Raoul and the Symmetry Way

Recent bibliography

L. Maiani and L. Bonolis, *The Charm of Theoretical Physics (1958-1993)*, Eur. Phys. J. H **42**} (2017), 6 11;
L. Maiani, *Raoul Raffaele Gatto: an unforgettable Maestro* , Il Nuovo Saggiatore 2018;
G. Battimelli, F. Buccella, P. Napolitano, *Raoul Gatto, a great Italian scientist and teacher in theoretical elementary particle physics* , Giornale di Fisica, 2018.

- Born in Catania in 1930, studied physics at Scuola Normale Superiore di Pisa, graduated with Marcello Conversi and Bruno Ferretti in 1951.
- Assistant to Ferretti in Roma
- In 1956, left for the United States, to become a staff member of the Lawrence Radiation Laboratory in Berkley.
- The group of Luis Alvarez was discovering new hadrons with the hydrogen bubble chamber.
- Gatto absorbed quickly the exciting atmosphere of the laboratory, and wrote several papers on the symmetries of the weak interactions and the phenomenology of weak decays of hyperons, based on the data collected by the Alvarez group.

1960. Back in Roma

- In 1960, Gatto came back to Roma, called by Amaldi to teach at Scuola di Perfezionamento
- he brought to Italy the new ideas that were flourishing at the time in the US, concerning the application of symmetry and group theory to particle physics,
- a new line of research for the Italian theoretical physics, more based on traditional lines of QED, Fermi Weak Interactions, Dispersion Relations and peripheral model for Strong Interactions;
- Theoretical Physics in Italy: Puppi, Ferretti, Radicati; new chairs: Cini, Dallaporta, Caldirola, later Morpurgo
- Gatto's research program is described in a CV written in 2011 (an *a posteriori* but appropriate description of what happened):
- ***…a research based on innovative theoretical ideas while in touch with the research programs of the big, international laboratories, with the participation of recently graduated investigators, several of which have later obtained scientifically prestigious positions***
- [*…una linea di ricerca basata su idee teoriche innovative pur restando connessa ai programmi dei grandi laboratori internazionali, facendovi partecipare giovani laureati, molti dei quali per il loro valore sono arrivati a posizioni scientificamente prestigiose*]

1. Particle Physics in the Fifties:
Cosmic Rays yield to Particle Accelerators

Milla Baldo Ceolin's recollections (Adv. in Nucl.& Part. Phys.)

1953. Cosmic Rays Conference in France

The news, just arrived, of recent experiments at the Cosmotron did not create surprise or preoccupation… C. F. Powell (who had discovered the true Yukawa meson, the pion) commented, "Gentlemen, we have been invaded . . . the accelerators are here,"

Figure 5 The Padova-Venice Conference in 1957. A rest in the area of the San Giorgio isle in Venice. From left to right: B. Touschek, T.D. Lee, W. Pauli, and R. Marshak.

1957. Venice Conference, Jack Steinberger presented evidence for parity non conservation in Λ^0 purely hadronic weak decays. …T.D. Lee gave a talk on weak interactions...the two-component ...neutrino theory and ... lepton conservation; Bruno Touschek, ...proposed that a suitable gauge transformation of the neutrino field, imposed to keep $m_\nu = 0$, leads to two-component neutrinos; he elaborated on the equivalence of two-component and Majorana neutrinos. One of the most successful theoretical models...was the one presented by Robert Marshak and George Sudarshan, leading to the universal *V-A* theory—another triumph for the Fermi theory.

Marshak & Sudarshan, contrary to the then-current experimental evidence, stated that all weak interactions are of type *V-A* with $G_V \simeq G_A$, ..lepton conservation is incorporated, neutrinos are two-component spinors and all particles participate in the weak interactions in the same two-component manner. …suggestion came that weak interactions arise from the exchange of a charged vector, *W*.

Fermi-Yang (1949) and Sakata Models (1956)

- Fermi-Yang (1949): (p, n)=N are elementary, $\pi = \bar{N}N$
- Sakata: one new constituent to account for strange particles:

$$\mathrm{S} = \begin{bmatrix} p \\ n \\ \Lambda \end{bmatrix}$$

$$\mathrm{mesons} = \mathrm{S}\bar{\mathrm{S}}; \quad \mathrm{baryons} = \mathrm{SS}\bar{\mathrm{S}}$$

- one clear predictions: there must exist baryons with strangeness S=+1.
- ***Unfortunately it is a wrong prediction! no such resonance appears in K^+p scattering (S= +1) while many appear in K^-p scattering (S= -1).***
- Basic symmetry of Sakata model: SU(3), unitary transformations of the Sakata triplet:

$$\begin{bmatrix} p \\ n \\ \Lambda \end{bmatrix} \rightarrow U \begin{bmatrix} p \\ n \\ \Lambda \end{bmatrix}$$

- U=Unitary complex matrix, 3x3, det U=1.

