Progress on G4 FDIRC Simulation

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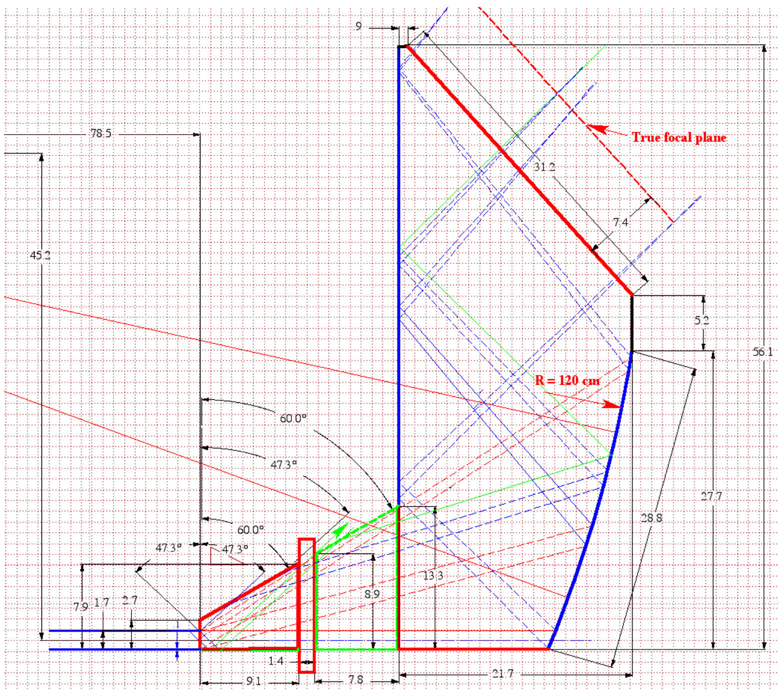
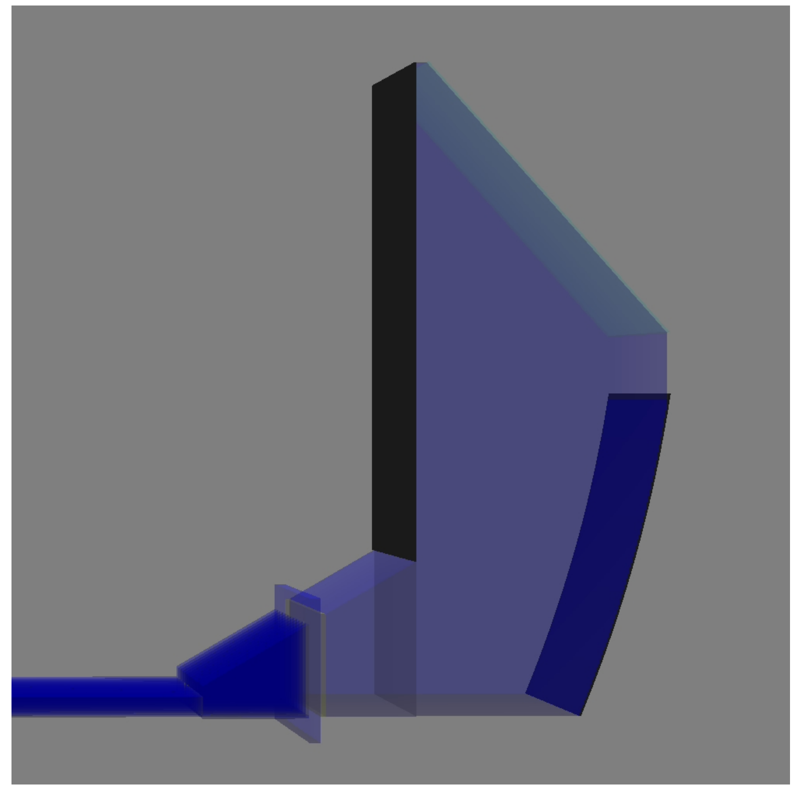
Since SLAC Workshop…

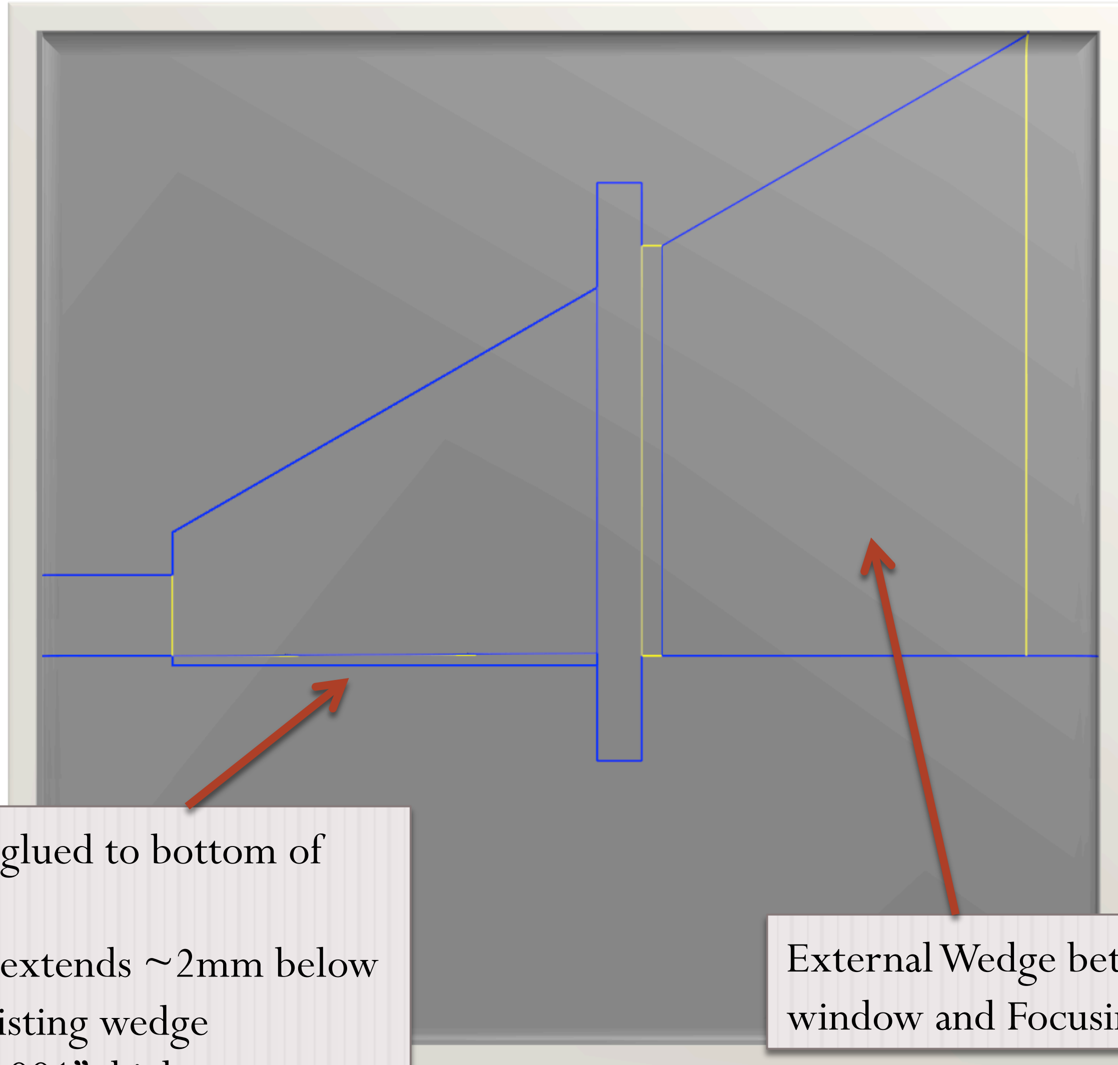
- Spent some time trying to streamline and speed-up the reconstruction technique
  - Needed quicker turnaround on resolution measurements
- Looked at Side Reflection question
- Tried different Wedge Geometries
  - Current BaBar wedge
  - "Micro-Wedge" glued to bottom of BaBar wedge
  - Replace wedge with block (bad, won't talk about)
- A few weeks ago, Jerry sent me a new design that I've implemented
- This is the design that I'll present results for today

