

LHCb Status Report

LHCC open session

Jean-François Marchand on behalf of the LHCb collaboration

LAPP - CNRS/IN2P3
et Université de Savoie Mont Blanc

November 30, 2017



- **Operations**

- 2017 data taking
- Alignment and calibration

- **Physics** (Selection of results published since the last LHCC meeting)

- Charmless b -baryon decays
- CP -violation in beauty
- Charm mixing and CPV
- Searches

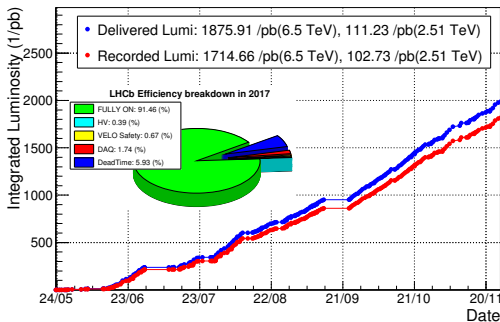
- **Upgrade**

- Status and plans

Operations

Status of 2017 data taking

LHCb Integrated Luminosity in p-p in 2017

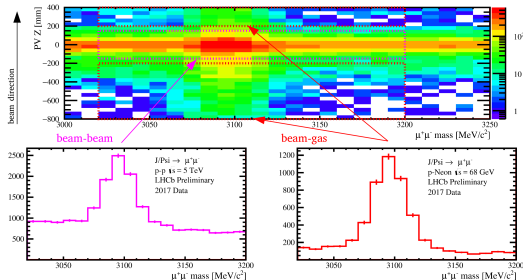
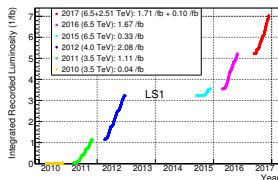


- Thanks a lot to the LHC for the great performance !!
- Despite known LHC difficulties we reached our target of 1.7 fb^{-1} in 2017

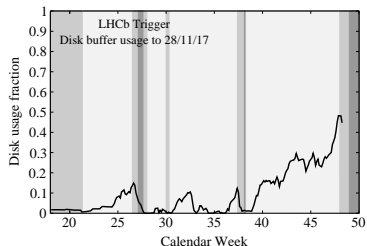
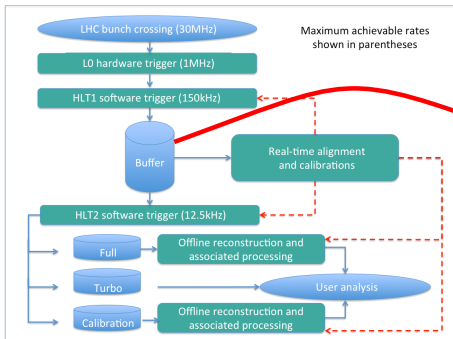
- pp collisions at 13 TeV
- Xe-Xe collisions
- Simultaneous pp and fixed-target collisions at 5 TeV

Total: 7 fb^{-1}

LHCb Cumulative Integrated Recorded Luminosity in pp, 2010-2017



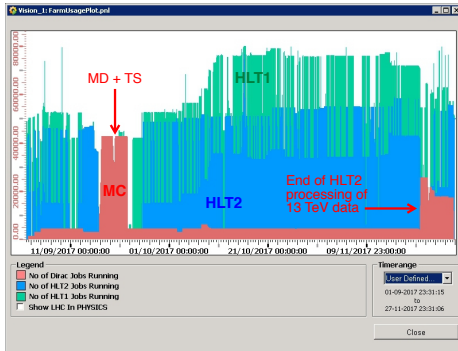
Trigger



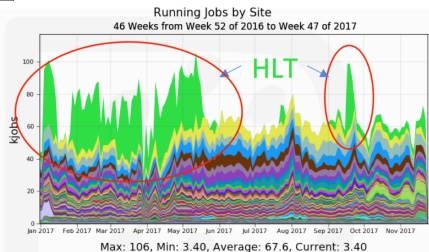
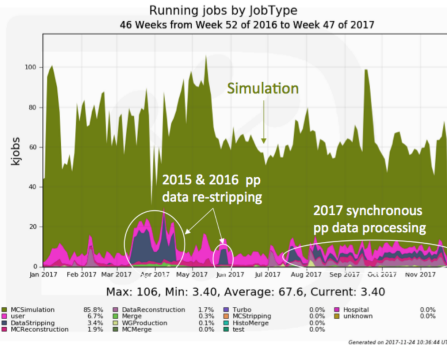
Run 2 strategy

