Focusing DIRC prototype

J. Va'vra, SLAC

Present collaborators:
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Plan of this talks

- **Summary of the prototype status**
- **Principle of DIRC-like detectors :**

  (BaBar DIRC, Focusing DIRC prototype, TOP counter, Ultimate DIRC)
- **Focusing DIRC prototype design parameters:**

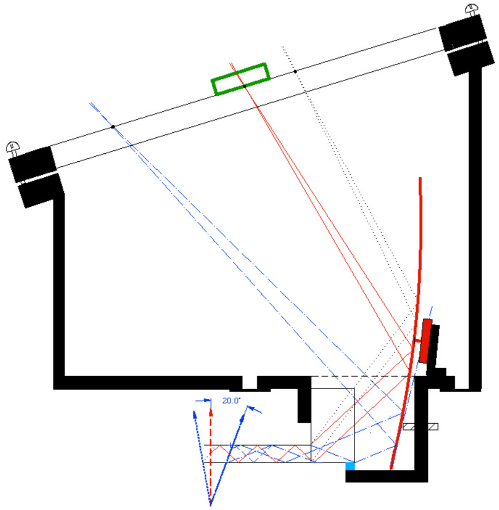
  (Optical design, mechanical design, etc.)
- **Methods of testing:**

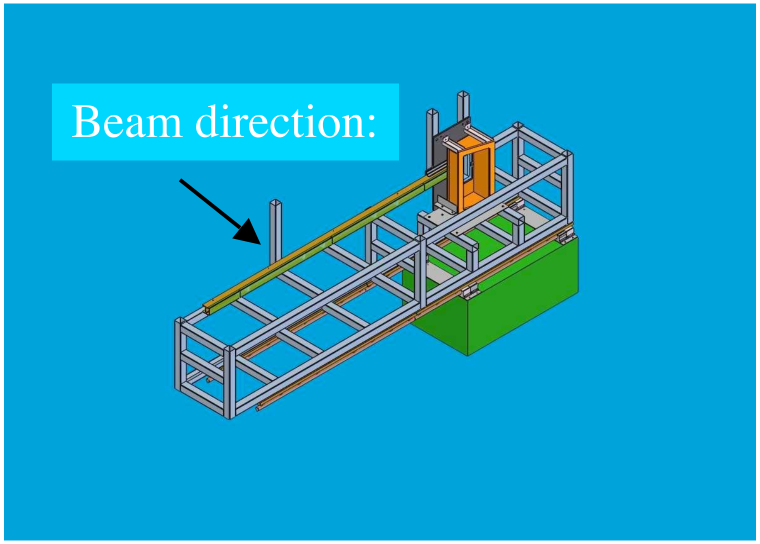
  (New timing laser diode, APDs to evaluate it, scanning setup, etc.)
- **Electronics:**

  (Amplifier, Constant fraction discriminator, TDC, etc.)
- **Results with new detectors:**

  (Flat Panel H-8500, MCP-PMT, gaseous detectors ?)

Focusing DIRC prototype concept

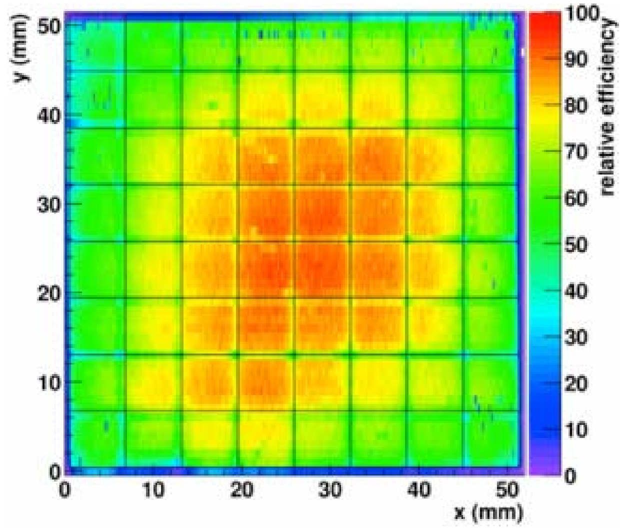


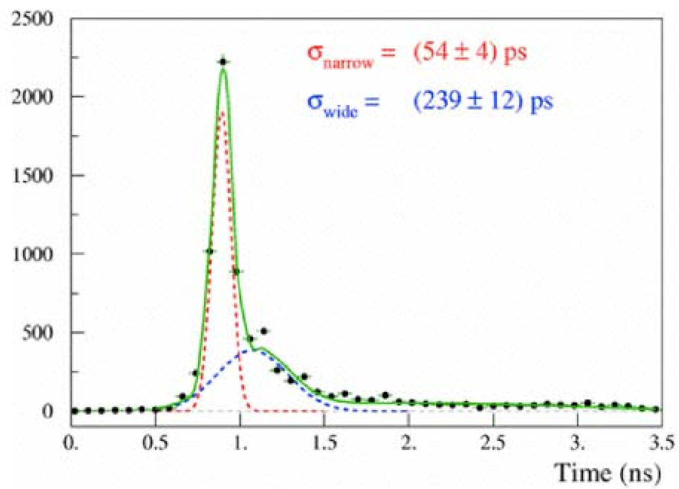


- **3D imaging:** x,y, and TOP
  (TOP = time-of-propagation of photon in the bar)
- **TOP is measured to σ <100ps**, which allows:
  a) to get the 3-rd dimension, and
  b) to correct out the chromatic error contribution to the Cherenkov angle error.
- **Spherical mirror** removes a thickness of the bar from the resolution consideration.

Focusing DIRC prototype status

Burle MCP-PMT:





- **The main accomplishments so far:**

  a) New photon detectors tested:
  - Burle MCP-PMT
  - Hamamatsu Multi-anode H-8500 PMT.

  b) Developed a methodology to measure the timing resolution to < 100ps for single photon, and the relative response across the PMT face.

  d) Developed new electronics.

  e) Designed optics of the prototype.

  f) Prototype's mechanics is almost finished.

- **Long road still ahead … :**

  a) Actual tests in the cosmic ray telescope, and then in the test beam.

  b) Learn how to correct the chromatic effects.

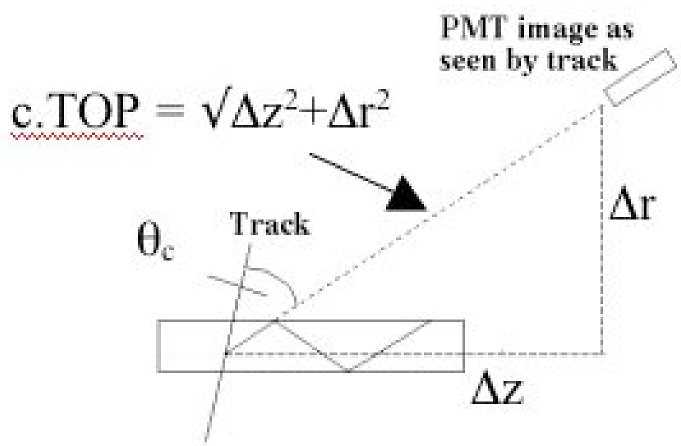
  c) Aging tests of MCP-PMT detectors.

  d) Improve efficiency of MCP-PMT detectors.

  e) Tests in the magnetic field of 1.5 Tesla.

  f) Design a final electronics, etc.

DIRC principle



- A concept invented by B. Ratcliff
- $\mathbf{TOP(\Phi,\theta_c) = [L/v_g(\lambda)]\, q_z(\Phi,\theta_c)}$

  θ_c - Cherenkov angle,

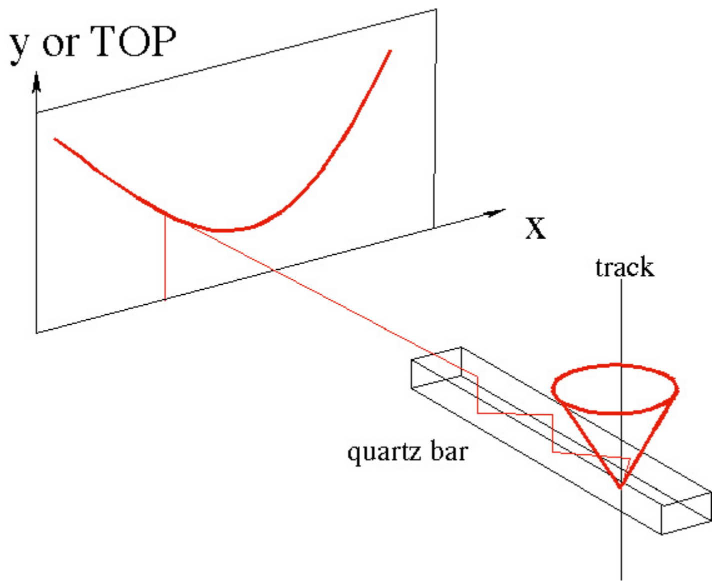
  L - distance of light travels in the bar,

  $v_g(\lambda)$ - group velocity of light,

  λ - wavelength , and

  $q_z(\Phi,\theta_c)$ - z-comp. of the unit velocity vector.
- To determine the Cherenkov angle θ_c, one measures (a) a track position, (b) a photon time-of-propagation (TOP), and Δz and Δr ($\equiv \Delta y$). This <u>over-determines</u> the triangle.
- In the present BaBar DIRC, the time measurement is not good enough to determine the Cherenkov angle θ_c. The time is, however, used to reduce the background.

