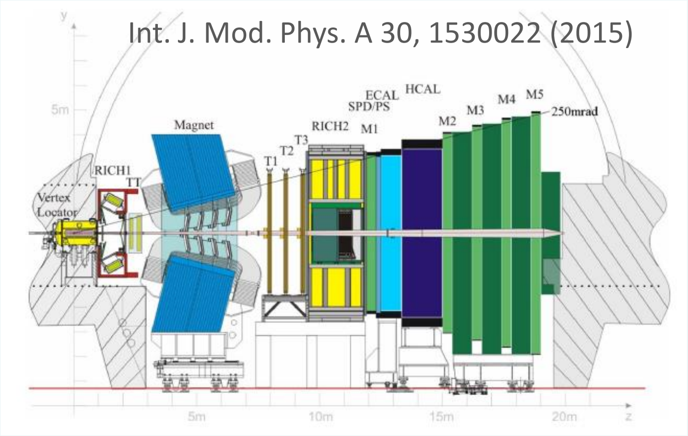
Heading to HL-LHC: the Muon Detector for the LHCb Upgrade II

M. De Serio (University of Bari and INFN Bari)
on behalf of the LHCb Collaboration

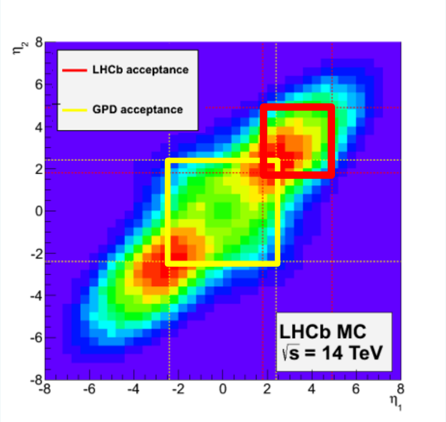
Outline

- The LHCb experiment in a nutshell
- LHCb upgrade(s): motivations and status of Upgrade phase I
- Towards Upgrade phase II
- The LHCb Muon detector: from present to future

- Forward single-arm spectrometer covering the pseudo-rapidity range of $2 < \eta < 5$



Int. J. Mod. Phys. A 30, 1530022 (2015)



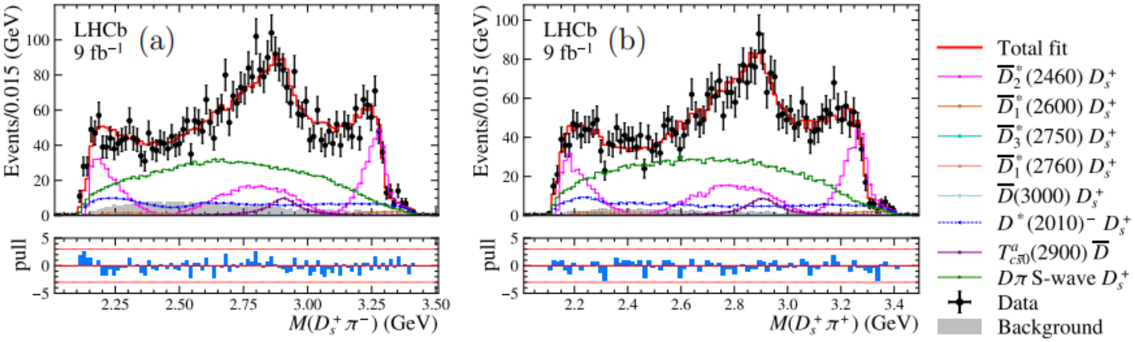
- Originally designed for the study of CP violation and rare decays in beauty and charm, LHCb has proved to be a general purpose detector with a rich physics program
- Excellent performance in Runs 1 and 2:
  - Momentum resolution $\boldsymbol{\Delta p/p} \sim \mathbf{0.5}$% below 20 GeV/c, **~ 1%** at 200 GeV/c
  - Impact parameter resolution **IP ~** $(\mathbf{15} + \mathbf{29}\ \boldsymbol{pT}$ [GeV]) $\boldsymbol{\mu m}$
  - Decay time resolution $\boldsymbol{\sigma_t} \sim \mathbf{45}$ **fs** for $B_s \to J/\psi\ \varphi$
  - PID efficiency (mis-ID prob.): e ~90% (e→h ~5%) k ~95% (π→K ~5%) μ ~97% (π→μ 1-3%)

Selection of LHCb highlights

Runs 1+2 integrated luminosity $9 fb^{-1}$

EXOTIC SPECTROSCOPY

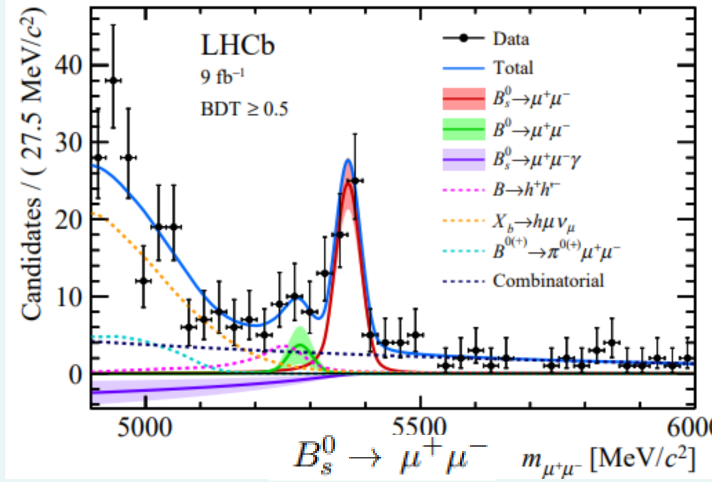
LHCB-PAPER-2022-026 in preparation



$T^a_{c\bar{s}0}(2900)^{++}([c\bar{s}u\bar{d}])$ and its neutral isospin partner, $T^a_{c\bar{s}0}(2900)^{0}([c\bar{s}\bar{u}d])$

