LHCb Status Report

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on behalf of the LHCb Collaboration

138th LHCC Open Session, CERN
June 5th, 2019

UNIVERSITÄT
HEIDELBERG
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SEIT 1386

Outline

Upgrade and Operations

Physics Analysis and Publications

Disassembly & Installation at LHCb

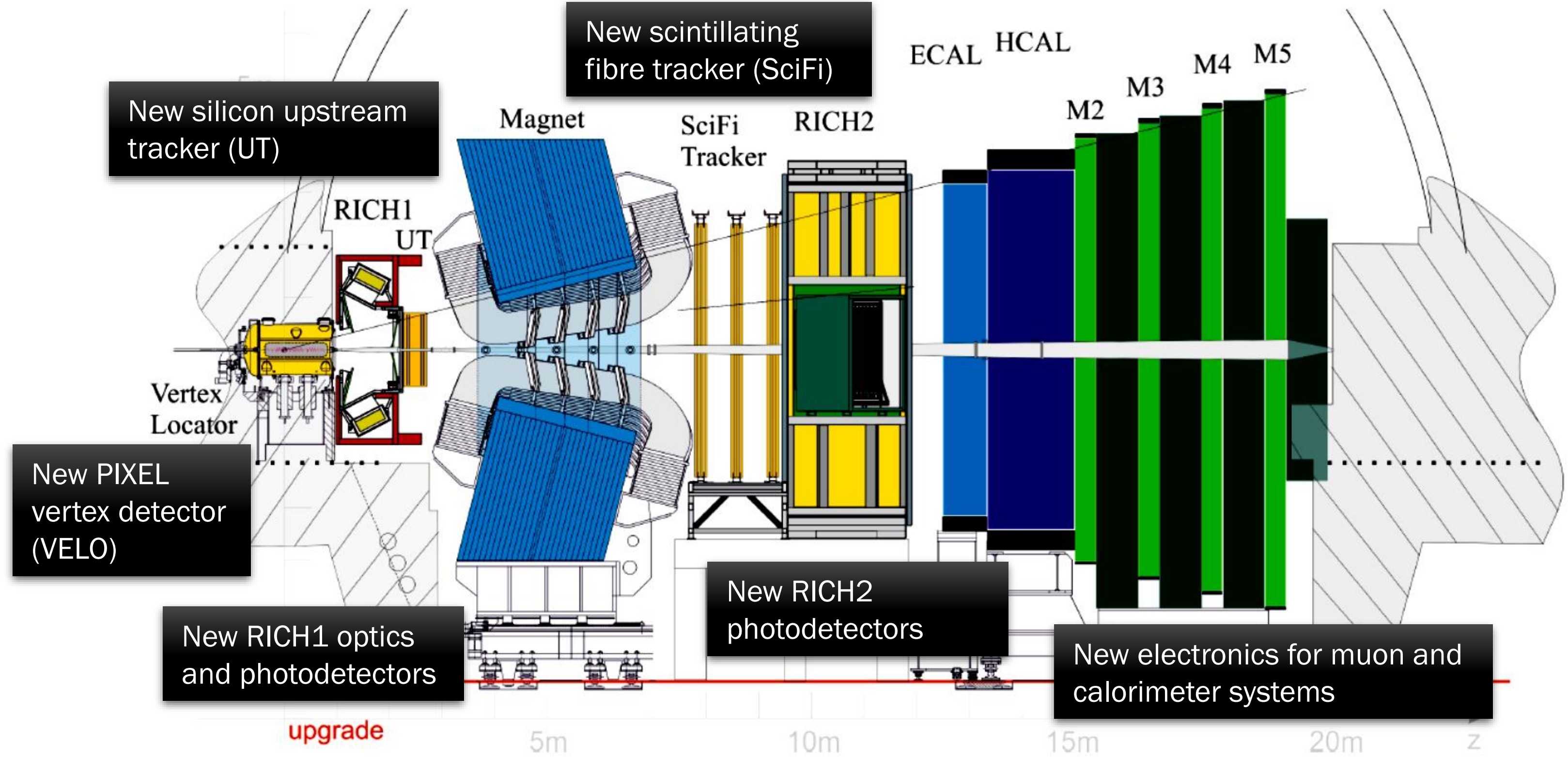
- Velo, RICH 1, TT, IT, OT, M1, Calorimeter Lead, PS/SPD are out
  - all obsolete services are removed
- dismantling is well on schedule, and done safely
- installation of upgrade services:
  - Modules 1-4 of 6 for Event Filter farm in place
  - Long distance fibres being installed with very good progress
  - Installation of new cooling plants advancing well
  - First new copper cables in place
  - Sub-systems will start to enter the experimental cavern in June

- Watch our weekly videos!
  https://www.youtube.com/watch?v=CKLu1xewv7I

http://lhcb-media.web.cern.ch/lhcb-media/LS2/Final/LHCC-LHCb-LS2-May.mp4

LHCb Upgrade

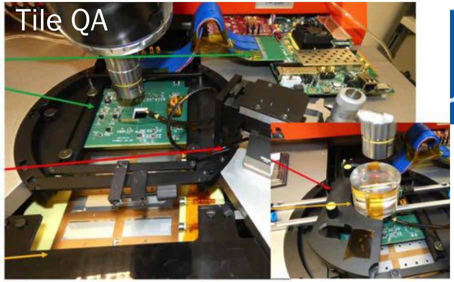
- 50 fb^{-1}, $2\times10^{33}\ cm^{-2}s^{-1}$
- All front-end electronics read out at 40 MHz
- 30 MHz avg. input to a full software trigger

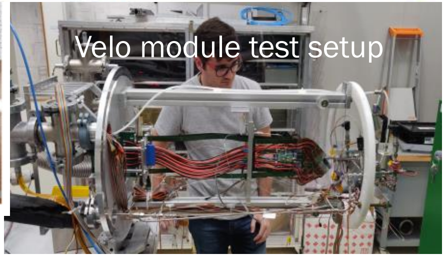


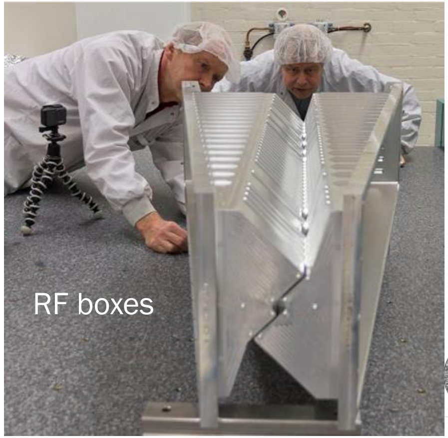
[LHCB-TDR-12]
[LHCB-TDR-13]
[LHCB-TDR-14]
[LHCB-TDR-15]
[LHCB-TDR-16]
[LHCB-TDR-17]
[LHCB-TDR-18]

VELO

- New <u>hybrid pixel detector </u>for LHCb! Evaporative CO_2 cooling in silicon microchannels.
- <u>Project progressing very well</u>, although the schedule is tight given the complexity.
- VeloPix ASIC bump bonding to silicon pixel sensors is complete.
- Module construction:
  - Several pre-production modules available;
  - Production site readiness review next week.
- RF boxes:
  - First installation pair complete; machined to 250 um thin, leak tight.
  - Second pair almost complete (in final weeks of machining).
- High speed copper links 50% manufactured.
- Other components (vacuum feedthrough boards, electronics…) on schedule.
- Large scale mechanics (base, hood, isolation vacuum volumes, piping and valve assembly) progressing well. First half currently being prepared







