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String theory and the crisis in particle physics

a Samizdat on particle theory

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Bert Schroer
CBPF, Rua Dr. Xavier Sigaud 150
22290-180 Rio de Janeiro, Brazil
and Institut fuer Theoretische Physik der FU Berlin, Germany

Contents

Abstract

This is a reformulated presentation of an earlier version. Besides strengthening previous observations, it reflects also some changes in the authors viewpoint as a result of a three month (April-June 2006) participation in weblogs in which this issue was addressed.

1 An anthology of the crisis in fundamental physics

There can be no doubt that after almost a century of impressive success fundamental physics is in the midst of a deep crisis. Its epicenter is located in particle theory, but its repercussions may influence the direction of experimental particle physics and affect adjacent areas of fundamental research. They also gave rise to quite bizarre changes in the philosophy of fundamental sciences which partially explains the general interests beyond the community of specialists in particle physics.

One does not have to be a physicist in order to notice with amazement that there are reputable particle physicists [1] who propose to abdicate the autonomous observational setting of physics which since the time of Galileo, Newton, Einstein and the protagonists of quantum theory and quantum field theory has been a de-mystification of nature by mathematically formulated concepts with experimentally verifiable consequences. They instead propose to permit more metaphorical ways of reasoning of the kind used in other human activities particularly in religion and part of philosophy. Instead of “cogito ergo sum” the new *anthropic* maxim coming from string theory permits its inverse use in the sense that our human existence can be incorporated into a theory which on its own would not be able to select among myriads of solutions of universes with different physical laws the one we are living in. Anthropic reasoning as a temporary auxiliary selective device (pending further refinements of a theory) would not go against the traditional scientific spirit.

But the anthropic principle used by some string theorists is not a refinement in this sense; without its invocation one has not been able to make any testable physical prediction from string theory (apart from arguments that all the solution incorporate some form of Einstein-Hilbert gravity and some (hopefully) broken form of supersymmetry) because it has not been possible to at least identify an experimentally observable property which is shared by its myriads of solutions. Rather the anthropic principle has been advocated as a permanent substitute for a physical selection principle.

This led to the antropic dogma of a *multiverse* instead of a universe i.e. the belief that all these different solutions with quantum matter obeying different laws (including different values of fundamental constants) exist and form "the landscape". To put it more bluntly, string theory only describes our material world if one is prepared to throw in one's own existence as a kind of boundary condition in order to uniquely specify (hopefully) the one solution which describes our world. In this way the antropic principle and the landscape is the saving grace by which the original claim of a unique "theory of everything" could be rescued.

Although such a picture is not (yet?) shared by a majority within the rather large string theory community of particle theorists, it would be difficult to overlook a general trend in particle theory away from the traditional scientific setting based on autonomous physical principles towards more free-wheeling metaphoric consistency arguments for proposed computational prescriptions. The ascend of this metaphoric approach is inexorably linked to the increasing popularity of string theory and the marketing skill of its proponents to secure a lavish funding which partially accounts for its present hegemonic status in particle theory.

Parallel and by no means independent to this development the particle physics community experienced a deepening frustration about failed attempts to make further progress about the standard model which has remained particle physics finest achievement ever since its discovery more than 3 decades ago. Particle physics up to that time was a continuous success story; since the inception of QFT its setting in terms of Lagrangian quantization enriched by perturbative renormalization, symmetries and the incorporation of the classical gauge principle had led to a previously unimaginable precise description of relativistic quantum matter without ever having to abandon or modify any of the causality and stability (positive energy) principles which characterize local quantum physics.

But it became gradually clear that this success had its prize in that one apparently had entered a labyrinth from which an improvement (e.g. a reduction of the high number of free parameters by finding relations between them) based on the Lagrangian setting of QFT does not seem to be possible. Those successful ideas about symmetries and gauge theory which led to this success of the standard model do not seem to be able to move it beyond by providing answers to forthcoming fundamental questions. This new unaccustomed experience of an era of continuously successful Lagrangian QFT[1] coming to an abrupt and apparently long-lasting halt is at the root of the growing feeling of being caught in a deep crisis. This feeling is heightened by the dominance of string theory whose metaphoric aspects have not only prevented to extract any observational implication but also created a state of conceptual confusion about its relation to the successful physical principles of QFT. Its hegemonic tendencies to downgrade alternative ideas gives this crisis a deeply worrisome dimension.

One would like to view the exact sciences in particular particle physics, as a human activity which follows an intrinsic autonomous path. The resulting knowledge may have an impact on philosophy, the humanities and the development of society, but their feedback into fundamental research in physics is generally believed to be negligible. This of course was never the case. Without the appearance of the sociological changes leading from the dark ages to the era of enlightenment, the curiosity of man about its material world would probably not have led to the beginning of the scientific method of quantitative measurements at the time of Galileo. But once the scientific method was on track, and fundamental research obtained an autonomous status independent of its utilitarian relevance for society, most of us would expect that from thereon the progress in the exact sciences unfolds basically in an autonomous manner with the rapid propagation of information and knowledge through mass communications and the process of globalization accelerating its growth, but not determining its direction.

The main points of this essay is to argue that the nature of the present crisis in particle physics does not support such a upbeat view. As human nature led to global catastrophes and social dislocations, human fallacies and erroneous trends may derail scientific projects in which case the improvement of

[1] In most textbooks the content of QFT has been identified with its Lagrangian setting in terms of formal functional integral representations. In cases one want to stress the fact that the use of this terminology incorporates every model which fulfils the underlying principles of QFT (the Lagrangian method is a only special attempt to implement these principles), we sometimes prefer "local quantum physics" (LQP) or "algebraic QFT" (AQFT).

communications may worsen the situation. The ethics of science (intellectual honesty, critical distance) has developed as part the ethics of western civilization. The subordination of human activities and values to the forces of a globalized market has led to ethical erosions. The personal satisfaction experienced by an discoverer of a scientific truth which used to be the main driving force in the past has given way to more material market-oriented motivations. Here I am not thinking primarily of the loss of moral standards regarding the increasing number of falsified or plagiarized scientific results. As long as the natural sciences maintain the primate of verifiability, human fallacies of this kind committed by individuals cannot derail it. The danger of an erroneous trend in particle physics is rather emanating from the hegemonic tendencies of scientific monocultures.

For the present particle theorist to be successful it is not sufficient to propose an interesting idea via written publication and oral presentation, but he also should try to build or find a community around this idea. The best protection of a theoretical proposal against profound criticism and thus securing its long-time survival is to be able to create a community around it. If such a situation can be maintained over a sufficiently long time it develops a life of its own because no member of the community wants to find himself in a situation where he has spend the most productive years on a failed project. In such a situation intellectual honesty gives way to an ever increasing unwillingness and finally a loss of critical abilities as a result of self-delusion.

I would like to argue that these developments have been looming in string theory for a long time and the recent anthropic manifesto [1] (which apparently led to a schism within the string community) is only the extreme tip of an iceberg. Since there has been ample criticism of this anthropic viewpoint (even within the string theory community), my critical essay will be directed to the metaphoric aspect by which string theory has deepened the post standard model crisis of particle physics. Since in my view the continuation of the present path could jeopardize the future research of fundamental physics for many generations, the style of presentation will occasionally be somewhat polemic. (no ad hominem attacks). Polemics in science should, if at all, only be used in very extreme situations. One occasion in the past where its application was more than justified was in Jost's superb rebuttal [2] of the unproven claims made at the height of the S-matrix bootstrap of the 60's.

Although the S-matrix bootstrap idea led to a fashion and a formation of a community (a rather large community in relation to the number of theoreticians at that time), its only one decade lasting command of a good part of particle physics was not long enough to obtain hegemonic control. Its influence waned when the perturbative Lagrangian QFT made a strong return which culminated in the gauge theoretic formulation of the standard model. The already more than three decade lasting lack of progress in attempts to get beyond the standard model provided the empty space from where string theory could develop into its status of a dominating monoculture.

One is used to call a collection of ideas a theory, if their mathematical formulation permit an interpretation in terms of a realization of an underlying physical principle with experimentally verifiable consequences. For a phenomenological description of empirical data the requirements are less stringent. String theory is strictly speaking neither a theory in this sense, nor a phenomenological description. It started as a phenomenological description of hadronic scattering data and later became a collection of ideas for the unification of all known forces. As a result of its mathematical sophistication which it acquired during the last two decades, its critical evaluation (beyond pointing out that it had no observational verifiable consequences) is quite demanding and interesting. The attraction it exerts on particle physicists cannot be reduced to the seducing power of its protagonists although without the support it received from Nobel laureates in particle theory[2] it would not enjoy its present dominating status. Lacking a conceptual basis, the mathematics and the computations are not of much help to get some orientation of what it really presents. The best way is to follow its meandering history and to pinpoint the metaphoric nature of some of its arguments.

Before I return to the question to what extend string theory reflects the less desirable side of the present Zeitgeist, it is helpful to review in more detail some relevant episodes in the history of particle physics.

The beginning of relativistic particle theory is inexorably linked to Jordan's "Quantelung der Wellenfelder" which merged with Dirac's multi-particle formalism. QFT according to Jordan draws on a par-

[2]The most vocal criticism came from experimental particle physcs old guard; Burt Richter called the supersymmetry (which constitutes an important aspect of string theory) "a social construct".

allelism to classical fields which amounted to a quantization of the classical canonical structure of the Lagrangian formalism. Jordan's point of view about this was more radical than Dirac's because any structure which fitted into the classical field formalism was a potential candidate for quantization, it was not necessary that it belonged to real observed classical physics[3] as initially required by Dirac.

In the light of this it is remarkable that two years after his discovery Jordan was dissatisfied with the use of what he called the "classical crutches" (klassische Kruecken) of quantization and pleaded for a more intrinsic access to the physical content of QFT [5]. It is perhaps not accidental that this happened exactly at a time when he realized together with Pauli that the pointlike nature of quantum fields required by quantization are (unlike quantum mechanical observables) necessarily rather unwieldy singular objects which could lead to trouble in building up interactions by their local couplings.

But Jordan's dream of a more autonomous approach built on principles intrinsic to local quantum physics remained unfulfilled for a long time to come; the history of QFT between the early 1930's and the late 40's is characterized by apparently incurable ultraviolet problems. This "ultraviolet crisis" led to many speculative and "revolutionary" ideas (some of them quite weird, at least in retrospect). As a result of the Tomonaga-Schwinger-Feynman-Dyson renormalized perturbation theory and its immediate physical success in QED, these ideas went into the dustpan of history.

Despite a formidable technical and conceptual enrichment, renormalization is quite conservative in terms of physical principles; it was not necessary to introduce a single physical principle beyond the ones which were already (indirectly or directly) in place in the pre-renormalization setting. But without renormalization theory and its successful application to QED, quantum field theory probably would not have been able to survive in the pantheon of physics.

However Jordan's plea for intrinsicness was not laid to rest; rather perturbative renormalization elevated it to a higher level. Instead of the pre-renormalization ultraviolet problem, there was the new problem which consisted in the realization that the perturbative division into non-renormalizable and renormalizable models was rather technical; it was based on a formal quantization procedure which required the implementation of interactions by the recipe of coupling pointlike free fields rather than by letting the principles which underlie QFT determine an intrinsic way of classifying and computing models. According to the computational tools of quantum mechanics (equal time commutation relations, functional integral representation), the problem of renormalization revealed itself as one of removal of ultraviolet divergencies based on the differentiating between formal Lagrangian parameters and their physical (measured) counterparts.

The use of these tools in QFT as opposed to QM is of somewhat "artistic" kind; they can only be used as a suggestive starting point. What is important is their formal intuitive physical appeal which (with some ad hoc rules and a lot of hindsight) leads to a robust unique (up to reparametrization of the physical counterparts of the Lagrangian parameters) perturbative result whose veracity is independent of whether the starting point is valid or not. In fact the renormalized result, apart from some superrenormalizable 2-dimensional models, violates the ETCR as well the functional integral representation, which is the meaning of "artistic". Although such somewhat metaphorical arguments are often successfully used in particle theory, it is nevertheless comforting to know that the framework of quantum field theory (LQP, AQFT) always permits to replace them with autonomous ones. In the case at hand the intrinsic logic of LQP leads to the setting of "causal perturbation" in which the interaction in lowest order is specified as a Wick-ordered invariant polynomial in terms of pointlike local covariant free fields[4] (the interaction Lagrangian) and the incriminated ETCR, the free Lagrangian or functional integrals are not used in this approach. The causality principle together with Poincaré covariance and energy momentum positivity is then iteratively used for an computation of higher orders; in each step paying attention to the singular operator-valued distributional nature (instead of ETCR or functional integral) of the objects which act within an auxiliary Hilbert space of free fields. The freedom left after fulfilling those principles consists in a pointlike localized (contact) term of Wick-ordered free field polynomials restricted by the symmetries of the model. One then invokes a minimality principle which limits the scaling degree of these contact

[3]In [4] it is mentioned that by the time the Goettinger group learned about Schroedinger's results, Jordan already had a field quantized version.

[4]Covariant free fields describing (m,s) particles are related to the unique (m,s) unitary Wigner particle representation by intertwining functions for which there is a countably infinite choice [3][6]. Whereas the causal approach is consistent with any such choice, the functional integral setting (which involves the free part of the action) limits this choice to those free fields which can be derived from a Lagrangian.

term to be not larger than that of the iteration[5]. The renormalizable theories are then those for which the number of parameters in the Wick polynomial in every order remains finite; in this case they can be absorbed into redefinition of the original masses and coupling strength plus possibly new couplings which should have been added to the starting (first order) interaction polynomial. Models in which the number of parameters increases with the perturbative order are called non-renormalizable. In this way the increase in the number of free parameters is coupled to the growth in the short-distance singular behavior for coalescing spacetime points. The characterization of the Lagrangian frontier delimiting perturbative renormalizable problems is part of the famous power counting criterion [3]. Such models are (as a result of their diminished predictive power) less interesting; as "effective QFT" they are sometimes used for phenomenological descriptions of particle interactions. The belief that non-renormalizable Lagrangian are not of fundamental significance is supported by looking at exactly solvable two-dimensional models. In all of these models the pointlike fields have a short distance scaling behavior with a finite scaling degree. But on the other hand one does know by now many low-dimensional models which *do not fit into a Lagrangian quantization framework* which indicates that Lagrangian quantization and causal perturbation only covers a small part of QFT. Since these problems are the subject of ongoing research, they will be addressed in the last section.

