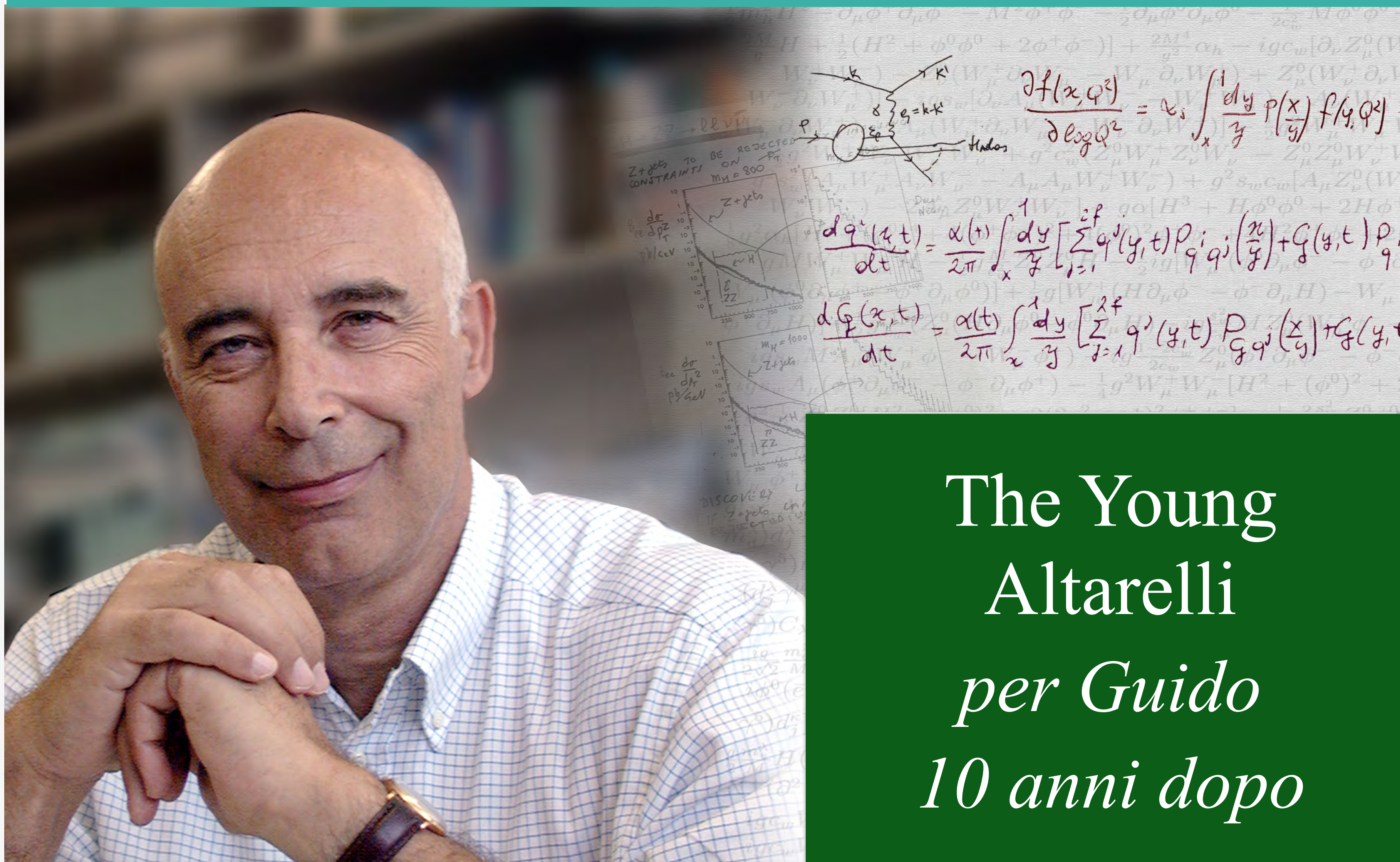
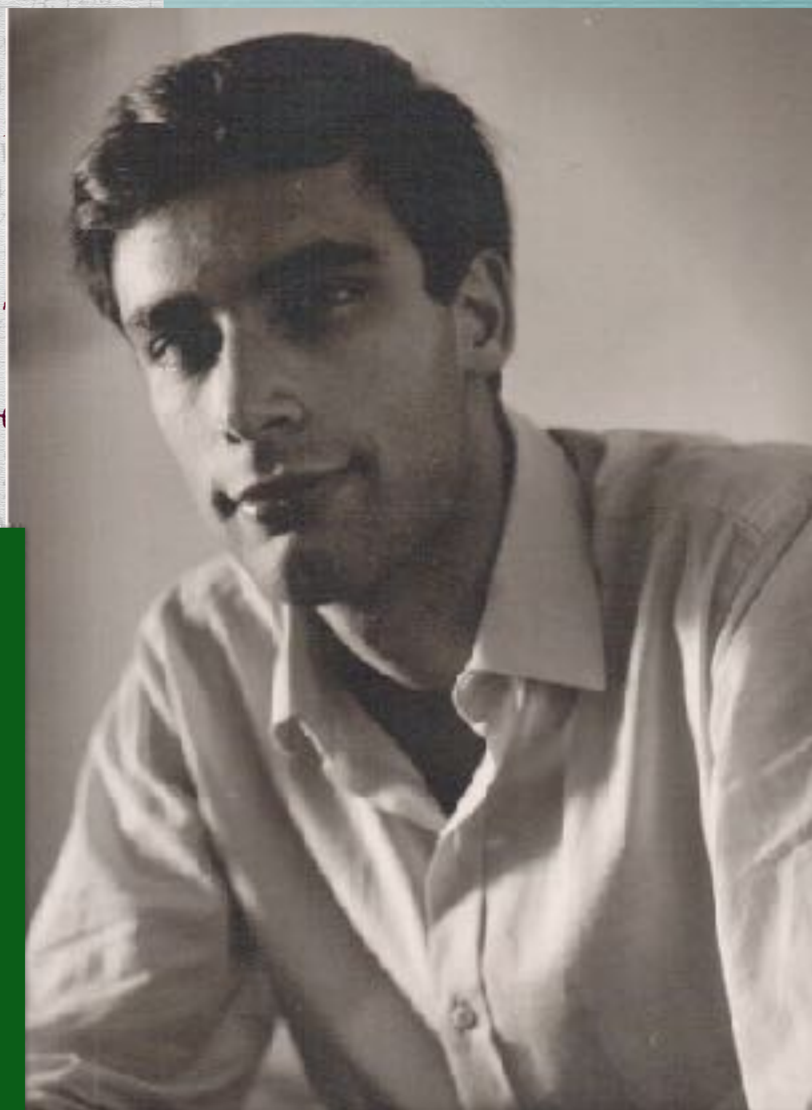


The Young Altarelli

per Guido

10 anni dopo



Luciano Maiani

Università di Roma La Sapienza

Roma3, 2/12/2025

GUIDO ALTARELLI-RENOWNED PAPERS

1. **"Octet Enhancement of Nonleptonic Weak Interactions in Asymptotically Free Gauge Theories"**
   G. Altarelli and L. Maiani.
   Phys. Lett. B **52**, 351 (1974).
   948 citations counted in INSPIRE as of 01 Jun 2016

   ← 1016

2. **"Asymptotic Freedom in Parton Language"**
   G. Altarelli and G. Parisi.
   Nucl. Phys. B **126**, 298 (1977).
   5734 citations counted in INSPIRE as of 01 Jun 2016

