V.Y. Glaser

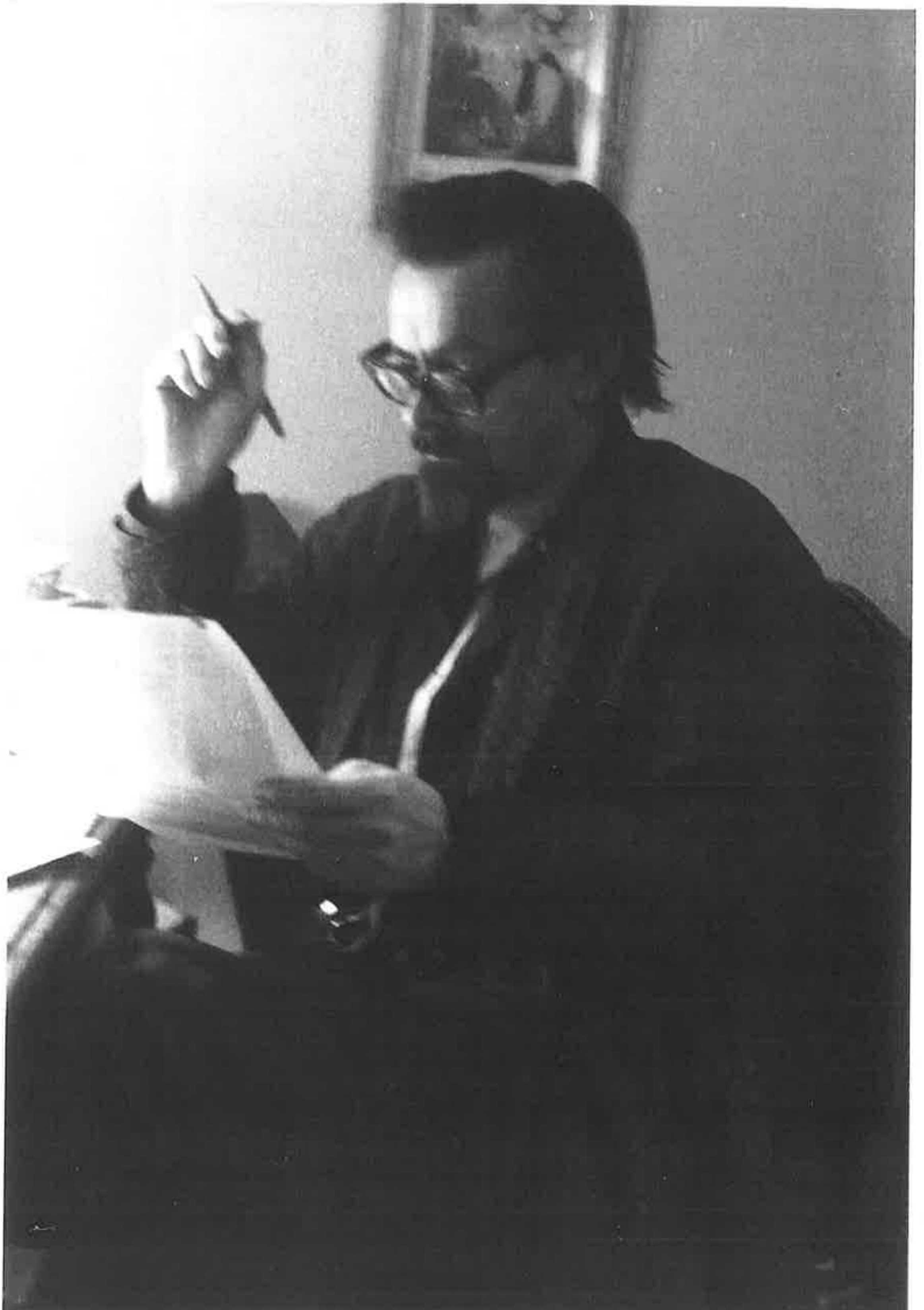
SOME RETROSPECTIVE REMARKS

by Ph. Blanchard

- OPENINGS
- MATHEMATICS IN PHYSICS
- GREAT ENCOUNTERS ALONG THE WAY

  Zagreb, Göttingen, Copenhagen, Geneva, Strasbourg, Bures sur Yvette
- USING MATHEMATICS WITH CLARITY AND ELEGANCE

  Quantum Mechanics, Quantum Field Theory



Vladimir Glaser

Né le 21/4/1924 à Gorizia (Italie), diplomé en Physique à l'Université de Zagreb (Yougoslavie) en 1950, Thèse en Physique Théori-que à Zagreb (1953), Carrière universitaire à l'Université de Zagreb: successivement assistant, puis professeur de Physique Théorique jusqu'en 1957. Durant cette période un séjour à l'Institut Max Planck à Göttingen (1951/52), plusieurs séjours de quelques mois à Copenhague à l'Institut de Niels Bohr. Depuis 1957 membre de la section théorique du CERN, interrompu par un séjour d'une année à l'Institut des Hautes Etudes Scientifiques à Bures.

