# Personal and Scientific recollations of Aurelio Grillo

Giorgio Parisi

Aurelio was born in 1945: he was three years older than me.

- We did not see each other too much while he was dong the university. However we started to see each other very frequently after he left the university: we had a very good common friends, Massimo Testa.
- When I got a fellowship at the National Frascati Laboratories (January 1971), he had already a permanent position.
- Frascati had the largest $e^+e^-$ colliding beam (the project energy was 1.5+1.5 Gev, unfortunately not 1.6 Gev+1.6 Gev): it was constructed under the scientific leadership of Bruno Tousheck.
- A wonderful theory group: Paolo di Vecchia, Antonino Drago, Mario Greco, Sergio Ferrara and Etim Etim.

## Aurelio, the conformist

Aurelio started to work (with Calogero, di Vecchia and Drago) on the unitarization of the Veneziano model.

The situation changed when (1971) Raul Gatto came to Rome. He strongly pushed Aurelio and Sergio Ferrara to work on the conformal group.

A total of 15 papers (most of them written between 1971 and 1974). I joined the group later and I cosigned 5 of them.

The conformal group $O(4,2)$ is an extension of the direct product of Lorenz group and dilatations. If a quantum field theory is scaling invariant, i.e. the trace fo the energy-momentum tensor is zero, usually the theory is also conformal invariant.

**Why to study the conformal group?** Bjorken scaling was suggesting the the strong interaction theory were scaling invariant at high energies.

# Conformal Invariance in Quantum Field Theory.

A. F. GRILLO

*Laboratori Nazionali di Frascati del CNEN - Frascati*

(ricevuto il 7 Aprile 1973)

Since the discovery of scaling behaviour in deep inelastic electroproduction [1], quite a lot of theoretical investigations have been devoted to the study of the origin of this phenomenon.

Various models, such as the parton model, have been invented, that give a partially satisfactory (or unsatisfactory) explanation of experimental results, but the most important achievement which emerges is the emphasis that has been put on fundamental properties of field theory such as dilatation [2-6] and conformal [6-9] invariance.

It is an important idea, due to WILSON [3], that the renormalization procedure of any sensible field theory could eventually give an anomalous part to the dimension of fields: this comes from the infinite strength renormalization, and is a parameter which is determined by the interaction and in some sense characterizes the dynamics.

## The standard folklore, at least in some circles

At high energy the strong interaction were a strong coupled theory.

The theory was strongly coupled at large scale. Naturalness implied that the physical coupling constant $g$ is such that

$$\beta(g) = 0\,.$$

Asymptotic free theories (that were not known at that time) are **not natural**: there are two scales of masses: $\Lambda_{QCD}$ and the quark masses.

The strong interaction theory was not know. We were using symmetry arguments in order to get predictions in*terra incognita*.

## Some of Aurelio's results

(FGG) Positivity restriction on anomalous dimensions.

(FGG) Manifestly conformal covariant operator-product expansion.

(FGG) Conformal algebra in two space-time dimensions and the Thirring model

(FGGP) The shadow operator formalism for conformal algebra, vacuum expectation values and operator products.

(FGGP) Covariant expansion of the conformal four-point function.

(FGG)Tensor representations of conformal algebra and conformally covariant operator product expansion

The collaboration faded around in 1973-1974

- Logistic difficulties.
- Scientific reasons: Asymptotic freedom for strong interactions.

The scaling invariant strong interaction theory was free. Scaling corrections can be computed in perturbation theory.

The interest of conformal theories for strong interactions disappeared.

Second order phase transitions in $D = 2, 3$ provide non trivial strongly coupled scaling invariant theories. Critical exponents (measured!) are related to anomalous dimensions.

**The conformal bootstrap** idea of FGG.

The conformal invariant Wilson expansion gives:

$$\langle \phi(x)\phi(y)\phi(z)\phi(t)\rangle = \sum_{\mathcal{O}} \int dw \langle \phi(x)\phi(y)\mathcal{O}(w)\rangle \langle \tilde{\mathcal{O}}(w)\phi(z)\phi(t)\rangle$$

This is not symmetric (exchange $x$ with $z$).

