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SciFi Front-End Electronics: Calibration and Results on detector performance

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The LHCb Experiment is commissioning its first upgrade to cope with increased luminosities of LHC Run3, being able to improve on many world-best physics measurements. A new tracker based on scintillating fibers (SciFi) replaced Outer and Inner Trackers delivering an improved spatial resolution for the new LHCb trigger-less era, with a readout capable of reading ˜524k channels at 40MHz. Fully automated calibration of SciFi Front-End Electronics is based on dedicated software tools and operational procedures, validated during SciFi commissioning. This oral presentation describes the SciFi electronics design, implementation, and calibration and presents results showing the detector's performance after commissioning.

Summary (500 words)

The LHCb tracker for Run3 covers an area of 340 m2 using a novel technology, with more than 10,000 km of a 250 µm diameter blue-emitting scintillating fiber. This Scintillating Fiber Tracker (SciFi) achieves a spatial resolution better than 80 µm, hit efficiency better than 99%, and can handle higher luminosities thanks to its higher granularity and a trigger-less 40 MHz Read-Out. These substantial improvements posed new challenges to the on-detector electronics, which has to process signals from 4096 linear arrays of 128-channel Silicon Photomultipliers (SiPM) each, placed at the fiber ends and cooled to -40 °C. The low photo-electron statistics required a very sensitive digitizer, the high channel density (4 channels per mm) demanded careful PCB design, and possibly most challenging, the sheer data volume required high-speed data transmission and ultimately needed to implement an advanced zero-suppression clustering mechanism in the Front-End Electronics.
A custom-made ASIC (PACIFIC) processes SiPM analog signals, providing signal shaping, charge integration over a time window, and discrimination. The need to reduce the data volume shaped the electronics design at every step and constrained the digitized output of each 250 µm SiPM channel, which consists of only 2 bits encoding the result of signal discrimination over three programmable thresholds. Even so, the throughput of each 2048-channel SciFi Read-Out Box at 40 MHz would be an intractable 164 Gbps. Therefore, significant data reduction was necessary before channeling data to the 4.48 Gbps GBTx serializers. Hit clustering provides such a data reduction, but its complexity, combined with the relatively low radiation doses expected, resulted in the choice to perform digital signal processing and fast control handling in radiation-tolerant flash-based Microsemi Igloo2 FPGAs. A research program validated the usage of such FPGA in our radiation environment, and since last year, SciFi routinely operates for data taking with LHC beam using these devices. PACIFIC ASIC, FPGAs, GBT chipset, and specially designed DC-DC converters have been packed into 256 units called Read-Out Boxes, each of which reading 2048 SiPM channels with a zero suppressed data output rate of up to 71 Gbits/sec, resulting in a total bandwidth of over 18 Tbits/sec.
This complex design requires several re-programmable parameters to accommodate changes in the operational conditions, like fiber signal deterioration and increasing noise on SiPMs. The continuous recalibration of parameters such as clock delays, temperature-dependent bias, threshold settings, and others is crucial to retain the detector's best performance during its lifetime. A wealth of databases and software tools are required to fully automate the process of taking data, analyzing them to determine the best operational settings, and transferring these to the detector electronics configuration. Developing these tools has been a monumental enterprise starting from the SciFi assembly and pre-commissioning, and automatic calibration procedures have been instrumental for commissioning after installation in 2022, ensuring that SciFi could take LHC collision

data and perform as expected.
This oral presentation will give an overview of SciFi electronics design and implementation, tools and methods for electronics calibration, and show results on detector performance.

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