LHCb status report

Oscar Augusto de Aguiar Francisco

oscar.augusto@cern.ch

On behalf of the LHCb Collaboration

148th LHCC meeting – open session

17/Nov/2021

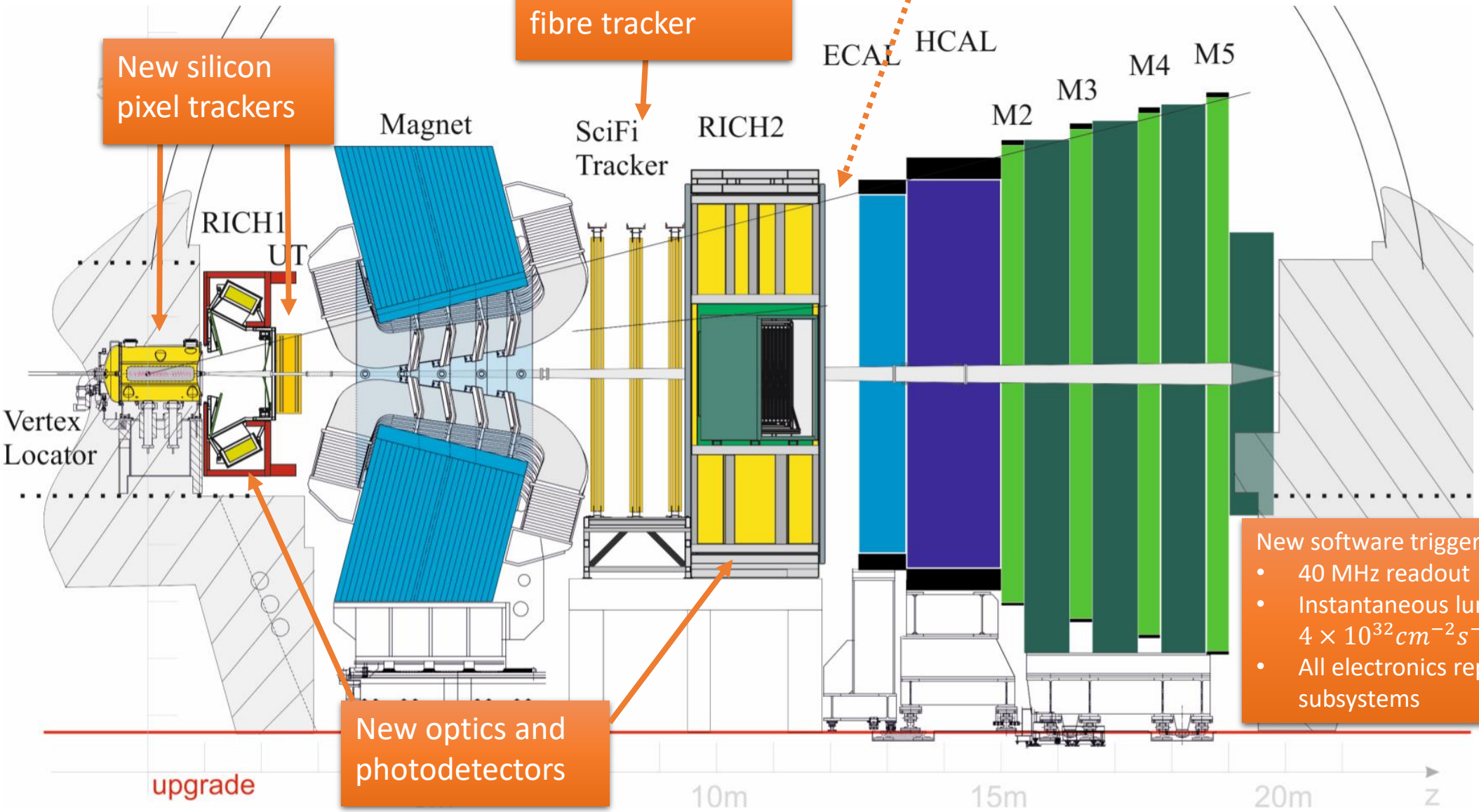
Photo by Max Brice, CERN

LHCb Upgrade I

first muon station, preshower and scintillating pad detectors removed

New scintillator fibre tracker

New silicon pixel trackers



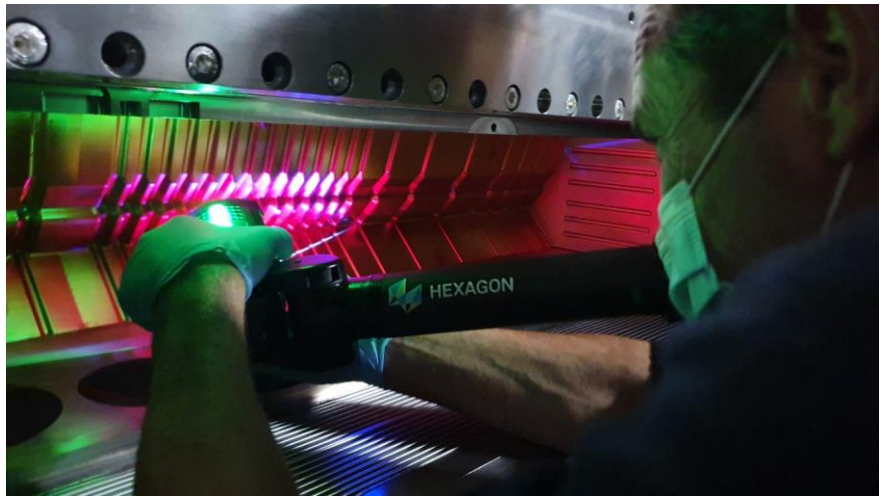
New optics and photodetectors

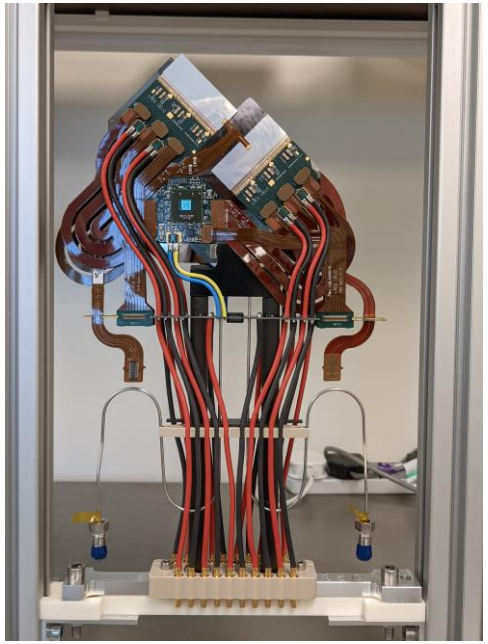
New software trigger based detector
- 40 MHz readout
- Instantaneous luminosity $4 \times 10^{32} cm^{-2} s^{-1}$ to $2 \times 10^{33} cm^{-2} s^{-1}$
- All electronics replaced in all subsystems

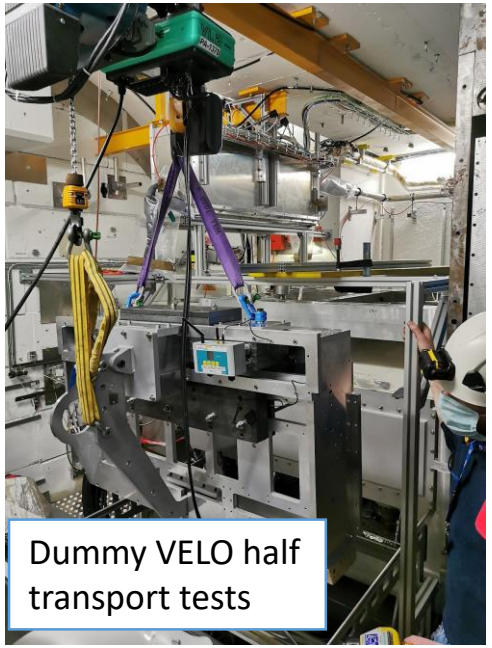
VELO

- Ongoing delivery from Module Assembly sites
- All 52 detector grade modules produced
- All modules installed on the first half
- Dummy transport made last week to CERN in preparation for the C-side transport in December
- Second half expected by early February 2022 (tight schedule)