Nuclear Democracy

$$\pi^+ = p\bar{n} \;\rightarrow\; ?? \;\rightarrow\; n = \bar{p}\pi^+$$

which is which?

- in the presence of very strong interactions (unitarity saturated) there is no clear distinction between composites and constituents:
- for this reason, in the sixties, ***nuclear democracy*** (G. Chew and S. Frautschi) was considered the most promising approach;

XVI. ARE ALL STRONGLY INTERACTING PARTICLES COMPOSITE?

In high-energy physics, on the other hand, the range of energies easily allows excitation and breakup of any particle. This circumstance motivated Chew and Frautschi[72] to conjecture that they should all be treated on the same basis. there is hope that their coupling constants and mass ratios can be determined from unitarity and maximal analyticity requirements. The way towards fulfilling this hope is believed to lie in the further development of the self-consistent or "bootstrap" method of calculation which was described in Chapter 7.

2. The Magic Sixties

- It became clear in the 50's that the weak point of Fermi&Yang and Sakata models is that proton, neutron and Λ do not have any special role in the panorama of hadrons. M. Gell-Mann and independently, Y. Ne'eman, choose the road of ***Symmetry***
- Let us imagine that there exists a group G of transformations of the fundamental degrees of freedom of the strong interactions (whatever they are) which leave the Hamiltonian invariant.
- Given a transformation $g \in G$, for example G=SU(2), the effect of g on p and n states, would be of the form:

$$\begin{bmatrix} p \\ n \end{bmatrix} \rightarrow U(g) \begin{bmatrix} p \\ n \end{bmatrix}$$

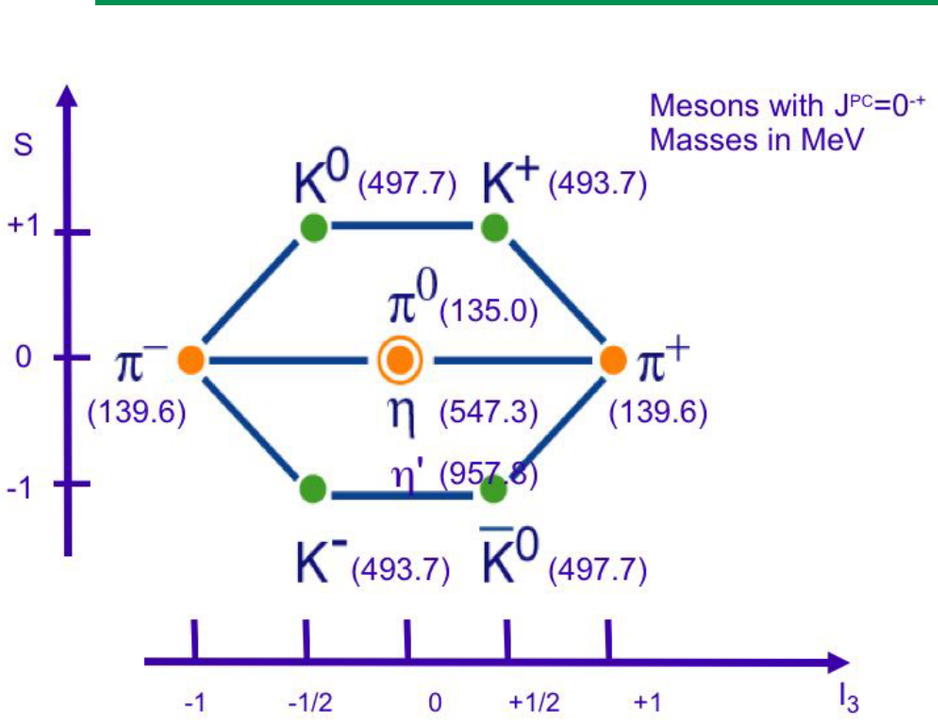
with U a function of g.

