A novel approach to detector calibration parameter determination and detector monitoring

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OUTLINE:

• LHCb, vertex detector
• Data processing
• Detector parameters optimisation
The LHCb experiment @ the LHC

Forward spectrometer

**Acceptance:** \( \sim 10 - 300 \) mrad

**Luminosity:** \( 2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \)

**Nr of B’s / 2 fb\(^{-1}\) (nominal year):** \( 10^{12} \)

**Detector:**
- excellent tracking
- excellent PID

**Reconstruction:**
- muons: easy
- hadronic tracks: fine
- electrons: OK
- \( \pi^0 \)'s: OK, though difficult
- neutrinos: no

Mission statement

- Search for new physics probing the flavour structure of the SM
- Study CP violation and rare decays with beauty & charm hadrons

\( \sigma(\text{inclusive}) \sim 80 \text{ mb} \)

\( \sigma(b \overline{b}) \sim 0.5 \text{ mb} \)

All b-hadron species produced
Vertexing

- Precise reconstruction and separation of primary and secondary vertices - identification of beauty & charm meson decays

Tracking

- Excellent pattern recognition
- Precise determination of track parameters
  \( \Rightarrow \) excellent momentum resolution
  \( \delta p/p = 0.35\% \) to \( 0.55\% \)
  \( \Rightarrow \) excellent impact parameter (IP) resolutions

Beauty & charm mesons

Excellent
- mass resolution 15-40 MeV
- propertime resolution \(~50\) fs
21 April 2010: first reconstructed beauty particle

LHCb Event Display

$B^+ \rightarrow J/\Psi(\mu\mu) K^+$
Candidate
Precise tracking and vertexing (1/2)

Crucial to LHCb physics programme

- Hit resolution versus strip pitch for 2 bins of the projected angle
- Evaluated for R sensors using residuals of long tracks

Hit resolution depend to 1st order on:
- projected angle
- strip pitch
Precise tracking and vertexing (2/2)

Crucial to LHCb physics programme

- Best such resolutions at the LHC

$z - \text{res} = \frac{Z - \text{Const}}{N^{\text{Power}}} + \text{Epsilon}$

$(1.14/N^{0.96} + 0.3) \text{ mm}$

$IP = \text{Impact Parameter}$

Primary vertex

$\pi^-$

$\pi^+$

Direction of B
The LHCb VErtex LOcator

Highest precision vertex detector at the LHC
2 retractable detector halves:
  ~8 mm from beam when closed, retracted by 30mm during injection
21 stations per half with an R and a $\phi$ sensor
2 extra pile-up stations per half
  - recognition of multiple interaction collisions at the trigger level
# read-out channels: ~ 200k
Non-zero suppressed data rate ~ 4 GB/s!
VELO – modules

Purpose :

- Hold the sensors fixed wrt module support
- Connect electrical readout to the sensors and routing of signals to DAQ system
- Provide means of cooling to the sensors

- Sensor-sensor positioning accuracy < 5µm
VELO – sensors

- Highly segmented; $n^+$ on $n$
- 2048 strips per sensor
- Design operation at -7 degrees
- Read out at 1 MHz

**Φ sensors**

- Measure the azimuthal angle
- Stereo angle $20^\circ$ for the inner strips ($10^\circ$ for the outer strips)
- Pitch: $36 - 97 \, \mu m$

**R sensors**

- Measure the radial distance
- Divided in quadrants
- Pitch: $40 - 102 \, \mu m$

Data
VELO data processing
Achieving the best performance
Data processing chain

- **VELO sensor**

- **TELL1 = DAQ board**

- **Event banks**

- **VELO sends analogue → signal digitised on TELL1s**

- **TELL1s: 4 FPGAs with firmware, which work on integers**
  (Why FPGAs? Faster / better / more reliable / cheaper)

- **Mimicking the integer operations on FPGAs: need for a software emulation**
VELO data output (i.e. raw event) types

Raw event types (main ones)

