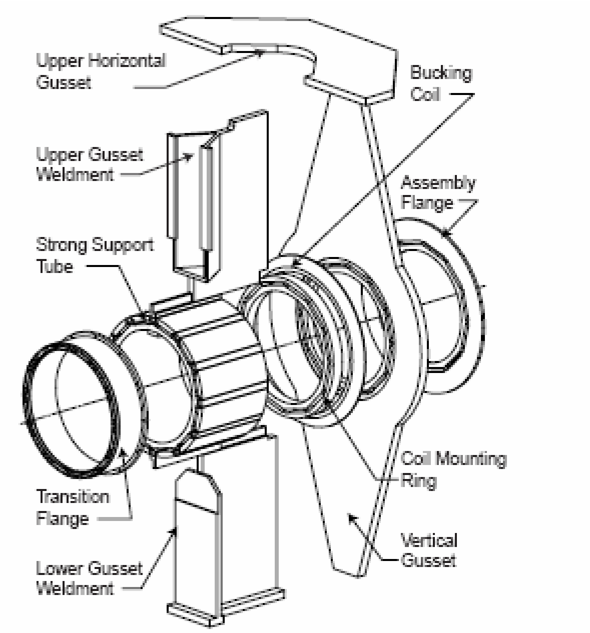
Simple considerations for the SOB Redesign for SuperB

Blair Ratcliff

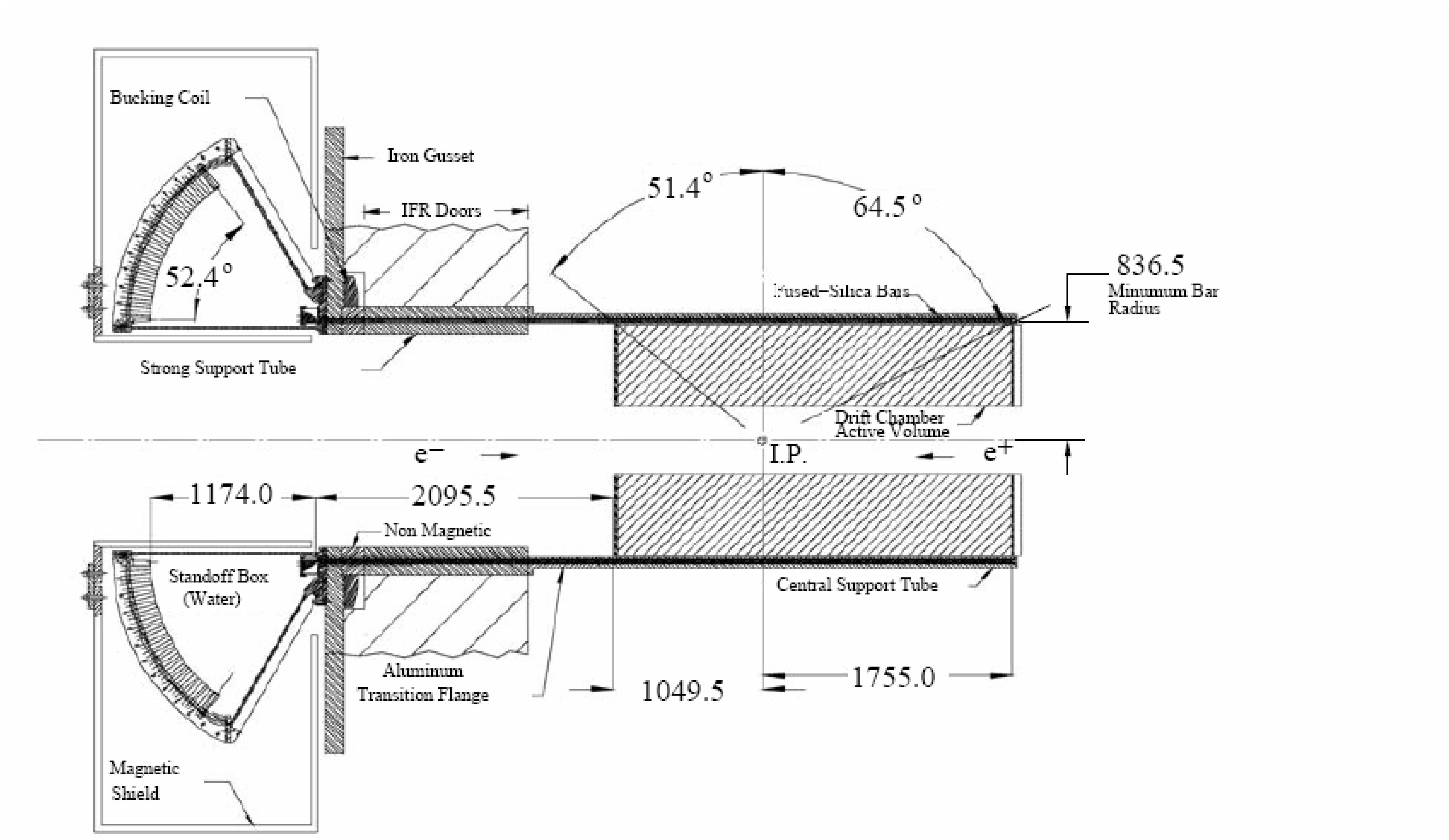
- Default CDR Redesign Assumptions
- Reminder- Babar Barbox design
- PMT candidates
- SOB Fill
- Imaging
- A look at some SOB options for the redesign
- Comments

Default Assumptions for SuperB Redesign (CDR version)

- **Retain intact BaBar DIRC Bar Boxes. (This means that we here assume that the wedge and window structure remain)**
- **Retained BaBar support structure (CST, SST, yoke etc)**
- **Build new SOB attached to the assembly flange. In principle, this could use any coupling medium, any type of focusing, any PMT, and could be one volume or modular (bar box by bar box).**