   ← 8736

3. **"Large Perturbative Corrections to the Drell-Yan Process in QCD"**
   G. Altarelli, R. K. Ellis and G. Martinelli.
   Nucl. Phys. B **157**, 461 (1979).
   846 citations counted in INSPIRE as of 01 Jun 2016

4. **"Partons in Quantum Chromodynamics"**
   G. Altarelli.
   Phys. Rept. **81**, 1 (1982).
   735 citations counted in INSPIRE as of 01 Jun 2016

5. **"Leptonic Decay of Heavy Flavors: A Theoretical Update"**
   G. Altarelli, N. Cabibbo, G. Corbo, L. Maiani and G. Martinelli.
   Nucl. Phys. B **208**, 365 (1982).
   871 citations counted in INSPIRE as of 01 Jun 2016

   ← 926

6. **"Vector Boson Production at Colliders: A Theoretical Reappraisal"**
   G. Altarelli, R. K. Ellis, M. Greco and G. Martinelli.
   Nucl. Phys. B **246**, 12 (1984).
   549 citations counted in INSPIRE as of 01 Jun 2016

7. **"The Anomalous Gluon Contribution to Polarized Leptoproduction"**
   G. Altarelli and G. G. Ross.
   Phys. Lett. B **212**, 391 (1988).
   729 citations counted in INSPIRE as of 01 Jun 2016

8. **"Vacuum polarization effects of new physics on electroweak processes"**
   G. Altarelli and R. Barbieri.
   Phys. Lett. B **253**, 161 (1991).
   706 citations counted in INSPIRE as of 01 Jun 2016

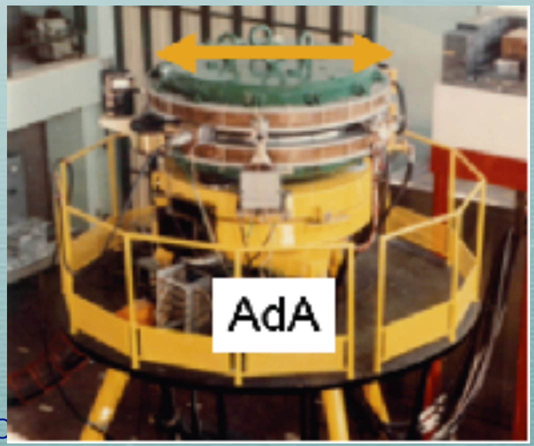
1. Guido and the '59 ners

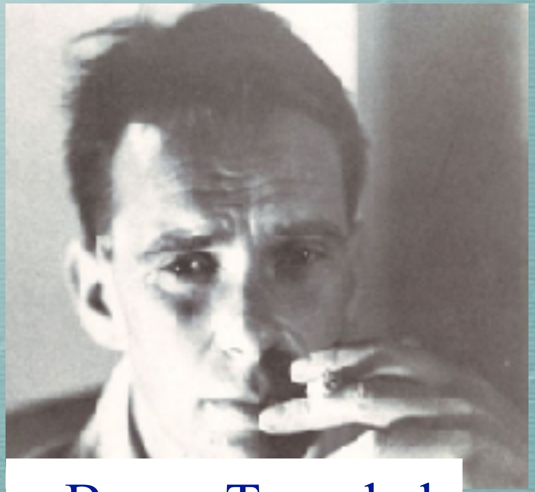
- Italy 1955 to 1965:
  - strong economic growth (the Italian miracle)
  - confidence in science and technology
  - 1957: Mario Tchou, at Olivetti, develops the first Personal Computer, based on a new technology: the transistors (discovered in 1947)
  - 1959: ElectroSynchrotron completed in Frascati by INFN (Giorgio Salvini leader)
  - 1960: Bruno Touschek propose to build the first $e^+ e^-$ collider, AdA;
  - AdA is promptly financed by the Atomic Energy Council (CNEN)
  - Raoul Gatto comes back to Frascati from Berkeley and brings the new ideas about Symmetries of Elementary Particles
  - Nicola Cabibbo is hired by Salvini as first theorist in Frascati
  - 1961: Cabibbo and Gatto write *The Bible* of e+e- physics

Mario Tchou

Giorgio Salvini

Year 1959 sees the enrollment in Universita' di Roma Sapienza of a class of talented students, Guido among the first, attracted to physics by the new exciting developments.





Bruno Touschek

The ’59 ners (cont’d)

• Besides Guido, who graduated with the best votes, the class was really remarkable (in parenthesis their final destination):

-Franco Buccella, Giovanni Gallavotti, Sergio Doplicher, myself (Th. Phys.)
-Claudio Procesi (Math.),
-Massimo Cerdonio (Grav. Waves), Piergiorgio Picozza (Pamela satellite)

• Promising young people kept their promises
• Guido went to Frascati with Buccella, to make a thesis in QED under Gatto and they graduated in september 1963;
• (I made an experimental thesis on solid state detectors, graduated in february 1964, then moved to Theory)
• Nicola Cabibbo meanwhile had gone to CERN (making few experiments (!!) and writing the paper with the Cabibbo angle (!!!)) and then to Berkeley
• in 1963 Gatto moved to the University of Florence, followed by Guido, Buccella, Gallavotti and myself
• one year later, Giuliano Preparata joined,
• Gabriele Veneziano graduated with Gatto but left almost immediately to Weizmann.

2. *Gattini* at work in Florence

• Gatto was masterly leading the large group of ambitious, young *gattini* as well as the somewhat older people he had found in Firenze (Marco Ademollo, Claudio Chiuderi, Giorgio Longhi)

