全国第十八届重味物理与CP破坏研讨会（HFCPV2021）

LHCb upgrades and prospects

Hang Yin (尹航)

Central China Normal University

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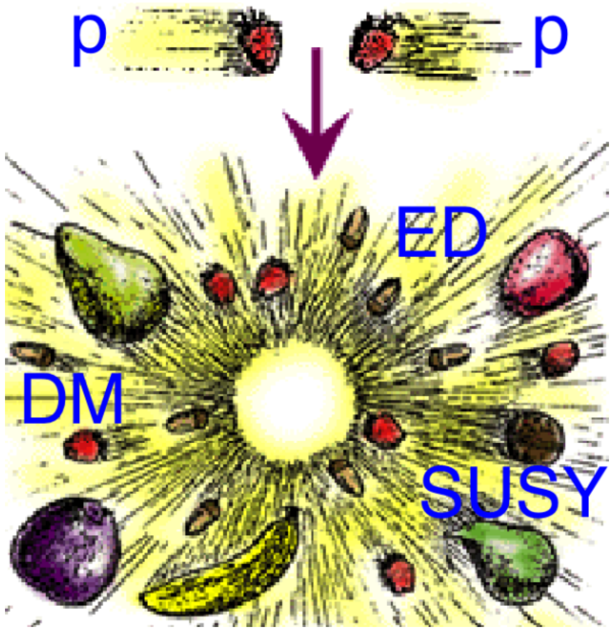
Standard Model

- **Standard Model (SM) works beautifully up to few hundred GeV, but must be an effective theory valid up to some scale**
- SM is unable to answer many key-questions:
  - Dark matter candidates?
  - Source of baryon asymmetry generation?
  - Origin of flavour (what underlies the family replication)?
  - Source of the hierarchy in the W couplings to the different quarks?
  - ……
- Unlike the discoveries of $W/Z/top/Higgs$, which were theory-guided
  - More rely on the experiments inputs

Paths to new Physics at LHC

➢ **Direct search**

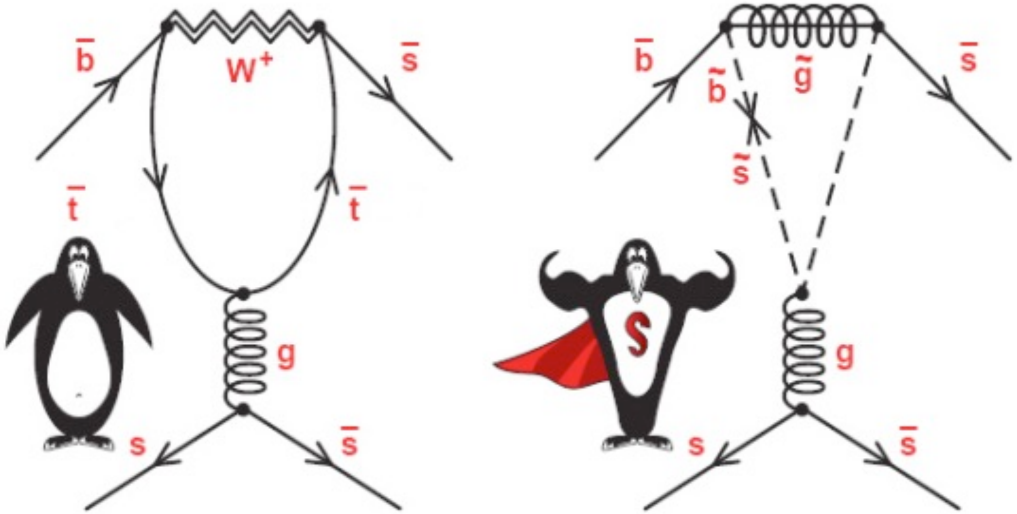
The "relativistic" way



Masses and production cross section limited by collision energy

• **Indirect search (Flavour physics)**

The "quantum" way

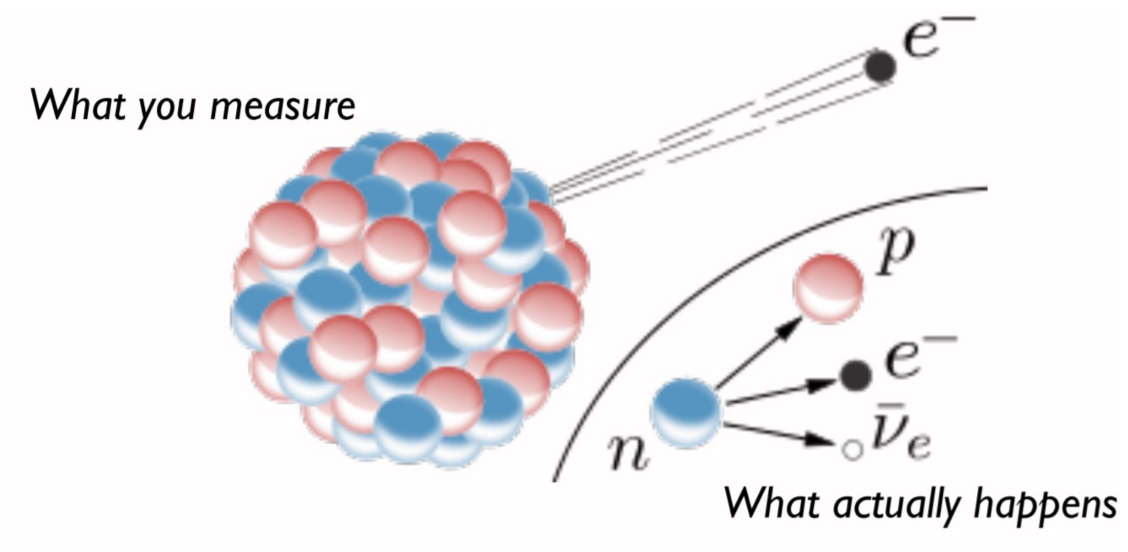


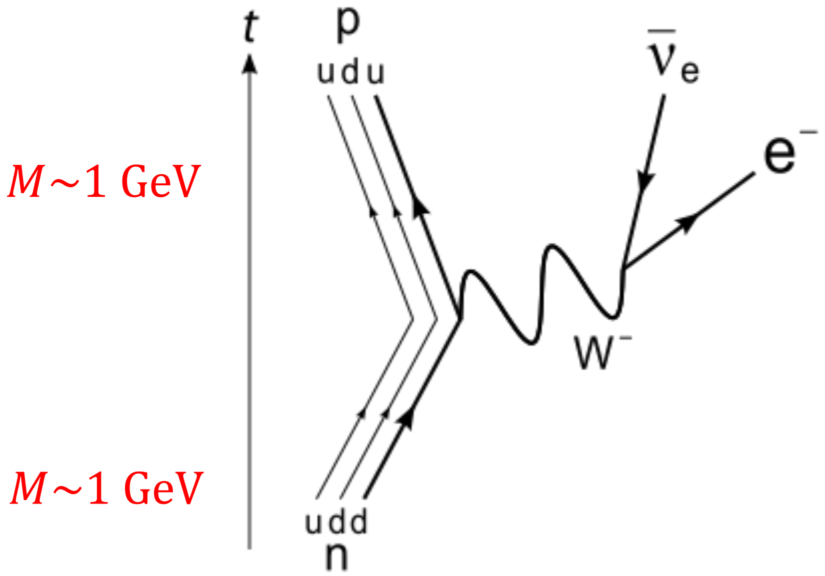
Sensitive to much higher mass scales O(10 - 100TeV)

CP violation measurements!

An example of indirect search

- β decay of the neutron:
  Phenomena taking place at ~ 1 GeV reveals physics at the 100 GeV scale





Flavour physics is a key-tool

- CP violation and FCNC: sensitive probes of short distance physics
  - Probed scales: $\gg 1$ TeV, depending on C_{NP}
  - Many tests limited by statistics not by systematics nor theory

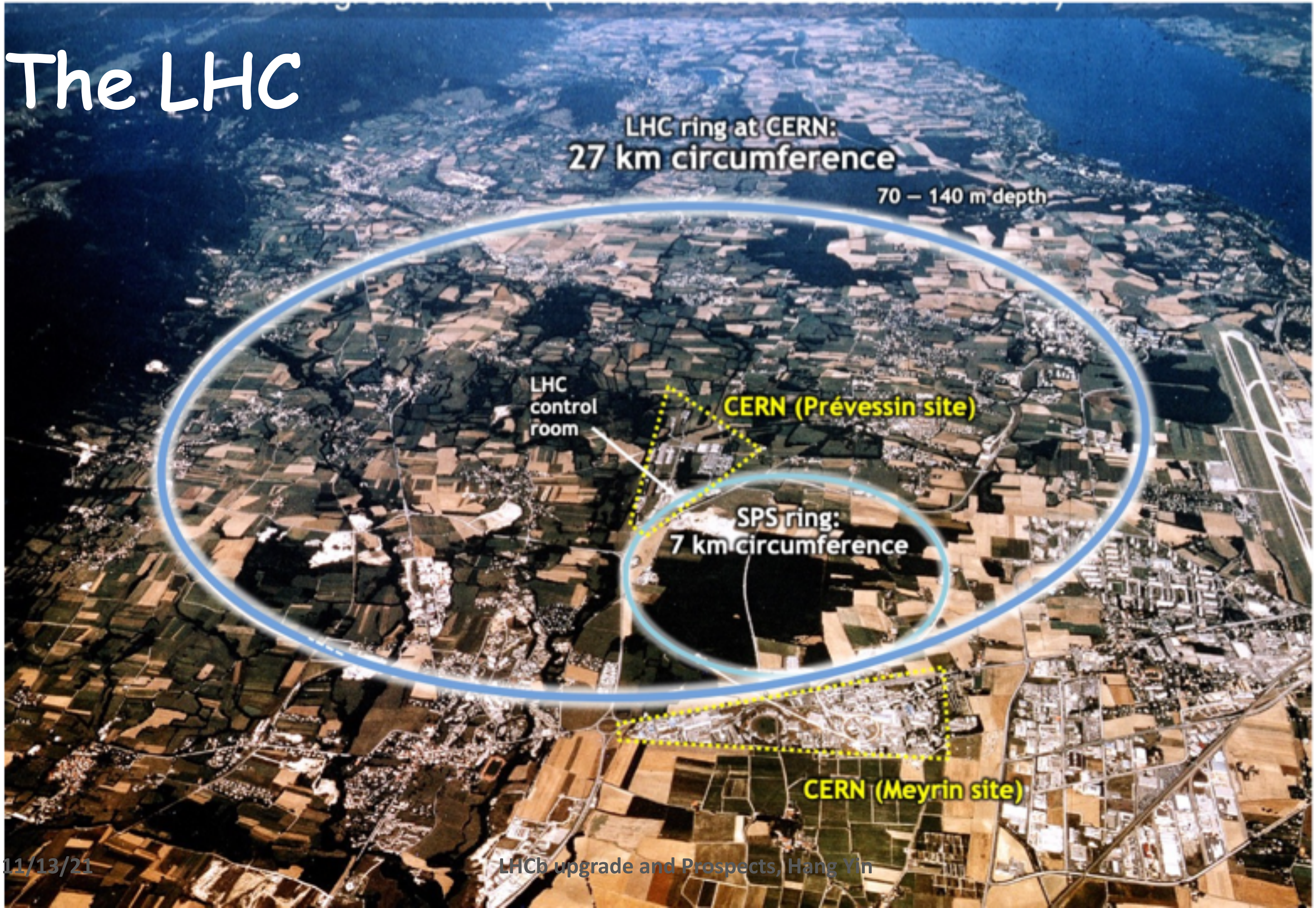
$A(\psi_i \rightarrow \psi_j + X) = A_0 \left(\frac{c_{SM}}{v^2} + \frac{c_{NP}}{\Lambda_{NP}^2}\right)$, where Λ_{NP}^2 (C_{NP}) is NP scale (coupling)

- 1964: CP violation in the decay of Kaon meson
  - Observation of $K_L \rightarrow \pi\pi$

