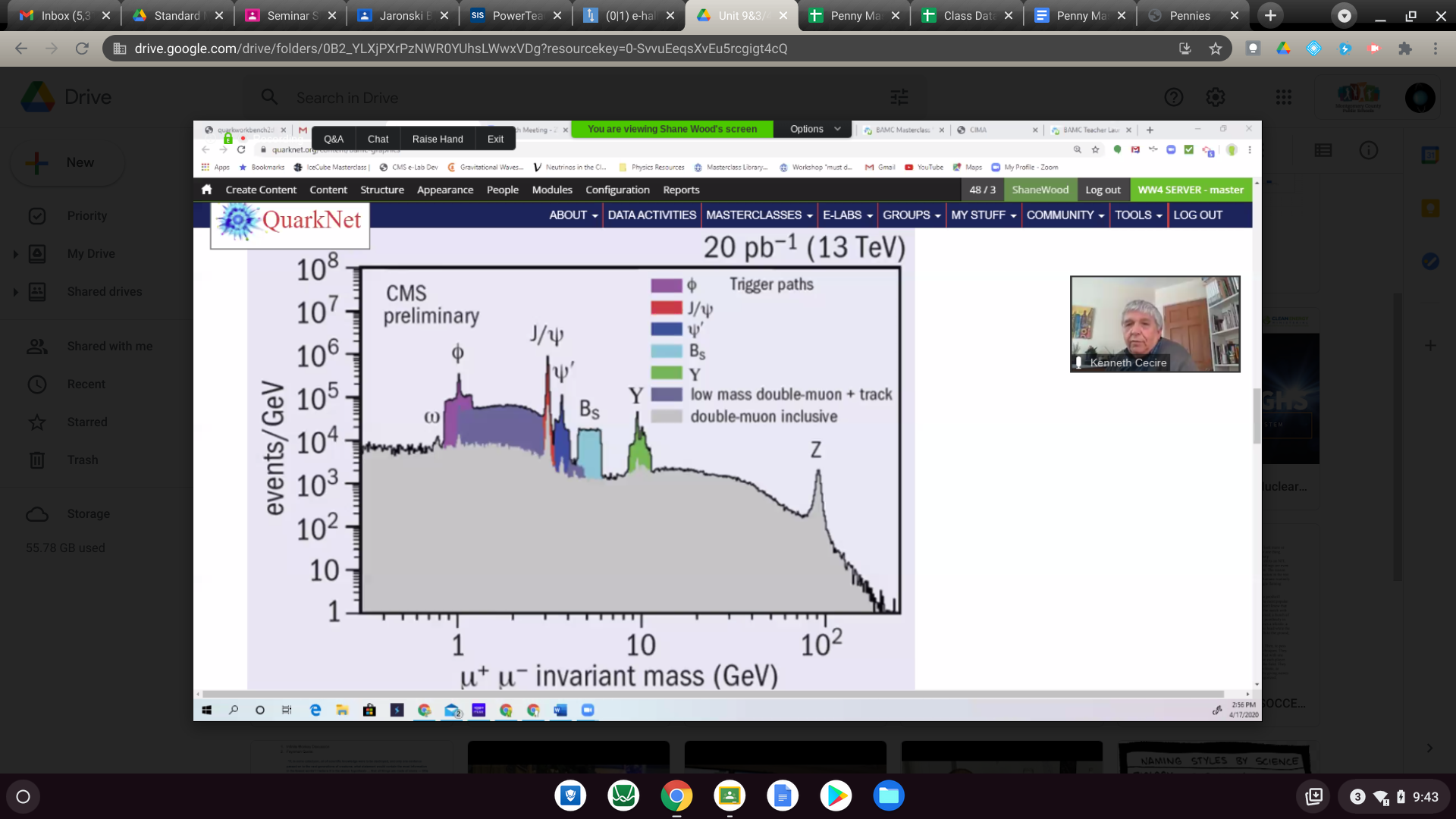


Image shown below is a digital reconstruction of a Higgs boson decay within the CMS Detector.

*Image Credit: “Observation of a New Particle with a Mass of 125 GeV”. CMS Experiment, CERN. 4 July 2012.*