For a more perspective view of renormalization I find the following presentation very helpful. Once the free field content and the symmetries (particles+symmetries) of a model are specified one can associate with it a universal formal Bogoliubov-Shirkov S-matrix which is the time-ordered exponential involving all Wick-monomials subject to the symmetry restrictions. This is an infinite-parametric formal object similar to one in which Wilson uses in his renormalization group formulation. This infinite-parametric object is strictly auxiliary, there is no model corresponding to this universal S-matrix. Individual models rather result from the search for finite-parametric "islands" which are stable under certain renormalization group transformations. Renormalization theory is the art of finding such islands and the above construction is according to our best knowledge the only possible one in case one starts with pointlike fields. To discover other islands we may try to encode the given particle content and symmetries in free string like fields (see last section). The fact that one only knows the standard pointlike way of implementing interactions does not mean that other islands do not exist.

The problem is always one of the finiteness of the numbers of parameters and never one of ultra-violet divergencies in finite perturbative orders. The older literature encountered divergencies in intermediate steps because it follows a more quantum mechanical setting which ignores the intrinsically singular nature of quantum fields in intermediate steps and only recovers it at the end[6]. It is not wrong to talk about perturbative divergences, but this terminology gives too much prominence to unphysical intermediate aspects and tends to cause misunderstandings with newcomers. The only genuine divergence in QFT is the break-down of convergence of its perturbative series.

An age old problem of QFT which resisted all attempts to solve it is the *problem of existence* of models i.e. whether there really exist a QFT behind the Lagrangian name and perturbative expressions. Since there are convincing arguments that perturbative series do not converge (they are at best asymptotic expressions) this is a very serious and (for realistic models) unsolved problems[7]. The problem that particle physics most successful theory of QED is also its mathematically most fragile has not gone away. In this sense QFT has a very precarious status very different from any other area of physics in particular from QM. This is very annoying and in order to not to undermine the confidence of newcomers in QFT the prescribed terminology is to simply use the word "defined" or "exists" in case some consistency arguments (usually related in some way to perturbation theory) have been checked.

These problems become even worse in theories as string theory (which in the eyes of string protagonists are supposed to supersede QFT). In this case one faces in addition to the existence problem the conceptual difficulty of not having been able to extract characterizing principles from ad hoc recipes. Unlike in

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[5] For an up-to-date state of art information about advanced perturbation theory I refer to the many contributions coming from a group at the University of Hamburg (http://unith.desy.de/research/aqft/).

[6] Hence the correst way of saying the string theory has no divergencies in its perturbative (according to genus) expressions is to state that the itrration does not introduce any parameter at all (similar to what one expects to occur nonperturbatively in QCD).

[7] A notable exeption are the recent existence proofs for certain nontrivial (in the sense of nontrivial scattering) strictly renormalizable two-dimensional models which significantly extends the constructive control on superrenormalizable polynomial scalar field interactions attained in the 60's. More on this is contained in the last section.

renormalizable QFT there exists up to date no n-th order proof that string theory is free of renormalization parameters.

Even though renormalization theory (despite its crucial role in arriving at a new ultraviolet-controlled computational setting) did not really add a new physical principle, its covariant setting was instrumental for a profound understanding of the particle-field relation. It replaced the relativistic quantum mechanical setting (the basis of the older textbooks of Wenzel and Heitler) which, although being adequate for lowest order (no loop diagrams) processes, turned out to be unsuitable for this task[8]. In the new setting it was possible to extract a large-time asymptotic relation which illuminated the connection between particles and fields without invoking perturbation theory; the resulting LSZ scattering theory was shown to be a direct consequence of the principles [8].

The upshot of this conceptual progress was that asymptotic particle states and the scattering matrix had the status of truly intrinsic quantities, whereas quantum fields (apart from symmetry-generating currents) loose the aspect of individuality which they enjoyed in classical physics before the quantization; in fact there are infinitely many ways of choosing field coordinatizations and they can be grouped into local equivalence classes of which every (interpolating) member field is describing the same particles whose charge numbers and spacetime representation invariants (mass, spin) are related to the class. In other words the particle state is uniquely related to the class and not to the field.

The deepening of the field-particle relation led also to the revival of an idea by Heisenberg (which in its original form was discussed at some conferences shortly before the start of the second world war) to explore the feasibility of a direct S-matrix construction without passing through a field theory setting; in this way one expected to obtain a non-singular and more intrinsic way to pursue particle physics. For lack of concrete results the interest waned and only re-appeared in the 1950s and 1960s in connection with some non-perturbative conceptual advances in the wake of renormalization theory (which were mainly driven by the issue to make QFT fit for describing strong interactions). On the one hand the adaptation of the Kramers-Kronig dispersion relation to relativistic particle scattering and the related more general interest in analytic properties of scattering amplitudes and (electromagnetic) formfactors nourished the (exaggerated, as it turned out later) hope that many dynamical aspects could perhaps be understood as consistency relations between analytic properties and reasonable assumptions about asymptotic high- and low-energy (threshold) behavior. Initially the aims of these investigations were quite modest in that particle physicists were already satisfied when they succeeded to derive experimentally verifiable sum rules from current commutation relations and analytic properties (the prototype being the Thomas-Kuhn sum rules which played an important role in the transition from old to new QT).

The most important post-Heisenberg conceptual enrichment of S-matrix theory (coming originally from Feynman's graphical formulation of renormalized perturbation theory) was however the *crossing* property often called (by abuse of language) crossing symmetry. Its off-shell version is a formal property which relates scattering graphs with other ones obtained by crossing pairs of external lines in incoming and outgoing configurations; in certain cases it could be verified outside perturbation theory by studying "axiomatically derived" analytic behavior following from locality and positivity of energy. For on-shell quantities as scattering amplitudes or formfactors of currents such derivations (for those configurations for which they were possible) were quite demanding; often on-shell crossing properties were simply postulated in order to explore their observable consequences, leaving their derivation from the causality and spectral principles of QFT to future progress. It is of course standard practice to use interesting properties as working hypothesis, even if one is not yet in the possession of a conceptual derivation[9] from known principles; the only problem with that is that after the passing of time and even with better conceptual insights and mathematical tools available, one may have forgotten about their problematic status. I think this is what happened to the crossing property.

The emerging so-called "S-matrix bootstrap program", which owed its second life (after Heisenberg's first attempt) to the important but incompletely understood crossing property, was on top of the physical fashions of the late 50's and maintained its leading role through the 60's. Some of its points were quite

[8] The quantum mechanical view of the particle-field relation became problematic after Furry and Oppenheimer observed that the presence of interactions made it impossible to obtain a space-time separation of one field states $A(x)\left|0\right\rangle$ into a one particle states and their vacuum polarization companions.

[9] The conjecture that on-shell crossing is a relic left by spacelike (anti)commutativity is plausible but there exists up this date no mathematical derivation (see remarks in next section). It does not hold in the more general Buchholz-Fredenhagen setting of string-like localized fields [8] (see also last section).

reasonable; but the human weakness of making exaggerated promises ("a unique theory of everything" except gravity) and finally the strong return of QFT in the form of nonabelian gauge theories led to its demise. Among the few valuable points it contributed is the attention it drew to the fact that an on-shell approach (if it succeeds) is not only free of ultraviolet problems but it is also manifestly independent of the infinite number of possibilities for pointlike field coordinatizations (leading all to the same physics); in this sense it addressed (together with the independently emerging algebraic QFT) for the first time Jordan's plea for intrinsicness of the description, in particular the abandonment of classical crutches).

The emphasis on an intrinsic description is well known in mathematics; it underlies the invariant description of modern differential geometry which not only liberated geometry from the use of singular coordinates, but also from the use of any coordinatization altogether. This should be understood only as an analogy (i.e. the use of modern differential geometry in the formulation of QFT does not make the latter more intrinsic) because the implementation of intrinsicness in QFT turns out to be a much more radical step than in differential geometry. But the antagonistic bellicose tone in which the underlying bootstrap philosophy was set against QFT ("QFT is like a mortally wounded soldier dying on the battlefield...") undermined its credibility in the eyes of most physicists. In my opinion, looking at this situation in retrospect, this delayed an interesting chance to enrich QFT by adding a new viewpoint for several decades (see next section).

Since there was no operator formalism in which the underlying ideas (invariance, unitarity, crossing, maximal analyticity) could have been implemented, the problem of constructing a crossing symmetric, unitary, maximally analytic S-matrix was ill-formulated. Tinkering with properties of Beta functions and their representation in terms of Gamma functions, Veneziano was able to construct the first model for an apparent[10] crossing symmetric elastic scattering amplitude. His proposal did not satisfy unitarity, but the realization that his on-shell prescription allowed an auxiliary field theoretic description in terms of a (off-shell) two-dimensional conformal field operators theory and that it also admitted an auxiliary presentation in terms of the canonical quantization of a classical relativistic Nambu-Goto string Lagrangian contributed significantly to its theoretical attraction. It also nourished the hope that the model can be unitarized in a later stage. Its main popularity it however enjoyed among strong interaction phenomenologists who actually (for reasons which nowadays hardly anybody remembers) liked the idea of satisfying crossing already with infinite towers of intermediate particle states, *duality* = crossing among with (infinitely many) one-particle without the participations without the participation of the multiparticle scattering continua as would be required for an S-matrix coming from QFT. In conjunction with the phenomenological use of ideas of Regge poles, the emerging trajectory pictures (mass versus spin) had a certain phenomenological charm, and although infinite particle towers cause some field theoretic headache[11], there was no reason to reject it as a *phenomenological proposal* which captures some aspects of strong interactions and to worry about those conceptual problems later.

But this never happened; the dual model became a phenomenological orphan and after its string-theoretic completion, by the time it was presented as a TOE (this time including gravity), the conceptual problem behind the crossing-duality relation was forgotten, and a chance to understand something about conceptual relations of string theory to QFT was (presumably permanently) lost. Particle physics these days is generally not done by individuals but by members of big groups, and when these big caravans have passed by a problem, it will remain in the desert. A reinvestigation (naturally with improved mathematical tool and grater conceptual insight) could be detrimental to the career of somebody who does not enjoy the security of a community.

In its new string theoretical setting its old phenomenological flaw of containing a spin=2 particle was converted into the "virtue" of the presence of a graviton. The new message was the suggestion that string theory (as a result of the presence of spin two and the apparent absence of perturbative ultraviolet divergencies) should be given the status of a fundamental theory at an energy scale of the gravitational Planck mass $\sim 10^{19} GeV$ i.e. as a true theory of everything (TOE), including gravity. Keeping in mind that the frontiers of fundamental theoretical physics (and in particular of particle physics) are by their very nature a quite speculative subject, one should not be surprised about the highly speculative radical aspects of this proposals; we know from history that some of our most successful theories originated as

[10] It is not the before-mentioned crossing of S-matrices coming from QFT (see later remaks).

[11] Unless only a finite number of particles remain as stable objects (and infinitely many are converted to poles in the second Riemann sheet) one gets into trouble with locality (this can be seen in the context of d=1+1 factorizing theories).

speculative conjectures. What is however worrisome about this episode is rather its uncritical reception. After all there is no precedent in the history of physics of a phenomenologically conceived idea for laboratory energies to became miraculously transmuted into a theory of everything by just sliding the energy scale upward through 15 orders of magnitudes and changing the terminology without a change in its mathematical-conceptual setting[12].

A future critique of string theory (probably done by historians of physics) would be incomplete, if it would miss out on these conceptual confusions at its cradle. I found it useful to review them in more detail in the next section because they never entered the discourse on string theory. Whereas the S-matrix bootstrap proposal contained some interesting conceptual points (see last section), ST turned out to be a step into conceptual dark ages from its very beginnings; its inexorable metaphoric character is a birth defect.

The most profound conceptual investment into QFT which led finally to its autonomous formulation (i.e. the answer to Jordan's quest) is the algebraic setting of QFT named AQFT. The first vague ideas date back to the late 50s and the reader gets a first impression about its aims, concepts and its own mathematical formalism up to the end of the 80s in the book by R. Haag [8]. In fact he uses the name *local quantum physics* precisely because it exposes its conceptual structure[13]. Its history and its structural results are of little relevance to string theory, but its recent contributions to non-Lagrangian constructions as well as its radically new insight into QFT, a theory of which we hitherto thought that we know it, are important untapped investments into a future post-string era (see last section).

2 Metaphoric aspects of string theory

Looking at the early history of string theory, it is somewhat surprising that neither the relation of the phenomenological dual model to the concept of crossing property (abstracted from QFT), nor its later mutation into string theory as an alleged fundamental theory of all forces was given the critical attention and scrutiny which such apparently paradigmatic changes deserve. After all the Veneziano duality is at odds with the field theoretical view of crossing and the knowledge and interest in conceptual aspects of local quantum physics already reached a certain level of maturity at that time. I think that the explanation is the same as for the present imbalance between computational effort and conceptual investment in string theory, namely string theorists do not have the patience and ability it takes to spot potential paradigmatic cross roads and use their enigmatic power (which would have forced them to moderate their free-roaming "assume as you go" attitude). It is much easier to accept its new rules and explore its consequences by doing many calculations; leave the interpretation and the conceptual problems in a temporary metaphoric state.

What made the situation worse is that to those who have a good grip on the conceptual basis of QFT, string theory did not seem sufficiently attractive to spend a lot of time. The problem is not that they deny the necessity to leap into a conceptual "blue yonder"[14] in certain situations, but rather that they want to be sure that at least the point of departure is conceptually sound. A proposal for a theory in which the S matrix is defined by computational recipes instead of being derived from basic principles of local quantum physics (as was already achieved in the LSZ and Haag-Ruelle scattering theory [8]) does not attract much of their attention, unless its phenomenological success outweighs its conceptual shortcomings. This certainly was not the case; the dual model lost the little phenomenological support it enjoyed initially, when two years later large momentum transfer hadron scattering measurements came into serious conflict with its predictions. Most particle theorists who have some familiarity with quantum field theoretical principles expect from a new theory that it should not fall back on already achieved conceptual conquests and achievements.

