Remote Data Activities in Particle Physics Education

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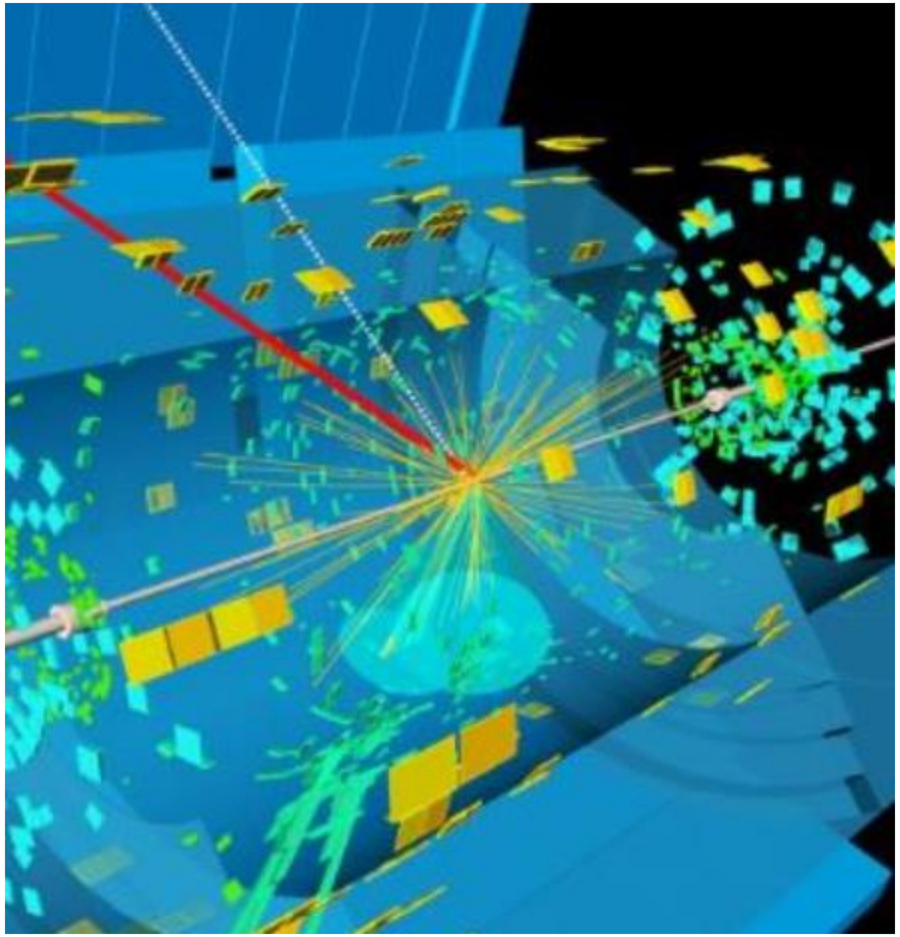
These slides accessible at:
https://web.quarknet.org/media/pust_09sep2021.pdf

QuarkNet African School of Fundamental Physics and Applications NSF Fermilab

Our Plan

- Introduction
- Cloud Chamber
- Quark Puzzle
- Rolling with Rutherford
- Mass of the Z Boson
- Discussion and Q&A



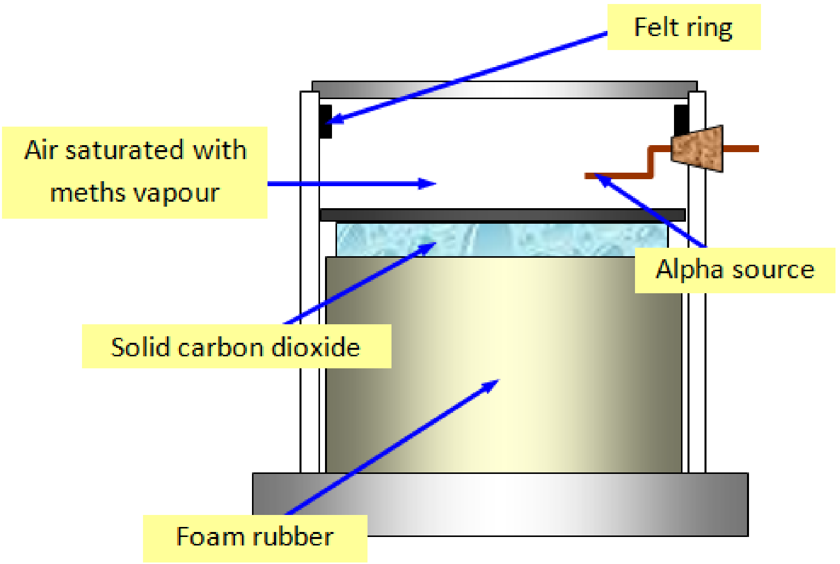
What, Why, and What Again

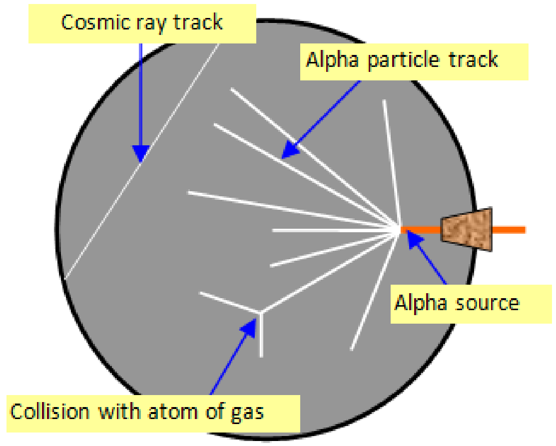
- Contemporary particle physics is at the cutting edge of science: naturally interesting and motivating.
- Using authentic data puts learners in the physics moment.
- Students can apply the physics they learn in school to understanding recent research; they can use analysis of recent research to help them understand the physics they learn in school.
- All of this can help learners:
  - Understand the basic physics they need to learn.
  - Open their eyes to the wonders of physics.

- *We can do these activities remotely when we cannot meet students face-to-face.*

Cloud Chamber

- See the traces of actual atomic and subatomic particles.
  - Chamber has supersaturated alcohol vapor
  - Particles leave condensation trails
- [You can build one!]





https://www.schoolphysics.co.uk/age14-16/glance/Nuclear%20physics/Cloud%20chamber/index.html

Cloud Chamber

- Observe the video of a cloud chamber.
- Characterize particle tracks:
- Length (long-medium-short)
- Width (thick-thin)
- Shape (straight-curvy-curly-dot)
- Frequency (often-sometimes-rarely)

Cloud chamber,Brookhaven National Laboratory teacher meeting, 2007.

