FDIRC prototype CRT test and its impact on FDIRC at SuperB

J. Va'vra, SLAC

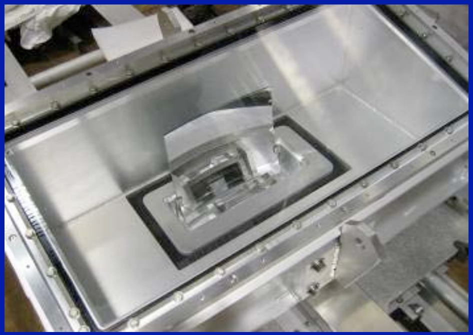
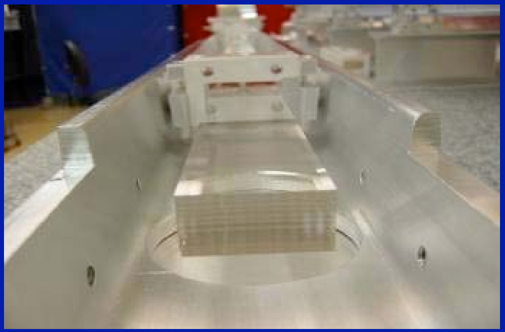
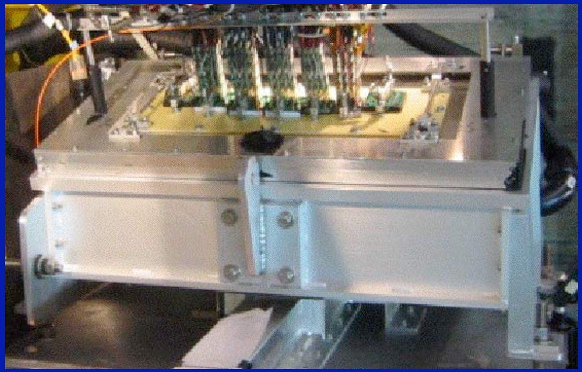
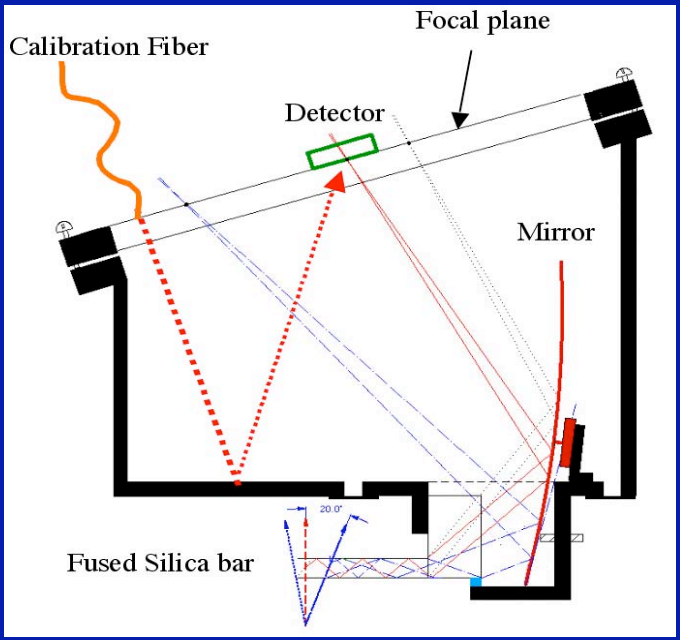
Content

- Reminder of "unsolved" tail problem in DIRC.
- Reminder of an old FDIRC simulation with the Mathematica program.
- Its impact in the data analysis of FDIRC prototype CRT data.
- Impact on FDIRC at SuperB.

FDIRC prototype in CRT

Focusing DIRC prototype optics

Built by M. McCulloch, R. Reif and J. Va'vra

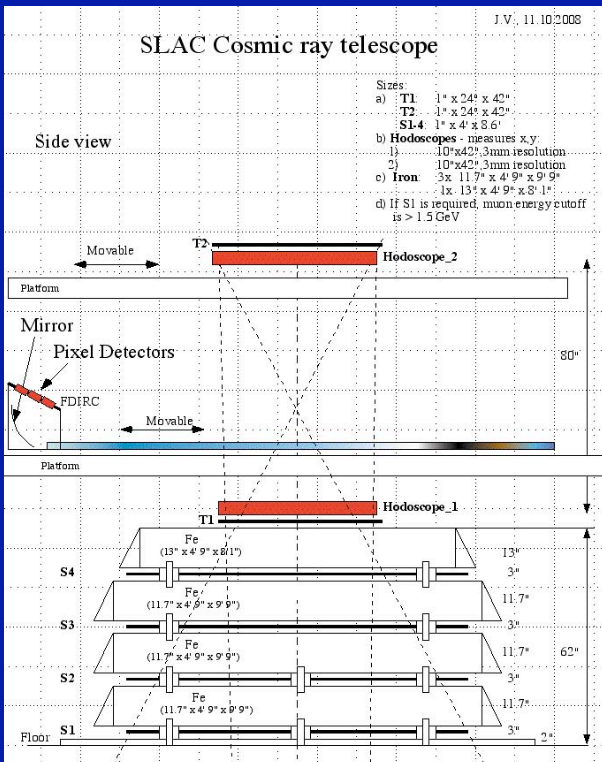





- **Radiator:**
  - 1.7 cm thick, 3.5 cm wide, 3.7 m long fused silica bar (the same as for BaBar DIRC).
- **Optical expansion region:**
  - filled with a mineral oil to match the fused silica refraction index (KamLand oil).
  - optical fiber for the electronics calibration.
- **Focusing optics:**
  - a **spherical mirror** with 49 cm focal length focuses photons onto a detector plane in x & y.