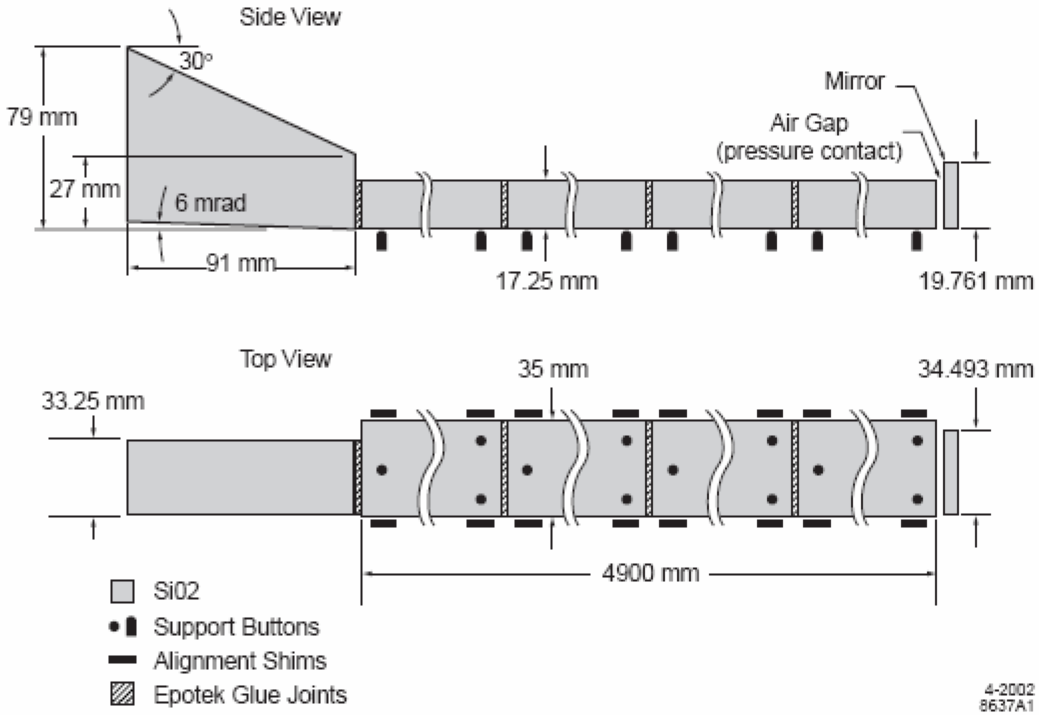


DIRC Barrel



Bucking Coil
Iron Gusset
IFR Doors
51.4°
64.5°
52.4°
836.5
Minumum Bar
Radius
Fused−Silica Bars
Strong Support Tube
Drift Chamber
Active Volume
e−
I.P.
e+
1174.0
2095.5
Non Magnetic
Standoff Box
(Water)
Central Support Tube
Aluminum
Transition Flange
1049.5
1755.0
Magnetic
Shield

DIRC Bars


Side View
30°
79 mm
27 mm
6 mrad
91 mm
17.25 mm
Mirror
Air Gap
(pressure contact)
19.761 mm
Top View
33.25 mm
35 mm
34.493 mm
4900 mm
Si02
Support Buttons
Alignment Shims
Epotek Glue Joints
4-2002
8637A1

Dirc Radiator components

Table 4
Production tolerances of DIRC radiator components.

Quantity	Specification	Primary Issue
	Bar Production	
Width	$35.000\ ^{+0.000}_{-0.500}$ mm	Mechanical
Thickness	$17.250\ ^{+0.000}_{-0.500}$ mm	Mechanical
Length	$1225.000\ ^{+0.000}_{-0.500}$ mm	Mechanical
Surface Roughness	better than 5 Å rms on sides and faces better than 20 Å rms on ends	Surface reflectivity Photon loss
Surface Flatness	flat to 0.1 mm over entire length	Angle smearing
Edge Sharpness	total area of chips less than 6 mm^2 per side	Photon loss
Squareness	0.25 mrad; rms of side-to-face angles better than 0.4 mrad	Angle smearing
Parallelism	parallel to 25 μm across the bar length	Angle smearing
	Mirror Production	
Width	$34.493\ ^{+0.000}_{-0.254}$ mm	Mechanical
Height	$19.761\ ^{+0.000}_{-0.254}$ mm	Mechanical
Thickness	$3.000\ ^{+0.000}_{-0.254}$ mm	Mechanical
Reflectivity	better than 92 % above 300 nm	Photon loss
	Window Production	
Length	437.00 ± 0.01 mm	Mechanical
Width	124.00 ± 0.01 mm	Mechanical
Thickness	9.576 ± 0.005 mm	Mechanical
Flatness	flat to 2.5 μm	Mechanical, gluing
Parallelism	parallel to 2.5 μm	Mechanical, gluing
	Wedge Production	
Length	91.00 ± 0.2 mm	Mechanical
Height	79.00 ± 0.01 mm 27.00 mm (reference)	Mechanical Mechanical
Width	$33.25\ ^{+0.00}_{-0.45}$ mm	Mechanical
Surface Roughness	20 Å	Surface reflectivity
Angles	60 degrees ± 1 minute of arc 90 degrees ± 1 minute of arc 6 mrad ± 1 minute of arc	Angle bias Angle bias Angle bias
Bevel	1 mm on 60 degree edge	Gluing

BaBar Optical Design and Implications for SuperB

“Optimized” Pinhole optical focusing design of BaBar implies significant Design Constraints in SuperB (assuming the reuse of intact BaBar Barboxes):

•52.4 deg in H_2O SOB ➔ 46 degrees total coverage in SiO_2 alpha (y) space…..Defined by wedge

•SOB Pinhole Z(y)= 1174 mm.

Pinhole Z(x)= 1083 mm

•6 mrad angle on wedge bottom. Rotates downward going photons by an additional 12 mrad inside the SiO2.

➔a slight under “focus” for the chosen standoff distance at 0 degrees in alpha(x). The under-focus gets worse as the standoff distance shrinks.

➔A significant limit to performance when used in a lens focused system.

•H20 fill ➔ magnification ➔ 1.474/1.34=1.1

PMT Candidates

Nominal "best" candidate is probably the H8500/H9500 Hamamatsu Flat Panel PMT or variants.

- Packing fraction is good (89%)….about the same as BaBar's effective array eff. with light catchers added (neglecting rib regions)
- Blue sensitivity is ~80-85% x BaBar's PMTs.
- Fast (~400 ps TTS (FWHM))
- "Conventional" PMT lifetime
- Commercial Production Scale
- Cost ~1.6 K$/ea.
- Coupling to a liquid medium could be a challenge.
- Versions with 3x3mm (256) or 6x6 mm(64)pixels, Can make rectangular pixels to keep down channel count (e.g. 3x12mm)

HAMAMATSU

FLAT PANEL TYPE MULTIANODE PHOTOMULTIPLIER TUBE ASSEMBLY

H9500, H9500-03

52 mm Square, Bialkali Photocathode, 12-stage,
16 × 16 Multianode, Small Dead Space, Fast Time Response

APPLICATIONS

- Small Animal Imaging
- Compact Gamma Camera
- Scinti-mammography
- 2D Radiation Monitor

SPECIFICATIONS

GENERAL

Parameter		H9500	H9500-03	Unit
Spectral Response		300 to 650	185 to 650	nm
Peak Wavelength		400		nm
Photocathode Material		Bialkali		—
Window	Material	Borosilicate glass	UV glass	—
	Thickness	1.5		mm
Dynode	Structure	Metal channel dynode		—
	Number of Stages	12		—
Number of Anode Pixels		256 (16 × 16 matrix)		—
Pixel Size / Pitch at Center		2.8 × 2.8 / 3.04		mm
Effective Area		49 × 49		mm
Dimensional Outline (W × H × D)		52 × 52 × 33.3		mm
Packing Density (Effective Area / External Size)		89		%
Weight		177		g
Operating Ambient Temperature		0 to +50		°C
Storage Temperature		-15 to +50		°C

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter	H9500	H9500-03	Unit
Supply Voltage (Between Anode to Cathode)	-1100		V
Average Anode Output Current in Total	100		µA
Divider Current at -1100 V	180		µA

CHARACTERISTICS (at 25 °C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous Ⓐ	50	60	—	µA/lm
	Blue Sensitivity Index (CS 5-58) Ⓑ	8.0	9.5	—	—
Quantum Efficiency at 420 nm		—	24	—	%
Anode Sensitivity	Luminous Ⓒ	—	90	—	A/lm
Gain Ⓒ		0.5×10^6	1.5×10^6	—	—
Anode Dark Current per Channel Ⓓ		—	0.05	—	nA
Anode Dark Current in Total Ⓓ		—	13	50	nA
Time Response Ⓔ	Rise Time Ⓕ	—	0.8	—	ns
	Transit Time Ⓖ	—	6	—	ns
	Transit Time Spread (FWHM) Ⓗ	—	0.4	—	ns
Pulse Linearity per Channel (±2 % deviation)		—	0.2	—	mA
Anode Uniformity (Condition Figure 3)		—	1: 4	1: 6	—
Cross-talk Ⓘ		—	5	—	%

NOTES

Ⓐ: The light source is a tungsten filament lamp operated at a distribution temperature of 2856 K. Supply voltage is 150 volts between the cathode and all other electrodes connected together as anode.

