Particle physics in the 60 and 70 and the legacy of contributions by J. A. Swieca

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October 2007

Abstract

After revisiting some high points of particle physics and QFT of the two decades from 1960 to 1980, I comment on the work by Jorge Andre Swieca. I explain how it fits into the quantum field theory during these two decades and draw attention to its legacy in the ongoing particle physics research.

1 A brief recollection of QFT in the 60 and 70s

The years from 1960-1980 mark one of the high points in particle physics. During these two decades QFT obtained its firm conceptual basis and its range of applicability to particle physics was considerably expanded to include all interactions apart from (the still elusive) quantum gravity. This progress draws mainly on the postwar discovery of perturbative renormalized QED (in independent work) by Feynman, Schwinger and Tomonaga, with important conceptual and mathematical additions and refinements by Dyson. The non-covariant prewar quantum mechanical perturbation formalism which was adapted to the use in QFT and can be found in pre 1948 QFT textbooks (Heitler, Wenzel) was ill-suited for going beyond tree diagrams; it was getting unmanageable for processes involving interaction-induced vacuum polarization (loop diagrams) which meanwhile, i.e. shortly after the second world war, became experimentally accessible. The observational verification of these effects were the entrance permission for QFT into the pantheon of established physical theories; in fact the new and stupendously precise and successful covariant formulation of QFT placed it into a very distinguished position within that pantheon.

The progress was foremost methodological. It was not necessary to undergo a new conceptual revolution to achieve these surprising new results. Renormalized QED confirmed the conceptual innovations of the protagonists of QFT

(Dirac, Jordan) which were achieved two decades before. Without this convincing experimental confirmation of the effects of vacuum polarization in QED, QFT probably would have disappeared for some time from the screen of particle physics and the more speculative and metaphoric attempts trying to exorcise the "ultraviolet catasrophe" may have continued into the 50s. In this way the protagonists of renormalization theory became the saviours of QFT by prevented such a scenario.

The young avant-garde of the post-war years in particle theory did not set out to become revolutionaries. Their resounding success, for which three of them received the Nobel prize, resulted from their innovative and often technically quite demanding computations which made obsolete the prior wild speculations about the ultrviolet catastrophe of their more "revolutionary" predecessors. They established the correctness of the principles on which the true revolutionaries of the 20s and 30s founded QFT. Without their achievements in QED the discovery of the standard model would have hardly been possible.

The situation changed after 1980, when the theoretical progress about the Standard Model gradually entered an era of stagnation and part of the particle physics community, spoiled by almost 4 decades of continuous success of often rather simple-minded ideas and ill prepared to make some new conceptual investment, invented a new research subject were one could be "revolutionary" without being too critical and, different from any previous situation in particle physics, without having the Damokles sword of observational hanging over their heads. Apart from this last remark it is reminiscent of the more metaphorical ideas with which some physicists (including Heisenberg) tried to cure the "ultraviolet problem" of QFT prior to renormalized perturbation theory. But the number of physicists working on speculative problems instead of searching for a more appropriate computational method which is more faithful to the underlying conceptual structure of QFT was much smaller; in addition "ultraviolet catastrophe era" did not last much longer than a decade, not enough time to cause any rupture or long lasting mark.

Three decades of string theory since 1980 have left their mark on particle physics. One can dispute its scientific impact, but its influence on the sociology of science in particular of particle physics is beyond question. At no time before has particle physics been turned into a globalized monoculture which despite suffering from a discrepancy between pretense and substanciveness enjoys that much material and intellectual support. The holy Grail of post string physics is a TOE i.e. a theory of everything unifying all forces. For those who have been convinced that this is a reasonable goal in particle physics (instead of continuing the path of unification i.e. carrying forward the heritage of physical research which started with Faraday and led us to the Standard Model) this became a self-sustaining enterprize. There is hardly any fundamental criticism from the outside and the criticism inside the group usually does not go beyond checking whether a paper stayed within the rules of the game. The several decade lasting dominance of hunting for the TOE has created a generation of specialist who lack the broad knowledge about particle physics of earlier preelectronic times which makes my task (to present the conceptual situation of the 60-80s along the path of the contributions of J. A. Swieca) in this essay somewhat difficult.

The interest of the media was always more on the entertainment side of science than about the scientific relevance. This is completely legitimate since science is a human cultural activity and the only way to impart scientific knowledge to broader public is by highlighting the more entertaining metaphorical aspects of it. The public excitement about Einstein after the observational result on the gravitational deflection of light is a good example. But the borderline between satisfying legitimate public curiosity about new developments in science and hyping up some protagonists of a multi-universe TOE (an oxymoron!) to the level of sports heros is ill-defined and probably detrimental to particle physics.

In any case the sociological and intellectual situation in particle physics during the two decades 1960-1980 was very different from how it developed afterwards. The discovery of renormalized QED led to the useful world of perturbative renormalization in QFT which was later enriched by nonabelian gauge theory, QCD and finally the Standard Model. The main distinction to the present, as I see it, is that there was more criticism, including auto-criticism; this was considered as an important counterbalance to the necessary speculative frontiers of particle physics research. Physicists had a greater awareness that a delicate equilibrium between innovative ideas and a critical spirit is the precondition for progress in particle physics. Sometimes the critical and the innovative abilities came together; A famous figure who combined these two qualities in his persona was Wolfgang Pauli. He impressive creativity was accompanied by a cutting criticism, if necessary even against himself[1]. The sociology in particle physics has changed, nowadays it is not so much the predictive power and the theoretical conclusiveness which determines the status of a theory, but more the market value and its accretion in a globalized world.

In stating such observations one should be careful of not being accused to glorify the past at the cost of the present. There was a critical situation in the two decades before the 80s which resulted from a clash between those who advocated a pure S-matrix approach and those who considered the S-matrix and the analytic properties of scattering amplitudes as an important part of QFT to be derived from locality and spectral properties of QFT. This led to a confrontation of the S-matrix bootstrap with QFT at the end of the 60s. It was a struggle about a pure S-matrix approach cleansed of all field theoretic aspects; the fervor of its proponents was certainly related to the fact that is was already based on the idea of a unique theory of everything (TOE) (the unique S-matrix bootstrap [5]). On the other side of the fence was QFT enriched by the LSZ/Haag-Ruelle scattering theory which was shown to be a structural consequence of QFT. The ideological fervor found its strongest expression in conference reports were the S-matrix bootstrap proponents felt more free to celebrated their victory over QFT.

[1]After having worked for almost two years (together with Heisenberg) on the ill-fated "nonlinear spinor theory" (a kind of precursor of quarks in which all the observed nuclear particles are composites of a fundamental spinor field), Pauli abruptly (without looking for excuses) criticized and abandoned these attempts.

The counter message from quantum field theorists was more subdued and essentially amounted to remind particle physicists that even if one's main interest are on-mass-shell observables as scattering amplitudes and formfactors, one needs the interpolating fields as the carriers of the locality principle to implement the desired S-matrix and formfactor properties. Indeed the bootstrap program lacked even the means to implement the crossing property (which partially follows from QFT) and, which is an even more serious flaw, they never got to the requirements which macro-causality imposes on any multi-particle S-matrix of particle physics. These properties were first listed by Stueckelberg and they imply in particular forgot to mention in their list of requirements those macrocausality properties of the S-matrix which probably were first listed by Stueckelberg and they basically consisted in the spacelike cluster factorization and the absence of timelike precursors. The ferocity of that struggle on the side of the S-matrix purist [2] is hard to understand in retrospect, but the future of particle theory could have taken another turn if it would not have been for the saving grace of nonabelian gauge theory which led to a surge in particle theory starting at the beginning of the 70s and which sent the first TOE (everything-gravity) in form of the S-matrix bootstrap into the dustbin of history.

