Beam Phase and Intensity Monitor for LHCb

Zbigniew Guzik, IPJ, Warsaw, Poland
Richard Jacobsson, CERN

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Motivation 1

- Global clock stability
  - LHCb: 14 km of fibre between SR4 and PA8 at a depth of ~1m
  - Estimated max. diurnal drift 200 ps
  - Estimated max. seasonal drift 8 ns

- Aid in the coarse and fine time alignment of the experiment
  - Measure bunch phase bunch-by-bunch

Effect of temperature variations on distribution fibres
(Source: Asservissement en phase d'une liason fibre optique, rapport de stage, Avril-Juin 2002, Abdelhalim Kelatma (AB/RF))
Motivation 2

- Monitor individual bunch position

- Bunch structure
  - LHCb off nominal IP with 7.5m
  - See single bunch (-gas) crossings
  - Ghost or displaced bunches (compare LEP)

- Bunch intensity bunch-by-bunch
  - Trigger conditions
  - Check trigger/detector timing alignment

- Interface the measurement directly with the data taking
  - Bunch information in the event data
  - Bunch crossing trigger/gate
- 1158 Beam Position Monitors (BPMs) in the LHC of the Button Electrode type
  - Two per IP for exclusive use by the experiments

- Located ~146m on either side of the IP on the incoming beam in LHCb
Button Electrodes (BPTX)

- Sum voltage from all four buttons
  - Signal amplitude ~independent of position

<table>
<thead>
<tr>
<th>Beam intensity (ppb)</th>
<th>BPTX output [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>450 GeV</td>
</tr>
<tr>
<td>Pilot (5 \times 10^9)</td>
<td>-1.3 ... 2.2</td>
</tr>
<tr>
<td>Year 1 (4 \times 10^{10})</td>
<td>10 ... 18</td>
</tr>
<tr>
<td>Nominal (1.15 \times 10^{11})</td>
<td>-29 ... 51</td>
</tr>
</tbody>
</table>

\[ \sum V_{\text{button}} \]

\[ \sigma_{\text{beam}} \text{ (450 GeV) } = 375 \text{ ps} \]

\[ \sigma_{\text{beam}} \text{ (7 TeV) } = 250 \text{ ps} \]
Signal transmission

- Signal cables installed between BPTXs and the LHCb “LHC rack” in counting houses
  - \( \frac{1}{2} \)” Nexan CMA50 coaxial cable
  - Approximately 200m (to be measured precisely), 4.2ns/m
  - Attenuation 3.3dB/100m (160 MHz), 5.9dB/100m (450MHz)

Pulse from single button with nominal beam at 7 TeV
Expected Signal

<table>
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<tr>
<th>Beam intensity (ppb)</th>
<th>BPTX output [V]</th>
<th>200 m CMA50 cable [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>450 GeV</td>
<td>7 TeV</td>
</tr>
<tr>
<td>Pilot ($5 \times 10^9$)</td>
<td>-1.3 ... 2.2</td>
<td>-1.7 ... 3.7</td>
</tr>
<tr>
<td>Year 1 ($4 \times 10^{10}$)</td>
<td>10 ... 18</td>
<td>-14 ... 30</td>
</tr>
<tr>
<td>Nominal ($1.15 \times 10^{11}$)</td>
<td>-29 ... 51</td>
<td>-39 ... 85</td>
</tr>
<tr>
<td></td>
<td>450 GeV</td>
<td>7 TeV</td>
</tr>
<tr>
<td>Pilot ($5 \times 10^9$)</td>
<td>-0.6 ... 1.2</td>
<td>-1.2 ... 2.4</td>
</tr>
<tr>
<td>Year 1 ($4 \times 10^{10}$)</td>
<td>-4.4 ... 9.6</td>
<td>-10 ... 19</td>
</tr>
<tr>
<td>Nominal ($1.15 \times 10^{11}$)</td>
<td>-12 ... 28</td>
<td>-30 ... 55</td>
</tr>
</tbody>
</table>

