Franco Selleri and his contribution to the research of foundations of Relativity Theory

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Abstract: The Italian theoretical physicist Franco Selleri (1936-2013) played an important role, among others, in the modern research of foundations of Relativity Theory. The present work outlines his contribution to critical studies on Special Relativity Theory. After an introduction about his life and his research in Particle Physics and foundations of Quantum Mechanics, it is showed his contribution in foundations of Relativity Theory, consisting in the introduction of a new theory, the Weak Relativity, based on the so-called Inertial Transformations. Moreover, it is also analyzed an example of this theory regarding the Sagnac effect.

Keywords: Foundations of Relativity Theory, Franco Selleri's critical attitudes, History of Physics.

1. Introduction

The present work deals with the research activity of the Italian theoretical physicist Franco Selleri in the field of foundations of Relativity Theory. In his last book, *Weak relativity*, he faces up to the large problems and paradoxes inherent the Theory of Special Relativity (henceforth, TSR) and the Theory of General Relativity (TGR).

His work has showed, among others things, that Lorentz Transformations (LT) in TSR form part of a more general set of Equivalent Transformations (ET), that differ only in the value assumed by a synchronization parameter whose name is e_1. For $e_1 = 0$, we have what Selleri calls Inertial Transformations (IT):

> I believe that [the Lorentz transformations] are not correct. The good transformations of the physical reality are the following ones: x', y', z' transform in the same way as in the Lorentz transformations, but t'= tR. Much simpler. This is a theory in which you have absolute simultaneity…and a space that is not mixed with time as in relativity, but still moving clocks slow down. And it is a theory having a privileged system so having the Lorentz ether and explaining all the experimental data…there is a completely new approach and there is a full development of this type of ideas (*Interview of Franco Selleri by Olival Freire on 2003 June 25*).

Selleri is going to show how among many equivalent theories, only the so-called Theory of Inertial Transformations (henceforth, TIT), based on absolute simultaneity, can explain not only everything that TSR explains but also what TSR fails in.

After two paragraphs concerning the life of Franco Selleri, his legacy on Particle Physics and foundations of Quantum Mechanics, and his research on the foundations of Relativity Theory, we are going to describe briefly a peculiar case, the Sagnac effect.

2. Selleri's life and research

Franco Selleri was born in Bologna on October 9th, 1936, in a family with no specific scientific attitudes at all. His father was a railway controller and his mother was a housewife. Selleri attends scientific high school named "Augusto Righi" in Bologna, and he speaks notably about his teacher Graffi. This has been a basic contact because, concerning his teacher, Selleri states that:

> He had really a robust personality and he could push people to be interested in mathematics and physics. […] I think that if I decided to be a physicist it was his merit. Not that he suggested to me in particular to study physics at the university, but just his type of personality was very strong and influential for me (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).[1]

Due to some economic problems in his family, Selleri decides to entry to the faculty of engineering for the greater job opportunities it offers. But a recruiting advertisement by professor Giampietro Puppi[2] in which young people were sought for working in particle physics, proves to be decisive for his choices. In fact,

> [Selleri gave his libretto with the grades] to him and he said, "You can come even tomorrow." So I switched from engineering to physics and then I was very happy because that was my real interest (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).

Selleri graduates in Bologna in the academic year 1957-1958 (at the age of 22) with professor Puppi, discussing a thesis entitled *Analisi dell'interazione pione-nucleone*. In Selleri's research career is possible to find three different periods, even if they are not clearly well separated in time. They are related to peculiar areas: Particle Physics, foundations of Quantum Mechanics and foundations of Relativity Theory.

In particle physics, during the years 1958-69, Selleri spends some periods abroad. In 1959, he is in Geneva at CERN, where he introduces the so-called *one pion exchange model*,[3] acquiring a reputation in the world of particle physics. From 1961 to 1965, he is

[1] The underlined sentence is ours.
[2] He studied at Padua University with Bruno Rossi and Giancarlo Wick.
[3] That is, the suggestion that in an anelastic process is it possible to change a pion. In this view, during a collision between two protons, the target proton emits a virtual positive pion, becoming a neutron; the incident proton scatters elastically on this virtual pion, making it as a real pion in the final state.

in USA to the "Cornell University" in Ithaca, attracted by the presence of Nobel Prize Hans Albrecht Bethe. But, once in USA:

> slowly, I started to develop a critical attitude towards contemporary physics. I mean I had a very strong drive. I liked physics very, very much and I was very active, but it was soon evident that there were problems, fundamental problems in physics. My model was, so to say, overcome by a different model that was called the one pion exchange model with absorption. It was very odd conceptually. […] Perhaps today it does not seem so terrible, I know, but for me it was shocking. That was a frustrating development. I was very young and naive, so it was very difficult to take. So I slowly realized that if something like that was possible, that meant there were great problems in physics. And somehow I got very soon the conviction that the problems came from the foundations of quantum mechanics. That is to say, the problems in elementary particle physics are due to the fact that quantum mechanics is poorly understood and anyway is a very abstract idea (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).[4]

In 1965, he decides to come back Italy. Then he finds that:

> Bologna University was in trouble in physics at the time. There were struggles and problems. They had made mistakes in the choices of people to head the physics institute, that is my feeling anyway. So that was strongly reflected on the "climate", I mean the political and cultural climate. In Bari there was this new university and I met with Bari people in a congress and they told me they would be happy if I came to their university, so I left Bologna and its problems and came here. […] [In Bari University] they were experimentalists, because Bari at that time had no theoretical physicists yet. It so happened that I published the first paper in theoretical physics of Bari University. […] I think that for me it was a very good decision to come here, not only because the human relationships were much better, much more relaxed than in Bologna, but also because here I had space to do what I wanted and I had no great difficulties in doing foundations of quantum mechanics. In Bologna it would have been more difficult (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).

He starts receiving teaching assignments in Bari University since the academic year 1967-68 (Bari, Archivio Generale dell'Ateneo di Bari). On May 1969, he is confirmed as a lecturer in theoretical physics. He becomes full professor in Bari on February 14, 1984.

During the period in which he is going to Bari, Selleri is moving his activity from particle physics to foundations of Quantum Mechanics, even if,

> in the beginning I thought that I would have made research both in particle physics and in quantum mechanics, but slowly I was completely attracted by the foundational problems (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).

His first published paper on foundations of Quantum Mechanics, whose title is "On the wave function of Quantum Mechanics", comes out on *Nuovo Cimento* (Selleri 1969). But

[4] The underlined sentence is ours.

his full transition to foundations of Quantum Mechanics is still in progress, since he states that:

> perhaps in 1971 or 1972 I was in Sweden. And it was in the library of the physics department of the University of Gothenbourg that I found in French the book by Bernard d'Espagnat, *Conceptions de la Physique contemporaine* (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).

But in 1969, in Frascati, Selleri, during the description of the importance to create an alternative theory to Quantum Mechanics states that:

> the philosophical prejudice in favour of a realistic philosophy is strong in the large majority of physicists. This prejudice did not turn against QM simply because very few people knew its real implications. The book of d'Espagnat should hopefully contribute to give a better comprehension of them.[5]

The book from d'Espagnat is dated 1965 so it is not clear when he has known it. Anyway, Selleri says:

> It was a revelation. It was something fantastic to see how many problems were open in quantum mechanics. It was fascinating to see that so many possibilities were open. So it was clear that the Copenhagen approach was not unique, was not obligatory. We had a philosophical freedom (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).

Henceforth, Selleri devotes himself to foundations of Quantum Mechanics, with a huge amount of publications and works related, *inter alia*, the following topics:

- the Empty Waves, for the study of the Einstein-De Broglie picture of wave-particle duality;
- the Einstein-Podolsky-Rosen Paradox, dealing mostly with Bell's Theorem, its proof and the meaning of the experimental investigations;
- the probabilistic Local Realism, the most general formulation of our idea still leading to the validity of Bell's inequality;
- the Inequalities of Local Realism, showing that Bell's inequality is just one of an infinite set of inequalities that are consequences of local realism.[6]

Since 1994, he starts researching almost exclusively on foundations of Relativity Theory, still publishing several articles and books, even if a paper showing Selleri's contribution

[5] This is an excerpt from a typescript found in the Selleri's private documents. It concerns a lecture held in Laboratori Nazionali INFN/CNEN in Frascati in 1969 titled "Quantum Theory and hidden variables".

