Upgraded Fast Beam Conditions Monitor for CMS online luminosity measurement.

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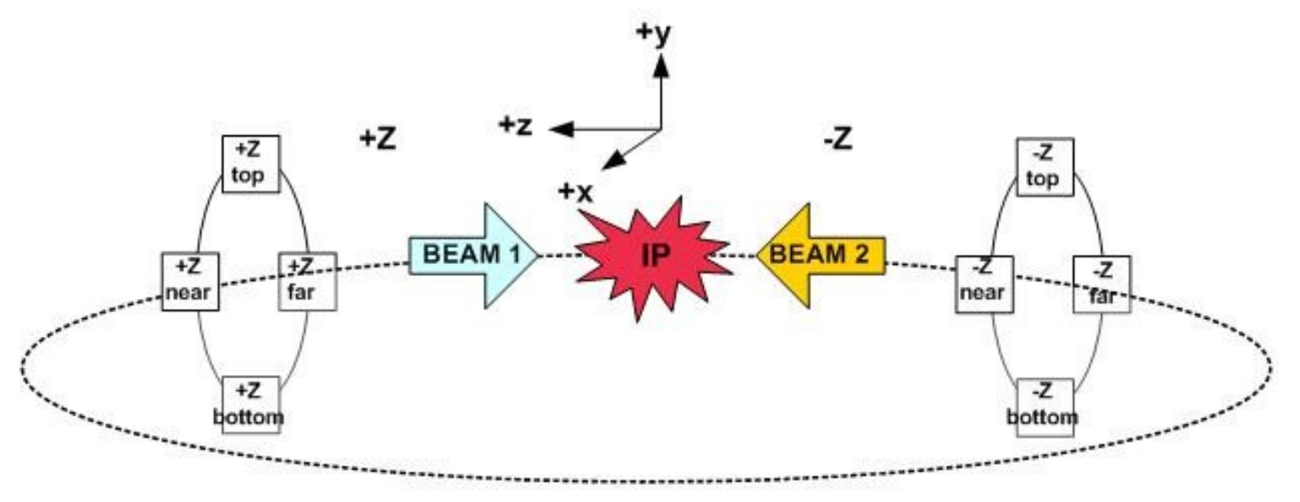
On behalf of the CMS Collaboration

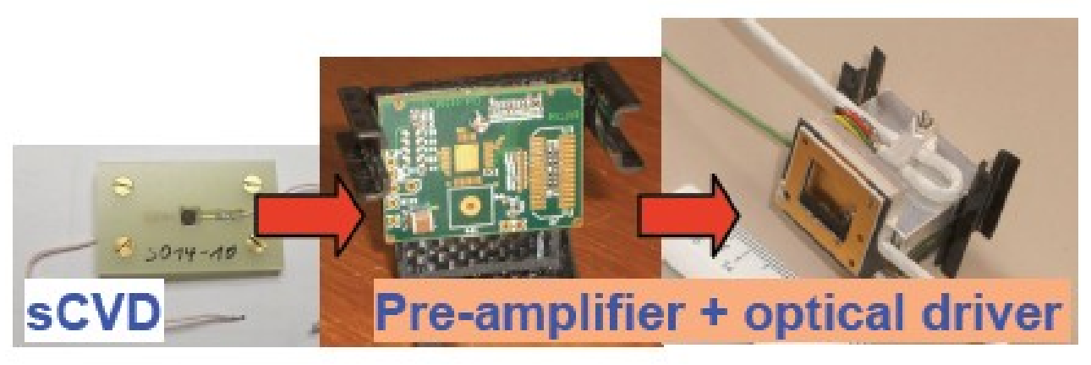
Overview of BCM1F

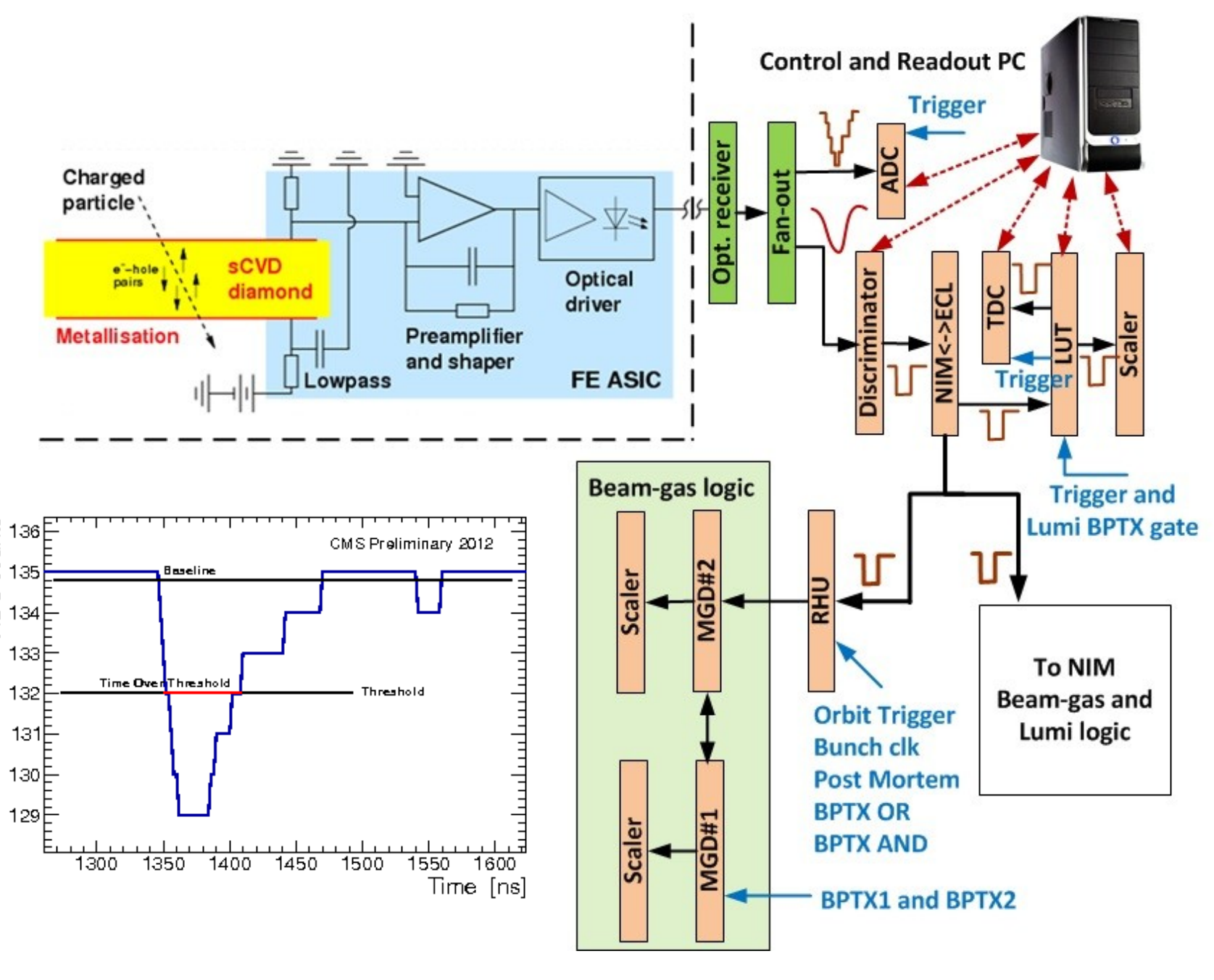
The CMS Fast Beam Condition Monitor (BCM1F) provides bunch-by-bunch information on the flux of beam halo and collision products passing through the inner CMS detector. The system was originally designed to monitor the condition of the beam to ensure low enough tracker occupancy for data-taking. However,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