- L0 bandwidth optimized for the wide physics programme: Tuned for 2017, updated regularly to match LHC plans
- Buffer data on disk after HLT1
- Real-time alignment and calibration
- Data processed by HLT2 asynchronously

Number of jobs running



- Better optimisation of resource usage
- MC production on the HLT farm in parallel with data taking



Online alignment and calibration (1/2)

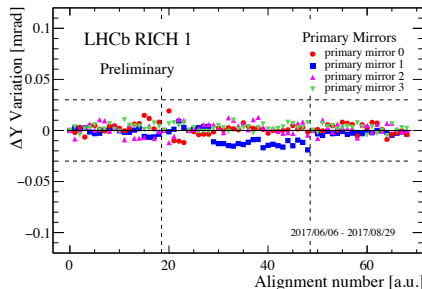
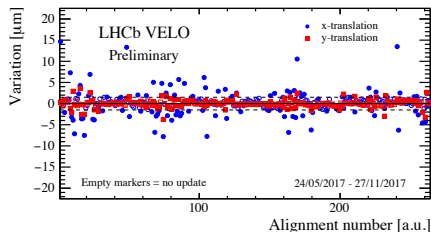
- **Real-time alignment per fill**

- Alignment of the full tracking system: VELO, TT, T stations
- Alignment of PID detector: RICH mirrors and Muon chambers

- **Real-time calibration per run or per fill**

- RICH calibration
- OT time calibration
- Calorimeter calibration

- **Full automatization of Rich mirror alignment and improved Calo calibration**



Online alignment and calibration (2/2)

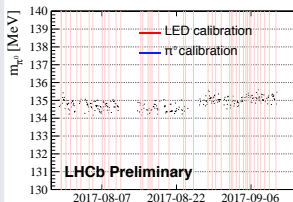
Calorimeter calibration

Relative calibration

- **After each fill:** LED amplitudes compared with a reference \Rightarrow **automatic HV update**
- Reference file adjusted after each absolute calibration

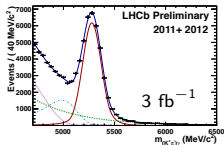
Absolute calibration

- \approx **Once per month**
- Cesium scan for HCAL
- Fine π^0 calibration for ECAL $\left\{ \begin{array}{l} \rightarrow \text{Iterative procedure (6016 cells), on HLT farm} \\ \rightarrow \text{Activated in 2017} \end{array} \right.$



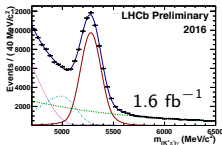
- Effect of the π^0 calibration on radiative decays $B_d^0 \rightarrow K^*(\rightarrow K^+\pi^-)\gamma$

Run 1



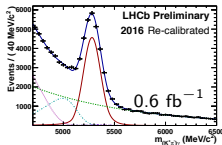
$$\sigma = 90.7 \pm 0.6 \text{ MeV}$$

2016



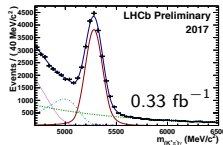
$$\sigma = 101.3 \pm 0.1 \text{ MeV}$$

2016
offline re-calibration



$$\sigma = 84.4 \pm 0.7 \text{ MeV}$$

2017



$$\sigma = 85.1 \pm 0.7 \text{ MeV}$$

Physics

Implications of LHCb measurements and future prospects

8-10 November 2017
CERN
Europe/London timezone

Search...

Overview

Timetable

Contribution List

Registration

Participant List

Videconference Rooms

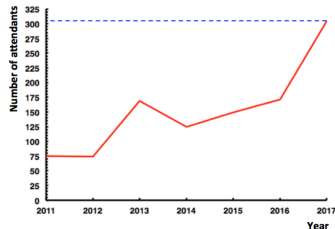
This is the 2017 edition of a series of workshops between the LHCb collaboration and the theory community. It follows similar meetings held on 10-11 Nov. 2011, 16-18 April 2012 (which resulted in a paper published in EPJ C 73 (2013) 2373), 14-16 Oct. 2013, 15-17 Oct. 2014, 3-5 Nov. 2015 and 12-14 Oct. 2016.

The purpose of the meeting is to consider the latest results from LHCb, discuss possible interpretations and identify important channels and observables to test leading theoretical frameworks in the near future of LHCb data-taking.

The meeting will be arranged in four streams, with three conveners each.

