Particle Timing and Distance

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Project Overview

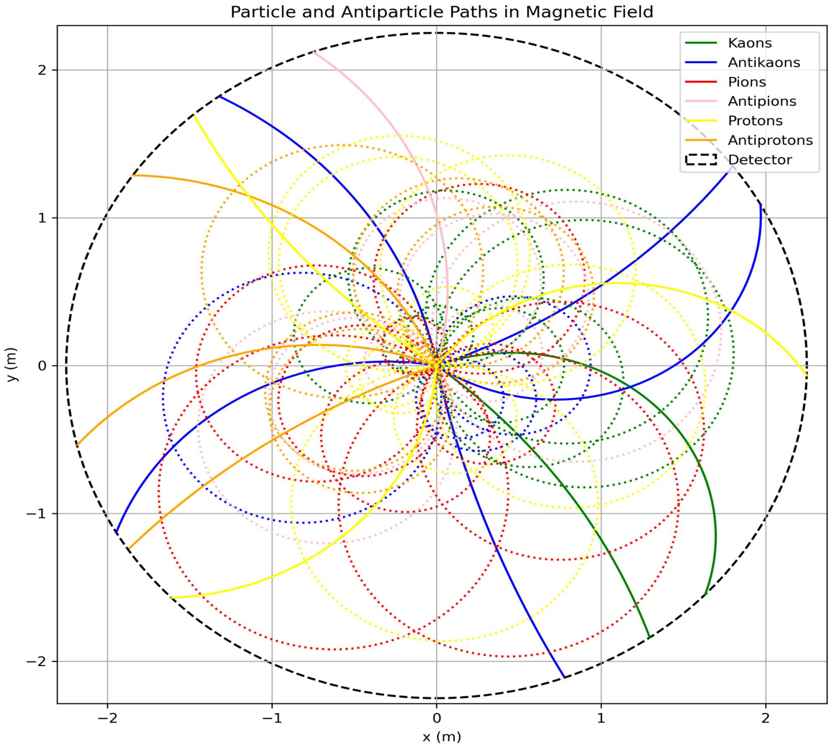
- In flavour physics it is very important to correctly identify charged hadrons.
- Possible by measuring their time-of-flight from one point in the detector to another.
- Hadrons differ in their mass, m = p/(gamma*velocity) = p/(gamma*distance/time)

<u>Project:</u> Is it possible to distinguish charged hadrons by measuring their time-of-flight with the tracking detectors?

