LHCb latest results and new perspectives

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on behalf of LHCb
outline

• Updates on lepton universality
• CKM γ and mixing parameters measurements
• CP violation measurement: 2 body K-π puzzle
• Spectroscopy
• Future and conclusions
LHCb detector

- Muon System
- RICH Detectors
- Vertex Locator (VELO)
- Calorimeters
- Tracking System

~1 cm
pp collision Point
LHCb detector

- Electrons radiate bremsstrahlung photons when interacting with detector.
  - When it happens before the magnet it lead to increased uncertainties on momentum and energy.
- Bremsstrahlung recovery: searches for energy deposits in the calorimeter and adds back to electron energy.
Data aquisition

- Large heavy flavour dataset collected (9.0 fb\(^{-1}\)) during run 1 and 2.
  - Precision tracking
  - Excellent PID using RICH
Lepton Universality
Lepton universality overview

- B → s l^+ l^- transitions are flavour-changing neutral currents (FCNC) which means they are suppressed in the standard model (SM).
- Branching fractions of $O(10^{-7})$-$O(10^{-8})$.
- In the SM coupling of gauge fields to the three charged leptons (e, μ, τ) are identical → Lepton Universality (LU)

arXiv:2110.09501v2[hep-ex]
Lepton universality overview

• Ratios of the form:

\[ R_H = \frac{B \to H \mu \mu}{B \to H e e} \approx 1 \]

in SM, except for small corrections due to different lepton masses.

• Easy method to be applied:
  - Hadronic uncertainties cancel in ratio \( (O(10^{-4})) \).
  - QED corrections up to \( O(10^{-2}) \).

Significant deviation from unitity \( \rightarrow \) New physics (NP) beyond SM
Lepton universality Run II

- Two tests for LU using 9.0 fb\(^{-1}\) dataset

- \(B^0 \rightarrow K_s^0 l^+ l^-\): \(R_{K_s^0} = \frac{B^0 \rightarrow K_s^0 \mu \mu}{B^0 \rightarrow K_s e e}\)

- \(B^+ \rightarrow K^{*+} l^+ l^-\): \(R_{K^{*+}} = \frac{B^+ \rightarrow K^{*+} \mu \mu}{B^+ \rightarrow K^{*+} e e}\)

- Isospin partners of \(B^+ \rightarrow K^+ l^+ l^-\) and \(B^0 \rightarrow K^{*0} l^+ l^-\) and the same NP is expected.
Yields and $R_{K_S}$ are extracted from a simultaneous maximum likelihood fits to data.

First observation for both channels!
Yields and $R_{K^*}$ are extracted from a simultaneous maximum likelihood fits.
Lepton universality Run II

- $B^0 \rightarrow K_s^0 \mu^+ \mu^-$: $R_{K_s^0} = \frac{B^0 \rightarrow K_s^0 \mu \mu}{B^0 \rightarrow K_s^0 e e} = 0.66^{+0.20}_{-0.15} \text{(stat)} +0.02_{-0.04} \text{(syst)}$ 1.5σ

- $B^+ \rightarrow K^{*+} \mu^+ \mu^-$: $R_{K^{*+}} = \frac{B^+ \rightarrow K^{*+} \mu \mu}{B^+ \rightarrow K^{*+} e e} = 0.70^{+0.18}_{-0.13} \text{(stat)} +0.03_{-0.04} \text{(syst)}$ 1.4σ

- Same pattern seen in other LU tests
Lepton universality Run II

arXiv:2103.11769v2[hep-ex]

• The lhcb also investigated the LU in the isospin partner $B^+ \rightarrow K^+ l^+ l^-$

$$R_{K^+} = \frac{B^+ \rightarrow K^+ \mu\mu}{B^+ \rightarrow K^+ e\,e}$$
Lepton universality Run II

- $B^+ \to K^+ l^+ l^-$:

$$R_{K^+} = \frac{B^+ \to K^+ \mu \mu}{B^+ \to K^+ e e} = 0.846^{+0.042}_{-0.039} \text{(stat)}^{+0.013}_{-0.012} \text{(syst)}$$

3.1$\sigma$
Flavour Anomalies

- In addition to LU violation, several other anomalies in $b \rightarrow s \ell^+ \ell^-$ decays emerged over the past decade:
  - Branching fractions of $b \rightarrow s \mu^+ \mu^-$ decays.
  - Multiple measurements below SM predictions.
  - Branching fraction of $B^0_{(s)} \rightarrow \mu^+ \mu^-$ decays.

- Angular analysis of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ and $B^+ \rightarrow K^{*+} \mu^+ \mu^-$.

- Some observables offering complementary evidence for NP with a standard deviation above 3$\sigma$. 

