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On behalf of the LHCb VELO Group  

11th ICATPP Conference  
Villa Olmo, Como, 5-9 Oct. 2009

Results from the  
first LHC beam reconstructed tracks  
in the LHCb Vertex Locator

The LHCb detector @ the LHC  
VELO – VErtext LOcator  
VELO commissioning highlights  
First LHC-induced tracks with the VELO
The LHCb experiment @ the LHC

**Forward spectrometer**

**Acceptance:** $1.8 < \eta < 4.9$

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

**Nr of B’s / 2fb$^{-1}$ (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

**Tracking:**

*Expected tracking resolution*

\[ \frac{\delta p}{p} = 0.35\% \text{ to } 0.55\% \]

**Vertexing:**

*Expected primary vertex resolution*

~10\(\mu m\) transverse plane and ~60\(\mu m\) in the longitudinal one

*Expected Impact parameter resolution*

\[ \sigma_{IP} = 13 \mu m + 35 \mu m/p_T \]

**RICH performance:**

*Cherenkov angle resolution*

0.6-1.8 mrad

*Particle identification in p range 1-100 GeV*

$\pi$, $K$ ID efficiency > 90%, misID<~10%

**Calorimeter resolution:**

*Design ECAL resolution*

\[ \sigma(E)/E = 10\%\sqrt{E} + 1\% \text{ (E in GeV)} \]

*HCAL resolution from test-beam data*

\[ \sigma(E)/E = (69\pm5)\%\sqrt{E} + (9\pm2)\% \text{ (E in GeV)} \]
The VErtex LOcator – VELO

**Trigger**
- Fast reconstruction of primary vertices
  - select single-interaction collisions
- Enrichment of B-content in selection

**Tracking**
- Excellent pattern recognition
- Precise determination of track parameters

**Vertexing**
- Precise reconstruction and separation of primary and secondary vertices

**Expected primary vertex resolution**
- ~10µm transverse plane and ~60µm in the longitudinal one

**Expected tracking resolution**
- $\delta p/p=0.35\%$ to $0.55\%$

**Expected Impact parameter resolution**
- $\sigma_{IP}=13\mu m+35\mu m/p_T$

**B-mesons**
- Expected mass resolution
  - 12-25 MeV
- Expected proper-time resolution
  - ~40fs
VELO – overview

- 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
- Operation in secondary vacuum
- 300$\mu$m foil separates detector from beam vacuum
- Bi-phase CO$_2$ cooling system
**Purpose:**

- Hold the sensors fixed wrt module support
- Connect electrical readout to the sensors
- Provide means of cooling to the sensors

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

- Highly segmented; $n^+$ on $n$
- 2048 strips per sensor
- Radiation tolerant. Expected radiation dose:
  - $1.3 \cdot 10^{14} n_{eq}/cm^2/year$ at $r = 0.8$ cm
  - $5 \cdot 10^{12} n_{eq}/cm^2/year$ at $r = 4.2$ cm
- Design operation at -7 degrees

<table>
<thead>
<tr>
<th>$\Phi$ sensors</th>
<th>$R$ sensors</th>
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<tbody>
<tr>
<td>- Measure the azimuthal angle</td>
<td></td>
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<tr>
<td>- Stereo angle 20° for the inner strips (10° for the outer strips) $\Rightarrow$ 2 regions</td>
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<tr>
<td>- Pitch: 36 - 97 µm</td>
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<tr>
<td>- Measure the radial distance</td>
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<tr>
<td>- Divided in quadrants</td>
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<tr>
<td>- Pitch: 40 - 102 µm</td>
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VELO modules & sensors
Commissioning – overview

2007
- Installation
- Cosmics cannot be used for commissioning

2008
- Comparisons of noise level with data taken in assembly
- Single module operations under Neon atmosphere
- Multi-module testing, full half powered for the first time, etc.
- First operation in vacuum on 18th June
- Full detector operated under vacuum
- Cooling down of detector with modules @ -5 C
- Beam in SPS-to-LHC transfer line stopped on the « TED beam dump » on 22nd-24th August and 5th-6th September

2009
- TED run in June
- Tuning of the timing
- High rate tests at 1 MHz
- Operation under final conditions (vacuum and temperature)
- Next TED run just a week away – 12th Oct. !