- Zero-suppressed banks
  - main input to the reconstruction
    - clusters from hits
    - 1 bank per sensor

- Non-zero suppressed (NZS) banks
  - Full data as read out by a sensor
    - main input to emulation

- Error banks
  - Contains information on errors produced by the TELL1 boards

- ZS data rate: 50 bytes x 1 MHz = 50 Mb / s
TELL1 acquisition boards processing

Set of algorithms on TELL1 board
- Data synchronisation, buffering
- TELL1s first digitise the analogue signals from the sensors
- Suppress noise and perform clusterisation
- Algorithms implemented in FPGAs on TELL1s

Algorithms require ~ $10^6$ configuration parameters:
- Most important are
  - Pedestals
  - Clusterisation thresholds

⇒ Need to be determined and optimised!
How ... ?
Detector parameter determination & optimisation

Standard approach:

- FPGA algorithm parameters typically determined via standalone calculations or measurements

But how to achieve the best performance given
- complex chain of algorithms
- very large number of configuration/calibration parameters

Novel approach:

- Integrate determination of detector parameters in the data processing framework itself
  - Full integration in the LHCb software framework
- Use non-zero-suppressed data output by the TELL1s and emulate the data processing to tune its calibration parameters
TELL1 processing and emulation

TELL1 = DAQ board

TELL1 processing

NZS bank

Emulation + NZS data: means of determining and optimising the TELL1 processing parameters

Emulated ZS bank = emulated clusters

Emulation + NZS data: means of determining and optimising the TELL1 processing parameters

ZS bank = clusters

~10^6 configuration parameters!

Emulated ZS bank = emulated clusters

(emu. = RAW ⇒ bit perfectness)
The Vetra software project

Main characteristics of Vetra:

- LHCb software project for the VELO detector (also silicon tracker)
- Mimics the whole processing sequence
- Implements in C an emulation of the TELL1 algorithms run on the FPGAs (VHDL)
- Can treat as input the same data format(s) as output by the TELL1s - NZS, ZS, etc.
- Highly flexible and configurable, with Python

⇒ Unique framework for the determination and tuning of the various types of TELL1 parameters

Other benefits:

- Allows for self-consistency checks ↔ bit-perfectness of the TELL1 emulation
- Provides monitoring of all processing steps
- Provides at the same time a software framework and tools for TELL1 studies (e.g. new algorithms) and the online and offline monitoring of the VELO
- Also used in test-beam and laboratory tests
TELL1 parameter determination – procedure

- **TELL1 board**
- **Noise NZS banks**
- **Vetra**
- **Bit-perfect emulation**
- **NEW parameters**
- **Analyses**
- **Present Calibration parameters**
- **Database**
- **XML file**

**TELL1 parameter determination – procedure**

1. **TELL1 board**
2. **Noise NZS banks**
3. **Vetra**
4. **Bit-perfect emulation**
5. **NEW parameters**
6. **Analyses**
7. **Present Calibration parameters**
8. **Database**
9. **XML file**
Pedestal correction and its monitoring

Raw

Pedestal corrected

Pedestal Bank
Detector monitoring and data quality

- Uses the Vetra framework and "tools"

**Average sensor noise**

- **A-side**
- **C-side**

**Sensor occupancy**

- Mean histogram of all channels

**ADC for r clusters associated to a track**
Contents of "Pedestal" monitoring: Pilled for NZS data

Pedestal: Pedestal values that are subtracted (from VeloCond database).
1D: Average pedestal subtracted values in each channel
2D: Pedestal subtracted values in each channel.
VeloMoniGUI – Data Quality Summaries (DQS)

