DIRC for a Higher Luminosity B Factory

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10^{36} Workshop
SLAC

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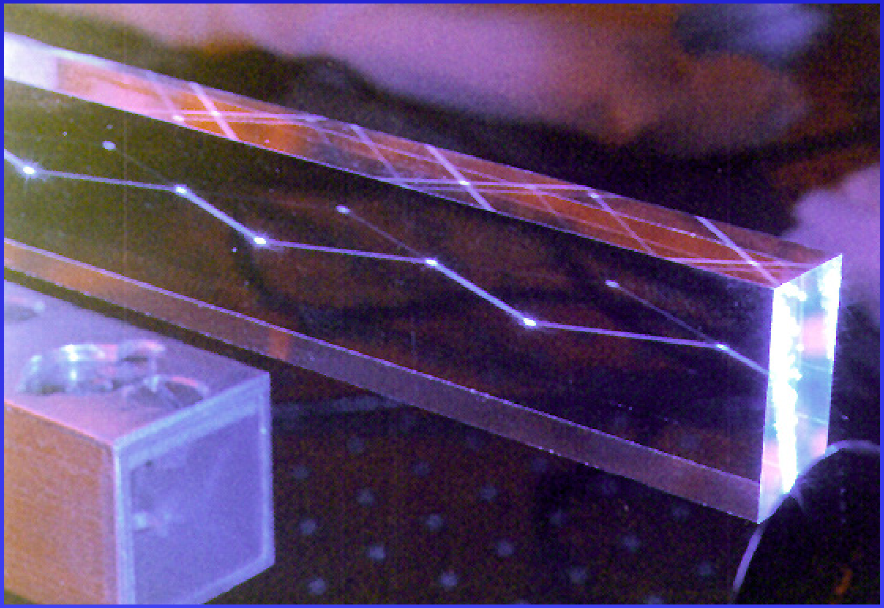


Overview

- Current performance
  - — What defines the resolution ?
  - — What have been the challenges ?
- Limitations and challenges in 10^{36} machine, possible solutions
- Current R&D status
- Other extensions

Current Design and Its Limitations

BABAR DIRC is a 3D device: PMT position (x, y) and time (t).
Track trajectory known from tracking system (additional uncertainty)
Unknown variables: θ_C and φ_C.

Single photon resolution using x, y measurements only :
$\sigma(\theta_{C,\gamma}) = \sigma_{\text{geometric}} \oplus \sigma_{\text{chromatic}} \oplus \sigma_{\text{transport}}$
with

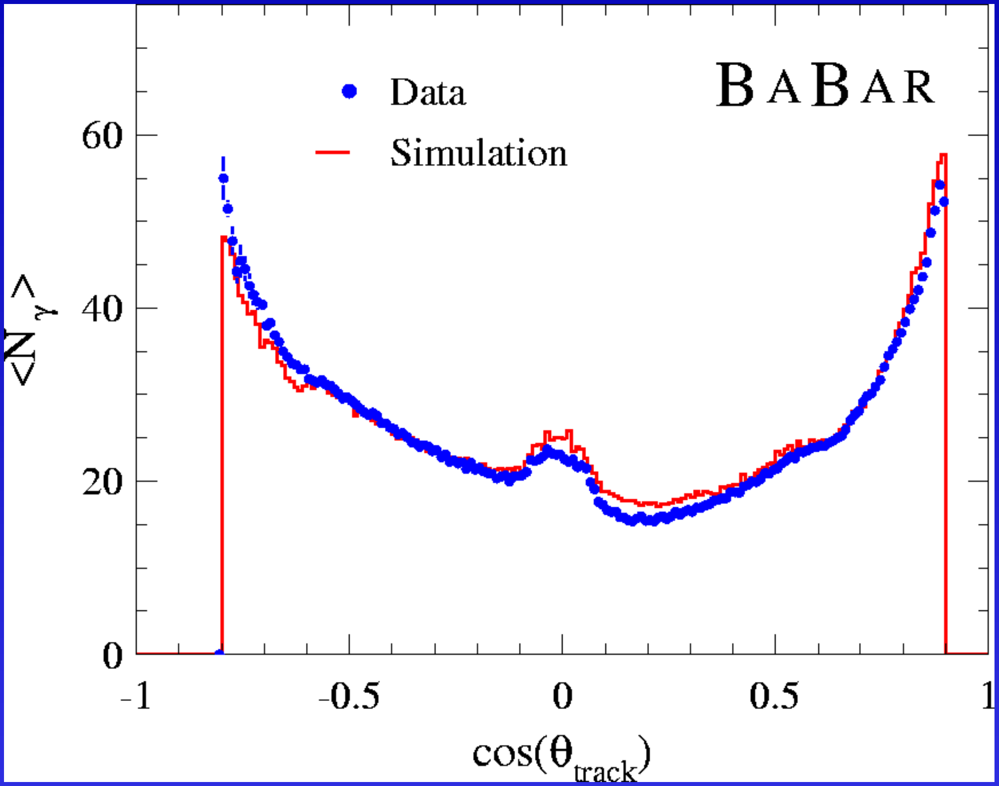
- $\sigma_{\text{geometric}} \approx 7.2$ mrad (from PMT and bar size)
- $\sigma_{\text{chromatic}} \approx 5.4$ mrad (from photon production process)
- $\sigma_{\text{transport}} \approx 2$ mrad–3 mrad (from bar imperfections)

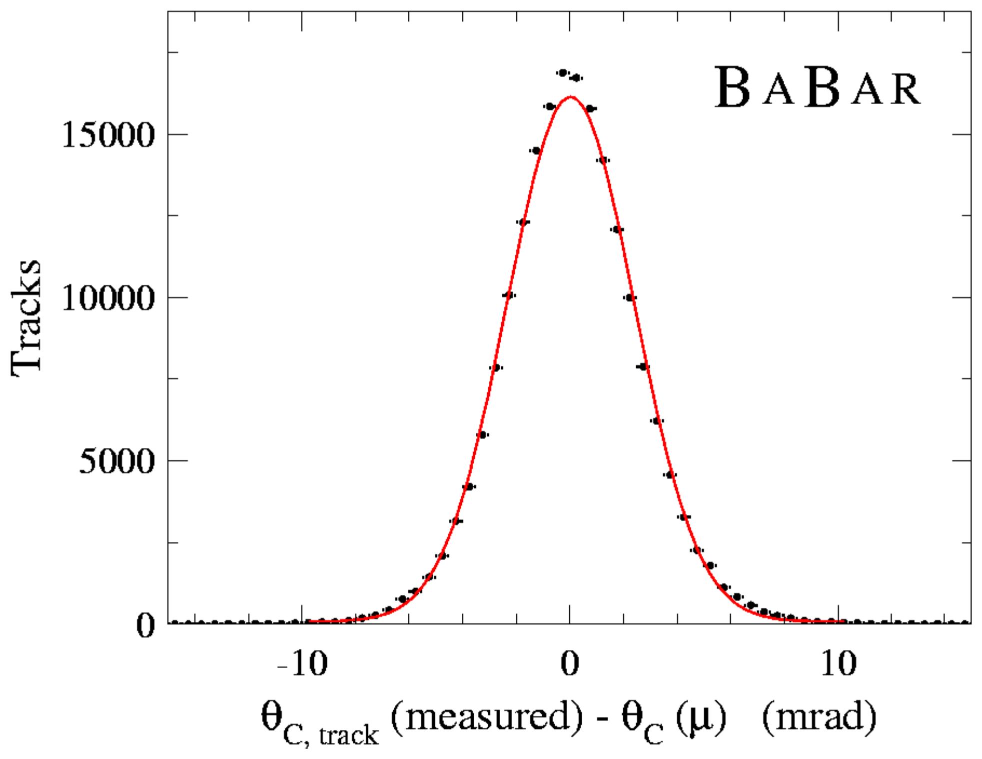
Expected : $\sigma(\theta_{C,\gamma}) = 9.5$ mrad
Measured : $\sigma(\theta_{C,\gamma}) = 9.6$ mrad

Current Design and Its Limitations

Example: $e^+e^- \longrightarrow \mu^+\mu^-$ events:
Per track 20-60 detected photons.

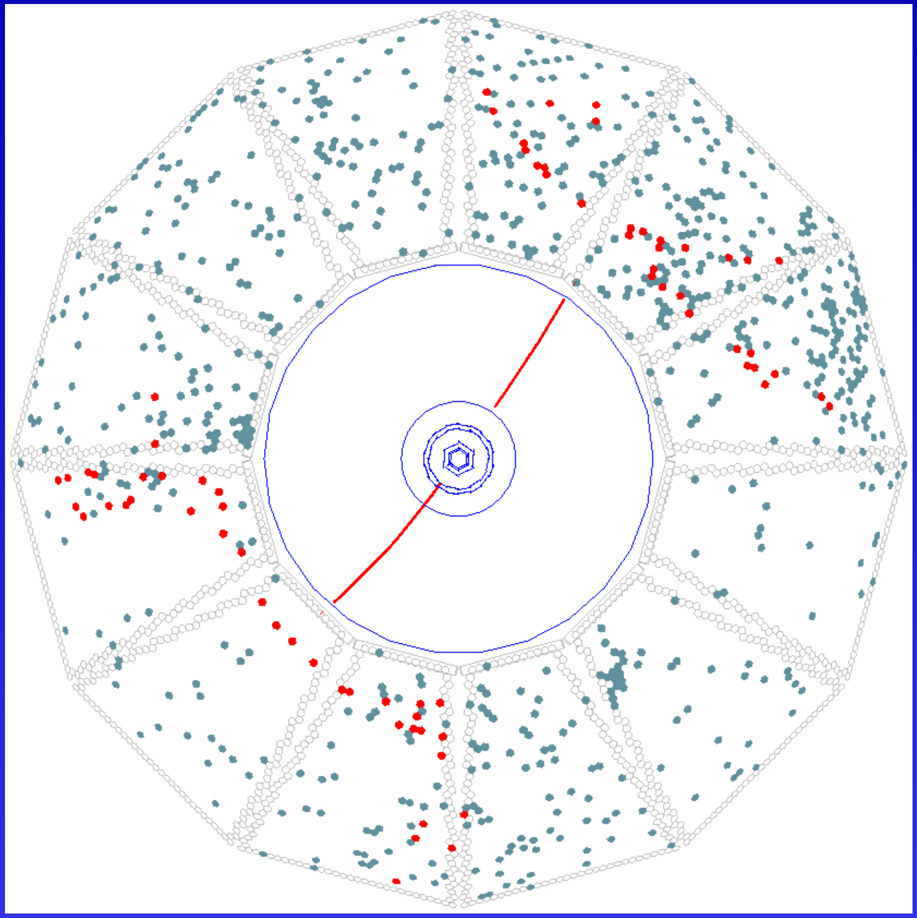
$$\sigma(\theta_C) = \frac{1}{\sqrt{N_\gamma}}\,\sigma(\theta_{C,\gamma}) \oplus \sigma_{\text{correlated}}$$