There is however a somewhat ironical epilogue to this second crisis (remember the first was the "ultraviolet catastrophe crisis"). Those properties as unitarity, invariance and the crossing property which permitted a mathematically clear formulation in two dimensions were completely sound; in connection with a nuclear democracy setting of boundstates they turned out to be extraordinarily successful in a more modest setting of two dimensional factorizing models. Instead of a TOE as expected from the metaphoric bootstrap idea, one obtains a rich nonperturbative world of (infinitely) many models which have infinite vacuum polarization clouds but no on-shell particle creation, in other words instead of one theory of everything one obtained an infinite family of theories of something. In view of the fact that this is the first nonperturbative construction (including a mathematical existence proof) of strictly renormalizable non-Lagrangian models not a small accomplishment. But a valuable addition to QFT was not at all what the protagonists of the S-matrix bootstrap had in mind. Since this issue is relevant in connection with Swieca's contributions, we will return to it in the next section.

The doom of the S-matrix bootstrap was the beginning of a more serious crisis. The difficulty with implementing the crossing property (it mixes the one-particle contributions with those of the scattering continuum after analytic continuation) led Veneziano to the *duality* requirement in which the formal crossing (not the QFT crossing) was obtained with the help of infinitely many intermediate one-particle states. This dual S-matrix Ansatz led eventually to the string theory of the 80s and became a fashionable topic of present day

[2]The first attempt to bypass QFT and formulate particle physics solely in terms of the S-matrix is due to Heisenberg [4]. Heisenberg wrote down models of unitary Poincaré-invariant operators but what was missing in modern parlance was the cluster-factorization property which is notoriously difficult to implement by hand but comes for free if the S-matrix results from a QFT. The very important later addition of crossing came from renormalized QFT.

particle physics.

After this interlude on developments outside and in antagonism to QFT, it is time to look more closely at the aftermath of perturbative renormalization theory, the area which attracted Swieca's interest.

With an enhanced confidence in the physical relevance of QFT, it was now possible to revisit some old problems which, despite the new methodological progress, did not loose any of their conceptual challenge. One of those was the problem of "particles versus fields"[3]. Already in the 30's, shortly after the discovery of vacuum polarization noticed first in conserved currents of charged free fields by Heisenberg, Furry and Oppenheimer [1] perceived to their surprise that interacting Lagrangian fields applied to the vacuum inevitably generate (infinite with perturbative order $\rightarrow \infty$) vacuum-polarization "clouds" in addition to the desired one-particle component. The ubiquitous presence of polarization clouds implied a drastic conceptual change as compared to the particle-field relation in quantum mechanics where the (second quantized) basic field applied to the vacuum generated a one-particle state and appropriately smeared (with the help of bound state wave functions) products of the basic field applied led to bound states. In the post renormalization research the important step in the clarification of the field-particle dichotomy issue was the derivation of the S-matrix from the large-time asymptotic behavior of fields which led to the recognition that in spite of their central role in measurements, the ontological status of particles in QFT is considerably weakened. The Lehmann-Symanzik-Zimmermann (LSZ) asymptotic condition and the Haag-Ruelle scattering theory [2] are landmarks of that research. It became clear that in contradistiction to QM mutiparticle states only acquire a frame-independent meaning through scattering theory in asymptotic large time regions. Localized states in interacting theories always contain infinite vacuum polarization clouds and their presence is the most characteristic spacetime dimension independent property of QFT[4]. This also led to a better understanding of the relation of the vacuum polarization clouds as intrinsic *local* indicators of the presence or absence of interactions. Last not least the S-matrix aspects of QFT also led to a re-appraisal of Wigner's 1939 intrinsic representation theoretical classification of positive energy irreducible representations of the Poincaré group as an intrinsic (and unique) way of characterizing particles which is conceptually superior to the description in terms of linear hyperbolic covariant (spinorial) field equations. Whereas the latter is highly non-unique, Wigner's setting is unique. Scattering theory is based on the idea that every state under large-time asymptotic interpretation is a superposition of n-fold tensor products of Wigner representations. Without the asymptotic stability properties of n-fold particle localization it is not possible to formulate

[3]This particle-field relation is a problem in the setting of field theoretic localization and the associated vacuum polarization. It should not be confused with the particle-wave duality of QM which is related to the uncertainty relation and Born's probabilistic definition of localization.

[4]For the (later mentioned) d=1+1 factorizing model the S-matrix is purely elastic but despite the absence of on-shell particle creation the interaction-caused vacuum polarization clouds ("virtual" or off-shell particle creation) are fully present.

scattering theory of particles within the setting of QFT[5].

Another insight into the old pre-renormalization struggle with ultraviolet divergences of a more formal kind was the recognition that pointlike fields are rather singular objects which required testfunction smearing (distribution theory) and that what was previously perceived as an ultraviolet divergency was rather an ambiguity in the continuation of distributions defined on restricted testfunction (which vanish when all coordinates coalesce) to the diagonal[6]. The parameters appearing in the (minimal) extension in the case of renormalizable theories can be absorbed in those parameters (masses, couplings) which were there from the beginning, whereas in nonrenormalizable theories the number of additional parameters increases with the perturbative order (as well as the polynomial degree of boundedness) and hence such models remain as useless in the new finite setting of causal perturbation as they were in the old setting based on ultraviolet divergence and cutoffs.

In these remarks I tried to sketch the Zeitgeist and the scene which Jorge André Swieca encountered when he entered particle physics and which accompanied him though the 2 decades of his scientific activity.

2 Jorge André Swieca, his work and its legacy

Every physicist in Brazil and even many people outside physics knows the name Swieca; this is partially due to the fact that an important yearly taking place physics summer school organized by the university of Sao Paulo is called *Jorge André Swieca Summer School in Particle and Fields*. But few physicists of the younger generations are familiar with Swieca's contributions to particle physics and the legacy of his work in present developments. Some of the problems he proposed, investigated and, in some cases, completely solved led to questions which are still in the forefront of discussions. They intertwine the present research in QFT in an interesting way with the particle theory of the 60/70; hence a fresh look at Swieca's work is more than just doing scientific archeology.

This is in particular true about his first paper after having obtained his PhD at the USP in Sao Paulo in 1964, a paper written together with Haag at the University of Illinois in 1963 under the title "When does a Quantum Field Theory describe Particles?" [6] The authors aim at a completely intrinsic conceptual understanding of particles without whose presence one cannot set up scattering theory in terms of local properties of fields. To obtain the existence of Wigner particle states from local properties of interacting fields was an old dream of Haag and his formulation of scattering theory was already a product of its pursuit. Although there is no definite answer up to this day to the central question these authors ask in the title of their paper, the richness of the research it led to is quite impressive.

