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Real time tracker based upon local hit correlation circuit for silicon strip sensors

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ABSTRACT

For the planned high luminosity upgrade of the Large Hadron Collider (LHC), a significant performance improvement of the detectors is required, including new tracker and trigger systems that makes use of charged track information early on. In this note we explore the principle of real time track reconstruction integrated in the readout electronics. A prototype was built using the silicon strip sensor for the ATLAS phase-II upgrade. The real time tracker is not the baseline for ATLAS but is nevertheless of interest, as the upgraded trigger design has not yet been finalized. For this, a new readout scheme in parallel with conventional readout, called the Fast Cluster Finder (FCF), was included in the latest prototype of the ATLAS strip detector readout chip (ABC130). The FCF is capable of finding hits within 6 ns and transmitting the found hit information synchronously every 25 ns. Using the FCF together with external correlation logic makes it possible to look for pairs of hits consistent with tracks from the interaction point above a transverse momentum threshold. A correlator logic finds correlations between two closely spaced parallel sensors, a “doublet”, and can generate information used as input to a lowest level trigger decision. Such a correlator logic was developed as part of a demonstrator and was successfully tested in an electron beam. The results of this test beam experiment proved the concept of the real time track vector processor with FCF.

1. Introduction

An upgrade of the Large Hadron Collider (LHC), the High Luminosity LHC (HL-LHC), is under way and it is expected to be finished by mid 2020s. This upgrade is performed in multiple phases. The Phase-II upgrade for ATLAS, a general purpose detector, is designed to match the requirements of the increased luminosity in the (HL-LHC) [1]. The instantaneous luminosity is assumed to increase up to $7 \times 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. This requires a performance improvement in the trigger and data acquisition system (DAQ) to guarantee the same physics performance of the detector during operation.

Currently, ATLAS uses a Level 1 (L1) trigger with 100 kHz maximum rate to read the full data from the entire detector front end electronics. The planned baseline for the Phase-II upgrade is to insert a 1 MHz Level 0 (L0) trigger to retrieve partial tracker information, and then incorporate this information in a Level 1 (L1) decision to read the full experiment, with an average Level 1 (L1) rate of up to 400 kHz.

An alternative to relying on a (L0) trigger would be to retrieve reduced information from the tracker at the full 40 MHz bunch crossing rate, as is the case for the calorimeter and muon systems. The correlator scheme described in this note addresses this alternative by reducing the tracker data volume in situ and in real time. Data reduction is needed because full triggerless readout of all tracker data from every collision is not considered technically feasible with low mass and low power. The correlator approach

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0168-9002/

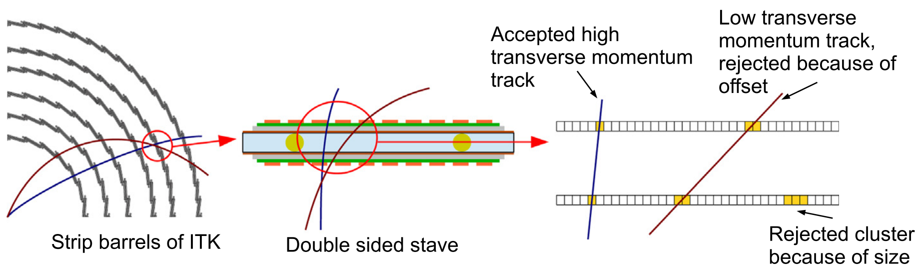

Fig. 1. On the left is a sketch of the inner tracker strips barrel. Each barrel is built out of staves, which are actively cooled support structures. Strip sensors are mounted on both sides of the stave. The curvature of particle tracks depends on the transverse momentum due to the applied magnetic field in the inner tracker. In the middle is a sketch of a stave cross-section with sensors on both sides. On the right is a sketch representing hits from particles with some possible reconstructed tracks. The figures are not to scale and only represent the principle of the correlator.

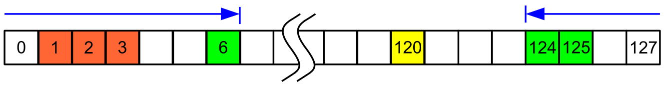

Fig. 2. Sketch of the FCF search procedure for one bank, where each ABC130 has two of these blocks. Each square represents a strip and all the filled squares indicate a detected hit. The number in the squares is the strip address used by the ABC130. Strips 1–3 form a 3-hit cluster, which is ignored. A 1-hit cluster at address 6 and a 2-hit cluster is observed at address 124–125. These hits are valid and detected by the FCF. The hit at address 120 is also a valid 1-hit cluster but is ignored, because already two other clusters were found. The arrows indicate the direction of the cluster search.

provides a data reduction factor of 20–40 [2], comparable to the baseline of reading data from just 1 out of 40 collisions with an externally supplied 1 MHz L0.