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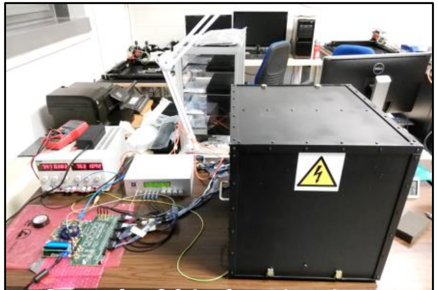
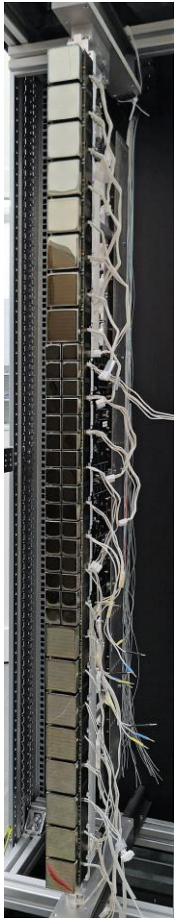
RICH

- Dismantling of RICH 1 complete, HPD removal from RICH 2 to begin soon
- Upgrade RICH 1 installation about to begin, mechanics under way
- Spherical mirrors almost completed, flat mirror tender completed
- MA-PMT columns for RICH 1 & 2: 22+24 = 46 columns (+spares)
  - all 3500 MaPMTs tested, CLARO asic: all received (100k) 100% pass rate
  - Digital readout board (PDMDB): production of PCBs completed, first complete boards being received
  - received most BaseBoard, FEBs and BackBoard batches, all undergoing QA
- Commissioning Lab (ComLab@CERN) ready to integrate columns

PDMDB



Setup for Q&A of readout boards



An assembled MaPMT column

UT

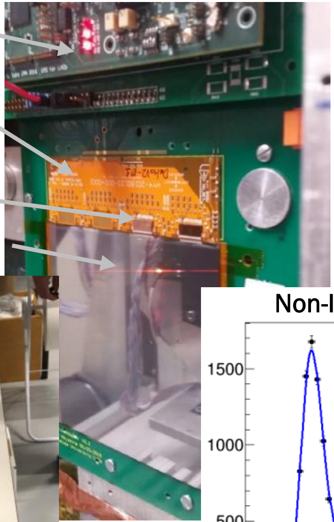
- SALT v3 asic received and tested, v3.5 sent for prod.
  - Issues seen in the previous version largely fixed
  - Test beam at Fermilab in March. Good results.
- Slice test setup in progress at Point 8
  - instrumented stave with realistic power, cooling and proto mechanics.
- Now to finalize the hybrid and start production
  - Hybrid production June 2019, QA and tools ready
- Sensors:
  - received all A-type, pre-series of B,C,D, prod. in Oct. 2019.
- Readout electronics: production started
  - Flex cables pre-series available, under test
- Bare staves: production finished
- Integration infrastructure at progressing full speed

GBT D.B.

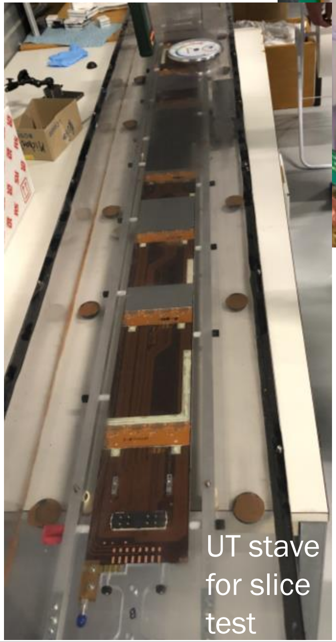
Delta-v2 Hybrid

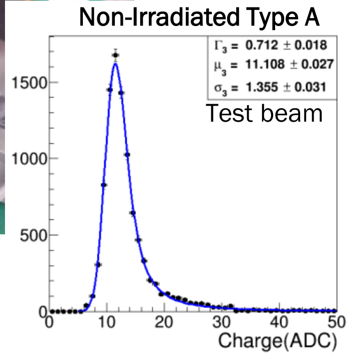
SALTv3 ASICs

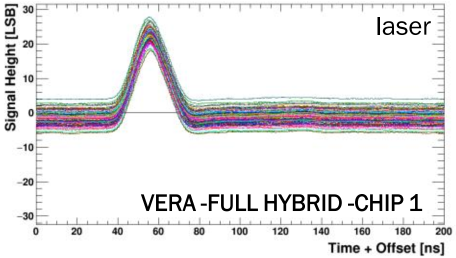
Type A sensor



UT test beam module







SciFi Tracker

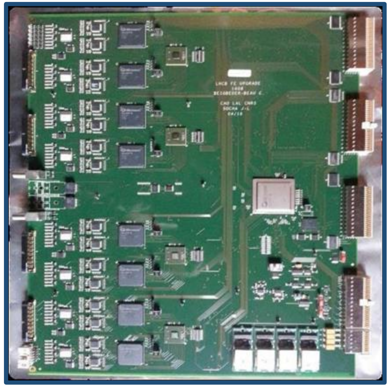
- Excellent progress! First scintillating fibre detector for LHCb.
- C-Frame 1 (of 12) nearly complete
  - already equipped with modules. Electronics in Wk 25
- All 5500 SiPM arrays delivered and tested
- Electronics:
  - 40% of PACIFIC boards prod. and tested (100% of ASICS)
  - 60% of Cluster boards prod. and tested
  - Master Boards
    - 50 boards in pre-series delivered and tested
    - 500 boards to be delivered in batches soon
- SiPM Cold-box to Fibre Module assembly on schedule
  - All QA test results look good
- Readout and control of the prototype C-Frame (4 ROB) with PCIe40/WinCC (LHCb Upgrade read-out)
- Schedule is tight but experience will help us optimize the commissioning .

Front-end tester at Point 8

C-Frame 1 with fibre modules

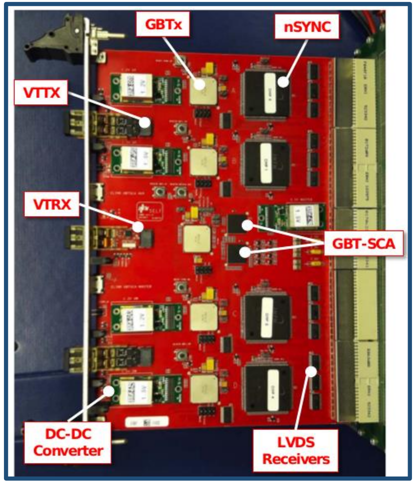
Calorimeter and Muon

- To be produced: electronics boards + shielding plugs
  - All electronics in production and testing
    - **MUON: nSYNCs (prod. & tested), nODE (pre-prod.):** 40MHz readout, each nODE equipped with 4 nSYNCs, **nSB, nPDM (pre-prod.):** system configuration and pulsing **, nBP (pre-prod.):** custom Back Plane for nPDM/nSB crates
  - Full production finished in November
- New shielding plug, (3 parts, design finalized)
  - order placed last December, parts expected in the coming month
- Upgrade activities are proceeding well

