Spatial Response of Photon Detectors used in the Focusing DIRC prototype

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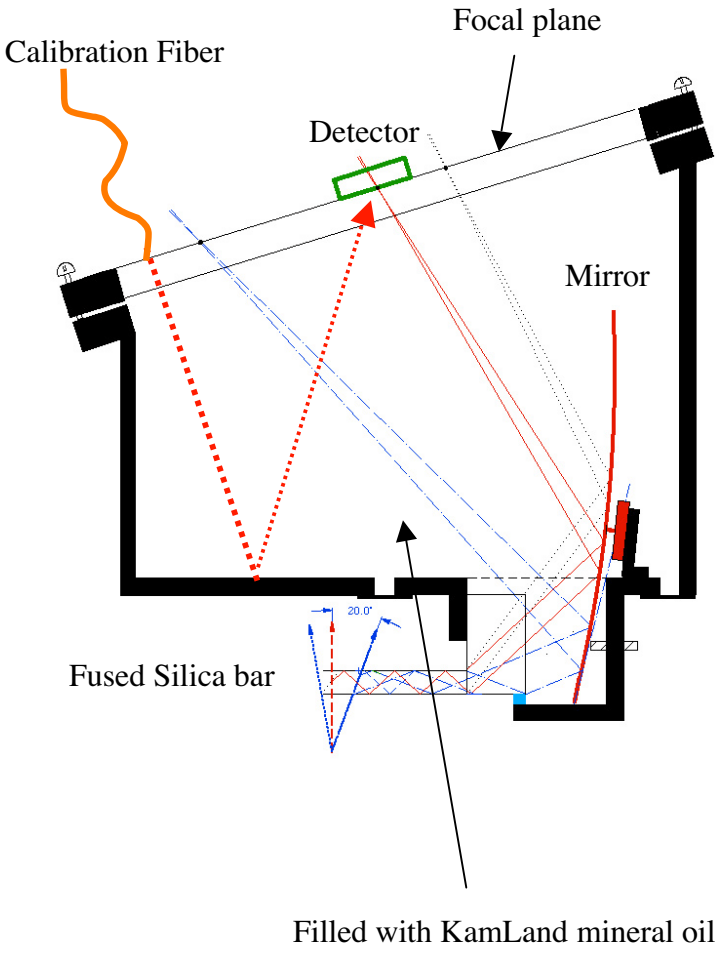
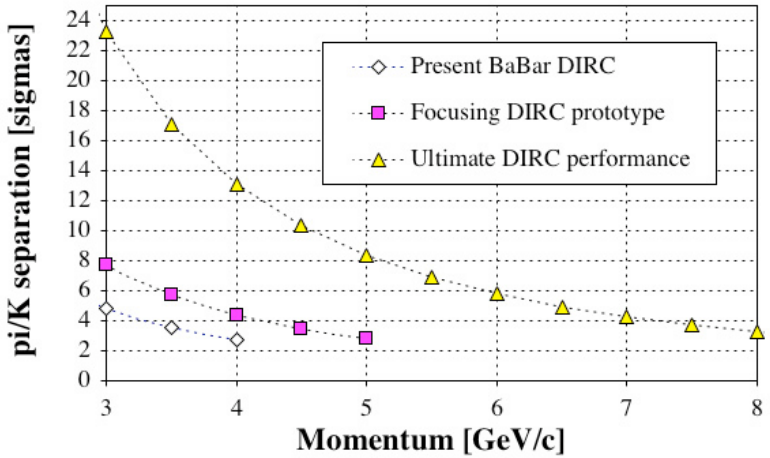
SLAC

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 to correct out the chromatic error contribution to the Cherenkov angle error, and to suppress the background.
- **Spherical mirror** removes a bar thickness from the resolution consideration.
- The size of the prototype designed to yield a similar angular resolution as the present BaBar DIRC, given the pad size of the chosen photon detectors.
- **<u>At present, we do not have a solution for a detector working in the magnetic field.</u>**

