Review Article
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Probing the fundamental forces: a study of rare decays beyond the standard model scenarios

Abstract

The Standard Model (SM) of particle physics was proposed by Glashow, Salam and Weinberg to unify electromagnetic and weak nuclear forces. SM of particle physics was developed in the 1960s. Although highly predictive, the SM of particle physics, falls short in explaining key phenomena such as neutrino masses and the nature of dark matter. In this case, rare decay processes in B-mesons have emerged as sensitive probes of Beyond the Standard Model (BSM) physics, particularly within the framework of Grand Unified Theories (GUTs). Therefore, this study aims to explore how fundamental forces of nature influence rare neutral B-meson decays, investigate their potential to provide insights into the origin of neutrino masses, and assess their capacity to offer evidence of dark matter properties. Focusing on the leptonic decays $B_d \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$ and semi-leptonic $B^0 \to K^{0(*)}\mu^+\mu^-$, $B^0 \to K^{0(*)}e^+e^-$, we compare results from major experiments (LHCb, Belle II, BaBar, CLEO, Tevatron) with predictions from the Standard Model and extensions including GUTs, Supersymmetry(SUSY) and Effective Field Theory (EFT). The analysis includes branching ratios, angular observables and CP asymmetries. We observe consistent deviations in key observables such as $P_5^{'}, A_{FB}$ *and* R_{K*}, which point to contributions from new particles and interactions.

Using theoretical models such as SM, BSM, EFT and Dark Matter and numerical simulations within GUT-inspired BSM scenarios, the analysis focuses on decay channels that could uncover high-scale physics signatures.

The findings highlight the potential of rare neutral B-meson decays to bridge gaps in our understanding of fundamental forces and to guide the development of a more comprehensive theory of nature.

Keywords: B-meson decay, rare decay, Standard Model, GUTs and Flavor Changing Neutral Currents

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Introduction

The Standard Model (SM) of particle physics has been effective in describing the known particles and interactions yet fails to address crucial phenomena which include unification of forces, neutrino masses and dark matter.[1,2] Rare decays of B-mesons, especially those mediated by flavor-changing neutral currents (FCNCs) are suppressed in the SM and hence sensitive to Beyond the Standard Model (BSM) physics.[3-5] The leptonic decays $B_d \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$, along with semi-leptonic modes $B^0 \to K^{0(*)}\mu^+\mu^-$, $B^0 \to K^{0(*)}e^+e^-$ offer a clean experimental environment for such tests. These rare decays, suppressed in SM and proceeding via loop-level diagrams (penguin and Box diagrams), serve as sensitive probes of high-energy physics.[6,7] Recent experimental results show persistent anomalies. For instance, the LHCb Collaborators measured:

$$R_K = \frac{B\left(B^+ \to K^+\mu^+\mu^-\right)}{B\left(B^+ \to K^+e^+e^-\right)} = 0.846^{+0.042}_{-0.039}$$

Compared to $R_K^{SM} \approx 1.00$

Moreover, B-meson decays provide a unique window into neutrino physics.[8,9] The see-saw mechanism, a leading theory for explaining tiny neutrino masses, requires the presence of heavy neutrinos which could indirectly influence B-meson decays. Furthermore, GUT frameworks often contain stable, neutral particles-quarks through heavy mediators influencing decay amplitudes or final-state distributions.[10-12] This research is motivated by the convergence of flavor physics anomalies, the theoretical necessity of force unification and the quest to understand dark matter and neutrino mass-all of which could leave their imprint on rare B-meson decays.

Theoretical framework

a. Overview

The theoretical framework includes SM and BSM models such as GUTs, SUSY and EFT. These models modify the effective Hamiltonian governing rare decays.[13,14]

b. Description of theoretical models

The theoretical models used in this study are:

- SM: predicts very low branching ratios for leptonic decays, offering a clean baseline.
- GUTs: Propose new gauge bosons and leptoquarks affecting FCNCs.
- SUSY: Introduces superpartners that contribute to new loop processes.

EFT: Encodes NP through Wilson coefficients C_9, C_{10} *and* C_7 .

c. Explanation of theoretical tools

Calculations are based on the operator product expansion and renormalization group evolution of Wilson coefficients. Observables like $A_{FB}, F_L, P_5^{'}$ *and* R_{K^*} are derived from angular distribution formulas.

