A new on-line luminometer and beam conditions monitor using single crystal diamond sensors.

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Introduction

The Fast Beam Condition Monitor (BCM1F) detector is one of the subsystems of the CMS Beam Radiation Instrumentation and Luminosity (BRIL) project. It is designed for bunch by bunch luminosity and beam background measurements.

The BCM1F Detector consists of 4 half-ring PCBs (C-shapes), positioned 1.8 m on +Z and -Z end of the interaction point at a radius of 6.5 cm from the beam pipe, as sown in Fig.1. The chosen position is a "Golden location", because of the maximum of the time difference between incoming Machine Induced Background (MIB) particles and outgoing collision products of 12.5 ns.

24 single-crystal CVD diamond sensors 5 x 5 mm^2 are installed, 6 sensores on each C-shape. Each sensor has a 2 pad metalization. The signal of each pad is read out and shaped by a frontend radiation hard ASIC, and converted to an optical signal which is then transmitted to the backend electronics.

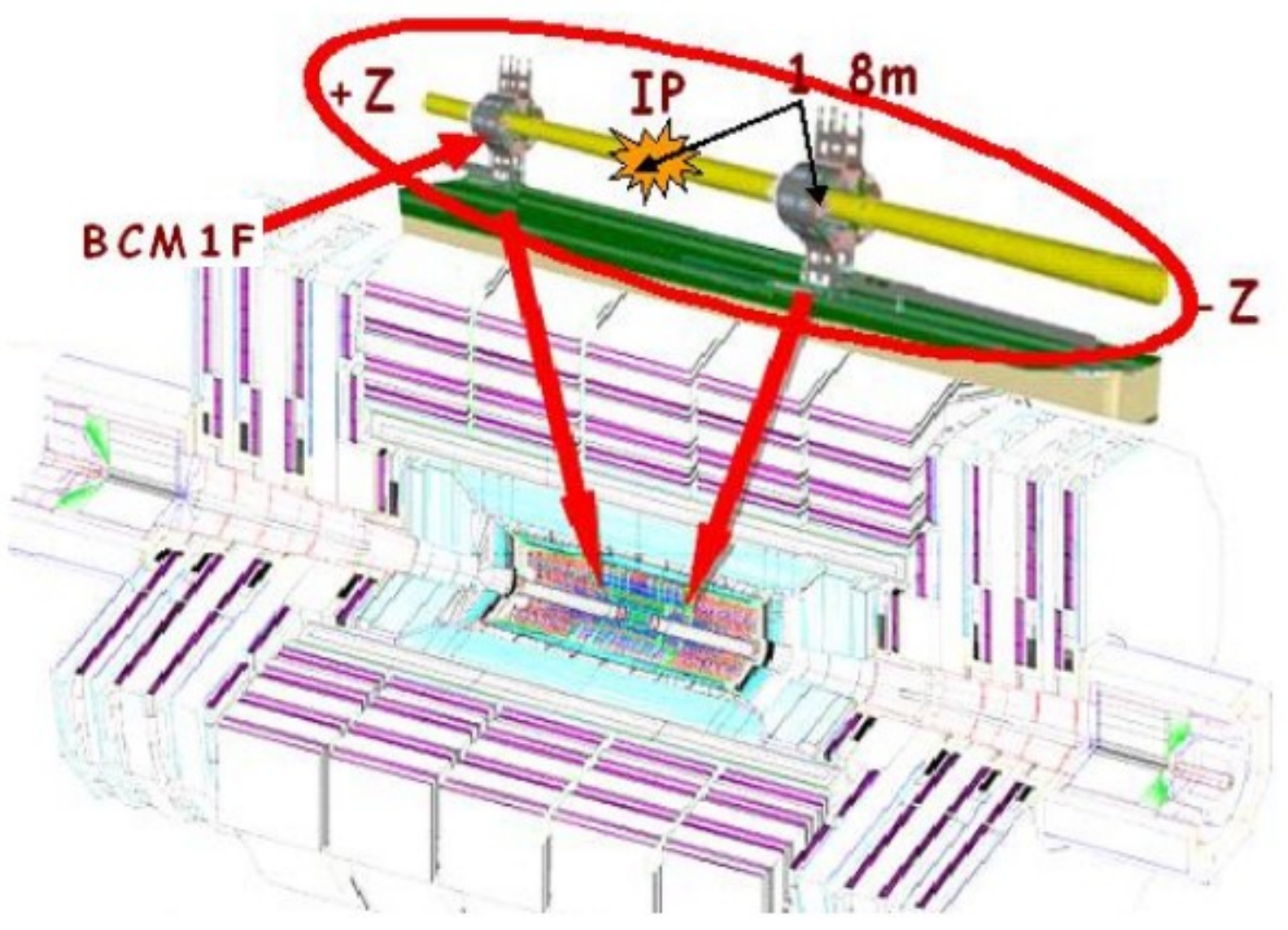

Fig.1: The location of BCM1F in the CMS experiment.

Diamond sensors

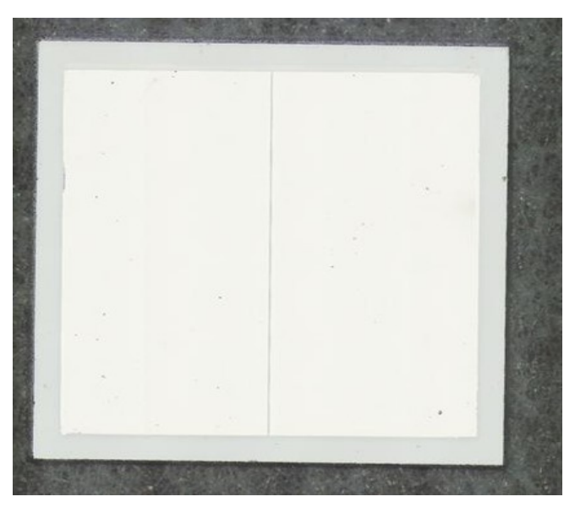

Fig.2: sCVD diamond with a 2 pad metalization.

sCVD diamond sensors were chosen for the BCM1F detector, as they match the requirements to be installed in radiation hard environment close to the beam pipe:

- small size, what is important in terms of limited space near beam pipe;
- fast response, what allows to reach sub-nanosecond time resolution;
- radiation hard;
- no cooling for operation.

