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Jorge A. Swieca's contributions to quantum field theory in the 60s and 70s and their relevance in present research

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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 relevance to the ongoing particle physics research. A particular aim of this article is to draw attention to the relevance of what at the time of Swieca was called "the Schwinger Higgs screening mechanism". which, together with recent ideas which generalize the concept of gauge theories, have all the ingredients to revolutionize the issue of gauge theories and the standard model.

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1 A brief recollection of quantum field theory in the 60 and 70s

The years from 1960-1980 mark a high point in particle physics. During these two decades quantum field theory (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 quantum electrodynamics (QED) in independent work by Feynman, Schwinger and Tomonaga, with important conceptual and mathematical additions and refinements by Dyson. The non-covariant pre-war quantum mechanical perturbation formalism which 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), of which some consequences became experimentally accessible shortly after the second world war. The observational verification of these effects was the entrance permit for QFT into the pantheon of established physical theories; in fact the new and for many (but not all) measurements stupendously precise and successful covariant formulation of QFT which led to the *Standard Model* 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 true revolutionary protagonists of QFT (Dirac, Jordan) which were achieved two decades before. But without the convincing experimental confirmations of the effects of vacuum polarization in QED, QFT may have disappeared for some time from the screen of particle physics, and the wildly speculative and metaphoric attempts trying to excorcise the "ultraviolet catastrophe" may have continued well into the 50s. By preventing such a scenario, the protagonists of renormalization theory saved QFT and made it fit for furthergoing innovations.

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 rendered obsolete the prior wild speculations about the ultraviolet catastrophe of their more "revolutionary" predecessors (who often preferred speculation over calculation). 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 later discovery of the Standard Model would have hardly been possible and the conceptual confusion, which is characteristic for large parts of contemporary particle theory, would have arrived much earlier and without the intervention of string theory.

The situation continued up to the end of the 70s. After 1980 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 largely simple-minded ideas invented a new research subject where one could be "revolutionary" and dream about a theory of everything (TOE). It is certainly interesting and important to analyse the reasons for the decline of particle physics in detail, but this is not the intention of this article. To the contrary, here we want to show on hand of some typical concrete illustrations how some valuable ideas got lost and how their resumption could lead out of the present stalemate.

Different from the rather short-lived ultraviolet crisis, the crisis associated with the dominance of a TOE in form of the superstring already lasts many decades and there is no end in sight since all the competent potential critics who enjoy the general esteem of the particle physics community are either gone or silent[1].

Apart from the magnitude and the number of involved researchers and publications, the present situation is vagely reminiscent of a period of frame of mind when some physicists, including Heisenberg, tried to cure the "ultraviolet problem" of QFT prior to renormalized perturbation theory by invoking speculative ideas without comprehensible connections to QFT. But the number of physicists working on speculative problems (instead of extending the conceptual range of QFT or searching for a more appropriate computational method which is more faithful to the underlying conceptual structure of QFT) was comparatively smaller at that time; in addition the "ultraviolet catastrophe era" did not last much longer than a decade, not enough time to cause any rupture or long-lasting mark.

This time the situation is much more serious. Perhaps the most lasting damage consists in the fact that an enormous amount of knowledge has been lost. In fact, as previously mentioned, the main motivation for this essay is to bring back some knowledge and a frame of discourse in which some of the old cut off ideas can be adapted to the new situation.

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 on particle physics, is beyond question. The several decades lasting dominance of hunting for the TOE has created a community of specialists who lack the broad knowledge about particle physics of earlier preelectronic times which makes my task to counteract these tendencies by recreating some of the lost ideas following the path of of contributions by J. A. Swieca quite challenging.

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 main distinction; to the present, as I see it, is that there was more criticism, including auto-criticism; this was considered an asset because, as the ultraviolet episode had shown without a strong counterbalance to the necessary speculative frontiers, particle theory would go astray. Any speculative jump into the "blue yonder" was done from a conceptually solid platform so that in case of failure of the incursion, there was always the return option and the possibility to inestigate a slightly different direction. This option does not exist anymore in string theory; whereto could a string theorists return to ? To the dual model, the S-matrix bootstrap or to that kind of string-infected QFT of articles and modern text books? Physicists in those days had a much greater awareness that a delicate equilibrium between innovative ideas and a critical mind 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

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[1] The silence does however not mean consent; for example Steve Weinberg voted with with his feet against the new turn in particle theory already more than 20 years ago.

creativity stood next to his cutting criticism, which if necessary he even against himself[2]. 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. The 60s and 70s were the high point of what in Germanic languages can be expressed in terms of one word: "Streitkultur"[3].

In stating such observations one should be careful of not become 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 in those days for the first time that magic idea of a unique theory of everything (TOE) entered the discussion (the unique S-matrix bootstrap of all forces apart from gravity [2]). On the other side of the fence there was QFT enriched by the LSZ/Haag-Ruelle scattering theory [3] which was shown to be a structural consequence of the principles underlying QFT. The ideological fervor found its strongest expression in conference reports were the S-matrix bootstrap proponents felt more free to celebrate what they perceived as their (premature) victory over QFT.

The counter message from quantum field theorists essentially amounted to remind particle physicists that even if one's main interest are the on-mass-shell observables as the scattering amplitudes and formfactors, one still needs the interpolating fields as the carriers of the locality principle to implement the desired S-matrix- and formfactor- properties by deriving them from the basic spectral and causality properties of particle physics. Indeed the bootstrap program lacked even the means to implement its most celebrated addition to particle theory, the crossing property (which follows from QFT [4]) and, which is an even more serious flaw, it never addressed those requirements which *macro-causality* imposes on any multi-particle S-matrix of particle physics [5]. These properties were first listed by Stueckelberg who also used them to criticise the previously mentioned Heisenberg S-matrix proposal[4]; they basically consisted in the spacelike cluster factorization and the absence of timelike precursors (the macro-causal origin of the Feynman $i\varepsilon$ prescription).

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[2] 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) abandoned and criticized these attempts after Feynman showed him the fallacies.

[3] There seems to be no equivalent expression in english. It includes a sharp, sometimes aggressive exchange of different views, which, even in case where it sounded personal, did not really aim at the persona but his ideas and interpretations. There were many such exchanges at conferences and sometimes also in articles [1].

[4] The first attempt to bypass QFT and formulate particle physics solely in terms of the S-matrix is due to Heisenberg [6]. 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.

The ferrocity of the struggle on the side of the S-matrix purist against QFT 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 except gravity) in form of the S-matrix bootstrap into the dustbin of history.

There is however a somewhat ironic 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 the context of two dimensionsial factorizing models (section 7) were completely sound; in connection with the *nuclear democracy* setting of boundstates they turned out to be extraordinarily successful within a more modest setting of two-dimensional factorizing models [4]. 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 later part of the essay (section 7).

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 [8] to the *duality* requirement in which a formal crossing property (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 the most fashionable topic of present day particle theory, as a result of its bizarre consequences it also entered deeply into the popular science culture.

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, one of the area which attracted Swieca's interest.

With an enhanced confidence in the physical relevance of QFT, it was possible at the beginning of the 60s to revisit some old problems of QFT which, despite the new methodological progress of renormalization theory, did not loose any of their conceptual challenge. One of those was the problem of "particles versus fields"[5]. Already in the 30's, shortly after the discovery of vacuum polarization noticed first in studying conserved currents of charged free fields by Heisenberg, Furry and Oppenheimer [7] perceived to their surprise that interacting Lagrangian fields applied to the vacuum inevitably generate infinite (increasing with with perturbative order) vacuum-polarization "clouds" in addition to the desired one-particle component. It maybe helpful to present some details of these observations within a modern conceptual setting. Heisenberg's observation in modern

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[5] 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 [5].

terminology was that a "partial charge" in a spatial sphere of radius $\not R$ and volume V

$$Q_V = \int_V j_0(x,t) d^3x \tag{1}$$
$$j_\mu(x,t) =: \phi^*(x,t) \overleftrightarrow{\partial}_\mu \phi(x,t) :$$

diverges quadratically and he realized that such an object, which would be perfectly finite (even zero on the ground state) in QM, must diverge in QFT as a result of the presence of particle-antiparticle creation operators whose appearance is characteristic for QFT in contradistiction to QM. The occurance of such particle-antiparticle pairs is what is meant by the terminology *vacuum polarization.* In the interacting case (the one studied by Furry and Oppenheimer) the number of such pairs is actually infinite (vacuum polarization "cloud"). In both cases the vacuum polarization contribution disappears in the limit $V \rightarrow \infty$ so that $Q\Omega = \lim_{V\rightarrow\infty} Q_V \Omega = 0$ i.e. the charge of the vacuum is zero as expected.

