LHCb Vertex Locator commissioning and results from the first LHC beam reconstructed tracks

Silvia Borghi

University
of Glasgow

on behalf of the LHCb VELO group

The LHCb experiment

- ❖ LHCb is an experiment dedicated to heavy flavour physics at the LHC.
- ❖ Its primary goal to look for indirect evidence of new physics in CP violation and rare decays of beauty and charm hadrons.
- ❖ Forward spectrometer: $1.9 < \eta < 4.9$ [$b\bar{b}$ – pairs produced correlated in space]
- ❖ Luminosity: $2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ [10^{12} $b\bar{b}$ -pairs per year]

Main detector requirements

- ➡ Reconstruction in harsh radiation environment
- ➡ Selective trigger system [$b\bar{b}$ -production cross-section small]
- ➡ Good vertex resolution [proper time]
- ➡ Good particle identification [K/ π separation]

VELO: VErtexLOCator

Reconstruction

- Precise tracking

Vertexing

- Need to separate primary and secondary vertices

Trigger

- Fast reconstruction primary vertices
- B-decay selection

Expected Tracking Performance

LHCb acceptance: $1.9 < \eta < 4.9$

For typical B decay modes:

- primary vertex resolution:
 - x, y : $\sim 10 \mu\text{m}$, z : $\sim 60 \mu\text{m}$
- proper time res.: $\sim 40 \text{ fs}$
- B mass res.: 12 - 25 MeV
- Impact parameter resolution
 $13 \mu\text{m} + 35 \mu\text{m}/p_t$

VELO Layout

- ❖ 2 retractable detector halves: 5 mm from beam when closed, 30mm from beam during injection
- ❖ 21 stations per half with an R and ϕ sensor
- ❖ 2 Pile-Up stations per half [trigger]
- ❖ Operates in secondary vacuum
- ❖ 300 μ m foil separates detector from beam vacuum
- ❖ 2 phase CO₂ cooling system

Sensors

n^+ in n-bulk sensors [300 μm]

- inherently radiation tolerant
- strip isolation via p-spray
- expected radiation dose:
 - $1.3 \cdot 10^{14} n_{\text{eq}}/\text{cm}^2/\text{year}$ at $r = 0.8 \text{ cm}$
 - $5 \cdot 10^{12} n_{\text{eq}}/\text{cm}^2/\text{year}$ at $r = 4.2 \text{ cm}$

after 3-4 years [$\sim 8 \text{ fb}^{-1}$]: run partially depleted

Φ Sensor	R Sensor
<ul style="list-style-type: none"> ▪ Measuring the azimuthal angle ▪ Stereo angle 20° for the inner strips (10° for the outer strips) ▪ Pitch: 36 - 97 μm 	<ul style="list-style-type: none"> ▪ Measuring the radial distance. ▪ Divide in quadrants. ▪ Pitch: 40 - 102 μm

Module

Basic functions:

- ➡ hold the sensors in a fixed position relative to the module support.
- ➡ connect the electrical readout to the sensors
- ➡ enable cooling of the sensor.

- double-sided hybrid to balance stresses due to "bi-metallic" effects
- sensor-sensor accuracy: $<5\mu\text{m}$
- analogue front-end read-out: 2 x 16 Beetle chips
- cooling: 2-phase CO_2 [silicon @ -5°C]

Vacuum System

- silicon detectors operated in vacuum
- RF shield of $300\text{ }\mu\text{m}$ Al [3% Mg]
 - constitutes beam-pipe in VELO region
 - shape allows for overlapping sensors [alignment]

This is what Beam1 will see ...

