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Focusing DIRC design for Super B

J. Va'vra

SLAC National Accelerator Laboratory, CA, USA

Abstract **– In this paper we present a new design of the Focusing DIRC for the Barrel PID to be used at the proposed Super-B factory. The new imaging optics is made of a solid Fused Silica block with a double folded optics using two mirrors, one cylindrical and one flat, focusing photons on a detector plane conveniently accessible for the detector access. The design assumes that the BaBar bar boxes are re-used without any modification, including the wedges and windows. Each bar box will have its own focusing block, which will contain 40 H-9500 (or H-8500) MaPMTs according to present thinking. There are 12 bar boxes in the entire detector, so the entire SuperB FDIRC system would have 480 MaPMTs. The design is very compact and therefore reduces sensitivity to the background. The chosen MaPMTs are fast enough to be able both to reject the background and to perform the chromatic correction. The 3D optics simulation is coded with the Mathematica program. The work in this paper was a basis of the LDRD proposal made to SLAC in 2009 [1].**

I. INTRODUCTION

DIRC (Detector of Internally Reflected Cherenkov light) [2-4] is a part of the BaBar detector that was crucial to the performance of Babar's science program. The BaBar DIRC [5] uses ~1800 gallons of water as the optical coupling medium in the region between the fused silica bars and ~11,000 photon PMT detectors. Such design probably would have difficulty to cope with the backgrounds anticipated at the SuperB factory, where we expect luminosity of $\sim 10^{36} cm^{-2} sec^{-1}$.

The new design has a much smaller camera whose coupling material is solid fused silica. The reduced volume and different material alone reduce the sensitivity to background by about one order of magnitude. The imaging is provided by a mirror structure focused onto an image plane containing multi-anode photomultiplier tubes (MaPMTs) rather than the pinhole focusing of the BaBar DIRC onto an imaging device made up of individual conventional PMTs. The very fast timing of these new tubes will provide many additional advantages - improving the resolution performance; measuring the chromatic dispersion term in the radiator [6-8]; allowing the separation of ambiguous solutions in the folded optical system; and providing another order of magnitude improvement in background rejection headroom.

Author benefited from the previous experience gained with a design and subsequent operation of the Focusing DIRC prototype. It was designed by ray tracing with the Vellum/Graphite drafting program, which was later on verified with a Mathematica-based ray tracing program [9]. The same steps were followed for a design of the Focusing block presented in this paper and at SuperB meetings [10-11].

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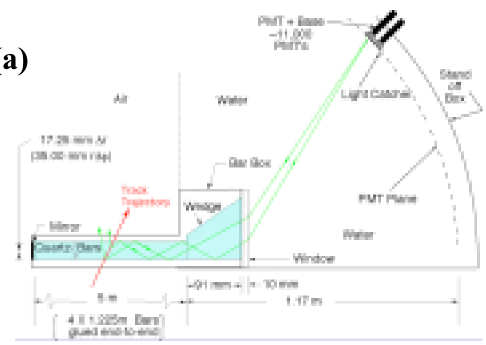
The FDIRC simulation in this paper considers a track entry at certain dip angle, the Cherenkov photon production and propagation along the square Fused silica bar (geometry as in BaBar DIRC), wedge at the end of the bar (geometry as in BaBar), and a solid Fused Silica block with a double folded optics using two mirrors, one cylindrical and one flat, focusing photons on a detector plane conveniently accessible for the detector access. Imaging is done following each photon step by step as it bounces from various surfaces.

The basic principle of the focusing DIRC (or FDIRC) is that it is capable not only of measuring an (x,y) coordinate for each photon with an angular resolution similar to the present BaBar DIRC, but, in addition, measuring each photon's time-of-propagation (TOP) along the Fused Silica bar with ~150-200 ps single-photoelectron timing resolution (the present BaBar DIRC has a timing resolution of only $\sigma \approx 1.6$ns). The basic point is that it should work as a RICH imaging detector even if the timing does not work.

II. PRINCIPLE OF BaBar DIRC

Fig. 1a show a pin hole imaging principle of Ring Imaging with DIRC at BaBar. The wedge, shown in detail on Fig.1b, is used to direct the photon rays into a detector phase space. Fig.1c shows a real implementation in the bar box. This arrangement complicates the new optics, as one has to design it to work with the wedge and the bar box window. Fig.1d shows DIRC bars in the clean room, and Fig.1e bar box, which we plan to re-use.