- Mixing and CP violation in Beauty and Charm [Stefan Schacht, Alex Pearce, Wenbin Qian, email [a1](#)]
- Semileptonic decays, rare decays, and tests of lepton flavour universality [Danny van Dyk, Marianna Fontana, Stefanie Reichert, email [a1](#)]
- Electroweak physics, heavy flavour production, implications for (n)PDFs, and exotica searches [Rhory Gauld, Martino Borsato, Emilie Maurice, email [a1](#)]
- QCD spectroscopy and exotic hadrons [Graham Moir, Jibo He, Ivan Polyakov, email [a1](#)]

All interested theorists are welcome to participate, and are encouraged to register at the [workshop INDICO page](#) (there is no registration fee). To express interest in giving a presentation, please contact the conveners (once defined) of the relevant stream. Unfortunately, to allow informal discussion, we must restrict the participation to exclude members of competing experiments.

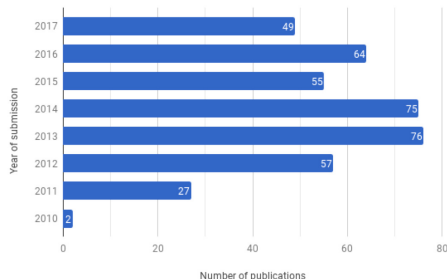


- Joint LHCb-theory workshop to:
 - Consider the latest results from LHCb
 - Discuss possible interpretations
 - Identify important channels and observables to test leading theoretical frameworks in the near and long-term future
- **More than 300 physicists** crowded the Main Auditorium during **3 days**

<https://indico.cern.ch/event/646856/>

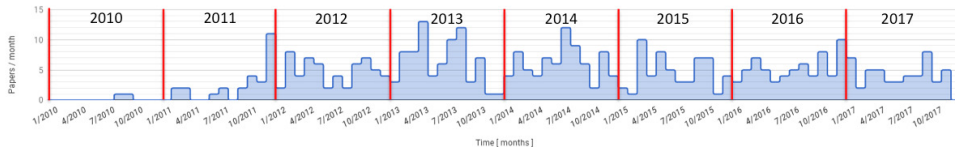
Paper status

Publications per year



- 405 papers in total
 - 49 in 2017
 - 9 since last LHCC
- Further 12 papers close to submission

Papers submitted per month



Submitted since last LHCC week

- 2017-026 Measurements of $\Lambda_c^+ \rightarrow pK^- K^+$, $\Lambda_c^+ \rightarrow p\pi^- \pi^+$ and $\Lambda_c^+ \rightarrow p\pi^- K^+$ branching ratios
- 2017-027 Measurement of the $\mathcal{B}(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)$ branching fraction using three-prong τ decays
- 2017-030 Measurement of CP observables in $B^\pm \rightarrow DK^{*\pm}$ decays using two- and four-body D -meson final states
- 2017-031 Search for the lepton-flavour violating decays $B_{(s)}^0 \rightarrow e^\pm \mu^\mp$
- 2017-032 First observation of $B^+ \rightarrow D_s^+ K^+ K^-$ decays and a search for $B^+ \rightarrow D_s^+ \phi$ decays
- 2017-034 First measurements of relative branching fractions of charmless four-body Λ_b^0 and Ξ_b^0 decays
- 2017-035 Measurement of the ratio of branching fractions $\mathcal{B}(B_c^+ \rightarrow J/\psi \tau^+ \nu_\tau)/\mathcal{B}(B_c^+ \rightarrow J/\psi \mu^+ \nu_\mu)$
- 2017-037 Measurement of the B^\pm production cross-section in pp collisions at $\sqrt{s} = 7$ and 13 TeV
- 2017-038 Search for dark photons produced in 13 TeV pp collisions

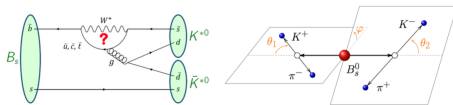
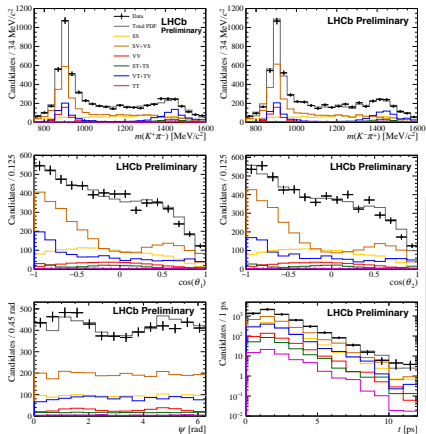
Preliminary

