Simulation Study for LHCb UT in Upgrade II

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Outline

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  - CMOS Chip Options
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- The Simulation of Upgrade-II UT
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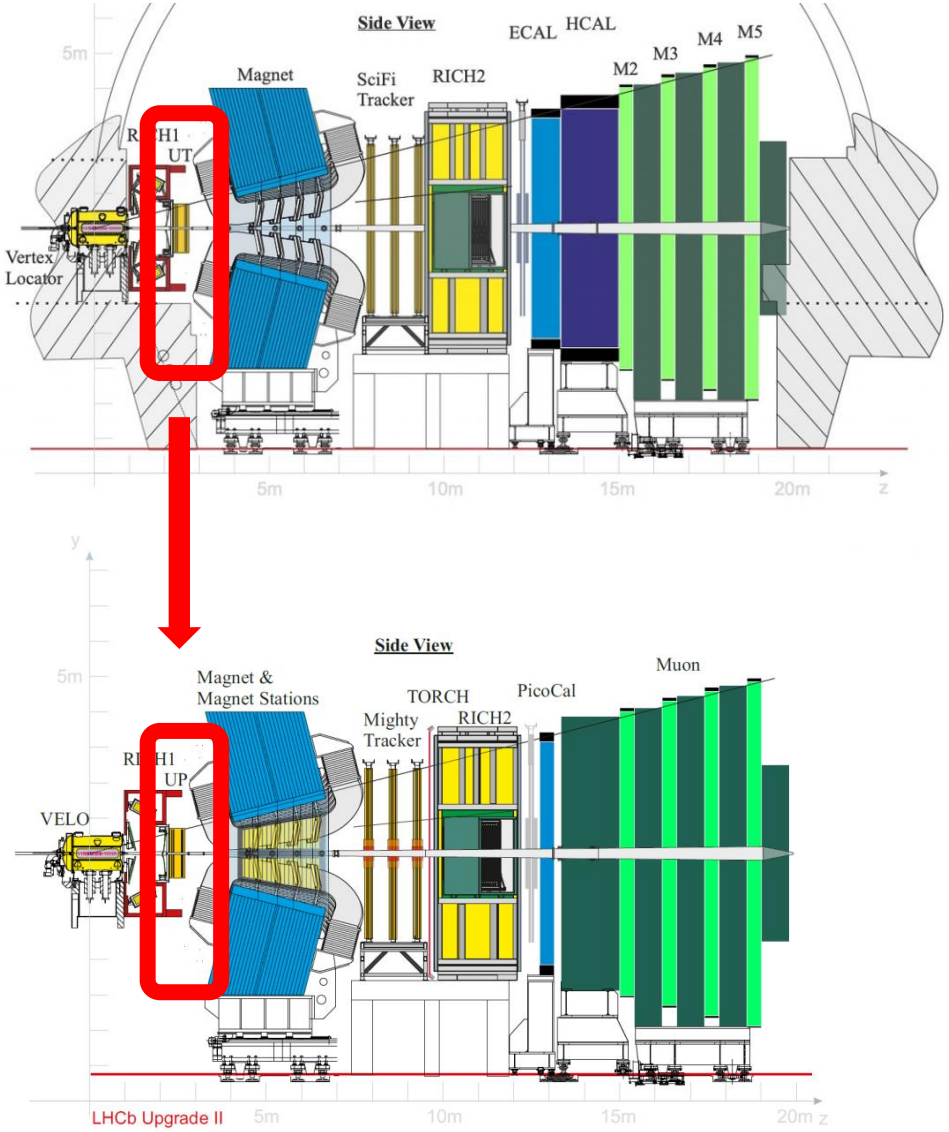
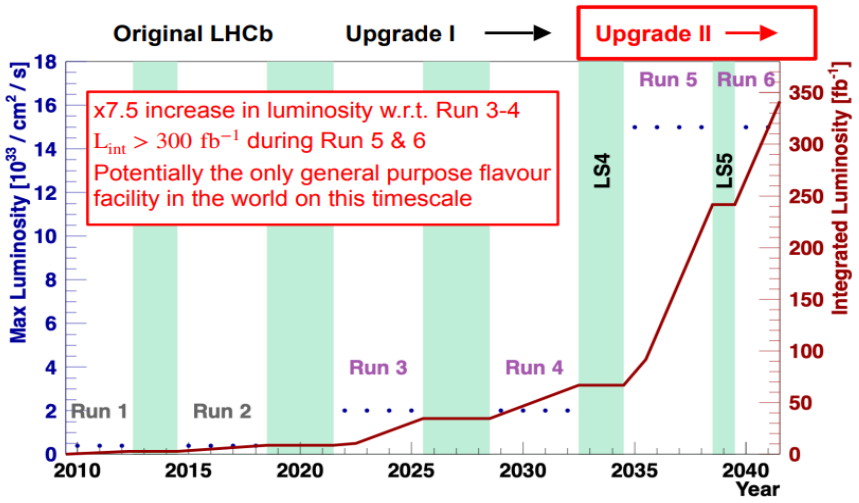
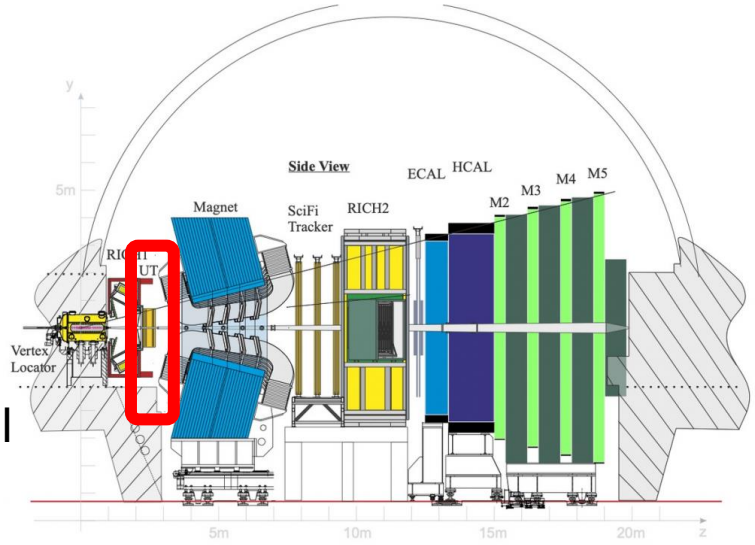
- Summary and Outlook