DIRC-like detectors



- **DIRC-like detectors** are detectors which are using the internally reflected Cherenkov light, as opposed to CRID, which used the transmitted light.
- The DIRC-like concept uses a "pinhole" geometry, where the bar's exit area, together with a photon detecting pixel position, define the photon exit angles in 2D; the time and the track position defines the 3-rd coordinate if time is measured well enough (<100ps).
- **Differences in imaging methods:**

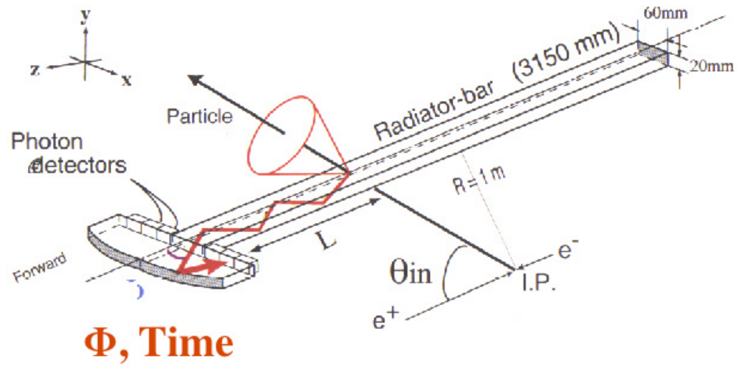
  BaBar DIRC: x & y

  Focusing DIRC prototype: x & y & TOP

  TOP counter: x & TOP

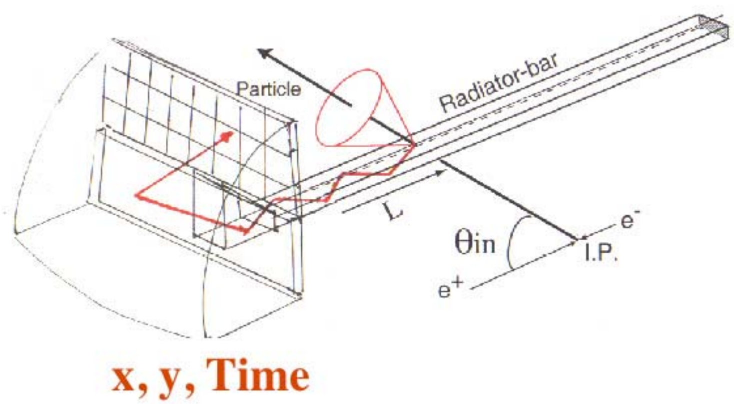
Examples of two "DIRC-like" detectors

TOP counter with a mirror (Nagoya):



- **2D imaging:**
  a) x (gives Φ angle)
  b) TOP (σ < 80ps).

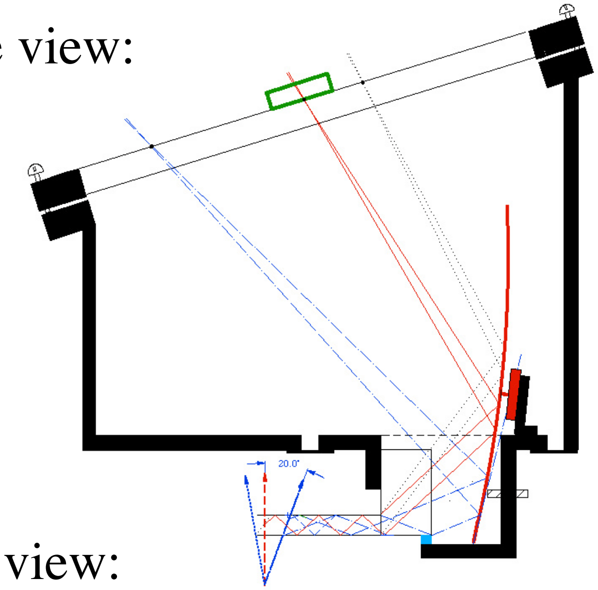
Focusing DIRC prototype (SLAC):



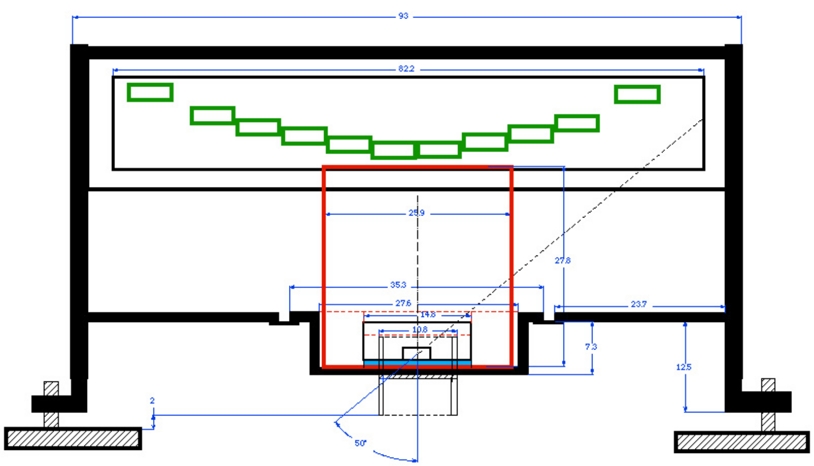
- **3D imaging:**
  a) x-coordinate
  b) y-coordinate
  c) TOP (σ < 100ps).

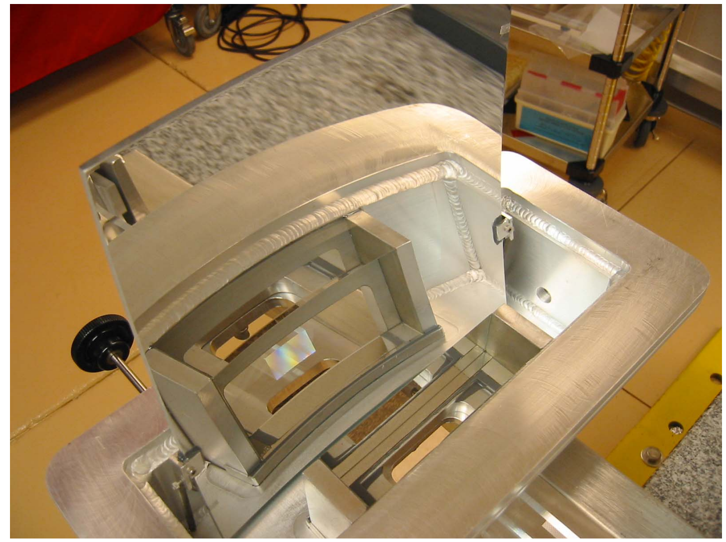
Focusing DIRC Prototype almost finished

Side view:

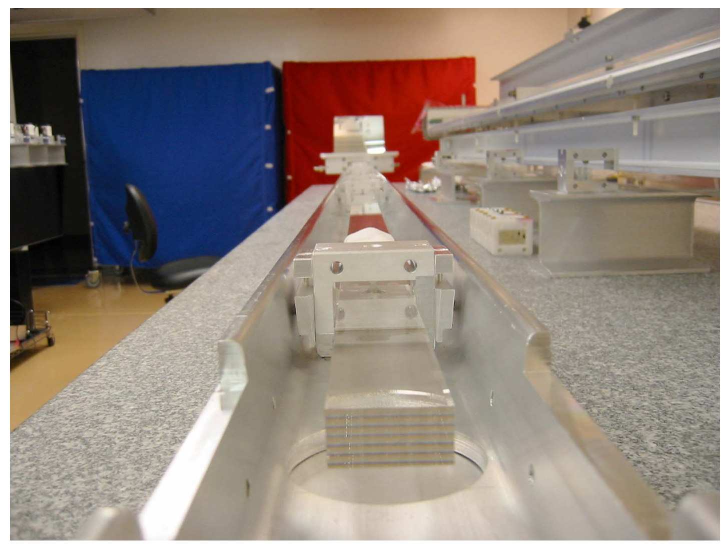


Back view:



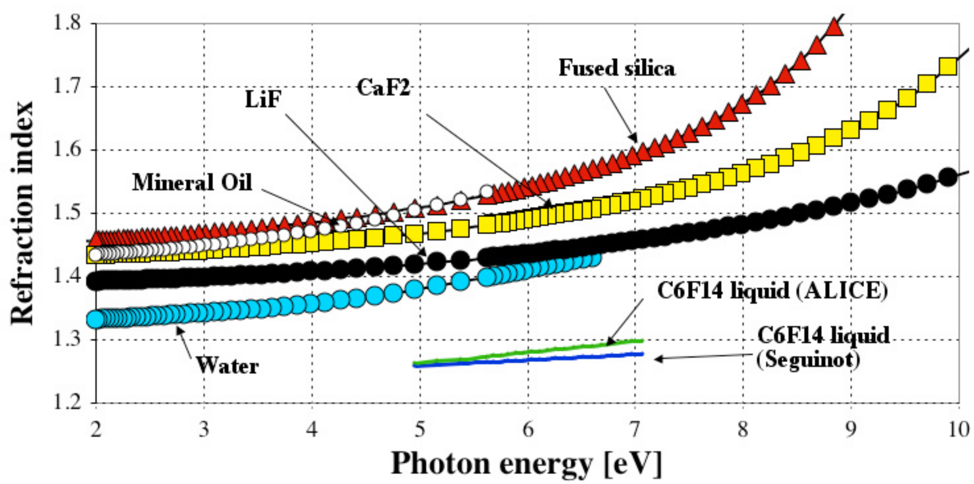


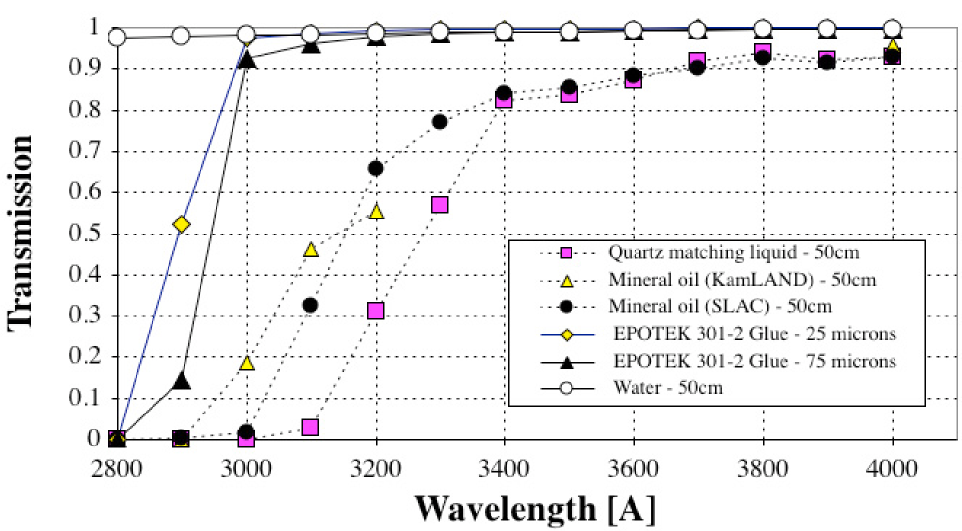
CRID Spherical mirror



3.66m long BaBar DIRC bar

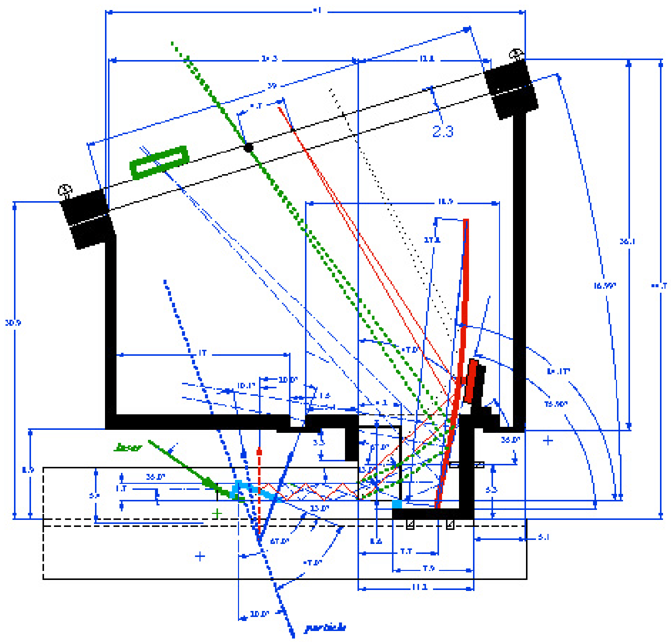
What matching liquid to use in the box ?



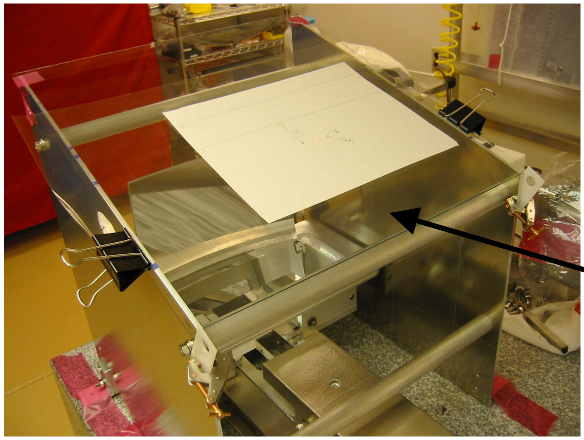


- KamLand experiment mineral oil is good match to Fused silica refraction index.
- However, its transmission is worse than that of water.
- No purification attempted yet at SLAC.
- In BaBar DIRC, it is the EPOTEK-301-2 optical glue which limits the bandwidth.
- The mineral oil is a temporary solution, as the final mirror of the Focusing DIRC would be made of solid Fused silica, probably.
- The impact of the mineral oil transmission on efficiency will be discussed later.

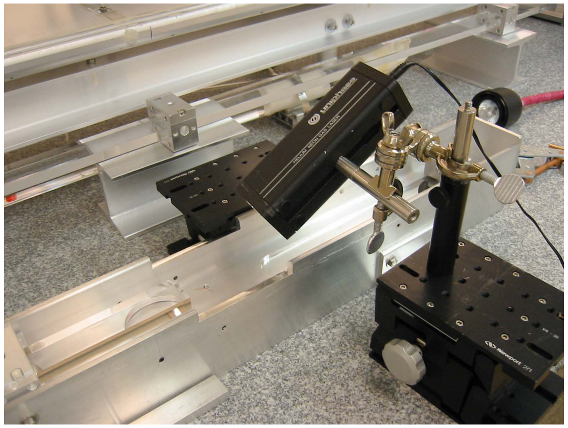
Focusing DIRC prototype - can we run without oil?



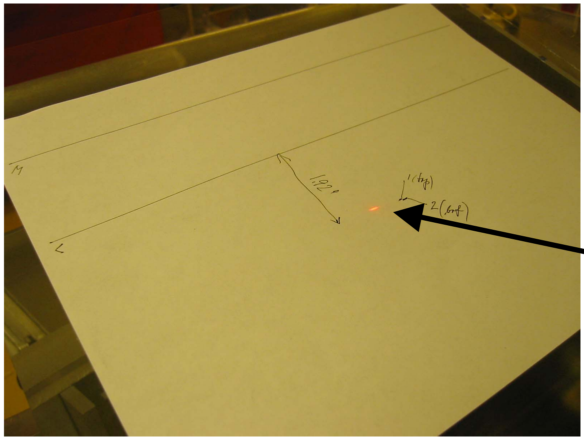
- It is possible, if necessary.
- One can even switch to water.



Make an artificial Focal plane using a glass

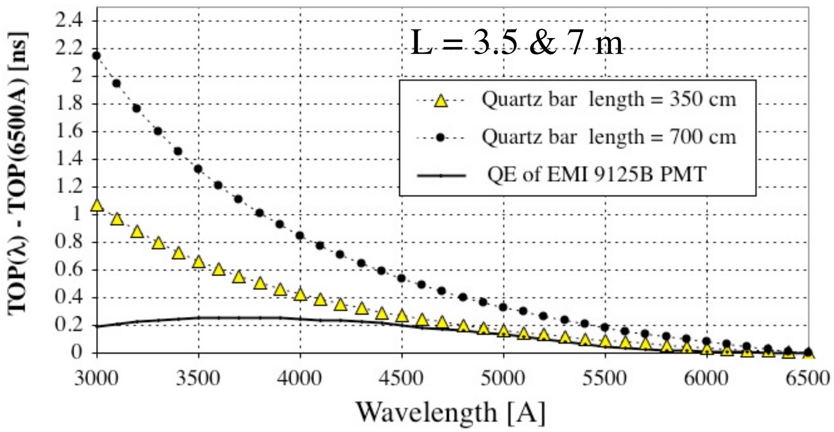


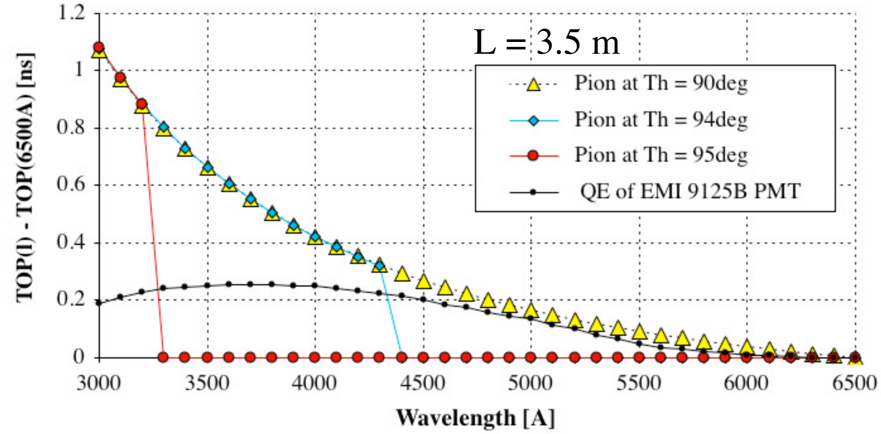
Shine a laser at a particular angle into a bar