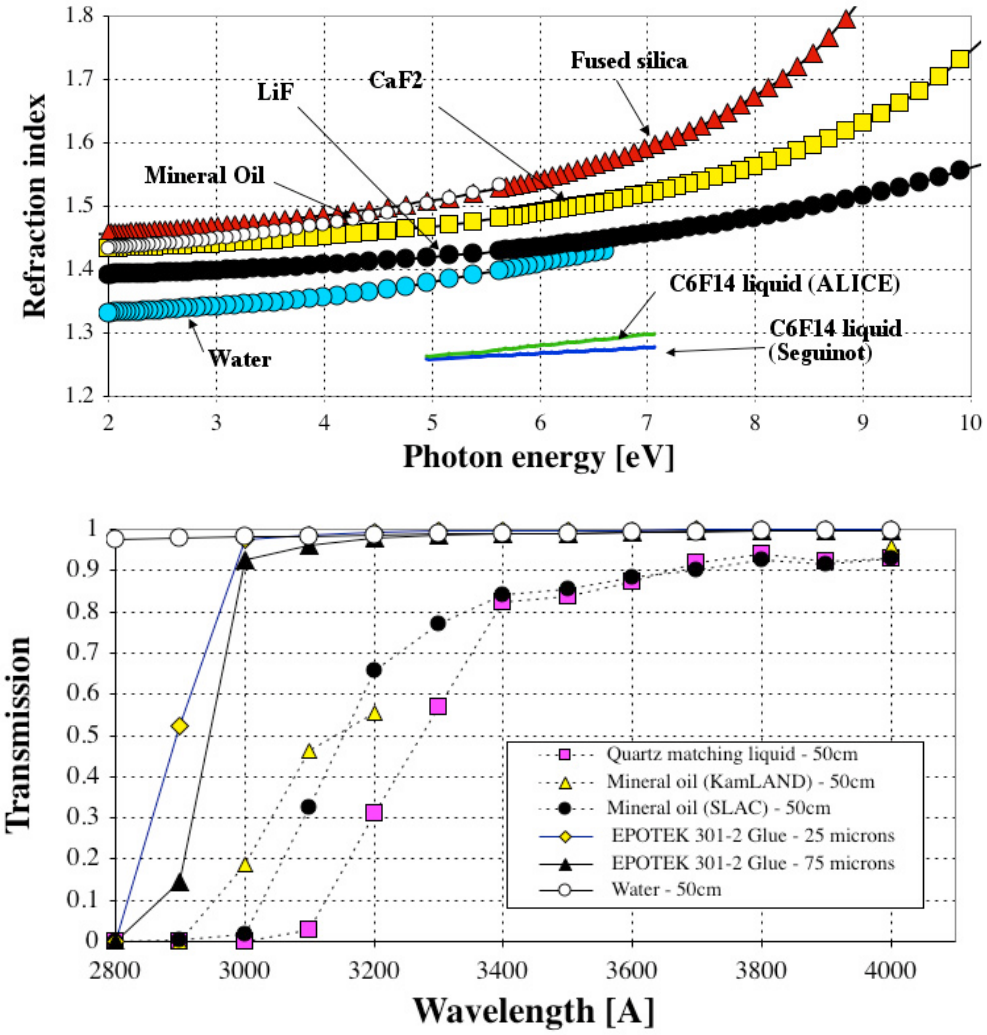
Expected performance and angular errors



- **"Focusing DIRC"** estimate assumes ~6mm^2 pixel size, completely corrected chromatic error, optics to remove the bar thickness, no loss of photons in the photon detectors.
- **"Ultimate DIRC"** estimate assumes, in addition, an "infinitely precise" photon detector.

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
Total $\Delta\theta_c^{photon}$	~9.6	~4.8	~3.3

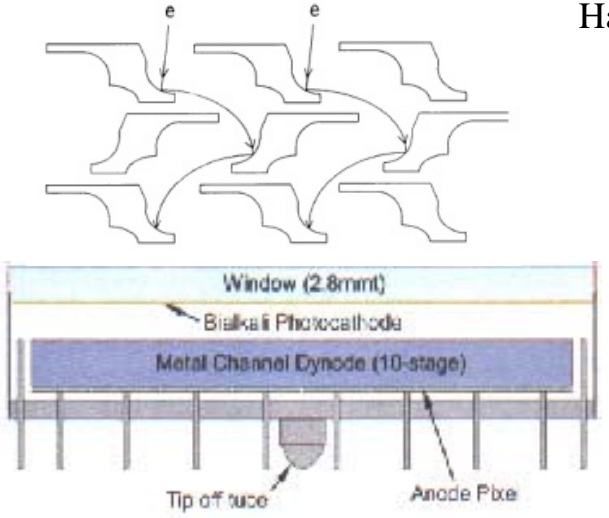
What matching liquid to use in the box ?



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

Hamamatsu H-8500 Flat panel MaPMT

Hamamatsu Co. data sheet

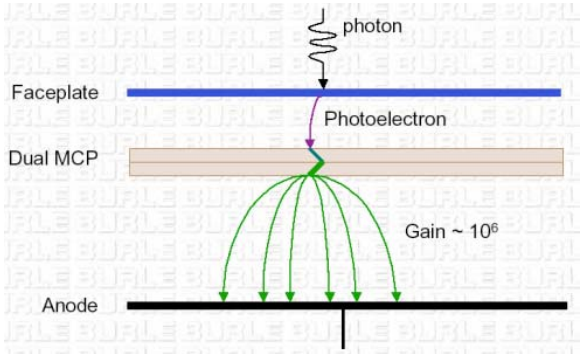


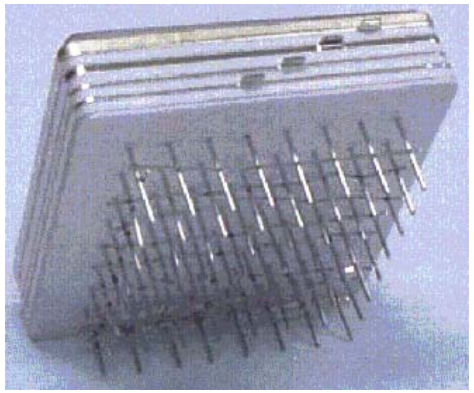
Hamamatsu data on H8500 Flat Panel MaPMT (some SLAC measurements included)

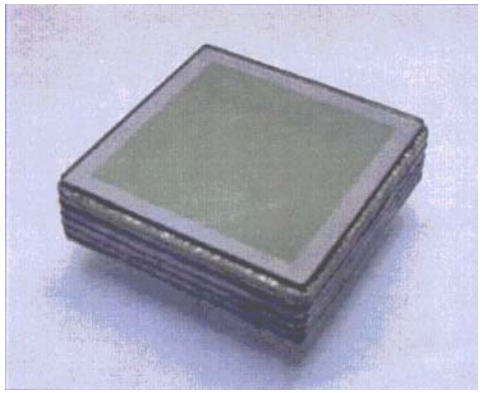
Parameter	Value
Photocathode type	Bialkali
Number of dynodes	12
Total average gain @ -1kV	~10^6
Geometrical collection efficiency of the 1-st dynode	70-80%
Geometrical packing efficiency	97%
Fraction of late photoelectron arrivals (SLAC estimate)	~5%
Total fraction of "in time" photoelectrons detected	**65-75%**
SLAC measurement of single electron resolution (σ_{narrow})	~140ps
Matrix of anode pixels	8 x 8
Number of anode pixels	64
Pixel size	6mm x 6mm