Introduction

- **LHCb**
  - A single-armed forward spectrometer at the Large Hadron Collider
  - Aiming to study flavor physics like CP violation and rare decays
- **LHCb Upgrade II**
  - LHCb is planning a major upgrade (Upgrade II)
  - The High-Lumi LHC ($\mathcal{L}$= 1.5×10^{34}cm^{-2}s^{-1})
- **Upgrade-II UT**
  - Upstream Tracker (UT) : a key component of the tracking system
  - The current UT can't be kept for Upgrade II
    - Much increased hit density requires higher granularity
    - Bandwidth for high data rate
    - Radiation hardness
  - Therefore, Upgrade-II UT detector will use CMOS Monolithic Active Pixel Sensors(MAPS) technology, named **Upstream Pixel tracker** (**UP**)





CMOS Chip Options

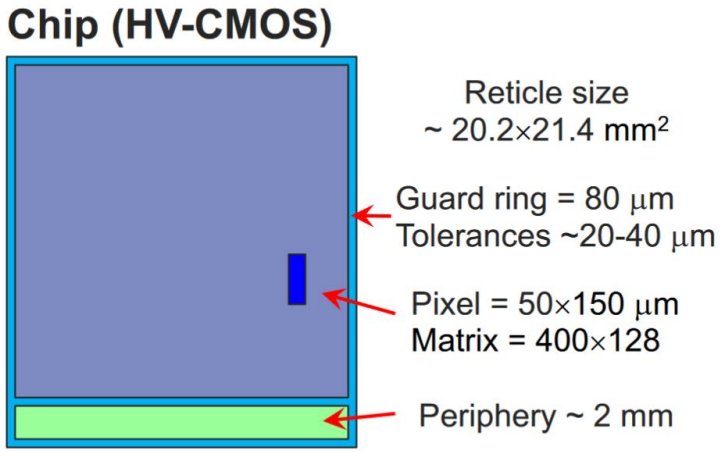
➢ Two Design for CMOS Chip

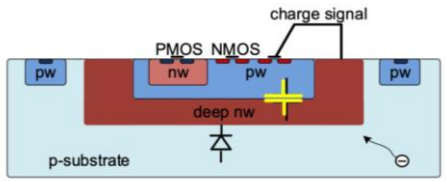
The ongoing R&D studies indicate that monolithic active pixel sensors can be considered as very strong candidates for UP.

Two approaches are being pursued to develop CMOS chips:

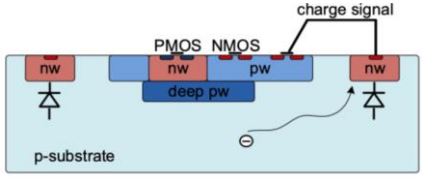
- Large fill-factor or high-voltage (**HV-CMOS**) with large electrode
- Low fill-factor or low-voltage (**LV-CMOS**) with small electrode

More details in Zhiyu's talk.





High-Voltage CMOS



CMOS with small electrode

Characteristics	HV-CMOS	LV-CMOS
	Circuitry inside the collection well	Circuitry outside the collection well
Chip size	**2.0×2.0cm²**	**3.5×3.5cm²**
Pixel size	**50×150μm²**	**30×30μm²**
Chip thickness	~100μm	
Position resolution	15, 40μm	5-10μm
Radiation dose	3×15neq/cm², or 240 Mrad TID	
Data rate per chip	Up tp 9Gb/s	Up to 30Gb/s
Time resolution	O(1)ns	
Power consumption	100-300 mW/cm2	
Radiation dose	3×15neq/cm2, or 240 Mrad TID	

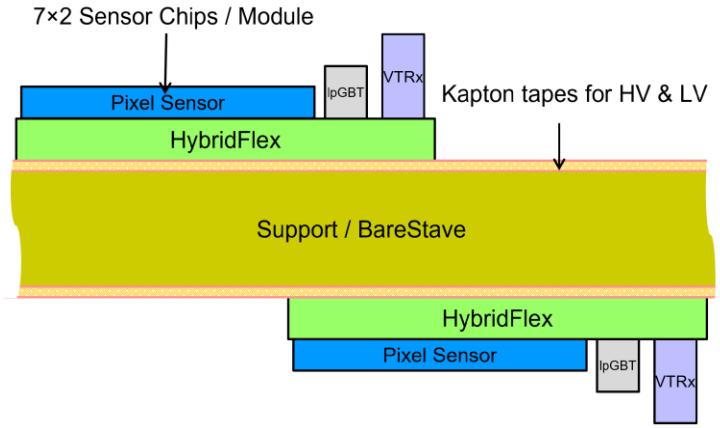
Detector Structure

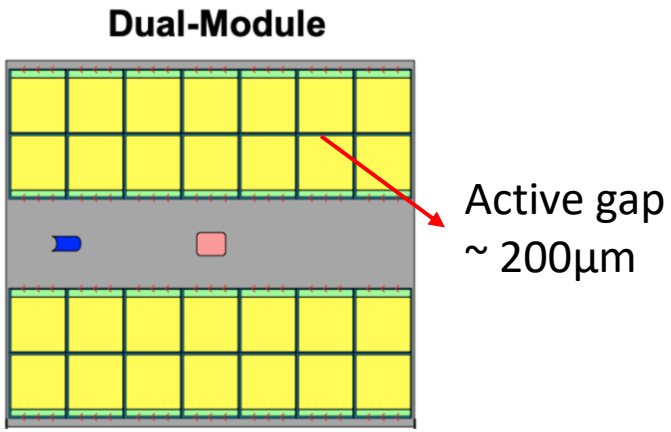
➢ UP Modules Structure for HV-CMOS design