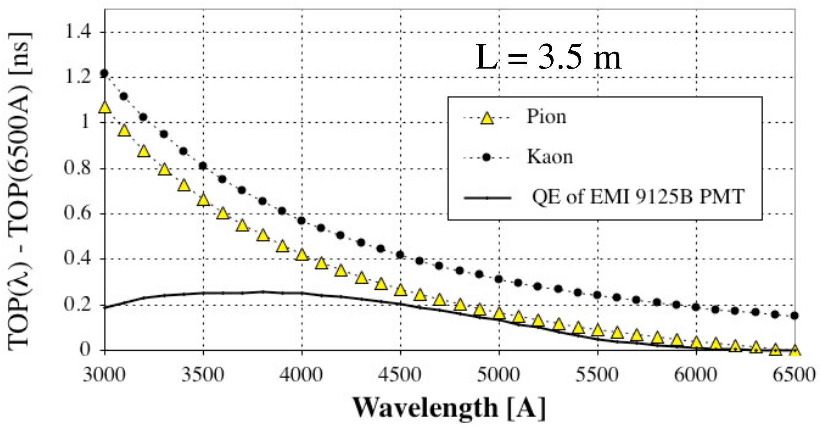


Within a mm of a spot where I expected it

Timing dependence on the chromaticity

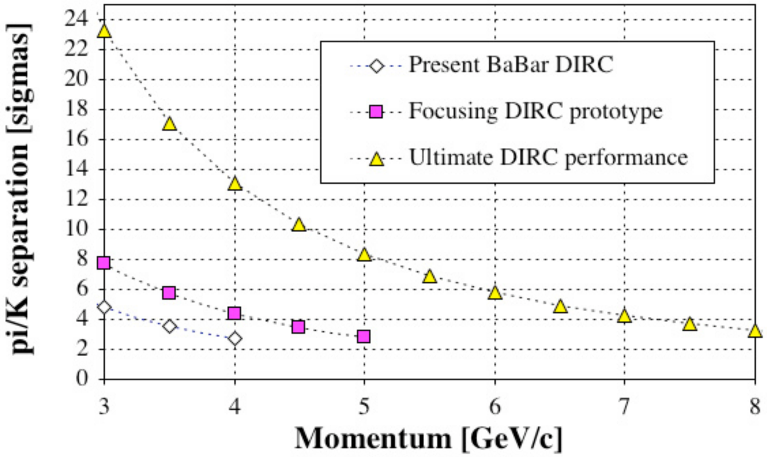






- **Bialkali photocathode.**
- **$\Theta_{track} = 90^o$.**
- **Photons propagate in y-z plane only in these calculations.**
- **4 GeV/c, ~3.5m or 7m long bar.**
- **1-2ns overall effect.**
- **Need 100-150ps resolution to see it.**
- **One can introduce a chromatic cut by a slight change of incident angle. Could be useful in the test beam.**

Expected performance and angular errors

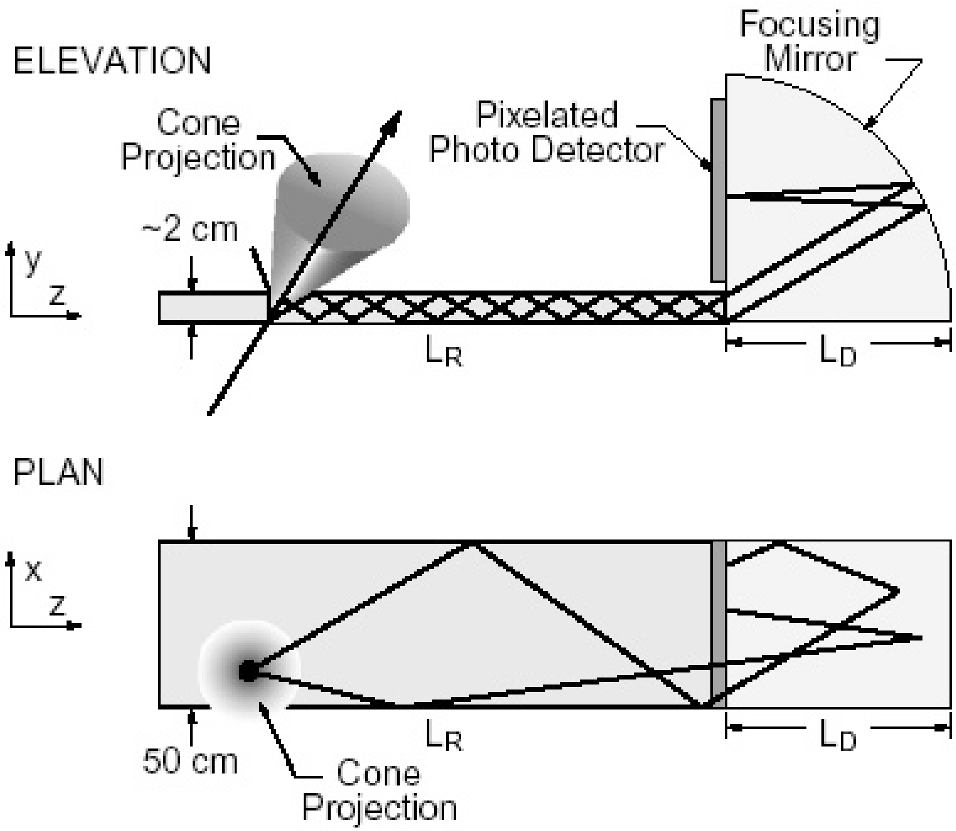


- **Focusing DIRC assumes ~6mm^2 pixel size, completely corrected chromatic error,optics to remove the bar thickness, no loss of photons in the photon detectors, and improvement in tracking accuracy compared to BaBar DIRC.**
- **The ultimate DIRC assumes, in addition, an "infinitely precise" photon detector, and a further tracking improvement.**

Contribution to Cherenkov angle resolution [mrads]	Present BaBar DIRC	Focusing DIRC prototype	Ultimate DIRC of the future
$\Delta\theta_{track}$	~1	~1	~1
$\Delta\theta_{chromatic}$	~5.4	~1	~1
$\Delta\theta_{transport\ along\ the\ bar}$	2-3	2-3	2-3
$\Delta\theta_{bar\ thickness}$	~4.1	~1	~1
$\Delta\theta_{PMT\ pixel\ size}$	~5.5	~4	~1
$\Delta\theta_c^{track}$	~2.4	~1.5	~1.0
Total $\Delta\theta_c^{photon}$	~9.6	~4.8	~3.3

Focusing DIRC detector - "ultimate" design

B. Ratcliff, Nucl.Instr.&Meth., A502(2003)211

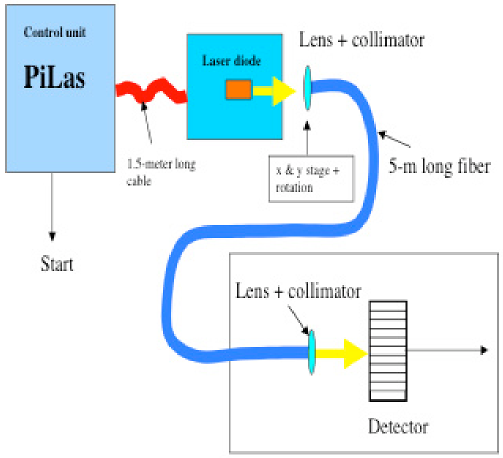


- Goal: a true 3D imaging using x,y and TOP.
- The real question is what would be a photon detector !!

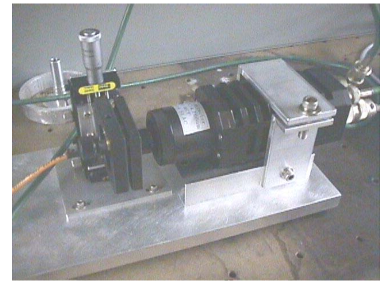
What are the candidates for a photon detector ?

