Status of LHCb

- Collaboration matters
- Run 1 + Run 2 summary
- Physics output and selected physics results
- The LHCb upgrade
- Conclusions and outlook

G. Passaleva

INFN – Florence and CERN

On behalf of the LHCb collaboration

RRB – 29/04/2020

Collaboration matters

- The collaboration keeps growing. Four new groups joined the collaboration as associate members:
  - ★ Helmholtz-Institut für Strahlen-und Kernphysik (HISKP) at Bonn University (Bonn, Germany)
  - ★ La Salle-Universitat Ramon Llull (Barcelona, Spain)
  - ★ Maastricht University (Maastricht, The Netherlands)
  - ★ INFN and University of Perugia (Perugia, Italy).

- The new LHCb Spokesperson elect is Prof Chris Parkes (Manchester University, UK). He will take over in July for three years.

- The new Physics Coordinator elect is Dr Niels Tuning (Nikhef, The Netherlands). He will take over in August for two years.

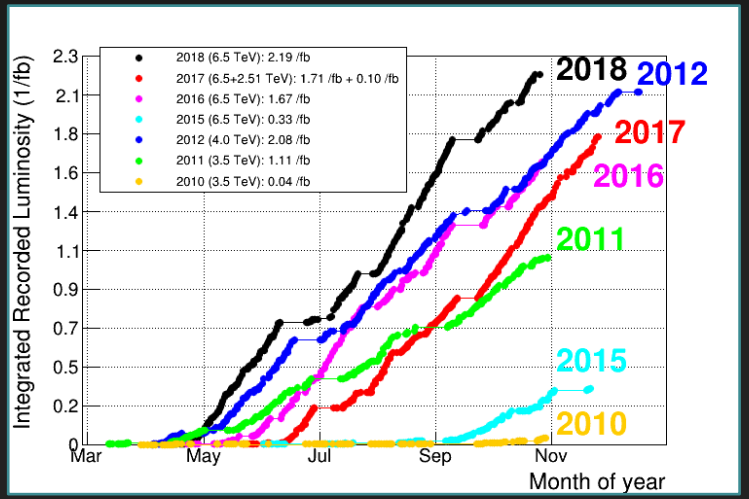
Run 1 + Run 2 summary

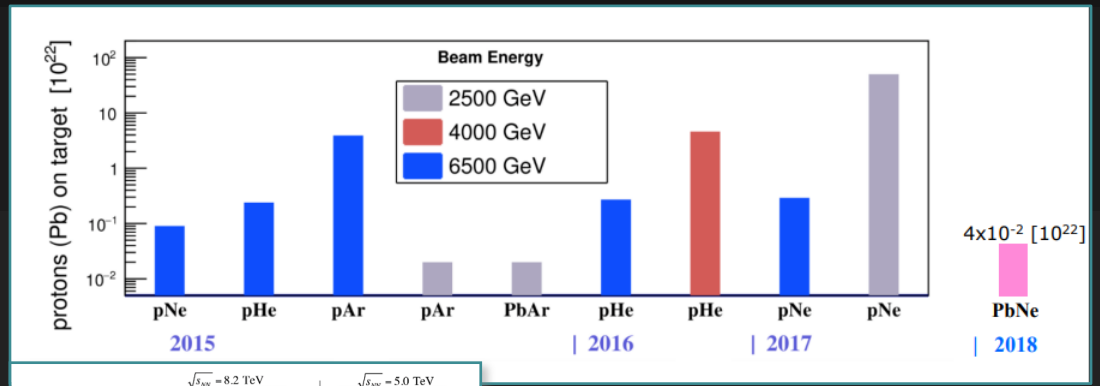
At work on our legacy data

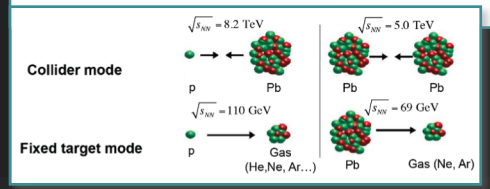
Run 1 + Run 2: a lot of data to analyse…

- A lot of data to analyse
- High statistics implies stricter control of systematics
- Calibration, reprocessing, control samples…

- Different c.o.m. energies
- Collider mode
- Fixed target mode
- Combined
- p-p, Pb-Pb, p-Pb, p-A, Pb-A (A= He, Ne, Ar)

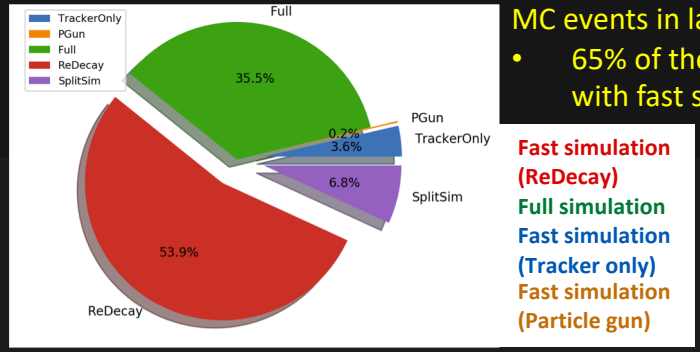






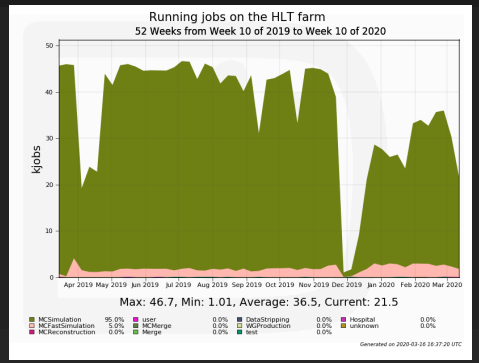
Operations: offline computing

- Intense and complex operation activities during LS2
  - ★ Monte Carlo productions are using ~90% of the computing power
  - ★ Using the online farm for MC production: ~40% of the sample.
  - ★ About a factor 2 more MC events produced in 2019, thanks to fast simulation (~75% of the Monte Carlo events).

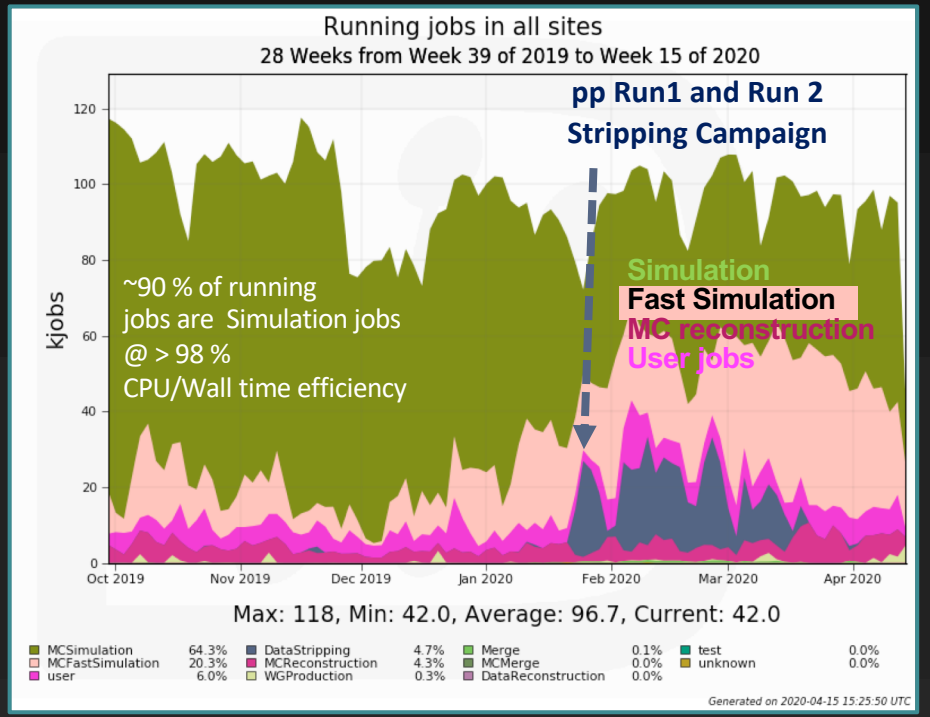


MC events in last 365 days
- 65% of the events produced with fast simulation

Fast simulation (ReDecay)
Full simulation
Fast simulation (Tracker only)
Fast simulation (Particle gun)



MC events in last 365 days
- 40% of the events produced on the online farm



Operations: Run 1 + Run 2 data reprocessing campaign

- Full Run 1 + Run 2 reprocessing. Up to date calibrations and pre-selections (“Stripping”*)
- Reprocessing of full pp Run1 and Run2 data for the legacy measurements completed
- Reprocessing of heavy ion and fixed target data samples ongoing.
- A monumental work that engaged our operation and computing teams for ~2 years

