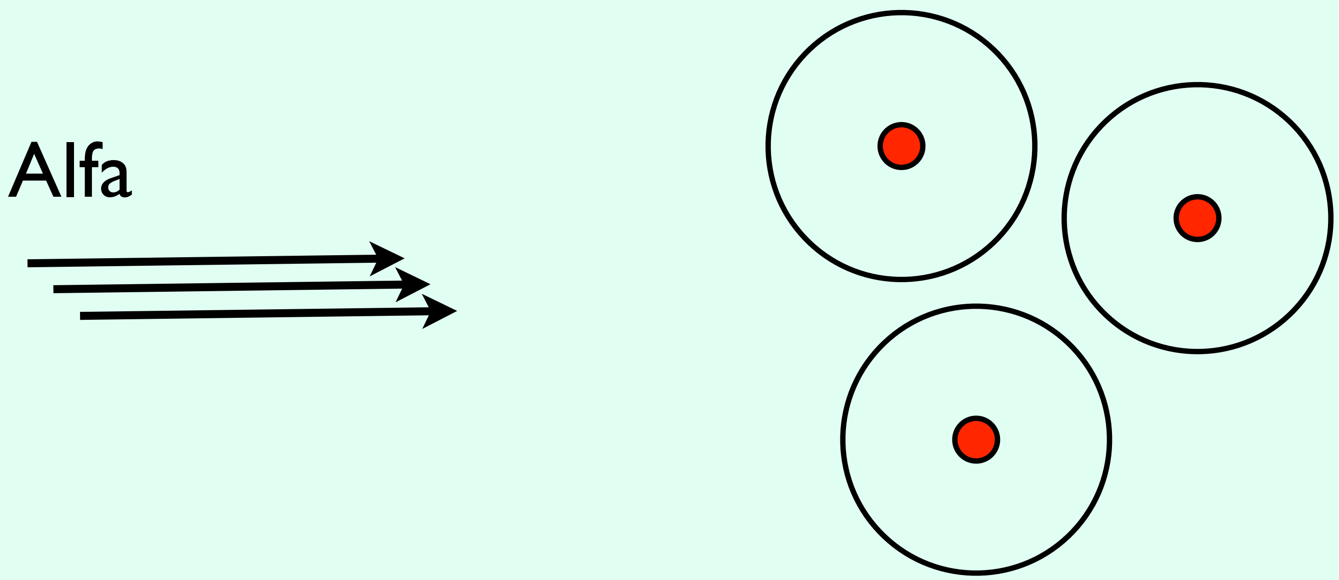
El bosó de Higgs

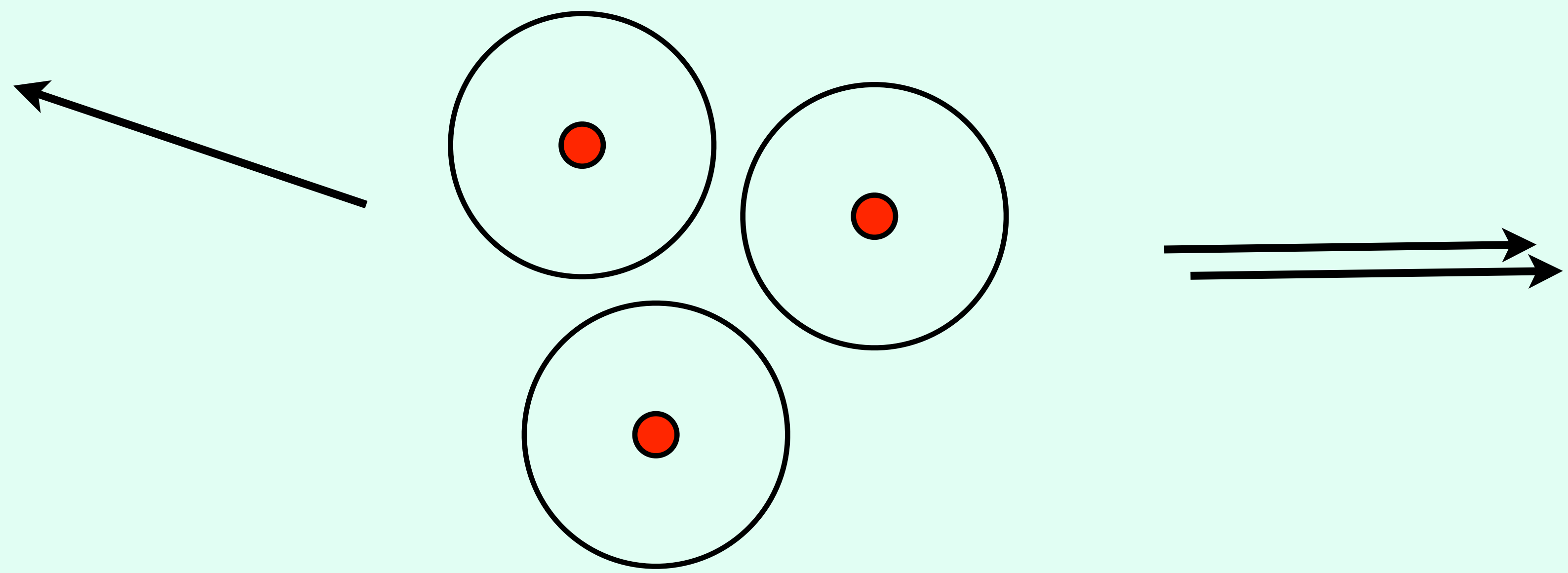
Eduard Massó
Universitat Autònoma Barcelona