[6] This is an excerpt from a typescript found in the Selleri's private documents. Selleri prepared it on September 1991, grouping 25 complete papers in the different groups above reported. As Selleri stated: "The present collection has been prepared for the Cesena conference Bell's theorem and the Foundations of Modern Physics (October 7-10, 1991) and has been made possible by a grant of the Commission of the European Communities (D.G. XII) for which we are very grateful". The author of the present paper is trying to put in order, as a further work in his PhD studies, all documents that Selleri left in Bari.

on foundations of Relativity Theory was already written in 1990. Its title was *Space-time transformations in ether theories* (Selleri 1990).

A possible reason for this involvement might come from the following evidence:

> the idea of real waves really requires a medium. And in recent years I switched to the foundations of relativity to see if a logical space existed for such a medium. […] With relativity I could go much deeper and I have basically a new theory that can replace special relativity. […] I was influenced by Prokhovnik (1967) and his books and by John Bell who wrote an article on the foundations of special relativity (1976) (*Interview of Franco Selleri by Olival Freire on 2003 June 24*).

Selleri keeps on working until the end, although his last years are marked by an illness. He dies in Bari on November 20th, 2013, at the age of 77.

3. Selleri's legacy on foundations of Relativity

The research of Franco Selleri regarding the foundations of Relativity Theory has been just as important for him as that concerning the foundations of Quantum Mechanics, enough to make him say that:

> A point I would like to make is to stress again the importance of what I have done in the foundations of special relativity. Because now we have a completely new theory which is different from relativity. […] So I was unable to build a new quantum theory, but at least I built a new relativity and I strongly believe it is correct (*Interview of Franco Selleri by Olival Freire on 2003 June 25*).

Selleri founds, in his studies:

> E1. Set of experiments insensitive to clock synchronization, that is, set of experiments with outcome predicted equally well by the theory of the inertial transformations (TIT) and the TSR. The set includes, for instance, experiments made by Michelson-Morley, Kennedy-Thorndike, Maiorana, Ives-Stilwell, Fizeau, the TAI (International Atomic Time),
> E2. Set of experiments preferring the TIT over the TSR/TGR, that is, set of experiments predicted correctly by TIT, but not finding a rational explanation from the TSR and/or the TGR. In this set are included: Sagnac effect, zero acceleration discontinuity of the velocity of light, aberration of the starlight, block universe paradox,
> E3. Set of experiments preferring the TSR/TGR over the TIT: empty set (Selleri 2015, p. 58-59).

The conclusion seems to be clear:

> the TIT explains all the examined experiments, while the two Einstein relativistic theories have serious problem with the experiments of the second set. In this way we will see that there is an important logical space for a theory alternative to the TSR. […] In view of the results […], which hopefully should constitute a serious blow to

> conventionalism, one can say that the simultaneity adopted in the TSR, more than conventional, is arbitrary and, it turns, not correct. My recent research has shown that the arbitrariness of relativistic simultaneity opens a logical space to a different theory, (the theory of the inertial transformations) that agrees with experiments even better than the TSR. (Selleri 2015, p. 59).

Here is intended to show briefly the research path held by Franco Selleri to reach the Theory of Inertial Transformations (TIT), showing, moreover, with a specific case, how it is able to explain not only all that the TRS explains but also what TSR fails to do. Concerning TIT, Selleri states that:

> now we have a completely new theory which is different from relativity […] at least I built a new relativity and I strongly believe it is correct (*Interview of Franco Selleri by Olival Freire on 2003 June 25*).

3.1. The Selleri road from Lorentz to Inertial Transformations

The Einstein's theories of Special and General Relativity are very powerful tools explaining a lot of phenomena and predicting others properly. But they have also received a great deal of criticism regarding their reliability. It would not be right to conclude that any comparison of the theoretical predictions with the experiments was invariably solved with a perfect agreement. Even if the Theories of Relativity are correct from the point of view of mathematical formalism, they are not coherent and free from contradictions. For instance, in the mathematical shell of TSR, the time-related report for two reference systems, called S_0 and S, the latter being in motion with respect to the former, depends only on x_0, neither on y_0 nor z_0, creating in this way a oddness between the points of space, which is conversely not only real but homogeneous. So:

> something external, something unnecessary, something that maybe is going to get complicated the theory has been introduced. That is the original sin of TSR! (Selleri, 2011, p. 28. Our rendering).

