Research Outline

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This research outline contains a brief description of the research work I have been doing as a doctoral student at New York University in the last five years.

Most of this work has been developed under the guidance of Prof. A. Sirlin and was focused on the analysis of the predictions of the Standard Model and their comparison with the experimental data, in order to constrain the missing parameter (the mass of the Higgs boson) and check the quality of the predictions of the theory.

In 1999, in collaboration with Prof. A. Sirlin and A. Ferroglia, I applied the FAC, PMS, and BLM optimization methods to the QED corrections to the muon lifetime in the Fermi V-A theory. The optimized expressions were employed to estimate the third-order coefficient in the $\alpha(m_\mu)$ expansion and the theoretical error of the perturbative series. We used the results to clarify how the QED corrections to muon decay and the Fermi constant $G_F$ should be used in the Standard Model (about which there were incorrect assertions in the literature) and what is the natural choice of scales if running couplings are employed [2].

During the following year, I studied a variety of topics: these included techniques for two-loop calculations, applications of the background field method, algebraic renormalization, and calculations involving a non-anticommuting $\gamma_5$.

In 2001, together with Prof. A. Sirlin and A. Ferroglia, I studied in detail the advantages and disadvantages of the most widely used renormalization schemes for the electroweak sector of the Standard Model, namely the on-shell and the $\overline{MS}$ schemes. We presented a novel approach to renormalize the electroweak sector, the Effective Scheme of Renormalization, in which $\sin^2 \theta_{\text{eff}}^{\text{lept}}$, measured at the $Z^0$ peak, is identified with the basic renormalized electroweak mixing parameter. This approach shares the desirable convergence properties of the $\overline{MS}$ scheme and provides a framework for calculations that are strictly independent of the electroweak scale in finite orders of perturbation theory. We illustrated the method with precise calculations of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$ and $M_W$, as functions of $M_H$. These results incorporate reducible and irreducible two-loop contributions of order $g^4 m_t^2 / M_W^2$, and use $\alpha, G_F$ and $M_Z$ as inputs. We then compared our results with the ones obtained in the $\overline{MS}$
and on-shell schemes in order to analyze the scheme and scale dependence of the electroweak corrections [3]. In [4], we reconsidered the numerical results for $\sin^2 \theta_{\text{eff}}$ and $M_W$ obtained in our renormalization scheme in the light of new experimental data, with a particular emphasis on the implications of these calculations for the Higgs boson search and the theoretical prediction of $M_W$.

In 2002, we extended the application of the Effective Scheme to the calculation of the partial widths $\Gamma_i$ of the Z boson. We also presented simple expressions for $\sin^2 \theta_{\text{eff}}$, $M_W$, and $\Gamma_i$ in the on-shell, $\overline{MS}$, and Effective renormalization schemes, that reproduce the detailed results from numerical calculations with great accuracy. Their domain of validity extends to the range of the Higgs boson mass values probed by current experiments, and to the range of $\Delta a_h^{(5)}$ results from recent calculations. Our results, together with some applications of these formulas (comparative analysis of the above mentioned schemes, predictions for the mass of the Higgs boson, discussion of the discrepancy of the $\sin^2 \theta_{\text{eff}}$ values derived from the leptonic and hadronic sectors) are illustrated in [5].

In the last few months, I've been working at two different projects. In collaboration with Prof. A. Sirlin, I implemented the covariant regularization of the contributions of fundamental particles to the vacuum energy density in different regularization frameworks. We explored the role played in this context by the scale invariance of free field theories in the massless limit and discussed rules of correspondence between dimensional regularization and cutoff calculations [6].

A second project was carried out in collaboration with Prof. A. Sirlin and A. Ferroglia. We derived gauge independent form factors for Möller scattering at $s \ll m_W^2$. We also discussed a gauge and process-independent running parameter $\sin^2 \theta_W(q^2)$, based on the pinch-technique self-energy $a_{\gamma Z}(q^2)$ that has good properties both at low $s$ values and at $q^2 = m_Z^2$ [7].

Since September 2001, I have been also collaborating with Prof. A. Sokal on a high-precision Monte Carlo study of the three-dimensional Ising model, using a Swendsen-Wang algorithm.

The aims of the project are to determine the critical exponents and scaling functions of the three-dimensional Ising universality class, and also to test the efficiency of the Swendsen-Wang algorithm, calculating its dynamic critical exponents [8, 9].

In the first run of our project, at particular large lattice sizes, we found large systematic errors that we discovered to be related with long-range correlations in the random-number generator. We decided that, in preparation for future studies on larger lattices, it was worthwhile to study the details of these correlations and their effect on a collective cluster model such as the Swendsen-Wang algorithm [10].

Very recently I started a new collaboration with Prof. A. Sokal and M. Polin. The aim of the project is to determine the critical exponents and scaling functions of the two-dimensional Potts model for non-integer values of $q$, using the new Chayes-Machta algorithm. The results will be compared with the predictions from conformal field theory.
Summary of my Research Activity


