New FDIRC for SuperB

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Content

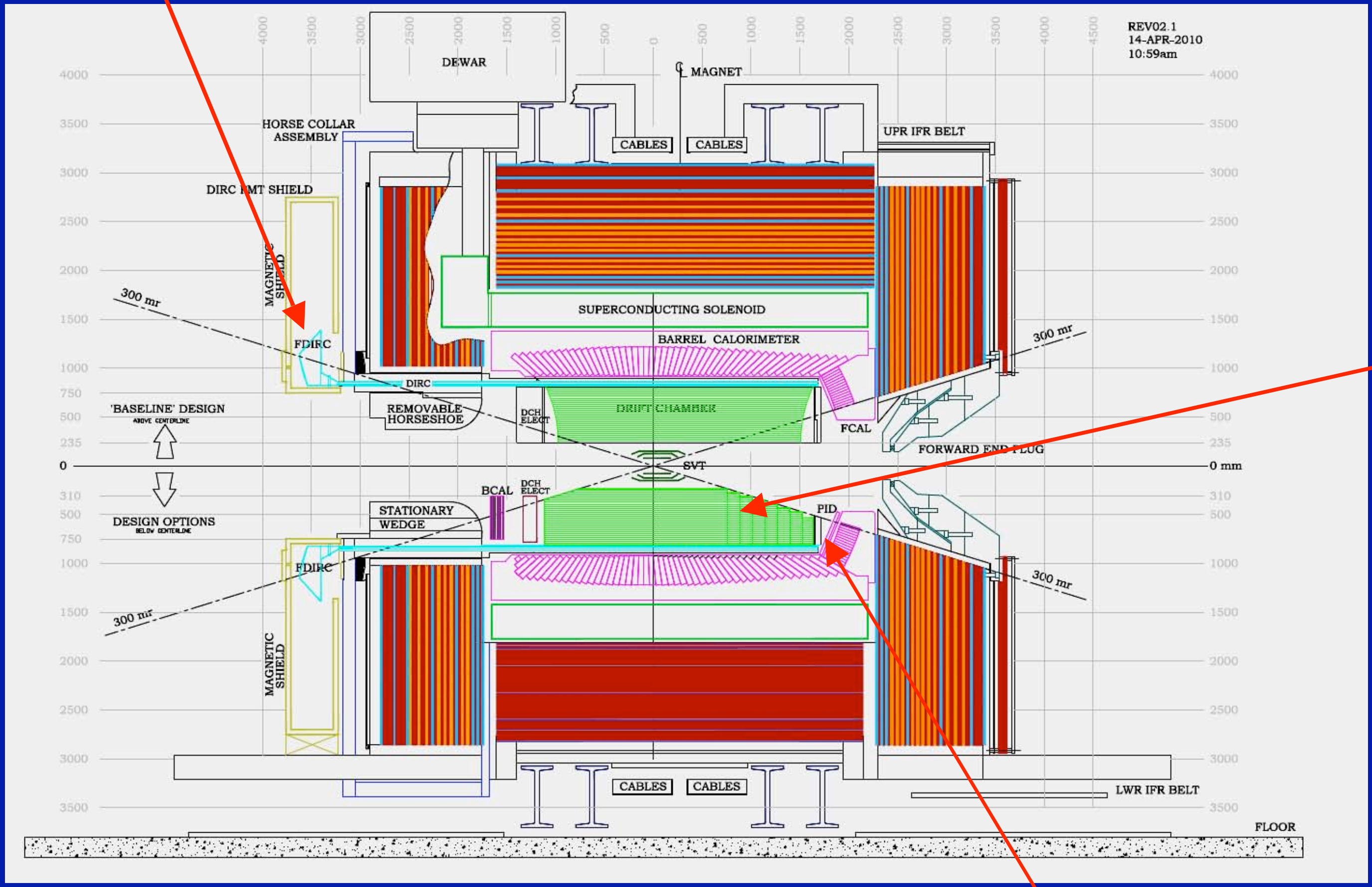
- SuperB detector
- Lessons from the FDIRC prototype: What timing resolution do we need to correct the chromatic error ?
- Design of the new FDIRC for SuperB
- Simulation with Mathematica
- MC simulation
- Expected performance
- Conclusion

Super-B detector

New Focusing DIRC (FDIRC)

Nominal design

Option

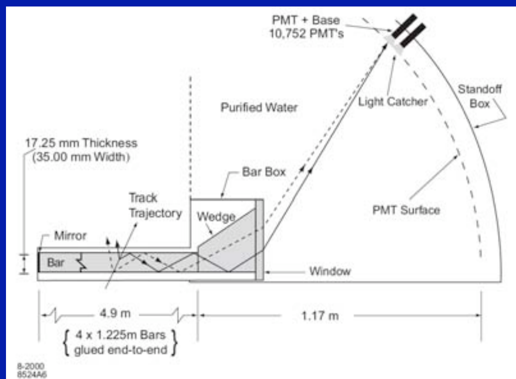


Cluster counting in new DCH ??

Forward TOF or Forward Aerogel RICH ??

BaBar DIRC ---> SuperB FDIRC

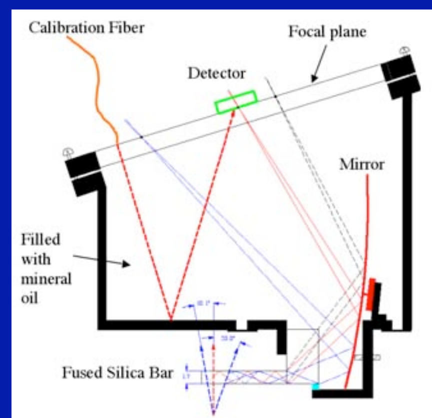
BaBar DIRC



DIRC proved to be a very reliable detector at BaBar. We all learned to like it.

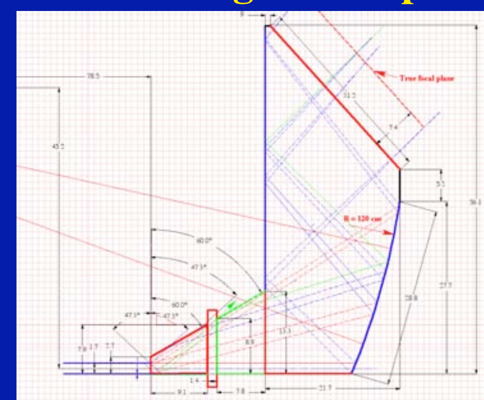
- **Long-term accumulated experience**

FDIRC prototype



Prototype verified the focusing concept, use of highly pixilated detectors, developed MC methods, and established that the chromatic error can be corrected by timing

FDIRC design for SuperB



3D imaging (x, y & time), 25x smaller volume and 10x faster than BaBar DIRC

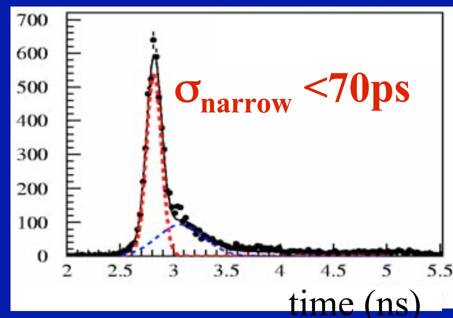
Lessons from FDIRC prototype:

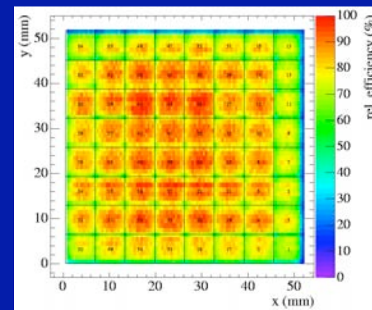
- New fast highly pixilated detectors
- 10x better timing resolution than DIRC
- Correction of the chromatic error
- Methods to design the optics
- Ring aberration

Focusing DIRC prototype photon detectors

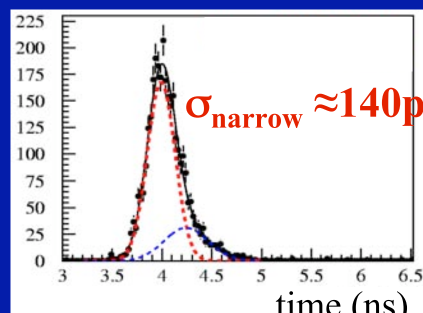
C. Field et al., Nucl.Inst.&Meth., A 553 (2005) 96

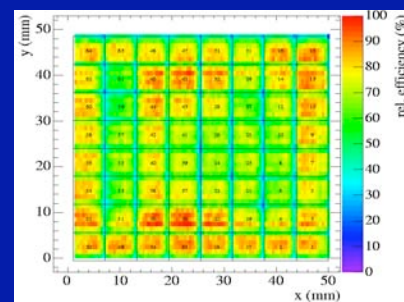
1) Burle 85011-501 MCP-PMT (64 pixels, 6x6mm pad, σ_{TTS} ~50-70ps)