Present FDIRC test in CRT

Cosmic Ray Telescope (CRT):

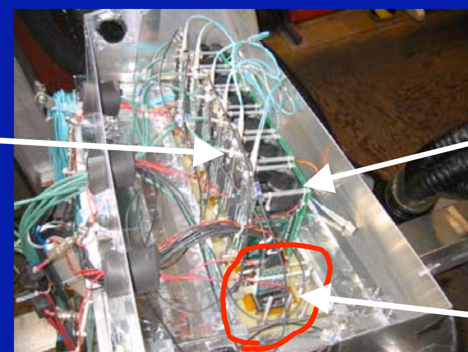
(described in SLAC-PUB-13873 (2010):

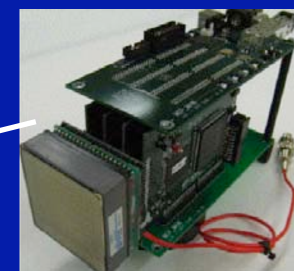


Present electronics:

L.L. Ruckmann, K. Nishimuram, G. Varner and J. Va'vra, Nucl. Instr. & Meth. A623 (2010) 303

BLAB2 Electronics:





Old SLAC Amplifier for analog monitoring

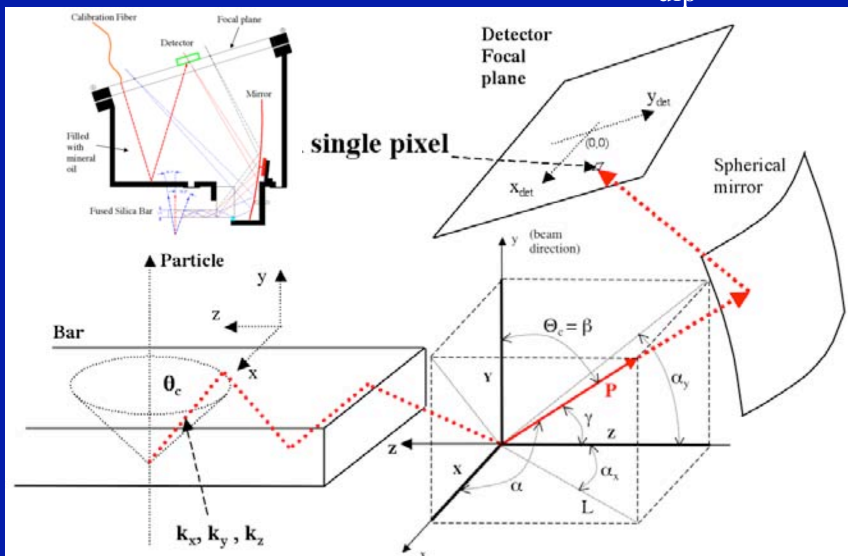
- **T1*T2*S1*Qtz_counter rate ~ 6k/24 hours <=> E_{muon} > 1.6 GeV.**
- **The prototype has 7 H-8500 MaPMTs.**
- **Presently it uses BLAB2 electronics.**

Focusing DIRC prototype pixel reconstruction

J.F. Benitez, I. Bedajanek, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff., K. Nishimura, K. Suzuki, L.L. Ruckmann, J. Schwiening, J. Uher, G. Varner and J. Va'vra,

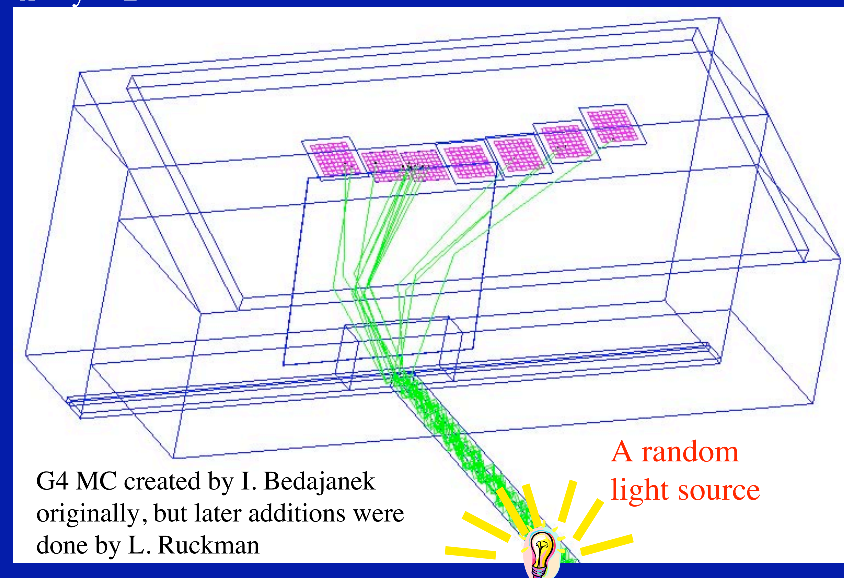
SLAC-PUB-12803, 2007 and Nucl. Instr. & Meth. A595(2008)104-107

Prototype coordinate systems - $\theta_{dip} = 90^o$:



J. Vavra, "FDIRC prototype design" log book, page 129

k_x,k_y,k_z determined from Geant 4 simulation:



Note: random source allows population of all pixels. If one switches to perpendicular tracks, Cherenkov photons populate a narrow band of pixels

- **Each detector pixel has a unique assignment of k_x,k_y,k_z from MC for average λ (420 nm):**

  $k_x = \cos\alpha$, $k_y = \cos\beta$, $k_z = \cos\gamma$ - photon direction cosines in th ebar coordinate system

  L_{path} (direct) $= z_{particle\ position} / k_z$ - Photon path length in bar #1

  L_{path} (indirect) $= (2*L_{bar} - z_{particle\ position}) / k_z$ - Photon path length in bar #2

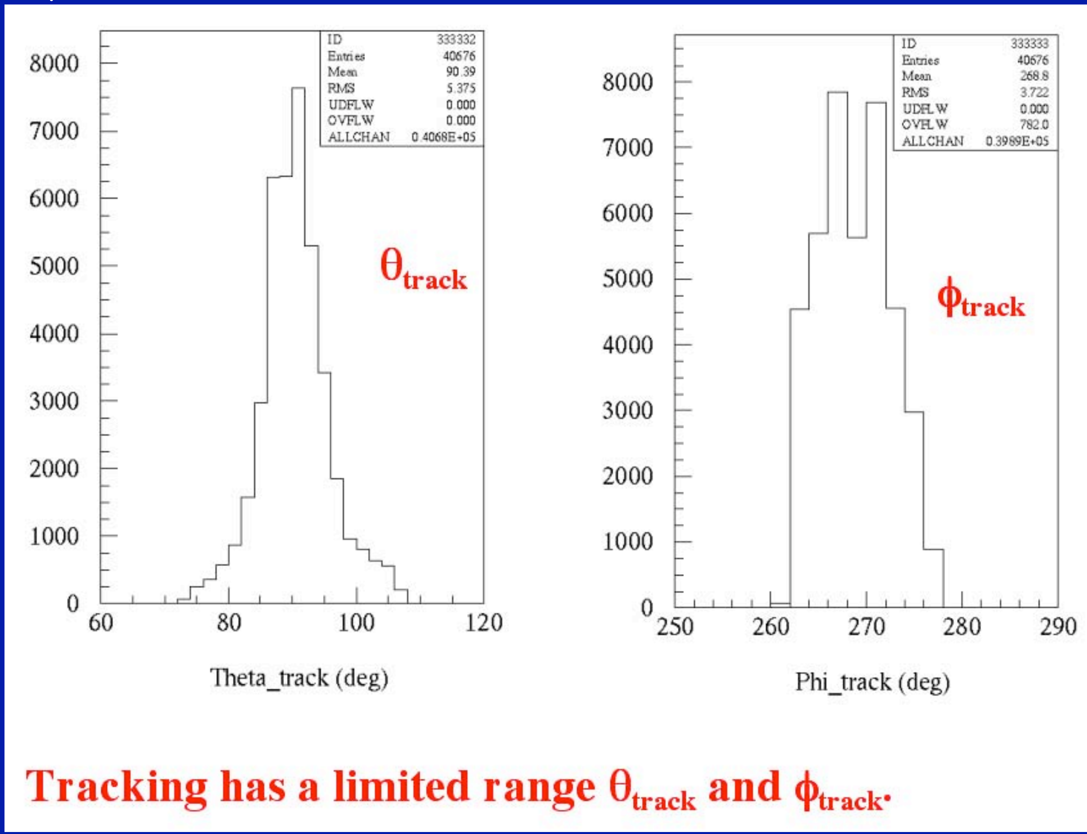
  TOP $= L_{path} / v_g = L_{path}\, n_g / c = L_{bar}\, n_g/(k_z\, c)$ - time-of-propagation in bar fron a track entry point

