Status of LHCb Upgrade I

- 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 – 30/10/2019

Collaboration matters

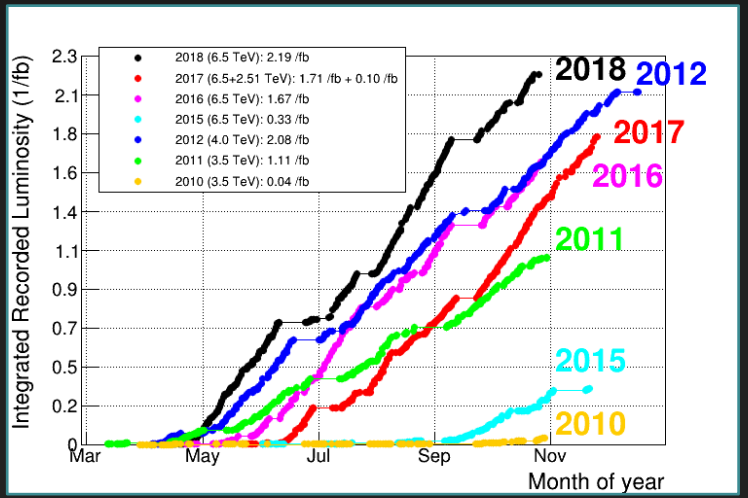
- The collaboration keeps growing
  - ★ Peking University (Beijing, China) joined as full member
  - ★ Valencia IFIC (Valencia, Spain) moved from associate to full member
  - ★ Monash University (Melbourne Australia) joined as associate member

Run 1 + Run 2 summary

A lot of physics in our granary

Luminosity 2010-2018: a round 10 fb^{-1}…

- Got exactly the target luminosity that was hinted at the times of the Technical Proposal (~1998)!



Including:
- 0.04 fb^{-1} 2010 and
- 0.13 fb^{-1} 2017 (√s=5TeV)

Integrated luminosity counters in 2018 [1/pb]

	Recorded	Delivered	Efficiency
Current Fill	0.0	0.0	0.0
Annual	2190.9	2456.5	89.2
Mag DOWN	1055.7	1174.1	89.92
Mag UP	1133.7	1280.8	88.51
2010-2018	9227.1	10180.9	90.63

Excluding:
- 0.04 fb^{-1} 2010 and
- 0.13 fb^{-1} 2017 (√s=5TeV)

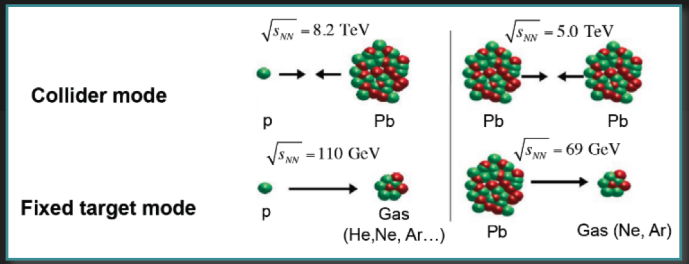
	Recorded Lumi (pb^{-1})	Delivered Lumi (pb^{-1})
2011	1.11	1.22
2012	2.08	2.20
Run-1	3.2	3.4
2015	0.33	0.36
2016	1.67	1.88
2017 (5TeV)	1.71 (0.10)	1.86 (0.13)
Run-2	3.7	4.1
Total	6.9	7.5
2018	2.19	2.45
Total	9.1	10.0

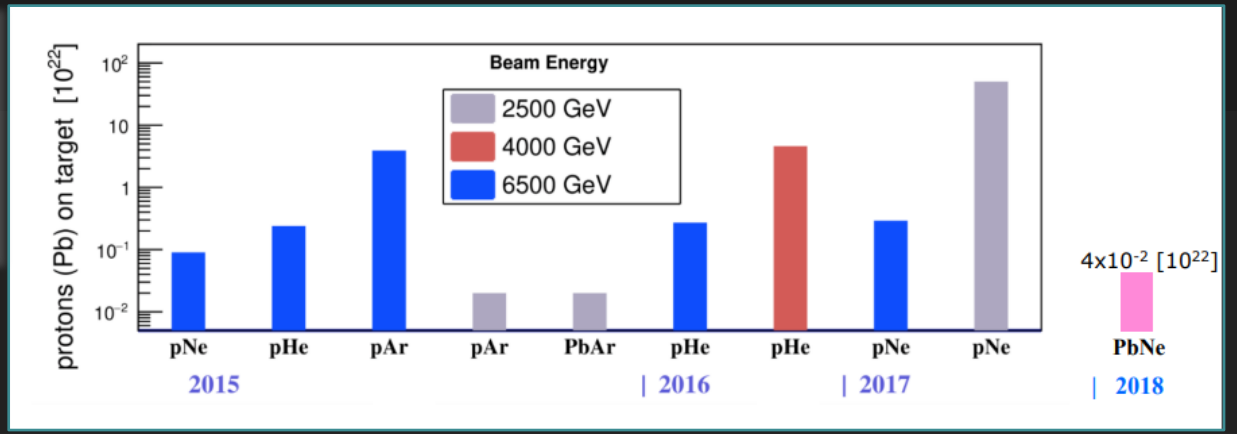
27 Nov 2018 - LHCC - N. Tuning

…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

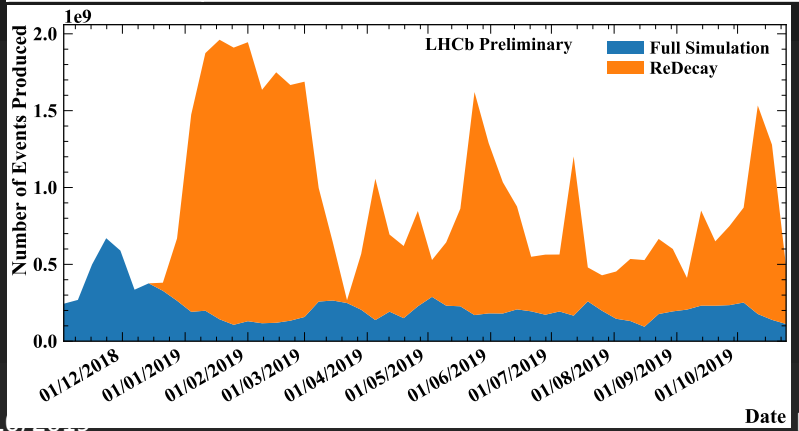




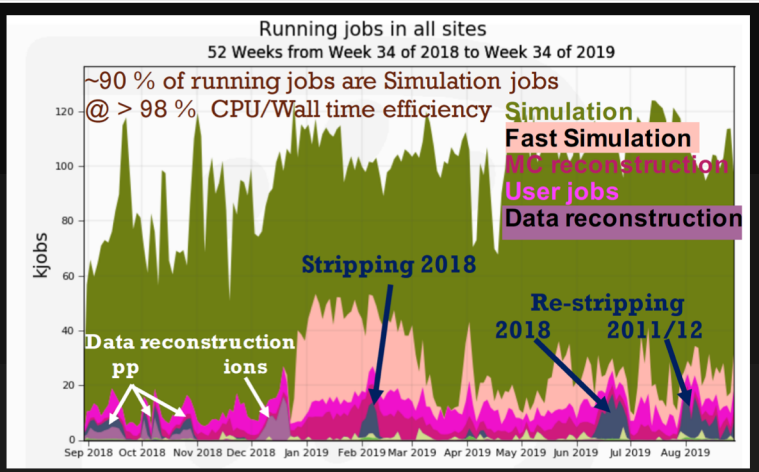
Operations: offline computing

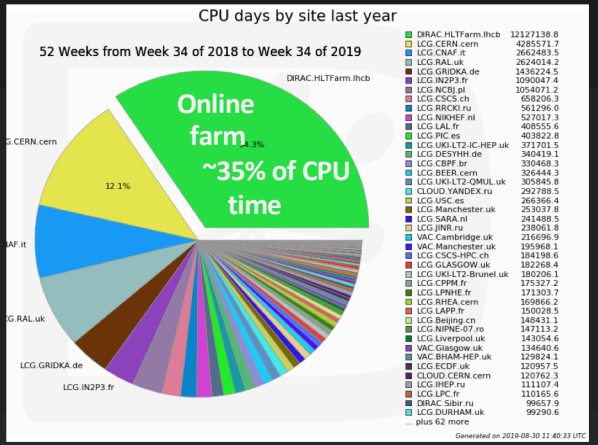
- Intense and complex operation activities during LS2
  - ★ MC productions are using more than 90% of the computing power
  - ★ Using the online farm for MC production: ~35% of the sample.
  - ★ ~85% of MC events produced with fast simulation in the last year
  - ★ Reprocessing campaign of Run1 and Run 2 data ongoing
  - ★ Deploying Upgrade software

Data set	Status
2018	completed
2011-2012	completed
2015-2016	Final validation - Production starting. Production time: ~2 months
2017	Validation ongoing



Events in last 365 days
- 85% of the events produced with fast simulation





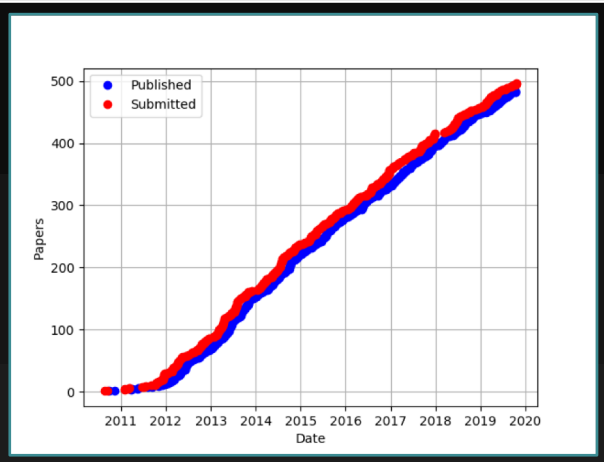
Selected physics results

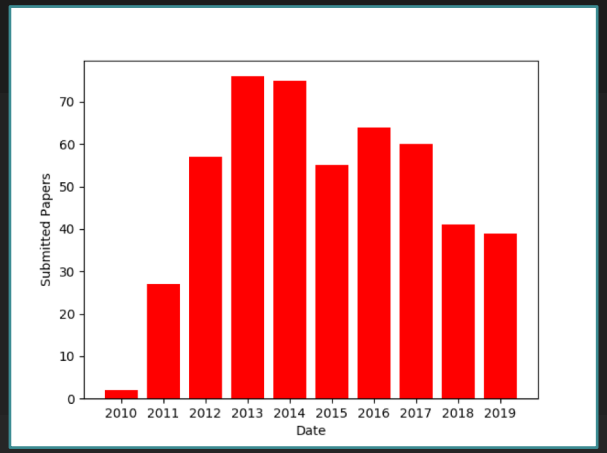
An overview of recent physics highlights