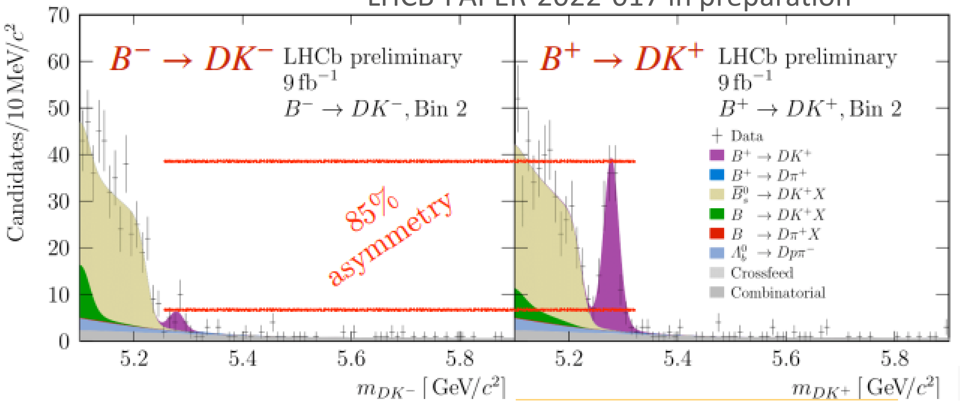
RARE DECAYS

Phys. Rev. Lett. 128, (2022) 041801



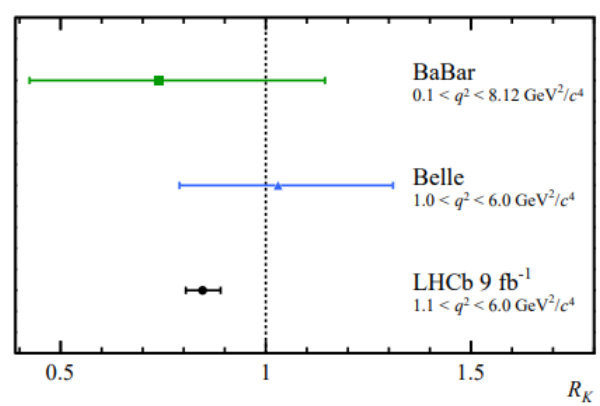
CPV

LHCB-PAPER-2022-017 in preparation



LFU

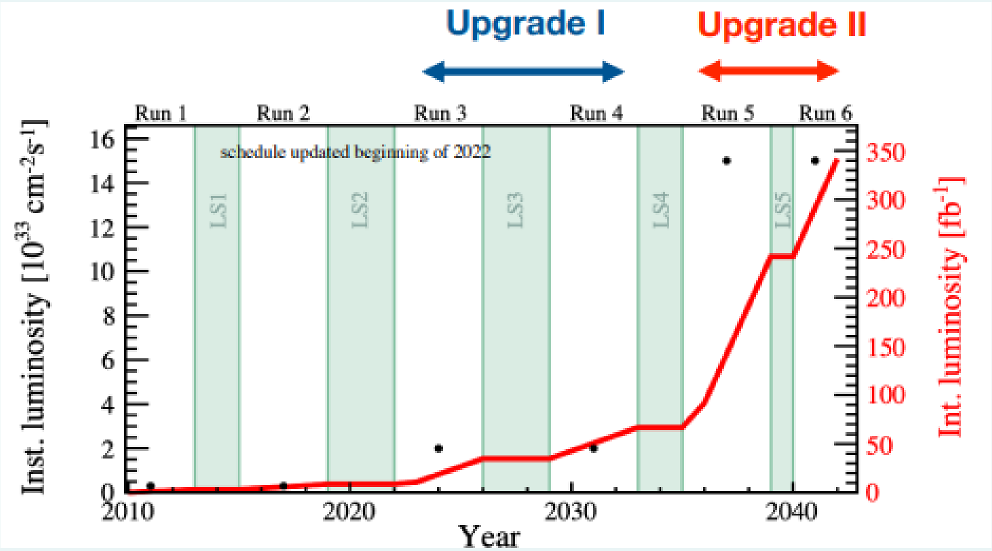
Nat. Phys. 18, 277–282 (2022)



See talks on LHCb physics results:
Z. Xu (Sept. 5) and YH Yang (Sept. 8)

LHCb upgrade(s): motivations

- **Fully exploit LHC luminosity increase for flavor physics studies**
- No evidence for *New Physics* in Runs 1 and 2, but ***interesting anomalies*** observed (e.g. LFU) to be further investigated
- Need more data to improve precision of several measurements, e.g.
  - $BR(\boldsymbol{B_s} \rightarrow \boldsymbol{\mu}+\boldsymbol{\mu}-)$ down to ~ 10% of the SM prediction
  - CKM γ angle down to ~ 1°
  - CPV in charm sector below 10^{-4}



LHCb upgrade phase I

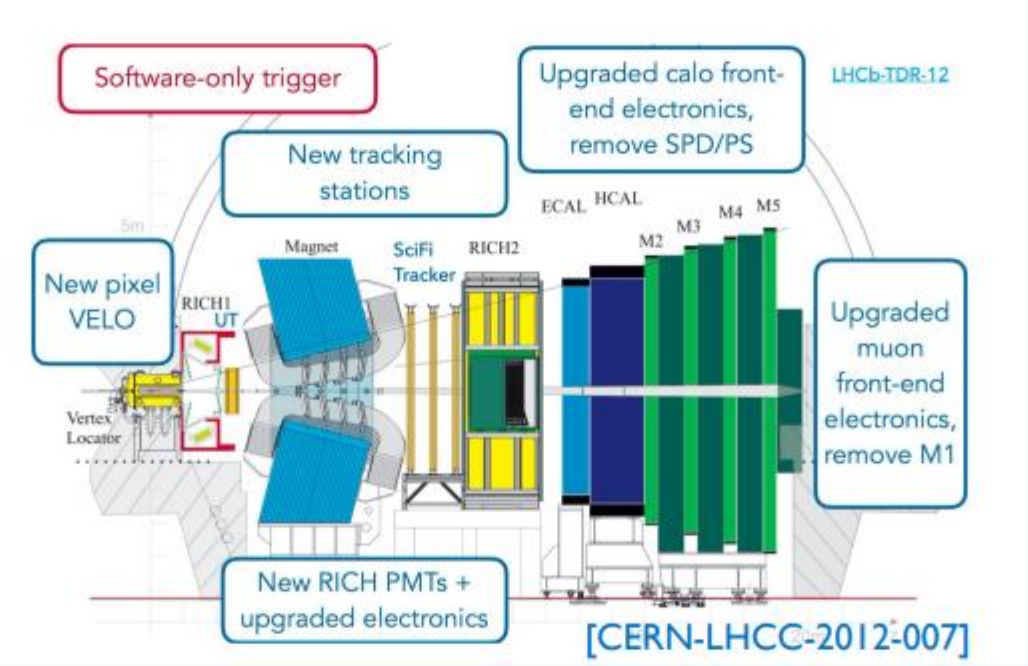
$\mathcal{L}_{peak} = 2\times10^{33}$ cm^{-2}s^{-1} with ~ 5 visible interactions, expected to collect about 50 fb^{-1} in Runs 3+4