(a)



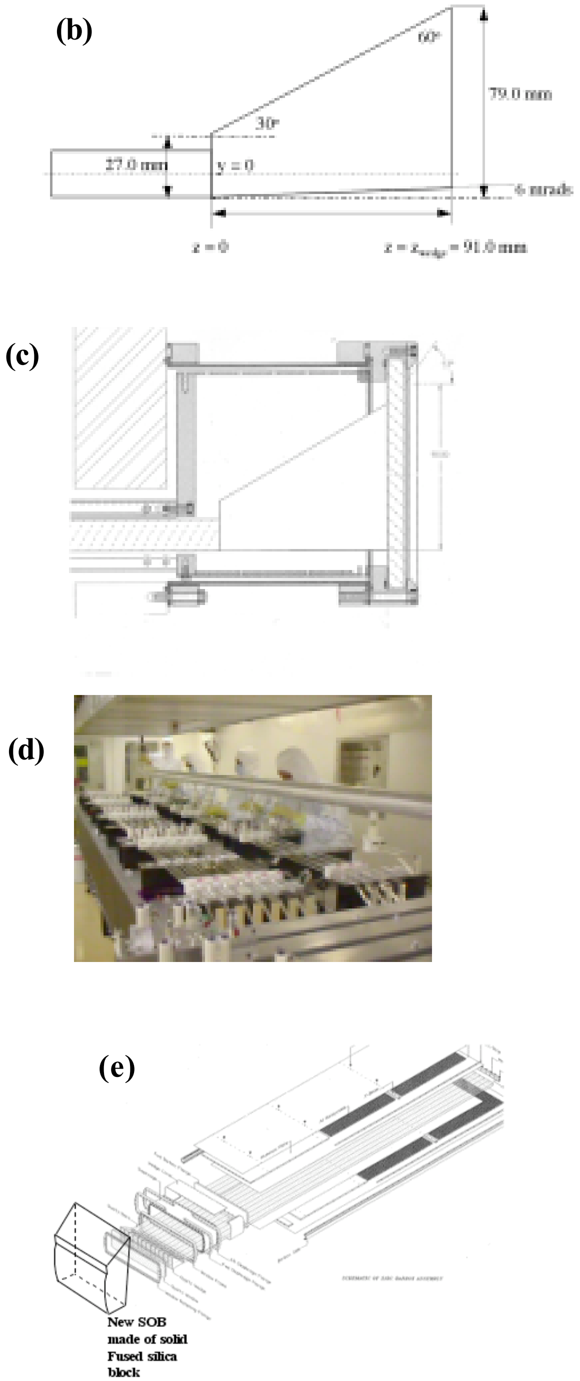


Fig. 1. (a) Principle of BaBar DIRC, (wedge at the end of each bar direct light into a photon detector, (b) wedge dimensions, (c) Real BaBar bar box end with the wedge as it protrudes from a magnet, (d) DIRC bars in clean room, and (e) BaBar bar box, which we plan to re-use without any changes; the picture shows a new Focusing block added to it. The bar box end puts a definitive constraint on possible optical solutions for the Super B optics.

III. NEW FOCUSING BLOCK DESIGN

A. Focusing block

Fig. 2 shows the present design of the Focusing block for the FDIRC at SuperB. We plan to build it out of Fused silica, ideally out of one piece. It surface has to be polished only to ~30 Angstroem rms, as photons bounce in it only a few times. This will reduce the cost. It has double-folded optics with two mirrors, one cylindrical and one flat. The Focusing block has to be coated on the mirror surfaces, except in the region where the focusing block matches with bar box. We propose to couple the bar box window and the Focusing block with a two-component RTV (see examples in Ref.12).