- 2017-033 Anatomy of the decay $B^0 \rightarrow K_S^0 \pi^+ \pi^-$ and first observation of CP asymmetry in the transition $\overline{B}^0 \rightarrow K^{*-} (892) \pi^+$
- 2017-039 Search for the suppressed $\Lambda_c^+ \rightarrow p \mu^+ \mu^-$ decay and observation of the $\Lambda_c^+ \rightarrow p \omega$ decay
- 2017-040 Studies of the resonance structure in $D^0 \rightarrow K^\mp \pi^\pm \pi^+ \pi^-$ decays
- 2017-042 Search for excited B_c^+ states
- 2017-044 Search for direct CP violation in $\Lambda_c^+ \rightarrow pK^- K^+$ and $\Lambda_c^+ \rightarrow p\pi^- \pi^+$ decays using semileptonic Λ_b^0 decays
- 2017-045 Search for the decays of charmed beauty mesons to two charm mesons
- 2017-046 Updated determination of D^0 - \overline{D}^0 mixing parameters and CP violation in $D^0 \rightarrow K^+ \pi^-$ decays
- 2017-047 Measurement of CP asymmetry in $B_s^0 \rightarrow D_s^\mp K^\pm$ decays
- 2017-048 Measurement of the CP -violating phase ϕ_s^{dd} in quasi-two-body $B_s^0 \rightarrow (K^+ \pi^-)(K^- \pi^+)$ decays
- 2017-049 Evidence for the rare decay $\Sigma^+ \rightarrow p \mu \mu$

Measurement of $\phi_s^{d\bar{d}}$ in $B_s^0 \rightarrow (K^+\pi^-)(K^-\pi^+)$ decays

LHCb-PAPER-2017-048

- Gluonic penguin decay - New particles may enter the loop
- Combination of CP eigenstates in final state \Rightarrow Interference between B_s^0/\bar{B}_s^0 mixing and decay \Rightarrow CP violating phase ϕ_s



Using 3 fb^{-1} at 7 and 8 TeV

- Time-dependent amplitude analysis
- **First measurement of the CP-violating phase ϕ_s using $b \rightarrow d\bar{d}s$ transition**
 $\phi_s^{d\bar{d}} = -0.10 \pm 0.13(\text{stat}) \pm 0.13(\text{syst}) \text{ rad}$
- Consistent with SM expectation ($\phi_s^{d\bar{d}} \approx 0$ in SM) and with the corresponding result of $\phi_s^{s\bar{s}}$
 $\phi_s^{s\bar{s}} = -0.17 \pm 0.15(\text{stat}) \pm 0.03(\text{syst}) \text{ rad}$

- Also { **First determination of the CP asymmetry of the $(K^+\pi^-)(K^-\pi^+)$ final state**
 Best, sometimes first, measurements of 19 CP-averaged amplitude parameters
- CERN seminar last week: <https://indico.cern.ch/event/656775/>

First measurements of relative branching fractions of charmless four-body Λ_b^0 and Ξ_b^0 decays

LHCb-PAPER-2017-034

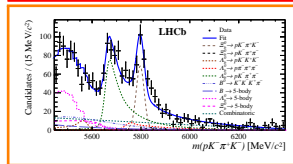
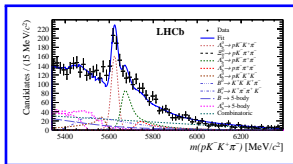
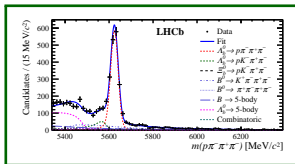
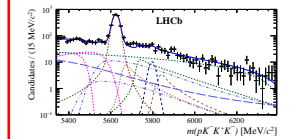
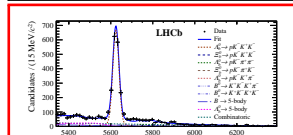
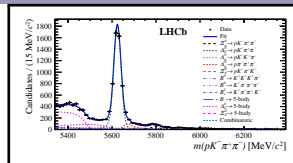
- Multibody charmless decays of weakly interacting b -flavoured baryons
→ relevant to observe **CP violation in b -baryon decays**

- 6 decay modes observed:

Using 3 fb^{-1} at 7 and 8 TeV

$$\left\{ \begin{array}{l} \Lambda_b^0 \rightarrow p \pi^- \pi^+ \pi^- \\ \Lambda_b^0 \rightarrow p K^- K^+ \pi^- \\ \Lambda_b^0 \rightarrow p K^- \pi^+ \pi^- \leftarrow \text{NEW} \\ \Xi_b^0 \rightarrow p K^- \pi^+ \pi^- \leftarrow \text{NEW} \\ \Xi_b^0 \rightarrow p K^- \pi^+ K^- \leftarrow \text{NEW} \\ \Lambda_b^0 \rightarrow p K^- K^+ K^- \leftarrow \text{NEW} \end{array} \right.$$

