

The roots of the Standard Model: a tribute to Tom Massam

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Tom Massam at the "Ettore Majorana International Centre for Scientific Culture" where he created in 1972 the International School of Theory Application of Computers, which from now on will have his name.

The frontier of our Physics is the Unification of the Three Fundamental Forces (gravitational, electroweak, strong subnuclear) and the existence of phenomena which cannot be explained by the so-called Standard Model: in few words, the Standard Model (SM) and what can exist Beyond it (BSM).

These frontiers have their roots in more than half a century of research work in many labs by many physicists in the most important laboratories in Europe: CERN (Geneva), DESY (Hamburg), ADONE (Frascati) and Gran Sasso of INFN in Italy; the last one is the most powerful underground laboratory of this planet. In all these labs half a century has been the time that Tom Massam has given to me with his extraordinary intelligence, work capacity and "scientific fidelity".

The "scientific fidelity" was (and is) based on the fact, that if in a group there are different scientific views there is the danger that a large amount of time can be lost for discussions of conflicting conceptual views. It is much more fruitful if the time is spent in order to get the best technological and experimental solution in the chosen field. My gratitude for Tom is also due to the fact that in

our group he has established a very high level of "scientific fidelity". The present status of experimental Physics corresponds to a large number of people working together; the number being of the order of three powers of ten. The "scientific fidelity" is needed more than ever. In the middle of the XX century the number of physicists working in a group was of the order of one power of ten and even at the level of few fellows. Nevertheless the "scientific fidelity" was needed.

In all activities undertaken by me, both in Physics and in Scientific Culture, Tom was my most precious and faithful collaborator. He is one of the founders of the "Ettore Majorana International Centre for Scientific Culture", established at CERN in the early sixties of last century, with its headquarters in what the Emperor Frederick II, *stupor mundi*, wanted to be the first City of Europe, Erice. At the Erice Centre, Tom created in 1972 the International School of Theory Application of Computers, which from now on will have his name.

I had the privilege of knowing Tom at the Fermi Summer School of Physics in Varenna (Italy) where I was the Vice Director. Dr. Thomas Massam was coming from the Chadwick Laboratory; in 1956 he was able to get his B.Sc (Hons) and later his PhD at the University of Liverpool. He knew the results of the Blackett group on the totally unexpected V-particles, later called "strange" by Gell-Mann and many other physicists. The topics discussed at the Fermi School in Varenna were the existence of a new quantum number called "strangeness" (additively conserved in strong interactions), the effects of "Virtual Physics" in the properties of the "elementary particles" and the experimental plus theoretical research work needed. Tom was the most active student of the School and knew my work at Imperial College in the Blackett group [1] where the observation of the pair production of "heavy mesons" with positive and negative "strangeness" allowed to overcome the Fermi's criticism against the existence of the new quantum number called "strangeness". This is how our life-long collaboration started.

When Tom started to work with me there was no Standard Model which is the triumph of Relativistic Quantum Field Theory (RQFT). Many difficulties gave a lot of support to the enemy number one of RQFT, the so-called Scattering-Matrix (S-matrix) whose founders are John A. Wheeler (1937) and Werner K. Heisenberg (1943). They pointed out a number of important advantages of S-matrix theory over conventional quantum field theory.

With the so-called "maximal analyticity", the S-matrix theory gained a dynamical content and became during the late fifties a strong competitor of quantum field theory. The physicists involved were Gell-Mann, Goldberger, Landau, Mandelstam, Pomeranchuk, and the author of "*Nuclear Democracy*" Geoffrey F. Chew, who wrote: «*Let me say at once that I believe the conventional association of fields with strong interacting particles to be empty. It seems to me that no aspect of strong interactions has been clarified by the field concept. Whatever success theory has achieved in this area is based on the unitarity of the analytically continued S-matrix plus symmetry principles. I do not wish to assert (as does Landau) that conventional field theory is necessarily wrong, but only that it is sterile with respect to the strong interactions and that, like an old soldier, it is destined not to die but just to fade away.*» [G. Chew, "S-Matrix Theory", W.A. Benjamin Inc. (1963)], [2].

"Virtual Physics" coming from RQFT was considered an unnecessary complication. At the 12th Solvay Conference devoted to "*The Quantum Theory of Fields*" Marvin Goldberger said: "*From a philosophical point of view and certainly from a practical one the S-Matrix approach at the moment seems to me by far the most attractive*" [Proceedings of the 12th Solvay Conference, Interscience, New York (1961)], [3].

