PROCEEDINGS OF SCIENCE

Two unforgettable years with Hector

Gabriele Veneziano*
Collège de France, Paris, France
and
Theory Division, CERN, CH-1211 Geneva 23, Switzerland
E-mail: gabriele.veneziano@cern.ch

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*Speaker.

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1. Another lucky coincidence

As a high school student in Florence I had the luck of being taught by some excellent teachers: Professor Tebaldo Liverani, in particular, was the one who initiated me to loving maths and physics. His preference, he once confessed, went to the former. However, after some hesitation, mine went to the latter as I entered the local University in 1960.

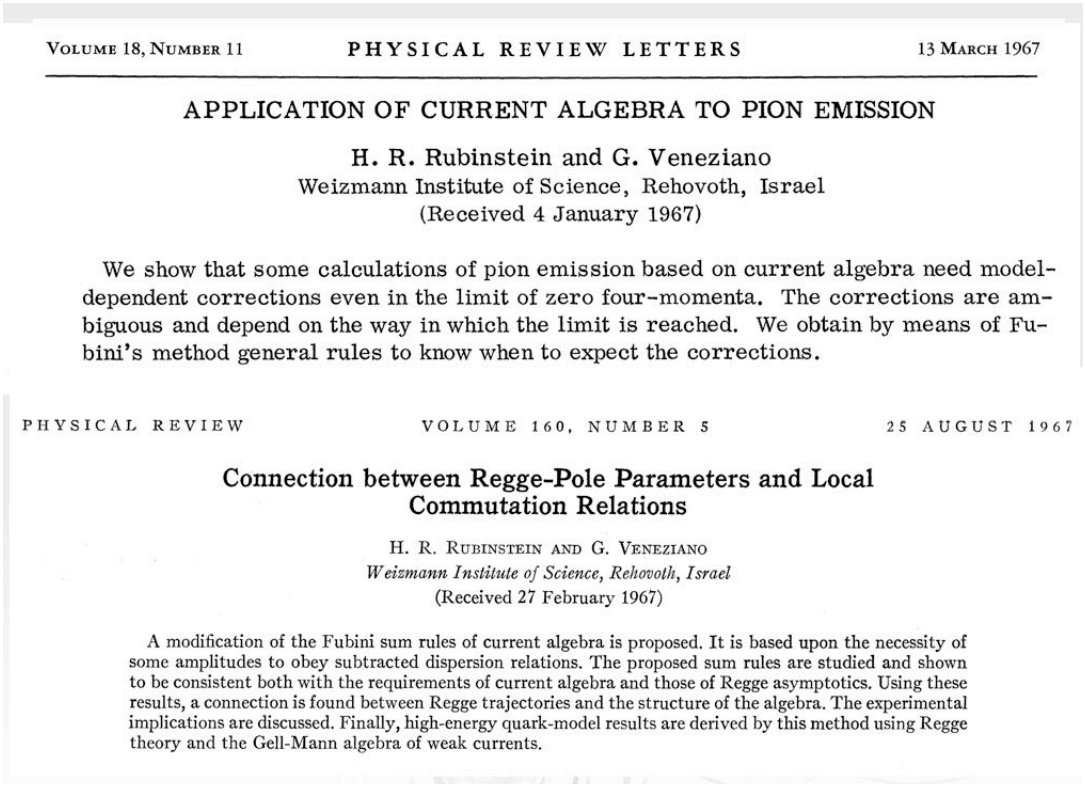
Three years later I had to make another choice, this time about which branch of physics to go for. I was about to be "recruited" by the local high-energy experimental group when, just in time, Professor Raoul Gatto moved from Cagliari to Florence and "rescued" me to theoretical physics. At the end of 1965 I received my "Laurea" in physics defending a thesis on some applications of the group $SU(6)_W$. Only later I learned that the W in there apparently stood for Weizmann ...