Ⓑ: The value is cathode output current when a blue filter(corning CS 5-58 polished to 1/2 stock thickness) is interposed between the light source and the tube under the same condition as Note Ⓐ.

Ⓒ: Measured with the same light source as Note Ⓐ and with the anode-to-cathode supply voltage and voltage distribution ratio shown in Table 1 below.

Ⓓ: Measured with the same supply voltage and voltage distribution ratio as Note Ⓒ after 30 minutes storage in darkness.

Ⓔ: Those are test data when a signal from a central channel of 256 anodes is used, while all photocathode are illuminated by pulsed light source.

Ⓕ: The rise time is the time for the output pulse to rise from 10 % to 90 % of the peak amplitude when the whole photocathode is illuminated by a delta function light pulse.

Ⓖ: The electron transit time is the interval between the arrival of delta function light pulse at the entrance window of the tube and the time when the anode output reaches the peak amplitude. In measurement, the whole photocathode is illuminated.

Ⓗ: Also called transit time jitter. This is the fluctuation in electron transit time between individual pulses in the single photoelectron event, and defined as the FWHM of the frequency distribution of electron transit time.

Ⓘ: Supply Voltage: -1000 V   Light Source: Tungsten filament lamp + blue filter (corning CS 5-58 polished to 1/2 stock thickness)
Aperture Size: Approx. 2 mm × 2 mm
One anode is illuminated through the aperture and the output of the adjacent anodes are calculated as relative value, with 100 % being equal to the output of the illuminated anode. The cross-talk is the relative value of the adjacent anodes expressed in %.

Table 1: Voltage Distribution Ratio and Supply Voltage

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	GR	P
Distribution Ratio	1	1	1	1	1	1	1	1	1	1	1	1	0.9	0.1	

Supply Voltage: -1000 V,   K: Cathode,   Dy: Dynode,   GR: Guard Ring   P: Anode

Figure 1: Typical Spectral Response

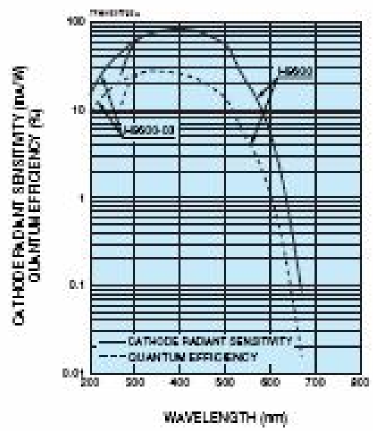


Figure 2: Typical Gain Characteristics

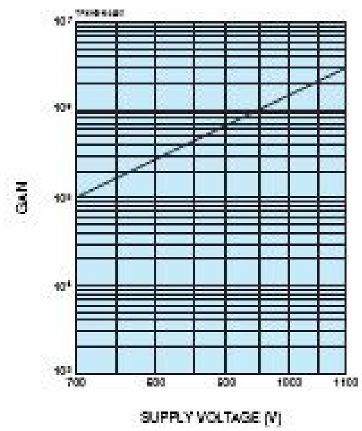
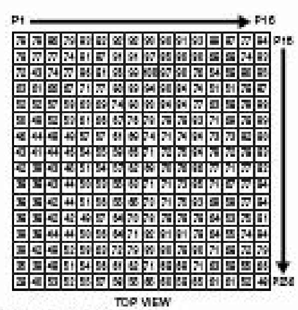
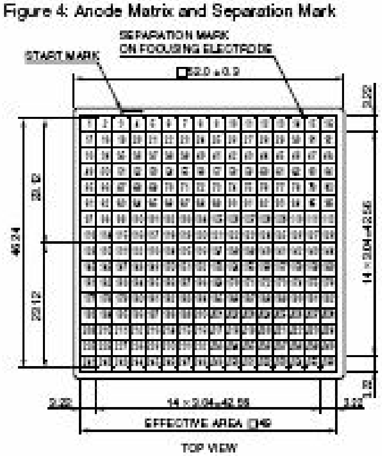


Figure 3: Anode Uniformity (Example)



SUPPLY VOLTAGE: -1000 V
LIGHT SOURCE: TUNGSTEN LAMP with BLUE FILTER (DC LIGHT)
SPOT ILLUMINATION (APERTURE SIZE): 3 mm square on each channel

Figure 4: Anode Matrix and Separation Mark



The start mark and the separation marks are put on an electrode plate inside.

SOB Coupling Material-I

Some issues for SiO_2 vs. H_2O vs. Mineral Oil vs. Air

- ***Refractive Index***
  - Fresnel Cutoff angle (90, 65, ~90, 43 deg)➔ Reduced number of photons and significant additional dip angle dependence of photon number
  - Magnification (1, 1.1, 1, 1.47)➔ Scales SOB Z by 1/M for pinhole focusing (Number of pixels is ~ constant for constant resolution)
  - Dispersion at media interface (a significant effect only for air)
- ***Transmission***
  - UV cutoff for Mineral Oil ~330 nm (Oil and processing dependent)
  - May want to cutoff UV to reduce group dispersion if using time imaging, but reduces # photons. May want to use a different photocathode, and a sharp cutoff filter instead of relying on Oil cutoff.
- ***Backgrounds***
  - Air is certainly the lowest background fill for both neutrons and gammas.
  - Scintillation light probably small for all materials as long as they are cleaned
  - Good Neutron efficiency undesirable so worst to best is **(H_2O > Mineral Oil > SiO2 >Air)**
  - Short radiation length not desirable so worst to best is (**SiO_2 > H_2O > Mineral Oil >Air)**

SOB Coupling Material-II

Some issues for SiO_2 vs. H_2O vs. Mineral Oil vs. Air

- ***Cost/ Availability***
  - Cost of Mineral oil/ Water/Air fills are essentially the cleaning and flow systems. Mineral Oil costs about $10 gallon.
  - SiO_2 projected cost about $350/kg. A 40 x 50 x 50 cm focusing block ➔ 220 KG ➔ 77K$ (~1 M$ for the SOB fill material plus fabrication costs). The largest block that seems to be available is ~ 25 cm in the smallest dimension (Corning 7980 Dave Navan (315-379-3661) Navand@corning.com, and there are is likely some index periodicity perpendicular to this dimension. So joints are likely necessary perpendicular to Z in the standoff block

- ***Design/Operations:***
  - **Fluid coupling to PMTs?**
  - **Modular vs. open SOB?**
  - **Compact designs easier to shield**
  - **Fluids can leak. Need a flow system (with purification?).**
  - **Direct coupled systems optically stable, but mechanical support may be tricky**

