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The LHCb VELO Upgrade II (2031)

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LHCb has recently submitted a physics case for a an Upgrade II detector to begin operation in 2031. It will follow the Upgrade I which is currently under construction and will run from 2021 onwards. It is designed to run at instantaneous luminosities of 2×10^{34} cm$^{-2}s^{-1}$, an order of magnitude above Upgrade I, and accumulate a sample of more than 300 fb^{-1}. At this intensity, the mean number of visible proton- proton interactions per crossing would be 56, producing around 2500 charged particles within the LHCb acceptance. Efficient real-time reconstruction of charged particles and interaction vertices within this environment represents a significant challenge. To meet this challenge it is foreseen to modify the existing spectrometer components to increase the granularity, reduce the amount of material in the detector and to exploit the use of precision timing.

In particular, the LHCb upgrade physics programme is reliant on an efficient and precise vertex detector (VELO). This subdetector enables real time reconstruction of tracks from all LHC bunch crossings in the software trigger system. The Upgrade II luminosity poses significant challenges which necessitate the construction of a new VELO with enhanced capabilities. Compared to Upgrade I there will be a further order of magnitude increase in data output rates accompanied by corresponding increases in radiation levels and occupancies. To cope with the large increase in pile-up, new techniques to assign correctly each b hadron to the primary vertex from which it originates, and to address the challenge of real time pattern recognition, are needed. These challenges will be met by the development of a new 4D hybrid pixel detector with enhanced rate and timing capabilities in the ASIC and sensor. Improvements in the mechanical design of the Upgrade II VELO will also be needed to allow for periodic module replacement. The design will be further optimised to minimise the material before the first measured point on a track (which is dominated by the RF foil) and to achieve a more fully integrated module design with thinned sensors and ASICs combined with a lightweight cooling solution. As well as improving the VELO performance, quantified by the impact parameter resolution, these changes will also be beneficial both in improving the momentum resolution of the spectrometer and reducing the impact of secondary interactions on the downstream detectors.

It is envisaged that the readout ASIC will follow the VeloPix/Timepix4 development path and will be designed in 65 nm. A novel design will include in-pixel timing and calibration, allowing the pixel time stamps to reach a precision of 20 ps, and a new custom output serialiser will be included. The R&D programme will explore the capabilities of combining fast timing information with small pixel size, and examine clock distribution issues for fine timing over a full system. The capabilities of the sensor to deliver fast timing will be explored for different sensor designs.

The needs of the Upgrade II VELO will be outlined, along with the R&D steps envisaged to achieve the goal of a 4D pixel tracker.

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