Time of Flight in SiD

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The Search for Kaons Via Time of Flight

- First, the entire momentum spectrum of the quarks should be explored in a MC particle simulated environment, and then compared with the detector level data
  - Provides cross-check that detector simulation works
  - Compute from jet finding algorithms as well
- Explore low momentum particles from these jets: find strange kaons
  - Use Time of Flight (TOF) to ID particles as kaons or pions - presence of kaons in a jet suggests occurence of Higgs to Strange decay

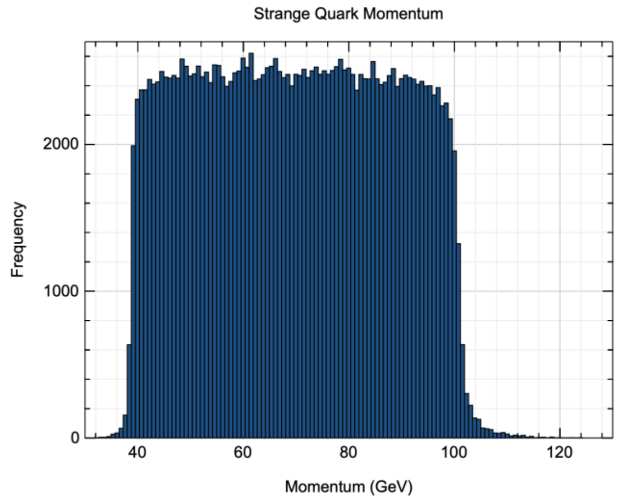
Kinematic Properties of Strange Jets (MC Particles)

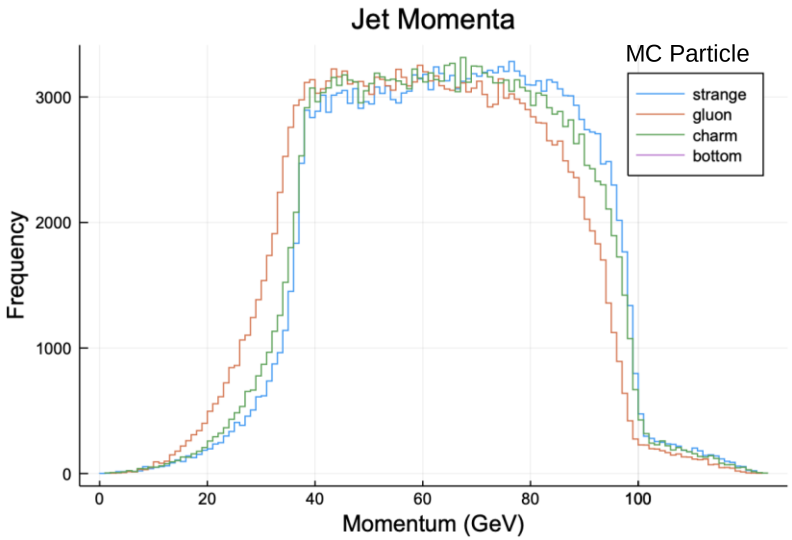
- Can the momentum spectrum of the quarks and decay products be ascertained in a purely analytical way? Does the data we collect from jets particles match our predictions?
- If we assume $p_0 = 0$and $E_{tot} = 250GeV$, then the Higgs and Z-bosons must have the same magnitude of momentum in opposite directions.
- From $E_{tot}^2 = (p)^2 + (m)^2$(in natural units) which leads to $E_{tot} = \sqrt{p^2 + m_z^2} + \sqrt{p^2 + m_H^2}$the momentum of the Higgs and Z bosons can be deduced (~ 63 GeV)
- Can apply similar analysis to find limits of decay quark momentum (let’s assume quarks are massless) - the limits are given by the case in which one quark moves parallel to the Higgs, and the other antiparallel