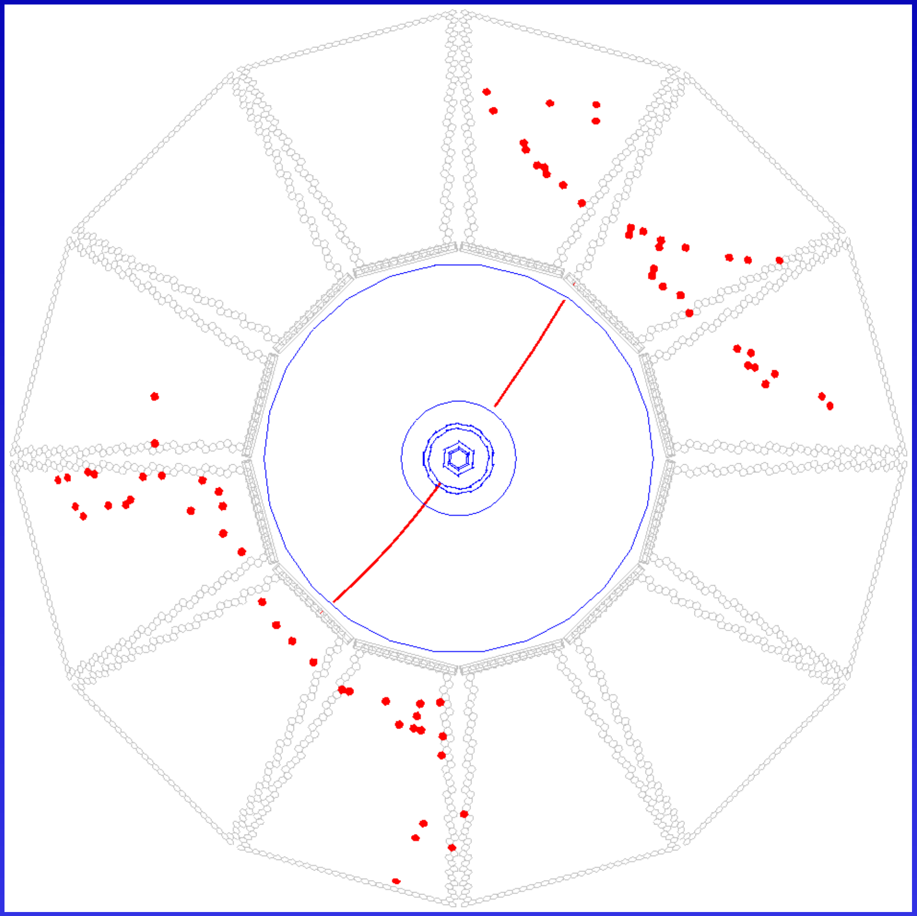


with $\sigma_{\text{correlated}} \approx 1.6$ mrad
(alignment and track uncertainty)
$\Rightarrow \sigma(\theta_C) \approx 2.4$ mrad
Information from time not sufficiently precise to improve θ_C resolution.

Current Design and Its Limitations



±300 ns trigger window



±8 ns Δt window

80 kHz–200 kHz $\otimes$ 10752 PMTs $\otimes$ ± 300 ns trigger window

500–1300 background hits (10% occupancy)

Hit time helps to resolve ambiguities and efficiently reduce background.

Overview

- Current performance

  Performs fine; close to design; significant impact on physics analysis

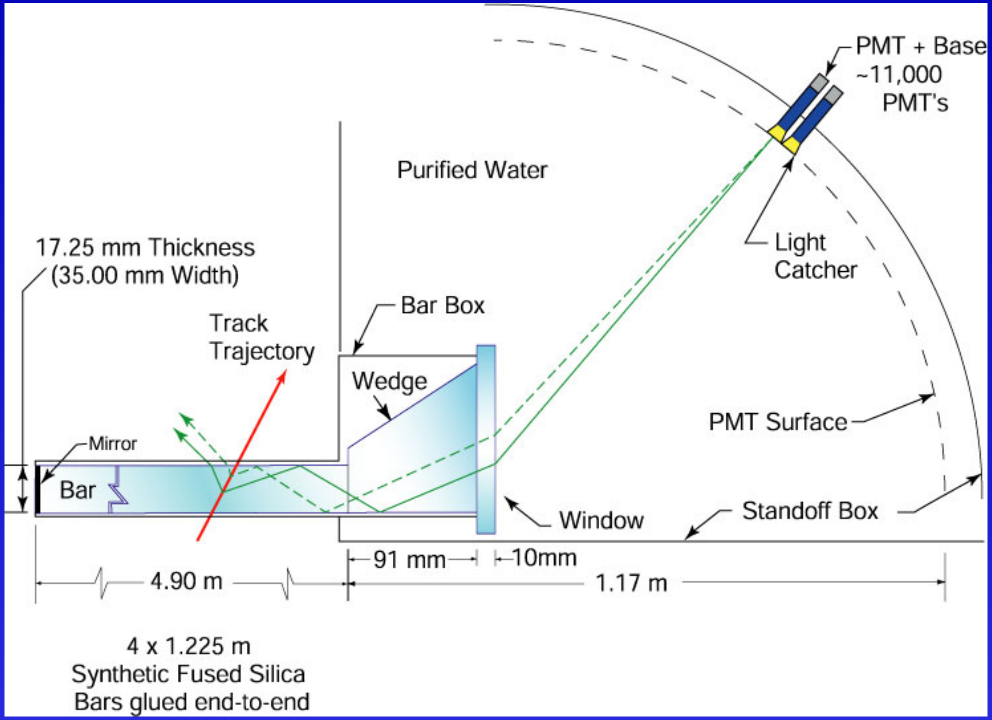
  Main issue: background in SOB; reduced by shielding.
- Limitations and challenges in 10^{36} machine, possible solutions

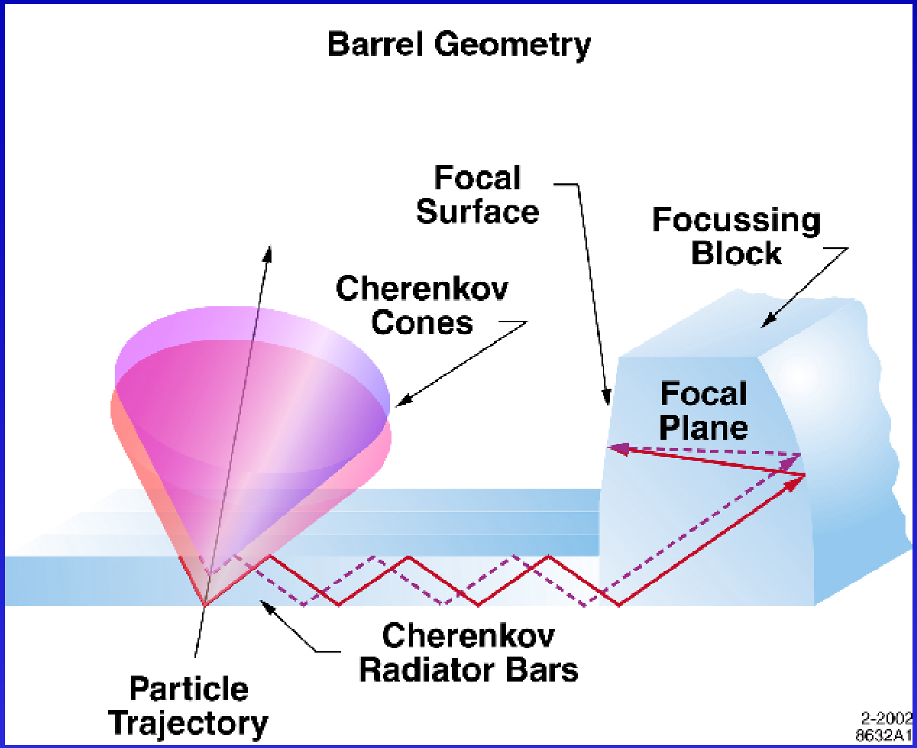
  — Low radiation $\longrightarrow$ no degradation issue.

  — Requirement on resolution does not change.

  — Higher background $\longrightarrow$
- Current R&D status
- Other extensions

Detection System





Reduce size of Stand-Off Box ⇒ less background

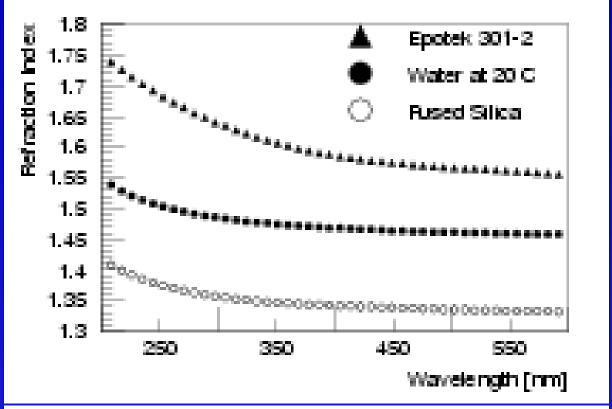
Go from pin-hole to focusing optics ⇒ reduced bar size uncertainty

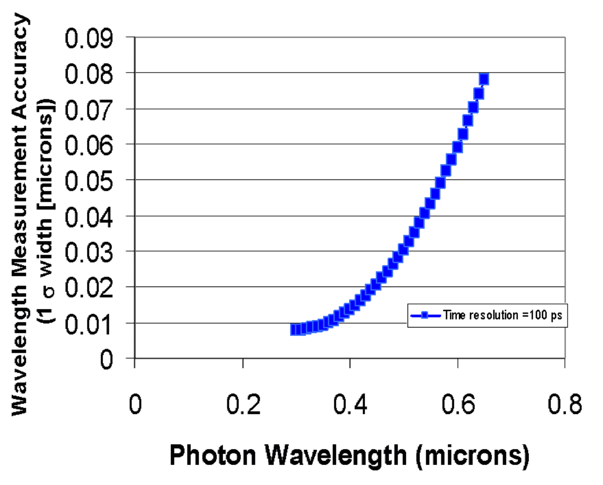
Smaller PMTs ⇒ reduced PMT size uncertainty

PMTs with improved time resolution ⇒ reduced chromatic uncertainty

⇒ tighter time cuts ⇒ better background reduction

Detection System





Source of chromatic uncertainty:

- Photons are generated with different wavelengths
- $\theta_C = \theta_C(\lambda, \beta, m, \ldots)$

Ways to reduce chromatic uncertainty:

- Reduce wavelength range in system
  $\Rightarrow$ lower number of photons detected
- Measure energy of photon
  $\Rightarrow$ no (practical) detection devices available
- Measure hit time precisely

From hit time, time of track passing radiator, and photon path length
$\Rightarrow$ Group velocity of photon in transport system
$\Rightarrow$ Refractive index in transport system
$\Rightarrow$ Wavelength of photon

Overview

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  Performs fine; close to design; significant impact on physics analysis

  Main issue: background in SOB; reduced by shielding.
- Limitations and challenges in 10^{36} machine, possible solutions

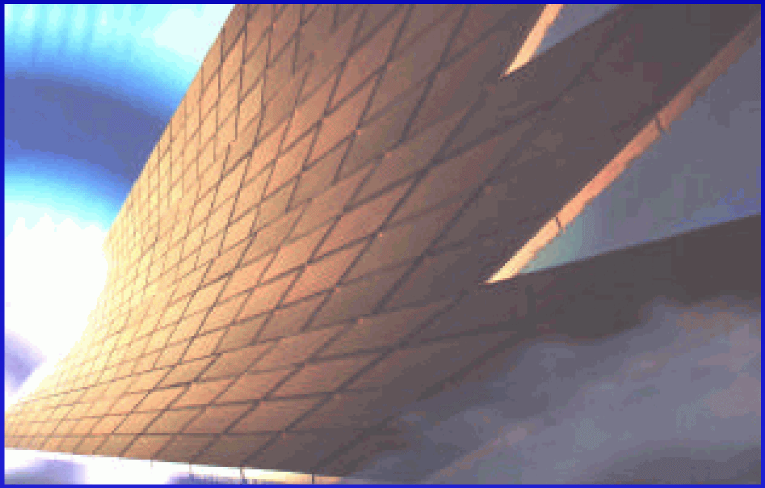
  Main issue: higher background;

