The Vertex Locator (VELO) at the LHCb experiment

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The Vertex detector @ LHCb.

Module production phase.

Testbeam results.

Absolute Luminosity measurements.

Conclusions.
The Vertex Locator (VELO) is situated close to the IP.

Precise tracking and reconstruction of primary and secondary vertices.

+ Pile-up veto to reject multiple interactions (1st level trigger).

See K. Rinnert’s talk for details.
The Vertex Locator

- Two detector halves with 21 silicon modules each.
- Retractable: silicon at 6 mm from the beam during physics condition, 30 mm during injection. A strategy has been defined to ensure the VELO closing process is accurate and quick: a precision of 15(50) \( \mu m \) in the closed(open) position and a time <0.1 s @ ±20 mm can be achieved.
- Harsh non-uniform radiation environment: up to \( 1.3 \times 10^{14} \text{ n}_{eq} \text{ cm}^{-2} \text{ year}^{-1} \) when fully closed.
- Detector operated in a secondary vacuum (<10\(^{-4}\) mbar) and separated from the beam vacuum (<10\(^{-8}\) mbar) by 300 \( \mu m \) thick aluminum foil (RF-box).
- Modules cooled via a CO\(_2\) cooling system (sensors at \( \sim -5 \) \(^{\circ}\)C).
- 2 Pile-up stations part of the 1\(^{st}\) level trigger.
Velo sensors

Innermost strip @ 7 mm from the beam: $1.3 \times 10^{14} \text{n}_{\text{eq}} \text{ cm}^{-2} \text{ year}^{-1}$ (max expected fluence).

→ n⁺ strips in n-bulk sensors (300 μm) and p⁺ rectifying contact on back side.

After 3-4 years (~8 fb⁻¹) runs partially depleted.

φ-sensor
- 2048 strips
- measuring the azimuthal angle.
- 683 inner strips (low radii) and 1365 outer strips (large radii).
- pitch: 36 – 97 μm

R-sensor
- 2048 strips
- measuring the radial distance.
- divided in 4 quadrants.
- pitch: 40 – 102 μm
Strips routed via a second metal layer to the Beetle front-end chips.

Electronic components mounted on polyimide (kapton) circuits: excellent radiation hardness and vacuum properties.

kapton circuits glued back to back on a carbon fibre substrate.

cooled (-5 °C on sensor) by a CO$_2$ circuit via cooling cookies mounted on the carbon surface.
Finally, a fully assembled VELO half!

The module production comprised 35 steps:

- 6 visual inspections.
- 6 metrologies.
- 7 electrical tests.
- 4 vacuum tests.
Module Production (II)

- At Liverpool
- Before burn-in

Rejected
Testbeam results

- In November 2006 a partially assembled VELO half has been tested in a 180 GeV pion beam. Targets were integrated to validate the performance of the vertex reconstruction software.
- Signal/Noise ~ 20-24 (24-29) for R (φ) sensors.
- Resolution: 8.5–25 μm (with increasing strip pitch).
- Interactions between pion beam and targets & sensors.
- Gap between R and φ sensors ~ 2 mm.
The testbeam data has been used to develop an alignment procedure, fundamental for the LHCb detector performances:

- Proper-time estimation \[ \tau = \frac{d \cdot m_B}{c \cdot |p_B|} \]
- Trigger efficiency [0.5 mrad tilt \( \rightarrow \) 30% events lost]
- Vertex resolution
The method:

- Inject a small quantity of gas (e.g. Xenon) in the vertex detector region.
- Reconstruct bunch-gas interaction vertices.
  → get beam angles, profiles and relative positions.
  → calculate the overlap integral.
- Initial steps: (i) use the residual gas present in the detector region and (ii) turn off the ion pumps to increase the pressure.

\[
L = fN_1 N_2 2c \cos^2 \left( \frac{\phi}{2} \right) \int \rho_1(\vec{x}, t) \rho_2(\vec{x}, t) d^3 x dt
\]

measured by AB group  measured by LHCb

- 10⁻⁷ mbar Xe
- 10¹¹ p/bunch
- ~ 30 Hz per bunch

<1% statistical uncertainty after few minutes.
Once calibrated by this method, any given reaction can be used to measure the absolute luminosity in a continuous way.

The channel $Z^0 \rightarrow \mu^+\mu^-$ is an ideal candidate:
- rate $\sim 30$ mHz
- clear signature
- negligible background

Several studies already carried out

The reference cross-section can be normalized to measure the absolute luminosity of the LHC experiments.

Still under study.

\[ \Delta p/p(750 \text{ GeV}) \approx 3\% \]

\[ \Delta M/M \approx 2 \times 10^{-4} \]
Conclusions

- The Vertex Locator is a complex detector situated around the interaction point of the LHCb experiment.
- It is designed for primary and secondary vertex reconstruction and to play a vital role in the on-line and off-line event selection.
- Many results from the testbeam in November 2006:
  - S/N: 24-29 (\(\phi\)), 20-24 (R).
  - Resolution: 8.5–25 \(\mu\)m.
  - Alignment procedure.
- The silicon module construction phase is now complete and the detector has entered the integration and commissioning phase:
  - Vacuum vessel, vacuum system, positioning control system, \(\mathrm{CO}_2\) cooling machine.
  - Electronic components.
  - Commissioning of the read-out and control system.
- The VELO will be also used to attempt measuring the absolute luminosity with a novel method based on vertex reconstruction of beam-gas interactions (statistical error <1% in few minutes).
- The VELO looks forward for the first data in 2008!
Back up slides
Final System for the Pit:
Gas injection system for luminosity monitoring:
- Gas bottle: a few bar liter (say Xe, 20 bar x 1 l)
- Service pressure $p_{svc} \approx 1$ bar
  - adjustable by hand (reducing valve), between about 0.5 and 5 bar
  - monitored with High Pressure gauge (via VELO PLC)
- Fill valve:
  - monitored/controlled by VELO PLC
  - default closed
- Bypass valve:
  - monitored/controlled by VELO PLC
  - default closed
- Fixed restriction: $C_{\text{restric}} \approx 5 \times 10^{-9}$ l/s (Xe). Thus, flow to TP301 will be about $5 \times 10^{-6}$ mbar l/s (1 bar Xe).
- Create desired pressure in PS300 (about $10^{-7}$ mbar) by adjusting TP301 pumping speed (control rotation speed 20-100% remotely) and/or the service pressure.
- Turn off VELO ion pumps
- Open GV302

Some interlocks (to be discussed...)
- "inject" closed if PE301 > limit
- "inject" closed if PE411or412 > limit
- "inject" closed if "bypass" open
- "inject", "fill" and "bypass" closed if PS300 failure
- etc...
Example

Bunch-Gas rate:

\[ R_{pA} = a_{pA} \sigma_{pA} N f n d \]

- \( a_{pA} \): detector acceptance
- \( \sigma_{pA} \): \( \sigma_{p1H} A^{0.7} \) (40 mb @ \( \sqrt{s}=114.5 \) GeV)
- \( N \): \( 10^{11} \)
- \( f \): 11.2455 kHz
- \( n \): \( 2.5 \times 10^9 \) cm\(^{-3}\) (10\(^{-7}\) mbar @ 293 K)

Example
If \( A=131(Xe) \) d=20 cm and \( a_{pA}=0.4 \)
\[ \Rightarrow R_{pA} = 30 \text{ Hz} \] (\( R_{pp}=3.3 \) kHz)