Major upgrade of the detector; fully software trigger with detector readout at 40MHz

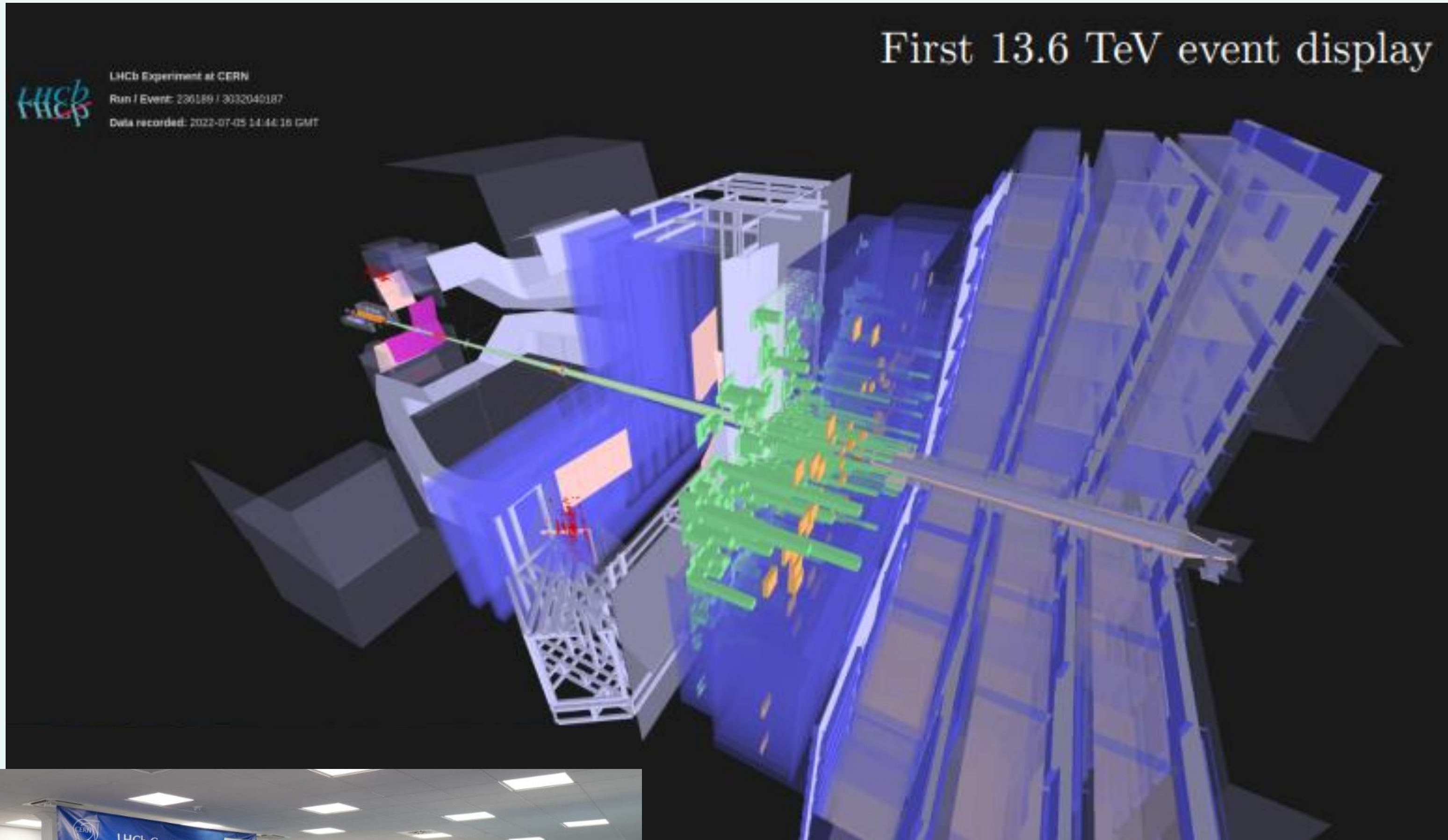
Partial reconstruction and selection to reduce data flow from 40 Tb/s to 1-2 Tb/s in HLT1 (GPUs)