$\sum V_{\text{button}}$

$\sigma_{\text{beam}}$ (450 GeV) = 375 ps

$\sigma_{\text{beam}}$ (7 TeV) = 250 ps

Pulse from single button after 200m with beam at 7 TeV

Signal from BPTX on SPS compared to simulation ($4.2 \times 10^{10}$ and 100m cable)
Acquisition Board

- Developing custom made acquisition board
  - Beam Phase and Intensity Monitor (BPIM)
  - 6U VME, one per beam

- Summary of functions:
  - Measure time between bunch arrivals and LHC bunch clock locally
    - Bunch-by-bunch for a full turn filled in FIFO
    - Triggered via controls interface
    - <100 ps precision
  - Measure continuously bunch intensities bunch-by-bunch
    - 12-bit resolution
    - Output intensity on front-panel at 40 MHz (8/4-bit resolution)
    - Triggered via controls interface, fill in FIFO with intensities for full turn
  - Output “bunch crossing trigger” on GP outputs
  - Interfaced directly to LHCb Timing and Fast Control system
    - Bunch information fed into event data
    - May be used in the trigger control
  - Readout via Experiment Control System
Input stage

- Configurable attenuator to normalize the amplitude range for pilot/nominal(ultimate) beam
  - Two selections using a special RF relay from Omron
  - Output of the attenuator is buffered with an ultra-fast gain device

- Board is driven with the LHC bunch clock and orbit signal

- The phase and the intensity measurement circuits are adjusted with only one programmable delay on the incoming clock which covers entire 25ns range
- Full wave rectifier
- Active integrator circuit
- Differential 12-bit A/D conversion
- Integrator charge reset using an RF MOSFET
Phase Measurement

- Based on ultra-high performance TDC-GPX from Acam
  - R-Mode: 27 ps resolution over 10 μs at 40MHz
- Pulse is discriminated with programmable threshold
- First version based on zero-crossing detector
  - Zero-crossing moves with varying bunch size/shape
  - 450GeV/7TeV: ~100 ps
- Measurements with respect to every 8th bunch clock edge
Digital Processing

- Large FPGA:
  - Readout and control interfaces for ADC/TDC
  - Control of attenuator selection
  - Control of threshold DAC
  - Programmable clock delay
  - Linearization of converter characteristics
  - Output compressed 8/4-bit intensity data on FP
  - Produce bunch crossing trigger or gate

- Commanded via control interface, FPGA starts filling FIFOs with phase and intensity measurements of a full orbit upon the following orbit pulse
Board Control

- Main control interface based on on board Credit-Card-sized PC with Ethernet.
  - Board busses (Local Bus, I2C, JTAG) produced from PCI bus in a “Glue Logic” FPGA on separate mezzanine

- Alternatively, board may be controlled via a standard 32-bit VME interface implemented in an FPGA

- FPGA programming
  - FPGA may be programmed directly from the CCPC
  - Configuration device may also be programmed directly from the CCPC or onboard header.
  - VME interface FPGA is programmed via a header
Bunch crossing information is used in the Timing and Fast Control system and information is put in the ODIN Data Bank which is appended to the event data.
Conclusions

- First prototype of Beam Phase and Intensity Monitor developed for the LHCb BPTXs
  - Variable attenuator for pilot/first year/nominal beam
  - Measuring beam intensity per bunch continuously
  - Outputting intensity measurement at 40 MHz via LVDS interface
  - Outputting bunch crossing trigger/gate or whatever based on intensity/timing
  - Resolution of intensity measurement - 12 bits
  - Measuring phase between incoming bunch signal and bunch clock continuously
  - Resolution of phase measurement better than 100ps
  - Accumulates data from full turn triggered by control interface
  - Credit Card PC based control interface and VME interface
  - 6U VME board
    - Directly interfaced to the Timing and Fast Control system in LHCb
      - Bunch crossing information in event data

- Board is being mounted and will hopefully be tested on beam in Oct-Nov

- Improvements:
  - Zero-crossing detection replaced with bunch size/shape independent method

- Interest in the other experiments?