An LHCb general-purpose acquisition board for beam and background monitoring at the LHC

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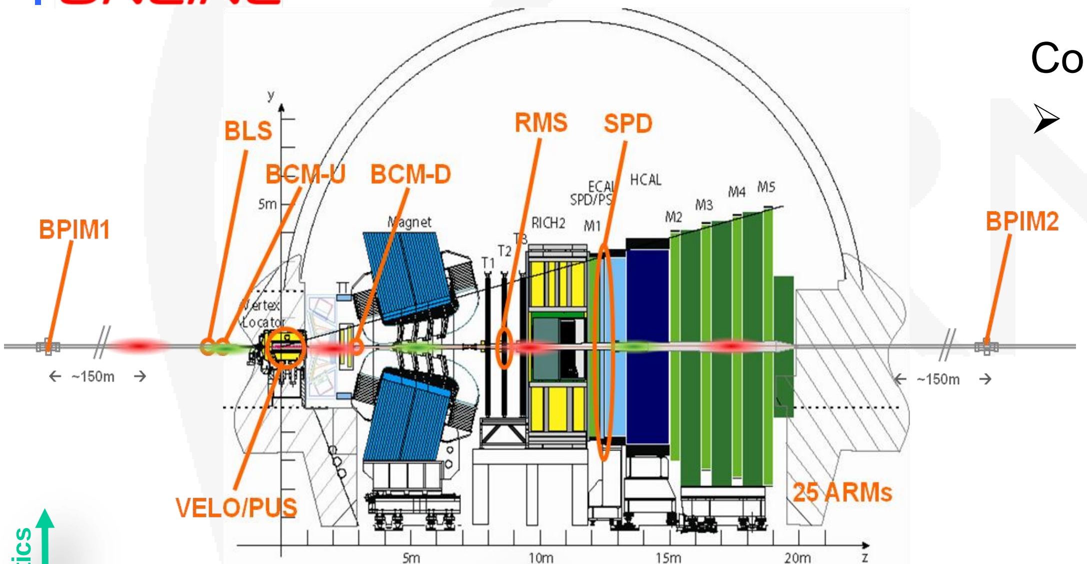
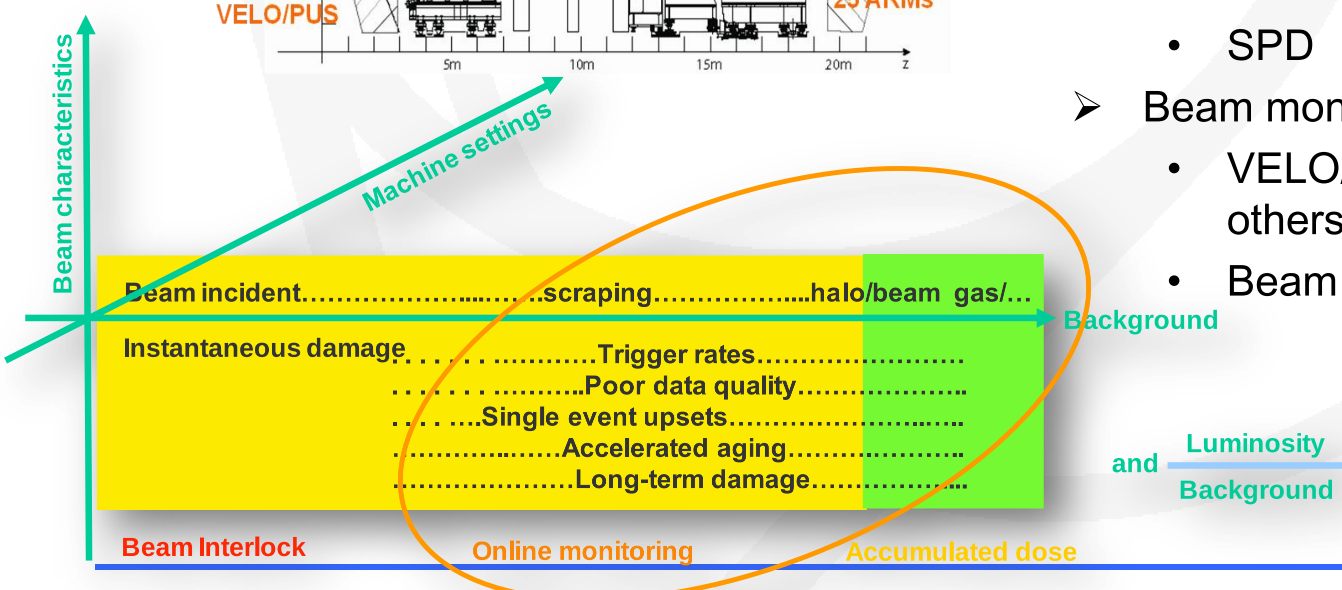
Intro: Beam and Background Monitoring @ LHCb



Complete study framework which involves:

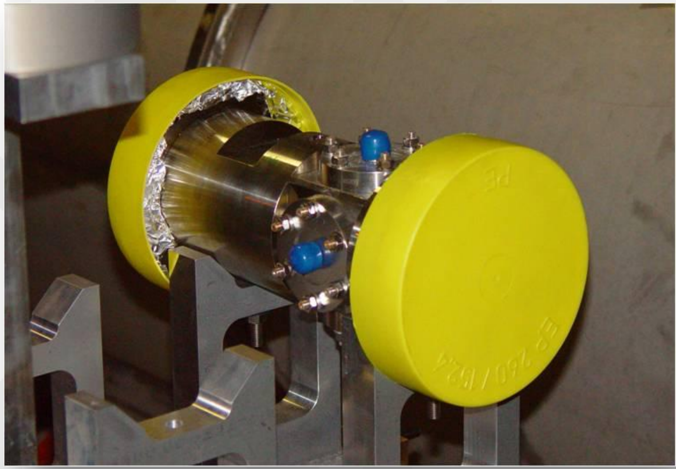
- Background monitoring
  - Beam Condition Monitor
  - Metal-foil based Radiation Monitoring System
  - Active Radiation Monitors
  - Beam Loss Scintillator
  - VELO/PUS
  - SPD
- Beam monitoring
  - VELO/PUS (and indirectly also the others above)
  - Beam Phase and Intensity Monitor

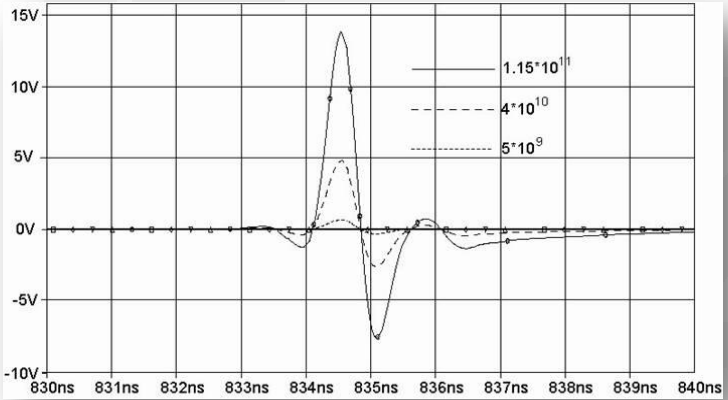


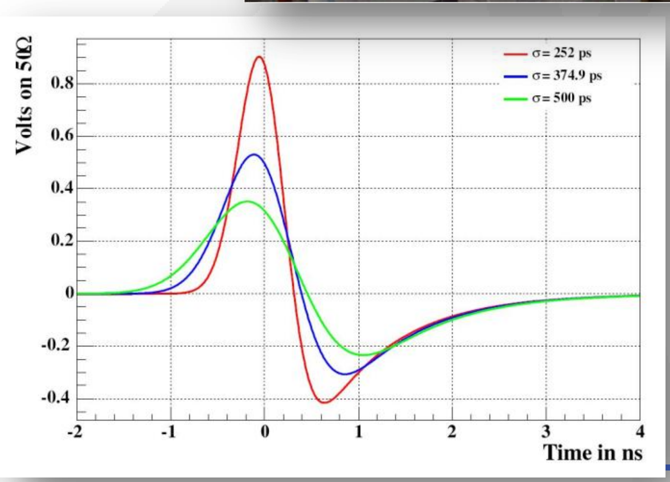
LHCb BPIM-BPTX system

It is of extreme importance that the phase of the LHC clock remains stable with respect to the bunch arrival times at the location of the LHCb detector