Detector alignment and calibration in real time

Full reconstruction with offline quality in real time in HLT2



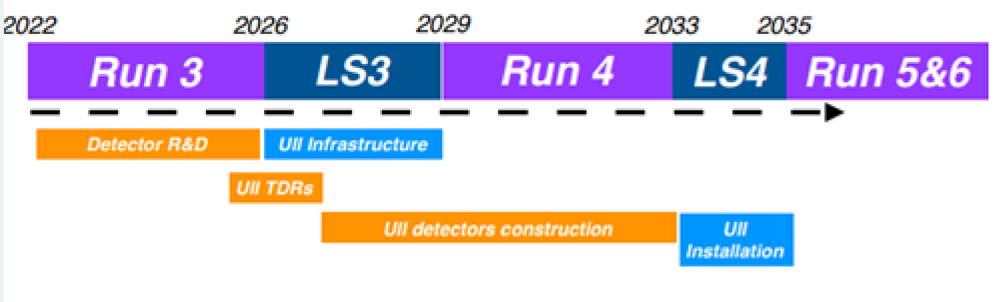
LHCb upgrade phase I

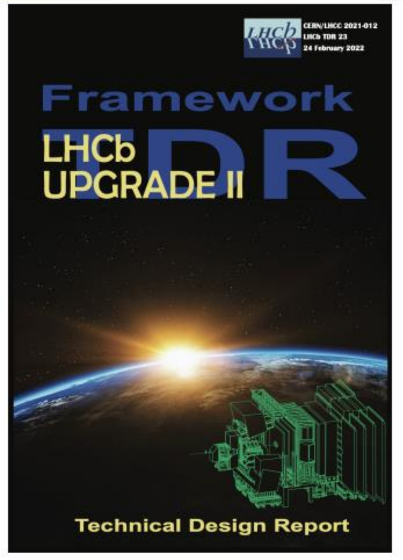


Now taking data!

Path towards LHCb upgrade phase II

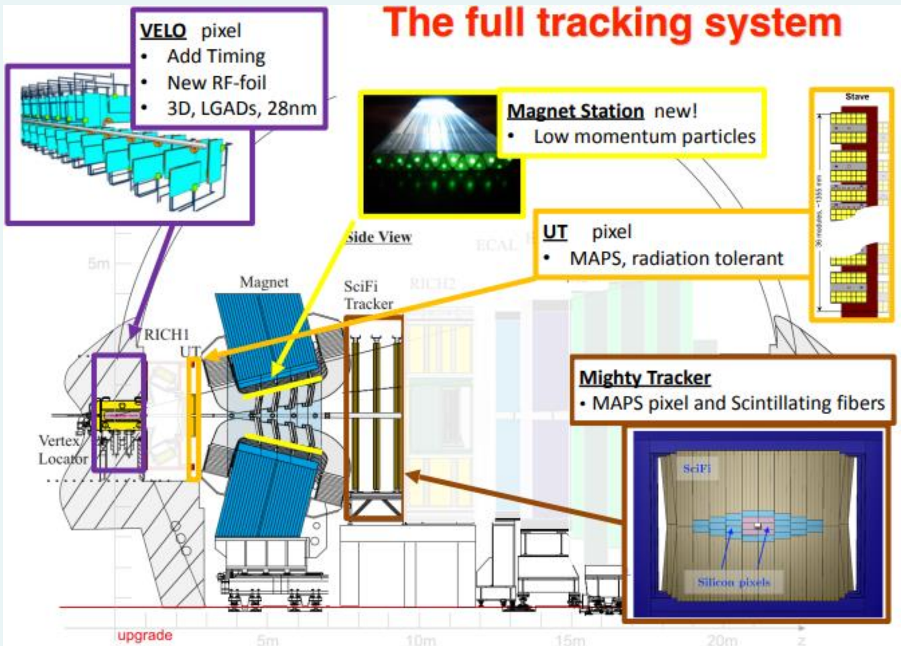
- **Expression of Interest (LHCC 2017-003)**
- **Physics case (LHCC 2018-027)**
- **Strong support from European Strategy for Particle Physics (2020)**
- **Framework TDR approved (LHCC-2021-012, https://cds.cern.ch/record/2776420/)**



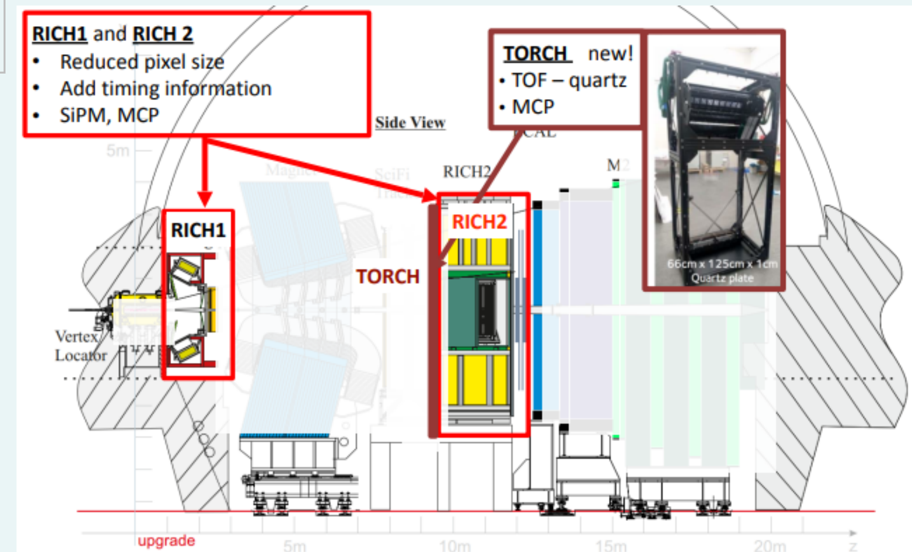


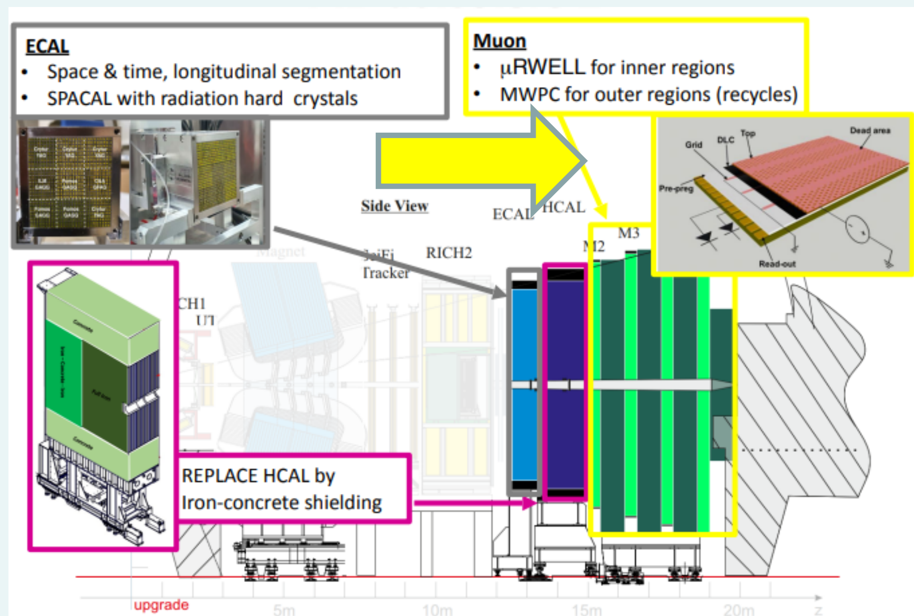
LHCb upgrade phase II

$\mathcal{L}_{peak} = 1.5 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$ with **~ 40 visible interactions**
Expected to collect about 300 $\mathrm{fb^{-1}}$ in Runs 5+6



