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Past and Future @CERN/TH (1954--20?4)

A **personal** account of how work @ cern/th has evolved during the **past** 50 years

Some **personal** thoughts about how it may evolve in the **future**

No attempt to be complete, objective, historical

For a more historical account of CERN-40 see:

"Physics in the CERN TH Division" by J. Iliopoulos (CHS-39, Dec. 1993)

The Past

1. Revolutions in our understanding
2. Revolutions in our tools and style

Revolutions in our understanding (1954-2004)

Half a century of remarkable achievements in our understanding of Nature at its deepest level

2nd half of a great century for physics (THE century of physics?) that began with two profound conceptual revolutions: Quantum Mechanics and Special Relativity

QM and SR came as two conceptually unrelated developments. For theorists, much of what has happened since had to do with finding a consistent framework within which QM & SR happily coexist… and which fits the data

Combination of theoretically sound ideas, ingenious experiments, and technical developments (accelerators, computing) made all this an incredibly successful story

I will try to retrace the developments of our understanding of elementary particles and fundamental forces as it could be seen through the eyes of a theorist at CERN

I was lucky enough to be active -and at the beginning of my career- by the mid 60's, the start of a "golden decade" during which our theoretical ideas truly underwent a "phase transition"

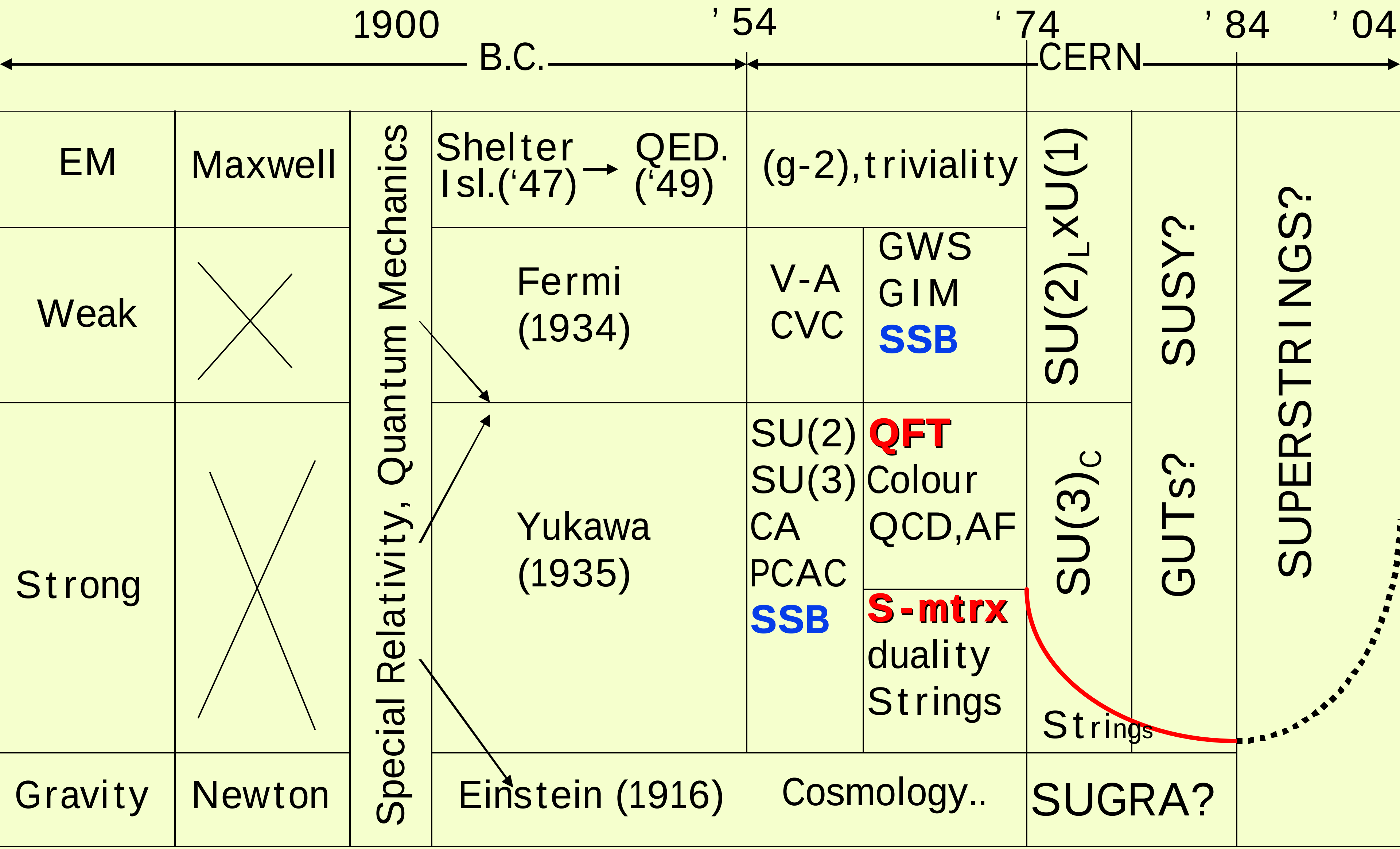
[Actually, I only joined CERN in 1976. But, even during the previous decade, I was visiting TH at regular intervals in or around the summer (basically every year from '67 to '74) This allowed me to take CERN/TH's "temperature" at regular intervals and to feel its evolution from year to year]