Jerry's New Design





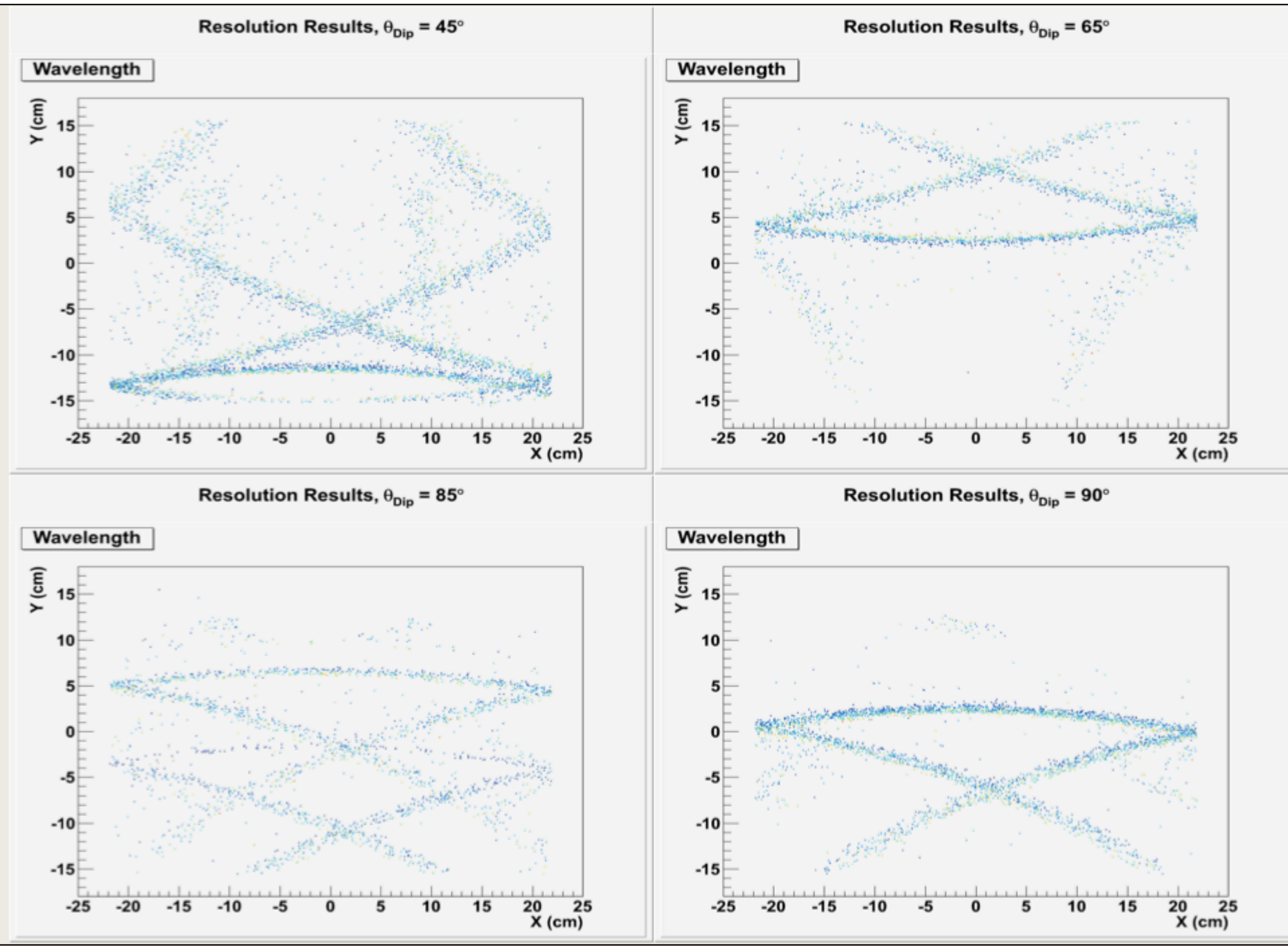
Key New Features



"Micro-Wedge" glued to bottom of existing wedge.

- Micro-Wedge extends ~2mm below from edge of existing wedge
- Glue joint is 0.001" thick

External Wedge between existing window and Focusing Block



Some Ring Images

Color-coded by wavelength

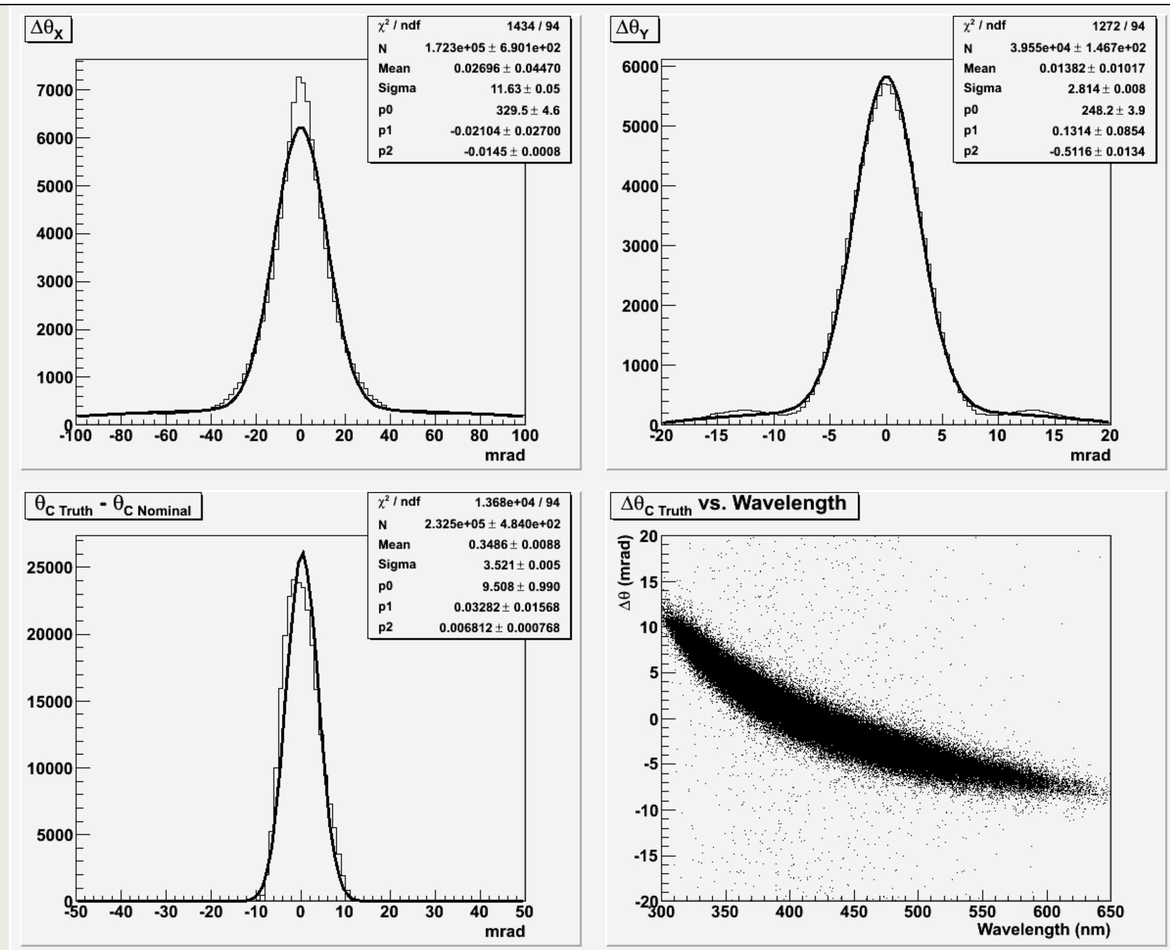
2000 events in each plot, 4GeV π

Simulation Options

- Looked at three different geometry options
  1. Default, as drawn (i.e. with micro-wedge and glue joint between micro-wedge and wedge
  2. No Glue Joint
     - Not really an option, just wanted to see if there was any visible effect due to Fresnel reflections from the glue-quartz interface
     - Preliminary look shows ~10% of photons reflect from this interface for shallow dip angles (45° ~ 55°, 1 GeV momentum π), smaller fraction as dip angle increases
  3. No Micro-Wedge
     - Everything else is external to the bar box, so would really need to justify making the modification
- Then simulated 4 GeV momentum π at dip angles of 45°, 55°, 65°, 75°, 85° and 90°
  - Was previously looking at 1 GeV π, but MS has significant contribution to resolution at that momentum. More interesting to look at higher *p*.
  - Recall: K-π Cerenkov angle difference at 4 GeV = 6.5 mrad, implies 3 σ separation requires resolution of 2.2 mrad

Single Photon Resolution

- Cerenkov Angle Reconstruction
  - For each geometry, generate a "dictionary" of single photons
    - Random over all 12 bars in a bar box
    - Random direction
    - Monochromatic (410 nm)
  - Record position at focal plane, time of arrival after leaving quartz bar, and angles, θ_x and θ_y at the exit of the quartz bar
  - For simulated tracks, for each photon hit generated:
    - Look in "dictionary" for photons within same pixel as hit
      - Currently using 3mm x 3mm pixels
    - Grab t, θ_x, and θ_y and calculate θ_C based on track's dip and phi angle, and Δt (hit time – expected time from dictionary)
      - (8-fold ambiguity from reflections in x, y, and z) $\times$ (# photons from dictionary)
  - Only look at hit solutions with $|\Delta t| < 3$ ns
    - No simulation of PMT time resolution yet but this should be pretty loose for tubes being considered
  - Including Quantum Efficiency based on H8500, plus charge collection efficiency and packing efficiency (dead space)