Some Properties of Coupling Materials

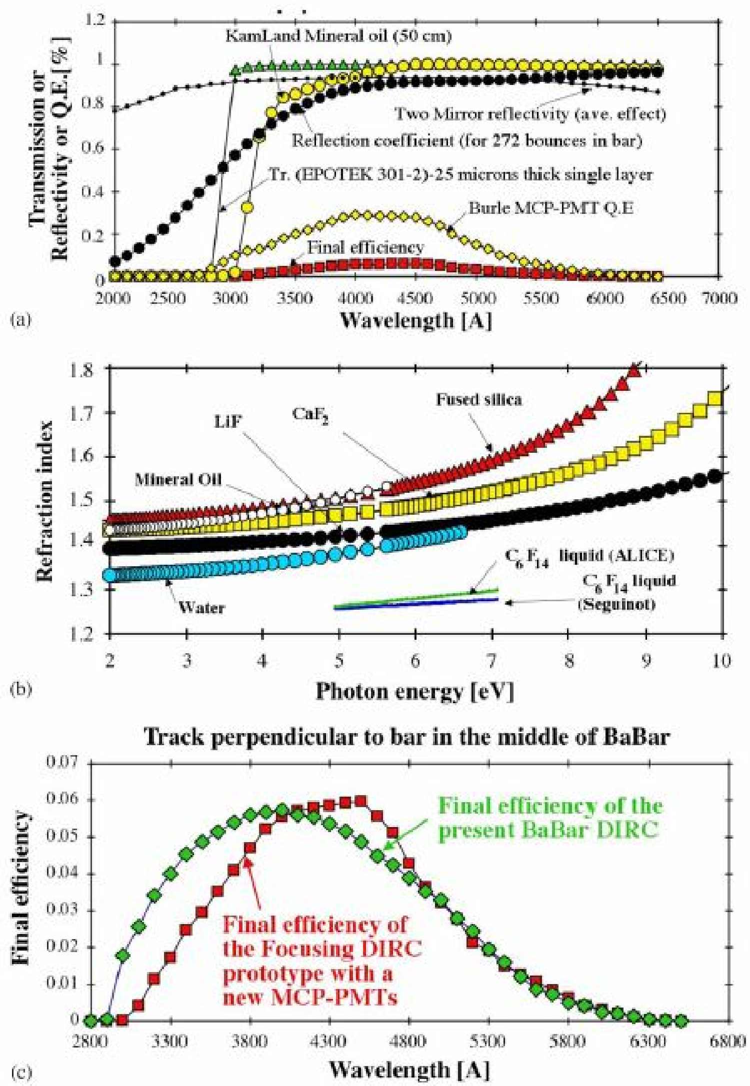


Fig. 2. (a) Various efficiencies in the focusing DIRC prototype if placed into BaBar, assuming that we take Burle MCP–PMT quantum efficiency [4]. (b) Refraction index of several materials, including water, mineral oil and fused silica. (c) An estimate of the relative final detection efficiency of the focusing DIRC prototype and the present BaBar DIRC, assuming that we would build the focusing DIRC according to Fig. 1, i.e., including the KamLand mineral oil transmission, Burle's recently quoted MCP–PMT QE, and the best present estimate of future MCP–PMT collection and boundary efficiencies by Burle (see Table 1).

Different DIRC Imaging Schemes

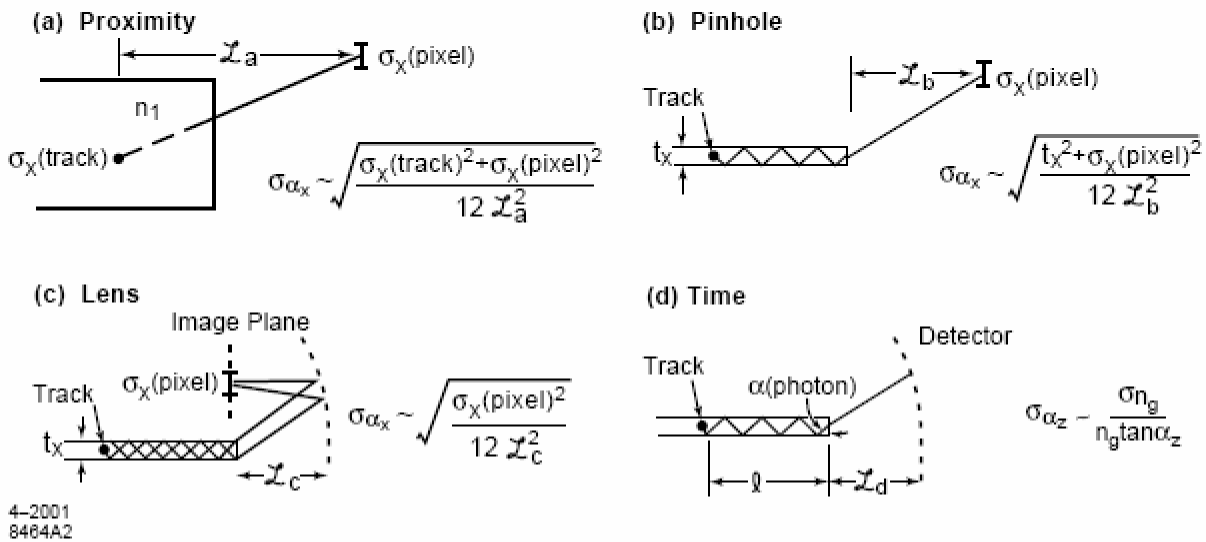


Figure 3. Illustrations of four different DIRC imaging schemes: (a) proximity (b) pinhole (c) lens (d) time. Simple estimates of the imaging and detector part of the resolution obtained on the photon angle in the projection shown are noted for each scheme. These estimates should be treated as pedagogic approximations. For simplicity, all position and detector resolutions are treated as though they are pixelized, and the indices of refraction of the Cherenkov radiator and the imaging region are taken to be the same. The time dimension resolution estimate (d) is given for the dispersion limiting case where the time measurement resolution itself is not the limiting factor. Sec. 4.3 describes the more general case.

We will likely use either pinhole in 2-d or lens imaging in 1-d plus pinhole in the other (+ time). With the H8500 timing resolution, the effective angular resolution from timing is close to the dispersion limit over most of the DIRC phase space.

Comments on Nominal versus “real” resolutions

• An actual system is in 4-D (3-D space + time), with correlations between dimensions. (Note that in our usual language we say the DIRC is a 3-d imaging system- 2 in space (2-d imaging) plus one in time.)

• Transport is non-linear (sometimes highly so), especially at media interfaces.

• Geometry is non-linear.

• Focusing systems have optical aberrations that vary as a function of angles. Bars images have periodic structure (Kaleidoscope effect).

• Resolution can be quite non-Gaussian.

• Translation between resolution in measurement space and Cherenkov space is angle dependent and non-linear.

➔ None the less, much can be learned from nominal considerations, especially by comparing different schemes. (Note also that actual BaBar resolutions can be understood at the 10% level or better in this manner). Of course, eventually a fully correlated study needs to be done to make certain all regions have adequate performance.

