Progress on development of the new FDIRC PID detector

N. Arnaud [c], A.Yu. Barnyakov [a], M.Yu. Barnyakov [a], C. Beigbeder [c], M. Benettoni [j], M. El Berni [c], M. Borsato [c], D. Breton [c], L.Burmistrov [c], G. Collazuol [j,k], B.Dey [g], F. Gargano [e], F. Giordano [e,f], H. Jawahery [i], E.A. Kravchenko [a], S.A. Kononov [a], H.Lebbolo [d], D.W.G.S. Leith [b], F. Loparco [e,f], M.N. Mazziotta [e], J. Maalmi-Di Bello [c], K.Nishimura [h], A.P. Onuchin [a], M. Posocco [j], V. Puill [c], B.Ratcliff [b], D.Roberts [i], G. Simi [j,k], A.Stocchi [c], D. Shtol [a], R. Stroili [j,k], V.Tocut [c], E.Twedt [i], G.S.Varner [h], **J. Va'vra [b,+]**

a Budker Institute of Nuclear Physics, Novosibirsk, Russia

b SLAC, Stanford University, CA 94309, U.S.A.

c LAL (IN2P3/CNRS and Univ. Paris Sud), France

d LPNHE (IN2P3/CNRS, Universités Pierre & Marie Curie et Paris Diderot), France

e Istituto Nazionale di Fisica Nucleare, Sezione di Bari, 70126 Bari, Italy f Dipart. di Fisica ''M. Merlin'' dell'Universita` e del Politecnico di Bari, Bari, Italy

g University of California, Riverside, U.S.A.

h University of Hawaii, Honolulu, HI 96822, U.S.A.

i University of Maryland, U.S.A.

j Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy k Dipartimento di Fisica e Astronomia "G. Galilei," Università di Padova, I-35131 Padova, Italy

[+] Speaker

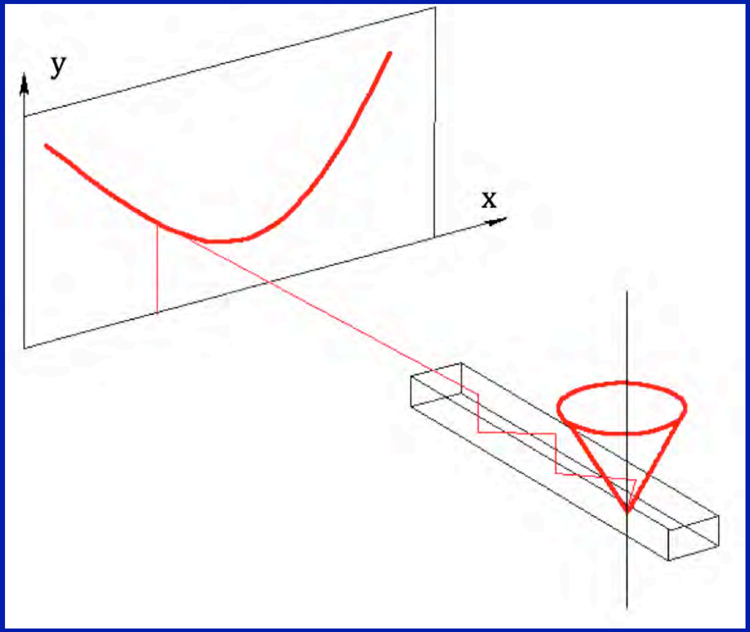
Content

- BaBar DIRC.
- New FDIRC design for SuperB.
- Construction of FDIRC prototype for CRT tests at SLAC.
- Status of R&D results.
- Conclusion

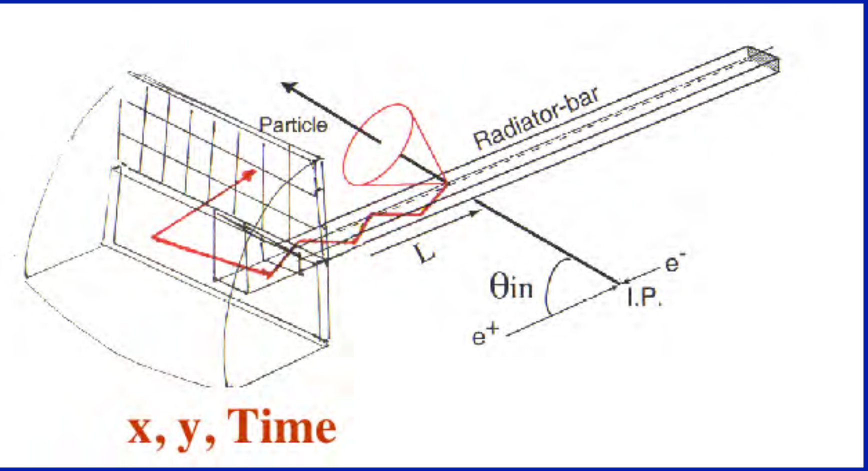
DIRC principle

Detector of Internally Reflected Cherenkov light – concept invented by B. Ratcliff

a) Pin hole camera without focusing:



b) Pin hole camera with focusing:



(What camera is it ? - subject in this talk)

- **Example of non-focusing DIRC is BaBar DIRC; example of focusing DIRC (FDIRC) will be presented in this talk.**
- **The overall aim of FDIRC is to create much smaller and faster photon camera than BaBar DIRC. Constraint: use the same radiator (bar box).**

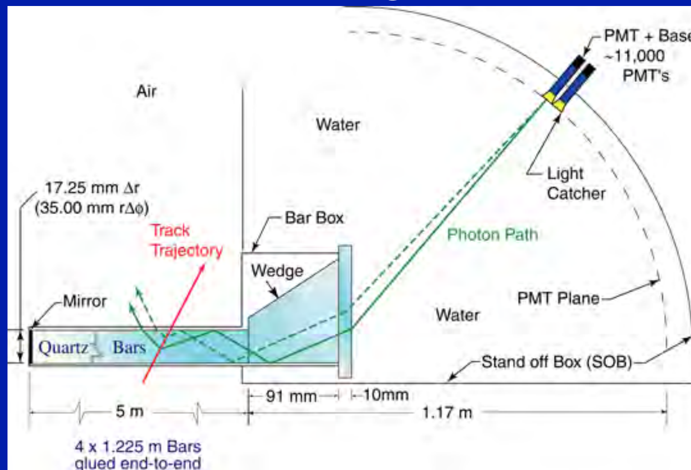
BaBar DIRC

- Very successful PID detector
- π/K separation up to 3-4 GeV/c
- Many similar efforts are under way

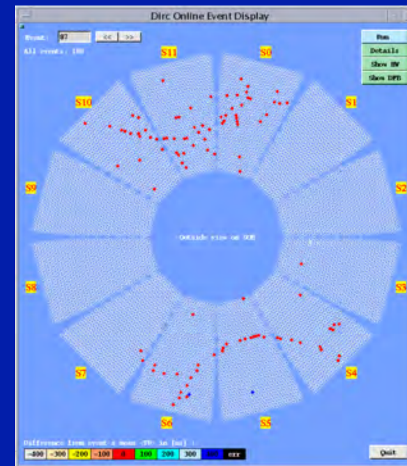
BaBar DIRC

SLAC-PUB-5946 and NIM A583 (2007) 281.

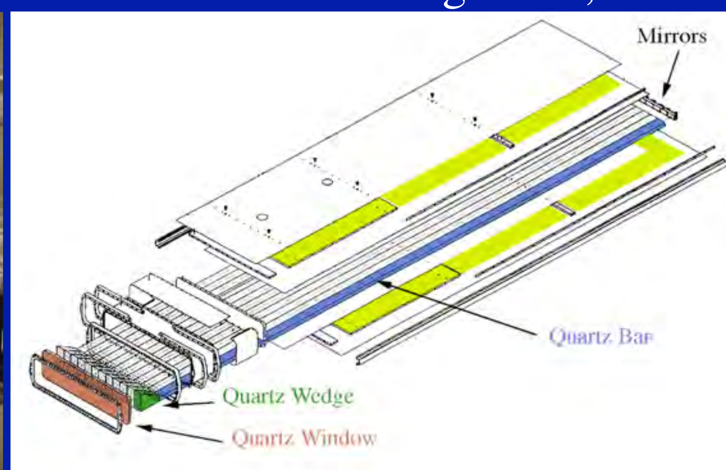
Pin hole focusing:



Photon detector: ~11,000 pmts



Quartz Radiator: 144 bars, each bar made out of 4 segments, total bar length is 5 meters:



Resolution per photon:

- σ_{time} ~1.7ns
- $\sigma_{\Theta c}$ (total) ~9.6 mrad
- $\sigma_{chromatic}$ ~5.4 mrad

Resolution per track:

- $\sigma_{\Theta c}$ ~2.5 mrad ($\mu^+\mu^-$)
- $\sigma_{\Theta c}$ ~3.0 mrad (Bhabhas)

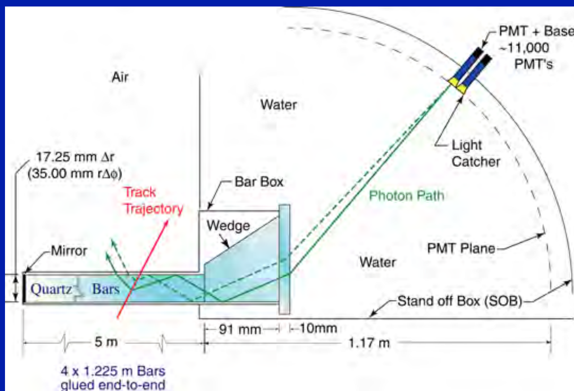
New FDIRC design for SuperB

- New detector needs to cope with **100x higher luminosity** than BaBar
- New FDIRC compared to old BaBar DIRC:

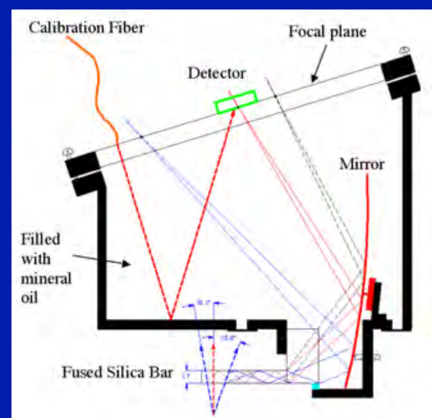
a) **~10x better timing resolution**
b) **~25x smaller volume** (photon camera)
c) **~1.6x more pixels** (in space domain)
d) **~14x more pixels** (if one includes a time domain)
e) **Pixels (x,y) alone determine θ_c angle !!!!**
f) **Use Fused Silica instead of water or oil.**
g) **New optics has to work with the old bar box.**

BaBar DIRC ---> SuperB FDIRC

BaBar DIRC



1-st SLAC FDIRC prototype (oil filled)



3D imaging (x, y & time):

(a) No. of 2D (x,y) pixels: ~11,000

(b) Time window : ± 8ns

(σ_{time}~1.7ns /photon)

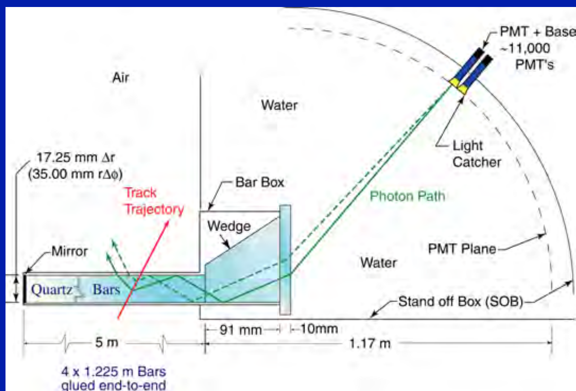
(c) No. of 3D pixels: ~ **77,000**

(no. of time pixels: ~40ns/(1.7*√12)ns ~ 7)

The very first RICH detector demonstrating that the chromatic error can be corrected by timing, it also contributed to understanding of Cherenkov angle tails, etc.

