Searches for new physics at LHCb

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Report Content

- Mainly focus on the following results:

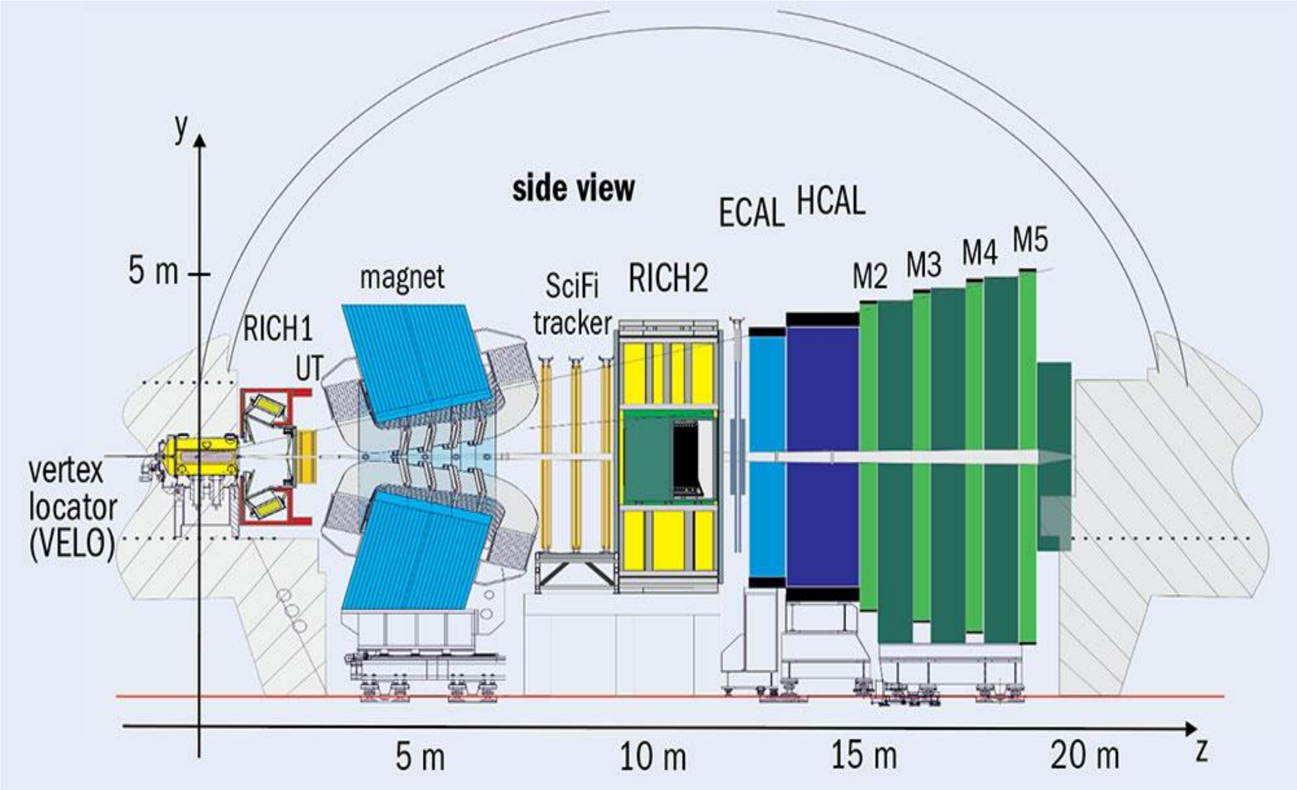
• CPV Searches

• Rare decay (including LFV)

• LU test results

https://lhcbproject.web.cern.ch/Publications/LHCbProjectPublic/Summary_all.html

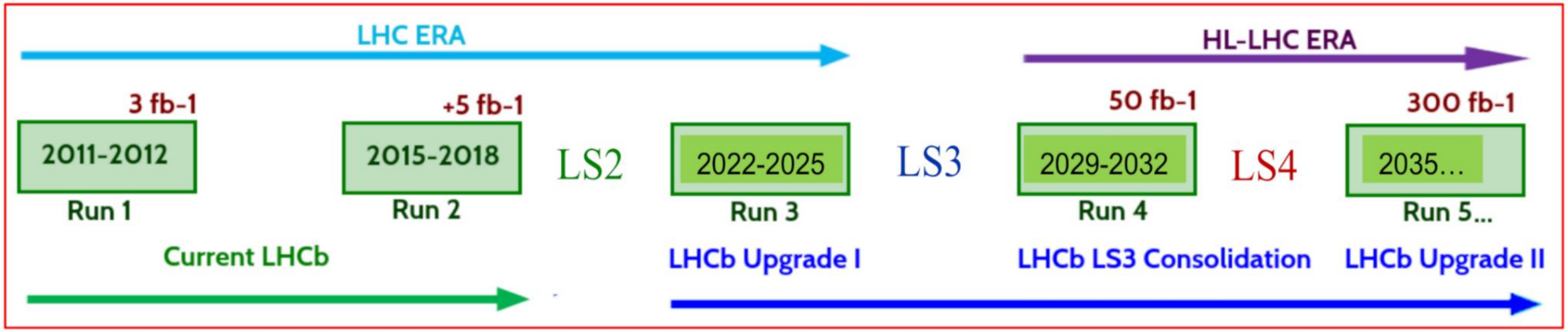
LHCb detector

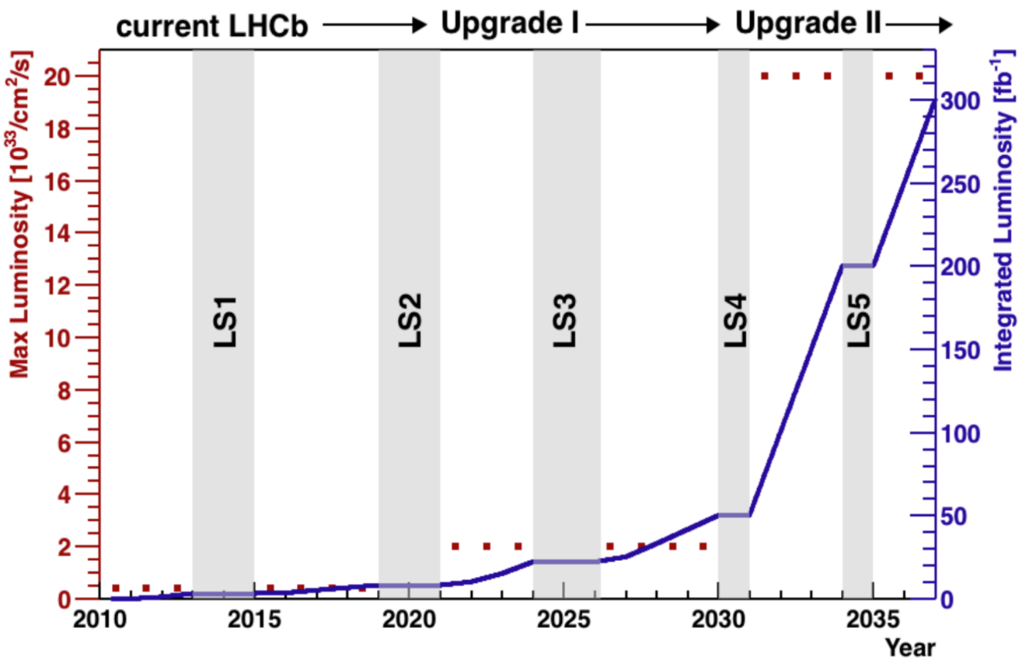


- 优秀的顶点、径迹重建和粒子鉴别等性能，灵活高效的在线触发系统

- 单臂前向的谱仪，对应于前向η范围2<η<5。在LHC上专门用于重味物理。
  - LHC pp对撞中，$b\bar{b}$强子对在前向和后向相对于束流方向（Z-方向）的小极角上产生。
- 包括一个高精度的径迹探测系统、两个环形的切伦科夫探测器、一个量能器系统和一个μ子探测器。

Data taking





- LHCb Run-I（2010-12）：3 fb^{-1} 7/8 TeV pp data

  Run-II（2015-18）： 6 fb^{-1} 13TeV pp data
- Run-III（2022-24），may take 30 fb^{-1}的13 TeV pp data

Direct CPV in $B^{\pm} \to h^{\pm}h'^{+}h'^{-}$ and $B^{\pm} \to h^{\pm}h^{+}h^{-}$

- The role of short/long distance contributions to the generation of the strong-phase differences:

  ⇒ is long-standing debate

  ⇒ for direct *CPV*, and three-body decays offer a way of answering

- With 5.9 fb^{-1} 13 TeV pp collision data with the LHCb 2015-2018

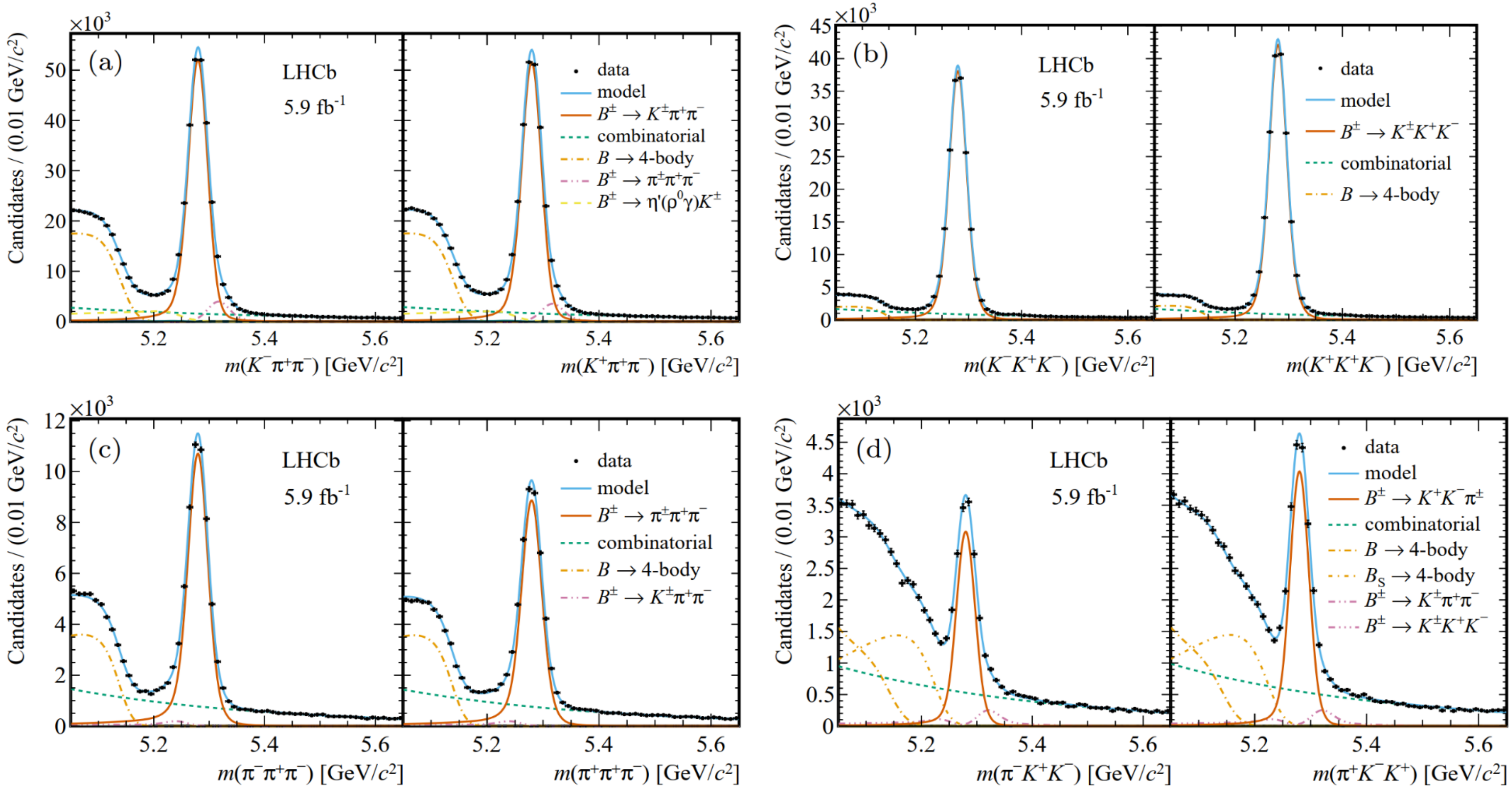
  ⇒ previously observed *CP* asymmetry in $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$ decays is confirmed,

  ⇒ *CP* asymmetries are observed with a significance of $> 5\sigma$ in the $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $B^{\pm} \to K^{\pm}K^{+}K^{-}$ decays,

  ⇒ while the *CP* asymmetry of $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ is confirmed to be compatible with 0

PRD 108 (2023) 012008

Direct CPV in $B^{\pm} \to h^{\pm}h'^{+}h'^{-}$ and $B^{\pm} \to h^{\pm}h^{+}h^{-}$



$A_{CP}(\boldsymbol{B}^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = +0.011 \pm 0.002 \pm 0.003 \pm 0.003 \Rightarrow$ Consistent with *CP* conservation

$A_{CP}(\boldsymbol{B}^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.037 \pm 0.002 \pm 0.002 \pm 0.003$ 8.5σ

$A_{CP}(\boldsymbol{B}^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.080 \pm 0.004 \pm 0.003 \pm 0.003$ 14.1σ

$A_{CP}(\boldsymbol{B}^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.114 \pm 0.007 \pm 0.003 \pm 0.003$ 13.6σ

first observation

PRD 108 (2023) 012008

Search for Direct CPV in $B^{\pm} \to PV$

- Theoretical developments using different approaches have resulted in many predictions for CP asymmetries.