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ISSN 0 370-1573

PHYSICS REPORTS

A Review Section of Physics Letters

LAST NUMBER OF THIS VOLUME

ESSAYS IN MATHEMATICAL PHYSICS

in memoriam V. Glaser

edited by

A. MARTIN and M. JACOB

Volume 134 **Numbers 5 & 6**

March 1986

PRPLCM 134(5 & 6) 273–395 (1986)

NORTH-HOLLAND · AMSTERDAM

OPENINGS

I am happy to have been asked to speak about Yurko Glaser, his thinking and its actions. It is an honor for me to pay tribute to the brilliant achievements of this leading mathematical physicist, gifted teacher and exceptional friend.

It was in Strasbourg at the spring meeting of the RCP 25, where we first met 1967. At this time I was in Zürich at the ETH, working on the Paul-Fierz model of the infrared catastrophe under the direction of Res Jost.

Yurko was born on April 21, 1924 just before the discovery by Schrödinger, Heisenberg, Dirac, Born ... of modern Quantum Theory in the mid 1920's.

Carlo Rubbia was also born in Gorizia, Görz, Friaul – Julisch Venetien. Quantum Theory before 1925 – the Old Quantum Theory (Planck, Einstein, Bohr, Sommerfeld ...) – was part craft part art. Old principles had been founded wanting, new ones had not yet been discovered.

Modern Quantum Theory was a real revolution of our understanding of physical process. Compared with this change, Einstein's relativity, born in 1905, seem not much more than very interesting variations on nevertheless classical themes.

Yurko studied at the University of Zagreb, where he received his Diploma in 1950 and his Ph.D in 1953 under the supervision of W. Heisenberg. He moved to Göttingen in 1951-1952 and made his first important contributions to physics, a book of QED published 1955 in Zagreb and outstanding results on QFT, the attempt to clarify the compatibility of special relativity theory with Quantum Theory. Yurko moved back to Zagreb in 1953, initially as a research assistant then as chairman of the Ruder Boskovic Institut.

In 1957 Yurko went to CERN as a permanent member of the Theory Division and then remained there until his death in 1984. Visits to Göttingen, Copenhagen, Strasbourg and Bures sur Yvettes (IHES) had a strong impact on him.

Yurko's main interest was in Quantum Field Theory where he produced his masterpiece in collaboration with Jacques Bros, Henri Epstein and Raymond Stora but he was also interested in nonrelativistic Quantum Theory. He was a man with many cultural interests, with a remarkable taste for music and literature. He appreciated much Dante and Shakespeare. Moreover he was an excellent skier.

I had the big luck to collaborate with Yurko between 1970 and his death. I worked on Epstein-Glaser renormalization. In collaboration with Roland Seneor we proved the existence of the Green's functions in QED in all orders of perturbation theory.

After my departure from CERN I remained in close contacts with Yurko. During my frequent visits to Geneva we had many lively discussions, among other things, about the S-matrix in QED à la Fadeev and the stability of matter.

For Yurko mathematics was invisible culture, a "conditio sine qua non" to structured logical thinking and one of the keys to the development of other sciences. For him mathematics can and must be associated to all types of human activity.

Metaphor and analogy exists in mathematics and physics as well as in literature and religion. Rhetoric exists in mathematics as it exists in politics. Aesthetic exists in mathematics as it exists in the arts.

MATHEMATICS IN PHYSICS

- The role of mathematics
  - Taking by physicists with mixed feeling of admiration and irritation
  - The unreasonable effectiveness (E. Wigner)
  - The pernicious influence (J. Schwartz)
- No “axiomatic” approach (à la Descartes ...) in Physics

  {Axiom} → Model

- Not essential and perhaps dangerous relation?
  - Physics introduce lack of rigors in M
  - Mathematics would sterilize “true research in ϕ

- Intuition to discover

  Logic to prove H. Poincaré

- Some triomphs of theoretical physics non mathematical in their internal structure? QED the most precise theory ever invented does not (presumably) make sense

- The way to fundamental discoveries

  1) Heuristic non rigorous arguments (dubious math)

  2) Emergence of correct path (swoly!)