Any physical theory can not represent the final form of knowledge. Selleri rightly points out that:

> the lesson to learn from epistemology (Popper, Lakatos, Kuhn) is about the conjectural, provisional, improvable nature of the physical theories of the XXth century. […] Einstein did not hide the transitoriness of his creations. On April 4, 1955 [in his last paper] It ended with the following words: 'The last, quick remarks must only demonstrate how far in my opinion we still are from possessing a conceptual basis of physics, on which we can somehow rely'. In a way this is a declaration of failure, but one has to admire the ethical dimension of the great scientist who had devoted the superhuman efforts of a lifetime to the attempt of reaching the deepest truths of nature and now, arrived at the end, declares to posterity: 'I did not succeed' (Selleri 2015, pp. 26-27).

Indeed, the two theories of relativity present a series of paradoxes. Selleri makes explicit an absolutely incomplete list of paradoxes, for the TSR:

> 1. The idea that the simultaneity of spatially separated events does not exist in nature and must therefore be established with a human convention; 2. The relativity of simultaneity, according to which two events simultaneous for an observer in general are no more such for a different observer; 3. The velocity of a light signal, considered equal for observers at rest and observers pursuing it with velocity 0.99 c ; 4. and 5. The contraction of moving objects and the retardation of moving clocks, phenomena for which the theory does not provide a description in terms of objectivity; 6. The hyper-deterministic block universe of relativity, fixing in the least details the future of every observer; 7. The conflict between the reciprocal transformability of mass and energy and the ideology of relativism, which declares all inertial observers perfectly equivalent so depriving energy of its full reality; 8. The existence of a discontinuity between the inertial reference systems and those endowed with a very small acceleration; 9. The propagations from the future towards the past, generated in the TSR by the possible existence of superluminal signals; 10. The asymmetrical ageing of the twins in relative motion in a theory waving the flag of relativism (Selleri 2015, p. 28).

These paradoxes can be completely overcome as soon as the new TIT is accepted. Selleri applies the theory to six different tests: the Sagnac effect; the rotating platform; linear accelerations; overcoming the block universe; the aberration of starlight and the superluminal propagations.

3.2. From Lorentz to Inertial Transformations: mathematical steps and considerations

It is well known that the Lorentz Transformations (LT), which form the basis of the TSR, are:

$$x = \frac{x_0 - vt_0}{R}$$
$$y = y_0$$
$$z = z_0$$
$$t = \frac{t_0 - \frac{v}{c^2}x_0}{R}$$

where $R = \sqrt{1 - \frac{v^2}{c^2}}$

Reza Mansouri and Roman U. Sexl (1977a, 1977b, 1977c) pointed out that the LT contain a conventional term in the transformation of time which depends on x coordinate.

Selleri's reasoning is as follows: given two inertial reference frames, S_0 and S, the following standard assumptions are advanced:

> (i) Space is homogeneous and isotropic and time homogeneous, at least from the point of view of observers at rest in S_0;

> (ii) Relative to the isotropic system S_0 the velocity of light is "c" in all directions, so that clocks can be synchronized in S_0 with the Einstein method and the one way velocities relative to S_0 can be measured;
> (iii) The origin of S, observed from S_0, moves with velocity $v<c$ parallel to the $+x_0$ axis, that is according to the equation $x_0=vt_0$;
> (iv) The axis of S and S_0 coincide for $t=t_0=0$ (Selleri 2015, pp. 72-73).

Starting from these assumptions, the so-called General Transformations (GT) are obtained:

$$x = f_1(x_0 - vt_0)$$
$$y = g_2 y_0$$
$$z = g_2 z_0$$
$$t = e_1 x_0 + e_4 t_0$$

For instance, Lorentz contraction of moving objects is thus obtained for: $f_1 = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ and $g_2 = 1$; Larmor retardation of moving clocks is obtained if we put: $e_1 v + e_4 = \sqrt{1-\frac{v^2}{c^2}}$; and the invariance of the two way velocity of light, is get for: $g_2 = f_1\sqrt{1-\frac{v^2}{c^2}}$ and $e_1 v + e_4 = f_1\left(1-\frac{v^2}{c^2}\right)$.

