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FDIRC Reconstruction

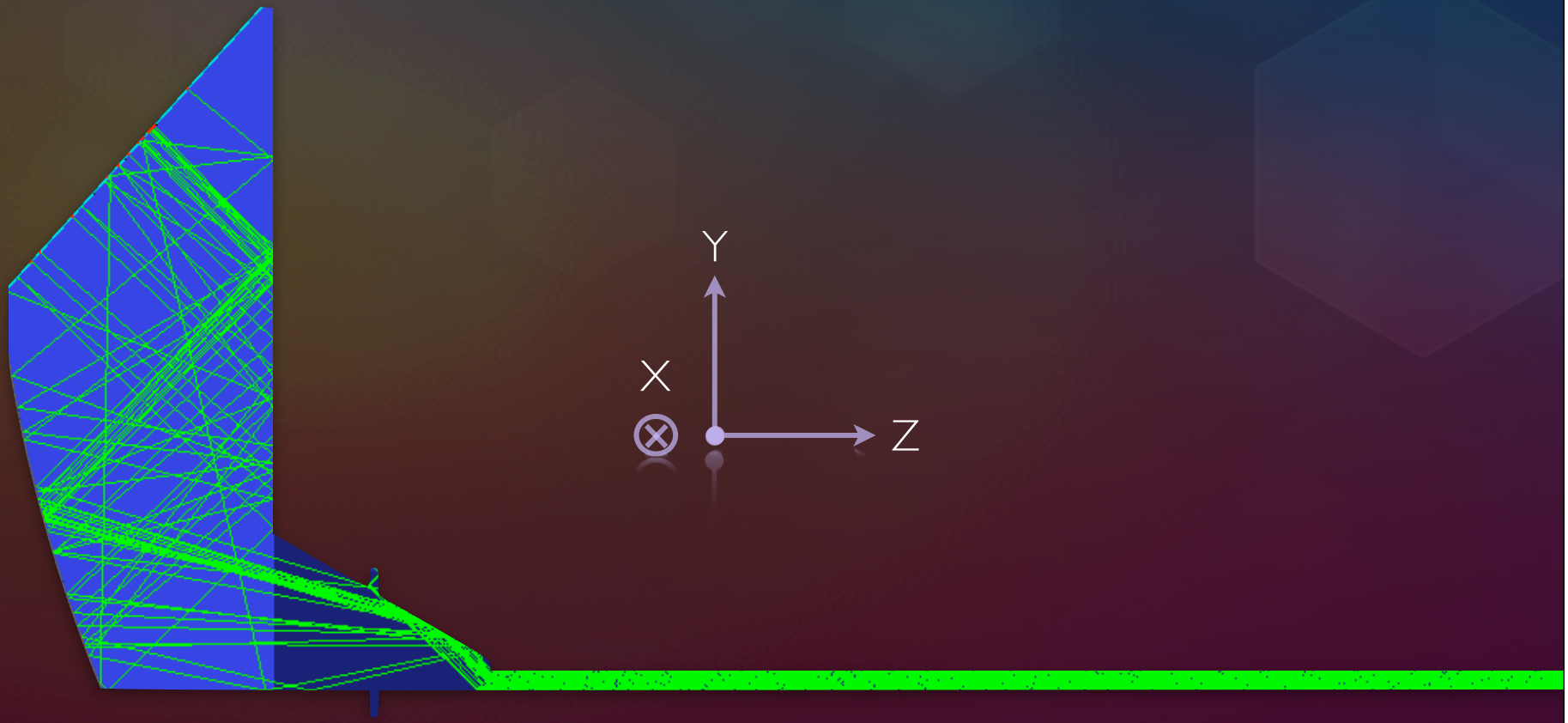
Reconstruction Overview

- The goal is to determine the angle that a given photon measured in the FDIRC makes with respect to a track
- If we call the track direction vector $\mathbf{p}$ and the photon direction at the point of creation $\mathbf{k}$, then:

$$\cos\theta_C = \hat{\mathbf{p}} \cdot \hat{\mathbf{k}} = p_x k_x + p_y k_y + p_z k_z$$

- Tracking system measures $\mathbf{p}$, FDIRC measures $\mathbf{k}$.
- FDIRC needs to translate a hit in a PMT pixel into a k-vector
- Note that k_x, k_y and k_z are not independent (unit vector):