  3) Proper mathematical framework appears

- Dyson's birds and frogs

  Birds ~ broad visions

  Frogs ~ intricate details

  Both are needed !

- Dieudonné to Grothendiek:

  “to take pleasure by generalizing to simplify by generalizing” *Poincaré*
- The message of Quantum Science:

  Operator algebras, Q-probability, SPD have been invented to be used in Quantum Theory.

YURKOs GREAT ENCOUNTERS ALONG THE WAY

Göttingen MPI for Physics   W. Heisenberg

„Feldverein“ (Pauli !)

Lehmann Symanzik Zimmermann

LSZ → GSZ

Haag, Lüders, Zumino, Thirring, Källen

→ 5 books dedicated to QED

- Y. Glaser, Kovarijantna kvanta elektrodynamika JAZU Zagreb (1955)
- W. Thirring, Principles of QED, Academic Press (1958) Original version in German 1955
- R. Källen, L’electrodynamique quantique, Lille 1957 CNRS (1959)
- D. Kastler, Introduction à l’electrodynamique quantique, Dunod (1960)
- P. Urban, Topics in applied QED, Springer (1970)

- Heisenberg's ambitious projects
  - Fundamental theory of elementary particles explaining all known particles (stable and unstable) in terms of a single basic particle
  - Search for observable quantities

    S-matrix from basic principles

The S-matrix is the roof of the theory, not its foundation (Heisenberg 1956)

- T.D. Lee's model, Phys. Rev. 95 (1954)

$$\mathcal{H} = \mathcal{H}^B \otimes \mathcal{H}^F$$

$$\uparrow \qquad \uparrow$$

$$\theta \qquad N, V$$

Elementary interaction N + θ $\leftrightarrow$ V

- Modification by Glaser and Källen

  A model of an unstable particle, Nucl. Phys. 2 (1956)

– The Thirring model in 2 dimensions

$$\mathcal{L} = \bar{\psi} \; i\, \gamma\psi - \frac{g}{2} \bar{\psi}\, \gamma^{\mu}\, \psi . \, \gamma^{\mu}\, \psi$$

- renormalizable in 2 dimensions
- explizit solution given by Yurko G.
- equivalence with the Sinus Gordon model

Yurko's first publications

1) New relativistic two-body equation, Phys. Rev. 98 840 (1955)
2) With H. Lehmann and W. Zimmermann, Nuovo Cimento 6 (1957) 1122

CERN (Copenhagen then Geneva)

Jacques Prentki, André Martin, Bruno Zumino, John Bell, Markus Fierz, Raymond Stora, Rudolf Haag (1975), H. J. Borchers, R. Streater, O. Steinmann ... and many others

The big time in CERN:

- 20 papers (QM, QFT, Spin Glas),
  in collaboration with
  P. Collet, J.P. Eckmann, J. Bros, H. Epstein,
  D. Iagolnizer, A. Martin, H. Grosse, W. Thirring,
  D. Buchholz, S. Coleman, R. Stora, A. Jaffe
- Many discussions with
  M. Fierz parastatistics
  J. Bell measurement problem
  B. Zumino supersymmetry

With experimental physicists:

The ISR and SPS experiments provide spectacular proofs of Yurko's result on maximum growth of cross-sections and comparison of particle-particle and particle-antiparticle collisions

Rudolf Haag spent 1975 one year in CERN shared the office with Yurko

- Synthesis general relativity of QM
- Events in QM

IHES (Bures sur Yvette)

1958: Motchane's idea: IHES should be a place where

Mathematics: Dieudonné, Grothendieck, Connes, Konsevich, Thom, Bourgignon, ...

and

Physics: Ruelle, Jost, van Hove, Gell Mann, Fröhlich, ...