According to my best knowledge this paper is the first in which the difference between the quantum mechanical and the quantum field theoretical concept of

[5]These ideas about the particle-field relation appear for the first time in [6].
[6]This idea received its first formal mathematical perturbative setting in [3].

phase space in QFT is seriously addressed. Whereas in QM the number of quantum states which can occupy a finite phase space region Ω is finite, namely maximally $\Omega/\hbar^3$, it was known that (in the case of free fields) the number of states below a certain energy and localized in a compact spacetime region $\mathcal{O}$ is still infinite, even if one, following Haag and Swieca, circumvents the prereq-uisites of the Reeh-Schlieder theorem[7] by admitting only operators Q from a subset of the local algebra $\mathcal{A}(\mathcal{O})$ consisting of all O-localized operators whose norm is below a certain bound namely (copying from their paper)

$$\|Q\| \leq e^{\kappa r} \|Q\Omega\| \tag{1}$$

with $\kappa =$ smallest mass and r the radius of a (without loss of generality) double cone $\mathcal{O}$. But a detailed calculations for free fields led Haag and Swieca to the result that although the number of states in a finite phase space region (finite spacetime localization and finite energy) is really infinite, it is "essentially finite" in the sense of being a compact set i.e. a set whose cardinality deviates only mildly from the quantum mechanical finiteness per phase space cell. There was good reason to believe that interactions did not not change the situation and therefore the authors expected that their compactness criterion may be a good starting point for understanding the local origin of the one-particle structure and the asymptotic large time stability of n-fold localized particle states. Their most ambitious aim was to find an answer to the question what properties of local fields lead to asymptotic completeness which is the assertion that every state in the theory can be represented as a superpositions of multi-particle theories. They did not quite achieve this and the derivation of particle properties from local aspects of fields has remained in the focus of fundamental research up to this day. This is not surprising because in contrast to QM a multiparticle state at finite times becomes a meaningless concept in the presence of interactions; from the times of Furry and Oppenheimer it was already known that it is *not even possible to locally create a pure one-particle state* without the admixture of vacuum polarization clouds (formed from particles-antiparticle pairs). In other words there is sharp antagonism of the notion of particles with the localization inherent in QFT. For this reason Haag and Swieca take great care for defining n-particle states in terms of asymptotic counter-coincidence arrangements with a Wigner Poincaré representation theoretic tensor product strucure which according to my best knowledge up to date is the only consistent and unique way of avoids contradictions of massive particles[8] with field localization in the presense of interactions.

From a contemporary point of view the reason behind this contrast is the substantial conceptual difference between the quantum mechanical "*Born localization*" and the field theoretic *modular localization* (for a recent treatment of this subject which often falls prone to misunderstandings see [7][8]). The way

[7]The Reeh-Schlieder theorem [2] states that the family of state vectors, obtained by applying smeared fields with test functions sopported in a given space time region, is dense in the Hilbert space. This initiated many discussions since it defies quantum mechanical intuition.

[8]In the presence of zero mass one may end up with infraparticles which require a different scattering framework.

modular localization increases the state density in the phasespace of QFT as compared to that in QM is through the persistent presence of vacuum polarizations at the horizon (the causal boundary) of a localization region. Relativity in the form of the covariant transformation property alone is not sufficient for vacuum polarization, as the existence of "direct particle interaction" shows [8]. However every covariant quantum with a sharply defined maximal velocity will lead to the localization-caused polarization clouds.

Quantum fields as e.g. certain generalized free fields which, as the result of their too many degrees of freedom were considered to be pathological since they cause violation of the *timeslice property* and did not pass the Haag-Swieca phase-space test either [6].

Later other authors re-investigated this problem and succeeded to sharpen the estimate by showing that via the use of a slightly different formulation one could replace compactness by *nuclearity* can be essentially replacing compactness by nuclearity. Compact subsets in infinite dimensional Hilbert spaces are smaller than bounded sets and nuclear sets are even more "thinned out".

This important step was taken two decades after the Haag-Swieca paper by Buchholz and Wichmann [9]. This more stringent (but harder to establish) phase space property of QFT went a long way to to clarify some thermal aspects of QFT. Roughly speaking it assured the existence of a thermal equilibrium KMS state once one knows the local observables in their vacuum representation [10]. Since the thermal representation is unitarily inequivalent to the vacuum representation this is not as simple as its sounds. ich are even more thinned out i.e. somewhere between the finite case of QM and the H-S compactness.

It is interesting to take a more detailed look of what was accomplished. The map whose nuclearity is under discussion is a map from operators in an operator algebra of local observables $\mathcal{A}(\mathcal{O})$ to states in the Hilbert space H. More precisely their sharpened version states that the set of state vectors obtained by applying the energy damping operator $e^{-\beta H}$ to the local algebra $\mathcal{A}(\mathcal{O})$ defines a nuclear map Θ

$$\Theta_{\mathcal{O},\beta} : \mathcal{A}(\mathcal{O}) \rightarrow H, \quad A \rightarrow exp(-\beta H)A\Omega, \; A \in \mathcal{A}(\mathcal{O}) \tag{2}$$

A set of states is called *nuclear* if it can be included in the range of a trace-class operator. A nuclear set in a Hilbert space H is a set which is dominated by the range of a trace-class operator. Since a trace class operator is always compact, nuclear sets are a fortiori compact.

A more intrinsic implementation of the phase space idea which uses only objects which refer to local algebras consists in employing instead of the exponential damping factor involving the Hamiltonian the modular operator $\Delta_{\tilde{\mathcal{O}}}$ which is associated with a slightly bigger region $\tilde{\mathcal{O}} \supset \mathcal{O}$ [2]. The modular operator is an mathematical object which is directly related to the algebra $\mathcal{A}(\mathcal{O})$ whereas the Hamiltonian belongs to the global operator algebra.

For "pathological" field models, as the generalized free field considered by Haag and Swieca (in order to show that a reasonable phase space behavior is not a consequence of locality and energy-momentum positivity alone), the thermal representations may either not exist at all or they may lead to a maximal (Hagedorn) temperature. This is a serious problem in theories with infinite particle towers as string theory.

Needless to add that the issue is still very much alive and the original aim of understanding the role of phase space degrees of freedom in relating particles and their properties with fields is still on the research agenda, as a look at a most recent paper shows [11]. Looking at the introduction of this paper the author leaves no doubt about where this line of research originated. In my view the Haag Swieca work belongs to those few papers of the middle of last century with carry an important legacy since the ideas around the size of the phase space in QFT, and the subtle consequences for particle physics are still far from closure. Although the validity of the asymptotic convergence and the asymptotic completeness of particle states has meanwhile been established for the class of factorizing models [41], the Haag-Swieca quest for a general structural derivation of these properties from local properties has not yet been accomplished; another indication that QFT is still a far cry from its closure.

A second set of problems which received a lot of attention during the two decades under discussion was *symmetry and symmetry-breaking*. Both issues were initially investigated in the formal Lagrangian quantization setting; the first presentation of Lagrangian spontaneous symmetry breaking is due to J. Goldstone [12]. An older version of spontaneous symmetry breaking in the setting of spin-lattices goes back to Heisenberg and his theory of ferromagnetism; although as a result of its special nature in solid state physics it was not perceived as a special illustration of a vastly general phenomenon in systems with infinite degree of freedoms which includes QFT.

The Lagrangian setting in Goldstone's derivation left the problem of a more autonomous[9] understanding of this new phenomenon in particle physics still open; this includes the identification of the (if possible most general) structural properties which lead to sponateously broken symmetries. Of course by "broken" one does not just mean the absence of a symmetry, but rather an intrinsic mechanism of spontaneous breaking which permits to recognize the presence of an original symmetry in the broken phase. There are two such situations in QFT, the Goldstone spontaneous symmetry breaking, whose signal is the appearance of a massless Boson, and the Schwinger-Higgs [13][15] *screening mechanism*, which typically leads to a mass gap in gauge theories (and which was independently discovered by Brout and Englert [16]). As in the case of the Goldstone spontaneous symmetry breaking versus the Heisenberg ferromagnet, it was preceeded by Anderson's [17] discovery of an analog mechanism in condensed matter physics.

In the intrinsic setting of QFT the Goldstone theorem states that a conserved current in QFT may not lead to a global charge as a result of bad infrared behavior of some of its matrix elements; in order for this to happen there must exist a "Goldstone boson" in the model i.e. a zero mass particle which couples to the

[9]An understanding which does not refere to the way a model has been constructed but only uses intrinsic properties of its presentation in terms of expectation values.

conserved current in a specific way in order to prevent the large-distance covergence of the integrated current to the "would be" charge. Kastler, Robinson and Swieca [18] proved that the a necessary structural requirement in any covariant local QFT for this to happen is that the spectrum reaches down to zero. By using the Jost-Lehmann-Dyson representation Ezawa and Swieca [19] succeeded to sharpen this statement by proving the existence of a zero mass particle which couples in a specific way to the current. With this result the Goldstone theorem changed from an statement about certain Lagrangian models to a structural theorem in QFT. The insight gained into QFT was than transferred by Swieca to solid state physics in order to understand the connection of range of forces and broken symmetries [20].

