THE QGCW PROJECT

THE ‘QUARK GLUON COLOURED WORLD’ PROJECT

BCF Collaboration

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World Federation of Scientists, Beijing, Geneva, Moscow, New York
Ettore Majorana Foundation and Centre for Scientific Culture, Erice, Italy

CERN, Geneva, 30 April 2018

I PHYSICS ⇒ Problems

II DETECTORS Technology ⇒ TOF (WR 15ps)

• 4π Systems
- → EM
- → Nuclear
- → Subnuclear
- → Nothing

III BEAM-BEAM INTERACTION Technology

⇓

Synchronization

IV REFERENCES

I

PHYSICS

PHYSICS $\Rightarrow$ Problems

THE COLOURLESS CONDICTION

THE PHYSICS OF THE QUARK-GLUON-COLOURED WORLD (QGCW)

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**.

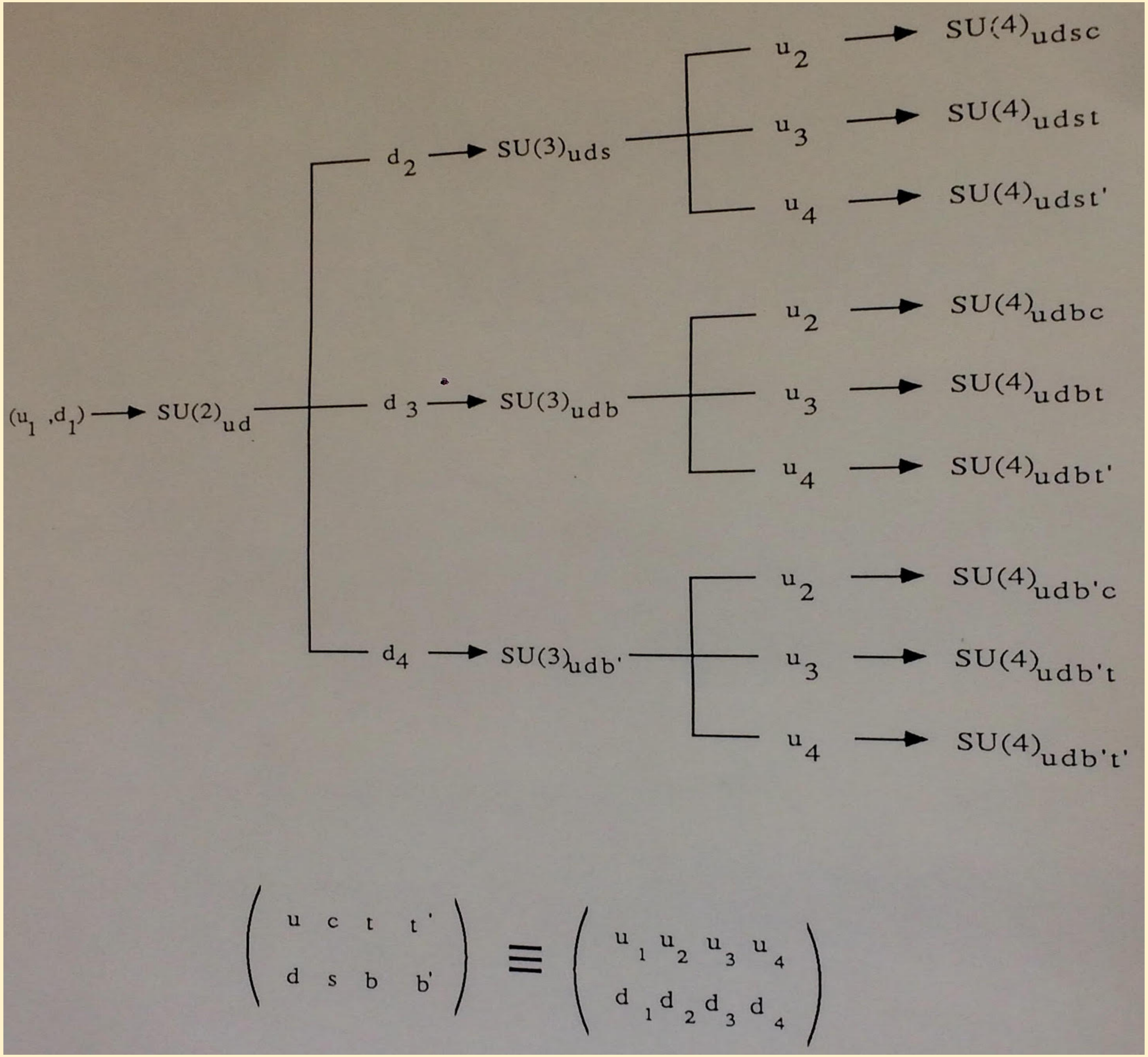
THE PROBLEMS

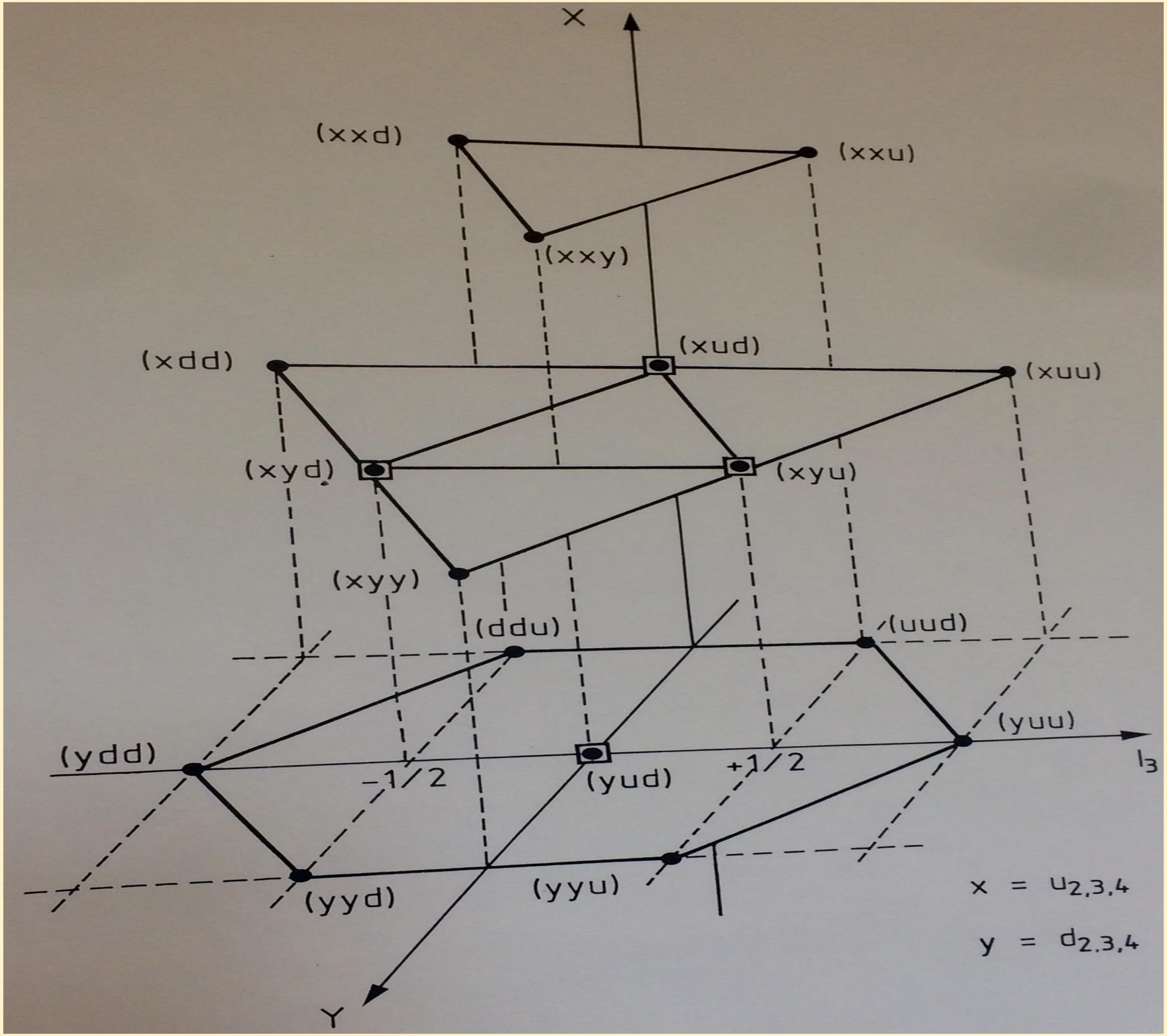
1st problem – In the QGCW there are all states allowed by the $SU(3)_C$ colour group.

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.

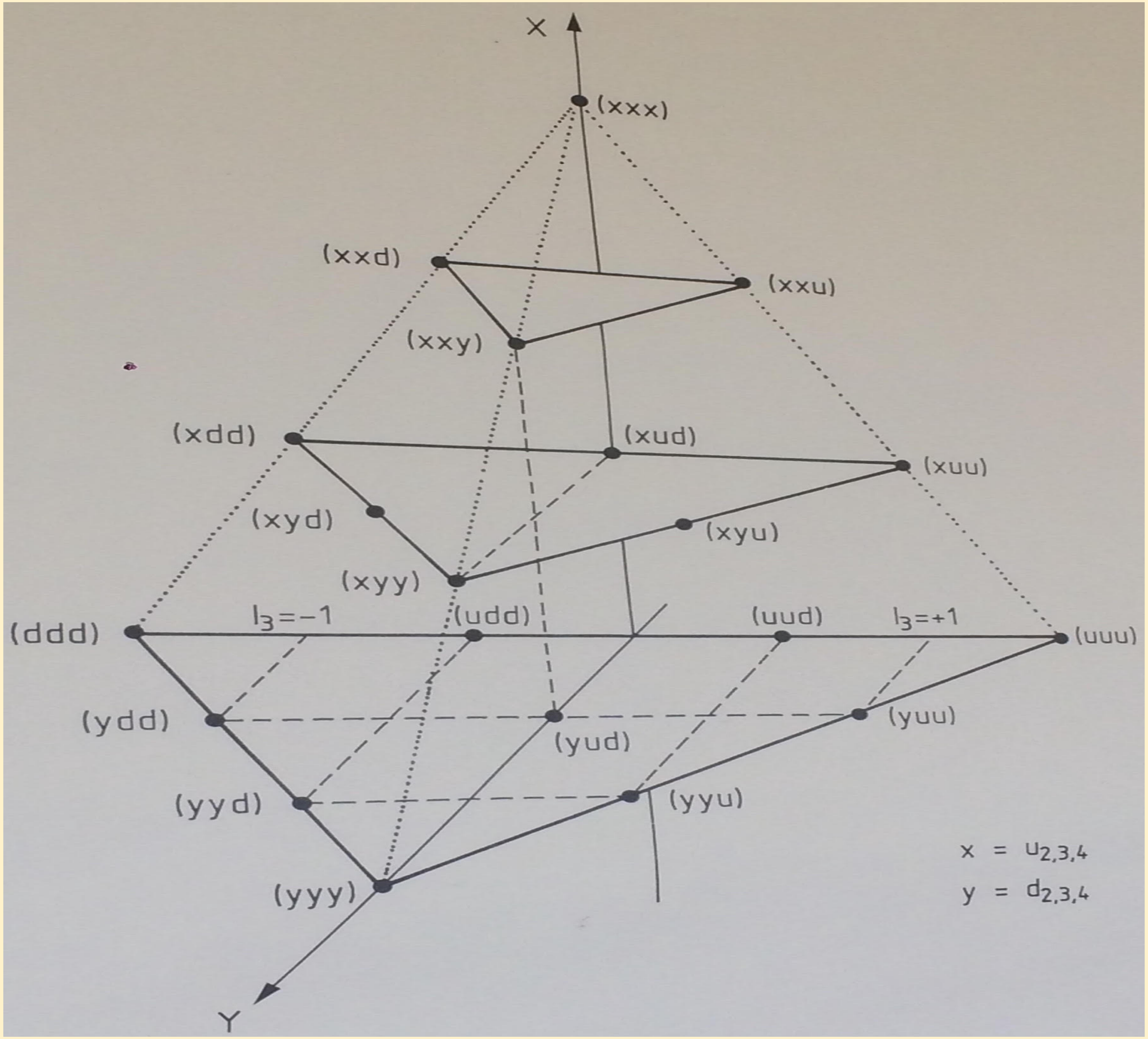
Examples
Octects
&
Decuplets etc.