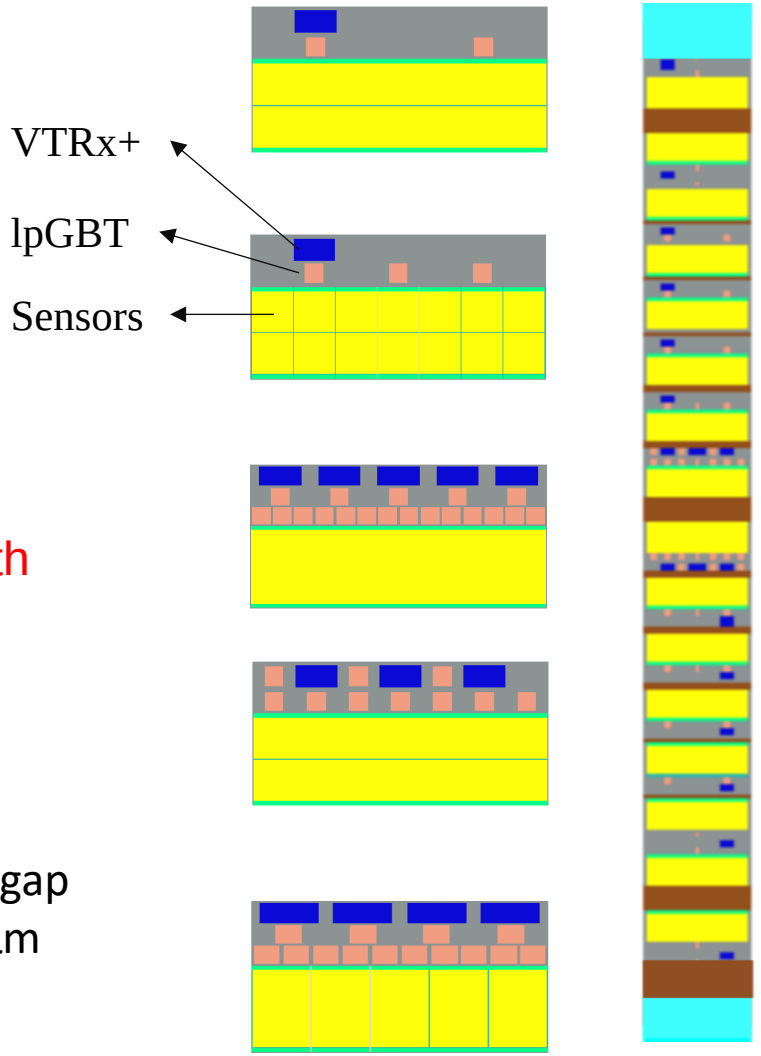
14 CMOS chips and supporting electronic components are attached to a hybrid flex to form a UP module

- 14 CMOS sensor chips split in two rows
- VTRx+ and lpGBT: ensure the normal operation and data acquisition
- The expected data rate → the numbers of lpGBT and VTRx+
- Dual modules → regions located further away from the beampipe

The picture below shows the view from side. Modules are mounted on both sides of the stave, ensuring overlaps of sensitive areas at the sensor edges





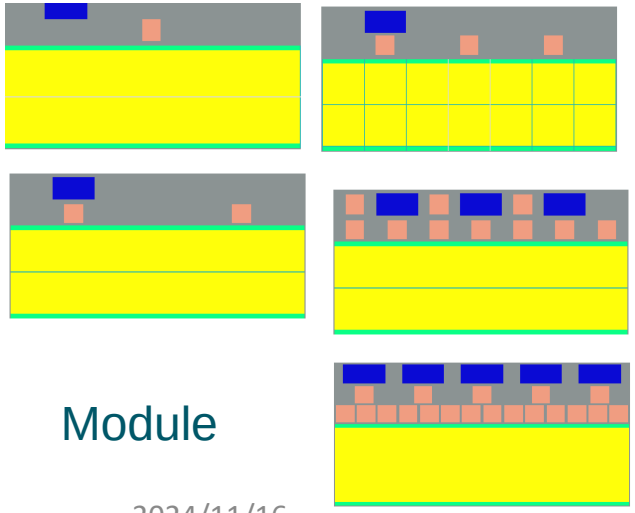


Detector Structure

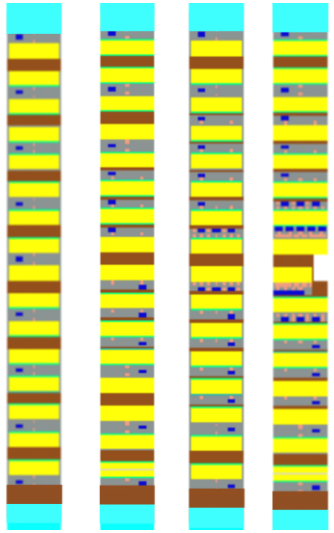
- **UP Geometry Structure for HV-CMOS design**
  - Geometry modelling of the UP detector is completed, with the following hierarchy
    - Plane: **4 detector planes** (layers), at Z position similar to the current UT
    - Stave: Each layer consists of **10 staves** in 4 types
    - Module: Each stave equipped with **32 modules** in 5 types
    - Chip: **14 chips in a 7×2 array** are interconnected to a flex circuit to form a module

