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Readout electronics for a Hybrid Avalanche Photon Detector

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ABSTRACT: This article presents the development of readout electronics for a Hybrid Avalanche Photon Detector (HAPD), the baseline photon sensor for the Belle II Ring Imaging Cherenkov Detector (RICH). The HAPD sensor with the readout electronics enable will enable position sensitive detection of single photons. An overview of the RICH readout system is given.

KEYWORDS: Cherenkov detectors; Data acquisition circuits; Modular electronics; Front-end electronics for detector readout

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Contents

1 Introduction

The successful physics program of the Belle experiment at KEK, Tsukuba, Japan, resulted in an upgrade of the KEKB machine and of the Belle detector. The aim of the Belle II experiment is to collect about 40 times larger sample of B mesons which would allow measurements of rare decays of B and D mesons with unprecedented precision. In the forward direction (given by the center-of-mass direction of the products), the proximity focusing RICH with an aerogel radiator will efficiently separate kaons from pions up to a particle momentum of 4 GeV/c [1].

The RICH consists of an aerogel radiator, an expansion volume and a position sensitive detector of single photons [2]. To maximize the kaon-pion separation efficiency, the detector's area of approximately 4 m^2 requires position sensitive single photon sensors with granularity of about $5 \times 5\,mm^2$. The sensor and the readout electronics for the RICH detector have to fit into a limited available space of about 25 cm in length between the central drift chamber and the electromagnetic calorimeter. They should operate in a 1.5 T magnetic field perpendicular to the detector plane and should sustain elevated radiation levels. In ten years of operation a fluence of 10^{12} cm^{-2} of 1 MeV equivalent neutrons is expected in the detector area.

2 Photon detector and readout electronics

A 144 channel Hybrid Avalanche Photon Detector (HAPD) is our candidate for the sensor of single photons ([2, 3]). It is 76×76 mm^2 in area with 67% of active area. The total amplification of the sensor is of the order of 50000. In order to fit the electronic readout into the available volume which extends 50 mm behind the HAPD sensor, the readout system was designed on a 12 layer FR4 glass-reinforced epoxy laminate (figures 1, 2) [4].

The SA02 readout board has 4 SA02 ASIC chips [2] and an HAPD connector on the top side, while the FPGA (Xilinx Spartan 6), used for data processing and communications, is placed on the bottom side between the two extension connectors (figure 1). The power for the electronics and

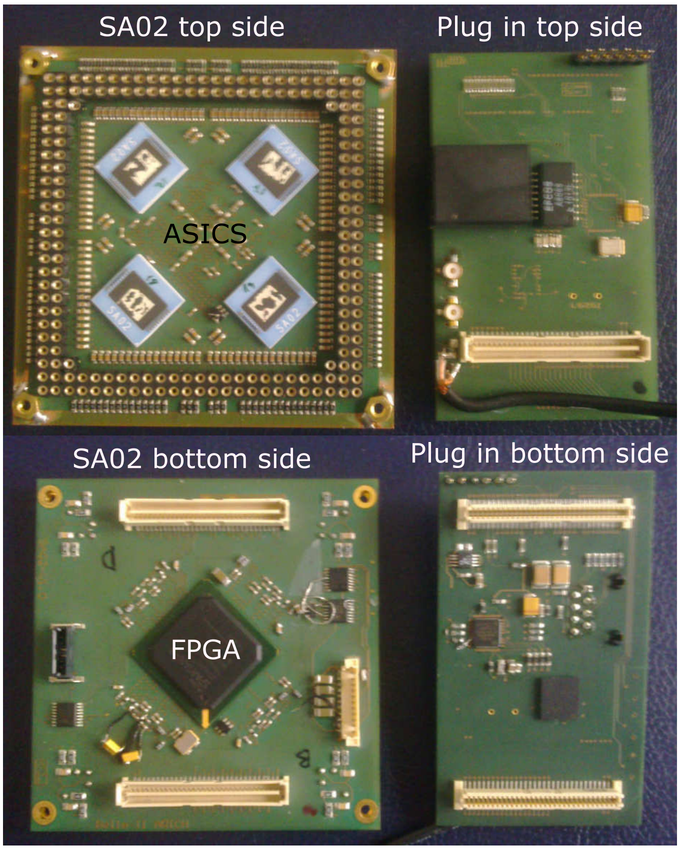

Figure 1. SA02 board and Plug in board.

bias voltage for the APDs are fed to the laminate via two independent connectors, while the high voltage is connected directly to the HAPD.

