Subnuclear Physics: Past, Present and Future
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www.pas.va/content/dam/accademia/pdf/sv119/sv119-zichichi.pdf

The Reasons for this Symposium on Past, Present and Future of Subnuclear Physics

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This is the first time that the Pontifical Academy of Sciences places the field of Subnuclear Physics at the centre of its attention. On behalf of all my colleagues engaged in this frontier of Modern Science I would like to express to our President, H.E. Professor Werner Arber and to our Chancellor H.E. Monsignor Marcelo Sánchez Sorondo, our deep gratitude.

This Seminar has two purposes: one is *Pure Physics*, the other is *Scientific Culture*.

Our field of activity competes in terms of number of people and of financial support with gigantic projects such as the one aimed at having the man going to the satellite of the Sun called Mars. This is why we cannot ignore the "tax payers", i.e. the Culture of our Time, called Modern Culture.

As you know H.H. Benedict XVI has focused the attention of Modern Culture to the complex property of our form of living matter called Reason.

The greatest achievement of Reason in the Immanentistic Sphere of our existence is the Rigorous Experimental Logic, called Science.

- Science is the latest achievement of Reason;
- it came 3 thousands years after the discovery of the Rigorous Theoretical Logic, called Mathematics;

- and 10 thousands years (probably even 50.000) after the discovery of Permanent Collective Memory (better known as Written Language).

The future of Subnuclear Physics needs our engagement in order to have the Culture of our Time supporting Subnuclear Physics. For this to happen depends on our engagement for Scientific Culture. Let me give you an example.

When people see my friend David Scott, Commander of Apollo XV, performing the famous Galilei experiment at the Moon and saying "*Galilei was Right*" we need to explain that if this could be done it is because in our Labs we have been able to continue the Galileian search in trying to understand the Logic of Nature: i.e. first level Science.

Tonight you will see the NASA film at the Michelangelo's Italian State Basilica "*Santa Maria degli Angeli e dei Martiri*".

It is first level Science that has given all instruments we use in every day-life and the life-expectations of over 80 years to our form of living matter.

We need to let "tax payers" know that the effective motor for progress in the immanent part of our world is scientific discovery, which is a direct consequence of Reason.

Thanks to H.H. Benedict XVI, Reason is finally going to be a strong part of Modern Culture.

Our field is the most recent achievement of Reason in the search to understand the Logic of Nature.

It was borned slightly more that a (1/2) century ago, in 1947 with three discoveries:

1) the Lamb-shift;
2) the so much wanted but never found before "nuclear glue", i.e. the π–meson and
3) the "Strange–particles".

Let me show few pictures of years 1929, 1947, 1947 and 1963.

– 1929 –

Figure 1: Lord Patrick Maynard Stuart Blackett, Pyotr L. Kapitza, Paul Langevin, Lord Ernest Rutherford, Charles Thomson Rees Wilson outside Cavendish Laboratory (1929).

– 1947 –

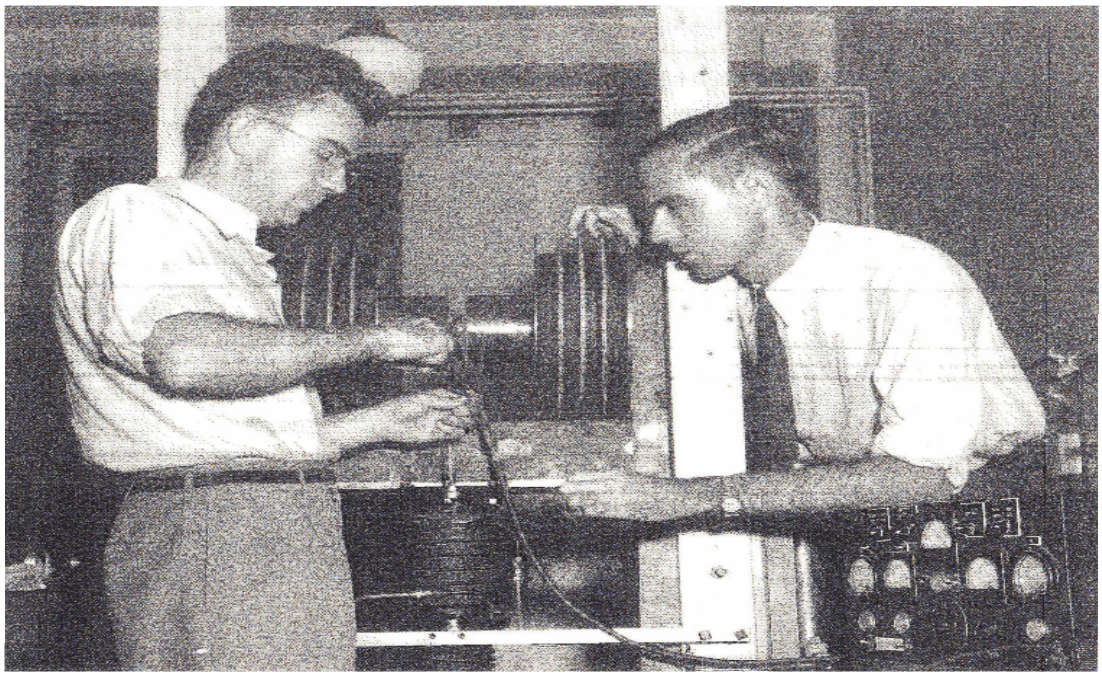
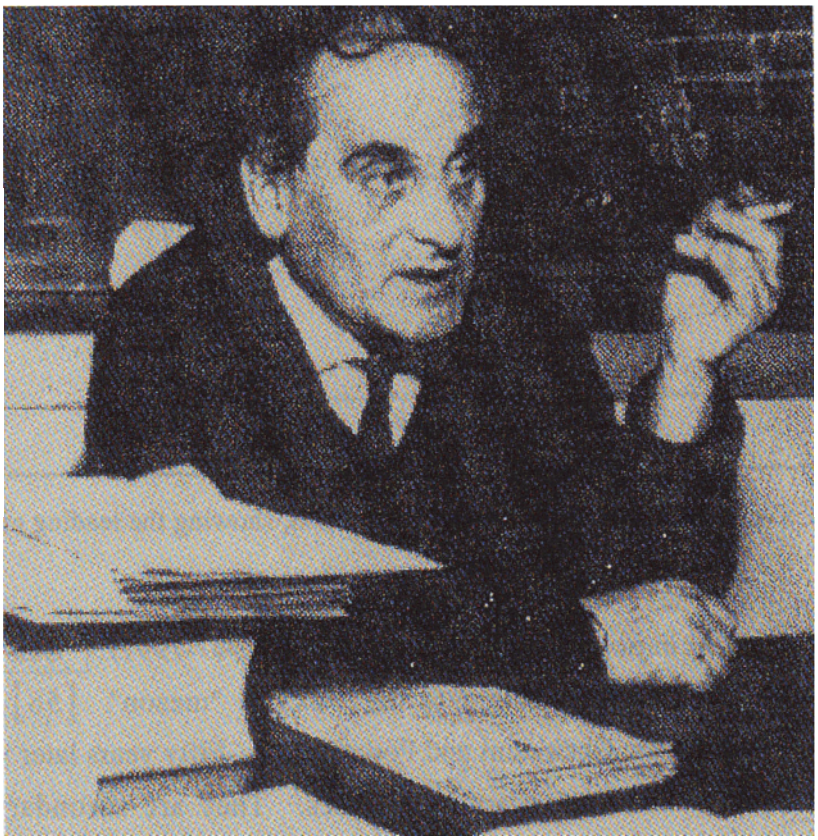


Figure 2: This picture was taken in September 1947 and shows W.E. Lamb and R. Retherford working on the Lamb-shift experiment.

– 1947 –

π–meson

Giuseppe Occhialini and Cecil Frank Powell

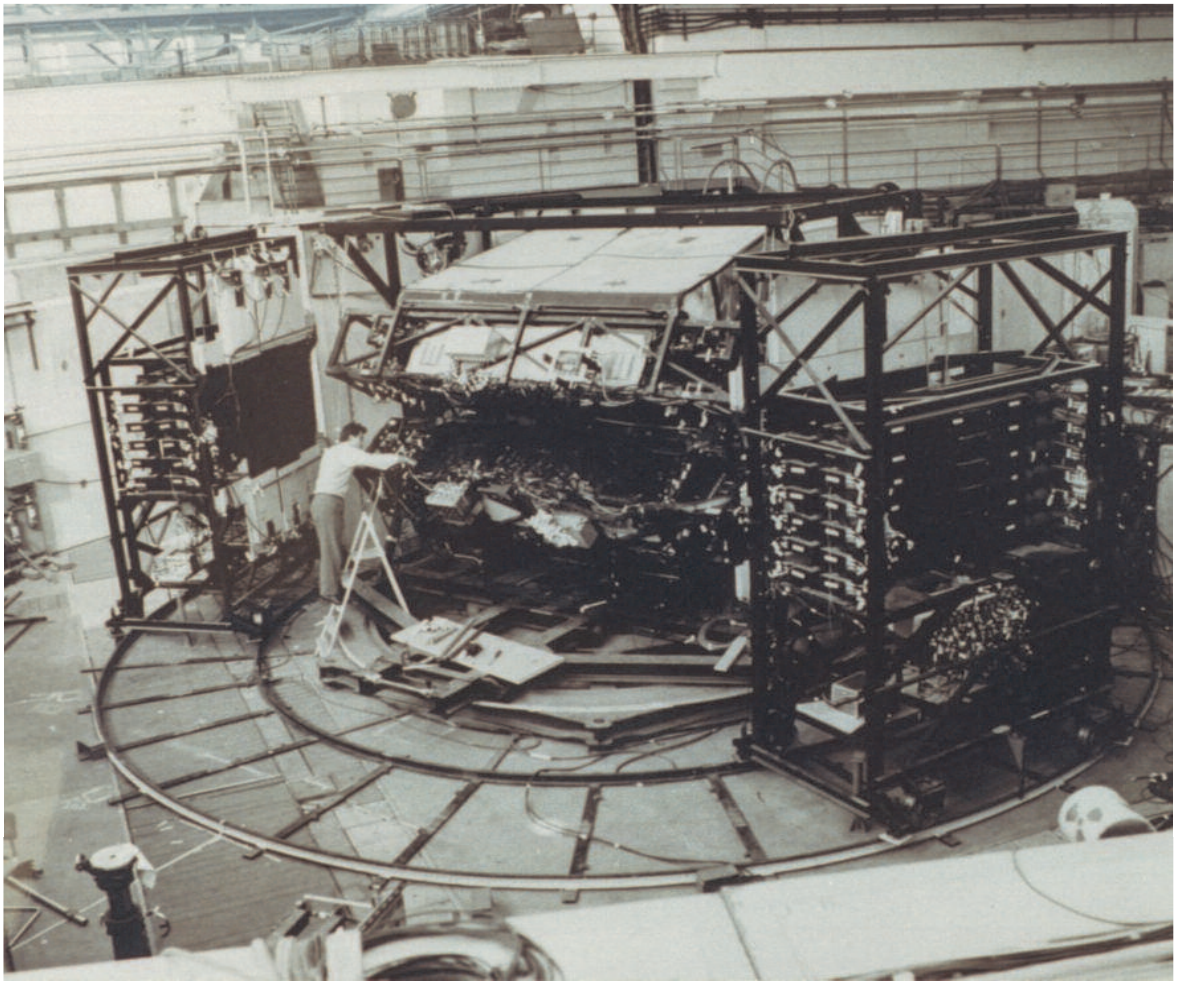


Giuseppe Occhialini

Figure 3

– 1963 –

This is the first example of what is now "standard" in experimental subnuclear physics: very large acceptance detectors.



On the rails the "neutron missing mass spectrometer".

PAPLEP
Proton AntiProton into Lepton Pairs
first search for the 3rd lepton
and
$\theta_{PS} \neq \theta_V$.

Figure 4

The "pre-shower" technology implemented in the CERN experimental set-up for the study of the rare decay modes of the pseudoscalar and vector mesons.

SUBNUCLEAR PHYSICS: PAST, PRESENT AND FUTURE

Why Past?

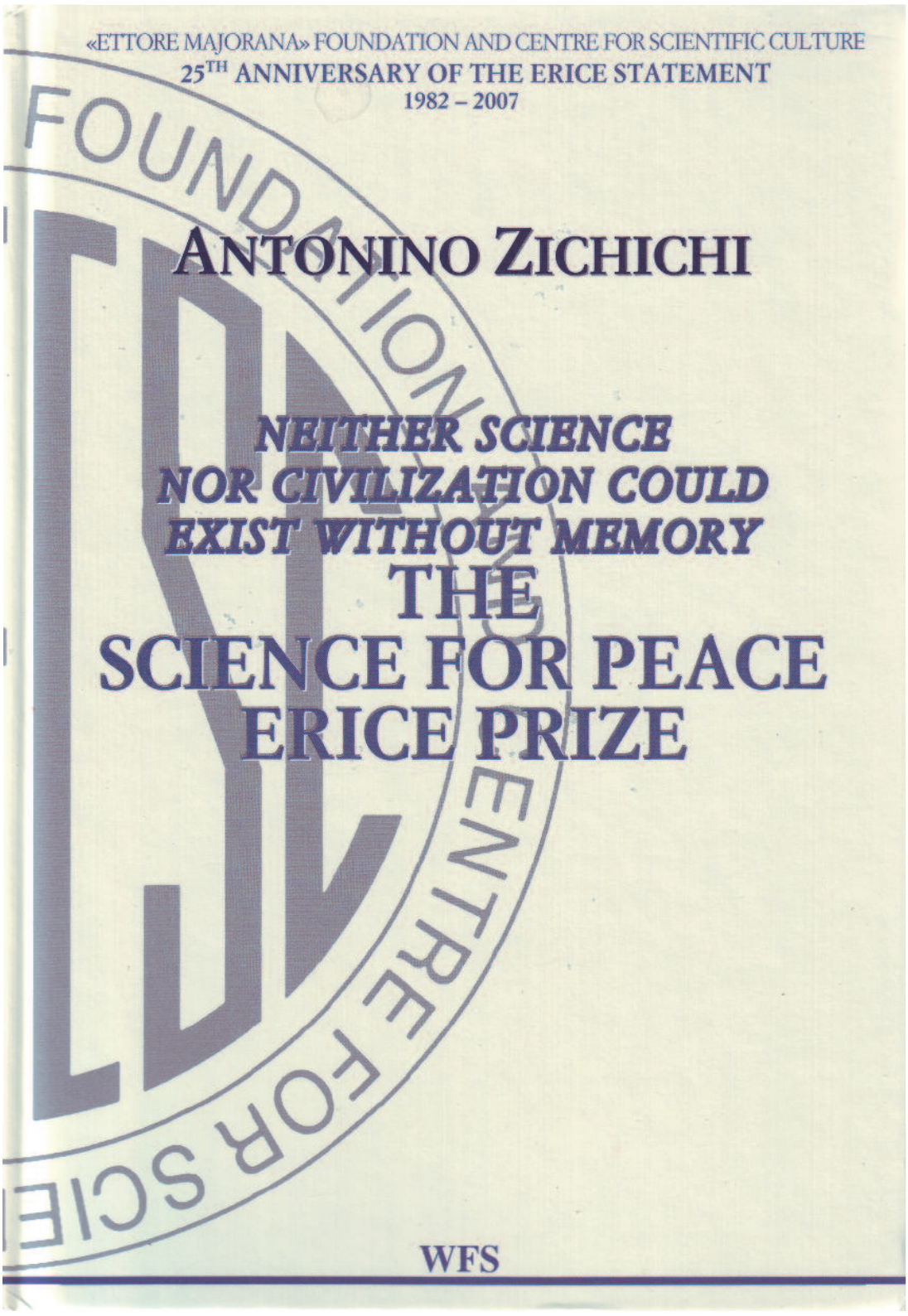
Enrico Fermi: *Neither Science Nor Civilization Could Exist Without Memory*.

On the occasion of the twenty-fifth anniversary of the Ettore Majorana Foundation and Centre for Scientific Culture (EMFCSC), in order to promote the values of scientific culture worldwide and following a proposal by the World Federation of Scientists (WFS), a special law was voted unanimously by the Sicilian Parliament to establish the

"Ettore Majorana Prize – Erice – Science for Peace".

The Prize is to be awarded to men of Culture and Science, who played a leading role in promoting and implementing the goals outlined in the "Erice Statement".

P.A.M. Dirac, P.L. Kapitza, A.D. Sakharov, E. Teller, V.F. Weisskopf, J.B.G. Dausset, S.D. Drell, M. Gell-Mann, H.W. Kendall, L.C. Pauling, A. Salam, C. Villi, R. Doll, J.C. Eccles, T.D. Lee, L. Montagnier, Qian Jaidong, J.S. Schwinger, U. Veronesi, G.M.C. Duby, R.L. Garwin, S.L. Glashow, D.C. Hodgkin, R.Z. Sagdeev, K.M.B. Siegbahn, Y.P. Velikhov, J. Karle, J.M.P. Lehn, A. Magnéli, N.F. Ramsey, H. Rieben, J.J. van Rood, C.S. Wu, R.L. Mössbauer, A. Müller, H. Kohl, M.S. Gorbachev, H.H. John Paul II, R. Clark, M. Cosandey, A. Peterman, R. Wilson, J. Alderdice, J.J. Friedman, M. Koshiba, S. Coleman, A.N. Chilingarov, P.C.W. Chu, L. Esaki, W.N. Lipscomb Jr., J. Szysko, M.-K. Wu, H.A. Hauptman, D.H. Hubel, R. Huber, B.I. Samuelsson, H. Sun, A.E. Yonath, G. 't Hooft, Y.T. Lee, W. Arber, S.C.C. Ting.



You are invited to propose
one name with the Motivation for the 2012 – Prize.

Figure 5

Present and Future need no explanation

1947 SUBNUCLEAR PHYSICS is born
Lamb–shift
π–meson
Strange particles

These three great discoveries are now understood as being:

1) the first example of "virtual" physics;
2) the first example of a bound system made of a quark-antiquark ($q\bar{q}$) pair;
3) the first example of a new flavour beyond the first family.

Without "Virtual Physics" we could never have reached the dream of Gauge Unification and the great competition with Historian who have invented "Virtual History".