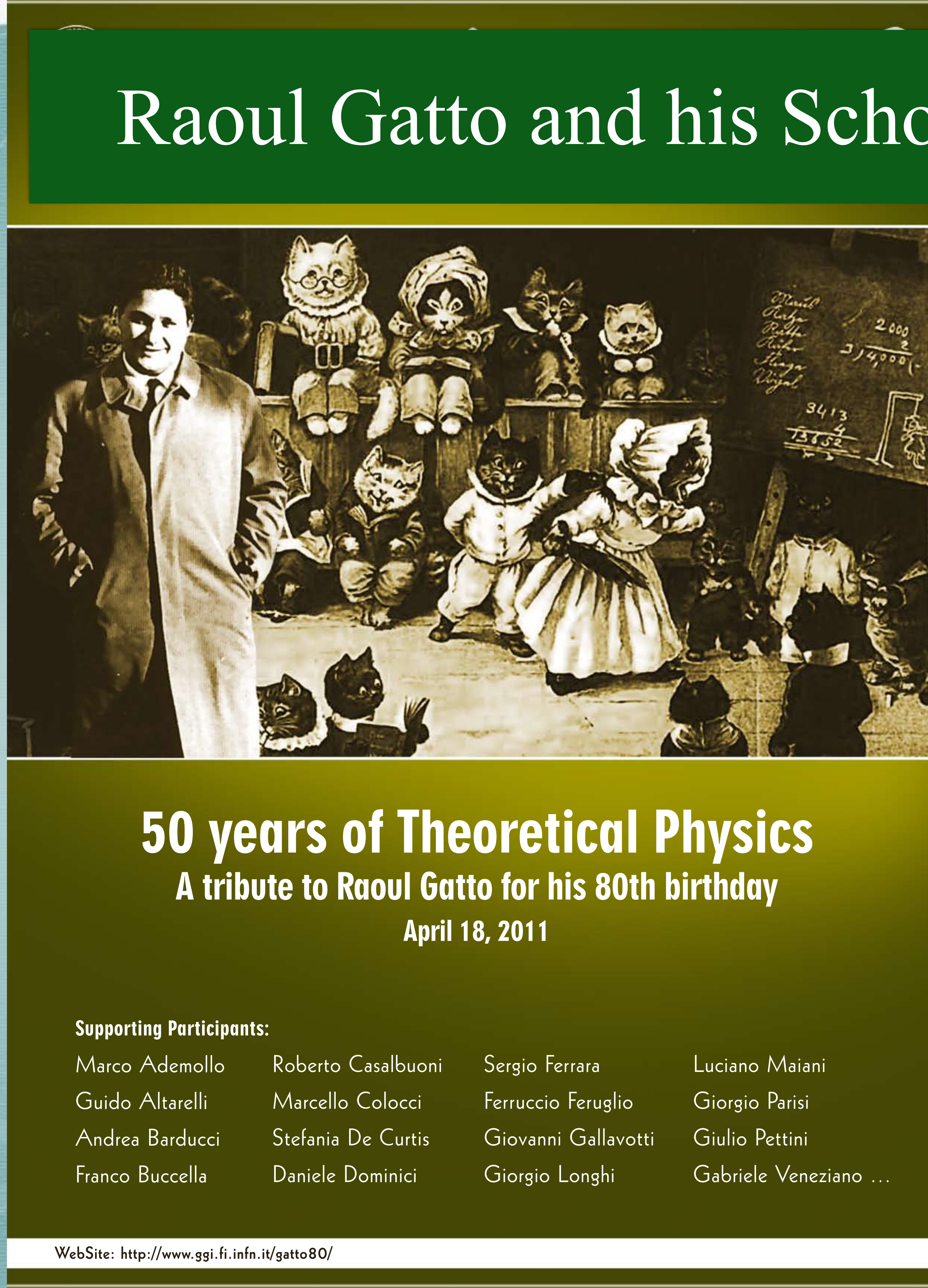
•he was putting everybody in front of advanced but accessible problems (radiative corrections, SU(3), SU(6), U(12), quark statistics, CP violation, weak interactions…you name it) he would discuss your results, send you back if not convinced, or write a draft paper

•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 Harari & co, who were working on the same subjects

• Guido emerged for his authority, clarity and sense of humour, and also for his capacity to work with the Firenze people: he worked with Longhi, became good friend of Ademollo and, in particular, of Chiuderi.

Raoul Gatto and his School of *gattini*



Leaving Florence

•however exciting, we *gattini* were mostly taking the measure to physics and to life….

• the best work out of Firenze came from the old hands: Gatto Ademollo's theorem of non renormalisation (of Cabibbo's vector amplitudes by 1st order SU(3) breaking)

•the Firenze school dissolved in 1967-1968:
Gatto went to Geneva and then to Padova
Guido went to New York University (with Rita and new born Claudia) and then to Rockefeller Institute
Giuliano and I went back to Roma to work with Cabibbo,
later Giuliano went to Princeton, then to SLAC, CERN…

Guido Altarelli taking a video at Hyde Park, London. Helping him Massimo Altarelli, on the left Giorgio Capon.
Early ’60 ?

Claudia with Guido, 1968

•Winter 1970 with Pucci.
We visited the Altarelli in NY from Cambridge, Mass.

3. Going Electroweak

• In NY Guido worked on deep inelastic reactions (the beginning of a long story…) with Hector Rubinstein and then with Preparata and Brandt.
•Guido was back in Roma in 1970, as Assistant professor.
•In 1971, Veltman and ’t-Hooft proved that the Weinberg Salam theory is renormalizable
•everybody became electroweak
•Discussions with Nicola how to compute EW corrections to the muon g-2
•a new territory, at least for us, a lot of calculations and a lot of fun
•also many difficulties with inconsistent calculations: we called it ***the rebellion of the matrices*** !!
•…but we got it

G . Altarelli, N. Cabibbo and L. Maiani, Phys. Lett. B 40 (1972) 415.

• at about the same time as other distinguished people:

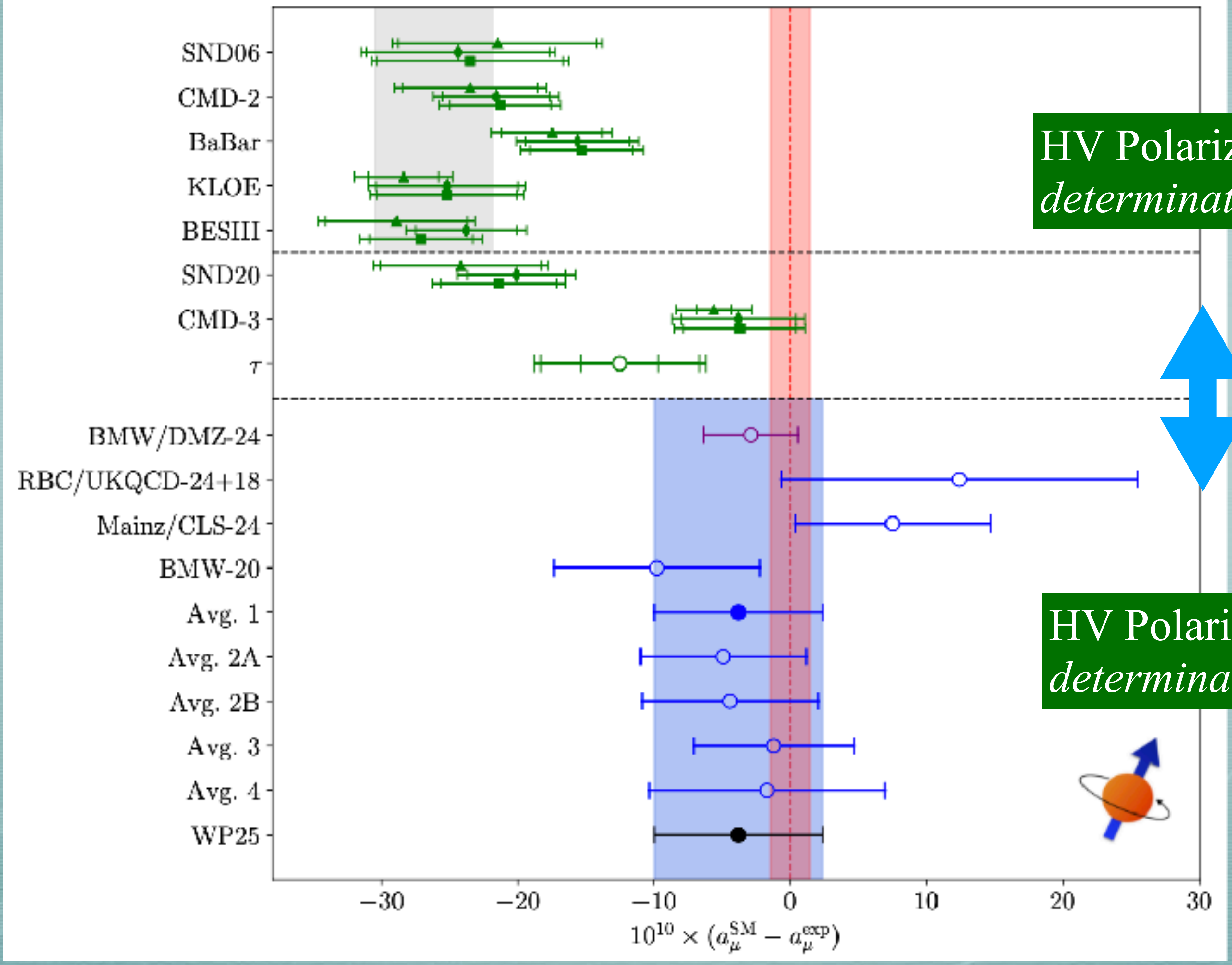
$$a_\mu^{\mathrm{EW}}[\text{1-loop}] = \frac{G_\mu m_\mu^2}{8\sqrt{2}\pi^2}\left[\frac{5}{3} + \frac{1}{3}\left(1 - 4\sin^2\theta_{\mathrm{W}}\right)^2 + \mathcal{O}\left(\frac{m_\mu^2}{M_W^2}\right) + \mathcal{O}\left(\frac{m_\mu^2}{m_H^2}\right)\right], = 194.8 \times 10^{-11},$$

