A Future Vertex Locator with Precise Timing for the LHCb Experiment

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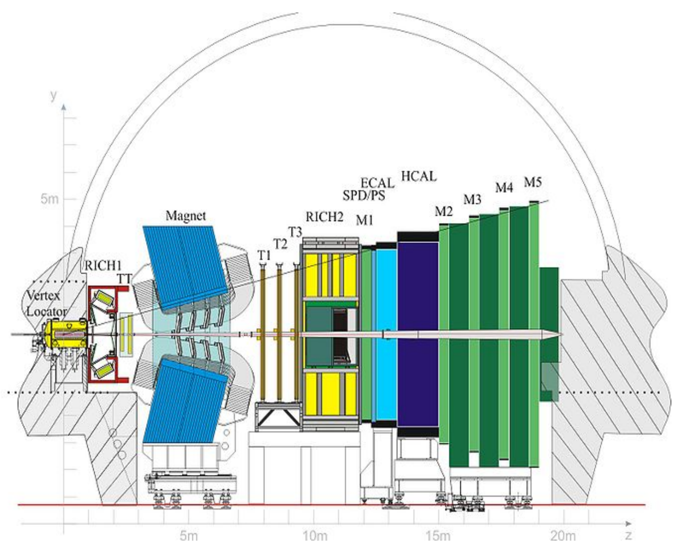
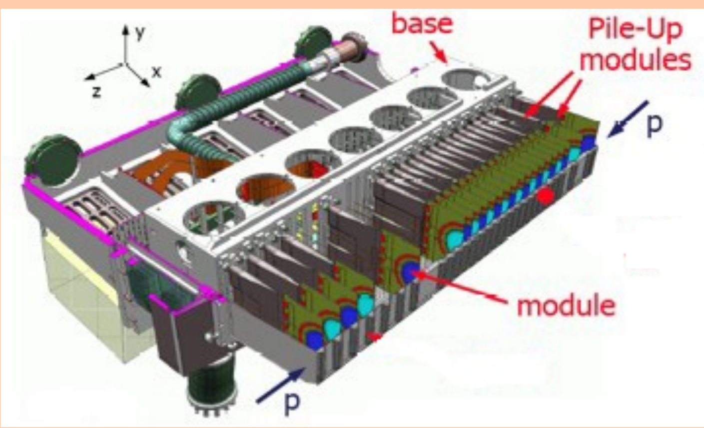
Introduction

The Vertex Locator (VELO) is a crucial component of the LHCb experiment, placed immediately around the proton-proton interaction region. It is a silicon strip detector which precisely determines the trajectories of charged particles, and reconstructs primary and secondary vertices. This is essential for achieving the physics goals of the experiment.



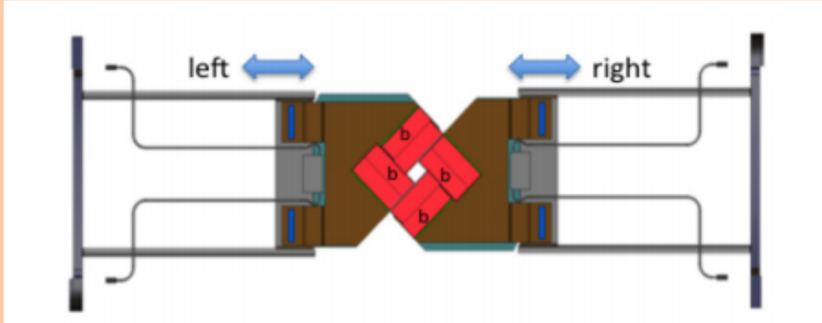
Current VELO design



$L = 4 \times 10^{32}\ cm^{-2}\ s^{-1}$

Fig. 1 Current VELO design.

VELO Upgrade I (Run 3-4)



$L = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$

Fig. 2 In 2019-2020 the VELO will be upgraded from a microstrip to a pixel detector, placed closer to the beam, and with full 40 MHz readout.

VELO Upgrade II (Run 5+)