Optical inspection and size measurement

68 diamond were tested in the laboratory to choose 24 for installation. Before metallization, inspection with optical microscope was done to exclude the presence of possible defects and to do a precise thickness measurement. After metallization a second inspection to check metallization quality and to measure the pad size and gap between pads was done (see Fig.2).

Electrical characterisation and Charge Collection Efficiency (CCE)

Only diamonds with leakage current in the pA range up to 1000 V of bias voltage were accepted. An example of the result is shown in the Fig.3. Also signal stability over time was required and CCE close to 100%. An example of the CCE as a function of the bias voltage is presented in the Fig.4.

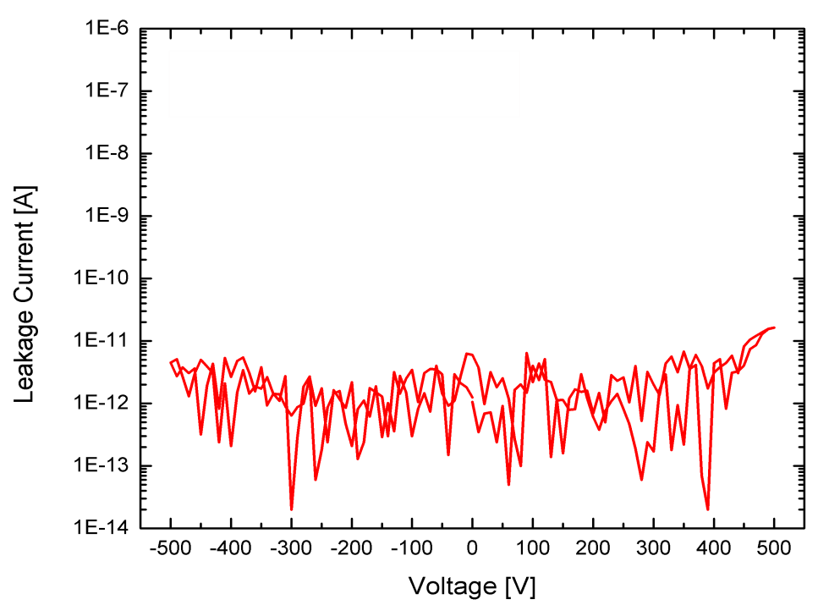

Fig.3: The leakage current as a function of the bias voltage.

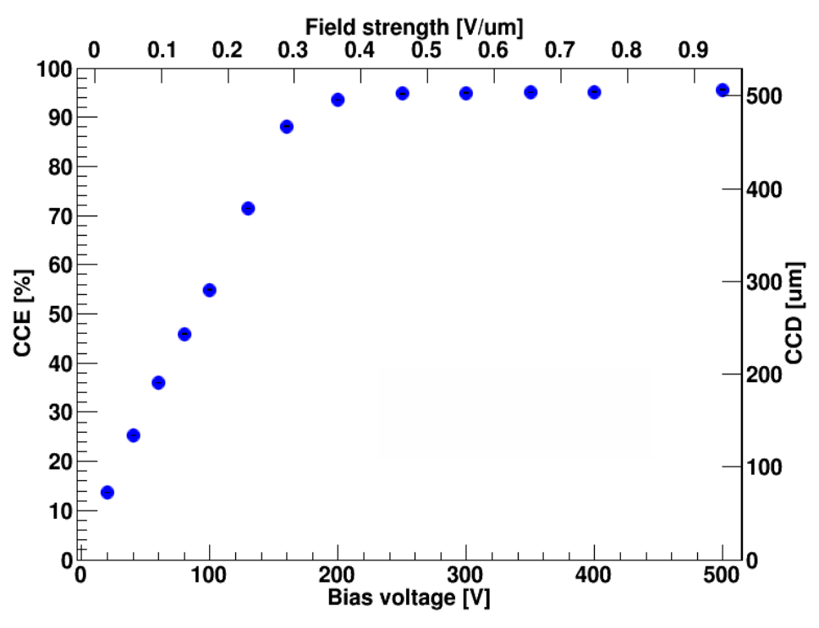

Fig.4: The CCE as a function of the bias voltage.

Testbeam at DESY-II, 5 GeV electron beam

Sensors

Two sCVD diamond sensors were tested:

- one pad sensor as reference;
- two pad sensor to study signal sharing and edge effects.

TB setup

The box with sensors and frontend electronics was mounted between EUDET Telescope planes in the DESY-II 5 GeV electron test beam, as shown in Fig.5. The telescope information was used for track reconstruction. Events with only one track per trigger were selected for the analysis.

Results

Amplitude spectra, as shown in Fig.6, are made to measure signal to noise ratios. For full CCE the S/N is larger than 35. Using the track reconstruction from the telescope, the sensor response and signal sharing were measured as a function of the impact point on the sensor, as shown in Fig.7. Excellent response homogeneity was found over each pad.

