The CMS Beam Halo Monitor Electronics

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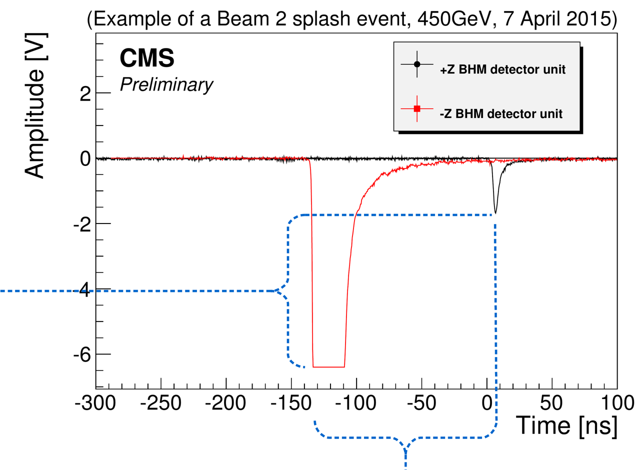
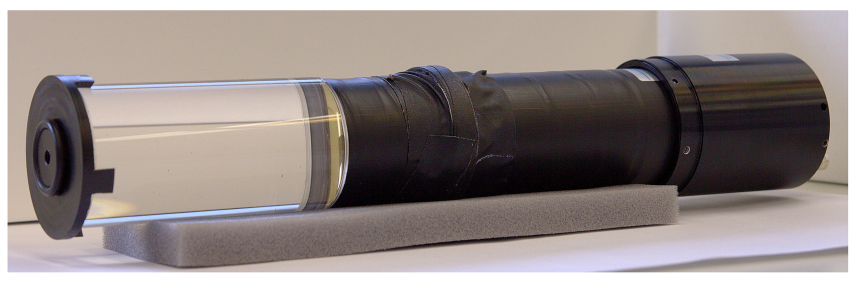
The Beam Halo Monitor

A new monitoring system has been installed in the CMS cavern for measuring the beam background at high radius [1].
This detector is composed of synthetic quartz Cherenkov radiators, coupled to fast photomultiplier tubes.

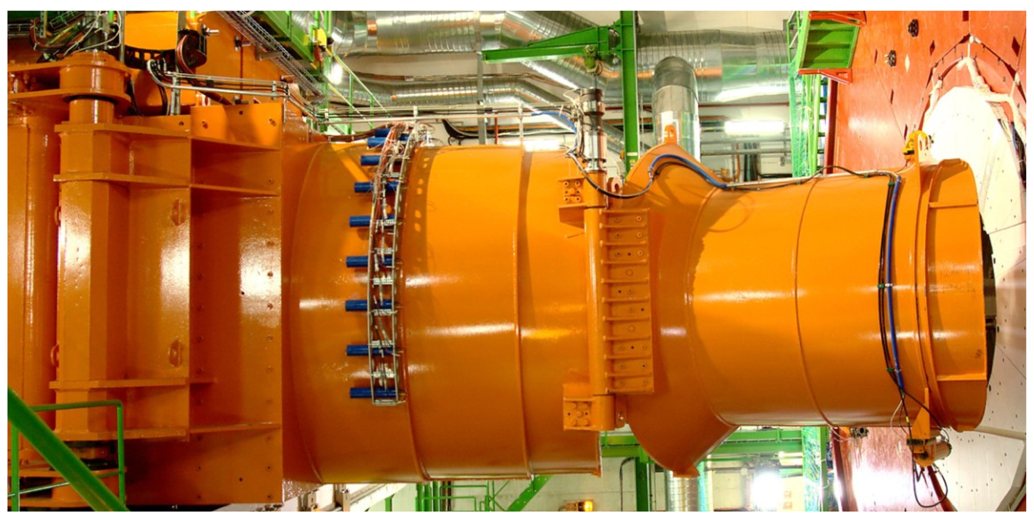
The Beam Halo Monitor (BHM) uses:
- signal amplitude
  from the directionality of Cherenkov light
- timing information
  owing to the detector placement along the z-axis of CMS and the prompt nature of Cherenkov light

to discriminate machine induced background, composed primarily of muons, from *p-p* collision products.