Antinomies and paradoxical situations arising from theoretical research or new experimental results were the valuable catalyzers of great conceptual advances in the last century; but to find deep ones and unravel their enigmatic power requires extraordinary knowledge, skill and perseverance. Whereas some at least partially successful attempts were made to understand the relation of (on mass-shell) crossing

[12] Some geometrical enrichments came much later and did not really modify the core of the situation.

[13] The book is very scanty on computational details.

[14] This phrase was occasionally used by Feynman (probably with the history of his own discovery of the path integral representation in mind).

to the principles of QFT[15], there exists unfortunately no serious investigation of the physical origin of duality and its physical consequences. In particular there was never any serious attempt to understand the difference between the (on-shell) crossing (partially supported by rigorous arguments of AQFT) and the duality in the formal sense of Veneziano which requires infinite particle towers in terms of spacetime principles of local quantum physics.

This lack of physical understanding increased when prescriptions were found which in principle could incorporate the non-unitary elastic scattering amplitude of Veneziano into a unitary scattering matrix for particles in the infinite tower. The string theoretic reformulation of the dual model was important for this incorporation and for the extension of this Veneziano amplitude from a proposal for two-particle elastic scattering to an arbitrary large number of particles, but it does not solve problems of consistencies. In local quantum physics the unitary scattering operator including its physical cluster factorization and its crossing properties are *not the result of prescriptions* but are deducible consequences of well established spacetime locality and stability principles (via time-dependent scattering theory). In theories in which relations of the S-matrix to spacetime aspects is not known, there are certain prerequisites which are to be checked in order that the unitary operator under consideration merits the name S-matrx.

A model of interacting particles does not have to be micro-causal, but without assuring some form of macro-causality the whole physical interpretation goes down the drain. Whereas in string theory Poincaré invariance of the string S-matrix is achieved by choosing the appropriate required higher spacetime dimension and unitarity is related to the interpretation of the higher order string corrections as a process of perturbative unitarization, the sticking point is the cluster factorization for processes involving more than two particles. Clustering is part of macro-causality[16]. Apparently this property remained unchecked in string theory.

There exist theories of relativistic particles which fulfill these minimal requirements [7], which have been constructed by (mathematically and conceptually very skilled) nuclear physicists who gave them the name *direct particle interactions*. The reason why string theorists take cluster factorization for granted without comment is probably the vague analogy of their tube pictures with Feynman graphs. Given the subtlety one encounters with S-matrix cluster properties in particle theories outside QFT, the connections of the string theoretic S to a particle physics scattering operator remain metaphoric.

The remainder of this section will look at metaphoric aspects of string theory, some of a quite worrisome kind. To avoid misunderstandings, metaphorical arguments are sometimes also used (for reasons of brevity and intuitive appeal) in QFT, but they can in all cases be replaced by autonomous derivations; QFT is a fully autonomous theory which (thanks to the deep notion of its causal localization) even contains its own physical interpretation.

To illustrate this point and convey the intended meaning of *metaphoric versus autonomous* (or intrinsic), consider the following example from *thermal QFT*. One is accustomed to describe the thermodynamic limit as a sequence of box-quantized systems in Gibbs states and one thinks of the thermodynamic limit sequence as that of mutually included subsystems i.e. the QFT of the smaller box as being included in that of the bigger box. Strictly speaking this picture is metaphoric since the differently sized boxes belong to unitarily inequivalent representation of the canonical commutation relation (even their C*-algebras are different). This metaphoric aspect of the standard approach to quantum statistical mechanics was the reason which led Haag Hugenholz and Winnink in the early 60 to elaborate a formulation for *open systems* [8] which replaces the Gibbs states by the more general notion of KMS states and thus formulates relativistic thermal problems in Minkowski spacetime from the very start. It turn out that the definition of a finite subsystem is anything but simple. One first must understand the meaning of localization in the relativistic setting of QFT [6]. Unlike in the second quantized formulation of QM, it is not possible to write the full vacuum representation of relativistic causal QFT as a tensor product of a finitely localized part and its spatially disjoint localized part, even though the finitely localized subalgebra commutes with its causal disjoint.

The breakdown of quantum mechanical tensor factorization in QFT as a result of a radical change

[15] Off-shell crossing in the setting of Feynman diagrams is an almost trivial property, but to show that the mass shell restriction commutes with this relation requires a substantial amount of analytic work [10].

[16] Clustering expresses the weakening of interactions in spacelike directions and certain multiparticle $i\varepsilon$ prescriptions (with the right sign) are related to timelike re-scattering and the absense of precursors. Direct particle interaction theories are the only known macro-causal relativistic theories outside of local QFT and their very existence shows among other things that QFT is definitely not the result of special relativity+clustering.

in the algebraic structure corresponds has been fully understood by AQFT; for a presentation in the physical context of a famous Fermi Gedankenexperiment I refer to [6] and previous discussions cited therein. Whereas the full algebra is of the same type as in QM, the (sharply) localized subalgebras are of a completely different type (hyperfinite type III_1 factor, the *monades* in the last section).

The physical reason is that[17] the infinitely strong vacuum-polarization at the causal boundary (horizon) has a thermal manifestation and prevents a tensor factorization in the aforementioned sense. By allowing the vacuum fluctuation to settle down in a "collar" region of size ε, one can achieve a tensor factorization into the original finite subsystem augmented by contributions from the collar of fuzzily localized matter and an appropriately defined causally separated outside. The only requirement on a QFT for insuring this *split property* is that the density of phase space degrees is such that the existence of a ground state representation implies the existence of thermal states [9]. The state resulting from restricting the vacuum to the localized subalgebra (either with sharp boundary or its fuzzy counterpart resulting through extension with the ε collar) is a thermal state of finite temperature with a finite εdependent localization entropy which is proportional the area of the horizon and has a $|ln\varepsilon|$ divergence in the sharp localization limit $\varepsilon \to 0$ (see last section). The above box quantization approach has suppressed this boundary effect of vacuum polarization at the prize of destroying the inclusion picture for the thermodynamic limit sequence for open systems (although in this case the thermodynamic *limit* is the same, no matter whether one uses the metaphoric box argument or the autonomous open system method).

It is quite interesting to start a critique of string theory concerning its apparently incurable metaphoric nature by asking whether the word "string" in its name has any intrinsic meaning in its quantum theoretical realm. In the setting of the quantization of the 10 dimensional supersymmetric version of the classical Nambu-Goto string this would amount to ask whether the localization, which is intrinsically related to the physical free one-string state-space (the state space after the BRST descend from pseudo-unitary to unitary), can be viewed as being generated by pointlike fields or whether one needs stringlike generators. Since the representation is one of a tower of massive particle in which no zero-mass infinite spin Wigner representations occur (which would destroy the pointlike generating property of the representation), the canonical quantization of the classical N-G string is a theory with pointlike localized generators. In fact since the c-number character of the graded (supersymmetric) commutator of the Nambu-Goto operator is a c-number, the autonomous content of the associate field theory is a *graded generalized free field*.

The classical string character (which passes to the infinite component test function spaces) before the BRST descend becomes metaphoric once one arrives at the physical quantum BRST-invariant sub-theory. No matter what one says about the classical string and its infinite dimensional test function counterpart, the pointlike localization is an autonomous property of the quantum theory which is inexorably linked to the unitary representation of the Poincaré group. Assigning a string localization would be completely metaphoric (it will not show up in the commutation structure of two free string fields). This metaphoric aspect carries over to the euclidean tube picture; there is no administrable Osterwalder-Schrader apparition which improves the interpretation in the presence of interactions.

Different from QFT, the quantum Nambu-Goto string field seems to be only a device which sets the infinite tower mass spectrum, it does not play any role in the formulation string interaction. As already mentioned, the recipes for interactions in terms of splitting and recombining tubes in Euclidean space do not reveal properties of localization. In fact a scattering matrix as a result of its asymptotic interpretation does not contain any direct informations about localization. Such information is only revealed by those localized operators which interpolate incoming and outgoing states i.e. whose large-time asymptotic limits lead to that S-matrix. But these are not the kind of questions which would attract string theorists.

Another metaphoric claim of string theorist which goes beyond terminology is the statement that ST contains QFT in a large distance (low energy) limit. For a rigorous proof one would have to solve string theory and show that is contains objects which asymptotically for large distances approach the correlation functions a task which even in case of the relativistic QFT$\to$nonrelativistic QM relation would be asking the impossible. The message from this last case that metaphoric arguments (e.g. looking at functional representations without actually doing the functional integrals) may turn out to lead to wrong results. Take for example the case of 2+1 dimensional QFT which have braid-group statistics. If the spin is anyonic (i.e. not semi-integer) the statistics is plektonic and the upholding of the spin-statistics theorem in such a case prevents the nonrelativistic limit to be a (second quantized) QM; it remains

[17] Take for simplicity a causally complete region as e.g. a spacelike wedge or a double cone.

a nonrelativistic QFT. Only if one relinquishes the plektonic commutation relations, but preserves the anyonic spin one finds Wilczek's anyons in the form of quantum mechanical Aharonov-Bohm dyons[18]. The theoretical reason why QM is physically relevant is that its more fundamental QFT counterpart has the same Fock-space structure or to but it more bluntly: without the existence of relativistic local bosonic and fermionic free fields there would be no QM. There are simply no free (on-shell) plektons and consequently also no plektonic QM. Only after having indications about a structural compatibility "scale sliding arguments" on classical actions in functional representations become trustworthy. The message from this illustration is that one theory can only be asymptotically (e.g. for long distances) contained in a more fundamental one if the structures harmonize. Whereas one has convincing knowledge about the intrinsic structure of QFT, the metaphoric state of ST prevents such comparison and the claim that it contains QFT becomes dubious.

The power of dominance through metaphoric connections to other areas shows up in its most overt form in the CFT-ST relation. Chiral CFT is the most valuable theoretical laboratory for AQFT. In particular, as a result of its modular operator algebra concepts, it led to the recognition that the two-dimensional Nelson-Symanzik (N-S) duality for thermal states in massive 2-dim theories (part of the standard Euclideanization of QFT) in the context of chiral theories passes to the much more subtle angular "temperature duality" [11][26] which as a special result (restricting to the thermal expectation of the identity operator = partition function) identifies the chiral partition function with a (Hecke type) modular form and explains the $SL(2,\mathbb{Z})$ modular relation as the Verlinde analog of the N-S duality. String theorists with their magic metaphoric power are able to interpret the (Bargmann-Hall-Wightman) analytic domains in terms of localization of ST objects. A metaphorically trained eye of a string theorist is even able to see a type II string behind certain modular forms. *Metaphoric annexation* of other areas as CFT is of course quite easy and it seems there is little resistance.

A critical review of ST would miss out on its objective, if it ignores a contribution which string theorists considers as one of their most important achievements: *the Maldacena AdS-CFT conjecture.* The fact that thousands of publications were written about this problem and that even the still ongoing research has not been able to come any closer at proving/disproving this conjecture is a unique mind-bending phenomenon in the history of particle theory. There is a lot to be learned by exploring its sociological aspects and implications, but in this section our critical review will be strictly limited to scientific aspects of this conjecture.

The rather subtle issue is best approached by starting with a mathematical statement before getting to the specific formulation of the Maldacena conjecture and its history. As is well known since the 60's the n+1 dimensional anti de Sitter spacetime (AdS) and the n dimensional conformal QFTs (CFT) have identical spacetime symmetry groups. A profound mathematical theorem reveals that there is a even a unique correspondence between LQP (local quantum physics) models[19] in n+1 dimensional AdS spacetime with a n-dimensional conformal invariant LQP model. In the appropriate jargon is a special kind of *holography* in which the substrate of quantum matter on both sides of the correspondence (as well as the Hilbert spaces) is the same, but the way quantum matter is organized in spacetime (and hence the physics which depends on spacetime organization of quantum matter) is slightly different.

As all mathematical theorems in QFT are of a structural kind, the corresponding mathematical theorem at hand does not allow to explicitly identify the model together with a Lagrangian name (even if the starting model would result from a Lagrangian), it only relates their LQP algebraic structures. For the following arguments it convenient to use the (infinite) covering tube $\mathbb{R}\times B_n$ and its boundary $\mathbb{R}\times S_{n-1}$ as geometric descriptions of AdS and CFT spacetimes (coordinates in which the conformal infinity has occurs at finite values.). Causally complete regions on the conformal boundary correspond to the causal shadow which they cast into the bulk, and for those causally complete regions in the bulk which reach up to the boundary, the corresponding region on the boundary is simply the intersection with the boundary. Without loss of generality one may take for a system of causally boundary region the so-called double cone (diamond-shaped) regions, then the corresponding bulk regions which intersect

[18]This is a n-particle QM which satisfies clustering but permits no second quantized represenration in terms of field operators.

[19]The only reason for trading the standard terminology QFT with LQP (local quantum physics) is to alert the reader that the mathematical theorem is not valid in the setting of Lagrangian quantization but rather needs the more general LQP framework of QFT; in fact one consequence of the theorem is that not both sides of this correspondence can be Lagrangian, if one side is than the other is a non-Lagrangian QFT [12][13][14][15].

the boundary in a double cone are wedge-shaped regions. Any double cone region $\mathcal{O}$ in the bulk which is not such a wedge region can be obtained by intersecting (possibly infinitely many) wedge regions. The theorem asserts that the system of conformal double cone algebras which make up the algebraic structure of the CFT corresponds to the system of the mentioned wedge algebras in the bulk. Vice versa any O-localized bulk algebra is obtained from intersection of wedge algebras with the boundary. In this way the spacelike commutativity of one side passes to the corresponding one on the other side.