RF foil metrology





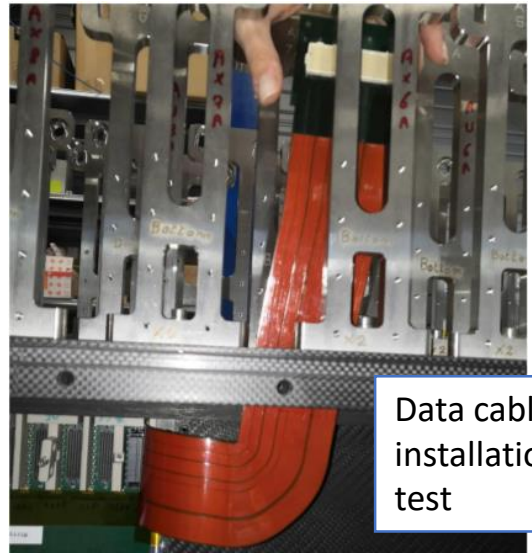


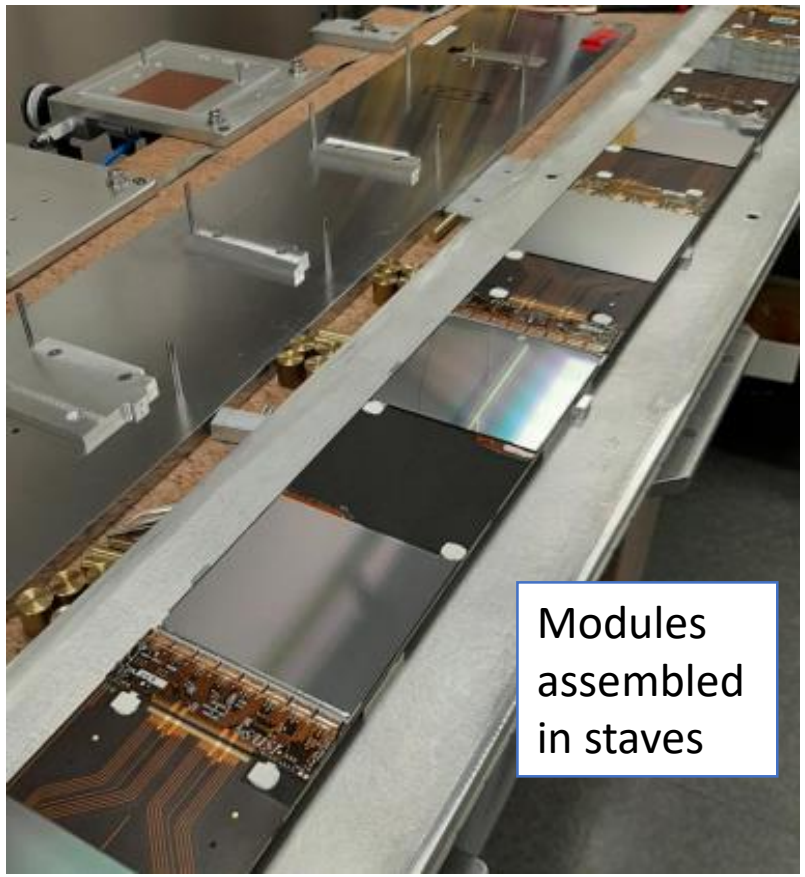
Dummy VELO half transport tests

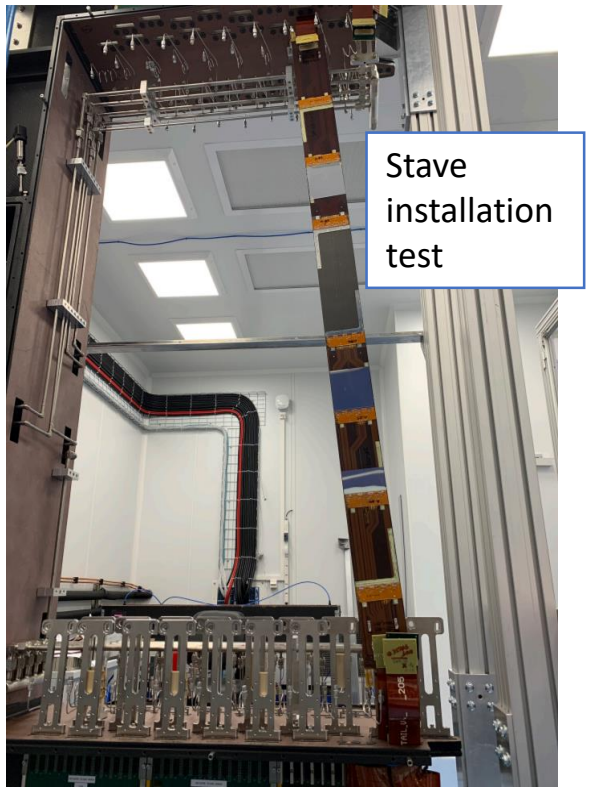
UT

- All staves ready for first half
  - Next shipping to CERN will provide enough staves for the first side
- Preparation of the detector infrastructure
  - Cooling installed on both detector boxes
  - Assembly tests of the HV and data cables
- Halves installation:
  - First side installed before cavern closure
  - Previous experience will allow a faster installation of the second half in, for example, June/22 technical stop