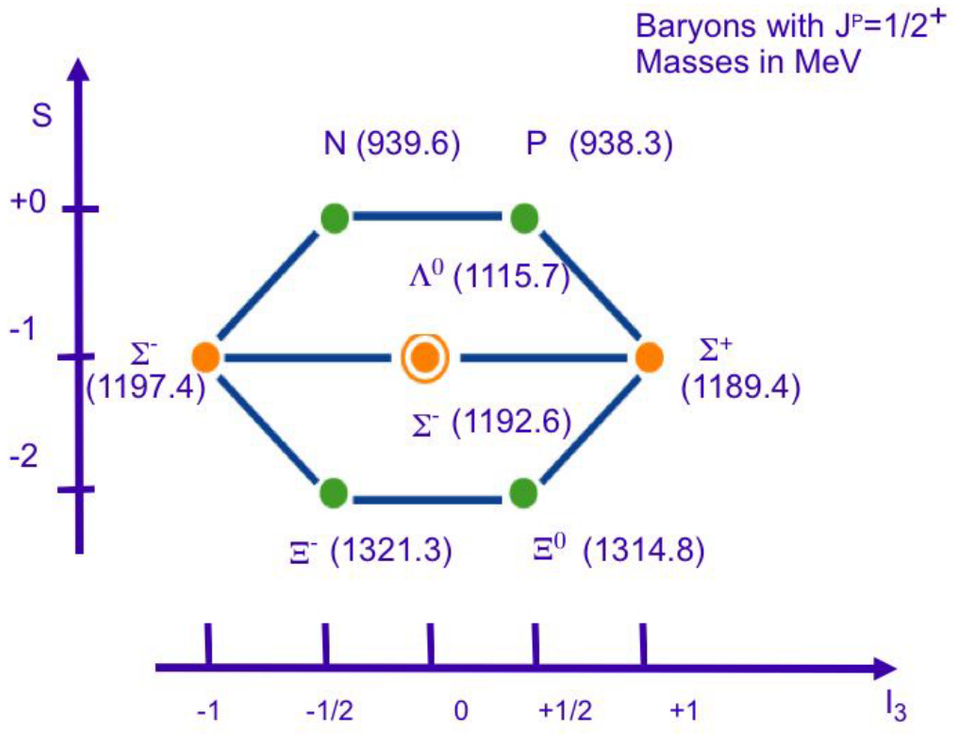
- If we carry out two successive transformations, first g_1 and then g_2, the effect will be to obtain the product transformation of the two: $g=g_2\, g_1$. Correspondingly, we expect:

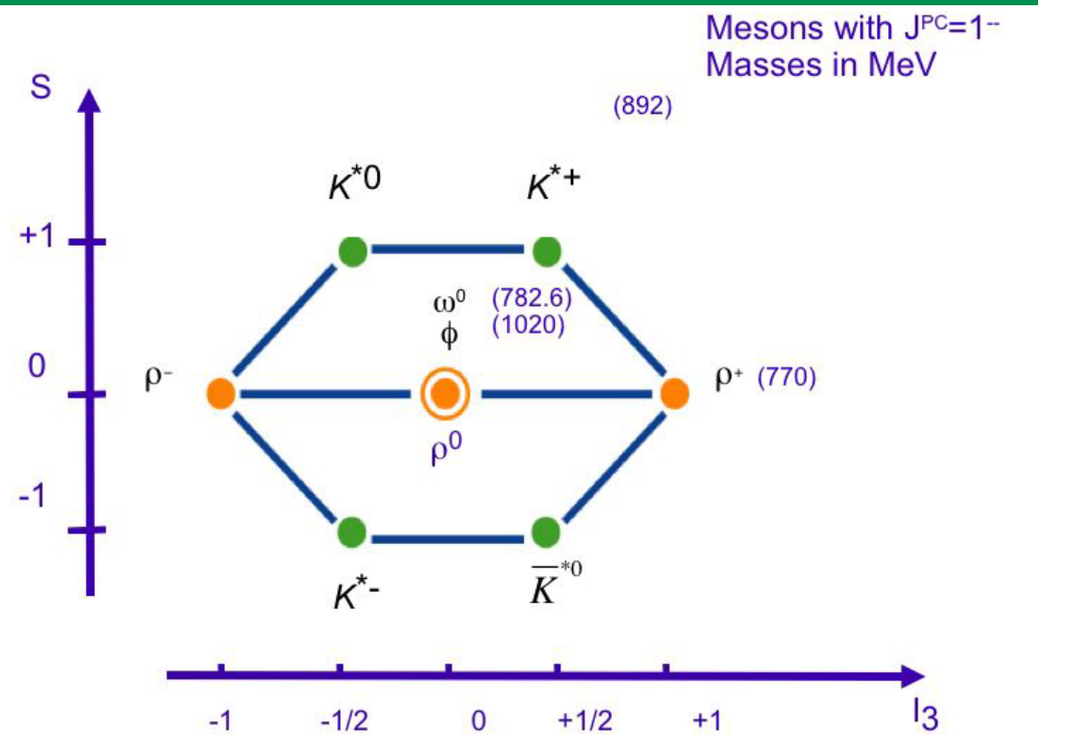
$$U(g_2) \cdot U(g_1) = U(g_2 \cdot g_1)$$