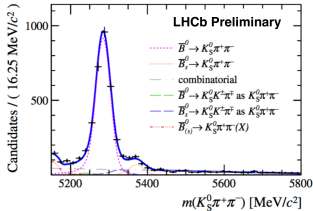
- Branching fractions determined relative to $\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K^- \pi^+) \pi^-$
- New channels to search for CP-violating asymmetries in fully charged four-body decays of Λ_b^0 and Ξ_b^0 baryons



Anatomy of the decay $B^0 \rightarrow K_S^0 \pi^+ \pi^-$ and first observation of CP asymmetry in the transition $\bar{B}^0 \rightarrow K^{*-}(892) \pi^+$

LHCb-PAPER-2017-033

- $B^0 \rightarrow K_S^0 \pi^+ \pi^-$ proceeds through flavour-specific quasi 2-body amplitudes and offers possibility to measure CP asymmetries
- Time-integrated analysis of 3-body Dalitz Plot of charmless decay $\bar{B}^0 \rightarrow K_S^0 \pi^+ \pi^-$
- DP of the decay modelled by an isobar parametrisation of the underlying amplitudes
- Model fit to the data to measure the relative branching fractions and the CP asymmetries of flavour specific final states



Using 3 fb⁻¹ at 7 and 8 TeV

$$\begin{aligned}
 \mathcal{A}_{CP}(K^{*-}(892) \pi^+) &= -0.308 \pm 0.060 \pm 0.011 \pm 0.012, \\
 \mathcal{A}_{CP}((K\pi)_0^{*-} \pi^+) &= -0.032 \pm 0.047 \pm 0.016 \pm 0.027, \\
 \mathcal{A}_{CP}(K_2^{*}(1430)^- \pi^+) &= -0.29 \pm 0.22 \pm 0.09 \pm 0.03, \\
 \mathcal{A}_{CP}(f_0(1680)^- \pi^+) &= -0.07 \pm 0.13 \pm 0.02 \pm 0.03, \\
 \mathcal{A}_{CP}(f_0(980) K_S^0) &= 0.28 \pm 0.27 \pm 0.05 \pm 0.14,
 \end{aligned}$$

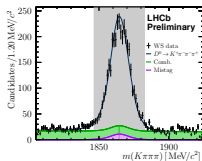
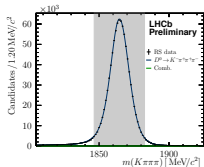
(Errors are stat, syst and model)

- **First observation of a CP -violating asymmetry in the $\bar{B}^0 \rightarrow K^{*-}(892) \pi^+$ decay at 6σ**
- CP asymmetry between $\bar{B}^0 \rightarrow K^{*-}(892) \pi^+$ and $B^0 \rightarrow K^{*+}(892) \pi^-$ decay rates is determined to be: $\mathcal{A}_{CP}(K^{*\pm}(892) \pi^\mp) = -0.308 \pm 0.062$
- In good agreement with world average $\mathcal{A}_{CP}(K^{*\pm}(892) \pi^\mp) = -0.23 \pm 0.06$, but improved precision

Studies of the resonance structure in $D^0 \rightarrow K^\mp \pi^\pm \pi^+ \pi^-$ decays

LHCb-PAPER-2017-040

- Time-integrated amplitude analysis of
 - $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+ \rightarrow$ Cabibbo-Favoured, termed as Right-Sign (RS)
 - $D^0 \rightarrow K^+ \pi^- \pi^+ \pi^- \rightarrow$ Doubly Cabibbo-Suppressed, termed as Wrong-Sign (WS)
 ⇒ **first amplitude analysis of the WS decay**
- Using $B \rightarrow D^*(2010)^+ \mu^- X$, with $D^*(2010)^+ \rightarrow D^0 \pi_{\text{slow}}^+$ as clean source of $D^0 \rightarrow \mu$ and π_{slow} charges used to infer D flavour



Using 3 fb^{-1} at 7 and 8 TeV

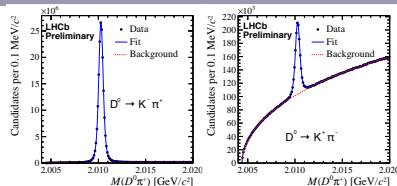
- Largest contributions from axial resonances with decay modes:
 - $D^0 \rightarrow a_1(1260)^+ K^-$ for $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$
 - $D^0 \rightarrow K_1(1270/1400)^+ \pi^-$ for $D^0 \rightarrow K^+ \pi^- \pi^- \pi^+$
 → Consistent with general picture that W -emission topologies crucial in describing these decays
- Coherence factor of the decays is computed from the amplitude models:
 - $R_{K3\pi} = 0.458 \pm 0.010(\text{stat}) \pm 0.012(\text{syst}) \pm 0.020(\text{model})$
 - ⇒ **Consistent with direct measurements**
- These amplitude models will be useful in future measurements of the unitarity triangle angle γ and in charm mixing and CP -violation

