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The Crystal-Barrel/TAPS Experiment at ELSA
Current Status of the CsI(Tl) Calorimeters

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Abstract. The Crystal Barrel experiment at ELSA, as a medium-energy hadron physics experiment, is focused on baryon-spectroscopy and meson-photoproduction. The experimental setup includes three different, φ-symmetric calorimeters covering almost the complete solid angle. The detector system, together with a polarised target and a linearly or circularly polarised photon beam, allows in addition to the measurement of cross sections also the measurement of single- and double-polarisation observables. Baryon resonances up to masses of 2.5 GeV can be investigated.
In the course of a major upgrade of the CsI(Tl) calorimeters, two different techniques to detect the light generated in the crystals are compared with the known performance of the existing photodiode readout. The aim of the new techniques is to enable the calorimeter to be a first level trigger source while keeping a very good energy resolution comparable to the present photodiode readout.
The first solution is a complete redesign of the crystal readout, featuring two 10 mm × 10 mm APDs mounted directly on the crystals. With an integrated, fast preamplifier, this readout will allow both an energy measurement and the generation of a fast timing-/trigger-signal. The second solution is a modification of the existing setup. The photodiode will continue to provide the energy information while two additional SiPMs will create the timing-/trigger-signal.

1. Overview
To gain a detailed knowledge of the spectrum and the properties of baryons, photoproduction experiments are performed at the 3.5 GeV electron accelerator ELSA in Bonn [1]. The Crystal Barrel detector [2][3] with its almost 4π coverage is ideally suited to measure multi photon final states. The experiment is a fixed target experiment, it utilises a tagged beam of unpolarised, longitudinally or circularly polarised photons, created via bremsstrahlung from the (polarised) electron beam of the accelerator facility. As a reaction target either the Bonn Frozen Spin Target [4] or a pure liquid hydrogen target or a deuterium target can be used. Due to the forward boost of the reaction products, the forward angles are of special concern and three modular and interchangeable detectors were built to provide coverage of the region from 30° down to 2° depending on the physical demands.
In 2001 the Crystal Barrel calorimeter was modified to work with a wall of 528 TAPS BaF_2 detector modules [5], covering the solid angle from θ=30° to 6°. For the current measurement period, a new forward detector of 90 CsI(Tl) crystals was built to fit directly into the open forward cone, covering θ from 27.5° to 11.2°, while a smaller TAPS setup of 216 BaF_2 detector modules covers the area from 10.4° down to 1.6° (Fig.1).

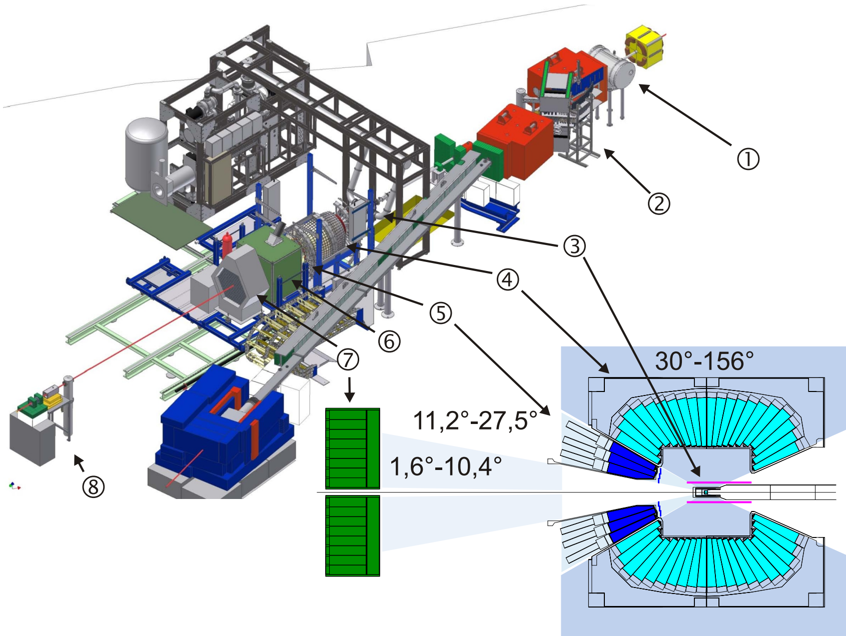

Figure 1. (schematic) view of the Crystal Barrel experiment.

