The backward end-cap for the PANDA electromagnetic calorimeter

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Abstract. The PANDA experiment at the new FAIR facility will cover a broad experimental programme in hadron structure and spectroscopy. As a multipurpose detector, the PANDA spectrometer needs to ensure almost 4\pi coverage of the scattering solid angle, full and accurate multiple-particle event reconstruction and very good particle identification capabilities. The electromagnetic calorimeter (EMC) will be a key item for many of these aspects. Particle energies ranging from some MeVs to several GeVs have to be measured with a relative resolution of 1\% \( + 2\% / \sqrt{E/\text{GeV}} \). It will be a homogeneous calorimeter made of PbWO\textsubscript{4} crystals and will be operated at -25\degree C, in order to improve the scintillation light yield. With the exception of the very forward section, the light will be detected by large area avalanche photodiodes (APDs). The current pulses from the APDs will be integrated, amplified and shaped by ASIC chips which were developed for this purpose. The whole calorimeter has been designed in three sections: a forward end-cap, a central barrel and a backward end-cap (BWEC). In this contribution, a status report on the development of the BWEC is presented.

1. Introduction

The physics programme covered by the PANDA experiment will be focused on strong interaction studies using an antiproton beam and an internal target. The physics topics range from hadron structure and spectroscopy to nuclear physics and are summarised in ref. [1], together with an account of the expected performances, achievable by the designed apparatus. For many physics channels, electromagnetic final states including electrons, positrons and gammas have to be reconstructed and these particles need to be detected within a solid angle of approximately 4\pi. In addition, particle identification is needed by many of the planned measurements. For these reasons, the electromagnetic calorimeter (EMC) [2] will play an important role for the successful operation of the spectrometer.

The Panda Collaboration decided in favour of a PbWO\textsubscript{4} homogeneous calorimeter which will be operated at -25\degree C and has a goal relative energy resolution of 1\% \( + 2\% / \sqrt{E/\text{GeV}} \). The EMC will be divided into three parts, a forward end-cap, a central barrel and a backward end-cap (BWEC) which is the subject of this contribution. The total solid angle acceptance will be about 99\% of 4\pi and the large polar scattering angles from 140\degree to 170\degree will be covered by the
Figure 1. Left: technical drawing of the PANDA spectrometer. The white box shows the position of the backward end-cap of the electromagnetic calorimeter. A close-up of this region is shown on the right. The beam direction is from left to right and the target position is where the beam pipe becomes narrower. The target region is surrounded by the micro-vertex detector (in dark grey) and the straw tubes tracker (STT, in orange). The ring-shaped volume upstream of the STT (in light blue) is the backward end-cap of the calorimeter.

BWEC. This range is important for those physics channels which are particularly sensitive to the forward and backward kinematics, e.g. the time-like form factor measurement from the exclusive proton-antiproton annihilation into leptons. For other proposed experiments, like the extraction of transition distribution amplitudes from the $\bar{p}p \to e^+e^-\pi^0$, where the pion should be detected only at the very forward and very backward polar angles, the BWEC will be essential.

The most severe constraints to the development of the BWEC are imposed by the geometrical boundary conditions. The BWEC will be situated inside the barrel and all services to the inner detectors will be routed through its central hole or through the narrow gap between BWEC and barrel (Fig. 1).

On the other hand, the requirements in terms of signal readout are favourable. In this scattering angle region, counting rates up to only 1 kHz are expected and particle energies ranging from about 10 MeV to 1 GeV have to be measured, which is one order of magnitude less than the dynamic range required to the forward end-cap (10 MeV to 10 GeV).

2. Mechanical construction
An overview on the mechanical design of the BWEC is shown in Fig. 2. The detector will hang from an arm-shaped support structure which will lie on a platform mounted on rails, in order to be able to move out the BWEC from the spectrometer and grant access to the inner detectors. In order to attach the crystals to the support structure, two aluminium mounting plates are foreseen. One of them will be at the border between the cold volume and the other one completely inside of it. The mounting plates will be held together by basalt-fibre-reinforced plastic feet which have enough mechanical strength for supporting the weight of the full structure (about 1.5 ton) but have a low thermal conductivity.

The crystals will be kept inside carbon-fibre-reinforced alveoli which will be glued to aluminium parts, called inserts, which in turn can be screwed to the cold mounting plate (see Fig. 3).

Because of the tight geometrical constraints imposed to the BWEC very high accuracy is needed for the realisation of all mechanical parts.
3. Cooling system

In order to improve the scintillation light yield of PbWO$_4$ the calorimeter will be operated at $-25^\circ$C. Because of the dependence of the light output on the temperature, it is necessary to avoid strong temperature gradients and fluctuations inside the detector volume, in order to improve the linearity of the detector response and the energy resolution.

One important item for having a good thermal stability will be the insulation, because relevant heat sources (i.e. the read-out electronics of the inner detectors) will be placed in the vicinity of the BWEC. Vacuum insulating panels (VIP) will be used for this purpose.

