Bruno Touschek, la fisica teorica romana e la formazione della Teoria Standard

Luciano Maiani, Sapienza e INFN

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Abstract

Personal recollections on theoretical particle physics in the years when the Standard Theory was formed. In the background, the remarkable development of Italian theoretical physics in the second part of the last century, with great personalities like Bruno Touschek, Raoul Gatto, Nicola Cabibbo and their schools.

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arXiv:1707.01833 [physics.hist-ph]

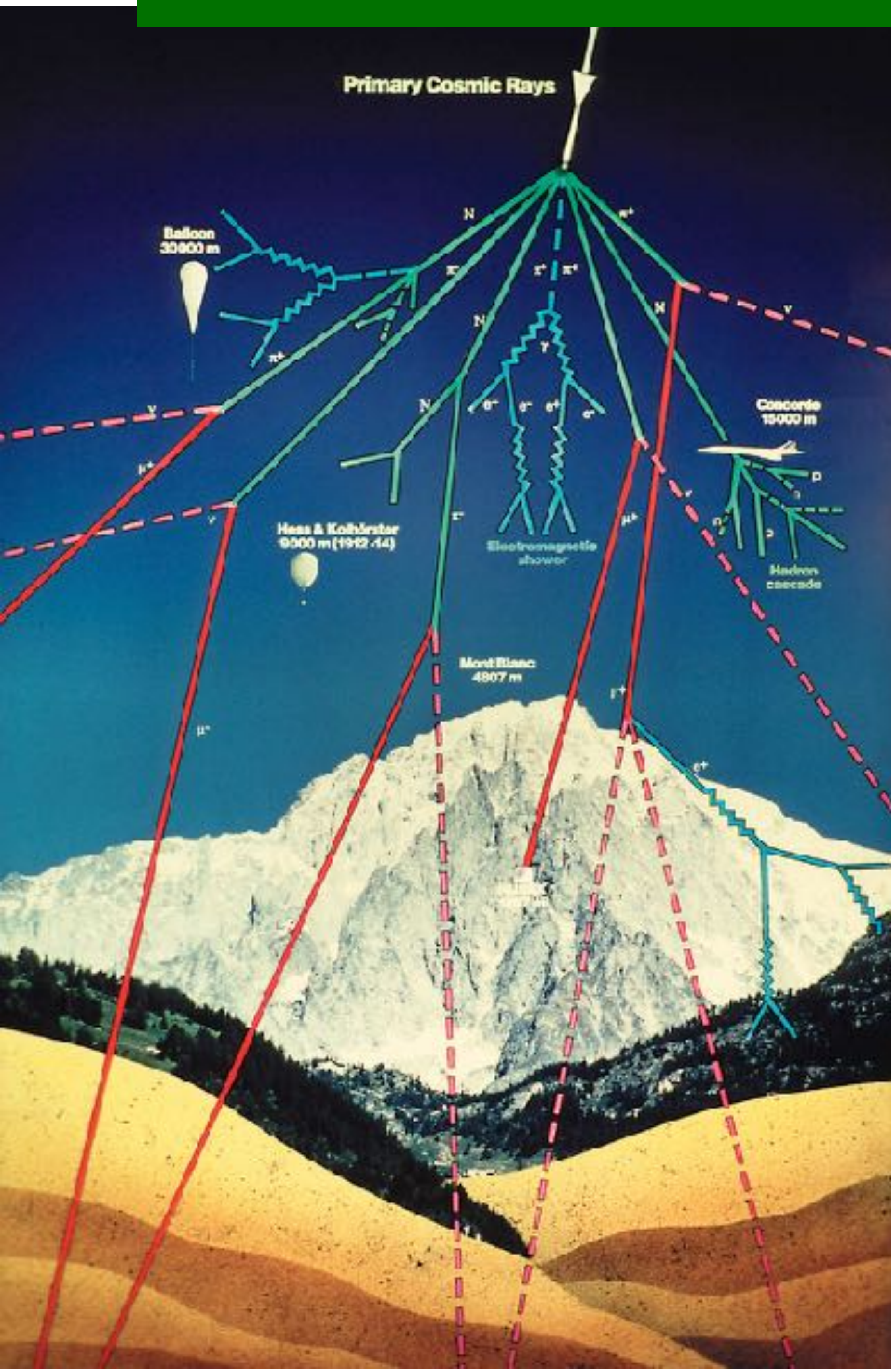
The Charm of Theoretical Physics (1958-1993)*

Oral History Interview

Luciano Maiani[1,a] and Luisa Bonolis[2,b]

[1] Dipartimento di Fisica G. Marconi and INFN, Piazza A. Moro 2, 00185 Rome, Italy
[2] Max Planck Institute for the History of Science, Boltzmannstraße 22, 14195 Berlin, Germany.

1. Where all started: the mesotron (1937)



- C. Anderson, S. Neddermeyer (1937) discover a new particle produced in the upper atmosphereat high altitude by the collisions of Cosmic Rays.
- 1946 (Roma): M. Conversi, E. Pancini e O. Piccioni, prove that the mesotron (μ particle, today) **is not** the particle responsible for the nuclear forces, proposed by H.Yukawa;
- Many consider this discovery the birth of modern Elementary Particle physics

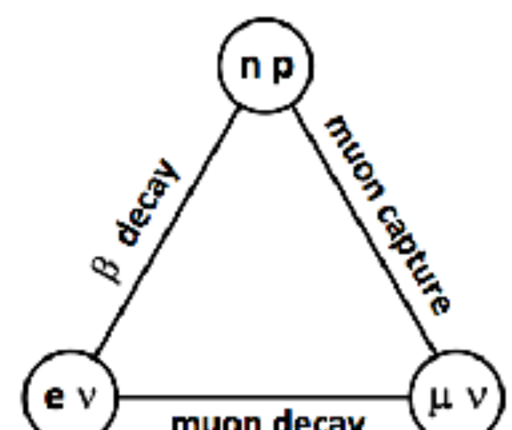
The mesotron and its siblings

V. Weisskopf, V. P. Dzhelepov and B. M. Pontecorvo, 1963, Dubna

- Everybody (Fermi, Marshak, etc.) was worried: *where is it the pion*
- Pontecorvo asked a simpler question: *but then, what is it the mesotron*
- a surprising answer: it is a second generation electron
- *who ordered that ?*(I. Rabi)
- 1940-1950: a *particle zoo* emerges from the study of cosmic rays interactions;
  - The new particles do not arise from further subdivision of normal matter (atoms, nuclei, nucleons, atomic and nuclear forces)
  - what is the role of μ particle in the fundamental forces?
- a provisional answer for the muon: Universality of the Weak Interactions (Puppi,1950)

