Development of Upstream Tracker using MAPS for LHCb Upgrade II

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LHCb Upgrade II

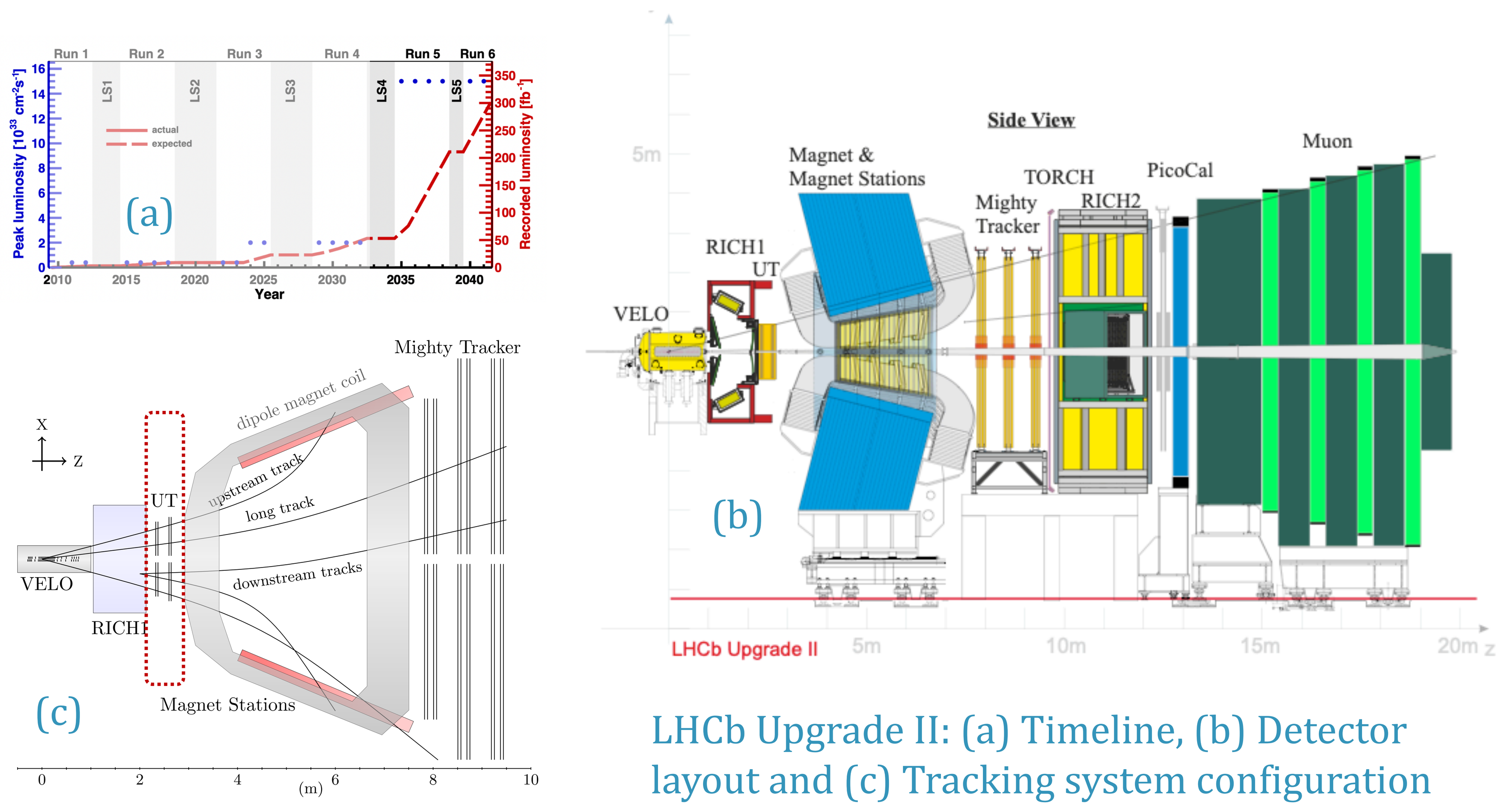
LHCb is a single-armed forward spectrometer at the Large Hadron Collider. To fully exploit the flavour physics potential at the High-Lumi LHC, LHCb is planning a major upgrade (Upgrade II) in the long-shutdown 4, to achieve:

- Instantaneous luminosity of $1.5\times10^{34}\,\mathrm{cm^{-2}s^{-1}}$
- An integrated luminosity of ~300 $\mathrm{fb^{-1}}$ in the whole LHC lifetime
- Fully software-based trigger system

Upstream Tracker (UT) is a key component of the tracking system, located upstream of the magnet, playing important roles:

- Reducing false matching between VELO and T-station segments
- Speeding up real-time reconstruction of long tracks
- Ensuring reconstruction efficiency of long-lived particles like K_S and Λ

Current UT, based on silicon strip detectors, will not be able to operate under the Upgrade II condition, and has to be upgraded with high-granularity, radiation-hard technology, and MAPS is a most promising technology option.

