# GEANT4 Model of FDIRC

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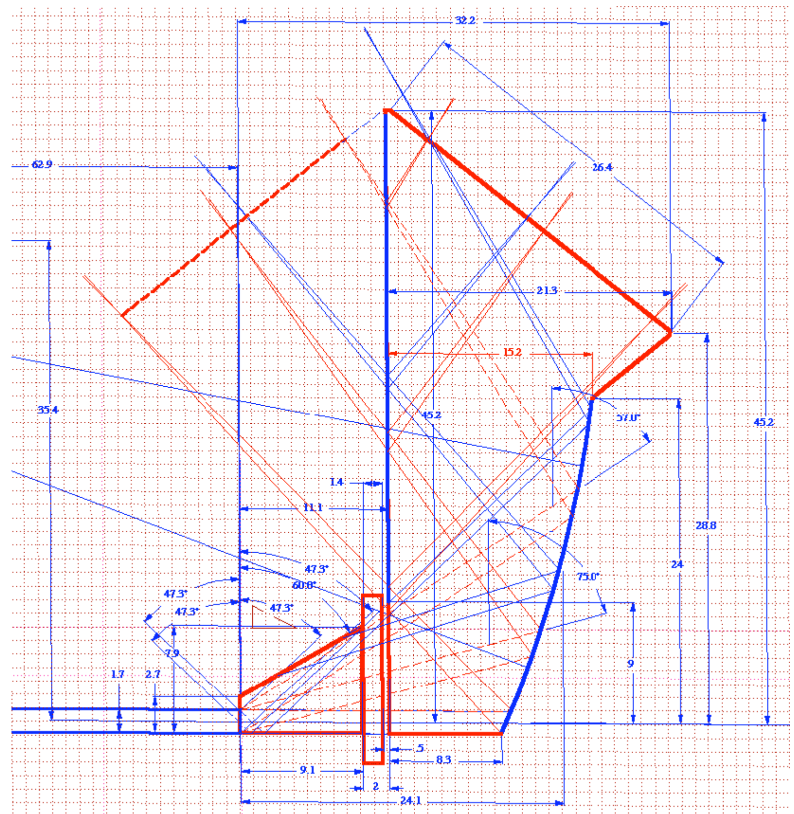
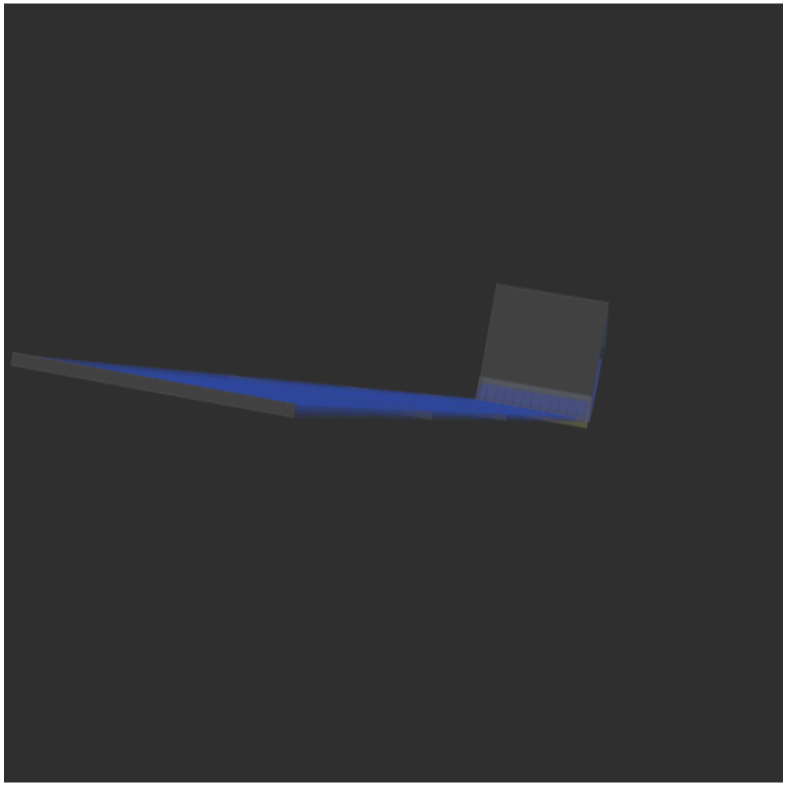
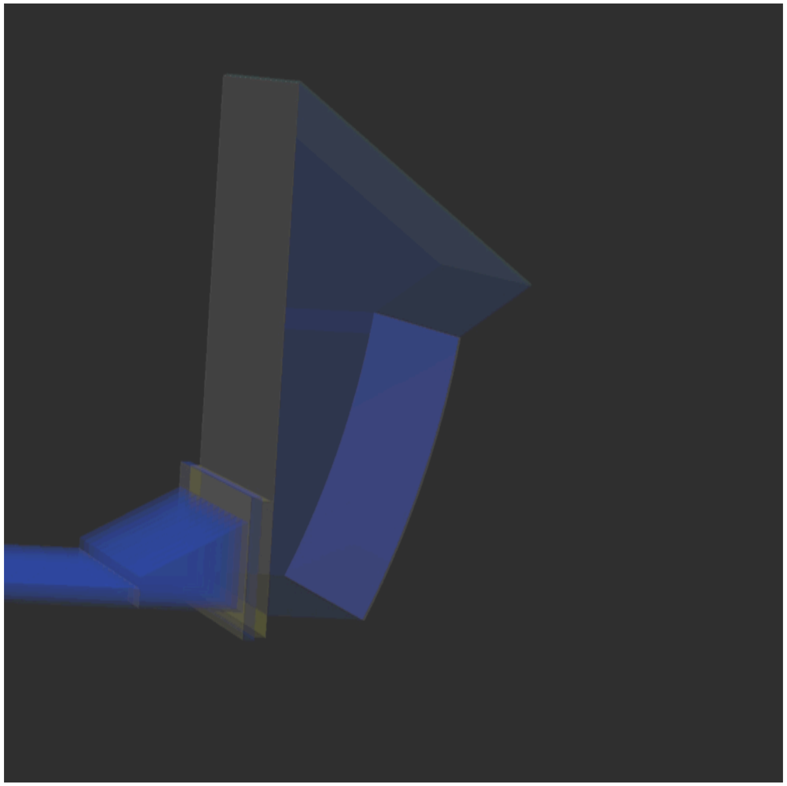
# Based on Jerry's Design

- The GEANT4 model is based on Jerry's design as detailed in SLAC-PUB-13763
- Currently, all of the optical elements are being modeled.
  - Full bar-box of quartz bars
    - 12x4 bars with glue joints
  - Mirror at end of bars
  - Quartz Wedge, w/ 6mrad slope on bottom
  - Quartz Window
  - All quartz Focusing Block (FBLOCK)
    - Cylindrical mirror
    - Vertical planar mirror
- Not in place at the moment is any modeling of photodetectors
  - Implies no QE corrections
- Borrowed some code, esp. material properties, from fDIRC prototype simulation code.
  - Thanks to SLAC folks!