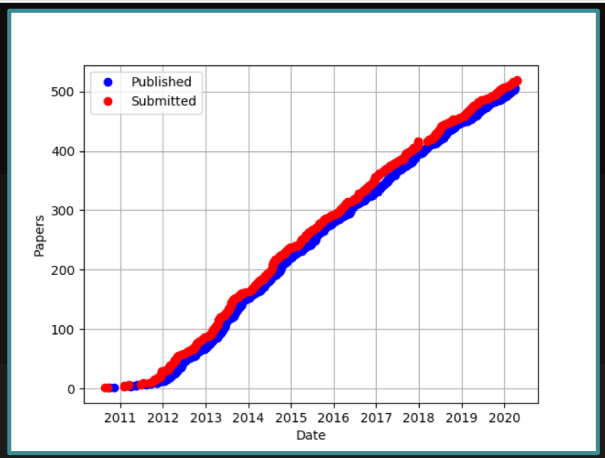
Data set		Status
pp Runs	2018	completed
	2011 and 2012	completed
	2015 and 2016	completed
	2017	completed
Ions Runs	2017 pNe	completed
	2018 PbPb	Under test
	2018 PbNe	Under preparation

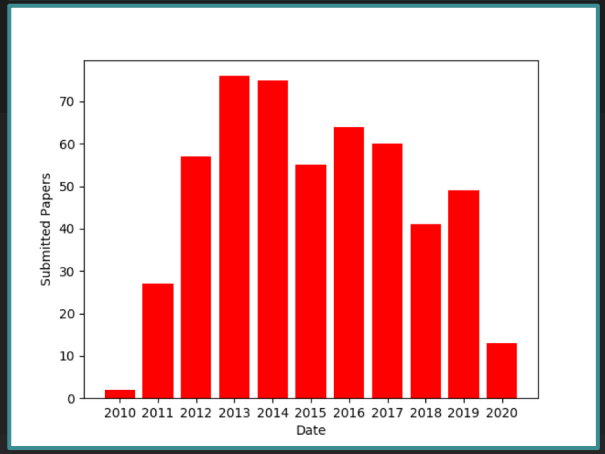
*Stripping sorts the data into streams and applies a dedicated offline selection for each analysis

Physics: paper production

- 519 papers (submitted + published) total – 49 in 2019, 13 in 2020
- +4 Conference Notes
- +23 papers since Oct ‘19 RRB

- 7 more being processed by Editorial Board
- 39 further under collaboration review, several more under working group review

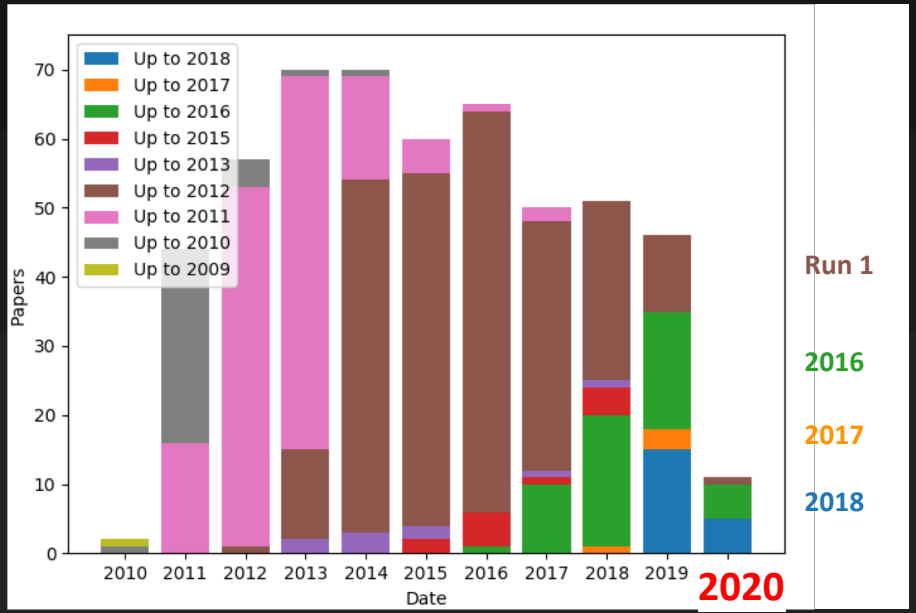




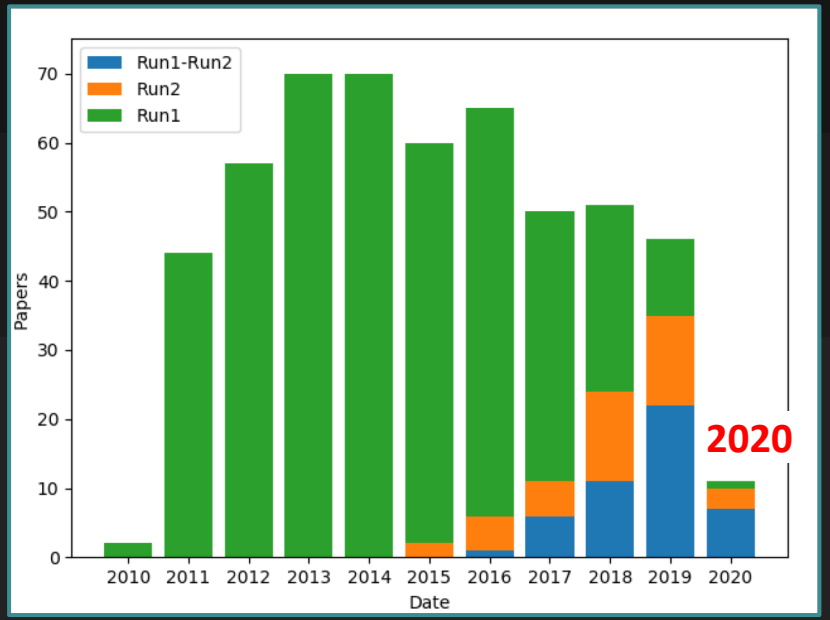
Year of submission

Physics: paper production

- Analysis of full Run 2 data in full swing!
- Substantially growing number of Run 1+ Run 2 analyses
- Several with full Run 1+ Run 2 dataset



Year of approval



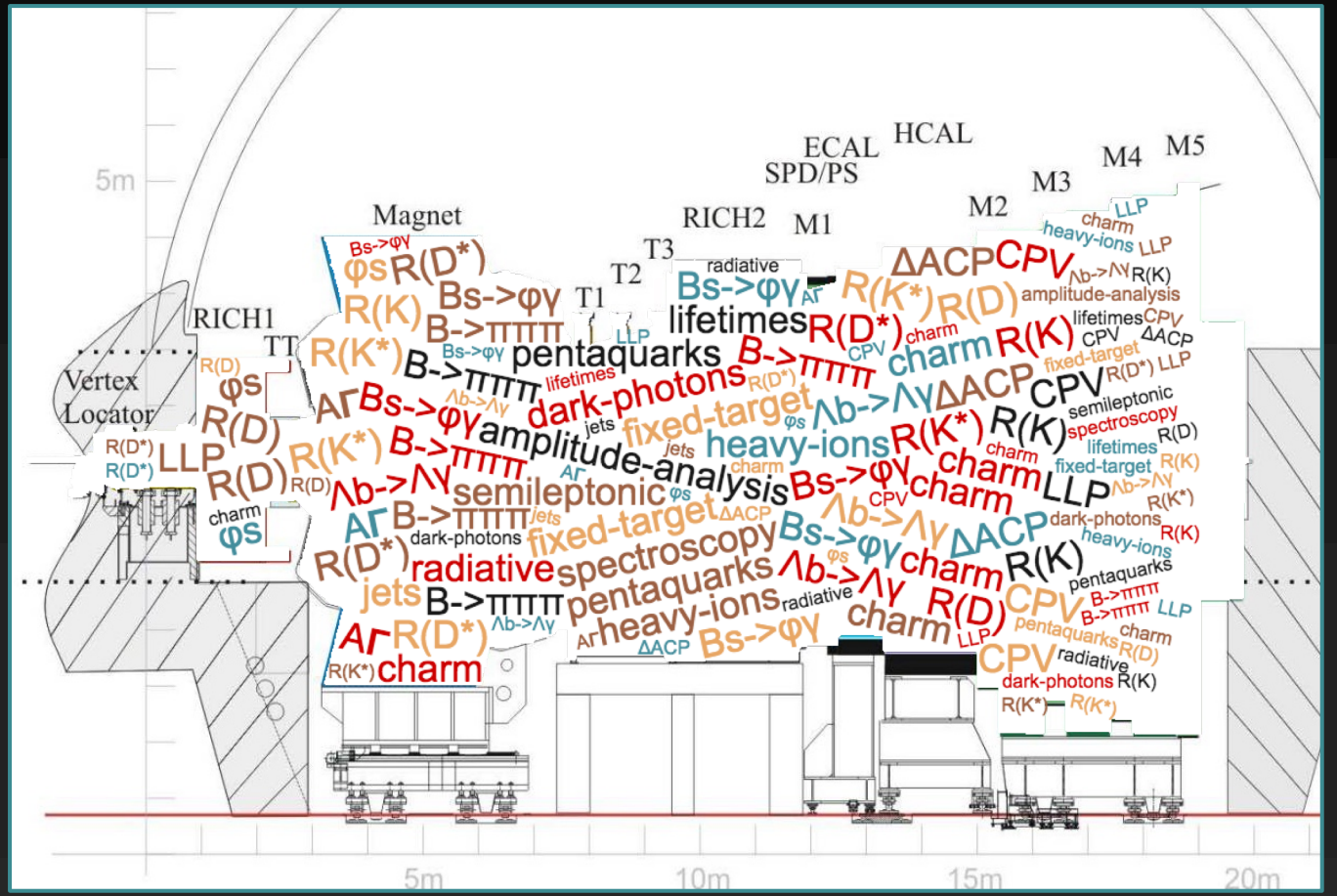
Year of approval

Selected physics results

An overview of recent physics highlights

Recent physics highlights

- Many new results published this year
- Increasing number exploiting the full Run 1 + Run 2 data set (9 fb^{-1})
- Will show only a few of them