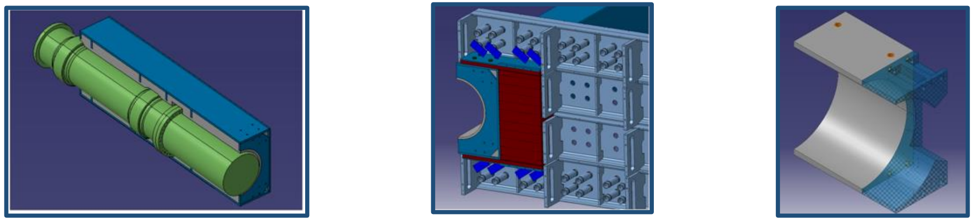


278 CALO FEB needed

+21 Control Boards
+144 HV/Calib/Moni



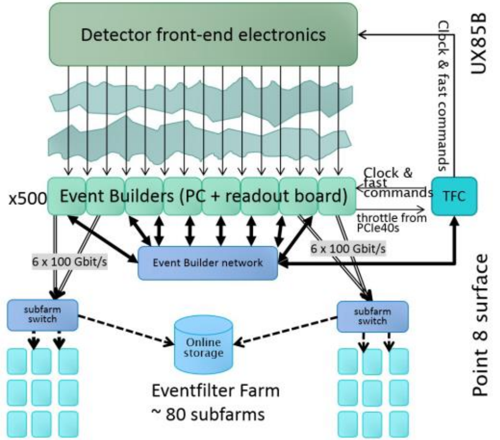
Muon nODE
1120 needed
+48 nSB
+8 nPDM



Details of the new Muon shielding plugs

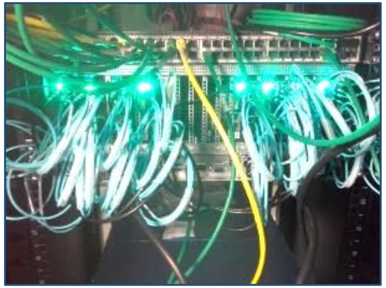
Online

- Containers for Event Filter Farm and Event Builder:
  - First 4 modules installed, 2 more in Nov. 2019
  - 40% of the long-dist. optical fibres from detector to the EFF installed
- Event Builder:
  - simulation of traffic is now working for 500 nodes and gives confidence in scalability of system.
  - Review of Upgrade Event Builder on June 6
- Vertical Slice Test will allow checking simulation results at a scale of 20% of the final system.
- PCIe40 (LHCb readout) production in full swing.
  - First production batch of ~40 just delivered



The PCIe40

Installation of one of the HLT farm modules



Event builder: Vertical slice setup already cabled with fibres and operational

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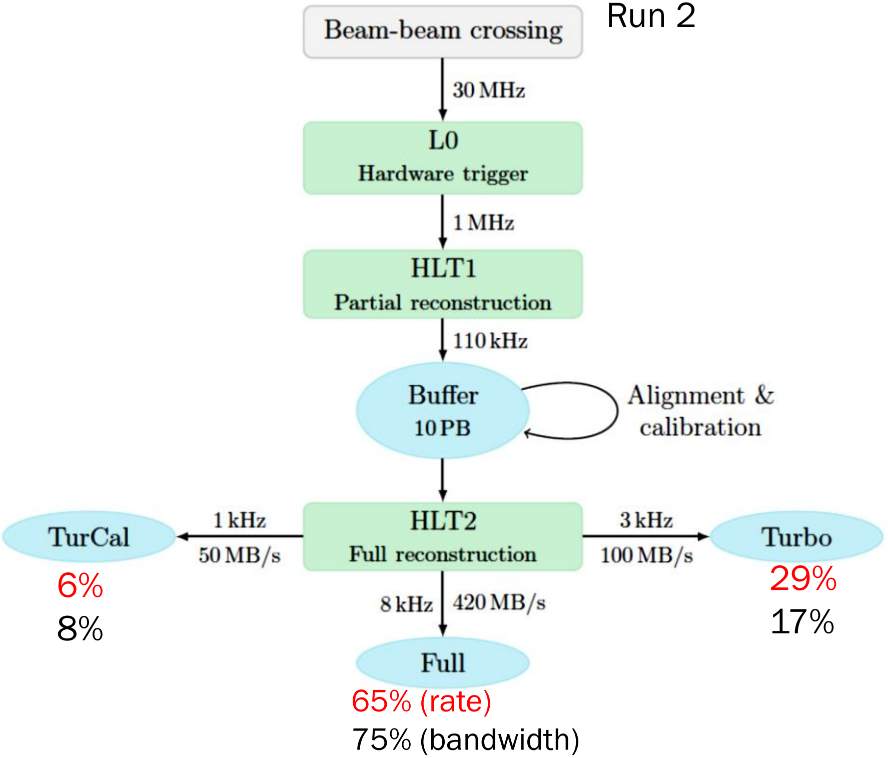
Real-time Analysis

- Quality reconstruction in the final trigger stage (HLT2), it is no longer necessary to run another reconstruction offline
  - LHCB-TDR-018
  - [*JINST* 14 (2019) P04006]

- Turbo model = exclusive selections, no additional objects
- Complete persistence = Turbo model for inclusive triggers,
- Selective persistence
  - explicit specification.
  - Event size reduction without sacrificing information needed offline
  - key for the migration to RTA model for Run3



Persistence method	Average event size (kB)
Turbo	7
Selective persistence	16
Complete persistence	48
Raw event	69

Run2: JINST 14 P04013

Comput. Phys. Commun. 208 35-42

Real-time Analysis

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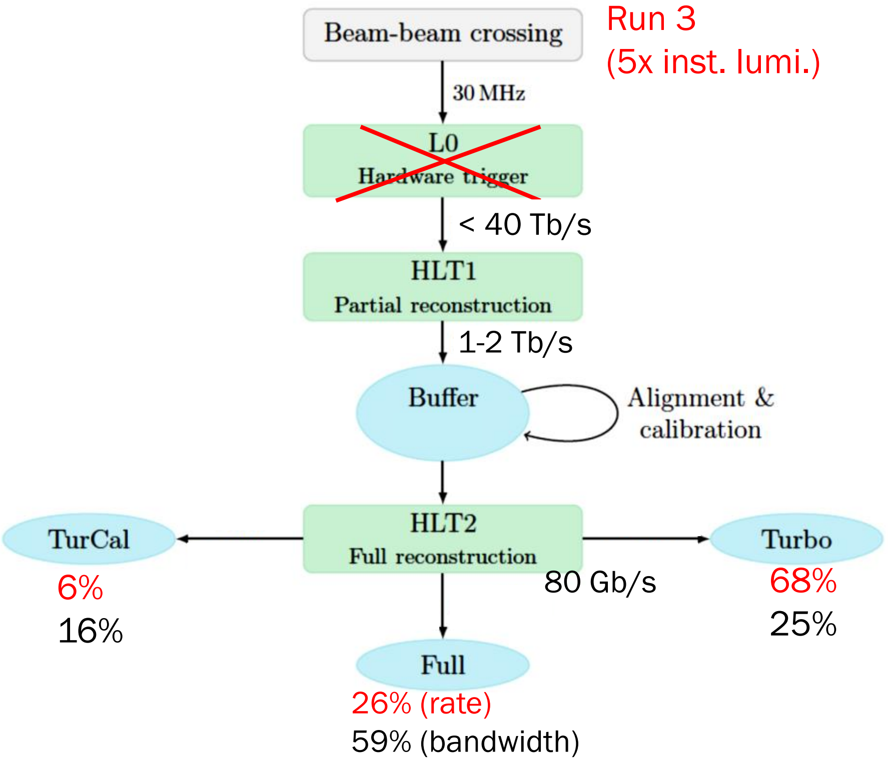


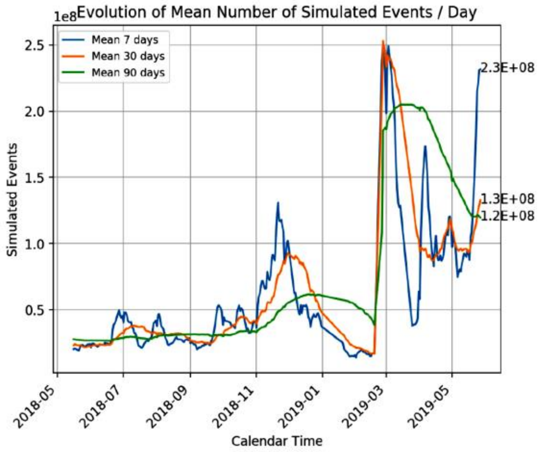
Persistence method	Average event size (kB)
Turbo	~~7~~ few
Selective persistence	~~16~~ tens
Complete persistence	~~48~~ ↓
Raw event	~~69~~ 200–250

