LHCb Overview

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On behalf of the LHCb Collaboration

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Physics goals

Precisely understand the Standard Model while trying to break it at the same time.

SM + New Physics Searches

QCD + EW + Direct + Indirect
Precisely understand the standard model while trying to break it at the same time

**Physics goals**

For example:

- Spectroscopy
- Unitarity triangle
- Long-lived exotics
- Lepton Universality

**SM** + **New Physics Searches**
The LHCb detector

A forward spectrometer located @ Interaction Point 8 of the LHC
Embarking on second ‘production year’ of Run 2 (after a ‘start-up’ year in 2015). Operating at higher energy and at 25 ns bunch-crossing (+ detector improvements). Run 2 will go to end of 2018 – expect to increase the beauty sample by x3 or more.
Origin of CP Violation in the Standard Model

\[ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \]
Rule of the game: over-constrain the triangle and see if it closes
Measurement of $\gamma$

The weak phase $\gamma$ can be measured in the interference of $b \rightarrow c$ and $b \rightarrow u$ decays.

$$A(B^{-} \rightarrow D^{0}K^{-}) = a$$

$\downarrow CP$

$$\bar{A}(B^{+} \rightarrow D^{0}K^{+}) = a$$

$$\gamma = \arg \left(-\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}\right)$$

$$A(B^{-} \rightarrow \bar{D}^{0}K^{-}) = ae^{-i\gamma_{BE}e^{i\delta_{B}}}$$

$\downarrow CP$

$$\bar{A}(B^{+} \rightarrow D^{0}K^{+}) = ae^{+i\gamma_{BE}e^{i\delta_{B}}}$$
$B^\pm \rightarrow D^{(*)0} h^\pm$

$B^\pm \rightarrow D^0 K^\pm$ and $B^\pm \rightarrow D^{*0} K^\pm$ with $D^{*0} \rightarrow D^0 \pi^0 / D^0 \gamma$

LHCb-PAPER-2017-021
CP observables in $B^{\pm}\rightarrow D \ K^{*\pm}$

Results consistent with and more precise than BaBar [PRD 80 (2009) 092001]

Uses 2- and 4-body $D^0$ decay modes (+ Run 2 data)

Rates and CP asymmetries provide constraints on $\gamma$

$$R_{K\pi}^+ = 0.020 \pm 0.006 \text{ (stat)} \pm 0.001 \text{ (syst)}$$

4.2$\sigma$ evidence of suppressed ADS mode

[LHCb-PAPER-2017-030]
Global fit to $\gamma$

$$\gamma = (76.8^{+5.1}_{-5.7})^\circ$$

World average (HFLAV)

$$\gamma = (76.2^{+4.7}_{-5.0})^\circ$$

Many more Run-2 updates and channels expected soon
Expect $O(1^\circ)$ precision after LHCb upgrade
Measurement of $\sin 2\beta$

Interference between mixing and decay

\[
\mathcal{A}_{(c\bar{c})K_S^0}(t') \equiv \frac{\Gamma(\bar{B}^0(t') \rightarrow (c\bar{c})K_S^0) - \Gamma(B^0(t') \rightarrow (c\bar{c})K_S^0)}{\Gamma(\bar{B}^0(t') \rightarrow (c\bar{c})K_S^0) + \Gamma(B^0(t') \rightarrow (c\bar{c})K_S^0)} = S \sin(\Delta m t') - C \cos(\Delta m t'),
\]

\[
\sin(2\beta) = \sin(2\phi_1)
\]

$\Delta \Gamma = (-0.2 \pm 1.0) \times 10^{-2} \text{ ps}^{-1}$ (HFLAV)
Flavour Tagging

$\pi^+$

SS pion
SS kaon (for $B_s^0$)

$B^0$

$J/\psi$

$K^{*0}$

$u \bar{d}$

$\bar{b} \ b$

$\bar{b} \ d$

$b \ x$

$h_b$

OS charm

$K^+$

OS kaon

$\ell^-$

OS muon
OS electron

$\rightarrow c$

$\rightarrow X \ell^-$

PV

SV

OS vertex charge

same side

opposite side
What do we measure?

\[ B^0 \rightarrow J/\psi(e^+ e^-)K^0_S \text{ and } B^0 \rightarrow \psi(2S)(\mu^+ \mu^-)K^0_S \]
Updated LHCb average (all modes)

\[ C(B^0 \rightarrow [c\bar{c}]K_S^0) = -0.017 \pm 0.029 \]

\[ S(B^0 \rightarrow [c\bar{c}]K_S^0) = 0.760 \pm 0.034 \]
Spectroscopy & EW
Observation of the doubly charmed baryon $\Xi_{cc}^{++}$