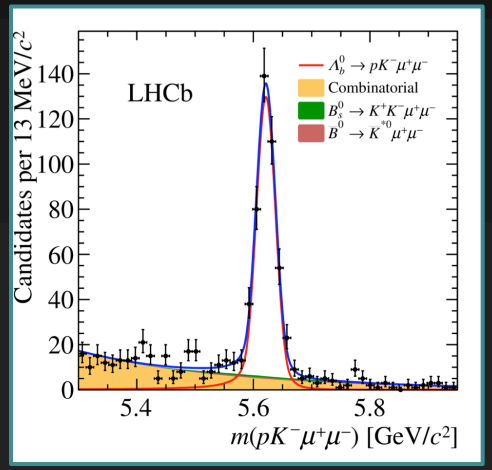
Rare decays

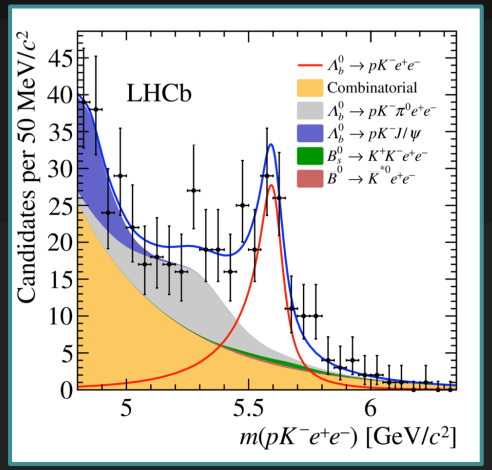
- *Test of lepton flavour universality in baryon decays*
- *Angular analysis of $B^0 \longrightarrow K^*\mu^+\mu^-$ decays*

Test of lepton universality with $\Lambda^0_b \to pK^-\ell^+\ell^-$ decays

[arXiv:1912.08139, Run1+Run2 4.7 fb^{-1}]

- First test of LFU with baryons
- Measure the ratio $R^{-1}_{pK} = \dfrac{\mathcal{B}\left(\Lambda_b^0 \to pK^- e^+ e^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to pK^- J/\psi(\to e^+e^-)\right)} \Big/ \dfrac{\mathcal{B}\left(\Lambda_b^0 \to pK^- \mu^+ \mu^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to pK^- J/\psi(\to \mu^+\mu^-)\right)}$
- dilepton mass-squared range: $0.1 < q^2 < 6$ GeV^2





First observation of this decay

$$R^{-1}_{pK} = 1.17^{+0.18}_{-0.16} \pm 0.07$$

For comparison with other LFU tests:

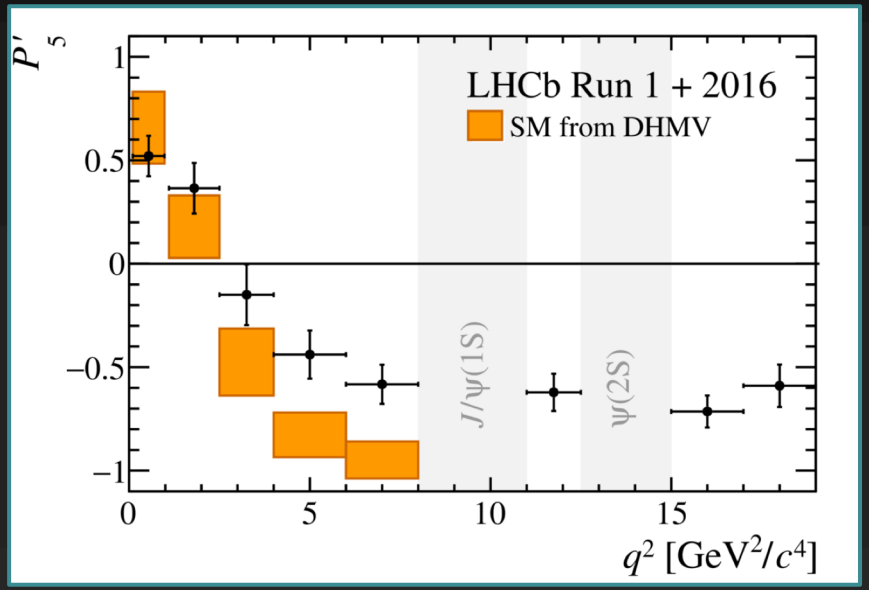
$$R_{pK} = 0.86^{+0.14}_{-0.11} \pm 0.05$$

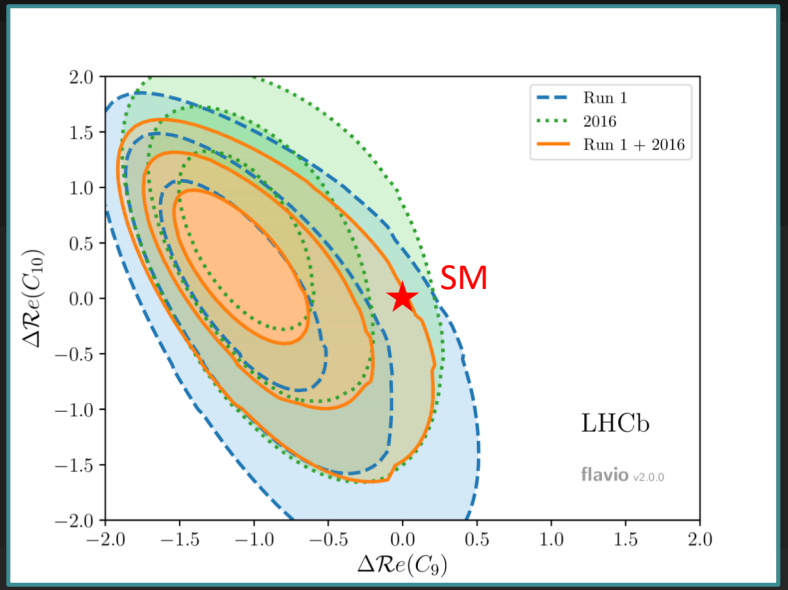
Results compatible with the SM within 1σ
Intriguingly again on the low side…

Angular analysis of $B^0 \to K^*\mu^+\mu^-$ decays

[arXiv:2003.04831, Run1+Run2 4.7 fb^{-1}]

- Rare decay strongly suppressed in the SM ☞ very sensitive to new physics
- A set of optimised observables can be extracted from the angular distributions(the $P^{(\prime)}_i$ variables)
- Distinctive local tension in P'_5 seen by LHCb and other collaborations
- New analysis with x2 statistics with respect to the previous.
- Results compatible with previous analysis. Interpretation within an effective theory favours a deviation from the SM at the level of 3.3σ (caution: model-dependent)





CP violation measurements

- *Search for additional CP violation sources in charm (A_Γ)*

By Tobias R. – Metoc - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2520370

CPV in charm

- Now that direct CP violation is established, look for additional CPV sources
- A_Γ is the "holy grail" – sensitive to new physics
- It can be extracted from time-dependent CPV measurements

$$A_{CP}(f,t) \equiv \frac{\Gamma(D^0 \to f,t) - \Gamma(\bar{D}^0 \to f,t)}{\Gamma(D^0 \to f,t) + \Gamma(\bar{D}^0 \to f,t)}$$

$$\approx a_{CP}^{dir}(f) - \frac{t}{\tau_{D^0}} A_\Gamma(f) \quad (f = \pi^+\pi^-/K^+K^-)$$

$$A_\Gamma = (-2.9 \pm 2.0 \pm 0.6) \times 10^{-4}$$

Semileptonic D^0 tagging

- Combining with PRELIMINARY result from LHCb-CONF-2019-001

$$A_\Gamma = (-1.1 \pm 1.7 \pm 0.5) \times 10^{-4}$$

LHCb preliminary

- Still statistically limited
- Need Upgrade II to reach sensitivity to SM

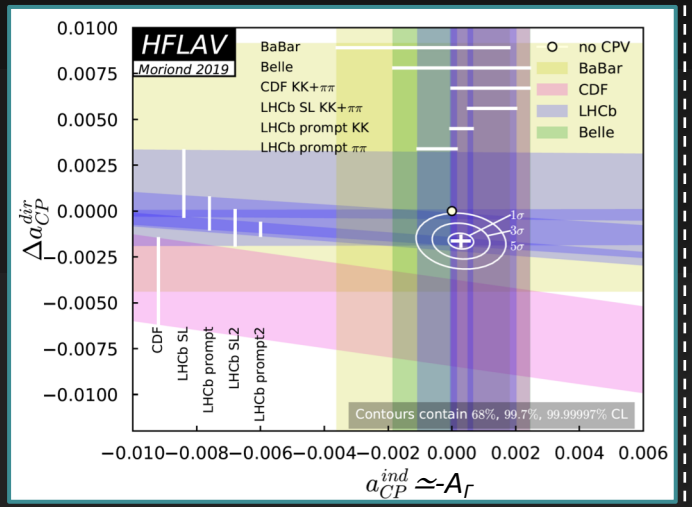
[Phys. Rev. D101 (2020) 012005, Run1+Run2 9fb^{-1}]

$$\Delta A_{CP} \approx \Delta a_{CP}^{dir} - \frac{\Delta\langle t\rangle}{\tau_{D^0}} A_\Gamma$$