BaBar DIRC ---> SuperB FDIRC

BaBar DIRC



100x higher luminosity →

3D imaging (x, y & time):

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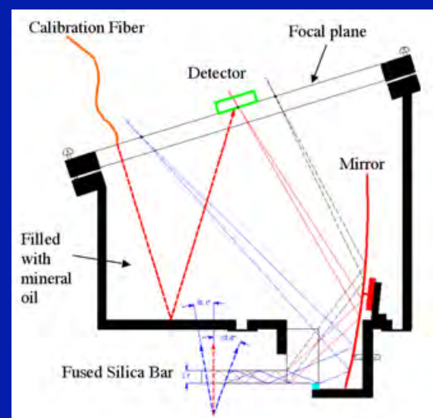


The very first RICH detector demonstrating that the chromatic error can be corrected by timing, it also contributed to understanding of Cherenkov angle tails, etc.

3D imaging (x, y & time):

(a) No. of 2D (x,y)pixels: ~18,432

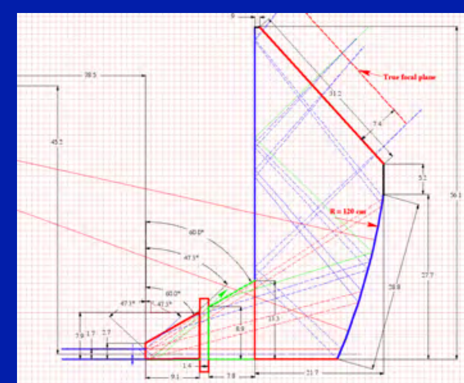
(b) Time window : ± 1-1.5 ns

(σ_{time}=200-250ps /photon)

(c) No. of 3D pixels: ~ **1.06×10^6**

(no. of time pixels: ~40ns/(0.2*√12)ns ~ 58)

FDIRC design for SuperB (solid Fused Silica)

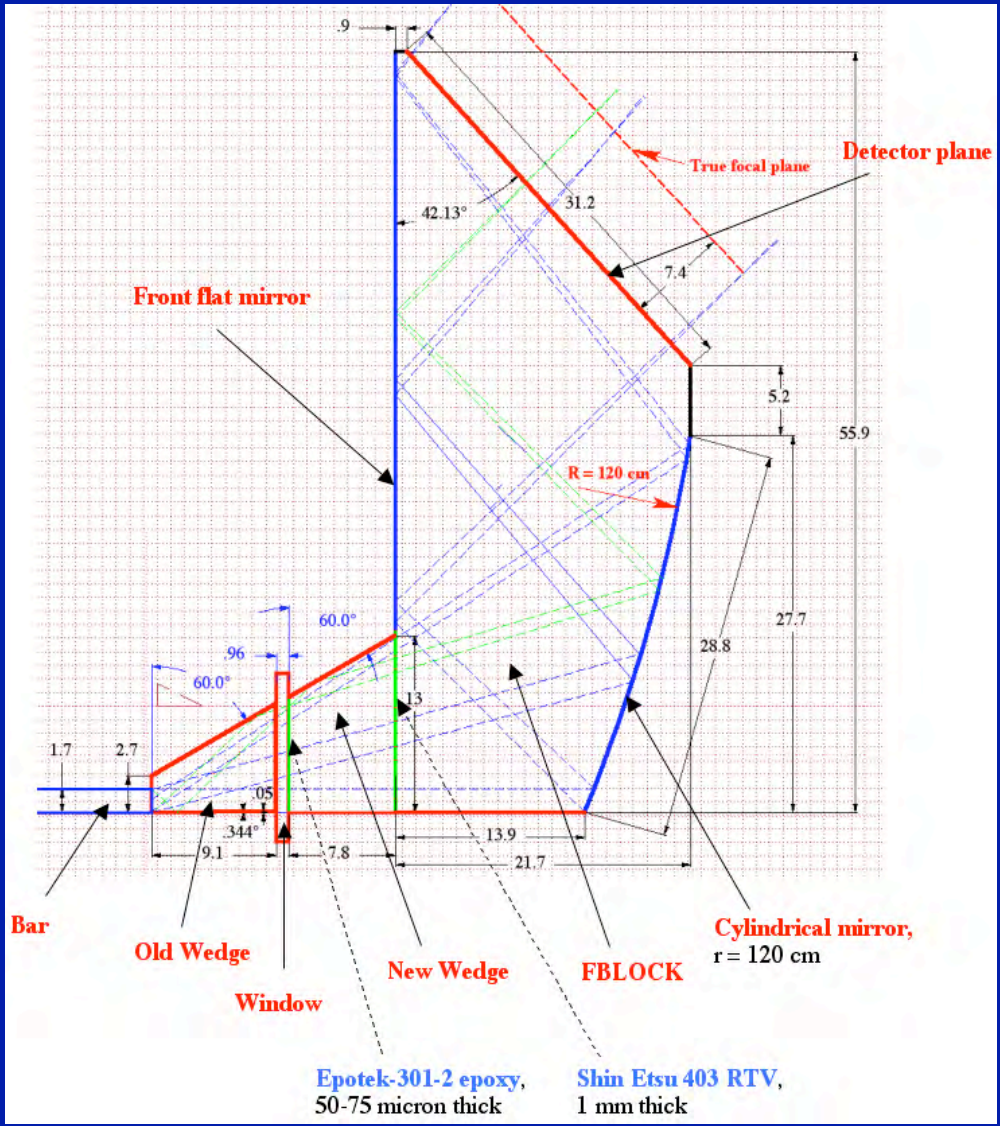


14x more pixels than BaBar DIRC

FDIRC photon camera design

Main points :

- Cherenkov angle is determined by x-y pixels alone
  (A high resolution timing is not needed !!!)
- Time is used to (a) cut the background, (b) to do chromatic corrections and (c) to be part of PID max. likelihood.
- Added a new Wedge
  (Old bar box wedge not long enough)
- Cylindrical mirror
  (To remove bar thickness; done in y-direction only)
- Double-folded mirror optics
  (To provide easy access to detectors)



Photon camera design references:

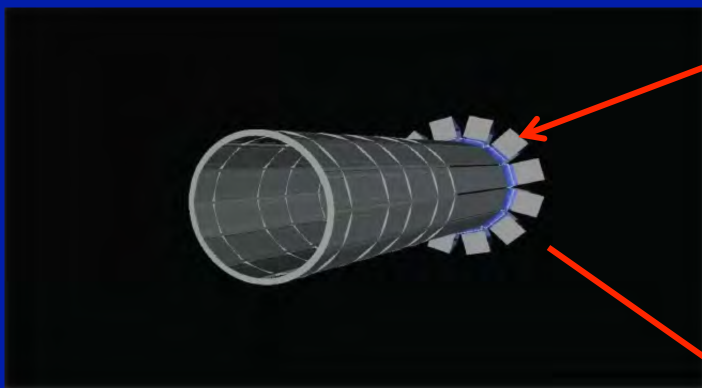
- Initial design by ray-tracing
  [SLAC-PUB-13464, SLAC-PUB-13763]
- Experience from the 1rst FDIRC prototype
  [SLAC-PUB-12236, NIMA595(2008)104]
- Geant 4 model
  [SLAC-PUB-14282]

There are other "DIRC-like" optical designs:

- For example the TOP counter in Belle-II.
- It requires TTS timing resolution: $\sigma \sim 40$ps.

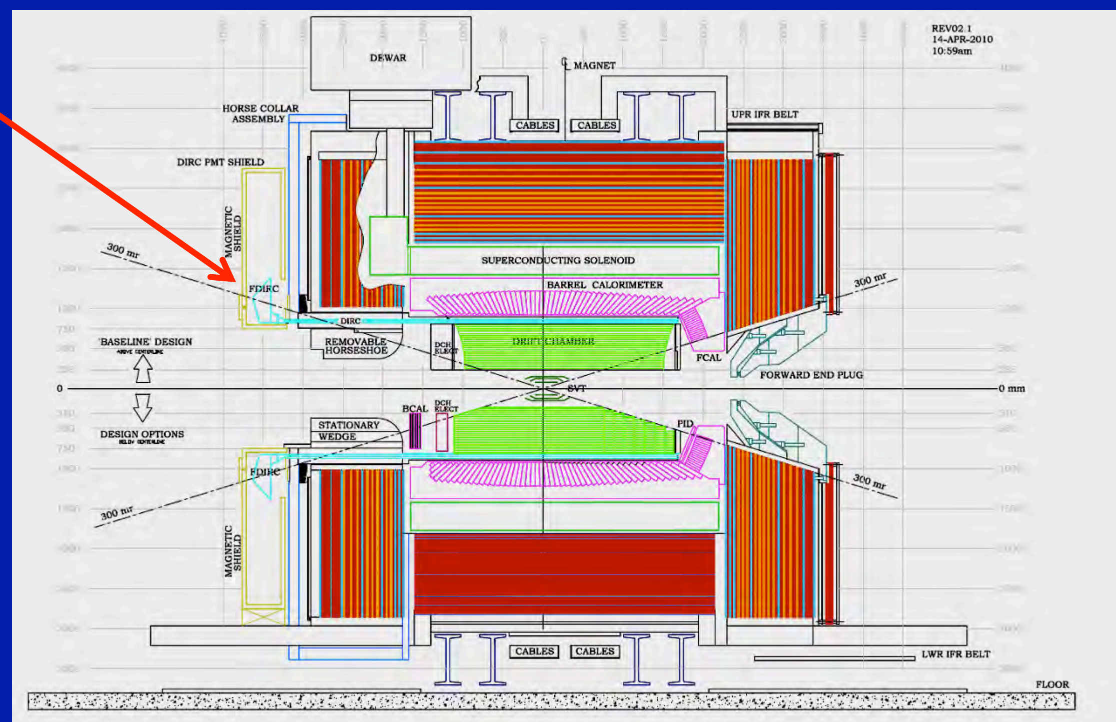
FDIRC photon camera is compact and can be shielded