INTERACT

Yurko was invited to spend a year at IHES (1963-1964) + many short visits

RCP25 (Strasbourg)

Organized by CNRS to improve the dialogue $M \cap \phi$

2 meetings/year spring and autumn

M = {Jean Leray, Pierre Lelong, Bernard Malgrange, Pierre Cartier, Jacques Dixmier, Alain Connes, ...}

Yurko enjoyed the lectures and discussions very much

USING MATHEMATICS WITH CLARITY AND ELEGANCE

Stability of Matter

- $$H_N = \sum_{i=1}^{N} \frac{p_i^2}{2m_i} + \sum_{i>j} V(x_i - x_j)$$

$E(N) \sim$ Energy

Problem: $E(N)$ extensive $\Leftrightarrow \lim_{N\to\infty} \frac{E(N)}{N} = \bar{E}$

One might expect $E(N) \sim N^2$ rather than $E(N) \sim N$

1967 Dyson – Lenard $E(N) \sim N$ for fermions
V Coulomb but $\bar{E} \ggg 1$

1969 Lévy – Leblond
V Newton

$$E_N \begin{cases} \nearrow \sim N^3 \text{ Bosons} \\ \searrow \sim N^{7/3} \text{ Fermions} \end{cases}$$

1976 Lieb RMP 48
Simon, Thirring ...

- Hydrogenic atom and Sobolev's inequality

Minimize $E_\psi = T_\psi + W_\psi$ with $\|\psi\|_2 = 1$

$$= \int_{\mathbb{R}^3} |\nabla\psi|^2 dx - z \int |\psi(x)|^2 |x|^{-1} dx$$

$$T_\psi = \|\nabla\psi\|_2^2 \geq S \|\psi\|_6^2$$

$$\Leftrightarrow \quad T_\psi \geq S \| \cdot \|_3$$

with $\rho_\psi = |\psi|^2$

$$E_\psi \geq \inf [S \|\rho_\psi\|_3 - z \int |x|^{-1} \rho_\psi \, dx$$

$$E \geq \frac{1}{3} z^2$$

Lower bound of $\sigma(H)$ $H \geq 0$

Yarko + R.A. Bertlmann

Simplest case

$$H = \frac{p^2}{2m} + V(x) \qquad V(x) \geq 0 \qquad x \in \mathbb{R}^d$$

$$t > 0 \qquad Z(t) = \mathrm{tr}\, e^{-tH} \leq \mathrm{tr}\, e^{-\frac{p^2}{2m}} e^{-tV}$$

$$\parallel$$

$$V(x) = \lambda |x|^s \qquad\qquad Z_c(t)$$

$$Z_c(t) = (2m)^{d/2}\, t^{-\delta}\, K_d$$

$$K_d = \int \frac{dy}{(4\pi)^{d/2}}\, e^{-V(y)}$$

$$Z_c(t) \geq \mathrm{tr}\, e^{-tH} = \sum_{k=1}^{\infty} e^{-tE_k}$$

$$\sigma(H) = \{E_k\}_{k \in \mathbb{N}}$$

$$\sum_{k=1}^{n} e^{-tE_k} \geq n\, e^{-tE_n}$$

$$\Longrightarrow \qquad E_n \geq \frac{1}{t} \ln \frac{n}{Z_c(t)}$$

Best bound given by sup over t

$$E_n^{s.c} = m^{\frac{-s}{2+s}} \left(\frac{n}{K_d} \right)^{1/\delta}$$

Generalize $\longrightarrow$ Physics Reports <u>134</u> (1986) 279–296

WIGHTMAN QFT IN A NUTSHELL

- Mathematical definition ↗ Q-Field Φ ? ↪ QFT ?

1956 $\Phi(x)$ ⟺ Operator valued Schwartz distribution

1956 QFT ⟺ Encoded in $\langle \Omega, \Phi(x_1) \dots \Phi(x_n) \Omega \rangle$

$\Omega \sim$ vacuum

$$\langle \Omega, \Phi(x_1) \dots \Phi(x_n) \Omega \rangle = F^{(n)}(x_2 - x_1, x_3 - x_2, \dots x_n - x_{n-1})$$

- Lorentz invariance

$$F^{(n)}(\Lambda \xi_1, \dots \Lambda \xi_{n-1}) = F^{(n)}(\xi_1, \dots \xi_{n-1})$$

- Spectral Condition

p = energy momentum

Physical states $p \in V_+ = \{ p \mid p^2 \geq 0 \}$

$$\Rightarrow \quad F^{(n)} = \mathcal{F} G^{(n)}$$

$$G^{(n)}(p_1, \dots p_{n-1}) \qquad p_j \in V_+ \ \forall j$$

$F^{(n)}$ is the boundary value for $\eta_j \to 0$ of a function of $z_i = \xi_i + i \eta_i$ holomorphic for $\eta_i = \operatorname{Im} z_i \in V_+$

This domain is called the tube !

