HAPPY BIRTHDAY

LUCIANO

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WELCOME TO THE CLUB

LUCIANO

- The long awaited experimental results are coming close.

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- The last year of theoretical speculations.

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- We feel quite confident that fundamental discoveries are ahead.
- A most exciting period to enter High Energy Physics.

PRECISION MEASUREMENTS

THEN

AND

NOW

Precision measurements at a given energy scale allow to guess new Physics at the next energy scale

Example : Yukawa's prediction of the π meson in 1934

The range of nuclear forces is of order 1 fermi ($\sim 10^{-13}$cm).

The Physics was correct, the details were not ! !

Example : The prediction for charmed particles in 1969

The absence, with very high accuracy, of certain weak decays

• We often say that revolutions in Physics come because an unexpected experimental result forces physicists to change their theoretical paradigms.

• This has often been the case in the past.

• But the revolution which linked permanently Physics and Geometry had a theoretical, even an aesthetic, motivation.

- The Fermi theory of the weak interactions was phenomenologically very successful

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- But it was a non-renormalisable theory

- First false hope :

  The strong interactions will provide a cut-off for the weak ones

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- The right answer :

  Control the radiative corrections

$$
\begin{array}{llllll}
A & \sim & C_0^1(G_F\Lambda^2) & +C_1^1 G_F M^2 & & \\
& + & C_0^2(G_F\Lambda^2)^2 & +C_1^2 G_F M^2(G_F\Lambda^2) & & +C_2^2(G_F M^2)^2 \\
& + & ..... & & & \\
& + & C_0^n(G_F\Lambda^2)^n & +C_1^n G_F M^2(G_F\Lambda^2)^{n-1} & +.... & \\
& + & ..... & & &
\end{array}
$$

Effective coupling constant : $\lambda = G_F\Lambda^2$

$A \ \sim \ \lambda^n \ + \ G_F M^2 \ \lambda^{n-1} \ + \ ...$

A $\sim$ "leading" + "next-to-leading" + ...

The Theory is valid up to a scale $\sim \Lambda$

$G_F\Lambda^2 \sim 1 \Rightarrow \Lambda \sim 300$ GeV

BUT PRECISION MEASUREMENTS CAN DO BETTER

B.L. Joffe and E.P. Shabalin (1967)

- At leading order

  Limits on Parity and Strangeness violation in strong interactions

  $G_F \Lambda^2 << 1 \Rightarrow \Lambda \sim 3$ GeV

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- At next-to-leading order

  Limits on $K^0 \rightarrow \mu^+\mu^-$ and $K^0 - \bar{K}^0$ mass difference

  $G_F \Lambda^2 << 1 \Rightarrow \Lambda \sim 3$ GeV

In the same way New Physics is predicted for LHC

• Three decades of intense experimental effort, mainly at L.E.P., but also at the Tevatron, B-factories, ν-physics and, now, LHC, have brought the agreement between the Standard Model and experiment to an impressive degree of accuracy.

• I want to exploit this experimental fact and argue that the available precision tests of the Standard Model allow us to claim with confidence that new physics is present at the TeV scale and the LHC can, probably, discover it.

• The argument assumes the validity of perturbation theory and it will fail if the latter fails. But, as we just saw, perturbation theory breaks down only when strong interactions become important. But new strong interactions imply new physics.

What we have learnt

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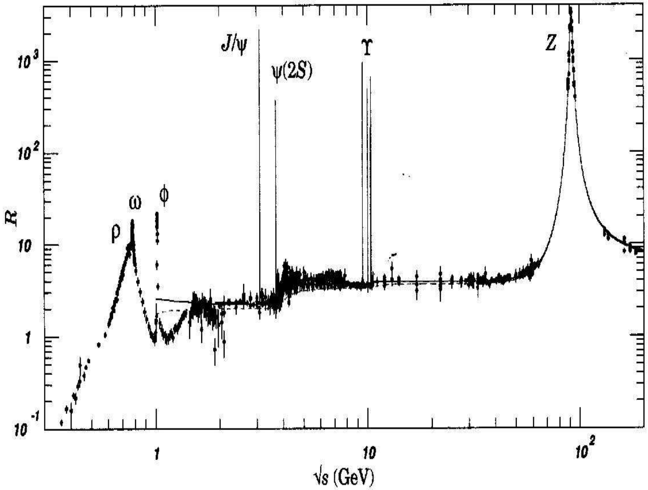
Outside the region of strong interactions