Physics: paper production

- 496 papers total – 39 in 2019
- +2 Conference Notes
- +20 since Apr ‘19 RRB

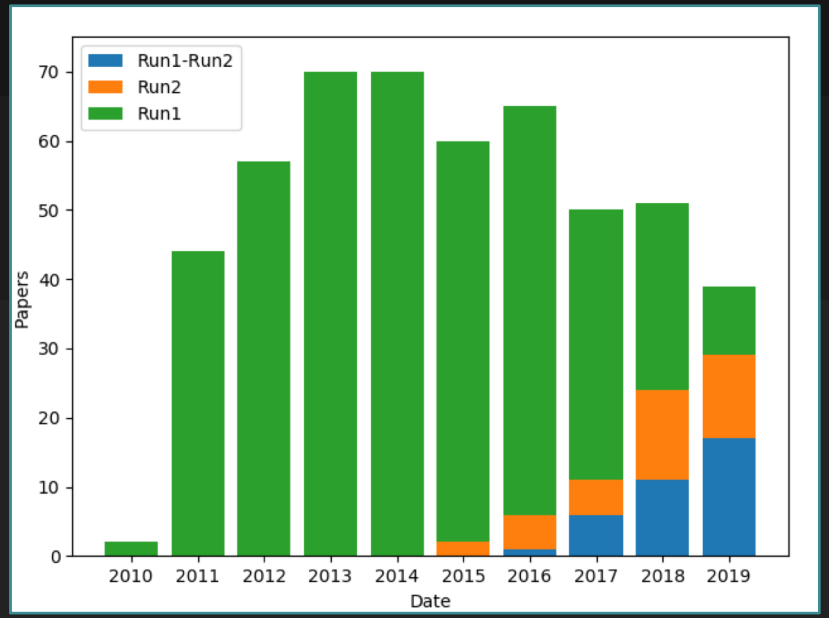
- 15 more being processed by Editorial Board
- 31 further under collaboration review, several more under working group review

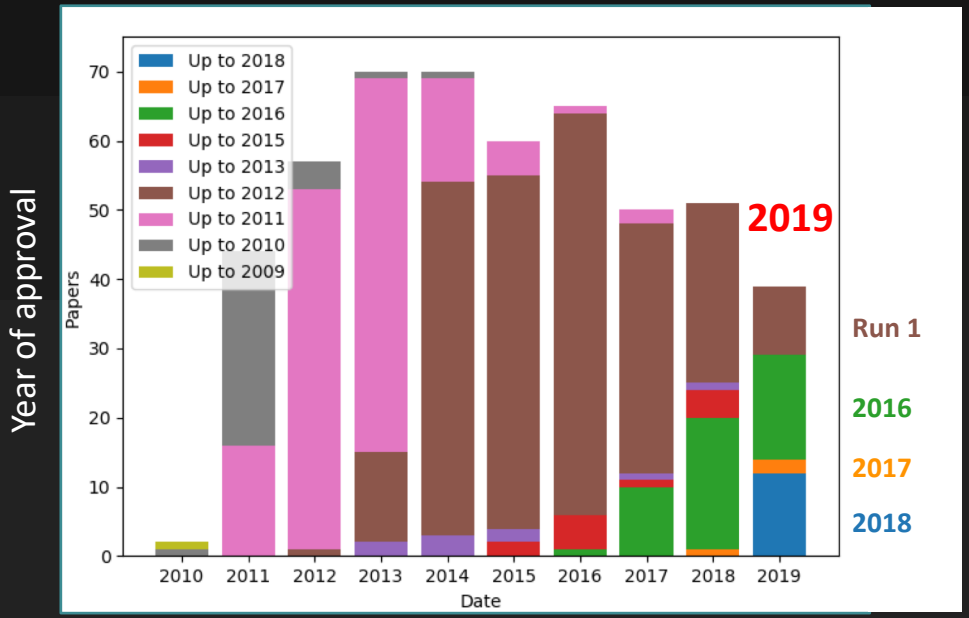




Physics: paper production

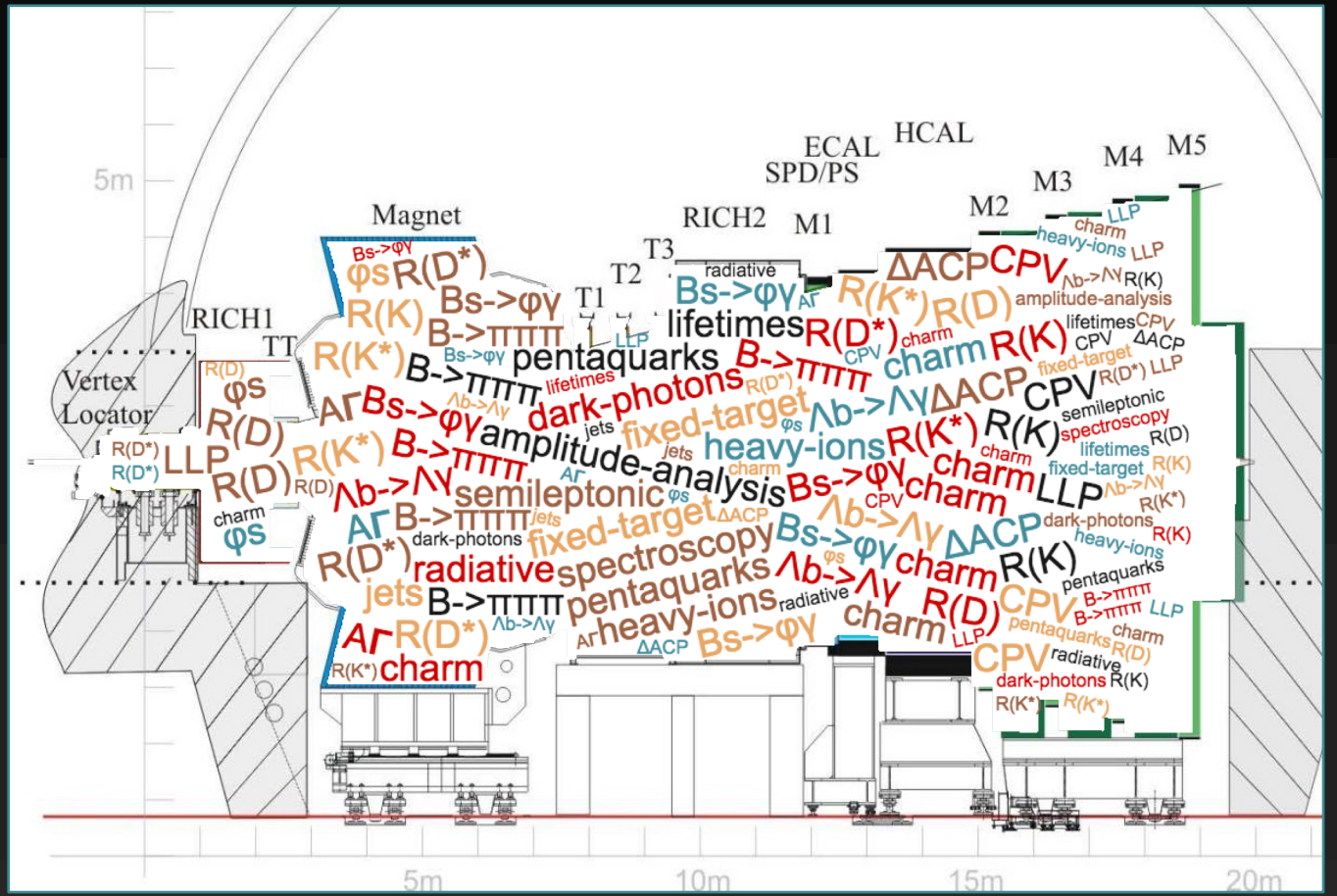
- Analysis of full Run 2 data in full swing!
- Substantially growing number of Run 1+ Run 2 analyses
- Several with full Run 1+ Run 2 dataset





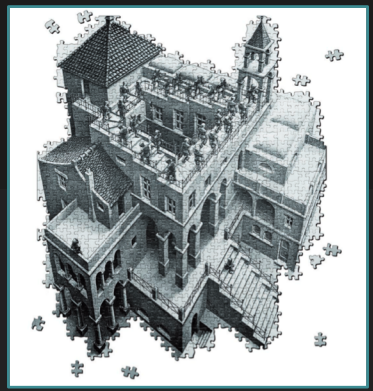
Recent physics highlights

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



Recap on CP violation measurements

- *Observation of CP violation in charm*
- *CP violation in B_s*
- *CP violation in baryons ?*



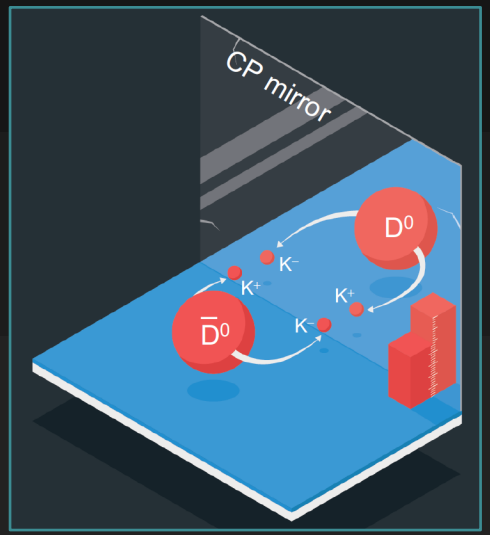
©Asimmetrie-Infn/F.Cuicchio/G. Riccobene

Observation of CP violation in charm

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

- Count how many D^0 and anti-D^0 decay into $\pi^+\pi^-$ and K^+K^-
  - ★ ☞ If matter = antimatter the number of the D^0 anti-D^0 decays should be equal
- For experimental reasons we prefer to measure the difference in matter-anti-matter asymmetry between decays into $\pi^+\pi^-$ and K^+K^-: ΔA_{CP}
  - ★ should be exactly zero if matter = antimatter
- Result:

$$\Delta A_{CP} = (-15.4 \pm 2.9)\times 10^{-4}$$



- A tiny but significant (5.3σ !) difference from zero!
- Roughly compatible with the SM
- However, theoretical predictions are way more uncertain than data
- Opens a new field of investigation!

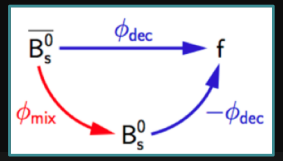
Full Run 1 + Run 2 sample!