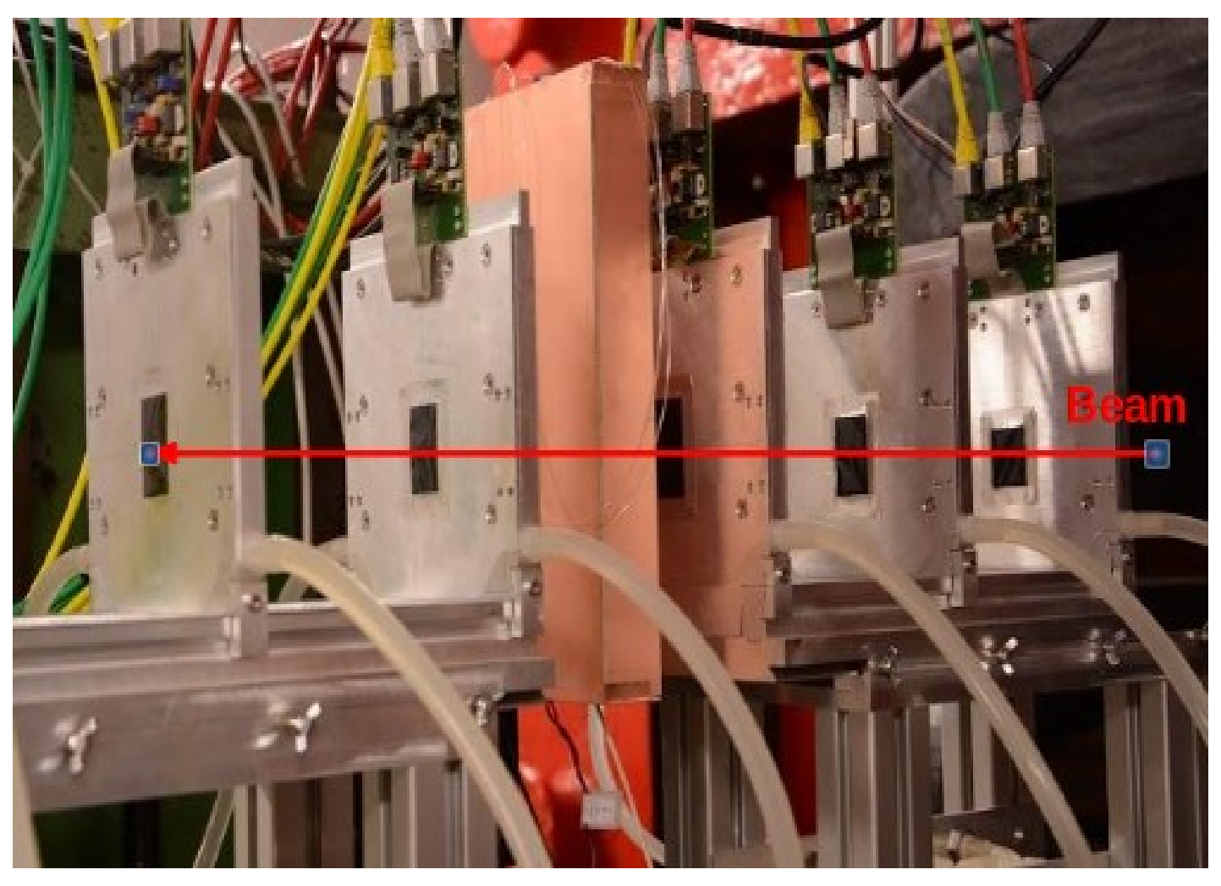

Fig.5: DESY-II testbeam setup. Shown is the EUDET telescope and the box with sensors.

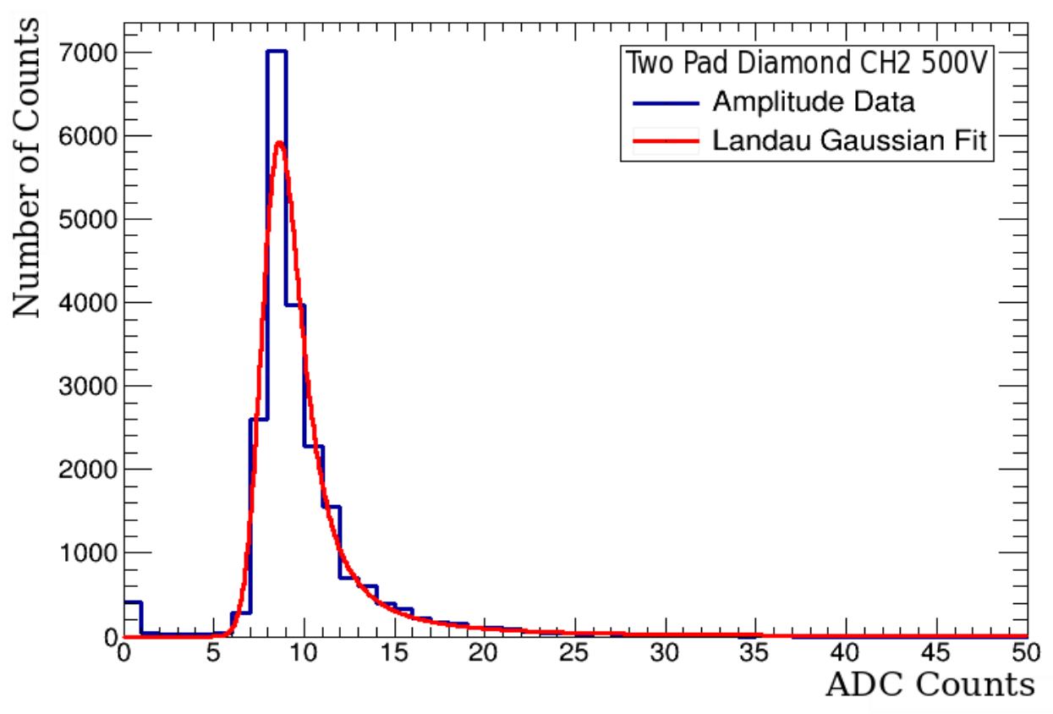

Fig.6: The distribution of the signal amplitudes for one pad of the two-pad sensor.