Shekinah's Approach: Geometric Solution

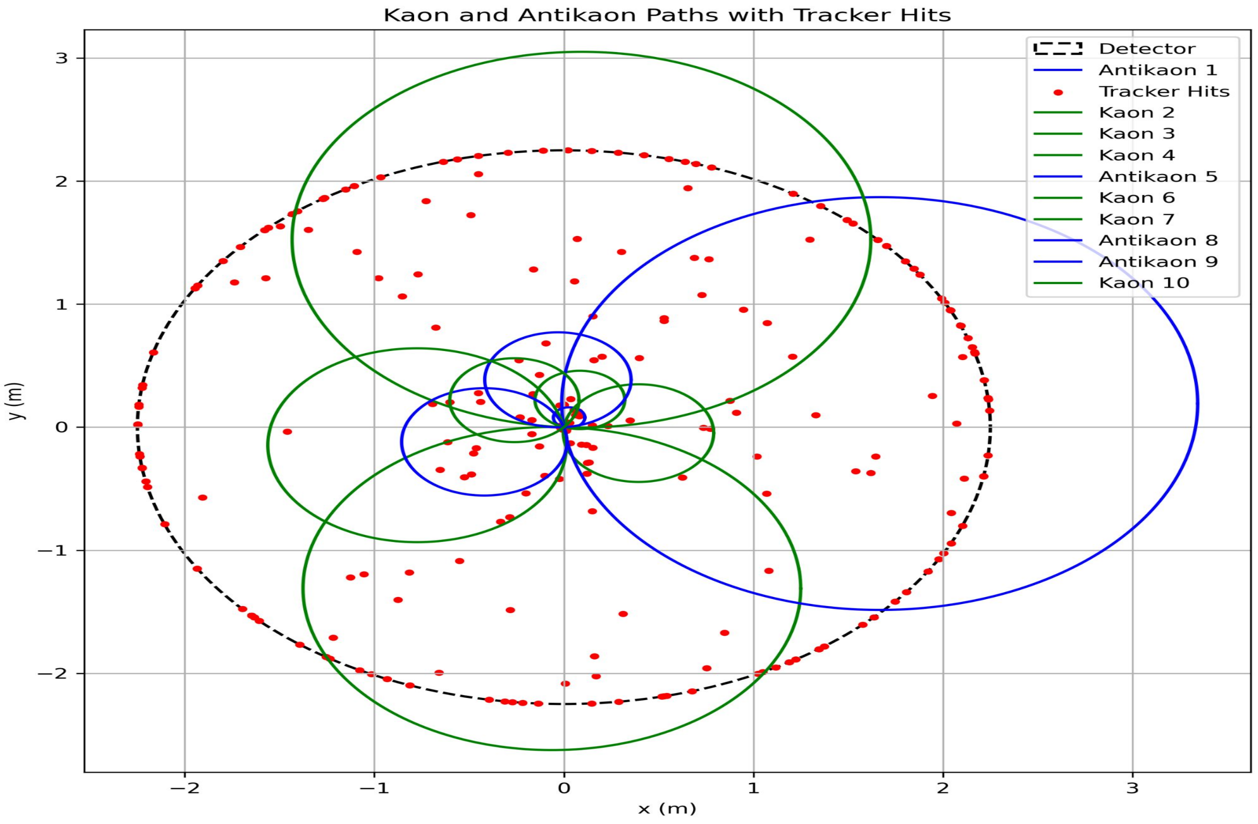
- Looking at kaons, pions and protons.
- Have momentum data, charge and the B field.
- Able to get the radius of the detector by plotting the Tracker.hits and extracting value from there.
- Used formula for gyroradius to calculate the radius of each circle described by each particle. ($r = p/qB$)
- Used another similar formula to get the centre of the circle for each particle. ($x=py/qB$).
- Plotted circular paths of the particles up to when they hit the detector.
- Checked whether they hit by checking for intersection points.

Plots Created



- Got radius of 20 particles and antiparticles each (kaons, pions, protons etc.).
- Solid lines: particles that hit the barrel => partial circles
- Dashed lines: particles that hit the endcaps => full circles

Plots Created



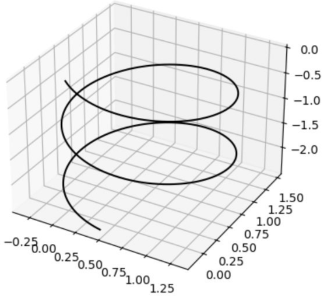
- Plotted tracker hits for 100 particles (detector boundary shows up).
- Also plotted full circular paths of particles not hitting detector.

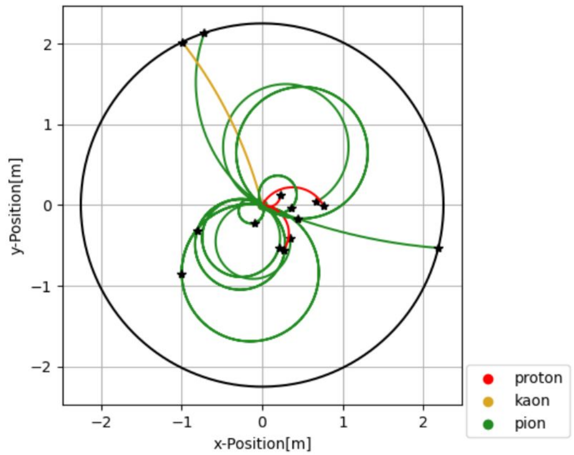
Jovani's Approach: Simulating the Propagation