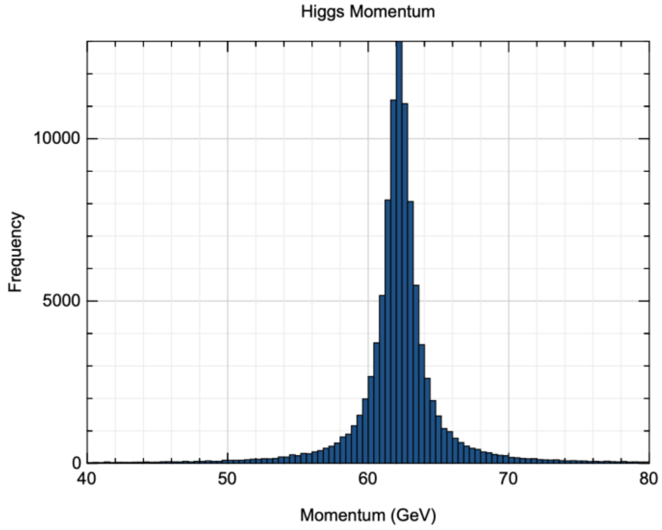
$$p_H = |p_1| - |p_2|$$

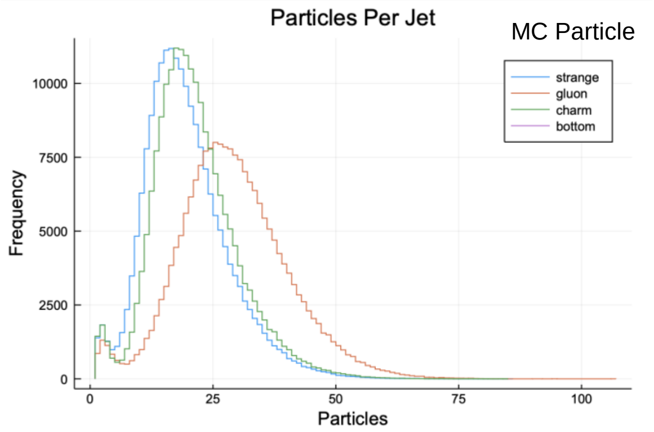
$$E_H = |p_1| + |p_2|$$

- Limits of quark momentum are ~38 GeV and ~101 GeV