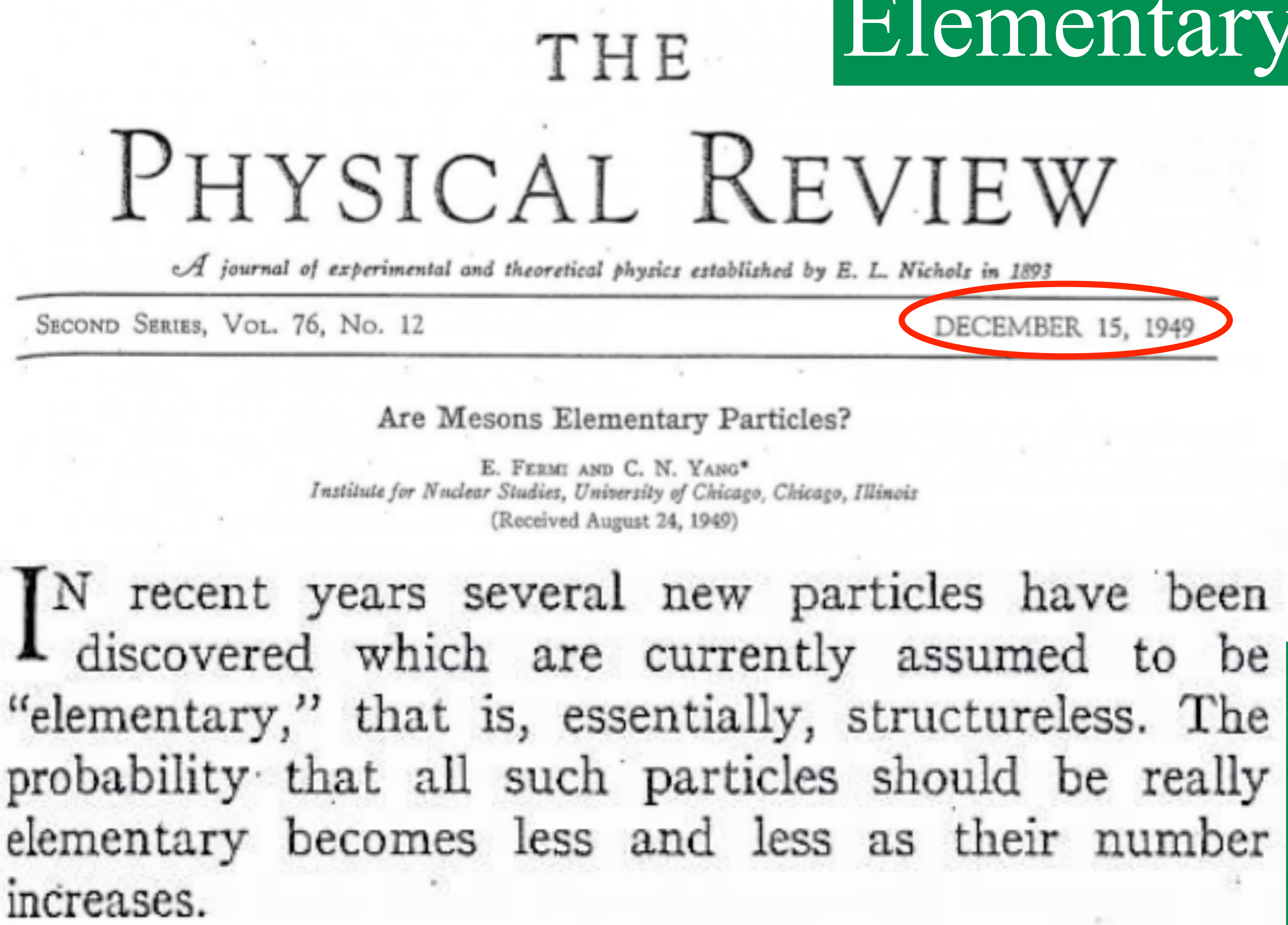
Graphic representation of the Universal Fermi Interaction in the 1950s: Puppi's triangle

- this line (after the work of Feynman and Gell-Mann,..Cabibbo) eventually led to electroweak unification (Glashow, Weinberg, Salam, Higgs...)
- but in fact we still do not have a plausible explanation of generations !



G. Puppi, Nuovo Cimento 5 (1948) 587 (in Italian)

Elementary Particles, what ?


THE

PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, VOL. 76, NO. 12 DECEMBER 15, 1949

Are Mesons Elementary Particles?

E. FERMI AND C. N. YANG*

Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received August 24, 1949)

IN recent years several new particles have been discovered which are currently assumed to be "elementary," that is, essentially, structureless. The probability that all such particles should be really elementary becomes less and less as their number increases.

muon
strange particles
Δ^{++}
.....

composite by "constituents" which are more elementary ?