$$k_z = \mathrm{sgn}(k_z)\sqrt{1 - k_x^2 - k_y^2}$$

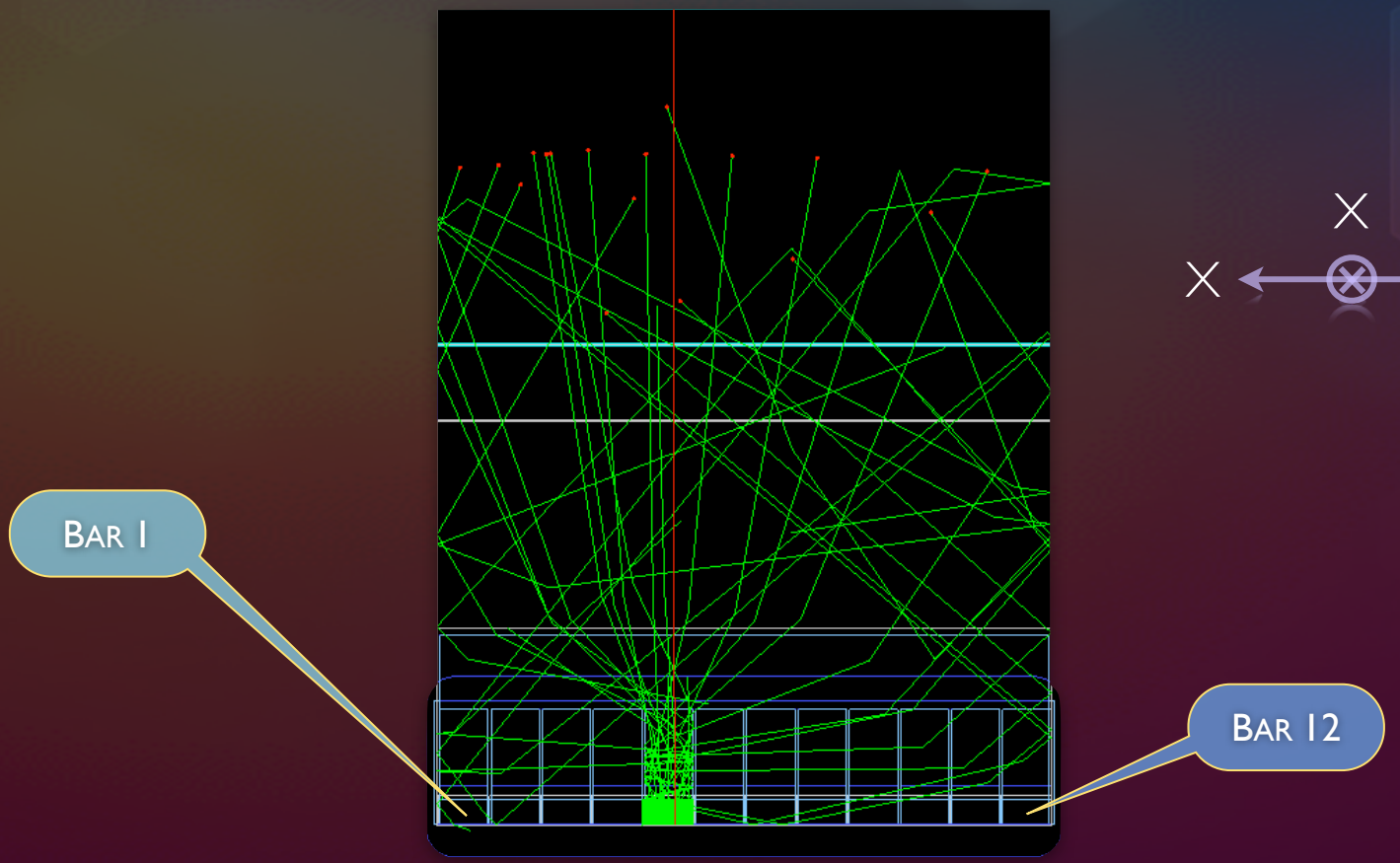


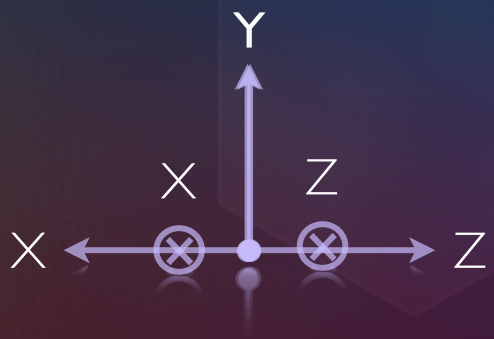
Define Sector Coordinate System

$z = 0$ is at IP, so FBLOCK and PMTs are at negative z.

Implies that all photons will have negative k_z when they get to the FBLOCK

Define Sector Coordinate System

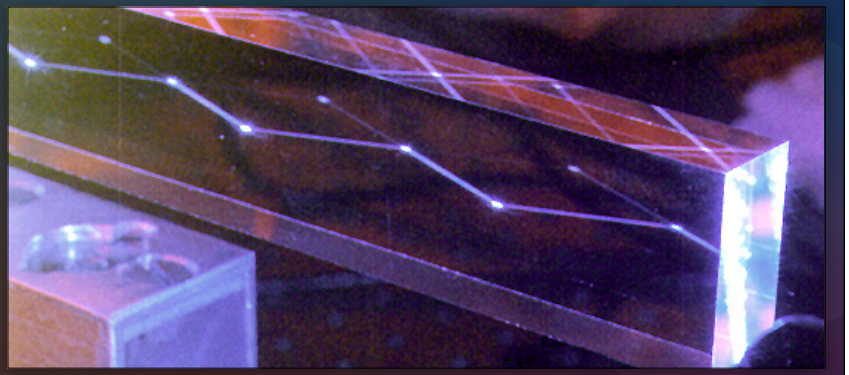




View from behind FBLOCK (from negative Z)

Note the bar 1 is at positive X, bar 12 is at negative X

Bar Ambiguiities (8-Fold Ambiguity)



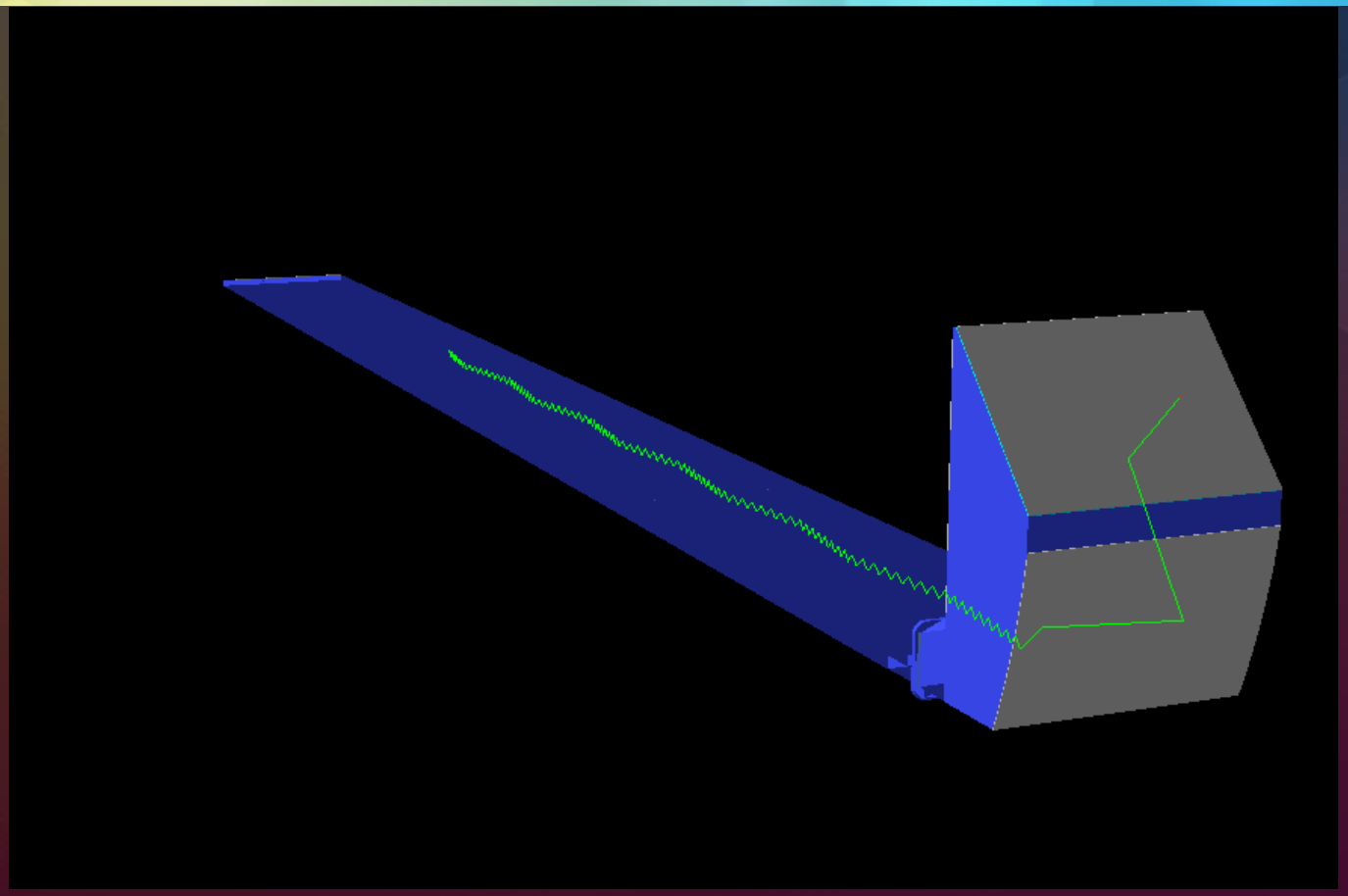
- As the photon propagates through the bar its direction changes w.r.t. its original direction:
  - Each bounce in the horizontal direction changes the sign of K_X
  - Similar for vertical bounces and K_Y
  - And forward-going photons that hit the end mirror change sign of K_Z
- In general, the photon's direction as it leaves the bar is related to the generated direction by:

$$\vec{\mathbf{k}}_{Bar} = (\pm)_x k_x \hat{x} + (\pm)_y k_y \hat{y} + (\pm)_z k_z \hat{z}$$

- We make no attempt to actually calculate the number of bounces so we treat these solutions as ambiguities
- In reality, timing will resolve the *Z*-ambiguity and some of the ambiguities will give rise to non-physical values of the Čerenkov angle.