I will try to insert this crucial decade inside a broader picture and also mention other remarkable theoretical (if not yet experimental) revolutions that took place after 1974.

I will thus split the discussion in 4 parts/periods:

1900-'54 B.C.
1954-'74 Genesis of the SM
1974-'84 SM Consolidation and BSM
1984-'04 Leaps forward

I will then come to other aspects of the way CERN/TH has evolved (tools, style) and conclude with some thoughts -and worries- about where we may be heading for


1900
'54
'74
'84
'04
B.C.
CERN
EM
Maxwell
Shelter Isl.('47)
QED. ('49)
(g-2),triviality
Weak
Fermi (1934)
V-A
CVC
GWS
GIM
SSB
Strong
Yukawa (1935)
SU(2)
SU(3)
CA
PCAC
SSB
QFT
Colour
QCD,AF
S-mtrx
duality
Strings
Gravity
Newton
Einstein (1916)
Cosmology..
SUGRA?
Special Relativity, Quantum Mechanics
SU(2)$_L$xU(1)
SU(3)$_C$
Strings
SUSY?
GUTs?
SUPERSTRINGS?

Gravitation and Cosmology 1916-1974

		1900		1954		1974		1984
EM	Maxwell	Special Relativity, Quantum Mechanics	Shelter Isl.('47) → QED. ('49)	RGE, triviality		$SU(2)_L \times U(1)$	SUSY?	SUPERSTRINGS?
Weak			Fermi (1934)	V-A CVC	GWS GIM **SSB**			
Strong			Yukawa (1935)	SU(2) SU(3) CA PCAC **SSB**	**QFT** Colour QCD,AF **S-mtrx** duality Strings	$SU(3)_C$ Strings	GUTs?	
Gravity	Newton		Einstein(1916), tests, Cosmology			SUGRA?		

Gravitation and cosmology (1916-1974)

1. Einstein's theory of General Relativity (1916)
2. Tests of GR(1919, ...)
3. Cosmological applications:

   a) Friedmann (1922) & the Hubble law (1929)
   b) Standard hot big bang model (FLRW 1935)
   c) CMBR (1965), BBN...

N.B. Not much effort to go beyond classical theory, little if any interest by the HEP community & @CERN

1900-1954

B.C.

			1900	’54		‘74 CERN		’84 ’04
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Gravity	Newton		Einstein (1916)	Cosmology..		SUGRA?		

1900-1954

1. Establishing foundations of Quantum Mechanics (Heisenberg, Schroedinger,...) (1900-1930)
2. Fermi's theory of weak interactions, the neutrino (1934)
3. Yukawa's theory of strong interaction, the pion (1935)

and, right after the war,

The birth of QFT (Shelter Island June 1947):QED, the first example of a quantum-relativistic theory w/precise predictions:

Lamb-shift, (g-2), ...

1954-1974

Genesis of the SM

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Renormalization group and triviality in QED

Two problems mitigated the enthusiasm for the smashing successes of QED (Cf. $(g\text{-}2)_\mu$ @ CERN):

1. Divergence of Perturbation Theory. But, even more,
2. RG evolution of α and the problem of zero charge (1955):

L. Landau: "The Lagrangian is dead. It should be buried, with all due honours of course" (From A. Sakharov's memoirs)

This, together with problems in providing a full quantum version of either Fermi's or Yukawa's theory, caused a certain uneasiness with QFT within the HEP community: S-matrix theory gained in popularity, particularly for Strong Interactions (Cf. G. Chew's bootstrap program)