~-a_{CP}^{ind}

ΔA_{CP} = (-15.4 ± 2.9)x10^{-4}

[Phys. Rev. Lett. 122 (2019) 211803, Run1+Run2 9 fb^{-1}]

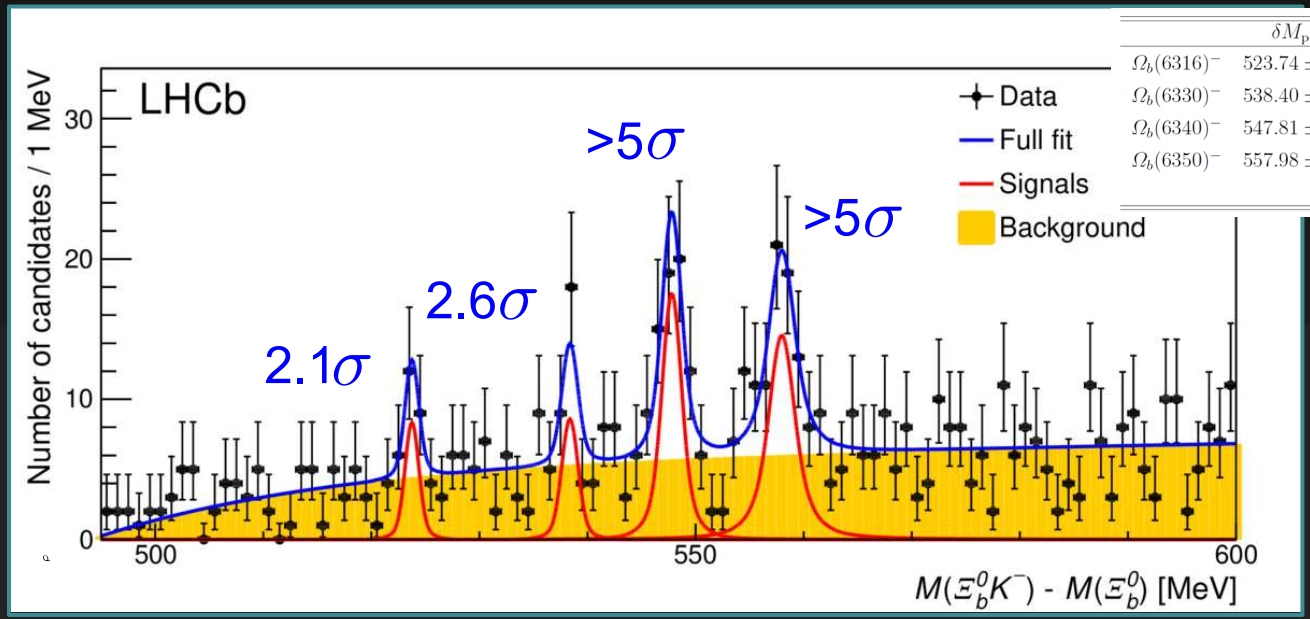


Spectroscopy

- *First observation of excited Ω_b^- states*

First observation of excited Ω_b^- states

- Great interest on LHCb observation of five new Ω_c^0 resonances (css) [arXiv:2001.00851, Run1+Run2 9 fb^{-1}]
  [Phys. Rev. Lett.118(2017) 182001]
- ☞ Search for excited Ω_b^- (bss – *b* counterpart or the Ω_c^0 resonances) states particularly interesting
- Four narrow peaks seen for the first time, two of them with large statistical significance



	δM_{peak} [MeV]	Mass [MeV]	Width [MeV]
$\Omega_b(6316)^-$	$523.74 \pm 0.31 \pm 0.07$	$6315.64 \pm 0.31 \pm 0.07 \pm 0.50$	< 2.8 (4.2)
$\Omega_b(6330)^-$	$538.40 \pm 0.28 \pm 0.07$	$6330.30 \pm 0.28 \pm 0.07 \pm 0.50$	< 3.1 (4.7)
$\Omega_b(6340)^-$	$547.81 \pm 0.26 \pm 0.05$	$6339.71 \pm 0.26 \pm 0.05 \pm 0.50$	< 1.5 (1.8)
$\Omega_b(6350)^-$	$557.98 \pm 0.35 \pm 0.05$	$6349.88 \pm 0.35 \pm 0.05 \pm 0.50$	< 2.8 (3.2)
			$1.4^{+1.0}_{-0.8} \pm 0.1$

- With this and many other results LHCb keeps providing world-leading results in the domain of hadron spectroscopy

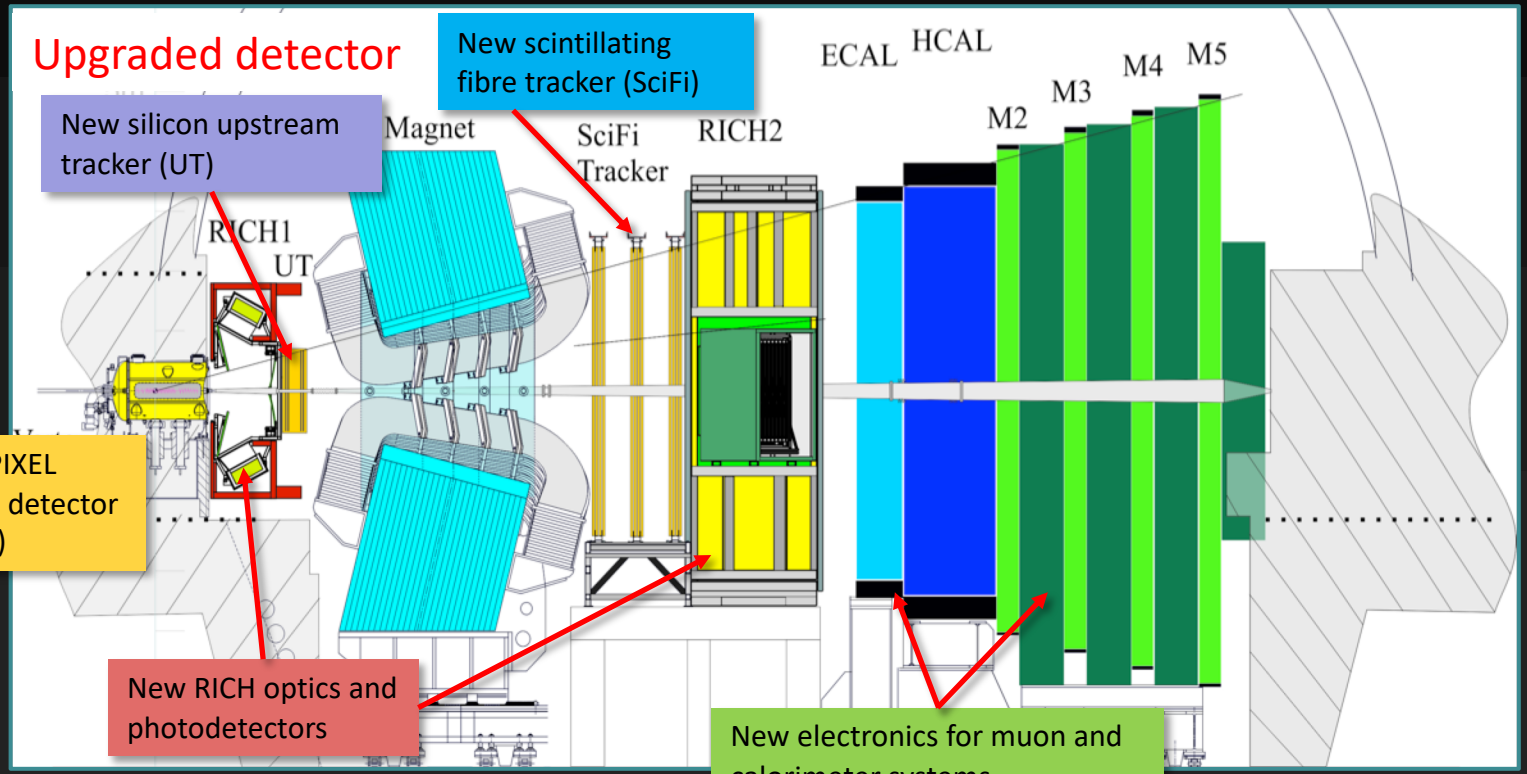
LHCb Upgrades

Moving towards Run 3…

…or: the status before COVID-19

LHCb Upgrade I in a snapshot

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



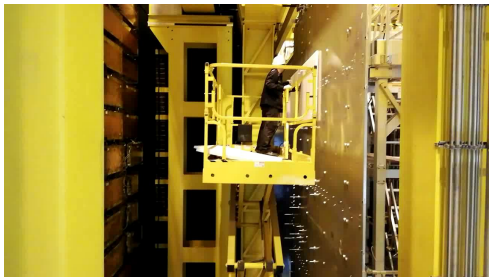
[LHCB-TDR-12]
[LHCB-TDR-13]
[LHCB-TDR-14]
[LHCB-TDR-15]
[LHCB-TDR-16]
[LHCB-TDR-17]
[LHCB-TDR-18]

L_{int} = 50 fb^{-1}
L = 2x10^{33}cm^{-2}s^{-1}

Very intense activity at LHCb site throughout LS2 !