Rutherford 1911

1871-1937



Rutherford 1911

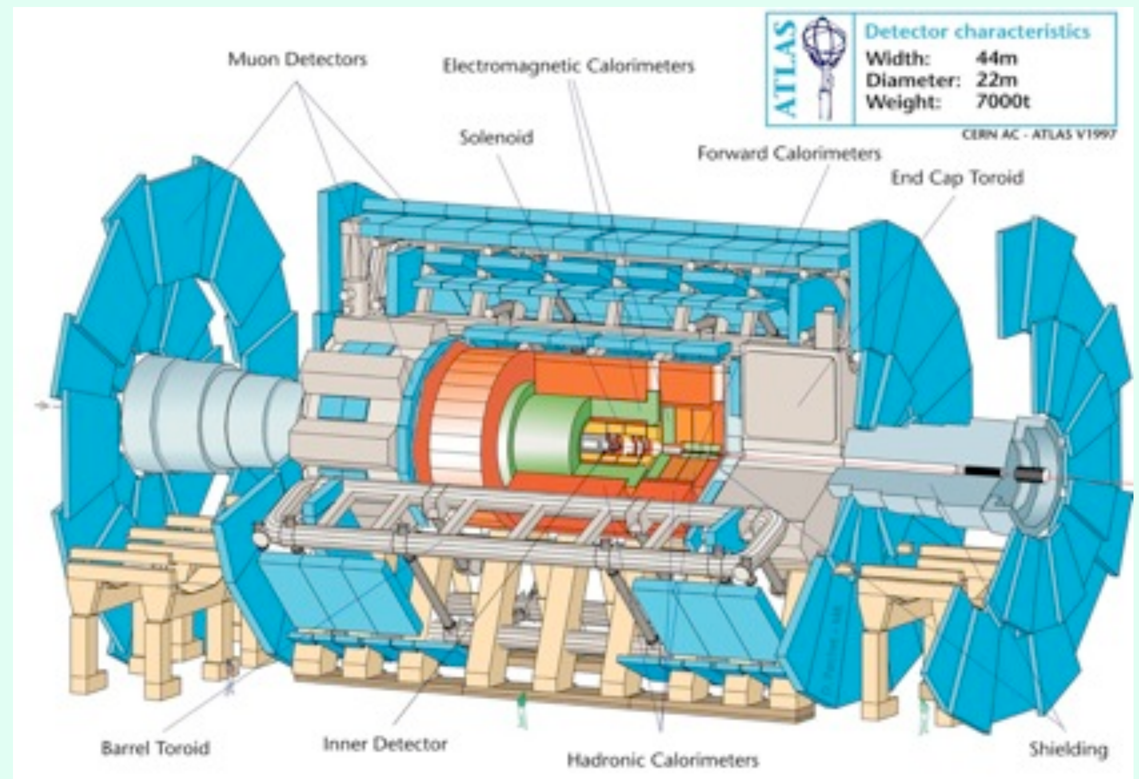


Experiments difusió
informen sobre petites distàncies

Microscopi de Heisenberg:

alta energia < > petita distància

CERN



Detector Atlas

Constituents de la matèria

electrons nuclis

↓

protons neutrons

↓

quarks

Col.lisions

Similars a electró: muó, etc.

Neutrins

Altres quarks

Partícules elementals

Forces (Interaccions)

<u>llarg abast</u>

- Gravitatòria
- Electromagnètica (em)

<u>curt abast</u>

- Feble
- Forta

Feble: responsable radioactivitat,
inici processos fusió

Forta: estabilitat nucli

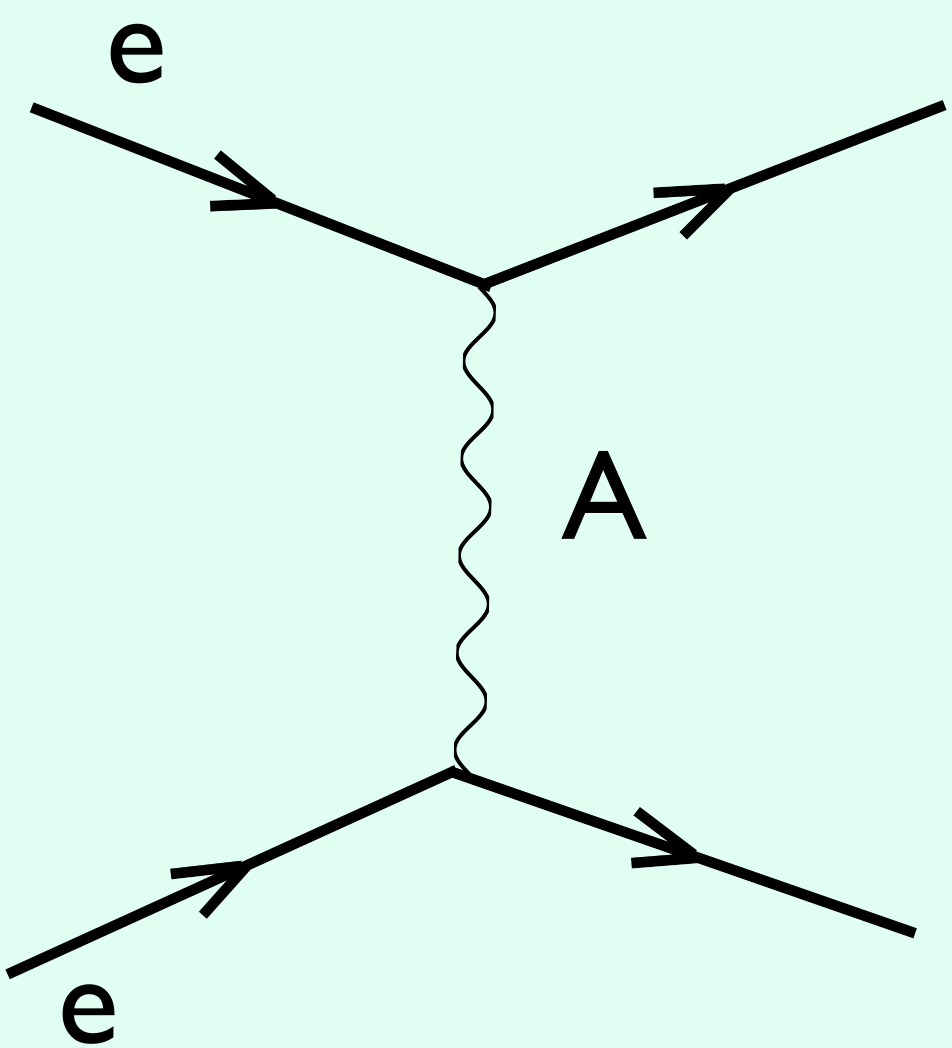
Interaccions de la matèria amb bescanvi de partícules