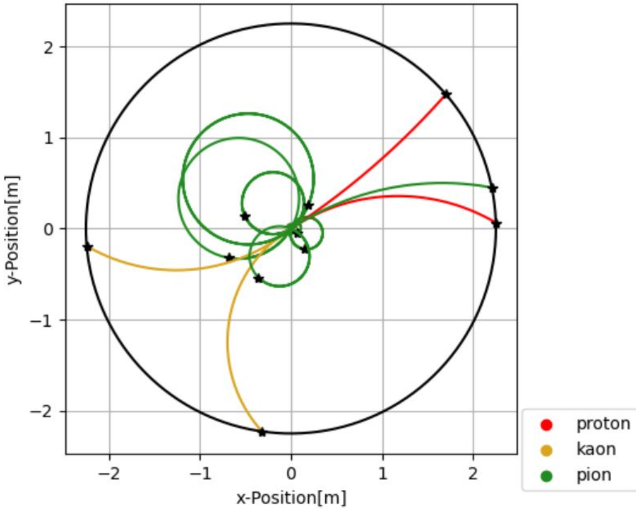
- Isolate the kaon, pion, and proton information into a seperate file with all relevant information
  - X,Y,Z momentum
  - Coordinates in main file
  - Particle Type
- Found the size of the tracker using information in the tracker hit data
- Using the equation F = (qv)x(B) plot the change in position over small step sizes.
- Determine whether the particle has touched the tracker by checking the distance of the particle from the center after each step.
- If the particle hits the ends of the cylindrical tracker, the steps stop
- Measure total travel distance of particle by adding the distance traveled over each step

Plots Created

- 3D Plot of a particle's motion





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Particle:
Ending X: 0.20842504810156415
Ending Y: -0.5239130855189521
Ending Z: -2.4999813594308375
Radius = 0.5638492013421037
Distance traveled:6.019038353051974
Cylinder End Reached
Step number: 79009
Particle Type: anti-pion

Particle:
Ending X: -0.7181453296479122
Ending Y: 2.132162386668041
Ending Z: -1.0427282442144126
Radius = 2.249855363710535
Distance traveled:2.6402861735801455
Radius Too High
Step number: 9300
Particle Type: pion

