• As of September 2014: 1075 members, from 68 institutes in 17 countries
• *Beautiful, charming, strange* physics program
Articles submitted since last LHCC

A stable physics output rate!

PAPER-2014-018 Search for $CP$ violation in $D^\pm \to K_S^0K^\pm$ and $D^\pm_S \to K_S^0\pi^\pm$ decays
PAPER-2014-022 Observation of $Z$ production in proton-lead collisions at LHCb
PAPER-2014-023 First measurement of the charge asymmetry in beauty-quark pair production
PAPER-2014-024 Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays
PAPER-2014-011 Effective lifetime measurements of the $B^0 \to K^+K^-$, $B^0 \to K^+\pi^-$ and $B^0 \to \pi^+K^-\pi^0$ decays
PAPER-2014-025 Measurement of the ratio of $B_s^\pm$ branching fractions to $J/\psi\pi^+$ and $J/\psi\mu^+\nu_{\mu}$
PAPER-2014-038 Measurement of $CP$ asymmetry in $B^0_s \to D^+_S K^\pm$ decays [LHCb, submitted to JHEP, arXiv:1407.6127]
PAPER-2014-017 Measurement of $CP$ violation and constraints on the CKM angle $\gamma$ in $B^\pm \to D K^\pm$ with $D \to K^0_S\pi^+\pi^-$ decays [LHCb, to appear in Nucl. Phys. B, arXiv:1407.6211]
PAPER-2014-043 Observation of $B^0 \to K^*\pm K^\mp$ and evidence of $B^0_s \to K^*\pi^\pm$ decays [LHCb, submitted to New J. Phys., arXiv:1407.7704]
PAPER-2014-032 Measurement of $CP$ asymmetries in the decays $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^{*+}\mu^+\mu^-$ [LHCb, submitted to Phys. Rev. Lett., arXiv:1408.0978]
PAPER-2014-030 First observations of the rare decays $B^+ \to K^{*+}\pi^-\mu^+\mu^-$ and $B^+ \to \phi K^+\mu^+\mu^-$ [LHCb, to appear in JHEP, arXiv:1408.1137]
PAPER-2014-046 Search for $CP$ violation using $T$-odd correlations in $D^0 \to K^+K^\mp\pi^\mp\pi^\pm$ decays [LHCb, to appear in JHEP, arXiv:1408.1299]
PAPER-2014-041 Measurement of the CKM angle $\gamma$ using $B^\pm \to D K^\pm$ with $D \to K^0_S\pi^+\pi^-$, $K^0_S\bar{K}^0\bar{K}^+\pi^-$ decays [LHCb, submitted to JHEP, arXiv:1408.2748]
PAPER-2014-040 Measurement of the $\chi_c(3P)$ mass and of the relative rate of $\chi_c1(1P)$ and $\chi_c2(1P)$ production [LHCb, submitted to JHEP, arXiv:1409.1408]
PAPER-2014-029 Measurement of the $\eta_c(1S)$ production cross-section in proton-proton collisions via the decay $\eta_c(1S) \to p\bar{p}$ [LHCb, submitted to Eur. Phys. J. C, arXiv:1409.3612]
PAPER-2014-051 Measurement of the $CP$-violating phase $\phi_s$ in $B^0_s \to D^+_s D^-_s$ decays [LHCb, submitted to PRL, arXiv:1409.4619]
Outline

- LS1 activities and Run II preparation
  - Run II Data taking
- Upgrade
- Summary of recent articles
  - Cross-sections, spectroscopy and particle properties
  - CP Violation and CKM matrix
  - Rare decays
LS1 activities
Recent LS1 activities

- Beam pipe: new support and tension monitor systems installed
- Precise re-evaluation of the magnet field map
- HeRSCheL: installation of detectors for forward physics
- Construction of new control room in good progress
- Trigger upgrade: works for fibres installation proceeding
- Maintenance of RICH photo-detectors

LS1 activities are progressing well in parallel with >19k visitors. LHCb will be ready for new data taking in 2015!
LHCb data taking in Run II: do more and better