Infinities in QFT inevitably indicate that certain concepts have not been properly understood. In the case at hand it is the singular nature of fields and currents. Very different from classical fields, covariant fields of QFT are "operator-valued" distributions i.e. objects which only after smearing with Laurant Schwartz test functions become (mostly unbounded) operators. The definition of a partial charge with finite vacuum polarization, which has the property of loosing its vacuum polarization cloud in an appropriately global limit, was first formulated by Swieca et al. [9]. We will return to these issues in section 4 when some of the mathematical details will be presented. There we will explain how in terms of spacetime smearing one defines a (dimensionless) partial charge $Q_{R,\Delta R}$ in a sphere of radius R with a shell of thickness ΔR for the vacuum polarization cloud to attenuate in such a way that the norm of the state $Q_{R,\Delta R}\Omega$ follows (apart from a logarithmic correction) for $\Delta R \rightarrow 0$ a dimensionless area law $area/\left(\Delta R\right)^2$. This preempts the behavior of (dimensionless) *localization entropy* which, as a result of the common vacuum polarization cause, also obeys such an area law even though in this case one cannot delegate the problem to the use of distribution theory since the localization entropy has no representation in terms of testfunction smearing. Hence QFT contains some quantities which, in contradistinction to QM, approach infinity in the limit of sharp boundaries. ¿From a conceptual point of view this is not much different to the volume divergence of in quantum statistical mechanics, in fact there are rather convincing arguments that both (heat bath and localization thermality) are related [10]. In most articles a momentum space cutoff is introduced when it comes to these sharply localized quantities. But this is awkward from a conceptual point of view because the word "cutoff" is used to express the physical validity of a theory at very high energies. Whereas it maybe very well true that a theory beyond a certain range may loose its physical validity, one cannot blame this on the vacuum polarization which in is a consequence of the causal locality principle. The present discussion as well as its entropic counterpart shows that these are properties within QFT i. e. in order to construct these objects one may need sophisticated tools (in the case of localization entropy the split property [10]) but everything is done within the given theory.

Some additional historical remarks about the use of distribution theory in QFT are in order. Already in the early 50s it became clear that without its use QFT would remain in a metaphoric state, consisting mainly of computational recipes as can be witnessed in many contemporary textbooks. Distribution theory was after group theory the main mathematical tool for particle theory and its use by quantum field theorists begun in the 50s. Swieca's adviser at the University of Sao Paulo, Werner Guettinger, was such a particle physicist in the forefront of this trend. As a result of a close cooperation with French mathematicians (including Grothendiek, Dieudonné and Schwartz [6]) mathematics and also particle theory at the University of Sao Paulo participated in this development quite early. With Jose Giambiagi these new mathematical tools became also known in Argentina at a quite early time.

The ubiquitous presence of polarization clouds imply a drastic conceptual revision of what one has learned about the relation between particles and fields in QM where (using the second quantization setting) the application of the elementary basic field to the vacuum generates a one-particle state, whereas the application of appropriately (with the help of bound state wave functions) smeared products of the basic field generate a bound state. In interacting QFTs the presence of infinite vacuum polarization clouds make it impossible to create a one-particle state by applying a field (more generally a compactly localized operator) to the vacuum without an attached polarization cloud.

Although the role of vacuum polarization in separating the structure of QFT from that of QM had its historical roots in the relation of global charges with conserved currents, the vacuum polarization aspects of QFT pervades almost every issue. This can be nicely illustrated in terms of formfactors. A *formfactor* is a general terminology used for matrix elements of a field between "bra" states, consisting of say n-k outgoing particles, and k incoming particles in "ket" states[7]. Taking the simplest case of a scalar field $A(x)$ between spinless states of one species it reads

$$\begin{aligned} & {}^{out}\left\langle p_{k+1},...p_n\left|A(0)\right|p_1...,p_{k-1},p_k\right\rangle^{in} \\ = & {}^{out}\left\langle -p_k^c,p_{k+1},...p_n\left|A(0)\right|p_1...,p_{k-1}\right\rangle^{in}+p_k^c-contr \end{aligned} \tag{2}$$

in words the incoming momentum p_k is "crossed" into the outgoing $-p_k^c$, where the c over the momentum indicates that the particle has been crossed into its antiparticle and the unphysical (negative mass-shell) momentum turns out to be defined in terms of analytic continuation properties (which in turn follow from the modular localization properties of QFT [4]). The $p_k^c-contr$ are contraction terms i.e. delta functions from inner products $\langle p_k|p_l\rangle$, $k+1\leq l\leq n$ multiplied with lower formfactors which are there in order to preserve analyticity (they compensate a nonanalytic delta contribution in the first term).

The relation (2) would be physically void if it would not come with an assertion of analyticity which connects the unphysical backward mass shell momentum with its physical counterpart. This kind of crossing property permits to reduce all formfactors of a localized operator A to the particle components of a "bang" on the vacuum $A\Omega$, the name for a sharp acoustic excitation here serves as a metaphor for local excitation of the

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[6] When I came to the USP for the first time in 1968, there were courses on distribution theory in the physics department given by a former PhD student of Laurant Schwartz.

[7] Here we make the standard assumption of scattering theory, namely the validity of *asymptotic copleteness.* In the absence of zero mass it is not only valid in paerturbation theory, but it also has been verified in exactly solved factorizing models (section 7)..

vacuum which contains the full energy-momentum spectrum up to infinity. In this setting the various components of the vacuum polarization cloud associated with the localized operator A are described by

$$\langle p_1, ...p_n \left| A \right| \Omega\rangle \, , \; n = 1, 2, ... \tag{3}$$

I prefer this terminology of a bang on the vacuum to that of a "broiling soup" which for short times is allowed to violate the energy-momentum conservation law. Admittedly both pictures use a somwhat metaphoric terminology, but the former has at least a precise physical content. It also gives a concrete meaning to the adaptation of *Murphy's law* to particle physics:

Claim 1 *What is not forbidden (by superselection rules) to couple does indeed couple*

Whether one considers this a benevolent or malevolent form of Murphy's law depends on ones aim; if one wants to apply operator methods from QM[8] (i.e. outside the the range of Murphy's law) to QFT one is in for serious trouble; if on the other hand one looks for a framework of a fundamental theory in which the different models are realizations of a few underlying principles the the law is an unmerited blessing. After this short step into the presence, let us continue our historical past.

In the post renormalization period of QFT the important step in the clarification of the field-particle dichotomy was the derivation of the S-matrix from the large-time asymptotic behavior of fields. One surprizing result was that in spite of the central role of the notion of a particle in measurements, the ontological status of particles in QFT is considerably weakened as compared to QM. The Lehmann-Symanzik-Zimmermann (LSZ) asymptotic condition and the Haag-Ruelle scattering theory [3] are landmarks in the unravelling the particle-field dichotomy. It became clear that quite different what one expects on the basis of an analogy with QM, mutiparticle states only acquire a frame-independent meaning through scattering theory i.e. at asymptotic large times. Sharply localized states in interacting theories always contain infinite vacuum polarization clouds and their presence is the most characteristic property of QFT[9]; their mathematical control requires often conceptually quite challenging ideas.

This research 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[10]. 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

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[8] This will inevitably lead to infinities and cutoffs which have not only no intrinsic meaning, but also convert the originally local theory into something which apart from mathematical problems has no known conceptual position.

[9] 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.

[10] The earliest such theorem can be found (under the name Jost-Schroer theorem) in [11]. A recent more powerful generalization characterising the absence of interactions in terms of properties of vacuum polarization clouds will appear in a paper by J. Mund [12].

(spinorial) field equations. Whereas the latter is highly non-unique (for a given physical spin there is always an infinity of spinorial wave functions), 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 scattering theory of particles within the setting of QFT[11].

The old pre-renormalization struggle with ultraviolet divergences came to an end when message that pointlike quantum fields are by their very nature rather singular objects which required testfunction smearing was headed also in n-th order perturbation theory where, together with causal locality, it led to the statement that the time-ordered correlation functions can be determined recursively from their lower order contributions up to a new delta function term (which only contributes on the total diagonal i.e. if all localization points coalesce). Together with a theorem about the structure of pointlike composites of the free fields [11] this fixes the form of the "counter-terms" of renormalization theory. If the iteratively determined part of the correlation function (together with an restriction on the singularity degree of counterterms) has a short distance behavior which can be majorized by a certain short distance scaling degree independent of the order of perturbation theory (determined by the power-counting limit), the resulting perturbation theory depends only on finitely many parameters and is referred to as "renormalizable". It is believed that only renormalizable theories have a conceptional mathematical reality outside perturbation theory[12]. This completely finite and cutoff formulation existed thanks to Epstein and Glaser [14] since 1973 and is the preferred renormalization setting for those who consider renormalization a foundational problem which should not be left to a set of computational recipes which perpetuate the mystic of ultraviolet divergences and their combat by ad hoc cutoffs which have no mathematical nor physical well-defined status within the assumed local original theory. The Epstein-Glaser perturbation theory is not the only cutoff-free formulation, but it is the one with the clearest relation to the underlying locality and spectrality principles and consequentially with the greatest distance to the quantization parallelism to classical field theory in form of the Lagrangian approach.