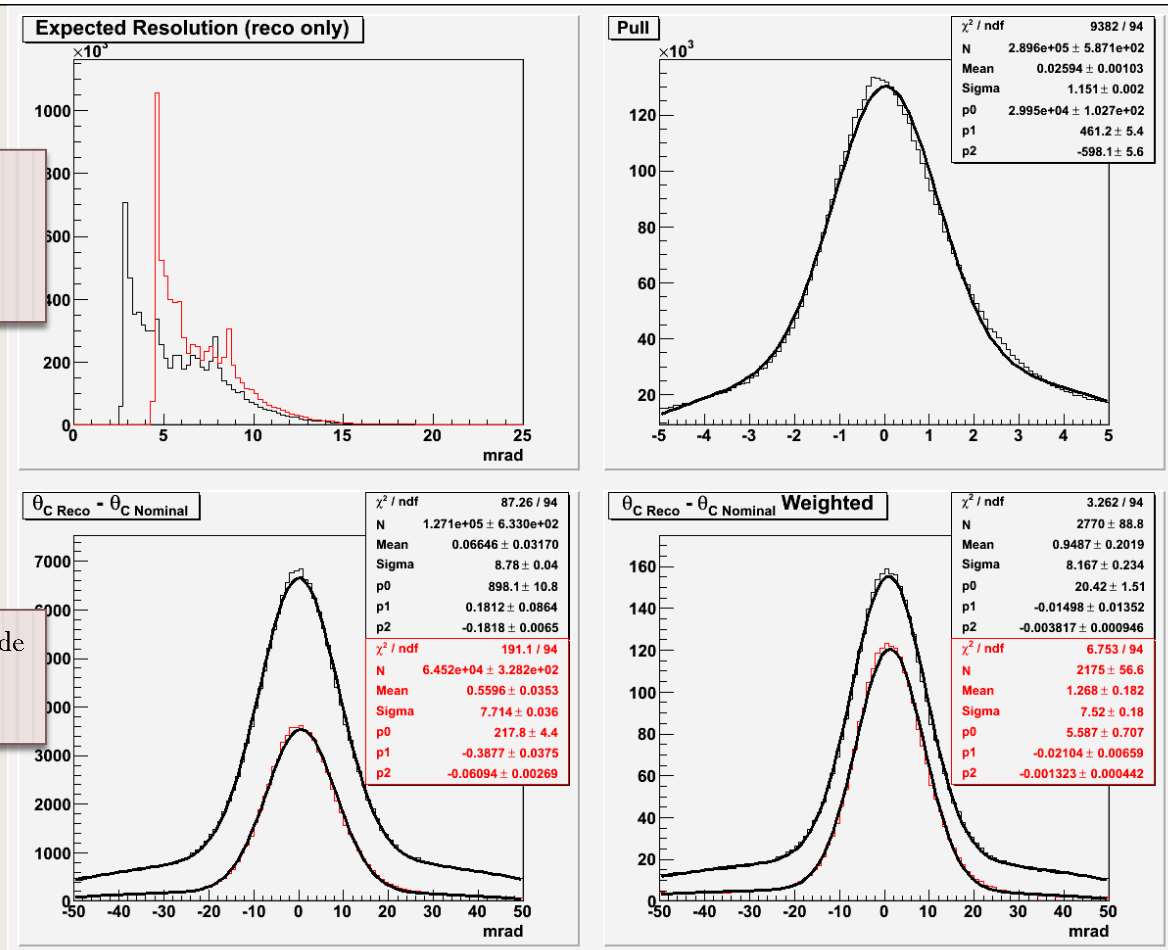


θ_X and θ_Y Resolutions

- Because we focus in *Y* but not in *X*, we have different (> x4) resolutions in θ_X and θ_Y
- Would like to account for this in the reconstruction
  - Central part of the ring is more focused than tails
  - Most of the side reflections contribute to the tails
- Can also see contribution from multiple scattering and chromatic effect (bottom two plots) : about 3.5 mrad at 4 GeV

Red plot includes contribution from MS, E-loss, chromatic effects (~3.5 mrad)

Red plots are removing side reflections from the Focusing Block.



Expected Photon Resolution

Can propagate θ_X and θ_Y resolutions into calculation of θ_C to determine a solution-by-solution expected resolution

Then, in θ_C reconstruction, weight events by $1/\sigma^2$ (lower-right plot)

Summary of Single Photon Resolutions

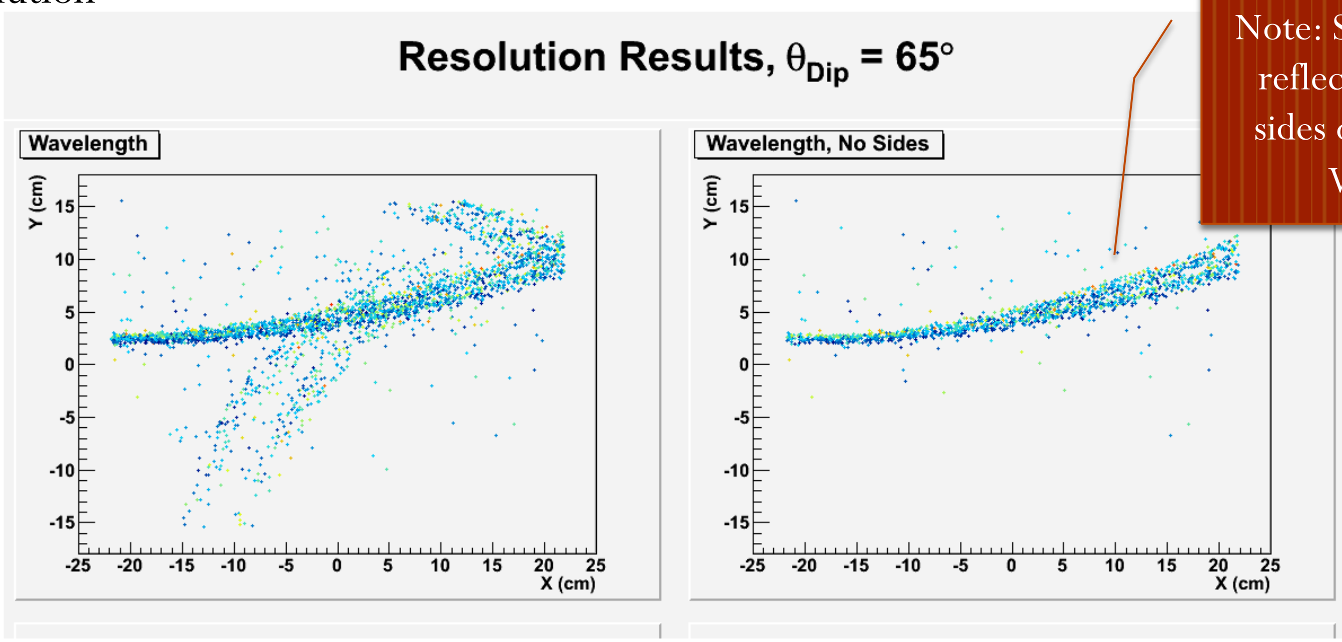
Geometry	$\sigma\ \theta_X$ (mrad)	$\sigma\ \theta_Y$ (mrad)	$\sigma\ \theta_C$ (mrad)
Default	11.6	2.81	8.17
No Glue	11.6	3.00	7.60
No μWedge	12.4	2.93	8.64
No Focusing Block Side Reflections			
Default	14.7	2.87	7.52
No Glue	14.7	3.03	6.86
No μWedge	14.7	2.96	8.16

Gain from μWedge of ~0.5 mrad

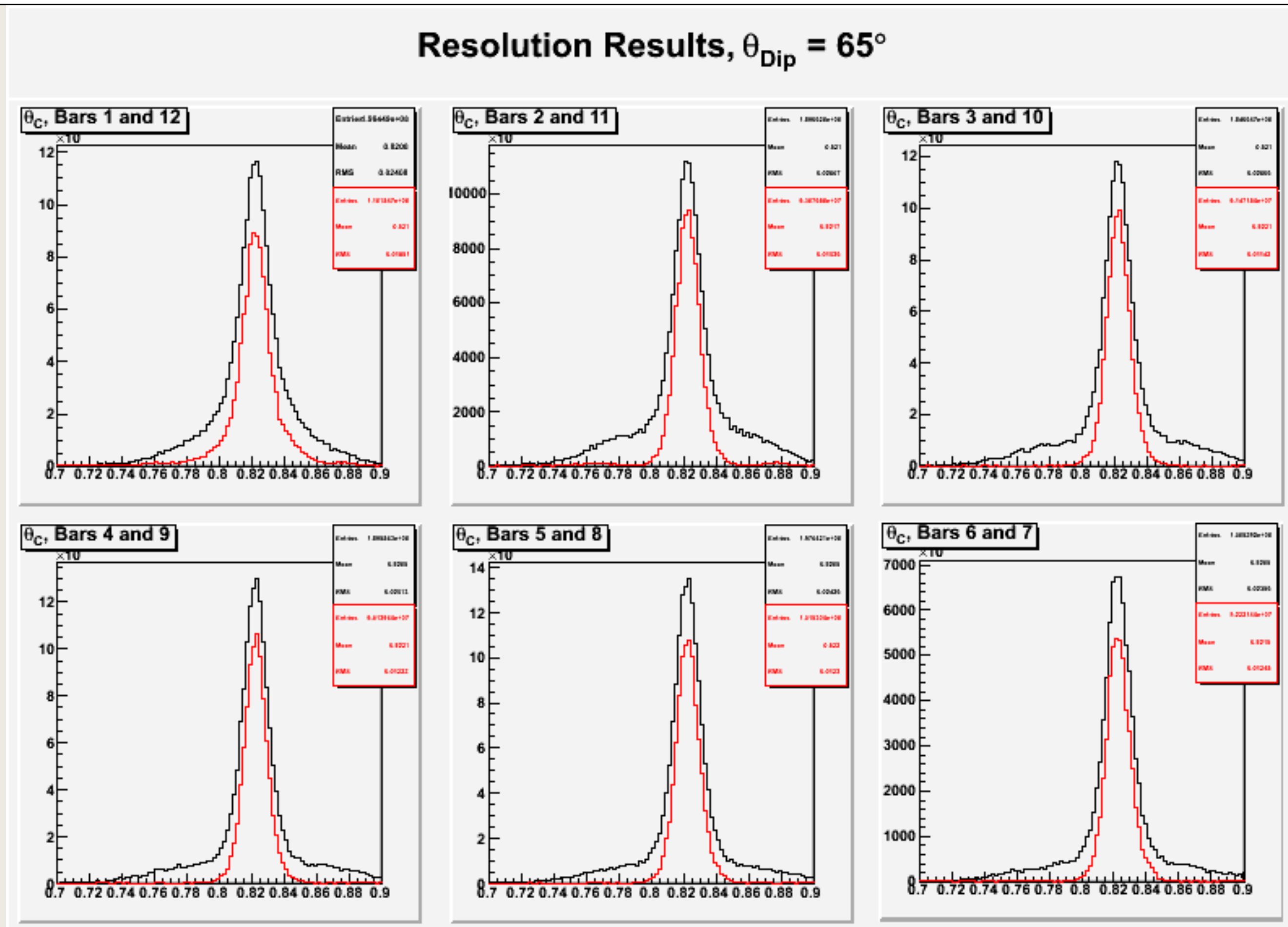
- $\sigma\ \theta_X$ gets worse w/o side reflections: Lever-arm effect
- But, $\sigma\ \theta_C$ gets better because we are primarily keeping photons in central part of the ring
- Compare $\sigma\ \theta_C$ to BaBar's 9.6 mrad from dimuon events

Side Reflections

- Removing reflections from the side of the Focusing Block simplifies the images and seems to improve the single photon resolution on average
- But, we would be throwing away photons and would therefore possibly degrade the net θ_C resolution
- Could end up with bar-dependent resolution
- For bars at the edges of the bar-box, image reflects on to itself and could degrade resolution