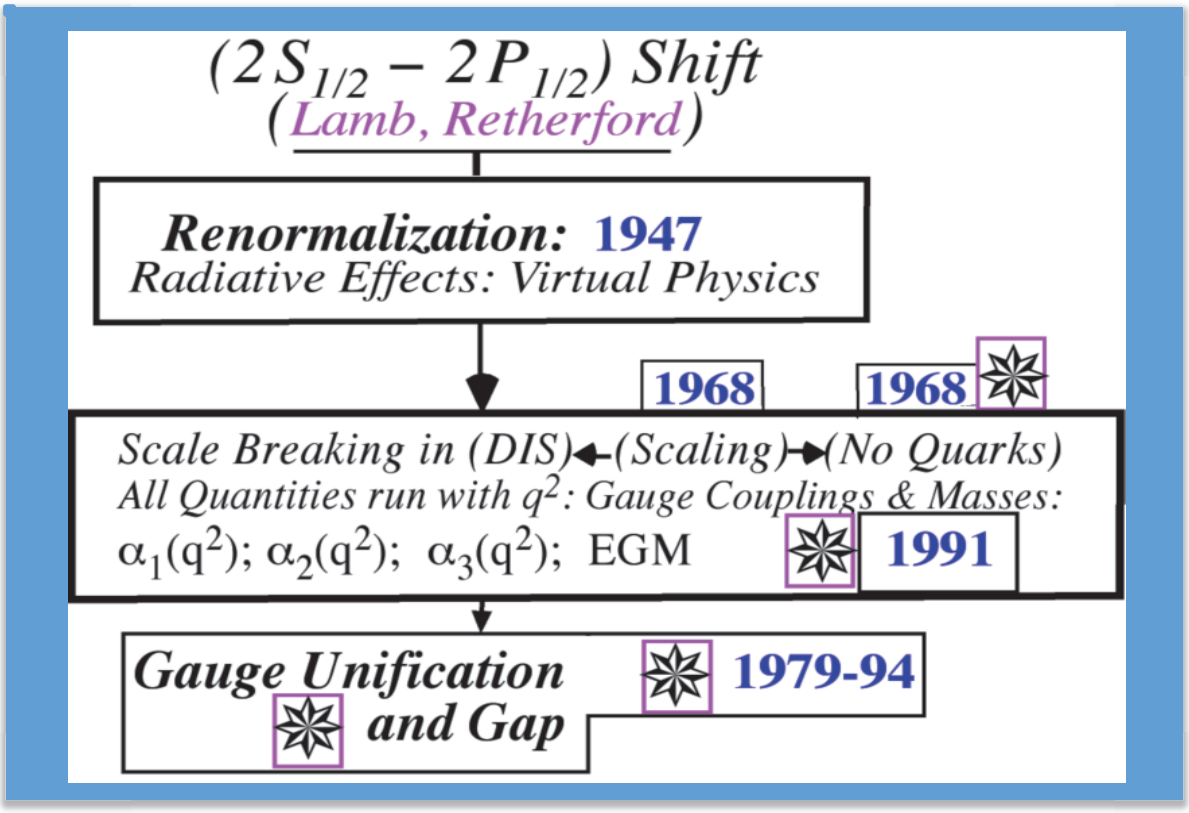


Figure 6

GUT (Grand Unified Theory): the Mathematics

THE UNIFICATION OF ALL FUNDAMENTAL FORCES

The lines in Figure 8 result from calculations executed with a supercomputer using the following system of equations:

$$\mu \frac{d\alpha_i}{d\mu} = \frac{b_i}{2\pi} \alpha_i^2 + \sum_j \frac{b_{ij}}{8\pi^2} \alpha_i \alpha_j$$

This is a system of coupled non-linear differential equations where the existence of the Superworld is taken for granted. This system describes how the gauge couplings (α_1, α_2, α_3) vary with "μ", the basic parameter which depends on the energy of the elementary process, from the maximum level of Energy (Planck Scale) to the energy level of our world.

Figure 7

During more than ten years (from 1979 to 1991), no one had realized that the energy threshold for the existence of the Superworld was strongly dependent on the "running" of the masses.

This is now called: the EGM effect (from the initials of Evolution of Gaugino Masses).

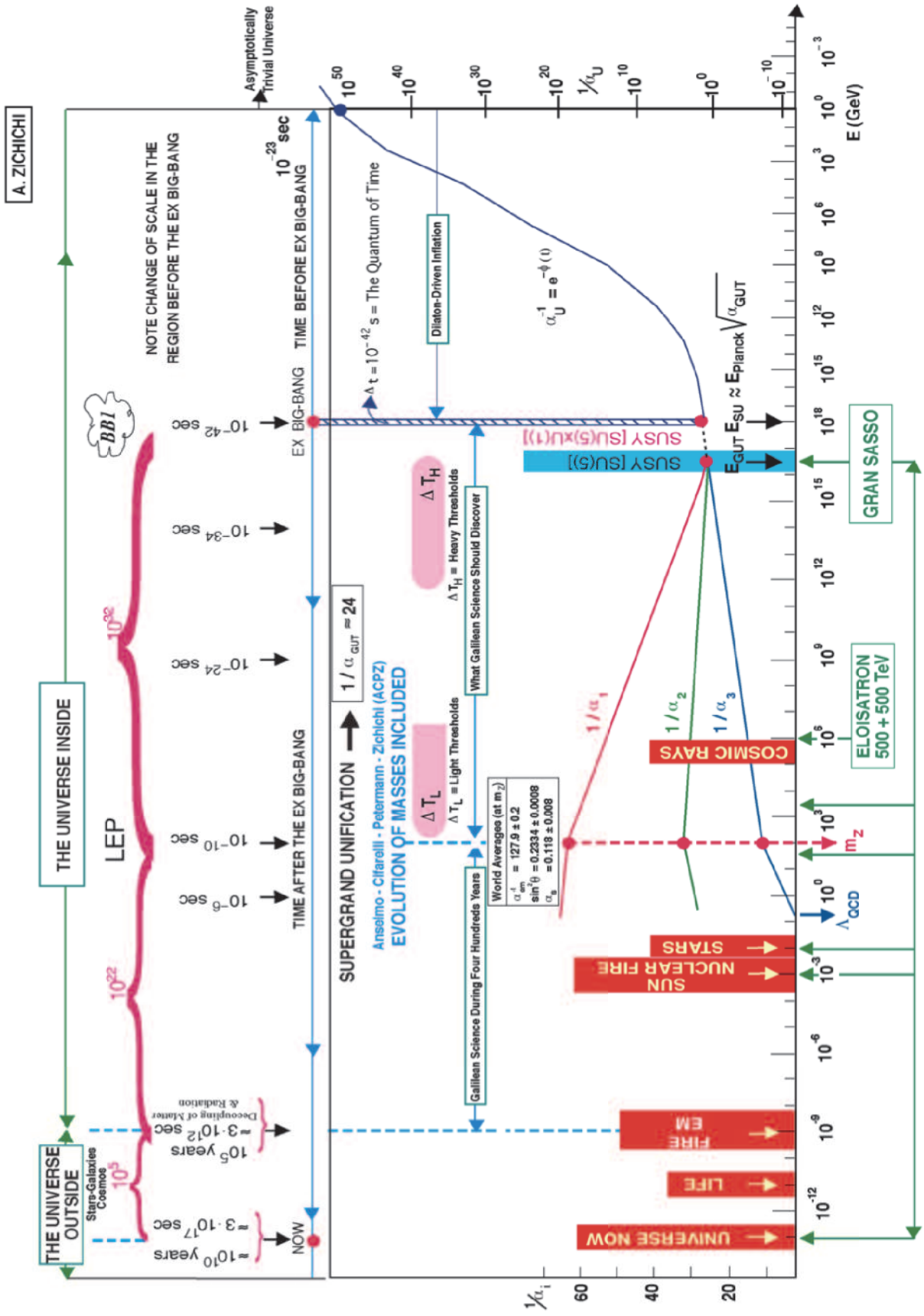

A. ZICHICHI
NOTE CHANGE OF SCALE IN THE REGION BEFORE THE EX BIG-BANG
Asymptotically Trivial Universe
TIME BEFORE EX BIG-BANG
EX BIG-BANG
TIME AFTER THE EX BIG-BANG
NOW
THE UNIVERSE INSIDE
THE UNIVERSE OUTSIDE
Stars-Galaxies Cosmos
Decoupling of Matter & Radiation
LEP
BBI
Dilaton-Driven Inflation
The Quantum of Time
SUPERGRAND UNIFICATION
1 / α GUT ≈ 24
Ansełmo - Cifarelli - Petermann - Zichichi (ACPZ)
EVOLUTION OF MASSES INCLUDED
ΔT_H = Heavy Thresholds
ΔT_L = Light Thresholds
What Galilean Science Should Discover
Galilean Science During Four Hundreds Years
World Averages (at m_Z)
SUSY [SU(5)]
SUSY [SU(5)×U(1)]
E_GUT E_SU ≈ E_Planck √α_GUT
COSMIC RAYS
GRAN SASSO
ELOISATRON 500 + 500 TeV
m_Z
Λ_QCD
STARS
SUN
NUCLEAR FIRE
FIRE EM
LIFE
UNIVERSE NOW
E (GeV)
1/α_i

Figure 8

To compute the energy threshold using only the "running" of the gauge couplings (α_1, α_2, α_3) corresponds to neglecting nearly three orders of magnitude in the energy threshold for the discovery of the first particle (the lightest) of the Superworld [1], as illustrated in Figure 9.

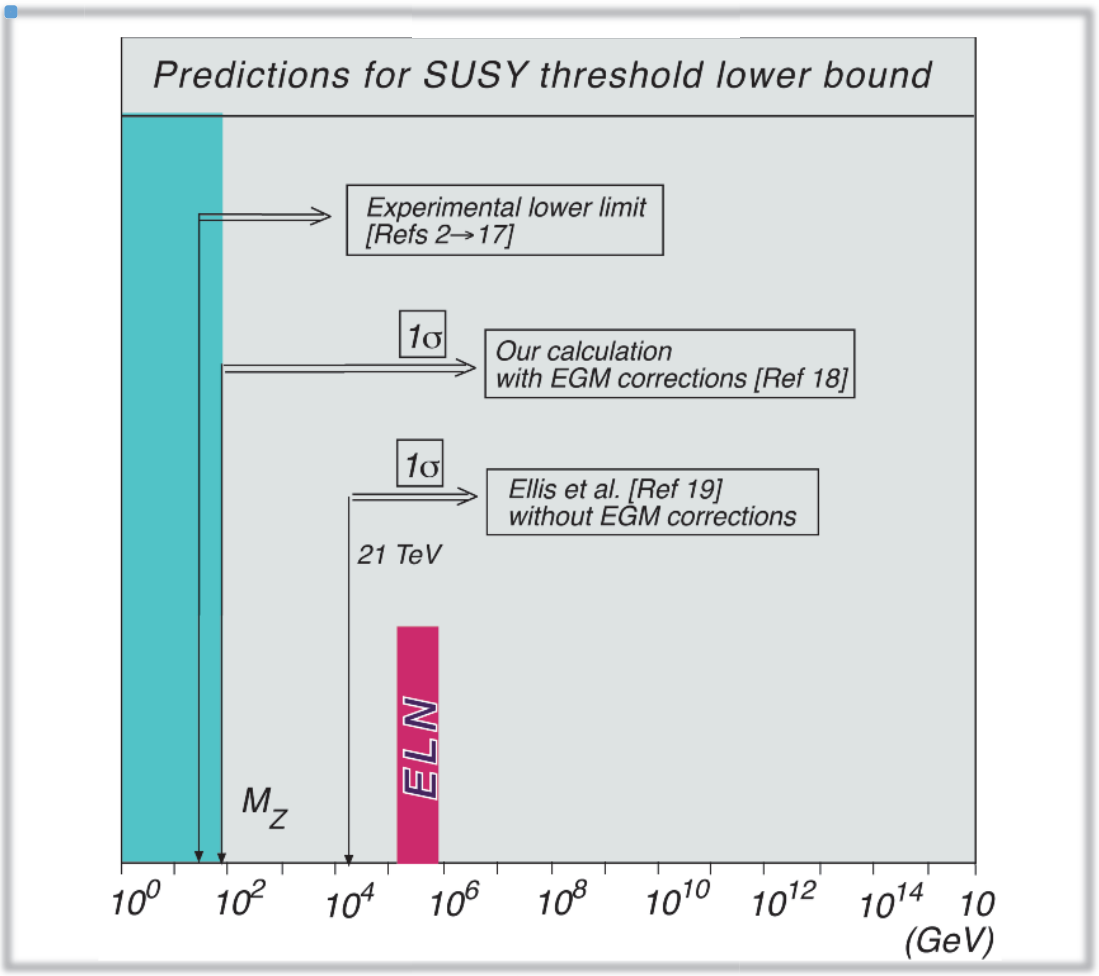


Figure 9

Figure 9 illustrates the EGM effect which lowers by a factor 700 the threshold for the production of the lightest superparticle.

The mathematical formalism used to obtain the results shown in Figures 8 and 9 is a system of three differential non-linear equations (shown in Figure 7) describing how the gauge couplings

$$\alpha_i \ , \ \alpha_j \ \text{(with } i = 1, 2, 3; \text{ and } J = 1, 2, 3 \text{ but } i \neq j),$$

vary with "μ", the basic parameter which depends on the energy of a given elementary process.

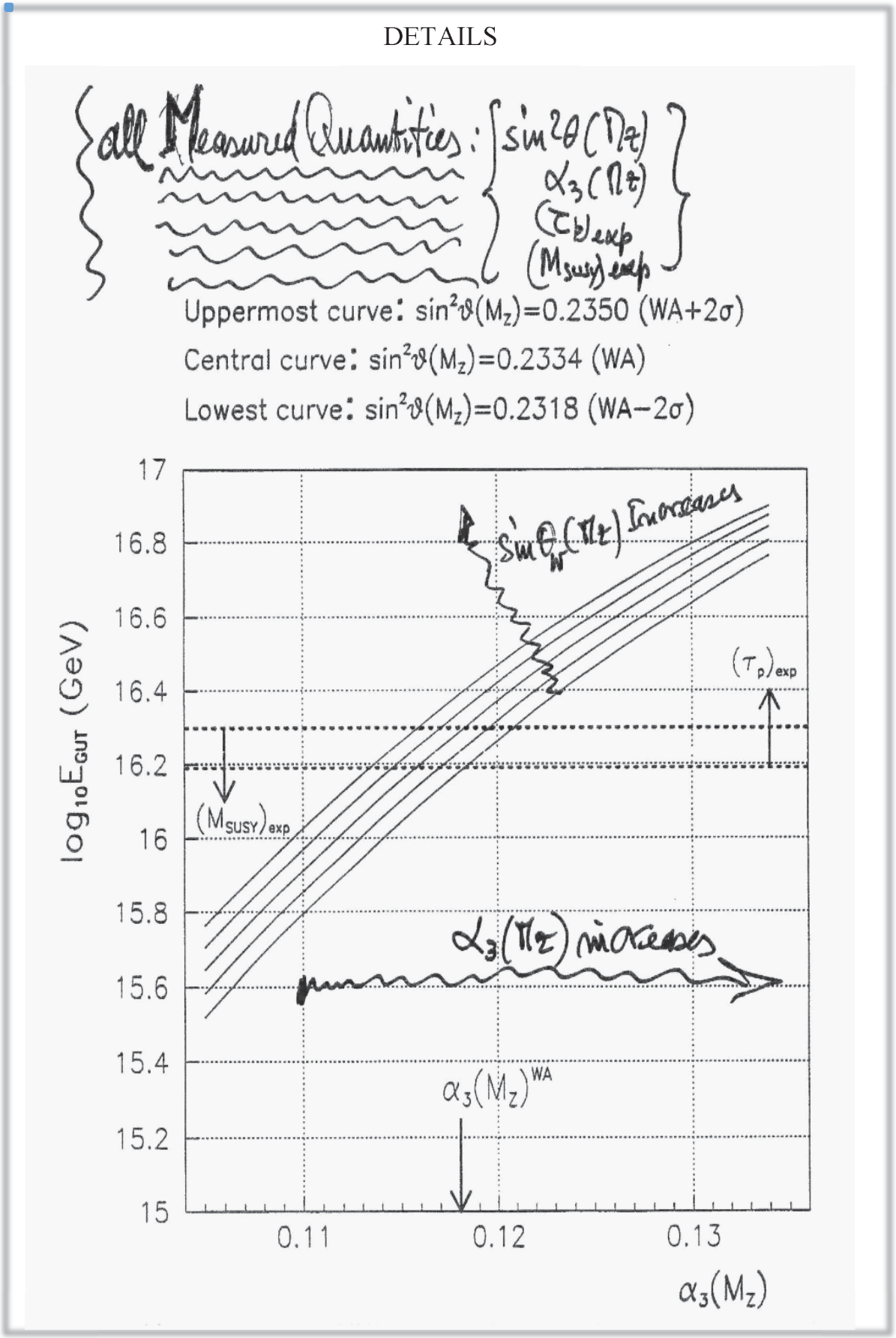

DETAILS
all Measured Quantities: sin²θ(Mz), α3(Mz), (τp)exp, (MSUSY)exp
Uppermost curve: sin²θ(Mz)=0.2350 (WA+2σ)
Central curve: sin²θ(Mz)=0.2334 (WA)
Lowest curve: sin²θ(Mz)=0.2318 (WA−2σ)
sin²θW(Mz) increases
(τp)exp
(MSUSY)exp
α3(Mz) increases
α3(Mz)WA
log10EGUT (GeV)
17
16.8
16.6
16.4
16.2
16
15.8
15.6
15.4
15.2
15
0.11
0.12
0.13
α3(Mz)