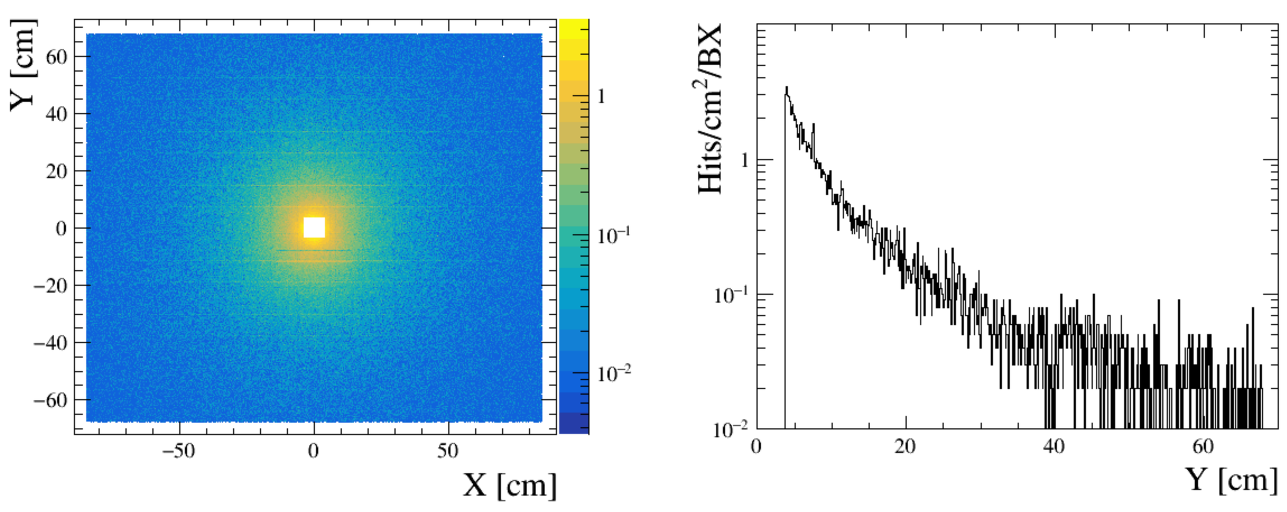


LHCb Upgrade II: (a) Timeline, (b) Detector layout and (c) Tracking system configuration

UT upgrade requirements

The CMOS sensors considered for UT in Upgrade II must provide good spatial resolution, especially in x-direction; it should has good timing resolution to tag the 25ns HL-LHC bunches. The sensor and electronics should be able to endure a maximum fluence of $3\times10^{15} n_{eq}\mathrm{cm}^{-2}$.

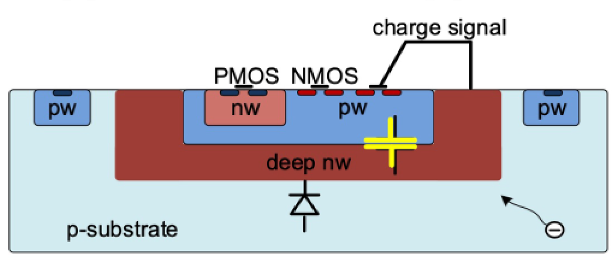
Characteristics	Specification
Hit density	~6 hits/cm^2/BX
Time resolution	O(1ns) for BX tagging
Pixel size	$30\times30\mu\mathrm{m}^2$ or $50\times150\mu\mathrm{m}^2$
Power	100~300 mW/cm^2
Radiation	$3\times10^{15} n_{eq}\mathrm{cm}^{-2}$, 240MRad



Hit density during proton-proton collision at a UT plane in Upgrade II condition

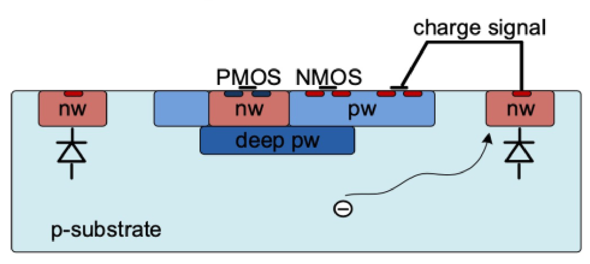
CMOS sensor options

Two approaches are being pursued for sensor development:



High-Voltage CMOS

- Circuitry inside collection well
- Intrinsically radiation hard
- Uniform electric field
- Fast charge collection
- Existing chip like ATLASPix3 in TSI 180nm process shows performance close to demand



CMOS with small electrode

- Small capacitance, low noise and low power consumption
- Radiation hardness with process modification
- Many successful prototypes chips like MATLA for other applications

Technology options considered

AMS 180nm / LFoundry 150nm

MightyPix under development for Mighty Tracker (MT), synergy with UT expected. Note that MightyPix is aimed for a lower radiation level.

SMIC 55nm

COFFEE prototypes developed to validate the process. COFFEE1 response to laser signal observed. COFFEE2 chip, on 1kΩ cm high-res substrate, shows a break-down voltage up to -70V.

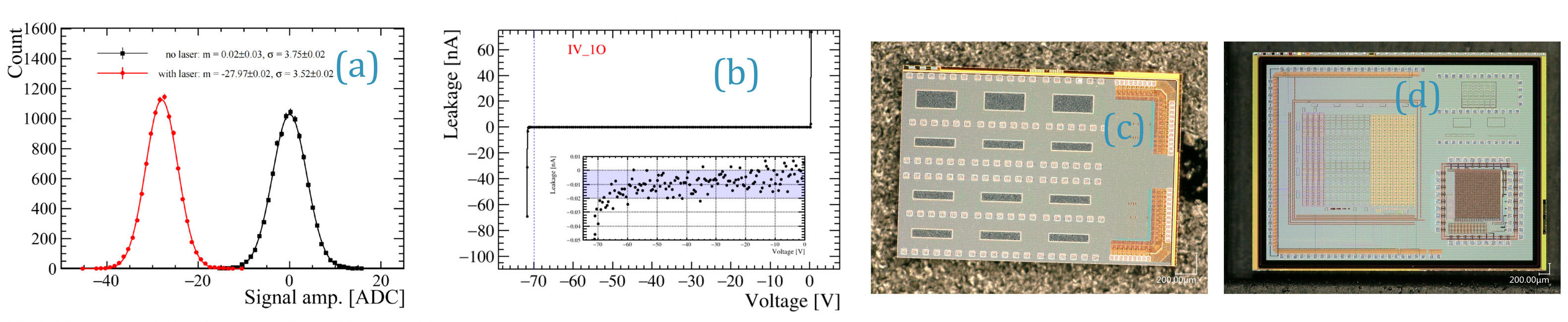
TowerJazz 180nm

Based on MALTA3 chip, development of LHCb-oriented readout periphery needed to cope with the high data rate.

TPSCo 65nm

Design of SPARC prototype on development of digitial blocks of readout periphery in TPSCo 65nm ongoing. Submission planned in 2024.

(a) Laser signal at COFFEE1; (b) IV curve at COFFEE2; Photos of (c) COFFEE1 and (d) COFFEE2

