# Demystifying Particle Detectors with Interactive Learning Tools

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## BACKGROUND

Data analysis in experimental particle physics comes in stages:

**Detector Data**
- Where does the data come from?

**Particle Identification**
- What particles did we detect?

**Event Reconstruction**
- What happened to produce those particles?

**Figure 1:** A flow chart of the stages of particle physics data analysis.

Particle Identification (PID) Playground is a collection of Jupyter notebooks that teach algebra-based physics students about the working mechanisms of detectors commonly used in particle physics experiments and how these detectors can be used to identify particles. These activities open with foundational topics in particle physics, such as vectors, special relativity, and the standard model. In later notebooks, students explore various subdetectors of the GlueX detector in Hall D of Jefferson National Laboratory by analyzing and visualizing data.

This poster describes the use of applets and interactive visualizations as a tool for supporting students' understanding of abstract physics concepts, such as the working mechanisms of the detectors used in nuclear and particle physics experiments.

## WHY JUPYTER NOTEBOOKS?

### STRUCTURED

Jupyter notebooks allow alternating portions of text and code, which helps form a narrative from snippets of code. It also allows seamless integration of explanations, code, and practice problems.

### REPRODUCIBLE

Jupyter notebooks facilitate reproducibility in line with open science principles. Sharing analyses alongside raw data enables others to recreate and validate the process, fostering a more comprehensive review of methods.

### INTERACTIVE

The Jupyter environment allows for several interactive widgets and quick execution of code, which allows students to make more direct connections between their code and the output.

### BROWSER-BASED

Platforms like Google Colaboratory allow students to run code on remote machines, which allows student to engage with the activities of Particle Identification Playground without installing or downloading anything onto their local computer.

## APPLETS

### VECTOR PLOTS

Because algebra-based physics students likely have no prior exposure to vectors, PID Playground introduces vectors in its first activity, "Introduction to Vectors."

The applet in this notebook allows students to create interactive visualizations of vectors in 3D space, which allows them to explore the relationship between vector components, direction, and magnitude. Students draw conclusions about the effect of scalar multiplication on the direction and magnitude, which students then use to normalize vectors for use in later activities.

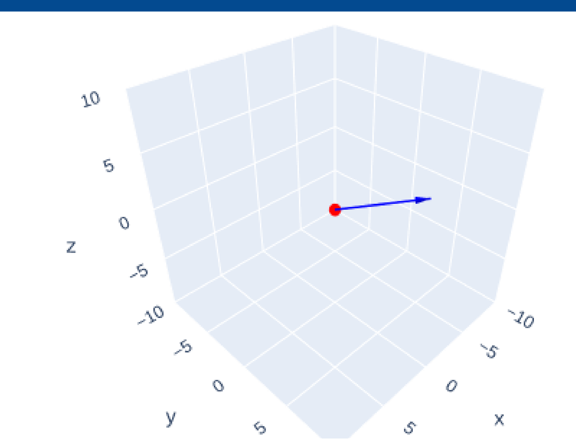

**Figure 2:** An interactive plot of a vector from the "Introduction to Vectors" activity. The plot can be rotated to view the vector from different angles.