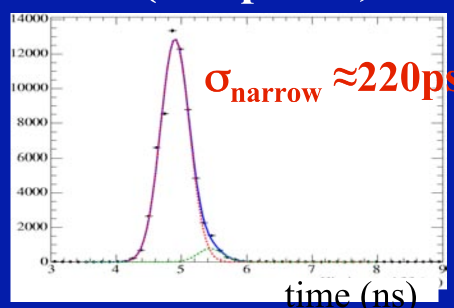


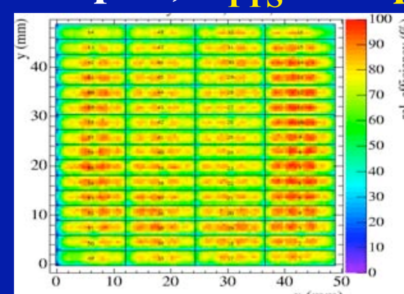
2) H-8500 MaPMT (64 pixels, 6x6mm pad, σ_{TTS} ~140ps)





3) H-9500 Flat Panel MaPMT (256 pixels, 3x12mm pad, σ_{TTS} ~220ps)



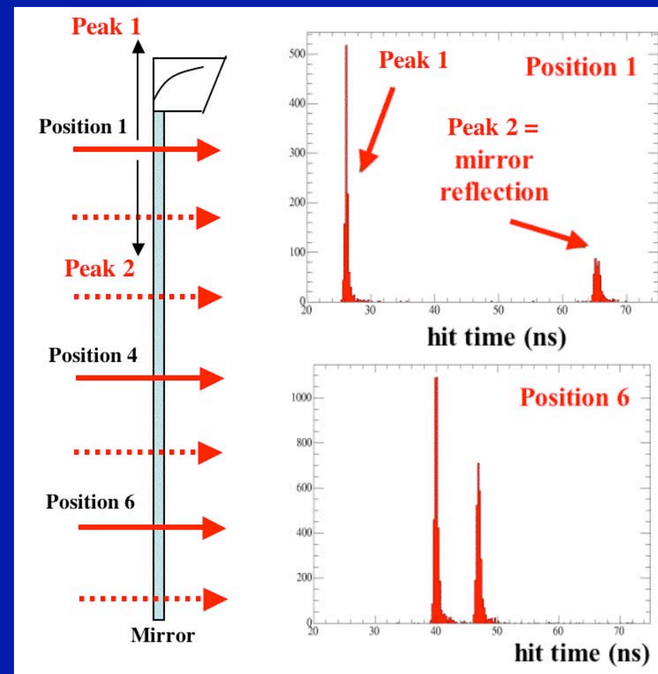


- **Timing resolutions were obtained using a fast laser diode in bench tests with single photons on pad center, and with the CFD electronics used on the FDIRC prototype.**

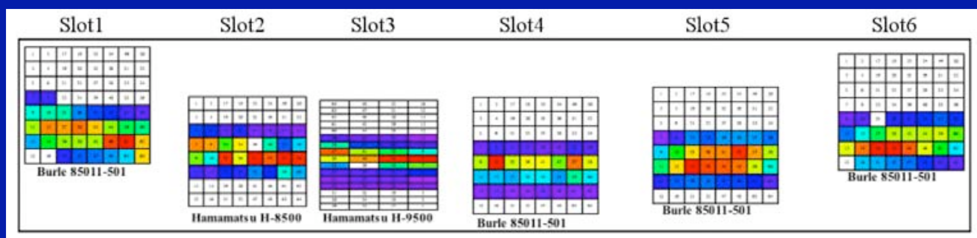
Cherenkov ring in pixel and time domain

J.F. Benitez, I. Bedajanek, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff. K. Suzuki, J. Schwiening, J. Uher and J. Va'vra, "Development of a Focusing DIRC," IEEE Nucl.Sci, Conference records, October 29, 2006, and SLAC-PUB-12236, 2006

Cherenkov ring in the time domain:

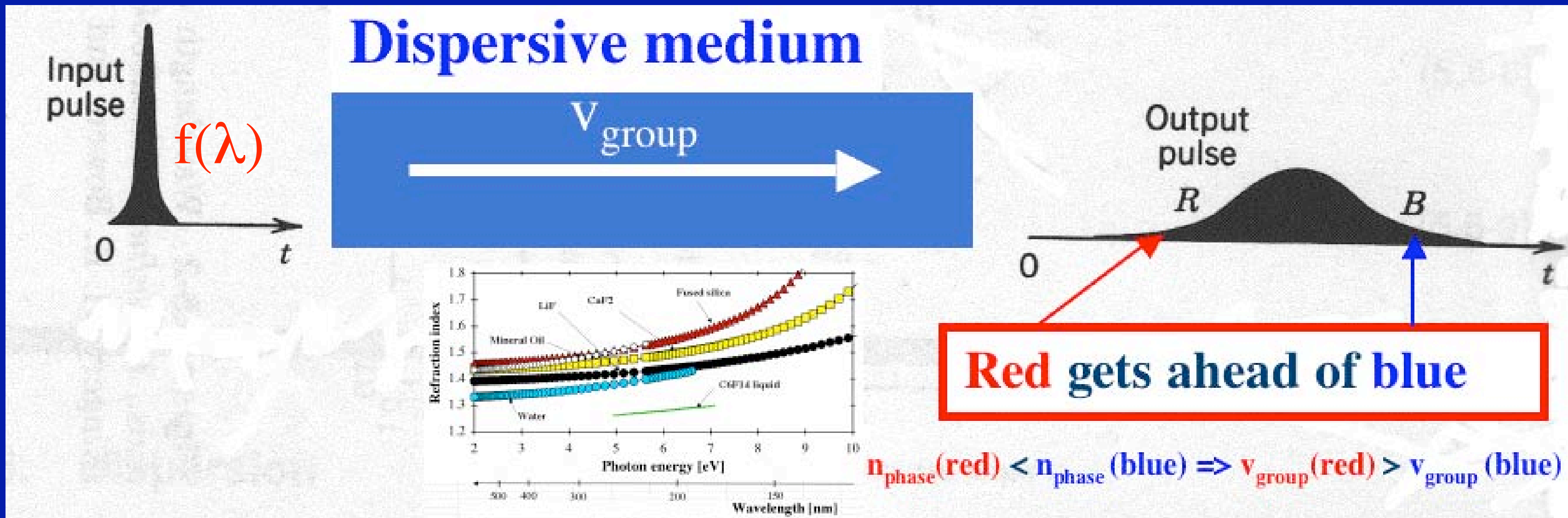


Cherenkov ring in the pixel domain:



- **Both domains can be used to determine θ_c.**
- **FDIRC uses time to resolve the forward-backward ambiguity, do chromatic corrections, reject the background; it will be used for PID in a likelihood analysis, etc.**

Color tagging by measurement of photon propagation time



$$v_{group} = c \, / \, n_{group} = c \, / \, [n_{phase} - \lambda * dn_{phase}/d\lambda]$$

$$t = TOP = L \, / \, v_{group} = L \, [n_{phase} - \lambda * dn_{phase}/d\lambda] / \, c$$ = Time-Of-Propagation

$$dt/L = dTOP/L = \lambda \; d\lambda * | - d^2n/d\lambda^2 | \, / \, c$$

dt is pulse dispersion in time, length **L**, wavelength bandwidth **dλ** , refraction index **n(λ)**

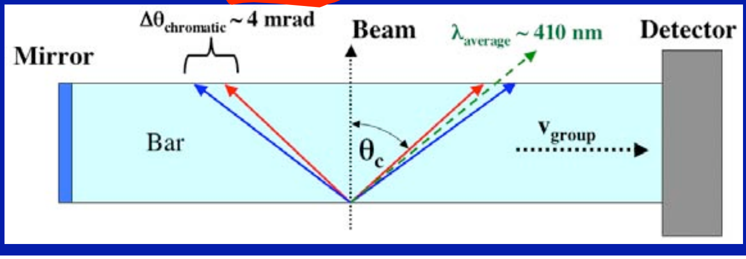
- We have determined in Fused Silica: **dt/L = dTOP/L ~ 40ps/meter**.
- **Our goal is to measure the color of the Cherenkov photon by timing !**

FDIRC prototype is the 1-st RICH detector to correct the chromatic error by timing

J.F. Benitez, I. Bedajanek, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff. K. Suzuki, J. Schwiening, J. Uher and J. Va'vra, SLAC-PUB-12803, 2007 and Nucl. Instr. & Meth. A595(2008)104-107.

