TIMING AND DETECTION EFFICIENCY PROPERTIES OF MULTI-ANODE PMTs FOR A FOCUSING DIRC

Outline:

• Motivation
  – R&D for upgrade of BABAR-DIRC

• Setup
  – Hamamatsu flat-panel PMT
  – Burle MCP

• Results

• Focusing DIRC Prototype and Test Beam Plans
**Context:**

SLAC group EB involved in design, construction, operation of **BABAR-DIRC**, novel § RICH detector, hadronic particle identification system for BABAR.

R&D program for compact, faster photon detection to further improve performance of BABAR-DIRC system at higher luminosity B factory → **Focusing DIRC Prototype**

**Group of people working on R&D project at SLAC:**

- R. Clive Field
- Mayank Jain
- Francisco LePort
- Blair N. Ratcliff
- Jochen Schwiening
- Thomas Hadig
- David W.G.S. Leith
- Gholam Mazaheri
- Aakash Sahai
- Jaroslav Va’vra

§ B.N. Ratcliff, SLAC-PUB-6047 (Jan. 1993)
A charged particle traversing a radiator with refractive index \( n \) with \( \beta = \frac{v}{c} > \frac{1}{n} \) emits Cherenkov photons on cone with half opening angle \( \cos \theta_c = \frac{1}{n\beta} \).

If \( n > \sqrt{2} \) some photons are always totally internally reflected for \( \beta \approx 1 \) tracks.

**Radiator and light guide:** Long, rectangular Synthetic Fused Silica (“Quartz”) bars

(\textit{Spectrosil}: average \(<n(\lambda)> \approx 1.473\), radiation hard, homogenous, low chromatic dispersion)

Photons exit via wedge into expansion region (filled with 6m\(^3\) pure, de-ionized water).

Pinhole imaging on **PMT array** (bar dimension small compared to standoff distance).

(10,752 traditional PMTs ETL 9125, immersed in water, surrounded by hexagonal “light-catcher”, transit time spread \( \approx 1.5\text{nsec}, \approx 30\text{mm diameter} \))

**DIRC** is a 3-D device, measuring: \( x, y \) and **time** of Cherenkov photons, defining \( \theta_c, \phi_c, t_{\text{propagation}} \) of photon.
BABAR-DIRC successful, essential to most BABAR physics analyses§.

Resolution, PID performance close to design.

Timing resolution: \(1.7\text{ns per photon}\)

Cherenkov angle resolution: \(9.6\text{mrad per photon} \rightarrow 2.4\text{mrad per track}\)

**Limited currently by:**
- size of bar image \(\sim 4.1\text{mrad}\)
- size of PMT pixel \(\sim 5.5\text{mrad}\)
- chromaticity \((n=n(\lambda))\) \(\sim 5.4\text{mrad}\)

**Could be improved by:**
- focusing optics
- smaller pixel size
- better time resolution

\[9.6\text{mrad} \rightarrow 4-5\text{mrad per photon} \rightarrow 1.5\text{mrad per track}\]

\[2.7\sigma \rightarrow 4.3\sigma \pi/K \text{ sep. at } 4\text{GeV/c}\]

Better time resolution also essential for background suppression at higher luminosities.

§J. Schwiening, RICH02, SLAC-PUB-9473 (Aug. 2002)
Multi-anode PMT with 64 pads

Photocathode: Bialkali
Multiplier: 12 stage metal channel dynode
Geometry: 8 x 8 pads
49mm x 49mm effective area
89% packing density
Spectral response: 300nm … 650nm
Gain: 1 \cdot 10^6
Cross-talk: < 3%
Uniformity: 1:3
Transit time spread: 400ps

(from Hamamatsu data sheet)
Multi-anode PMT with 64 pads

Photocathode: Bialkali
Multiplier: 25µm pore MCP
Geometry: 8 x 8 pads
51mm x 51mm effective area
67% packing density
Spectral response: 165nm … 660nm
Gain: $0.5 \cdot 10^6$
Uniformity: 1:1.25
Transit time spread: 50-60ps

(from Burle data sheet)
**EXPERIMENTAL SETUP**

Two setups used in parallel

**Light source:**
Pilas pico-second laser in single photon mode; 
$\lambda=635\text{nm}/430\text{nm}$; pulse jitter FWHM < 35ps/60ps