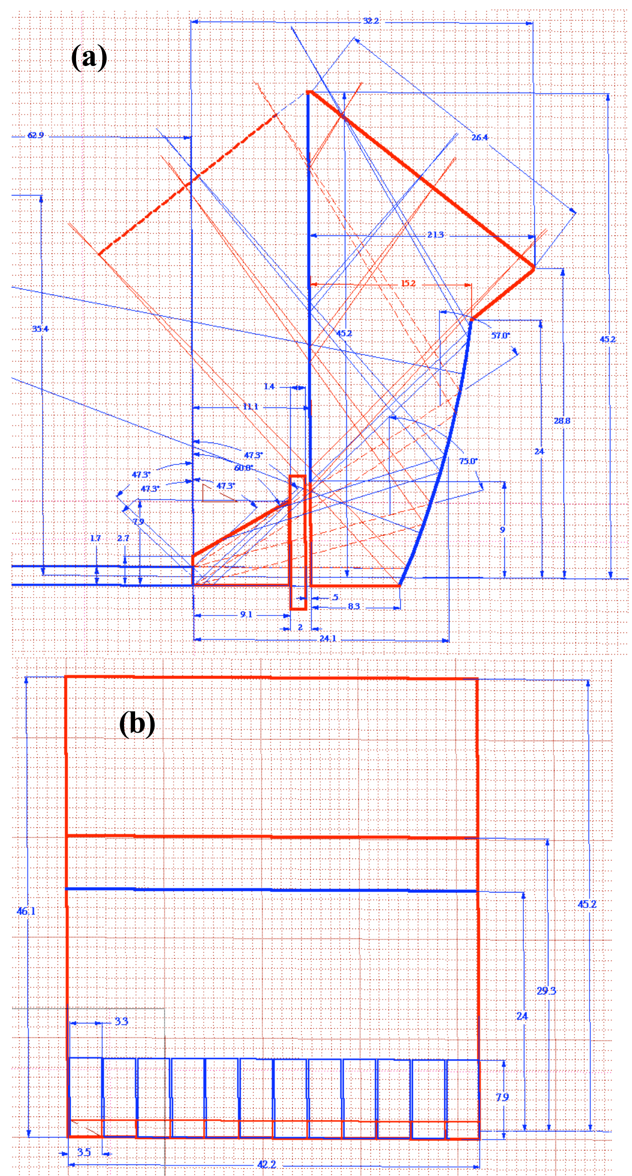
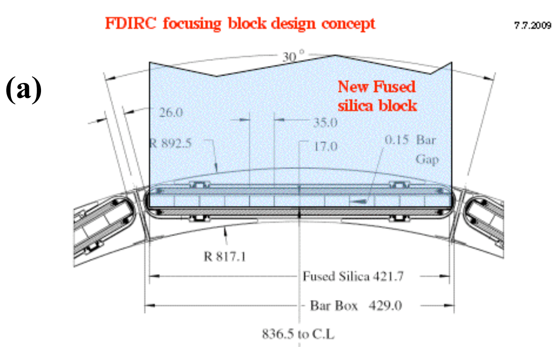


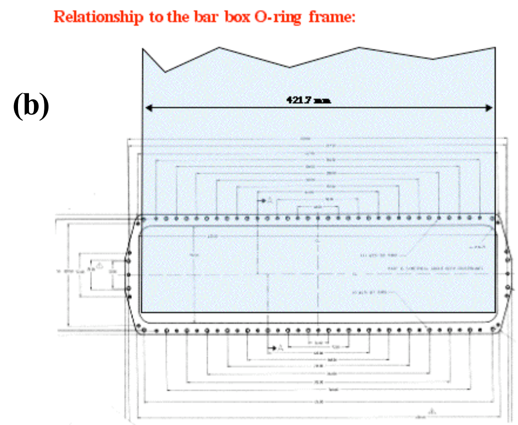
Fig. 2. (a) A side view of the FDIRC focusing block with a cylindrical and flat mirrors, and focal plane. The cylindrical mirror radius is 90 cm, with a center at (z_{center} = 62.9 cm, y_{center} = 35.4 cm).. (b) A front view of the of the FDIRC focusing block and 12 wedges and bars. This design corresponds to a file: FDIRC_SOB_design_3a.vc6.