- Lorentz invariance ⟹ $F^{(n)}(z_1, \dots z_{n-1})$ can be continued to complex Lorentz transformation

New domain of analyticity called extended tube

Local commutativity

$$[\phi(x), \phi(y)] = 0 \quad \text{if } (x-y)^2 < 0$$

$F^{(n)}(z_1, \dots z_{n-1})$ can be further analyticaly extended when $z_1, \dots z_{n-1}$ runs over the extended tube

$$z_1, \dots, z_{j-1} + z_j, -z_j, z_j + z_{j+1}, \dots, z_{n-1}$$

permuted extended tube

$F^{(n)}(z_1, \dots z_{n-1})$ is analytic and single valued in the union of the extended tube and permuted extended tube.

Main Theorem

To a sequence $F^{(n)}$ of distributions satisfying the Wightman axioms there correspond a unique field satisfying all the axioms and having the distributions $F^{(n)}$ as Wightman distributions

CONNECTION BETWEEN WIGHTMAN, LSZ AND GLZ QFT

W Phys. Rev (1956)

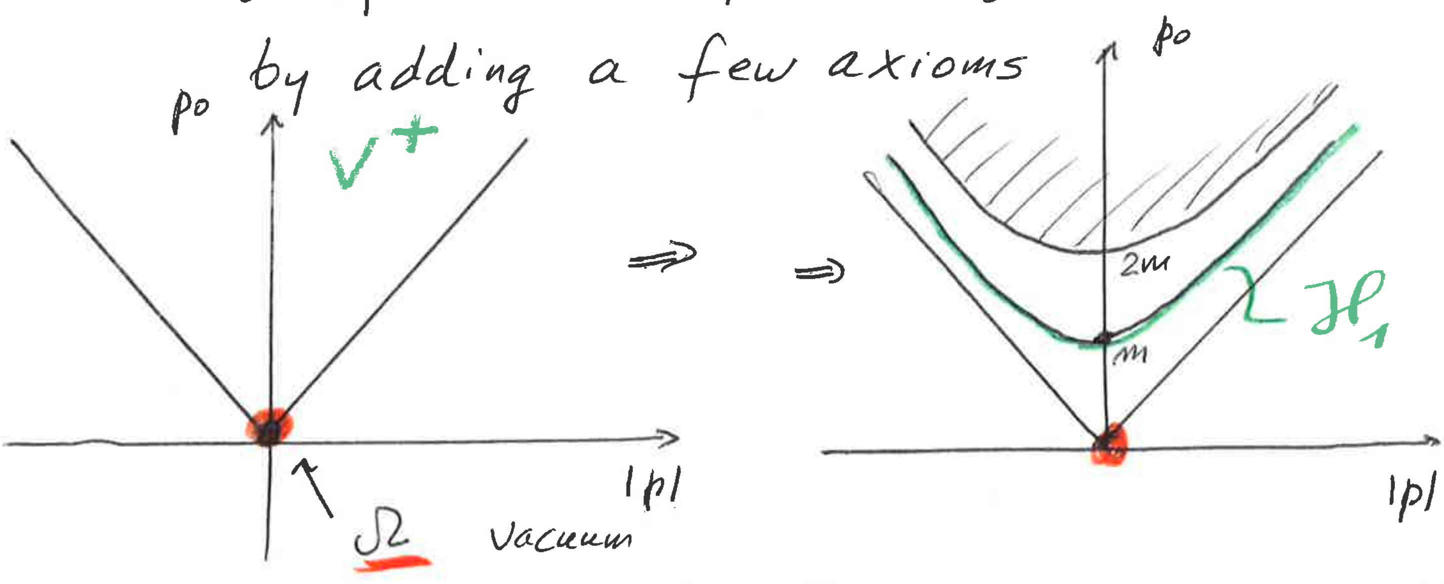
LSZ Nuovo Cimento (1955)

GLZ Nuovo Cimento (1957)

Two formulations of QFT

- W = high level of mathematical rigor, interacting fields, local aspect of the theory, never talks of particles, removed from experiments
- LSZ = less rigor, intuition, S-matrix, perturbation theory, particles in the center, interacting fields called "interpolating fields", more closer to experiments but far away of understanding dynamic
- STEINMAN CMP (1968, 1970)

LSZ can be obtained rigourosly as a special case of a Wightman theory by adding a few axioms