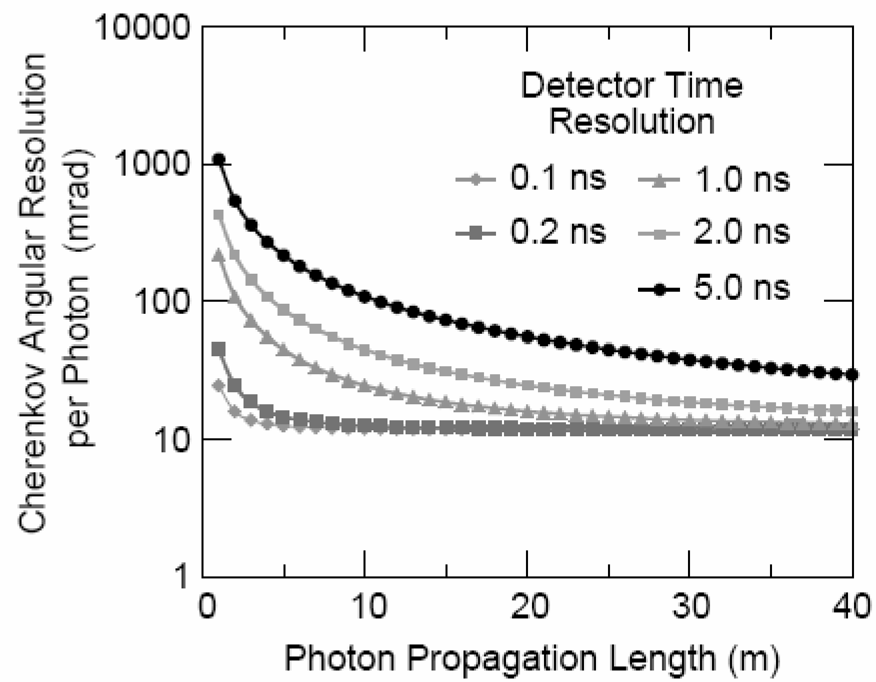
Using timing to measure angles

Good news:

(1) With H8500-like timing resolution, the effective angular resolution from timing is close to the dispersion limit over most of the DIRC phase space.

(2) My calculation (in this model) seems pessimistic compared to our prototype measurements (We get ~2/3 the resolution predicted here in the FDIRC prototype). This is thought to be mostly because the bandwidth is cutoff in the UV compared to my calculation here that used DIRC PMT response.

➔ Competitive time imaging probably requires UV cutoff above 340 nm or so.



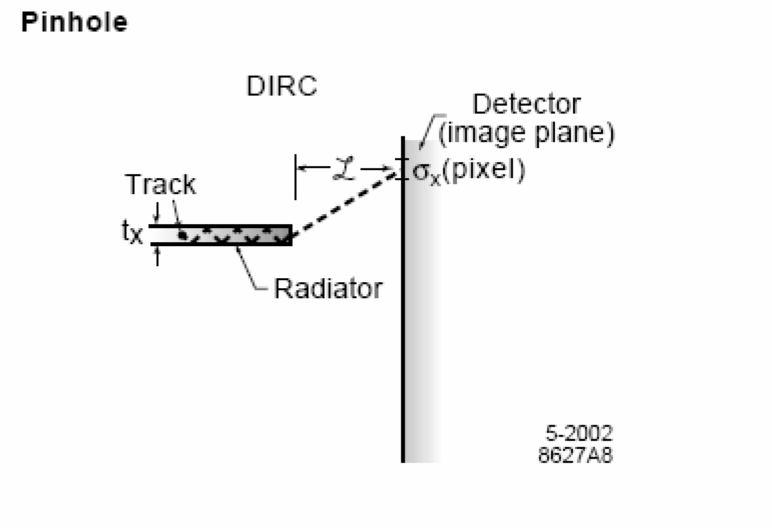
Bad News:

The Cherenkov Angular resolution goes like 1/tan ($\alpha(z)$), which is fairly close to infinity for k_x=0 photons near the front of the bar where the fast tracks are concentrated.

Nominal BaBar Angle Resolution (y)

$$\sigma(\alpha_{\mathrm{y}}) \approx \frac{\sqrt{\sigma^2(t_y)+\sigma^2(pmt)}}{ML_y}$$

$$\approx 7.2mrad$$

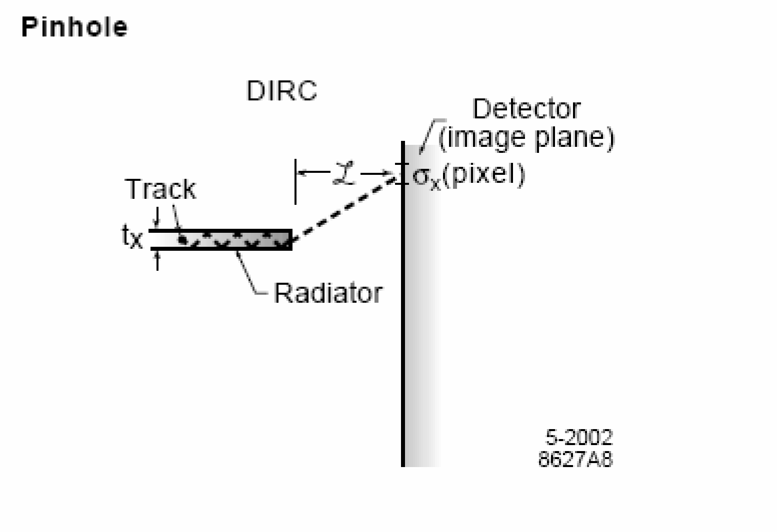


Where M = 1.1, L_y= 1174 mm,
σ(pmt)= 31/sqrt(16)=7.75
σ(t_x)= sqrt(17.25^2/12+(3.25/2)^2)=5.2 mm
where the last term ((17.25-0.012*L_y)/2) accounts for the under-focusing from the wedge.

Nominal BaBar Angle Resolution (x)

$$\sigma(\alpha_x) \approx \frac{\sqrt{\sigma^2(t_x)+\sigma^2(pmt)}}{ML_x}$$

$$\approx 10.4\ mrad$$



At x=0, where M = 1.1, L_x= 1083 mm,
σ(pmt)= 31/sqrt(16)=7.75
σ(t_x)= sqrt(33.25^2/12)=9.6 mm

•Note that the pinhole width here is the wedge width (not the bar width). At alpha(x) =0, alpha(x) resolution plays no role in Theta_c resolution, but it begins to play a significant role at larger alpha(x) value. With BaBar's toroidal PMT geometry, the behavior versus alpha(x) is complex but in first order the resolution improves like 1/cos(α_x).