Particle:
Ending X: -0.8046263284386508
Ending Y: -0.31413072786255847
Ending Z: -2.017865899813539З
Radius = 0.863771753766077
Unfactored Distance:8.268972402536324
Distance traveled:10.244700110275437
Max Steps Reached
Step number: 100000
Particle Type: anti-pion
```

- Sample plots of 10-15 particles each

- Data about each particle plotted

What we did next…

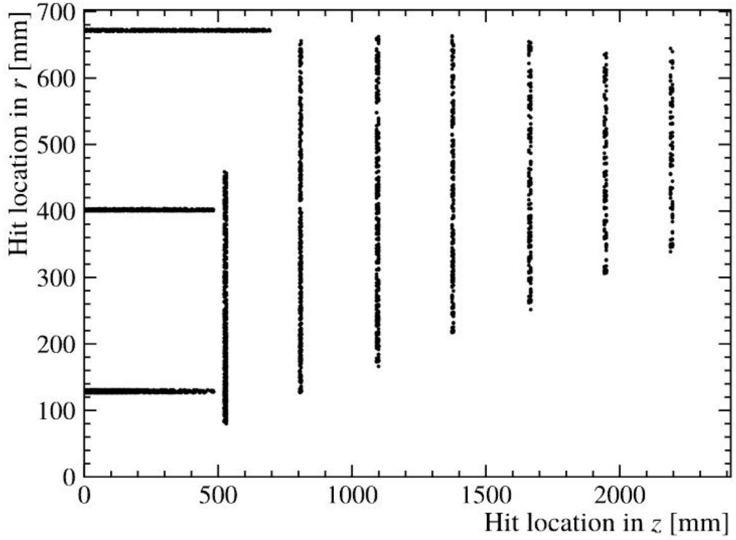
- Working on particles that hit the endcaps.
- Can get helical distance.
- Can get the time from data.
- Get velocity.
- Get mass using formula:

$$p=\gamma m v \quad \text{where} \quad \gamma = 1/\sqrt{(1-v^2/c^2)}$$

- Trace back mass to particle by estimations and see which are right.

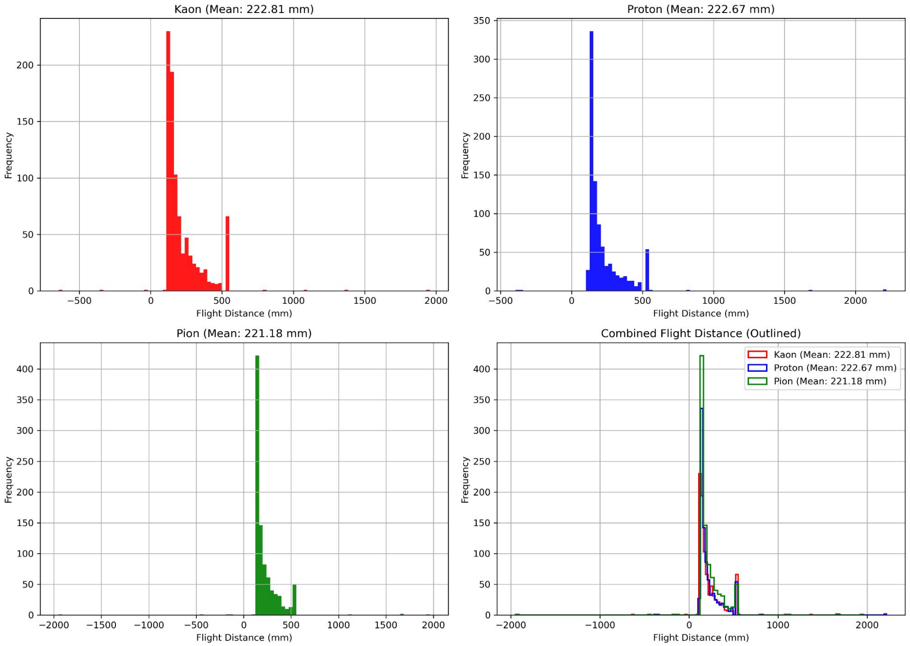
Utilizing Simulations to Identify Particles

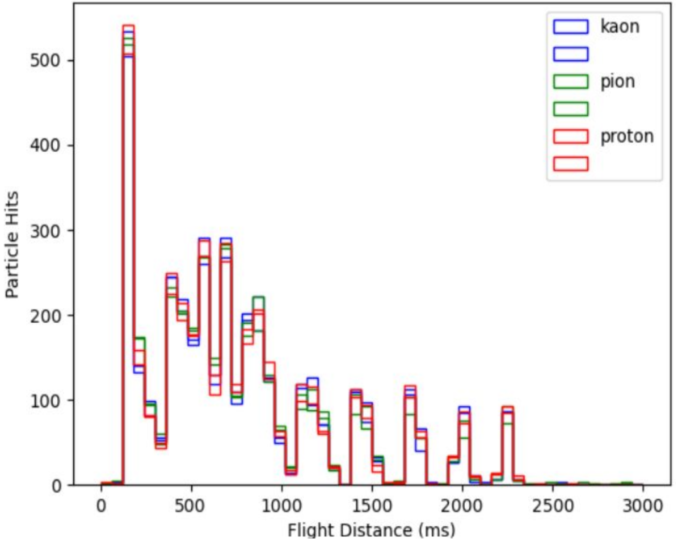
- So far: used fast simulation without proper detector information
- Now: full simulation with information about every hit