Burle 85011 MCP-PMT

Burle Co. data sheet



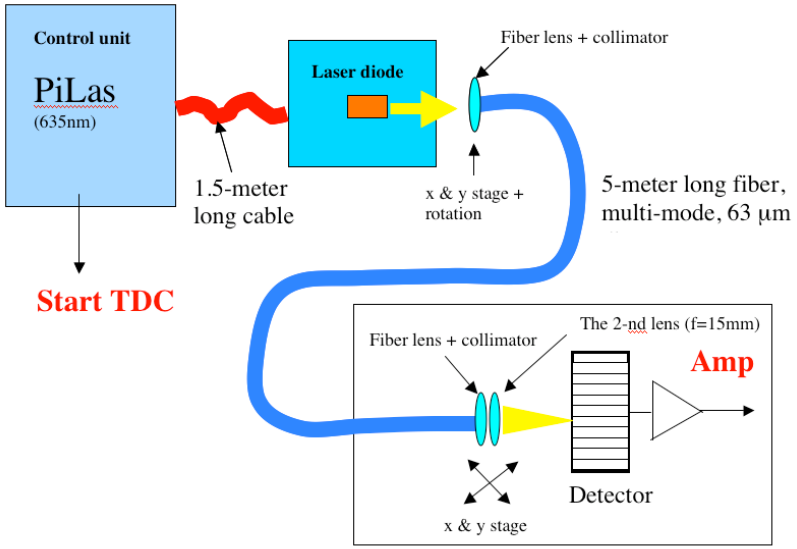


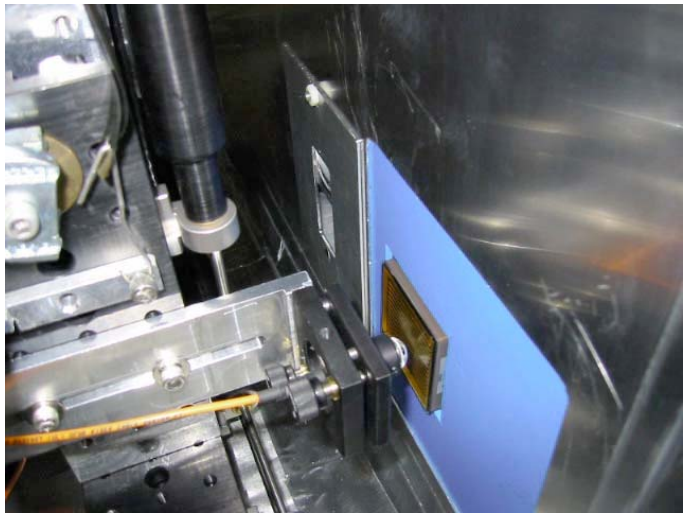


Burle data on 85011 MCP-PMT (some SLAC measurements included)

Parameter	H85011-501	H85011-403	New tube
Photocathode type	Bialkali	Bialkali	Bialkali
Number of MCPs per PMT	2	2	2
Total average gain @ -2.3kV	~5x10^5	~5x10^5	~10^6
MCP hole diameter	25μm	25μm	10μm
MCP hole angle relative to perpendicular	12^o	12^o	12^o
Geometrical collection efficiency of the 1-st MCP	60-65%	60-65%	70%
Geometrical packing efficiency (for raw tube)	67%	67%	85%
Fraction of late photoelectron arrivals (SLAC estimate)	~20%	Tail is cut	Tail is cut
Total fraction of "in time" photoelectrons detected	**30-35%**	**30-35%**	**~50%**
SLAC measurement of single electron resolution (σ_{narrow})	60-80ps + tail	60-80ps	-
Amplifier used in SLAC measurement	Elantec 2075C	Elantec 2075C	-
Voltage gain of SLAC amplifier	130	130	-
Matrix of anode pixels	8 x 8	8 x 8	32 x 32
Number of pixels	64	64	1024
Pixel size	5mm x 5mm	5mm x 5mm	1mm x 1mm

Scanning setup to measure the PMT spatial response

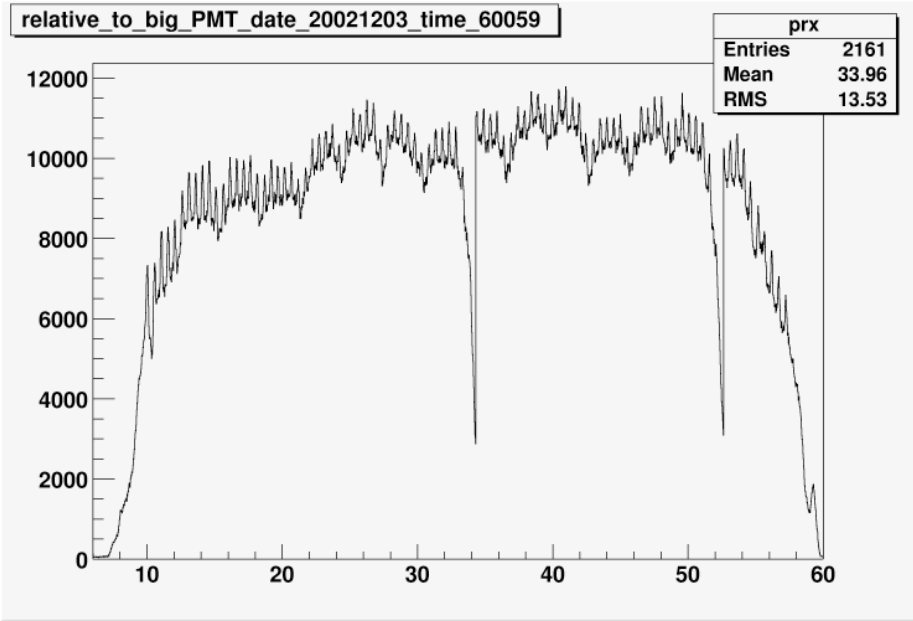




- **x&y stage for the fiber final focus :**
  Stepper motor moves the end of the fiber equipped with a lens, resulting in the spot size of ~150 μm. The linear motor is set typically to:
  x-step ~ 100μm & y-step ~ 1mm.
- **Light source:**
  - PiLas laser diode operating in single photoelectron mode.
  - 635 & 430nm (on loan from T. Sumyioshi).
  - Fiber is 63μm dia. multi-mode fiber, equipped with lenses at both ends.
- **Analysis:**
  - **A hit is accepted into the efficiency definition if it is within a time window, and it is on the same pad as the laser head is pointing to.**
  - **To get a relative efficiency we normalize to the 2 inch dia. Photonis XP 2262B PMT** (or the DIRC PMT, ETL 9125FLB17).
  - DAQ trigger rate: 20kHz.