PID detectors

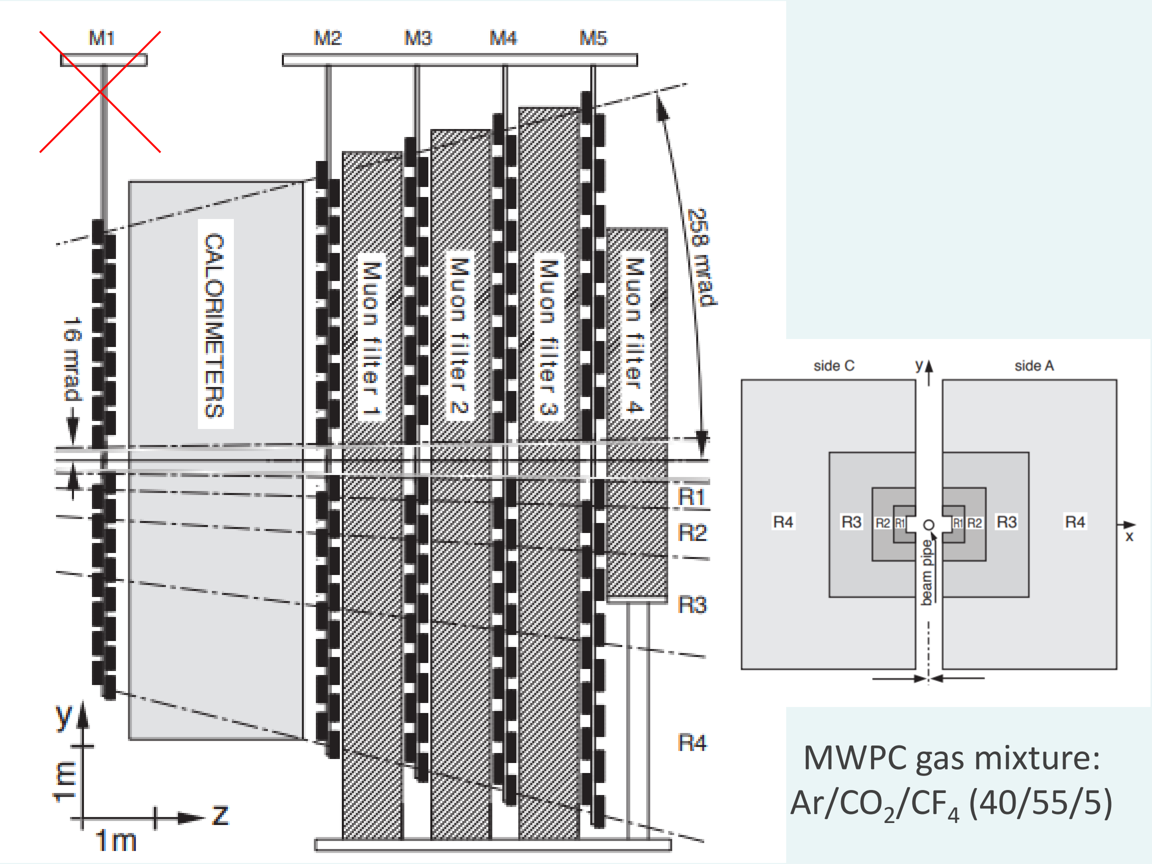




Detector challenge!

Key ingredients:
- improve granularity
- exploit timing
- radiation hardness

The current LHCb Muon detector



MWPC gas mixture: $Ar/CO_2/CF_4$ (40/55/5)

Excellent performance in Runs 1 and 2:

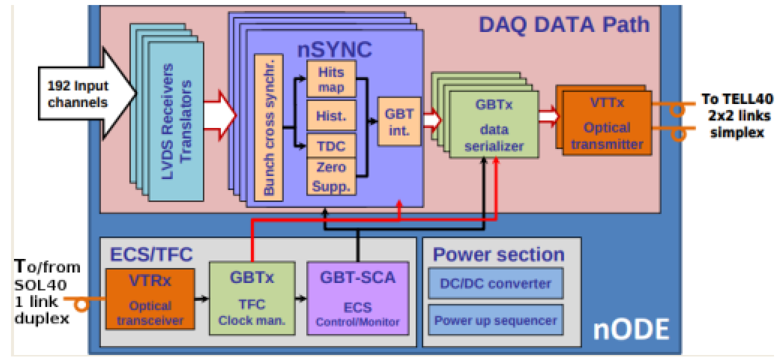
- Detection efficiency > 99% in all regions
- Muon ID efficiency ~ 97%
- No significant ageing

2013 JINST 8 P02022

- Four stations instrumented with 4-gap MWPCs interleaved with iron filters (M1 removed after Run 2)

