Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B 834 (2010) 77–115

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Higgs pseudo-observables, second Riemann sheet and all that ☆

Giampiero Passarino [a,b], Christian Sturm [c], Sandro Uccirati [d,*]

[a] *Dipartimento di Fisica Teorica, Università di Torino, Italy*
[b] *INFN, Sezione di Torino, Italy*
[c] *Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA*
[d] *Institut für Theoretische Teilchenphysik, Universität Karlsruhe, 76128 Karlsruhe, Germany*

Received 26 January 2010; accepted 15 March 2010

Available online 19 March 2010

Abstract

The relation between physical observables measured at LHC and Tevatron and standard model Higgs pseudo-observables (production cross section and partial decay widths) is revised by extensively using the notion of the Higgs complex pole on the second Riemann sheet of the S-matrix. The extension of their definition to higher orders is considered, confronting the problems that arise when QED (QCD) corrections are included in computing realistic observables. Numerical results are presented for pseudo-observables related to the standard model Higgs boson decay and production. The relevance of the result for exclusion plots of the standard model Higgs boson for high masses (up to 600 GeV) is discussed. Furthermore, a recipe for the analytical continuation of Feynman loop integrals from real to complex internal masses and complex Mandelstam invariants is thoroughly discussed.

Keywords: Feynman diagrams; Loop calculations; Radiative corrections; Higgs physics

☆ This work is supported by the European Community's Marie Curie Research Training Network *Tools and Precision Calculations for Physics Discoveries at Colliders* under contract No. MRTN-CT-2006-035505, by the U.S. Department of Energy under contract No. DE-AC02-98CH10886 and by the Deutsche Forschungsgemeinschaft through Sonderforschungsbereich/Transregio 9 *Computergestützte Theoretische Teilchenphysik*.

* Corresponding author.
E-mail addresses: giampiero@to.infn.it (G. Passarino), sturm@bnl.gov (C. Sturm), uccirati@particle.uni-karlsruhe.de (S. Uccirati).

0550-3213/$ – see front matter © 2010 Published by Elsevier B.V.
doi:10.1016/j.nuclphysb.2010.03.013

1. Introduction

The search for a mechanism explaining electroweak symmetry breaking has been a major goal for many years, in particular the search for a standard model (SM) Higgs boson, see for instance Refs. [1] and [2]. As a result of this an intense effort in the theoretical community has been made to produce the most accurate NLO and NNLO predictions, see Refs. [3–6]. There is, however, a point that has been ignored in all these calculations: the Higgs boson is an unstable particle and should be removed from the in/out bases in the Hilbert space, without destroying the unitarity of the theory. Therefore, concepts as the *production* of an unstable particle or its *partial decay widths* do not have a precise meaning and should be replaced by a conventionalized definition which respects first principles of quantum field theory (QFT).

The quest for a proper treatment of a QFT of unstable particles dates back to the sixties and to the work of Veltman [8] (for earlier attempts see Ref. [9]); more recently the question has been readdressed by Sirlin and collaborators [10]. Alternative approaches, within the framework of an effective theory can be found in Ref. [11].

In this paper we discuss the relation between physical observables and Higgs pseudo-observables by considering the extension of their definition to higher orders in perturbation theory, confronting the problems that arise when perturbative corrections in quantum electrodynamics (QED) and quantum chromodynamics (QCD) are included. Numerical results are also presented. Our work can be seen as an extension of complex-mass schemes to include complex external momenta (for previous work see also Ref. [12]), addressing systematically the question of the analytical continuation of Feynman loop integrals.

This paper is organized as follows. In Section 2 we summarize the conceptual setup. In Section 3 we present general arguments on complex poles. In Sections 4 and 5 we discuss pseudo-observables, on-shell observables and unitarity. The analytical continuation of Feynman loop integrals into the second Riemann sheet of the S-matrix is examined in Section 6. In Section 7 we present the inclusion of QED and QCD corrections and renormalization schemes are highlighted in Section 8. Numerical results are given in Section 9 and in Section 10 we close with our conclusions.

2. Formulation of the problem

There are two old questions in relating measurements to theoretical predictions:

– Experimenters (should) extract so-called *realistic observables* from raw data, e.g. $\sigma(pp \to \gamma\gamma + X)$ and need to present results in a form that can be useful for comparing them with theoretical predictions, i.e. the results should be transformed into pseudo-observables; during the deconvolution procedure one should also account for the interference background – signal;
– Theorists (should) compute pseudo-observables using the best available technology and satisfying a list of demands from the self-consistency of the underlying theory [13].

Almost from the start it is clear that a common language must be established in order to avoid misunderstandings and confusion. A typical example can be found in Higgs physics where, frequently, one talks about *Higgs production cross section* or *Higgs partial decay widths*. After the discovery phase, in absence of which the future of high energy physics cannot be ascertained, one will need to probe the properties of the discovered resonance, like spin and couplings. In this