After the Bar

- Once the photon leaves the bar it propagates through:
  - Wedge
  - Window
  - New Wedge
  - FBLOCK
  - (and various glue joints)
- Then detected in a pixel of a PMT
- Challenge is to map a hit in a pixel (and knowledge from track about which bar was hit) to a (K_X, K_Y) direction at the exit of the bar



Single Photon Generator

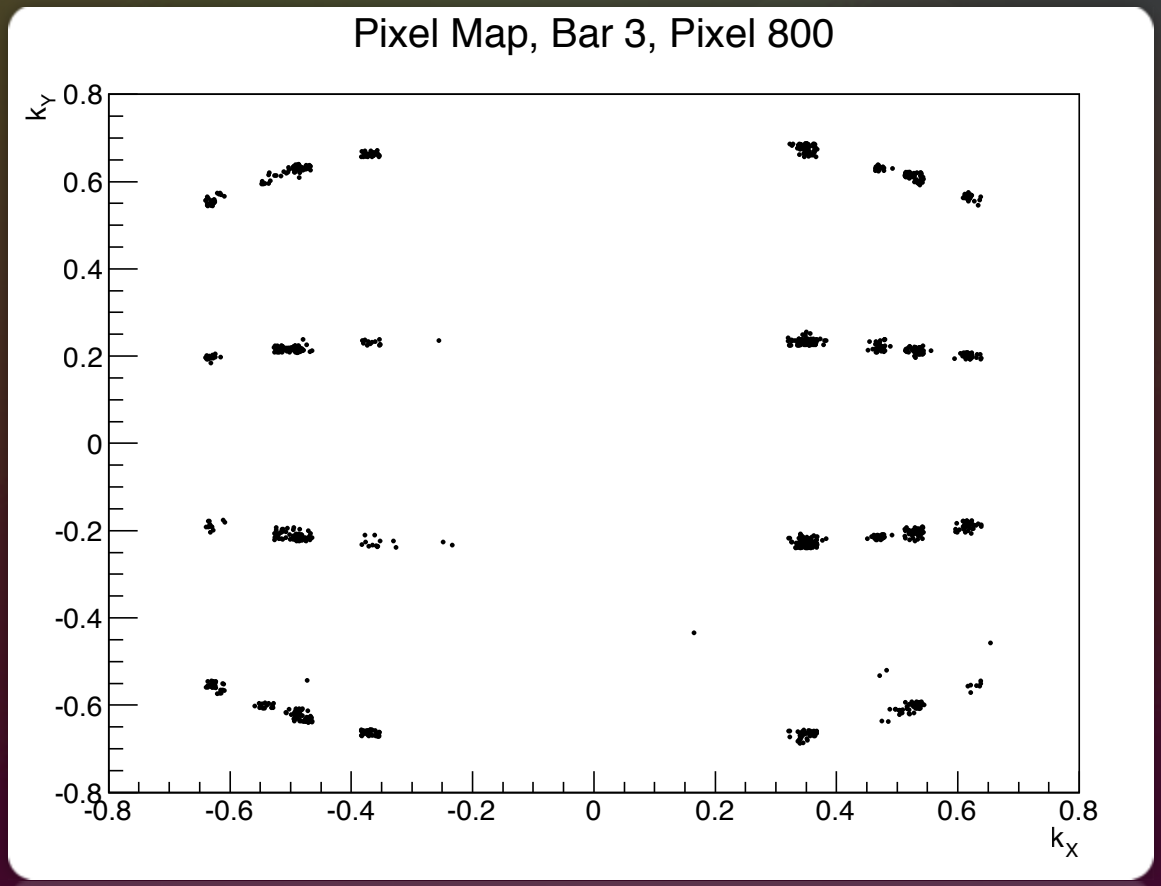
This mapping is done be propagating single photons with a fixed wavelength through the detector

Photons are generated isotropically in direction

Only about 27% are internally reflected and hit PMTs

Photon Dictionary

- The output of the single photon simulation is used to create a dictionary or look-up table that maps (Bar, Pixel) information to (K_X, K_Y, T)
- For fully instrumented FDIRC, there are 12 (bars) x 48 (PMT) x 32 (Pixels) = **18,432** cells in the dictionary
- There can be multiple paths that go from a given bar to a given pixel, so each cell needs to be multi-valued
  - This is on top of the 8-fold Bar Ambiguity



K_Y VS K_X

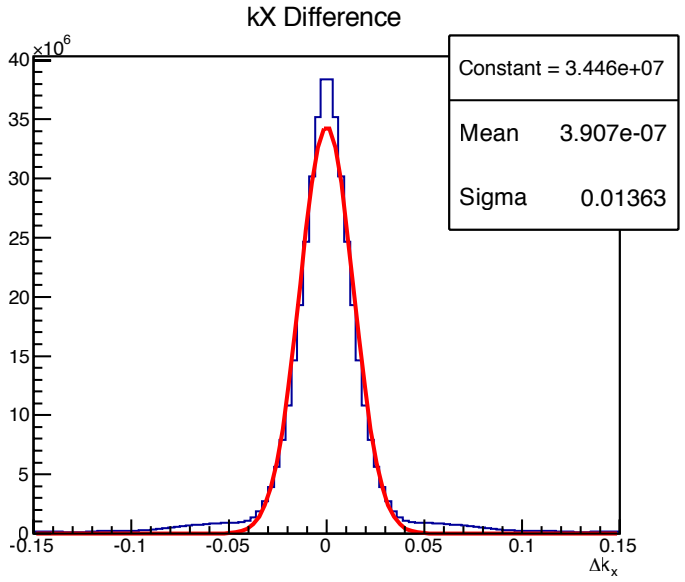
- ONE PIXEL: BAR 3, PIXEL 800
- THESE ARE THE (K_X, K_Y) "COORDINATES" OF PHOTONS THAT LEFT BAR 3 AND HIT PIXEL 800
- EACH CLUSTER OF PHOTONS REPRESENTS A DISTINCT PATH THAT MAPS A PHOTON FROM THIS BAR TO THIS PIXEL

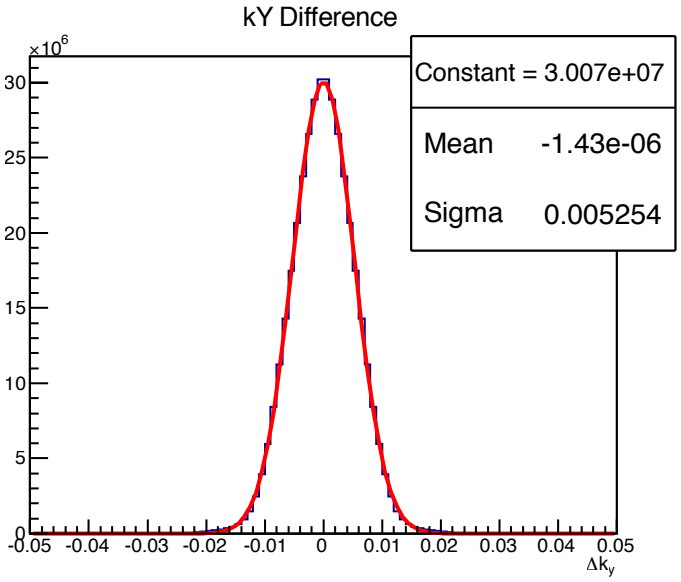
Clustering Algorithm

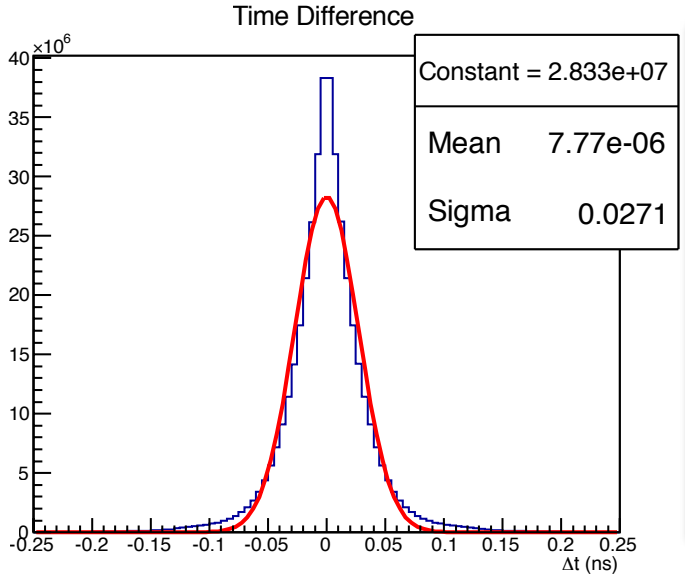
- Run a simple "nearest neighbor" clustering algorithm on all of the raw data from the previous page to reduce the dictionary to a set of clusters
- "Nearest" is defined by a distance in (k_x, k_y, time) space:

$$d_{i,j}^2 = \frac{\left(k_{x,i} - k_{x,j}\right)^2}{\sigma_{k_x}^2} + \frac{\left(k_{y,i} - k_{y,j}\right)^2}{\sigma_{k_y}^2} + \frac{\left(t_i - t_j\right)^2}{\sigma_t^2}$$

- The closest pair within a pixel is merged into a single cluster
  - Store average (k_x, k_y, time)
  - Also store RMS of (k_x, k_y, time) and number of photons used in the cluster



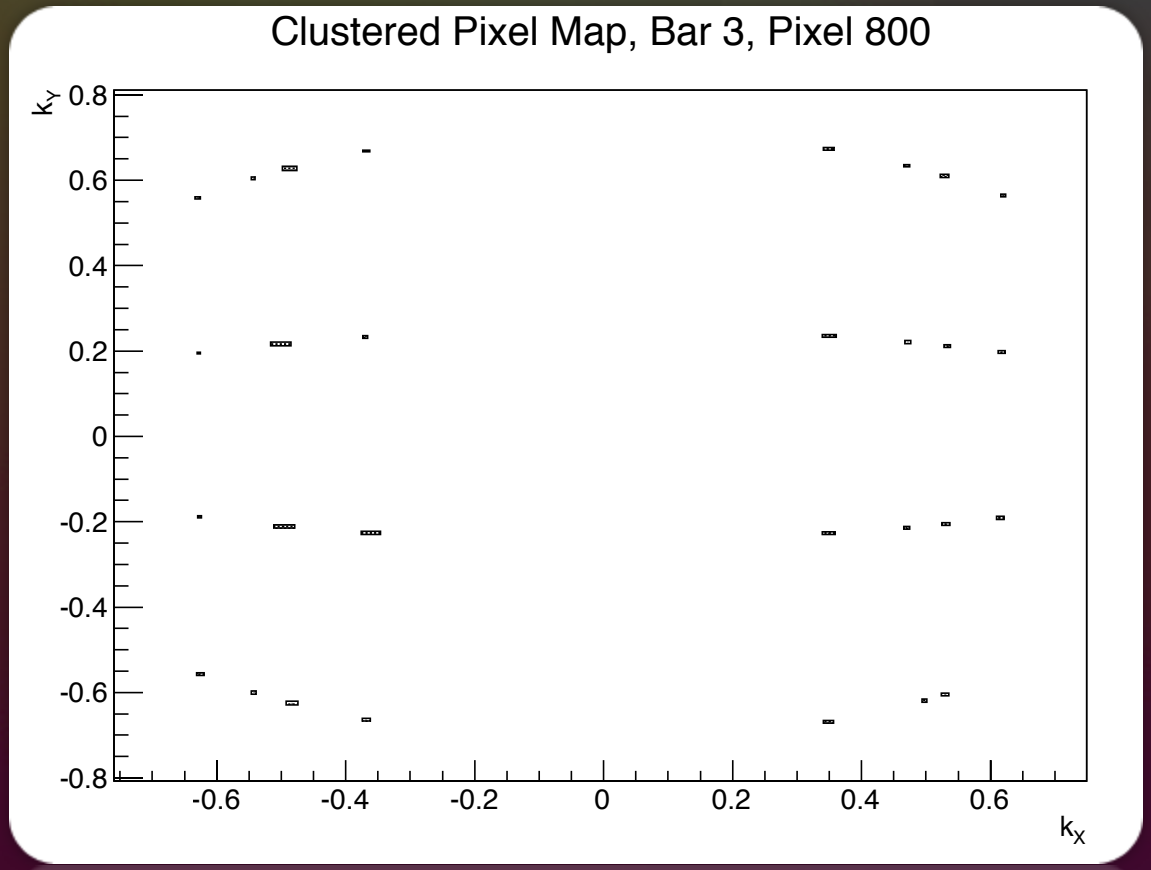




Resolutions Used to Determine Cluster Separation

Clustering Algorithm

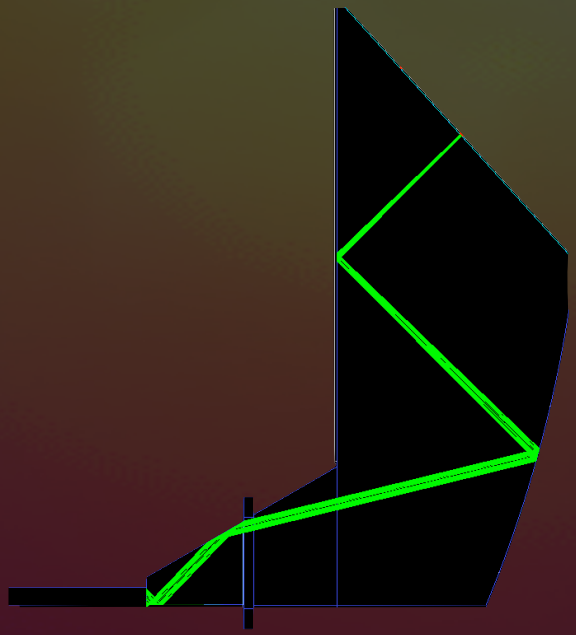
- Each merging reduces the number of clusters by one
- Run recursively until the nearest distance is greater than some cutoff
- The time to run this scales like N^3.
  - Currently takes about 1 day of CPU using 5 Million generated photons per bar, 12 jobs running in parallel.
  - If we wanted 10 times the statistics, for example, it would take 3 years.