  Solution: smaller Stand-Off Box; smaller detector size; very good timing resolution
- Current R&D status

  — Are there any detectors with these specifications ?
- Other extensions

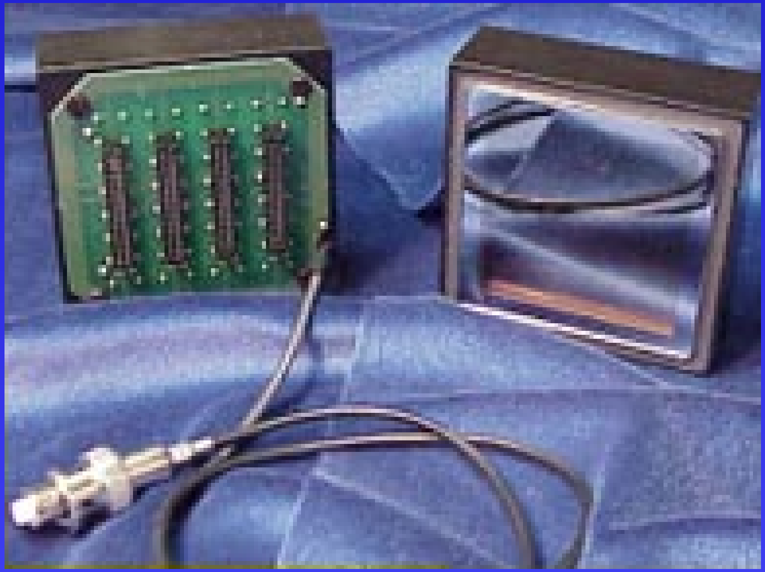
PMT Choices

Hamamatsu H-8500 flat panel



- 8×8 pads
- 52 mm $\times$ 52 mm size
- relatively low gain $(1.6 \cdot 10^6)$

Burle 85011 MicroChannelPlate



- 8×8 pads
- 71 mm $\times$ 71 mm size
- very low gain $(0.6 \cdot 10^6)$

MCPs typically longevity problems

R&D status

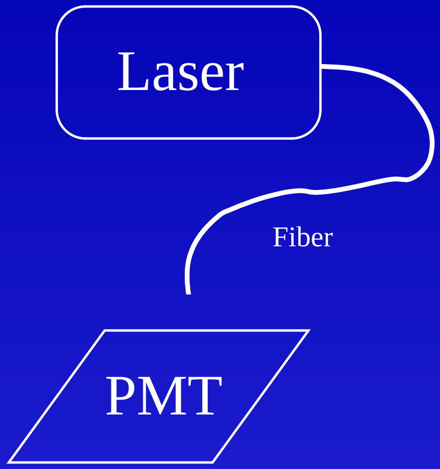
Light source

Pilas pico-second laser

$\lambda = 635$ nm

$\sigma_{\text{pulse}} < 35$ ps

Operated in single photon mode

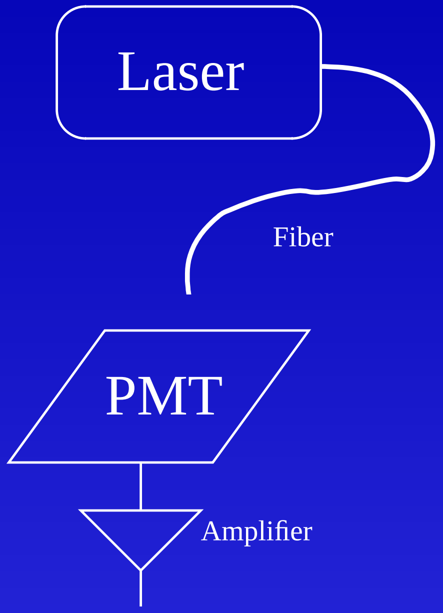


PMT

Hamamatsu H-8500 early pre-production

Burle 85011

R&D status



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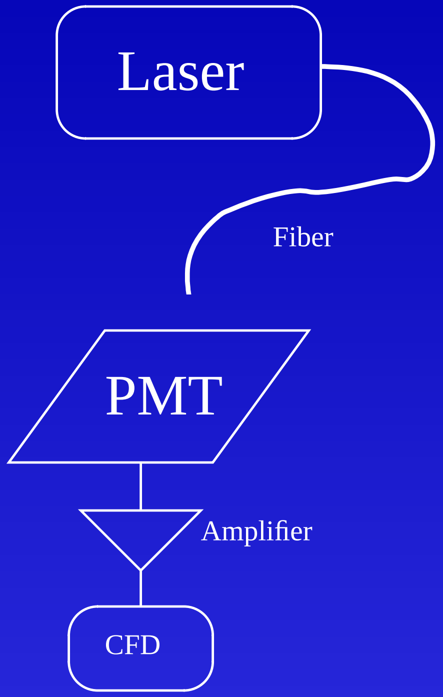
Amplifier

Elantec EL2075C, Philips 779

R&D status



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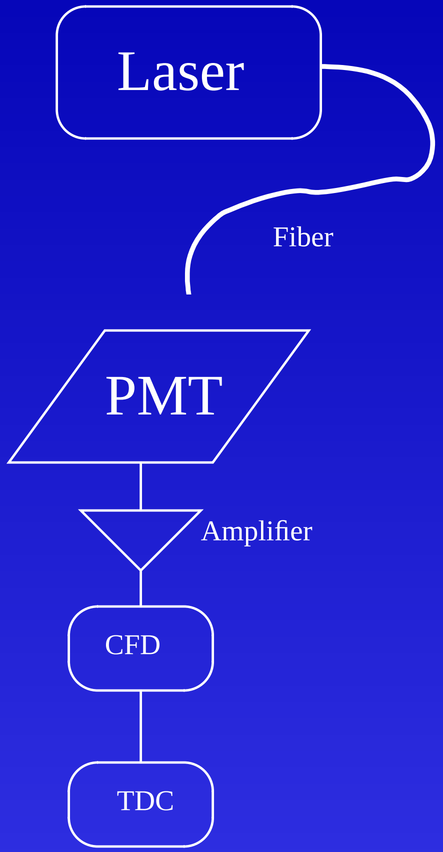
Readout

constant fraction discrimination

R&D status



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- Burle 85011

Amplifier

- Elantec EL2075C, Philips 779

Readout

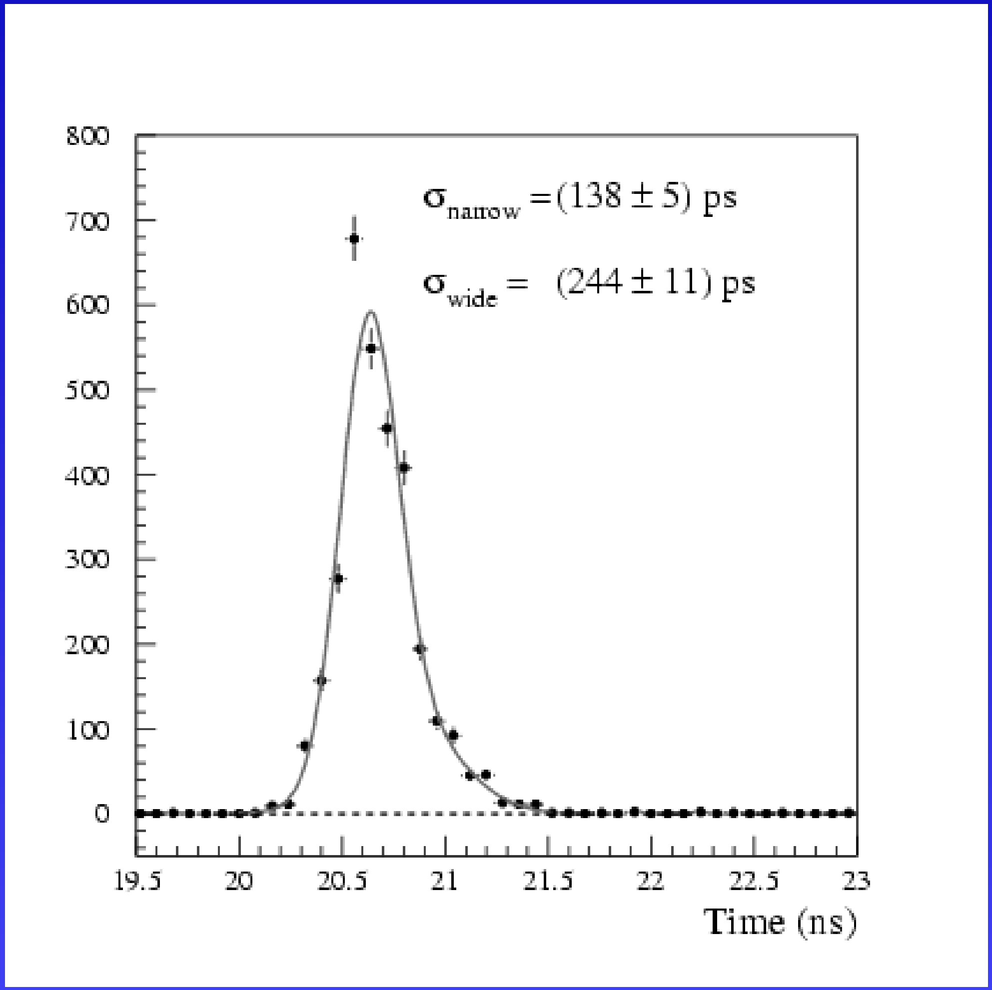
- constant fraction discrimination
- LeCroy 2228A, 22 ps per count TDC
- CAMAC based readout

R&D status

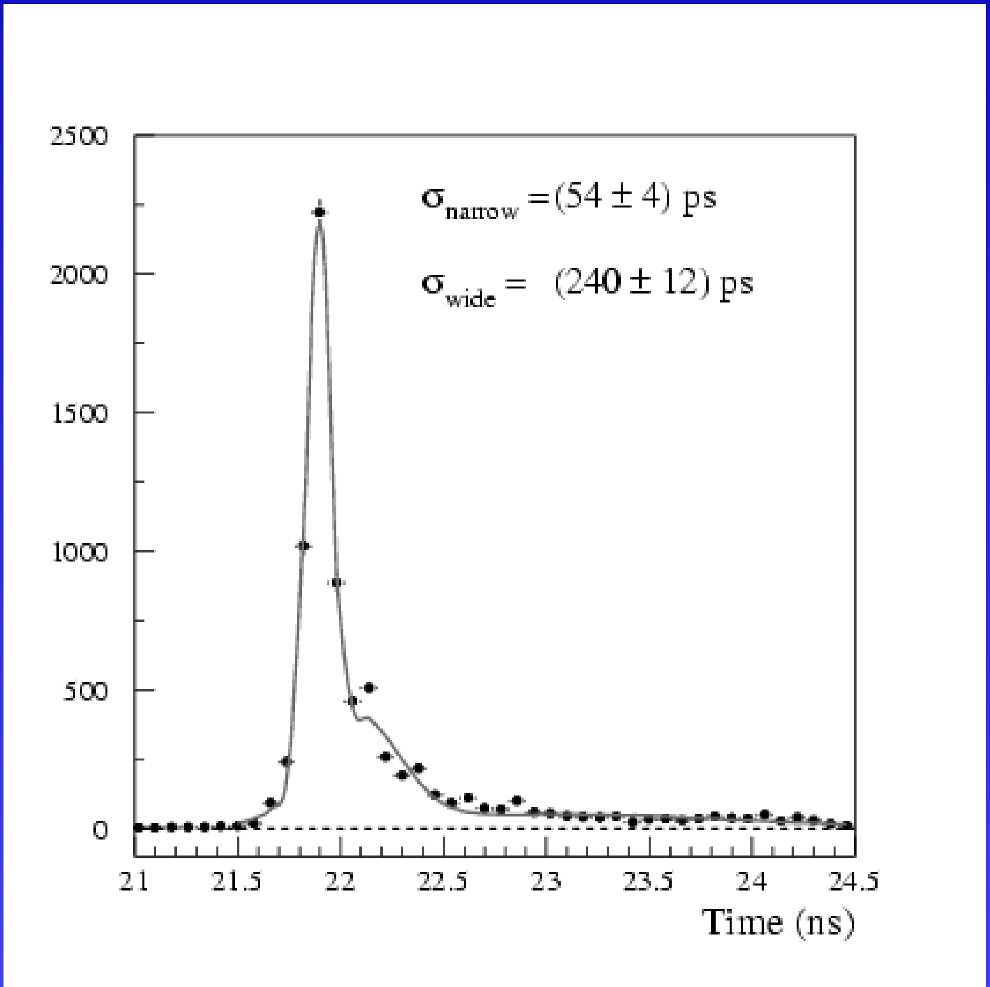
Using pico second laser (35 ps FWHM), low intensity ≈ single photons