  ⇒ Many of these are focused on charmless two-body and quasitwo-body B-meson decays, in particular those to two pseudoscalar mesons ($\boldsymbol{B \to PP}$) and to a pseudoscalar and a vector meson ($\boldsymbol{B \to PV}$)

- **5 different $B \to PV$ decays from 4 final states:** $\boldsymbol{B}^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$, $\boldsymbol{B}^{\pm} \to K^{\pm}K^{+}K^{-}$, $\boldsymbol{B}^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$, $\boldsymbol{B}^{\pm} \to \pi^{\pm}K^{+}K^{-}$

  ⇒ $\boldsymbol{B}^{\pm} \to \rho(770)^0 K^{\pm}$, $\boldsymbol{B}^{\pm} \to \rho(770)^0\pi^{\pm}$, $\boldsymbol{B}^{\pm} \to K^*(892)^0\pi^{\pm}$, $\boldsymbol{B}^{\pm} \to K^*(892)^0 K^{\pm}$, $\boldsymbol{B}^{\pm} \to \phi(1020)K^{\pm}$

- With 5.9 fb^{-1} 13 TeV *pp* data, recorded with the LHCb 2015-2018:

  ⇒ $A_{CP}(\boldsymbol{B}^{\pm} \to \rho(770)^0 K^{\pm}) = +0.150 \pm 0.019 \pm 0.011$, **first observation**

  ⇒ For the other four decay channels, compatible with zero

arXiv:2206.02038

Search for Direct CPV in $B^{\pm} \to PV$

- **Summary of measurements for:**

$$\boldsymbol{B}^{\pm} \to R(h_1^- h_1^+) h_3^{\pm}$$

Decay channel	This work	Previous measurements
$B^{\pm} \to (\rho(770)^0 \to \pi^+\pi^-)\pi^{\pm}$	$-0.004 \pm 0.017 \pm 0.009$	$+0.007 \pm 0.011 \pm 0.016$ (LHCb [20,21])
$B^{\pm} \to (\rho(770)^0 \to \pi^+\pi^-)K^{\pm}$	$+0.150 \pm 0.019 \pm 0.011$	$+0.44 \pm 0.10 \pm 0.04$ (BaBar [28]) $+0.30 \pm 0.11 \pm 0.02$ (Belle [22])
$B^{\pm} \to (K^*(892)^0 \to K^{\pm}\pi^{\mp})\pi^{\pm}$	$-0.015 \pm 0.021 \pm 0.012$	$+0.032 \pm 0.052 \pm 0.011$ (BaBar [28]) $-0.149 \pm 0.064 \pm 0.020$ (Belle [22])
$B^{\pm} \to (K^*(892)^0 \to K^{\pm}\pi^{\mp})K^{\pm}$	$+0.007 \pm 0.054 \pm 0.032$	$+0.123 \pm 0.087 \pm 0.045$ (LHCb [19])
$B^{\pm} \to (\phi(1020) \to K^+K^-)K^{\pm}$	$+0.004 \pm 0.014 \pm 0.007$	$+0.128 \pm 0.044 \pm 0.013$ (BaBar [26])

The LHCb results

arXiv:2206.02038

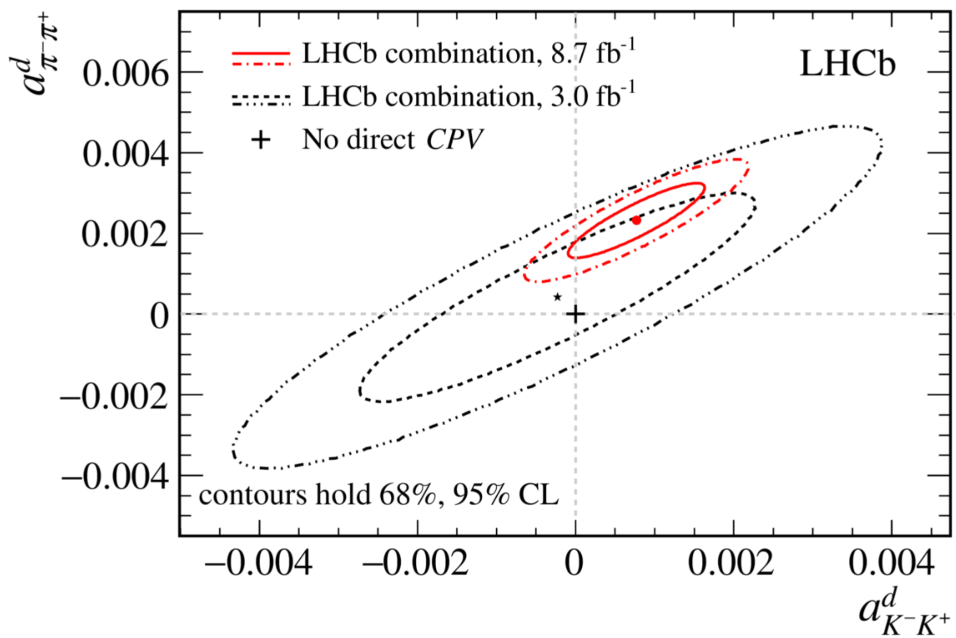
Time-integrated CPV in $D^0 \to K^-K^+$ decays

- The D^0 mesons are required to originate from promptly produced $\boldsymbol{D^{*+} \to D^0\pi^+}$
  - $\pi^{\pm}$ is used to determine the flavor of the charm meson at production.
- The time-integrated CPV is measured to be:

$$\mathcal{A}^{CP}(K^-K^+) = [6.8 \pm 5.4\,(\text{stat}) \pm 1.6\,(\text{syst})] \times 10^{-4}.$$

- The direct *CPV* in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays, are derived by combining $A^{CP}(K^-K^+)$, giving:

$$a^d_{K^-K^+} = (\ 7.7 \pm 5.7) \times 10^{-4},$$
$$a^d_{\pi^-\pi^+} = (23.2 \pm 6.1) \times 10^{-4},$$



- **1.4σ and 3.8σ derivation** for $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$
- The **first evidence for direct *CPV*** in a specific D^0 decay

PRL 131 (2023) 091802

Search for CPV in $D^+_{(s)} \to K^-K^+K^+$ decays

- For the charm, CPV are very small: direct CPV (*i.e.* in the decay) can occur only for Cabibbo-suppressed (CS) decays, expected at $O(10^{-3})$.
- For doubly Cabibbo-suppressed (DCS) decays, CPV is essentially forbidden, thus its observation would indicate a manifestation of BSM physics.
- To date there is only one observation of CPV in the charm sector, through the difference of *CPV* in $\boldsymbol{D^0 \to K^+K^-}$ **and** $\boldsymbol{D^0 \to \pi^+\pi^-}$. $\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}$
- thus important to extend to different charm-hadron species decaying into a broad range of final states, including not only CS but also DCS decays
- A model-independent search for direct CPV in the Dalitz plots of the **CS** $\boldsymbol{D_s^+ \to K^-K^+K^+}$ **and DCS** $\boldsymbol{D^+ \to K^-K^+K^+}$ **decays**

  - with 5.6 fb^{-1} Run-II data
- Divide the Dalitz plot in 2D bins and computing, for each bin, the significance of the difference in the numbers of $\boldsymbol{D^+_{(s)}}$ candidates and $\boldsymbol{D^-_{(s)}}$ candidates,

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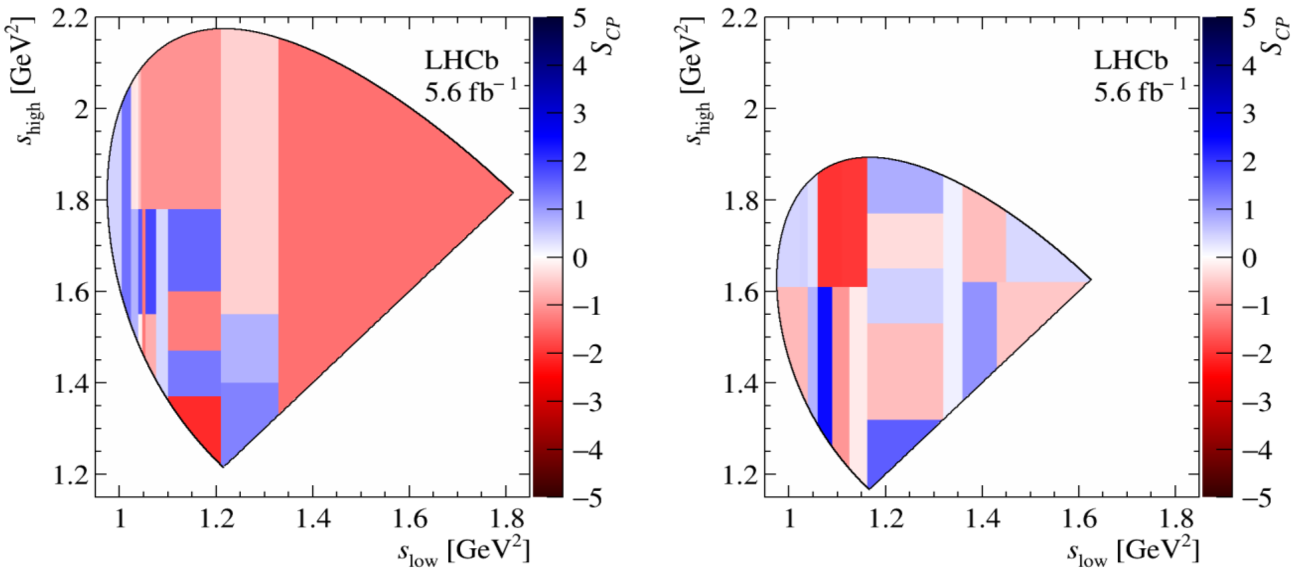
Search for CPV violation in $D^+_{(s)} \to K^-K^+K^+$ decays

- binned model-independent technique used, local *CP* observable S_{CP}

$$S^i_{CP} = \frac{N^i(D^+_{(s)}) - \alpha N^i(D^-_{(s)})}{\sqrt{\alpha(\delta^2_{N^i(D^+_{(s)})} + \delta^2_{N^i(D^-_{(s)})})}}, \quad \text{with } \alpha = \frac{\sum_i N^i(D^+_{(s)})}{\sum_i N^i(D^-_{(s)})},$$



S_{CP} across the Dalitz plot for (left) $D^+_{(s)} \to K^-K^+K^+$ and (right) $D^+ \to K^-K^+K^+$ signal candidates using 21 bins

- Results (p-values): 13.3% for $D^+_{(s)} \to K^-K^+K^+$ and 31.6% for $D^+ \to K^-K^+K^+$; No evidence for CP violation is found.
- The first search for CP violation in the CS channel $D^+_s \to K^-K^+K^+$ and in the DCS channel $D^+ \to K^-K^+K^+$

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Search for CPV in the phase-space of $D^0 \to \pi^+\pi^-\pi^0$

- Multi-body charm decays provide a powerful tool to probe CPV. In these decays, PS-dependent local CP asymmetries can arise from the interference among intermediate resonances
- Studies of these local asymmetries provide additional sensitivity to observation of CPV, complementing studies of PS integrated asymmetries and two-body decays.

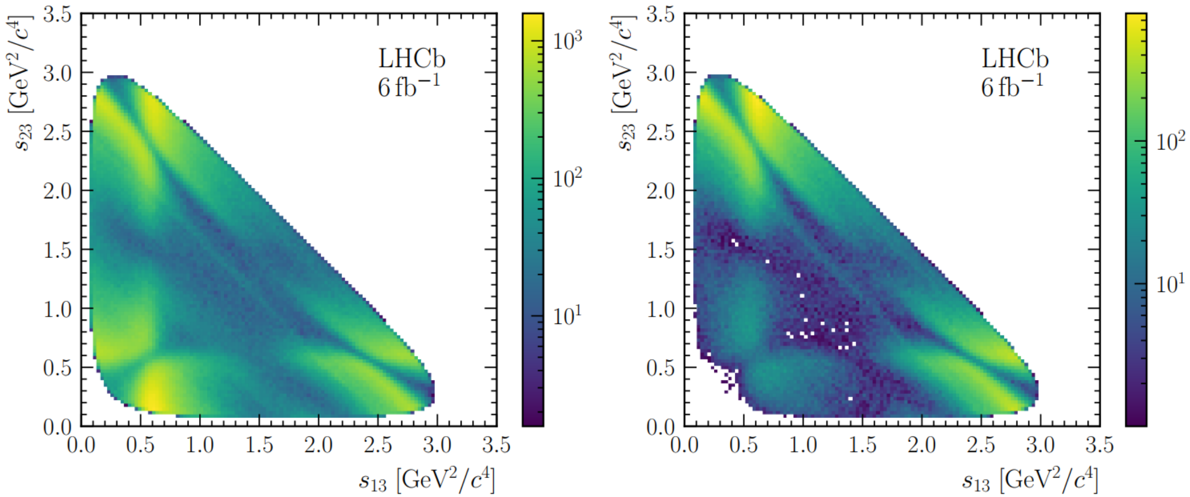


Figure 2: Dalitz plots for the background-subtracted signal samples for (left) the resolved and (right) merged π^0 categories, with the two $m^2(\pi^\pm\pi^0)$ variables chosen for the projection. The three $\rho^{\pm,0}$ resonances dominate the phase space.