Cooling system

- bi-phase CO₂ cooling system
- Operation temperature of the sensors below -5 °C
- Detector temperature (evaporator) is controlled by the pressure in the accumulator

Electronics overview

Readout chain for one side of one module

TELL₁ board

- Analog input from 64 links
- 10bit ADC @ 40 MHz
- FPGA for pre-processing (pedestal subtraction, cross-talk, common mode suppression, clustering)
- Maximum output rate is 1.1 MHz

**All components were installed.
Each system commissioned stand-alone.**

Production, testing and installation

Vacuum Tank

Electronics

CO₂ cooling

Module production

Module burn-in

Installation
of one half

Lowering into the
LHCb cavern

October
2007

TIPP09 - 12 March 2009

Fully Assembled VELO Half

Commissioning the VELO

✓ Single module operation under Neon atmosphere – **18th March 2008**.

✓ Noise level compared with previous data taken in assembly

✓ Operation of 15 modules on **15th May 2008**

✓ Single module test of 2nd half – from **2nd June 2008**.

✓ Full half powered for first time – **June 10th 2008**.

✓ First operation in vacuum – **18th June 2008**

✓ Full detector operated under vacuum.

✓ Operated cooling fully loaded at -25C

✓ Modules @ -5C

System @ full power

VELO under vacuum

After 18 weeks of pumping:

9×10^{-7} mbar

2×10^{-9} mbar

Specifications of the pressure 10^{-4} mbar in Detector volume and 10^{-8} in the beam volume

LHC synchronization test

in August and September 2008

- Beam 2 dumped on injection line beam stopper (TED)
- Beam
 - 1 shot each 48 seconds
 - About $5 \cdot 10^9$ protons per shot
- TED is an absorber at the end of the injection line
 - 4m tungsten, copper, aluminium, graphite rod in a 1m diameter iron casing
 - 340m before LHCb along beam 2
 - 8 mrad horizontally and 12 mrad vertically from LHCb beam axis

Photo during installation

Results on TED data

- First data taken on Friday 22nd August 2008
 - ◆ Powered HV channels of 10 modules (5 in each half)
- Data taken on 24th August and in September
 - ◆ Powered all HV channels
- About 410 events with about 2000 tracks

Friday 22nd August 2008

- Powered HV channels of 10 modules:
5 modules on A side and on C side

Sunday 24th August 2008

- Powered all HV channels
- 76 sensors readout

5th and 6th September 2008

- Powered all HV channels
- 76 sensors readout

Points distribution

Event display of
a typical event

Alignment method

Alignment of the VELO is following sequence:

1. Module alignment
 - ◆ Alignment via MILLEPEDE
 - ◆ Minimisation done with single matrix inversion
2. VELO half alignment
 - ◆ Alignment via MILLEPEDE
 - ◆ Minimisation done with single matrix inversion
3. Sensor alignment
 - ◆ An iterative approach based on residuals

Difference of Alignment constants evaluated with August and September data

Difference of align. constants
for X and Y translations

A side

C side

- ➡ The detector displacement from metrology is less than $10 \mu\text{m}$
- ➡ Module alignment precision is $5 \mu\text{m}$ for X and Y translation and $200 \mu\text{rad}$ for Z rotation

VELO Resolution

- ➡ VELO resolution
 - ◆ Linear dependency on the pitch
 - ◆ Dependency on the track angle
- ➡ 85%-90% clusters are one strip clusters
- ➡ Resolution evaluated integrating the results of all sensors

Evaluation of the resolution versus the projected angle

Conclusions

- All components fully installed and tested
 - First operation of whole detector under vacuum in June 2008
 - Full detector operated under vacuum for 18 weeks
 - 99.2% of channels fully operational
 - First ever reconstructed LHC induced tracks in TED events end of August
 - These tracks allow the evaluation of the VELO performance improvements foreseen after the proper calibration of DAQ boards parameters.
- ➡ The current module alignment has a precision of $5\text{ }\mu\text{m}$ for X and Y translation and $200\text{ }\mu\text{rad}$ for Z rotation $\Rightarrow$ micron level precision foreseen with improved resolution

**The VELO is ready for the next LHC beam ...
... to contribute to new physics results**