Note: Still includes reflections from sides of External Wedge

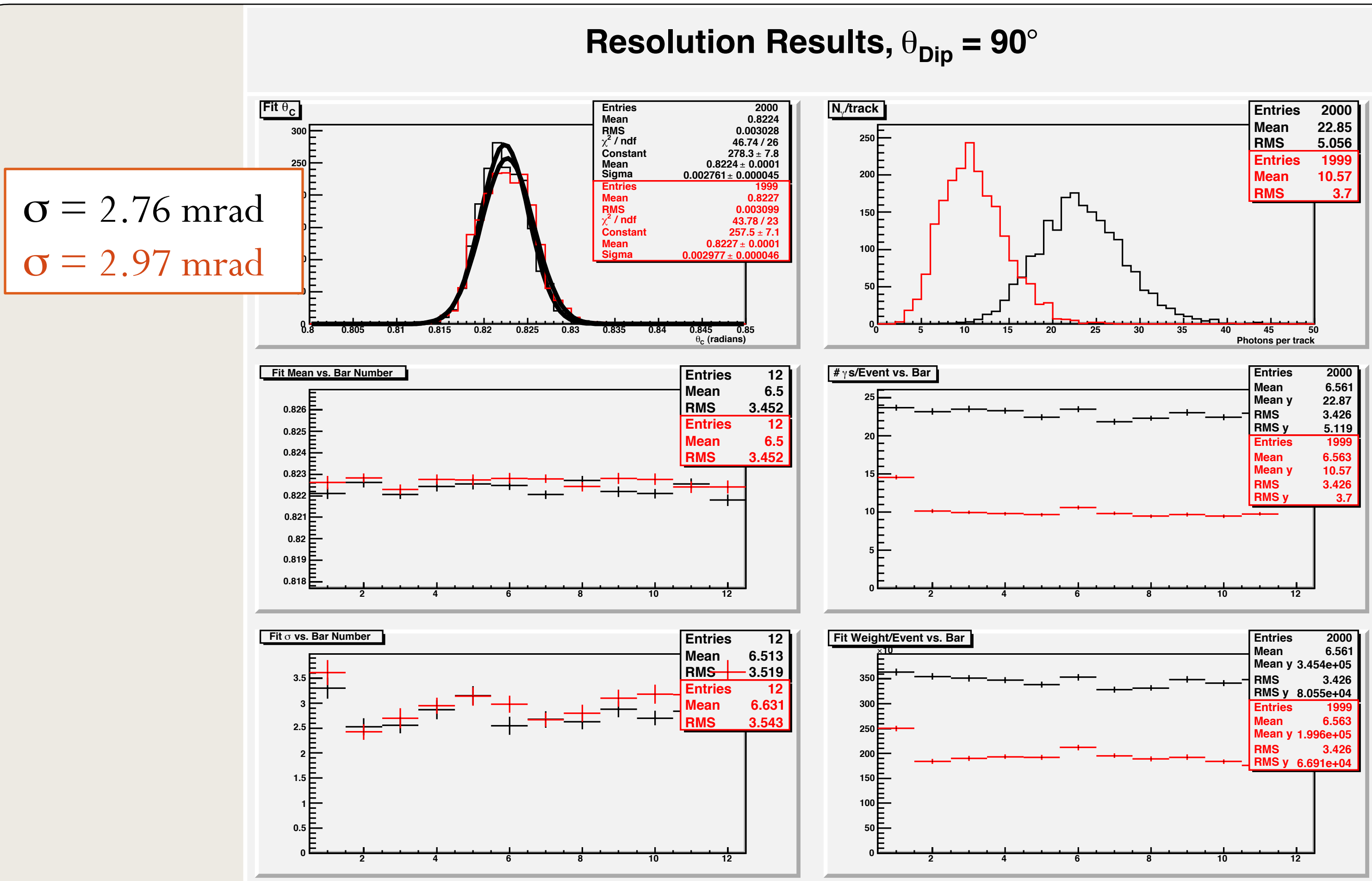


Reconstructed θ_C vs. Bar Number

Side reflections add significant non-Gaussian tails

There's a noticeable broadening for bars 1 & 12 – reflections map onto non-reflected image

I haven't removed side reflections from the external wedge, so there's also a broadening w/o FBLOCK side reflections

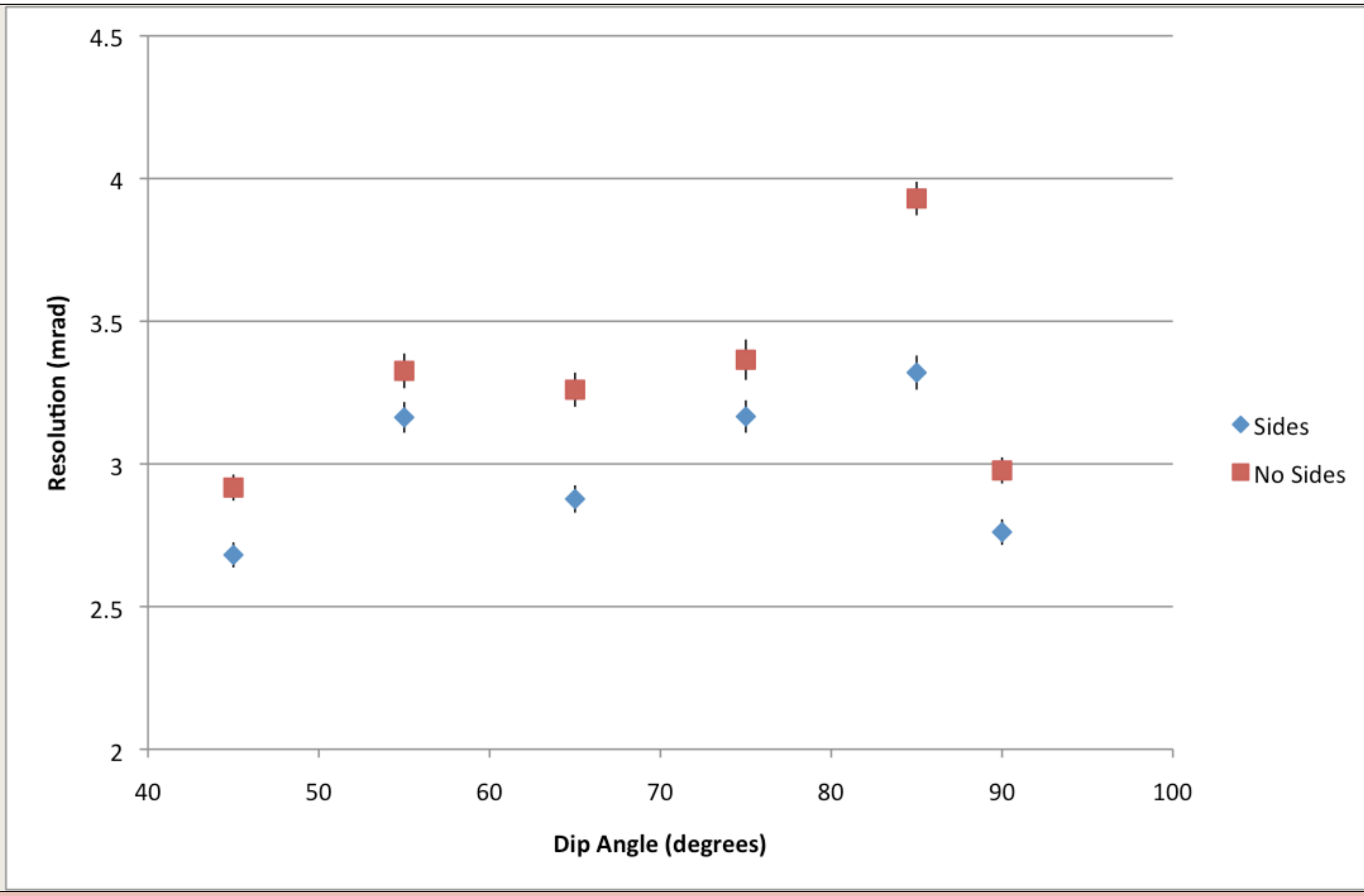


Event Fits for θ_C

On an event-by-event basis, I fit for the value of θ_C, can look at mean and RMS of fit results vs. bar number

Improved single photon resolution w/o side reflections is lost due to loss of photons - Better to keep

Thought: Could we slope the sides so the images don't map onto themselves near the edges? (I think this was in one of Jerry's earlier designs)



Resolution vs. Dip Angle

With and without side reflections

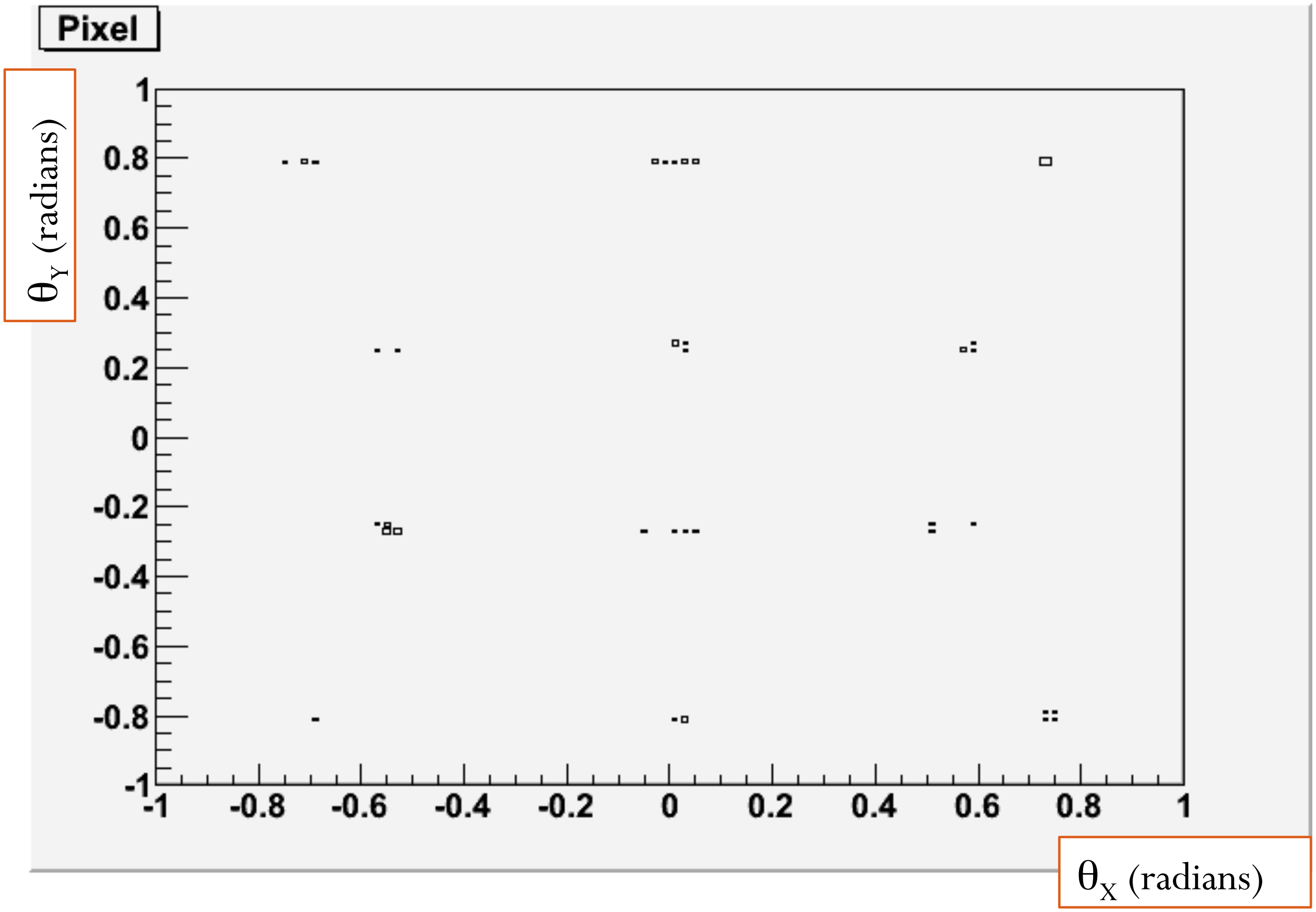
Keeping side reflections is generally better