Resolution of the scanning system Hamamatsu Flat Panel H8500 MaPMT #2:

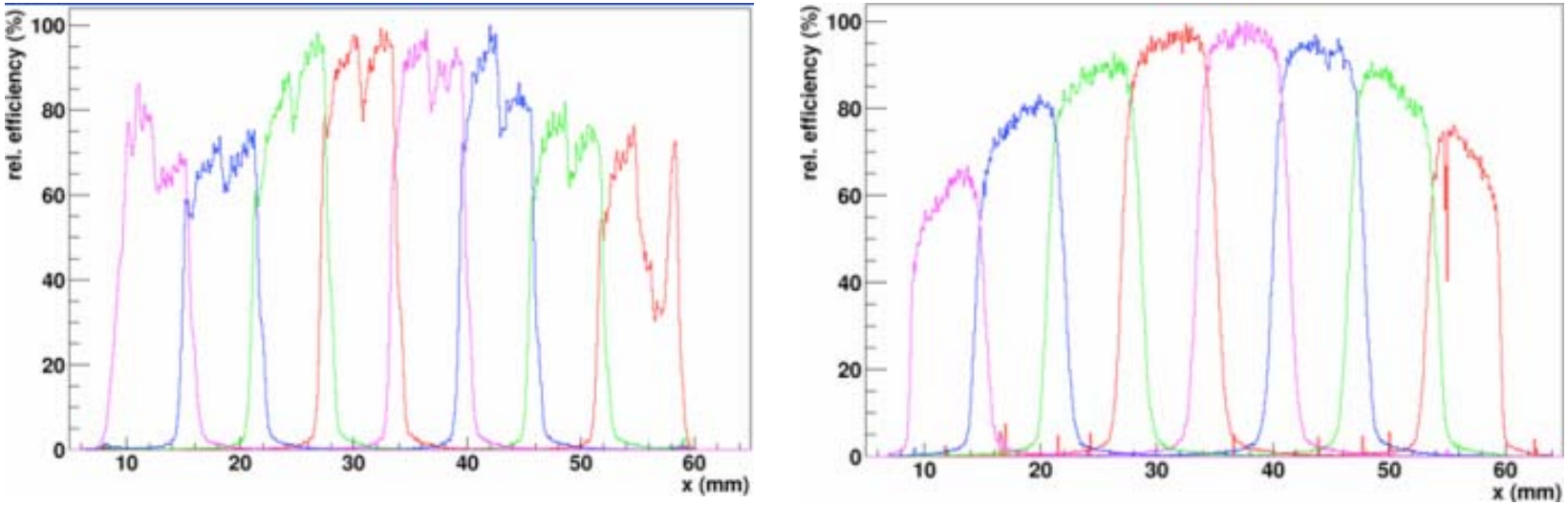
Micro-structure of the dynode electrodes:



- **<u>Resolution:</u>** Clearly see the details of the dynode electrode structure. **Spatial resolution of the system is less than 150 μm, for a step size of 25μm.**
- <u>Electronics chain used in this test:</u>
  Final SLAC amplifier, LeCroy 4413 discriminators with 100mV threshold, LeCroy 3377 TDCs with 0.5ns/count.

An example of the relative response along a line scan across 8 pads

Hamamatsu Flat Panel H8500 PMT #2: **Burle 85011-501 MCP-PMT #3:**

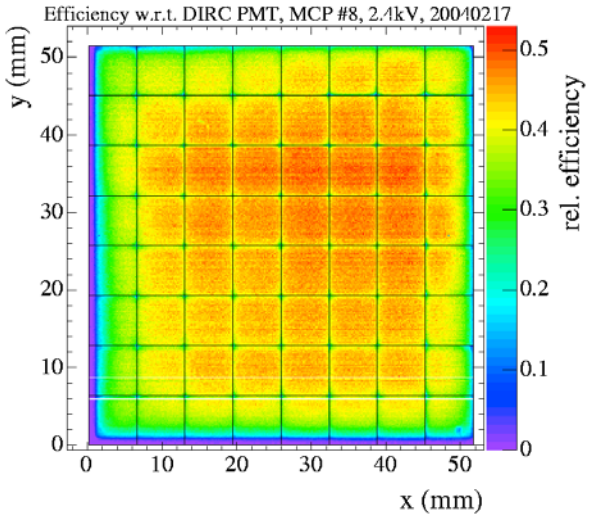


- The Hamamatsu MaPMT uniformity is ~1:2.5 and the Burle MCP-PMT uniformity is ~1:1.5, in this example.
- Electronics chain used in this test:
  Final SLAC amplifier, LeCroy 4413 discriminators with 100mV threshold, LeCroy 3377 TDCs with 0.5ns/count.

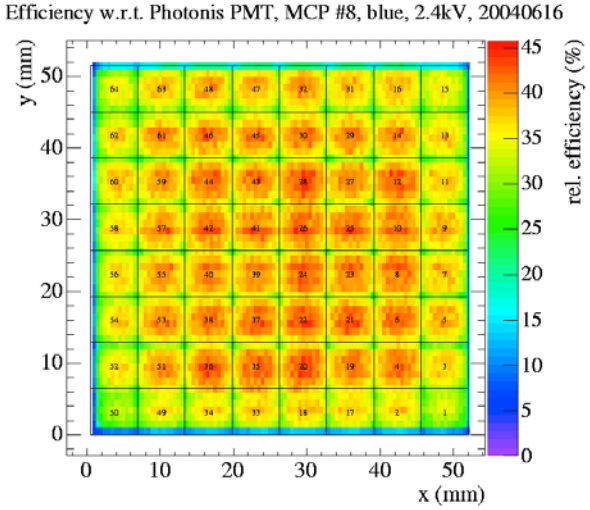
Burle MCP-PMT #8 relative detection efficiency

(Normalized to the Photonis XP 2262B PMT)

635nm:



430nm:



- At **635nm**, which is close to the end of the Bialkali Q.E. range, the relative efficiency scaling to the Photonis PMT is not very reliable.