$L = 2 \times 10^{34}\ cm^{-2}\ s^{-1}$

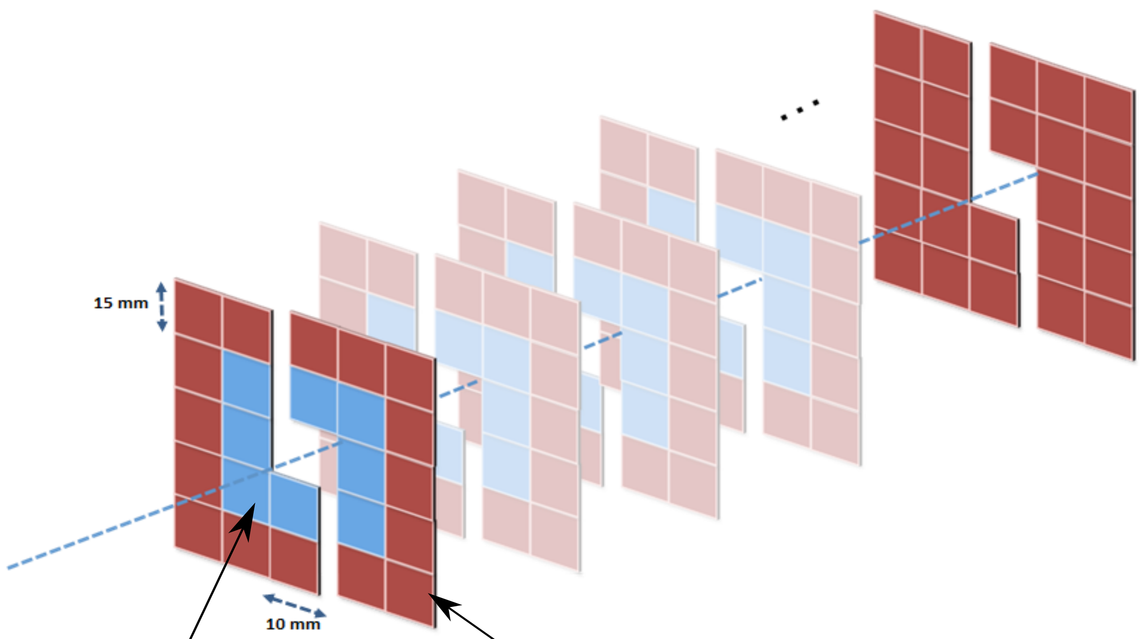
From Run 5 onwards, the LHCb experiment will take advantage of the HL-LHC to collect 50x more luminosity than in Run 2. The VELO must be upgraded to ensure that the physics performance can be sustained in this high multiplicity environment.

In this project we examine the benefits of a detector design comprising silicon pixels with precise timing information.

Project details and goals

- The '4D' detector model is implemented in the silicon pixel model of the VELO.
- At Run 5 around 50 primary vertices per event are expected which is increasing the probability of mis-association of the secondary vertex(SV) to the primary(PV).
- The percent of assigning the wrong PV is strongly related of whether we use only spatial information or timing + spatial.
- A Monte Carlo simulation is made to employ the new detector model.

The VELO Upgrade II detector model



Inner detector
- small pixels
- radiation hard
- timing optional

Outer detector
- precise timing
- looser requirements on radiation hardness and pixel size

Simulation procedure

1. Event generation

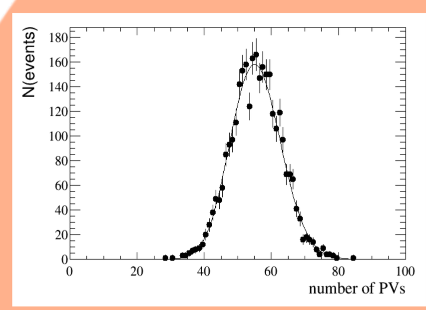


Fig. 3 Distribution of a number of PVs generated.

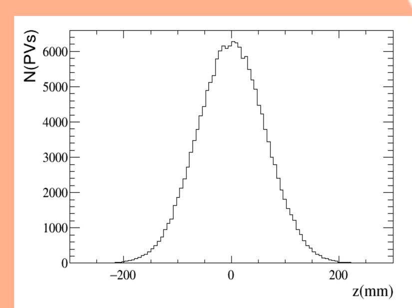


Fig. 4 Z position of PVs along beam line.

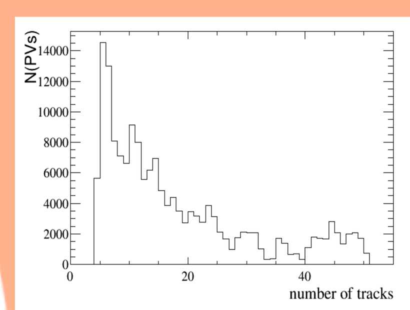


Fig. 5 Number of tracks that come out of the PV.

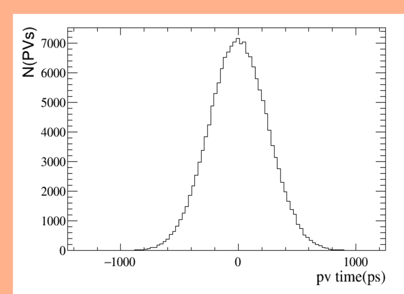


Fig. 6 Time position of PVs along the beam line.