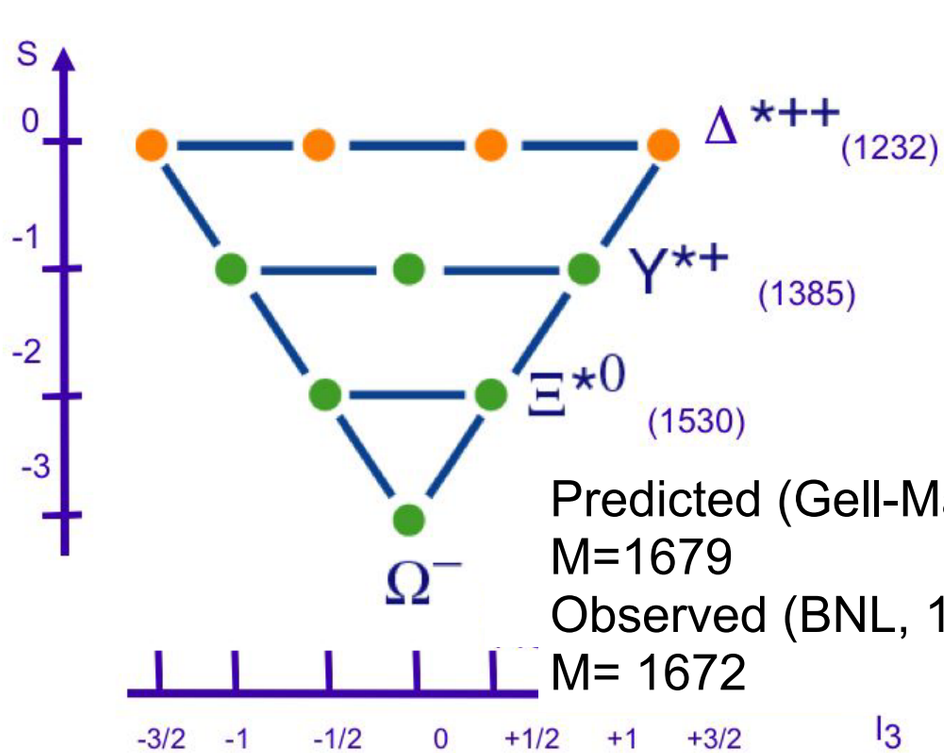
- The matrices U(g) provide a ***representation*** of the group G, in the mathematical sense of the term: the law of multiplication of the group is ***represented*** by the product of the matrices U (this is well known in quantum mechanics for space rotations or for the Lorentz group).

The particle revolution: the *Eightfhold Way* for the lowest mass Baryons and Mesons (hadrons)





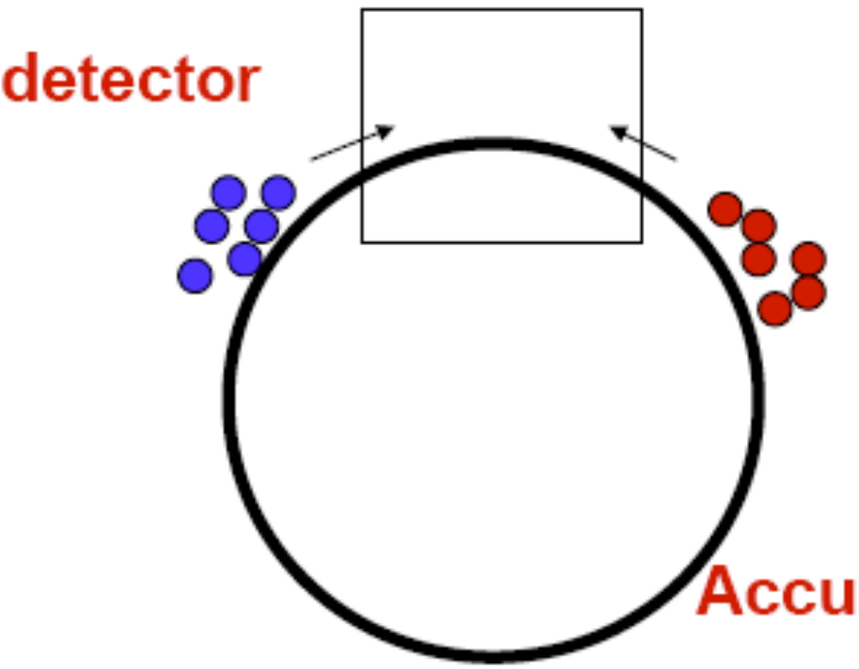


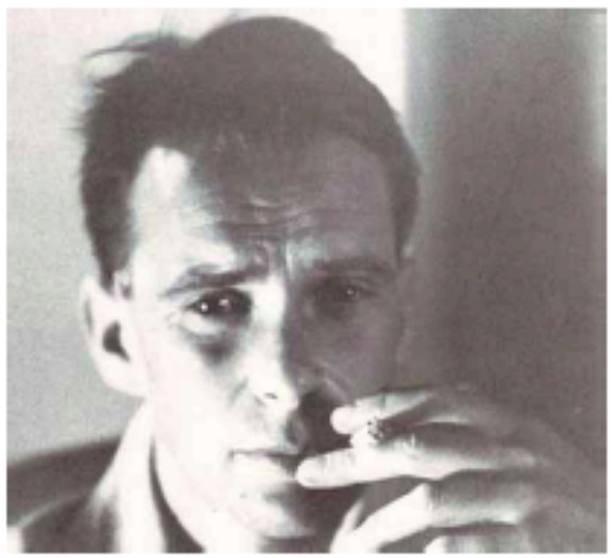


Predicted (Gell-Mann, 1962)
M=1679
Observed (BNL, 1964)
M= 1672

AdA's birth

Bruno Touscheck at Frascati:

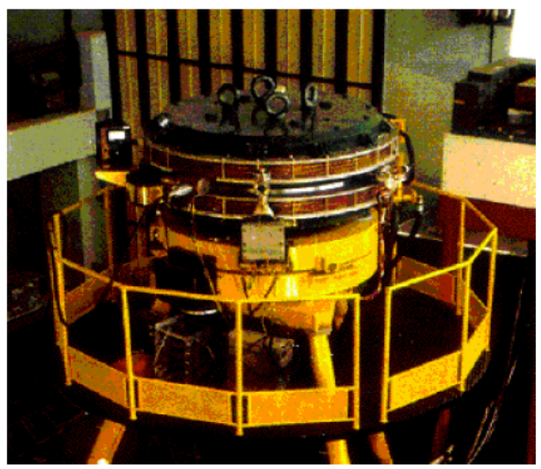




Bruno Touschek

After escaping from a concentration camp during the Second World War, the Austrian-born Touschek began work in Göttingen and Glasgow, and eventually reached Rome in 1952. On 7 March 1960 he gave a historic seminar at Frascati that would change the face of physics. Pointing out the importance of carrying out a systematic study of electron-positron collisions, he suggested that this could be achieved by constructing a single magnetic ring in which electrons and positrons circulate at the same energy but in opposite directions. Soon afterwards, the first electron-positron accumulation ring, AdA, was built under his leadership in Frascati.

AdA at Frascati: history



3. Gatto in Frascati (1960-1963)

PHYSICAL REVIEW VOLUME 124, NUMBER 5 DECEMBER 1, 1961

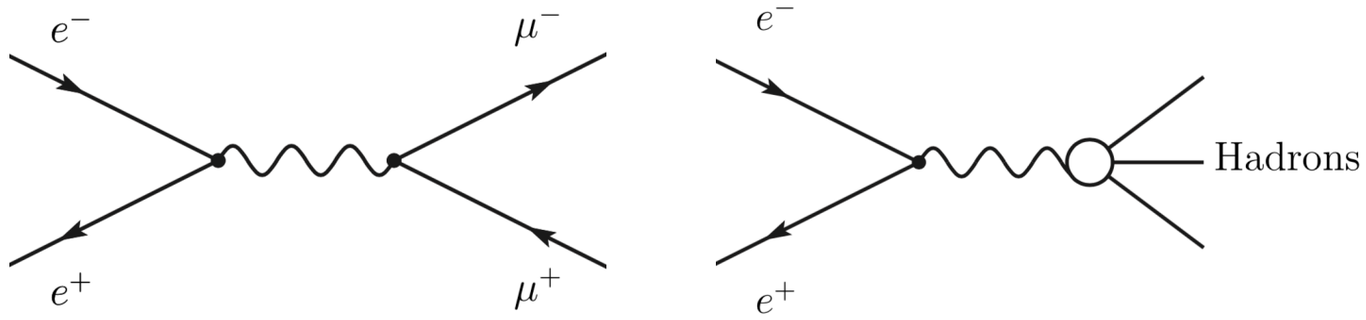
Electron-Positron Colliding Beam Experiments

N. CABIBBO AND R. GATTO
Istituti di Fisica delle Università di Roma e di Cagliari, Italy and
Laboratori Nazionali di Frascati del C.N.E.N., Frascati, Roma, Italy
(Received June 8, 1961)

- in 1960, Gatto becomes director of theory group at Frascati laboratories.
- He found there Nicola Cabibbo, freshly graduated with Touschek and recruited in Frascati by Salvini.
- Gatto and Cabibbo wrote a long article that summarised the theoretical perspectives of high energy electron-positron collisions: *The Bible.*
- In these years QED meant finding the UV cutoff (the motivation of e-e colliders investigated by Richter in the US)
- the Bible of Frascati showed very clearly the potential for elementary particle physics of future experiments with AdA and Adone: discover all kind of particles coupled to the photon.
- for a few years the only theoretical papers on the physics of e^+e^- annihilations were those coming out of Rome and Frascati, *the exhilarating experience of expanding into a vacuum* (N. Cabibbo,1997).