New measurement of the B_s mixing phase ϕ_s

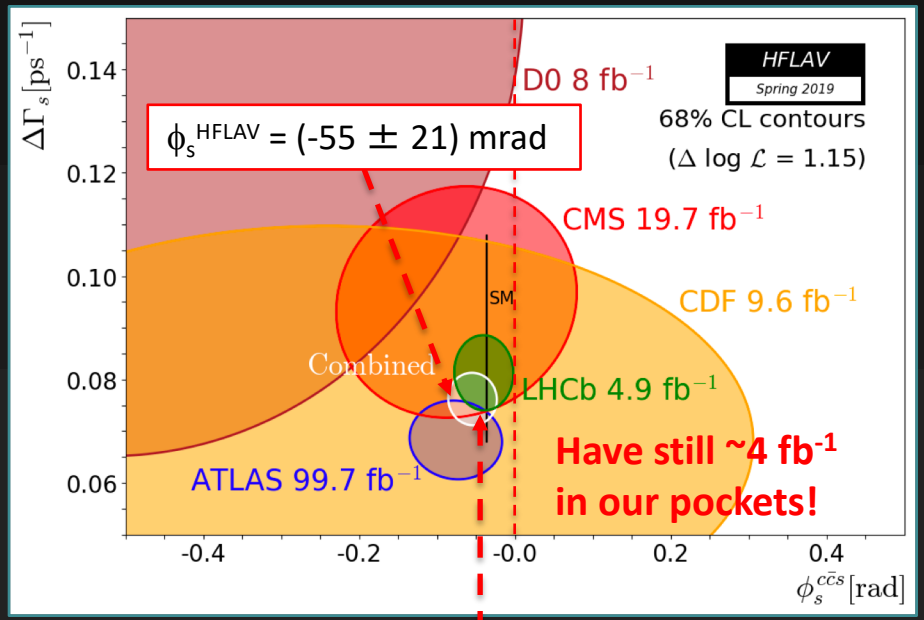
[Eur. Phys. J. C 79 (2019) 706, Run2 1.9 fb^{-1}]

[Phys. Lett. B797 (2019) 124, Run2 1.9 fb^{-1}]

- Measure the phase difference between the two processes
- Precisely determined within the SM:
  $\phi_s^{SM} = (-36.8^{+0.96}_{-0.68})$ mrad (CKMFitter)
  $\phi_s^{SM} = (-37.0 \pm 1.0)$ mrad (UTFit)



- VERY sensitive to contributions from new particles beyond the SM
- Very high precision measurement
- Updated measurements with Run 2 data:
  $B_s \to J/\psi\phi$ and $B_s \to J/\psi\pi\pi$



- Combining with Run 1 yields

$$\phi_s = (-41 \pm 25) \text{ mrad}$$

- HFLAV combined value approaching the sensitivity to observe a non zero value!

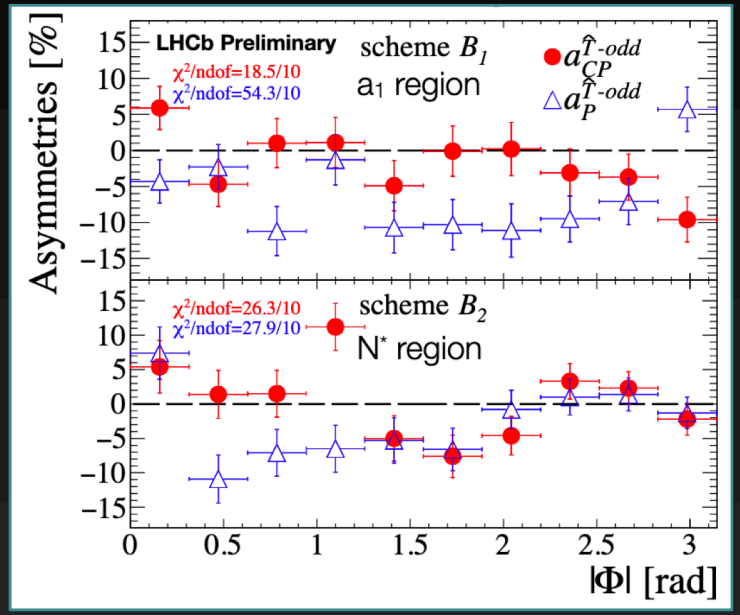
Search for CP violation in baryons

New!

[LHCb-PAPER-2019-028, Run1+Run2 6.6 fb^{-1}]

- So far CP violation observed only in mesons. No observation yet in baryons
- Search for CP and P violation in $\Lambda_b \to p\pi^-\pi^+\pi^-$
- Look for CP and P violation also in specific regions of the kinematic parameters ("phase-space")

- No CP violation observed, although hints of deviations at the level of 2.9σ are present
- P violation observed for the first time in b-baryons at 5.5σ level



$$a_P^{\hat{T}\text{-odd}} = -3.98 \pm 0.70 \pm 0.17$$
$$a_{CP}^{\hat{T}\text{-odd}} = -0.70 \pm 0.70 \pm 0.17$$

Results integrated over the full phase-space show P violation at 5.5σ

Results integrated over the full phase-space show no CPV

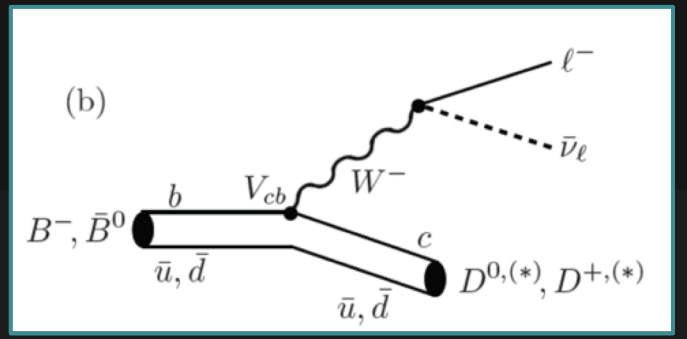
Rare decays

- *Recap on lepton flavour universality*
- *Search for $K_S \longrightarrow \mu^+\mu^-$*

Tests of lepton flavour universality

- Lepton flavour universality can be checked in several B meson decays involving leptons in the final state

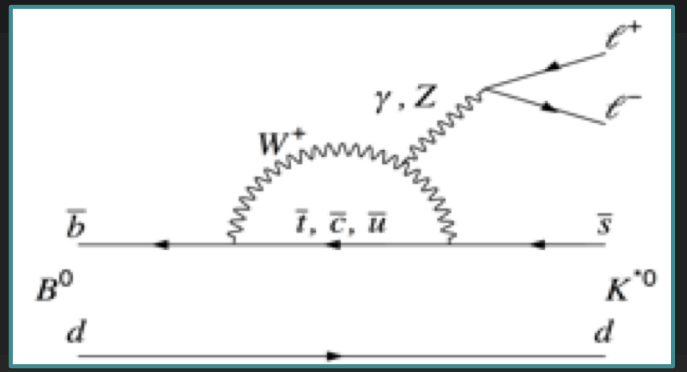
- Two main classes of decays have been studied:
  - ★ Semileptonic $B^0 \to D^{(*)-} l^+ \nu$ - tree level decay
  - ★ $b \to s l^+ l^-$ decays e.g. $B^0 \to K^{(*)0} l^+ l^-$ - FCNC decays



- Observables:

$$R(D^*) = \frac{BF(B \to D^* \tau \nu)}{BF(B \to D^* \mu \nu)} \overset{SM}{=} 0.252 \pm 0.003$$

$$R(K^{(*)}) = BF(B \to K^{(*)} \mu^+ \mu^-) / BF(B \to K^{(*)} e^+ e^-) \underset{SM}{\sim} 1$$



- Theoretically clean!

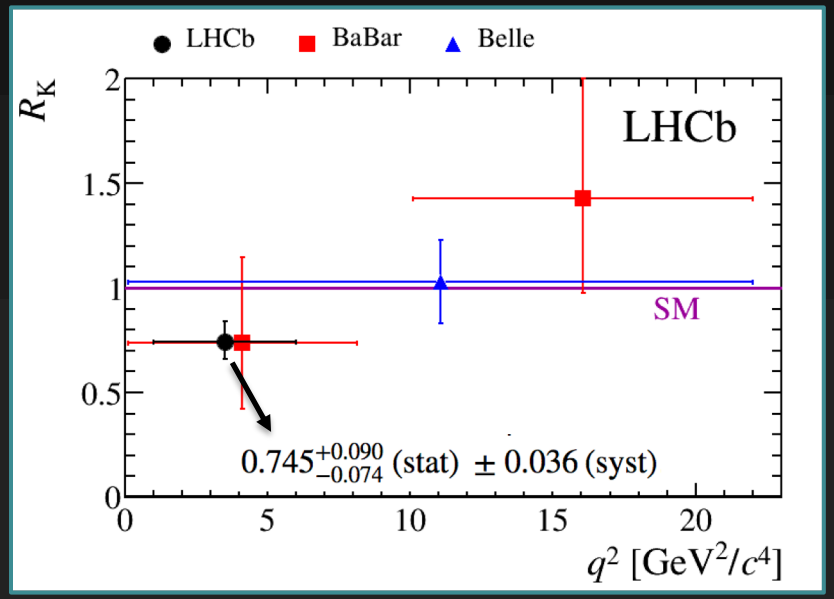
Tests of lepton universality: R(K) and R(K*)

[Phys. Rev. Lett. 113 (2014) 151601, JHEP 08 (2017) 055 Run1 3 fb^{-1}]

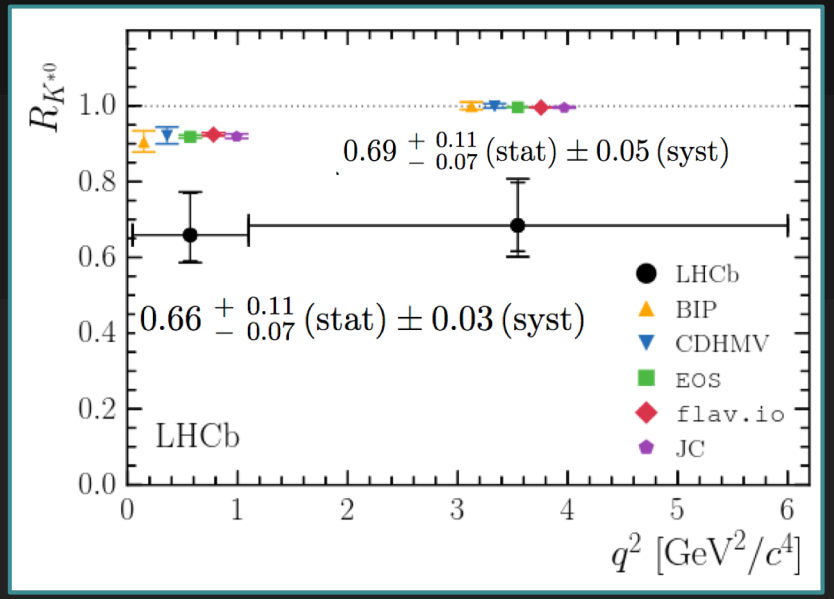
Test the LFU in electroweak penguin decays (e.g. the class of FCNC decays $b \to s l^+ l^-$)

- Old results for R(K) and R(K*) (Run 1 only):

[Phys. Rev. Lett. 113 (2014) 151601]



