BANCO ESPAÑOL DE IDEAS

Manuel Aguilar Benítez de Lugo

Higgs o no Higgs; esta es la cuestión

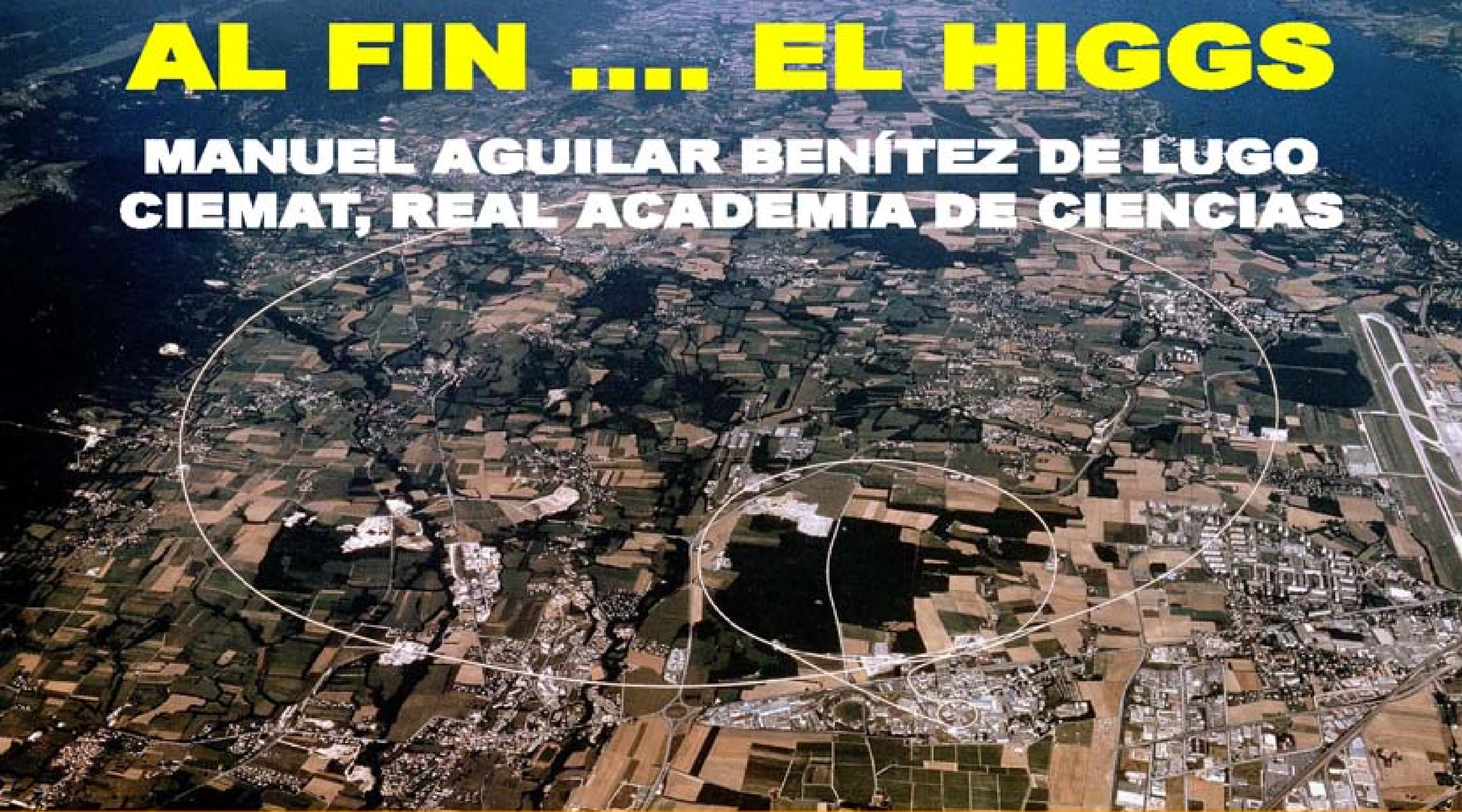
Manuel Aguilar Benítez de Lugo
Director del Departamento de
Investigación Básica del CIEMAT.