CO2 manifold installation

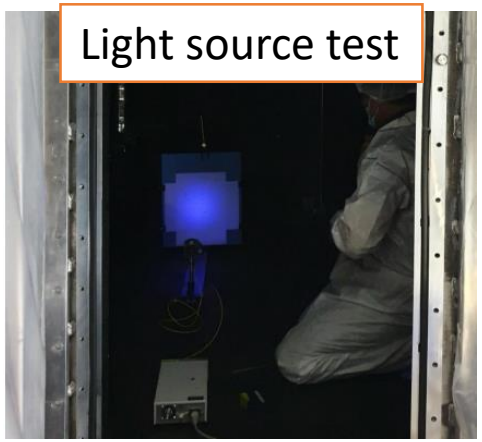

Data cable installation test

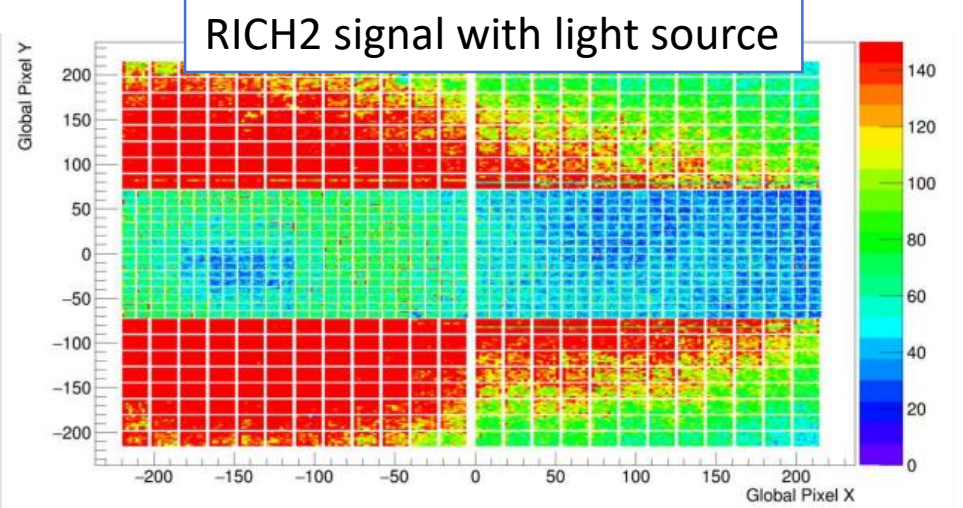

Modules assembled in staves

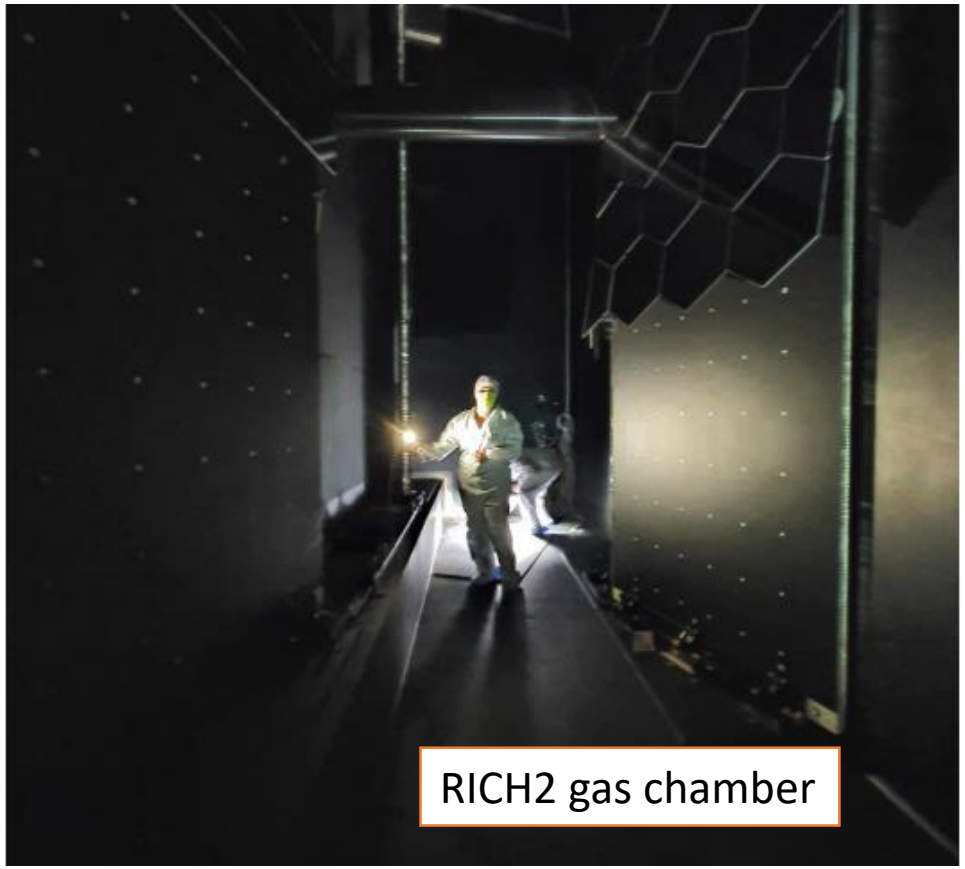

Stave installation test

LHCb-TDR-015

RICHes


Light source test



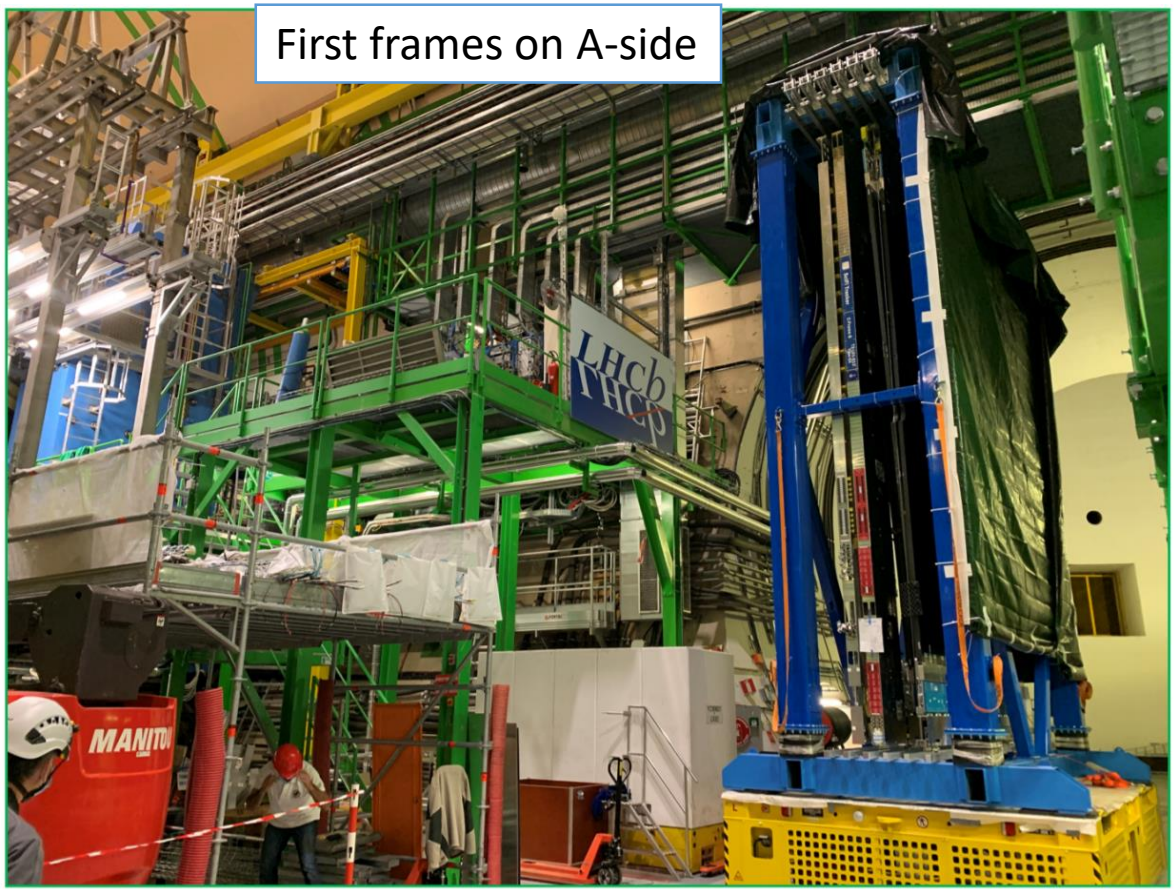

RICH2 gas chamber

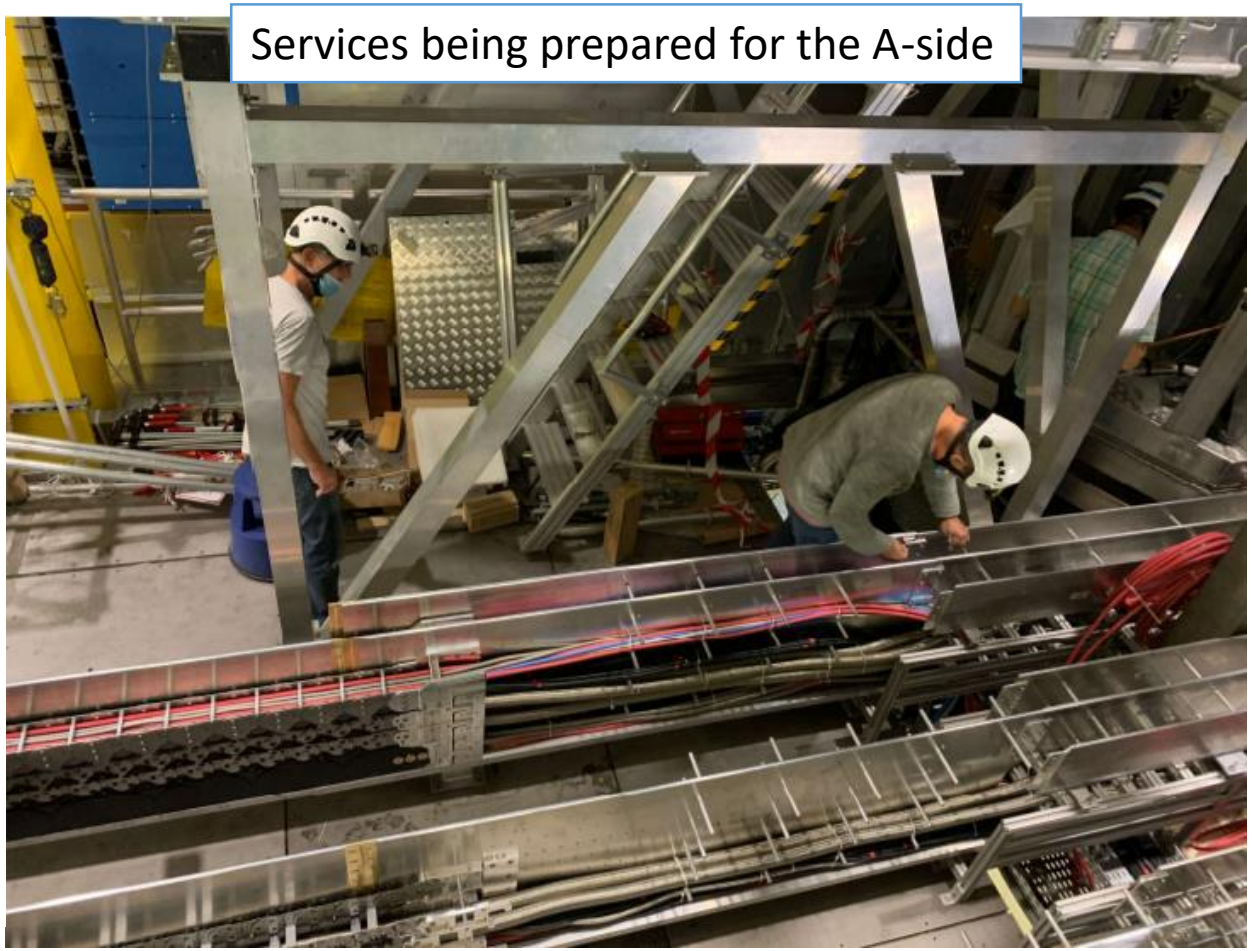
LHCb-TDR-014

- RICH2 installation complete
  - Took data during the beam test in October
- RICH1 being commissioned on surface
  - Gas enclosure, mirrors, quartz windows installed
  - PMT columns installation on-going in the next weeks


RICH2 mirrors


RICH1 commissioning





SciFi

LHCb-TDR-015

- All modules attached to all frames for the whole detector
- One side of the detector completely installed, connected and aligned
- Second side, first 2/6 frames installed
- Installation of the last frames expected in Jan-Feb ‘22
- Tight but achievable schedule

CALO and MUON

LHCb-TDR-014

CALO

- All are equipped with new control and frontend boards and a new HV system
- Upgraded CALO movement system

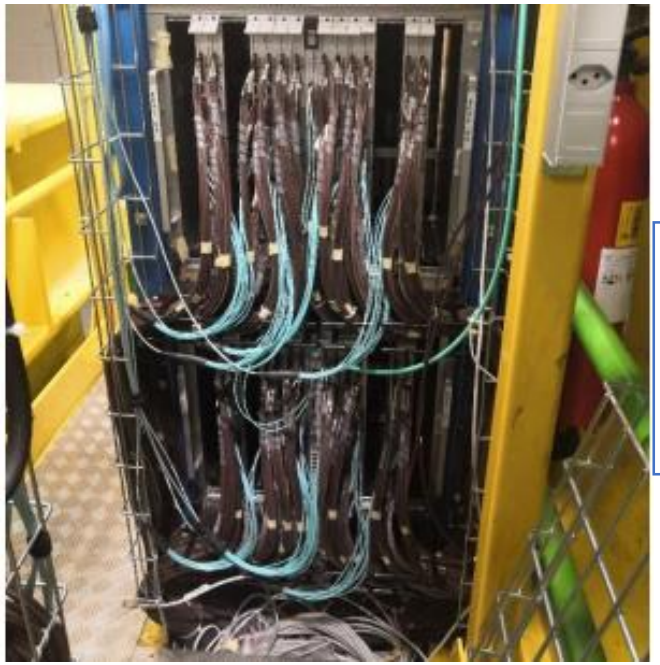
MUON

- New electronics fully installed
- All electronics and optical fibers retested

Commissioning ongoing for the calorimeter & muon system

Both took data in the beam test

New MUON Front end electronics

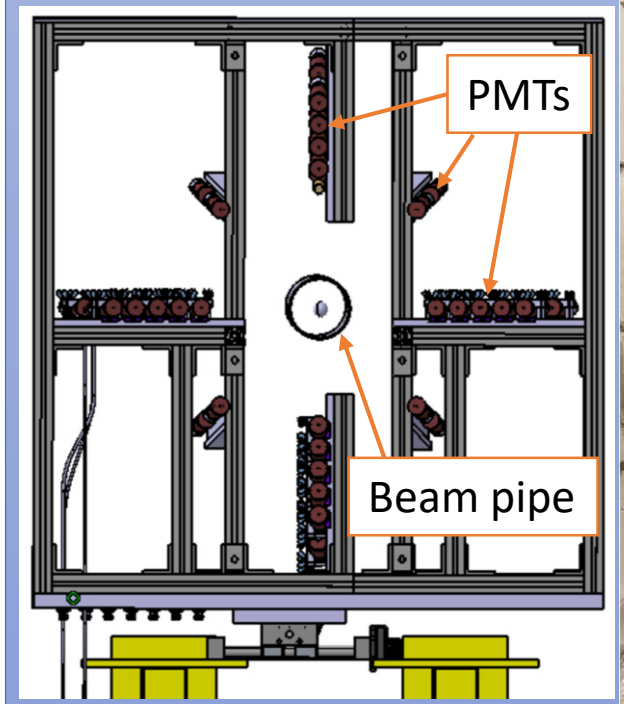


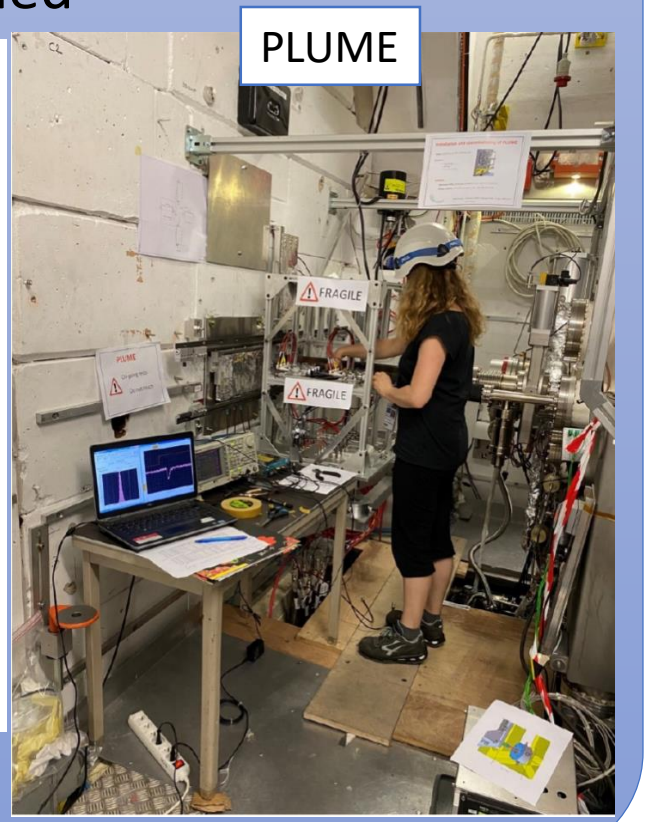
New CALO frontend and control boards installed

PLUME, RMS and BCM

PLUME: luminosity measurement with quartz tablets + PMTs

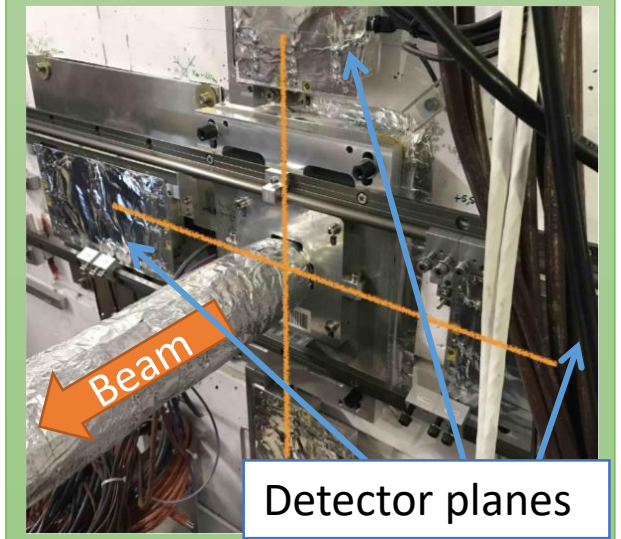
Installed and pre-aligned





RMS: Radiation monitoring system (luminosity and beam background monitor)

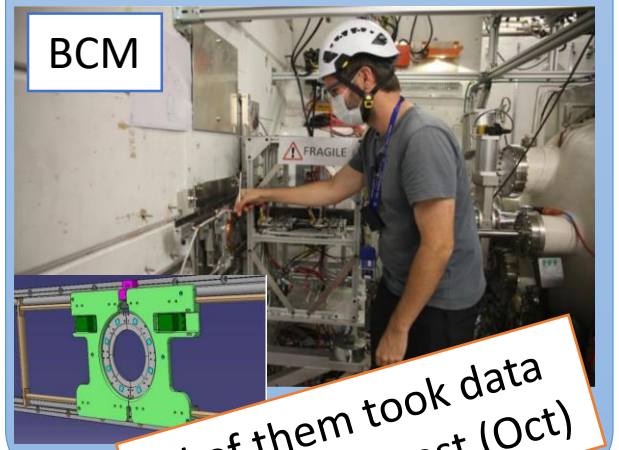
Metal foil detectors installed and pre-aligned



BCM: beam condition monitor
(produces beam abort protecting LHCb)