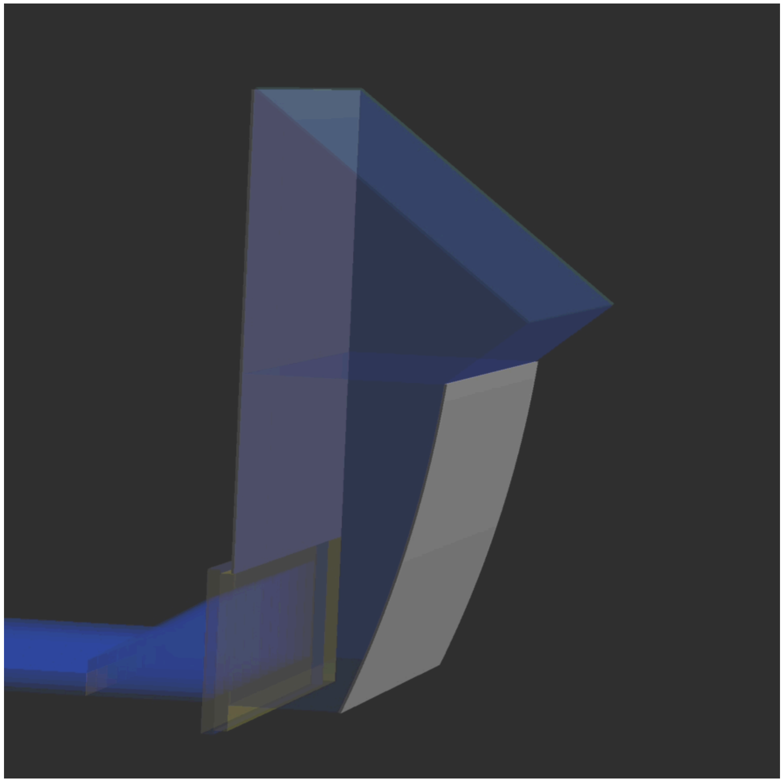


# Some Pictures…

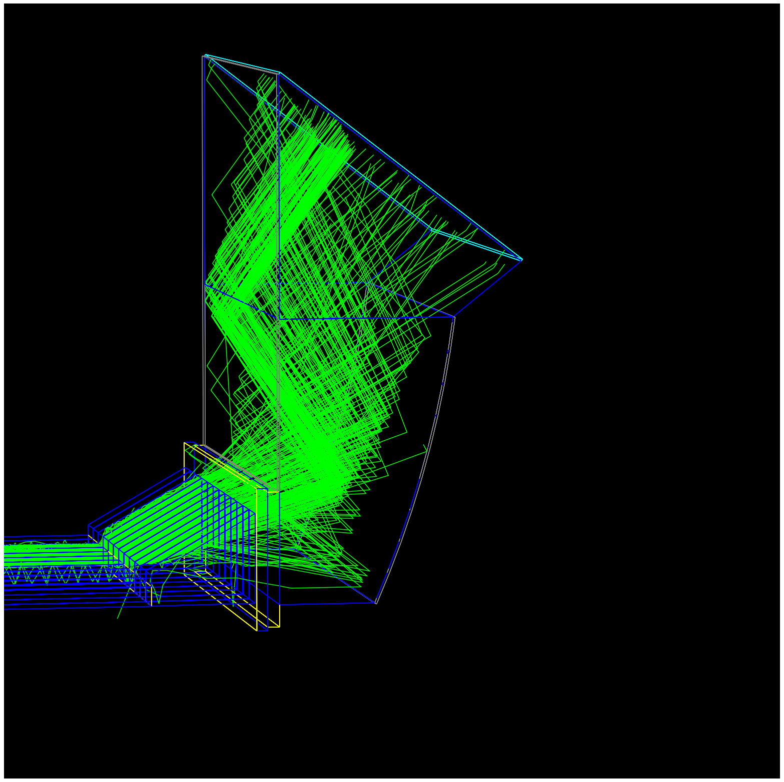




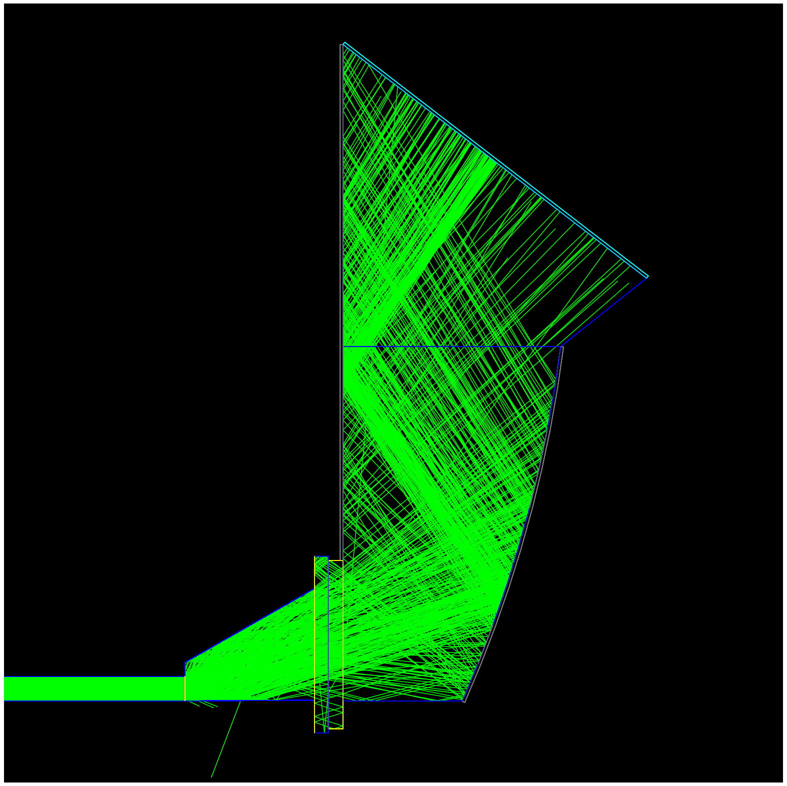
# More Pictures…

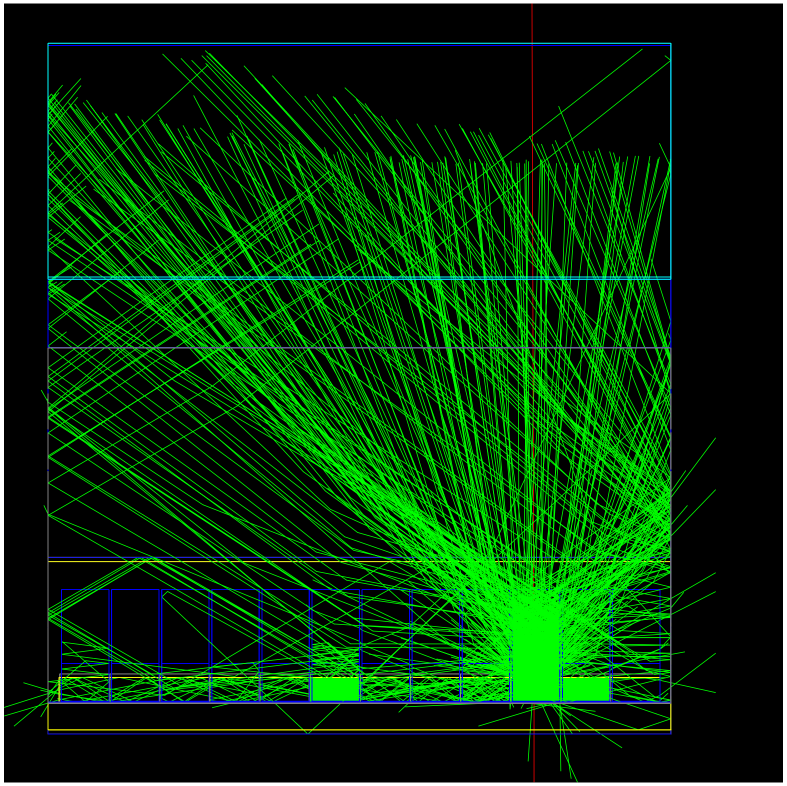


Green lines = Optical Photons



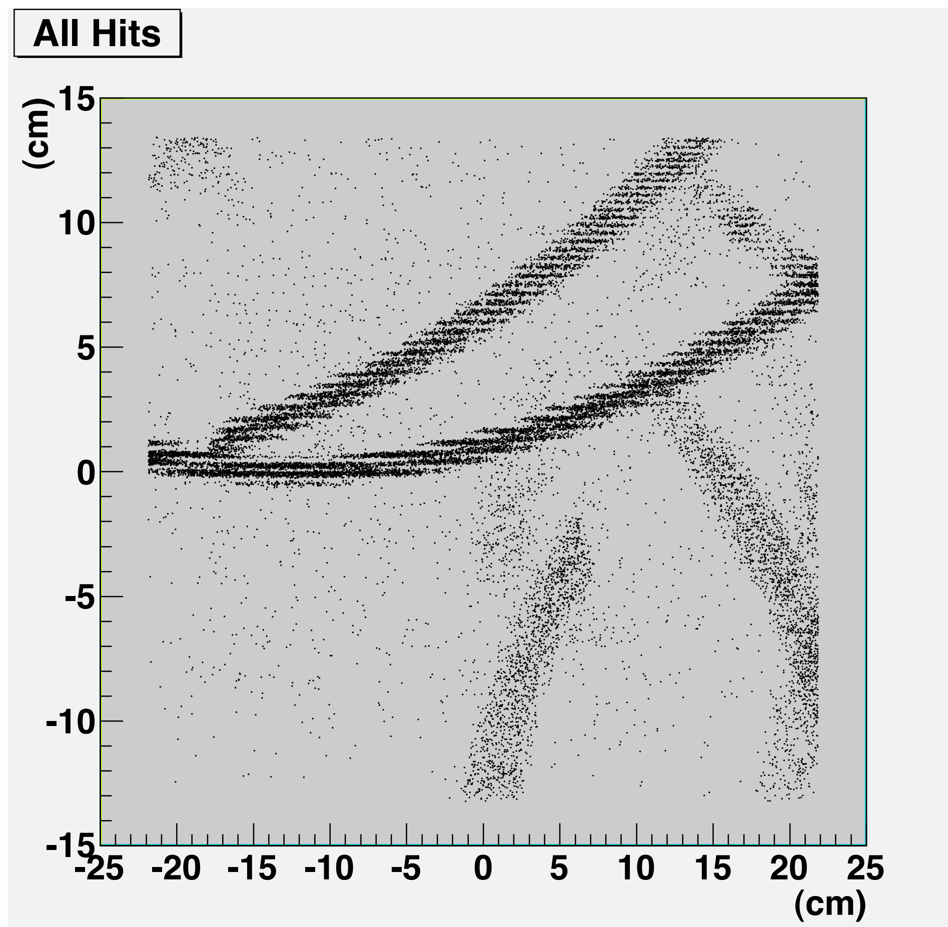
# And some more…





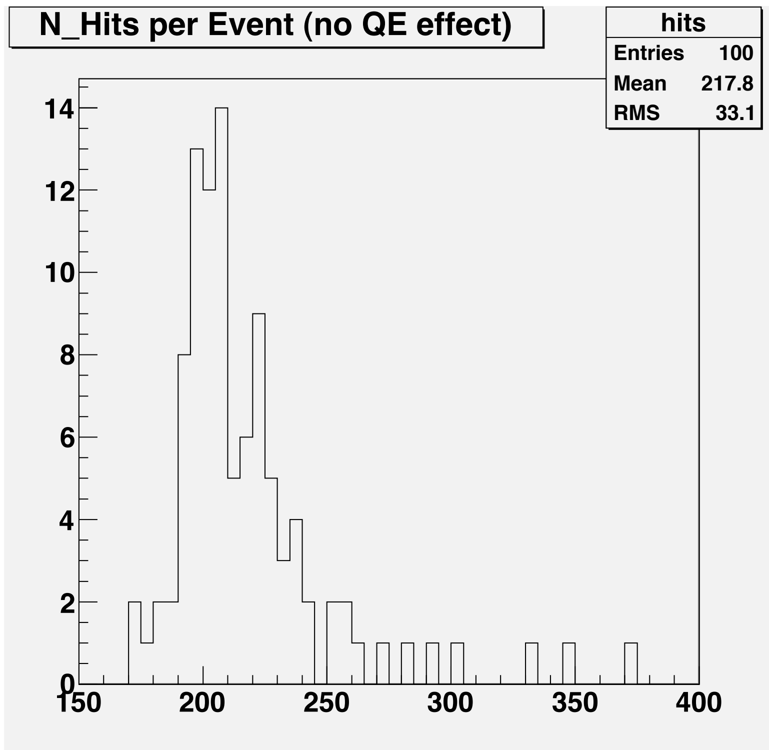
# Photon Hits on Focal Plane

- 3 GeV momentum π
- Dip angle of 120 degrees
- Center of third bar from the end
    - Shows reflection from side of FBLOCK
- 100 events, all with same initial conditions

