Poster ID: 20

MAPS-based Upstream Tracker for The LHCb Phase-II Upgrade

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01 Introduction

01. LHCb Detector

The LHCb detector, illustrated in Fig. 1, is designed for studies in flavor physics and functions as a forward general-purpose detector:

- The forward single-arm spectrometer features a unique coverage in pseudo-rapidity (2 < η < 5).
- It observes 40% of the heavy quark production cross-section within only 4% of the solid angle.
- Precision measurements are conducted in the beauty and charm sectors.
- It also investigates topics such as QCD, EW, and heavy ion collisions.

02. Upstream Tracker

The Upstream Tracker (UT) is located upstream of the LHCb bending magnet. Since 2023, LHCb has been operating at a maximum luminosity of $\mathcal{L}_{\max} = 2 \times 10^{33}\ cm^{-2}s^{-1}$ due to an upgraded detector. It is expected to collect data at a higher luminosity of $1.5 \times 10^{34}\ cm^{-2}s^{-1}$ starting from around 2035, which represents an increase approximately 7.5 times compared to Run 3 and Run 4 (as shown in Fig. 2). The current UT is struggling to handle the increased data rate and high occupancy levels.

03. Upgrade-II UT

The Upgrade-II UT (UP) detector will utilize CMOS Monolithic Active Pixel Sensors (MAPS) technology. In this poster, we outline the proposed design, performance studies, and R&D plan.

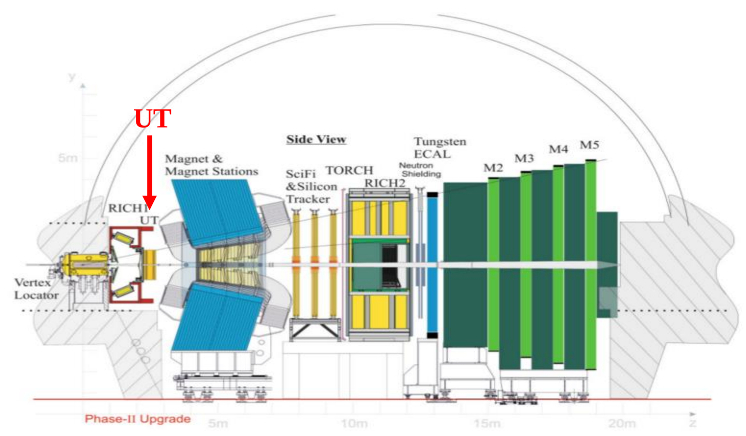

Fig. 1: LHCb Detector at Upgrade II

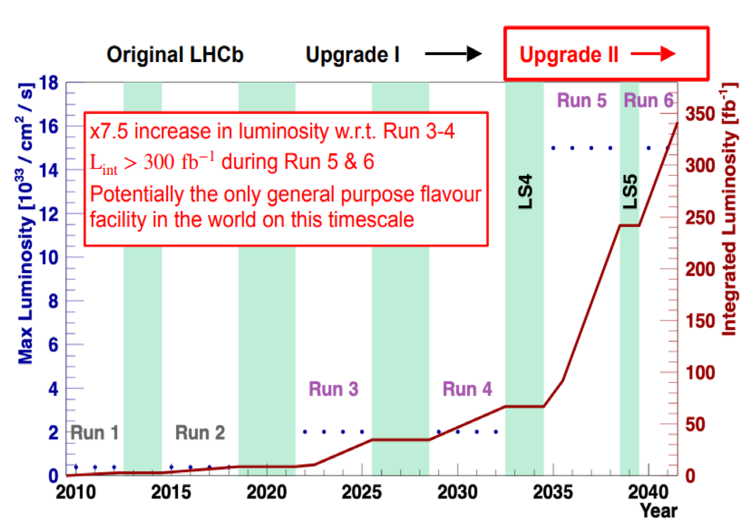

Fig. 2: Upgrade II timeline

02 Detector Design

01. Detector Structure

A potential detector layout is shown in Fig. 3. Each plane consists of 12 staves, with each stave made up of multi-MAPS modules.