FDIRC PID detector:



Photon camera

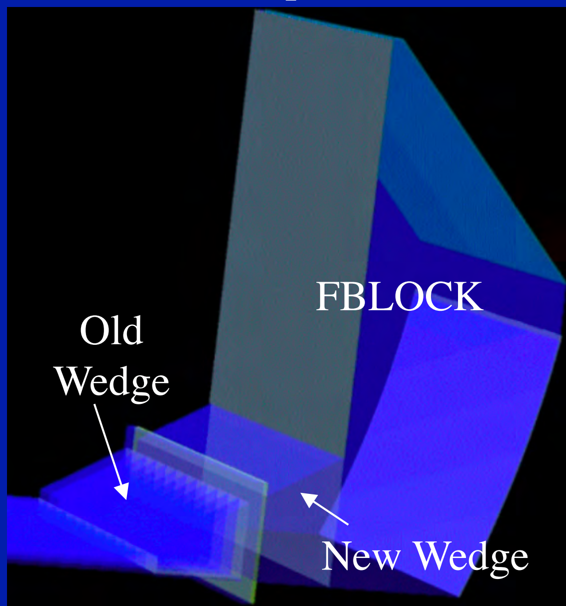
SuperB detector



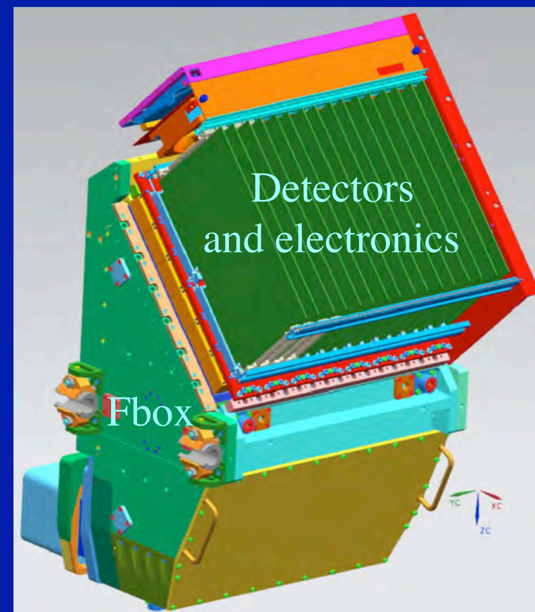
New FDIRC photon camera volume is ~ 25 x smaller than BaBar DIRC camera.

FDIRC photon camera

Photon camera optics:



Photon camera mechanics and electronics:



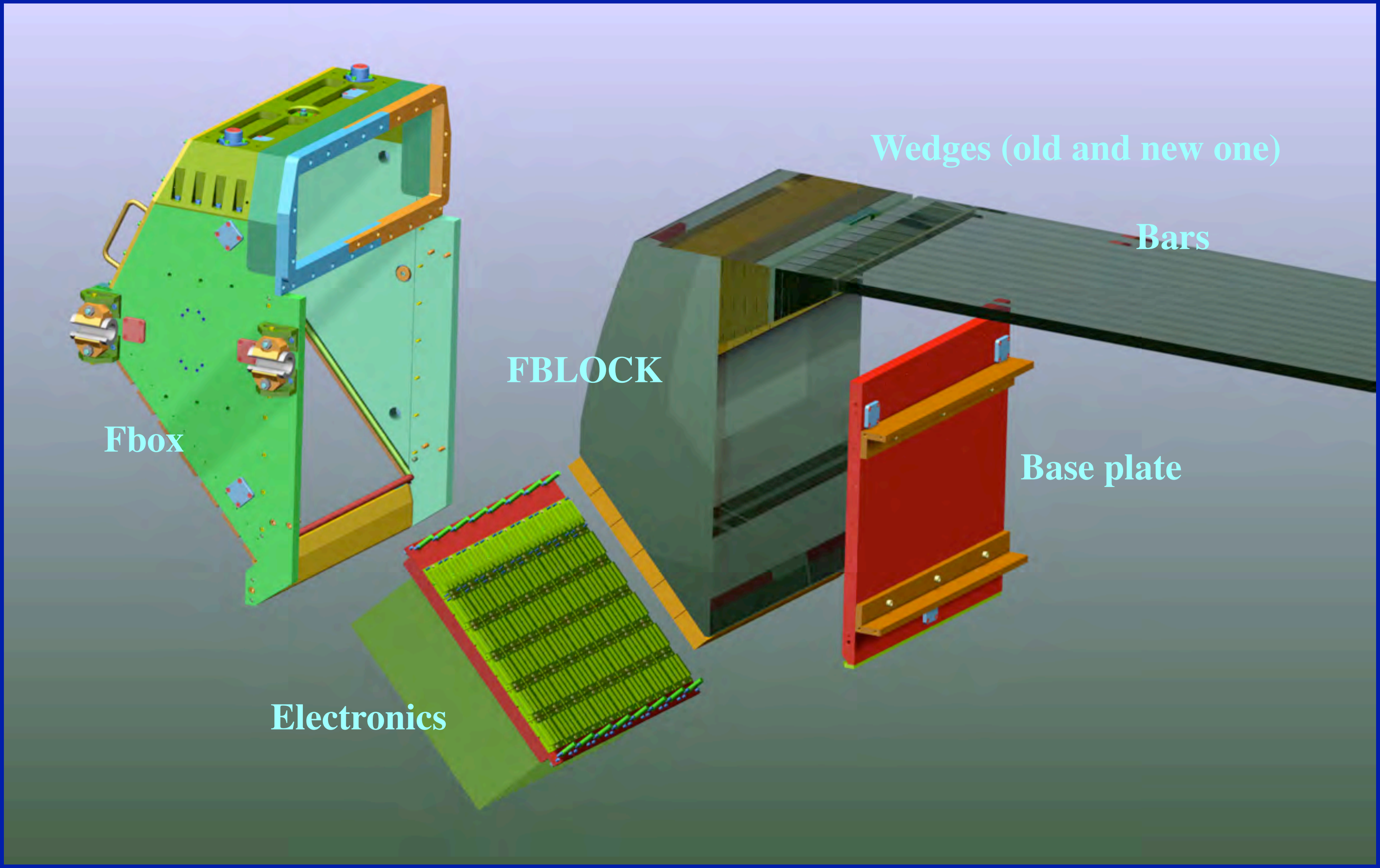
Photon detectors: highly pixilated H-8500 MaPMTs

- Total number of photon cameras: 12
- Total number of detectors per camera: 48
- Total number of detectors in the entire system: 576
- Total number of pixels in the entire system: $576 \times 32 = 18{,}432$

Construction of FDIRC prototype

- We have demonstrated that a fully solid state fused silica camera is "**buildable and affordable**".

How it goes together ?

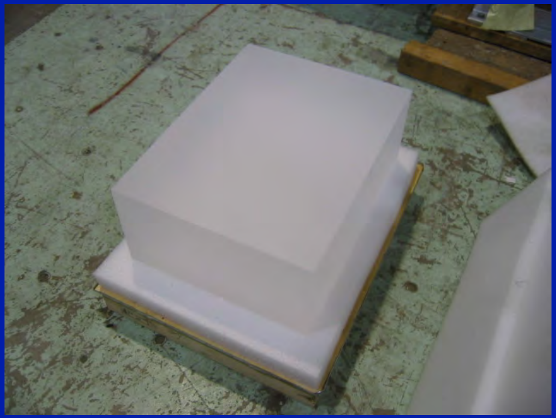


Production of FBLOCK optics was not trivial

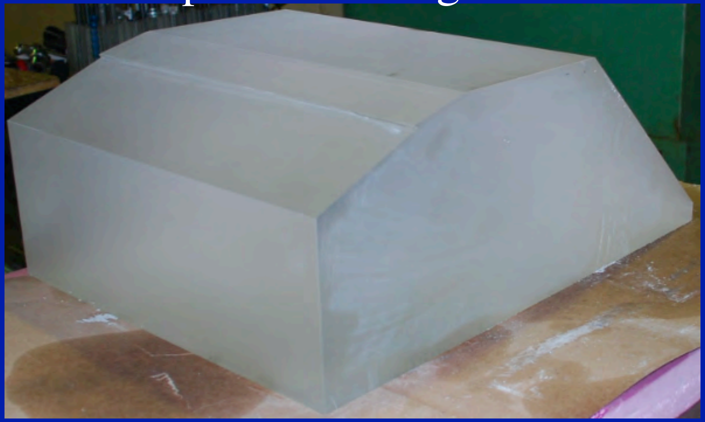
Start from 60” dia. boule:

(Only an example to show a shape)

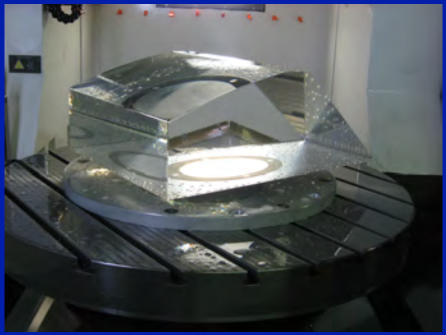
Cut a block out of it:



Shape after a rough saw cut:



Machining more precise shape on NC machine:



Polishing side:

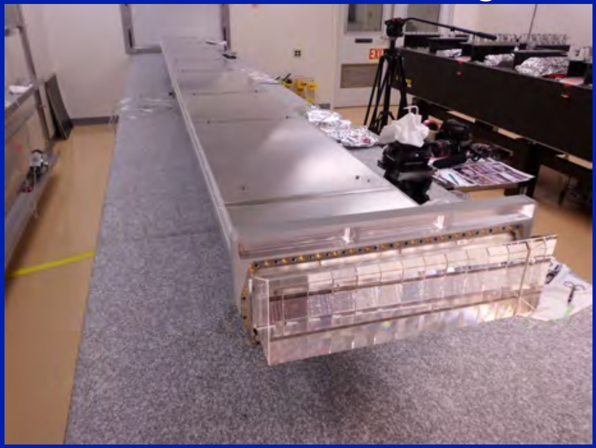
Finished FBLOCK:

- **We demonstrated that this kind of camera is buildable for acceptable cost and within a reasonable time schedule.**

Building a new FDIRC photon camera

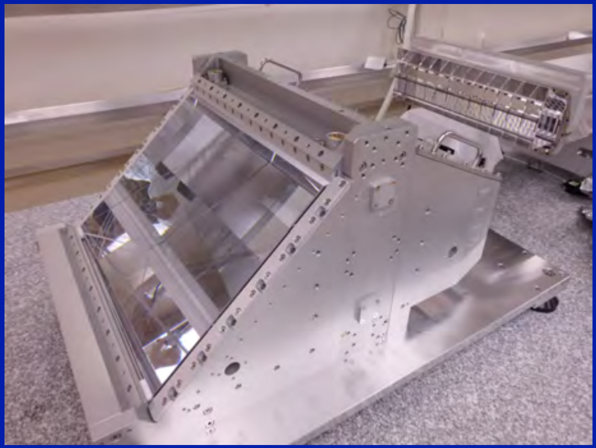
New Wedge glued to bar box:

Bar box with the new Wedge:



Measuring FBLOCK:

FBLOCK placed into Fbox:



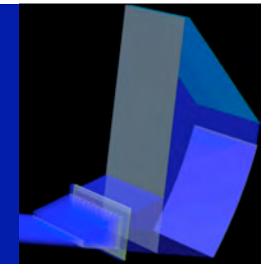
- **Optical coupling between bar box window and new Wedge is 50-75 μm-thick Epotek 301-2 epoxy.**

Photon camera being assembled in CRT

- **Optical coupling between FBLOCK and new Wedge is 1 mm-thick RTV. This is to be able to decouple them if we find it necessary.**

FDIRC test in CRT

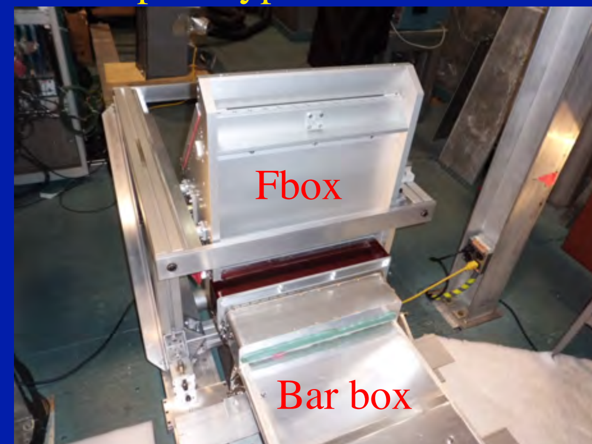
(Test will start running in July-August)



SLAC Cosmic Ray Telescope (CRT):

- ~1.5 mrads track resolution
- > 1.6 GeV muon energy
- 3D tracking
- 46" thick iron absorber, ~ 55" x 90" size

FDIRC prototype located in CRT:

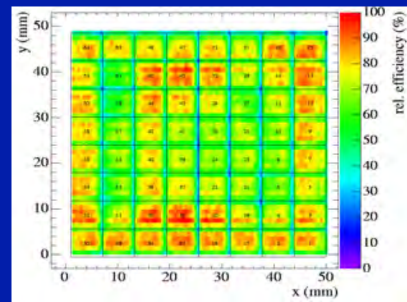


- **Fabrication of the Full scale FDIRC prototype optics and mechanics successfully finished !!!**
- **The electronics will be installed in June.**

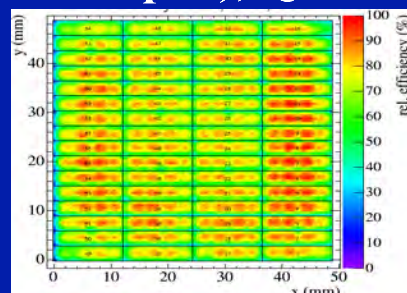
FDIRC photon detectors

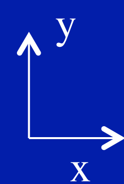
See more on detector studies in a poster by F. Gargano

1) **H-8500** (6 x 6mm pad), QE ~ 24% – **nominal design in TDR**



2) **H-9500** (arrange to 2.8 x 12mm pad), QE ~20-24%.



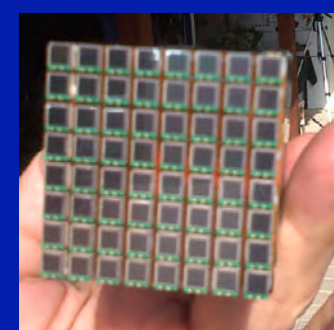


NIM A553(2005)96

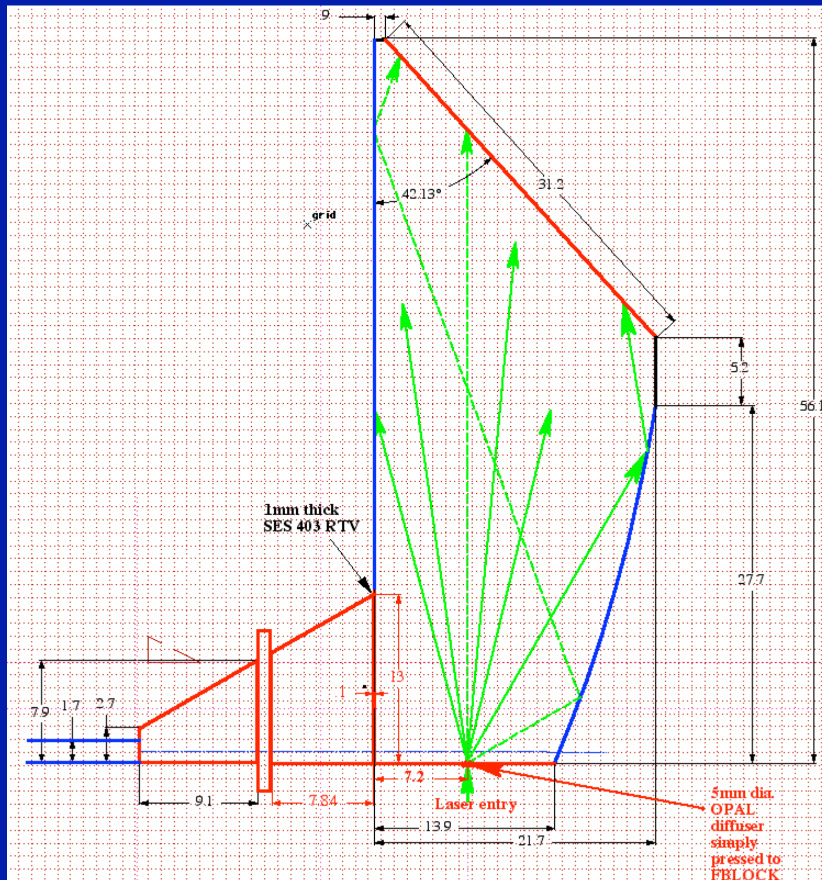
Prefer to have small pixels in y-direction to fully utilize our focusing in y, and would like to have as high QE as possible.

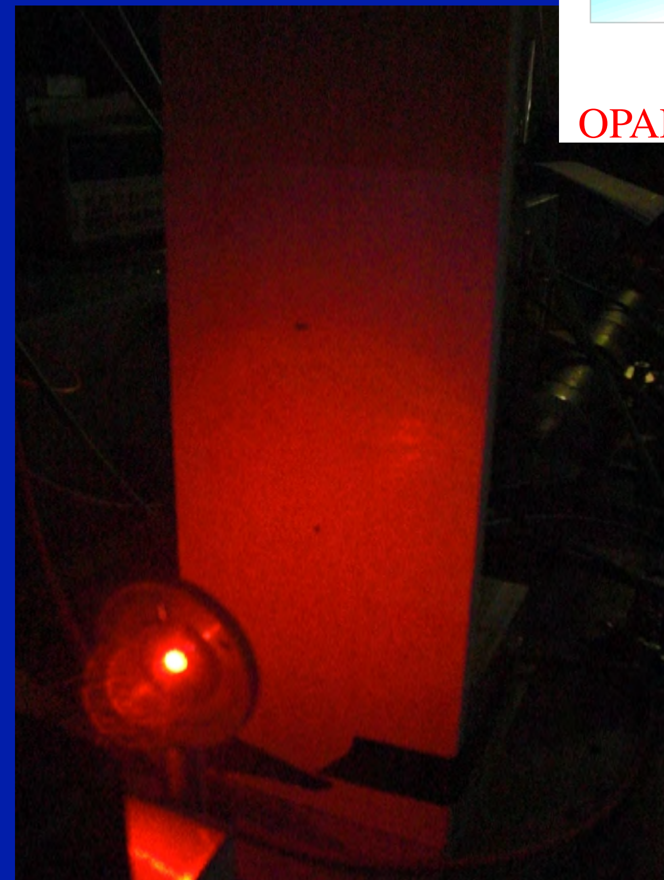
3) **R11256-00-M64** (arrange to 2.8 x 24mm pad), **Super Bialkali QE ~ 36%.**

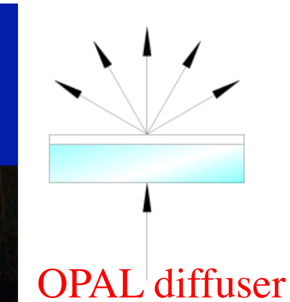
4) **Hamamatsu SiPMT array**
(arrange to 3 x 6mm pads), **PDE ~ 52%.**
Not sure yet about this direction !!