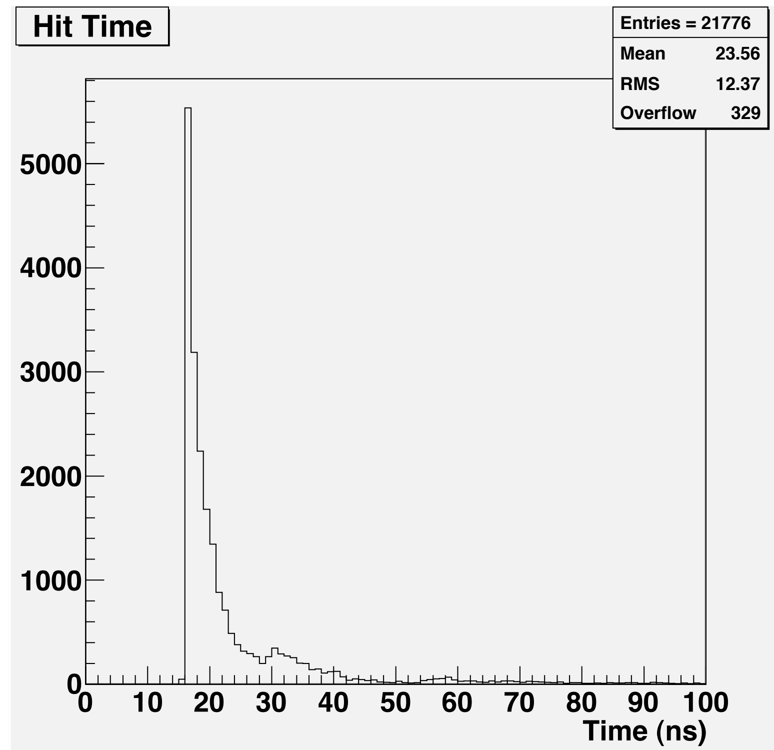


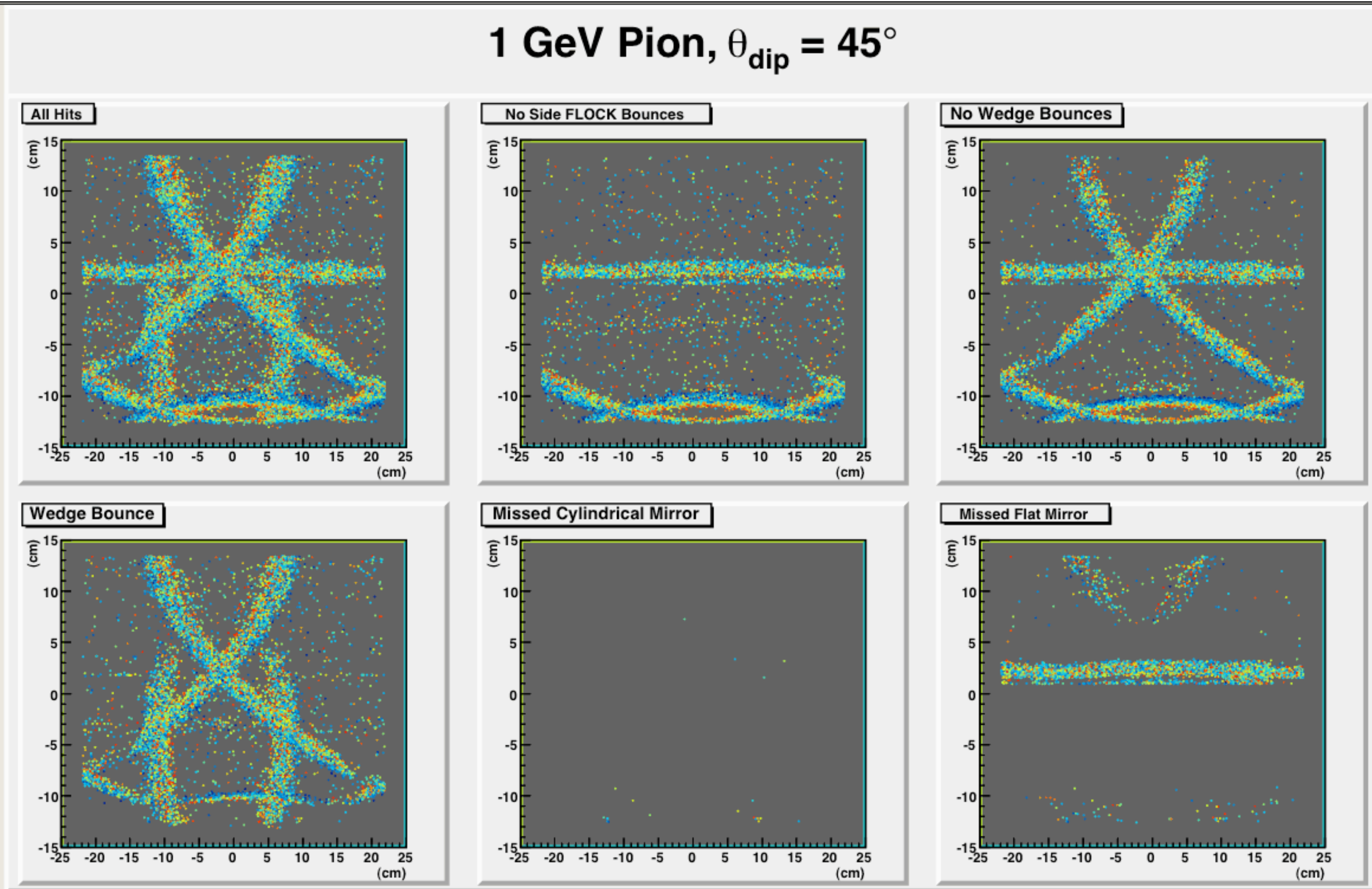
# Hits per event and Timing

## Hits (no Photodetector sim)



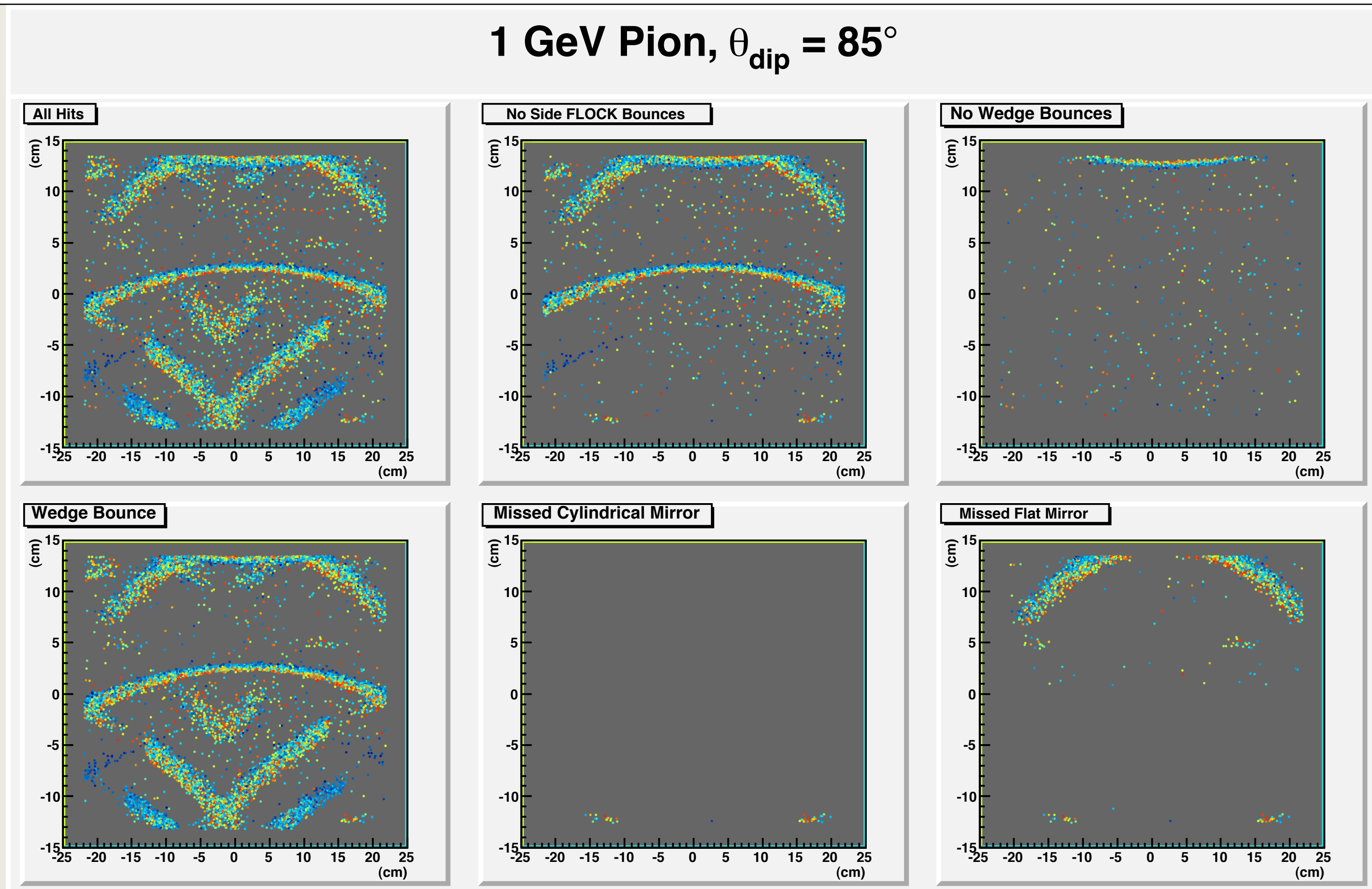

## Hit Time





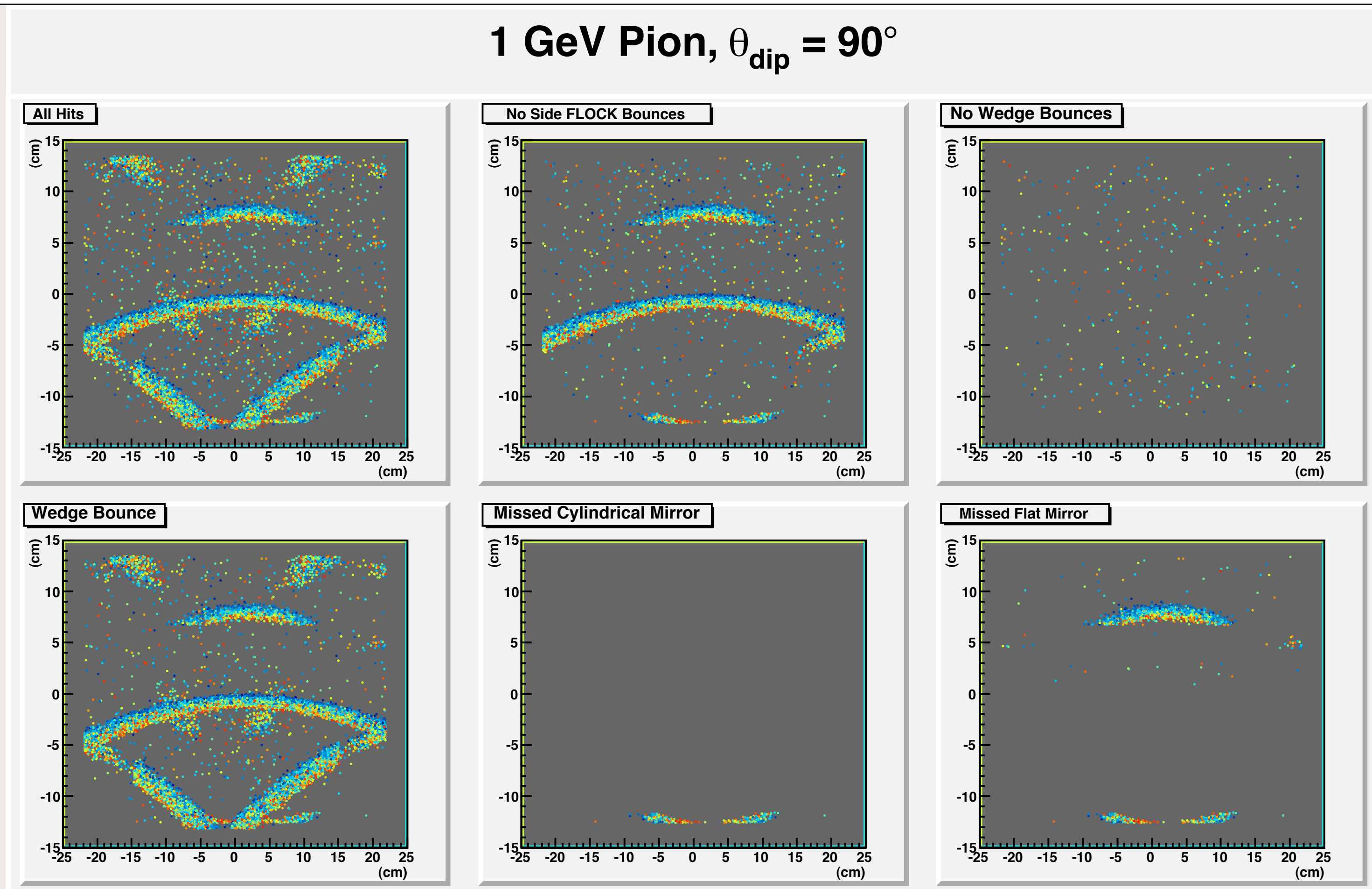

# 45° Dip Angle, 1 GeV pion in central bar

- Color of hit corresponds to wavelength of photon: You can see smearing from chromatic effects
- Easy to break down hits based on their paths and try to understand various features