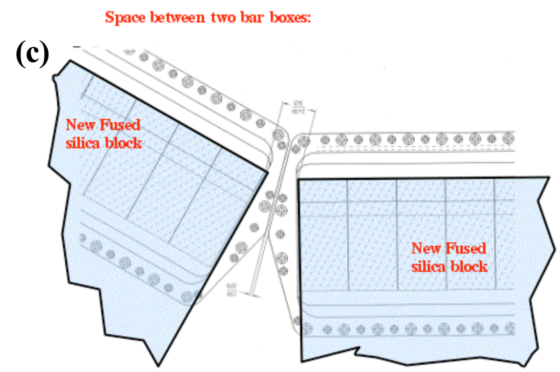
The radius of the cylindrical mirror is 90 cm. Its center is located at z_{center} = 62.9 cm and y_{center} = 35.4 cm, with the center of the coordinate system at the end of the bar (z = 0) and center of the bar (y = 0), z-axis pointing along the bar, and y-axis pointing up. The role of the cylindrical mirror is to remove the Cherenkov angle resolution contribution from the bar thickness. To do that one has to establish a focal plane using parallel lines coming directly from the bar end without touching the wedge sides. Each pair is corresponding to different possible Cherenkov angle. That procedure was used to generate Fig.2a. However, one finds that photons bouncing off the wedge inclined sides are slightly out of focus. This problem did not exist in the Focusing DIRC prototype [9], and it is entirely caused by the wedge. Nevertheless, we think this is not a big handicap in the design (see discussion later about the pixel resolution). The radius of the mirror, as well as other Focusing block dimensions were chosen to provide a sufficient photon path length (typically 60 cm), to give a good pixel contribution to the Cherenkov angle resolution. Fig.2b shows the Focusing block from front view. If the Focusing block is built out of Fused silica, its weight will be ~50 kg.

Figs.3a-d show the Focusing block design relative to the existing bar box. The pictures do not show the mechanical support design, which will have to be very delicate as one cannot exercise a large force on the bar boxes. The Focusing block also has to be in a light-tight aluminum enclosure with a relatively easy access to the detectors and the electronics.

Since a photon would bounce in the Focusing block only a few times, it is not required to have the same polish surface as in case of BaBar bars where number of bounces can easily be up to ~1500 (the bars have 5-7 Angstroem rms). We would specify the surface polish to ~30 Angstroem rms. The two mirror surfaces are coated with aluminum. The side surfaces are polished as photons will reflect by internal reflection; the detector surface as well. The small surface above the cylindrical mirror and below the detector surface are not polished. The bottom of the Focusing block may be polished, although one may choose not to.







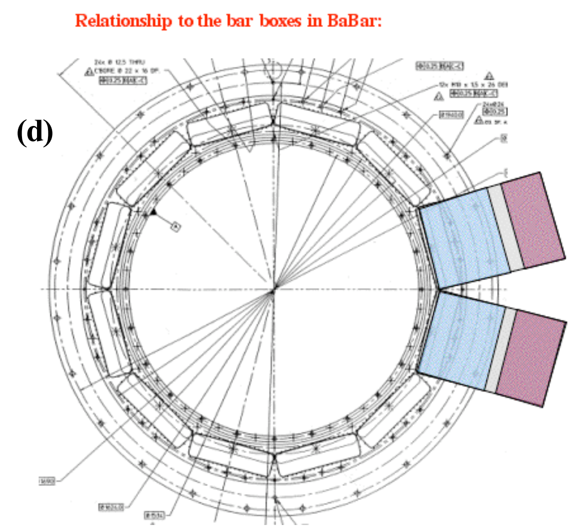


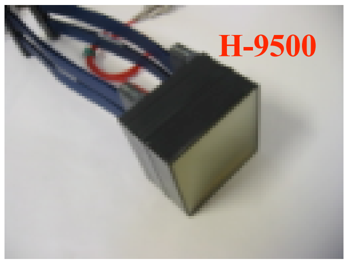
Fig. 3. Focusing block and its coupling to (a) bar box showing individual bars, (b) bar box window, (c) a gap between two bar neighboring bar boxes, and (d) the overall picture showing twelve Focusing blocks per SuperB.detector.

B. Photon detector choice

Fig.4a shows our preferred choice of the photon detector: H-9500 with modified pixel structure shown on Fig.4b. Shorting of the pixels would be made directly on the ASIC board. The proposed pixel size is 3 mm x 12 mm, which would make a 64-pixel device out of nominally a 256-pixel device. We have studied this particular pixel arrangement with our laser setup. The single photoelectron scan is shown on Fig.4c [13,14].