J/ψ
ψ(2S)
Υ
Z
ρ
ω
φ
R
10^3
10^2
10
1
10^-1
1
10
10^2
√s (GeV)

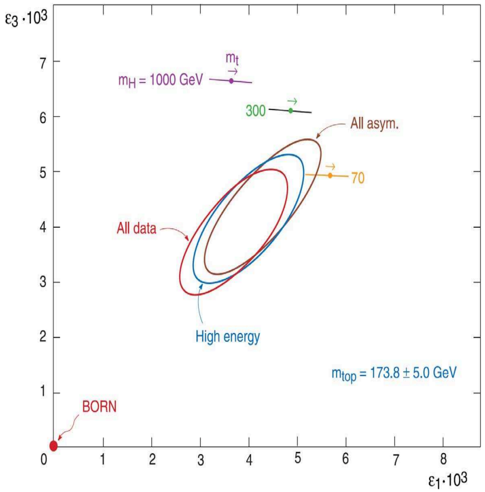
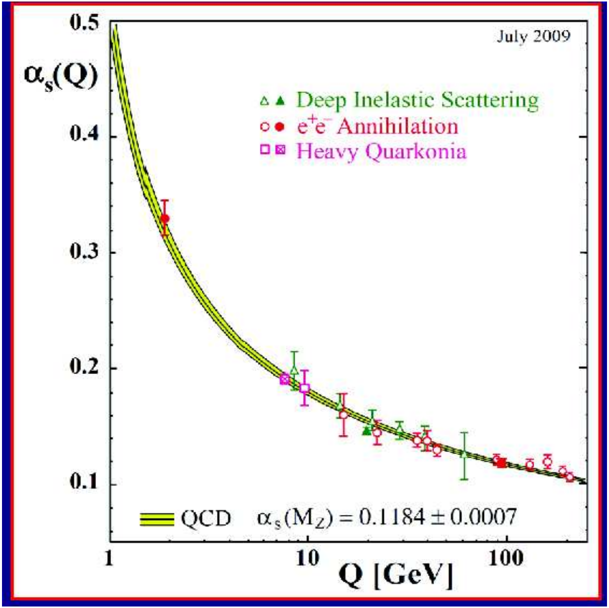


Figure 6: Data vs theory in the ϵ_3-ϵ_1 plane (notations as in fig.5)

$$\epsilon_1 = \frac{3 G_F m_t^2}{8\sqrt{2}\pi^2} - \frac{3 G_F m_W^2}{4\sqrt{2}\pi^2} \tan^2\theta_W \ln\frac{m_H}{m_Z} + \ldots \qquad (1)$$

$$\epsilon_3 = \frac{G_F m_W^2}{12\sqrt{2}\pi^2} \ln\frac{m_H}{m_Z} - \frac{G_F m_W^2}{6\sqrt{2}\pi^2} \ln\frac{m_t}{m_Z} + \ldots \qquad (2)$$


July 2009
$\alpha_s(Q)$
0.5
0.4
0.3
0.2
0.1
Deep Inelastic Scattering
e^+e^- Annihilation
Heavy Quarkonia
QCD $\alpha_s(M_Z) = 0.1184 \pm 0.0007$
1
10
100
Q [GeV]

Why ?

-We do not really understand why.

Why ?

Dyson's argument :

$A_n \sim \alpha^n (2n-1)!!$

Perturbation theory breaks down when $A_n \sim A_{n+1}$

$2n+1 \sim \alpha^{-1}$

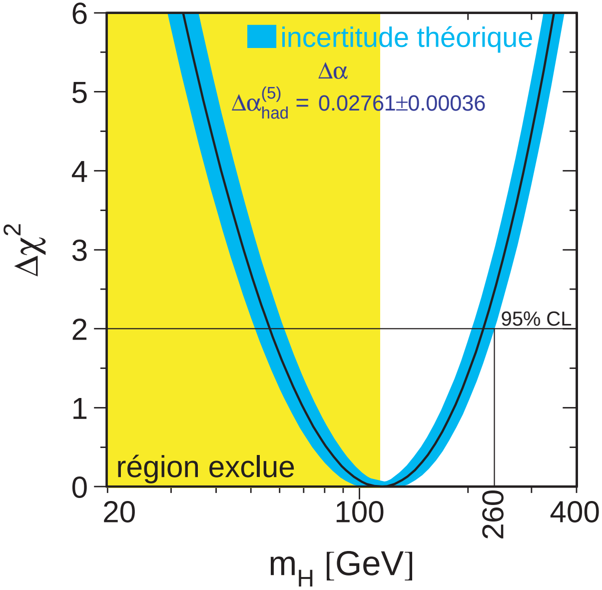
For QED $n >> 1$; For QCD ? ? ?