Cloud Chamber

- What can students find?
  - Long, thin, straight track (muon)
  - Short, fat track (alpha particles coming from radon atoms)
  - Curly or zig-zag tracks (electrons and positrons)
  - V-shaped tracks (particle decays)

- Teacher Notes
- Student Guide

MAKING TRACKS I: CLOUD CHAMBER
TEAM REPORT FORM

Use this form or take separate notes using this format. You need only one completed form per team.

Date: ______________________________ Class: _________________________________

Team members: ____

Some suggested descriptor words:

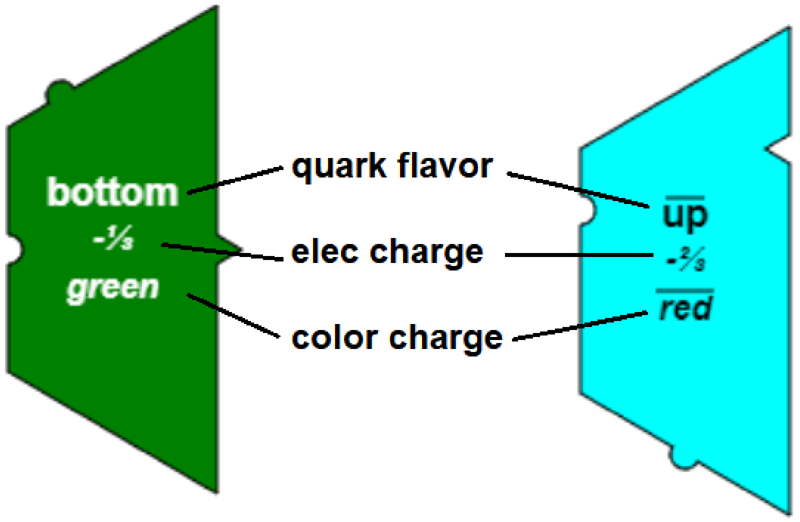
Length of Track	Width of Track	Shape of Track	How Often Observed
Long	Thick	Straight	Common
Medium	Thin	Curvy	Sometimes
Short		Curly	Rarely
		Dot	

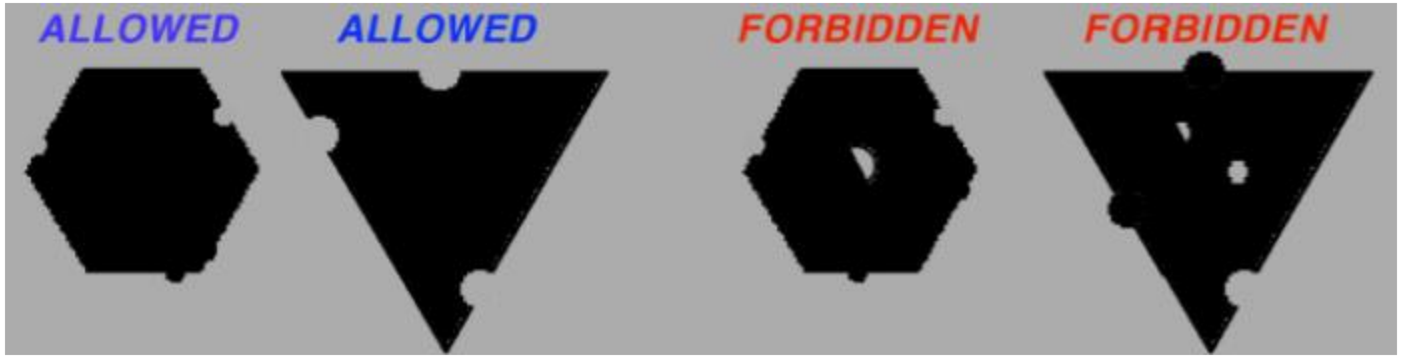
Table of observed tracks:

Type	Description	Sketch
1		
2		

Have some fun: Quark Puzzle

- Move puzzle pieces to make 2-quark mesons and 3-quark baryons
- Follow the puzzle rules
  - Tabs must fit into same-shape notches
  - Tabs may not overlap anything else
  - No open spaces between quark puzzle pieces
- Work out quark combination rules for
  - Electric charge
  - Color charge
  - Matter and antimatter

