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# Upgraded Fast Beam Conditions Monitor for CMS online luminosity measurement

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## Abstract

The CMS beam and radiation monitoring subsystem BCM1F during LHC Run I consisted of 8 individual diamond sensors situated around the beam pipe within the tracker detector volume, for the purpose of fast monitoring of beam background and collision products. Effort is ongoing to develop the use of BCM1F as an online bunch-by-bunch luminosity monitor. BCM1F will be running whenever there is beam in LHC, and its data acquisition is independent from the data acquisition of the CMS detector, hence it delivers luminosity even when CMS is not taking data. To prepare for the expected increase in the LHC luminosity and the change from 50 ns to 25 ns bunch separation, several changes to the system are required, including a higher number of sensors and upgraded electronics. In particular, a new real-time digitizer with large memory was developed and is being integrated into a multi-subsystem framework for luminosity measurement. Current results from Run II preparation will be shown, including results from the January 2014 test beam.

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# Upgraded Fast Beam Conditions Monitor for CMS online luminosity measurement

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# 1. Overview of BCM1F

The CMS Fast Beam Condition Monitor (BCM1F)[1] provides bunch-by-bunch information on the flux of beam halo and collision products passing through the inner CMS detector[2]. The system was originally designed to monitor the condition of the beam to ensure low enough tracker occupancy for data-taking. However, BCM1F's purpose has evolved to include fast measurement of luminosity in order to function as an online luminometer.

## 1.1 Run I Setup

During LHC Run I, BCM1F consisted of 8 5mm x 5mm single-crystal CVD diamonds positioned around the beam-pipe at a radial distance of 4.5 cm, 1.8 meters from the interaction point. The position of the two BCM1F planes in the z coordinate was such that the collision products and the beam gas products had the maximum possible separation in arrival times, 12.5 ns. Diamond was chosen based on several factors: it requires no cooling, has a good signal-to-noise ratio, and is radiation-hard. Each diamond sensor was integrated into a frontend readout module including a radiation-hard preamplifier and an optical driver. Power and readout of BCM1F is independent from the rest of CMS, which lets BCM1F take data even when CMS is not running.

A charged particle passing through the diamond sensor creates a signal on the metallized pads on both surfaces of the diamond. This signal is read out through a preamplifier and shaper and passed through an optical fiber to the backend electronics, located in the underground service cavern. From there the information travels through two paths. A discriminator detects hits passing a threshold cut, and the digital signals are passed through a coincidence unit (LUT) and counted using a scaler and, more recently, a dedicated readout board (RHU). In parallel, the analog signals are recorded by an ADC for efficiency studies. The deadtime of the ADC is too high to use it for full-time readout, however.

## 1.2 Run I Results

BCM1F was successfully tested as a luminometer during Run I[3]. BCM1F participated in CMS-wide van der Meer scans, which provide the calibration for the absolute luminosity

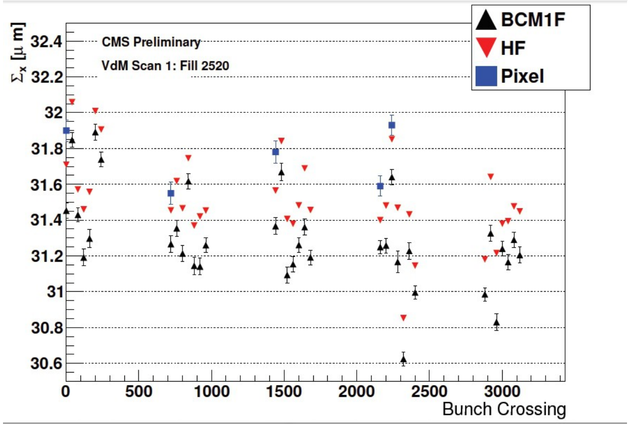

*Figure 1: Calibration scan results comparing BCM1F to other luminosity subsystems.*