Figure 10

The GAP between E_{GUT} and E_{Planck}

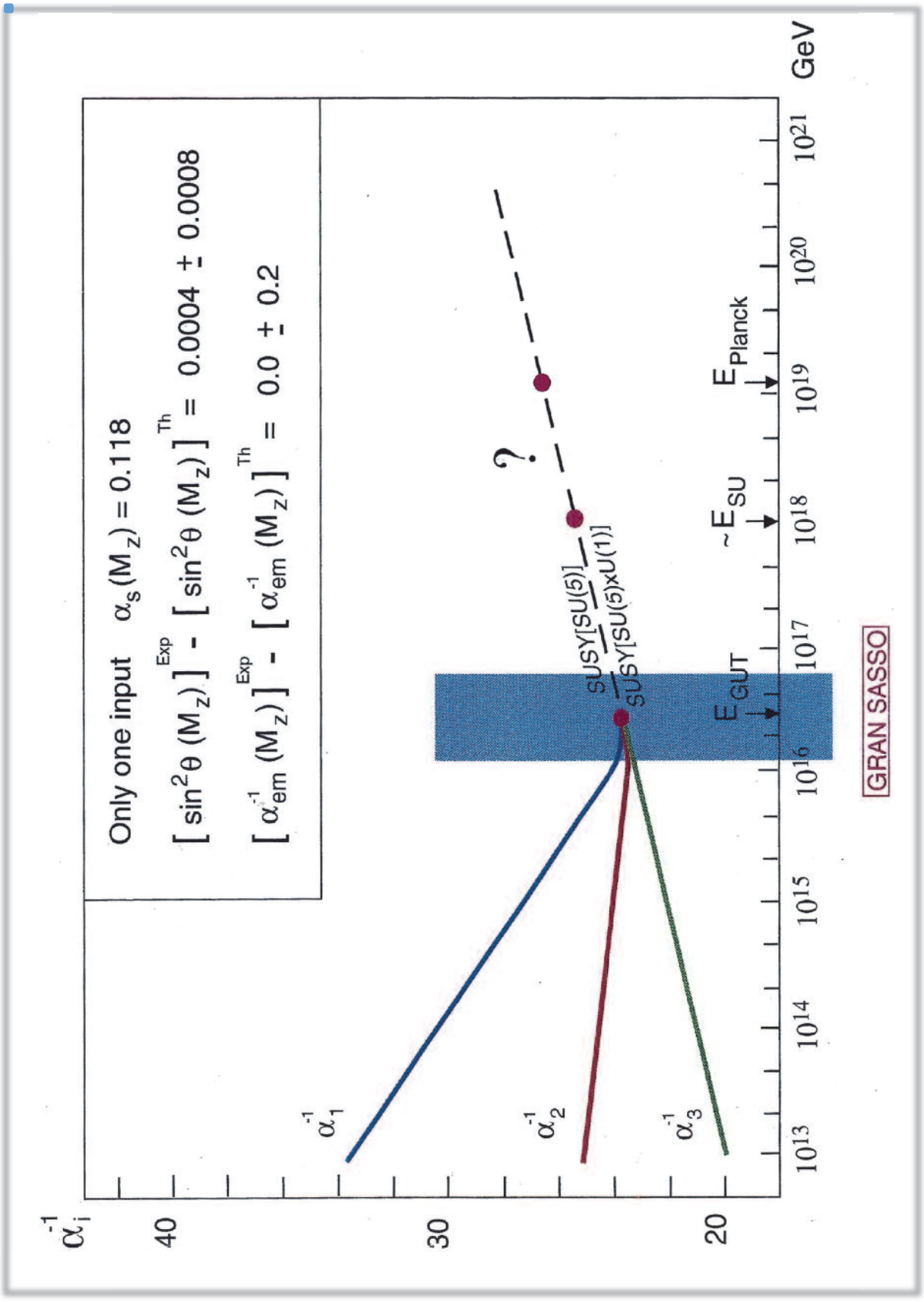
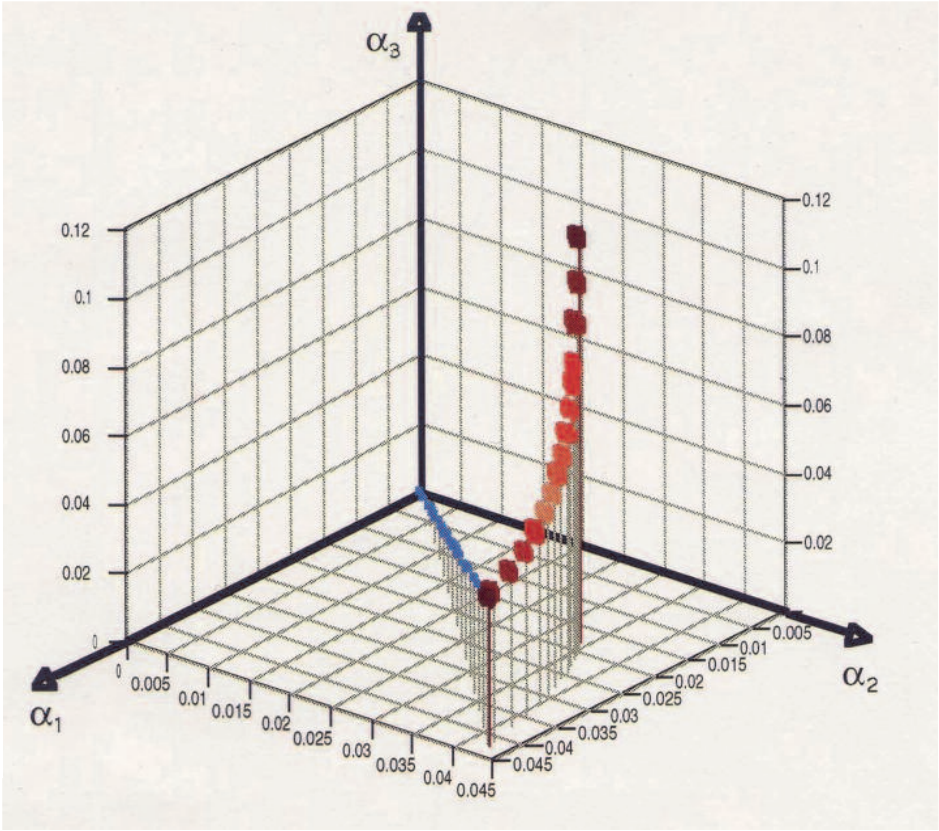


Figure 11

A different way to describe how the gauge couplings α_1, α_2, α_3 vary with energy is reported in Figure 12. The simplest way to get GUT (the point where all fundamental forces are together: Grand Unification Theory) would be the straight line. But the real world does not follow this "platonic" straight line.

The sequence of points (the big red points), in steps of 100 GeV, is very different from the Platonic line (dotted blue points). The way nature goes is reported by the sequence of the big red points which are the result of the mathematics reported in Figure 12.

PLATONIC VERSUS REAL GUT



The "big" red points **represents the real GUT**. They have a sequence of 100 GeV in energy. The last point where the "ideal" platonic straight line intercepts the theoretical prediction is at the energy of the Grand Unification. This corresponds to $E_{GU} = 10^{16.2}$ GeV. Other detailed information on the theoretical inputs: the number of fermionic families, N_F , is 3; the number of Higgs particles, N_H , is 2. The input values of the gauge couplings at the Z^0-mass is α_3 $(M_Z) = 0.118 \pm 0.008$; the other input is the ratio of weak and electromagnetic couplings also measured at the Z^0-mass value: $\sin^2 \theta_W (M_Z) = 0.2334 \pm 0.0008$.

The Platonic GUT is the straight line of the "dotted" blue points.

Figure 12

All problems mentioned so far are based on computations using the existence of Virtual Phenomena which have to obey the Fundamental Logic of Nature, i.e. Virtual Physics which is the most exact limit we are able to compute towards the perfect knowledge of the Logic of Nature started by Galileo Galilei.

Virtual Physics has given rise to the existence of Virtual History.

From Virtual Physics to Virtual History

What is Virtual History? If we compare Virtual History and Virtual Physics, the conclusion is that only if destiny was there Virtual History could obey the same Logic as Virtual Physics does.

VIRTUAL HISTORY

'WHAT IF ?'

	In History ≡ EWRL		In Science ≡ EBUS
I	What if Julius Caesar had been assassinated many years before?	*I*	What if Galileo Galilei had not discovered that $F = mg$?
II	What if Napoleon had not been born?	*II*	What if Newton had not discovered that $F = G\frac{m_1 \cdot m_2}{R_{12}^2}$?
III	What if America had been discovered a few centuries later?	*III*	What if Maxwell had not discovered the unification of electricity, magnetism and optical phenomena, which allowed him to conclude that light is a vibration of the EM field?
IV	What if Louis XVI had been able to win against the 'Storming of the Bastille'?	*IV*	What if Planck had not discovered that $h \neq 0$?
V	What if the 1908 Tunguska Comet had fallen somewhere in Europe instead of Tunguska in Siberia?	*V*	What if Lorentz had not discovered that space and time cannot both be real?
VI	What if the killer of the Austrian Archduke Francisco Ferdinand had been arrested the day before the Sarajevo event?	*VI*	What if Einstein had not discovered the existence of time-like and space-like real worlds? Only in the time-like world, simultaneity does not change, with changing observer.
VII	What if Lenin had been killed during his travelling through Germany?	*VII*	What if Rutherford had not discovered the nucleus?
VIII	What if Hitler had not been appointed Chancellor by the President of the Republic of Weimar Paul von Hindenburg?	*VIII*	What if Hess had not discovered cosmic rays?
IX	What if the first nuclear weapon had been built either by Japan before Pearl Harbour (1941) or by Hitler in 1942 or by Stalin in 1943?	*IX*	What if Dirac had not discovered his equation, which opens new horizons, including the existence of the antiworld?
X	What if Nazi Germany had defeated the Soviet Union?	*X*	What if Fermi had not discovered weak forces?
XI	What if Karol Wojtyla had not been elected Pope, thus becoming John Paul II?	*XI*	What if Fermi and Dirac had not discovered the Fermi–Dirac statistics?
XII	What if the USSR had not collapsed?	*XII*	What if the 'strange particles' had not been discovered in the Blackett Lab?

Table 1

1947 SUBNUCLEAR PHYSICS is born

Lamb–shift *OK*

π–meson *NOW*

Strange particles

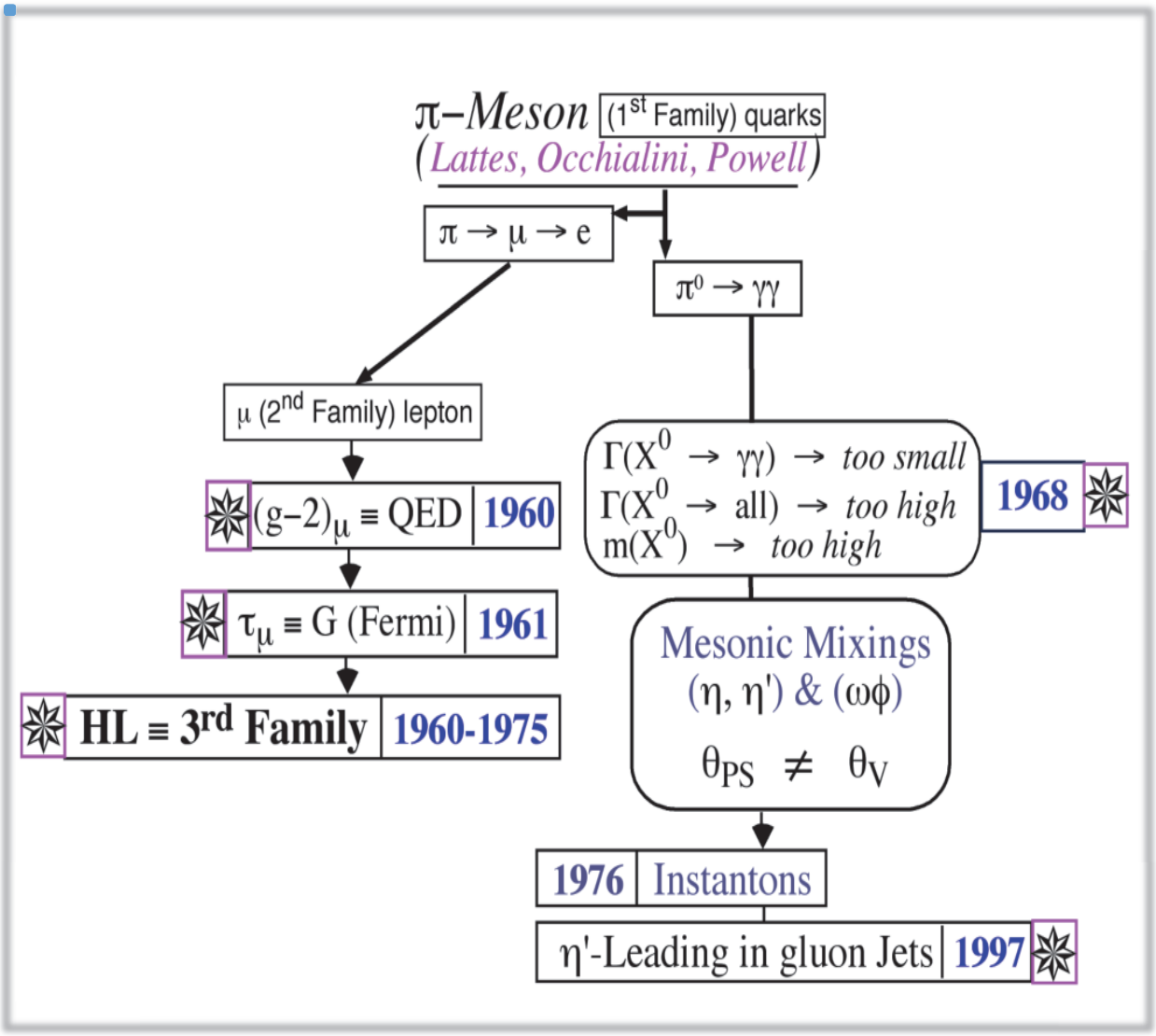


Figure 13

From the π–meson to the Third Family of Leptons

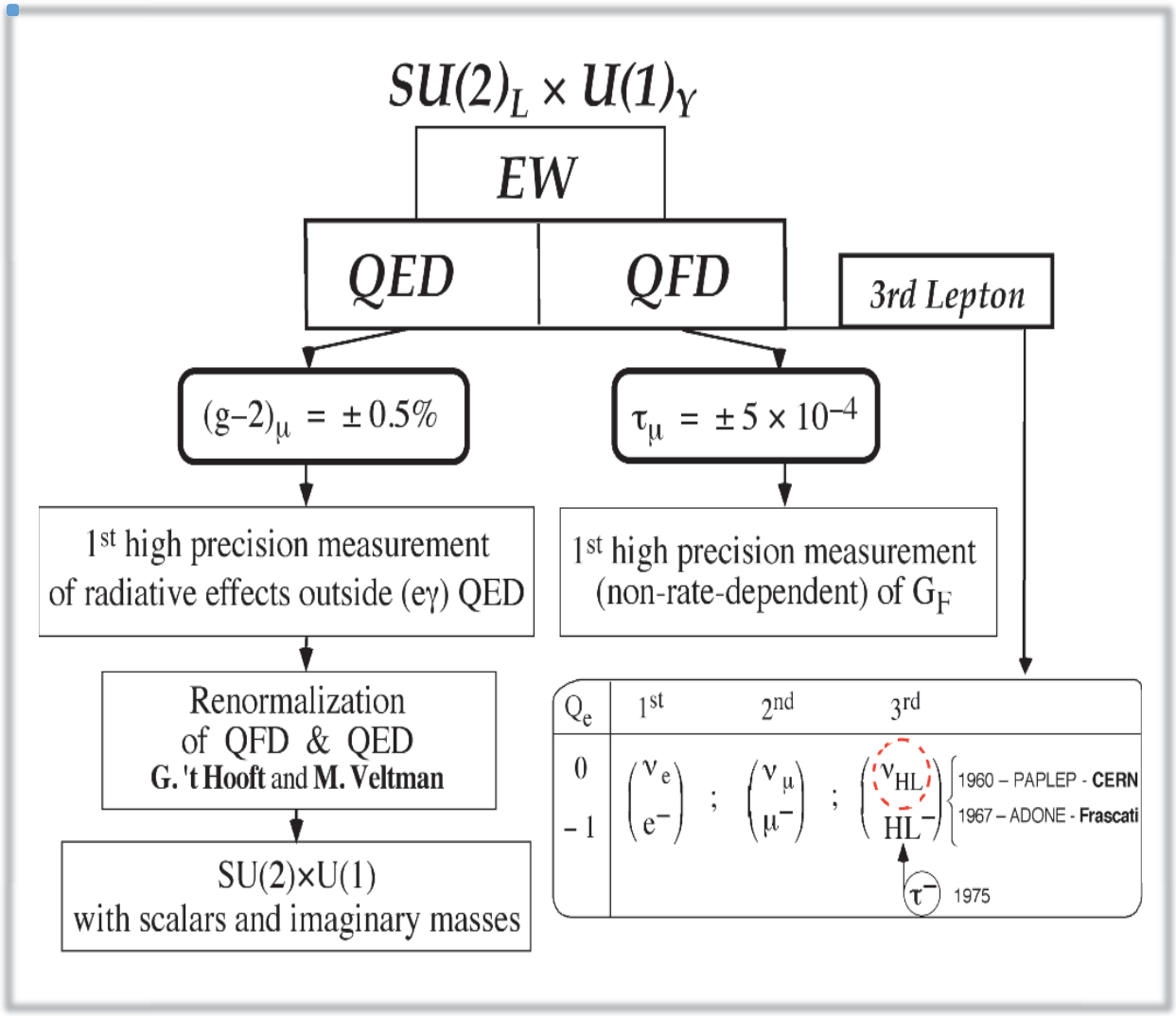


Figure 14

$$* \quad (g-2)_\mu \equiv (\pm)\ 0{,}5\%$$

This experiment required the construction of the largest and highest precision "flat" magnet of the world, whose schematic drawing is reported in Figure 15.

