Abstract A highly compact and fast VME based read-out board for BaF$_2$-scintillation detectors has been designed, developed and finally tested in an in-beam experiment. Adapted to the excellent properties of BaF$_2$, the unit allows to digitize time, energy and pulse-shape information of 4 detector channels in parallel. The board is piggy-back plugged onto a motherboard containing a high-speed 12-bit ADC and the VME Interface, commercially available in the customized version CAEN V874A. Both combine to one single VME slot. A first measurement of the photon response of a TAPS sub-array with energy tagged photons up to 2.6 GeV documents the full functionality and excellent performance.

I. INTRODUCTION

The photon spectrometer TAPS [1] has been planned and built more than ten years ago by an European collaboration to investigate high energy photons as well as neutral mesons in relativistic heavy ion collisions or photonuclear reactions, respectively, performed at different European accelerator facilities. The high multiplicity of hadronic reaction products requires a very efficient discrimination against charged and neutral particles as well. Therefore, BaF$_2$ has been chosen as the most appropriate scintillator material due to its high light output, fast response and the selectivity of its pulse-shape to the nature of the impinging probe. Today the modular detector system comprises 576 large hexagonally shaped BaF$_2$ crystals of 25 cm length and a veto detector system consisting of thin plastic scintillator elements [2] of identical granularity to identify already online hits of charged particles. In order to exploit energy, time and pulse-shape measurements over a large dynamic range with high precision, several CAMAC based electronic modules had been developed within the TAPS collaboration, such as multi-channel constant-fraction or leading-edge discriminators, separate gated charge sensitive analog-to-digital converters and time-to-digital converters.

In the present scheme, only the time information is directly deduced close to the detector set-up after distributing the photomultiplier signal in an active split. All analog and digital information is transmitted over a long distance to the counting room for final digitization, which unfortunately degrades the achievable resolution due to signal attenuation and shaping in passive delays or coaxial cables as well as cross-talk in the transmission lines. In addition, the complex set-up increases the installation time when moving TAPS from one to the next accelerator facility.

Today the repair of the existing electronics becomes more and more obsolete and limited by the lack of those components, which were designed exclusively for TAPS. In addition, planned experiments combined with complex detector systems, such as the HADES dilepton spectrometer at GSI, Darmstadt, will require high count rate capabilities, much faster digitization within less than 10 µs, optimum resolution, flexibility and the compatibility to complex trigger architecture. Therefore, the development of a new highly compact electronics to be located directly near the detector modules including the digitization of the complete detector response became mandatory and will significantly improve the overall performance and consequently reduce the installation time drastically.

II. THE GENERAL CONCEPT

The concept is based on VMEbus-standard and should provide the complete digitized detector information in a single module, handling at least four scintillator channels in parallel. In order to exploit the excellent capabilities of BaF$_2$-detectors, the integration of the scintillation signal over the total response...
time (typically 2µs) as well as during its fast component (~20ns), both performed with a high and a low gain, are mandatory. The considered amplitude range of the anode signal of the photomultiplier used (Hamamatsu R2059-01) is determined by the fast component and should not exceed ~5V at 50Ω input impedance to guarantee a fully linear response.

A pulse-shape analysis exploiting the correlation of the fast scintillation component with the total light yield allows to distinguish photons and hadrons, as illustrated in Figs. 1 and 2. Therefore, the detector signal has to be split to feed all four independent integration circuits in parallel.

To perform time-of-flight and coincidence measurements with high resolution, the timing signal has to be deduced based on constant-fraction technique with minimum walk. In particular, the integration gate for the fast component has to be positioned without jitter for pulse-shape analysis. The output of the Constant Fraction Discriminator (CFD) identifies the response of the detector and therefore should be considered as the main start signal for the Charge-to-Amplitude Converter (QAC) of the energy integration as well as for the Time-to-Amplitude Converter (TAC) for the time measurement. Using the externally generated event trigger as a common stop of the TDC will avoid long active or passive delays (~400 to 600ns) of the timing signals of each individual detector.

At least two additional Leading Edge Discriminator (LED) circuits are necessary for a flexible event and trigger selection. In general, all logic timing information has to be externally available as input into scalers or the already existing TAPS Multiplicity Coincidence Unit (MCU) [3]. The MCU allows to derive trigger conditions such as coincidences between BaF₂ detectors on the CFD or LED level or between photon and veto-detectors for charged particle identification. The module has been designed and manufactured by KVI, Groningen, as a VMEbus based (6HE) unit. The different combinations and levels of coincidences and corresponding multiplicities are programmable and can be selected and determined by five high speed FPGAs (ispLSI 3320, ispLSI 2096, Lattice).