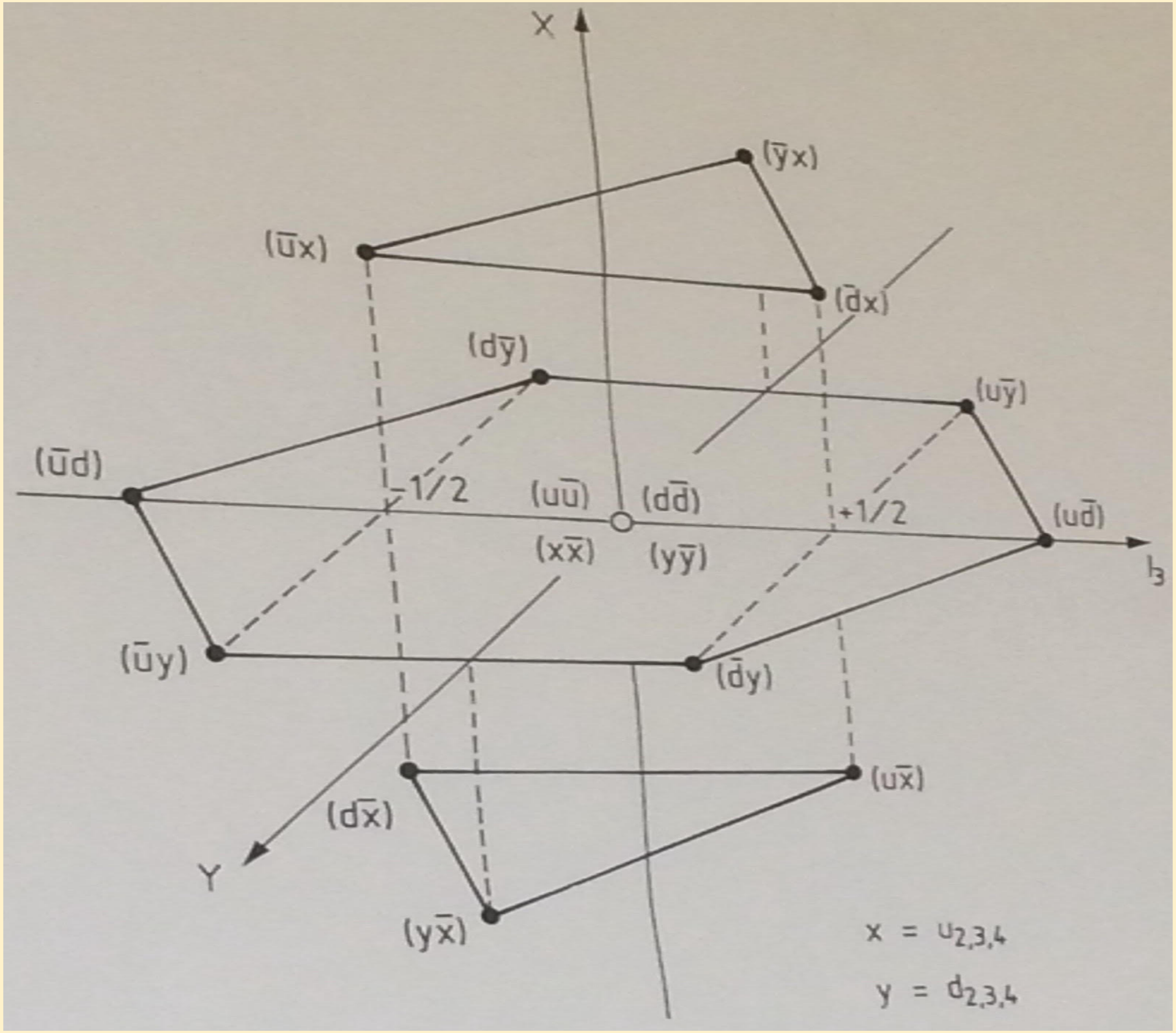
in my Studio at CERN


$(u_1, d_1) \rightarrow SU(2)_{ud}$
$d_2 \rightarrow SU(3)_{uds}$
$d_3 \rightarrow SU(3)_{udb}$
$d_4 \rightarrow SU(3)_{udb'}$
$u_2 \rightarrow SU(4)_{udsc}$
$u_3 \rightarrow SU(4)_{udst}$
$u_4 \rightarrow SU(4)_{udst'}$
$u_2 \rightarrow SU(4)_{udbc}$
$u_3 \rightarrow SU(4)_{udbt}$
$u_4 \rightarrow SU(4)_{udbt'}$
$u_2 \rightarrow SU(4)_{udb'c}$
$u_3 \rightarrow SU(4)_{udb't}$
$u_4 \rightarrow SU(4)_{udb't'}$
$\begin{pmatrix} u & c & t & t' \\ d & s & b & b' \end{pmatrix} \equiv \begin{pmatrix} u_1 & u_2 & u_3 & u_4 \\ d_1 & d_2 & d_3 & d_4 \end{pmatrix}$



X
(xxd)
(xxu)
(xxy)
(xdd)
(xud)
(xuu)
(xyd)
(xyu)
(xyy)
(ddu)
(uud)
(ydd)
(yud)
(yuu)
−1/2
+1/2
I_3
(yyd)
(yyu)
Y
$x = u_{2,3,4}$
$y = d_{2,3,4}$


X
(xxx)
(xxd)
(xxu)
(xxy)
(xdd)
(xud)
(xuu)
(xyd)
(xyu)
(xyy)
(ddd)
I3=−1
(udd)
(uud)
I3=+1
(uuu)
(ydd)
(yud)
(yuu)
(yyd)
(yyu)
(yyy)
x = u2,3,4
y = d2,3,4
Y


X
$(\bar{y}x)$
$(\bar{u}x)$
$(\bar{d}x)$
$(d\bar{y})$
$(u\bar{y})$
$(\bar{u}d)$
$-1/2$
$(u\bar{u})$
$(d\bar{d})$
$+1/2$
$(u\bar{d})$
I_3
$(x\bar{x})$
$(y\bar{y})$
$(\bar{u}y)$
$(\bar{d}y)$
$(u\bar{x})$
$(d\bar{x})$
Y
$(y\bar{x})$
$x = u_{2,3,4}$
$y = d_{2,3,4}$

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 lower energy 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

$U \equiv p_{\perp}$ (transverse momentum)

$T \equiv$ 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.

5th problem
The Mathematical Structure

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.

THE REASON WHY WE SHOULD TECHNOLOGICALLY BE PREPARED TO DETECT TOTALLY UNEXPECTED EVENTS

Thirty years ago 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: the mass-energy named after Planck, $\mathbf{E_{Planck}}$, something like **seventeen powers of ten** above the **Fermi** scale, $\mathbf{E_{Fermi}}$, that already seemed to be an extremely high level of energy.

Now, after thirty years, it comes about the novelty of our time: $\boxed{\textbf{Complexity}}$. But 'Complexity' is 'ill-defined'; nevertheless people speak of 'Complexity' as a source of new insights in **Physics**, **Biology**, **Geology**, **Cosmology**, **Social Sciences** and all those intellectual activities which look at the world through the lens of a standard analysis in terms of either **Simplicity** or **Complexity**.

We have investigated the two basic experimental evidences which characterize Complexity.

In fact, the existence of Complexity emerges from two experimentally well-established basic elements:

1) the Anderson-Feynman-Beethoven-type phenomena (AFB), i.e. phenomena whose Laws and Regularities ignore the existence of the Laws of Nature from which they originate;
2) the Sarajevo-type effects, (UEEC), i.e. Unexpected Events with Enormous Consequences.

These two basic elements
are needed in the
Logic of Nature, which allows
the existence of **Science**
(the asymptotic limit of **Simplicity**)
and of **History**
(the asymptotic limit of **Complexity**).

UEEC IN HISTORY AND IN SCIENCE

	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 Charles VII had not been able to win the 100 years war?	*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 Napoleon had not been born?	*IV*	What if Becquerel had not discovered radioactivity?
V	What if Louis XVI had been able to win against the 'Storming of the Bastille'?	*V*	What if Planck had not discovered that $h \neq 0$?
VI	What if the 1908 Tunguska Comet had fallen somewhere in Europe instead of Tunguska in Siberia?	*VI*	What if Lorentz had not discovered that space and time cannot both be real?
VII	What if the killer of the Austrian Archduke Franz Ferdinand had been arrested the day before the Sarajevo event?	*VII*	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.
VIII	What if Lenin had been killed during his travelling through Germany?	*VIII*	What if Rutherford had not discovered the nucleus?
IX	What if Hitler had not been appointed Chancellor by the President of the Republic of Weimar Paul von Hindenburg?	*IX*	What if Hess had not discovered cosmic rays?
X	What if Pyotr Kapitza accepted to be the leader of the USSR H-bomb Project as wanted by Stalin?	*X*	What if Dirac had not discovered his equation, which opens new horizons, including the existence of the antiworld?
XI	What if Nazi Germany had defeated the Soviet Union?	*XI*	What if Fermi had not discovered weak forces?
XII	What if Karol Wojtyla had not been elected Pope, thus becoming John Paul II?	*XII*	What if Fermi and Dirac had not discovered the Fermi–Dirac statistics?
XIII	What if Gorbachev had not been defeated by Yeltsin?	*XIII*	What if Yukawa had not proposed the existence of a "meson" in order to have the nuclear glue?
XIV	What if the USSR had not collapsed?	*XIV*	What if the 'strange particles' had not been discovered in the Blackett Lab?

We have reviewed [1–4] the present status of all we know in the Reductionistic achievements together with our present understanding of the rigorous attempts towards the basic features which allow Complexity to exist, i.e. AFB phenomena and UEEC events.

The conclusion is that

Complexity exists at the Fundamental Level.

- Therefore **Totally Unexpected Effects** should **show up**.
- **Effects**, which are impossible to be predicted on the basis of **present knowledge**.
- Where these effects are most likely to be no one knows.
- **But**, the more appropriate way is 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.

A STRONG SUPPORT IS COMING FROM RQST (RELATIVISTIC QUANTUM STRING THEORY)

Let us consider what happens with the only mathematical structure to be in a position of describing the physics at the Planck scale: the Relativistic Quantum String Theory (**RQST**).

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

One of this minima is the vacuum needed for our world, with 3 space plus one time dimensions (not being both real) plus all the other properties illustrated in figures 1 and 2.

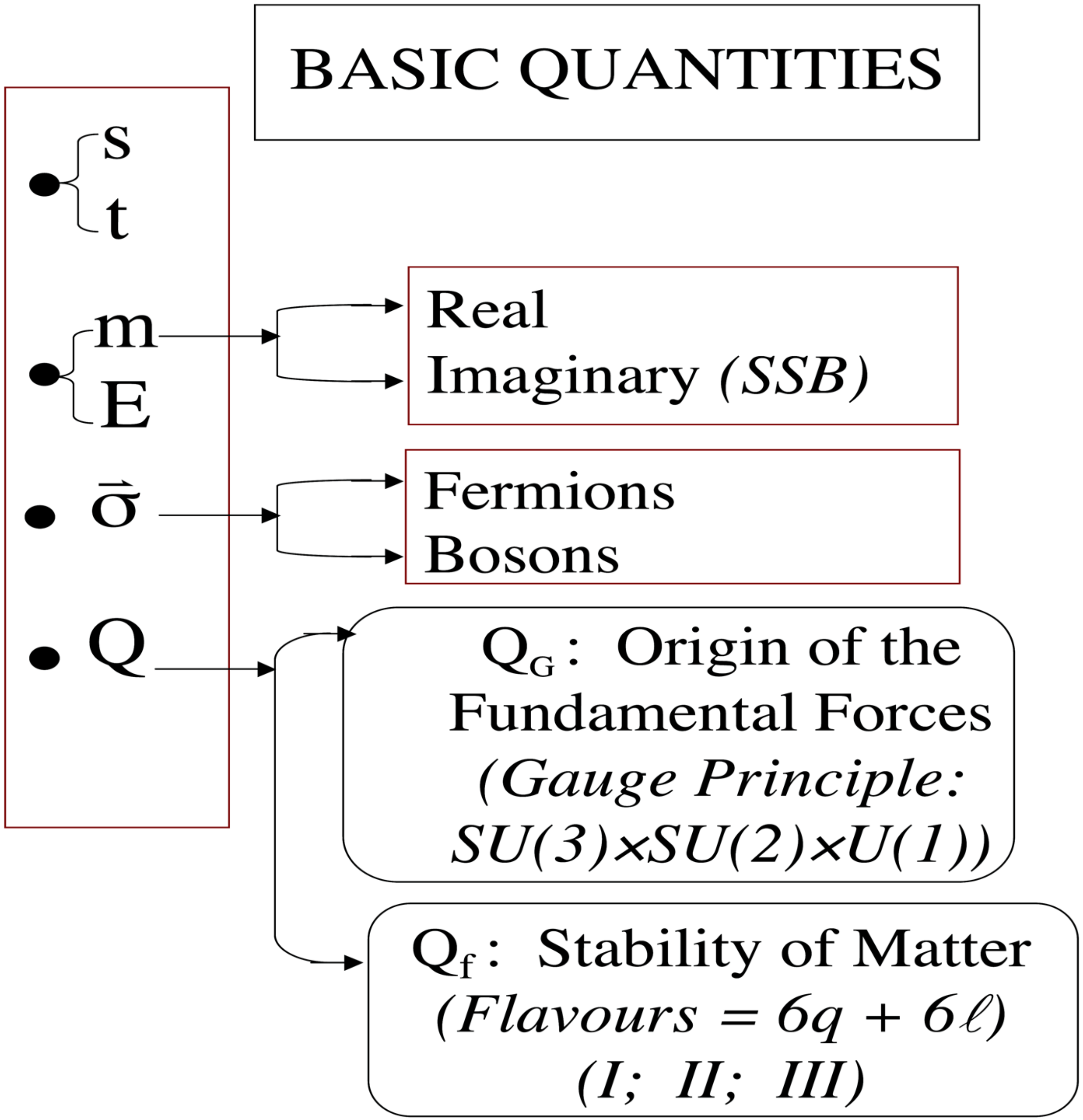

BASIC QUANTITIES
s
t
m
E
$\vec{\sigma}$
Q
Real
Imaginary *(SSB)*
Fermions
Bosons
Q_G : Origin of the Fundamental Forces *(Gauge Principle: SU(3)×SU(2)×U(1))*
Q_f : Stability of Matter *(Flavours = 6q + 6ℓ) (I; II; III)*

Figure 1

SM&B

THE STANDARD MODEL AND BEYOND

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

- 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 Symmetry Group (not containing U(1)) ⇒ 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 2

The theoretical discovery of the **Landscape** (Leonard Susskind) [5], 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) [6].

This discovery corroborates all that we have put in evidence:

Complexity exists at the fundamental level.

In fact, UEEC events and AFB phenomena exist at all scales, as illustrated in the Figure 3.