All Run 3 diamond sensors ready

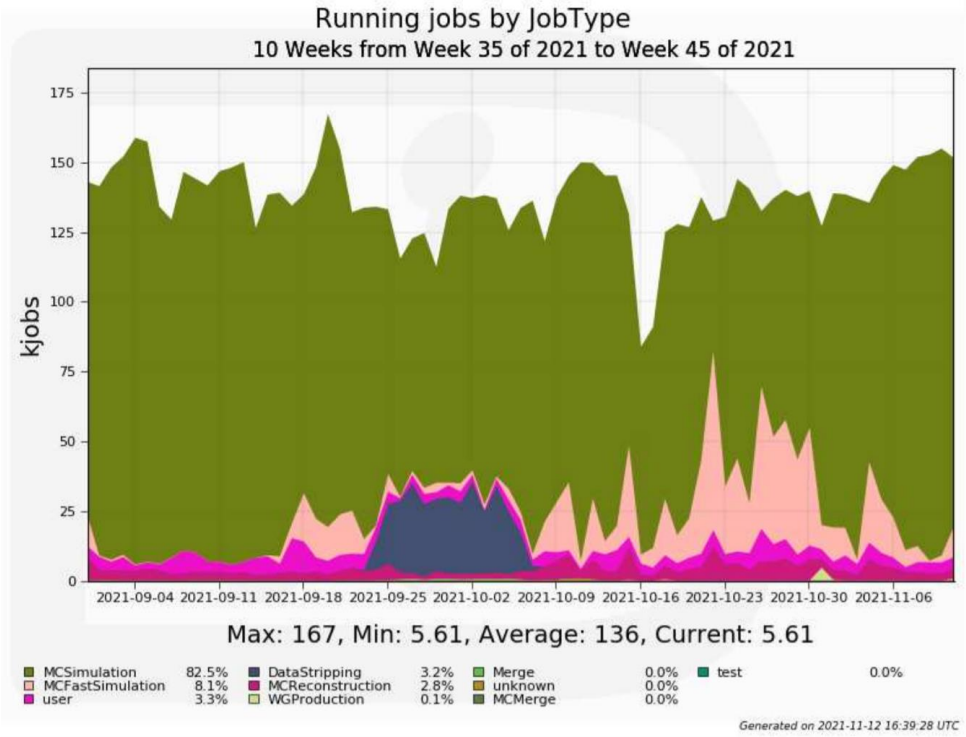
Upstream station installed



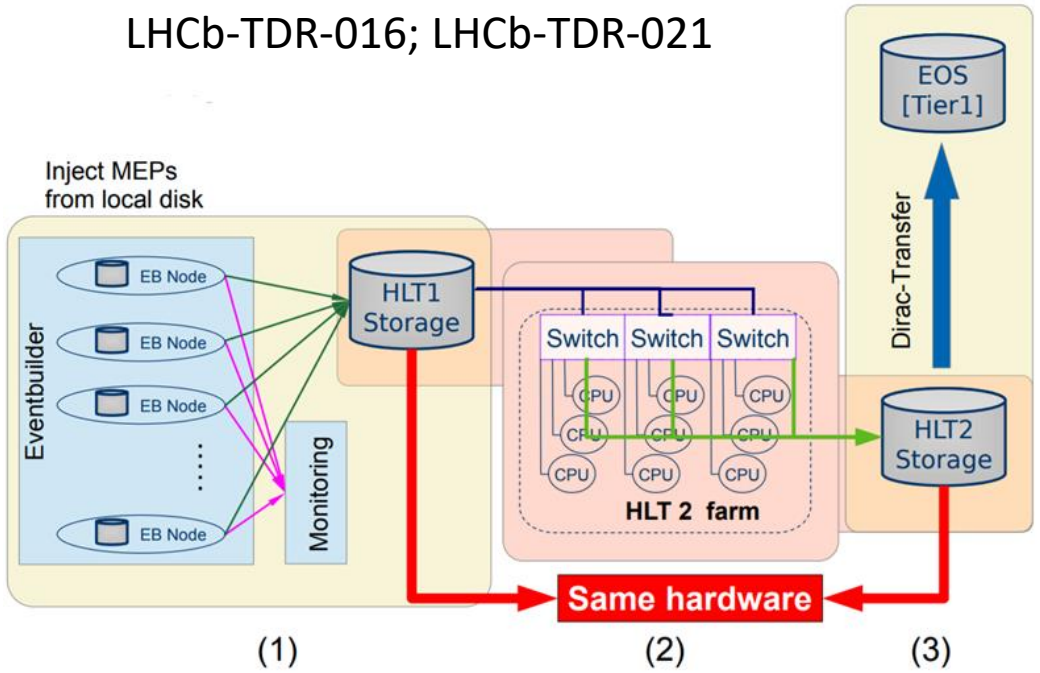
All of them took data in the beam test (Oct)

Operations

- ~93% of the resources being used for MC production
- Reprocessing of the Run 2 data to be finished by the end of the year
  - Main purpose to add additional analysis channels
  - 2017 and 2018 done, 2016 in the pipeline



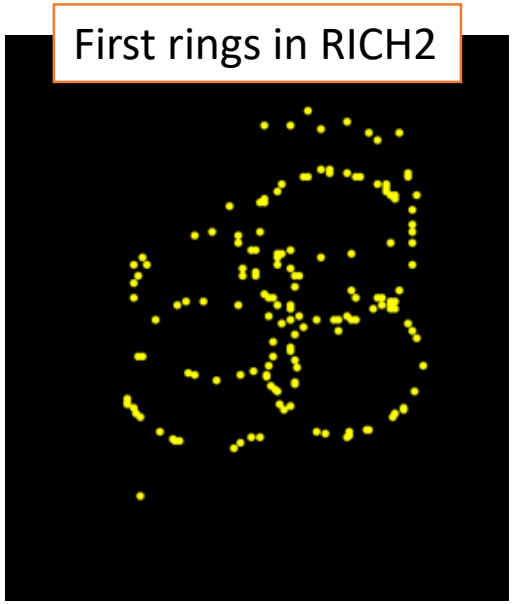
LHCb-TDR-016; LHCb-TDR-021

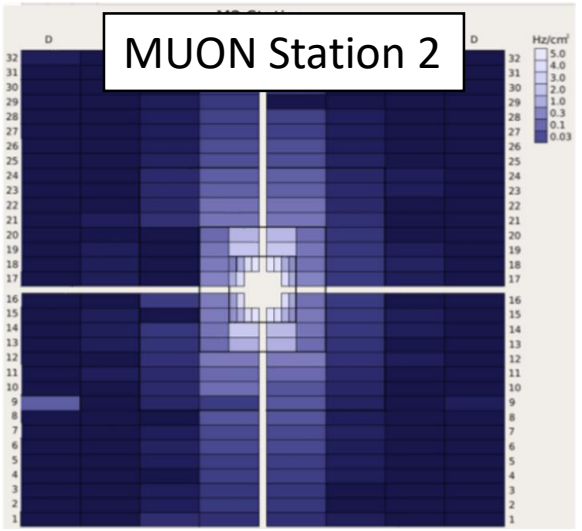


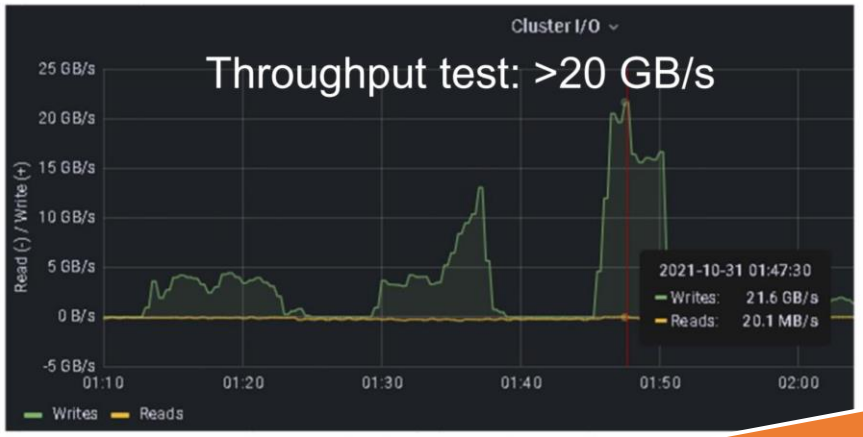
- October FEST (Full Experiment System Test)
  - Joint effort of all software projects
  - Run simulated data through the whole Online and Offline chain to verify the readiness of data processing
  - Exercise all aspects from data production in event builders to long term storage in EOS
    - With low rates and only partially available hardware
    - HLT1/Allen integration with event output storage and basic monitoring (1)
    - HLT2 processing of HLT1 output (2)
    - Transfer of HLT2 output files to EOS (3)

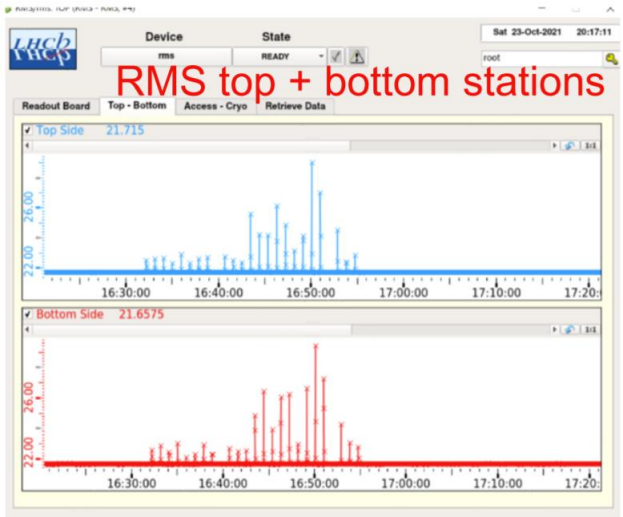
Operations: Pilot beam

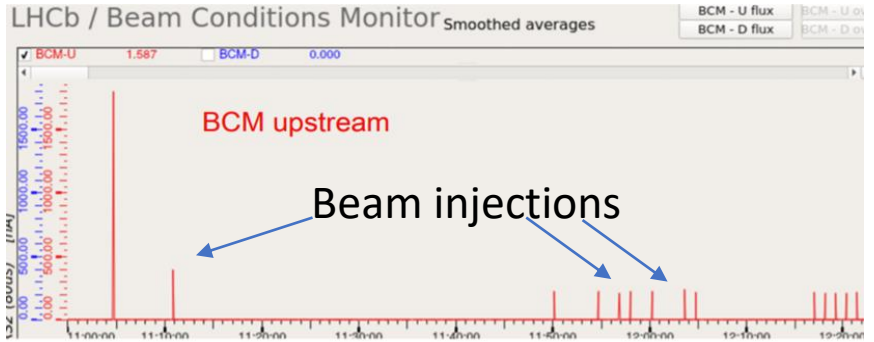
- Fantastic beam test with all installed subdetectors:
  - RICH2, Calorimeters and MUON
  - PLUME, BCM and RMS
- All subdetectors were time aligned within a few days
- HLT1 and HLT2 running in passthrough mode using CALO lines
- Data throughput tested down to the writing











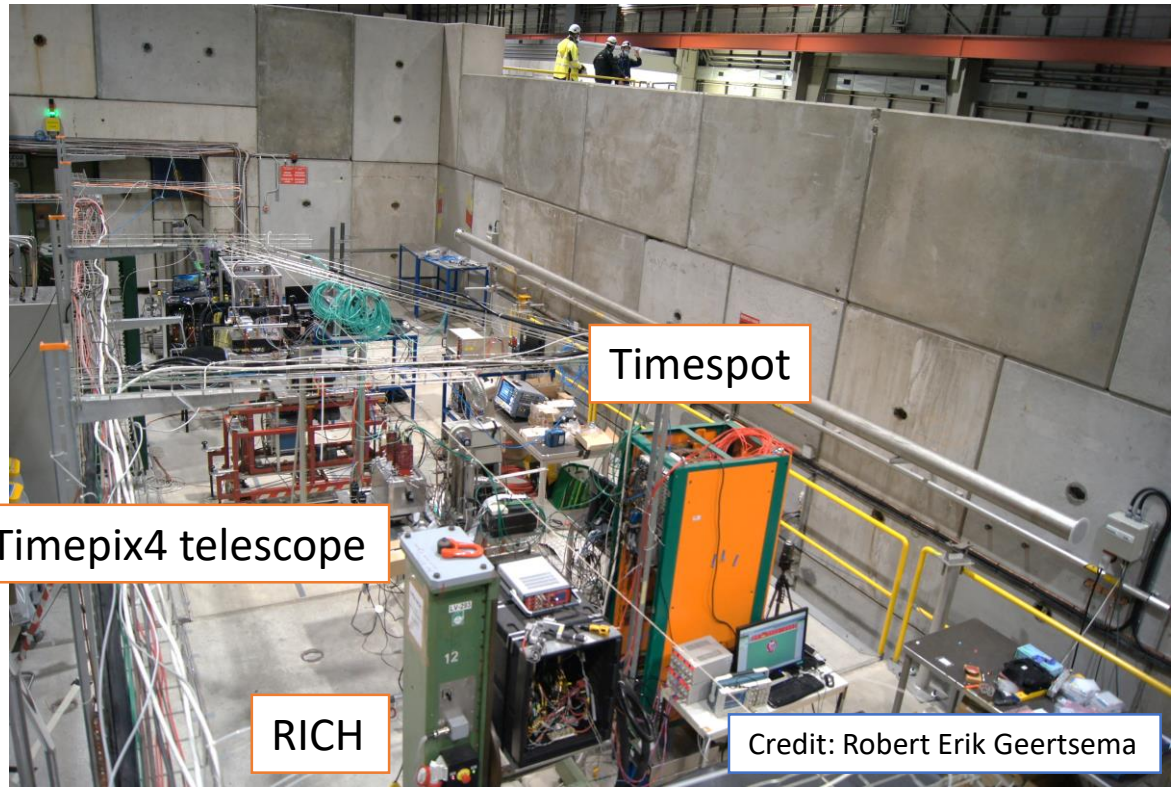
Thanks to LHC for excellent beam performance!

