Performance of the Fast Beam Conditions Monitor BCM1F of CMS in the first running periods of LHC

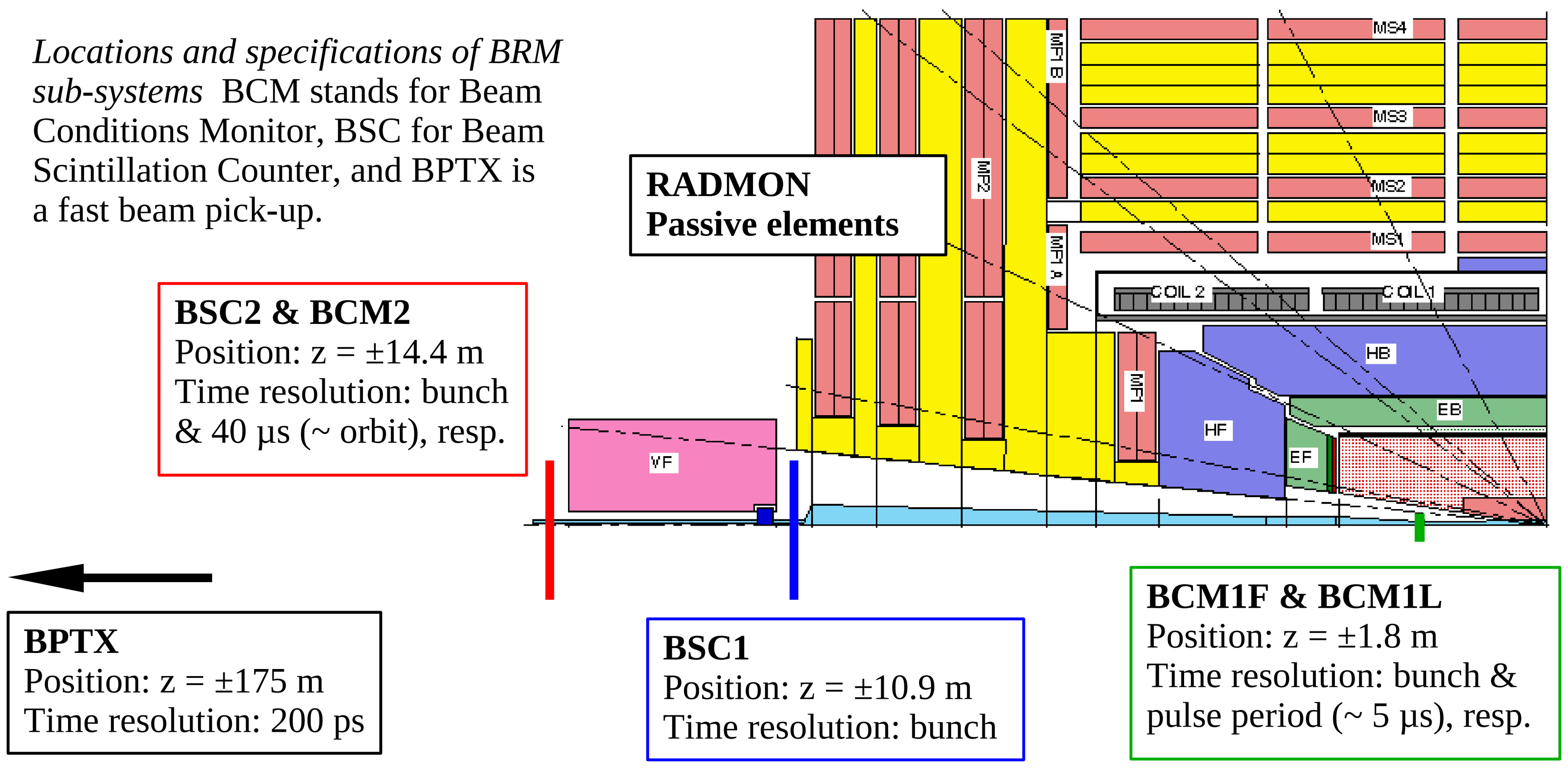
Ringo S. Schmidt on behalf of the CMS-BRM group

DESY, Zeuthen and Brandenburg University of Technology, Cottbus, Germany

The CMS Beam Conditions and Radiation Monitoring System (BRM)[1]

The Compact Muon Solenoid (CMS)[2] is a multi-purpose detector experiment at interaction point (IP) 5 of the Large Hadron Collider (LHC). Beam losses in the LHC would cause serious harm to detector components, so their advent must be detected in order to avert any damages. A safety system is needed that allows diagnosis of adverse beam conditions and can initiate beam aborts or shut down vulnerable detectors, if necessary. Throughout the CMS detector, the beam conditions and the radiation level are monitored by seven sub-systems working on different time scales. These systems must be active whenever there might be beam in the LHC.