**Amplifier:**
Elantec EL2075C, 40x, 2GHz bandwidth
(for MCP added Philips 779, 10x)

**Readout:**
double-threshold discriminator
LeCroy 2228A TDC
(22ps per count)

**Motion-controlled x/y stage:**
typical scan step size 100$\mu$m
repeatability < 7$\mu$m

**Amplifier:**
Elantec EL2075C, 40x, 2GHz bandwidth

**Readout:**
single-threshold discriminator
LeCroy 2277 TDC
(500ps per count)

Recent improvements to electronics:
see poster N36-38
**RESULTS I: TIMING**

**Hamamatsu H8500:**

- $\sigma_{\text{narrow}} = 138 \text{ps}$  
  ($\sigma_{\text{wide}} = 245 \text{ps}$)

- Resolution at upper limit of required precision for chromatic corrections

**Burle 85011-501:**

- $\sigma_{\text{narrow}} = 54 \text{ps}$  
  ($\sigma_{\text{wide}} = 239 \text{ps}$)

- Core resolution excellent match to requirements
- Long tail due to recoil electrons
**RESULTS II: UNIFORMITY**

Detection efficiency measured relative most efficient point on PMT
(oration of: cathode effic., collection effic., anode effic. spectral effic.)

Hamamatsu H8500 at 635nm:
- uniformity ~1:2.5
- variations caused by lower gain along the edges

Burle 85011-501 at 635nm:
- uniformity ~1:1.5
- variations caused by lower gain along the edges

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IEEE2003, Portland, October 2003

Joizen Schwiening, SLAC
RESULTS III: SUB-STRUCTURE

Uniformity variations within one line of the PMT

Hamamatsu H8500 at 635nm:

- significant variations from pad to pad
- two main maxima within pad
- slot microstructure clearly visible

Burle 85011-501 at 635nm:

- smooth variations from pad to pad
- no obvious substructure within pad

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IEEE2003, Portland, October 2003

Jochen Schwiening, SLAC
RESULTS IV: EFFICIENCY

Detection efficiency measured relative to DIRC PMT (ETL 9125FLB17)

**Burle 85011-501 (ID#3) at 430nm**
- good uniformity
- efficiency 50-60% of present DIRC PMT

**Burle 85011-501 (ID#2) at 635nm**
- good uniformity
- efficiency 70-100% of present DIRC PMT

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scan: 500µm%1mm, 430nm

scan: 100µm%1mm, 635nm
R&D FOR FOCUSSING DIRC

- Eliminate effect of bar size with focusing optics.

- Smaller photo detector pixel $\rightarrow$ better $\theta_C$ resolution.

- Decrease size of expansion region (source of accelerator-induced background).

- 50-100ps timing allows partial correction of chromatic effects $\rightarrow$ better $\theta_C$ resolution.

- 50-100ps timing allows tight cuts to suppress background photons.
**Chromatic Effects in DIRC**

**Cherenkov photon production**

$$\cos \theta_c(\lambda) = \frac{1}{\beta n(\lambda)}$$

$$\sigma_{\theta_c}(i) = \frac{\delta n}{\tan \theta_c} \quad \text{(For } \beta=1\text{)}$$

**Time dispersion during photon transport**

$$\delta^2 t_p(i) = \delta^2 L_p(i) + \frac{2C(L_p,n_g)}{L_p(i)n_g(i)} + \delta^2 n_g(i)$$

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Example: Fused Silica Bar

Refr. Index and Dispersion vs. Wavelength

B.N. Ratcliff, RICH02, SLAC-PUB-9508 (Sep. 2002)
Chromatic error ($\theta_c = \theta_c(\lambda)$) so far considered to be irreducible contribution to error on Cherenkov angle measurement.

**How can we correct for chromatic effects?**
- use propagation dispersion effect,
- precision timing, 50-100ps resolution, required to constrain $\lambda$, correct $\theta_c$.

Effect of propagation dispersion on measured photon arrival time (3.66m long DIRC bar, bialkali photocathode): ~1ns difference over 300…650nm range

*J. Va’vra, 9th Pisa meeting on advanced detectors*
Prototype under construction.

- Single radiator bar (3.66m length) made from DIRC radiator bar pieces.

- Spherical mirror for focusing.

- Mineral oil as matching liquid (KamLAND) in expansion region.

- **10 Burle MCPs**, 64 channels each; combine neighboring channels in x direction.

- 320 TDC channels, 50-100ps resolution per pixel per photon.

- Goal: measure and correct chromatic effects.

- Test beam at SLAC planned for spring 2004.

Stay tuned for IEEE 2004…