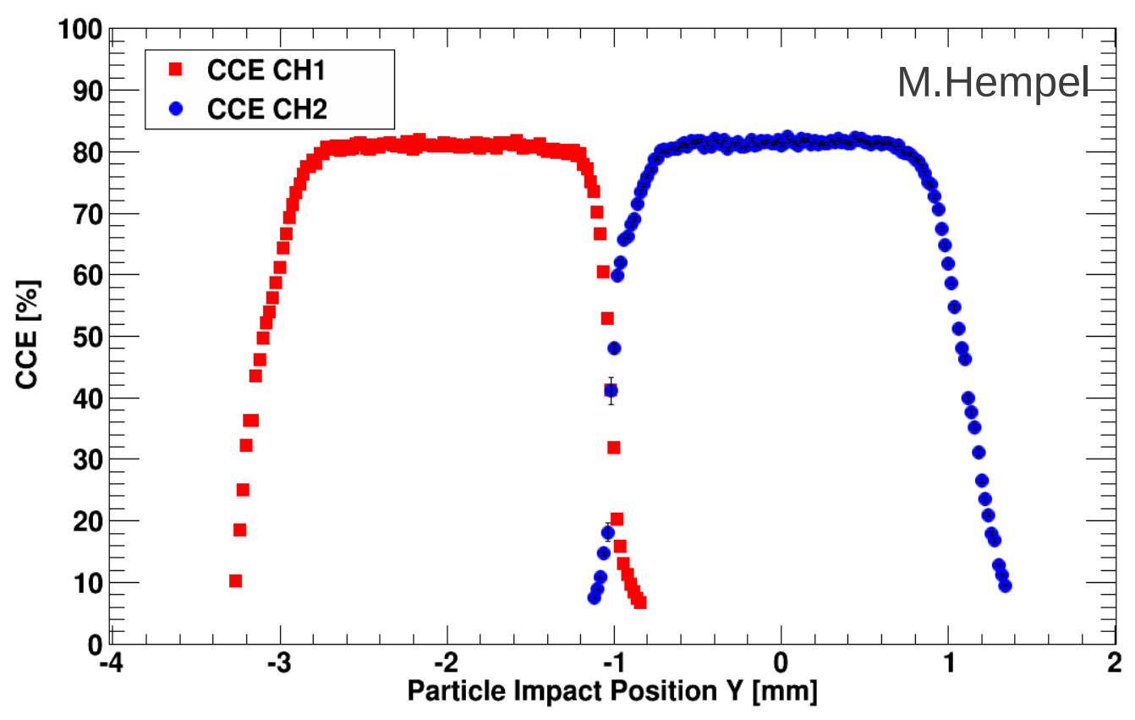

Fig.7: The charge collection efficiency as a function of the beam particle hit position.

Radiation hard ASIC

The design goals

Dedicated front end ASICs have been developed in radiation hard 130 nm CMOS technology. The requirements were linearity up to 10 fC input signal, a gain of 50 mV/fC, an equivalent noise of less that 1000 electrons, a quasi-Gaussian pulse shape with a full-width at half maximum of less than 10 ns and a short recovery time for input signals above the linear range.

Successful application at LHC

The required parameters were verified in measurements done in the laboratory and confirmed during first measurements at the LHC with circulating beam. Data from the BCM1F detector was recorded using a 500 MS/s flash CAEN ADC. An example of the measured signal is shown in Fig.8. Its amplitude is ~70 mV (1 ADC count = 4 mV) and the width is ~10 ns at half maximum, which corresponds to the expectation of a signal from a Minimum Ionising Particle (MIP).

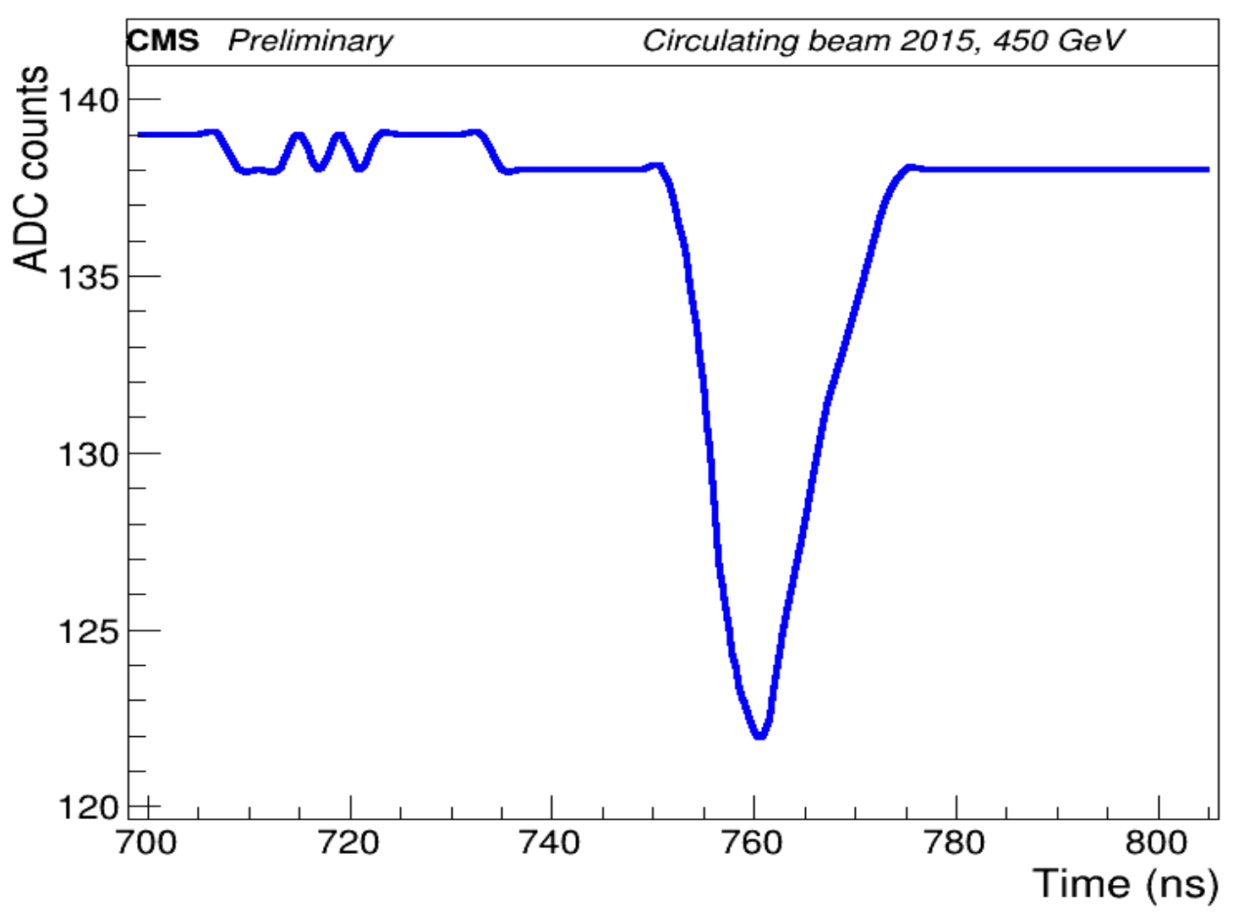

Fig.8: The response of the BCM1F detector to a single relativistic particle of the machine induced background.