2. Event reconstruction

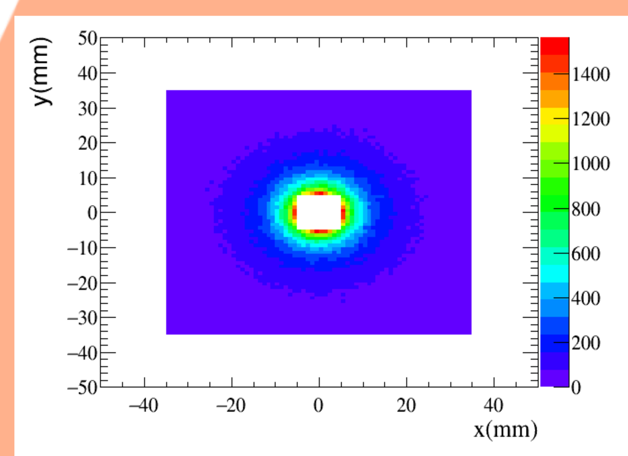


Fig. 7 Hit map of a module of the VELO Upgrade II.

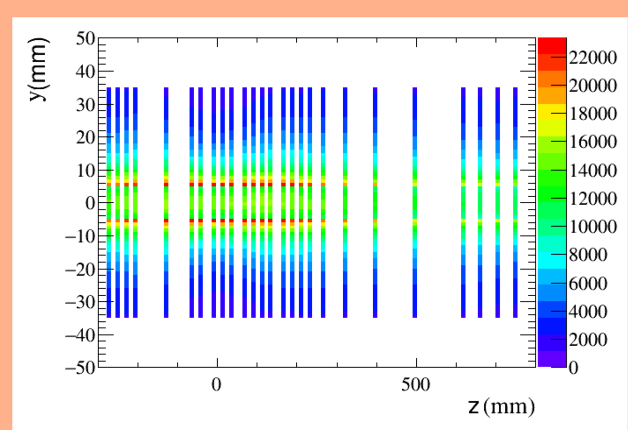


Fig. 8 Hit map of y and z position of hits.

3. PV association to SV

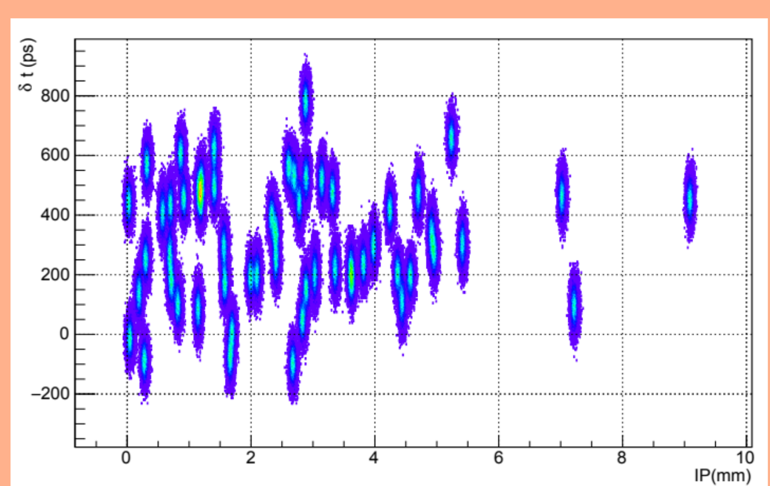
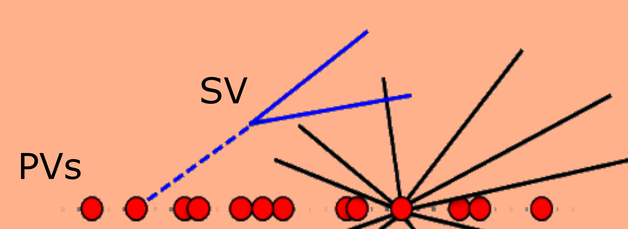


Fig. 9 δ_t as a funtion of IP for PVs in an event.