In these remarks I tried to sketch the Zeitgeist and the scene which Jorge André Swieca encountered in the beginning of the 60s when he entered particle physics and which he, partially together with others, contributed to shape through the two decades of his scientific activity.

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[11] These ideas about the particle-field relation appear for the first time in [13].

[12] The perturbative series in QFT are all known to diverge; so RPT has no conceptional significance for the existence of a model (a unique situation which has no counterpart in other branches of theoretical physics). However in the special setting of two-dimensional factorizing models (section 6) all the exactly solved models are also renormalizable in the perturbative sense.

2 The Haag-Swieca work on phasespace degrees of freedom

What makes Jorge Andre Swieca an interesting figure in connection with a review of particle physics of the 60s and 70s is that, although he started his career in the highly conceptual-mathematical oriented group of researchers on local quantum physics (LQP) which formed at the beginning of the 60s at the University of Illinois in Champaign-Urbana around Rudolf Haag, he belonged to the very few individuals from that background who used their basic knowledge not only in to advance the conceptual framework of LQP, but also in order to solve problems closer to the application of QFT to the ongoing particle physics. This allowed him to have a more critical and in many cases also more profound access to solutions than others. It is the purpose of this essay to exemplify this by reminding the reader of some of them and arguing that they have been forgotten prematurely.

To follow the ideas of Swieca is also pleasant from another point of view. The subject of spontaneously broken symmetries and the Schwinger-Higgs screening mechanism were certainly quite competetive subjects at the time, but Swieca's contributions to these topics were quite original and different. I am quite sure that revisting these subjects with a modern hindsight will be a new experience for many in the younger generation.

This is in particular true about his first paper, after having obtained his PhD at the University of Sao Paulo in 1964, a paper written together with Rudolf Haag at the University of Illinois in 1963 under the very ambitious title "when does a Quantum Field Theory describe Particles?" [13] The authors aim at a completely intrinsic conceptual understanding of particles solely in terms of localization properties of fields. At that time the idea was gaining force that every property of QFT must be traced back to causal localization since this is the only autonomous principle[13]. The quantization of theories with a maximal velocity (QFT) as compared with those without (QM) are much more restrictive; whereas QM either nonrelativistic or its relativistic DPI version [5]) is not subject to restrictions (beyond the requirement that the interaction potentials are not too long ranged) interactions in QFT are significantly more curtailed. According to renormalizable Lagrangian quantization the local couplings ony consist of finitely many coupling constants and accepting the widespread belief that higher spin interactions are ill-defined (nonrenormalizable) there exists only a finite number of renormalizable interacting models.

The remarkable finding in the Haag-Swieca paper was that the locality principle in QFT requires more phase space degrees of freedom than the famous well-known law of a finite number of degrees of freedom per unit phase space cell in QM; in fact their result was that the phase space cardinality does not surpass that of a compact set. It was Haag's old dream ever since the birth of local quantum physics (LQP) or algebraic QFT (as it is often called) that relativistic particles, as first intrinsically classified (i.e. without use of classical quantization-parallelism) by Eugene Wigner, are the asymptotic

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[13] This was not the impression one was getting from tsking standard textbooks. For this reason the terminology *local quantum physics* (LQP) was used whenever the underlying principles and their consequences and not the (perturbative) quantization were the main focus of interest.

stable and unique carriers of the locality principle. Whereas in a given theory there are myriads of fields ("interpolating" fields in the terminology of LSZ) which have the same fleeting observational content, particles are autonomous unique elementary objects. Whereas fields are the carriers of the locality principle, the asymptotic particle states are the measured objects. Assuming the existence of an spectrally isolated one-particle state (the mass-gap assumption), Haag's idea that the spectral and locality properties are sufficient to derive the LSZ asymptotic condition was beautifully vindicated. But the title of the Haag-Swieca paper was more ambitious since the new aim was the very existence of one particle states. Although there is no definite answer up to this day to the central question which 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 *phase space* in QFT is seriously addressed. Whereas, as mentioned 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 prerequisites of the Reeh-Schlieder theorem[14] by admitting only such operators Q which from a subset of the local algebra $\mathcal{A}(\mathcal{O})$ consisting of all O-localized operators whose norm is below a certain bound on the vacuum Ω namely (copying from their paper)

$$\|Q\| \leq e^{\kappa r} \|Q\Omega\| \tag{4}$$

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 crucial 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, a problem which was left open by the LSZ-Haag-Ruelle scattering theory. 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[15]; from the times of Furry

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[14] The Reeh-Schlieder theorem [3] 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.

[15] Even the existence of a compactly localized one-particle state with no additional vacuum polarization admixture is inconsistent with the presence of interactions. Only for the noncompact wedge regions this is possible; but even in this case the domains of definition of such vacuum **p**olarization-**f**ree-**g**enerators

and Oppenheimer it was already known that it is *not possible to locally create a pure one-particle state* without the admixture of vacuum polarization clouds (formed from particles-antiparticle pairs). In other words although states with a prescribed number of particles exist no such state can be locally generated; 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 which they relate to the representation theoretic (Wigner's Poincaré representation theory) tensor product strucure which according to my best knowledge is the only consistent and unique way of avoids contradictions of massive particles[16] with field localization in the presense of interactions. Only in free fiel theory there is a close relation between particles and smeared free fields with the mass-shell projection of the test function being the particle wave function.

¿From a contemporary point of view the reason behind this contrast is the substantial conceptual difference between the quantum mechanical "*Born localization*" (in the relativistic context the Born-Newton-Wigner localization) which formed our physcal and mathematical notion of particles and the field theoretic *modular localization;* for a recent treatment of this subject, which often falls prone to misunderstandings, see [15][5]). The way 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 [5]. 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 [13].

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.* Compact subsets in infinite dimensional Hilbert spaces are smaller than bounded sets and nuclear sets are even slightly more meagre.

This important step was taken two decades after the Haag-Swieca paper by Buchholz and Wichmann [16]. 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 [17]. Since the thermal representation is unitarily inequivalent to the vacuum representation this is not as simple as its sounds.

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

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(PFGs) have very restrictive properties.

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

operator $e^{-\beta H}$ to the local algebra $\mathcal{A}(\mathcal{O})$ defines a nuclear map Θ

$$\Theta_{\mathcal{O},\beta} : \mathcal{A}(\mathcal{O}) \to H, \quad A \to exp(-\beta H)A\Omega, \; A \in \mathcal{A}(\mathcal{O}) \tag{5}$$

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 of the modular operator $\Delta_{\tilde{\mathcal{O}}}$ which is associated with a slightly bigger spacetime region $\tilde{\mathcal{O}} \supset \mathcal{O}$ [3]. The modular operator is a mathematical object which is directly related to the algebra $\mathcal{A}(\mathcal{O})$.

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 [18]. 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 [19], 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.

3 Lost knowledge and the Maldacena conjecture

The knowledge about the phase space restrictions which distinguish pure mathematical models of QFT (axiomatic QFT) from those with physical relevance remained limited to the rather small community of LQP. With increasing frequency since the 80s most practioners view QFT basically as a collection of computational recipes. This is sufficient if one adresses known computational tools as scattering theory or renormalized perturbation, at least as long as one does not forget their limitation i.e. in the case of perturbation theory the fact the perturbative series is not even Borel summable and hence although one can draw suggestive ideas from it, perturbation has nothing to say about the *existence* of a model. But even though one cannot decide whether a model associated to Lagrangian quantization exists, one has all reasons to be quite confident that if it exists it will be a theory whose degrees of freedom cardinality is that as postulated by Haag and Swieca.

A violation would lead to the loss of temperature states (or at least the appearance of a Hagedorn temperature) and the breakdown of the QFT adaptation of the causal propagation property thus leading to a clash with properties attributed to the Lagrangian quantization. Of course the violation of any of those properties does not create any mathematical problem.