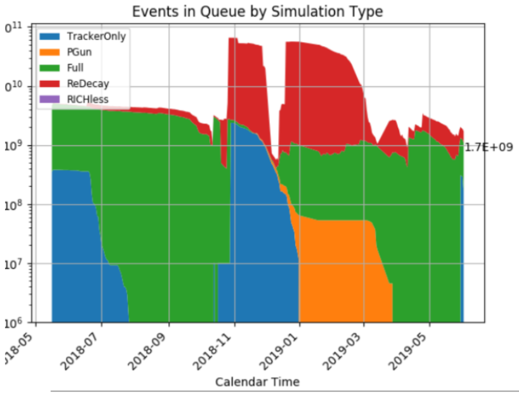
Run2: JINST 14 P04013

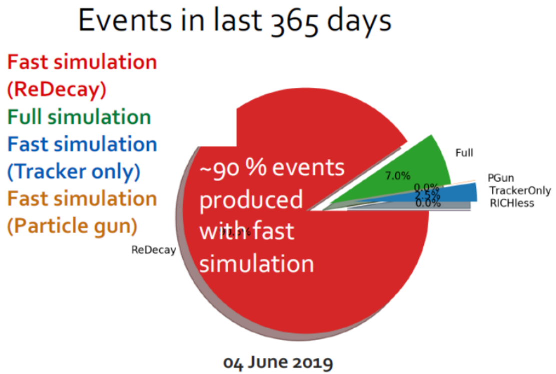
Comput. Phys. Commun. 208 35-42

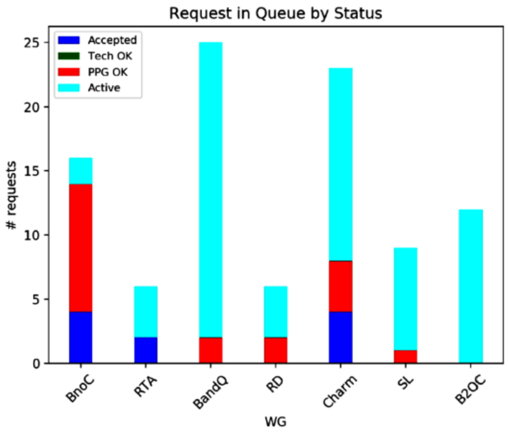
Simulation

- Increasing use of fast MC techniques
- ReDecay: is one of most popular techniques [Eur. Phys. J. C (2018) 78: 1009]
- only the few participating particles in the signal decay under study are of interest
- Re-decay the signal N times but reuse the rest of the event from previously simulated events = an order of magnitude increase in speed
- Be careful: the resulting events are not statistically independent anymore



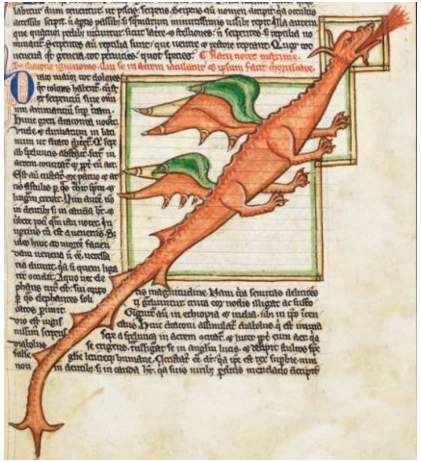




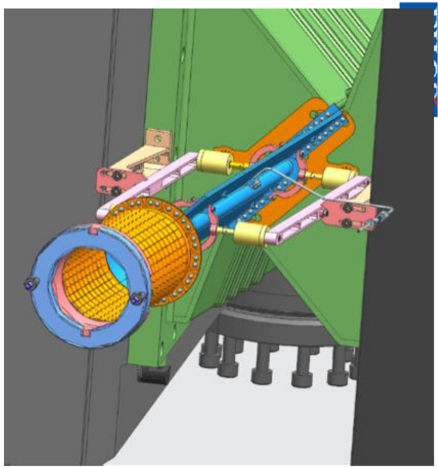


SMOG 2

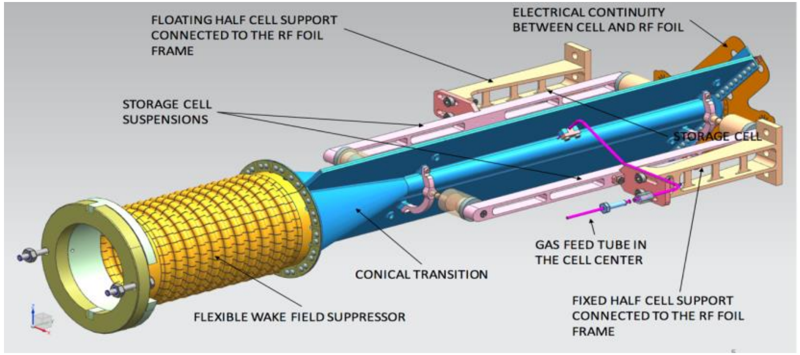
- LHCb has a unique fixed target physics programme at LHC [LHCb-PUB-2018-015]
  - Heavy ions
  - Cosmic ray physics
  - Useful for early measurements such as p/He cross-section
- New SMOG will increase by up to two orders of magnitude the effective target areal density [CERN-LHCC-2019-005 ; LHCB-TDR-020]
- significant increase of the luminosity for fixed-target collisions.
- Multiple gas capabilities being studied
  - Impact on accelerator



Dragon illustration in 13th century manuscript - Wikimedia Commons

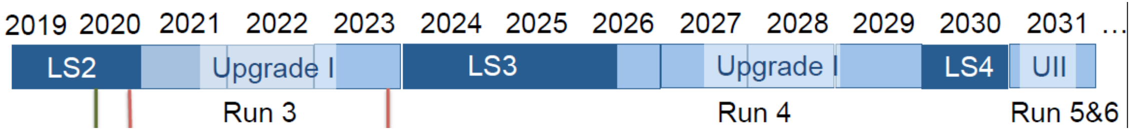


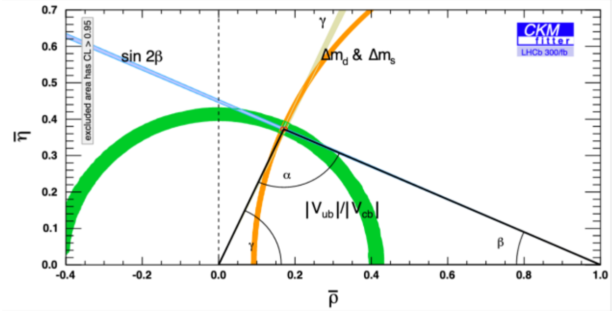
SMOG connected to the VELO RF boxes



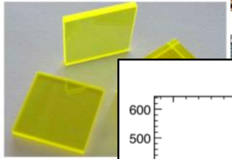
Technical drawing of the gas storage cell to be installed inside the VELO

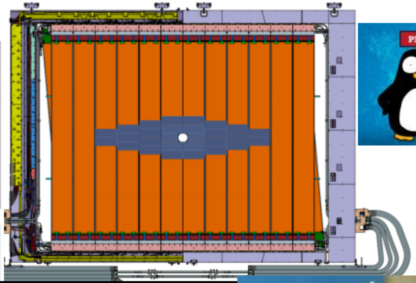
Upgrade II



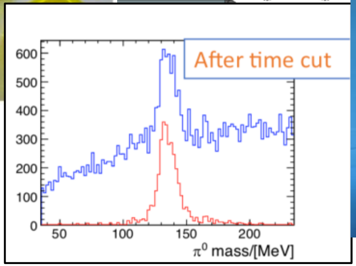


- The case for the upgrade was very well received at the ESPP meeting in Granada.
- Physics Case:
  - Collect 250 fb^{-1} more ($2\times10^{34}\,cm^{-2}s^{-1}$)
  - CERN-LHCC-2018-027 (arXiv:1808.08865)
  - Order of magnitude increase in precision over current results
  - Rare Decays, CP violation, Heavy Ions





- Detector Ideas Summary:
  - Timing needed in the VELO, and PID (TORCH)
  - More granular rad-hard calorimeter with timing
  - Chimera tracking detector from silicon/DMAPS (inner) and scifi (outer) aka the Mighty Tracker
  - Non-cpu options for tracking

