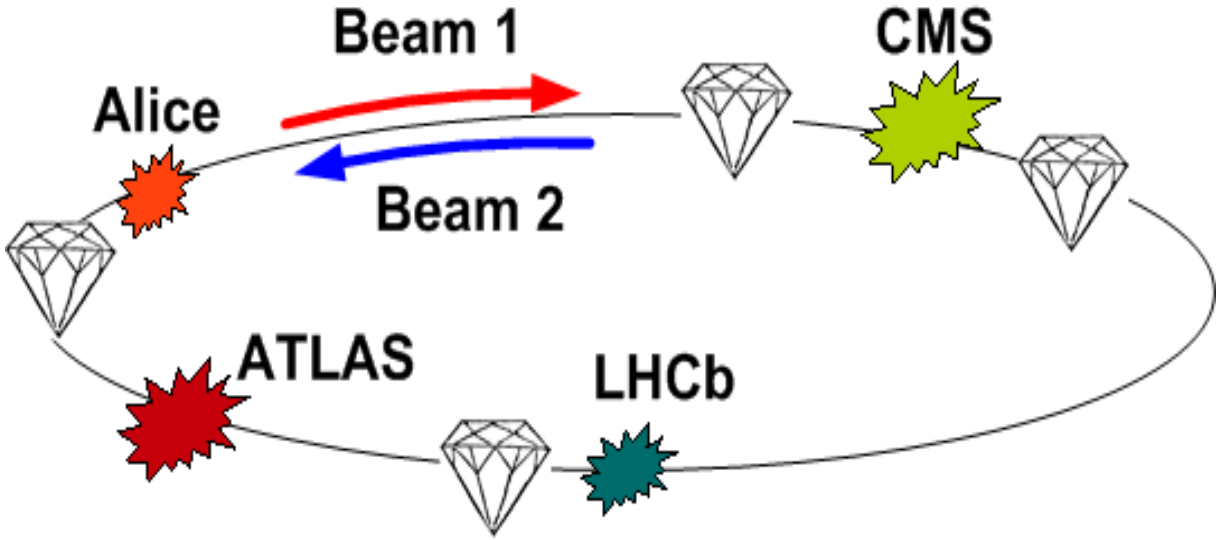


Diamond sensors as beam conditions monitors in CMS and LHC

Maria Hempel – DESY Zeuthen & BTU Cottbus
on behalf of the BRM-CMS and CMS-DESY groups

3rd CARAT Topical Workshop on Diamond Detectors
GSI Darmstadt, 11th - 13th December 2011

Outline

1. Description of the CMS Beam Conditions and Radiation Monitoring system (BRM)

2.The Beam Conditions Monitor (BCM)

3. The Fast Beam Conditions Monitor (BCM1F)

4. The CMS BCM1F results

5. The LHC BCM1F

6. Summary

Description of the CMS BRM

The BRM system of the Compact Muon Solenoid detector in LHC :

- Measures the radiation level close to or inside all sub-detectors.
- Monitors the beam halo/gas with different time resolution.
- Supports beam tuning.
- Protects CMS in case of adverse beam conditions by firing a beam abort signal.

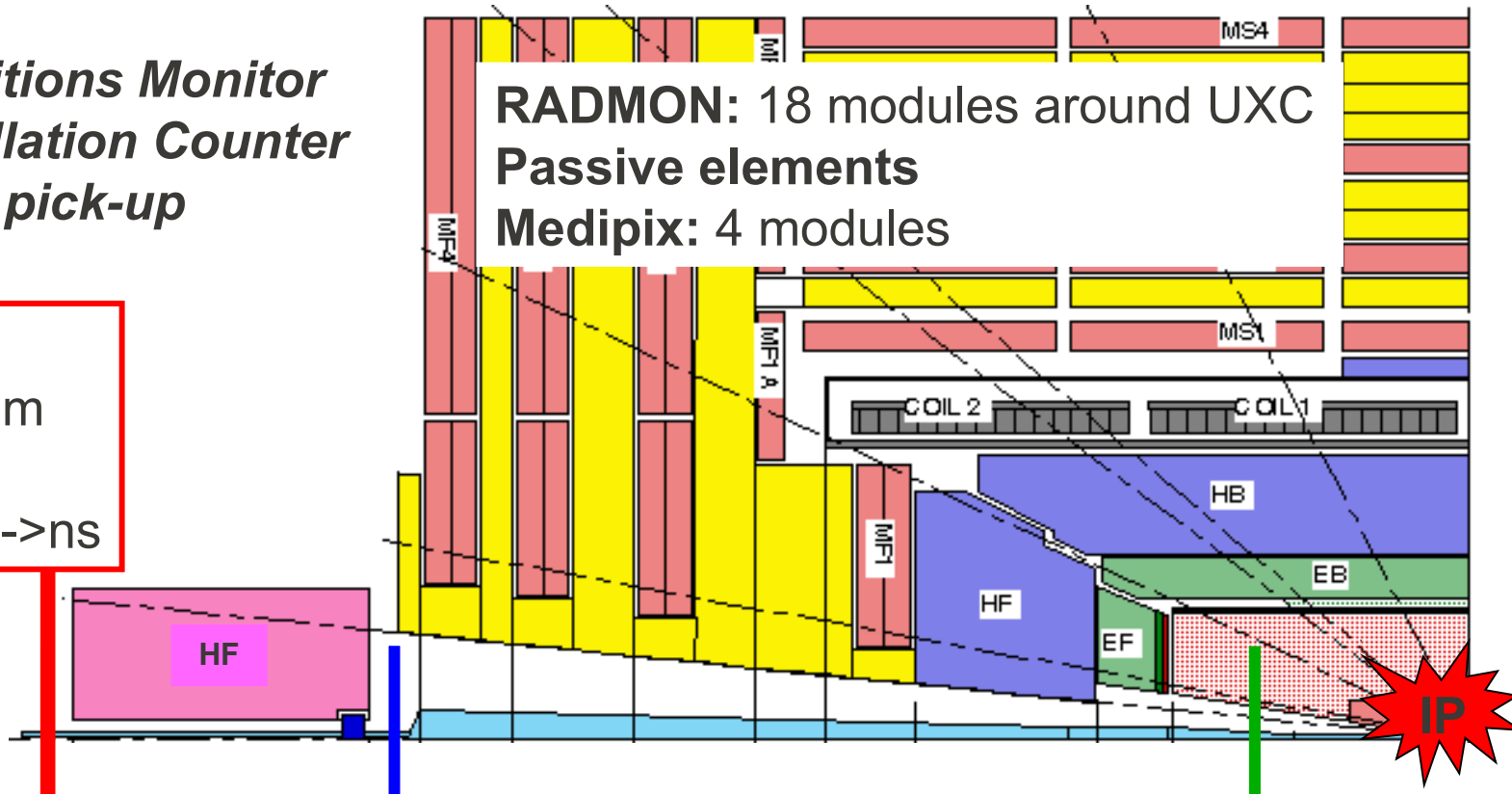
It is composed by several sub-systems:

- *BCM: diamond based current monitor with 40μs time resolution (Beam Abort & BKGD3).*
- *BSC: Beam Scintillator Counters (triggers, rates & time info of background and collision products at low lumi).*
- *BPTX: beam pick-up (triggers).*
- *BCM1F: diamond detector for monitoring beam halo, collision products and instantaneous online lumi.*

BRM subsystems in CMS

CMS half cross section and location of BRM detectors

BCM: Beam Conditions Monitor
BSC: Beam Scintillation Counter
BPTX : Fast beam pick-up



BCM2 & BSC2
Position: z = ±14.4 m
Time resolution:
BCM2->40µs, BSC->ns

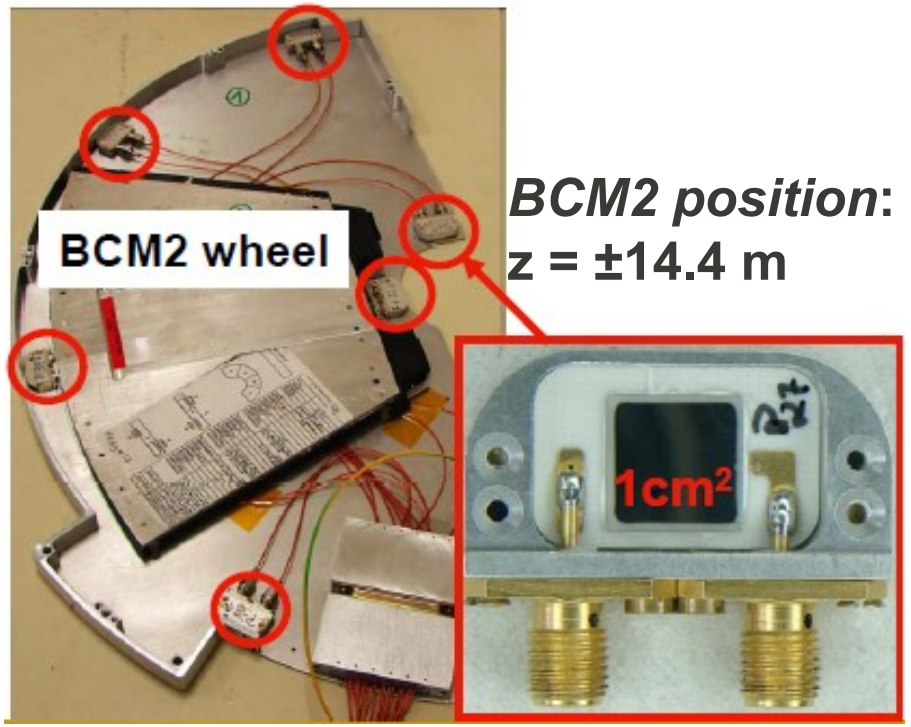
BPTX
Position: z = ±175 m
Time resolution: 200ps

BSC1
Position: z = ±10.9 m
Time resolution: ns

BCM1F, BCM1L and PLT
Position: z = ±1.8 m
Time resolution: BCM1F->ns

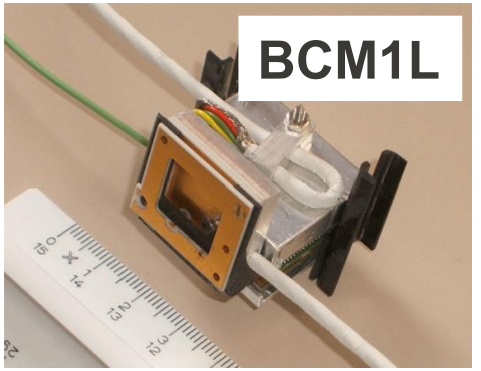
The Beam Conditions Monitor (BCM)

- BCM measures sensor current in diamonds.
- It is composed by 2 subsystems: BCM2 and BCM1L
- BCM2 can dump the beam in case the *abort thresholds* (set to protect Pixel and Tracker from too high particle fluxes) are reached.