The current LHCb Muon detector

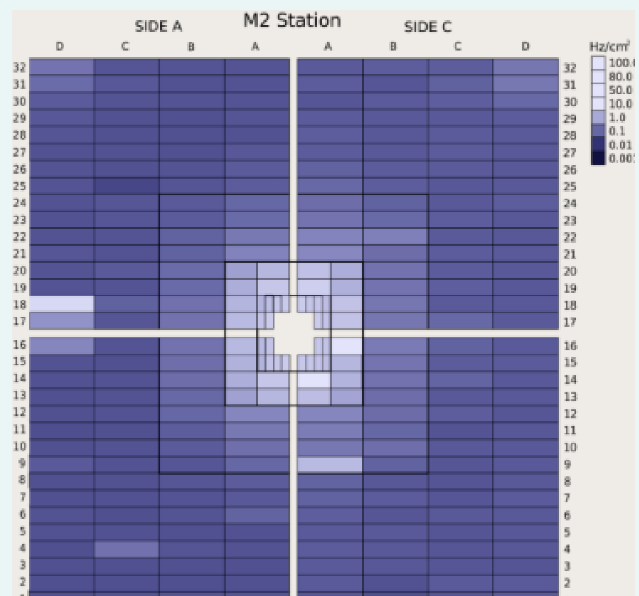
- New Off-Detector electronics to cope with 40MHz RO rate



nODE boards equipped with 4 nSYNC chips performing
BX alignment, zero suppression, hit arrival time measurements

NIM A 936 (2019) 378

Upgrade I commissioning is proceeding smoothly



M2 station, illumination map at 6.8 TeV

The future LHCb Muon detector

Requirements:

- rate capability up to 1 MHz/cm^2 in the innermost regions and increased granularity w.r.t. present;
- rate capability up to 10 kHz/cm^2 in the external regions;
- new FE electronics and readout scheme

Baseline option (under study):

- Inner regions (R1-R2): **µRWells**
- Outer regions (R3-R4): **MWPCs**

Other options for outer regions:

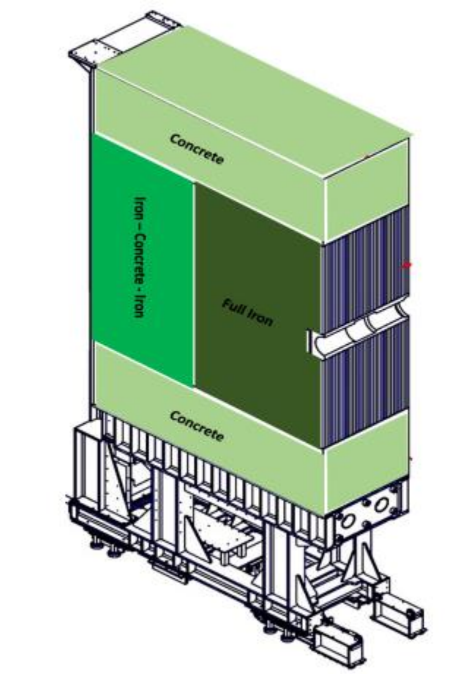
- **New-generation RPCs, Scintillating Tiles**

LHCC-2021-012

Rates (kHz/cm^2)	M2	M3	M4	M5
R1	749	431	158	134
R2	74	54	23	15
R3	10	6	4	3
R4	8	2	2	2

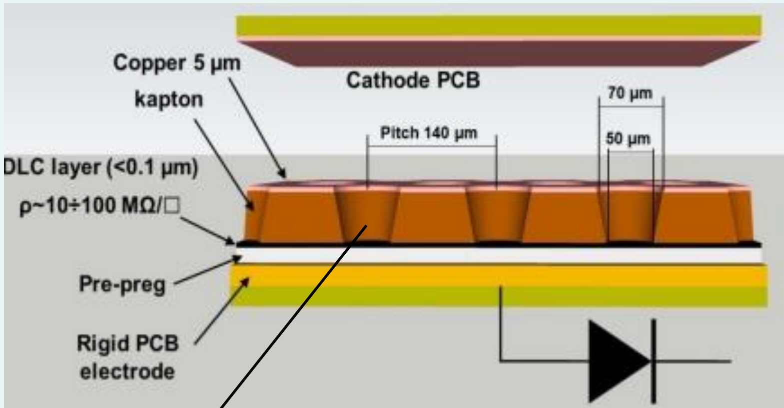
Area (m^2)	M2	M3	M4	M5
R1	0.9	1.0	1.2	1.4
R2	3.6	4.2	4.9	5.5
R3	14.4	16.8	19.3	22.2
R4	57.6	67.4	77.4	88.7

Expected maximum rates (shielding included)

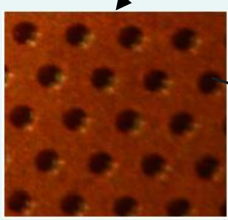


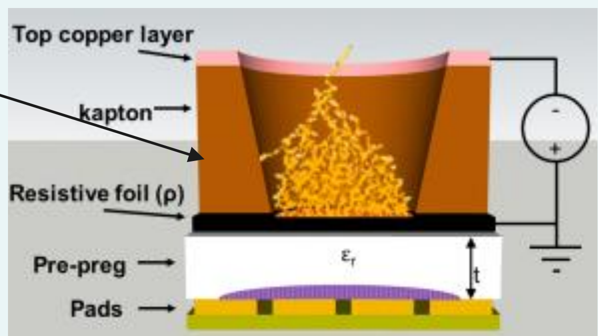
Structure of the additional shielding to be installed in front of station M2 (replacing HCAL)

The µRWell technology



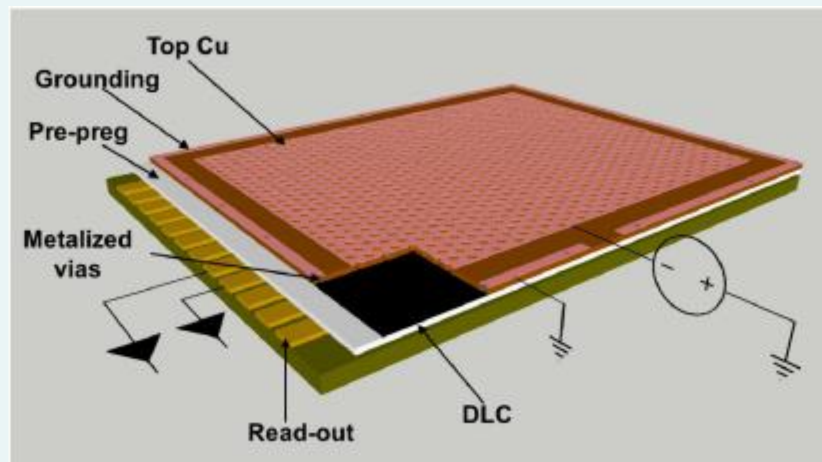
- Cathode PCB
- WELL-patterned kapton foil (with a top Cu-layer) acting as an amplification stage
- Resistive DLC (Diamond-Like-Carbon) layer with ρ ~ 40÷100 MΩ/□
- Readout PCB with pad segmentation