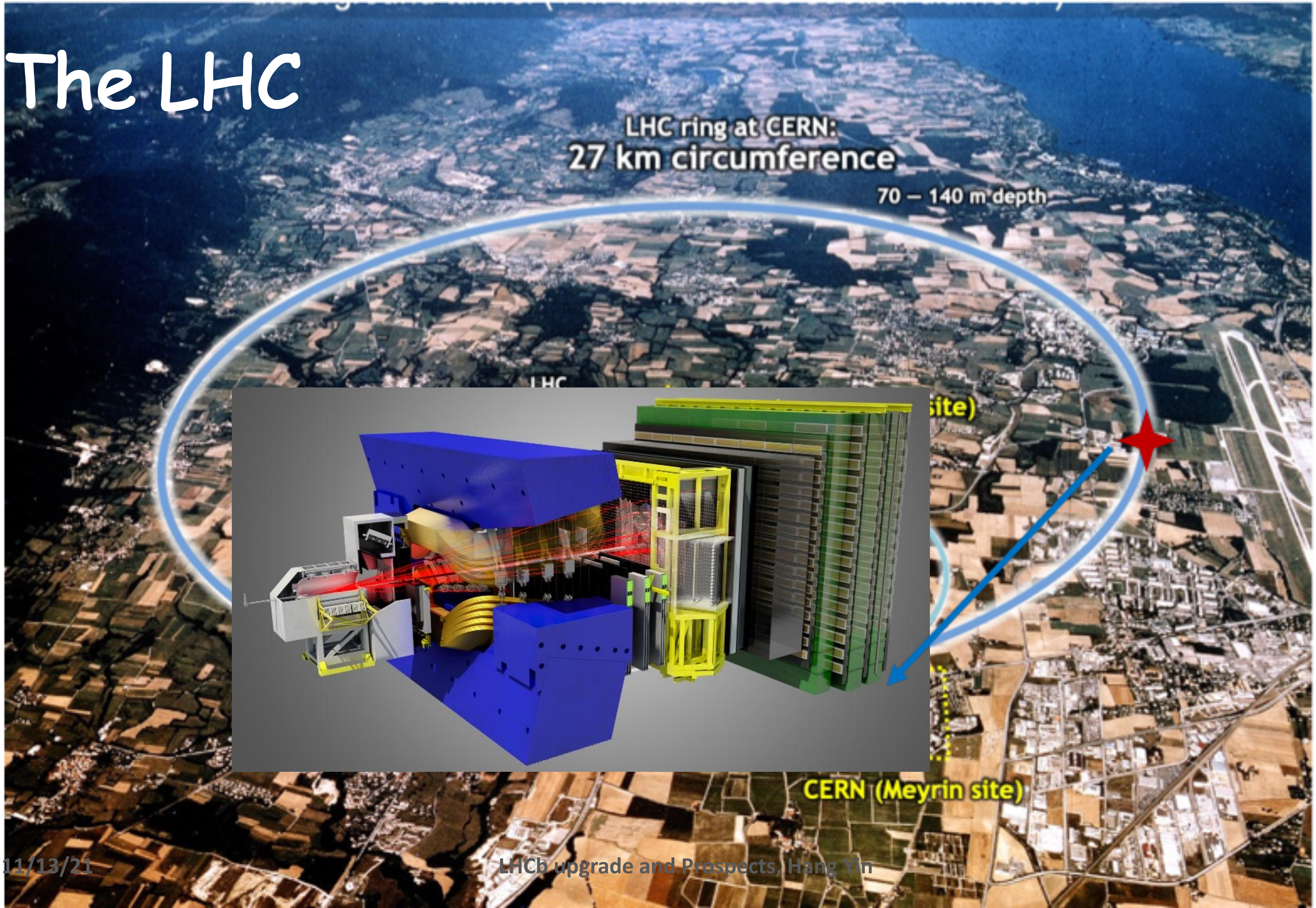
  $\Longrightarrow$ Three generations
- 1987: B_d mixing from ARGUS ($\sqrt{s} = 10$ GeV)
  - $\Delta\mathrm{m_d} \sim 0.00002 \times \left(\frac{m_t}{\mathrm{GeV}/c^2}\right)^2\ ps^{-1} \sim 0.5\ ps^{-1}$

  $\Longrightarrow m_t > 50$ GeV

The LHC

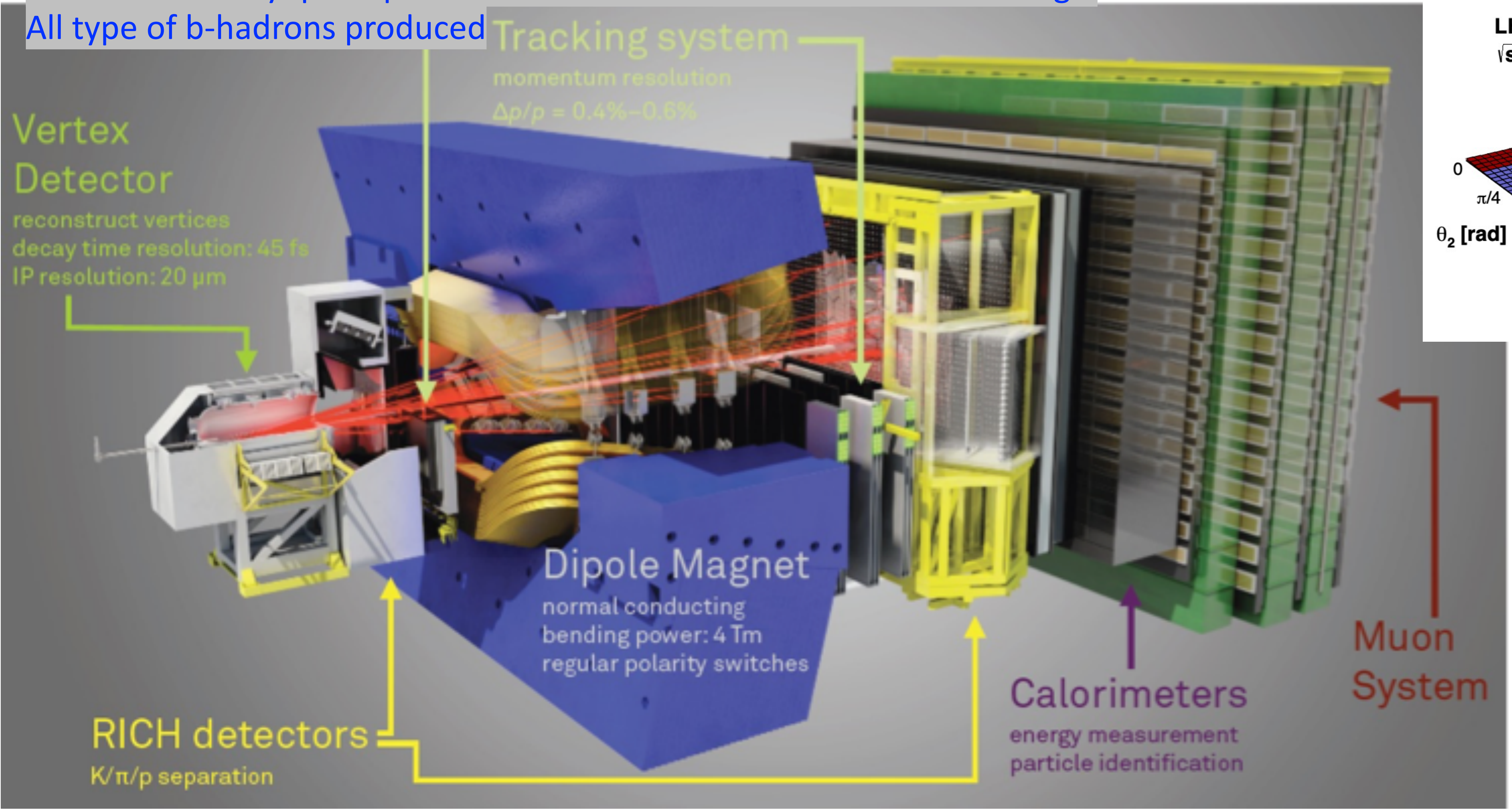

LHC ring at CERN:
27 km circumference
70 – 140 m depth
LHC
control
room
CERN (Prévessin site)
SPS ring:
7 km circumference
CERN (Meyrin site)

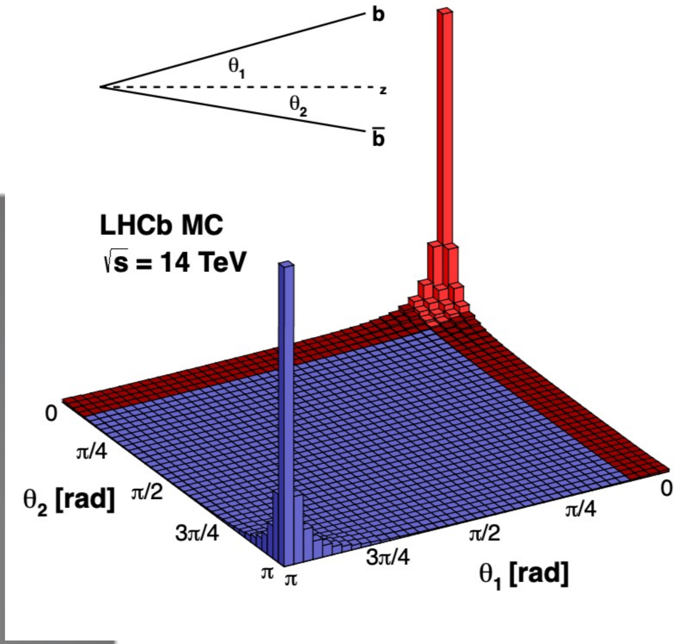
The LHC

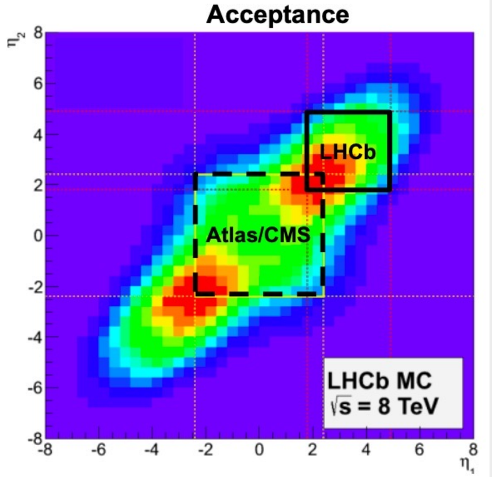

LHC ring at CERN:
27 km circumference
70 – 140 m depth
CERN (Meyrin site)

The LHCb detector

40% of the heavy quark production cross section in 4% of the solid angle
All type of b-hadrons produced