- Using data like the initial momentum, tracker hit times, and hit positions for simulated particles, we want to find how accurate the particle identification is.
  - By finding the reconstructed mass, we can see how inaccurate the values are and how often a kaon, proton, or pion might be mistaken for one another



Flight Distance Graph

- Histogram of the distance traveled by each particle using the initial momentum and magnetic field: calculated the helical distance traveled until tracker is hit.

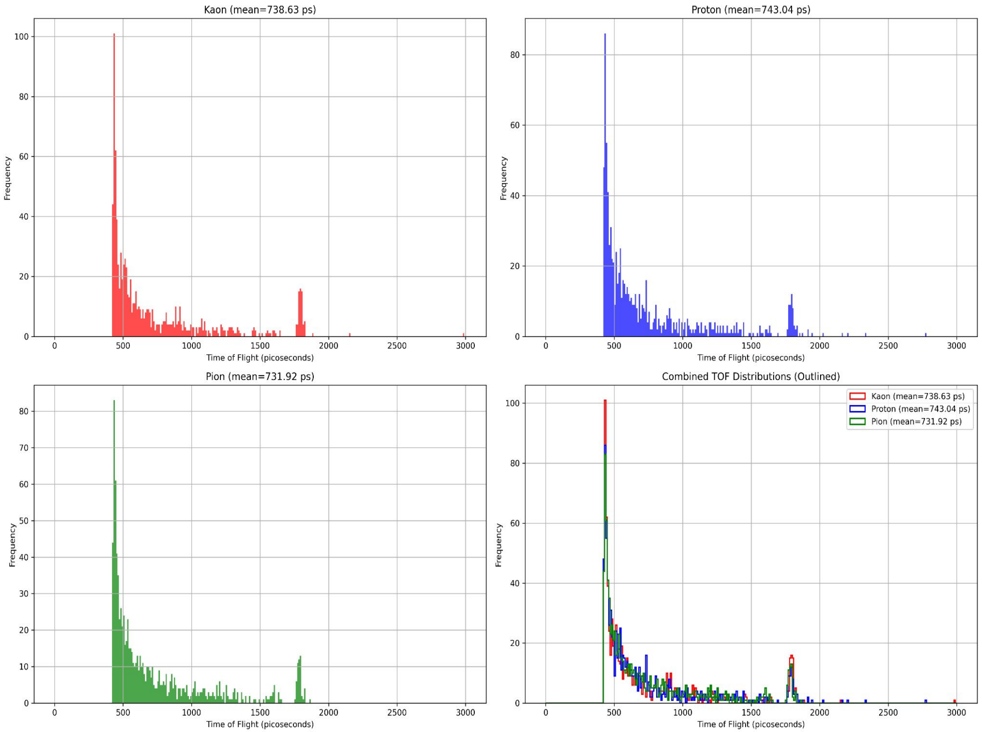


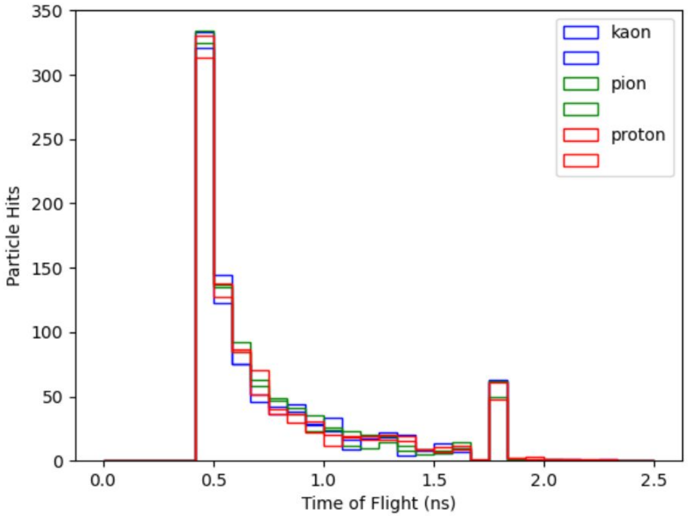


- Flight distance with multiple tracker hits

Time of Flight Graph

- Histogram plotting the simulated time of flight for particles using the “hit.time” variable for the simulation: Protons have a longer TOF.





Protons? Longer time of flight?

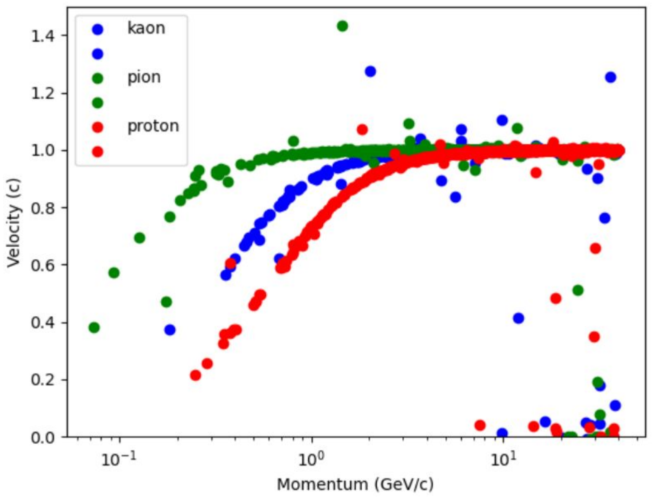
- $t=L/v$