To be added

$$\langle \Omega, A \mathcal{H}_1 \rangle \neq 0$$

equal to those of a free field LSZ – assumption

Asymptotic assumptions LSZ

1) describe free particles by free field

2) Cluster property

$k = 1 \dots n-1, \qquad y = y_1 \dots y_{n-k}$

$$\lim_{\lambda \to \infty} W_n(x, y + \lambda a) = W_k(x) W_{n-k}(y)$$

if $a^2 < 0$

Scattering event ⇒ particles far apart ⇒ interaction can be neglected ⇒ description by free fields

3) S – matric

$$A^{out}(x) = S^* A^{in}(x) S$$

4) Asymptotic Completeness

$$\mathcal{H} = \mathcal{H}_{in} = \mathcal{H}_{out}$$

GLZ Theorem ⟺ LSZ counterpart of Wightman's reconstruction theorem

EQUIVALENCE OF OSTERWALDER-SCHRADER AND WIGHTMAN FORMULATION OF QFT

Dyson in 1949 : problems in QED can be avoided by replacing t by it

$$\tau = it \quad \text{Wick rotation}$$

Wigner : time ordered Green functions of Euclidean QED

Osterwalder – Schrader (1973, 1975) :
Euclidean Field Theory

$$\text{Euclidean QFT} \xrightarrow[t \to it]{} \text{W-QFT}$$

Euclidean QFT + O.S. Axioms for the Schwinger function S_n

$$\Downarrow \quad \text{Analytic continuation}$$

W-QFT + W-Axioms

- Question :

  Wightman Axioms $\Longleftrightarrow$ O.S Axioms

V. Glaser CMP $\underline{37}$ 257 – 272 (1974)

The main point of Glaser's approach is to stress the fact that the analytic behavior off the diagonal is completely governed by the analytic structure on the diagonal

$$\Phi_n(z) = A(z_1) \cdots A(z_n)\Omega$$

$$A_{nm}(\bar{z}', z) = \langle \Phi_n(z'), \Phi_m(z) \rangle$$

Diagonal $A_{nn} \Longleftrightarrow n = m$

$\Phi_n(z)$ is a tempered analytic function in the tube

$$\mathcal{T}_n = \{ z \in \mathbb{C}^{4n} \mid \operatorname{Im} z_1 \in V_+ , \operatorname{Im}(z_k - z_{k-1}) \in V_+ \}$$
$$k = 2, \dots n$$

Positivity condition

$$\sum_{n,m} \int A_{nm}(\bar{z}', z) \, \bar{f}_n(z') f_m(z) \, d\mu(z) \geq 0$$

$$d\mu(z) = e^{-\Phi_n(z)} \, d\lambda_n(z)$$

↑ Lebesgue measure on $\mathbb{C}^n$

Results

- The $S_n(x_1, \dots x_{n+1})$ can be analytically continued into the product of the right complex planes

$$\mathcal{P}_+^{n+1} = \{ z = x + iy \in \mathbb{C}^{n-1} \mid x \in \mathbb{R}_+^{n-1} \}$$

The functions $W_{n+1}(iz^0, z)$ can be analytically continued into the tube

$$\mathcal{T}_n = \{ z \in \mathbb{C}^{4n} \mid \operatorname{Im} z_k \in V_+ \quad k = 1 \dots n \}$$

Quantum Energy Inequalities

Epstein Glaser Jaffe Nuovo Cimento 36 (1965)

→ Energy density of Wightman fields admit negative expectation values

→ Contradiction with the positivity of the energy-momentum tensor of classical relativity ensuring causality.

Solution of the conflict

Smearing out the densities in space or time

→ Classical positivity restored at medium and large scales

THE POLYNOMIAL MAP

Yurko, R. Stora, J. Wess, B. Zumino in 1981 discussed about the mathematical structure of the Higgs potential in SS theories

B. Zumino in "Unified Theories of Elementary Particles", Springer Verlag (1988)

J. Wess and J. Gabber, SS and Supergravity, Princeton Series in Physics (1983)

$Z = (Z_1, \dots Z_n)$, $W = (W_1, \dots W_n) \in \mathbb{C}^n$

Polynomial maps

$$Z \to W(Z) \qquad W_i(Z) = P_i(Z)$$

Special case

$$P_i(Z) = \frac{\partial}{\partial Z_i} L(Z)$$

Minima of

$$V(Z) = |P(Z)|^2 = \sum_{i=1}^{n} |P_i(z)|^2$$

- V is a plurisubharmonic function

$$Z(t) = Z_0 + ht \qquad h \in \mathbb{C}^n$$

$$\frac{\partial^2}{\partial t \, \partial \bar{t}} V(Z(t)) = \sum_{k=1}^{n} \left| \sum \dot{Z}_i \frac{\partial P_k}{\partial Z_i} \right|^2 \geq 0$$

V cannot have anywhere a local maximum unless $V = \text{const} \Rightarrow P(z) = \text{const}$.