[1]Radiator Target
[2]Electron Tagging System
[3]Polarized Target Cryostat
[4]Crystal Barrel Detector
[5]Forward Detector
[6]CO_2-Čherenkow
[7]MiniTAPS
[8]Photon Beam Monitor

2. Current Status and Performance of the CsI(Tl) Calorimeters

In the present configuration, the Crystal-Barrel/TAPS experiment consists of three calorimeters, the BaF_2 calorimeter wall *MiniTAPS* and the two CsI(Tl) calorimeters *Crystal Barrel* and *CB Forward Calorimeter* (Fig. 2).

2.1. The Central Detector with the Crystal Barrel Calorimeter

The experiment's central detector consists of the Crystal Barrel as a main calorimeter and the Inner Detector for charge identification and first level trigger capability.

The 1230 CsI(Tl) crystals of the Crystal Barrel are arranged in 20 rings of 60 crystals each, covering the solid angle from 30° - 150° in θ (6° × 6° resolution) and one ring of 30 crystals covering 150° - 156° in θ (12° × 6°). The readout of the crystals is performed by photodiodes attached to wavelength shifting plates that cover the complete rear face of the crystals (Fig. 3-top). In each crystal's end cap enclosure is a preamplifier/driver electronic, providing amplification for 50 meter signal transmission to the ADC system. A special oil cooling system stabilises the temperature of the main calorimeter. With this readout, the Crystal Barrel reaches a measured energy resolution of $\sigma_{(E)}/E = 2.5\%/\sqrt[4]{E_{[GeV]}}$. The reconstructed angular resolution for the center of an electromagnetic shower is better than 1.5° [2]. In 1999, with the relocation to the ELSA facility, the original Fera-ADC readout was replaced by a FastBus 12 bit dual range ADC system [6]. Due to the long risetime of the shaped photodiode signals, the calorimeter cannot be used in a fast first level trigger scheme. For a second level trigger decision, a gated cellular cluster logic is used to calculate the event by event particle multiplicity within typically $4\,\mu$s ($(1+N_{Part})\times 0.8\,\mu$s [7]).

The Inner Detector as second part of the central detector system provides the missing first level trigger capability. It is a cylindrical fibre detector of 513 scintillating fibres arranged in three layers. Two of the three layers are wound around the detector in oposite directions, that way providing a redundant detection of charged particles and their direction. The reconstructed angular resolution is 0.1° in θ and 0.4° in φ, the detection efficiency for charged particles is measured to be 98% [3]. Matching of charged particles to hits within the Crystal Barrel is possible with a calibrated time resolution of 0.9 ns.

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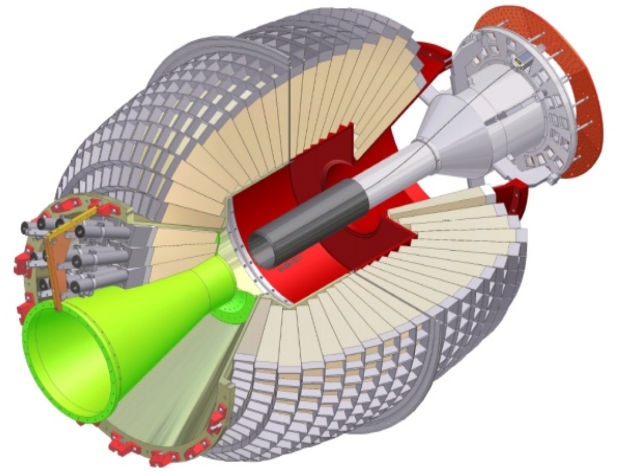

Figure 2. The *Crystal Barrel calorimeter* (center) with its *Inner Detector* (from the right) and the Crystal Barrel *Forward Detector* (from the left).

Figure 3. Photodiode readout of one of the main calorimeter crystals (top) and PMT readout of one of the forward calorimeter crystals (bottom).

2.2. The CB Forward Detector with the Forward Calorimeter

The CB Forward Detector was build in 2005 to cover the forward region between 30° and 10° in θ. 90 of the original Crystal Barrel crystals form the calorimeter part while a subdetector of 180 plastic scintillator tiles provides charge identification.

