21st November 2021

May all the forces be with you: the eras of LHCb

Chris Parkes

- Achievements of LHCb
- Status of Upgrade I
- Opportunities for Upgrade II

LHCb Original 2009-2018

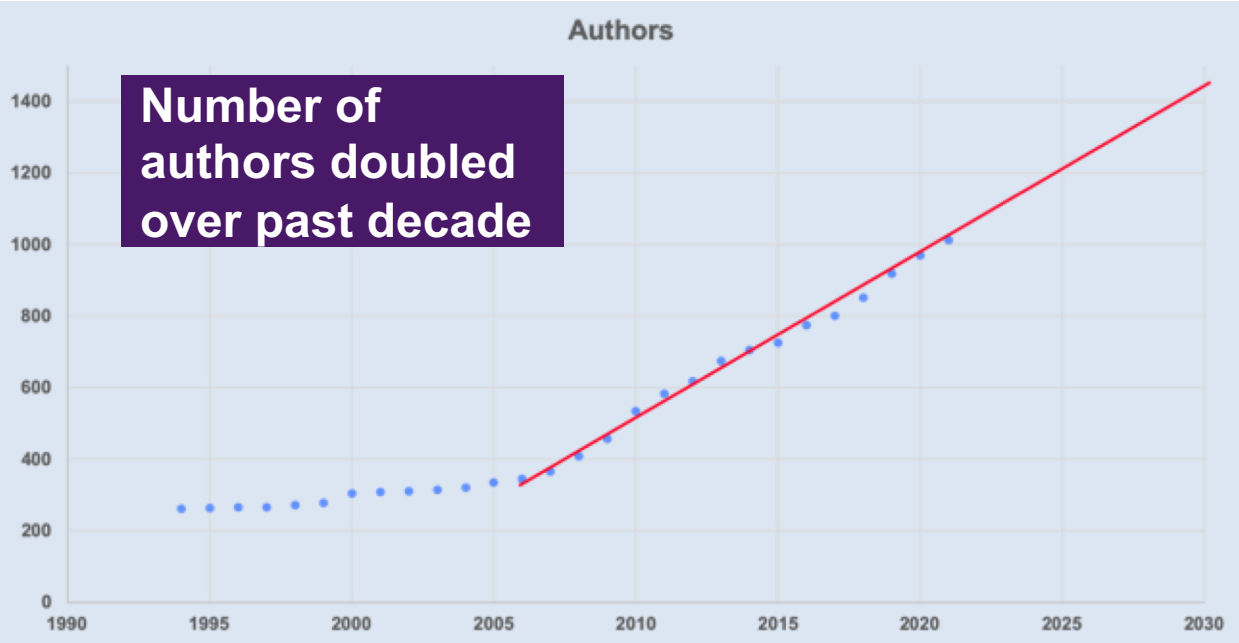
LHCb Upgrade I 2022-2030

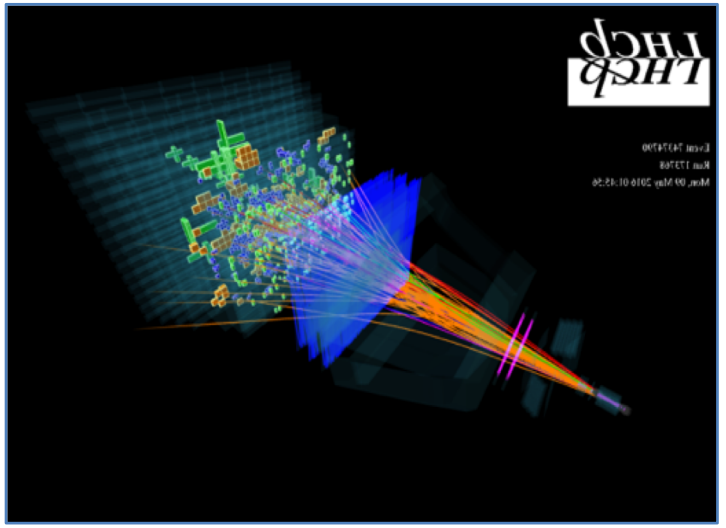
LHCb Upgrade II 2032-

Acknowledgement - slides from many colleagues !