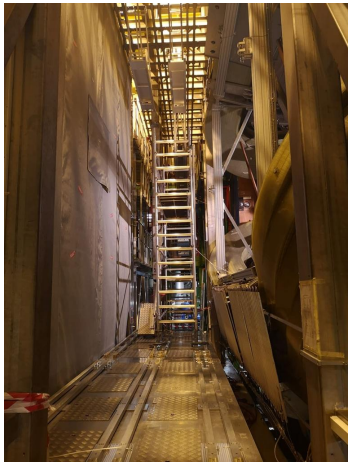
- All old detectors and obsolete equipment removed
- Installation of services nearly completed: ready to install and test detectors

SciFi neutron shielding installation on M1 wall



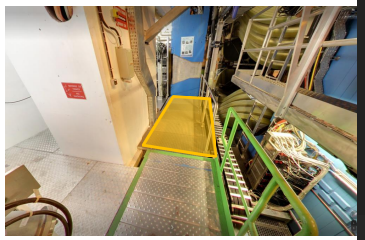
Cooling plants installation

Platforms modifications



Cables installation

new HCAL beam shielding



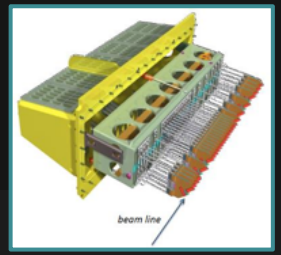
Will discuss later on impact of covid-19 lockdown

Upgrade: construction

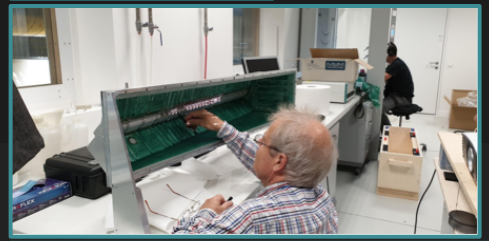
Working… (and preparing to restart full steam)

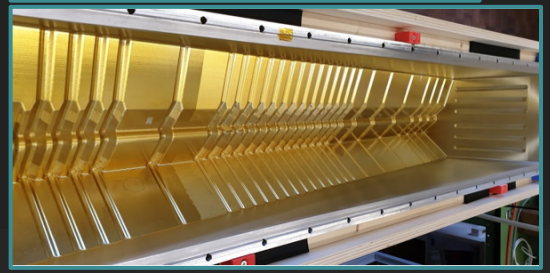
Upgrade: VELO

- Module production delayed due to assembly problem was resumed in February
- RF foil etched and coated, ready for installation
- All other parts of the project progressing well

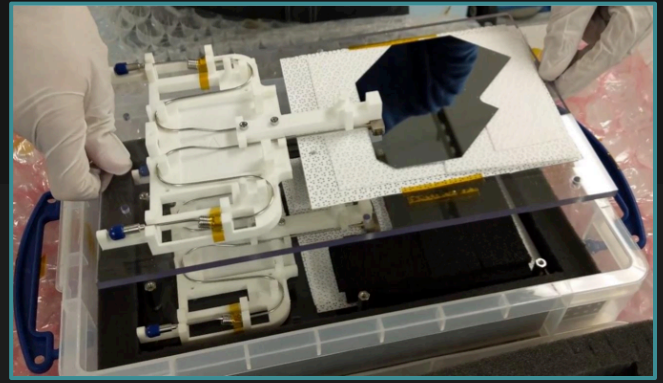


RF foil treatment: etching to 150µm, torlon internal coating,
NEG outer coating preparation

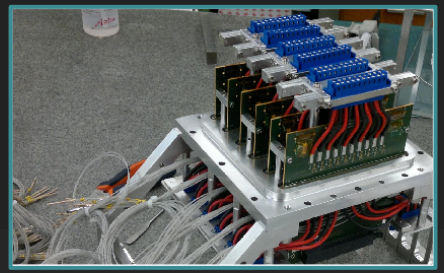




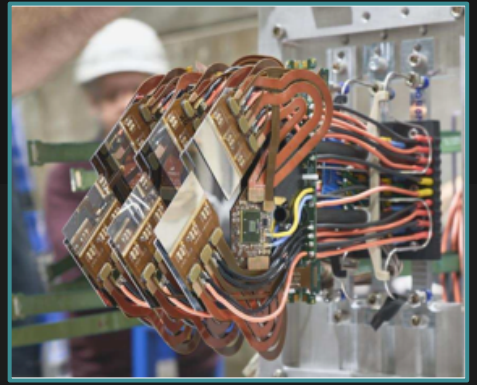
Preparation of µ-channel cooling plates



Vacuum Feed Through being assembled



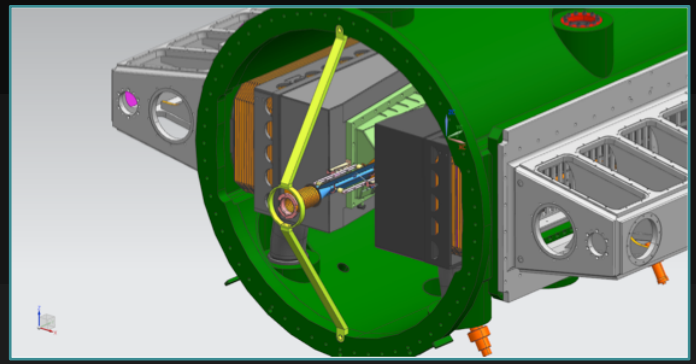
VELO modules

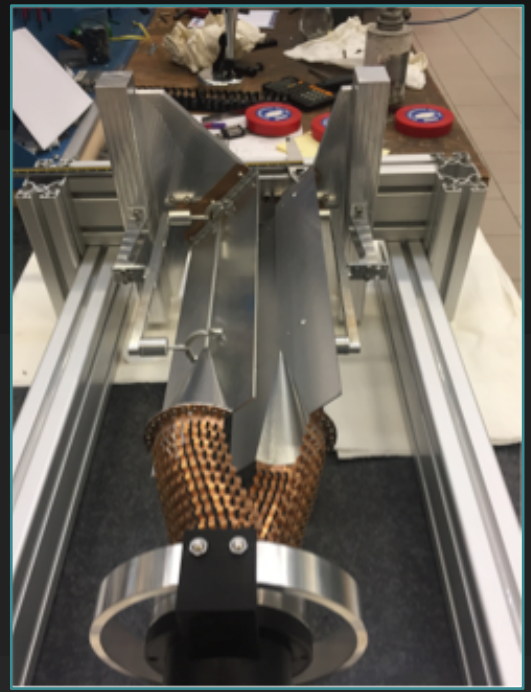


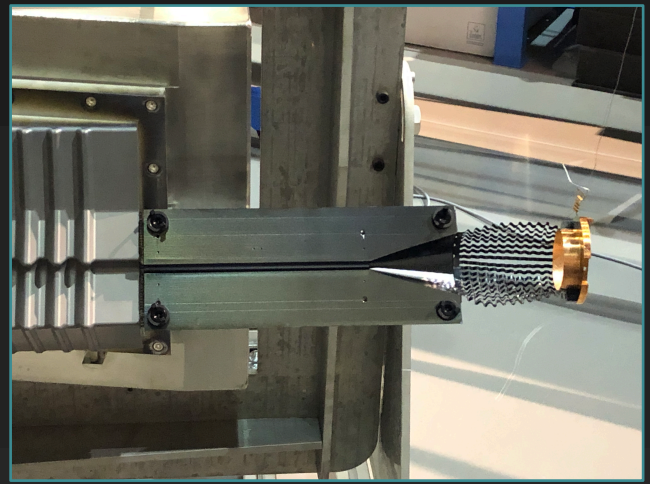
preparation @P8 for RF foil installation

Upgrade: SMOG2

- New fixed target system (SMOG2): based on a gas storage cell connected to VELO
  - ★ Significant increase of the luminosity for fixed-target collisions
- SMOG2 system ready to be installed together with VELO RF foil