# 85° Dip Angle, 1 GeV pion in central bar

- Color of hit corresponds to wavelength of photon: You can see smearing from chromatic effects
- Easy to break down hits based on their paths and try to understand various features




# 90° Dip Angle, 1 GeV pion in central bar

- Color of hit corresponds to wavelength of photon: You can see smearing from chromatic effects
- Easy to break down hits based on their paths and try to understand various features



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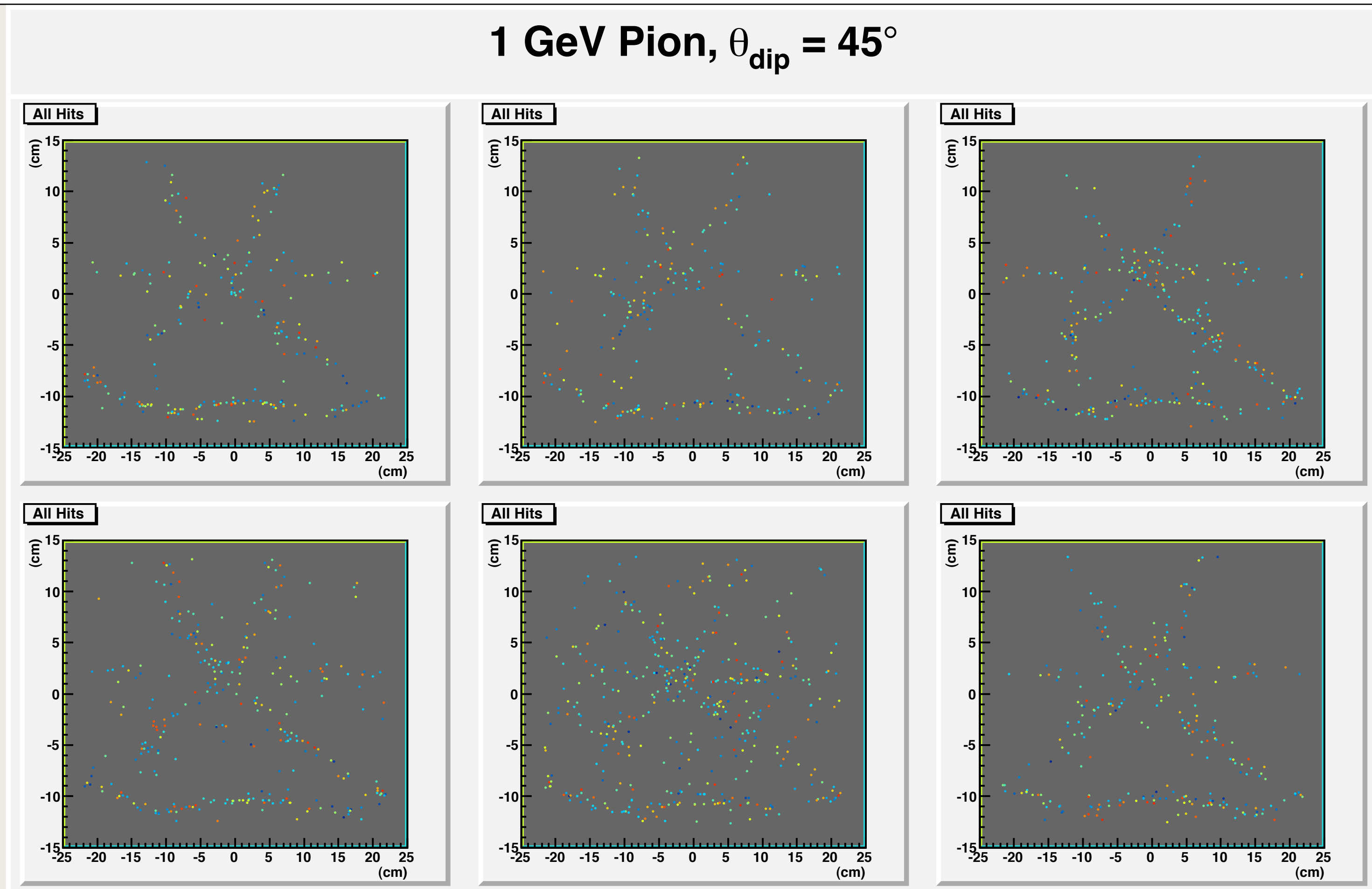
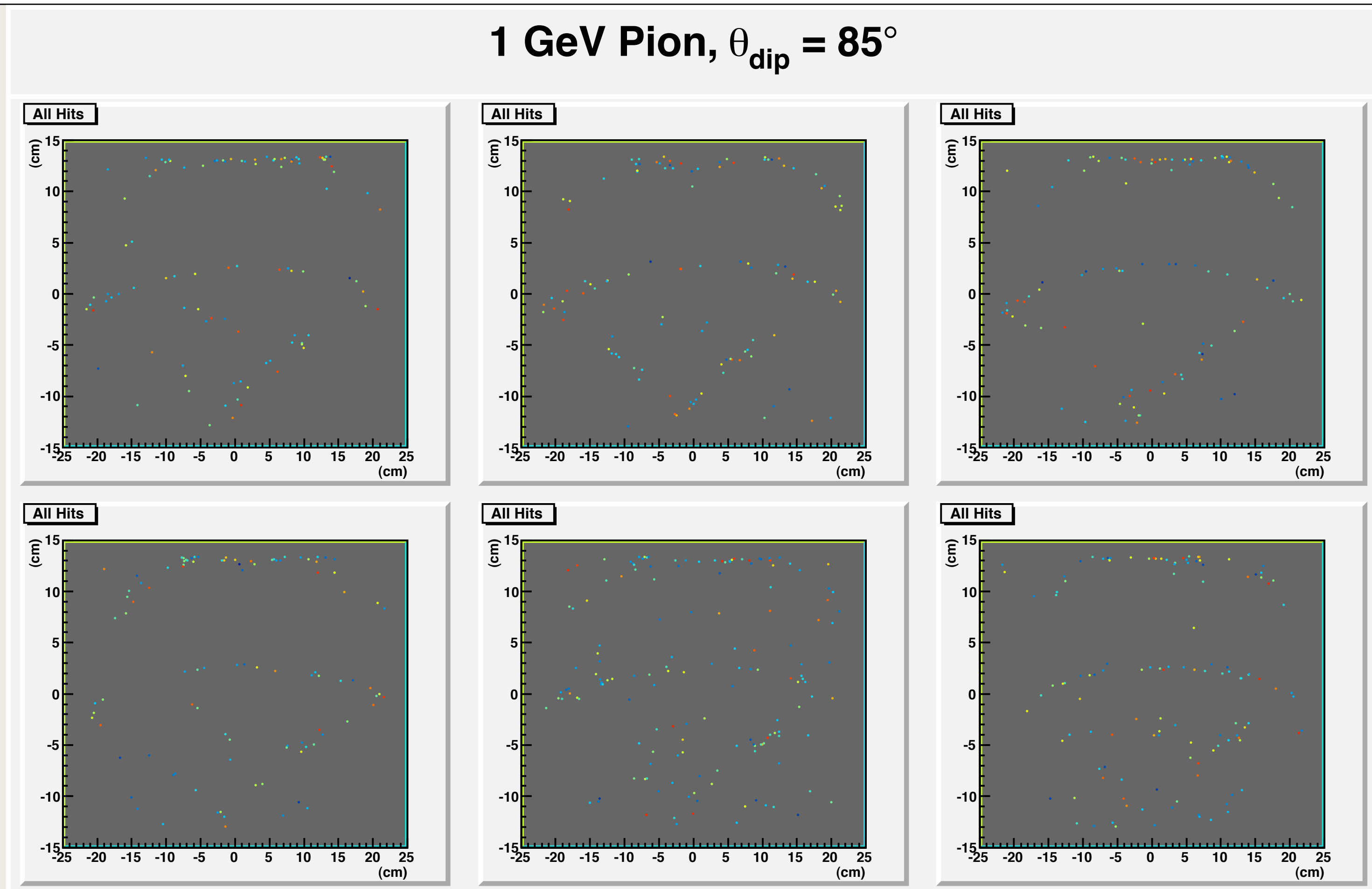