Because Cherenkov angle correlates with time-of-propagation (TOP), one can correct the Cherenkov ring chromatic broadening by time. To be able to do the chromatic correction, <u>one needs a single photon resolution of ~200ps.</u>

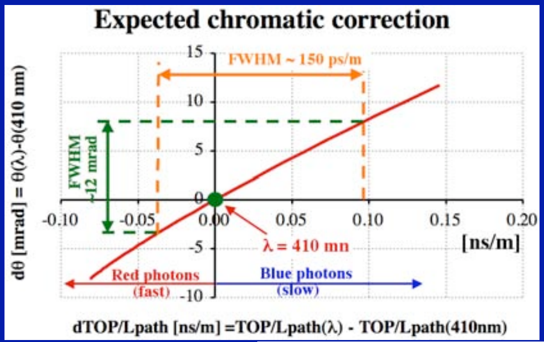
Tagging color by time in 5m-long DIRC bar:



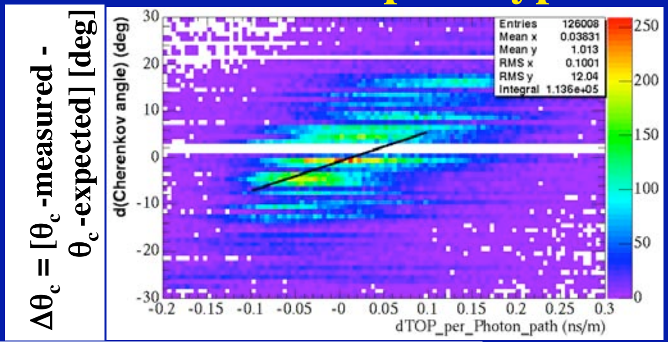
Cherenkov angle production controlled by n_{phase} ($\cos\theta_c = 1/(n_{phase}\beta)$): θ_c **(red) < θ_c (blue)**

Propagation of photons is controlled by n_{group} ($v_{group} = c_0/n_{group} = c_0/[n_{phase} - \lambda * dn_{phase}/d\lambda]$): v_{group} **(red) > v_{group} (blue)**

Excel calculation:



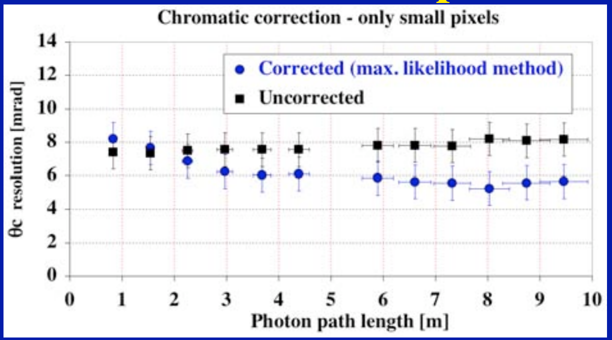
Data from the prototype:



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

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

Result with 3 mm pixels:

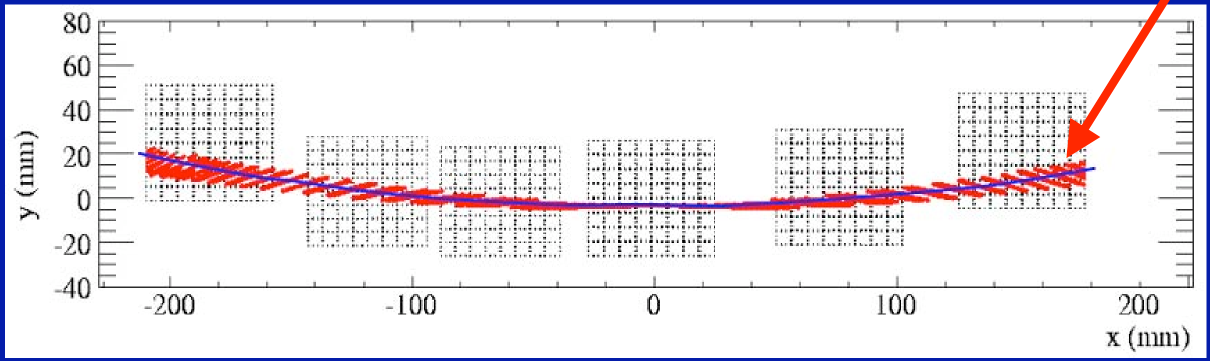


Consistent with expectation

Summary of error contributions to θ_c

J.F. Benitez et al., PUB-12803, 2007 and Nucl. Instr. & Meth. A595(2008)104-107.

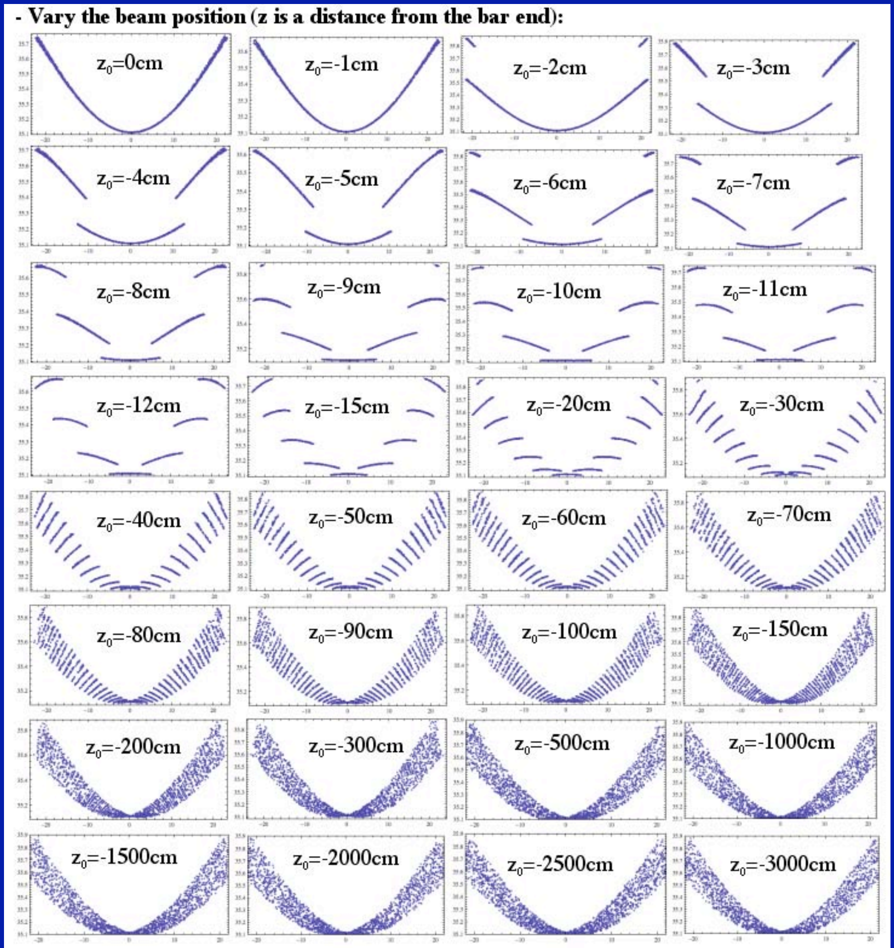
- **Chromatic smearing: ~ 3-4 mrad**
- **Pixel size (~6mm x 6mm pixel size): ~5.5 mrad**
- **Optical aberrations: 0 mrad (at ring center) to 9 mrad (in outer wings of Cherenkov ring)**

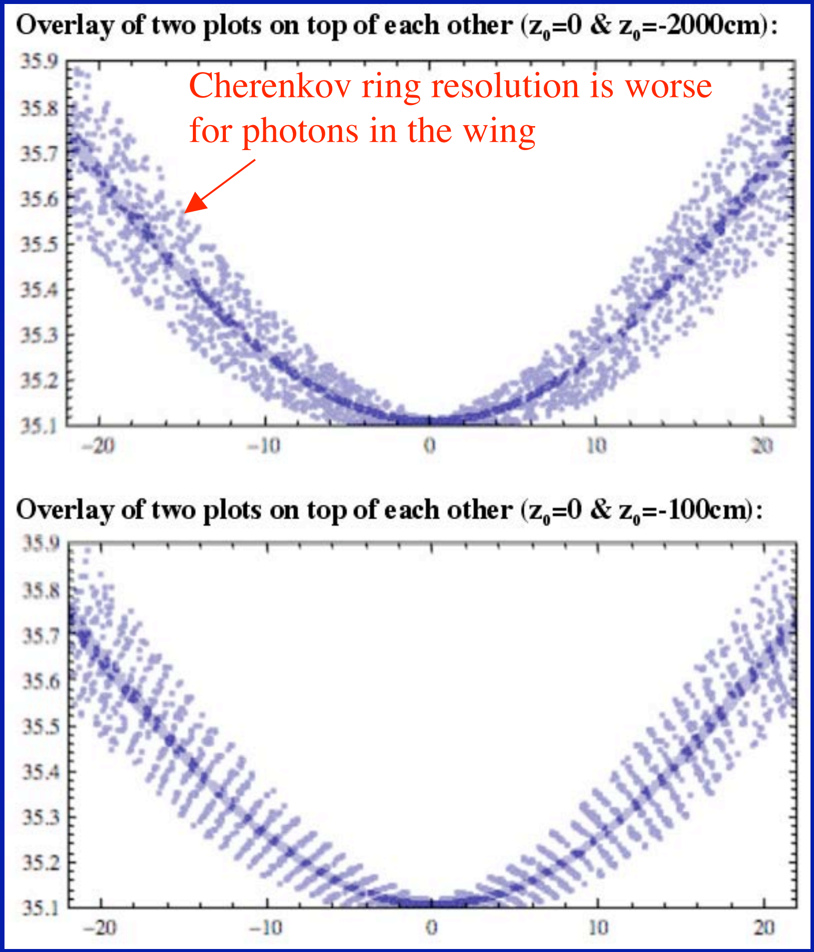


Total θ_c resolution: ~9.6 mrads

Optical aberration in FDIRC prototype

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





- **The optical aberration (kaleidoscopic pattern) is due to bar/mirror acting on pieces of ring, as determined by Mathematica-based ray tracing.**
- **Non-focusing (no mirror) DIRC has a similar aberration due to a bar alone.**