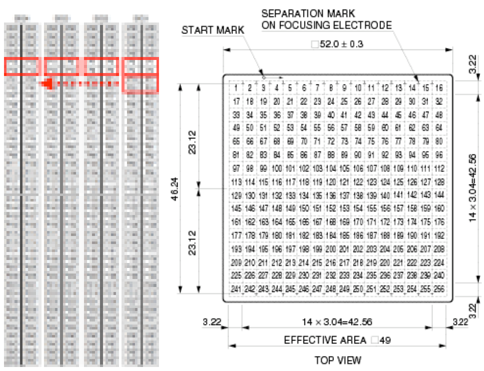
However, Hamamatsu Co. is telling us that to make ~500 H-9500 detectors may take ~3 years, given the present production rate capability. Furthermore, they do not know if this tube would be available with a SBA photocathode (super Bialcali photocathode). Therefore, we do have to consider a back up choice using the H-8500 MaPMTs (see Fig.4d). One could use them either as 64-pixel devices with 6 mm x 6 mm pixels, or 32-pixel devices with 6 mm x 12 mm pixels. This choice would be made based on the future MC studies.

(a)

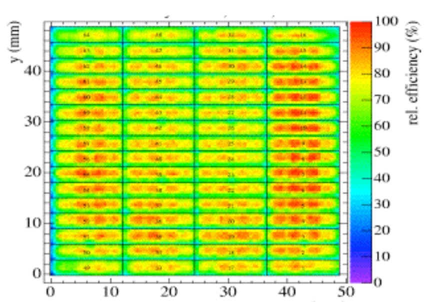


H-9500 connector: Pad matrix on the anode plane:

(b)



(c)



(d)

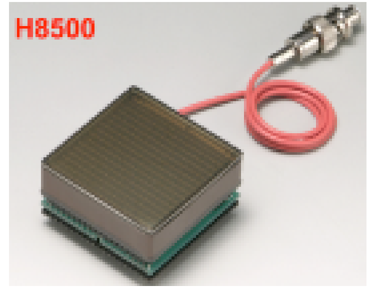
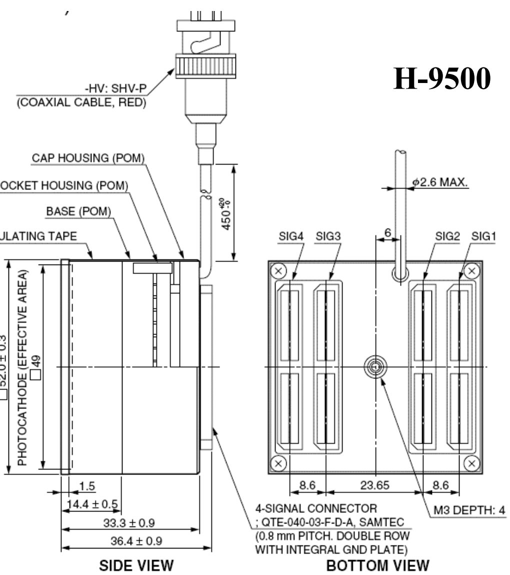


Fig. 4. (a) H-9500 MaPMT is the present detector choice. (b) Four small pads will be shorted together creating a 64-pixel device out of nominally a 256-pixel device.. (c) The single electron laser scan with such an pixel arrangement. Each pixel size is 3 mm x 12 mm, where the smaller side is aligned with a y-coordinate in the bar coordinate system. (d) A 64-pixel H-8500 MaPMT, which may be used as a back up for the photon detector.

C. Detector arrangement on the Focusing Block

Fig.3a shows the dimensions of H-9500 MaPMT. Figures 3b-c show their arrangement on the Focusing block. The idea is to hold them with a carbon composite matrix. The detectors would be coupled to Fused silica with an RTV cookies, each prepared separate on a MaPMT before insertion. To make a bubble-free contact the carbon composite matrix would have a vacuum port to help the detector seating without an air. There are 40 H-9500 MaPMTs per each Focusing block, i.e., 480 in the entire DIRC. In case that H-9500 will not be available, we would choose the H-8500 MaPMT (see Fig.3d for dimensions of its footprint).