Run I Setup



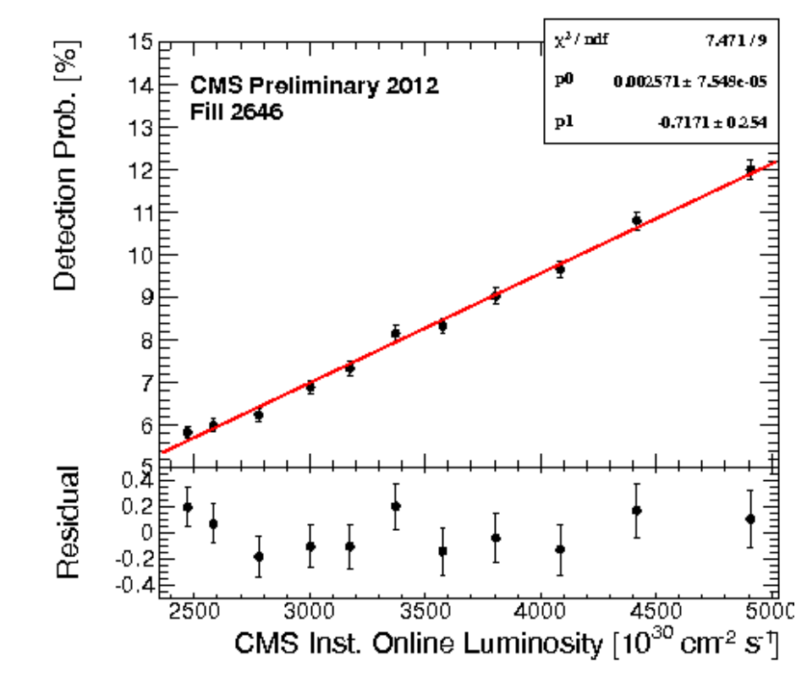
During LHC Run I, BCM1F consisted of 8 5mm x 5mm single-crystal CVD diamonds positioned around the beam-pipe at a radial distance of 4.5 cm, 1.8 meters from the interaction point. The position of the two BCM1F planes in the z coordinate was such that the collision products and the beam gas products had the maximum possible separation in arrival times, 12.5 ns. Diamond was chosen based on several factors: it requires no cooling, it has a good signal-to-noise ratio, and it 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.

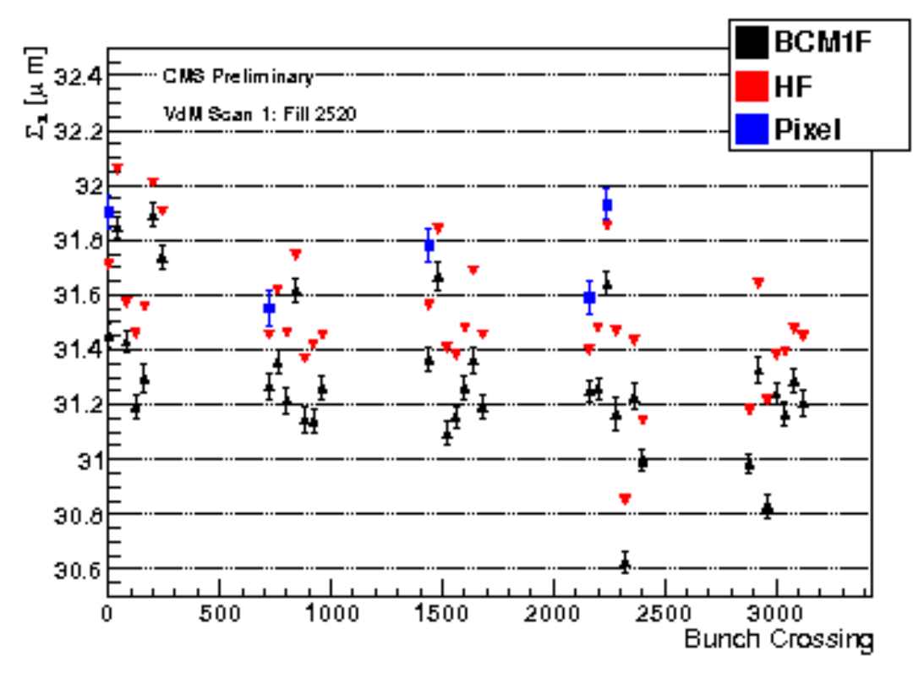




A charged particle passing through the diamond sensor creates a signal on the metallized pads on both surfaces of the diamond. This signal is read out through a preamplifier and shaper and passed through an optical fiber to the backend electronics, located in the underground service cavern. From there 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, later, a dedicated board (RHU). Additionally, a multiple gating and delay (MGD) system was developed to provide precisely timed gates for the measurement of beam-gas and albedo rates. 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.