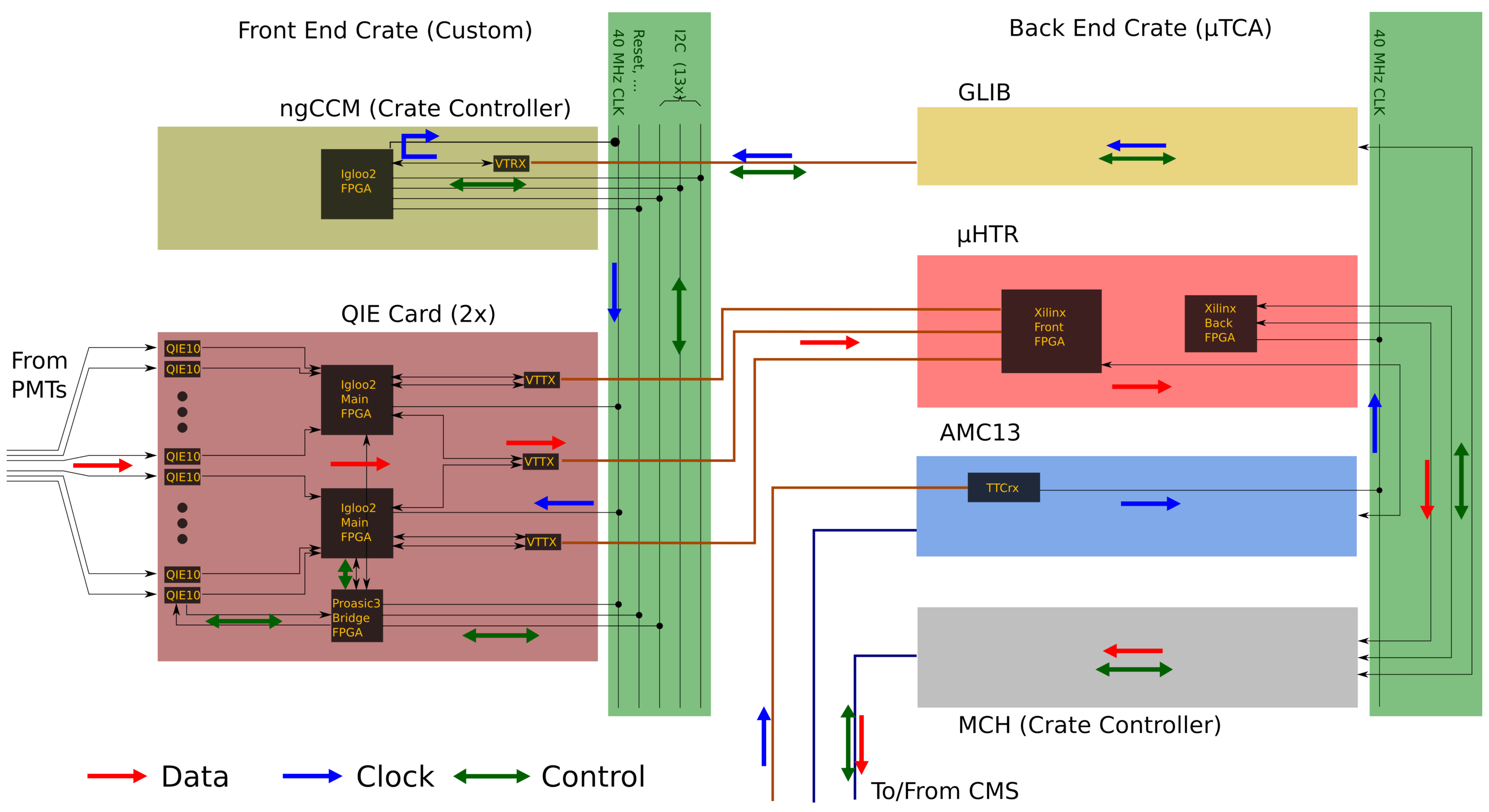
52 mm Ø x 100 mm synthetic quartz bar, coupled to a UV sensitive Hamamatsu R2059 PMT.
Particles coming from the "front" (left in the picture) create Cherenkov light that propagates towards the PMT. Light produced by particles coming from the "back" is absorbed on the front thanks to a layer of black paint on the quartz face.



40 BHM detector units (blue cylinders) are installed on the CMS rotating shielding, 20 on each end, at a radius of 1.8 m from the beam pipe and a distance of 20.6 m from the Interaction Point.
Their front face is pointed towards the incoming beam in order to be sensitive to beam background.