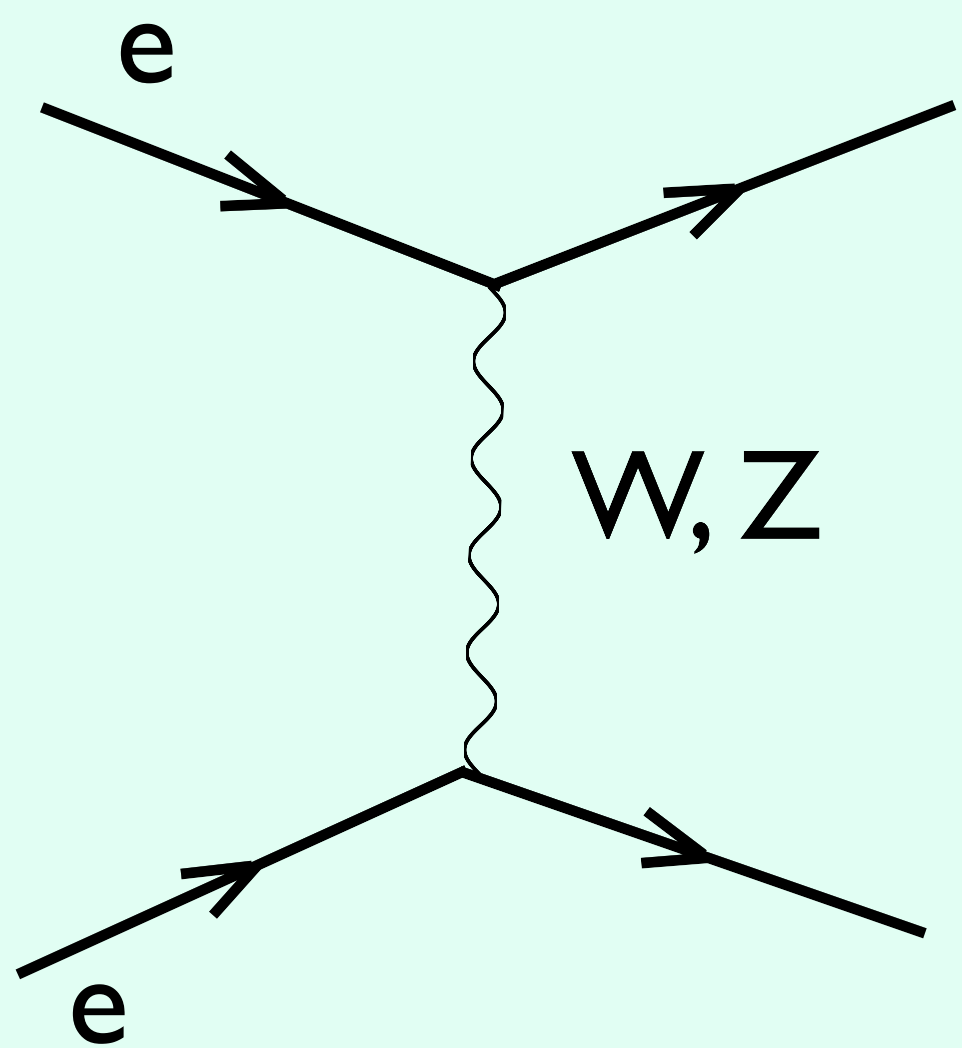
Marc teòric: Mecànica Quàntica
(Teoria Quàntica de Camps)

Interaccions electromagnètica i feble

Forta: no rellevant per Higgs
Grav.: encara no hi ha teoria completa

Fotons i Bosons Febles





A=fotó
(int. electromagnètica)

W,Z=bosons febles
(int. feble)

Principi Gauge

Simetria gauge

e

Canvi de propietats
sense efectes físics

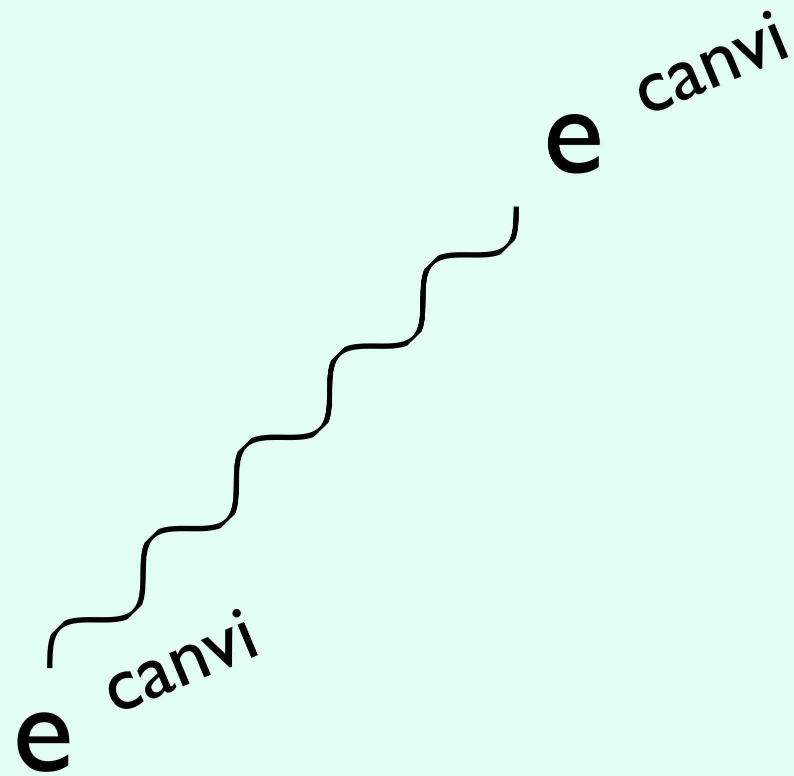
e canvi

Principi Gauge

e canvi

e canvi

Principi Gauge



Unificació electrofeble

Necessari distinció entre
- A llarg abast, partícula sense massa
- W,Z curt abast, partícula massiva