The loss of knowledge about these subjects of the 60s did not remain without consequences with respect to the issue of the anti de Sitter-conformal field theory (AdS$_{n+1}$-CFT$_n$) correspondence. It has been known for a long time that QFTs on n+1 dimensional anti de Sitter spacetime (de Sitter spacetime with negative curvature) and QFTs on n-dimensional conformal models on n-dimensional Dirac-Weyl compactified Minkowski space share the same vacuum-preserving spacetime symmetry group $\overline{O(4,2)}$ and as a result of the close connection between the concept of localization and covariance it always appeared plausible that there could be in addition to the shared spacetime groups also a local correspondence between these two models in different spacetime dimensions; though it could not extend to the point-like generating fields simply because there is no invertible pointlike transformation of a spacetime to a lower dimensional one.

The issue lay dorment for many years the model only served as a remainder that the Einstein-Hilbert equations admits solutions with closed timelike worldlines and hence had to be supplemented by additional requirements which exclude such "time-machine" solution.

The issue returned when Maldacena [20] proposed that the old idea that the anti de Sitter spacetime AdS_5 and conformal quantum field theory in one less dimension CFT_4 could share more than just the spacetime symmetry group $O(4,2)$. He proposed the idea that a possible connection between the two QFTs could perhaps support another independent speculative idea that gauge theories may be related two some form of spin two gravity theory; this did not make the AdS spacetime more physical, but as a mathematical-theoretical laboratory such a connection together with the AdS-CFT mathematical underpinning would have been been very unusual.

In the context of a supersymmetric N=4 Yang-Mills theory, which was the only 4-dimensional theory for which the vanishing of the Beta function in low order had been established, this has nourished hopes that the theory may be conformally invariant and therefore serve could serve as a candidate in a CFT-AdS correspondence. On the AdS side the Maldacena conjecture placed a theory which contained a supersymmetric interaction involving a s=2 symmetric tensor representing a 5-dim. gravitational field, which represents the gravitation theory whose related to gravity in 5 dimensions.

Two remarks on this conjecture are in order. In the 70s there have been rigorous and elegant methods to prove the absence of radiative corrections to certain anomalies as well as of the Beta function[17]. They consisted in combining the parametric Callen-Symanzik equations with the Ward identities in order to abstract an equation for which the nonvanishing of a certain coefficient in lowest perturbative order already establishes the identical vanishing of the desired expression to all orders. Apparently the knowledge about these techniques have been lost, so that it becomes a matter of faith to accept the

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[17] The Beta function is known to appear in the trace ot the enrgy momentum tensor and its vanishing is the prerequisite for conformal invariance in the sence that the zero mass limit exist and is conformal invariant.

claimed properties from the lowest order computation. When I claim that knowledge has been lost after the 1980 string revolution I have such illustrations in mind.

The second remark which adds weight to the title of this section is the following. Even if one does not worry about details about the conformal status of the supersymmetric N=4 Yang Mills theory and the prescise nature of the object on the AdS side which correspond to it, there is the big problem to understand why both of the theories should be physical in the sense of having the physically required phase space degrees of freedom in their respective spacetime dimensions in the sense of the previous section. Already simple minded arguments would suggest that starting from a 5-dimensional *physical* AdS theory and reordering them according to the spacetime structure of a 4-dimensional conformal QFT would lead to an abundance i.e. to precisely such a situation (breakdown of causal propagation) which Haag and Swieca ruled out by their degrees of freedom requirement. If one starts on the other hand from a physical CFT_4 model, the degrees of freedom are too "anemic" in order to fill the AdS_5, they will hover near the boundary of AdS and are unable to "fill" the higher dimensional spacetime in order to produce a physical QFT. The opposite problem of an "overpopulation" could threaten the conformal side, not in a mathematical sense but in the sense of obtaining a sick physical theory.

This simple minded argument has been mathematically established [21]. It can be nicely illustrate in case of a free AdS field where one can explicitely see that the CFT is a *generalized free field* whose Kallen-Lehmann spectral funtion increases in such a way that it is pathological[18] in the sense of the previous section. The other direction i.e. starting from a conformal free field is a bit tricky since the direct use of pointlike fields is not possible. Since there exists however a one-to-one relation between certain spacetime regions a correspondence between operator subalgebras is straightforward. The local AdS-CFT correspodence as a statement of a structural property, including the mismatch of degrees of freedom, has been proven by Rehren [21]. Obviously correspondences between theories in different dimensions cannot be formulated between pointlike fields. They can be established between noncompact (wedge-like) regions, and by taking intersections between the associated algebras one can obtain the fine localization structure on each side of the correspondence [21].

The equality of degrees of freedom in a relation between QFT of different dimension is strongly related to the equality of the spacetime symmetry groups. It does not occur in the holographic relation between a QFT in a bulk region and that of its horizon. Such holographic relations are necessarily *degrees of freedom reducing holographic projections* accompanied by the reduction of the symmetry group: of the 10 parametric Poincaré group in 4 dimensions only a 7 parametric subgroup survives the projection. In the case the cardinality of degrees of freedom on the lightfront corresponds precisely to what is "physical" in the sense of Haag and Swieca.

The fact that there have been more than 6000 publication on such a relativ narrow subject as the conjecture about AdS$_5$-CFT$_4$ correspondence (on which according to the above remarks one anyhow cannot expect a physical solution) is a measure of the depth

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[18] In physical theories the operator algebra of a spacetime region $\mathcal{O}$ is equal to that of its causal completion $\mathcal{O}''$. In the case of presence of too many degrees of freedom there are "*poltergeist" degrees of freedom entering "sideways": so that the causally completed algebra becomes bigger* $\mathcal{A}(\mathcal{O}'') \supset \mathcal{A}(\mathcal{O})$.and the timeslice principle [3] is violated.

of the crisis which particle theory entered after the end od the 70s.

An observer knowing the past and returns after a 30 year absence and takes a look at the present situation may suspect that the physical facts have changed, that manifolds with time-machines as AdS and QFT without thermal state and without causal propagation (breakdown of time-slice property) became meanwhile acceptable because of some new physically motivated facts which support such ideas. But this is not the case; the sad fact is that this decline occurs because the generation, which has been raised in the shadow of a TOE, has become less critical and more metaphoric in their pursuit of particle theory. They think that particle theory can be trained like a dog to be obedient to their ideas about a TOE; indeed string theory does not admit thermal states for all temperatures and hence requires the abandonment of the degree of freedom picture of the previous section.

Large parts of knowledge has been lost, and with the unshakable confidence which only an ideology as a TOE supports (but which is alien to the autocritical spirit of traditional science) there is in the eyes of many (who entered particle theory after 1980) no virtue to loose time in studying old ideas while there is the historical chance of participating in the project of a theory of everything. This explains why there has been (and still is) this incredible number of papers on a subject which only by ideology and certainly not by scientific content justifies that many publications.

The fact that an increasing number of physicists who have been formed in the presence of these problems are now referees in formerly reputable journals is certainly aggravating the situation and does not leave much hope for the near future. Another detrimental aspect of this situation is that of premature (before a problem has been solved) given awards which confer to award winner the aura of protection and unvulnerability which is respected by referees and editorial boards of journals, have essentially destroyed the old "Streitkultur" at the time of the 60/70s which was important to keep particle theory on a high level.

4 Spontaneously broken symmetries

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 [22]. 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.

In the Lagrangian setting Goldstone's derivation established the existence of a symmetry breaking in a particular model and it was left to the reader to decide take this either as a property of a special model or class of models or to muster enough faith to belief in a general structural theorem of QFT behind this observation. In order to prepare the ground for a more autonomous discussion[19] it was necessary in a first step to state

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[19] An understanding which does not refere to the way a model has been constructed but only uses

the meaning of quantum symmetry in a way that a spontaneous breakdown of such a symmetry looks like a meaningful natural generalization.

The starting point Swieca and collaborators took was that of a conserved quantum current and its expected role in implementing a symmetry on local operators but now with a more precise definition of a partial charge in terms of test function smearing of the zero component of the current.

The test function smearing of the current tames the vacuum polarization cloud and for the "tamed" partial charge contained in the region $|\mathbf{x}| \leq R$ one defines

$$\begin{aligned} & Q_R = j_0(f_R, f_d) \qquad (6) \\ & f_d = 0 \ \ for \ \ |x_0| \geq d, \ f_R(\mathbf{x}) = \begin{array}{c} 1 \ for \ \ |\mathbf{x}| < R \\ 0 \ for \ \ |\mathbf{x}| \geq R + \varepsilon \end{array} \end{aligned}$$

Using the conservation law for the current one can then show that on any local operator $A \in \mathcal{A}(\mathcal{O}_R)$ the commutation relation with Q_R is the same as with the global charge i.e. algebraically there is no divergence problem of the partial against the global charge but of course one wants convergence properties on states and this is where the control of vacuum expectations is essential and this is also where the difference between bona fide symmetries and spontaneously broken symmetries are beginning to show up.

