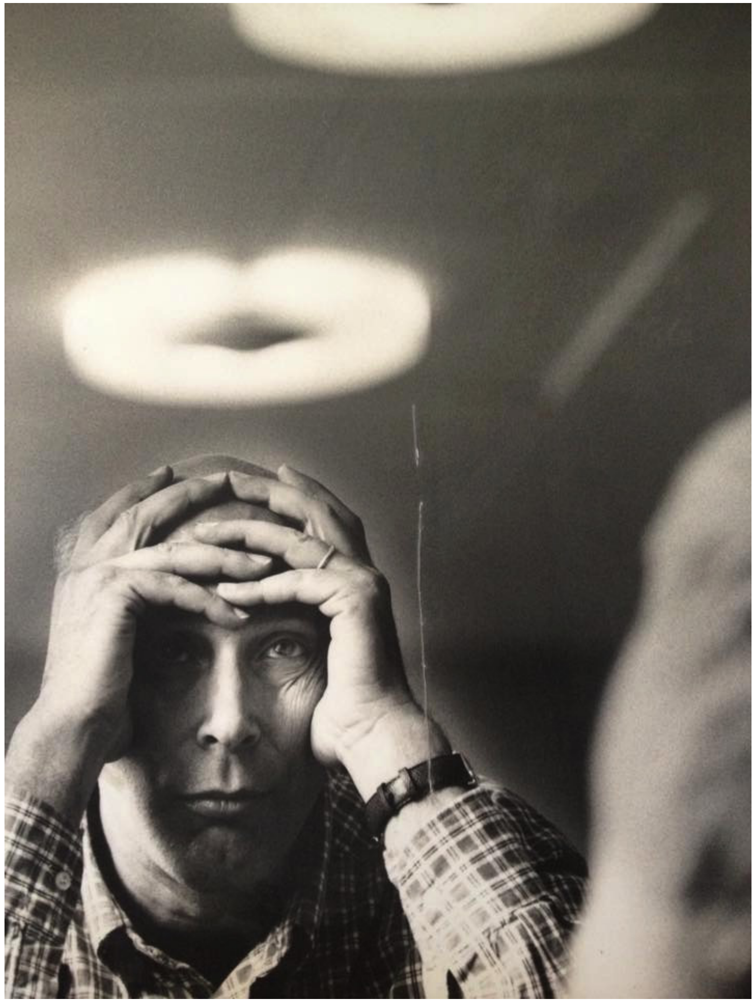
Historical and personal recollections of Guido