A,W,Z partícules spin =1

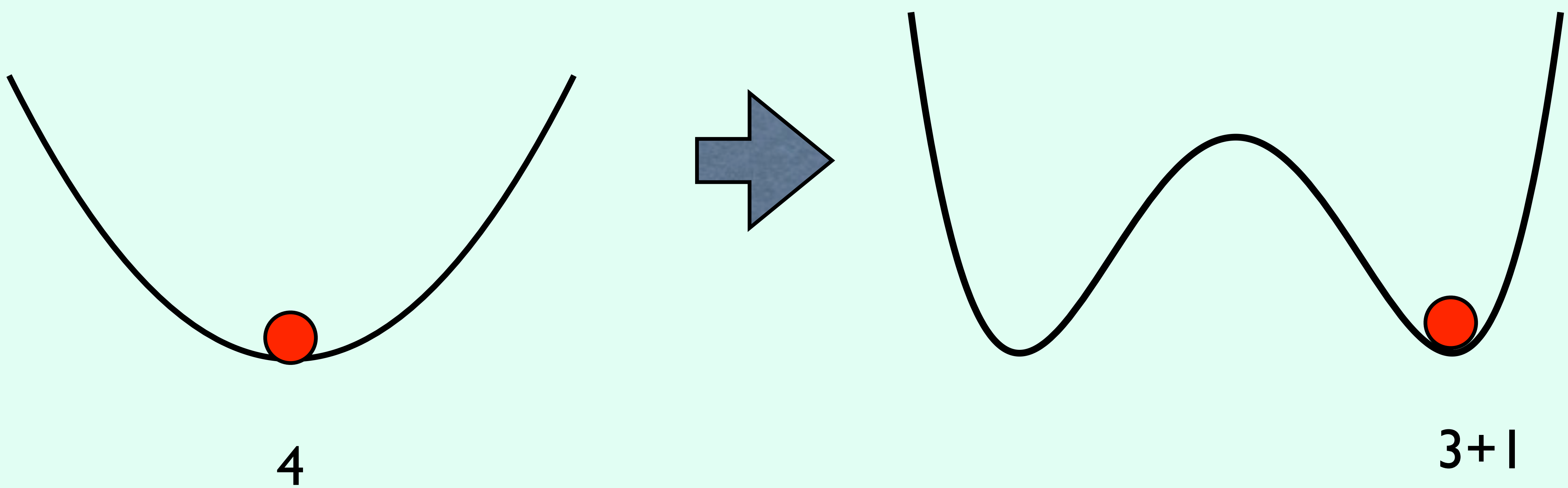
Graus de llibertat: A: 2
W,Z:3

Camp de Higgs 4 graus de llibertat

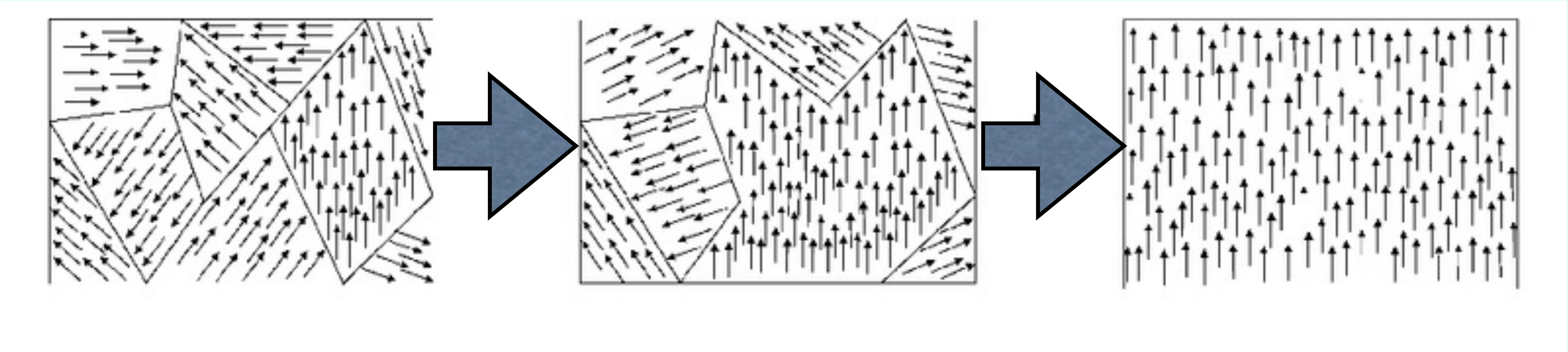
3 -> W+,W-,Z
1-> Bosó de Higgs

Trencament espontani simetria gauge

Teoria simètrica
Estats no simètrics
Simetria amagada



Ferromagnetisme



MODEL ESTANDÀRD
Teoria gauge
amb trencament espontani simetria

- Matèria

- Mediadors interaccions:
  - Fotó (sense massa)
  - W,Z (amb massa)

vàlid a nivell correcciones quàntiques

- Bosó de Higgs   Necessari per a la consistència

Bose (1894-1974)

Bosó de Higgs

Kibble, Guranik,Hagen
Englert,Brout

Publicació (1964) Peter Higgs

VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

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(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

The simplest theory which exhibits this behavior is a gauge-invariant version of a model used by Goldstone[2] himself: Two real[4] scalar fields φ_1, φ_2 and a real vector field A_μ interact through the Lagrangian density

$$L = -\tfrac{1}{2}(\nabla\varphi_1)^2 - \tfrac{1}{2}(\nabla\varphi_2)^2 - V(\varphi_1^{\,2}+\varphi_2^{\,2}) - \tfrac{1}{4}F_{\mu\nu}F^{\mu\nu}, \qquad (1)$$

where

$$\nabla_\mu\varphi_1 = \partial_\mu\varphi_1 - eA_\mu\varphi_2,$$

$$\nabla_\mu\varphi_2 = \partial_\mu\varphi_2 + eA_\mu\varphi_1,$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu,$$

e is a dimensionless coupling constant, and the metric is taken as $-+++$. L is invariant under simultaneous gauge transformations of the first kind on $\varphi_1 \pm i\varphi_2$ and of the second kind on A_μ. Let us suppose that $V'(\varphi_0^{\,2}) = 0$, $V''(\varphi_0^{\,2}) > 0$; then spontaneous breakdown of U(1) symmetry occurs. Consider the equations [derived from (1) by treating $\Delta\varphi_1$, $\Delta\varphi_2$, and A_μ as small quantities] governing the propagation of small oscillations about the "vacuum" solution $\varphi_1(x) = 0$, $\varphi_2(x) = \varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\} = 0, \qquad (2a)$$

$$\{\partial^2 - 4\varphi_0^{\,2}V''(\varphi_0^{\,2})\}(\Delta\varphi_2) = 0, \qquad (2b)$$

$$\partial_\nu F^{\mu\nu} = e\varphi_0\{\partial^\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\}. \qquad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^{\,2})\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu = A_\mu - (e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$

$$G_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu = F_{\mu\nu}, \qquad (3)$$

into the form

$$\partial_\mu B^\mu = 0, \quad \partial_\nu G^{\mu\nu} + e^2\varphi_0^{\,2}B^\mu = 0. \qquad (4)$$