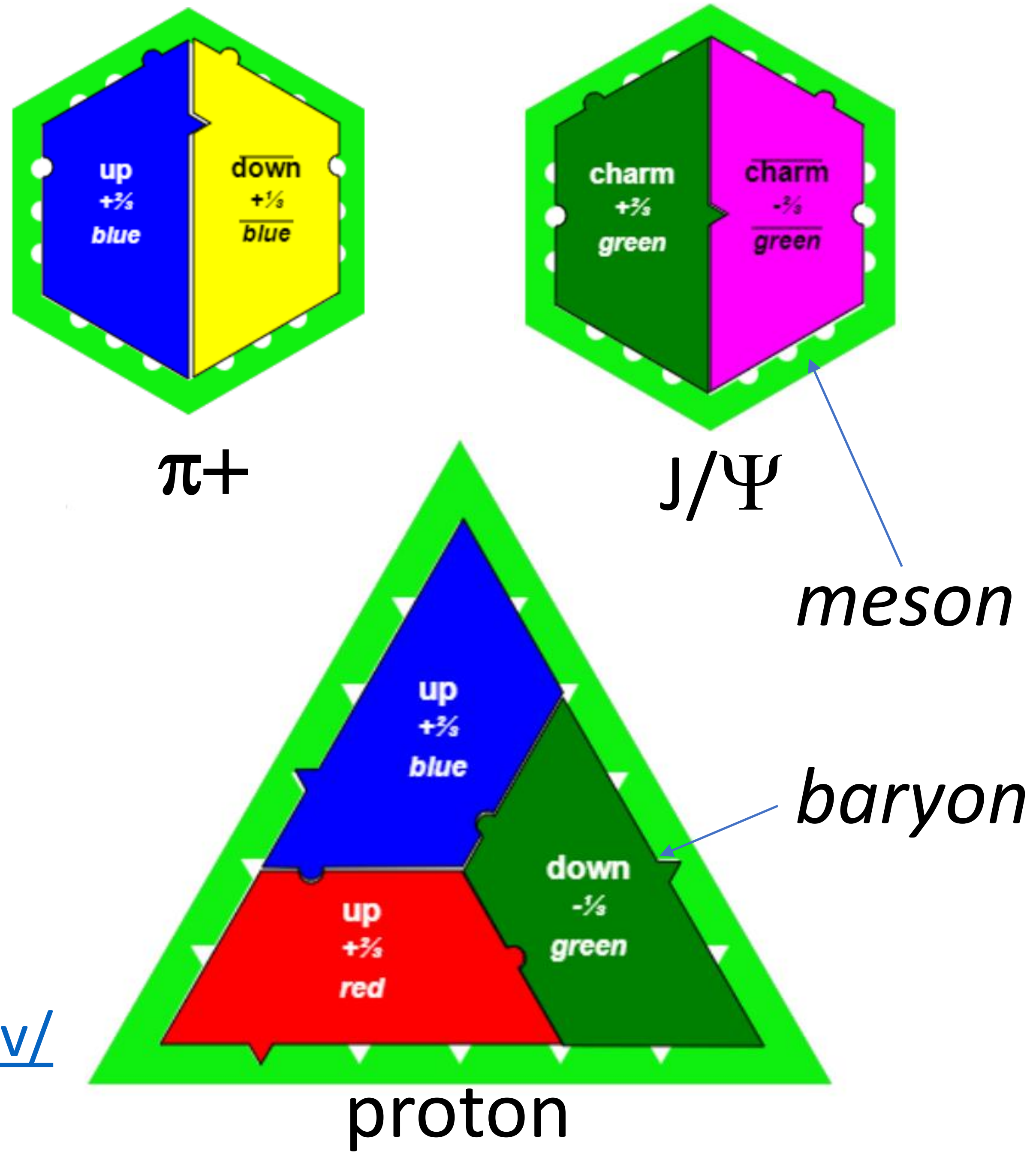




Quark Puzzle

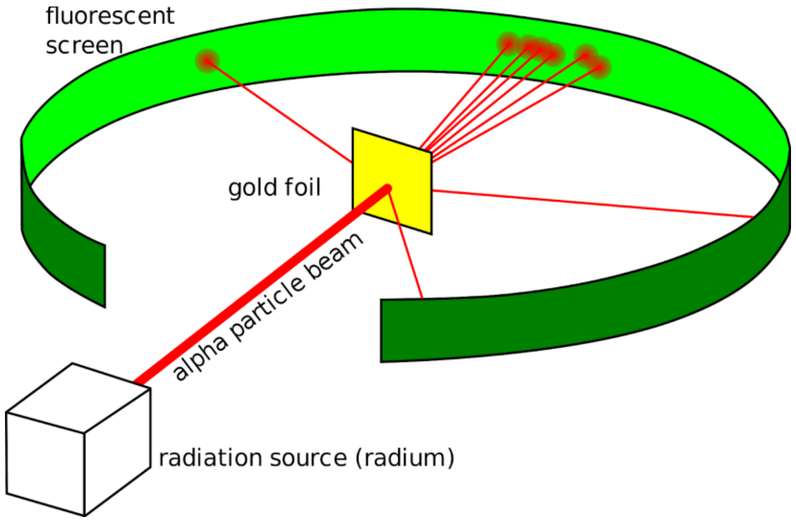
- Teacher Notes
- Student Guide
- Take a look at the puzzle
- Results table
- Students learn:
  - quark combination rules
  - quark names and characteristics
  - meson and baryon structure

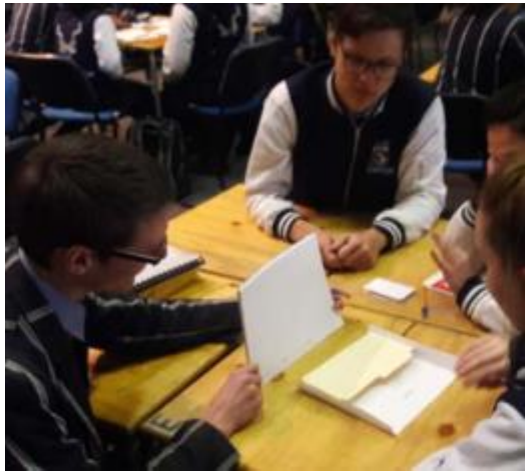
- Look up particles at https://pdg.lbl.gov/

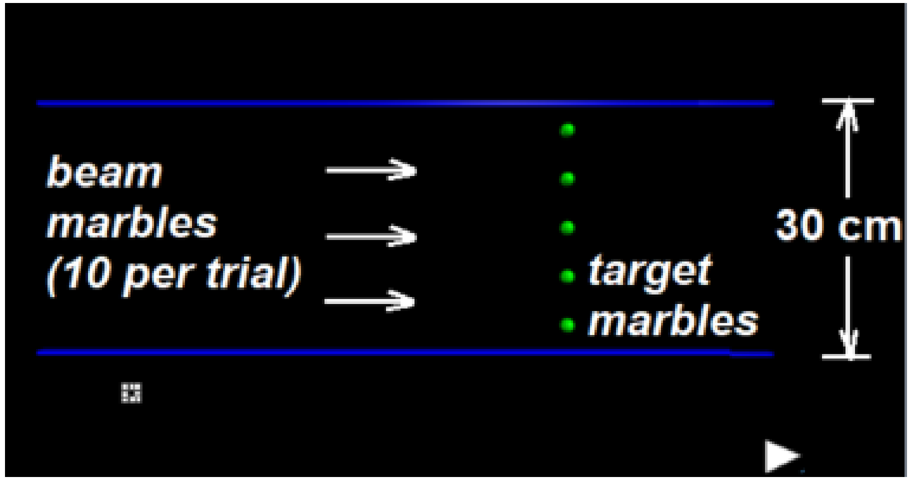


Rolling with Rutherford

- *Not* original Rutherford experiment
- An intro to:
  - How physics is done
  - Using indirect evidence
  - Using probability and statistics
- Based on the <u>prototypical</u> particle experiment

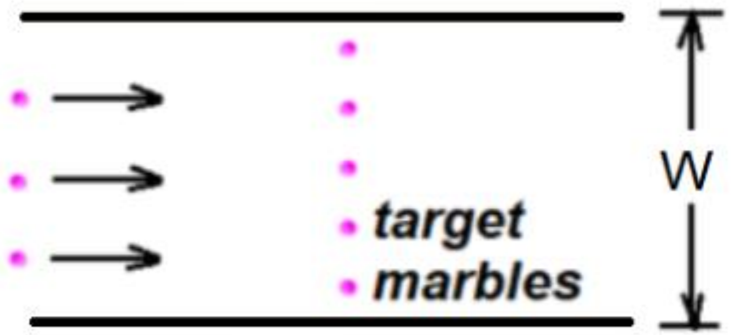






Let’s try it!