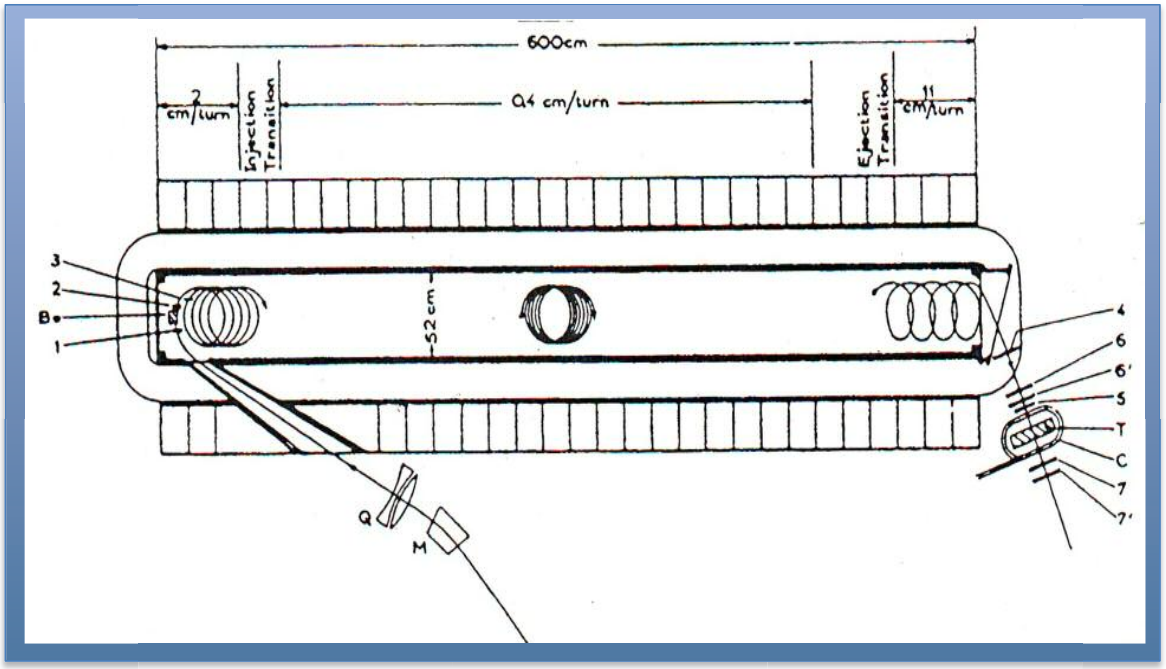
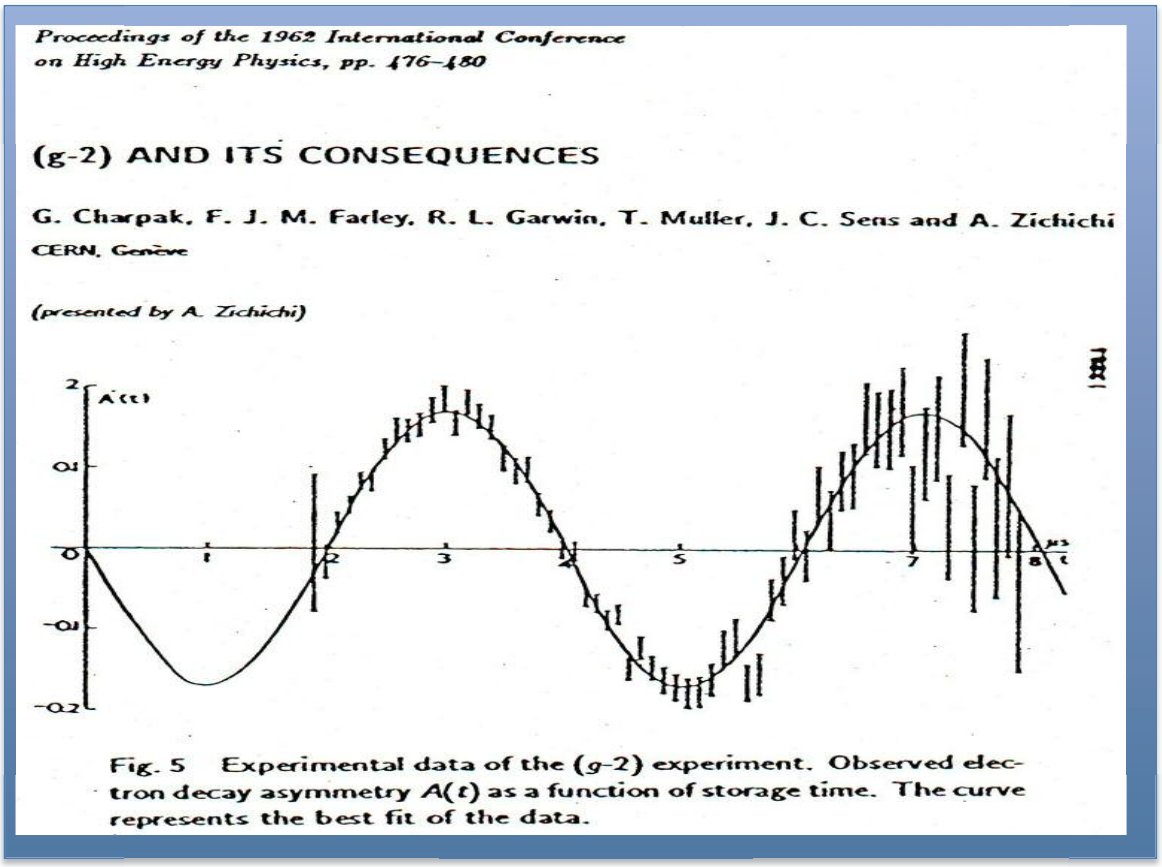


Figure 15: (Figure from [20]). General plan of the 6-metre magnet. *M*: bending magnet; *Q*: pair of quadrupoles; 1, Be, 2, 3: injection assembly consisting of Be-moderator and counters 1, 2, 3; *T*: methylene-iodide target; counters 66', 77': "backward" and "forward" electron telescopes. A stored and ejected muon is registered as a coincidence 4, 5, 66' $\overline{7}$, gated by a 1, 2, 3 and by either a forward or backward electron signal.



Proceedings of the 1962 International Conference on High Energy Physics, pp. 476–480

(g-2) AND ITS CONSEQUENCES

G. Charpak, F. J. M. Farley, R. L. Garwin, T. Muller, J. C. Sens and A. Zichichi
CERN, Genève

(presented by A. Zichichi)

Fig. 5 Experimental data of the (g–2) experiment. Observed electron decay asymmetry $A(t)$ as a function of storage time. The curve represents the best fit of the data.

Figure 16

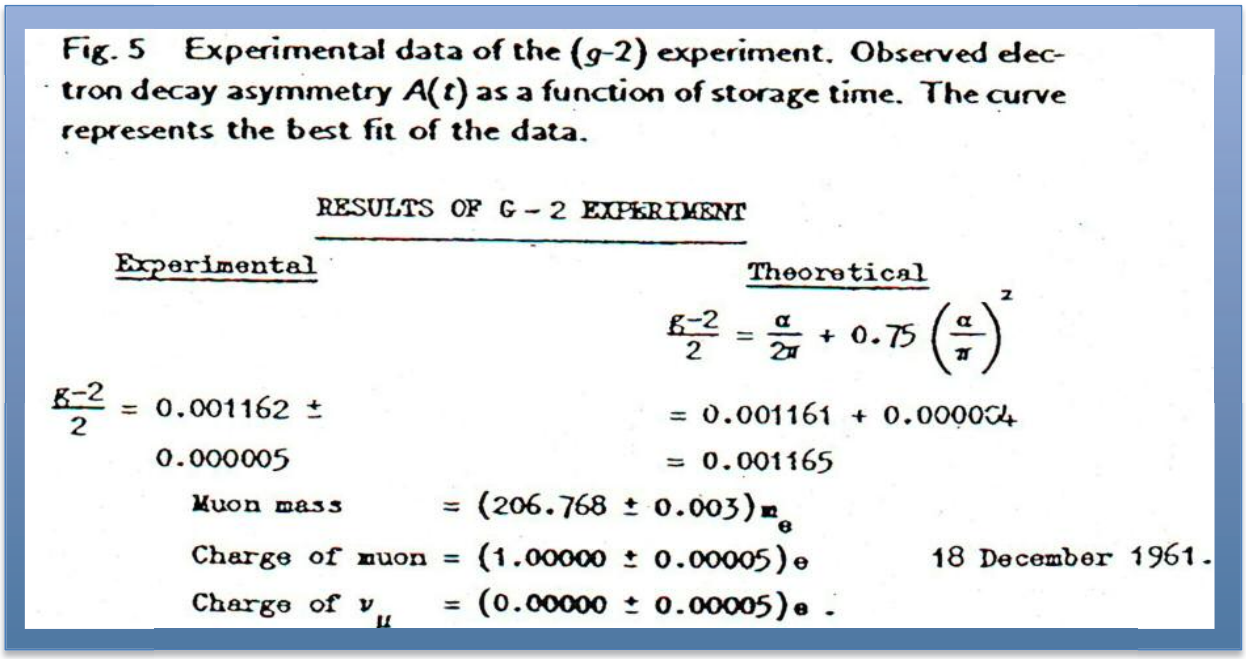


Fig. 5 Experimental data of the $(g-2)$ experiment. Observed electron decay asymmetry $A(t)$ as a function of storage time. The curve represents the best fit of the data.

RESULTS OF G – 2 EXPERIMENT

Experimental

$\frac{g-2}{2} = 0.001162 \pm 0.000005$

Theoretical

$\frac{g-2}{2} = \frac{\alpha}{2\pi} + 0.75\left(\frac{\alpha}{\pi}\right)^2$

$= 0.001161 + 0.000004$

$= 0.001165$

Muon mass $= (206.768 \pm 0.003)\, m_e$

Charge of muon $= (1.00000 \pm 0.00005)\, e$

Charge of $\nu_\mu = (0.00000 \pm 0.00005)\, e$.

18 December 1961.

Figure 17

The first high precision measurement of QED radiative effects outside the (electron and photon) world [21] are in Figures 16 and 17.

Conclusion: the μ is a heavy electron to within ± 0,5%.

$$\tau_\mu \equiv GF \equiv \pm 5 \times 10^{-4}$$

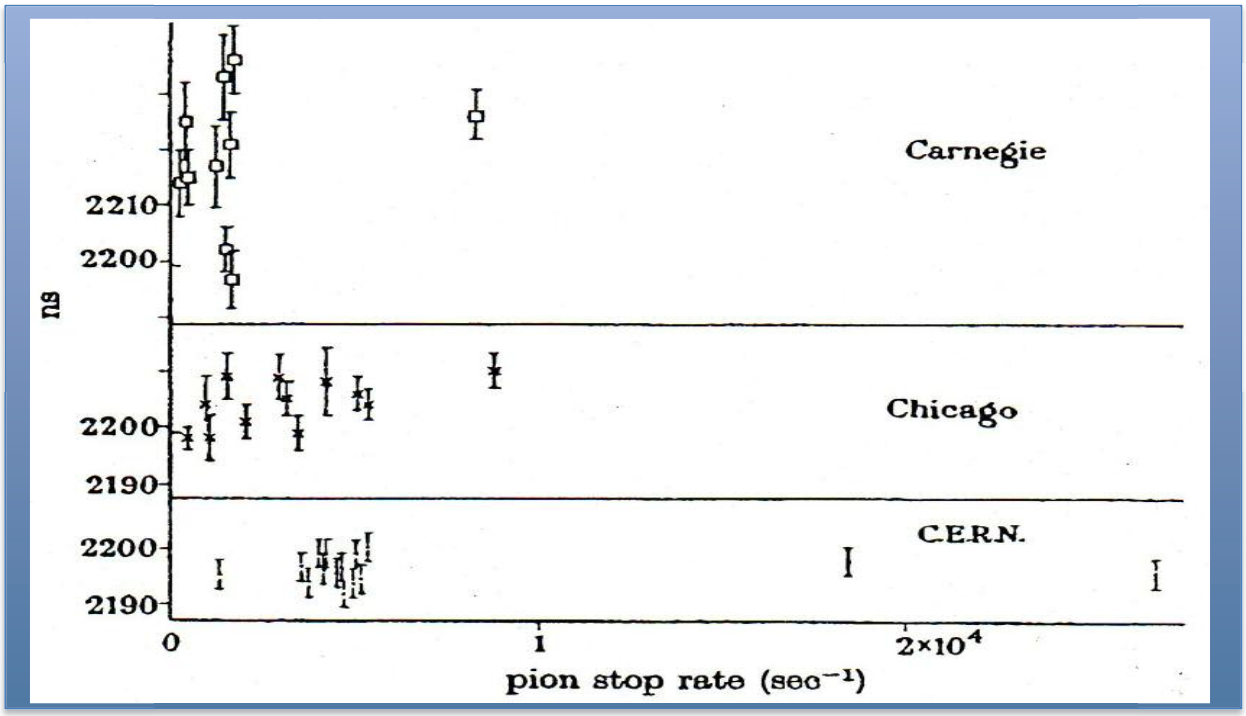


Figure 18: (Figure from [22]) The diagram above shows that the experimental results on τ_μ obtained in Chicago and Carnegie were affected by a rate dependent systematic effect which invalidates the data. The CERN result is the first without this trouble.

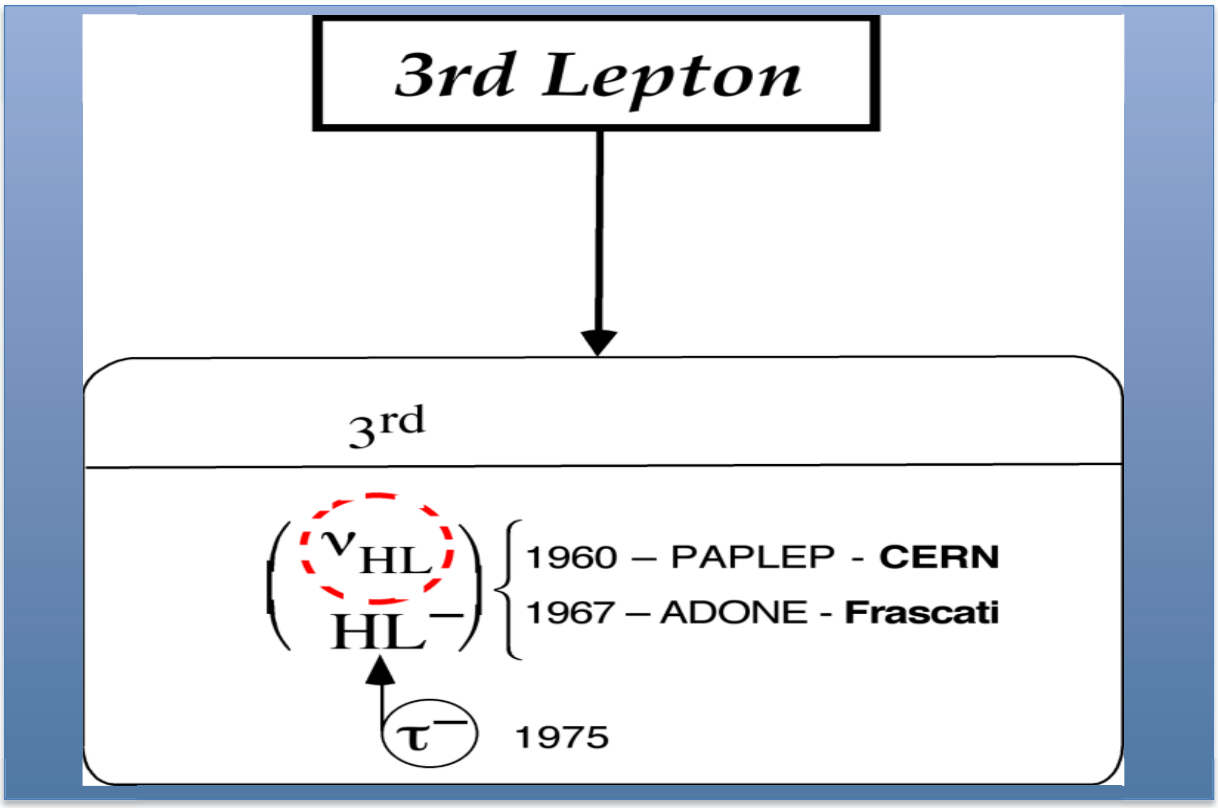


Figure 19

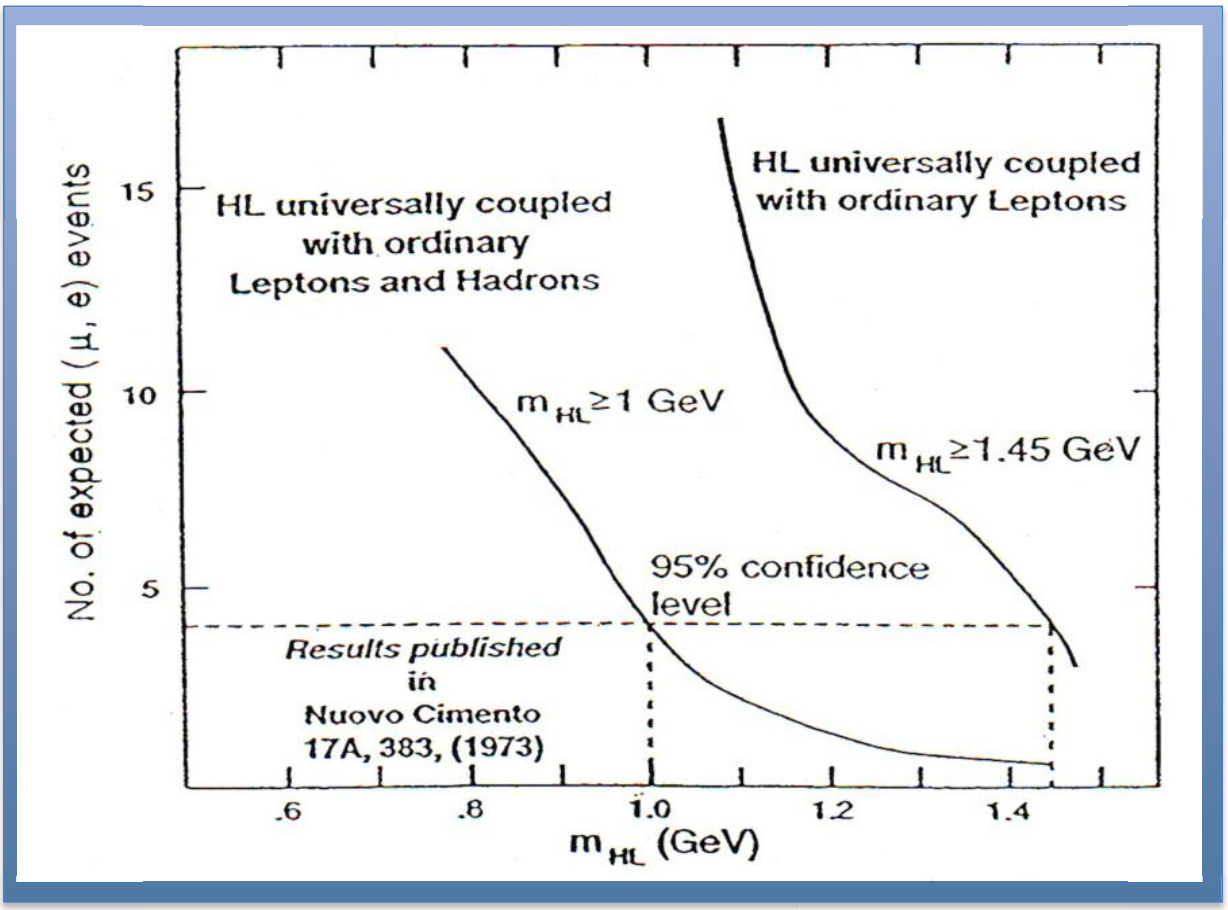


Figure 20: (Figure from [23]) The expected number of ($e^{\pm}$ $\mu^{\mp}$) pairs vs. m_{HL}, i.e. the heavy lepton mass, for two types of universal weak couplings of the heavy lepton.