    } match with different data rates

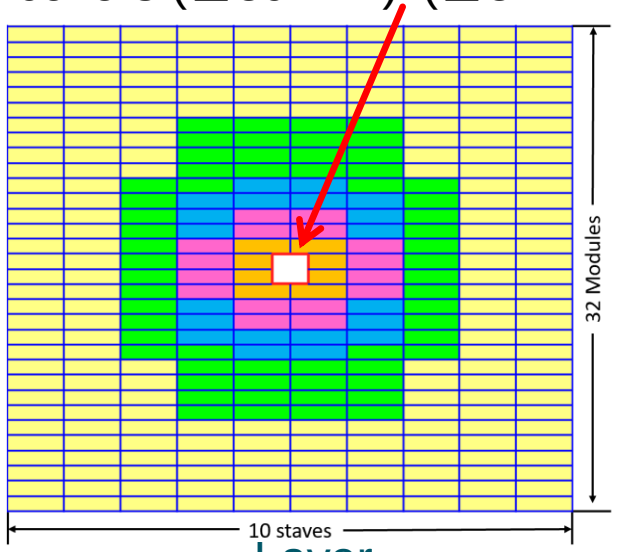
  - The central 4x4 chips are removed for beam pipe, covers (±39 mm)x(±37 mm)



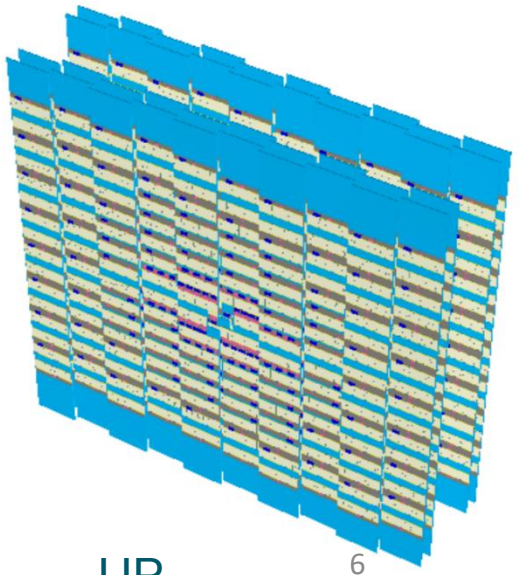
Module



Stave



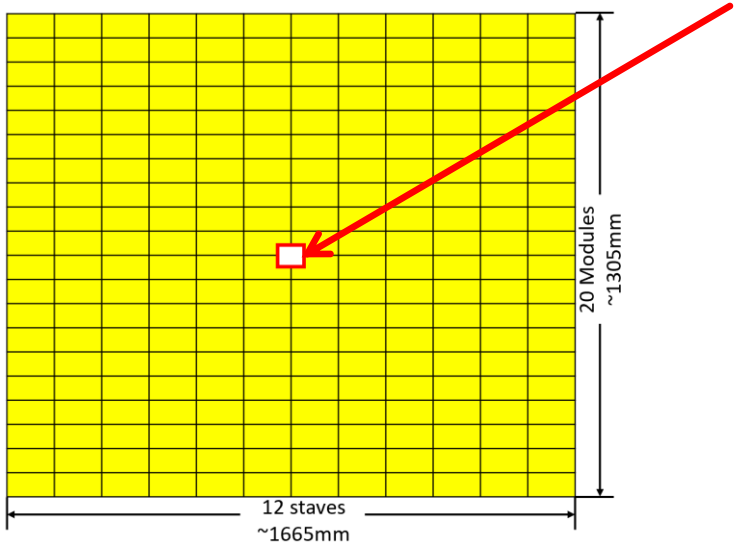
Layer

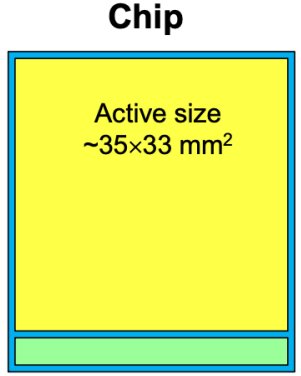


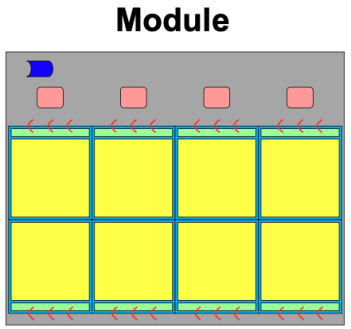
UP

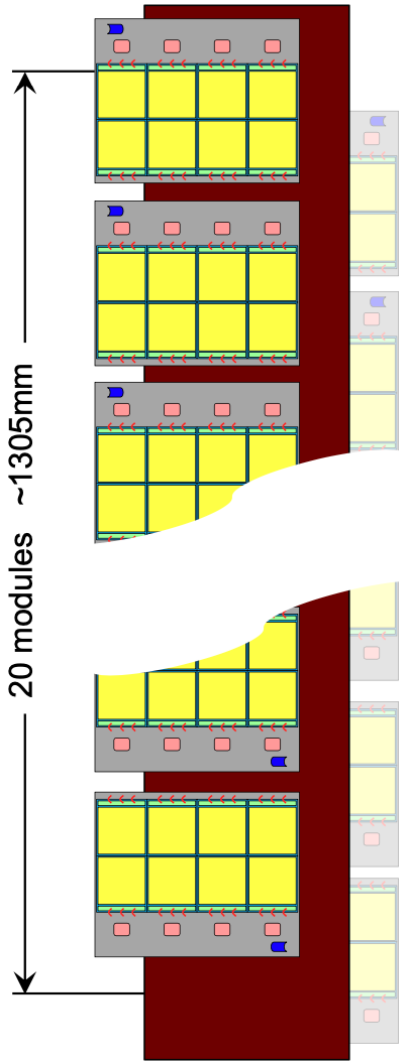
Detector Structure

- **UP Geometry Structure for LV-CMOS design**
  - Difference between LV-CMOS design and HV-CMOS design
    - Pixel size 30×30 μm²
    - Active size by chip 35×33 mm²
    - Each module consist of 8 chips in a 4×2 array
    - Only one type of module