Discovery of the $\Omega^-$ 1964

Two SU(4) baryon 20-plets

$\Xi_{cc}^{++}$ will decay via Strong+electromagnetic

$\Xi_{cc}^{++}$ will decay via Weak decay

LHCb run II at $\sqrt{s} = 13$ TeV, $\sim 1.7$ fb$^{-1}$

Dedicated exclusive trigger ensuring high efficiency, full event reconstruction at trigger level
Observation of the doubly charmed baryon $\Xi_{cc}^{++}$

Fully reconstruct the decay chain:

$$\Xi_{cc}^{++} \rightarrow K^- \pi^+ \pi^+ \Lambda_c^+ (\rightarrow p K^- \pi^+)$$

Peaking structure remains significant ($> 12\sigma$) after requiring minimum decay time, $t > 5\sigma_t$. It is indeed a weak decay.

Observation of Signal yield: $313 \pm 33$ candidates

$m(\Xi_{cc}^{++}) = 3621.40 \pm 0.72(\text{stat}) \pm 0.27(\text{syst}) \pm 0.14(\Lambda_c^+) \text{ MeV}$
Measurement of $Z \rightarrow bb$ @ 8 TeV

Looking at $pp \rightarrow (Z \rightarrow bb)j$ events $\rightarrow$ Events with 3 jets, where two are b-tagged.

$$p_T(j_{1,2}) > 20 \text{ GeV}, \quad 2.2 < \eta(j_{1,2}) < 4.2, \quad 45 < m_{jj} < 165 \text{ GeV}.$$  

Tough measurement because of abundant QCD background.

$$\sigma(pp \rightarrow Z)B(Z \rightarrow b\bar{b})$$ 

$$= 332 \pm 46(\text{stat.}) \pm 59(\text{syst.}) \text{ pb}$$

Measurement is compatible with the aMC@NLO prediction.
Indirect NP search
Lepton Universality

NP particles could contribute a charged Higgs in the tree, a Z’ in the penguin, etc.
Measurement of $R(D^*)$

What do we measure?

$$K_{had}(D^*) = \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_{\tau})}{BR(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)}$$

[\sim 4\% precision$^*$]

$$R(D^*) = K_{had}(D^*) \times \frac{BR(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)}{BR(B^0 \rightarrow D^{*-} \mu^+ \nu_{\mu})}$$

[\sim 2\% precision$^*$]

Signal and normalisation have very similar topologies $\rightarrow$ benefit from a reduction of systematic uncertainties (trigger, PID).

(*) PDG 2016
New LHCb measurement gives $R(D^*)=0.285 \pm 0.019\text{(stat)} \pm 0.025\text{(syst)}$

Compatible with SM expectation but also fully supporting previous measurements of high value.
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Compatible with SM expectation but also fully supporting previous measurements of high value.

Results are internally consistent and $4\sigma$ from SM prediction.

LHCb-PAPER-2017-027
Measurement of $R(K^*)$

What do we measure?

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \rightarrow K^{*0} \mu^+ \mu^-)}{\mathcal{B}(B^0 \rightarrow K^{*0} J/\psi \rightarrow \mu^+ \mu^-)} \bigg/ \frac{\mathcal{B}(B^0 \rightarrow K^{*0} e^+ e^-)}{\mathcal{B}(B^0 \rightarrow K^{*0} J/\psi \rightarrow e^+ e^-)}$$

A double ratio to minimize to the uncertainties from the lepton identification.
Measurement of $R(K^*)$

$$R_{K^*0} = \begin{cases} 
0.66^{+0.11}_{-0.07} \text{ (stat)} \pm 0.03 \text{ (syst)} & \text{for } 0.045 < q^2 < 1.1 \text{ GeV}^2/c^4, \\
0.69^{+0.11}_{-0.07} \text{ (stat)} \pm 0.05 \text{ (syst)} & \text{for } 1.1 < q^2 < 6.0 \text{ GeV}^2/c^4.
\end{cases}$$

Result to be added to a collection of tensions measured in $b \rightarrow s \ell^+\ell^-$ transitions.
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Result to be added to a collection of tensions measured in $b \rightarrow s l^+l^-$ transitions.
LHCb has been performing really well. Precision SM measurements. Observation of new states. We are observing some tensions… We are hopeful for a bright future.