New FDIRC for SuperB

Design aim:

1. ~10x better timing resolution than BaBar DIRC.
2. ~25x smaller volume than BaBar DIRC.
3. Highly pixilated detector (16-32k pixels/system).
4. Avoid water as optical coupling medium.
5. FDIRC measures photons in 3D (x,y and time), which allows the chromatic error correction.
6. θ_c resolution, based on pixels alone, is about the same as in the BaBar DIRC.
7. Time, however, plays a role to determine θ_c even in FDIRC, and will be included in the final PID likelihood hypothesis.
8. Electronics design should be conservative using TDC/ADC concept.

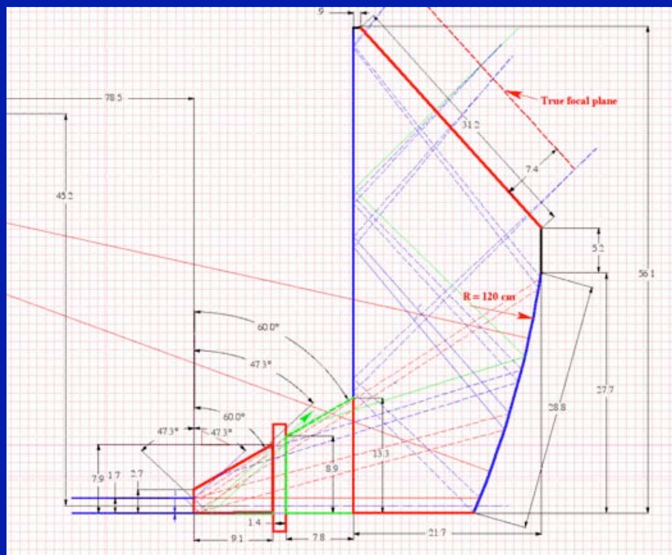
Important condition:

Use the existing BaBar bar boxes without significant changes.

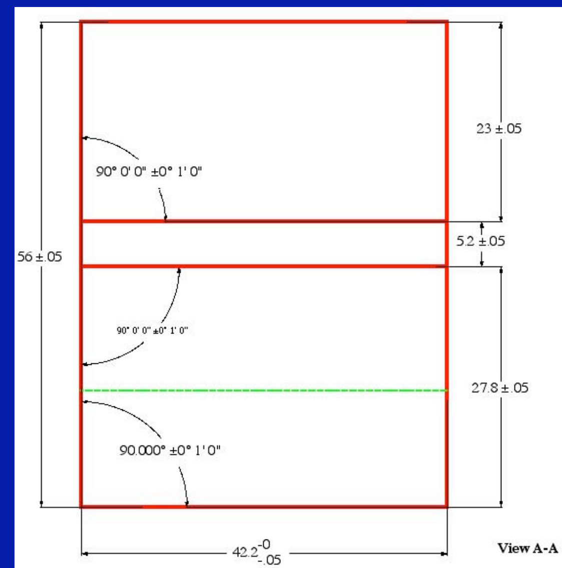
FDIRC for SuperB: optics design

J.Va'vra, SLAC-PUB-13763, 2009

Side view:



Back view:

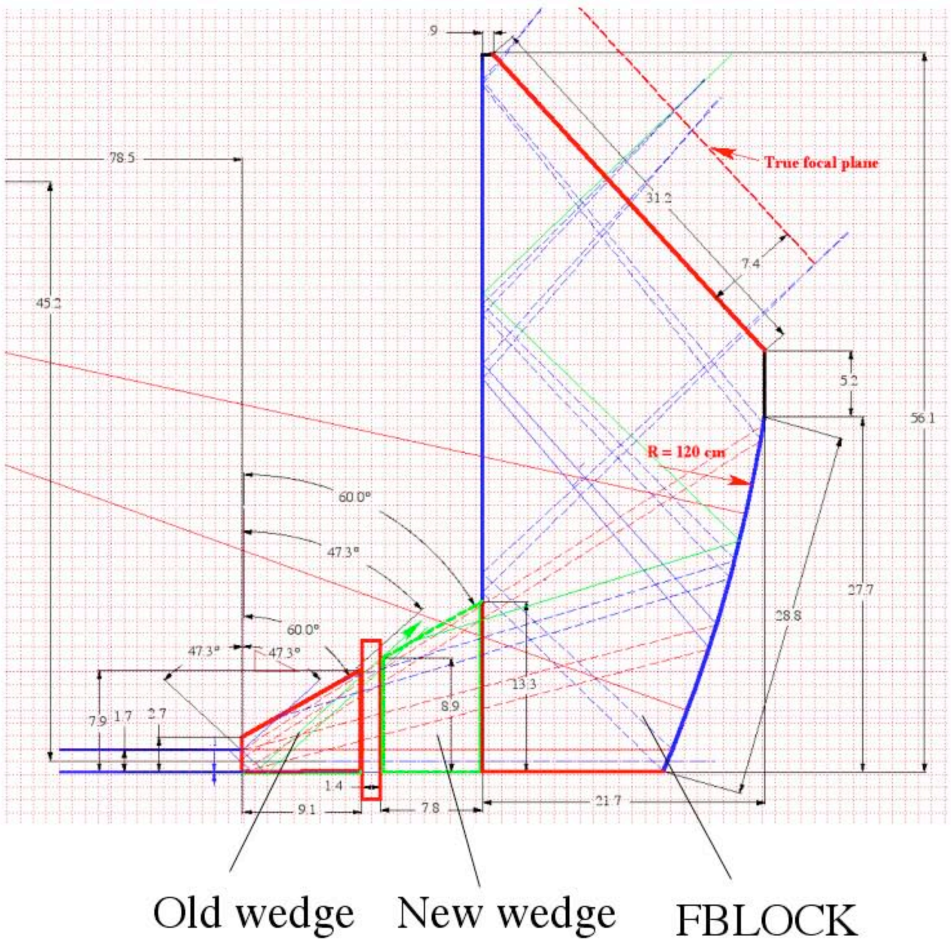


- **Optics of the detector camera was designed by ray tracing. Then various things were checked by a Mathematica ray tracing program. Finally a full check by a MC simulation.**
- We have to live with the **existing bar box**, which includes the **old wedge**, which has **two complications: (a) it has a 6 mrad inclined angle at the bottom, intended to do a simple focusing, and (b) it is not long enough to bring all rays onto the cylindrical mirror, thus not all rays would be focused.** Therefore, we have added a New Wedge outside the box.
- Cylindrical mirror radius is **120 cm**.
- **Double-folded mirror optics** allows a good access to photon detectors.
- Will measure the timing resolution for a single photon to **150-200ps.**
- **Focusing in y only** => would like to use small pixels in y, and large pixels in x-direction.