Imposing this symmetry we should get the dimensions of the operators $\phi$ and $\mathcal{O}$'s.

The sum of $s$-wave poles is equal to the sum of $t$ wave poles.

No simple solutions with a few terms. We were stuck.

**We were on the right track!!!**

$D = 2$ Here the conformal group is much larger.

In 1984 KPZ computed the $2D$ equivalent of

$$\langle \phi(x)\phi(y)\phi(z)\phi(t)\rangle = \sum_{\mathcal{O}} \int dw \langle \phi(x)\phi(y)\mathcal{O}(w)\rangle \langle \tilde{\mathcal{O}}(w)\phi(z)\phi(t)\rangle$$

One could get perfect symmetry with only few terms.

Exact computation of the exponents in $D = 2$.

$D = 3$. With new ideas and summing more than 100 terms (brute force) the 3D critical exponents were obtained with increasing high controlled precision starting from 2010.

At that times wee met very frequently outside work, playing poker, drinking beer ...

Aurelio had a strange luck at poker.

I remember that once in 8 consecutive deals he had 7 very good deals

- 1 quads
- 1 flush
- 3 full houses
- 2 straights

An impressive sequence.

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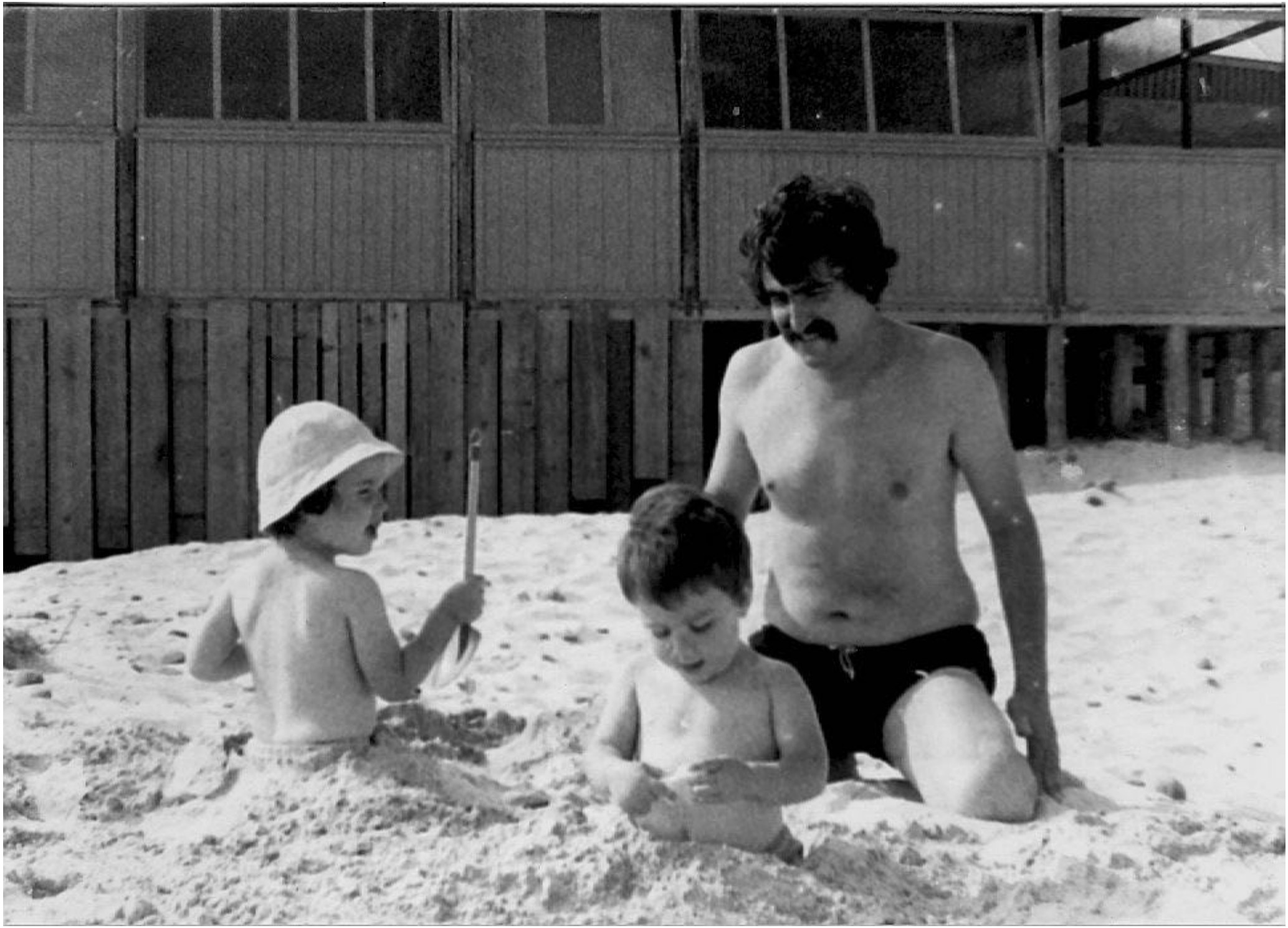
**He lost all the deals**

