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A Long Buffer Readout System for Large-Area Gamma-Ray Facilities

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One of the constraints for next generation large-area gamma-ray facilities with a large number of readout channels is the cost of the complex data acquisition (DAQ) system. We suggest here a novel approach - the Long Buffer ReadOut System (LiBROS).
LiBROS comprises both the trigger, based on a Field-Programmable-Gate-Array (FPGA), and the readout system based on Flash Analog-To-Digital Converters (FADCs). The analog signal for each channel is split into two branches: trigger branch and data branch. The trigger branch is fed to discriminators which produce time-over-threshold (TOT) logic signals. We suggest to digitize these signals with only 1-bit resolution but high rate of 1 GHz, directly inside the FPGA, exploiting the SerializerDeserializer (SerDes) feature. In this manner, start and stop time of the TOT signal are tagged, determining the signal arrival time with a precision of better than 1 ns. With precision time reconstruction by the trigger system, the data branch thus can have a limited bandwidth and, therefore, a reduced FADC sampling rate. This minimized FADC datastream can be directly piped into the FPGA memory in serial mode, using only one FPGA input pin per data channel. Each FPGA chip can thus serve a large number of readout channels, with a cost reduction of at least 4 compared to DAQ approaches, as currently used in Imaging Atmospheric Cherenkov Telescopes (IACTs).
Moreover, due to the large FPGA memory and suppressed data volumes, the suggested DAQ approach will feature an extremely long data buffer depth of >50 μs. This allows for a simple and powerful central trigger system architecture, for arrays covering more than several km^2. The high integration, low cost and simplicity of the concept offers it for any air-Cherenkov facility with a large number of readout channels.

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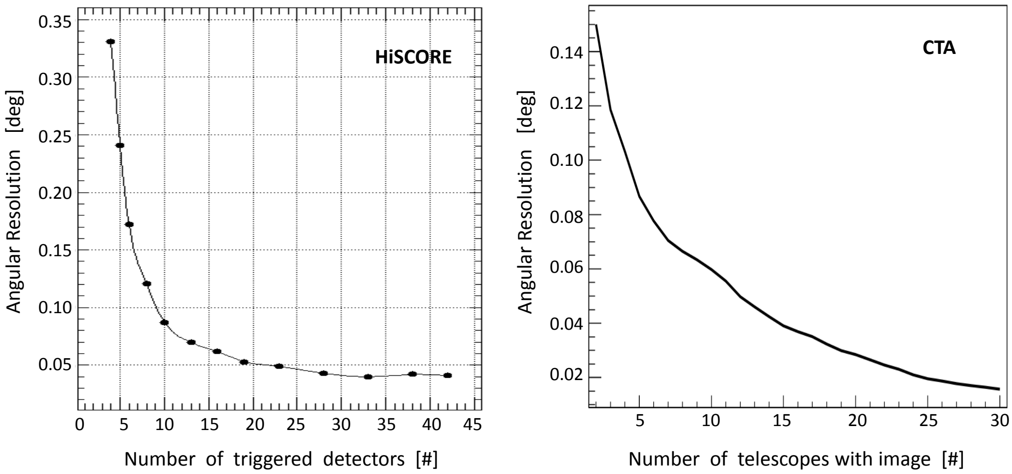

Figure 1: *Left:* Angular resolution (68% containment) of a HiSCORE-like array for gamma-rays versus the number of triggered detectors. *Right:* Dependence of the CTA angular resolution (68% containment) for gamma-rays on the number of telescopes with images.

1. Introduction

To reduce the costs of large-area instruments and to provide a wide field of view (FoV), the recently proposed concepts for air-Cherenkov facilities like HiSCORE [4] follow the design of the AIROBICC array, composed of simple non-imaging optical detectors: a large photomultiplier (PMT) and a light guide with angular acceptance of $\sim 30^{\circ}$ (half-cone angle). This low cost design allows to build an array of extremely large area, sensitive in the PeV gamma-ray energy range. However, the trigger threshold for HiSCORE optical detectors is rather high due to the large acceptance for the diffuse night sky background (NSB) light. The angular resolution of the air-Cherenkov instrument crucially depends on the number of triggered detectors, or, in case of IACTs, on the number of telescopes with good images (see Fig.1). Thus, reducing the trigger threshold for the optical detectors is of great importance.