Run I Results



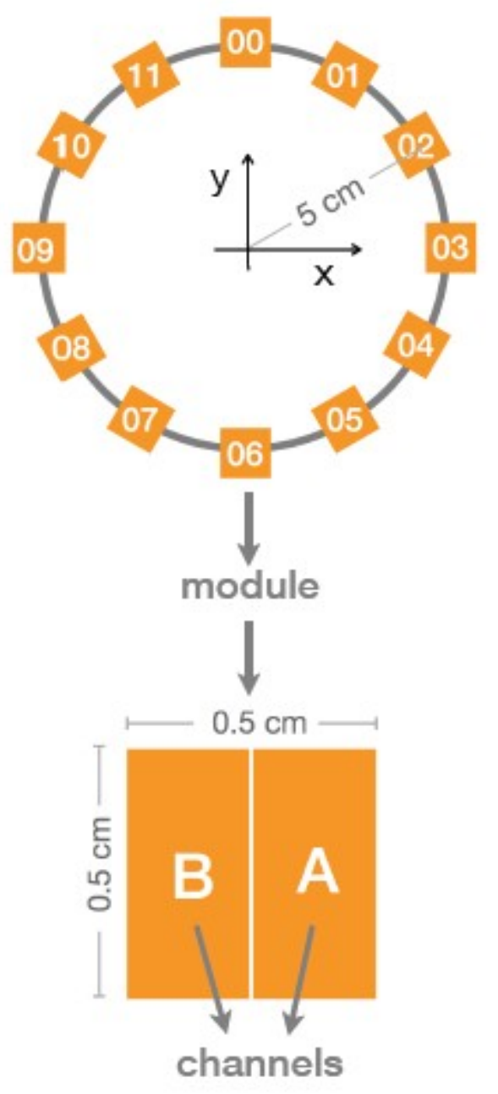


BCM1F was successfully tested as a luminometer during Run I. The BCM1F detection probability was measured to be extremely linear with luminosity, which demonstrates its suitability for use in the measurement. BCM1F also participated in CMS-wide van der Meer scans, which provide the calibration for the absolute luminosity measurement. During a van der Meer scan, the LHC's two proton beams are scanned across each other in the x and y coordinates, with the BCM1F hit rate recorded at each scan step. The calibration constant can be extracted from the fit of the produced curve. 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.

Upgrade Concept

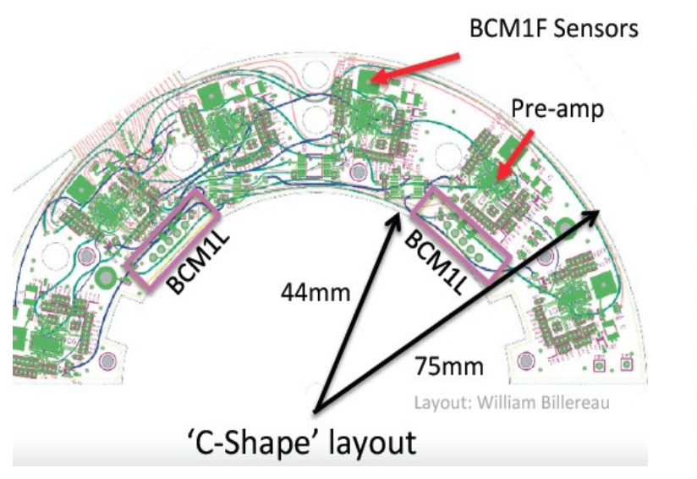
The upgrade of the LHC has multiple implications for the BCM1F system. First, the higher luminosity means a higher hit rate in BCM1F. At a luminosity of 10^{34} $cm^{-2}s^{-1}$, the BCM1F charged particle flux is around 3 x 10^7 $cm^{-2}s^{-1}$. BCM1F should be able to handle the increased radiation 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.

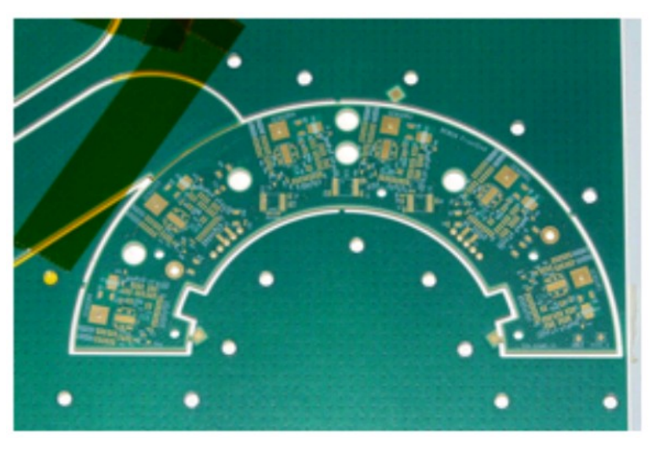
The BCM1F upgrade strategy addresses these conditions. To increase the system's dynamic range and maintain linearity, the number of channels is being increased. The system will be expanded from 8 to 24 diamonds, and each diamond will have two metallization pads for a total of 48 channels. This makes 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.