Laser calibration in FDIRC





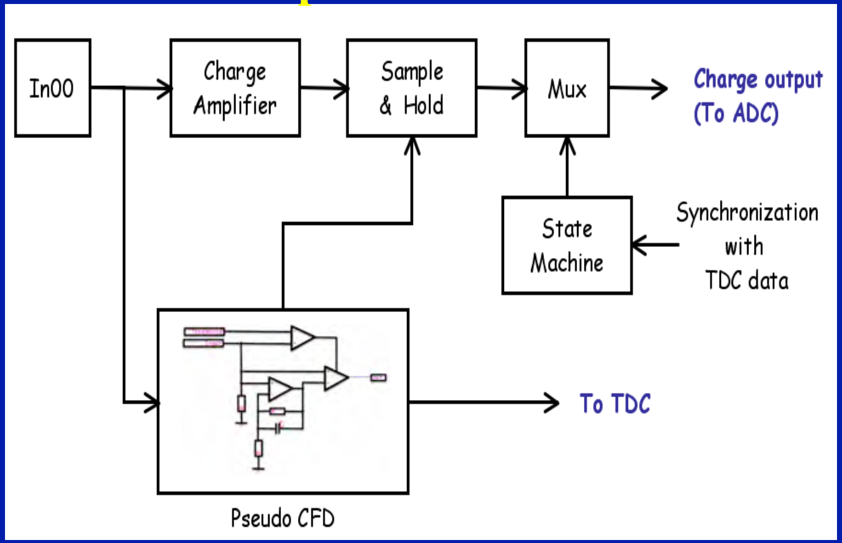


- **Opal diffuser distributes light uniformly across the detector plane.**
- **There are several photon pathways into a given pixel, but based on the MC simulation their time separation should be good enough.**

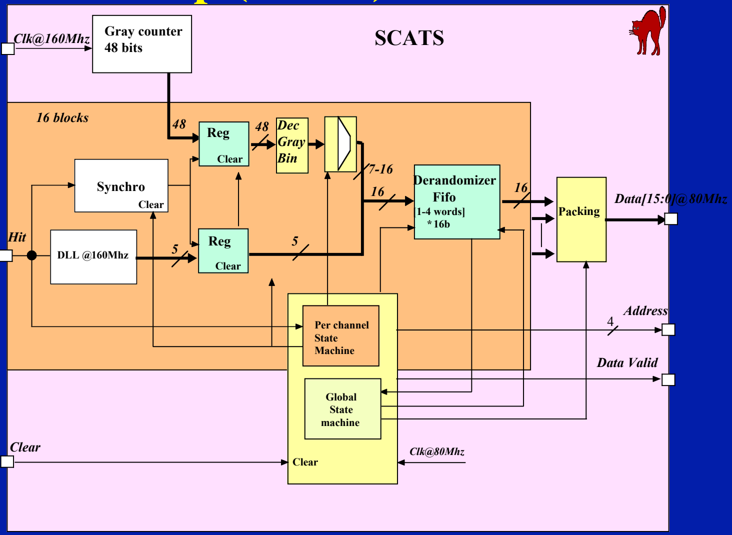
Design of FDIRC electronics for SuperB

See more on electronics in a poster by C. Beigbeder and D. Breton

Front-end chip:



TDC chip (SCAT):



Time measurement:

- CFD on a chip
- σ ~ 100ps resolution / photon
- 1 MHz max background rate / pixel
- 50 ns double pulse resolution min

ADC measurement

- 8-10 bit (?)
- allows PMT monitoring & improves the θ_c resolution by charge sharing.

TDC parameters:

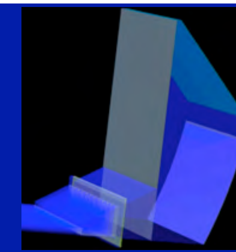
- resolution: 200ps / count, 100ps resolution
- dead time at the input: ~25ns
- maximum rate (all chan. firing): 5 MHz/channel
- maximum rate (1 chan. firing): 20 MHz/channel
- 1% dead time @ 500 kHz input rate on all channels
- 3% dead time @ 1MHz input rate on all channels
- 10 SCAT chips delivered
- Bench tests are starting.

R&D status

- Correction of chromatic error by timing
- Better understanding of Cherenkov angle tails
- Pixel size
- Abberation of Cherenkov rings
- Radiation damage of optical components
- Effect of background rates on FDIRC performance.
- Better understanding of H-8500 timing, gain uniformity, etc.

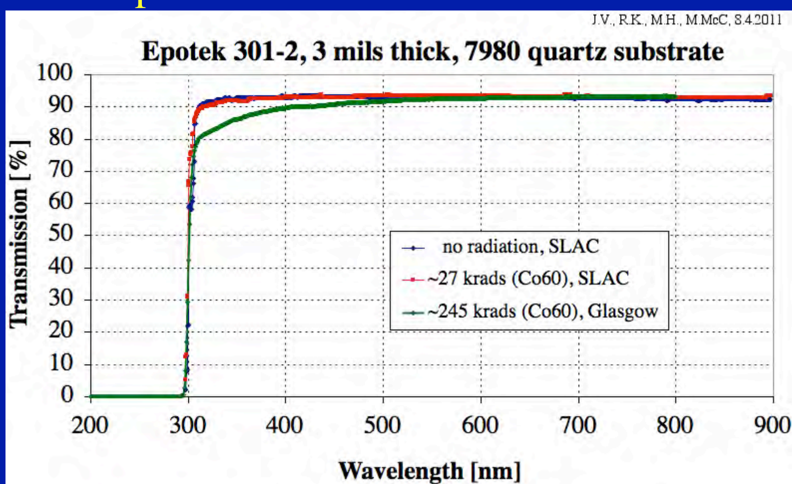
Radiation damage of optical materials

New R&D results

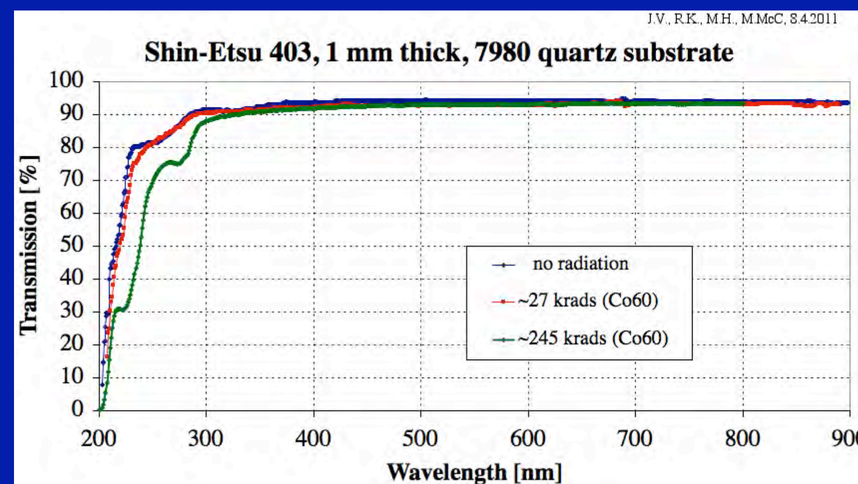


- **Bars are made of Spectrosil 2000 fused silica** (NIMA 515 (2003) 680)**.**
- **FBLOCK and new Wedge are made of Corning 7980 Fused silica.**
- **Both types of fused silica materials are radiation hard.**
- **Radiation hardness of two glues used for FDIRC:**

Epotek 301-2:



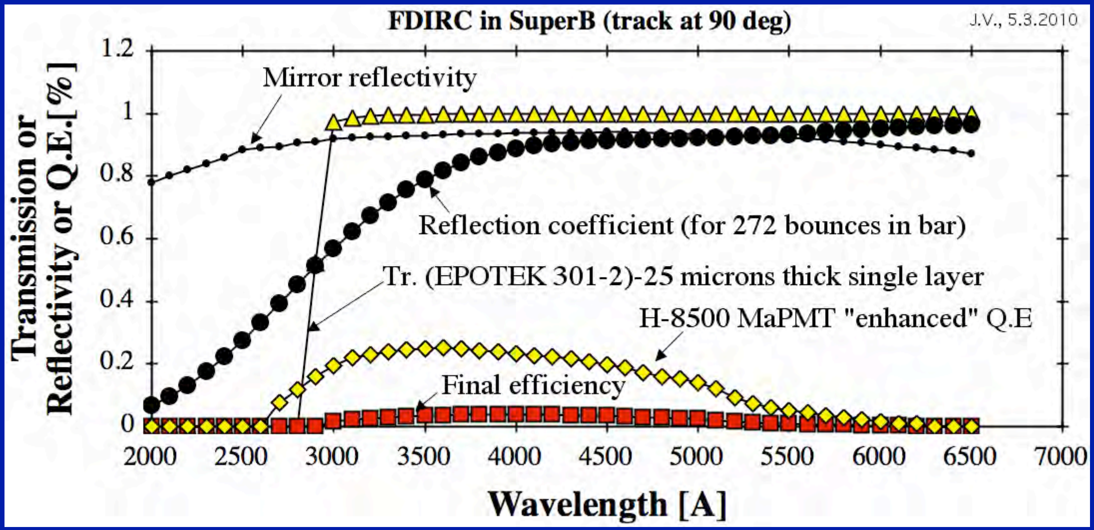
Shin-Etsu 403 RTV:



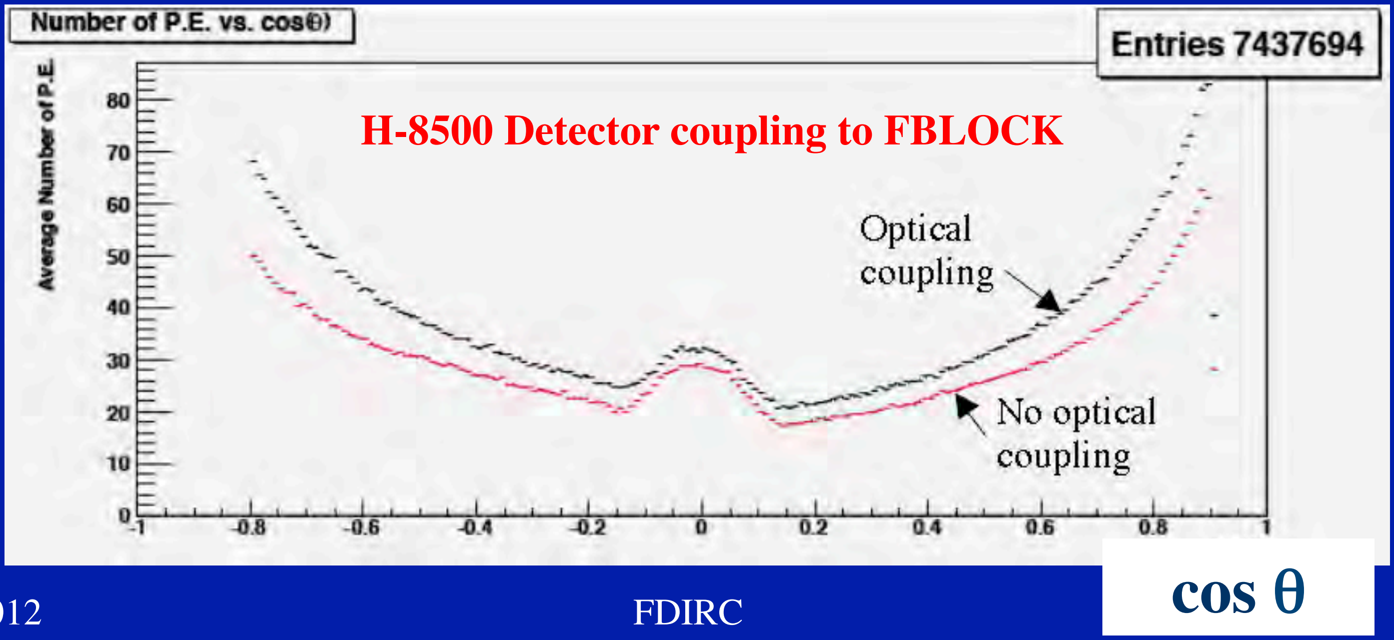
We should be fine at SuperB.