***BCM2 position*:**
z = ±14.4 m

Detector	**32 pCVD diamonds**
Size	**10×10×0.4 mm³**
Metallization	**9×9 mmTungsten Titanium**
Bias voltage	**200V**



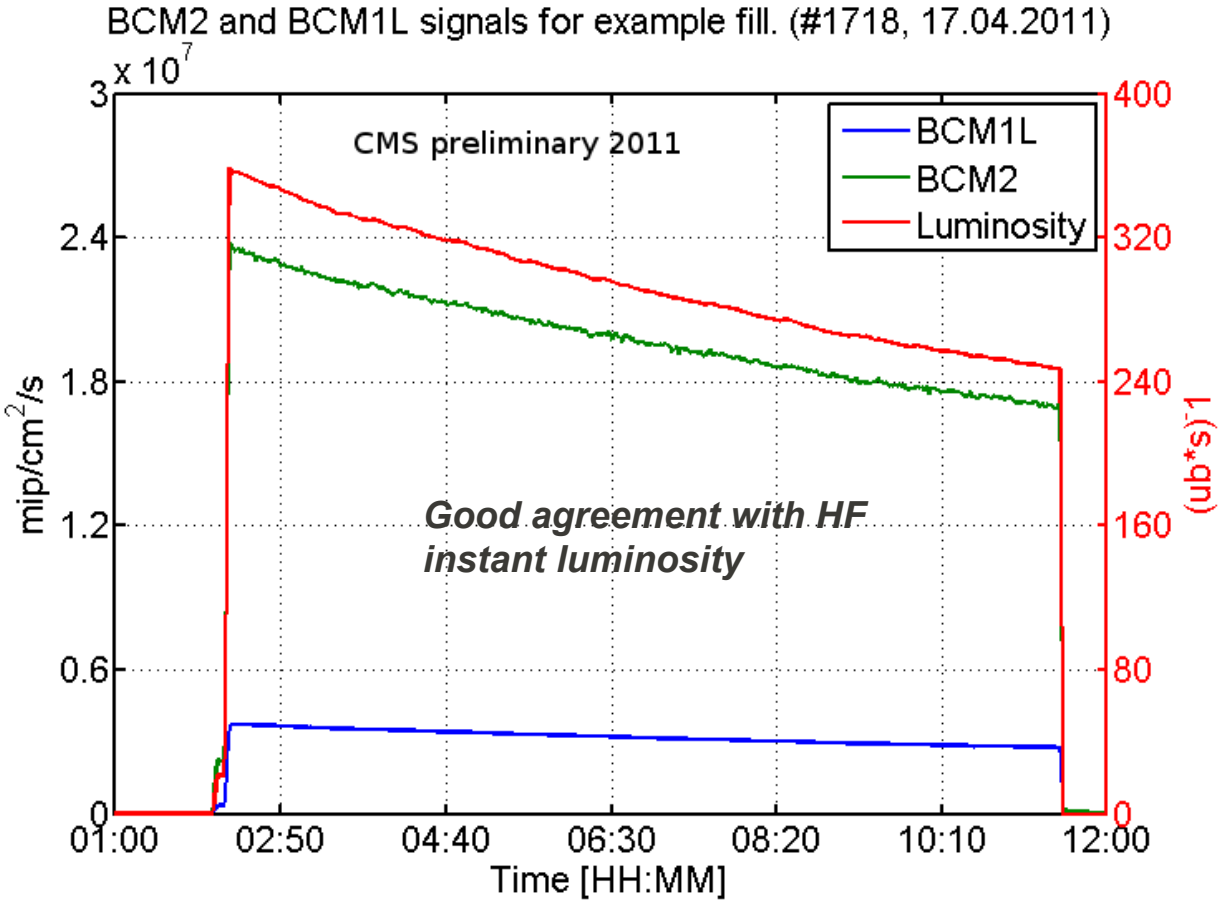
***BCM1L position*:**
z = ±1.8 m

BCM measurements with beam

BCM has been integrated in the LHC beam abort since the first running of LHC.

It delivers information about the beam conditions to CMS and LHC and can be used for the monitoring of beam loss events at long and short time scale.

Typical signal current during a proton Fill dominated by collision products



Plots courtesy of Moritz Guthoff (CERN)

Description of the CMS Fast Beam Conditions Monitor (BCM1F)

Particle detector with nanosecond time resolution measuring the beam halo particles and collision products

Tasks:

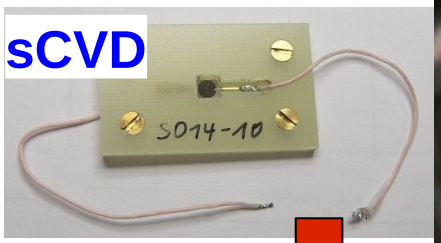
- **Monitoring and protection**
- **BKGD1 (total flux in the inner detector region) to LHC**
- **BKGD2 (beam halo flux) to LHC**
- **Instant luminosity to CMS**

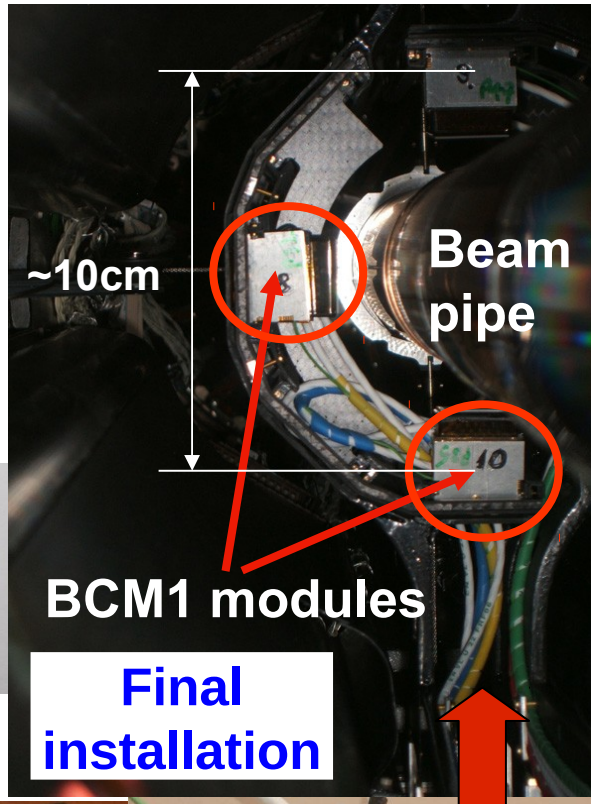
Requirements:

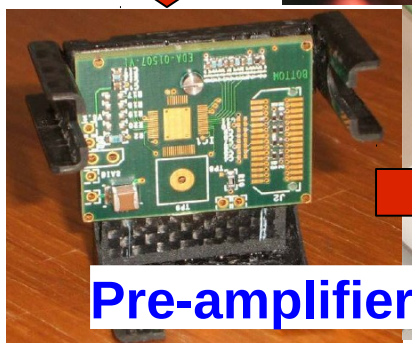
- **Detection of MIPs**
- **Low power and radiation hardness**

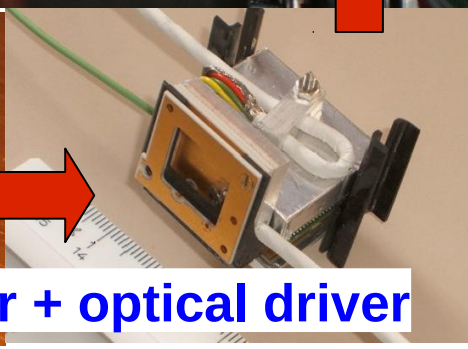
Design:

4 Single Crystal Chemical Vapor Deposition (*sCVD*) diamond sensors (5 *x* 5 *x* 0.5 mm³) in 4 modules at Z= ± 1.8m (~6.25ns) on both sides of the CMS IP, r < 5 cm





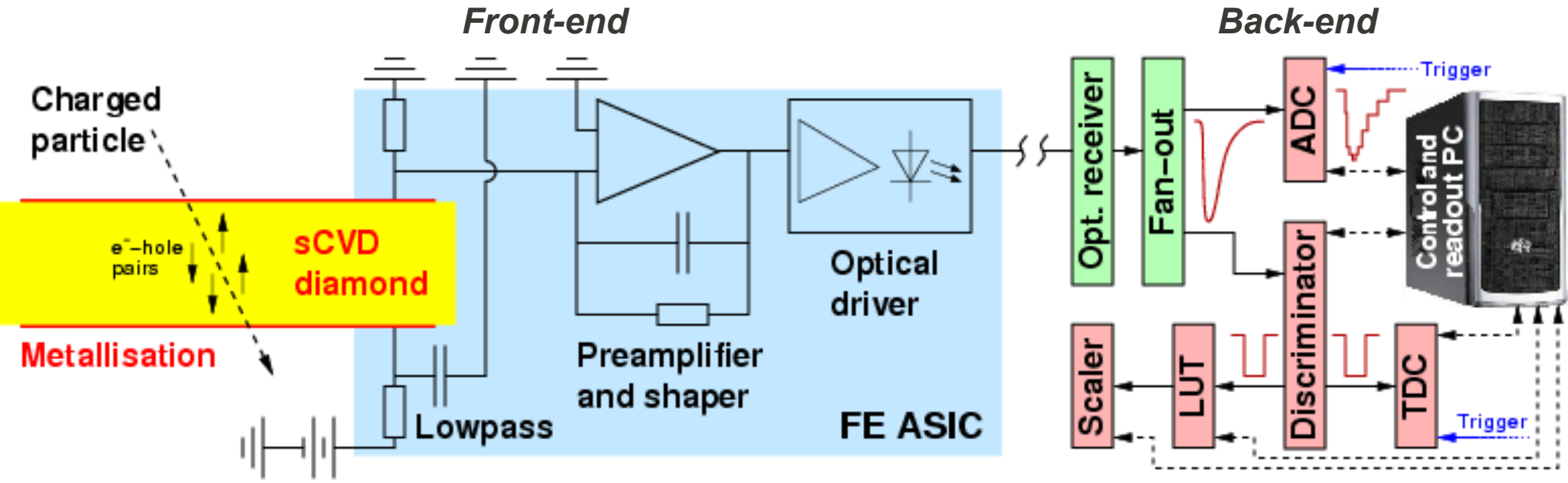




BCM1F components

Front-end:
Metallized sensors operate as solid state ionization chambers. A charge sensitive pre-amplifier collects the induced charges and shapes a proportional signal that is transmitted to the counting room as analog optical signal.