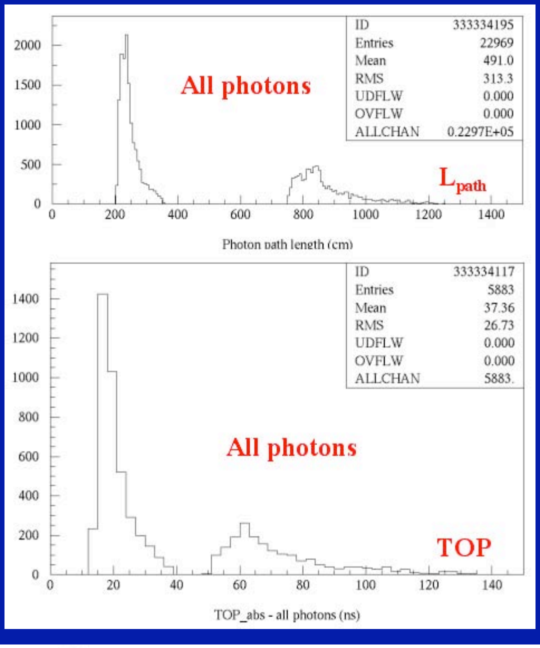
  $\cos\theta_c = \vec{k}_{photon} \cdot \vec{k}_{track}$ - Cherenkov angle with 3D tracking

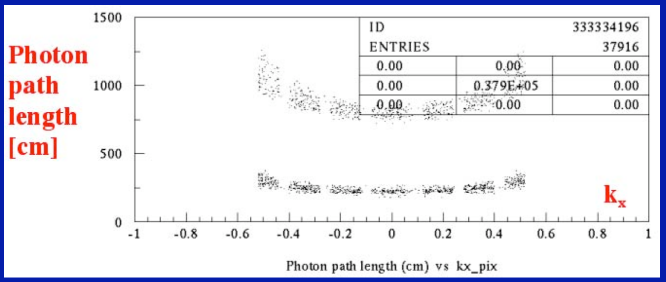
Present reach of FDIRC prototype

Position #3 along z-direction, hodoscopes in a nominal position, tracks close to $\theta \sim 90^o$

E_μ > 1.6 GeV:







- **Tracking has a limited range in θ, φ and z.**
- **As a consequence there is a limited reach in L_{path}, TOP, n_x, n_y, etc.**

A comment on tails

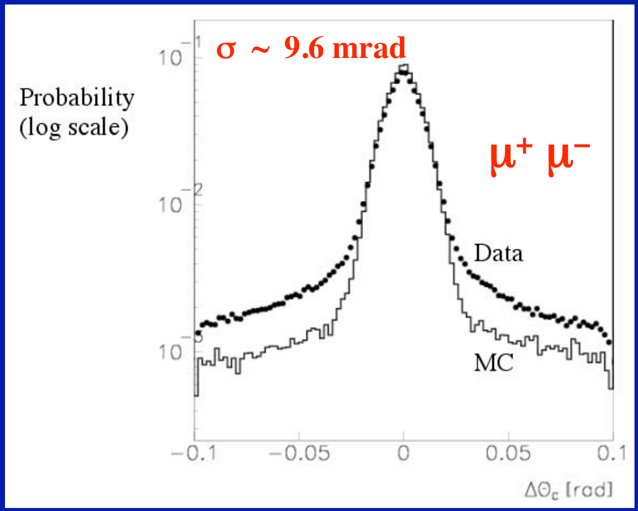
BaBar: tail in the θ_c distribution

K. Yarritu, S. Spanier and J. Va'vra, DIRC note 141, 2001

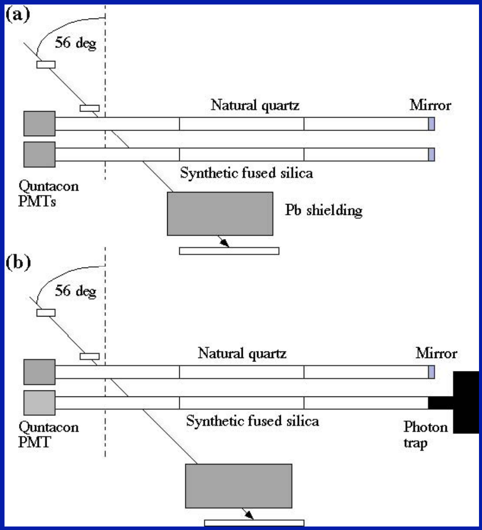
- **Cherenkov distribution has two components: (a) narrow, and (b) wide. This was observed at BaBar. Some contribution to the tail comes from ambiguity overlaps, δ-rays, glue reflections, etc. Generally only ~60% of the tail is explained by BaBar MC. This is NOT presently understood !! These are candidates to explain it:**

  - **There are at least four or more candidates to explain it:** (a) quartz sub-surface damage when polishing, (b) photons re-scatter when entering a glue joint at grazing angles, and (c) photons scatter when propagating through a long path in quartz, etc.

