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Finnish CMS-TOB cosmic rack

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Abstract

We present a cosmic rack, the FinnCRack. This device is a silicon strip detector-based telescope that measures tracks of cosmic particles. The FinnCRack is constructed using components of the Tracker Outer Barrel (TOB) of the CMS experiment at the CERN LHC. The device is part of the TOB integration and verification effort together with its sister telescope, the CERN CRack. Both CRacks mimick a six degree slice of the TOB barrel structure. The FinnCRack is intended to (a) serve as a platform for TOB software development, both analysis and online software such as run control; (b) be used for noise and cluster shape studies; (c) act as a reference tracker in detector studies; and (d) provide a testbed for track-based alignment testing and development. The construction and setup of the FinnCRack have been documented in detail—the entire chain from connecting cables to physics data analysis—and the operation guide was tested in practice. Both these actions serve the purpose of training and attracting future HEP students. We also showed that we were able to measure cosmic muon tracks.

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1. Introduction

The Compact Muon Solenoid (CMS) is one of the four Large Hadron Collider (LHC) experiments and is presently being constructed at CERN. Before the CMS goes operational, several types of large scale tests are needed in order to minimise the probability that unwanted features remain in the apparatus. Large test setups are also needed for testing CMS-related software.

Tracker Outer Barrel (TOB) [1] is the outer part of the CMS central tracking detector [2]. During LHC uptime it is impossible to obtain physical access to the CMS tracker, and even during maintenance breaks it will be both time-consuming and complicated. Easily accessible setups are thus needed to emulate the TOB.

Two cosmic racks, the Finnish Cosmic Rack (FinnCRack) and the CERN Cosmic Rack, have been constructed for these purposes (Fig. 1). The CRacks will be used to add knowledge about the properties and behaviour, such as crosstalk, of the TOB hardware. Having more than one setup adds redundancy and reduces the possibility that any anomaly seen is an artefact.

A cosmic rack based on CMS hardware and software is a useful device for testing questions related to the initial CMS run. A CRack allows gaining experience needed to operate CMS hardware and software. This kind of experience and hand-on practising can accelerate the learning of CMS operation, and thus leads to a more efficient pilot run and consequently to earlier and more accurate physics results. The cosmic rack serves especially well as a testbed for alignment studies [3]. Alignment has the most important effect in early CMS operation. It is also needed later due to time-dependent effects and maintenance breaks. Alignment issues can be studied on a small scale with test beam setups [4], but cosmic setups are preferred since they provide tracks with wide angular and positional spread [5].

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Fig. 1. The FinnCRack apparatus.

The method used in the alignment studies [3] improves the quality of the track reconstruction, both by lowering the χ^2 and by increasing the number of reconstructed tracks. The cosmic setup is thus used to validate the alignment software, as well as the rest of the data acquisition (DAQ) and analysis software. The possibility to use the cosmic rack for validating measurements of the TOB rod precision points is also under study.

In future high-energy physics (HEP) experiments the sensor radiation hardness will be a major limitation for silicon sensor use. In the proposed LHC upgrade the fluence of fast hadrons will reach $10^{16}\,cm^{-2}$ with the proposed luminosity of $10^{35}\,cm^{-2}\,s^{-1}$ [6]. This is beyond the operational limits of present silicon detectors and thus novel, more radiation tolerant sensors are needed. Research activity is ongoing within the CERN RD39 and RD50 collaborations aiming to develop semiconductor sensors matching the radiation hardness requirements [7,8]. Several detector materials are proposed [7,9–13], e.g. high resistivity magnetic Czochralski silicon (MCz) [9]. None of these recently developed technologies can be adopted to a large scale HEP experiment prior to systematic testing. The FinnCRack, requiring no accelerator beam time, can therefore be used as an efficient R&D tool for sensor development for future HEP experiments and their upgrades. The prototype sensors can be customised to fit directly into the FinnCRack setup.

Development of hardware-oriented software, e.g. the Run Control [14], requires appropriate hardware. The FinnCRack setup acts as an independent, operational test setup outside CERN. All parts of the online software can be used with it.

2. The FinnCRack

The readout hardware comprises e.g. silicon strip detectors [15]. Two detectors are bonded to each other, and each detector pair is bonded to a hybrid containing readout electronics via a pitch adaptor. Six or 12 such modules together with supporting electronics [16] and mechanical support structures form a superstructure; a rod [1]. The rods are arranged in layers [17]. There can be up to two rods in a layer, and up to 10 layers totally. The relative position of the rods in a layer, i.e. the extent of the overlap region as well as the rotation angle, is similar to those of the TOB.

The LHC is a synchronous device where primary events occur at known instants in time. The front-end chip [18] that reads the signal from the strip detector is designed to exclude signals that occur at unwanted points in time [18]. The time of arrival of cosmic particles is, however, not known in advance; therefore the trigger electronics must establish the timing of the primary event in addition to generating a decision to trigger. One can either associate a muon passage with the closest clock pulse of the readout or use time-gating to discard particles that are temporally separated from a clock-cycle. The latter approach reduces the trigger rate. The former results in a large sampling time jitter.

The FinnCRack trigger is produced using two scintillators and four photomultiplier tubes; a coincidence of four pulses is required for a trigger. The scintillators are 1400 mm long, which increases trigger jitter since the time of flight for light inside the scintillating material depends on the particle hit position.