- Use rolling-simulation.
- Record results (count marbles that bounce back to *left*) in Google form. (If you want to use it, make a copy.)
- We will inspect the result.
- Calculate the diameter of the marble!
  - Hint: $P=nD/W$ is almost right but gives you 2x the better answer. Why?
- Teacher Notes



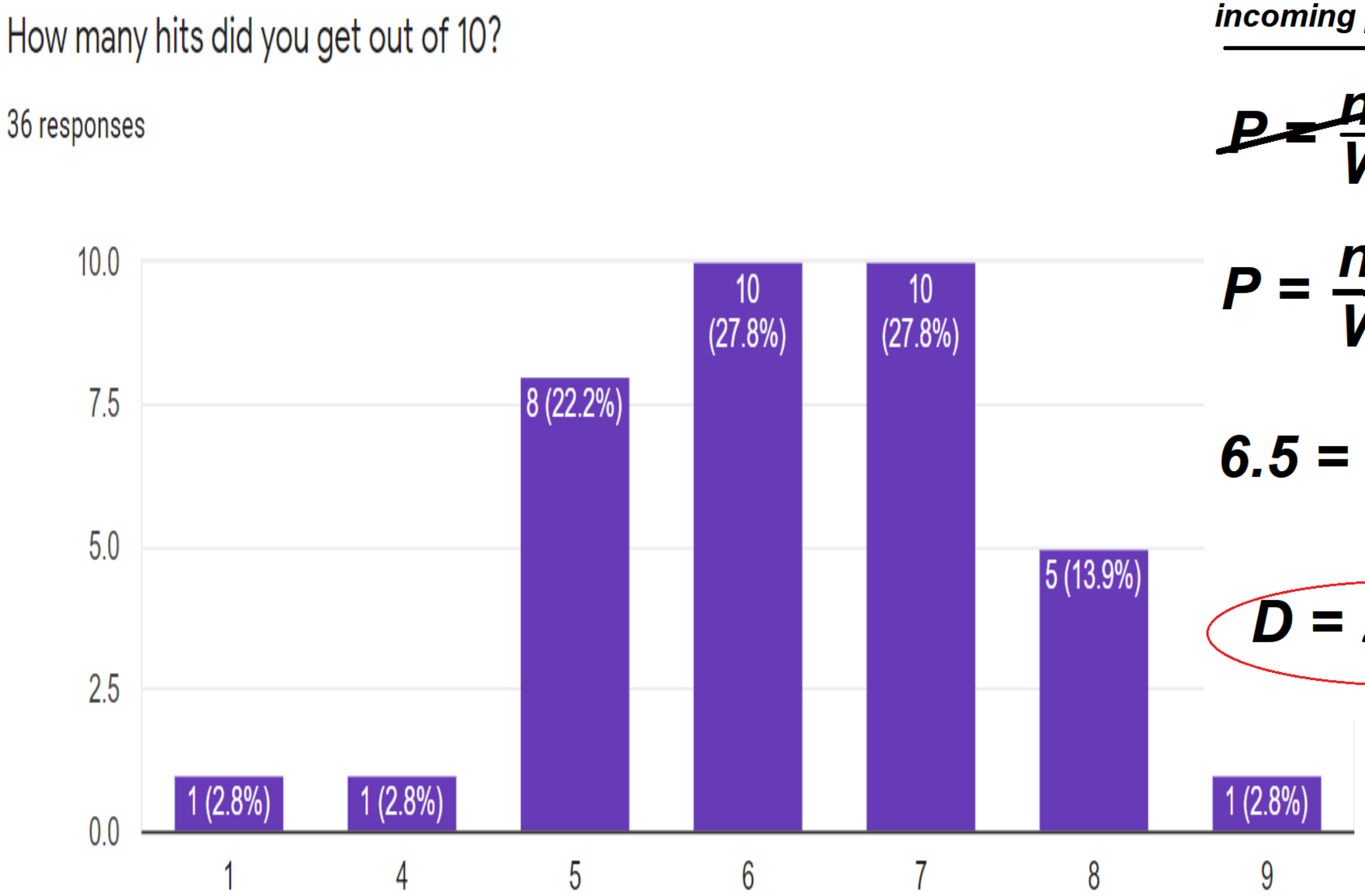
P = probability of a hit

n = number of target marbles

W = width of “beam pipe” = 30 cm

D = diameter of marble

Results with Rutherford



Result from African School of Physics, July 2021.