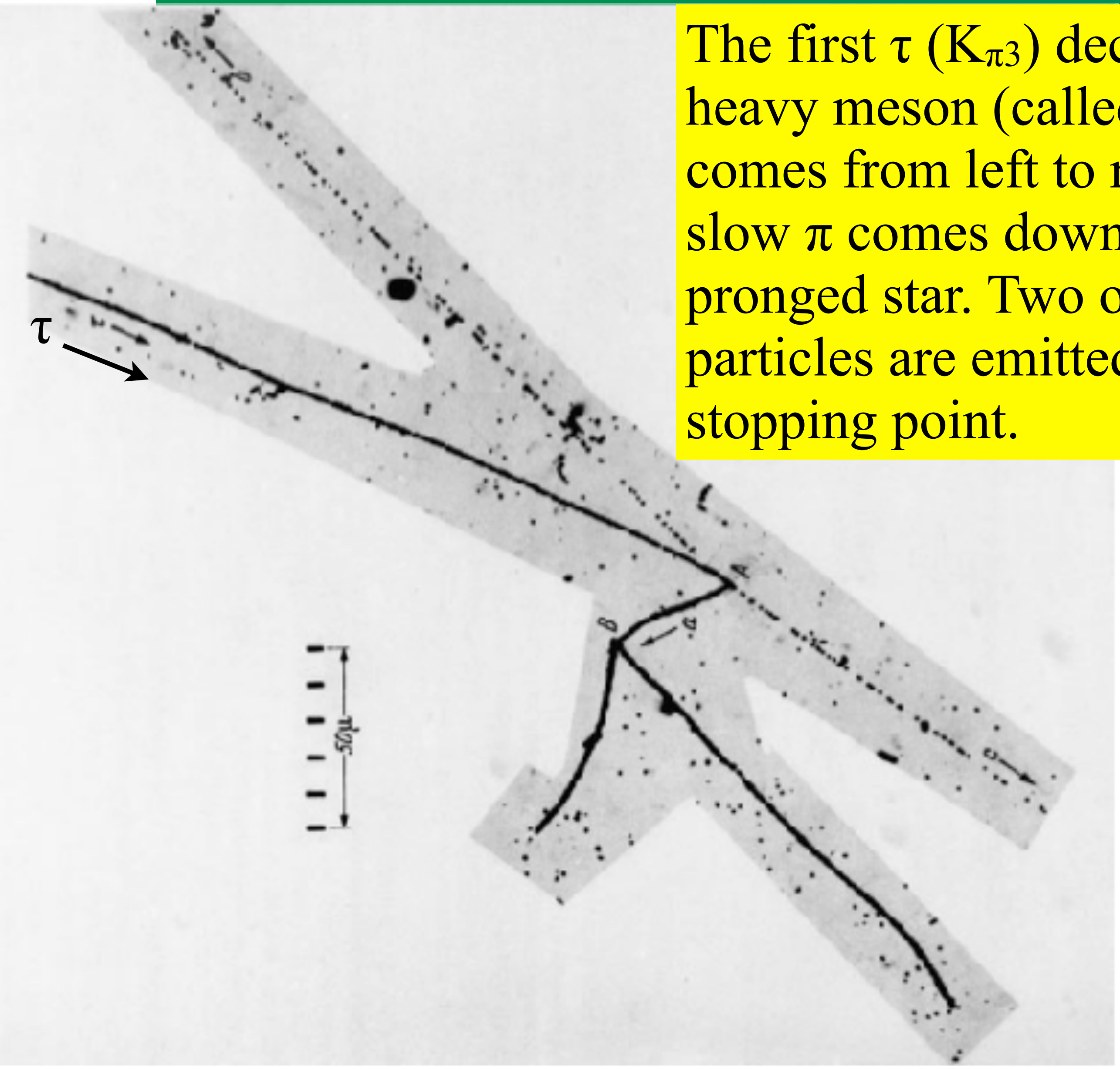
related by a large symmetry?
possibly including spin ?

Fermi&Yang's proposal:

$$\pi^+ = p\bar{n}$$

π has to have negative parity !!!

il primo evento di decadimento $K \to 3\pi$ (Bristol, 1948)



The first τ ($K_{\pi 3}$) decay: the primary heavy meson (called τ in the picture) comes from left to right and stops. A slow π comes down and makes a two-pronged star. Two other lightly ionizing particles are emitted from the first stopping point.

Figure 3 Beppo Occhialini talking in favor of the G-stack exposure at the Pisa Conference. Pisa, 1955. Accanto a Beppo, Bruno Touschek.

Particle Physics in transition

THE DISCREET CHARM OF THE NUCLEAR EMULSION ERA

Milla Baldo Ceolin

Annu. Rev. Nucl. Part. Sci. 2002. 52:1–21

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. Padua-Venice Conference, Italy

… ***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…elaborated on the equivalence of two-component and Majorana neutrinos. .

Marshak & Sudarshan stated, contrary to the then-current experimental evidence, that all weak interactions are of type *V-A* with $G_V \simeq G_A$, lepton conservation is incorporated, two component neutrinos (***R. Feynman***: *after 23 years, we come back to Fermi, except for the factor* $(1-\gamma_5)$!)

The suggestion was made that the weak interactions are mediated by charged vector bosons, the $W^\pm$.

Accelerators had taken over

The constituent way, first attempts

- Fermi&Yang (1949): only F=(p, n) are elementary,

$$mesons = F\bar{F}$$

- Sakata (1956): one new constituent to account for strange particles: S= (p, n, Λ),

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

- one clear predictions: there must exist baryons with strangeness S=+1. ***Unfortunately it is a wrong prediction, no such particle seen until today*** !
- basic symmetry of Sakata model: SU(2)= isotopic spin symmetry ⇒ SU(3), unitary transformation of the Sakata triplet

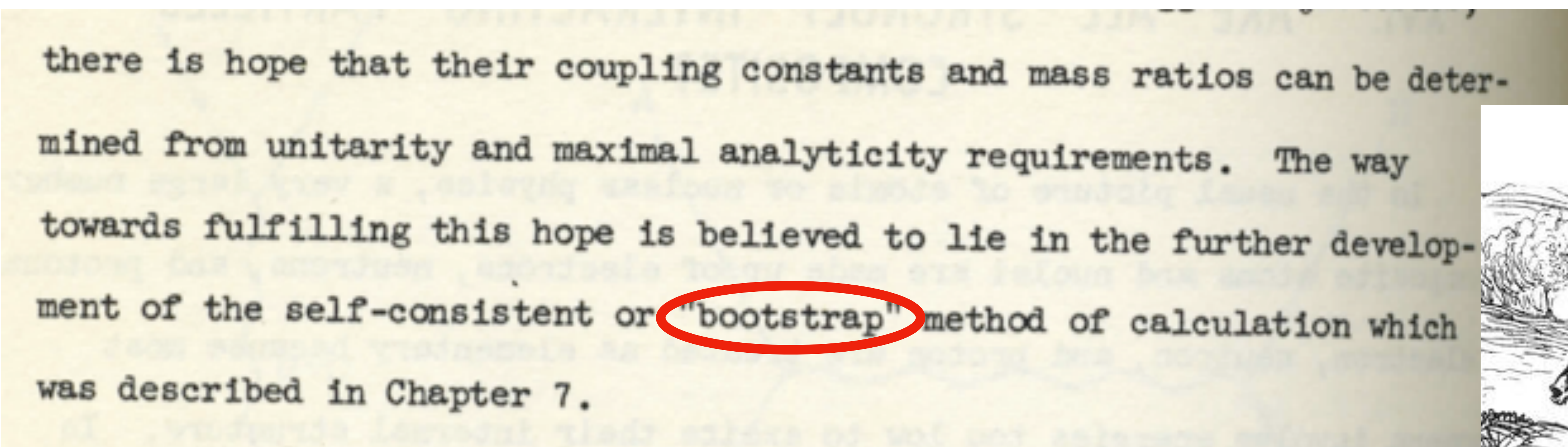
Nuclear Democracy

- in the presence of very strong interactions (unitarity saturated) there is no clear distinction between composites and constituents:

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

which is which?