Back-end: **the optical signal is converted into electrical signal and is processed and stored independently of the CMS DAQ framework.**
The main data-acquisition devices are: scalers, ADC, TDC and LUT (FPGA)

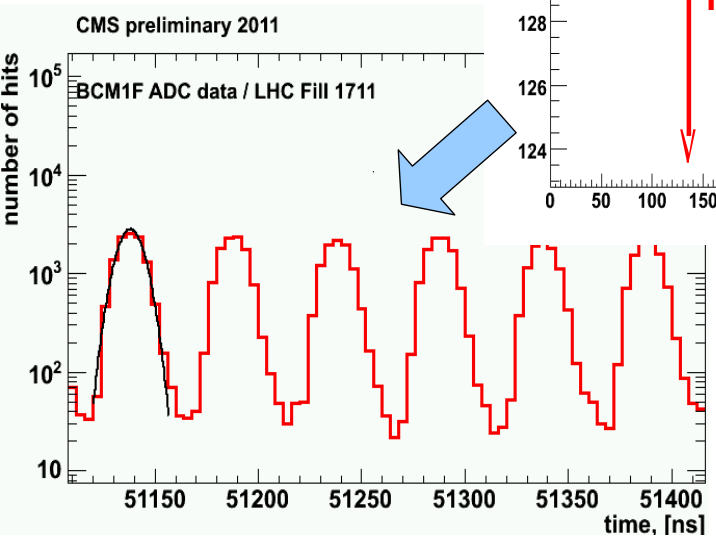


Signal sampling with the ADC

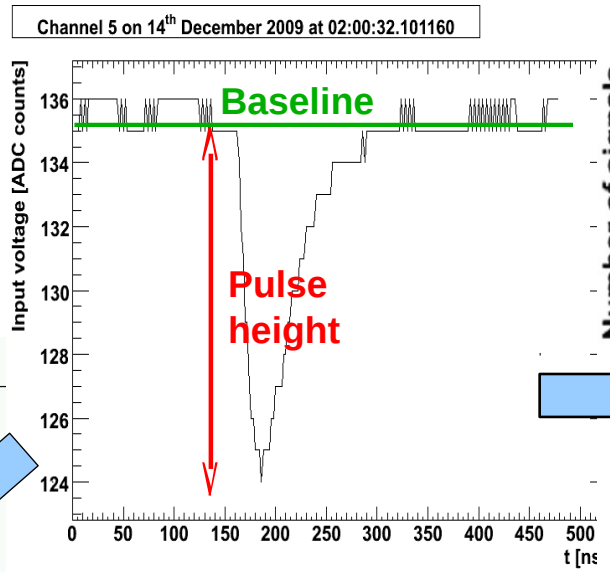
The sensor signals are digitized in a VME CAEN v1721 flash ADC.

Data are used for characterization and maintenance: baseline monitoring, test pulse readout, signal spectra, performance studies.

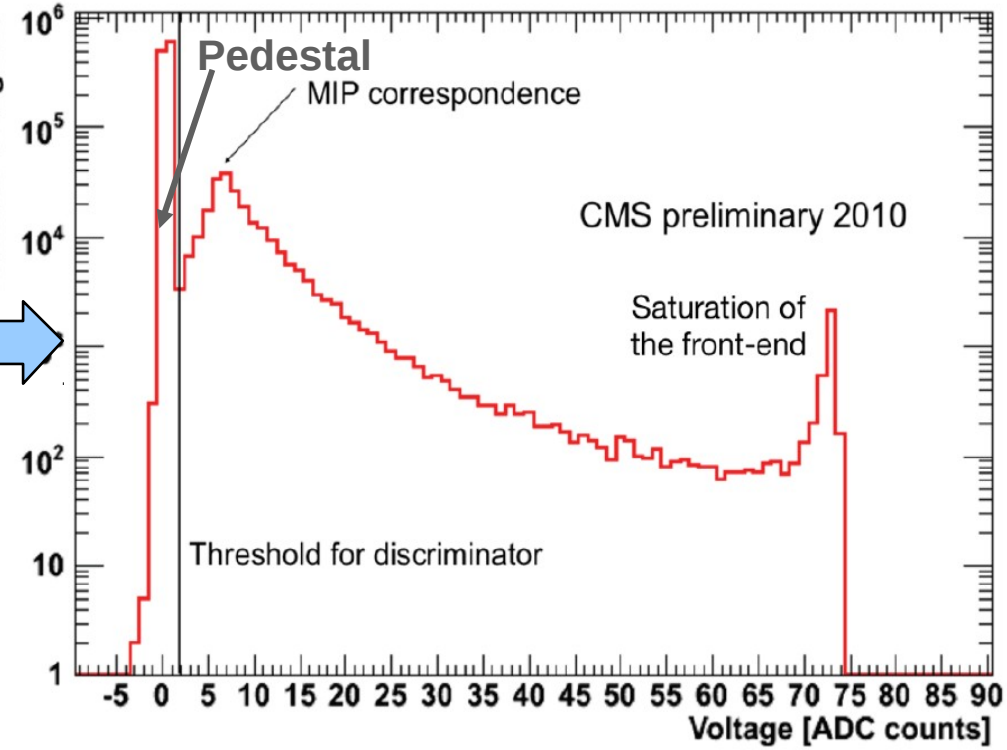
Width of arrival time distribution (6ns) obtained from 50ns colliding bunches



Sampled BCM1F signal



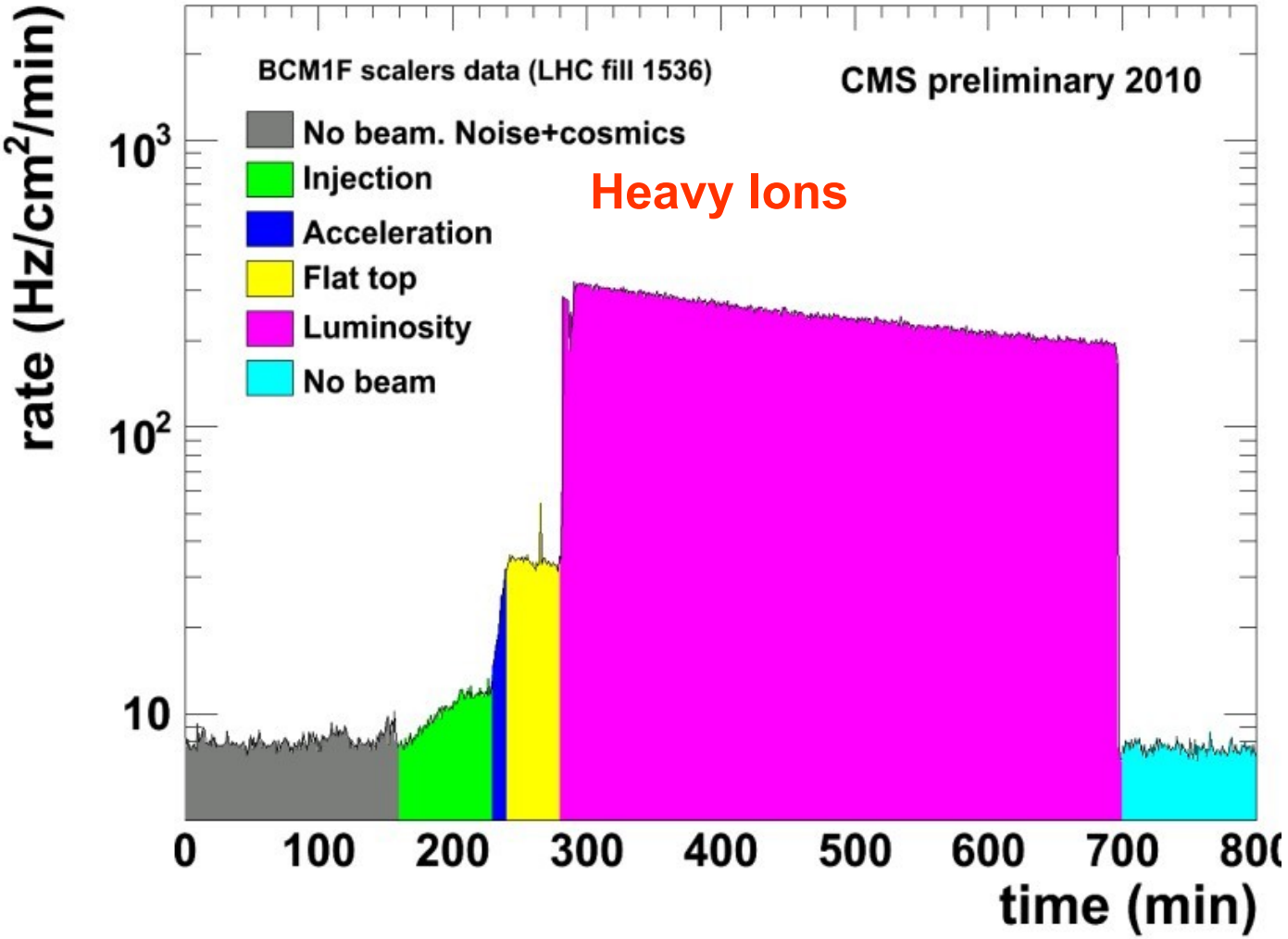
Amplitude spectrum



Particle rates

Sensor signals are counted in a CAEN v560B scaler and forwarded to LHC as BCKD1 (flux in inner detector region).