Locations and specifications of BRM sub-systems BCM stands for Beam Conditions Monitor, BSC for Beam Scintillation Counter, and BPTX is a fast beam pick-up.

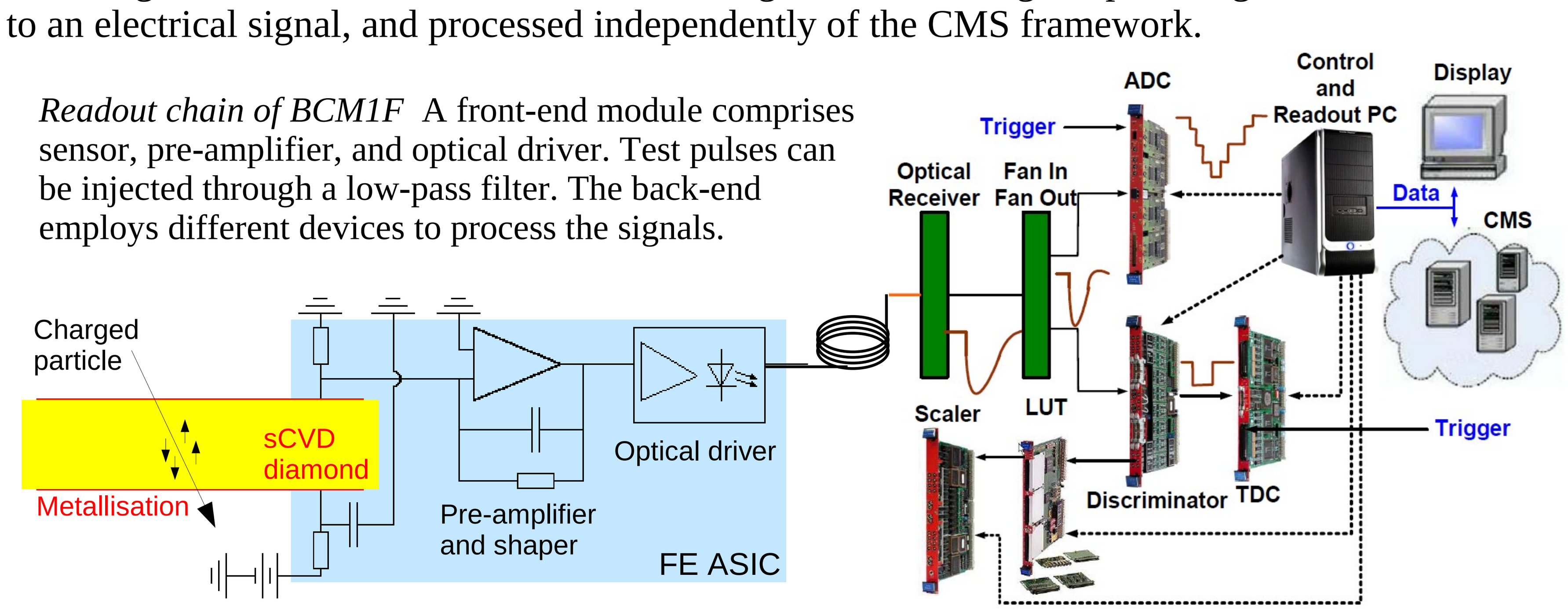


The Fast Beam Conditions Monitor, BCM1F[3]

Conceptual design Four modules, consisting of sensor, pre-amplifier, and optical driver, are arranged around the beam pipe on either detector side at distances of 4.5 cm from the nominal beam axis and ±1.8 m from the IP. They measure the flux of beam halo particles as well as collision products, thereby providing *CMS Background 1* for LHC. Particularly radiation-hard components are needed in this situation. Additional requirements are low power dissipation and excellent time resolution in order to detect single relativistic charged particles bunch by bunch.