- At **430nm**, the relative efficiency is 50-60% relative to the Photonis PMT, if we include the late arrivals. This is approximately expected based on the MCP design (to be compared with the geometrical MCP collection efficiency (cathode-to-top MCP) of 60-65%, shown on page 6).

- Electronics chain used in this test:

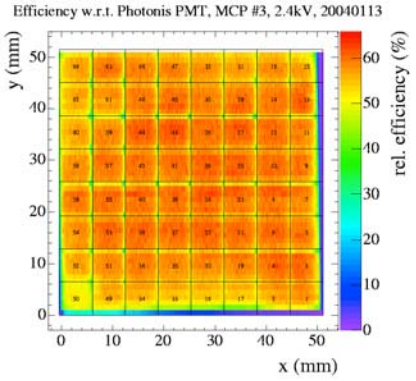
  Final SLAC amplifier, LeCroy 4413 discriminators with 100mV threshold, LeCroy 3377 TDCs with 0.5ns/count

- Light source: PiLas laser diodes operating in the single photoelectron mode (635nm & 430nm).

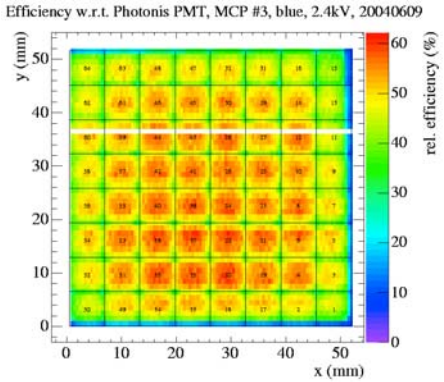
Example #1 of a few scans

Burle MCP-PMT #3

635 nm:

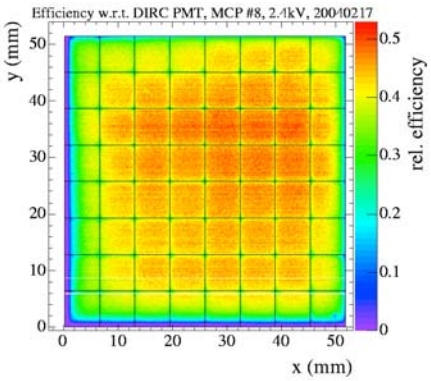


430nm:

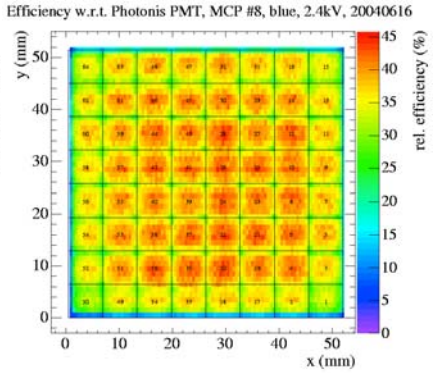


Burle MCP-PMT #8

635 nm:

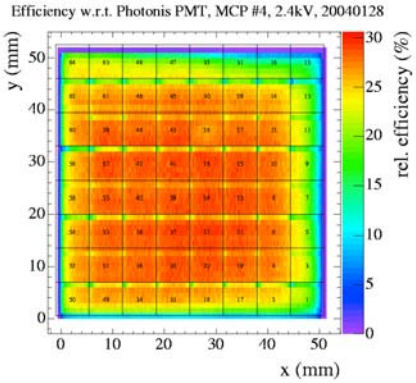


430nm:

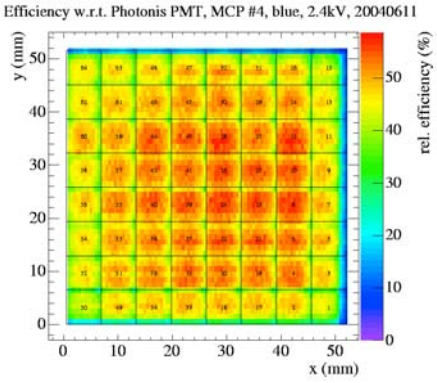


Burle MCP-PMT #4

635 nm:

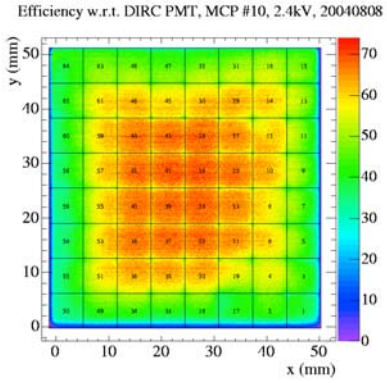


430nm:

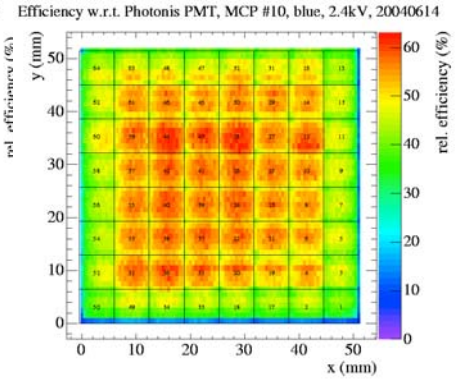


Burle MCP-PMT #10

635 nm:



430nm:

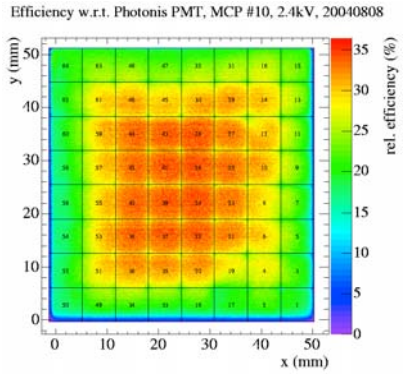


- Typical relative efficiency is 50-60% of the 2 inch dia. Photonis XP 2262B PMT at 430nm. The efficiency drops to 30-50% around the edges at 430nm.