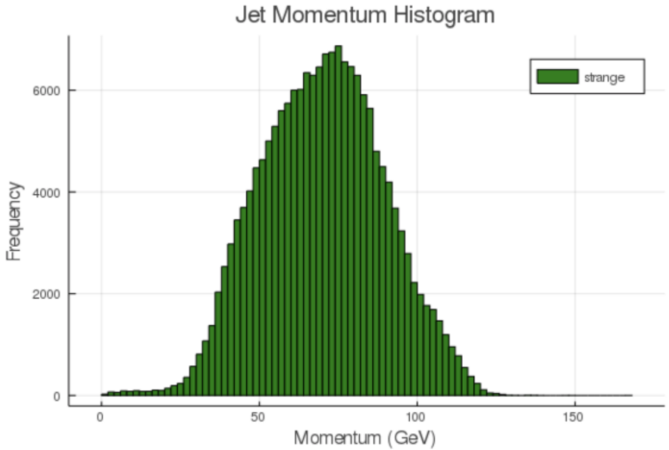

Strange Quark Momentum

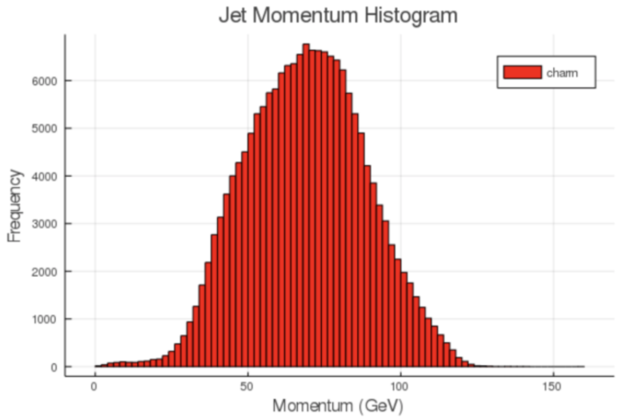

Jet Momenta

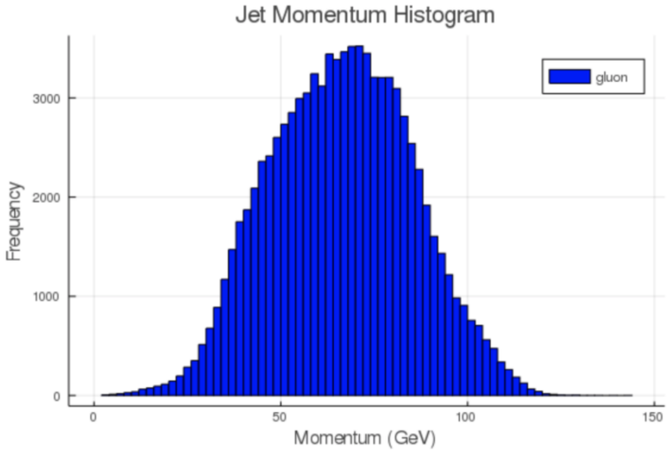

Higgs Momentum

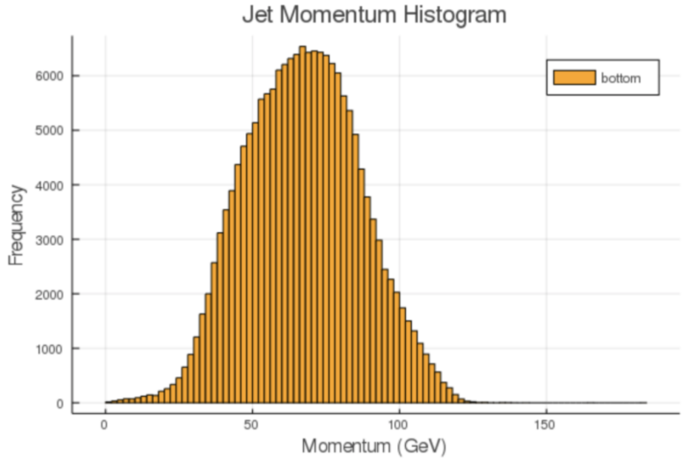

