Summary Talk: Field Theory

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We present a summary of the contributions on Field Theory at the XXII Brazilian National Meeting on Particles and Fields.

In the meeting of this year, there were a total of 165 contributions in the form of panel and oral sections, besides two plenary and three parallel talks. As occurred in the previous meetings, these talks refer to recent and/or significative subjects in the Field Theory. At this year, one talk was on the Anti-de Sitter (AdS)–Conformal Field Theory (CFT) correspondence, two on nonconcommutative theories, one on application of field theory in condensed matter and one on derivative expansions and finite temperature. I find also important to mention that there were 14 contributions from the Cosmology and Gravitation sector which also concerns to field theory. The quantum and semiclassical aspects of gravitation as well as quantum fields in classical and curved background are subjects whose interest has been increasing year after year.

It might be tedious and uninteresting to make an analysis of each contribution (or group of them) isolated from the general view of where this work is in the context of the Field Theory as a whole. The main reason is that one of the purposes of this talk is to let people of other areas know what has been done in Field Theory.

In my opinion, another important point would be to situate the works within the development of the corresponding research groups in Brazil in order to have an idea of what has been done in each group during the last years. Concerning this last part, we refer to the careful analysis of Prof. Marcelo Gomes in the summary talk of the last meeting. I am going to concentrate on the first part.

We may say that the success of the Field Theory starts from the quantization of the electromagnetic and fermion fields, describing the electromagnetic interaction (QED), where there is a fantastic agreement with experiments. QED is a gauge theory whose symmetry group is the $U(1)$. In the year 1954, Yang and Mills proposed an extension for this gauge theory in order to include non-Abelian fields. This was achieved by considering more general groups $SU(N)$, where the number of gauge fields is N^2-1. Even though considered a very nice theoretical idea, the first successful application of the Yang-Mills fields just occurred almost fifteen years later (1968), in the consistent description of the weak interaction in a unified theory also involving QED. The corresponding symmetry group is the $SU(2)_L \otimes U(1)_Y$ (where "L" means "left doublets" and "Y" refers to the hypercharge) and its development was due to Glashow, Salam and Weinberg. It is opportune to mention that the experimental observation of weak gauge fields took fifteen years more, after the construction of powerful accelerators.

Later on, the strong interaction was also formulated as a Yang-Mills theory, whose symmetry group is the $SU(3)$ and the basic ingredients are not protons and neutrons, as in the old Nuclear Physics, but quarks and gluons. Nowadays, the gauge theory whose symmetry group is $SU(3) \otimes SU(2)_L \otimes U(1)_Y$, also known as *standard model*, correctly explains all the events we know involving weak, electromagnetic and strong interactions. The standard model and problems related with confinement, vacuum QCD etc. are always an interesting area of research in quantum field theory [1, 2, 3, 4][1]. We also mention that problems related to the *Casimir Effect* have increased of interest in recent years [5,6,7,8,9,10,11,12].

The path integral formalism in Field Theory has a very high resemblance with the partition function in Statistical Physics. The intersection of these initially distinct subjects leads to a fruitful line of research because the knowledge of each one could be used into the other. The so called *Quantum Field Theory at Finite Temperature*, or *Thermal Field Theory,* has always been an interesting research subject

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[1] These references concern the papers of the meeting. There are works which may appear in more than one place. I apologize for references put in a wrong way.

[13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24]. In the meeting of this year, it was devoted a parallel talk on this subject, involving the *Derivative expansion technique* and *Chern-Simons theories* [25].

Of course, quantum field theories were initially formulated for the spacetime dimension where we live, $D = 4$. However, a great deal of interest emerged for quantum fields at lower dimensions, $D = 3$ and $D = 2$ (even at $D = 1$). These research lines were initially considered as just a theoretical laboratory for field theories at $D = 4$. There are many interesting research areas at this part, involving *Chern-Simons theories* [26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39], *Anyons* and *Fractons* [18, 40], *Nonlinear Sigma-model* [41, 42, 43, 44], *Schwinger* and *Chiral-Schwinger* models [45, 46] etc. Nowadays, field theories at spacetime dimensions lower than $D = 4$ still have a plenty of interest by their own rights [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71] and not only as a theoretical laboratory for $D = 4$. Further, they have also connection with the real world, in a research area involving condensed matter with many interesting applications [72, 28, 73, 74, 75, 76, 77, 78, 79]. It was also devoted a parallel talk on this subject [80].