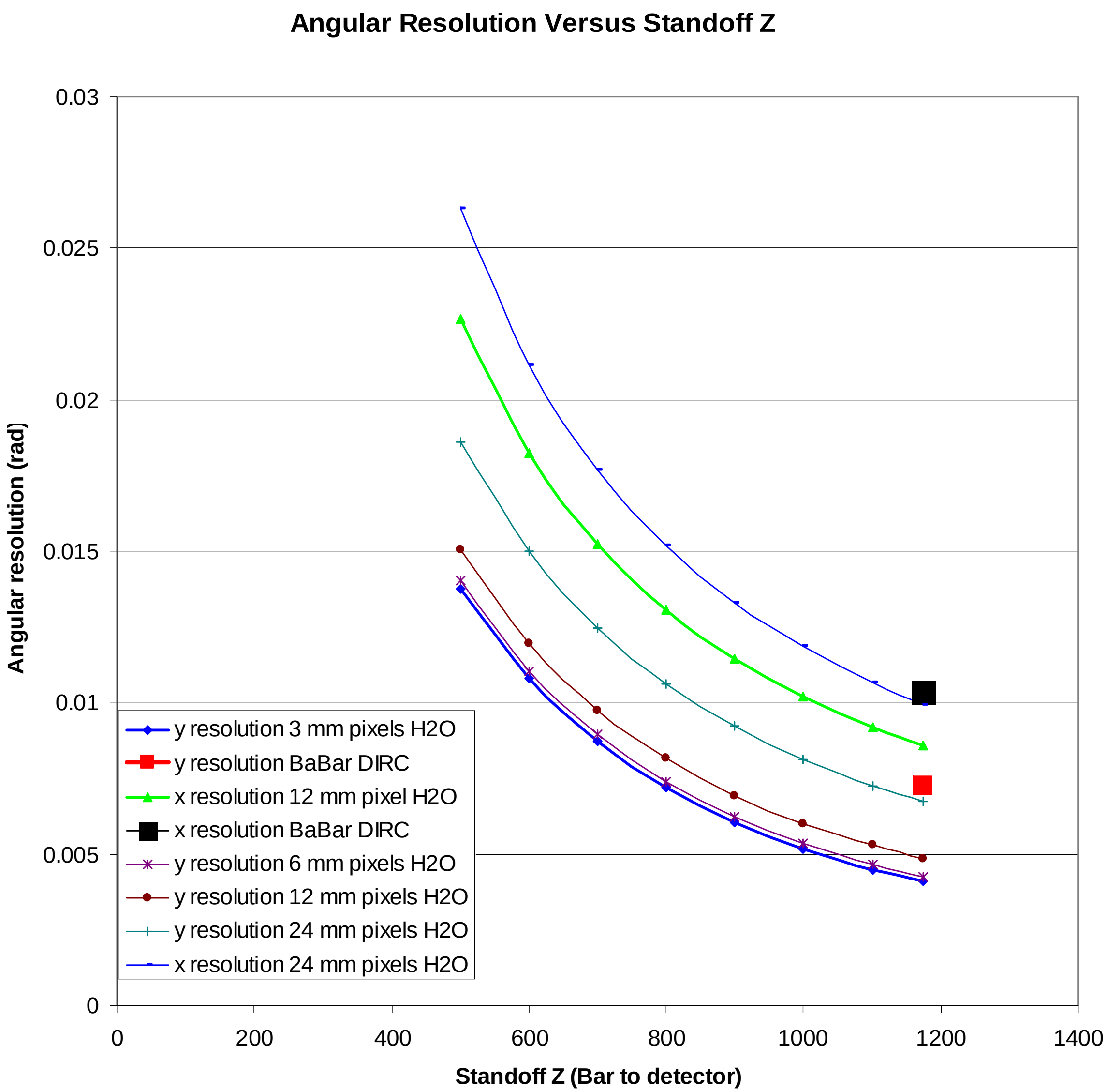
Some SOB redesign examples

- 2-d pinhole
- focused in y, pinhole in x
- resolution optimized “under-focused” in y, pinhole in x.

(this means that the detector is located at a distance that is smaller than the lens focusing distance at a position where the upward and downward going images overlap)

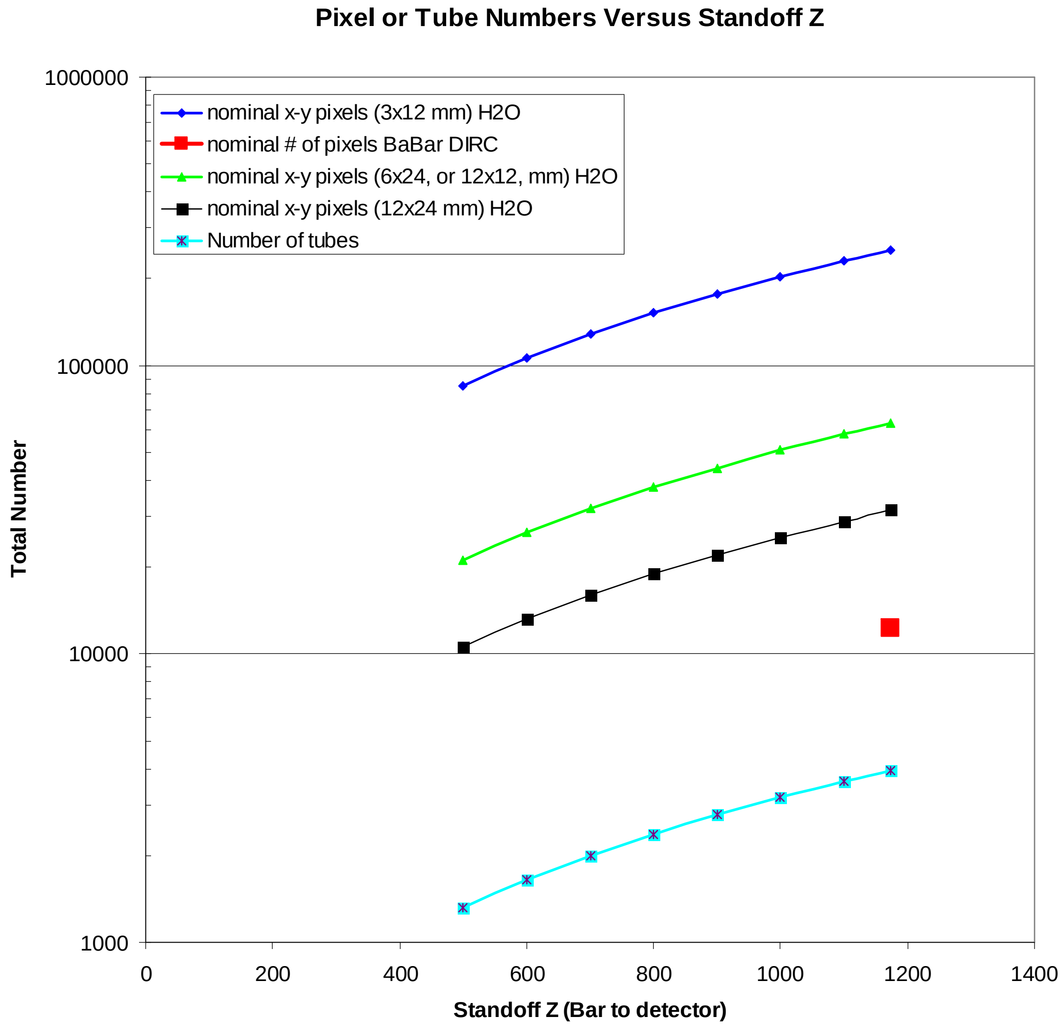
Note that the time dimension is not included in the estimates