The SA02 ASIC chip packed in a LTCC BGA package, measures $13\,\mathrm{mm} \times 13\,\mathrm{mm}$ and has 36 input channels. It is responsible for the digitization of signals from the HAPD sensor. Each channel line consists of a charge sensitive preamplifier (CSA), a second order shaper circuit and one bit comparator for digitalization. Its output is a single ended 1.65 V signal, with the width equal to time over threshold. Threshold levels are equal for all channels, but channel offsets can be set individually in steps of 3 mV. The ASIC has a separate single output for monitoring signals at different stages in the front end. The amplification factor of the charge sensitive preamplifier and the shaping time allow adjustments to optimize the signal to noise ratio.

A supplementary Plug in board (figure 1, 2) provides firmware boot, control, monitoring and acquired data transmission from the SA02 board, where the SiTCP protocol is used for communication over the Ethernet network [5].

The detector works as a single photon counter. The implemented readout core on the FPGA consists of bit shifting serial input serial output (SISO) registers for each of the 144 channels and supplementary logic for communication and data transfer. The digitized analog signals are fed to a state transition detection circuit. The detected events are introduced in the SISO shift register with adjustable shifting clock. At trigger event, the last four bits stored in the SISO registers are sent to the data acquisition system.

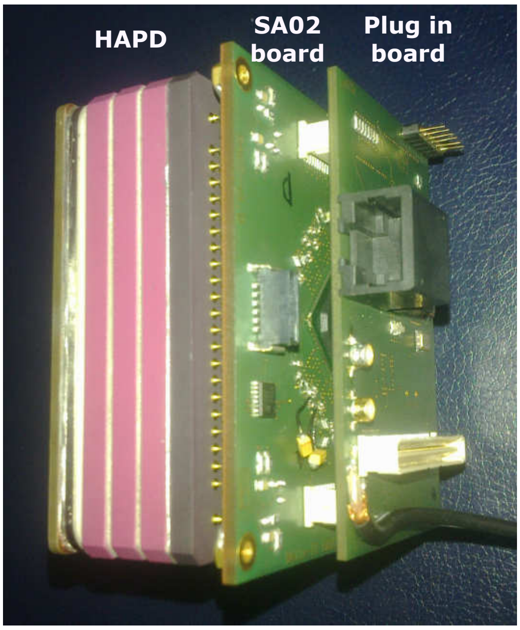

Figure 2. HAPD equipped with SA02 and Plug in board.

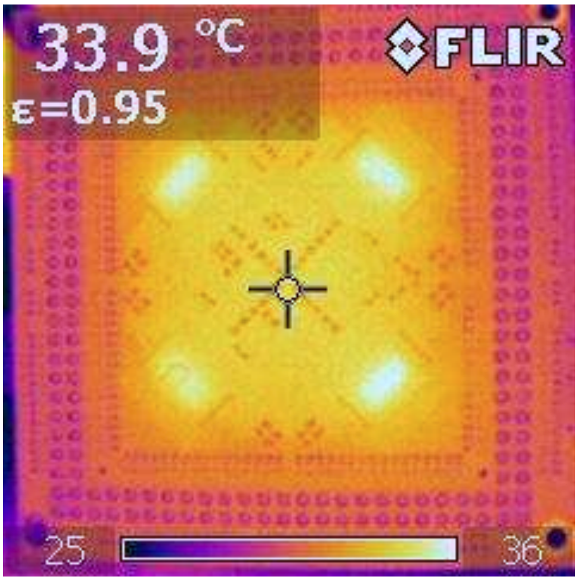

Figure 3. Thermal image of an SA02 board.

For operation the SA02 board requires several different low voltages to power the FPGA and ASIC chips. The power consumption of both electronic boards amounts to about 1 W, of which 300 mW is due to the Ethernet controller. Most of the power is dissipated on the ASIC chips. At an ambient temperature of 25°C, we made an infrared image of the SA02 board in the thermal equilibrium state (figure 3). The figure shows the temperature distribution on the board with the maximum temperature on the ASICs chips. With no cooling except for the surrounding air, the maximum temperature on the SA02 board reached 36°C.

