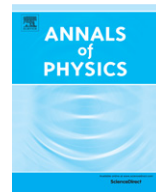




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The (IR-)relevance of the Gribov ambiguity in $SU(2) \times U(1)$ gauge theories with fundamental Higgs matter

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HIGHLIGHTS

- Gribov horizon influences gauge propagators in a strong-coupling regime.
- No influence of Gribov horizon in weak-coupling.
- Inclusion of $U(1)$ factor leads to very rich behavior of propagators.

ARTICLE INFO

Article history:

Received 27 November 2013

Accepted 23 January 2014

Available online 31 January 2014

Keywords:

Gribov

Standard model

Propagator

ABSTRACT

It is well accepted that dealing with the Gribov ambiguity has a major impact on correlation functions in gauge-fixed Yang–Mills theories, in particular in the low momentum regime where standard perturbation theory based on the Faddeev–Popov approach fails. Recent results, derived from functional tools (Dyson–Schwinger equations or exact RG) or the effective Gribov–Zwanziger action method, pointed towards e.g. gauge boson correlation functions that are not compatible with the properties of observable degrees of freedom. Although such an observation is a welcome feature for gauge theories exhibiting confinement, it would be a discomfort for gauge theories supplemented with Higgs fields, cf. the experimental success of the electroweak model based on a $SU(2) \times U(1)$ gauge group. The purpose of this short note is to assure that the effective action resolution to the Gribov ambiguity reduces to the standard

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<http://dx.doi.org/10.1016/j.aop.2014.01.014>

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Faddeev–Popov method in the *perturbative* regime of sufficiently small coupling/large Higgs condensate, thereby not compromising the physical particle spectrum of massive gauge bosons and a massless photon for the $SU(2) \times U(1)$ gauge–Higgs model. The closer the theory gets to the limit of vanishing Higgs condensate, the more the Gribov problem resurfaces with all its consequences. We give some speculations w.r.t. the Fradkin–Shenker insights about the phase diagram.

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1. Motivation

The continuum path integral or canonical Hamiltonian quantization of gauge theories require the choice of a gauge fixing condition. This is perfectly well understood in the Abelian case, but in the non-Abelian case the nontrivial topology of the gauge group can spoil the simple picking up of a unique gauge field per set of gauge equivalent fields that fulfills the gauge condition. This problem was first investigated by Gribov in [1] for the Landau and Coulomb gauges, and later on many nontrivial results were more rigorously probed in the work of Zwanziger, Dell’Antonio and others [2]. Also in curved spaces, some results were booked in more recent times [3].

In a series of papers, we and others investigated the dynamical stability and further quantum alterations to the seminal results of Gribov and Zwanziger [4]. The ensuing propagators of the gauge bosons (gluons) and Faddeev–Popov ghosts are in good agreement with their lattice counterparts [5]. The Gribov–Zwanziger approach is thus one example of effective functional approaches to non-Abelian gauge fixed theories, thereby supplementing other potential approaches as in [6]. The propagators proposed by us recently also found use in studies of Casimir effect [7] or the finite temperature phase diagram [8,9].

A key observation of the nonperturbative Landau gauge gluon propagator is the violation of positivity, that is the gluon is not a particle that has a physical interpretation with associated Källén–Lehmann spectral integral representation with positive density. This violation of positivity is well-appreciated from simulational and analytical approaches [10], and it can be seen as a signal of confinement: gluons cannot be observed. In the Gribov–Zwanziger approach, this violation of positivity annex unphysicalness of the gluon is imminent because of the presence of complex conjugate poles in the propagator [11].

This led us to the interesting question what the consequences would be of the gauge fixing ambiguity and its Gribov–Zwanziger resolution when the gauge theory is coupled to a Higgs sector, most notably in the case of a $SU(2) \times U(1)$ theory with fundamental Higgs matter, of physical relevance to the electroweak sector of the Standard model. At the energies at which the electroweak theory is probed, a valid perturbation theory with a set of 3 observable massive gauge bosons and a massless photon should be the outcome. Complex conjugate masses or a positivity violation in the gauge boson sector should thus preferably not manifest themselves. Of course, the Gribov problem is still there, irrespective whether Higgs field are present or whether the Higgs mechanism takes place. The issue of having multiple solutions to the gauge fixing condition is a classical observation, only influenced by having a non-Abelian gauge field structure. We would thus rather like to find out under which circumstances treating the Gribov copy problem becomes trivial at the quantum level, thereby not affecting the standard perturbative expansion and accompanying results on the spectrum etc.

The difference or not between a confining and Higgs-like spectrum of gauge–Higgs system is a very deep question, most notable brought to attention in the seminal theoretical lattice work of Fradkin and Shenker [12]. They presented evidence, using either an area or perimeter law for the Wilson loop expectation value to label the confining and Higgs phase, that both regions are analytically connected in a (gauge coupling, Higgs vev) diagram. From lattice works as [13], one also learns that the 2 regions are separated by a line corresponding to a 1st order phase transition, whereby it is crucial

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