COMPLEXITY AT THE FUNDAMENTAL LEVEL: CONSEQUENCES FOR LHC

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Abstract

This lecture – delivered at the 2006 Erice School – is closely linked to the one delivered in 2004, where the existence of Complexity at the fundamental level has been fully discussed. Here the consequences of Complexity for LHC are treated and the QGCW Project is presented. The references have been updated since the final edition of the lecture – also presented at the 2007 Erice School – has been printed on March 2008. If complexity exists at the fundamental level the expectations must fall outside all possible predictions. The QGCW should be the source for totally unexpected phenomena.

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COMPLEXITY
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1 SEVEN DEFINITIONS OF COMPLEXITY

People speak of 'Complexity' as a source of new insights in physics, biology, geology, cosmology, social sciences and in all intellectual activities which look at the world through the lens of a standard analysis in terms of either Simplicity or Complexity. **But 'Complexity'** is ill-defined, as shown by the existence of at least seven definitions of Complexity.

Definition Number 1

Complexity is a property of systems that are somewhere in between a completely random and a completely regular state, often described by a highly non linear set of equations but sometimes not describable by equations at all.

Definition Number 2

Bad ones:

1) Chaos.
2) The need for lengthy calculations.
3) The need for many distinct variables.

Better ones:

4) Unexpected difficulty when attempting to describe something in a precisely formulated theory.
5) What is left over after all systematic approaches failed.

But it could also be that: Complexity is an excuse for sloppy thinking.

Definition Number 3

The Complexity of a theory (problem) is the minimum amount of computer time and storage required to simulate (solve) it to a specified level of precision.

DEFINITION NUMBER 4

If we admit that biological or linguistic evolution, or financial dynamics are complex phenomena, then their typical dynamics is somehow between strong chaos (i.e. positive Lyapunov exponents) and simple orbits (i.e. negative Lyapunov exponents). In other words, Complexity (or at least some form of it) is deeply related to the edge of chaos (i.e. vanishing maximal Lyapunov exponent). Since the edge of chaos appears to be related paradigmatically to an entropy index 'q' different from unity, there must be some deep connection between Complexity and generalized entropies such as 'S_q'.

DEFINITION NUMBER 5

From the mathematical point of view:

- A problem can be polynomial, which means that it is not to hard to predict surprises.
- A problem can be NP or NP-complete, which represent different degrees of difficulty in predicting surprises.
- •• Surprises means: UEEC event.
- •• That degree of difficulty can be associated with the level of Complexity.

DEFINITION NUMBER 6

A system is 'complex' when it is no longer useful to describe it in terms of its fundamental constituents.

DEFINITION NUMBER 7

The simplest definition of Complexity: '*Complexity is the opposite of Simplicity*'. This is why we have studied the platonic Standard Model (Addendum 1) and its extension to the platonic Superworld (Addendum 2).

These seven definitions of Complexity must be compared with the whole of our knowledge (see later) in order to focus our attention on the key features needed to study our real world.

2 COMPLEXITY EXISTS AT ALL SCALES

The Logic of Nature allows the existence of a large variety of structures with their regularities and laws which appear to be independent from the basic constituents and fundamental laws of Nature which govern their interactions.

But, without these laws it would be impossible to have the real world which is in front of us and of which we are part of. A series of complex systems is shown in figure 1.

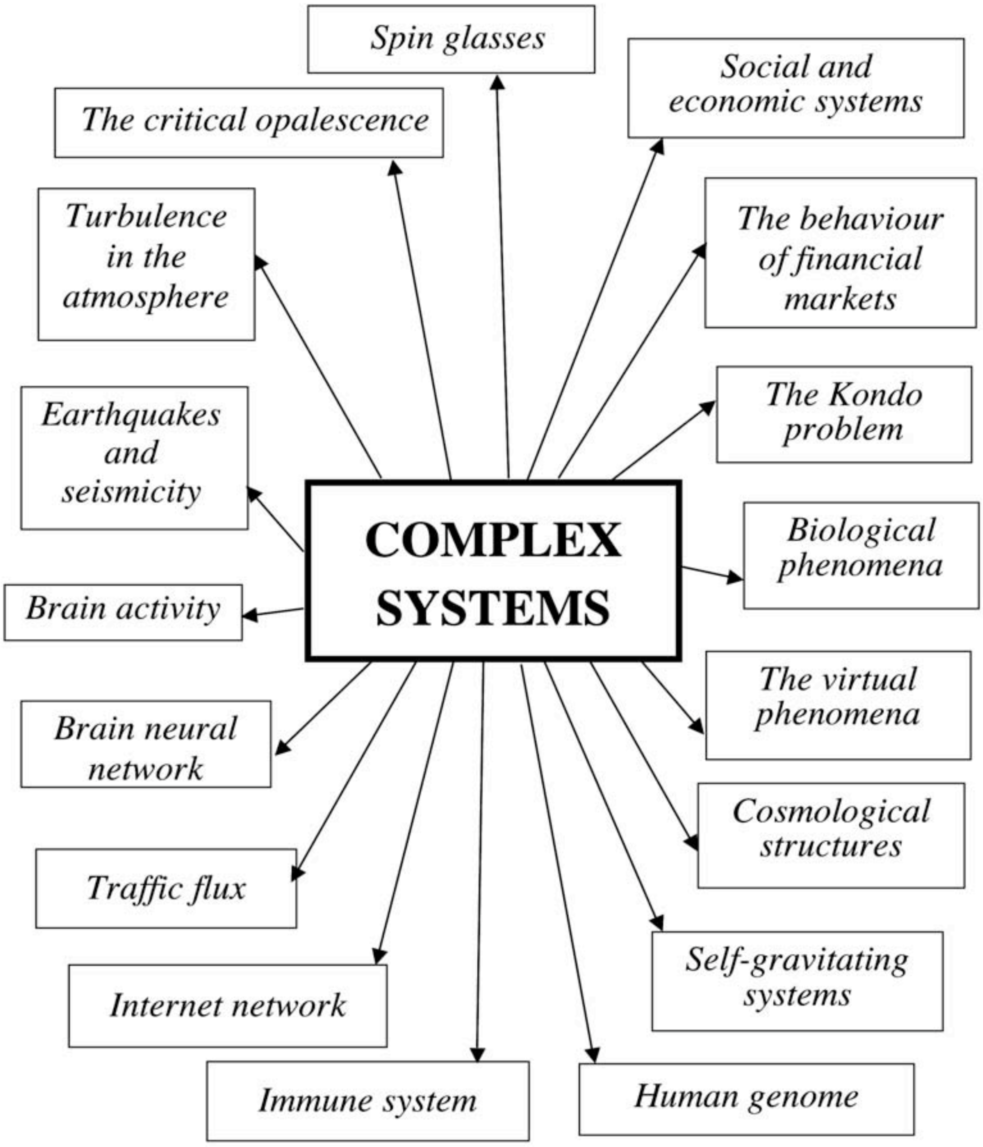


Figure 1

As you can see, we go from traffic flux, to the internet network, to earthquakes and seismicity, to social and economic systems, to the behaviour of financial markets, to the study of cosmological structures, and so on.

The experimental evidences for the **existence** of **Complexity are two**:

1) The <u>A</u>nderson-<u>F</u>eynman-<u>B</u>eethoven-type phenomena (**AFB**) i.e. phenomena whose laws and regularities ignore the existence of the Fundamental Laws of Nature from which they originate;
2) The Sarajevo-type effects, i.e. <u>U</u>nexpected <u>E</u>vents of quasi irrelevant magnitude which produce <u>E</u>normous <u>C</u>onsequences (**UEEC**).

The only certainty about Complexity is the existence of these experimentally observable effects. The **AFB** will be discussed in chapter 3 and the **UEEC** in chapter 4. These effects exist at all scales, and therefore Complexity exists at all scales, as illustrated in figure 2.

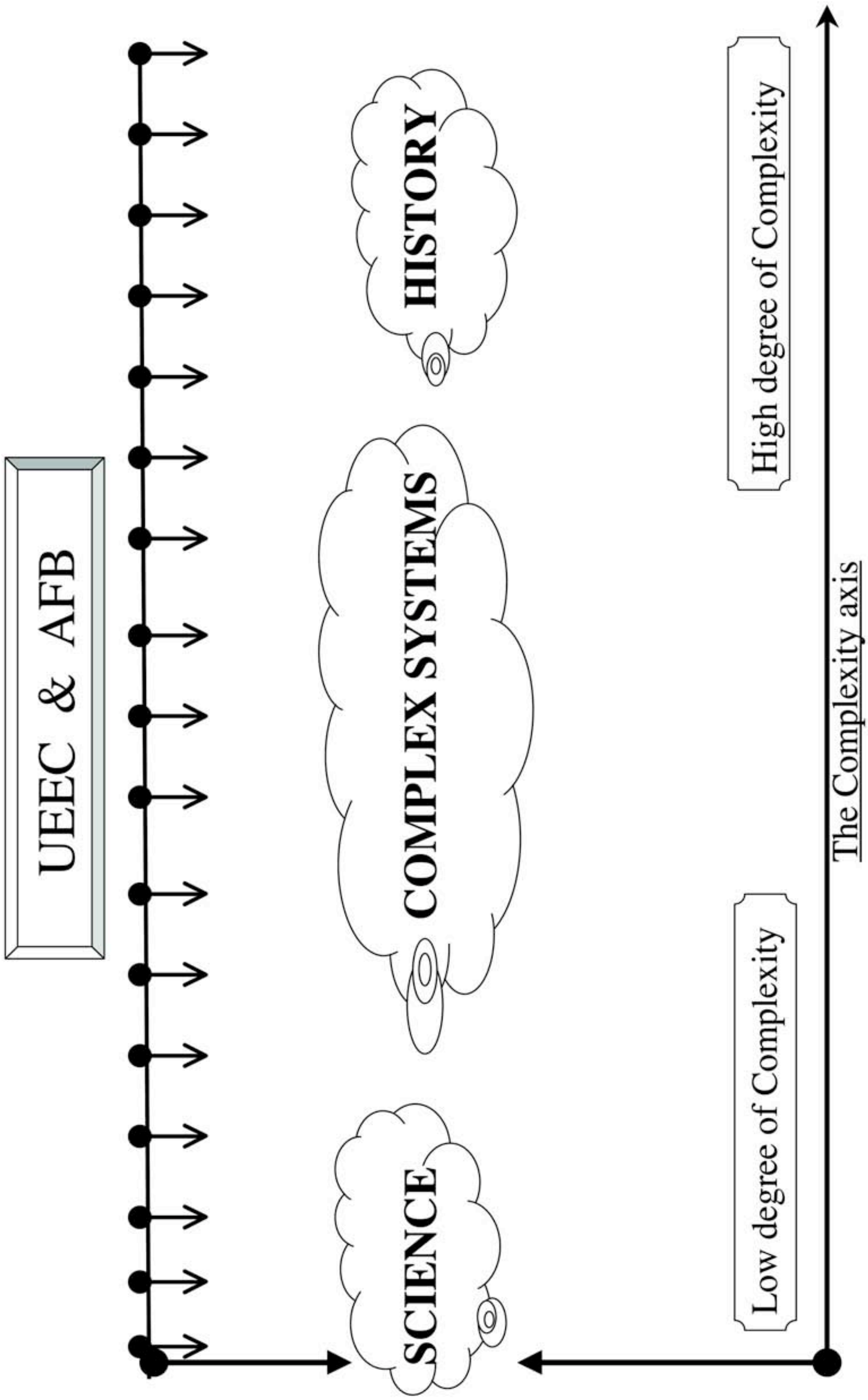


Figure 2

3 AFB PHENOMENA FROM BEETHOVEN TO THE SUPERWORLD

Beethoven and the laws of acoustics.

Beethoven could compose superb masterpieces of music without any knowledge of the laws governing acoustic phenomena.

But these masterpieces could not exist if the laws of acoustics were not there.

The living cell and QED.

To study the mechanisms governing a living cell, we do not need to know the laws of electromagnetic phenomena whose advanced formulation is QED.

All mechanisms needed for life are, to a great extent, examples of electromagnetic processes. If QED was not there, Life could not exist.

Nuclear physics and QCD.

Proton and neutron interactions appear as if a fundamental force of nature is at work: the nuclear force, with its rules and its regularities.

These interactions ignore that protons and neutrons are made with quarks and gluons.

Nuclear physics does not appear to care about the existence of Quantum ChromoDynamics (QCD), the fundamental force acting between quarks and gluons at the heart of the subnuclear world.

Nuclear physics ignores QCD but all phenomena occurring in nuclear physics have their roots in the interactions of quarks and gluons.

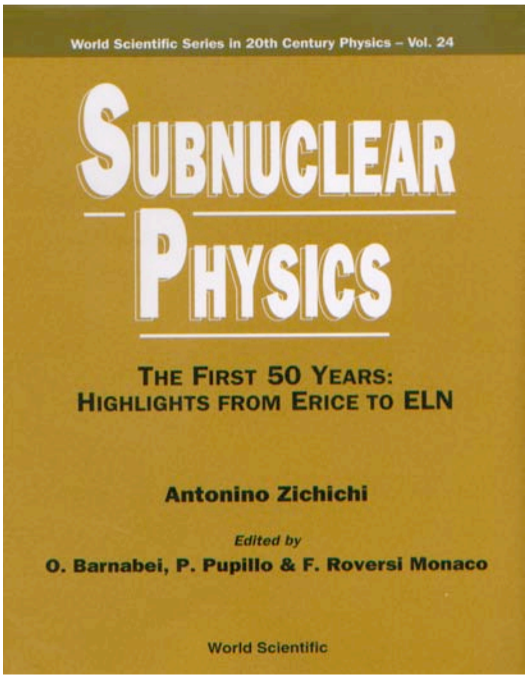
In other words, protons and neutrons behave like Beethoven: they interact and build up nuclear physics without 'knowing' the laws governing QCD.

The most recent example of Anderson-Feynman-Beethoven-type phenomenon: **the World could *apparently* not care less about the existence of the Superworld**.

4 UEEC EVENTS, FROM GALILEI UP TO SM&B

In figure 3 there is a sequence of **UEEC** events from Galilei to Fermi-Dirac and the 'strange particles'.

In figures 4, 5, 6 from Fermi-Dirac to the construction of the Standard Model and in figure 7 a synthesis of the UEEC events in what we now call the Standard Model and Beyond (**SM&B**). These figures (4, 5, 6) cover the first fifty years of Subnuclear Physics, whose detailed description can be found in my book whose front page is reproduced below.



‘UEEC’
TOTALLY UNEXPECTED DISCOVERIES
FROM GALILEI TO FERMI-DIRAC AND THE ‘STRANGE’ PARTICLES

I	Galileo Galilei discovery of $F = mg$.
II	Newton discovery of $F = G\frac{m_1 \cdot m_2}{R_{12}^2}$
III	Maxwell discovers the unification of electricity, magnetism and optical phenomena, which allows him to conclude that light is a vibration of the EM field.
IV	Planck discovery of $h \neq 0$.
V	Lorentz discovers that space and time cannot be both real.
VI	Einstein discovers the existence of time-like and space-like worlds. Only in the time-like world, simultaneity does not change, with changing observer.
VII	Rutherford discovers the nucleus.
VIII	Hess discovers the cosmic rays.
IX	Dirac discovers his equation, which opens new horizons, including the existence of the antiworld.
X	Fermi discovers the weak forces.
XI	Fermi and Dirac discover the Fermi–Dirac statistics.
XII	The ‘strange particles’ are discovered in the Blackett Lab.