- for this reason, in the years 60's, the most promising approach (G. Chew and S. Frautschi) was ***nuclear democracy***: ***all hadron particles are to 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.

Bootstrap: raising himself by pulling the boots of his own shoes..or by its pigtail (Baron of Munchausen)

Nuclear Democracy(cont'd)

- Nuclear Democray and bootstrap had no real, recognized success,
- but it inspired the string theory of Gabriele Veneziano, which at present is the basis of many theories of Quantum Gravity
- For sub-nuclear particles, the meaning of constituents was understood only in 1973:
- Nuclear democracy holds: all subnuclear particles are on the same level, ***they are all composite***...
- ... quarks and gluons are elementary and the ***fundamental strong interactions become weak at short distance*** (D. Gross & F. Wilczek, D. Politzer)
- Well inside the proton, constituents keep their personality.

2. Gatto and Cabibbo in Roma and Frascati

- After the Diploma at Scuola Normale di Pisa (1951) Roul Gatto went to Roma as assistant to Ferretti. In 1956, he left for the United States, to become a staff member of the Lawrence Radiation Laboratory in Berkley.
- The group of Luis Alvarez was in full production, discovering new hadrons with the hydrogen bubble chamber. Gatto absorbed quickly the exciting atmosphere of the laboratory.
- Works on the symmetries of the weak interactions (Fermi's imprinting on Italian theoretical physics) and the phenomenology of weak decays of hyperons, in close contact with the Alvarez group.
- Coming back (1960) Gatto became the director of the newly formed theory group at Frascati, bringing to Italy the new ideas flourishing at the time in the US, concerning the application of symmetry and group theory to particle physics.
- He found, as junior partner, Nicola Cabibbo, freshly graduated with Bruno Touschek and recruited in Frascati by Salvini.

Gatto and Cabibbo in Roma and Frascati (cont'd)

- Cabibbo, graduated in 1958, tutor Bruno Touschek
- first thoretical physicist in Frascati
- meets with Raoul Gatto (5 years elder) back from Berkeley;
- exciting times in Frascati:
  - Touschek and collaborators are building the first e^+e^- collider (AdA), to be followed by Adone (1969), a new particle (the eta meson), SU(3), etc.
  - Cabibbo & Gatto author an important article on e^+e^- physics (the Bible)
  - in 1961, they investigated the weak interactions of hadrons in the framework of the newly discovered SU(3) symmetry (precursor of the Cabibbo theory).
  - Brilliant younger collaborators
    - G. Da Prato, U. Mosco, G. De Franceschi
    - G. Altarelli and F. Buccella (graduated with Gatto), G. Gallavotti (with Touschek)
  - Preparation of ADONE experiments prompted the renewal of QED studies.

Bruno Touschek as a teacher

- In year 1962-63, Touschek was teaching Statistical Mechanics
- He would present his lecture, consulting personal notes that he had probably prepared the night before, as if he had just discovered what he was illustrating.
- Extremely clear and precise, Touschek spoke a perfect Italian with a fascinating Austrian accent and sometime old fashioned expressions. He referred to the heat bath to reach thermal equilibrium as "vasca di bagno" and described his revolutionary idea of making head-on electron-positron collisions as "treno-contro-treno". One could see the perfect image of a scientist and a perfect introduction to what research in physics might be.
- Meeting Bruno convinced me that research was my destination but, at the same time, made me doubt that I could be able to work in theoretical physics.

Marcello Cini and the Dispersion Relations School

- In Roma, during the late 50's and 60's, theoretical alternatives to field theory were explored by Marcello Cini, with many young colaborators.
- Among them, M. Cassandro, L. Sertorio, M. Restignoli and, later L. Violini, M. Lusignoli, M. Toller, D. De Maria.
- Subjects run from Fundamentals of Quantum Mechanics to Dispersion Relations, Regge Poles, Relativistic Thermodynamics, etc.
- In the early 60's, some of the youngest roman theorists (Altarelli, Buccella, Gallavotti, Preparata…myself) followed Gatto in Florence to pursue a research closer to particle phenomenology:

  SU(3), neutrinos, …SU(6), quarks, etc.
- in 1967, N. Cabibbo, after US and CERN, settled in Roma soon joined by Preparata and myself, from Florence.
- It was, for me, the beginning of a collaboration that lasted, with various interruptions, for more than 40 years.

3. Late 1960's

....hopes of a basic theory for strong, e.m. and weak interactions

•well established results:

-Gell-Mann-Zweig quarks in 3 flavours (baryons=qqq, etc.

$$q = \begin{bmatrix} u \\ d \\ s \end{bmatrix}$$

-Cabibbo theory of semileptonic decays, ΔS=0,1:

$$\mathcal{L}_F = \frac{G_F}{\sqrt{2}} J^\lambda J^+_\lambda$$

$$J^\lambda = \bar{\nu}_e \gamma^\lambda (1-\gamma_5) e + \bar{\nu}_\mu \gamma^\lambda (1-\gamma_5)\mu + \bar{u}\gamma^\lambda(1-\gamma_5) d_C$$

$$d_C = \cos\theta d + \sin\theta s$$

quarks: only one weak doublet:

$$\begin{pmatrix} u \\ d_C \end{pmatrix}_L ; (s_C)_L ; d_R ; u_R ; s_R$$

•clouds:

-do quark clash with Fermi-Dirac statistics? first ideas about color (Han-Nambu)

-basic strong interactions: *gluon (abelian) mediated* ? *dual-like* (Veneziano model)?

-Fermi theory not renormalizable. W boson? strong interaction form factors?