Particles Per Jet

Jet Momentum from Reconstructed Particles



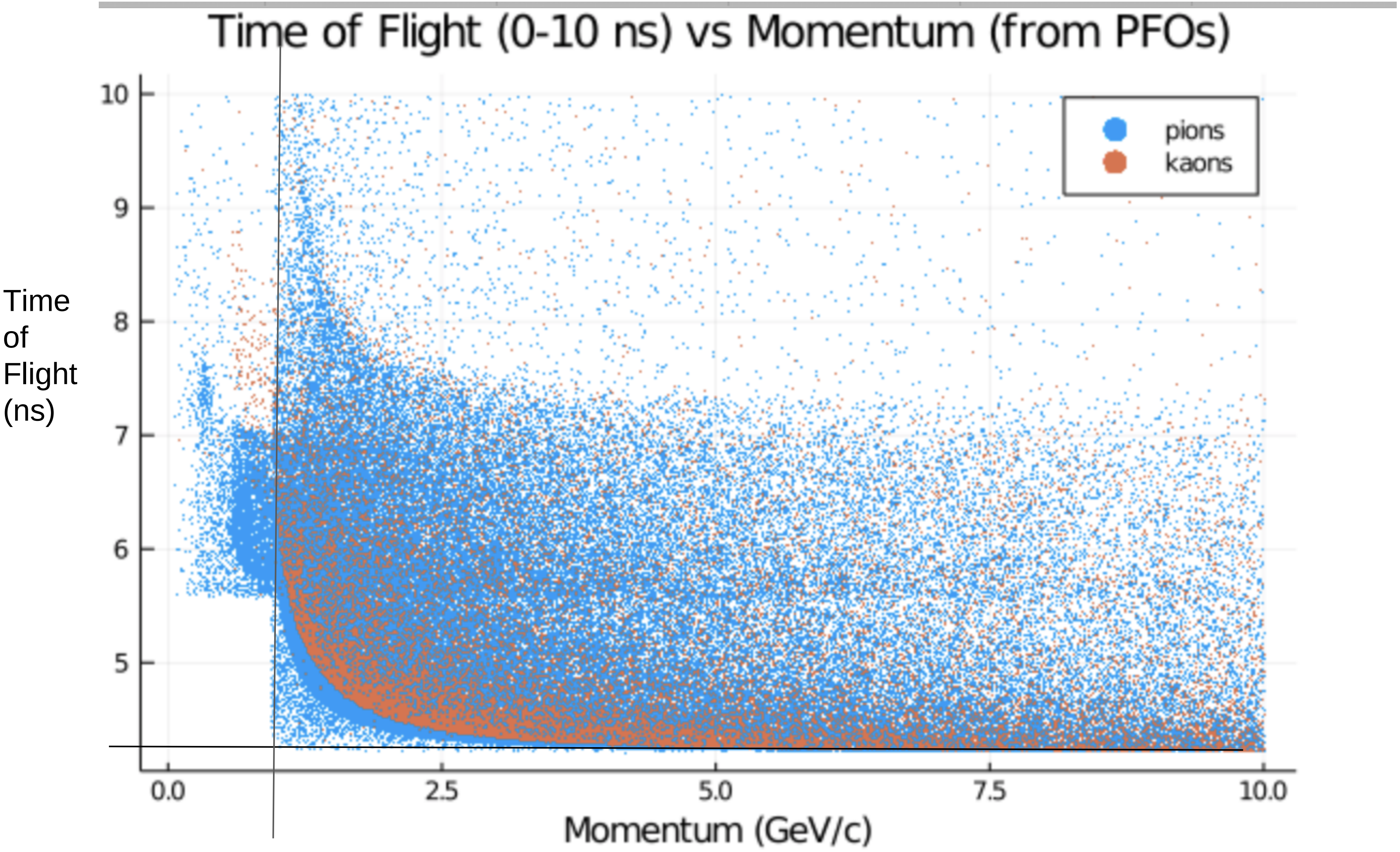






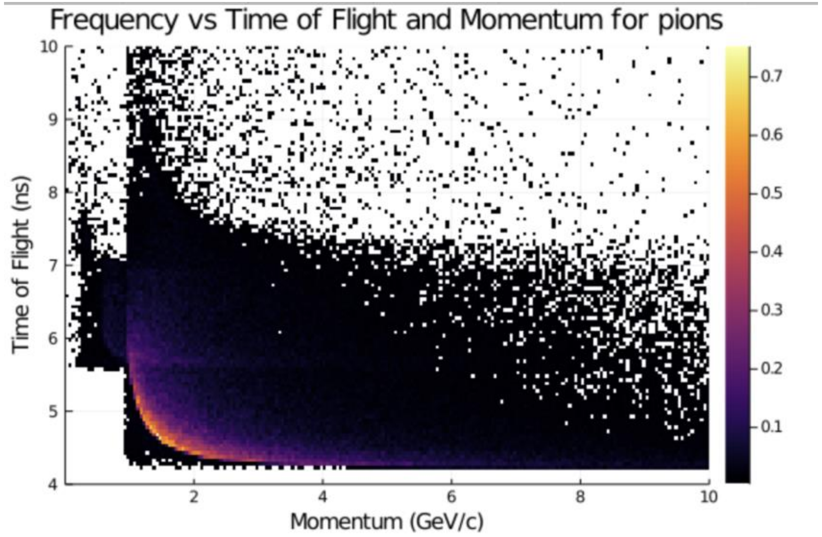
Pions vs Kaons Differentiation for Low Energy Tracks