(a)



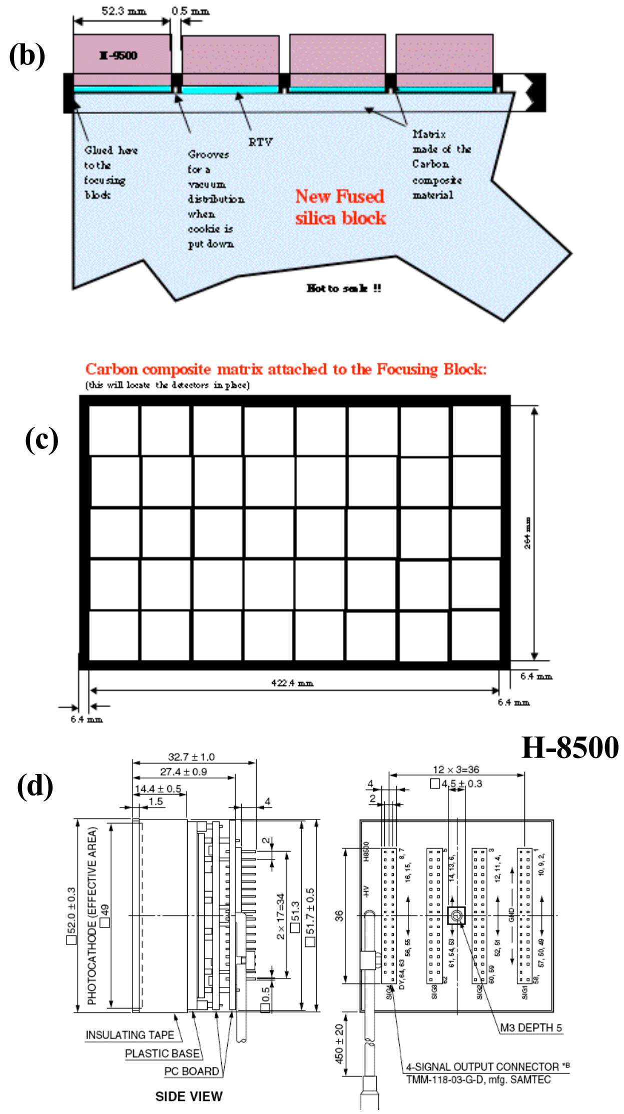


Fig. 5. (a) A footprint of the H-9500 MaPMT. (b) Present concept of a holder. (c) The detector holding matrix made of carbon composite material holding 40 detectors in one Focusing block. (d) A footprint of the H-8500 MaPMT for comparison. Both tubes would work in the carbon composite matrix.

IV. CHERENKOV RING IMAGES WITH NOMINAL FOCAL PLANE

The Cherenkov ring images are more complicated than what we had in the FDIRC prototype or BaBar DIRC. This is mainly because each Focusing block has square side boundaries, which cause reflections, which breakes the Cherenkov rimg into segments. However, we believe this is acceptable to the analysis. In DIRC analysis each pixel gets its assignment of direction cosines, k_x, k_y, k_z, and a time-of-propagation, TOP, from a MC program, independent of a given optics. For comparison, Ref. 10 has the Focusing block in a wedge shape, where the ring is not as much broken, but only for central bars in the bar box.

D. Cherenkov ring images for various θ_{dip} angles

Fig. 6 shows the ring image for track dip angle of 90°. One clearly sees that various parts of the Cherenkov ring have different resolution, depending on the photon path. Going through the images from top down: (a) very top piece of the ring: photon bounces off the bottom wedge surface, cylindrical mirror, the Focusing block sides before it goes to focal plane without touching the flat mirror; (b) next portion of the ring: photon bounces off the bottom wedge surface, cylindrical mirror, before it goes to focal plane without touching the flat mirror; (c) Next piece of the ring: photon bounces off the top wedge surface, cylindrical mirror, the flat mirror, before it goes to focal plane without touching the flat mirror; (d) The bottom ring: photon bounces off the bottom wedge surface, misses the cylindrical mirror, before it goes to focal plane without touching the flat mirror – this portion of the ring is not in a focus.