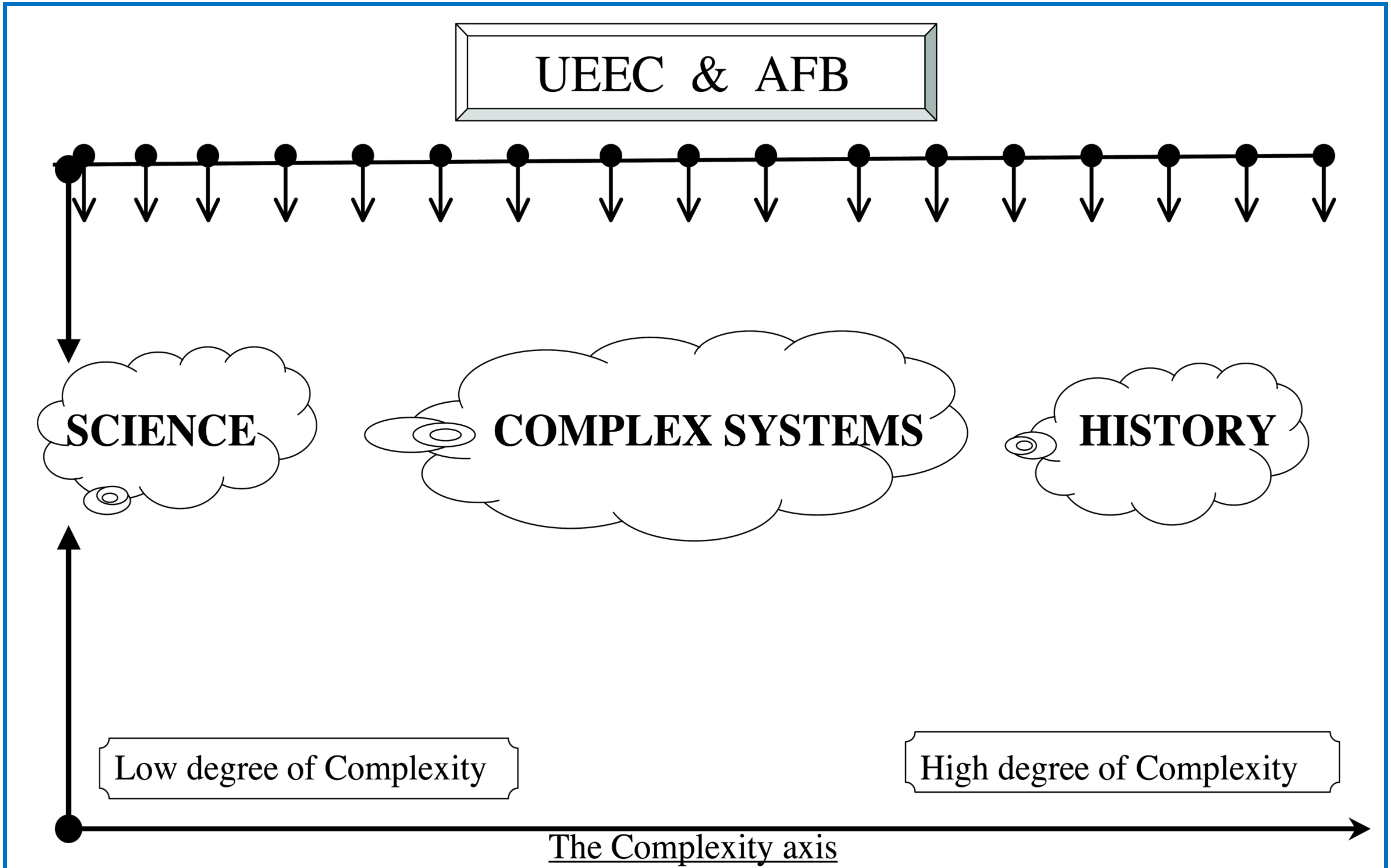

UEEC & AFB
SCIENCE
COMPLEX SYSTEMS
HISTORY
Low degree of Complexity
High degree of Complexity
The Complexity axis

Figure 3

Figure 4 illustrates the extrapolation of our present knowledge, from the highest energy levels so far investigated to the LHC.

Other facilities exist the world over, but they are all planned to search for events which can be predicted on the basis of our knowledge.

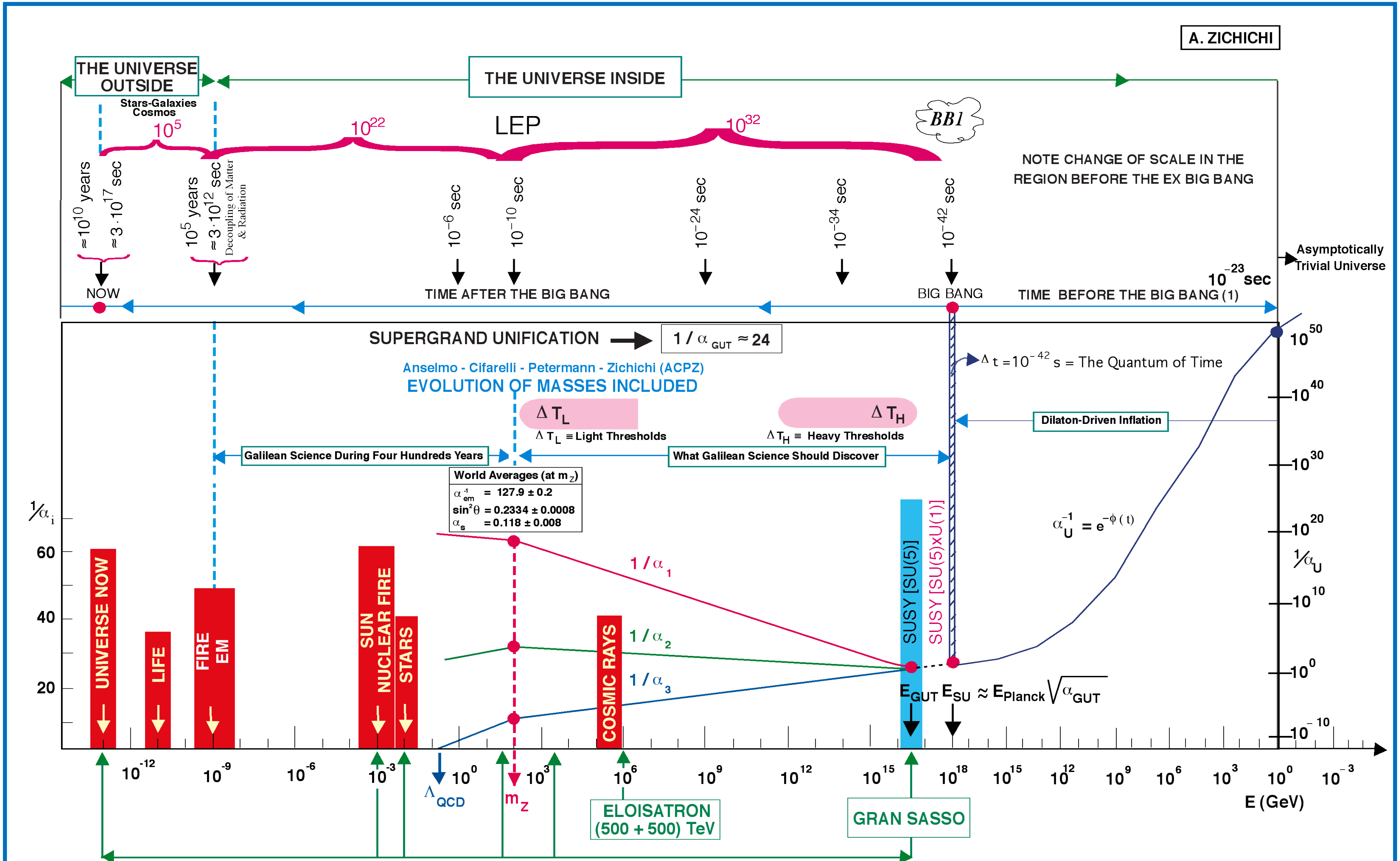

A. ZICHICHI
THE UNIVERSE OUTSIDE
THE UNIVERSE INSIDE
Stars-Galaxies
Cosmos
10^5
10^{22}
LEP
10^{32}
BB1
NOTE CHANGE OF SCALE IN THE REGION BEFORE THE EX BIG BANG
$\approx 10^{10}$ years
$\approx 3 \cdot 10^{17}$ sec
10^5 years
$\approx 3 \cdot 10^{12}$ sec
Decoupling of Matter & Radiation
10^{-6} sec
10^{-10} sec
10^{-24} sec
10^{-34} sec
10^{-42} sec
NOW
TIME AFTER THE BIG BANG
BIG BANG
TIME BEFORE THE BIG BANG (1)
10^{-23} sec
Asymptotically Trivial Universe
SUPERGRAND UNIFICATION
$1/\alpha_{GUT} \approx 24$
Anselmo - Cifarelli - Petermann - Zichichi (ACPZ)
EVOLUTION OF MASSES INCLUDED
$\Delta t = 10^{-42}$ s = The Quantum of Time
ΔT_L
ΔT_H
$\Delta T_L \equiv$ Light Thresholds
$\Delta T_H \equiv$ Heavy Thresholds
Dilaton-Driven Inflation
Galilean Science During Four Hundreds Years
What Galilean Science Should Discover
World Averages (at m_Z)
α_{em}^{-1} = 127.9 ± 0.2
$\sin^2\theta$ = 0.2334 ± 0.0008
α_s = 0.118 ± 0.008
$1/\alpha_i$
60
40
20
UNIVERSE NOW
LIFE
FIRE EM
SUN NUCLEAR FIRE
STARS
COSMIC RAYS
$1/\alpha_1$
$1/\alpha_2$
$1/\alpha_3$
SUSY [SU(5)]
SUSY [SU(5)xU(1)]
$\alpha_U^{-1} = e^{-\phi(t)}$
$1/\alpha_U$
10^{50}
10^{40}
10^{30}
10^{20}
10^{10}
10^{0}
10^{-10}
E_{GUT} $E_{SU} \approx E_{Planck}\sqrt{\alpha_{GUT}}$
10^{-12}
10^{-9}
10^{-6}
10^{-3}
10^{0}
10^{3}
10^{6}
10^{9}
10^{12}
10^{15}
10^{18}
10^{15}
10^{12}
10^{9}
10^{6}
10^{3}
10^{0}
10^{-3}
E (GeV)
Λ_{QCD}
m_Z
ELOISATRON (500 + 500) TeV
GRAN SASSO

Figure 4

All these extrapolations ignore the fact that, the status of our knowledge is the one reported in the figure 5 below.

In fact, after 400 years of Reductionism, the present trend is to go from **Reductionism** to **Holism** and the Future could be dominated by the **Science being NP-complete**.

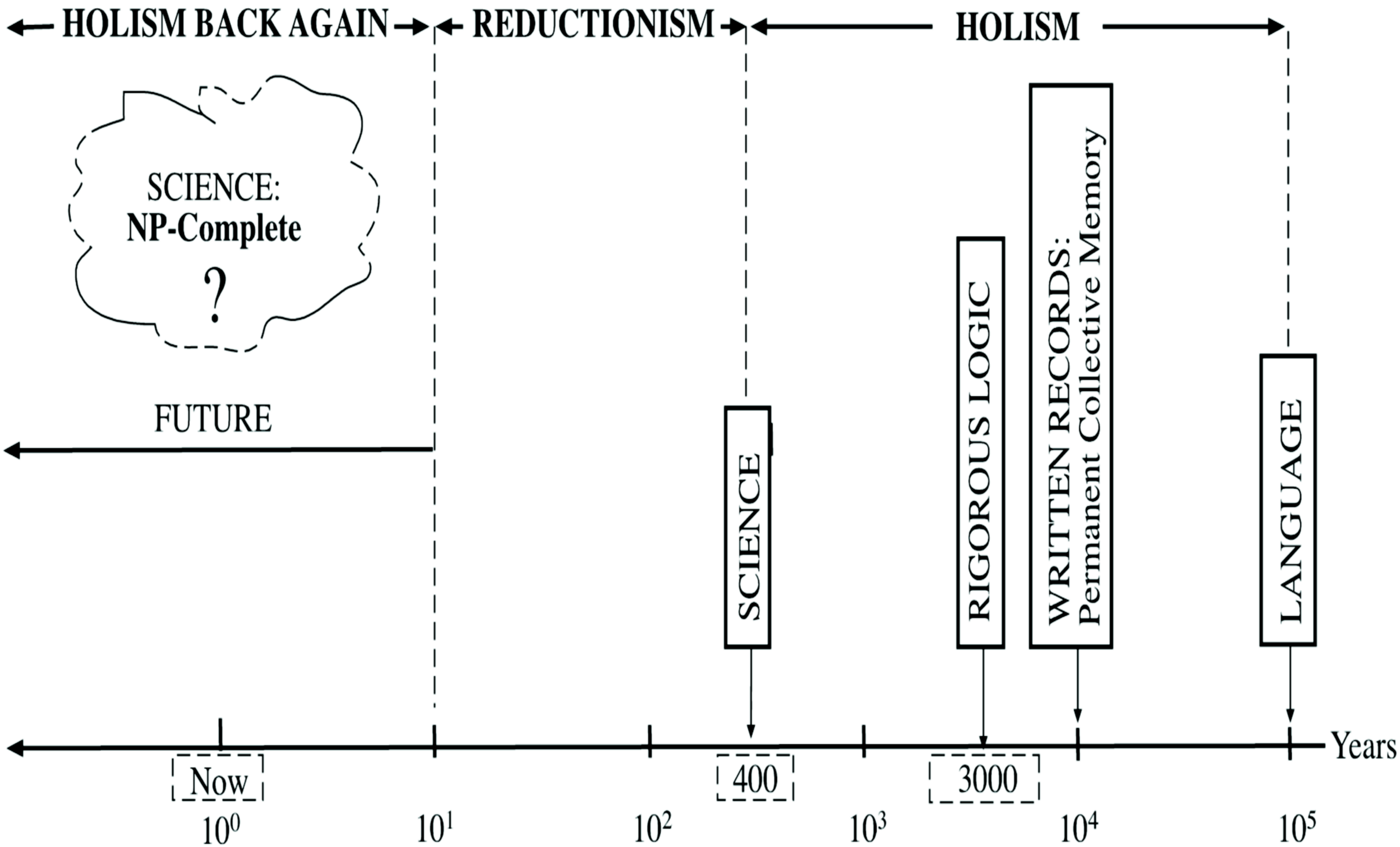

HOLISM BACK AGAIN
REDUCTIONISM
HOLISM
SCIENCE:
NP-Complete
?
FUTURE
SCIENCE
RIGOROUS LOGIC
WRITTEN RECORDS:
Permanent Collective Memory
LANGUAGE
Years
Now
400
3000
10^0
10^1
10^2
10^3
10^4
10^5

Figure 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 series of surprises that we cannot easily predict*'.