- Confining potential

$$\Rightarrow \lim_{|z| \to \infty} V(Z) = +\infty$$

independently of the way $Z \to \infty$

- Necessary condition for confinement

$$J(P) \not\equiv 0$$

$$J(P) = \det \partial P_i / \partial z_j$$

General class of non-confining potentials

$$P_i(z) = C_i + \sum_{i=1}^{n-1} p_{ij}(z) H_i(z)$$

p_{ij} polynomials

H_i homogeneous polynomials of degré $\deg H_i \geq 1$

- For a confining potential $\exists\, z_0 \in \mathbb{C}^n$ such that $V(z_0) = 0$

This property follows from

- V confining $\Rightarrow$ $P(\mathbb{C}^n) = \mathbb{C}^n$

Proof $\quad S = \{ z \in \mathbb{C}^n \mid J(z) = 0 \}$

$J \not\equiv 0 \qquad S$ closed algebraic variety of dimension $n-1$

$\Rightarrow \mathbb{C}^n \setminus S$ open connected set

$$\Omega = P(\mathbb{C}^n \setminus S)$$

$\Rightarrow$ non empty open connected set

Consider $\partial\Omega$

$\Rightarrow \mathbb{C}^n \setminus \partial\Omega$ is again an open connected set in $\mathbb{C}^n$

Philippe Blanchard • Erwin Brüning

Mathematical Methods in Physics

Distributions, Hilbert Space Operators, Variational Methods, and Applications in Quantum Physics

Second Edition

Dedicated to the memory of
Yurko Vladimir Glaser and Res Jost,
mentors and friends

Birkhäuser

Ann. Inst. Henri Poincaré,
Vol. XXIII, n° 2, 1975, p. 147-209.

Section A :
Physique théorique.

Green's functions for theories with massless particles (in perturbation theory)

by

Philippe BLANCHARD (1) **and Roland SENEOR** (2)

ABSTRACT. — With the method of perturbative renormalization developed by Epstein and Glaser it is shown that Green's functions exist for theories with massless particles such as Q. E. D., and $\lambda : \phi^{2n}$: theories. Growth properties are given in momentum space. In the case of Q. E. D., it is also shown that one can perform the physical mass renormalization.

RÉSUMÉ. — A l'aide de la méthode de renormalisation perturbative développée par H. Epstein et V. Glaser on montre l'existence des fonctions de Green pour des théories comprenant des particules de masse nulle telles que l'électrodynamique quantique et les théories $\lambda : \phi^{2n}$. On donne des propriétés de croissance dans l'espace des moments. Pour l'electrodynamique, on montre qu'il est possible d'effectuer la renormalisation de la masse à sa valeur physique.

I. PRELIMINARIES

1. Introduction

Notations are those of [*1*]. Any change will be explained.

It has been shown in [*1*] that for $g_i(x)$ in $\mathscr{S}(\mathbb{R}^4)$ the various field ope-

(1) C. E. R. N., Geneva and University of Bielefeld (W. Germany).
(2) C. E. R. N., Geneva and Centre de Physique Théorique, École Polytechnique, Paris.

Blanchard

Ref.TH.1156-CERN

LE RÔLE DE LA LOCALITE DANS LA RENORMALISATION PERTURBATIVE EN THEORIE QUANTIQUE DES CHAMPS *)

H. Epstein et V. Glaser
CERN - Genève

R E S U M E

Cette conférence, faite à la réunion de Strasbourg de mai 1970 résume un article à paraître prochainement par les mêmes auteurs [1].

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*) Conférence présentée à la réunion de mai 1970 de la R.C.P. No 25 à Strasbourg.

Ref.TH.1156-CERN
8 May 1970

EXISTENCE (EN THEORIE DES PERTURBATIONS) DES FONCTIONS DE GREEN DE L'ELECTRODYNAMIQUE QUANTIQUE *)

P. Blanchard et R. Seneor +)

CERN - Genève

*) Rapport présenté au colloque sur la renormalisation, CNRS, Marseille, 14-18 juin 1971.

+) Centre de Physique Théorique de l'Ecole Polytechnique (Paris).