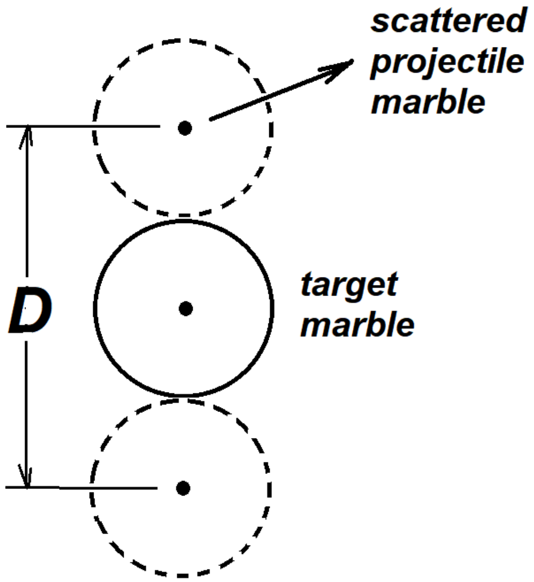
incoming projectile marble

$$\cancel{P = \frac{nD}{W}}$$

$$P = \frac{n(2D)}{W-D}$$

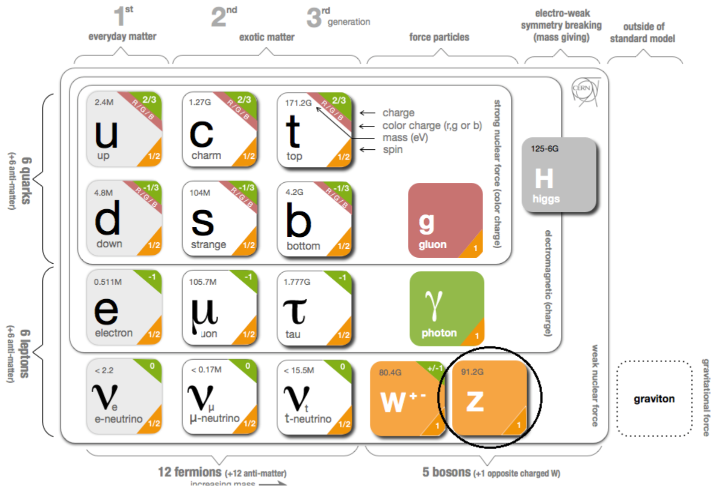
$$6.5 = \frac{5(2D)}{30\text{ cm} - D}$$

$$D = 2.1\text{ cm}$$



Invariant Mass of the Z Boson

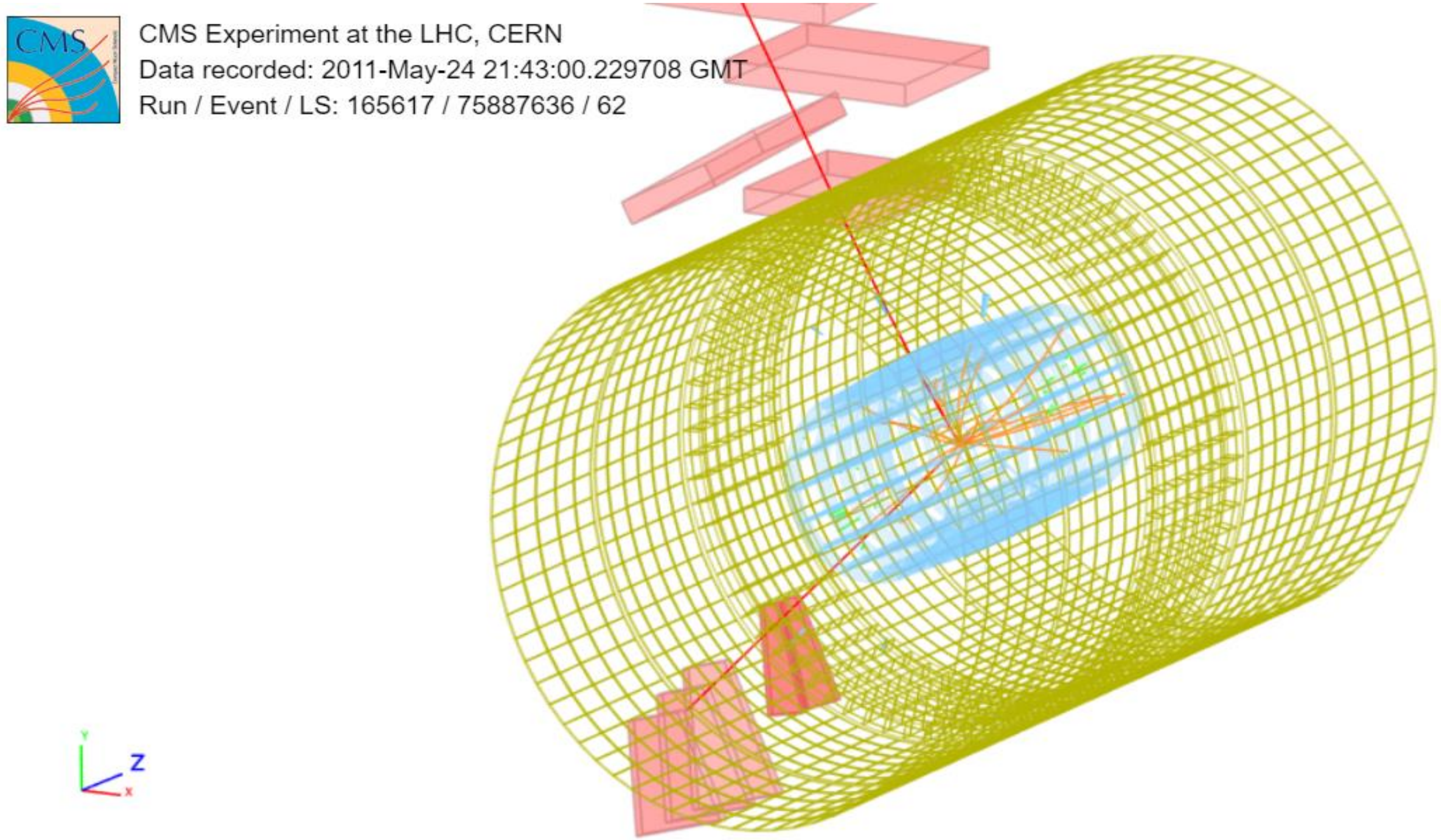
- Protons collide in LHC.
- Z bosons are sometimes produced.
- Z bosons always decay before we can see them.
- Z bosons sometimes decay to muon and antimuon.
- Use momenta and energies of muons to work backwards to Z mass.
- We will use only events in x-y plane.



