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# The New APD Based Readout for the Crystal Barrel Calorimeter

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Abstract. The CBELSA/TAPS experiment at ELSA measures double polarization observables in meson photoproduction off protons and neutrons. To be able to measure purely neutral reactions off polarized neutrons with high efficiency, the main calorimeter has to be integrated into the first level trigger. This requires to exchange the existing PIN photo diode by a new avalanche photo diode (APD) readout. The newly developed readout electronics will provide an energy resolution compatible to the previous set-up and a fast trigger signal down to 10 MeV energy deposit per crystal. After the successful final tests with a 3x3 CsI crystal matrix in Bonn at ELSA and in Mainz at MAMI all front-end electronics were produced in fall 2013. Automated test routines for the front-end electronics were developed and the characterization measurements of all APDs were successfully accomplished in Bonn.

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## 1. Introduction

The systematic investigation of the baryon excitation spectra demands an extension of the experimental program from the photoproduction off protons towards the photoproduction off neutrons, and gives rise to the necessity of measuring entirely neutral final states. The world data on all-neutral final states is sparse [1], which makes an experiment able to obtain such data very desirable. The planned instrumental improvements of the Crystal Barrel calorimeter, the central component of the CBELSA/TAPS experiment, will allow a study of such processes (e.g.  $\gamma n \to n\pi^0, \gamma n \to n\eta$  with a high efficiency and full solid angle coverage. A new readout based on avalanche photo diodes (APDs) has been developed and tested for the CsI(Tl) crystals of the Crystal Barrel calorimeter in order to replace the existing PIN diode readout, which was optimized for a good energy resolution but did not provide a timing information of the analog signal [2]. With the new APD readout a fast timing signal in addition to the energy information for every single CsI(Tl) crystal is available, allowing an integration of the main calorimeter into the fast trigger decision of the CBELSA/TAPS experiment.

## 2. Experimental Setup

The setup of the CBELSA/TAPS experiment located at the ELSA electron accelerator in Bonn [3] is shown in Fig. 1. Photons are produced by scattering electrons off different radiators (e.g. a

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**Figure 1.** The experimental setup of the CBELSA/TAPS experiment at ELSA. Inset: the main crystal barrel detector with forward cone and inner detector.

diamond crystal) receiving unpolarized, linearly or circularly polarized photons. Several different reaction targets are available, e.g. transversely or longitudinally polarized butanol targets. The according target is surrounded by the Crystal Barrel main and forward detector consisting of 1320 CsI(Tl) crystals and an inner detector which is used to identify charged particles. In forward direction the angular coverage is closed down to 1° by the MiniTAPS detector. The complete setup offers a close to  $4\pi$  angular coverage with a high detection efficiency for neutral particles. It is therefore ideally suited to measure crosssections and polarization observables for the photoproduction of final states with neutral mesons decaying into photons.

## 3. Avalanche Photo Diodes

Several devices can be used in order to convert the light output from a scintillator into a analog signal. PIN photo diodes, photomultipliers, silicon photomultipliers (SiPM) and avalanche photo diodes (APD) are the most common devices. A PIN photo diode shows a small temperature dependency of the generated charge per photon. This devices are used in strong magnetic fields. The drawback is the signal to noise ratio (SNR) which is smaller compared to the other devices, if all devices are operated at room temperature.

APDs show a better SNR than PIN photo diodes due to their intrinsic amplification and they can also be used in strong magnetic fields of a few Tesla, but their temperature dependence is quite large. We investigated the characteristics of the S11048(X3) APD from Hamamatsu [4] which will be used in the upgrade of the Crystal Barrel calorimeter to provide a fast trigger signal down to an energy of 10 MeV per crystal.

#### 3.1. Gain Temperature Dependence of APDs

Fig. 2(a) depicts the gain temperature dependence of the S11048(X3) APD from Hamamatsu. It shows a coefficient of roughly  $-2.3 \frac{\%}{K}$  around 27.5 °C. Its behavior between 20 °C and 40 °C



**Figure 2.** Gain temperature dependence of S11048(X3) APDs; 2(a): temperature dependence of one APD; red: fit using eqn. 1. 2(b): Gain temperature dependence at  $G(V_{\text{bias}}) = 50$  at 25 °C for a sample of 3500 APDs.

is described by the function

$$G(T) = a + b \cdot (1 + \frac{c}{100})^T$$
(1)

which is plotted in red in Fig. 2(a) alongside the data. The temperature dependence of the S11048(X3) APD was measured for 3500 pieces to investigate the variations within the sample used to upgrade the CB detector. The result is shown in Fig. 2(b).

A more detailed description of the measurement of the APD gain and its temperature dependence will be given in section 4. There are various approaches to stabilize the gain of an APD. This is mainly done by automatically adjusting the bias voltage of the APD.