Electron-Positron annihilation into μ+μ- and hadrons, $q^2>0$

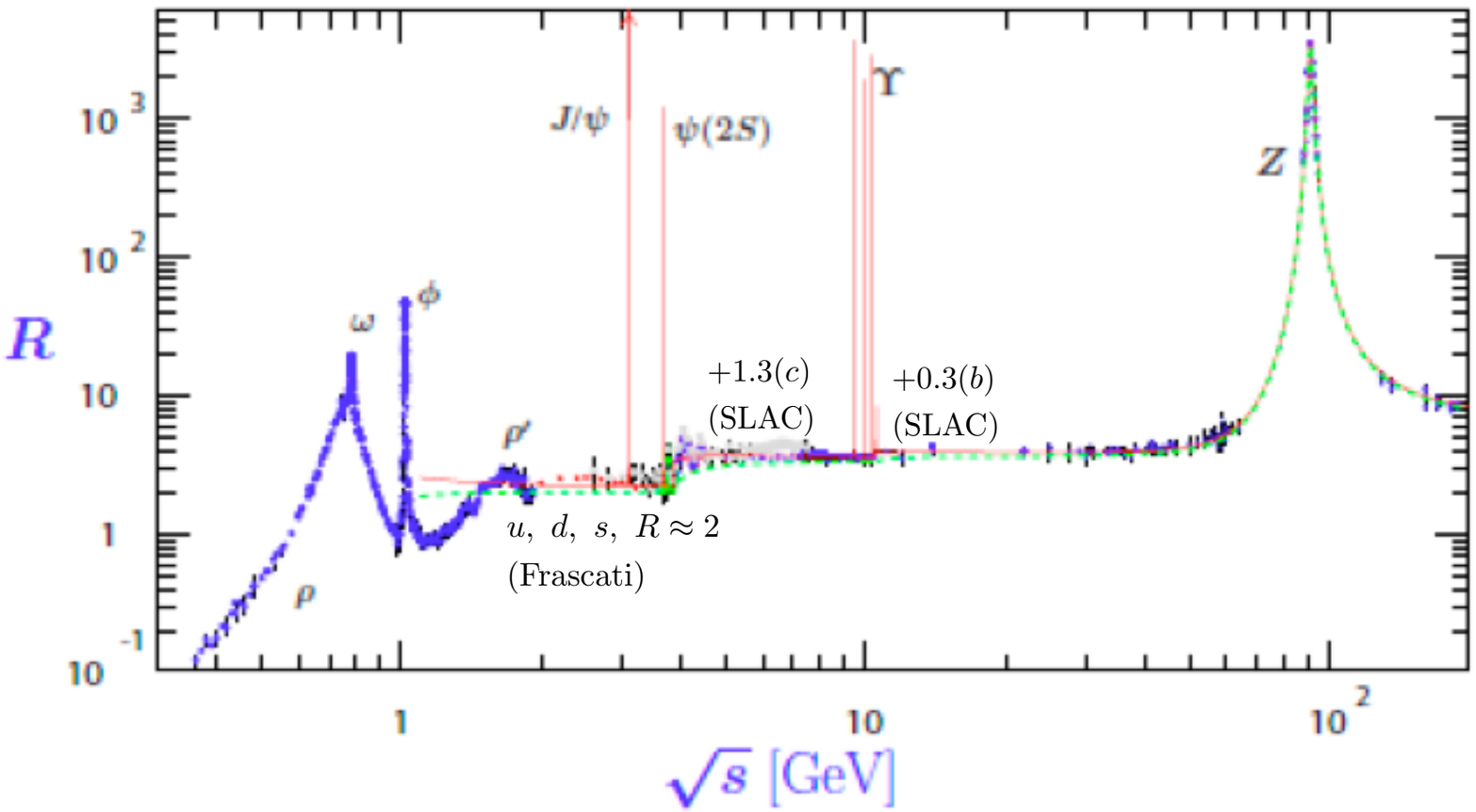
$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



Point-like, spin 1/2 fermions (i=flavour, each in N_c colours):

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} = \sum_i N_c \cdot Q_i^2$$

- Annihilation $e^+ e^- \to$hadrons vs. $e^+ e^- \to \mu^+ \mu^-$
- Above resonances, hadron process described by the simple diagram
  - At ADONE, Frascati, expt: R~ 2; three colors predict: R = 3 (4/9+1/9+1/9)=2
  - above the charm threshold R increases by about 1.3 units, that is: 4/9x3=4/3 !!



- Confirmations of three colors at Frascati
- Discovery of new quark flavors at high energy
- Neutrino counting from Z decay

Impressive scientific production

- Two neutrinos: Cabibbo and Gatto made the hypothesis that there is a muon neutrino different from the electron neutrinos: two massless neutrinos to explain the suppression of $\mu \rightarrow e\,\gamma$ decay

IL NUOVO CIMENTO Vol. XXI, N. 5 1° Settembre 1961

Consequences of Unitary Symmetry for Weak and Electromagnetic Transitions.

N. CABIBBO and R. GATTO (*)

Istituti di Fisica delle Universita di Roma e di Cagliari
Laboratori Nazionali del CNEN - Frascati

(ricevuto il 14 Agosto 1961)

- Properties of the weak currents under SU(3) symmetry, the Eightfold Way of Gell-Mann and Ne'eman,
  - matrix elements, selection rules of semileptonic decays
- different normalisation required by data of the strangeness changing versus the strangeness conserving current
- crucial steps that later led to Cabibbo's theory.

IL NUOVO CIMENTO Vol. XVI, N. 1 1° Aprile 1960

generalised mass terms

A Theorem on the Elimination of Contact Muon-Electron Interactions.

N. Cabibbo, R. Gatto and C. Zemach (*)

Istituto di Fisica dell'Università e Scuola di Perfezionamento in Fisica Nucleare - Roma
Istituto Nazionale di Fisica Nucleare - Sezione di Roma

(ricevuto il 4 Febbraio 1960)

Summary. — A general theorem on the elimination of possible contact muon-electron interactions is given which includes as particular cases a theorem by Cabibbo and Gatto and a theorem by Feinberg, Kabir and Weinberg for particular types of interactions.

