Trigger-less readout system with pulse pile-up recovery for the PANDA Electromagnetic Calorimeter

M. Kavatsyuk[a], G. Tambave[a], M.. Hevinga[a], P.J.J. Lemmens[a], P. Schakel[a], F. Schreuder[a], R. Speelman[a], H. Löhner[a,*],
on behalf of the PANDA Collaboration

[a]*Kernfysisch Versneller Instituut, University of Groningen, Zernikelaan 25, NL-9747 AA* **Groningen**, *The Netherlands*

Abstract

A simple, efficient, and robust on-line data-processing scheme was developed for the digital front-end electronics of the electromagnetic calorimeter of the PANDA spectrometer at FAIR, Darmstadt. The implementation of the processing algorithm in FPGA enables the construction of an almost dead-time free data acquisition system. The prototype of a complete trigger-less readout chain has been developed and evaluated. The precision of time synchronisation commands has been verified. A pile-up recovery algorithm was developed and evaluated over a large dynamic range of signal amplitiudes.

Keywords: Electromagnetic calorimeter, sampling ADC, digital filtering, feature extraction, trigger-less readout, pile-up recovery

---

1. Introduction

The PANDA collaboration at FAIR, Germany, will investigate yet undiscovered charm-meson states and glueballs in antiproton annihilations to study QCD phenomena in the non-perturbative regime [1]. A multi-purpose detector for tracking, calorimetry and particle identification is presently being developed to run at high luminosities providing annihilation rates up to 20 MHz. The PANDA electromagnetic calorimeter (EMC) [2] is depicted in fig. 1 and composed of $PbWO_4$ (PWO) crystals which are cooled to -25 $^\circ C$ and coupled to large-area avalanche photo-diodes or vacuum photo-triodes/-tetrodes. Individual crystals will be exposed to single-detector hit rates up to 500 kHz causing a pileup probability up to 15%. The photo-sensor signals are continuously digitized by Sampling ADCs (SADCs) and analyzed on-line in FPGAs to detect hits and extract energy and time information. The on-line digitizer algorithm was designed, optimized and implemented [3] in VHDL for a Xilinx FPGA. In order to gain flexibility and selectivity at high data rates, the PANDA collaboration develops the trigger-less readout system [4]: all detector channels are self triggering entities and able to detect and pre-process signals and to transmit only the physically relevant information, sorted according to precise time-stamps. To verify the performance of the pile-up recovery algorithm over a large dynamic energy range (1000) for different pulse-amplitude combinations, the pile-up pulses were simulated using a measured and fitted pulse-response function. We present results for the prototype of a trigger-less readout chain including as key ingredient the synchronous optical link connection.

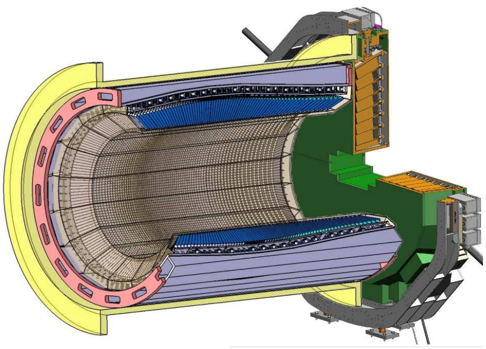

Figure 1: The barrel and forward-endcap components of the Panda EMC showing the mounting structure of individual PWO crystals and subunits of 16 crystals, respectively.

2. Trigger-less readout

The logic scheme of the developed readout chain is presented in fig. 2. The readout includes digitizer, data concentrator (DCON) and data-acquisition (DAQ) modules. The digitizer module is located inside the EMC volume, and contains SADCs for continuous digitisation of the preamplifier signals and an FPGA for on-line data processing. The feature-extraction algorithm, implemented in the FPGA, includes dynamic baseline compensation, hit detection and extraction of the hit information. Using a serial optical-link connection, these reduced data are transferred to the DMUX module, located outside the PANDA detector. This type of data connection is dictated by the high data rate and mechanical constraints. The DCON module collects data from several digitisers and performs data pre-processing, e.g. on-line pile-up recovery [5], time-ordering, and event pre-building. The pre-processed data are sent to the DAQ for on-line reconstruction of the physics signatures, like shower detection and particle identification.

The trigger-less readout concept requires precise time-synchronisation of all data acquired by the digitizer modules.

---

[*] Corresponding author. Tel. +31 50 363 3614; fax: +31 50 363 4003
Email address: `loehner@kvi.nl` (H. Löhner)

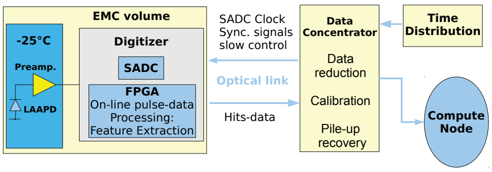

Figure 2: The logic scheme of the trigger-less readout for the Panda EMC.

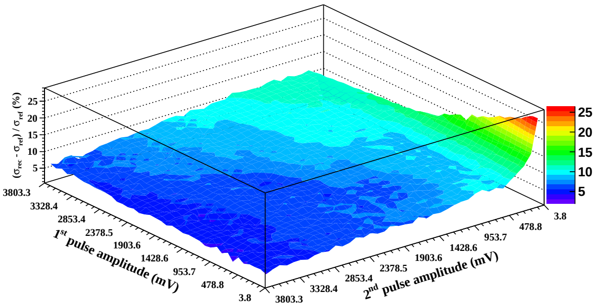

Figure 3: The relative difference $[(\sigma_{rec} - \sigma_{ref})/\sigma_{ref}]$ between the recovered (σ_{rec}) and reference (σ_{ref}) energy resolution as function of the first and second-pulse amplitude.