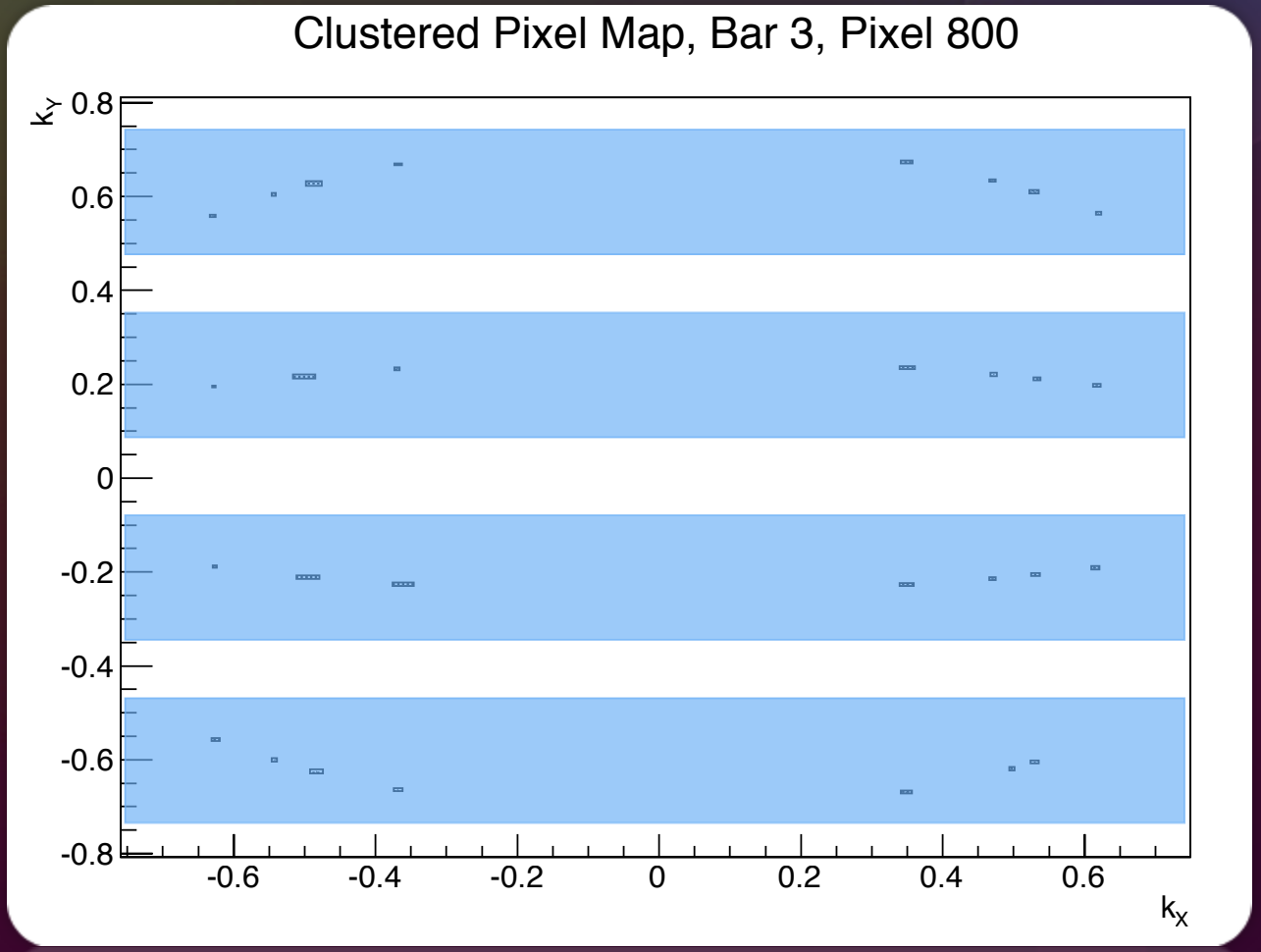


CLUSTERED: K_Y VS K_X

- ONE PIXEL: BAR 3, PIXEL 800
- REQUIRE THAT THERE BE AT LEAST 5 PHOTONS IN THE CLUSTER
- SIZE OF MARKER REPRESENTS RMS OF CLUSTER