- Use 2015 to 2018 data, 6 fb^{-1}
- flavour-tagged $D^0 \to \pi^+\pi^-\pi^0$ is obtained by selecting $D^{*+} \to D^0(\pi^+\pi^-\pi^0)\,\pi^+$

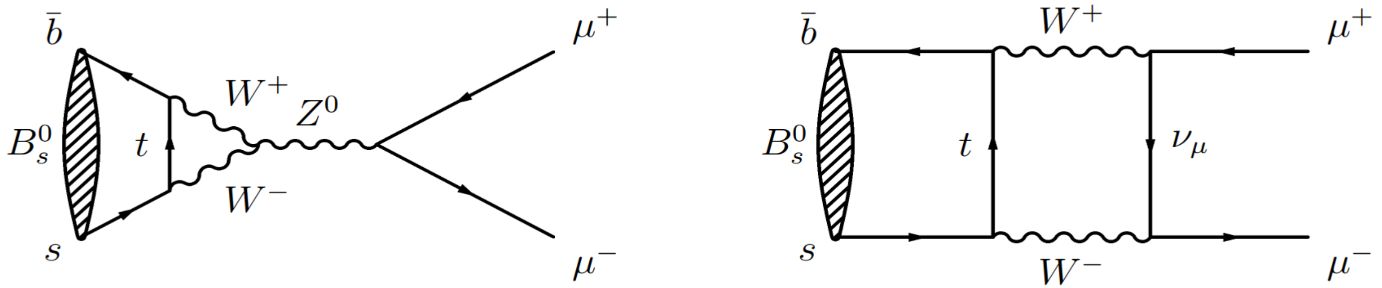
- **no evidence is found for *CPV* in localised regions of the PS**

JHEP 09 (2023) 129

Rare decay searches

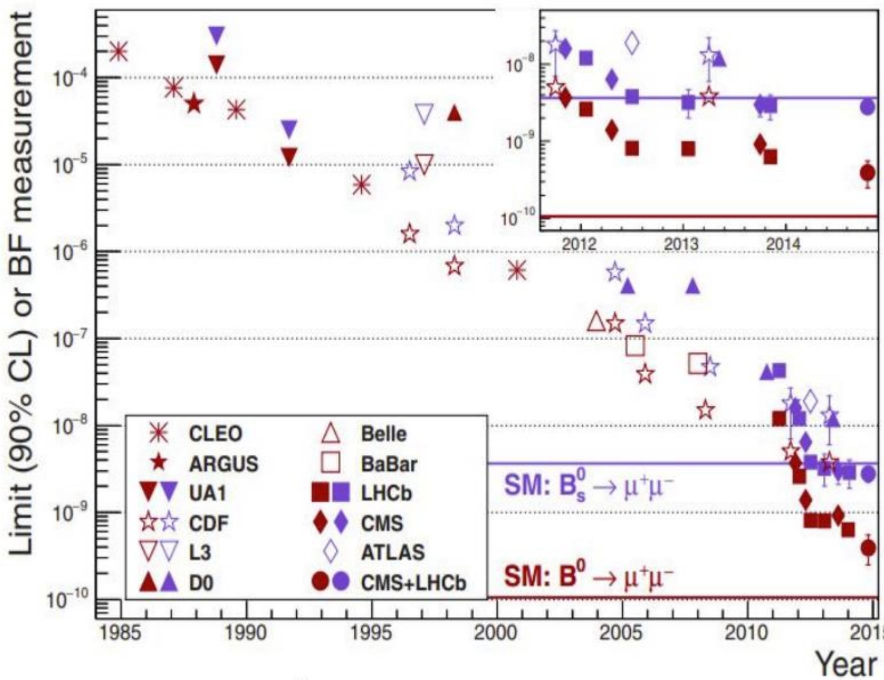
(including LFV)

Measurement of $B_s^0 \to \mu^+\mu^-$ and search for $B^0 \to \mu^+\mu^-$



(a) (b)

- Highly suppressed in SM, (i)Cabibbo suppressed, (ii)Helicity suppressed
- Extremely rare in SM ($B_s^0 \to \mu^+\mu^-$ ~$(3.66\pm0.14)\times10^{-9}$, $B^0 \to \mu^+\mu^-$ ~$(1.03\pm0.05)\times10^{-9}$).
- powerful probes for detecting deviations from the SM due to new physics contributions mediated, for instance, by heavy Z' gauge bosons, leptoquarks or non-SM Higgs bosons

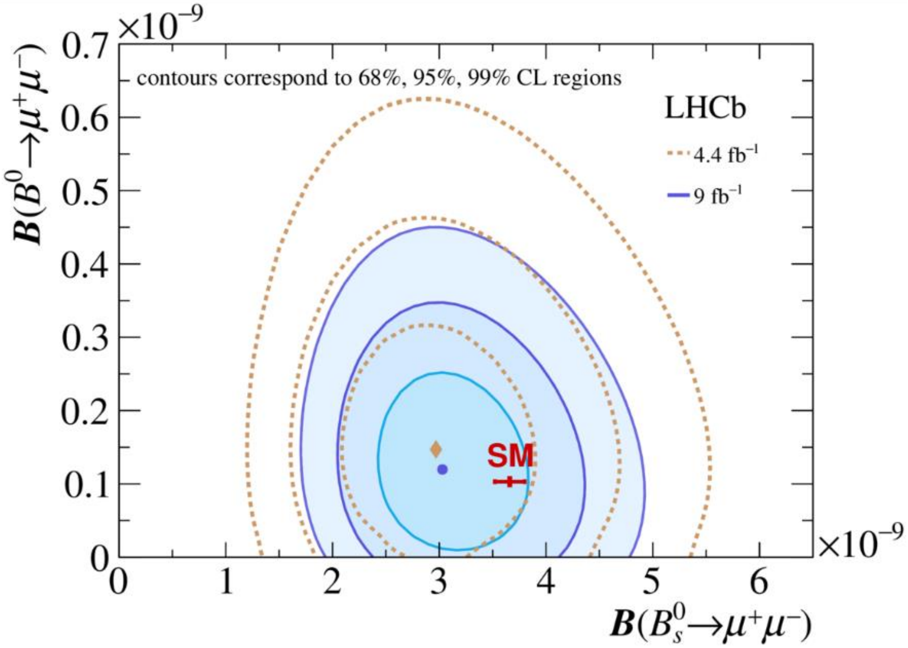


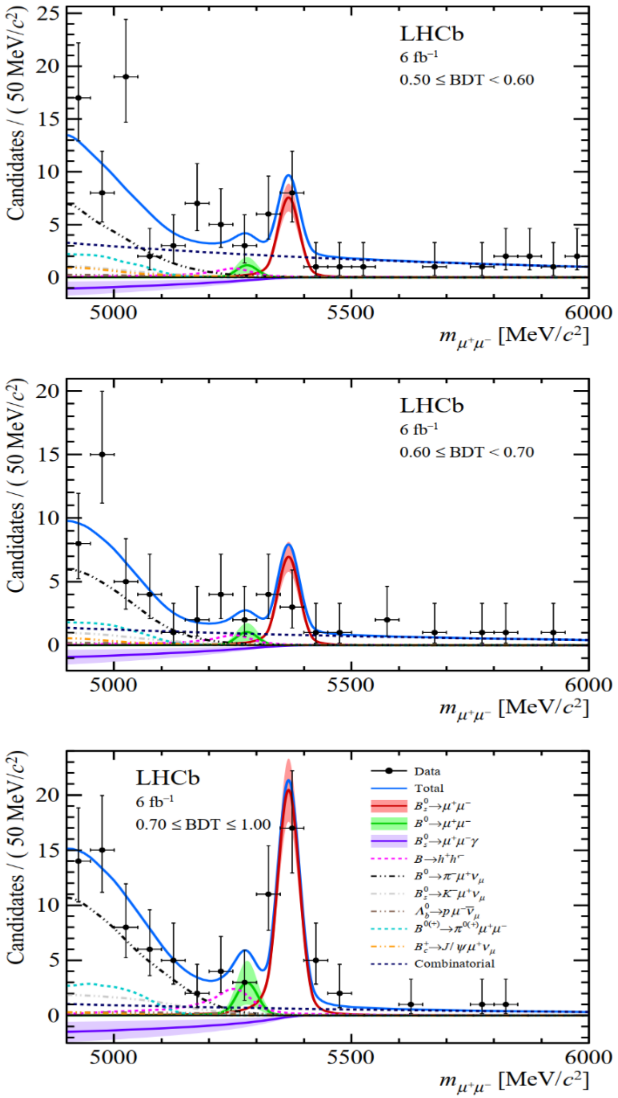
PRL 128, (2022) 041801
PRD105 (2022) 012010

LHCb Run 1 + Run 2, $B_s^0 \to \mu^+\mu^-$

- Branching ratios, consistent with SM:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.09^{+0.46+0.15}_{-0.43-0.11}\right) \times 10^{-9} \qquad \mathcal{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}$$



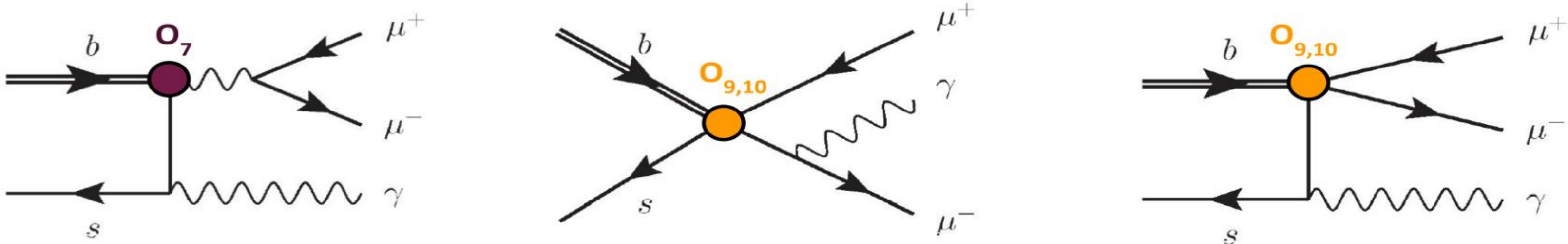


- Systematic uncertainties of $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$: dominated by the uncertainty on *fs/fd* (3%) and the knowledge of the background from specific processes (9%), respectively.

PRL 128, (2022) 041801 PRD105 (2022) 012010

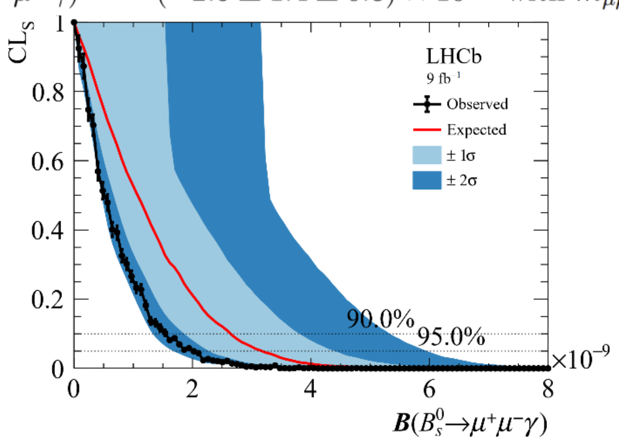
Search for $B_s^0 \to \mu^+\mu^-\gamma$

- Compared to the $B_s^0 \to \mu^+\mu^-$ amplitude, the additional suppression arising from the photon is compensated by no longer helicity suppressed, increasing the total predicted BR
- The $B_s^0 \to \mu^+\mu^-\gamma$ process is a powerful probe of SM, being sensitive to C7 , C9 and C10, While $B_s^0 \to \mu^+\mu^-$ is only sensitive to C10

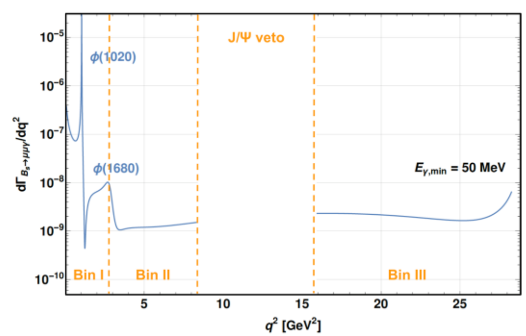


- Indirect search: $\mathcal{B}(B_s^0 \to \mu^+\mu^-\gamma) < 2.0 \times 10^{-9}$

$\mathcal{B}(B_s^0 \to \mu^+\mu^-\gamma) = (-2.5 \pm 1.4 \pm 0.8) \times 10^{-9}$ with $m_{\mu\mu} > 4.9\,\text{GeV}/c^2$.



- Direct search (coming very soon):
  - Direct photon search first time
  - Probe low q^2 regions for the first time



PRL 128, (2022) 041801

PRD 105 (2022) 012010

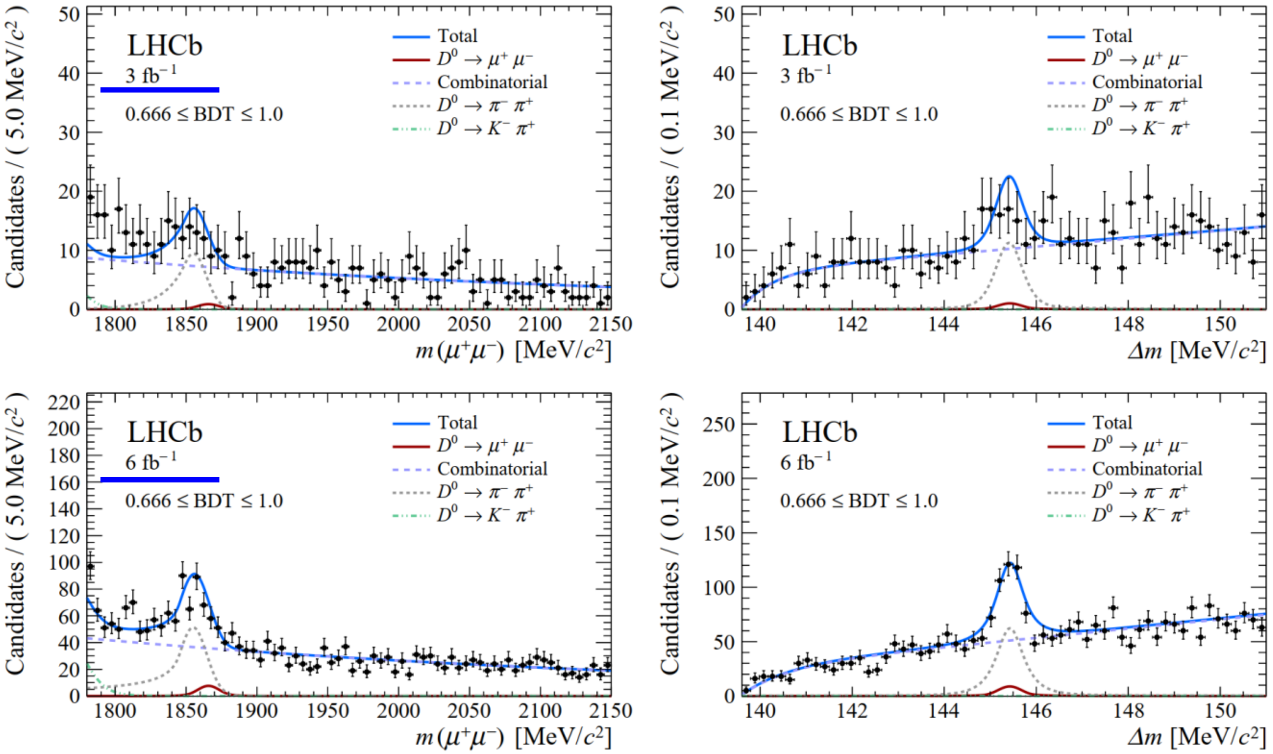
Search for $D^0 \to \mu^+\mu^-$

- It is among the most interesting charm-hadrons decays, being fully leptonic and additionally suppressed by helicity reasons.
- SM short-distance contribution extremely suppressed：10^{-18}； long-distance contribution：10^{-13}
- However the rate can be enhanced in many NP models:
  - new particles could mediate the $D^0 \to \mu^+\mu^-$ decay at tree level.
  - SUSY models with R-parity symmetry violation would allow tree level contributions
- The rate is correlated to the rate of D^0 - $\overline{D}^0$ mixing in many NP models. This is of uttermost importance given the recent first observation of the mass difference between neutral charm-meson eigen-states

PRL 131 (2023) 041804

Search for $D^0 \to \mu^+\mu^-$

- Searched for using $D^{*+} \to D^0\pi^-$ decays, as this improves the background rejection and allows the yield of the decay to be obtained. Charge conjugate processes are implied throughout.