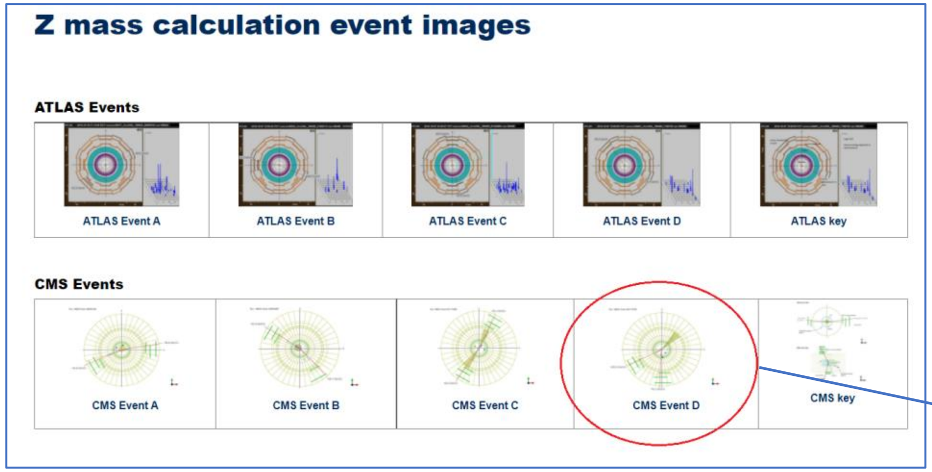
Invariant Mass of the Z Boson

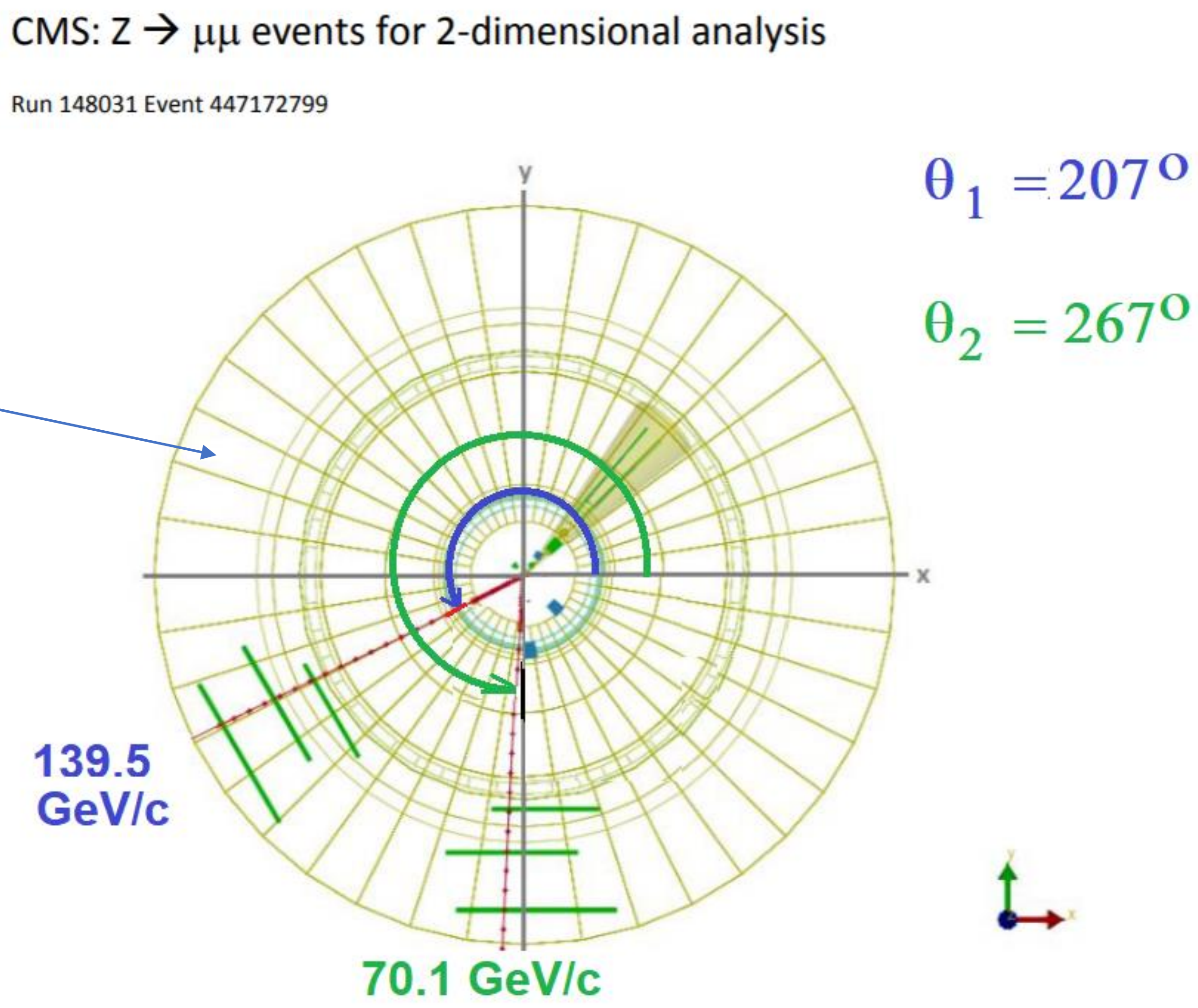
- Topics include:
  - Vector addition
  - Conservation of momentum and energy
  - A little relativity (one equation)
- Get event from Z-data.

- Teacher Notes
- Student Guide
- ATLAS Z-boson video



Invariant Mass of the Z Boson





Angle measurement hints:

- Radial lines in CMS events a 9 degrees apart.
- Chrome has a protractor extension.
- Estimates are OK!

Invariant Mass of the Z Boson

Muon momentum components:

$p_{1X} = p_1 \cos\theta = (139.5\ \mathrm{GeV/c})\cos(207^{o}) = -124.3\ \mathrm{GeV/c}$

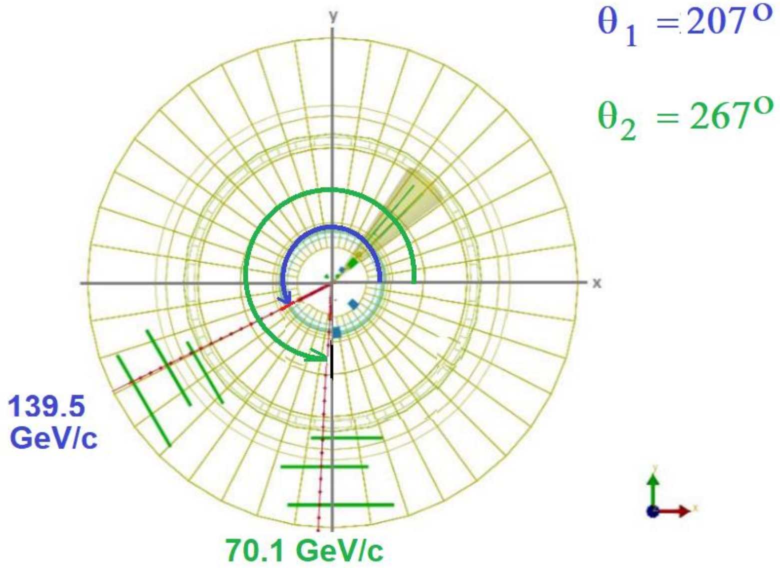
$p_{1Y} = p_1 \sin\theta = (139.5\ \mathrm{GeV/c})\sin(207^{o}) = -63.3\ \mathrm{GeV/c}$

