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Development of a digital trigger system to identify recoil protons at COMPASS-II

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The GANDALF framework has been developed to deliver a high precision, high performance detector readout and trigger system for particle-physics-experiments such as the COMPASS-II experiment at CERN. Combining the high performance pulse digitization and feature extraction capabilities of twelve GANDALF modules, each comprising a Virtex-5 SX95T, with the strong computation power of a Virtex-6 SX315T FGPA operated on the TIGER module, we present a digital trigger system for a recoil proton detector.

Summary

For the deep-virtual-compton-scattering (DVCS) program at the COMPASS-II experiment the recoil proton detector CAMERA was built. CAMERA is able to perform time-of-flight and energy deposit measurements of the recoil protons in the scattering. Due to the fast risetime (below 3ns) and the high pile-up-rate in this detector region, the analog signals of the detector have to be digitized with high resolution prior of discrimination. In order to deliver a comprehensive readout- and trigger-system, the GANDALF-Framework was designed.

In this application, the GANDALF modules are configured as analog-to-digital converters with a sampling of 1GSps and 12bit amplitude resolution. Through the implementation of a pulse-feature-extraction-algorithm in the Virtex-5 FPGA of the GANDALF module we are able to perform a streaming, dead time free feature extraction with high timing resolution (<10ps). The information is transferred continuously with low latency (<100ns) to the Trigger module (TIGER) for 'proton trigger' generation. Therefore, a high-speed link with 1 GB/s per module using the VXS backplane has been developed.
The TIGER module is placed in the center of the VXS crate where the pulse features, computed in real-time, of all 96 readout channels are combined to form the trigger decision. This allows the reconstruction of the proton track and its energy deposit on-the-fly. With the pulse feature information, the trigger is able to select specific proton signatures that are well known from Monte-Carlo simulations, such as the dependency of energy deposit on proton velocity in real-time.

The main challenge when implementing the digital trigger was to handle the vast amount of data coming from the GANDALF modules. With an expected hit rate of about 10 MHz per detector channel the design has to handle a total 12 GB data per second. This data, consisting of timestamp and amplitude information, has to be organized and coincidences between different detector channels have to be formed in order to reconstruct the proton tracks. The coincidences are computed digitally by comparing the timestamps of the hits. After the reconstruction of the proton tracks, look-up tables can be used to perform sophisticated cuts that take the whole event topology into account.
For the integration into the first level trigger of the experiment, the TIGER trigger decision has to be computed within less than 1μs. Furthermore, the emitted trigger signal has to have a fixed latency with respect to the beam particle. However, achieving a fixed latency within digital computations is not as natural as it is for analog trigger systems. Thus, a special technique to release the trigger was implemented. It allows to set the trigger latency to a specific value that correlates to the physics event without the need of changing cable lengths.

The trigger system was setup and commissioned successfully for the DVCS pilot run in 2012. It was mainly used for the calibration of CAMERA and in tagging mode to identify proton tracks online for DVCS reactions.

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