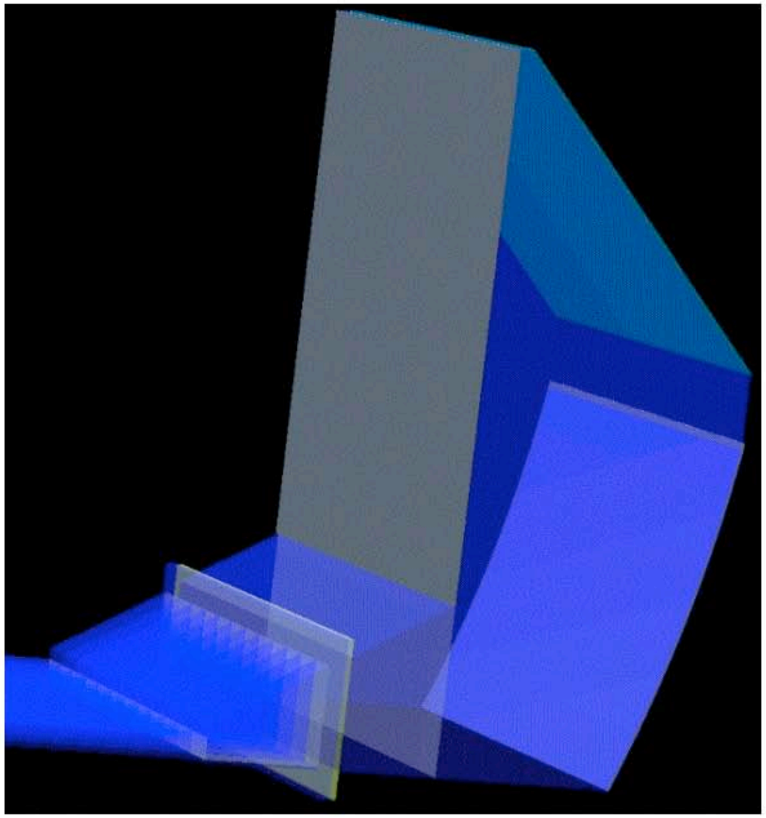
Ray tracing & MC simulation

J. Va'vra, Simulation with Mathematica, SLAC-PUB-13464 & SLAC-PUB-13763,
D. Roberts, "Geant 4 model of FDIRC", SuperB meeting, Annecy, Oct. 2009

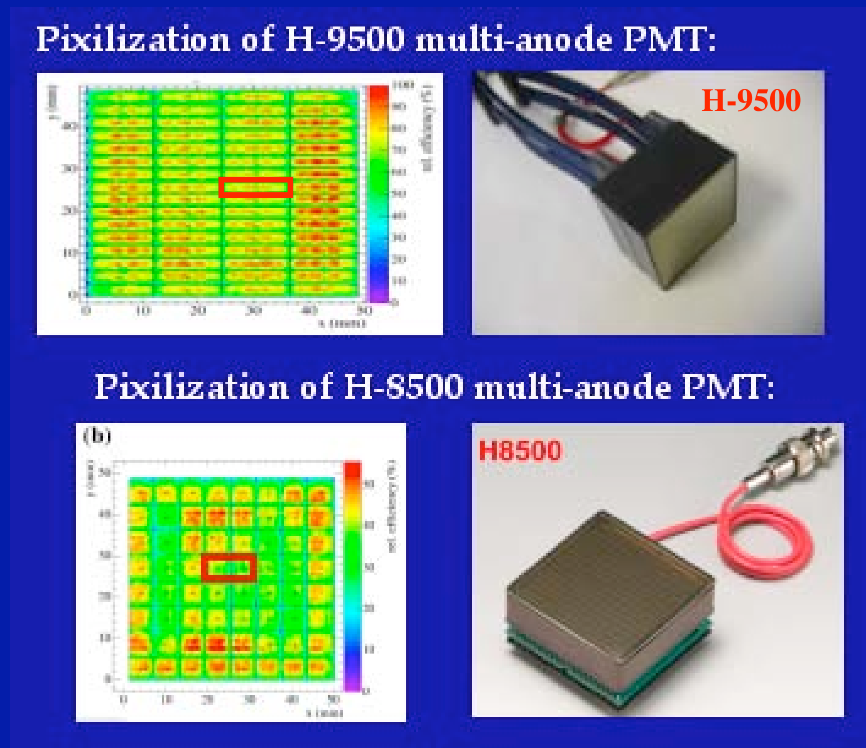
Ray tracing:



Geant 4 model:



FDIRC photon detectors

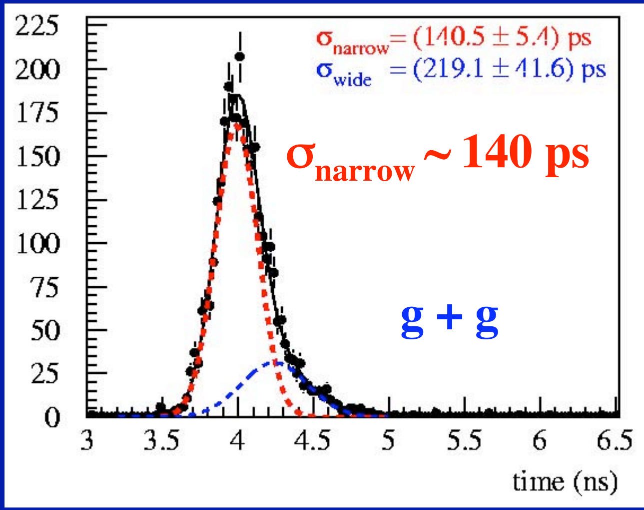


- H-8500: (a) Preferred by medical community, (b) much smaller price than H-9500, (c) smaller TTS spread (σ ~140ps), (d) available with "enhanced" QE (~24%), (e) Hamamatsu "strongly" recommends this tube to keep a reasonable delivery schedule of large quantities
- H-9500: Better Cherenkov angle resolution

Single electron timing response

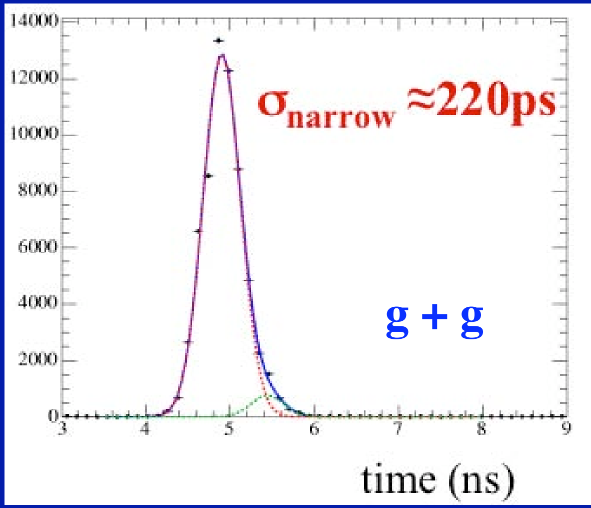
J. Va'vra et al., SLAC-PUB-12236, 2007

H-8500 TTS distribution:



(Measured with a 635 nm PiLas laser)

H-9500 TTS distribution:

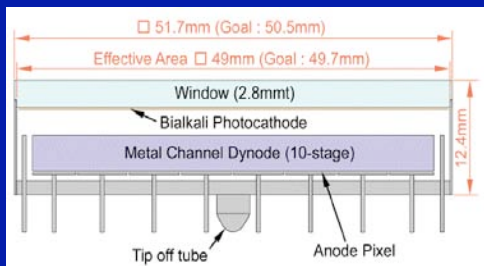


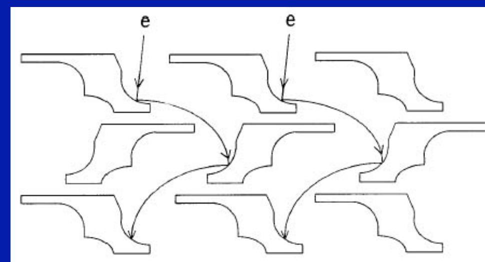
(Measured with a 407 nm PiLas laser)

- **H-8500 has a better TTS resolution than H-9500.**
- **Both are good enough to do the chromatic corrections.**

Hamamatsu H-8500 & H9500 Flat panel MaPMTs

Hamamatsu data





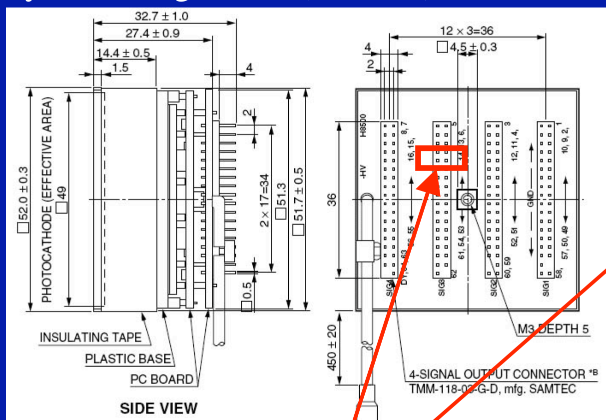
Parameter	Value
Photocathode: Bi-alkali QE at 420nm	20 % (-> 24%) *
Geometrical collection efficiency CE of the 1-st dynode	75% (-> 80%) *
Geometrical packing efficiency (dead space around boundary)	89%
PDE = Total fraction of "in time" photoelectrons detected	~ 13% (->16-17%) *
Photocathode uniformity	1:1.5 to 1:2.5
Number of dynodes	12
Total average gain @ -1kV	$\sim 10^6$
Fraction of photoelectrons arriving "in time"	~95%
σ_{TTS} - single electron transit time spread	~ 140-150 ps
Matrix of pixels (H8500 & H9500)	8 x 8 & 16 x 16
Number of pixels (H8500 & H9500)	64 & 256
Pixel size (H8500 & H9500)	5.8 x 5.8 & 2.9 x 2.9 [mm^2]