All additional functions such as slow control for discriminator settings, a multiplexer etc. have to be implemented on the board, which will be piggy-back plugged onto the multi-layered motherboard containing a high-speed 12-bit Amplitude-to-Digital Converter (ADC) and the VME Interface. This device is already commercially available in the customized version CAEN V874A [4]. Both should combine to one single VME slot.
III. THE READ-OUT BOARD

A. General Description

The basic structure of the presented read-out board is illustrated in Fig. 3. The BaF$_2$ signal is distributed to the discriminators (CFD, LED1, LED2) and 4 integration circuits QAC1 to QAC4. The trigger signals are delivered to the frontpanel as well as to the control unit of the board, a programmable logic device (PLD XILINX XCR3256XL), which under the condition of an accepted event provides the appropriate long integration gate, the bit-pattern of the event and the reset functions in case of a fast clear request. In addition, the PLD handles the slow control of discriminator settings. The energy and time information is transferred via a multiplexer to the fast ADC.

The CFD signal represents the main start signal and its function can also be simulated by an external testpulse. As illustrated in the block diagram of Fig. 4, both signals trigger alternatively a monostable multivibrator (OneShot) of 2.5µs length to accommodate the typical pulse shape of a BaF$_2$ signal, dominated by the decay time of 620ns of the slow component. Therefore, the acceptable mean count rate of an individual channel is limited to 400kHz. The output signal for the MCU (MCUCFD, width 800ns) as well as the integration gate of the fast component (SGATE, width 20ns) are directly generated. The latter can be inhibited in case of the busy or halt status of the motherboard (HALTIN, MBUSY). The SGATE signal, converted into TTL, is starting a timer in the PLD, which generates the long integration gate (LGATE, width 2.0µs) as well as verifies the coincidence with the first level trigger. This COMIN signal has to arrive within a time window of 500ns width, starting after a delay of 250ns. In case of a positive decision, the information of all responding discriminators is stored. Otherwise, the conversion of the energy and time information is reset immediately via RSTTTTL and RST2. The general reset of the signal processing can be initiated by the external logic input signal FASTRST. The trigger information COMIN serves in addition as a precise common stop of the time measurement. Both LED signals are handled in a similar way.

B. The Constant Fraction Discriminator

A CFD is primarily required to provide online a timing reference with minimum walk to set the integration gate of the fast scintillation component, a measurement which can not be walk-corrected off-line. The design concept of the implemented CFD is similar to the CAMAC-based FCC8 module, which was designed in a joint development by the Institut des Physique Nucléaire d’Orsay and GANIL within the TAPS collaboration and became commercially available via GANELEC.

The CFD circuit is buffered by an operational amplifier (OPAM) and an additional OPAM stabilizes the DC-offset to
achieve the functionality of an automatic walk adjustment. A slightly positive DC-level improves stability and sensitivity of the subsequent comparator. The values for the fraction of $f=1/3$ and the internal delay of $\Delta = 2.5\text{ns}$ are fixed and adapted to the effective risetime determined by the initial photomultiplier signal and the implemented OPAM. Within the dynamical range up to $-5V$ the minimum discriminator threshold can be as low as $-10\text{mV}$, corresponding to a dynamic range of 500.

C. The Energy Integration

The charge integration of the fast and the total scintillation component is foreseen twice with low and high gain (relative ratio: 5/1). Its conversion into an amplitude is performed by a fast two channel gated QAC ASIC designed with 1.2$\mu$m BiCMOS technology [5]. It can integrate fast negative impulse currents up to 100mA with a maximum output voltage of 2.5V. The integration gates as well as the reset option are initiated by fast ECL logic.

The extremely fast risetime of the BaF$_2$ response ($\approx3\text{ns}$) causes, however, an integral non-linearities up to 8%, which can be avoided by additional active and passive shaping, leading to an effective risetime of approx. 10ns. The 50ns delayed BaF$_2$ signal is passively split except for the circuit treating the fast component at high gain which requires an additional amplification stage (see Fig. 5). To exploit the full input conversion range of the ADC of 3.85V, all QAC outputs are amplified by a factor 1.5. The pedestals can be adjusted by means of a 13-bit DAC.

Therefore, the present solution foresees a two step TAC, where the time offset is provided by the first stage. The faster discharge of the capacitor allows a typical reset time below 1.5µs. The time offset and the acceptable time range are separately adjustable within a few hundred nanoseconds.