The Compact Muon Solenoid (CMS) experiment proposes to use hit correlations from two closely spaced layers to reduce the tracker information read from each collision [3]. Their proposed correlation hardware is different from that presented here.

The idea of the real time tracker is to use the information from two adjacent detector layers. Hit information of detected particles is directly analyzed in real time in situ every 25 ns, corresponding to the time between two collisions. This is done with a dedicated correlation logic, called "correlator", implemented on the module. A module is an assembly of silicon sensors and readout electronics. The correlator reconstructs track vectors across two layers and filters them by the transverse incident angle, using the cluster size and azimuthal offset between the clusters on the two layers. The incident angle is correlated with the transverse momentum for particles coming from the interaction point.[1] Secondary particles from interactions in the detector material can have any angle–momentum correlation and constitute a background. A sketch of the real time tracker concept is shown in Fig. 1. See also reference [4].[2]

The newest version of the front end application specific integrated circuit (ASIC) for reading the strip sensor is the ATLAS Binary Chip 130 (ABC130). This chip includes a logic block called the Fast Cluster Finder (FCF), to find clusters within 6 ns and read out their digital positions once every 25 ns clock period. A cluster is defined here as one or two adjacent hit strips. Larger clusters with 3 or more hit strips are ignored, as these are inconsistent with the small transverse incidence angles of interest, as was shown in previous studies [5]. An exception are clusters that are broadened by delta rays, which we therefore will reject, incurring a ~2% efficiency penalty.

The cluster information is serially transmitted at a maximal rate of 640 Mbps per line. Two lines are used per chip, so each chip can transmit the clusters at up to 1.28 Gbps. This fast readout provides the complete cluster information every 25 ns. An external correlator ASIC processes the cluster information to find correlations. The correlator filters the correlations depending on the incident angle. Only hits passing the filter are sent off-detector for use by the trigger system, without any level 0 trigger stage. Reference [6] discusses the FCF design while reference [7] describes the electronics for the ATLAS Phase-II upgrade.

The strip sensors for the upgrade will be either for the barrel part or the endcap. There are different geometries for the two parts. The modules used here are intended for the barrels. They have a pitch of 74.5 μm and are 310 μm thick. There are two kinds of sensors: short strip sensors with a strip length of 2.5 cm and four rows, and two row sensors with 5 cm long strips. Each row has 1280 strips [8]. The strip sensors will be placed on different barrels with radii between 0.4 m and 1 m [1]. Each barrel is designed to be built with staves. A stave is a carbon fiber composite structure with active cooling. Silicon strip modules are mounted on both sides and are separated by ~5 mm [2]. With these radii, strip pitch and an ~5 mm spacing within the doublet, the targeted P_T range is from a few GeV/c to about 20 GeV/c.

In this work a proof of principle prototype correlator was developed with an FPGA [9] using two rows of a short strip sensor prototype. The system contains four different printed circuit boards (PCB): (1) FPGA board, (2) interface board (IB), (3) support board and (4) hybrid board, which are described in Section 4. The correlator can read the FCF lines from two hybrid boards with 10 ABC130 and find correlations between two rows of 1280 strips each. A doublet with two sensor modules was constructed to demonstrate the principle. The development of the demonstrator for the real time tracker was presented in reference [10], and reference [11] describes the final design used in the test beam experiment.

2. ABC130 with fast cluster finder

The ABC130 is the newest generation of the ATLAS Binary Chip. It implements the front end electronics (FEE) chain for the ATLAS silicon strip tracker in the Phase-II upgrade. The ABC130 can read 256 channels, which are arranged in two rows and implemented as two separate 128-channel blocks, one for each row. Each channel has an individual FEE chain with a one bit analog to digital converter (ADC). The threshold of the ADC can be set globally for the chip. It is further possible to adjust the threshold of each channel to compensate small differences between the channels. An additional mask register allows masking bad channels right after the ADC.

There are two FCF logic blocks integrated in the ABC130, each working on one row of 128 channels and independent of the conventional readout. The FCF finds clusters of one or two hits as

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector, and the z-axis along the beam line. The x-axis points from the (IP) to the center of the (LHC) ring, and the y-axis points upwards. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam line. Observables labelled "transverse" are projected into the x–y plane.

[2] The term "self-seeded trigger" is used in the references instead of real time tracker.