# Some Single Event Images

No Quantum Efficiency!

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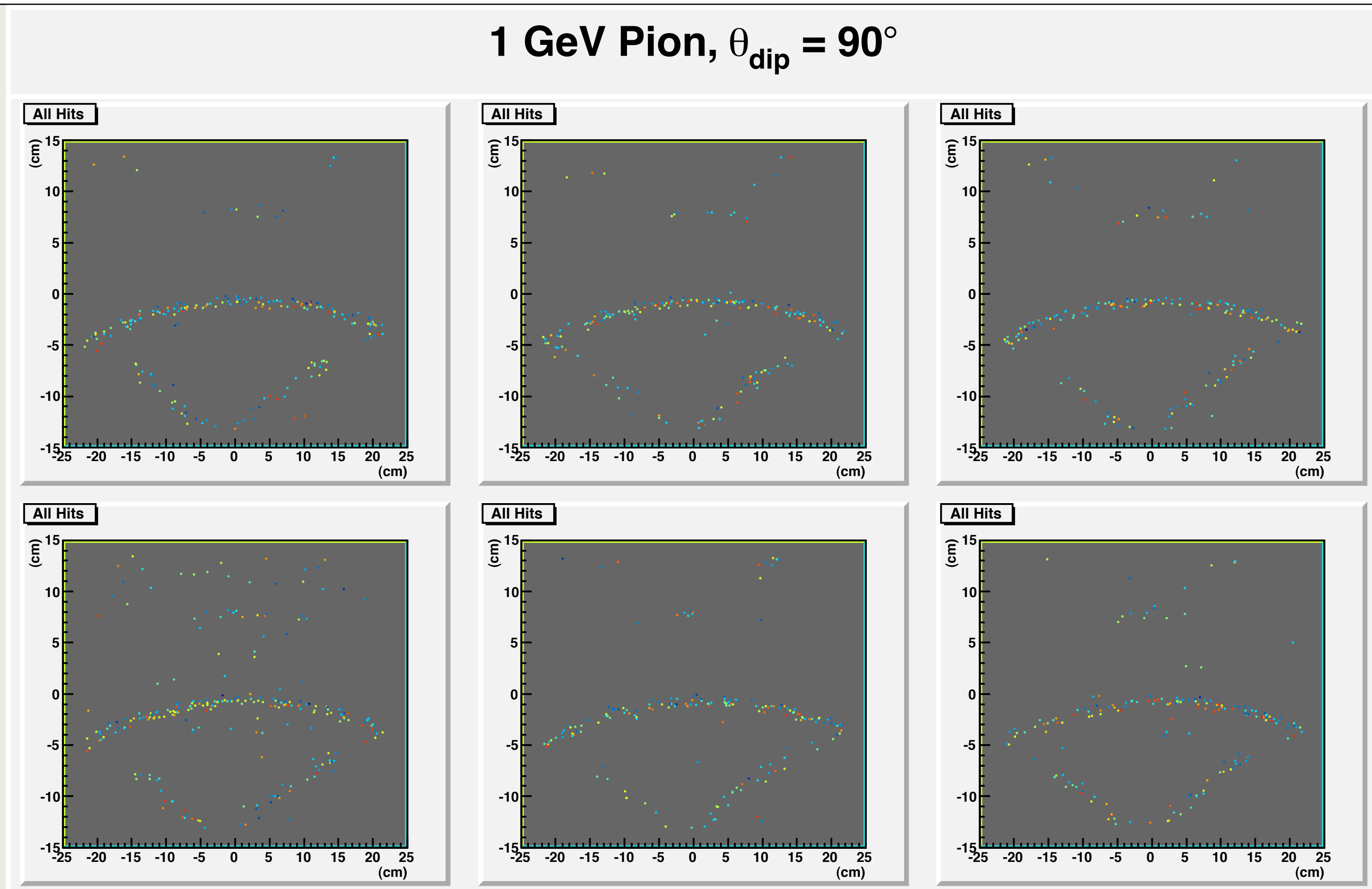


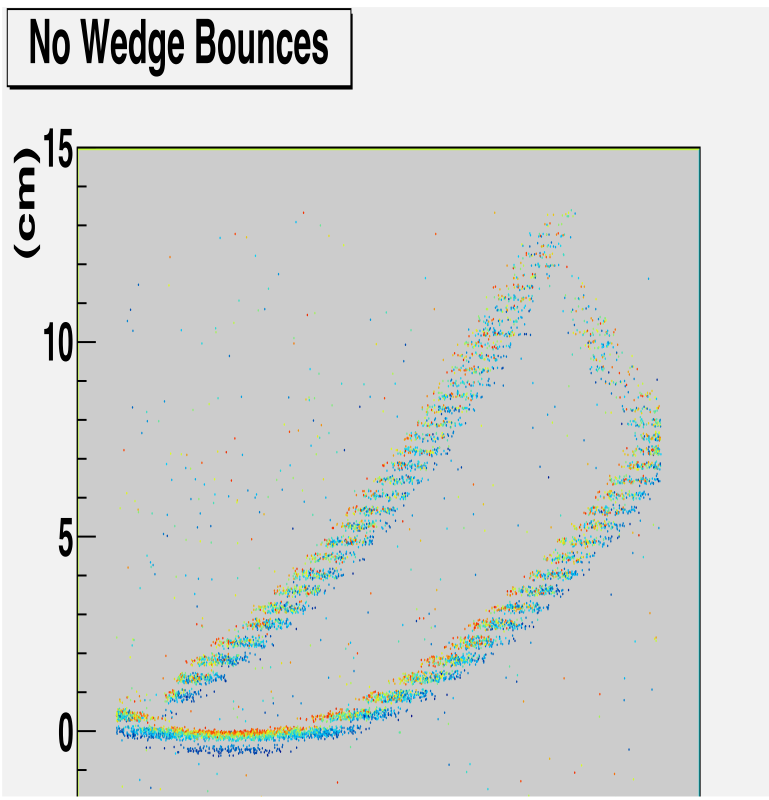

# Some Single Event Images

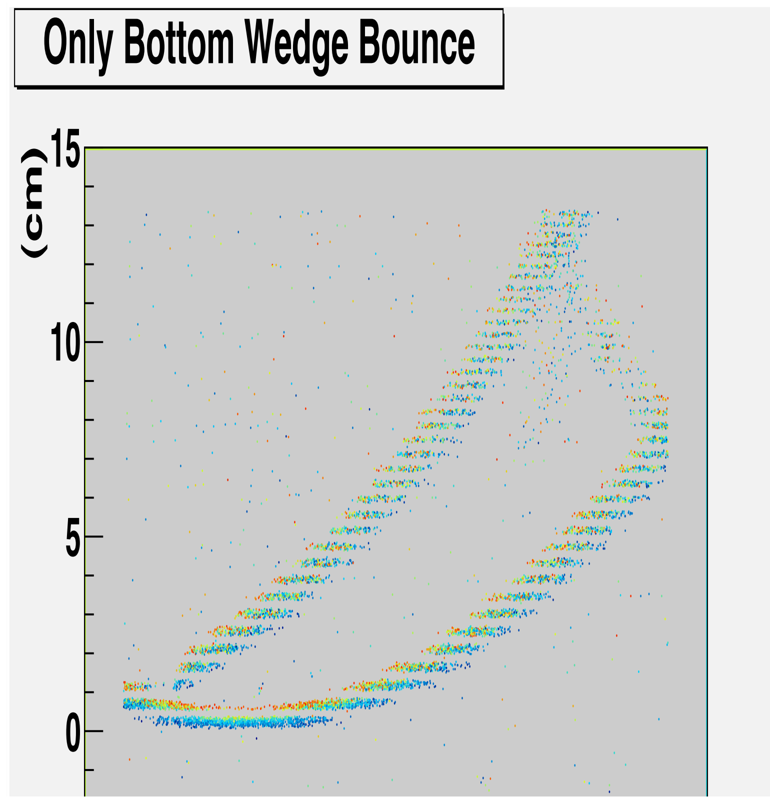
No Quantum Efficiency!