One then may ask the question whether the involved algebras of the LQP setting of CFT are generated by standard (e.g. Lagrangian) pointlike fields in the standard sense of QFT; by this we mean pointlike fields whose timelike propagation is causal in the sense that their knowledge in a small time-slice of finite spacial extension fixes uniquely the field in its double-cone shaped causal completion. A QFT with a "normal" amount of degrees of freedom has this property[20]. But if e.g. the AdS theory is normal QFT in this sense, one would expect that if a bulk theory which becomes one-to one mapped onto its timelike boundary at infinity (the conformal theory as a *brane* at infinity), then too many degrees of freedom have been compressed into the lower dimensional one and the resulting conformal theory does not allow a description of its double cone algebras as being generated by normal pointlike (in particular Lagrangian) fields. Precisely this turns out to be the case. Vice versa if one starts from a normal CFT, one would expect that there are not enough degrees of freedom to "fill the bulk", which could lead to the triviality of the above $\mathcal{O}$-intersection. In that case the conformal degrees of freedom "get stuck on the boundary". Indeed if one takes a region on the boundary and covers it with double cone of smaller and smaller size, the net effect of the corresponding wedges in the bulk also become smaller i.e. the extension into the bulk can be made arbitrarily small. But this is incompatible with AdS algebras generated by pointlike (in particular) Lagrangian fields. This means that *only one of the corresponding theories is compatible with the properties of a Lagrangian QFT*, although both theories are QFT in the more general sense of the LQP framework.

A simple concrete illustration is provided by taking a 4-dim. free scalar massless field (which is normal in the above sense), where the "hollowness of the "corresponding AdS bulk can be explicitly verified. The opposite direction is even easier to illustrate: the hologaphic projection of a free field on AdS is a conformally covariant generalized field with an increasing Kallen-Lehmann spectral function (bad phase space properties) which defines a QFT outside the Lagrangian setting. If the free fields are supersymmetric then their spacelike commutation relations are graded. A Lagrangian supersymmetric Yang-Mills theory is normal in this sense of the theorem and its inverse AdS bulk theory is certainly a QFT albeit not a Lagrangian QFT. But a AdS QFT is not a string theory.

Unfortunately the Maldacena conjecture has not been clearly formulated. In its string theoretical setting it relates a certain kind of conformal invariant 4-dimensional supersymmetric Yang-Mills theory with a certain kind of 5-dimensional supersymmetric string theory (coming from a certain 10 dimensional string via compactification). Maldacena considers SU(N) gauge theories with $N \to \infty$. Such limits are known to be not QFTs even though they maintain this property for each fixed N [15]. I have tried all possibilities of what Maldacena could have meant and none of them seem to be consistent with the above structural theorem. Since the interpretation of string calculations is metaphoric, It would not help me to look at (perturbative or other) any one of those myriads of papers. With so many problems at hand, the additional problems with the alleged conformal nature[21] of SUYM appear comparatively innocuous.

A globalized community which produces thousands of papers about a rather simple holography (i.e. one which involves a rather mild reprocessing of spacetime organization of quantum matter) is in my view a very new ominous phenomenon in particle physics.

Its existence contradicts all naive beliefs in progress. Instead of a growing diversity of as a result of an increasing number of particle physicists one observes the dominance of monocultures made even worse by the existence of media and improved communications. This raises the serious question whether physics is not suffering from the results of its own past impressive progress.

But what makes specifically the Maldacena issue (with its approximately 4 thousand contributions) so bizarre is that there are a few papers in which the previous theorem has been proven [12][13][15]. They are clearly written, but a reaction of the community (which the authors probably expected) never came. The papers probably did not have the blessings of the community leaders.

[20] Technically speaking the required property is a strengthening of Einstein causality which bears the name *Haag duality*.
[21] The vanishing of the β-functions is necessary but not sufficient for conformal invariance.

The pertinent question to be asked here is how can a community of more than 500 members through some collective amnesia ignore a rigorous mathematical theorem if that theorem covers the general case of the AdS-CFT equivalence? If the conjecture is outside the theorem (hard to believe if the word CFT has its autonomous mathematical physics meaning) then somebody should have explained in public why this is the case. Has the ethics in particle physics already sunk so low that metaphorical arguments overrule mathematical theorems which illustrate a conceptually clear point? Do volumes of rampant calculation outside any conceptual lead wipe out mathematical theorems? Could this be what is meant with "the end of science"? This theme will be taken up within a more general sociological context in the next section. There are only two papers in which this bizarre situation has been pointed out [16][17] but the community had become addicted to the metaphoric lure of time-less conjectures.

The Maldacena conjecture has been used to claim (see next section) that the fate of string theory is inexorably linked to that of a (minimal supersymmetric) version of the standard model. What looks to some string theorists as a marvelous achievement, namely that as a result of the conjecture the glory of the standard model becomes part of string theory is at closer sight a conceptional hiccup, because there are now two versions of the standard model, the one claimed before the Maldacena conjecture (the standard model as a low energy limit) and the Maldacena one.

3 Sociological aspects of the string theory community,

In this essay I will argue that the involvement of string theory in the crisis of particle physics cannot really be understood in terms of some metaphorical turns in (parts of) particle theory without taking a also closer look at the philosophical and sociological changes arising from the building of a globalized community around string theory. My experience with string theoreticians is admittedly marked by a certain distance since my underlying philosophy has basically remained "Wilsonian". I do not mean this in the literal sense of Wilson's momentum space renormalization group formulation (i.e. approximating euclidean functional integrals up to energies which at least include the range one is interested in), but rather in the more philosophical sense that an existing well-working theory will always be asymptotically (not necessarily in terms of distance) included in a future one, so that material reality will reveal itself like putting together a (possibly infinite) Russian matryoshka. Perhaps somewhat different from Ken Wilson (I do not know his opinion on this point), I am convinced that every level can be described in conceptually complete and mathematically rigorous way; by this I mean that no knowledge of the next layer and no cutoff is required for mathematical consistency. In view of the still precarious situation of the mathematical existence of nontrivial models (for more remarks see last section) this is presently not more than an educated guess. Especially for the physically relevant models this "existence problem" (which to many practicing quantum field theorist looks pretty academic) is closely linked with the lack of trustworthy nonperturbative understanding. Often it is said that the Wilson renormalization group setting solves the existence problem by dumping the details of the next layer of reality beyond the range of QFT. But there are indications that the blaming of the difficulties of mathematical existence of QFT on bad ultraviolet behavior may be somewhat misleading[22]. In fact I believe that the 70 year old impairment of QFT of not knowing whether those objects we talk about in QFT really exist still will be overcome. In the not so distant future QFT will enjoy the same conceptual status as other areas of physics. Certainly QFT has little to do with that narrow-minded caricature of an already closed theory which is particularly popular in the string community.

Having stated my viewpoint, the reader will not be surprised that my sympathies with TOEs (theory of everything) leave a lot to be desired. The idea that Einstein's Dear Lord permits some string theorist to find a closure to fundamental physics, so that for the rest of all days the curiosity of humanity about its material world will end in intellectual boredom (or at best can be re-directed into filling in some technical details, finding new applications or preparing something for the entertainment industry) appears to me outright quixotic. Ideas like this probably will be cited by historians in a distant future as representing the hubris and intellectual (not necessarily personal) arrogance of a past Zeitgeist.

To be sure, speculative ideas which lend themselves to geometric visualization always (already at the time of Einstein) attracted the attention of some wide-eyed young physicist (and many science journalist)

[22] Note that string theory, if anything, has a much worse existence problem; it is not even possible to give an intrinsic characterization, the only thing one has are cooking recipes.

who tried to get some millage by exploring their metaphoric content. But never before did the cultivation of metaphors become the main subject of a group of hundreds of scientists.

The message of having a final theory for the millennium continues to be a central propagandistic point of the string community. Let us start with a particular extreme illustration namely a quotation of a line by which a well-known Harvard professor with some reputation within the string community used to sign off his contributions to discussion groups (he apparently stopped after getting a tenure track position at Harvard). It reads as follows :

Superstring/M-theory is the language in which God wrote the world.

Note the difference of this God who has to follow the logic of string theory (perhaps because "there is no other game in town", see next section) to Einstein's Dear Lord.

When, at the beginning of this year, I wrote a prior version of this essay, I was under the impression that the author of this phrase was an enthusiastic novice whose adoration of string theory has carried him overboard and left him in some cranky fringe region from where he continues to nerve those particle physicists by swear-words who are not sufficiently impressed with ST. Each time I looked at his signing off, an old limerick which I red a long time ago came to my mind. It originates from pre-war multi-cultural Prague where, after a performance of Wagner's Tristan and Isolde by a maestro named Motl, an art critic (who obviously did not like the performance) wrote instead of a scorcher for the next day's Vienna newspaper the following spooner (unfortunately untranslatable without a complete loss of its lovely polemic charm):

Gehn's net zu Motl's Tristan
schaun's net des Trottels Mist an,
schaffn's lieber 'nen drittel Most an
und trinkn's mit dem Mittel Trost an

After having participated in Peter Woit's weblog and also occasionally followed links to other weblogs during March-June 2006 I have to admit that my above conclusions about Lubos Motl were wrong. He definitely represents something much more worrisome than an uninhibited name-calling (crackpot, rat, weasel.....) character who operates on the fringes of ST and denigrates adversaries of string theory[23] in such a way that this becomes an embarrassing liability to the string community. If that would be true, then at least the more prominent string theorists, who still try to uphold standards of scientific ethic in their community, would keep a certain distance and the whole affair would not even be worth mentioning in an essay like this. But as supporting contributions of Polchinski and others to Motl´s weblog show, this is definitely not the case. My final conclusion is that the young and intelligent Harvard professor Lubos Motl has decided to build his career on offering a catering service for the string community. He obviously is a quick scanner of the daily hep-th server output, and by torching papers which are outside the credo of string theorists (i.e. LQG, AQFT) he saves them time. The downgrading of adversaries is something which has at least the tacit consent of the community. It is evident that he is following a different road from that of using one's intellectual potential for the enrichment of knowledge about particle physics. If one can build a tenure track career at a renown university by occasionally publishing a paper but mainly keeping a globalized community informed by giving short extracts of string-compatible papers and playing the role of a Lord of misuse to outsiders who have not yet gotten the message, the transgression of the traditional scientific ethics[24] for reasons of career-building may become quite acceptable. It would be interesting to see into what part of this essay the string theorists pitbull will dig his teeth.

The string community is not the only community in which an idea which lacks of experimental support and theoretical coherence and normally would have remained the subject of some remark or a few publications gains momentum through community-building around it especially in case it promises lots of calculations end rapid papers. By attracting the attention of a Nobel laureate the community may even become a global player. This phenomenon can be observed even in such venerable areas of physics as thermodynamics and statistical mechanics [18]. Whether the positive side (sharper focus on a problem) outweigh it potential negative collateral damage (loss of critical distance) only history can tell But the power and glory of the community around string theory is certainly the most impressive phenomenon.

[23] I invite all readers to look at the low level name-calling contributions from string theorists in weblogs whenever a discussion leads to critical remarks which goe against their metaphors.

[24] In the local ideom of the Viennese author of that little 4-line spooner such a person would be called a Schlawiner (wangler) and certainly not a Trottel.

There is no question that string theory has a strong sociological basis. The interest in popular science has played a crucial role in spreading its messages. Its complex mathematics compel its presenters to stick to its metaphorical and entertaining aspects (which often are a quite fair approximation of its slick conceptual content). A typical Wikipedia presentation of superstrings which highlights its metaphorical content in form of a reads as follows:

In the 1990s, Edward Witten and others found strong evidence that the different superstring theories were different limits of an unknown 11-dimensional theory called M-theory. These discoveries sparked the second superstring revolution. When Witten named M-theory, he didn't specify what the "M" stood for, presumably because he didn't feel he had the right to name a theory which he hadn't been able to fully describe. Guessing what the "M" stands for has become a kind of game among theoretical physicists. The "M" sometimes is said to stand for Mystery, or Magic, or Mother. More serious suggestions include Matrix or Membrane. Sheldon Glashow has noted that the "M" might be an upside down "W", standing for Witten. Others have suggested that the "M" in M-theory should stand for Missing, Monstrous or even Murky. According to Witten himself, as quoted in the PBS documentary based on Brian Greene's "The Elegant Universe", the "M" in M-theory stands for "magic, mystery, or matrix according to taste."

Only physics constructs of communities who are re-assured of their hegemonic power can present themselves in such a manner of playful self-coquetry.

In the same presentation one also finds the following phrase which used to be the opening mantra of string theory talks for many years:

String theory is a model of fundamental physics whose building blocks are one-dimensional extended objects (strings) rather than the zero-dimensional points (particles)

In recent times the emphasis on the stringlike localization of their objects as opposed to pointlike has somewhat subsided, but it would probably be too optimistic to think that this could have something to do with a better appreciation of the intrinsic meaning of localization of quantum objects.

The string theory community has introduced new methods of scientific production which transcend the traditional scientific ethics. A typical example of how facts are manufactures is illustrated by recalling the following sequence of events. In one of first reactions immediately after the appearance of Maldacena's paper Witten writes (arXiv:hep-th/9802150):

Recently, it has been ***proposed*** *by Maldacena that large N limits*
of certain conformal field theories in d dimensions can be described
in terms of supergravity (and string theory) on the product
of d + 1-dimensional AdS space with a compact manifold.

After more than two thousand publications on this subject the terminology changes and the new formulation which serves as the opening remark to a 2002 paper by Maldacena et al (and which afterwards became the accepted community formulation) reads (arXiv:hep-th/
0202021):

The ***fact*** *that large N gauge theories have a string theory description*
was believed for a long time. These strings live in more
than four dimensions. One of the surprising aspects of AdS/CFT
correspondence is the fact that for N = 4 super Yang Mills these
strings move in ten dimensions and are the usual string of type
IIB string theory.

The ultimate use of the Maldacena conjecture is only available in audio form. In the last of three invited talks by D. Gross at the university of Princeton (http://www.princeton.edu/WebMedia/lectures/) one person in the audience asked whether it is possible that after all the ST may still turn out to be wrong. His answer is: *this is not possible (*or rather in the words of Gross ***string theory cannot be killed****) because it is linked (via the above fact) to the standard model*, meaning that the Maldacena relation between a certain type of compactified string with 5 uncompactified spacetime dimensions and a certain supersymmetric minimal extension of the standard model endows the ST with the glory of the standard model.