LHCb Collaboration

- **1000** authors from **90** institutes in **20** countries



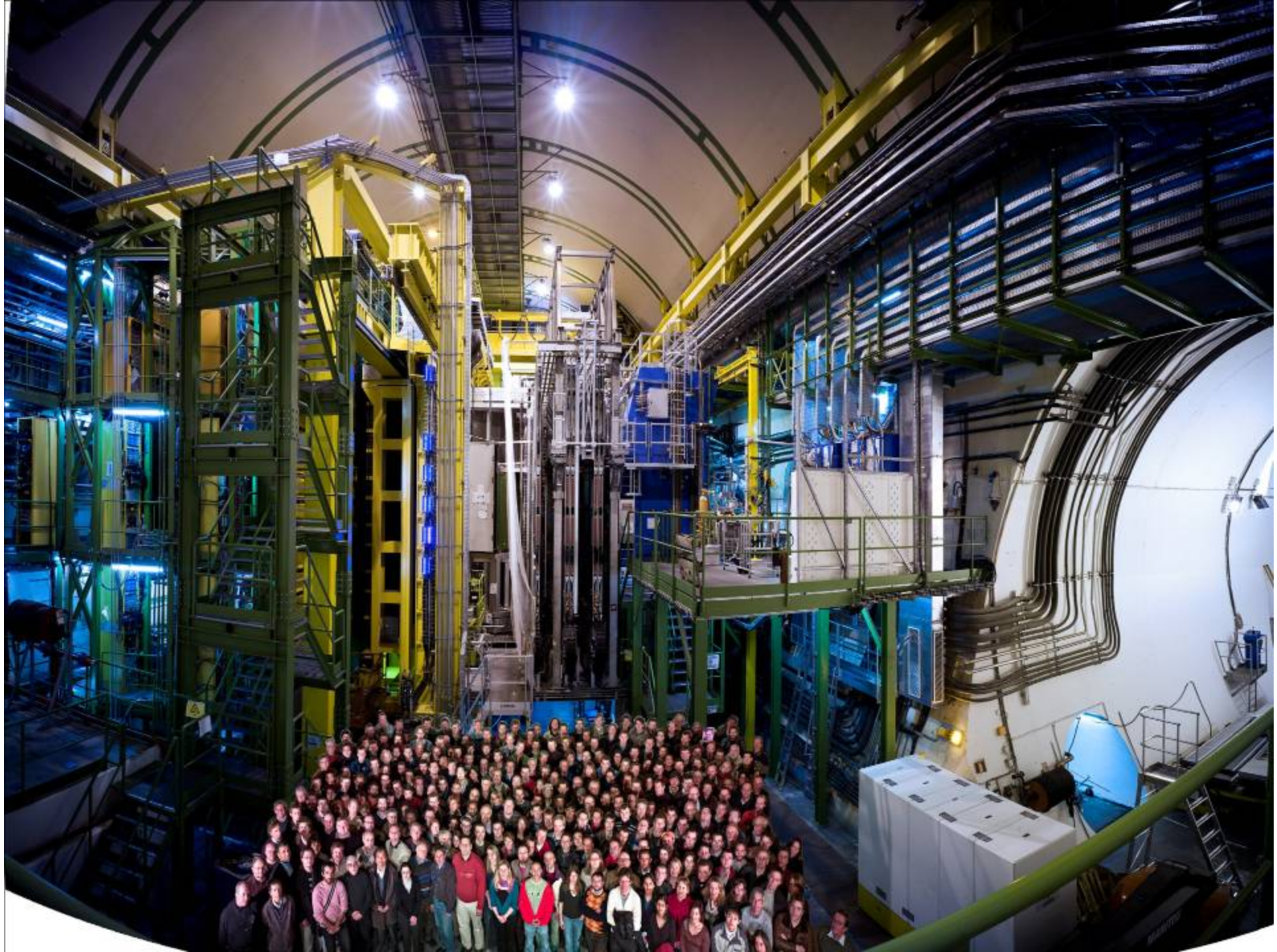


LHCb - Original

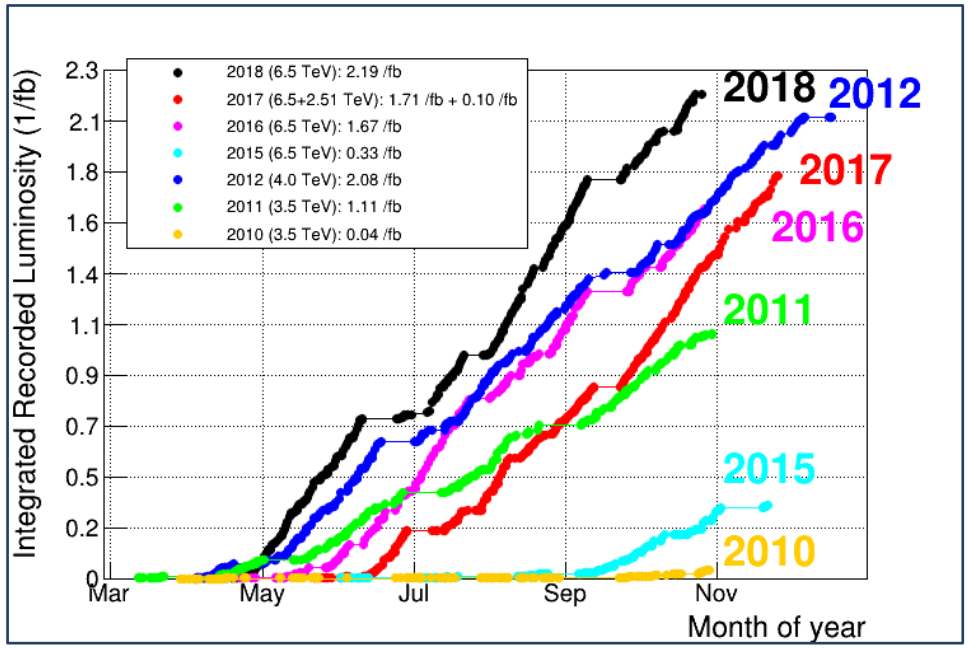
Ist Era: a glorious history

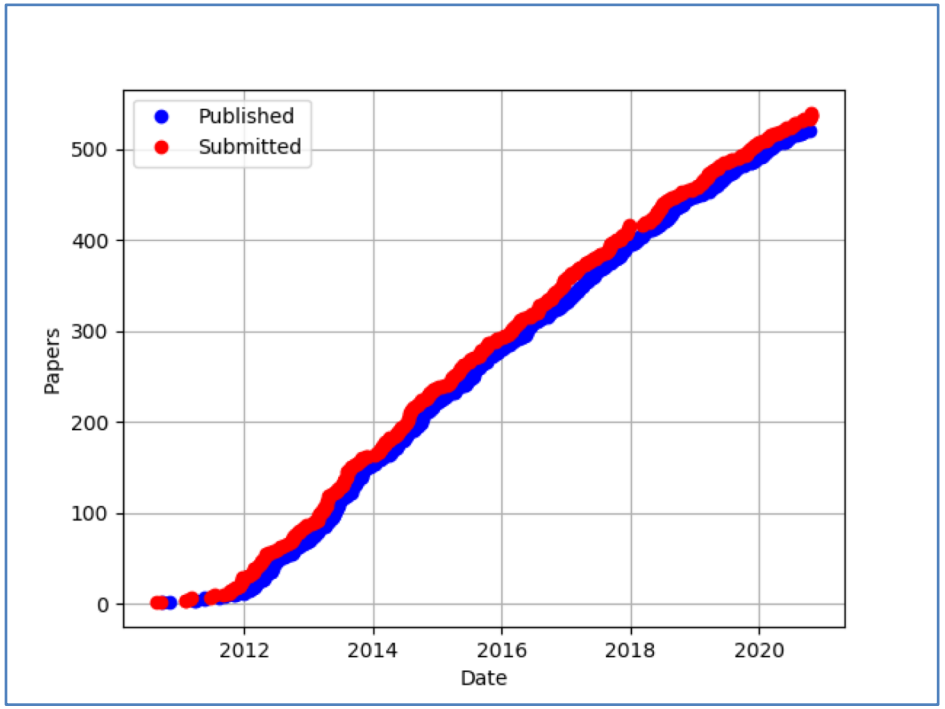
The experimental equivalent of making
"the Kessel run in less than 12 parsecs"

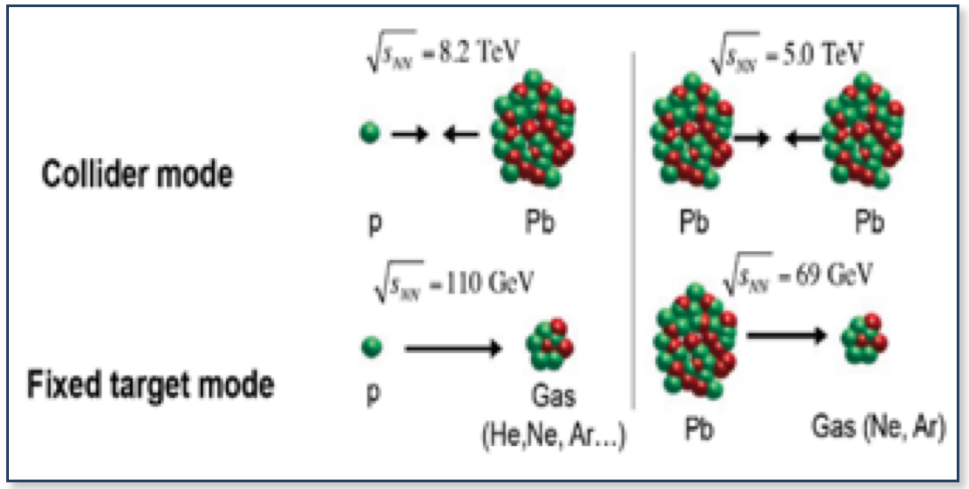
LHCb – A New Hope



LHCb data taking







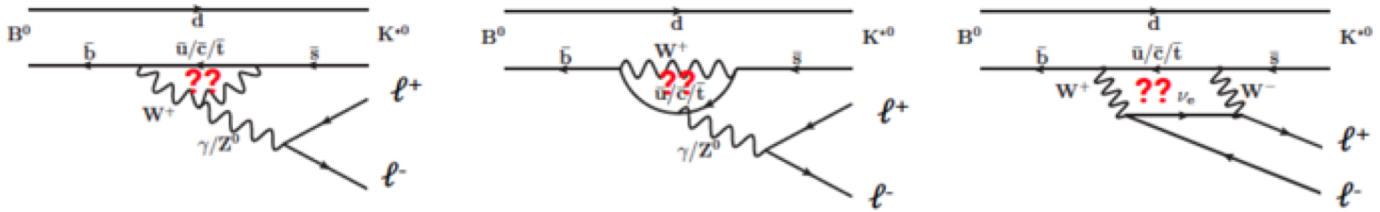
- Delivered 10 fb^{-1}
  - Originally stated aim of 1997 !
- 600 papers
- & modes of running never considered….

Recent Highlights: “The Flavour Anomalies”

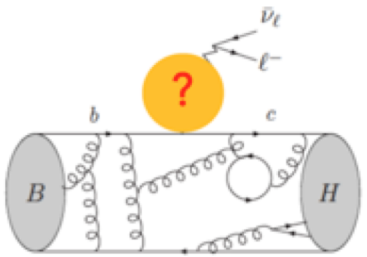
- Results from LHCb in tension with standard model at ~ 3σ Lepton Flavour Universality (e/μ/τ) ratios

“I find your lack of faith disturbing”