The the strength of the divergence in the limit $\varepsilon \to 0$ (the limit of sharp partial charge) can easily be computed from the two point function of the current and follows, apart from a possible logarithic ε-divergence the leading term follows the dimensional rule, which for a dimensionless charge would be $\frac{area}{\varepsilon^2}$ with the area being proportional to R^2; for the leading term the details of the test function do not play any role. The large distance limit in which one expects the global charge to emerge is very different. First one observes that even in the best of all cases (namely the current associated to a free field) the convergence to the global charge for $R \to \infty$ is only in the sense of weak convergence and even then only on a certain dense set of states. This is easily proven for theories with a mass gap. At this point there is precisely one step which could spoil the convergence namely the presence of a massless and spinless particle which couples to the current and prevents the weak convergence on the vacuum. This is the famous Goldstone boson. The proof that the spontaneous breaking requires the presence of a $\delta(\kappa^2)$ contribution in the Kallen-Lehmann function of the current. A very beautiful proof of this theorem with the help of the Jost-Lehmann-Dyson representation was given by Ezawa and Swieca.

Note that the famous field vacuum expection value (the Nambu-Goldstone "condensate") is not an intrinsic aspect of spontaneous symmetry breaking but a technicality of its implementation in certain Lagrangian models. For this reason one will not find such concepts in structural investigations; as useful as they may be in model calculation, at the end of the day they disappear from the observables which are dominated by masses and spin of particles as well as scattering amplitudes and formfactors of currents.

The state of art on symmetry versus spontaneous symmetry breaking of the 60s can be found in the 1970 Cargese lecture notes. In these notes these ideas are also adapted to nonrelativistic many body problems. In that case the vacuum polarization effects are

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intrinsic properties of its presentation in terms of expectation values.

absent and the locality principle is replaced by assumptions about the range of interactions.

In the years after 1970 there were several refinements.

Since the problem of conserved currents was the first in the history of QFT which brought the issue of vacuum polarization into the fray, it suggests itself to ask whether other later contexts for vacuum polarization led to similar surface proportionality. This is indeed the case for the *localization entropy*

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 [23][25] *screening mechanism*, which typically leads to a mass gap in gauge theories (and which was independently discovered by Brout and Englert [26]). As in the case of the Goldstone spontaneous symmetry breaking versus the Heisenberg ferromagnet, it was preceeded by Anderson's [27] 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 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 [9] 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 [28] 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 [29].

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 [30] 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.

5 The Schwinger-Higgs screening mechanism and the standard model

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 question to understand under what circumstances such integrals vanish. In that case the conservation law of charges become ineffective and copious particle production of "screened" particles would violate the charge selection rules which holds in the electrically charged phase . Of special physical interests for the discussion of screened charges are identically conserved currents of the Maxwell type

$$j^\mu = \partial_\nu F^{\mu\nu} \tag{7}$$

Swieca showed [31] 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 resulting in a weakened smoothness/analyticity properties of the electromagnetic formfactors. The other side side of the medal is the statement that a massive "photon", which requires more analyticity, is only possible in case of a vanishing 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*[20].

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 [35] some beautiful work on a concrete two-dimensional model which Schwinger [23] 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 [24], spontaneous symmetry-breaking of a continuous symmetry group cannot occur for d=1+1[21], 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

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[20] Despite the similarities in the Lagrangians the point of view in the paper by Higgs [25] and similar publications by Kibble [32] as well as Brout and Englert [26] are quite different from the present screening setting.

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

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.

Neither Schwinger's nor Swieca's understanding of the mechanism of screening was without historical precedent. In the setting of a quantum mechanical Coulomb gas the idea goes back to Debeye (Debeye screening) and the reader finds a nice presentation which satisfies all mathematical physics exigencies in [39][33]. The point is that under certain circumstances the potential for large distances is not of Coulomb but rather of Yukawa type; the quantum mechanical system becomes self-screening. A closely related screened system is a plasma.

In QFT charge screening does not need the presence of many Coulomb charges, rather the vacuum polarization inherits this role. The result is a much more radical kind of sreening in which the unscreened and the screened system are unitarily inequivalent and live in different Hilbert spaces[22]

It is somewhat ironic that the Schwinger-Higgs screening mechanism, whose precise understanding is of crucial importance for contemporary particle physics, is not as well understood as Goldstone's spontaneous symmetry breaking with which it is sometimes confused ("fattening of the photon from swallowing the vacuum condensate of the spontaneous symmetry breaking"). But the mechanism of symmetry breaking in both cases is quite different. In spontaneous symmetry breaking the integral over the charge density diverges, whereas in the screening case it vanishes.

$$\lim_{R\to\infty} Q_{R,\Delta R}^{spon}\psi = \infty, \quad \lim_{R\to\infty} Q_{R,\Delta R}^{sreen}\psi = 0 \tag{8}$$

A zero total charge is not a basis for a charge symmetry, i.e. the particles setting in place the screening process can be copiously produced. The physical manifestation of the first breaking is the appearance of a zero mass particle ("Goldstone boson") whose model independent existence, as mentioned in the previous section, was established in a theorem (using the Jost-Lehmann-Dyson spectral representation) by Ezawa and Swieca [28] whereas the screening theorem showing the existence of a "massive photon" (at the loss of half the degrees of freedom of the complex scalar field in the Higgs sreening model so that only a real sclar field remains) is due to Swieca [31]. Note that the symmetry-breaking in the screening mode is that of the breaking of the electric charge conservation[23]. To talk about a symmetry-breaking of local gauge symmetry is somewhat misleading because local gauge symmetry is a name for a formalism to get from an unphysical but technically useful setting back to local observables which has nothing to do with physical symmetries.

The standard version of the Higgs mechanism does not mention the screening point of view which is due to Schwinger and Swieca, but apparently has not been emphasized or noticed by Higgs. This physical shortcoming does not render neither Higgs' nor the Brout-Englert version incorrect because at the end in QFT it is the renormalized correlation functions of the local observables and not the physical ideas and mnemonic crutches which

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[22] The fact that the sceened Schwinger model in the limit of short distances passes to the charged Jordan model illustrates this point [34].

[23] It is important to remember that scalar QED has one parameter more (the $g\left|\Phi\right|^4$ term) than its spinor counterpart.

are used during their constructions which define its intrinsic physical content. However the idea that idea that scalar electrodynamic admits another "screened" mode in which no additional Higgs field is needed but the degrees of freedom regroup in such a way that a real component of the complex field supplies the additional transverse degrees of freedom by which vector-mesons differe from photons. Since massive fermions do not permit a perturbative self-screening, one uses always the perturbatively accessible scalar screening mechanism in which case the electric charge becomes screened but the spinor charges continue to be associated with a conserved global charge. The constrasting version is that of Brout-Englert of a two-step process in which the zero-mass Goldstone boson from the global Goldstone symmetry-breaking lift the photon to a vector-meson.

The relation between smooth momentum behavior and localization properties which Swiece observed in the course of proving his theorem was the starting point of Buchholz and Fredenhagen [40] who proved that massive superselection sectors with mass gaps on an algebra of local observables are in the worst case generated by semiinfinite stringlike localized fields instead of pointlike fields. The influence of Swieca's ideas is acknowledged in the text of this and other papers of these autors written at the same time.

In his proof Swieca noticed that in theories with a Maxwell structure (7) the non-vanishing of the charge requires the presence of certain nonlocal properties which are absent in case of screening. In the 60s and 70s there was the vague conjecture that electrically charged particles cannot be particles in the sense of Wigner i.e. affiliated with irreducible representations of the Poincare group. With other words there was a suspicion that behind the infrared divergencies of LSZ scattering theory applied to QED there was something more dramatic than the infrared treatment of Bloch Nordsiek and the more QFT compatible description of Yennie, Frautschi and Suura which led to finite soft photon inclusive cross section revealed. There were some soluable two dimension models in which the particle mass shell figuratively speaking is sucked into the continuum so that instead of a particle the theory described "infraparticles". In these models the fields which led to such two-point functions were not pointlike but rather semiinfinite stringlike. But it took another two decades to show that this is precisely what happens with fields of electrically charged particles [41]. Here the charge flux through arbitrarily large surfaces (the quantum Gauss flux) assures the the best (tightest) possible localization cannot be better than a semiinfinite spacelike string. This is quite interesting since the appearance of necessarily noncompact localized objects in a theory which was thought to have pointlike generating fields is somewhat unexpected.