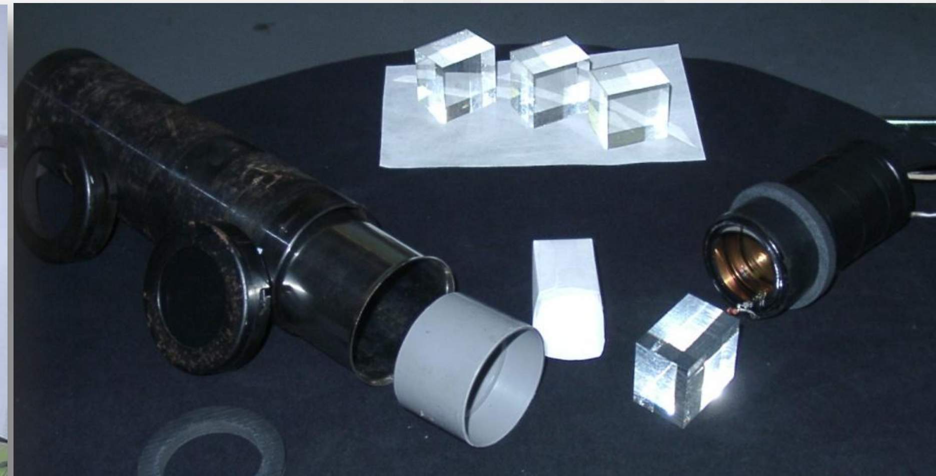
Monitoring performed using two Beam Pick-Up Timing Experiments (BPTXs) dedicated to LHCb and located along the LHC ring: formed by 4 electrostatic button electrodes producing a bipolar signal which is the representation of the beam (bunch-by-bunch) inside the beam pipe







LHCb BLS system



Scintillator 3x4x4 cm^3 wrapped in TYVEK

PMT1 HM R2490-05 2"diam, multi-mesh

PMT2 EMI 9839A 2"diam, pan-type

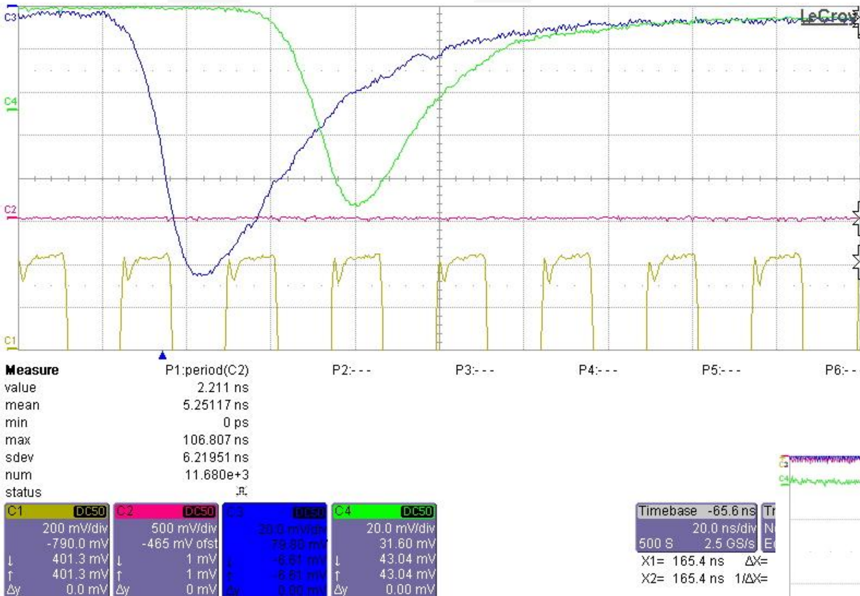
LED red-light, fast

Shielded against stray magnetic field

→Installed in front of LHCb VeLo on the horizontal plane of the beam pipe: ~12cm away from beam pipe

→Very inexpensive detector (non rad-hard)

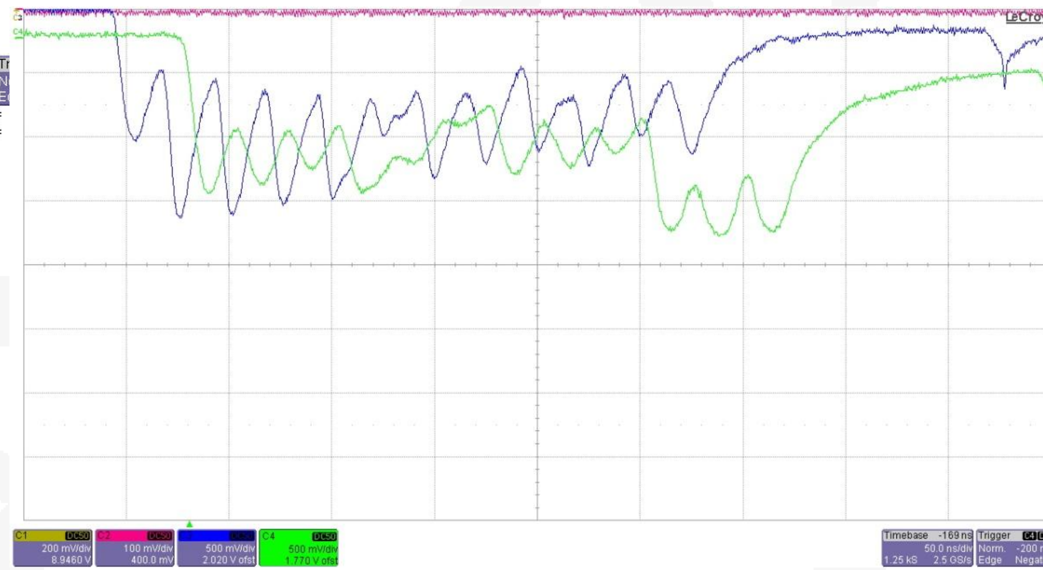
LHCb BLS system



← Pulses from both scintillators with real pilot beam injected through LHCb:

- ✓ width of ~2 clock cycles
- ✓ 10-15ns rise time

Train of bunches injected (and stopped before going through LHCb) at a spacing of 25ns (test on June 2009) →



Beam and Background FOM @ LHCb

BPIM-BPTX

- *Beam intensity*: independent LHCb measurement of total beam intensity and bunch-by-bunch intensity to be used for offline analysis and luminosity correction
- *Bunch structure*: so-called LHC filling scheme
- *Beam phase with respect to sampling clock edge*: keep the LHCb detector within +/- 0.5ns from optimal sampling point

BLS:

- *Beam losses*:
  - ✓ Losses during injection: LHCb under the fire of showers at injection
  - ✓ Losses during circulating beams: beam Halo, fast losses due to scraping, losses due to beam movements, increasing background, beam-beam effects, etc...
  - ✓ Abort gap monitoring: look for ghost bunches, beam debunching due to RF, wrong filled bunches
- *LHCb independent luminosity measurement*: cross-check with official LHCb luminosities measurement (from L0CALO trigger rate) and substitute LHCb official measurement whenever not available (detector not running or not ready during collisions). Bunch by bunch luminosity.