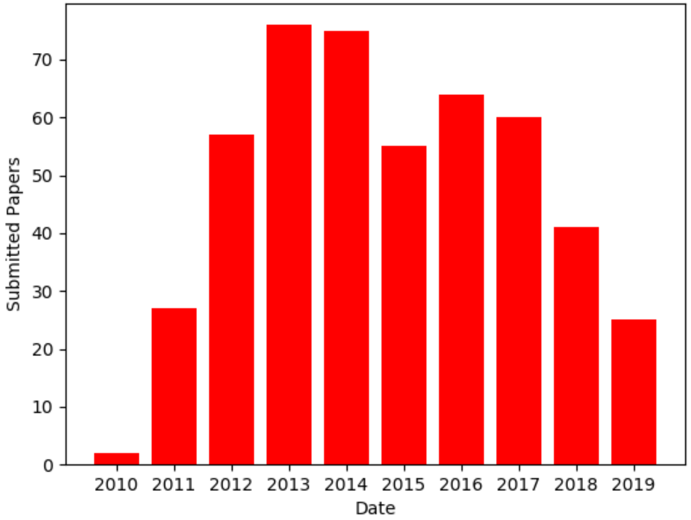


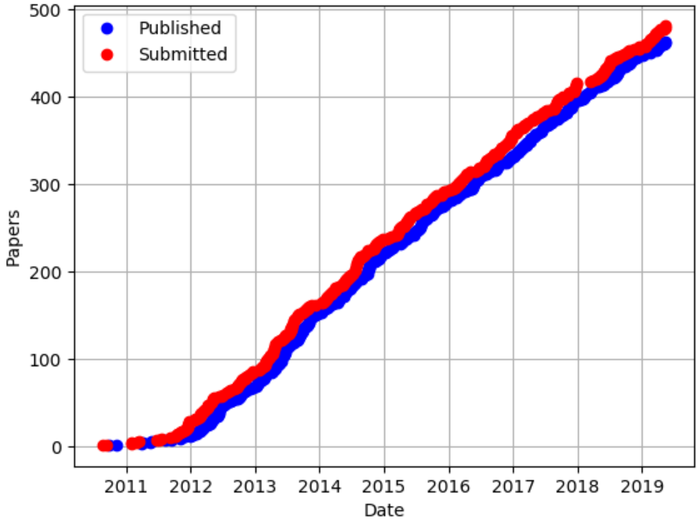
Physics Analyses and Publications

(since the last LHCC)

Publications

- 482 total publications
- 25 papers submitted to journals in 2019
  - 16 since last LHCC
- 9 being processed in the Editorial Board
- About 20 more in preparation





Submitted

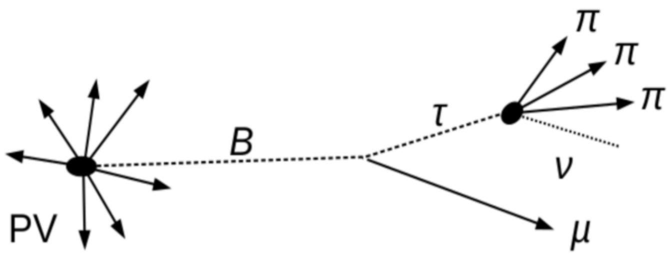
PAPER-2019-004	Amplitude analysis of the $B^0_{(s)} \to K^{*0}\,\bar{K}^{*0}$ decay and measurement of its branching fraction relative to the $B^0_s \to K^{*0}\,\bar{K}^{*0}$ decay
PAPER-2019-016	Search for the lepton-flavour-violating decays $B^0_s \to \tau^\pm\mu^\mp$ and $\mathrm{B}^0 \to \tau^\pm\mu^\mp$
PAPER-2019-015	Measurement of the mixing-induced and CP-violating observables of $B^0_s \to \phi\gamma$ decays
PAPER-2019-011	A search for $\Xi^{++}_{cc} \to D^+pK^-\pi^+$ decays
PAPER-2019-012	Measurement of charged hadron production in Z-tagged jets in proton-proton collisions at $\sqrt{s} = 8\,TeV$
PAPER-2019-010	First observation of the radiative decay $\Lambda^0_b \to \Lambda\gamma$
PAPER-2019-014	Observation of a narrow pentaquark state, $P^+_c(4312)$, and of two-peak structure of the $P^+_c(4450)$
PAPER-2019-007	Observation of an excited B^+_c state
PAPER-2019-009	Search for lepton-universality violation in $\mathrm{B}^+ \to K^+\ell^+\ell^-$decays
PAPER-2019-006	Observation of CP-violation in charm decays
PAPER-2019-005	Near-threshold $D\bar{D}$ spectroscopy and observation of a new charmonium state
PAPER-2018-044	Measurements of CP asymmetries in charmless four-body Λ^0_b and Ξ^0_b decays
PAPER-2019-003	Measurement of the CP-violating phase ϕ_s from $B^0_s \to J/\psi\,\pi^+\pi^-$ decays in 13 TeV pp collisions
PAPER-2019-001	Measurement of the mass difference between neutral charm-meson eigenstates
PAPER-2019-002	Search for CP violation in $D^+_s \to K^0_S\pi^+, D^+_s \to K^0_SK^+$ and $D^+_s \to \phi\pi^+$ decays
PAPER-2018-051	Amplitude analysis of $B^\pm \to \pi^\pm K^+K^-$ decays

Preliminary

PAPER-2019-013	Updated measurement of time-dependent CP-violating observables in $B^0_s \to J/\psi K^+K^-$ decays
PAPER-2019-020	Observation of the of the fragmentation-fraction ratio f_s/f_u variation with B-meson kinematics
PAPER-2019-021	Measurement of CP observables in the process $\mathrm{B}^0 \to DK^{*0}$ with two- and four-body D decays
PAPER-2019-019	Measurement of CP-violation in the $B^0_s \to \phi\phi$ decay and search for the $\mathrm{B}^0 \to \phi\phi$ decay
PAPER-2019-008	Precision measurement of the Λ^+_c, Ξ^0_c, and Ξ^+_c baryon lifetimes
PAPER-2019-017	Amplitude analysis of the $B^\pm \to \pi^\pm\pi^+\pi^-$ decay
PAPER-2019-018	Observation of several sources of CP-violation in $B^+ \to \pi^+\pi^+\pi^-$ decays
PAPER-2019-022	Search for the lepton-flavour violating decays $B^+ \to K^+\mu^\pm e^\mp$
PAPER-2019-021	Measurement of CP observables in the process $B^0 \to DK^{*0}$ with two- and four-body D decays
CONF-2019-001	Search for time-dependent CP violation in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays

Lepton flavour violating decay $B^0_{(s)} \to \tau^{\pm}\mu^{\mp}$

- Search for lepton-flavour violating decays $B^0_{(s)} \to \tau^{\pm}\mu^{\mp}$
- BR in SM very small: ~10^{-54}
- Can be strongly enhanced in NP models: up to $O(10^{-9} - 10^{-5})$
- Look for three prong τ decays



[LHCB-PAPER-2019-016, Run1 3 fb^{-1}] arXiv:1905.06614 Submitted to PRL

Mode	Limit	90% CL	95% CL
$B^0_s \to \tau^{\pm}\mu^{\mp}$	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

World Best limits (Factor of 2)