A sketch of a quarter of the BCM1F detector and PLT

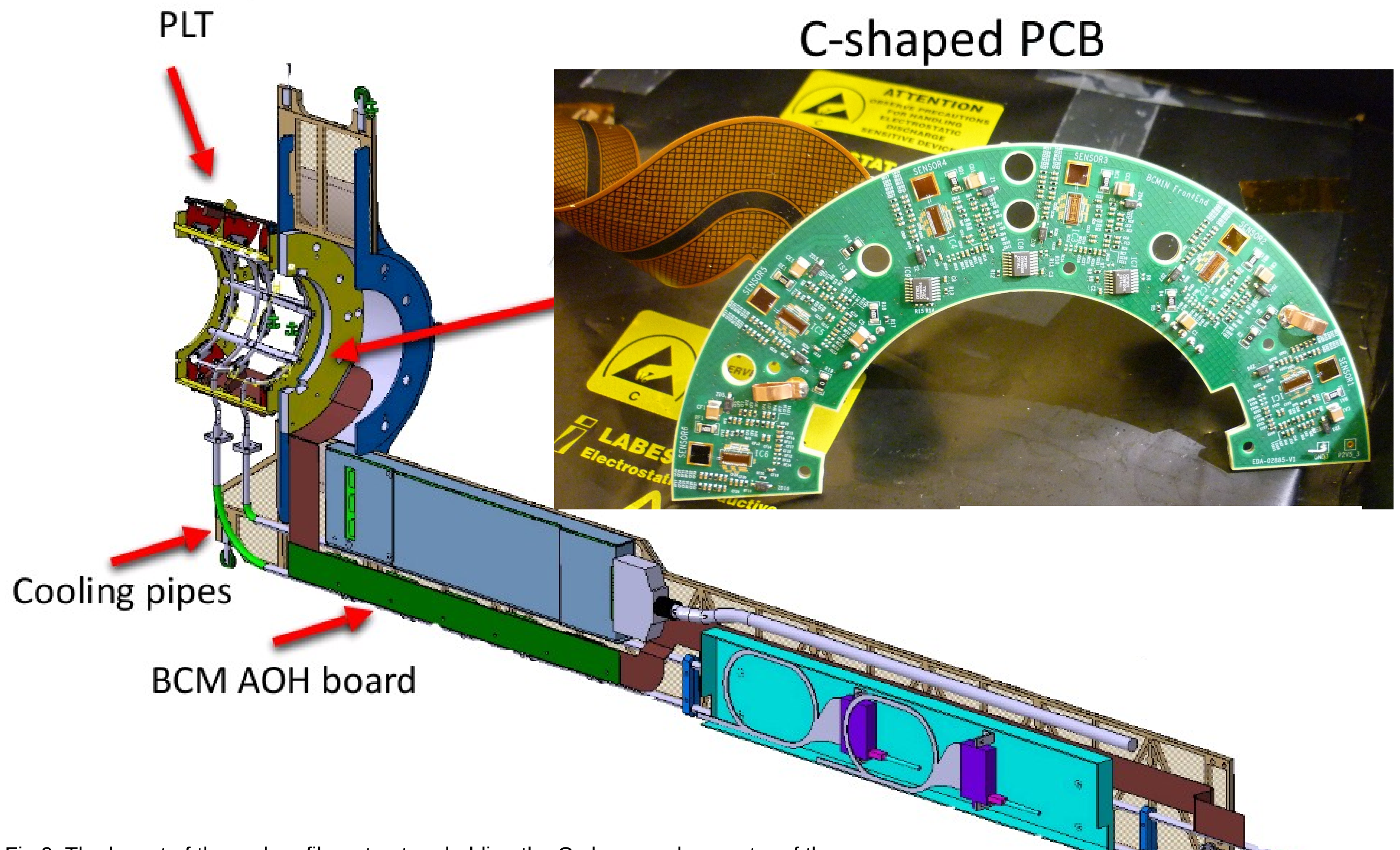

Fig.9: The layout of the carbon fibre structure holding the C-shape and a quarter of the Pixel Luminosity Telescope (PLT). The C-shape assembled with sensors and front-end ASICs is shown on the right top. The AOH boards convert the electrical signals from ASICs to optical signals, send via optical fibers to back-end electronics. There are no galvanic connections between the BCM1F board and the cooling lines. The AOH hybrids are cooled via an insulating ceramic plate and heat conductive paste.

BCM1F backend

The received optical signals are converted into electrical signals. These copies are then transmitted to the backend electronics. A sketch of the backend electronics is shown in Fig.10.

The Real-time Histogramming Unit (RHU) provides deadtimeless full-orbit histograms with 6.25-ns binning. 6 RHU boards are currently successfully operating and providing online measurement and publishing of BCM1F rates.

ADC systems areinstalled in VME and μTCA. CAEN flash VME ADCs with 2 ns sampling time are used to record data from all channels. These data is needed for detector performance monitoring, e. g. amplitude spectra and arrival time. For higher rates a deadtime less μTCA ADC system is under development, allowing also deconvolution of the signals.

