

APD Screening and Matching for the PANDA Target Electromagnetic Calorimeter

Thomas Held

August 2019

Preamble

This document is a summary of talks and corresponding discussions held in a meeting at Bochum University on July, 10th 2019. The presentations were given by J. Reher (APD screening) and M. Steinke (APD matching). The meeting joined M. Albrecht, F. Heinsius, T. Held, and the Technical Coordinators of the PANDA experiment L. Schmitt and A. Belias.

Logistics

The APDs for the readout of the vast majority of the lead tungstate crystals in the PANDA target electromagnetic calorimeter are manufactured by Hamamatsu (type S11048) and delivered in boxes of 50 APDs each. Upon arrival at Bochum University the APDs will be assigned to serially numbered batches of APDs. After a first screening the APDs will be given to Strahlencentrum Giessen for irradiation and annealing and sent back to Bochum where a second screening takes place. APDs already screened at the Photo Sensor Laboratory of GSI will be screened at Bochum University only once after irradiation and annealing at Giessen University. Batches containing APDs prior to and after irradiation are distinctively numbered.

The storage of APDs at Bochum University is done in the original, numbered boxes from the vendor stored in drawer boards. Box number and respective APD position within the corresponding box are stored in the PANDA Forward Endcap Production Data Base.

Screening

The APD screening is conducted inside of two climate chambers available in Bochum. Each chamber contains two setups with a screening capacity of 15 APDs each (fig. 1). The resulting single climate chamber load of 30 APDs is chosen to be a 'screening batch'. Thus two batches, that is 60 APDs, can be screened in parallel. With an APD screening run duration of about 10 hours the nominal throughput is four batches of APDs per weekday, half of that on weekends. Screening batches are prepared and numbered in ascending order. The APD serial numbers within a batch are digitally recorded in an ASCII file and transferred to the data base. A digital photographical image of every batch, showing the APDs serial numbers and the batch number, is archived allowing retrospective checks.

The screening procedure comprises the recording of AC and DC characteristic curves of the APDs at two temperatures. One temperature is chosen to be 20°C which is the nominal laboratory temperature of the manufacturer and hence allows a comparison of data taken with the ones given by the vendor, the most important one being the APD bias voltage for a gain of 100. The second temperature the measurements are done at is the operating temperature of the PANDA target spectrometer EMC of -25°C.

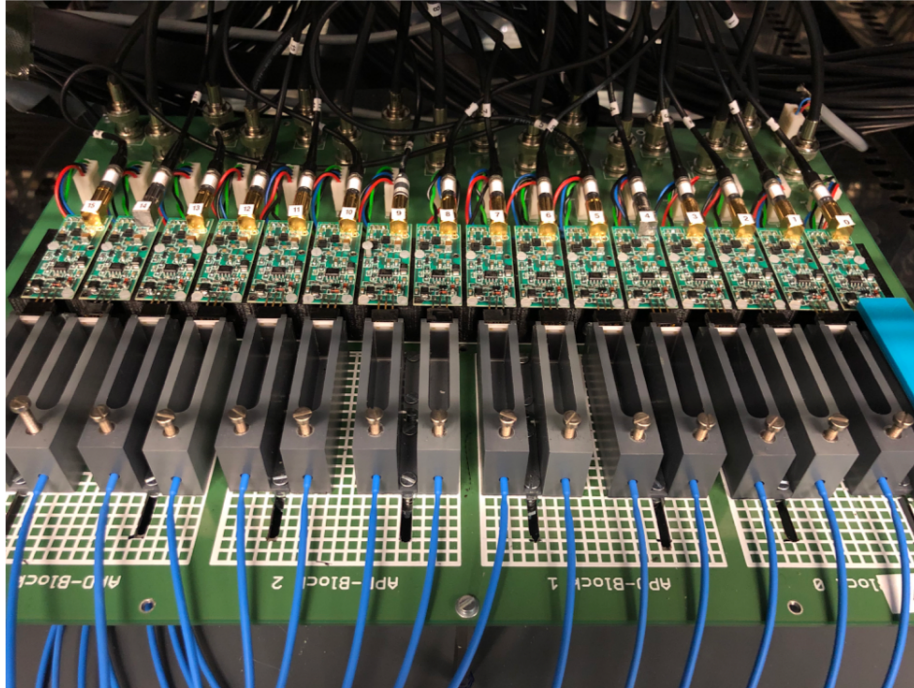


Figure 1: Screening setup inside of a climate chamber.