D. The Time Measurement

Based on the trigger concept and the event characterization a typical dynamical range of 200ns with a time offset of 400ns is required. The basic concept to operate in common stop mode is similar to a 32-channel TDC designed by R.Bassini et al. [6],[7]. Within an integration gate, determined by the start and stop signals, respectively, a capacitor is charged up. In the original version, the time offset is achieved by an appropriate negative DC level. However, the large time offset necessary in the present scheme would require an extreme offset voltage and cause an unacceptable long reset time above 5µs.

Fig. 5. Schematic block diagram of the integration circuit for the energy information.

IV. OVERALL PERFORMANCE

A. Intrinsic Resolutions and Performance

The performance of the 12-layer board, the layout of the different components, the cross-talk and the intrinsic resolutions have been tested, optimized and determined with pulse generators or true BaF$_2$ detector signals initiated by radioactive sources. All four energy measurements can be performed with an integral non-linearity $< 1.2\%$ over an effective spectral range of 3840 channels, which corresponds to a maximum total integrated charge of 5500 pC for the integration of the total light output with low gain. The corresponding values for the three additional integration circuits are 100pC (SGS), 500pC (SG) and 1000pC (LGS) in case of the high and low gain of the fast component and the high gain of the total scintillation signal, respectively. The resolution of the pedestal amounts to $\sigma = 0.8$ channels. In case of a time measurement in a fixed range between 400ns to 600ns after the CFD trigger the conversion gain amounts to 52ps/channel. A non-linearity $< 0.025\%$ and an intrinsic resolution of $\sigma_t < 50\text{ps}$ have been achieved with a time generator (EG&G 462). Any time shift caused by cross-talk due to additional input channels does no exceed a value of 60ps.

Due to the fast digitization and short reset times, the complete board comprising all four independent input
channels can be read-out up to a rate of 75kHz in case of accepted events. A count rate up to 400kHz per each channel can be handled for rejected CFD-triggers, limited by the needed reset time. Fig. 6 shows a picture of the described read-out board containing the complete circuits to handle four BaF$_2$ detector signals.

Fig. 6. Photograph of the read-out board containing the complete circuits to handle four BaF$_2$ detector signals.

B. Complete Test-Experiment

A first series of manufactured prototype units has been tested in an accelerator experiment measuring the response function to high energy photons using a 19-module array of TAPS BaF$_2$-detectors. Exploiting the tagging facility at ELSA (Bonn, Germany), the electromagnetic shower initiated by mono-energetic photons of 15 different energies between 0.8 and 2.6GeV has been detected and off-line reconstructed. The photon beam of ~ 1.5cm diameter was directed onto the central BaF$_2$ element. A large plastic scintillator mounted in front allowed the rejection of impinging charged particles, primarily electrons or positrons due to photon conversion in air between the production target and the detector. The deposited energy and the relative time of each detector element as well as a timing information of the responding tagger channel to identify the photon energy have been recorded eventwise.

The simultaneous measurement of the fast and total light output allows in addition to reject pile-up events, which do not fulfill the linear correlation for photons (see Fig. 2). The relative energy calibration has been obtained by irradiating each detector with the direct beam and by recording the energy loss of minimum ionizing cosmic muons in the individual detector modules. The absolute calibration is taken from GEANT3 simulations. Fig. 8 illustrates the overlay of deduced line-shapes for selected incident photon energies.

The achieved energy resolution $\sigma/E$, summarized in Fig. 9, is close to the values expected from GEANT3 simulations taking into account only the experimental discriminator threshold of ~ 18MeV. The observed energy resolutions well above 1GeV energy are primarily determined by the fluctuations of the shower leakage. The conversion gain of the recorded energy spectra was determined by the photomultiplier bias and covered a range up to 2.3GeV in each individual detector module. When hitting the array in between two modules, an experimental time resolution of $\sigma_t=175$ps per detector element has been obtained from the relative time spectrum of two adjacent detector modules. Summarizing, the presented data document the successful operation of the new read-out electronics and a fully sufficient performance.

Fig. 8. Response function of a 19-module TAPS subunit to monoenergetic photons measured with the new read-out electronics.
Fig. 9. The measured energy resolution of a TAPS sub-array consisting of 19 BaF$_2$ scintillator modules. The detector signal have been digitized with the new read-out board.

V. CONCLUSION AND OUTLOOK

A new highly compact read-out board coupled to a commercially available ADC motherboard (CAEN V874A) has been developed, built and brought into full functionality. The single VME (6HE) unit allows the complete digitization of the energy, pulse-shape and time information of 4 BaF$_2$ detectors in parallel. The mass production of a slightly modified version is scheduled beginning 2003 to ensure that a complete read-out of the TAPS spectrometer in combined operation with the Crystal Ball [8], to be installed at MAMI (Mainz, Germany), can start in fall 2003.

VI. REFERENCES