[JHEP 08 (2017) 055]



~2-2.5 σ away from SM

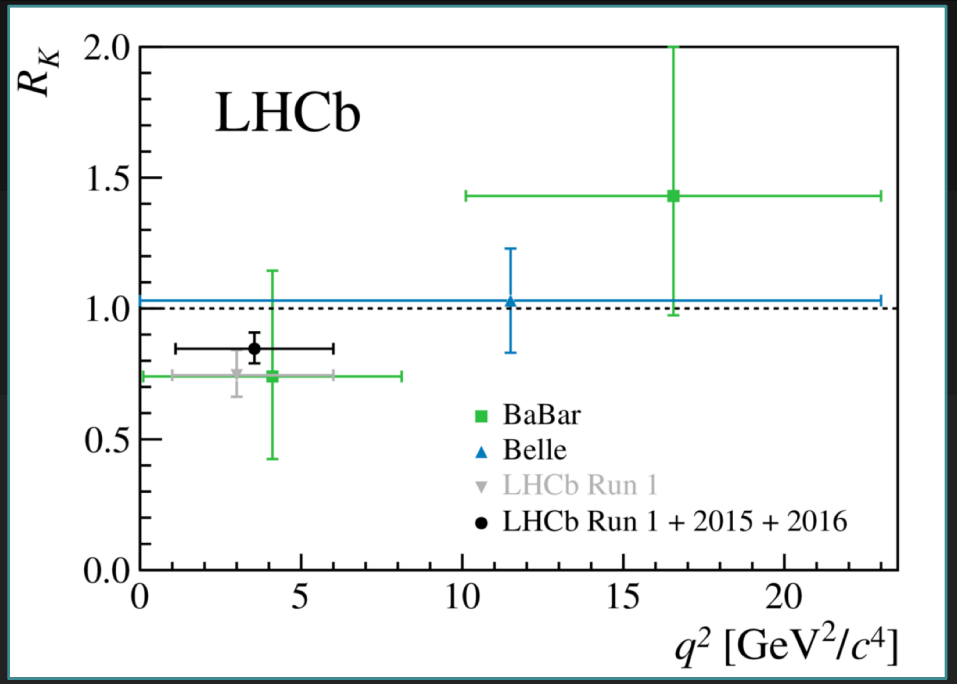
Tests of lepton universality: new measurement of R(K)

[Phys. Rev. Lett. 122 (2019) 191801, Run1 + Run 2, 5 fb^{-1}]

- New measurement re-analysing Run 1 data and adding ~2 fb^{-1} of Run 2 data

$$R_K = 0.846^{+0.060}_{-0.054}(stat)^{+0.016}_{-0.014}(syst)$$

- Situation essentially unchanged: still 2.5σ away from the SM prediction
  - ★ Better precision but central value closer to the SM



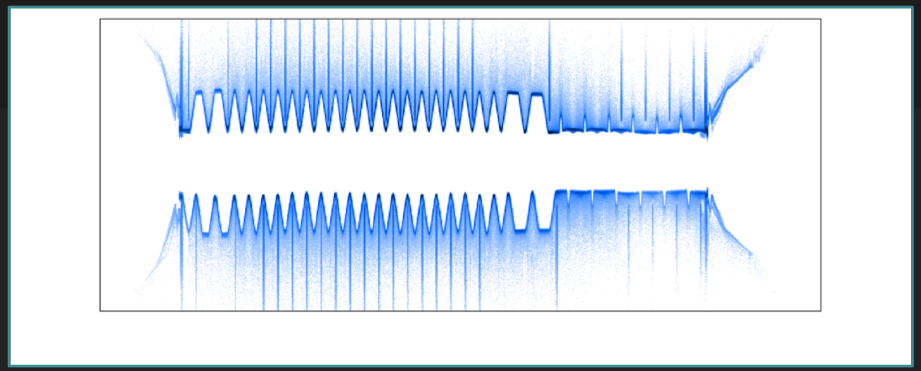
- Need more data: inclusion of 2017+2018 data will double the statistics
- Other measurements in preparation
  - ★ Update of R(K*), other decay channels (e.g. $\Lambda_b \rightarrow pKl^+l^-$ aka R(pK))

Search for $K_s \to \mu^+\mu^-$

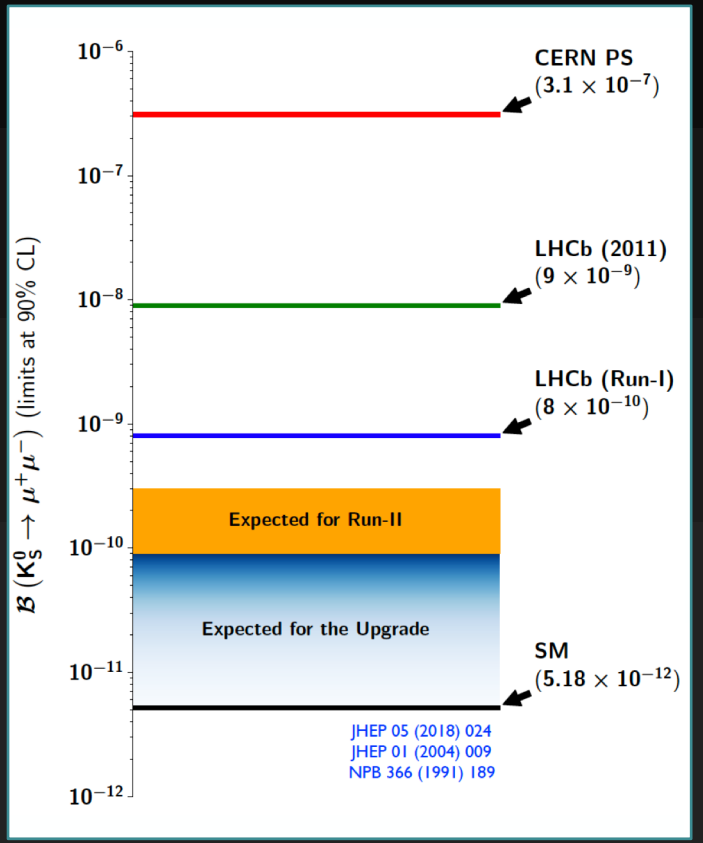
New!

[LHCb-CONF-2019-002, Run 2, 5.6 fb^{-1}]

- Strongly suppressed FCNC transition – can be enhanced by NP
- New measurement using Run 2 data set
- Extremely rare decay – background suppression challenging
  - ★ Dominant source $K_s \to \pi^+ \pi^-$
  - ★ need to strongly suppress secondary vertices from material interaction



Tomography of VELO provides a map to reject background



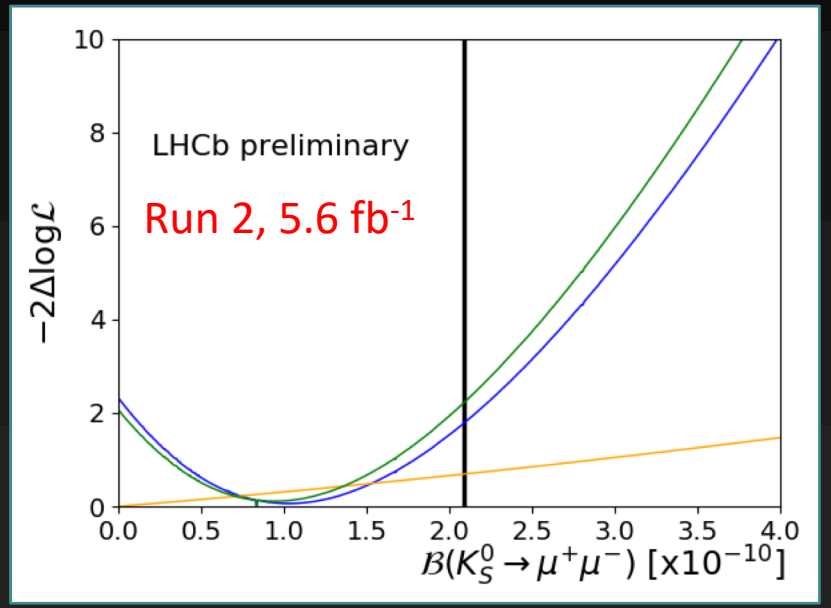
Search for $K_s \rightarrow \mu^+\mu^-$

New!

[LHCb-CONF-2019-002, Run 2, 5.6 fb^{-1}]

- Limit from Run2 data: 2.6 x 10^{-10} @ 95% CL
- Can combine with Run1 result, limit improves to:

  2.4 x 10^{-10} @ 95% CL
- Limit improved by factor of four w.r.t. previous (LHCb Run1)
- Scope to do much better with the upgrade!
- Could greatly benefit from new all-software trigger.



Lifetime measurements

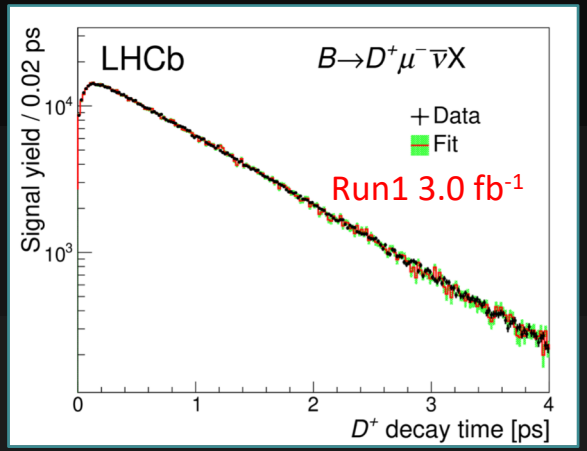
- *Measurement of charm baryon lifetimes*

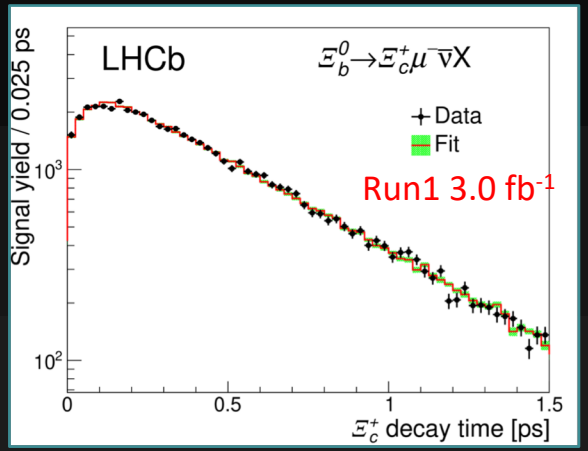
Charm baryon lifetimes

[Phys. Rev. D100 (2019) 032001 , Run1 3.0 fb^{-1}]

- New measurement of Λ_c^+, Ξ_c^+ and Ξ_c^0 lifetimes
- Baryons selected from semileptonic b-baryon decays
- Measured relative to the D^+ lifetime
- Large samples!