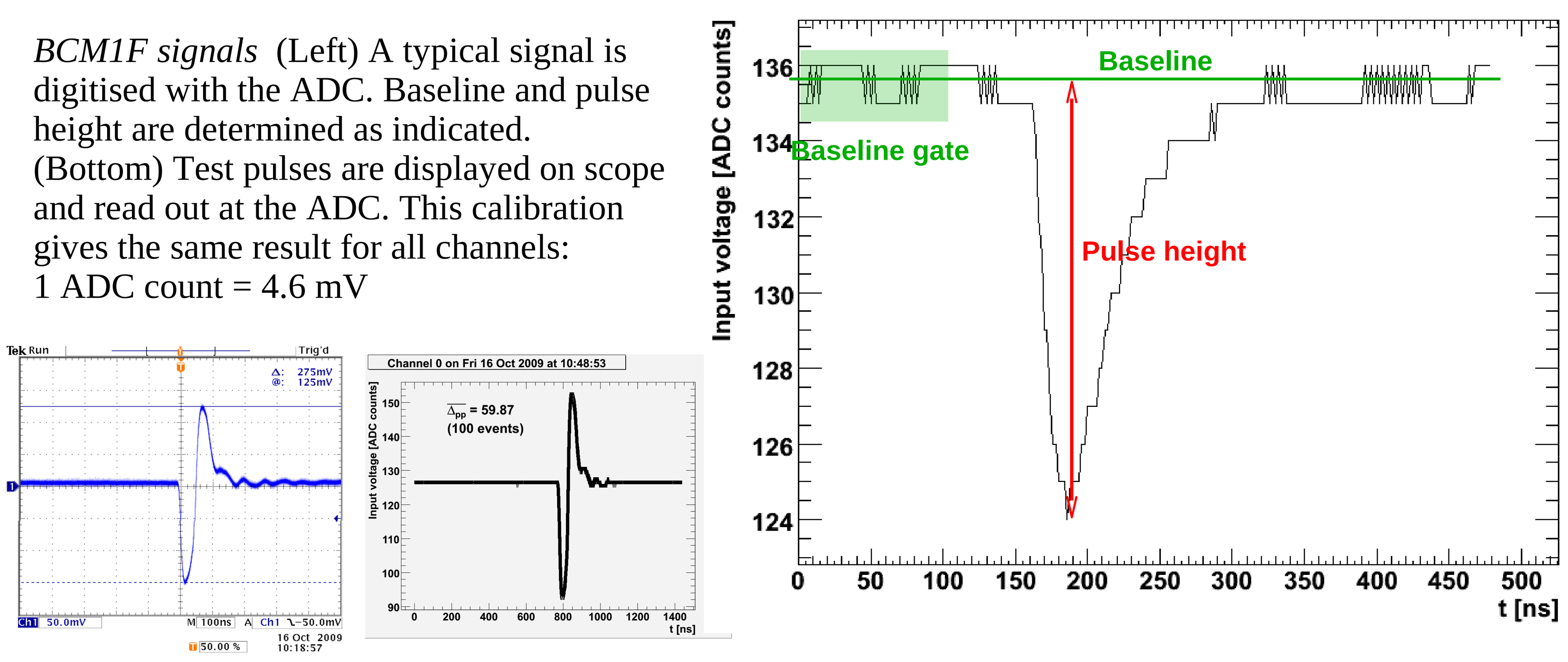
Readout chain The sensors are single-crystal chemical vapour deposition diamonds of the size 5 mm × 5 mm × 400 μm. They are metallised on both sides and operated as solid state ionisation chambers. The charge-sensitive pre-amplifier collects the charges induced and shapes a proportional signal. This is transmitted to the counting room as analogue optical signal, converted back to an electrical signal, and processed independently of the CMS framework.

Readout chain of BCM1F A front-end module comprises sensor, pre-amplifier, and optical driver. Test pulses can be injected through a low-pass filter. The back-end employs different devices to process the signals.