Run I Data Taking

40 MHz bunch crossing rate

LO Hardware Trigger: 1 MHz readout, high $E_T/P_T$ signatures

450 kHz $h^+$

400 kHz $\mu/\mu$

150 kHz $e/\gamma$

Defer 20% to disk

Software High Level Trigger

29000 Logical CPU cores

Offline reconstruction tuned to trigger time constraints

Mixture of exclusive and inclusive selection algorithms

5 kHz Rate to storage
LHCb data taking in Run II: do more and better

Defer trigger after HLT1 instead of L0. Perform calibration and alignment before HLT2 in real-time.
Real-time calibration and alignment

$\sigma_{\Upsilon(1S)} = 86\text{MeV/c}^2$

$\sigma_{\Upsilon(1S)} = 44\text{MeV/c}^2$

- Alignment performances equal to offline improve background rejection
- PID selection can improve purity for suppressed channels
- Some physics analyses can be done directly on HLT output
Trigger streams division in Run II

- Full stream to offline reconstruction as Run I
- Parked stream to be processed after data taking
- Turbo stream for immediate data analysis out of HLT processing
The LHCb upgrade

- Increase levelled luminosity up to $2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
- Fully flexible software trigger up to 40 MHz
- Record 20 to 100 kHz
- Upgrade VELO and Tracker
A word on the LHCb upgrade status

- TDRs ready: Trigger TDR under review
- Milestones have been defined for each project
- The division of resource allocation is being finalised and will be presented to the October RRB
Cross-sections, spectroscopy and particle properties
Precision luminosity measurements at the LHC
LHCb-PAPER-2014-047 - Submitted to JINST

Calibration of instantaneous luminosity fundamental for cross-section measurements

\[ L = N_1 N_2 \nu_{\text{rev}} 2c \int \rho_1(x, t, z, t) \rho_2(x, t, z, t) dx dy dz dt \]

Two independent methods:
- van der Meer scan
- Beam Gas Imaging: unique to LHCb

Observed not factorizability of beam density profile
2D fit with improved description
• Visible cross-sections measured at different energies and beams
• The two methods have similar precision and mostly uncorrelated systematics
• Precision on the average reference cross-section of 1.12% (1.16%) without (with) propagation to physics data.

Most precise luminosity calibration at a bunched-beam hadron collider
Measurement of the forward W boson cross-section in pp collisions at \( \sqrt{s} = 7 \) TeV

LHCb-PAPER-2014-033 - Submitted to JHEP

- Inclusive \( W \to \mu\nu \) cross-section in forward region
- Probes low \( x \) values where theoretical uncertainties are larger
- Pseudorapidity \( 2 < \eta < 5 \)
- Compatible with and complementary to GPD
First observation of the decay $\chi_b(3P) \rightarrow \Upsilon(3S)\gamma$

- Study of $\chi_b$ meson production in $pp$ collisions at $\sqrt{s} = 7$ and 8 TeV
- Quarkonia states production described by NRQCD
- Measurement of production ratio $\mathcal{R}_{\Upsilon(nS)}^{\chi_b(mP)} \equiv \sum_{i=1,2} \frac{\sigma(pp \rightarrow \chi_{b\,i}(mP)X \rightarrow \Upsilon(nS)\gamma X)}{\sigma(pp \rightarrow \Upsilon(nS)X)}$
- First observation of the $\chi_b(3P) \rightarrow \Upsilon(3S)\gamma$, previously neglected in theory predictions

Precision measurement of $\chi_{b\,1}(3P)$ mass also performed: $m_{\chi_{b\,1}(3P)} = 10511 \pm 1.7 \pm 2.5$ MeV/c$^2$

Important inputs to quarkonia production and as references for ion collisions
Measurement of the $\bar{B}_s^0$ meson lifetime in $D_s^+\pi^−$ decays

LHCb-PAPER-2014-037 - Accepted by PRL

• Measurement of flavour specific ($f_s$) lifetime of $\bar{B}_s^0$ using $D^+_s\pi^−$ final state
• Due to fast mixing, equal admixture of heavy and light mass eigenstates
• Normalised to $\bar{B}_s^0 \to D^+\pi^-\pi^-$ and $B^- \to D^0\pi^-\pi^-$ decays

$\tau_{f_s} = (1.535 \pm 0.015 \pm 0.012 \pm 0.007)\text{ps}$

Most precise measurement to date and consistent with previous measurements!