Final Comments

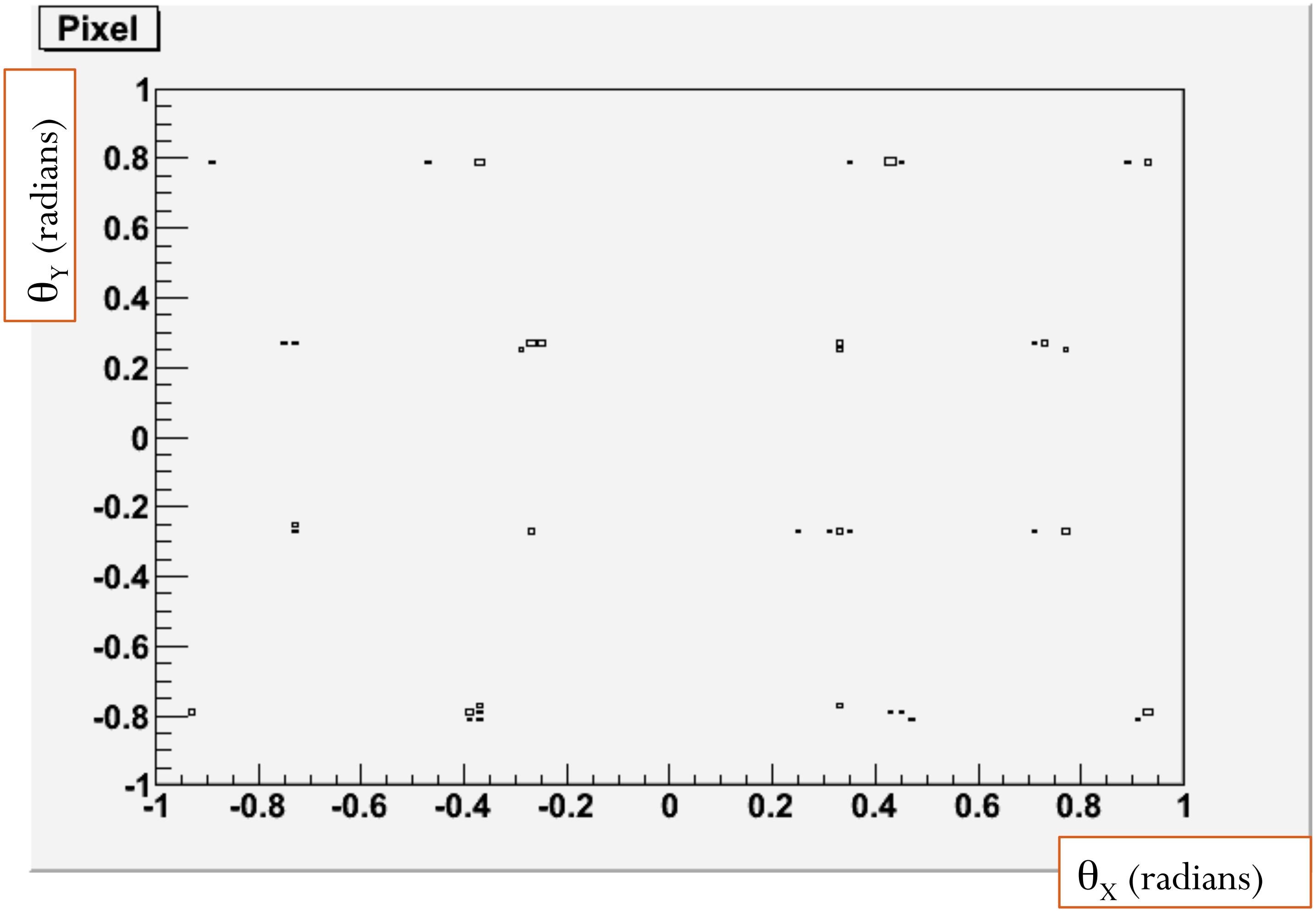
- Single photon resolution is comparable or better than BaBar DIRC
  - Still some effects not included in the simulation
- However, θ_C resolution doesn't seem to reach the target of 2.2 mrad for 3σ K-π separation at 4 GeV
- Lack of photons?
  - QE, Charge Collection, Dead Space????
  - $\langle N_\gamma \rangle$ 13~30, depending on dip angle
- Or could be non-optimal analysis
  - But remember that goal is to compare geometry options, so even if it's non-optimal, it shouldn't be biased
  - Resolution on θ_C doesn't seem to go like $1/\sqrt{N_\gamma}$. Problem with weighting or handling ambiguities?