The whole complex of conserved currents, including some subtleties in the unbroken case caused by the ubiquitous presence of vacuum polarization clouds, was nicely presented by Swieca 1967 in his Cargese lectures. Even after four decades these notes ([21]) are still recommendable. This work on spontaneous symmetry breaking brought Swieca the respectable Brazilian *Santista prize.* The quest for a profound structural understanding of spontaneous symmetry breaking (as well as numerous attempts to exemplify spontaneous symmetry breaking in concrete models) remained an area of research up to this day since it is of interest to explore the Goldstone mechanism under the most general physical assumptions.

The second way of breaking a symmetry, namely the Schwinger-Higgs mechanism, is strictly speaking a *screening mechanism for charges.* In the formulation with pointlike covariant vector potentials and BRST ghosts it is often called "gauge symmetry breaking" (see below). The charge screening problem is not related to a large distance divergence from integrating over zero components of conserved currents, but rather to understand under what circumstances such integrals vanish so that the conservation law of these charges become ineffective and copious particle production of screened particles violating the naively expected charge selection rules can take place. Of special physical interests for the discussion of screened charges are identically conserved currents of the Maxwell type

$$j^\mu = \partial_\nu F^{\mu\nu} \tag{3}$$

Swieca showed [22] that the presence of a corresponding nontrivial charge implies the existence of photons (as well as a certain nonlocality of the charge carries with respect to the $F_{\mu\nu}$ observables) and, as the other side of the medal, that a massive "photon" is only possible with vanishing (screened) charge. In a QED-like theory with a would be charged scalar field there exists a phase in which this scalar field contributes to its own screening and the resulting physical particle is not subject to the charge superselection rules while the "photon" has turned into massive vectormeson, in short one arrives at the *Higgs mechanism.*

Swieca was not only familiar with Schwinger's idea that QED may exist in another *massive photon phase* (which goes back to the end of the 50s), but he also contributed together with John Lowenstein [23]) some beautiful work on a concrete two-dimensional model which actually Schwinger [13] had proposed in order to illustrate his idea of a massive phase in QED-like gauge theories. In contrast to the Goldstone situation in which, according to a well-known early argument in condensed matter physics [14], spontaneous symmetry-breaking of a continuous symmetry group cannot occur for d=1+1[10], there is no such dimensional restriction for the Schwinger-Higgs screening mechanism and therefore Schwinger's model of massless two-dimensional "QED" is a valid demonstration and also a reminder that the mass-generating Schwinger-Higgs mechanism strictly speaking does not deal with symmetry breaking. Since this screening mechanism has been found in the context of gauge theories, it is somewhat misleadingly referred to as broken "gauge symmetry". To the extent that this refers to local gauge invariance this may cause misunderstandings since the terminology ignores the fact that the local gauge freedom parametrizes the *liberty of changing spurious ghost degrees of freedom* which leave no trace in the physical cohomology space. It is however a valid terminology to the extend that it refers to *global gauge invariance* associated with the electron/positron charge which, as a result of screening, looses its selective power with a resulting reduction of symmetry. The global gauge invariance in gauge theories are the global limit of the local invariance but contrary to the latter it is related to the selection rule of the electric charge.

It is somewhat ironic that the Schwinger-Higgs mechanism, whose precise understanding is of crucial importance for contemporary particle physics, is not as well understood as Goldstone's spontaneous symmetry breaking. A better understanding may require a basic revision of local gauge invariance in terms of a more intrinsic description of interactions involving $s \geqq 1$ fields. It turns out that there are two way to lower the short distance behavior of such fields either by remaining in the physical Hilbert space and allowing instead of pointlike covariant fields a semi-infinite spacelike "stringlike" localization or modifying the pointlike fields with the help of (pointlike) BRST ghosts which permits to retain the standard perturbative formalism but requires a cohomological return to ghostfree physical observables at the end of the computation. Whereas the second formalism exist in the form of free fields [7], the use of stringlike ghostfree fields in interactions is presently being studied.

One pressing question in connection with the Higgs particle is this: must a perturbative renormalizable interacting between several massive spin=1 particles always be accompanied by a massive scalar particle? If the answer is yes the next question would be: does this also hold outside perturbation theory as a structural consequence of locality? And if the answer to the second question is also positive one would finally like to know whether this idea admits a generalization to higher spin.

There are many important new question in this short-distance improving string-localized setting. All have the same motivation as gauge theories namely to find a way to enlarge the set of renormalizable interactions. Whereas gauge theory does this by appealing to the quantization of the classical Maxwellian

[10]In QFT this can be directly seen from the infrared-behavior of the zero mass two-point function.

field theories in the setting of vector potentials, the totally intrinsic formulation in terms of string-localized potentials departs from the fact that although there exist *no pointlike covariant potential wave function in the unique Wigner photon space*[11]. t

Via the Fock construction one can immediately pass to the Wigner-Fock tensor space where the objects where the string-like localized covariant wave functions turn into corresponding semi-infinite spacelike string-localized covariant potential operators. This space only contains physical states and hence there is no place for gauge transformations.

As mentioned, unlike the quantization procedure, the path from the Wigner representations to these fields is completely intrinsic, nowhere there is any reference to classical gauge theory. Pointlike fields can be viewed as singular limits of compactly non-singular operators when the connected compact region shrinks to a point. Analogously the prototype for a causally complete non-compact region is a spacelike cone whose localization region in the infinitely narrow limit (the tightest localization) becomes a spacelike semi-infinite string. which with shrinking diameter shrink to strings. Poincaré transformations transforms both families into themselves, which is then inherited as a covariant transformation property by their singular limits.

Whereas some of these important questions can probably be answered in a new setting of perturbation theory for stringlike fields, the nonperturbative problems would presumably require structural arguments based on the connection between localization and analyticity of generalized formfactors of thze kind as they are needed in the proof of Swieca's screening theorem. Especially for the Riemann tensor like point-localized "field strength" and their stringlike metric tensor potentials $g_{\mu\nu}$ this would be very interesting. Only after these questions have been answered, the "screened versus liberated charge" issue, which underlies Swieca's screening theorem, will have come to a closure.

Whereas in Schwinger's original treatment it was very hard to identify the gauge invariant content of the Schwinger model, the L-S presentation clarified the chiral symmetry breaking and the ensuing emergence of a Θ-angle as a consequence of the Schwinger-Higgs mechanism. In this way it became obvious that the gauge invariant content of the model was generated by a free massive field and thus the physical content became elegantly separated from gauge dependent unphysical aspects of the Lagrangian setting in which Schwinger first presented the model. Among all free fields, a massive field in two dimensions is very peculiar since its short distance zero mass limit (as a result of its infrared property) defines an algebra with has continuously many "liberated" charge sectors (so that the massive model may be considered as a charge-screened version). This has a vague analogy with the way quarks become "visible" in the short distance limit of QCD. The gauge-independent intrinsic content of the Schwinger model which consists in a two-dimensional neutral scalar free field is capable to ex-

[11]Meanwhile, under the influence of studies of *duals* of gauge theories, the *nonintrinsic nature* of the concept *of gauge theory,* which was a minority opinion at the time of Swieca, seems to have been accepted by the majority of particle physicists.

plain why for short distances the screening passes to charge liberation[12]. There remains however an important difference between the screening of charges, a process in which the gauge potentials become associated with massive "photons", and confinement of (generally nonabelian) charges, in which the charges associated with representations of the fundamental theory are "confined" and only their composites appear in the physical spectrum of the theory.