The rates reflect the different stages of a beam fill



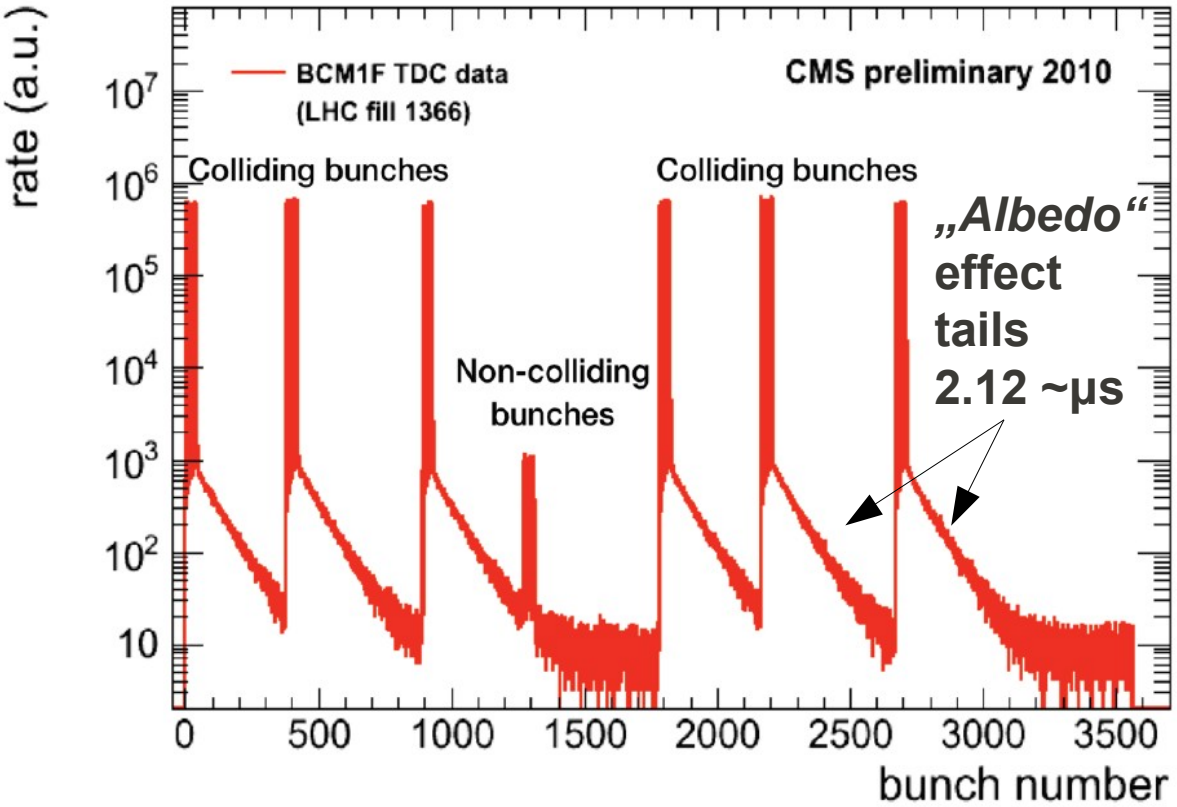
Time information

Sensor signals are time digitized by a multi-hit VME TDC CAEN v767 board with 0.8 ns resolution using the LHC orbit as reference.

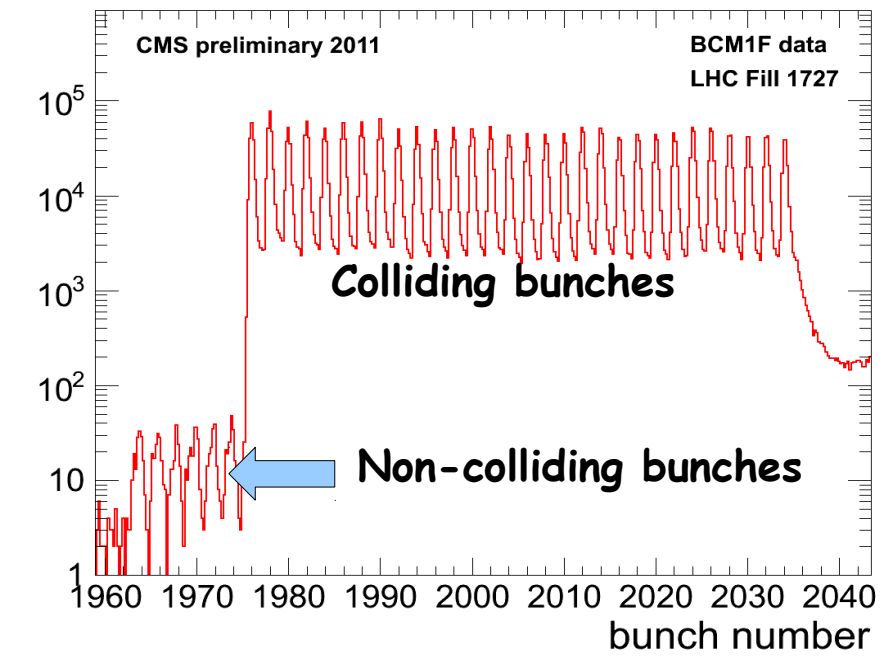
Using the arrival time distribution of the hits, the bunch number identification is done and published to the CMS control room.

$$BN = \frac{t_{TDC} - 6290}{24.95} + 1$$

Bunch ID plot



Zoom in 50ns bunches



CMS beam-gas flux measurement (BKGD 2)

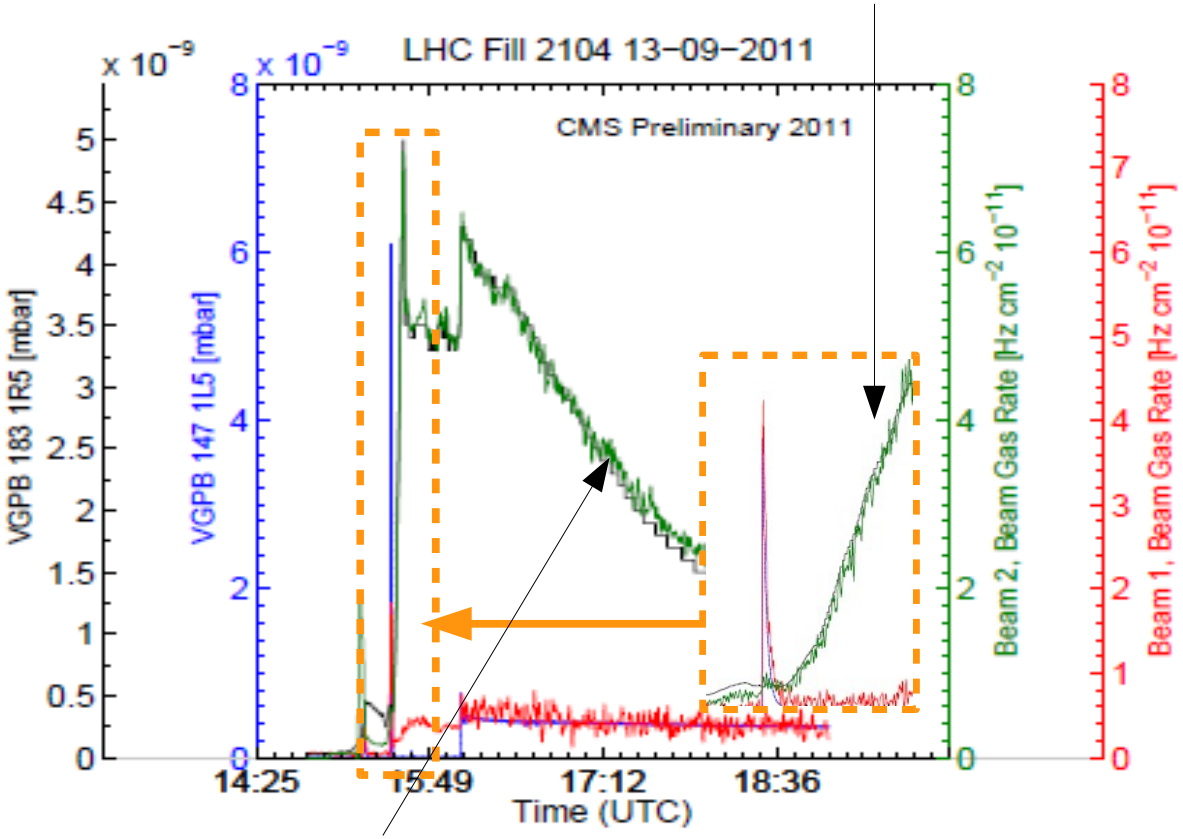
BCM1F provides beam halo and beam gas flux to CMS and LHC, using rates of non-colliding bunches corrected for the *„Albedo“* effect:

- **Gate non-coll. bunches using BPTX**
  - **Measure only beam halo**
- **Calculate the Albedo rates**
- **Substract the Albedo rates**
- **Corrected beam halo is BKGD2**