Identifying the Paths

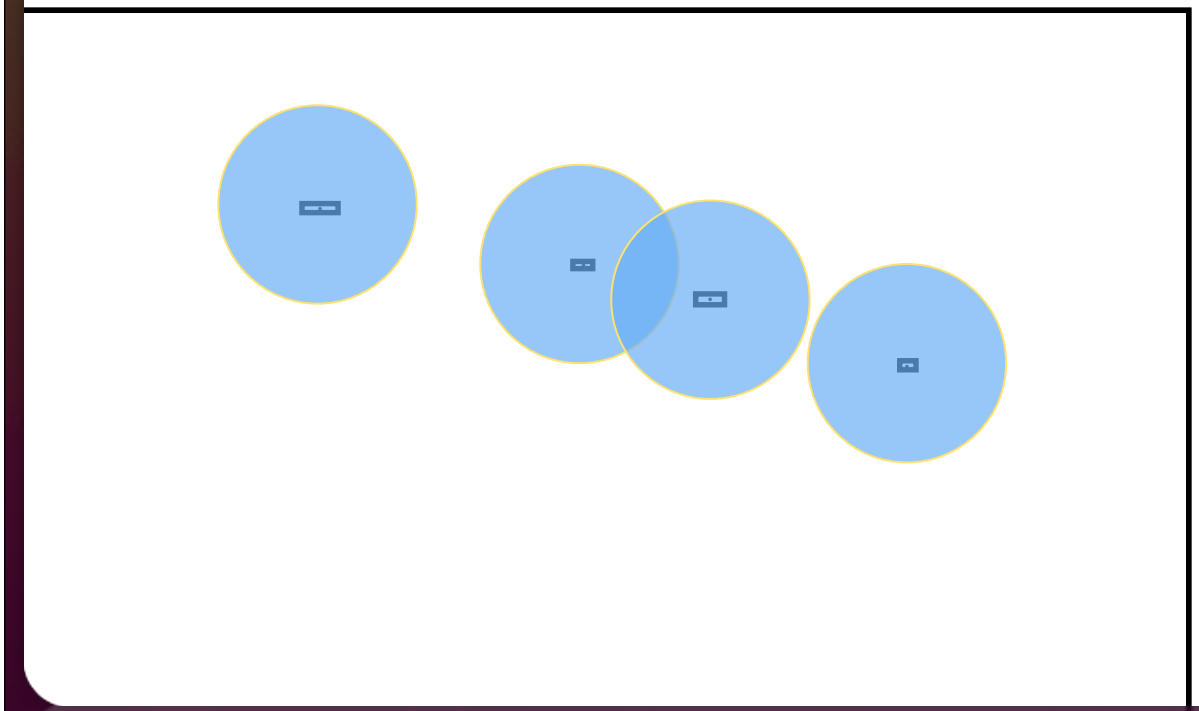


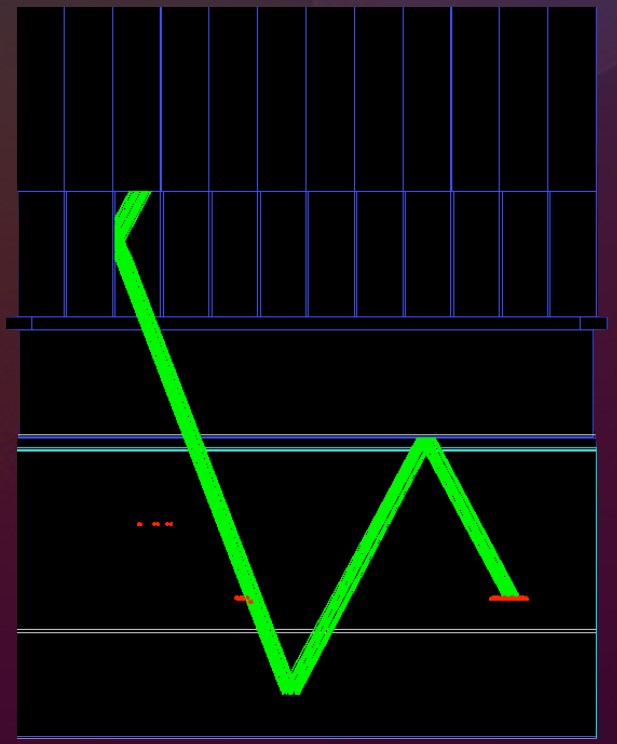


Four Distinct Groups in k_Y

Identifying the Paths

, Pixel 800

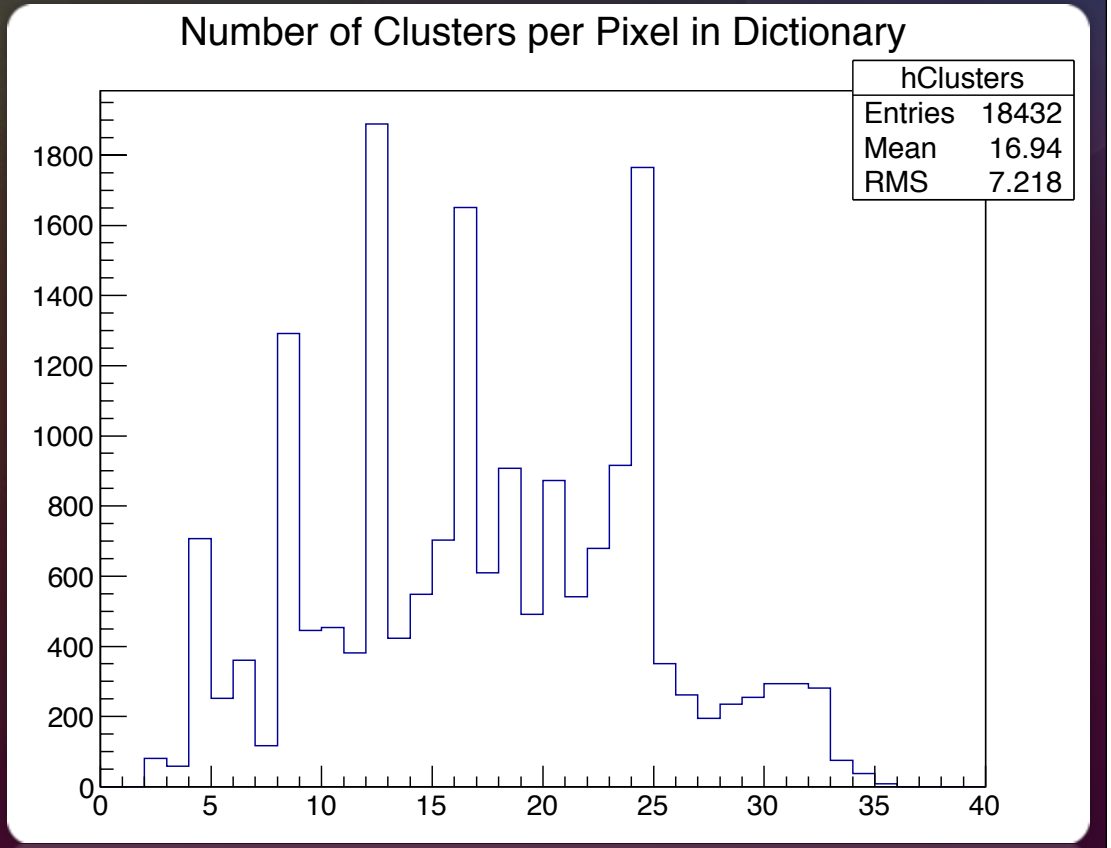




Several Distinct Groups in Kx

Number of Clusters/Pixel

- Require >=5 photons in a cluster
- Remember, this is on top of the 8-fold abmiguity

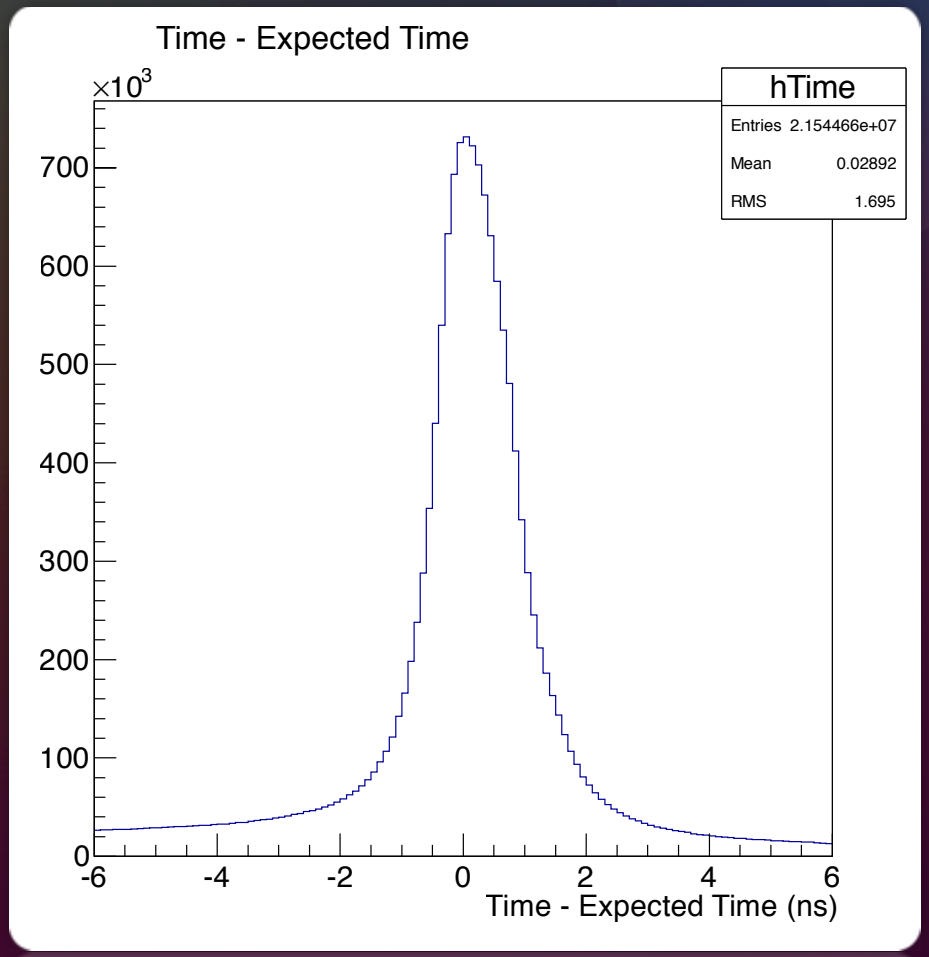


Look at Single Photon Resolution

- Simulated 100,000 cosmic-like muons.
- Similar acceptance to CRT
- This is using fully instrumented FDIRC, so is a little different from prototype, but technique would be similar