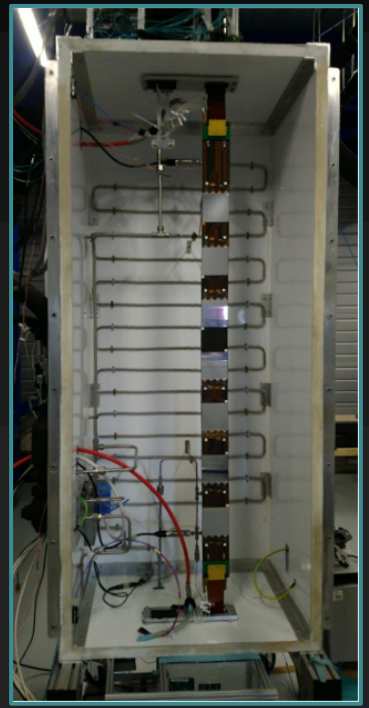


Upgrade: Upstream Tracker

- Mass production of staves started ⇒ soon shipments to CERN for assembly
- Installation delayed due know issues with ASIC, tight schedule

staves construction chain: mechanical support, cooling pipes, flex cables

wire-bonded modules mounted on staves

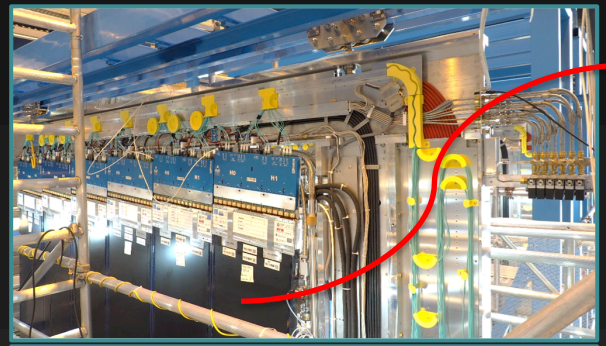


stave installation in assembly hall at CERN

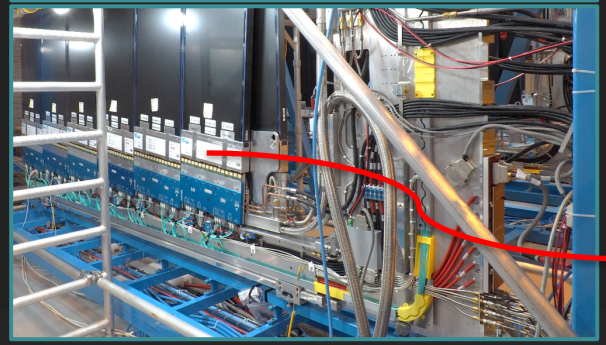
detail of the 10x10 cm^2 UT sensors

Upgrade: SciFi

- Installation of first C-frame was completed early this year
- 3/12 C-frames well advanced – need to install 6/12 before beam pipe installation – Tight schedule!



SciFi Modules

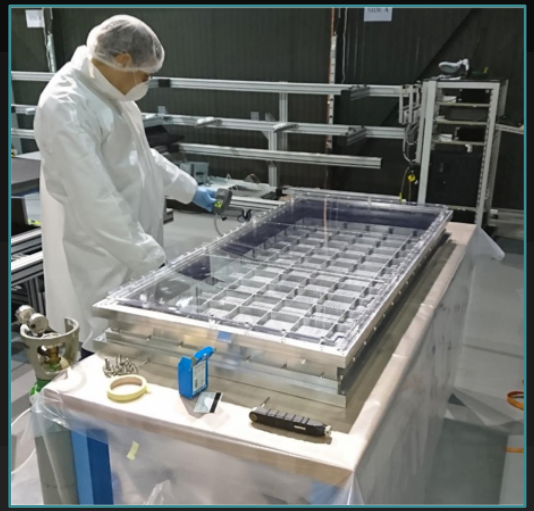


"cold boxes" with SiPM (-40 C)

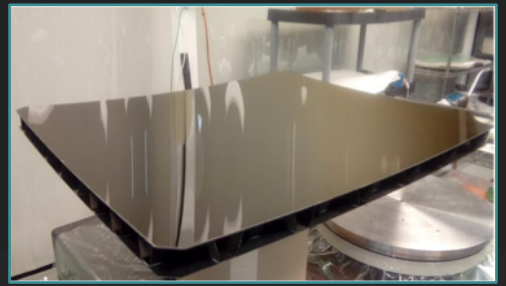
Transport and integration test in the cavern performed in preparation for installation

Upgrade: RICH

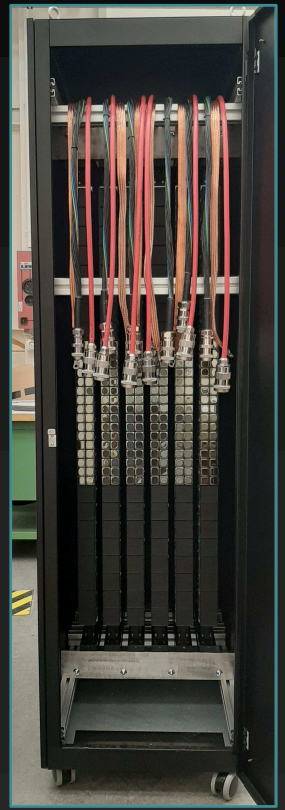
New quartz window developed and installed on a new supporting frame
More work on the gas enclosure needed before installation



Spherical mirrors have been coated at CERN and ready

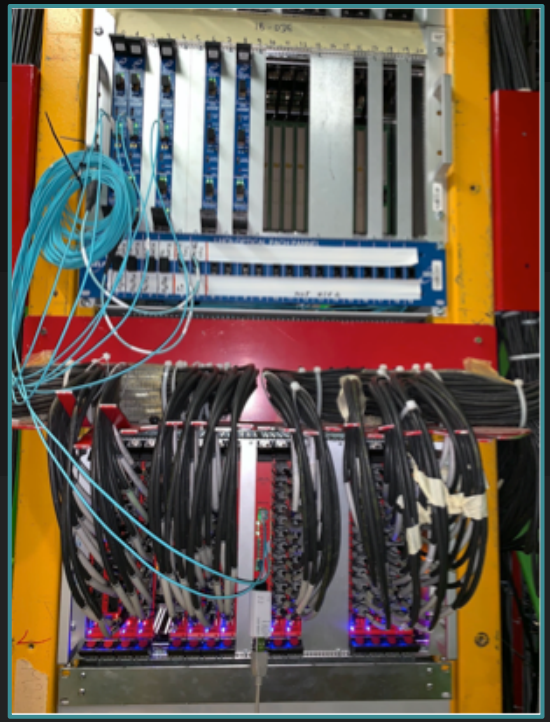


Production and qualification of photon detectors completed
Production and testing of electronics almost finished
Commissioning of photon detector columns well advanced



Upgrade: Calorimeters, Muon system

- Both systems progressing well

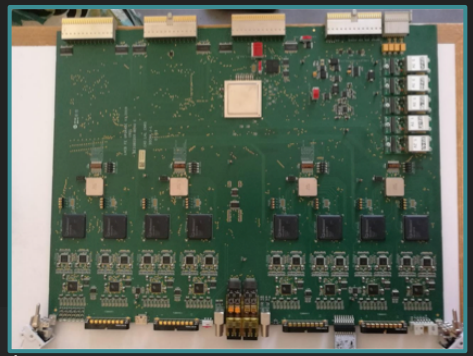


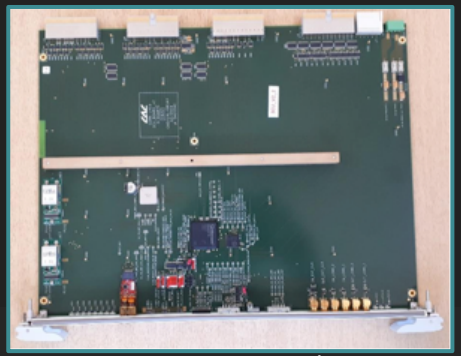
MUON commissioning ongoing at CERN: population of M4 and M5

Production of MUON electronics boards completed

Installation of patch panels for both ECAL and HCAL

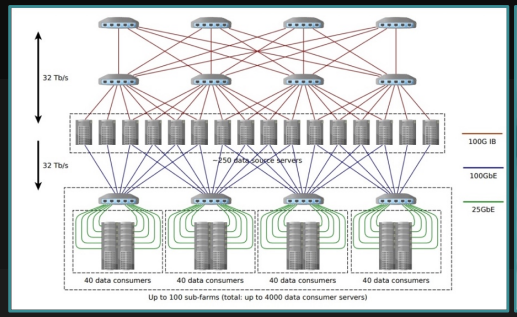
CALO FEB and control boards under production and test

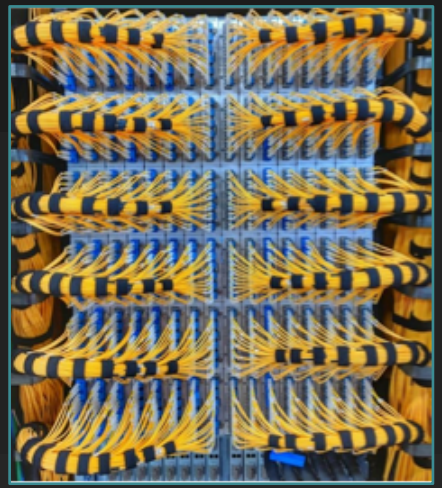




Upgrade: Online

- Construction and commissioning of common DAQ boards (PCIe40) almost completed.
- Event builder technology chosen (dedicated network)