Manufacturer	Name	PMT	σ_{TTD} [ps]
Photonis	Quantacon	XP2020	250
Photonis	PMT	XP2020/UR	150
ETL	**DIRC PMT**	9125B	1500
Hamamatsu	**Flat-panel**	H-8500	~130
Hamamatsu	Multi-mesh	R-6135	~80
Burle	**MCP-PMT**		<50
Dolgoshein	Silicone PM	SiPM	~60

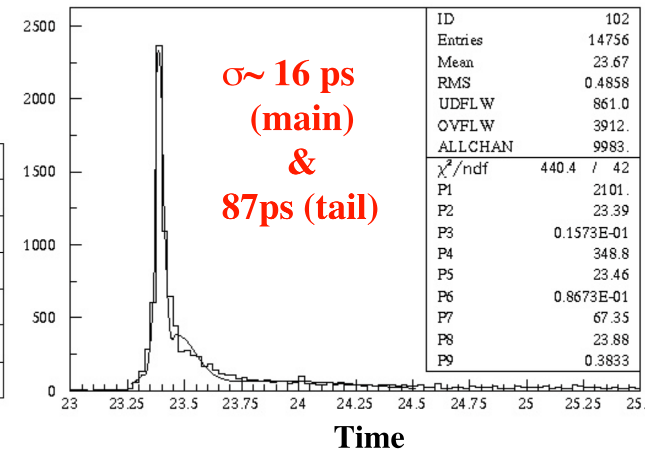
How to verify that the light pulser works or is tuned properly ?



APD:



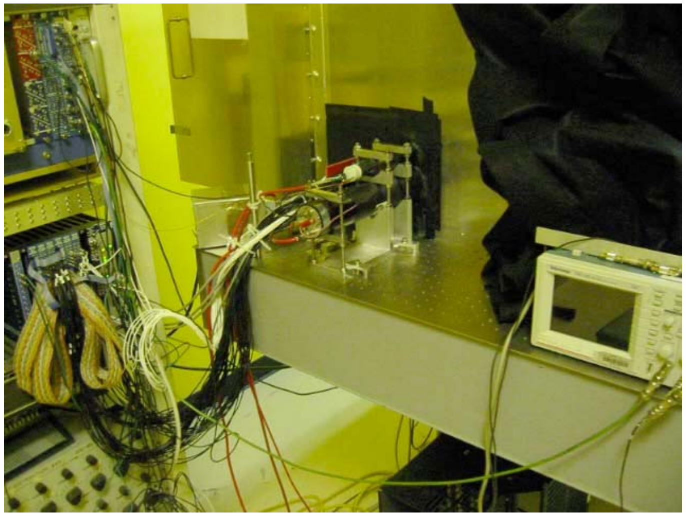
Result with APD:

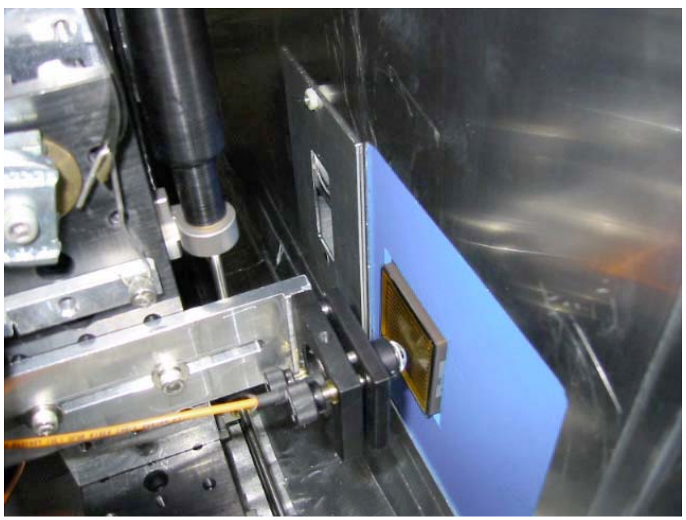


Parameter	PiLas 043G	PiLas 063G	Hamamatsu
Wavelength	430 nm	635 nm	394 nm
Tolerance [nm]	± 10	± 5	
Spectral width [nm]	< 7	< 7	
FWHM of light pulse spread	< 60 ps	~35 ps	34 ps
Light pulse jitter relative to trigger	~2 ps	~2 ps	±10 ps
Peak power [mW]	> 140	> 200	

- To verify that the laser works as advertised, use a <100 μm dia. GaP APD operating in a Geiger mode with active quenching.
- Systematic errors at this level of timing resolution are non-trivial. A true result is somewhere between 16-25ps. Nevertheless, it is reassuring that our result is consistent with what the manufacturer of the laser diode claims.

Scanning setup

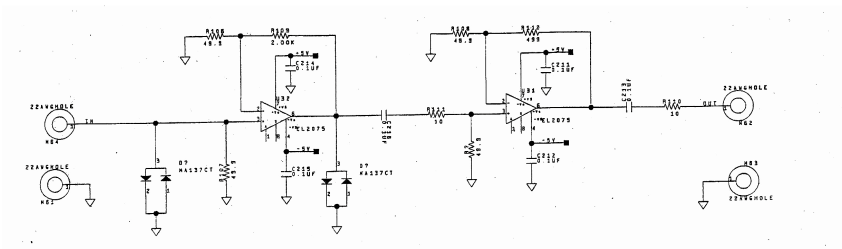




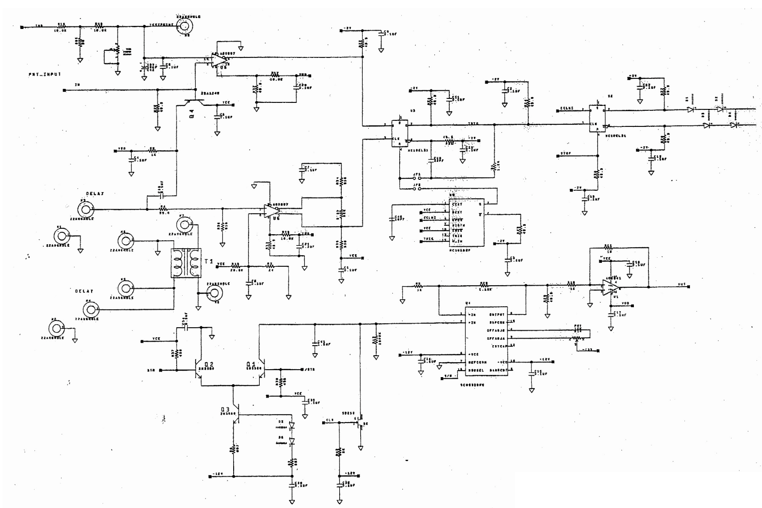
- We have built a stepper motor controlled scanning setup to measure the relative PMT response.
- The setup uses a PiLas laser diode operating at 635nm (on one occasion, we borrowed a 430nm version of this laser diode from T. Sumyioshi).
- A single photon mode of operation.
- Spot size: <1mm
- A hit is accepted if it is within a time window.
- To get a relative efficiency we normalize a count to a DIRC and Photonis PMTs.
- Typically: X-step = 100μm
  Y-step = 1mm.

Focusing DIRC prototype electronics at the moment

Amplifier:

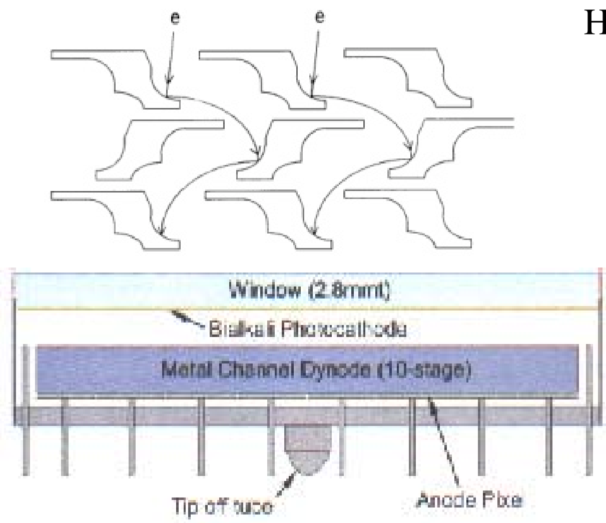


CFD:

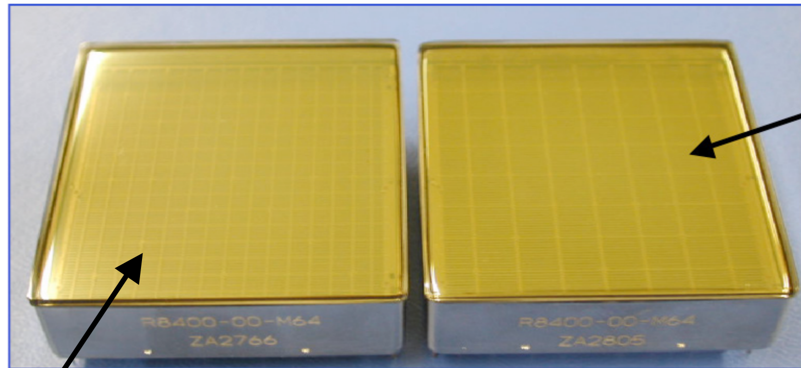


- Elantek 2075EL amplifier
- BW ~2GHz @ Gain = 1
- Voltage Gain: ~130x
  (Done with two stages: 13x10)
- TDC: TAC & 12 bit ADC
- Prototyping finished
- Building 350 channels
- This type of electronics is just for this prototype.