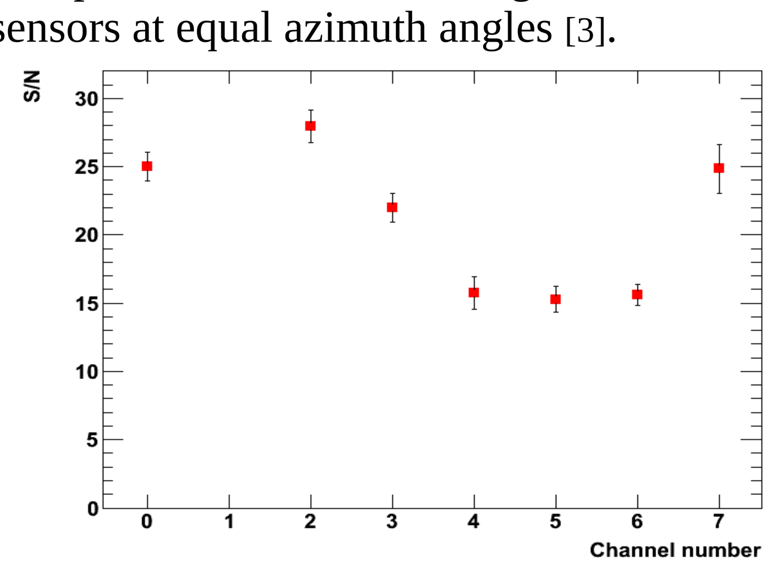


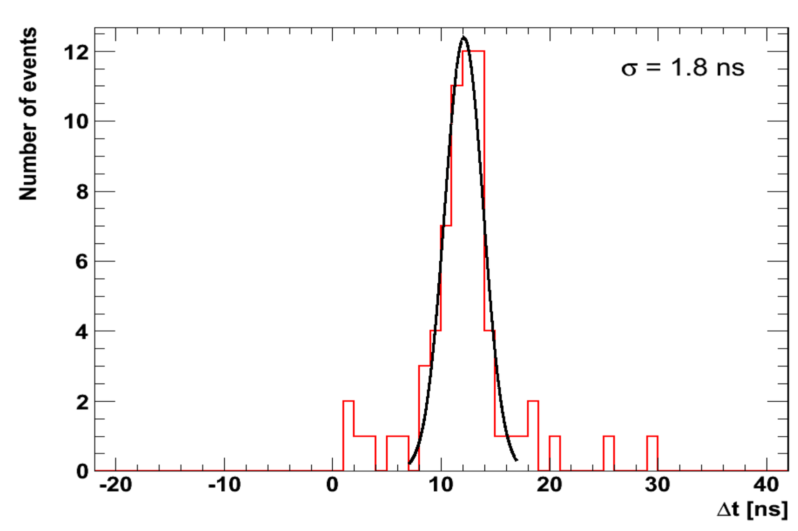
Data acquisition In the back-end, the analogue signals are fanned out in order to be processed and analysed in different aspects. For example, an analogue sum of all eight channels can be used as a trigger source. As well as the signals of the eight channels, this is fed in to a discriminator that supplies scalers and time-to-digital converters (TDC) with logical signals. An analog-to-digital converter (ADC) samples the input voltages to obtain digitised images of the signals.

BCM1F signals (Left) A typical signal is digitised with the ADC. Baseline and pulse height are determined as indicated. (Bottom) Test pulses are displayed on scope and read out at the ADC. This calibration gives the same result for all channels: 1 ADC count = 4.6 mV



Characterisation Digitised signals are exploited to understand the performance of the system. It entirely meets the expectations as could be proved already in the initiatory runs of LHC in 2008. The plots below show the signal-to-noise ratio of the detectors* and the time difference between sensors at equal azimuth angles [3].