Giorgio Parisi

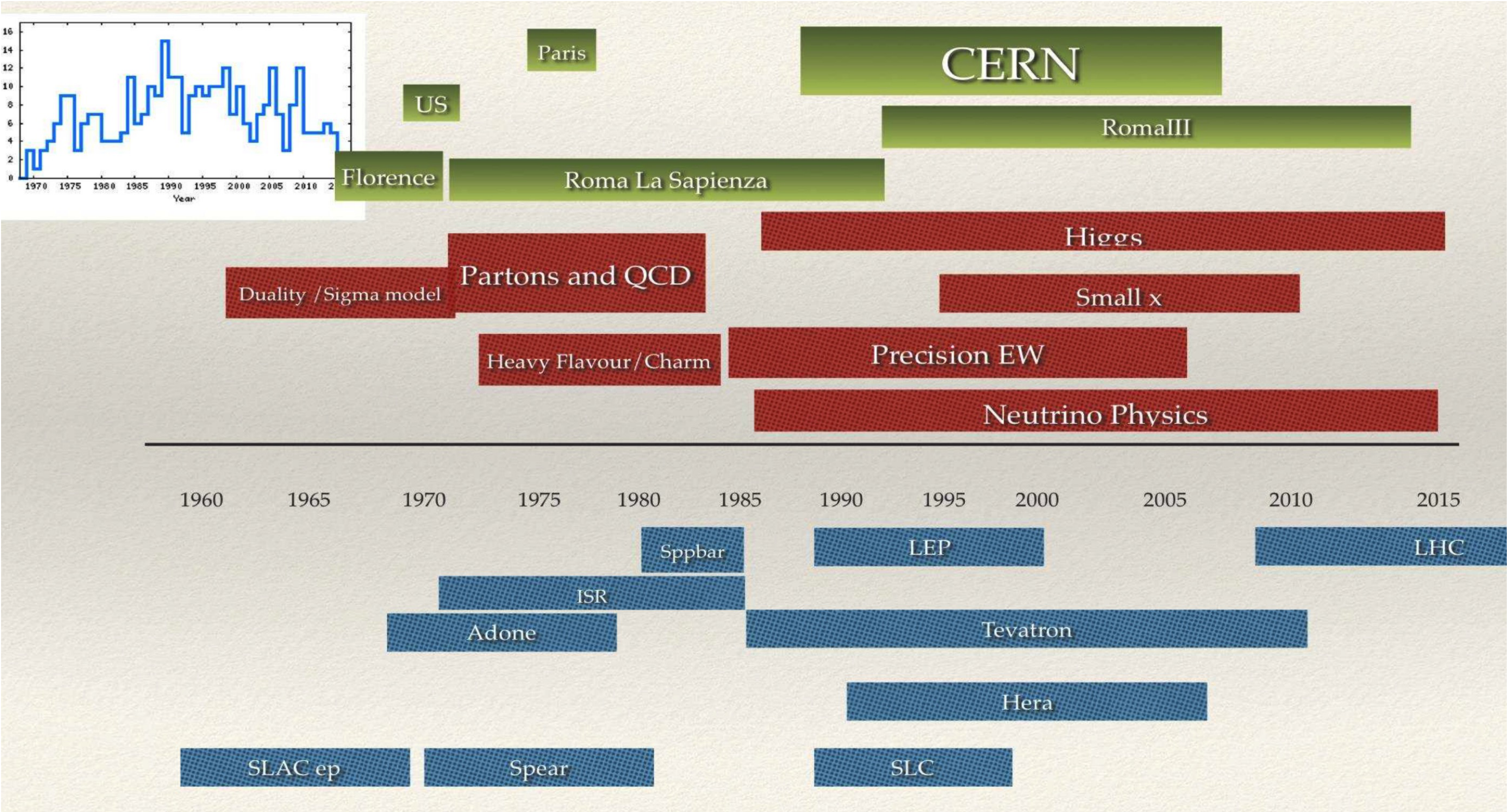


Guido Altarelli was born in Rome on 12 July 1941 and died in Geneva on 30 September 2015.

- Guido graduated in Physics from Rome University in 1963 with Raul Gatto (who was in Florence at that time). The thesis was done in collaboration with his friend Franco Buccella on the process $e^+e^- \to e^+e^- + \gamma$.
- In 1964 he went to Florence to join the very lively and large group of young researchers (*gattini*) who were working together under the careful and inspiring supervision of Gatto.
- In 1968-1970 he spent two years in New York (at New York University and at Rockefeller University).
- In 1970 he became professor of theoretical physics in Rome. In this period he spent long periods in other institutions as the ENS in Paris and Boston University.
- In 1987-2006 he became Senior Staff Physicist at the Theory Division of CERN, and he was the Theory Division Leader in 2000-04. In 1992 he moved to the newly founded University Rome 3.
- He received three very prestigious awards: the Julius Wess Award (2011), the J. J. Sakurai Prize APS (2012) and the High Energy and Particle Physics Prize of the EPS (2015).

- In Florence he worked with Gatto and the other gattini (among them Buccella, Luciano Maiani and Giuliano Preparata), mostly on topics that were fashionable at that time (e.g. SU(6) symmetries, Regge poles).
- After his arrival to Rome his scientific interests moved firstly toward the parton model and later concentrated on what we now call the Standard Theory, following the strong tradition of the Rome school, led by Nicola Cabibbo, of using field theory tools to understand particle physics.
  Many of these works were written with Nicola Cabibbo, Mario Greco, Keith Ellis, Maiani, Guido Martinelli, Giorgio Parisi and Roberto Petronzio.
- Among the most important contributions are the papers on Octet enhancement of non-leptonic weak interactions in asymptotically free gauge theories: for the first time it was shown that the newly born QCD was able to contribute to solving some of the old mysteries of weak interactions (in this case the dominance of the $\Delta I = 1/2$ strangeness changing processes over the much weaker $\Delta I = 3/2$ processes).
  Other important contributions of this period his paper are the Altarelli-Parisi equations and the first NLO corrections to the nave parton model: he discovered large QCD correction prediction in $\mu^+ + \mu^-$ production in hadronic corrections.