$p_{2X} = p_2 \cos\theta = (70.1\ \mathrm{GeV/c})\cos(267^{o}) = -3.7\ \mathrm{GeV/c}$

$p_{2Y} = p_2 \sin\theta = (70.1\ \mathrm{GeV/c})\sin(267^{o}) = -70.0\ \mathrm{GeV/c}$

CMS: Z → μμ events for 2-dimensional analysis

Run 148031 Event 447172799



Invariant Mass of the Z Boson

Momentum components of Z-boson:

$$p_x = p_{1X} + p_{2X} = -124.3 \text{ GeV/c} - 3.7 \text{ GeV/c} = -128.0 \text{ GeV/c}$$

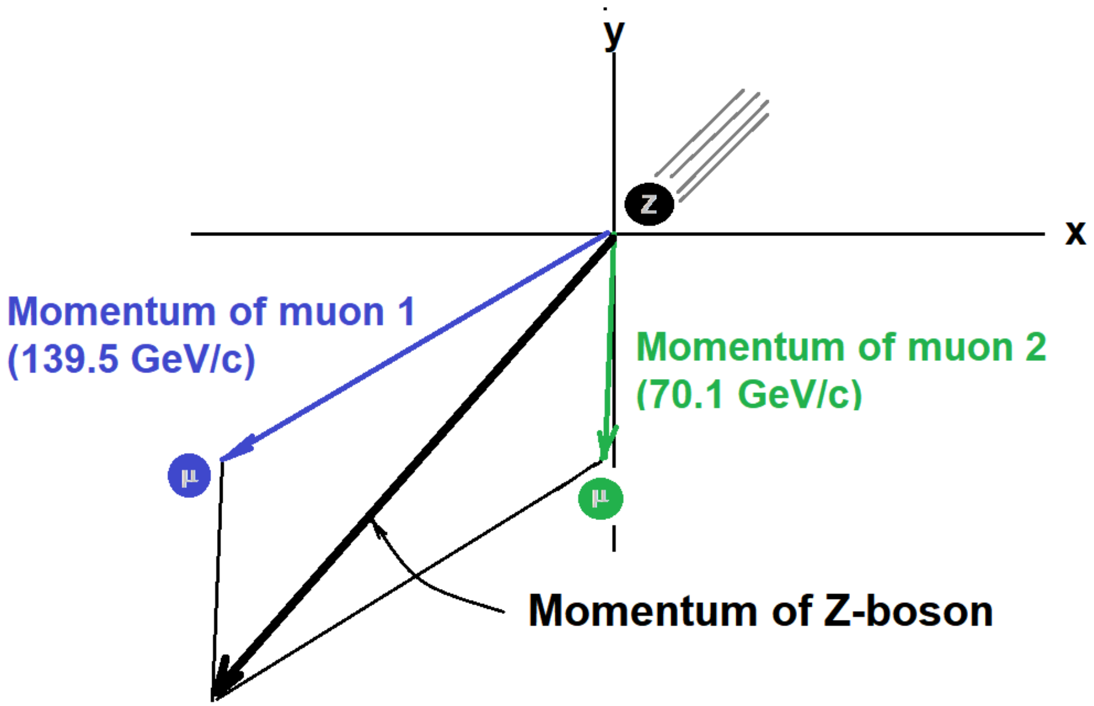
$$p_y = p_{1Y} + p_{2Y} = -63.3 \text{ GeV/c} - 70.0 \text{ GeV/c} = -133.3 \text{ GeV/c}$$

Magnitude of Z-boson momentum squared:

$$p^2 = p_x^2 + p_y^2 = (-128.0 \text{ GeV/c})^2 + (-133.3 \text{ GeV/c})^2 = 34153 \text{ GeV}^2/c^2$$

Energy of Z-boson:

$$E = E_1 + E_2 = 139.5 \text{ GeV} + 70.1 \text{ GeV} = 209.6 \text{ GeV} ; \; E^2 = 43932 \text{ GeV}^2$$



Invariant Mass of the Z Boson: take it home!

Energy-mass-momentum:

$E^2 = p^2c^2 + m^2c^4$ **(if p >> m in GeV/c and GeV/c^2, then E = pc)**

Apply to the Z-boson:

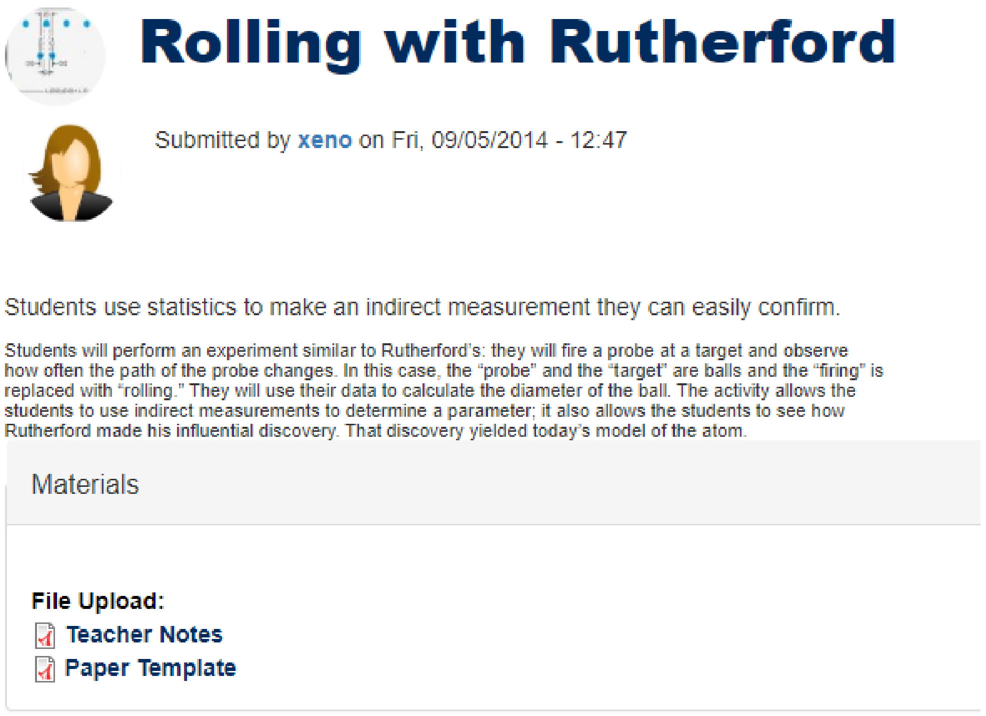
$43932\ \text{GeV}^2 = (34153\ \text{GeV}^2/c^2)c^2 + m^2c^4$

m = 98.9 GeV/c^2 or, more colloquially among physicists, m = 98.9 GeV

Now that we've done all that, here is the easy online method.