R. Jackiw, Steven Weinberg, Phys.Rev. D5 (1972) 2396
I. Bars, M. Yoshimura, Phys.Rev. D6 (1972) 374
K. Fujikawa, B.W. Lee, A.I. Sanda, Phys.Rev. D6 (1972) 2923

Breaking News!!

Last Update:

T. Aliberti *et al.*, arXiv:2505.21476v3 [hep-ph] 11 Sept. 2025



HV Polariz.: *data-driven determinations*

HV Polariz.: *lattice-QCD determinations*

4. QCD Renormalization of 4-fermion operators, 1974

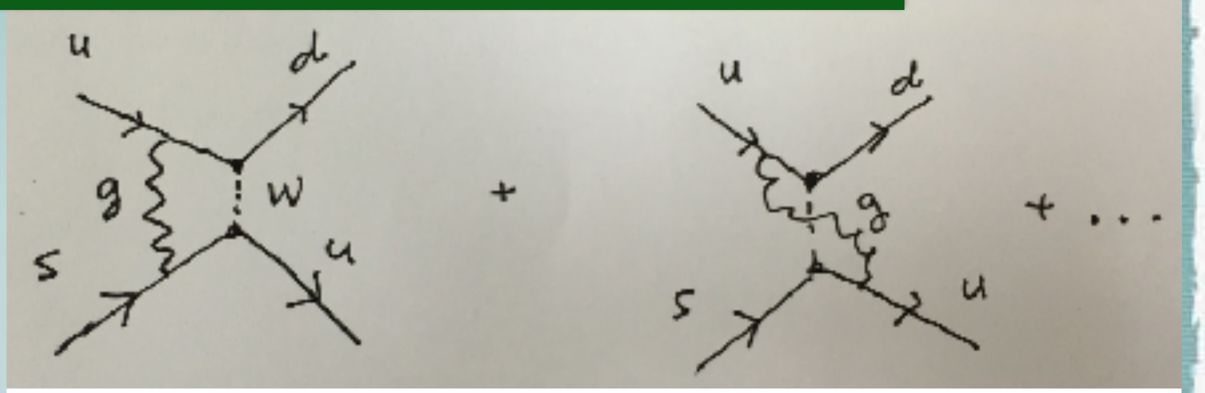
- The octet (or $\Delta I=1/2$) enhancement is a prominent feature of the non leptonic decays
  - the product of the Cabibbo currents for u→d (I=1) and s→u (I=1/2) should lead to a balanced mixture of 1/2 and 3/2, while the lifetimes of K_S ($\Delta I=1/2$) is much shorter than the lifetime of K^+ ($\Delta I=3/2$)

- Ken Wilson (1969) had noted that the strong interactions, which respect Isospin conservation, could renormalise differently the two components,
- However, without a theory of the strong interactions he could not test the idea
- But what about QCD?
- Gluons could be exchanged up to momenta of the order of M_W, and perturbation theory would give predictable renormalization effects of order $[\alpha_S \gamma \log(M_W/\mu)]^n$, which would add up to factors of $(M_W/\mu)^d$, with some anomalous dimension d;
- with the scale of K decays $\mu \ll M_W$, the enhancement could be sizeable for d>0

QCD Renormalization Group, 1974

- How can flavor-blind QCD tell isospin 1/2 from isospin 3/2?
- answer came from an old Feynman observation: if quarks were bosons, the Fermi interaction of non leptonic would be pure ΔI=1/2

- proof:
  - -Fierz rearrangement exchanges u ⇆d
  - - the Fierz of Dirac matrices gives -1
  - -field exchange gives +1(boson) or -1(fermion)
  - - with bosons we get -1, i.e the pair ud is in I=0, the operator has I=1/2



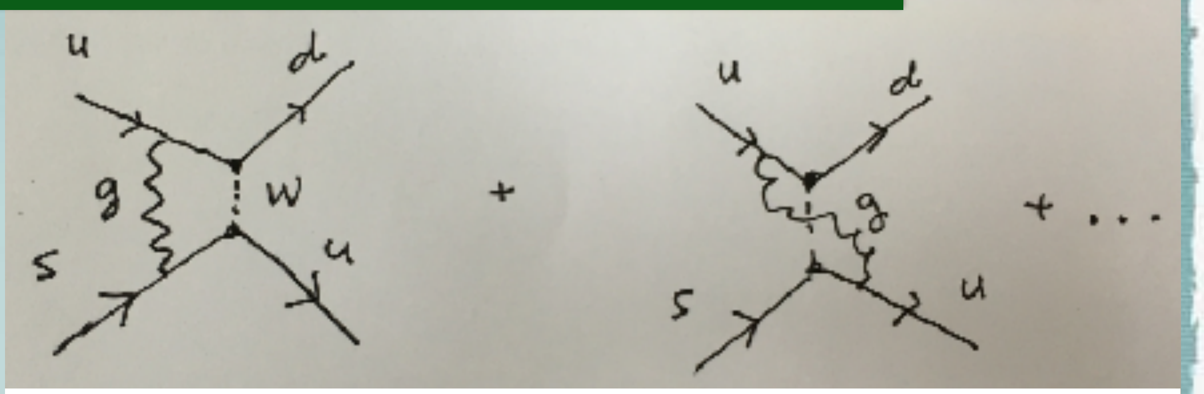
four fermion operator $(\Delta S = -1) =$

$$\bar{s}\gamma_\mu(1-\gamma_5)u \times \bar{u}\gamma^\mu(1-\gamma_5)d$$

with color : $=$

$$\bar{s}^\alpha\gamma_\mu(1-\gamma_5)u_\alpha \times \bar{u}^\beta\gamma^\mu(1-\gamma_5)d_\beta$$

QCD Renormalization Group, 1974



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  - - with bosons we get -1, i.e the pair ud is in I=0, the operator has I=1/2
- with coloured quarks we have to exchange also: α⇆β
  - - QCD renormalizes differently color symmetric and color antisymmetric
  - - color antisymmetric gets an additional -1 ⇒ ud pair has I=0
  - - we found that the anomalous dimensions in QCD ***enhance the color antisymmetric and suppress the symmetric combination*** !!!!