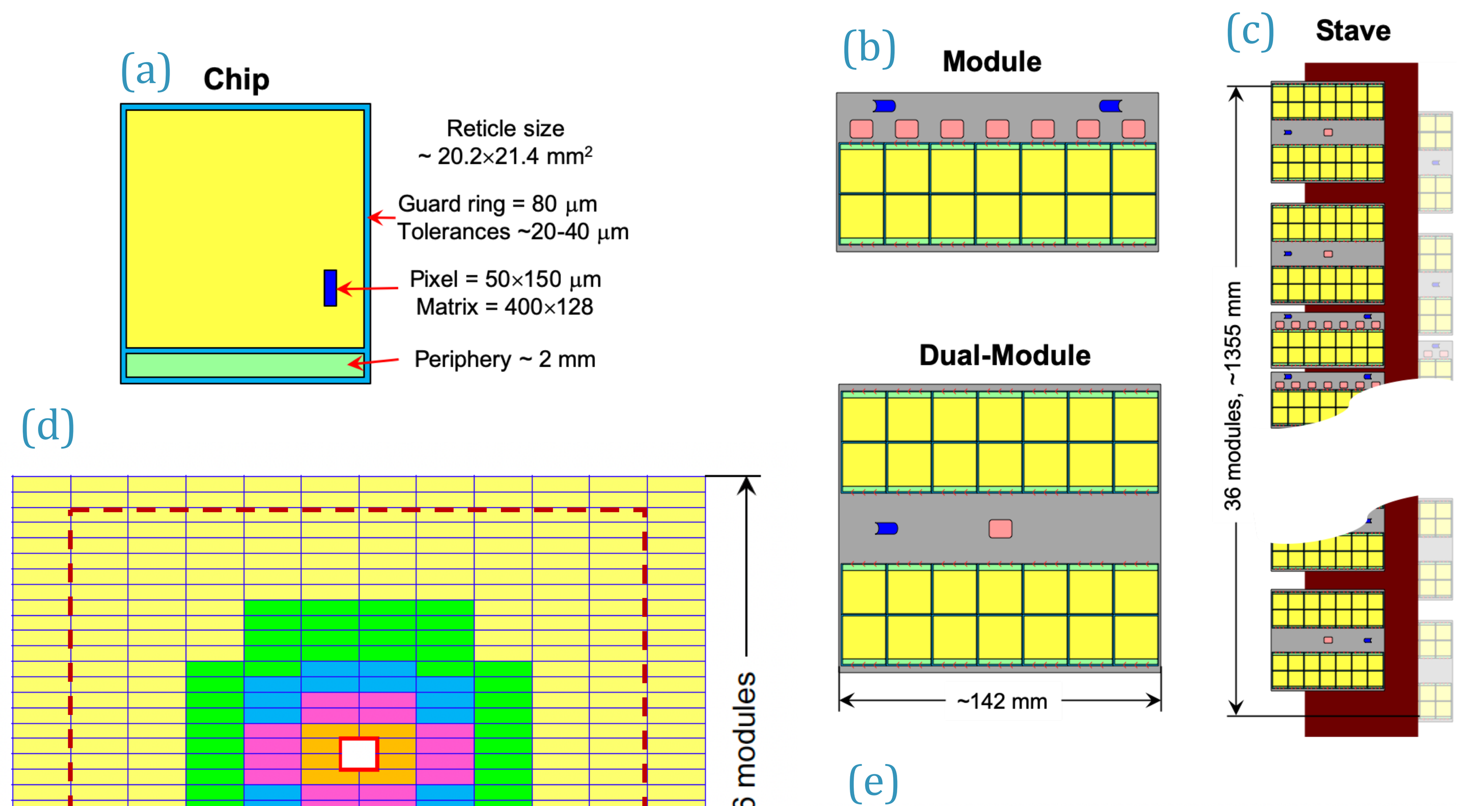


System design and layout

The U2UT detector has 4 detector planes, at z-positions similar to current UT

- Each plane consists of 12 staves, each has 36 modules mounted on both sides
- Assuming 2×2 cm^2 chip size, a module has 14 or 28 chips for optimal use of lpGBT links; optical conversion on the modules

Updated baseline considers reducing coverage in the outermost region for cost reduction with minimal impact on physics.