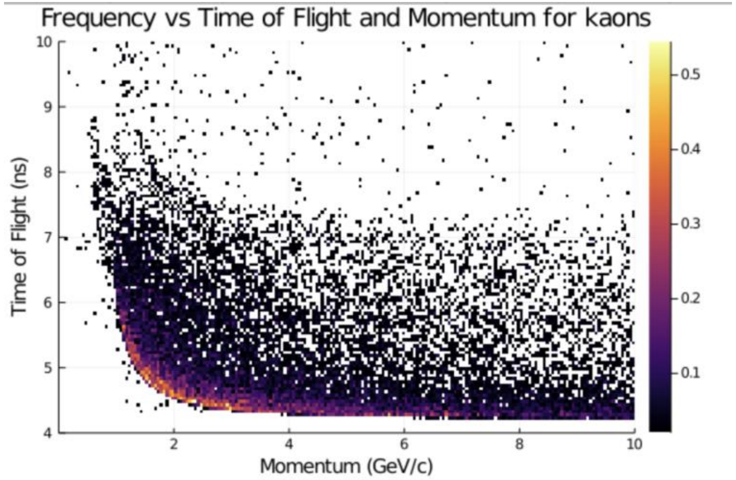
- As discussed by Chester, the key to understanding the Higgs to Strange coupling is through an analysis of jet composition
- Almost all reco particles are identified as pions; how many are actually kaons, which we would expect from a strange decay chain?
- The most easily recognizable difference between the two is the mass
  - $\pi^{\pm} \sim 139.57018$ MeV/c^2
  - $K^{\pm} \sim 493.677$ MeV/c^2
- For a given momentum, each particle should have a different required time of flight to reach the detector
- Data collected from both barrel and end caps, ensured one-to-one relationship
- Goal: cut all particles with a less than 50% Kaon likelihood rate

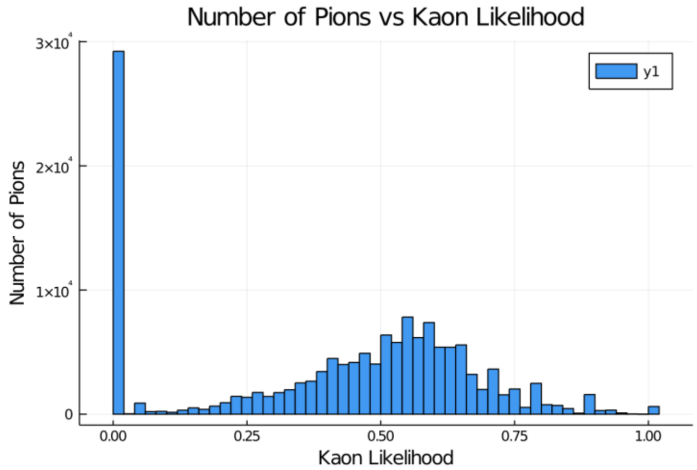

Time of Flight (0-10 ns) vs Momentum (from PFOs)
Time of Flight (ns)
10
9
8
7
6
5
0.0
2.5
5.0
7.5
10.0
Momentum (GeV/c)
pions
kaons

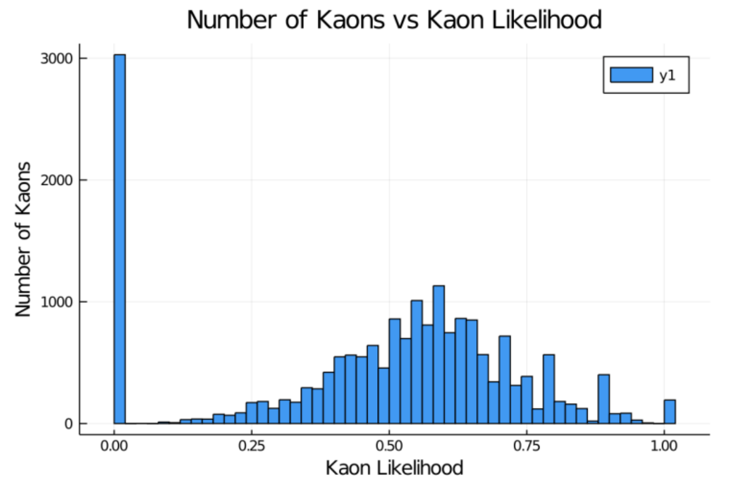
Exploring 2D Histograms

- Developed 2D histograms for both kaons and pions separately
    - Each cell gives the proportion of pions/kaons that have the specified Momentum and TOF (L_pi and L_K)
    - Assumed a 0.05 GeV Momentum binning and a 50 ps time binning
- Determined the likelihood a given particle is a kaon or a pion by comparing relative probabilities
    - pi_likelihood = L_pi / (L_pi+L_K)
    - K_likelihood = L_K / (L_pi+L_K)
- Despite tuning parameters and bin resolution, not nearly enough data for significant statistics


