Impact of the NLO Hadronic Effects on the Lepton-Nucleon Scattering

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The presented short paper outlines the importance of the careful theoretical examination of the Next-to-Leading Order (NLO) corrections for many processes. The special attention is paid to the case of the electron-nucleon scattering. The partially computerized procedure developed by our group, which has allowed accounting for the NLO hadronic degrees of freedom, is briefly described. Some ideas for future projects which could benefit from the use of our procedure, like electromagnetic form factors of nucleons, virtual Compton scattering, and hadron leptoproduction, are included.

Motivation and Introduction

Multi-loop effects in electroweak interactions play a crucial role in tests of the Standard Model, and require careful theoretical evaluation. The new generation of experiments needs the backgrounds and radiative effects calculated to a much higher precision than previously. According to [1], the radiative corrections can be as large as 30% of uncorrected cross section depending on the experiment conditions. Done by hand, the calculations usually lead to unavoidable approximations. We extended computational packages such as FeynArts [2] and FormCalc [3] for the evaluation of one-loop electroweak radiative corrections for lepton–nucleon scattering and obtained numerical results in good agreement with the current experimental data [4]. In lepton-nucleon interactions, it is important to include hadronic sector as well. So far, the best candidate for the phenomenological description of low-energy QCD processes has been Chiral Perturbation Theory (ChPBTh). In ChPBTh, determining the range of valid and contributing degrees of freedom to a given problem is often a challenge. However, the recent developments in the automatization of the NLO calculations in perturbative field theory give us the possibility to address this issue.

Lepton-Nucleon Scattering

Electroweak properties of the nucleon can be studied by parity-violating electron-nucleon scattering at low to medium energies. Resent and planned experiments like G0 [5, 6] or Q_{Weak} [7] can measure the asymmetry factor coming from the difference between cross sections of left-and right-handed electrons very precisely. The asymmetry is calculated as:

$$A = \frac{d\sigma_R^{tot} - d\sigma_L^{tot}}{d\sigma_R^{tot} + d\sigma_L^{tot}} \cong A_{LO} + \frac{Re\left(M_{LO}^{\gamma} M_{NLO}^{Z}\right)_R - Re\left(M_{LO}^{\gamma} M_{NLO}^{Z}\right)_L}{|M_{LO}^{\gamma}|^2_{R(L)}},$$

where A_{LO} is a leading order asymmetry and the last term is a parity-violating NLO contribution. However, before physics of interest can be extracted, at least the NLO contribution to electroweak scattering needs to be carefully evaluated. The NLO corrections have been addressed by many researchers like [8, 9, 10] and [11], but more work still needs to be done. For example, the results of a study of two-boson (γ and Z) exchange corrections in parity-violating electron-proton elastic scattering including the intermediate states described by nucleons and delta resonance done in [12] differ significantly from those in [13]. Q_{Weak} [7], soon to be started at JLab, is a 2200 hour measurement of the PV asymmetry in elastic e-p scattering at $Q^2 = 0.026\, GeV^2$ which aims to carry out the first precision measurement of the proton's weak charge. With about 4% combined statistical and systematic errors, Q_{Weak} will either establish conformity with the Standard Model or point to New Physics. It is crucial that all the relevant corrections for such important experiment as Q_{Weak} are carefully accounted for, and preferably by several theory groups to allow comparing results.

The partially computerized procedure developed by our group allowed calculating large number of Feynman diagrams at different momentum transfers as well as performing an extensive analysis of the dependence on poorly constrained parameters to evaluate realistic uncertainties. We have included all the possible contributions arising from the Standard Model degrees of freedom and made some progress towards accounting for the hadronic degrees of freedom. For the lepton-hadron scattering, we can do the exact calculation of the model-independent corrections to the lepton current, and do model-dependent evaluation of hadronic current corrections, box graphs, self energies contribution and electromagnetic radiation of the charged particles (Soft and Hard Photon Bremsstrahlung). Our calculations are done in the on-shell renormalization scheme using Feynman gauge.

In [14], we computed the radiative corrections to the parity-violating asymmetries with accounting for the NLO effects using form factors for the hadronic currents. Dirac and Pauli form factors were taken in the dipole/monopole approximation and with no strange quark contribution. The final asymmetries were treated with both Soft and Hard-Photon Bremsstrahlung (SPB+HPB) contributions according to [15]. The computed results for the asymmetry agreed with theoretical predictions of G0 group [5]. With the NLO contributions to the parity-violating asymmetries found to be close to 20%, [14] yet again demonstrates the importance of the NLO effects for the lepton-nucleon scattering. An extension of FeynArts, called the CHM (the Computational Hadronic Model) was developed in [16] to include the hadronic sector using ChPBTh. The model included the octet of mesons, baryons, and the decuplet of resonances. One of the most interesting applications of the model shown in [16] were the studies of the dynamical dipole polarizabilities of the nucleon which produced both low energy and near-one-pion threshold behaviour in good agreement with [17].

Further Applications

Our computational approach can be used for a wide range of applications like electromagnetic form factors for nucleons, virtual Compton scattering, and hadron leptoproduction, just to name a few. For example, in case of the electromagnetic form factors of nucleons calculated with ChPBTh, it is not completely clear what is responsible for deviations between theory and experiment at higher momentum transfers. The results obtained in [18] within ChPBTh describe the experimentally measured form factors quite well, but only with a momentum transfer up to $0.1\,GeV^2$. The authors [18] have suggested that higher-order effects may be very important and have to be studied in the framework of Next-to-NLO calculation or by including additional dynamical degrees of freedom. With our computational model, one should be able to run full calculations with the octet of pseudoscalar mesons, baryons and vector mesons and the decuplet of resonances included. The calculations up to two loops are possible, too. Another important application of our approach can be found in the analysis of the virtual Compton scattering, which can offer insights on the dynamical nucleon's structure over a wide kinematic range. The spin-independent part of Compton amplitude was evaluated in [19], for example, but the spin-dependent part needs more attention. The studies of semi-inclusive processes of hadron leptoproduction, an important tool for the testing QCD predictions of nucleon structure, could benefit from our model being used to better account for the radiative corrections to the hadronic tensor (i. e. hadron vertex corrections and the box diagrams). There are many packages developed for high-energy physics (see [20]), but the low-energy sector is not served nearly as well. We hope that our computational model can eventually serve a much larger community. At the moment, source files are available by request from the authors. In the future, we plan to make the files available though a website, complete with a manual, an automatic installer, the template codes for the selected processes, and the MC generators.

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