•Schwinger ideas about EW unification+Yang-Mills

- Glashow's SU(2)⊗U(1) (1961)

- Brout-Englert-Higgs Mechanism (1965) -> Weinberg-Salam (1967)

•embedding Cabibbo theory in SU(2) ⊗ U(1) leads to unobserved Flavor Changing Neutral Currents. Does Unification work for leptons only ? Or may form factors suppress these processes?

A TURNING POINT IN 1968

•In the late Sixties, few peple believed that the basic strong interactions between quarks could be described by field theory

•In the more established framework, Bootstrap, Regge Poles etc., a very promising new idea came out, the Dolen-Horn-Schmid Duality (1967):

-the sum of baron resonances, s-channel resonances reconstructs the (is dual to) Regge behavior in the t-channel

R. Dolen, D. Horn, and C. Schmid, 3. D. Horn and C. Schmid, CALT-68- 127 (1967); Phys. Rev. 166, 1768 (1968).

• Duality is a new kind of bootstrap condition, and the result raised a lot of interest, which reached its maximum in 1968 when the Veneziano Dual Model of pion-pion scattering came out. Everybody went Dual. Gabriele Veneziano, Nuovo Cimento A. 57 (1): 190–7 (1968).

• Field theory for particle physics became an exoteric discipline, with few practioneers worldwide

•However, in a ***bottom-up*** fashion, few authors addressed the problem of higher order weak interactions in the simplest theory with ***one charged vector boson coupled to the Cabibbo currents***, and found a startling result at one-loop level.

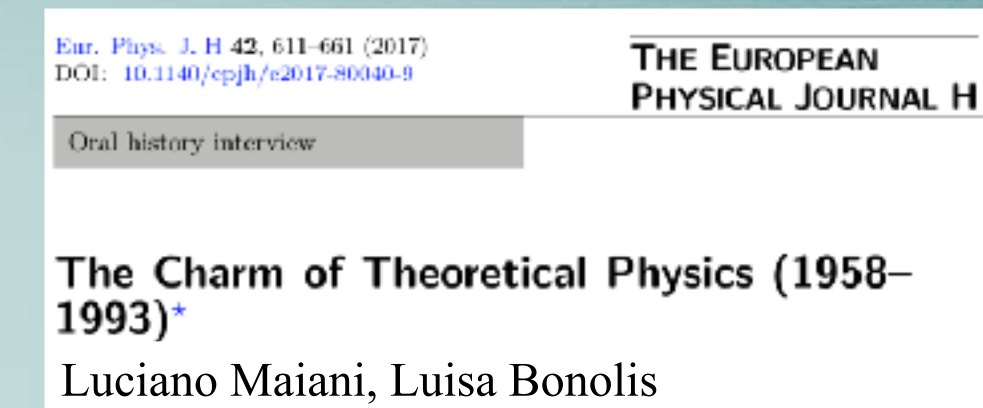
B. L. Ioffe and E. P. Shabalin, Yadern. Fiz. 6, 828 [Soviet J. Nucl. Phys. 6, 603 (1968)]; F. Low, Comm. Nucl. Part. Phys. 2 (1968) 33; R. N. Mohapatra, J. S. Rao and R. E. Marshak, Phys.Rev.Lett., 20, (1968), 634; R. N. Mohapatra and P. Olesen, Phys. Rev. 179 (1969) 1417.

The Vienna HEP Conference, August-September 1968, marked the real turning point. Ideas about Duality and higher order weak interactions were presented and widely discussed. SLAC data on deep inelastic electron scattering were presented for the first time, indicating the onset of Bjorken scaling. Higher order weak interaction results and flavour changing neutral currents were discussed

THE FIRST WEAK INTERACTION LOOP

B. L. Ioffe and E. P. Shabalin, Yadern. Fiz. 6, 828 [Soviet J. Nucl. Phys. 6, 603 (1968)]; F. Low, Comm. Nucl. Part. Phys. 2 (1968) 33; R. N. Mohapatra, J. S. Rao and R. E. Marshak, Phys.Rev.Lett., 20, (1968), 634; R. N. Mohapatra and P. Olesen, Phys. Rev. 179 (1969) 1417.

- At one loop, with ***one charged vector boson coupled to the Cabibbo currents,*** $K_L \to \mu^+\mu^-$ and $K^0 - \bar{K}^0$ mixing are generated, with amplitudes of order: $\sin\theta \cos\theta\, G(G\Lambda^2)$, where G is the Fermi constant, Λ is an ultraviolet cutoff.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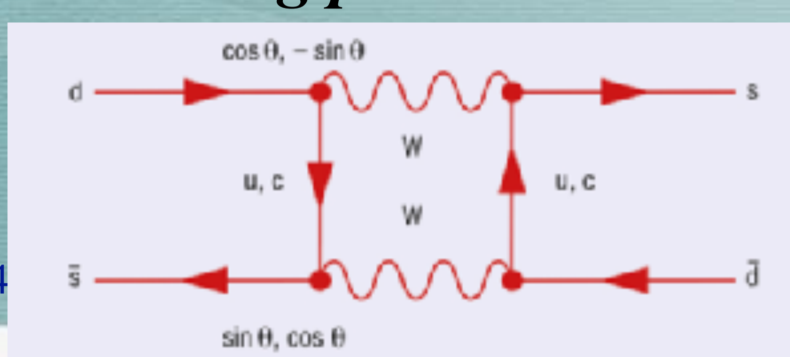
THE EUROPEAN PHYSICAL JOURNAL H