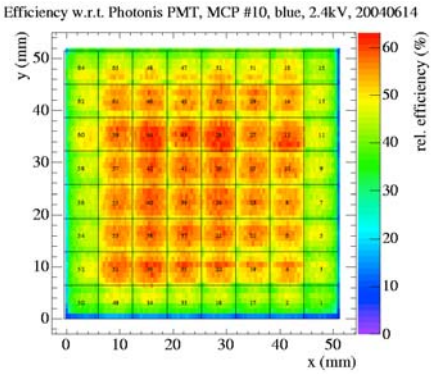
Example #2 of a few scans

Burle MCP-PMT #10

635 nm:

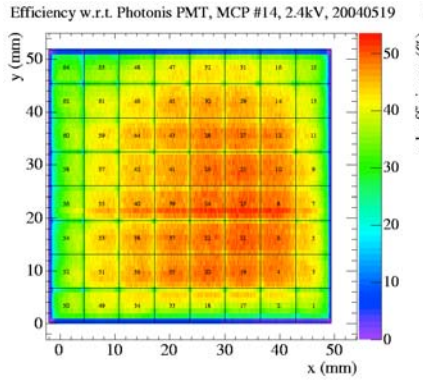


430nm:

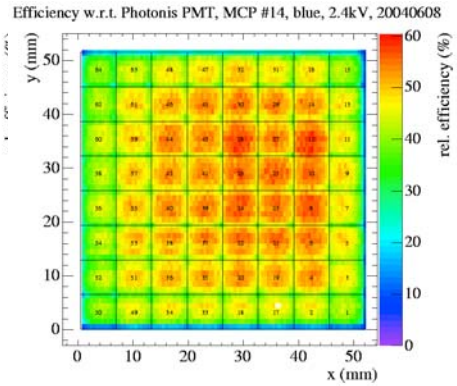


Burle MCP-PMT #14

635 nm:

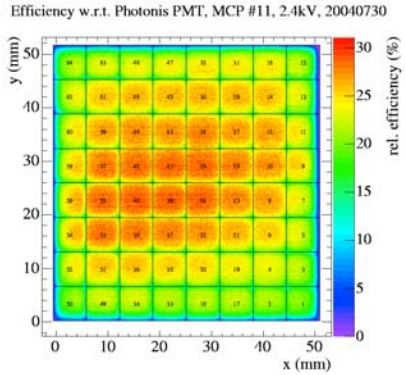


430nm:

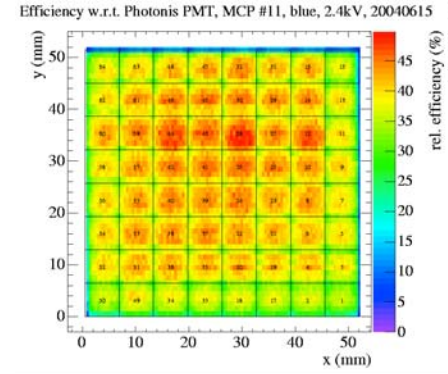


Burle MCP-PMT #11

635 nm:

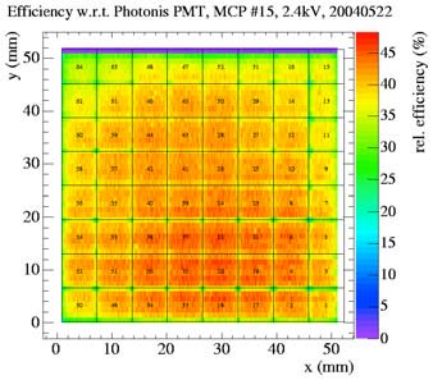


430nm:

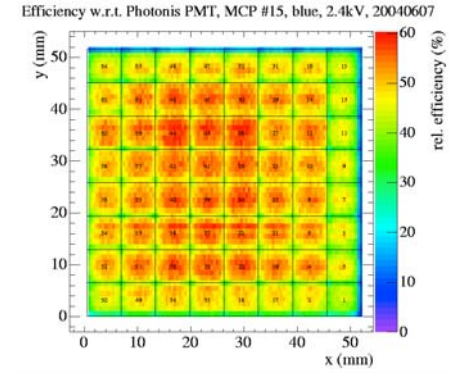


Burle MCP-PMT #15

635 nm:



430nm:

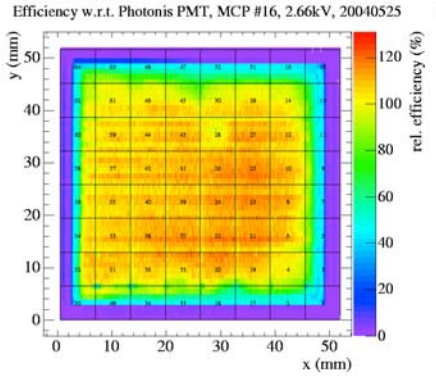


- Typical relative efficiency is 50-60% of the 2 inch dia. Photonis XP 2262B PMT at 430nm. The efficiency drops to 30-50% around the edges at 430nm.