Working in Florence as one of Gatto's "gattini" was very stimulating. However, having always lived at home in my family in Florence, I felt the need to enlarge my horizons, both in physics and in life in general. I had already met Edy and, together, we made plans to move to Israel to continue our respective studies after getting married in the summer of 1966. This is how I decided to apply to the Feinberg Graduate School of the Weizmann Institute having in mind Zvi Lipkin and Haim Harari as my likely future mentors. These were indeed the two names I mentioned to Raoul Gatto when, after learning that I had decided to leave Florence for Rehovot, he asked: " yes, but who is there at the Weizmann Institute?"

I was easily accepted to the graduate school (having passed a Laurea under Raoul Gatto meant having already a good acquaintance with high-energy theory and a decent CV) but, apparently (Zvi told the full story at the social dinner here), it was decided that I would be assigned to a young theorist who had moved to Israel a year or so earlier from Paris: Hector. This would turn out to be one more lucky coincidence to play a crucial role in my life, probably the most important one as far as my professional career went. I thus met Hector for the first time in the fall of 1966.

Meeting Hector, being his student, and gradually becoming his collaborator, was almost a shock to me, so accustomed to an italian "safety distance" between teachers and students. We heard at this symposium about how Hector could be tough and uncompromising when it came to arguing with the establishment (even at the risk of having to face unpleasant consequences). Well, there was a complementary side to such a trait of his character: he would never make a younger collaborator or a student feel any gap in the relative hierarchy. From day one we would discuss and work together as real colleagues. Hector's enthusiasm was very contagious and beneficial and soon our collaboration started producing results. But besides doing physics we also started having social life together: tennis matches before work in the morning, walks in the "pardes" (citrus growth) near the institute after lunch, nice dinners and/or evening coffees: I still recall that Edy and I were initiated to Camembert cheese at Helen and Hector's house!

I also appreciated very much his sharp (and occasionally cynical) wit about many things in life: from Middle East policy to music, from travel tips to gossips. He would often joke about the fact that, in Israel, a Ph.D. student salary, being tax-exempt, was effectively higher than a Professor's salary so that he would probably ask me one day for a loan. He must have felt Israel's relative isolation (in spite of the amazing flux of important visitors) and was kind of obsessed by the daily arrival of the mail. One could hear the postman arrive while we were discussing in the common coffee room on the first floor. He would immediately dash downstairs just to come back up saying,



VOLUME 18, NUMBER 11 PHYSICAL REVIEW LETTERS 13 MARCH 1967

APPLICATION OF CURRENT ALGEBRA TO PION EMISSION

H. R. Rubinstein and G. Veneziano
Weizmann Institute of Science, Rehovoth, Israel
(Received 4 January 1967)

We show that some calculations of pion emission based on current algebra need model-dependent corrections even in the limit of zero four-momenta. The corrections are ambiguous and depend on the way in which the limit is reached. We obtain by means of Fubini's method general rules to know when to expect the corrections.

PHYSICAL REVIEW VOLUME 160, NUMBER 5 25 AUGUST 1967

Connection between Regge-Pole Parameters and Local Commutation Relations

H. R. RUBINSTEIN AND G. VENEZIANO
Weizmann Institute of Science, Rehovoth, Israel
(Received 27 February 1967)

A modification of the Fubini sum rules of current algebra is proposed. It is based upon the necessity of some amplitudes to obey subtracted dispersion relations. The proposed sum rules are studied and shown to be consistent both with the requirements of current algebra and those of Regge asymptotics. Using these results, a connection is found between Regge trajectories and the structure of the algebra. The experimental implications are discussed. Finally, high-energy quark-model results are derived by this method using Regge theory and the Gell-Mann algebra of weak currents.

Figure 1

more often than not, "nothing, nothing". And perhaps there was a bit of irony when, as an associate Professor, he was talking about a higher-ranked colleague as a "Professor gadol" (big Prof.) ...