1. — Introduction.

Gell-Mann and Feynman have remarked (1) that if one considers the expansion of a hypothetical muon-electron interaction in powers of momentum transfer, the decay rate inferred from the leading term of such an expansion by invoking gauge invariance is identically zero. Later, this result was shown (2) by two of us (N.C. and R.G.) to be contained in a general equivalence theorem. The theorem states that weak interactions of the form

$$\bar{\mu}(x)\gamma(\partial - ieA)(1+\gamma_5)e(x) + \text{h. c.}\,, \tag{1}$$

(*) On leave of absence from Department of Physics, University of California, Berkeley, Cal. (U.S.A.).

(1) M. Gell-Mann and R. P. Feynman: *Annual International Conference on High Energy Physics at CERN*, edited by B. Ferretti (Geneva, 1958), p. 261.

(2) N. Cabibbo and R. Gatto: *Phys. Rev.*, **116**, 1134 (1959); see also R. Gatto: *Lectures at the International School of Physics in Varenna*, June 1959 (to appear in *Suppl. Nuovo Cimento*).

- Less known, but equally remarkable, a paper on the diagonalization of the fermion lagrangian, in presence of parity violating fermion bilinears
- The concepts developed here, and in a similar paper by Feinberg, Kabir and Weinberg, were to be used later to show that
  - divergent higher order weak interactions do not produce parity or strangeness violation (Bouchiat, Iliopoulos and Meyer, 1967; Cabibbo, Maiani, 1968)
  - that the interaction of the Higgs field with fermions can be diagonalised to produce quark masses and the Cabibbo-Kobayashi-Maskawa mixing matrix.

- Gatto and Cabibbo, worked with young physicists of the area (Da Prato, De Franceschi) and visitors from abroad (Berman, Zemach).
- While in Frascati, Guido Altarelli and Franco Buccella, two most bright students of the young generation, joined Gatto to compute the cross section of electrodynamic processes suitable to measure Adone's luminosity (Giovanni Gallavotti, of the same generation, was working on a similar process, under the guidance of Touschek).
- Gatto's program of attracting young investigators to particle physics was taking momentum.

4. Gatto in Florence (1963-1966)

- Gatto had become full professor at Universitá di Cagliari in 1960, a position he kept commuting from Frascati.
- The Frascati period came to an end in 1963, when he was called as full professor in Firenze, to replace Giacomo Morpurgo who had moved to Genova. In Firenze, Gatto was joined by his former students, Altarelli and Buccella, and by Gallavotti. I joined as well, moving from experimental to theoretical particle physics with a fellowship from Istituto Superiore di Sanitá.
- In the Physics Institute of Arcetri there were Enrico Celeghini, recruited by Gatto in Cagliari, and older people who had been working with Morpurgo: Marco Ademollo, Claudio Chiuderi, Giorgio Longhi, Enrico Giusti, Emilio Borchi, Mario Poli.
- Gabriele Veneziano was writing his dissertation under the supervision of Gatto. Giuliano Preparata was also making a dissertation with Gatto, in Roma, and joined Firenze by the end of 1964.