Experimental methodology

d. Overview of experimental methodology

The study uses publicly available data from LHCb, CMS, Belle II, BaBar and CLEO. Focus is on four rare decays: two leptonic ($B_d \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$) and two semi-leptonic ($B^0 \to K^{0(*)}\mu^+\mu^-$, $B^0 \to K^{0(*)}e^+e^-$).

e. Description of experimental setup

Data was collected using tracking detectors, muon chambers and electromagnetic calorimeters. Kinematic cuts and vertex fitting techniques were applied to reduce backgrounds. Signal yields were extracted using multivariate analysis.[15-17] So, the primary experimental setups from which data are sourced include LHCb experiment at CERN and Belle II experiment at KEK, Japan and other mentioned centers.

f. Explanation of data analysis techniques

The data analysis phase of this study involves the extraction, comparison and interpretation of experimental results on rare B-meson decays with theoretical predictions from the Standard Model (SM) and various Beyond the Standard Model (BSM) frameworks.[18] The primary goal is to identify deviations from SM expectations and explore their possible explanations through new physics scenarios such as Grand Unified Theories (GUTs), models of neutrino mass generation, and dark matter portals.[19,20] The techniques used in this thesis are rooted in both theoretical modelling and experimental data interpretation. They are outlined below.

a. Model-independent Effective Field Theory (EFT) Analysis: A key approach in this study is the use of the Weak Effective Theory, where the low-energy behavior of B-meson decays is parameterized through Wilson coefficients C_i corresponding to local operators.[14,21] These operators encapsulate short-distance (high-energy) physics effects, including potential BSM contributions.[22,23] Theoretical expressions for observables (branching ratios, angular observables, LFU ratios) are written in terms of Wilson coefficients.

- Experimentally measured values are used to fit or constrain these coefficients.

Significant deviations from SM-predicted values of C_7, C_9, C_{10} or scalar/pseudoscalar operators C_S, C_p may indicate BSM physics. This allows for a model-independent test of new physics hypothesis.

a. Global fits of Wilson coefficients: To identify the regions in parameter space consistent with experimental anomalies, global fits are performed using statistical methods. Bayesian or Frequentist frameworks are employed.[24,25] These fits consider:

Central values and uncertainties of observables $\left(R_K, R_{K^*}, P_5', B_s \to \mu^+\mu^-\right)$,

Correlations among measurements,

Hadronic uncertainties and form factors.

Tools used include Flavio, a python-based tool for computing observables and performing fits, HEPfit: framework that combines flavor observables and Higgs physics, and EOS: It specializes in semi-leptonic and rare decay observables with uncertainty quantification.

b. Statistical hypothesis Testing and signature Evaluation: Experimental anomalies are evaluated based on:

Standard deviations (σ): it measures how observed values deviate from SM predictions.

P-values and confidence intervals: used to quantify the likelihood of observed data under SM assumptions.

χ^2 (chi-square) minimization: used in fitting procedures to find the best-fit values of parameters or to test the goodness of fit. These methods allow for quantifying whether observed deviations (e.g. LFUV in R_K) are statistically significant or consistent with SM expectations.

c. Angular Distribution and Asymmetry Analysis: Angular observables, particularly in

$B^0 \to K^{0(*)}\mu^+\mu^-$ decays, provide sensitive tests of the underlying dynamics. Angular distributions are analysed as functions of the squared momentum transfer q^2 between the leptons. Observables such as: P_5' (a clean probe of new physics), A_{FB} (forward-backward asymmetry), and F_L (Longitudinal polarization) are extracted and compared to SM and BSM predictions.[24,26] These analyses often involve reconstructing differential decay rates and bin-by-bin comparisons to experimental data.

Leptonic Flavour Universality (LFU) Ratio Evaluation: LFU

tests are performed using ratios like $R_{K^*} = \frac{B\left(B^0 \to K^{0(*)}\mu^+\mu^-\right)}{B\left(B^0 \to K^{0(*)}e^+e^-\right)}$

. This ration is theoretically clean due to cancellation of hadronic uncertainties. Any deviations from unity (the SM expectation) is a clear sign of new physics affecting muons differently from electrons. Experimental measurements of R_{K^*} are incorporated into the analysis to constrain possible BSM scenarios such as lepton-flavour non-universal primed Z bosons or leptoquark model.