- b ➔ s $l^+ l^-$: FCNC

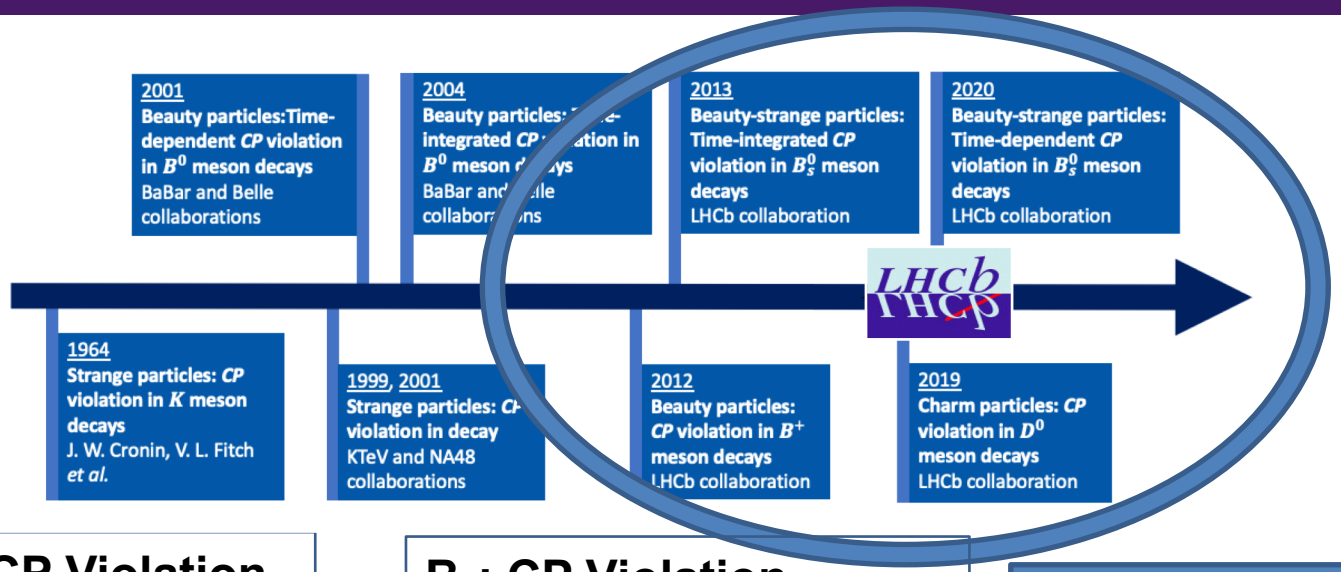


- b ➔ c l^- υ : tree-level decay



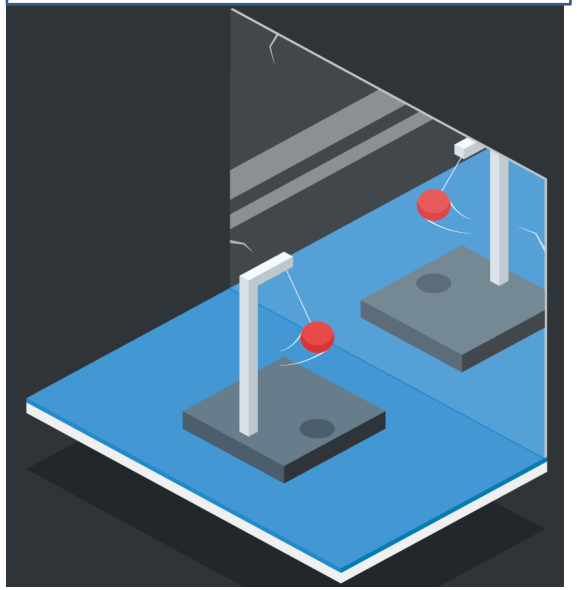
Inspired many theoretical papers some of which attempt to explain the full range of anomalies using new physics such as Z’ or lepto-quarks

Recent Highlights: CP Violation Discoveries



Charm: CP Violation in decay

B_s: CP Violation Time-dependent



Many precision measurements !

CKM angle γ

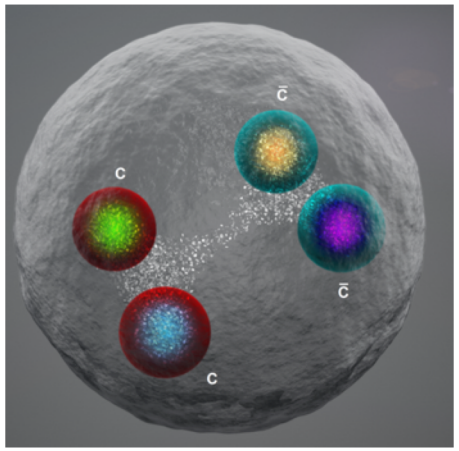
B_s mixing induced CPV phase φ_s

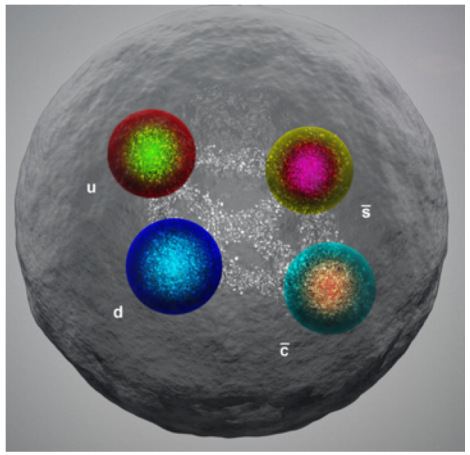
Recent Highlights: Exotic Hadrons

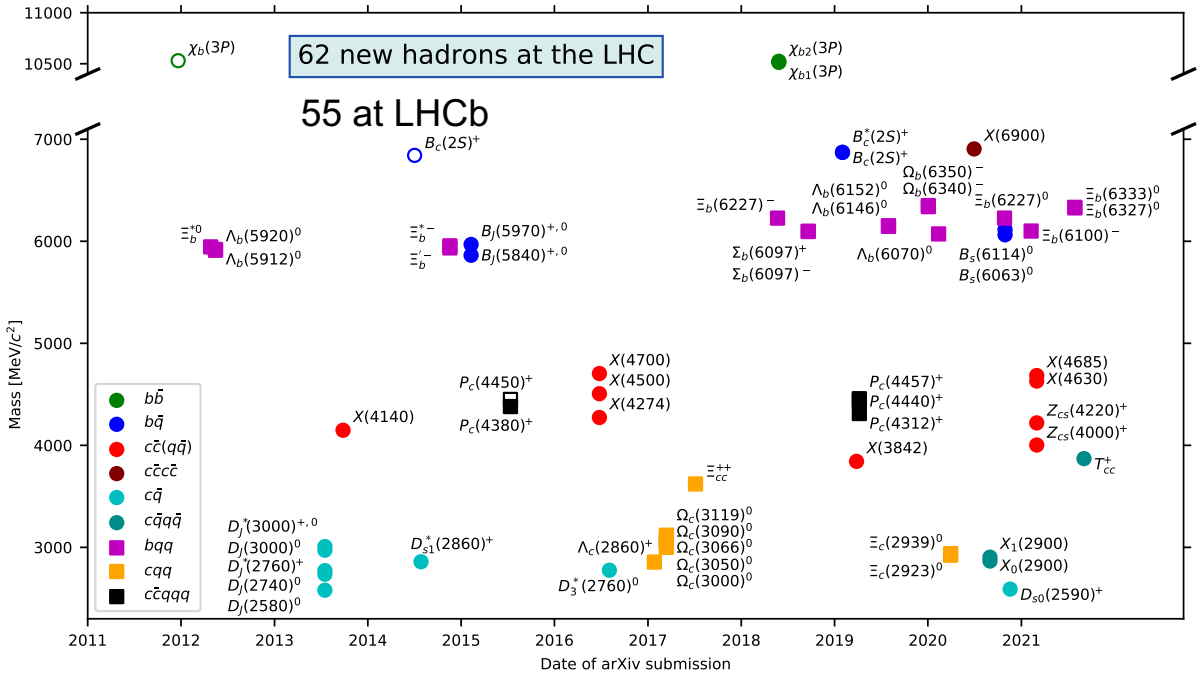
- Tetraquarks
- Pentaquarks

Understanding nature:

tightly bound vs molecular states







- > 50 hadrons discovered at LHCb for 50th anniversary of hadron colliders
- 17 Exotic states (16 LHCb)
  - A new era – clarity starting to emerge, formation of multiplets

LHCb – Upgrade I

Upgrade I

2021-2029

"Do or not do. There is not try."