It was necessary to establish if "Virtual Physics" was present as theoretically predicted in the most

elementary particle known, the "muon" also called "heavy electron" since this particle had no nuclear forces acting on it. Let me quote the Abdus Salam Nobel Lecture: «Zichichi had been badgering me since 1958 with persistent questioning of what theoretical avail his precise measurements on $(g-2)$ for the muon as well as those of the muon lifetime were, when not only the magnitude of the electromagnetic corrections to weak decays was uncertain, but also conversely the effect of non-renormalizable weak interactions on "renormalized" electromagnetism was so unclear» [Gauge Unification of Fundamental Forces, Abdus Salam, *Nobel Lecture*, 8 December 1979, from *Nobel Lectures, Physics 1971-1980*, Stig Lundqvist (ed), World Scientific (1992)]. Two key experiments were needed: the $(g-2)$ and the muon lifetime.

To measure with high precision the anomalous magnetic moment of the "muon", also known as the $(g-2)$ value, it was necessary to invent a new technology able to capture in a "polynomial" magnetic field a muon in order to let it rotate thousands times thus allowing the intrinsic magnet of the particle to show its "anomalous" value due to the "Virtual Physics". Tom became an enthusiastic supporter of the "Virtual Physics" experimental checks, whose existence now no one would dare to question [4].

Concerning the muon lifetime, now it is also given for granted that we understand the so called "weak interactions". So much we know that we have discovered how these interactions are mixed with the electromagnetic forces: in the Standard Model we have in fact the "electroweak interactions" which represent the proof of how much we know about these two fundamental forces of Nature: QED and QFD (Quantum ElectroDynamics and Quantum FlavourDynamics).

Half a century ago it was necessary to prove that all weak interactions have one and only one "weak charge". For this to be experimentally proved it was needed the high precision determination of the "weak charge"; i.e. the muon lifetime. Previous measurements in many labs (Carnegie, Chicago) [5], were affected by "systematic" effects which invalidated the needed conclusion. How to overcome this difficulty was our contribution in this field and our first paper (with Tom) came out on the measurement of the Fermi coupling (weak charge). Even now the problem is open to why the "weak charge" is splitted into pieces: one part is for particles like the neutron which has zero strangeness and the other part for particles like the lambda-zero (Λ^0) which has the strangeness quantum number. Why the weak charge is divided into pieces even now nobody knows. What everybody wanted to know was (and is) what happens to a particle which has neither "strangeness" nor strong charge: the weak charge should be at the 100% level. The best example was the "muon". This was the reason for measuring the muon lifetime with a precision of one part half per mille [6] with the systematic effects reduced to zero.

Let me mention only few papers in order to recall some moments of our very active collaboration with many papers published. In the middle sixties the search for heavy leptons started at CERN and later in ADONE when the theoretical trend was for the non existence of other leptons: two were already too many, a famous theoretical physicist was repeating. Despite these theoretical predictions the search for final states with acoplanar ($e\mu$) pairs was performed, thus establishing that the mass of a third lepton must be higher than 1000 MeV. Its discovery came few years later in USA, the only difference being the slightly higher energy of the collider and a set-up coarsely copied.

During the same years the problem for the existence of a "scalar" meson was coming, in order to explain why all elementary particles possess the property called "mass". This meson was called S^0 and its existence was experimentally proved in USA. We found at CERN that the S^0 meson discovered in USA was not there. This S^0 meson became later the very famous Higgs boson. During

the same years the search for fractionally charged particles (quarks) started to be at the centre of our physics. As well as new problems concerning the mixing between mesonic states.

The quark problem is still very relevant, while the mixing between mesonic states, thanks to the "Instantons", seems to be over.

Our group started the search for fractionally charged particles [$(\pm \frac{1}{3}; \pm \frac{2}{3}; \pm \frac{4}{3})$ (e), where " e " is the unit of all electrically charged particles] having as source the cosmic rays and later the CERN machines. Neither "asymptotic freedom" nor "confinement" were theoretically existing; our group gave the best experimental proof for the fact that if "quarks" exist, they cannot escape from the Subnuclear Universe. When the theoretical description of the interaction between quarks and gluons, thanks to QCD (Quantum ChromoDynamics), came out with the so called "asymptotic freedom" we studied the highest energy (pp) and neutrino-nuclei collisions and concluded that, despite the decreasing value of the QCD coupling with increasing energy (this effect being the consequence of "asymptotic freedom"), it was impossible for the quarks to come out from the Subnuclear Universe (whose frontiers are at the Fermi length $\approx 10^{-13}$ cm).

In simple "words", quarks appeared to have the property called "confinement". But this property could not be theoretically predicted by QCD. Nevertheless it was experimentally present even at the highest level of energy. Tom was an enthusiastic supporter of "confinement" being experimentally present without any theoretical support.

And now back to the rare decay modes of all mesons.

In 1969 a new detector (using neutron) was invented, in order to allow the rare decay modes of all mesons to be studied. The discovery of the decay mode ($X^0 \rightarrow \gamma\gamma$) proved that this meson was a pseudoscalar particle and not a tensor. Its name from X^0 became η' . The exact values of the large mesonic pseudoscalar mixing and the very small mesonic vector mixing were established. The theoretical understanding of the mesonic mixings came many years later with the "Instantons": a new fundamental component of the "Standard Model".