In fact one such object is probably known to most readers. It is a formal expression for a physical electrically charged scalar field

$$\Phi(x;e) = \text{"}\phi(x)e^{\int_0^\infty ie_{el}A^\mu(x+\lambda e)e_\mu d\lambda}\text{"} \tag{9}$$

This Jordan-Dirac-Mandelstam (DJM) expression appeared (according to the best of my knowledge) for the first time in a 1935 paper by Pascual Jordan as the best description for the field of a charged particle in a situation in which non of the pointlike objects is physical. What makes the situation so difficult is that this physical object has to be introduced by hand, it is not part of the perturbative renormalization formalism but its perturbative construction requires setting up a seperate formalism. The screening situation has a different problem. As with all situations involving massive vectormesons (including massive QED [42]) the gauge formalism (Gupta-Bleuler or BRST) has no intrinsic physical meaning, its only purpose is that of a catalyzer: it helps to get over the power counting barrier; once the renormalization has been done one can return to the ghostfree physical vectorfields of short distance dimension 2 times logarithmic corrections. But in dowing this, there remains a bad taste in the mouth because one is forced to move between two description which have no precise mathematical relation with each other namely the so-called renormalizable and the unitary gauge. Even the best treatment of screening [36] in which the physical content of a massive vectormeson interacting with a selfconjugate (the charge has been screened) scalar field is most clearly presented comes with this problem which first was noticed in massive QED.

Behind the Schwinger-Higgs screening mechanism hides a fundamental problem whose understanding is of great importance for the future of the standard model and more generally of interactions involving massive higher spin fields: does the requiement of compact localization in the presence of interacting $s \geq 1$ require the presence of lower spin "satellites"? This would be reminiscent of supersymmetry, except that it would be related to the most basic principle of QFT and to the mind game of some physicists. A better comparision may be the zero mass Goldstone boson which the theory needs in order to break global charge conservation in the presence of a conserved current.

Whereas in Schwinger's original treatment it was very hard to identify the gauge invariant content of the Schwinger model, the Lowenstein-Swieca 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 explain why for short distances the screening passes to charge liberation[24]. 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 [37][38]. 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 an 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

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[24] 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.

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 [40] 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 sent these authors on a much more general track of investigating the connection between localization and particle spectra [43]. 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 $\Psi(x,e)$ 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 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 an open problem 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.

6 The unfinished business of gauge theory

A better understanding of the physics behind gauge theories requires a basic conceptual revision of local gauge invariance in terms of a more intrinsic description of interactions involving $s \geqq 1$ fields. If the fields are massive the minimal spinorial description (for s=1 vectors with s.d.d.=2) has short distance dimension which are above the power counting barrier and continue to grow with increasing physical spin. But by allowing covariant generating fields which are semiinfinite string localized one can always reach the value s.d.d =1 which then opens the possibility to write down interactions which fulfill the power counting criterion and are therefore candidates for renormalizable models. In the massless case there is a much more compelling reason for stringlike "potentials" instead of pointlike "field strength". This and the reason for the quotation marks becomes clear if one compares the possibilities for pointlike covariant fields in both cases.

Whereas in the massive case the infinitely many covariant dotted/undotted spinorial field associated with a Wigner representation (m>0,s) are obeying the following inequalities between the spinorial indices and the physical spin [5]

$$\begin{aligned} &\Psi_{m>0,s}^{(A,\dot{B})},\ \left|A-\dot{B}\right| \leq s \leq \left|A+\dot{B}\right| \\ &\Psi_{m=0,s}^{(A,\dot{B})},\ s=\left|A-\dot{B}\right| \end{aligned} \tag{10}$$

the Wigner representation theory limits the spinorial spins for a given physical spin severely as seen in the second line. Never mind the classical field theory, but in the intrinsic (not relying on classical quantization parallelism) Wigner representation theory and also in QED there is in particular no place for pointlike vectorpotentials for which $s=1$ and $\left|A-\dot{B}\right|=0$. On can of couse enforce the existence of pointlike covariant objects by leaving the setting of quantum theory and playing the game of ghosts known under the acronym of Gupta-Bleuler a BRST (which has a larger region of applicability than G-B. There are certain things which can be done with such a formalism, but it also leads to serious limitations. The fact is that there is clash between the positivity requirements of quantum theory (the unitary transformation properties of photon creation/annihilation operators) and the covariant vector transformation law. The big surprise is that in the massless case the full spinorial formalism for massless fields i.e. *the full spectrum of spinorial indices* in the first line (10) can be recuperated if one admits semiinfinite spacelike strings (any confusion with string theory must be avoided [44]) i.e. fields of the form $\Psi_{m=0,s}^{(A,\dot{B})}(x,e)$ where e is a spacelike string direction. The only prize is a weaker localization: semiinfinite stringlike instead of pointlike.

A $s=1$ vector potential is then of the form $A_\mu(x,e)$ and an $s=2$ potential associated with a field strength which has a linearized form of the Riemann tensor would be of the form of a symmetric tensor $g_{\mu\nu}(x,e)$. These stringlike free fields would fluctuate in x and e, In the case of the vectorpotential this fluctuation of the spacelike unit vector in 3-dimensional de Sitter space (to make the fluctuation more picturesque and on the same footing) space it the reason for the lowering of the short distance dimension in x, namely $s.d.d.A_\mu(x,e)=1$.

In the massive case there is no structural (representation theoretical) necessity to introduce string localized potentials but they nevertherless exist and come with the attractive property of $s.d.d.=1$ independent of spin which at least potentially increases the existence of new renormalizable string interactions. In case of the Higgs screening model if the string formulation fulfills also the finer points of renormalization theory as generalization of the E-G iteration to string localized fields (for which there are good indications) this would lead to a unified treatment without the metaphoric aftertaste from being forced to move between two different descriptions.

The new formalism[25] is expected to address those problems which remained outside the range of the gauge formalism as the question about how to deal with nonlocal physical objects i.e. objects which cannot be described in terms of pointlike generating fields. They would be generated by semiinfinite strings as the example of electrically charged fields and their associated *infraparticles* [45] show. In Yang Mills theories one expects the existence of a much stronger form of semiinfinite string localization which may be the key for the understanding of the expected "invisibility" of gluons and quarks. Whereas in QM particles can be confined into a compact cage by a suitably chosen potential, the only resource which is available to QFT is the noncompact localization of its most basic particle like constituents. However string-like localization alone is not enough as the very visible string-like localized charged particles of QED demonstrate. One must show that the gluon strings are of a very different kind, a point to which we will return with some more speculative remarks.

In any case the only resource which QFT has in order to hide (gluon or quark) degrees of freedom is to prevent them to be pointlike generated. The only presently known way to introduce interactions in four spacetime dimensions is the local coupling between free fields and use stringlike instead of pointlike fields. The only situation in which finite spin field necessitate the introduction of stringlike "potentials" for structural reasons is the case of "potentials" for higher spin field strength. Wigner's representation theory does not envisage a necessity to introduce generating wave functions (and associated fields) localized on higher dimensional subspaces and although the problem of interacting operator algebras is different, there are rather convincing arguments that one never has to go beyond semiinfinite string-like localized generators in the interacting operator-algebraic case either [33].

Since the higher spin string-localized potentials are not Lagrangian objects, the standard perturbation setting (either in operator or in functional integral form) is not an option. Hence the main new technical problem is the adaptation of the perturbative Epstein-Glaser iteration to string fields. The first test of the new theory should be the construction of the stringlike charged fields by keeping all the points e in 3-dim. de Sitter space of the vector-potential $A_\mu(x,e)$ different during the computation and taking their local limit only at the end, just like in the construction of composite fields from Wightman functions. Note that the reason for introducing a ghost formalism ala Gupta-Bleuler or BRST is dispensed with since the fields already have their lowest operator dimension and the BRST invariance is nothing but e-independence. In the zero mass s=1 Wigner case the $A_\mu(x,e)$ exists and has the minimally possible dimension $s.d.d. = 1$, its existence does not have to be bought by sacrifying the Hilbert space of quantum theory via the (intermediary) presence of ghosts. This has an extension to any zero mass $s > 1$, there always exists a "potential" with s.s.d.=1 whose appropriate (higher) derivative belongs to the admitted "field strength" according to the second line in (10).

In the massive case the necessity for either ghosts or string-localization enters through the back door: it renders a theory whose higher spin fields have increasing s.d.d. to s.d.d.=1 "potentials" which lead to renormalizable (in sense of power counting) couplings.