2. Current Algebra: Sept. 1966 – Feb. 1967

I still remember the first talk I was asked to give at the Weizmann Institute. It was about a paper I had written a few months earlier in Florence on the problem of saturating some current algebra sum rules. It was one of the first seminars I had ever given and certainly the first one in English, a language I had some scholastic knowledge of, but no practice with. The presentation must have turned out to be quite a disaster, but Hector was probably impressed by its content and we kept discussing the subject in private. This was, I believe, the beginning of our collaboration.

Hector and I started immediately to work on the then fashionable subject of current algebra in which we both had some experience. By the winter of 1967 we had already submitted two papers, one to Phys. Rev. Letters and one to Phys. Rev. (see Fig. 1). In the former we pointed out that, in several cases, current algebra cannot, by itself, make unambiguous predictions about the so-called soft-pion limit of scattering amplitudes (a few years later that observation turned out to be useful in a paper I wrote at MIT in collaboration with M. Ademollo and S. Weinberg). In the second, we were dealing with the consistency and interplay between current algebra and Regge's theory of high energy scattering, thereby starting a research line that would occupy us for sometime.

Figure 2

3. Playing with Superconvergence: winter 1967 -> summer 1967

The following six months of activity with Hector focussed on what turned out to be a very fruitful direction. This was the result of many factors. On the one hand Miguel Virasoro, accepting Hector's invitation, had arrived from Argentina. He soon joined the two of us while one of my former assistant Professors in Florence, Marco Ademollo, also decided to collaborate although he had meanwhile left Florence for a visiting position at Harvard. A second important push in the right direction came from a visit to the Weizmann Institute by Sergio Fubini (see photo in Fig. 2, where he is surrounded by Hector, Miguel, myself and a few other theorists). Sergio and collaborators had written an impressive series of papers that went far beyond the original current algebra program.

Our concern thus gradually shifted from current algebra sum rules to similar ones dealing exclusively with hadronic interactions, the so-called superconvergence sum rules of Fubini and collaborators, as well as their generalization known as Finite Energy Sum Rules. A very important question remained unanswered. We knew of two possible contributions to the sum rules: one, at low energy, related to the production of metastable states (resonances), the second, relevant at high energy, implied by (the Chew-Mandelstam application of) Regge's theory of complex angular momentum. The problem had to do with an intermediate energy range (say around a few GeV) in which both contributions appeared to the present in the data and was about whether in this region the two contributions had to be added (as one would have very naively thought).

The paper shown in Fig. 3 expresses clearly our thoughts on the subject at the time. It is

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Saturation of Superconvergent Sum Rules at Nonzero Momentum Transfer.

M. Ademollo
Istituto di Fisica dell'Università - Firenze

H. R. Rubinstein, G. Veneziano and M. A. Virasoro
Weizmann Institute of Science - Rehovoth

(ricevuto il 6 Luglio 1967)

1. – Introduction and general discussion.