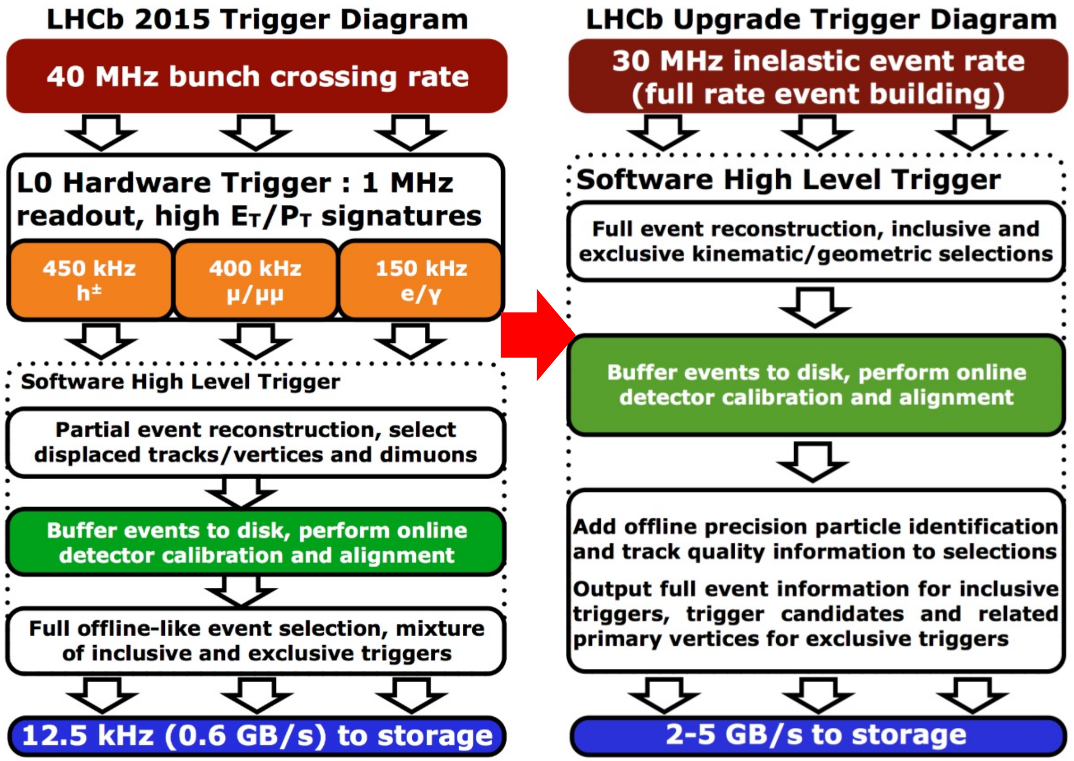
The LHCb detector

In 2021: 1000 authors from 86 universities or laboratories

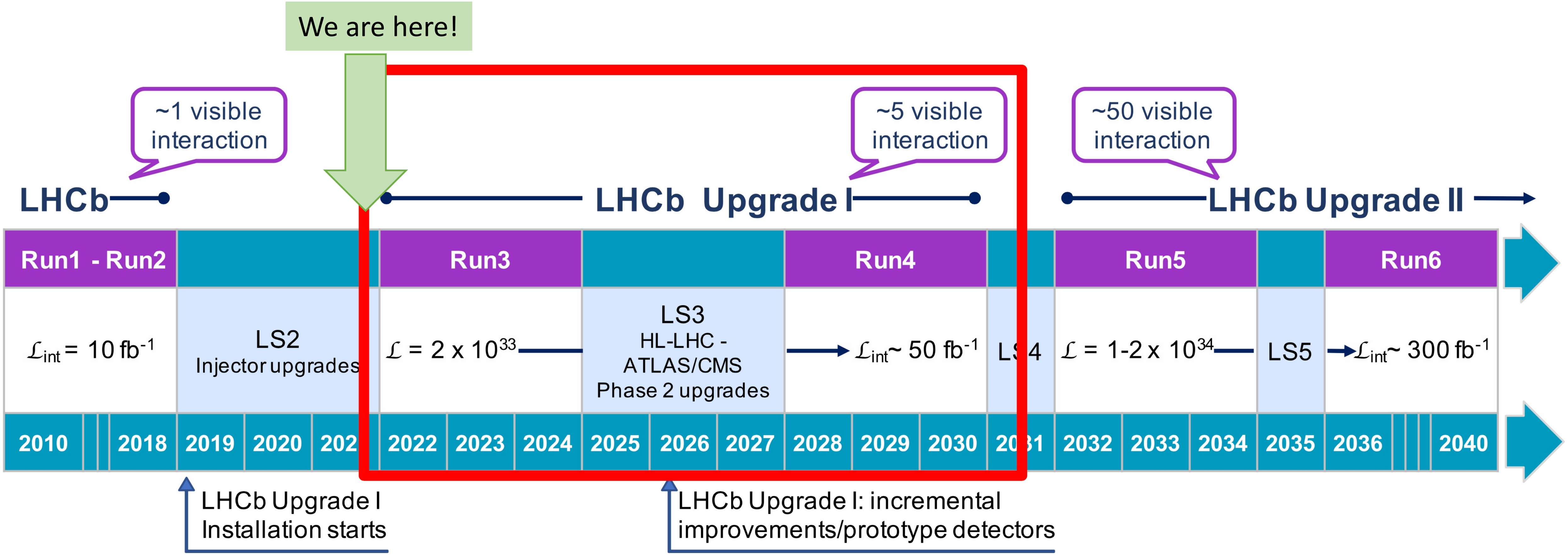
- Indirect search for New physics: via precision measurements of CKM, CPV and RD
- QCD+EW precision measurements at large rapidity
- Hadron spectroscopy
- Direct search of new partilces beyond SM
- Heavy-ion physics

Motivations for upgrading LHCb

- Go beyond Flavor physics: from exploration studies to precision studies
  - No significant signs of New Physics in Run1 and Run2
  - But anomalies observed: $R(D^*), R(K), R(K^*)$, angular analysis of $K^*\mu^+\mu^-$ and more
- For more precision
  - $Br(B_s \to \mu^+\mu^-)$ down to ~10% of SM
  - CKM γ angle to ~1^0
  - $2\beta_s$ to precision < 20% of SM value
  - charm CPV search below 10^{-4}
- Only one way forward
  - remove limitations from hardware trigger



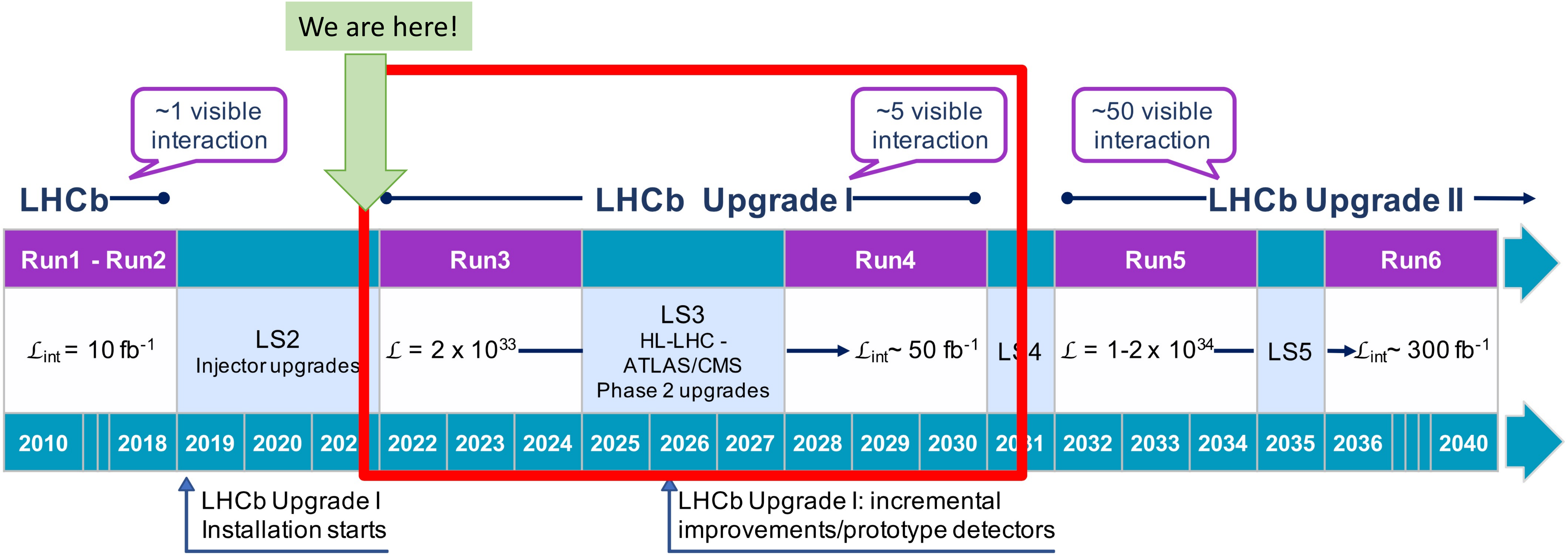
LHCb schedule



LHCb Phase-I upgrade ongoing now during LS2 for Run-3 and Run-4

- Full software trigger and readout all detectors at 40 MHz
- Replace tracking detectors+PID+VELO
- $L{\sim}2{\times}10^{33}\ \mathrm{sec}^{-1}\ cm^{-2}$: ×5 wrt Run2, 5.5 visible interations/crossing
- Consolidate PID, tracking and ECAL during LS3

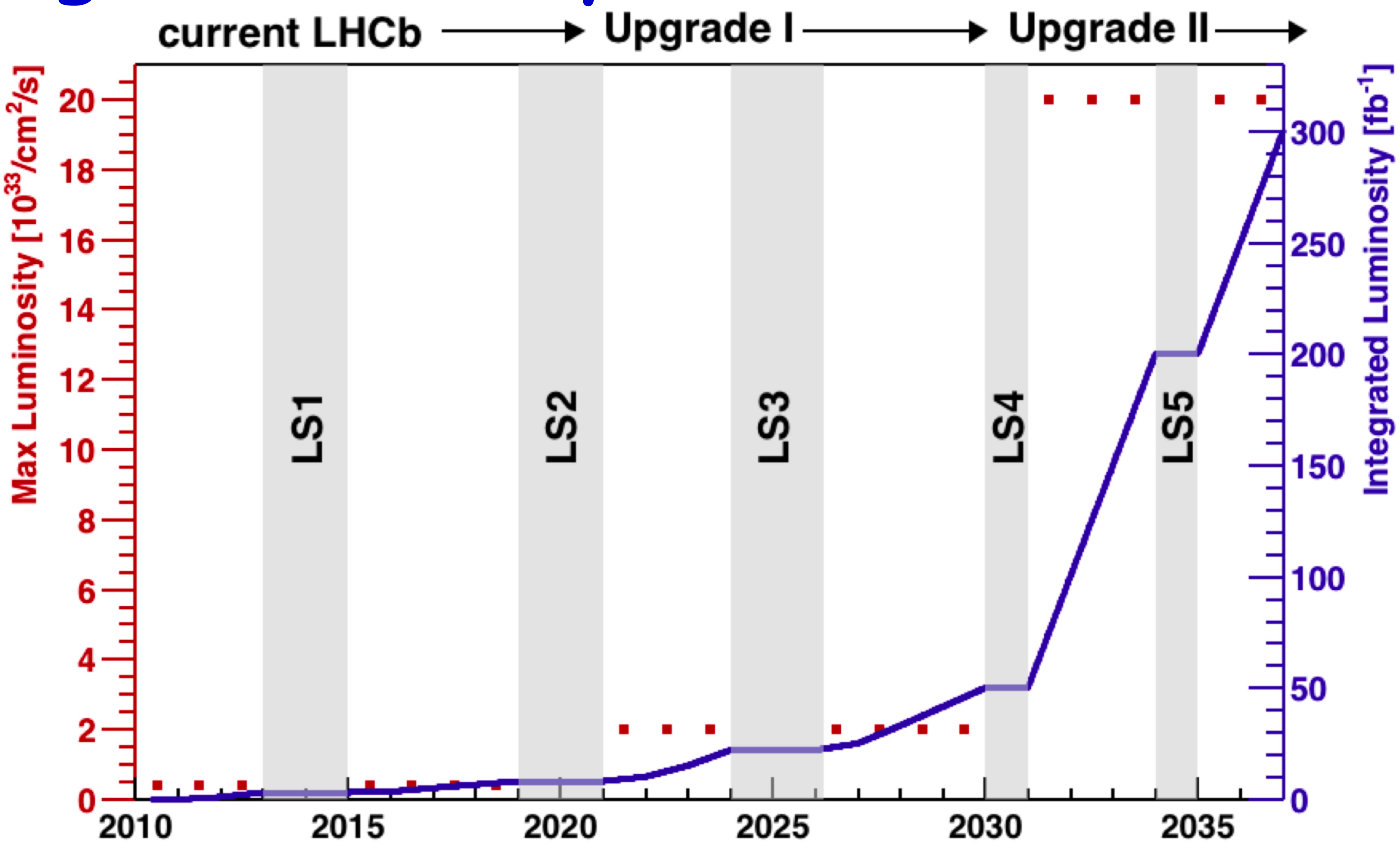
LHCb schedule



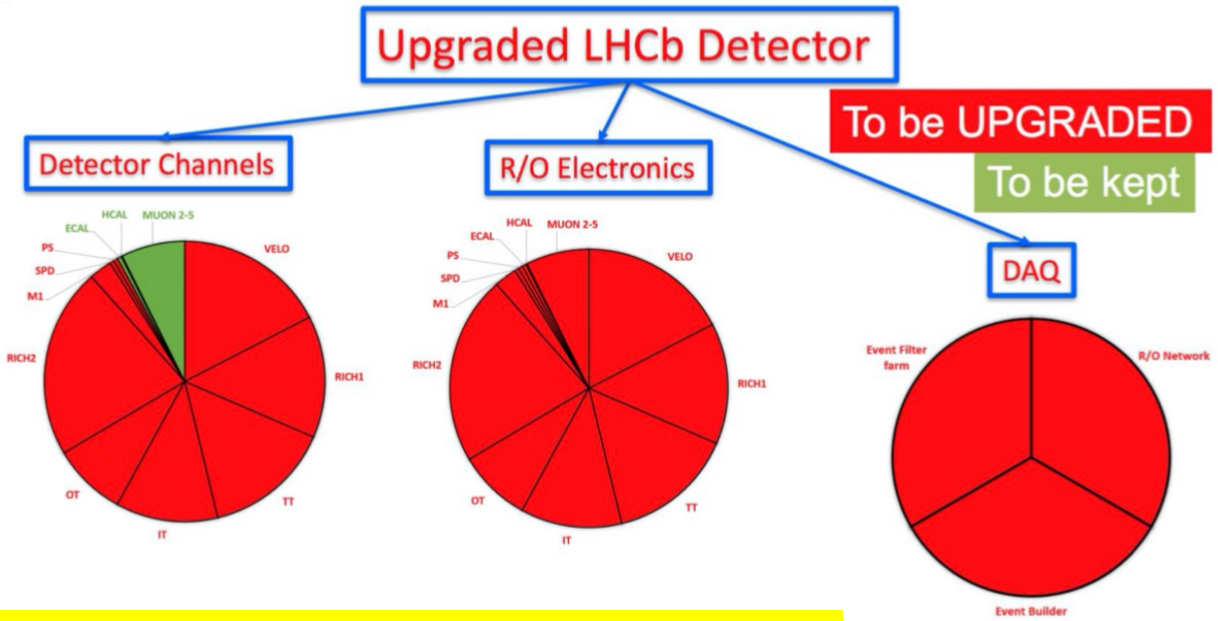
LHCb Phase-II upgrade during LS4 beyond Run-4

- Use new detector technologies + timing
- $L{\sim}1{\times}10^{34}\ \sec^{-1}\ cm^{-2}$