- $\Delta I = 1/2$ Rule in non-leptonic decays:

$$R = \sqrt{\frac{\Gamma(K_S^0 \to \pi^+\pi^-)}{\Gamma(K^+ \to \pi^+\pi^0)}} \sim 20$$

- 1974. The enhancement of the $\Delta I = 1/2$ is supported in QCD by the Renormalization Group equations. To one loop accuracy, we found

$$\frac{\mathcal{O}^-}{\mathcal{O}^+} \sim 5$$

G. Altarelli and L. Maiani,
M. K. Gaillard and B. W. Lee,

Breaking News from Lattice QCD

- 2020. Recent, non perturbative Lattice QCD calculation finds:

$$\frac{Re(A_0)}{Re(A_2)} = 22.45(6)$$

R.~Abbott *et al.* [RBC and UKQCD], PR D 102 (2020) 054509

- QCD do explain the $\Delta I = 1/2$ Rule !!

3. Università di Roma in the Seventies

In Roma, Pucci and I used to see Guido and Nicola even out of work, with wives and small kids.

- Sometime we would go to Fregene, in the nice seaside house of the Altarelli’s, and to Grottaferrata, in the country house of the Cabibbo’s.
- We saw also other Roma professors, Salvini, Conversi, Careri and families.
- New younger people joined in: Massimo Testa, Giorgio Parisi (Nicola’s graduate students), Keith Ellis (a young italian-scottish speaking student, attracted to Roma by Preparata and recruited in our group by Guido), Roberto Petronzio, and later, Guido Martinelli (also recruited by Guido)

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•From time to time the Physics Department was occupied by the students, but we could find always a quiet office in Istituto Superiore di Sanita, across the road, where I worked.

•Roma and Italy were striken by social turmoil and terrorism, but our was a quiet, intellectually stimulating, academic life that I remember with pleasure and that did not come back.

•I moved in the University as full professor in 1976 and Guido took the chair shortly after, in 1980.

4. Rome-Paris and, later, Utrecht

- With John Iliopoulos in Paris, very close relations were established between Roma and the group of Phil Meyer in Orsay;
- When Meyer's group moved from Orsay to Ecole Normale Superieure, in 1974, Guido Altarelli and I were living in rue d'Ulm (Keith Ellis was also around).
- The discovery of the J/Psi raised a lot of questions and we (Roma + Paris) offered to go to Utrecht to discuss with Tini and Gerard, a meeting which became the annual *Triangular Meeting Paris-Roma-Utrecht*, rotating among the three towns;
- Guido took a crucial sabbatical in ENS in 1976-1977
- later, Giorgio Parisi came in and so Nicola Cabibbo, during my sabbatical in ENS, 1977-1978.
- It was remarked, at that time, that Roma people saw CERN only from the airplane, flying to Paris...
- ... and we all lived under the surveillance of Claude Bouchiat and the quiet but firm protection of Phil Meyer.

J Iliopoulos, PLENARY REPORT ON PROGRESS IN GAUGE THEORIES, London 1974
… *As it is often the case, whenever someone talks about freedom, it invariably turns out that he really means something else. The same is true here.*

DGLAP

- Quarks are not completely free in deep inelastic reactions
- deviations from exact Bjorken-Feynman scaling must be expected
- asymptotic freedom in QCD makes them calculable
- Parisi was after scaling violations very early, but all seemed very complicated and unintuitive
- Then came Altarelli-Parisi, in1977, with a similar contribution from Dokshitzer in the same year, anticipated by Gribov and Lipatov in 1972: DGLAP

G. Altarelli and G. Parisi, *Asymptotic Freedom in Parton Language,* Nucl.Phys. B126 (1977) 298
Yu.L. Dokshitzer, *Calculation of the Structure Functions for Deep Inelastic Scattering and e+ e- Annihilation by Perturbation Theory in Quantum Chromodynamics*, Sov.Phys. JETP 46 (1977) 641
V.N. Gribov, L.N. Lipatov, *Deep inelastic e p scattering in perturbation theory*, Sov.J.Nucl.Phys. 15 (1972) 438

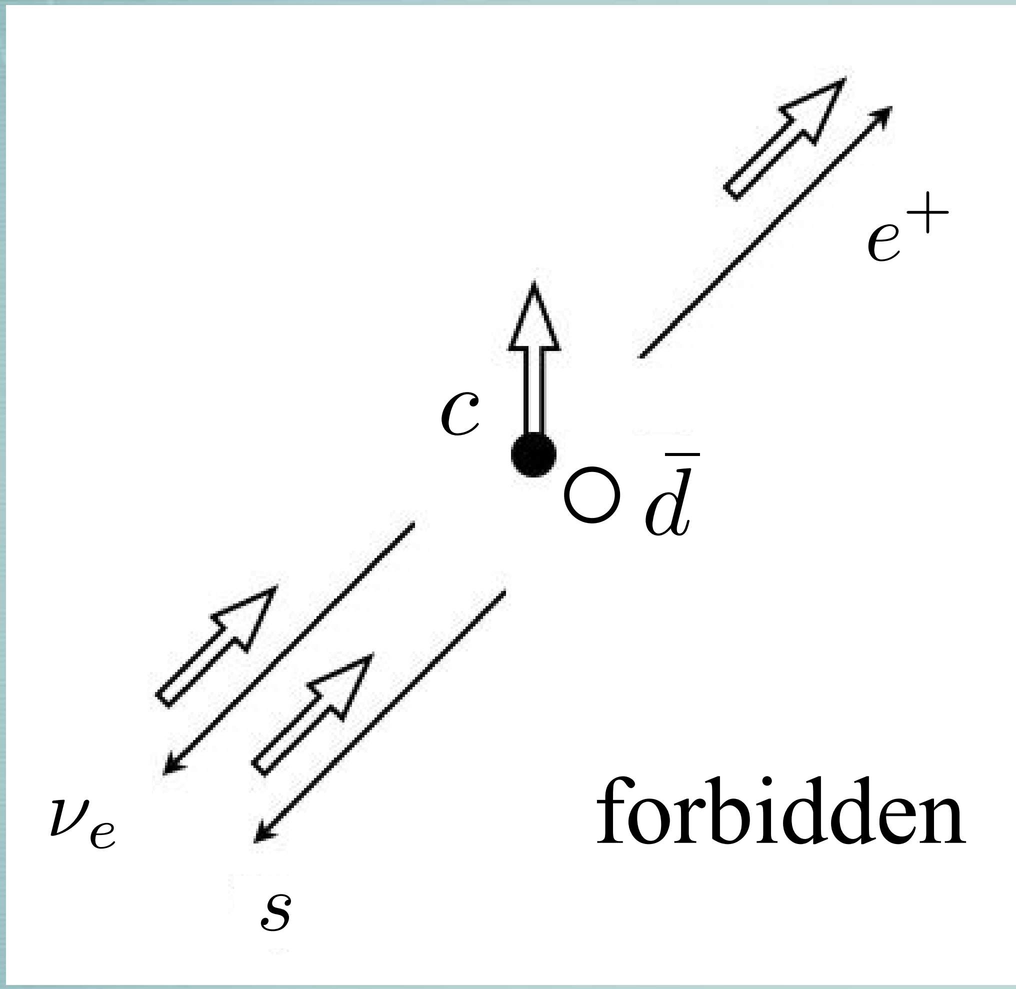
- the AP paper had an enormous impact, it made easier to understand the physics and simpler to compare experimental data with theory