“TED runs”: see next slides ...
Tests with beam-induced tracks – TED runs

What are these “TED runs” ?

- Passage of secondary tracks through the LHCb detector coming from a dump of LHC’s beam 2 on the TED
- TED=Transfer line External beam Dump
  - 4m W/Cu/Al/graphite rod in 1m iron casing
  - absorber located 340m before LHCb

Why does the VELO need them ?

- Cosmics not exploitable given the VELO geometry

Goals of these real data sample studies:

- Test the “DAQ recipes”
- Tuning the timing
- Commission the monitoring (online, offline)
- Test the pattern recognition
- Check performance of alignment algorithms
TED runs – runs & data samples

1\textsuperscript{st} RUN
22-24 August 2008
22\textsuperscript{nd} : 10 modules powered on (5 in each half)
24\textsuperscript{th} : all HV on; 76 sensors read out

2\textsuperscript{nd} RUN
5-6 September 2008
- All HV on
- 76 sensors read out

3\textsuperscript{rd} RUN
6-7 June 2009
All HV on

About 60000 tracks collected in total!


First Event
22-08-2008 @ 17h33

Eduardo Rodrigues
11\textsuperscript{th} ICATPP Conference, Villa Olmo, Como, 5 Oct. 2009
June 2009 TED run – VELO timing (1/2)

Procedure:

- (Timing first estimated from cable lengths, known delays)
- Sample in time slots of ±25ns around best guess of timing settings for signal
- Perform the tuning using TED data

Signal peak slightly off from “nominal” (index=7)

Spillover on top of noise

Threshold effect

All monitored online, with zero-suppressed data
Timing could be set with precision better than 2ns with ~100 clusters/sensor/step.
June 2009 TED run – signal-to-noise

MPV – Most Probable Value of ADC distribution

- Use clusters on tracks
  - $\Phi : 34.4$
  - Outer w/o Metal: 35.3
  - Inner: 34.4
  - Outer w Metal: 33.6
- $R: 32.8$

$\Rightarrow$ signal-to-noise:

- $\Phi: 20$
  - Outer W/Metal: 19
  - Inner: 20.5
  - Outer w/o Metal: 23
- $R: 18$

(ADC distributions fitted with a Landau)
June 2009 TED run – pattern recognition

- Pseudo-efficiency calculated by interpolation, per sensor

⇒ pseudo-efficiencies:
  - Φ sensors: ~ 97.4%
  - R sensors: ~ 96.9%

Large search window: 5σ of resolution + tolerance of 100 µm (5 mrad)
June 2009 TED run – tracks

Low intensity run: $2-5 \times 10^9$ protons

High intensity run: $\sim 10^{10}$ protons

Av. 5.6

Av. 13.9
TED runs – alignment

2008
- First alignment with real tracks
- Modules position differences with respect to metrology within 10 µm

2009
- High statistics
  ⇒ possible to check for the 1st time
  the distance between detector halves with “traversing tracks”
Detector halves separated by 2.000mm and then moved to 2.450mm, i.e. $\Delta x = 450 \, \mu m$

Analysis based on only 1000 tracks determined the relative distance between the detector halves to be $\Delta x = 445 \pm 10 \, \mu m$!
Selecting ‘high-p’ tracks: selecting particles coming from the TED region

- \((-4 \text{ m}, 8 \text{ m})\) and \((-10 \text{ m}, 10 \text{ m})\) at \(z=350\text{m}\)
- Mean \(\theta\) : 16 mrad (\(\theta < 35\) mrad)
- 85%-90% 1-strip clusters

⇒ binary resolution expected
Conclusions and Outlook

- VELO fully installed and tested
- First operation of full VELO back in June 2008
- First ever beam-induced tracks seen in August 2008
- Very successful commissioning with ~60000 tracks reconstructed
- Obtained resolution ~10µm and alignment better than 10µm
- Required performance for physics has been achieved

VELO ready for when the LHC beam will see

when traversing it!