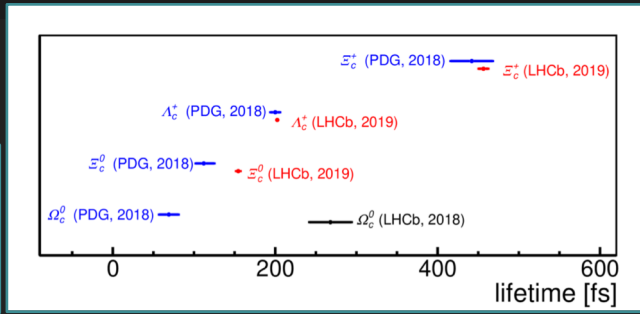
H_c	Yield (10^3)
D^+	809.4 ± 1.3
Λ_c^+	303.5 ± 0.7
Ξ_c^+	55.8 ± 0.5
Ξ_c^0	21.6 ± 0.2





- Better precision by x3-4 wrt World Average
- Lifetime of Ξ_c^0 3.3σ larger than WA

$$\tau_{\Lambda_c^+} = 203.5 \pm 1.0 \pm 1.3 \pm 1.4 \text{ fs}$$
$$\tau_{\Xi_c^+} = 456.8 \pm 3.5 \pm 2.9 \pm 3.1 \text{ fs}$$
$$\tau_{\Xi_c^0} = 154.5 \pm 1.7 \pm 1.6 \pm 1.0 \text{ fs}$$



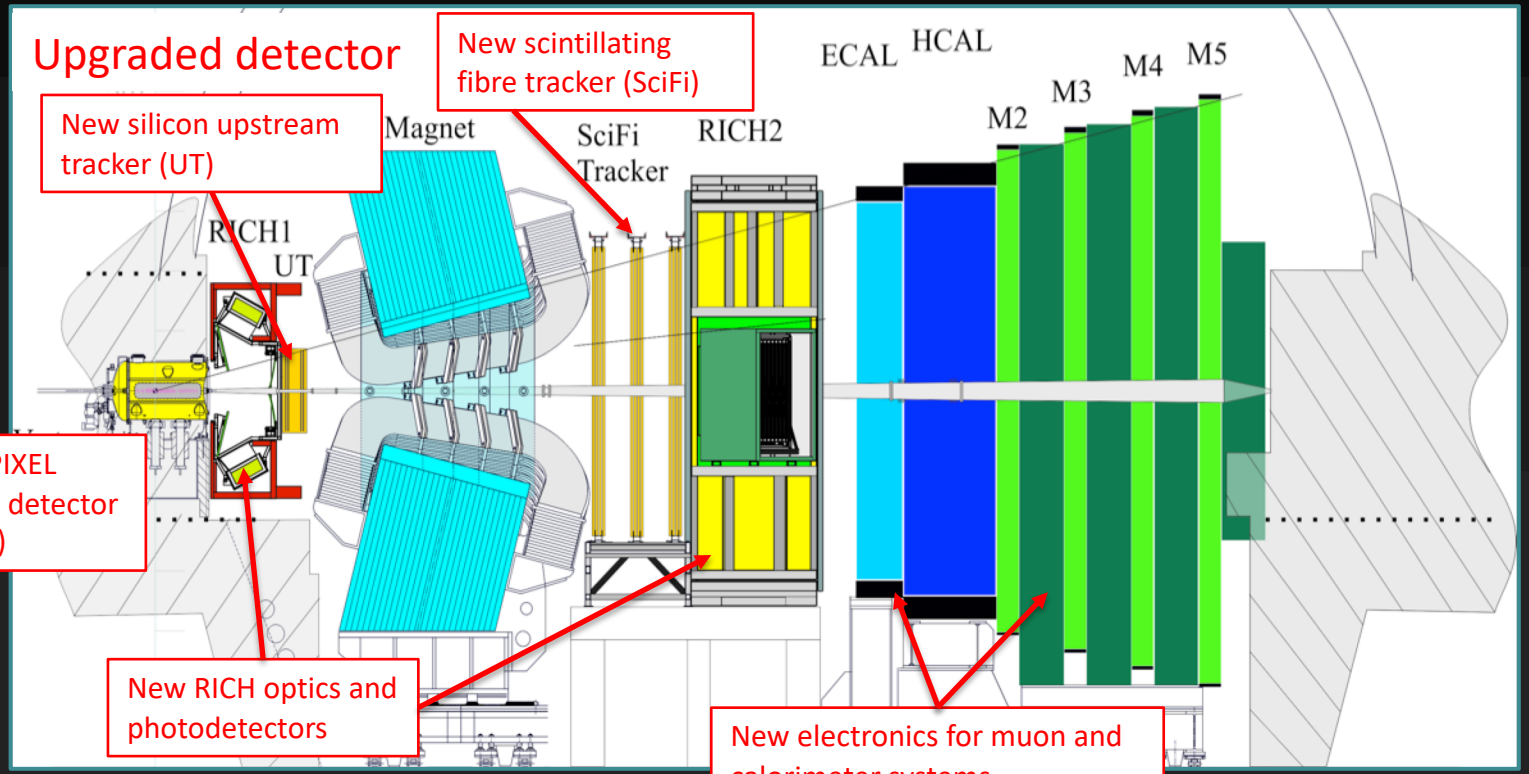
Upgrade

Moving towards Run 3

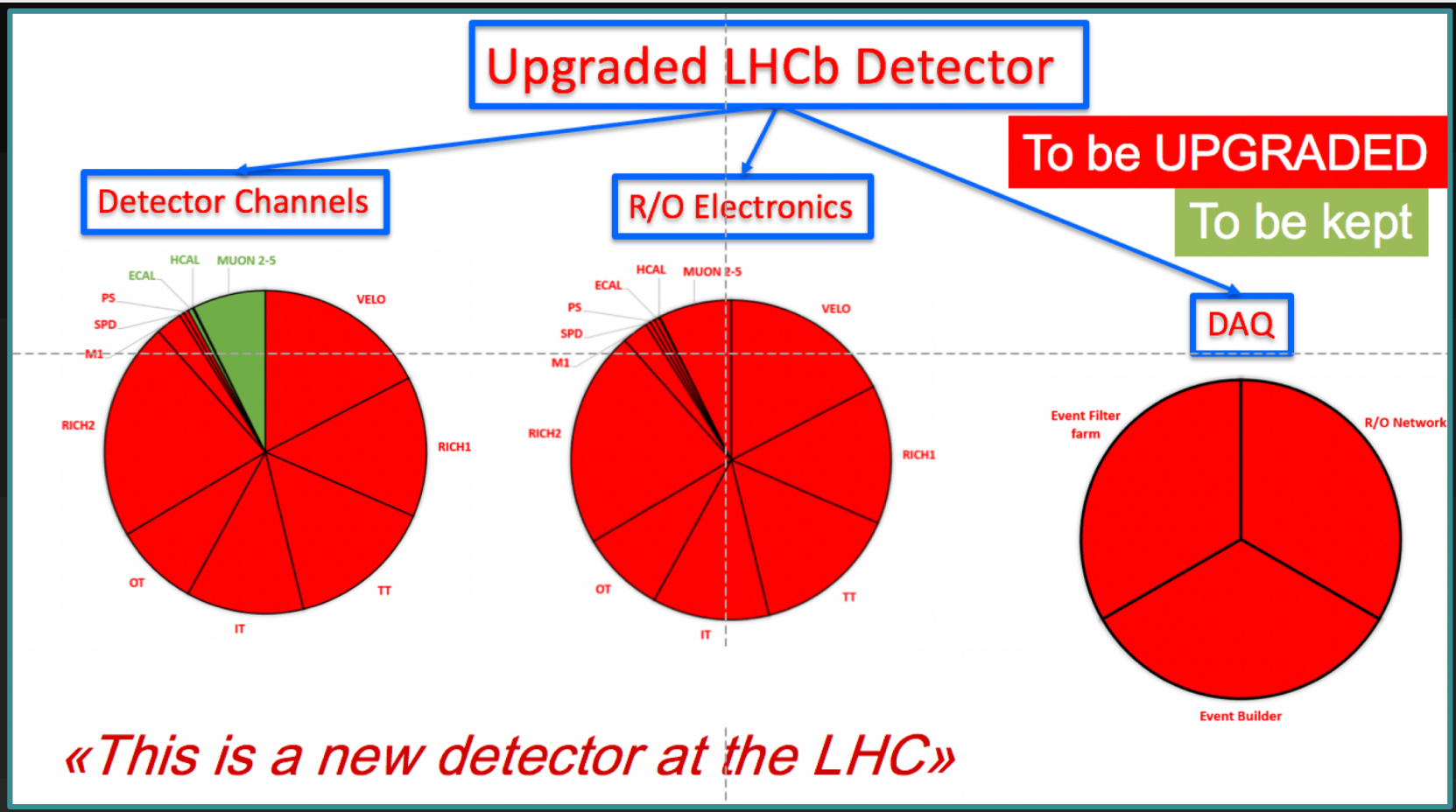
LHCb Upgrade I in a snapshot

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]

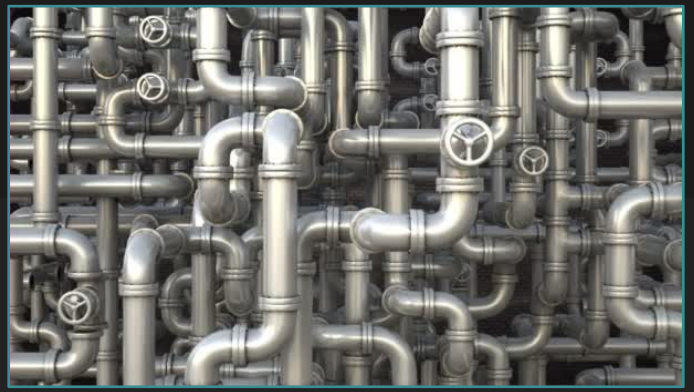


LHCb Upgrade I in snapshot



Upgrade: installation

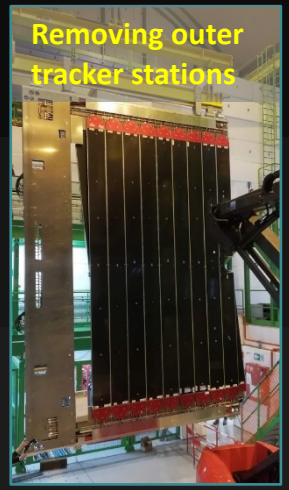
Sorting out infrastructure and services



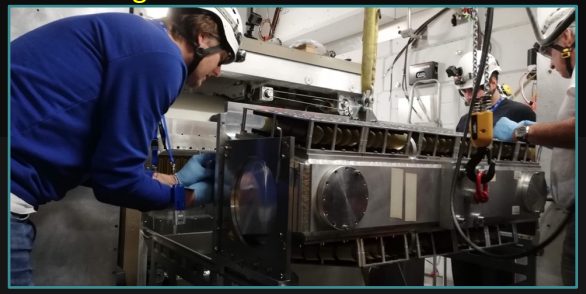
Very intense activity at LHCb site!