- Each module features 14 chips arranged in a 7 × 2 array, interconnected through a flexible circuit.
- The lpGBT ASIC, which is radiation tolerant and serves functions such as data, timing, trigger, and control for the HL-LHC, will be used for data acquisition.
- A total of 36 modules are installed alternately on both sides of a supporting bare stave, resulting in 12 staves for each plane.

A four-plane detector based on HVCMOS is proposed. Layout using other MAPS technology like CMOS with low fill-factor is similar.

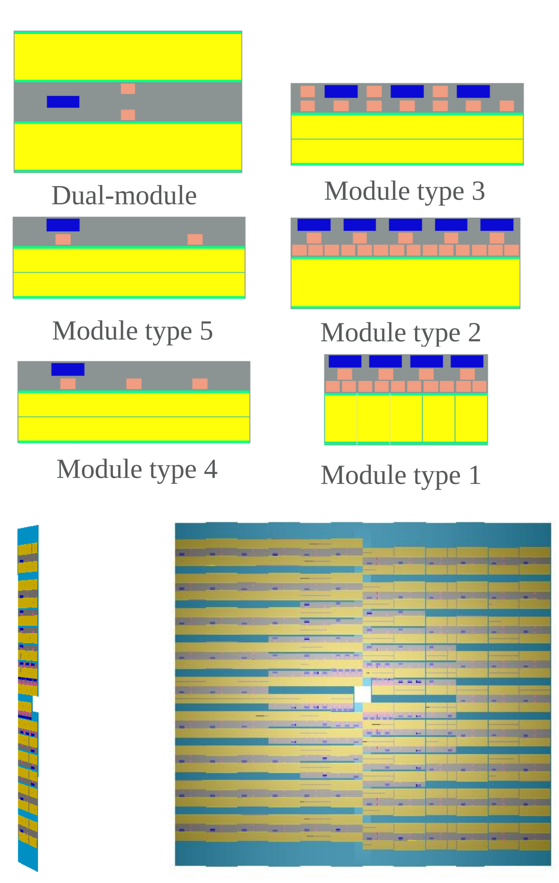

Fig. 3: Geometry construction using DD4hep

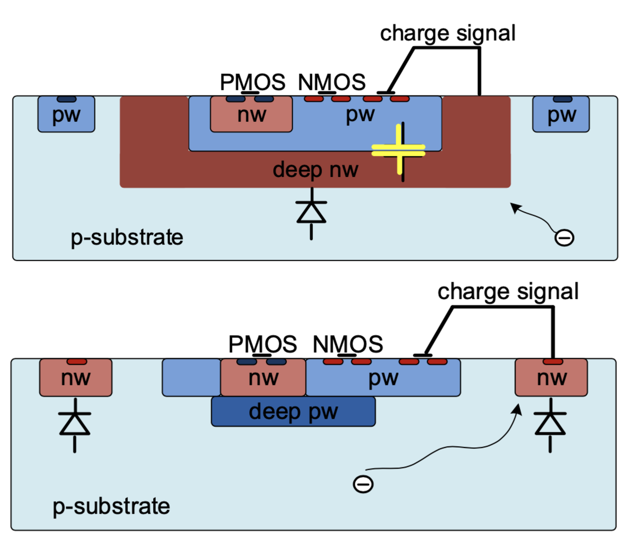

Fig. 4: The schematic of HV-CMOS (top) and CMOS with low fill-factor (bottom)

02. CMOS Sensor

The ongoing R&D studies suggest that monolithic active pixel sensors are promising candidates for the UP.

To enhance the depletion in the sensing volume and improve the speed and radiation tolerance of the detector, DMAPS (Depleted Monolithic Active Pixel Sensors) implementations adopt two distinct approaches: one is high fill-factor or high-voltage (HVCMOS), and the other is CMOS with low fill-factor.

03 Software Simulation

01. Software Development

The detector description has been developed using both the DetDesc and DD4hep frameworks. The "fake digitization" study was conducted at the MCTruth level. A material budget scan was carried out in both frameworks, yielding consistent results.

Fig. 6 illustrates the radiation length of the first layer of the UP plane in both x/y and η/ϕ views. The final plot presents the projection map along the η axis.