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[25] There is no linear pointlike generated subspace generated by applying the interacting gluon potential to the vacuum in the Yang-Mills case.

Whether the step of working with string-localized potentials is just a trick to overcome the renormalization barrier or whether there remain really string-localized objects in the resulting interacting theory has to be decided case by case.

In QED the electrically charged particles are string-localized (infraparticles) and the physically important currents and field strengths are point-localized; the string-localization of the vector-potential has been fully transferred to the electrical charge carrying field, the string-localization of the potential itself has no *direct* consequence for the field strength which remains point-like. The appearance of string-like charged fields and associated infraparticles are consequences of the weaker localization of the (still) covariant vector-potentials; whereas the e-dependence of the latter can be eliminated by passing to field strength by differentiation, the string localization entered the electrically charged fields in a very nontrivial way, i.e. there are different degrees of non-triviality for string-localization. Different from the logic in the standard treatment of the infrared problem [46][47] the delocalization of charged particles to infraparticles via the QFT vacuum polarization[26] is the primary mechanism and the breakdown of scattering theory and its replacement by a theory of cross sections with finite infrared photon resolution is a consequence. This breakdown of the scattering theory via the infra-particle mechanism is much more radical than the violation of scattering amplitudes in Coulomb scattering by the appearance of logarithmic phase factors [48]. In that case (as in all cases of QM) the structure of one particle states is not affected wheras in QED the free irreducible one electron Wigner state becomes a reducible infraparticle state whose free mass shell has been dissolved into the continuum in the presence of interaction with photons. In fact the string direction of a charged particle spontaneously breaks the Lorentz covariance because a physical charge one state contains actually infinitely many spin s=1 carrying infrared soft photons. The fact that the lattice description has problems to describe these properties even in the abelian case cast some clouds on the claims that the invisibility of the gluon degrees of freedom can be described in the lattice setting.

In the screened scalar QED the only function of the stringlike vector-potential is to render the coupling renormalizable, there is no delocalization on the scalar matter field, the originally complex scalar field just looses half of its degrees of freedom and becomes a real i.e. chargeless field [36]. This suggests the following approach: select among all renormalizable (in sense of power-counting) couplings between a string-localized massive vectorpotential with a real field the one for which for which either the real file or a composite is pointlike there exists a pointlike composite. A similar situation is expected for Yang-Mills fields: there are certain interactions between such string-localized gluons for which certain polynomials of these string-localized fields turn out to be point-localized. The form of the renormalizable interactions and the local polynomials should be solely determinded in terms of pointlike localization requirements; the gauge group is only a mnemonic devise for finding the polynomials in terms os string localized gluons.

The new principle to look for pointlike polynomials within a set of power-counting renormalizable couplings of string-localized objects is also expected to lead to a wealth of models involving higher spin fields.

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[26] In the standard QFT situation the infinite vacuum polarization cloud comes from infinite energies (the local sharpness of a "bang" onto the vacuum) whereas for a bang with an electrically charged field there are also infinitely many infrared photons in the charged bang state.

The previous results about the abelian theories with string-localized vector mesons lead one to expect that the issue of localization plays an even more prominent role. It seems to be quite illusionary to blame the direct invisibility of gluons and quarks on a "confinement" of these objects in a literal sense i.e. in a limitation to a cage created by themselves and other objects. It is more plausible to think that a different, much stronger version of string localization leads to this property. In the case of electrically charge fields in QED the charged object are primarily visible through the photons they emit, but when all photons above a certain energy resolution of the detector have been emitted the softer photons as well as the charged particle is out of sight. Gluons play both roles at once, that of a would be charged particle and that of radiated photons. These are of course only metaphors, but they at least indicate that the problem of string localization may be linked to visibility to the counter registration of gluonic degrees of freedom. If future research shows that a gluon operator applied to the vacuum happens to create a state in the third (infinite spin) Wigner class, this argument about invisibility of a energy-momentum carrying string-localized state would be significantly strengthened.

The reader who is familiar with the gauge theoretic formulation may have noticed that the string vector potentials have a formal similarity with vector potentials in the axial gauge. In fact the difference is mainly one of interpretation. From the gauge theoretic point of view e is a gauge parameter. But then the occurance of the severe perturbative infrared divergencies, which prevented well-defined perturbation calculations in the axial gauge, remains a mystery; why should an inert gauge parameter create such massy infrared problems? The long range nature of string-localized fields explains this (since e in our view is not a gauge parameter) and tells one what to do; mathematically the vectorpotential is an operator-valued distribution in x and e. In order to obtain the DJM formula (9) for a charged field not by hand but within a perturbative formalism which includes string-localized fields, it is necessary to keep all the inner $e's$ in loop graphs distinct and study their confluence limit at the end.

There remains of course the question why these observations were not already made at the time of Swieca, in particular since they fit so perfectly into the screening setting and the perceived nonlocality of electrically charged fields at that time on the basis of the quantum Gauss law. It was only necessary to notice that the gap in the spinorial description of the $(m=0, s\geq 1)$ Wigner representations can be filled with string localized spinorial free fields $\Psi^{(A,\dot{B})}(x,e)$. There is no easy answer to that question, but I think the fact that the role of localization as the dominating physical principle of QFT was not yet fully appreciated explains the missed chance to a certain degree.

The change came in more recent times when the concept of modular localization was discovered [49][50][15]. Only then it was finally possible to understand the field theoretic content of the third Wigner representation family of massless infinite spin representations, the first being the massive and the second the massless finite helicity representation family. Generations of physicists, including Steven Weinberg, tried in vain to force this rather large representation family into the scheme of pointlike fields. The recognition that this third family has no compact localization [50] and can be described in terms of semiinfinite string localized fields [15]. This was the eye opener for looking at the mentioned spinorial gap of the massless finite helicity representations.

This episode shows the importance of keeping unsolved or only partially solved problems in one's memory even in the presence of the widespread opinion that they have been solved (gauge theory, electrically charged fields, Schwinger-Higgs screening) or rendered irrelevant in the shadow of a theory of everything. The idea that one is in the possession of a new theory which either explains the old problems or renders them superfluous is as presumptuous now as it has been in the past. The underlying philosophy at the time of Swieca was that it possible in particle theory to come to gradual conceptual unification, but certainly not that of a theory of everything (TOE). But also the idea that by playing with exclusively with "effective QFT" one could come to new insights would have appeared strange to the QFT community of which Swieca was a member. There are of course areas in physics (solid state physics, quantum chemistry) in which there is no hope to derive and describe observed phenomena from fundamental laws. The fascination with the various gauge theories in the standard model comes from the conviction that the basic problems of particle theory can be understood in terms of a few fundamental laws.

But even in QED this is presently wishful thinking, not to mention its nonabelian version. The important step is to make some conceptual headway in the largely unknown landscape of QFT and then exemplify the new point in a reasonably controlled model; this was the way progress came about in the 60s and 70s. At no point did people think in those times that QFT is a theory whose foundations are known apart from some details. Rather the prevalent philosophical view was a certain astonishment that a more than 40 year old theory had relinquished so few of its secrets. All other physical theories offered illustrative mathematically controllable models in the presence of interactions, not so QFT about which one only knew free fields and some low-dimensional near free models without a nontrivial scattering matrix. Fortunately this situation has improved somewhat (see next section) but it still would be impudent to claim that QFT is a largely known subject. Even some usually optimistic followers of the gauge principle became recently aware to their surprise that gauge theory is not an intrinsic concept since by looking at the *physical* local fields of a gauge theory it is impossible to decide whether the correlations come from a gauge theory or some non-gauge description[27]. The description of localization of electrically charged fields and particles, charge-screening and higher spin interactions, as well as the fate of gluon and quark degrees of freedom are unsolved fundamental problems which "effective" QFT does not address but whose solution it needs for its credibility.

The metaphoric ideas in an article about the legacy of Swieca on issues about which most people have quite solidified (but not solid) notions may sound provocative, but they are only reminders that most of the foundational question have remained open. After 40 years of research there is the pressing problem whether the present setting of gauge theory is the appropriate framework. The modular localization concept re-interprets the gauge invariant local observables as e- independent subobjects of a theory which includes string-like generating fields. In doing this certain objects as electrically charged fields and their associated infraparticles which as "nonlocal" objects were hitherto outside the the gauge formalism (and had to be defined by hand (9)) are now incorporated. it becomes clear that these open problems related to interactions with non-pointlike fields cannot be answered in the present setting about gauge theory.

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[27] 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 a majority of particle physicists.