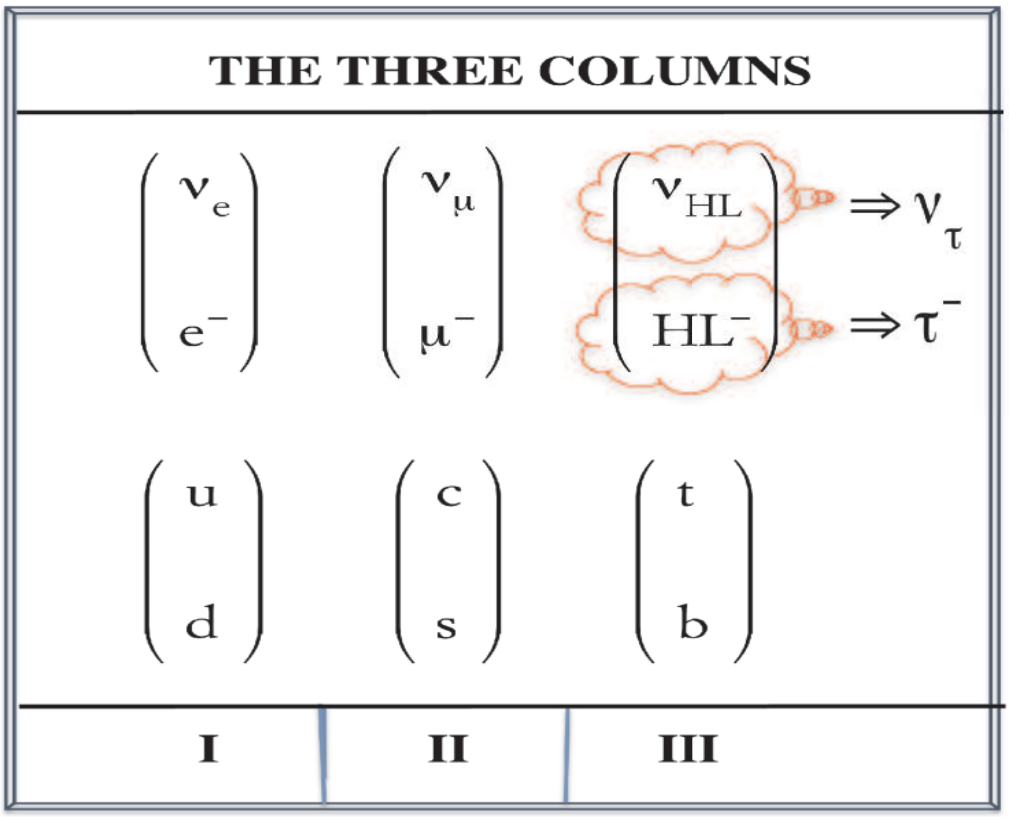


Figure 21

From the π−meson to the Instantons we need the experimental discovery of $\theta_{PS} \neq \theta_V$

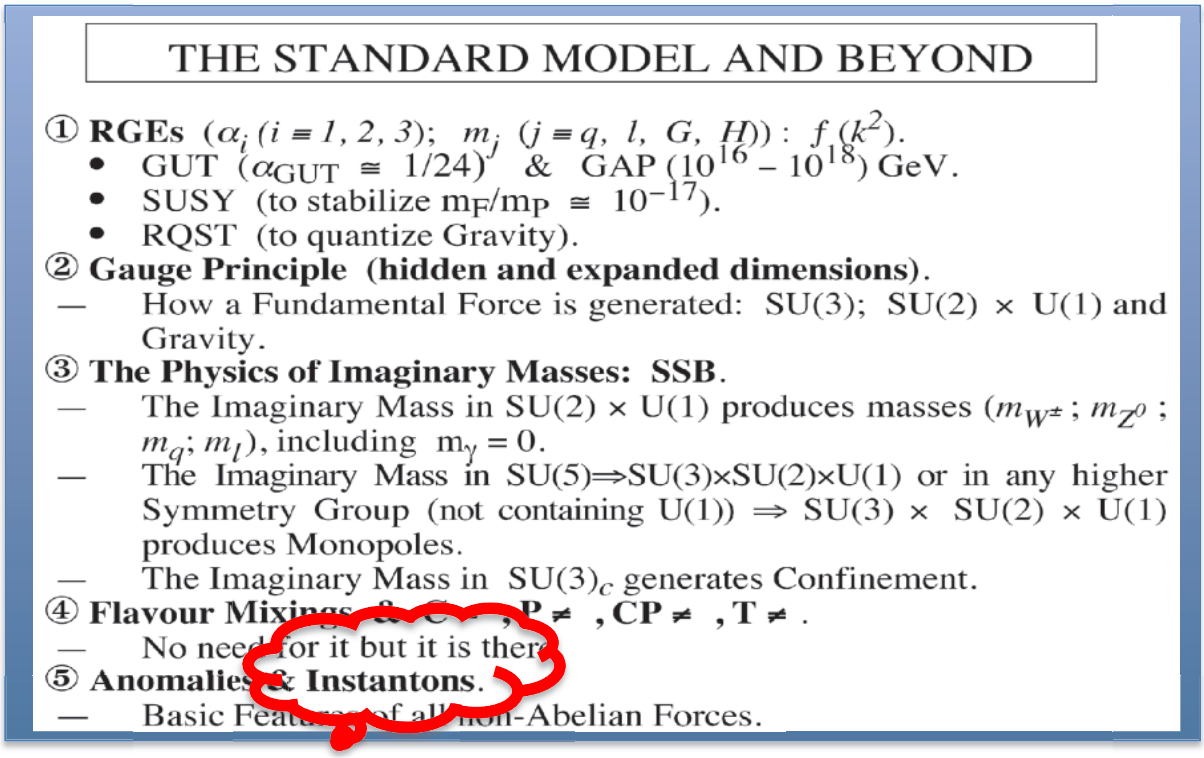


Figure 22

1947 SUBNUCLEAR PHYSICS is born

Lamb–shift *OK*

π–meson *OK*

Strange particles *NOW*

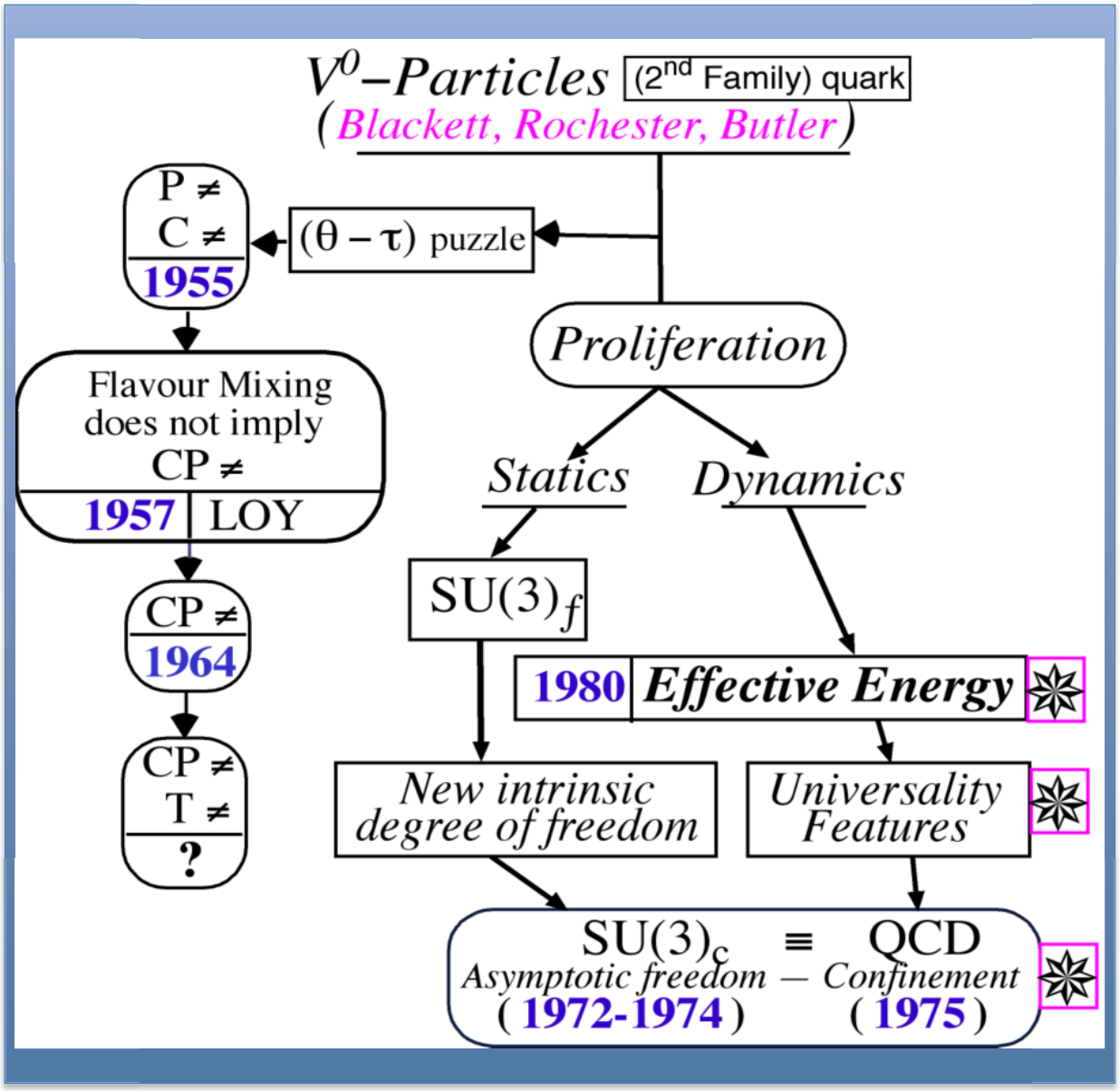
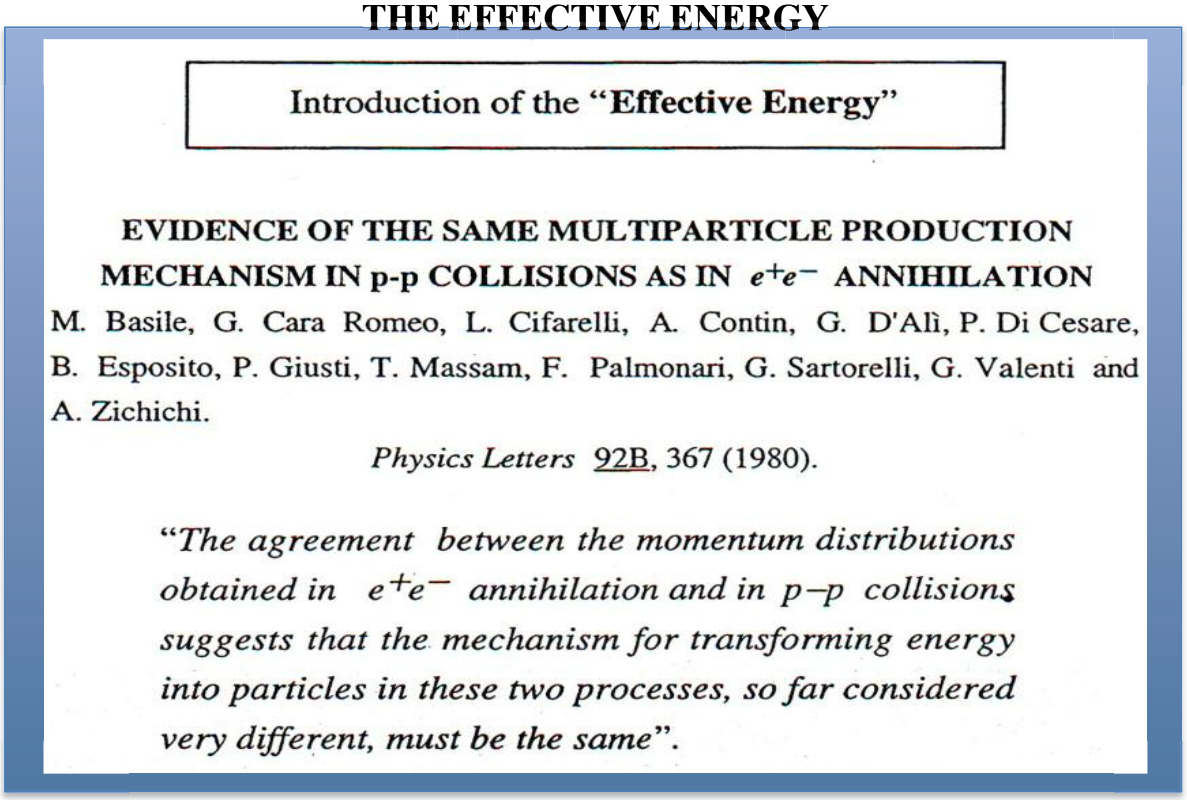


Figure 23

THE EFFECTIVE ENERGY



Introduction of the "**Effective Energy**"

EVIDENCE OF THE SAME MULTIPARTICLE PRODUCTION MECHANISM IN p-p COLLISIONS AS IN e^+e^- ANNIHILATION

M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Alì, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi.

Physics Letters 92B, 367 (1980).

"The agreement between the momentum distributions obtained in e^+e^- annihilation and in $p-p$ collisions suggests that the mechanism for transforming energy into particles in these two processes, so far considered very different, must be the same".

Figure 24: The first paper where the effective energy was introduced in the study of high energy (pp) interactions at ISR.

The proliferation in the "dynamic" sector was the multitude of final states produced by pairs of interacting particles, in strong, electromagnetic and weak processes:

Strong	EM	Weak
π p	γ p	ν p
K p	e p	
p p	μ p	
p n	e^+e^-	
$\bar{p}$ p		

It is the introduction of the effective energy which allowed one to put all the different final states on the same basis.

This basis is the quantities measured in the multihadronic final states:

i) the average charged multiplicity; $< n_{ch} >$;

ii) the fractional energy distribution; $d\sigma / dx_i$;

iii) the transverse momentum distribution $d\sigma / dp_{t_i}$; etc. .... .

THE END OF A MYTH: HIGH-P_T PHYSICS

M. Basile, J. Berbiers, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Alì, C. Del Papa, P. Giusti, T. Massam, R. Nania, F. Palmonari, G. Sartorelli, M. Spinetti, G. Susinno, L. Votano and A. Zichichi.

Opening Lecture in Proceedings of the XXII Course of the "Ettore Majorana" International School of Subnuclear Physics, Erice, Italy, 5-15 August 1984: "Quarks, Leptons, and their Constituents" (Plenum Press, New York-London, 1988), 1.

"So far, the main picture of hadronic physics has been based on a distinction between high $-p_T$ and low $-p_T$ phenomena.

In the framework of parton model, high $-p_T$ processes were the only candidates to establish a link between

- *purely hadronic processes*
- *(e^+e^-) annihilations*
- *(DIS) processes.*

The advent of QCD has emphasized in a dramatic way the privileged role of high $-p_T$ physics due to the fact that, thanks to asymptotic freedom, QCD calculations via perturbative methods can be attempted at high $-p_T$ and results successfully compared with experimental data [1]. The conclusion was: we can forget about everything else and limit ourselves to high $-p_T$ physics.

Being theoretically off limits, low $-p_T$ phenomena, which represent the overwhelming majority of hadronic processes (more than 99% of physics is here), have been up to now neglected. By subtracting the leading proton effects in order to derive the effective energy available for particle production and by using the correct variables, the BCF collaboration has performed a systematic study of the final states produced in low $-p_T$ (pp) interactions at the ISR and has compared the results with those obtained in the processes listed below:

Process		Data Sources
(e^+e^-)		SLAC, DORIS, PETRA
(DIS)		SPS/EMC
(pp)	Transverse physics	ISR (AFS)
$(\bar{p}p)$		SPS Collider (UA1)
(e^+e^-)		PETRA/TASSO (leading subtraction)

The results of this study [2-18] show that, once a common basis for comparison is found by the use of the correct variables, remarkable analogies are observed in processes so far considered basically different like

- *low $-p_T$ (pp) interactions*
- *(e^+e^-) annihilations*
- *(DIS) processes*
- *high $-p_T$ (pp) and $(\bar{p}p)$ interactions*

This is how universality features emerge, and this is the basis to proceed for a meaningful comparison, i.e.:

first identify the correct variables to establish a common basis,
then proceed to a detailed comparison."*

* *The root of this new approach to the study of hadronic interactions goes back a long time to a proposal by the CERN-Bologna group: "Study of deep inelastic high momentum transfer hadronic collisions" PMI/com-69/35, 8 July 1969."*

Figure 25: Reproduction of the conclusions of a review paper [24].

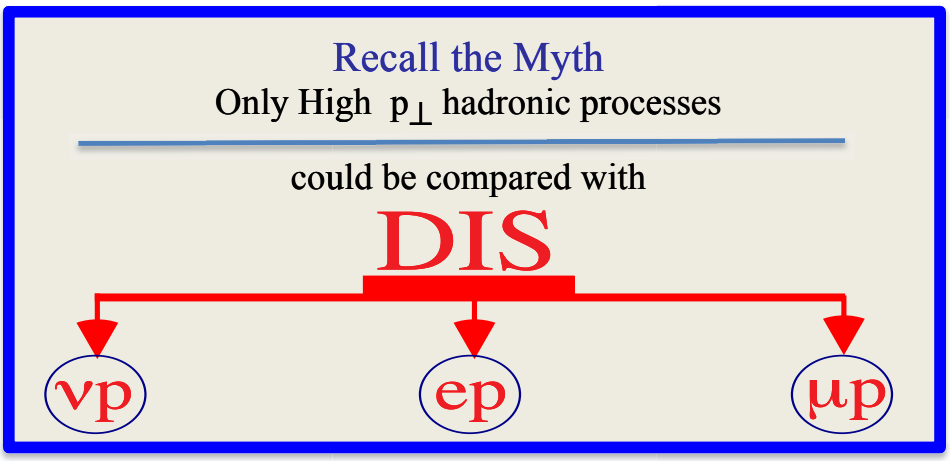


Figure 26: A synthesis of the high transverse momentum myth.