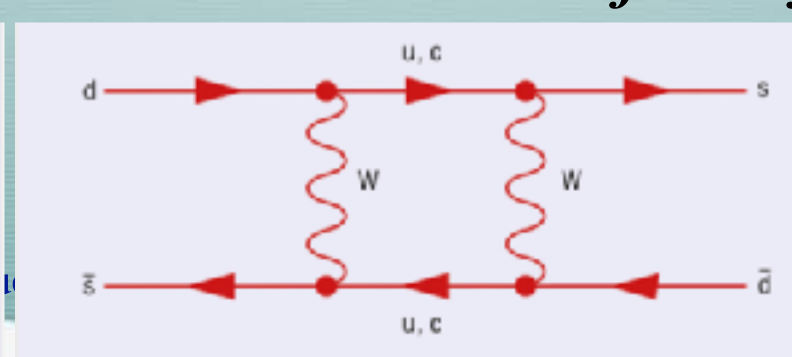
Oral history interview

The Charm of Theoretical Physics (1958–1993)*

Luciano Maiani, Luisa Bonolis

- The strict limits existing at the time implied a surprisingly small value of Λ,
- $\Lambda \sim 2 - 3\ GeV$, to be compared with the naturally expected value: $\Lambda = G^{-1/2} \sim 300$ GeV.
- The result led in 1970 to the GIM Mechanismx: the introduction of a charm quark to cancel the quadratic divergence, interpreting the cutoff ($\Lambda = 2 - 3$ GeV) as the predicted charm mass, $m_c \sim 1.5$ GeV.
- GIM gives the possibility to include quarks in the Glashow-Weinberg -Salam gauge theory based on $SU(2)_L \otimes U(1)_R$.
- ***It was the first instance in which quark and W loops were taken seriously and led to startling predictions that indeed have been verified a few years later.***





see CERN Courier, 24 January 2020

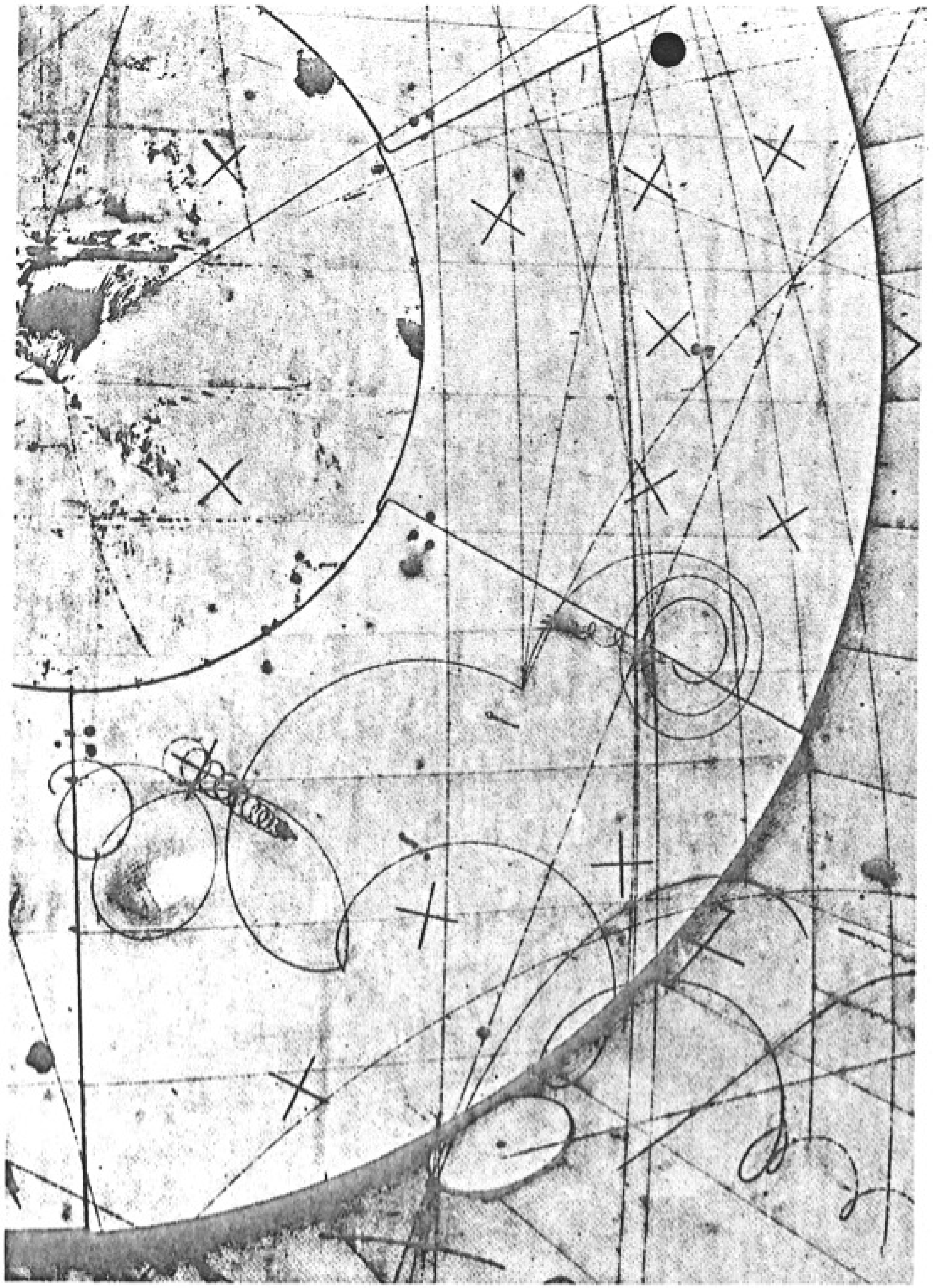
January 1970, at Cambridge, Mass.….

Eur. Phys. J. H **42**, 611 (2017)
arXiv:1707.01833 [physics.hist-ph]

- By the end of January (1970) I think we had understood all the essentials
- I remember one day going to the Legal Sea Food for lunch where my wife Pucci joined us. Pucci told to Shelly (Glashow) how happy and excited I was about the new result and the work we were doing. He replied: *He is right, this paper is going to be on all school books*
- Shelly was fantastic. . . In another occasion, a seminar given by him to the experimentalists of Harvard working at the CEA (Cambridge Electron Accelerator). Shelly introduced by saying:
- *Look, with charm we have essentially solved particle physics.*
- *Except*, he added, *for CP violation*.

The neutrino production of an excited charmed meson, D*, is captured by this spectacular picture taken at the CERN Hydrogen Bubble Chamber, with the decay chain of D* fully reconstructed

(J.Blietschau~ et al. [Aachen-Bonn-CERN-Munich-Oxford Collaboration]. *Production of Charmed Mesons in Neutrino Interactions in Hydrogen*. Physics. Lett. **86B** (1979) 108.