Swieca and collaborators have made attempts to explain the difference between screening and charge confinement in a mathematically controllable two-dimensional context [24][25]. But there are limits to analogies for screening versus confinement concepts in higher spacetime dimensions. In d=1+1 all the models used for that purpose were superrenormalizable and hence they fulfilled the requirement of asymptotic freedom in a almost trivial manner; for strictly renormalizable theories this is a somewhat harder problem, even if they are two-dimensional. In 4-dim. QCD it took the computational ingenuity of Politzer, Gross and Wilszeck to arrive at the consistency check for the asymptotic freedom conjecture. If the model is soluble, as the strictly renormalizable factorizing Gross-Neveu model, one is able to rewrite the Callan-Symanzik parametric differential equations in terms of physical mass parameters from where one can read off a proof of asymptotic freedom. In QCD one does not know a physical reparametrization which is of course related to the lack of knowledge about the physical confinement phase. A full proof beyond a consistency check is probably not possible without knowing more about the confinement problem.

Nowadays it is hard to imagine that at the time of Swieca there was still resistance against the Schwinger-Higgs mechanism. He once told me that he was not able to convince Peierls that a massive phase of gauge theory could exist; Peierls apparently insited that the quantized Maxwell structure cannot be reconciled with massive photons.

Swieca's work on charge screening and the mass spectrum was deepened by Buchholz and Fredenhagen [26] who succeeded to supply it with the mathematical rigor and the conceptual astuteness of local quantum field theory. The weak point in Swieca's screening proof was related to certain analytic properties in particle momenta of formfactors. Buchholz and Fredenhagen proved these properties and realized that they can be used to settle other even more ambitious problems. In fact this started these authors on a much more general track of investigating the connection between localization and particle spectra [27]. Their physical motivation was to reconcile the nonabelian gauge structure with the massiveness of the QCD particles. The main result of this work (which considerably widens the realm of QFT) in modern parlance says that assuming the existence of (pointlike) local observables and the existence of a spectral gap (expected in QCD as the result of confinement), the generator of charges are covariant semiinfinite spacelike string fields $A(x,e)$ where the unit vector e represents the spacelike direction of the semi-infinite string which starts at x; in particular there is never any need to introduce generating quantum fields into

[12] It is somehow easier to associate the Schwinger model with the process of short distance charge liberation than to start with free charges and go the opposite way of screening.

QFT with a mass gap whose localization goes beyond point- and string- like extension (be aware this is not string theory!). All objects with larger localization can be obtained from interacting string-like fields. Pointlike fields constitute a special case when the field is e-independent.

The methods of algebraic QFT used by those authors are not model-specific and it is up to now to give an intrinsic physical characterization of what is meant by a nonabelian Maxwell structure. So what the authors ended up with was a framework allowing semi-infinite string-localized fields to arise from rather general assumptions about the energy-momentum spectrum but it is presently not possible to decide whether this mechanism is taking place in QCD.

In any case this illustrates in a nice way that the legacy of an idea may sometimes pass through methodological improvements from one problem to another.

During my affiliation with the University of Pittsburgh in the 70's I felt attracted by some peculiarities of conformal theories as e.g. problem of how the Huygens principle of free massless classical fields in even spacetime dimensions passes to the quantum case. Conformal QFT enjoyed already some short-lived interests a decade before, but as a result of problems to reconcile conformal interactions with the particle structure it naturally fell into disgrace at a time when all attention in QFT was directed towards dispersion relations and scattering theory.

The starting observation was that some of the zero mass models which were new at that time, as e.g. the massless Thirring model, did not fulfill Huygens principle [28], even though by the standards of checking the infinitesimal form of invariance (commutations with the would be generators) they were conformally covariant. Instead of a propagation on the mantle of the light cone, these models propagated inside the cone, which, in analogy to acoustics, was termed "reverberation". In the setting of Minkowski spacetime the global propagation even violated causality because timelike distances inside the lighcone can be transformed into spacelike separations. In order to have a mathematically solid starting point, Swieca together with Völkel re-visited to the zero mass free fields case in order to prove that not only the Poincaré generators, but also the remaining conformal generators have a well-defined mathematical functional analytic definition. The details were actually quite tricky [29]. This work was later taken up by Hislop and Longo [30] who placed this into the more general context within the setting of algebraic QFT.

On a second visit to Brazil I collaborated with Swieca on the interacting case. We understood that anomalous dimensions always activate the covering of the conformal group as well as the covering of the (Dirac-Weyl) compactified Minkowski spacetime. This is one of the few cases where the presence of interactions is directly linked to group representation theory[13], this in turn can only occur in the presence of interactions which made it an interesting research topic up to present times.

[13]The idea that the dynamical aspects of massive QFT could be governed by the representation theory of a non-compact group was very popular, but these attempts ended in No Go theorems connected with the name O'Raifeartaigh and Coleman-Mandula.

One consequence of the presence of a nontrivially represented diagonolizable center Z of the conformal covering which is in the center of the field algebra was that fields which one expected to carry an irreducible representation of the conformal group in fact only behaved irreducibly under infinitesimal transformations and therefore admitted a decomposition with respect to the center of the covering group. The result was a very rich conformal decomposition theory [31][32] whose application to the problem of commutation relations led us straight into what we called the conformal nonlocal decomposition theory.

In contradistinction to the undecomposed fields, these new fields seem to have a simpler timelike commutation struture. Since there existed no controllable 4-dim. model we adapted our decomposition theory to two dimensions. In that case the conformal group factorises together with the QFT into two chiral components and our chiral test model was the exponential of the free massless boson (whose rich charge structure was already known). These chiral models live on a light ray so that space- and time- like coalesce to lightlike and the distinction between spacelike distances and the Huygens region is lost. The commutation relations of the Z-reduced field is that of "anyons" i.e. abelian representations of the braid group which appear as numerical factors if one changes the order in the product of two operators. The decomposition theory for the massless Thirring model is completely analogous.

This gave rise to the hope that conformal anomalous dimension fields in higher spacetime dimension have simple anyon-like commutation relation in the timelike Huygens region and this may be an algebraic structure which, if coupled with the spacelike (anti)commutation, may provide the additional algebraic structure which is necessary for a classification and construction of higher-dimensional conformal QFT in analogy to the lightlike plektonic commutation structure of chiral models (where space- and timelike coalesce to lightlike distances).

Although there have been some exciting new results about the structure of observable algebras[33][34] (which by definition live on the Dirac-Weyl compactified Minkowski spacetime and do not require the introduction of its covering), the unravelling of higher dimensional conformal field theory still remains a challenging theoretical problem to date.

The operator-based algebraic research about the global conformal decomposition theory 1974/75 by Swieca and collaborators came to an halt after it was noted that the component fields (nowadays called "conformal blocks") as a result of their dependence on the central (source and range) projectors associated to the conformal covering, were neither ordinary (Wightman) fields nor did they have a natural euclidean setting and hence they were outside the prejudices of those times.

The Z-component fields in the 2-dimensional context (the only context in which we had some constructive control) which lacked the properties of Wightman fields[14] and neither fitted into the euclidean setting of QFT led to a stop

[14] Certain Z components annihilate the vacuum i.e. they violate the Reeh-Schlieder property ("the state-field relation") which does not happen for Wightman fields.

of this line of reseach. As far as I know the only work before the beginning of the 80s which went beyond the results obtained by Swieca and his collaborators was some unpublished work by Lüscher and Mack in which the beginning of the c-quantization (of what was later called) minimal models was noticed and the special role of the conformal Ising field theory at the value $c = \frac{1}{2}$ was highlighted.