Updated determination of D^0 - \bar{D}^0 mixing parameters and CP violation in $D^0 \rightarrow K^+ \pi^-$ decays

LHCb-PAPER-2017-046

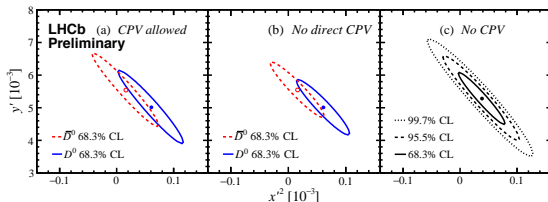
- Study $D^0 - \bar{D}^0$ oscillations using $D^{*+} \rightarrow D^0(\rightarrow K^+ \pi^-) \pi^+$ decays

Using 5 fb^{-1} at 7, 8 and 13 TeV



- Assuming CP conservation:** Mixing parameters determined to be

$$\begin{cases} x'^2 = (3.9 \pm 2.7) \times 10^{-5} \\ y' = (5.28 \pm 0.52) \times 10^{-3} \\ R_D = (3.454 \pm 0.031) \times 10^{-3} \end{cases} \rightarrow \text{Twice as precise as previous LHCb results}$$
- Allowing for CP violation:** Measurement performed separately for D^0 and \bar{D}^0
 - Direct CP -violating asymmetry $\mathcal{A}_D = (-0.1 \pm 9.1) \times 10^{-3}$
 - Magnitude of the ratio of mixing parameters $1.00 < |q/p| < 1.35$ at 68.3% CL



- No evidence yet for CP violation in charm mixing**

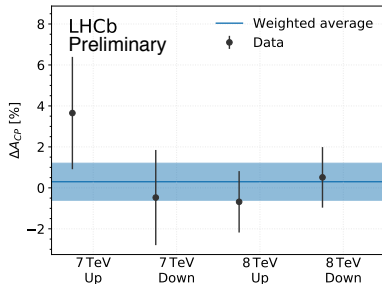
Search for direct CP violation in $\Lambda_c^+ \rightarrow pK^-K^+$ and $\Lambda_c^+ \rightarrow p\pi^-\pi^+$ decays using semileptonic Λ_b^0 decays

LHCb-PAPER-2017-044

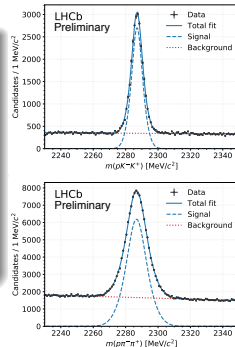
- Search for CP violation in decays of Λ_c^+ baryon to the Singly Cabibbo-Suppressed (SCS) $\begin{cases} pK^-K^+ \\ p\pi^-\pi^+ \end{cases}$ final states
- Each Λ_c^+ candidate is reconstructed in association with a μ , with hypothesis they are from $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- X$ decays
- Difference in CP asymmetries found to be

$$\Delta A_{CP} = A_{CP}^{\text{Raw}}(pK^-K^+) - A_{CP}^{\text{Raw}}(p\pi^-\pi^+)$$

$$= (0.30 \pm 0.91(\text{stat}) \pm 0.61(\text{syst}))\%$$



Using 3 fb^{-1} at 7 and 8 TeV

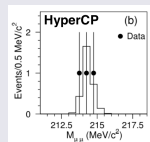


- 1st search for CP violation in 3-body Λ_c^+ decays
- More data are required to be sensitive to the magnitude of CP violation predicted by the SM in the charm sector

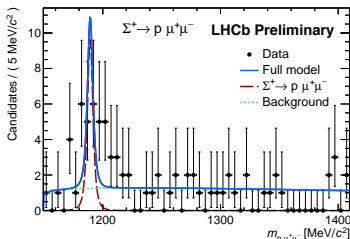
- Strange physics provides a unique & complementary probe to test SM wrt beauty and charm
- **Evidence for $\Sigma^+ \rightarrow p\mu^+\mu^-$ at 4.0σ**
- Measured branching fraction of $2.1^{+1.6}_{-1.2} \times 10^{-8}$, consistent with the SM predictions
- Standard distribution of dimuon invariant mass
- **HyperCP result not confirmed with present statistics**