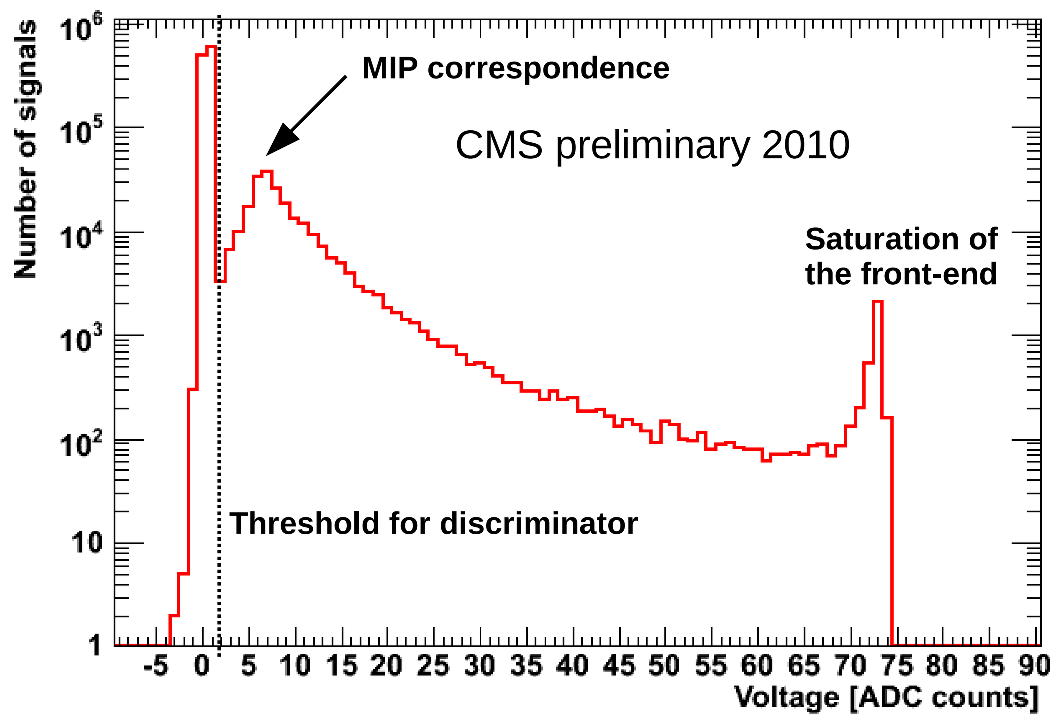


* Channel 1 had a faulty cable in 2008. Meanwhile, this has been replaced, and Channel 1 delivers data as well.

Signal Spectra from the ADC

The pulse height spectrum of signals taken in a run with colliding bunches is displayed for ADC input channel 0. The trigger used for this measurement was an OR of all BCM1F channels, discriminated with a threshold of −24 mV. Therefore, a fraction of the events contains merely the baseline, which accumulates to the pedestal peak at about zero pulse height. The maximum position of the signal peak is considered the pulse height for a minimum ionising particle (MIP). The local minimum between those peaks is used to determine the optimal threshold to be set in the discriminator. The third peak at the upper end of the spectrum is caused by signals in saturation of the front-end electronics, an effect that arises at about ten times the MIP amplitude.

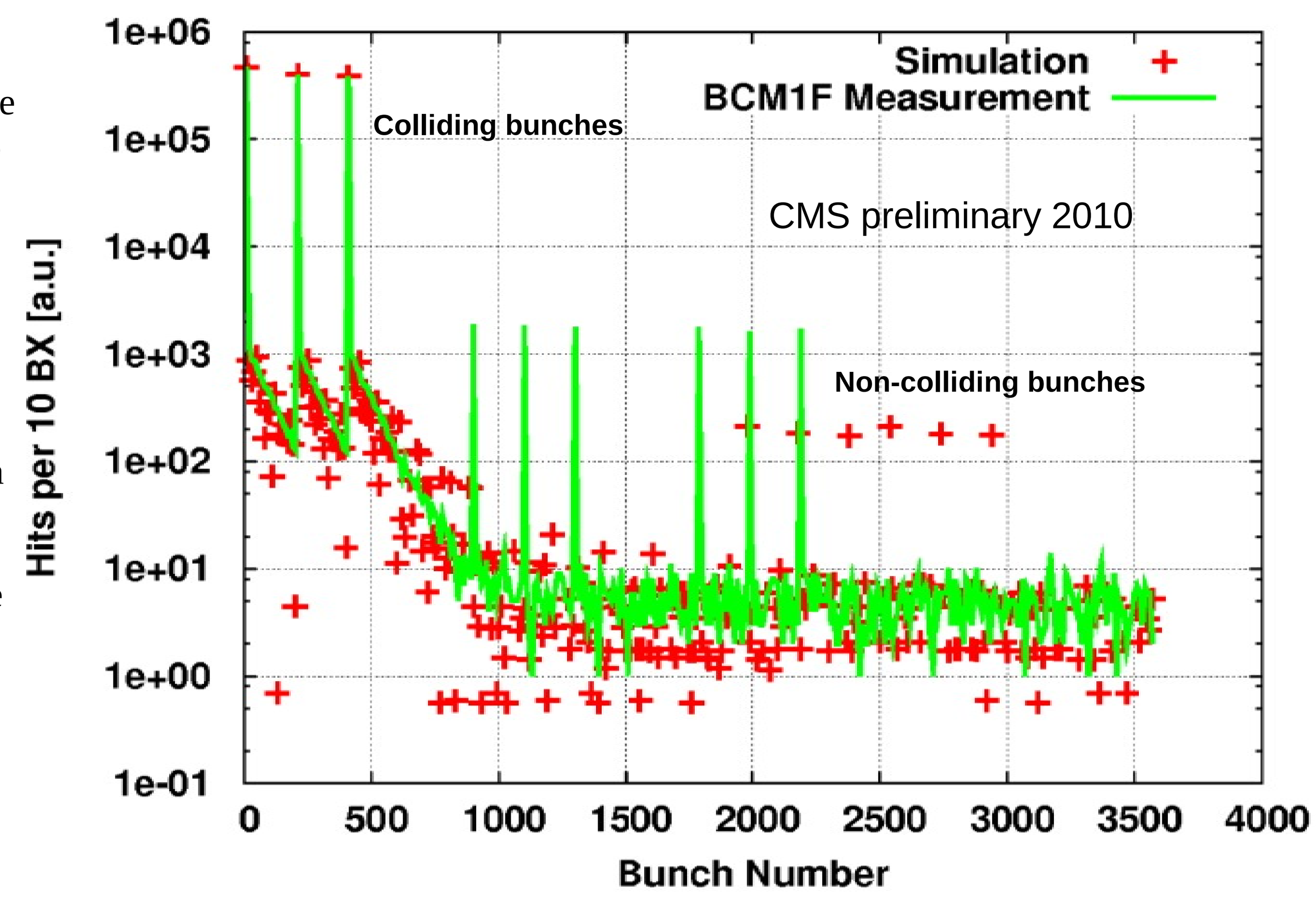
Pulse height This spectrum, obtained from the ADC, exhibits three peaks. The minimum between pedestal and signal peak is used to discriminate between noise and signals. The third peak is caused by signals with a pulse height that exceeds the limitations of the front-end electronics (about 10 MIPs).



