LHCb VELO telescopes

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on behalf of the LHCb VELO testbeam group
BTTB6
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• Update Timepix3 telescope
• Some performance figures
• VeloPix mini telescope
LHCb VELO timepix3 telescope at SPS

- Built for LHCb VELO upgrade sensor characterisation
- Each plane: 300 \( \mu \text{m} \) Silicon on 700 \( \mu \text{m} \) Timepix3, no PCB
- Simultaneous ToA and ToT measurement
- Data driven readout with SPIDR
Telescope introduction II

- High tracking rate, \( \sim 10 \) Mtracks/cm\(^2\)/s by design
- Tested up to 5 Mtracks/cm\(^2\)/s without loss of performance
- Four TDC inputs with 260 ps bins to ease integration of DUTs
- Analysis with Kepler (Gaudi based) reconstruction framework
- Telescope used by many LHCb and non-LHCb groups

![Graph showing fr_non associated clusters vs Rate [MHz/cm\(^2\)] for LHCb Preliminary plane 5]
Performance: Spatial resolution

- Pixel dimensions 55 x 55 $\mu$m$^2$
- Detector planes at 9° angles (yaw, pitch) for optimal resolution
- (biased) Resolution 3 – 4 $\mu$m
- No significant contribution from (mis)alignment
Performance: Pointing resolution

Pointing resolution near DUT: $x\approx 1.67 \, \mu m$ & $y\approx 1.57 \, \mu m$
Some improvement possible: lower threshold

- Default threshold 1000 e-
- Lower threshold gives up to 10% resolution improvement
  - due to slightly larger cluster size
- Some extra noise for very low thresholds
Performance: Time resolution

- Timing stable from run to run
- Offset determined per run

Time resolution per plane $\sigma_{\text{int}} = \sim 1$ ns
- worse than expected (1.56 ns / $\sqrt{12}$)
- due to residual timewalk and charge collection time

Telescope time resolution $\sigma_{\text{tel}} = \sigma_{\text{int}} / \sqrt{8} = 0.35$ ns
- too optimistic?, residuals might be correlated
- Dedicated study required, some data available
Resolution versus bias voltage

- Charge collection, hence timing will improve with higher bias voltage
- However, we do not want to compromise spatial resolution
- Seems that spatial resolution barely changes from 100 to 150 V bias
- Improvement on time resolution not yet determined
VeloPix
Reminder: LHCb VeloPix

- Derived from Timepix3, tailored to LHCb Vertex Locator
- Binary readout, radiation hard
- No trigger, read out all data, AND high luminosity -> huge data rates (20 Gbit/s/chip)
- First chip version fully functional but had some flaws -> version used in mini-telescope
- Issues solved for 2nd version of VeloPix, final qualification ongoing

14 mm
## Comparison VeloPix and Timepix3

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Pixel arrangement</strong></td>
<td>256 x 256</td>
<td></td>
</tr>
<tr>
<td><strong>Pixel size</strong></td>
<td>55 x 55 µm²</td>
<td></td>
</tr>
<tr>
<td><strong>Peak hit rate</strong></td>
<td>80 Mhits/s/ASIC</td>
<td>800 Mhits/s/ASIC 50 khits/s/pixel</td>
</tr>
<tr>
<td><strong>Readout type</strong></td>
<td>Continuous, trigger-less, TOT</td>
<td>Continuous, trigger-less, binary</td>
</tr>
<tr>
<td><strong>Timing resolution/range</strong></td>
<td>1.5625 ns, 18 bits</td>
<td>25 ns, 9 bits</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td>&lt;1.5 W</td>
<td>&lt; 2 W</td>
</tr>
<tr>
<td><strong>Radiation hardness</strong></td>
<td>400 Mrad, SEU tolerant</td>
<td></td>
</tr>
<tr>
<td><strong>Sensor type</strong></td>
<td>e- and h+ collection</td>
<td>e- collection</td>
</tr>
<tr>
<td><strong>Max. data rate</strong></td>
<td>5.12 Gbps</td>
<td>20.48 Gbps</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>130 nm CMOS</td>
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</table>
VeloPix mini telescope

- Most VeloPix functions tested in lab and with Timepix3 telescope
- Except high rate performance

- Built a 5 layer (mini) telescope
- Reusing Timepix3 telescope HW
- Tested in High Rate area at Fermilab
High rate test area at Fermilab (M03)

32 GeV $\pi$

Telescope

Collimator

DAQ

10x DAQ + Slow/Run Control
A look at the data

- First attempt to run telescope, many last minute fixes …
- Step wise increase of beam rate to > 200 Mtracks/cm$^2$/s
- One spill of 4.2 seconds gives about 40 Gbytes on disk
- Analysis with modified version Kepler framework
- First results look OK, but still need to analyse highest rate runs in detail

14 mm residuals ~ 10 um
(as expected)

first VeloPix tracks!
Beam rate

- Beam rate seems to fluctuate significantly, even at millisecond scale
- Average rates are misleading
- Some analysis challenges ahead
Summary

- LHCb Timepix3 telescope operated successfully > 3 years
  - Workhorse for LHCb VELO upgrade program
  - Also frequently used by other LHCb and non-LHCb groups
- Spatial resolution < 2 µm, time resolution < 1 ns, track rate > 5 Mtracks/cm²/s
  - Minor improvements possible
- Built VeloPix mini-telescope to test VeloPix at high-rate at FNAL
  - Interesting and challenging ‘exercise’
- Successfully acquired data with rates > 200 Mtracks/cm²/s
- Results so far as expected; high rate data to be analysed in greater detail
  - Still on the agenda: timewalk measurement of VeloPix with Timepix3 telescope
Back up
Timepix3 telescope networking

- TPX3
- SPIDR
- DAQ PC 1
  - 10 GbE
  - DAQ + Slow
- DAQ PC 2
- DAQ PC N
- 1 GbE switch
- 1 GbE
- Run control
  + config PC
  (+online mon)
- Online Monitoring
  PC
- Offline PC
  backup to EOS
- 1 GbE
  - Moni
- 1 GbE
  - Offline

- not installed