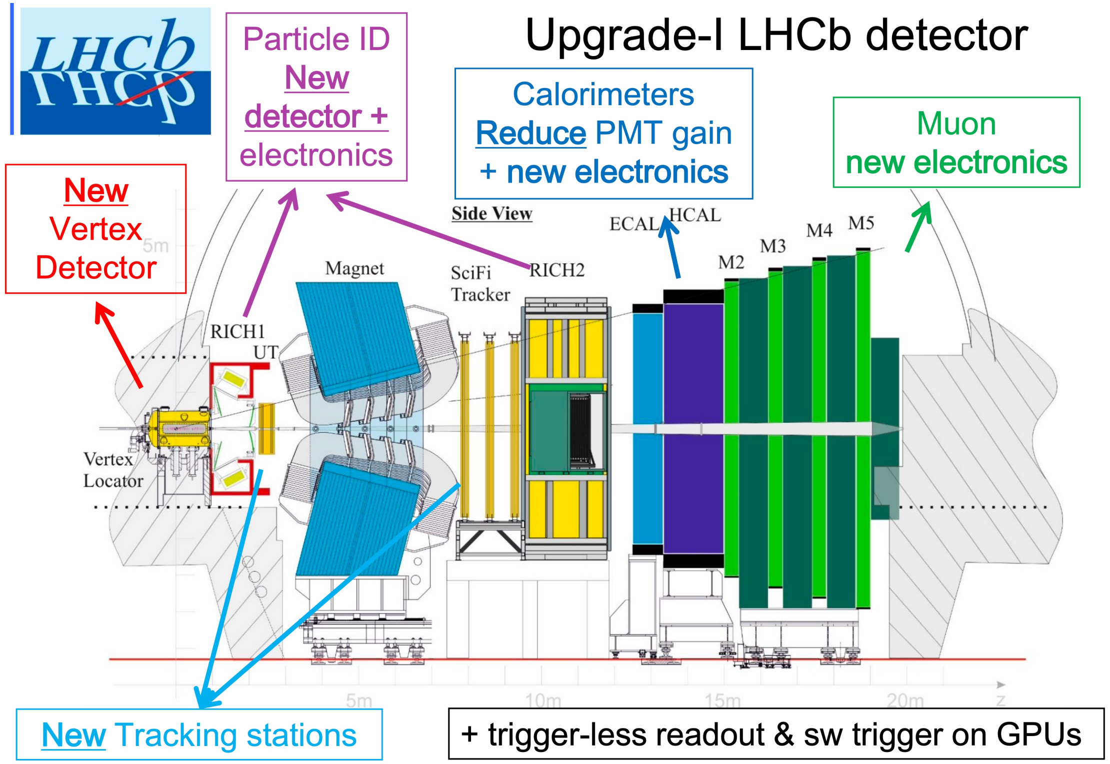
Target luminosity



LHCb Phase-I Upgrade



Comput. Phys. Commun. 208 (2016) 35-42



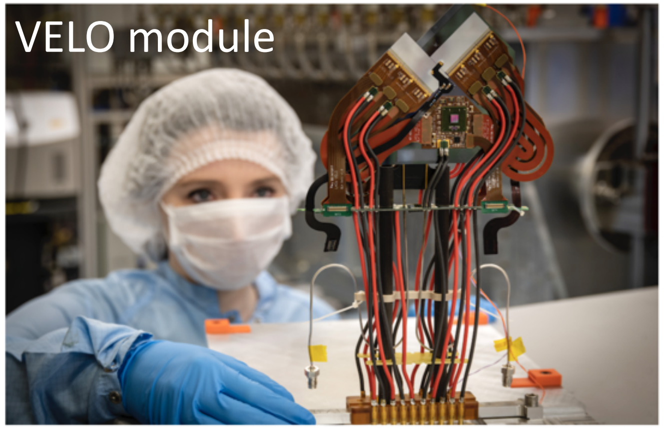
~2% of the events will contain a reconstructible b-hadron

Particle type	Run I (kHz)	Upgrade (kHz)
b-hadrons	17.3	270
c-hadrons	66.9	800
Light long-lived hadrons	22.8	264