Another important task will be to remove uniformly the heat produced inside the cold volume (e.g. by the front-end electronics) as well as the heat coming from the outside (through cables and the not perfect insulation). To this end, a system of pipes for a cooling medium are being developed. The constraints to this system, apart from having a compact design, are: it needs uniformly distributed pipes, the heat exchange through the pipe walls should be maximised, and the pressure drop along the system should be lower than 0.5 bar, in order to be integrated into the leak-less cooling plant foreseen for PANDA. In order to match these requirements, cooling shells encasing the detector will be manufactured by laser sintering. A prototype for such a shell was already designed and produced (Fig. 4). Finite element simulations are being performed for finding the most appropriate design in terms of pressure drop and cooling efficiency.
Figure 4. Laser sintered alumide/polyamide cooling shell.

The temperature will be monitored at some significant points in the cold volume by self-manufactured flat Pt-100 sensors (Fig. 3).

4. Readout electronics
The scintillation light pulses are detected by large area avalanche photodiodes (APD), like in most of the PANDA calorimeter (see [2] for details). Each crystal will be equipped with two APDs. The APD output pulses are read out by means of a customised ASIC, called APFEL (ASIC for Panda Front-end Electronics), which is developed at the GSI [3]. The integrated circuit implements a charge sensitive preamplifier as input stage, followed by a shaper and a main amplifier with two different gains and two output signals (see the schematics in Fig. 5) which have to be sent to a sampling ADC for digitisation. With the two amplification gains it is possible to enlarge the dynamic range of the measurement matching the input range of the ADC.

Since it is not yet decided, whether the sampling ADCs will be placed on the support structure, close to the detector or rather some metres away, outside of the spectrometer, booster boards have been developed for driving the APFEL-ASIC output signals over several metres of cable.

In Fig. 5, the output pulse of an APFEL-ASIC is shown. One can see the smooth shape of the pulse which have a FWHM of about 1 µs. The signal was obtained by reading out an APD which was illuminated with a short LED pulse of about 70 ns of duration. The test was performed at room temperature and no bias voltage was applied to the APD. The signal was transmitted by the booster boards over 10 m of cable.

5. Tests with prototypes
Before constructing the final setup of the BWEC, prototype tests are being performed. A first arrangement with four PbWO₄ crystals has been set up and tested with cosmic rays. Since the APFEL chips were not yet available at the time of these tests, the APD pulses were read out with charge sensitive preamplifiers from the University of Basel which were also developed for PANDA [4]. A sample result from these tests is shown in Fig. 6. The improvement obtained by the cooling is quite clear. At room temperature the bias voltage of the APDs has to be raised, in order to obtain visible pulses, up to a value at which the dark pulses are amplified making the signal baseline very unstable. Cooling down the crystals, one has to lower the bias voltage in order to keep the pulse within the input range of the ADCs (sampling ADC of type SIS3301 by Struck GmbH were used to digitise the signals). This way the baseline is much more stable and the pulses are cleaner.

Currently, a new prototype with 16 crystals is being built. In the new setup, the APD pulse readout is performed by APFEL ASICs. Almost all components will be the same as in the final BWEC setup. Besides the tests with cosmic rays, a test beam at the MAMI facility at Mainz is foreseen for July 2014. The test measurements will be performed in the so-called tagger hall, where experiments with real photons are usually run. In this hall the MAMI electron
bin is scattered on a radiator producing a secondary gamma beam. The momentum of the electrons after the radiation is analysed in a dipole magnet, providing an energy measurement of each single gamma. These “tagged” photons are a very well suited tool for performing a calorimeter characterisation. The main objective of the beam tests is studying the dependence of

Figure 5. Left: schematics of the printed circuit implemented in the APFEL ASIC (see [3] for details). Right: output signal of an APFEL ASIC, where the input pulse was produced by an APD which was irradiated with a short (~70 ns) LED pulse. The yellow and cyan waveforms are the positive and negative differential outputs, respectively, whereas their difference is shown in red.

Figure 6. Left: test prototype for cosmic ray measurement. Inside the light-blue insulating box four PbWO$_4$ crystals are kept at −28°C (this temperature differs from the design operation temperature of the PANDA EMC just for convenience operating the available chiller). The APD pulses are amplified by charge sensitive preamplifiers SP883a02 [4] and a 10-fold linear amplifier. Plastic scintillators are place above and below the prototype and are used for triggering. Right: examples of cosmic ray events at different temperatures. The improvement in the pulse height is clearly visible.
the calorimeter response on several parameters like incoming particle energy, angle and position, temperature of the crystals, APD bias voltage, and count rate. It will be the first time that the APFEL ASICs are tested in a full arrangement with a gamma beam.

6. Conclusions
The EMC will be an essential ingredient for the physics programme of the future PANDA experiment. Since a full solid scattering angle coverage is required for many measurements, the calorimeter end-caps play an important role. In this contribution the design, development and construction of the backward end-cap have been addressed. Many of the activities related to these topics are being put forward at the Mainz University within the Helmholtz-Intitut and the Institut für Kernphysik and at the GSI. Currently, the design of the equipment is mostly settled and tests with prototypes are being performed for finalising all needed subsystems. Within the next year, the construction of the final setup of the BWEC is planned to begin and the advancement of the project is, as of now, within the schedule required by the PANDA Collaboration.

Acknowledgments
This project is supported by the German Bundesministerium für Bildung und Forschung through the grant 05P12UMFP9.

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