Equation (4) describes vector waves whose quanta have (bare) mass $e\varphi_0$. In the absence of the gauge field coupling ($e = 0$) the situation is quite different: Equations (2a) and (2c) describe zero-mass scalar and vector bosons, respectively. In passing, we note that the right-hand side of (2c) is just the linear approximation to the conserved current: It is linear in the vector potential, gauge invariance being maintained by the presence of the gradient term.[5]

When one considers theoretical models in which spontaneous breakdown of symmetry under a semisimple group occurs, one encounters a variety of possible situations corresponding to the various distinct irreducible representations to which the scalar fields may belong; the gauge field always belongs to the adjoint representation.[6] The model of the most immediate interest is that in which the scalar fields form an octet under SU(3): Here one finds the possibility of two nonvanishing vacuum expectation values, which may be chosen to be the two $Y = 0$, $I_3 = 0$ members of the octet.[7] There are two massive scalar bosons with just these quantum numbers; the remaining six components of the scalar octet combine with the corresponding components of the gauge-field octet to describe

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massive vector bosons. There are two $I = \frac{1}{2}$ vector doublets, degenerate in mass between $Y = \pm 1$ but with an electromagnetic mass splitting between $I_3 = \pm\frac{1}{2}$, and the $I_3 = \pm 1$ components of a $Y = 0$, $I = 1$ triplet whose mass is entirely electromagnetic. The two $Y = 0$, $I = 0$ gauge fields remain massless: This is associated with the residual unbroken symmetry under the Abelian group generated by Y and I_3. It may be expected that when a further mechanism (presumably related to the weak interactions) is introduced in order to break Y conservation, one of these gauge fields will acquire mass, leaving the photon as the only massless vector particle. A detailed discussion of these questions will be presented elsewhere.

It is worth noting that an essential feature of the type of theory which has been described in this note is the prediction of incomplete multiplets of scalar and vector bosons.[8] It is to be expected that this feature will appear also in theories in which the symmetry-breaking scalar fields are not elementary dynamic variables but bilinear combinations of Fermi fields.[9]

---

[1]P. W. Higgs, to be published.

[2]J. Goldstone, Nuovo Cimento 19, 154 (1961); J. Goldstone, A. Salam, and S. Weinberg, Phys. Rev. 127, 965 (1962).

[3]P. W. Anderson, Phys. Rev. 130, 439 (1963).

[4]In the present note the model is discussed mainly in classical terms; nothing is proved about the quantized theory. It should be understood, therefore, that the conclusions which are presented concerning the masses of particles are conjectures based on the quantization of linearized classical field equations. However, essentially the same conclusions have been reached independently by F. Englert and R. Brout, Phys. Rev. Letters 13, 321 (1964): These authors discuss the same model quantum mechanically in lowest order perturbation theory about the self-consistent vacuum.

[5]In the theory of superconductivity such a term arises from collective excitations of the Fermi gas.

[6]See, for example, S. L. Glashow and M. Gell-Mann, Ann. Phys. (N.Y.) 15, 437 (1961).

[7]These are just the parameters which, if the scalar octet interacts with baryons and mesons, lead to the Gell-Mann–Okubo and electromagnetic mass splittings: See S. Coleman and S. L. Glashow, Phys. Rev. 134, B671 (1964).

[8]Tentative proposals that incomplete SU(3) octets of scalar particles exist have been made by a number of people. Such a rôle, as an isolated $Y = \pm 1$, $I = \frac{1}{2}$ state, was proposed for the κ meson (725 MeV) by Y. Nambu and J. J. Sakurai, Phys. Rev. Letters 11, 42 (1963). More recently the possibility that the σ meson (385 MeV) may be the $Y = I = 0$ member of an incomplete octet has been considered by L. M. Brown, Phys. Rev. Letters 13, 42 (1964).

[9]In the theory of superconductivity the scalar fields are associated with fermion pairs; the doubly charged excitation responsible for the quantization of magnetic flux is then the surviving member of a U(1) doublet.

SPLITTING OF THE 70-PLET OF SU(6)

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(Received 18 September 1964)

1. In a previous note,[1] hereafter called I, we proposed an expression for the mass operator responsible for lifting the degeneracies of spin-unitary spin supermultiplets [Eq. (31)-I]. The purpose of the present note is to apply this expression to the 70-dimensional representation of SU(6).

The importance of the 70-dimensional representation has already been underlined by Pais.[2] Since

$$\underline{35}\otimes\underline{56} = \underline{56}\oplus\underline{70}\oplus\underline{700}\oplus\underline{1134}, \qquad (1)$$

it follows that $\underline{70}$ is the natural candidate for accommodating the higher meson-baryon resonances. Furthermore, since the SU(3)⊗SU(2) content is

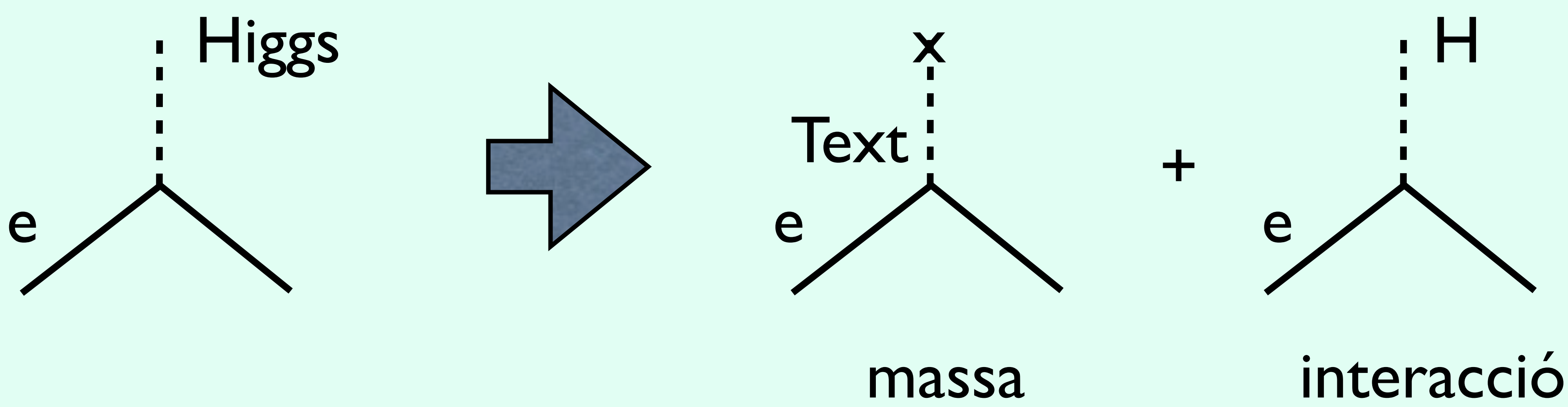
$$\underline{70} = (\underline{1},\underline{2}) + (\underline{8},\underline{2}) + (\underline{10},\underline{2}) + (\underline{8},\underline{4}), \qquad (2)$$