- 2-D fit to the $m(\mu^+\mu^-)$, and the mass difference between the D^{*+} and D^0: Δm
- for the most sensitive BDT interval

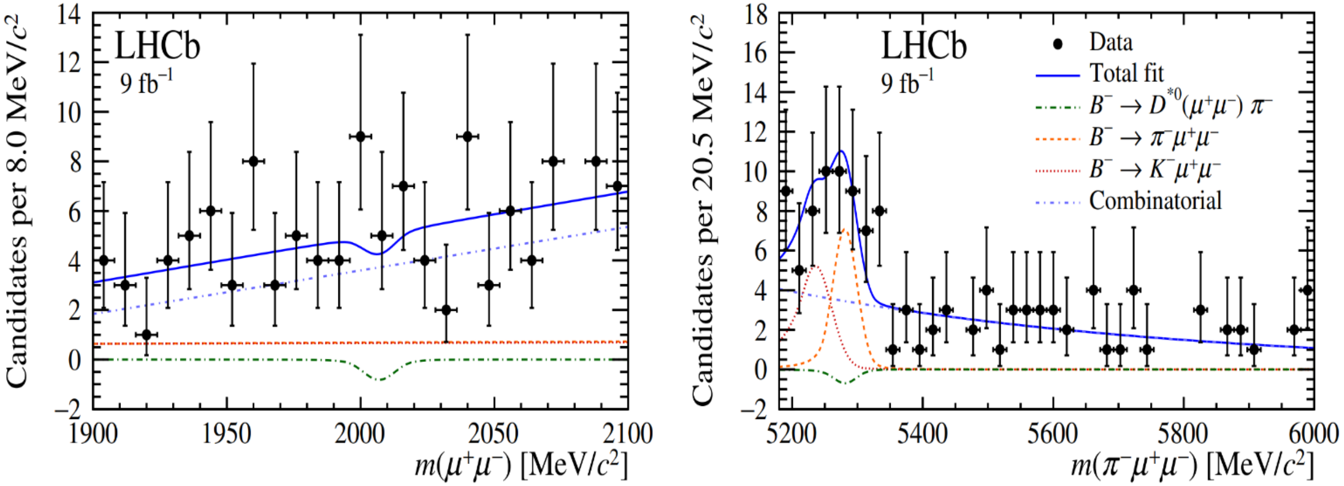
$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 3.1\,(3.5) \times 10^{-9} \text{ at } 90\ (95)\%\ \text{CL}\ .$$

- Most stringent limit on the relevant FCNC couplings in the charm sector, allowing to set additional constraints on NP

PRL 131 (2023) 041804

Search for $D^* (2007)^0 \to \mu^+\mu^-$ in $B^- \to \pi^-\mu^+\mu^-$

- First search for a rare charm-meson decay exploiting production via B decay
- The most promising approach appears to be with the $B^- \to \pi^- D^{*0} (\mu^+\mu^-)$ decay chain since the displaced vertex and exclusive final state provide powerful background rejection capabilities.



Reconstructed (left) $\mu^+\mu^-$ and (right) $\pi^-\mu^+\mu^-$ mass for the selected candidates,

$$\mathcal{B}(D^{*0} \to \mu^+\mu^-) < 2.6\,(3.4) \times 10^{-8} \text{ at } 90\ (95)\%\ \text{CL}\,.$$

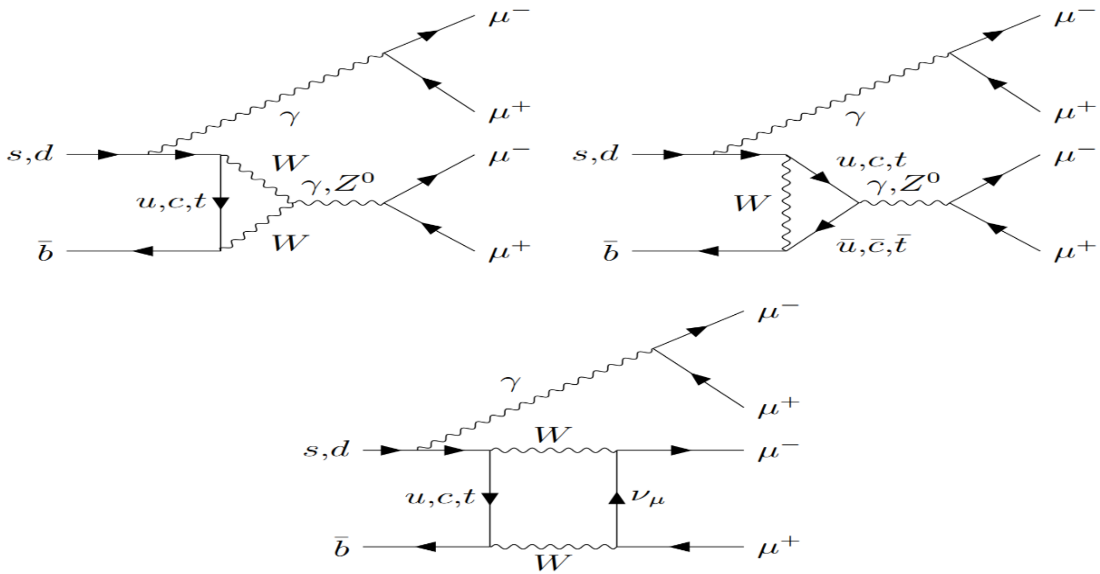
- The first search for a rare charm-meson decay exploiting its production in B-meson decays. the most stringent limit on D^{*0} decays to leptonic final states.

Eur. Phys. J. C 83, 666 (2023)

Search for the rare decays $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to \mu^+\mu^-\mu^+\mu^-$

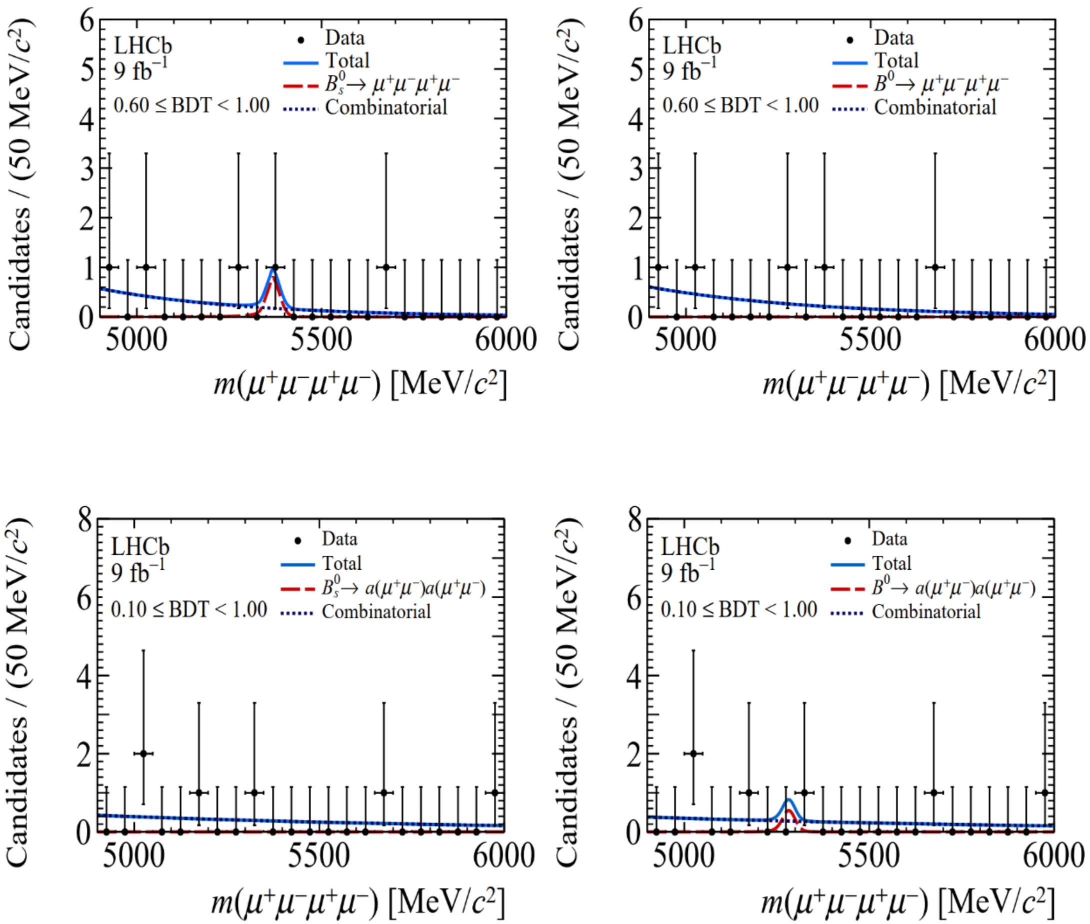
- Highly suppressed in SM: BR ($B^0 \to 4\mu$)~ 10^{-12}, BR($B_s^0 \to 4\mu$)~ 10^{-10}
- For example, decays via scalar and pseudoscalar Sgoldstino particles into a pair of dimuons in the MSSM may lead to significant enhancements of the BRs
- Furthermore, the decays into a pair of dimuons mediated by BSM light narrow scalars, $B^0_{(s)} \to a(\mu^+\mu^-)a(\mu^+\mu^-)$, naturally occur in the extensions of SM

  - In particular, such models can account for the long-standing tension of the anomalous magnetic dipole moment of the muon, as well as the widely discussed anomalies in transitions



Search for the rare decays $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to \mu^+\mu^-\mu^+\mu^-$

- No evidence for the six signal decay modes, with the most significant excesses found in the $B^0_{(s)} \to J/\psi(\mu^+\mu^-)\mu^+\mu^-$ searches, amounting to 2σ



$$\mathcal{B}\left(B_s^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 8.6 \times 10^{-10},$$
$$\mathcal{B}\left(B^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 1.8 \times 10^{-10},$$
$$\mathcal{B}\left(B_s^0 \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right) < 5.8 \times 10^{-10},$$
$$\mathcal{B}\left(B^0 \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right) < 2.3 \times 10^{-10},$$
$$\mathcal{B}\left(B_s^0 \to J/\psi\left(\mu^+\mu^-\right) \mu^+\mu^-\right) < 2.6 \times 10^{-9},$$
$$\mathcal{B}\left(B^0 \to J/\psi\left(\mu^+\mu^-\right) \mu^+\mu^-\right) < 1.0 \times 10^{-9}.$$

- The most stringent limits on each of the six decays

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Search for $K^0_{S(L)} \to \mu^+\mu^-\mu^+\mu^-$

- They are FCNC process that has not yet been observed. In SM its decay rate is highly suppressed, with an expected branching fraction:

$$\mathcal{B}(K^0_S \to \mu^+\mu^-\mu^+\mu^-)_{SM} \sim (1\text{–}4) \times 10^{-14}.$$

$$\mathcal{B}(K^0_L \to \mu^+\mu^-\mu^+\mu^-)_{SM} \sim (4\text{–}9) \times 10^{-13}.$$

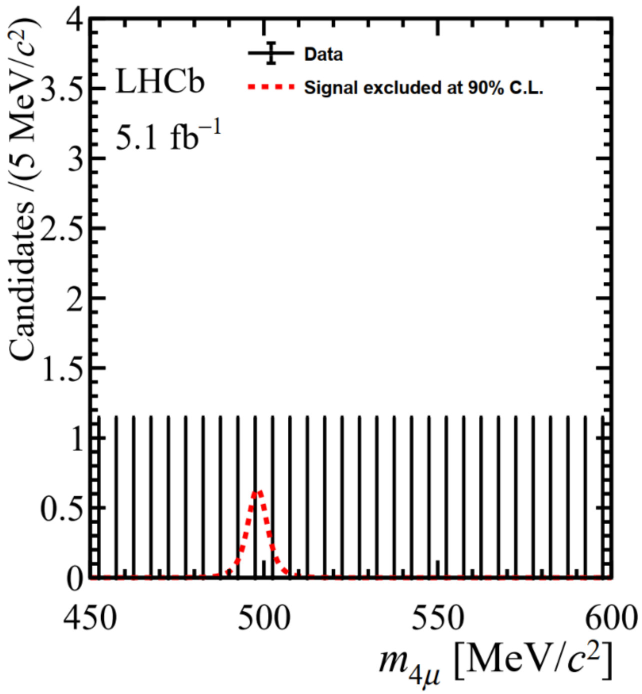
- BSM can lead to large enhancements of $B(K^0_{S(L)} \to \mu^+\mu^-\mu^+\mu^-)$. For instance, proposed **dark-sector scenarios** can enhance the BR by up to $\sim 2 \times 10^{-12}$

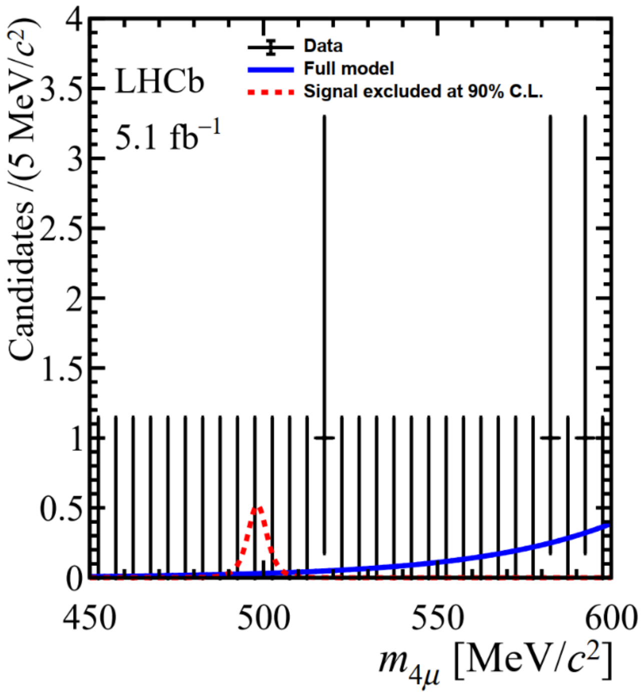
- To date, no direct experimental search of these decays has been performed.