FUNDACIÓN
RAMÓN ARECES

BEI

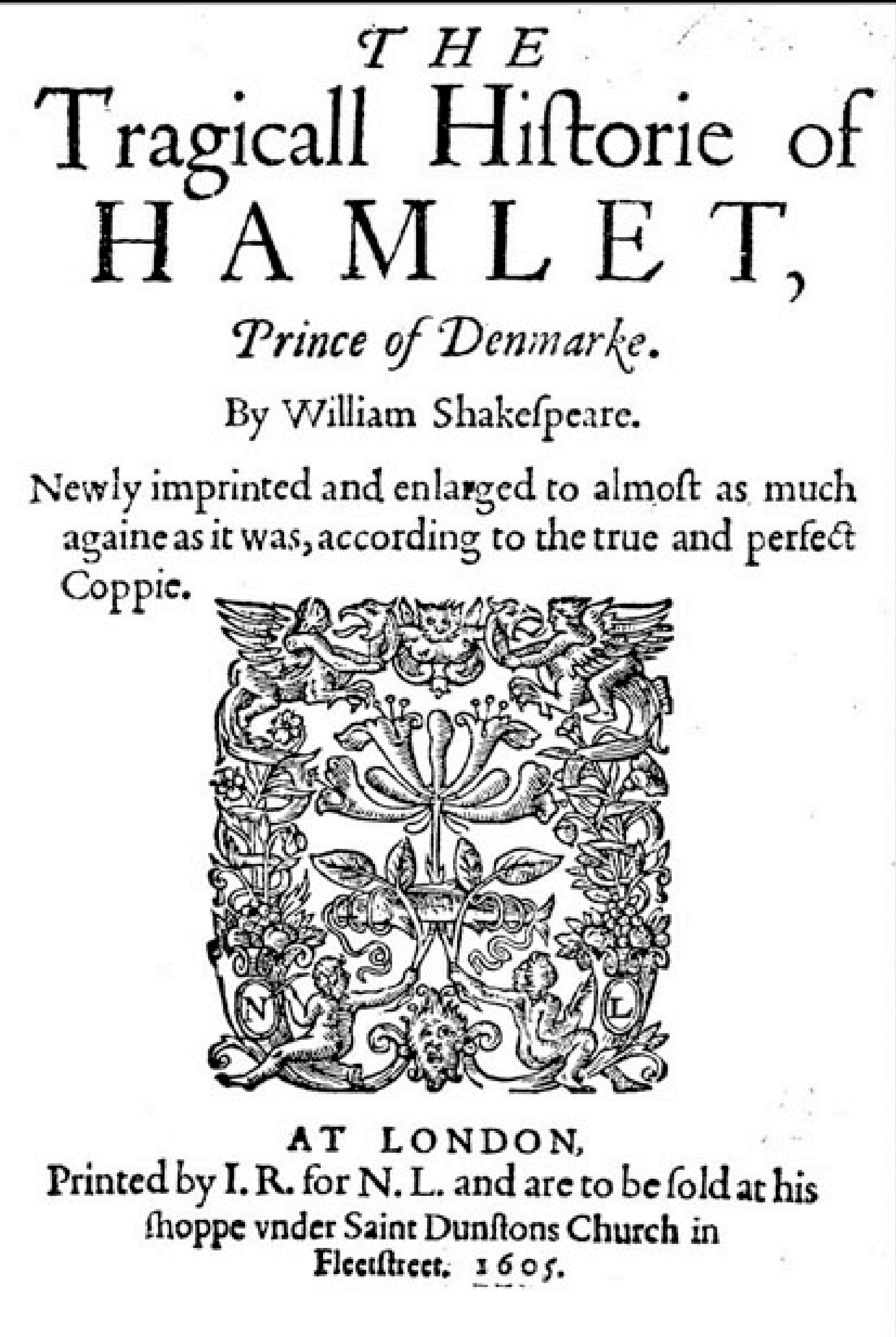
AL FIN .... EL HIGGS

MANUEL AGUILAR BENÍTEZ DE LUGO
CIEMAT, REAL ACADEMIA DE CIENCIAS



FUNDACIÓN RAMÓN ARECES, 16 JULIO 2012

HIGGS O NO HIGGS, ESTA ES LA CUESTIÓN



THE

Tragicall Hiſtorie of

HAMLET,

Prince of Denmarke.

By William Shakeſpeare.

Newly imprinted and enlarged to almoſt as much againe as it was, according to the true and perfect Coppie.

AT LONDON,

Printed by I. R. for N. L. and are to be ſold at his ſhoppe vnder Saint Dunſtons Church in Fleetſtreet. 1605.

BÚSQUEDA DE LA PARTÍCULA DIVINA EN EL CERN: OBRA EN CURSO

MANUEL AGUILAR BENÍTEZ DE LUGO
CIEMAT, REAL ACADEMIA DE CIENCIAS

FUNDACIÓN ARECES, 24 OCTUBRE 2011

EXPECTATIVAS

PREDECIR ES ALGO MUY DIFÍCIL, ESPECIALMENTE ACERCA DEL FUTURO, *Niels Bohr*

ES YA MUY DURO CONOCER EL PASADO; SERÍA INTOLERABLE CONOCER EL FUTURO, *William Somerset Maughan*

- Esperar hasta finales de 2012 para descubrir (excluir) el bosón de Higgs del Modelo Estándar
- Difícil predecir cuando aparecerán señales de física más allá del Modelo Estándar