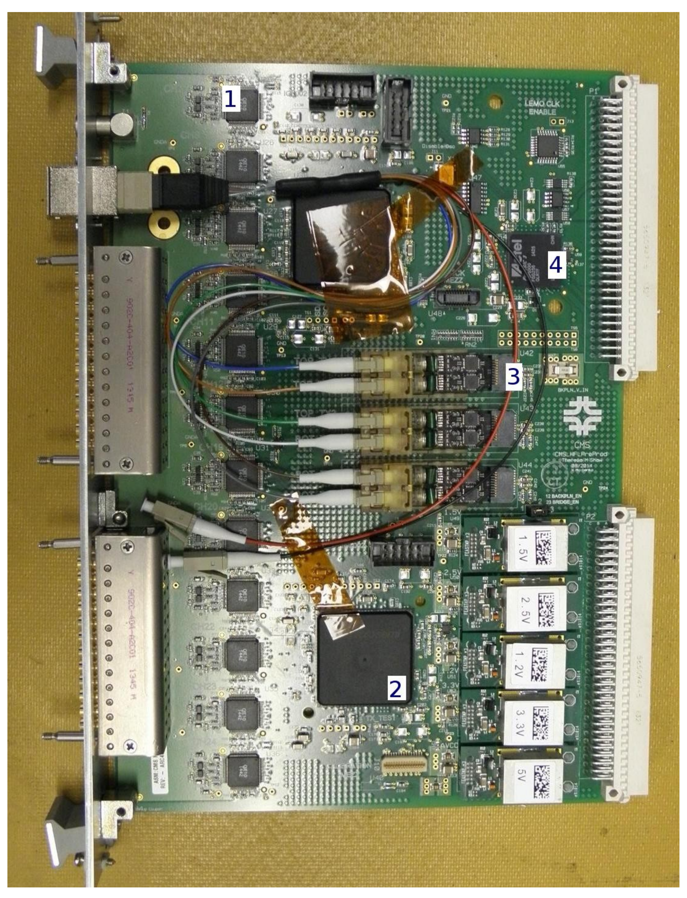
Electronics

The readout chain of BHM uses many components developed for the Phase 1 upgrade to the CMS Hadron Forward (HF) calorimeter electronics [2], with a dedicated firmware and readout adapted to the beam monitoring requirements.
These components are split into a fully custom, radiation hard Front-End and a µTCA-based Back-End, connected by optical links.



Minimal modifications are required for use in BHM, such as the ability to operate during beam ramp (during which the system clock is varying) and the capability to generate and store per-channel occupancy histograms in the readout board.
The use in BHM precedes the complete installation of the HF upgrade, and therefore uses pre-production models of some of the boards.

Front-End



The Front-End electronics are based on the QIE10 ASIC, which provides high dynamic range charge integration and digitization and a 6 bit TDC with 500 ps resolution [3].

This ASIC is hosted on the readout module, which features:
1. 24 QIE input channels
2. Two IGLOO2 FPGAs that format and serialize data at 5.0 Gbps
3. Optical links with CERN VTTx
4. ProASIC 3L "Bridge" FPGA for slow control and monitoring

The ngCCM (new gen. Clock Control Module) card is the Front-End crate controller. It manages clock distribution and fast control over backplane lines, as well as slow control through I^{2}C and JTAG buses.

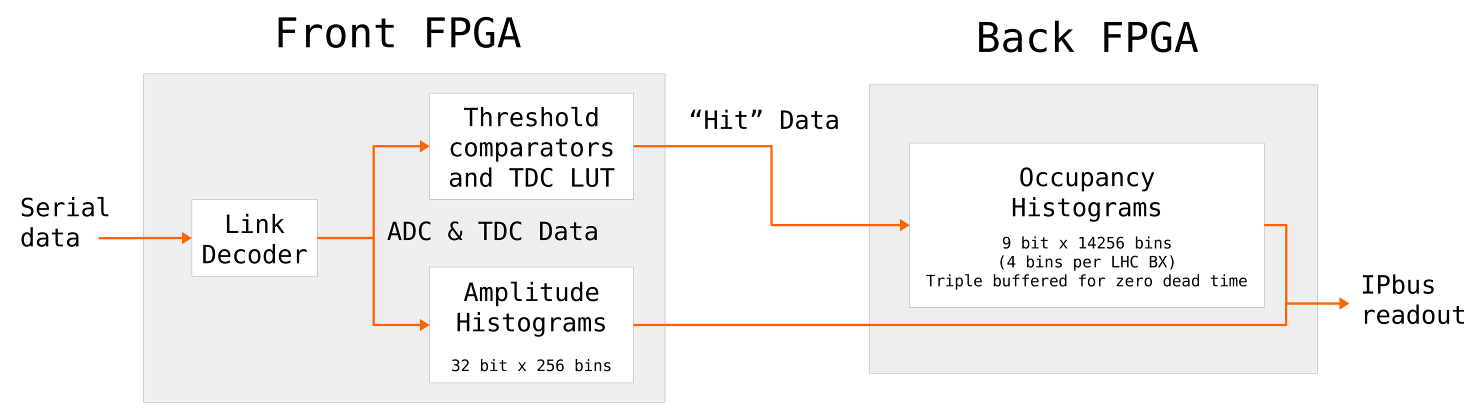
Back-End and DAQ

The Back-End is based on a commercial µTCA crate and MCH (controller hub). Readout and slow control use a Gigabit Ethernet link with the IPbus protocol.