- All old detectors and obsolete equipment removed
- All new cooling systems installed
- All optical fibres in place
- New computing centre in place
- Watch our videos!

Removing outer tracker stations



Removing the old VELO



~19k optical fibres, 99.8% OK!

New computing center completed

New cooling transfer lines

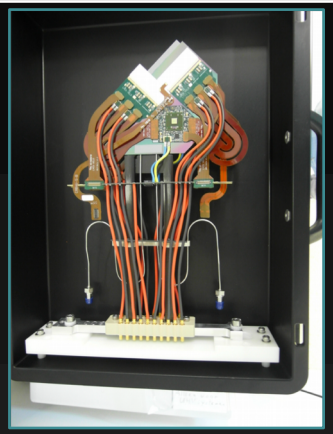
Installation of new RICH1 First upgrade detector in place!

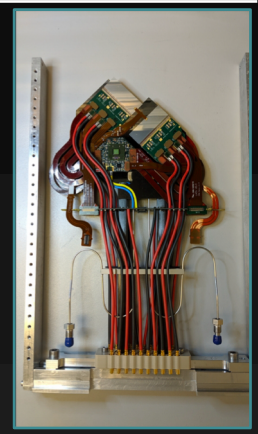
Upgrade: construction

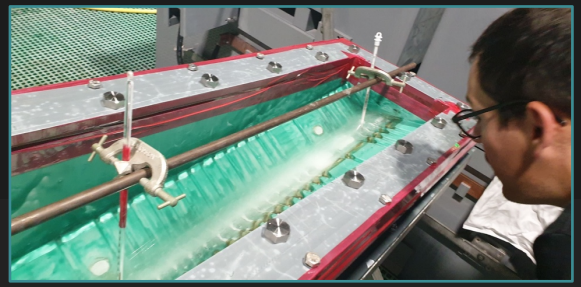
Working full steam

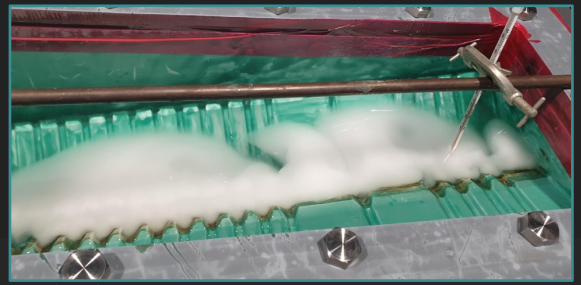
Upgrade: VELO

- Production of VELO modules started, although still not at the nominal pace
- Mechanics and readout electronics progressing well
- Important decision to proceed to RF-foil etching: successfully thinned down to 150 µm
- Tight schedule!

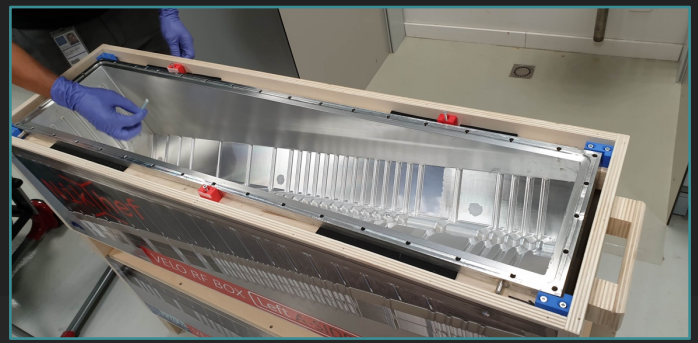






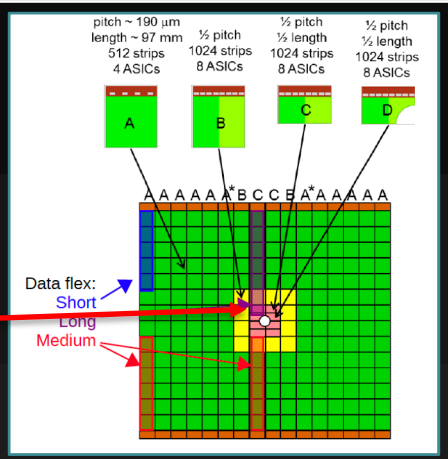


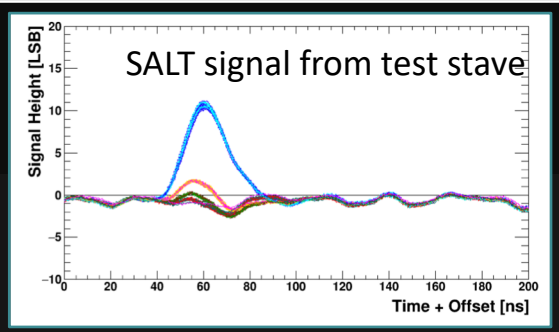
VELO etching with NaOH solution
Green area is passivated
Etched boxes are now at Nikhef for final metrology and coating

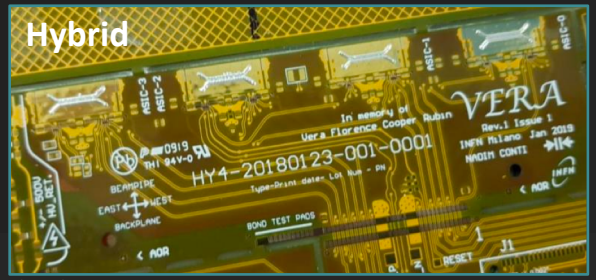


Upgrade: UT

- SALT3.5
  - ★ 18 wafers received in early July
  - ★ Wafer testing completed in summer
  - ★ Good yield: ~82 % => ~6850 chips
- SALT3.8 (8-chip hybrid version): diced chips at CERN, ready for final tests
- Hybrids and flex cables being produced
- Ready to start stave production
- Readout electronics and mechanics progressing well
- Tight schedule !



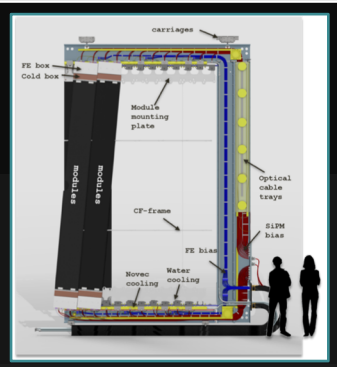


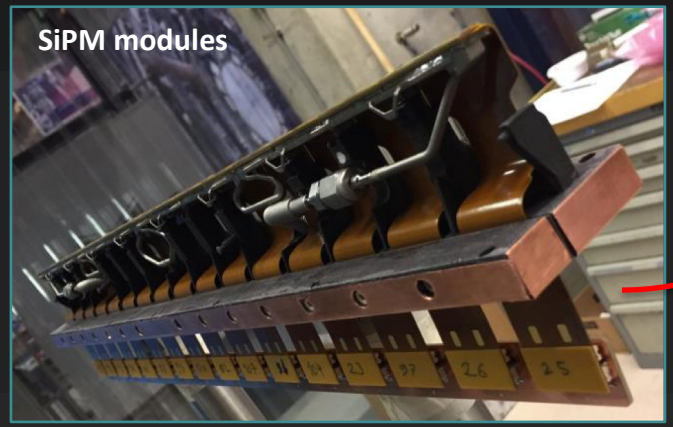


UT slice test with an instrumented stave at CERN

Upgrade: SciFi

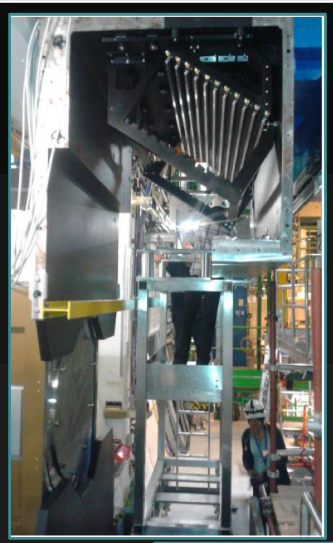
- All components at hand, installing detector stations (“C-Frames”)
- Very complex objects, including cooling system at -40°
- 3/12 C-frames well advanced – need to install 6 before beam pipe installation
- Tight schedule!

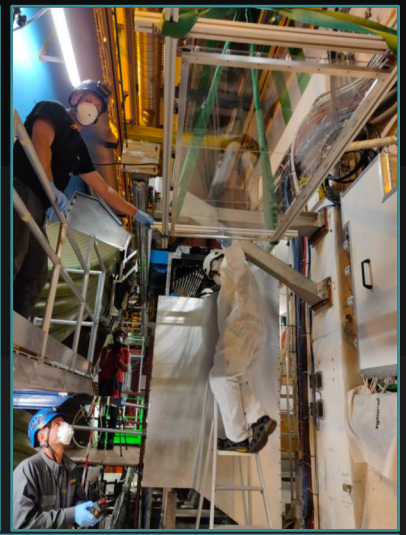




Upgrade: RICH

- All components for photon detection system at hand
- Readout electronics produced
- Q&A well advanced, components at CERN for “column” assembly
- RICH1 spherical mirrors at CERN for coating
- Mechanics progressing well
- RICH1 MaPMT support chassis and gas enclosure installed.
- Unfortunately problem: the quartz window cracked
  - ★ Need to build a new one
  - ★ Essentially no input on schedule but additional work needed

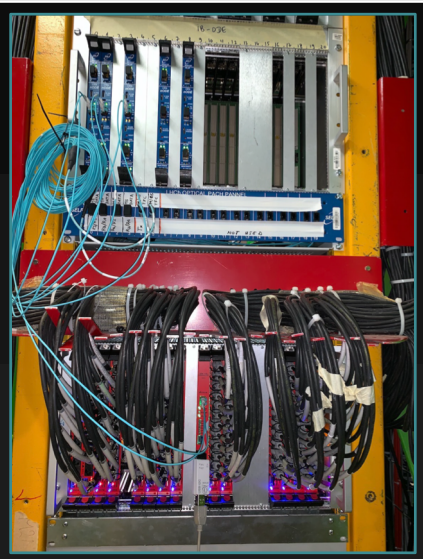




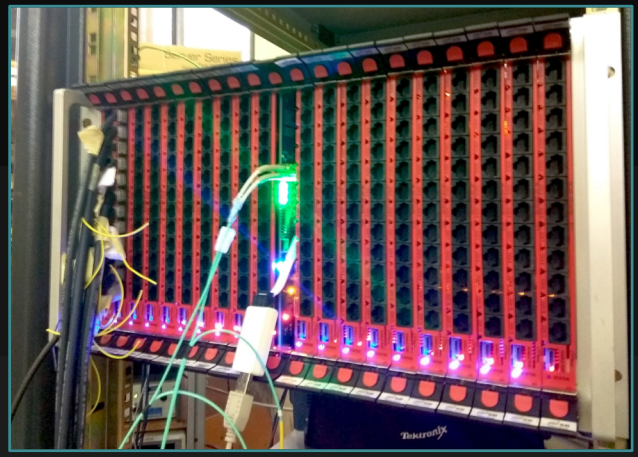
Upgrade: Calorimeters, Muon system

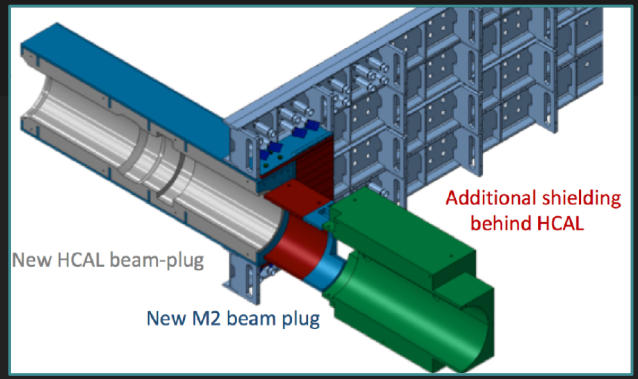
- Muon system
  - ★ All new electronic boards in production
  - ★ First boards already at CERN, commissioning already ongoing
  - ★ Additional shielding: pieces at CERN, ready for installation