BaBar DIRC data vs MC:



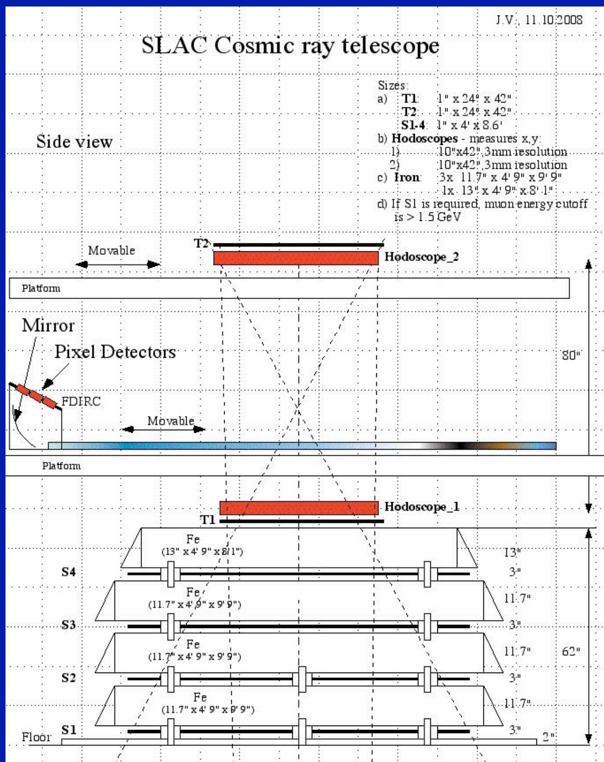
A special test trying to explain it with glue or scintillation (?):
K. Yarritu, S Spanier and J. Va'vra: DIRC Note #141, 2001:
(http://www.slac.stanford.edu/~jjv/activity/dirc/DIRC_Note_141.pdf)
Note: based on this work, glue reflections are in the BaBar MC



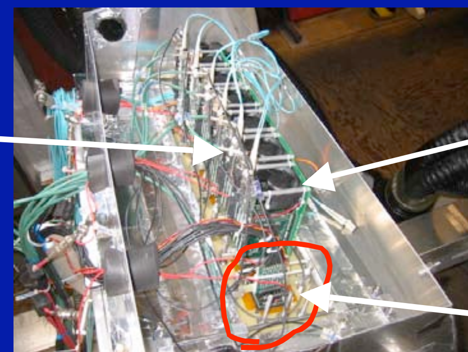
Present FDIRC test in CRT

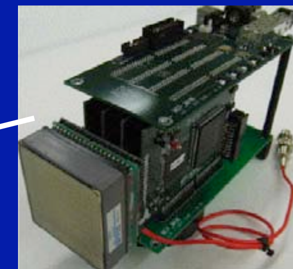
L.L. Ruckmann, K. Nishimuram, G. Varner and J. Va'vra, Nucl. Instr. & Meth. A623 (2010) 303

Cosmic Ray Telescope (CRT):
(described in SLAC-PUB-13873 (2010):



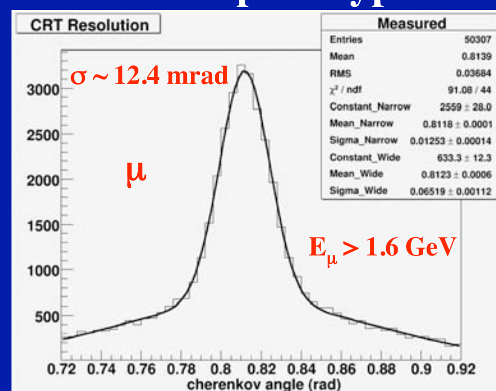
BLAB2 Electronics:

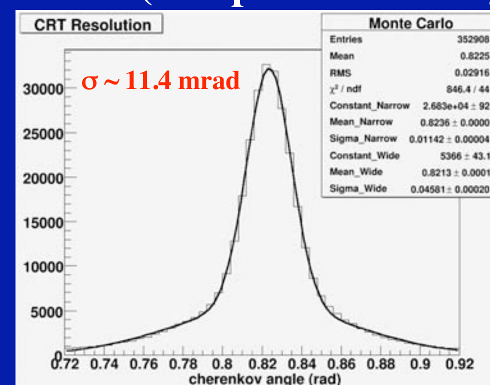




Old SLAC Amplifier for analog monitoring

E_μ > 1.6 GeV:
CRT FDIRC prototype data & MC (accept all track angles):





(L.L. Ruckmann's thesis; but there was an independent data analysis by J. Va'vra)

- **T1*T2*S1*Qtz_counter rate ~ 6k/24 hours <=> E_{muon} > 1.6 GeV (bottom stack)**
- **Tail was not explained either by the FDIRC prototype MC.**

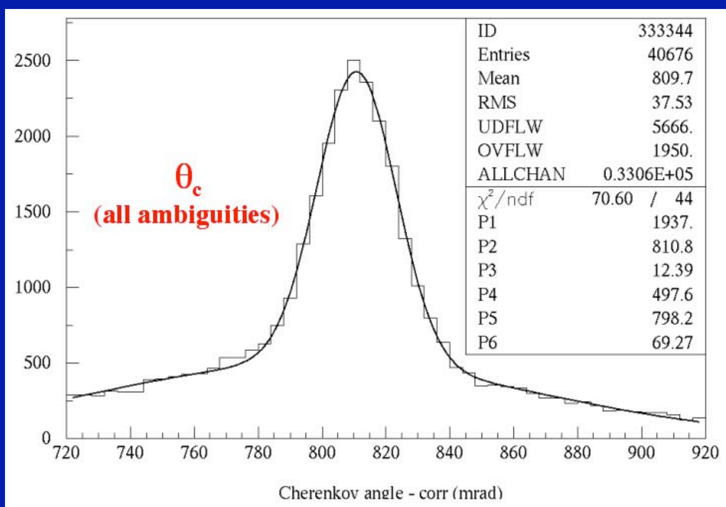
Reduction of tails by removing of ambiguities

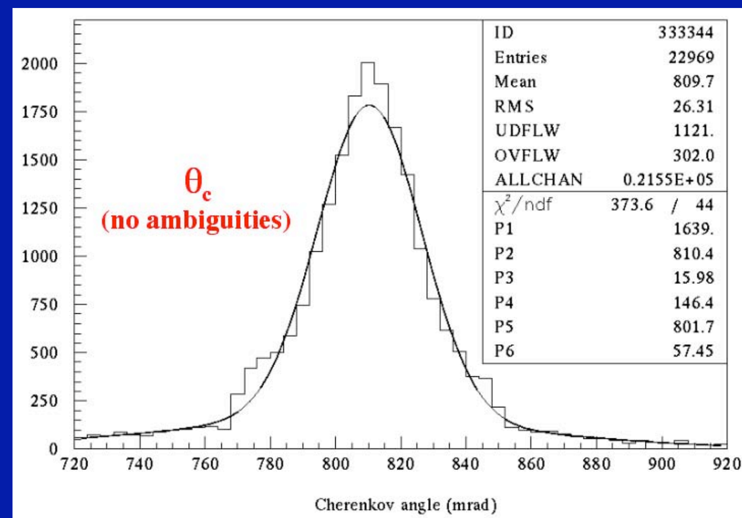
J. Va'vra
with many useful comments from B. Ratcliff, B. Medows, S. Aston and J. Schwiening

A new treatment of ambiguities in FDIRC prototype CRT analysis:

(a) remove both solutions if they both are within 40 mrads (~4σ) of the expected θ_c,
(b) remove a "far away" solution (more than 40 mrads) if the other one is within 40 mrads of the expected θ_c,
(c) remove solutions if both are more than 40 mrads from θ_c.