Backup Slides

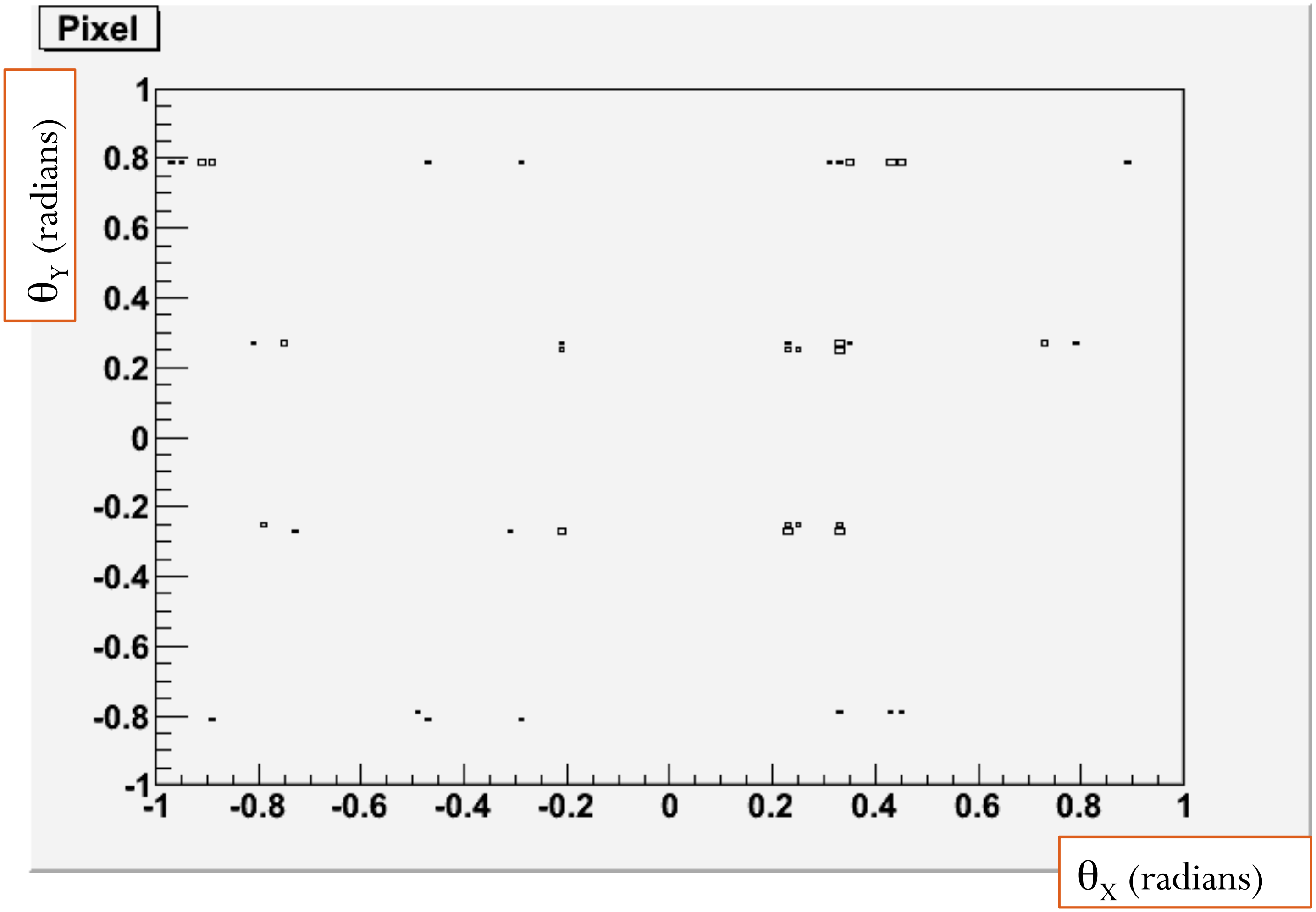
Photon Dictionary, Central Pixel, Bar 6



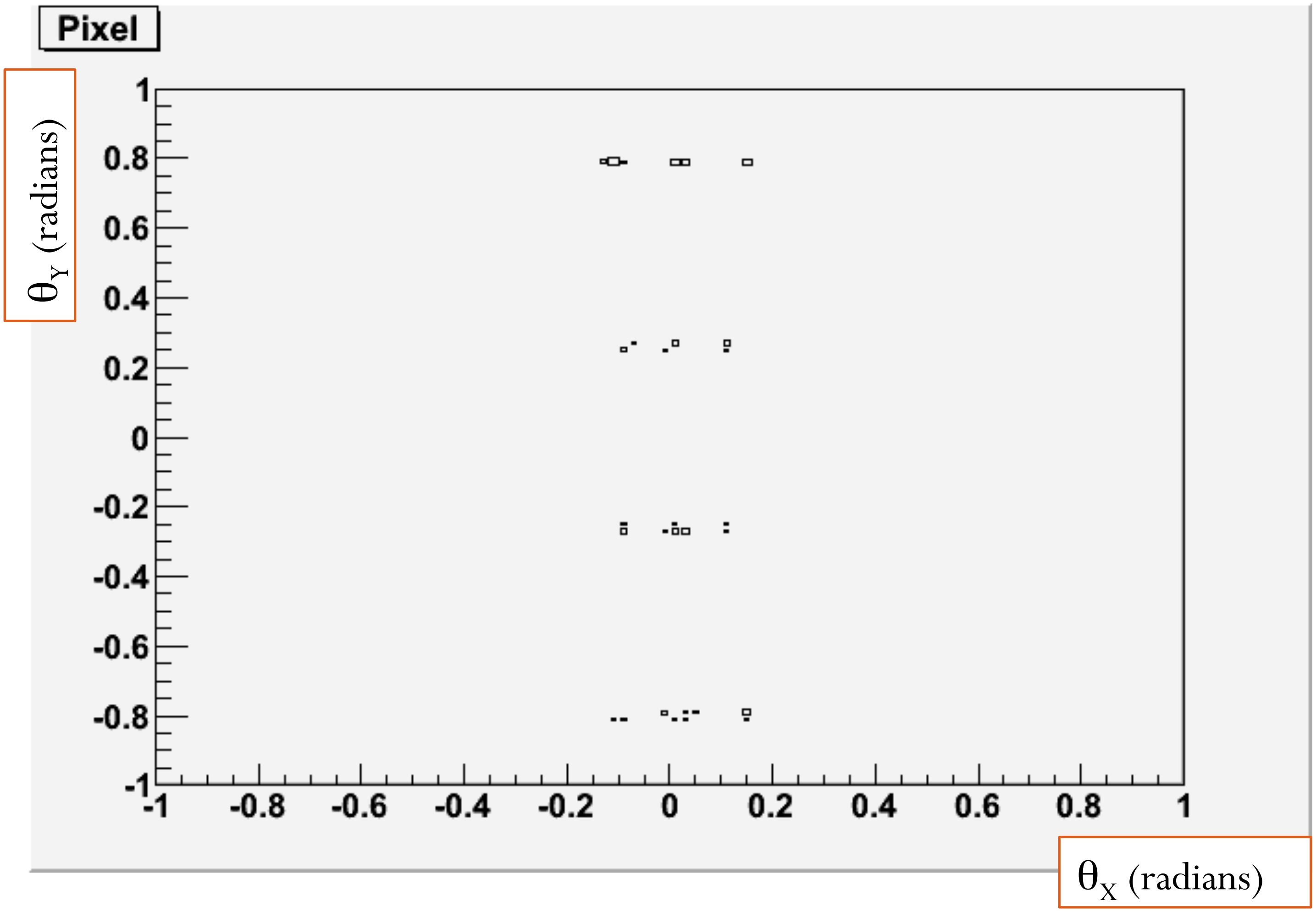
Photon Dictionary, Central Pixel, Bar 1



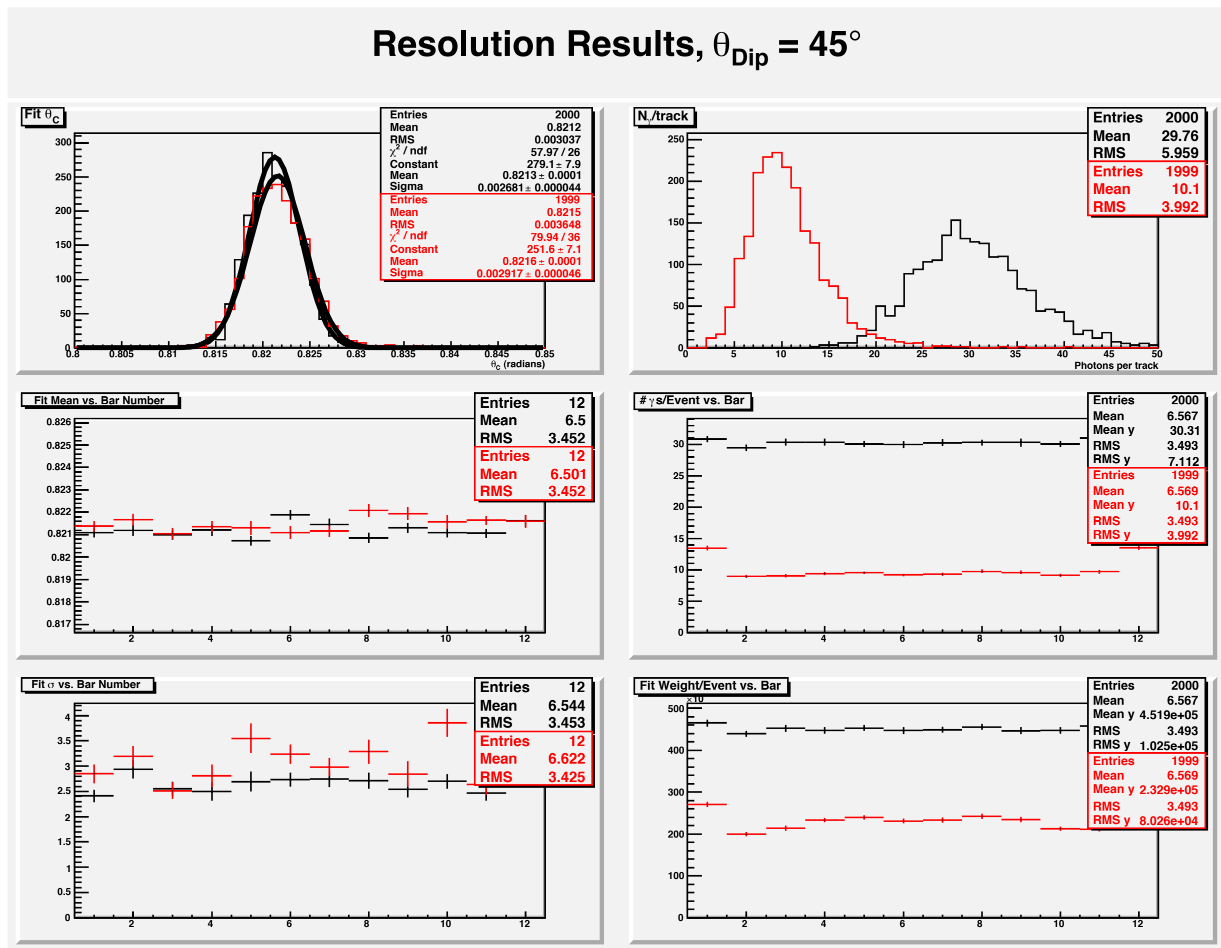
Photon Dictionary, Edge Pixel, Bar 6



Photon Dictionary, Edge Pixel, Bar 1

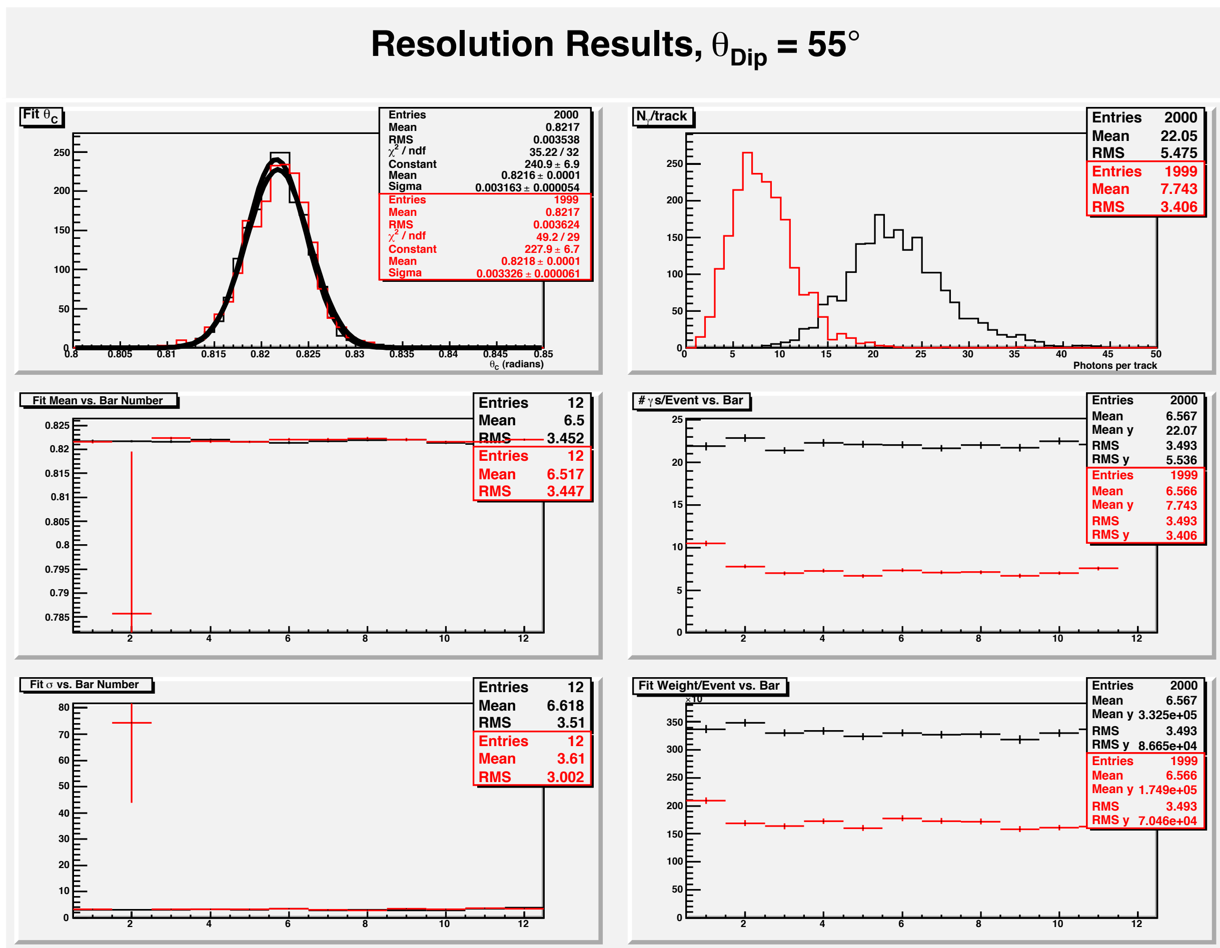


45 degrees



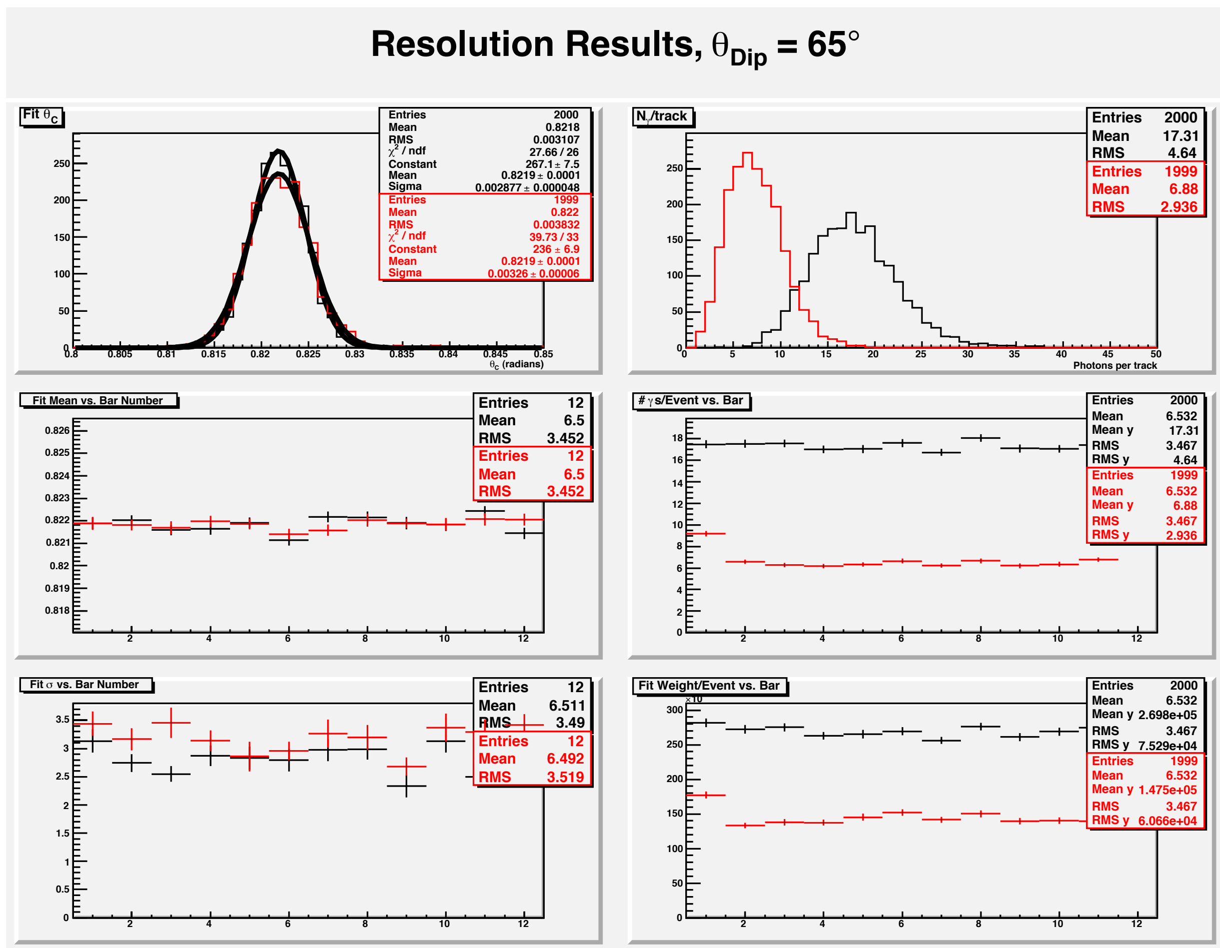
Resolution Results, θDip = 45°
Fit θc
Entries 2000
Mean 0.8212
RMS 0.003037
χ2 / ndf 57.97 / 26
Constant 279.1 ± 7.9
Mean 0.8213 ± 0.0001
Sigma 0.002681 ± 0.000044
Entries 1999
Mean 0.8215
RMS 0.003648
χ2 / ndf 79.94 / 36
Constant 251.6 ± 7.1
Mean 0.8216 ± 0.0001
Sigma 0.002917 ± 0.000046
θc (radians)
Nγ/track
Entries 2000
Mean 29.76
RMS 5.959
Entries 1999
Mean 10.1
RMS 3.992
Photons per track
Fit Mean vs. Bar Number
Entries 12
Mean 6.5
RMS 3.452
Entries 12
Mean 6.501
RMS 3.452
γs/Event vs. Bar
Entries 2000
Mean 6.567
Mean y 30.31
RMS 3.493
RMS y 7.112
Entries 1999
Mean 6.569
Mean y 10.1
RMS 3.493
RMS y 3.992
Fit σ vs. Bar Number
Entries 12
Mean 6.544
RMS 3.453
Entries 12
Mean 6.622