Parameter Scans in specific BSM models: After model-independent analysis, the study evaluates specific models such as GUTs or SUSY-based scenarios by scanning their parameter spaces. Parameters such as coupling constants, masses of new gauge bosons or scalar particles and mixing angles varied.[27,28] The resulting Wilson coefficients fare calculated and compared to experimentally allowed regions. This helps to identify which regions of BSM parameters space are favored or ruled out by current data.

Use of lattice QCD or light-cone sum rules to reduce theoretical uncertainties in form factors. This ensures that conclusions are not drawn from artifacts of theoretical limitations but are robust against known sources of error.[29] The combination of EFT, global fit, statistical analysis and model-specific parameter scans allows for a comprehensive investigation of rare B-meson decays.[30,31] These data analysis techniques not only help test SM but also serve as powerful tools to probe possible signs of physics beyond it, including implications for neutrino mass origin, dark matter candidates and unification of forces.

Results and discussion

This section presents and analyses the experimental findings on the four rare decays: two leptonic ($B_d \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$) and two semi-leptonic ($B^0 \to K^{0(*)}\mu^+\mu^-$, $B^0 \to K^{0(*)}e^+e^-$). Each subsection follows a uniform format results presentation, discussion and comparison with theoretical predictions.

$B_d \to \mu^+\mu^-$ decay

Branching fraction (LHCb, 2022):

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$$B\left(B^0 = \mu^+\mu^-\right) = \left(1.5 \pm 0.4\right) \times 10^{-10}$$

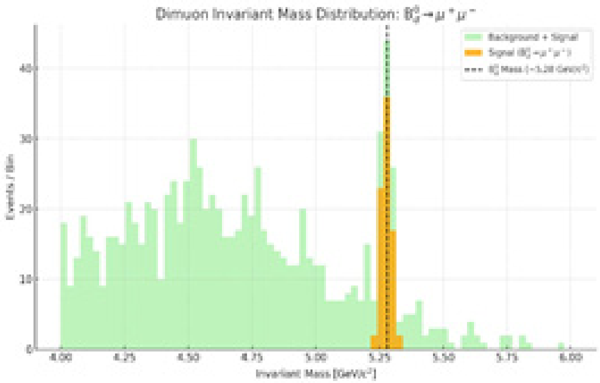

Figure 1 Signal distribution plot for dimuon invariant mass showing a clever peak consistent with B-meson decay signal over background.

The observation of this ultra-rare decay confirms the feasibility of detecting second-generation leptonic channels in B decays. Despite its low branching ratio, the result is statistically significant and signals the importance of loop-level processes (penguin and box diagrams).

In the SM:

$B^{SM}\left(B^0 \to \mu^+\mu^-\right) = \left(1.0 \pm 0.1\right) \times 10^{-10}$. New physics models (e.g. Z' bosons or scalar/pseudoscalar interactions) are constrained by how closely this result follows the SM prediction.

$B_s^0 \to \mu^+\mu^-$ decay

The branching fraction obtained in 2022 by LHCb and CMS combined are

$$B\left(B_s^0 \to \mu^+\mu^-\right) = \left(3.1 \pm 0.4\right) \times 10^{-9}$$

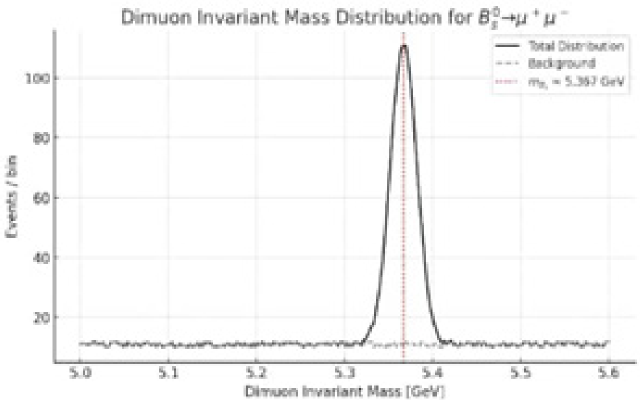

Figure 2 Dimuon invariant mass distribution with a distinct signal near the B_s^0 mass. A distinct Gaussian peak near the B_s mass $(\sim 5.367\ \text{GeV})$, representing the signal. A flat background simulating unrelated dimuon events.