Some of these questions have been sucessfully addressed already by Swieca who, in lack of modular string localization, connected the failure of pointlike locality of charged states with weaker analytic and smoothness properties of electric formfactors i.e. matrix elements of currents in charged states. The problems commented on in this section are in my view extensions of ideas which got lost, but whose continuation may be helpful to overcome the present crisis of almost 40 years of stagnation on fundamental problems. After 40 years of partially successful dominance of "effective" QFT, it is time to again turn the foundational wheel on renormalizable higher spin interactions.

7 Factorizing models and Swieca's contribution to "nuclear democracy"

Another interesting idea of Swieca, which I consider as an important part of his legacy, has to do with massive 2-dimensional factorizing models. Some introductory remarks are necessary. This research goes back to certain quasiclassical observations by Dashen, Hasslacher and Neveu [51] suggesting the integrability of a family of d=1+1 theories including the d=1+1 massive Sine-Gordon- and Thirring- models.

The first attempts to understand the particle spectrum in connection with the S-matrix of these models pointed to to the old S-matrix based approach and led to a modest revival of the old bootstrap S-matrix idea but now specialized to factorizing 2-dimensional models [52]. 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 more modest) explicit realization in an infinitely large family of d=1+1 models with a factorizing but nontrivial S-matrices with the crossing property [53].

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 magics 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[28] [54]. The models confirm the *nuclear democracy* idea which results from the locality principle of interacting QFT, namely all particle states with the same superselecting charge quantum number which have the same charge are necessarily coupled with each other as illustrated for formfactors under the heading of Murphy's law in the introduction. A special corrolar of this tight internal connectivity of QFT is the principle of nuclear democracy for boundstates which says that different clusters of particles which share the same superselected charge lead to the same bound states. The cluster may alreasdy contain bound states hence bound states may be viewed as being composed of their own kind. This nuclear democracy property removes the standard hierarchical order elementary-bound which dominates QM from the screen of QFT; the only remaining hierarchy is that of fundamental charge-fused charge. But even this becomes blurred due to the existence of the "self-equivalence": Sine-Gordon soliton (massive Thirring field) $\simeq$ Sine Gordon soliton + Sine Gordon stuff (arbitrary number),

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[28] 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.

where I tried to exemplify the idea with the help of a concrete example- 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 infinity [55] and in this way become unobservable (confined "quarks"), showing that there is no contradiction between nuclear democracy and such a primitive kind of confinement.

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. The states of particles belonging to different superselected charges are of course orthogonal, but those corresponding to different composites with the same fused charge lead to 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 realized that factorizing models presented a rich theoretical laboratory for testing ideas. One such idea was his conjecture that the principle of nuclear democracy may permit to define and construct certain models in a completely intrinsic way on the basis of the "minimal" version of nuclear democracy 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 anti-particle, 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 [77] and more recently also the formfactors of this Z(N) model have been constructed [56]. 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[29] and the Z(N) and the chiral SU(N) model are representative illustrations. With the conceptual framework of the Haag "school" in the background, Swieca belonged to the meanwhile increasing minority of particle physicist who 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 which is not tolerable from a philosophical point of view. 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.

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[29] 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.

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 [57]. 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 [58]) 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. [59] proposed such a symmetry protecting (from the S-matrix point of view restoring) mechanism caused by infrared clouds[30]. This was a different mechanism from that proposed by Witten [60] in the same model for the same reason. Witten's proposal was further elaborated by Abdalla, Berg and Weisz [61]. 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 [62], 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 structures 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 [63]. 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 [64]. The statistics in the sense of field commutation 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*[31]) but on one occasion, when he was convinced that an interesting proposal would not stand up to physical requirements of macro-causality, he also proved a No-Go theorem [65]; 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 [66]. In recent times the nonlocality aspect reappeared in the veil of "noncommutativity" through the backreaction

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[30] 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.

[31] In his own words [78]: *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.*

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 spacelike 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 [65].

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 over short or long that locality is an extremely restrictive requirement but it is much harder for them to realize that there are even more severe conceptual restrictions which have wrecked all 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 [66]). 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 [67]. But this has not and cannot be obtained by modifying the construction of QFT since the way in which the cluster property arise in these quantum mechanical models is not compatible with second quantization.

Physicists before the 80s had to learn the hard way about the conceptual barriers in departing from the realm of locality. Looking at the lighthearted manner in which contemporary particle physicists have ignored the issue of macro-causality in their search for noncommutative theories, one cannot help of thinking of déja vu, even if the motivation has changed, the naiveté remained on the level of the Lee-Wick proposal. This is not completey surprising since 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.

8 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. André he was on a stop-over on his return to Sao Paulo, after having written his thesis (with W. Guettinger[32] as his adviser) in Munich which he was going to defend at the University of Sao Paulo. The main purpose of his stop-over at 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 extraordinary 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.

Before I continue to write about some episodes connected with my visits to Brazil, some memories about my first scientic encounters with Swieca are in order.

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 [68], 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

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[32] 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 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 Swieca also had a very close relation. There was also a close cooperation between French mathematics at the USP in Sao Paulo which led to several visits of Laurant Schwartz.

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 [69]. This work was later taken up by Hislop and Longo [70] 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 structural properties of interacting QFTs. 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[33]; this in turn can only occur in the presence of interactions which made it an interesting research topic up to present times.

One consequence of the presence of a nontrivially represented diagonolizable center $\mathbb{Z}$ 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 [71][72] 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 [73] [74] (which by definition live on the Dirac-Weyl compactified Minkowski spacetime and do not require the introduction of its covering), the full understanding of higher dimensional conformal field theory still remains a challenging theoretical problem to date.

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[33] 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.

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 which also had their spell on us.

The $\mathbb{Z}$-component fields in the 2-dimensional context (the only context in which we had some constructive control) which lacked the properties of Wightman fields[34] and neither fitted into the euclidean setting of QFT therefore led to a temporary stop of this line of reseach. As far as I know the only work before the beginning of the 80s which went beyond these results 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 shortly 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 $\mathbb{Z}$-decomposition theory nicely harmonizes with the BPZ conformal block drcomposition. 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) representations of the braid group of the kind as they appeared naturally in Vaughn Jones mathematical subfactor theory. To understand the relation between the old work from the time with Swieca and the new BPZ setting was not a simple matter[35], K.-H. Rehren and myself worked almost two years on this task of linking the old view about conformal decomposition theory with the new [75].

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 felt more secure at the Ponteficia Universidade Calolica (PUC) in Rio de Janeiro, a private university under the umbrella of the at that time 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 coming. This aggravated his health and certainly contributed to his premature death at the end of 1980.

Different from the Pinochet regime in Chile, the US was probably not directly involved in the installation of its Brazilian counterpart, but the Brazilian generals received US sympathy and support after their military take over in a coup. At that time there was a deep gap between the proclaimed US democratic ideals and the consequences of their

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

[35] 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.

realpolitik in the name of anti-communism. But apart from my short visits to Brazil these problems were removed from my life; 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 André felt the same way; although we rarely discussed politics. Only some years ago I learned that around 1970 the military regime offered him a diplomatic post in Israel (presumably that of a scientific attache) which he declined, certainly 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[36], it was quite easy to agree with him 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 more 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 [51]. 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 property and a fusion picture for higher boundstates from the lowest one. This was a resurrection of the old S-matrix bootstrap picture but now in the more limited context of two-dimensional dactorizing S-matrices [52].

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 who I had the pleasure to advise 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 setting. 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[37] facilitated his start. An article which reflects the state of art can be found under [78].

Within his short time he made important contributions and introduced a whole new generation of Brazilean physics 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. I had the good luck to enter particle physics in interesting times and to meet and collaborate with remarkable individuals as J. A. Swieca.

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

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[36] 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.

[37] The topics led to several master- and PhD thesis by his students e.g. [79].

summer school organized by the university of Sao Paulo is called *Jorge André Swieca Summer School in Particle and Fields.* This is more than justified by the fact that the particle theory research in Brazil started with Swieca and his school. But few physicists of the younger generations are familiar with the actual content of 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 as attempted in the present essay is more than just doing scientific archeology.

Jorge André Swieca was not Brazilean by birth. He was born 1936 in Warsaw and fled with his parents the Russian occupied part of Poland shortly after it was divided between Hitler and Stalin. The odyssey which started with a trip on the Transsib to Wladivostok (with the 4 year old André without papers hidden underneath a seat at each control) and then continued with the ferry to Yokohama only ended after spending two years in Japan and Argentine before his parents finally were able to settle down in Rio de Janeiro/Brazil.

As many Jewish survivors of the holocaust, Jorge André had a trauma which can be summerized by the agonizing thought "why I and not the others" which in my opinion contributed at least as much to his taking his life than the physical state after his bypass heart surgery.

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