2015 JINST 10 P02008

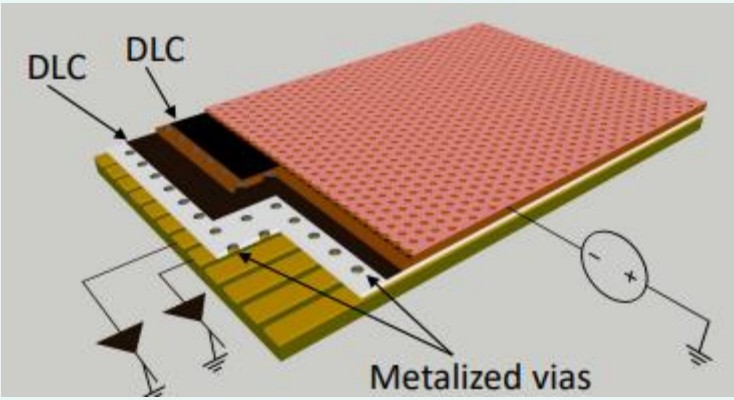
Single Resistive layer (SRL)



The µRWell performance

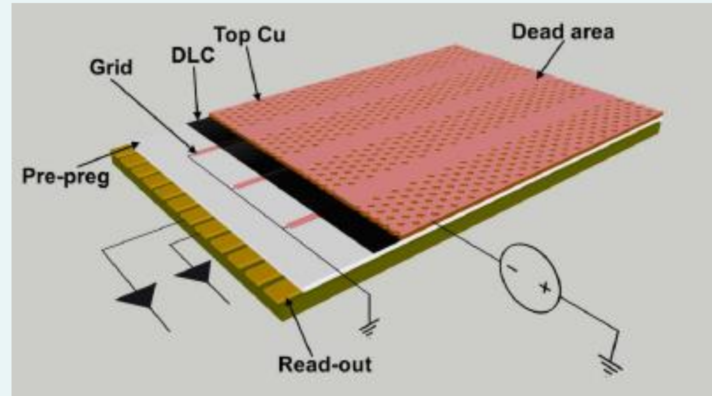
HIGH-RATE LAYOUTS

Double Resistive layer (DRL)



Two resistive layers interconnected through
a matrix of conductive vias

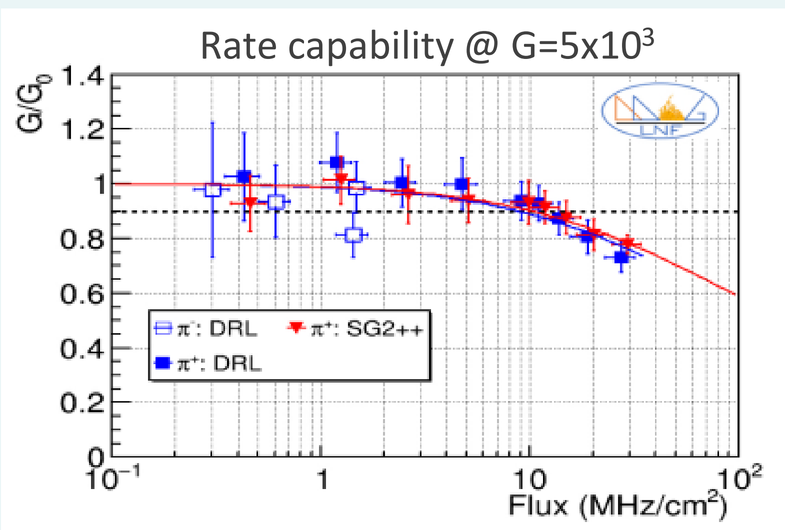
Single grid (SG)

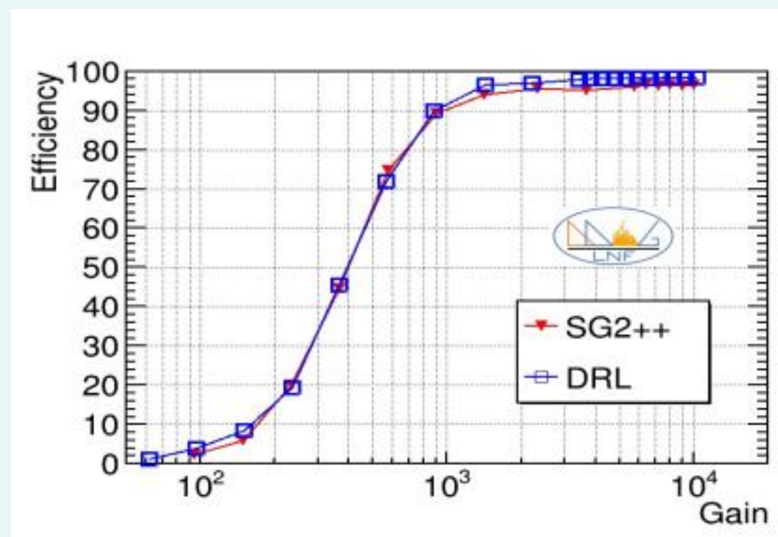


DLC grounded by a conductive grid

2020 JINST 15 C09034

Gas mixture: Ar/CO_2/CF_4 (45/15/40)

