Development of 144ch HAPD for Aerogel RICH for Belle Upgrade

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KEK

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Introduction

• PID has been a key issue in B factory experiments.
  • The situation is the same in future B factory:
    • $b \rightarrow d\gamma$ v.s. $b \rightarrow s\gamma$, flavour tagging ...
• ACC (Aerogel Cherenkov Counter) is used in Belle.
  • Threshold type
  • Separation only up to ~ 2GeV in the endcap region
• As an upgrade of the endcap ACC, we are developing Proximity Focusing Aerogel RICH.

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Introduction

- Target: $4\sigma \pi/K$ separation at $1<p<4$ GeV/c.
- $\theta(\pi) - \theta(K) = 23$ mrad for 4 GeV/c particle (in case of aerogel radiator with $n=1.05$).
- Limited by the space.

The scheme of Aerogel RICH has been confirmed by a test using $4\times4$ array of flat-panel PMT (Hamamatsu H8500)

However, H8500 cannot be used in the magnetic field.
144ch HAPD

Requirement to photodetector

- Position sensitive (~ 5×5 mm²); Large effective area.
- Immune to 1.5T magnetic field.
- Coverage of Belle endcap region (~ 2×2 m²; 10⁵ channels)

Candidate: 144ch HAPD (Hybrid Avalanche Photo Detector)

- Developed with Hamamatsu Photonics.
- 144 channels, 4 APD chips (36ch/chip)
- Effective area 64mm×64mm (65%).
HAPD Performance

Noise level

- Bias voltage dependence of Noise.
- Measured with HV OFF.
- Noise level is estimated from the width of pedestal.
- Full depletion at >50V.
- Leakage current increases at ~300V.
- No large chip dependence.

Pulse Height Distribution

- Measured with HV ON.
- Light source: LED.

Clear separation between pedestal and 1 p.e. peak!!
HAPD Performance

\(\times 100\)

- Gain of 4 HAPD samples for each APD chip.
- Measured with HV \(-7\) kV.
- Typical gain 40000-100000.
- Avalanche gain depends on chip and bias voltage.
Readout with ASIC

Readout system requires:

- High density front-end electronics (100k ch)
- High gain with very low noise amplifiers
- Deadtime-less readout scheme (Pipeline)

We have developed ASICs for the front-end electronics.

- Production at VDEC (Tokyo Univ)
- Process: ROHM CMOS 0.35 [μm]
- Target Noise Level: 1200 [e] @ 80pF (HAPD)
- Std. Input Signal: 12000 e
- #(channel) = 18 [ch/chip]
- Power Consumption = 3 [mW/ch]
- Shaping time 0.3 ~ 2.0 [μs]
- Variable gain 1.25 ~ 20
- Common threshold.
- Channel-by-channel offset adjustment (±200 mV)

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HAPD Readout with ASIC

- Distribution of output of ASIC (digital) for 1000 LED clocks.
- Irradiate 1 p.e. level photon to 1 channel.

Successfully readout 1 p.e. level signal from HAPD using ASIC for the first time!!

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HAPD Readout with ASIC

- 2d scan with 0.4mm step.
- LED on x-y stage.
- Several dead channels from HAPD and ASIC. (0~3 per APD chip and 0~2 per ASIC)

Edge channels sometimes have inefficiency/cross-talk (distortion of electric field inside tubes)
(might be recovered in the magnetic field)
Beam Test at Fuji Beam Line

Bremsstrahlung photon $\rightarrow e^-$

~2 GeV electron beam converted from Bremsstrahlung photons from KEKB main ring (electron) at Fuji area (opposite site of Belle detector).