    - Each stave consists of 20 modules
  - The beam hole inefficient area covers (±34 mm)x(±32.5 mm)



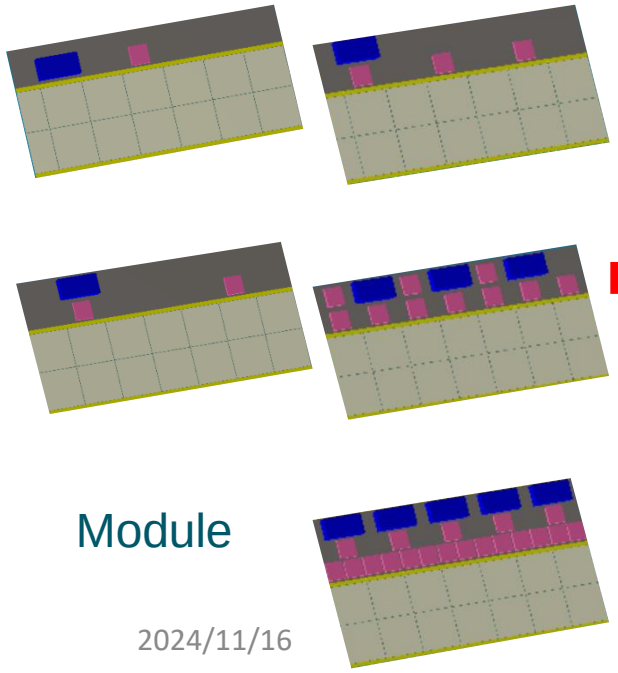




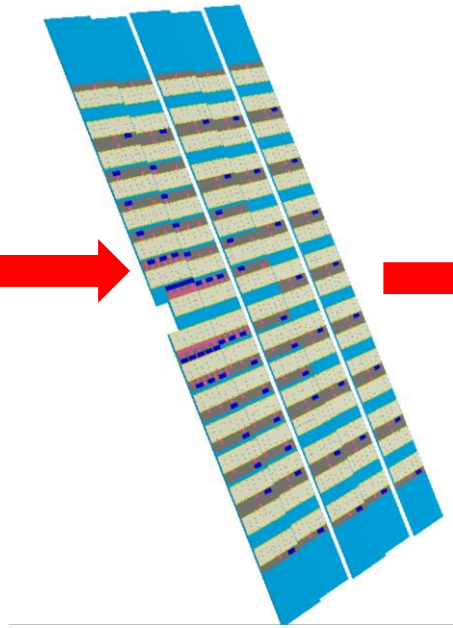


Geometry Description in DD4hep

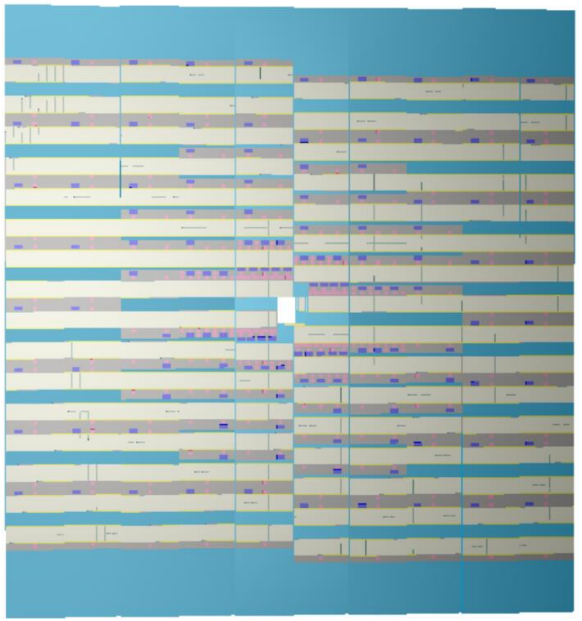
- **The Simulation of UP (with HV-CMOS)**
  - The detector description has been implemented in the LHCb software framework with our code
  - The plots bellow show the geometry construction using DD4hep
    - The MAPS-based UP has 4 layers, at z-positions similar to the current UT
    - Each layer consisting of 10 staves equipped with 32 modules
    - There are 5 types for module