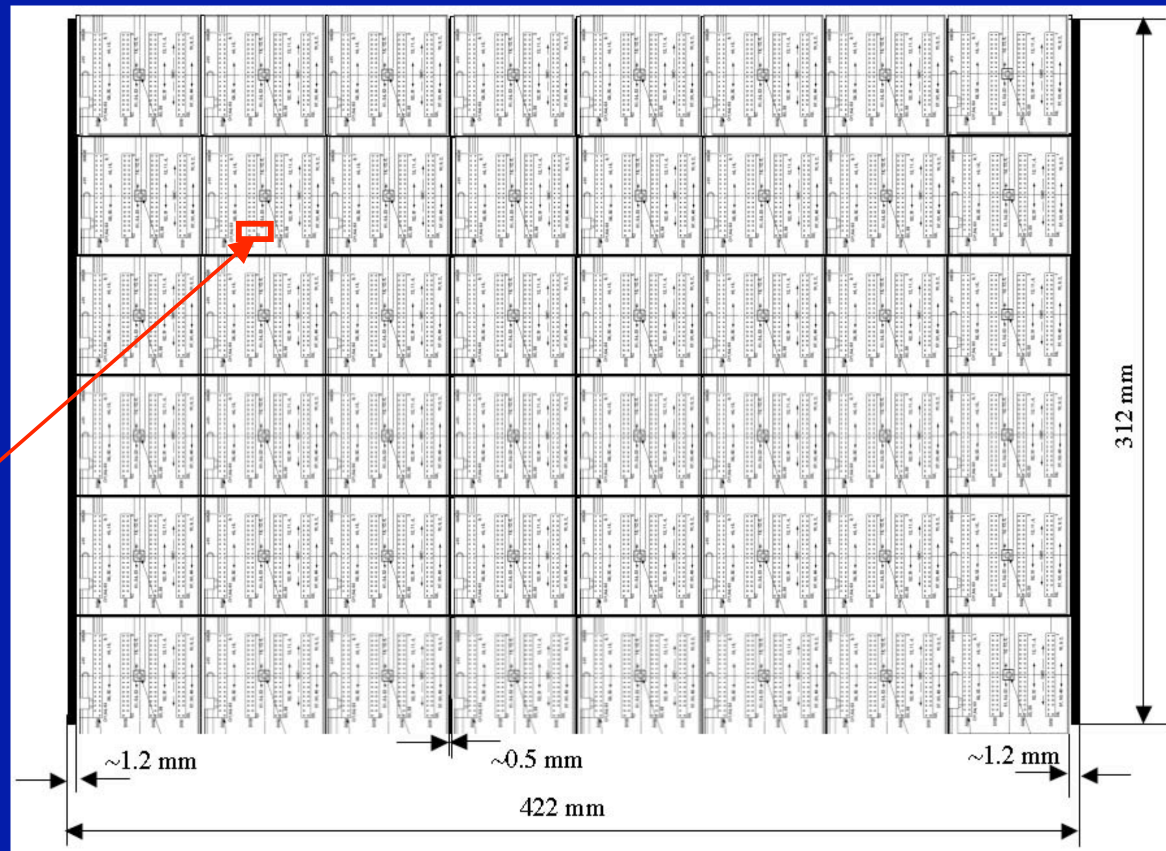
* - now available with a Super QE (24%) and better collection efficiency (80%)

Detector matrix on the camera

J. Va'vra, SuperB workshop, Annecy, 2010

Detector precision is determined by a holding screw (H-8500):

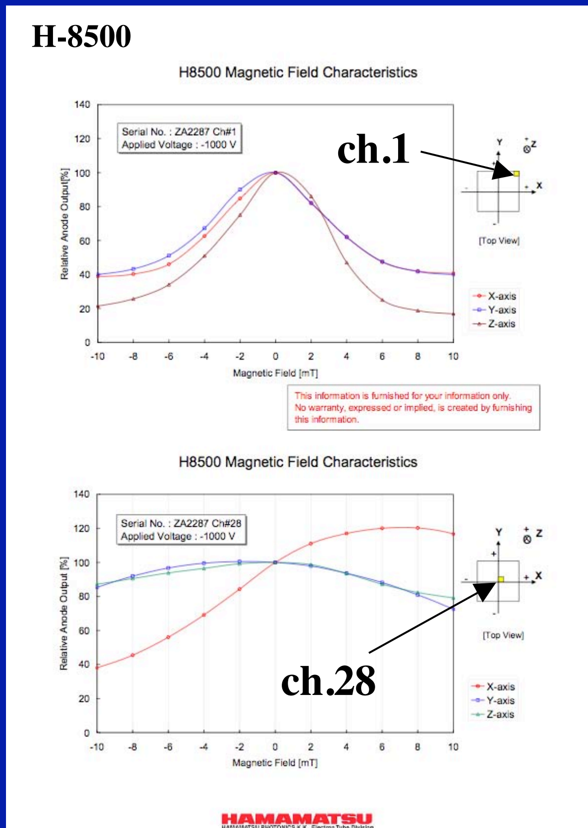




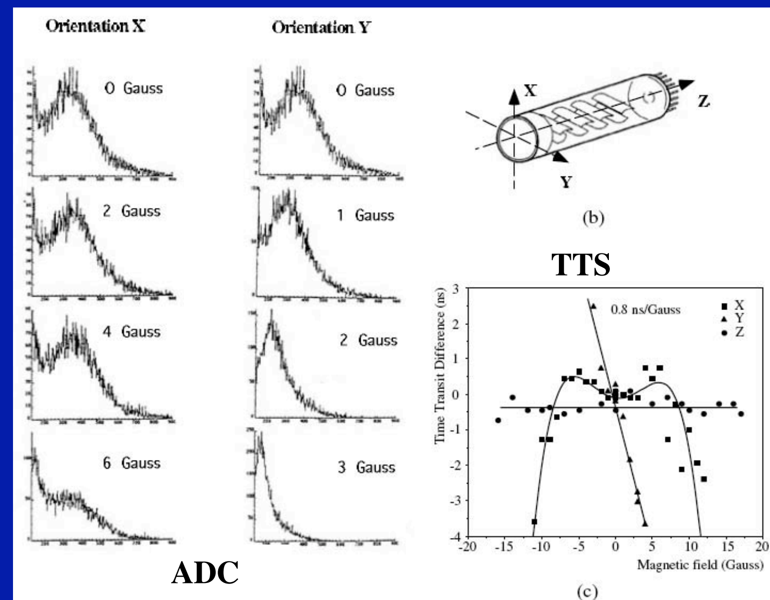
Short two pads together

- **Number of H-8500 detectors: 48 = 8 x 6 per camera.**
- **Total number of detectors: 576 = 48 x 12 per entire system.**
- **Total number of pixels (H-8500): 18,432 = 12 x 48 x 32 per entire system.**

H-8500 sensitivity to magnetic field



DIRC tube (from DIRC NIM paper):



- **DIRC PMT tube was much more sensitive to magnetic field (~1 Gauss is a very visible effect).**
- **H-8500: edge pixels are more sensitive than center pixels:**
  up to ~20% amplitude loss at ~20 Gauss; up to ~60% amplitude loss at ~50 Gauss
- **We will need a magnetic shield, but it may not need to be as massive as in BaBar**

Present FDIRC predicted performance

Doug Roberts, SuperB workshop, Annecy, 2010

Table 1: FDIRC performance simulation by Geant 4 MC.

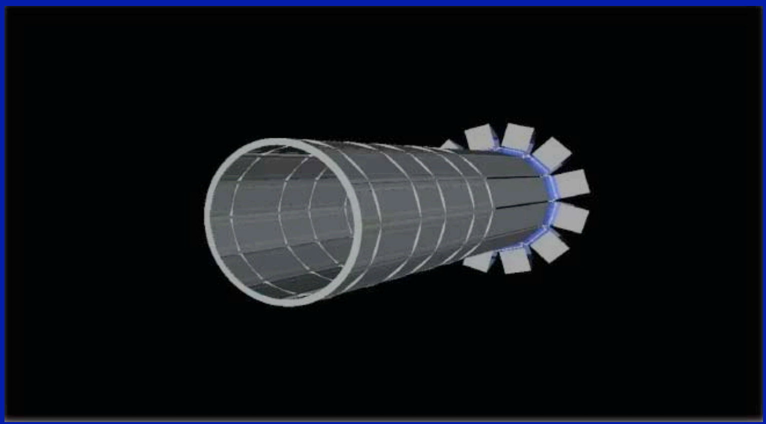
Design	Option	θ_c resolution [mrad]
1	FDIRC with 3 mm x 12 mm pixels with a micro-wedge	8.1
2	FDIRC with 3 mm x 12 mm pixels & no micro-wedge	8.8
3	FDIRC with 6 mm x 12 mm pixels with a micro-wedge	9.0
4	FDIRC with 6 mm x 12 mm pixels & no micro-wedge	9.6