Both:

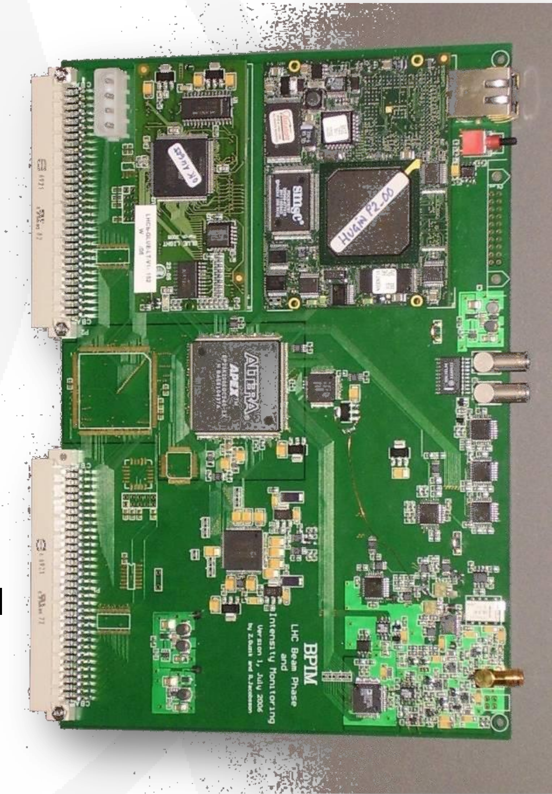
- *Live feedbacks to LHCb control room and LHC control room for shifters*: automation, alarms, archiving!

→ ***General purpose custom-made electronics LHCb board***

A common electronics board: “BPIM”

→ Initial spec: custom-made acquisition board

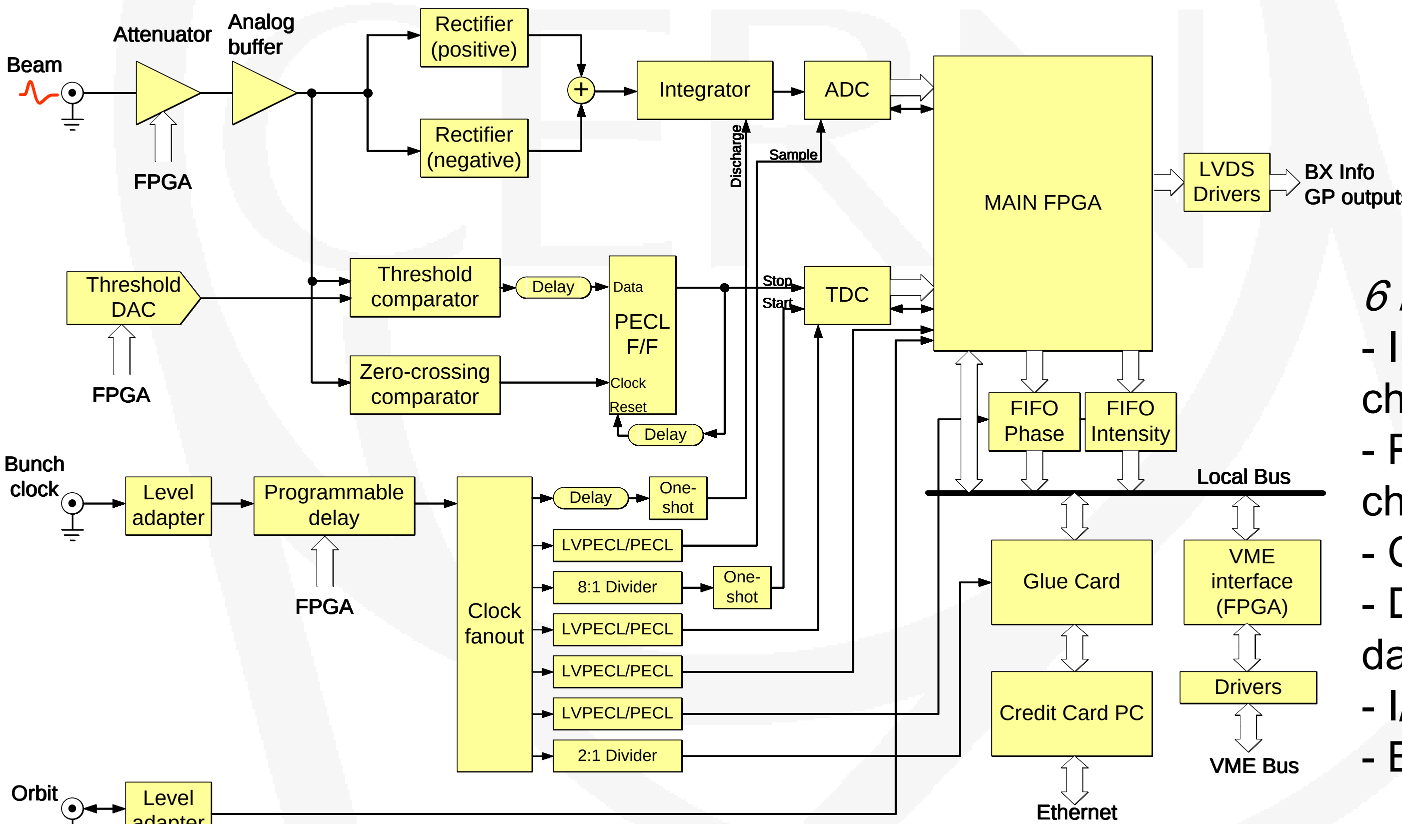
- ✓ 6U VME. LHC orbit and bunch clock inputs.
- ✓ Online analysis of a bipolar pulse: FWHM 1 ns at 40 MHz, ±5Vmax processing amplitude (onboard attenuator for higher pulses)
- ✓ Measure time between bunch arrivals and LHC bunch clock locally
  - Bunch-by-bunch for a full LHC turn filled in FIFO
  - Triggered via controls interface
  - <100 ps precision and averaging phase as a function of bunch crossing (TDC-GPX, 27ps)
- ✓ Measure continuously bunch intensities bunch-by-bunch
  - 12-bit resolution by integrating pulse per bunch (pipelined ADC)
  - Output intensity on front-panel at 40 MHz (8/4-bit resolution)
  - Triggered via controls interface, fill in FIFO with intensities for full turn
  - Intensity per bunch as a function of bunch crossing
- ✓ Readout and control via Experiment Control System, CCPC based interface (VME alternatively). *Glue logic* for interfacing protocols.
- ✓ Interfaced directly to LHCb Timing and Fast Control system, 3 outputs
- ✓ Data processing on FPGA (ALTERA EP20K200, with 8000 LEs), two 16bx16b FIFOs for storage, EEPROM for firmware storage and load
- ✓ Initially only developed for BPTX system



BPIM timeline

- → September 2006, first conceptual presentation by R. Jacobsson at 12th LECC in Valencia: PSPICE simulations, first PCB draft
  - ✓ http://cdsweb.cern.ch/record/989402/files/lhcb-2006-055.pdf
- → February 2007, first PCB produced, mounting started, lots of debugging and fixing in first prototype
- → May 2007, second prototype produced and mounted, tests in lab
- → September 2007, tests in SPS as readout board on a real BPTX:
  - ✓ http://cdsweb.cern.ch/record/1082870/files/CERN-THESIS-2008-007.pdf
- → January 2008, production of a batch of 8 boards
- → September 2008, BPIM sees first beam reading out first BPTX pulse
  - ✓ Some adaptation neede because performances of BPTX different from signal generator
- → January 2009, 3 BPIMs go to ALICE (waiting for beam...)
- → July 2009, 2 BPIMs installed in BLS readout (waiting for beam...)
- → October 2009, all BPIMs see beam again
- → May 2010, commissioning with LHCb detector, LHCb timing adjusted, BLS was first detector to signal 3.5 TeV collisions in point 8
- → Continuous monitoring and analysis of data