2nd Era

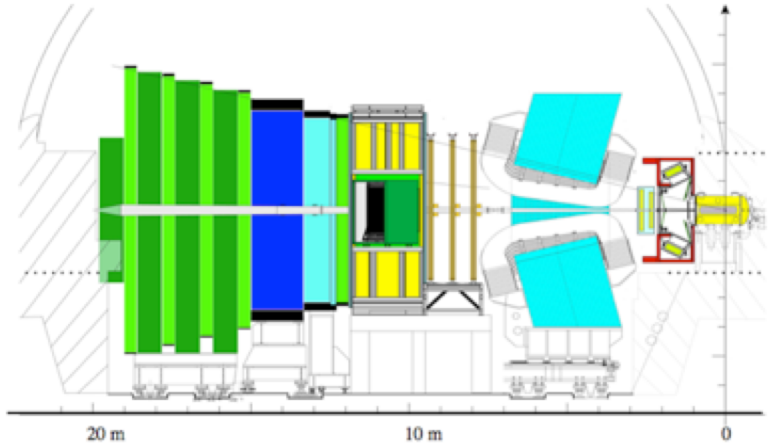
- Factor 5 increase in luminosity
- A new detector
- A new paradigm for particle physics:

Fully software trigger

LHCb – Strikes back

Aims & Critical Components

- LHCb core topics:
  - study CP violation
  - rare B decays
    - →New Physics



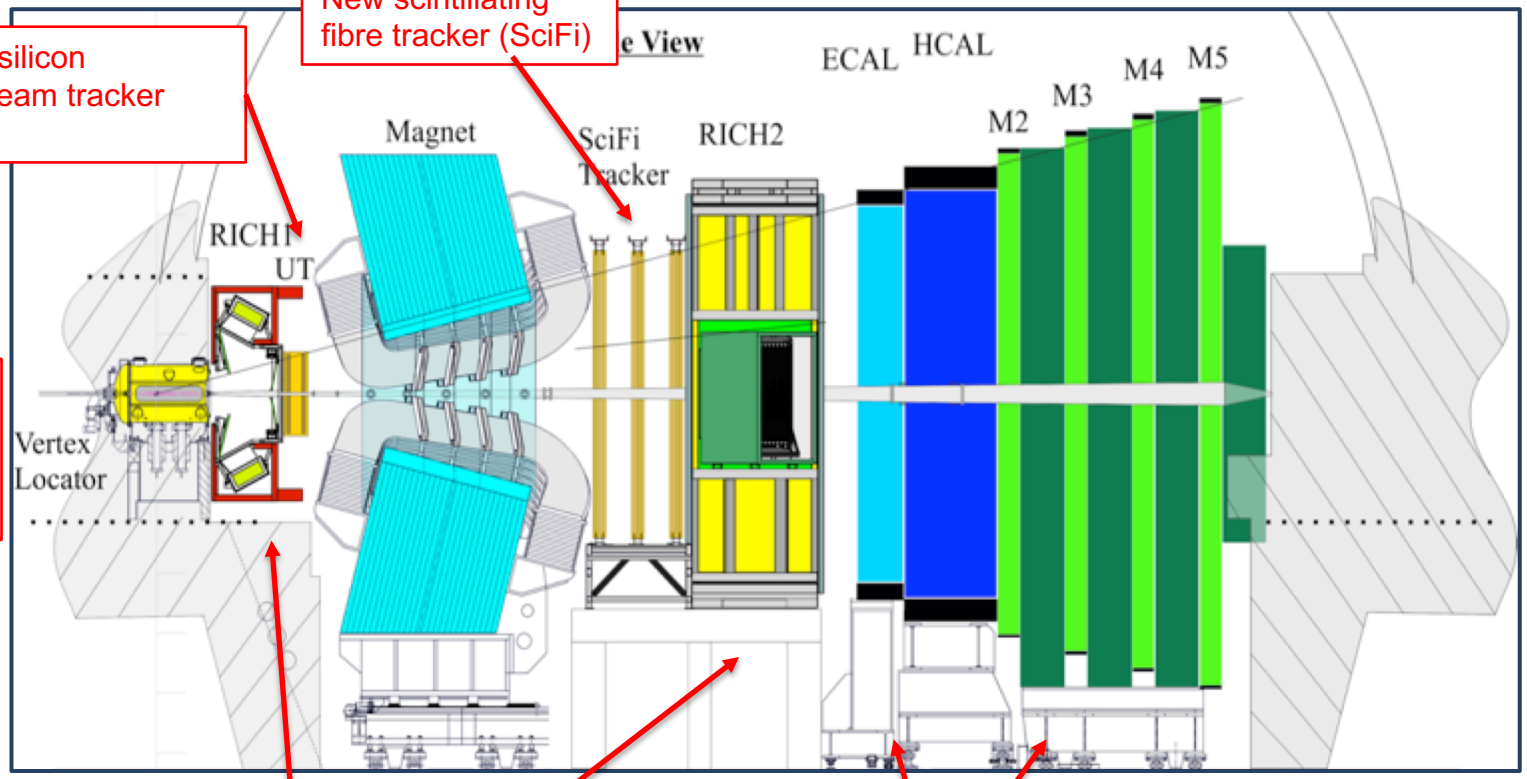
- Requirements:
  - efficient **trigger** on leptons and hadron channels
  - efficient **particle ID** for flavour tagging and background rejection
  - good **proper time resolution** for time dependent measurements of Bs decays
  - good **B mass reconstruction** for background rejection

LHCb Upgrade I in a snapshot

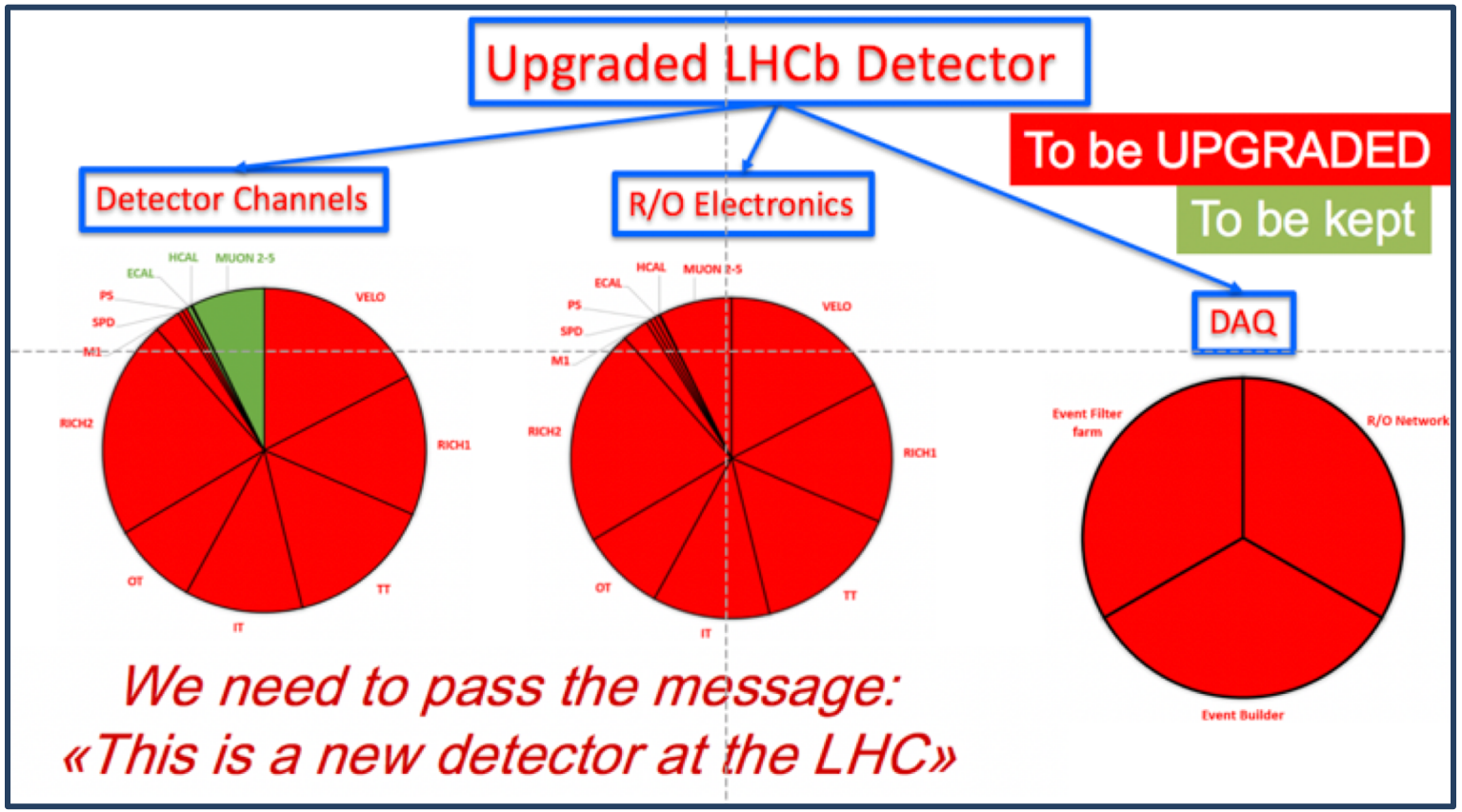
CERN-LHCC-2012-007

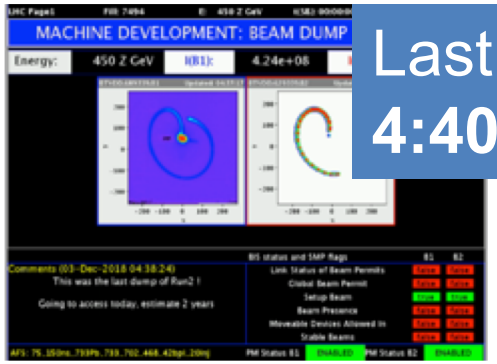
All sub-detectors read out at 40 MHz for a **fully software trigger**