II

DETECTORS

DETECTORS TECNOLOGY

- **Phase Transitions**
- **TOF**
- **Preshower**

PHASE TRANSITIONS

- If **smooth** and **uniform** nothing happens

At high energies we do not know how many phase transitions can be involved. The higher the energy, the more complex is the interacting system of particles and more phase transitions can be involved.

In fact the evolution of the Universe has gone through a series of phase transitions whose last step was at the Fermi Energy when

$$\text{the } SU(2) \times U(1)$$

generated QED and QFD.

The present knowledge
of Energy versus Phase transitions
is in the next figure,
where there is
a very large GAP between
the Fermi energy level ($\simeq 10^2$ GeV)
and the GUT ($\simeq 10^{16}$ GeV)

Time, Energy and Phase Transition

t(sec)	E(GeV)	Phase Transition
10^{-44}	10^{18}	Planck epoch $\equiv$ Quantum Gravity $\equiv$ Supergravity Superstring
10^{-35}	10^{16}	GUT

QGCW

10^{-10}	10^{2}	Weak Symmetry Breaking $\equiv$ Fermi epoch
10^{-5}	10^{-1}	Confinement Transition
$1\text{-}10^{2}$	$10^{-3}\text{-}10^{-2}$	Nucleo-Synthesis
10^{12}	10^{-9}	Recombination/Galaxy Formation
10^{17}	10^{-13}	Today

PHASE TRANSITION

could produce

- **QGCW**
- **Concentration of “False Vacuum Energy”**
- **Super Heavy Magnetic Monopoles**
- **Cosmic Strings**
- **“Topological defects”**

PHASE TRANSITION

Quark
Gluon Plasma
QGP

Quark
Gluon Coloured
World

✱

QGCW

n° of states
much larger
than all known

***

Going up from the Fermi energy level

nothing is known up to the

E_{GUT} ($\simeq 10^{16}$ GeV)

and

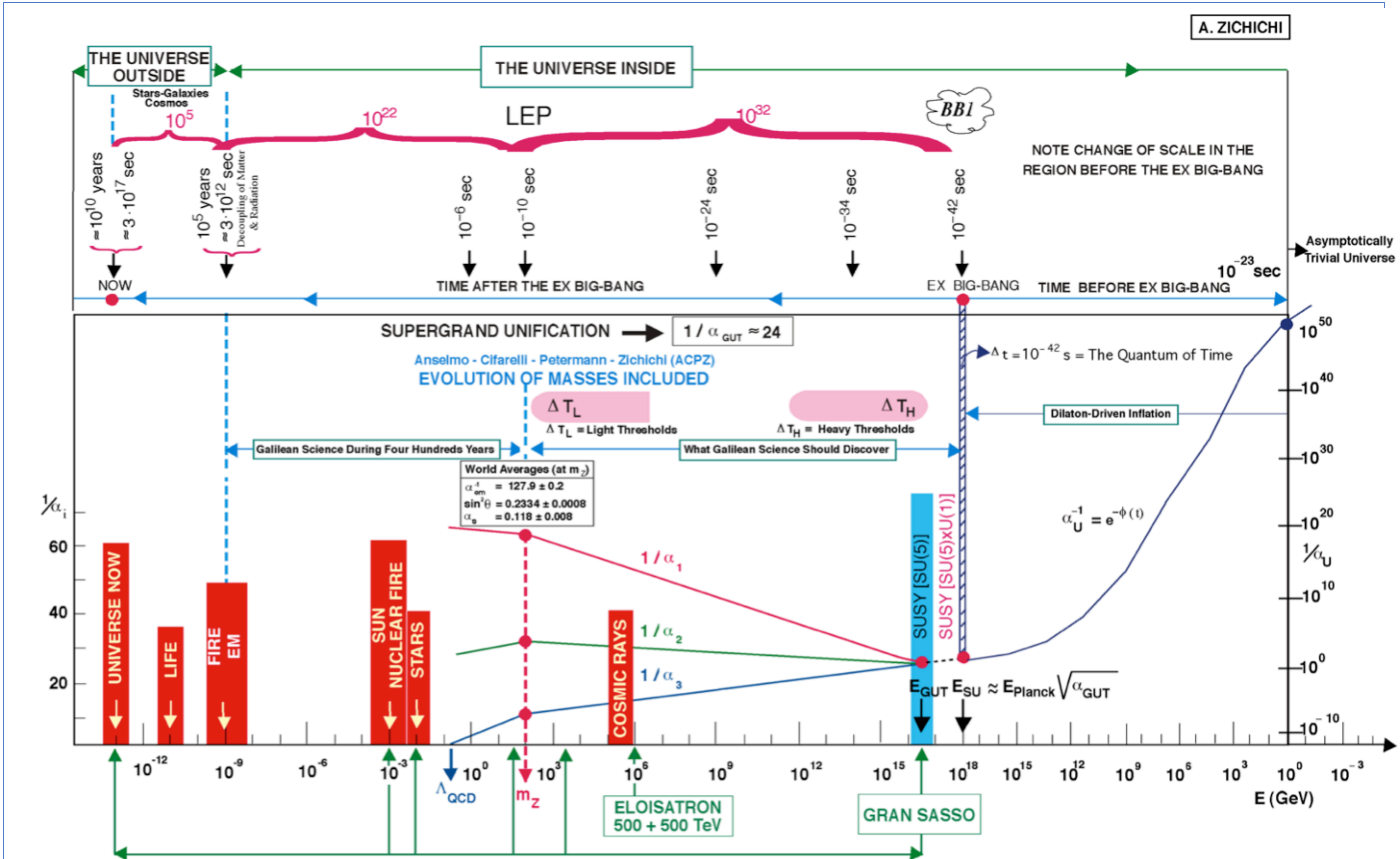
E_{Planck} ($\simeq 10^{19}$ GeV)

E_{GUT} ($\simeq 10^{16}$ GeV) is
where the three gauge couplings
(α_1 α_2 α_3) converge,
and E_{SU} ($\simeq 10^{18}$ GeV)
the energy level where RQST
(Relativistic Quantum String Theory)
puts the origin of
the gravitational force,
and E_{Planck} is at (10^{19} GeV).

The **GAP** between

E_{GUT} and E_{SU}

could indeed be another source of phase transitions.



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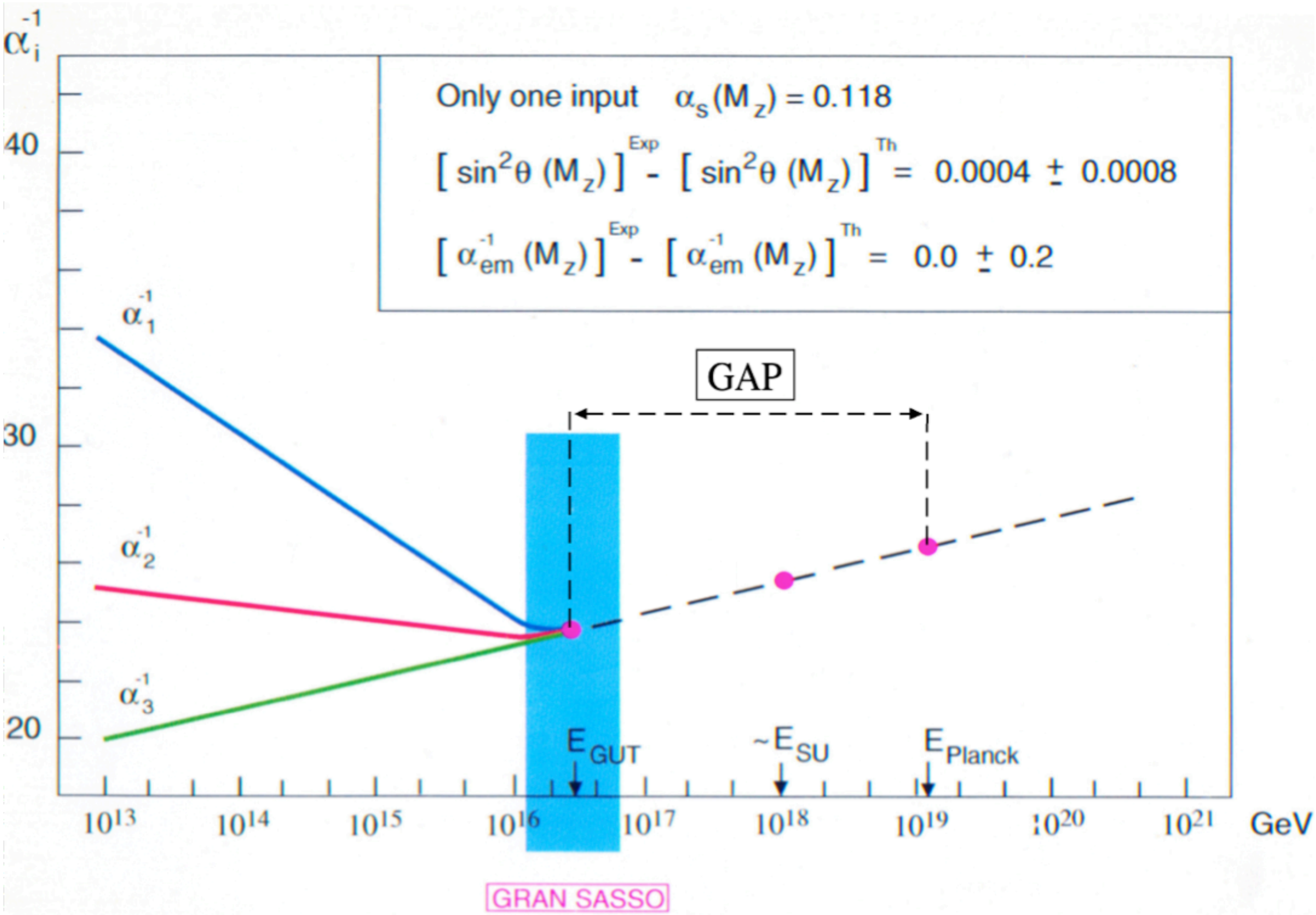
UNIVERSE NOW
LIFE
FIRE EM
SUN NUCLEAR FIRE
STARS
COSMIC RAYS
SUSY [SU(5)]
SUSY [SU(5)xU(1)]
ELOISATRON 500 + 500 TeV
GRAN SASSO
E (GeV)

Figure 6



α_i^{-1}
40
30
20
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_1^{-1}
α_2^{-1}
α_3^{-1}
GAP
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 7

THE UNIFICATION OF ALL FUNDAMENTAL FORCES

The lines in Figure 6 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 included. 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. 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).

Figure 8

On many occasions, during the activities of the International School of Cosmology and Gravitation, I have been discussing with friends and colleagues (including John Wheeler [7], Nathan Rosen [8] and Peter Bergmann [9]) how it happens that no one has been able so far to derive two basic values of our Universe:

① the number of protons, neutrons and electrons, $N_{(p\,n\,e)}$, which our Universe is made of, i.e.

① $N_{(p\,n\,e)} \simeq 10^{80}$;

and

② the volume of our Universe, V(U), which is empty, i.e.

② $V(U) \simeq 98\%$.