General overview of the board

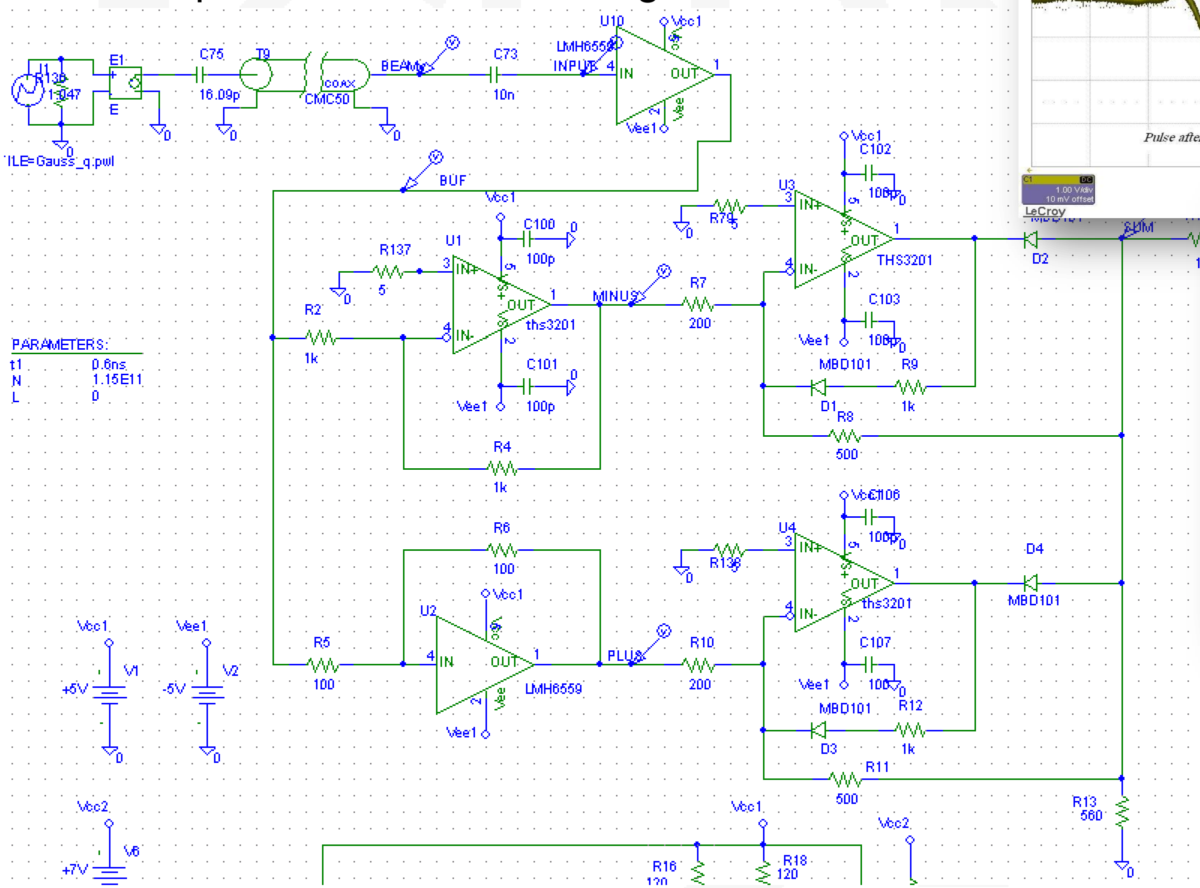


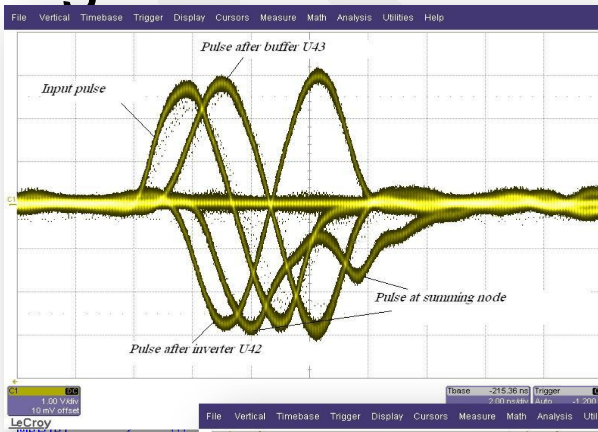
6 logical blocks:

- Intensity measurement chain
- Phase measurement chain
- Clock distribution
- Digital processing and data accumulation
- I/O interfaces
- Board control via ECS

In depth: analog chain

Analog chain for the intensity measurement, involving current amplifiers, buffers and integrator



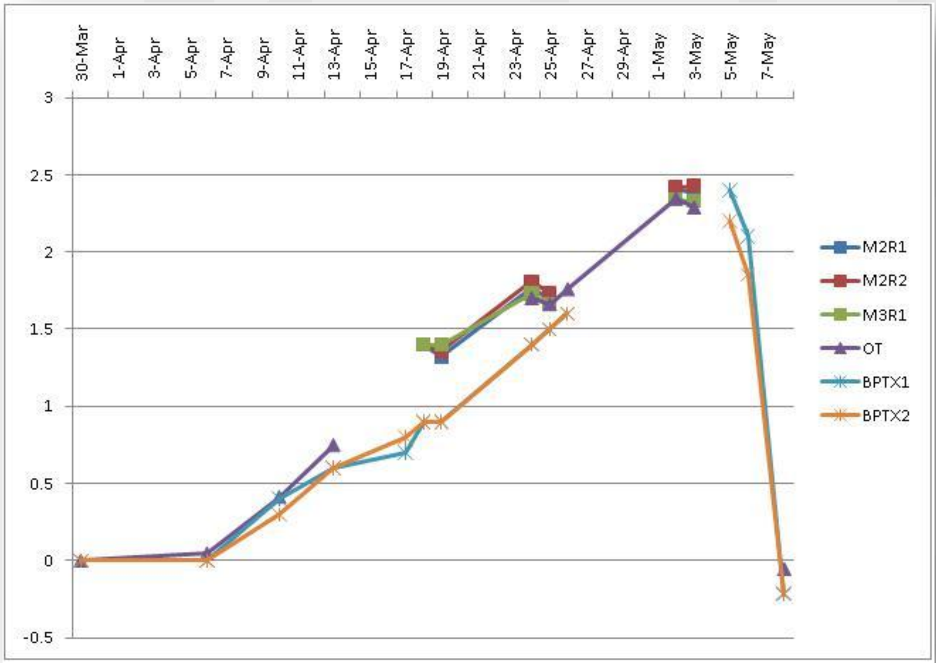


Very fast current amplifier used for the inverters stages
→ slew rate 10 V/ns (THS3201D, BW 1.8GHz)