Upgraded detector



LHCb Upgrade I in a snapshot





Last beam of Run 2 dumped
4:40 am 3rd December 2018

Upgrade I Installation started
8:00 am 3rd December 2018

LHCb Upgrade I: Tracking [VELO, UT, SciFi]

VELO

Hybrid pixel detectors (55μm pitch)

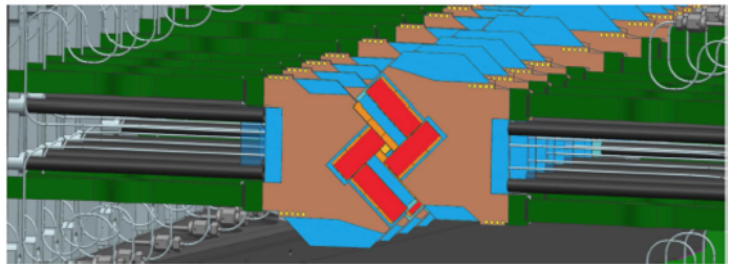
Close to the LHC beam (5.1 mm)

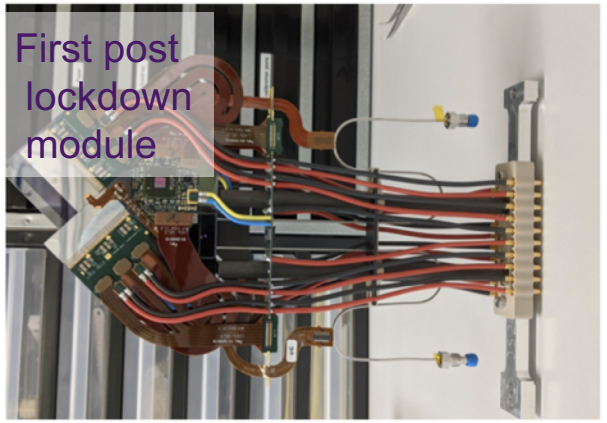
retracted/reinserted each fill

Innovative silicon microchannel cooling

Bi-phase CO_2 cooling

DAQ capable of handling 40TB/s





UT

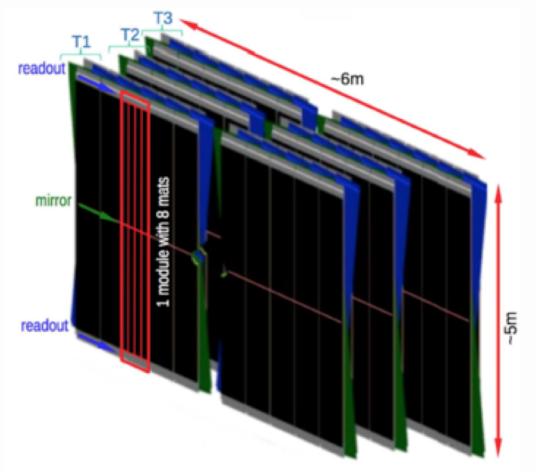
Tracking before magnet

- Facilitate track matching upstream/downstream

Particles decaying after VELO

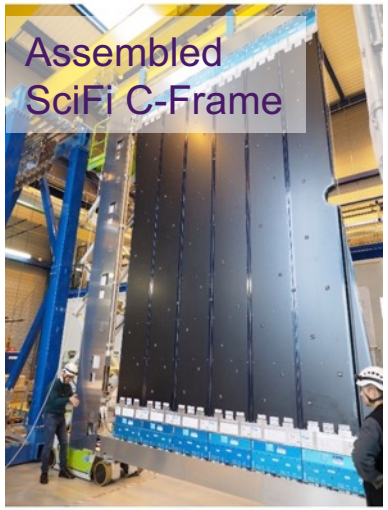
4 planes of silicon strips

- Pitch 95-195 μm
- Stereo angle to assist pattern recognition



SciFi

- Large scale tracking stations after magnet
- Scintillating Fibres
  - 250μm diameter, 2.5m long
- Signal readout by SiPMs
  - Operate at -40 C
- 12 layers of mats, 6 layers in each mat
  - 12,000 km of fibre !



LHCb Upgrade I: Particle Identification [RICH, CALO, Muons]

RICH

Two RICH Detectors: charged pion/Kaon/proton identification

- Gas radiators
- Before Magnet: 2-40 GeV
- After Magnet: 30-100 GeV

- Multi-anode photomultipliers, with FE-ASIC readout
  - 3000 units

CALO

New readout electronics

Muons

New readout electronics

HCAL beam plug

RICH1 gas enclosure at LHCb

RICH2 photodetector array

Muon commissioning rack

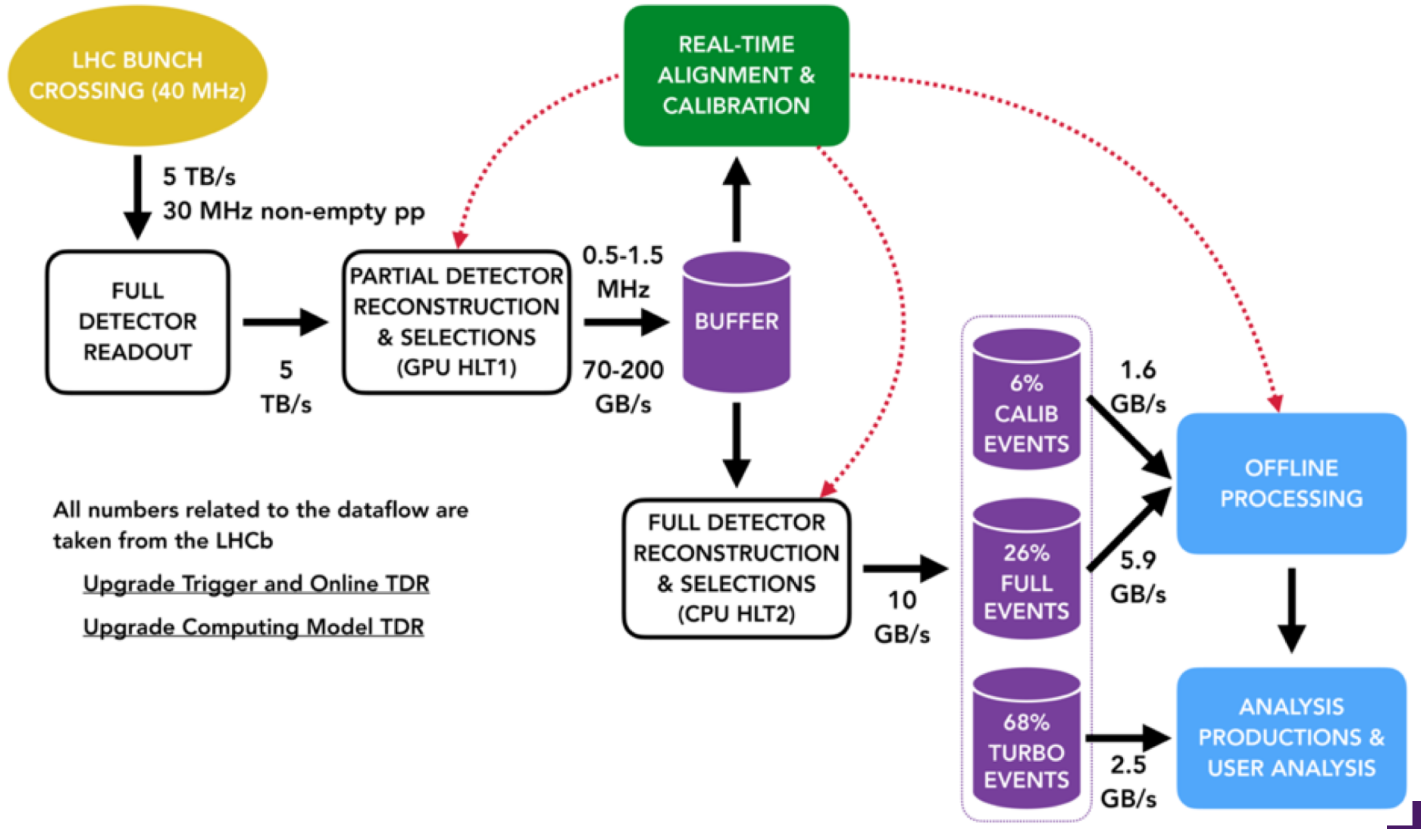
CALO Front-end board Test bench

LHCb Upgrade I: Computing, Online & Trigger

- FPGA DAQ cards
- Graphical Processing Units (GPUs) co-processors in HLT1
- Full reconstruction & Selection in HLT2
- Offline processing & analysis productions
- Monte-Carlo Simulation
- GRID computing