Frequency vs Time of Flight and Momentum for pions


Frequency vs Time of Flight and Momentum for kaons


Number of Pions vs Kaon Likelihood

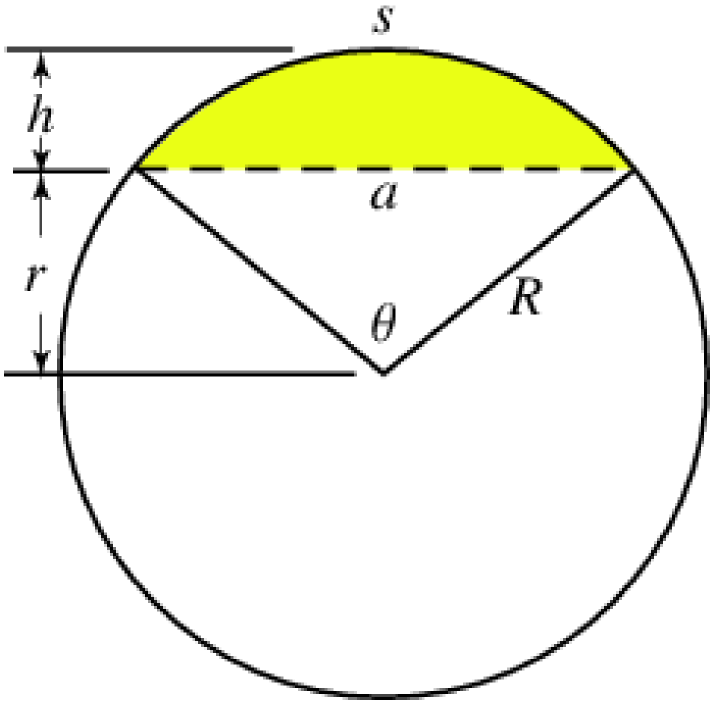

Number of Kaons vs Kaon Likelihood

Momentum vs TOF function

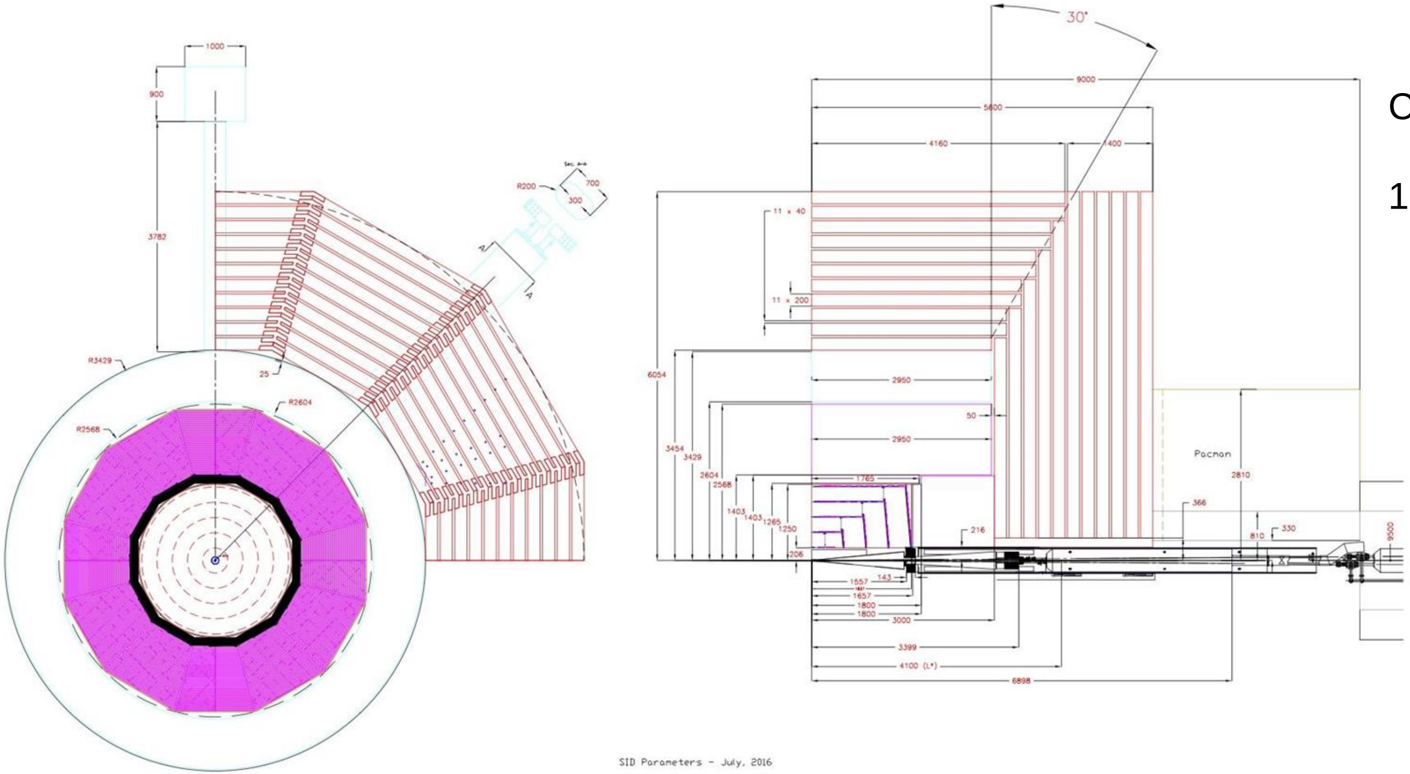
- Due to shortcomings of the 2D histogram approach, I developed a function to determine the TOF as a function of Momentum
  - Outputs two different values, one if particle is a kaon, one if it is a pion
  - Fit a Gaussian of width 1 ns, centered at the calculated value, and determined the value of the function at the measured TOF
  - Determined pion vs kaon likelihood by comparing relative probabilities (like 2D histogram)
- Developed two separate functions, one for particles that hit the barrel, other for end cap
  - End cap function relatively trivial, $t = h/v$ where h is given by distance from vertex to endcap (supplied by engineering schematic) and v is z-component of the velocity

Geometry of the Barrel Function

- All values for momentum, velocity, and arc length are projected onto the xy plane
- S represents the path taken by the particle, where R is the radius of curvature, and a is the radius of the barrel
- Since s = Rθ, and θ/2 = $\sin^{-1}(a/(2R))$
  s = $2R\sin^{-1}(a/(2R))$
- The radius of curvature of the particle is given by P/(qB)
- The arc length is divided by the transverse component of the velocity to give TOF