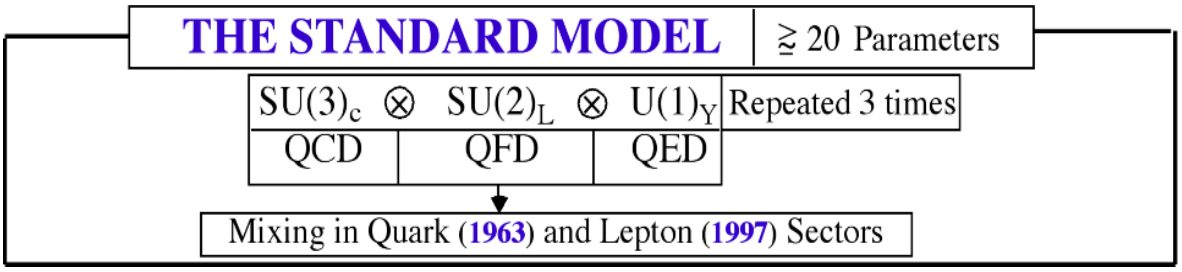


Figure 27

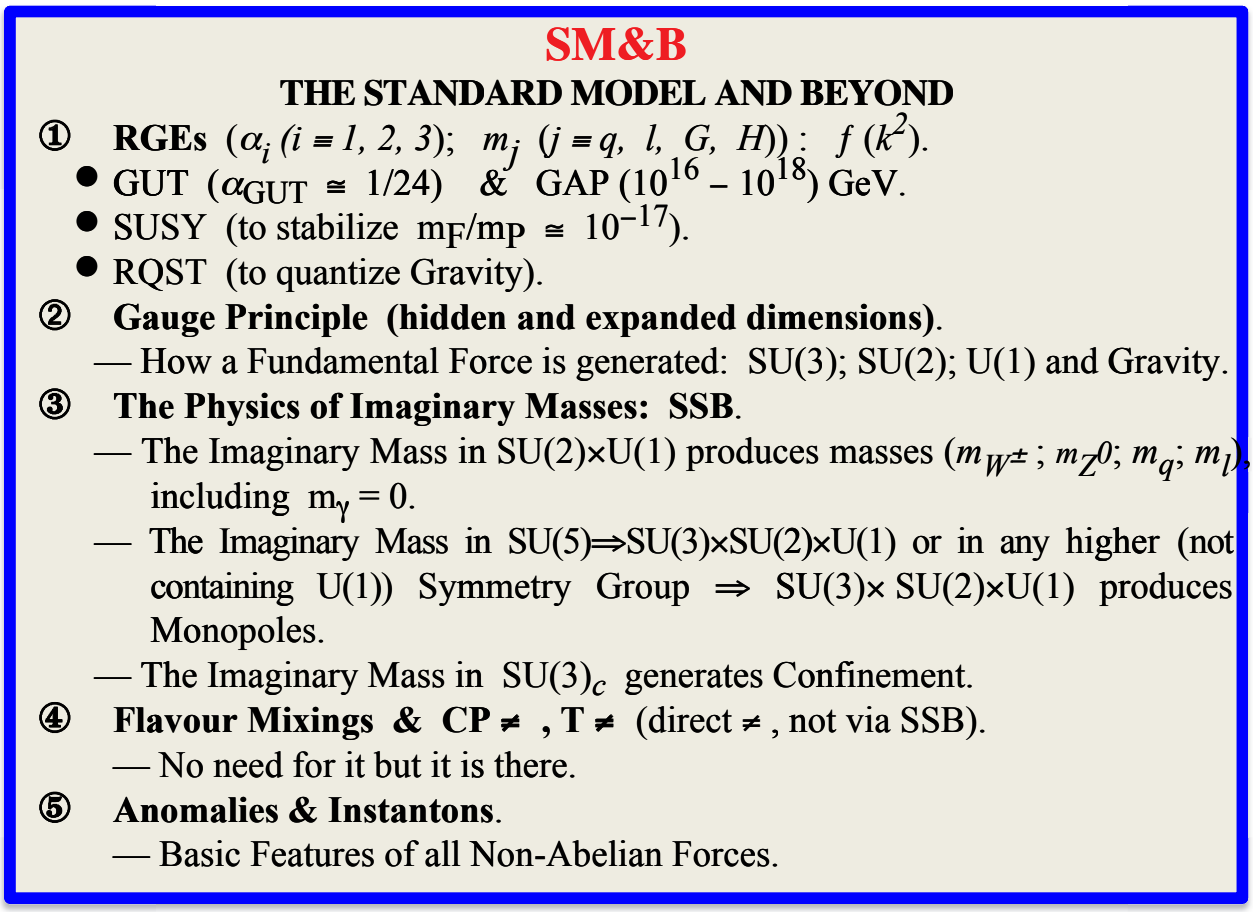


Figure 28

NOTE

q	≡ quark and squark;	m_F	≡ Fermi mass scale;
l	≡ lepton and slepton;	m_P	≡ Planck mass scale;
G	≡ Gauge boson and Gaugino;	k	≡ quadrimomentum;
H	≡ Higgs and Shiggs;	C	≡ Charge Conjugation;
RGEs	≡ Renormalization Group Equations;	P	≡ Parity;
GUT	≡ Grand Unified Theory;	T	≡ Time Reversal;
SUSY	≡ Supersymmetry;	≠	≡ Breakdown of Symmetry Operators.
RQST	≡ Relativistic Quantum String Theory;		
SSB	≡ Spontaneous Symmetry Breaking.		

Figure 29

The five basic steps in our understanding the Logic of Nature

① The renormalization group equations (RGEs) imply that the gauge couplings (α_i) and the masses (m_j) all run with k^2. It is this running which allows GUT, suggests SUSY and produces the need for a non point-like description (RQST) of physics processes, thus opening the way to quantize gravity.

② All forces originate in the same way: the gauge principle.

③ Imaginary masses play a central role in describing nature: SSB & Confinement.

④ The mass-eigenstates are mixed when the Fermi forces come in: the matrix describing the mixing is the product of two fundamental matrices. Why the mixing is there?

⑤ The Abelian force QED has lost its role of being the guide for all fundamental forces. The non-Abelian gauge forces dominate and have features which are not present in QED.

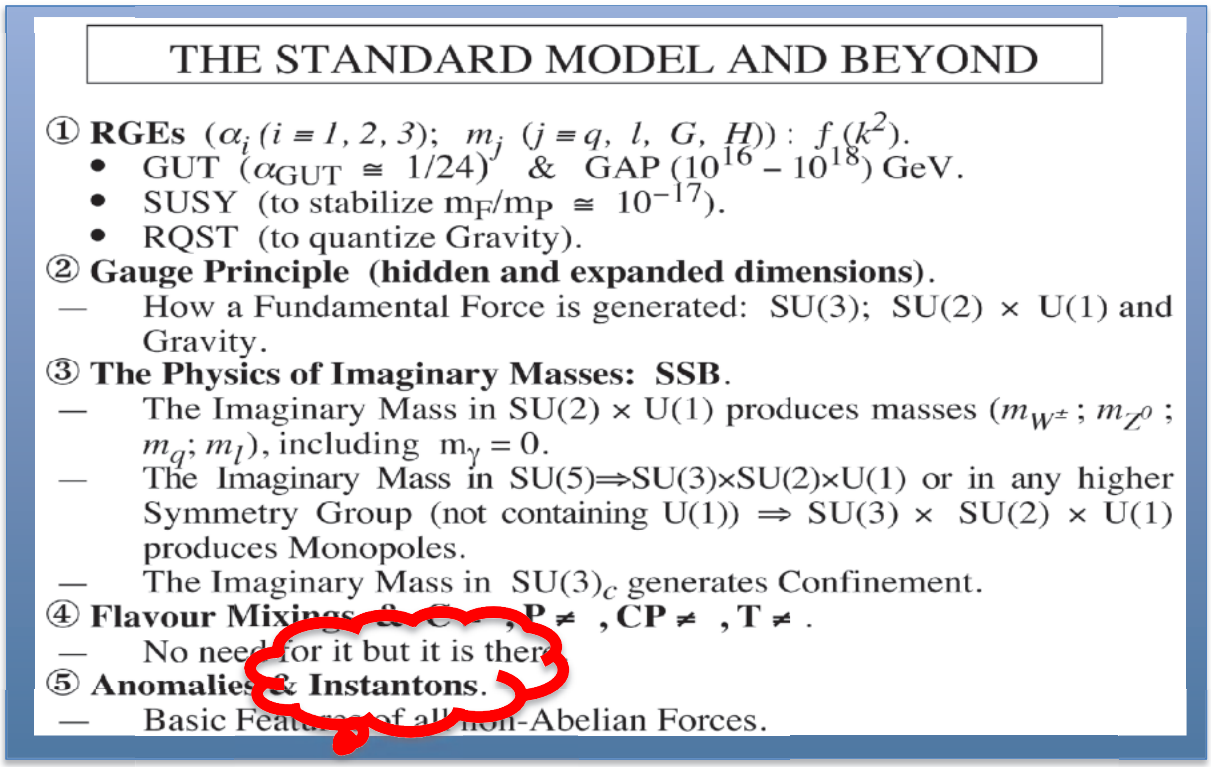


Figure 22

Instantons

The Instanton [25, 26] is a solution of the classical field equations in Euclidean space-time. It is originated by the properties of the vacuum which is strongly coupled to the field quanta of a given gauge force. In a quantized world the Instanton corresponds to tunnelling effects in Minkowski space-time. These tunnelling effects are recognized in practice by the fact that they violate a global symmetry-law. There are two kinds of Instantons, one for QCD and one for the QFD, the electro-weak forces.

In both cases, $SU(3)_c$ and $SU(2)_L$, i.e. QCD and QFD, the effects produced by the Instantons can be understood in terms of the properties of the Dirac sea. In fact, the vacuum, made of fermions, has fermionic properties.

In QCD, these properties determine the "non-spontaneous", i.e. direct, breakdown of "chirality" invariance. This has allowed to understand the behaviour of the η and the η' mesons [27, 28, 29, 30].

In $SU(2)_L$ the effect of Instantons is linked to the fact that the non-Abelian gauge force, QFD, acts only on left-handed states and Instantons generate baryon number non-conservation, which is another U(1) breaking.

Instantons typically have the effect of explicity breaking U(1) symmetries.

Why we need the Instantons? In order to explain $\theta_{PS} \neq \theta_V$.

SU(3) States

Note that the SU(3) states are (in terms of the quark composition):

$$\eta_8 = \frac{u\bar{u} + d\bar{d} - 2\,s\bar{s}}{\sqrt{6}}$$

(8^{th} multiplet of SU(3) octet)

$$\eta_1 = \frac{u\bar{u} + d\bar{d} + s\bar{s}}{\sqrt{3}}$$

(SU(3) singlet).

In the real world we have the physical states

$$J^{PC} = 0^{-+} \begin{cases} \eta(m \cong 500\text{Mev}) \equiv \dfrac{u\bar{u} + d\bar{d} - \sqrt{2}s\bar{s}}{\sqrt{4}} \\ \eta'(m \cong 950\text{Mev}) \equiv \dfrac{u\bar{u} + d\bar{d} + \sqrt{2}s\bar{s}}{\sqrt{4}} \end{cases}$$

$$J^{PC} = 1^{--} \begin{cases} \omega(m \cong 750\text{Mev}) \equiv \dfrac{u\bar{u} + d\bar{d}}{\sqrt{2}} \\ \phi(m \cong 1020\text{Mev}) \equiv s\bar{s} \end{cases}$$

with $\theta_{PS} \approx 10°$

$$\begin{Bmatrix} \eta = \eta_8 \cos\theta_{PS} - \eta_1 \sin\theta_{PS} \\ \eta' = \eta_8 \sin\theta_{PS} + \eta_1 \cos\theta_{PS} \end{Bmatrix}$$

and $\theta_V \approx 45°$

$$\begin{Bmatrix} \omega = \omega_8 \cos\theta_V - \omega_1 \sin\theta_V \\ \phi = \omega_8 \sin\theta_V + \omega_1 \cos\theta_V \end{Bmatrix}.$$

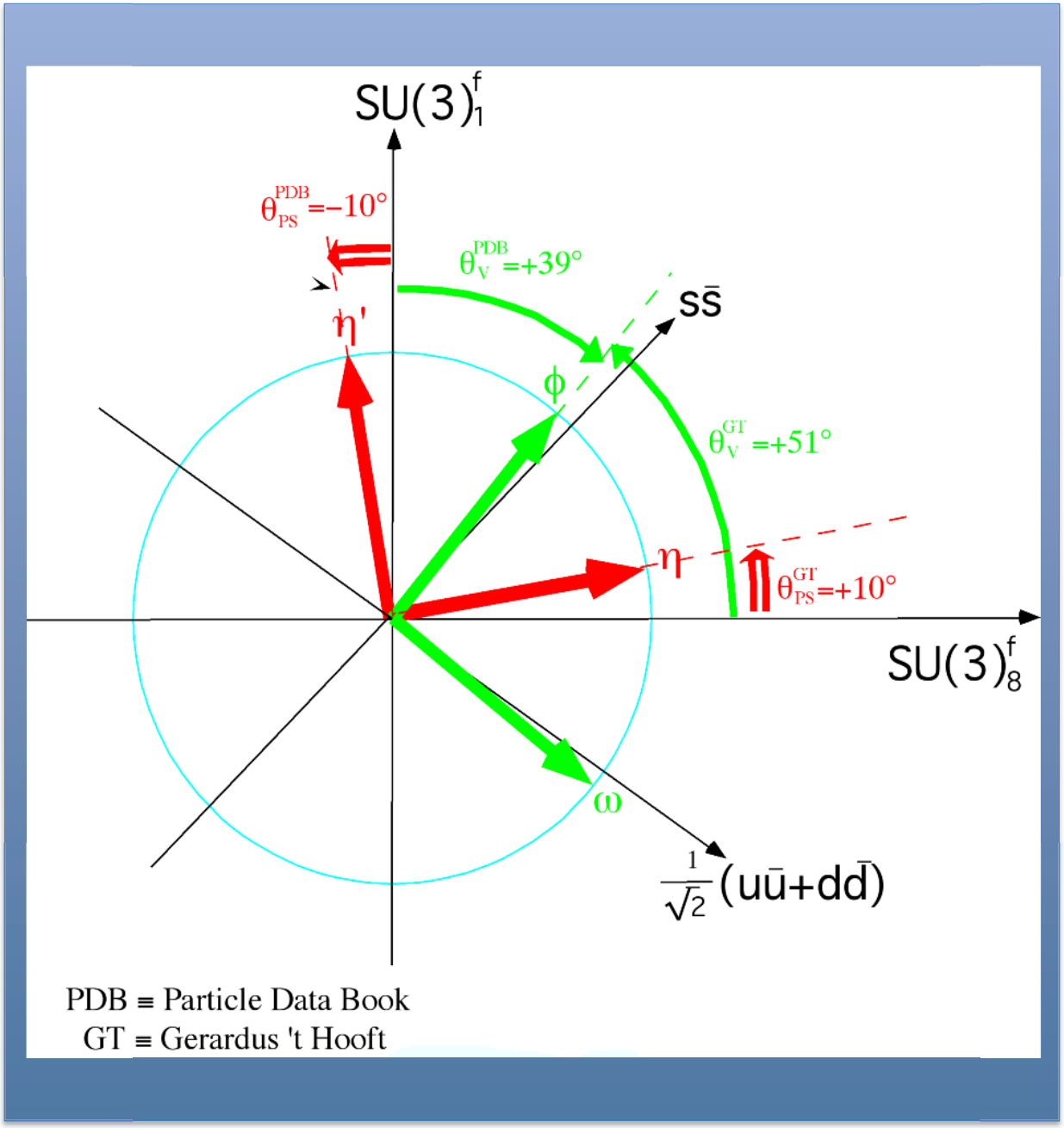
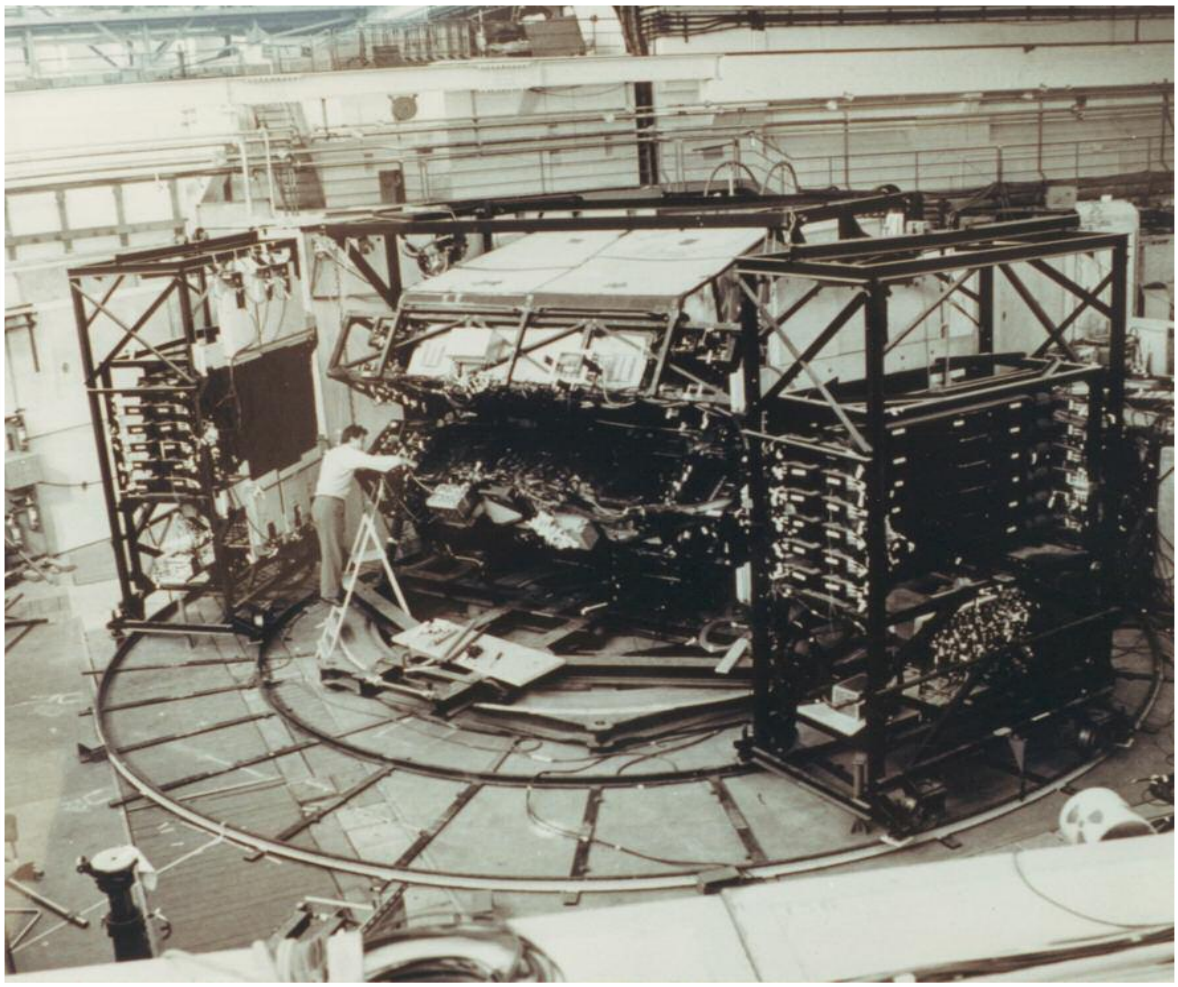

SU(3)$_1^f$
θ_{PS}^{PDB}=−10°
θ_V^{PDB}=+39°
η'
ss̄
ϕ
θ_V^{GT}=+51°
η
θ_{PS}^{GT}=+10°
SU(3)$_8^f$
ω
$\frac{1}{\sqrt{2}}$(uū+dd̄)
PDB ≡ Particle Data Book
GT ≡ Gerardus 't Hooft

Figure 30

– 1963 –

This is the first example of what is now "standard" in experimental subnuclear physics: very large acceptance detectors.



On the rails the "neutron missing mass spectrometer".

PAPLEP
Proton AntiProton into Lepton Pairs
first search for the 3rd lepton
and
$\theta_{PS} \neq \theta_{V}$.

