Aerogel RICH and TOP: status report

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Belle upgrade – side view

Two new particle ID devices, both RICHes:

Barrel: Time-Of-Propagation (TOP) or focusing DIRC

Endcap: proximity focusing RICH
Endcap: Proximity focusing RICH

K/p separation at 4 GeV/c:
$q_c(p) - q_c(K) \approx 23$ mrad

measured: $s_0 \approx 13-14$ mrad

$\rightarrow 6s$ separation with $N_{pe} \approx 10$

Beam test results with 2cm thick aerogel tiles: $>4s$ K/p separation

$\rightarrow$ NIM A521 (2004) 367

$\rightarrow$ Scatı

$\rightarrow$ need more photons
Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

→ stack two tiles with different refractive indices: “focusing” configuration

NIM A548 (2005) 383
Focusing configuration – data, 2004

4cm aerogel single index

2+2cm aerogel

March 17, 2006
Multiple radiator: Optimisation of radiator parameters

Minimized: error per track

\[ \sigma_{\text{track}} = \frac{1}{\sqrt{N_{\text{det}}}} \sqrt{\sigma_{\text{emp}}^2 + \sigma_{\text{det}}^2 + \sigma_{\text{rest}}^2} \]

Vary parameters \( n_2 - n_1, D_0, D_2/D_1 \)

→ Robust design, little influence from variation in \( n_2 - n_1 \) and \( D_2/D_1 \)

→ Physics/0603022
Comparison with the data

Single photon sigma vs $n_2 - n_1$

Data: december 2005 beam test
Curve: expectation

$n_2 - n_1$
Multiple radiators: optimized

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>one</th>
<th>two</th>
<th>three</th>
<th>four</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (cm)</td>
<td>1.9</td>
<td>3.2</td>
<td>4.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Single photon $s_0$</td>
<td>12.8</td>
<td>12.5</td>
<td>12.6</td>
<td>12.8</td>
</tr>
<tr>
<td>$N_p$</td>
<td>5.7</td>
<td>9.0</td>
<td>11.9</td>
<td>14.7</td>
</tr>
<tr>
<td>$S_{\text{track}}$</td>
<td>5.4</td>
<td>4.2</td>
<td>3.7</td>
<td>3.3</td>
</tr>
</tbody>
</table>

→ The improvement in $S_{\text{track}}$ comes from the increase in the number of photons.
Photon detectors for the aerogel RICH requirements and candidates

Need: Operation in a high magnetic field (1.5T)
Pad size ~5-6mm

Candidates:
- MCP PMT (Burle 85011)
- large active area HAPD of the proximity focusing type

Problems: sealing the tube at the window-ceramic box interface, photocathode activation changes the properties of APD.
Photon detector R&D: Burle MCP-PMT

BURLE 85011 MCP-PMT:

- multi-anode PMT with 2 MCPs
- 25 mm pores
- bialkali photocathode
- gain ~ $0.6 \times 10^6$
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 64(8x8) anode pads
- pitch ~ 6.45mm, gap ~ 0.5mm
- active area fraction ~ 52%

count rates - all channels: charge sharing at pad boundaries

March 17, 2006  →  Proc. IEEE NSS 2004
Burle MCP PMT beam test

Resolution and number of photons (clusters)

- $s_j \sim 13$ mrad (single cluster)
- number of clusters per track $N \sim 4.5$
- $s_j \sim 6$ mrad (per track)
- $-> \sim 4$ s p/ K separation at 4 GeV/ c

Open questions

Operation in high magnetic field:
- the present tube with 25mm pores only works up to 0.8T, for 1.5T need $\sim 10$ mm pores
- 10mm version with 4 channels available since June, tests done (J. Va’vra)

Number of photons per ring: too small. Possible improvements:
- bare tubes (52%-&gt;63%)
- increase active area fraction (bare tube 63%-&gt;85%)
- increase the photo-electron collection efficiency (from 60% at present up to 70%)
- $->$ Extrapolation from the present data 4.5 $->$ 8.5 clusters per ring

Aging of MCP-PMTs?
TOP counter R&D status

- Ring Imaging Cherenkov counter with precise measurement of the Time Of Propagation (and TOF)
- Quartz Radiator & Photon Detector
- Reconstruct ring image from \((X, TOP)\)

\[ TOP = \frac{L}{v^z_g(\lambda)} \]