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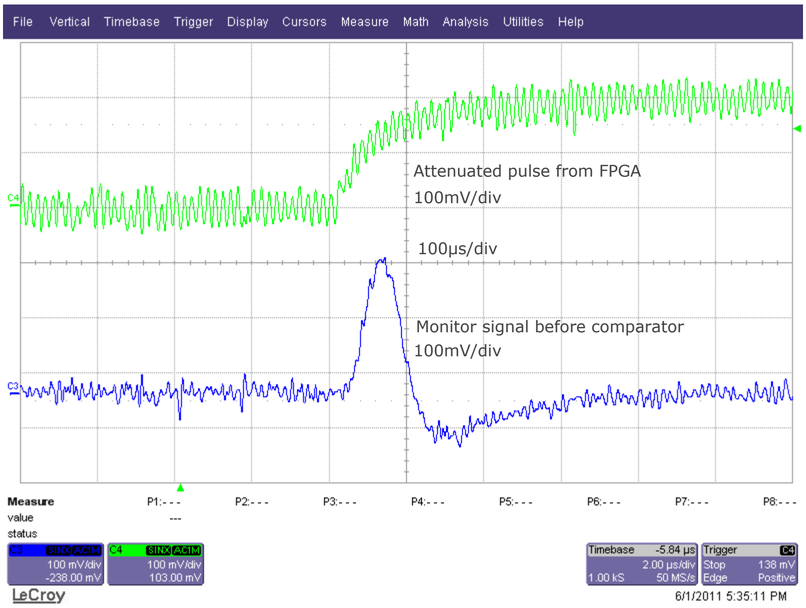

Figure 4. An ASIC response (blue trace) to the the attenuated signal generated by FPGA (green trace).

For internal tests, the SA02 board incorporates a variable amplitude step generator. One of the FPGA outputs is fed trough a digitally controlled resistor and a 0.1 pF capacitor into the SA02 ASIC. The amplified and shaped signal response is shown in figure 4.

3 Bench test — Single photon measurements

The test measurements with single photons are made by using light emitted from a blue LED. With the collimated beam, we scanned the surface of the HAPD, mounted on the computer controlled translation stage. The high voltage and bias voltages for the HAPD are set to the manufacturer's nominal values. A signal generator generates a trigger signal for the readout electronics and the LED at a rate of about 1 kHz. Blue light, emitted from the power controlled LED, is fed into the box using a multimode optical fiber. The frame with the optical fiber and the collimator is attached to the translation stage 1 cm away form the detector's surface.

We first verified the operation of an arbitrary pad on the sensor, where multiple photons can be observed as seen in figure 5. The oscilloscope screen image shows the analog amplified and shaped signals from the observed channel. A threshold scan of the corresponding measurement is shown in figure 6.

With the LED light emission reduced, to a level where mostly single photons are observed, an area $10\,\mathrm{mm} \times 10\,\mathrm{mm}$ of the HAPD was scanned in steps of 300 μm with the light beam of about the same width. The HAPD sensitive area is clearly seen in figure 7.

4 Belle II aerogel RICH readout system

The aerogel RICH detector will consist of 456 HAPD sensors. The analog signals will be amplified and digitized by the SA02 board. The Merger board, built around Virtex 5 FPGA, is intended to