Less than a decade after Swieca´'s work, and after Swieca's premature death in December 1980, chiral conformal QFT became the center of attention after Belavin Polyakov and Zamolodchikov discovered the existence of the class of "minimal chiral models". It was not difficult to see that our central Z-decomposition theory nicely harmonizes with the BPZ conformal block fields. One could also see that their commutation relations still represented the braid group, but some of the the new representations were not abelian (anyons) but rather nonabelian (plektons) of the kind as they appeared naturally in mathematics in Vaughn Jones subfactor theory. To understand the relation between the old work with Swieca and the new BPZ setting was not a simple matter[15], K.-H. Rehren and myself worked almost two years on this task [35].

Another interesting idea of Swieca, which I consider as an important part of his legacy, has to do with massive 2-dim. factorizing models. Here some introductory remarks are necessary. This research goes back to certain quasiclassical observations by Dashen, Hasslacher and Neveu [55] suggesting the integrability of theories such as the d=1+1 massive Sine-Gordon- and Thirring-like models.

The first attempts to understand the particle spectrum in connection with the S-matrix of these models led to a modest revival of the old bootstrap S-matrix idea in the context of certain 2-dim. models [36]. This bootstrap program which was so exuberantly praised in the 60, and fell out of fashion after the discovery of QCD, finally found an interesting albeit modest explicit realization in d=1+1. Within the class of factorizing d=1+1 S-matrices it led to a classification of unitary S-matrices with the crossing property [37].

In addition it was found that if one abandons the ideology of S-matrix supremacy over QFT, including the metaphorical hope that the S-matrix bootstrap by some magic selects a unique TOE (theory of everything), and rather considers the classification of factorizing S-matrices as the first step in a construction of "factorizing" QFTs, one ends up with an extremely rich quantum field theoretic harvest[16] [38]. The models confirm the *nuclear democracy* idea which results from the locality principle of interacting QFT, namely all particles which have the same charge (invariant inner quantum number) as a cluster of other particles in the same theory can be viewed as a bound states of such a cluster.

This even holds if the masses of the particles of the original particles go to

[15]This is not surprizing since one important mathematical tool namely the representation theory of Kac-Moody algebras and loop groups did not yet exist or was not known outside mathematics.

[16]At this point other actors (the Zamolodchikovs, Faddeev, Witten, Smirnov) entered who brought important knew ideas. The present status of the bootstrap-formfactor program has many contributers and its review is not the aim of these notes.

infinity [39] and in this way become unobservable (confined "quarks"), showing that there is no contradiction between nuclear democracy and confinement. The nuclear democracy principle is best understood through associating particles to interpolating fields; in contradistiction to the particle number hierarchy in the setting of QM, the only condition on an interpolating field (generally a local composite field in terms of the field which one used to define the theory) is that it is local and carries the superselected charge of the particle. In interacting theories locality does not permit the field states of the infinitely many composite fields with the same charge to have vanishing mixed two point function[17]. The states of particles belonging to different superselected charges are of course orthogonal, but those corresponding to different composites with the same fused charge are the same particle states apart from the fact that their composite interpolating fields have to be renormalized by different constant. In some sense this democracy principle makes QFT conceptually simpler than QM, but it also creates immense computational problems if one tries to use similar operator methods as in QM. The path from the factorizing S-matrix to a uniquely associated QFT goes through the construction of formfactors i.e. of multi-particle matrixelements of operators.

Swieca's interest in this rich class of controllable models arose mainly from the possibility to test certain general conjectured structural properties of QFT which are outside the range of perturbation theory. He immediatly realized that factorizing models presented a rich theoretical laboratory for testing ideas. One such idea was his conjecture that the principle of nuclear democracy inherent to QFT may permit to define and construct certain models in a completely intrinsic way without referring to a Lagrangian. For example his definition of a "minimal" factorizing Z(N) model is that of a factorizing model of particles with N charges numbered as n=0, 1, ..., N-1. The vacuum belongs to n=0, n=1 represents the "fundamental" particle whose N-fold composition leads back to the vacuum sector, so that its N-1 fold composition must play the role of the antiparticle, the N-2 composite is the antiparticle of the n=2 bound state etc. The minimalistic realization of this "the antiparticle as a bound state of N-1 particle" principle led to a unique S-matrix [43] and more recently also the formfactors of this Z(N) model have been constructed [44]. This recent result also confirmed that the only consistent field statistics (field commutation relations) which one can associate to this model is the abelian braidgroup statistics as postulated by Swieca.

Most of the factoring S-matrices leading to uniquely associated QFTs are outside the Lagrangian framework[18] and the Z(N) model is a representative illustration. With the conceptual framework of the Haag "school" in the background, Swieca belonged to the meanwhile increasing minority of particle physicist who

[17] All local states which can couple (is not separated by superselection rules) to each other always do couple. This positive adaptation of Parkinson's law in the setting of QFT is at the root of nuclear democracy.

[18] This is to be expected since the set of factorizing S-matrices is nuch larger than what can be encoded into the local renormalizable coupling of fields and since every factorizing unitary crossing S-matrix has precisely one set of crossing formfactors and hence one QFT.

believed that the Lagrangian quantization approach to QFT does not exhaust the richness of QFTs. After all the Lagrangian quantization required a strange parallelism of the more fundamental QFT to its less fundamental classical counterpart. By now one knows that only a small fraction of factorizing models are "Lagrangian" and the Z(N) model was perhaps the first non-Lagrangian model. This is so because the richness of factorizing unitary S-matrices with crossing property is much larger than what can be encoded into local coupling of fields.

The chiral SU(N) Gross Neveu model resembled the Z(N) model concerning the minimalistic antiparticle description and anyonic statistics, but assigns an additional problem which attracted Swieca's attention [42]. This had to do with the question of how the apparent chiral symmetry breaking could be reconciled with the Mermin-Wagner theorem and its much simpler field-theoretic analog (infrared behavior of the two-point function in d=1+1 [45]) which forbids a spontaneous breaking of a continuous symmetry in two dimensions. With the hindsight of abelian charge-creating infrare-clouds in two dimensions from previous work, Swieca et al. [46] proposed such a symmetry protecting (from the S-matrix point of view restoring) mechanism caused by infrared clouds[19]. This was a different mechanism from that proposed by Witten [47] in the same model for the same reason. Witten's proposal was further elaborated by Abdalla, Berg and Weisz [48]. But on the pure S-matrix level it was not possible to decide which off-shell version was correct. In a forthcoming paper by Babujian, Foerster and Karowski [49], the formfactors of this model have been constructed and their result clearly selects the solution of Swieca et al..

The plethora of two-dimensional commutation structure led to the question whether for those two-dimensional models which described the scattering of particles the statistics in the sense of field commutations is already reflected in the one-particle states. This is certainly the case in higher dimensional QFT. The answer was negative, i.e. two-dimensional particles are statistical "schizons" since the fields associated with the particle can always be changed by multiplying it with a disorder variable [50]. Since the statistics is related to crossing, the bootstrap-formfactor construction of factorizing models selects a particular assignement which, if desired, may be changed after the theory has been constructed. According to the spin-statistics theorem this is not possible in higher dimensions. In d=1+2 QFT the (braid-group) statistics is determined in terms of the (anomalous) spin and this connection is already pre-empted in the setting of Wigner's classification of one-particle states [51]. The statistics in the sense of field cummutation relations is also intrinsic in d=1+1 conformal theories.

Swieca's main interest was focussed on constructive aspects of QFT (in particular the use of *low-dimensional controllable models as a theoretical laboratory*[20]) but on one occasion, when he was convinced that an interesting pro-

[19]The Coleman theorem is not mention in the paper but its knowledge is not of much help for figuring out the concrete restoration mechanism in the model at hand. The existence of two different proposals from just knowing the S-matrix demonstrates this.