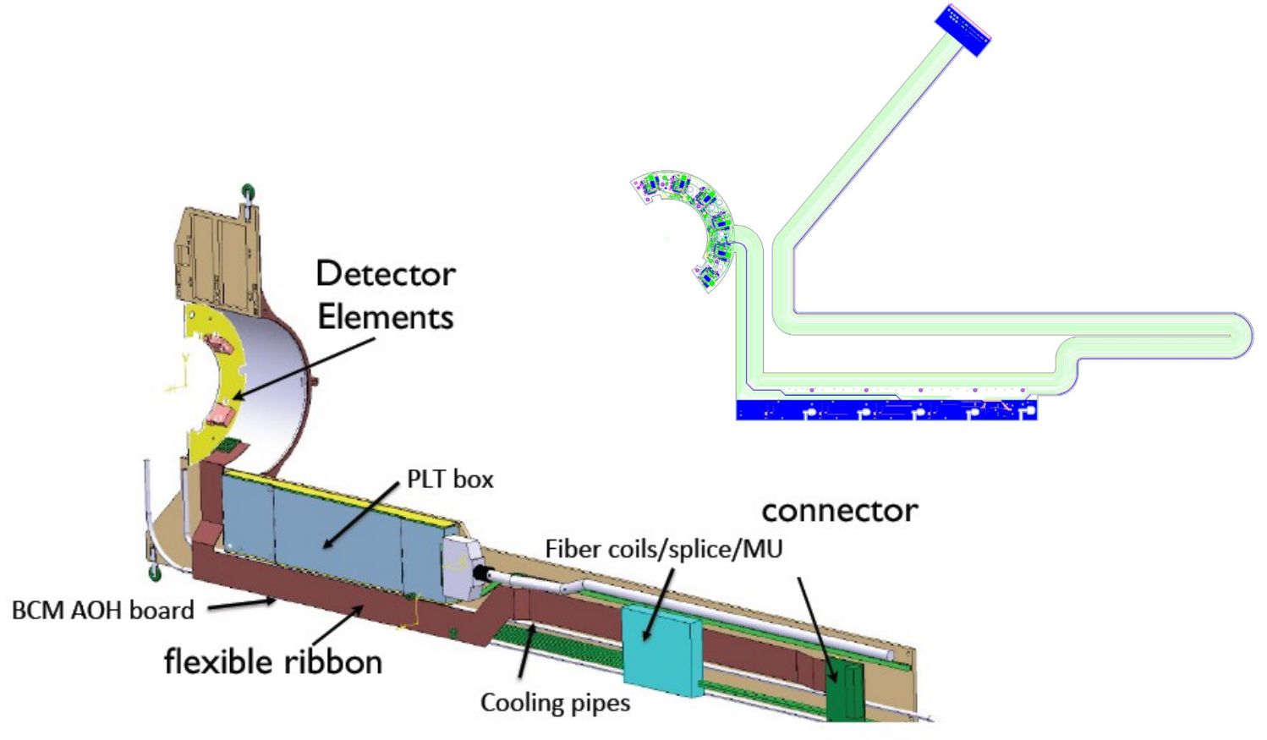
This expansion means the entire readout system must also be scaled up to 48 channels. In addition, faster electronics will increase sensitivity to hits that are close in time. Furthermore, to complete BCM1F's development as an online luminometer, the readout will be integrated into the existing CMS luminosity DAQ system.

Upgrade Carriage Design

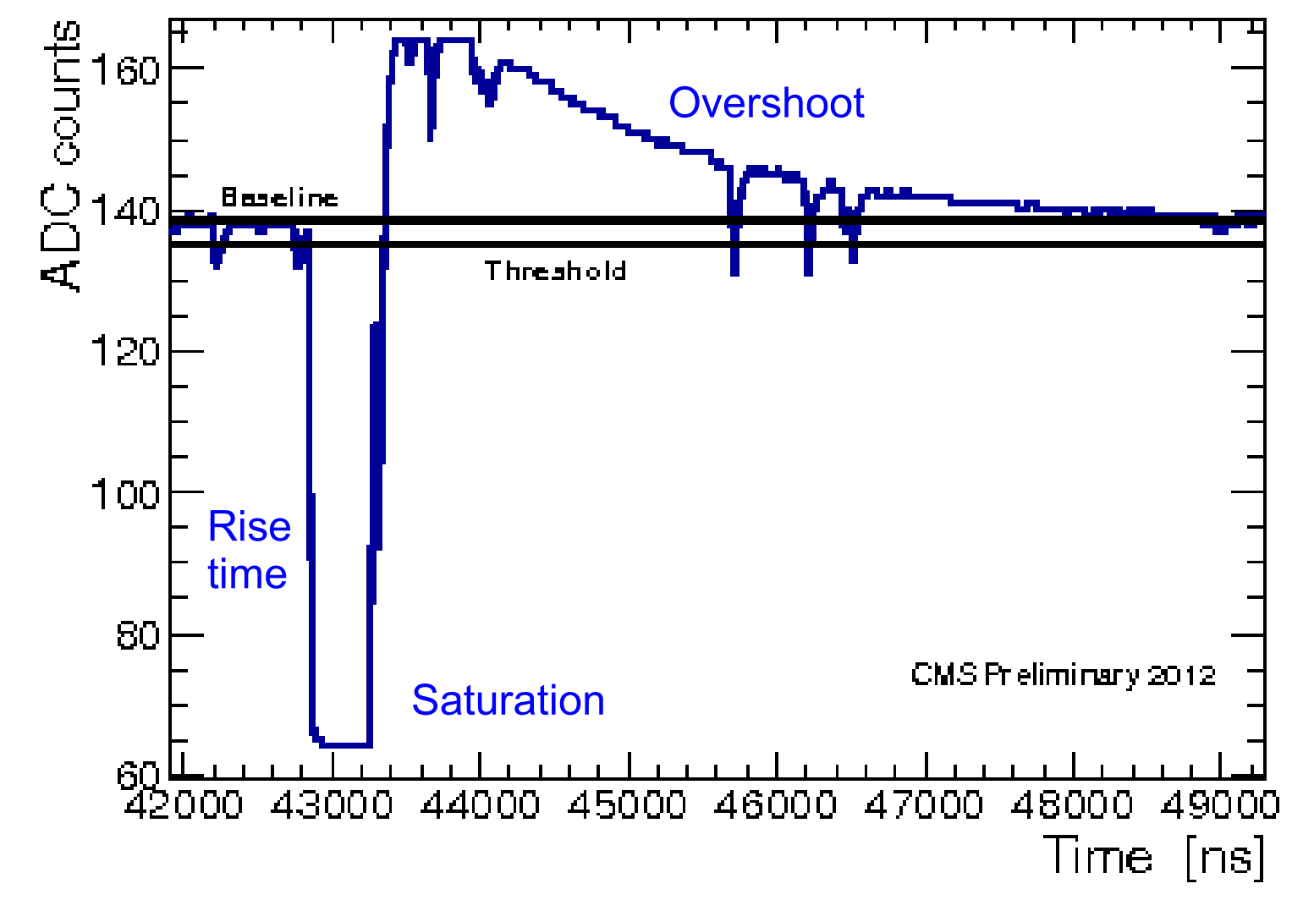




The detector carriage for the upgrade consists of a carbon-fiber frame carrying a semi-rigid PCB. The rigid C-shape holds the BCM1F sensors as well as the frontend electronics. The optical components are mounted on the rigid arm of the PCB, further away from the beamline than in Run I in order to lower 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.