Now, starting from GT, two conditions are introduced, based on solid empirical evidence: that the speed of light in the two directions is the same in all directions and in all SRI, i.e. $c_2(\theta)=c$; and that the delay of the clock depends on the usual R-factor when the clock moves with respect to S_0. Then, the so-called Equivalent Transformations (ET) are obtained:

$$x = \frac{x_0 - vt_0}{R}$$
$$y = y_0$$
$$z = z_0$$
$$t = Rt_0 + e_1(x_0 - vt_0)$$

In the ET, all theories equivalent to TSR are present. For instance, the Lorentz Transformations are get as a special case of ET if: $e_1 = -\frac{v}{c^2 R}$. As Selleri says:

> The provisionally free parameter e_1 defines in S the simultaneity of distant events, or, which is the same, chooses the clock synchronization method to apply in S. Clearly, then, an appropriate denomination for e_1 is "synchronization parameter".

> […] Most experts of the foundation of the relativistic theories consider e_1 essentially a free parameter to be fixed by the convention concerning clock synchronization, but […] [is here showed] the opposite, namely that physical phenomena require a fixed value of e_1, precisely e_1=0. A theory different from the TSR is clearly needed (Selleri 2015, pp. 80-81).

Thus, different synchronization conventions lead to different values of the e_1 parameter and to different theories of space and time which are, to a large extent, empirically equivalent. But, in all cases, except for the TSR, these values imply the existence of a privileged reference system.

Absolute simultaneity, i.e. the absence of spatial coordinates in the transformation of time, thus leads to the Inertial Transformations (IT), with e_1 =0:

$$x = \frac{x_0 - vt_0}{R}$$
$$y = y_0$$
$$z = z_0$$
$$t = Rt_0$$

While the LT of TSR introduce a symmetry between spatial and temporal variables, forcing the latter to a geometric role in a four-dimensional space, the IT, according to Selleri:

> imply a complete liberation of time from the merely geometrical role to which it had been forced in the Minkowski space. Furthermore, they predict that the velocity of light relative to an inertial system S moving with respect to the privileged system S_0 is not isotropic. […] A property implied by IT is absolute simultaneity. […] [Its] existence [...] does not imply that time is absolute: on the contrary, the v-dependent factor in the transformation of time gives rise to time-dilatation phenomena similar to those of TSR. A clock at rest in S is seen from S_0 to run slower, but a clock at rest in S_0 is seen from S to run faster so that both observers agree that motion relative to S_0 slows the pace of clocks (Selleri 2015, p. 83).

IT are only the latest in a series of transformations proposed as an alternative to LT. Referring to the text *Weak Relativity* for a complete demonstration of the six situations in which TIT explain the above cases better than the TSR, the specific case of the Sagnac effect is discussed here.

3.2. An application of Weak Relativity Theory: the Sagnac effect naturally explained

Let Selleri's words introduce us to the experiment:

> In the Sagnac 1913 experiment a platform was made to rotate uniformly around a vertical axis at a rate of 1-2 rotations per second. In an interferometer mounted on the platform, two interfering light beams, reflected by four mirrors, propagated in opposite directions along a closed horizontal circuit defining a certain area A. The rotating system included also the luminous source and a photographic plate record-

> ing the interference fringes. On the pictures obtained during a clockwise and a counterclockwise rotation with the same frequency, Sagnac observed the interference fringes in different positions and measured the displacement Δz by overlapping the two figures. This Δz is strictly tied to the relative time delay with which the two light beams reach the detector. Sagnac observed a shift of the interference fringes every time the rotation was modified. […] The experiment was repeated many times in different ways, with the full confirmation of the Sagnac results. […] Surprisingly theoreticians were little interested in the Sagnac effect, as if it did not pose a conceptual challenge (Selleri 2015, pp. 114-116).

More than a century after the Sagnac effect, no one has succeeded in giving a theoretical explanation based on the TSR and TGR.

There is a temporal difference Δt_0 in the two paths of light propagating in opposite directions:

$$\Delta t_0 = \frac{2L_0 v}{c^2 R^2} = \frac{2Lv}{c^2 R}$$

$L_0 = LR$ is the disk circumference measured by observers, at rest in the laboratory, who are seeing the rotating disk, whereas L is the circumference of the disk measured by observers at rest on the disk. On the disk there are different speeds in the parallel and antiparallel case from which $\Delta t = \frac{2L\Gamma}{c}$. Seen from the disk, the delay is therefore $\Delta t = \Delta t_0 R\left(1+\frac{c^2 e_1 R}{v}\right)$. The consistency of $\Delta t = R\Delta t_0$, $\Delta t_0 = \frac{2L_0 v}{c^2 R^2}$ and $\Delta t = \frac{2L\Gamma}{c}$, allows us to find the proper value of e_1. In fact, setting $R = \frac{\Delta t}{\Delta t_0}$ and requiring the same phenomenon, we have $R = \frac{2L\Gamma}{c}\frac{c^2}{2L_0}\frac{R^2}{v}$. By applying $L_0 = LR$, we have $1 = \frac{c}{v}\Gamma$ and, as it is $\Gamma = \frac{v}{c} + ce_1 R$, the obtained result is only possible for e_1=0. Only the absolute simultaneity of TIT allows us to understand the Sagnac effect, giving it a rational description! For all other values of e_1 you have wrong results. For instance, in the TSR, in which $e_1 = -\frac{v}{c^2 R}$, the wrong prediction Δt=0 occurs.

4. Conclusions

Selleri proposed himself to show that the best theory of space and time is TIT, based on absolute simultaneity. It implies the existence of a privileged isotropic inertial reference system. He states that: thus compatible with a new form of relativity principle. Einstein based the theory of special relativity on two principles which together lead necessarily to the Lorentz transformations. In an important sense we can consider Einstein's relativity

as a strong principle. When it says that the physical laws "are not affected" by a change of reference system, it requires the laws of nature to have exactly the same form in all inertial reference frames

> It is possible to resynchronize clocks in all inertial frames in such a way as to select a different, arbitrarily chosen frame as "privileged". Such a resynchronization of clocks (ROC) does not modify any empirical consequence of the theory, which is thus compatible with a new form of relativity principle, weaker than adopted by Einstein in the Theory of Special Relativity (TSR) (Selleri 2015, p. 250).

The main question is how to identify the privileged system. After attempts and failures, Selleri points out that we can not give a positive answer to this question. We can only move from one privileged system to another, which is always arbitrary. A certain relativism therefore remains. A plausible name given by Selleri for the TIT is that of Weak Relativity. We can therefore consider two formulations of the relativity principle: a Strong Relativity, according to which the laws of physics are exactly the same in all inertial systems. This is the Einstein's formulation; and a Weak Relativity, stating merely the impossibility to measure the absolute velocity of Earth. This last principle does not demand necessarily the validity of LT.

Selleri, very honestly, also points out unclear points, and makes profession of intellectual honesty giving priority to physics:

> We must admit that our results may seem somewhat contradictory. On the one hand, they point to a theory of space and time in which such conceptions as absolute velocity, privileged frame and absolute simultaneity have a central role; while, on the other hand, relativism comes back in the arbitrariness of the choice of the 'privileged' inertial frame [...] [But now] the new relativistic requirements are much weaker than before […] and, even more important, the LT has to be replaced by IT. Any violation of LT found at any time will imply that strong relativity itself does not hold as a description of nature (Selleri 2015, pp. 264; 269).

> From the point of view of the inertial transformations the validity of weak relativity appears accidental, more than fundamental. It would be enough to discover a very small non-invariance of the two way speed of light to make the whole game of resynchronization impossible (Selleri 2015, p. 250).

> the TSR is mathematically "unstable", in the sense that any shift, however small, of any one of the four f_1, g_2, e_4, e_1 [in the GT] away from its relativistic values implies necessarily the existence of a privileged reference frame (Selleri 2015, p. 269).

Concerning his works, it emerges an approach directed by Selleri to a global analysis of physical phenomena, as demonstrated by the introduction of extended models like the One Pion Exchange Model, the Local Realism or the Weak Relativity. It reveals in him a continuous ability to create acute and valid *gedankenexperimenten*, an absolute honesty in searching for experimental evidence, proposing conclusive experiments, quoting authors and presenting a clear state of the art inherent in each single topic. Moreover, there

is always a clear ability to go down different paths, even abandoning them, and a courageous admission of one's own failures. Always objective and honest, he throughout fought for his ideas, even at the price sometimes of net judgments and different breakups with other scientists, he has always proposed to experimentally verify his theories. In addition, as we have seen, Selleri has always conducted every research in physics taking into account a wide range that included the history and philosophy of physics, convinced that:

> physics is a human activity and from us inherits the habit to parade the successes and to hide difficulties and failures. […] One should never forget that behind the equations of a theory there is a huge qualitative structure made of empirical results, generalizations, hypotheses, philosophical choices, historical conditionings, personal tastes, conveniences (Selleri 2015, p. 27).

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