

PID Playground: Teaching Particle Identification Using Jupyter Notebooks

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PURPOSE

Data analysis in experimental particle physics comes in stages:

Public Data

- Where does the data come from?

Particle Identification

- What particles did we detect?

Reconstruction

- What happened to produce those particles?

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

In the push towards open science, several efforts have made this analysis pipeline more accessible. For example, CERN's Open Data portal releases data from a variety of CERN experiments to the public¹. Furthermore, collaborations like QuarkNet and websites like Particle Physics Playground offer activities that teach high school students and undergraduates about particle physics and reconstruction^{2,3}. However, there are no resources that teach high school and undergraduate students about modern particle identification (PID) methods.

Particle Identification Playground provides Jupyter notebooks to teach students about particle identification. The only prerequisites to get started are python skills, and algebra-based physics. Together with CERN's Open Data and publicly available resources on reconstruction, students will be able to develop all the research skills necessary to conduct thorough analysis of experimental data as early as high school.

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

In line with the open science model, using Jupyter notebooks allows other scientists to follow along with the analysis performed. When published with raw data, third parties can recreate the analysis, which enables for more thorough inspection of the 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.

NOTEBOOK TOPICS

INTRODUCTORY NOTEBOOKS

Students learn to create and interpret 2D histograms in ROOT, the most widely used data analysis library in particle physics.

After completing these notebooks, students should be able to:

- Calculate the magnitude of a vector based on its components
- Compute linear combinations of vectors
- Recognize the formulas for relativistic energy and momentum
- Interact with the DataFrame object in Pandas
- Classify particles as hadrons, leptons, mesons, baryons, and/or antibaryons

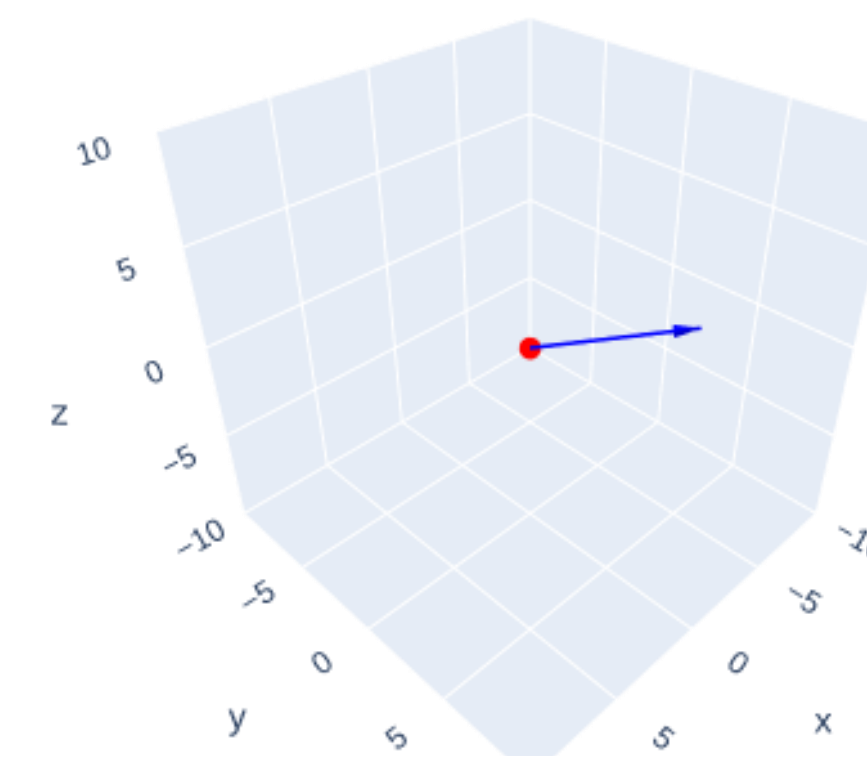


Figure 2: An interactive plot of a vector from the "Introduction to Vectors" activity. The plot can be rotated to view the vector from different angles.