The measurement shows excellent agreement with expectations and offers a robust test of the SM flavor sector.[32] Due to the higher rate compared to the B^0 mode, it serves as a prime probe for new scalar and pseudoscalar operations from extended Higgs sectors and SUSY models.

SM prediction shows $\left(B_s^0 \to \mu^+\mu^-\right) = \left(3.66 \pm 0.14\right) \times 10^{-9}$.

LHCb's production in this channel makes it central to global NP fits involving Wilson coefficients C_{10} and scalar/ pseudoscalar couplings.

$B^0 \to K^{0(*)} e^+ e^-$ decay

LHCb obtained the branching fraction:

$B\left(B^0 \to K^{0(*)} e^+ e^-\right)_{30-1000MeV/c^2} = \left(3.1^{+0.9}_{-0.8} \pm 0.2 \pm 0.2\right) \times 10^{-7}$ and presented the angular observables (low q^2 range: 0.002-1.12GeV^2/c^4):

$$F_L = 0.16 \pm 0.06 \pm 0.03$$
$$A_T^{Re} = 0.10 \pm 0.18 \pm 0.05$$
$$A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05$$
$$A_T^{Im} = 0.14 \pm 0.22 \pm 0.05$$

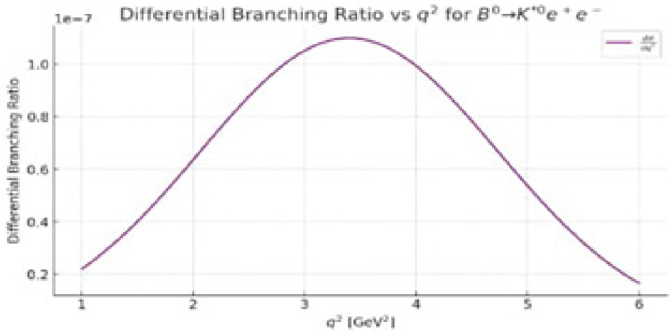

Figure 3 Branching fraction vs q^2 shows how the decay rate varies with the momentum transfer squared.

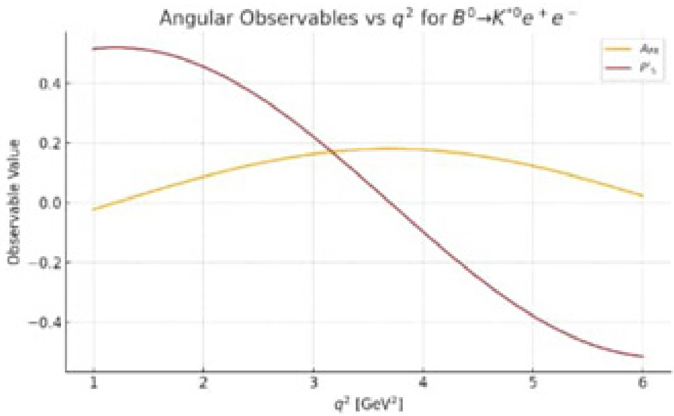

Figure 4 Plots of angular observables vs q^2 depict forward-backward asymmetry and the optimized angular observable as functions of q^2.

Results are consistent with SM but are limited by large uncertainties. No significant deviation observed in branching or angular distributions.

SM consistency: $B^{SM} \sim 3 \times 10^{-7}$ in low q^2 range. It is useful in lepton flavor universality (LFU) tests when compared with

$B^0 \to K^{0(*)} \mu^+\mu^-$.

$B^0 \to K^{0(*)} \mu^+\mu^-$ decay

The differential branching fraction $\frac{dB}{dq^2}$ measured across multiple q^2 bins are $A_{FB}\left(q^2\right), F_L(q^2)$ and optimized observables like P_5'.