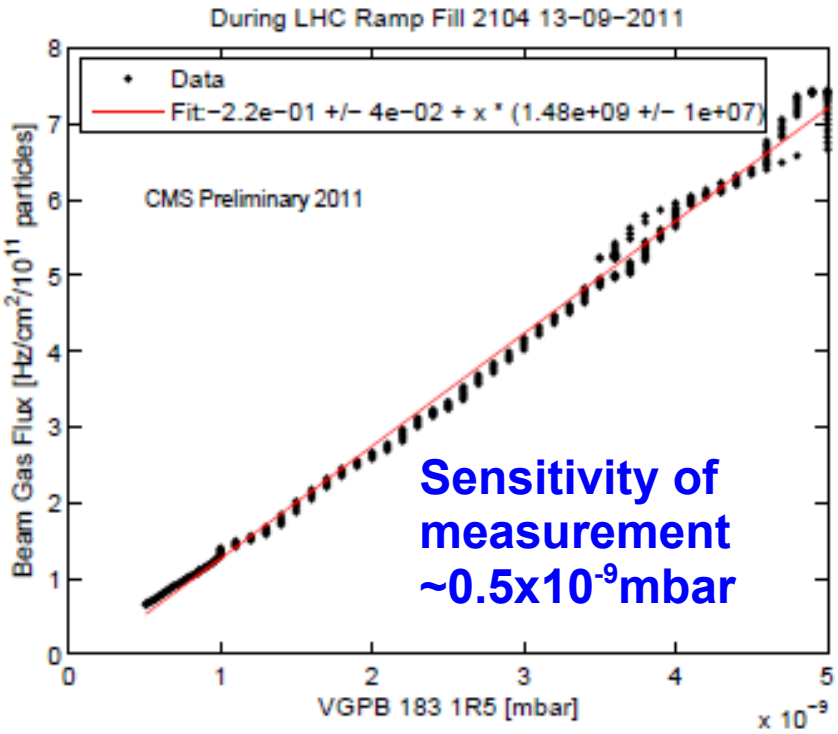
} Gated counting

Correlation of beam-gas rates and vacuum pressure

During the LHC ramp, an increase in vacuum pressure on the left side of CMS measured by the vacuum gauge VGBP 147 1L5 is followed by an increase of beam1-gas flux. Later, the same happens for beam 2 on the right side of CMS



Better vacuum conditions, especially on the right side of CMS during the fill, and the reductionbeam 2 beam-gas flux



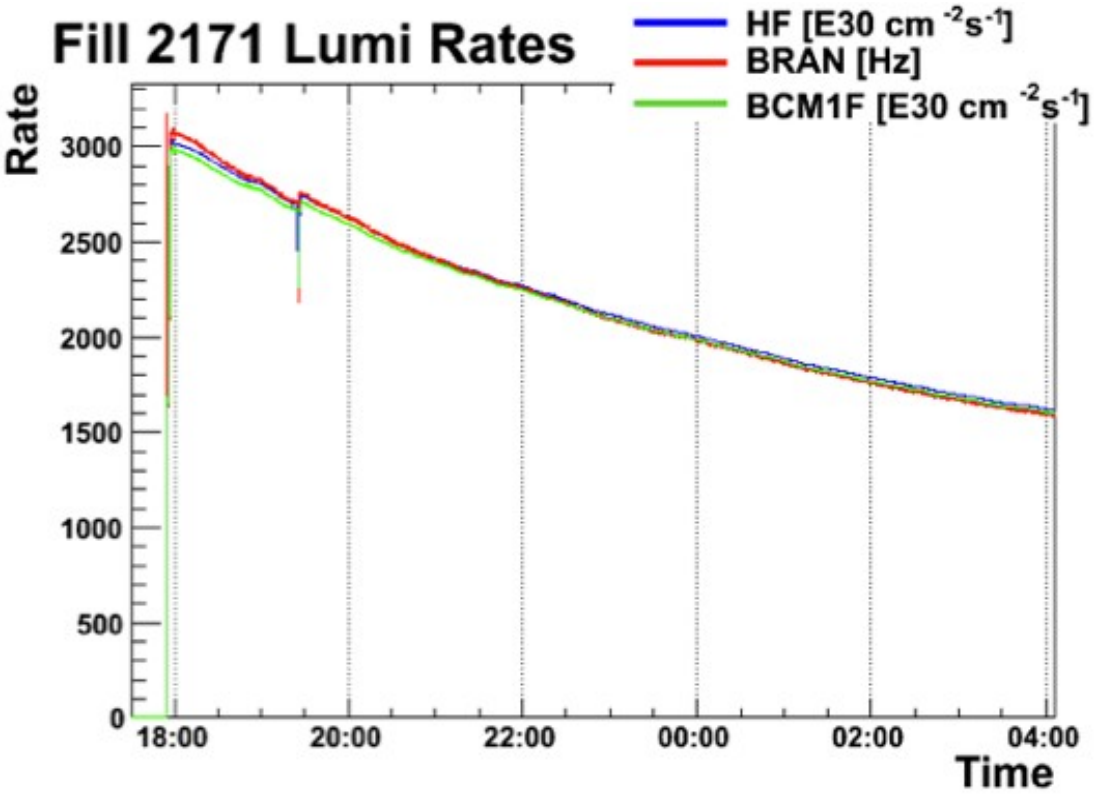
The correlation of the normalized beam-gas measurement for beam 2 with the vacuum pressure measured by the vacuum gauge VGPB 183 1R5 during the ramp, confirms that the particle flux is dominated by beam-gas interactions.

Instantaneous luminosity monitor

The BCM1F count rates are proportional to the HF instant luminosity. Since BCM1F is decoupled from the central CMS DAQ it provides instant online luminosity even when HF lumi is not available.

The BCM1F +Z and -Z signals for colliding bunches are given by a 12 ns gate provided by BPTX. Assuming HF is perfect, a BCM1F lumi calibration factor is calculated.

Studies are still on going to correct the non-linearities and to extract bunch by bunch luminosity.



Feedback to CMS and LHC

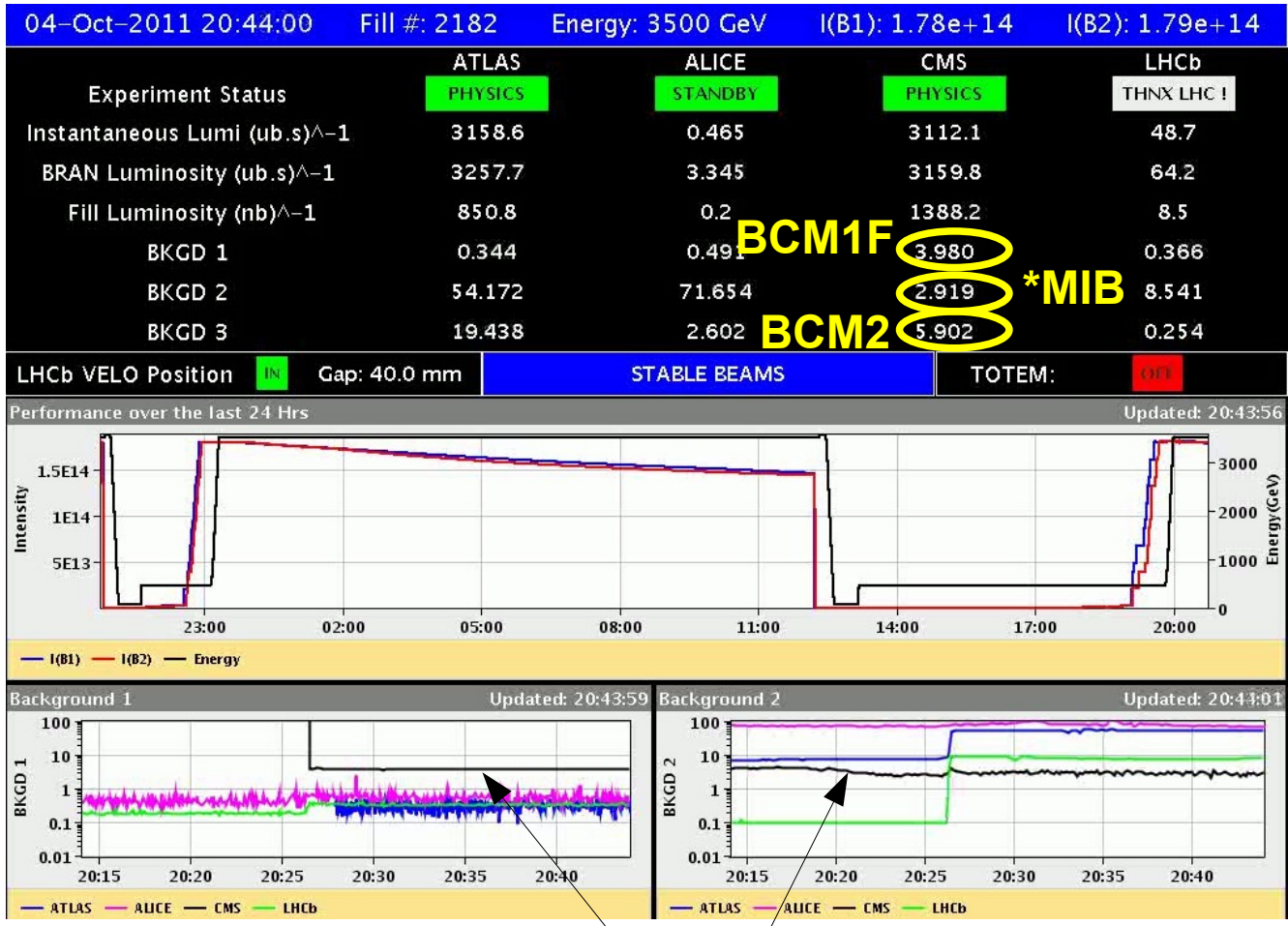
All our measurements are available in CMS control room.

Published background numbers indicate normal/safe operation.

Based on these numbers pixel and tracker decide in the beginning of a fill if they will switch on their detectors.