HISTOGRAMS IN ROOT

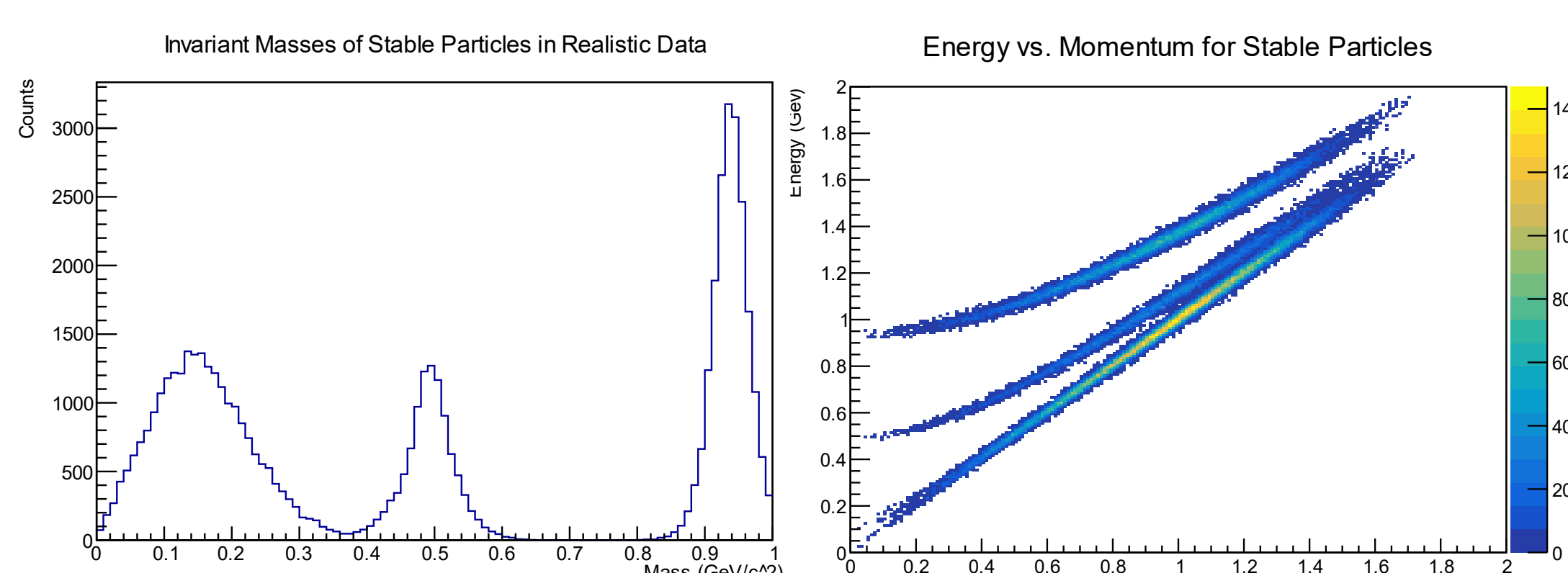


Figure 3: Histograms created in "Introduction to ROOT" and "2D Histograms in ROOT"

Students learn to create and interpret 2D histograms in ROOT, the most widely used data analysis library in particle physics.

After completing these notebooks, students should be able to:

- Describe the goals of particle identification
- Interpret 1D and 2D histograms
- Create, fill, and draw 1D and 2D histograms in ROOT
- Associate mathematical and visual depictions of error and statistical fluctuations in 1D and 2D histograms

DRIFT CHAMBERS AND TRACKS

Students explore drift chambers and how they are used to measure the momentum of charged particles.