For this purpose the PANDA experiment employs a time distribution system [6], which includes a specially designed data-transfer protocol. The clock and time information is distributed using optical-link connections. A time jitter of the synchronisation commands of less than 23 ps was measured. In order to guarantee such a stable phase a special "bit phase locking" procedure during the initialisation of the serial connection has to be followed.

3. Pile-up recovery

Measurements performed with an LED light-pulser suggest that the pulse shape is stable within a large dynamic range. Therefore, we expect a linear relation between the pulse amplitude (A) and the pulse integral (I_{single}), i.e., $I_{single} = k{\cdot}A$, where k is a calibration constant. In case of pile-up of two pulses, we determine the first-pulse amplitude (A_1) and the integral (I_{tot}) of the pile-up pulse structure, which contains the energy information of both pulses. Thus, $A_2 = (I_{tot} / k) - A_1$, where A_2 is the recovered second-pulse amplitude. The energy recovery method was studied for data collected using an LED light pulser over a time difference ($\Delta T'$) interval of $1\ ns < \Delta T' < 600\ ns$. It was shown that the second pile-up pulse amplitude can be recovered up to $\Delta T'$ larger than the pulse rise time of 50 ns [5]. Since the measured pulse width is about 280 ns, the pulses above $\Delta T' = 280\ ns$ are completely separated and are used as reference. Therefore, the pile-up effect was simulated in the time interval of $50\ ns < \Delta T' < 280\ ns$.

From data measured with tagged photons [7] a pulse response function was derived. This response function was used to introduce two additional pulses into measured signal traces over a time difference interval of $50\ ns < \Delta T' < 280\ ns$ for the first and second-pulse amplitudes in the range from 3.8 mV to 3.8 V. In this way, the amplitude and time of the introduced pulses were precisely controlled, while the realistic noise level from the measured signals was preserved. The relative difference $[(\sigma_{rec} - \sigma_{ref})/\sigma_{ref}]$ between the recovered (σ_{rec}) and the reference (σ_{ref}) energy resolution as function of the first and second-pulse amplitudes is shown in fig. 3.

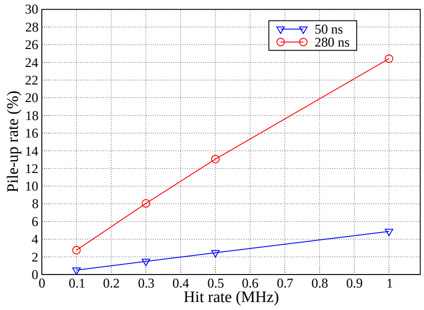

Figure 4: The pile-up rate as a function of the EMC hit rate is estimated using a Poissonian time-distribution function. The circles indicate the pile-up rate at a hit-response time of 280 ns and the triangles indicate the remaining pile-up rate after pile-up recovery for an effective hit-response time of 50 ns.

While the signal amplitude can be recovered on the % level, the resolution can be recovered on the 10% level for almost all the combinations of the first and second-pulse amplitudes in the range from 3.8 mV to 3.8 V. The maximum deviation of 20% is seen at the lowest pulse amplitudes. The pulse pile-up was simulated for a matrix of 5×5 crystals. To this end we exploited the amount of energy deposition measured for tagged photons in the prototype calorimeter (proto60) [7]. The pile-up recovered cluster energy resolution is 20 % worse than the reference cluster energy resolution corresponding to the proto60 results. The improvement on the pile-up rate was estimated using a Poissonian time-distribution function and is shown as a function of the EMC hit rate in fig. 4. The pile-up rate observed in the pulse overlap region up to a time difference of 280 ns is significantly reduced by recovering all pulses arriving after a time delay of about 50 ns. After applying the recovery method, the pile-up rate at a maximum hit rate of 500 kHz is reduced to 2.4%.

In summary, the trigger-less readout concept for the PANDA EMC was developed and successfully implemented and applied. The feature-extraction algorithym was developed including energy and time definition and pulse pile-up recovery. A small jitter in the time-synchronisation of the synchronous optical link connection was verified. In the near future, data will be collected with a prototype detector array exposed to tagged photons at high rates using the online pile-up recovery.

[1] Physics Performance Report for PANDA: Strong Interaction Studies with Antiprotons, The PANDA Collaboration, arXiv:0903.3905v1 [hep-ex]

[2] PANDA EMC Technical Design Report, The PANDA Collaboration, arXiv:0810.1216v1 [physics.ins-det]

[3] E. Guliyev et al., Nucl. Instr. and Meth. in Phys. Res. A 664, 22 (2012)

[4] M. Kavatsyuk et al., Conference Record, 2011 IEEE Nuclear Science Symposium, Valencia, Spain, October 23-29, 2011, 43; DOI 10.1109/NSSMIC.2011.6154360 (http://ieeexplore.ieee.org).

[5] G. Tambave et al., Conference Record, 2011 IEEE Nuclear Science Symposium, Valencia, Spain, October 23-29, 2011, 2163; DOI 10.1109/NSSMIC.2011.6154438 (http://ieeexplore.ieee.org).

[6] I. Konorov et al., Conference Record, 2009 IEEE Nuclear Science Symposium, Orlando, Florida, USA, October 25-31 2009, N25-249; DOI 10.1109/NSSMIC.2009.5402172 (http://ieeexplore.ieee.org).

[7] M. Kavatsyuk et al., Nucl. Instr. and Meth. in Phys. Res. A 648, 77 (2011)