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Report

on the thesis by Hrachya Asatryan titled “Strong interaction corrections for weak radiative B-meson decays” presented for the degree of Candidate of Physical and Mathematical Sciences in Specialization 01.04.02-Theoretical Physics

Rare flavor-changing neutral current (FCNC) processes play a central role in the landscape of modern high-energy physics, as they provide sensitive probes of physics beyond the Standard Model (BSM). The process $B \rightarrow X_s \gamma$ is of particular importance due to the high degree of precision achieved in both theoretical predictions and experimental measurements. Given the expected increase in experimental precision, NNLO calculations are required on the theory side, involving the evaluation of three-loop Feynman diagrams with multiple mass scales. The first part of the thesis by Hrachya Asatryan is devoted to these multi-loop corrections. In this part both analytic and recent semi-analytic and numerical methods are applied and then the corresponding results are compared for the rare decay $b \rightarrow s \gamma$ at the order $O(\alpha_s^2)$. Massive vector fields are an important component of the Standard Model, which provides a comprehensive description of the properties of elementary particles. The second part of the thesis investigates the local characteristics of the vacuum state for a massive vector field in the presence of planar parallel boundaries. This topic of this part is related to the Casimir effect.

The thesis consists of three chapters, conclusion, and bibliographic references. It includes 21 figures and 3 tables. The Introductory part gives a short review of the literature related to the topic of the

thesis. After the literature review the author presents the practical importance and the summary of basic results. Then, the contents of separate chapters are briefly described.

The first chapter is devoted to a systematic comparison of various modern methods of Feynman diagram calculations. The analytic method, which was the standard approach until very recently, is described and applied on a set of diagrams contributing to the process $b \rightarrow s\gamma$. However, given the complexity of some of the diagrams contributing to this decay stemming from multiple mass scales, the analytic method does not always yield results of the required accuracy. Thus, the author has conducted an extensive comparison of various modern libraries and packages that can be used to evaluate Feynman diagrams with very high precision. A method is then developed that can be used to evaluate the complete amplitude of the $b \rightarrow s\gamma$ decay at the order $O(\alpha_s^2)$ using the modern packages AMFlow and DiffExp.

In the second chapter of the thesis the author applies the developed method for the complete evaluation of the three-loop $O(\alpha_s^2)$ contributions to the $b \rightarrow s\gamma$ decay amplitude generated by the current–current operators O_1 and O_2 , for physical values of the charm-quark mass m_c . This framework yielded high-precision results for all diagram classes that contribute to the decay. An expansion is constructed that converges across the entire physical range of the ratio $z = m_c^2 / m_b^2$, with m_b being the mass of b-quark. These results are then cross-validated by comparing with independent computational packages, as well as comparing the results near the asymptotic limit $z \rightarrow 0$ with the results reported by an independent group, achieving excellent agreement in all cases.

The third chapter of the thesis is in a relatively different thematic direction. It investigates the vacuum expectation values of bilinear combinations of a massive vector field in the geometry of two parallel plates in background of Minkowski spacetime. Considering applications in theories with additional spatial dimensions, the problem is discussed in the general case of spatial dimension. Two types of boundary conditions are discussed generalizing the perfect electric and perfect magnetic conductor boundary conditions in Maxwell's electrodynamics (PEC and PMC conditions respectively). For comparison, the corresponding vacuum expectation values for a massless vector field are also investigated. The boundary-induced contributions in the vacuum correlators for the vector potential and field tensor are explicitly separated. This is an important step because the renormalization of the expectation values in the coincidence limit of the spacetime points is reduced to the renormalization in

the problem where the boundaries are absent. As local characteristics of the vacuum state the expectation values of the electric and magnetic fields squares, of the Lagrangian density and energy-momentum tensor are studied. The normal stress is uniformly distributed in the region between the plates and vanishes in the remaining regions. It is shown that the Casimir forces acting on the plates are attractive for both types of boundary conditions. The numerical results are presented for 3-dimensional space. The corresponding energy density is positive for PMC condition and negative for PEC condition. In the case of PEC condition and in the zero mass limit, the expressions for the vacuum expectation values are reduced to the corresponding results for a massless vector field. For PMC condition, the zero mass limit of the vacuum energy-momentum tensor differs from the corresponding expectation value for the massless vector field. This difference comes from the contribution of the longitudinal polarization mode in the massive theory which is absent in the massless case.

The key result of the thesis is an expression for the amplitude of the decay $b \rightarrow s\gamma$ for an arbitrary mass of the c-quark across the entire physically relevant range. The developed method is also expected to be a part in the $O(\alpha_s)$ evaluation of the decay $b \rightarrow s\gamma\gamma$ which is another actively studied decay in high-energy physics. The author's publication list contains 5 papers covering the results of the thesis. The articles have been published in respected peer-reviewed journals, which attest to the quality of the work done in the thesis. The thesis is clearly written and well presented. The results of the thesis will play an important role in the continued comparison between theoretical and experimental results in B-physics.

While the overall quality of the thesis is high, I would like to make several minor remarks.

1. Although the third chapter addresses an interesting and relevant problem in quantum field theory in bounded systems, its connection to the flavor-physics part of the thesis could have been discussed in greater detail in the Introduction in order to better emphasize the unifying methodological aspects of the work.
2. In some sections of the technical discussion, additional intermediate explanations could improve accessibility for readers not already familiar with multi-loop computational techniques. The phenomenological implications of the obtained NNLO results could be elaborated further, in particular regarding their quantitative impact on the updated Standard Model prediction for the $B \rightarrow X_s\gamma$ branching ratio. These remarks, however, do not diminish the scientific value of the results obtained.
3. In the third chapter, local physical characteristics of the vacuum state are investigated. An important global physical quantity in the study of the Casimir effect is the total energy of the vacuum. It would

be desirable to investigate this quantity as well and compare it in the two cases of the boundary conditions discussed.

These comments, however, do not diminish the scientific value of the results obtained. The methods and techniques applied are appropriate to the subject matter. The thesis satisfies the requirements of the Higher Education and Science Committee of the Republic of Armenia for theses seeking the degree of Candidate of Physical and Mathematical Sciences. The results obtained in the thesis are fully presented in the publications. The abstract completely reflects the content of the thesis.

Based on the above, I conclude that Hrachya Asatryan deserves to be awarded the degree of Candidate of Physical and Mathematical Sciences in the specialization 01.04.02 - "Theoretical Physics".

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A handwritten signature in black ink, appearing to read "Odintsov", written in a cursive style.