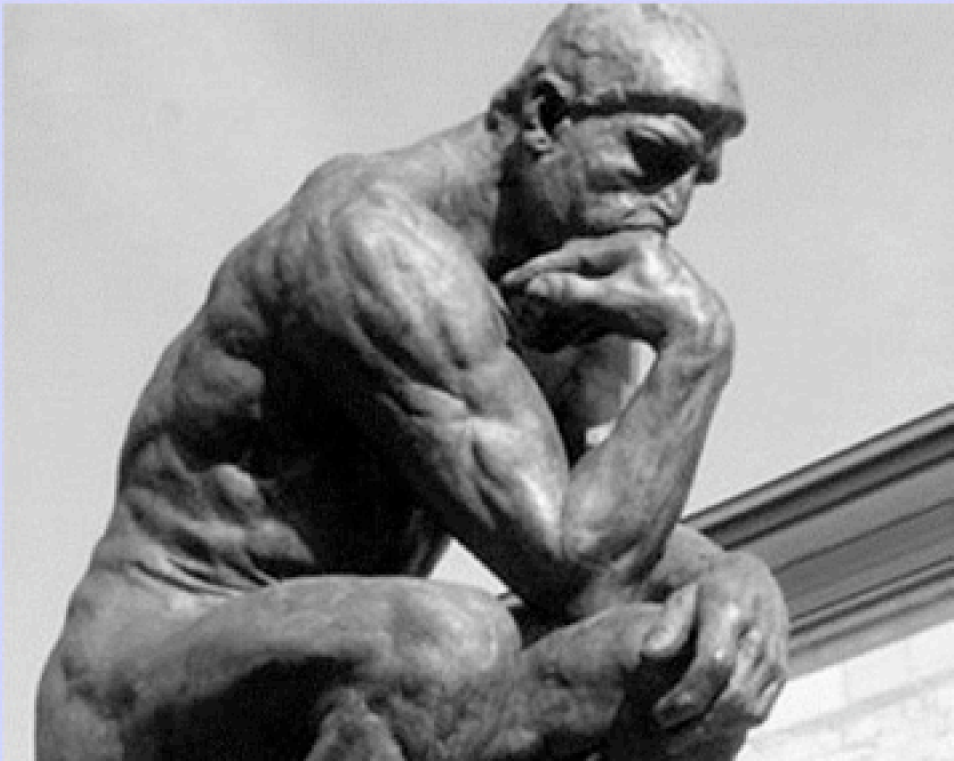
CERN-4 JULIO 2012

M. Aguilar-Benítez, J. Alcaraz, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo, N. Colino, B. de la Cruz, A. Delgado, D. Domínguez, C. Fernández-Bedoya, J.P. Fernández, A. Ferrando, J. Flix, M.C. Fouz, P.García-Abia, O. González, S. Goy, J.M. Hernández, M.I. Josa, G. Merino, E. Navarro, J. Puerta, A. Quintairo, I. Redondo, L. Romero, J. Santaolalla, M. Soares, C. Willmott

¿ ORIGEN, EVOLUCIÓN, COMPOSICIÓN DEL UNIVERSO ?

¿ ORIGEN, EVOLUCIÓN DE LA VIDA ?

¿ ORIGEN DE LA CONSCIENCIA ?



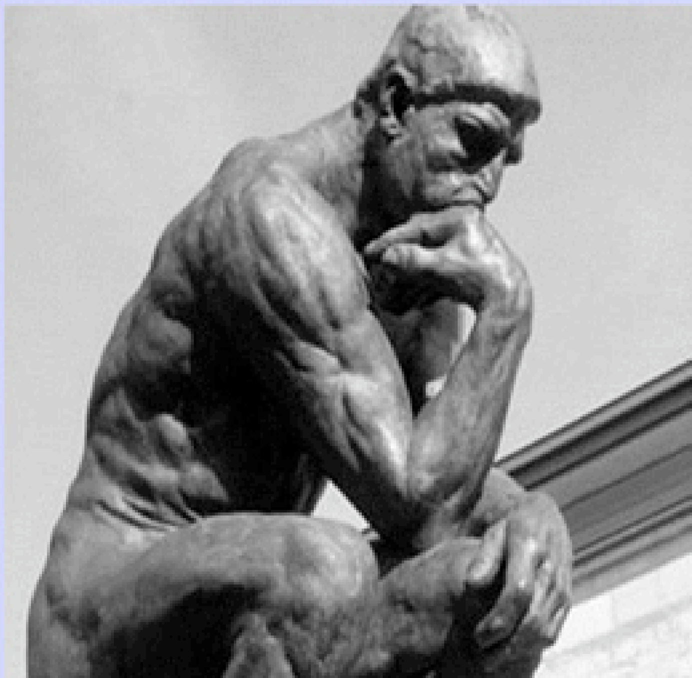
ACERCA DEL UNIVERSO

¿ DE QUÉ ESTÁ HECHO ?

¿ CÓMO ESTÁ HECHO ?

¿ CÓMO SE HA CREADO Y CÓMO HA EVOLUCIONADO ?