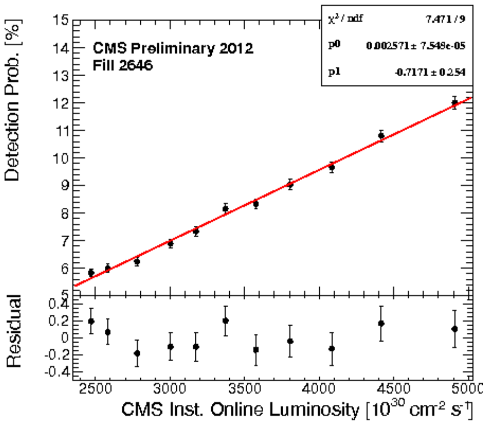

*Figure 2: Sensor hit probability with instantaneous luminosity.*

measurement. The calibration constant can be extracted from fitting the rate as a function of beam separation distance. The results of the calibration scan show that the BCM1F bunch-by-bunch measurement agrees on average to within a percent of the values measured by the other luminosity systems, the forward hadronic calorimeter (HF) and the pixel detector, as shown in Fig. 1. The BCM1F detection probability was also measured to be extremely linear with luminosity, as shown in Fig. 2.

## 2. BCM1F Upgrade

### 2.1 Upgrade Concept

The upgrade of the LHC has multiple implications for the BCM1F system. First, the higher luminosity means a higher hit rate in BCM1F. At a luminosity of 1034 cm-2s-1, the BCM1F charged particle flux is around 3 x 107 cm-2s-1. BCM1F should be able to handle the increased radiation and more hits per unit area. Second, the move to 25-ns bunch spacing means BCM1F should be prepared for a higher frequency of hits in time, as well, requiring a faster response to avoid pileup effects.

The BCM1F upgrade strategy addresses these conditions. To increase the system's dynamic range and maintain linearity, the number of channels is being increased. The system will be expanded from 8 to 24 diamonds, and each diamond will have two metallization pads for a total of 48 channels. This makes it more likely that there will be more channels without hits during a given bunch crossing (important for the zero-counting aspect of the luminosity measurement), as well as more likely that at least one channel will register a hit due to beam gas.

### 2.2 Upgrade Carriage Design

The detector carriage for the upgrade consists of a carbon-fiber frame carrying a semi-rigid PCB. The rigid C-shape holds the BCM1F sensors as well as the frontend electronics. The optical components are mounted on the rigid arm of the PCB, further away from the beamline than in Run I in order to lower their radiation exposure. In addition, the optical components will benefit passively from the cooling system for the Pixel Luminosity Telescope (PLT), also carried on the C-shape. The shape of the PCB allows it to fold out into an extended length, letting the piece be manufactured from a single PCB panel. Production of the PCB is in progress, with one board already being assembled and tested.

### 2.3 Improving Frontend Electronics

The frontend electronics in the Run I system had several sources of inefficiency. The rise time was 25 ns, the same as the foreseen bunch spacing interval for LHC Run II. In addition, occasional large signals caused the preamplifier output to remain over threshold for a period on the order of 100 ns. During this time no signals could be detected. After this saturation, the amplifier signal would then go into an overshoot state lasting up to several µs, during which time any signals would not necessarily pass the detection threshold.

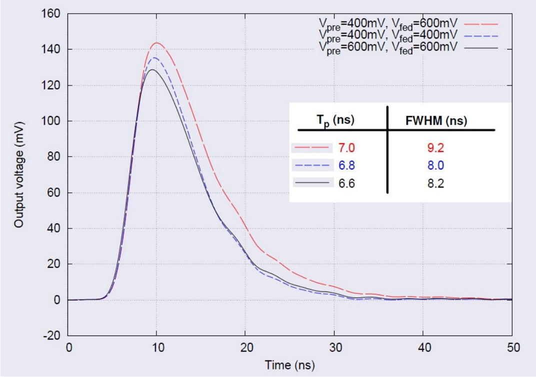

*Figure 3: ASIC response to MIP signals showing fast rise time.*

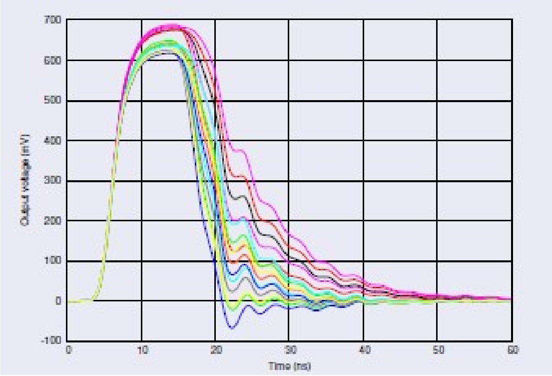

*Figure 4: ASIC response to large signals showing short recovery time.*

To deal with these inefficiencies, a new fast frontend ASIC has been developed at AGH-Krakow using IBM CMOS8RF 130nm technology. It has ~50 mV/fC charge gain and less than 1k e- equivalent noise charge. The rise time is around 7 ns for MIP signals, as shown in Fig. 3. In addition, for large signals, the time-over-threshold is less than ~30 ns, and the overshoot time is very small, as shown in Fig. 4. This is a large improvement in behavior and will address the issues seen in the previous system.