Improving Frontend Electronics

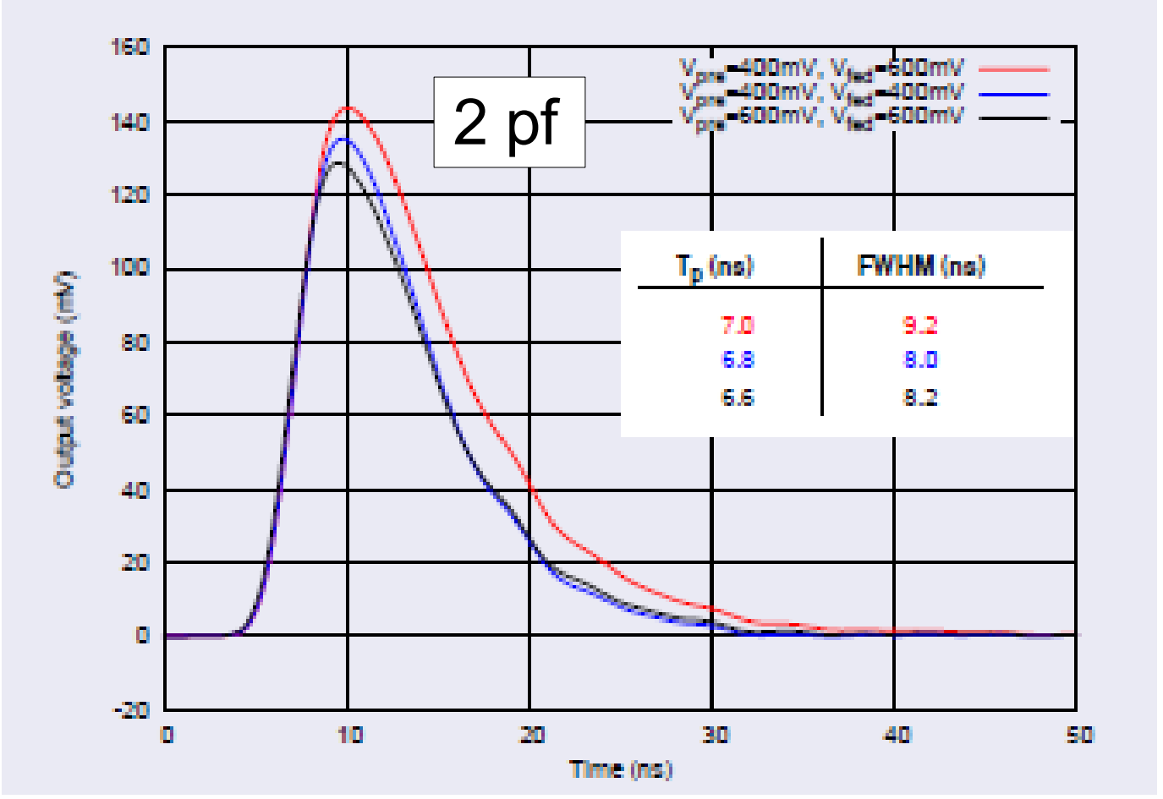


Sources of inefficiency in Run I frontend electronics

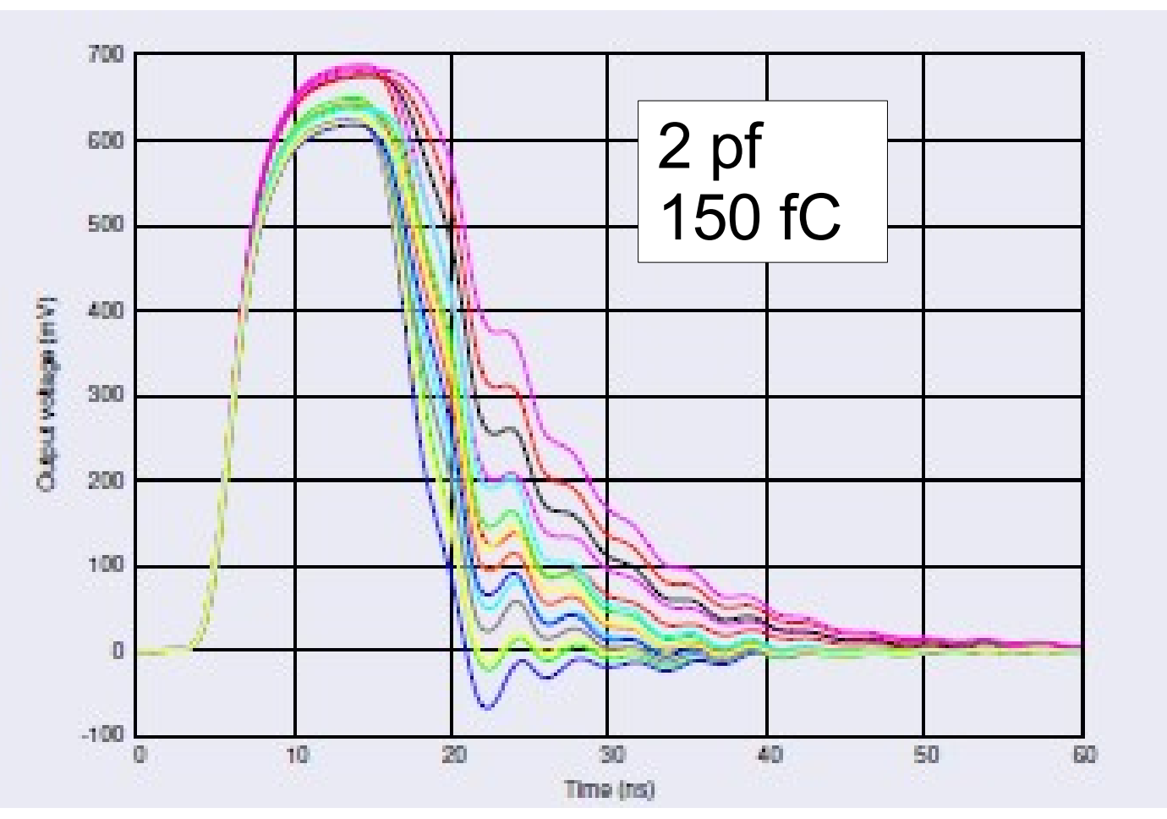
The frontend electronics in the Run I system had several sources of inefficiency. The rise time was 25 ns, the same as the foreseen bunch spacing interval for LHC Run II. This could potentially cause a large variation in detected signal arrival time. In addition, occasional large signals caused the preamplifier 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.