Constant fraction discriminator, fast amplifier: Elantec EL 2075C

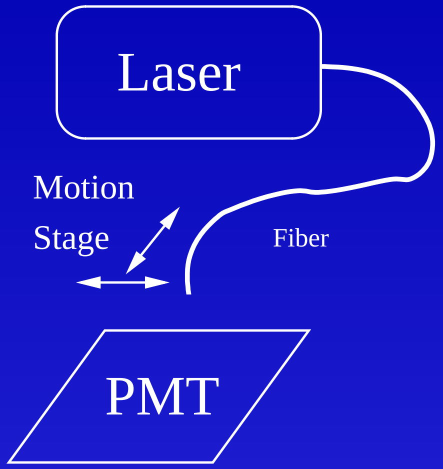
Hamamatsu:



Burle:



R&D status



Light source

Pilas pico-second laser

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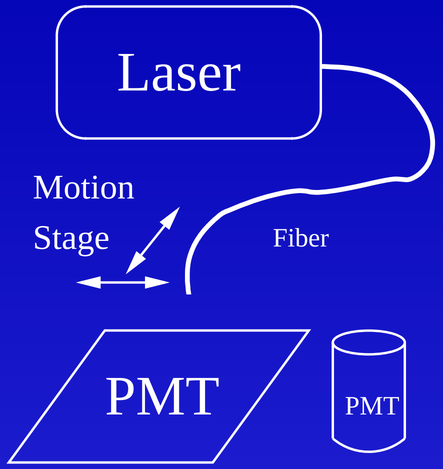
Operated in single photon mode

Motion Controller:

Repeatability $< 7\ \mu$m

R&D status



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PMT

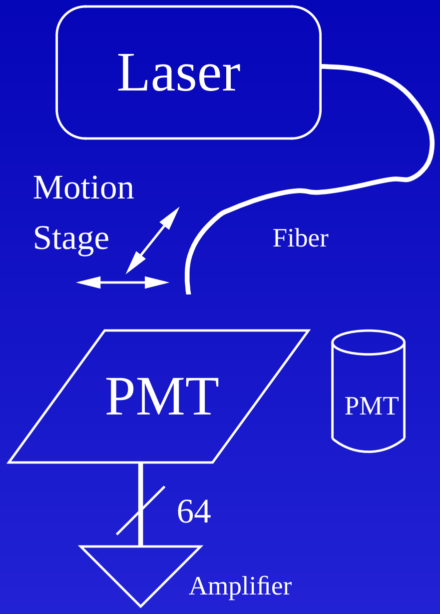
Hamamatsu H-8500 early pre-production

Burle 85011

Laser Intensity Monitoring

Two standard PMTs used for calibration
(Photonis XP2262B, EMI 9125FLB17)

R&D status



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Laser Intensity Monitoring

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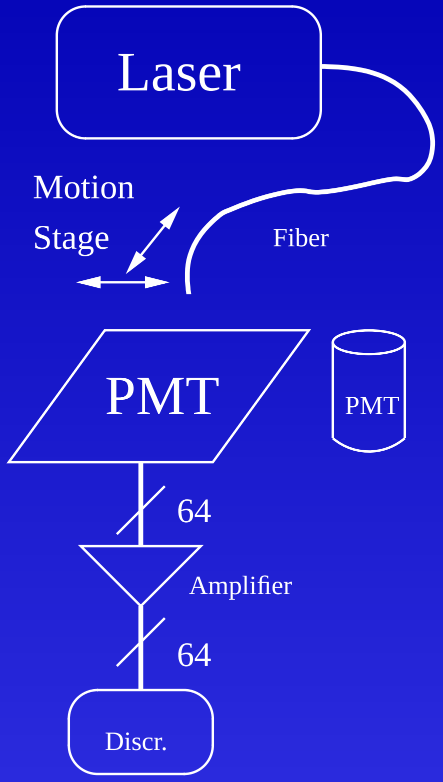
Amplifier

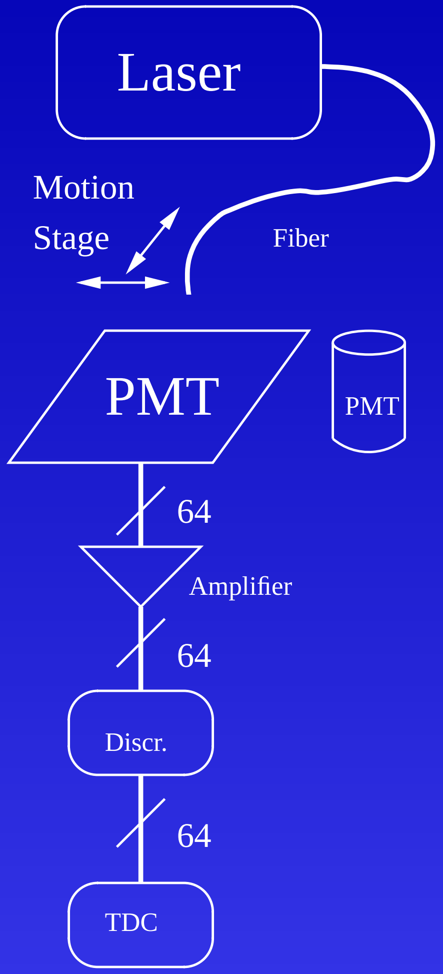
Elantec, EL2075C

Readout

Single threshold discrimination



R&D status



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Operated in single photon mode

Motion Controller:

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PMT

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Laser Intensity Monitoring

Two standard PMTs used for calibration

(Photonis XP2262B, EMI 9125FLB17)

Amplifier

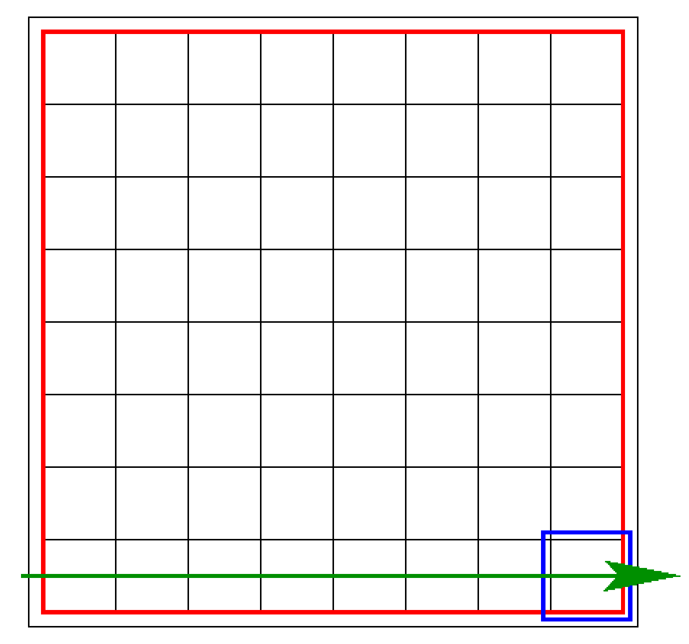
Elantec, EL2075C

Readout

Single threshold discrimination

500 ps per count TDC (LeCroy 2277)

Overview of Scans



Goal: To determine

- rel. efficiency variations of pads
- rel. efficiency variations within a pad
- visible structures of PMT

Scans:

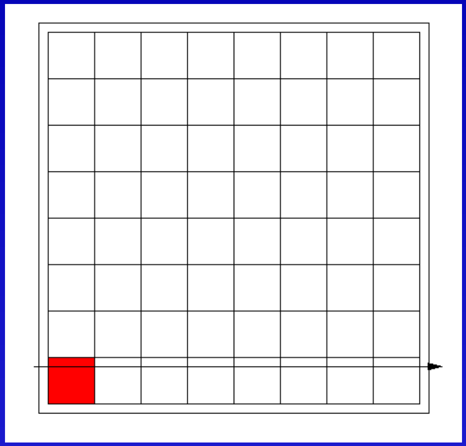
- Across the PMT along a line
- Across the whole PMT
- Across a single pad

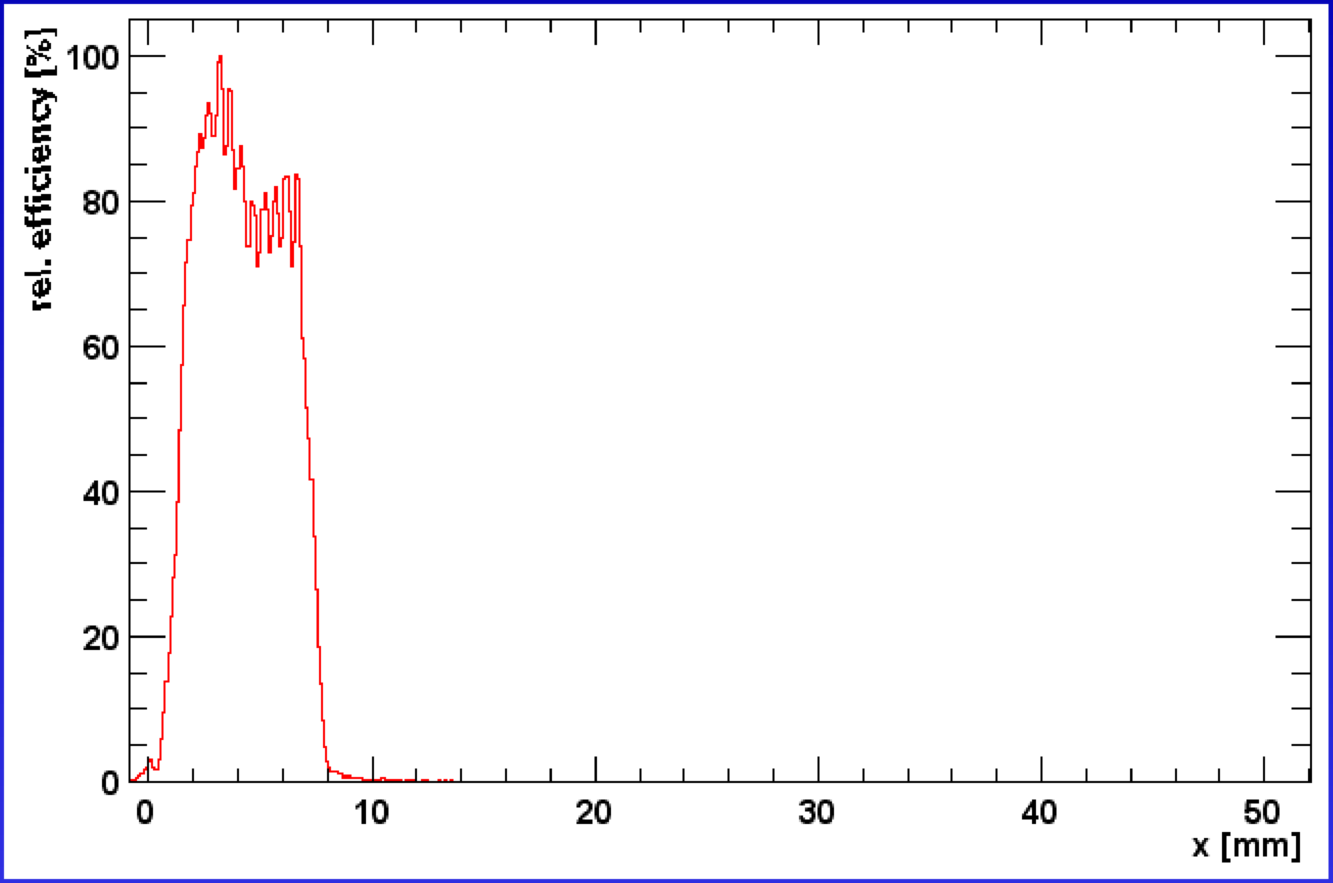
Note:

"Rel. efficiency" is a convolution of:

- Cathode efficiency
- Anode efficiency
- Spectral efficiency

Scan of one Line across the PMT, Hamamatsu





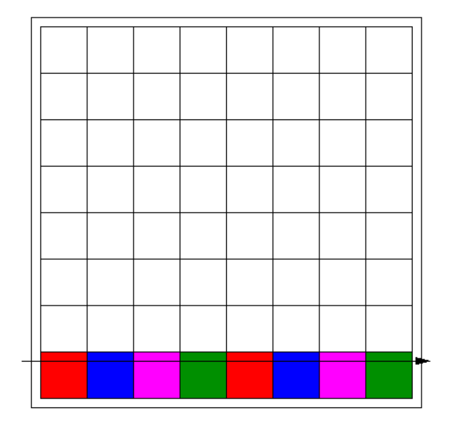
Scan step size:

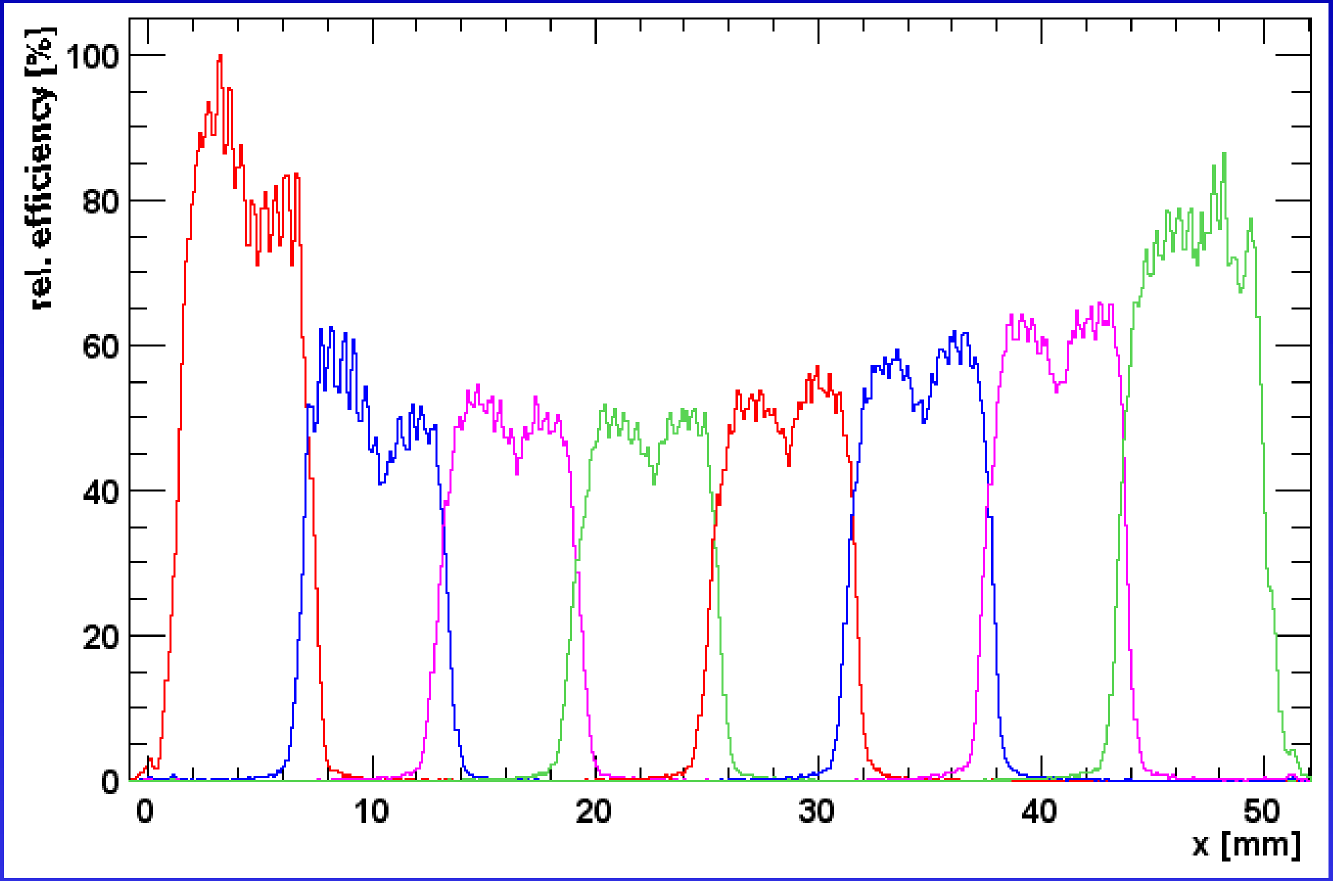
- $100\ \mu$m

Conclusions:

- Steep pad edges
- 2 main peaks per pad, addl. microstructure
- cross talk $< 1\%$ (addl. 3% electr. x-talk)

Scan of one Line across the PMT, Hamamatsu





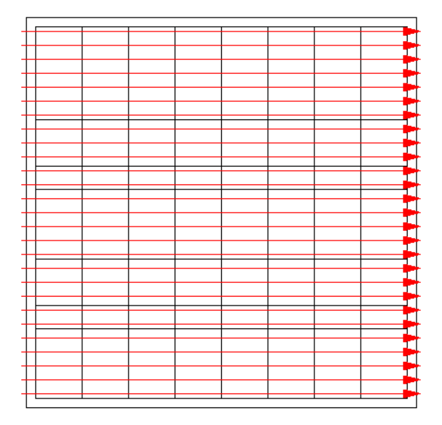
Scan step size:

- 100 μm

Conclusions:

- Steep pad edges
- 2 main peaks per pad, addl. microstructure
- cross talk $< 1\%$ (addl. 3% electr. x-talk)
- Factor 2 to 4 difference in pad efficiency
- At pad boundary: charge sharing

Scan of full PMT, Hamamatsu

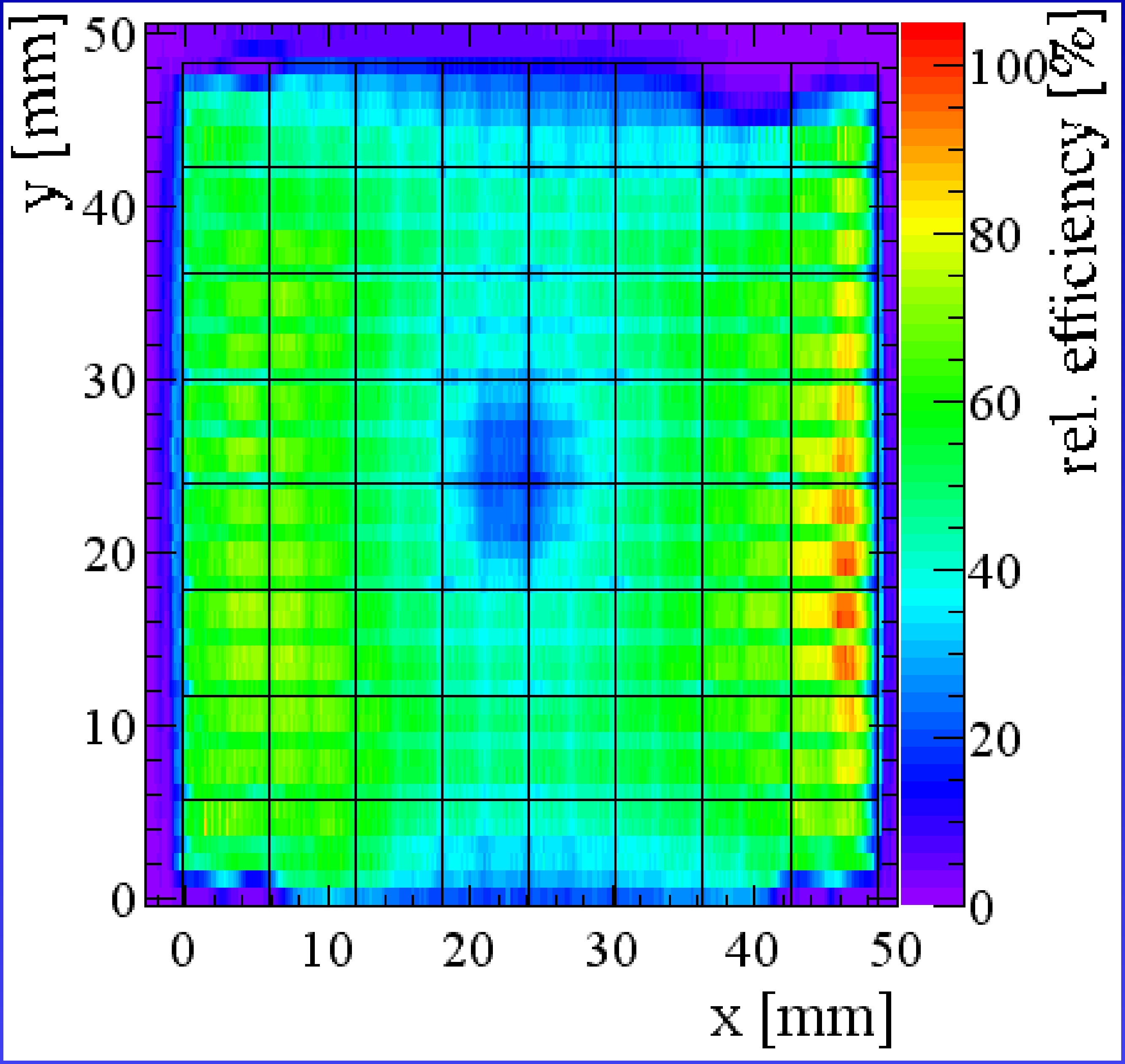


Scan step size:

- 1.0 mm vertical
- 100 μm horizontal

Conclusions:

- Strong variations of rel. efficiency (factor 2-4)



