A digital calorimetric trigger for the COMPASS experiment at CERN

J. Friedrich[a], S. Huber[a], B. Ketzer[a], M. Krämer[a], I. Konorov[a], A. Mann[a] and S. Paul[a]

[a]Physik Department E18, Technische Universität München, 85748 Garching, Germany

mkraemer@e18.physik.tu-muenchen.de

Abstract

In order to provide a trigger for the Primakoff reaction, in 2009, the trigger system of the COMPASS experiment at CERN will be extend by an electromagnetic calorimeter trigger. Since it was decided to gain from various benefits of digital data processing, an FPGA based implementation of the trigger is foreseen, running on the front-end electronics, which are used for data acquisition at the same time. This, however, includes further modification of the existing trigger system to combine the digital calorimeter trigger, with its higher latency, and the analogue trigger signals, which will also make use of digital data processing.

I. The COMPASS experiment at CERN

The **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy (COMPASS), is a fixed target experiment at CERN, which uses Muon and Hadron beams from the **S**uper **P**roton **S**ynchroton (SPS) to address a wide variety of physic programs. Thereby the beam is provided in Spills, having a slow extraction from the accelerator, which last around $5\,sec$, followed by approximately $30\,sec$ without extraction. COMPASS is a $60\,m$ long, two staged magnetic spectrometer (see Figure 1), where both stages are equipped with hadronic and electromagnetic calorimeter. Due to the two electromagnets, having an integrated magnetic field of $1\,Tm$ and $4\,Tm$, respectively, COMPASS has a large acceptance range. [1]

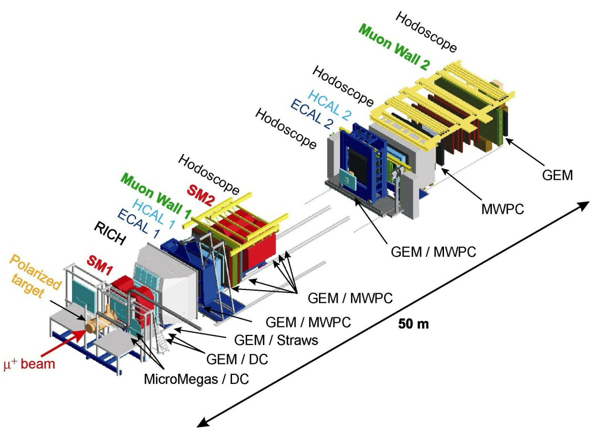

Figure 1: *Rendered view of the compass spectrometer (muon setup).*

The physics program of COMPASS addresses, among other topics, some reactions like Primakoff or Deeply virtual Compton scattering, which either directly or indirectly produce high energetic photons. Therefore an electromagnetic calorimeter trigger is desirable. However the electromagnetic calorimeter of the second spectrometer stage was not equipped with trigger logic, so far. Thus in December 2009 the decision was taken to design a trigger system including this detector. The following section will give a short overview of the calorimeter and readout and discus the trigger logic and implementation in particular.

II. ECAL2 - One of the electromagnetic calorimeters of COMPASS

A. Signal detection

The electromagnetic calorimeter, which is placed more downstream in the COMPASS spectrometer and provides calorimetry for the second stage, ECAL2, consist of 3068 cells, $3.8 \times 3.8cm^2$ each, which are organized in a 64×48 grid. It has a hole of 2×2 cells allowing the beam to pass by. The central part is equipped with 860 Shashlik modules, while the outer part is completed with GAMS and radiation hard GAMS modules. Photo multipliers are used to amplify the signals, which are feed through shaper cards to the readout electronics.

B. Readout

The readout, based on **F**ield **P**rogrammable **G**ate **A**rrays (FPGAs), utilizes versatile sampling **A**nalog to **D**igital **C**onverters (ADCs) mounted on mezzanine cards (see [2]), which themselves are mounted on 9U VME carrier cards (Figure 3). Using 12 Bit ADCs capable of sampling at 40 MHz in a interleaved mode, one mezzanine card reads out 16 channels at a combined sampling frequency of 80 MHz (Figure 2). Four of this mezzanine cards are mounted on one carrier card, which therefore provide 64 channels and is equipped with another FPGA to manage the mezzanine sampling ADCs. In total 3072 channels are readout like this.