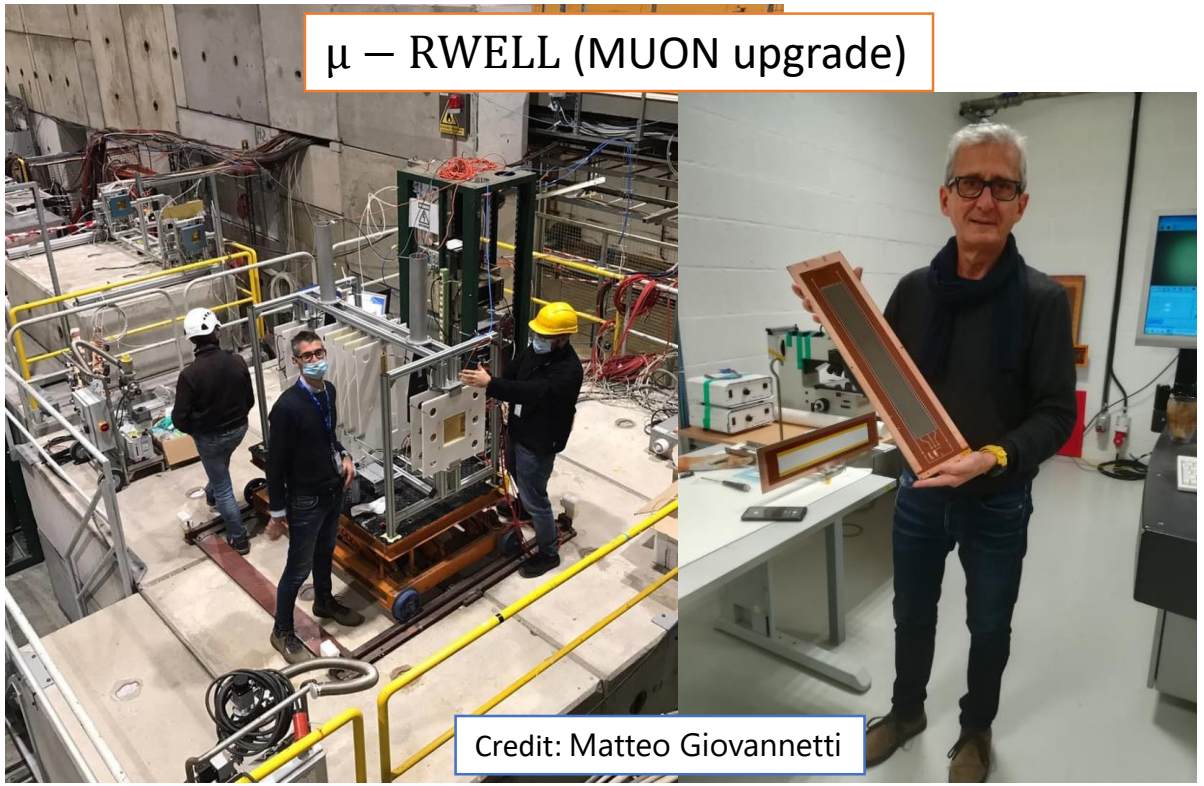
Upgrade II (2030)

LHCB-TDR-023

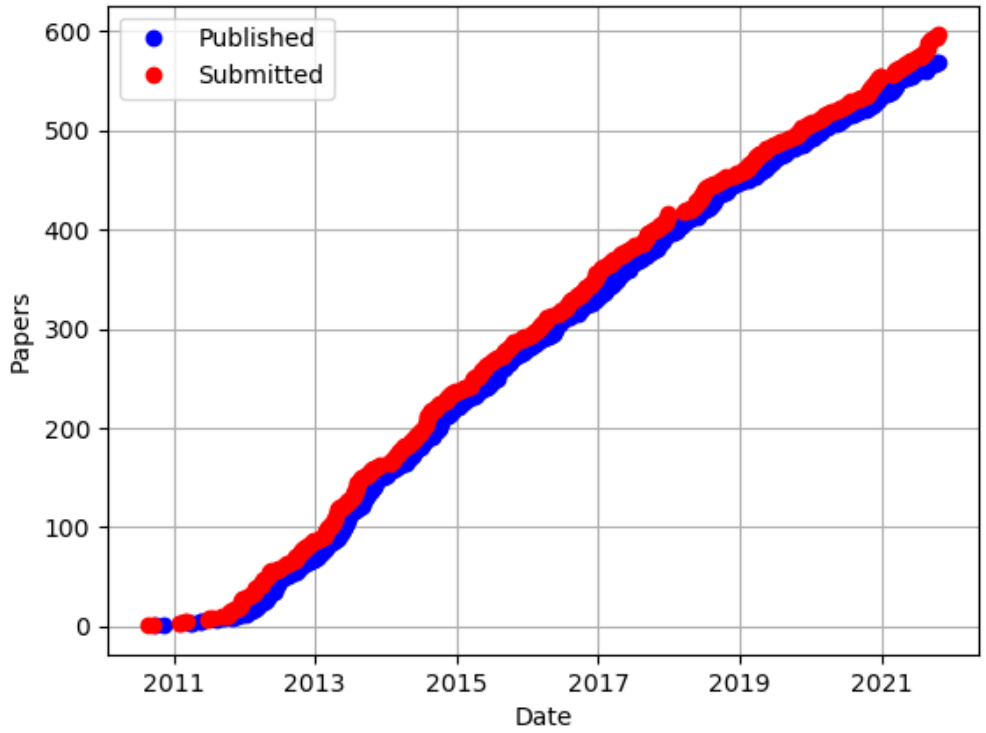
- Framework Technical Design Report (FTDR)
  - Baseline design and subdetectors roadmap for R&D
  - Under review with LHCC
  - Subdetectors upgrade options are presented with the target to record 300fb^{-1}

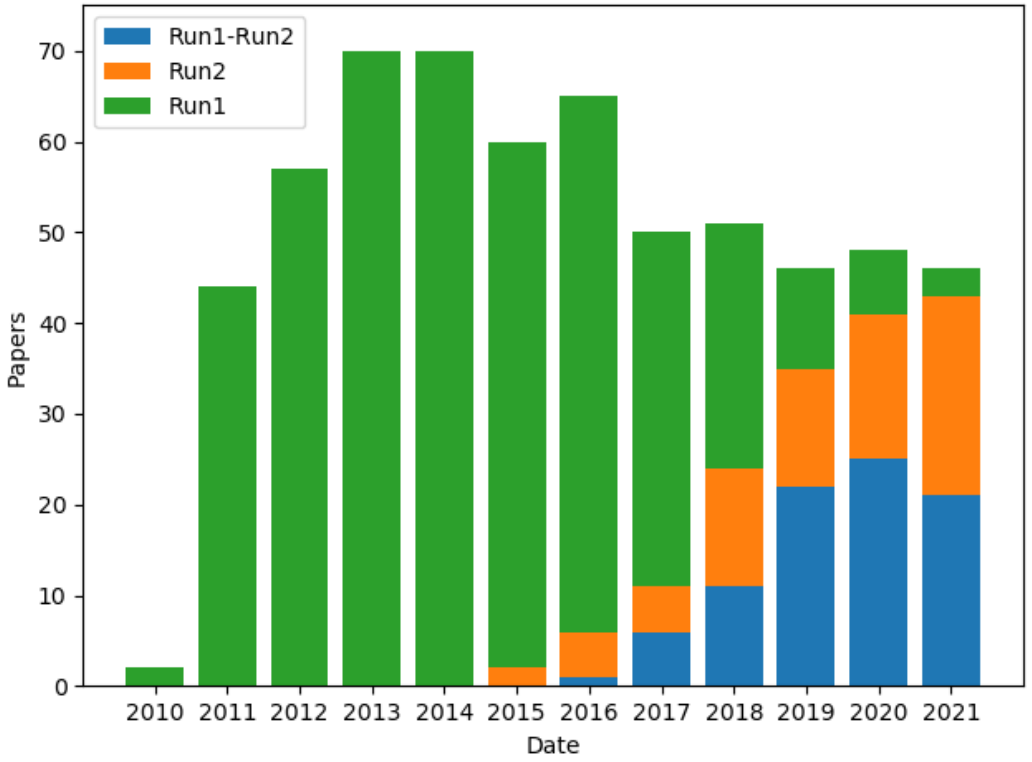
- Testbeam activities for RICH, VELO, ECAL and MUON





Physics output





Physics highlights

Discussed in this presentation

Paper submitted since last LHCC

- [PAPER-2021-038] Tests of lepton universality using $\mathrm{B}^0 \to K_s^0 \ell^+ \ell^-$ and $B^+ \to K^{*+} \ell^+ \ell^-$ decays
- [PAPER-2021-035] Angular analysis of $D^0 \to \pi^+ \pi^- \mu^+ \mu^-$ and $D^0 \to K^+ K^- \mu^+ \mu^-$ decays and search for CP violation
- [PAPER-2021-034] Study of the B_c^+ decays into charmonia and three light hadrons
- [PAPER-2021-033] Simultaneous determination of CKM angle γ and charm mixing parameters
- [PAPER-2021-032] Study of the doubly charmed tetraquark T_{cc}^+
- [PAPER-2021-031] Observation of an exotic narrow doubly charmed tetraquark
- [PAPER-2021-029] Study of Z bosons produced in association with charm in the forward region
- [PAPER-2021-028] Search for massive long-lived particles decaying semileptonically at $\sqrt{s} = 13$ TeV
- [PAPER-2021-026] Measurement of $\chi_{c1}(3872)$ production in proton-proton collisions at $\sqrt{s} = 8$ and 13 TeV
- [PAPER-2021-025] Observation of two new excited Ξ_b^0 states decaying to $\Lambda_b^0 K^- \pi^+$
- [PAPER-2021-024] Measurement of the W boson mass
- [PAPER-2021-023] Updated search for B_c^+ decays to two charm mesons
- [PAPER-2021-021] Measurement of the lifetimes of promptly produced Ω_c^0 and Ξ_c^0 baryons
- [PAPER-2021-020] Measurement of J/ψ production cross-sections in pp collisions at $\sqrt{s} = 5$ TeV
- [PAPER-2021-019] Search for the doubly charmed baryon Ξ_{cc}^+ in the $\Xi_c^+ \pi^- \pi^+$ final state