# No Wedge Bounces vs. Just Bottom

Note that images don't line up. The wedge introduces some smearing in the image. May require some re-optimization of the focal plane?

- About half of the photons bounce off the bottom of the wedge.
- 60% bounce off top and/or bottom



# Resolution Measurement

- Pictures are nice and can tell us some qualitative things, but we would really like to be able to quantify the resolution in order to be able to truly optimize the optical design and answer questions like:
  - Is there a more optimal position for the focal plane
    - Strike compromise between wedge-bounced and non-wedge-bounced photons with under-focused design
  - Do reflections from the vertical sides of the FBLOCK help or hurt?
    - How does resolution depend on bar number in the bar box in both cases?
  - What is the optimal pixel size for photodetectors?
  - Can we use timing to improve resolution?
  - How well can we resolve multiple tracks in the same FBLOCK?
  - What is the ultimate $K/\pi$ separation we can expect?
  - Many other questions I'm sure…

# Ring Reconstruction

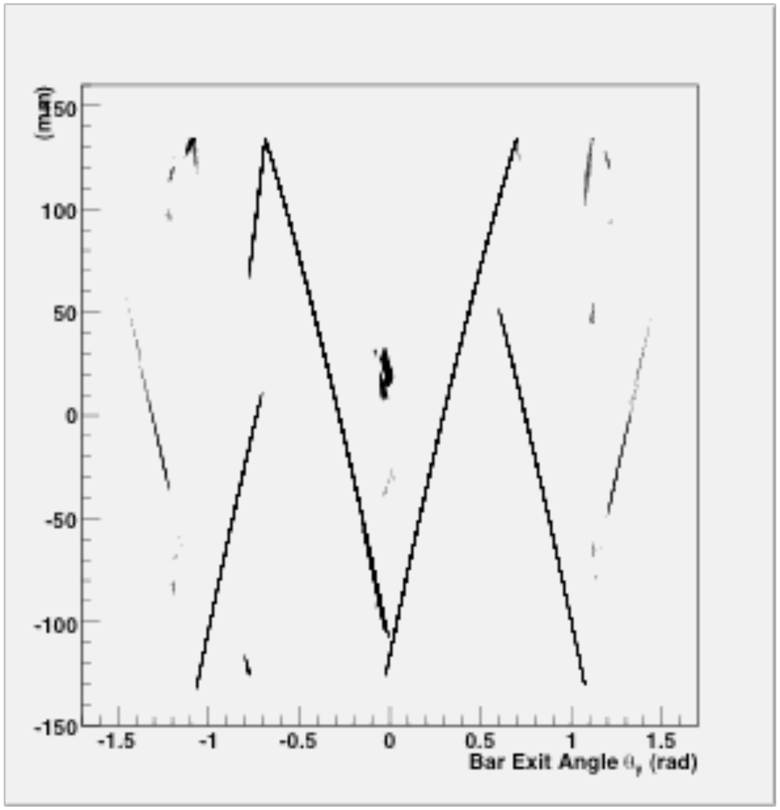
- I've made an attempt to reconstruct images from this design in order to start to quantify the resolution
- **This is very, very preliminary**

# Reconstruction Technique

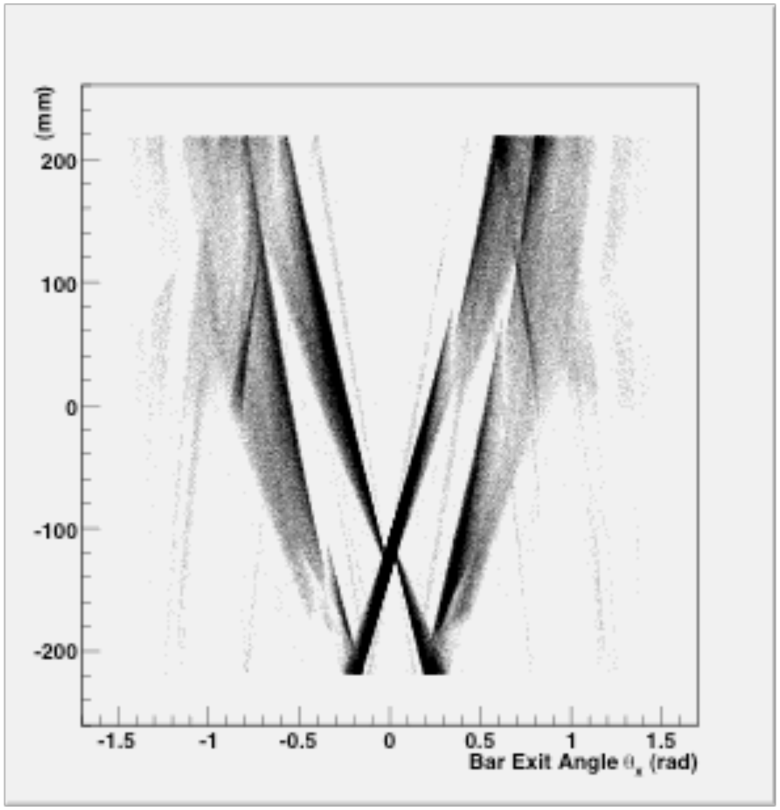
- Start by generating single photons that are propagated through the optical system and on to the focal plane.
- However, the map from $(x,y)$ position on the focal plane to photon angles at the exit of a quartz bar is multi-valued
  - There are many distinct photon paths that can produce a hit at that same location.
    - Bounces off the wedge, off the sides of the FBLOCK, missing mirrors, etc.
  - For a given hit, we don't know *a priori* which path the photon took.
- I generated 1M single photons with isotropic initial direction and fixed wavelength of 400nm
  - All have initial $k_z$ component pointing toward FBLOCK, otherwise isotropic over that half-sphere
  - Initial position randomly distributed within cross-section of a quartz bar and randomly along $z$-axis
  - For now, only generated photons in the third long bar from the edge of the bar box.
    - Easy to generalize code to look at all 12 bars
- A little more than 1/3 of the photons produce hits on the focal plane
- For each photon, store its exit angles, $\theta_x$ and $\theta_y$, as it leaves the quartz bar, position on the focal plane, time, and various other quantities

# Exit Angle v.s. Position on Focal Plane

## Y-View (Focused)




## X-View (Unfocused)



# Reconstruction (cont.)

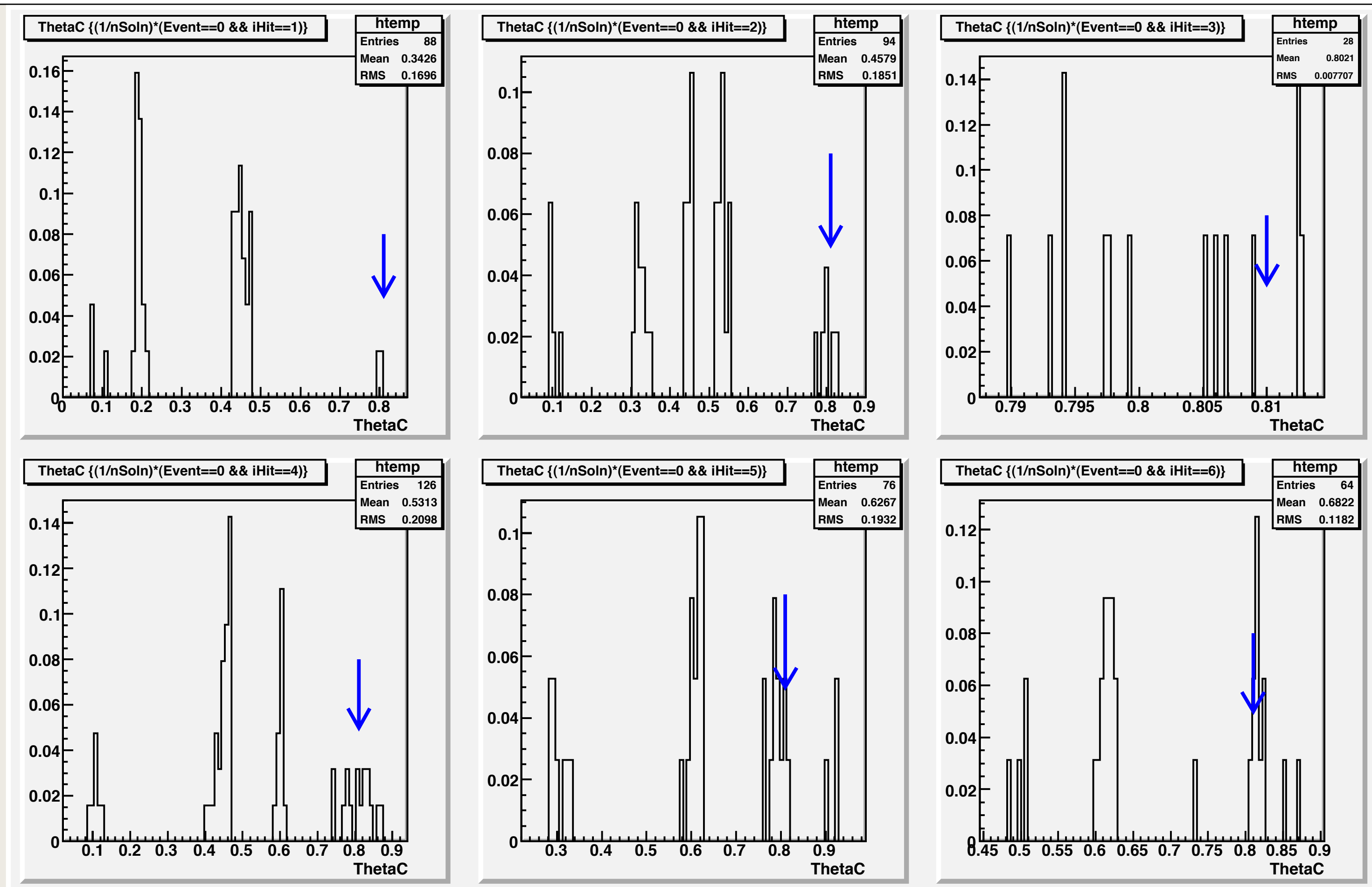
- For each photon hit in an image, search the single photon database for photons within 1 "pixel" size of the hit
  - Since we don't have a finalized pixel configuration, this is a parameter in the code
  - Currently using 3mm x 3mm pixels, easy to change
  - "Pixels" are centered on hit, not fixed in space as they would be for real detector
  - No implementation of hit merging for photons hitting same pixel, however
  - No dead space
- For each single photon within the pixel size, grab its $\theta_x$ and $\theta_y$
- Using initial track direction $\{\theta_{dip}, \phi\}$ (unsmeared) calculate $\theta_C$