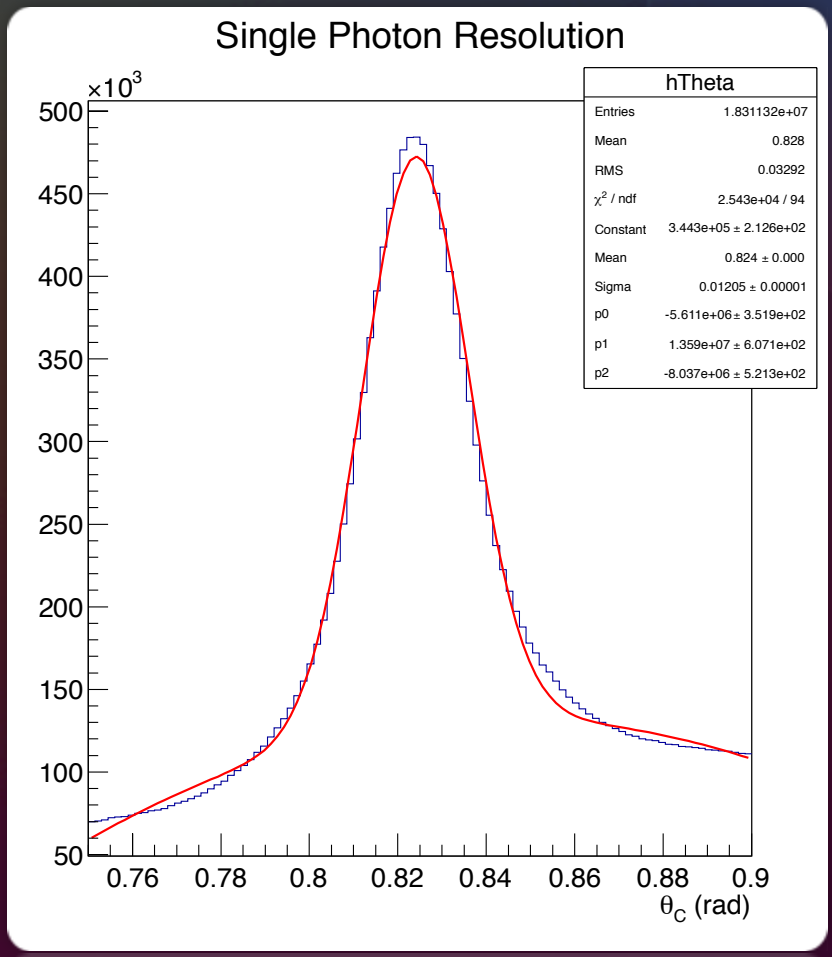
Time Resolution

- Cutting on photon time - expected time resolves z-ambiguity and others
- No time smearing in simulation
- There is chromatic smearing
- Cut at +/- 3 ns



Single Photon Resolution

- Total number of Photons:
  - 1,164,423
- Total Number of Entries:
  - 18,311,324
- Implies on Average 15.7 solutions / photon still survive
- Sigma ~ 12 mrad

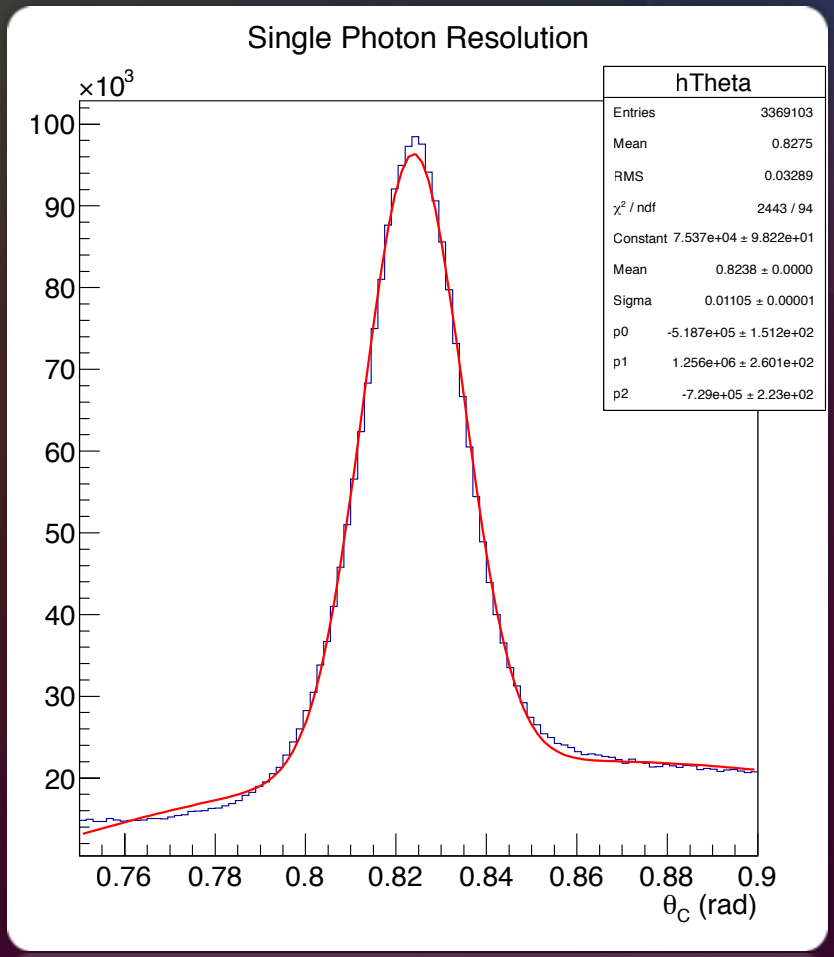


Different Clustering

- Looking at the reflection symmetry in the K_Y vs. K_X plots, and given that we are accounting for the 8-fold ambiguity explicitly, it might make sense to cluster in $|K_X|$, $|K_Y|$ instead
- The symmetry isn't perfect
  - Trade off between having too many solutions vs. fewer but maybe not as accurate
  - But we are probably double counting at some level

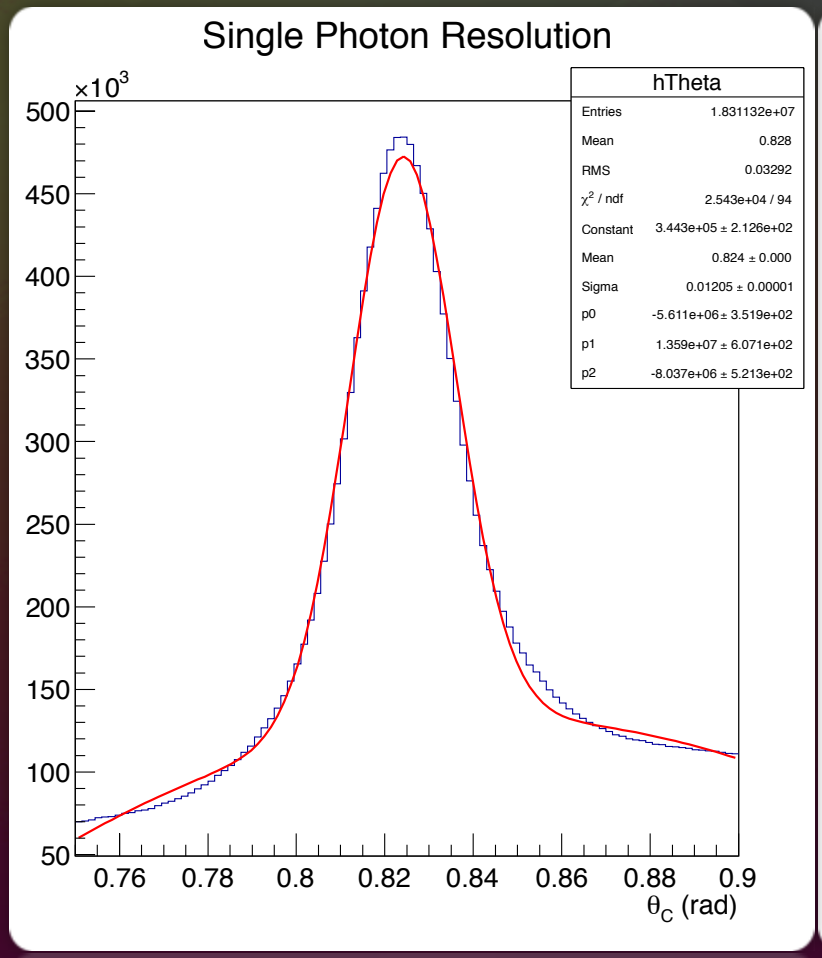
Single Photon Resolution

- Total number of Photons:
  - 1,082,728
  - Total Number of Entries:
  - 3,369,103
- Implies on Average 3.1 solutions / photon still survive
- Sigma ~ 11 mrad