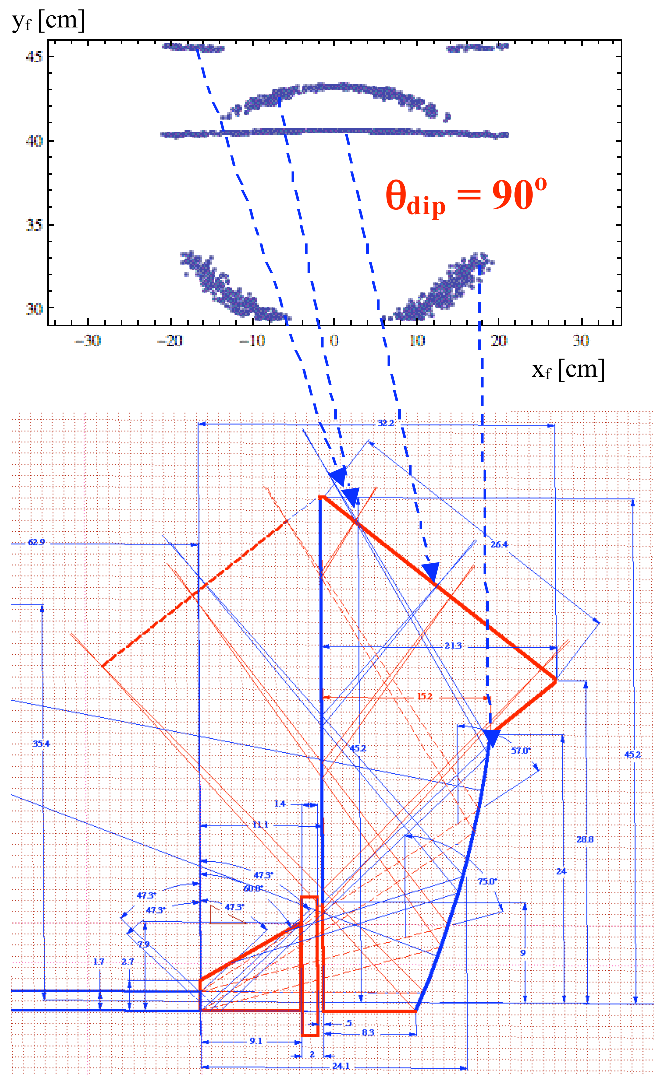


Fig. 6. Cherenkov ring image at $\theta_{dip} = 90^o$. It is more complicated than what one have observed either in the FDIRC prototype or BaBar DIRC. The bottom part correspond to photon, which miss the cylindrical mirror are therefore not focused. Very top part correspond to photons bounced off to inclined wedge surface and are slightly out of focus. Middle section of the ring corresponds to photons coming directly from the bar without touching the wedge; they are in perfect focus.

Fig. 7 shows how the ring images quickly changes as one changes the dip angle. The images get more simple in the range of dip angles between 50-75°. We show the most complicated images.

The radius of the mirror, as well as other Focusing block dimensions were chosen to provide a sufficient photon path length (it varies, but it is typically ~60 cm, when all photon path segments are summed up), to give a good pixel contribution to the Cherenkov angle resolution even for pixel sizes of 6 mm in y-direction. For a 90° dip angle and well focused portion of the ring in the Fig.6, a typical pixel contribution to the Cherenkov angle resolution is ~1.4 mrad for 3 mm pixels, and ~2.8 mrad for 6 mm sizes. The least focused portion of the ring on the Fig.6, gives pixel resolutions of ~2 mrad and 4 mrad respectively. This is still better pixel resolution than that if Babar DIRC.