Indication for the LHC control room about beam quality.

http://op-webtools.web.cern.ch/op-webtools/Vistar/vistars.php?usr=LHC3



Background 1 **Background 2**

CMS in black

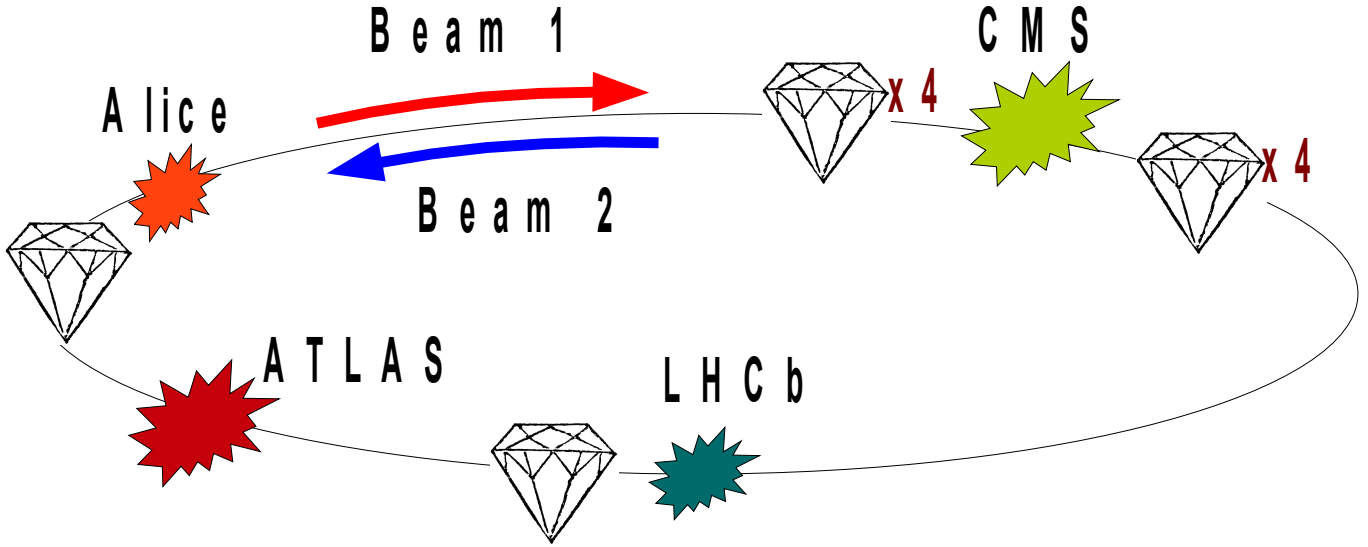
**MIB: Machine Induced Background*

The BCM1F for LHC (BCM1F4LHC)

The BCM1F system was considered by the LHC Beam Loss Monitoring group (BE-BI-BL) to be useful as a beam halo and beam gas monitor for LHC at several positions around the orbit.

As a consequence, the LHC ring is being equipped with scCVD diamond sensors distributed around the ring and that will monitor the beam losses.

So far, two BCM1F modules have been installed and are already delivering signals. Six more diamonds will be installed along 2012.

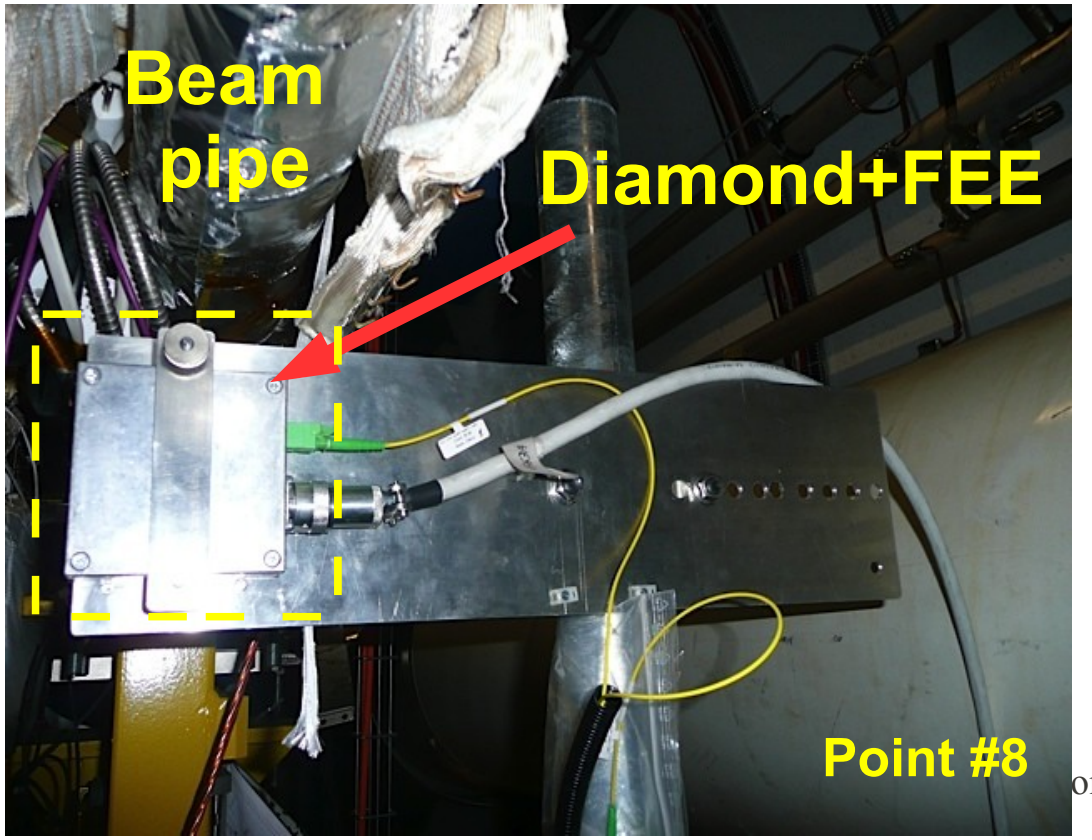


Installation of diamonds and back-end

Location of diamonds and FEE

Point #8 of the LHC ring close to a vertical collimator and at 70.501 m from the LHCb IP. It is located below the vacuum chamber, 20 cm away from the center of the beam pipe.

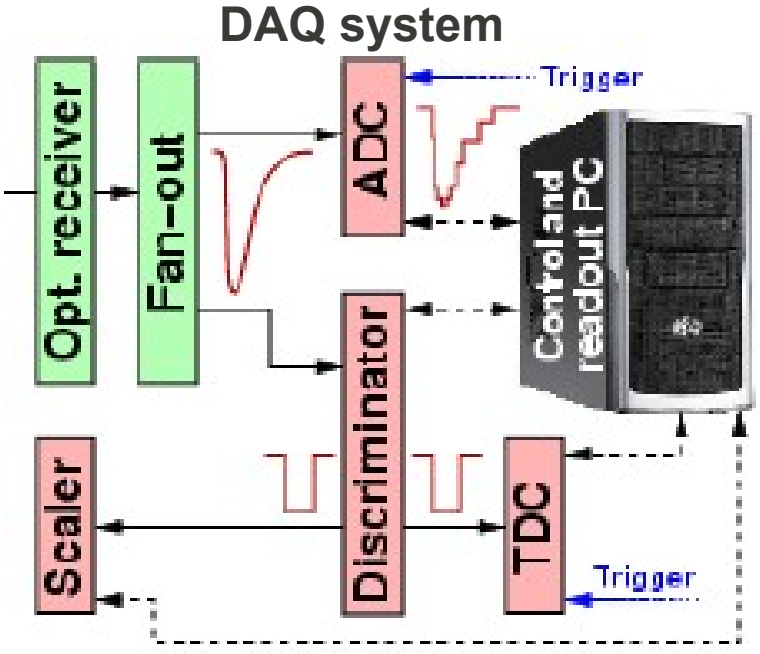
Point #2: at about the same distance from Alice IP.



Back end

The optical signals are carried to the CERN Prevessin site where they are transformed back into electrical and read out by the DAQ system composed by:

Counters → they supply hit rates
ADCs→signal digitization
TDCs→signal time info.