From https://mathworld.wolfram.com/CircularSegment.html

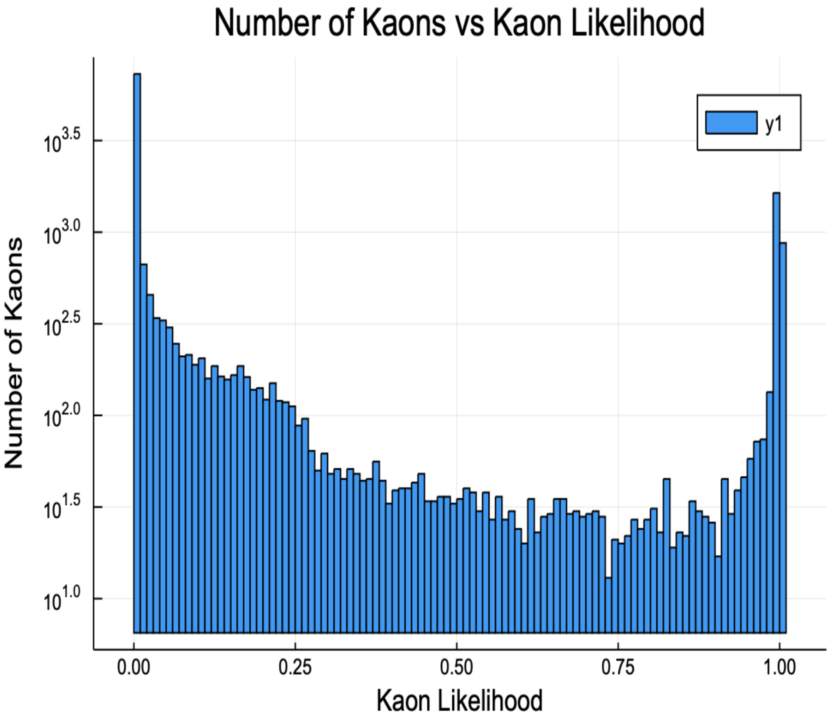


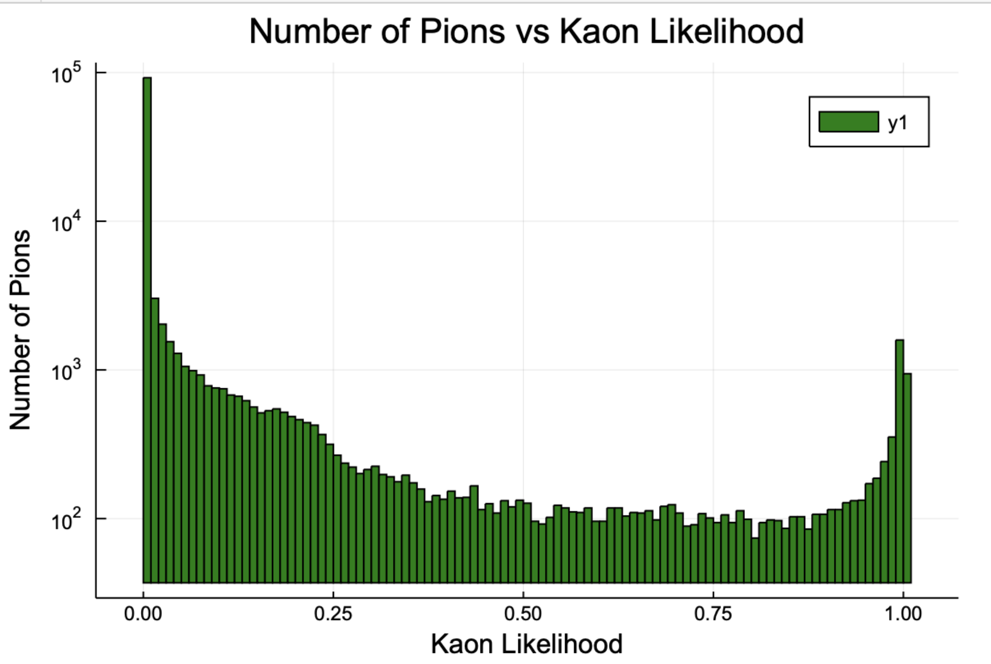
SID Parameters - July, 2016

Costheta cut:

1657/sqrt(1657^2+1265^2)

From https://confluence.slac.stanford.edu/display/SiD/SID+Engineering?preview=/170767215/213904747/SiDparJuly2016.pdf





Percent of Kaons with a Kaon Likelihood above 0.5: **23%**

Percent of Pions with a Kaon Likelihood above 0.5: **6.48%**

Concluding Remarks

- Confident in effectiveness of reconstructing particles by detector simulation
    - Verified by jet momentum analysis comparison between MC Particle and Reco tracks
- We were able to reconstruct the time of flight from the interaction point to the timing layer
    - Though simulation provides consistently larger times than constructed function
- We were able to determine particle ID from a given momentum and TOF
- Possible Future Work: Debug function and explore other differentiation techniques