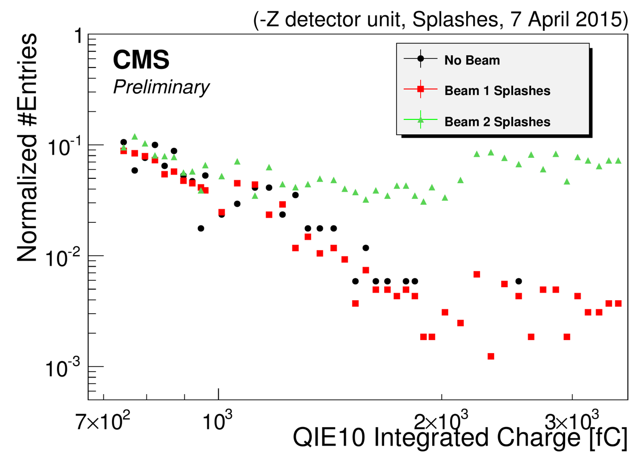
Following the standard CMS setup, an AMC13 card is used to decode TCDS commands, distributing the global clock to the remaining boards.

A CERN GLIB card is configured as ngFEC (new gen. Front End Controller) and controls the Front-End ngCCM via a 4.8 Gbps bidirectional optical link.

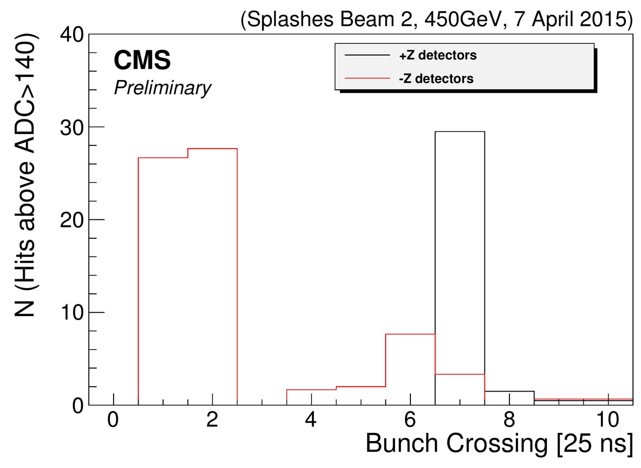
The HCAL µHTR (µTCA HCAL Trigger and Readout module), equipped with two Virtex 6 FPGAs and 24 optical link receivers, handles the data from the Front-End. The firmware loaded on these FPGAs is the most important difference from the baseline HCAL implementation. The Front FPGA histograms amplitude data and computes hits based on both amplitude and timing. The Back FPGA histograms these hits as a function of their BX number.



The occupancy histograms therefore provide a count rate per LHC BX, with a finer subdivision for in-time and out-of-time particles. The histograms integrate and are subsequently read out every 2^{14} LHC orbits (about 1.5 s), with no dead time thanks to triple buffering of the histogram memory.
Amplitude histograms provide charge spectra from the PMTs and are used for monitoring and calibration studies.