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		1954-1974	
Weak	Fermi (1934)	Strangeness(‘53-’55) ~~P~~ (‘56), JJ int. V-A (‘57), CVC (‘58), PCAC(‘61) Cabibbo (‘63)	~~CP~~ (‘64) GSW(‘67) GIM(‘70) --> J/ψ (‘74) **SSB (local)** Renormalizability of GSW(‘71)
Strong	Yukawa (1935)	$SU(2)_I$ --> SU(4) $SU(3)_F$ --> SU(6) (lost importance) **Current Algebra** **SSB (global)** PS-mesons as QNGB’s (‘61) Regge(‘59), MP(‘62)	**QFT** Naïve quark model, Colour, Free QFT? Quarks are for real, AF& Conf., **QCD**, Lattice(‘74),1/N(‘74) **S-Matrix** Sum rules, Nuclear democracy, Superconvergence, FESR, duality bootstrap, DRM, **String Theory**

From a talk by Gell-Mann (Erice '67) to the birth of String Theory (CERN '68)

Erice, summer 1967: An inspiring talk by M. Gell-Mann at Erice. Two highlights got stuck in my mind:

1. "Nature only reads books in free field theory" (or was it later?)
2. Dolen-Horn-Schmit duality and the possibility of a "cheap bootstrap" program (as opposed to Chew's) based on it

Oct '67-May '68: ARVV (HU+WIS) applied that idea to $\pi\pi \dashrightarrow \pi\omega$

Summer '68: I completed at CERN the work I had begun just before leaving Israel. After discussing with several people @CERN/TH, I submitted it to Nuovo Cimento. By the Vienna Conference (Aug. Sept.) it had already received much attention and was soon named the Dual Resonance Model: no one knew, but string theory was born!

A sentence by Sergio Fubini (~ 1970) expressed well those days' feelings

"A piece of 21st century physics
that fell accidentally on this century"

The string reinterpretation of the DRM (~1970) did not make its magic properties less mysterious but made DRM more "respectable"

A visit by ‘t Hooft and a lunch seminar by S. Weinberg (MIT 1971)

Before ‘t Hooft’s paper of 1971 S. Weinberg would rarely talk about his 1967 model. He was working mainly on chiral Lagrangians and even got interested in DRM (AVW paper)

But when ‘t Hooft’s paper appeared Steve immediately grasped its importance, invited G’tH to MIT for a seminar (and discussions), and then he himself gave a lunch (journal club) seminar

After filling the blackboard with the EW Lagrangian he added something like: this is not a pretty Lagrangian, neither it is clear whether it has anything to do with the real world, but it seems to define a consistent QFT of EW int’s from which definite predictions can be drawn…

A seminar at CERN/TH by Sid Coleman (1973)

Title: The price of asymptotic freedom
Abstract: Non abelian gauge theories.

One finally did have an answer to Gell-Mann's puzzle…Nature was reading books in asymptotically free QFT

At the same time NAGT could possibly explain the absence of free quarks by their highly non-trivial behaviour at large distance

NAGT also solved Landau's zero charge problem..

String's Surrender (~1974)

I still felt there was something true and unique in the way string theory was reorganizing perturbation theory diagrams, something very unlike what any normal QFT does

QCD's answer came from 't Hooft's work at CERN. In a suitable large-N_c limit QCD diagrams get reorganized as to mimic a string theory

That was enough for me (and for most string theorists of the time). Those interested in strong interactions (sadly?) turned a page and switched to QCD

Meanwhile, in a paper that went totally unnoticed,
J. Sherk and J. Schwarz proposed (1974) to
reinterpret string theory as a theory of quantum gravity
and kept working on it…

In just a couple of years, QFT had made a spectacular come-back and it was the turn of S-matrix theory to fall in disgrace

1974-1984

SM Consolidation and BSM

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A period of theoretical consolidation and experimental verification...

NC, J/Ψ discovery, W&Z, ...(see DT's talk)

CKM matrix, $\not{C}\not{P}$

Wilson's lattice gauge theory, confinement

QCD parton model, Jets

Instantons, $1/N$, $U(1)$, Strong CP, ..

...but also

It saw the first attempts to go beyond the SM with GUTs, SUSY*), SUGRA, and the hope, soon dashed, that some suitable QFT (e.g. D=11 SUGRA) could provide a consistent theory of quantum gravity

*) First discovered (in the West) in DRM, became a bona-fide QFT after the work of Wess and Zumino (CERN, 1974)

1984-2004

The leap forward

		1900		1954		1974		1984
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A seminar by Tom Banks (fall 1984)

Tom Banks arrived from the US for a short visit to CERN
As soon as we met he asked: Have you heard about SO(32)?
I probably answered: what do you mean?