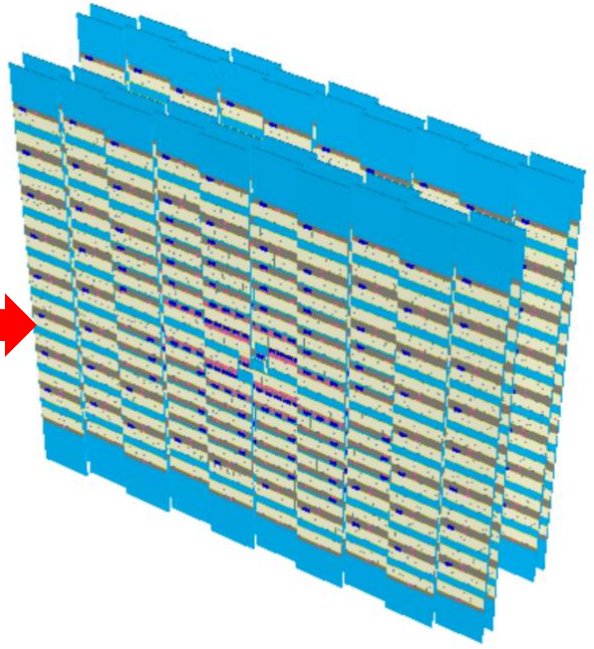
Module



Stave



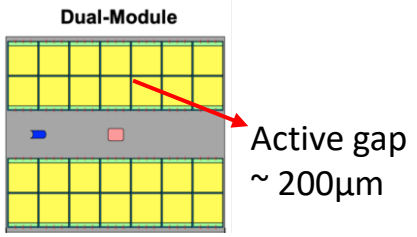
Layer

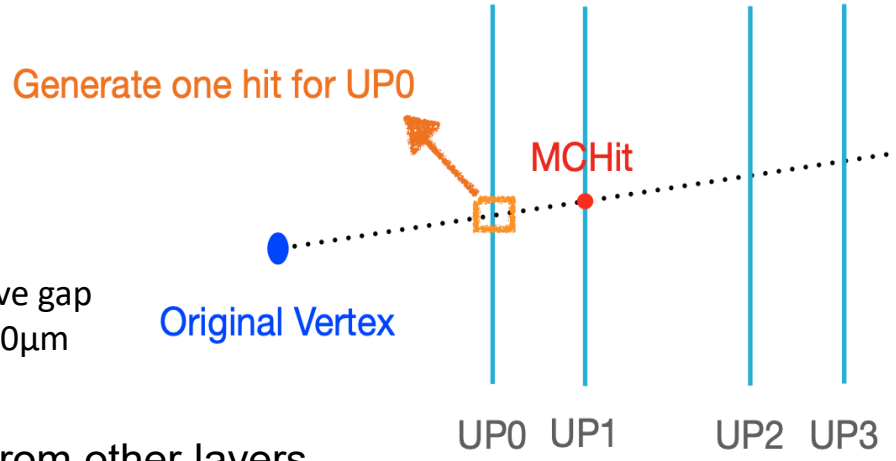


UP

Hit Density

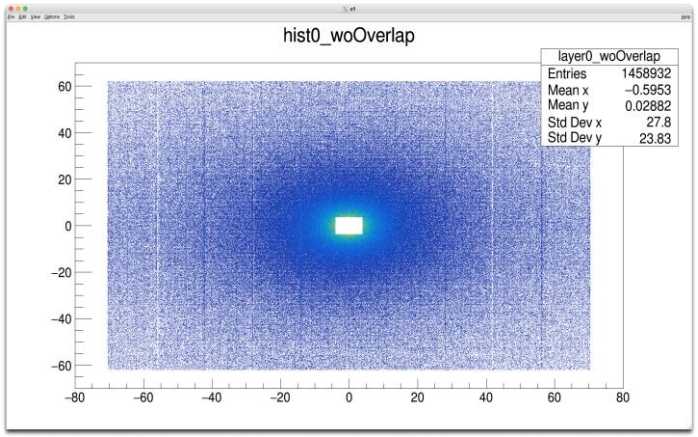
- **The simulation study of the UP detector**
  - Using simulation samples generated under Upgrade II conditions
  - Described using the DD4hep framework



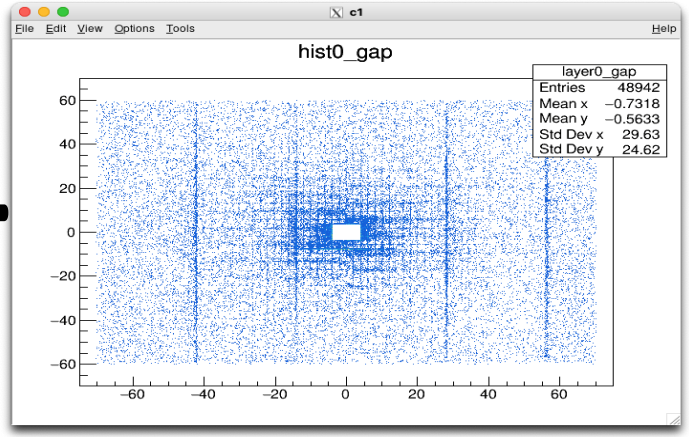


- **Loop through all tracks, for each track**
  - Remove overlap → Save only one MChit in one layer
  - Generate hits for Gap → If there is no MCHit in one layer, produce one from other layers