Figure 3

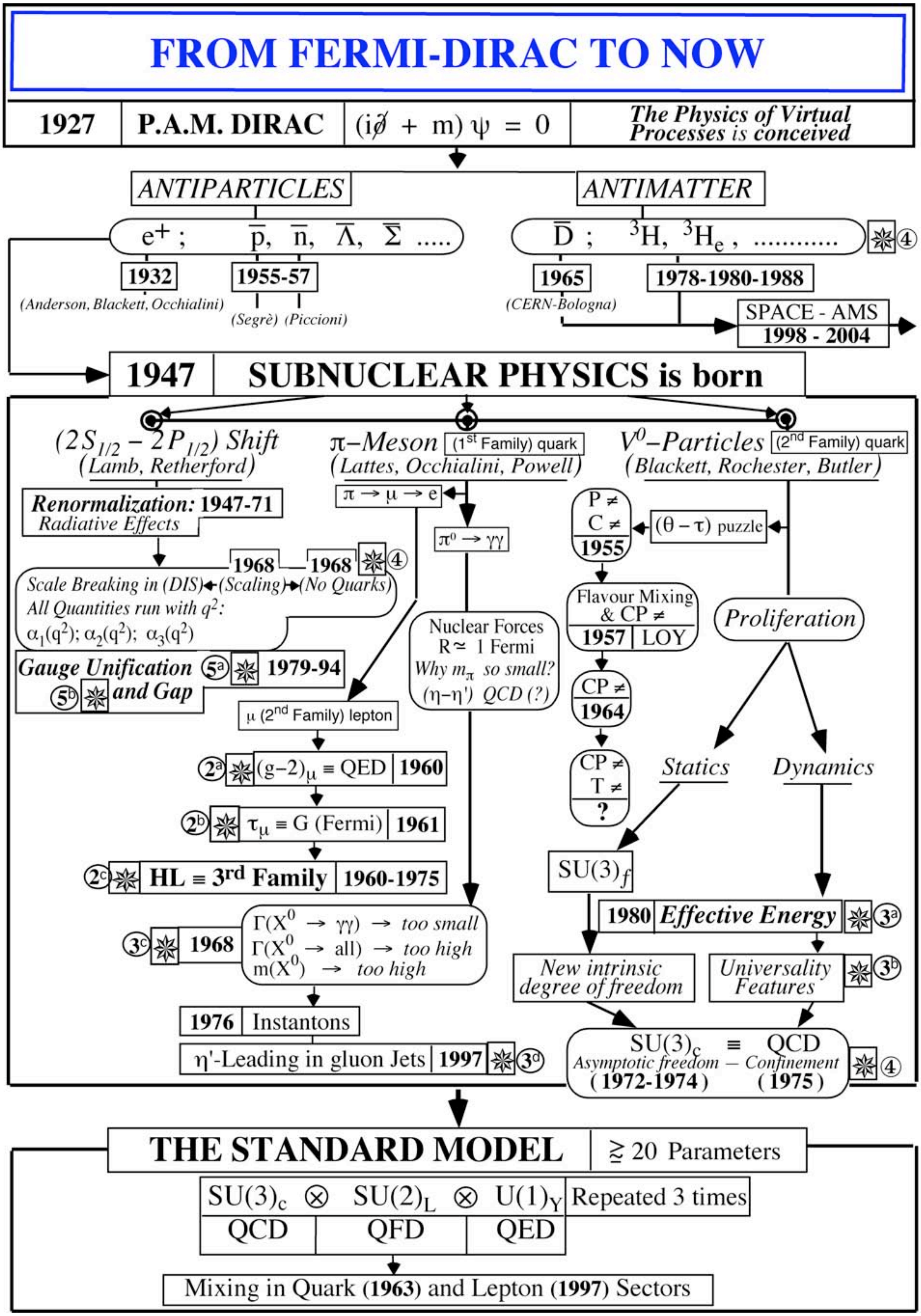

FROM FERMI-DIRAC TO NOW
1927
P.A.M. DIRAC
(i∂̸ + m) ψ = 0
The Physics of Virtual Processes is conceived
ANTIPARTICLES
ANTIMATTER
e+ ; p̄, n̄, Λ̄, Σ̄ .....
D̄ ; ³H, ³He , ...
④
1932
(Anderson, Blackett, Occhialini)
1955-57
(Segrè) (Piccioni)
1965
(CERN-Bologna)
1978-1980-1988
SPACE - AMS
1998 - 2004
1947
SUBNUCLEAR PHYSICS is born
(2S1/2 – 2P1/2) Shift
(Lamb, Retherford)
π–Meson
(1st Family) quark
(Lattes, Occhialini, Powell)
V0–Particles
(2nd Family) quark
(Blackett, Rochester, Butler)
Renormalization: 1947-71
Radiative Effects
π → μ → e
π0 → γγ
P ≠
C ≠
1955
(θ – τ) puzzle
1968
1968
④
Scale Breaking in (DIS)
(Scaling)
(No Quarks)
All Quantities run with q2:
α1(q2); α2(q2); α3(q2)
Nuclear Forces
R ≃ 1 Fermi
Why mπ so small?
(η–η') QCD (?)
Flavour Mixing
& CP ≠
1957
LOY
Proliferation
Gauge Unification
⑤a
1979-94
⑤b
and Gap
μ (2nd Family) lepton
CP ≠
1964
Statics
Dynamics
②a
(g–2)μ ≡ QED
1960
CP ≠
T ≠
?
②b
τμ ≡ G (Fermi)
1961
②c
HL ≡ 3rd Family
1960-1975
SU(3)f
③c
1968
Γ(X0 → γγ) → too small
Γ(X0 → all) → too high
m(X0) → too high
1980
Effective Energy
③a
New intrinsic degree of freedom
Universality Features
③b
1976
Instantons
η'-Leading in gluon Jets
1997
③d
SU(3)c ≡ QCD
Asymptotic freedom – Confinement
(1972-1974) (1975)
④
THE STANDARD MODEL
≳ 20 Parameters
SU(3)c ⊗ SU(2)L ⊗ U(1)Y
Repeated 3 times
QCD
QFD
QED
Mixing in Quark (1963) and Lepton (1997) Sectors

Figure 4

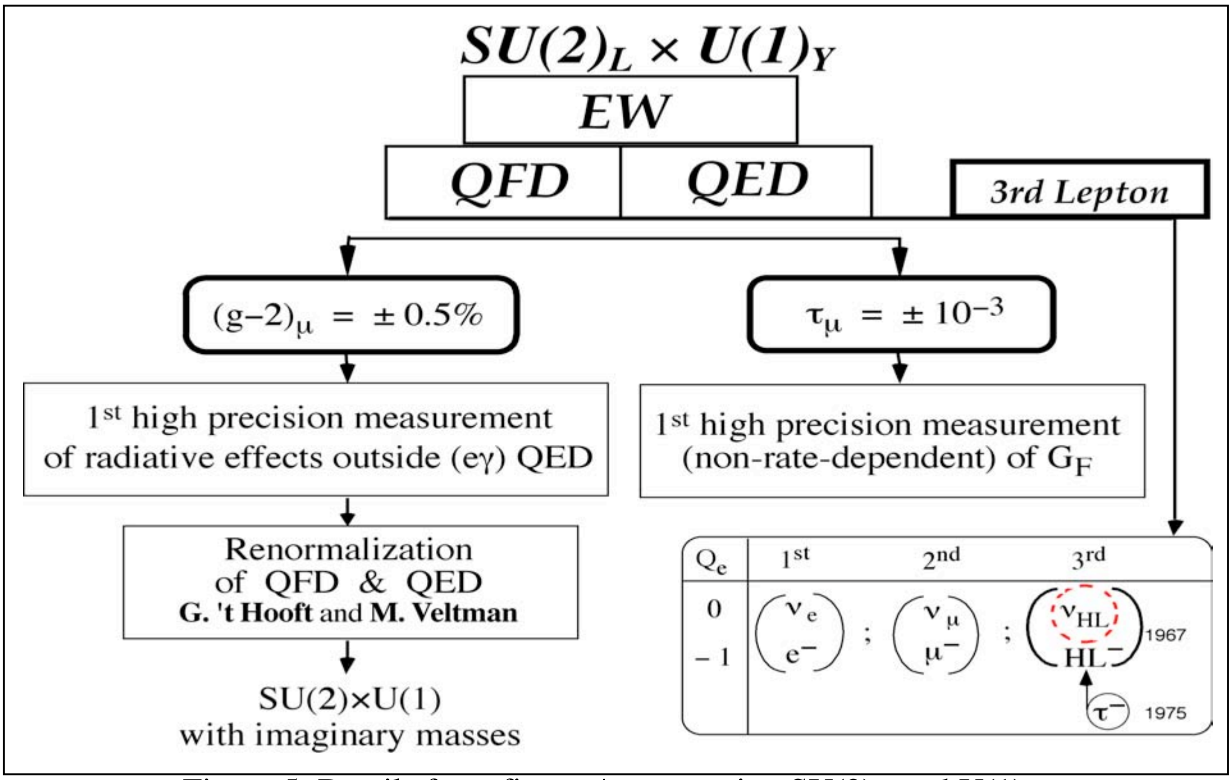


Figure 5: Details from figure 4, concerning $SU(2)_L$ and $U(1)_Y$.

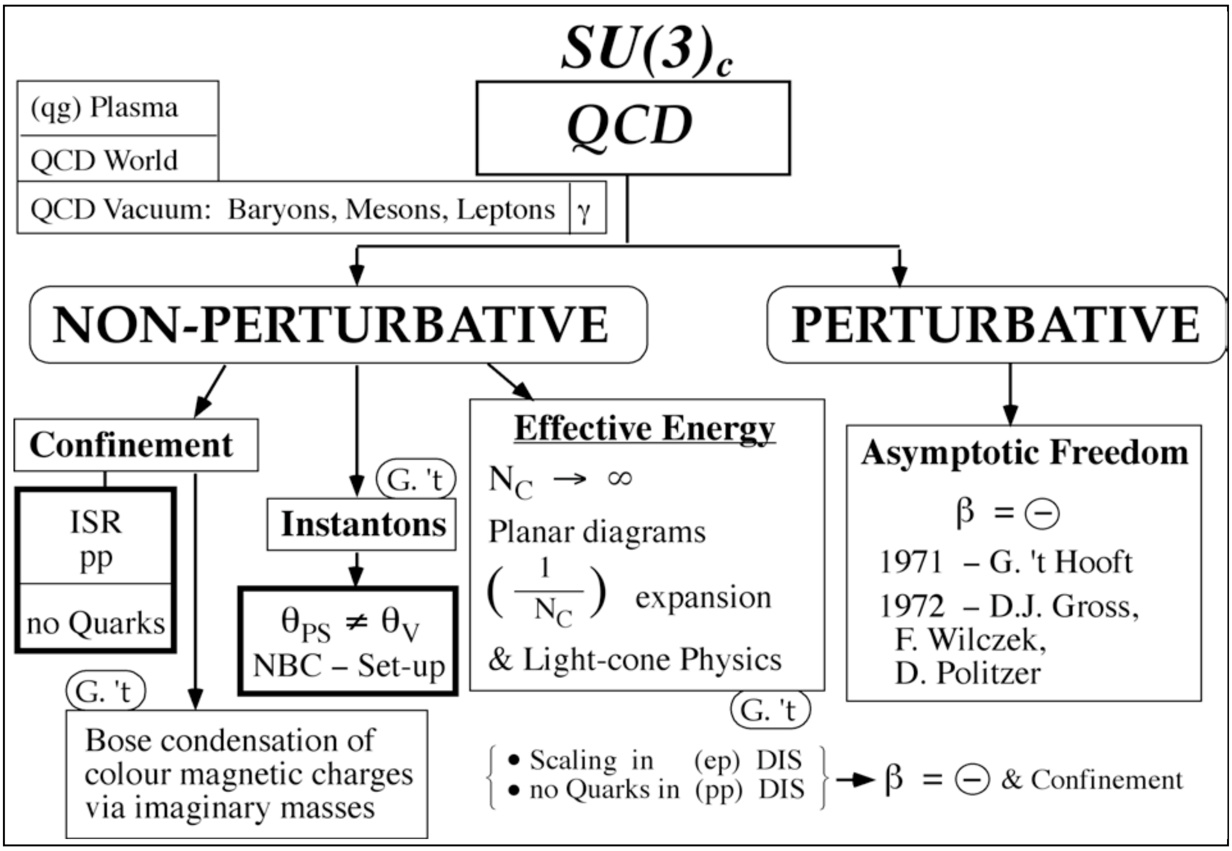


Figure 6: Details from figure 4, concerning $SU(3)_c$.

SM&B

THE STANDARD MODEL AND BEYOND

① RGEs (α_i ($i \equiv 1, 2, 3$); m_j ($j \equiv q, l, G, H$)) : $f(k^2)$.

- GUT ($\alpha_{GUT} \cong 1/24$) & GAP ($10^{16} - 10^{18}$) GeV.
- SUSY (to stabilize $m_F/m_P \cong 10^{-17}$).
- RQST (to quantize Gravity).

② Gauge Principle (hidden and expanded dimensions).

— How a Fundamental Force is generated: SU(3); SU(2); U(1) and Gravity.

③ The Physics of Imaginary Masses: SSB.

— The Imaginary Mass in SU(2)×U(1) produces masses ($m_{W^\pm}$; m_{Z^0}; m_q; m_l), including $m_\gamma = 0$.

— The Imaginary Mass in SU(5)⇒SU(3)×SU(2)×U(1) or in any higher (not containing U(1)) Symmetry Group ⇒ SU(3)×SU(2)×U(1) produces Monopoles.

— The Imaginary Mass in $SU(3)_c$ generates Confinement.

④ Flavour Mixings & CP ≠ , T ≠ .

— No need for it but it is there.

⑤ Anomalies & Instantons.

— Basic Features of all Non-Abelian Forces.

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.			

The five basic steps in our understanding 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. ④ The mass-eigenstates are mixed when the Fermi forces come in. 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 7

Let me dedicate some attention to discuss UEEC events in nuclear physics.

Nuclear Physics and the UEEC events.

It is considered standard wisdom the fact that nuclear physics is based on perfectly sound theoretical predictions. People forget the impressive series of UEEC events discovered in what I have decided to call the ‘Yukawa gold mine’.

Let me quote just three of them:

1 The first experimental evidence for a cosmic ray particle believed to be the Yukawa meson was a lepton: the muon.
2 The decay-chain: $\pi \rightarrow \mu \rightarrow e$ was found to break the symmetry laws of Parity and Charge Conjugation.
3 The intrinsic structure of the Yukawa particle was found to be governed by a new fundamental force of Nature, Quantum ChromoDynamics: QCD.

As you know 2007 was the centenary of the birth of Hideki Yukawa, the father of theoretical nuclear physics. In 1935 the existence of a particle, with mass intermediate (this is the origin of ‘mesotron’ now ‘meson’) between the light electron, m_e, and the heavy nucleon (proton or neutron), m_N, was proposed by Yukawa [1].

This intermediate mass value was deduced by Yukawa from the range of the nuclear forces. Contrary to the general wisdom of the time, Yukawa was convinced that the particles known (electrons, protons, neutrons and photons), could not explain how protons and neutrons are bound into the extremely small dimensions of a nucleus.

In order to make this ‘prediction’, Yukawa needed the Heisenberg uncertainty principle: a totally unexpected theoretical discovery.

The origin of it was the totally unexpected discovery of the dual nature of the electron (wave and particle) and of the photon (wave and particle).

Heisenberg himself tried to explain the binding forces between the proton and the neutron, via the exchange of electrons, in order not to postulate the existence of a new particle. The very light electron, m_e, could not stay in the very small dimension of the nucleus.