Figure 4

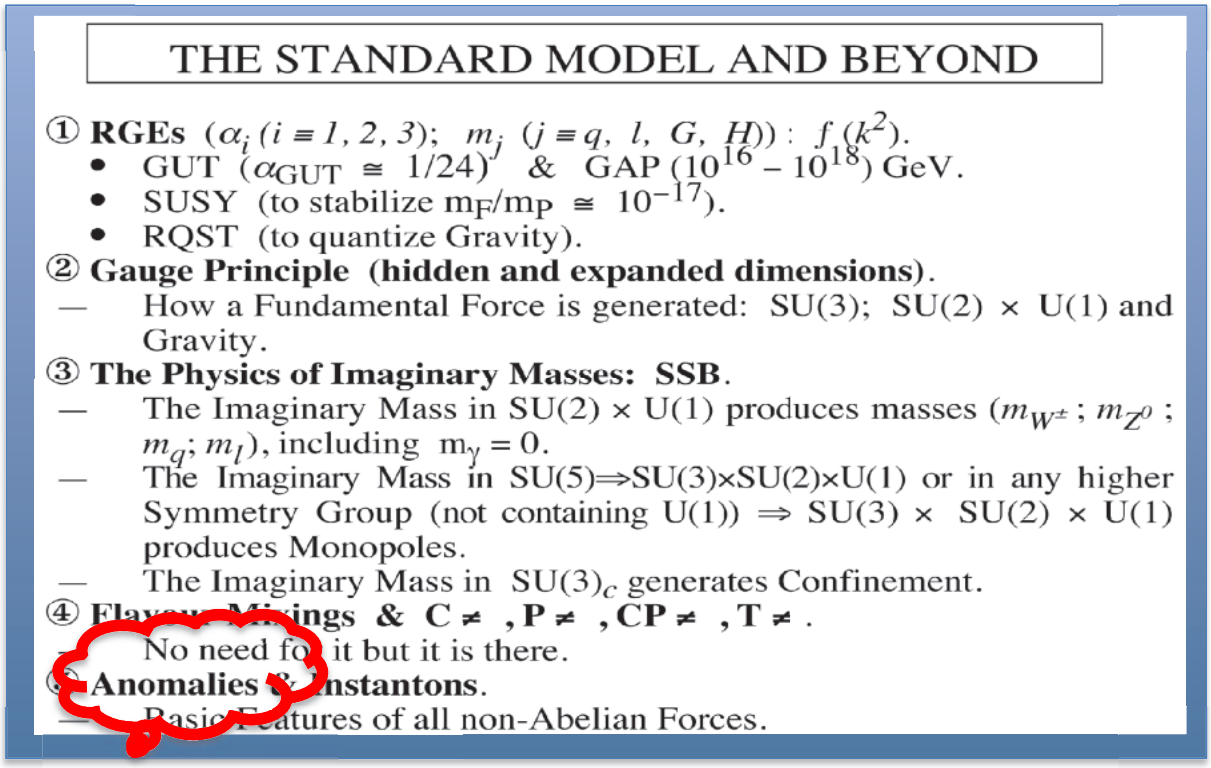


Figure 22

Anomalies

The anomalies correspond to quantum effects [31, 32].

The term "anomaly" is not so well-chosen since it refers to several different features in elementary particle theory. The term originated in QED where radiative effects were first discovered. It was introduced in order to describe quantum effects in Abelian QFT such as the "anomalous" magnetic moment of the muon.

- **Non-Abelian QFT have chiral anomalies** which must be cancelled, thus imposing severe conditions on the basic structures of the matter fields (example: the top quark needed in the third family).
- **Anomalies exist also in Abelian theories**, such as those needed to describe $\pi^0 \rightarrow \gamma\gamma$ [33, 34, 35]. They can thus be used to predict physical processes.

Relativistic Quantum String Theory (RQST)

The Standard Model deals with only two of the three known forces.

However quantum mechanics is contagious and gravity cannot avoid quantization.

Much of our hope has become focused on string theory.

Unfortunately **RQST** has not yet descended to low energy, and goes on making predictions at inaccessible energies.

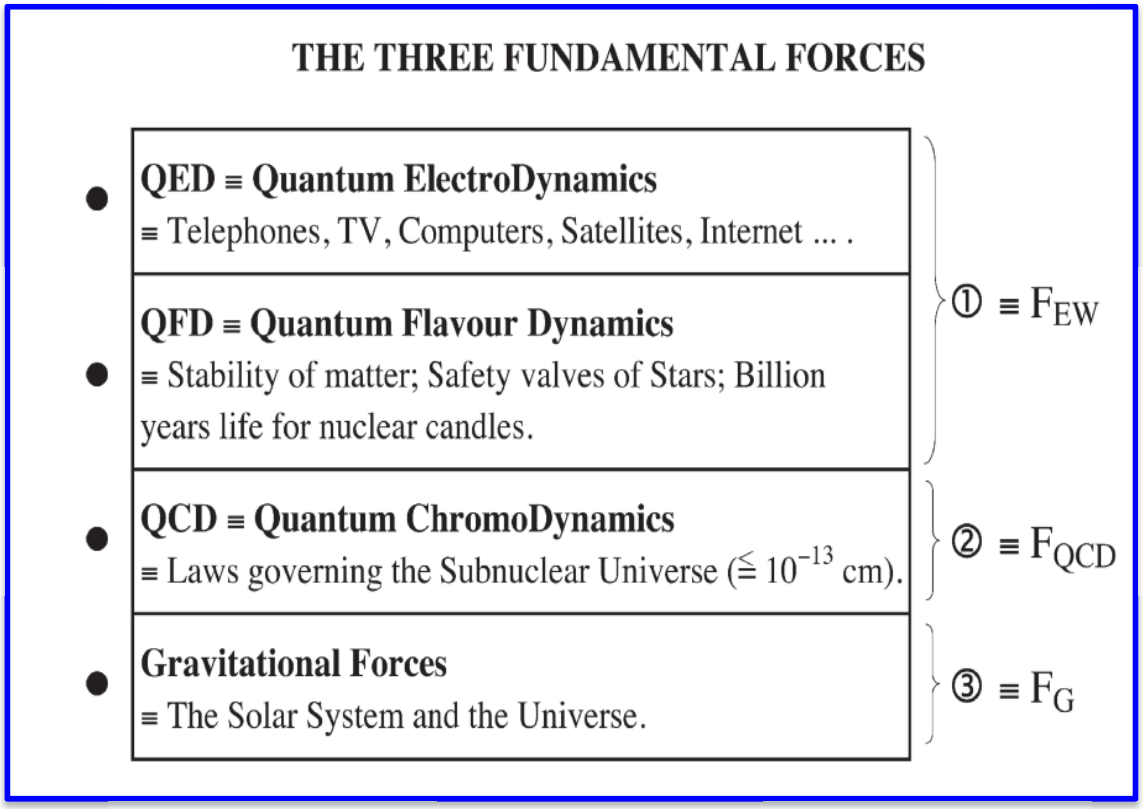


Figure 31

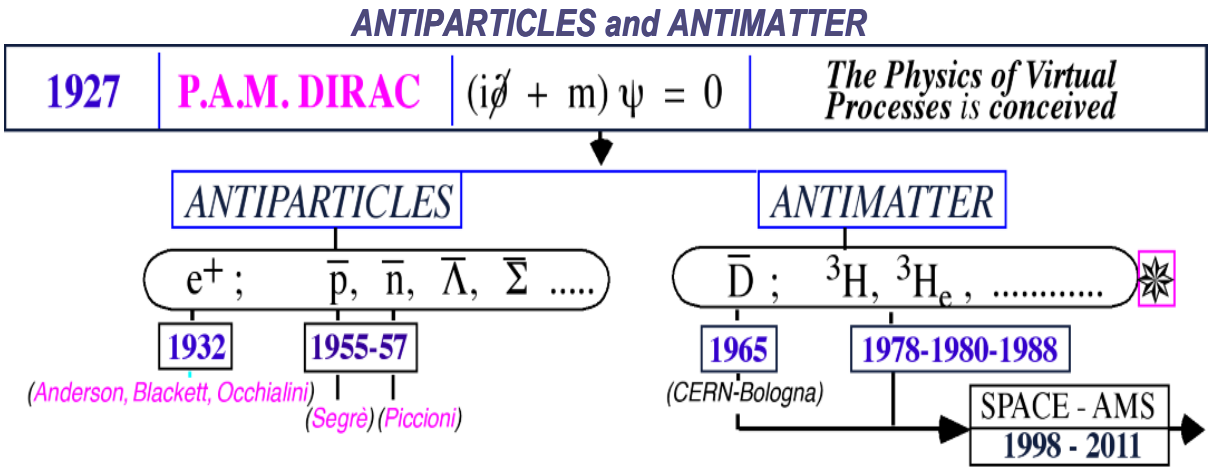


Figure 32

The problem of understanding the difference between mass and matter is illustrated in Figure 33. The incredible series of events which originated with the problem of understanding the stability of matter is shown in Figure 34, together with the unexpected violation of the Symmetry Operators (C, P, T, CP) and the discovery of Matter-Antimatter Symmetry.

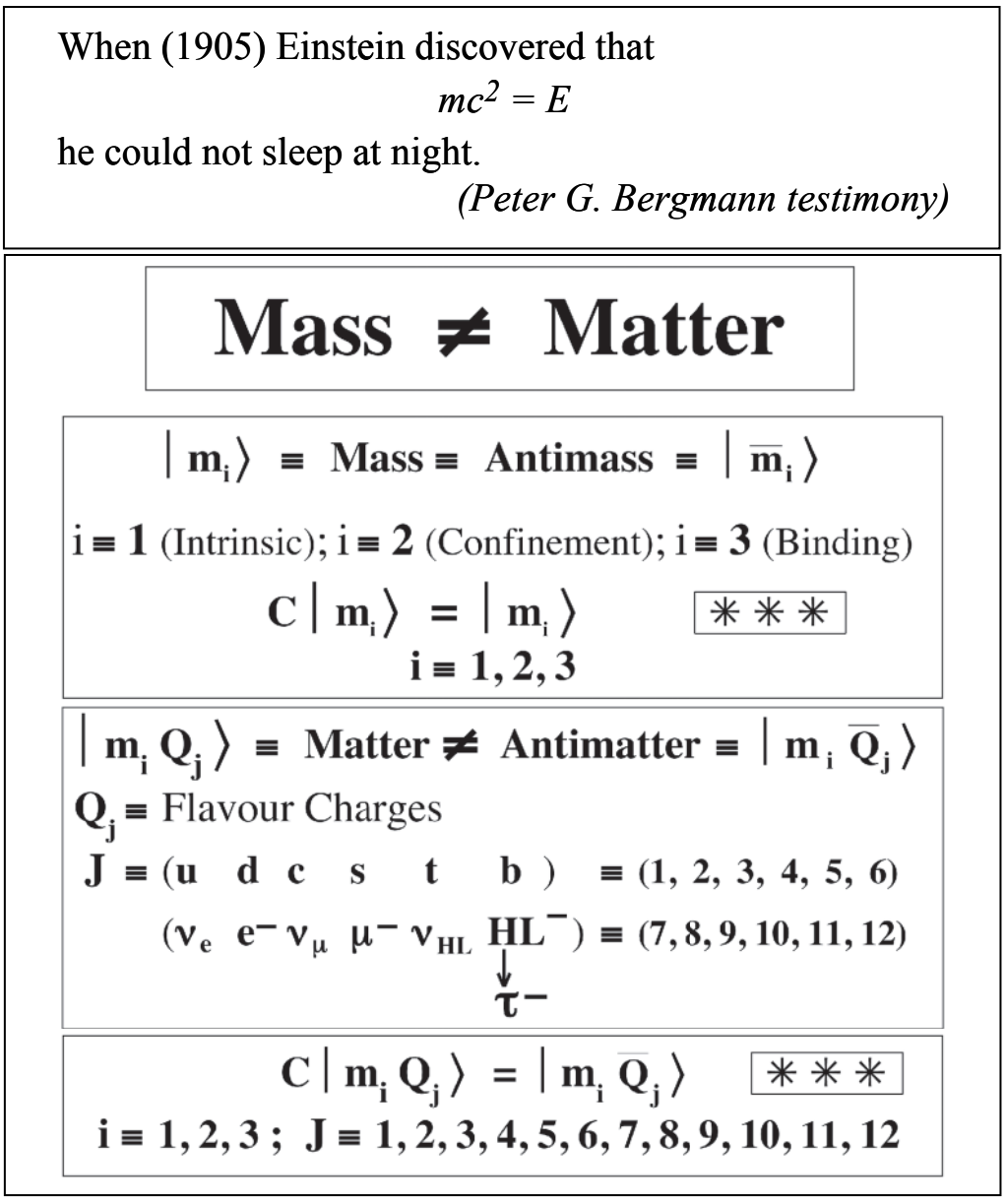


Figure 33

Figure 34 shows seven decades of developments, started from the antielectron and C-invariance and brought us to the discovery of nuclear antimatter and to the unification of all gauge forces.

THE INCREDIBLE STORY
TO UNDERSTAND THE ORIGIN OF THE STABILITY OF MATTER
SEVEN DECADES FROM THE ANTIELECTRON TO ANTIMATTER
AND THE UNIFICATION OF ALL GAUGE FORCES

- **The validity of C invariance from 1927 to 1957**.

After the discovery by Thomson in 1897 of the first example of an elementary particle, the Electron, it took the genius of Dirac to theoretically discover the Antielectron thirty years after Thomson.

1927 → Dirac equation [36]; the existence of the antielectron is, soon after, theoretically predicted. Only a few years were needed, after Dirac's theoretical discovery, to experimentally confirm (Anderson, Blackett and Occhialini [37]) the existence of the Dirac antielectron.

1930-1957 → **Discovery of the C operator** [(charge conjugation) H. Weyl and P.A.M. Dirac [38]]; discovery of the P Symmetry Operator [E.P. Wigner, G.C. Wick and A.S. Wightman [39, 40]]; discovery of the T operator (time reversal) [E.P. Wigner, J. Schwinger and J.S. Bell [41, 42, 43, 44]]; discovery of the CPT Symmetry Operator from RQFT (1955-57) [45].

1927-1957 → Validity of C invariance: e^+ [37]; $\bar{p}$ [46]; $\bar{n}$ [47]; $K_2^0 \to 3\pi$ [48] but see LOY [49].

- **The new era starts: C ≠ ; P ≠ ; CP ≠** (*) .

1956 → Lee & Yang P ≠ ; C ≠ [50].

1957 → Before the experimental discovery of P ≠ & C ≠, Lee, Oehme, Yang (LOY) [49] point out that the existence of the second neutral K-meson, $K_2^0 \to 3\pi$, is proof neither of C invariance nor of CP invariance. Flavour antiflavour mixing does not imply CP invariance.

1957 → C.S. Wu et al. P ≠ ; C ≠ [51]; CP ok [52].

1964 → $K_2^0 \to 2\pi \equiv K_L$: CP ≠ [53].

1947-1967 → QED divergences & Landau poles.

1950-1970 → The crisis of RQFT & the triumph of S-matrix theory (i.e. the negation of RQFT).

1965 → Nuclear antimatter is (experimentally) discovered [54]. See also [55].

1968 → The discovery [56] at SLAC of Scaling (free quarks inside a nucleon at very high q^2) but in violent (pp) collisions no free quarks at the ISR are experimentally found [57]. Theorists consider Scaling as being evidence for RQFT not to be able to describe the Physics of Strong Interactions. The only exception is G. 't Hooft who discovered in 1971 that the β-function has negative sign for non-Abelian theories [58].

1971-1973 → β = – ; 't Hooft; Politzer; Gross & Wilczek. The discovery of **non-Abelian** gauge theories. Asymptotic freedom in the interaction between quarks and gluons [58].

1974 → All gauge couplings α_1 α_2 α_3 run with q^2 but they do not converge towards a unique point.

1979 → A.P. & A.Z. point out that the new degree of freedom due to SUSY allows the three couplings α_1 α_2 α_3 **, to converge towards a unique point** [59].

1980 → QCD has a "hidden" side: the multitude of final states for each pair of interacting particles: (e^+e^- ; $p\bar{p}$; πp; Kp; νp; pp; etc.)
The introduction of the Effective Energy allows to discover the Universality properties [60] in the multihadronic final states.

1992 → All gauge couplings converge towards a unique point at the gauge unification energy: $E_{GU} \cong 10^{16}$ GeV with $\alpha_{GU} \cong 1/24$ [61, 1] .

1994 → The Gap [62] between E_{GU} & the String Unification Energy: $E_{SU} \cong E_{Planck}$.

1995 → **CPT loses its foundations at the Planck scale (T.D. Lee)** [63].

1995-1999 → **No CPT theorem from M-theory (B. Greene)** [64].

1995-2000 → A.Z. points out the need for new experiments to establish if matter-antimatter symmetry or asymmetry are at work.

(*) The symbol ≠ stands for "Symmetry Breakdown".

Figure 34

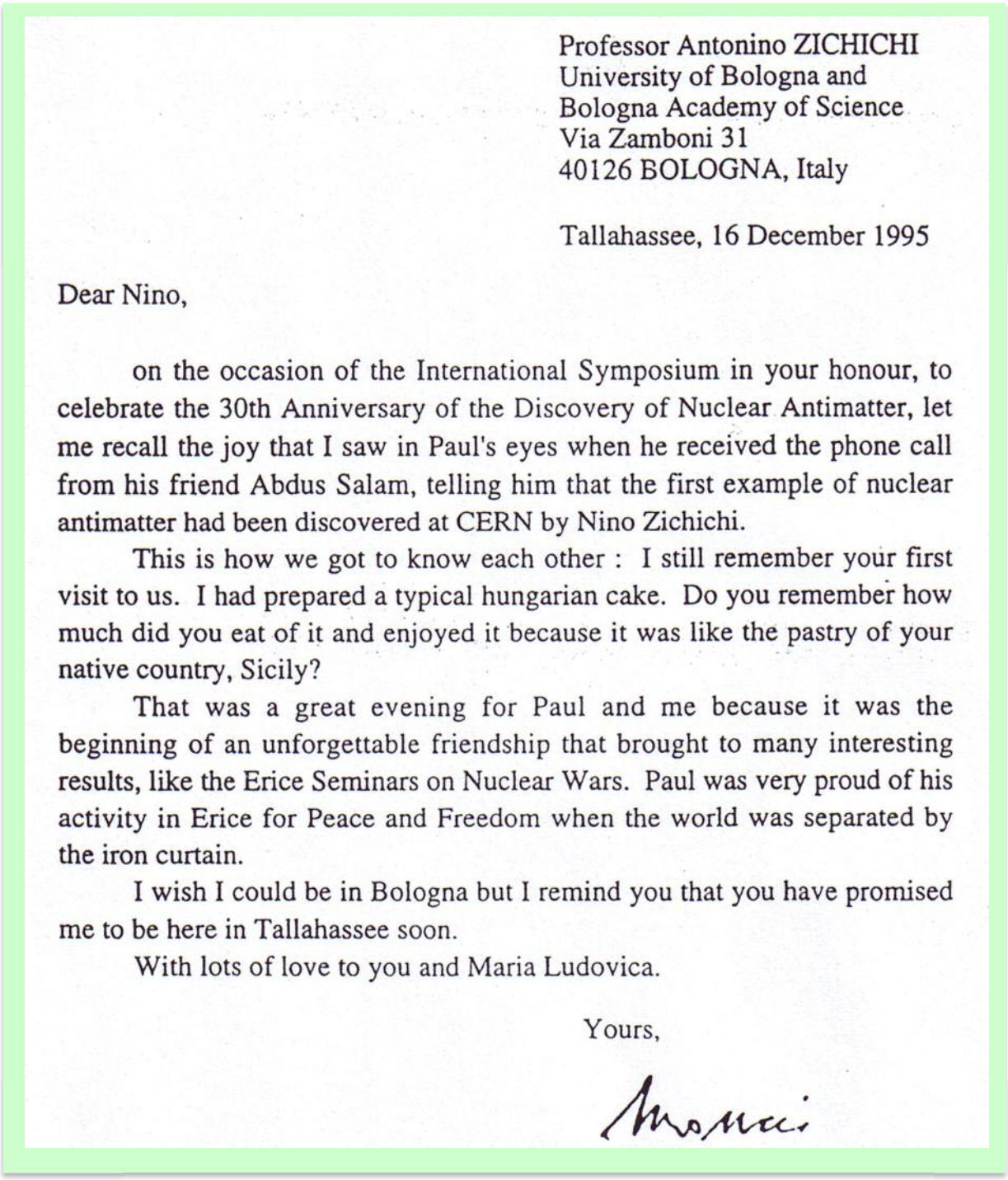
50th ANNIVERSARY OF THE KARLSRUHE NUCLIDE CHART

ANTIPARTICLES AND ANTIMATTER: THE BASIC DIFFERENCE

Antonino Zichichi
CERN, Geneva, Switzerland
Enrico Fermi Centre, Rome, Italy
INFN and University of Bologna, Italy

«*Those who say that antihydrogen is antimatter should realize that we are not made of hydrogen and we drink water, not liquid hydrogen*». These are Dirac's own words to a group of physicists (Figure 35) gathered around him, who, with a single equation [36, 65], opened new horizons to human knowledge.