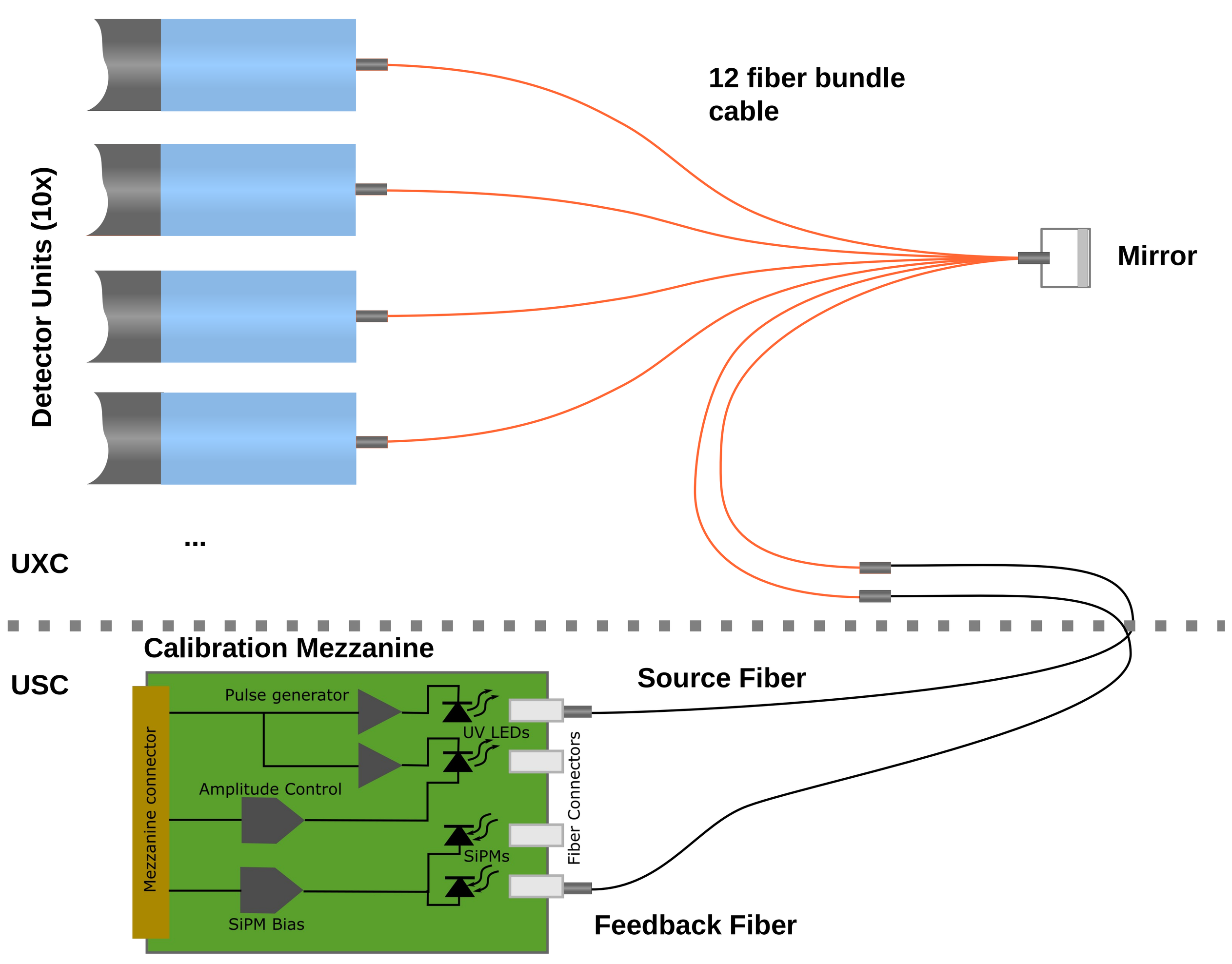
An amplitude histogram of a BHM detector installed on negative end (left), and (right) an occupancy histogram, both readout by the uHTR during beam splash events, April 2015



Histograms are read out by a software which is based on the XDAQ framework.
The data is not part of the normal CMS event data, instead an algorithm processes individual channel data to produce a single background rate per beam every Lumisection; this number is then published to CMS and the LHC.

Calibration System

A calibration and monitoring system has been installed in BHM, to evaluate the performance variations in the PMTs and the Cherenkov radiators.
The system uses a light signal produced by UV emitting pulsed LEDs and driven to each detector unit through quartz optical fibers and passive optical splitters, composed of a fiber bundle coupled with a mirror.



The light is injected on the front of the quartz bar, and the resulting PMT signal is compared with that of a reference Silicon Photomultiplier that receives the same light signal through the splitter.

The LED pulser circuit is housed on a mezzanine card mounted on the QIE front-end card, while the reference SiPM are read out by QIE input channels.
Each LED feeds ten detector units through one splitter, requiring a total of four sources for the whole system.

References

[1] Cherenkov Detector for Beam Quality Measurement, *S. Orfanelli et al.*, CMS-CR-2015-119
[2] CMS Technical Design Report for the Phase 1 Upgrade of the Hadron Calorimeter, *J. Mans et al.*, CERN-LHCC-2012-015
[3] QIE10: a new front-end custom integrated circuit for high-rate experiments, *A. Baumbaugh et al.*, JINST 9 Jan 2014

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