Preliminary since the last LHCC

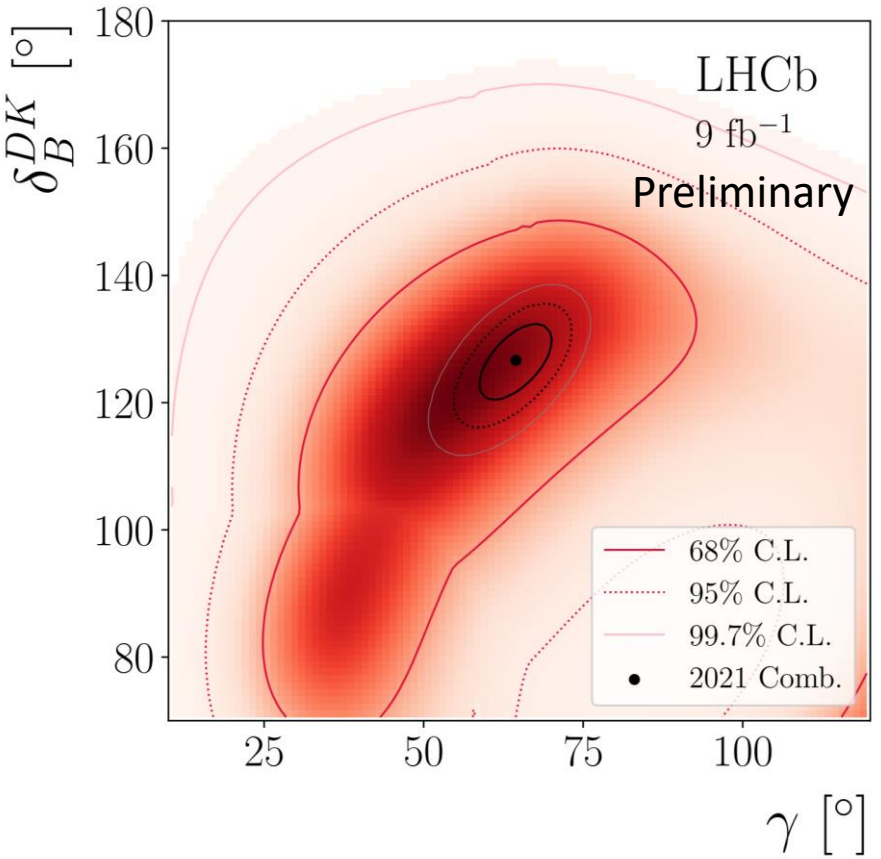
- [PAPER-2021-036] Constraints on the CKM angle γ from $B^\pm \to D h^\pm$ decays using the $D \to h^\pm h^\mp \pi^0$ final states
- [PAPER-2021-037] Precision measurement of forward Z boson production in proton-proton collisions at $\sqrt{s} = 13$ TeV
- [PAPER-2021-039] Searches for rare B_s^0 and B^0 decays into four muons
- [PAPER-2021-030] Measurement of the photon polarization in $\Lambda_b^0 \to \Lambda \gamma$ decays

Constraints on the CKM angle γ from $B^{\pm} \to Dh^{\pm}$ decays using the $D \to h^{\pm}h^{\mp}\pi^0$ final states

LHCB-PAPER-2021-036

- Run 1+2 dataset (9 fb^{-1})
- Supressed channel $B^{\pm} \to \left[\pi^{\mp}K^{\pm}\pi^0\right]_D K^{\mp}$ is observed for the first time (7.8σ)
- 11 CP observables are measured with world-best precision
- Results are interpreted as:
  - r_B: The ratio of the magnitudes of the $B^- \to \overline{D_0}K^-$ and $B^- \to D_0^- K^-$ amplitudes
  - δ_B: the relative strong phase
  - γ: the relative weak phase determine the size of the CP violation

$$\begin{aligned} \gamma &= (56^{+24}_{-19})^\circ \\ \delta_B &= (122^{+19}_{-23})^\circ \\ r_B &= (9.25^{+1.04}_{-0.85}) \times 10^{-2}. \end{aligned}$$



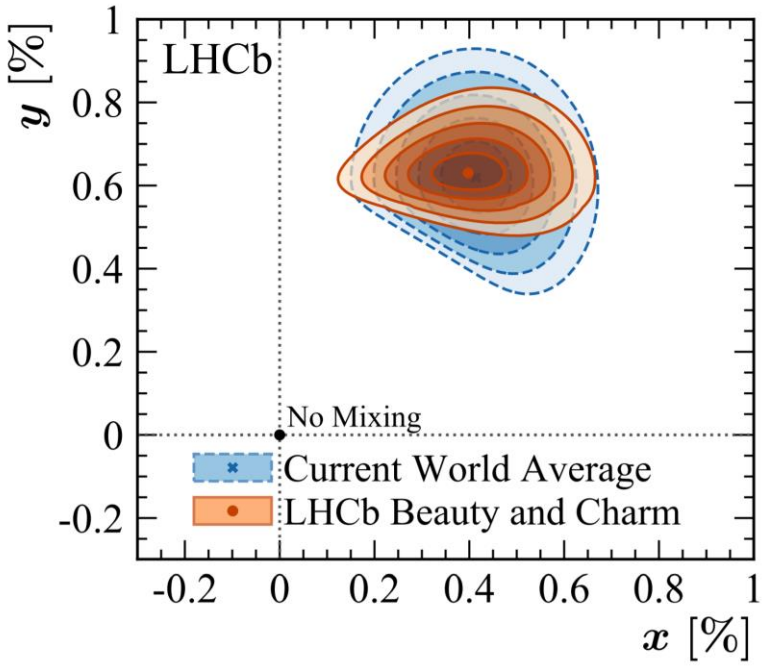
Simultaneous determination of CKM angle γ and charm mixing parameters

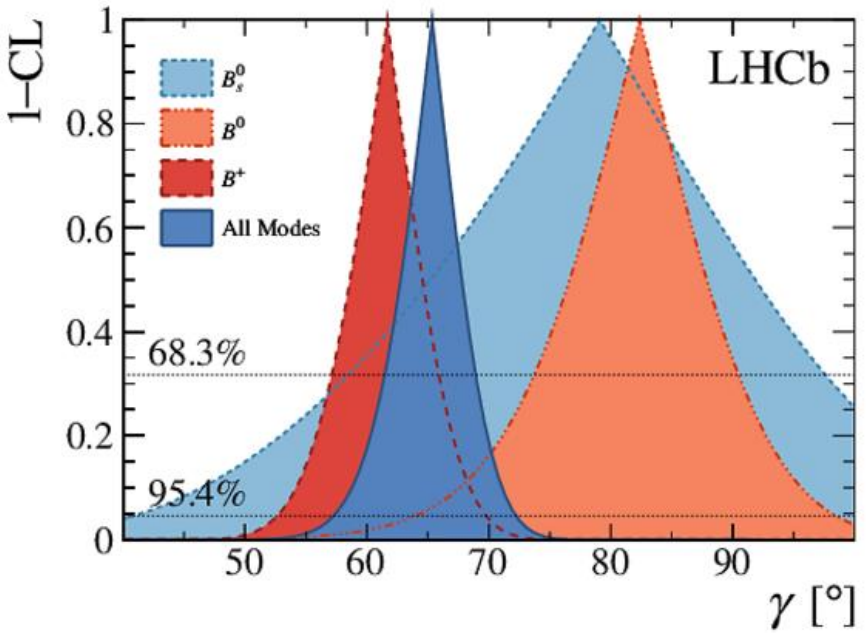
LHCB-PAPER-2021-033

- Run 1 or 1+2 datasets
- More than 20 LHCb publications combined in this study:
  - 151 input observables to determine 52 free parameters
- Includes 7 new and updated inputs from B-meson and 8 inputs from D-meson decays
- Comparison of the γ with the global fit

$$\gamma = 65.4^{+3.8}_{-4.2} \quad \text{CKMfitter: } \gamma = 65.6^{+0.9}_{-2.7}$$

- Charm mixing y improved by a factor 2



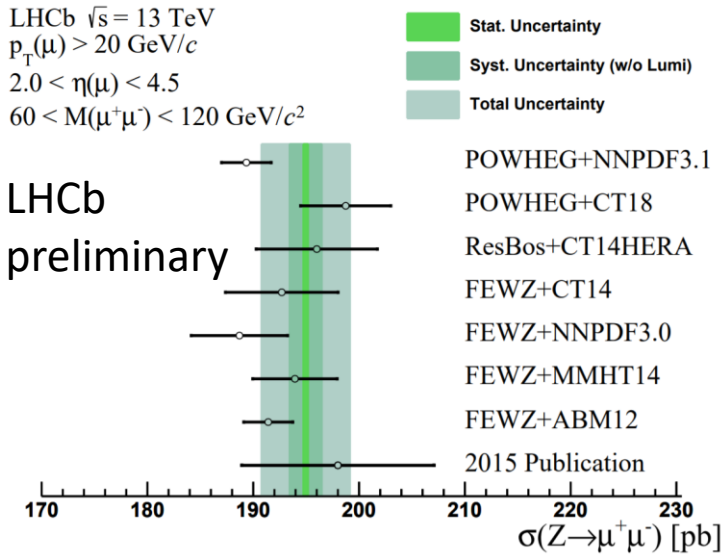


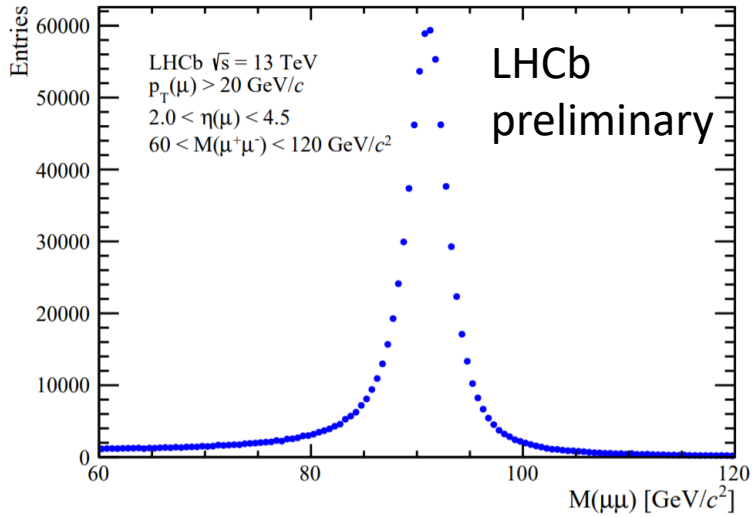
Precision measurement of forward Z boson production in proton-proton collisions at $\sqrt{s} = 13$ TeV