we may assume that partial occupancy of the $\underline{70}$ representation has already been established through the so-called γ octet[2] $(\frac{3}{2})^-$. Recent experiments appear to indicate that some $(\frac{1}{2})^-$ states may also be at hand.[3] With six masses at one's disposal, our formulas can predict the masses of all the other occupants of $\underline{70}$ and also provide a consistency check on the input. Our discussion of the $\underline{70}$ representation thus appears to be of immediate physical interest.

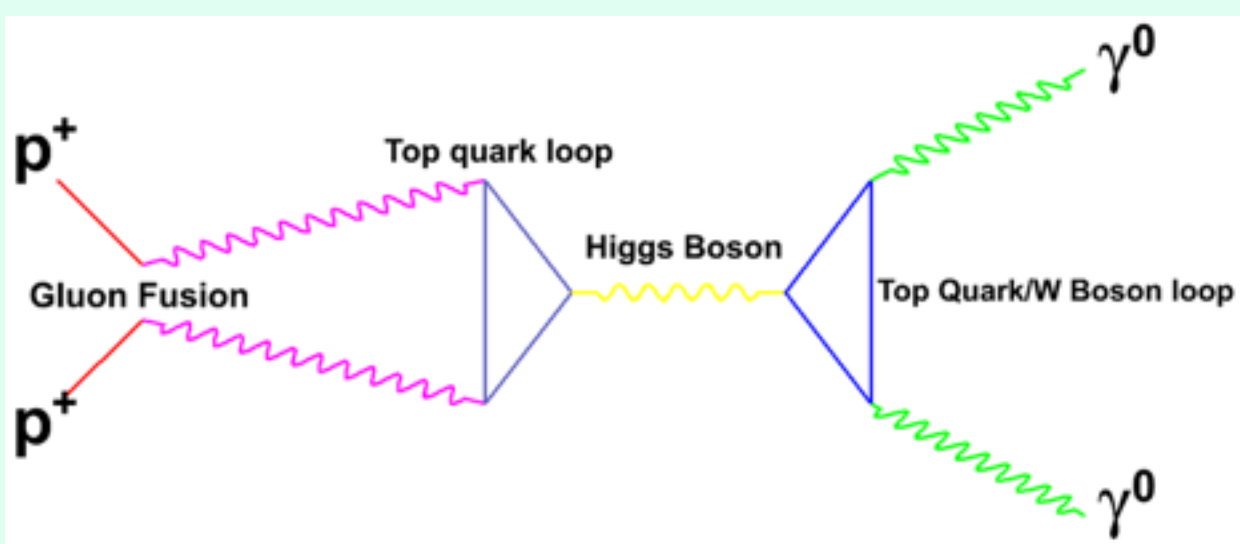
Similarment altres 3+2 autors

Generació massa

Higgs al cor de la generació massa W,Z
i també de les altres partícules elementals