Projects:

Online
Real Time Analysis (RTA)
Data Processing & Analysis (DPA)
Simulation
Computing



LHCb – Upgrade II

Upgrade II
2031-

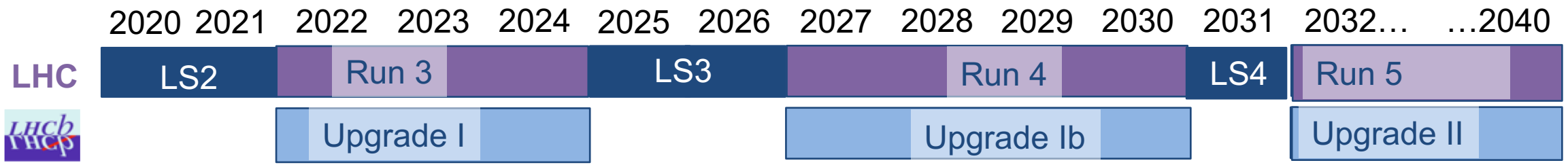
"Power! *Unlimited* power!"

LHCb – the final return

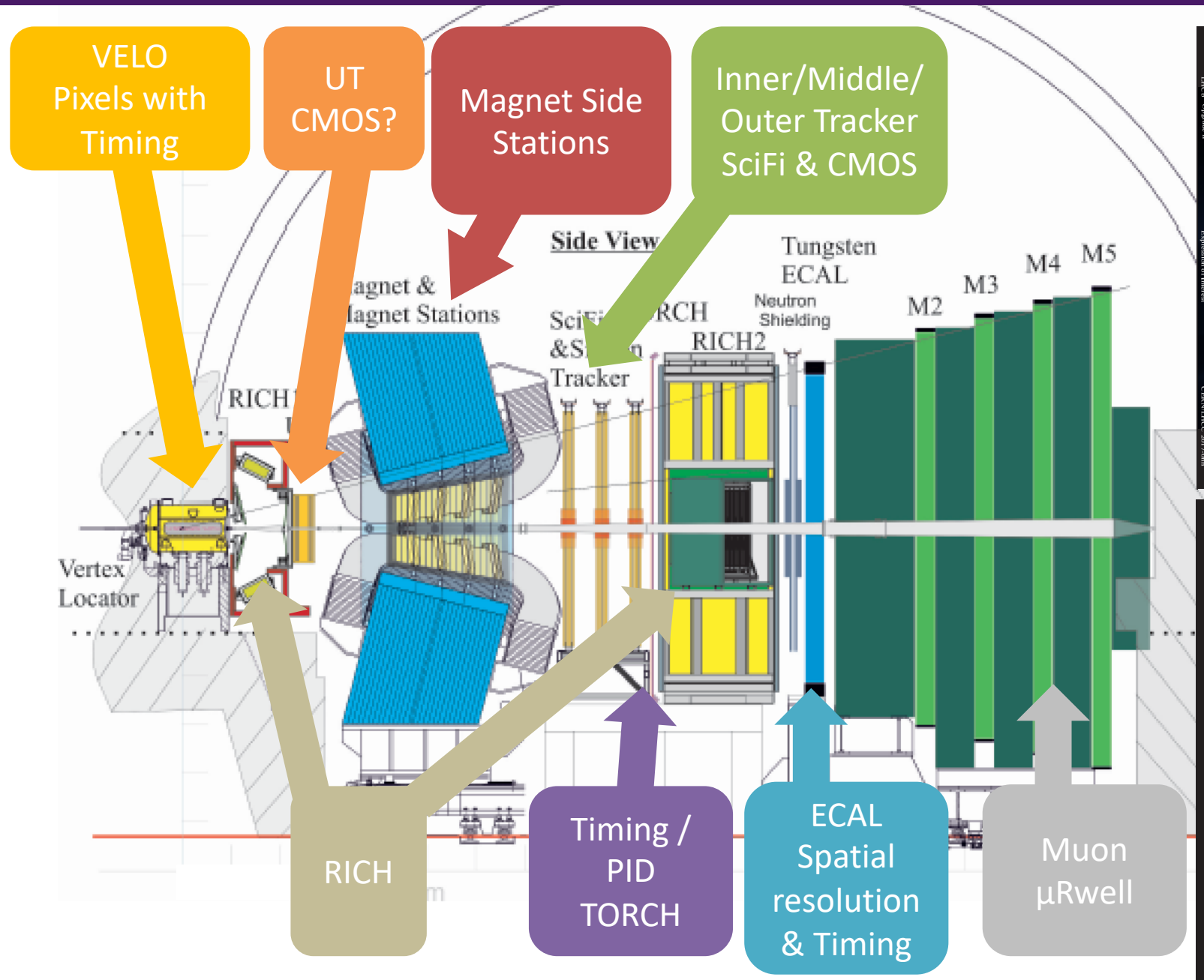
Final Era

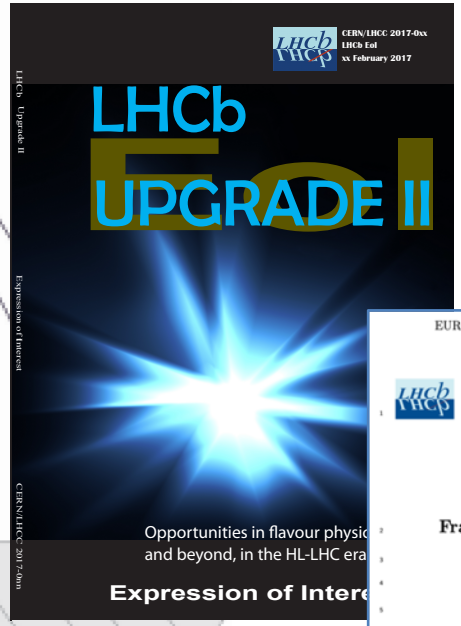
~ factor 40 lumi above LHCb- original

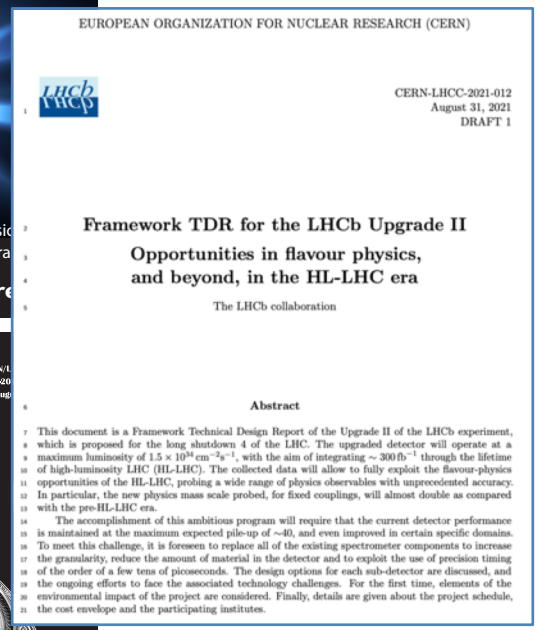
- Exploiting the full Flavour physics potential of the HL-LHC
  - Opportunities for innovative detector development



Upgrade II Detector






EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2021-012
August 31, 2021
DRAFT 1