MC: Number of photoelectrons

FDIRC wavelength bandwidth:



At present we do not plan to optically couple detectors to the photon camera



MC:Optical aberration: error contributions to θ_c

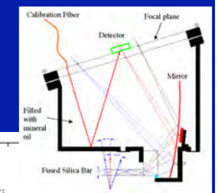
SLAC-PUB-12803 (2007) & NIMA595(2008)104 & NIMA639(2011)282

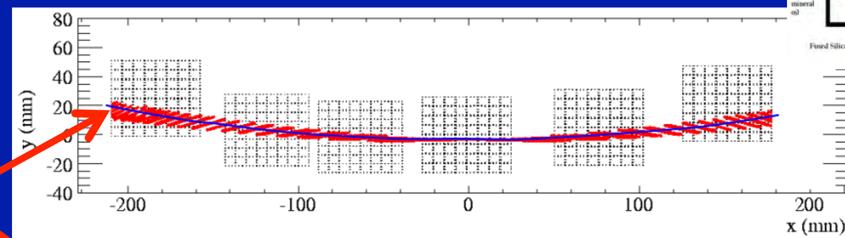
Cherenkov angle resolution per single photon	FDIRC (mrads)
Chromatic error	~5.5 *
Pixel contribution (**6/3 mm^2**)	5.5 / 2.8
Optical aberration	1 – 9
Transport along the bar	2-3
Bar thickness	~ 1
Old Wedge inclined surface	~3.5 **
Final error [mrads]	**10.0 / 8.8**

(If we correct the chromatic error: 8.4 / 7.0 mrads)

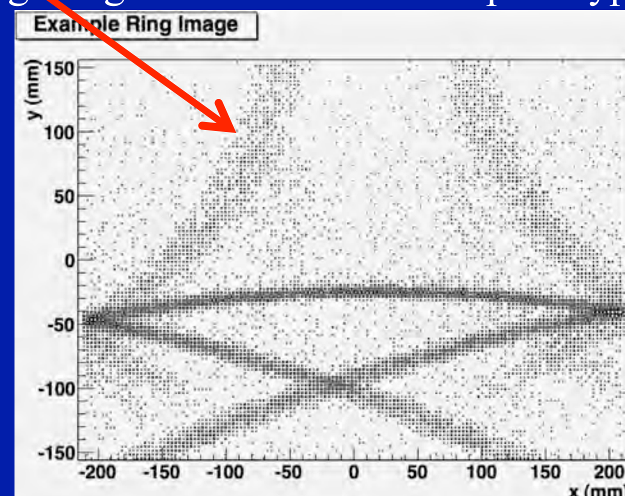
Cherenkov angle resolution per track	FDIRC (mrads)
BaBar DIRC	2.4
FDIRC (with 3mm pixels & QE~36% & chromatic correction)	1.85

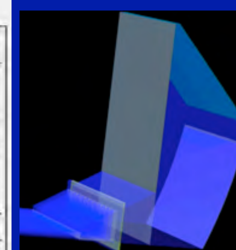
Ring image in the 1-st FDIRC prototype:





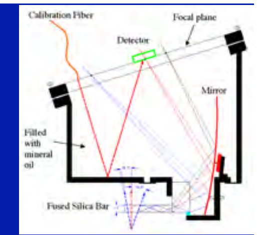
Ring image in the final FDIRC prototype:





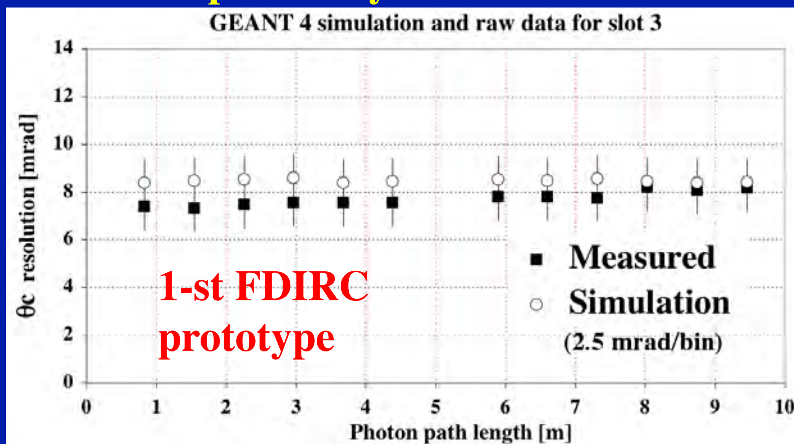
* It is intended to remove the chromatic error by timing.
** This error is caused by a 6 mrads inclined surface on the bottom of the old wedge (a feature of old DIRC).

Why do we consider smaller pixel size ?

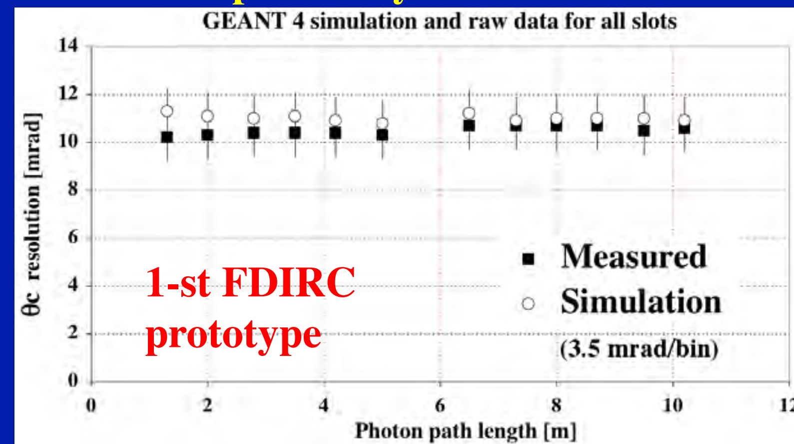


SLAC-PUB-12803:

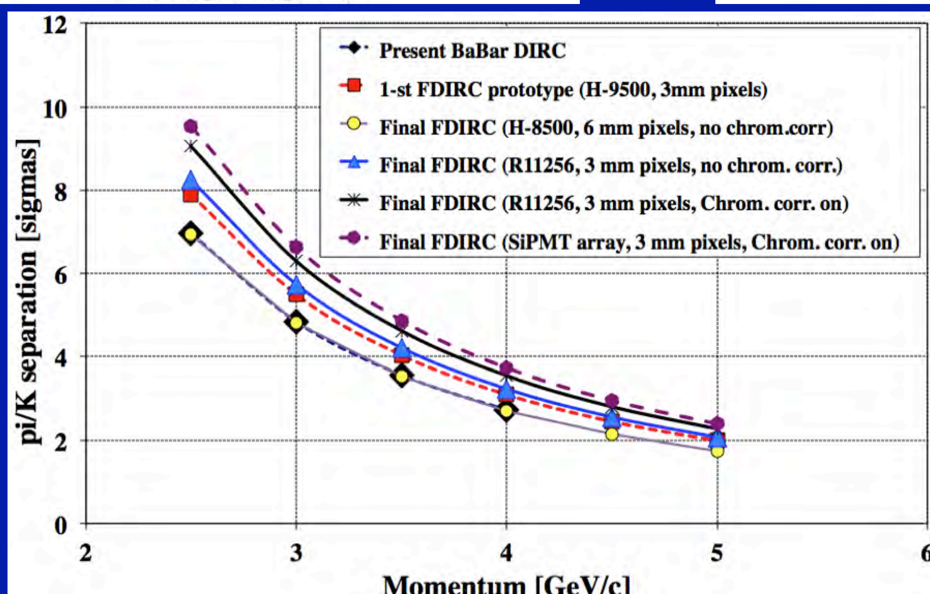
3 mm pixels in y-direction:



6 mm pixels in y-direction:



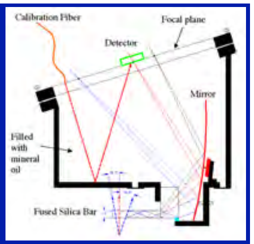
FDIRC π/K PID performance:



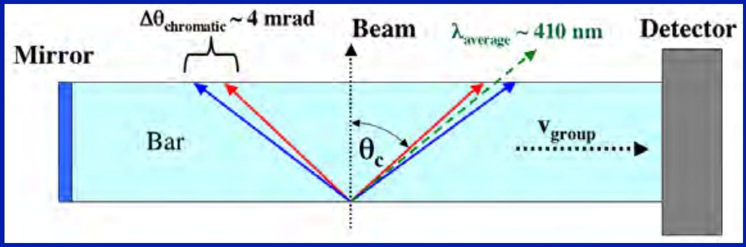
- A choice of R11256 with a super-bialkali QE ~ 36% and 3mm pixel size in the y-direction would lead to a significant improvement.
- SiPMT solution would be even better, but…

1-st FDIRC prototype: chromatic correction

SLAC-PUB-12803, 2007 & NIMA595(2008)104



Tagging color by time in 5m-long DIRC bar:



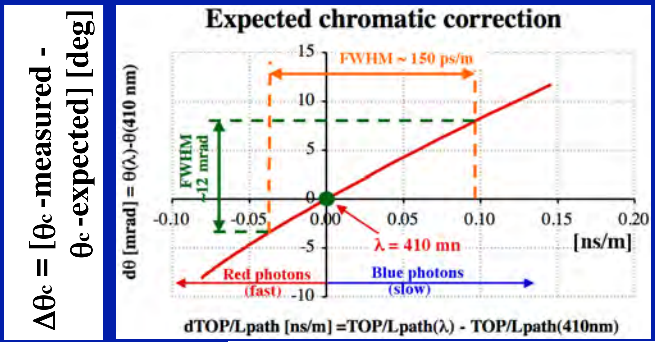
θ_c (red) < θ_c (blue)

v_{group} (red) > v_{group} (blue)