- The analysis data(13 TeV, 5.1 fb^{-1}) sample is split according to the L0 hardware trigger decision: **TIS and xTOS**; $K^0_S \to \pi^+\pi^-$ as normalization

PRD108 (2023) L031102

Search for $K^0_{S(L)} \to \mu^+\mu^-\mu^+\mu^-$





$\mu^+\mu^-\mu^+\mu^-$ candidates in the (left) xTOS trigger category, and (right) TIS trigger category.

$$\mathcal{B}(K^0_S \to \mu^+\mu^-\mu^+\mu^-) < 5.1 \times 10^{-12},$$
$$\mathcal{B}(K^0_L \to \mu^+\mu^-\mu^+\mu^-) < 2.3 \times 10^{-9},$$

PRD108 (2023) L031102

The baryon and lepton number violating decays $B_s^0 \to p\mu^-$ and $B^0 \to p\mu^-$

- Matter-antimatter asymmetry is a serious challenge to our understanding of nature. Proposed three necessary conditions to produce such a large matter-antimatter asymmetry, **one of which is baryon number violation.**
- Various violation processes have been searched for in τ , Λ, D, J/ψ, and B decays by the CLEO, CLAS, BESIII and BABAR experiments, but no evidence has been found so far.

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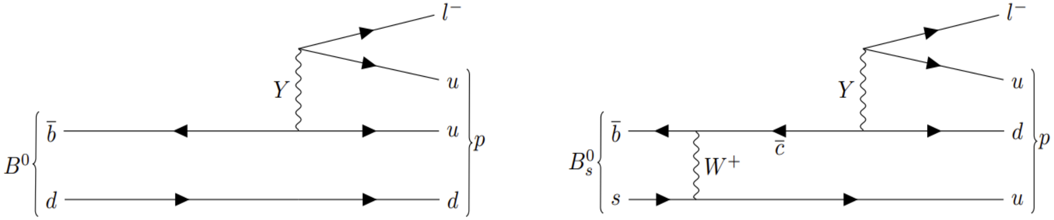
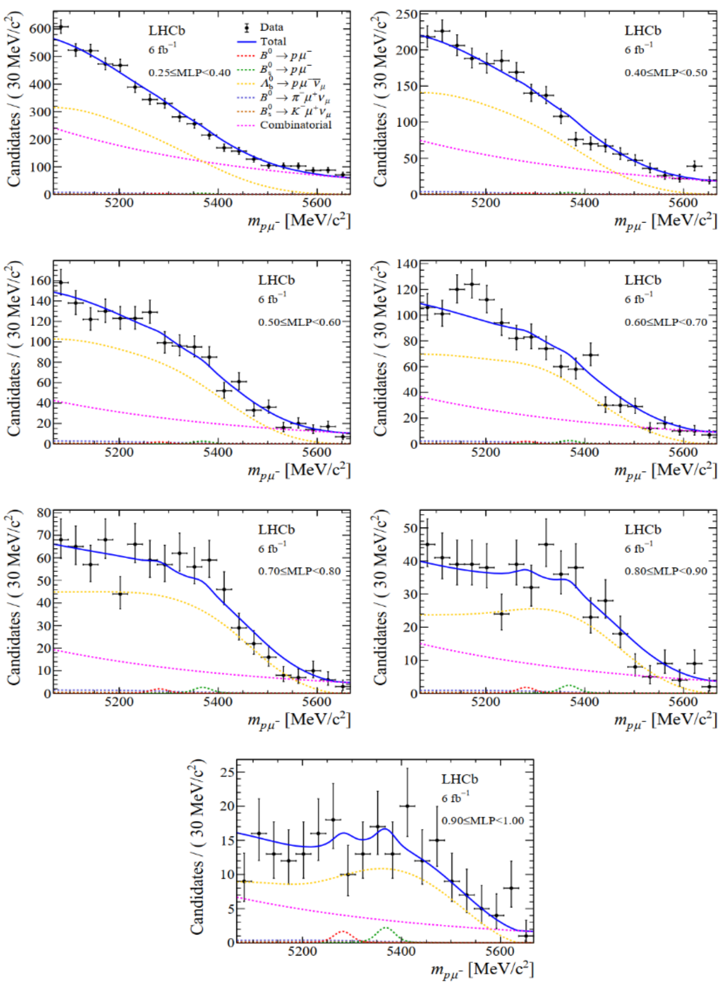
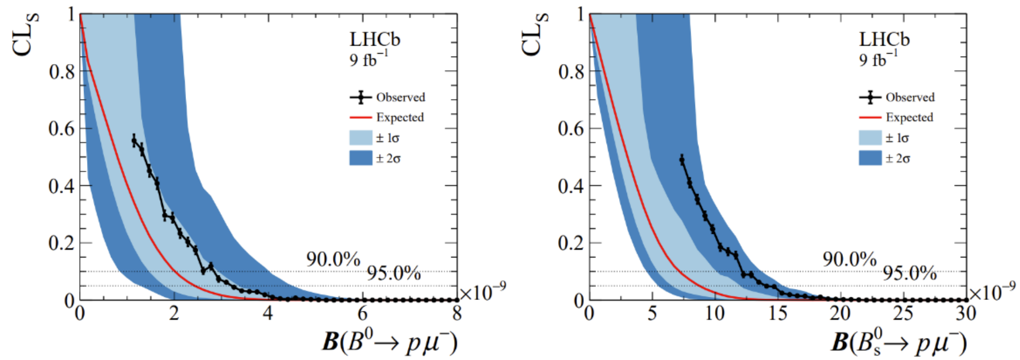


Figure 1: Hypothetical Feynman diagrams of $B^0_{(s)} \to p\ell^-$ mediated by a hypothetical Y boson.

- Mass distribution of signal candidates for Run 2 samples in regions of MLP.





- Results from the CLs scan used to obtain the limit on BR($B^0 \to p\mu^-$) and BR($B_s^0 \to p\mu^-$)
- the first upper limits on these decays

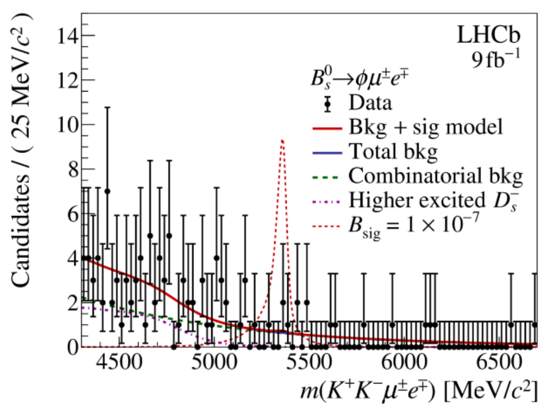
Channel	Expected	Observed
$B^0 \to p\mu^-$	$1.9\ (2.4) \times 10^{-9}$	$2.6\ (3.1) \times 10^{-9}$
$B_s^0 \to p\mu^-$	$7.0\ (8.6) \times 10^{-9}$	$12.1\ (14.0) \times 10^{-9}$

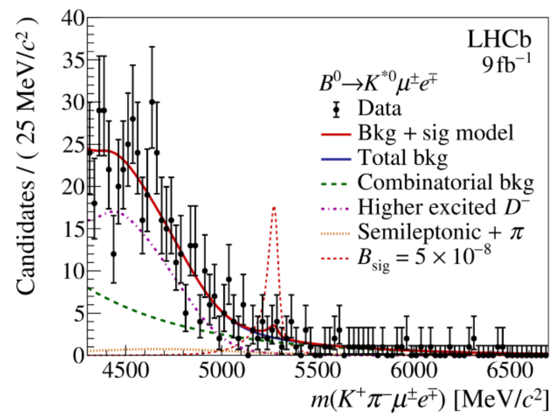
PRD108 (2023) 012021

LFV decays $B_s^0 \to \phi\mu^\pm e^\mp$, $B^0 \to K^{*0}\mu^\pm e^\mp$

- An observation of LFV decays involving charged leptons would constitute a clear and unambiguous sign of New Physics
  - Specific NP scenarios that can induce LFV b-hadron decays include models with scalar or vector leptoquarks and models with additional Z' bosons
- the flavour anomalies in rare $b \to sl^+l^-$ also make LFV important, as lepton flavour non-universality is closely connected with LFV

$$\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7\times10^{-9}(6.9\times10^{-9}),$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8\times10^{-9}(7.9\times10^{-9}),$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 10.1\times10^{-9}(11.7\times10^{-9}),$$
$$\mathcal{B}(B_s^0 \to \phi\mu^\pm e^\mp) < 16.0\times10^{-9}(19.8\times10^{-9})$$





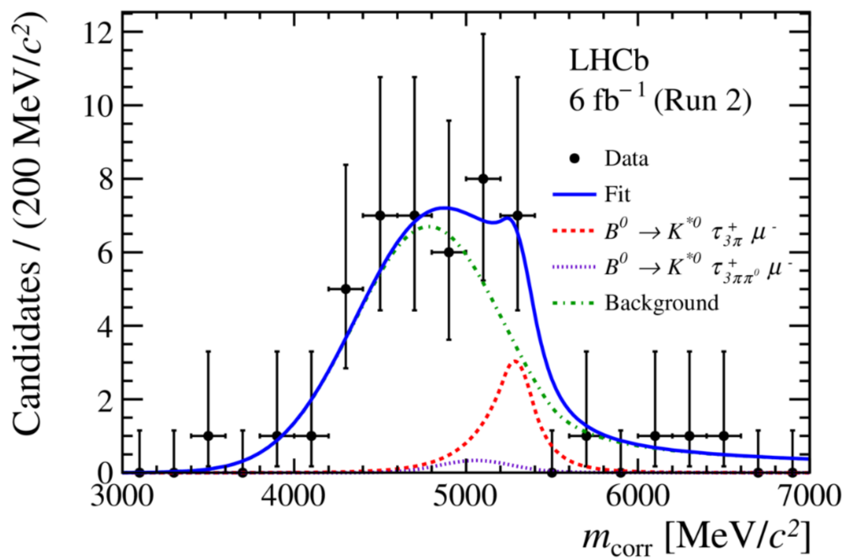
- The world's most stringent limits to date

arXiv:2207.04005

LFV decays $B^0 \to K^{*0}\mu^{\pm}\tau^{\mp}$

- Not ever investigated by any prior experiment

corrected mass



$$\mathrm{BR}(B^0 \to K^{*0}\mu^-\tau^+) < 1.0(1.2)\times 10^{-5},\ \mathrm{BR}(B^0 \to K^{*0}\mu^+\tau^-) < 8.2(9.8)\times 10^{-6}$$

- The world's most stringent limits to date

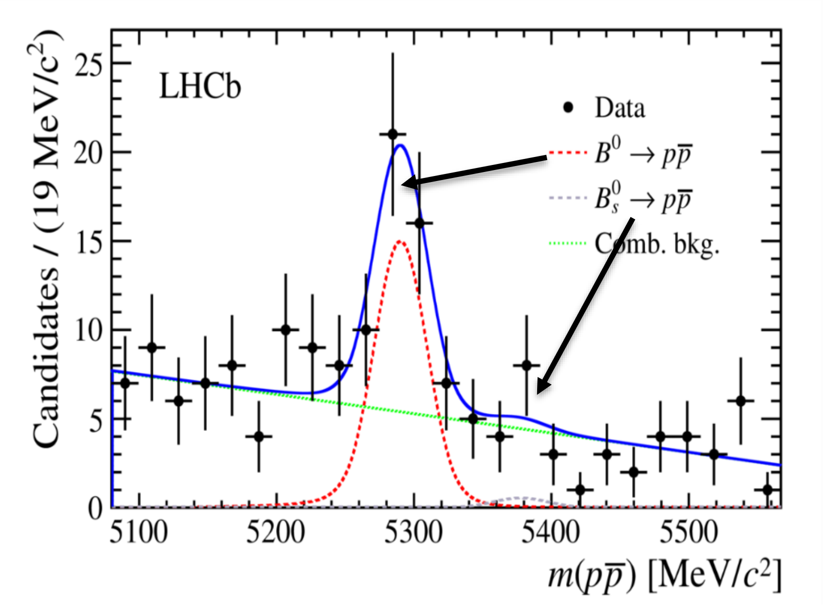
JHEP 06 (2023) 143

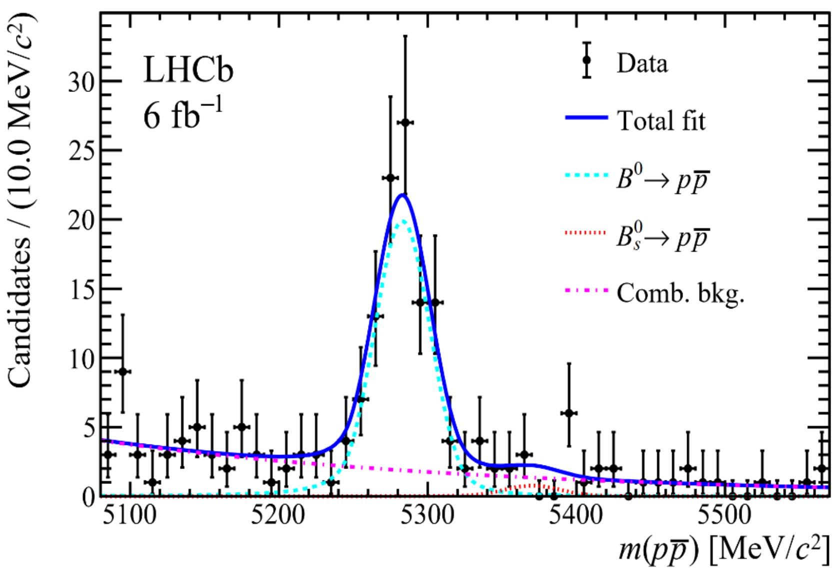
Search for the rare hadronic decay $B_s^0 \to p\bar{p}$

- To date only three charmless two-body baryonic decays have been observed, namely the $B^+ \to p\bar{\Lambda}(1520)$, $B^+ \to p\bar{\Lambda}$ and $B^0 \to p\bar{p}$ modes.