The author of the uncertainty principle and father, with Dirac and Pauli, of Quantum Mechanics, did not realise this contradiction. The need for a new particle was the reason. What no-one was able to predict is the ‘gold-mine’ hidden in the production, the decay and the intrinsic structure of this ‘particle’.

This 'gold-mine' is still being explored nowadays and its present frontier is the Quark-Gluon-Coloured-World (QGCW) [2].

I have recently described [3] the unexpected conceptual developments coming from the study of the production, the decay and the intrinsic structure of the Yukawa particle.

Let me just quote the most relevant UEEC events: chirality−invariance, spontaneous symmetry breaking, symmetry breaking of fundamental invariance laws (P, C, T), anomalies, and 'anomaly-free condition', existence of a third family of fundamental fermions, gauge principle for non-Abelian forces, instantons and existence of a pseudoscalar particle made of the quanta of a new fundamental force of Nature acting between the constituents of the Yukawa particle.

A few cases (seven) where I have been directly involved are summarised in figure 8. Each **UEEC** event is coupled with a **despite**, in order to emphasize the reason why the event is unexpected.

UEEC EVENTS
IN THE CONSTRUCTION OF THE
SM&B ≡ MY PERSONAL EXPERIENCE

① ***The 3rd lepton*, HL** (now called τ) with its own neutrino, ν_{HL} (now called ν_τ),
despite the abundance of neutrinos: ν_e and ν_μ.

② ***Antimatter***
despite S-matrix and C, P, CP, T breakings.

③ ***Nucleon Time-like** EM structure*
despite S-matrix.

④ ***No quarks** in violent (pp) collisions*
despite scaling.

⑤ ***Meson mixings***
$\theta_V \neq \theta_{PS}$ **:** $(51^\circ) \neq (10^\circ) \neq 0$ **despite** $SU(3)_{uds}$.

⑥ ***Effective energy:*** the QCD-light
despite QCD.

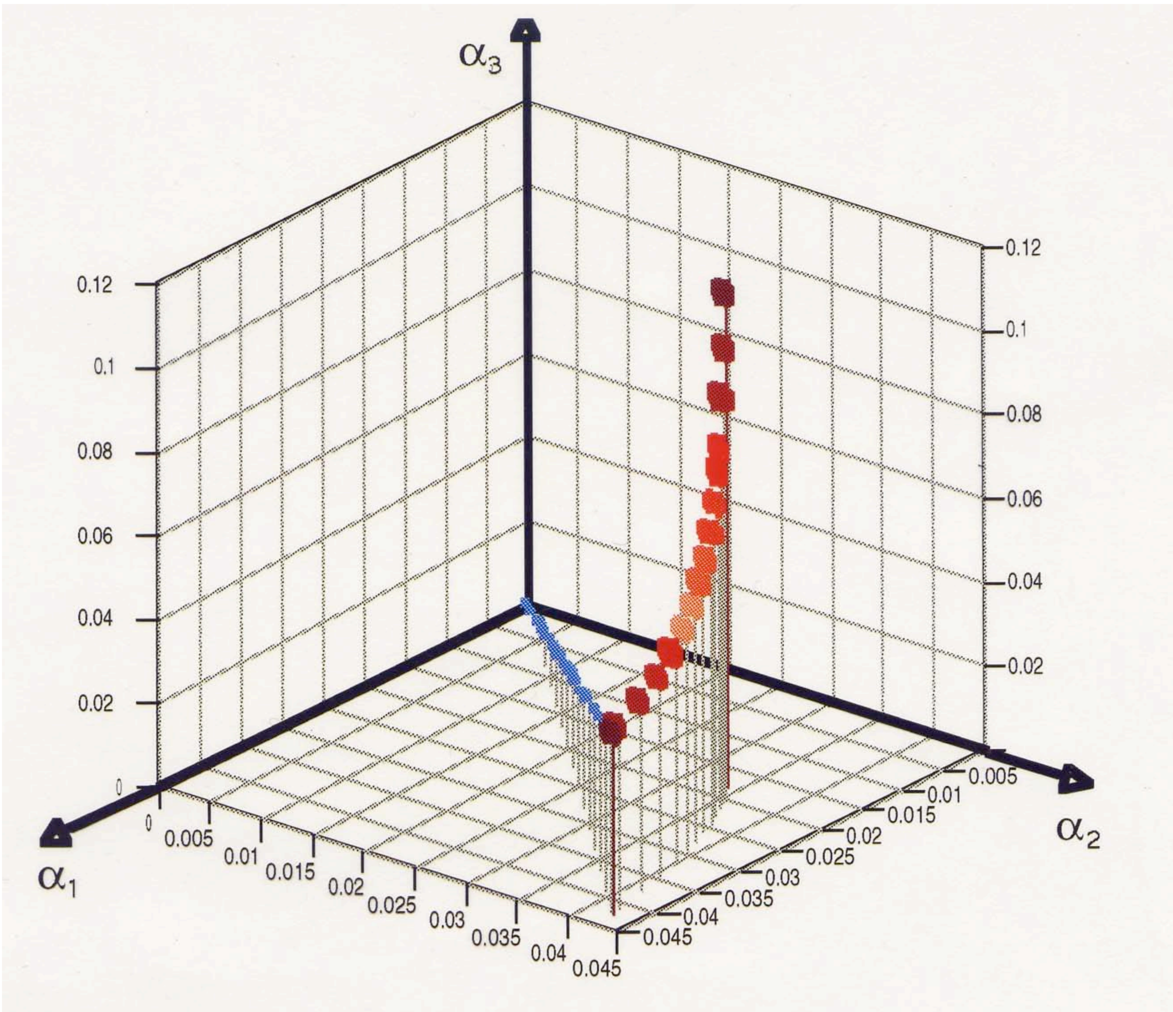
⑦ ***The running** of α_1 α_2 α_3 versus **energy** at* **a point E_{GU}**.
(1979) (1991) **despite** straight line convergence.

EGM

Figure 8

The **SM&B** is the greatest synthesis of all times in the study of the fundamental phenomena governing the Universe in all its structures. The basic achievements of the **SM&B** have been obtained via UEEC events; moreover the **SM&B** could not care less about the existence of Platonic Simplicity.

An example is shown in figure 9 where the straight line (small dots) would be the Platonic simple solution towards the Unification of all Fundamental Forces.



The points 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* $\alpha_3\,(M_Z) = 0.118 \pm 0.008$*; the other input is the ratio of weak and electromagnetic couplings also measured at the* Z^0*-mass value:* $\sin^2\,\theta_W\,(M_Z) = 0.2334 \pm 0.0008$.

Figure 9

Nevertheless the effective unification is expected to be along the sequence of points (the big ones) computed using the Renormalization Group Equations (**RGEs**) [4].

Platonic Simplicity for the unification of all forces is again reported in Addendum 1 and Platonic Supersymmetry for the existence of the Superworld is discussed in Addendum 2. We will see how many times the platonic Simplicity is violated when we construct the Superworld.

In Addendum 3 there is a synthesis of UEECC events needed in the process of construction of the SM&B [5]. The numerous violations of Simplicity are the proof that Complexity exists at the fundamental level of scientific knowledge where we have proved that **AFB** phenomena and **UEEC** events are present.

The conclusion is that Complexity exists at the elementary level. In fact, starting from Platonic Simplicity, the **SM&B** needs a series of 'ad hoc' inputs [5].

5 THE TWO ASYMPTOTIC LIMITS: HISTORY AND SCIENCE

The real world seems to be characterized by two basic features, which are one on the opposite side of the other: *Simplicity* and *Complexity*.

It is generally accepted that *Simplicity* is the outcome of *Reductionism*, while *Complexity* is the result of *Holism*.

The most celebrated example of *Simplicity* is *Science* while the most celebrated example of *Complexity* is *History*.

Talking about asymptotic limits, the general trend is to consider ***History*** as the asymptotic limit of *Holism* and of *Complexity*; ***Science*** as the asymptotic limit of *Reductionism* and of *Simplicity*, as illustrated in figure 10.

The Logic of Nature allows the existence of ***Science*** (the asymptotic limit of Simplicity) and of ***History*** (the asymptotic limit of Complexity), which **share a property, common to both of them**.

It is interesting to define ***Science*** and ***History*** in terms of this property, **probably the only one**, which they share; i.e. **Evolution**.

- Science is the Evolution of our Basic Understanding of the laws governing the world in its Structure ≡ **EBUS**.
- History is the Evolution of the World in its Real Life ≡ **EWRL**.

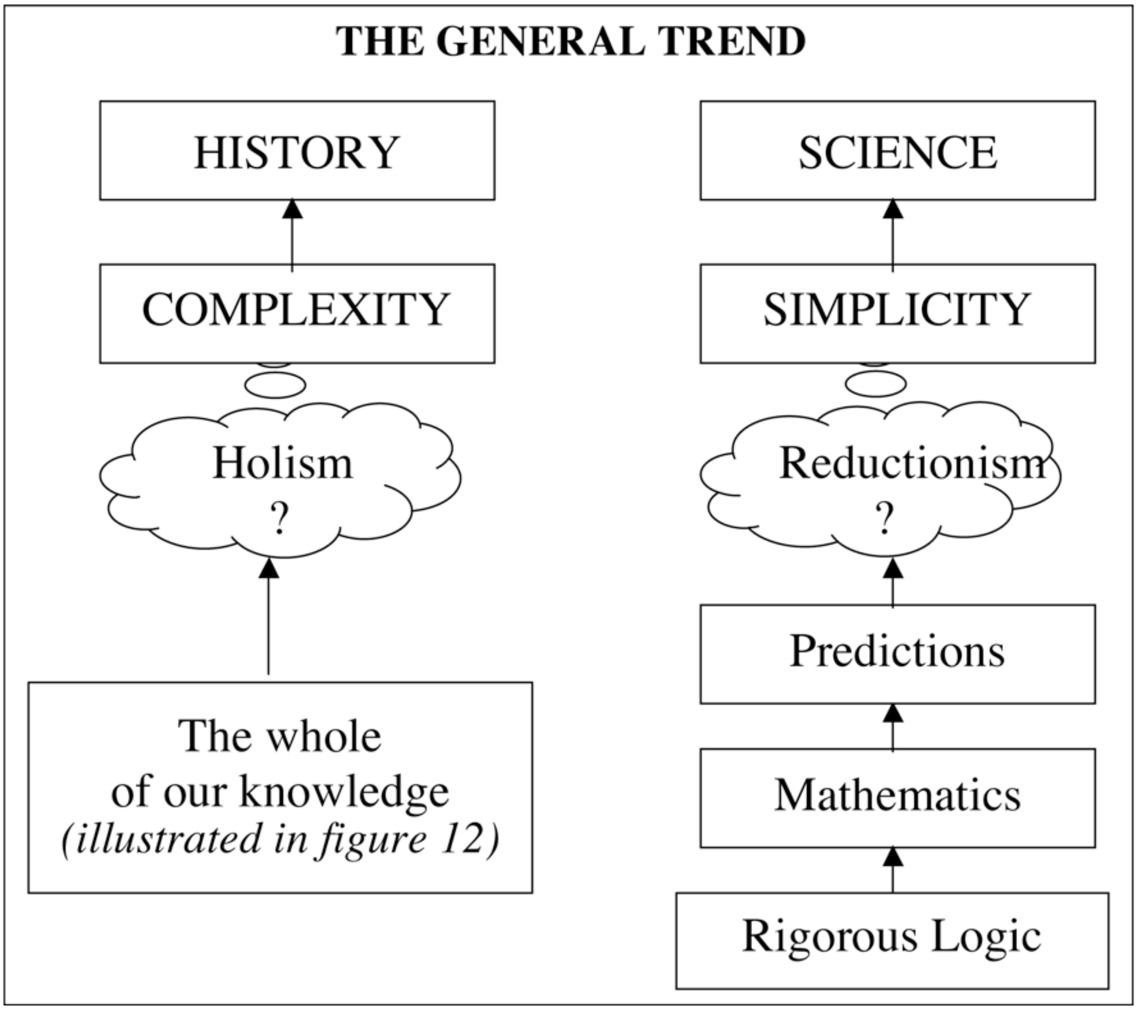


Figure 10

In Table 1 we compare these two supposedly asymptotic limits — History and Science — on the basis of 'What if?'; a condition elaborated by the specialists in what is now known as 'virtual history' [6].

On the basis of 'What if?' these specialists conclude [6] that the world would not be as it is, if one, or few, or any number of 'What if?' had not been as History tells us. This is not the case for Science. The world would have exactly the same laws and regularities, whether Galileo Galilei or somebody else had discovered F = mg (F ≡ force; m ≡ mass; g ≡ acceleration due to gravity), and so on for all the other scientific discoveries.

It is in the consequences of 'What if?' that the two asymptotic limits of Simplicity and Complexity seem to diverge, despite the fact that the sequence of 'What if?' in Science belongs to the 'totally unexpected events' (UEEC) exactly like the others listed in the column of History.

TABLE 1

'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 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 be both 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 the cosmic rays?
IX	What if the first nuclear weapon had been built either by Japan before Pearl Arbour (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 the 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?

6 THE BASIC POINTS ON COMPLEXITY AND PREDICTIONS

What are the experimental evidences for **Complexity** to **exist**, and for **Predictions** to **exist**?

In the previous chapters 3 and 4 we have discussed the experimental basis for the existence of Complexity, i.e., AFB and UEEC events.

We will now discuss the experimental evidence for the existence of predictions and the sequence which correlates UEEC and predictions.

Predictions.

The experimental evidences for the **existence** of **Predictions are** the very many results of scientific reproducible experiments.

Quantum Electro-Dynamics, QED, is the best example. The anomalous magnetic moments, in symbols (g–2), of the electron (e) and of the muon (μ):

$$(g-2)_{e,\ \mu}$$

are theoretically computed at an extraordinary level of precision (few parts in ten billion parts for the electron) and are experimentally verified to be correct. Could the

$$(g-2)_{e,\ \mu}$$

be theoretically predicted before the discovery of the Maxwell equations and the existence of Quantum Electro-Dynamics (QED)? The answer is obviously no.

The sequence which correlates UEEC events and Predictions.

Predictions at the **fundamental level of scientific knowledge** depend on **UEEC events**.

For example: it is the discovery of the laws governing electric, magnetic and optical phenomena (all totally unpredicted) which produced the mathematical structure called QED.

The mathematical structure was not discovered before the innumerable series of **UEEC** events was found in electricity, magnetism and optics. This series of UEEC events allowed Maxwell to express 200 years of experimental discoveries in a set of 4 equations.

The mathematical formalism comes **after** a totally unexpected discovery: an **UEEC event** which no one was able **to predict**.

In the whole of our knowledge rigorous predictions exist only in Science. These predictions are based on the mathematical description of a single UEEC event or a series of UEEC events. This description can either be the result of new mathematics (example the Dirac δ-function) or the use of existing mathematical formalism (example: the Einstein use Ricci tensor calculus).

The UEEC event at the origin of the Dirac equation is the fact that the electron was not a 'scalar' particle but a spin ½ object.

The UEEC event at the origin of Einstein mathematical formulation of the gravitational forces are the discoveries of

$$\text{Galilei } (F = mg)$$

and of

$$\text{Newton } \left(F = G\frac{m_1 \cdot m_2}{R_{12}^2}\right).$$

These are just two examples of the fact that the greatest steps in the **progress of Science** come from totally unpredicted discoveries.

This is the reason why we need to perform experiments, as Galileo Galilei realized 400 years ago.

Even when we have a mathematical formalism coming from a series of UEEC events, if this formalism opens a new frontier, as it is the case for the Superworld, the experimental proof is needed to verify the validity of the new theoretical frontier.