- In the 80's he got interested in predictions for future CERN experiments, e.g. for production of jets, heavy-vector mesons and other exotic objects like Higgs and supersymmetric particles. He has also written seminal papers on the decay of heavy quarks and he continued the analysis of the consequences of QCD on weak interactions, computing the two loops contributions, the first NLO computation for weak interactions.
- Guido started to be deeply interested in polarized proton structure function, where he discovered, together with Graham Ross, the crucial interplay between the gluon anomaly and polarization effects.
- The interaction with CERN's environment produced abundant results e.g. on the construction of a model independent analysis of the electroweak data (with Riccardo Barbieri), on the Higgs mesons (theoretical predictions on the mass, production cross section) and on many other problems.
- With the new millennium Guido starts a new subject. He is fascinated by the elegance of the tri-bimaximal neutrino mixing: many of his papers (mostly with Ferruccio Feruglio) are dedicated to the search of the origins of this baffling symmetry.



From Mario Greco's talk at Vulcano

When Guido and myself were both in Paris (Guido in the ENS and myself in the IHES of Bures), we wrote a the paper *Asymototic freedom in parton language*.

Guido liked to remark that this is the most quoted French paper in high energy physics.

The motivations of the paper were clearly stated in the introduction.

Speaking of scaling violations in QCD we wrote:

In spite of the relative simplicity of the final results, their derivation, although theoretically rigorous, is somewhat abstract and formal, being formulated in the language of renormalization group equations for the coefficient functions of the local operators which appear in the light cone expansion for the product of two currents.

In this paper we show that an alternative derivation of all results of current interest for the Q^2 behaviour of deep inelastic structure functions is possible. In this approach all stages of the calculation refer to parton concepts and offer a very illuminating physical interpretation of the scaling violations. In our opinion the present approach, although less general, is remarkably simpler than the usual one since all relevant results can be derived in a direct way from the basic vertices of QCD, with no loop calculations being involved (the only exception is the lowest order expression for the running coupling constant which we do not rederive).

This method can be described as an appropriate generalization of the equivalent photon approximation in quantum electrodynamics (Weizsaker-Williams .... Cabibbo, Rocca).

In order to explain the content of the paper I have to speak of the light cone expansion for the product of two currents. Let me first make a few remarks:

- Very few things were known on strongly interacting quantum field.
- People were very careful in making assumptions that were not proved and nearly nothing was proved.
- Wilson (Poliakov) operator product expansion was considered to be a solid result

$$A(x)B(0) \to_{x \to 0} \sum_C C(0)|x|^{-d_A - d_B + d_C}$$

The dimensions of the operators were the canonical one in free theory. They could be different from the canonical ones in an interacting theory.

- The total cross section for "virtual gamma"+ proton (i.e. deep inelastic scattering) can be written in terms of the function

$$G(x^2, x_0) = \langle p|J(x)J(0)|p\rangle \ .$$

Kinematical considerations imply that the region relevant for deep inelastic scattering is $x^2 \approx 0$, i.e. the light cone.

- Biorken scaling for deep inelastic scattering was transformed in the naive light cone expansion by Brandt and Preparata (1969)

$$J(x)J(0) \rightarrow_{x^2\rightarrow 0} \frac{O(x_0, 0)}{x^2}$$

$O(x_0, 0)$ is a bylocal operator.

- If we neglect the dependence of the running coupling constant on the momenta, one has something like

$$M_n(q^2) \equiv \int_0^1 dx x^{n-1} F(x,q^2)\ ; \quad M_n(q^2) = C_n \exp(\gamma_n(\alpha)\log(q^2)) \tag{1}$$

- If we specialize to QCD, we consider only valence quark and we take care of the running coupling constant, we get the final formulae

$$\frac{\partial M_n(q^2)}{\partial \log(q^2)} = \gamma_n(\alpha(q^2))\,.$$

If we use Mellin trasform we finally get at the first order in $\alpha(q^2)$

$$\frac{\partial F(x,q^2)}{\partial \log(q^2)} = \int_x^1 \frac{dy}{y} F(x,q^2) P_{q,q}(x/y)$$

$$P_{q,q}(z) = \frac{8}{3}\frac{\alpha(q^2)}{4\pi}\left(\frac{1+z^2}{(1-z)_+} + \frac{3}{2}\delta(z-1)\right)$$

When we wrote our work (spring '77), all that was known.