The screening setup inside each climate chamber consists of two identical main PCBs containing 16 HV connectors and a common ± 6 V connection supplying 16 original PANDA Forward Endcap preamps (Basel University) screwed to the board. The preamps are equipped with a socket accepting the two APD electrode pins. The APDs are suspended in individual plastic mounts for easy mounting and removal and will be connected to the preamp socket by linear movement of the mount to and from the preamp, respectively. The mount is also equipped with one optical fibre each illuminating the APD. The distance between fibre end face and APD is chosen to achieve a full illumination of the whole photo sensitive area of the APD. One of the 16 channels on each main PCB setup permanently contains a reference APD in order to monitor the intensities of the light sources.

The optical fibres are connected to a light pulser system similar to the ones built for the PANDA target calorimeter, modelling the wavelength, pulse shape and intensity of lead tungstate scintillation signals in the PANDA Forward Endcap EMC, supplemented by a DC operated blue LED. The APD bias voltages are supplied by Iseg HV modules (type EHS F4 10p) as foreseen for the PANDA target electromagnetic calorimeter operation.

The recording of DC characteristic curves, that is the bias voltage dependent DC current drawn by each APD when illuminated with constant blue light from

the DC operated LED light source, is done by using the ampere meter capability of the Iseg high voltage supplies.

AC characteristic curves are measured using the scintillation like LED pulses and the readout of the APDs with the connected preamplifiers. Digitization of the preamp signals is done by PANDA Forward Endcap calorimeter SADCs. So the total readout and supply environment corresponds to the one used in the PANDA experiment - except for the preamp low voltage power supplies (Basel University) which will later on be replaced by Wiener PL512 low voltage modules.

The whole screening circle comprises four single measurements: Light current (DC LED light source) and pulsed measurement (lead tungstate scintillation like pulses with a repetition rate of about 60 Hz) at 20°C and -25°C each.

During the light current measurement the APD bias voltage is varied from 1 V to 480 V in steps of 1.1 V, the stepsize being optimized for a total screening duration not exceeding 10 h (including cooling and heating periods) in order to be able to safely manage two screening runs a day. In case an APD exceeds a current limit of 100 μ A the bias voltage increase for this particular channel is stopped. For every bias voltage set and read back the resulting current is recorded.

The pulsed measurement is done with the same step size and the same values recorded. The pulsed light intensities are sufficiently low to not measurably contribute to the current. However, the precision of the internal no load current correction of the Iseg HV modules is insufficient and results in remaining indicated currents in the order of the typical APD dark currents at -25°C. Therefore the remaining no load currents of all HV channels are measured and correspondingly subtracted from the APD currents measured. These no load current measurements as a function of the HV value set need to be regularly rechecked, This is done about once in a month. The quality of a linear fit to the measured I/U curve is an indication of the suitability of the respective HV channel for APD screening purposes. This selection of HV channels is necessary as uncertainties in the current measurement at low voltages (10-40 V, APD gain of 1) dominate the accuracy of the APD gain determination.

Additionally the preamp output signal amplitude and integral is recorded during the pulsed measurement, both in high and low gain channels of the SADC boards.

Change of batches is done in two shifts a day (morning and evening). Before inserting new batches the prepared serial number file is checked by the shifter. After inserting of the APDs a test program is started that visually shows the correct connection of all APDs by displaying waveforms of all APD channels both in high and low gain SADC channels. Then the automated measurement is started that controls the climate chambers, the HV settings and records a detailed measurement protocol. The shifter is given a detailed screening manual (<https://panda-wiki.gsi.de/foswiki/pub/EMC/ForwardEndcapDocuments/ScreeningManual.pdf>) including hints for trouble shooting and a check list (fig. 2). The work done by the shifter finally is entered in an electronic logbook (fig. 3), where batch numbers of removed and inserted

batches are logged and problems encountered is reported on.

Exchange of APDs with Strahlenzentrum Giessen

The first time screened APDs will be given to Strahlenzentrum Giessen for irradiation and annealing. These treatments are conducted using PCBs equipped with sockets to accept 60 APDs (two batches) each (fig. 4). Anode and cathode connection of all APD slots are wired in parallel and will be shorted by the use of jumpers on the boards. (Alternatively a common bias voltage can be applied to the APDs.) The PCBs are designed for a direct insertion in the irradiation setup at Giessen and will also be used for transport between Bochum and Giessen University. The boards are stackable, secured by screws, for compact and safe shipping. Thus shipping, irradiation, and annealing is done on the PCBs without the need for removing the APDs, thereby saving handling time and keeping stress off the APD contacts.