- Run-I result:

  BR($B^0 \to p\bar{p}$)= $(1.25\pm0.27\pm0.18)\times10^{-8}$





PRD108 (2023) 12007

Search for the rare hadronic decay $B_s^0 \to p\overline{p}$

- No statistically significant excess of the decay is observed.

The 90% (95%) upper limit on the $B_s^0 \to p\overline{p}$ decay branching fraction is set at

$$\mathcal{B}(B_s^0 \to p\overline{p}) < 4.4\ (5.1) \times 10^{-9} \text{ at } 90\%\ (95\%) \text{ CL.}$$

- Using the measured quantities and the equation below, the branching fraction of the ($B^0 \to p\overline{p}$) decay is measured more precisely to be:

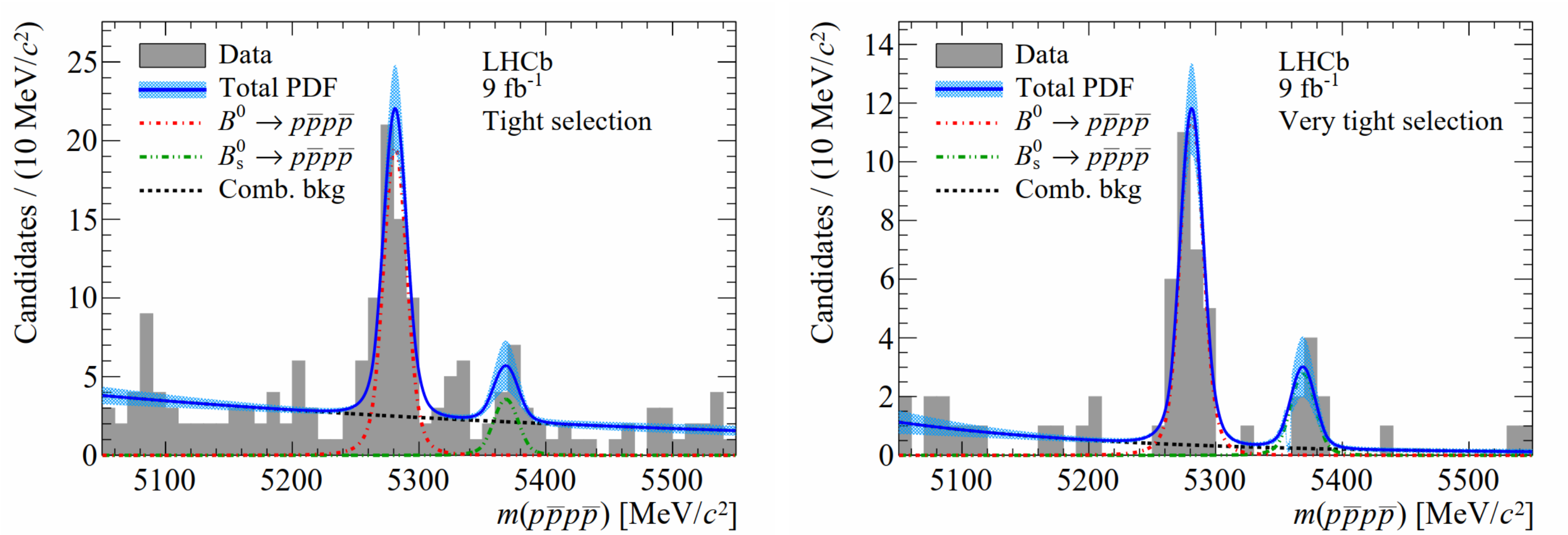
$$\mathcal{B}(B_{(s)}^0 \to p\overline{p}) = \frac{N(B_{(s)}^0 \to p\overline{p})}{N(B^0 \to K^+\pi^-)} \times \frac{\varepsilon_{B^0 \to K^+\pi^-}}{\varepsilon_{B_{(s)}^0 \to p\overline{p}}} \times \mathcal{B}(B^0 \to K^+\pi^-) \times \frac{f_d}{f_{d(s)}}, \qquad (1)$$

$$\mathcal{B}(B^0 \to p\overline{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04) \times 10^{-8},$$

PRD108 (2023) 12007

The rare hadronic decay $B^0_{(s)} \to p\bar{p}p\bar{p}$

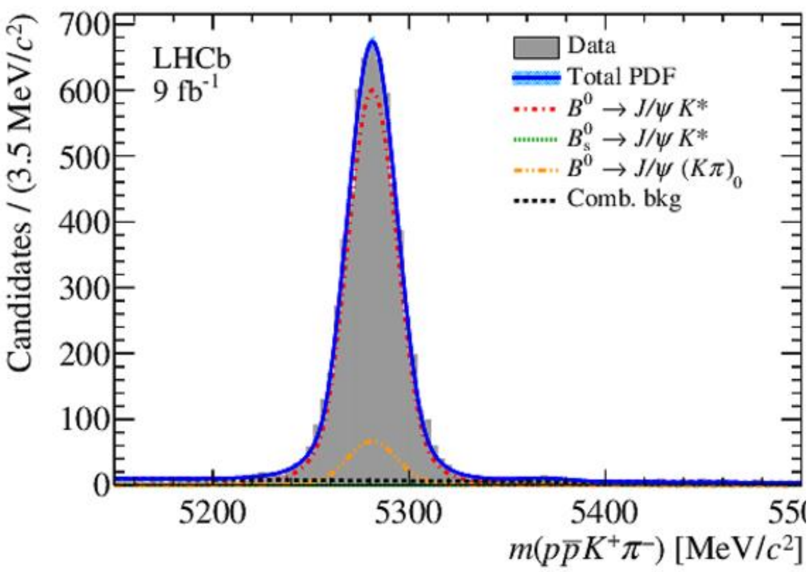
- No reliable theoretical prediction for $B^0_{(s)} \to p\bar{p}p\bar{p}$ decays for now, a first measurement of the corresponding BR would allow to better understand the underlying dynamics
- The BRs of multi-body baryonic decay modes may be significantly increased due to a threshold enhancement effect in the baryon-antibaryon invariant mass, while two-body baryonic decays (such as $B^0_{(s)} \to p\bar{p}$) are suppressed
- B^0 / B^0_s: significance of 9.3σ and 4.0σ

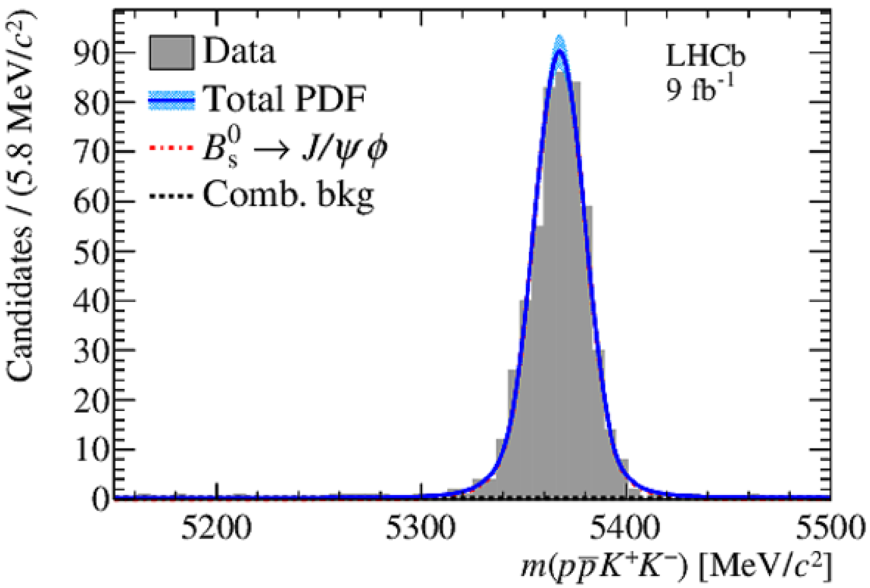


PRL. 131 (2023) 091901

The rare hadronic decay $B^0_{(s)} \to p\bar{p}p\bar{p}$

- The branching fractions are measured relative to the topologically similar normalisation decays： $B^0 \to J/\psi(\to p\bar{p})K^{*0}(\to K\pi)$ and $B_s^0 \to J/\psi(\to p\bar{p})\phi(\to KK)$
- Results: BR($B^0 \to p\bar{p}p\bar{p}$)= (2.2±0.4±0.1) $\times 10^{-8}$ and BR($B_s^0 \to p\bar{p}p\bar{p}$)= (2.2±1.0±0.2) $\times 10^{-8}$

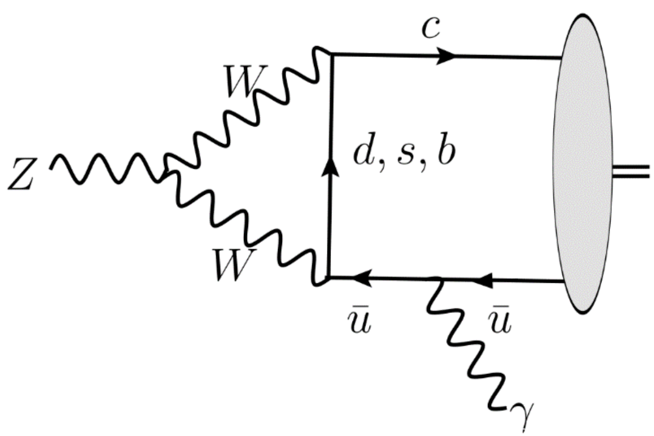


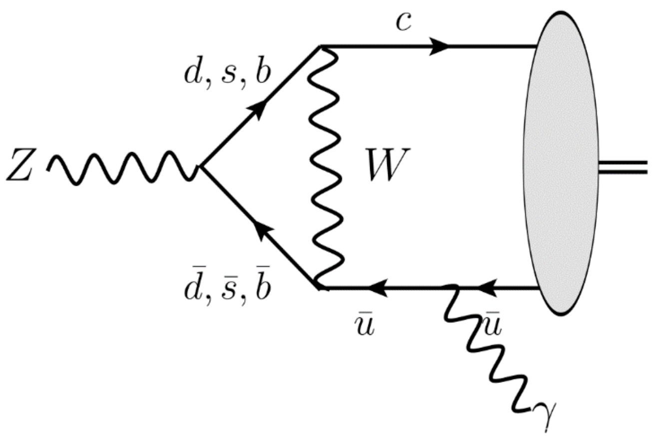


PRL. 131 (2023) 091901

Search for $W^+ \to D_s^+\gamma$ and $Z \to D^0\gamma$

- Hadronic-radiative W/Z decays can provide stringent tests of the QCD factorization formalism
- 40 years from the discoveries of the W and Z bosons, no hadronic-radiative decay of these bosons has been observed, by ATLAS/CMS/CDF
- The current best limit is 9 × 10−7 for the branching fraction of the Z → ϕγ decay
- $\boldsymbol{W^+ \to D_s^+\gamma}$: $(3.7 \pm 1.5) \times 10^{-8}$ predicted in the SM
- $\boldsymbol{Z \to D^0\gamma}$: FCNC process; heavily constrained by the existing precision measurements from flavour physics, resulting in a negligible BR ($\sim 10^{-15}$)

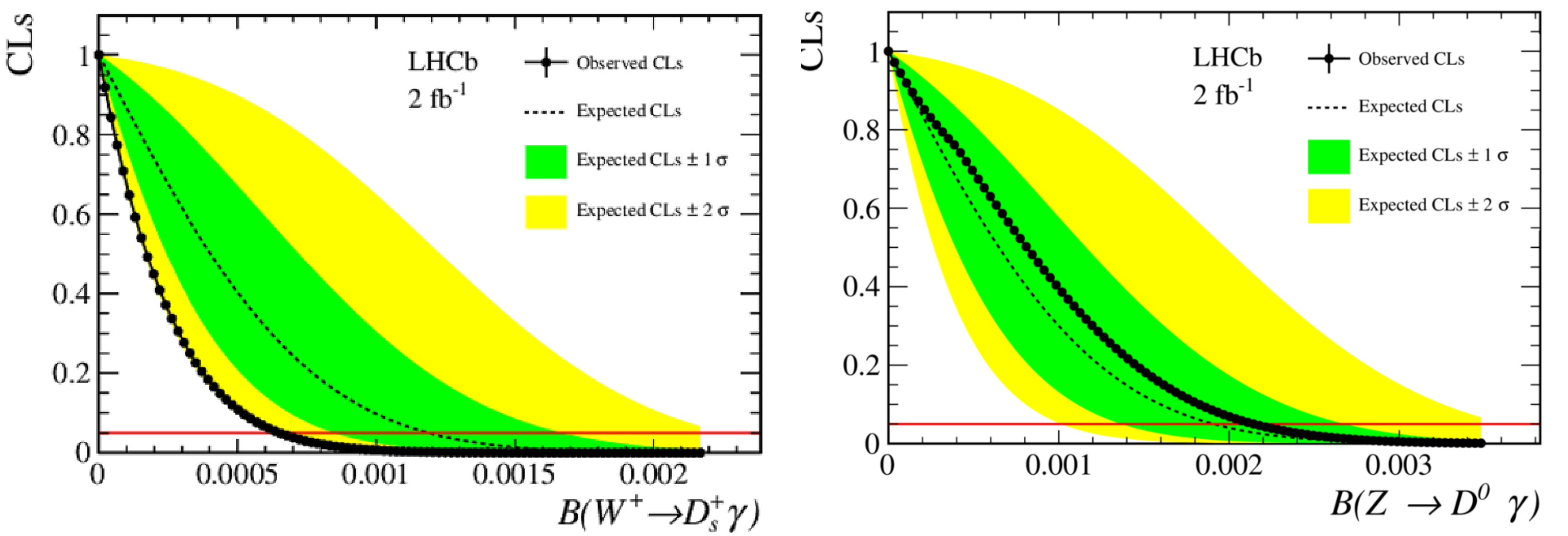




arXiv:2212.07120

Search for $W^+ \to D_s^+\gamma$ and $Z \to D^0\gamma$

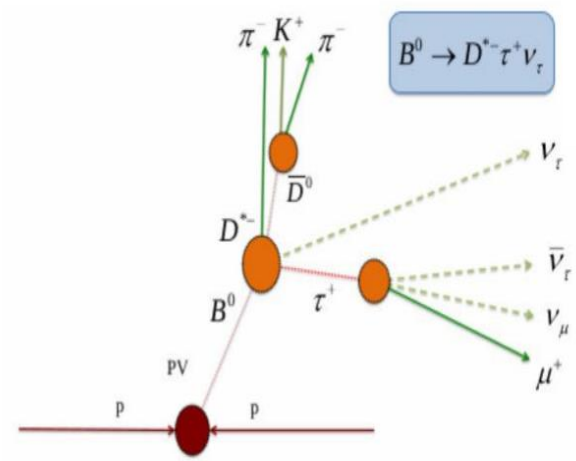
- The upper limits are 6.5×10^{-4} and 2.1×10^{-3}, respectively
- The first reported search for the $Z\to D^0\gamma$ decay, while the upper limit on the the $W^+ \to D_s^+\gamma$ branching fraction improves upon the previous best