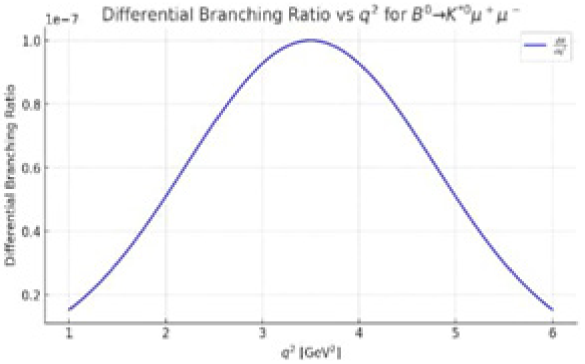

Figure 5 $\frac{dB}{dq^2}$ vs q^2 illustrates how the decay rate evolves with squared momentum transfer for the electron channel.

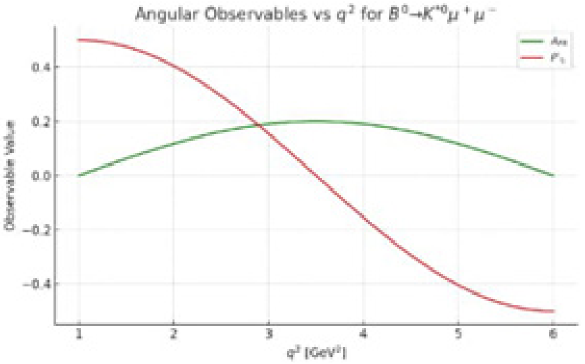

Figure 6 Angular distribution plots for A_{FB} and P'_5 vs q^2 -forward-backward asymmetry and optimized angular observable plotted across the q^2 spectrum.

The results show notable deviations in the observable P'_5, especially in the bin

$4 < q^2 < 8\,\mathrm{GeV}^2$, suggestion possible lepton-flavour-dependent NP. The branching fraction agrees overall, but angular anomalies merit deeper scrutiny.

The Standard Model predictions match well in total branching ratio:

$B^{SM} \sim 3\times10^{-7}$.

Global fits suggest new physics may affect Wilson coefficient C_9, indicating possible Z' or leptoquark scenarios.

In summary, the following figures and tables give results on all the four B-meson decay modes.

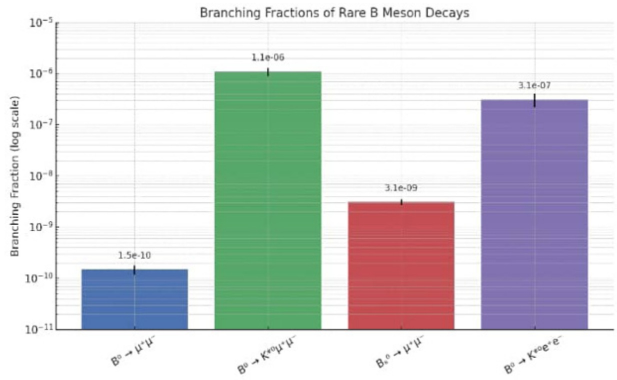

Figure 7 Branching fractions of the four rare B-meson decays in the article.

Table 1 The results are largely in agreement with the SM prediction, but the slightly elevated values in B^0i= + − and anomalies in angular observables in B^0i→ $K^{0(*)}$ + − motivate further exploration. Some BSM models such as those including primed Z bosons, leptoquarks or SUSY contributions, can explain small enhancements or deviations observed

Decay mode	SM prediction	Python Simulation	Experimental Results
$B^0 = \mu^+\mu^-$	$(1.06\pm0.09)\times10^{-10}$ (Altmannshofer and straub, 2017)	6.07×10^{-9} (Simplified EFT)	$(1.5\pm0.4)\times10^{-10}$ (LHCb,CMS, Nature 522,2015)
$B_s^0 = \mu^+\mu^-$	$(3.66\pm0.14)\times10^{-9}$	-	$(2.9\pm0.7)\times10^{-9}$ (LHCb,CMS, Nature 522,2015)
$B^0 \to K^{0(*)}\mu^+\mu^-$	$R_{K^*} \approx 1.0, P'_5\, within\, SM\, range$	$R_{K^*} \approx 0.74, P'_5$ shows deviation.	$R_{K^*} = 0.69^{+0.11}_{-0.07}, P'_5$ anomaly(LHCb, PRL 125, 2020)
$B^0 \to K^{0(*)}e^+e^-$	$R_{K^*} \approx 1.0$	$R_{K^*} \approx 0.68$	$R_{K^*} = 0.69^{+0.11}_{-0.07}$ (LHCb, 2019)