After completing this notebook, students should be able to:

- Describe the role of drift chambers in a particle detector
- Define tracks and hits
- Identify which particles leave tracks
- Use individual hits to determine the position of a track
- Find the momentum and charge of a particle based on the curvature of a track

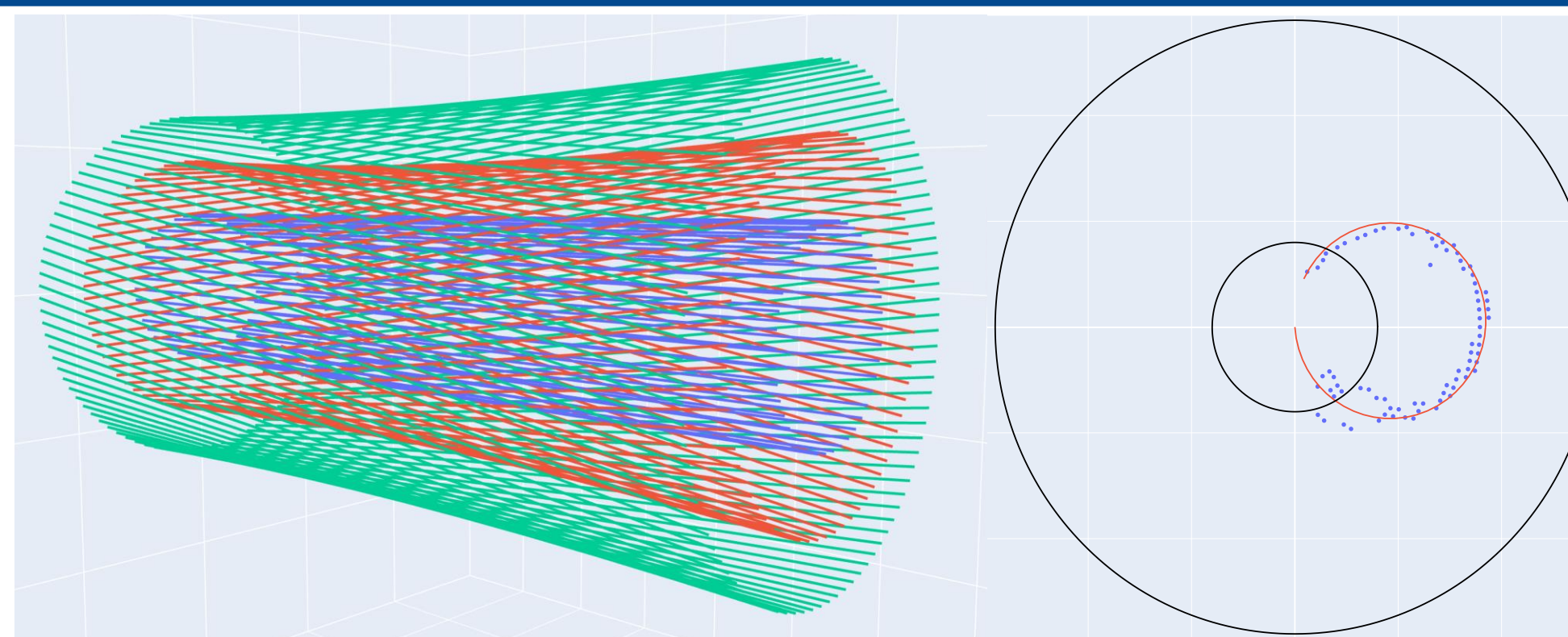


Figure 4: A 3D interactive plot of wires in a drift chamber and a track-fitting applet, which finds the momentum of a track in the CDC based on the path (shown in red).