A few days later he gave a talk about a recent paper by Green and Schwarz which provided the first example of an anomaly-free superstring theory with chiral fermions, i.e. of a theory that could in principle describe both the SM of HEP and quantized gravity.

1984-1994:The (S)Matrix, reloaded

This became known as the first string revolution; string theory came back to the spotlight as a Theory Of Everything (TOE), in particular as a consistent quantum theory of gravity

Some beautiful mathematical developments led to over-optimistic claims that one would soon arrive not only at an experimentally viable TOE but that the choice would be uniquely determined by theoretical consistency

As time went by those hopes started to fade away...but in any case

The conceptual barrier between gravitational and gauge interactions was gone forever

A brief encounter at CERN with A. Sakharov (~ 1987)

He had become very interested in String Theory (see his Memoirs) and came to see me about several issues

He had a particularly burning question: is the induced-gravity idea (AS 1968) born-out in string theory?

I gave him a straight answer: No! In string theory gravity is already present at tree-level, loops just renormalize G_N by a finite amount (in IG, G_N is entirely determined by loops)

Years later, after his death, I came back to the issue and concluded that IG is also possible in string theory and, actually, could be a very interesting option...

1994-2004

The second string revolution took place, bringing new theoretical tools and ideas (branes, dualities) but also making the dream of uniqueness even more difficult to realize

While the number of theories went down to a single theory, called M-theory, the number of solutions went up by many orders of magnitude...

Large extra dimensions, brane world, low-scale gravity...

A growing awareness of cosmological data... and puzzles

Revolutions in our tools

1. Mathematics
2. Computers

Mathematical tools for TH

- The level of mathematical sophistication needed in order to follow some theoretical developments (e.g. in string theory) has reached unprecedented levels
- This is reflected in the mathematical background of the average young theorist today

Increase in Computing Power

- I still remember the computing facilities when I did my Master thesis in Florence in 1965: punching cards to compute a one-dimensional integral on an big IBM machine took a big chunk of my time
- Lattice calculations could not have been conceived at that time. They still rely today on an exponential growth of computing power

Revolutions in style

1. Specialization
2. Comm. tools: fax, e-mail, archives, web
3. The side-effects

Specialization

- In the early days of my career I could basically follow all that was happening in HE theory: there were fewer areas and they were closer to each other, the number of new papers/month was manageable
- Now every field is very specialized and trying to follow what's going on (or even to look at what's new on the archives) requires a big effort
- Language barriers are often another obstacle

Communication, search tools

- Fax
- E-mail
- Archives
- WEB and its search engines

The side-effects

- Unfortunately all these goodies come with some side-effects
- Mathematics, Computers, Archives…

What about the future?

1. New theoretical ideas?
2. New tools, new style?

New Theoretical ideas

- The past 30 years have not been scarce in terms of new theoretical ideas
- The problem if any was elsewhere: the lack of experimental checks on whether any of those ideas had much to do with real life
- The relative status of TH and EXP determines to a large extent the way we make progress

TH vs. EXP: three cases

- EXP much ahead of TH: (HEP in the 50's and 60's, CKM, Neutrino masses, Astro and Cosmo-particle physics today)

  ==> tough (for theorists) but challenging
- EXP & TH roughly even: (QED, HEP in 70' and 80's: SM vs. LEP, HERA, Tevratron etc. data)

  ==> perfect
- TH much ahead of EXP (beg. of GR, HEP theory in the last two decades, Quantum gravity, Superstrings)

  ==> easy (for theorists) but dangerous

Precise experimental numbers mean little without a theory matching that precision,

while

Theoretical research, without the guide of experiments, tends to make random walks

Possibly, while waiting for great news from LHC, TH should appeal more to astro and cosmo-particle data where the situation looks much alike particle physics in the 50’s and 60’s: lots of good data, little understanding (DM, DE, CMB, UHECR, GRB,…..)

New tools, new styles

Computing power is going to grow, allowing us to tackle problems we have not been able to deal with in the past (e.g. LGT, NGR)

Means of communications will also improve making access to information easier and easier

But we have to watch the side-effects…particularly on the youngest generation

What could be at stake

1. Free choice of research
2. Embarking in risky projects
3. Enlarging and deepening one's knowledge
4. Interactions among different areas of TH and those with EXP

Dangers exist but, if we are aware of them, they can be overcome

Another golden era, I am pretty sure, is just around the corner…