- Calorimeters
  - ★ New front-end ASIC: completed
  - ★ HV/Monitoring/calibration boards: completed
  - ★ Front-end boards: production delayed
  - ★ Control boards: delayed (linked to the above)
  - ★ Production completed and installation in February 2020 – may become tight



New Muon system electronics commissioning





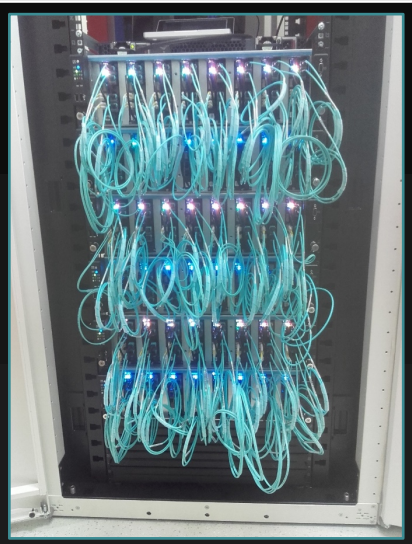
Additional muon shielding

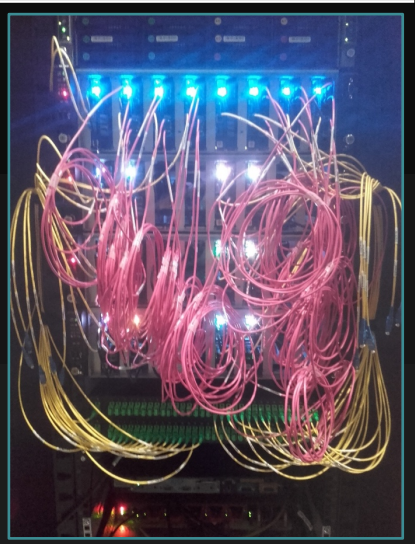
Upgrade: Online

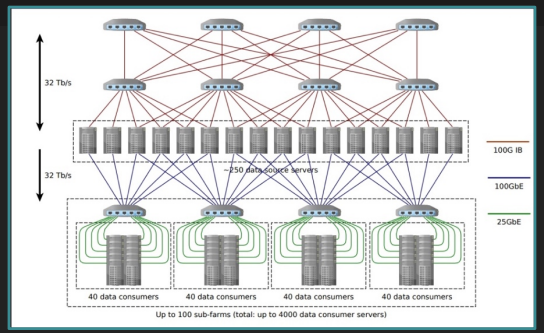
- Construction of common DAQ boards (PCIe40) progressing well: 68% produced and tested.
- Acceptance test setup running full steam
- Vertical slice to test the whole DAQ chain

- Review of event builder technology held in Jun
  - ★ two alternative technologies being considered, with different network configurations
  - ★ Decision will be taken in December

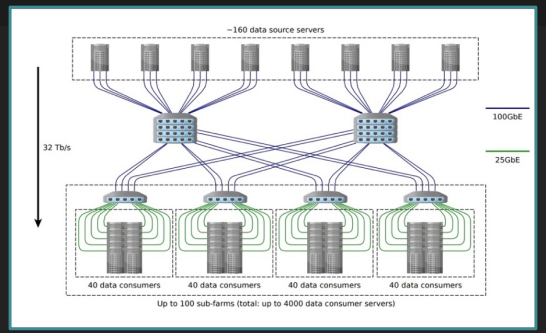
- Computing centre buildings completed







Dedicated EB

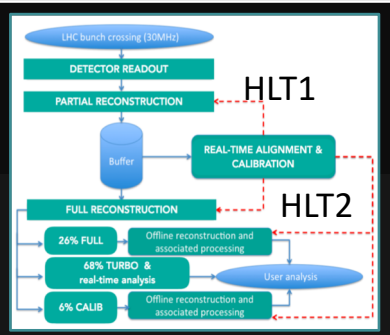


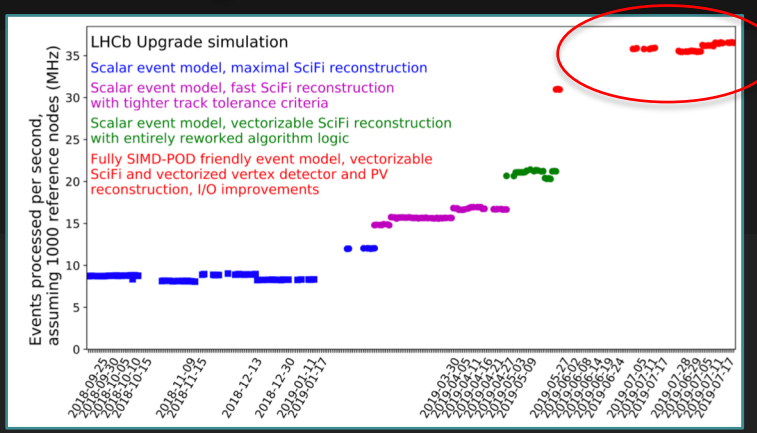
Distributed EB

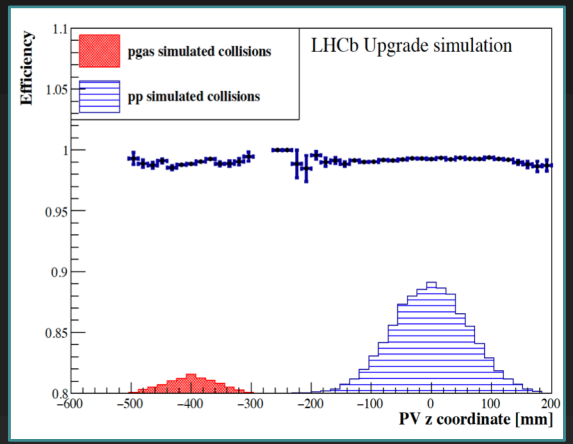
Upgrade: full software trigger

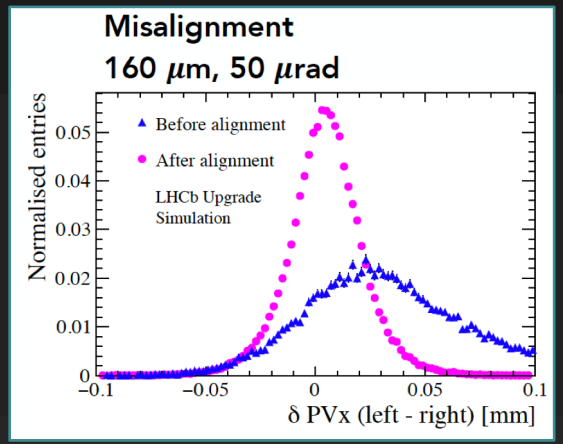
- Development under the responsibility of the Real-Time Analysis Project (RTA)
- Major break-trough in summer: HLT1 throughput >30 MHz
- Very promising physics performance studies
  - ★ Fixed target (-> demonstrates full flexibility!)
  - ★ Real time alignments
- Development of HLT2 selections started

HLT1 must process 30Mevents/sec



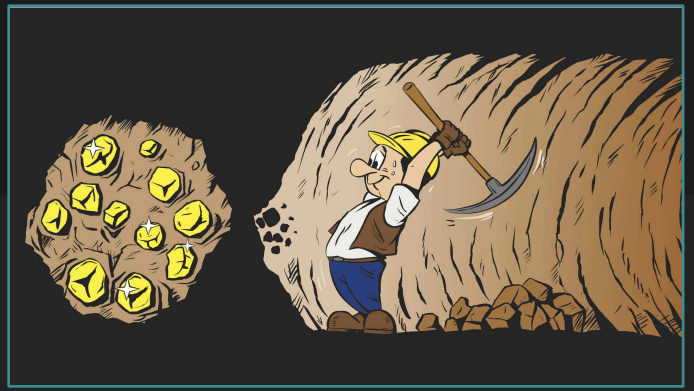




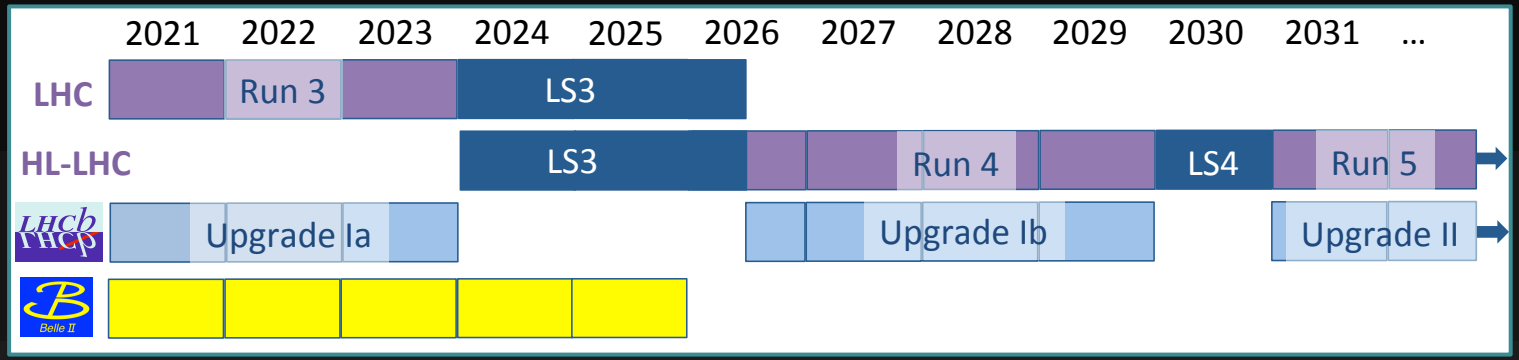


Upgrade II

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



LHCb Upgrade II

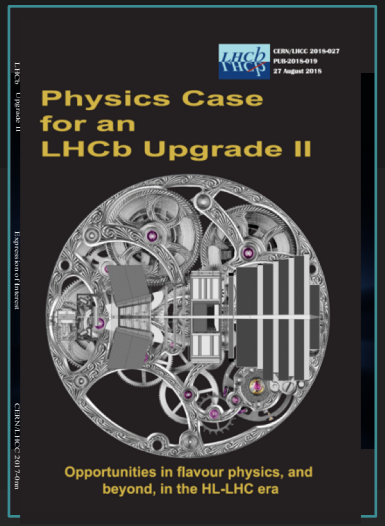


[arXiV:1808.08865]