IONIZATION ENERGY LOSS

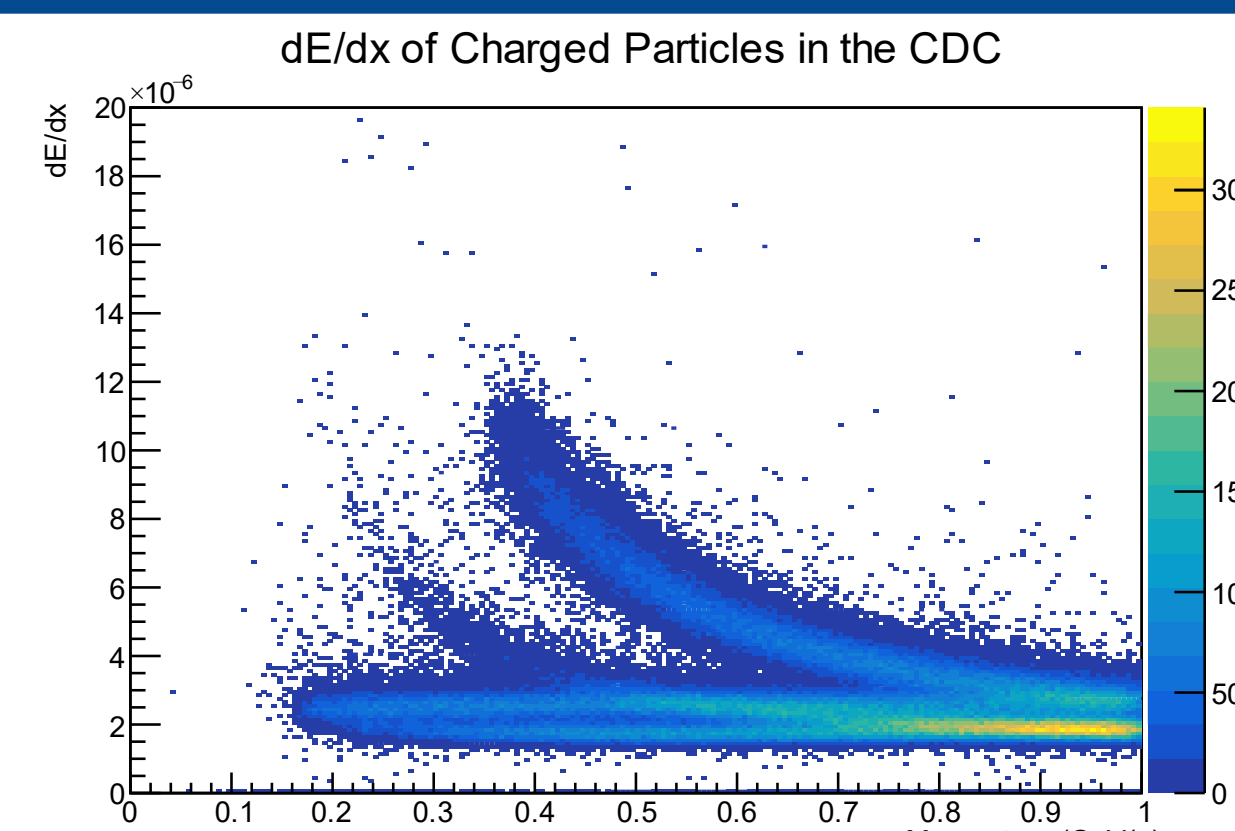


Figure 5: A 2D histogram of ionization energy loss (dE/dx) and momentum.

At fixed momentum, different particles will lose energy at different rates. Students explore how they can use ionization energy loss to identify particles.

After completing this notebook, students should be able to:

- Name the effects that cause different particles to lose different amounts of energy in drift chambers
- Demonstrate the separation power of dE/dx analysis using ROOT's TH2D class
- Classify different charged particles based on their energy loss at fixed momentum

FUTURE TOPICS

- **Time of Flight:** Using velocity and momentum measurements for PID
- **DIRC:** Using the fact that different particles emit light at different angles for PID
- **Calorimeters:** Detectors that measure the energy of particles
- **Neutral PID:** Using features of signals left in calorimeters to identify neutral particles
- **Machine Learning:** Training boosted decision trees (BDTs) to use all information from the detector for PID