THE EVOLUTON OF THE UNIVERSE FOLLOWING THE SCHWARZSCHILD EQUATION

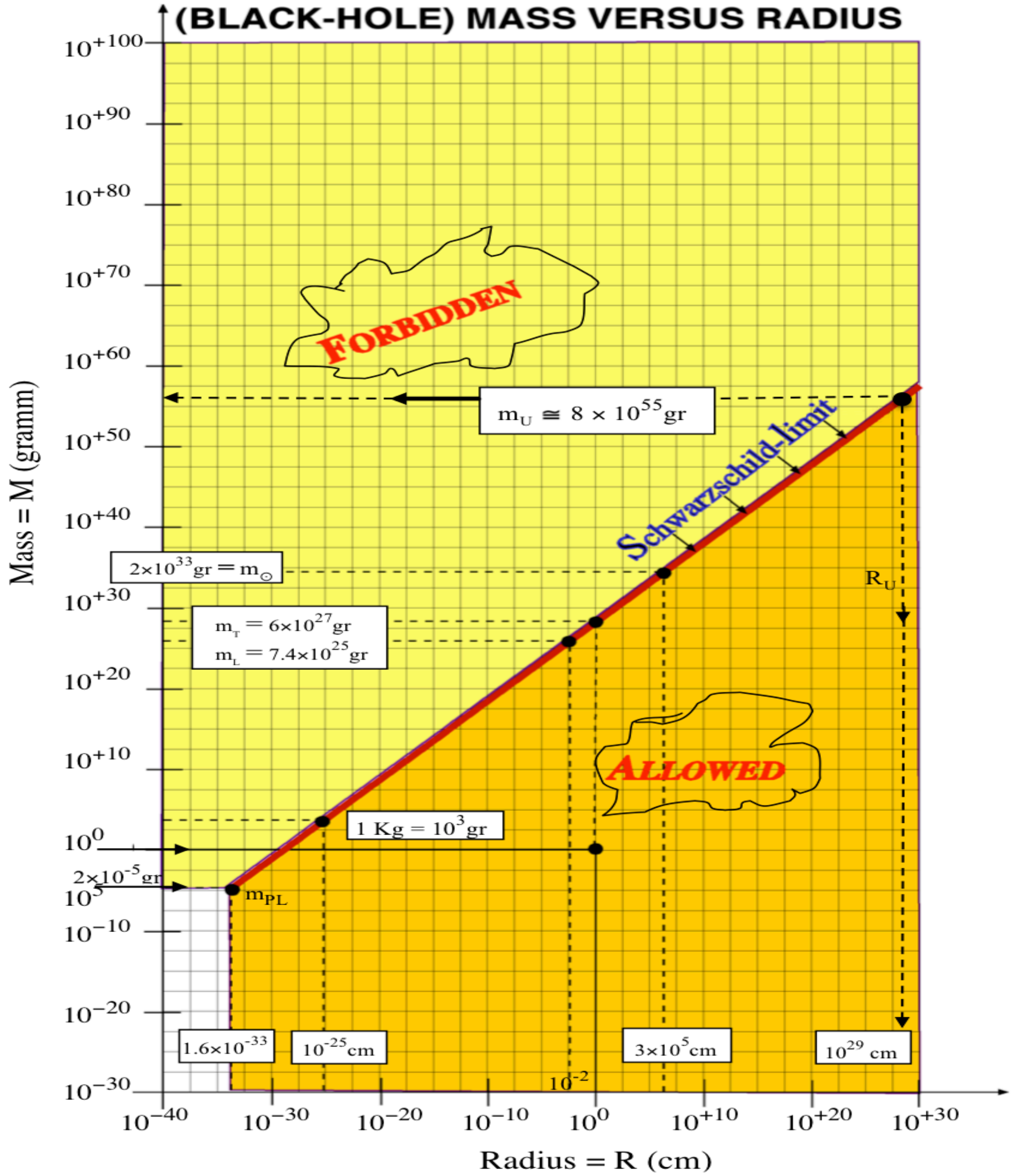


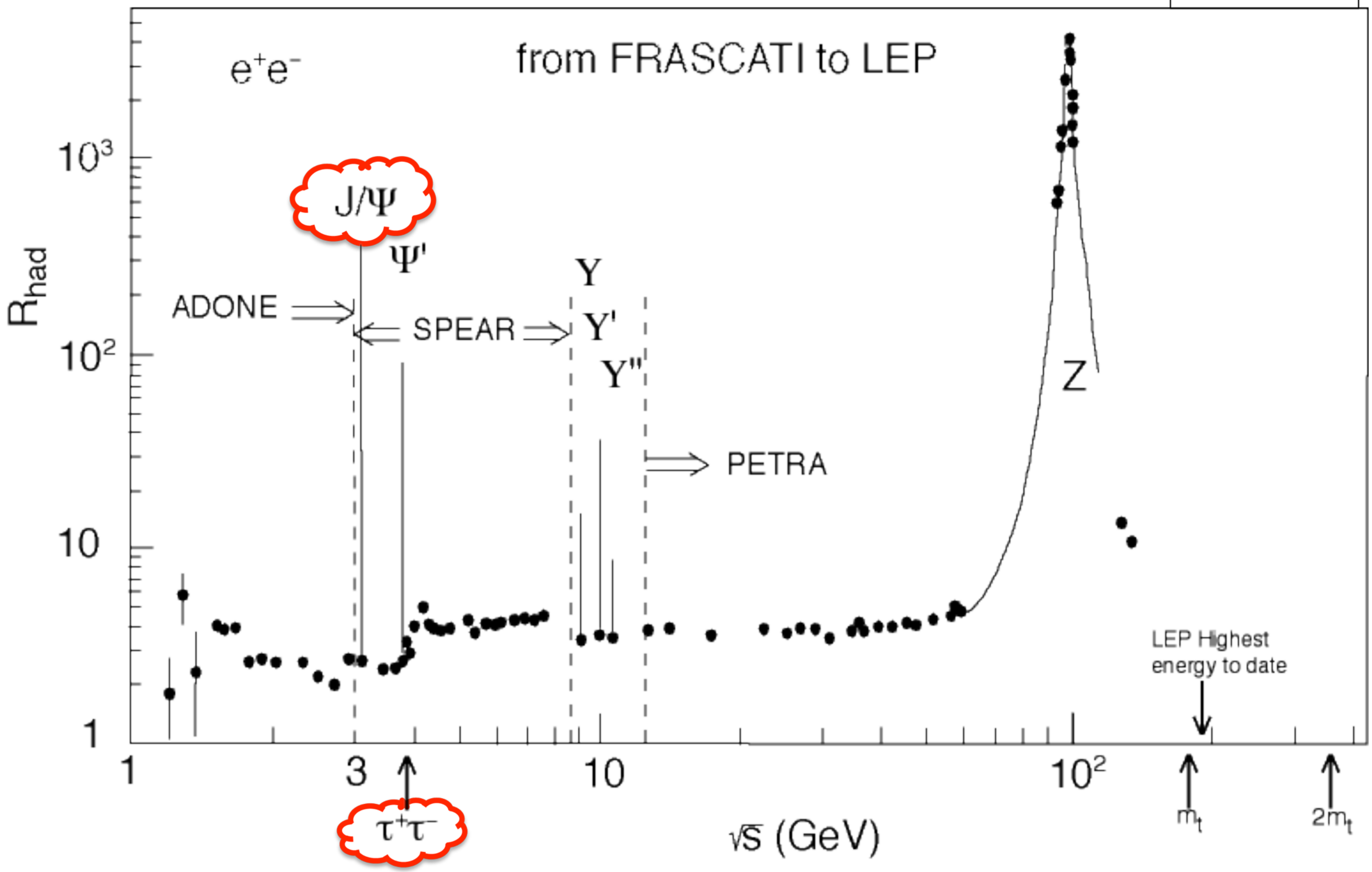
Figure 9

If we could see the inner structure of these Black–Holes we would find that, the matter they are made with, is the one familiar to us, i.e. the matter made with (p, n, e). The primordial Black–Holes, as said before, are made with matter whose charge is only the gravitational charge.

All we could at present say on the correlation between the Subnuclear Universe and the one with Stars and Galaxies is therefore to explain why: $N_{(p\,n\,e)} \simeq 10^{80}$ and $V(U) \simeq 98\%$; and to predict the existence of two types of Black–Holes: Primordial Black–Holes where matter has only the gravitational charge and Standard Black–Holes where matter is made with p, n, e.

***

The existence of
missing knowledge in the Energy scale
should be investigated
on the basis of our knowledge,
not considered to a “Desert”
as it has been the case of the Past
(<u>see from Frascati to LEP</u>)



from FRASCATI to LEP
e^+e^-
R_{had}
10^3
10^2
10
1
J/Ψ
Ψ'
ADONE
SPEAR
Υ
Υ'
Υ''
PETRA
Z
LEP Highest energy to date
1
3
10
10^2
$\tau^+\tau^-$
$\sqrt{s}$ (GeV)
m_t
$2m_t$

Figure 10

TOF

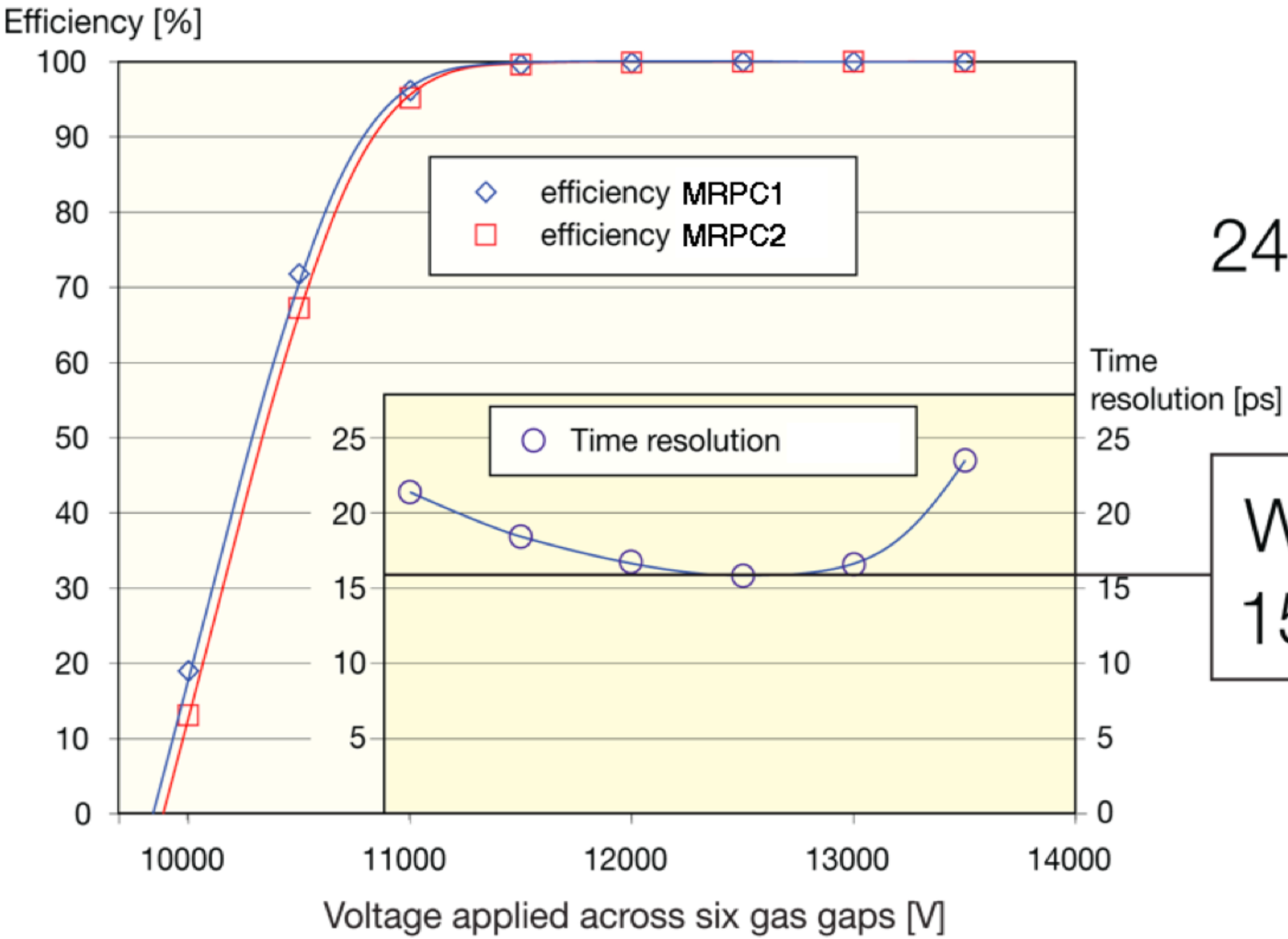
We would like to mention a result that is a world record in the measurement of the Flight Times

(TOF ≡ Time Of Flight)

of particles in the Subnuclear Universe.

TOF is necessary to distinguish heavy from light particles. If the particle is heavy its TOF will be longer than that of a light particle. However, the times involved are fractions of billionths of a second, called "picoseconds" (thousandths of billionths of a second). The record obtained [10] exceeds the precision of the 20 picoseconds frontier (15.8 ps) (see Figure).

LAA TOF - World Record



24 gap MRPC

World record
158×10^{-1} ps

This record will allow to study many properties of the Subnuclear Universe. It is interesting to let the public realize the meaning of a picosecond. Our brain under the thousandth of a second it does not work anymore. If our brain could work at picosecond times we could elaborate in just one of our seconds what human intelligence has been able to produce from the dawn of Civilization to today. The basic instrument for the TOF technology, called MRPC (Multigap Resistence Plate Chamber), is the result of five years of studies and research carried out in close collaboration between CERN, INFN (National Institute of Subnuclear Physics) and the University of Bologna.