Today we have a reasonable mathematical formalism to describe the **Superworld**, but in order to know if the Superworld exists we need the experimentally reproducible proof for its existence.

7 THE LESSON NEEDED FOR THE FUTURE

We have proved that AFB and UEEC – which are at the origin of Complexity, with its consequences permeating all our existence, from molecular biology to life in all its innumerable forms up to our own, including History – do exist at the fundamental level [7–10] and [5].

It turns out that Complexity in the real world exists, no matter the mass-energy and space-time scales considered.

Therefore the only possible prediction is that:

- **Totally Unexpected Effects** should **show up**.

- **Effects**, which are impossible to be predicted on the basis of **present knowledge**.

We should be prepared with **powerful experimental instruments**, **technologically at the frontier of our knowledge**, to discover Totally Unexpected Events in all laboratories, the world over (including CERN in Europe, Gran Sasso in Italy, and other facilities in Japan, USA, China and Russia). All the pieces of the Yukawa gold mine [3] could not have been discovered if the experimental technology was not at the frontier of our knowledge.

Example: the cloud-chambers (Anderson, Neddermeyer), the photographic emulsions (Lattes, Occhialini, Powell), the high power magnetic fields (Conversi, Pancini, Piccioni) and the powerful particle accelerators and associated detectors for the discovery – the world over – of the **SM&B** as synthetically reported in chapter 4.

This means that we must be prepared with the most advanced technology for the discovery of totally unexpected events like the ones found in the Yukawa gold mine.

The mathematical descriptions, and therefore the predictions – for new phenomena to be discovered in the field opened by the given UEEC event – come after the UEEC event, never before.

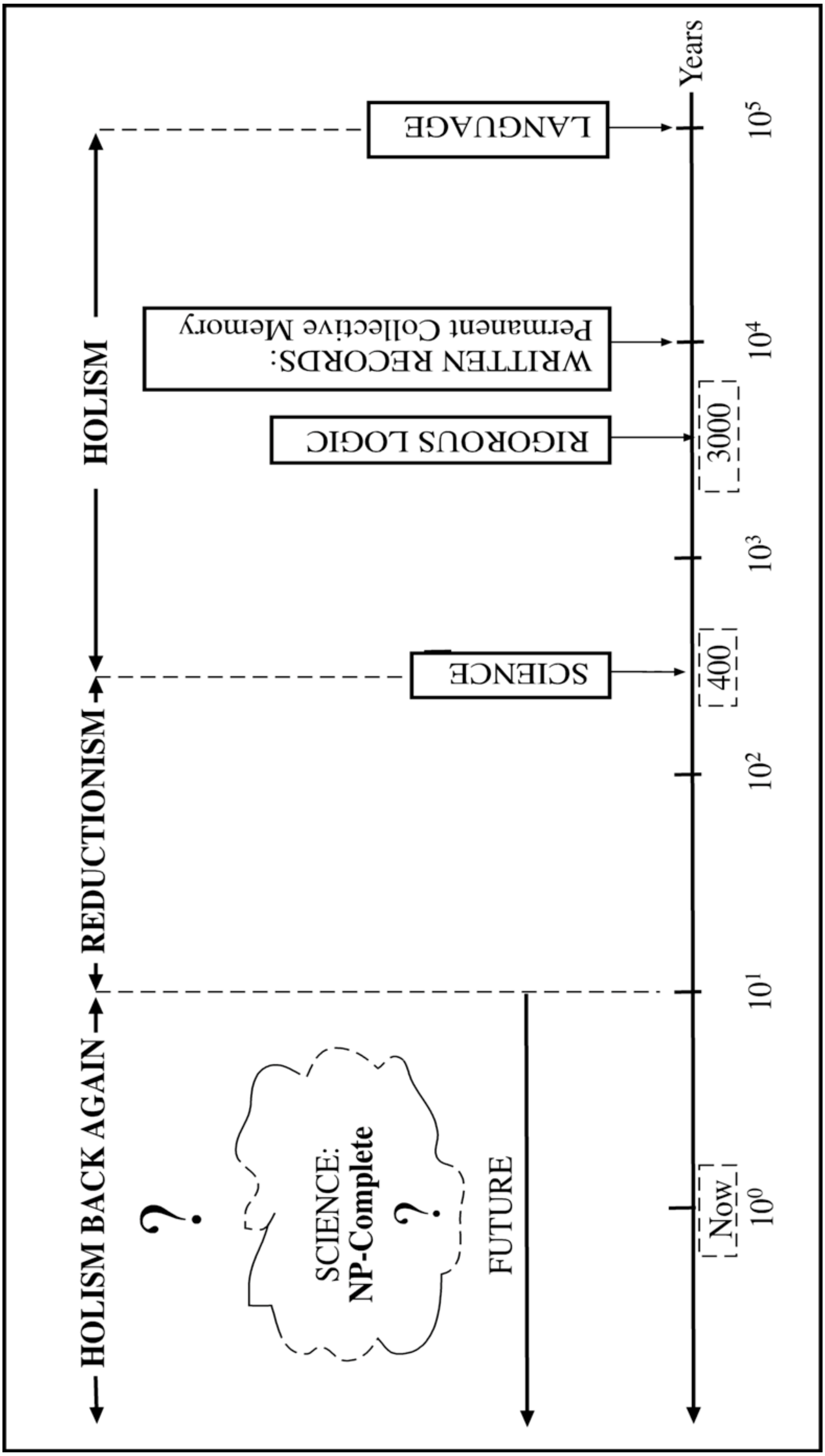
<u>Recall</u>:

- The **discoveries in Electricity**, **Magnetism** and **Optics** (UEEC).
- **Radioactivity** (UEEC).
- The **Cosmic Rays** (UEEC).
- The **Weak Forces** (UEEC).
- The **Nuclear Physics** (UEEC).
- The **Strange Particles** (UEEC).
- The **3 Columns** (UEEC).
- The **origin of the Fundamental Forces** (UEEC).

The present status of Science is reported in figure 11.

It could be that Science will be mathematically proved to be 'NP-complete'. This is the big question for the immediate future [11].

It is therefore instructive to see how Science fits in the whole of our knowledge as reported in figure 12.



HOLISM BACK AGAIN
REDUCTIONISM
HOLISM
?
SCIENCE:
NP-Complete
?
FUTURE
SCIENCE
RIGOROUS LOGIC
WRITTEN RECORDS:
Permanent Collective Memory
LANGUAGE
Now
400
3000
10^0
10^1
10^2
10^3
10^4
10^5
Years

Figure 11

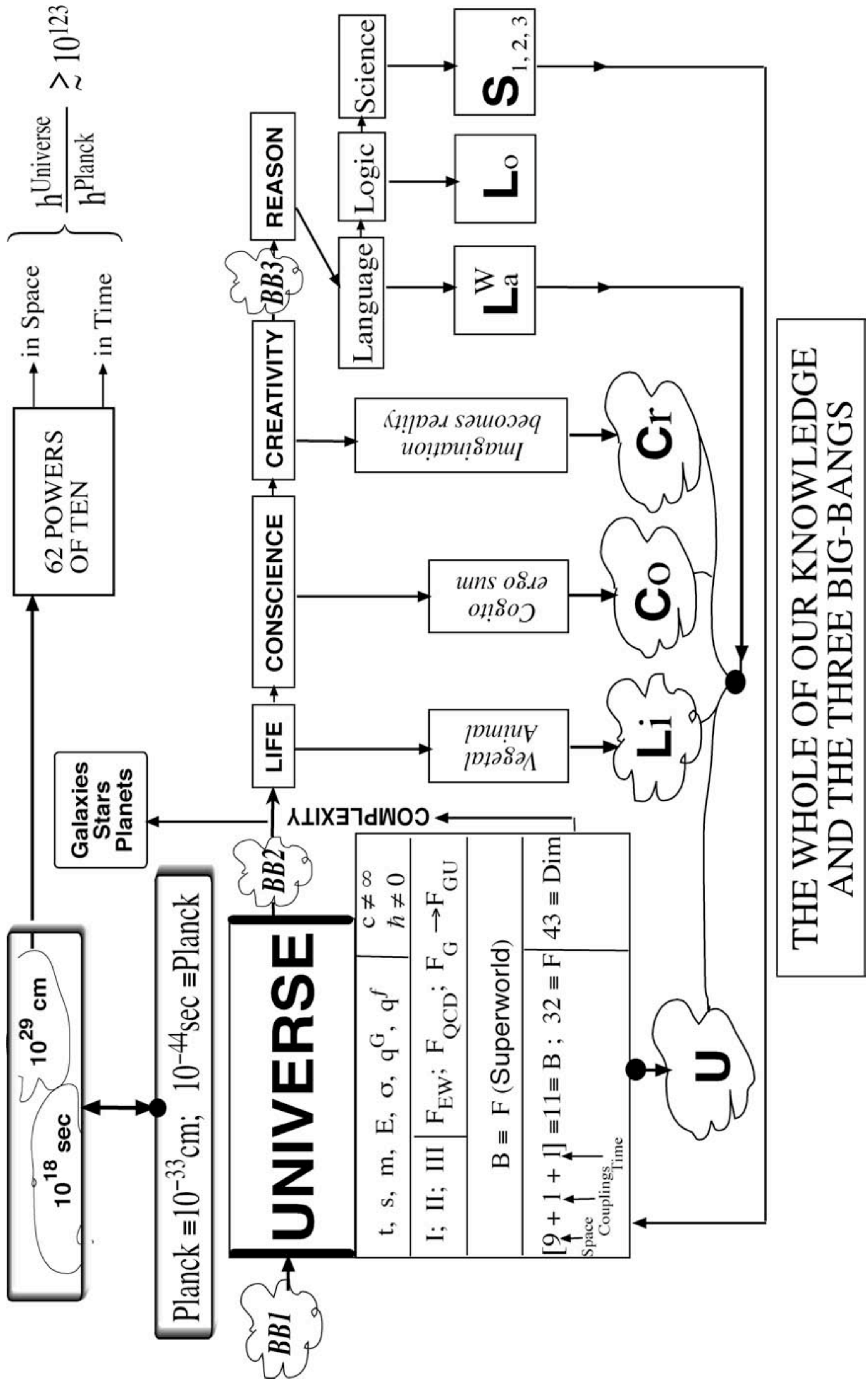

THE WHOLE OF OUR KNOWLEDGE
AND THE THREE BIG-BANGS
UNIVERSE
BB1
BB2
BB3
LIFE
CONSCIENCE
CREATIVITY
REASON
COMPLEXITY
Galaxies
Stars
Planets
62 POWERS
OF TEN
in Space
in Time
Vegetal
Animal
Cogito
ergo sum
Imagination
becomes reality
Language
Logic
Science
Planck

Figure 12

Let me point out that Science is the consequence of us being the only form of leaving matter endowed with Reason, from where the sequence of Language–Logic–Science has been originated [12]. The time-sequence of Language–Logic–Science is shown in figure 13.

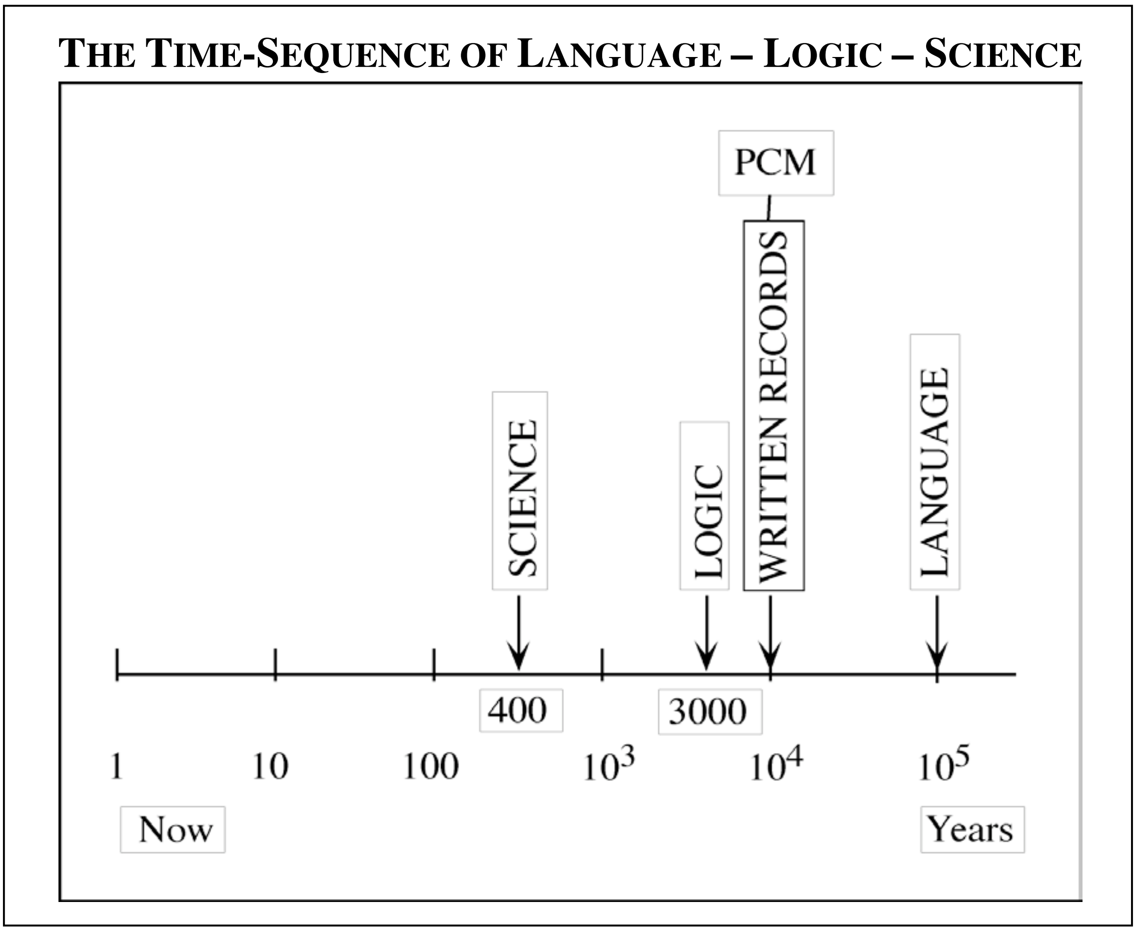


Figure 13

The experimental evidence is that UEEC events dominate our life as the evolution of the world in its real life (EWRL ≡ History) and the evolution of our basic understanding of the laws governing the world (EBUS ≡ Science) do show (see Table 1).

We confront the present status of physics with Ten Challenges in Addendum 4.

The next UEEC event must be outside these Ten Challenges.

We should be aware of the fact that it would be great if, **for the first time in the 400 years of Galilean Science, the sequence of UEEC** events could enjoy a **formidable stop**.

The final question is: why the greatest achievements of Science have always been originated by totally unexpected events?

8 FROM PLANCK TO COMPLEXITY

Four centuries of Galilean research work based on Reductionism, i.e. on the identification of the simplest elements in the study of Nature, has allowed us to get the greatest achievement of Science, i.e. the so called **Standard Model** and its extension (**SM&B**), illustrated before in figure 7.

This extension predicts GUT (the Grand Unification Theory), the existence of the Superworld and the resolution of the quantum-gravity problem via the powerful theoretical structure of RQST (Relativistic Quantum String Theory).

All these developments started thirty years ago when a great scientific novelty came; all experimental discoveries obtained with our powerful accelerators were to be considered only matters of extremely low energy.