Very careful layout

Performances with real LHC beam

1. Keeping the LHCb experiment on time …

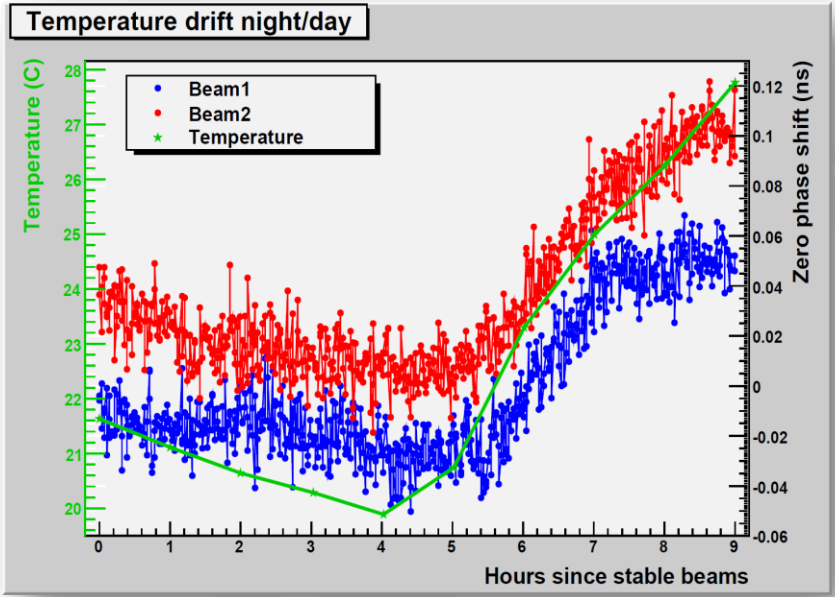


→ LHCb experienced a drift of about 2.3ns over a period of about 1 month (March – May 2010)
  - ✓ Phase of the sampling clock edge drifted because of temperature drift (via fibres)

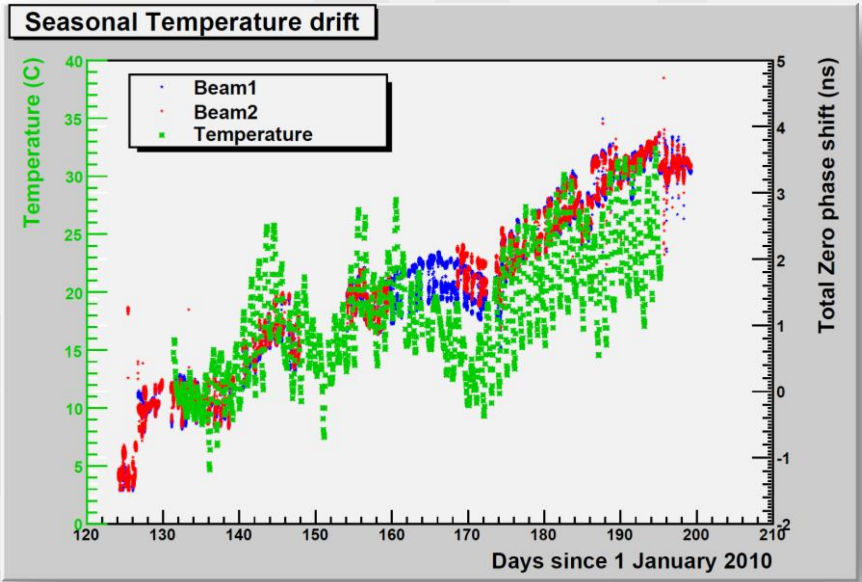
→ Same drift was observed by two detectors in LHCb equipped with TDCs (Outer Tracker and MUONs stations)
  - ✓ Commissioning phase of BPIM and calibration with LHCb detectors
  - ✓ Realignment of the phase

→ For LHCb a positive shift (+) corresponds to a delay of the clock edge with respect to the beam passage
  - ✓ the beam is earlier with respect to our optimal sampling point

Performances with real LHC beam



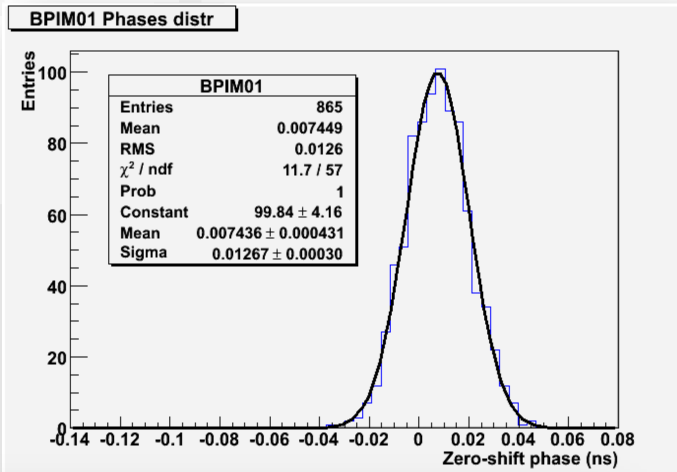
→ LHC Fill 1222
- ✓ Temperature drifted by 8 C in 5 hours
- ✓ Beam1 and beam2 clock phase shifted by ~100ps

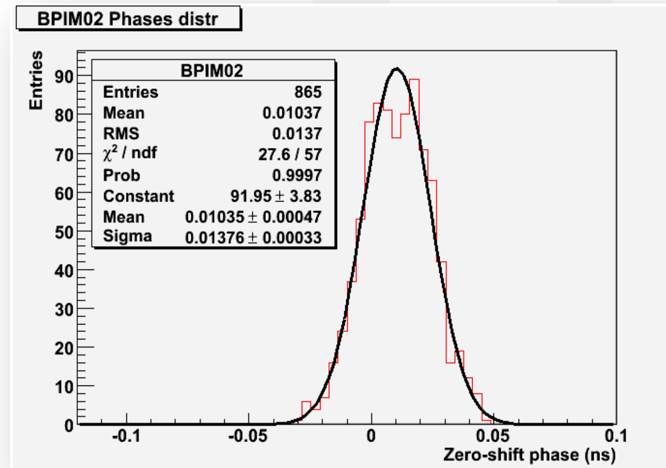


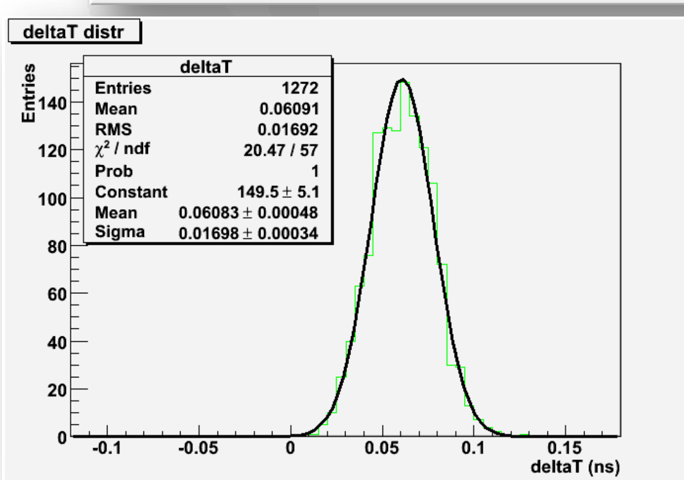
→ 90 days running period
- ✓ Temperature drifted by 15 C
- ✓ Clock edge phases drifted by ~4.5ns
- ✓ Average of 260ps/deg over the 13km of fibres from RF4 to LHCb