Where to Find More

- [QuarkNet Data Activities Portfolio]()
- [Remote learning adaptations]()



Rolling with Rutherford

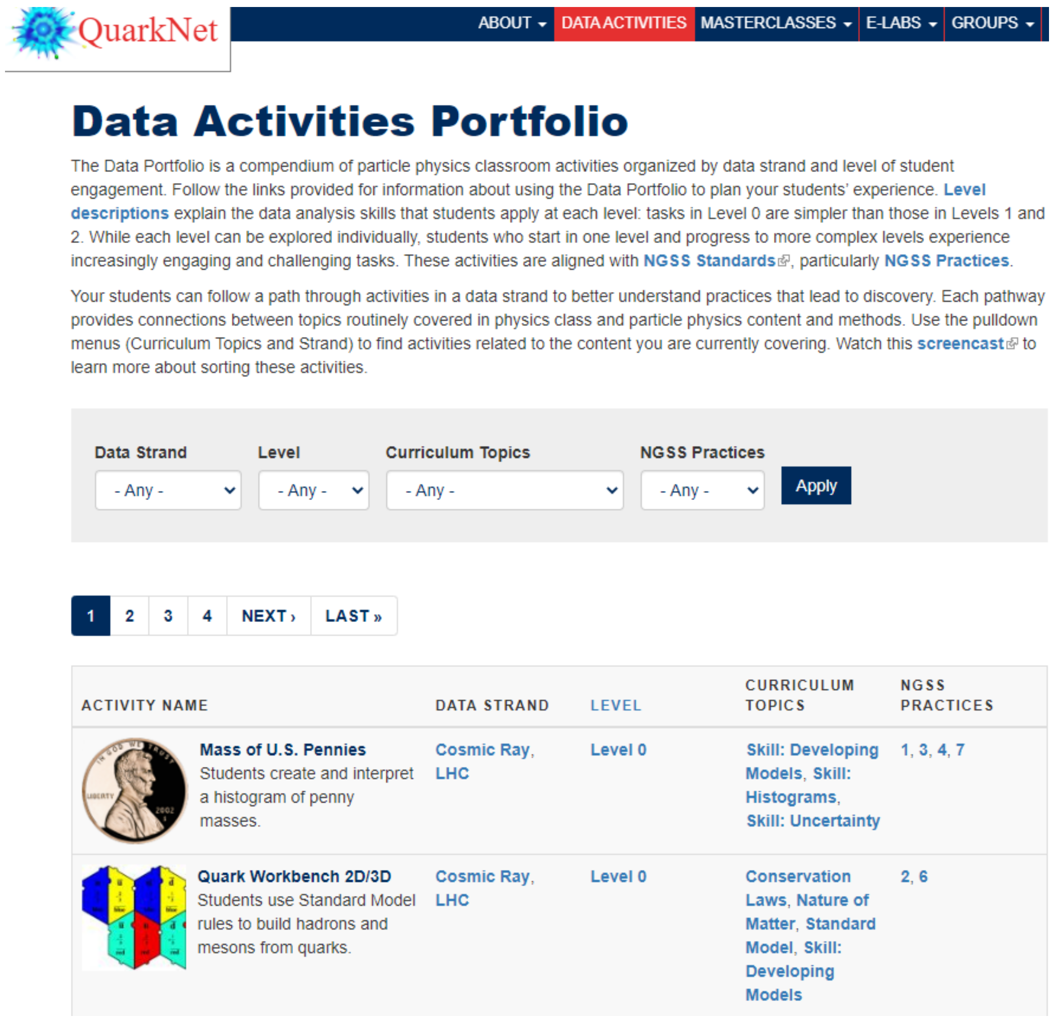
Submitted by **xeno** on Fri, 09/05/2014 - 12:47

Students use statistics to make an indirect measurement they can easily confirm.

Students will perform an experiment similar to Rutherford's: they will fire a probe at a target and observe how often the path of the probe changes. In this case, the "probe" and the "target" are balls and the "firing" is replaced with "rolling." They will use their data to calculate the diameter of the ball. The activity allows the students to use indirect measurements to determine a parameter; it also allows the students to see how Rutherford made his influential discovery. That discovery yielded today's model of the atom.

Materials

File Upload:
Teacher Notes
Paper Template



QuarkNet

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Data Activities Portfolio

The Data Portfolio is a compendium of particle physics classroom activities organized by data strand and level of student engagement. Follow the links provided for information about using the Data Portfolio to plan your students' experience. **Level descriptions** explain the data analysis skills that students apply at each level: tasks in Level 0 are simpler than those in Levels 1 and 2. While each level can be explored individually, students who start in one level and progress to more complex levels experience increasingly engaging and challenging tasks. These activities are aligned with **NGSS Standards**, particularly **NGSS Practices**.

Your students can follow a path through activities in a data strand to better understand practices that lead to discovery. Each pathway provides connections between topics routinely covered in physics class and particle physics content and methods. Use the pulldown menus (Curriculum Topics and Strand) to find activities related to the content you are currently covering. Watch this **screencast** to learn more about sorting these activities.

Data Strand	Level	Curriculum Topics	NGSS Practices	
- Any -	- Any -	- Any -	- Any -	Apply

1 | 2 | 3 | 4 | NEXT › | LAST »

ACTIVITY NAME	DATA STRAND	LEVEL	CURRICULUM TOPICS	NGSS PRACTICES
Mass of U.S. Pennies Students create and interpret a histogram of penny masses.	Cosmic Ray, LHC	Level 0	Skill: Developing Models, Skill: Histograms, Skill: Uncertainty	1, 3, 4, 7
Quark Workbench 2D/3D Students use Standard Model rules to build hadrons and mesons from quarks.	Cosmic Ray, LHC	Level 0	Conservation Laws, Nature of Matter, Standard Model, Skill: Developing Models	2, 6

Questions and Discussion