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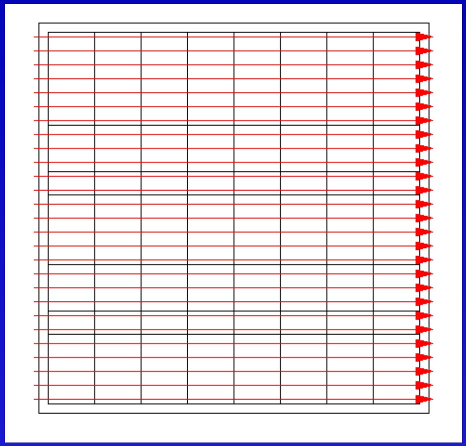

Scan step size:

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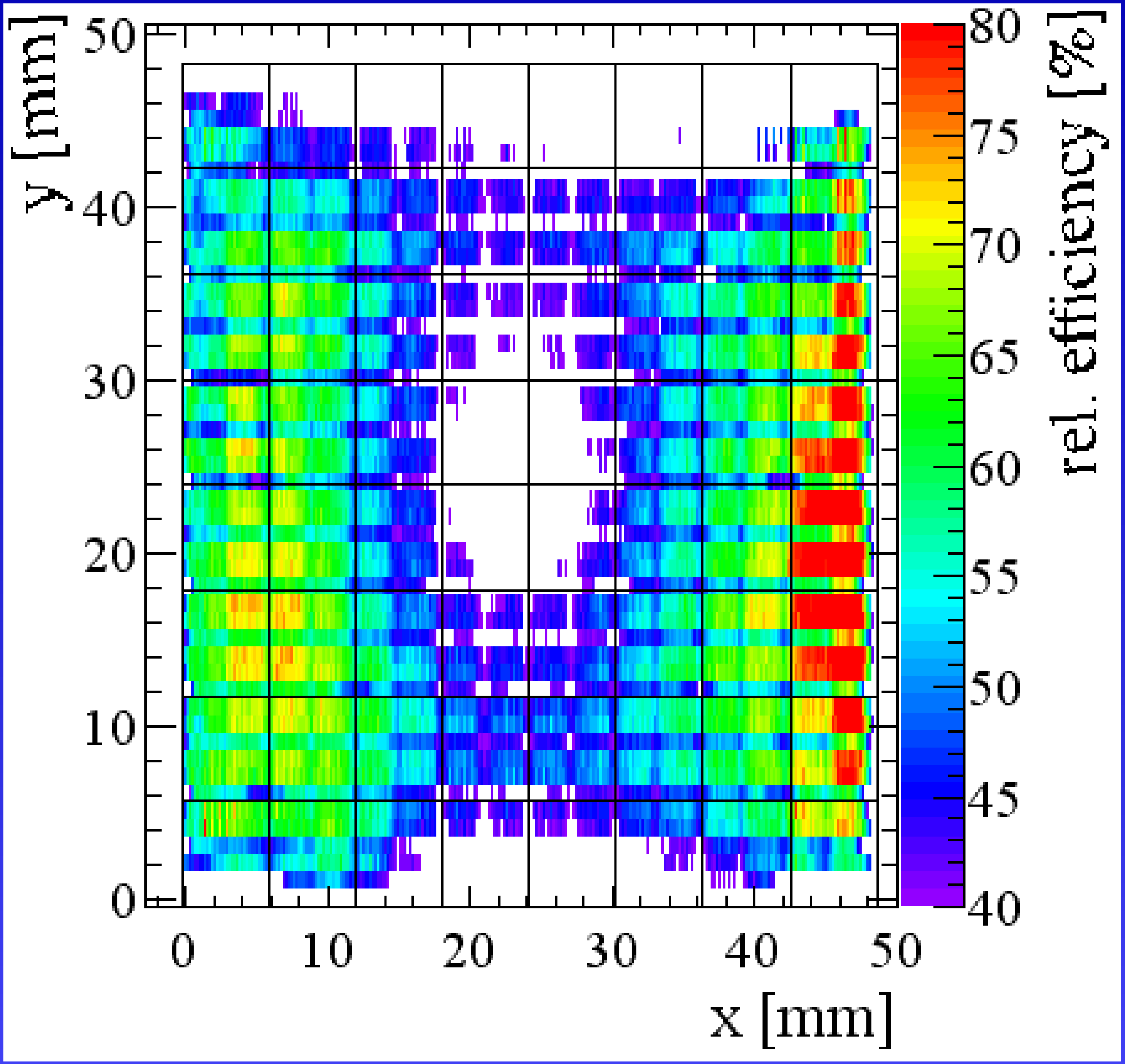
- 100 μm horizontal

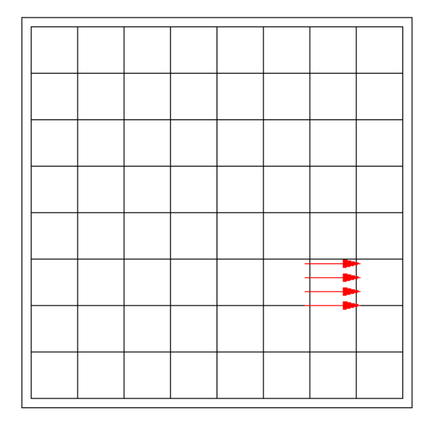
Conclusions:

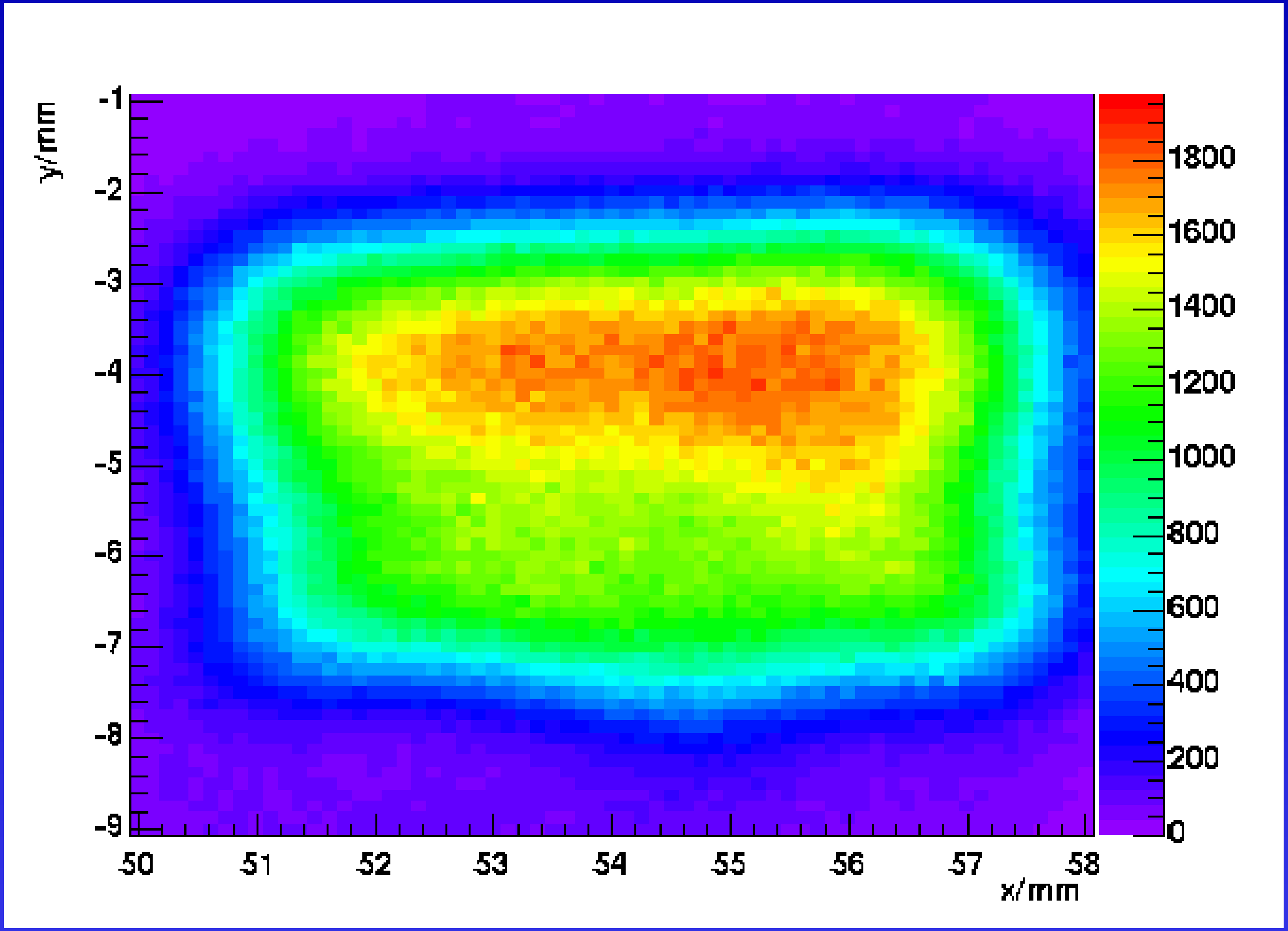
- Strong variations of rel. efficiency (factor 2-4)
- Obvious pad boundaries
- Pad structure visible



Zoom into z axis

Detailed Scan of one Pad, Hamamatsu





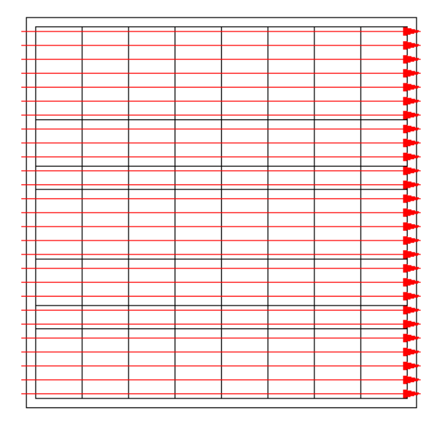
Scan step size:

- 100 μm vertical
- 100 μm horizontal

Conclusions:

- 4 high efficient regions
- Factor 2 variation within pad

Scan of full PMT, Burle



Scan step size:

- 1.0 mm vertical
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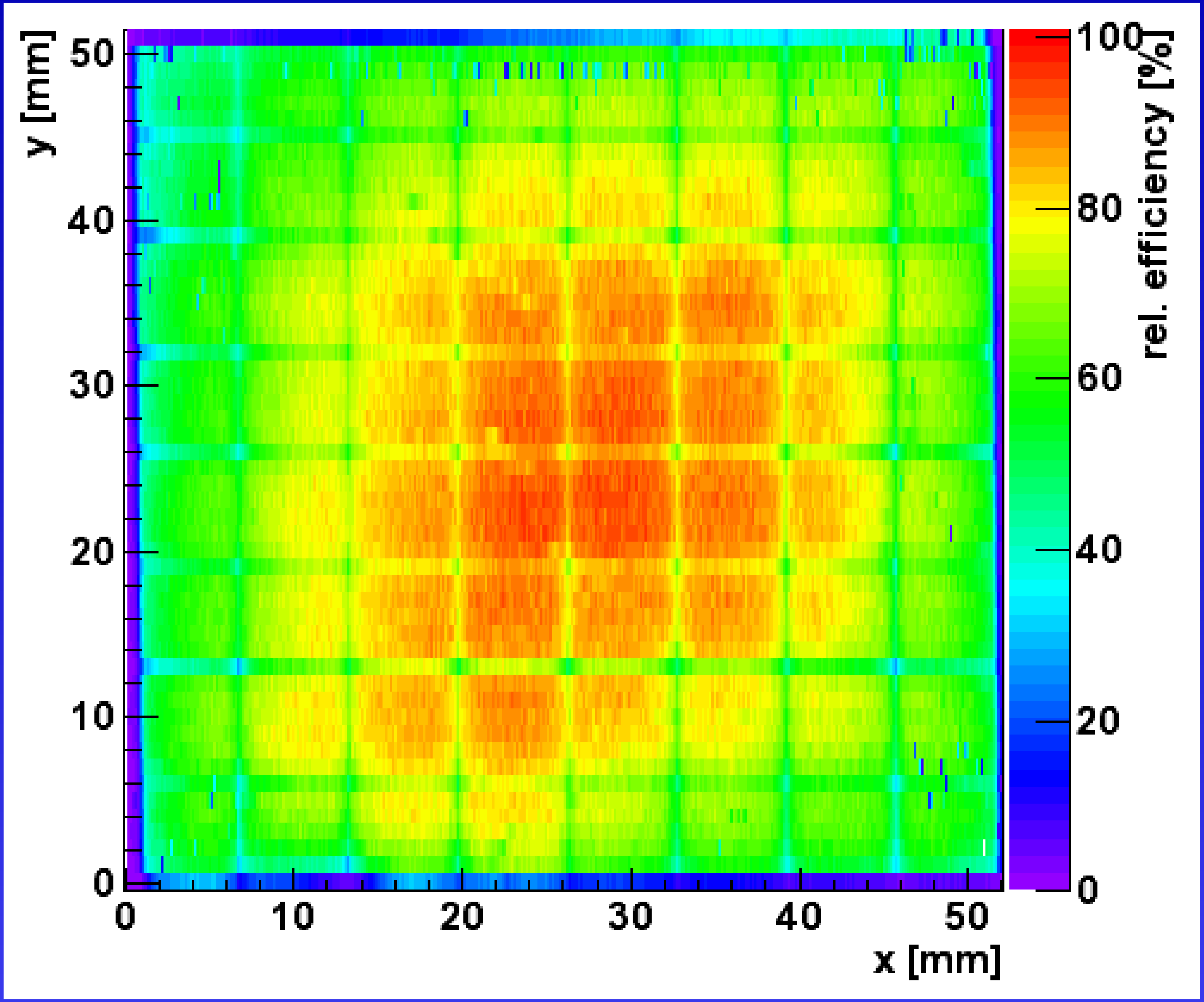
Conclusions:

- Variations of rel. efficiency (factor 2)



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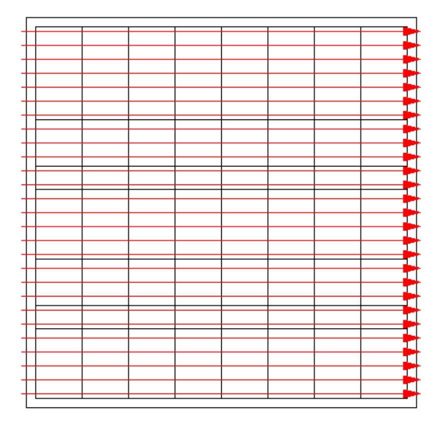

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Conclusions:

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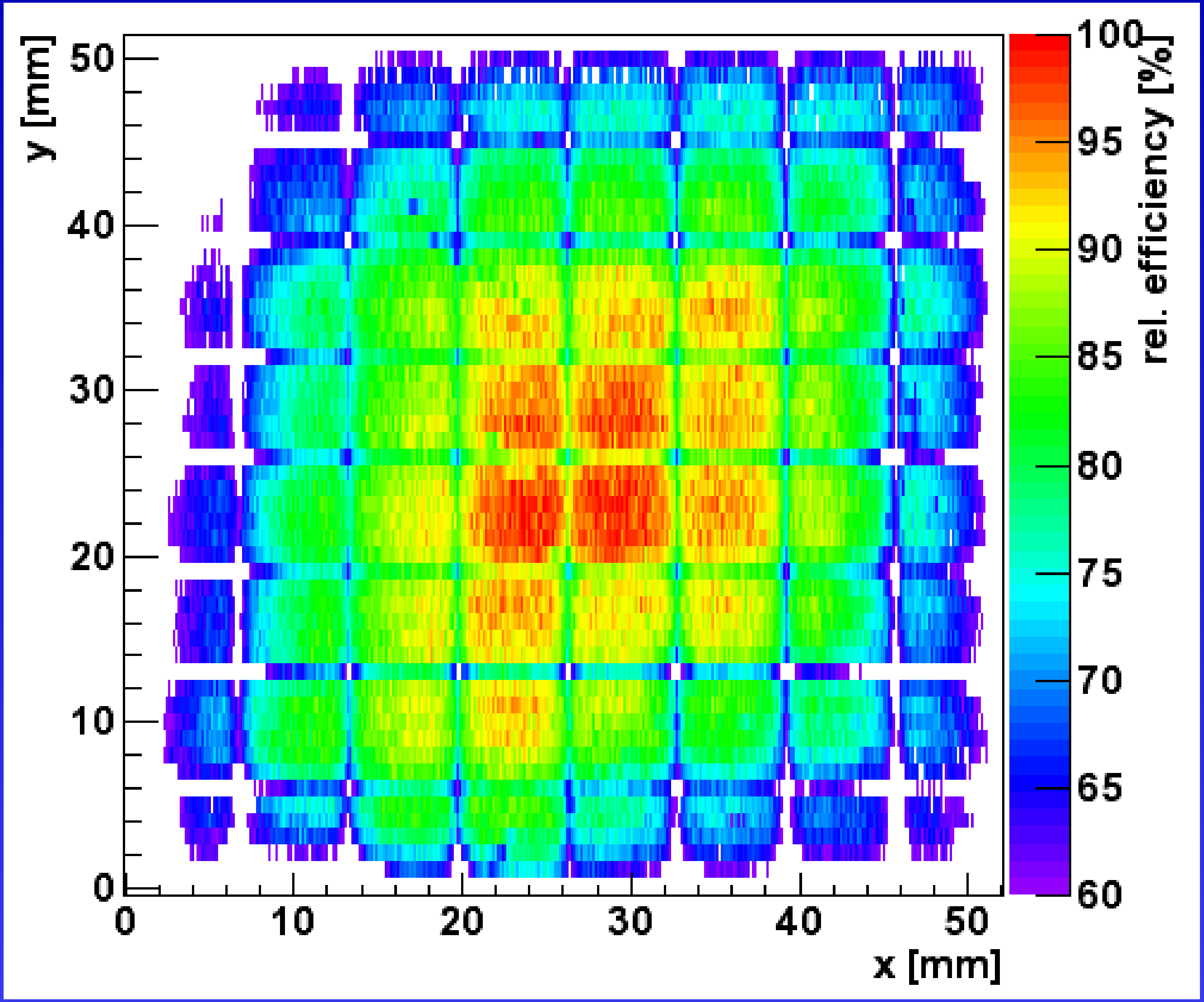
  - Obvious pad boundaries
- No pad structure visible



Zoom into z axis

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  Performs fine; close to design; significant impact on physics analysis

  Main issue: background in SOB; reduced by shielding.

- Limitations and challenges in 10^{36} machine, possible solutions

  Main issue: higher background;

  Solution: smaller Stand-Off Box; smaller detector size; very good timing resolution

- Current R&D status

  Candidates for detector with < 100 ps resolution and 6 mm $\times$ 6 mm pad size exist; first test promising but lower quantum efficiency, gain

  Next steps: Designing and building prototype to test setup

  Will test prototype in our Cosmic Ray Telescope.

- Other extensions

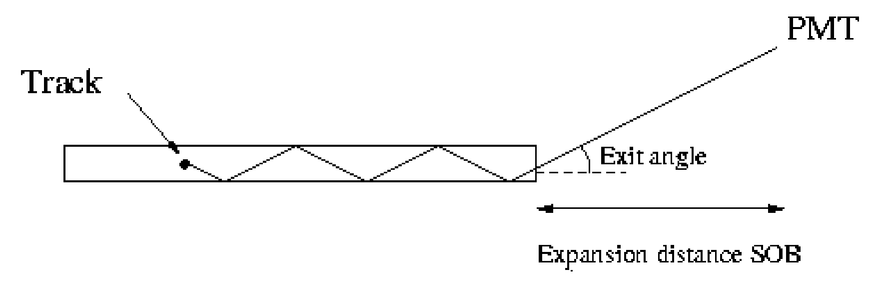
  — Is there a way to significantly improve the resolution ?

  — What else is effecting the total resolution ?

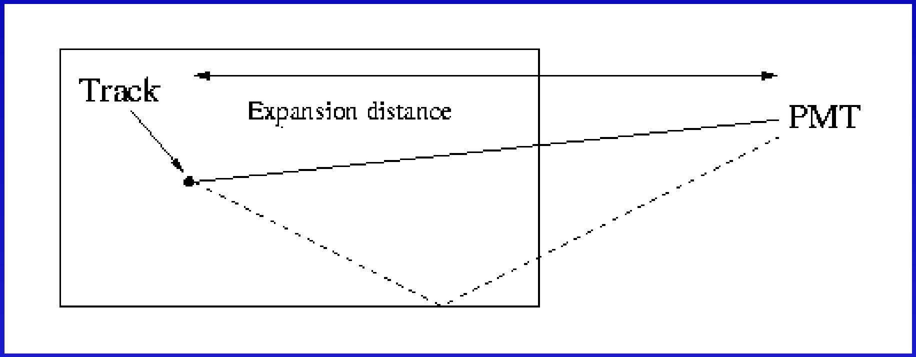
  — Where can the PID be improved ?

Transport System

Current BaBar DIRC uses 12 barboxes with 12 bars each



- Large number of reflections from bar sides during transport.
- Point where photon exits bar unknown $\Rightarrow$ angle uncertainty
- Resolution:
  $$\sigma_\alpha \approx \frac{1}{L_{\text{SOB}}}\sqrt{\sigma_x^2(\text{bar}) + \sigma_x^2(\text{pixel})}$$
- $t_x = \sqrt{12}\sigma_x$ bar size.
- (for focusing optics: $t_x = 0$)
- Note: $\sigma_\alpha \neq \sigma(\theta_C)$



- Small number of reflections.
- Resolve ambiguities from reflections by time measurement (?).
- Point where photon exits bar calculable
- Resolution (no side reflection):
  $$\sigma_\alpha \approx \frac{1}{L_{\text{expansion}}}\sqrt{\sigma_x^2(\text{track}) + \sigma_x^2(\text{pixel})}$$
- $\sigma_x(\text{track})$ uncertainty of track
- Smaller number of reflections $\Rightarrow$ less influence of surface effects

Estimation of Resolution

Current BaBar DIRC

- $\sigma_\alpha \approx \frac{1}{L_{\text{SOB}}}\sqrt{\sigma_x^2(\text{bar}) + \sigma_x^2(\text{pixel})}$
- $t_x = 35.0$ mm, $\sigma_x(\text{pixel}) = \frac{1}{\sqrt{16}}28$ mm, $L = 1200$ mm $\Rightarrow \sigma_x \approx 10.2$ mrad
- $t_y = 17.5$ mm, $\sigma_y(\text{pixel}) = \frac{1}{\sqrt{16}}28$ mm, $L = 1200$ mm $\Rightarrow \sigma_y \approx 7.2$ mrad
- with water magnification: $\sigma_{x/y} \approx 9.2$ mrad$/6.5$ mrad.