Hamamatsu H-8500 Flat panel PMT



Hamamatsu Co. data sheet



256 ch Focusing Type

64 ch Focusing Type

Collection Efficiency is improved.

Tested this one so far

New

(We have not tested the new one yet)

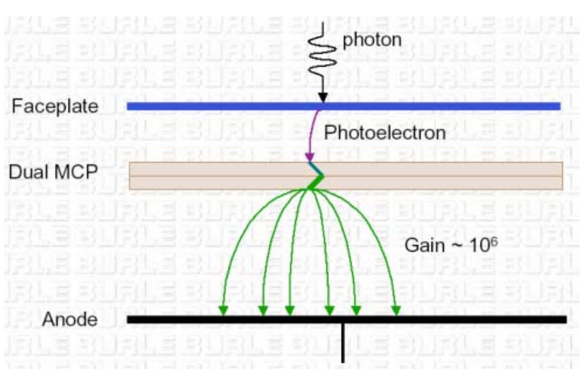
Parameter	Value
Photocathode type	Bialkali
Number of dynodes	12
Total average gain @ -1kV	$\sim 10^6$
Geometrical collection efficiency of the 1-st dynode	**70-80%**
Geometrical packing efficiency	**97%**
Measured single electron resolution (σ_{major}) - SLAC	138ps
Fraction of late photoelectron arrivals	~5%
Matrix of anode pixels	8 x 8
Number of anode pixels	64
Pixel size	5mm x 5mm

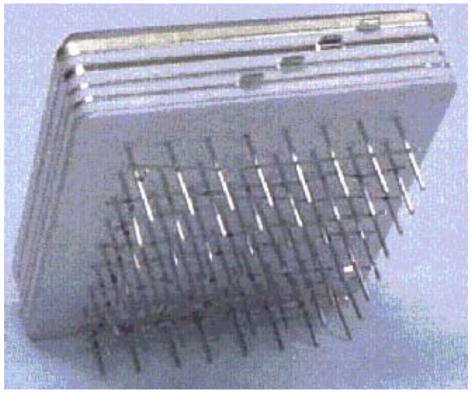
<--- Parameters of the old PMT.

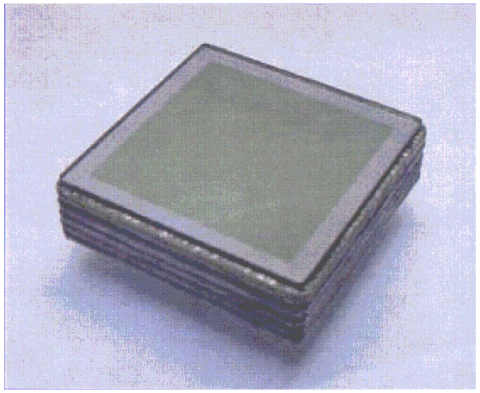
70-80% total photoelectron loss

Burle 85011-501 MCP-PMT

Burle Co. data sheet





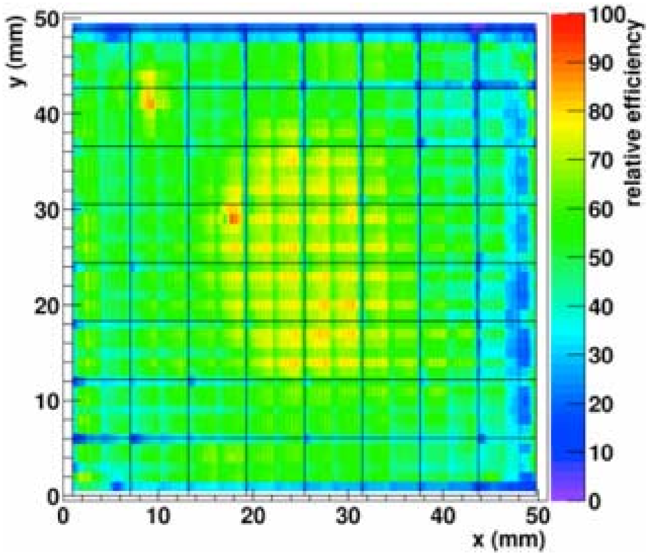


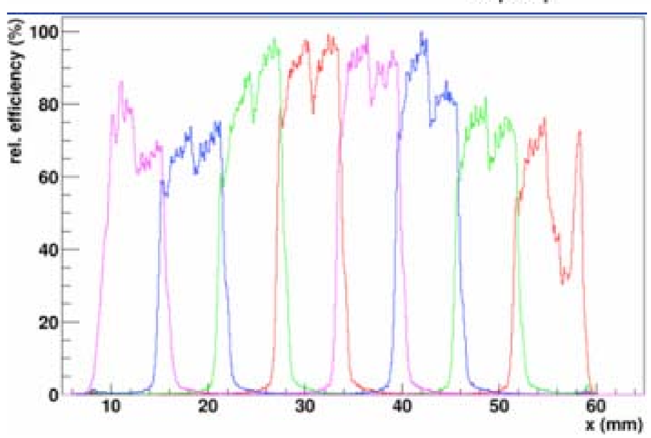
Parameter	Present	Future plan
Photocathode type	Bialkali	Bialkali
Number of MCPs	2	2
Total average gain @ -2.4kV	~$5x10^5$	~10^6
MCP hole diameter	25μm	10μm
MCP hole angle relative to perpendicular	12°	12°
Geometrical collection efficiency of the 1-st MCP	**60-65%**	**70%**
Geometrical packing efficiency (raw tube)	**67%**	**85%**
Fraction of late photoelectron arrivals	**~20%**	**-**
SLAC measurement of single electron resolution (σ_{major})	54ps	-
Amplifier used in SLAC measurement	Elantec 2075C	-
Voltage gain of SLAC amplifier	130	-
Matrix of anode pixels	8 x 8	32 x 32
Number of pixels	64	1024
Pixel size	5mm x 5mm	1mm x 1mm

50-60% total photoelectron loss

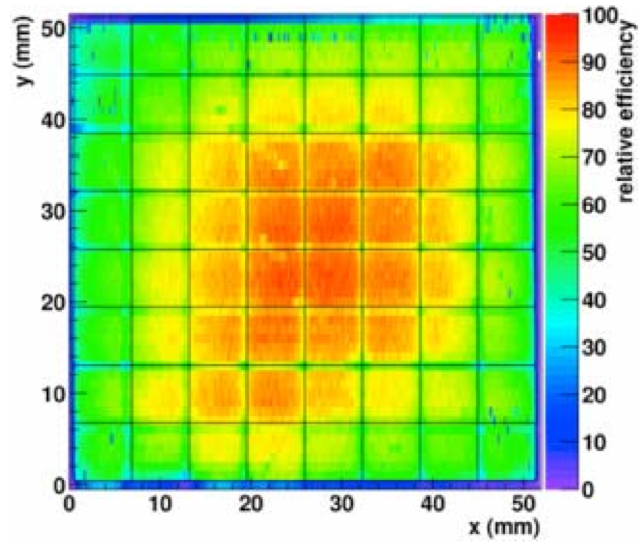
Detection efficiency relative to most efficient point on PMT at 635nm

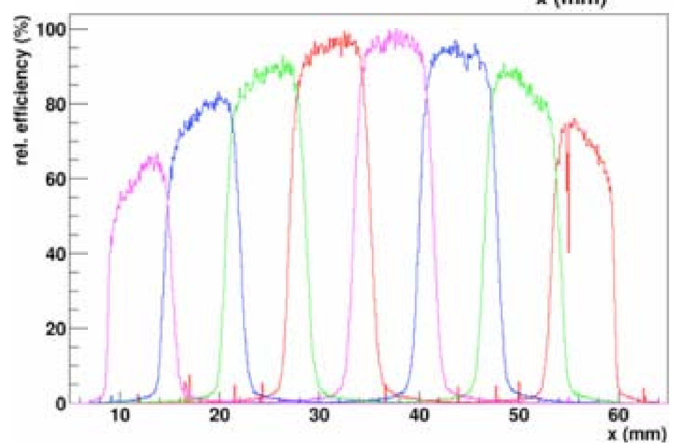
Hamamatsu Flat Panel H8500 PMT:
- uniformity ~1:2.5
- due to gain variation