$$\cos\theta_C = \frac{1}{\sqrt{\tan^2\theta_x + \tan^2\theta_y + 1}}\left(\tan\theta_x\cos\phi\sin\theta_{dip} + \tan\theta_y\sin\phi\sin\theta_{dip} + \cos\theta_{dip}\right)$$

  - 4-fold ambiguity relating angles at bar exit to angles at photon creation
  - But, all the tracks I generated have $\phi = 0$, so really 2-fold
- Only keep solutions with $\cos\theta_C > 0.6$ (physical limit ~2/3, but allow for some resolution effects)

# Reconstruction (cont.)

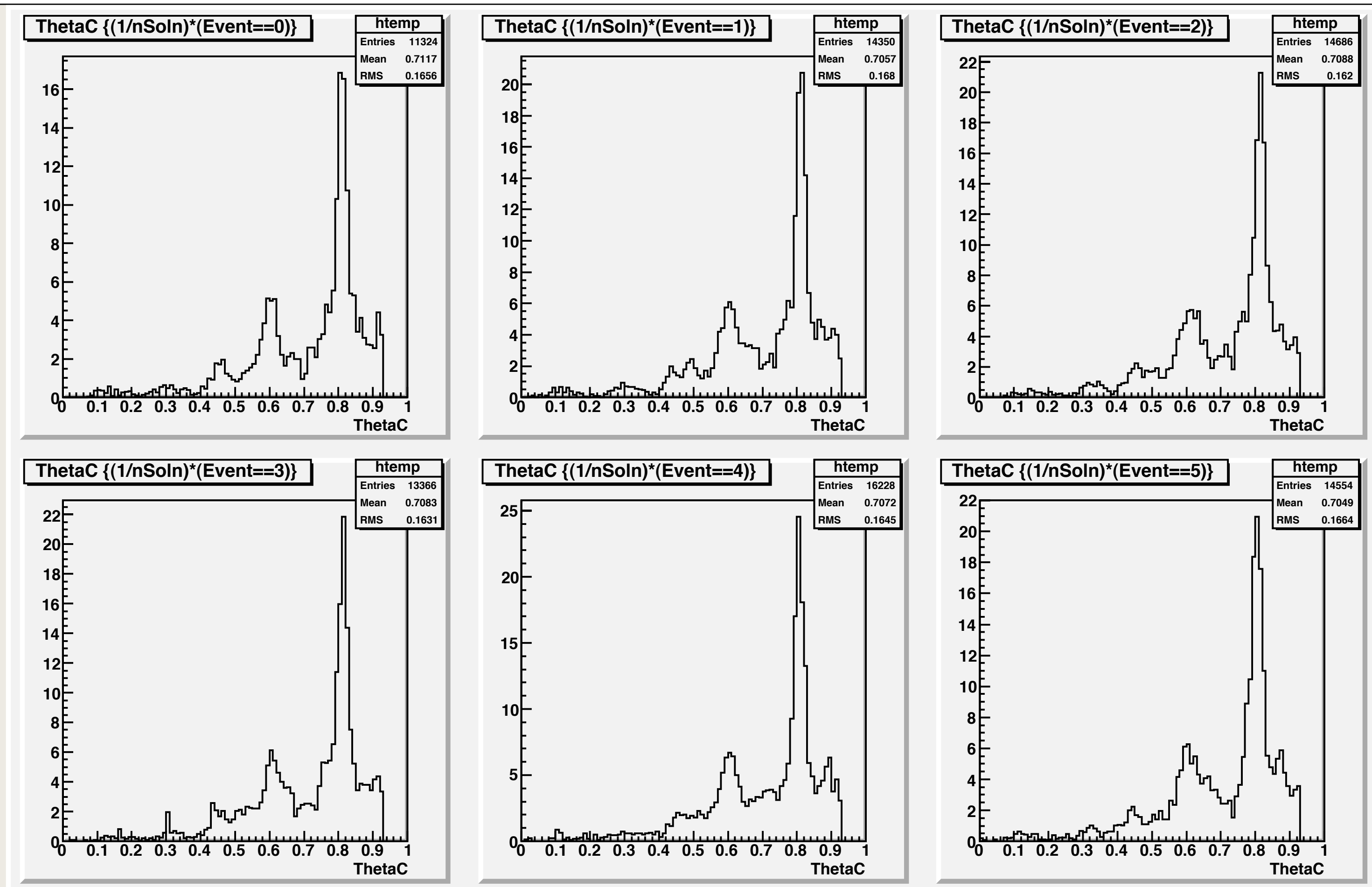
- For each hit, store all valid solutions for $\theta_C$, normalized by the number of valid solutions for that hit
  - Each hit will contribute an overall weight of 1, independent of the number of solutions
  - On average about 30~60 solutions/hit, depending on dip angle
- Accumulate solutions for all hits in an event
- Hopefully a clear peak appears!




# Single Hits, first 6 hits in first event

1 GeV momentum pion

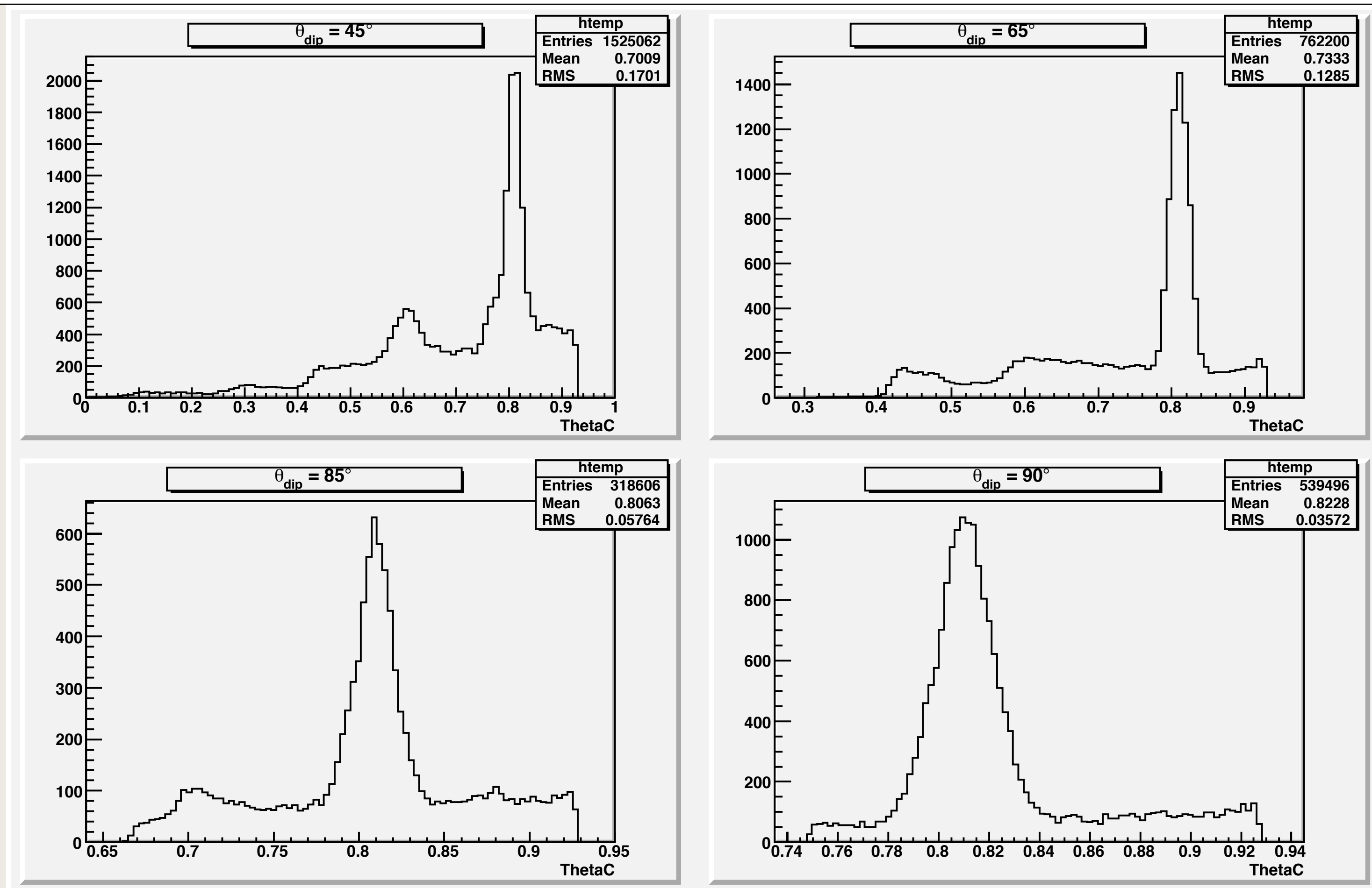
Expected $\theta_C = 0.81$ radians, indicated by Blue Arrow