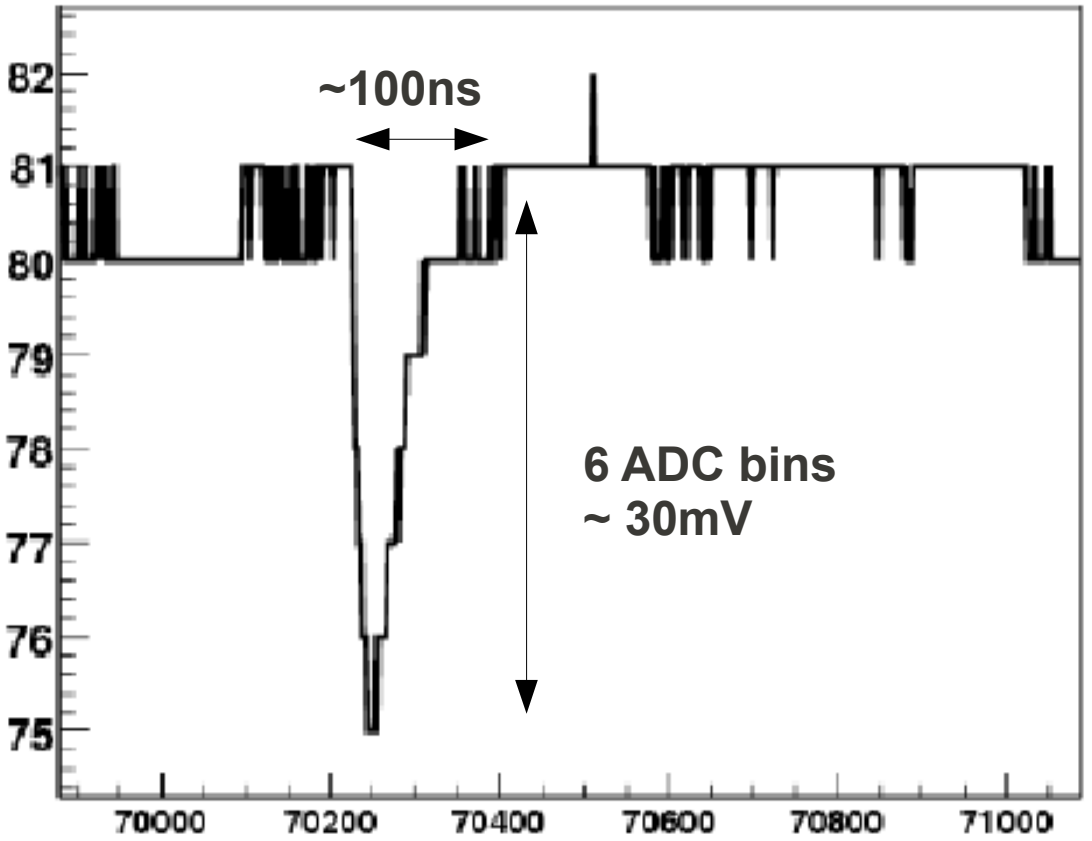


BCM1F4LHC performance: first results

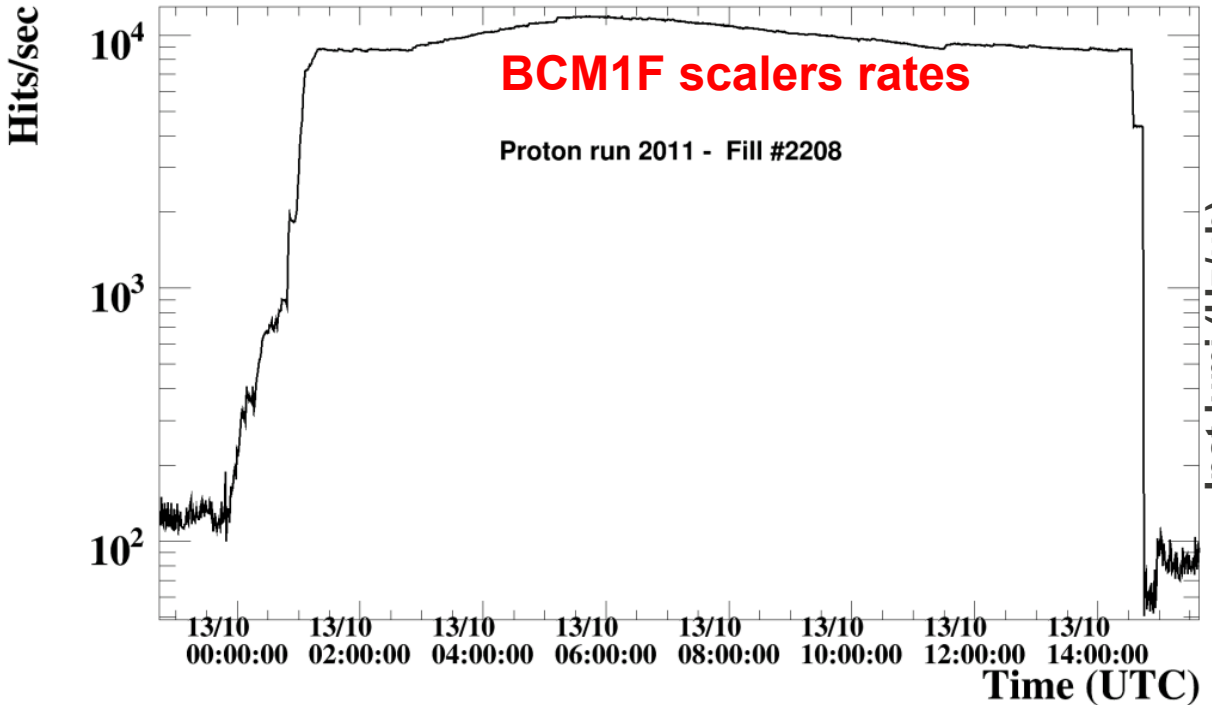
At the time being data is recorded for the 2 installed diamonds:

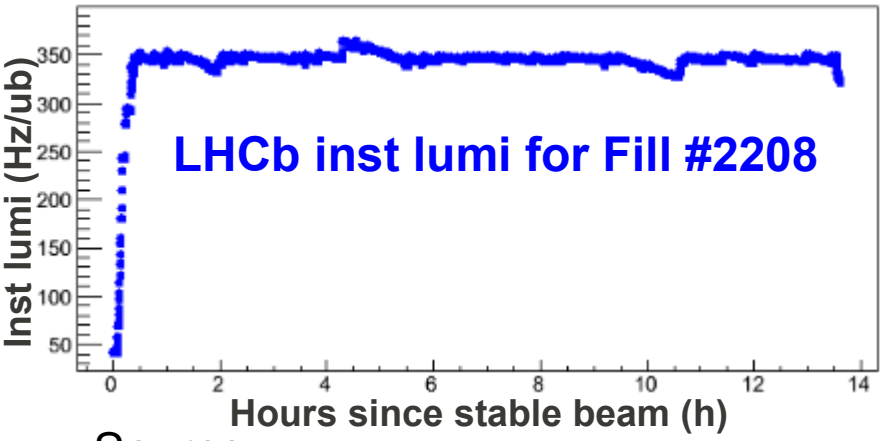
- Scalers rates
- Signal spectra
- Time structure of signals

Example of sampled signal of sensor in P#8

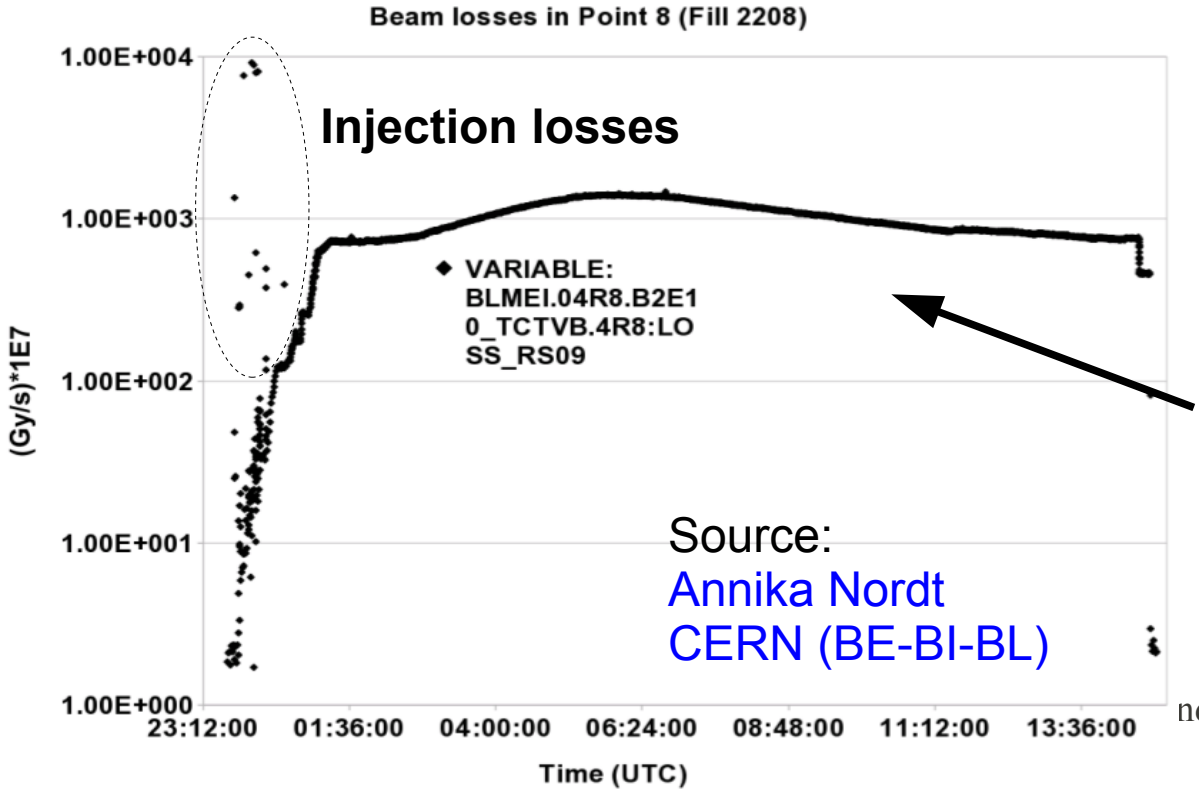


Scalers rates (in sensor in P#8)





Source:
https://lbweb.cern.ch/groups/online/OperationsPlots/2011LumiPerFill/2208_LumiPerFill.png

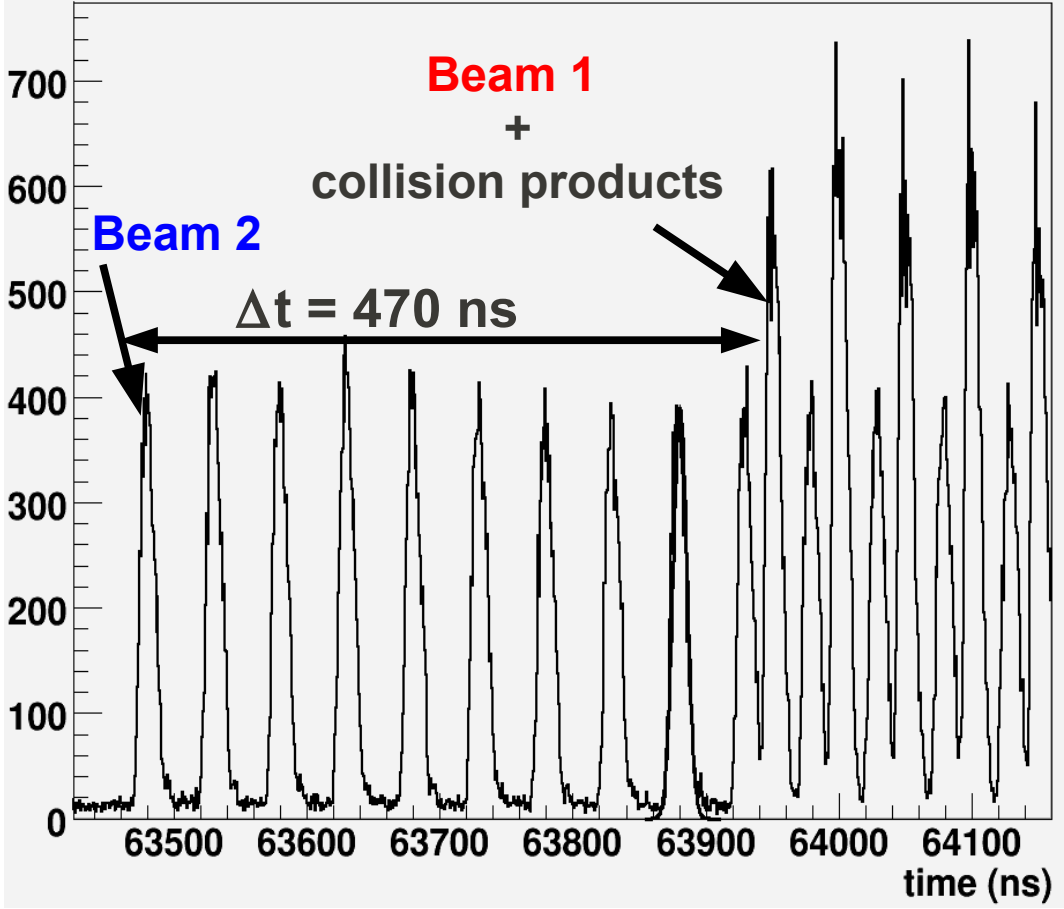


Source:
Annika Nordt
CERN (BE-BI-BL)