The scale of energy on which to direct the attention to understand the Logic that rules the world, from the tiniest structures to the galactic ones, had to be shifted at a much higher level: to the mass-energy named after Planck, E_{Planck}, something like seventeen powers of ten above the Fermi scale, E_{Fermi} , that already seemed to be an extremely high level of energy.

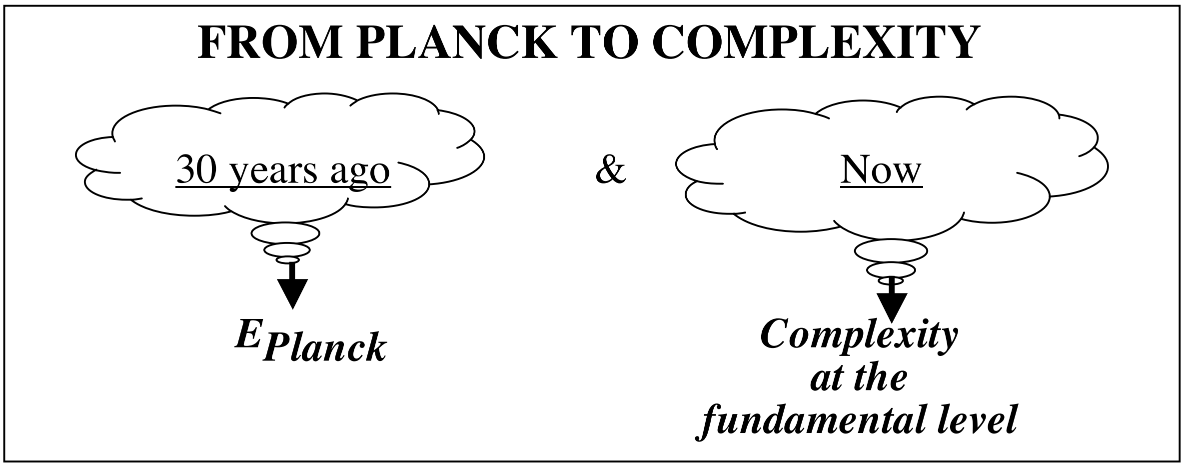


Figure 14

Now, after thirty years, it comes about the novelty of our time, illustrated in figure 14: Complexity exists at the fundamental level [5]. In fact, **AFB** and **UEEC** events exist at all scales, as reported all along this lecture and summarized in figure 2.

This result is corroborated from the mathematical structure (the only one) to be in a position of describing all that happens at the Planck scale: the Relativistic Quantum String Theory (**RQST**).

This mathematical structure produces innumerable minima of energy, named **Landscape**.

The theoretical discovery of the **Landscape** (Leonard Susskind) [13], has been followed by another formidable discovery in mathematical physics: the most rigorous model of RQST (Raphael Bousso and Joseph Polchinski) is **NP-complete** (Michael R. Douglas and Frederik Denef) [14].

This discovery corroborates all that we have put in evidence during the last five years [7–10]: **Complexity exists at the fundamental level** [5].

We do not know what will be the final outcome of String Theory.

What we know is that: '*The world appears to be complex at every scale.* ***Therefore*** *we must expect a continued series of surprises that we cannot easily predict'*.

But, with the advent of the LHC it will be possible to study the properties of the Quark-Gluon-Coloured-World (QGCW), which is a world totally different from all we have been dealing with since the origin of Science.

9 CONSEQUENCES FOR LHC: THE QGCW PROJECT

9.1 INTRODUCTION

With the advent of the LHC supercollider at CERN we propose to study the properties of the '**new world'** which is produced in a collision between heavy nuclei ($_{208}Pb^{82+}$) at the maximum energy so far available in our planet, i.e. 1150 TeV (1.15×10^{15} eV). The 'new world' is the **Quark-Gluon-Coloured-World** (QGCW).

We avoid in purpose to call it 'quark-gluon plasma' since, in the extremely high energy collision between heavy ions, many QCD open-colour-states should be produced.

The number of these QCD open-colour-states is by far higher that the number of baryons and mesons so far known, since these baryons and mesons have to obey the condition of being QCD-colourless.

In chapter 9.2 we discuss four basic new problems addressed by the QGCW project. In chapter 9.3 how to detect the properties of the new world (QGCW), in chapter 9.4 we discuss the two most difficult technical problems to solve in order to study the QGCW; in chapter 9.5 the synchronization issues, including four relevant details. The conclusions in chapter 10.

9.2 THE PHYSICS OF THE QUARK-GLUON-COLOURED WORLD (QGCW): THE NEW WORLD

The basic purpose of the project is to study the Quark-Gluon-Coloured World (QGCW) which is totally different from our world made of QCD vacuum with colourless baryons and mesons. We want to search for specific effects due to the fact that the colourless condition is avoided.

1st problem – In the QGCW there are all states allowed by the $SU(3)_c$ colour group. The number of possible states is by far more numerous than the number of colourless baryons and mesons which have so far been built in all Labs, since the colourless condition is not needed. **Question**: What are the consequences on the properties of the QGCW?

2nd problem – Light quarks versus heavy quarks. Are the coloured quark masses **the same** as the values we derive from the fact that baryons and mesons need to be in a colourless state? It could be that all six quark flavours are associated with nearly 'massless' states like those of the 1st family (u, d). In other words the reason why the 'top' quark appears to be so heavy ($\simeq 10^2$ GeV) could be due to the fact that it must satisfy some, so far unknown, condition related to the fact that the final state must be QCD-'colourless'.

We know that confinement produces masses of the order of a GeV. Therefore, according to our present understanding, the QCD 'colourless' condition could not explain the heavy quark mass, but since the origin of the quark masses is still not known, it cannot be excluded that in a QCD coloured world, the six quarks are all nearly massless.

If this was the case, the masses we measure are heavier than the effective coloured quark masses. In this case all possible states generated by 'heavy' quarks would be produced in the **QGCW** at much less temperature than the one needed in our world made with baryons and mesons, i.e. QCD colourless states.

Here again we should try to see if with masses totally different from those expected, on the basis of what we know about colourless baryons and mesons, new **effects** could be detected due to the existence of all six flavours at relatively low temperature in the QGCW world.

3rd problem – To search for effects on the thermodynamic properties of the QGCW. Are these properties going to be along the ‘extensivity’ and / or ‘non-extensivity’ conditions?

4th problem – **Derive the equivalent** Stefan-Boltzmann Radiation Law for the QGCW. The relation between **energy density** at emission **U**, and **Temperature** of the source **T**, is

$$U = cT^4$$

in classical Thermodynamics.

In the QGCW the correspondence should be

U ≡ $p_\perp$ (transverse momentum)

T ≡ average energy in the CM system.

In the QGCW the production of ‘heavy’ flavours should be studied versus $\langle p_\perp \rangle$ and versus $\langle E \rangle$. The expectation is

$$\langle p_\perp \rangle \equiv C \cdot \langle E \rangle^4$$

and any deviation would be extremely important.

The study of the properties of the QGCW should produce the correct mathematical structure able to correctly describe the QGCW; the same mathematical formalism should allow to go from QGCW to the Physics of Baryons and Mesons (PBM) and from here to a restricted component of PBM, namely Nuclear Physics, where all properties of the nuclei should find a correct description.

9.3 HOW TO STUDY THE NEW WORLD: QGCW

An example is illustrated in the figure 15 below where beams of known particles (p, n, π, K, μ, e, γ, ν) bombard the QGCW and a special set of detectors measures the properties of the outcoming particles.

Totally unexpected effects should show up if Nature follows the Logic of Complexity at the Fundamental level.

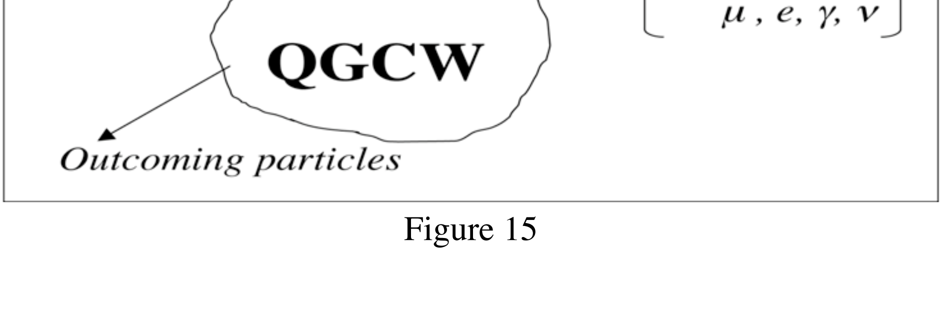


Figure 15

9.4 THE NEW TECHNOLOGY NEEDED TO STUDY THE QGCW

The technology needed covers two fields: one is the accelerator technology, the other is the detectors technology.

The first step in the accelerator technology refers to the availability of a proton beam able to bombard the QGCW produced in the lead-lead collisions.

The LHC physics program foresees lead-lead collisions with a design luminosity of 10^{27} cm^{-2} s^{-1}. For this to be achieved an upgrade of the ion injector chain comprising Linac3, LEIR, PS and SPS machine is needed. Each LHC ring will be filled in 10 min by almost 600 bunches, each of 7×10^{7} lead ions. Central to the scheme is the Low Energy Ion Ring (LEIR), which transforms long pulses from Linac3 into high brilliance bunches by multi-turn injection, electron cooling and accumulation.

The total collision energy between heavy ions, $_{208}Pb^{82+}$ (fully stripped), is 1150 TeV. Table 1 shows the basic parameters of the lead-ion injectors.

Table 1: NOMINAL PARAMETERS OF THE LEAD ION INJECTORS

	Linac3	LEIR	PS	SPS
Output energy	4.2 MeV/n	72.2 MeV/n	5.9 GeV/n	177 GeV/n
^{203}Pb charge state[1]	27+/54+	54+	54+/82+	82+
Output Bρ [Tm][1]	2.28/1.14	4.80	86.7/57.1	1500
# Batches to fill next machine	4–5	1	13,12,8	12
Bunches/ring		2 (1/8 PS)	4	52,48,32
Ions per pulse[2]	1.15×10^{9}	9×10^{3}	4.8×10^{3}	$<4.7\times10^{9}$
Ions/LHC bunch	1.15×10^{9}	2.25×10^{2}	1.2×10^{2}	9×10^{7}
Bunch spacing [ns]		352	100	100
ε^{*}_{rms} [μm] $= (\beta\gamma)_{rel}\,\sigma^2/\beta_{twitss}$	0.25	0.7	1.0	1.2
ε_1 [eVs/u/bunch]		0.05	0.05	0.24
4 σ bunch length		200 ns	4 ns	2 ns
Repetition time [s]	0.2–0.4	3.6	3.6	~50

[1]Values before/after stripping.
[2]50 eμA × 200 μs Pb^{54+} Linac3 output after stripping.

Once the lead-lead collision is available, the problem is to synchronize the ‘proton’ beam with the QGCW produced. This problem is at present under study.

The detector technology is also under intense R&D since the synchronization needed is at a very high level of precision; the status of the problems is reported in the following chapter 9.5.

9.5 SYNCHRONIZATION ISSUES RELATED TO THE QGCW PROJECT

The present limit of precision timing is given by the stability of master clocks and of optical fiber signal transmission lines.

Present timing signal stabilities is of order **nanoseconds.** Synchronization to the level down to **femto-seconds (10^{-15} sec)** between distributed equipment, accelerators RF systems, and between accelerator beam bunches will in future be required.

Synchronization at CERN LHC

The CERN network of accelerators requires the transmission, over long distances, of precise timing pulses. These timing pulses are derived from a master clock and therefore the ultimate time accuracy of the pulses is determined by the quality of the transmission of the clock frequency itself. A similar problem arises when two machines need to be synchronized RF-wise. In all cases the transmission of a CW wave in the frequency range of several hundred MHz over distances up to several kilometers is the key to a proper synchronization.

Optical fibers are used as transmission media and a 4 km optical fiber link was installed already in 1978 between the CERN SPS and its injector for the purpose of synchronizing the two machines. In preparation for the LHC, its timing distribution and its synchronization challenges, a special R&D project (RD12) had been set-up to study solutions for machine and experiments. A common solution to the timing, trigger and control (TTC) system requirement for machine and experiments leads to an important economies of scale and permits a rationalization of the requirements for development, operation, and support efforts.

The common systems allows to control the detector synchronization and delivers the fast signals and messages that are phased with the LHC clock, orbit or bunch structure. These include the bunch-crossing clock, level-1 trigger decisions, bunch and event numbers, as well as test signals and broadcast commands.

In the framework of the LHC common project RD12 the development and test of a multi-function optoelectronic TTC system was launched. The TTC system needed to meet the requirement of central signal broadcasting and local distribution at the different sub-detectors of the experiments.

A laser transmitter, modulator, encoder, VME-bus interface and machine interface have been developed as well as a subminiature radiation-hard optical fiber connector, active device mount and photo-detector / preamplifier.

A radiation-hard timing receiver ASIC is being designed which will generate the full range of decoded signals for electronics controllers from a single input and a PMC receiver module is being developed to facilitate initial applications.

The system incorporates programmable coarse and desktop facilities to compensate for different particle flight times and detector, electronics, propagation and test generator delays.

It can also transmit asynchronous slow controls and data such as individually addressed channel enables and calibration parameters to several thousand destinations. More details are published by the RD12 collaboration in their final report.

Synchronization challenges of the QCGW project

For the QCGW project it will be mandatory to improve the LHC timing system. One needs to provide a much shorter and predictable constant time delay distribution of RF signals than presently available at LHC. One should aim at carrying time information with resolution and stability to order of femtoseconds over distances of kilometers.

The R&D for the QCGW project needs to concentrate on research of **stability properties of optical fibers** for signal transport, on the development of an **improved microwave oscillator** (master clock), and on beam instrumentation.

LHC heavy ion particle bunches at high energies have rise-times of a few nanoseconds, the rise-time of proton bunches could be as low as 100 picoseconds, for photons and lasers one is in the femtosecond range. Therefore, referring to the rising or front edge of a bunch requires timing precision covering nanoseconds, picoseconds or even femtoseconds.

The key timing component in a synchrotron is the RF generator of the accelerating RF cavity. Charged particles moving through the cavity will see the longitudinal electrical field in the cavity gap. As a result, they are captured in the 'RF bucket' as bunches and thus are localized inside the synchrotron vacuum pipe.

By definition a 'bunch phase' is the momentary longitudinal position of the leading front or, in electrical terms, the rising edge of the moving particle bunch.

So, a bunch phase refers to the local position where it is momentary seen. The bunch phase can also be described in angular terms when referring it to a geometric reference point of the ring accelerator. To capture a bunch in a cavity implies that there is a relation between the bunch phase to the cavity RF phase. The presence of a charged bunch of particles is detected by a capacitive pick up in the vacuum pipe. These 'Beam Position Monitors' allow to measure the bunch phase in real-time and thus enables the cavity synchronization by controlling the phases of the RF-cavities. It is essential for proper acceleration to maintain phase differences of less than a few degrees between all cavities in the accelerator complex.

A precise reference signal common to all RF cavity stations is needed to operate with the same signal references during acceleration ramps. Otherwise, all RF-cavities will have arbitrary phases. At each group cavity system one has to select one reference signal for phase locking the cavity phases.

This is not only valid for a single accelerator synchronization. It is a rather direct extrapolation if one has to control a whole complex build out of synchrotrons and storage rings: Each of the named 'phase references' in a single accelerator system can be referenced to a wider spanned 'campus reference' in the same manner.

A system that transmits standard time- and frequency signals at the same time using signal-multiplexing techniques, could distribute more common time and frequency reference signals as well. These signals will all have the same predictable delay and link all local generated RF signals and additional time- and trigger-signals (TTC) reference planes of the whole campus site together. Thus, a common coherent campus synchronous network is built. This has been the basic idea for the LHC synchronization scheme.

