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# Future timing detectors in LHCb and beyond

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This article describes the plans and the current status of the R&D activities related to the integration of timing information into the LHCb Experiment for the Upgrade II phase. As we will see, the harsh environment in which the detector will operate imposes on many sub-detectors stringent requirements in terms of time resolution.

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# 1. Introduction

The LHCb detector [1] is a single arm forward spectrometer dedicated to the study of heavy flavour physics. It features excellent tracking resolution and particle identification capabilities. The experiment is expected to collect up to 50 fb$^{-1}$ by the end of Run 4 with the current configuration. The Upgrade II phase program foreseen after 2030 is even more ambitious with the goal of collecting up to 300 fb$^{-1}$ of data and measuring many physics observables with a precision unattainable at competing experiments. In the following I will briefly describe ideas and the ongoing R&D activities for a new 4D detector.

# 2. The LHCb Upgrade II detector

The Upgrade II detector will have to cope with a luminosity of $\mathcal{L}$=1.5×10$^{34}$ cm$^{-2}$s$^{-1}$, which represents a 7.5 fold increase with respect to current one, and more than 40 interactions per bunch crossing. This means that some significant modifications to the current configuration will have to be made in order to survive in the much harsher environment [2]. The inner part of the current SciFi tracker will be replaced with silicon technology in what will become known as Mighty Tracker, a new time of flight detector, called TORCH, will be installed to provide PID capabilities in the low momentum region (< 10 GeV/c). Another important aspect to consider is that some sub-detectors will have to integrate timing information to cope with the increased occupancy and these will be discussed in the section below.

## 2.1 The 4D VELO

The LHCb VELO [1] is designed to reconstruct tracks and PVs in real time with remarkable resolution. Such performances are crucial to associate the heavy flavor decays to their corresponding primary vertex and the same performances will have to be maintained for the Upgrade II phase. Studies foresee a fluence of 6×10$^{35}$ 1 MeV n$_{eq}/cm^2$ at 5.1 mm inner radius. With such high level of pile-up the addition of timing information with a single hit time resolution of 50 ps or better is required [2] if one is to recover the current reconstruction efficiency, as shown in Fig. 1

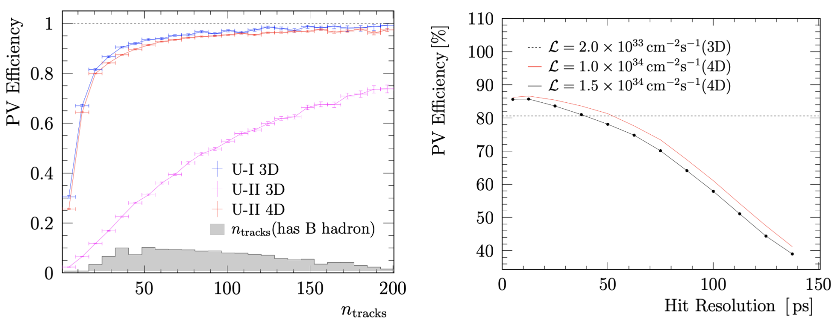


**Figure 1:** Left: Simulated PV reconstruction efficiency vs n$_{tracks}$ for the current (blue) detector and for the Upgrade II scenario with no timing information (pink) and with the addition of timing information (red). The current VELO performance is recovered if timing information is used. Right: Average PV reconstruction efficiency vs single hit time resolution. Source [2]

Concerning the choice of the sensor technology an intense R&D activity is ongoing, where different options are being tested and evaluated. Possible sensor technologies that could meet the requirements described above are planar sensors, 3D sensors [3], LGAD sensors [4] and SiEM sensors [5]. Testbeam campaigns where sensors are coupled to the new TimePix4 ASIC have already shown encouraging timing performances [6].

### 2.2 The Upgrade II RICH detector

Physics programme at LHCb relies on good PID to identify charged hadrons in the final state. The PID is provided by two RICH detectors in the momentum range 10-100 GeV/c [1]. MaPMTs with dimensions 3×3 mm$^2$ are currently being used as photodetectors. In order to maintain current performances the occupancy in the photo-detector plane must be below 30%. In the high luminosity phase this can be achieved by reducing the pixel size of the photodetector down to 1×1 mm$^2$ and adding the timing information to the Cherenkov photons. According to detailed simulations the time resolution required is below 100 ps [7], as shown in Fig. 2. Possible candidates are commercial SiPMs and MaPMTs or the novel LAPPD [8] and an intense R&D activity is ongoing to characterize them, both in labs and in dedicated testbeam campaigns. New sophisticated cooling techniques are also being developed to mitigate the effect of radiation damage, especially after irradiation up to $1{\times}10^{13}$ for 1MeV $\mathrm{n}_{eq}/cm^2$.