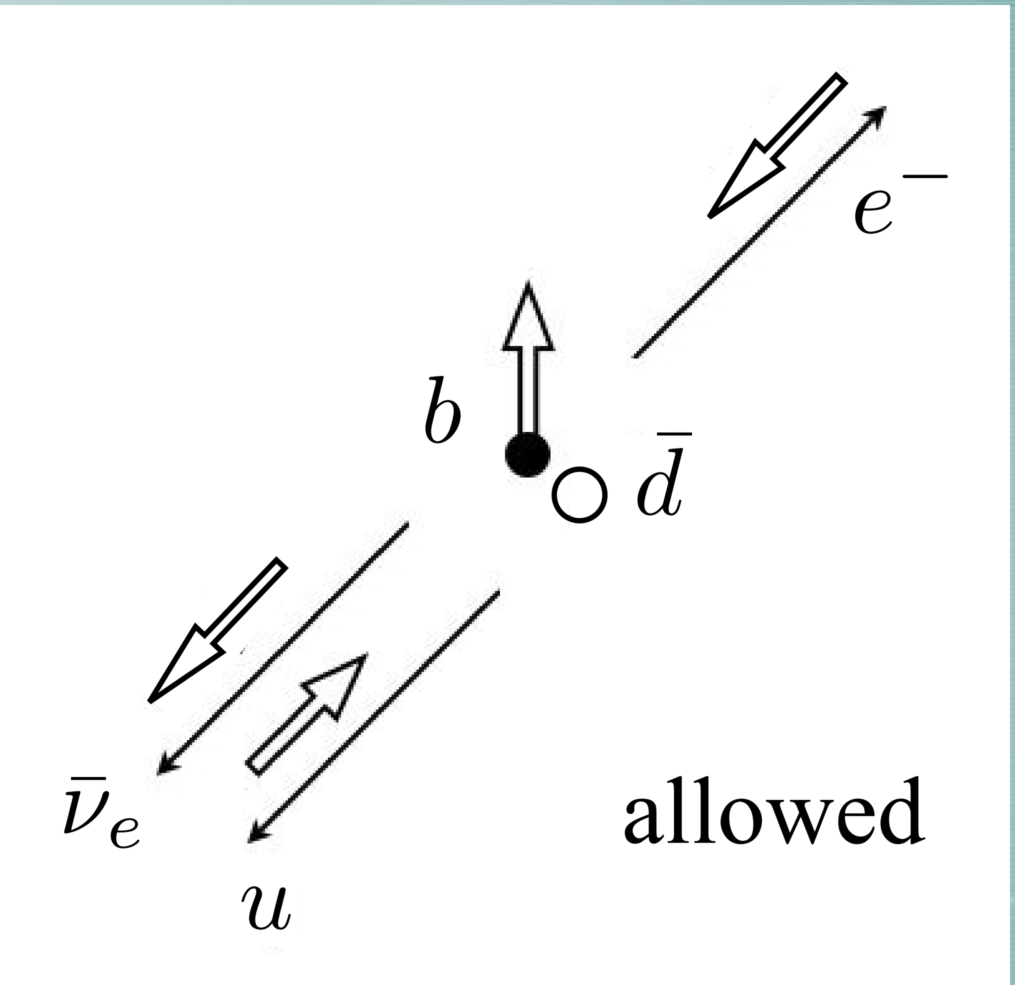
5. Charm semileptonic decay

- The charm quark mass is quite larger than Λ_{QCD}, the invariant mass of the hadronic final system is also $>>\Lambda_{QCD}$, and we can use parton model + perturbative QCD to compute the energy spectrum of the emerging charged lepton and the semileptonic width.
- While in Paris, Cabibbo and myself worked out the semileptonic rate of the charm quark and later (with G. Corbo') the electron energy spectrum
- After discovery of the b quark, with even a larger mass, we thought our formulae for the energy lepton spectrum near the end point could be used to determine the Cabibbo-Kobayashi-Maskawa matrix element V_{ub}, not determined by the total rate.
- However Paolo Franzini (then still in Cornell with CLEO) observed that the lepton end point in b decay corresponds to small hadron masses and therefore non perturbative corrections come in.

Semileptonic decays of c vs. b quarks

Charged lepton energy end point configurations in c and b decay





charm decay is dominated by inelastic, large mass, hadron configurations: perturbative QCD corrections are adequate.

beauty decay is dominated by small mass, hadron configurations: resummation of perturbative QCD corrections is required.

The QCD experts get in

G. Altarelli, N. Cabibbo, G. Corbo, L. Maiani and G. Martinelli, *Leptonic Decay of Heavy Flavors: A Theoretical Update*, Nucl. Phys. B 208 (1982) 365.

- The two Guidos, Altarelli and Martinelli, came in, with the crucial resummation of the perturbative terms and the result provided a valuable tool in the estimate of V_{ub} from inclusive rates

- An alternative method to obtain V_{ub} from **ex**clusive rates is provided by the lattice computation of the the form factor of B meson → light flavoured vector meson.

Inclusive average: $|V_{ub}| = (4.41 \pm 0.15 \; {}^{+0.15} \; {-0.19}) \times 10^{-3}$
R. Kowalewski and T. Mannel in PdG 2014
Fit to the experimental partial rates and lattice results:
$|V_{ub}| = (3.23 \pm 0.31) \times 10^{-3}$ J.M. Flynn, Y. Nakagawa, J. Nieves, H. Toki, Phys. Lett. **B 675** (2009) 326

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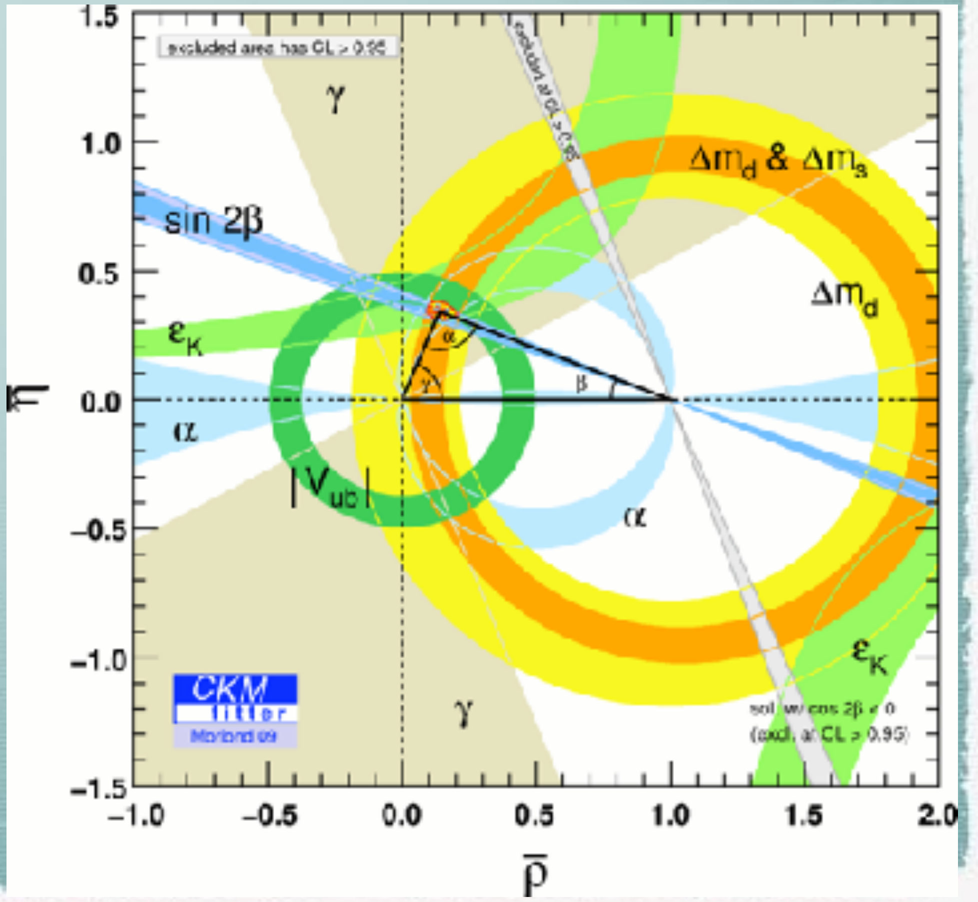