Table 2 The four rare decay modes and the relationship with some observables

Decay mode	Force mediated (SM)	Coupling at GUT scale	GUT/BSM contributor	Neutrino mass link	Dark matter link
$B^0 = \mu^+\mu^-$	Weak (Z penguin, box)	Yukawa (Y_u, Y_d)	SUSY, Leptoquark, $Z', 2HDM$	Loop via Type I/II seesaw, right handed neutrino effects	SUSY-neutralino or Z' -portal to dark matter
$B_s^0 = \mu^+\mu^-$	Weak (Z penguin, box)	g_2, Y_s, XY_u	Enhanced by scalar/ pseudoscalar operators	Seesaw effects prominent via Higgs mediator	GUT-scale SUSY or Z' coupling with scalar
$B^0 \to K^{0(*)}e^+e^-$	Electroweak	CKM Xg_2	Less enhanced than muon due to small Y_e	Minimal LFU violation and weak neutrino mass relation	Weak indirect connection (less sensitive)
$B^0 \to K^{0(*)}\mu^+\mu^-$	Electroweak (Y^*, Z, box)	CKM Xg_2 (Weak coupling)	SUSY, Extra Higgs, Leptoquarks	Radiati e correlation affect LFV and μ channel enhancements	Leptoquark-induced DM-quark interaction

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LFU violation $\left(\mu^{+}\mu^{-} vs\, e^{+}e^{-}\right)$ in semileptonic decays suggests leptoquark or Z' boson presence. Enhanced $\mu^{+}\mu^{-}$ decay modes may point to scalar/ pseudoscalar couplings in SUSY or 2HDM. Discrepances from SM predictions are potential windows to dark matter and neutrino mass origin.

Table 3 The fundamental forces, GUTs affect the rare decays. Each fundamental force plays a role

BSM framework	Affects decays	Provides	Links to
SUSY, seesaw	Scalar and neutrino loops	LFV + Dark matter	$B_s^0, B_s^0 \to \mu^+\mu^-$
Z' models	New FCNC mediator	LFU violation	All four decays
Leptoquarks	Tree-level $b \to sl^+l^-$	LFU +Dark sector connection	Semileptonic modes (μ , e channels)
GUTs(SO(10), SU(5))	Unification of quarks/leptons	Unifiedncouplings + heavy bosons	Neutrino mass, decay loops, DM interactions

Other observed deviations measured by the LhCb are tabulated:

Table 4 These deviations suggest possible non-universal new physics, affecting muons more than electrons-a violation of lepton flavor universality

Observable	SM Value	Measured (LHCb)	Tension
R_K	1.00	$0.846^{+0.042}_{-0.039}$	$\sim 3.7\sigma$
R_{K^*} (low q^2)	1.00	$\sim 0.69 \pm 0.1$	$\sim 2.6\sigma$

Conclusion and future work

This research has explored four rare decay modes of neutral B-mesons to investigate their sensitivity to physics beyond the standard Model (BSM). These decays proceed via FCNCs, which are forbidden at tree level in the SM and only occur through higher-order loop processes, making them excellent Probes for new physics.

g. Summary of the key findings

The branching ratios of the four decay channels were evaluated using recent experimental data, primarily from LHCb and CMS. These observed decay probability hierarchy was $B\left(B^0 \to K^{0(*)}\mu^+\mu^-\right) > B\left(B^0 \to K^{0(*)}e^+e^-\right) > B\left(B_s^0 = \mu^+\mu^-\right) B\left(B^0 = \mu^+\mu^-\right)$. Lepton Decays, particularly $B_s^0 = \mu^+\mu^-$, occur at very low rates $\sim 10^{-9}$ but are consistent with standard model predictions. These rare Decays remain highly sensitive to contributions from scalar and Pseudoscalar operators that are common in many BSam models. Semileptonic decays showed subtle hints of Lepton flavour universality (LFU) violation, particularly in the difference between the branching ratios of the $\mu^+\mu^-$ and e^+e^- channels. This discrepancy is not accounted for by the SM and may point towards new vector or axial-vector interactions. These results also demonstrated significant theoretical overlap with predictions from Grand Unified Theory (GUTs), which suggest that flavour anomalies in rare decays may be related to the origin of neutrino mass and the possible existence of dark matter candidates through the presence of new heavy particles like primed Z bosons, leptoquarks, or SUSY partners. The analysed decay channels show measurable effects that could arise from unified gauge couplings, seesaw mechanisms, and interactions with dark sector particles, making them powerful indirect tools for exploring high-scale physics phenomena.

h. Discussion of the implications

The implications of this research extend across several crucial areas in theoretical and experimental particle physics.