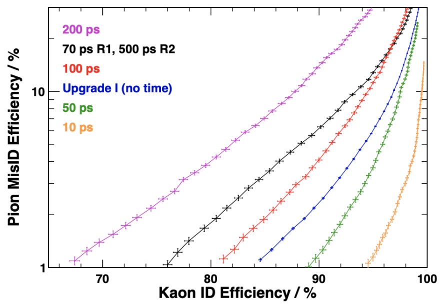


**Figure 2:** Pion misID efficiency as a function of kaon ID efficiency for different value of the single Cherenkov photon hit time resolution. The blue curve corresponds to the current benchmark performance. Source [10]

Sensors will be coupled directly to the FastIC ASIC [9], which will provide time information with its internal TDC, and data will be sent to the back-end boards via optical links. No intermediate FPGA is foreseen.

### 2.3 The TORCH detector

The TORCH [11] is a novel large area TOF detector that will provide the PID information in the low momentum region (< 10 GeV/c) where both kaons and protons are below the RICH threshold. It will be probably placed right before RICH2, which is about 10 m away from the interaction point. This detector exploits the Cherenkov light reflection inside a quartz bar to give a precise measurement of the time of arrival of the particles. Assuming that 30 photons are detected per track, a single photon time resolution of 70 ps is needed to obtain a 15 ps/track resolution, which is necessary to obtain a $3\sigma$ separation between two particle hypothesis. The photons are detected by MCP-PMT sensors, for which prototypes have been developed by Photek UK[12].

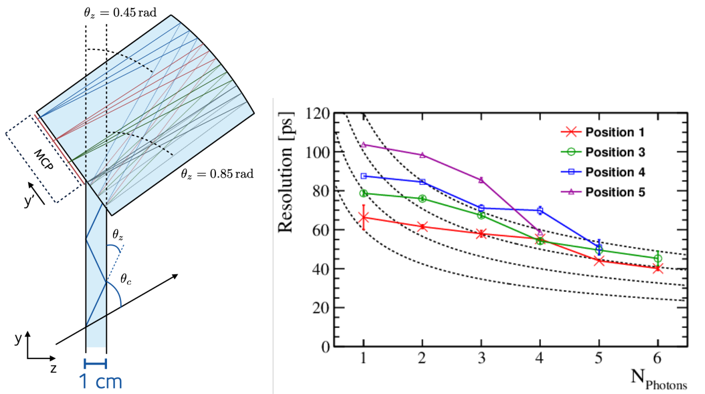


**Figure 3:** Left: Side view of the TORCH detector where a particle crosses the quartz bar and the Cherenkov light is focused on the MCP plane after many reflections. Right: Measured time resolution as a function of the number of photons emitted by the track. Source [13]

Initial timing characterization of the system was done with the sensor coupled to the NINO ASIC and HPTDC chips developed by ALICE for their TOF. The time resolution was measured to be scaling well with the number of detected photons photons [13], as shown in Fig. 3. Future plans are likely to foresee the use of the more recent FastIC ASIC, as it is done for the RICH.

### 2.4 The Upgrade II ECAL

ECAL is crucial for wide range of flavour-physics goals as it provides precise measurement for $e^{\pm}$, $\gamma$ and PID. It Must be able to sustain radiation dose up $6\times10^{15}$ for 1MeV $n_{eq}/cm^2$ during Upgrade II and the introduction of fast timing (few tens of ps resolution) for pile up mitigation is needed. A promising rad hard prototype that is being tested is the so called SPACAL [2]. SPACAL is made of spaghetti-like rad hard crystal fibers that scintillate and transport light. Two different materials have been tested so far: YAG and GAGG crystals[14].

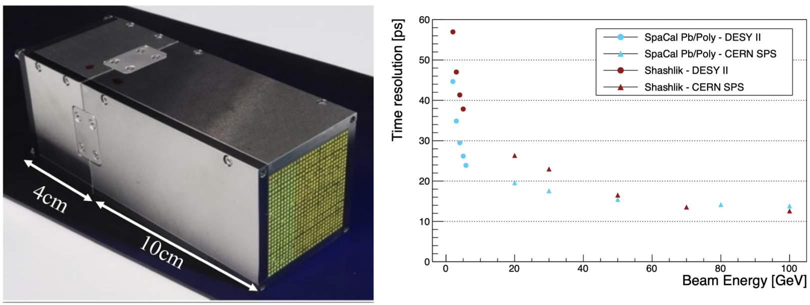


**Figure 4:** Left: Front view of the SPACAL prototype tested with particle beam. Right: Measured time resolution as a function of the electron beam energy. Source [2]

Concerning the readout the analog signal produced by the photodetectors is sent to the back end electronics via a 12 m analog link, where the waveform is sampled at several giga-samples per second and processed by FPGAs to extract the digital time of arrival and energy measurement information. First test beam results reveal impressive timing capabilities with time resolution reaching 15 ps for electron energies > 100 GeV [15].

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