6. International dimension and CERN

•The scientific reputation of the young Altarelli grew fast, in the 70s and 80s,

•reasons: originality and depth of thinking, breath of interests, which I could only partially represent today, clarity of presentations

•capacity to interact with different people of different ages, theorists, experimentalists,

•teach and mentor younger investigators (many examples in the audience)

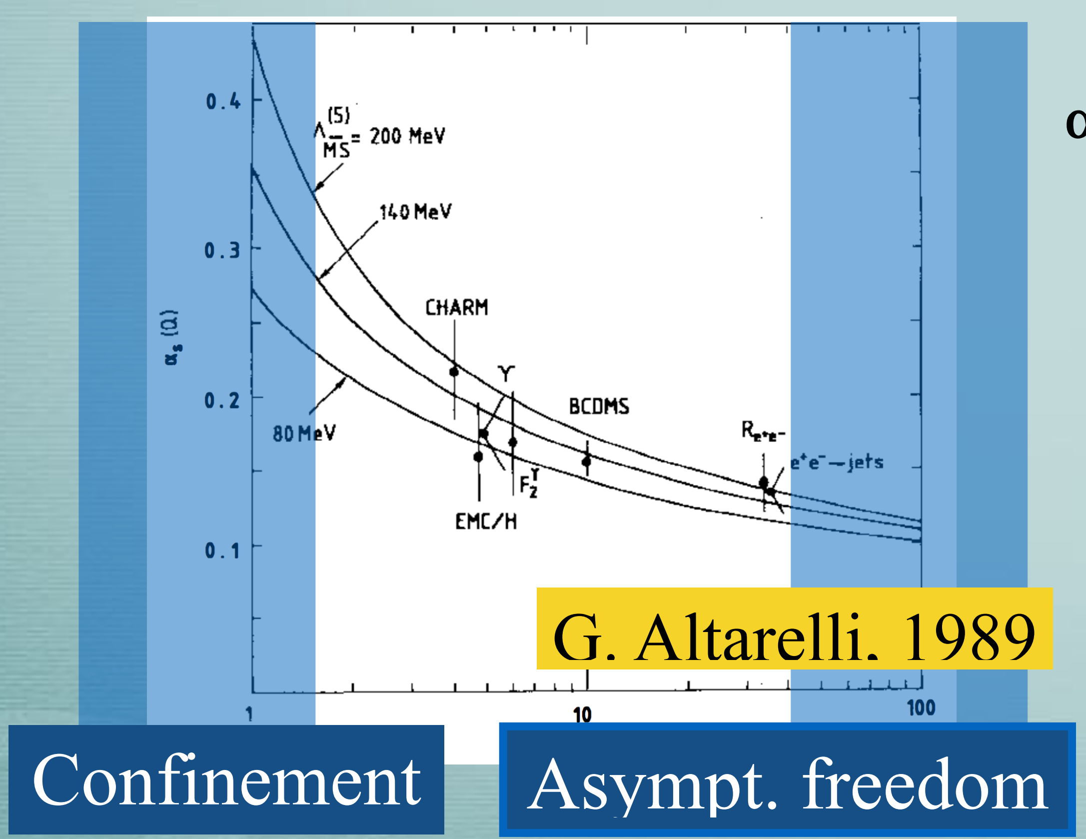
• Roma became tight for Guido: his decision to accept CERN's offer, in 1987, came unwanted but not unexpected.

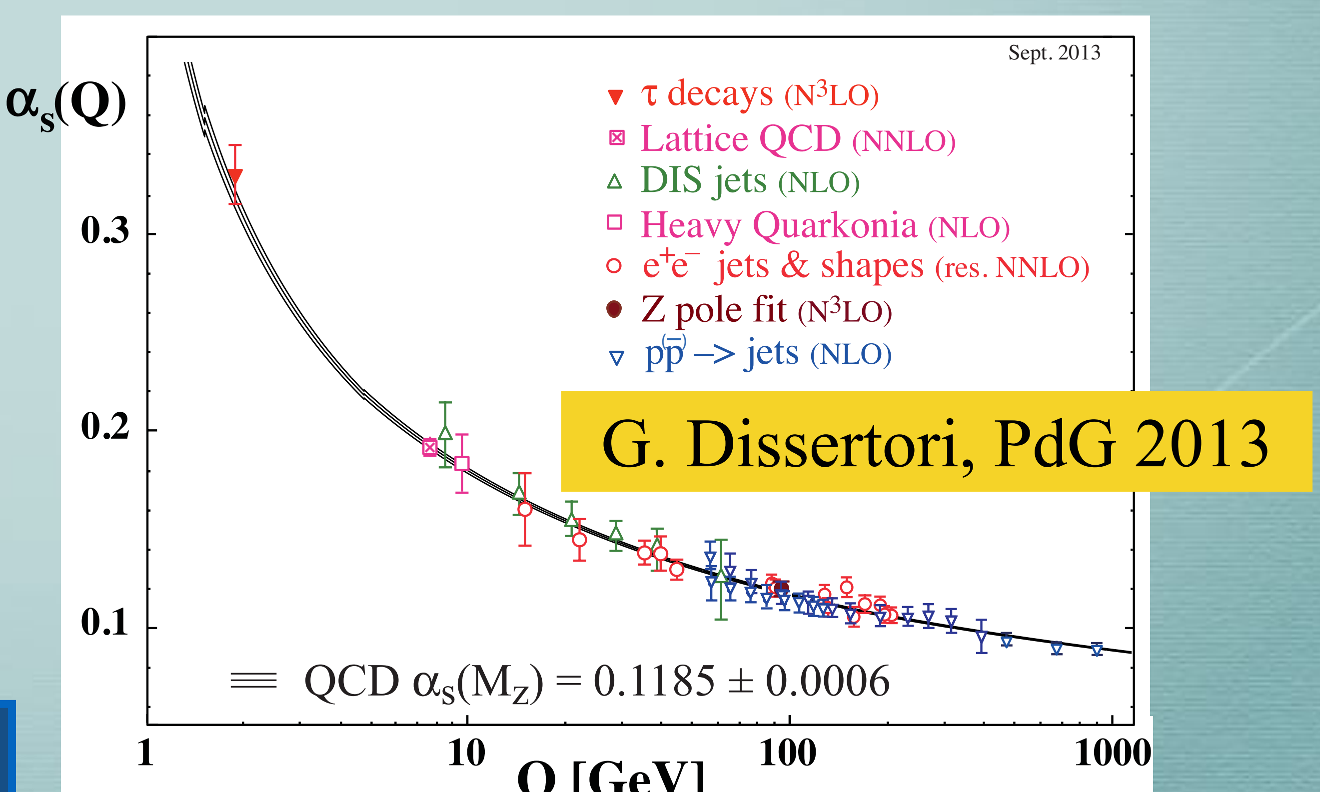
• If not as tight as before, our friendship remained. I found Guido again when coming to CERN as DG, and was glad to propose him as TH Division leader, with absolutely general consensus,

• … and greatly appreciated his loyalty and sense of institution in difficult times, when he refrained from joining the vocal minorities, even if he did not agree with some decisions of CERN's top management.