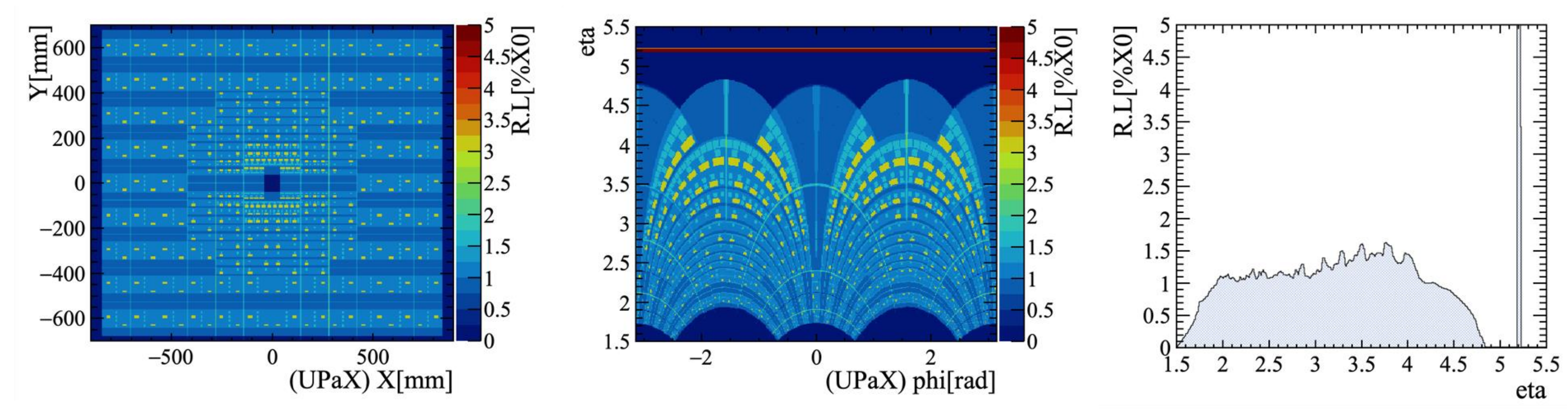

Fig. 6: Radiation length in DD4hep

02. Performance of UP

The performance studies of the UP detector utilize simulation samples generated under Upgrade II conditions, described using the DD4hep framework within Gauss/Gaussino. The proton-proton collision sample contains minimum bias and inclusive b-hadron events generated by Pythia, simulating HL-LHC conditions with a center-of-mass energy of $\sqrt{s} = 14$ Tev. Fig. 7 shows average hit densities in proton-proton collisions at HL-LHC, up to ~ 4.5 hits/cm²/BX. There are 2574 colliding bunches and the baseline instantaneous luminosity is $1.5 \times 10^{34}\ cm^{-2}s^{-1}$.

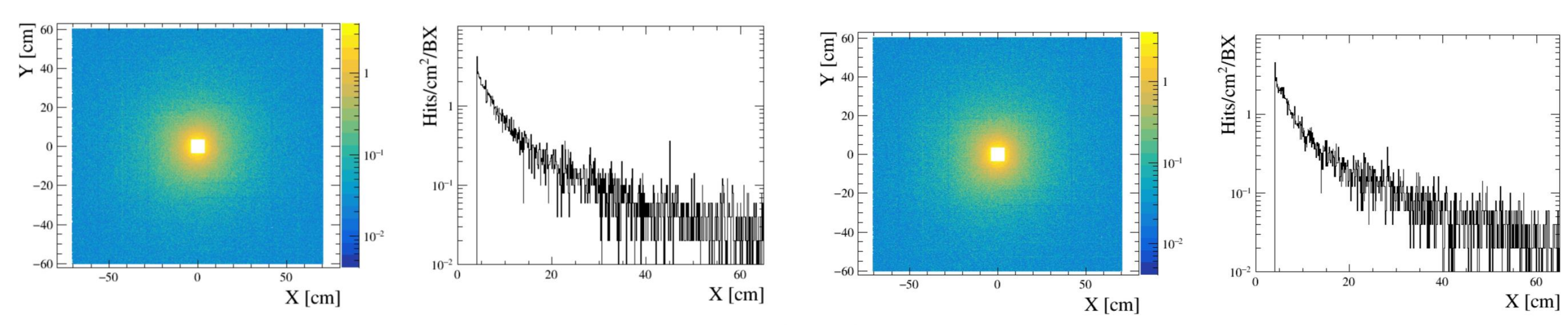

Fig. 7: Mean UP hit density per bunch for (left) minimum bias and (right) inclusive b events.