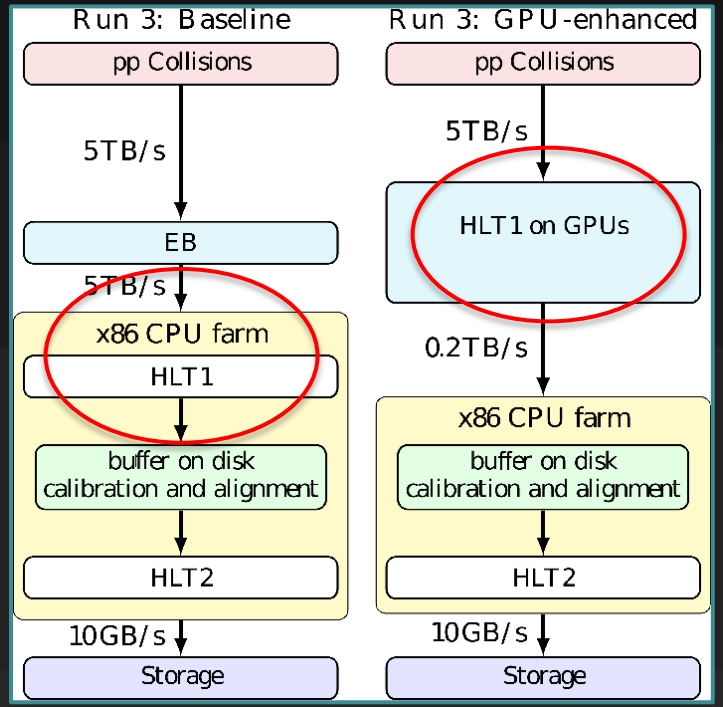


New data centre constructed, commissioned and connected to cavern via long distance fibres, old farm moved

Servers for Event Builder identified, order placed

Upgrade: full software trigger

- Development under the responsibility of the Real-Time Analysis Project (RTA)
- Development advancing – several HLT2 selections already in place.
- Two technology options for HLT1 – Review completed, final decision imminent




draft

LHCb-XXX-20YY-ZZZ
March 13, 2020

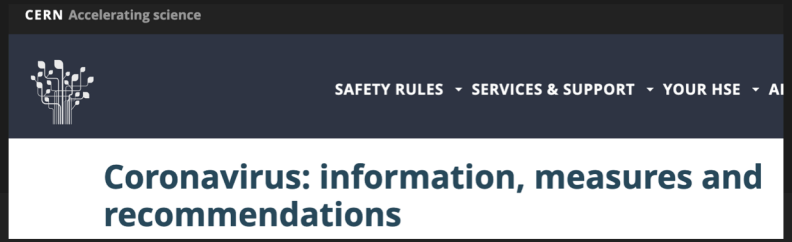
Technical design and performance of a GPU HLT1


draft

LHCb-TDR-2020-001
April 20, 2020

HLT1 Technology Comparison Document

Impact of COVID-19 crisis



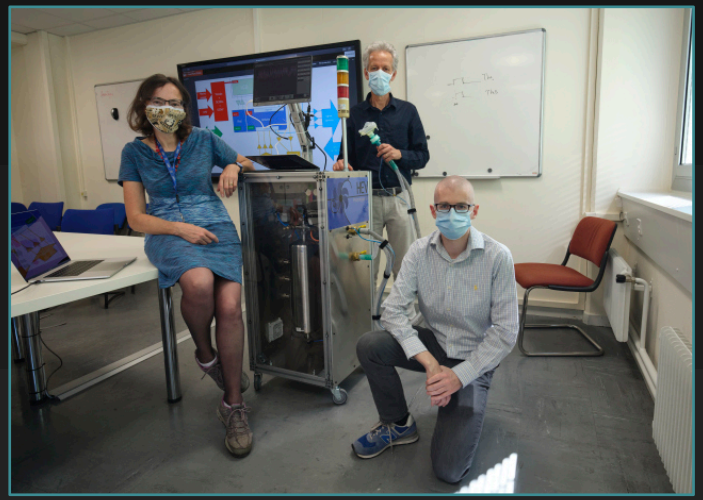
Impact of COVID-19 crisis

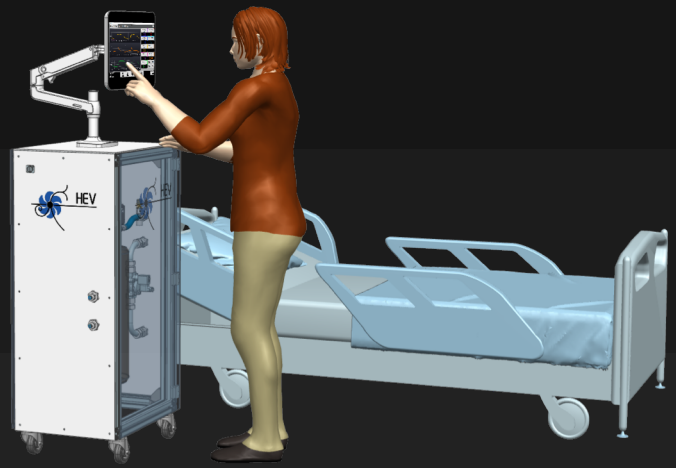
- Analysis activities still going on very well: ~50 analyses in final or review phase!
  - ★ Experience on video-only workshops and large meetings positive – e.g. workshop on future upgrades
- Following closely CERN management guidelines to prepare for the restart
  - ★ Preparation for cautious resumption of very selected high-priority activities
  - ★ few people, maintain physical distance – use of adequate PPEs – apply hygienic precautions.
- Planning a few “pilot” activities, for example:
  - ★ Installation of event-builder nodes (first batch, just arrived at CERN)
  - ★ Installation of RF foil
  - ★ Commissioning of RICH2 photon detector columns

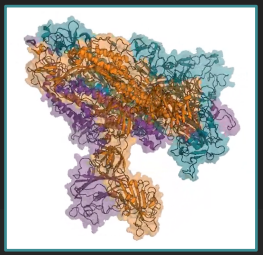
- Impact on upgrade activities still to be fully evaluated
  - ★ Roughly, the time of lock down until full resumption of work translates into a linear delay in all those areas that depend on physical intervention, i.e. all the upgrade construction work.
  - ★ Lockdown and travel restrictions in the various countries makes it difficult to re-build the construction and installation teams at CERN. Presumably this will restart slowly over summer
  - ★ For example: SciFi, VELO, UT rely heavily on personnel from US, UK, Germany, NL to be at CERN

“CERN against COVID-19” and LHCb

- Some LHCb members strongly involved in “CERN against COVID-19” initiative
  - ★ HEV ventilator – aimed at milder cases of the disease, design based on components that are cheap and easy to obtain







  - ★ Folding@home – LHCb trigger farm computing resources devoted to this worldwide initiative to study protein folding, including COVID-19. Mainly old HLT farm nodes

Conclusions and outlook

Conclusions and outlook

- The march towards the Upgrade I is continuing
  - ★ All subsystems progressing - installation ongoing
  - ★ Impact of COVID-19 to be fully assessed
  - ★ Preparing for the restart
- LHCb continues to provide a wealth of excellent physics results

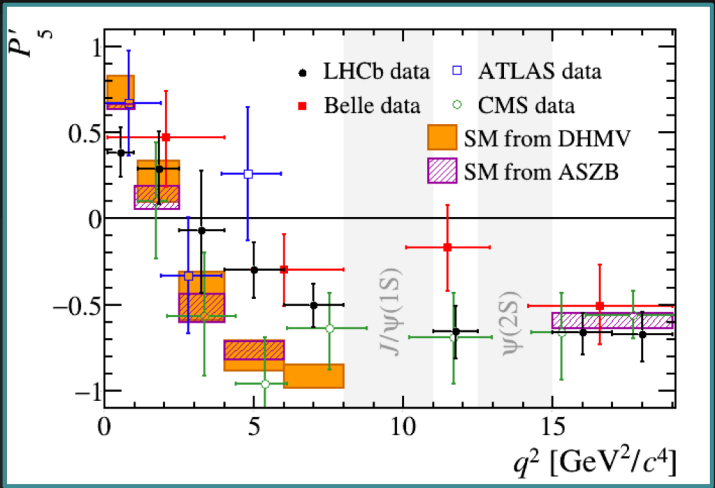
- This is my last RRB meeting as LHCb spokesperson
- Let me wholeheartedly thank all the Funding Agency delegates and the CERN management for the strong support given to LHCb throughout my mandate

Thank you !

