The old LHCb detector
- Forward arm spectrometer, focusing on b- and c-hadron decays
- Studies rely on secondary vertices identification
- Integrated luminosity 10 fb$^{-1}$
VErtex LOcator
LHCb Upgrade I

- Increase operational luminosity
  - $4 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \rightarrow 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- Remove hardware trigger and readout at full rate
  - $1 \text{ MHz} \rightarrow 40 \text{ MHz}$ readout
- Collect 50 fb$^{-1}$ data
- Increase number of visible interactions
LHCb Upgrade I

- Increase operational luminosity
  - $4 \times 10^{32} \text{ cm}^{-2} \text{s}^{-1} \rightarrow 2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
- Remove hardware trigger and readout at full rate
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- Collect 50 fb$^{-1}$ data
- Increase number of visible interactions

---

**Detector Channels**
- old
- upgrade

**Efficiency**
- old
- upgrade

**Track origin vertex**
- old
- upgrade

**IP resolution**
- old
- upgrade

Evaluate at $\nu = 7.6$, $\sqrt{s} = 14$ TeV
## VELO Systems Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>old VELO</th>
<th>VELO Upgrade I</th>
<th>VELO Upgrade II</th>
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</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>R, (\phi) strips, semicircular</td>
<td>pixels, L shaped geometry</td>
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<tr>
<td></td>
<td>173,032 strips (~0.2 M)</td>
<td>41 M pixels</td>
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<tr>
<td>Distance From Beam</td>
<td>8.2 mm</td>
<td>5.1 mm</td>
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<tr>
<td>Maximum Fluence</td>
<td>(4.3 \times 10^{14}) 1 MeV neq cm(^{-2})</td>
<td>(8 \times 10^{15}) 1 MeV neq cm(^{-2})</td>
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<tr>
<td>HV Tolerance</td>
<td>500 V</td>
<td>1000 V</td>
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<tr>
<td>ASIC Readout Rate</td>
<td>1 MHz</td>
<td>40 MHz</td>
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</tr>
<tr>
<td>Total Data Rate</td>
<td>~150 Gb/sec</td>
<td>2.8 Tb/sec</td>
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<tr>
<td>Power Consumption</td>
<td>~ 0.8 kW</td>
<td>~ 1.6 kW</td>
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<tr>
<td>Operating Temperature</td>
<td>~ -8 °C</td>
<td>~ -25 °C</td>
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### VELO Systems Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>Upgrade I (2010–2019)</th>
<th>VELO Upgrade II (2021–?)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>R, φ strips, semicircular pixels, L shaped geometry</td>
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</tr>
</tbody>
</table>
VELO Upgrade I

proton beam

50 cm
VELO Upgrade I

RF foil
primary vacuum
modules
proton beam
read-out chain
air
secondary vacuum
RF foil
RF foil

Description

- Physical barrier for the beam-VELO vacua
- Front-end electronics protection from beam charge
- Has to withstand 10 mbar pressure variation

Total material budget:
250 µm: 21.3% $X_0$
150 µm: 20.9% $X_2$
RF foil

Milling and etching

Video of the milling process: url
RF foil

Milling and etching

Video of the milling process: [url](url)
RF foil

Installation finished!

- Delayed due Covid-19
- Real-time remote support via zoom
Microchannel cooling
Microchannels

Idea and manufacture

• Evaporative CO\textsubscript{2} cooling provides small temperature drop
• Cooling up to 30 W per module while keeping the material budget low
• Complex production of high quality substrates
Readout chain
Sensors and ASICs

- Sensors
  - $55 \times 55 \, \mu m^2$ pixels
  - 4 sensors, thickness 200 um

- VeloPix ASICs based on Timepix3
  - 256x256 pixels
  - Data driven readout
  - Up to 800 Mhits/s/ASIC
Module

- **Sensors**
  - 55 × 55 µm² pixels
  - 4 sensors, thickness 200 µm
- **VeloPix ASICs based on Timepix3**
  - 256x256 pixels
  - Data driven readout
  - Up to 800 Mhits/s/ASIC
Readout

- Sensors
  - 55 x 55 µm² pixels
  - 4 sensors, thickness 200 µm
- VeloPix ASICs based on Timepix3
  - 256x256 pixels
  - Data driven readout
  - Up to 800 Mhits/s/ASIC
VELO module assembly

The LEGO® for physicists!