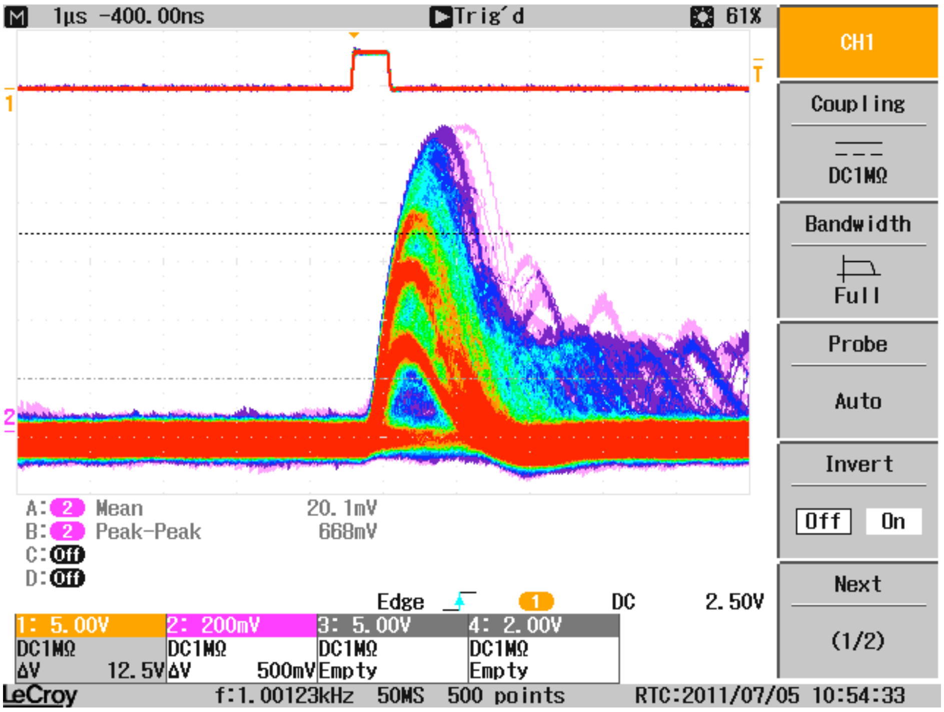

Figure 5. Accumulated of response to a multiphoton illumination. The single channel signals are first amplified and shaped. Electrical signals from single, double and triple detected photons are clearly visible.

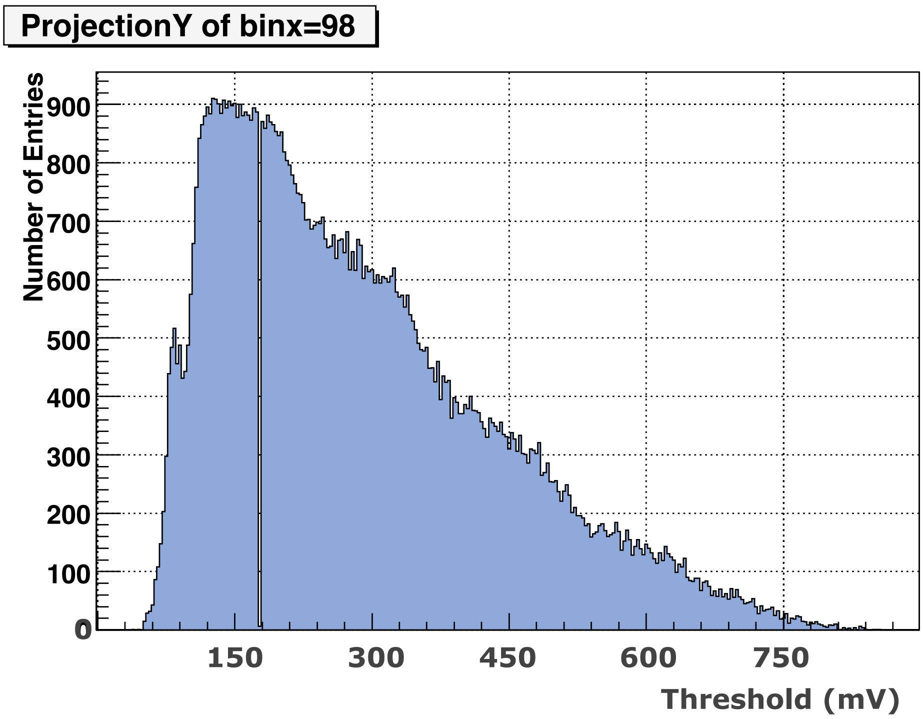

Figure 6. Number of detected hits as a function of the threshold.