The analog trigger pulse is fed to a Trigger and Sequencer (TSC) card [19]. The TSC performs time-gating. It forwards the trigger information to the other components of the readout system. The TSC acts as a simulator of the CMS trigger to the Data Acquisition System (DAS). The trigger is received from the TSC by the Front End Controller (FEC). The FEC distributes the trigger signal to the front end electronics [20]. In addition, the FEC sends calibration data [16] to the front end. The measurement data are transmitted from the front end to back end in analog form, and is received by the Front End Driver (FED). The FED digitises, and optionally performs cluster finding [21] on the received data.

The online software used in the FinnCRack is the *Release32*, which is a commonly used installation available at the distributed file system at CERN [22]. The *Release32* is a stable snapshot of the mainstream CMS tracker data acquisition software. Using the official CMS software allows the FinnCRack to provide feedback for CMS software development. Initially the CERN CRack was the first setup to utilise the full official software chain [16,22,23].

The online software consists of several applications, which can be run on multiple hosts. All applications of the *Release32* are configured and operated using the standard XDAQ [24] interface. The DAS stores the measurement data on a hard disk in ROOT [25] format. In a medium-scale setup such as the FinnCRack, all measured information associated with all accepted triggers can be stored. In the future, filtering is needed due to the large amount of data. The DAS also collects statistics of the measured data. The set of data available depends on the type of run. The DAS contains a tool for visualising the incoming data [22].

The Object-oriented Reconstruction for CMS Analysis (ORCA) [23] is a data analysis framework used to reconstruct tracks from measured data. The ORCA

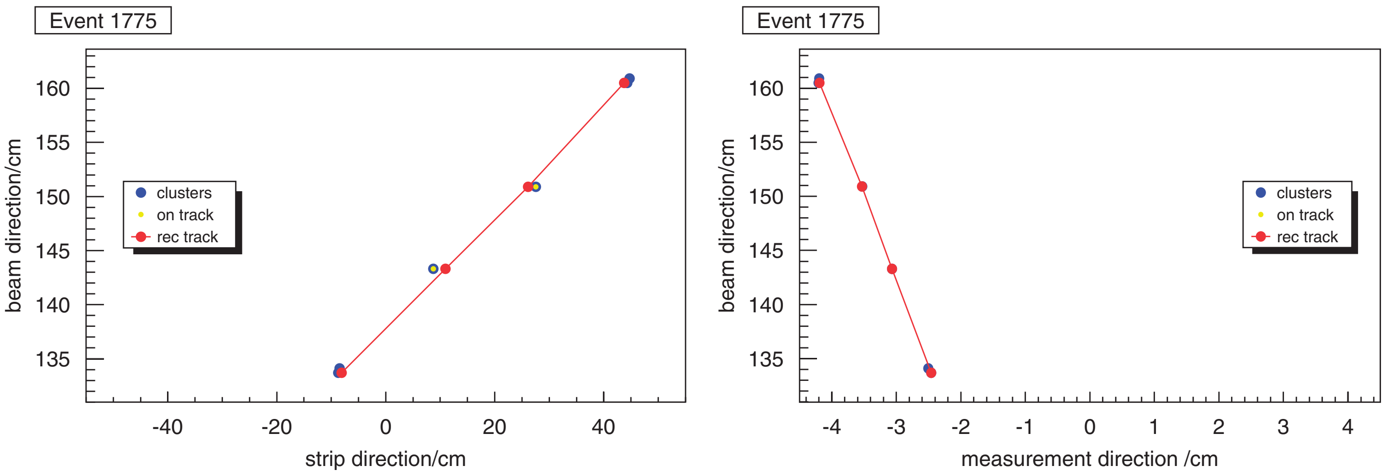

Fig. 2. Two projections of an unaligned example track from Ref. [27].

application used to analyse FinnCRack data stores its results in PAW [26] Ntuple format, from which it can be converted into ROOT [25] file format. Even though ORCA is a flexible analysis tool, the last analysis steps are often done with ROOT. The reason is that ORCA reconstruction is heavy, both in CPU and wallclock time. Separating reconstruction and analysis speeds up the analysis because re-execution of reconstruction can be avoided while working with analysis. The ROOT software also contains a convenient data visualisation package.

3. Results

We have built the FinnCRack setup and shown that it can measure cosmic muon tracks (Fig. 2). The setup fulfills the alignment and software development related tasks described in the introduction. The data quality is sufficient for the detector research and development task.

The setup was tested during the summer of 2005. The test showed that with the present level of documentation an undergraduate student was able to set up the acquisition system without prior knowledge of HEP. In the summer 2005 data set [27] the average amount of tracks per event was low. This was due to the trigger geometry, the low amount of rods and dead regions in the available rods. The existence of genuine tracks has been established by obtaining the amount of tracks in those events that qualify as a track candidate. A track candidate is an event containing at least one hit on at least four layers. In addition, at least two of the hits must be 3D hits [28]. In an example run with 100,000 events, 2000 were used for calibration. Of the remaining 98,000 events 94,900 did not pass the track candidate criteria and of the remaining 3100 events 2107 did not contain a track and 993 did.

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