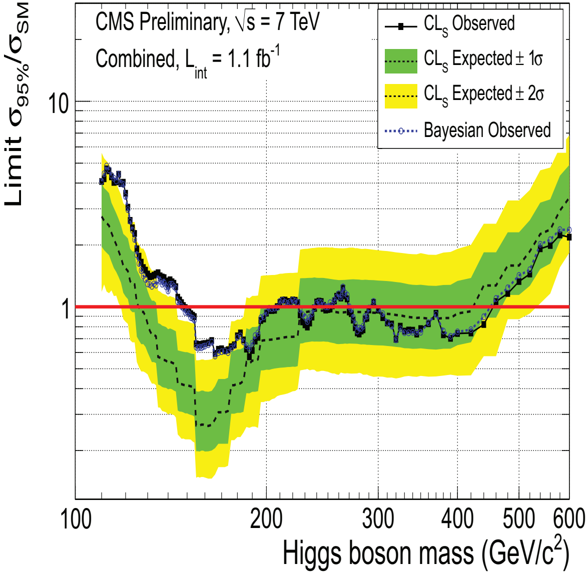
• All but one of the parameters of the Standard Model have been quite accurately determined by experiment.

• The precision of the measurements often led to successful predictions of new Physics. (Ex. Neutral currents, Charmed Particles, Gauge bosons, New quarks, etc)

• The last remaining parameter is the Higgs boson mass.

• Through the radiative corrections it enters into the determination of other physical quantities, but the dependence is only logarithmic. (Screening Theorem).


incertitude théorique
Δα
$\Delta\alpha^{(5)}_{had}$ = 0.02761±0.00036
95% CL
région exclue
$\Delta\chi^2$
0
1
2
3
4
5
6
20
100
260
400
m_H [GeV]



CMS Preliminary, $\sqrt{s}$ = 7 TeV
Combined, L_{int} = 1.1 fb^{-1}
CL_S Observed
CL_S Expected ± 1σ
CL_S Expected ± 2σ
Bayesian Observed
Limit $\sigma_{95\%}/\sigma_{SM}$
10
1
100
200
300
400
500
600
Higgs boson mass (GeV/c^2)

Limits on the Standard Model Higgs mass :

1) 160 GeV $\geq m_H \geq$ 114 GeV (Exp.)

2) $m_H = 85^{+39}_{-28}$ GeV (From global fit)

3) $m_H \leq \mathcal{O}$(1TeV) (Validity of perturbation)

4) $m_H \geq \mathcal{O}$(130GeV) (Vacuum stability)

$\mathbf{m_H^2} \sim \lambda$

$$\frac{d\lambda}{dt} = \frac{3}{4\pi^2}[\lambda^2 + 3\lambda h_t^2 - 9h_t^4 + ...]$$

Validity of perturbation

The Landau pole does not occur up to Λ

$\Lambda \sim 1\,TeV \rightarrow m_H \leq 0.8\,TeV$

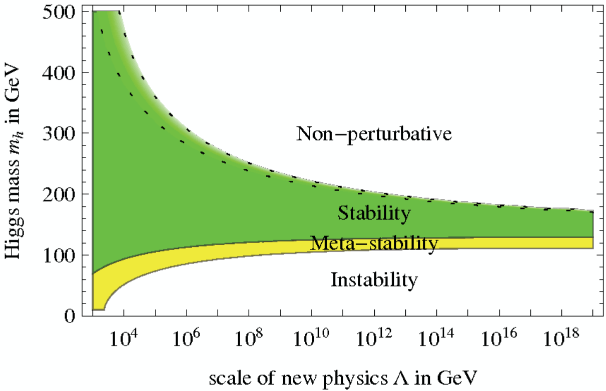
$\Lambda \sim 10^{16}\,GeV \rightarrow m_H \leq 180\,GeV$

Vacuum stability

$$\lambda > 0$$

for $\Lambda \sim 10^{16} GeV$

$$m_H \geq 110 - 120 GeV$$



Higgs mass m_h in GeV
500
400
300
200
100
0
Non−perturbative
Stability
Meta−stability
Instability
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
scale of new physics Λ in GeV

Can we “predict” the value of the Higgs mass ?