New fast frontend ASIC

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. In addition, for large signals, the time-over-threshold is less than ~30 ns, and the overshoot time is very small. This is a large improvement in behavior and will address the issues seen in the previous system.



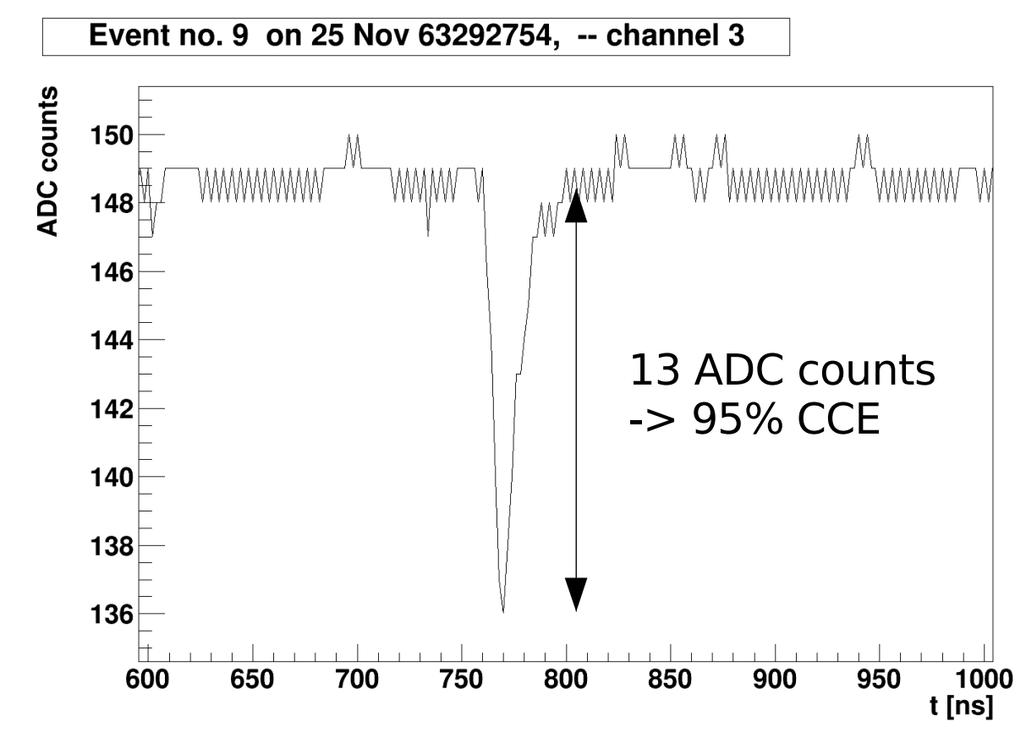
ASIC behavior for MIP signals. Rise time is ~7 ns.

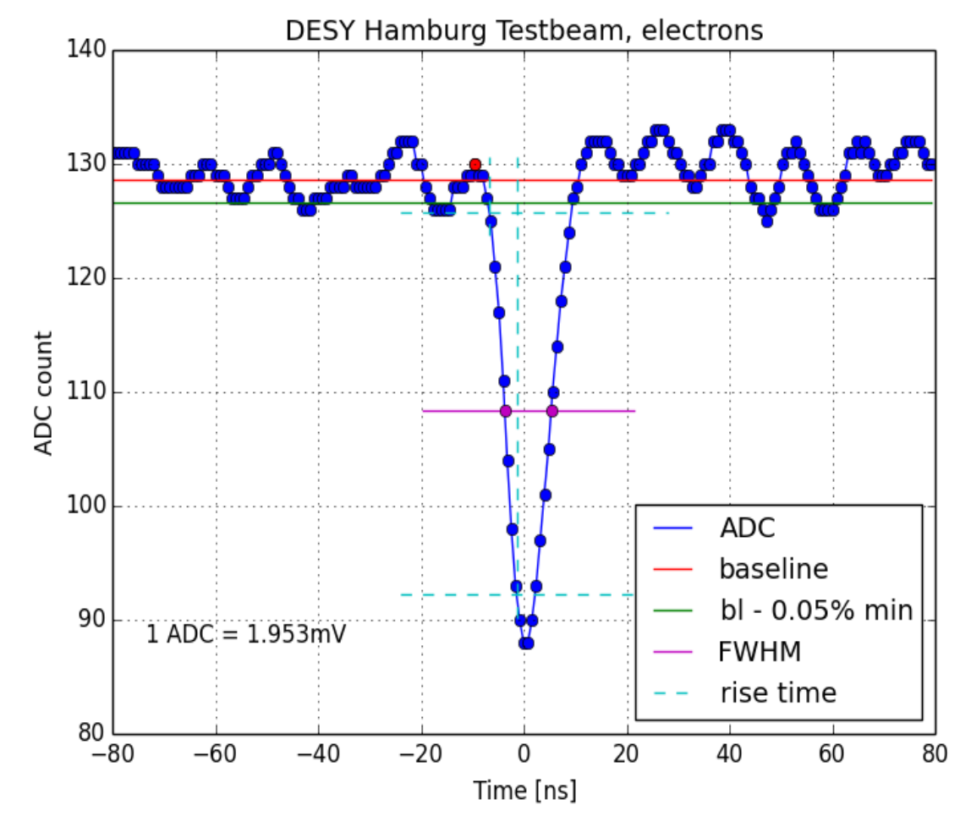


ASIC behavior for large signals. Each colored line represents one trial.