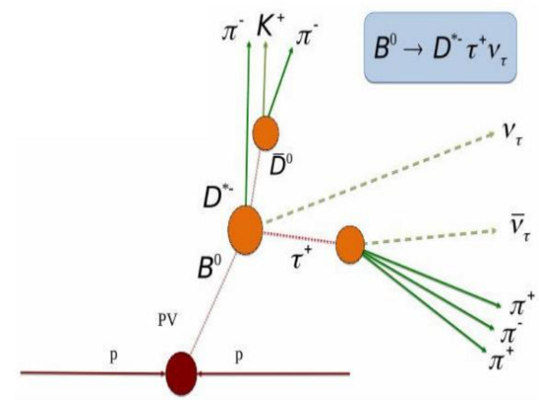
arXiv:2212.07120

Test of lepton universality in $R(D^{(*)})$

R(D$^{(*)}$) Measurements



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)} \tau \nu_\tau)}{\mathcal{B}(B \to D^{(*)} \mu \nu_\mu)}$$



Muonic $\tau \to \mu\bar{\nu}\nu$:

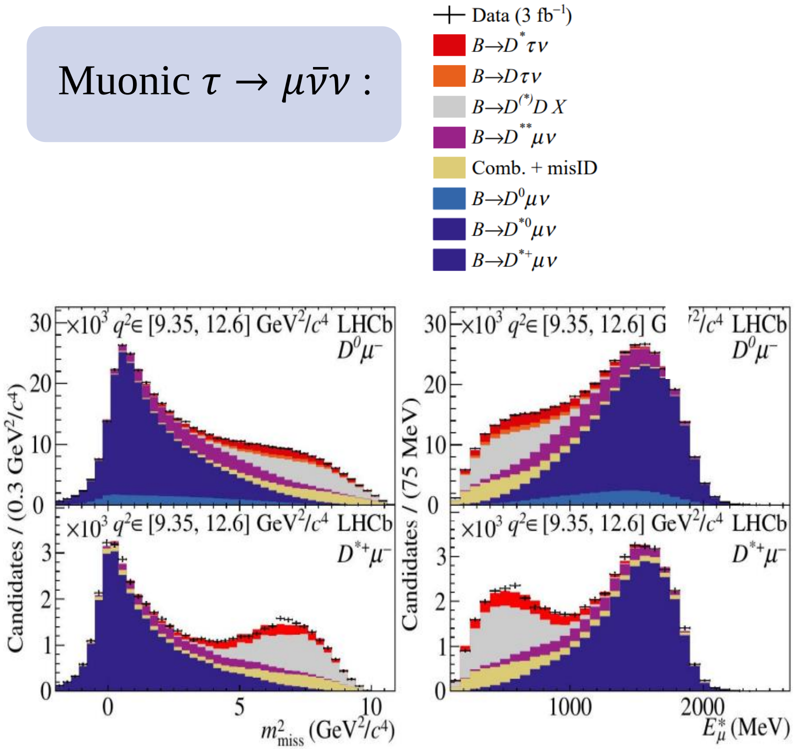
- Large statistics
- Study of τ and μ modes in one dataset
- measure R(D) and R(D*) simultaneously

Hadronic $\tau \to \pi\pi\pi(\pi^0)\bar{\nu}$:

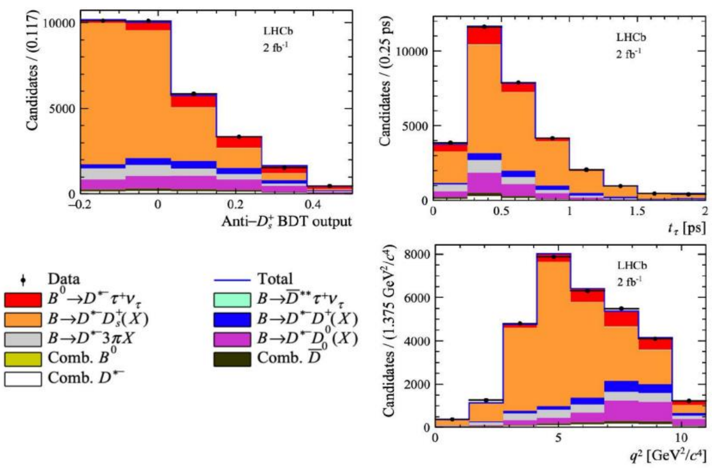
- Relatively high purity
- External BR measurement for normalization
- Decay vertex of τ well measured to suppress dominant backgrounds
- 3π dynamics important for the separation of $B \to D*DX$ backgrounds

$R(D^{(*)})$ Measurements

Muonic $\tau \to \mu\bar{\nu}\nu$:



Hadronic $\tau \to \pi\pi\pi(\pi^0)\bar{\nu}$:



Using Run-I 3 fb^{-1} data:

$R(D^*)$ = 0.281±0.018 (stat.) ±0.024(syst.)

$R(D)$ = 0.441±0.060 (stat.) ±0.066(syst.)

$\rho = -0.43$

1.9σ deviation from SM

Using Run1+2 5 fb^{-1} data:

$R(D^*)$=0.257±0.012(stat.)±0.014(syst.)±0.012(ext.)

Agreement w/ SM <1σ

arXiv:2302.02886

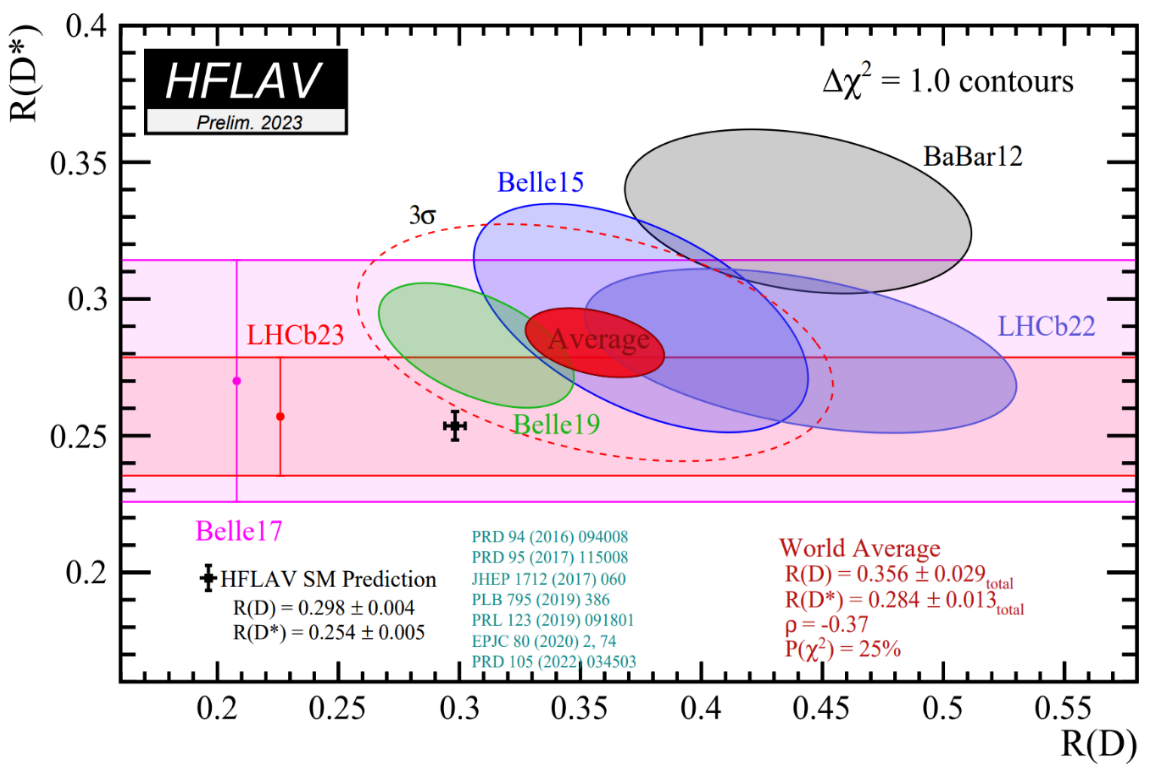
arXiv:2305.01463

PRL 131 (2023) 111802

Updated R(D)-R(D*) world averages

- Updates with inclusion of two new results (LHCb22, LHCb23)
  - $R(D^*) = 0.284 \pm 0.013$
  - $R(D) = 0.356 \pm 0.029$

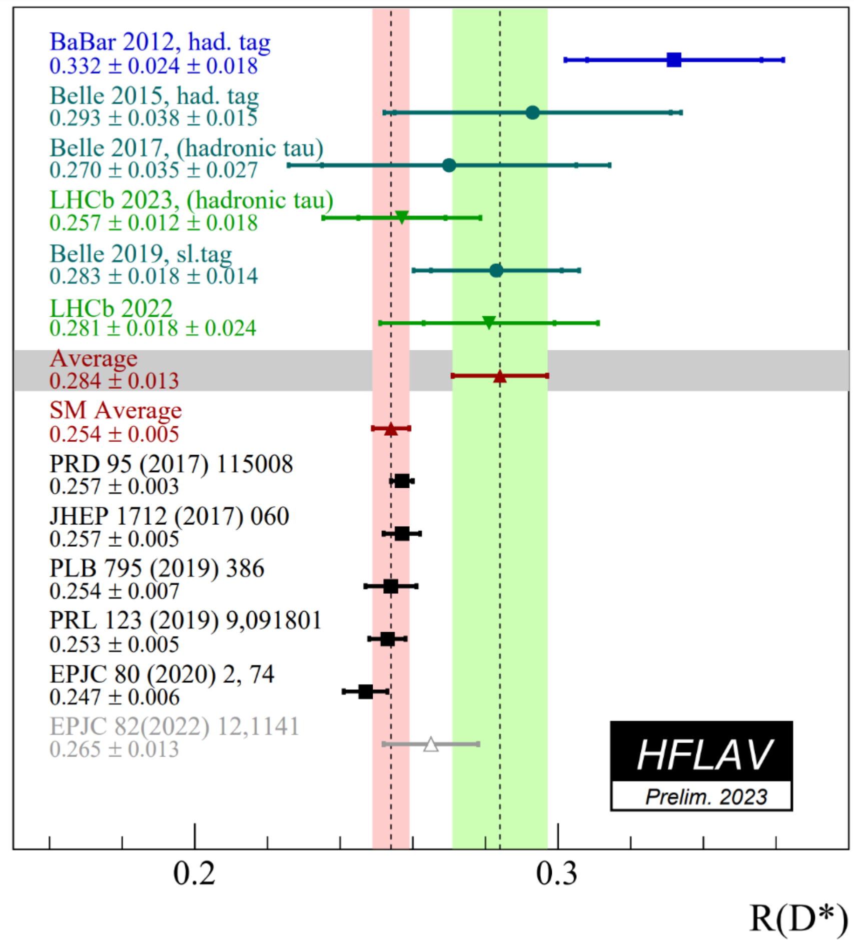
- Deviation from SM for combined R(D) – R(D*) now moves from 3.3σ to 3.2σ



arXiv:2212.13072
arXiv:2301.03214
PRL 131 (2023) 111802

Updated R(D*) world averages

- Updates with inclusion of two new results (LHCb22, LHCb23)
  - R(D*) = 0.284±0.013
  - R(D) = 0.356±0.029
- Deviation from SM for combined R(D∗) now at 1.9σ



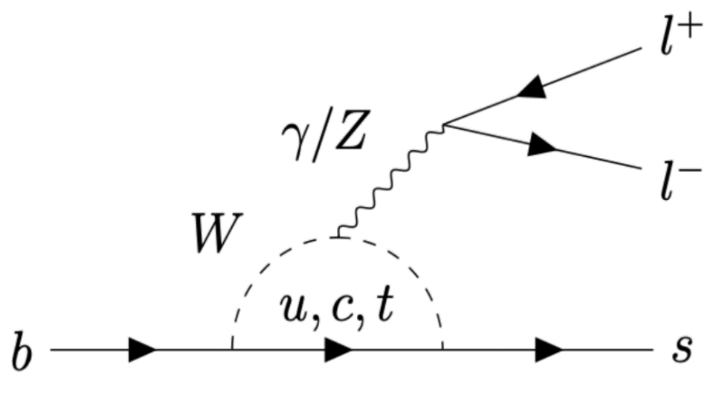
arXiv:2212.13072
arXiv:2301.03214

Test of lepton universality in

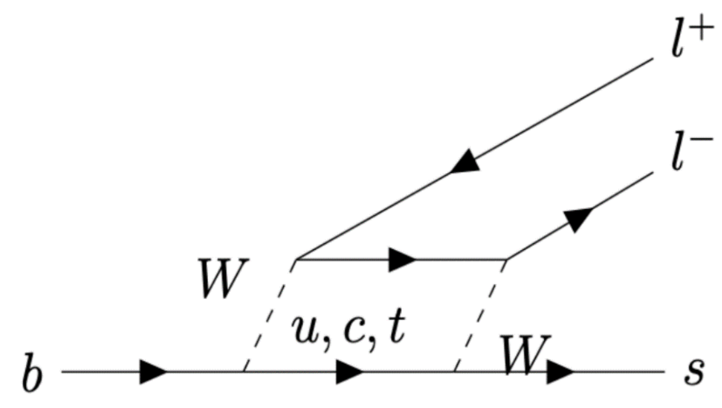
$b \to s\ell^+\ell^-$

The underground physics of $b \to s\ell^+\ell^-$

- Rare nonresonant semileptonic $b \to s\ell^+\ell^-$ decays, **particularly sensitive of LU**
  - theoretical uncertainties on ratios of decay rates controlled at few % level
  - Measure ratio of branching fraction to cancel hadronic uncertainties
- The measurements are powerful tests that can probe BSM particles up to O(50 TeV)
  - NPs can couple to internal loop and produce sizeable deviation to SM prediction



(a) Electroweak penguin.