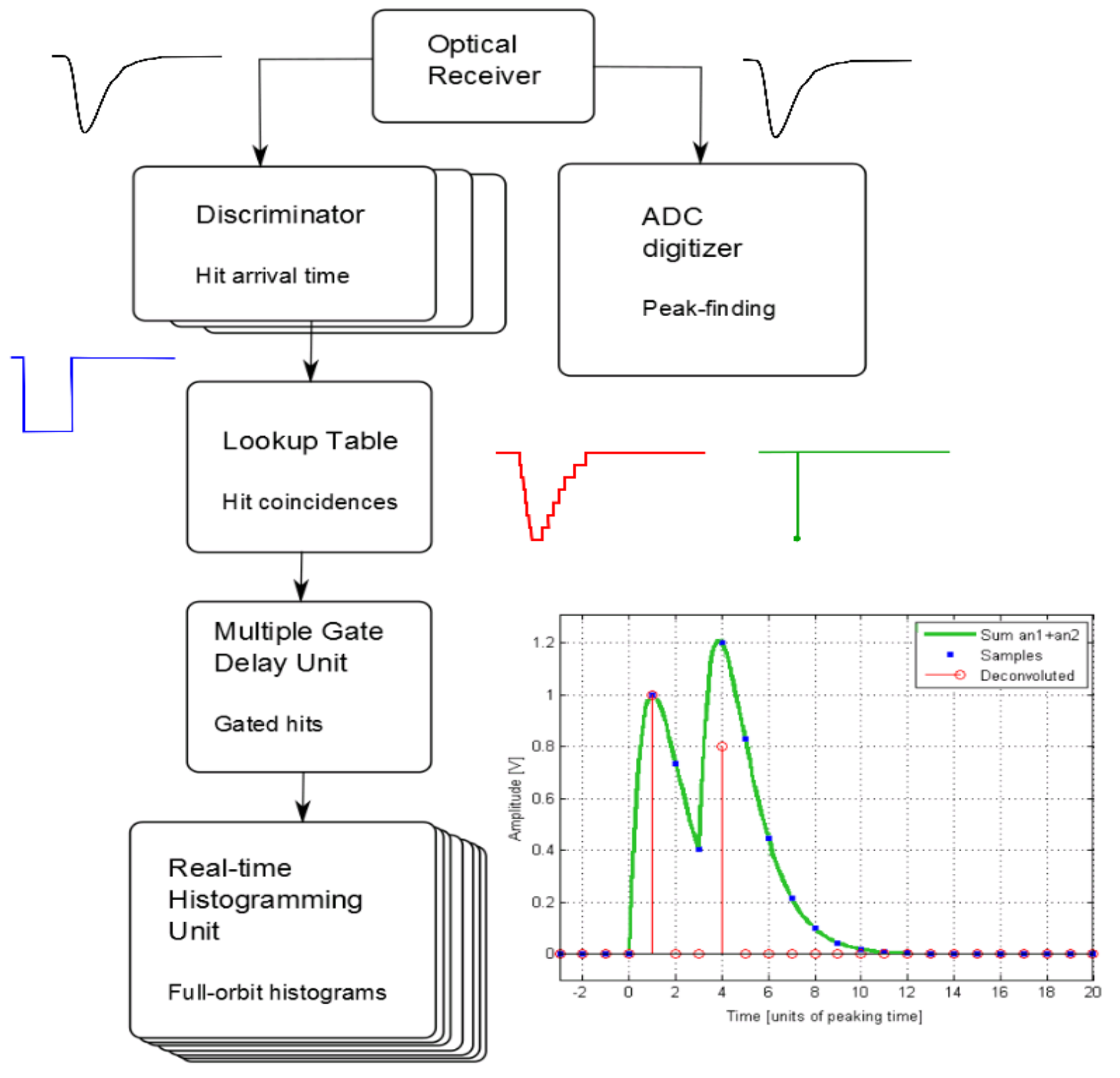

Fig.10: Sketch of BCM1F backend electronics.

First results from successful operation of the BCM1F detector in Run II

Amplitude spectrum

The VME ADC data was collected with the first colliding beams in the LHC. An example of the signal, corresponding to one MIP particle crosing the diamond sensors is shown in Fig.8. For all recorded signals during Fill 3679 the amplitude spectrum was reconstructed using a simple peak finding algorithm. In Fig. 11 it is seen that the pedestal and the MIP peak are clearly separated. From this plot also the threshold for future analysis to cut noise pedestal is defined to be 20 mV. The MIP amplitude distribution is expected to have peak around 70 mV, what is confirmed by the observation.

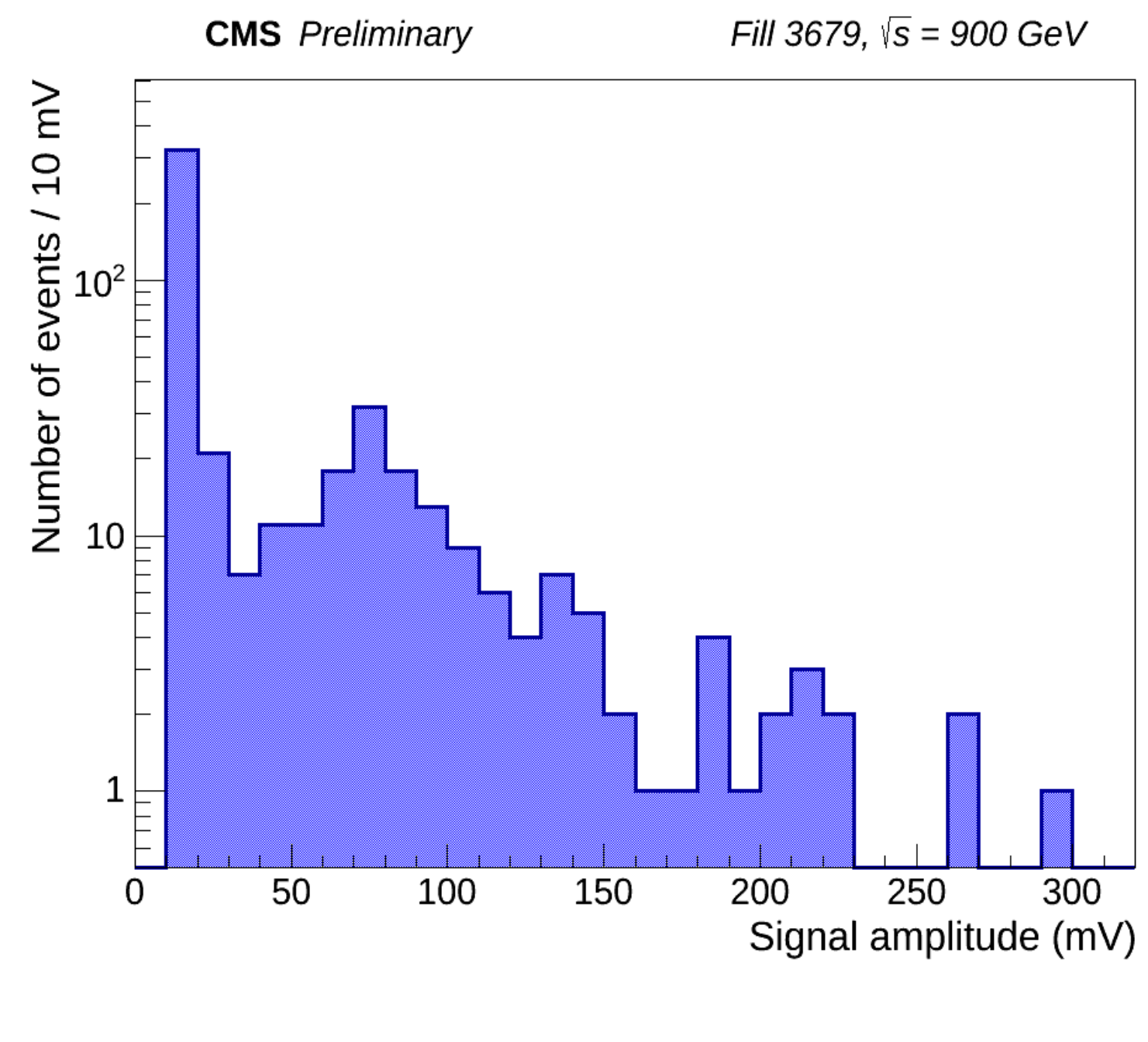

Fig.11: An example of the BCM1F detector amplitude spectrum.