The desired wide FoV of the instrument implies angular acceptance of NSB light from any direction within the FoV. On the other hand, the angular spread of Cherenkov photons from a single EAS, hitting the detector is $\leq 5^{\circ}$. Thus, to reduce the threshold of the instrument, we introduce the concept of *minimal imaging* (see [14], these proceedings): focus the shower light by means of a spherical Fresnel lens into a small area in the focal plane - the shower "angular" image. The term "minimal" refers to the fact that the shower image is affected by rather large spherical aberrations of the Fresnel lens and does not reproduce the initial angular distribution of the shower light precisely. Nevertheless, spherical aberrations are nearly constant over the wide FoV. This keeps the image compact. The diffused light from NSB in turn can not be concentrated and illuminates the focal plane uniformly. Restricting the signal region only to the small area of the shower image, a large fraction of the NSB light is discarded and the signal to noise ratio is greatly improved (i.e. the threshold reduced).

For multichannel detectors the cost of the data acquisition system (DAQ) can put severe con-

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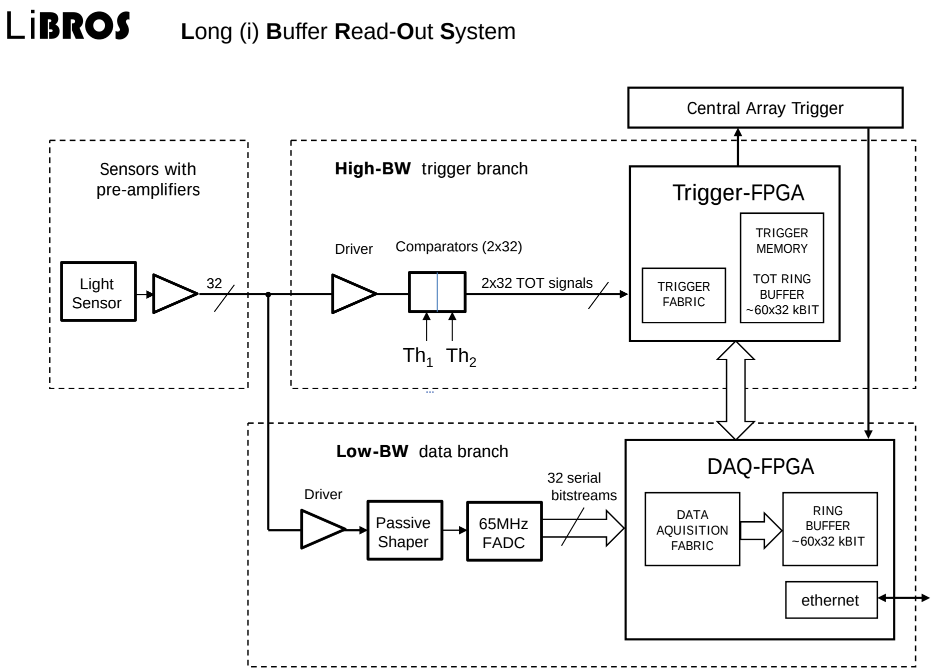

Figure 2: Scheme of the LiBROS DAQ-architecture with it's key features (for 32 channels in a detector station): High-BW trigger branch with TOT signal arrival time measurement (to better than 1 ns), and the Low-BW data branch with serial FADC readout. The DAQ-FPGA and the Trigger-FPGA are only conceptual architecture blocks and can be contained within one FPGA chip. In addition, the central array trigger (shown in upper right box) searches for trigger coincidences in several stations; it operates on the ns-precision digital trigger time stamps sent from each LiBROS station, and reports array-trigger decisions back to the station for data buffer readout.

straints on the feasibility of the design. We propose a new DAQ architecture that combines severe cost reduction with significant performance improvements: the **L**ong (i) **B**uffer **R**ead**O**ut **S**ystem (LiBROS).

2. LiBROS - a dead-time free readout and trigger system

The main feature of LiBROS is the intelligent trigger system, based on the Trigger-FPGA, that determines the signal arrival times with a precision of better than 1 ns. The concept of the DAQ-architecture is shown on Figure 2. The fast SiPM signal with full-width-half-maximium (FWHM) of $\sim$3 ns is split into two branches: the high-bandwidth branch and the low bandwidth branch, denoted as High-BW and Low-BW.