Interaccions Higgs predites però massa Higgs no



La paciència com a mare de la ciència

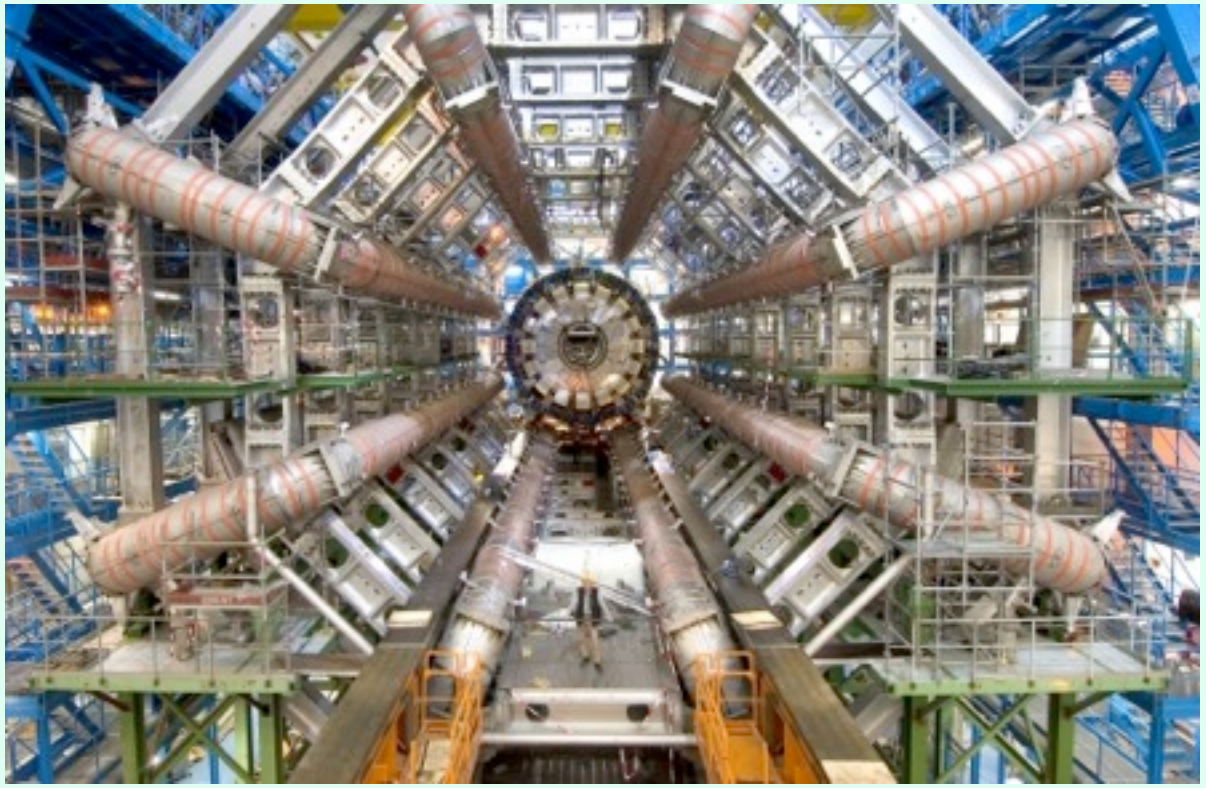
1960’s → 2010’s

La paciència com a mare de la ciència

1960's

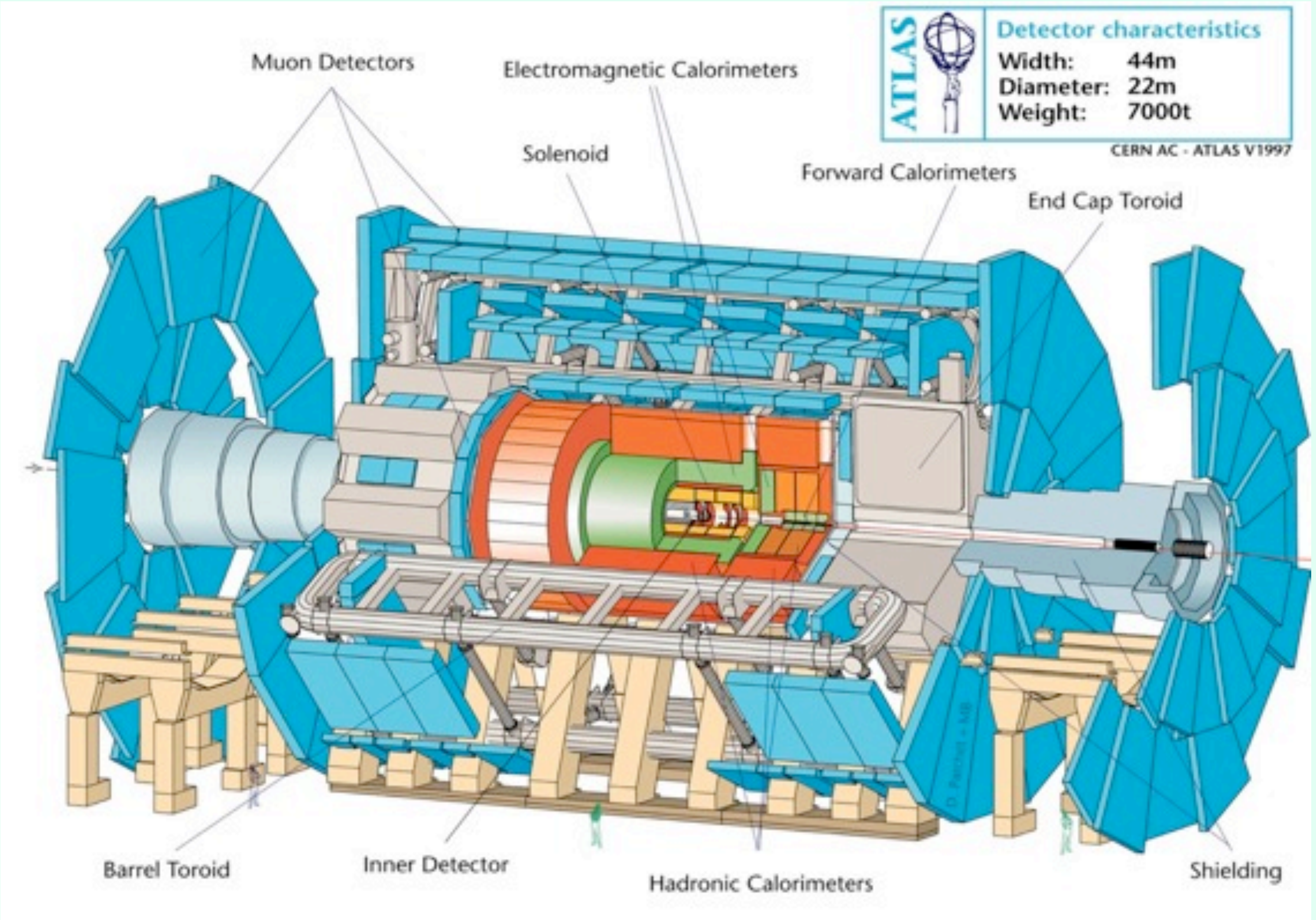
2010's

LHC @ CERN



Atlas

ATLAS @ CERN & CMS



Descoberta Higgs

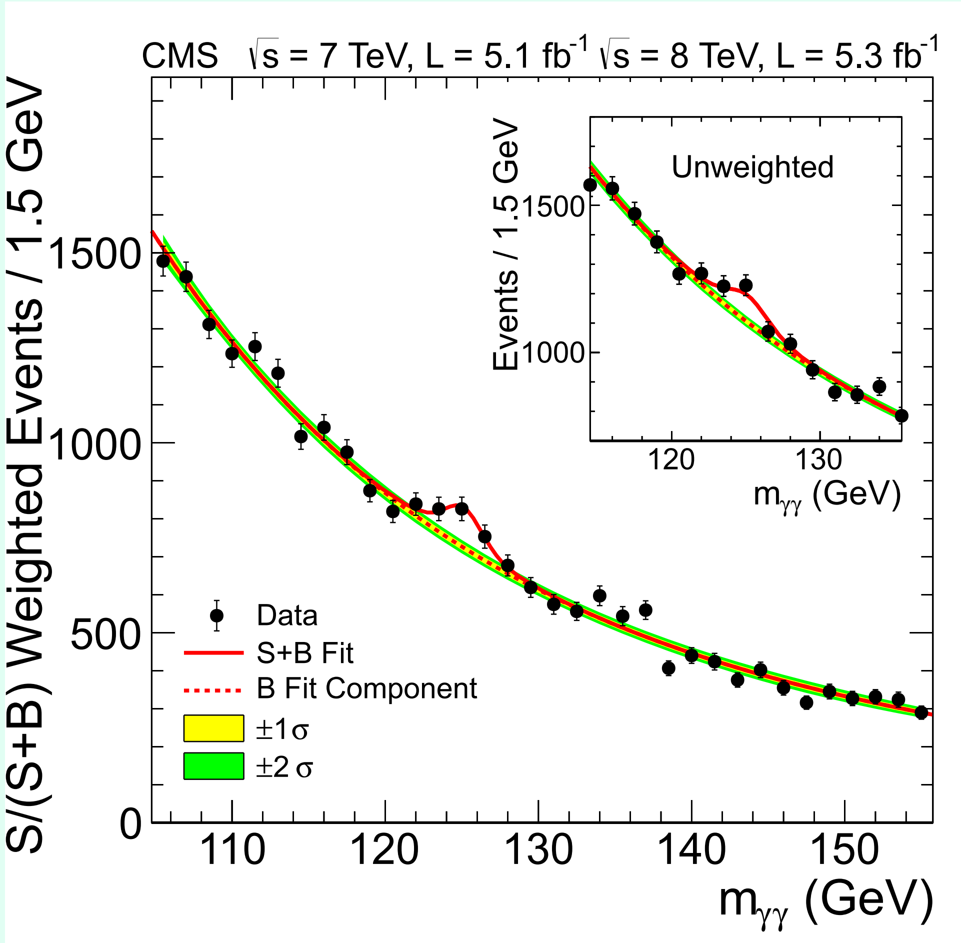


Figure 3: The diphoton invariant mass distribution with each event weighted by the $S/(S+B)$ value of its category. The lines represent the fitted background and signal, and the coloured bands represent the ± 1 and ± 2 standard deviation uncertainties on the background estimate. The inset shows the central part of the unweighted invariant mass distribution.

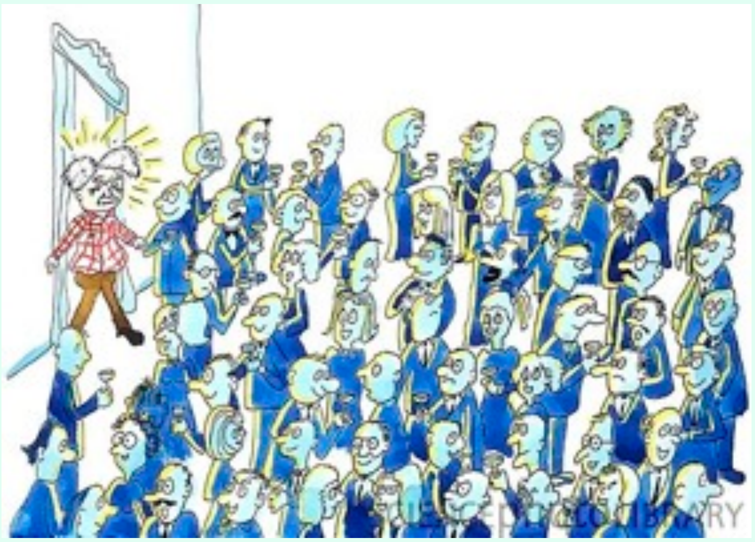
Massa m=125 GeV

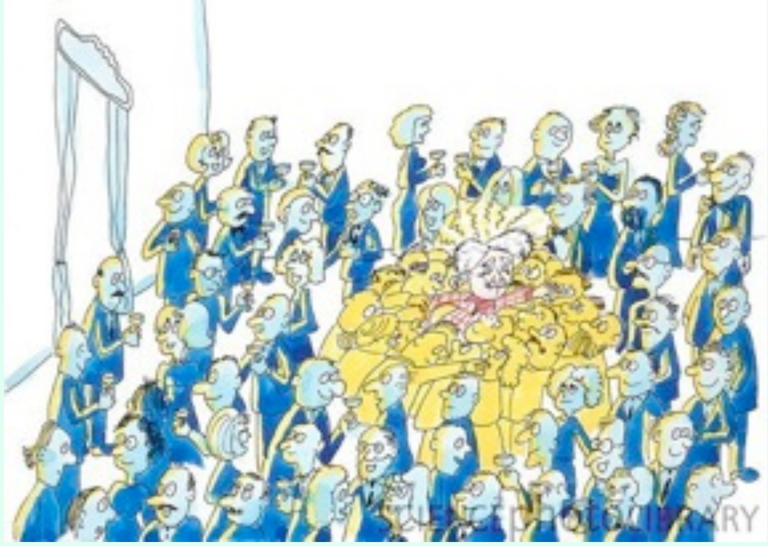
Propietats consistents amb Higgs estàndard