What Standard means in the SM

- I have been able to illustrate only a small part of Guido's work, essentially limited to the QCD applications to the weak interactions;
- this was, in the '70s and '80s, a very significant testing ground for the early QCD;
- the capacity to cope with different phenomena was the very basis of the SU(3)⊗SU(2)⊗U(1) theory
- Guido was one of those who contributed most to establishing the Standard Theory paradigm, in particular with his capacity to interpret the data coming out of LEP experiments.





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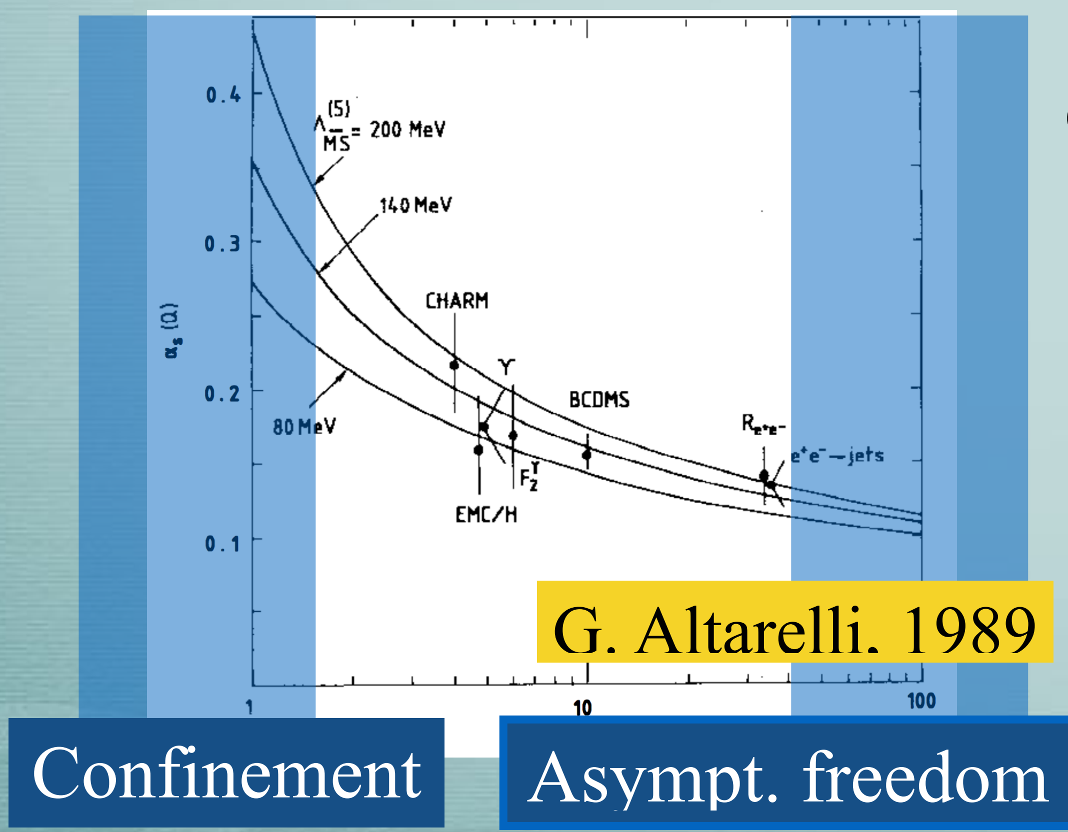

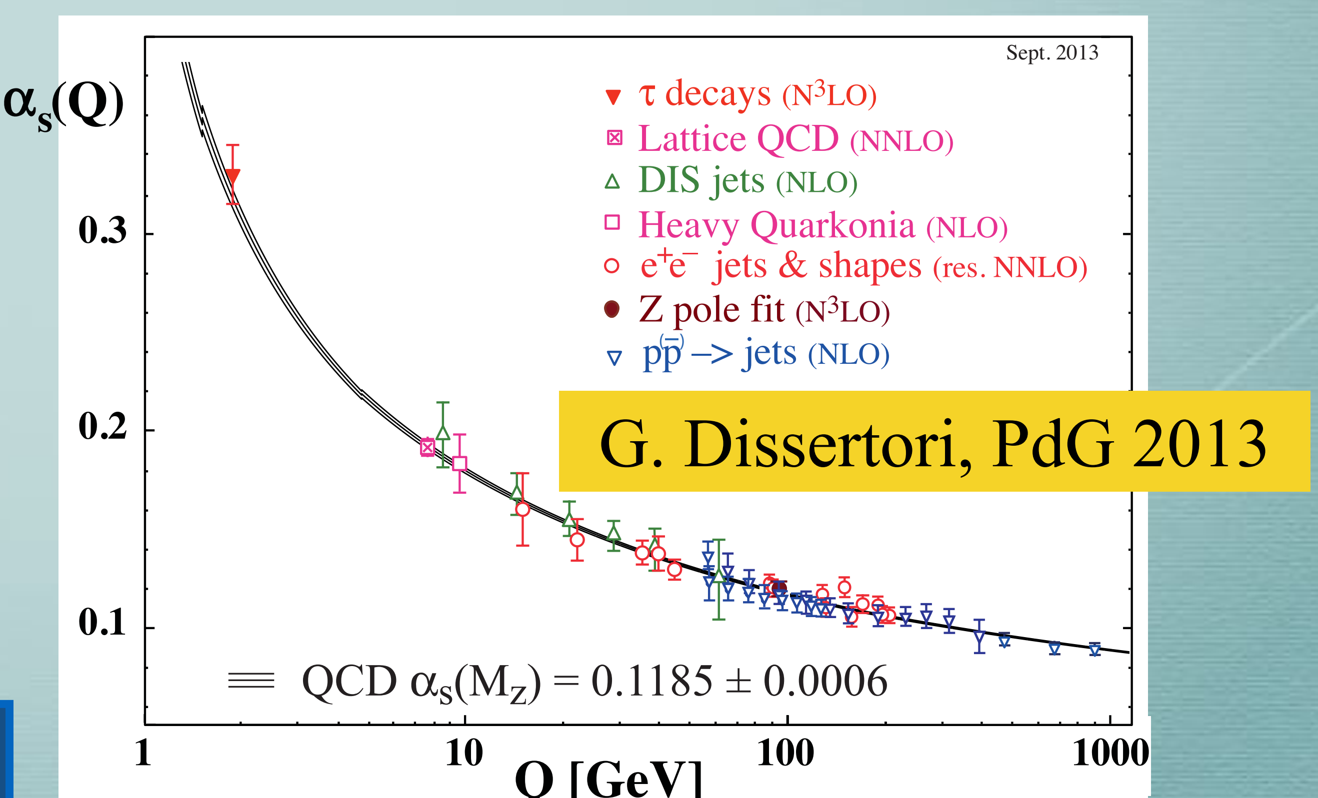

This is why we have to be extremely grateful to Guido and also why we miss him so much