#### 3.2. Gain Voltage Dependence of APDs

The APD needs an external bias voltage for the internal amplification mechanism. The gain of the amplification depends on the applied bias voltage, shown in Fig. 3(a) for a S11048(X3) APD of Hamamatsu. The measured data is described very well by the following modified Miller function in a region where the gain is about 50:

$$G(V_{\text{bias}}) = \frac{a}{(1 - \frac{V_{\text{bias}}}{b})^c} \quad . \tag{2}$$

If the bias voltage is changed according to the temperature of the APD, a stable gain behavior is achievable. For such a compensation not only the temperature dependence but also the gain voltage dependence needs to be well known. Therefore this dependence of all 3500 S11048(X3) APDs were measured. To compare their behavior and to design a simple compensation algorithm the gain voltage dependence around G = 50 was approximated linearly. It was found to be on average 2.95  $\frac{\%}{V}$ . The values obtained for all 3500 APDs can be seen in Fig. 3(b).



**Figure 3.** 3(a):Gain voltage dependence of a S11048(X3) APD; red: fit using eqn. 2. 3(b): Gain voltage dependence at 27.5 °C for the sample of 3500 S11048(X3) APDs.

#### 4. Gain Monitoring and Light Pulser Measurements

One possibility to overcome the gain temperature dependence is to continuously measure the gain of the APD. A common method is to illuminate the APD with a continuous light source and to measure the current flowing through the APD with and without an applied bias voltage. A drawback of this method is its requirement that the current flowing through the APD needs to be measured quite precisely. Utilized in a calorimeter setup this demands a second read-out chain.

This disadvantage can be overcome if pulsed light is used for the gain measurement. Using the light pulse as fixed reference peak seems to be obvious, but a reference measurement is still necessary to get rid of long term variations in the light pulser setup. A reference measurement at  $V_{\text{bias}} = 0$  can be used. At this bias voltage no internal amplification takes place inside the APD. Furthermore the generated charge per photon shows no strong dependence on the temperature. However, this needs extra efforts because the capacitance of the APD at about 7.1 nF without bias voltage is quite large compared to 280 pF at a bias voltage for an amplification of 50. On the one hand the noise increases due to the high capacitance, on the other hand the signal is lower due to the missing internal amplification. In addition, there is a charge division between preamplifier and APD which results in further reduction of the signal. This can be compensated by a modified preamplifier. Still the SNR is bad compared to the case where the bias voltage is applied. This can be avoided with high statistics in the measurement and a sufficiently high intensity of the light pulser. As the dark current only manifests as noise but not as a signal seen by a charge sensitive preamplifier, a background subtraction is not necessary when pulsed light is used. The gain is proportional to the quotient of the light of the pulses with and without bias voltage. Knowing about the charge devision between APD and preamplifier and therefore choosing a sufficiently high coupling capacitance, the gain of the APD can directly be calculated from these two measurements.

This method is used to determine the gain temperature and voltage dependence of the 3500 S11048(X3) APDs, illuminating the APDs with  $2 \mu s$  pulses. A small setup (shown in Fig. 4) consisting of an insolated temperature controlled box with four APD slots was designed. The APDs are read out by charge sensitive preamplifiers SP 917 developed by the Physics Department Basel and supplied with a constant bias voltage from a precise ISEG HV.



Figure 4. Setup used for characterizing APDs.

The 4 signals are shaped outside the box and read out by a sampling ADC, located on a VFB 2.2 FPGA board of ELB-Elektroniklaboratorien Bonn, with a provided firmware to extract baseline and area of the pulses. These values are also directly provided as multi channel analyzer spectra. Measurements were carried out supplying the APD with a defined bias voltage and also without bias voltage, short circuit the HV supply with  $1 M\Omega$  to ensure a complete discharge.

A automated routine taking approximately 4 hours to retrieve gain temperature and voltage dependence was carried out for 3500 APDs. The gain is continuously determined, while the box is heated from 20 to 27.5 °C and the APD is supplied with a bias voltage specified from Hamamatsu for a gain of 50 at 25 °C (G = 50). Stabilized at 27.5 °C, the most probable temperature for operating the calorimeter, the gain voltage dependence of the APD is determined. Therefore a voltage from 0 V up to 5 V above the specified voltage for G = 50 varying between 335 V and 415 V is applied, leading to a gain of 0 up to approximately 100. Afterwards the temperature dependence is further measured from 27.5 °C up to 40 °C and then down to 20 °C, securing the equality of the temperature of the APD to one of the measuring sensor. Otherwise hysteresis effects of the measurement might arise by changing the temperature to fast. Hence the temperature variation was limited to 17.5 °C per hour.

The described method for the determination of the gain will also be used to monitor the gain of the APDs online in the CB detector and is already implemented in the prototype setup. Light guides connected to each crystal offer the possibility to insert short light pulses from a LED which is placed in a stabilized surrounding. Reference measurements at  $V_{\text{bias}} = 0$  V are only necessary to eliminate external changes like e.g. a varying light intensity. With this measurement the gain determination is a pure relative measurement. The gain is directly determined by inserting marked light pulser events into the data stream while data taking or using a spill break of the ELSA accelerator.