$E_\mu > 1.6$ GeV:

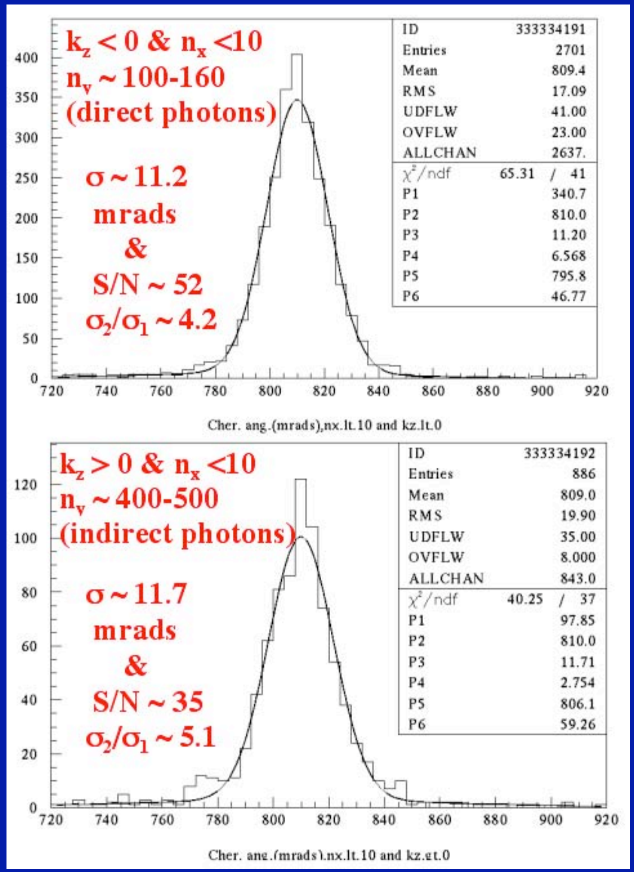


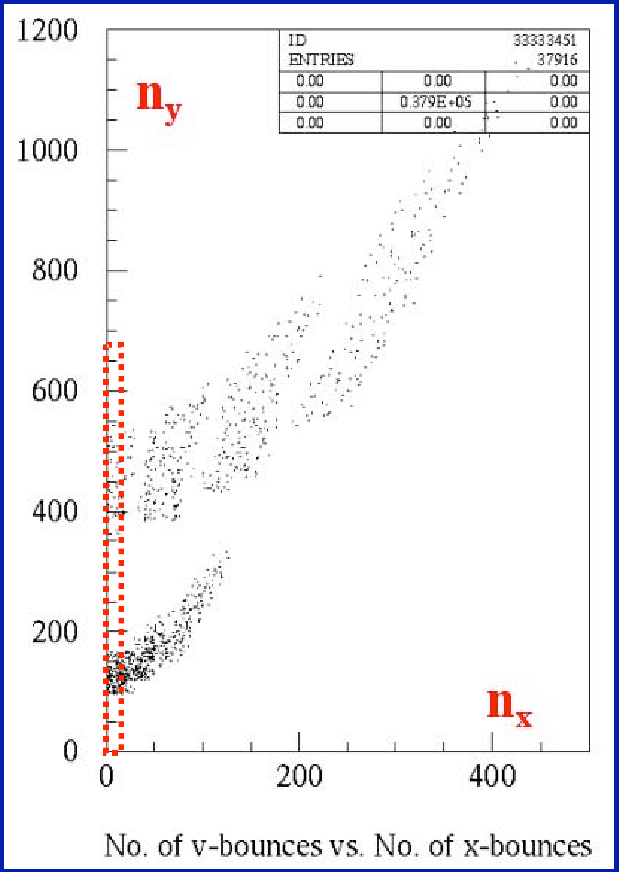


- **This is a new data analysis.**
- **No MC work yet done for this condition, so I will stop here, as far as tails.**
- **However, I will mention only one result, which, I think is telling something.**

Cherenkov angle resolution = $f(n_y)|_{nx < 10}$

E_μ > 1.6 GeV:





Note: Small n_x means small k_x, which means that photons come from the central ring region

- **From here I tend to conclude that the Cherenkov angle resolution is almost independent of number of bounces from top surface (n_y). However, the S/N ratio is worse and σ_2/σ_1 is larger ! Some photons are leaking out of the peak.**

Poorer resolution in Cherenkov ring wings - penalty for designs with a mirror

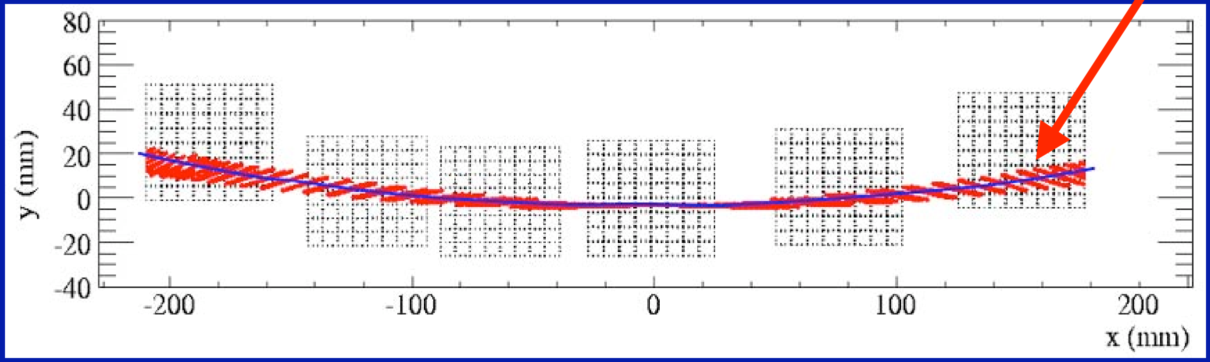
Summary of error contributions to θ_c

J.F. Benitez, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff. L.L. Ruckmann, J. Schwiening, G. Varner and J. Va'vra, SKAC-PUB-12803, 2007, and Nucl. Instr. & Meth. A595(2008)104-107.