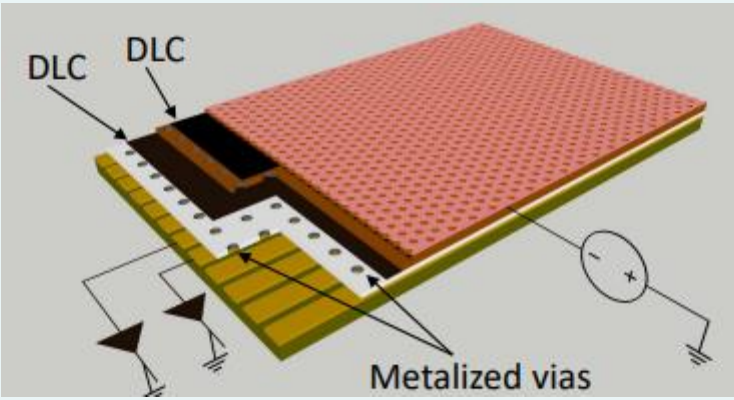




The µRWell evolution

HIGH-RATE LAYOUTS

Double Resistive layer (DRL)



Two resistive layers interconnected through
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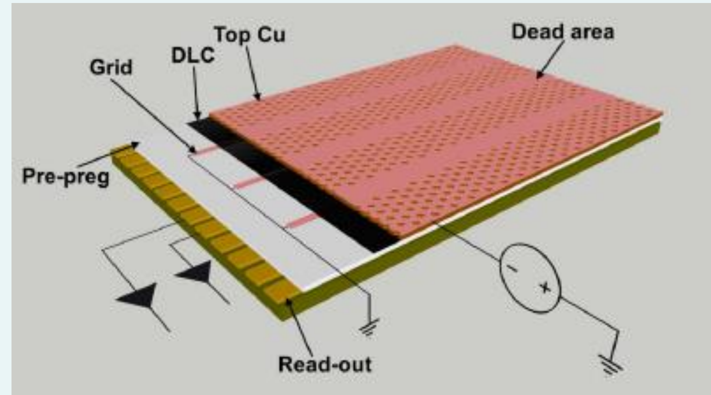
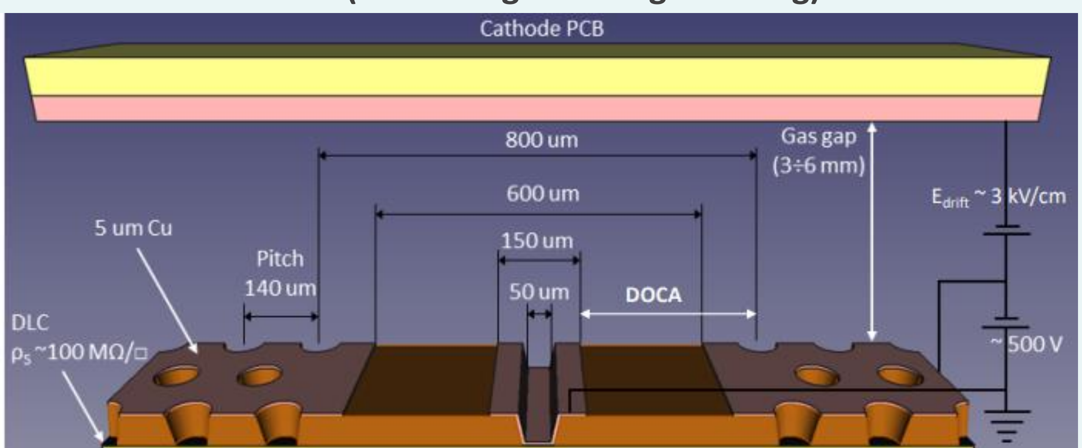
Single grid (SG)



DLC grounded by a conductive grid

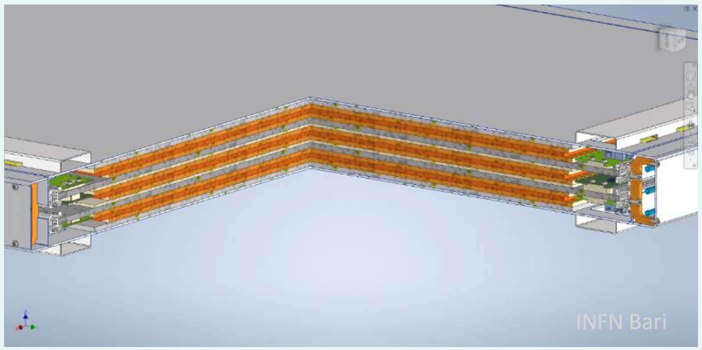
PEP (Patterning – Etching – Plating)



Grounding by Cu and kapton etching

Other detector options

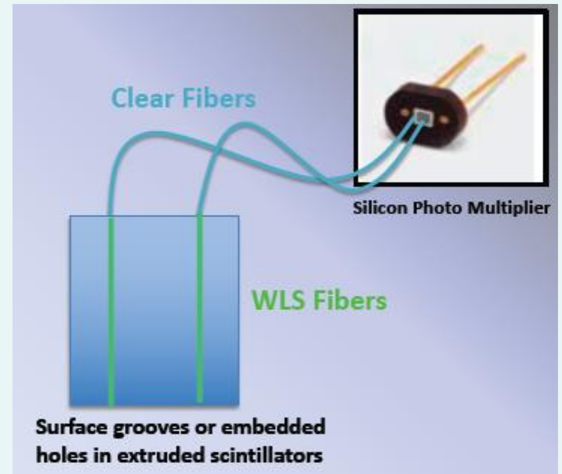
NEW GENERATION RPCs



Intense R&D activity ongoing:

- improve the rate capability (up to several kHz/cm^2) $\Rightarrow$ reduce electrode resistivity and thickness, reduce average charge per event
- study and optimize detector performance with eco-friendly gas mixtures

SCINTILLATING TILES



1-2 cm-thick tiles read out by WLS/clear fibers and SiPM

- Compact, easy-to-build solution
- Main drawback: radiation-induced SiPM damage $\Rightarrow$ adequate shielding against neutrons

Conclusions

- LHCb Upgrade II has been proposed to fully exploit HL-LHC for flavor physics studies.
- In order to keep the same performance in Run 5 and beyond, new detector technologies are under study.
- The Muon detector has shown excellent performance in Runs 1 and 2.

The detector commissioning after Upgrade I is currently ongoing.

In parallel, an intense R&D activity is in progress: **heading to HL-LHC**.