Genève, le 8/2/82

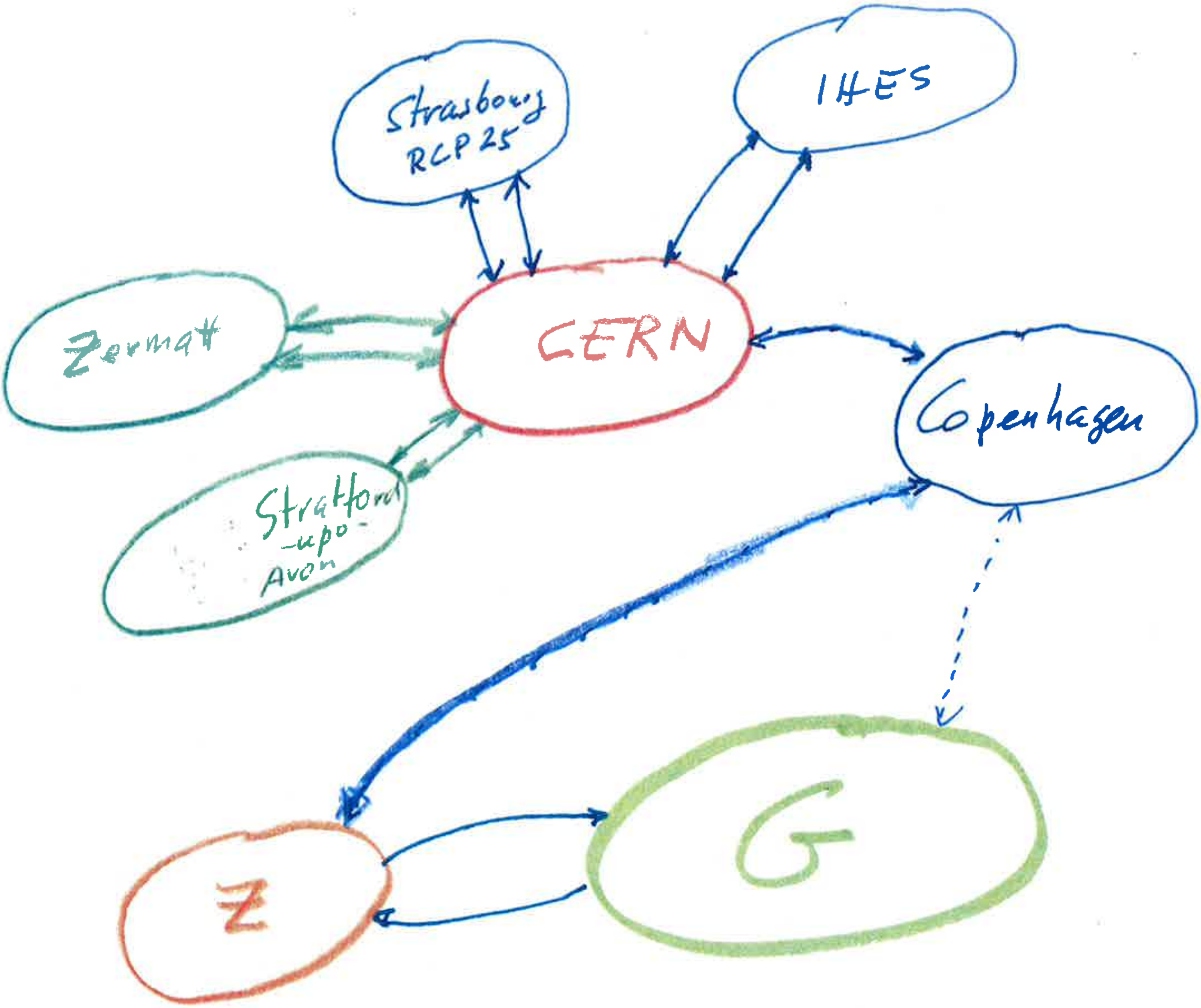
Mon cher Blanchard,

Je t'écris de nouveau parceque je n'ai pas réussi à te joindre par téléphone. Je te remercie d'abord pour ta lettre et ton manuscript, que j'ai parcouru avec plaisir.

Je t'écris principalement pour te dire, que le CERN est d'accord pour te payer un séjour de 2 semaines, comme convenu. Moi je suis ici tout le temps jusqu'au 13 Mars, quand on part pour deux semaines à Zermatt. D'après ta lettre c'est la periode qui te convenait le plus. Donc je t'attend avec plaisir. Après le 27 Mars je suis de nouveau ici si par hasard tu changerais de programme.

Avec toutes mes amitiées ton

Jurí Glaser



Yurko's graph