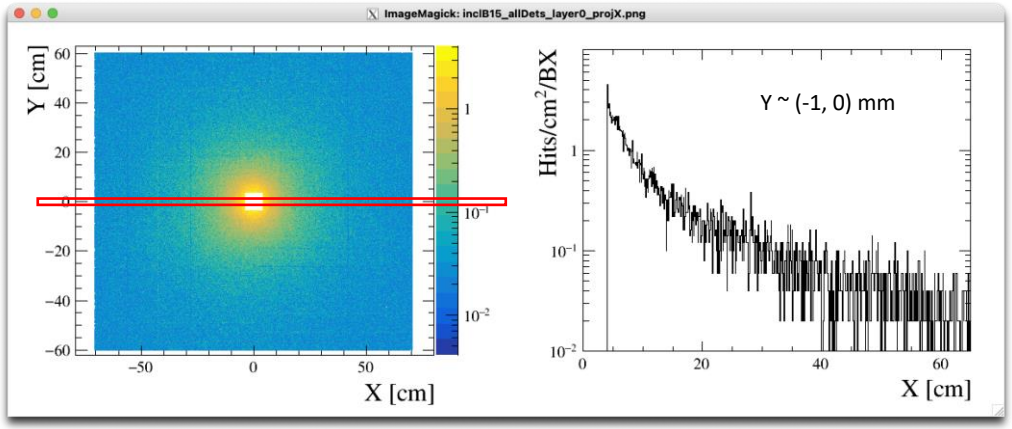
- The average hit densities per bunch crossing in proton-proton collisions at HL-LHC is up to **~4.5 hits/cm2/BX**



Remove overlap



Generate hits for Gap

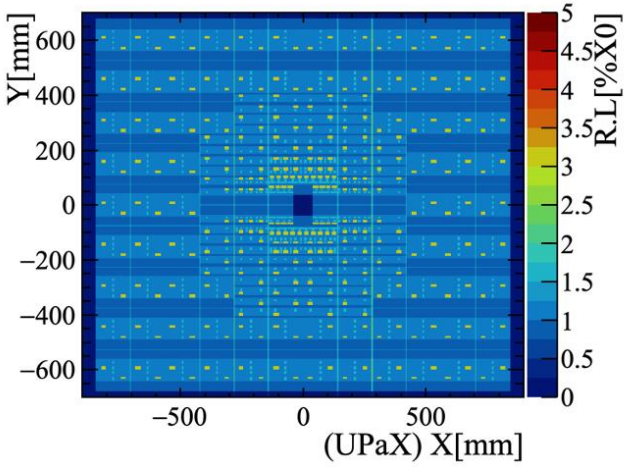


$L=1.5\times 10^{34}\ cm^{-2}s^{-1}$

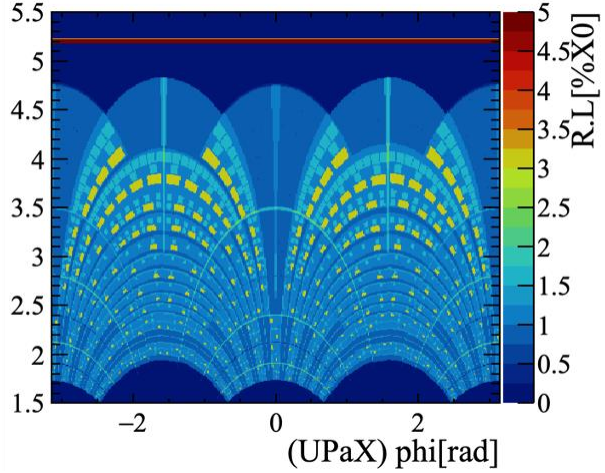
Material budget

➢ Material Budget

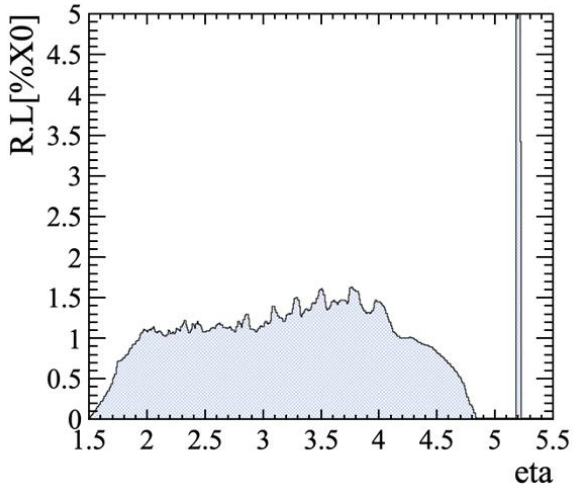
- Detector description has been developed both in **DetDesc** and **DD4hep** framework
- The material budget scan was performed in two frameworks with **consistent results**
  - Plot (a) and (b) illustrate the radiation length of the **first layer** of UP in both x/y and η/ϕ views
  - Plot (c) presents the projection map along the η axis
- A preliminary material budget estimate for **one layer** in the range 2<η<5 is **1.2% X_0**
- A careful optimization of the material budget is still ongoing



(a)



(b)

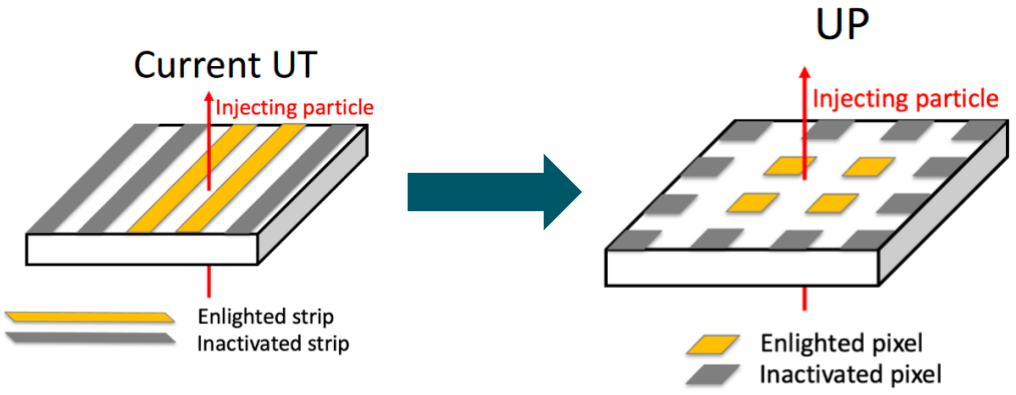


(c)