Related studies are accomplished at Boole:

- **Pixel Occupancy** : The maximum pixel occupancy was estimated to be 0.256% using 1.2K miniBias MC events, which aligns with the estimates provided in the FTDR.
- **Reconstruction Efficiency**: Fig. 8 shows the reconstruction efficiency for the Velo-UP tracks and the Velo-UP-SciFi tracks. In this study, the Velo and SciFi are in their Run 3 configurations. The efficiency is at the same level as the current detector.

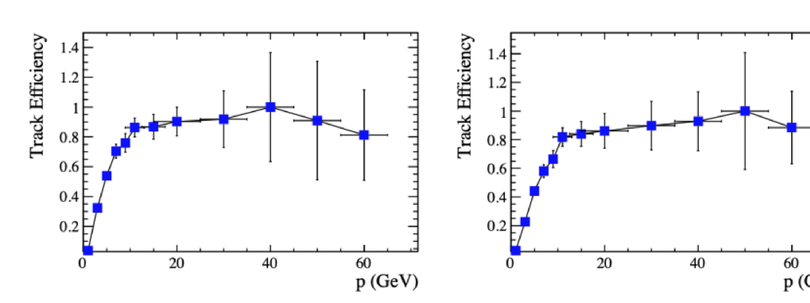

Fig. 8: The tracking efficiency as a function of the total momentum, for (left) the Velo-UP tracks and (right) the Velo-UP-SciFi tracks.

04 Updated baseline

During the studies for the scoping document, the baseline of a UP plane has evolved towards a reduction of the outer acceptance for cost reduction with minimal impact on physics, shown by the red dashed box in Fig. 9.

UP new geometry model:

- The UP features four detector layers at Z positions similar to the current UT.
- Coverage reduction:
  - Number of staves decreased from 12 to 10.
  - Number of modules reduced from 36 to 32.
  - Overall detection area reduced by 26%.
- The central 4×4 chips are removed for beam pipe, covers (±39 mm) ×(±37 mm).

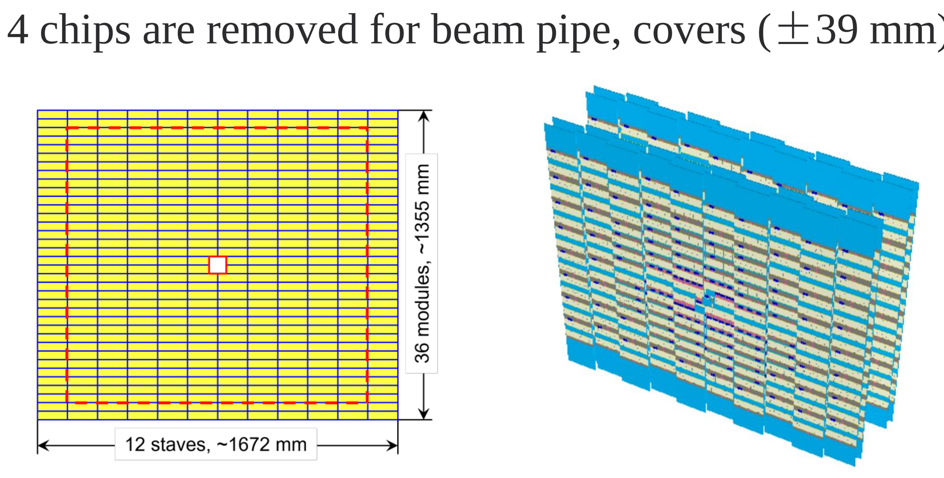

Fig. 9: Layout of a plane (left) and 4-layer detector (right) of updated baseline with reduced coverage.

Reference and links:

[1] "Framework TDR for the LHCb Upgrade II Opportunities in flavour physics, and beyond, in the HL-LHC era", CERN, Geneva, LHCb Collaboration, CERN (Meyrin)

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