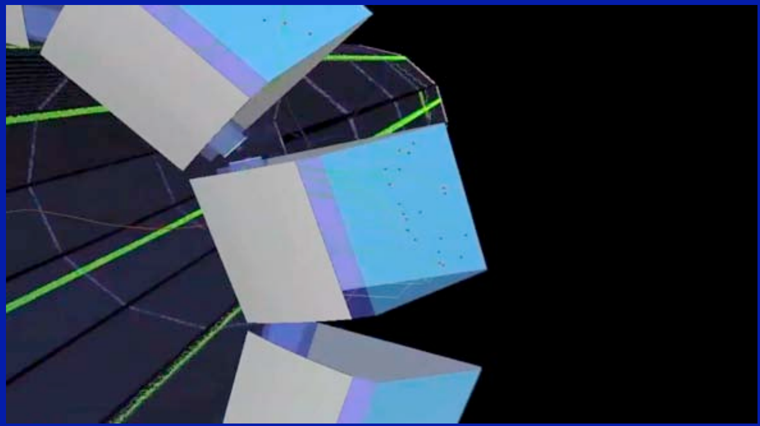
- **The most conservative decision, which is a design #4, would give the same performance as the BaBar DIRC (~9.6 mrads for di-muons).**
- **However, one should point out that FDIRC will correct out the chromatic error by timing, which would reduce the error by 0.5-1 mrads.**

FDIRC in FullSim

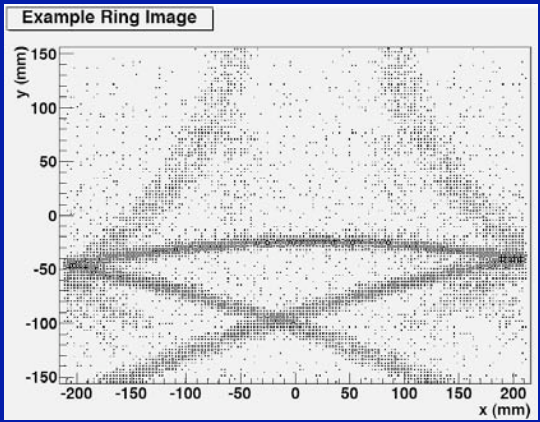
Doug Roberts, SuperB workshop, Annecy, 2010

MC model:





Ring image at 4 GeV/c with 3mm x 3mm pixels:



Each bar has a different image

- Rings are not circles !

We are handling the problem presently as follows (J.V.):

a) MC-based assignments of k_x, k_y, k_z, TOP_{direct} & $TOP_{indirect}$ for each pixel, and for tracks with $\theta_{dip} = 90^o$ and $z = z_{middle}$.

b) $\cos\theta_c = \bar{k}_{track} \cdot \bar{k}_{pixel}$ for any track direction

(this procedure is used presently in the FDIRC prototype running in the CRT test, and works OK)

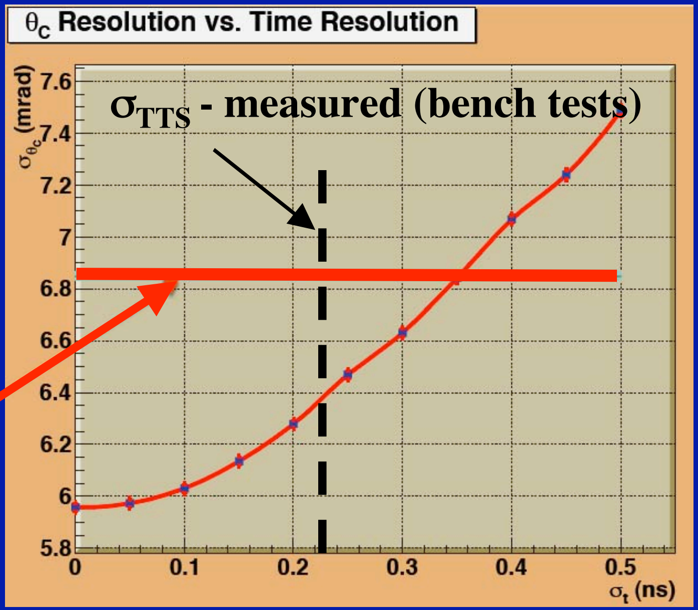
A full FDIRC model implemented in MC. A full analysis is yet to be worked out.

FDIRC MC simulation: chromatic corrections

D. Roberts, SuperB workshop, Annecy, 2010

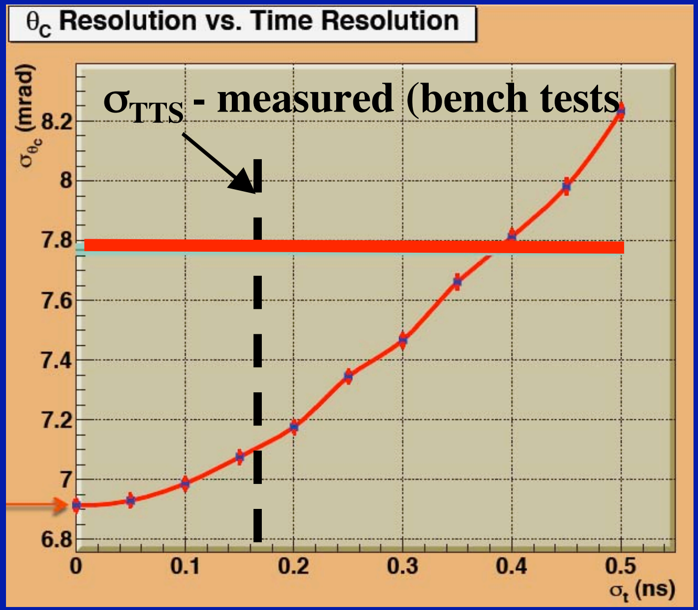
Solution with the micro-wedge in:

3mm x 12mm pixels (H-9500):



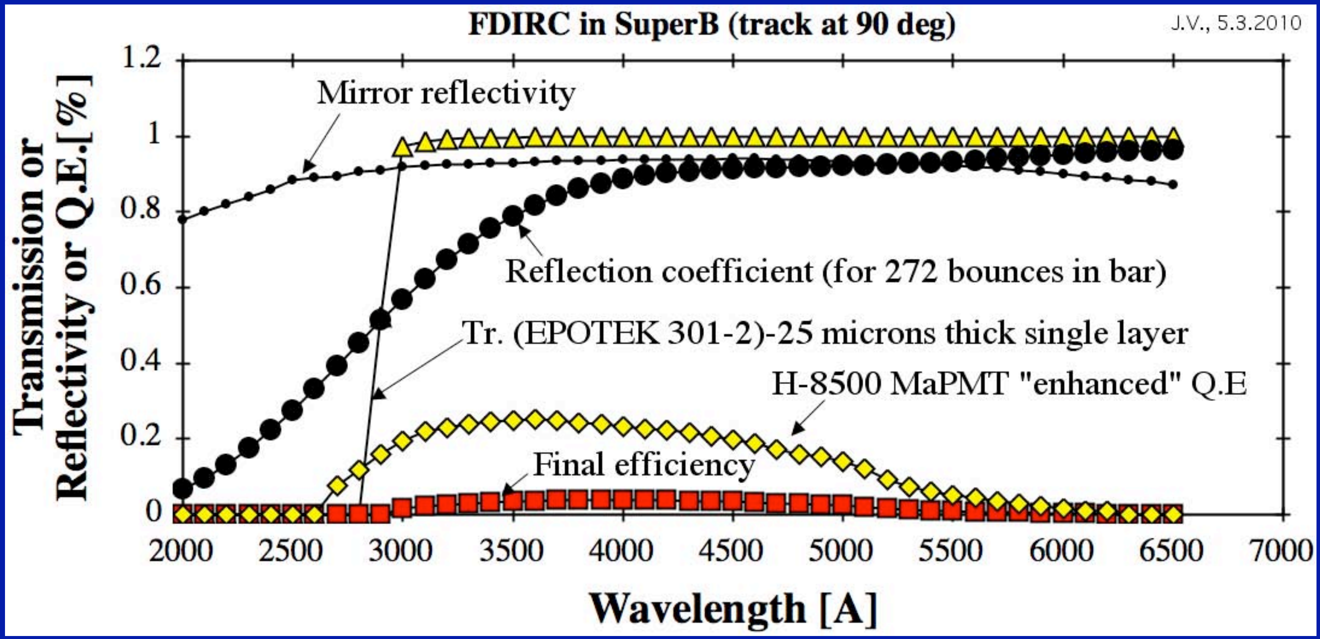
No correction

6mm x 12mm pixels (H-8500):



- **According to this simulation, we could gain ~0.4-0.8 mrads in θ_c resolution if we do the chromatic correction by timing.**
- **Results consistent with the FDIRC prototype beam test and MC results.**