- Since all particles (protons, pions, and kaons) are produced with similar momentum in high-energy physics experiments, their velocities are determined by the relativistic momentum formula:

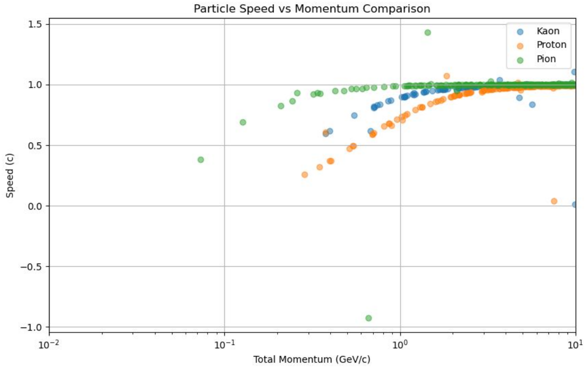
  $$\boldsymbol{p=\gamma m v}$$

- For the same momentum p, the velocity v decreases as mass mm increases, leading to a longer time of flight.

Momentum vs Velocity Graph

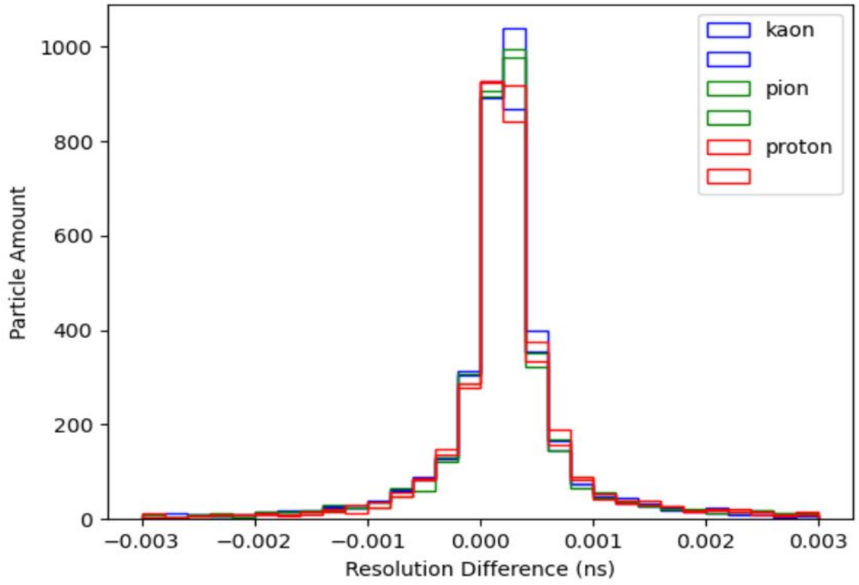
- Using the hit time and the calculated helical distance, we found the measured velocity of the particle and compared it to the measured momentum.
- P increases, γ increases, v→c.





Timing resolution

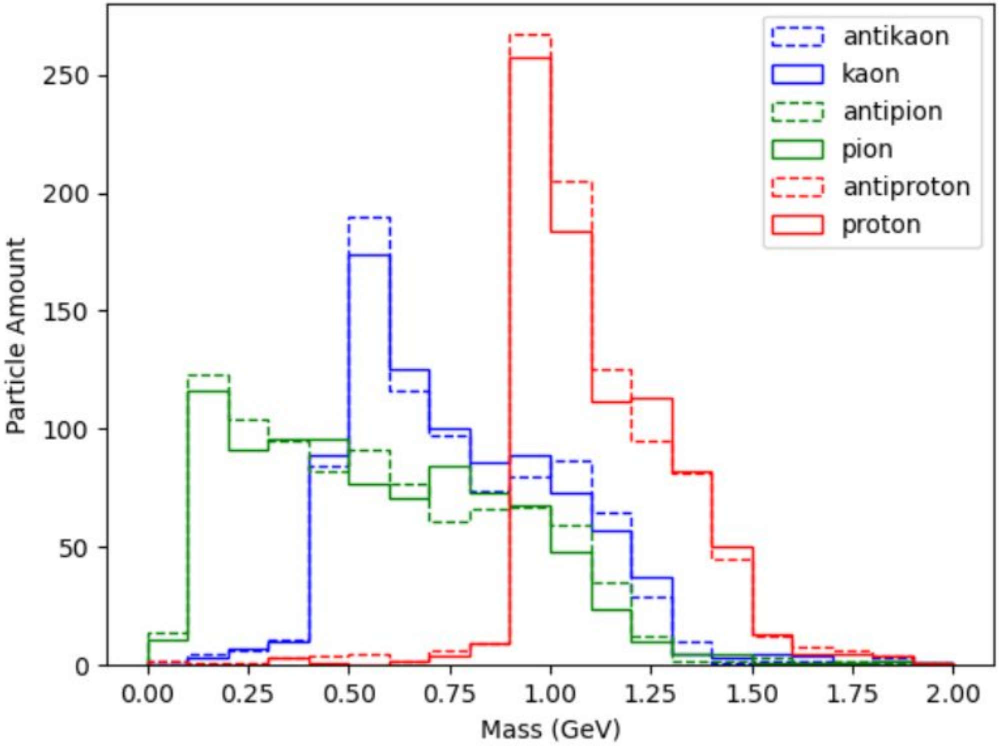
- Calculate true time of flight from momentum and flight distance.
- Resolution = measured time - true time.
- Magnitude is of order ps (no simulation of the readout or other electronics).



Using Reconstructed Mass to Determine Particle Type

- Using calculation on the momentum, flight distance and the simulated tracker hit time, we found the simulated mass of the particle.