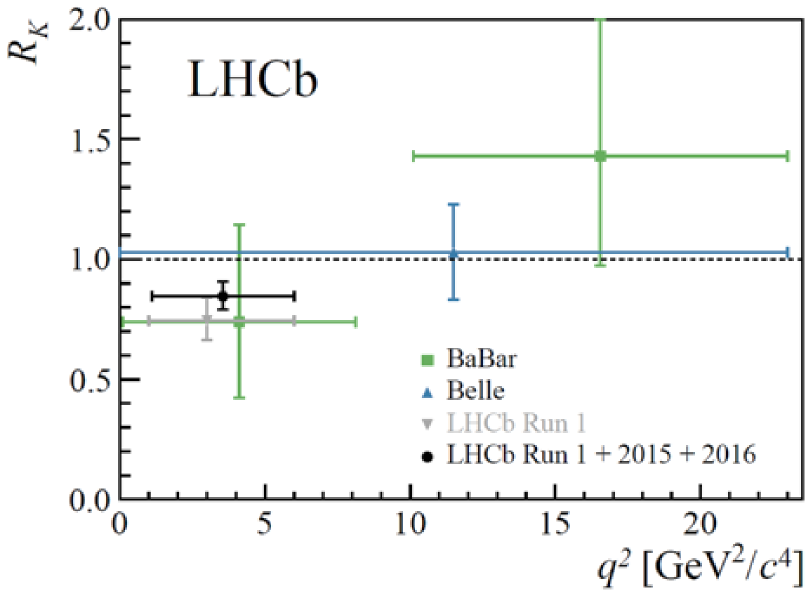
Lepton universality

[LHCB-PAPER-2019-009]
Phys. Rev. Lett. 122 (2019) 191801
arXiv:1903.09252

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu\mu)}{\mathcal{B}(B^+ \to K^+ ee)} \Big/ \frac{\mathcal{B}(B^+ \to K^+ J/\psi(\mu\mu))}{\mathcal{B}(B^+ \to K^+ J/\psi(ee))}$$

= 1 (cancels e/μ efficiency differences)

1.014 ± 0.035 (stat. + syst.)



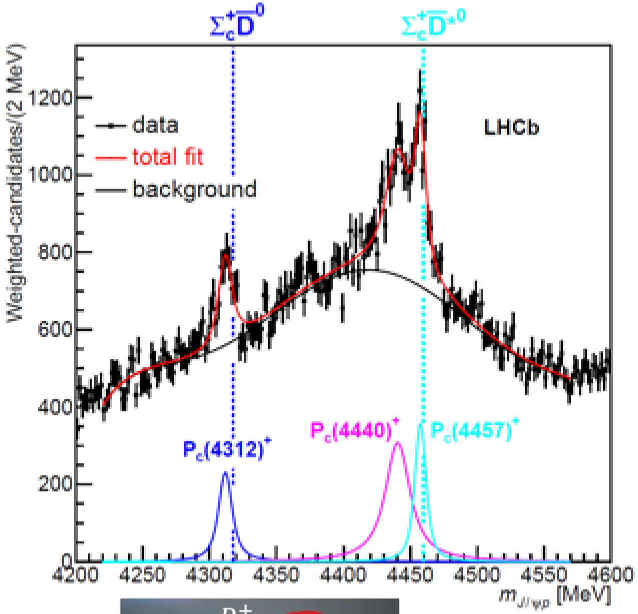
Global fit to 2011 - 2016 data

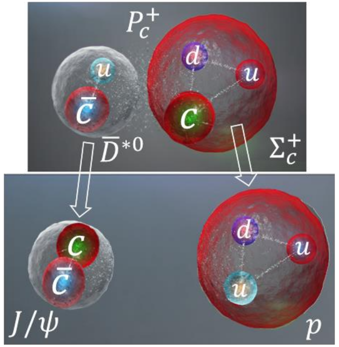
$$R_K = 0.846\,^{+0.060}_{-0.054}\,^{+0.016}_{-0.014}$$

- consistent with the SM expectation at the level of **2.5 σ**
- the most precise measurement to date
  - Using integrated luminosity of 5 fb^{-1}
  - Still 4 fb^{-1} in 2017+2018 to analyse
  - Will benefit from the Upgrade data
  - Other observables to investigate still (higher q^2, other $B \to s\ell\ell$, etc.)

Observation of new pentaquarks

- A narrow peak from $\Lambda_b^0 \rightarrow J/\psi\, p K^-$ decays is observed near 4312 MeV with a width comparable to the mass resolution
  - Analysis uses full Run 1 and 2 data
  - statistical significance of 7.3σ
- The structure at 4450 MeV is now resolved into two narrow peaks, at 4440 and 4457 MeV
  - statistical significance of this two-peak interpretation is 5.4σ
- Indication of a bound state
- Full amplitude analysis required to better determine the nature of the states





[LHCB-PAPER-2019-014, Accepted by PRL]
arXiv: 1904.03947

CP violation in charm

[LHCB-PAPER-2019-006, Accepted by PRL]
arXiv:1903.08726

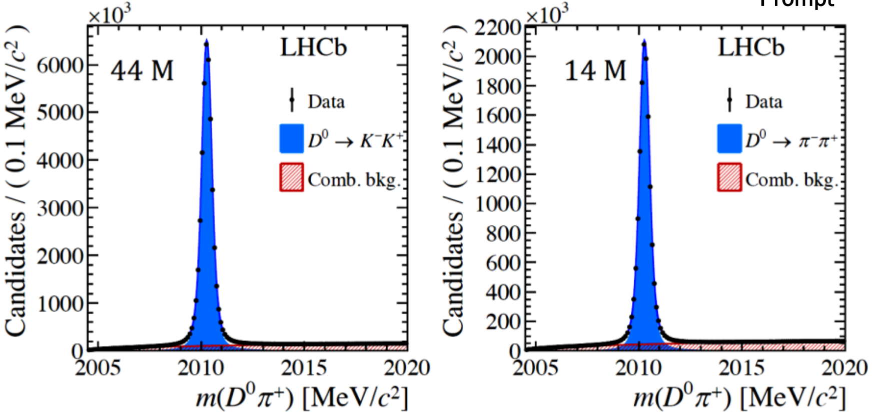
$$\Delta A_{CP} \equiv A_{CP}(D^0 \to K^- K^+) - A_{CP}(D^0 \to \pi^- \pi^+)$$

$$\Delta A_{CP} \simeq \Delta a_{CP}^{\text{dir}} \left(1 + \frac{\overline{\langle t \rangle}}{\tau(D^0)} y_{CP}\right) + \frac{\Delta \langle t \rangle}{\tau(D^0)} \Delta a_\Gamma$$

~0.01 ~ 0.00003

- ΔA_{CP} is primarily sensitive to direct CP-violation
  - largely insensitive to systematic uncertainties.
- differs from zero by **5.3σ**
  - SM expectations 10^{-4} -- 10^{-3}
- the first observation of CP violation in charm particle decays
- Reconstruction performed online (Turbo stream)
  - Comput. Phys. Commun. 208 (2016) 35

Prompt



Run 1 and 2 combined result

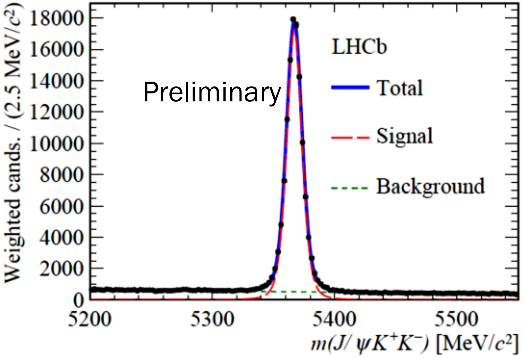
$$\Delta A_{CP} = (-1.54 \pm 0.29) \cdot 10^{-3}$$

$$\Delta a_{CP}^{dir} = (-1.56 \pm 0.29) \cdot 10^{-3}$$

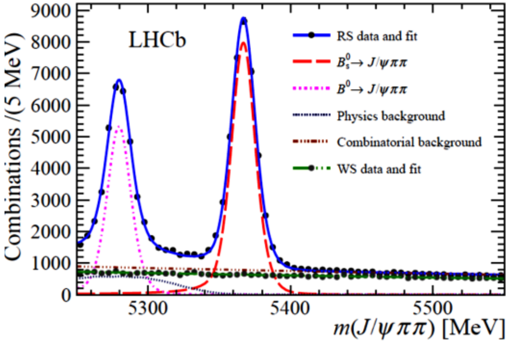
Measurement of CP violation in $B_s^0 \to J/\psi h^+ h^-$