FDIRC prototype test beam result in ESA:

- **Chromatic error: ~ 3-4 mrad**
- **Pixel size (~6mm x 6mm pixel size): ~5.5 mrad**
- **Optical aberrations: 0 mrad (at ring center) to 9 mrad (in outer wings of Cherenkov ring)**

This pattern was discovered by our student J. Benitez during the FDIRC prototype development:

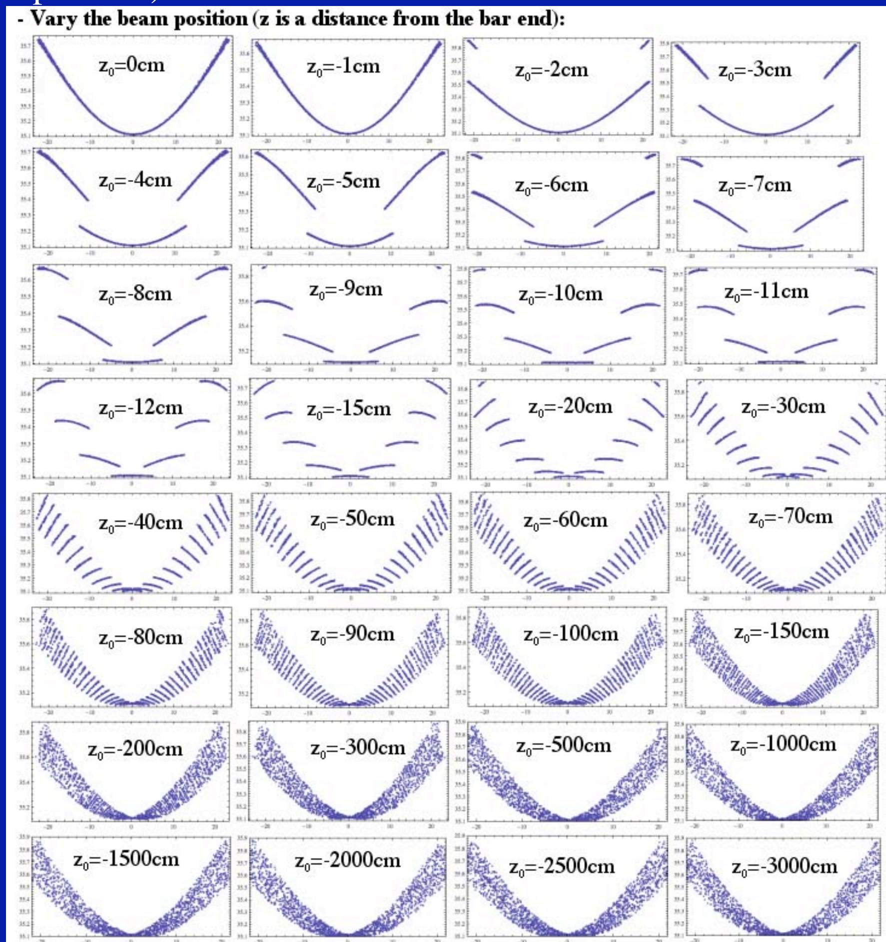


Total θ_c resolution in FDIRC prototype: ~9.6 mrads

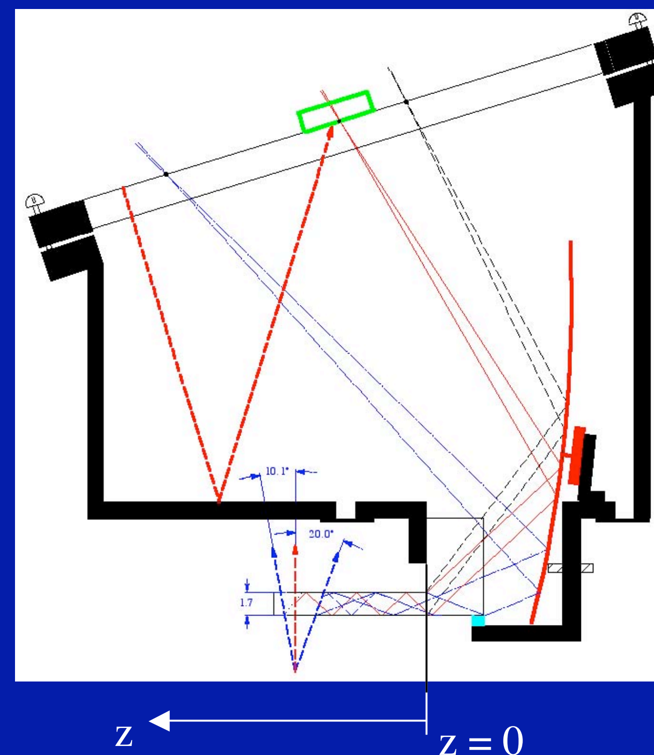
Optical aberration = f(z)

$\theta_{dip} = 90^o$,
(direct photons)

J.Va'vra, "Simulation of the FDIRC Optics with Mathematica", SLAC-PUB-13464, Nov., 2008



FDIRC prototype with spherical mirror:

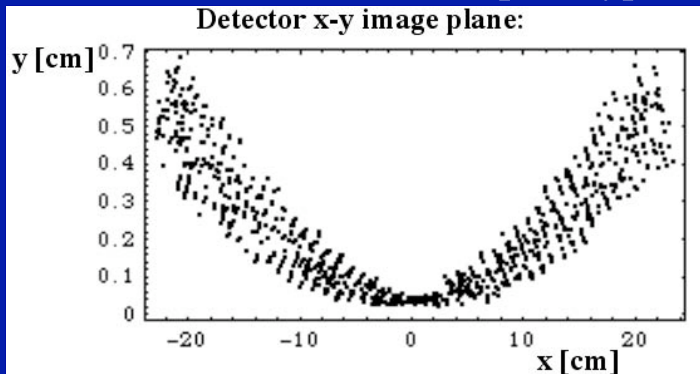


- **The optical aberration (kaleidoscopic pattern) is due to a square bar acting on pieces of the ring.**

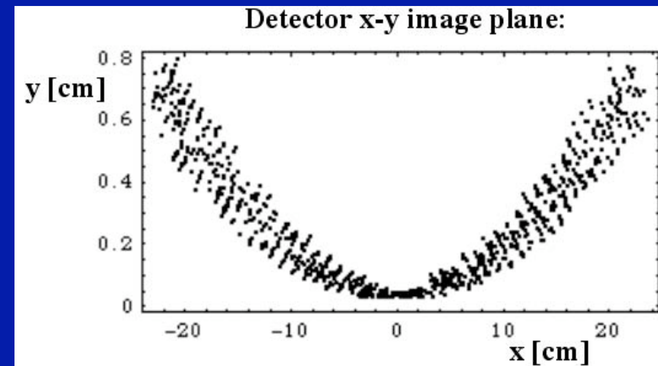
FDIRC prototype simulation

J.Va'vra, "Simulation of the FDIRC Optics with Mathematica", SLAC-PUB-13464, Nov., 2008