Burle 85011-501 MCP-PMT:
- uniformity ~1:1.5
- due to gain variation

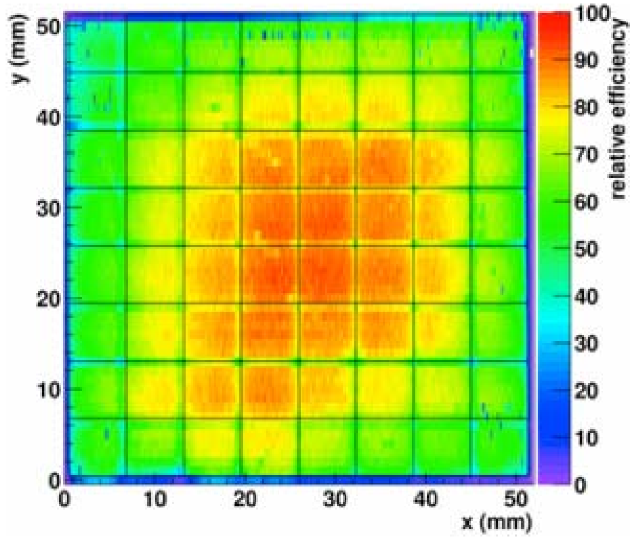




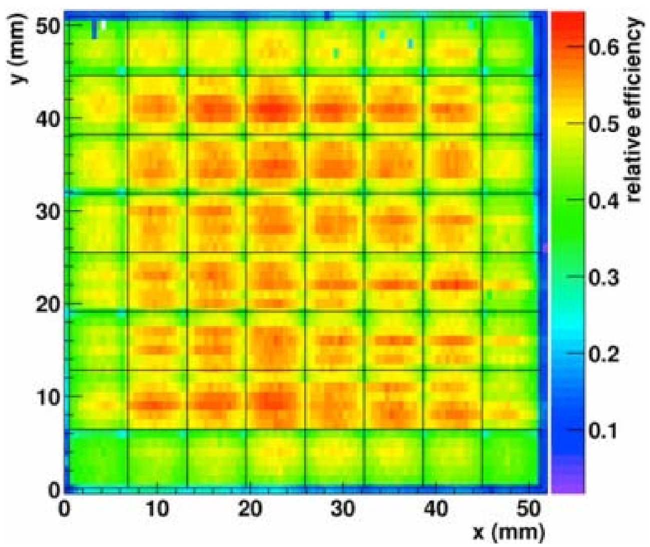
Burle MCP-PMT detection efficiency measured relative to DIRC PMT

(ETL 9125FLB17)

635nm:



430nm:

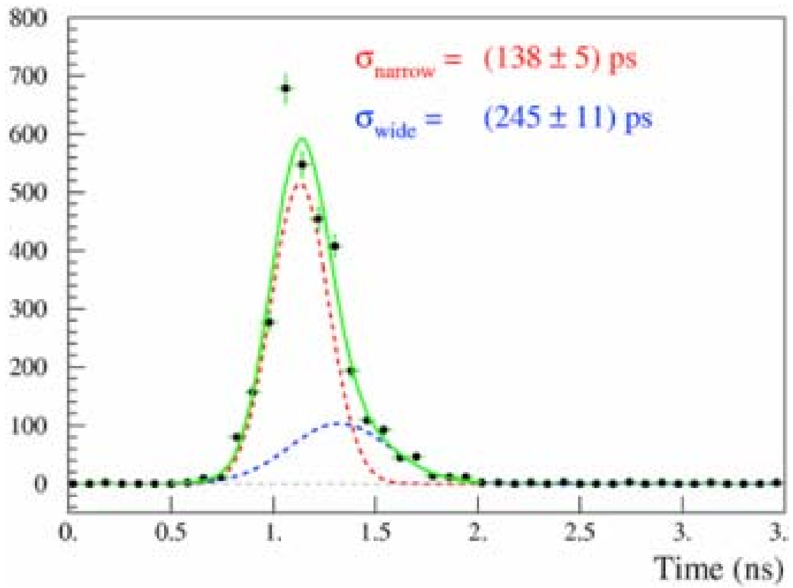


- At 635nm, which is close to the end of QE of Bialkali photocathode, and therefore not very reliable, the relative efficiency is 70-100%.

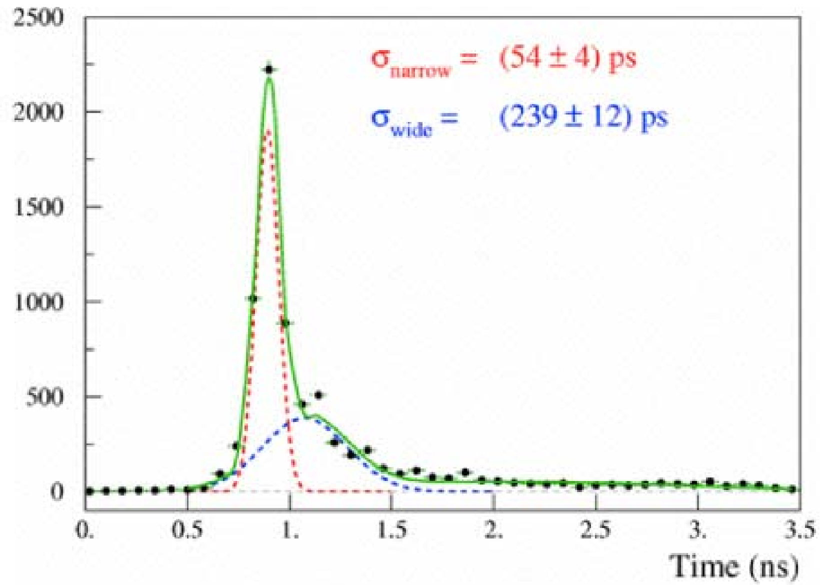
- At 430nm, the relative efficiency is 50-60% of the present DIRC PMT, as expected!!

Timing studies

Hamamatsu Flat Panel H8500 PMT:



Burle 85011-501 MCP-PMT:

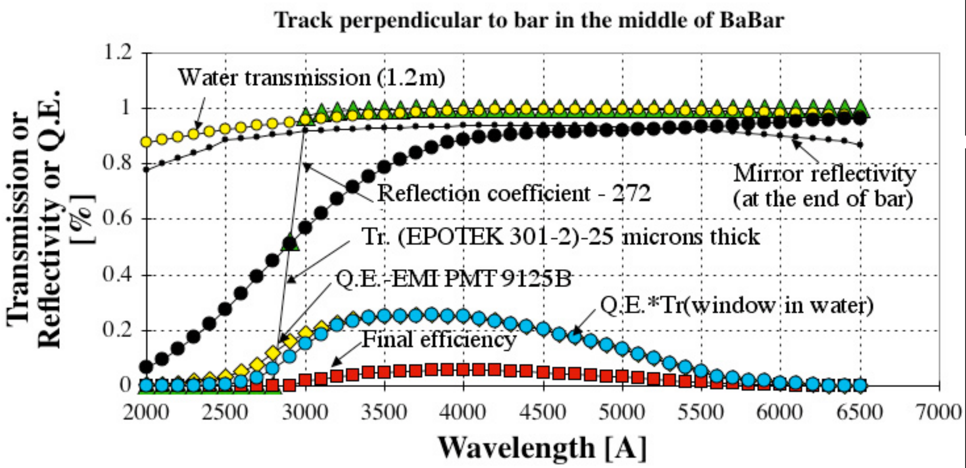


- Use the 635nm PiLas laser diode for timing studies.
- Hamamatsu PMT resolution is still good enough to correct the chromatic error, but not good enough for true 3D-imaging.
- Burle MCP-PMT has a very long tail due to recoil electrons from the MCP surface (~20% effect). To reduce this effect, Burle Co. is planning to reduce the distance between the MCP surface and the cathode.

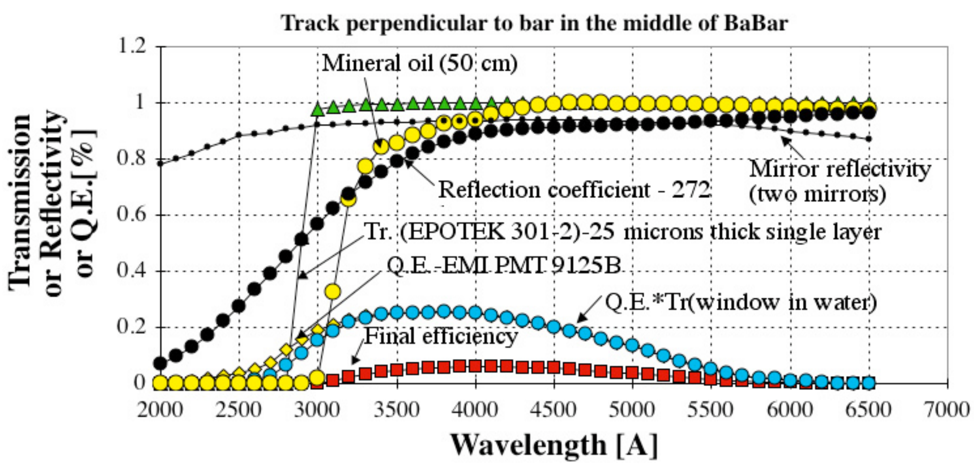
BaBar DIRC and Focusing DIRC relative efficiency

J. Va'vra, Nucl.Instr.&Meth., A453(2000)262

BaBar DIRC:



Focusing DIRC:



- **BaBar DIRC:**
- ETL PMT 9125B (Bialkali)
- **N_o :** 31 cm^{-1} & **N_{pe}/ring :** 28 **@θ_{track} = 90°**.