Performances with real LHC beam

2. Resolution of phase measurement …





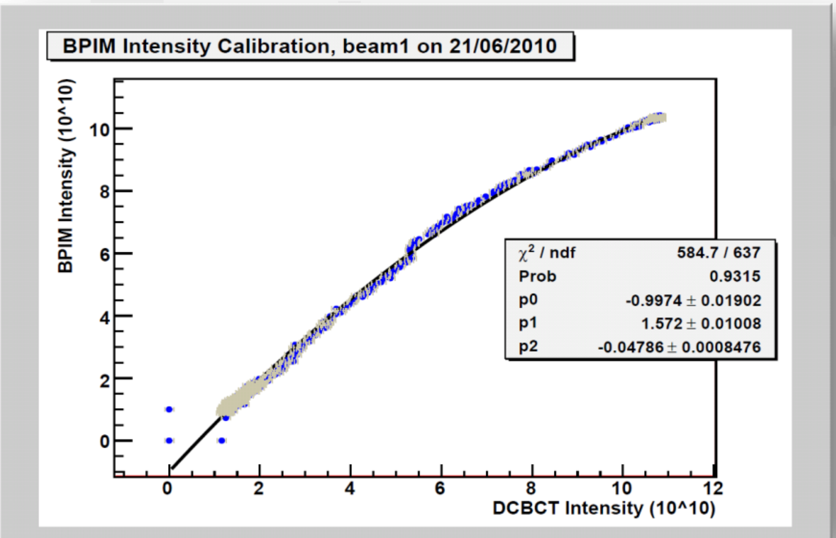


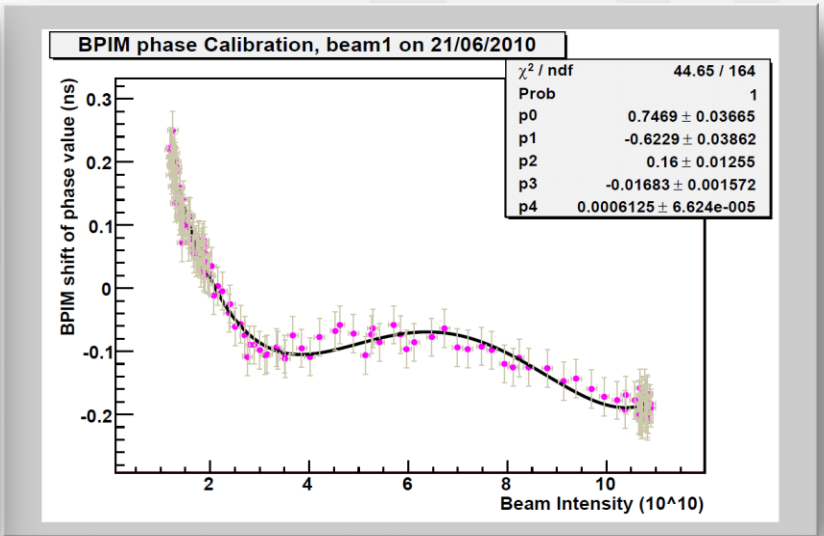
→ Data taken from a stable period (no drift was observed) in LHC Fill 1233

- ✓ 13-14ps resolution for single bunch phase measurement
- ✓ 17ps resolution for deltaT measurement (not taking into account uncertainties on cable lengths, compatible with statistical error)

Performances with real LHC beam

3. Dependance on beam intensity …





→ Strong non-linearities
- ✓ Correction curves, difficult to reproduce (only few cases). Need more system calibration!

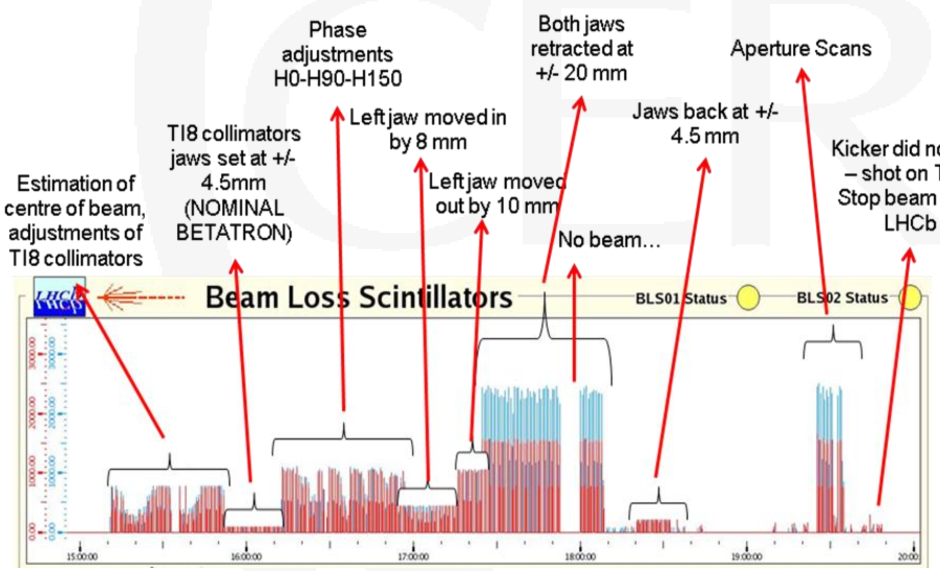
Intensity resolution: (data taken from LHC Fill 1250)

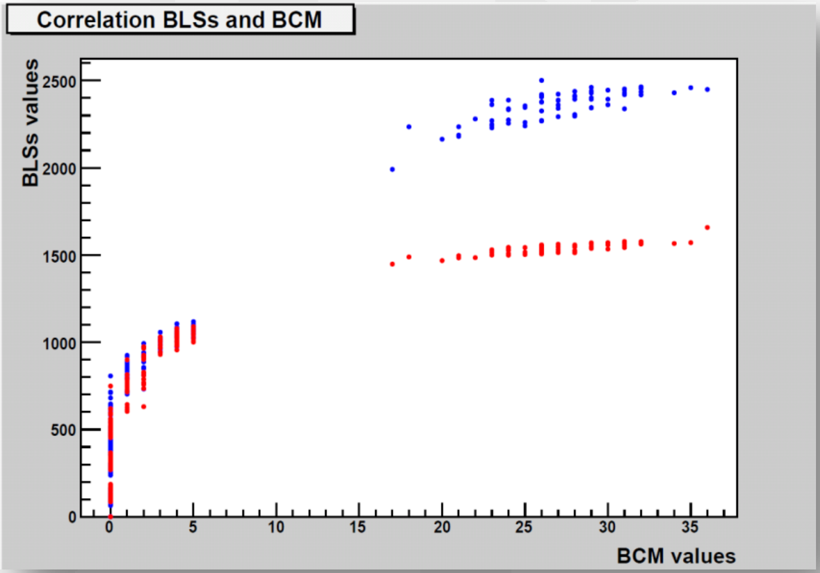
→ For BPIM01: 1 ADC = 1.4345 * 10^8 ppb

→ For BPIM02: 1 ADC = 1.7391 * 10^8 ppb
- ✓ Due to baseline subtraction (~20ADC counts above baseline), the minimum intensity measurable by the system is ~4*10^9 ppb.
- ✓ Reflections in the cables when high intensity beam: raise threshold above baseline

Performances with real LHC beam

4. Commissioning of the injection transfer lines and TDI settings …





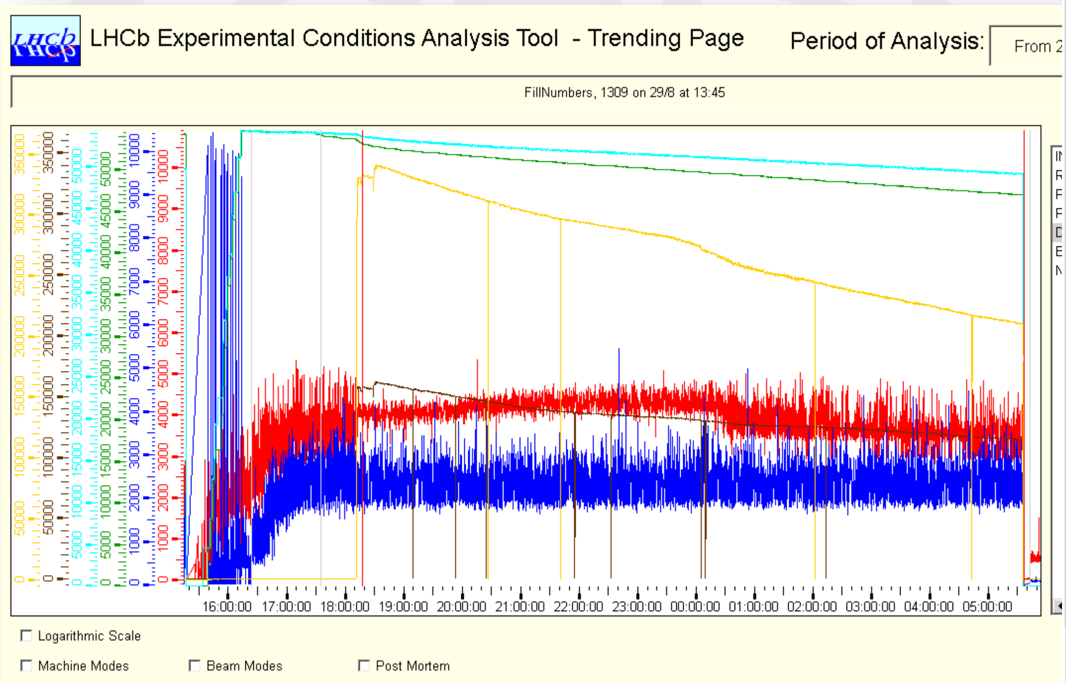
→ Possible to "calibrate" the position of the collimators with "desired" losses