The sensor delivers hits due to the collision products in LHCb and beam gas interactions due to bad vacuum quality

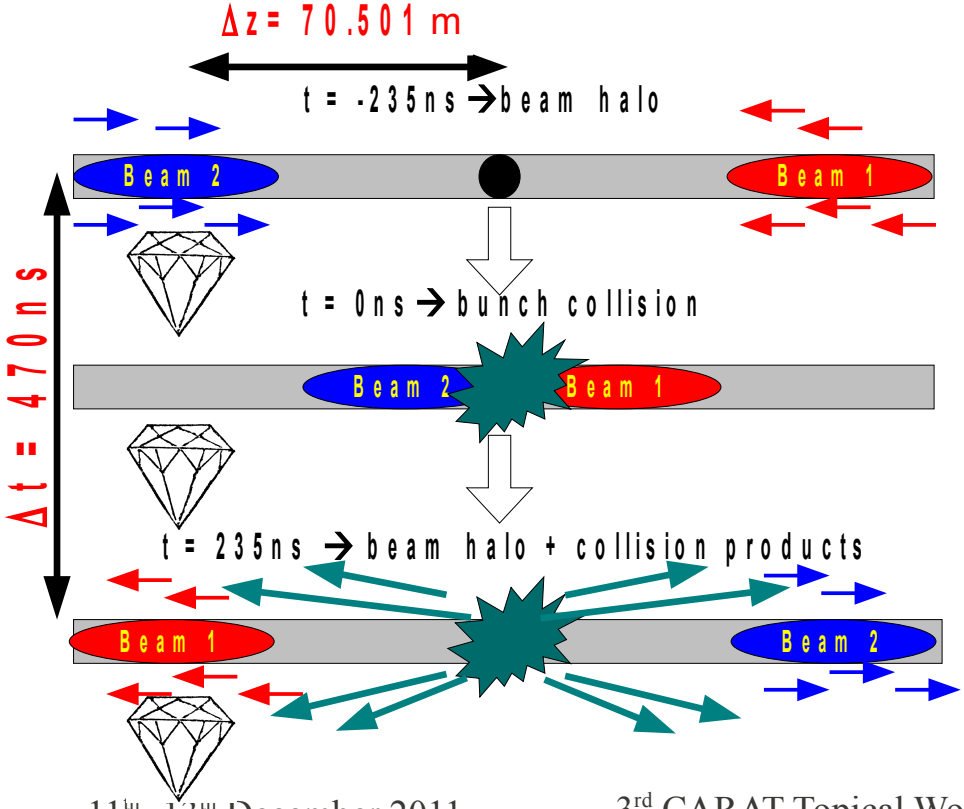
Time information (in sensor in P#8)

The results from the TDC data analysis agree with the expected time of the signals delivered by the sensor



Time of hits delivered by the TDC

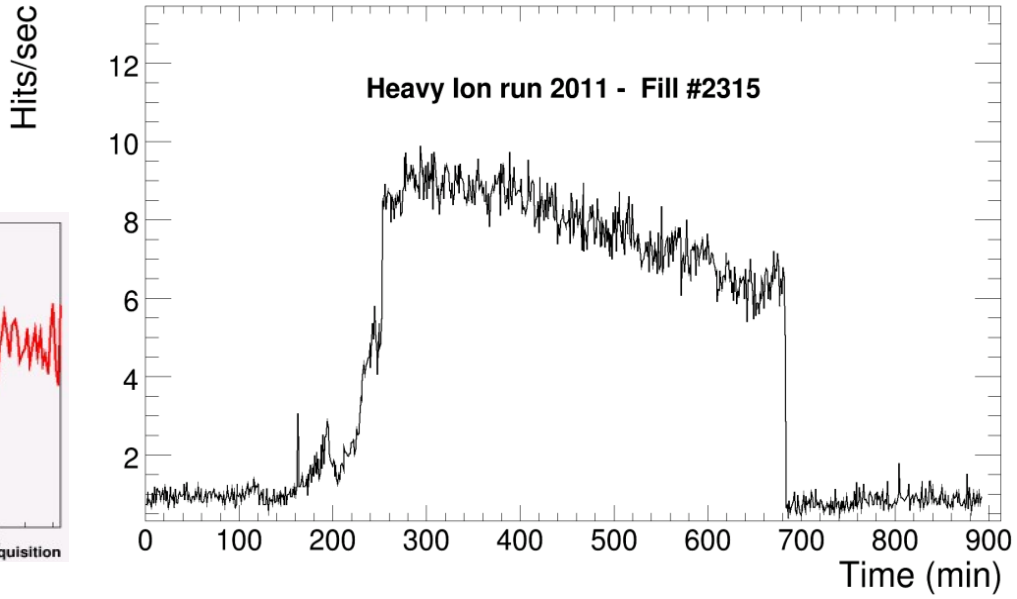
Time diagram of expected hits in sensor



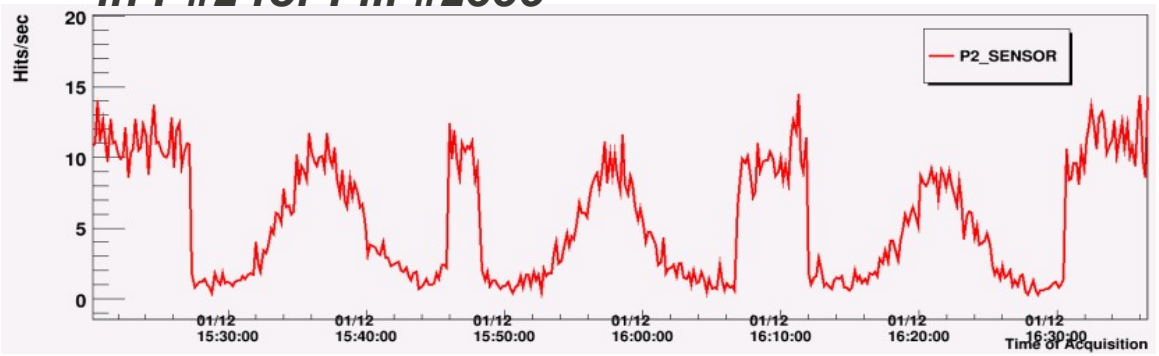
Sensitivity to HI

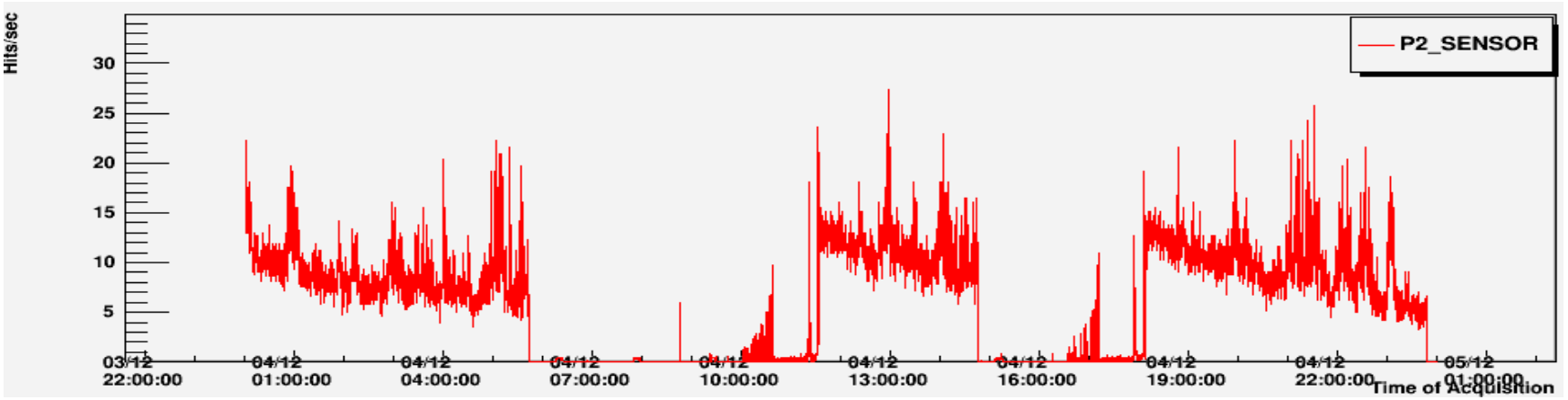
Although the rates expected from the diamond sensors with HI are low, the sensitivity is still enough to detect beam features:

Rates in diamond in P#8 for HI Fill #2315



VdM scans in Alice observed with diamond in P#2 for Fill #2335





Summary

- The BRM system is a valuable tool in the daily safe operation of the CMS detector.
- It has been working in a reliable mode since LHC start in 2008
- Data from BCM1F was used to validate the performance
- BCM1F is a beam conditions monitor
- It became a key tool to measure BKGD1 (collision products), BKGD2 (beam halo rate) and instantaneous luminosity
- The LHC ring is being equipped with additional BCM1F modules
- The first results are promising

Additional Slides

CMS beam-gas flux measurement (BKGD 2)

BCM1F provides beam halo and beam gas flux to CMS and LHC, using rates of non-colliding bunches corrected for the *„Albedo“* effect:

1- Gate non-coll. bunches using BPTX
2- VETO gate > 900ns to count only non-coll. bunches
3- Gate Beam1 and Beam2
4- Calculate „Albedo“ rates 40 ns before non-coll. bunch train.
5- Correct rates and normalize by bunch charge