Time over threshold vs. signal amplitude

Time over threshold as well as signal amplitude are quantities which are used to discriminate signals from noise.

Using the threshold, defined from amplitude distribution and the simple peak finding program, the time over threshold of each signal is plotted against the signal amplitude. VME ADC data from Fill 3679 was used. The distribution is presented in Fig. 12. It is seen that time over threshold stays below 30 ns even for large signals, as it was required for LHC operations.

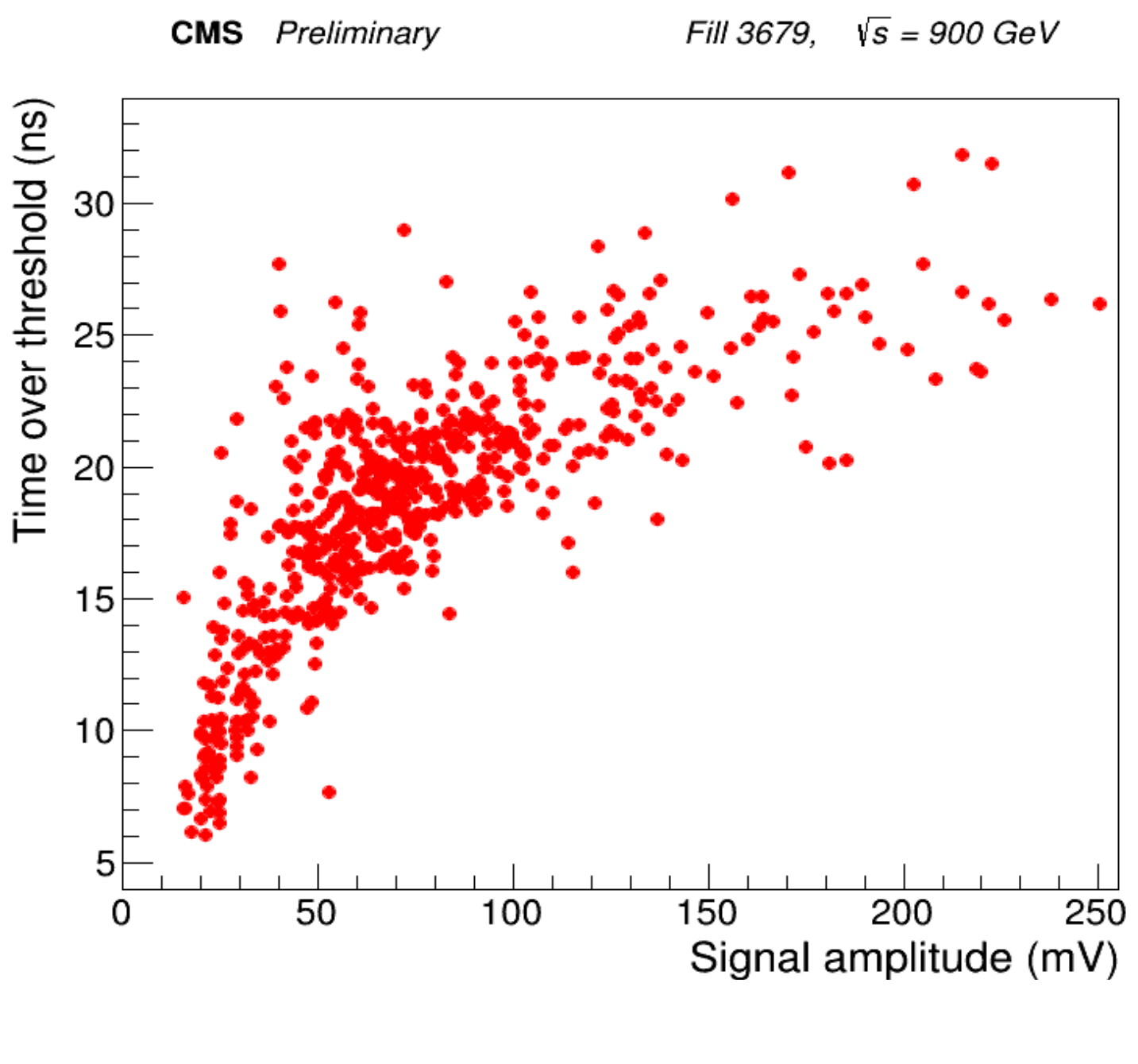

Fig.12: Time over threshold vs. signal amplitude.

The BCM1F count rates

A first prototype of Real-time Histogramming Unit was installed in September 2012 and commissioned during 2012-2013 running. As it showed excellent performance, 6 upgraded modules are installed to serve 48 channels of BCM1F detector. Already from first days of operetion of the LHC in Run II RHUs providing count rates to online monitors of the CMS detector. On Fig.13 it is illustrated how at the time when the beam loss starts the count rates of BCM1F detectors are rapidly growing. The beam intensity as a function of time is shown in blue. The count rates of the BCM1F detectors are shown in red and black. Zero of the time scale corresponds to 5:15 29/04/2015 (GMT).