Figure 35: Dirac surrounded by young physicists in Erice, after a lecture when he explained the difference between antiparticles and antimatter. It is on this occasion that he made the statement previously quoted.



Professor Antonino ZICHICHI
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40126 BOLOGNA, Italy

Tallahassee, 16 December 1995

Dear Nino,

on the occasion of the International Symposium in your honour, to celebrate the 30th Anniversary of the Discovery of Nuclear Antimatter, let me recall the joy that I saw in Paul's eyes when he received the phone call from his friend Abdus Salam, telling him that the first example of nuclear antimatter had been discovered at CERN by Nino Zichichi.

This is how we got to know each other : I still remember your first visit to us. I had prepared a typical hungarian cake. Do you remember how much did you eat of it and enjoyed it because it was like the pastry of your native country, Sicily?

That was a great evening for Paul and me because it was the beginning of an unforgettable friendship that brought to many interesting results, like the Erice Seminars on Nuclear Wars. Paul was very proud of his activity in Erice for Peace and Freedom when the world was separated by the iron curtain.

I wish I could be in Bologna but I remind you that you have promised me to be here in Tallahassee soon.

With lots of love to you and Maria Ludovica.

Yours,

Mancy

Figure 36: Letter by Mrs Mancy Dirac.

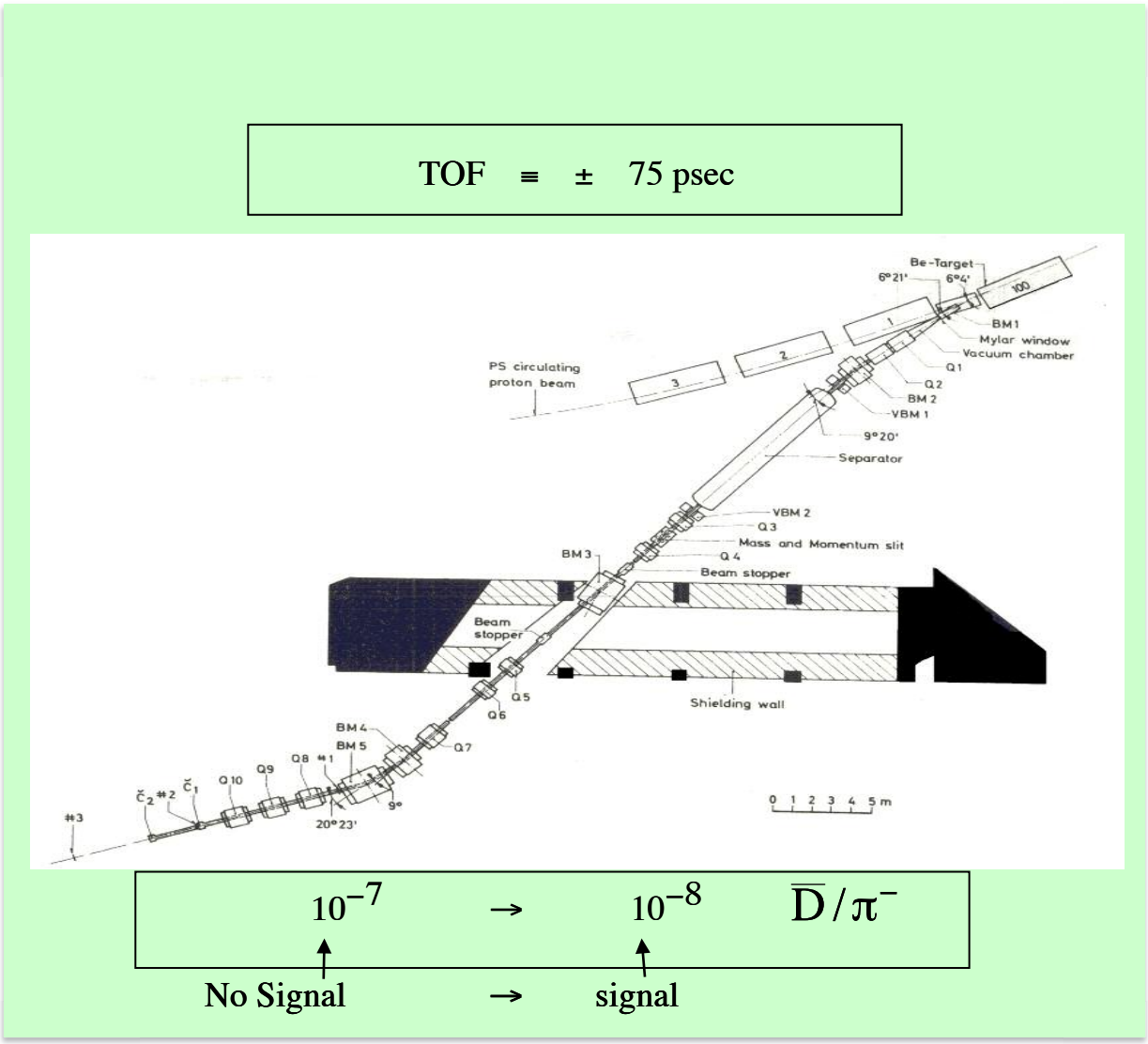

Figure 37: Schematic layout of the experimental set-up that allowed the discovery of antimatter. The combined system of bending magnets (BM) coupled with magnetic quadrupoles (Q) and the Separator allowed to have the most intensive negative beam ever built (authors of the beam-project: M. Morpurgo, G. Petrucci and A. Zichichi). The scintillation counters, #1, #2, #3, are for the time of flight (TOF) measurements. The precision achieved was 75 psec. $\check{C}_1$ and $\check{C}_2$ are Cerenkov detectors for particles identification.

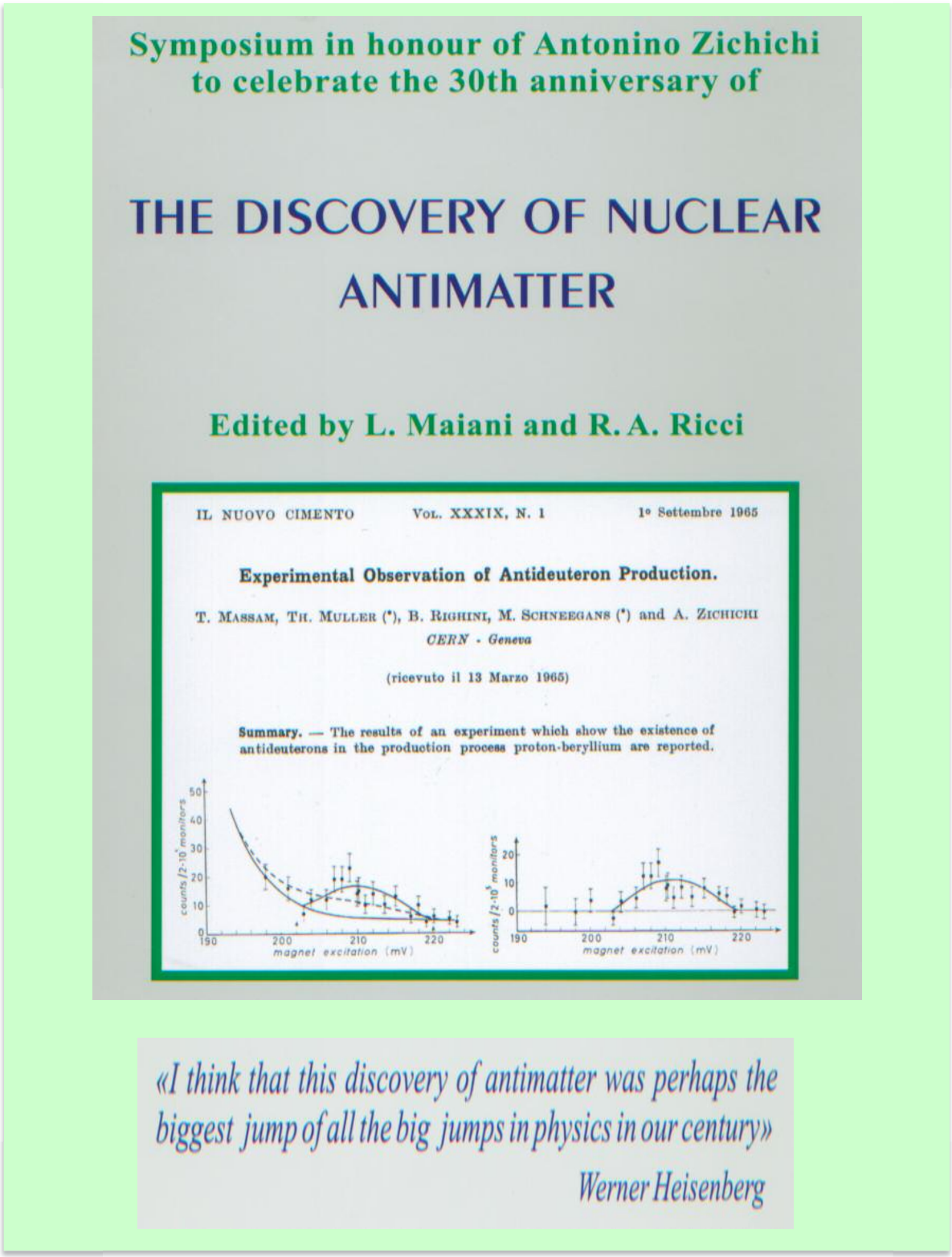

Figure 38: Front cover of the book celebrating the 30th anniversary of the antideuteron discovery.

Note – 1

To obtain water, hydrogen is not sufficient by itself. You also need oxygen whose nucleus is made of 8 protons and 8 neutrons. Hydrogen is the only element in Mendeleev's Table to be constituted of two charged particles, the electron and the proton, without any role being played by the Nuclear Forces.

The first element on which Nuclear Forces come into play is the heavy hydrogen, whose nucleus, called deuteron, is made with one proton and one neutron. For these two particles to remain together the "nuclear glue" is needed. Starting from the heavy hydrogen, all the elements of the Table, to exist, must have their nuclei made with protons, neutrons and the nuclear glue.

If these last two ingredients, the neutron and the nuclear glue, were not available, nothing but the "light" hydrogen could exist. Farewell water and farewell all material which we are familiar with.

Note – 2

In Dirac's famous statement, 70 years of theoretical and experimental discoveries are taken into consideration, with the conclusion that the existence of antimatter is supported exclusively on an experimental basis.

In fact – as evidenced by T.D. Lee [63], – the CPT theorem is invalidated at the Planck Scale ($\cong 10^{19}$ GeV) where all Nature's Fundamental Forces converge. Since the Grand Unification is the source of everything, if CPT collapses at the energy level of the Grand Unification we can then bid farewell to all that derives from CPT.

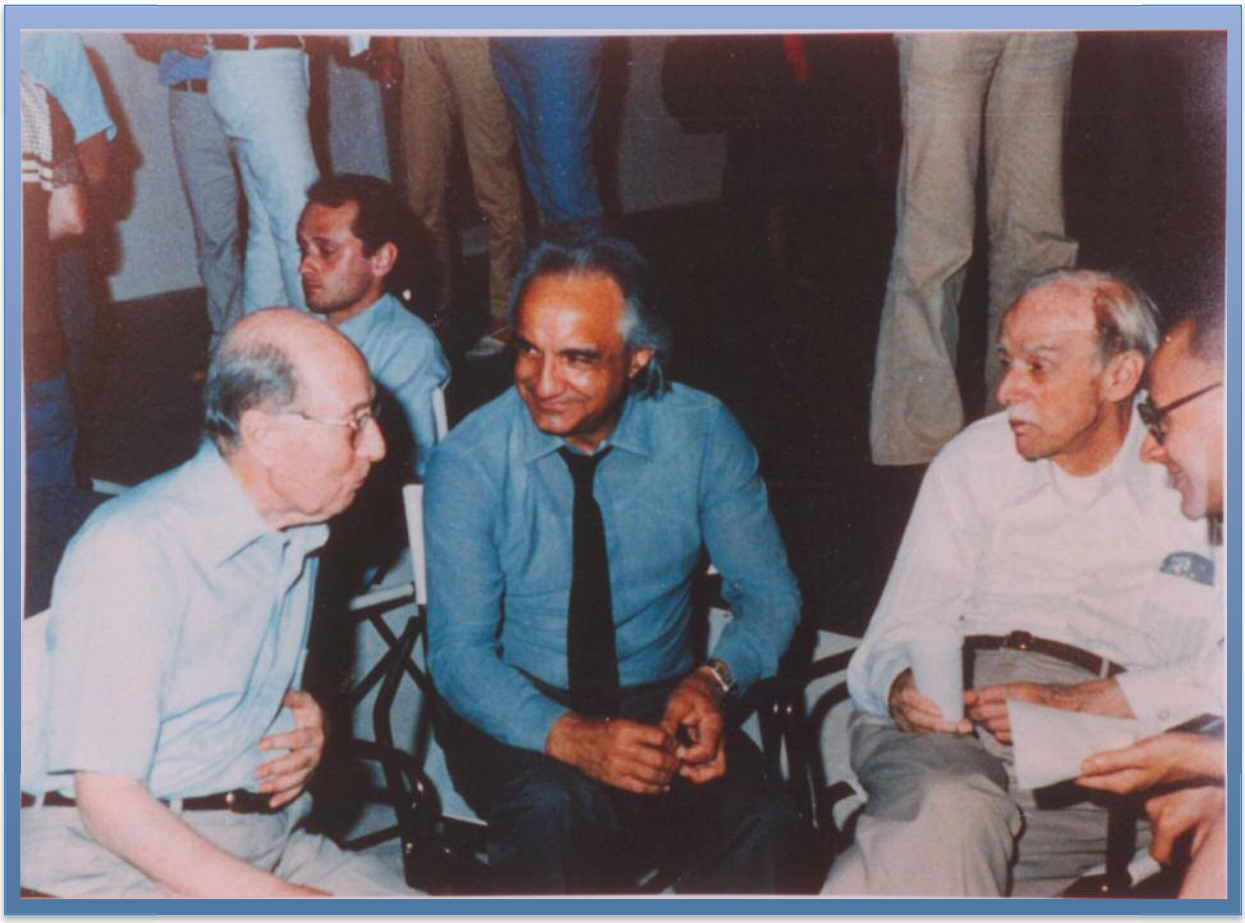

Figure 39 : Eugene P. Wigner, A. Zichichi and Paul Dirac (Erice, 1982).

Conclusions

This Seminar is devoted to review the main steps as seen from the reference frame, each one of us has choosen and cannot therefore be unbiased.

Let me cite Rabi:

«Physics is Intellectual Freedom.
Our interest is to understand nature.
It is to our liking to choose the best way.
Every physicist has his own interests
and his own likes and dislikes».

This Seminar should review the development of Subnuclear Physics associated with a concrete concern about the future of our field.

It is this concern at the origin of our activity devoted towards the implementation of new projects.

The experimental results acquired so far in Subnuclear Physics tell us that the Standard Model cannot be the definitive theory, in spite of the fact that it is the most powerful synthesis of all known and rigorously measured phenomena.

Looking back at the last 64 years, the amount of new knowledge acquired is really overwhelming.

Richard P. Feynman – 1964, Erice – Global & Local Consevation Laws from *Discussions* at the International School of Subnuclear Physics.

«If a cat were to disappear in Pasadena and at the same time appear in Erice, that would be an example of global conservation of cats. This is not the way cats are conserved. Cats or charge or baryons are conserved in a much more continuous way. If any of these quantities begin to disappear in a region, then they begin to appear in a neighbouring region. Consequently, we can identify a flow of charge out of a region with the disappearance of charge inside the region. This identification of the divergence of a flux with the time rate of change of a charge density is called a local conservation law. A local conservation law implies that the total charge is conserved globally, but the reverse does not hold. However, relativistically it is clear that non-local global conservation laws cannot exist, since to a moving observer the cat will appear in Erice before it disappears in Pasadena.»

We could relax and enjoy the Standard Model, but we already know that this superb synthesis is just the starting point of a new horizon.

For this new horizon to be investigated, a project for a new collider able to work at extreme energy and luminosity is needed.

This is ELN (**E**uroasiatic **LO**ng **I**ntersecting **S**torage **A**ccelerator), a (pp) collider with the highest energy and luminosity which could be built with simple extrapolation of the presently known technologies.

The ELN project is very ambitious but we should be encouraged by our previous experiences.

In fact, the path leading to the ELN has already gone through the Gran Sasso project (now the largest and most powerful underground laboratory in the world), the LEP-white-book which allowed this great European venture to overcome the many difficulties that had blocked its implementation during many years, the HERA collider (now successfully completed), and the roots of LHC, as for example the 5-metres diameter (not 3 metres) for the 27 Km (not 13 Km) LEP tunnel, and the LAA-R&D project, implemented to find the detector technologies needed for **LHC**.

These past achievements in project realization are mentioned in order to corroborate my optimism and enthusiasm in encouraging new actions and new ideas for the future of Subnuclear Physics in Europe and in the world, all having as focus CERN, the greatest Subnuclear Physics Lab in the world.

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