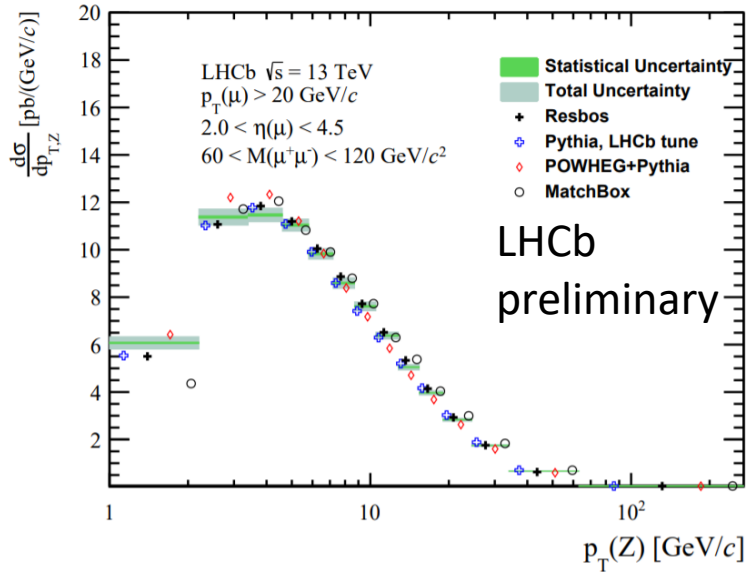
LHCB-PAPER-2021-037

- Run 2 dataset (5.1fb^{-1})
- Unique information to the PDFs global fitting, specially in the large and small x region
- Most precise measurement of Z boson production cross-section in the forward region at $\sqrt{s} = 13$ TeV to date

$$\sigma_{pp\to Z\to\mu^+\mu^-} = 194.96 \pm 0.22 \pm 1.50 \pm 3.90 \text{ pb}$$





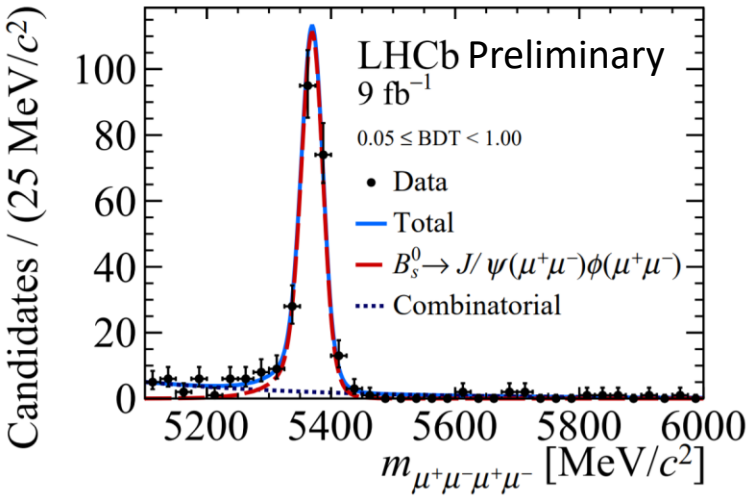


Searches for rare B_s^0 and B^0 decays into four muons

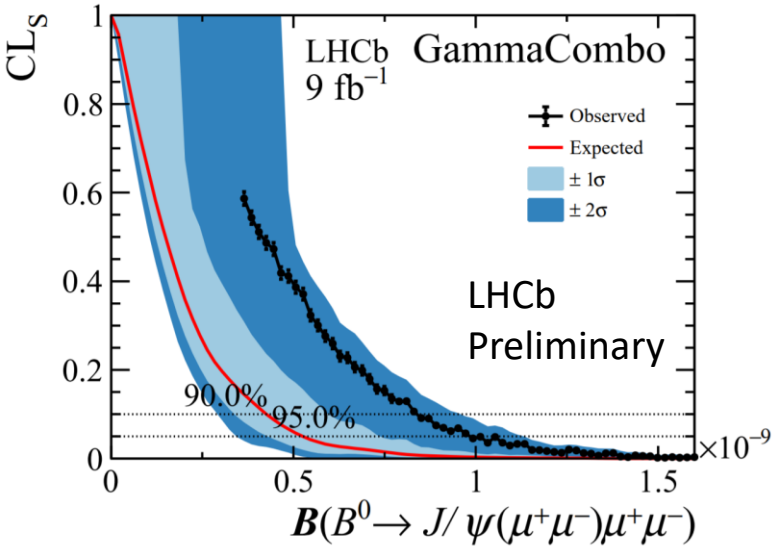
- Run 1+2 dataset (9 fb^{-1})
- Expected Branching fraction is very small according to the SM ($BR(B_s^0 \to \mu\mu\mu\mu) \sim 10^{-10}$ and $BR(B^0 \to \mu\mu\mu\mu \sim 10^{-12})$.
- Increased BR could be a sign of BSM physics
- Non-resonant, $J/\psi\mu\mu$ and a($\mu\mu$)a($\mu\mu$) (m_a = 1 GeV) modes are taken into account
- Models which predict a low mass scalar (a) around 1 GeV can explain the anomalies in magnetic dipole of the muon and $\bar{b} \to \bar{s}\mu\mu$
- No evidence was found for all modes. The limits at 95% confidence level are:

$$\mathcal{B}\left(B_s^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 8.6 \times 10^{-10},$$
$$\mathcal{B}\left(B^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 1.8 \times 10^{-10},$$
$$\mathcal{B}\left(B_s^0 \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right)|_{m_a=1\,\mathrm{GeV}/c^2} < 5.8 \times 10^{-10},$$
$$\mathcal{B}\left(B^0 \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right)|_{m_a=1\,\mathrm{GeV}/c^2} < 2.3 \times 10^{-10},$$
$$\mathcal{B}\left(B_s^0 \to J/\psi\left(\mu^+\mu^-\right)\mu^+\mu^-\right) < 2.6 \times 10^{-9},$$
$$\mathcal{B}\left(B^0 \to J/\psi\left(\mu^+\mu^-\right)\mu^+\mu^-\right) < 1.0 \times 10^{-9}.$$

Normalization mode



No evidence found (< 2σ)



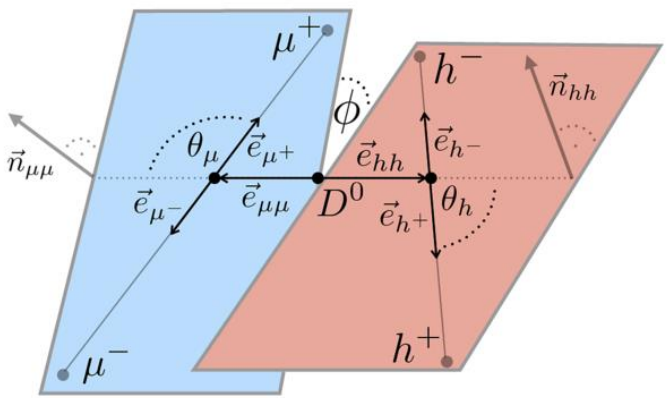
Angular analysis of $D^0 \to \pi^+\pi^-\mu^+\mu^-$ and $D^0 \to K^+K^-\mu^+\mu^-$ decays and search for CP violation

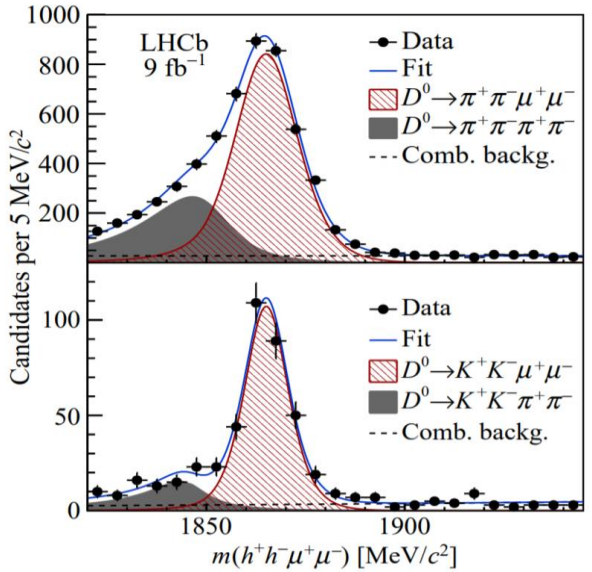
LHCB-PAPER-2021-035

- Run 1+2 dataset (9 fb^{-1})
- 8 angular observables and 8 angular asymmetries based θ_μ, θ_h and ϕ. For example:

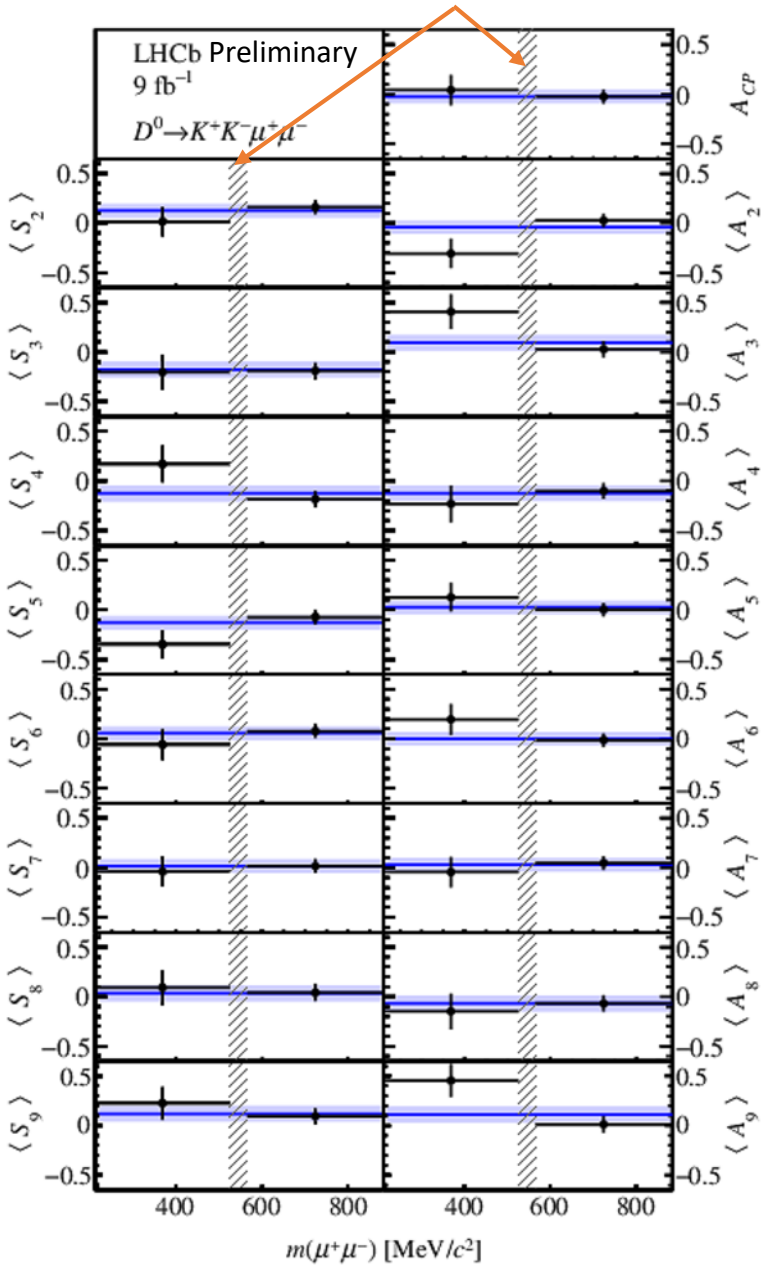
$$\langle I_2 \rangle = \frac{\Gamma(|\cos\theta_\mu| > 0.5) - \Gamma(|\cos\theta_\mu| < 0.5)}{\Gamma(|\cos\theta_\mu| > 0.5) + \Gamma(|\cos\theta_\mu| < 0.5)}$$

- CP averages and asymmetries are constructed based on the observables for D_0 and $\bar{D}_0$ in addition to the A_{CP}
- First full angular analysis of a rare charm decay ever performed
- The results are consistent with expectations from the Standard Model and with CP symmetry