#### 5. New Front End Electronics - the High Voltage Supply

One important part of the new front end electronics is the high voltage supply of the APDs. Since each APD needs a certain bias voltage varying between 335 V - 415 V to achieve a defined amplification, a board for the remote adjustment of the incoming bias voltage to the desired value [5] was designed. Additionally this board includes, aside from an identification chip and monitoring ADCs, a temperature compensation circuit. By using a negative temperature coefficient thermistor (NTC), the temperature of the APD is approximated and a generalized

average correction is applied to the bias voltage supply. This correction is held as simple as possible and was designed with only passive elements. Its aim is only to reduce the gain temperature dependence, offering a temperature region where the dependence is minimized.

## 5.1. Performance of the Temperature Compensation

The temperature compensating high voltage board was tested using a light pulser designed as prototype for the upgraded Crystal Barrel experiment. In addition there were simulations [6] to adjust the circuit according to the measured gain temperature and voltage dependence, choosing a very flat gain dependence region to occur around 27.5 °C. Fig. 5 shows the result of a test



Figure 5. Simulation and measurement of the HV board temperature compensation. The discrepancy arises from a simplified simulation.

measurement between 20 °C and 35 °C. The measured APD gain using the compensation circuit shows even a flatter behavior than in the simulation. This is most probably caused by assuming a linear gain and temperature dependence around gain 50 and 27.5 °C and neglecting gain and temperature dependencies in the simulation.

## 5.2. Testing of the Final Readout

The complete new readout was tested in several different experiments. The latest test was carried out at MAMI in Mainz in January 2014. An array of  $3 \times 3$  crystals equipped with the final electronics was set up and a readout as it will be used in the experiment. The tagged photon beam of MAMI created by bremsstrahlung of an electron beam with an energy of 1.6 GeV and 180 MeV was directly focussed on the central crystal. The new electronics provide a fast trigger signal of each crystal. The OR of all crystals in coincidence with the OR of 32 used tagger bars of the tagging system formed our trigger. Measurements were carried out to determine the energy and time resolution at different photon rates to ensure a high rate capability of the electronics.

## 5.3. Performance of Final Upgrade Electronics

To analyze the energy resolution, the energy sum measured with all 9 crystals of the detector array is plotted against the energy of the incoming photon. The projection of each used tagger bin shows an energy resolution information for the specific tagger bar energy. The result is shown in Fig. 6 for different rates for both electron beam energies. The rate in the central



Figure 6. Energy resolution of a  $3 \times 3$  subunit with new front end electronics compared to PIN diode readout [2] and simulations.

crystal above a threshold of  $6.5 \,\mathrm{MeV}$  is used as reference. In the current setup the crystals in the forward angle show a maximum rate of approximately  $1.5 \,\mathrm{ks^{-1}}$  above  $6.5 \,\mathrm{MeV}$  during production beamtimes. Three reference points of CB at LEAR are also shown.



Figure 7. Time resolution of the central crystal in a  $3 \times 3$  matrix with new front end electronics.

Due to the upgraded front end electronics it is now possible to retrieve a timing signal of each single crystal. These signals were read out for testing purposes using a TDC of CAEN. The resulting time resolution is shown in Fig. 7.

## 6. Conclusion

The upgrade of the Crystal Barrel calorimeter readout is currently in progress. The 3500 S11048(X3) APDs of Hamamatsu show a average temperature dependence of  $(2.27\pm0.08)\frac{\%}{K}$  and voltage dependence of  $(2.9\pm0.08)\frac{\%}{V}$ . With a specially designed high voltage supply board, equal for all APDs, a circuit to compensate the gain variations with temperature was introduced, which results in a reduction of the gain dependence to  $\pm 1.5\%$  in a region from 20 °C to 35 °C. The gain of the APDs is determined with a light pulser using a relative measurement without applied bias voltage, a method which will be implemented for monitoring purposes in the calorimeter. Tagged photon beam tests showed that the energy resolution of the new readout electronics also achieves 2.5% at 1 GeV. Due to the upgrade it is possible to also achieve a time information of each crystal with a resolution of  $\sigma_t \leq 10 \,\mathrm{ns_{RMS}}$  for an energy deposit  $E_{\mathrm{crystal}} \geq 20 \,\mathrm{MeV}$ . The timing signals, included in the first level trigger, will lead to a improved trigger efficiency on neutral reactions. This upgrade will allow detailed studies of double polarized photoproduction off the neutron at the CBELSA/TAPS experiment.

## References

- [1] Arndt R.A. et al.: Analysis of pion photoproduction data Phys. Rev. C 66 (2002) 055213
- [2] Aker, E. et al.: The Crystal Barrel Spectrometer at LEAR. Nuclear Instruments and Methods in Physics Research A (1992) Nr. 321, S. 69–109
- [3] Hillert, W.: The Bonn Electron Stretcher Accelerator ELSA: Past and future. European Physical Journal A(28):139–148, 2006
- [4] Hamamatsu Photonics K.K.: Delivery Specification Sheet, Doc. No. K30 B70082
- [5] Design by C. Honisch and M. Steinacher
- [6] Simulations carried out by M. Steinacher