As in the original setup, the CsI(Tl) crystals have been arranged in three rings of 30 crystals each, with a covarege of 6° in θ and 12° in φ. Due to the needed holding structure for the detector, they now cover an area of 27.5° down to 10.2° with respect to the production target. To provide the desired first level trigger capability on photons, the crystals have been outfitted with lightguides and photomultipliers instead of the original photodiodes (Fig. 3-bottom). With fast, risetime compensating discriminators [8] a calibrated time resolution of 1.3 ns has been reached (Fig. 4). The first level trigger capability is achieved by a clusterfinder solution based on SRAM lookup units for the 90 crystals. The decision time for the whole system is 70 ns with an overall detection efficiency of 99,9% and a multiplicity accuracy of 95% [9].

For charged particle identification an additional subdetector based on plastic scintillator tiles was developed and mounted in front of the crystals (Fig. 9). The scintillation light is detected via thermoformed WLS fibres, which lead to multi anode PMTs outside of the detector. A time resolution for charged particles of $\sigma(t) = 1.7$ ns was reached, with a typical detection efficiency of 95%. The 180 scintillators match exactly the solid angle of the calorimeter crystals and allow, by a two layered, shifted setup, a spatial resolution of $6° \times 6°$ for the impact point of a charged particle [10].

2.3. Detector Trigger and DAQ system

The current data acquisiton consits of three parts.

The first part is the main trigger system. The trigger signals from all subdetectors are fed into a main trigger unit in which the desired trigger conditions can be selected to enhance specific reaction channels. Several trigger conditions can be used in parallel to optimise the use of beam time. After a fast first level trigger decision (∼200 ns), the main calorimeter's cluster finder is gated and the final trigger decision, either experiment wide readout or fast reset, is performed. In parallel to the production trigger conditions, calibration and monitoring triggers are used for online monitoring of the detectors.

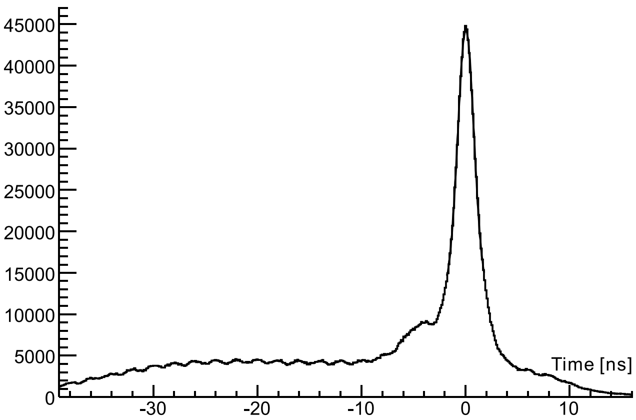

Figure 4. Calibrated time resolution for photons in the Forward Detector CsI(Tl) calorimeter. With a $\sigma(t)$ of 1.3 ns, the detector is able to resolve the bunch structure of the accelerator

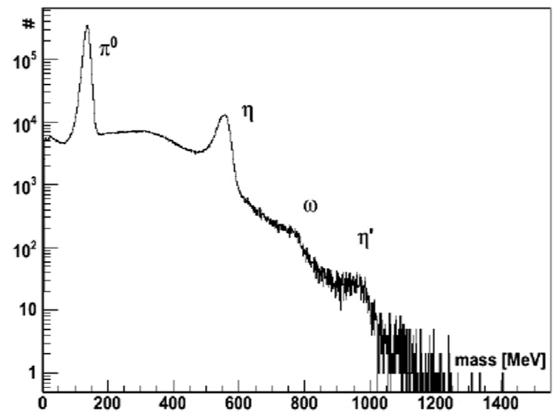

Figure 5. Online $\gamma\gamma$-invariant mass spectrum for events with three clusters (1 charged + 2 neutral) in the calorimeters.