### 3D MODELS OF DETECTORS

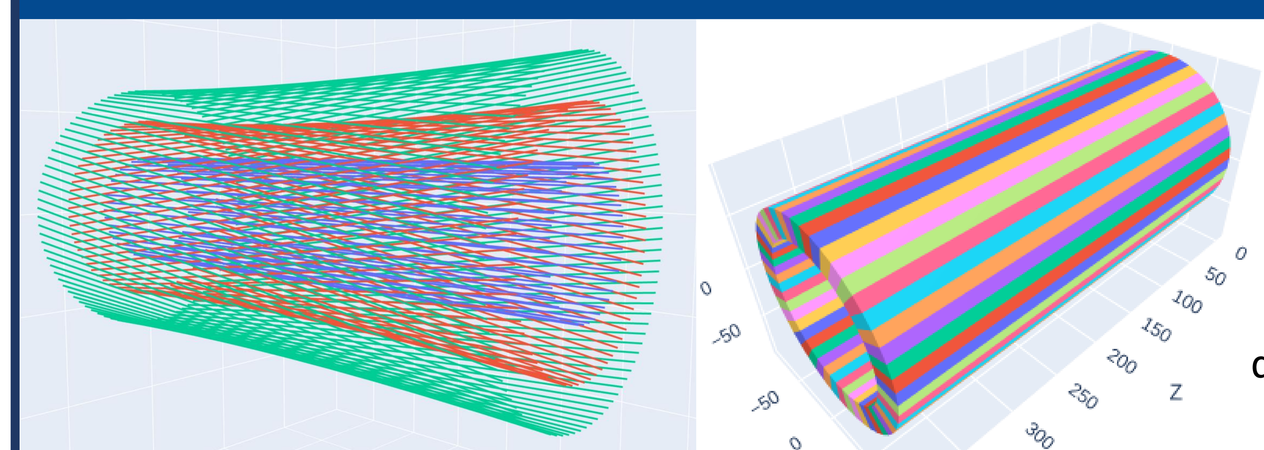

**Figure 3:** 3D models of the GlueX Central Drift Chamber (left) and the GlueX Barrel Calorimeter (right).

To introduce students to the geometry of the detectors used by the GlueX experiment, PID Playground uses 3D, interactive models of two of the primary detectors: the Central Drift Chamber (CDC) and the Barrel Calorimeter (BCal).

Students then use the geometry of these detectors to derive quantities, such as energy and momentum, from the raw data provided by the detectors. They use their derived relationships to process simulated raw detector into data that can be used to identify particles.

### TRACK FITTING

To examine how drift chambers can be used to measure the momentum of particles that leave a "track" in the detector, students are introduced to a track fitting applet in the "Drift Chambers and Tracks" activity.

With this applet, students explore how particles with different momenta and different charge behave differently in the magnetic field of the detector. They analyze the curvature of particle paths to determine momentum and can adjust track parameters to observe their impact on the resulting fit.

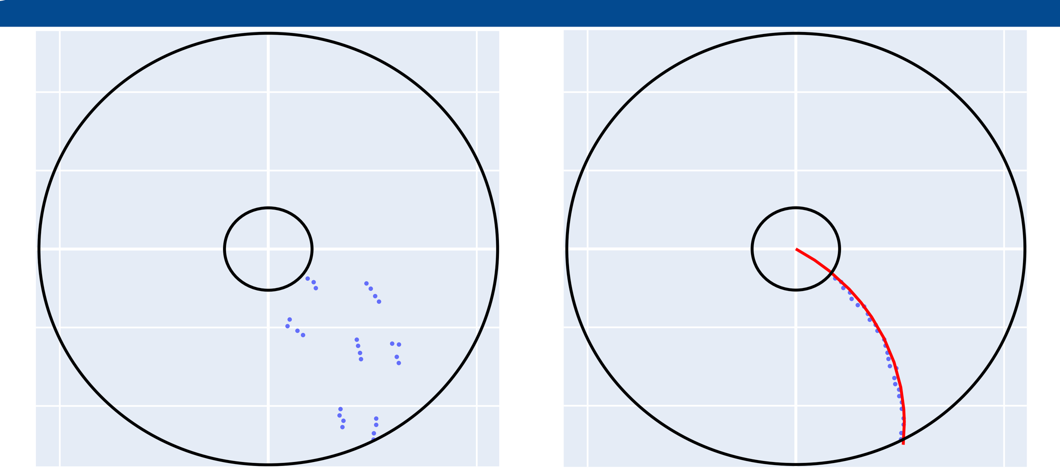

**Figure 4:** A collection of hits in the GlueX CDC before track fitting (left) and after track fitting (right). The path shown in red is determined by the momentum of the particle.