Includes expected trigger and reconstruction efficiencies

LHCb Phase-I Upgrade: status

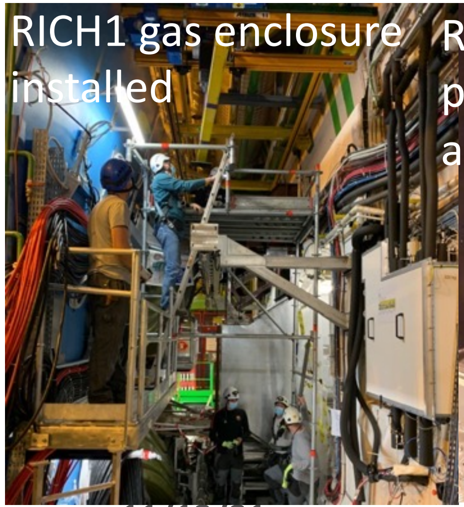
Travel restrictions

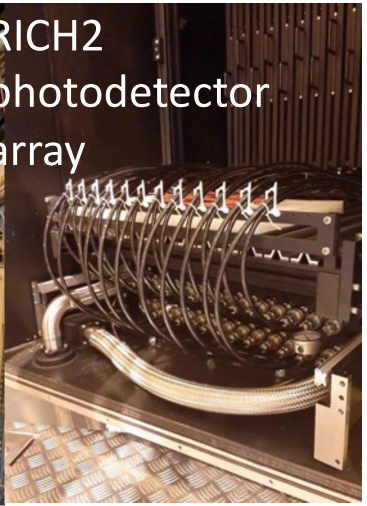


VELO
Modules: first half completed
Half Assmenbly: expected to start soon

UT
Modules: main type production nearly compelte
Mounting

SciFi
Four (of 12) assembled frames & cable chains installed



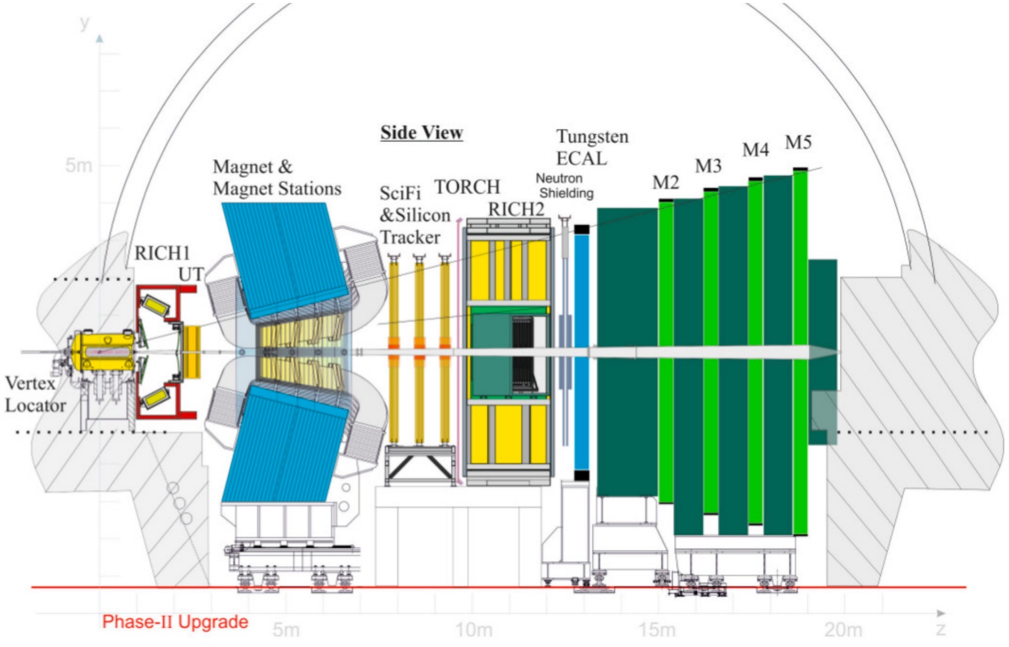


RICH: commisioning
RICH1 enclosure installed and leak tested

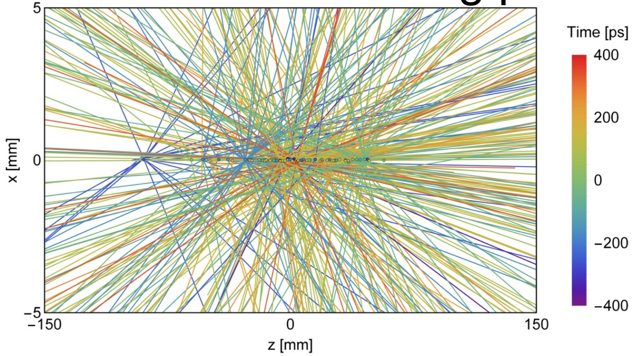
RICH2 Photodetector arrays installed

CALO&Muons: commisioning
Front-end board installation

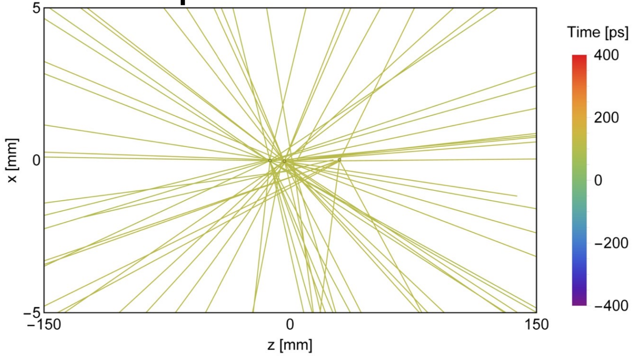
LHCb Phase-II Upgrade



25 ns bunch crossing period

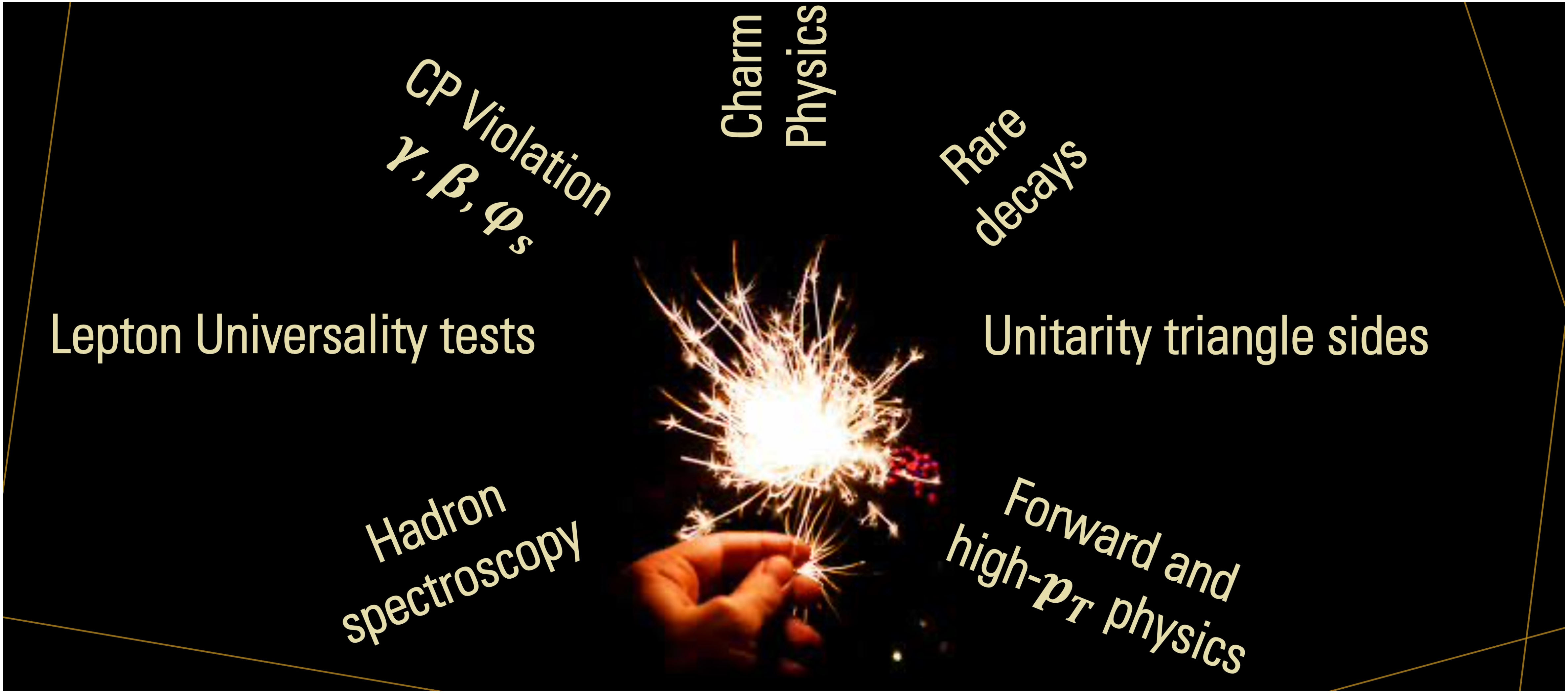


20 ps time window



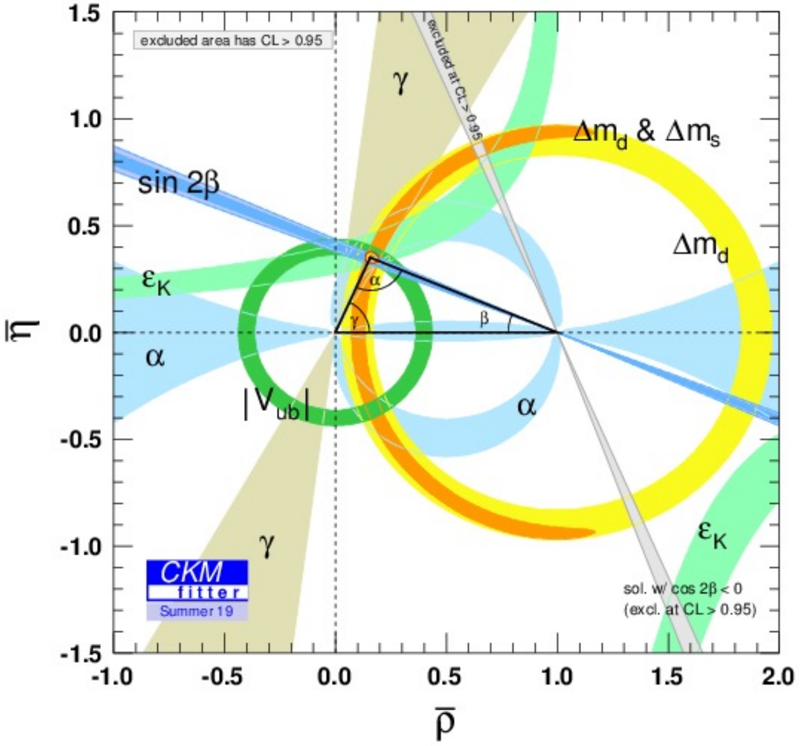
- The Phase-II upgrade involve changes to nearly all parts of experiment
  - Vertexing: pixel detector with timing
  - Hadron PID: RICH with timing and imporved resolution+TORCH for low-p
  - Tracking: Magnet side stations + (pixel) inner tracker
  - Calorimeter: timing + improved resolution
  - Muon system: alternative technologies for high rate regions
- Timing information will be crucial:
  - → 4D precision detector

Rich physics programme after Upgrades

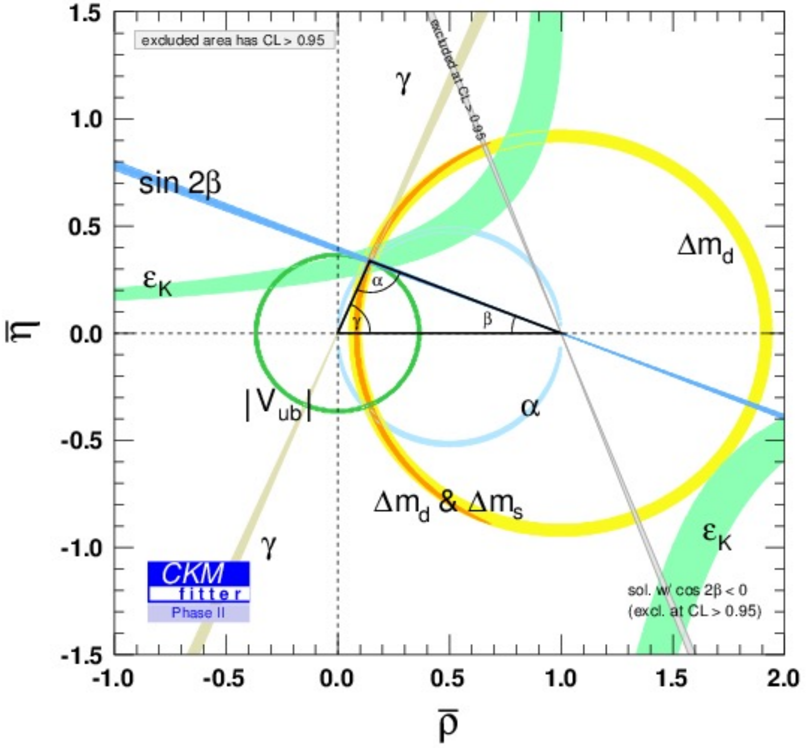


CKM measurements

2019



LHCb Phase II

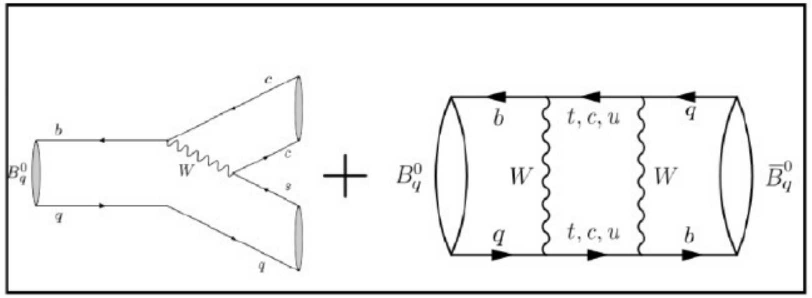


LHCb (300 fb^{-1}), Belle-II (50 ab^{-1})
ATLAS & CMS (3000 fb^{-1})

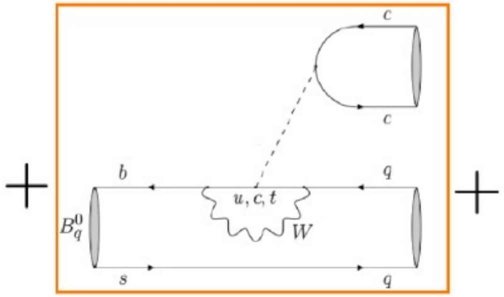
$\boldsymbol{\sigma_\gamma \approx 5^\circ\ (2019) \rightarrow 1^\circ\ (\text{Phase 1}) \rightarrow 0.35^\circ\ (\text{Phase 2})}$

B_s^0 mixing phase, Φ_s

- CP-violation phase arising from interference between mixing and decay, precisely predicted
- Golden channel exploited by LHCb, ATLAS, CMS: $B_s^0 \to J/\psi\, \phi$
  - Statistically limited
  - HFLAV combination: $\phi_s = -0.041 \pm 0.025\, rad$

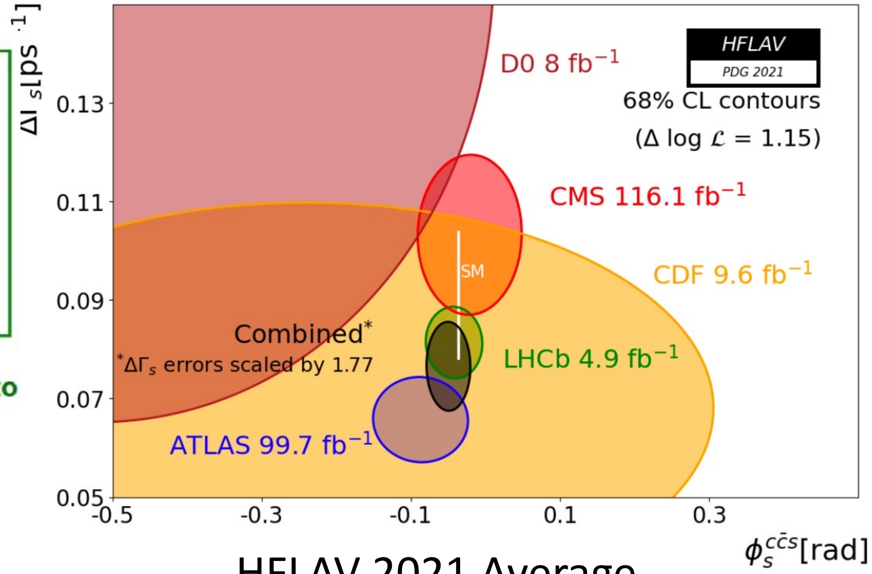


Dominant SM “tree” contribution



Higher order “penguin” contributions from non-perturbative hadronic effects

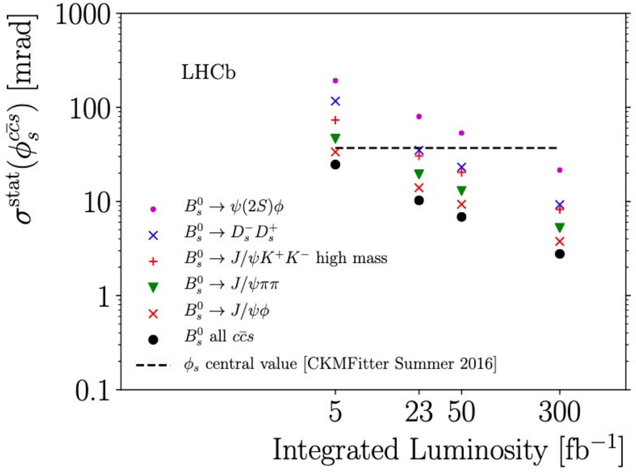
NP could be difficult to distinguish from penguins...



HFLAV 2021 Average

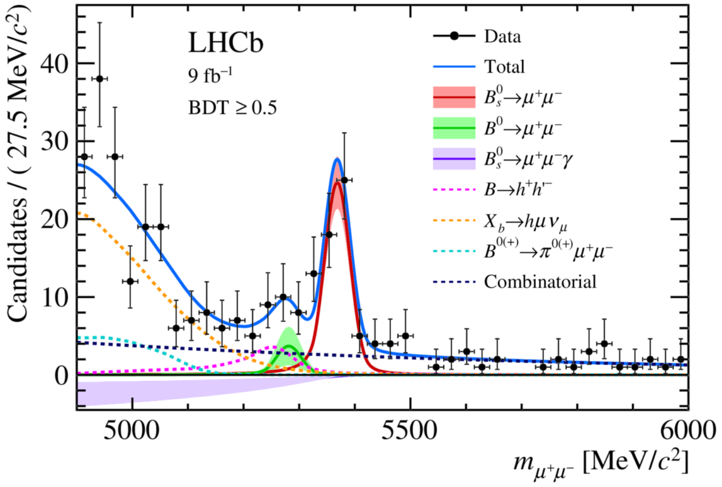
B_s^0 mixing phase, Φ_s

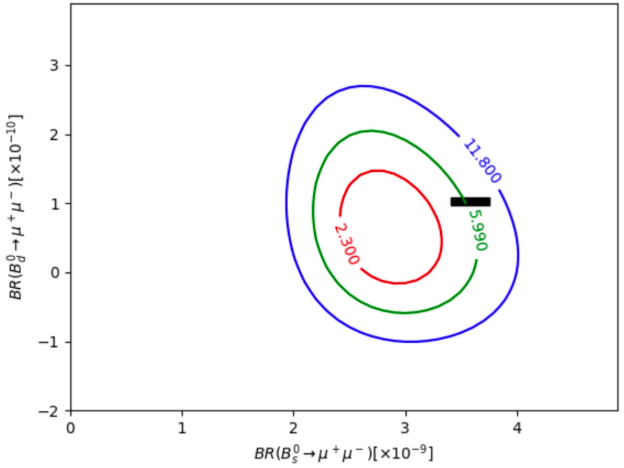
- CP-violation phase arising from interference between mixing and decay, precisely predicted
- Golden channel exploited by LHCb, ATLAS, CMS: $B_s^0 \to J/\psi\,\phi$
  - Statistically limited also @ 300 fb^{-1}. LHCb precision < 3 mrad
  - Same performance as in Run 2 (tagging power etc.)
  - Expect precision of the penguin pollution will scale similarly



$B_{(s)}^0 \to \mu^+\mu^-$

- Golden modes in NP searches: precisely predicted in the SM
- With 2011-2018 LHCb data (9 fb^{-1}): The SM point is near the 2σ band
  - $Br(B_s^0 \to \mu^+\mu^-) = 3.09^{+0.46+0.15}_{-0.43-0.11} \times 10^{-9}$
  - $Br(B^0 \to \mu^+\mu^-) = 1.2^{+0.8}_{-0.7} \pm 0.1 \times 10^{-9}$
- With 300 fb^{-1} data-set:
  - $Br(B^0 \to \mu^+\mu^-)$: statistical precision will be 10%
  - Yields will allow effective lifetime (2%) and TD CP asymmetries (10-20%)