Matching of APDs

In the PANDA target calorimeter radiation damages in the lead tungstate crystals with the consequence of light yield losses will arise during the years of data taking. In order to keep the energy resolution of the calorimeter this will require an increase of the initial APD gain of 200. In the forward endcap of the target calorimeter the usage of a 32(16) channel HV regulator board (Bonn University) per 16(8)-crystal submodule is foreseen. Supplied by a single Iseg HV channel per 8 APDs it allows the fine adjustment of the bias voltage of every single APD in the forward endcap submodules (32/16 APDs in the 16/8-crystal submodules). As the regulator board is still undergoing radiation hardness tests and because of the limited voltage adjustment capability of the HV distributor boards, groups of eight similar APDs each are needed for the APD equipped submodule production.

The similarity of APDs is considered as similarity of the gain curves (gain vs. bias voltage) in the relevant region of the initial nominal operation gain and a higher gain value needed as the light yield of the crystals declines.

So the matching criterion was chosen to be the minimum spread s of differences in the necessary bias voltages of APD groups for a gain of 200 and a gain of 300:

$$s = \frac{1}{n-1} \sum_{i,j=0; i < j}^{n-1} ((U_{i,200} - U_{j,200})^2 + (U_{i,300} - U_{j,300})^2) \quad (1)$$

The matching algorithm is based on three classes.

The APD class contains data sets for warm and cold screening results, data supplied by the manufacturer (Hamamatsu) and a streamer.

The Multiplet class comprises a container of n APD instances and the spread function s (eq. 1) to be minimized.

Checklist: APD Screening

Name of Screener: _____
 Date and Time: _____
 Climate Chamber: _____
 Previous Batch: _____
 Next Batch: _____

- ☐ Checked if previous measurement finished successfully
- ☐ Verified that the HV supply is off and switched off the LV supply
- ☐ Checked serial of first APD in each setup against serial file
- ☐ Removed previous Batch
- ☐ Verified Serials of previous Batch, noted deviations on previous page
- ☐ Verified Serials of next Batch, noted deviations below
- ☐ Inserted new Batch
- ☐ Turned LV supply back on
- ☐ Ran test program and verified that all channels show clean signals
- ☐ Started screening at _____

Errors found in serial file:

Batch Number	Position	Serial in List	True Serial

Signature: _____

☒ Completed ☐ Not Completed ☒ Failed

Figure 2: Check list to be filled in by the shifter.

9/5/2019

ELOG apd

PT-Labor | apd | MuPix |


APD-Screening Logbuch Bochum, Page 1 of 18

Logged in as "Jan Reher"

ELOG

New | Find | Select | Import | Config | Logout | Last day | Help

Full | Summary | Threaded

 -- All entries -- ▾ -- Type -- ▾ -- Category -- ▾ 354 Entries

Goto page 1, 2, 3 ... 16, 17, 18 Next All

ID	Date	Author	Type	Category	Subject	Text	
359	Thu Sep 5 07:43:23 2019	Tom	Routine	CTS01 and CTS02	Started Screening of 00133 and 00134	CTS01: Removed batch 00131, checked serials.dat of batch 00133, inserted, tested, and started screening of batch 00133.	
358	Wed Sep 4 10:26:04 2019	Jan Reher	Routine	CTS01 and CTS02	Screening Batches 00127, 00128, 00129, 00130	Yesterday in the evening: Removed 00125 and 00126, started screening 00127 and 00128 according to checklist.	
357	Tue Sep 3 10:36:40 2019	Sven Pankonin	Routine	CTS01 and CTS02	Screening Batch 00125 and 00126	CTS01: Removed Batch 00123, checked serials. Checked Serials of Batch 00125, inserted,	
356	Mon Sep 2 12:14:58 2019	Jan Reher	Routine	CTS01 and CTS02	Screening Batch 00123 and 00124	CTS01: Removed Batch 00121, checked serials. Inserted Batch 00123, tested, started	
355	Sun Sep 1 17:26:31 2019	Matthias Steinke	Probleme	CTS01 and CTS02	started screening of 00121 and 00122	CTS01: removed 00119, checked serials. checked serials and inserted 00121, tested and started screening.	
354	Sat Aug 31 15:13:10 2019	Jan Reher	Routine	CTS01 and CTS02	Screening Batch 10119 and 10120	Removed Batch 10117 and 10118, verified serials of those Batches. Verified serials of 10119, inserted	
353	Fri Aug 30 21:01:43 2019	Jan Reher	Routine	CTS01 and CTS02	Screening Batch 00117 and 10118	Removed Batches 00115 and 00116, verified serials. Verified serials of Batch 00117,	
352	Fri Aug 30 08:39:59 2019	Tom	Probleme	Batch Definitions	Found Typo in serials.dat of Batch 00016 by Chance	Accidentally changed to directroy 00016 instead of 00116 and found a typo in its serials.dat: 3rd and 4th entry are identical (...52),	
351	Fri Aug 30 08:38:12 2019	Tom	Routine	CTS01 and CTS02	Screening of Batches 00115 and 00116	CTS01: Removed batch 00113, checked serials.dat of batch 00115, inserted, tested, and started screening of batch 00115.	
350	Thu Aug 29 19:37:55 2019	Matthias Steinke	Routine	CTS01	Started Screening of Batch 00113	removed 00111, checked serials checked serials, inserted 00113, tested, started screening	
349	Thu Aug 29 18:48:11 2019	Matthias Steinke	Routine	CTS02	inserted 00114	removed 00112, checked serials checked serials and inserted 00114 testing did not work b/c the daqServer	
348	Thu Aug 29 09:10:25 2019	Tom	Routine	CTS01	Screening of Batch 00111	CTS01: Fixed setup 1, slot 9 by replacing broken JFET on preamp board.	
347	Thu Aug 29 08:15:49 2019	Tom	Probleme	CTS01	Prepared Screening	Started prepared screening of batch CTS01: Removed batch 00109, checked serials.dat of batch 00111, inserted, tested, and started screening of batch 00111.	