The second part is the main DAQ system, it is based on a parallel readout scheme to minimize dead time due to data digitalisation and collection. Each subdetector is equipped with its own readout processor (local event builder), which collects the digitised data in a buffer as fast as possible. A global event builder collects and combines the data from all subdetectors and stores it on disk. The synchronisation of all local event builders is controlled over a special hardware synchronisation bus to guarantee data consitency event by event. The average event rate in the experiment is 1 kHz with a data rate written to disk of 8 MB/s.
The third part is a slowcontrol and online monitor system that constantly monitors all experimental parameters. The slowcontrol on the one hand monitors temperatures, voltages etc. and stores them in a database. It provides a web interface for accessing the database and changing detector parameters. An overview page warns the online crew in case of problems in the detectors. The online monitor on the other hand constantly copies events out of the incoming datastream. These events are instantantly displayed as raw spectra for all detectors. In parallel a preliminary calibration and analysis of the data is performed at a rate of 20 Hz. The display of these data provides the main tool to constantly monitor the experiment's performance while data taking. Problems within the experiment are instantly visible due to online spectra diverging from the norm and are marked accordingly. In fig. 5 shown is the one month sum of a typical online spectrum, in this case the $\gamma\gamma$-invariant mass of three particle events with one charged hit. In the logarithimc plot, the π^0 and η signal is clearly visible.

3. Future Readout Options

To improve the performance of the whole Crystal Barrel detector system, a full first level trigger capability on neutral and charged particles is desired. In addition the detection of charged particles will be improved by measuring the sign of charge and the momentum of the charged tracks in a new TPC, replacing the Inner Detector. For that, the whole calorimeter will again be placed in a magnetic field. The present readout with classical photomultipliers has to be replaced by a detection scheme working in 1.5 Tesla environment. Two different readout options are currently under investigation, either a complete redesign of the crystal readout based on avalanche photodiodes (APDs) or a modification of the current readout by adding silicon photomultipliers (SiPMs) to the present wavelength shifter.

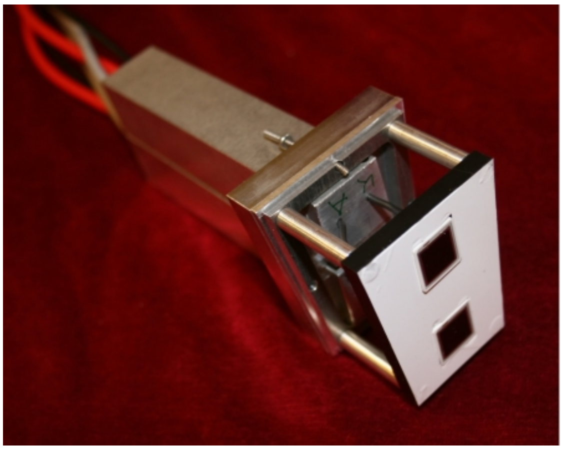

Figure 6. Readout option with two 1 cm^2 APDs attached directly to the CsI(Tl) crystals.

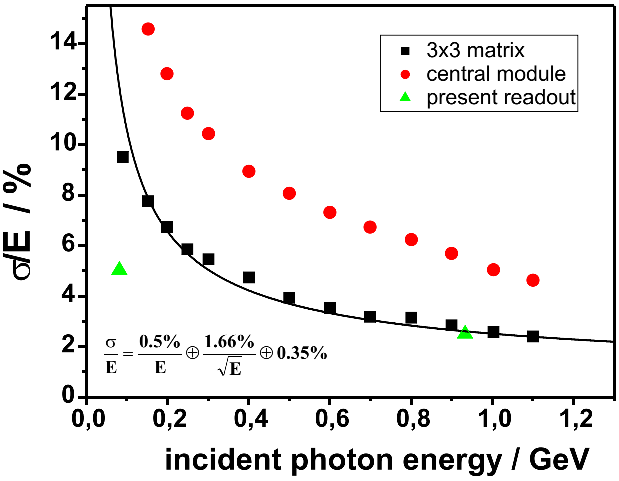

Figure 7. Energy resolution with the APD readout, compared to the current PD readout.