Outsiders may want to see this as a manifestation of intellectual dishonesty of one or several individuals, but I would maintain that it is more the result of delusions arising from the collective group phenomenon of self-validation. It is only this continuous self-validation by which, in the absence of connection to the physical word, it succeeds to maintains its hegemonic status. Of course David Gross would not have said this as an individual researcher without a community behind him (say 20 years earlier, when the formation of this community began). In this particular case I think that his confidence is more related to the existence of large community behind him than to the enhanced status derived from the Nobel prize.

Any young physicist who wants to play this game and be a member of this community must internalize certain metaphors which it considers a fundamental. As the previous illustration shows, after an influential actor imposed his way of thinking some years of discussions of his idea within the community will be sufficient to create a fact. This change of terminology is probably not even perceived by the community members because they may have already internalized this in its intended final factual form long before the publication of thousands of papers.

With woefulness one re-visits the famous 1918 address "Principles of research" of Einstein in honour of Planck, which in the present context appear as coming from another planet:

In the temple of science there are many mansions, and various indeed are they that dwell therein and the motives that have led them thither. Many take to science out of a joyful sense of superior intellectual power; science is their own special sport to which they look for vivid experience and the satisfaction of ambition; many others are found in the temple who have offered the products of their brains on this altar for purely utilitarian purposes. Were an angle of the Lord to come and drive all the people belonging to this two categories out of the temple, the assemblage would be seriously depleted, but there would still be some man, both of present and past times, left inside. Our Planck is one of them, and that is why we love him.

There are several aspects which distinguishes string theory from other attempts of domination in particle physics. One is its mathematical complexity. One needs some familiarity with almost all areas of mathematics (ironically except operator algebras which has become the main mathematical tool of AQFT). As a result there exists hardly anybody (perhaps with the exception of Witten) who is able to follow all the developments. Even those who work on the Maldacena issue do not know all the aspects of the problem (contained in over four thousand publications); this creates the strange situation that even the contributors to its validation do not really know it. In their thesis work they acquire a highly specialized computational knowledge which does hardly touch any of the conceptual problems mentioned in this essay. As postdocs they do not find time for conceptual investments either; the publish or perish alternative has become remorseless even for string theorists (after many academic positions in physics and mathematics were already filled by string theorists from previous generations).

Due to a total lack of global knowledge (which they often share with their advisers) the intellectual level of their work is poor. As a result they tend to blindly depend on leading figures who have this global knowledge. This explains the worship to Ed Witten. It would be hard to imagine a scene where before talks by Pauli or before Feynman's charismatic presentations young people in the corridors would whisper: *what will he tell us*? But this was of course before the relation of mathematics to particle physics became a subject of metaphors (exerting a Harry Potter-like spell to bright young physicists and inviting to extend them participate and extend the game). It is amazing that mathematicians draw their innovating ideas from this metaphoric connections to physics, whereas mathematical problems coming from the rich conceptual operator algebraic structure of autonomous AQFT (see last section) only draws a minority attention. I think it is just this metaphoric vagueness which temporarily permits them to stray away and allows some space outside their otherwise rather methodical scientific life.

Another important difference of string theory to prior hegemonic attempts in particle physics is its ability to hold on for more than three decades. Its predecessor, the bootstrap S-matrix theory, dominated particle physics for only one decade; not enough for seriously effecting the development of QFT. The three decades of ST dominance have succeeded to accomplish precisely that. Knowledge about deep field theoretic conceptual achievement of QFT are not any more passed on; graduate students often learn QFT from courses taught by professors who already started their career in string theory and transmit QFT in terms of its string theoretic caricature (which consist in reducing it to some computational rules and stripping it of its rich conceptual structure so that it looks like a closed theory). It is quite common to meet postdocs who know incredible details about Calabi-Yau spaces but have not the faintest idea about (pre-electronic) time-dependent scattering theory and the related subtle role of vacuum polarization in the connection between particles and fields. QFT for them was just a set of rules to evaluate euclidean functional integrals.

A recent paper (http://arxiv.org/abs/hep-ph/0604255v1) sheds a particularly damaging spotlight on how strong and successful argument of falsifiability of local QFT are perverted into a metaphoric string theory version. In the late 50s, in the aftermath of the Kramers-Kronig dispersion relations, the question of whether there are model-independent experimentally verifiable consequences which test the underlying causality and stability (spectral) properties of QFT. These investigations started by technically quite demanding systematic investigations of analytic and crossing properties of on-shell restrictions of Feynman diagrams. Somewhat later (thanks to the rigorous derivation of the powerful Jost-Lehmann-Dyson spectral representation) many analytic properties of unitary S-matrices coming from QFT (forward dispersion relations, Lehmann ellipses, Froissart bounds) were directly derived from the principles underlying QFT. One rigorous consequence, the forward pion-nucleon scattering dispersion relation whose experimental violation would have shattered the foundation of QFT was successfully tested at the Brookhaven National Laboratory and our confidences in the extended applicability of QFT for short distances was strengthened.

In the mentioned recent paper the authors proposed that bounds and analytic properties of this kind could be used to decide whether ST is a theory according to Popper's falsifiability criteria. Since in case ST has any underlying principles, they are unknown and nobody has made the slightest attempt to derive such properties from perturbative expression (as mentioned previously, not even the validity of the much coarser cluster-factorisability has been checked), the ST appropriation of the falsifiability issue remains a mindless attempt to defend an untenable situation. How can one draw conclusions from rampant calculations which are thrown upon us without any conceptual guide? This state of affairs shows that some of the members of the string community try their best to narrow the gap to the meta-metaphoric level of the papers which the Bogdanov brothers managed to get published.

¿From a scientific viewpoint ST may be a failed theory, but who in the ST community would have the guts to say this after having invested many years (for some people their whole scientific life) into this project? I expect that their protagonists will defend it with teeth and claws. They will appropriate any successful idea into their metaphoric setting (greatly facilitated by the absence of any autonomous concepts) and nobody would doubt their ability to find excuses if the planned LHC experiments do not show (broken) supersymmetry and additional (compactified) higher dimensions.

Finally one should ask the question whether the pretension of ST to represent the final theory for the millennium has an analog in present day ideologies. A similar sociological question was asked shortly after the discovery of QM. In a book by P. Foreman [19]

Weimar culture, causality and quantum theory1918-1927: Adaptation by German physicists and mathematicians to a hostile intellectual environment. Hist. Stud. Sci, 3:1-115

he proposes the thesis that a theory in which the *classical certainty* is replace by *quantum probability* could only have been discovered in war-ridden Germany where Spengler's book *the decline of the west* which represented the post world war I Zeitgeist in Europe had its strongest impact. I am very sceptical of Foreman's arguments, I think the more palatable explanation is that the high level of German science especially on theoretical subjects was not at all affected by the destruction; in particular there was no state-sponsored anti-Semitism which would have weakened that high level.

But in the case at hand I really do believe that the building of the ST community and its hegemonic power on particle physics is coupled to the millennium Zeitgeist. My arguments are as follows. After the end of the cold war, ideologists proclaimed that global capitalism is the final social order at the turn of the millennium, *the end of history*. The future world will be democratic and everybody will have a happy life free of wars and social conflicts. This ideological setting was quite successful for strengthening the hegemonic grip of globalized capitalism on the world order. Science is a very important part for the presentation of its power and glory, and a theory of everything for quantum matter at the end of the millennium and the promise of an *end of fundamental physics* fell on extremely fertile ground.

ST enjoys strong support in the US and the European union together with other states is spending billions of dollars on the LHC accelerator and its five detectors which among other things are designed for the task of finding traces for two of string theories "predictions" namely supersymmetry and extra dimensions.

It is inconceivable that metaphoric ideas without any experimental support would have been compatible with any other Zeitgeist. Philosophers and sociologists of the *Frankfurt school of critical theory* have anticipated this dialectic change from enlightenment into irrationality. According to Horkheimer[25] and Adorno: *enlightenment must convert into mythology.*

Indeed the metaphoric nature of the scientific discourse, which gained acceptability through ST, is the ideal projection screen of a mystical *end of time belief at the turn of the millennium.* No other idea coming from science had such a profound impact on the media and on popular culture. Physics departments at renown universities have become the home for a new type of scientist who spends most of her/his time travelling in order to spread the message of extra dimensions, landscapes of multiverse etc. This had the effect that people outside of science think of intergalactic journeys, star wars, Ufos, poltergeists (from extra dimensions) etc. if they hear the word superstring (http://www.mkaku.org/articles/.).

The ominous analogy in the western political domain of rationality converting into mysticism (e.g. intelligent design) is the e.g. increasing influence of fundamentalist new-born Christians whose closeness to the center of the big power give their end-time phantasies about an Armargeddon in the middle east a dangerous dimension. The achievements of enlightenment and rationality as democracy and the rule of law convert into destructive hegemony and ideological delusions. I leave it up the reader to expand this analysis about parallel developments in the unfolding Zeitgeist.

There is some positive message for young bright string theorists who find themselves in a situation of having invested the best years of their productive life into a failed project without having acquired a good knowledge of particle physics. My advice would be to try to fill these gaps and take additional courses related to the philosophy of science and sociology. There will be *a lot of questioning of the educated public* about how the quest for a unified theory of matter and gravitation converted into metaphoric thinking and mysticism of ST and extra dimensions and why they were misled by scientific writers and some scientist. There are no simple straightforward answers; only former members of the community with a insider knowledge, complemented by a good perception of sociological forces and knowledge about the history of western philosophy, will be capable to reveal to the educated public what really happened. This will be the best service they can provide at the appropriate time, much better than spreading the string theory credo at some colleges or schools where they may end after a failed academic career.

My critical observations have some points in common with those of the science writer John Horgan [20]. But I sharply differ from his conclusion that particle physics came to an (and became "ironic" science) end because there are no more challenging conceptual open spaces. I never have seen so many fundamental open problems as there are at present. I think that Horgan in his book *the end of science, facing the limits of knowledge in the twilight of the scientific age* has tacitly internalized the string theorists claim of a TOE. The present crisis in particle physics has nothing to do with having reached limits of knowledge, rather particle physics became the victim of its success in a quite different sense from Horgan's.

It is evident that the attempt to maintain and strengthen the continuous fast-paced success which particle theory enjoyed within a good part of the last century by subjugating science to the laws of the globalized market had the opposite effect from what may have been intended. The increased pressure towards a more efficient way of scientific production has left little time for exploring difficult new directions; it is much easier to build an academic career within an existing monoculture by internalizing its metaphoric concepts. At the end the publish or perish alternative is not only effecting young, and nowadays even less young theorists by taking away the free time for pursuing new thoughts (which during Einstein's time (the patent office) and even during the later years of his quantum mechanics adversaries was an essential part of scientific life), but science itself as we know it may be its ultimate victim.

The system of assigning the highest impact indices to publications in journals which carter to string theory-influenced articles greatly favours this trend. The editorial boards of highest impact journals (e.g. JHEP) as well as that of the speakers at any of the fashionable string 200X conferences (e.g. http://strings04.lpthe.jussieu.fr) provide a rather complete list of Who is Who in the administration of the crisis. I am particularly saddened that even the Werner Heisenberg Max Planck institute was not spared the fate of falling prey to the millennium fad and I am sorry for all the enthusiastic bright students

[25] In Horkheimer's words: "!f by enlightenment and intellectual progress we mean the freeing of man from superstitious belief in evil forces, in demons and fairies, in blind fate – in short, the from fear – then denunciation of what is currently called reason is the greatest service reasoncan render." cited in M. Jay, The Dialectical Imagination. A History of the Frankfurt School and the Institute of Social Research, 1923-1950, Univ. of California Pr., 1996, p. 253.

who will be misled for a very long time to come. Looking at the list of the advisory board one immediately understands how this has happened.

4 The only game in town?

Despite its apparent lack of ability of predicting any new measurable effect which goes beyond the result of QFT and its recent successful adaptation to curved spacetime (CST), and notwithstanding its metaphoric ways of relating itself to the well-established principles of local quantum physics underlying particle theory for more than 3 decades, ST continues to dominate fundamental research. This metaphoric aspect of string theory is at the root of recent doubts about whether superstring theory fulfills the criteria of falsifiability spelled out by the philosopher Popper as a prerequisite for science[26]. There appeared meanwhile two books [21][22] in which this issue is addressed and one of the books already reveals its conclusions in its title "Not Even Wrong".

This kind of criticism may increase the awareness about the role of string theory in perpetuating the particle physics crisis, but even if the planned LHC experiments will confirm the absence of supersymmetry, this will not lead to an immediate change of direction. The main reason is that the long reign of the string monoculture with its metaphorical arguments has led to a big rupture in the conceptual development of local quantum physics. Even if ST enters calmer waters and its community disperses, the metaphoric way of reasoning which it made acceptable will continue for a long time in adjacent areas as braneworlds, extra dimensions, cosmology and conformal QFT.

There is a certain grain of truth if string theorists in hard-pressed situations (e.g. within panel discussions or interviews) adopt the argument of David Gross that superstring theory is "the only game in town". But similar to the words of a character in Kurt Vonnegut's short story (which Peter Woit [21] recently used in a similar context):

> *A guy with the gambling sickness loses his shirt every night in a poker game. Somebody tells him that the game is crooked, rigged to send him to the poorhouse. And he says, haggardly, I know, I know. But its the only game in town.*
> *Kurt Vonnegut, The Only Game in Town [23]*

the situation is partially self-inflicted; there are alternatives but their pursuit requires substantial support for new intellectual efforts within changed socio-economical conditions which are more favorable to long-time conceptual investments and less prone to succumb to the lure of spin doctors who represent the majority view of globalized groups. In this respect my criticism of the negative role of ST is not different from that expressed in the two mentioned books by Peter Woit and Lee Smolin. My advice about how one can get out of this situation of "no other game in town" differs however, although there are common points with Woit's emphasis on symmetry and representation theory as well as with Smolin's insistence on preserving a suitably formulated property of background independence in any attempts to make gravity compatible with quantum theory.

My hopes for a different direction are actually related to the existence of *a third way* whose pursuit neither requires a moratorium in fundamental theoretical research up to moment when new experimental data resolve the Higgs issue and find clues about supersymmetry (which the impatiently expected LHC data may not even be able to deliver), nor does it involve the risks of a whole community getting lost in the blue yonder of highly speculative ideas. This third way consists in *exploring QFT beyond its narrow Lagrangian quantization setting* using the very firm guidance of its underlying principles to learn more about its intrinsic structure. In practical terms it means bringing the computational side of scientific production in particle theory into a better balance with conceptual developments. The number of open well-formulated theoretical probIems is presently larger than at any other time in the history of particle theory.

