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Guido Altarelli

Collider Physics within the Standard Model

A Primer

Edited by James Wells

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Foreword

Guido Altarelli was a leading figure in establishing the Standard Model as the emerging description of the elementary particle world. Not only was he a mastermind behind the success of the theory, but I would say that he really incarnated its very essence. The same perfect synthesis of elegance, purity, and genius that defines the Standard Model also characterised Guido's scientific life. One of his most striking qualities was always his ability to identify the essence of a physics problem, to ask the right question, and to express the answer in a clear and penetrating way. So it is no surprise that Guido was in high demand as a speaker for summary talks at major conferences and as a lecturer in physics schools. Few others could match his ability in giving lucid overviews of a field, focusing on the critical issues and explaining in simple terms the most complicated concepts. His vision of the progress of particle physics has been an illuminating guide for generations of physicists, both theorists and experimentalists.

Guido Altarelli was born in Rome in 1941. After graduating from the university La Sapienza in Rome in 1963, he followed his advisor, Raoul Gatto, to Florence. There, he became part of the "Gattini", as the Florentine group of Gatto's students was affectionately known, after a nickname coined by Sidney Coleman during a Physics School at Erice. Besides Guido, the "Gattini" included some of today's most renowned Italian theoreticians such as Luciano Maiani, Giuliano Preparata, Franco Buccella, Gabriele Veneziano, and Roberto Casalbuoni, all of them of the same age within a year's difference. Towards the end of the 1960s, the Florentine group dispersed, as the various members left for different destinations. Guido went to the United States, staying at New York University (1968–1969) and Rockefeller University (1969–1970), where he worked on various aspects of strong interactions.

In 1970, he was appointed professor at La Sapienza in Rome. Those were the years in which the Standard Model was taking shape, after the proof of renormalisability by Veltman and 't Hooft and the discovery of asymptotic freedom by Gross, Wilczek, and Politzer. Then Guido turned his interests to the interplay between the strong and weak interactions. In particular, he made seminal contributions to the QCD corrections of non-leptonic weak interactions, proposing them as an explanation for the observed $\Delta I = 1/2$ rule. Together with Nicola

Cabibbo, Luciano Maiani, Giorgio Parisi, Guido Martinelli, Keith Ellis, and Roberto Petronzio, Guido succeeded in bringing back to Rome the splendour of the time of Enrico Fermi and the Via Panisperna boys. However, Guido's most celebrated work was not done in Rome. In 1977, he was in Paris, on leave at the École Normale Supérieure, while Giorgio Parisi was at the Institut des Hautes Études Scientifiques. Together, they wrote the famous paper "Asymptotic Freedom in Parton Language", which contains the QCD equation describing how parton densities vary with the energy scale, known today as DGLAP or, more simply, the Altarelli–Parisi equation.

In 1987, Guido moved to the CERN Theory Division, still keeping academic links with Rome, first teaching at La Sapienza and then at the University of Roma Tre. His scientific output at CERN was remarkable. In 1988, after a surprising result from the EMC measurement of the first moment of the polarised proton structure function, he emphasised, together with Graham Ross, the role of the gluon anomaly as a resolution of the apparent violation of quark model expectations. In the early 1990s, in a series of papers with Riccardo Barbieri, Francesco Caravaglios, and Stanislaw Jadach, he developed a model-independent parameterisation of new physics effects in electroweak observables. These studies were extremely influential in the interpretation of LEP data and are still used today for the construction of realistic theories beyond the Standard Model. During the last period of his scientific career, while continuing his research in QCD and the electroweak theory, Guido pursued with great interest the physics of neutrinos, as a tool to infer information about new structures coming from grand unified theories.

Besides his scientific contributions, Guido had a significant impact on CERN's experimental programme by bridging the activities between the theoretical and experimental communities. A famous example goes back to the time in which UA1 presented some unexpected mono-jet events, believed to be the first signal of supersymmetry. In the midst of the general excitement, he realised that, although any individual Standard Model process could not justify the data, when combined together in the so-called Altarelli cocktail, they could give a more mundane explanation of the observed excess. His sober scepticism prompted the experimentalists to reconsider the Standard Model interpretation, and, eventually, his explanation turned out to be the right one. Guido's leading role in advising and guiding the experimental community became even more prominent during the construction and operation of LEP and, later, of the LHC.

These lecture notes are a beautiful example of Guido's unique pedagogical abilities and scientific vision. They give a clear and accurate account of our present knowledge of the particle world, synthesised in the Standard Model. The reader is led from the basic framework of gauge theories to the structure of QCD to weak interactions and the Higgs sector, along a path which is a necessary prerequisite for any researcher interested in particle physics and which actually corresponds to the itinerary followed by Guido during his scientific life. Although today there are several textbooks on the Standard Model, it is difficult to match these lecture notes in terms of conciseness, clarity, and depth. These notes provide a unique resource for researchers—theorists and experimentalists alike—who want to approach the field, especially from the collider point of view, giving a global but complete picture

of the Standard Model and bringing the reader up to the very frontier of present knowledge.

The most touching aspect of these lecture notes is that reading them is just like listening to Guido. His style was direct and essential, and his logical thinking was always clear, profound, and focused on concepts rather than technicalities. From these lecture notes, the reader will not only learn about the Standard Model but also a way to approach physics. They are a faithful portrait of Guido, not only because they cover the field of his vast scientific activity but also because they convey his pragmatic and concrete vision of the world of physics. Guido's intellectual brilliance and physics intuition are perfectly reflected. They will be used regularly by generations of physicists and will remain as a tribute to an original and creative mind who did so much to shape the field of particle physics.

Geneva, Switzerland
June 2016

Gian Francesco Giudice

Preface

When editing this material, most of which dates from 2013, we felt that it was not the aim of this predominantly theoretical text to update the experimental data to the very latest results. After all, what endures at the core of this material are the principles of the Standard Model of particle physics, which Prof. Altarelli so skillfully elucidates. Up-to-date results and values can easily be looked up in the open-access literature which is now inherently part of high-energy physics.

Yet, the devil being typically in the details, we were confronted with plots included by Prof. Altarelli of quite various degrees of “publishability”. Sometimes they were taken from internal notes or unpublished proceedings. In those cases, and depending most of the time on the preferences of the authors, they could be published as such, had to be removed altogether, or had to be replaced by more up-to-date figures, such as was the case with a few figures labelled “preliminary” by the large collaborations.

In short, we would like to draw to the reader’s attention the fact that the references to experimental data mostly form a snapshot in time as selected by Prof. Altarelli in 2013. Above all, we opted for a minimalistic upgrade in referencing so as to make this exceptional material formally publishable with all permissions required in the first place.

Last but not least, we gratefully acknowledge the support by Monica Pepe-Altarelli for releasing this material and CERN for sponsoring the publication as an open-access book. We further thank Stephen Lyle for the technical editing of the manuscript.

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Geneva, Switzerland

Guido Altarelli

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