https://tau.ep1.rub.de:8080/apd/?id=359

1/2

https://tau.ep1.rub.de:8080/apd/?id=359

1/2

Figure 3: Electronic logbook to be used by the shifter.

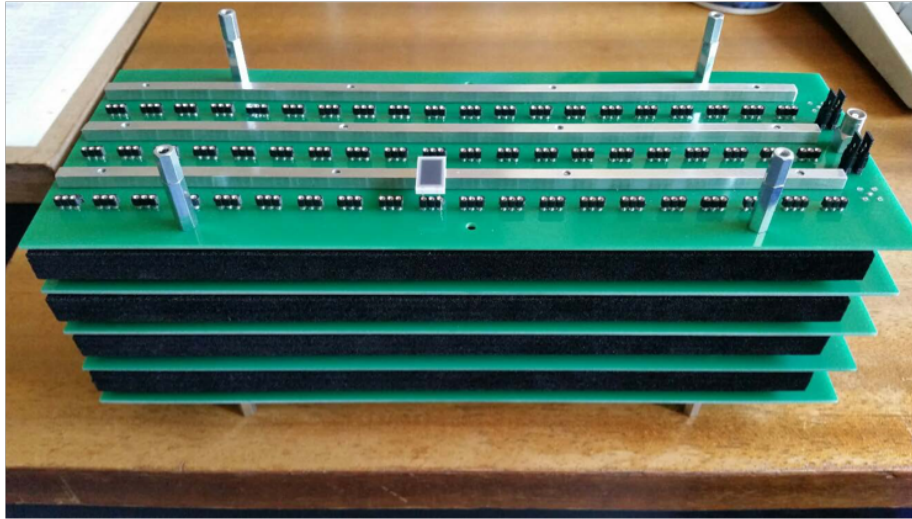


Figure 4: PCB stack as used for APD transport, irradiation, and annealing.

The `MultipletList` class comprises a container of `Multiplet` instances and a pair function that creates new `Multiplets` from all pairs of `Multiplets` on the list and stores them on a new `MultipletList`. In order to keep combinatorics small a cut on the spread function outcome of the new `Multiplets` is carried out at the beginning.

The matching algorithm builds a `MultipletList` from all good APDs, that is APDs with complete data sets and a margin of at least 14 V between its operation voltages for a gain of 200 and a dark current of $10 \mu\text{A}$, respectively. The latter voltage is a conveniently chosen 'breakdown' voltage that is safely measurable with the Iseg HV supplies without the need for current measurement range switching of the modules.

Then the pair function of the `MultipletList` class creates a list of suitable APD pairs and in a second iteration a list of paired pairs in order to get a list of groups of four APDs. Pairing on this list finally results in APD octets which are ordered according to their spread. Sorting the list with respect to the spread of the octets, submodules will be equipped with the lowest spread octets available

at the time of production. APDs taken from the pool of available fully measured APDs in groups of best suited octets for submodule build are removed from the APD list while newly screened ones constantly enter the list. This results in groups of sufficiently similar APD octets which are able to be supplied by a common high voltage channel in the experiment.

The spread of the first 12 groups of APD octets, selected from a pool of 2162 APDs, is in the range of $2.6 \cdot 10^{-4} \text{ V}^2 < s < 4.3 \cdot 10^{-4} \text{ V}^2$. This translates to a mean deviation of 21 mV in bias voltages for a gain of 200 and correspondingly a mean gain deviation of the APDs within the worst of the considered suitable APD octets of 0.14 % when supplied by a common high voltage for mean gain of 200.