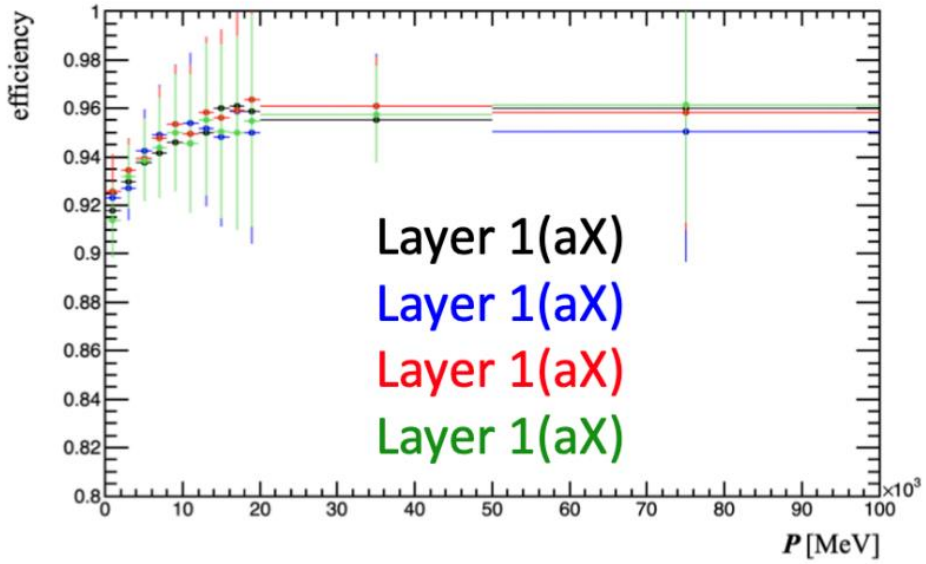
	Thickness [mm]	RL (2<η<4.5) [% X_0]
Pixel Sensor	0.200	0.24
lpGBT	1.250	0.07
VTRx+	4.000	0.13
HybridFlex	0.200	0.28
Kapton Tape	0.100	0.27
BareStave	4.000	0.21
One plane	**-**	**1.20**

UP Digitization

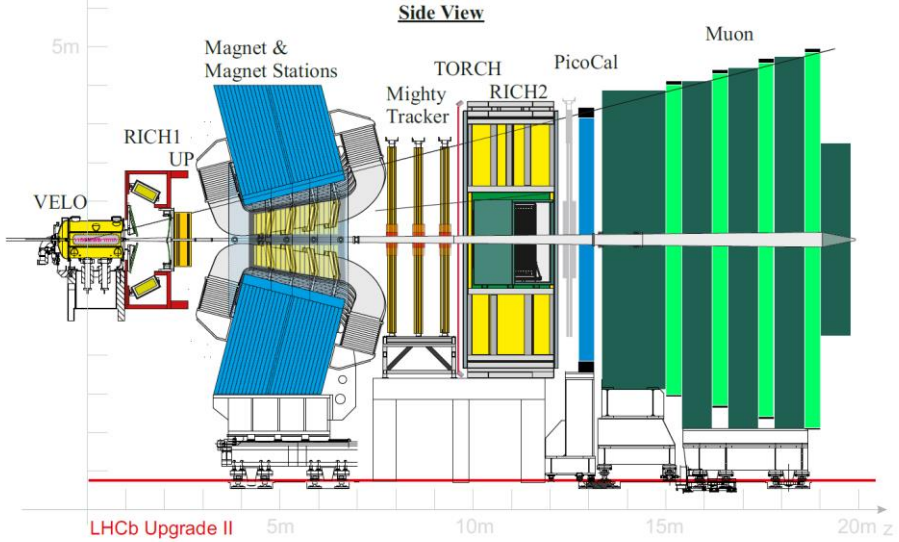
- **Occupancy distribution**
  - The distribution of the occupancy rate for the most busy chip on each module
  - In the most inner region, the highest occupancy is up to **0.26×10^{-2}**
- **Responding efficiency**
  - Particle response efficiency was treated as a function of particle momentum per layer compared with the current UT, both with efficiencies **around 95%**
- **The UPDigits based on DD4hep is currently under developed**



0.004	0.004	0.005	0.004	0.005
0.003	0.004	0.008	0.006	0.006
0.004	0.009	0.006	0.006	0.006
0.008	0.006	0.008	0.007	0.010
0.005	0.007	0.005	0.006	0.007
0.005	0.006	0.008	0.009	0.009
0.005	0.006	0.009	0.010	0.015
0.005	0.009	0.009	0.011	0.013
0.008	0.006	0.008	0.013	0.017
0.006	0.007	0.011	0.020	0.019
0.006	0.009	0.012	0.020	0.025
0.006	0.010	0.013	0.024	0.032
0.006	0.009	0.015	0.031	0.057
0.006	0.009	0.017	0.034	0.088
0.011	0.009	0.018	0.049	0.256
0.008	0.016	0.021	0.047	0.225



Summary and Outlook



- UP detector modelling and the UP part of the **Upgrade II scoping document** is finished
- Simulation Study
  - The average hit densities per bunch crossing in p-p collisions is up to **~4.5 hits/cm^2/BX**
  - In the most inner region, the highest occupancy is up to **0.26×10^{-2}**
  - The average material budget for one layer is **1.2% X_0**
- The LHCb Upgrade II is aiming for a TDR in 2026
- The UPDigits based on DD4hep is currently under developed


LHCb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Thank you !