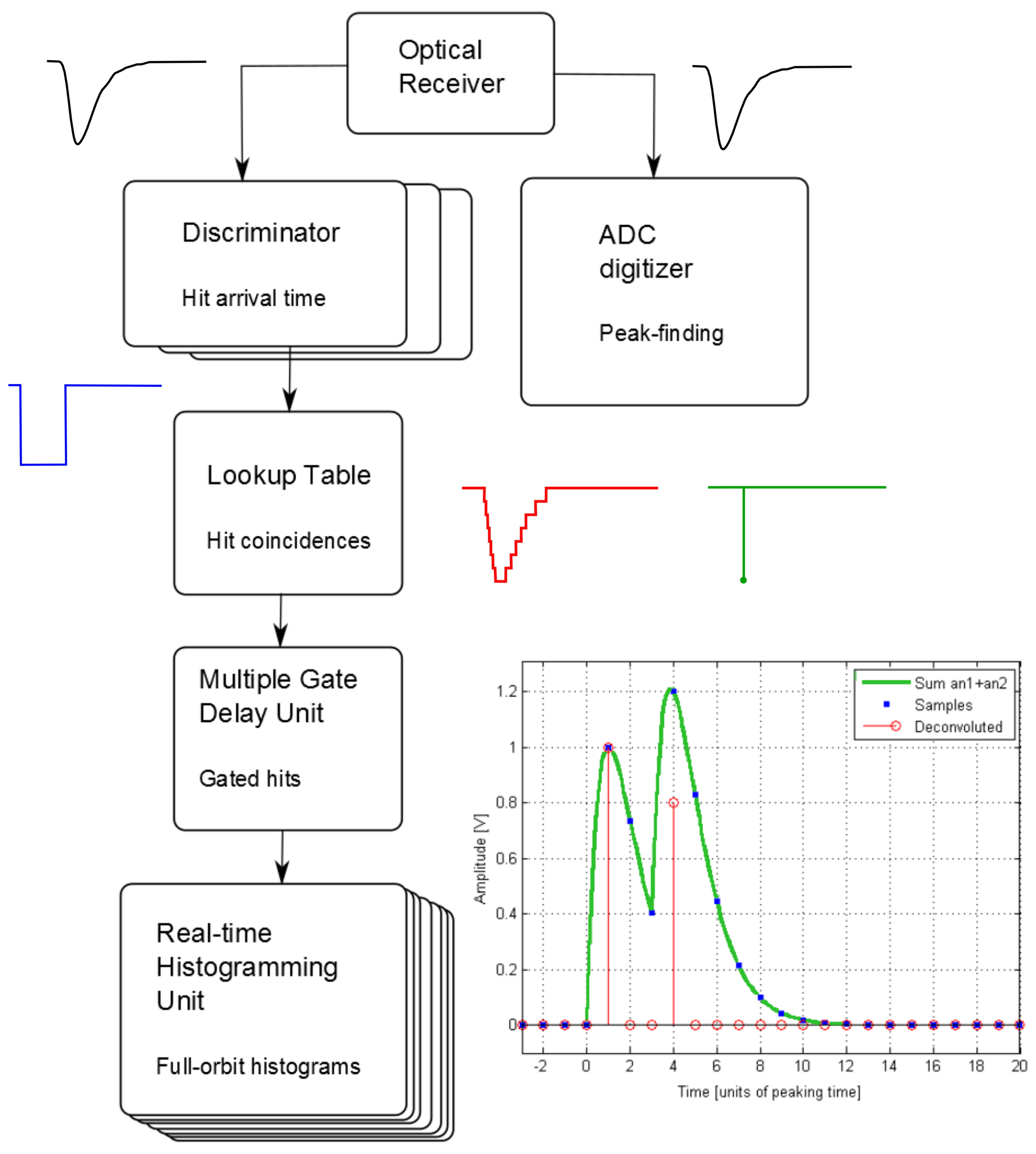
Test Beam Results

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 (upper plot) show a high measured charge-collection efficiency, as well as the fast rise time of the ASIC, in accordance with expectations. In addition (lower plot), the performance of a digitizer option (see section *Backend Electronics*) was measured. The current results are encouraging, and analysis is ongoing.





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.