The LHCb VELO Upgrade
Peter Svihra (peter.svihra@cern.ch)
ICHEP 2020, Prague
Bare module assembly
Bare module assembly

Substrate flatness

Microchannel substrate

Carbon-fiber legs

Cooling pipe clamp

Aluminum foot

Cooling pipes

@ UoM

@ CERN
Tiles gluing

- Using glue Stycast with cat-23LV
  - previously cat-9, discarded due to humidity related issue
Tiles gluing

- Using Stycast glue with cat-23LV
  - Previously used cat-9, discarded due to humidity related issue
Hybrid attachment and wire-bonding
Hybrid attachment and wire-bonding
Cables attachment

Bridge piece

LV cables

LV foot connector
Module testing
Mechanical performance

- Sensors designed to perform up to \(-1\) kV bias
Mechanical performance

- Sensors designed to perform up to $-1 \text{ kV}$ bias
- Mechanical deformation crucial due to alignment, components proximity and fragility
- Modules 10x thermal cycled

**IV characteristic of single tile**

**Mechanical deformation of module during cooling**
Mechanical performance

- Sensors designed to perform up to $-1$ kV bias
- Mechanical deformation crucial due to alignment, components proximity and fragility
- Modules 10x thermal cycled

Mechanical deformation of module during cooling

- Power consumption to increase with irradiation, good performance still expected in 10 years

Thermal performance of single tile
Communication performance

Equalization process of single ASIC

Equalization result of single tile
Communication performance

- **PRBS** tests bit error rate to check data integrity
  - 20 readout links, more links per ASIC closer the to interaction point
- 40 MHz readout
  - Maximum 800 Mhits/ASIC/s
  - Occupancy ~6 hits/ASIC/crossing

**Summary**

- **DAC Threshold trim**
- **Equalised to:** 0 sigma
- **Target:** 1439.6
- **Predicted:** 1439.6 +/- 4.1
- **Masked:** 65
- **Noise Width:** 6.3 +/- 0.8