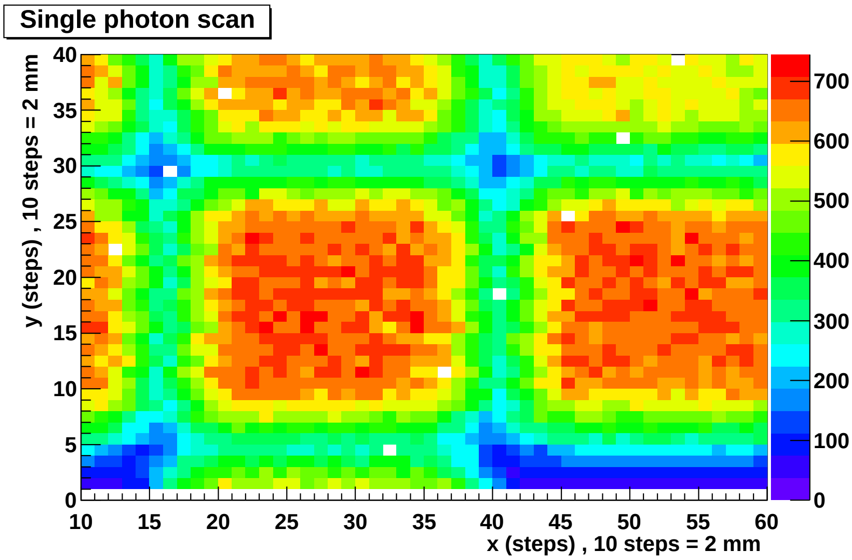

Figure 7. Response of the HAPD to single photons.

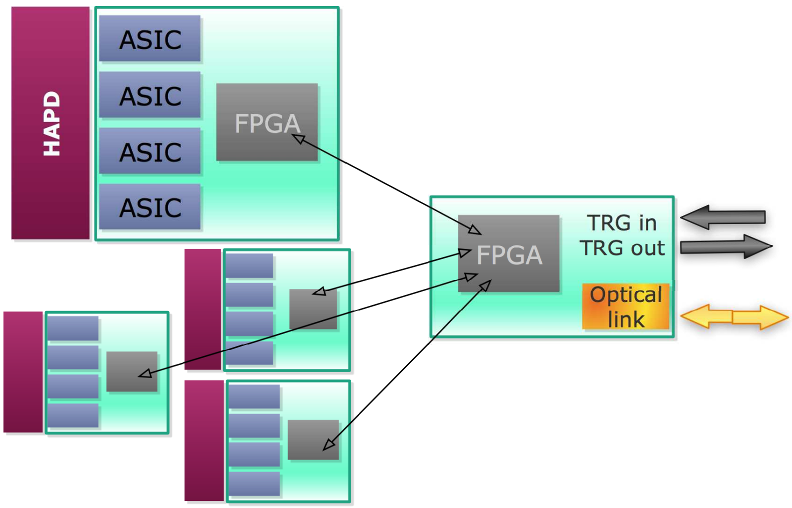

Figure 8. Scheme of the Belle II RICH readout system.

collect and process data from up to six SA02 boards (figure 8). The Merger board will replace the current Plug in board used for laboratory tests. It will be used for loading of the FPGA firmware to multiple SA02 boards, clock and trigger distribution, slow control and to perform compression on the acquired data. In the present prototype, the Merger board receives the trigger and clock signals via Ethernet cable. A small form-factor pluggable transceiver (SFP) slot using fiber optic link is used to transmit commands and send the data to the central DAQ [6].

The current version of SA02 board with the Plugin board was tested in the aerogel RICH prototype with six HAPD sensors at the CERN SPS H6 beamline with 120 GeV/c pions. Preliminary results from the beam test show good performance of the redesigned device.

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5 Summary

We are developing readout electronics for the Aerogel RICH of the Belle II spectrometer. The readout electronic system should fit in to the small gap (50 mm) at the rear end of the HAPD sensor. It is based on the SA02 readout board which incorporates four ASIC SA02 chips and an FPGA. The data will be transfered from six SA02 boards to the Merger board, which will send data via optical link to the common DAQ. The readout board performs according to expectations and allows efficient detection of single photons. In the future, a tolerance to radiation and operation in a magnetic field of the SA02 readout board will be tested. Future study will include the design of power supply distribution design, cabling and algorithms for data compression.

Acknowledgments

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References

[1] S. Korpar et al., *A novel type of proximity focusing RICH counter with multiple refractive index aerogel radiator*, *Nucl. Instrum. Meth.* **A 572** (2007) 429.

[2] T. Abe et al., *Belle II technical design report*, KEK Report 2010-1 [arXiv:1011.0352].

[3] S. Nishida et al., *Development of an HAPD with* 144 *channels for the aerogel RICH of the Belle upgrade*, *Nucl. Instrum. Meth.* **A 595** (2008) 150.

[4] A. Seljak et al., *Readout electronics for an HAPD detector*, 2011 *JINST* **6** C01083.

[5] T. Uchida et al., *Hardware-based tcp processor for gigabit ethernet*, *IEEE Trans. Nucl. Sci.* **55** (2008) 1631.

[6] M Nakao et al., *Data acquisition system for Belle II*, 2010 *JINST* **5** C12004.