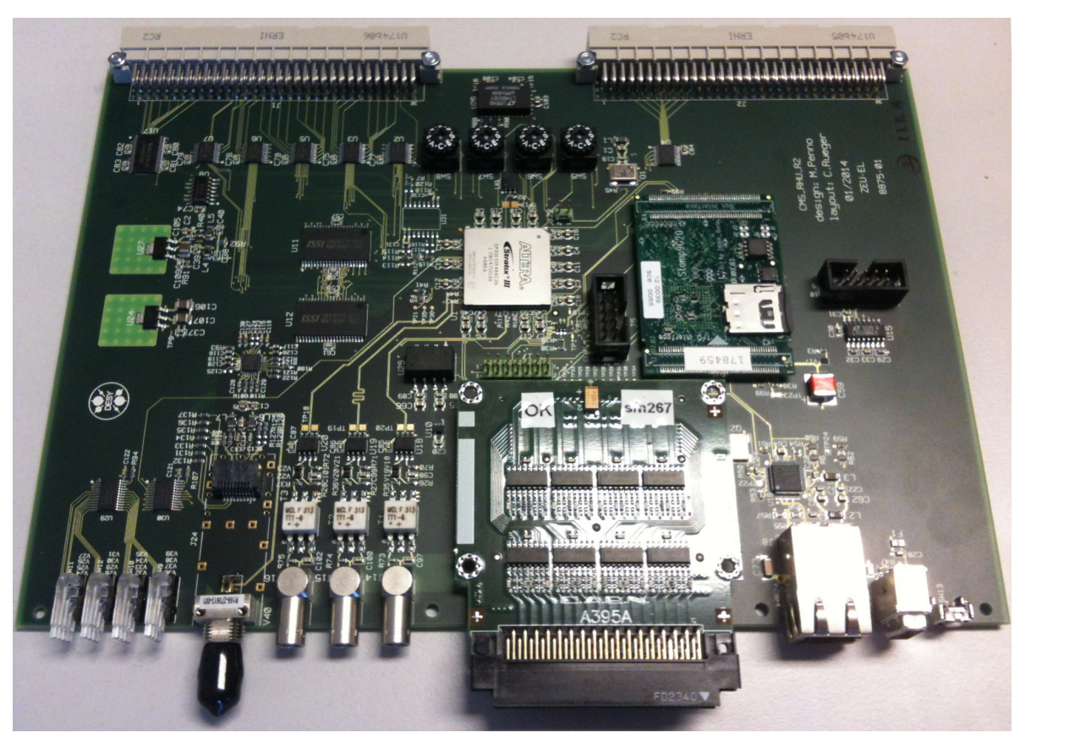
VME discriminator path

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 (see sections *Dedicated Readout Board* and *Luminosity Subsystem Integration* at right).

μTCA digitizer path

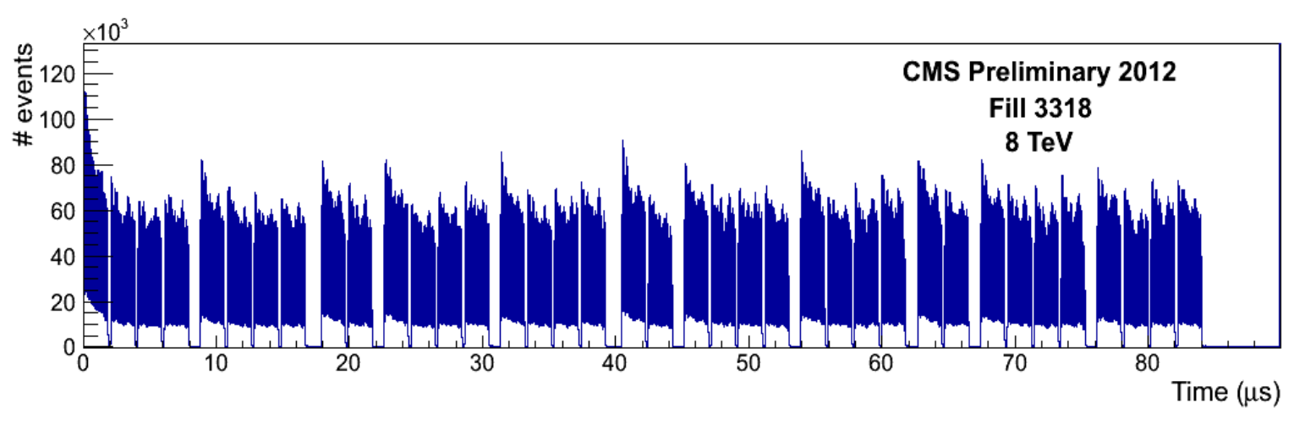
In parallel with the discriminator path, a μTCA digitizer system is being developed for the purpose of fast peak-finding. The digitizer will be able to identify both the arrival time and the peak height of arriving signals, and in particular will be able to distinguish overlapping signals, which is more 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 (see section *Luminosity Subsystem Integration* at far right).

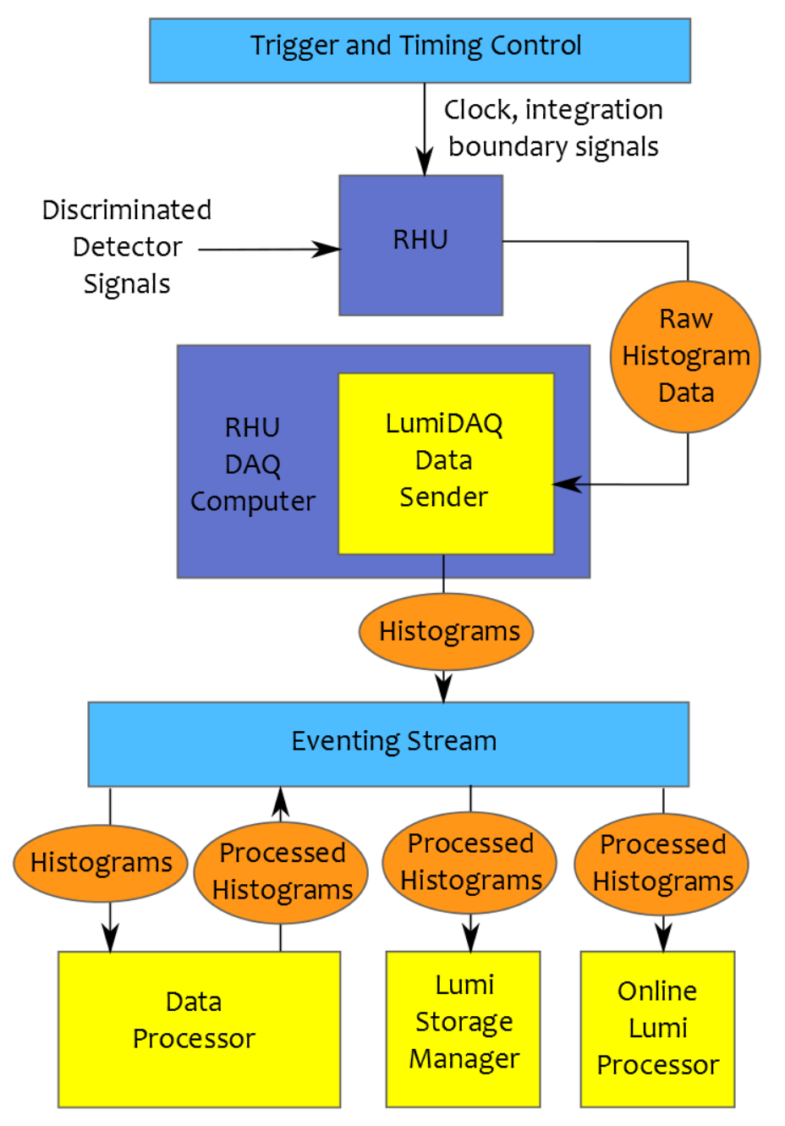


Dedicated readout board

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.



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.