- New results using 1.9 fb^{-1} from 2015 and 2016
  - LHC Seminar by F. Dordei
- 33,500 $B_s^0 \to J/\psi\pi^+\pi^-$ signal decays
  - 5D fit: time, 3 angles, $m_{\pi\pi}$
  - $\phi_s = -57 \pm 60 \pm 11\, mrad$
- 117,000 $B_s^0 \to J/\psi K^+K^-$ signal decays
  - Time-dependent angular analysis
  - Most precise single measurement to date
  - $\phi_s = -83 \pm 41 \pm 6\, mrad$

[LHCb-PAPER-2019-013]

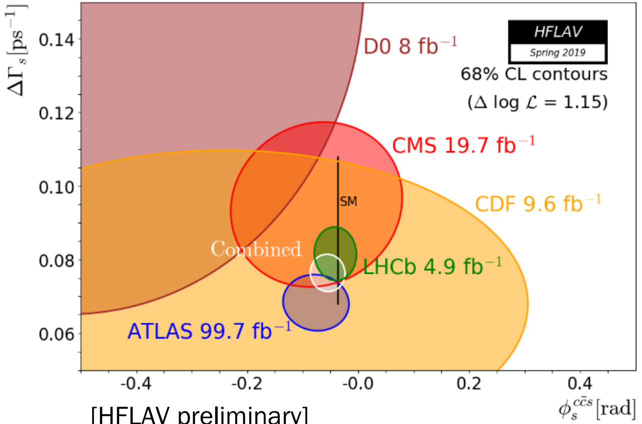


arXiv:1903.05530
[LHCb-PAPER-2019-003, Submitted to PLB]



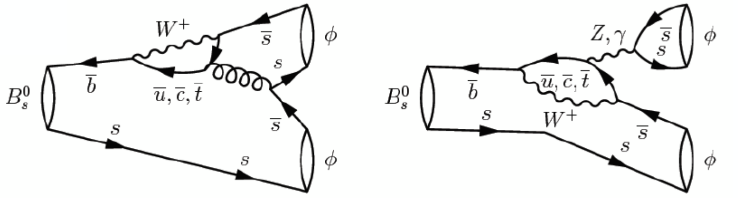
- LHCb average from combined 2011-2016 data analyses
  - $\phi_s = -41 \pm 25 \pm 6\, mrad$
  - $\Delta\Gamma_s = 0.0816 \pm 0.0048\, ps^{-1}$
- HFLAV [preliminary] average including ATLAS-CONF-2019-009
  - $\phi_s = -55 \pm 21\, mrad$
  - $\Delta\Gamma_s = 0.0764^{+0.0034}_{-0.0033}\, ps^{-1}$

$$\phi_s^{SM} \approx -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$



[HFLAV preliminary]

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



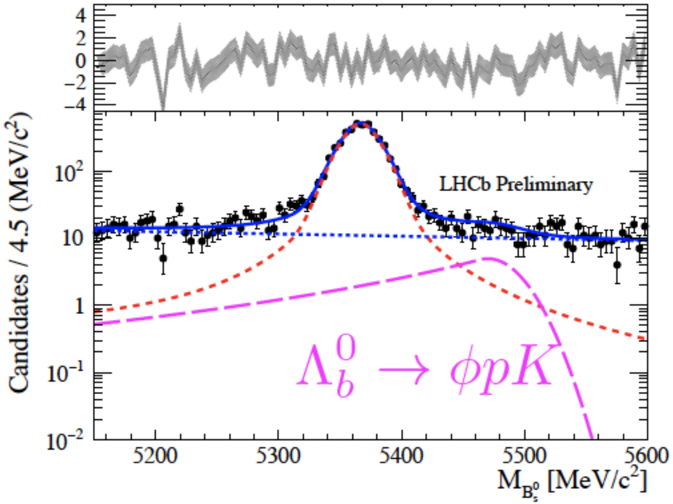
- Decay dominated by a penguin loop: enhanced sensitivity to New Physics
- Measure the CP-violating phase $\phi_s^{s\bar{s}s}$ analogous to ϕ_s.
- Perform time dependent angular analysis

LHCb preliminary

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

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

[LHCb-PAPER-2019-019, Run2 5 fb^{-1}]



- Consistent with SM predictions of CP-conservation in $b \rightarrow s\bar{s}s$ transistions: $\phi_s^{s\bar{s}s} < 20\ mrad$
  - [arXiv:0810.0249 Phys.Rev.D80:114026,2009

- Most stringent limit on the branching fraction

$$\mathcal{B}(B^0 \rightarrow \phi\phi) < 2.7 \times 10^{-8} \, (90\,\% \, \text{CL})$$

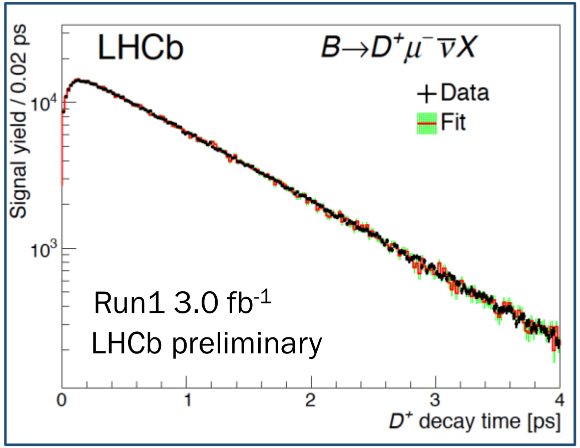
new measurement of Λ_c^+, Ξ_c^+ and Ξ_c^0 lifetimes

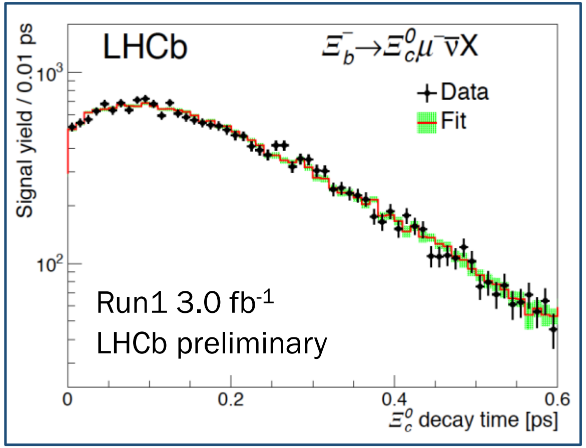
- Baryons selected from semileptonic b-baryon decays
- Measured relative to the D^+ lifetime
- Very large data sets

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

LHCb preliminary

[LHCB-PAPER-2019-008, Run1 3.0 fb^{-1}]