The ratio of lifetimes is measured to be:
$\tau(\bar{B}_s^0)/\tau(\bar{B}^0) = 1.010 \pm 0.010 \pm 0.008$
In perfect agreement with HQE predictions for $\Gamma_s/\Gamma_d$. 
Observation of overlapping spin-1 and spin-3 $\bar{D}^0 K^-$ resonances at mass 2.86 GeV/c$^2$

LHCb-PAPER-2014-035 and 36 - Accepted by PRL and PRD

- Study of the Dalitz plot of $B_s^0 \rightarrow D^0 K^- \pi^+$ decays using 3.0fb$^{-1}$ of $pp$ collisions
- Angular analysis to study quantum numbers of previously observed $D_{sJ}^*$ resonances
Observation of overlapping spin-1 and spin-3 $\bar{D}^0 K^-$ resonances at mass 2.86 GeV/c$^2$

LHCb-PAPER-2014-035 and 36 - Accepted by PRL and PRD

- $D_{sJ}^*(2860)^-$ is composed of two states one of spin 1 and one of spin 3 both observed with more than 10σ significance
- First observation of spin 3 states in $B$ decays and of a heavy flavour state with spin 3
CP Violation and CKM matrix
First evidence of CP violation in b-hadron decays with baryons in the final state

LHCb-PAPER-2014-034 - Accepted to PRL

- Search for CP asymmetry in Dalitz plane of $B^+ \rightarrow p\bar{p}K^+$ decays with $3\text{fb}^{-1}$
- Large asymmetries observed in $B \rightarrow hhh$: probe strong phase due to rescattering
- Baryons can have different behaviour

\[ A(m_{p\bar{p}} < 2.85\text{GeV}/c^2, m_{Kp}^2 < 10\text{GeV}^2/c^4) = -0.036 \pm 0.023 \pm 0.004 \]
\[ A(m_{p\bar{p}} < 2.85\text{GeV}/c^2, m_{Kp}^2 > 10\text{GeV}^2/c^4) = +0.096 \pm 0.024 \pm 0.004 \text{ (Significance of 4}\sigma) \]
Measurement of the semileptonic CP asymmetry in $B^0$ decays

LHCb-PAPER-2014-053 - To be submitted to PRL

- Measurement of CP violation in mixing through flavour specific $B^0 \to D^{(*)} \mu^+ X$ decays
  \[ a_{sl}^d \equiv \frac{\Gamma(\bar{B} \to B \to f) - \Gamma(B \to \bar{B} \to \bar{f})}{\Gamma(\bar{B} \to B \to f) + \Gamma(B \to \bar{B} \to \bar{f})} \]

- $a_{sl}^d = (-4.1 \pm 0.6) \times 10^{-4}$ in the Standard Model

- D0 experiment observed a discrepancy w.r.t. the SM

- Exploit untagged time dependent rate:
  \[ A_{meas}(t) = \frac{a_{sl}^d}{2} + A_D - (A_P + a_{sl}^d \frac{\cos(\Delta m_d t)}{\cosh(\Delta \Gamma_d t/2)}) \]
Measurement of the semileptonic CP asymmetry in $B^0$ decays

**LHCb-PAPER-2014-053 - To be submitted to PRL**

$$a^d_{sl} = (-0.02 \pm 0.19 \pm 0.30)\%$$

most precise measurement to date and compatible with the SM prediction and earlier measurements

The equivalent measurement for $B^0_s$ mesons is coming soon
Measurement of the CKM matrix angle $\gamma$

- Cabibbo-Kobayashi-Maskawa angle
  \[ \gamma \equiv \arg \left( -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right) \]