[References]
JHEP 1406 (2014) 133
JHEP 04 (2017) 142
ATLAS-CONF-2020-049
ArXiv:2108.09284
JHEP 02 (2016) 104
CKM $\gamma$ and mixing parameters
CKM $\gamma$ overview

- Huge progress in measurement of CKM parameters, largely driven by the LHCb experiment
CKM γ combination

- CKM γ is measured in decays sensitive to interference between favored $b \to c$ and suppressed $b \to u$ transitions.

- Unknown parameters from a single $B \to Dh$ decays can be obtained by combining D-decays modes to overconstrains.
CKM $\gamma$ combination

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<tr>
<th>$B$ decay</th>
<th>$D$ decay</th>
<th>Ref.</th>
<th>Dataset</th>
<th>Status since Ref.</th>
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<td>51</td>
<td>Run 1</td>
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</table>
CKM $\gamma$ combination results

- The combination uses a total of 151 input observables to measure 52 free parameters. Most notably,

$$\gamma = (65.4^{+3.8}_{-4.2})^o$$

most precise measurement from a single experiment.

- Charm mixing parameters (most precise to date):

$$x = (0.400^{+0.052}_{-0.053})\%$$

$$y = (0.630^{+0.033}_{-0.030})\%$$

arXiv:2110.02350v1[hep-ex]
CP violation
K-$\pi$ puzzle


• Isospin symmetry predicts that

$$A_{CP}(B^0 \rightarrow K^+ \pi^-) = A_{CP}(B^+ \rightarrow K^+ \pi^0)$$

• But BaBar and Belle measured these asymmetries to be different at more than $5\sigma$.

$$A_{CP}(B^0 \rightarrow K^+ \pi^-) = -0.084 \pm 0.004$$
$$A_{CP}(B^+ \rightarrow K^+ \pi^0) = 0.040 \pm 0.021$$

• Possibly NP in electroweak penguin sector.
K-π puzzle results

- Use $B^+ \rightarrow J/\psi K^+$ as control channel to cancel detection/production asymmetries. (result already comparable with world average!).

\[
A_{CP}(B^+ \rightarrow K^+ \pi^0) = 0.025 \pm 0.015 \pm 0.006 \pm 0.003 \quad 1.5\sigma
\]

\[
\Delta A_{CP}(K \pi) \equiv A_{CP}(B^0 \rightarrow K^+ \pi^-) - A_{CP}(B^+ \rightarrow K^+ \pi^0) = 0.115 \pm 0.014 \quad >8.0\sigma
\]
Spectroscopy
Exotic tetra and pentaquarks
**T\textsubscript{cc} tetraquark**

- All exotic states so far decay via strong interaction.
  - A discovery of a log-lived exotic state stable wrt strong interaction would be intriguing.
  - A hadron with two heavy quarks $Q$ and two light quarks $q$, $Q_1Q_2\bar{q}_1\bar{q}_2$, is a prime candidate $\rightarrow$ $bb\bar{u}\bar{d}$ hadron state.
  - Before LHCb, no consensus whether $bc\bar{u}\bar{d}$ and $cc\bar{u}\bar{d}$ exists and were narrow enough to be detected.


- $T(bb\bar{u}\bar{d})$ with $J^P = 1^+$ at $10,389 \pm 12$ MeV (near $B^{(*)}\overline{B}^{(*)}$ threshold)
- $T(cc\bar{u}\bar{d})$ with $J^P = 1^+$ at $3882 \pm 12$ MeV (near $D^{(*)}\overline{D}^{(*)}$ threshold)
T_{cc} tetraquark

- The LHCb analysed the $D^0D^0\pi^+$ final state and observed a $T(cc\bar{u}\bar{d})$ state with mass of about 3875 MeV/c$^2$.
- Narrow peak just below the $D^{(*)}\bar{D}^{(*)}$ mass threshold, as predicted.
- Reinforces the possibility of a $T(bb\bar{u}\bar{d})$ tetraquark state that is stable wrt to strong interactions.

arXiv:2109.01056v2[hep-ex]
The future

- The LHCb upgrade for Run3/Run4 aims to:
  - Collect $\sim 50 \, fb^{-1}$ at $L = 2 \times 10^{33} \, cm^{-2} \, s^{-1}$
  - $\sim 5$ visible interactions
  - $40 \, MHz$ readout of detector
  - Full software trigger will lead to a factor two gain for hadronic channels.

- Upgrade 2 for Run5/Run6
  - Collect $\sim 300 \, fb^{-1}$ at $L = 1.5 \times 10^{34} \, cm^{-2} \, s^{-1}$
Conclusions

• Many important results from LHCb Run 2 dataset:
  – Evidence of LU violation.
  – Improved precision of CKM γ measurement.
  – CP violation in the B → hh decays leads to a intriguing K-π puzzle.
  – Many new exotic states observed.

• Many important results to come in the next 2 years.

• LHCb upgrade to increase the dataset by a factor 5-10 will help to pin down many evidences revealed so far.
backup