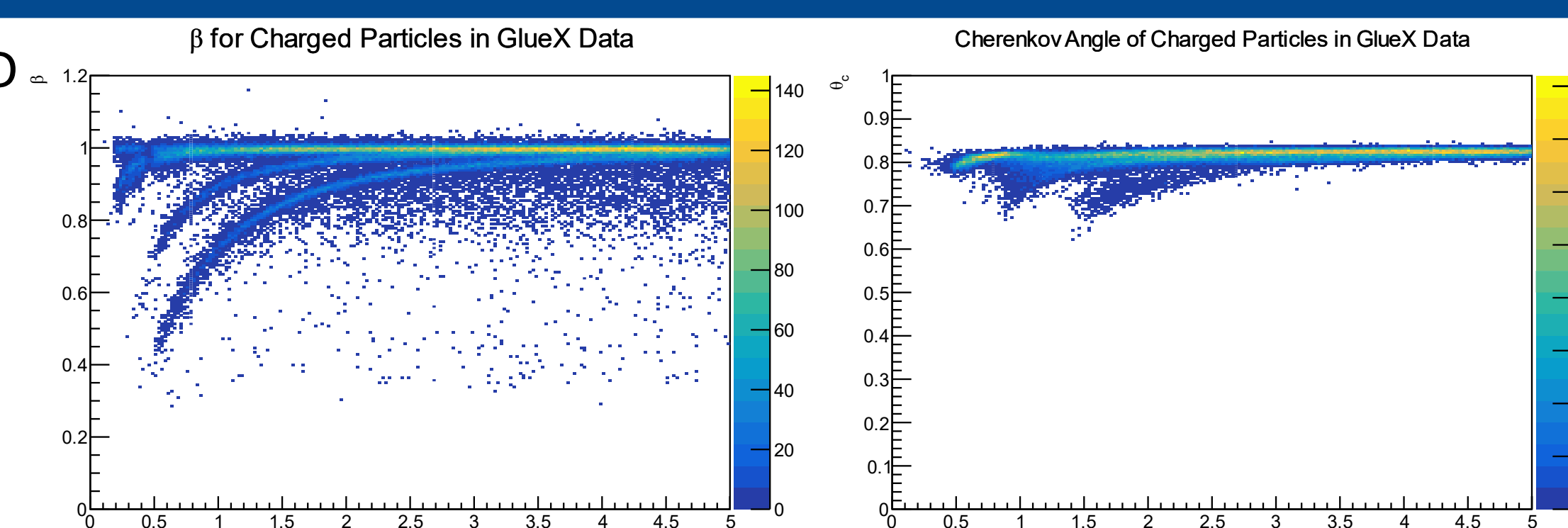


Figure 6: Left: A 2D histogram of beta (velocity over the speed of light) and momentum. Right: A 2D histogram of Cherenkov angle and momentum.

NEXT STEPS

NOTEBOOK DEVELOPMENT

PID Playground currently hosts 8 notebooks, but at least 6 more are planned. Notebooks will be released as they are developed, and all planned notebooks should be available within the next 4 months.

STUDENT FEEDBACK

As part of QubitxQubit's "Introduction to Quantum Computing" course, PID Playground will be offered as an option for a final project, which will provide student feedback from high school students and undergraduates.

ACCESSIBILITY

PID Playground was designed as a Universal Design for Learning (UDL) aligned resource, but there are always ways to improve accessibility. As notebooks are developed, they will be evaluated against UDL guidelines to identify and resolve any barriers to access.

REFERENCES

1. CERN Open Data Team. (2017, December 18). Welcome to Our Updated CERN Open Data Portal. CERN Open Data Portal. <https://opendata.cern.ch/docs/welcome>
2. Data Activities Portfolio. QuarkNet. (n.d.). <https://quarknet.org/data-portfolio>
3. Alexander, J., Bellis, M., Breimer, E., Depoian, A., Hagen, W., Mikulec, R., Moruzzi, D., Rera, R., Ryd, A., Sitterly, T., Smith, M., Spicer, S., Whinnery, D., Tamayo, G., Tuladhar, S. D. (n.d.). Particle Physics Playground. <https://sites.google.com/siena.edu/particle-physics-playground/home>

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