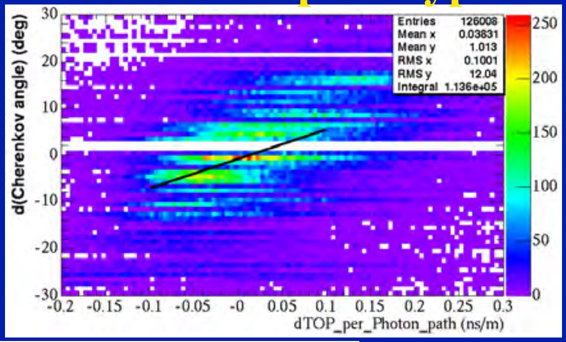
$\Delta\theta_c = f(\Delta TOP)$

TOP / Lpath = $1/v_{group}(\lambda)$

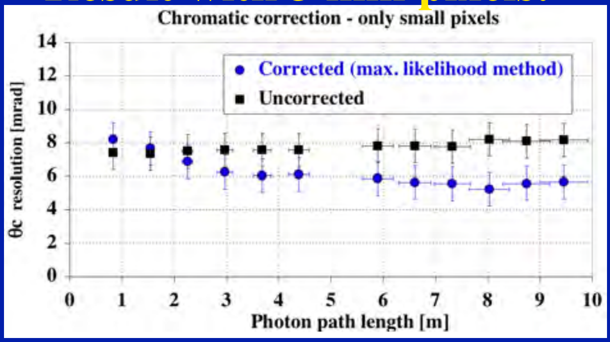
Calculation:



Data from the prototype:



Result with 3 mm pixels:



ΔTOP/Lpath = (TOP$_{measured}$ - TOP$_{expected}$)/Lpath [ns/m]

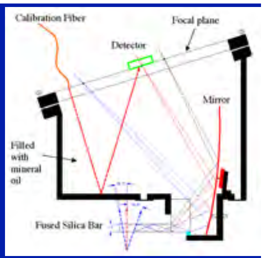
- **Because change in Cherenkov angle correlates with change in TOP/Lpath, one can correct the Cherenkov ring chromatic broadening by time.**
- **To be able to do the chromatic correction, one needs a single photon resolution of ~ 200ps.**

Conclusion

- We have designed and built the photon camera made of solid fused silica. Testing starts in July.
- FDIRC will have ~10x better timing resolution and ~25x smaller volume compared to the BaBar DIRC. This will be our main defense against the background at ~100x higher luminosity at SuperB.
- The Cherenkov angle is determined by x-y pixels only.
- Time will be used in the PID likelihood hypothesis, to correct chromatic errors, and reduce background.

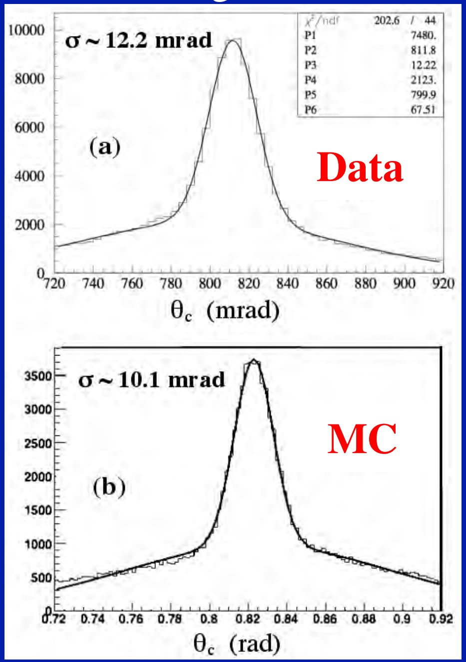
Appendix

1st FDIRC prototype: origin of tails

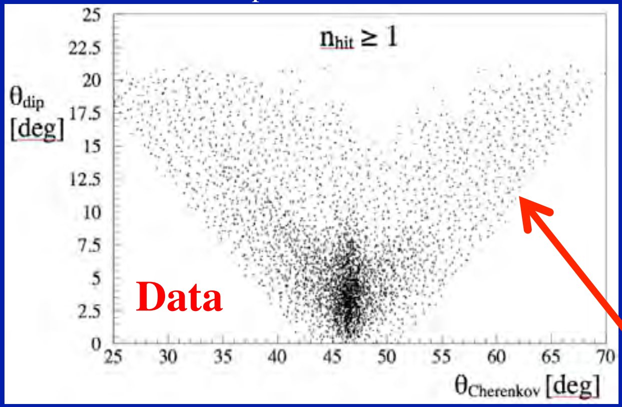


New results, to be published soon

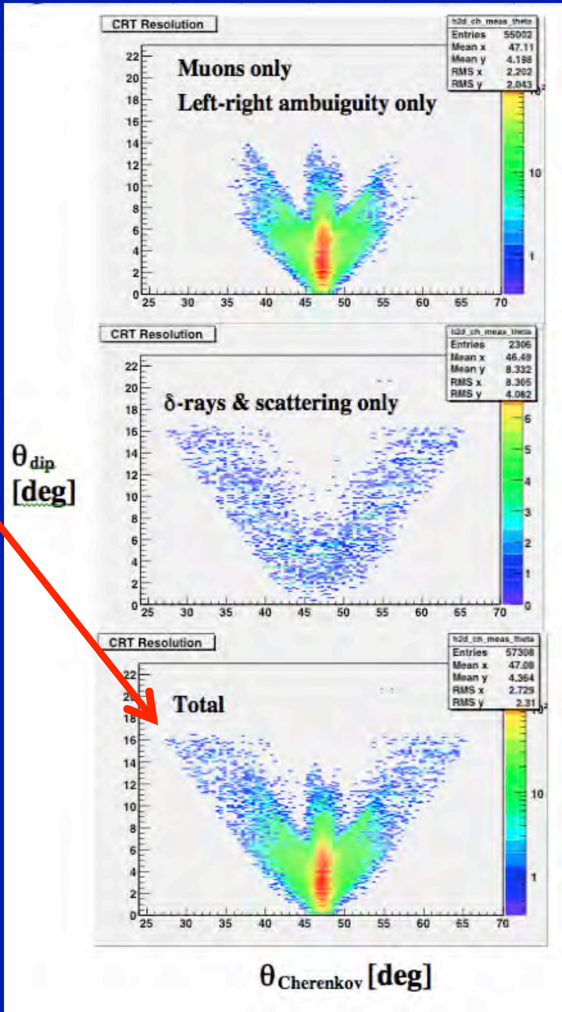
Cherenkov angle distribution:



Data: θ_{dip} vs. $\theta_{Cherenkov}$

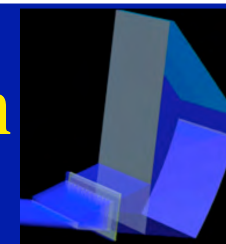


MC simulation: θ_{dip} vs. $\theta_{Cherenkov}$

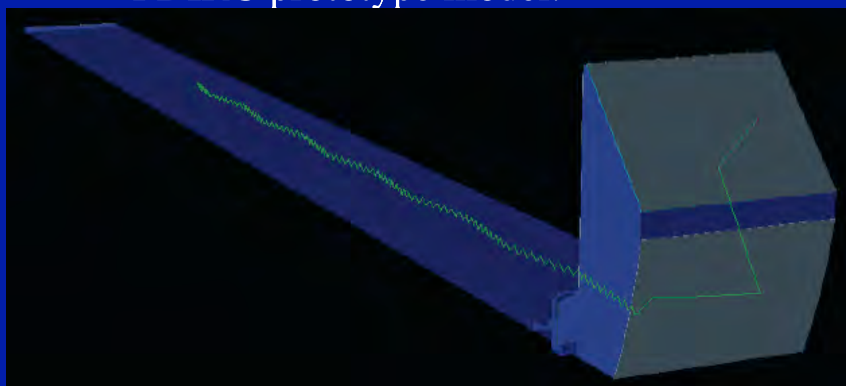


- **We do not know a sign of photon vector in x-direction as it leaves the bar. Have to try both signs, one sign is correct and the other one is wrong.**
  - **For very perpendicular tracks there is almost no effect.**
  - **However, the tail develops rapidly for 3D tracks.**
- **This ambiguity is the largest contribution to the tail in the Cherenkov angle distribution.**

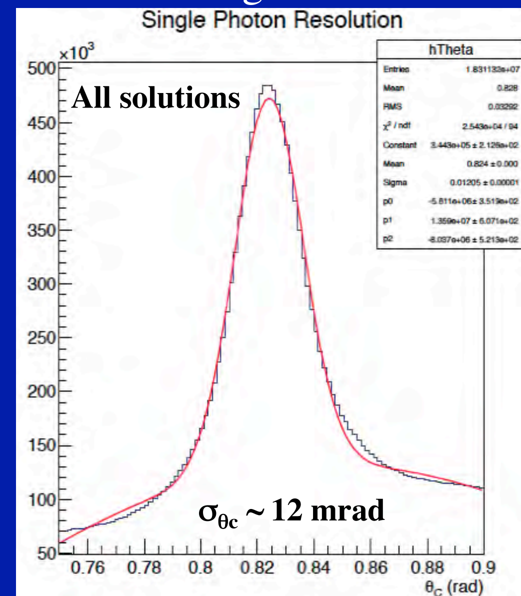
Final FDIRC prototype: MC simulation



FDIRC prototype model:

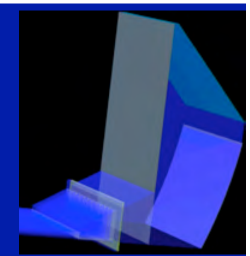


Cherenkov angle resolution:



(~16 solutions/photon)

- **Multiple photon paths to a given pixel -> leads to different θ_c solutions.**
- **More complicated than the 1-st prototype because of wedge and FBLOCK sides.**
- **Present methodology considers all solutions with "equal" weight. We are studying various methods how to (a) reduce number of solutions, (b) how to weigh them, or (c) eliminate some solutions by timing.**



FDIRC Expected rates

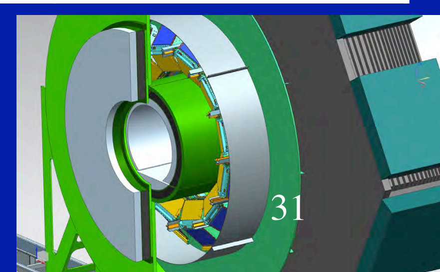
1) Contribution from active volume (cannot be shielded):

Lumi	H-8500 MaPMT rate	One single Double-pixel rate	Total dose (after 50 ab^{-1}) (~ 10 years)	Expected anode current	No problem for over 10 years if we limit current to:
10^{36}	~ 3.84 MHz	~ 120 kHz	~ 1.3 C/cm²/10 years	~ 1.2 µA /PMT	~ 10 µA /PMT

2) Contribution from FDIRC photon camera (with & without shielding):