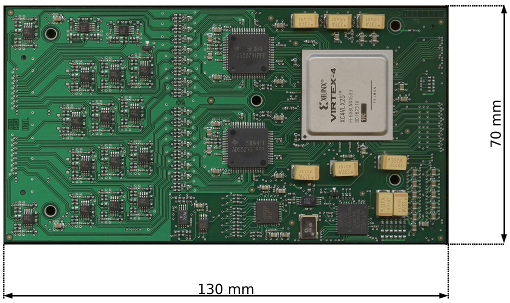

Figure 2: *Mezzanine sampling ADC module*

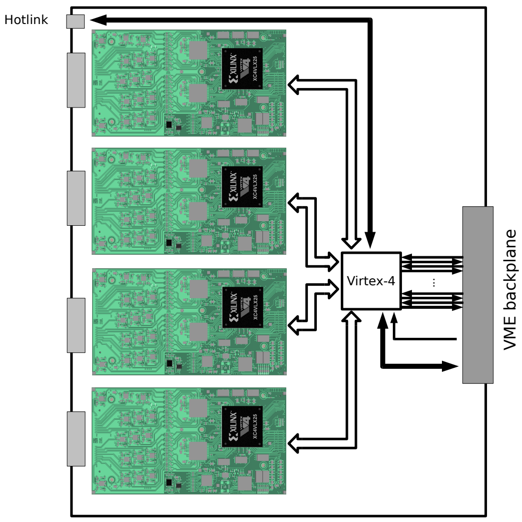

Figure 3: *VME carrier card*

III. The calorimetric trigger

The calorimetric trigger, which is implemented for ECAL2, is tightly integrated into the readout system running mostly on the FPGAs, which handle the readout. Only the dedicated backplane had to be developed.

A. Concept of the digital calorimetric trigger

The concept of the trigger, optimized for a planed Measurement of the Primakoff reaction in Autumn 2009, foresees summing up the energy of all signals, which belong to a certain time slice and occur in a selected part of the calorimeter. Thereby, the part can be chosen freely and can as well cover all calorimeter cells. Most efforts are spend detecting signals on channel level, using a digital constant fraction algorithm after an initial pedestal subtraction, which provides amplitude and timing of detected signals (see Section *B.*). The amplitudes of retrieved signals are normalized for each channel individually using energy calibrations, while the dispersion of signals is corrected using time calibration. This makes fine tuning on the hardware side, i.e. fine adjustment of high voltage bases and cable length, unnecessary, and therefore simplifies hardware adjustment. Both, energy and time calibrations are monitored and updated continuously, using CPU based online data processing (see Section *III.*). The summation of signals is implemented in several stages. 16 channels are summed on the ADC mezzanine card, while the outputs of the four mezzanine cards, which are mounted on one carrier card, are summed on that carrier card. Finally a custom VME back plane combines the data from eight carrier cards. Additionally multiple back planes can be interconnected, thus one or more back planes can provide a global sum. The VME back plane applies two threshold, setting the level on two independent outputs, which give triggers synchronous to the internal 80 MHz clock.

B. The constant fraction discriminator

The main component of this digital trigger is the pulse shape analysis, done on channel level, which consists of a digital implementation of a **C**onstant **F**raction **D**iscriminator (CFD).

Implementation

The digital CFD, calculates for each sample i the difference d_i between the signal s_i and a delayed and amplified version of the signal itself $a \cdot s_{i-n}$ (see Figure 4).

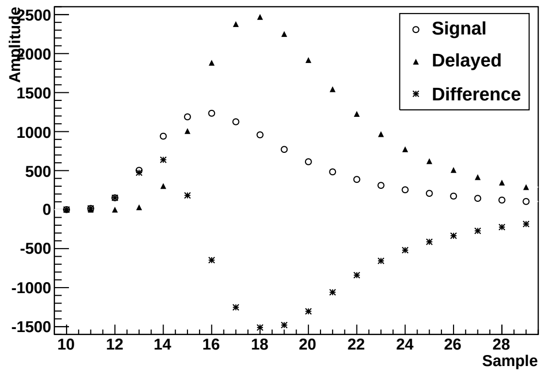

Figure 4: *The digital constant fraction discriminator: Shown is the signal, the delayed and amplified signal and the difference of both. The time of the signal is extracted by linear interpolation to the point, where the difference crosses zero.*

$$d_i = s_i - a \cdot s_{i-n} \quad (1)$$

Thereby the CFD triggers a signal under following conditions:

$$d_{i-1} > 0 \; AND \; d_i <= 0 \; AND \; s_{i+m} > thr, \quad (2)$$

where thr is a programmable threshold, which should be high enough to suppress noise. The time of the signal is made of a coarse time, which is given by the sample index,

$$t_{coarse} = i, \tag{3}$$

and a fine time, which is estimated by linear extrapolation to the zero crossing of d

$$t_{fine} = \frac{d_i}{d_{i-1} - d_i}. \tag{4}$$

Note, that the fine time is negative, thus the time of the signal t_{signal} in units of clock cycles is given by the sum of coarse and fine time.

$$t_{signal} = t_{course} + t_{fine} \tag{5}$$

In order to correct for the difference of signal generation and propagation in the analog part of the readout, a time shift t_{shift}, which is measured and continuously monitored using CPU based online data processing for each channel individually (see Section *C.*), is applied to the signal time.

$$t_{signal,sync} = t_{signal} + t_{shift} \tag{6}$$

The $t_{signal,sync}$ is used to determine the coincidence of signals in different calorimeter channels by filling a normalized amplitude to time bins. The normalized amplitude thereby is given by

$$a_{normalized} = c_{ecalib} \cdot s_{i+m}, \tag{7}$$

where c_{ecalib} is an integer coefficient, which depends on the energy calibration of the calorimeter and is optimized in respect to the desired dynamic range and trigger threshold as well as to the calibration constants of the calorimeter. It is set for each channel individual.