The High-BW branch is assigned to the trigger system. This branch is fed to fast comparators and the resulting time-over threshold signal (TOT) is directed to the Trigger-FPGA. For the Trigger-FPGA chip the cost-effective FPGA from Xilinx Spartan 6 family can be used. With the serialization feature for input signals (SerDes) [6], it is possible to digitize the input signal with

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high-frequency (∼1 GHz). This allows to tag the start and the stop of the TOT signal in steps of 1 ns directly in the Trigger-FPGA and to reconstruct the arrival time of the initial SiPM signal with a precision of ≤1 ns. To increase the signal timing precision we foresee as an option two comparators with different thresholds (denoted in Fig.2 as "Th_1", "Th_2") per SiPM signal and, correspondingly, two TOT signals are used to determine the signal arrival time. If the arrival time of the fast SiPM signal is reconstructed by the trigger system, a precise signal waveform recording by the Flash Analog-to-Digital-Converter (FADC) is not necessary and the FADC sampling rate can be reduced, enabling the readout system to possess a relatively low bandwidth.

The Low-BW branch is assigned to the readout system. To match the slow sampling rate of the FADC, an additional shaping of the fast SiPM signal is performed before supplying the signal to the FADC (see the "Passive shaper" block on Fig.2). Modern FADC with 65 MHz sampling rate, fully adequate for the signal duration, offer even serial readout: the serial bitstream of digital data is directly transferred to the readout system FPGA (DAQ-FPGA) and continuously stored in the DAQ-FPGA memory, functioning as a *long ring buffer*. Such an elegant solution with serial FADC output protocol allows to occupy only one FPGA pin per FADC data stream, greatly reducing the number of components and simplifying the design. In this approach, a readout of 32 channels per FPGA chip is achieved.

Moreover, the relatively large DAQ-FPGA memory and moderate FADC data rates provide the possibility for extremely long data buffering depth of >50 μs, compared to ∼4 μs DAQ buffer length of current IACTs. This allows to apply a global central trigger logic for very large arrays spreading over a many km^2.

The proposed LiBROS DAQ system is very cost effective, given the excellent timing and amplitude resolution. Table 1 gives the current prices (in Euro) for the LiBROS electronic components (DigiKey database). The total cost per channel amounts to 15 €only.

Component	Price	Components/channel
Pre-Amplifier (differential)	€3.34	1
Driver (OpAmp)	€1.46	2
Comparator (4-channel, PECL)	€5.18	1/2
FADC, 65MHz, 8-bit, (8-channel)	€26.3	1/8
Xilinx FPGA	€32.9	1/32
Other costs (PCB, etc..)	€3	1
Total (sum per channel):	∼€15	

Table 1: LiBROS components prices from DigiKey (for ∼1000 pieces) and the total cost per acquisition channel (PECL and PCB denote positive emitter-coupled logic and printed circuit board, correspondingly).

3. Central array trigger for a large-area facility

For optimal pointing resolution of non-imaging air-Cherenkov arrays (like HiSCORE [4] or ASGaRD [14]), light arrival times at all stations need to be measured with nsec-precision relative to each other. We suggest to use the CERN-developed White Rabbit time distribution system, which provides sub-nanosecond accuracy of local clocks in all detector stations, with intrinsic self-calibration. White Rabbit allows to build a complex central trigger system, that operates on the

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digital trigger times send over the WhiteRabbit ethernet network [15]. Photon arrival times at all stations are time-stamped with nsec-precision. To reduce the rate of accidental events, spuriously triggered by NSB light, the trigger signals from all stations will be analyzed by the coincidence logic of the central trigger. This allows to set minimal local station trigger thresholds, since dead-time effects are negligible for the novel LiBROS readout.

The suggested WhiteRabbit-based approach is ready to be used. It has been verified in long-term experience with the HiSCORE prototype arrays [15]. It will be used also in the Cherenkov Telescope Array [16].

4. Summary

We propose a novel DAQ system for large-area gamma-ray facilities, characterized by very low cost, simplicity, high intergration and scalability - with nansosecond time resolution over many km2, deadtime-free operation, and a straight-forward digital central array triggering concept. The proposed DAQ system can be used in air-Cherenkov experiments with a large number of read-out channels (imaging or non-imaging), or in other large-scale astrophysics facilities with similar requirements.

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