Expected number of photoelectrons

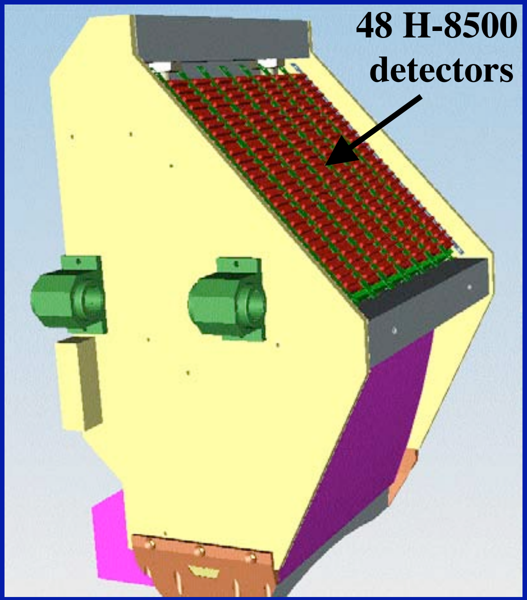


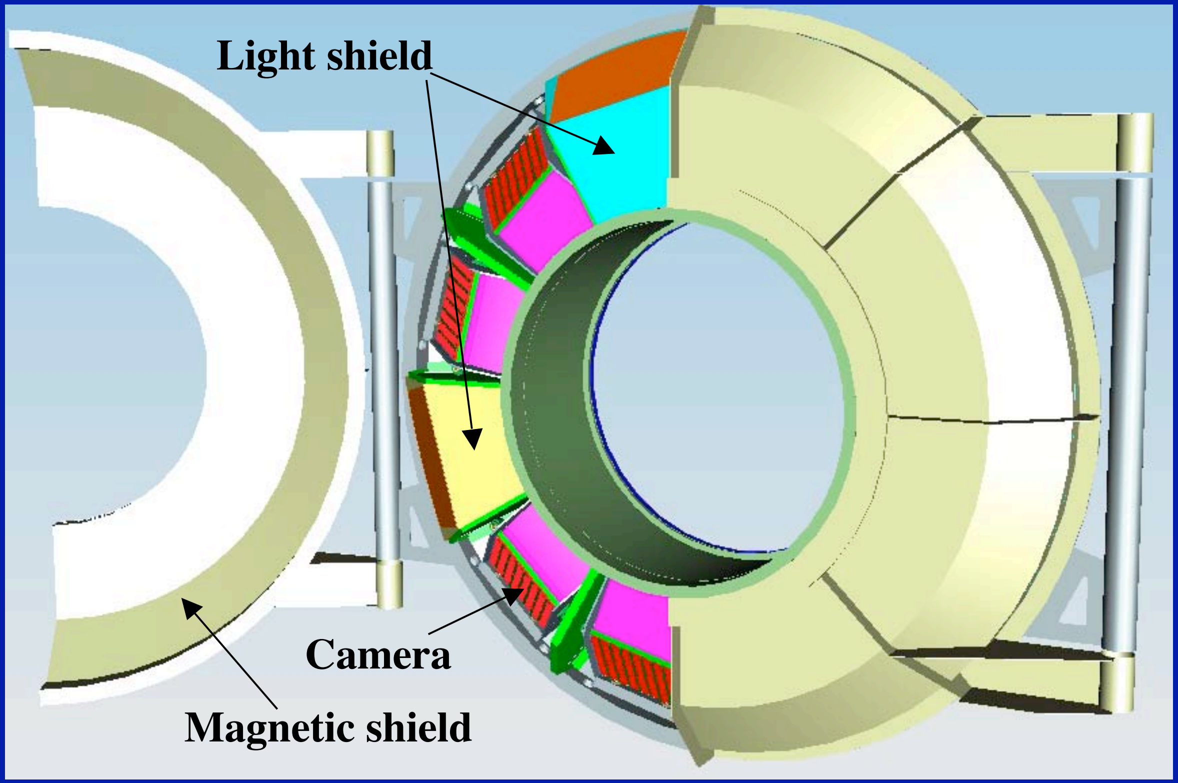
- **Based on this, expect $N_{pe} \sim 20$ pe/ring at $\theta_{dip} = 90^o$ and in the middle of the z-acceptance.**
- **This is for H-8500 MaPMT "enhanced" QE (24% peak), and proper packing efficiency and geometrical collection efficiency.**

FDIRC mechanical design

Massimo Benettoni, mechanical engineer from Padova U., Italy

FDIRC camera:



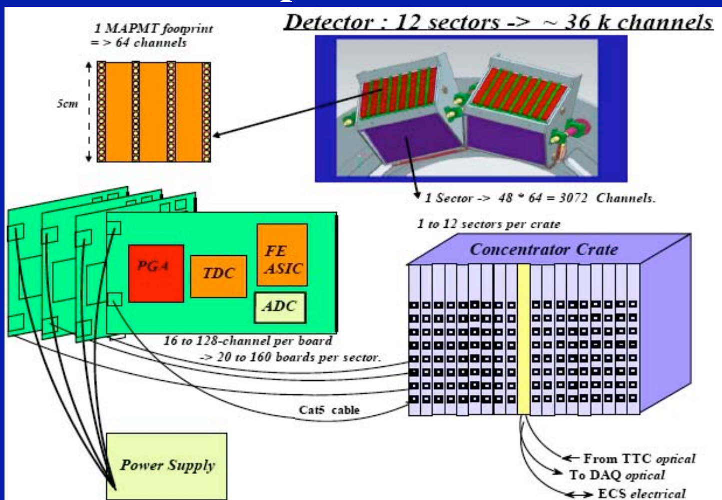


- **1 camera per bar box**
- **12 cameras to read the entire FDIRC**
- **~25x smaller total camera volume than what we had in BaBar DIRC**

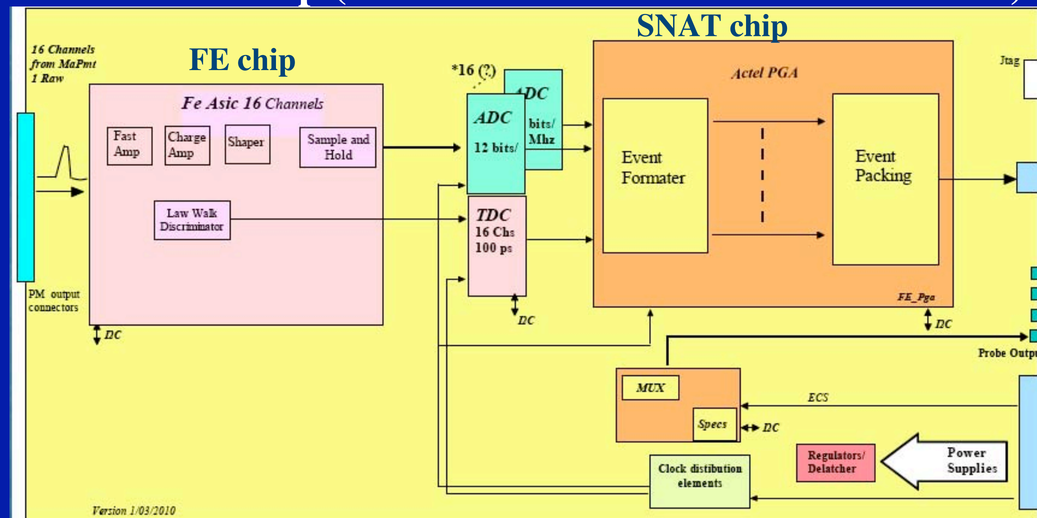
FDIRC TDC/ADC electronics

Christophe Beigbeder, electrical engineer from Orsay lab, France

Overall concept:



16-channel chip (takes care of one MaPMT connector):



- **FDIRC electronics is split in two parts:**
  - one directly mounted on the PMT receiving signals and processing it with TDC/ADC
  - the other one concentrates and pack all the channels to send data to the DAQ
- **Goals:**
  - **Max rate capability: ~2.5 MHz/pixel.**
  - **Double hit resolving time: ~ 50 ns.**
  - **$\sigma_{Electronics}$ ~ 100 ps, which allows to obtain σ_{Final} ~ 170-200 ps (H-8500).**

Conclusion

- **SuperB barrel FDIRC** has been designed with a camera made of solid Fused Silica. We are eagerly waiting for the SuperB approval to be able to proceed with the prototype.
- The detector will have **~10x better timing resolution** and **~25x smaller volume** compared to BaBar DIRC. This will be our main defense against the background at ~100x higher luminosities compared to BaBar (having quartz material, instead of water, also helps against the neutron background).
- **We generate the ring using the pixels only.** However, with a single photon resolution of ~170-200ps, FDIRC will **correct the chromatic error over most of the bar length.**
- **Time** plays a role to determine θ_c even in FDIRC, and **will be included in the final PID likelihood hypothesis.**