In the remainder of this section I will sketch some alternative ideas which have remained outside the paths of the great particle physics caravans. In all cases the conceptual basis for further work already exists, i.e. there will be no unfounded wild speculation.

[26]In this essay I will not enter the fruitless scholastic discussion of whether string theory is capable of leading to any falsifiable statements at all.

4.1 Beyond gauge theory, a different view of the Higgs issue

It may be interesting to the reader to first illustrate what I have in mind by pointing to new way of looking at gauge theory. For this purpose I start from Wigner's representation theory instead of Lagrangian quantization. Recent reviews [24][6] of the localization properties for irreducible positive energy representations of the Poincaré group based on the new concept of *modular localization* led to the conclusion that the sharpest localization which is in common to all positive energy representations is a *semiinfinite spacelike string-localization* (SSL) [6]. This means that all particles representations and associated free field algebras admit SSL generators but in the well-known cases (which includes all massive particles) one can pass to pointlike generators (pointlike fields). SSL generators are covariant objects of the form $A(x,e)$ where A may be vectorial (spinorial), x is a Minkowski spacetime point and e a spacelike directional unit vector. The semi-infinite string along which the field is localized is the halfline $x+\mathbb{R}_{+}e$ and two such objects commute when their entire halflines (and not only their $x's$) are spacelike disjoint. As a result of the fact that these fields fluctuate in both variables, it is helpful to picture e as a point in (one dimension lower) de Sitter spacetime. The are massive and massless positive energy representations. Whereas massive representations have semi-integer spin[27], the massless representations in d=1+3 fall into two classes: the rather large class of "infinite" spin representations (being characterized by a continuous parameter κ associated with an infinite semiinfinite helicity "tower"), and the finite semi-integer helicity representations which contain the photon as well as the hypothetical graviton. Whereas the optimal localization properties for the fields associated with the massive representations are of the well-known pointlike type [3], the age old controversy about the localization property of the Wigner *infinite spin* representations was finally laid to rest by showing (using the modular localization concept) that it is genuinely SSL[28]. The best localized finite helicity representations turn out to be somewhere between these cases in the following sense. Restricting for simplicity to integer helicity representations there are the well-known associated free pointlike tensor fields, which we will for brevity summarily call field strengths (for $h=1$ the electromagnetic field strength, a linearized form of the Riemann curvature tensor field strength for $h=2$ etc.). However in contrast to the massive case it is not possible to write the inner product of the Wigner representation space as an x-space integral involving a bilinear local "current" in terms of the one-particle field-strength wave function. It is well-known that there are no pointlike local operator potentials from which these field strengths can be derived[29]. The aforementioned theorem however assures the existence of a covariant SSL potential $A_{\mu}(x,e)$ acting in the *physical Fock space of the photon* which can easily be explicitly constructed [6]. An equivalent more intrinsic algebraic observation which we mention without further comments is the breakdown of *Haag duality* for local algebras generated by the pointlike $h\geq 1$ field strength in multiple connected regions [6].

It is well-known that the representation theoretical origin of local gauge theoretic formulation of QED is the observation that a pointlike perturbation formalism for minimal electromagnetic couplings in the Lagrangian setting requires to leave the quantum theoretical positivity by permitting the introduction of (Gupta-Bleuler, BRST) ghosts. This trick would lead to a contradiction with quantum physics if it were not for the lucky circumstance that the cohomological nature of the ghost formalism permits a return to a Hilbert space quantum physics at the end of the perturbative calculations. The return to local quantum physics (removal of ghosts) corresponds to the classical gauge principle which selects within all possible classical couplings of matter to vector potentials the one corresponding to Maxwell's theory.

Although there exist no pointlike vector potential in Wigner-Fock space, recent results have shown the existence of covariant SSL vector potentials. If one could formulate a perturbative approach in terms of these (in the free case explicitly known) SSL objects $A_{\mu}(x,e)$, the analogy with the classical gauge principle (which led to the BRST ghost formulation) would not be needed and the gauge principle would

[27] This is valid for $d\geq 1+3$. For $d=1+2$ there exist representations with anyonic spin which are necessarily stringlike localized and lead to fields with plektonic statistics accompanied by vacuum polarization (these fields have no mass-shell Fourier transforms).

[28] As a side remark we mention that this a relativistic quantum matter (as already observed by Wigner with strange thermodynamic properties) whose physical properties has not been studied.

[29] For the electromagnetic case h=1 the argument is quite old and amounts to the theorem that the Wigner representation space does not support the existence of a pointlike covariant vector potential. The representation theoretical argument for general h$\geq$ 1 can be found in [3][6]. Their nonexistence is of course related to the impossibility to find a bilinear density in the field strength associted with the inner product.

be taken care of by the old venerable locality principle[30]. The BRST invariant algebra (not really a subalgebra) would now correspond to a compactly localizable (i.e. e-independent) genuine subalgebra without any need to adjust the Hilbert space; the only "unphysical" aspects about the remaining e-dependent operators would be their noncompact string-like localization. Interactions which do not lead to compactly localized subalgebras generated by observable field strengths would correspond to unphysical couplings (previously: interactions which violate the gauge principle).

Formally the resulting e-dependent formalism correspond to the axial gauge formalism, but ignoring the interpretation of e as a fluctuating variable (which necessitates a smearing in the de Sitter spacetime points e as well as in the Minkowskian x) and considering it as a special gauge fixing parameter, one runs into the well-known infrared problems of the axial gauge which prevented its perturbative use. Far from being pathological, this singular behavior is just the physical manifestation which one expects of a noncompact localization as that of $A_\mu(x,e)$. On the other hand the ultraviolet behavior of the fields is shown to be not worse than that of its pointlike analog in the ghost formalism (whose application was the prerequisite for making the pointlike nature of potentials compatible with renormalizability according to the power counting criterion).

This observation is easily extended to all helicity representations for $h \geq 1$: in all these cases there are string-localized potentials with a good ultraviolet behavior (their scale dimension remains s.d.=1, independent of h) which live in the physical Wigner-Fock Hilbert space associated with the pointlike field strengths, whose short distance behavior, as well-known, increase with increasing helicity. For h=2 this formalism yields a string-dependent metric tensor potential $g_{\mu\nu}(x,e)$ associated with a pointlike field strength which has the same tensor symmetry properties as the Riemann tensor, an observation which may have some relevance in connection with the still elusive graviton. I do not know whether in all $h \geq 1$ cases there exists a pointlike gauge theory-like BRST description which brings the short distance dimension down to the value s.d.=1 required by power-counting, but SSL fields with these properties exist in all cases. This widens the possibilities of encountering renormalizable interactions in the sense of the finite-parametric renormalization group invariant islands mentioned in the introduction. In particular it invites new efforts in implementing quantum aspects through interactions of SSL potentials for gravitons.

The importance of these observations becomes clearer if one uses them for a more intrinsic reformulation of the standard model which is better suited to shed more light on the role of the Schwinger-Higgs mechanism. It has been known for some time that instead of starting within the zero mass gauge setting and generating the massive vector mesons by such a mechanism (i.e. via vacuum condensates), one could also start from free *massive* vector meson fields and use BRST ghosts to bring down their physical short-distance dimension from 2 to 1. The somewhat surprising observation made in such an approach [25] was that the formalism becomes inconsistent with the standard BRST rules unless one introduces additional physical degrees of freedom whose simplest version is that of a scalar field (without a Higgs condensate).

This may be taken as strengthening of the belief that the presence of these physical Higgs degrees of freedom is inexorably linked to the notion of self-interacting massive vectormesons. But the intermediate presence of unphysical degrees of freedom in the BRST formulation makes it difficult to pinpoint their physical origin of this link. On the other hand the trading of the BRST pointlike formalism with one based on SSL vectormesons could possibly de-mystify their physical origin; in this case the use of massive SSL free fields is not dictated by Wigner's representation theory (as it was in the massless case), rather it is required by the *improvement of the short distance dimension from 2 to 1* which lowers the minimally possible dimension of an interaction densities from 5 to 4 for achieving renormalizability without allowing ghosts. In other words a renormalizable perturbation theory involving string-localized massive vector potentials could not have local observables without having at the same time Higgs-like degrees of freedom. In particular there would be no reason to break one's head about such notorious problems as the (un)physical nature of Higgs condensates. Above all one would have understood that interacting massive vectormesons, different from interacting lower spin massive particles, require the presence of additional degrees of freedom in order to be compatible with the locality principle and renormalizabilty; this would have credibility even outside perturbation theory (since locality is not a concept limited to perturbation). In other words one would have converted the present Higgs folklore into a structural theorem about the

[30]The admission of SSL as auxiliary quantum objects remains well within the concepts of causal localization. Only observables are required to have pointlike generators.

QFT of interacting massive vectormesons, a very nice theoretical pre-advent achievement relevant for the interpretation of the future LHC experiments.

There is another potentially interesting problem which can be studied by these methods.

It is well known that (different from the nonabelian case) there are two versions of QED with massive photons, one of them containing a Higgs scalar and admitting a local physical electron operator and the other without Higgs degree of freedoms having local observables but no physical local electron field with an inverse power-like short distance behavior. It would be interesting to have a more intrinsic distinction between them by using the massive string-like description for the massive photon. Following ideas of Schwinger and Swieca, the Schwinger-Higgs mechanism in the QED setting (abelian gauge theory) is believed to lead to the screening electric charges. Looking at the reversed situation of charge liberation, one should obtain a perturbative understanding how the screened phase is passing to that of appearance of free electric charges (i.e. the analog of the passing of the Schwinger model into the charged Jordan model [26]).

Looking from a more general perspective at perturbation theory, one may ask whether there are other perturbative ways to arrive at power-series expansions of theories with a finite number of physical parameters on which a renormalization group acts as re-parametrization (see first section). In the introduction we explained such a scenario in terms of renormalization-group stable finite parametric islands in a universal infinite-parametric theory which is determined by the kinematical data only. The previous reformulation of gauge theory is in fact already a simple illustration of such a possibility because without the BRST ghost trick (i.e. the use of an unphysical catalyzer) this power counting would for any vectormeson interaction lead to $d \geq 5$ which is beyond the value permitted by the power counting theorem. The case of massive interacting vector potentials illustrates this in a particularly nice way: the starting physical pointlike field has d=2 and the corresponding interacting field *after the cohomological descend* has again d=2 (modulo logarithmic corrections); it is only in the intermediate use of the pointlike perturbative formalism that on needs the catalyzer in order to attain the renormalizability value d=1 . Hence the use of ultraviolet-improved SSL vectormesons from the start would de-mystify ghosts by placing also the intermediate steps into the realm of ghost-free local quantum physics. Could this lead to a finite-parametric island for spin=2 ? I do not know the answer, only new work will tell.

The formulation in terms of string-localized potentials also may shed new light on the age-old question whether gauge invariance has any intrinsic meaning. This issue of a "gauge principle" was always a controversial unresolved problem in AQFT. Interpreting the Seiberg-Witten duality as only a change in the field-coordinatization of the local algebras, this would suggest that lack of an intrinsic meaning (at least in those cases in which the dual is not a gauge theory). Re-formulated within the present setting of string-localized potentials, the question reads: does the observable structure (which excludes these objects) of a theory with massless stringlike vectorpotentials reveal that it is coming from such potentials? A positive answer may be related to the previous remark that the presence of massless vector-potentials leads to a breakdown of Haag duality of observables for multiply connected compact spacetime regions. The observable algebras of massive free fields obey Haag duality for all compact spacetime regions and the massless finite helicity representation constitute the only exception [6] (the idea goes back to unpublished work of Leyland Roberts and Testard cited therein). The interesting open question then is whether this continues to be an intrisic properties of observables in the presence of interactions.

4.2 Curved spacetime and a new setting for QFT

Another problem for which ideas coming from AQFT led to impressive (but little known) progress is QFT in CST (curved spacetime). Perturbation theory has been generalized to CST[31]. In that case the standard approach fails completely because there is no substitute for the properties of the vacuum and for Poincaré covariance. The way out which follows the logic of AQFT is to separate the problem into two parts, first extracting the perturbative algebraic structure (enriching the Bogoliubov-Shirkov S-formulation by a micro-local spectrum condition in terms of wave front sets) and afterwards to take care of the folium of states on this algebra. The algebraic construction includes the imposition of an adaptation of the Einstein local covariance principle which is very important in order to define the physical energy momentum tensor

[31] The literature on this is quite rich and a good starting point is to look at the most recent paper of Brunetti and Fredenhagen [27] and work once's way back to the prior important work of Radjikowski, Wald, Hollands and others.

and to be able to have a suitable composite field formalism (which in the free case replaces the Wick-formalism). These perturbative results have led to a reformulation in terms of a *functorial map between the category of Lorentzian causal manifolds and the category of topological *-algebras* which generalize the principles of QFT in such a way that the usual AQFT formulation in Minkowski spacetime re-emerges as a special case of the new formulation [29].

In all known cases the standard perturbation theory in Minkowski spacetime admits a generalization to any globally hyperbolic and causal manifold without any additional parameters (apart from a finite number of new locally covariant couplings to the external curvature tensor).

The reason why it took such a long time to adjust Einstein's classical local covariance principle to QFT in CST was that one wrongly thought that invariance under local isometries forces states to be invariant which of course (apart from some global symmetries) is not possible. The correct statement that local isometries leave a *folium of states* invariant but not its individual members. The crucial step which led to the formulation of quantum local covariance was the mentioned separation of the algebraic structure from that of quantum states. In the standard setting of (time-ordered) correlation functions both structures are intertwined and hence the formulation of QFT in CST required a quite different formulation. It turns out that the largest agreement with the classical formulation is in the algebraic structure and not in the structure of states. The more complicated action on states follows by dualization (states are normalized positive linear functionals on algebras).