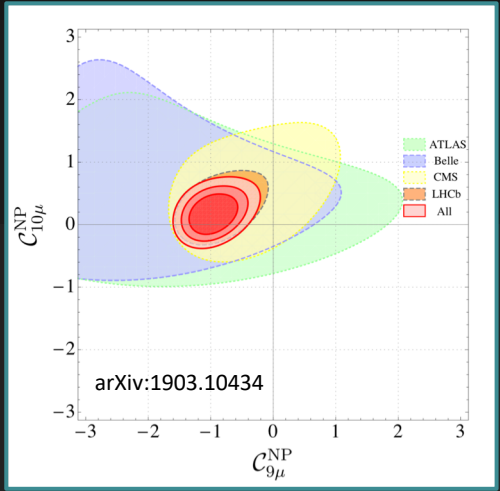
BACKUP SLIDES

Angular analysis of $B^0 \to K^*\mu^+\mu^-$ decays

- 3-body FCNC decays strongly suppressed in the SM ☞ very sensitive to new physics [arXiv:2003.04831, Run1+Run2 4.7 fb^{-1}]
- Final state containing a vector meson ☞ very rich angular structure, allows to extract several observables that can be compared with SM predictions
- A set of optimised observables can be defined where form factor uncertainties cancel at first order (the $P^{(\prime)}_i$ basis)
- Distinctive local tension in P'_5 seen by LHCb and other collaborations
- Interpretation of these results within an effective theory favours certain new-physics scenarios



Belle: PRL 118 (2017), **CMS:**PLB 781 (2018) 517541
LHCb: JHEP 02 (2016) 104, **ATLAS:** JHEP 10 (2018) 047

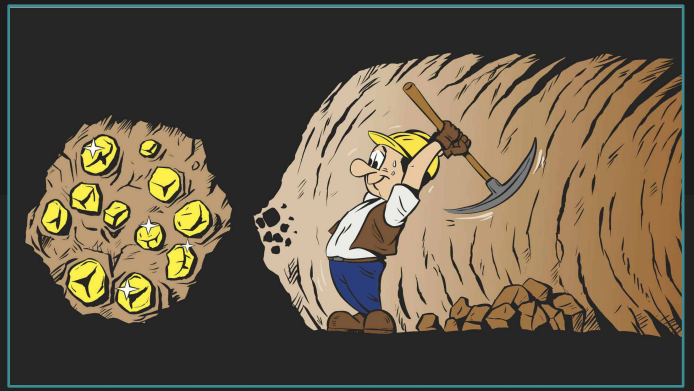


N.B. deviations from SM could be reabsorbed assuming large hadronic uncertainties, see e.g. JHEP06(2016) 116

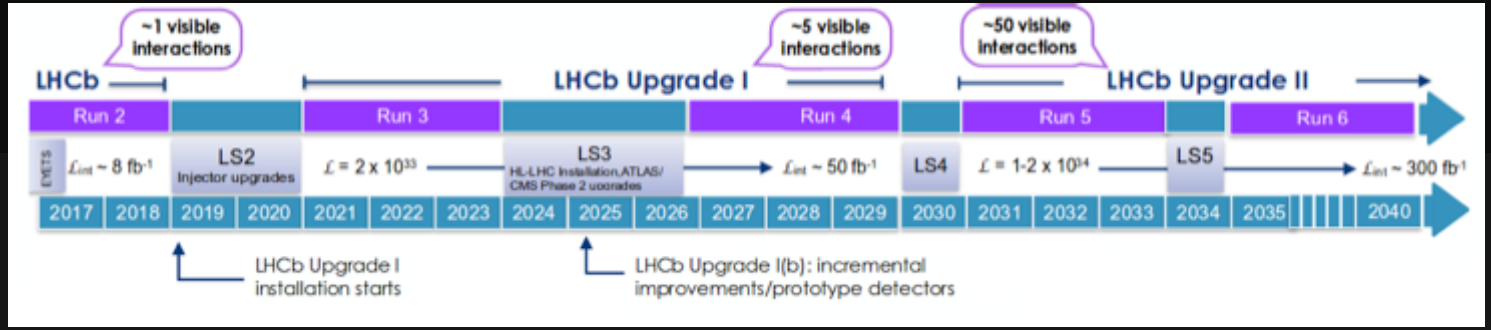
Non-exhaustive list of global fit examples: Eur. Phys. J. C79 (2019) 714, Phys. Rev. D100 (2019) 015045 Eur. Phys. J. C79 (2019) ,Eur. Phys. J. C79 (2019) 840, JHEP 06 (2019) 089

Upgrade II

LHCb Upgrade II: the ultimate exploitation of LHC for flavour physics



LHCb Upgrade II

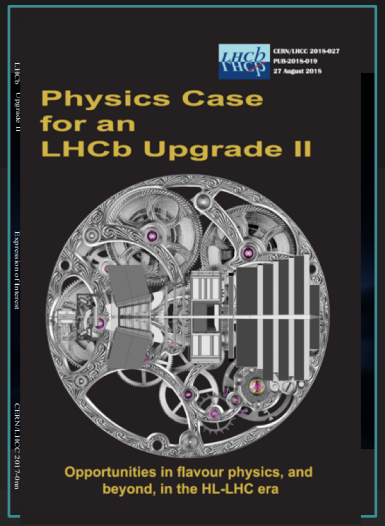


[arXiV:1808.08865]

- Aim to fully exploit HL-LHC for flavour physics and other opportunities in the forward direction
- Aim to collect > 300 fb^{-1} at L = 2x10^{34}, x10 with respect to Upgrade I
- Expression of Interest issued in 2017
- Feasibility study performed by LHC experts
- Physics case document released

[CERN-ACC-NOTE-2018-0038]

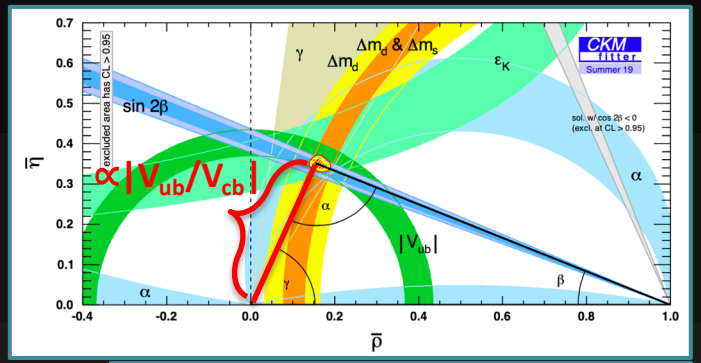
- Support for project in the "Physics Briefing Book : Input for the European Strategy for Particle Physics Update 2020" – "*The LHCb Upgrade II... will enable a wide range of flavour observables to be determined at HL-LHC with unprecedented precision*"
- Green light from LHCC and RB to proceed to a Framework TDR (expected 2021)



Measurement of $|V_{cb}|$ with $B_s^0 \to D_s^{(*)-} \mu^+ \nu_\mu$ decays

[arXiv:2001.03225, Run1 3fb^{-1}]

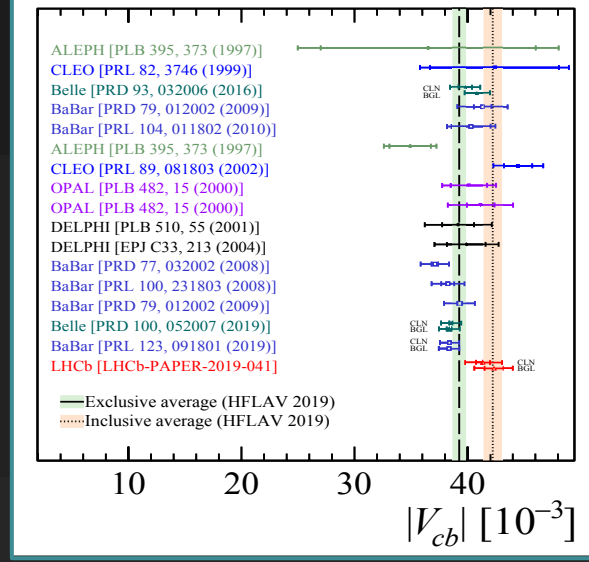
- Fundamental parameter of SM
- Need to measure it precisely to (over-) constrain the CKM Unitarity Triangle and spot possible new physics effects
- Problem: different measurement approaches ("inclusive" vs "exclusive") and parametrizations of hadronic effects (form-factors) used to give different results
- LHCb uses $B_s^0 \to D_s^{(*)-} \mu^+ \nu_\mu$ decays to measure $|V_{cb}|$ and constrain hadronic contributions (form-factors)
  - ★ Some advantage in using B_s^0 vs B^0 e.g. easier lattice-QCD calculations



- First determination of $|V_{cb}|$ from *exclusive* decays at a hadron collider and the first using B_s^0 decays:

$$|V_{cb}|_{\mathrm{CLN}} = (41.4 \pm 0.6(\mathrm{stat}) \pm 0.9(\mathrm{syst}) \pm 1.2(\mathrm{ext})) \times 10^{-3}$$
$$|V_{cb}|_{\mathrm{BGL}} = (42.3 \pm 0.8(\mathrm{stat}) \pm 0.9(\mathrm{syst}) \pm 1.2(\mathrm{ext})) \times 10^{-3}$$

- Results obtained using two different parametrizations of form-factors are compatible



…in a range of running modes!

- Different c.o.m. energies
- Collider mode
- Fixed target mode
- Combined
- p-p, Pb-Pb, p-Pb, p-A, Pb-A (A= He, Ne, Ar)

E (Z TeV)	$\sqrt{s_{NN}}$							
	pp		Pb-p		Pb-Pb		Xe-Xe	
	$\sqrt{s}=2E$		$\sqrt{s}=2E\sqrt{r}$		$\sqrt{s}=2Er$		$\sqrt{s}=2Er$	
1.38	2.76	2013						
2.51	5.02	2015 2017						
3.5	7	2011	4.40		2.76	2010 LHCb off		
4	8	2012	5.02	2013 2016	3.15			
6.37			8.00		5.02	2015 2018		
6.5	13	2015-2018	8.16	2016	5.13		5.44	2017