\(v_g(\lambda)\): The group velocity of light

⇒ Chromatic dispersion:

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TOP baseline design

- Radiator: Quartz bar of $255\text{cm}^L \times 40\text{cm}^W \times 2\text{cm}^T \times 18$ units in $\phi$ segmented at $\theta = 46^\circ$ to reduce chromatic dispersion error

- Photon detector: Multi-anode MCP-PMT at three readout planes SL10 (R&D w/ HPK): 5mm pitch linear array, $\sigma_{TTS} \sim 30$ ps.
Photon detectors for TOP counter

Tests on the bench: amplification and time resolution in high magnetic field.

3 MCP-PMTs studied: Burle (25 mm pores), BINP (6 mm pores), Hamamatsu SL10 (6 and 10 mm pores)

All: good time resolution at B=0, 25 mm pore tube does not work at 1.5T

\[ \rightarrow \text{NIM A528 (2004) 763} \]

SL10: cross-talk problem solved by segmenting the electrodes at the MCP
MCP ageing

Study tubes with and without protective Al foil (stops feedback ions to reach the photocathode, but reduces the photo-electron collection efficiency by 60%) from two producers, Hamamatsu and BINP, with bi-alkali photocathodes.

→ Al foil is needed
Expected performance with:
bi-alkali photocathode: <4s p/K separation at 4GeV/c (← chromatic dispersion)

with GaAsP photocathode:
>4s p/K separation at 4GeV/c
GaAsP vs bialkali:
Timing and pulse height spectra

TTS of MCP-PMt with GaAs/GaAsP may be worse due to the thickness of photocathode (1 micron instead of 10nm).
\[ \rightarrow \text{OK} \]

ADC: Gain $\sim 1.0 \times 10^6$

Pulse height spectra: OK
GaAsP MCP-PMT with pads

- Square-shape MCP-PMT with GaAsP photo-cathode
- First prototype
  - 2 MCP layers
    - f 10mm hole
  - 4ch anodes
  - Slightly larger structure
    - Less active area

- Enough gain to detect single photo-electron
- Good time resolution (TTS=42ps) for single p.e.
  - Slightly worse than single anode MCP-PMT (TTS=32ps)
- Next: check the performance in detail, increase active area frac., ageing
Summary

- Aerogel RICH: proof of principle OK, new ways found how to increase the number of photons (focusing radiator); photon detectors for 1.5T under development/study; progress in aerogel production methods (water jet cutting)

- TOP: MC study: reduce cromatic error; MCP PMT operation at 1.5T OK; MCP PMT with GaAsP tested, similar time resolution; ageing tests → need Al foil
Backup slides
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on $s_0$ and $N_{pe}$

Minimize the error per track:

$$s_{\text{track}} = \frac{s_0}{\sqrt{N_{pe}}}$$

Optimum is close to 2 cm

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Minimize track error vs. relative radiator thickness $D_2/D_1$ at fixed total thickness $D_0=4\text{cm}$ and refractive index difference $dn=0.009$

Minimize track error vs. $D_2/D_1$ and refractive index difference $n_2-n_1$ at fixed total thickness $D_0=4\text{cm}$

$\rightarrow$ robust design, little influence from variation in $n_2-n_1$ and $k$
Photon detectors for the aerogel RICH requirements and candidates

Needs:
- Operation in high magnetic field (1.5T)
- High efficiency at $\lambda >350\text{nm}$
- Pad size $\sim 5-6\text{mm}$

Candidates:
- large area HPD of the proximity focusing type
- MCP PMT (Burle 85011)
Development and testing of photon detectors for 1.5 T

Candidate: large area HPD of the proximity focusing type

Multialkali photocathode

-10kV
15~25mm

Pixel PD or APD

R&D project in collaboration with HPK

Tests with single channel and 3x3 channel devices look very promising.
59mm x 59mm active area (65%),
12x12 channels