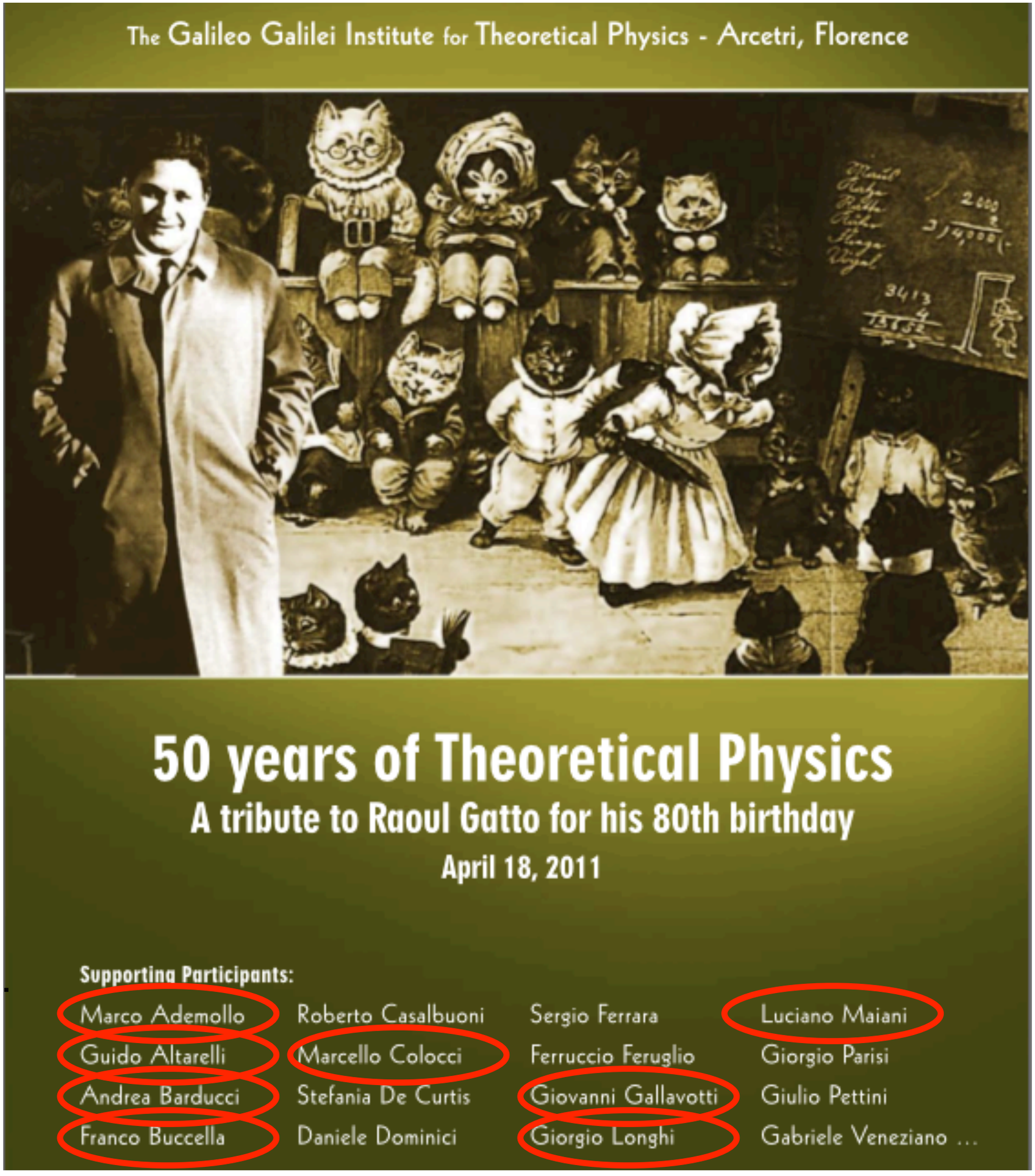
- Gatto had a very interesting and attractive personality. He was masterly leading the large group made by the ambitious, young *gattini* (we romans, the little cats) and the somewhat older people he had found in Florence.
- Gatto's secret was to put you in front of advanced but accessible problems
  - radiative corrections, SU(3), SU(6), U(12), quark statistics, CP violation, weak interactions … you name it.
  - In everyday life, Gatto was ***the boss***. He would come to your office and say: *Oh, there is this calculation… it could be done, if you like…*
  - later, he would discuss your results, send you back if not convinced, or write a draft paper. I still remember the afternoon when he assigned me my first calculation, an application of Gell-Mann's SU(3) symmetry to neutrino reactions, my first theoretical paper.
- Gatto's school participated in the struggle of theoretical physics of those years, towards a theory of the strong interactions. The main theme of our research was to go beyond the pure concept of symmetry, SU(3), SU(6) or higher, and delve deeper into the role of quarks.
- We learned that we could compete with other groups, in US and Israel. Sid Meshkov defined us the *Italian mafia*, opposed to the *Israeli mafia* of Haim Harari and colleagues, who were working on similar subjects. With Gatto our Maestro, we had been recognised as useful interlocutors

Gatto at Florence

The “Florence School” under the guidance of Raoul Gatto attacked with enthusiasm the exploration of the newly discovered symmetries of the hadrons, in particular the SU(6) symmetry and its “relativistic extensions” ....

in Florence at the time...

and Giuliano Preparata



Results from Arcetri

- QED calculations concerning electron-positron annihilation have been widely used by the experimental collaborations, in Frascati and elsewhere.
- The *most known* result, obtained by the old hands, is the *Gatto-Ademollo theorem*:
  - deviations from exact SU(3) in baryon and meson weak decays are only second order in the symmetry breaking parameter.
  - crucial role in the analysis of the experimental results and is today widely accepted to justify the excellent agreement of the Cabibbo theory with baryon and meson weak decays.
- An original and important paper by Gatto with Emilio Borchi contained the proposal, by the time really unortodox, of the existence of mesons made by a quark and an antiquark with one unit of relative orbital momentum. The idea became soon crucial for the classification of positive-parity meson resonances, A_1, A_2, B,…. that began to be discovered in these years.
- By 1966, the Florence experience came to an end.
- Some coming back to Roma (Giuliano and me), some going to the States (Altarelli and then Giuliano). Chiuderi moved to astrophysics. Veneziano, shortly after graduation went to Israel, to meet later the glory with the Veneziano dual model.
- In 1967, Gatto, now famous for his papers and for having grown so many pupils, went one year in Geneva and, in 1968, moved to Padova, where he joined Giovanni Costa, Mario Tonin, Gianfranco Sartori and other younger theorists.