- Measured at tree level from interference of $b \to c \bar{u}s$ and $b \to u\bar{c}s$ amplitudes

- Precision test of SM:
  \[ \gamma = (69.5 \pm 3.9) ^\circ \] from unitarity

Can be measured in $B$ decays
- $B^- \to D^0K^-$ and $B \to \bar{D}^0K^-$ with common $D$ final state
- Weak phase difference is $\gamma$
- Strong phase difference $\delta_B$

\[ r_B = \frac{|A_{\text{suppressed}}|}{|A_{\text{favoured}}|} \]

Various methods
- ADS: flavour specific final state
- GLW: CP eigenstate final state
- GGSZ: Dalitz plot analysis
- GLS: Single Cabibbo suppressed
- Time dependent
Measurement of the CKM angle $\gamma$ using $B^{\pm} \rightarrow DK^{\pm}$

- $D^0 \rightarrow K_{S}hh$ Dalitz plane distribution depends on interference:
  \[ A_B(m_{-}^2, m_{+}^2) \propto A + r_B e^{i(\delta_B - \gamma)} \bar{A} \]
- Model independent binned method
- Full dataset of 3fb$^{-1}$
- Improved analysis using $B \rightarrow D^* \mu \nu X$ decays to cross-check efficiency profile
Measurement of the CKM angle $\gamma$ using $B^{\pm} \rightarrow D K^{\pm}$

Distribution described in terms of $x_{\pm} \equiv r_B \cos(\delta_B \pm \gamma)$ and $y_{\pm} \equiv r_B \sin(\delta_B \pm \gamma)$

$x_+ = (-7.7 \pm 2.4 \pm 1.0 \pm 0.4) \times 10^{-2}$
$x_- = (+2.5 \pm 2.5 \pm 1.0 \pm 0.5) \times 10^{-2}$
$y_+ = (-2.2 \pm 2.5 \pm 0.4 \pm 1.0) \times 10^{-2}$
$y_- = (+7.5 \pm 2.9 \pm 0.5 \pm 1.4) \times 10^{-2}$

$r_B = 0.080^{+0.019}_{-0.021}$
$\delta_B = (134^{+14}_{-15})^\circ$.
$\gamma = (62^{+15}_{-14})^\circ$

consistent with world average and previous measurements.
Most precise single measurement of $\gamma$
Improved constraints on $\gamma$: CKM2014 update

LHCb-CONF-2014-004

Combination of LHCb results on the CKM angle $\gamma$.

- $B^+ \to Dh^+, D \to hh$, GLW/ADS, 1 fb$^{-1}$, Phys. Lett. B712 (2012) 203,
- $B^+ \to Dh^+, D \to K\pi\pi\pi$, ADS, 1 fb$^{-1}$, Phys. Lett. B723 (2013)
- $B^+ \to DK^+, D \to K^0_S hh$, model-independent GGSZ, 3 fb$^{-1}$, arXiv:1407.6211, submitted to Nucl. Phys. B.
- $B^+ \to DK^+, D \to K^0_S K\pi$, GLS, 3 fb$^{-1}$, Phys. Lett. B733 (2014) 36,
- $B^0 \to DK^{*0}, D \to hh$, GLW/ADS, 3 fb$^{-1}$, arXiv:1407.8136, submitted to Phys. Rev. D.
- $B^0_s \to D_s^\pm K^\mp$, time-dependent, 1 fb$^{-1}$, arXiv:1407.6127, submitted to JHEP.