Ceramic HPD box
Photon detector R&D – Burle
MCP-PMT bench tests

Proc. IEEE NSS 2004

Study uniformity of the sensitivity over the surface

- count rates - all channels: charge sharing at pad boundaries

- single channel response:
  - uniform over pad area
  - extends beyond pad area (charge sharing)
Burle MCP-PMT bench tests

charge sharing at pad boundaries

- slice of the counting rate distribution including the central areas of 8 pads (single channels - colored, all channels - black)

Proc. IEEE NSS 2004
Rectangular PMT: SL10

- 4ch linear array MCP-PMT

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo cathode</td>
<td>mutli-alkali</td>
</tr>
<tr>
<td>MCP ch $\phi$</td>
<td>10 $\mu$m</td>
</tr>
<tr>
<td># of MCP</td>
<td>2 stage</td>
</tr>
<tr>
<td># pixel/size</td>
<td>$1 \times 4$ / $5\text{mm} \times 22\text{mm}$</td>
</tr>
<tr>
<td>Geometrical C.E.</td>
<td>50%</td>
</tr>
<tr>
<td>Eff. area ($2\text{cm}^T$)</td>
<td>77%</td>
</tr>
<tr>
<td>Gain (HV)</td>
<td>$2 \times 10^6$ ($-3.5$ kV)</td>
</tr>
<tr>
<td>$\sigma_{TTS}$ (HV, B)</td>
<td>$\sim 30$ps ($-3.5$ kV, 1.5T)</td>
</tr>
</tbody>
</table>

- Gain $> 10^6$, $\sigma_{TTS} \sim 30$ps in $B = 1.5$ T: Confirmed

SL10

Lifetime: Q.E. of HPK

- Measurement Q.E. lifetime
- $\sim 700 \text{ mC/cm}^2$ output for one year operation. (BG rate $\times 20$)
- Rapid efficiency drop for PMT w/o Al layer
  $\Rightarrow$ Need Al layer

Graph:
- Life-Time -Output Charge vs Relative QE-
- AL no(R3809U-50 YA0071)
- AL yes(R3809U-50 CT0790)

Setup was changed.

1 month
Lifetime: Q.E. of BINP

- Need Al-layer, too.
- Lifetime $\sim 300\text{mC/cm}^2$ even w/ Al layer
  $\Rightarrow$ Need effort (Vacuum level)

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Gain is almost stable (> 80%@700mC/cm²)
If gain drops, we can raise high voltage up to recover it.
TOP counter MC

Simulation 2GeV/c, q=90 deg.

Expected performance with:
bi-alkali photocathode: <4s p/K separation at 4GeV/c (chromatic dispersion)
with GaAsP photocathode: >4s p/K separation at 4GeV/c
GaAsP photo-cathode

- High quantum efficiency
- Sensitive at longer wavelengths
MCP-PMT Performance

TTS of MCP-PMT w/ GaAs/GaAsP may be worse due to the thickness of photo-cathode. ⇒ should be checked

- multi(bi)-alkali (HPK/BINP) \(\sim 100\ \text{Å} \)
- GaAsP (HPK) \(\sim \mu\text{m} \)
- GaAs (BINP) \(\sim \mu\text{m}: \text{Just delivered} \)

<table>
<thead>
<tr>
<th>Measured MCP-PMT</th>
<th>HPK</th>
<th>BINP</th>
</tr>
</thead>
<tbody>
<tr>
<td>photo-cathode</td>
<td>multi-alkali GaAsP</td>
<td>multi-alkali (GaAs)</td>
</tr>
<tr>
<td>MCP ch (\phi)</td>
<td>6(\mu\text{m})</td>
<td></td>
</tr>
<tr>
<td># of MCP</td>
<td>2stage</td>
<td></td>
</tr>
<tr>
<td>anode</td>
<td>single</td>
<td></td>
</tr>
</tbody>
</table>
GaAsP MCP-PMT performance

- Wave form, ADC and TDC distributions
  - Enough gain to detect single photo-electron
  - Good time resolution (TTS=42ps) for single p.e.
    - Slightly worse than single anode MCP-PMT (TTS=32ps)
- Next
  - Check the performance in detail
  - Develop with the target structure
Cross-talk

- Time resolution becomes worse due to cross talk of neighbor signals.
- To reduce cross talk, divide electrodes on MCP.
- S/N is improved from ~5 to ~10.