We performed two beam tests for Aerogel RICH

Mar 17th-23rd
June 5th-12th

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Beam Test Setup

- Tracking using 2 MWPC
- $2 \times 3$ array of 144 ch HAPD
- HV at $-7$ kV.
- Bias voltage of HAPD is chosen at avalanche gain = 40.
  (or maximum bias voltage).
- Readout using 48 ASICs.
- ASIC offset is adjusted so that the noise is below the threshold.
  $\rightarrow$ threshold is typically $\sim 0.5$ p.e. level, but depends on each channel's gain and noise level.
- Standard aerogel ($n = 1.045$, thickness = 20mm, transmission length = 41mm @400nm), and many other aerogels.
Cherenkov Ring Observed

Succeeded to observe Cherenkov Ring using HAPD!!
Cherenkov Ring Observed

Result of quick analysis for a run with 2cm aerogel radiator

- Clear Cherenkov ring is observed!
- 4.8 photo-electrons per track.
  - Consistent with the old result with Flat-panel PMT (6.4 p.e.) if we consider smaller acceptance (84% → 68%) and gap btw HAPD.
- Resolution 12.4 mrad per photon (was 13.6 mrad)
- Single track resolution 5.7 mrad corresponding to 4.0σ K/π separation.

N(p.e.) = 4.8
σθ_c = 12.4 mrad
Background

However, background shape is different

beam induced hits, but why two peaks?

additional structure

Beam tends to pass the upper HAPD; the additional structure is considered to be related to the beam.
Background

Possible explanation

- AD is visible
- 4mm thick glass (1.5mm for Flatpanel PMT)

In order to understand the source of the background, we have tested different configuration (thicker glass, incident angle dependence).

Cherenkov Ring

- Cherenkov @ glass + reflection @ AD
- Cherenkov @ glass + reflection
- Cherenkov @ glass / direct hit to AD

Back scattering electron

Reflection @ AD

Aerogel

Photocathode

Glass

AD

HAPD

electron

photon
Threshold Dependence

Threshold dependence

- Reasonable behaviour.
- Background inside the ring also disappear except the background in the center.
- Fine scan is done in the second beam test.

Nominal setting

<table>
<thead>
<tr>
<th>Threshold (mV)</th>
<th>190mV</th>
<th>290mV</th>
<th>390mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Npe</td>
<td>100</td>
<td>500</td>
<td>1000</td>
</tr>
</tbody>
</table>

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Focusing RICH

- Thicker aerogel increases N(p.e.), but makes resolution worse.
- One solution is “focusing” RICH.
- Superimpose rings from two (or more) radiators with different indices.

\[
\begin{align*}
\text{Thicker } n_1 & \text{ increases } \text{N(p.e.)}, \text{ but makes resolution worse.} \\
\text{One solution is “focusing” RICH.} \\
\text{Superimpose rings from two (or more) } & \text{radiators with different indices.}
\end{align*}
\]

\[
\begin{align*}
\text{N.p.e} & \text{ vs Thickness (mm)} \\
\text{Resolution (mrad) for single vs multiple radiator} \\
\text{σ(track) (mrad) for single vs multiple radiator}
\end{align*}
\]

- aerogel indices 1.046, 1.050, 1.056, 1.064 for multiple radiator.

This focusing scheme was already studied before; confirmed by the beam test with HAPD.
Summary

- As an upgrade of the endcap ACC in Belle, we are developing Aerogel RICH detector.
- 144 ch HAPD is a perspective candidate of the photodetector.
  - Single photon peak can be clearly observed.
- Readout using ASIC
  - Successfully readout 1 p.e. level HAPD signal using ASIC.
- Beam test with a 2 × 3 array of 144 ch HAPD.
  - Cherenkov ring is observed with HAPD for the first time!
  - Reasonable performance (Np.e.; resolution)
  - Unknown background inside the ring (reflection at AD ...).

Future Plan

- More configuration has been studied in the second beam test; data will be analyzed soon.
  - Understand background; more realistic HAPD configuration etc.
- New version of ASIC was delivered. To be tested.
- Test under 1.5T magnetic field.
Backup
Aerogel RICH Development

cherenkov ring by image intensifier

2000 2001 2002 2003 2004 2005 2006

6×6 multi-anode PMT (R5900-M16)

4×4 flat-panel PMT (H8500)

σ(\text{angle}) = 14 \text{ mrad}
N(\text{p.e.}) = 6

σ(\text{angle}) = 13 \text{ mrad}
N(\text{p.e.}) = 9

Focusing Type

Try to increase detected photons without making the resolution worse

HAPD etc.