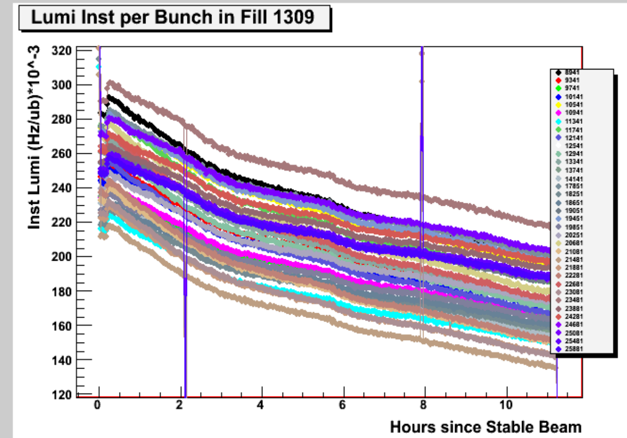
→ Whole range of losses is covered by BLS and BCM

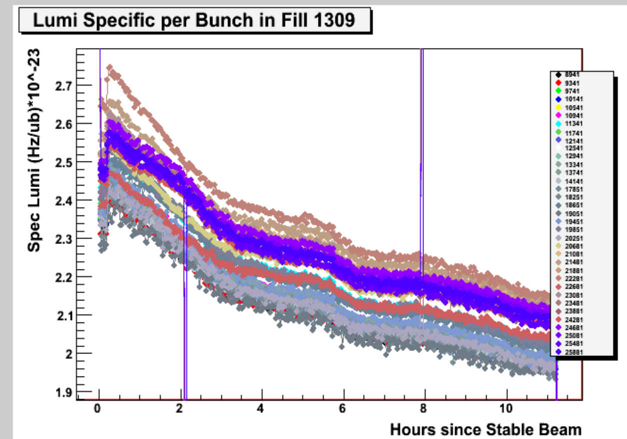
- ✓ BLS more sensitive than BCM
- ✓ BLS saturates at 10% of threshold BCM

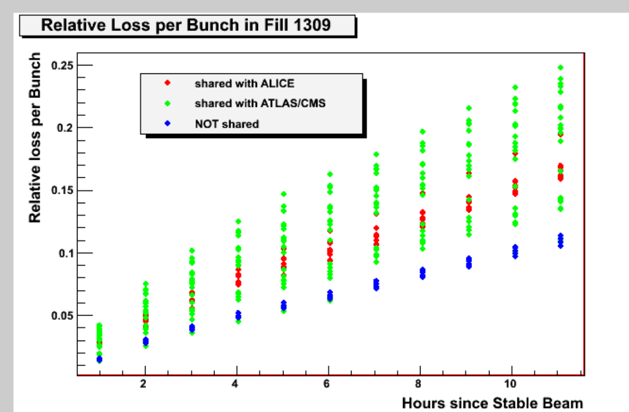
Performances with re

5. Luminosity measurements…









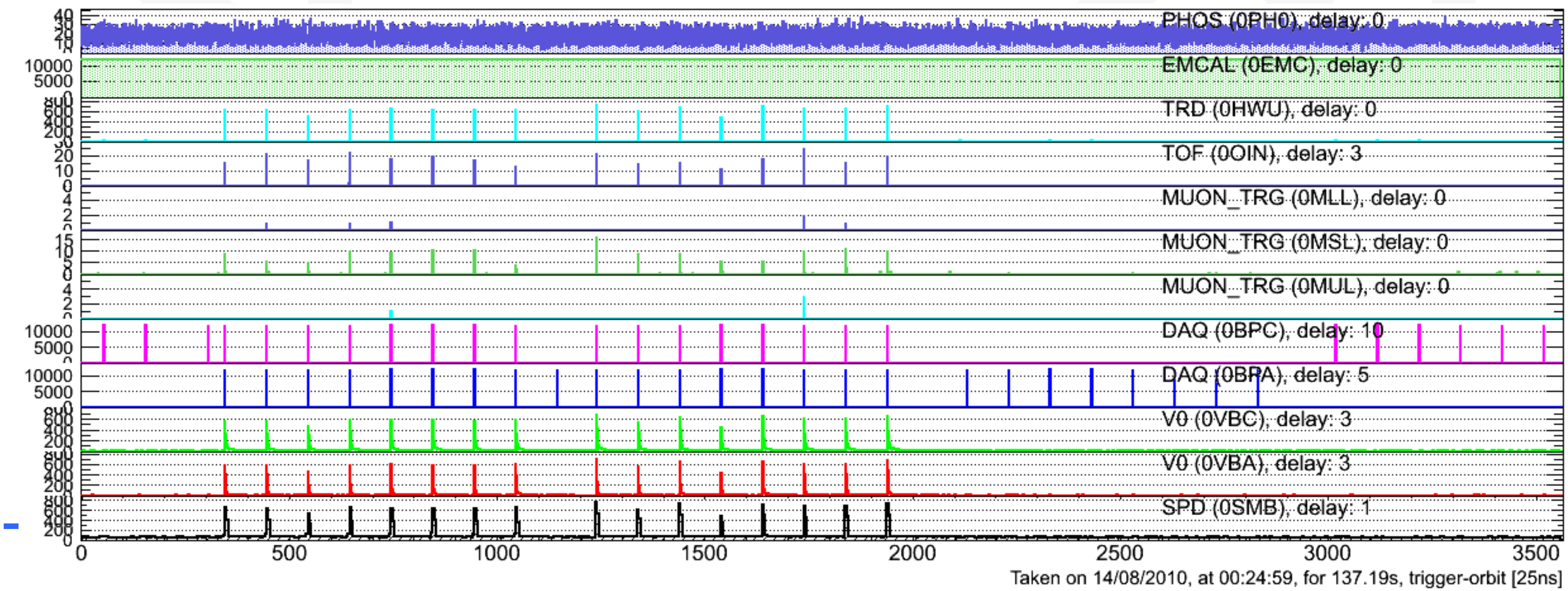
→ Different behaviour according to different machine modes