Timing Information from the TDC

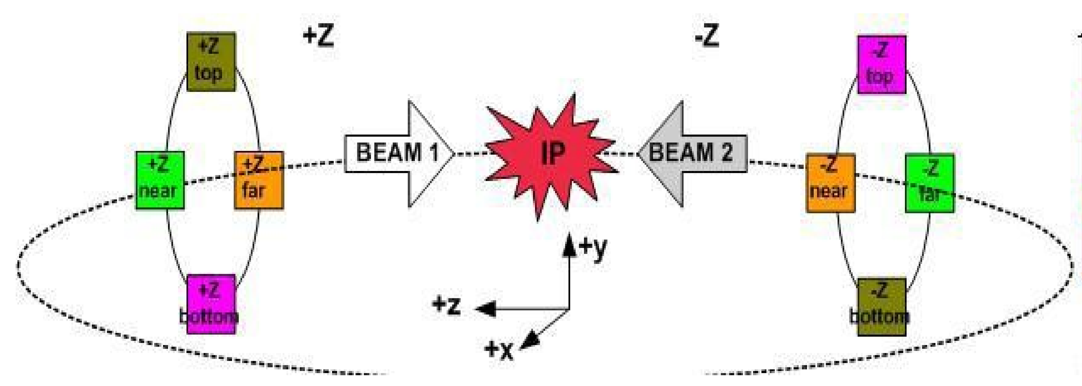
The time of hits in the TDC is displayed within the LHC orbit. The first three peaks represent colliding bunches. They have long tails up to the μs range. The peaks around bunch number 1000 and 2000, respectively, show three non-colliding bunches of each beam. A simulation has been performed by Steffen Müller to understand the reasons for these long tails. The results agree well with the data and confirm that scattered particles as well as decays of activated material contribute.

Time resolution The bunch structure of the LHC orbit is observed with the TDC (green line). Colliding and non-colliding bunches can be clearly distinguished by their hit rates. A detector simulation (red markers) shows very good agreement with the data.