# All Hits From One Event, First Six Events

Again, expected $\theta_C = 0.81$ radians

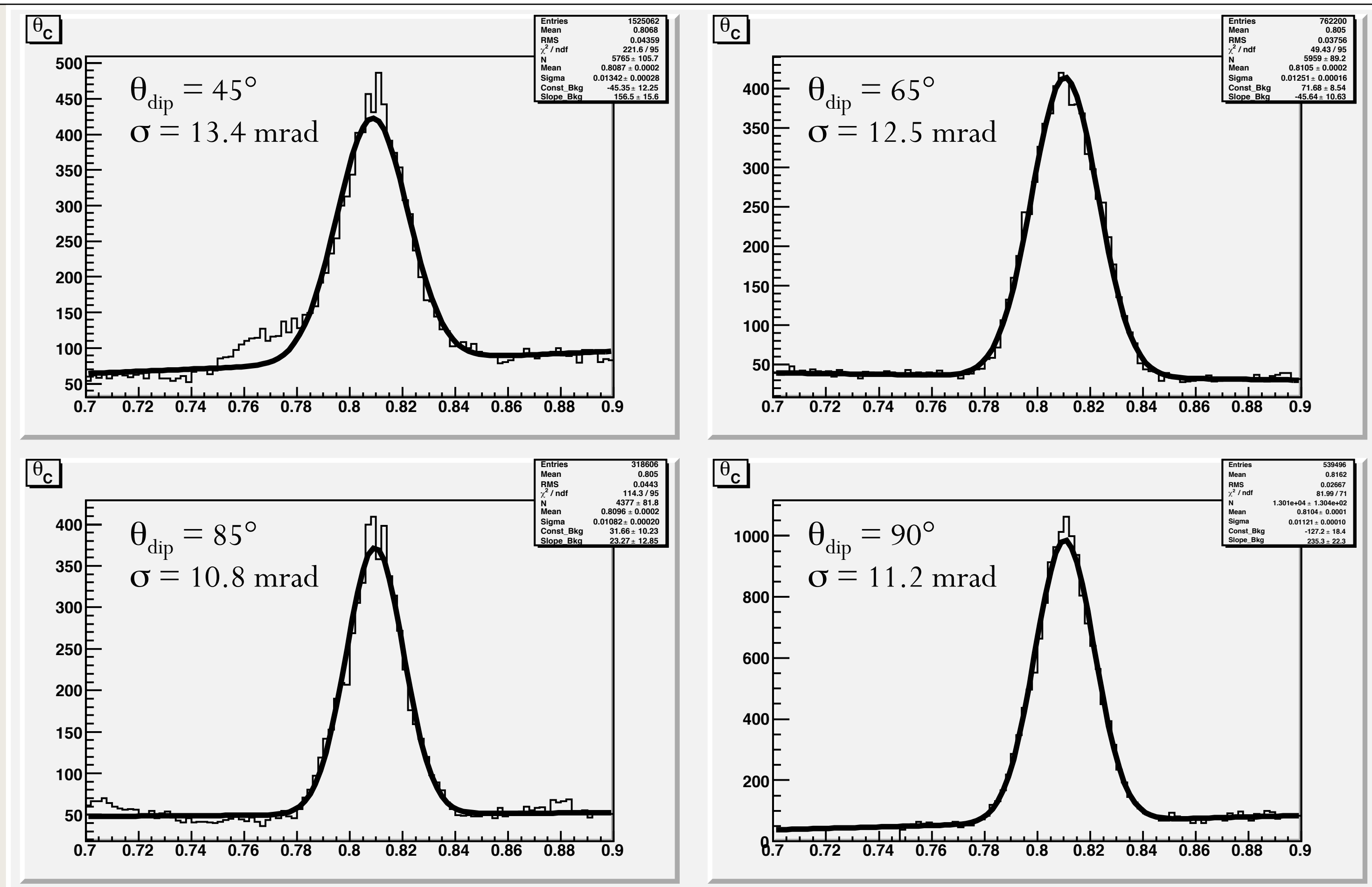
Dip angle of 45 degrees




# 4 Different $\theta_{dip}$ angles, 100 events each

Hard cutoff at $\theta_C$ around 0.93 radians from requirement that $\cos(\theta_C) > 0.6$

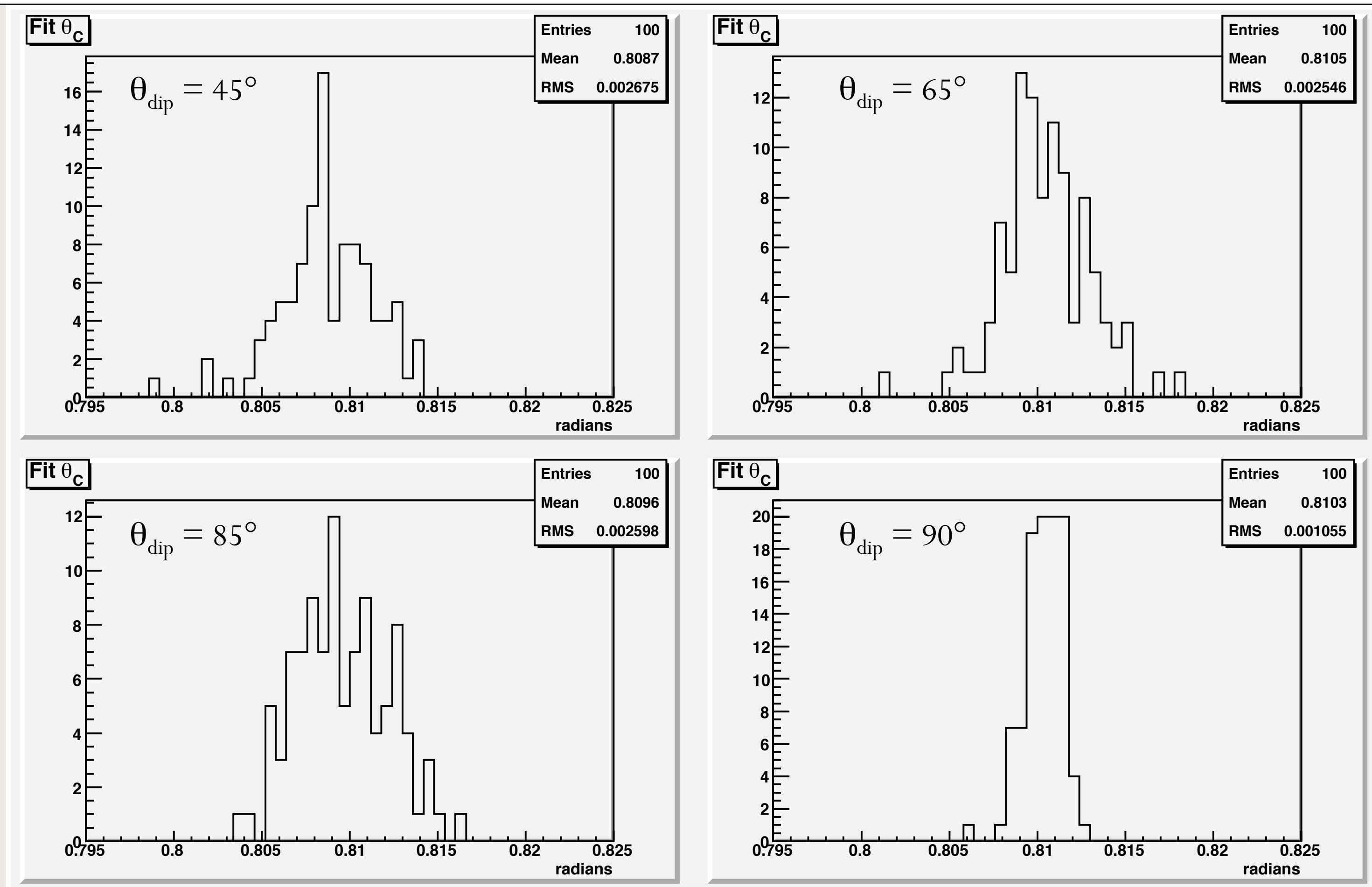
Note different scales on x-axis




# Fits to the peak

100 events each

Fit is just Gaussian + Line




# Separate Fits to All 100 Events

Plots show the mean of the Gaussian from each event

Means are right on, RMS ~ 2.6 mrad, except $\theta_{dip} = 90°$

Remember, no QE corrections, etc., so number of photons/event larger by factor of 5 or so.

# Still to do…

- These are just some samples of things to look at
- Obviously there is still a lot to do for the reconstruction algorithm, but it is a start (I think?)
- There's a lot that I would still like to understand in more detail
- More information could be used, like hit time
- I'm not by any means proposing that this be the way reconstruction is done!
  - It is unbelievably slow! (almost 1 minute/event on my Mac)
  - But, things could be done to optimize
- Need to start looking at the questions of interest as far as design optimization is concerned.
- Could use some help! I'm more than willing to share code.