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Digitization and real-time analysis of detector signals with GANDALF

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The Recoil-Proton Detector at COMPASS is built to identify protons of DVCS-processes and to trigger on the recoil particle. A front-end module was designed that allows both precise digitization of photomultiplier signals and real-time data-processing. With GANDALF, signals of 16 channels are converted by 12-bit 500 MHz ADCs, zero-time approximation is accomplished by DSP-algorithms in a Virtex-5 FPGA. Measurements yield resolutions below 50 ps for amplitudes up to 3.8% of the full dynamic range. In addition, GANDALF can be used as 128 channel TDC-system with a resolution of 150 ps.

Summary

Generalized Parton Distributions (GPD) are a useful tool to determine the total angular momentum of quarks and gluons. GPDs can be measured with Deep-Virtual-Compton-Scattering (DVCS), in which the incoming muon scatters off a target proton.

For the DVCS program [1] at COMPASS [2], a Recoil-Proton-Detector (RPD) is installed around the target, which allows proton detection by measuring the time-of-flight and the energy loss of charged particles in the detector. Expected rates in the order of a few MHz impose high demands not only on the digitization units but also on the trigger generating processes. GANDALF was built to fulfill these requirements and to serve as state-of-the-art TDC, scaler and logic system. Versatility is obtained by a modular design, in which all data is received from two exchangeable mezzanine cards.
As a transient recorder GANDALF hosts Analog Mezzanine Cards that combine eight analog inputs and the analog-to-digital conversion. Simulations have shown, that RPD read-out requires an effective resolution of larger than 10 ENOB. In GANDALF, signals are processed by 12-bit ADCs with a sampling rate of 500 MHz. The resolution was measured with signal-to-noise ratios along the full signal path to be better than 10 ENOB.

Real-time data-processing is made possible with Virtex-5 FPGA technology: Time information of a single pulse is calculated by DSP-optimized algorithms based on digital constant fraction discrimination. Combinations of delay and fraction factors were studied in simulations and zero-time approximation is carried out in real-time with minimum latency in the FPGA. As a result, the time resolution was found to be below 50 ps for amplitudes up to 3.8% of the full dynamic range. Higher precision can be obtained with the time-interleaved mode: Every input signal is sampled by two ADCs with a constant phase-shift between the corresponding clocks. The reduction of the input channels by a factor of two leads to an effective sampling frequency of 1 GHz.
Read-out is accomplished either by Ethernet, USB2.0, VME64x or the 160 MB/s S-Link [3] interface. A proton trigger can be transmitted by the VXS interface on the backplane to a dedicated trigger switch with 18 GB/s in total.

With Digital Buffer Cards, signals are routed directly to the FPGA: Each card connects 64 LVDS input channels with the DSP-Hardware. This allows GANDALF to be used as a 128 channel TDC- or scaler-system as well as mean-timer or veto-matrix. Actual research is focused on TDC-designs in the FPGA with resolutions better than 150 ps and the development of a trigger switch. This work is supported by BMBF.

[1] COMPASS Collaboration; CERN-SPSC-2009-003 SPSC-I-238
[2] COMPASS Collaboration; The COMPASS experiment at CERN; Nucl. Instrum. Methods Phys. Res., A 577 , 3 (2007) 455-518
[3] Owen Boyle, Robert McLaren, Erik van der Bij; The S-Link Interface Specification; http://www.cern.ch/HSI/s-link/

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