RMS 3.425
Fit Weight/Event vs. Bar
Entries 2000
Mean 6.567
Mean y 4.519e+05
RMS 3.493
RMS y 1.025e+05
Entries 1999
Mean 6.569
Mean y 2.329e+05
RMS 3.493
RMS y 8.026e+04

55 Degrees



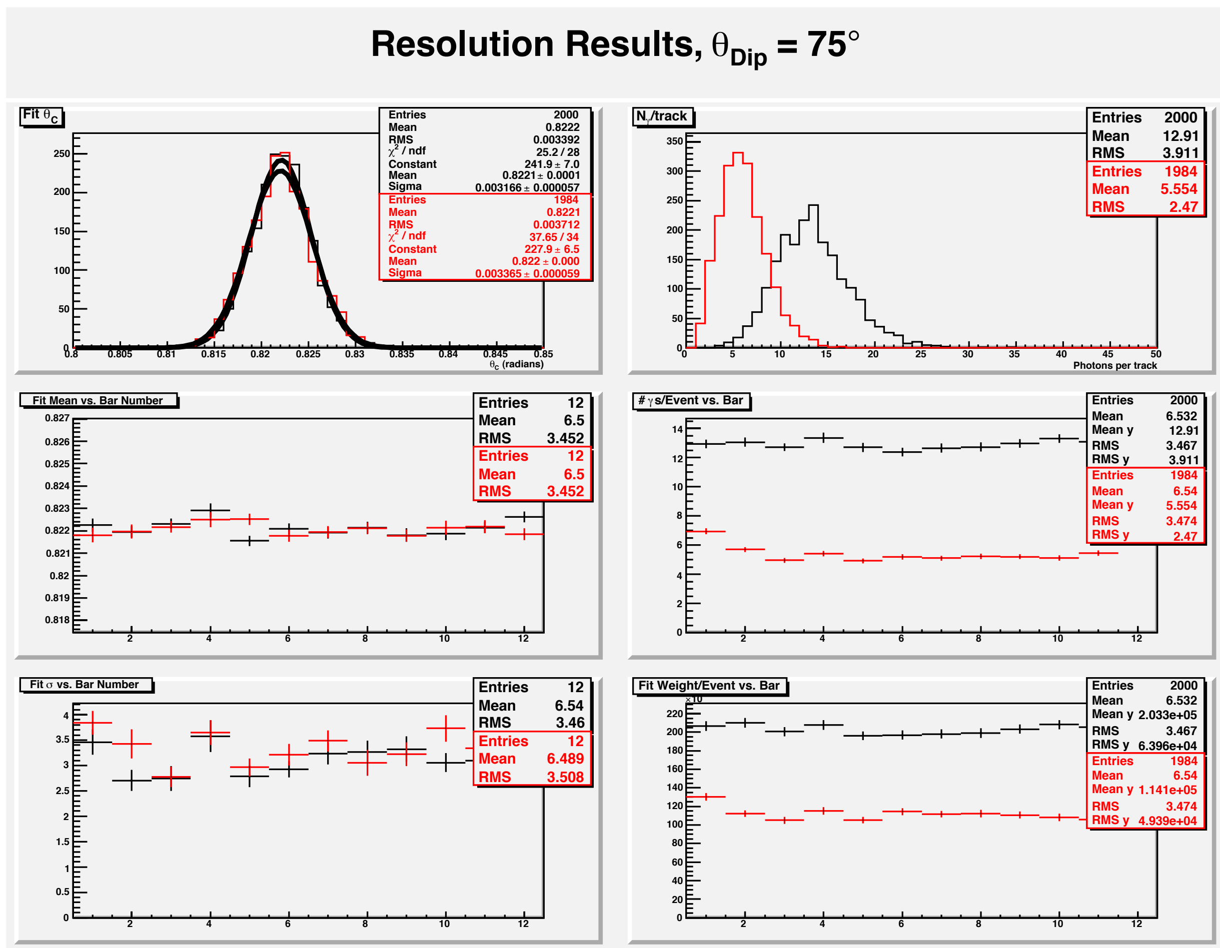
Resolution Results, θ_{Dip} = 55°
Fit θ_c
Entries 2000
Mean 0.8217
RMS 0.003538
χ^2 / ndf 35.22 / 32
Constant 240.9 ± 6.9
Mean 0.8216 ± 0.0001
Sigma 0.003163 ± 0.000054
Entries 1999
Mean 0.8217
RMS 0.003624
χ^2 / ndf 49.2 / 29
Constant 227.9 ± 6.7
Mean 0.8218 ± 0.0001
Sigma 0.003326 ± 0.000061
θ_c (radians)
N_γ/track
Entries 2000
Mean 22.05
RMS 5.475
Entries 1999
Mean 7.743
RMS 3.406
Photons per track
Fit Mean vs. Bar Number
Entries 12
Mean 6.5
RMS 3.452
Entries 12
Mean 6.517
RMS 3.447
γs/Event vs. Bar
Entries 2000
Mean 6.567
Mean y 22.07
RMS 3.493
RMS y 5.536
Entries 1999
Mean 6.566
Mean y 7.743
RMS 3.493
RMS y 3.406
Fit σ vs. Bar Number
Entries 12
Mean 6.618
RMS 3.51
Entries 12
Mean 3.61
RMS 3.002
Fit Weight/Event vs. Bar
Entries 2000
Mean 6.567
Mean y 3.325e+05
RMS 3.493
RMS y 8.665e+04
Entries 1999
Mean 6.566
Mean y 1.749e+05
RMS 3.493
RMS y 7.046e+04