η region [525,565] GeV/c^2



Study of the B_c^+ decays into charmonia and three light hadrons

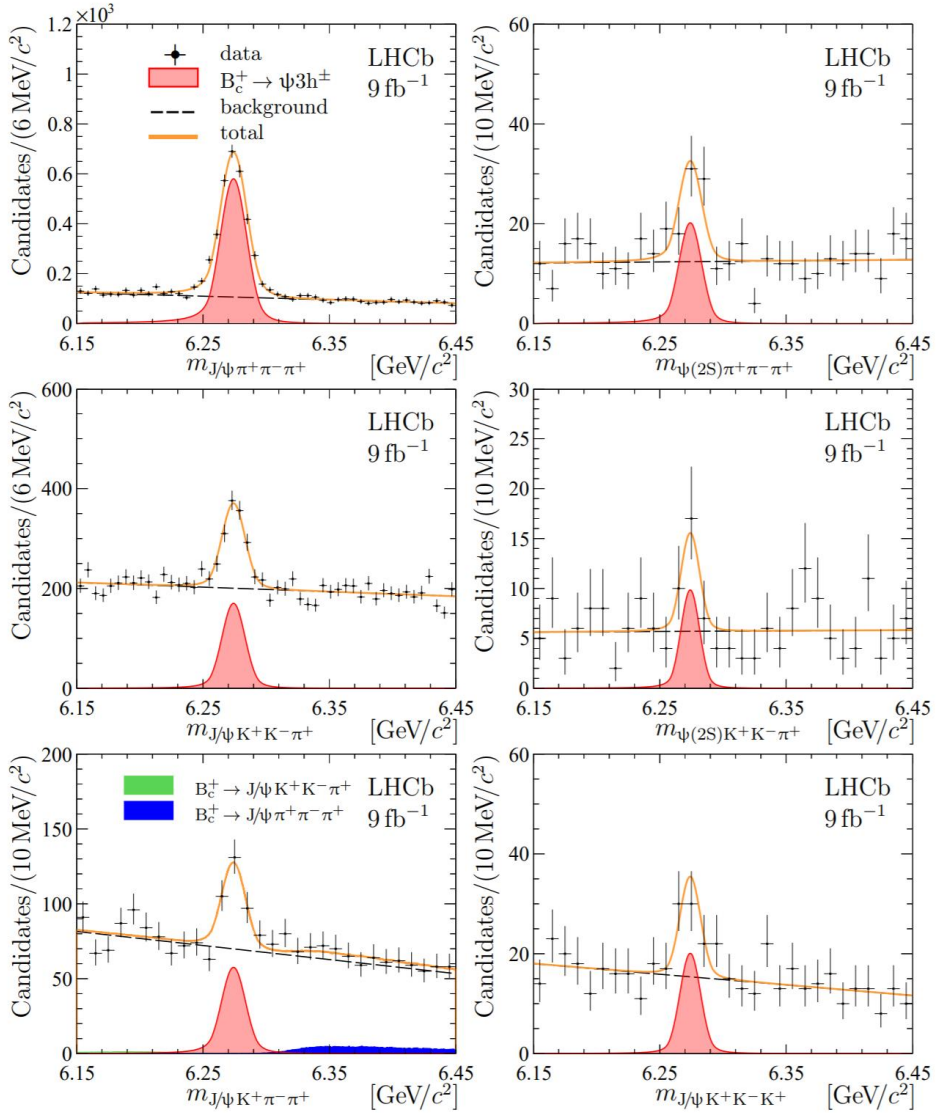
LHCB-PAPER-2021-034

- Run 1+2 dataset (9 fb^{-1})
- Simultaneous extended unbinned maximum-likelihood fit to the six mass and a two-dimensional distribution of $m_{J/\psi\pi^+\pi^-\pi^+}$ and $m_{J/\psi\pi^+\pi^-}$ (for $B_c^+ \to (\psi(2S) \to J/\psi\pi^+\pi^-)\pi^+$
- Many new B_c^+ decays observed:

1. $B_c^+ \to \psi(2S)\pi^+\pi^-\pi^+$ (5.8σ)
2. $B_c^+ \to J/\psi K^+K^-K^+$ (5.2σ)
3. $B_c^+ \to J/\psi K^+\pi^-\pi^+$ (7.8σ)
4. $B_c^+ \to \psi(2S)\pi^+$ with $\psi(2S) \to J/\psi\pi^+\pi^-$ (11.8σ)

- Evidence of $B_c^+ \to \psi(2S)K^+K^-\pi^+$ (3.7σ)
- Results are compatible with factorization of the $B_c^+ \to \psi 3h^\pm$ decays

	Value $[10^{-2}]$
$\mathcal{R}^{J/\psi\,K^+K^-K^+}_{J/\psi\,K^+K^-\pi^+}$	$7.0 \pm 1.8 \pm 0.2$
$\mathcal{R}^{J/\psi\,K^+\pi^-\pi^+}_{J/\psi\,\pi^+\pi^-\pi^+}$	$6.4 \pm 1.0 \pm 0.2$



Tests of lepton universality using $B^0 \to K_s^0 \ell^+ \ell^-$ and $B^+ \to K^{*+} \ell^+ \ell^-$ decays

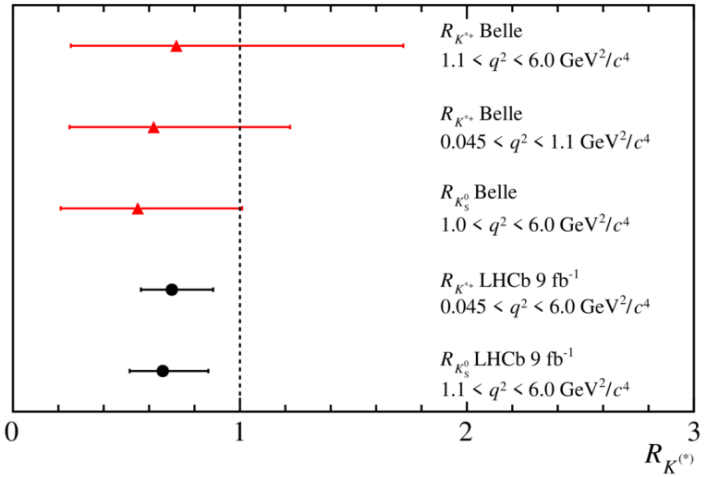
LHCB-PAPER-2021-038

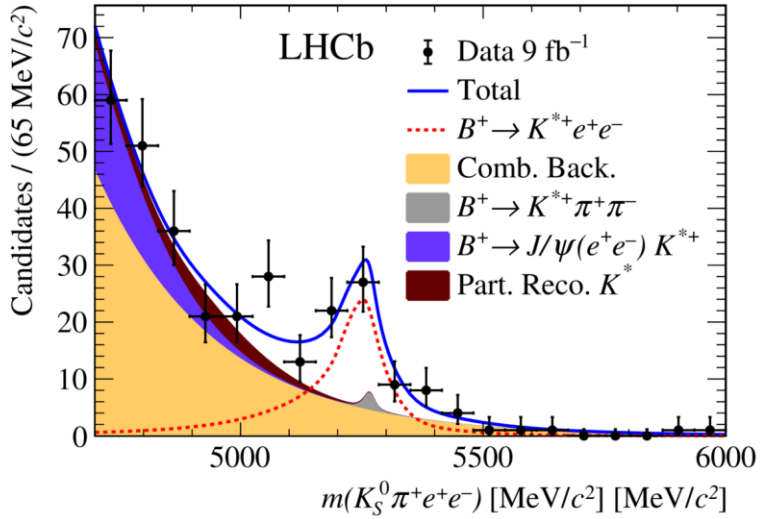
CERN seminar Oct 19th

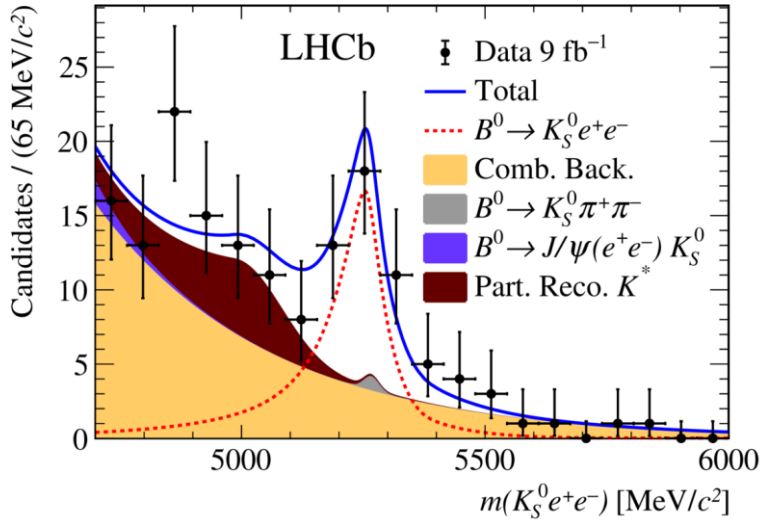
- **Recent dedicated workshop on Flavour Anomaly**
- **New lepton flavour universality test with K_s^0 and K^{*+}**
- Run 1 and 2 datasets
- First observation of $B^0 \to K_s^0 e^+ e^-$ and $B^+ \to K^{*+} e^+ e^-$ with 5.3σ and 6σ respectively
- Double ratio between non-resonant and resonant modes largely cancels the hadronic systematic effects :
  - $R_{H_s} = \frac{B(H_B \to H_S \mu^+ \mu^-)}{B(H_B \to H_S\, J/\psi(\mu^+\mu^-)} \Big/ \frac{B(H_B \to H_S e^+ e^-)}{B(H_B \to H_S\, J/\psi(e^+e^-)}$
- J/ψ satisfies lepton universality at 0.4% precision (PDG)

Values consistent with SM at 1.5σ and 1.4σ, with combined significance of 2σ

Precision is limited but same trend showing deficit of muons as in previous measurements







Final remarks

Wide physics programme including rare decays, EW, flavour and LFU tests

- New lepton flavour universality (LFU) test through $\mathrm{B}^0 \to K_S^0 \ell^+ \ell^-$ and $B^+ \to K^{*+} \ell^+ \ell^-$
- Most precise Z cross section in the forward region
- Dominating contribution to the world average γ average with the most precise single experiment measurement (constantly updated with new or updated measurements)

LHCb upgrade I

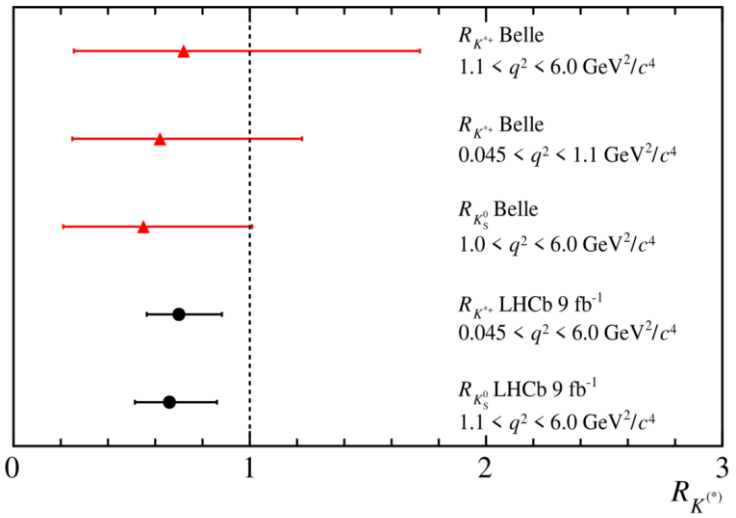
- Many subsystems already installed and profited from the fruitful beam test in Oct/Nov
- Tight schedule for some of the subsystems (VELO, UT and Scifi)

LHCb upgrade II

- FTDR defining the baseline design and R&D roadmap
  - In review with LHCC

Exciting and challenging times ahead! Especially with the beginning of Run 3!

R(K_S^0) and R(K^{*+})



First rings in RICH2