- 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 to proceed to a Framework TDR (expected 2021)

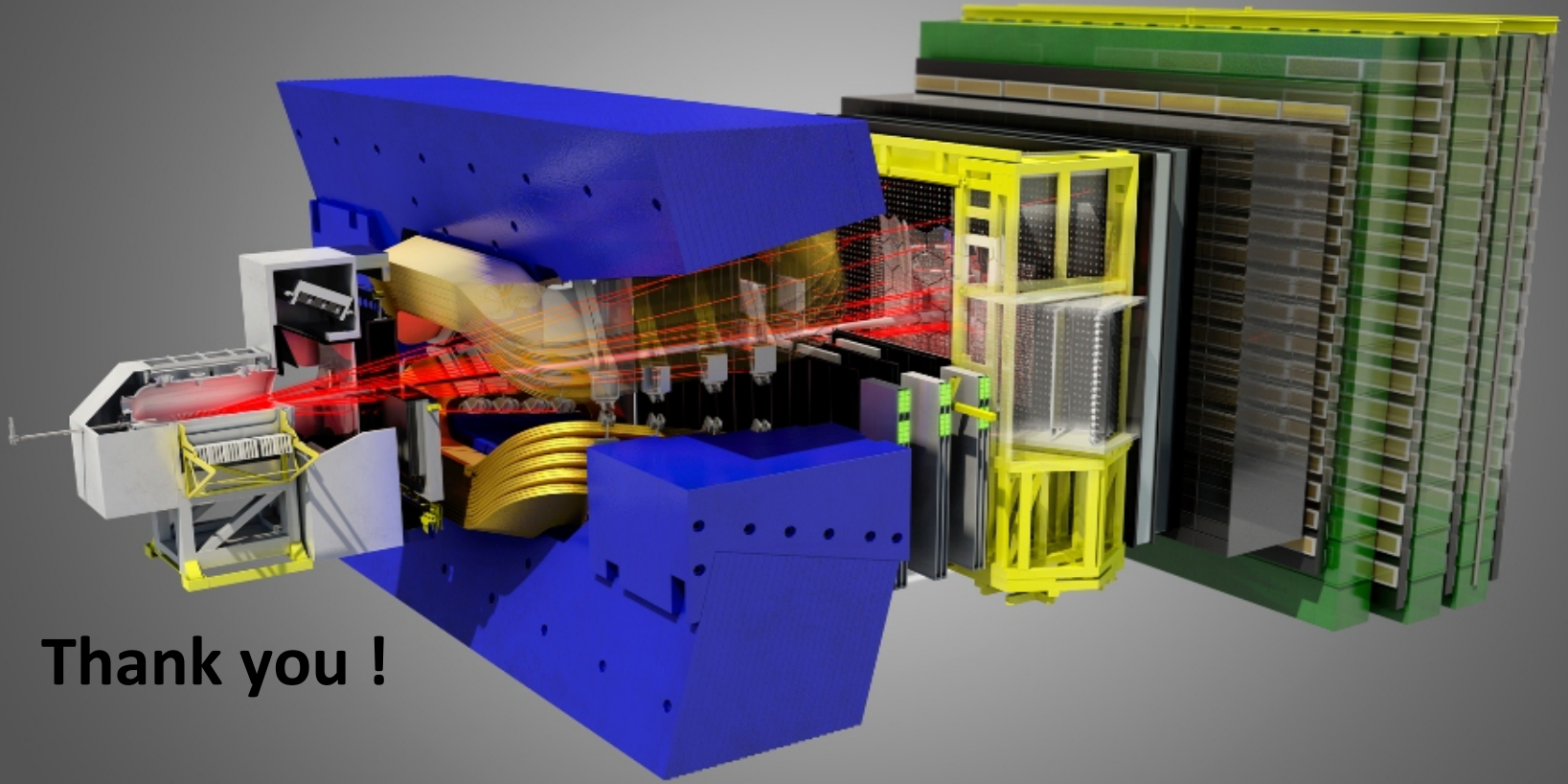


Conclusions and outlook

Conclusions and outlook

- Completed a successful first phase of LHCb
  - ★ We were delivered 10 fb^{-1} which was the goal in our Technical Proposal in 1998 !
  - ★ Collected data in a variety of running conditions
- LHCb continues to provide a wealth of excellent physics results
- The march towards the Upgrade I is continuing
  - ★ All subsystems progressing - installation ongoing!
  - ★ Schedule is tight, working hard to be ready for LHC Run 3!
- Looking into the far future:
  - ★ Expression of Interest for future upgrades submitted
  - ★ Physics case document released
  - ★ Green light from LHCC to proceed to a Framework TDR
  - ★ Clear case also for ESPP
  - ★ A lot of R&D opportunities !

[arXiv:1903.0925



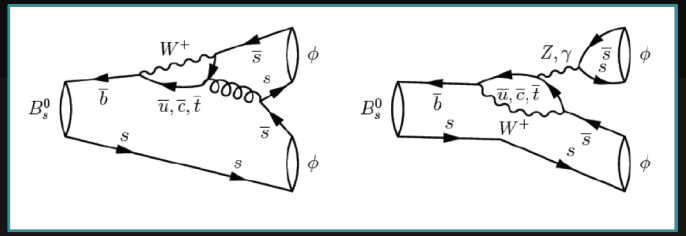
Thank you !

BACKUP SLIDES

Measurement of CP violation in $B_s \to \phi\phi$

[arXiv:1907.10003, Run2 2fb^{-1}]

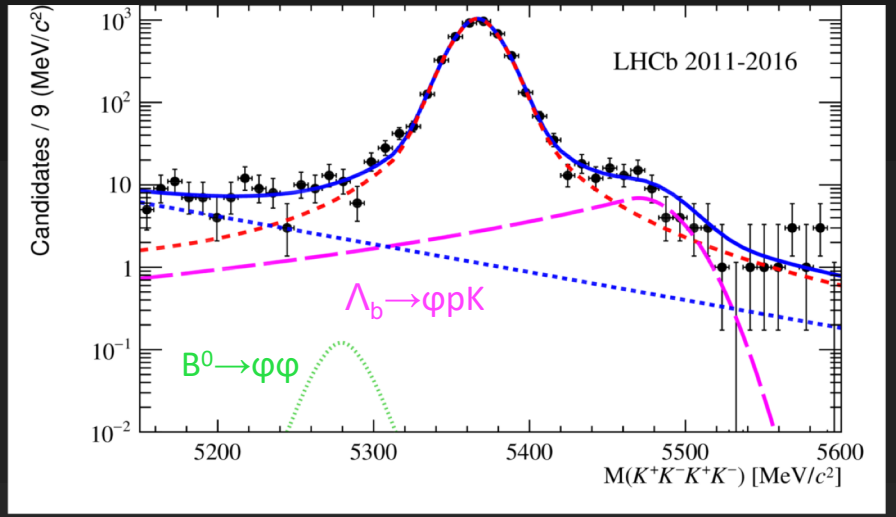
- Decay dominated by a penguin loop: enhanced sensitivity to New Physics
- Measure the phase $\phi_s^{s\bar{s}s}$ analogous to ϕ_s.
- SM predictions: $|\phi_s^{s\bar{s}s}| < 20$ mrad
  [arXiv:0810.0249 Phys.Rev.D80:114026,2009]



- Perform time dependent angular analysis

$$\phi_s^{s\bar{s}s} = -0.073 \pm 0.115 \pm 0.027 \text{ [rad]}$$

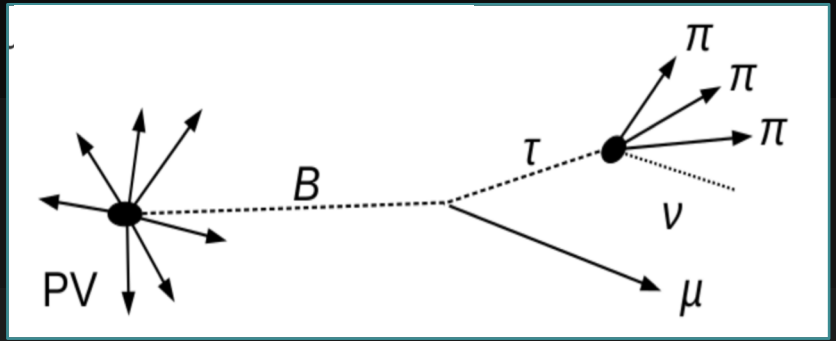
$$|\lambda| = -0.99 \pm 0.05 \pm 0.01$$



Lepton flavour violating decay $B^0/B_s \to \tau\mu$

[arXiv:1905.06614, Run1 3 fb^{-1}]

- Search for lepton-flavour violating decays $B^0/B_s \to \tau\mu$
- BR in SM awfully small: ~10^{-54}
- Can be strongly enhanced in NP models: up to O(10^{-8} – 10^{-5}) – link to LFUV models.



- Look for three prong τ decays

Mode	Limit	90% CL	95% CL
$B_s^0 \to \tau^\pm\mu^\mp$	Observed	3.4×10^{-5}	4.2×10^{-5}
	Expected	3.9×10^{-5}	4.7×10^{-5}
$B^0 \to \tau^\pm\mu^\mp$	Observed	1.2×10^{-5}	1.4×10^{-5}
	Expected	1.6×10^{-5}	1.9×10^{-5}

First limits

Best limits

New measurement of the B_s mixing phase ϕ_s

[Eur. Phys. J. C 79 (2019) 706, Run2 1.9 fb^{-1}]
[Phys. Lett. B797 (2019) 124, Run2 1.9 fb^{-1}]

Phys. Rev. Lett.114(2015) 041801
Phys. Lett.B736(2014) 186
Phys. Lett.B762(2016) 253
Phys. Rev. Lett.113(2014) 211801
JHEP08(2017) 037

- Combining with Run 1 yields
- $\phi_s = (-41 \pm 25)$ mrad
- $|\lambda| = 0.993 \pm 0.010$
- $\Gamma_s = 0.6562 \pm 0.0021$ ps^{-1}
- $\Delta\Gamma_s = 0.6562 \pm 0.0021$ ps^{-1}