Parton model

The deep inelastic structure functions measure the number of charged partons (quarks) carrying a fraction of momentum x in the infinite momentum frame. These leads to Bjorken scaling.

Equivalent photon approximation in quantum electrodynamics (Weizsaker-Williams...).

In QED one often finds that the net effect of radiative corrections is proportional to $\alpha \log(E/m_e)$ or $(\alpha \log(E/m_e))^k$. Various techniques can be used.

Cabibbo and Rocca (Cern Preprint, May 1974) wrote formulae like:

$$P_{e\to e\gamma}(\eta) = \frac{\alpha}{\pi}\frac{1+(1-\eta)^2}{\eta}\log(E/m_e)\,;\; P_{\gamma\to e^+e^-}(\epsilon) = \frac{\alpha}{2\pi}(1+(1-2\epsilon)^2)\log(E/m_e)$$

where η is the fraction of longitudinal momentum carried by the photon. and ϵ is the fraction of longitudinal momentum carried by the e^+.

These probabilities can be combined. They computed the probability of finding inside a γ a triplet γ, e^+, e^-: it is proportional to $P_{\gamma\to e^+e^-}P_{e\to e\gamma}\log(E/m_e)^2$.

In spring '77 Guido and I discussed about QCD scaling violations. Guido suggested that it would be pedagogically useful to derive the equations for scaling violations using the same tecniques of Cabibbo-Rocca; no loops: only the evaluation of the vertices in the infinite momentum frame.

Only the gluon splitting into two gluons function was missing. The computations where much simpler that the original computations base on the one loop corrections to the vertices of the operators entering in the Wilson product expansion of two currents.

The computation were particular transparent and simple when we extended it to the case of polarized partons.

The paper was a well done cocktail of renormalization group results, parton model and infinite momentum frame perturbation theory. Easy to drink and to swallow.

The paper was very successfully.

The paper was very clearly written: it was written by Guido, not by myself ;-) It was really pedagogic.

Personally I think that the most important result of the paper was not the construction of a practical way to compute scaling violations in deep inelastic scattering. It could have be done (it was already done) using the Mellin transformation.

The important point was to shift the focus from Wilson operator expansion to resolution dependent effective number of partons.

It was more than a computation: it was a shift in the language we use.

The Drell-Yan process $pp \to l^+l^- + \cdots$ could be not studied by a Wilson operator expansion. This is also true for jet production in hadronic collisions.

However it was possible to study these process by factorizing the amplitude for the process in a part containing the effective parton distribution at the relevant energy and the hard scattering that could be treated in perturbation theory.

This opportunity was immediately taken by Guido. All the next papers are published in '78:

Leptoproduction and Drell-Yan processes beyond the leading approximation in chromodynamics, G Altarelli, RK Ellis, G Martinelli.

Transverse momentum in Drell-Yan processes, G Altarelli, G Parisi, R Petronzio.

Transverse momentum of jets in electroproduction from quantum chromodynamics, G Altarelli, G Martinelli.

Processes involving fragmentation functions beyond the leading order in QCD, G Altarelli, RK Ellis, G Martinelli, S Y Pi.

His scientific success was inseparable from his human qualities. Guido aimed to get a deep understanding of the world, hence his great passion for history, especially that of the many countries he was travelling through.

Perhaps his most characteristic traits were his great kindness and intellectual honesty, coupled with a rather ironic view of himself and life in general. His great inquisitiveness, the enjoyment he derived from learning new things and putting the pieces of a puzzle together, allowed him to make great summaries of topical subjects, which allowed us to take stock of the current state of a field of research, indicating new directions to take.

He liked clear, precise formulations, which could be understood by all. He was not a reclusive or selfish scientist, interested only in what personal prestige might be gained from his research. Guido was also a researcher who worked with others within the large community of high-energy particle physics community in general.

Many of Guido's works, from the most famous to the lesser known, were conceived in a spirit not only of research, but also in a spirit of service to the community. It is difficult to think which would be the status of the field without his *seminal* contributions.

We all miss him very much, not only as an invaluable scientist, but also as a dear friend, always ready to help.