x/y Pinhole angular resolution versus standoff z



- H_2O Fill
- Open SOB

Pixel/Tube Counts for 2-d Pinhole



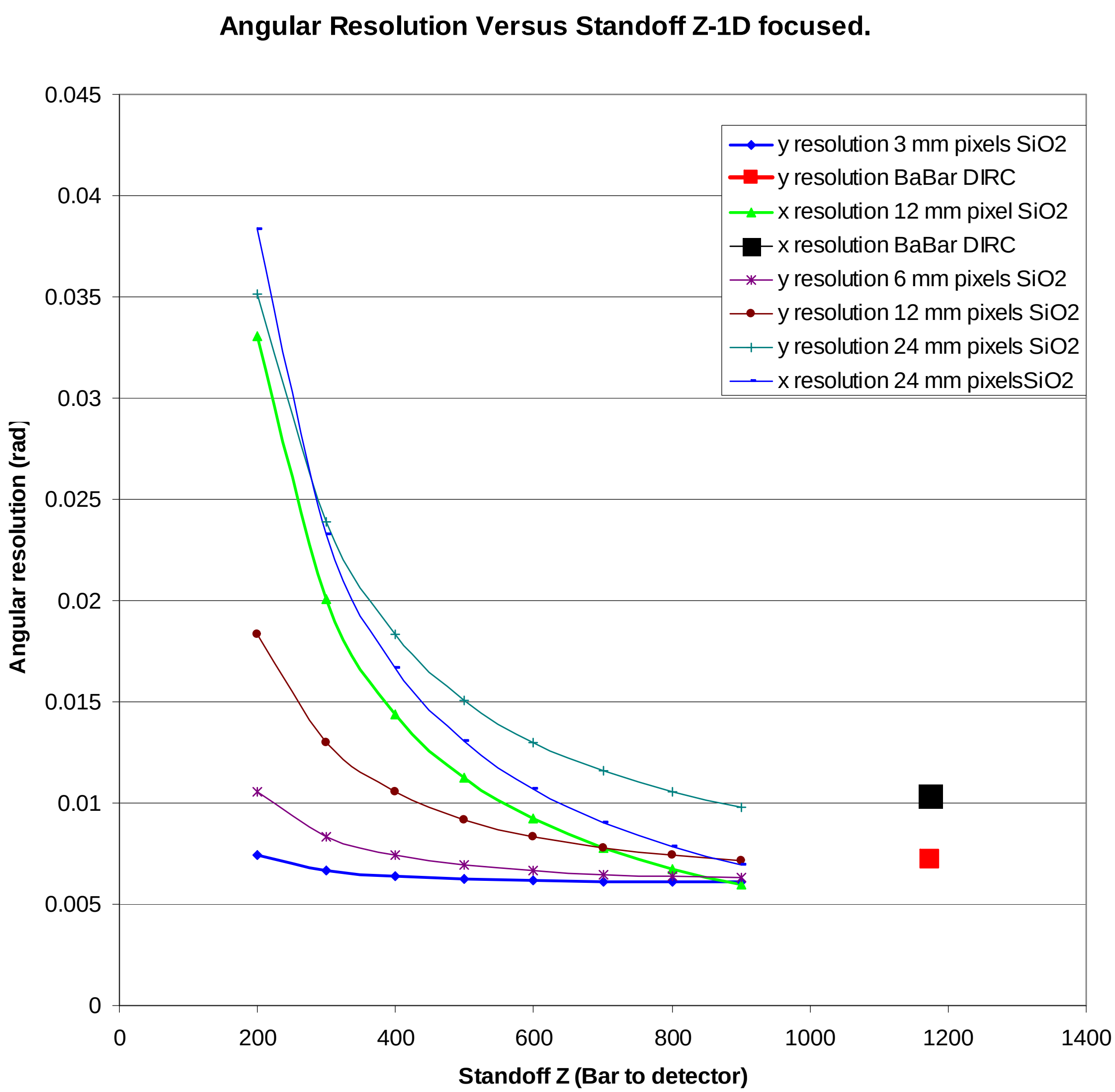
A reasonable choice might be Z=900 mm

So that nominally (BABAR)

1) 12x 12 (31 hex)mm pixels
2) σ(y)~ 6.9 (7.2) mrad
3) σ(x) ~11.4 (10.4) mrad
4) σ(t)~150 (1500) ps is a bonus for angle
5) 2762 tubes with 44K pixels.
6) Volume SOB ratio compared to BaBar ~0.6

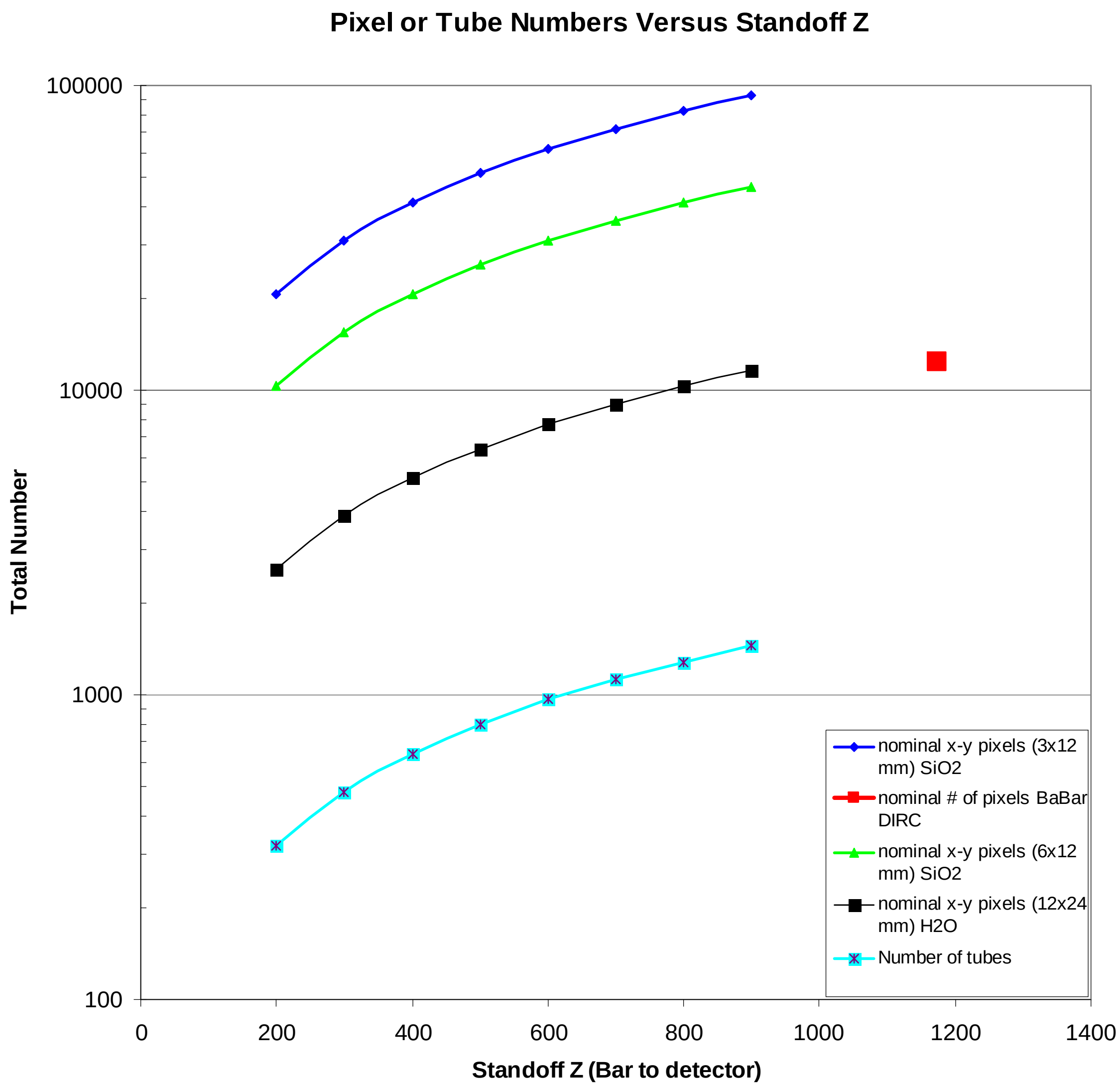
➔ expect ~ 20x better against backgrounds.