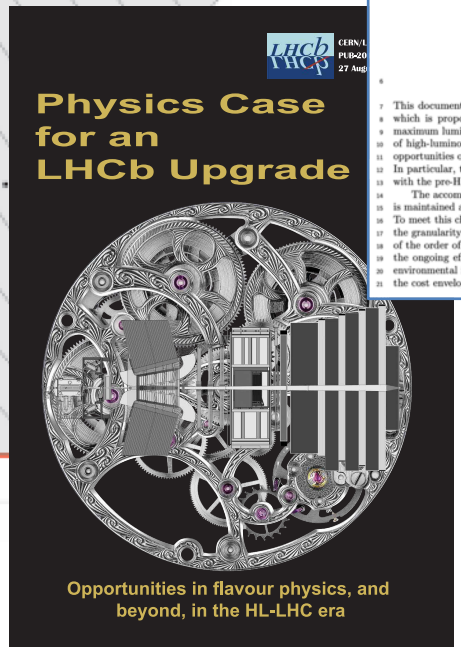
Framework TDR for the LHCb Upgrade II
Opportunities in flavour physics, and beyond, in the HL-LHC era

The LHCb collaboration

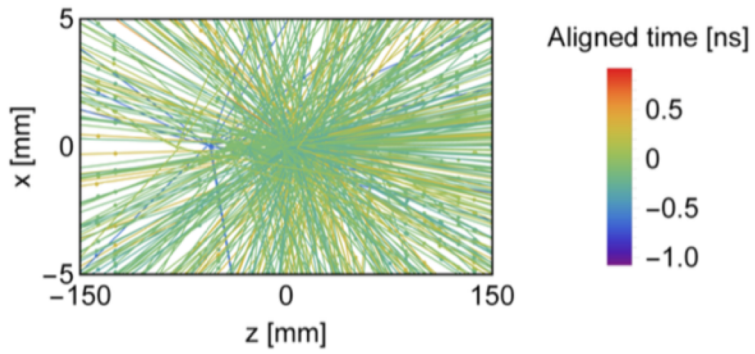
Abstract

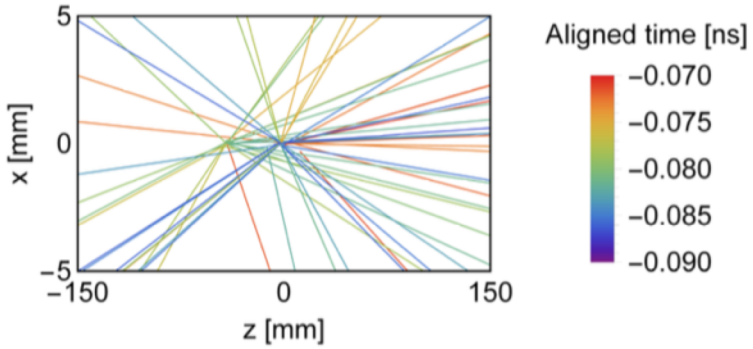
This document is a Framework Technical Design Report of the Upgrade II of the LHCb experiment, which is proposed for the long shutdown 4 of the LHC. The upgraded detector will operate at a maximum luminosity of $1.5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, with the aim of integrating $\sim 300\,\mathrm{fb}^{-1}$ through the lifetime of high-luminosity LHC (HL-LHC). The collected data will allow to fully exploit the flavour-physics opportunities of the HL-LHC, probing a wide range of physics observables with unprecedented accuracy. In particular, the new physics mass scale probed, for fixed couplings, will almost double as compared with the pre-HL-LHC era.

The accomplishment of this ambitious program will require that the current detector performance is maintained at the maximum expected pile-up of ~40, and even improved in certain specific domains. To meet this challenge, it is foreseen to replace all of the existing spectrometer components to increase the granularity, reduce the amount of material in the detector and to exploit the use of precision timing of the order of a few tens of picoseconds. The design options for each sub-detector are discussed, and the ongoing efforts to face the associated technology challenges. For the first time, elements of the environmental impact of the project are considered. Finally, details are given about the project schedule, the cost envelope and the participating institutes.



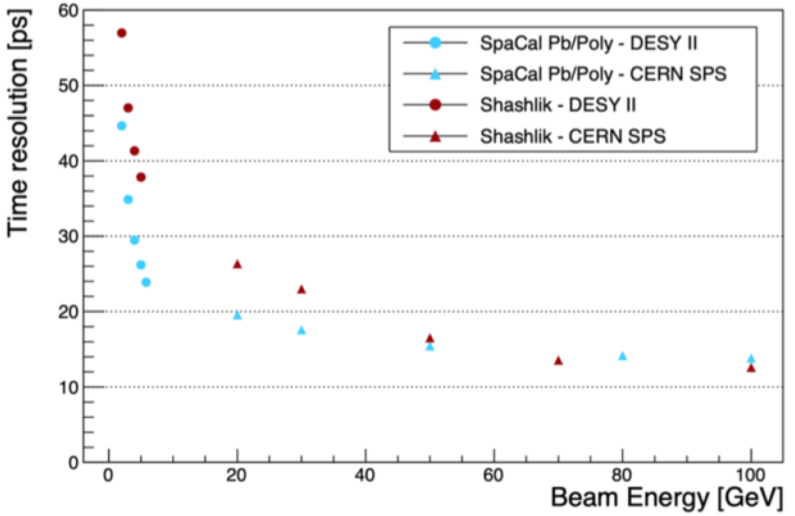
New dimensions - Precision Timing

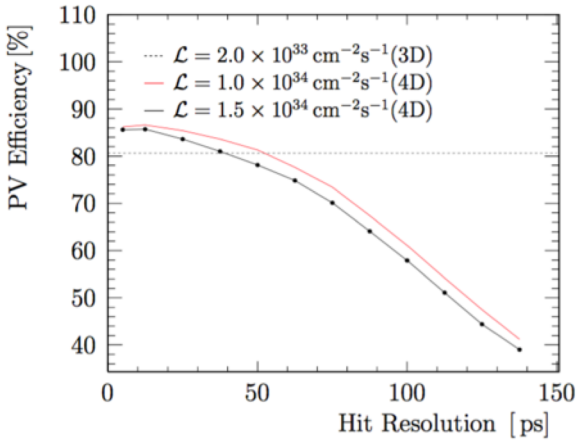




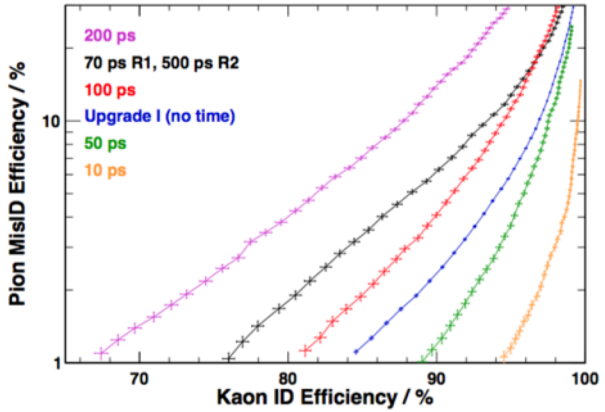
VELO: Radiation hard "4D" hybrid pixel detector with high spatial and timing precision(<50μm, <50ps)

CALO: "5D" Calorimetery – Energy, spatial, and timing performance.