Bars with focusing optics

- $\sigma_\alpha \approx \frac{1}{L_{\text{SOB}}}\sqrt{\sigma_y^2(\text{pixel})}$
- Pixel size 6 mm, $\sigma_y = 1.7$ mm, $L = 250$ mm $\Rightarrow \sigma_y \approx 6.9$ mrad
- Pixel size 2 mm, $\sigma_y = 0.6$ mm, $L = 250$ mm $\Rightarrow \sigma_y \approx 2.3$ mrad

Plate optics

- $\sigma_\alpha \approx \frac{1}{L}\sqrt{\sigma_x^2(\text{track}) + \sigma_x^2(\text{pixel})}$
- $\sigma_x(\text{track}) = 4$ mm, $\sigma_x(\text{pixel}) = 1.7$ mm, $L = 4000$ mm $\Rightarrow \sigma_x \approx 1.1$ mrad
- $\sigma_x(\text{track}) = 4$ mm, $\sigma_x(\text{pixel}) = 1.7$ mm, $L = 1000$ mm $\Rightarrow \sigma_x \approx 4.3$ mrad

SuperBaBar with plate optics in x and focusing in y:

- Pixel size 6 mm$(x) \times 2$ mm(y)
- $\sigma_x \approx 4.3$ mrad
- $\sigma_y \approx 2.3$ mrad

Tracking

Not really part of DIRC system
but DIRC requires good tracking and alignment:

- Tracking uncertainty has direct influence on resolution (correlated term !)
- Particle tracks might be distorted in radiator (decay, interactions, δ rays)

Addition of tracking detector outside of DIRC detector would help.

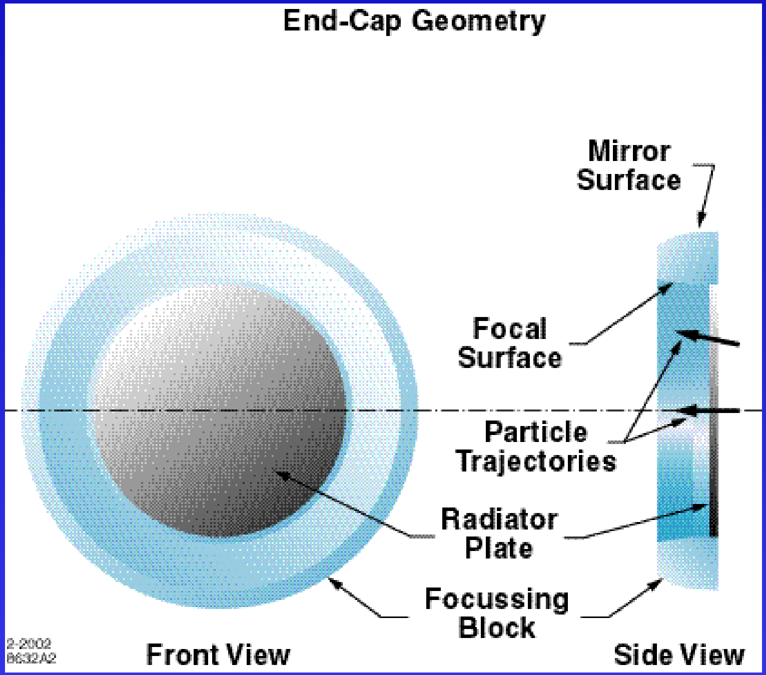
End-cap detector

BaBar DIRC is barrel only detector.
A fraction of the (high-momentum) particles leave in forward direction.

Idea: Add End-Cap device

Problems:

- Detectors inside magnetic field.
- Limited amount of space.



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- Limitations and challenges in 10^{36} machine, possible solutions

  Main issue: higher background;

  Solution: smaller Stand-Off Box; smaller detector size; very good timing resolution
- Current R&D status

  Candidates for detector with < 100 ps resolution and 6 mm $\times$ 6 mm pad size exist; first test promising but lower quantum efficiency
- Other extensions

  Plate geometry and smaller PAD sizes would improve resolution;

  Synthetic fused silica still material of choice;

  Tracking resolution important point to get further improvement;

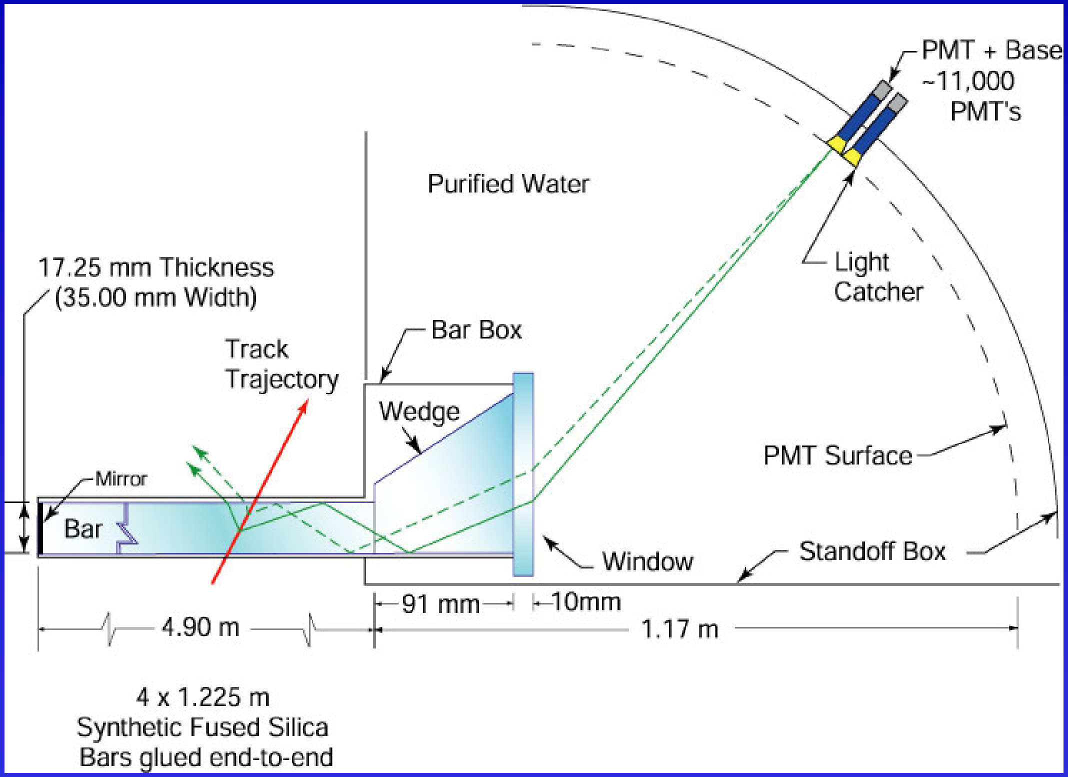
  End-cap device interesting, needs further studying.

R&D for new DIRC up and running in SLAC Group B

Current Design and Its Limitations

Four steps in DIRC system:

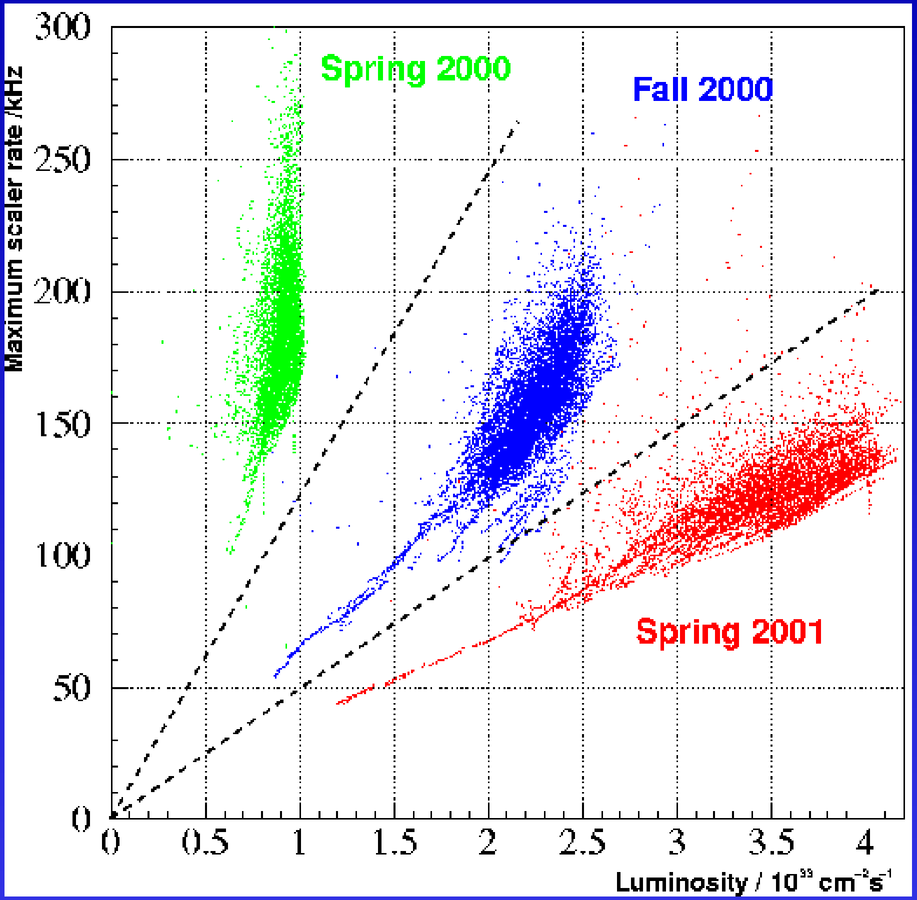
- Photons created in radiator
- Transported by internal reflection in light guide
- Expansion in Stand-Off Box
- Detection with PMT array



BaBar DIRC:

- ○ Synthetic fused silica as radiator and light guide.
- ○ Large Stand-Off Box outside magnetic field with 6000 l purified water.
- ○ Photo multiplier tubes (PMT) : ETL 9125B, ø$= 28$ mm, $\sigma_t \approx 1.5$ ns.

Current Design and Its Limitations



Background:

- Results in 10% occupancy
- Average rate: ≈ 80 kHz–200 kHz
- Mostly few MeV photons from conversions in Stand-Off Box

Increases with luminosity.

Reduced by adding shielding

Removed from sample by time cuts

Background induced rate estimate from special runs in February 2002:

$$R = 13\frac{\text{kHz}}{\text{A}} I_{\text{HER}} + 18\frac{\text{kHz}}{\text{A}} I_{\text{LER}} + 10\frac{\text{kHz}}{10^{33}\ \text{cm}^{-2}\ \text{s}^{-1}}\mathcal{L}$$

Limit in readout after TDC upgrade: 5% deadtime at ≈ 1 MHz.

Transport System

Requirements for radiator/transport material:

- Transparent (low photon loss over several meters of path).
- Radiation hard (BABAR DIRC: 5 kRad–10 kRad).
- High material uniformity.
- High quality optical finish (Surface uniformity < 5Å sms).
- Small radiation length X_0
  (to allow for precise calorimeter outside of DIRC system)

Synthetic fused silica seems to be best choice.

Plates :

Can plates be manufactured with a quality similar to single bars ?
Plates can be produced as shown by Belle, quality is unclear

Detection System

Main challenge regarding increase in luminosity with current DIRC:
Background from conversions in Stand-Off Box

Measures to reduce/handle background:

- Added shielding
- Improving readout electronics
- Reduce size of Stand-Off Box

θ_C resolution defined by:

- Imaging method (pin-hole)
- Bar size
- PMT size
- Size of Stand-Off Box