FILE INFO
- Time Stamp: 1256857427007104
- Events: 1235079

FILE INFO
- Noise
  - Avg noise (%): 2.04
  - Avg noise (Phi): 1.84

CROSS TALK
- # of noisy links: 435

PEDESTALS
- # of large residuals: 2474

ERRORS
- # TELL1 with >50 errors in last 1k: 0

CLUSTERS
- Strips: N/A
- Clusters: MPV
- R: N/A
- Phi: N/A

OCCUPANCY
- Avg % strip occ: N/A
- # strips >1 %: N/A

TRACKS
- # VELo tracks: N/A
- Avg # clusters/track: N/A
- Avg module mismatch %: N/A
- Sens with mismatch >20%: N/A
- Avg pseudoeff %: N/A
- # sens with pseudoeff <90%: N/A
- Avg residual pull: N/A

PRIMARY VERTICES
- Avg pos. X: N/A
- Avg pos. Y: N/A
- Avg pos. Z: N/A
- Avg L-R x pos: N/A
- Dist beam-VELO centre X: N/A
- Dist beam-VELO centre Y: N/A

Data Quality Summary

DQS information for RMS noise (NQS), occupancies (OQS), clusters (CQS), tracks (TQS), vertices (VQS), etc.

Push "Get the DQS" first to fill this page, then "ELOG submission" to send the values to the ELOG.
VeloMoniGUI – trending also possible

**Average noise (R)**

Contents of "Trends". Users should push the "Generate" button first to make the histograms.

After generating plots, they can be displayed via the drop-down menus.

By default, the X axis is set to "Run number".
Experience from the 2010 run

- We coped with the increase in LHC luminosity
  (LHCb runs under different conditions wrt ATLAS/CMS)

- VELO calibration performed with the emulation suite
  - New parameters determined and uploaded to the
    TELL1s acquisition boards when/if necessary
  ⇒ allows us to cope with extra increases in rate, via regular monitoring
    and determination of new parameters

- Approach successfully applied to collision data taken in 2010
  - Integration in the data processing framework was the choice to make

- Regular monitoring of the detector done on a daily basis
  - Noise, pedestals stability, hit and cluster reconstruction
    performance, etc.

- The Vetra software framework has also been adopted by the
  silicon tracker group for their tracking stations
So, does it work?
So, does it work?

LHCb Preliminary

$\sqrt{s} = 7$ TeV Data

- $m(1S) = 9452.1 \pm 2.9$ MeV/c$^2$
- $\sigma(1S) = 50.0 \pm 8.6$ MeV/c$^2$
- $N(1S) = 596 \pm 32$
- $m(2S) = 10015 \pm 2.9$ MeV/c$^2$
- $\sigma(2S) = 52.9 \pm 9.1$ MeV/c$^2$
- $N(2S) = 138 \pm 21$
- $m(3S) = 10347 \pm 2.9$ MeV/c$^2$
- $\sigma(3S) = 54.7 \pm 9.4$ MeV/c$^2$
- $N(3S) = 61 \pm 17$
Back-up slides
The LHCb detector

- **Ring Imaging Cherenkov**
- **Calorimeters**
- **Tracking** detectors
- **Muon System**

Acceptance:
- 10 mrad
- 250/300 mrad

**pp** collision

(side view)
Hit resolutions for VELO sensors

- Hit resolution versus strip pitch for 2 bins of the projected angle
- Evaluated for R sensors using residuals of long tracks

Hit resolution depend to 1st order on:
- projected angle
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Landaus – clusters and noise in the VELO

<table>
<thead>
<tr>
<th>Detector</th>
<th>S/N</th>
</tr>
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<tbody>
<tr>
<td>R</td>
<td>18.3</td>
</tr>
<tr>
<td>Phi Inner Strips</td>
<td>21.2</td>
</tr>
<tr>
<td>- Routed over outer strips</td>
<td></td>
</tr>
<tr>
<td>Phi Outer Strips</td>
<td>23.3</td>
</tr>
<tr>
<td>- No overlaid routing lines</td>
<td></td>
</tr>
<tr>
<td>Phi Outer Strips</td>
<td>19.6</td>
</tr>
<tr>
<td>- Overlaid routing lines</td>
<td></td>
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</tbody>
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