65 Degrees



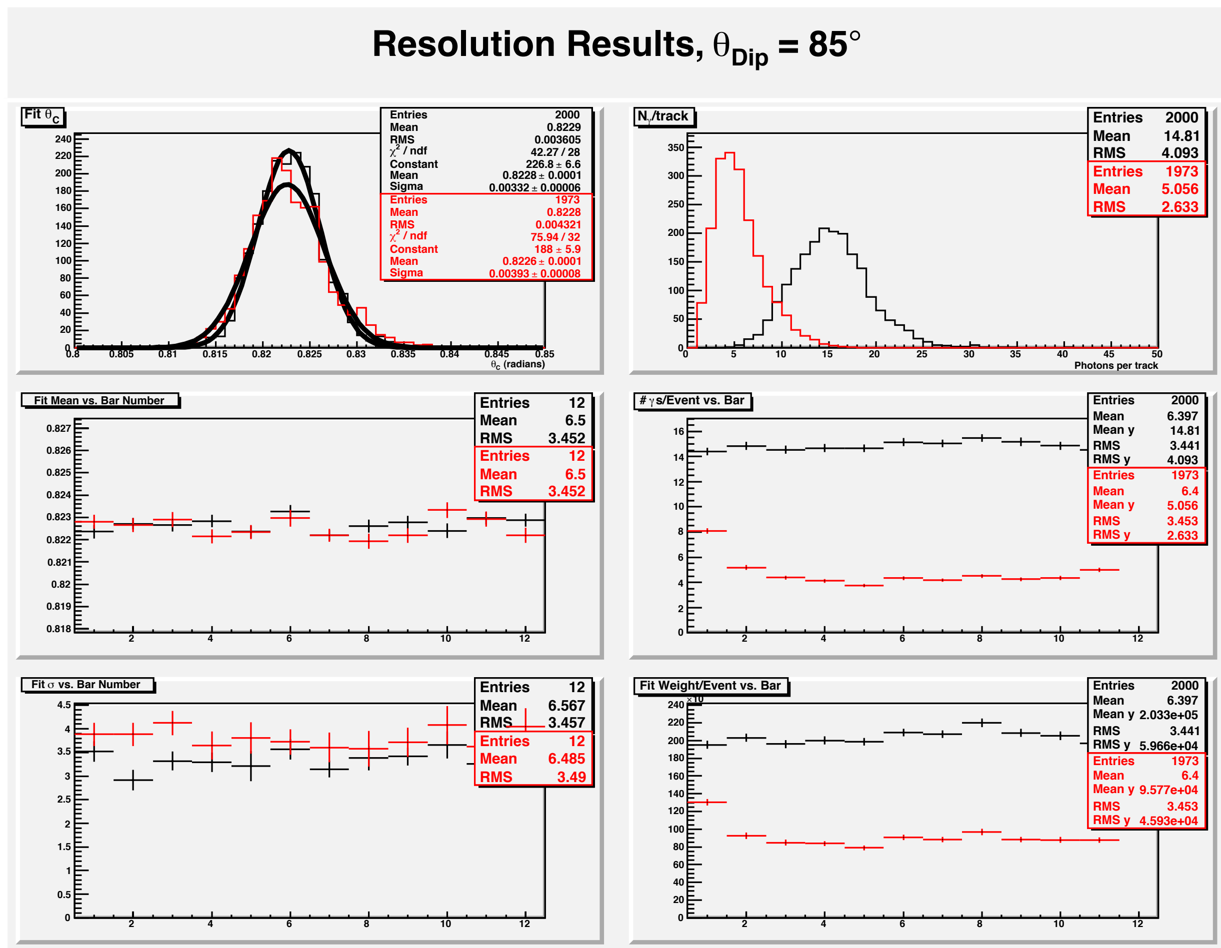
Resolution Results, θ_{Dip} = 65°
Fit θ_c
Entries 2000
Mean 0.8218
RMS 0.003107
χ^2 / ndf 27.66 / 26
Constant 267.1 ± 7.5
Mean 0.8219 ± 0.0001
Sigma 0.002877 ± 0.000048
Entries 1999
Mean 0.822
RMS 0.003832
χ^2 / ndf 39.73 / 33
Constant 236 ± 6.9
Mean 0.8219 ± 0.0001
Sigma 0.00326 ± 0.00006
θ_c (radians)
N_γ/track
Entries 2000
Mean 17.31
RMS 4.64
Entries 1999
Mean 6.88
RMS 2.936
Photons per track
Fit Mean vs. Bar Number
Entries 12
Mean 6.5
RMS 3.452
Entries 12
Mean 6.5
RMS 3.452
γs/Event vs. Bar
Entries 2000
Mean 6.532
Mean y 17.31
RMS 3.467
RMS y 4.64
Entries 1999
Mean 6.532
Mean y 6.88
RMS 3.467
RMS y 2.936
Fit σ vs. Bar Number
Entries 12
Mean 6.511
RMS 3.49
Entries 12
Mean 6.492
RMS 3.519
Fit Weight/Event vs. Bar
Entries 2000
Mean 6.532
Mean y 2.698e+05
RMS 3.467
RMS y 7.529e+04
Entries 1999
Mean 6.532
Mean y 1.475e+05
RMS 3.467
RMS y 6.066e+04

75 Degrees



Resolution Results, θDip = 75°
Fit θc
Entries 2000
Mean 0.8222
RMS 0.003392
χ2 / ndf 25.2 / 28
Constant 241.9 ± 7.0
Mean 0.8221 ± 0.0001
Sigma 0.003166 ± 0.000057
Entries 1984
Mean 0.8221
RMS 0.003712
χ2 / ndf 37.65 / 34
Constant 227.9 ± 6.5
Mean 0.822 ± 0.000
Sigma 0.003365 ± 0.000059
θc (radians)
Nγ/track
Entries 2000
Mean 12.91
RMS 3.911
Entries 1984
Mean 5.554
RMS 2.47
Photons per track
Fit Mean vs. Bar Number
Entries 12
Mean 6.5
RMS 3.452
Entries 12
Mean 6.5
RMS 3.452
γs/Event vs. Bar
Entries 2000
Mean 6.532
Mean y 12.91
RMS 3.467
RMS y 3.911
Entries 1984
Mean 6.54
Mean y 5.554
RMS 3.474
RMS y 2.47
Fit σ vs. Bar Number
Entries 12
Mean 6.54
RMS 3.46
Entries 12
Mean 6.489
RMS 3.508
Fit Weight/Event vs. Bar
Entries 2000
Mean 6.532
Mean y 2.033e+05
RMS 3.467
RMS y 6.396e+04
Entries 1984
Mean 6.54
Mean y 1.141e+05
RMS 3.474
RMS y 4.939e+04

85 Degrees



Resolution Results, θ_{Dip} = 85°
Fit θ_c
Entries 2000
Mean 0.8229
RMS 0.003605
χ^2 / ndf 42.27 / 28
Constant 226.8 ± 6.6
Mean 0.8228 ± 0.0001
Sigma 0.00332 ± 0.00006
Entries 1973
Mean 0.8228
RMS 0.004321
χ^2 / ndf 75.94 / 32
Constant 188 ± 5.9
Mean 0.8226 ± 0.0001
Sigma 0.00393 ± 0.00008
θ_c (radians)
N_γ/track
Entries 2000
Mean 14.81
RMS 4.093
Entries 1973
Mean 5.056
RMS 2.633
Photons per track
Fit Mean vs. Bar Number
Entries 12
Mean 6.5
RMS 3.452
Entries 12
Mean 6.5
RMS 3.452
γs/Event vs. Bar
Entries 2000
Mean 6.397
Mean y 14.81
RMS 3.441
RMS y 4.093
Entries 1973
Mean 6.4
Mean y 5.056
RMS 3.453
RMS y 2.633
Fit σ vs. Bar Number
Entries 12
Mean 6.567
RMS 3.457
Entries 12
Mean 6.485
RMS 3.49
Fit Weight/Event vs. Bar
Entries 2000
Mean 6.397
Mean y 2.033e+05
RMS 3.441
RMS y 5.966e+04
Entries 1973
Mean 6.4
Mean y 9.577e+04
RMS 3.453
RMS y 4.593e+04