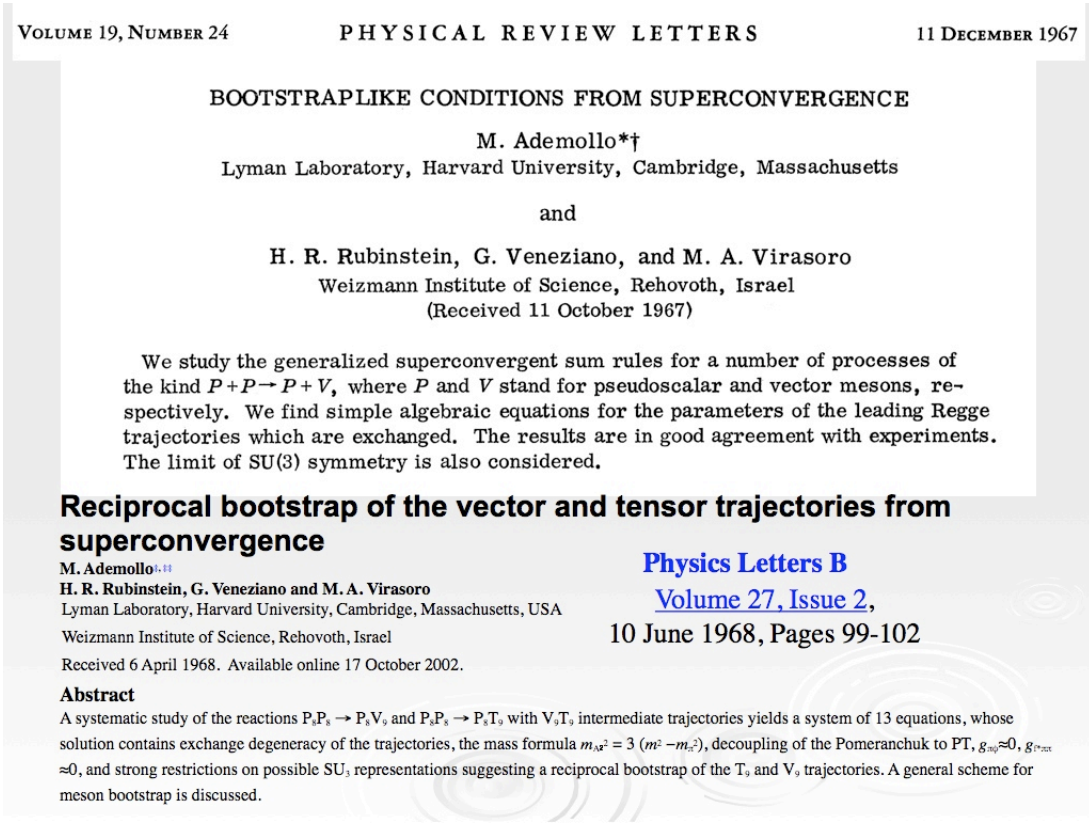
The two most successful tools in the theory of elementary particles developped in the last two years are current algebra and superconvergence. De Alfaro, Fubini, Furlan and Rossetti have studied the connections between these two techniques in a recent paper (1) where they have pointed out several problems concerning the consistency of these two approaches with other dynamical assumptions. One of the most important problems concerns the saturation of the sum rules when direct experimental information is not available. These sum rules have the general form (2)

$$\frac{1}{\pi}\int_{-\infty}^{\infty} \mathrm{Im}\, A(\nu, t)\, \mathrm{d}\nu = F(t)\,, \tag{1}$$

where F is zero in the case of superconvergence. The saturation of eq. (1) with a finite number of intermediate one-particle states is clearly inadequate at all t in the case of current algebra since the left-hand side can only give a polynomial in t.

Figure 3

evident that we were leaning, theoretically, towards the correct answer to that question. However, only after a fundamental paper by Dolen, Horn and Schmit (DHS) the answer given by Nature appeared sharply before our eyes. Being already theoretically prepared we immediately subscribed to it. By looking carefully into pion-nucleon charge-exchange scattering ($\pi^- + p \to \pi^0 + n$), DHS had found that in the intermediate-energy region the two descriptions (resonances and Regge poles) were complementary or, using the language of quantum mechanical particle-wave duality, were "dual" to each other. Hence the two contributions to the sum rules should *not* be added since this would result in a terrible "double counting" mistake. This observation became known as DHS duality. It is at the very base of string theory, although most of our young string theorists today have probably never heard about DHS ...



VOLUME 19, NUMBER 24 PHYSICAL REVIEW LETTERS 11 DECEMBER 1967

BOOTSTRAPLIKE CONDITIONS FROM SUPERCONVERGENCE

M. Ademollo*†
Lyman Laboratory, Harvard University, Cambridge, Massachusetts

and

H. R. Rubinstein, G. Veneziano, and M. A. Virasoro
Weizmann Institute of Science, Rehovoth, Israel
(Received 11 October 1967)

We study the generalized superconvergent sum rules for a number of processes of the kind $P+P \to P+V$, where P and V stand for pseudoscalar and vector mesons, respectively. We find simple algebraic equations for the parameters of the leading Regge trajectories which are exchanged. The results are in good agreement with experiments. The limit of SU(3) symmetry is also considered.