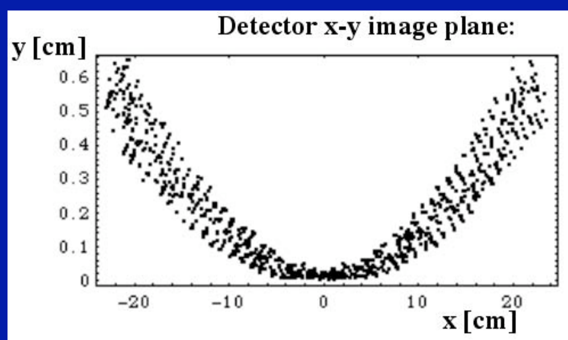
Spherical mirror (FDIRC prototype):



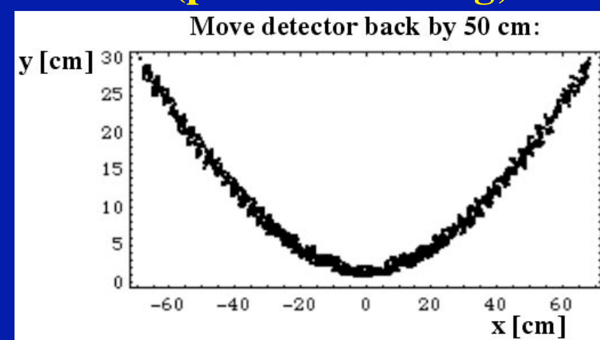
Cylindrical mirror (SuperB FDIRC):



Parabolic mirror:



No mirror (pin hole focusing, flat det. plane):



The aberration is not increasing near the ring wings

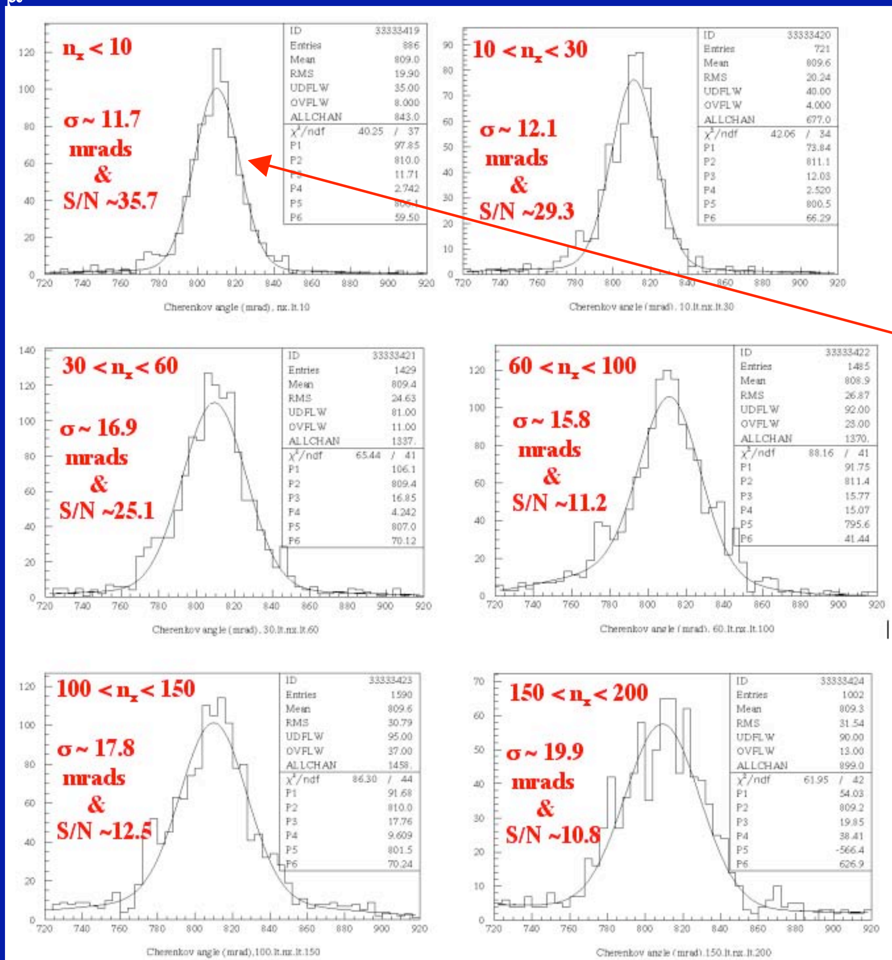
(note: one can see it better if one moves the image further)

- **It is the mirror which is causing a worse resolution near the end of the ring.**
- **The effect is 2x worse for spherical mirror compared to cylindrical mirror.**
- **The pin hole focusing has a kaleidoscopic effect also, but it does not grow towards ring edges ! In this sense, the pin hole focusing is better optics !!**

FDIRC prototype in CRT:
θ_c resolution gets worse near the ring edges

(using cuts on n_x)

E_μ > 1.6 GeV:



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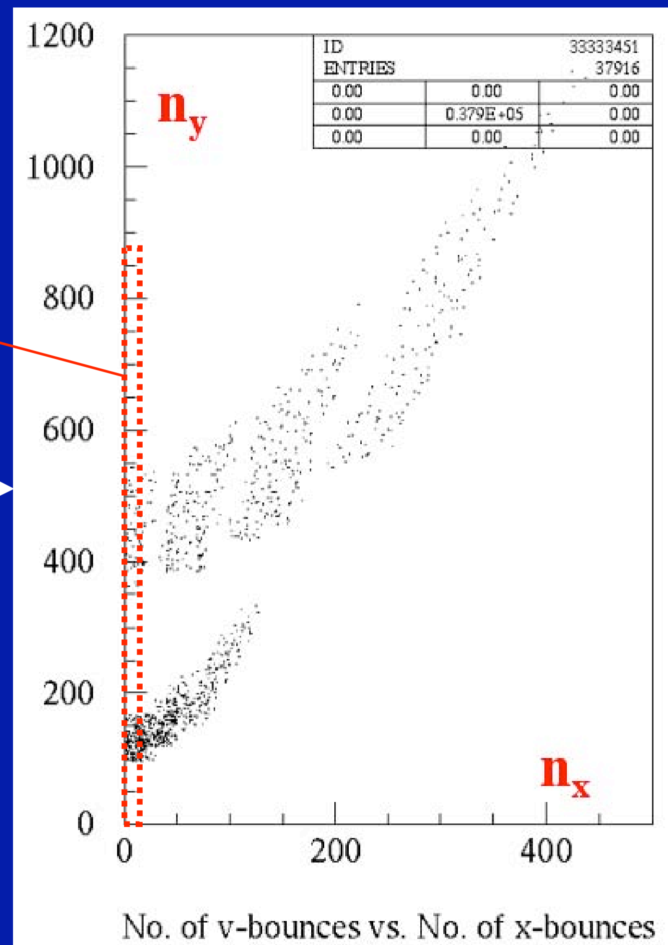