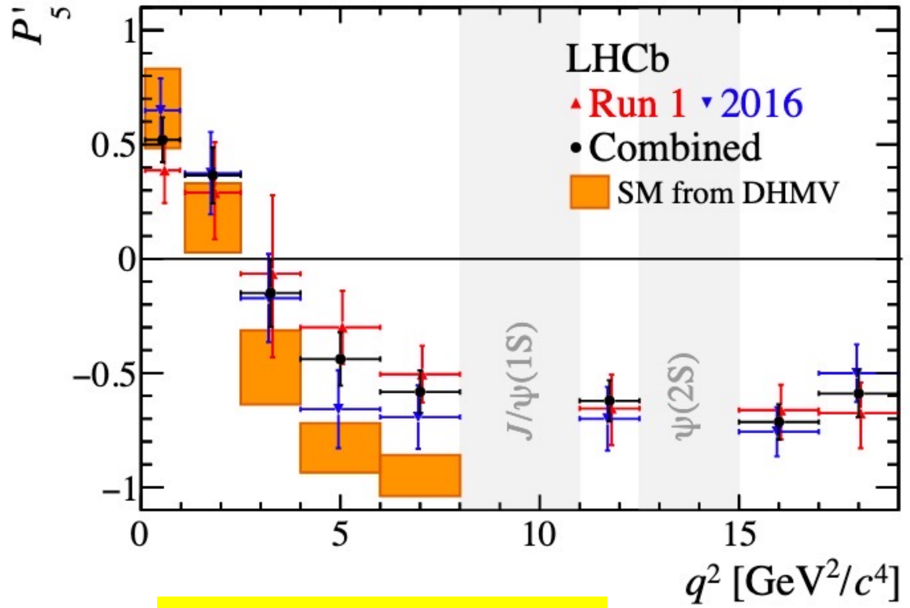


LHCb-Paper-2021-007

arXiv:2104.10058

$B^0 \to K^{*0}\mu\mu$

- ➢ $B^0 \to K^{*0}(\to K^+\pi^-)\mu\mu$ exhibits rich angular structure
- ➢ Measure optimised angular observables with reduced hadronic uncertainty, like P_5'
- ➢ Most precise measurement from LHCb is above the SM prediction

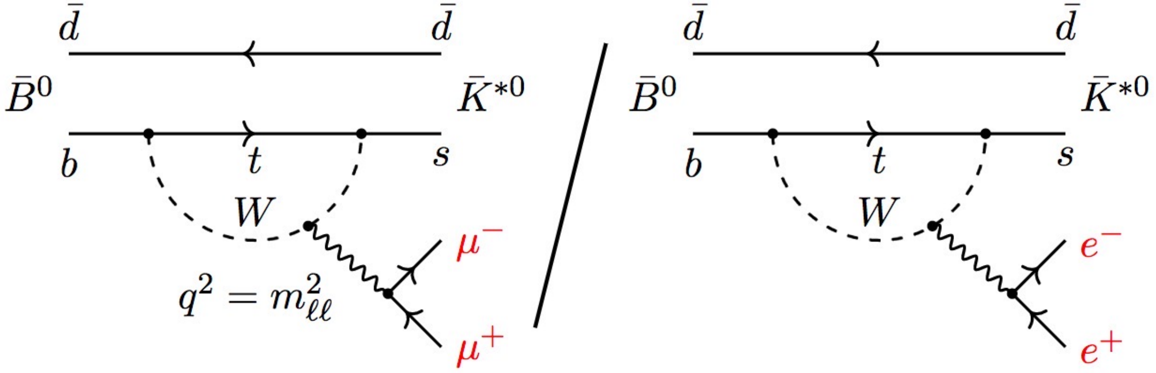


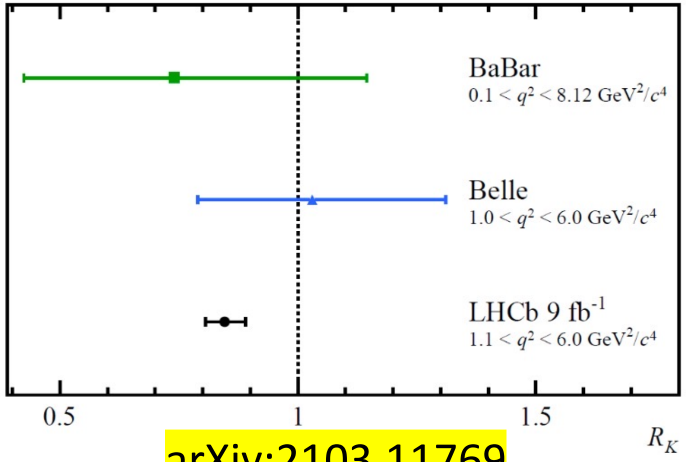
PRL 125 (2020) 011802

- Expect ~440 000 $B^0 \to K^{*0}\mu\mu$ candidates in Upgrade II
- Allows for determination of angular observables with unprecedented precision
- Different NP scenarios can be cleanly separated

Lepton universality: $R(K^{(*)})$

- LHCb results are consistently lower than 1
- Results from B-factories are compatible (with less precision)

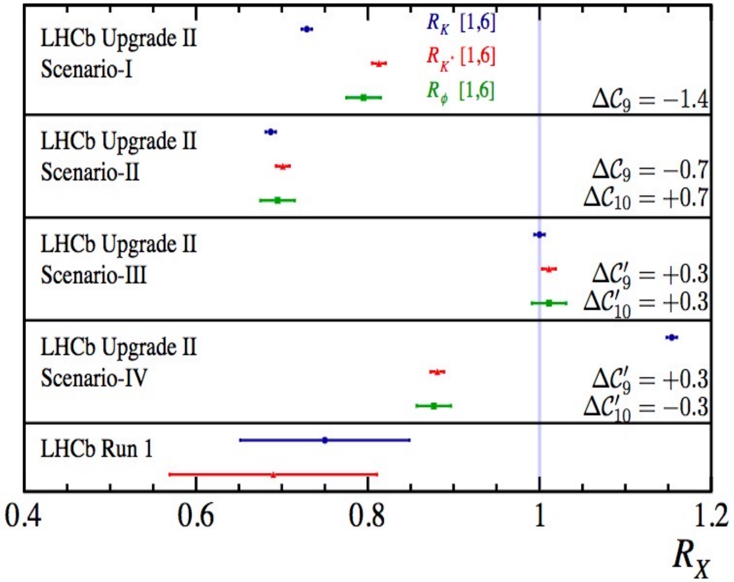




arXiv:2103.11769

Nominal NP components

Right-handed components



Expected yields

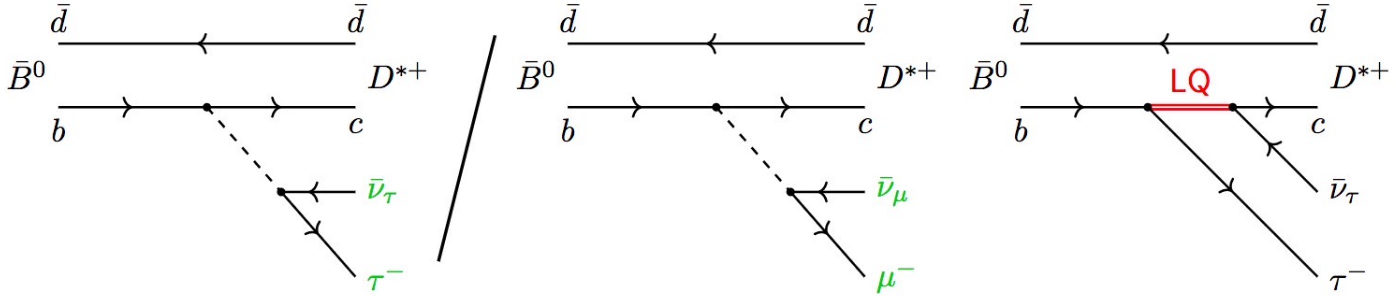
Yield	Run 1 result	8 fb^{-1}	23 fb^{-1}	300 fb^{-1}
$B^+ \to K^+e^+e^-$	254 ± 29	970	3300	46000
$B^0 \to K^{*0}e^+e^-$	111 ± 14	430	1400	20000
$B_s^0 \to \phi e^+e^-$	–	80	260	3700
$\Lambda_b^0 \to pKe^+e^-$	–	210	700	9800
$B^+ \to \pi^+e^+e^-$	–	20	75	1000
R_X precision	Run 1 result	8 fb^{-1}	23 fb^{-1}	300 fb^{-1}
R_K	$0.745 \pm 0.090 \pm 0.036$	0.046	0.025	0.007
$R_{K^{*0}}$	$0.69 \pm 0.11 \pm 0.05$	0.070	0.038	0.010
R_ϕ	–	0.163	0.089	0.024
R_{pK}	–	0.100	0.054	0.014
R_π	–	0.304	0.165	0.044

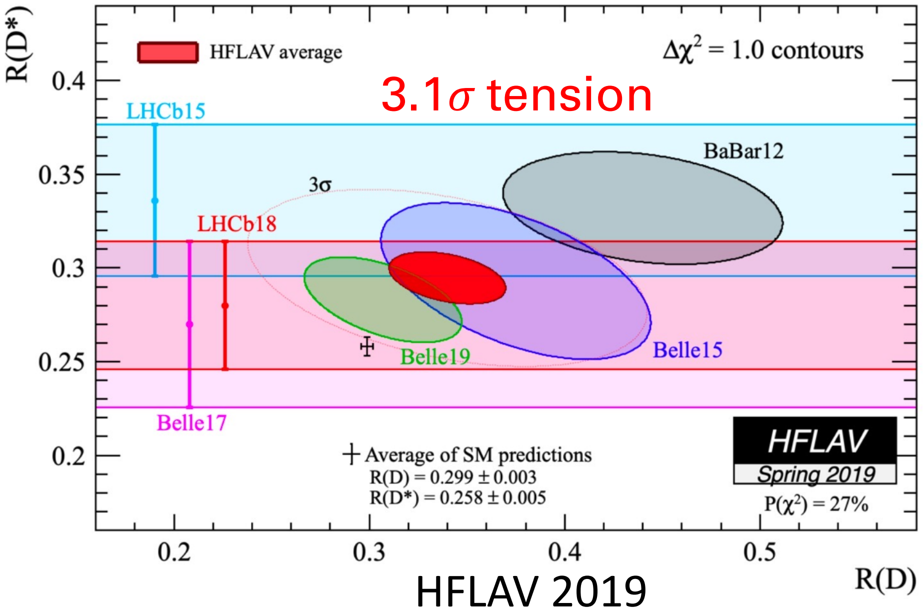
Expected Rx uncertainties

Upgrade 2: All 4 NP scenarios could be distinguished at >5σ !!

Lepton Flavour universality at tree level

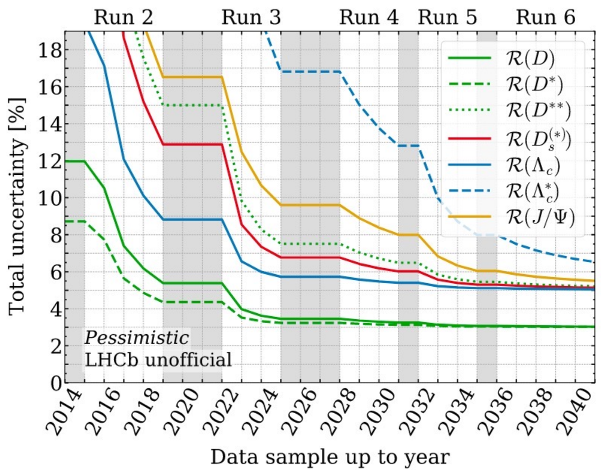
- Test of LFU in semitauonic decays are obtained measuring the following ratios: $R_X = \frac{\Gamma(B \to X_c \tau^+ \nu_\tau)}{\Gamma(B \to X_c \mu^+ \nu_\mu)}$, with $X_c = D^*\ or\ J/\psi$