### 2.4 January 2014 Test Beam

A BCM1F frontend unit was tested in the DESY test beam in 2014. The test board included single-pad-metallization and split-pad-metallization diamonds, as well as the new frontend ASIC. Results show a high measured charge-collection efficiency, as well as the fast rise time of the ASIC, in accordance with expectations. In addition, the performance of a digitizer option was measured. The current results are encouraging, and analysis is ongoing.

### 2.5 Backend Electronics

The backend electronics strategy will retain the parallel path design from the Run I setup. The "tried and true" VME discriminator path will be used for initial running, while a µTCA digitizer system with fast peak-finding will be commissioned for future use.

As in Run I, the analog signal will be passed to a fast, low-deadtime discriminator to measure hit arrival time. The resulting digital signal will be fed into a Lookup Table (LUT) unit to register hit coincidences between channels. In addition, a Multiple Gate and Delay (MGD) unit will provide gated hits for the purpose of separating collision products, beam background, and albedo or afterglow from secondary interactions in the detector body. This data will be read out by a dedicated board, the RHU, and passed to the DAQ for the luminosity subsystems.

A dedicated readout board, the Real-time Histogramming Unit (RHU), was developed at DESY-Zeuthen to record the BCM1F data for LHC Run II. The RHU provides deadtimeless readout of full-orbit histograms for 8 ECL input channels. The histograms are binned in 6.25-ns bins, or 4 bins per bunch crossing, for 14,256 bins per orbit. In addition it receives bunch clock, orbit clock, and beam abort signals. The histogram integration interval is taken from an optical timing signal received from the CMS clock and control system. The RHU has a 5 Mbit RAM FPGA as well as an on-board embedded Linux system and Ethernet readout. The first version prototype was installed in BCM1F in Sept. 2012 and validated during the remainder of the 2012-2013 run. The second version prototype has been tested, and the full production of the boards is in progress.

In parallel with the discriminator/RHU path, a µTCA digitizer system is being developed for the purpose of fast peak-finding. The digitizer will be able to identify both the arrival time and the peak height of arriving signals, and in particular will be able to distinguish overlapping signals, which is more difficult with a discriminator. The digitizer will also be able to take data as an ADC for efficiency studies.

The digitizer system being considered is based on FPGA mezzanine cards (FMCs) on a µTCA carrier board. Various hardware options are currently being evaluated. The FMCs are foreseen to have 4 channels each and be able to take 8-10 bit ADC data at 5 GS/s. The carrier board is foreseen to implement the peak-finding algorithm on the ADC data. The produced histograms (hits vs. time and hit amplitude spectra) will be passed directly to the DAQ system responsible for collecting the data from the different subsystems.

### 2.6 Luminosity subsystem integration

The BCM1F output histograms will be acquired via the LumiDAQ system. This is an expansion of an already-existing structure for taking luminosity data in order to accommodate all CMS luminosity subdetectors. A common timing signal will be distributed via optical fiber, defining the hit count integration interval. In addition, occasional transmitted counters will serve to keep the different subsystems synchronized.

The LumiDAQ software framework receives raw data from each of the subdetector readouts. The raw data is put into an eventing stream, from which downstream subscriber modules can retrieve the data for processing, storage, or publishing. Processed histograms may also be put back into the eventing stream for the same purpose. The software framework and the respective components are currently being developed.

## 3. Conclusion

BCM1F functioned well as a luminometer in LHC Run I. To deal with the increased luminosities and smaller bunch spacing expected during Run II, several updates to the system are being made. These include more channels, faster frontend electronics, dedicated backend electronics, and integration into the luminosity data-taking framework. Preliminary results from the 2014 test beam support a successful future operation of BCM1F as a luminometer.

## References

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[3] N. Odell. *Measurements of Luminosity and Normalised Beam-Induced Background Using the CMS Fast Beam Condition Monitor,* in proceedings of ICHEP2012, PoS(ICHEP2012)526.