- $D^0\bar{D}^0$ mixing and CP violation taken into account
- Auxiliary measurements on hadronic parameters
- Full combination and robust ($B \to DK$ only) combination
- Frequentist Feldman-Cousins method with “plug-in” treatment of nuisances and bayesian cross-check
• Robust combination:

\[ \gamma = (73^{+9}_{-10})^\circ \]

more precise than the B factories combination and more updates yet to come
Rare Decays
Observation of the rare $B^0_s \to \mu^+ \mu^-$ decay from the combined analysis of CMS and LHCb data

LHCb-PAPER-2014-049 - CMS-BPH-13-007 - To be submitted to Nature

- One of the most sensitive decays to look for physics beyond the SM
- FCNC and helicity suppressed, precise theoretical predictions:
  \[ \mathcal{B}^{SM}(B^0 \to \mu^+ \mu^-) = (3.66 \pm 0.23) \times 10^{-9} \]
  \[ \mathcal{B}^{SM}(B^0_s \to \mu^+ \mu^-) = (1.06 \pm 0.09) \times 10^{-10} \]
  \[ \mathcal{R} = 0.0295^{+0.0028}_{-0.0025} \]

\[
\mathcal{B}(B^0_s \to \mu^+ \mu^-) = \left( 2.9^{+1.1}_{-1.0} \right) \times 10^{-9} \quad (4.0 \sigma)
\]
\[
\mathcal{B}(B^0 \to \mu^+ \mu^-) = \left( 3.7^{+2.4}_{-2.1} \right) \times 10^{-10} \quad (2.0 \sigma)
\]

\[
\mathcal{B}(B^0_s \to \mu^+ \mu^-) = \left( 3.0^{+1.0}_{-0.9} \right) \times 10^{-9} \quad (4.3 \sigma),
\]
\[
\mathcal{B}(B^0 \to \mu^+ \mu^-) = \left( 3.5^{+2.1}_{-1.8} \right) \times 10^{-10} \quad (2.0 \sigma),
\]

\[ B_s, B^0, W^+ \]
\[ s, d, t, Z^0 \]
\[ t \]
\[ \mu^+ \mu^- \]
\[ \mu^- \]
\[ \mu^- \]
\[ \mu^- \]
\[ NP \]
\[ NP \]
\[ NP \]
\[ NP \]
Observation of the rare $B^0_s \rightarrow \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data
LHCb-PAPER-2014-049 - CMS-BPH-13-007 - To be submitted to Nature

- Full combination with simultaneous fit of the two datasets
- Shared common parameters: $\mathcal{B}(B^0_s \rightarrow \mu^+\mu^-)$, $\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)$, $\mathcal{B}(B^+ \rightarrow J/\psi K^+)$, $f_d/f_s$
- Small variations to original publications:
  * LHCb: $\Lambda^0_b \rightarrow p\mu^-\nu$ background included in default fit
  * CMS: corrected $\mathcal{B}(\Lambda^0_b \rightarrow p\mu^-\nu)$ and $q^2$, included lifetime bias correction
- Full frequentist Feldman-Cousins procedure for $\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)$

Results

\[ \mathcal{B}(B^0_s \rightarrow \mu^+\mu^-) = \left( 2.8^{+0.7}_{-0.6} \right) \times 10^{-9} \quad (6.2\sigma) \]

First observation of the $B^0_s \rightarrow \mu^+\mu^-$ decay

\[ \mathcal{B}(B^0 \rightarrow \mu^+\mu^-) = \left( 3.9^{+1.6}_{-1.4} \right) \times 10^{-10} \quad (3.0\sigma[FC]) \]

First evidence for an excess of events in the search for the $B^0 \rightarrow \mu^+\mu^-$ decay.
Both branching fractions are compatible with the SM.
Observation of the rare $B_s^0 \to \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data

LHCb-PAPER-2014-049 - CMS-BPH-13-007 - To be submitted to Nature

• Full combination with simultaneous fit of the two datasets
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LHCb-PAPER-2014-049 - CMS-BPH-13-007 - To be submitted to Nature

- Ratio of branching fractions, sensitive to MFV also measured: $R = \frac{\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)}{\mathcal{B}(B^0_s \rightarrow \mu^+\mu^-)} = 0.14^{+0.08}_{-0.06}$
- Compatibility with SM at 2.3σ level
- First LHC combined analysis bore fruits!
- Precision measurement expected in the upgrade
Search for the lepton flavour violating decay $\tau^− \rightarrow \mu^- \mu^+ \mu^−$