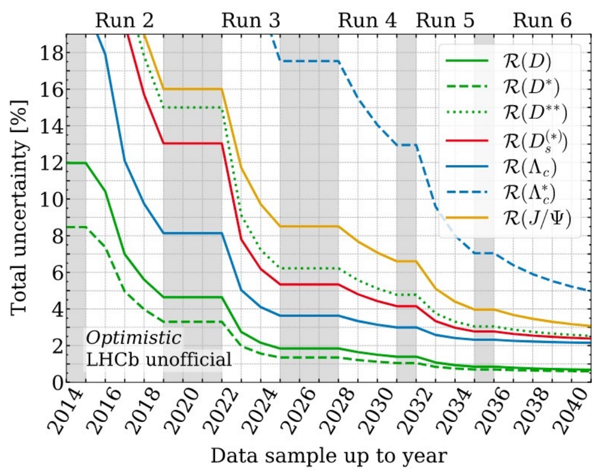




HFLAV 2019

Prospects





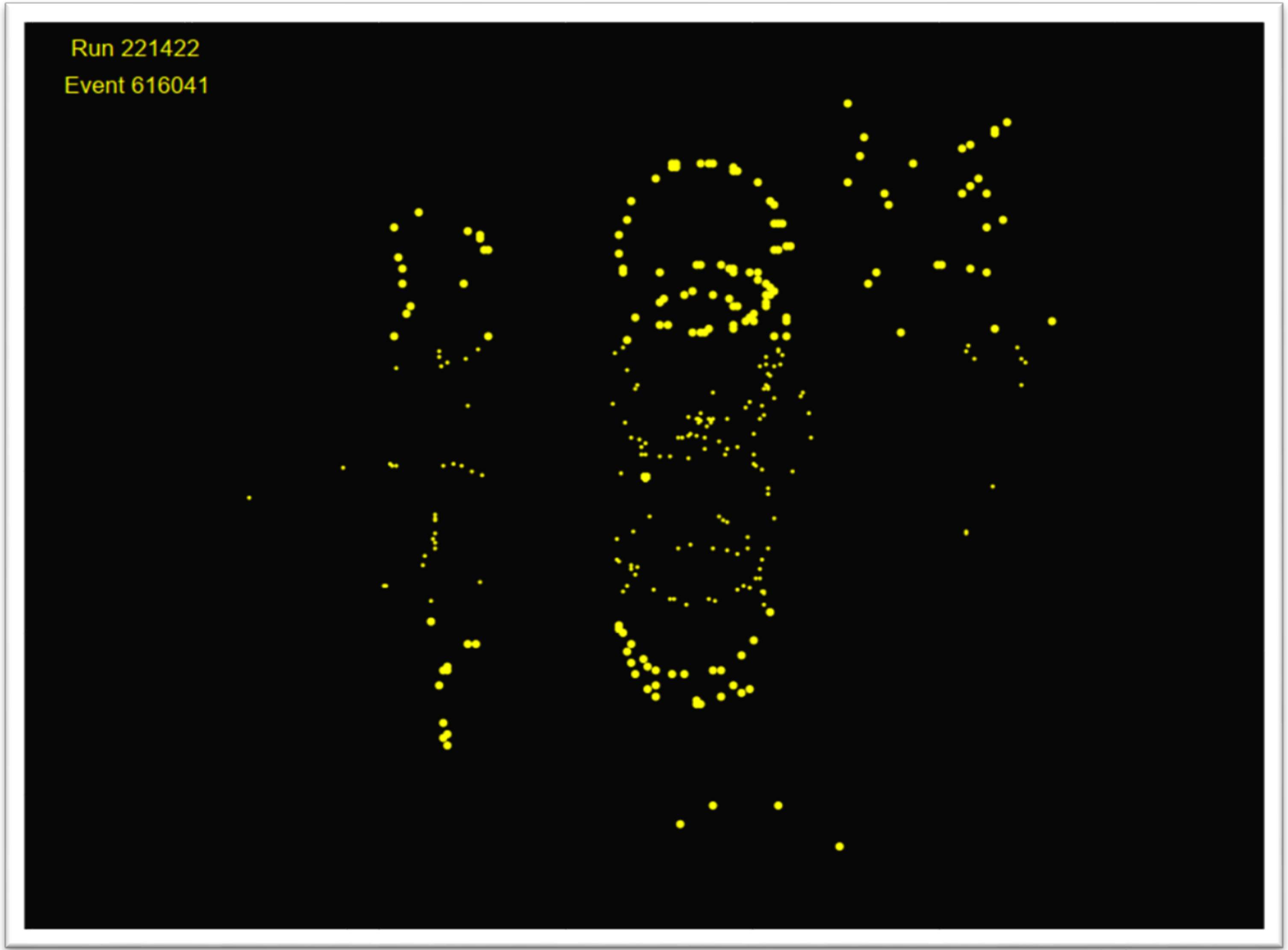
Expect ~O(10 M) $\bar{B} \to D^{(*)}\tau\bar{\nu}$ candidates

Sensitiveity in Upgrade II: $\frac{\sigma(R_{D^*})}{R_{D^*}} \sim 1\%$

More collisions are coming

- The first beam test in this year, start Oct.
- Looking forward to have stable beam collisions next year!!

The first rings from RICH



Conclusions

- Interest in precision flavour physics is stronger than ever
  - In case no direct evidence of NP pops out of the LHC
  - Flavour physics can play a key role
- The LHCb experiment successfully completed its first decade of data taking in the LHC Run1 and Run2
- Currently preparing the upgrade of the detector in view of Run3 and Run4
  - Aim at collecting at least $50\ \mathrm{fb}^{-1}$ by end of Run4
- Improvements in detector will open up many little-explored modes

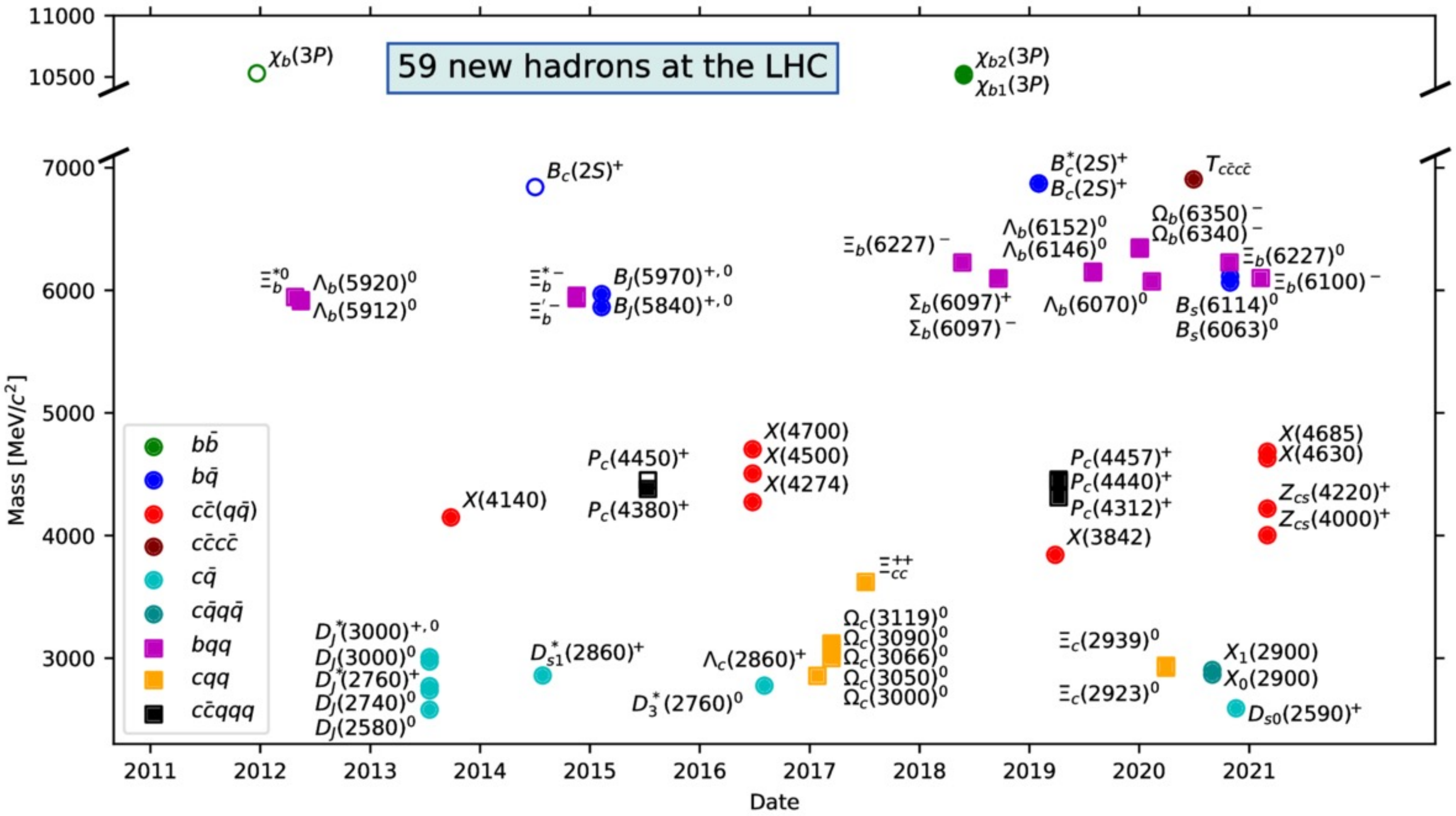
Exciting times ahead at LHCb!

BackUp

LHC: 59 hadrons discovered

LHCb-Figure-2021-001

- 52 discovered by the LHCb



Upgraded Vertex Detector

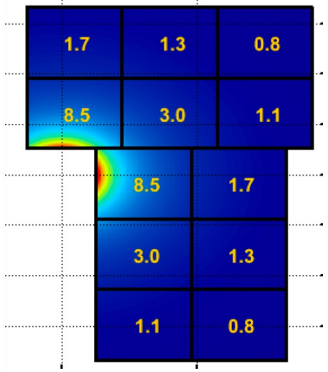
Future VELO must maintain same performance, but in harsher conditions

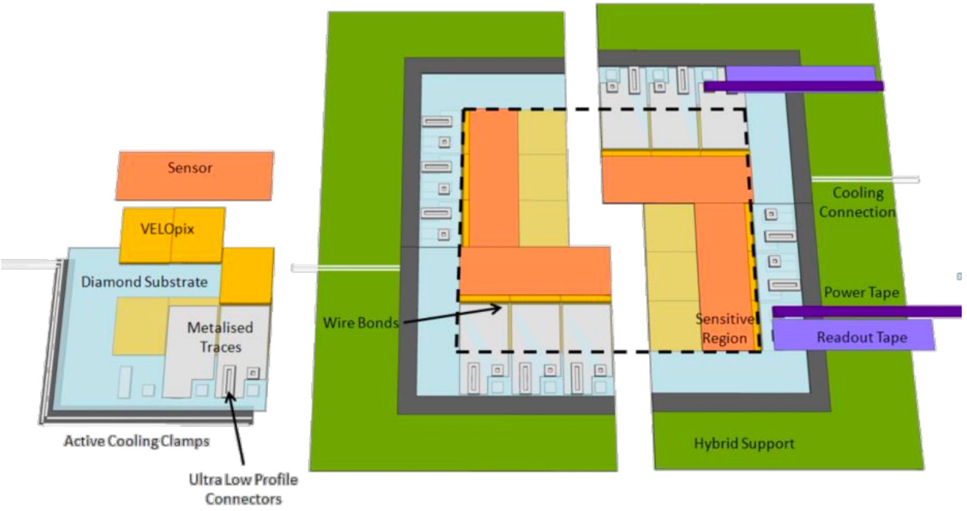
- Low material budget, cope with > radiation damage, deal with > multiplicities
- Trigger-less readout ASICs and provide fast and efficient reconstruction at HW level

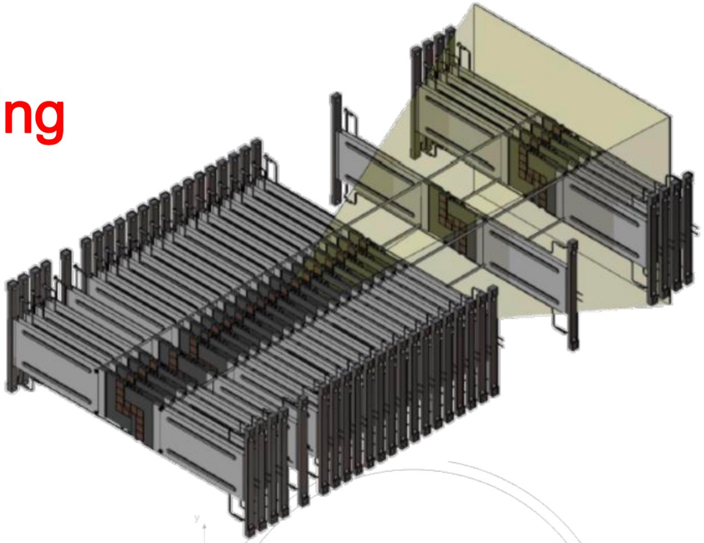
→ Recent technology reviews favored the choice of a