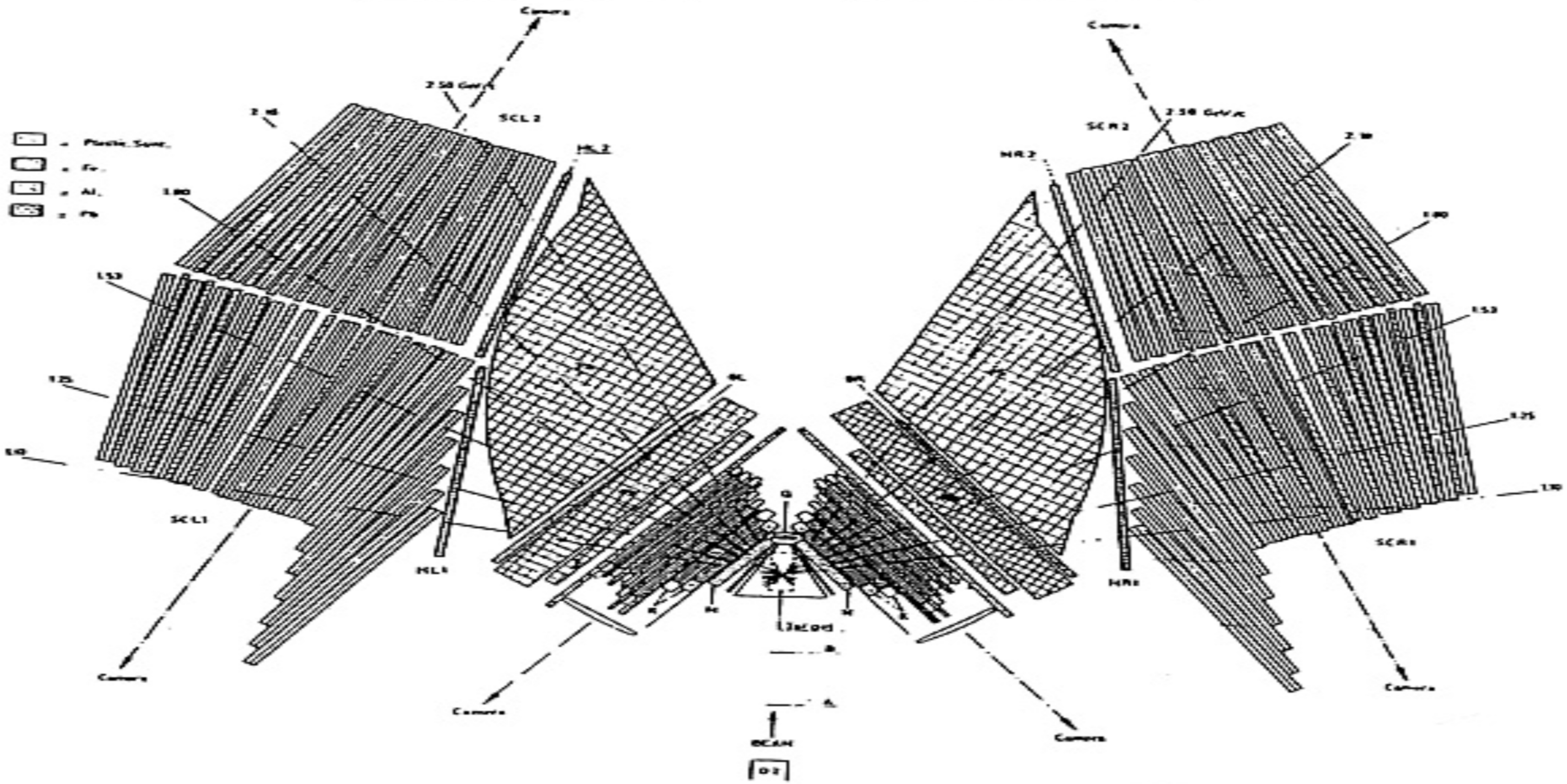
Preshower

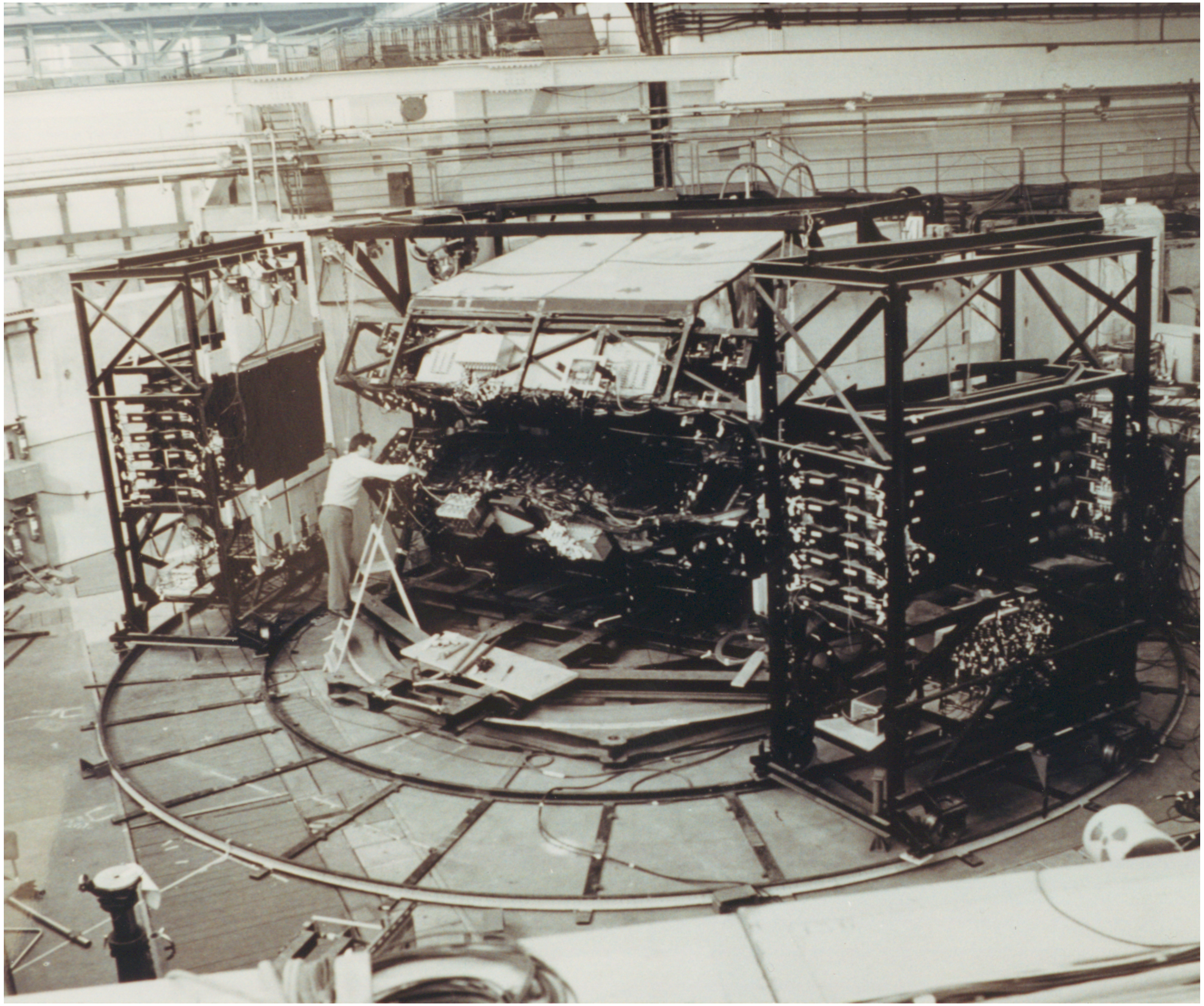
PRESHOWER $\pi/e = 5 \times 10^{-4}$

MUON PUNCH-THROUGH

To simultaneously detect $\mu^{\pm}e^{\mp}$ final states in $\bar{p}p$ annihilation.
The first experimental search for the **THIRD LEPTON** (HL $\equiv \tau$)
and the discovery of the Time-Like Structure of the Proton

$\boxed{(HL^{\pm}) \equiv \tau^{\pm}}$ & $\boxed{F_p^{em}(q^2)_{\text{time-like}}}$





– 1963 –

PAPLEP

Proton **A**nti**P**roton
into **L**epton **P**airs

first search for the 3rd lepton

and

$$\theta_{PS} \neq \theta_V \, .$$

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.

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".

III

BEAM-BEAM INTERACTION

***

THE TIME SYNCHRONIZATION

BEAM & QGCW

Let us mention one of the very many problems: the **time synchronization**, at the level better than 10^{-15} s, **between**

<u>the</u> colliding heavy ions

forming the **QGCW**,

<u>the</u> bombarding particles

simultaneously injected and

<u>the</u> emerging particles

from the bombarded **QGCW**.

The **synchronization issues** are between all the **detectors** equipments and the accelerators RF systems, including the accelerator beam bunches.

The **QGCW** is produced in a collision between heavy nuclei ($_{208}Pb^{82+}$) at the maximum energy.

The **QGCW** is composed by the enormous number of QCD open-colour-states.

These are by far more that the number of baryons and mesons so far known, since these hadrons have to obey the condition of being QCD-colourless.

We want to search for specific effects due to the fact that the **zero-colour condition is not needed**.

In principle, many different phase transitions could take place and a vast variety of complex systems should show up.

The properties
of this
new world
should open
unprecedented horizons
in understanding
the Logic of Nature.

How to study this new world is illustrated in Figure 11 where beams of known particles

$$(p, n, \pi, K, \mu, e, \gamma, \nu)$$

bombard the **QGCW** volume and a special set of detectors allows one to measure the properties of the outgoing particles.

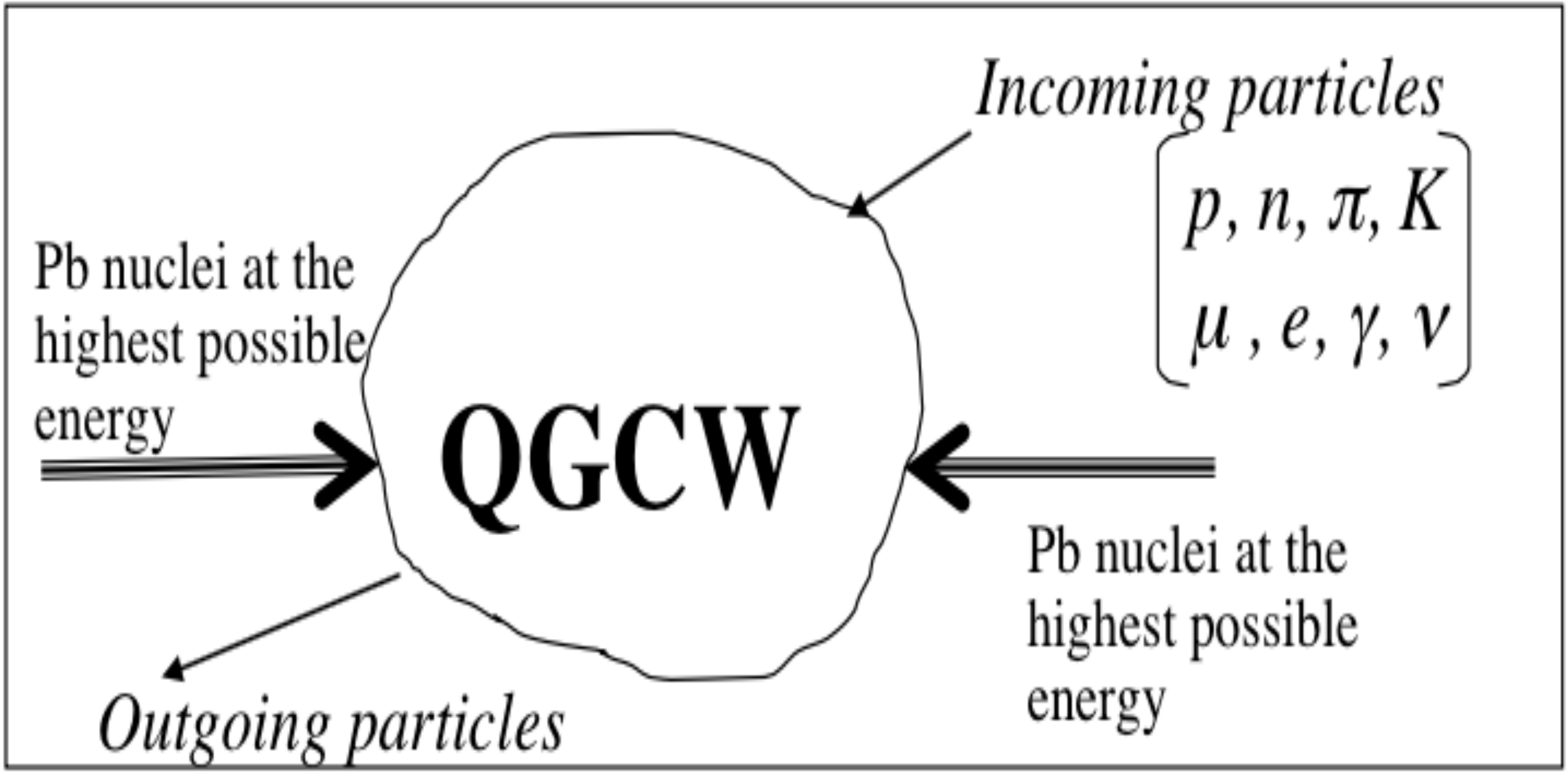


Figure 11. Schematic view of the proposed methodology for QGCW study (see text).

In Figure 11
the QGCW
is produced
by (PbPb) nuclei
colliding at the highest
possible energy.

Inside the QGCW volume there are free quarks and antiquarks, an enormous number of gluons and all open-QCD-colour-states allowed by SU(3)c.

If we bombard this **QGCW** volume with particles having only EM interactions (photons and charged leptons) these particles should have some difficulty in going through the **QGCW**.

But if we bombard
the same **QGCW** volume
with protons,
neutrons, pions
or any other hadron,
these particles should have
enormous difficulty
to go through.

The study
of the
outgoing particles
could reveal
totally unexpected effects.

For this to become frontier physics,

$\boxed{\text{R\&D work}}$

based on the upgrade of LHC

and of all detectors

$\boxed{\text{is the key issue}}$.

The upgrades
must cover
the accelerator technology
and the
detectors technology.

Our collider and detectors should be as powerful as possible in order to allow totally unexpected effects to be detected.

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

$$10^{27}\ \text{cm}^{-2}\ \text{s}^{-1}.$$

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 2 shows the basic parameters of the lead-ion injectors.

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_l [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.

TABLE 2

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.

We must be prepared
with the most
advanced technology
in order to discover
totally unexpected events
like the ones found
in the Yukawa gold mine.

Let us not forget the past experience.

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.

2. Nuclear Charges, Forces and other details in the QGZCW

Baryons and mesons mimic the existence of nuclear charges which produce the nuclear force. This force generates the “nuclear binding masses,” in analogy with the “electromagnetic binding” masses. There is a fundamental difference between these two types of “binding” masses.

The “electromagnetic” one is described by QED (Quantum ElectroDynamics), a Relativistic Quantum Field Theory (RQFT), whose origin is in the fundamental gauge forces $SU(2) \times U(1)$ broken at the Fermi scale.