basic principle

systematic study

performance improvement

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144ch HAPD

History

- 2002: single channel HPD
- 2003: 3×3-channel HAPD
- 2004: 1st prototype of 144-channel HAPD

- many dead chips, large noise

2007 Aug: new (good) sample

- All the 4 chips are alive.
- Quantum efficiency ~ 26.9% (peak)
- Maximum high voltage to photocathode = −8.5kV
- Maximum bias voltage:
  - chip A: 331V, chip B: 331V,
  - chip C: 337V, chip D: 343V

measure the performance
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Experimental Setup

- LED: 420nm
- PreAmp: ClearPulse 580K
- Shaper: ClearPulse 4417
- ADC: Amptek Pocket MCA
Uniformity

Measure uniformity for one APD chip (36 ch)

- No large channel dependence in gain, S/N.
- Problem in the channels at edge.
  - Similar effects seen in old samples.
  - Maybe distortion of the electric field inside the tube?

- too noisy with bias voltage
- dominated by the crosstalk from neighboring channel
ASIC Specification

Specification:

- Production at VDEC (Tokyo Univ)
- Process: ROHM CMOS 0.35 [μm]
- Target Noise Level: 1200 [e] @ 80pF (HAPD)
- Std. Input Signal: 12000 e
- #(channel) = 18 [ch/chip]
- Readout: Pipeline with shift register
- S/N = 10
- Power Consumption = 3 [mW/ch]

- Shaping time 0.3 ~ 2.0 [μs]
- Variable gain 1.25 ~ 20
- Offset adjustment
  - Overall ±200 mV
  - Channel by channel ±30 mV

![Graph showing noise level vs capacitance](image_url)

Measured noise level:

- ~1900 e @ 80 pF (HAPD)
ASIC Performance

Offset adjustment

before

after

Gain Difference

100mV

Gain = 5

(In this plot, 1 p.e. is assumed to be 12000e).

Linearity with reasonable range.

Gain = 2.5

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HAPD Readout with ASIC

HAPD   ASIC (8 chips)   digital I/O board (VME)

Readout of HAPD signal with the ASIC is tested.

- The surface of HAPD is covered by a black sheet except for one channel.
- Light corresponding to ~10 photons is emitted from LED.
- Trigger for readout is provided from LED control signal.
- Threshold is set to ~30000 e.

Only 2 ASICs are connected.

monitor signal of ASIC

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HAPD Readout with ASIC

LED OFF

- Distribution of output of ASIC (digital) for 1000 LED clocks.
- All the channels except the center are covered by black sheet.

LED ON

Successfully readout all the channels in one (APD) chips using 2 ASICs, simultaneously

A big step for HAPD readout

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In parallel, we start developing a new version of ASIC

- Present ASIC (developed for evaluation) is not enough for readout of large amount of channels.
- Drop out the digital part (shift registers) from the ASIC, so that it becomes more flexible. Digital part will be provided by external FPGA.
- More channels per chip (18 → 36 or 72).

New ASIC will be submitted on December

- Test production at MOSIS.
- TSMC 0.35 μm processes.
- With 12ch (with 3 × 3mm² chip) this time, but with more channels (e.g. 3 × 8mm² chip) in future.
HAPD Performance

Multi-photon

Bombardment gain (by Hamamatsu)

Q.E.

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Uniformity

<Measurement for the old sample>

Position Resolution

outside inside

0.1mm pitch scan

Problem in ch1 (channel at the edge)

photon incident position

Distortion of electric field?

• If so, the situation becomes better with the (1.5T) magnetic field.

• Will be tested.
Threshold Scan

Measure the efficiency of digital output varying the threshold.

↓

Estimate the pulse height and noise.

(1) Threshold Scan

- Measure the efficiency of digital output varying the threshold.
- Estimate the pulse height and noise.

(2) Measured data

- Sigma(z) = 0.003762 ± 0.0001
- Mean(p) = 0.08772 ± 0.006
- Sigma(p) = 0.004983 ± 0.0001

(3) Graph

- Pulse height and noise

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ASIC Analog Part

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ASIC Digital Part

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