$$m_Z/m_H = C \tag{3}$$

$$C = \frac{m_Z}{m_H} = \frac{\sqrt{g_1^2 + g_2^2}}{\sqrt{8\lambda}} \tag{4}$$

$$
\begin{aligned}
16\pi^2\beta_{g_1} &= g_1^3\frac{1}{10} \\
16\pi^2\beta_{g_2} &= -g_2^3\frac{43}{6} \\
16\pi^2\beta_{\lambda} &= 12\lambda^2 - \frac{9}{5}g_1^2\lambda - 9g_2^2\lambda + \frac{27}{100}g_1^4 + \frac{9}{10}g_1^2 g_2^2 + \frac{9}{4}g_2^4
\end{aligned}
\tag{5}
$$

$$\beta_z = \beta_{\eta_1} + \beta_{\eta_2} =$$
$$= \frac{-\lambda w}{16\pi^2 \rho z} \left[\left(\frac{27}{100}\rho^2 + \frac{9}{10}\rho + \frac{9}{4} \right) z^2 - \left(2\rho^2 + \frac{54}{5}\rho - \frac{16}{3} \right) z \right.$$
$$\left. +12(\rho + 1)^2 \right] \tag{6}$$

$$\eta_1 = \frac{g_1^2}{\lambda} \;\; ; \;\; \eta_2 = \frac{g_2^2}{\lambda} \;\; ; \;\; z = \eta_1 + \eta_2 \;\; ; \;\; \rho = \frac{\eta_1}{\eta_2} \;\; ; \;\; w = \eta_1 \eta_2 \tag{7}$$

First task of LHC

Study the Higgs sector of the theory.

Possible (Predictable) LHC Results

1) A Light Higgs is found

The Standard Model is **complete**

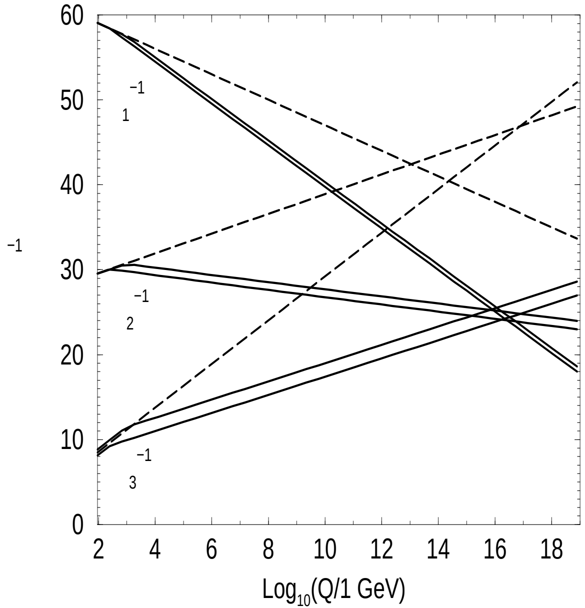
No new Strong Interactions $\Rightarrow$

Perturbation theory is reliable$\Rightarrow$

$m_H^2 \sim \alpha M^2$ $\Rightarrow$ Hierarchy

Possible Answers :

- Supersymmetry
- Possible solution of the dark matter problem
- Gauge coupling unification



60
50
40
30
20
10
0
−1
−1
1
−1
2
−1
3
2
4
6
8
10
12
14
16
18
Log10(Q/1 GeV)

- Theoretically very attractive
- Fermion-Boson connection
- Higgs-Gauge boson connection
- Non-renormalisation theorems
- Possible connection with Gravity
- BUT...The precise supersymmetry breaking mechanism is still unknown

Other answers to the hierarchy problem :

- Large extra dimensions
- Connection with Gravity
- More spectacular, less probable ? ?

Possible (Predictable) LHC Results

2) A Light Higgs is NOT found

- Seems unlikely, but...
- Perturbation theory breaks down
- $\Rightarrow$ New Strong Interactions

Possible Answers :

- Technicolor

The Higgs boson is a bound state of new, heavy fermions

- Little Higgs

The Higgs boson is a pseudo-Goldstone boson of a new symmetry

THE ABSENCE OF A LIGHT HIGGS

IMPLIES NEW PHYSICS

BUT A LIGHT HIGGS IS UNSTABLE

WITHOUT NEW PHYSICS

CONCLUSIONS

- THE TIME FOR SPECULATIONS WILL BE SOON OVER!

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- New Particles-New Laws ?
- Space-time ? Lorentz ?

- Who will guess the right answer ?

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- I BET ON LUCIANO !