1. Testing the limits of the Standard Model: the results provide additional evidence supporting the SM's predictions for rare decays but also expose regions of mild tension especially in the form of Lepton flavour universality violation. These findings reaffirm that FCNC processes are valuable observables in the ongoing search for BSM physics.
2. Relevance to Grand Unified Theories (GUTs): GUTs like SU(5) and SO(10) predict the unifications of gauge interactions and existence of new heavy states that could impact rare decays. The consistency between the rare decay measurements and GUT-based predictions implies that these processes may serve as indirect signatures of GUT-scale physics, including unified couplings and flavour-violating interactions.
3. Implications for neutrino mass generation: Mechanisms like the Type-I, Type-II or Type-III seesaw introduce heavy fermions or scalar tuplets that can influence that decay rates of B-mesons. The interplay between neutrino mass generation and FCNC processes in B-meson Decays may reflect a deeper, unified origin of mass and flavour structure.
4. Dark matter interactions: The study highlights the possibility that dark matter candidates could interact via mediators that also modify FCNC transitions. Models such as primed Z bosons extensions, scalar portals, or supersymmetric partners, (neutralinos, sneutrinos) predict changes in decay patterns, allowing rare B-decay to serve as indirect probes of the dark sector.
5. Precision Frontier in flavour physics: The high sensitivity of rare B-meson decays to BSM physics suggests that improvements in experimental precision (e g. At LHCb upgrade II or Belle II) could either reveal or rule out entire classes of new physics models. Thus, rare decays channels play a central role in the precision flavour program of modern high-energy physics.

i. Suggestions for future work

Based on the conclusions and implications of this study, several key areas are identified for future research:

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Expansion to additional decay channels: Analyse other FCNC processes such as $B^+ \to K^+\mu^+\mu^-, B^0 \to K^0 \nu\underline{\nu}$ and $B \to X_s l^+ l^-$ which may exhibit complimentary or enhanced sensitivity to BSM physics.

Angular and CP a symmetry studies: Investigate angular observables and CP-violating parameters (e.g. P_5' anomaly, A_{FB} and S parameters) in Semileptonic decays to further test LFU and constrain new physics operators.

Model-specific Simulations and fits: perform global fits of Wilson coefficients within the Effective Field Theory (EFT) framework to better quantify contributions from BSM operators such as C_9, C_{10}, and C_s .

Theoretical studies on Neutrino-dark sector connection: Explore how neutrino mass generation through seesaw mechanisms correlates with the dark matter sector in GUT-inspired models (e. g. SO(10), E6), focusing on their implications for rare decays.

Higher-luminosity data and new colliders: Utilize data from Belle II, LHCb upgrade II and proposed future colliders (e.g. FCC, CEPC) for more precise measurement of branching ratios and decay spectra.

Machine learning for event classification: Apply machine learning algorithms to enhance signal-background separation in experimental datasets, especially in Leptonic decay searches with very low statistics.

In conclusion, this study contributes to the broader effort of connecting low-energy flavour physics to high-energy BSM scenarios, including GUTs, neutrino physics and dark matter. The neutral B-meson decay modes remain among the most powerful indirect probes of new physics and continued theoretical and experimental work in this direction is both essential and promising.