[20]In his own words [57]: *Two-dimensional spacetime, despite all its peculiarities has proved many times to be a fruitfull theoretical laboratory where one can test a number of ideas in soluable modelsand many times draw inspirations for more realistic models.*

posal would not stand up to physical requirements of macro-causality, he also proved a No-Go theorem [52]; the object of the critique was the Lee-Wick proposal of using complex (+ complex conjugate) poles in Feynman propagators. Together with one of his students he showed that by reformulating the problem into a Yang-Feldman setting, the use of indefinite metric can be avoided and the problem with causality appear in sharper focus. It turns out that the Lee-Wick mechanism is untenable since it even violates the crudest form of macro-causality.

This No-Go statement should be viewed in the context of a long list of failed attempts to maintain Poincaré invariance without micro-causality [54]. In recent times the nonlocality aspect reappeared in the veil of "noncommutativity" through the backreaction of string theory on QFT. Since the hallmark of quantum physics versus classical physics has been noncommutativity, this terminology needs an explanation. Noncommutativity in the contemporary context means imposing a noncommuting structure on euclidean functional integrals or modifying the real time formulation directly so that the spacelike commutativity is violated. The construction of noncommutative theories is a special way to obtain non-local theories. Apart from attempts being guided by ideas from quantum gravity (absence of small black holes whose presence would make any measurement impossible), most of the proposals suffer from the lack of conceptual reasoning which as a result of sophisticated mathematics is often not visible to the untrained eye.

This becomes especially evident if one compares the conceptual level of present understanding with that during the two decades 60-80. In those days the notion of causal locality played a central role in the interpretation of QFT and it was generally acknowledged that the physics of momentum space (e.g. Feynman rules) has to be derived from localization of states and locality of operators; i.e. the Fourier transform of a translationally covariant operator has apriori nothing to do with the energy-momentum of an object registered in a counter, rather it is the mass-shell momentum in the sense of a geometric relation between two asymptoticically timelike removed events which lend physical interpretation to the momentum space. It was generally accepted that even if one is forced one day by new experiments to abandon micro-causality, there is a minimal set of macro-causal requirements which are indispensible for any kind of particle physics; i.e. these are the properties one must keep in any kind of relativistic particle theory. According to considerations going back to Stueckelnberg, the causal rescattering (in QFT often referred to as the *causal one-particle structure*) insures the absence of timelike precursors and together with the cluster property of the S-matrix constitutes the time- and space- like aspects of macro-causality. Although it was clear that the Lee-Wick proposal violated micro-causality, the violation of macro-causality and hence its physical inconsistency only became clear through [52].

The problem of whether one can weaken microcausality in a physically consistent way has remained in the forefront after Swieca's death in December of 1980, although the motivations for exploring non-local theories have been changing. Newcomers to QFT notice pretty fast that locality is an extremely restrictive requirement but it is much harder for them to realize that there are severe conceptual restrictions which wreck attempts to construct physically interpretable models which are "a bit non-local". Poincaré covariance and energy positivity severely limit such a spatial fall-off of the commutator (for a review of attempts at non-locality [54]). For example the commutator cannot decay faster than the Yukawa exponential if one wants to prevent falling back at a local theory. The only non-local setting which is under mathematical control and fulfills all macrocausality requirements which one is able to formulate in terms of particles is the direct particle interaction scheme of Coester and Polyzou [53]. But this has not and cannot be obtained by modifying the construction of QFT since the way in which the cluster property is implemented is not compatible with second quantization.

Physicists before the 80s had to learn about the conceptual barriers in departing from the realm of locality the hard way. Looking at the lighthearted way in which contemporary particle physicists have ignored the issue of macrocausality in their search for noncommutative theories, one cannot help of thinking of déja vu, even if the motivation has changed. The locality issue is one of the hardest in particle physics, and it seems that this lesson, which was learned the hard way in 60-80, has been forgotten and history is repeating itself.

3 Some personal recollections

I met Jorge André Swieca for the first time 1963 in the union hall of the University of Illinois in Champaign-Urbana. Whereas I was (after a 3-year research position with Haag) already about to return to the University of Hamburg and then settling down as an assistant professor at the University of Pittsburgh after having spend a short visiting period at the IAS, André he was on a stop-over on his return to Sao Paulo, after having written his thesis (with Guettinger[21] as his adviser) in Munich which he was going to defend at the USP. The main purpose of his side trip to the University of Illinois was to present himself to Rudolf Haag in order to inquire about the possibility of taking up a post doc position in Haag's group. He started his work at the University of Illinois around 1963 and stayed for 3 years. I met him again when I visited Champaign-Urbana around 1965 for a seminar talk; at that time he invited me to spend some time in Sao Paulo after his return. It was only in 1968 that I found the time to spend a couple of months at the USP in Sao Paulo.

The active members of the Brazilian physics community recognized his ex-

[21] W.Guettinger was at the ITP in Sao Paulo during the 50's and Swieca wrote his masters thesis under his guidance and followed him subsequently to Munich in order to write his PhD thesis. He belonged to a group of around 6 German scientists who were invited shortly after the ITP was founded. Most of them had a background in nuclear physics and they returned after the restriction on nuclear research in Germany was lifted (one became director of the nuclear research center in East Germany). Guettinger is a mathematical physicist who used the (at that time rather new) Laurent Schwarz theory of distributions in physical problems. His research interests at that time were very similar to those of Giambiagi to whom Andre also had a very close relation.

traordinary talent. Without their support he would not have received the Brazilian Santista science prize already in the late 60s, shortly after his return from the US. It was given to him for his contributions to the improved understanding of symmetries and their spontaneous breaking.

In the early 70s when the grip of the military dictatorship on public institutions especially on universities was getting tighter, many theoretical physicists, including André found some protection at the PUC in Rio de Janeiro, a private university under the umbrella of the relative progressive catholic church. A bypass heart surgery forced him to follow medical advice and look for a quieter place in the countryside. He continued his research at the smaller Federal University in Sao Carlos, only to realize some time after that the advice was not so good after all. Whereas at the PUC in Rio he was surrounded by well-intentioned and supportive colleagues, in Sao Carlos he had to engage in exhaustive struggles with the department chairman in order to salvage some agreements and promisses which were made to him before. This aggravated his health and certainly contributed to his premature death at the end of 1980.

Starting 1964 Brazil was under a military dictatorship. Different from the Pinochet regime in Chile, the US was probably not directly involved in its installation but it received a lot of sympathy and support after the military took power through a coup. Although there was a deep gap between the proclaimed US democratic ideals and the consequences of their realpolitik in the name of anti-communism, the overall image of the US was somewhat more positive than it is presently. One explanation is perhaps that the world of those days was bipolar and the actions the SU took on its neighbors were even more repugnant. In any case I enjoyed my 8 year stay in the US and apart from a critical distance to certain political developments it was my impression that Jorge Andre felt the same way. Only very recently I learned that around 1970 the military regime offered him a diplomatic post in Israel (perhaps that of a scientific attache) which he declined because he found the idea to represent a dictatorship not appealing.

With the shared scientific background as a result of having been a member of the "Haag school" of QFT[22], it was quite easy to agree between us on what are the interesting particle physics problems and to use our common stock of conceptual and mathematical knowledge to solve them. My first trip to Brasil in 1968 was the beginning of many visits to the USP in São Paulo and later to the PUC in Rio de Janeiro and the UF in Sao Carlos.