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

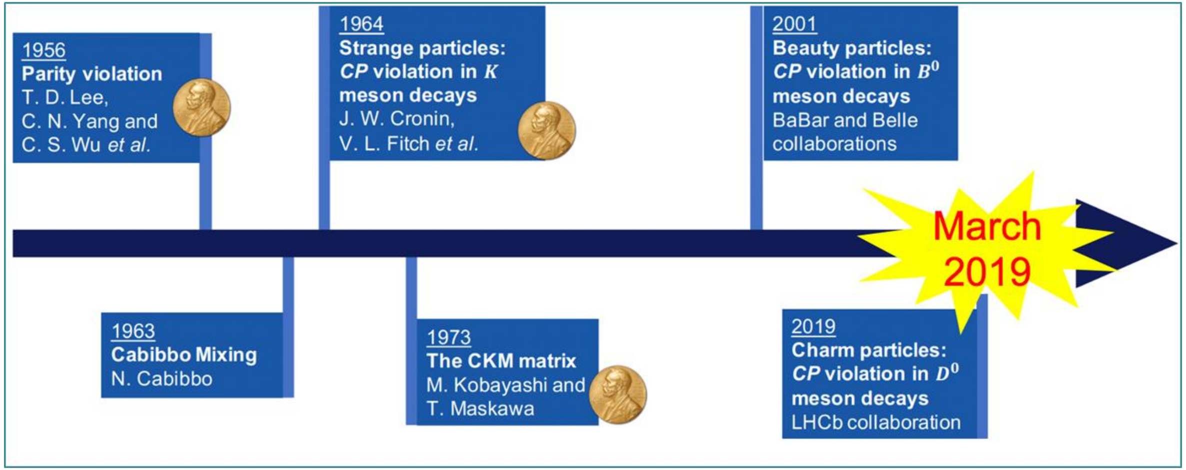
Stat. Syst. D+ lifetime uncertainty

LHCb preliminary

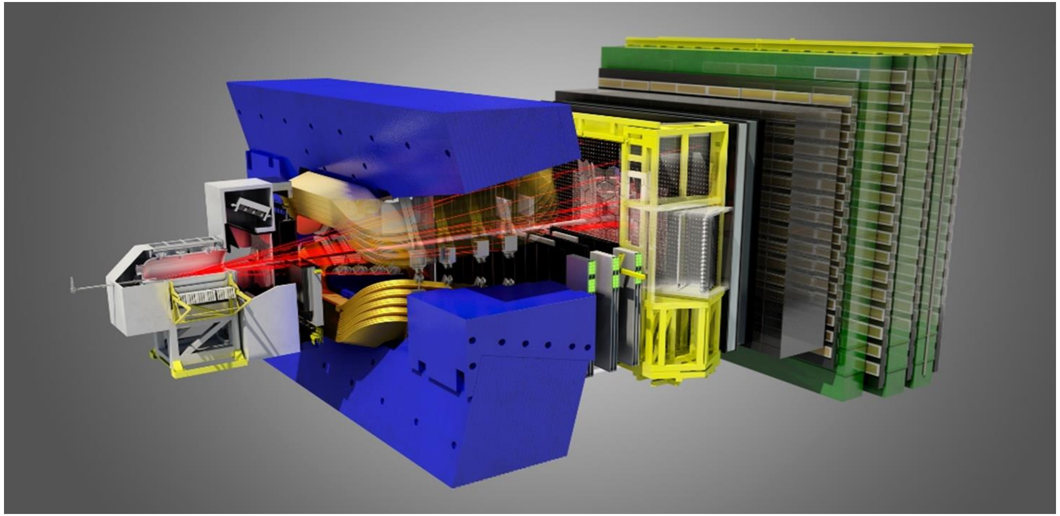
- Better precision by 3-4 times wrt world averages, but consistent.
- Lifetime of Ξ_c^0 3.3 sigma larger than WA of 112^{+13}_{-10} fs.

Conclusion

The milestones of Flavour Physics



- Run 1 & 2 data analyses progressing well with many World's Best measurements being published
  - Many more publications in the pipeline
- Upgrade 1 well under way
  - Old detector disassembly complete, with new installations started already
  - Detector production, construction and assembly under way for all detectors
  - Schedule is tight but still manageable
- Upgrade 2 on the horizon



Backups

Strategy – Prompt tag

NEW

LHCb-PAPER-2019-006

$$A_{\text{raw}}(f) = \frac{N(D^0 \to f) - N(\bar{D}^0 \to f)}{N(D^0 \to f) + N(\bar{D}^0 \to f)}$$

$D^{*+} \to D^0(\to K^+K^-)\pi_s^+$ | $D^{*+} \to D^0(\to \pi^+\pi^-)\pi_s^+$

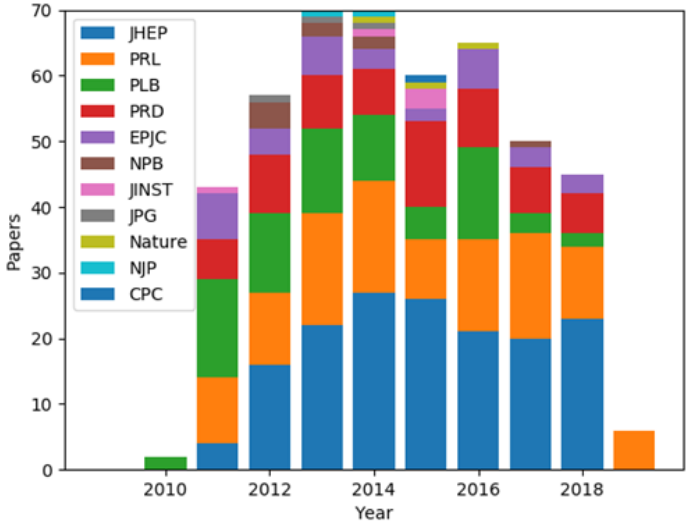
Valid up to $\mathcal{O}(10^{-6})$

$$A_{\text{raw}}(f) \simeq A_{CP}(f) + A_{\text{D}}(f) + A_{\text{D}}(\pi_s) + A_{\text{P}}(D^{*+})$$

- $A_{CP}(f)$: Physical *CP* asymmetry
- $A_{\text{D}}(f)$: D^0 detection asymmetry ➔ equal to 0, since K^-K^+ and $\pi^-\pi^+$ are symmetric final states
- $A_{\text{D}}(\pi_s)$: π_s detection asymmetry → Independent on the final state
- $A_{\text{P}}(D^{*+})$: D^* production asymmetry → Independent on the final state

If the **kinematics** of the D^{*+} and π_s for the two decay modes are equal

$$\Rightarrow A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) = A_{\text{raw}}(K^-K^+) - A_{\text{raw}}(\pi^-\pi^+)$$



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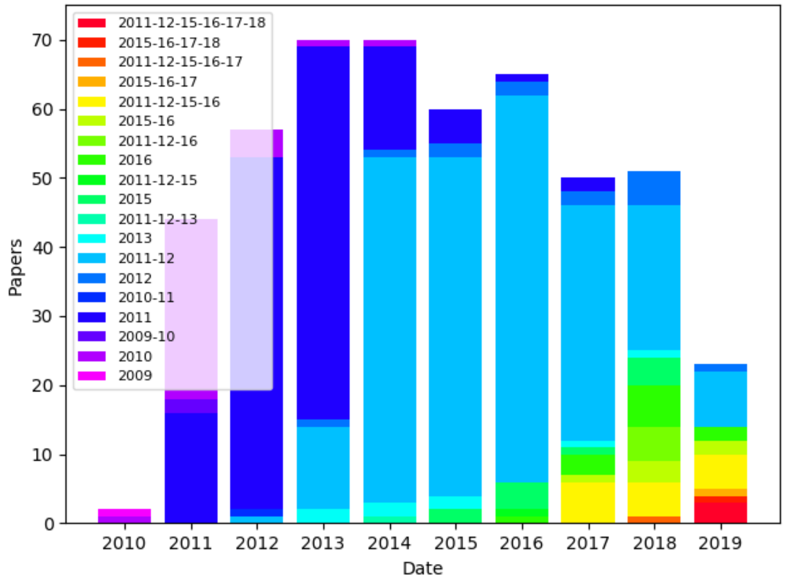

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Measuring φ_s

Definition of time-dependent CP asymmetry: $A_{CP}(t) = \frac{\Gamma(\bar{B}_s^0 \to f) - \Gamma(B_s^0 \to f)}{\Gamma(\bar{B}_s^0 \to f) + \Gamma(B_s^0 \to f)} = \eta_f \sin\varphi_s \sin(\Delta m_s\, t)$

Experimentally it becomes: $A_{CP}(t) = \eta_f \cdot e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2} \cdot (1 - 2\omega) \cdot \sin\varphi_s \cdot \sin(\Delta m_s\, t)$

Critical requirements:

- CP eigenvalue of the final state η_f → angular analysis
- Excellent decay-time resolution $\boldsymbol{\sigma_t}$~45 fs
- Tagging of meson flavour @ production: probability of getting the wrong tag $\boldsymbol{\omega}$

+ in the fit need to model decay-time efficiency $\boldsymbol{\varepsilon(t)}$ (due to selection and reconstruction) and angular efficiency $\boldsymbol{\varepsilon(\Omega)}$