The conceptual progress coming from these developments has been impressive. Many properties which previously were thought to require knowledge about the still elusive QG as background independence are already realized in this new CST setting of QFT. Although the perturbative quantization of general relativity needs a choice of a classical background, arguments have been proposed which show that the passing to another (sufficiently close) background is a symmetry property of the formal (perturbative increase of number of parameters) graviton perturbation theory of the Einstein-Hilbert interaction. Also grave doubts were raised [28] whether the existing estimates about the cosmological vacuum energy which violate local covariance can be taken serious. Finally most of the renormalization computations for quantum fields in external potentials are violating the local covariance principle and need to be re-done.

4.3 Modular theory and QFT in terms of positioning of monads

The previous illustrations show that, contrary to the message coming from string theorists, QFT is still far from having reached a conceptual closure. I will now present some recent result which emphasize this point in a much more dramatic manner.

In the algebraic approach the starting point for structural investigations of Poincaré invariant QFT has been a spacetime-indexed net of operator algebras which is required to fulfill certain physically motivated and mathematically well-formulated properties related to causal locality and stability of relativistic quantum matter (energy positivity, KMS for thermal states). It is fairly easy to show that the individual local operator algebras, in contradistinction to the generated global algebra, do not contain operators which annihilate the vacuum (separability) but nevertheless generate a dense set of states from the vacuum (cyclicity) which changes together with the localization region.

This so-called Reeh-Schlieder property turns out to be the prerequisite for applying the Tomita-Takesaki theory, which is an extremely rich and profound mathematical theory within the setting of operator algebras. It associates with a pair of a weakly closed operator algebra (von Neumann algebra) acting cyclic and separating on a reference state vector $(\mathcal{A},\Omega)$ two modular[32] objects: a one-parametric automorphism group of $\mathcal{A}$ and a TCP-like anti-unitary reflection J (called the modular involution) whose adjoint action maps $\mathcal{A}$ into its commutant operator algebra $\mathcal{A}'$. This theory unfolds its conceptual power in a situation of several such algebras within a common Hilbert space. In fact placing a finite number of such operator algebras into certain relative positions (which are natural within the logic of modular operator theory using the concept of modular inclusions and modular intersections), the various individual modular automorphism groups generate noncompact spacetime symmetry groups and the action of the latter on the original finite number of operator algebras generates a *net of operator algebras* with the properties demanded by AQFT. The opposite way around, each AQFT permits a representation

[32] The theory is a vast extension of the notion of (uni)modularity of Haar measures in group algebras to the general setting of von Neumann algebras and their classification [30].

in terms of a modular positioning of a finite number of such operator algebras. In case of a Moebius-invariant chiral QFT the number is two, for 3-dimensional QFT one needs 3 algebras and 4-dimensional QFT can be generated from 6 appropriately positioned algebras: the number increases with increasing spacetime dimension. A closer look reveals that the positioned algebras are necessarily *isomorphic copies* of one and the same operator algebra which according to Connes refinement of the Murray-von Neumann classification is the *unique hyperfinite type* III_1 *factor algebra*.

The best way to reveal the implications of these observations in an essay like this is to a convey their conceptual-philosophical content at the expense of their mathematical structure. If one identifies this distinguished algebra with the role of *monades* in Leibniz's construct of ideas about what constitutes reality, one finds a perfect match: *the physical reality of relativistic local quantum matter in Minkowski spacetime originates from the (modular) positioning of a finite number of copies of one abstract monade*; no sense of individuality can be attributed to the monade, apart from the fact that those hyperfinite factors allow inclusions and intersections (which points do not) it is as void of individual structure as a point in geometry (if you have seen one, you know them all). The rich content of a quantum field theoretical model including its physical interpretation (particles, spacetime and inner symmetries, scattering theory....) is solely encoded in the relative positions of a finite number of its monades [31]. In view of the conceptual simplicity and the radical aspect of this totally autonomous and rigorous setting for characterizing particle physics, there is no way in which one could think of QFT as a closed theory. There is simply too much unexplored terrain beyond the Lagrangian quantization approach (which in view of its parallelism to classical physics cannot really be considered as an autonomous setting).

The reader who is familiar with Vaughn Jones's subfactor theory will notice that the underlying philosophy of subfactor theory illustrates this monade picture in a simpler setting. Subfactor theory has become during the last 3 decades a mathematical very mature and rich theory. The underlying mathematical motivation in this case was to generalize the theory of finite and compact groups by passing from Galois's commutative setting to noncommuting operator algebras. To achieve this it suffices to identify the monade with the simpler (than type III) hyperfinite type II_1 factor in which a tracial state can be defined. This monade is too small for obtaining spacetime symmetries and localization- as well as thermal- properties which necessitate the previous field theoretic monades (as well as the replacement of *Jones inclusions* by *modular inclusions*). The theory of Jones inclusions is older than the notion of modular inclusion (which is the important concept in the above monade presentation of QFT) and has served as a source of inspiration to AQFT. It was preceded by the DHR theory of localized endomorphism which in the Doplicher-Haag Roberts work was crucial to unravel the spacetime localization origin of statistics and global inner symmetries in QFT.

It is interesting to look at the way in which this modular theory based setting of QFT leads to spacetime symmetry, localization and causality in Minkowski spacetime i.e. to ask the question what is the algebraic germ for the rich geometrical aspects of QFT. It turns out that this is related to the previously mentioned positions of the dense subspaces which are cyclically generated by acting with the monade on the vacuum. The relation is made precise by modular theory in terms of the domain of the unbounded involutive Tomita operator S. This encoding of geometric properties into abstract domain properties of unbounded operators is characteristic of Tomita operators; no other operator is capable to e.g. lead from the inclusion of domains to inclusions of geometric localization regions in Minkowski spacetime. This way of getting from physical principles of local quantum physics to geometric aspects is very different from say the better known Atiyah-Witten-Segal which uses the suggestive power of the classical geometric and topological aspects of euclidean functional integral representations for mathematical innovations independent of whether the motivating physical setting is metaphoric or autonomous[33]. AQFT is very different in its aims, it starts from mathematically rigorously formulated physical principle and derives consequences by operator algebraic methods. Using this approach in low dimensional QFT one arrives e.g. at braid group statistics [32] in low-dimensional QFT in a way which is reminiscent of Jones subfactor theory. Whereas the quasiclassical approximation on functional integrals for Chern-Simons actions leads to Jones polynomials without revealing their physical interpretation in terms of particle statistics, the

[33]For the derivation of the e.g. Jones polynomial it is of no importance whether the Euclidean Chern-Simons action fits into the Osterwalder-Schrader framework i.e. is associated with a physical correlation function (it is not!) as long as its mathematical meaning is well-defined and its quasiclassical approximation is under mathematical control. In such metaphoric QFT-math connections it is also of no interest whether objects "derived" in this way really fulfill the starting relation or not.

physical origin and interpretation remains clear in the algebraic approach. In fact the results suggests that since e.g. mapping class group invariants appear in d=1+2 Minkowski spacetime QFT together with braid group statistics, they should show up in the (still poorly studied) scattering theory of plektons (similar to partial waves in the standard formalism). Plektonic QFT is an unexplored area which as a consequence of the inextricable intertwining of inner/spacetime symmetries (breakdown of the Coleman-Mandula theorem) is expected to hide many surprises.

One should perhaps mention that the discovery of modular operator was made by mathematicians (Tomita, with considerable enrichments by Takesaki) as well as by physicists (Haag-Hugenholtz-Winnink). Naturally physicists do not aim at the greatest mathematical generality but rather introduce mathematical concepts which are designed to solve a specific physical problem. The physical problem which brought H-H-W into the conceptual proximity of modular theory was the formulation of quantum statistical mechanics for open systems (i.e. directly in the thermodynamic limit) [8]. I do not know any other case in the history of mathematical physics where a fundamental mathematical theory was simultaneously (and independently) discovered by mathematicians and physicists. After both sides realized this the concepts and terminology quickly merged together. Even in the historical example of quantum mechanics, the Hilbert space theory was already fully available and it took the physicists some years to become aware of it. The relation of AQFT to the mathematical operator algebra theory is very different from the more fashionable but inherently metaphoric mathematics-particle physics relation of typical articles in hep-th.

4.4 Modular theory, classification and construction of models

The fact that the above presentation of Poincare-invariant QFT in terms of positioning of monades is under rigorous mathematical control does not yet mean that it can be readily used for classifying and constructing models. To facilitate such a use it is advantageous to reformulate the monade assumption. One can show that the assumption of having a unitary representation of the Poincaré group and knowing its action on just one monade[34] is equivalent to the previous relative placement of several copies. Some additional thinking reveals that identifying this monade algebra to be wedge-localized (in the would be QFT to be constructed) is a good starting point, because the modular objects of a wedge algebra have a well-known physical interpretation. Hence knowing a wedge algebra (i.e. its position in B(H)), the action of the Poincaré group on it immediately leads to the knowledge of all wedge algebras and taking suitable intersection of these wedge algebras and unions of such intersections one obtains the full net of all spacetime indexed algebras i.e. the QFT associated with the original wedge-localized monade together with its covariant transformation property. If the intersections are the trivial algebra (i.e. complex multiples of the identity) then the wedge algebra has no associated QFT. From a practical point of view one does not compute directly with wedge algebras but rather with a generating system of wedge-localized operators which carry a known representation of the Poincaré group.

This rather abstract construction idea can be made to work under the quite strong restriction that there exist wedge-localized generators which, similar to free fields, upon their one-time application the vacuum create one particle states without the admixture of particle-antiparticle vacuum polarization clouds [33]. In case such vacuum-**p**olarization-**f**ree-**g**enerators (PFG) exist for subwedge spacetime regions (i.e. for regions whose causal completion is smaller than a wedge) it can be shown (by a slight generalization of the Jost-Schroer theorem [34]) that the theory is free in the sense of being generated by free fields. In some sense which can be made precise, wedge-localized PFG's are the best localized objects in interacting theories for which the field theoretic localization property and that of Wigner particles still coexist simultaneously; for subwedge localization the inexorable presence of interaction-caused vacuum polarization prevents the creation of only one particle states from the vacuum.

A detailed study of PFG wedge-localized generators with translation-invariant domains [35] reveals that they only exist in theories with a purely elastic S-matrix which is only possible in d=1+1 dimensions. It turns out that the resulting field theories are precisely those of the bootstrap-formfactor program [36] and the wedge-localized PFG's are the Fourier transforms of the Zamolodchikov-Faddeev algebra generators which in this algebraic setting receive a spacetime interpretation. Without the use of modular theory it was not possible to show that the calculated formfactors really belong to a well-defined QFT.

[34] This means that one knows the position of the wedge algebra within the full algebra B(H) of all operators i.e. the inclusion $\mathcal{A}(W) \subset B(H)$.

This existence problem of QFT in this context of factorizing models has meanwhile been solved [37][38] by showing that the double-cone intersections of wedge-localized intersection are really nontrivial. Although these models have no real particle creation via scattering, their formfactors (matrix-elements of localized operators) exhibit a very rich vacuum polarization structure. Since they are analytic in a small region around zero coupling strength and since there are general structural argument that their off-shell spacetime correlation functions admit *no* convergent power-series expansion for small couplings (they are at best only asymptotically convergent), these models suggest that on-shell quantities may have better perturbative properties than off-shell quantities. It would be very interesting to use them in order to study this problem in detail.

Without wedge-localized PFG's, i.e. outside factorizing models there are some still rather vague ideas of how the fact that the S-matrix has the interpretation of a relative modular invariant[35] may be used. They are based on the belief that the old S-matrix bootstrap of the 60s failed (even in form of a perturbative construction) because this somewhat surprising connection of the scattering operator with wedge-localized algebras and AQFT was not noticed and the hope that its use in a perturbative bootstrap-formfactor program could have a chance to improve this situation. I expect that combining some ideas of the old S-matrix approach with this recent framework of modular wedge localization one will obtain new insights into the construction of QFT.

It is my intense impression that the replacement of crossing and its substitution by Veneziano's duality was the *wrong turn at one of the most important cross roads of particle physics* and that it is not possible to make progress in particle physics without a new problematization of the bootstrap-formfactor idea. In particular I expect that the geometric aspects of gauge theory which were important to arrive at the formulation of the standard model will not be useful in order to go beyond.

Besides the importance the failed S-matrix bootstrap theory attributed to crossing, it also highlighted what was very appropriately termed *nuclear democracy,* which says that each particle can be interpreted as being composed of other particles (including itself) in the same theory insofar as the charge conservation allows it. In QFT this is completely natural as the result of the ubiquitous presence of vacuum polarization (the most important physical manifestation of the causal locality principle) which leads to a coupling of all those states for which conservation laws permit this. What was new is the claim that this is already realized on the level of the S-matrix. In the context of d=1+1 factorizing models whose S-matrix is determined in terms of an elastic two-particle amplitude the nuclear democracy picture holds in all cases and it allows the calculation of the S-matrix of all particles from the S-matrix of a "fundamental" particle. Here the marking is meant to indicate that what is fundamental is the charge of the particle i.e. all other charges result from fusing fundamental charges[36]. One can even go a step further and say that a fundamental object ψ is a coherent state of itself and other objects with a neutral charge according the intuitive idea

$$\psi \simeq \psi + b$$

Taking for example for ψ the state created from the vacuum by the application of the Thirring field and for b the lowest breather, it is possible to compute the S-matrix involving the ψ particle from the scattering of two breathers by converting this intuitive idea into an equation. One also finds an integrable analog of confinement. In the integrable $O(3)$ (or CP_1) the S-matrix may be obtained from the basic SU(2) factorizing S-matrix by considering the $O(3)$ particle as a composite object from two SU(2) particles in the limit of infinite SU(2) mass.

I do not think that such a picture applies to quark confinement. The accepted viewpoint among researchers in AQFT [39] is that quark has no direct physical existence[37] in whatever mathematically

[35]Tis means that its modular involution J is related to that of a corresponding free theory J_0 through $J=J_0 S_{scat}$ where S_{scat} is the scattering matrix.

[36]It is one of the most ironic aspects of particle theory that the protagonists of the S-matrix bootstrap (Chew, Stapp, Mandelstam) never took notice of the fact that their ideas (including nuclear democracy) work beautifully in the case of d=1+1 factorizing models (and only there). It is only in this special context that unitarity and crossing (combined with elasticity and factorization) lead to equations whose solutions can be classified. In general the determination of S-matrix cannot be separated from a field theoretic S-matrix-Formfactor setting.