As mentioned in the text, in the first half of the 70 there was a flurry about some quasiclassical observations on certain two-dimensional QFTs in which the quasiclassical particle spectrum seemed to be exact [55]. This signalled some form of integrability, but contrary to the integrability in QM (e.g. the hydrogen atom), the field theoretic setting required some new ideas. Concentrating on a particular model it was not difficult to see that the quasiclassical spectrum originates from a simple 2-particle scattering matrix together with factorization and

[22] Rudolf Haag is the protagonist of the algebraic approach to QFT an approach which tries to avoid the quantization paralellism to classical field theories in favor of a more intrinsic understanding.

a fusion picture for higher boundstates from the lowest one. Within a short time a group of enthusiastic young members of the newly formed QFT group at the Free University of Berlin around Michael Karowski and Peter Weisz found the general solution: the ingredients of the old (and meanwhile defamed) S-matrix bootstrap approach if augmented with factorization and a fusion mechanism for bound states consistent with the nuclear democracy principle worked in a beautiful manner. Upon taking notice of these developments Jorge Andre got quite excited about these results. He recognized the potential of these models as theoretical laboratories for testing all kinds of field theoretic ideas outside the perturbative access. His previous experience with simpler two-dimensional models as zero mass exponential bosons, the closely related Thirring model and a field theoretic version of Kadanoff's results on order/disorder variables[23] facilitated his start and last not least, he had the powerful conceptual background on QFT from his collaboration with Haag. Within a short time he made important contributions and introduced a whole new generations students to these new problems. In this way he played a crucial role in the formation of a whole generation of particle theorist in Brazil and the memory of his work has been preserved for already almost 3 decades by attaching his name to a yearly occuring physics summer school on various subjects.

I had the good luck to enter particle physics in interesting times and to meet and collaborate with remarkable individuals as J. A. Swieca.

References

[1] W. H. Furry and J. R. Oppenheimer, Phys. Rev. **45**, (1934) 245

[2] R. Haag, *Local Quantum Physics*, Springer 1996

[3] H. Epstein and V. Glaser, Ann. Inst. Henri Poincare A **XIX**, (1973) 211

[4] W. Heisenberg, Zeitschrift für Naturforschung I. (1946) 608, and references to prior work therein

[5] G. F. Chew, *S-Matrix Theory of Strong Interactions*, W. A. Benjamin Inc, New York 1961

[6] R. Haag, J. A. Swieca, Commun. Math. Phys. **1**, (1965) 308

[7] J. Mund, B. Schroer and J. Yngvason, Commun. Math. Phys. **268**, (2006) 621

[8] B. Schroer, *Localization and the interface between quantum mechanics, quantum field theory and quantum gravity*, in preparation

[9] D. Buchholz and E. H. Wichmann, Commun. math. Phys. **106**, (1986) 321

[10] D. Buchholz and P. Junglas, commun. Math. Phys. **121**, (1989) 255

[23] The topics led to several master- and PhD thesis by his students [56].

[11] W. Dybalski, *Correlations between Phase Space Regions and a Sharpened Nuclearity Condition in QFT*, arXiv:0706.4049

[12] J. Goldstone, Nuovo Cimento **19**, (1961) 154

[13] J. Schwinger, Phys. Rev. **128**, (1962) 2425. The idea of a sreened massive phas of QED appiered first in an IAEC report.

[14] N.D. Mermin and H. Wagner:, Phys. Rev. Lett. 17, (1966) 1133

[15] P. W. Higgs, Phys. Lett. **12**, (1964) 132

[16] R. Brout and F. Englert, Phys. Rev. Lett. **13**, (1964) 508

[17] P. W. Anderson, Phys. Rev. 1**30**, (1963) 439

[18] D. Kastler, D. W. Robinson and J. A. Swieca,Commun. math. Phys. **2**, (1965) 108

[19] H. Ezawa and J. A. Swieca, Commun. math. Phys. **5**, (1967) 330

[20] J. A. Swieca, Commun. math. Phys. **4**, (1967) 1

[21] J. A. Swieca, Cargese Lectures 1967

[22] J. A. Swieca, Phys. Rev. **D 13**, (1976) 312

[23] J. E. Lowenstein and J. A. Swieca, Ann. Phys. (N.Y.) **68**, (1971) 172

[24] Nucl. Phys. **B134**, (1978) 61

[25] L. V. Belvedere, K. D. Rothe, B. Schroer and J. A. Swieca, Nucl. Phys. **B153**, (1979) 112

[26] D. Buchholz and K. Fredenhagen, Nucl. Phys. **154 B**, (1979) 226

[27] D. Buchholz and K. Fredenhagen, Comm. math. Phys. **84**, (1982) 1

[28] M. Hortacsu, R. Seiler and B. Schroer, Phys. Rev. D **5**, (1972) 2519

[29] J. A. Swieca and A. H. Völkel, Commun. Math. Phys. **29**, (1973) 319

[30] P. D. Hislop and R. Longo, Commun. Math. Phys. **84**, (1982) 71

[31] B. Schroer and J. A. Swieca, Phys. Rev. D **16**, (1974) 480

[32] B. Schroer, J. A. Swieca and A. H. Völkel, Phys. Rev. D **11**, (1972) 11

[33] B. Bakalov, N. M. Nikolov, K.-H. Rehren and I. Todorov, Commun. Math. Phys. **271**, (2007) 223

[34] B. Bakalov, N. M. Nikolov, K.-H. Rehren and I. Todorov, Infinite Dimensional Lie Algebras in $D Conformal Quantum Field Theory

[35] K.-H. Rehren and B. Schroer, Nucl. Phys. B **312**, (1989) 715

[36] B. Schroer, T.T. Truoung and P. Weisz, Phys. Lett. B **63**, (1976), 422

[37] M. Karowski, H. J. Thun, T. T. Truong, and P. Weisz, Phys. Lett. B **67**, (1977) 321

[38] M. Karowski and P. Weisz, Nucl. Phys. B **139**, (1978) 455

[39] M. Karowski, V. Kurak and B. Schroer, Phys. Lett. **81B**, (1979) 200

[40] .H. J. Borchers, D. Buchholz and B. Schroer, Commun. Math. Phys. **219**, (2001) 125, hep-th/0003243

[41] G. Lechner, *An Existence Proof for Interacting Quantum Field Theories with a Factorizing S-Matrix*, math-ph/0601022

[42] V. Kurak and J. A. Swieca, Phys. Lett. **82B**, (1979) 289

[43] R. Köberle and J. A. Swieca, Phys. Lett. **86**, (1979) 209

[44] H. Babujian and M. Karowski, Phys.Lett. B**575** (2003) 144, arXiv:hep-th/0309018

[45] S. Coleman, Commun. Math. Phys. **31**, (1973) 259

[46] R. Köberle, V. Kurak and J. A. Swieca, Phys. Rev. D **20**, (1979) 897

[47] E. Witten, Nucl.Phys. **B145** (1978) 110

[48] E. Abdalla, B. Berg and P. Weisz, Nucl. Phys. **B157**, (1979) 387

[49] H. Babujian, A. Foerster and M. Karowski, *Exact SU(N) form factors and 1/N expansion*, in preparation

[50] B. Schroer and J. A. Swieca, Nucl. Phys. **B121**, (1977) 805

[51] J. Mund, J.Math.Phys. **44,** (2003) 2037

[52] G. C. Marques and J. A. Swieca, Nucl. Phys. **B43**, (1972) 205

[53] F. Coester and W. N. Polyzou, Phys. Rev. D **26**, (1982) 1348 and references therein

[54] B. Schroer, Annals Phys. **319,** (2005) 92

[55] R. F. Dashen, B. Hasslacher and A. Neveu, Phys. Rev. D 10, 4138 (1974)

[56] E. Marino and J. A. Swieca, Nucl. Phys. **B170**, (1980) 175

[57] J. A. Swieca, Fortschritte der Physik **25**, (1977) 303