The experimental results mentioned so far do represents many roots of the Standard Model. Let me quote two other examples of fundamental roots of the Standard Model, which are still of interest. One is the problem of "Antimatter" [7], the other is the existence of the "Effective Energy" [8].

Even in our day people believe that if antiparticles exist, Antimatter must be there. The proof of this is given by the fact that people consider the antihydrogen to be the first example of Antimatter. An atom of antihydrogen is made with an antiproton plus an antielectron. These two antiparticles have opposite electric charges. The existence of the antihydrogens atom is therefore granted by QED. No nuclear forces are needed for its existence. The first element of the Mendeleev Table is the atom of hydrogen, which is made with a proton and an electron. If we ignore the existence of the neutron, the Mendeleev Table would have this element: only one. Since 1932 we knew that the "neutron" exist. It is thanks to the existence of the neutron that the Mendeleev Table can have (nowadays) more than hundred elements: the first one in this Table is the so-called heavy-hydrogen, whose nucleus is made with a proton, nuclearly linked with a neutron. This is the simplest nucleus and is called Deuteron. All other elements of the Mendeleev Table need neutrons in addition to protons and electrons. The nuclear forces are needed in order to have protons and neutrons in the nucleus of each atom.

To have matter with more than hundred elements we need "protons", "neutrons" and "electrons". For Antimatter with as many elements as matter, we need "antiprotons", "antineutrons" and "antielectrons". The simplest antinucleus is the antideuteron.

If the antideuteron does not exist there will be no Antimatter. The existence of the antideuteron is granted if the forces acting between an antiproton and an antineutron are identical to the forces acting between a proton and a neutron. The existence of the antideuteron is granted if the nuclear forces are mathematically described by a RQFT. But if the S-matrix is the winning theory, the existence of the antideuteron is far from being granted.

The antideuteron was experimentally searched and not found at the level of 10^7 nuclear particles produced and zero antideuteron. The experiment needed to prove if the antideuteron exist was a very difficult one. A new technology had to be invented in order to measure the Time of Flight (TOF) of the particles with a very high precision. Tom was my most enthusiastic supporter and, using our new TOF technology we were able to demonstrate that the first example of Nuclear Antimatter was there with a production rate of one antideuteron for hundred million of nuclear elementary particles produced.

As T.D. Lee has pointed out [9], even nowadays no-one is able to derive the nuclear forces from their original force, Quantum ChromoDynamics (QCD). This is the force acting between quarks and gluons and it is a RQFT. The conclusion of T.D. Lee is that the existence of Nuclear Antimatter is based only on the experimental results.

The last work of Tom with me was at DESY in Hamburg where the effects of the leading proton in the highest energy leptons and protons interactions were studied. This is how we started to discover the "Effective Energy" in Subnuclear Physics. The Standard Model is not able to explain the existence of this fascinating feature of the final states produced by all types of initial states. No matter if the initial state has strong nuclear, electromagnetic and also weak forces; no matter what is the initial pair of interacting particles; the final states of particles produced are the same, provided the Effective Energy is the same. When I was discussing with Tom these problems it was given for granted that the final states of the particles produced had to be all different, due to the different initial states. Here I need to quote two great leaders in this field of theoretical physics: Vladimir N. Gribov and Gerardus 't Hooft.

Vladimir N. Gribov [10]: *"In the physics community there was a sort of gentlemen's agreement: please do not speak about results in contrast with the so much searched for gauge interaction to describe hadronic phenomena. These "hidden" results were the hadronic systems produced in the interactions between pairs of hadrons; they were all different. Each pair of interacting particles, when producing systems consisting of many hadronic particles, had its own final state. No-one knew how to settle this flagrant contradiction. I wish I had the idea of the "effective energy"."*

Gerardus 't Hooft [11]: *"Theoreticians were unable to prescribe what experimentalists had to look for to establish the universal nature of these final interactions. The experimental results were discouraging; scattering experiments yielded different final states for each pair of interacting particles. So it happened that these aspects of QCD had to wait until experimentalists themselves came with the right idea. The showers come with what is now called an "effective energy", and, in terms of this quantity, universality could be established [8]."*

From this synthesis on the roots of the Standard Model I hope the reader will grasp the meaning of my final statement: «Without Tom Massam it would not have been easy for me to do in physics and

in scientific culture what I have been able to do».

Tom is no longer with us. On December 1, 2016 he left his beloved family, Veronica with three children Peter, Steven, Paul, and his friends and colleagues with the unforgettable memory of his extraordinary life.

References

[1] *A Lesson for the Future of Our Science My Testimony on Lord Patrick M.S. Blackett*
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[2] See [1] pages 131-132.

[3] See [1] page 132.

[4] See [1] page 272.

[5] See [1] page 70.

[6] See again [1] page 70.

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[11] See [10] page 39.