(b) Box diagram.

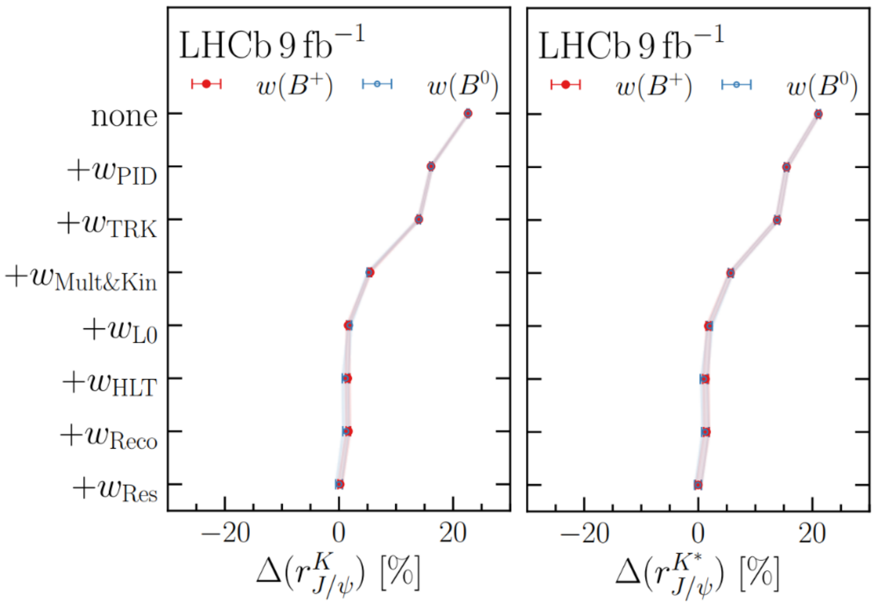
Some lowest order Feynman diagrams

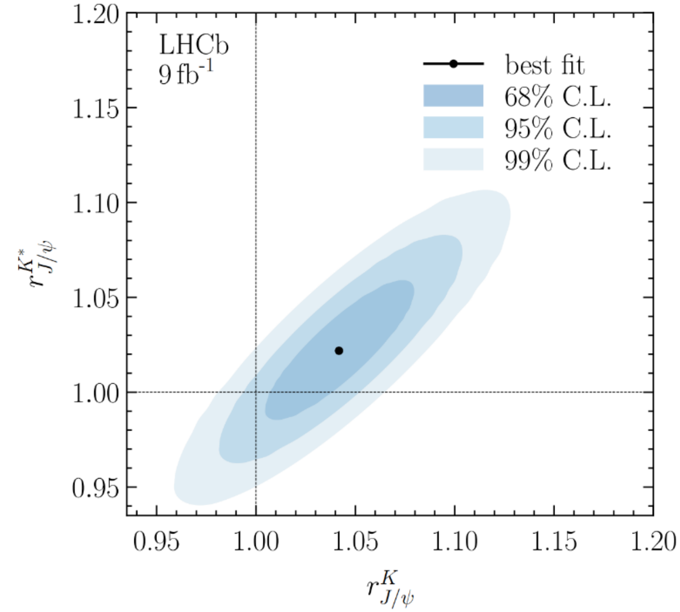
Validation of Efficiency Corrections with r(J/ψ)

- The $r_{J/\psi}^{K(*)}$ is measured:

$$r_{J/\psi}^{K(*)} = \frac{\mathcal{B}(B \to K^{(*)} J/\psi(\to \mu\mu))}{\mathcal{B}(B \to K^{(*)} J/\psi(\to ee))}$$

- Apply corrections, bring r close to SM:





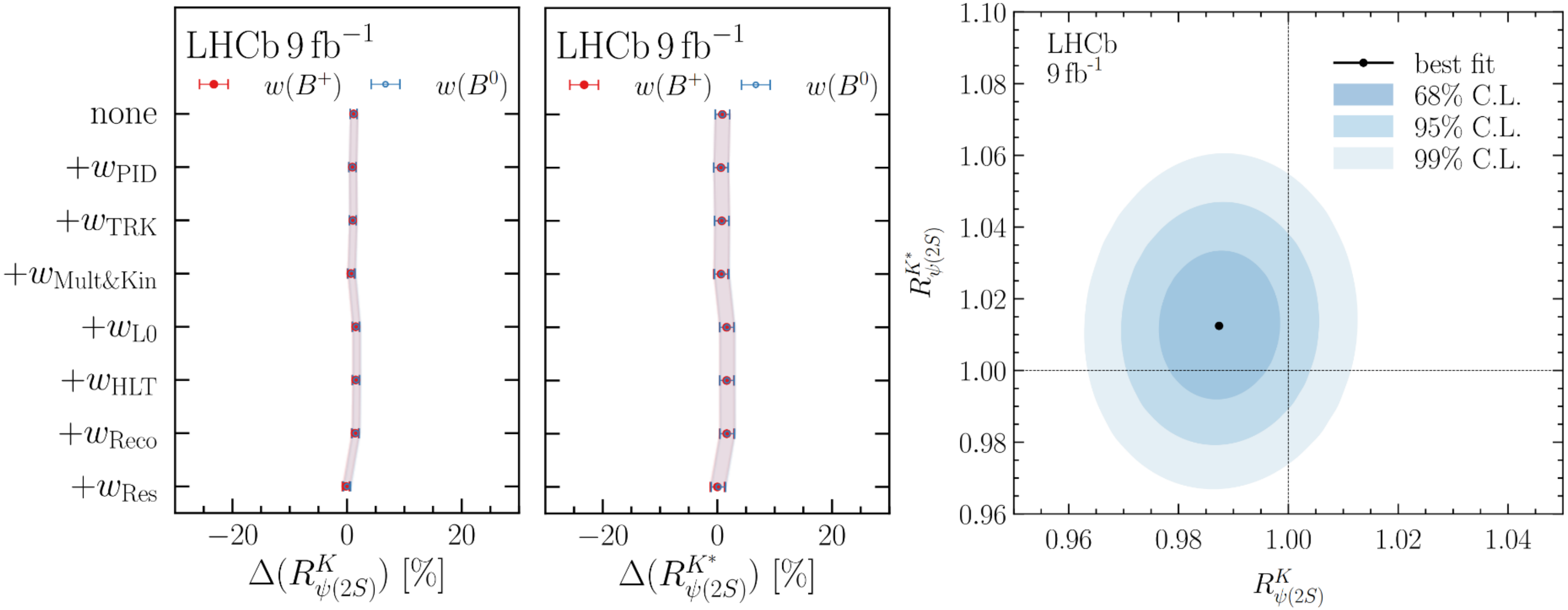
Phys. Rev. Lett. 131 (2023) 051803

Cross-check of Double-ratio with $R_{\psi(2S)}$

- Cross-check of double ratio:

$$R_{\psi(2S)}^{K^{(*)}} = \frac{\mathcal{B}(B\to K^{(*)}\psi(2S)\to(\to\mu\mu))}{\mathcal{B}(B\to K^{(*)}\psi(2S)\to(\to ee))} \times \frac{\mathcal{B}(B\to K^{(*)}J/\psi(\to ee))}{\mathcal{B}(B\to K^{(*)}J/\psi(\to\mu\mu))}$$

- Stability of $\boldsymbol{R_{\psi(2S)}}$ w.r.t. correction step shows cancelation of correction effect

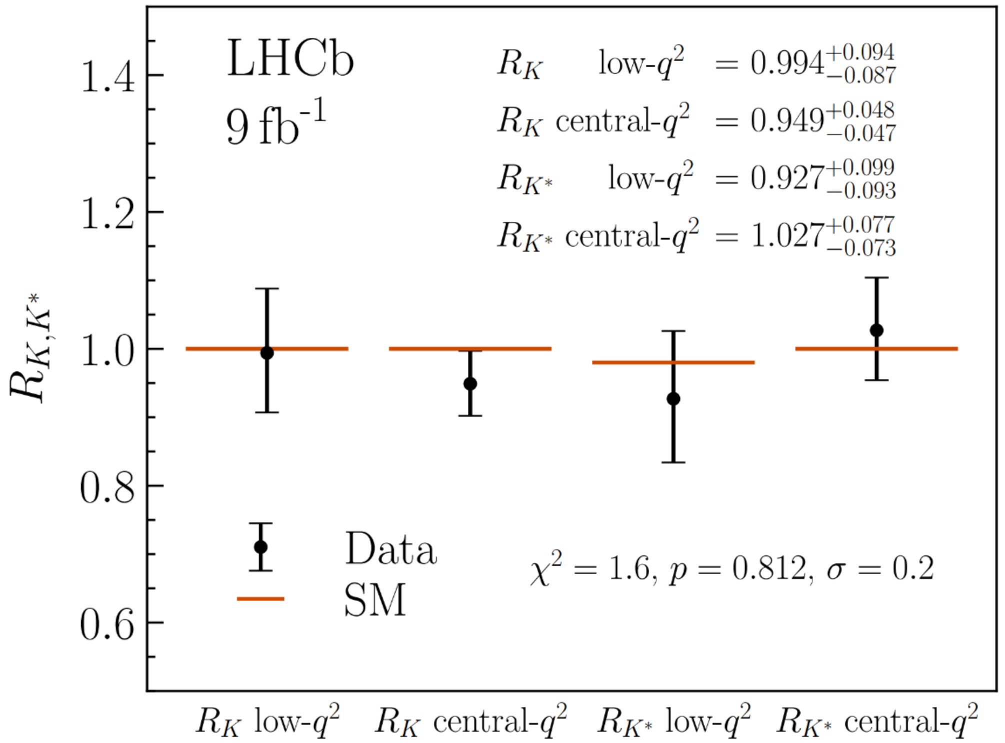


Phys. Rev. Lett. 131 (2023) 051803

The final results

- Measured values of LU observables in $B^+ \to K^+\ell^+\ell^-$ and $B^0 \to K^{*0}\ell^+\ell^-$ decays

  - low: $0.1 < q^2 < 1.1$ GeV^2/c^4，central: $1.1 < q^2 < 6.0$ GeV^2/c^4，



- Overall compatible with the SM.

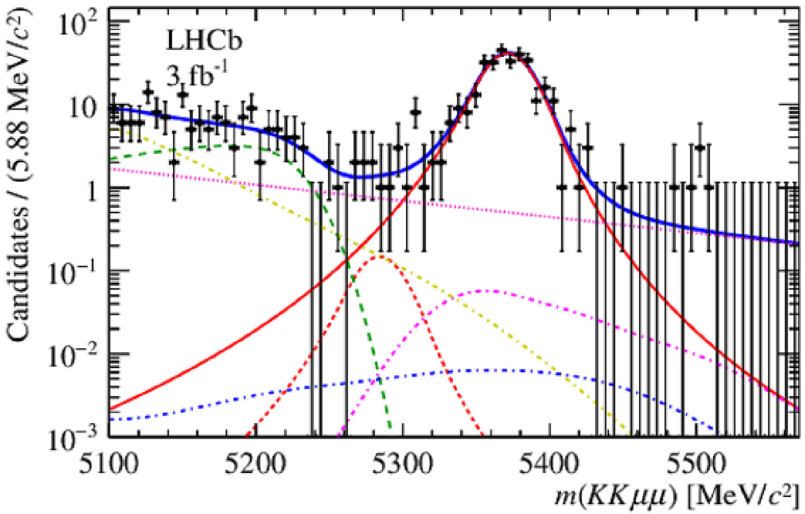
Phys. Rev. Lett. 131 (2023) 051803

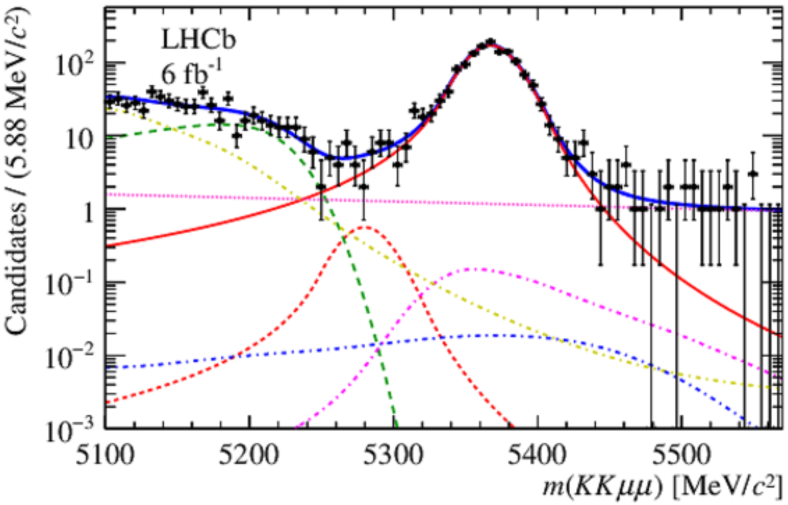
Summary

- LHCb's high statistics and excellent detector performance allow for high precision searches on CPV, rare decays, LU, etc.
- Still more results in the pipeline with full Run1+2 data; and new data (Run3) has started
- Complementary and cross-check with other experiments in many aspects.

谢谢大家！

Search for the $B^0 \to \varphi\mu^+\mu^-$





- No statistically significant excess of the decay $B^0 \to \varphi\mu^+\mu^-$
- An upper limit on its BR excluding the φ and charmonium regions in the dimuon spectrum, relative to that of the decay $B_s^0 \to \varphi\mu^+\mu^-$ is determined to be 4.4×10^{-3} at a 90% CL.
- Using the LHCb measurement of $\mathrm{B}(B_s^0 \to \varphi\mu^+\mu^-)$, an upper limit on $\mathrm{B}(B^0 \to \varphi\mu^+\mu^-)$ in the full q^2 range is set to be 3.2×10^{-9} at a 90% CL, which is compatible with the SM prediction.

JHEP 05 (2022) 67