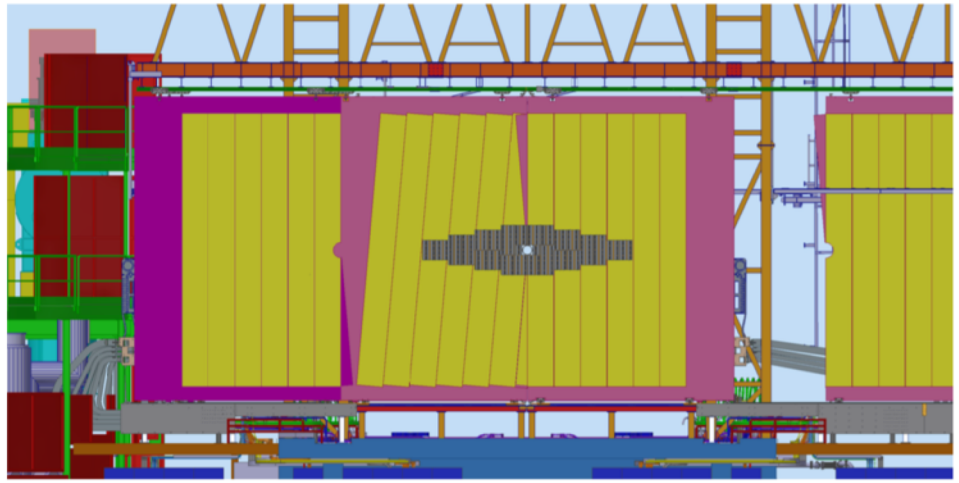




Hadron Particle Identification:
RICH: Timing key to mitigating pile-up in particle identification
TORCH: Innovative Time of flight based system

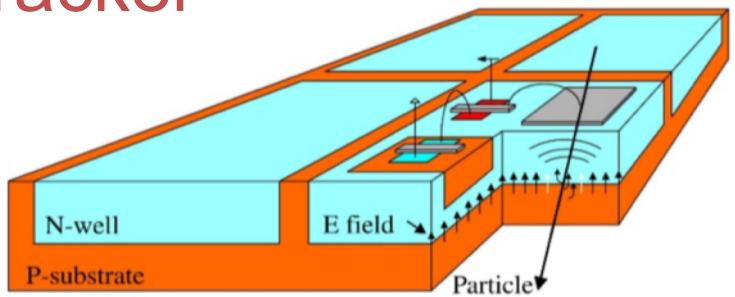


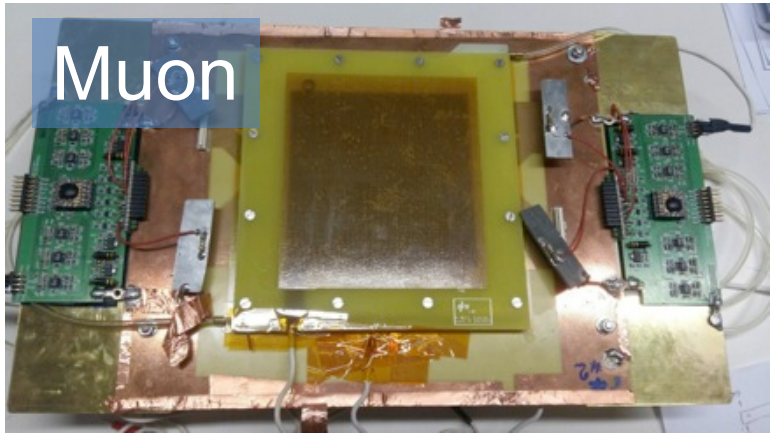
New Technologies - CMOS Tracking, µRWELL, Magnet side stations



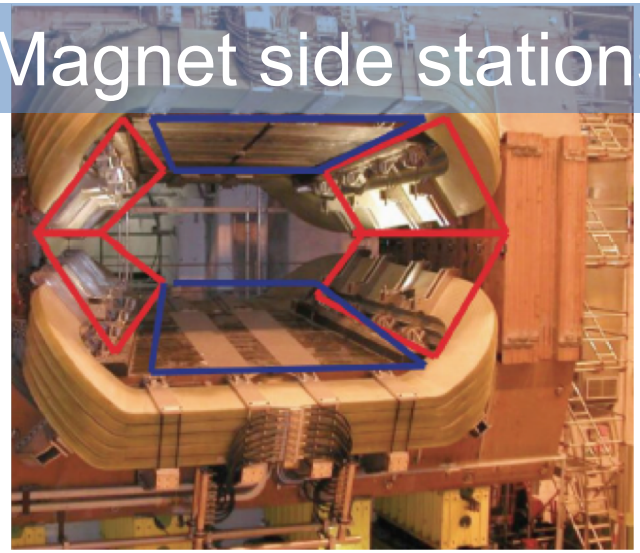
Hybrid Technology Tracker

- Scintillating fibres
- CMOS





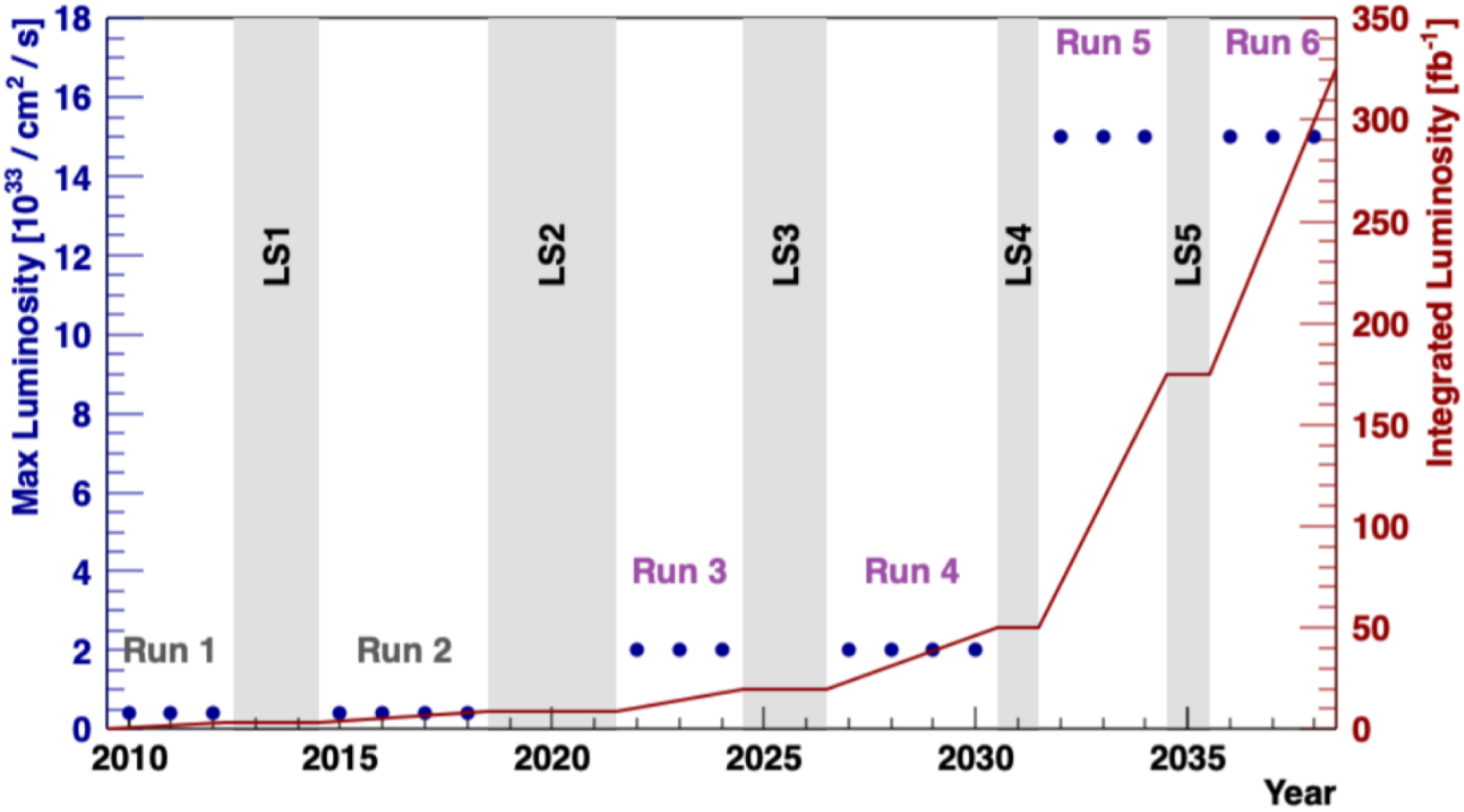
- New µRWELL technology



- Novel geometry

…. and whatever YOU think of….

LHCb – only at start of our voyage



And increased trigger efficiency for hadronic channels, increased flexibility, lower momentum reach….

Many Many Thanks !

Organisers and all those who have volunteered to help, and all participants

Summary: Opportunities at LHCb

LHCb	*Original*
	2009-2018
LHCb	*Upgrade I*
	2022-2030
LHCb	*Upgrade II*
	2032-

- Data Analysis
  - Exciting physics opportunities !
- Operations
  - Once in a decade opportunity !
- Detector Development
  - Drive the physics & technology of the future !

Huge array of opportunities at LHCb:

Physics working groups, Detector & Software Projects, Operations

May all* the forces be with you !

* OK, except gravity, but maybe a bonus one !