Reciprocal bootstrap of the vector and tensor trajectories from superconvergence

M. Ademollo[a,‡‡]
H. R. Rubinstein, G. Veneziano and M. A. Virasoro
Lyman Laboratory, Harvard University, Cambridge, Massachusetts, USA
Weizmann Institute of Science, Rehovoth, Israel

Physics Letters B
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10 June 1968, Pages 99-102

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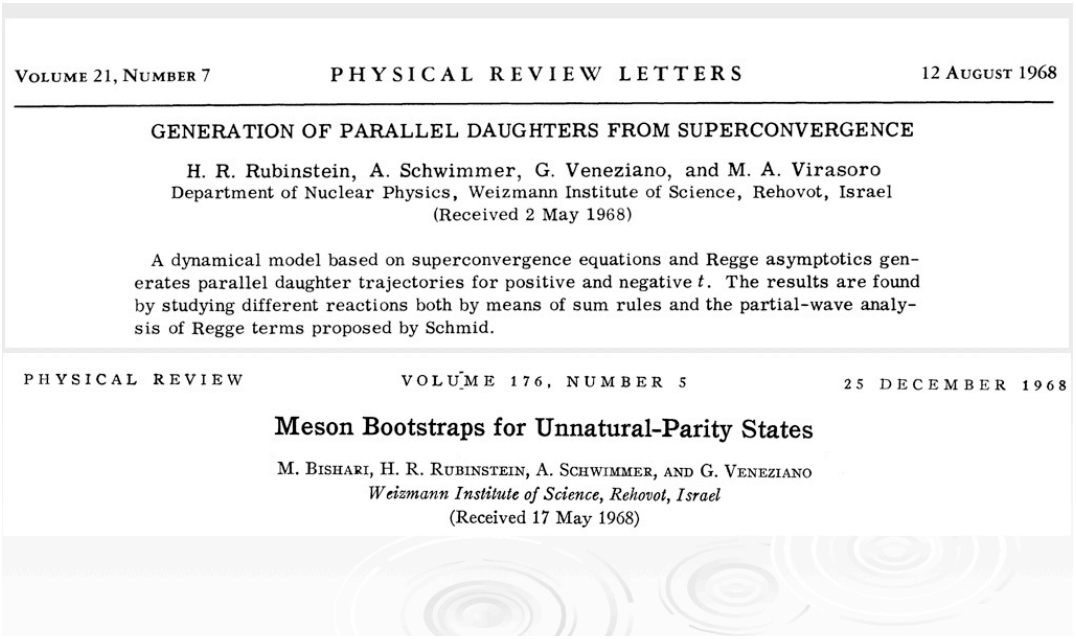
Abstract
A systematic study of the reactions $P_8P_8 \to P_8V_9$ and $P_8P_8 \to P_8T_9$ with V_9T_9 intermediate trajectories yields a system of 13 equations, whose solution contains exchange degeneracy of the trajectories, the mass formula $m_{A_2}^2 = 3\,(m^2 - m_\pi^2)$, decoupling of the Pomeranchuk to PT, $g_{\omega\eta'} \approx 0$, $g_{\Gamma\pi\pi} \approx 0$, and strong restrictions on possible SU_3 representations suggesting a reciprocal bootstrap of the T_9 and V_9 trajectories. A general scheme for meson bootstrap is discussed.

Figure 4

4. The cheap bootstrap works! September 1967–> June 1968

Personally, I heard of DHS duality at the summer school I attended in Erice in the summer of 1967. It was mentioned "en passant" by Murray Gell-Mann, already a famous Professor at Caltech, the institute where the DHS paper had been written. Gell-Mann said that the DHS observation opened the possibility of setting up a "cheap bootstrap" as opposed to the "expensive" one based on full non-linear unitarity and nuclear democracy (all hadrons are on the same ground) advocated by Geff Chew.