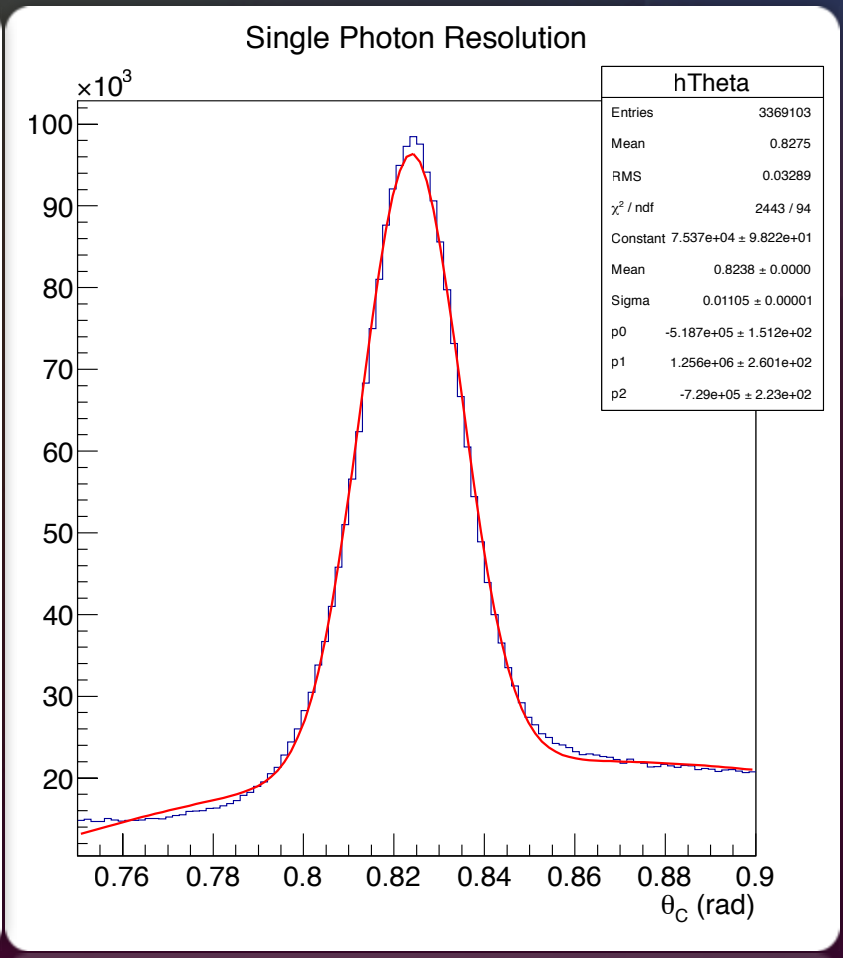


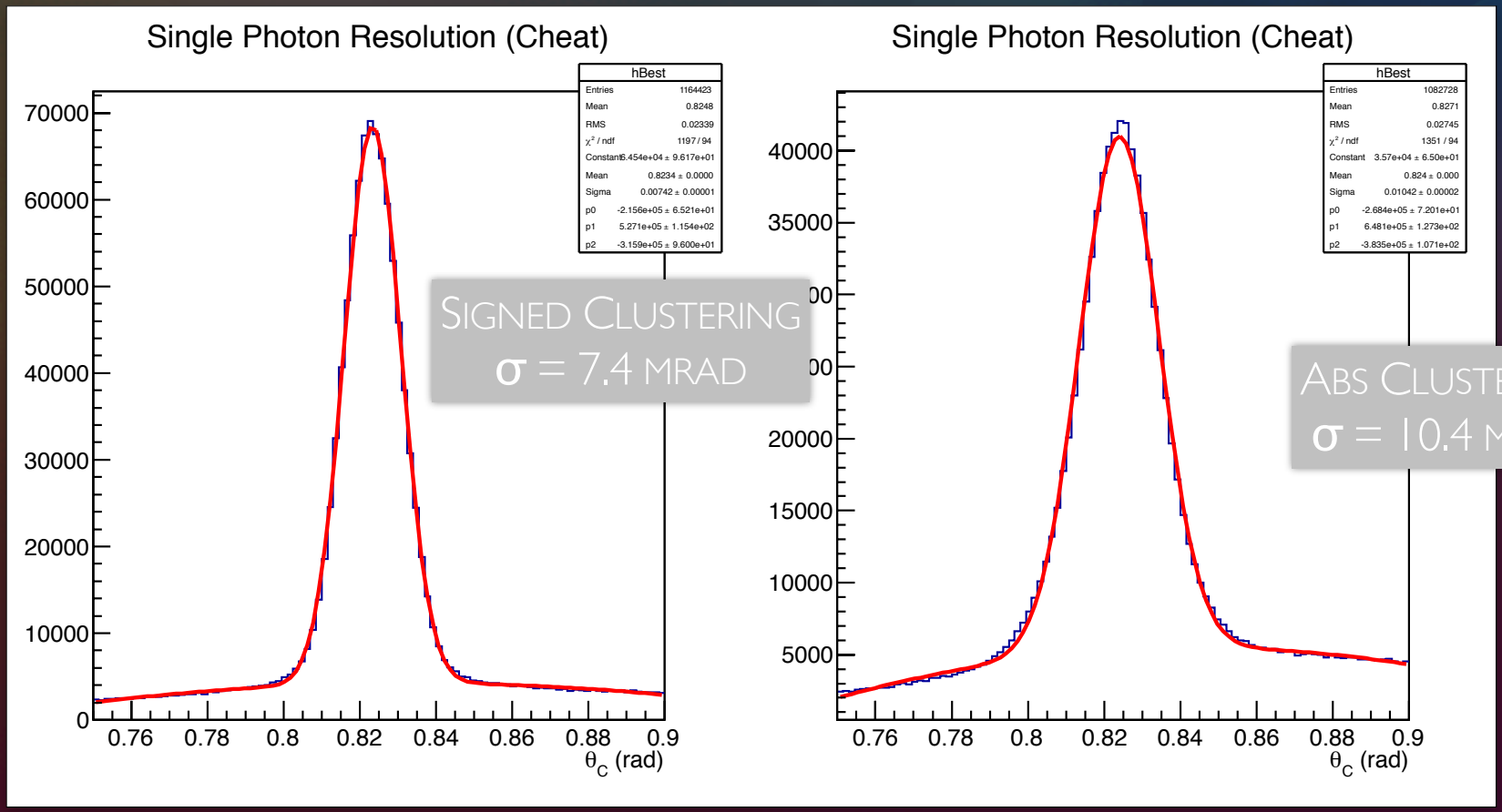
Abs Clustering

SIGNED KX, KY



ABS KX, KY





SIGNED CLUSTERING
σ = 7.4 MRAD

ABS CLUSTERING
σ = 10.4 MRAD

CHEATING TO PICK "BEST" SOLUTION

IF I TRY TO RESOLVE AMBIGUITIES BY PICKING THE SOLUTION FROM THE DICTIONARY THAT BEST MATCHES THE PHOTONS TRUE (K_X, K_Y) AS IT LEFT THE BAR, WE GET THE ABOVE PLOTS.

HERE WE SEE THE BENEFIT OF NOT DOING THE ABSOLUTE VALUE CLUSTERING. THE RIGHT SOLUTION IS IN THERE, WE JUST NEED TO DIG IT OUT SOMEHOW

CONCLUSION

- We are putting together tools and developing some understanding of the analysis issues that will be put to the test with the FDIRC prototype
- This has all been about single photon resolution. In the end, we want something associated with a track.
  - Could get some ambiguity resolving power from correlating solutions across photons
  - Also, there are only 5 discreet solutions that we are trying to distinguish: e, μ, π, K, p
- Still have to implement:
  - Chromatic correction
  - PMT cross talk