Online Analysis with Scalers und Look-up Table

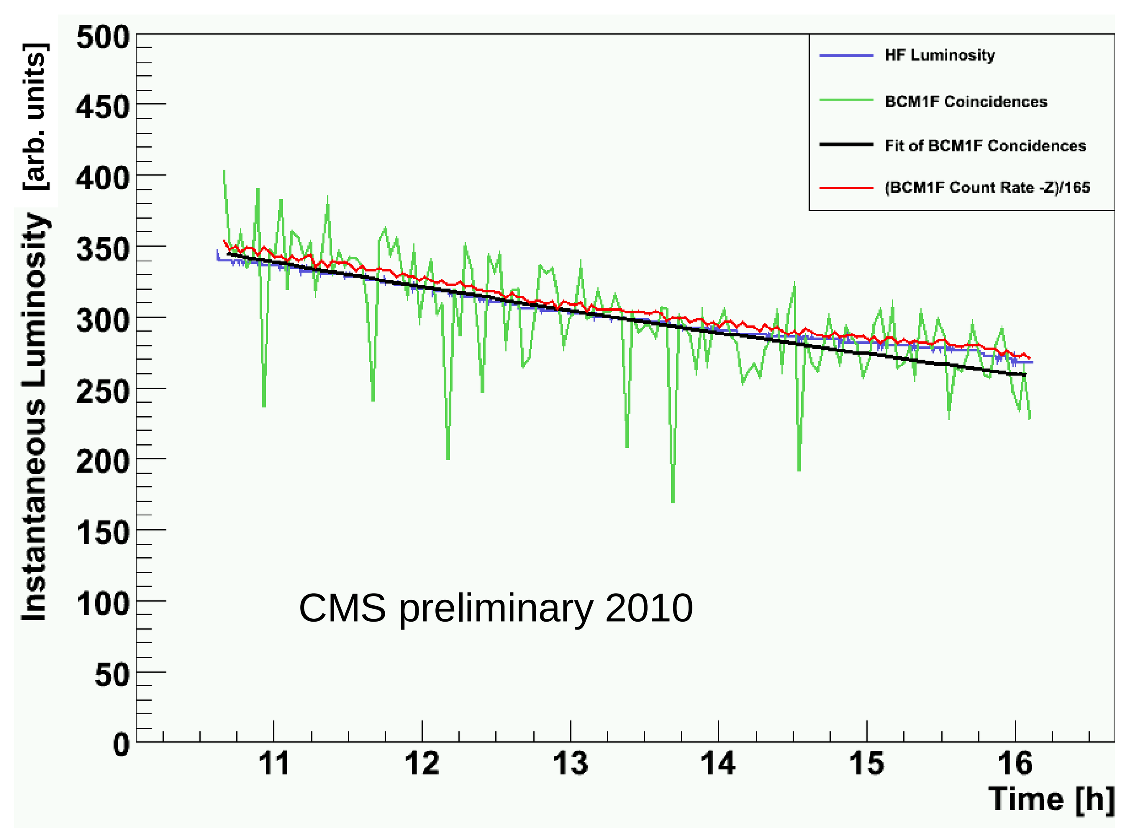
The discriminator output line to the scaler is listened in to by a multi-purpose board. A look-up table is programmed to its FPGA to find back-to-back coincidences of BCM1F signals, as illustrated below.



Coincidences in LUT	BCM1F channels
A	-Z top & +Z bottom
B	+Z top & -Z bottom
C	+Z near & -Z far
D	-Z near & +Z far

The coincidence rate is compared to the luminosity measured by the Hadron Forward calorimeter (HF) to explore the possibility to measure the luminosity with BCM1F. The HF result (blue line) has been scaled to the BCM1F coincidence rate (green line), which has been fit (black line) in order to compare the slopes more easily. In addition, the scaled count rate of BCM1F on the −z side is shown (red line). The course of the latter agrees better with the HF luminosity. This needs to be understood and, therefore, is still subject to investigations.

Current studies This plot shows a qualitative comparison of rates obtained from the BCM1F scalers to the luminosity measured by HF.
The rate of all back-to-back coincidences is fit to allow a comparison to the shape of the HF luminosity. The count rate of all −z channels as well as the HF luminosity are scaled to the level of the coincidence rate.



References:
[1] A.J. Bell on behalf of the BRM group, "Beam and Radiation Monitoring for CMS." Poster N30-242 presented at the IEEE NSS 2008, Dresden.
[2] The CMS Collaboration, " The CMS experiment at the CERN LHC." JINST 3 S08004, 2008.
[3] R. Hall-Wilton et al. "Fast beam conditions monitor (BCM1F) for CMS" Nuclear Science Symposium Conference Record, 2008. NSS 08. IEEE
[4] W. Lohmann et al., "Fast beam conditions monitor BCM1F for the CMS experiment" Nuclear Instruments and Methods in Physics Research A 614 (2010) 433-438