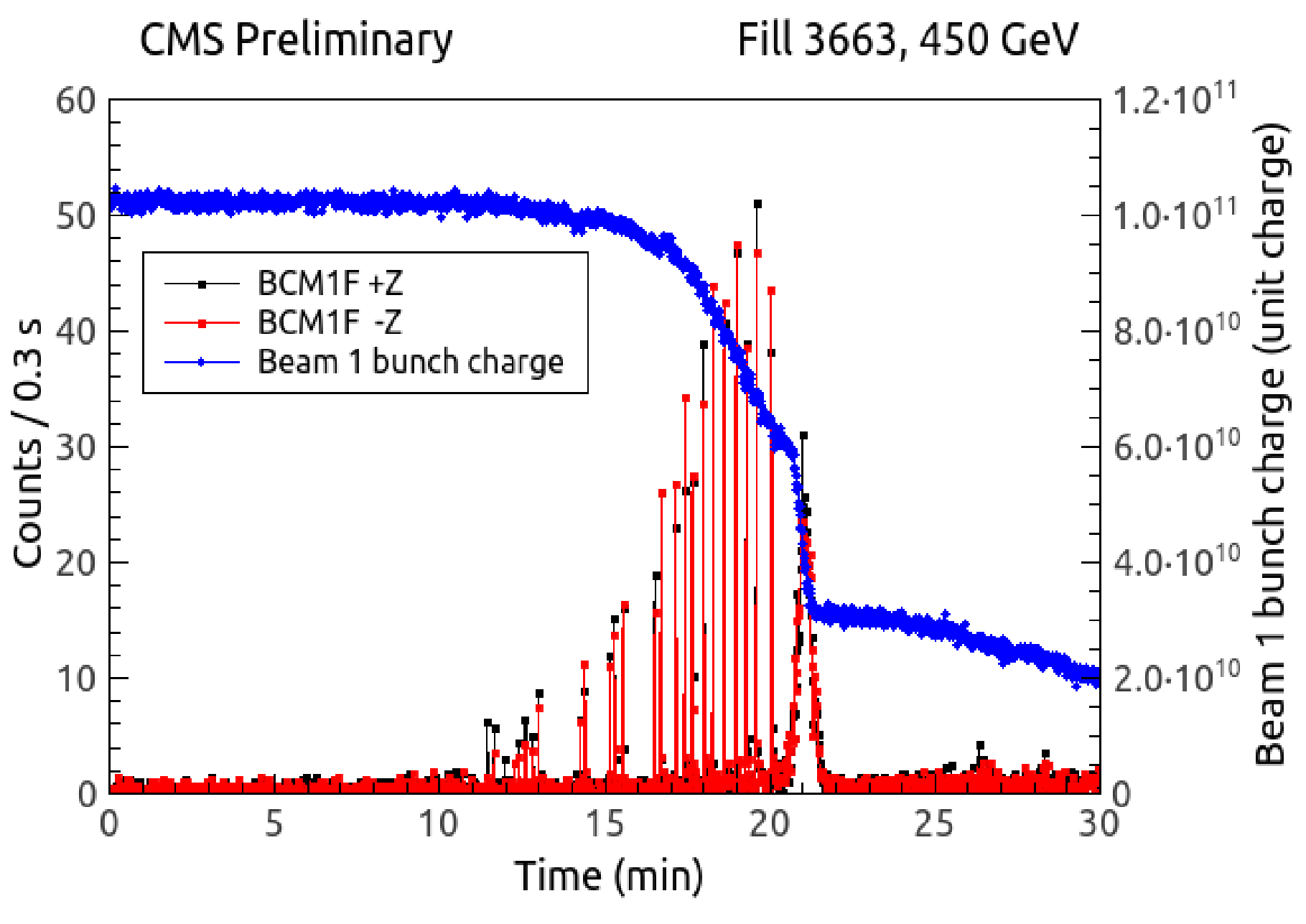

Fig.13: The BCM1F counting rates during a beam loss.

Outlook

During Run I the BCM1F detector based on single crystal diamond sensors has proven to be a robust and reliable beam-background and online luminosity monitor. The upgraded BCM1F system was successfully installed in the end of 2014. Twenty four diamond sensors, from 68 fully charactetised, passed the quality criteria. New radiation hard front end ASICs 130 nm CMOS technology match the requirements at the LHC operated with 25 ns bunch spacing.

Three data aquisition systems are running in parallel:

- The Real-time Histogramming Unit maps the arrival time of signals to a full LHC orbit with 6.25 ns binning;
- VME ADC;
- μTCA ADC system is under developement. It is deadtimeless and should replace VME ADC.

The BRIL group is working to provide reliable and valuable information to the CMS experiment and the LHC machine. Already from the first collisions data a very good agreement between the luminosity measurements of Hadron Forward Calorimeter (HF), the Beam Conditions Monitors (BCM) and the Pixel Luminosity Telescope (PLT).

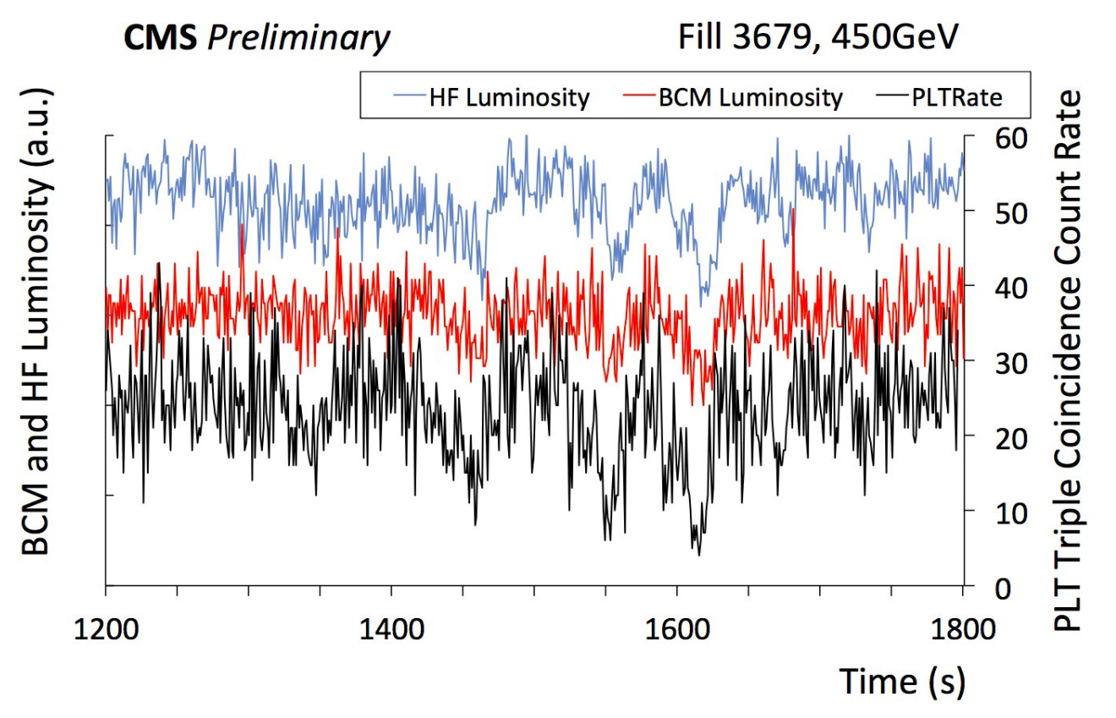

Fig.14: Illustration of agreement of luminosity measurements by HF, BCM and PLT.