The “nuclear binding mass” depends on the nuclear forces which are secondary effects whose origin is in QCD (Quantum ChromoDynamics). This is a fundamental force acting between quarks and gluons inside the "particles" called hadrons: baryons and mesons. The existence of the nuclear force was experimentally established in 1947 and its existence was associated with a nuclear field whose source was believed to be the nuclear charge of the nucleon believed to be elementary and having the two states called proton and neutron. The experimental discovery, during many decades after 1947 [5], of a large number of hadrons, i.e. of sources (baryons) and of quanta (mesons) opened the way to the discovery of QCD by Fritzsch, Gell-Mann and Leutwyler [6].

We now know that all hadrons are not elementary; the baryons are composed by quark triplets (qqq) and the mesons are composed of $(q\bar{q})$ pairs. Nuclei exist because protons and neutrons can be bound together by the residual QCD effects which generate attraction between nucleons. We also know that nuclear charges do not exist as fundamental charges. Their effects are the residues of QCD, once we go from **QGCW** to **QGZCW**.

The lightest nucleus (the deuteron) can exist because the residual QCD effects allow the proton and the neutron to attract each other, thanks to all virtual transition processes needed in order to go from **QGCW** to **QGZCW**.

The equality of the "binding masses" in nuclei and antinuclei is the proof that CPT invariance holds in these processes. If the transition processes from **QGCW** to **QGZCW** is CPT invariant, a nucleus should have the same value of the "nuclear binding mass" as its antinucleus, no-matter the number of nucleons needed for the given nucleus.

3. Examples of CPT Invariance including those that are not valid

It is given for granted that CPT invariance has been checked at very high level of accuracy thanks to the $(K\bar{K})$ mass difference (see Appendices 1 and 2).

We would like to call attention on the fact that experiments performed — and presented as proof for the validity of CPT invariance in the masses of elementary particles — do not involve the study of CPT invariance in the "nuclear binding masses." These experiments can in fact be grouped in two classes.

The first class comes from K-meson physics, where the mass difference between two K-mesons, the long-lived (K_L) and the two short-lived (K_S), $\Delta m_{K_L K_S}$, is the basic ingredient. A meson is composed with quark–antiquark pair and the nuclear binding is absent.

The second class has as basic ingredient the mass difference between protons and antiprotons [7]. The nuclear binding is not at work when only one nucleon is studied.

None of these experiments (a review is in Ref. 8) can study the validity of CPT in the field of "nuclear binding masses." The physics quantity called "mass" corresponds to four sources (Appendix 3). The nuclear binding is the one nearly forgotten.

As previously emphasized, purpose of the present analysis is to call attention on the "nuclear binding mass" which is strongly linked with the transition from **QGCW** to **QGZCW**.

Despite all efforts, no one has been able so far to theoretically describe the transition from **QGCW** to **QGZCW** having as basis two Relativistic Quantum Field Theories (RQFTs).

The first step would be the interaction between a proton and a neutron — which allows the deuteron to exist — described by a RQFT. This is not the case: we do not have a RQFT describing the nuclear forces.

All we know is the fact that the antideuteron exist and its mass is — within the experimental uncertainty — identical to the mass of the deuteron [9]. The "nuclear binding mass" is needed not only for the deuteron and for the antideuteron to exist but for all nuclei of the atoms of the elements in the Mendeleev Table. A mass difference between a nucleus and its antinucleus would imply CPT violation.

The most elementary example where the "nuclear binding mass" comes in is the deuteron (pn) whose counterpart is the antideuteron $(\bar{\mathrm{p}}\bar{\mathrm{n}})$. A very simple approximation to their masses is in Eq. (1):

$$\begin{aligned} m(\mathrm{d}) &= m_{\mathrm{p}} + m_{\mathrm{n}} - m_{\mathrm{pn}}^{\mathrm{Binding}} , \\ m(\bar{\mathrm{d}}) &= m_{\bar{\mathrm{p}}} + m_{\bar{\mathrm{n}}} - m_{\bar{\mathrm{p}}\bar{\mathrm{n}}}^{\mathrm{Binding}} . \end{aligned} \tag{1}$$

We are aware of the fact that this is a severe simplification. A review of this problem is in Ref. 8. Masses originate from the Hamiltonian which is an Operator, not a C number.

In addition to the particle masses (m_p, m_n) and the antiparticle masses ($m_{\bar{p}}, m_{\bar{n}}$), we have the nuclear binding effects, $m_{pn}^{Binding}$ and $m_{\bar{p}\bar{n}}^{Binding}$, which, contrary to the

QCD "Bag" effects (that produce positive masses), subtract mass to the (pn) and ($\bar{p}\bar{n}$) systems, respectively; the QCD "Bag" is a QCD non-perturbative confinement effect and, since QCD is a RQFT, it could be CPT invariant despite the problems created by the convergence of the gauge couplings at E_{GUT} and at the Planck scale, E_{Planck} [10].

Nevertheless, if all these processes are CPT invariant, we expect the mass difference between the deuteron and the antideuteron to be zero

$$\Delta m_{\mathrm{d\bar{d}}} = m_{\mathrm{d}} - m_{\mathrm{\bar{d}}} = 0\,. \tag{2}$$

The same arguments applied to ^{3}He and $^3\overline{\mathrm{He}}$ give zero for the mass difference between ^{3}He and $^3\overline{\mathrm{He}}$:

$$\Delta m_{(^3\mathrm{He};^3\overline{\mathrm{He}})} = m_{(^3\mathrm{He})} - m_{(^3\overline{\mathrm{He}})} = 0\,. \tag{3}$$

Any deviation from zero in Eqs. (2) and (3) would correspond to CPT breaking effects in the transition from **QGCW** to **QGZCW**.

If the mathematical formulation of a physics process can be expressed in terms of a relativistic, local, quantized, field theory (RQFT), this process has to obey CPT invariance. To violate this fundamental invariance of nature corresponds to break the basic conceptual structure of a RQFT.

The ALICE Collaboration has recently reported [11] the following limits:

$$\frac{\Delta m_{\mathrm{d\bar{d}}}}{m_{\mathrm{d}}} < 2.4 \times 10^{-4} \quad (\mathrm{CL{=}90\%}) \tag{4}$$

and

$$\frac{\Delta m_{(^3\mathrm{He};^3\overline{\mathrm{He}})}}{m_{(^3\mathrm{He})}} < 2.1 \times 10^{-3} \quad (\mathrm{CL{=}90\%})\,. \tag{5}$$

These are the highest precision proofs of CPT invariance in the "nuclear binding masses", given for granted that the Higgs mechanism [12–15], which generates the quarks masses, obeys CPT invariance.

APPENDIX 3: The four types of "masses"

The physics quantity called "mass" corresponds to four sources:

(i) The intrinsic masses of the fundamental fermions (quarks and leptons) are positive; their origin is proposed to be the so-called Higgs mechanism [12–15];

(ii) The confinement masses are positive and responsible for the hadrons to be heavier than their fundamental constituents. This is the so-called Bag effect which is a QCD confinement colour process. This effect is easy to notice when the constituents are light quarks: (u, d, s). This effect is not easy to notice when the constituents are heavy quarks: (c, b, t);

(iii) The electromagnetic binding masses (responsible for the existence of atoms and molecules) are negative; their origin is in QED, a Relativistic Quantum Field Theory (RQFT);

(iv) The "nuclear binding masses" are negative; their origin is strongly linked to the **transition** from **QGCW** to **QGZCW**.

APPENDIX 1: Anti Hydrogen is not Nuclear Antimatter

The hydrogen atom needs the masses of two elementary particles, the proton (p) and the electron (e), plus the electromagnetic binding between them (p, e). The existence of the hydrogen atom has nothing to do with the existence of nuclear matter, as emphasized by Dirac. In the sixties of last Century, the elementary particles were objects such as the proton (p) and the neutron (n), with antiproton ($\overline{p}$) and antineutron ($\overline{n}$) as antiparticles. The existence of nuclear matter needs a nuclear binding between protons and neutrons. The mass of the most elementary nucleus of matter, the deuteron (D), needs, in addition to the masses of the two elementary particles (p, n), also the negative nuclear mass produced by their binding. In the sixties there was no understanding of the mathematical structure needed to describe these nuclear binding forces.

Since the middle sixties, our understanding of the nuclear binding forces has evolved a lot thanks to QCD. And now a problem arises. The basic ingredients of QCD are the gluons (massless) and the quarks (massive). No one knows the scale where the intrinsic quark masses originate. If it is at the string unification scale (i.e. $\simeq 10^{19}$ GeV), the CPT theorem loses its foundations (T.D. Lee, 1995 [10]) and therefore, although particle theories with CPT violation are not presently known, it is yet of importance to check the equality of masses for particles and antiparticles. In fact, it could be that,

$$m_q \neq m_{\overline{q}} .$$

Let us disentangle:

i) the intrinsic mass associated with a quark (a structureless particle);

from

ii) the mass associated with a nucleon (a particle composed of three quarks plus many gluons);

and these two masses from

iii) the mass associated with nuclear matter, the simplest example being the deuteron.

It is often stated that the existence of a mass difference between the long-lived and the short-lived components of the $(K^0\overline{K}^0)$ system is the proof that matter-antimatter symmetry is broken. The experimental result is:

$$\Delta m_{K_L K_S} = m_{K_L} - m_{K_S} = (3.491 \pm 0.009) \times 10^{-6}\ \mathrm{eV/c^2}\ . \qquad (1a)$$

However this is the mass difference between two particle states, K_L and K_S, each one consisting of a mixture of a particle (K^0) and its antiparticle ($\overline{K}^0$). When (1a) is translated into the mass difference between the K^0 and the $\overline{K}^0$ the result is:

$$\Delta m_{K\overline{K}} = |\ m_{K^0} - m_{\overline{K}^0}\ | \lesssim 4 \times 10^{-10}\ \mathrm{eV/c^2}\ . \qquad (1b)$$

In other words there is no final statement (in the case of a meson) for the existence of any asymmetry between the mass of a particle (K^0, i.e. a $q_i\,\bar{q}_j$ system) and its antiparticle ($\overline{K}^0$, i.e. a $\bar{q}_i\,q_j$ system). Let us point out again that, what in the middle sixties was considered an elementary particle, is now understood to be a system of either a quark-antiquark ($q\bar{q}$) pair (mesonic state) bound by QCD colour confining forces, or a $(q\,q\,q)$ triplet (baryonic state) bound by QCD colour confining forces. The masses of these particles (mesons and baryons) are the result of the intrinsic quark masses, m_q, plus the QCD confining ("Bag") effects, m^{Bag}, plus some radiative effects, m^{Rad}.

A meson is already a mixture of a quark plus an antiquark; the search for an asymmetry between particle and antiparticle masses should have its best source in those particle states which consist only of quarks (such as the baryons), and not of quark-antiquark mixtures (such as the mesons). As mentioned before it is often stated that the mass difference between K^0 and $\overline{K}^0$ is the highest precision determination of matter antimatter symmetry (Appendix 2).

Keeping in mind the problem of the deuteron and antideuteron masses, let us consider the mass difference between a particle and its antiparticle, each one composed of quarks and gluons. The simplest example is the proton, whose mass is the result of the following components:

$$m_p \equiv 2\,m_u + m_d + m^{Bag}_{u\,u\,d} + m^{Rad}_{u\,u\,d} \qquad (2a)$$

where:

i) m_u , m_d are the intrinsic masses of the elementary constituents, the quarks;

ii) $m^{Bag}_{u\,u\,d}$ is the mass produced by the QCD colour forces acting between quarks and gluons and confining them within the proton radius;

iii) $m^{Rad}_{u\,u\,d}$, has been defined earlier.

The same parts appear in the mass of an antiproton:

$$m_{\overline{p}} \equiv 2\,m_{\overline{u}} + m_{\overline{d}} + m^{Bag}_{\overline{u}\,\overline{u}\,\overline{d}} + m^{Rad}_{\overline{u}\,\overline{u}\,\overline{d}} \qquad (2b)$$

If the interaction responsible for the intrinsic mass of a quark is CPT invariant, if the QCD confining effects and the radiative effects are all CPT invariant, the result is expected to be

$$\Delta m_{p\overline{p}} = m_p - m_{\overline{p}} = \text{zero}\ ;$$

the experimental limit is:

$$\Delta m_{p\overline{p}} = (22 \pm 40)\ \text{eV/c}^2 \simeq \text{zero} \pm 40\ \text{eV/c}^2\ . \qquad (2c)$$

And now, the deuteron-antideuteron masses:

$$m(D) = m_p + m_n - m^{Binding}_{p\,n} + m^{Rad}_{p\,n} \qquad (3a)$$

$$m(\overline{D}) = m_{\overline{p}} + m_{\overline{n}} - m^{Binding}_{\overline{p}\,\overline{n}} + m^{Rad}_{\overline{p}\,\overline{n}}\ . \qquad (3b)$$

In addition to the particle masses (m_p , m_n) and the antiparticle masses ($m_{\overline{p}}$, $m_{\overline{n}}$), we now have the nuclear binding effects, $m^{Binding}_{p\,n}$ and $m^{Binding}_{\overline{p}\,\overline{n}}$, which, contrary to the QCD "bag" effects (that produce positive masses), subtract mass from the (p n) and ($\bar{p}\bar{n}$) systems, respectively.

If all these processes are CPT invariant, we expect the mass difference between the deuteron and the antideuteron to be zero

$$\Delta m_{D\bar{D}} = m_D - m_{\bar{D}} = \text{zero} .$$

The experimental limit is:

$$\Delta m_{D\bar{D}} = \text{zero} \pm 80 \text{ MeV}/c^2 . \qquad (3c)$$

It would be interesting in future to see how these results [(1b); (2c); (3c)] compare among themselves, once they have reached the needed sensitivity. Notice that the mass uncertainty in (1a) is ($\pm 9 \times 10^{-9}$ eV), i.e. nearly ten orders of magnitude lower than the value ($\pm$ 40 eV) which characterizes the best mass difference so far measured in a particle-antiparticle system made up of three quarks (2c). Apart from being – as already emphasized – a mass difference between two particle states (not between a particle and its antiparticle), the reason for the extraordinary accuracy in $\Delta m_{K_L K_S}$ is in the fact that what is measured is a time-dependent "oscillation", whose value depends on Δm. Nevertheless, neither (1a, b) nor (2c) are measurements of mass differences between nuclear matter and nuclear antimatter states. In fact, the QCD-induced nuclear binding, which produces effects opposite in sign to the QCD confining forces, is absent in (1a, b) and (2a, b, c).