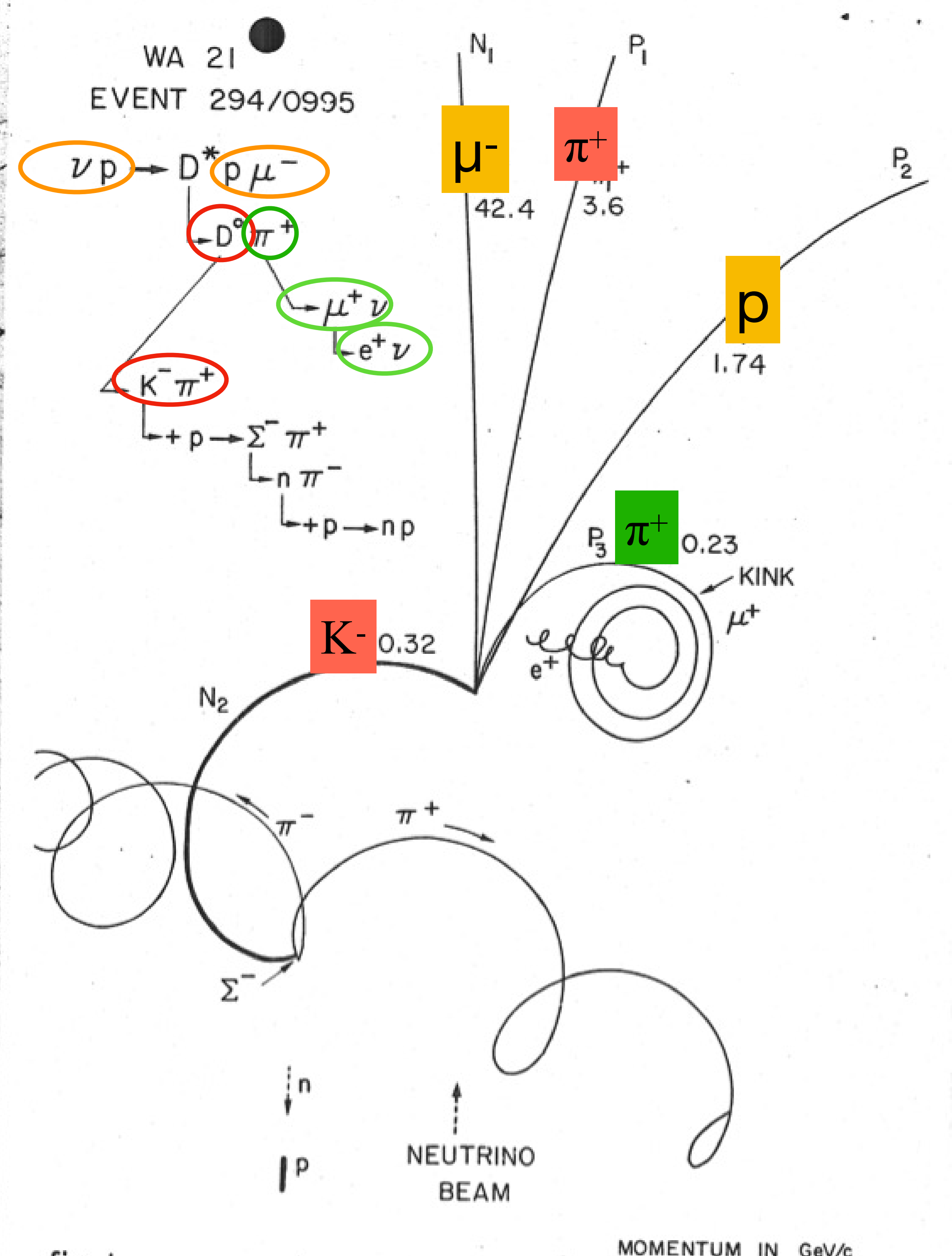


fig. I

4. BACK TO ROMA

- Coming back to Roma from the US (May 1970), I found Nicola Cabibbo and his present and former students (Giorgio Parisi and Massimo Testa) very excited by the results obtained by ADONE, which had started operating at the end of 1969.
- All detector had observed an unexpected abundant production of adrons in the region beyond the ρ, ω, ϕ resonaces,
- the ratio of the hadron cross section versus the $\mu^+\mu^-$ cross section was ~ constant and of order unity, as if the cross section went via the production of point-like constituents
- In analogy with the formulae found by Drell for deep-inelastic electron scattering, they were playing with the formula

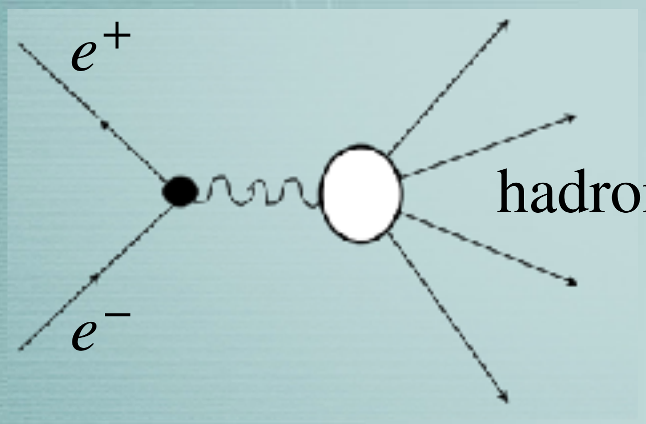
$$R = \frac{\sigma(h)}{\sigma(\mu^+\mu^-)} = \sum Q_i^2$$