Back at the Weizmann Institute after the summer the four of us identified a process ($\pi\pi \to \pi\omega$) which, while impossible to measure experimentally, made the cheap-bootstrap idea easy to implement theoretically, and started to work on it intensively. It did not take us too long to find that the program worked amazingly well (it took a bit longer to write the paper because of the slow communications between Israel and the US) and we submitted a short letter to Phys. Rev. Lett. with the first results (1st paper in Fig. 4). This happy scientific development was stained by a small incident (on which I prefer not to elaborate) which could have caused internal problems in the ARVV collaboration. Hector's realism and wit was crucial in solving the problem and in making the collaboration survive and actually come out stronger than before.



VOLUME 21, NUMBER 7 PHYSICAL REVIEW LETTERS 12 AUGUST 1968

GENERATION OF PARALLEL DAUGHTERS FROM SUPERCONVERGENCE

H. R. Rubinstein, A. Schwimmer, G. Veneziano, and M. A. Virasoro
Department of Nuclear Physics, Weizmann Institute of Science, Rehovot, Israel
(Received 2 May 1968)

A dynamical model based on superconvergence equations and Regge asymptotics generates parallel daughter trajectories for positive and negative t. The results are found by studying different reactions both by means of sum rules and the partial-wave analysis of Regge terms proposed by Schmid.

PHYSICAL REVIEW VOLUME 176, NUMBER 5 25 DECEMBER 1968

Meson Bootstraps for Unnatural-Parity States

M. BISHARI, H. R. RUBINSTEIN, A. SCHWIMMER, AND G. VENEZIANO
Weizmann Institute of Science, Rehovot, Israel
(Received 17 May 1968)

Figure 5

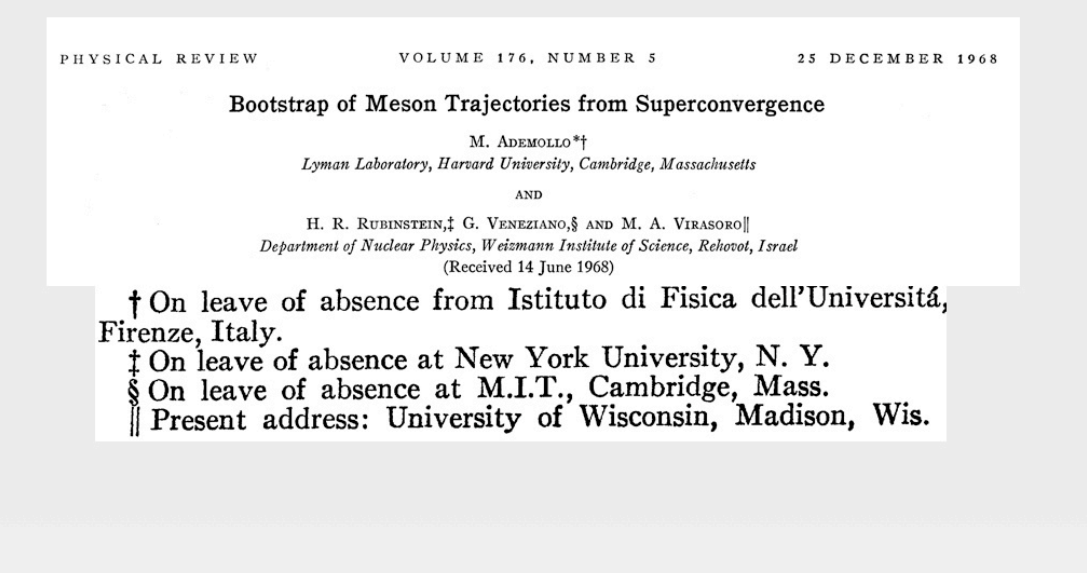
5. More Bootstrap more fun!