HyperCP observed 3 events, “Evidence for the Decay $\Sigma^+ \rightarrow p\mu^+\mu^-$, H. K. Park et al. (HyperCP Collaboration) Phys. Rev. Lett. 94, 021801”,

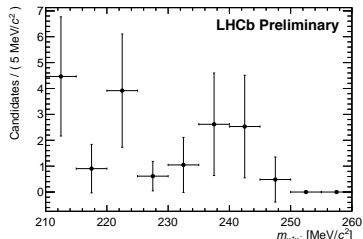
$$\mathcal{B}(\Sigma^+ \rightarrow pX^0(\rightarrow \mu^+\mu^-)) = (3.1^{+2.4}_{-1.9}(\text{stat}) \pm 1.5(\text{syst})) \times 10^{-8}$$



$$\mathcal{B}(\Sigma^+ \rightarrow pX^0(\rightarrow \mu^+\mu^-)) < 9.5 \times 10^{-9} (1.2 \times 10^{-8}) \text{ at 90\% (95\%) CL}$$

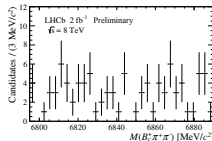
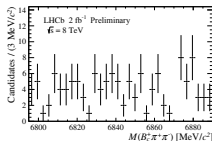
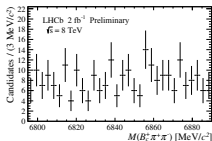
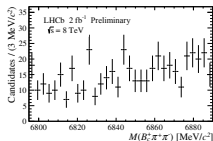


Background subtracted distribution of the dimuon invariant mass for $\Sigma^+ \rightarrow p\mu^+\mu^-$ candidates



Using 3 fb⁻¹ at 7 and 8 TeV

- $\begin{Bmatrix} B_c(2S)^+ \\ B_c^*(2S)^+ \end{Bmatrix}$ searched for via $\begin{Bmatrix} B_c(2S)^+ \rightarrow B_c^+ \pi^+ \pi^- \\ B_c^*(2S)^+ \rightarrow B_c^{*+} (\rightarrow B_c^+ \gamma) \pi^+ \pi^- \end{Bmatrix}$ with $B_c^+ \rightarrow J/\psi (\rightarrow \mu^+ \mu^-) \pi^+$
- Low energy photon not reconstructed $\Rightarrow \begin{cases} m_{B_c^*(2S)^+} \text{ centered at } M_{B_c(2S)^+} - \Delta M \\ \text{mass peak not significantly wider} \end{cases}$
- Theoretical predictions: $\begin{cases} m_{B_c(2S)^+} \in [6830, 6890] \text{ MeV} \\ \text{and } \Delta M \in [0, 35] \text{ MeV} \end{cases} \Rightarrow m_{B_c^*(2S)^+} \in [6795, 6890] \text{ MeV}$
- Selection based on a multi-layer perceptron (MLP) classifier to optimise the sensitivity



\Rightarrow **No significant signal found**

Using 2 fb^{-1} at 8 TeV

\mathcal{R}	$\sqrt{s} = 7 \text{ TeV}$	$\sqrt{s} = 8 \text{ TeV}$
ATLAS	$(0.22 \pm 0.08(\text{stat}))/\epsilon_7$	$(0.15 \pm 0.06(\text{stat}))/\epsilon_8$
LHCb	—	$< [0.04, 0.09]$

with

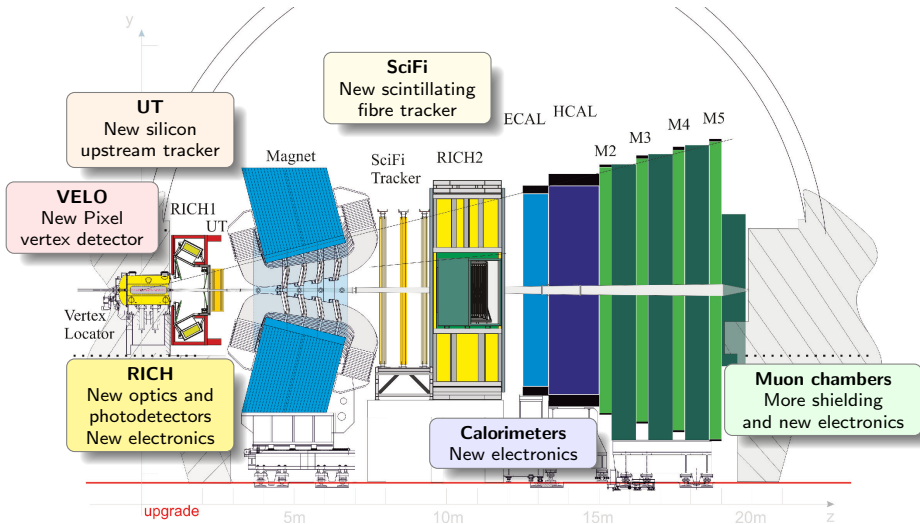
$$\mathcal{R} = \frac{\sigma_{B_c^{(*)}(2S)^+}}{\sigma_{B_c^+}} \cdot \mathcal{B}_{B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-}$$