To recapitulate, in these last decades, our understanding of the mass differences between particle-antiparticle and matter-antimatter states has developed and, apart from radiative effects, can be described in terms of three sources:

i) the intrinsic mass of some fundamental fermions (the quarks): m_q ;
ii) the "bag" effects due to QCD confining colour forces; these effects produce positive masses: m_{BAG} ;
iii) the binding effects due to QCD colour-neutral states (the mesons) acting between other QCD colour-neutral states (the nucleons); these effects produce negative masses: $m_{Binding}$ (the negative sign is explicitly shown in Fig. 2).

All these sources of masses, the intrinsic fermionic ones m_q, the QCD colour confining ones m_{Bag} and the QCD colour-neutral binding $m_{Binding}$, appear in nuclear matter and antimatter, as illustrated in Fig. 2.

$\sum m_{q_i} + m_{BAG} - m_{Binding} = m_{MATTER}$
$\sum m_{\bar{q}_i} + m_{\overline{BAG}} - m_{\overline{Binding}} = m_{\overline{MATTER}}$

Fig. 2: The three components in matter and antimatter masses.

Of these three sources of masses, the one which produces the intrinsic quark masses $m_q \equiv m_{Intrinsic}$ is certainly not due to QCD and supposed to be the "Higgs mechanism". The other two have the same origin, QCD, but are generated by drastically different QCD effects. It is clear that

$$m_{Intrinsic} \neq m_{Confining} \neq m_{Binding} \quad .$$

The experimental point is to study $m_{Intrinsic}$, $m_{Confining}$ and $m_{Binding}$; and compare quark-antiquark masses, particle-antiparticle masses, and matter-antimatter masses.

APPENDIX 2: The highest precision result on $\Delta m_{K\bar{K}}$ is useless for validity of CPT in quark masses

We discuss in this note how the mass difference, between a quark and its antiquark state, compares with the mass differences measured for particle antiparticle states (mesons and baryons). To study the mass differences between quark and antiquark states it is necessary to study the particle states made of three quarks (baryons), not those made of quark antiquark pairs (mesons).

Let us consider the best known mass differences, mentioned in Appendix 1

$$\left| \Delta m_{K\bar{K}} \right| \lesssim 4 \times 10^{-10} \text{ eV/c}^2 \; ; \tag{1}$$

$$\left| \Delta m_{p\bar{p}} \right| \leq 40 \text{ eV/c}^2 \; . \tag{2}$$

They differ by eleven orders of magnitude. The high precision result on $\Delta m_{K\bar{K}}$ can be of no value to establish if CPT holds in the quark antiquark masses.

This point needs to be discussed in some detail.

The masses of the K^0 meson and of its antiparticle state $\overline{K}^0$ are, respectively:

$$m_{K^0} = m_d + m_{\bar{s}} + m^{Bag}_{d\bar{s}} + m^{Rad}_{d\bar{s}}$$
$$m_{\overline{K}^0} = m_{\bar{d}} + m_s + m^{Bag}_{\bar{d}s} + m^{Rad}_{\bar{d}s} \qquad (1.1)$$

where

$m_d \equiv$ the mass of the fundamental fermion "d".

$m_s \equiv$ the mass of the fundamental fermion "s".

$m_{\bar{d}} \equiv$ the mass of the fundamental antifermion "$\bar{d}$".

$m_{\bar{s}} \equiv$ the mass of the fundamental antifermion "$\bar{s}$".

$m^{Bag}_{d\bar{s}} \equiv$ the QCD-Bag energy needed to confine the pair "$d\bar{s}$".

$m^{Bag}_{\bar{d}s} \equiv$ the QCD-Bag energy needed to confine the pair "$\bar{d}s$".

$m^{Rad} \equiv$ radiative corrections.

Let us suppose that a source of CPT breaking exists at some energy scale. This is certainly true at the string unification scale (E_{SU}) where CPT invariance loses its foundations (T.D. Lee [10]).

If this happens, we might expect

$$m_{q_i} \neq m_{\bar{q}_i}$$

where $m_{q_i} \equiv$ the mass of the quark with flavour "i"
$m_{\bar{q}_i} \equiv$ the mass of the antiquark with flavour "i".

Let us assume the simplest CPT breaking effect: i.e. all quark flavours differ from their antiquark states by the same amount Δm :

$$m_{q_i} = m_{\bar{q}_i} \pm \Delta m_i$$

(with $i = 1, 2 \dots 6$) and no effects of CPT breaking are present in the Bag and in the Radiative parts. There are two possibilities: either $m_{q_i} > m_{\bar{q}_i}$ or $m_{q_i} < m_{\bar{q}_i}$.

In both cases the final result would be the same.

The simplest CPT breaking possibility is that all Δm_i are equal. In this case

$$\Delta m_{K^0\overline{K}^0} = \text{zero}$$

despite the fact that $m_{qi} \neq m_{\overline{q}i}$.

The very small limit on the mass difference between the K^0 meson and its antistate $\overline{K}^0$,

$$\Delta m_{K\overline{K}} \gtrsim 4 \times 10^{-10} \text{ eV}/c^2 \tag{1}$$

might have no effect on the value of the difference between quark and antiquark states. For this difference to be investigated, we need to compare the mass of a particle (made of three quarks) and of its antiparticle (made of three antiquarks). Let us consider the proton; its mass is given by

$$m_p = 2\, m_u + m_d + m^{Bag}_{u\,u\,d} + m^{Rad}_{u\,u\,d}$$

where the symbols are self evident. For the antiproton we have

$$m_{\overline{p}} = 2\, m_{\overline{u}} + m_{\overline{d}} + m^{Bag}_{\overline{u}\,\overline{u}\,\overline{d}} + m^{Rad}_{\overline{u}\,\overline{u}\,\overline{d}} \ .$$

Assuming, as before, the simplest CPT breaking mechanism, which only affects the fundamental fermion masses,

$$m_{qi} \neq m_{\overline{q}_i} \quad \text{and} \quad m_{qi} = m_{\overline{q}_i} - \Delta\, m_i$$

without effects on m^{Bag} and m^{Rad}, we have from the experimental results [16]

$$\Delta m_{p\overline{p}} = (m_p - m_{\overline{p}}) = (22 \pm 40) \text{ eV} = 3\, \Delta m\, (q\overline{q})\ , \tag{2}$$

i.e. $$\Delta m\, (q\overline{q}) \lesssim 20 \text{ eV}/c^2\ .$$

To sum up: there are two particle-antiparticle limits (1) and (2): $\Delta m_{K^0\overline{K}^0}$ and $\Delta m_{p\overline{p}}$. The first one is 11 orders of magnitude better than the second one. These eleven orders of magnitude might be of no help in trying to establish if CPT holds for those mechanisms which provide the masses to the fundamental fermions called quarks. In other words, if a CPT violating effect on the quark-antiquark mass difference as large as

$$\Delta m_{q\bar{q}} = 20 \text{ eV/c}^2 ,$$

[which is more than ten orders of magnitude above the $\Delta m_{K\bar{K}}$ limit (1)] was the correct CPT breaking effect on the quark-antiquark mass difference, the result (1) could still hold true. In fact we have shown that the mass difference between mesons and antimesons might be zero even if the CPT breaking effects were very large on the mass difference between quarks and antiquarks.

CONCLUSIONS***

We propose the development and the realization of a new technology able to implement the collision between different particle states

$(p, n, \pi, K, \mu, e, \gamma, \nu)$

and the QGCW in order to study the properties of the Quark-Gluon-Coloured-World (QGCW).

In this 'new world' an enormous number of QCD-open-colour-states allowed by $SU(3)_C$ will exist; this number is by far higher that the number of baryons and mesons detected so far. **In principle many different phase transitions** could take place and a vast variety of **complex systems** should show up. The properties of this 'new world' should open unprecedented horizons in understanding the **Logic of Nature** [11].

***

ATTENTION PLEASE

THE “SPIN LESS FERMIONS” NEEDED IN SOLID STATE PHYSICS COULD BE THE “SCALAR-FERMIONS” OF THE QUARK GLUON COLOURED WORLD (QGCW) PROJECT

THE THEORETICALLY PREDICTED NEW STATES OF MATTER COULD BE OUR QGCW STATES

THE PROBLEM OF (CPT) INVARIANCE IN EXPERIMENTAL PHYSICS AND THE TIME OF FLIGHT (TOF) WORLD RECORD

BCF Collaboration

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The highest precision proof of CPT invariance in the "nuclear binding masses"

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The validity of CPT invariance in the field of "nuclear binding masses" has been studied for nuclei (antinuclei) with two and three nucleons (antinucleons): ($\mathrm{d}/\bar{\mathrm{d}}$) and ($^3\mathrm{He}/^3\overline{\mathrm{He}}$). It is discussed the importance of investigating the transition from the world where gluons and quarks carry their QCD colors (QGCW) to the world where gluons and quarks exist only with zero-QCD-color (QGZCW).

Keywords: CPT; nuclear forces; antimatter.

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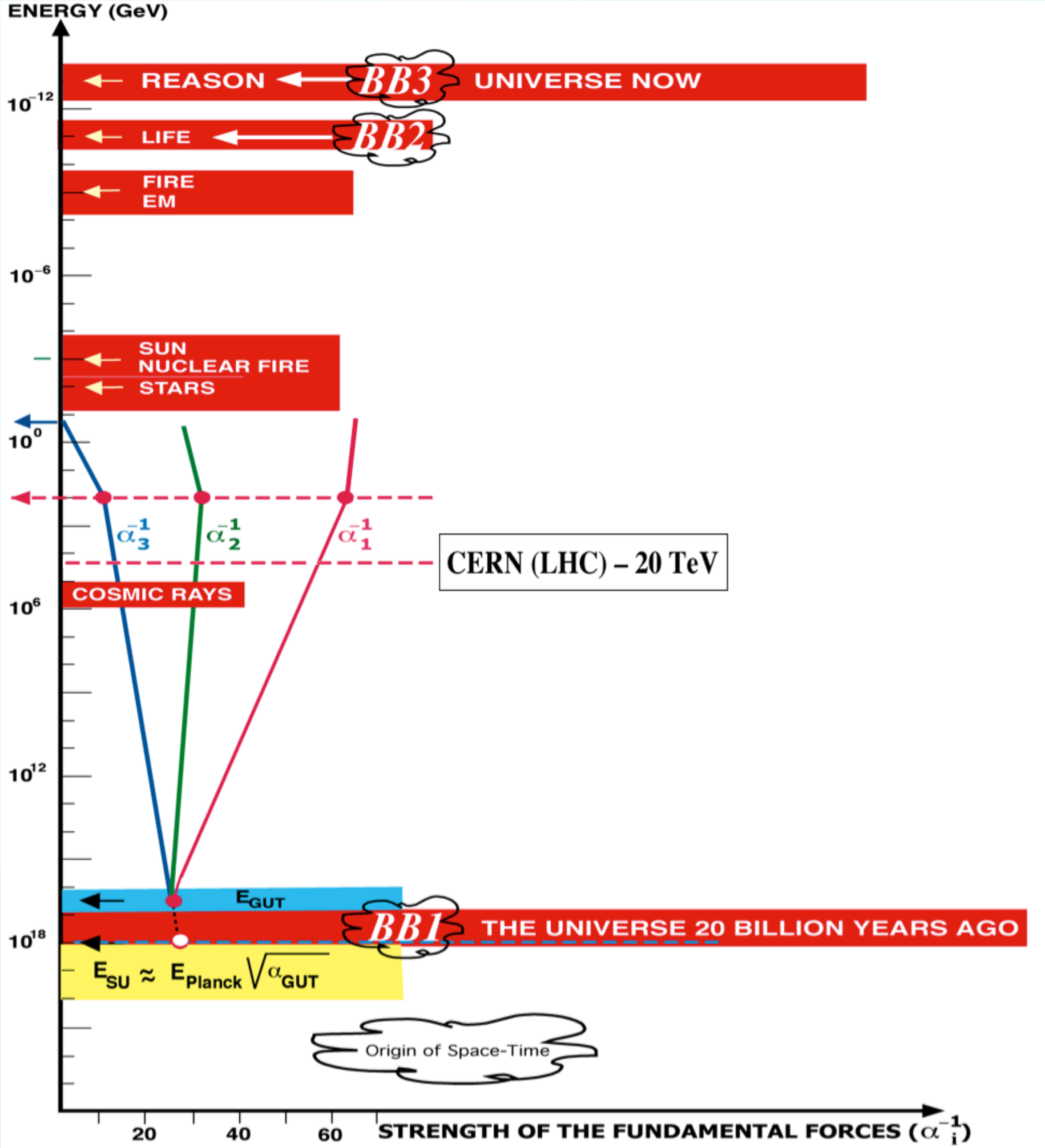
1. Introduction

The "nuclear binding" allows one to investigate the transition from the Quark Gluon Colored World (QGCW), where gluons and quarks carry their colors, to the Quark Gluon Zero Color World (QGZCW) where gluons and quarks are in their confined states called hadrons (baryons and mesons, particles with zero-QCD-color).

If the mathematical formulation of a physics process can be expressed in terms of a relativistic, local, quantized, field theory (RQFT), this process has to obey

* * *

THE THREE BIG-BANGS IN THE EVOLUTION OF THE UNIVERSE



IV

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