LHCb-PAPER-2014-052 - To be submitted to JHEP

- LFV $\tau^− \rightarrow \mu^- \mu^+ \mu^−$ decays would be unambiguous signs of New Physics
- Large $\tau$ production (85$\mu$b at 7 TeV) mainly from heavy quark decays
- Updated search with 3fb$^{-1}$
- Normalized to $D_s \rightarrow \phi(\rightarrow \mu\mu)\pi$: $B(\tau^− \rightarrow \mu^- \mu^+ \mu^−) = \frac{B(D_s^- \rightarrow \phi(\rightarrow \mu^+ \mu^-)\pi^-)}{B(D_s^- \rightarrow \tau^− \bar{\nu}_\tau)} \frac{f_{D_s}}{\varepsilon_{cal}} \frac{N_{sig}}{N_{cal}}$

No excess observed, upper limit with CLs method:

$$B(\tau^− \rightarrow \mu^- \mu^+ \mu^−) < 4.6(5.6) \cdot 10^{-8}$$ at 90 (95) % CL

Helps to improve world limit together with B factories
Conclusions

- LHCb experiment in good shape: exploiting the full statistics of Run I
- Wide range of physics topics: from large cross-sections to rare decays
- Stable physics output rate and many interesting results yet to come
- Many leading results but still room for NP in precision measurements
- Looking forward to the exciting Run II
- Upgrade program on track, ready for detector construction
Additional material
Evidence for CP violation in $B^+ \rightarrow p\bar{p}K^+ + \text{decays}$

LHCb-PAPER-2014-034 - Submitted to PRL

Forward-Backward asymmetry also studied in $B \rightarrow p\bar{p}h$ decays
Measurements of CP violation in the three-body phase space of charmless $B^{\pm}$ decays

**LHCb-PAPER-2014-044**

- Search for CP asymmetry in $B \rightarrow hhh$ decays with $3\text{fb}^{-1}$
- Integrated asymmetries measured

$$A_{CP}(B^{\pm} \rightarrow K^{\pm} \pi^+ \pi^-) = +0.025 \pm 0.004 \pm 0.004 \pm 0.007 \quad (2.8\sigma)$$

$$A_{CP}(B^{\pm} \rightarrow K^{\pm} K^+ K^-) = -0.036 \pm 0.004 \pm 0.002 \pm 0.007 \quad (4.3\sigma)$$

$$A_{CP}(B^{\pm} \rightarrow \pi^\pm \pi^+ \pi^-) = +0.058 \pm 0.008 \pm 0.009 \pm 0.007 \quad (4.2\sigma)$$

$$A_{CP}(B^{\pm} \rightarrow \pi^\pm K^+ K^-) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007 \quad (5.6\sigma)$$
Measurements of CP violation in the three-body phase space of charmless $B^{\pm}$ decays
LHCb-PAPER-2014-044

- Different asymmetries for $\pi\pi$ and $KK$ final states probably due to rescattering
- Contributions also due to interference of partial waves
- Full angular analysis needed to disentangle

<table>
<thead>
<tr>
<th>Decay</th>
<th>$N_S$</th>
<th>$A_{CP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$</td>
<td>$15,562 \pm 165$</td>
<td>$+0.121 \pm 0.012 \pm 0.017 \pm 0.007$</td>
</tr>
<tr>
<td>$B^{\pm} \to K^{\pm}K^{+}K^{-}$</td>
<td>$16,992 \pm 142$</td>
<td>$-0.211 \pm 0.011 \pm 0.004 \pm 0.007$</td>
</tr>
<tr>
<td>$B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$</td>
<td>$4329 \pm 76$</td>
<td>$+0.172 \pm 0.021 \pm 0.015 \pm 0.007$</td>
</tr>
<tr>
<td>$B^{\pm} \to \pi^{\pm}K^{+}K^{-}$</td>
<td>$2500 \pm 57$</td>
<td>$-0.328 \pm 0.028 \pm 0.029 \pm 0.007$</td>
</tr>
</tbody>
</table>