[37]The possibility that quarks have a direct intrinsic quantum meaning in the actual theory is not completely excluded. My favorite pet idea is that the observable algebra of QCD has an infinite energy representation sector which is described by an interacting SSL field which will fuse to yield composite pointlike fields of finite energy states. In this way the nuclear democracy property of QFT can be maintained in the aforementioned sense.

controllable theory is behind QCD, rather that in the *scaling limit this theory passes to another one* which has additional charges (charge liberation) in particular this limiting theory does possess physical objects with the quark charges. Both theories obey the principle of off-shell nuclear democracy as a result of the vacuum polarization property i.e. nuclear democracy in the sense of everything which is (by charge fusion rules) not forbidden to couple with something else really does couple. What this means in terms of an S-matrix in a theory with on-shell creation/annihilation of particles is presently not known.

4.5 Thermal aspects of modular localization, holography, localization entropy and black holes

The conceptual power of AQFT and in particular that of modular localization also shows up in problems of thermal QFT in the phenomenon of *localization thermality*. Via a rigorous algebraic formulation of holographic projection of localized quantum matter onto the causal horizon of the localization region it is possible to compute the entropy generated by the vacuum polarization which occurs near the horizon [40][41]. The causal horizon of any (causally complete) region is a *null-surface* and the holographic projection keeps the global algebra but radically changes its local net structure of the algebraic net of the bulk to that of the horizon. There is not much intrinsic meaning to say the theory lives in the bulk region or lives on the horizon because this is not a property which is intrinsic to the abstract algebraic substrate but rather depends on the way in which way one wants to spatially organize the given global algebraic substrate. The AdS-CFT holography described in the second section is a very special kind of holographic projection onto a timelike boundary (meaning it contains the timelike direction, often called brane) at infinity; since it is an isomorphism under which the symmetry group SO(4,2) remains invariant, the reprocessing of the (global) bulk spacetime net structure to that on the CFT boundary is rather straightforward and the name correspondence is much more appropriate than holographic projection (which we will henceforth only use in case of null-surfaces). The AdS-CFT correspondence is one between QFT on geodetical complete globally hyperbolic manifolds, but there are many models which permit "partial" isomorphisms between algebras associated with subregions of different spacetimes.

By far the most interesting case is the holographic projection on null-surfaces (not a correspondence!) because it permits to focus on aspects which are pretty much out of reach within the spacetime organization which the bulk setting imposes on quantum matter. Among other things it allows to focus on thermal aspects of localization as those which underlie the behavior of quantum matter enclosed in black holes. Since QFT is not a theory of metaphoric miracles there is a prize to pay in that other aspects, in particular particles and scattering theory, become blurred. Only in case of wedge-localized algebras in two-dimensional factorizing models one knows sufficient conditions which allow to uniquely invert the holographic map. The setting of wedge-localized algebras gives the simplest illustration of the power of holography on null-surfaces. Since the linear extension of its upper (or lower) horizon is the lightfront, it is not surprising that the holography in this case may be considered as an autonomous formulation of the previous metaphoric lightfront quantization. As its name indicates lightfront quantization was considered as a different quantization and as a result no attention was paid how it really links with the original model of bulk QFT; not even in the case of free fields one finds clear statements and in the context of interactions its metaphoric aspect was preventing any credible use within the conceptual setting of QFT. Lighfront holography saved some of its physical motivations and explains why it failed. The reason is that although in case of free fields there is still a linear relation to a corresponding generating field of the lightfront algebra, in the presence of interactions there is no such relation and the only way of relating the bulk matter with its holographic projection consists in using the field-coordinatization-independent methods provided by AQFT. With other words holography cannot be done in the usual Lagrangian quantization setting and even Wightman's more general formulation would be insufficient.

The starting observation is that the one parametric family of subalgebras which are obtained by sliding the wedge into itself along the unique lightlike direction contained in its (upper) horizon are identical to the corresponding subalgebras on the horizon. It is well-known how, by applying forming relative commutants and applying the concept of modular localization on resolves the local structure in the lightray direction and obtains a Moebius-covariant net of algebras indexed by intervals on the lightlike halfline (the longitudinal direction). These algebras still have a two-sided transverse extension and in order to also resolve the transverse local structure one uses the two-parametric "translative" subgroup of Wigner's little group (the stability group of a lightray, which is the E(2) Euclidean group). This subgroup tilts the wedge in such a way that the horizon remains in the lightfront but the edge of the wedge changes. Intersecting the infinitely extended slabs with their tilted version leads to the resolution of the local structure in the transverse direction. The resulting local net structure on the lightfront is very interesting, because the inexorable vacuum fluctuations of quantum fields have all been compressed into the longitudinal lightray direction whereas there are none in the transverse direction. It is precisely this absence of transverse vacuum fluctuations which leads to an (transverse) area proportionality of those quantities (entropy,energy...) which in heat bath thermal setting are intensive quantities.

It is well kown that the restriction of the vacuum state to localized regions as the wedge is a KMS thermal state at a fixed temperature whose value depends on how one normalizes the modular Hamiltonian (in the case of the wedge this is the boost generator of the wedge-preserving boost). KMS thermal states are well-known to fulfill the second thermodynamic law in its most general formulation i.e. before a quantitative notion of entropy has been introduced (no perpetuum mobile of second kind).

The holographic projection also greatly facilitates the computation of the entropy which is associated with the KMS thermal wedge-restricted vacuum i.e. the proportionality coefficient in the area behavior. The localization-caused vacuum entropy of a sharply localized algebra is formally infinite for the same reasons that the entropy of the (translation-invariant) global algebra in a heat-bath thermal KMS state diverges. Both algebras are what we previously called monades (hyperfinite type III_1 von Neumann factors), and in the standard treatment of heat-bath thermal behavior it is well known that one obtains the volume proportional entropy formula by approximating the monade with a sequence of finite box Gibbs states (the famous thermodynamic limit which defines thermodynamic equilibrium). The same idea works for the localization entropy, except that in this case the sequence consists of Gibbs states on fuzzy-localized approximands (type I factors) which converge to the KMS state on the sharp localized algebra from the inside of the localization region. Using the holographic representation of the sharp localized algebra, and introducing a lighlike interval of size ε into which the the vacuum polarization cloud of the approximands can spread (not a short distance singularity in the sense of correlations between field-coordinatizations), one obtains the following limiting logarithmic divergence behavior for the localization entropy

$$S_{loc} = \lim_{\varepsilon \to 0} Ac \left| \ln \varepsilon \right|$$

where A is the area[38] (of the edge of the wedge) and c is a constant which measures the degrees of freedom of the holographically projected matter (in typical cases it is equal to the Virasoro algebra constant). It turns out that the area behavior as well as the $|\ln \varepsilon|$ increase is a totally universal aspect of localized quantum matter and (as was mentioned in the previous footnote) its universality is linked to that of an auxiliary global heat bath thermal system on the lightfront at temperature 2π with respect to the suitably normalized generator of lightray translations. If one changes the end points of the smaller interval on the lightray the entropy changes multiplicatively by the logarithm of the harmonic ratio of the 4 points. On the other hand the area behavior which one encounters in certain classical field theories (of the Einstein-Hilbert kind) a la Bekenstein is more special and has nothing to do with vacuum fluctuations. As already stated at the end of the second subsection the quantum mechanical level counting kind of entropy is inconsistent with the local covariance principle. In the other hand the localization entropy complies with this principle.

This conceptual insight is of relevance for the ongoing discussion about entropy of black holes. In the case of Schwartzschild black holes there are two ways in which the Hawking effect has been presented.

One presentation is to take as the relevant state the restriction of a certain static ground state on the extended matter algebra (which lives on the extended Schwartzschild spacetime). Upon restriction to the spacetime outside the black hole appears as a thermal KMS state. In this description the localization entropy is the unique entropy which the rules of quantum statistical mechanics relates with the thermal Hawking situation since the Hamiltonian associated with the Killing symmetry (which has continuous spectrum and therefore admits no Gibbs state) has to be approximated by a sequence of discrete spectrum Gibbs states Hamiltonians; this is precisely what the described sequence achieves. This setting of the

[38] The product $A |\ln \varepsilon|$ is precisely the volume factor of a heat bath system on the lightfront whose Hamiltonian is the generator of the lightray translation. The isomorphism which maps this heat bath system (at $\beta = 2\pi$) to the vacuum-restricted localized one carries the thermodynamic limit into the inner approximand limit and maps the the longitudinal length factor L in $V = AL$ (conformally) into the $|ln\varepsilon|$.

Hawking effect is conceptually quite tight and does not offer much support for speculative uses of black hole physics towards the still elusive quantum gravity. The Hawking radiation is matter radiation without any involvement of gravitons, it is fully understood in the setting of QFT in CST and the entropy is the localization entropy associated with this situation.

The second way of describing the Hawking effect is the more physical. Instead of an equilibrium state one works with a non-equilibrium stationary state modelling a collapsing star. Fortunately the Hawking radiation at future lightlike infinity does not depend on details, one only needs the to know the short-distance behavior of the matter two-point function (for free fields) at the point where the star radius passes through the Schwartzschild radius. This was exactly Hawking's intuitive idea; it was later converted into piece of beautiful mathematical-conceptual physics in a paper by Fredenhagen and Haag [42]. Although there has been significant progress in operator algebra theory on defining an entropy flux in stationary non-equilibrium states which replaces the equilibrium entropy, the application to the entropy issue of black holes still remains as an interesting open problem.

The reason for mentioning these ongoing investigation is obvious. The area of black hole entropy has been under intense investigation. Although I sympathize with taking big jumps into the conceptual blue yonder in certain situation, I strongly believe that this should not be done without securing a strong basis from where the jump starts. I do not think that ST is able to provide such a basis.

4.6 Holographic symmetry and its relation to the classical BMS group

Another quite amazing consequence of null-surface holography is the emergence of a gigantic *holographic symmetry group [41].* If we denote the generating pointlike fields of the lightfront algebra by $A_i(x_\perp, x)$, with $x_\perp$ being the transverse and x the longitudinal (lightray) coordinates, their commutation read

$$[A_i(x_\perp, x), A_j(x'_\perp, x\prime)] = \delta(x_\perp - x'_\perp) \sum_{l(k)\geq 1} c_k \delta^{l(k)}(x - x\prime) A_k(x_\perp, x)$$

The quantum mechanical transverse delta function comprises the absence of transverse vacuum fluctuations and appears in all composite field commutation relation and even in semiglobal objects (i.e. global in the longitudinal sense); its ubiquitous presence is the reason for the area behavior (by integration over $x_\perp$). The longitudinal scale dimension of the fields which contribute on the right hand side determines the degree $l(k)$ of the derivative of the longitudinal delta function according the well-known rules of dimensional matching. The automorphism group of this transverse extended chiral algebra is very big since it includes in addition to transverse Euclidean transformations the infinite group of $x_\perp$-dependent chiral diffeomorphisms[39] of the circle (in particular those which fix the point infinity). In case the null-surface is the upper horizon of a Minkowski spacetime double cone (i.e. the mantle of a frustrum), its linear extension is the mantle of the (backward) lightcone and the transverse delta function in the above commutation relation is replaced by a delta function on the unit two-sphere (with the rotation group replacing the 3-parametric Euclidean group).

Parametrizing the mantle of the frustum in terms of spherical and lightray coordinates which run from $-\infty$ (the apex) to $+\infty$ we see that the holographic Diffeomorphism group contains (unphysical) copies of the Lorentz group and the so-called *supertranslations* In the Penrose limit of an infinitely large double cone these become identical to the generators of the classical Bondi-Metzner-Sachs group which is a semi-direct product (or cross product) of the Lorentz group with the supertranslations We remind the reader that the BMS group is defined in a geometric way without reference to QFT. Instead of looking for Killing isometries, one studies the much more general concept of transformations which fulfill the Killing equation in an appropriate asymptotic sense. The result is that semidirect product of angular dependent lightlike translations ("supertranslations") with the Lorentz group. The existence of a relation to the holographic group is not surprising in view of the similarity of Penrose's picture for (future) lightlike infinity.

The surprising aspect is the fact that the conceptual relation with respect to properties of the bulk matter is much deeper in the quantum case. Since holography is a change of spacetime encoding in the

[39]The (extended) chiral theories which appear in null-surface holography, unlike chiral components of two-dimensional conformal models, do not come with an energy-momentum tensor and hence their diffeomorphism invariance (beyond Moebius-invariance) need a seperate discussion.

same Hilbert space, the action of the holographic group is well-defined on the full algebra inasmuch as the global symmetry of the full algebra (Poincaré, conformal) has a well-defined action in terms of a geometric change of the null-surface. The only subgroup of the holomorphic group which acts as a diffeomorphism on the full algebra is the Poincaré group, all other holomorphic symmetries act in a "fuzzy" way which can only be described in terms of algebraic concepts (in the case of pointlike field coordinates in terms of a transformation on testfunction spaces). Naturally those quantum symmetries have no associated Noether theorem.

4.7 Conclusions

The main purpose of this section was to counteract string theorists self-validating claim that there are no other settings which are capable to incorporate gravity together with relativistic local quantum matter. In claiming that the non-renormalizabity of the Einstein-Hilbert action within the Lagrangian perturbative approach precludes any possibility of compatibility of making gravity compatible with the laws of QT, they are only stating the obvious fact that their view of QFT (defined in terms of functional integral representations) does not allow to do that. In this essay I emphasized that, as recent progress already foreshadows, the issue of QG will not be decided in an Armargeddon between ST and LQG[40], but QFT will enter as a forceful player once it has conceptually solidified the ground from where exploratory jumps into the blue yonder including a return ticket can be undertaken.

The problem is not that there are no other games in town, but rather that there are no bright young players who take the risk of jeopardizing their career by learning and expanding the sophisticated rules for playing other games. If an essay like this serves a an encouragement to a few young people to keep a critical distance from monocultures and rather become aware of the increasing number of unsolved fascinating and challenging problems which the big caravans left on their wayside, it has accomplished its intended purpose.

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