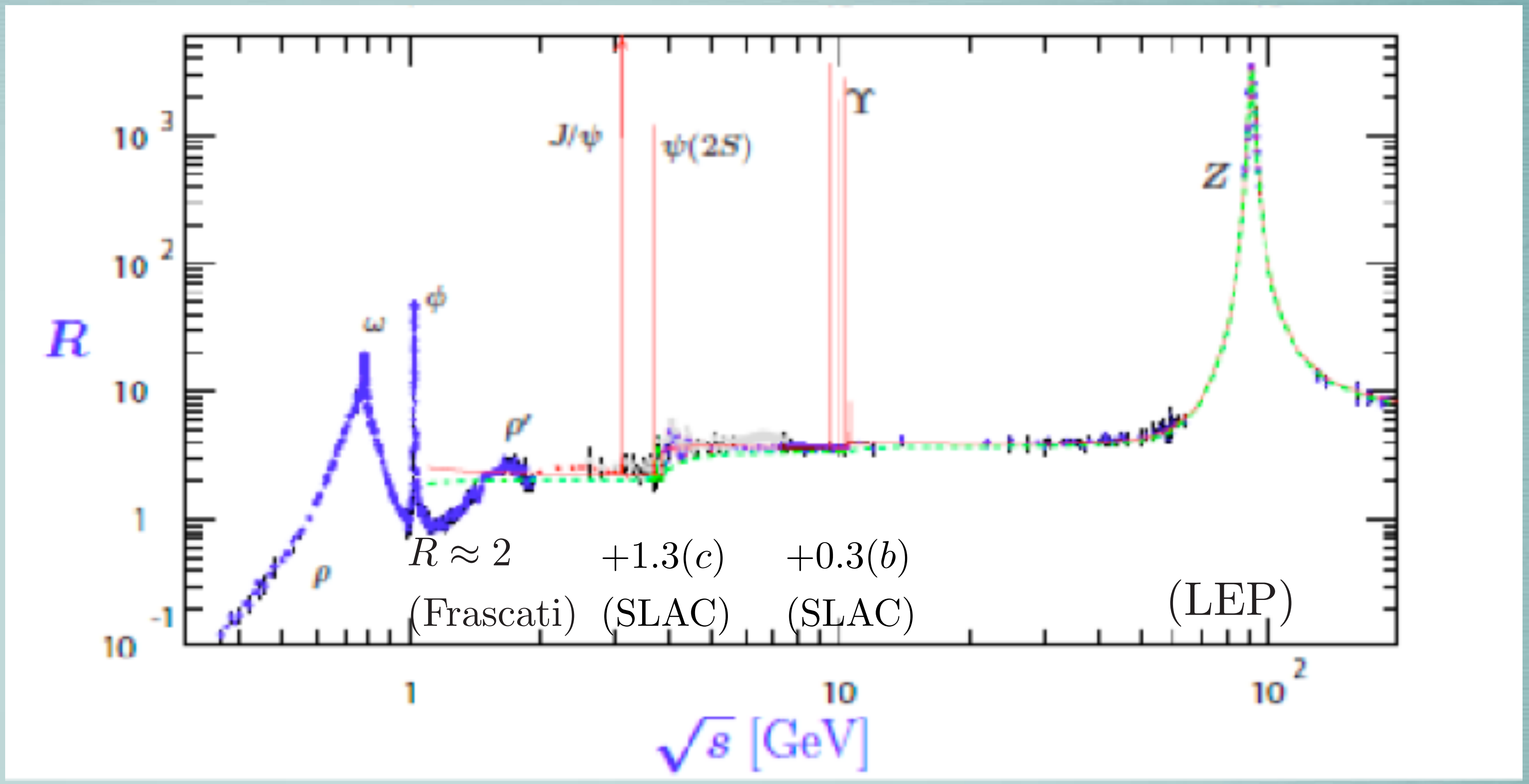
with Q_i the electric charge of the elementary consituents: which constituents?

- Needless to say, Touschek was excited as well: the unexpected result indicated the

ELECTRON-POSITRON ANNIHILATION (TODAY!!)

An universal probe for any form electrically charge matter





$$R = \frac{\sigma(h)}{\sigma(\mu^+\mu^-)} = \sum Q_i^2$$

= 2/3 (u, d, s, no color)
= 2 (u, d, s, in 3 colors)
= 2+1/3 (u, d, s, c in 3 colors)

Frascati data: 3 colors!
SLAC data: 3 colors *and* charm !

The association of J/Ψ with the $c\bar{c}$ threshold was first done in:

C. Dominguez, M. Greco. *Lettere al Nuovo Cimento* **12**, 439 (1975)

5. GOING ELECTROWEAK

- Guido Altarelli 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:

PdG 2013, A. Hoecker, W.J. Marciano

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

$$a_\mu^{\mathrm{EW}}[\text{2-loop}] = -41.2(1.0)\times 10^{-11},$$

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

today:
BNL -FNAL : 4.2 sigma:
$(251\pm59)\times10^{-11}$
??????

thanks to R. Barbieri !!!

..AND QUARKS

Volume 38B, number 7 PHYSICS LETTERS 3 April 1972

AN ANOMALY-FREE VERSION OF WEINBERG'S MODEL

C. BOUCHIAT, J. ILIOPOULOS and Ph. MEYER
Laboratoire de Physique Théorique et Hautes Energies, Orsay, France ‡

Received 11 February 1972

We discuss the difficulties of carrying the renormalization program in a theory containing Adler anomalies. We present some models of weak and electromagnetic interactions, involving both lepton and quark fields, in which the troublesome anomalies cancel.

- Adler's anomalies in SU(2)xU(1) were the last obstacle towards a renormalizable electroweak theory
- Anomaly cancellation requires quarks **and** leptons
- John's description of this work in a short letter sent immediately after: "***there must be charm, quarks have color and are fractionally charged.***"
- Asymptotic Freedom had just been found by Gross and Wilczek: it was the beginning of the Standard Theory

6. ROMA UNIVERSITY 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, 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).
- You'll find all their names appearing at first in the literature in association with Nicola, with Guido and sometimes with me.

- From time to time the Physics Department was occupied, 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.

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.

DGLAP

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.

- Quarks are not 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 has had an enormous impact, it made easier to understand the physics and simpler to compare experimental data with theory.

A few results of these wonderful years:

- parton-model description of e^+e^- annihilation into hadrons.

N. Cabibbo, G. Parisi and M. Testa, *Hadron Production In e^+ e^- Collisions*, Lett. Nuovo Cim. **4S1**, 35 (1970).

- electroweak contribution to the muon anomaly.

G. Altarelli, N. Cabibbo and L. Maiani, *The Drell-Hearn sum rule and the lepton magnetic moment in the Weinberg model of weak and electromagnetic interactions*, Phys. Lett. **B40**, 415 (1972).

- enhancement of non-leptonic weak interactions

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- parton densities in hadrons.

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7. CONCLUSION

•The discovery of W and Z in the first 1980s concluded the heroic phase of the construction of the Standard Theory

•from there on, up to the observation of the Higgs Boson in 2012, we have had only confirmations

•Not the final word??… future will tell what's beyond it

•Touschek idea of e^+e^- colliders has been an essential element of the verification of the Standard Theory

•$p\bar{p}$ and pp colliders have later completed the picture and play now a fundamental role in particle physics

•Our generation has been very lucky, indeed, to happen to be present, at the right place and in the right time, and it has been a great fun indeed.

MANY THANKS !!