Performance

In order to determine performance of this algorithm, the algorithm was modeled in C, respecting the limitations of the FPGA logic. Using various COMPASS raw data from 2008 and 2009, the time resolution and especially the possible temporal alignment of all calorimeter channels are determined by fitting the temporal residual (Figure 5) of all 3068 channels calorimeter channels with a double Gaussian function and a constant background. Thereby the trigger time, which is used as reference for the signal time, is measured by several TDC. In case of the calorimeter the uncertainty of the trigger time measurement is negligible in comparison to the uncertainty of the signal time. The time resolution is determined to $\sigma_t \approx 0.9\,ns$ by calculating the weighted mean of both Gaussian contributions.

$$\sigma_t = \frac{A_0 \cdot \sigma_{t,0} + A_1 \cdot \sigma_{t,1}}{A_0 + A_1} \approx 0.9\,ns \tag{8}$$

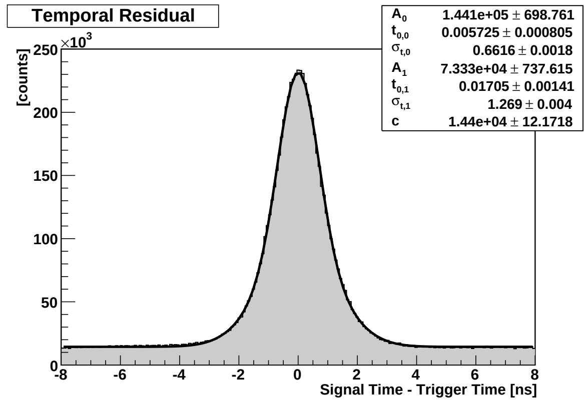

Figure 5: *Temporal residual of all 3068 ECAL2 channels after applying time shifts. Thereby a channel threshold of 10 ADC channels is used. The residual is fitted with a double Gaussian and a constant back ground.*

C. Monitoring

Since the quality of the recorded data depends on the quality of the trigger, there are several mechanisms foreseen to monitor the digital calorimetric trigger.

Monitoring of calibration

Energy and time calibrations, which are loaded into the FPGAs at runtime, are monitored and updated using online data processing. This task is addressed with *Cinderella*, the online filter of the COMPASS experiment, which is part of the readout system and is running on a computer farm on the experimental site ([3]). Thereby monitoring of the energy calibration is done using LED pulses, which are injected into the calorimeter, while time calibrations are extracted comparing signal times, which are extracted by pulse shape analysis, to the measured trigger time.

VME registers

Several VME registers, which are read out and written to a database once per spill, are utilized for online error detection. This registers include pedestals, which are updated upon each spill, and scalers for each individual channel. Comparing this with references provides online information about instabilities of the readout system and failing hardware.

Encode CFD information in the data stream

To provide more information for offline and online analysis the results of the CFD trigger, i.e. signal time and amplitude, are encoded into the data stream, which is written to tape. Comparison of the parameters from the FPGA based CFD with CPU based pulse shape analysis allows to detect misbehavior of the hardware. This task is addressed with the *Cinderella* online filter.

IV. Integration into the trigger system

To form the trigger decision in the FPGAs a time of $500\,ns$ is required. Signal generation, conversion and transport as well as the time of flight, which a particle needs to reach the calorimeter when passing the target, adds another $500\,ns$, which increases the latency of the digital trigger to $\approx 1\,\mu s$. Having a latency of $500\,ns$ for the analogue triggers in COMPASS, those have to be delayed by $0.5\,\mu s$ in addition, which in 2009 is achieved by adding delay cables. However for future prospects a digital solution based on FPGA is planned.

References

[1] COMPASS COLLABORATION, *Nucl. Instr. Meth. A* **577**, 455 (2007).

[2] A. MANN, A Versatile Sampling ADC System for On-Detector Applications and the AdvancedTCA Crate Standard, 15th IEEE-NPSS Real-Time Conference, 2007.

[3] T. NAGEL, Cinderella: an Online Filter for the COMPASS Experiment, diploma thesis, E18 TU Munich, 2005.