At that time Aurelio had not his beardwe are accustomed now.

Let me show some photographs of him **without his beard**.

A fake beard, not Aurelio's beard

Lysistrata (Aristophanes, 411 BC) Teatro Tor di Nona.
Physicists in the photo: Giorgio Parisi, Massimo Testa, Aurelio Grillo, Massimo Altarelli



In 1974 Aurelio started to look around and to study new topics.

- Radiative asymmetry in $e^+e^- \to e^+e^-$ near a narrow resonance with polarized beams near a narrow resonance (1975)
- Cosmological black hole production in grand unified theories (1981)
- Fermion-induced monopole-antimonopole annihilation (1983)
- Quantum stable vortices in the lattice U(1)-Higgs model (1989)
- Towards a precise determination of the order of the phase transition in compact pure gauge QED (1990)
- Microcanonical fermionic average method for Monte Carlo simulations of lattice gauge theories with dynamical fermions (1993)

Transforming himself into a refined experimentalist:**MACRO**.

Proposal for a large area detector dedicated to monopole search, astrophysics, and cosmic ray physics at the Gran Sasso Lab (G Giacomelli, A Baldini, G Rosa, F Grianti, A Grillo).

Performance of the MACRO streamer tube system in the search for magnetic monopoles (N Giglietto, M Goretti, M Grassi, A Grillo).

High-energy neutrino emission from binary X-ray sources.
Study of the ultrahigh-energy primary-cosmic-ray composition with the MACRO experiment.
Measurement of the atmospheric neutrino-induced upgoing muon flux using MACRO.

Vulcano

A new adventure: the Pierre Auger Observatory.

Properties and performance of the prototype instrument for the Pierre Auger Observatory.

The LIDAR system of the Pierre Auger Observatory, BM Connolly, A Filipcic, B Garcia, A Grillo.

Measurement of aerosols at the Pierre Auger Observatory B Fick, A Filipcic, B Garcia, A Grillo.

Measurement of the energy spectrum of cosmic rays above $10^{18}$ eV using the Pierre Auger Observatory.

Multi-resolution anisotropy studies of ultrahigh-energy cosmic rays detected at the Pierre Auger Observatory.

# Videos

## Cosmic Rays

**The long journey of cosmic rays**

This Video was realized by Aurelio Grillo, Pierre Auger Collaboration, and Vincenzo Napolano, INFN Communication Office.
Courtesy of Italian Institute for Nuclear Physics - INFN