✓ losses to be studied systematically and accurately

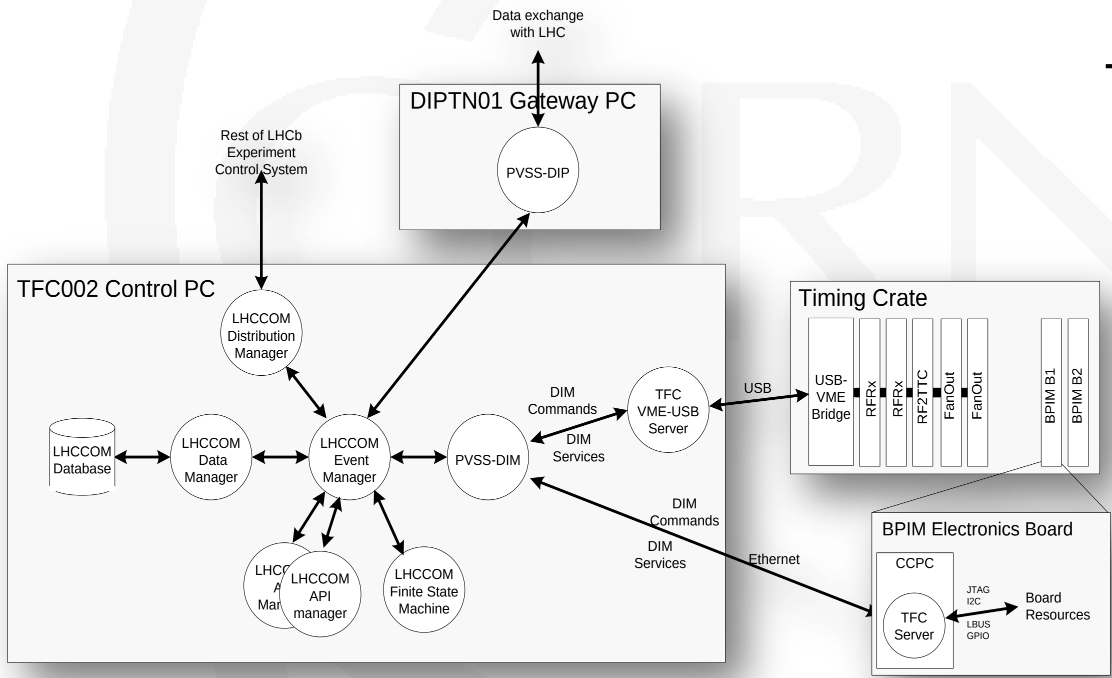
→ Need more calibration: scintillators are already ageing because non rad-hard, source of background are well described by simulation and in agreement, translate ADC in # of MIPs.

BPIM in ALICE

- → "Bunch masking"
  - ✓ Coincidence of two BPIMs (per beam) == collisions
  - ✓ Part of the "ALICE SMAQ" plot (0BPA and 0BPB): quickest trigger in ALICE!
- → Modification in order to see also pilot bunches
  - ✓ Amplification modified by factor ~4
- → Efficiency 100%: never missed a trigger!
- → Ready for Ion runs in ALICE: extremely important to have the system ready since day 1
- → The boards have proven to be working in a radiation environment without being affected by it



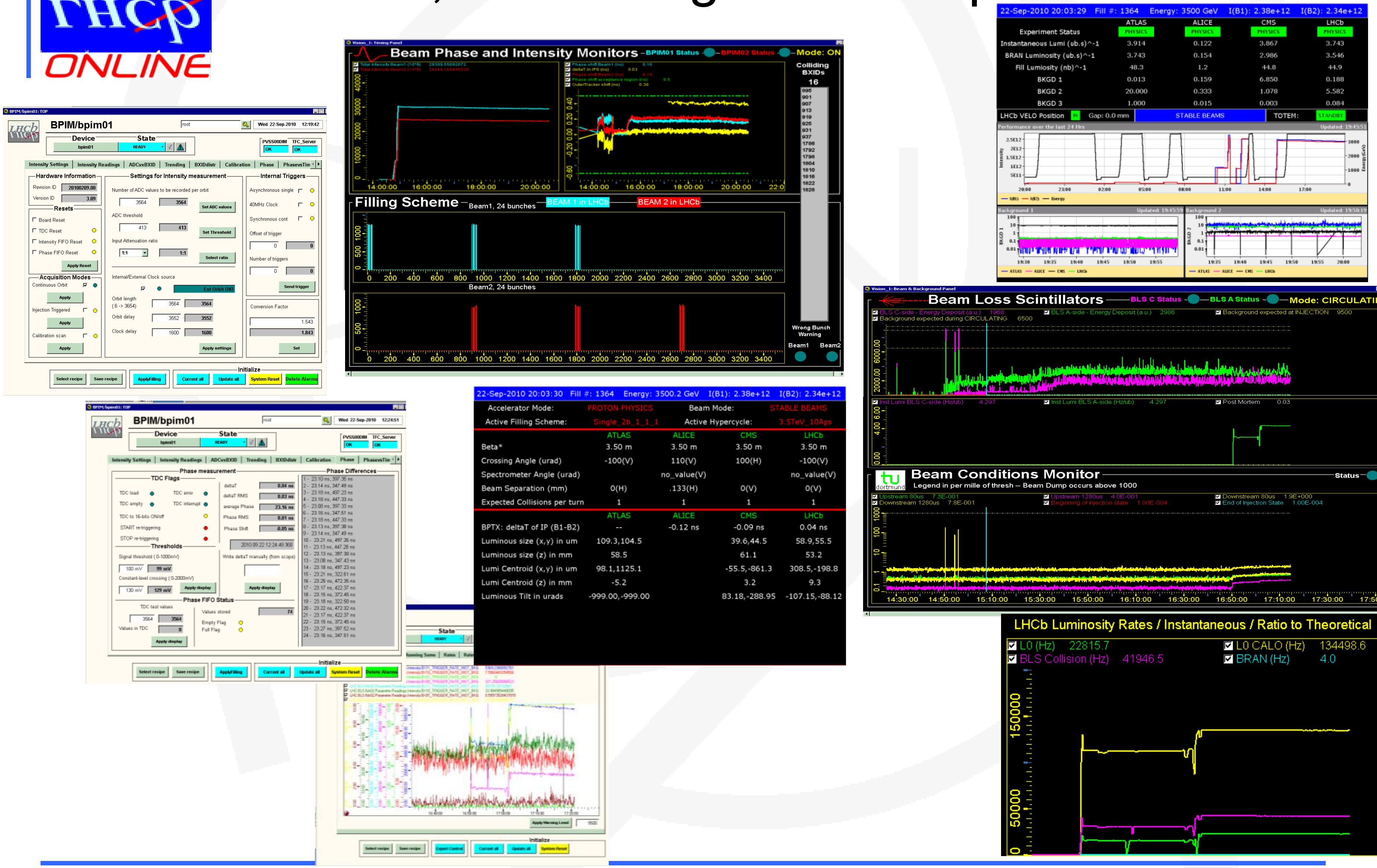
Control, monitoring and data presentation



- → Based on Credit Card-sized PC with Ethernet running a strip-down version of Linux
  - ✓ Access board resource via PCI bus converted to native hardware busses by *glue logic*
  - ✓ Server based on the same generic protocol on top of DIM allows the PVSS-based control system to configure and monitor the electronics

- → System allow for generic subscription to monitoring information for continuous archiving and permanent display in the LHCb control room

Control, monitoring and data presentation



Conclusions

→ LHCb has developed, produced and put in operation an extremely flexible, reliable and automated multi-purpose high performance acquisition board

→ Proven its great performance with first real LHC beam
- ✓ First resource in LHCb for monitoring timing
- ✓ First resource in LHCb for monitoring LHC filling scheme and possible ghost bunches
- ✓ First resource in LHCb for bunch-by-bunch dedicated measurements (intensity, phase, instantaneous and specific luminosity per bunch)
- ✓ Readout card for a LHCb scintillators system dedicated to beam and background monitoring
- ✓ Part of the ALICE trigger chain

→ Future plans:
- ✓ Make a second production batch
- ✓ Expand BLS with more scintillators (rad-hard)
- ✓ Finally put a front panel...