3.1. APD readout

For the APD readout, the current photodiodes would be replaced by two 1 cm^2 APDs of the PANDA type, attached directly onto the crystal rear face (Fig. 6). As with the present setup, a special preamplifier would be placed directly behind the APDs. First tests have been performed with an array of 3×3 crystals. With the PANDA amplifiers (thus not optimized for CsI(Tl) and our needs), the APDs readout already reached an energy resolution of $\sigma_{(E)}/E = 0.5\%/E \oplus 1.6\%/\sqrt{E_{[GeV]}} \oplus 0.35\%$, wich is similiar to the value known from the present photodiodes (Fig. 7). The time resolution of the APDs is with 1.8 ns close to the one measured with photomultipliers (1.3 ns). Currently under development is an optimized amplifier with a timing and energy output. Since the gain of APDs strongly depends on the temperature, methods for temperature stabilization are under investigation, the current design goal is a stabilisation of ±0.1 K at room temperature. Additionally, the prospects of a new readout system based on FADCs are currently investigated.

3.2. SiPM readout

The second readout option adds two SiPMs to the wavelength shifting plate of the present setup (Fig. 8). The energy readout and thus the known, good energy resolution of the photodiode is not touched. The SiPMs add the trigger capability to the calorimeter. The signals of both SiPMs are added and amplified on an additional board within the crystal endcap. First measurements proved the feasability of this method, with the presently tested SiPMs (MEPhI/PULSAR, 9 mm^2, 5kPixel) a trigger threshold of 27 MeV could be reached. Recent measurements on a 3×3 crystal array with an improved readout board suggest, that the threshold could be lowered to 20 MeV. Currently, the optimization of the SiPMs and amplifier boards for the desired trigger threshold of less than 20 MeV is under investigation. To reach this goal, an appropriate type of SiPM has to be chosen corresponding to the peak wavelength of the WLS (625 nm). Since dark counts are the main noise contribution, the size of the SiPM and number of pixels has to be optimized for the expected light yield at trigger level to suppress the SiPM inherent noise.

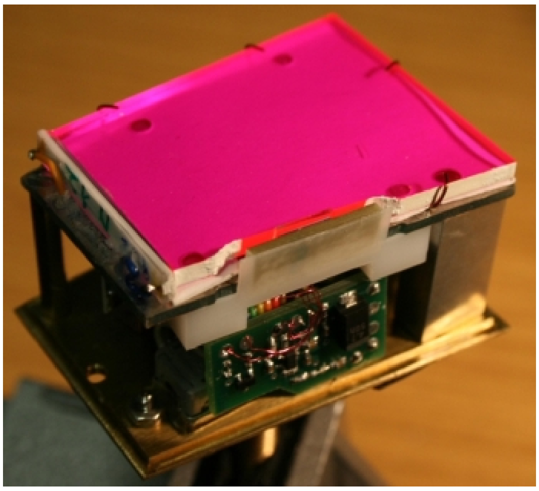

Figure 8. Readout option with two 9 mm^2 SiPMs additionaly attached to the WLS of the current setup.

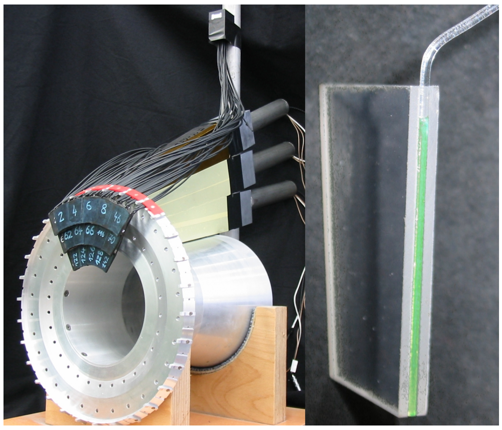

Figure 9. New subdetector for charge identification in the Crystal Barrel Forward Detector (left), based on 3 mm plastic scintillators with thermoformed fibre readout (right).

4. Summary

The Crystal Barrel calorimeter with its photodiode readout is now running for almost 20 years. In 1999, with its relocation to the ELSA facility, the detector system has been modified to fit the new experimental requirements. A new inner detector has been built and the calorimeter's readout system redesigned. In 2005, the forward region was transformed into a separate forward detector with a fast PMT readout. Since 1999, the calorimeters have been used in three different measurement periods and were a reliable source for competative and new data on baryon spectroscopy and meson photoproduction.

With a major redesign of the crystal readout, a first level trigger capability will be reached, extending the performance of the detector system substantially. New reaction channels will be made accessible over the full solid angle.

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