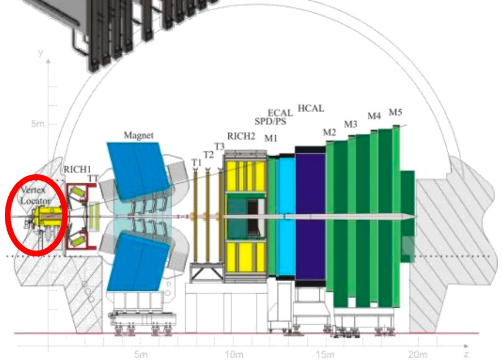
Si-pixel detector with microchannel cooling

occupancy



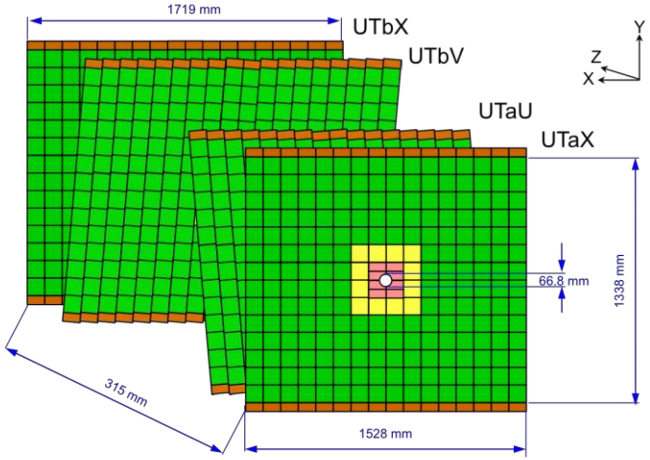


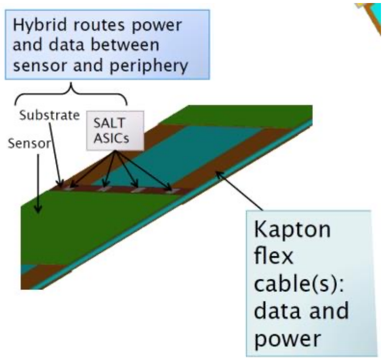


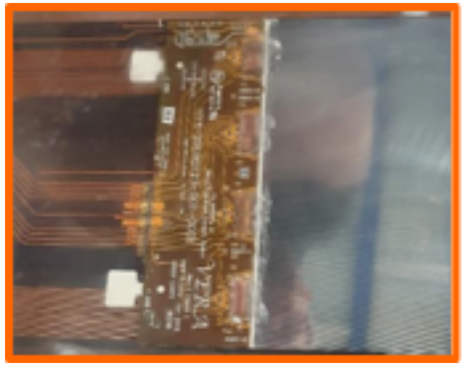


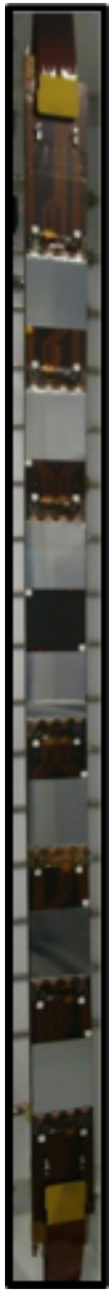
Upgraded Tracking System

- Silicon micro-strip detector
- Four layers (x, u, v, x) upstream of magnet: finer granularity and closer to beam
- Four types of sensors
- N- and p-type with 512 or 1024 strips
- 320/250 \mu m thick; 190/95 \mu m pitch
- Modules mounted on double sided staves
- Bi-phase co2 cooling pipe integrated in stave
- New read-out ASIC (SALT)
- 128 channles with 6-bit ADC
- Pedestal & common-mode subtraction, zero
- FE readout electronics mounted on detector









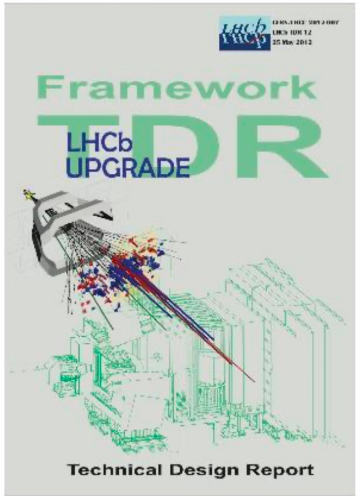
LHCb Phase-I Upgrade documents

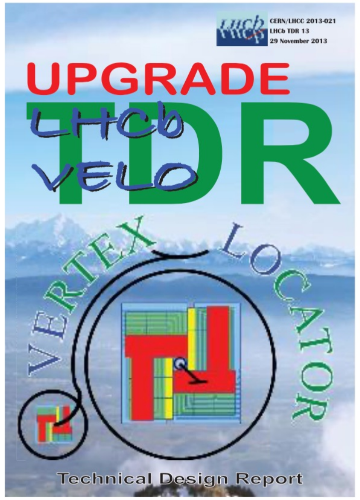

CERN/LHCC/2008-007
22 April 2008

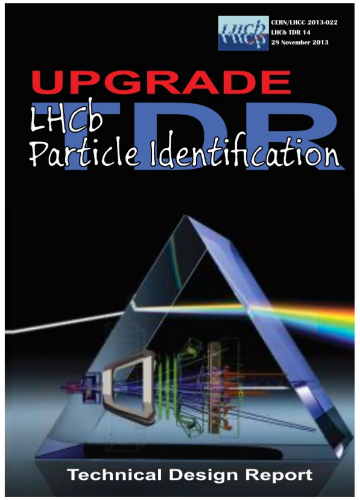
Expression of Interest
for an LHCb Upgrade

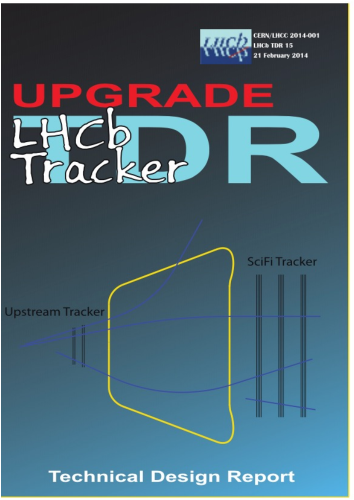
The LHCb Collaboration

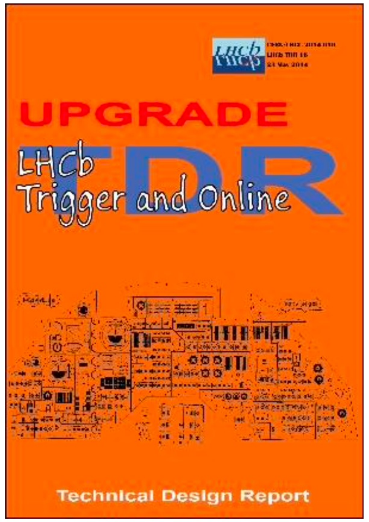
Abstract

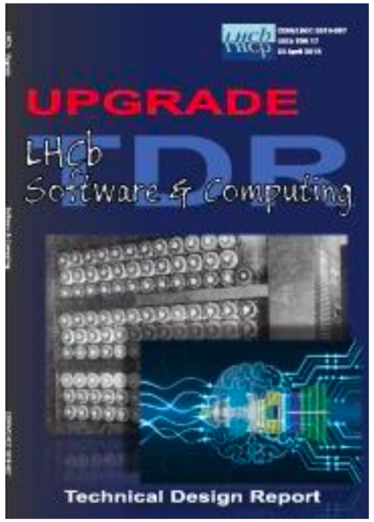












CERN-LHCC-2008-007
CERN-LHCC-2011-001
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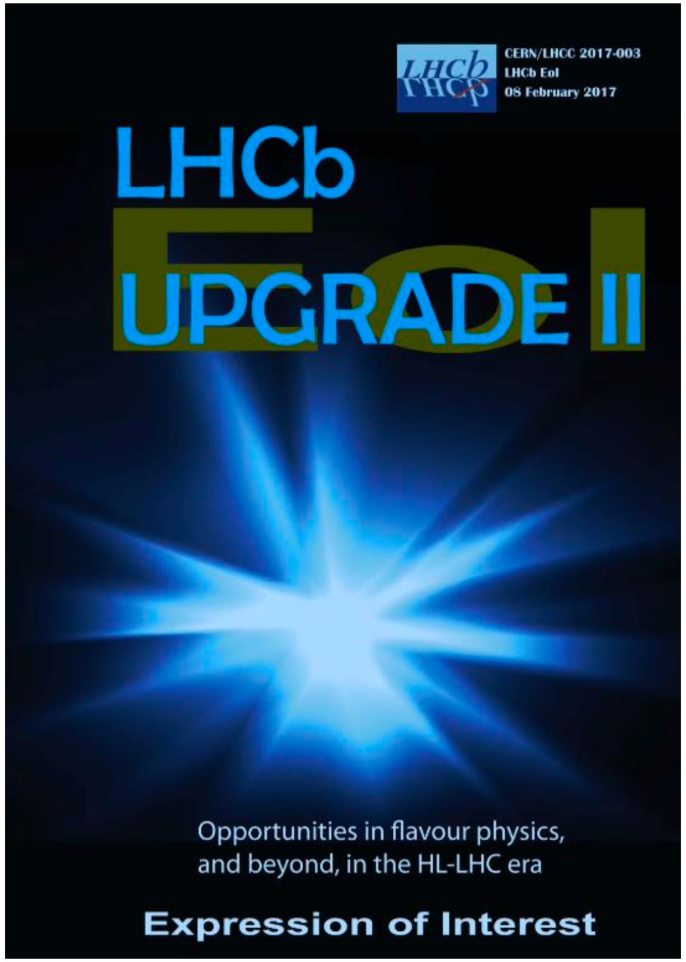
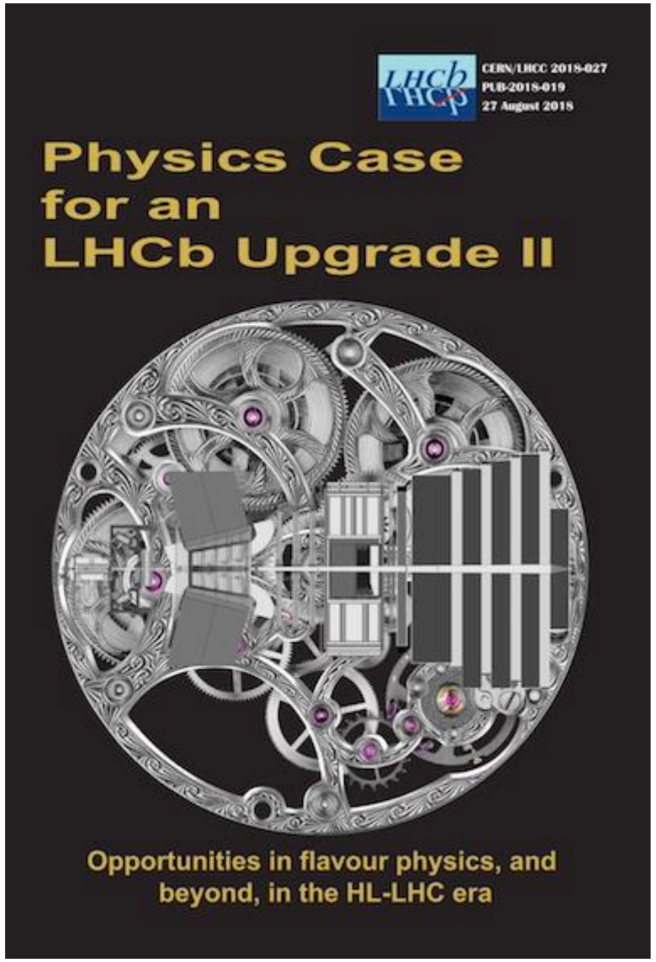
LHCb Phase-II Upgrade documents





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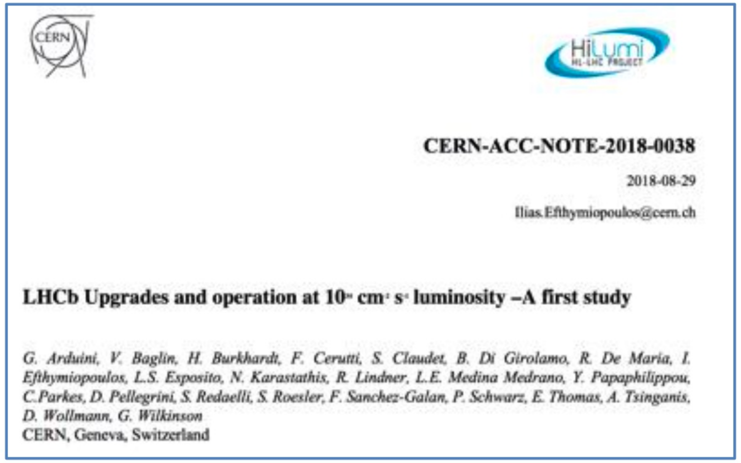

CERN-ACC-NOTE-2018-0038

2018-08-29

Ilias.Efthymiopoulos@cern.ch

LHCb Upgrades and operation at 10[illegible] cm[illegible] s[illegible] luminosity –A first study

G. Arduini, V. Baglin, H. Burkhardt, F. Cerutti, S. Claudet, B. Di Girolamo, R. De Maria, I. Efthymiopoulos, L.S. Esposito, N. Karastathis, R. Lindner, L.E. Medina Medrano, Y. Papaphilippou, C.Parkes, D. Pellegrini, S. Redaelli, S. Roesler, F. Sanchez-Galan, P. Schwarz, E. Thomas, A. Tsinganis, D. Wollmann, G. Wilkinson
CERN, Geneva, Switzerland