$$\delta_t = t_{SV} - t_{PV}$$



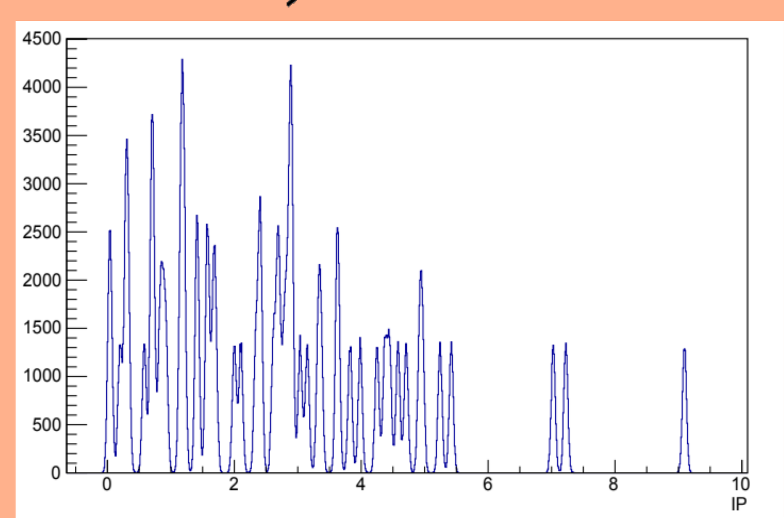


Fig. 10 IP distribution for PVs in an event.

4. Results

Without timing information: 15% PV mis-association

With timing: 2-4% →

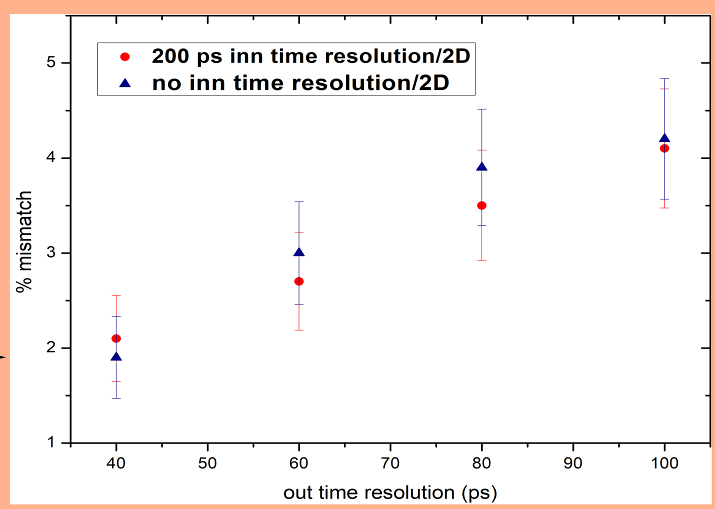


Fig. 12 PV mismatch fraction as a function of the time resolution in the outer part of the detector.

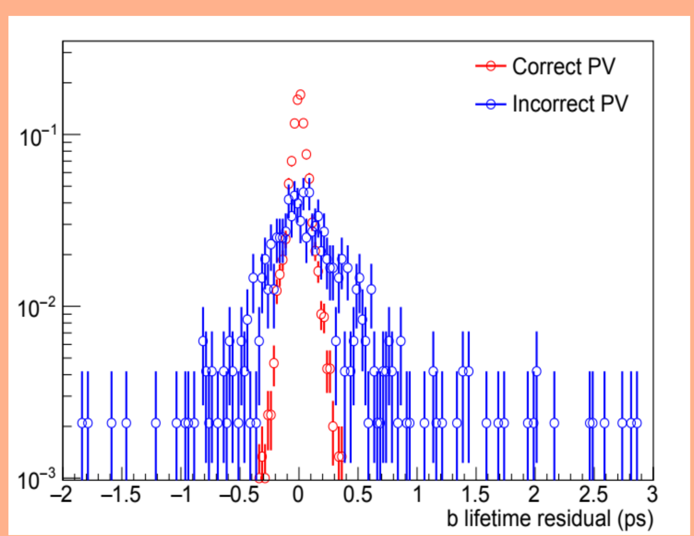


Fig. 11 b lifetime residual for the correct and incorrect PV.

Conclusion

- In this study a Monte Carlo simulation was conducted in order to study the performance of the VELO Upgrade II (Run 5).
- The detector model was developed by using the VELO Upgrade I (Run 3-4) and adding precise timing capabilities to the detector to test the potential improvement in associating long-lived particles to their correct PV.
- **It was concluded that timing improves the detector performance by reducing the fraction of PV mismatch from 15 % to < 5%.**
- **High performance can be achieved even without including timing in the inner detector.**

Future work

- Accounting for detector with different pixel sizes as this work considers 55 mm.
- Improving the selection algorithm for a PV mismatch by using machine learning techniques.
- Study the effect of including time information in track and vertex reconstruction

References:

[1] M.Williams, "Upgrade of the LHCb VELO detector",(2016),14th Topical Seminar on Innovative Particle and Radiation Detectors, JINST (2017) no.01, C01020, doi:10.1088/1748-0221/12/01/C01020.

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[3] LHCb Collaboration, Expression of Interest for a Phase-II LHCb Upgrade: Opportunities in flavour physics, and beyond, in the HL-LHC era (2017), CERN.