**Link test of a whole module**
Summary
Summary

- VELO upgrade in progress
- Impact of Covid-19, module production being resumed
  - Production sites recommissioned
- Produced modules performing as expected
  - Extensive quality assurance
  - Database tracking of all tests and status
- Preparations for commissioning and VELO assembly
Backup
<table>
<thead>
<tr>
<th>Module grading</th>
<th>Bare module</th>
<th>Tile gluing</th>
<th>Mechanical performance</th>
<th>Communication performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Substrate Flatness</strong></td>
<td>Grades (within $\eta_{25}$ &amp; $\eta_{75}$)</td>
<td>Grades (mean $\pm$ 2·stdev)</td>
<td>Grades (result interpretation – IV behaviour)</td>
<td>Grades (result interpretation – noise, pattern and mask)</td>
</tr>
<tr>
<td>- A ($\pm$ 50 µm)</td>
<td>- A (-40 µm, +120 µm)</td>
<td>- A (all OK)</td>
<td>- A (all OK)</td>
<td></td>
</tr>
<tr>
<td>- B ($\pm$ 75 µm)</td>
<td>- B (-30 µm, +150 µm)</td>
<td>- B (minor issues)</td>
<td>- B (minor issues)</td>
<td></td>
</tr>
<tr>
<td>- C ($\pm$100 µm)</td>
<td>- C (-20 µm, +180 µm)</td>
<td>- F (outside)</td>
<td>- F (major issues)</td>
<td></td>
</tr>
<tr>
<td>- F (outside)</td>
<td>- F (outside)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Glue Thickness</strong></td>
<td>Grades (mean $\pm$ 2·stdev)</td>
<td>Grades (mean $\pm$ 2·stdev)</td>
<td>Grades (ΔT of ASICs)</td>
<td>Grades (ΔT of ASICs)</td>
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<tr>
<td>- A ($\pm$ 20 µm)</td>
<td>- A ($\pm$ 20 µm)</td>
<td>- A (all &lt; 5 °C)</td>
<td>- A (all &lt; 5 °C)</td>
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<tr>
<td>- B ($\pm$40 µm)</td>
<td>- B ($\pm$40 µm)</td>
<td>- B (all near beam &lt; 5 °C)</td>
<td>- B (all near beam &lt; 5 °C)</td>
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<tr>
<td>- C ($\pm$60 µm)</td>
<td>- C ($\pm$60 µm)</td>
<td>- C (one near beam &lt; 7 °C)</td>
<td>- C (one near beam &lt; 7 °C)</td>
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<tr>
<td>- F (outside)</td>
<td>- F (outside)</td>
<td>- F (any &gt; 7 °C)</td>
<td>- F (any &gt; 7 °C)</td>
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<tr>
<td><strong>Tile Flatness</strong></td>
<td>Grades (mean $\pm$ 2·stdev)</td>
<td>Grades (mean $\pm$ 2·stdev)</td>
<td>Grades (max displacement)</td>
<td>Grades (max displacement)</td>
</tr>
<tr>
<td>- A (&lt; 30 µm)</td>
<td>- A (&lt; 30 µm)</td>
<td>- A (&lt; 100 µm)</td>
<td>- A (all &lt; $10^{-12}$)</td>
<td></td>
</tr>
<tr>
<td>- B (&lt; 45 µm)</td>
<td>- B (&lt; 45 µm)</td>
<td>- B (&lt; 150 µm)</td>
<td>- B (any, different tape &gt; $10^{-12}$)</td>
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</tr>
<tr>
<td>- C (&lt; 60 µm)</td>
<td>- C (&lt; 60 µm)</td>
<td>- C (&lt; 200 µm)</td>
<td>- C (any, same tape&gt; $10^{-12}$)</td>
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<tr>
<td>- F (outside)</td>
<td>- F (outside)</td>
<td>- F (outside)</td>
<td>- F (any &gt; $10^{-10}$)</td>
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<tr>
<td><strong>Tile placement</strong></td>
<td>Grades (Δx, Δy)</td>
<td>Grades (max displacement)</td>
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<tr>
<td>- A (&lt; 30 µm)</td>
<td>- A (&lt; 100 µm)</td>
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<td>- B (&lt; 45 µm)</td>
<td>- B (&lt; 150 µm)</td>
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<tr>
<td>- C (&lt; 60 µm)</td>
<td>- C (&lt; 200 µm)</td>
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<td>- F (outside)</td>
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<tr>
<td><strong>Displacement measurement</strong></td>
<td>Grades (max displacement)</td>
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<td>- A (all &lt; $10^{-12}$)</td>
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<tr>
<td></td>
<td>- B (any, different tape &gt; $10^{-12}$)</td>
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<tr>
<td></td>
<td>- C (any, same tape&gt; $10^{-12}$)</td>
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<tr>
<td></td>
<td>- F (any &gt; $10^{-10}$)</td>
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# Module assembly timescale

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<tr>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
<th>Day 9</th>
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<td>m3</td>
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<td>m4, m5</td>
<td>m4, m5</td>
<td>m6, m5</td>
<td>m5, m6</td>
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<td>bare module jig</td>
<td>m1</td>
<td>m2</td>
<td>m3</td>
<td>m4</td>
<td>m5</td>
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<td>m6</td>
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<td>m2</td>
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<td>m3</td>
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<td>m4</td>
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</tbody>
</table>

**m#** – module number

- **location**
- **assembly**
- **testing**

The LHCb VELO Upgrade I  Peter Sivhra (peter.sivhra@cern.ch)  ICHEP 2020, Prague
Readout chain

- Module
- VFB
- OPB
- Readout card