### VISUALIZING SHOWERS

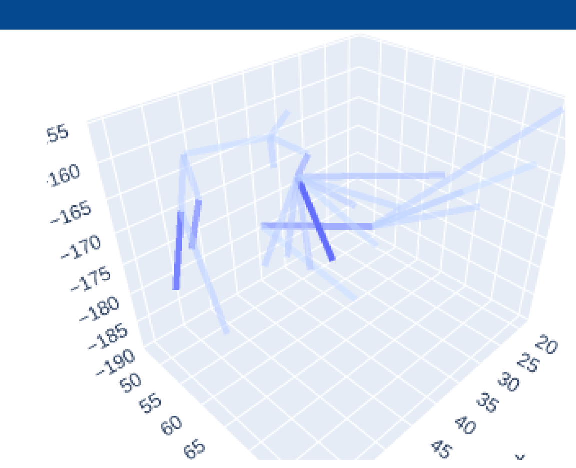

**Figure 5:** A 3D model of a shower produced in the GlueX BCal. Darker segments indicate higher energy deposits in the detector.

Calorimeters are the only particle detectors that experimental particle physicists use to detect neutral particles, so it is extremely important to understand how they can be used to identify particles.

This applet in the 'Calorimeters and Neutral PID' notebook enables students to visualize particle showers, which are complex cascades resulting from particle interactions with a calorimeter. By observing the 3D structure, students grasp the challenge of distinguishing between particles, especially neutral ones, in physics experiments.

### FINDING CUTS

Particles are commonly identified using cuts, which are requirements for signals to be attributed to a specific particle. For example, we might make a cut that says that any particle above a certain mass is considered a proton.

Using the cut-finding applet, students use sliders to adjust the parameters of a curve that they can then use to place a cut. Although not all cuts are placed on graphs, this applet makes it significantly easier to find suitable graphical cuts.

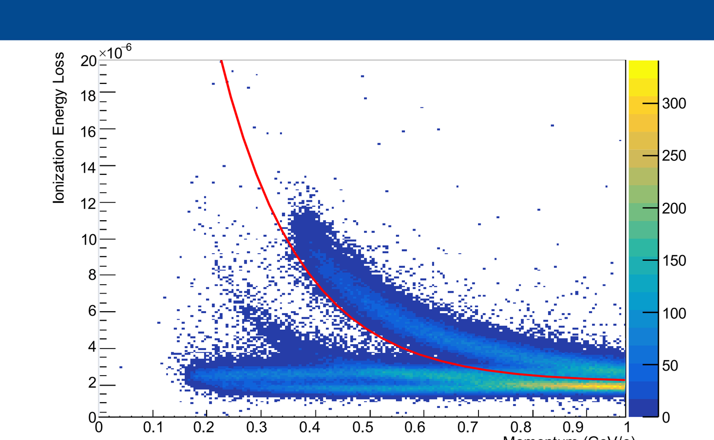


**Figure 6:** A cut-finding applet. Students use sliders to move the curve shown in red, which is used to divide the stripes. Each stripe on the plot shown represents a different particle.

## NEXT STEPS

### GENERALIZATION

The discussed applets are currently published in a python package called pidp_tools, though these applets are tailored to the scope of PID Playground. Further work is needed to make these applets suitable for broader use.

### EVENT RECONSTRUCTION

After we identify the particles in our data, we can perform event reconstruction! At least one notebook on event reconstruction is planned, which will ensure students are able to analyze experimental data from start to finish.

### EXPERIMENTAL DATA

The activities of PID Playground use simulation data. However, to provide a more authentic experience, there are plans to integrate real experimental data into select PID Playground activities.

## ACKNOWLEDGMENTS

Special thanks to Richard Jones, who has taught me everything I know about particle physics. He has been invaluable to the project, with his expertise surrounding both the GlueX detector and computing. I would also like to thank Diego Valente, who helped develop the pedagogical foundation of the project. He helped ensure that this project would be effective and accessible to a wide range of physics students, which helped the project achieve its core goals.

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### VISIT PID PLAYGROUND

To visit PID Playground, scan the QR code to the right or enter the URL shown below!

duberii.github.io/pid-playground

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