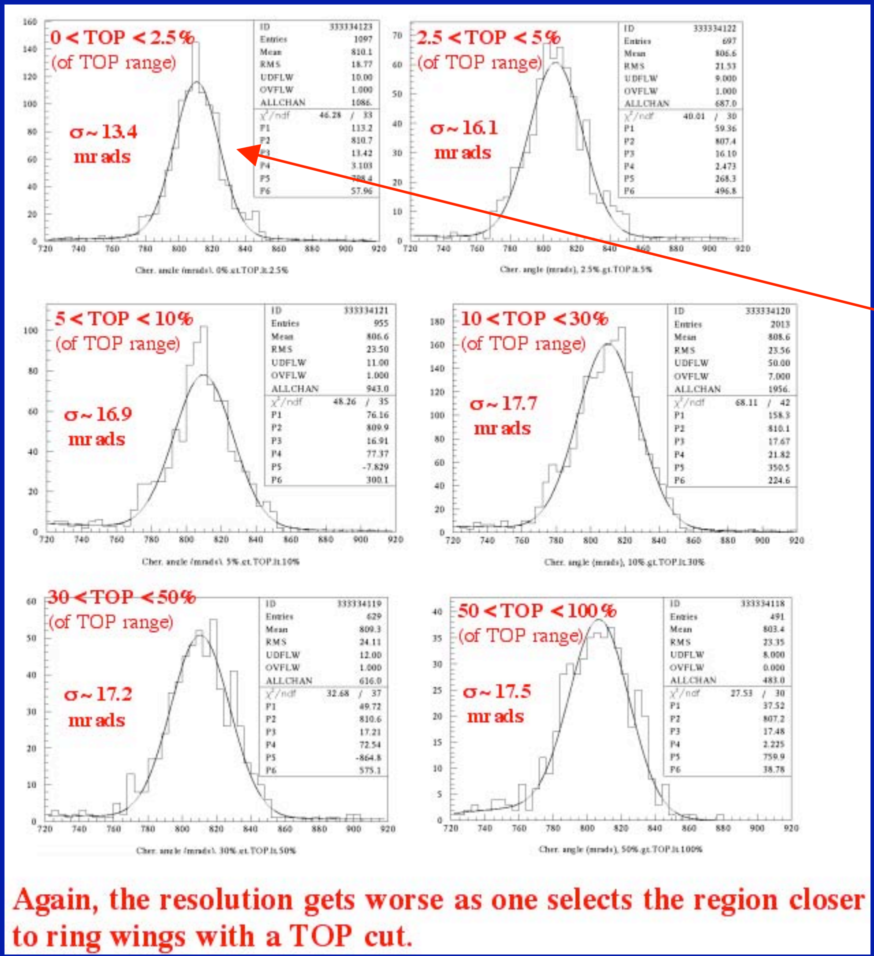
Note: Small n_x means small k_x, which means that photons come from the central ring region

- **This tends to confirm results of the Mathematica simulation.**

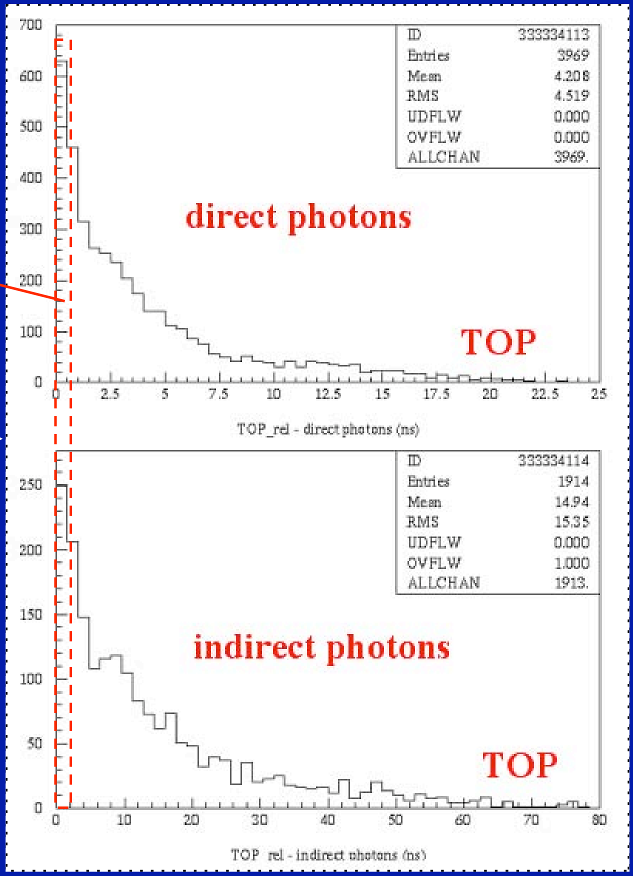
FDIRC prototype in CRT:
The earliest photons carry the best θ_c resolution

(using cuts on TOP)

E_μ > 1.6 GeV:



TOP relative range (offset subtracted)



Note:
Small TOP corresponds to photons coming from the central ring region

- **This tends to confirm results of the Mathematica simulation.**

Conclusion

- **CRT seems to be a useful scientific instrument** allowing to investigate effects which were not understood previously.
- Problem with the tail study is that all variables correlate with each other and therefore it is not easy to separate variables. **So far, the only clear effect is that the Cherenkov angle resolution does not depend on n_y.** One needs special runs such as shifting bar along the z-direction, or rotation around the bar z-axis, etc.
- **Data analysis from the FDIRC prototype in CRT confirms my previous studies with the Mathematica-based ray tracing, which concluded that the ring wings measures the Cherenkov angle less precisely. This is due to so called Kaleidoscopic effect, which is amplified by the mirror. The pin hole focusing does have the Kaleidoscopic effect also, but the resolution does not grow as one approaches the ring wings. The cylindrical mirror has the growth of this effect 2x smaller than the spherical mirror.**
- **As Blair pointed out, these photons should not be cut out, but instead we have to develop sensible PDE weights.**
- Last comment: CRT will not operate for ever without some maintenance funds to keep it operating.