$$= \frac{N_{B_c^{(*)}(2S)^+}}{N_{B_c^+}} \cdot \frac{\epsilon_{B_c^+ \rightarrow J/\psi \pi^+}}{\epsilon_{B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} (\rightarrow J/\psi \pi^+) \pi^+ \pi^-}}$$

If one assumes, as theoretically expected, that the dependence on p_T and y is mild, **ATLAS and LHCb results could be barely reconciled only if ATLAS has a very large relative efficiency for $B_c^{(*)}(2S)^+$ with respect to B_c^+**

Upgrade

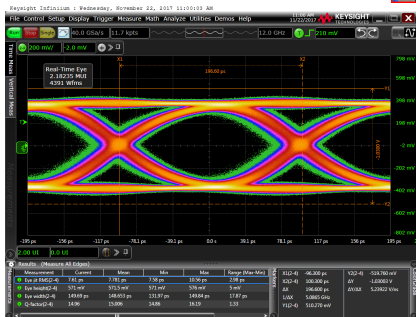
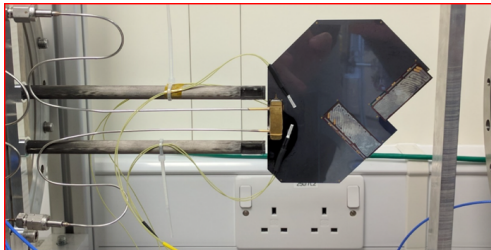
LHCb Upgrade



- Installation in LS2, operation in Run 3
- 40 MHz readout, flexible software-only trigger

LHCb Upgrade - VELO

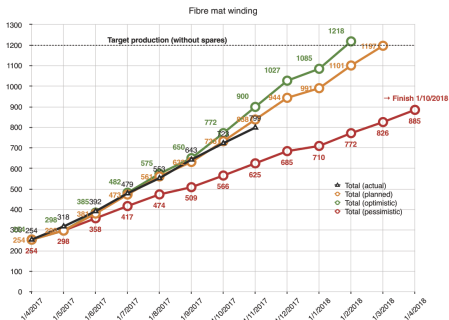
- Module EDR took place on Sept. 27-28 (Manchester)
- Converged on silicon μ channel substrate
- Ready to start final production and assembly



- VeloPix v2 ASIC is back from foundry
- Being tested, and so far seems all OK
- Radiation tests done last week-end

LHCb Upgrade - SciFi

- Fibre mat production progressing very well
- Module production progressing according to schedule
- First fibre modules arrived at CERN: the first upgrade components received!
- Infrastructure for the final SciFi assembly and installation is being prepared at CERN



LHCb Upgrade - RICH, Calorimeter, Muons

- **UT**

- Front-end ASIC received
- Tests ongoing

- **RICH**

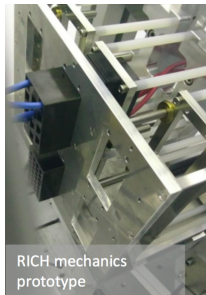
- MAPMT production & testing ongoing ($\approx 2000/3500$)

- **Calorimeters**

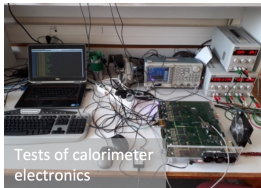
- Production of analog chips and boards progressing well

- **Muons**

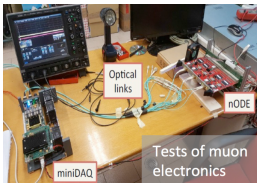
- Successful PRR of nSync ASIC and nODE boards
- Production of spare chambers completed, final tests ongoing at CERN



RICH mechanics prototype



Tests of calorimeter electronics



Tests of muon electronics



Tests of spare muon MWPCs

● LHCb Operations

- Reached our target of 1.7 fb^{-1} recorded in 2017 thanks to the LHC overall performance
- Excellent performance during 2017 data taking
- Optimal and dynamic use of resources to maximise the physics output

● LHCb Physics

- 9 papers submitted since the last LHCC meeting
- Many new results and updates upcoming

● LHCb Upgrade

- Huge progress over the past few months
- First parts already at Point 8