Probabilitat fluctuació: 1 entre 3.500.000

Imatges artístiques

Jordi (Georges) Boixader, (80's)





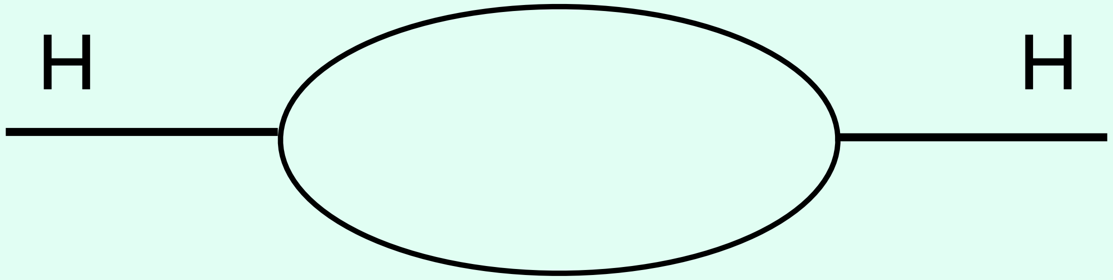
Alternatives ?

Models més complexos que el model estàndard
que donen també massa a W,Z

Restringits per dades experimentals,
especialment per les dades que s'obtindran
els proper any al CERN

Perquè alternatives ?

Control
correccions
quàntiques



cf. supersimetria

Esforç col.lectiu: CERN

Atlas ~ 4000 persones

CMS ~ 4000 persones

Prada ~ 7000 persones

Autors article descoberta (ATLAS)

Autors article descoberta (CMS)

CONCLUSIONS

- CERN estiu 2012
  Descoberta partícula consistent amb propietats del Higgs

- Treball a fer és confirmar (o no) la seva naturalesa

- Comprendre
  mecanisme trencament de la simetria feble
  control correccions radiatives