	Lumi	H-8500 MaPMT rate	One single Double-pixel rate	Total dose (after 50 ab^{-1})	Expected anode current	No problem for over 10 years if we limit current to:
without	10^{36}	~ 17.6 MHz	~ 550 kHz	~ 5.9 C/cm²/10 years	~ 5.6 µA /PMT	~ 10 µA /PMT
with	10^{36}	~ 1.92 kHz	~ 60 kHz	~ 0.6 C/cm²/10 years	~ 0.6 µA /PMT	~ 10 µA /PMT

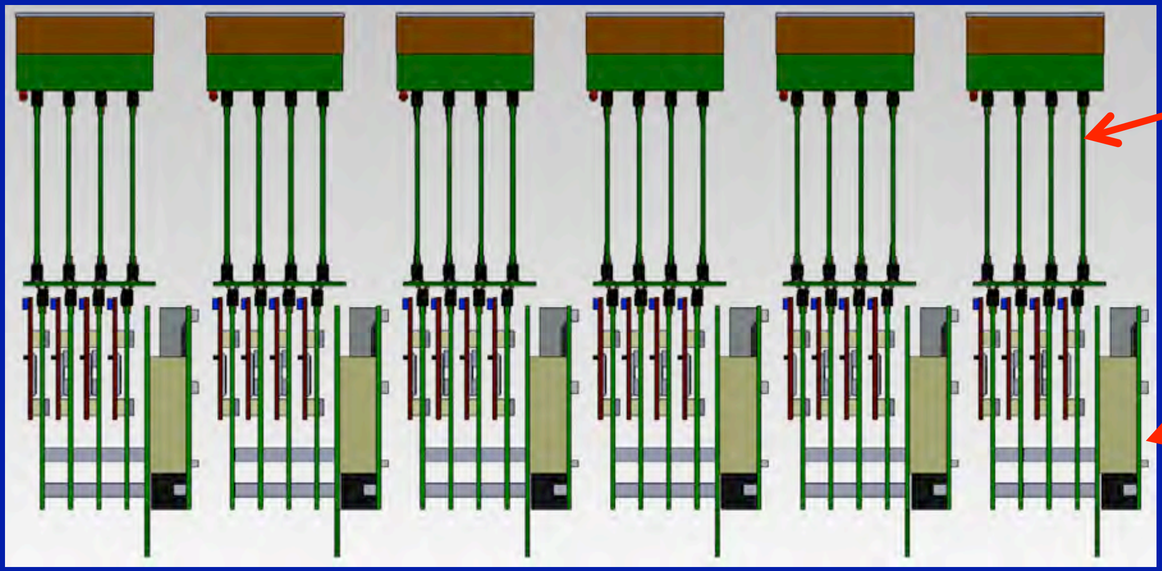
- A factor of ~ 2 safety only => need to shield photon camera:
  Shield: 10 cm Polyethylene + 10 cm lead + 2 x 2.5 cm steel + thicker tungsten. With the shield we gain a factor of ~10x.



SLAC amplifier + Hawaii IRS2 digitizer

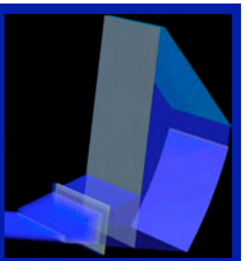
(this is how we will start the CRT FDIRC test)

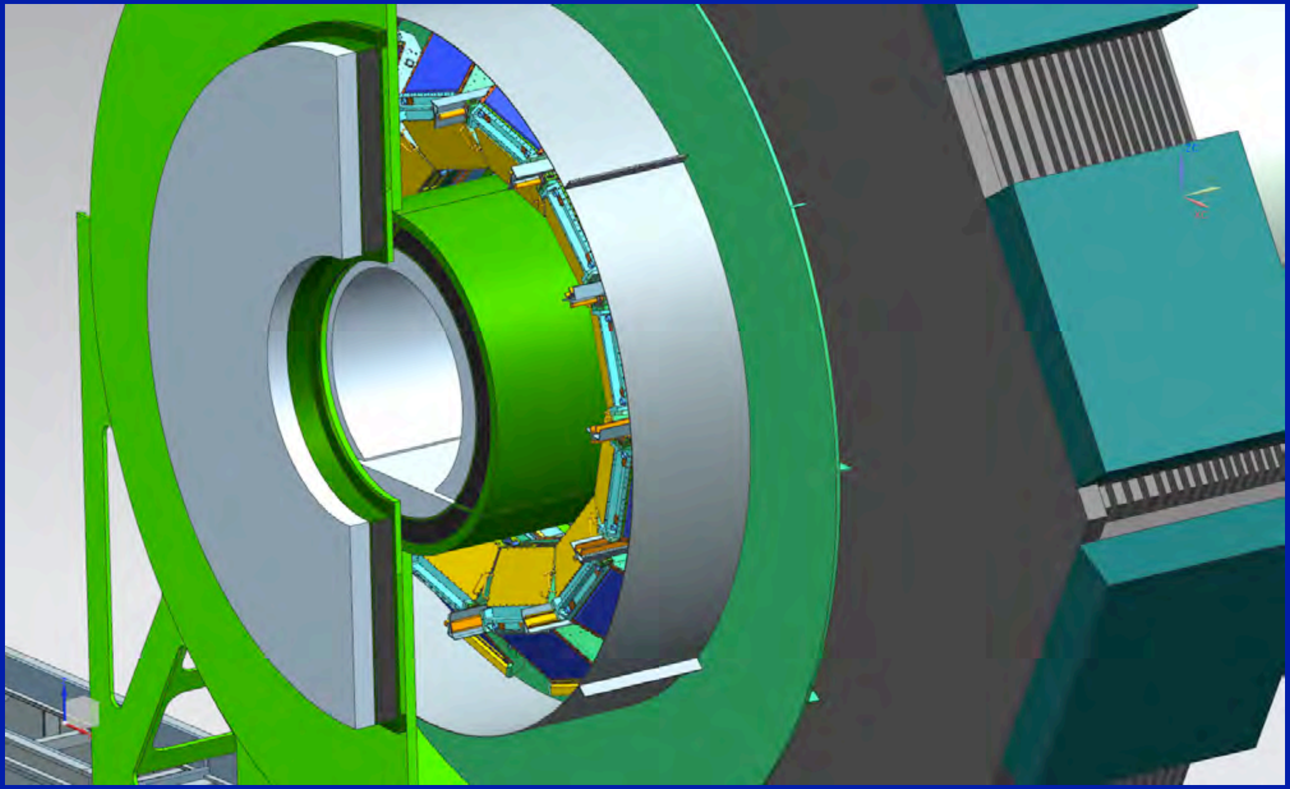
Top view:



- **Will be used initially in CRT to readout 12 H-8500 tubes.**
- **Benefit of this electronics: will have time & pulse height on every pixel.**

FDIRC shielding



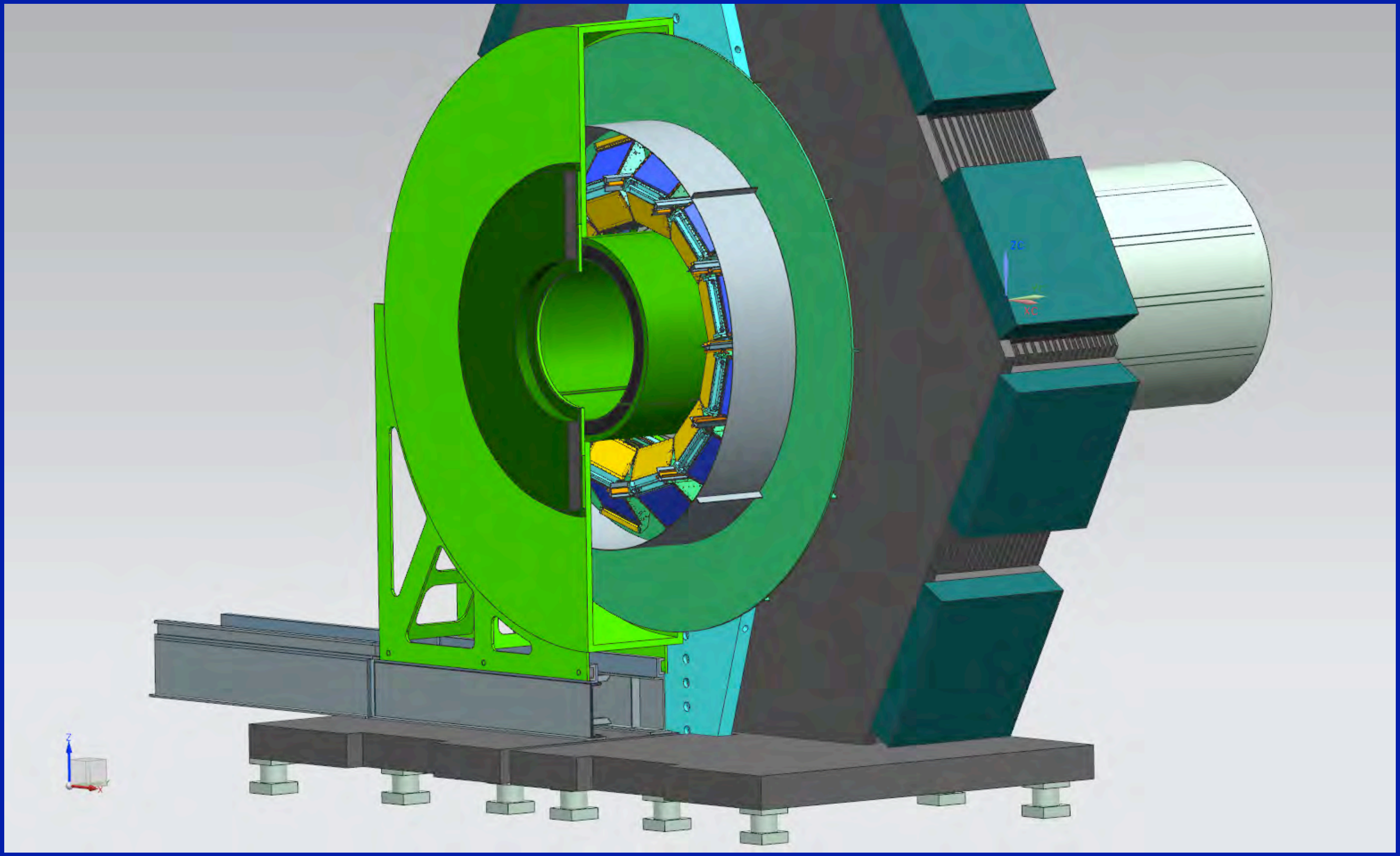


a) 10 cm thick Boron-loaded polyethylene.

b) 10 cm lead in between two 2.5 cm-thick steel plates

c) Need easy access to electronics.

FDIRC in SuperB detector



- **FDIRC is much more compact than BaBar DIRC photon camera.**