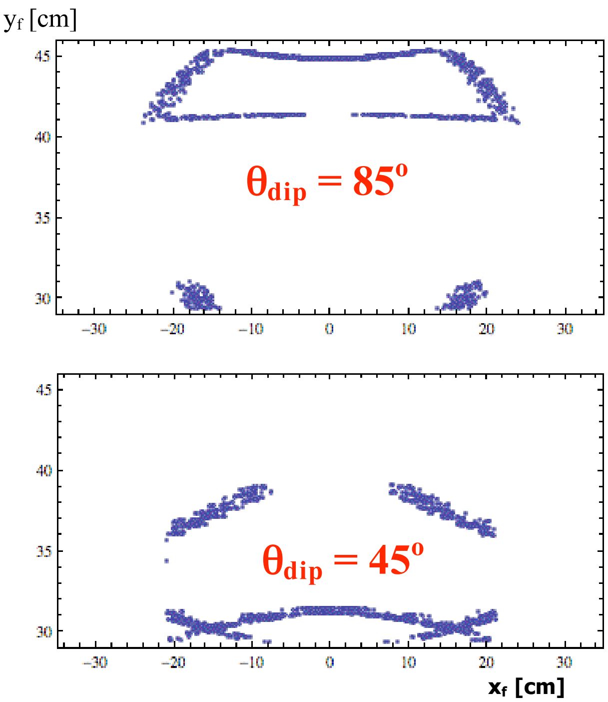


Fig. 7. Cherenkov ring images in the focal plane for two track dip angles for FDIRC with spherical mirror and no wedge. The Cherenkov image changes as a function of dip angle as a result of complicated optics of the Focusing block and the wedge.

VI. TUNING OF VARIABLES

A. Move the focal plane up by 1.2 cm (over-focused)

Fig. 8 shows the image of the Cherenkov ring at θ_{dip} = 90° for a photon plane moved up by ~1.2 cm. The motivation here is to make the Focusing block with a focal plane location, which a compromise between the focal plane formed out of "non-wedge-reflected " photons and a focal plane formed out of the "wedge-reflected " photons. The pixel resolution would be about the same. We believe that this design would work fine.

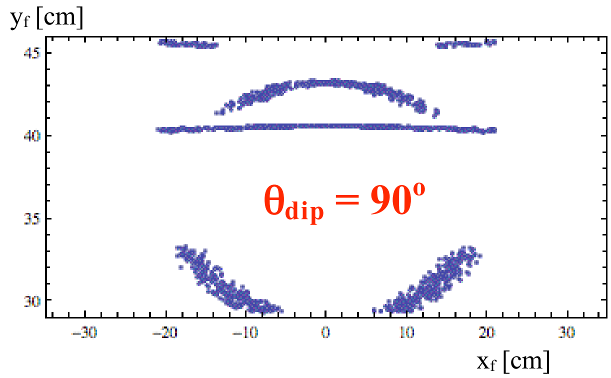


Fig. 8. The same view as on Fig. 6, but move the focal plane up by 1.2 cm to make average between a focus required by the wedge-bounced photons and non-wedge-bounced photons. This design corresponds to a file: FDIRC_SOB_design_4a.vc6.

B. Move the focal plane down by 3 cm (under-focused)

Fig. 9 shows the image of the Cherenkov ring at θ_{dip} = 90° for a photon plane moved down by ~3 cm. The motivation here is to make the Focusing block more compact. Although both images are slightly worse, the pixel contribution to the Cherenkov ring resolution is still less than 2 mrads at worst, and typically <1.5 mrads. We believe that this design would work fine. We conclude that the pixel resolution is not going to be affected substantially by moving the focal plane in the range of a few cm.

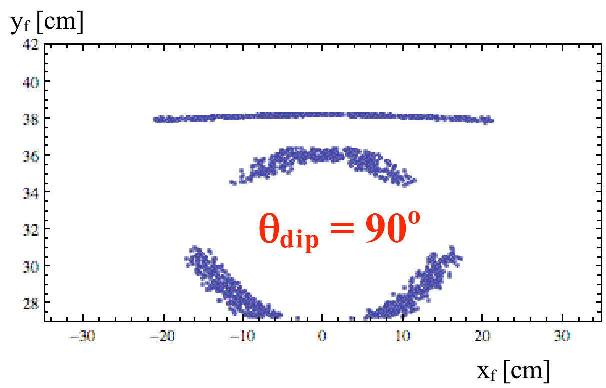


Fig. 9. The same view as on Fig. 6, but move the focal plane down by 3 cm to make an under-focused design. This design corresponds to a file: FDIRC_SOB_design_4a.vc6.

VII. CONCLUSION

Clearly, tuning of the Focusing block parameters has not finished by writing this note, and more work has to be done, especially when we transfer the FDIRC ray-tracing design into a future MC simulation.

ACKNOWLEDGEMENT

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