- By comparing the simulated mass with the mass of a proton, pion, and kaon, we found how accurate it would be to determine a particle based on its simulated mass.

Reconstructed Mass Graphs

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Proton Data:
Total Protons =1766
Correctly identified protons: 1736
Percent Correctly identfied: 0.9830124575311439
Percent Misrecognized as Kaon: 0.01245753114382786
Percent Misrecognized as Pion: 0.004530011325028313
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Kaon Data:
Total Kaons =1767
Correctly identified kaons: 831
Percent Correctly identfied: 0.4702886247877759
Percent Misrecognized as Proton: 0.5138653084323712
Percent Misrecognized as Pion: 0.01584606677985286
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Pion Data:
Total Pions =1809
Correctly identified pions: 496
Percent Correctly identfied: 0.2741846323935876
Percent Misrecognized as Proton: 0.3521282476506357
Percent Misrecognized as Kaon: 0.3736871199557767
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Actual Proton Number: 1766, Found Proton Number: 3281
Actual Kaon Number: 1766, Found Kaon Number: 1529
Actual Pion Number: 1766, Found Pion Number: 532
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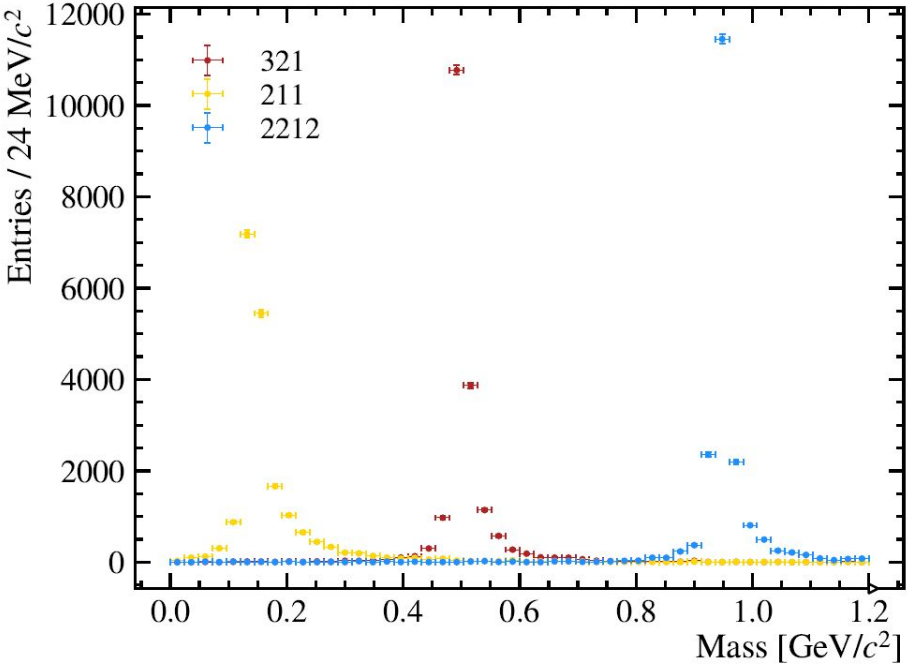
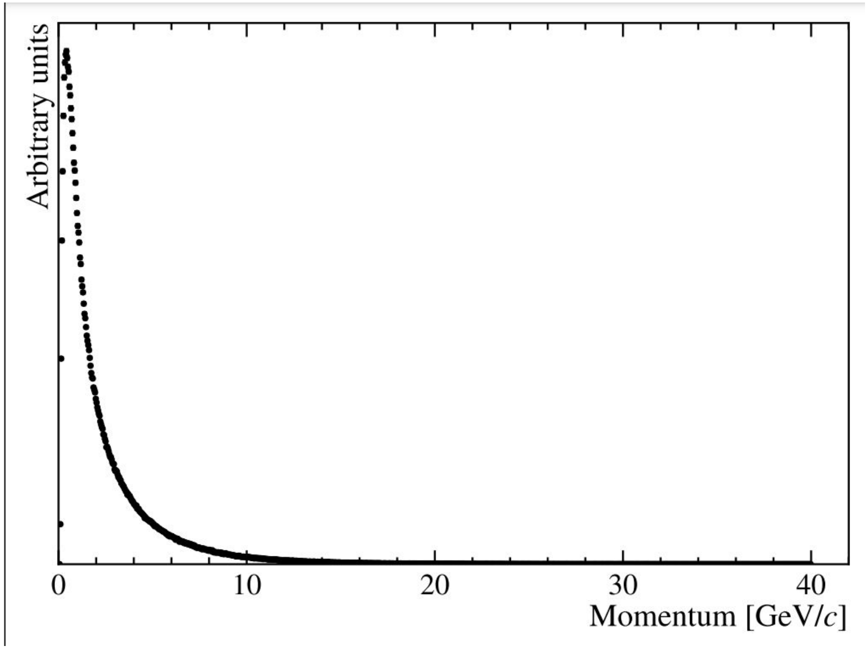
- High Proton Accuracy and Low Pion Accuracy. Overall, very common to misidentify particle to be proton

Reconstructed Mass Graph with Weighting





Summary and possible future studies

- Measured the purity of the particle identification based on a mass estimate.

Possible improvements:

- Use simulation with realistic momentum distribution (mostly 0-5GeV/c).
- Add realistic timing resolution for collider clock, read-out, etc.
- Implement more sophisticated methods for the estimate (e.g. likelihood).