The communications industry has created an RF signal transport technique called 'optical RF link' [15]. These devices are intended for linking broadband RF signals between mobile telephone base stations.

These optical links utilize direct modulated laser diode sources, which feed optical single mode fibers of several kilometers length and fast photodiodes at the receiving end of the fiber. The bandwidth of the analog link transmitter/receiver pair is beyond 2GHz in base-band mode. The RF signals are transmitted in base-band, they cover the frequency band of 900-1900 MHz as 'block' without up/down converting in frequency. The capabilities of these links match with present accelerator signal transport tasks: (i) analog transmission of multiple RF signals, (ii) constant delay properties of the transport fibers, the thermal length deviation coefficient of 'from the stock fibers' is about 7 ppm/K.

For a 1000m run of optical fiber (5ns/mgroup delay) a deviation of 35ps/K can be derived. For the target value of 40 K temperature variation (over the whole length) the total delay change is 1.4 ns.

For the QCGW project this value will have to be improved.

Transporting femto-second accelerator timing signals over long distances requires a new approach. One has to overcome effects of time jitter, typically induced by microphony, electromagnetic noise and temperature dependent variation of fiber cable length.

A possible solution could be based on the idea of a reference signal feedback system to stabilize the signal transmission. We think of using an extremely stable laser as an optical oscillator.

The laser provides reference signals (master clock) and in combination with a piezo-electric fiber stretcher one stabilizes the signal frequency transmitted through a long signal transport fiber cable in feedback mode. This idea is under study for X-FEL pulses and will be worked out in more detail for the QCGW project [15].

ANNEX 1: DETAILS ON TIMING DISTRIBUTION AT THE LHC

Extract from **Timing Distribution at the LHC** by Bruce.Taylor@cern.ch

The timing signals for each ring of LHC will be encoded and transmitted over optical links from the RF system to the PCR, where beam-synchronous messages will be added. High power laser transmitters will then broadcast the signals over single-mode optical fibers to the four LHC experiments, to the test beam areas, and to the beam instrumentation located around the LHC ring and on the SPS transfer lines. At the experiment areas, trigger information and local synchronous commands and data will be added. The regenerated signals will then be broadcast over multimode passive optical networks to several thousand destinations.

At the LHC, 'fast' timing signals must be distributed to all experiments and to the beam instrumentation of the machine. These signals are derived from the LHC RF generators and will be synchronous with the circulating beams, so that their frequencies will vary a little during acceleration. At 7 TeV, the bunch clock frequency will be about 40.07897 MHz while the orbit frequency will be 11.2455 kHz.

They are distinct from the 'slow' LHC timing signals, having a granularity of 1 ms, which will signal machine events and distribute UTC time for data tagging and post mortem applications.

At the LHC, distributing correctly synchronized signals to several thousand electronics channels presents some interesting challenges. The R&D work has been done in the framework of the RD12 TTC Project [16], which comprised members from all the LHC experiments, the Microelectronics and Beam Instrumentation Groups and two industrial partners.

The unified approach to TTC distribution developed by RD12 provides for the broadcasting of the fast timing signals through all the transmission stages from the RF generators of the LHC machine to the outputs of the timing receiver ASICs at the experiment and beam instrumentation destinations. That general path will be followed in this review of the system.

ANNEX 2: DETAILS ON LHC BUNCH STRUCTURE

Commencing with the timing of the LHC machine, it should first be noted that there has been an important change to the bunch structure described in the Yellow Book [17]. Initially it was proposed to accelerate trains of 84 bunches in the PS, 81 of which would be injected into the SPS, 3 being lost in the PS ejector. The difficulty with this configuration is that it would be dirty in the PS and SPS machines and there would be longitudinal stability problems in the PS with the 84-bunch trains.

Various solutions to these problems have been proposed and the one that has been retained as the current baseline foresees the acceleration of PS trains of 72 bunches which will be entirely injected into the SPS. In order to maintain an acceptable filling factor in the LHC with the 72-bunch PS trains, the SPS batches, which will be injected into the LHC, will comprise groups of 3, 3 and then 4 PS trains. So, whereas formerly we had quasi 12-fold symmetry in the LHC (the last PS train in the last SPS batch being suppressed to allow for the rise-time of the LHC extraction kicker), we now have quasi 4-fold symmetry with corresponding implications for the TTC synchronization algorithms [18].

As a result of this change the number of bunch crossings per orbit will be reduced from 2835 to 2808. Note that this applies only to ATLAS and CMS – since these experiments are diametrically opposite each other it is possible to phase the beams to make the LHC extractor gaps coincide at both of them. That is not possible at ALICE and LHCb, which will result in the loss of a further 188 bunch crossings per orbit at these experiments. It should also be noted that it is now expected that there may be quite a substantial initial running period with 75 ns instead of 25 ns bunch spacing. The expected rms collision length remains about 180 ps.

In the case of the LHC bunch structure for heavy ions, there may be several re-synchronizations during each orbit and there could be gaps, which are a non-integer number of bunch intervals in length.

But neither of these factors should be a cause for alarm, for in this case the bunch spacing concerned will be 100 ns or 125 ns. The TTC system will continue to distribute a 40.079 MHz clock during this mode of operation and the bunch crossings will remain in phase with this clock.

ANNEX 3: DETAILS ON CLOCK ARTEFACTS

On the other hand, at times there may be some artefacts in the distributed clocks. There could be a 1 ms hole in the SPS RF/5 clock occurring once before each transfer from the PS, because the LHC machine will be the master of the timing and the SPS has to be synchronized such that the SPS batches are injected into the correct part of the LHC orbit. That will be done by calculating back to the PS, so the PS and SPS have to be re-synchronized before each injection and during this time there may be an interruption in the clock.

The situation with colliding beams at the LHC will be more comfortable. In that case there could be a 1 ms hole in the bunch clock, which will occur once, and once only, before the very first injection from the SPS into the LHC. The reason for this is that a general RF system reset will be made prior to each LHC run in order to ensure that all the dividers have the correct phase and there may be an interruption to the clock while this is applied.

During these clock holes, the TTC system will continue to distribute a 40.079 MHz clock to the experiments. But developers should be aware that there may be a momentary phase perturbation when the system re-synchronizes with the real clocks when they are restored after the interruptions.

ANNEX 4: DETAILS ON DISTRIBUTION ARCHITECTURE

At present the RF timing generators are located in the BA3 Faraday Cage adjacent to the Prevessin Control Room (PCR).

Four clocks are available: the constant frequency 40.079 MHz LHC bunch clock, a pseudo LHC orbit signal obtained by dividing the clock by 3564, the real SPS orbit signal and the ramping SPS 40 MHz clock obtained by dividing the SPS RF by 5.

The PCR transmitters can each broadcast only one orbit and one clock signal simultaneously. The selected pair are encoded and used to modulate a high power laser, the output from which is split by a 1:32 optical tree coupler and broadcast via optical fibers to different destinations around the CERN sites.

At present these destinations include the test beam areas in the North and West halls and labs where beam instrumentation and TTC development work are being done. Finally they will include the LHC experiment areas. At the experiment areas the signals will be received by a TTC machine interface in which they are decoded.

10 CONCLUSIONS

We must be prepared with the most advanced technology for the discovery of totally unexpected events like the ones found in the Yukawa gold mine.

The occasion of the Yukawa Centenary (2007) has been of great value in order to draw attention to the impressive series of conceptual developments linked with his meson: chirality−invariance, spontaneous symmetry breaking, symmetry breaking of fundamental invariance laws, anomalies, and 'anomaly-free condition', existence of a third family of fundamental fermions, gauge principle for non-Abelian forces, instantons and existence of a pseudoscalar particle made of the quanta of a new fundamental force of Nature acting between the constituents of the Yukawa particle.

All the pieces of the Yukawa gold mine **could not have been discovered** if the experimental technology was not at the frontier of our knowledge, as already reported in chapter 7: the cloud-chambers (Anderson, Neddermeyer), the photographic emulsions (Lattes, Occhialini, Powell), the high power magnetic fields (Conversi, Pancini, Piccioni) and the powerful particle accelerators and associated detectors for the discovery – the world over – of the intrinsic structure of the Yukawa particle (quarks and gluons) which has brought us to QCD and now to the QGCW Project.

ADDENDUM 1
THE PLATONIC GRAND UNIFICATION

We report here again figure 9 from page 13 since this is the best examples of Platonic Grand Unification. The points 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 Grand Unification should be along the straight line (in blu) but Nature seems to follow the red points.

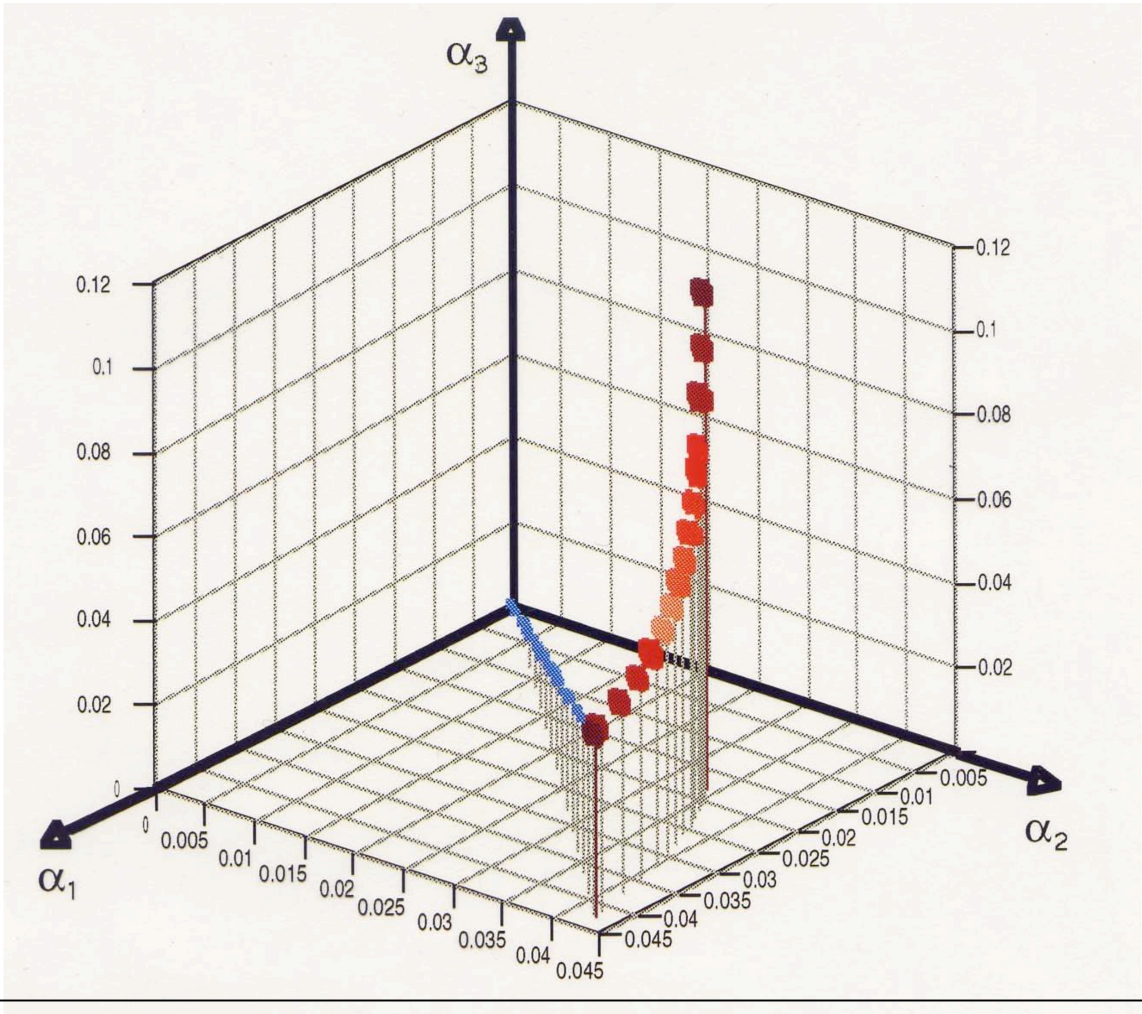


Figure 9 (from page 13)

ADDENDUM 2
THE PLATONIC SUPERSYMMETRY

THE PLATONIC CONCEPT OF SUPERSYMMETRY

The **Gauge Principle** should generate a
Gauge Force ⟶ **Gauge Bosons**
If *NATURE* was platonically *SUPERSYMMETRIC*
Supersymmetry Transformation should generate **Gauginos**

1st **DEVIATION FROM PLATONIC SIMPLICITY**
OUR FERMIONS ARE NOT THE GAUGINOS

2nd **DEVIATION FROM PLATONIC SIMPLICITY**
THE FUNDAMENTAL FERMIONS ARE OF TWO DIFFERENT CLASSES: LEPTONS AND QUARKS

3rd **DEVIATION FROM PLATONIC SIMPLICITY**
THERE IS NOT ONLY ONE BUT THREE FAMILIES OF FUNDAMENTAL FERMIONS

4th **DEVIATION FROM PLATONIC SIMPLICITY**
THE FUNDAMENTAL FERMIONS BECAME MIXED WHEN THE WEAK FORCES ARE SWITCHED ON: MIXINGS EXIST

5th **DEVIATION FROM PLATONIC SIMPLICITY**
THERE ARE DIFFERENT MIXINGS

Figure 16

ADDENDUM 3
EXAMPLES OF UEEC EVENTS IN THE CONSTRUCTION OF THE STANDARD MODEL AND BEYOND

There are very many UEEC events in the construction of the Standard Model and Beyond (SM&B). Let me select a group of problems where I have been directly involved: 1) the mass ≠ matter problem; 2) the mesonic mixings; 3) the Gribov QCD-light; 4) the Gap between the GUT energy and the string unification energy.

ADDENDUM 3–1
THE MASS≠MATTER PROBLEM

The fact that mass and matter had to be two different physical quantities, i.e. the mass ≠ matter problem, started with the Einstein discovery $E = mc^2$. The symbol 'm' originally was considered to represent 'matter' and thus the Einstein discovery become the problem of explaining the stability of matter. The meaning of 'm' had to be different from 'matter'. This is how the distinction between 'matter' and 'mass' come in the forefront of fundamental physics. Einstein proposed to solve the problem mass ≠ matter with the existence of just one 'charge', the electromagnetic one. But, seven decades and the sequence of UEEC events reported in figure 17 were needed to understand the stability of matter. The 'charge' needed for the mass ≠ matter problem is not the 'gauge' charge, like the electromagnetic one, but a set of 'flavour' charges; and these are 12, as reported in figure 18 where it is also specified that there are three classes of 'masses'.

ADDENDUM 3–2
THE PSEUDOSCALAR AND VECTOR MESONIC MIXINGS

The problem started when experimental physics was dominated by bubble chambers and the 'mixing' was determined using mass–formulae: i.e. a tautology. I designed and built a non-bubble-chamber detector, NBC; it consisted of an original neutron missing mass spectrometer coupled with a powerful electromagnetic detector which allowed to clearly identify all final states of the decaying mesons into (e^+e^-) or $(\gamma\gamma)$ pairs. The mass of the meson (be it pseudoscalar or vector) was measured by the neutron missing mass spectrometer. The two 'mixing angles', the pseudoscalar θ_{PS} and the vector θ_V, where directly measured (without using the masses) to be, not as expected by $SU(3)_{uds}$, i.e. $\theta_{PS} = \theta_V = 0$, but, $\theta_{PS} \neq 0$, $\theta_V \neq 0$ and totally different $\theta_{PS} \neq \theta_V$. Many years were needed and Gerard 't Hooft instantons to explain why $\theta_{PS} \simeq 10°$ and $\theta_V \simeq 51°$.