- **Focusing DIRC:**

  (if we would build it as it is for the Super BaBar - "know how" as of 1.10.2004).
- Burle MCP-PMT (Bialkali) - future version.
- **N_o :** 29 cm^{-1} & **N_{pe}/ring :** 27 **@θ_{track} = 90°**.
- **Main Degradation factors:**

  Mineral oil + MCP-PMT losses.

- **What we lost due to the mineral oil and MCP-PMT losses, we seem to gain back in other factors inherent in the BaBar DIRC. Examples:**

  - BaBar DIRC loses ~40% of photons at quartz/water interface due to mismatch of refraction indices.

  - Overall packing fraction loss in BaBar SOB is ~48%, due to sector gaps, light catchers, PMT packing.

Conclusions

- So far, no show stopper found.
- We learned how to measure the timing resolution on single photons, and a relative response to single photons across the PMT face.
- We are very close of completing the mechanics of the Focusing DIRC prototype. The first tests could start in February.
- However, much more has to happen in the area of the photon detectors before we would be able to build a final 3D Focusing DIRC:

  a) Detector efficiency improvements.

  b) Capability to run at 1.5Tesla.

  c) Photocathode aging.

  d) We need a real MC program to design the final optics.

  e) We need to develop a final electronics.

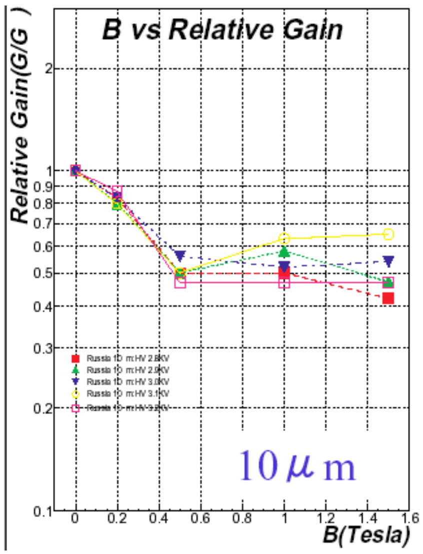
- We are excited because until this point, the chromatic error was considered an uncorrectable quantity.

Backup slides

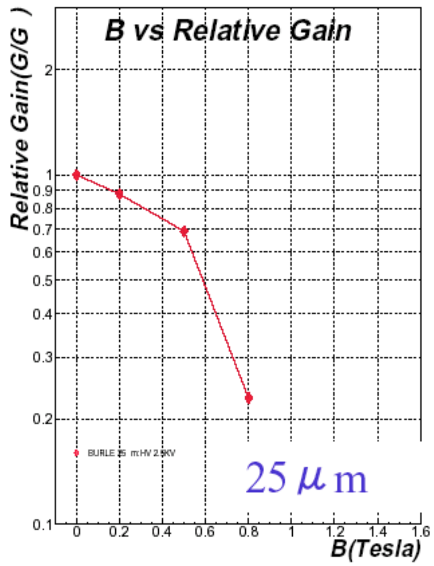
MCP operation in the magnetic field

Measurements by M.Akatsu et al., Nagoya, Japan - preliminary

Russia MCP:



Burle MCP:



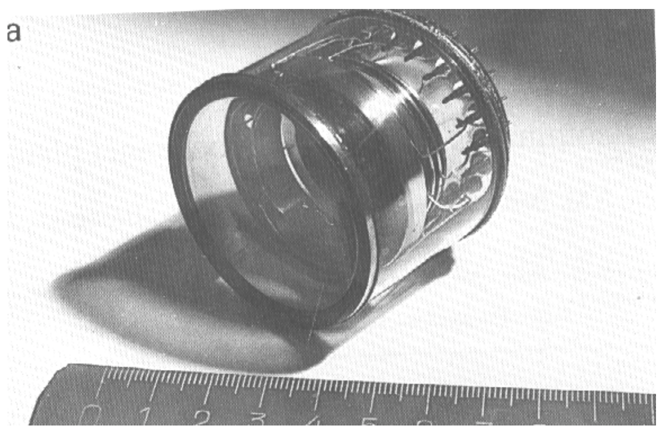
- **Gain in MCP:**
  $G \sim e^{(A*\text{MCP thickness/MCP dia})}$

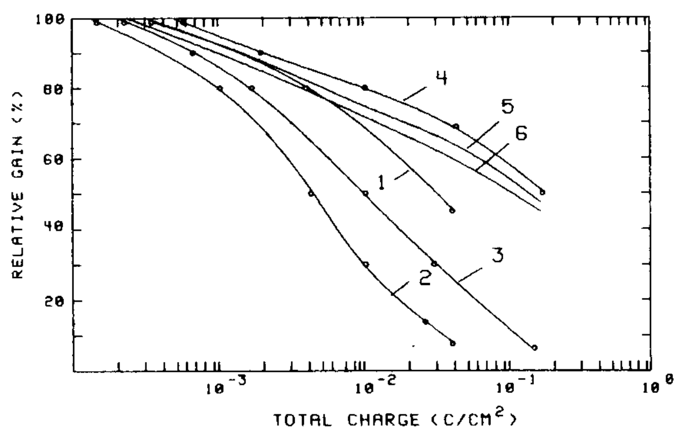
  gets severely reduced in a large magnetic field of 1.5 Tesla.

  The 25μm dia. holes are too large. One needs to reduce their size to ~10μm dia., or even less. This is our next step.
- In addition, one needs to increase the electric field between anode and cathode.

Aging of the MCP Bialkali photocathode by ions

V.V. Anashin et al., Nucl.Instr.&Meth., A357(1995)103



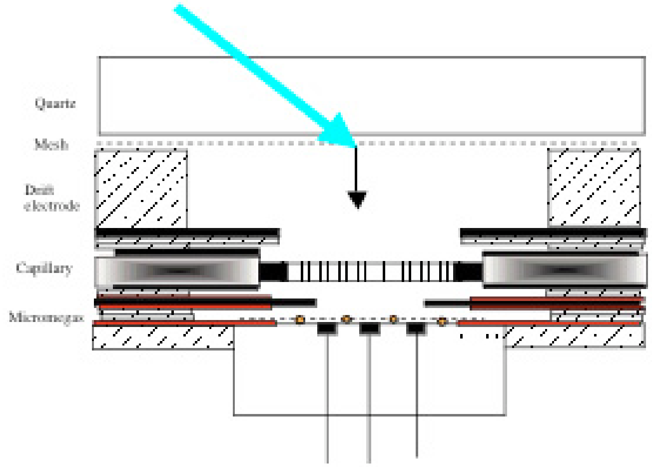


- Early work of V.V. Anashin et al. indicated real problem after an anode charge of **10-20mC/cm^2** (operated at a gain of 10^7!!!).
- DIRC, if equipped with such a MCP, would last a year only.
- That is why all manufacturers now incline holes (~12^o)., plus apply various tricks.
- Burle Co.'s measurement:

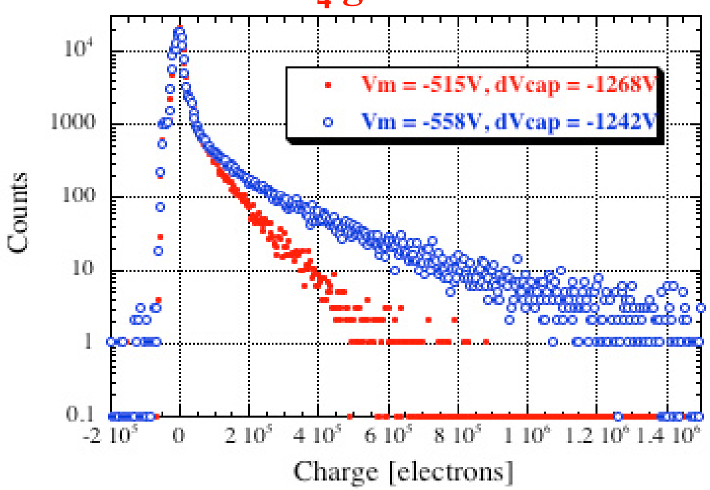
  a 50% response loss after ~200mC/cm^2, i.e., a factor of ~10 improvement. This was not yet verified by us !!

Capillary+Micromegas+pads

J.Va'vra,T. Sumiyioshi, presented at IEEE, Portland, Oregon, Oct. 2003



91%Ar+9%CH_4 gas at 1 bar:



- Works like a charm in the single electron mode!!
- Supports a very high gain (even though one would want to run at much lower gain in the final application).
- Would work at 1.5 Tesla.
- Timing resolution ? Based on the C. Williams results, one may reach a timing resolution of <100ps per single photon.
- How to add a Bialkali photocathode ? Talking to Burle Co. and Hamamatsu.
- Can a gaseous device compete with the vacuum MCP-PMT ?!