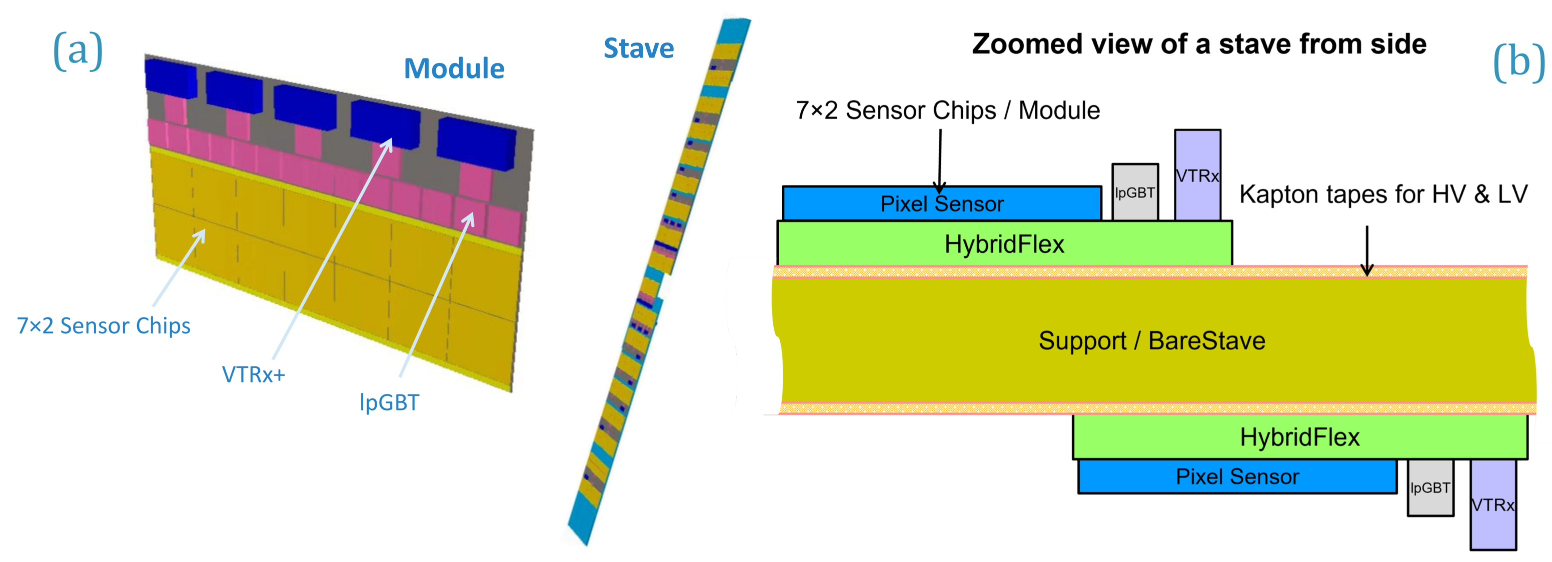


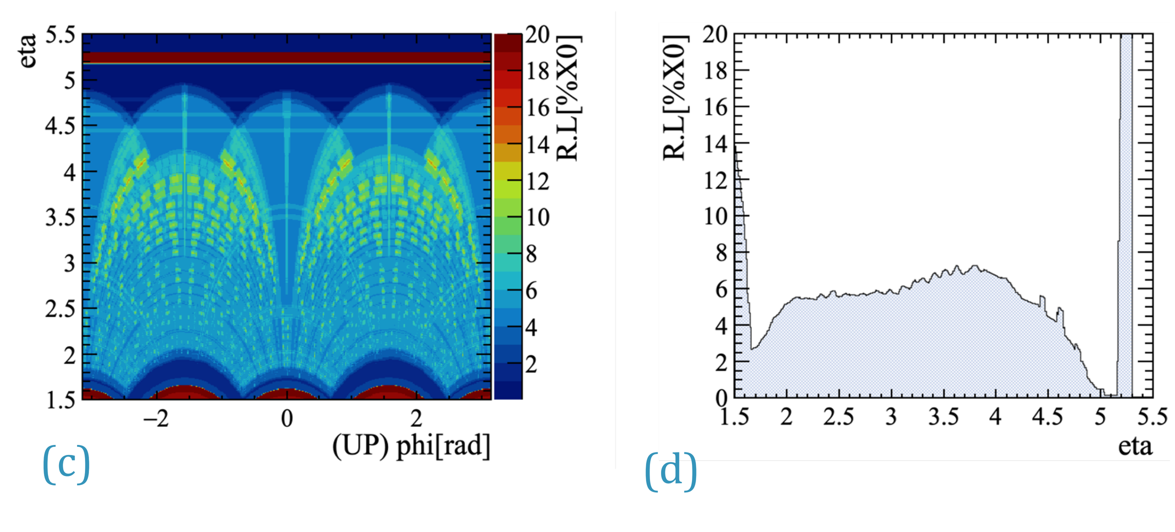
Ring	5	4	3	2	1
e-links / chip	1	1	1	1-3	2-7
Gbps / e-link	0.32	0.64	1.28	1.28	1.28
lpGBT / module	0.5	1	2	7	14/10
Num of modules	1312	240	80	64	32
Num of lpGPTs	656	240	160	448	384

A preliminary design of the U2UT system: (a) chip size, (b) single and dual-module, (c) a stave, (d) layout of a plane. Each box corresponds to a 2×7-chip module; the colour code corresponds to modules with different number of electronics components such as lpGBTs as listed in (e). The red dashed line indicate updated baseline with reduced coverage.

Detector modeling and simulation

The detector description has been implemented in the LHCb software framework, with realistic material assuming carbon dioxide cooling as in current UT.





(a) U2UT modules as implemented in LHCb software framework, using materials as illustrated in (b). Material scan is shown for the whole U2UT system in (c) ϕ and (d) η