ADDENDUM 3–3
THE GRIBOV QCD LIGHT

When the physics of strong interactions finally became the physics of quarks and gluons, QCD had a problem, defined by Gribov as being its 'hidden QCD side': i.e., the large number of different final states produced by different pairs of interacting particles, such as (πp, pp, $\bar{p}p$, Kp, e^+e^-, νp, μp, ep, etc.). I did not limit myself to suggesting that a totally different approach was needed to put all these final states on the same basis. I found what this basis could be and this is how the 'Effective Energy' became the correct quantity to be measured in each interaction. The 'Effective Energy' was not predicted by QCD. To perform this study, it was necessary to analyze tens of thousands of (pp) interactions at the ISR. This was done despite all the difficulties to be overcome. And this is how what Vladimir Gribov defined the 'QCD light' was discovered (figures 20 and 21). Gribov pointed out what follows. Newton discovered that QED light is the sum of different colours. In QCD we have quarks and gluons interacting and producing Jets made of many pions, as for example in the (pp) reaction

$$pp \rightarrow \pi + X$$

whose spectrum is shown in figure 20. The horizontal axis is for the fractional energy of the pion (also called Feynman x), while the vertical axis is for the number of pions having fractional energy x_F. The spectrum in figure 20 is the sum ($\sum$) of all spectra shown if figure 21 where each one corresponds to a single value of the 'effective energy' (defined in terms of $2E_{had}$).

ADDENDUM 3–4
THE GAP BETWEEN E_{GUT} AND E_{SU}

The exact use of the RGEs for the running of the three gauge couplings ($\alpha_1\ \alpha_2\ \alpha_3$) brings to the conclusion that the three gauge couplings ($\alpha_1\ \alpha_2\ \alpha_3$) converge at E_{GUT} which is two powers of ten below the String Unification Energy E_{SU}. This is shown in figure 22 and the details in figure 23.

The lines are the result of calculations executed with a supercomputer using a system of three weakly coupled differential non-linear equations:

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

describing the evolution of all phenomena including the superworld, from the maximum level of energy (Planck scale) to our world at the minimum of energy.

THE INCREDIBLE SERIES OF UEEC EVENTS
NEEDED TO EXPLAIN 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 [19]; 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 [20]) the existence of the Dirac antielectron.

1930-1957 → **Discovery of the C operator** [(charge conjugation) H. Weyl and P.A.M. Dirac [21]]; discovery of the P Symmetry Operator [E.P. Wigner, G.C. Wick and A.S. Wightman [22, 23]]; discovery of the T operator (time reversal) [E.P. Wigner, J. Schwinger and J.S. Bell [24, 25, 26, 27]]; discovery of the CPT Symmetry Operator from RQFT (1955-57) [28].

1927-1957 → Validity of C invariance: e^+ [20]; $\bar{p}$ [29]; $\bar{n}$ [30]; $K_2^0 \to 3\pi$ [31] but see LOY [32].

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

1956 → Lee & Yang P ≠ ; C ≠ [33].

1957 → Before the experimental discovery of P ≠ & C ≠, Lee, Oehme, Yang (LOY) [32] 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 ≠ [34]; CP ok [35].

1964 → $K_2^0 \to 2\pi \equiv K_L$: CP ≠ [36].

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 [37]. See also [38].

1968 → The discovery [39] 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 [40]. 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 discovers in 1971 that the β-function has negative sign for non-Abelian theories [41].

1971-1973 → β = – ; 't Hooft; Politzer; Gross & Wilczek. The discovery of **non-Abelian** gauge theories. Asymptotic freedom in the interaction between quarks and gluons [41].

1974 → All gauge couplings $\alpha_1\ \alpha_2\ \alpha_3$ 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 $\alpha_1\ \alpha_2\ \alpha_3$, **to converge towards a unique point** [42].

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 [43] 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 $\alpha_{GU} \cong 1/24$ [44, 45] .

1994 → The Gap [4] between E_{GU} & the String Unification Energy: $E_{SU} \cong E_{Planck}$.

1995 → **CPT loses its foundations at the Planck scale (T.D. Lee)** [46].

1995-1999 → **No CPT theorem from M-theory (B. Greene)** [47].

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 17

Mass $\neq$ Matter

$$|m_i\rangle \equiv \text{Mass} \equiv \text{Antimass} \equiv |\overline{m}_i\rangle$$

$\mathbf{i \equiv 1}$ (Intrinsic); $\mathbf{i \equiv 2}$ (Confinement); $\mathbf{i \equiv 3}$ (Binding)

$$C\,|m_i\rangle = |m_i\rangle \qquad \boxed{***}$$

$$\mathbf{i \equiv 1, 2, 3}$$

$$|m_i Q_j\rangle \equiv \text{Matter} \neq \text{Antimatter} \equiv |m_i \overline{Q}_j\rangle$$

$Q_j \equiv$ Flavour Charges

$\mathbf{j \equiv (u \;\; d \;\; c \;\; s \;\; t \;\; b) \equiv (1, 2, 3, 4, 5, 6)}$

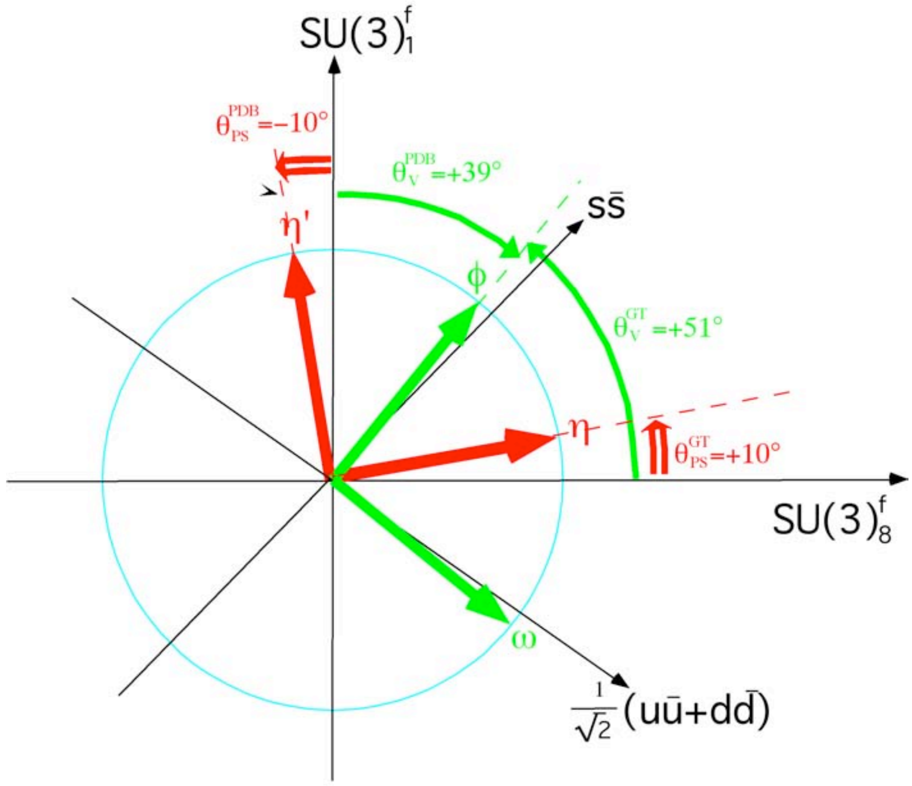
$\mathbf{(\nu_e \;\; e^- \;\; \nu_\mu \;\; \mu^- \;\; \nu_{HL} \;\; HL^-) \equiv (7, 8, 9, 10, 11, 12)}$

$\mathbf{\nu_{HL} \downarrow \nu_\tau \qquad HL^- \downarrow \tau^-}$

$$C\,|m_i Q_j\rangle = |m_i \overline{Q}_j\rangle \qquad \boxed{***}$$

$$\mathbf{i \equiv 1, 2, 3\,; \;\; J \equiv 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.}$$

Figure 18



PDB ≡ Particle Data Book
GT ≡ Gerardus 't Hooft

$$\boxed{\theta_{PS} \neq \theta_V}$$

Direct: Not Using Mass Formulae

Figure 19

$p\text{-}p \rightarrow \pi^+ + X$
Nominal Energy of the (pp) collision $= \sqrt{s} = 24$ *GeV*

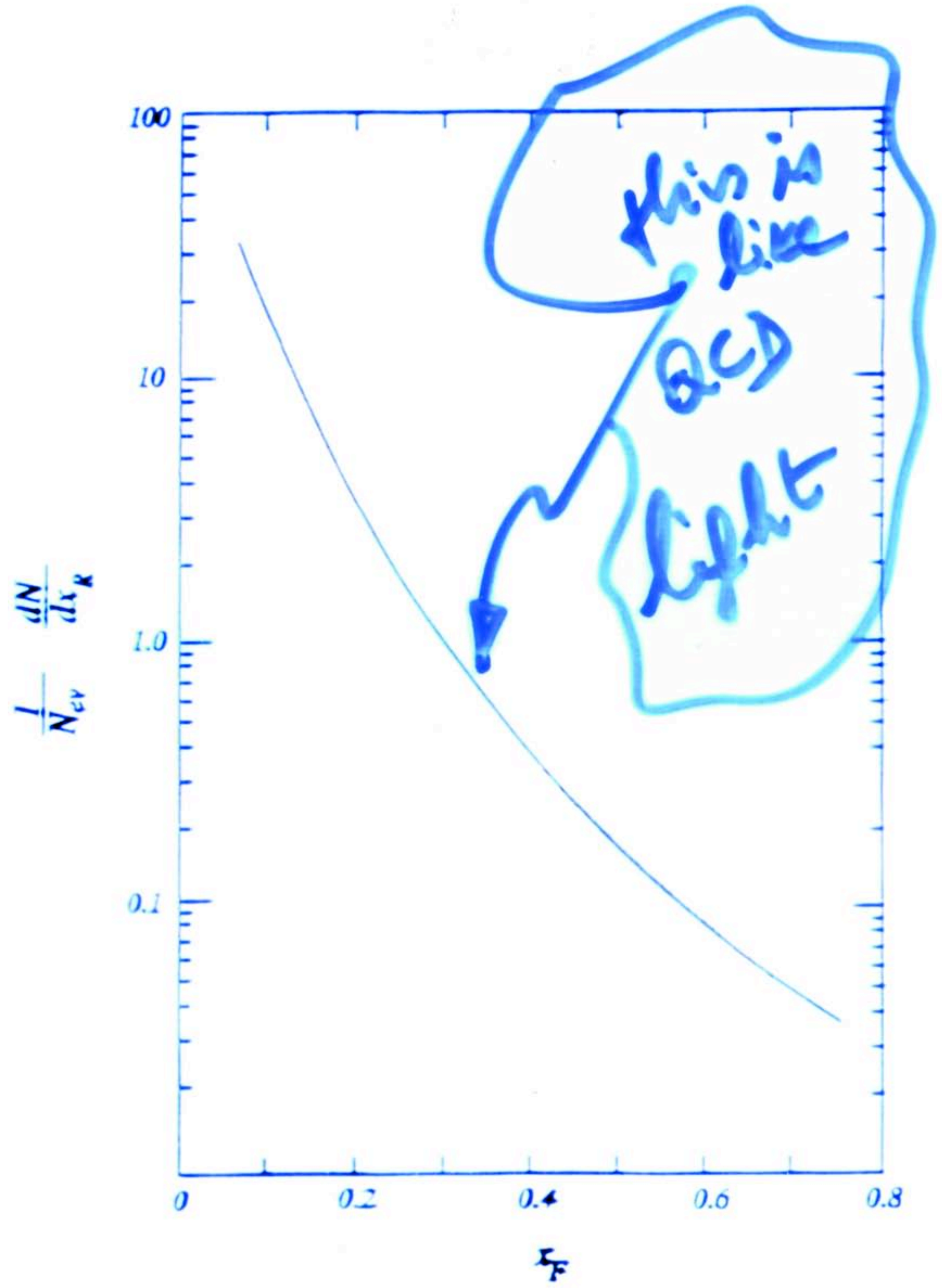


Figure 20

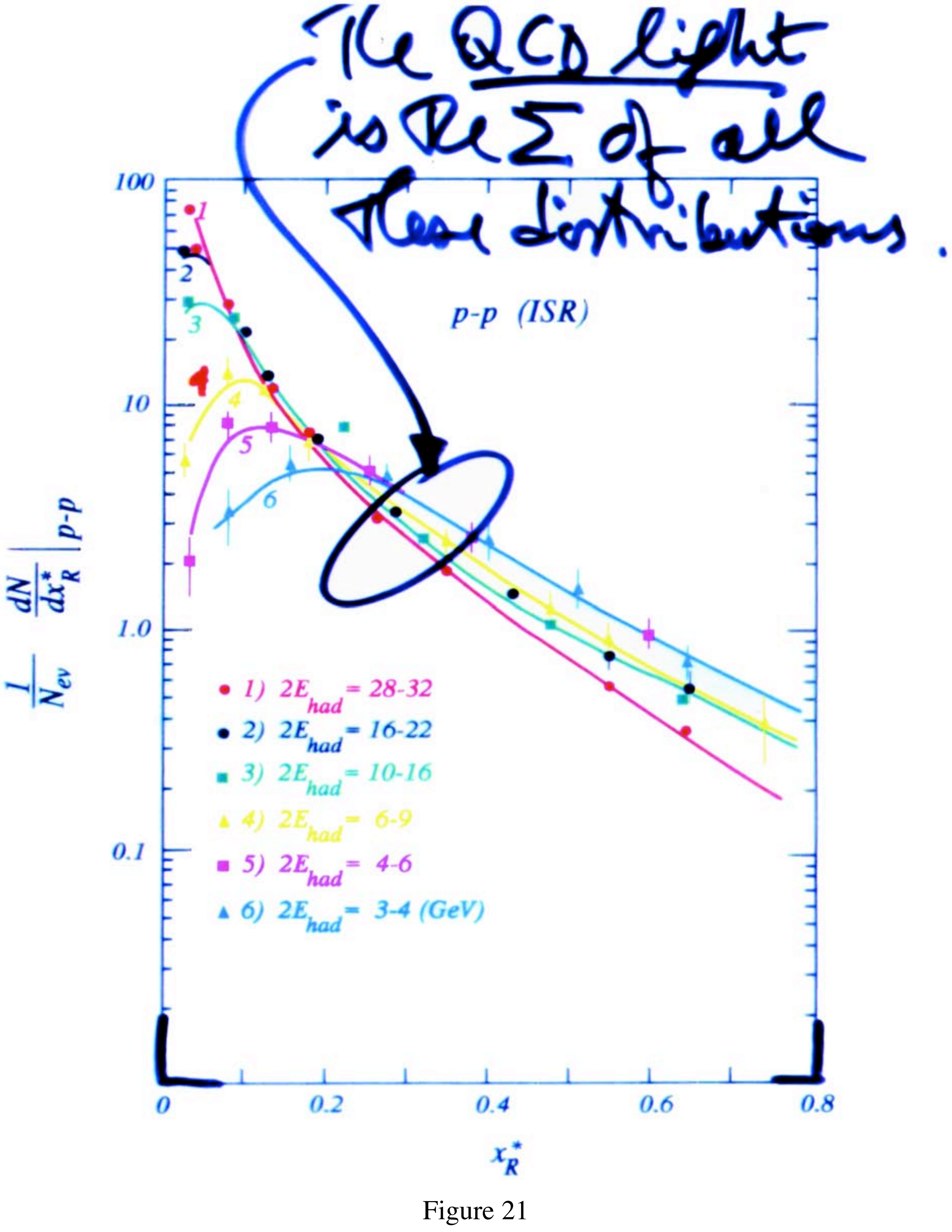

The QCD light is the Σ of all these distributions.
100
10
1.0
0.1
p-p (ISR)
$\frac{1}{N_{ev}} \frac{dN}{dx_R^*}\Big|_{p-p}$
1) $2E_{had}$ = 28-32
2) $2E_{had}$ = 16-22
3) $2E_{had}$ = 10-16
4) $2E_{had}$ = 6-9
5) $2E_{had}$ = 4-6
6) $2E_{had}$ = 3-4 (GeV)
0
0.2
0.4
0.6
0.8
x_R^*