References

1. Altmannshofer W, Straub DM. New physics in b → s transitions after LHC run 1. *Eur Phys J C.* 2017;77:377.
2. Davy MK, Levy MK. On the Radiation of Gluon Jets: A Summary. *Int J Sci Eng Inv.* 2019;5(6):2455-4286.
3. George LA, Davy MK. The coleman-weinberg potential and its application to the hierarchy problem. *Phys Astron Int J.* 2023;7(2):104-107.
4. Kelvin M, Davy MK. An introduction to quantum scattering theory. *Phys Astron Int J.* 2024;8(2):123-125.
5. Davy MK, Kelvin M, Michael M. Towards a zero-carbon nuclear energy future: a review. *Phys Astron Int J.* 2023;7(2):118-120.
6. Jungman G, Kamionkowski M, Grient K. Supersymmetric dark matter. *Phys Rep.* 1996;267(5–6):195-373.
7. Judith K, Davy MK. Gluon jets evolution in the quest for new physics. *Phys Astron Int J.* 2023;7(2):109-111.
8. George LA, Davy MK. The coleman-weinberg potential and its application to the hierarchy problem. *Phys Astron Int J.* 2023;7(2):104-107.
9. LHCb Collaboration. Measurement of CP-averaged observables in the $B^0 \to K^{*0}\mu^+\mu^-$ decay. *Phys Rev Lett.* 2019;122:191801.
10. Davy MK. Two-particle azimuthal harmonics in pA collisions. *Nucl Phys A.* 2019;983:293-309.
11. Capdevila B, Crivellin A, Descotes-Genon S, et al. Patterns of new physics in $b \to s\ell^+\ell^-$ transitions in the light of recent data. *J High Energy Phys.* 2018;2018(1):93.
12. Hui L. Wave dark matter. *Phys Rep.* 2017;1-101.
13. Hui L. Wave dark matter. *Phys Rep.* 2017;1-101.
14. LHCb and CMS Collaborations. Observation of the rare B^0_s $\to \mu^+\mu^-$ decay from combined CMS and LHCb data. *Nature.* 2020;522:68-72.
15. Zhang C. Multiparticle azimuthal angular correlations in p–A collisions. *Phys Rev D.* 2019;99(3):034009.
16. Davy MK, Nawa N. On the Future of Nuclear Energy and Climate Change: A Summary. *Int J Sci Eng Inv.* 2019;5(9).
17. Michael M, Manyika KD. Prospects of the Higgs boson: an overview. *Phys Astron Int J.* 2024;8(2):127-131.
18. Davy MK, Levy MK, Agripa H. A brief overview of radiation waste management and nuclear safety. *Phys Astron Int J.* 2023;7(2):150–151.
19. Bobeth C, Hiller G, van Dyk D. General analysis of $B \to K^* \ell^+ \ell^-$ decays at low recoil. *Phys Rev D.* 2014;89(3):034016.
20. Billard J. Direct detection of dark matter—APPEC committee report. Rep *Prog Phys.* 2014;77(6):066201.
21. Davy MK. Nuclear energy and sustainable development. *Phys Astron Int J.* 2022;6(4):142-143.
22. Davy MK, Hamweendo A, Banda PJ. On radiation protection and climate change–a summary. *Phys Astron Int J.* 2022;6(3):126-129.
23. Kabuswa Davy M. The Future of Theoretical Particle Physics: A Summary. *J Phys Astron.* 2017;5(1):109.
24. Schumann M. Direct detection of WIMP Dark Matter: Concepts and Status. *J Phys G Nucl Part Phys.* 2019;46(10):103003.
25. Davy MK. The road map to the Large Hadron Collider: A Summary.
26. Davy MK, George LA, Judith K. On the synopsis of the Higgs boson. *Phys Astron Int J.* 2023;7(2):113–116.
27. Davy MK, George LA, Judith K. On the synopsis of the Higgs boson. *Phys Astron Int J.* 2023;7(2):113–116.
28. Davy MK, Hamweendo A, Banda PJ. Automatic vehicle number plate recognition system. *Phys Astron Int J.* 2023;7(1):69-72.
29. Planck Collaboration. Planck 2018 results. VI. Cosmological parameters. *Astron Astrophys.* 2020;641:A6.
30. Buras AJ, Buttazzo D, Girrbach-Noe J, et al. Can we reach the Zeptouniverse with rare K and B decays? *J High Energy Phys.* 2015;2015(11):33.
31. Buras AJ, Buttazzo D, Girrbach-Noe J, et al. Can we reach the Zeptouniverse with rare K and B decays? *J High Energy Phys.* 2015;2015(11):33.
32. George LA, Davy MK. The coleman-weinberg potential and its application to the hierarchy problem. *Phys Astron Int J.* 2023;7(2):104-107.