After the success of the field quantization method in the weak, electromagnetic and strong interactions, the most natural step would be to use the same quantization rules into the Einstein theory of gravity. This did not work! The main reason is that quantum field theories deal with many infinite quantities which are either simple discarded, as the vacuum energy, or are intelligent circumvented (the renormalization program). Both these procedures cannot be applied to the gravity theory. First because sources of energy cannot be simple discarded in presence of gravity and second because the renormalization program simply does not work.

A first attempt to circumvent this problem was to follow the same idea before the advent of QED, that is, just quantum matter fields were quantized and interacting with a classical electromagnetic background. The corresponding research area of quantum matter and quantum gauge fields propagating in a classical gravitational background, and the problems related with geometrization, lead to a very interesting developments and constitute a very fruitful research area [81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91].

The current idea on this subject is that there must exist some more general formulation for the gravitational theory where the quantization procedures can be applied. The first consistent attempt was based on the *supersymmetry*, that is an extension of the Lorentz symmetry where the spacetime also has fermionic degrees of freedom. The corresponding supersymmetric theory of gravity, called *supergravity*, was then formulated and it contains the Einstein gravitational theory as a particular case. Both supersymmetry and supergravity always deal with interesting research problems to be solved [92, 93, 94, 95, 96, 97, 98, 30, 90, 99, 100, 101, 102].

However, the problems related with the infinities of quantum gravity were not completely solved with supergravity. An important step was done based on the idea that fields could not depend on points (considered to be a mathematical idealization), but on extended objects. Strings are the simplest extended objects. However, a field theory where fields are functions (or functionals) of strings is very difficult to be handled. What remained is the string idea itself, where elementary particles are not points, but vibrational states of strings. More general extended objects, the branes, were also considered, but it is opportune to say that they are not exactly the same of the modern branes. These are related to boundary surfaces described by strings. Anyway, string and branes (with their supersymmetric version) are a very fruitful research area [103, 104, 105, 106, 107, 87, 108, 109, 110, 111, 112, 113, 114]. There was a plenary talk involving string theory (and noncommutative fields) [115].

The mathematical structures of strings and branes are much more involved and their quantization led to a great development in the quantization methods and in the study of anomalies [116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131]. The treatment of constrained systems (Dirac, symplectic, Senjanovic etc. [132, 133, 134, 135, 136, 112, 38, 137] were nicely improved, based in the BRST symmetry. The works of Batalin, Fradkin, Vilkovisky and Tyutin are very relevant in the quantizations methods known in literature as BFV (Hamiltonian), BV (Lagrangian), and BFT (Hamiltonian embedding) [41, 138, 139, 140]. Mathematical structures and their algebras, as well as problems related to Lax pairs, KP hierarchy, integrable models acquired much interest [141, 142, 143, 144, 145, 34, 146, 147, 148].

Another aspect of extended objects is that they are consistently quantized just in the spacetime dimension $D = 10$. This might means that there exists some compactification procedure which leads to our spacetime dimension [28, 149]. There is another interesting aspect in (super)string theories. At first, it appeared to exist five independent theories for them. But now we know that they are connected by duality, together with supergravity at $D = 11$ (we are going to explain below why an extra dimension appears). It is important to emphasize that supergravity is again a very interesting research area. The consequence of the duality among string and supergravity theory is that they must be different manifestation of a some fundamental theory, called *M-theory* in literature, that should be formulated at $D = 11$. In this line of research, problems related to duality [150, 151, 152, 153, 39, 154] and topology [155, 98, 156, 157, 158, 154, 159, 160, 161, 162] have a great deal of interest.

After a brilliant work due to J. Maldacena, published in 1998, the old idea (and dream) of a total unification and to have a unique theory able to describe everything is again in evidence. As it was said, there were problems to include gravitation in the family of quantum gauge theories. On the other hand, after the advent of strings, the problem has changed in a reversed way. String theories naturally contain gravity, but the difficulty was to include Maxwell and Yang-Mills theories into this formalism. Maldacena conjectured that there exists a duality between (super)string theories or supergravity in AdS_{D+1}-spaces and conformal gauge theories living in the boundary at D-dimensions (that is why the previous critical dimension $D = 10$ of superstrings has changed do $D = 11$). It is true that a unified theory of everything might be still far, but the duality among all the string theories and supergravity at $D = 11$ and the work of Maldacena have certainly shed new light on this old dream. This line of research, including the recent works of Lisa Randall and Raman Sundrum and the possibility of noncommutative fields, is the most recent subjects in quantum field theory [163, 164, 165, 166, 167, 168]. There was a parallel talk on AdS/CFT correspondence [169] and a plenary talk on noncommutative fields [115, 170]. It might be opportune to say that it was also planned a plenary talk on AdS/CFT with Maldacena himself, that had confirmed but declined few weeks before the meeting by virtue of personal problems.

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