Figure 21

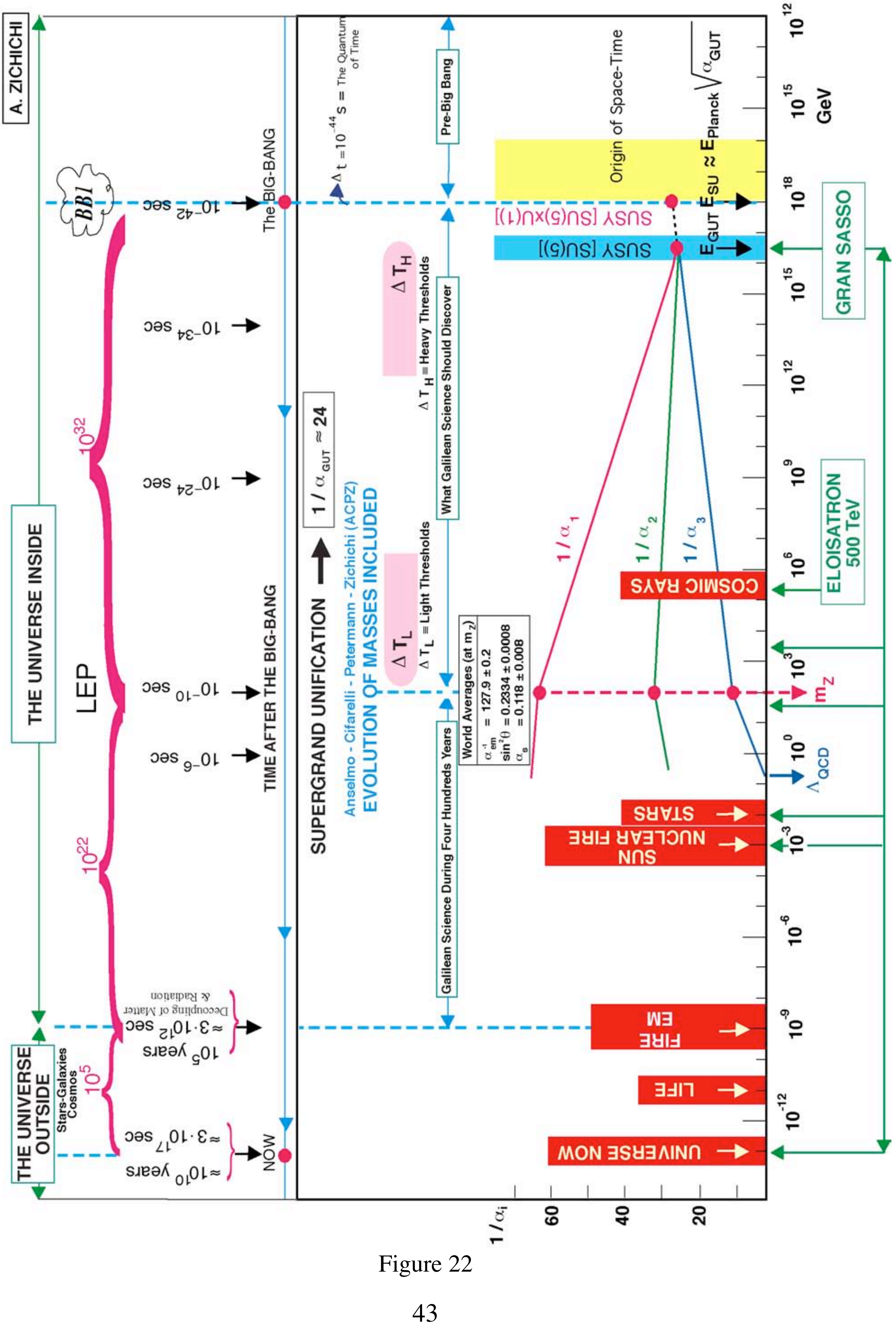
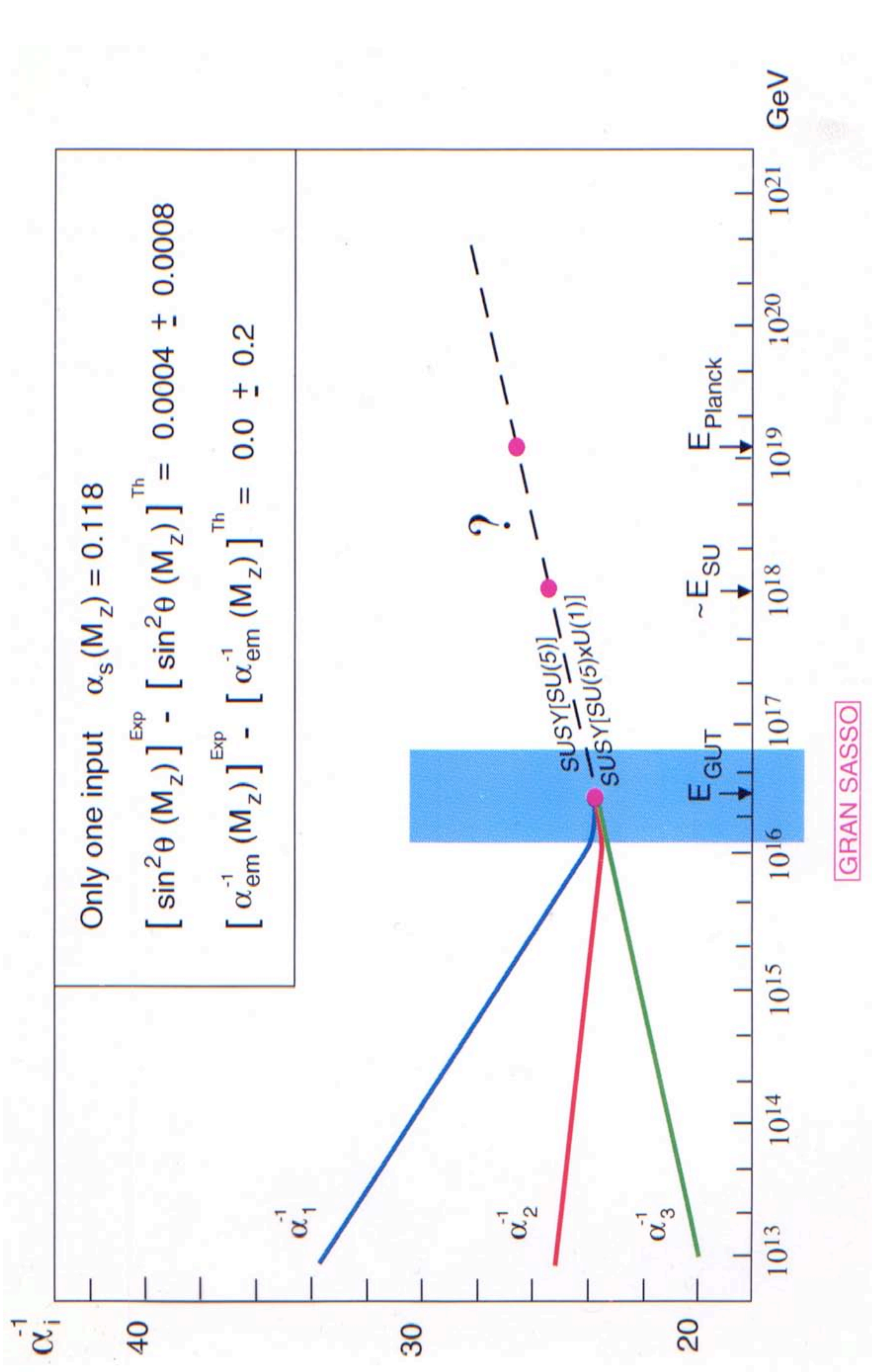

A. ZICHICHI
THE UNIVERSE OUTSIDE
Stars-Galaxies Cosmos
THE UNIVERSE INSIDE
LEP
Decoupling of Matter & Radiation
NOW
The BIG-BANG
TIME AFTER THE BIG-BANG
SUPERGRAND UNIFICATION
Anselmo - Cifarelli - Petermann - Zichichi (ACPZ)
EVOLUTION OF MASSES INCLUDED
Galilean Science During Four Hundreds Years
What Galilean Science Should Discover
Pre-Big Bang
Heavy Thresholds
Light Thresholds
World Averages (at m_Z)
Origin of Space-Time
SUSY [SU(5)]
SUSY [SU(5)xU(1)]
UNIVERSE NOW
LIFE
FIRE EM
SUN NUCLEAR FIRE
STARS
COSMIC RAYS
ELOISATRON 500 TeV
GRAN SASSO
GeV

Figure 22



Only one input $\alpha_s(M_Z) = 0.118$
$[\sin^2\theta(M_Z)]^{Exp} - [\sin^2\theta(M_Z)]^{Th} = 0.0004 \pm 0.0008$
$[\alpha_{em}^{-1}(M_Z)]^{Exp} - [\alpha_{em}^{-1}(M_Z)]^{Th} = 0.0 \pm 0.2$
α_i^{-1}
40
30
20
α_1^{-1}
α_2^{-1}
α_3^{-1}
SUSY[SU(5)]
SUSY[SU(5)xU(1)]
?
E_{GUT}
$\sim E_{SU}$
E_{Planck}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
GeV
GRAN SASSO

Figure 23

ADDENDUM 4
THE TEN CHALLENGES OF SUBNUCLEAR PHYSICS

Here is the list.

1 Non-perturbative QCD.
2 Anomalies and Instantons.
3 The Physics of NSSB (non-Spontaneous Symmetry Breaking: CP $\neq$, T $\neq$, CPT $\neq$ (*) Matter-Antimatter Symmetry).
4 The Physics of Imaginary Masses: SSB (part of this is the Higgs particle/particles).
5 The Physics of 43 dimensions (part of this is Supersymmetry).
6 Flavour mixing in the quark sector.
7 Flavour mixing in the leptonic sector.
8 The problem of the missing mass in the Universe.
9 The problem of the Hierarchy.
10 The Physics at the Planck scale and the number of expanded dimensions. Here the most interesting consequence would be that for a given expanded dimension it could be that the Planck scale goes down to the range of the Fermi scale, as illustrated in figure 24.

(*) The symbol $\neq$ means that a Symmetry law is non spontaneously broken as it happens with C, P, CP and T). [C (charge conjugation, i.e. interchange of charges with anti-charges); P (parity, i.e. interchange of left and right); T (inversion of the arrow of Time)]. The products CP and CPT mean the simultaneous Symmetry laws for all operations CP and CPT, respectively. The existence of Matter-Antimatter Asymmetry would be a proof of CPT $\neq$.

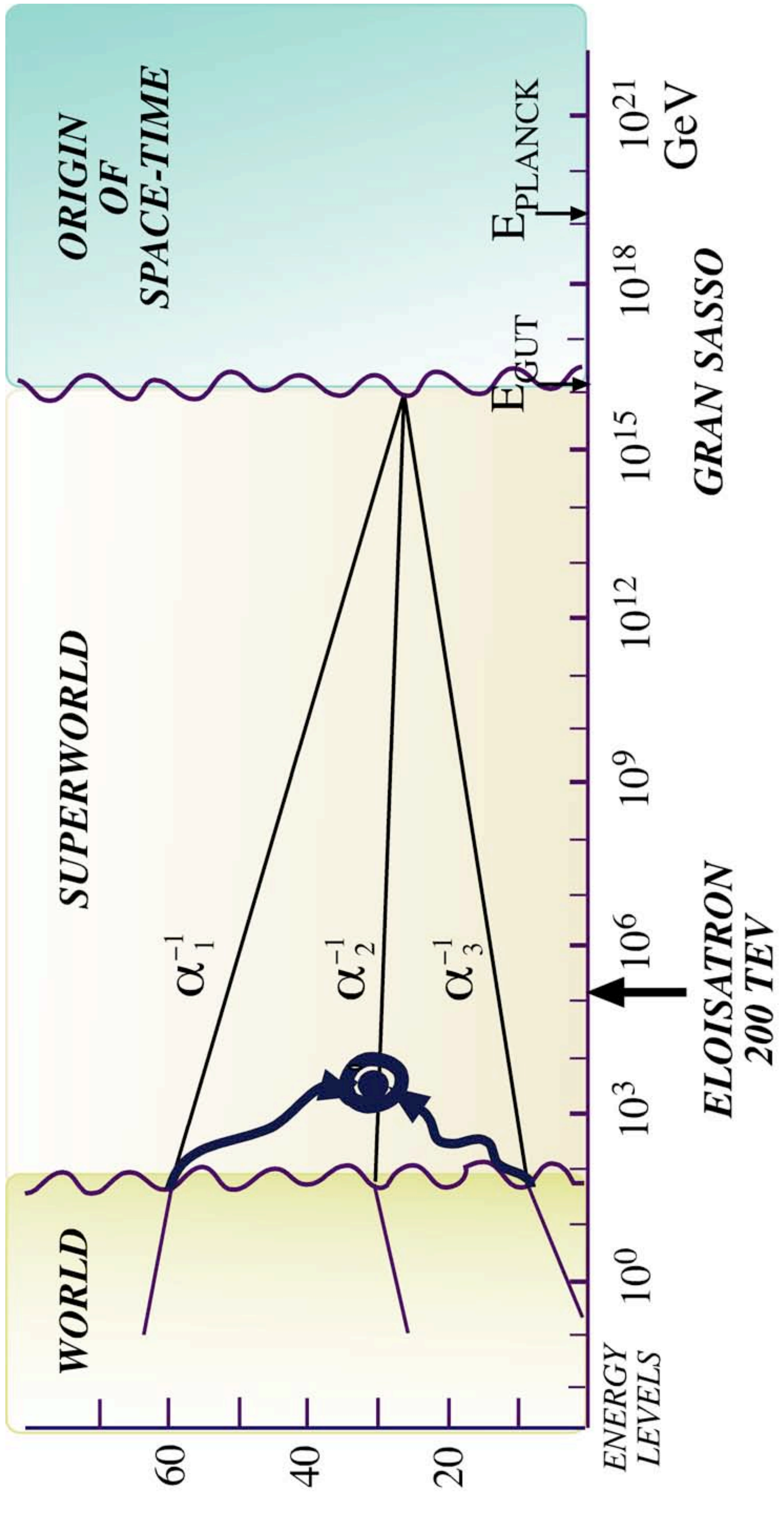

WORLD
SUPERWORLD
ORIGIN OF SPACE-TIME
α₁⁻¹
α₂⁻¹
α₃⁻¹
60
40
20
ENERGY LEVELS
10^0
10^3
10^6
10^9
10^12
10^15
10^18
10^21
GeV
E_GUT
E_PLANCK
ELOISATRON 200 TEV
GRAN SASSO

Figure 24

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- 31st, 32nd and 33th Course of the International School of Solid State Physics, Erice (Italy), July 2004, '*Complexity at the Elementary Level*'.

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