x/y angular resolution (1-d focused in y, pinhole in x) versus standoff z



- 12 SIO_2 Focusing Blocks attached to front of present Barboxes
- Fully Modular
- Symmetric Standoff assumed. Mirror to bar assumed equal to focal distance. Detector at 1-d focus
- Note that resolution in y is dominated by 6 mrad wedge rotation for downward going photons

Pixel/Tube Counts for 1-d y focused system with x pinhole



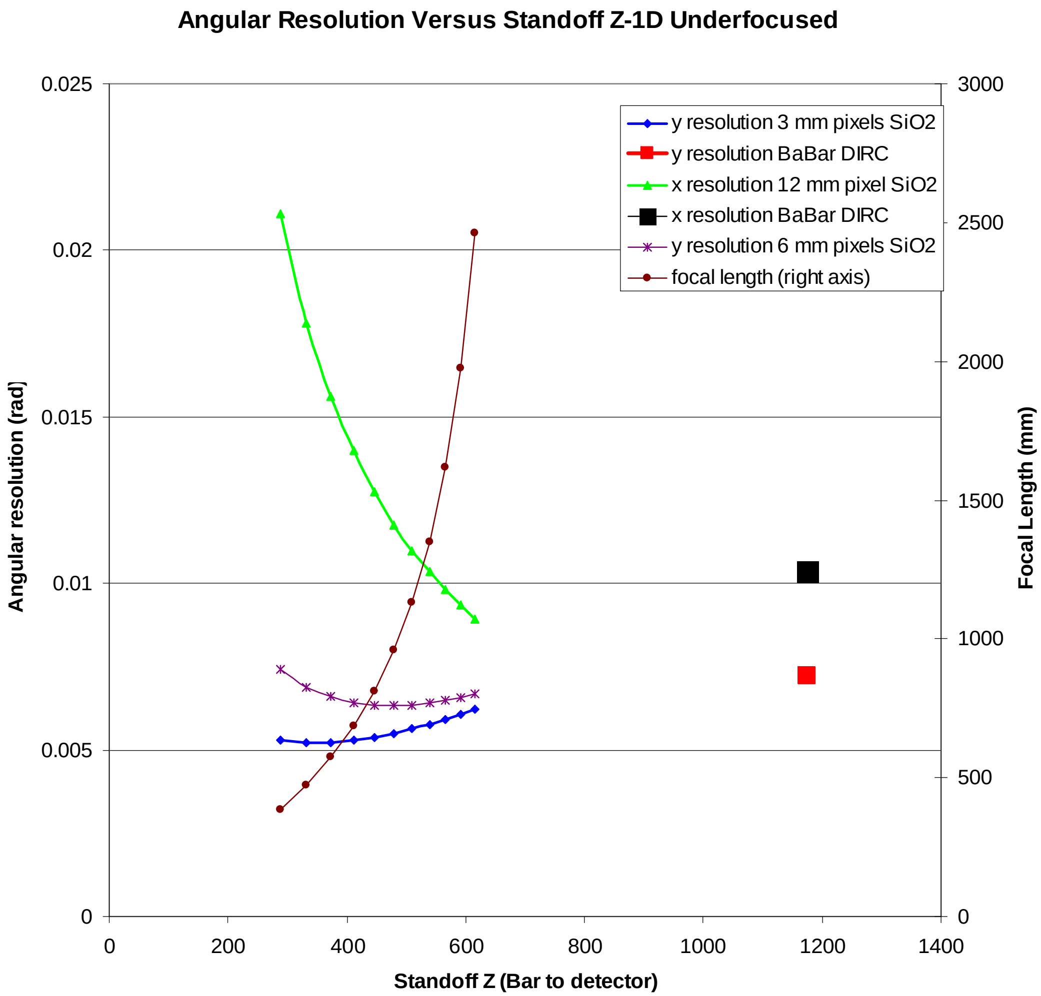
A reasonable choice might be f=z=500 mm

So that nominally (BABAR)

1) 6x 12 (31 hex)mm pixels
2) σ(y)~ 6.9 (7.2) mrad
3) σ(x) ~11.2 (10.4) mrad
4) σ(t)~150 (1500) ps is a bonus for angle
5) Nominal 800 tubes with 26K pixels. Probably need ~10% to more to account for finite tube size.
6) Volume SOB ratio compared to BaBar ~0.13 (but SiO2 versus H2O)

➔ expect ~ 80x better against backgrounds.

x/y angular resolution (1-d optimized under focused in y, pinhole in x) versus standoff z



- 12 SIO_2 Focusing Blocks attached to front of present Barboxes
- Fully Modular
- Symmetric Standoff assumed. Mirror to bar assumed equal to focal distance. Detector at optimzed1-d position for minimum resolution.
- Note that resolution in y is slightly improved at same standoff Z compared to detector at focus. Does this help in x as well????

Pixel/Tube Counts for 1-d y under-focused system with x pinhole

A reasonable choice might be the same as the 1-d focused system f=z=500 mm

So that nominally (BABAR)

1) 6x 12 (31 hex)mm pixels
2) σ(y)~ 6.4 (7.2) mrad
3) σ(x) ~11.2 (10.4) mrad
4) σ(t)~150 (1500) ps is a bonus for angle
5) Nominal 800 tubes with 26K pixels. Probably need ~10% more to account for integer number of tubes/module.
6) Volume SOB ratio compared to BaBar ~0.13 (but SiO2 versus H2O)

➔ expect ~ 80x better against backgrounds.

Concluding Remarks

•Need to do full studies in a program that handles the full 4-d problem with aberrations.

•Should really be looking at $\sigma(\theta_c)$ rather than the linearized 1-d space angular resolutions. However, the naïve approach does get BaBar's resolution about right.

• A slightly longer wavelength effective detector bandwidth (and/or cutting off UV somewhat above 300 nm) is probably beneficial. Comes ~ naturally with oil coupling.

•Keeping BaBar Bar Boxes intact seems ~ reasonable, but it does limit attainable performance. Other considerations (e.g., ageing or bar cleanliness) may force another decision.

• A SIO_2 modular structure seems feasible. Is it worth the cost?

• An optimized under-focused system in both x and y might be promising.