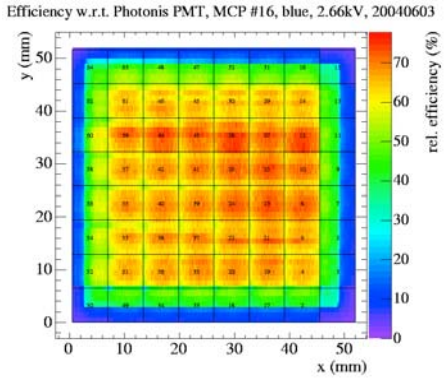
Example #3 of a few scans

Burle MCP-PMT #16

635 nm:

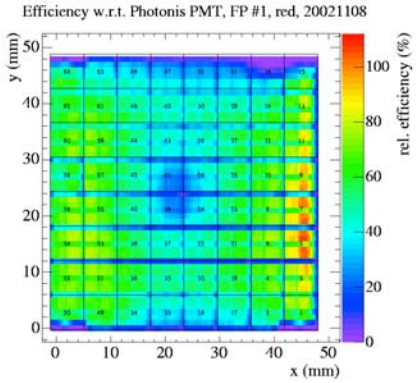


430nm:

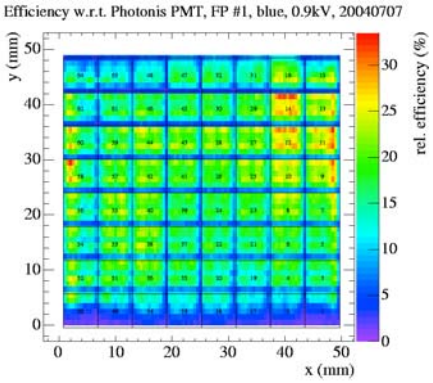


Hamamatsu MaPMT #1

635 nm:

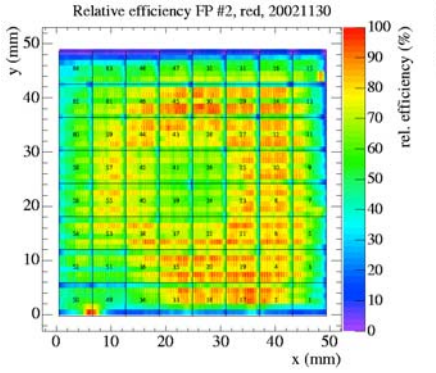


430nm:

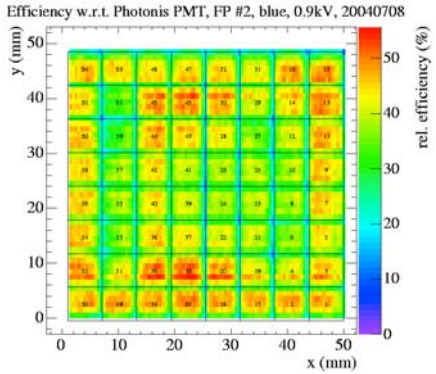


Hamamatsu MaPMT #2

635 nm:

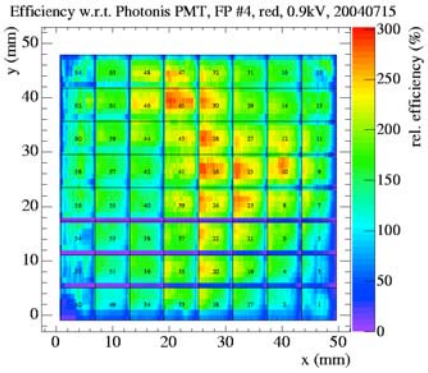


430nm:

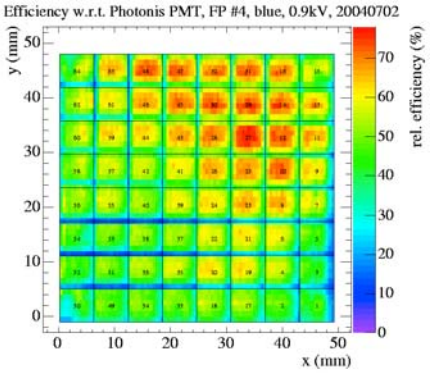


Hamamatsu MaPMT #4

635 nm:



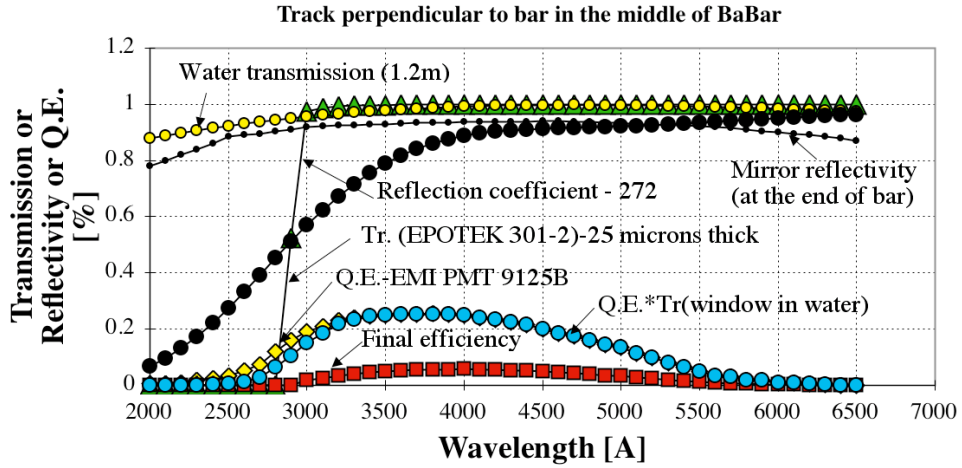
430nm:



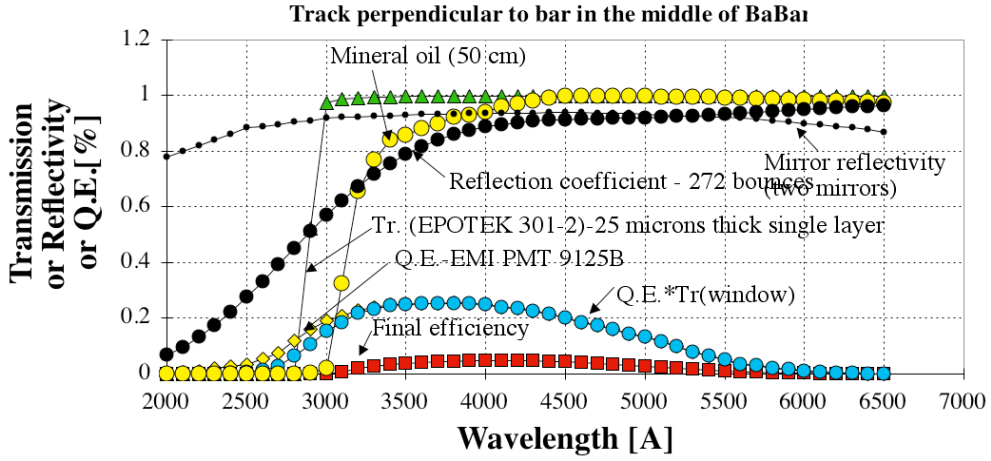
- MCP-PMT #16 has large inefficiency around edges. However, this is still new experimental tube, and therefore it should not be taken as general observation (it has the MCP-to-cathode distance of 0.75 mm).
- **Hamamatsu Flat Panel MaPMT relative efficiency is 50-70% of the Photonis XP 2262B PMT at 430nm. The efficiency drops to 30-50% around the edges at 430nm.**

Exercise in an estimate of the BaBar DIRC and Focusing DIRC prototype relative efficiencies

BaBar DIRC:



Focusing DIRC prototype:

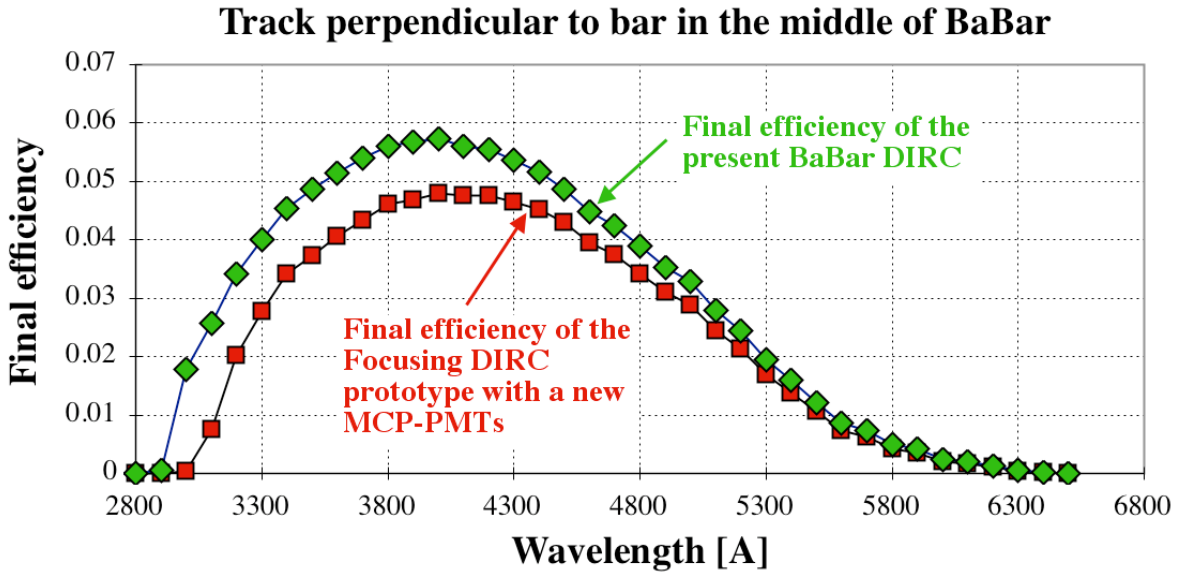


- **BaBar DIRC:**
- ETL PMT 9125B (Bialkali)
- **N_o :** 31 cm^{-1} & **N_{pe}/ring :** 28 @θ_{track} **= 90°** .

- **Focusing DIRC:**
- Burle MCP-PMT (Bialkali) - "new tube" (see parameters of the"new tube" on page 6)
- **N_o :** 29 cm^{-1} & **N_{pe}/ring :** 27 @θ_{track} **= 90°**.
- **Main Degradation factors:**
  Mineral oil + MCP-PMT losses.

- **The loss due to the mineral oil and the MCP-PMT must be compensated in other factors inherent in the BaBar DIRC, such as:**
  - 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.
- **See next page for more details.**

Relative efficiency of the BaBar DIRC and the Focusing DIRC prototype



- **Both designs have almost the same final efficiency, assuming that one has a "new MCP" - see page 6.**
- **Therefore, at least on a paper, the Focusing DIRC as described in this paper, is possible. However, one cannot tolerate any new losses! For example, any oil transmission deterioration, or a loss by a factor of two as per design such as the MCP85011-501 tube (see see page 6).**
- **Clearly, further improvements in detector efficiency is needed.**
- Similarly, if one can make the final focusing element out of the solid fused silica, one would gain in efficiency.

Conclusions

- We have studied spatial resolution of a number of MCP-PMTs and MaPMTs with a scanning setup with a spatial resolution of ~150μm. Many detailed microstructures are revealed, especially in case of Flat Panel MaPMTs.
- Typical relative measured efficiency at 430nm, normalized to the Photonis PMT, is typically 50-60% for the Burle MCP-PMTs, and 60-70% in good regions for the Hamamatsu Flat panel MaPMT. Both tubes have edge effects where the efficiency drops by ~10-20%.
- The performance of a detector based on the Focusing DIRC prototype, would be actually comparable to the present BaBar DIRC, provided that one would not create further inefficiencies.
- However, before the detectors mentioned in this talk can be considered for a real application, one has to do many things, such as (a) investigate aging issues, (b) develop more compact integrated electronics, etc.
- **The Focusing DIRC prototype is in the test beam at SLAC.**