This first paper on the DHS-duality bootstrap was followed by a more complete analysis by ARVV published in Phys. Letters (also in Fig. 4). Meanwhile, two young students, Moti Bishari and Adam Schwimmer, joined the effort. In a paper by Hector, Adam, Miguel and myself (Fig. 5) the prediction of parallel daughter trajectories was first made. In retrospect this was a very important observation connected to the now-famous degeneracy of states in string theory. In another paper with Adam and Moti (Fig. 5 again) the whole program was extended to hadrons with so-called "unnatural parity".

In that period Hector, Miguel and myself also carried out, in parallel, a very different research program dealing with the asymptotic behaviour of form factors in different composite models for the hadrons. Miguel is summarizing that part of the collaboration (extended to Daniele Amati and Roberto Iengo) which also had interesting developments within the modern framework for strong interactions (counting rules for QCD form factors).

6. The collaboration dissolves, but the way had been paved!

The summer was approaching fast and the three of us had already made plans for the coming academic year. As one can see in Fig. 6, Hector was going to NYU for a sabbatical. Miguel was heading for Madison, Wisconsin, as a postdoc, after a summer visit at home. Marco would stay a second year at Harvard. I would see him soon in Boston, since I was going to join Sergio Fubini at the new Center for Theoretical physics at MIT for my first postdoc (after spending the summer at CERN).



PHYSICAL REVIEW VOLUME 176, NUMBER 5 25 DECEMBER 1968

Bootstrap of Meson Trajectories from Superconvergence

M. ADEMOLLO*†
Lyman Laboratory, Harvard University, Cambridge, Massachusetts
AND
H. R. RUBINSTEIN,‡ G. VENEZIANO,§ AND M. A. VIRASORO‖
Department of Nuclear Physics, Weizmann Institute of Science, Rehovot, Israel
(Received 14 June 1968)

† On leave of absence from Istituto di Fisica dell'Universitá, Firenze, Italy.
‡ On leave of absence at New York University, N. Y.
§ On leave of absence at M.I.T., Cambridge, Mass.
‖ Present address: University of Wisconsin, Madison, Wis.

Figure 6

The collaboration was soon going to disperse. Working at a distance those days was not at all trivial (we had managed with much effort with two sites, going to four was unthinkable). We decided that, before splitting apart, we should write a long paper summarizing what we had achieved so far on the "Bootstrap of meson trajectories from superconvergence". The paper (see Fig. 6) was sent to Phys. Rev. in mid June 1968 when, I guess, Hector, Miguel and myself were already far apart.

A few days earlier, while still in Israel, I had a first intuition of a compact, closed-form solution of the bootstrap in terms of a certain 'Beta function" ... The paper would be written a month or so later at CERN and widely discussed at a conference in Vienna that I attended before flying over to Boston. The collaboration had fallen apart but the way to Dual-Resonance-Models and to string theory had been paved!

7. Concluding remarks

When these days someone asks me about how String Theory was conceived I explain that there is nothing farther from truth than saying that it was an inspired guess of my own. Quite the opposite: it was just the natural, almost inevitable outcome of two years of hard work with Hector and with a fantastic group of colleagues in Israel and elsewhere. It was a true bottom-up approach to theoretical physics: with hindsight, we now believe that some kind of strings do emerge from QCD because of quark confinement. They leave distinct marks in the data, like the linear Regge trajectories and the DHS duality that led to the work I described here and, eventually, to String Theory (the wrong one unfortunately!).

In my last picture (Fig. 7) I am celebrating, with Hector, the Oskar Klein medal I received in June 2007. It was like the happy ending of a story that had started 40 years earlier in Israel. We all knew, by then, that Hector was not in good health and we feared that the worse could happen any

Figure 7

time. Hector himself knew, of course, and openly talked about it, but chose to follow his instinct and his passions and to live the kind of life he loved till the last moment. In any case I'm sure there would have never been a happy event like the one on the picture without those two unforgettable years with Hector.

Acknowledgements

I wish to thank the organizers of this marvellous symposium that made it possible to bring back to life so many souvenirs that Hector left forever in our minds, and to share them.