DISCIPLINA CIENTÍFICA QUE TRATA ESTAS CUESTIONES
FÍSICA DE PARTÍCULAS ELEMENTALES

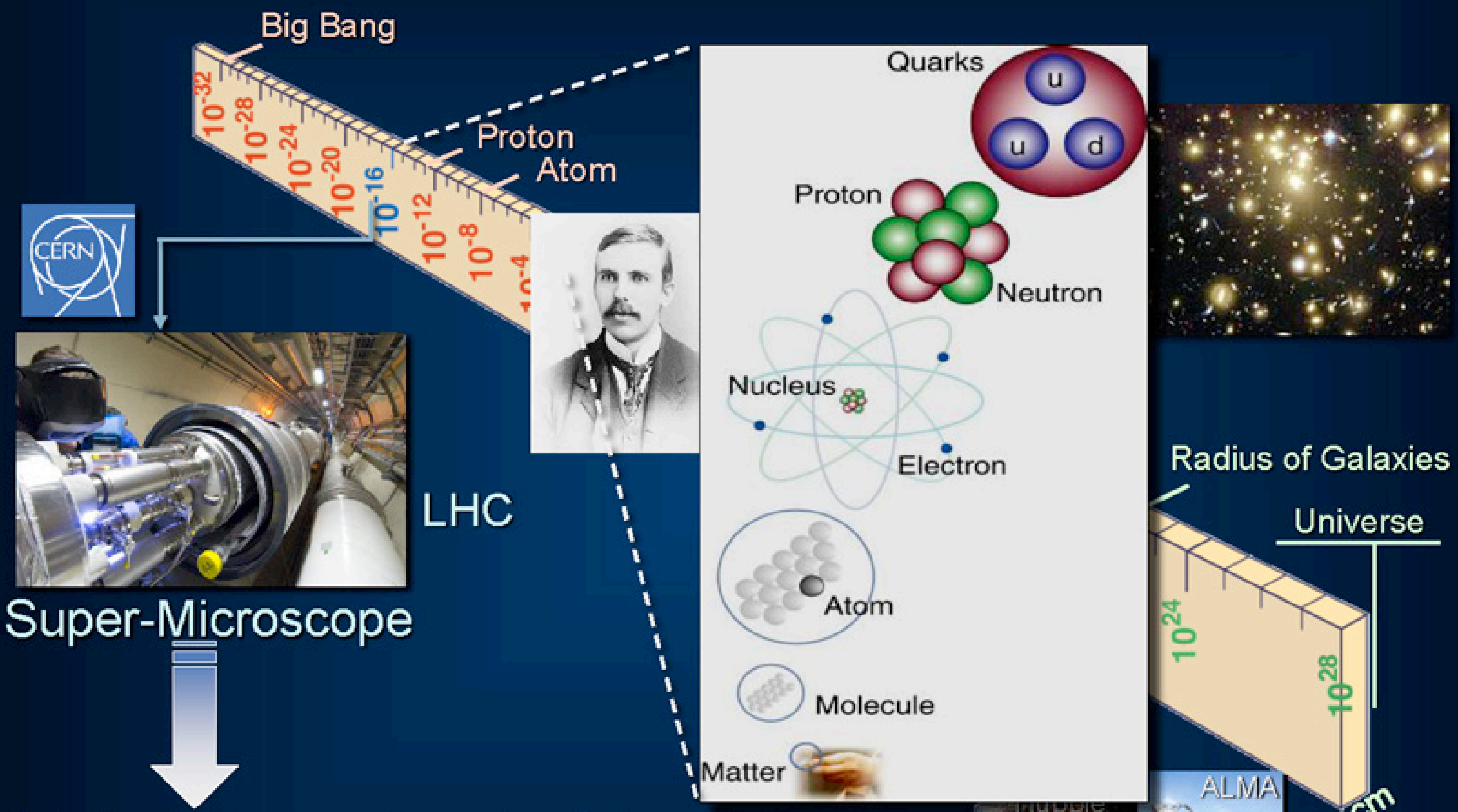


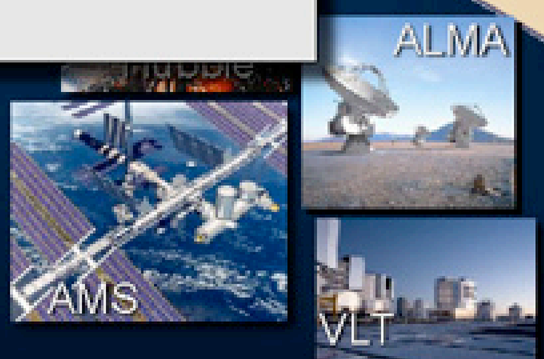
En los últimos 100 años hemos avanzado mucho en la comprensión de estas cuestiones, de lo infinitamente grande y de lo infinitamente pequeño, pero todavía queda mucho por conocer

...

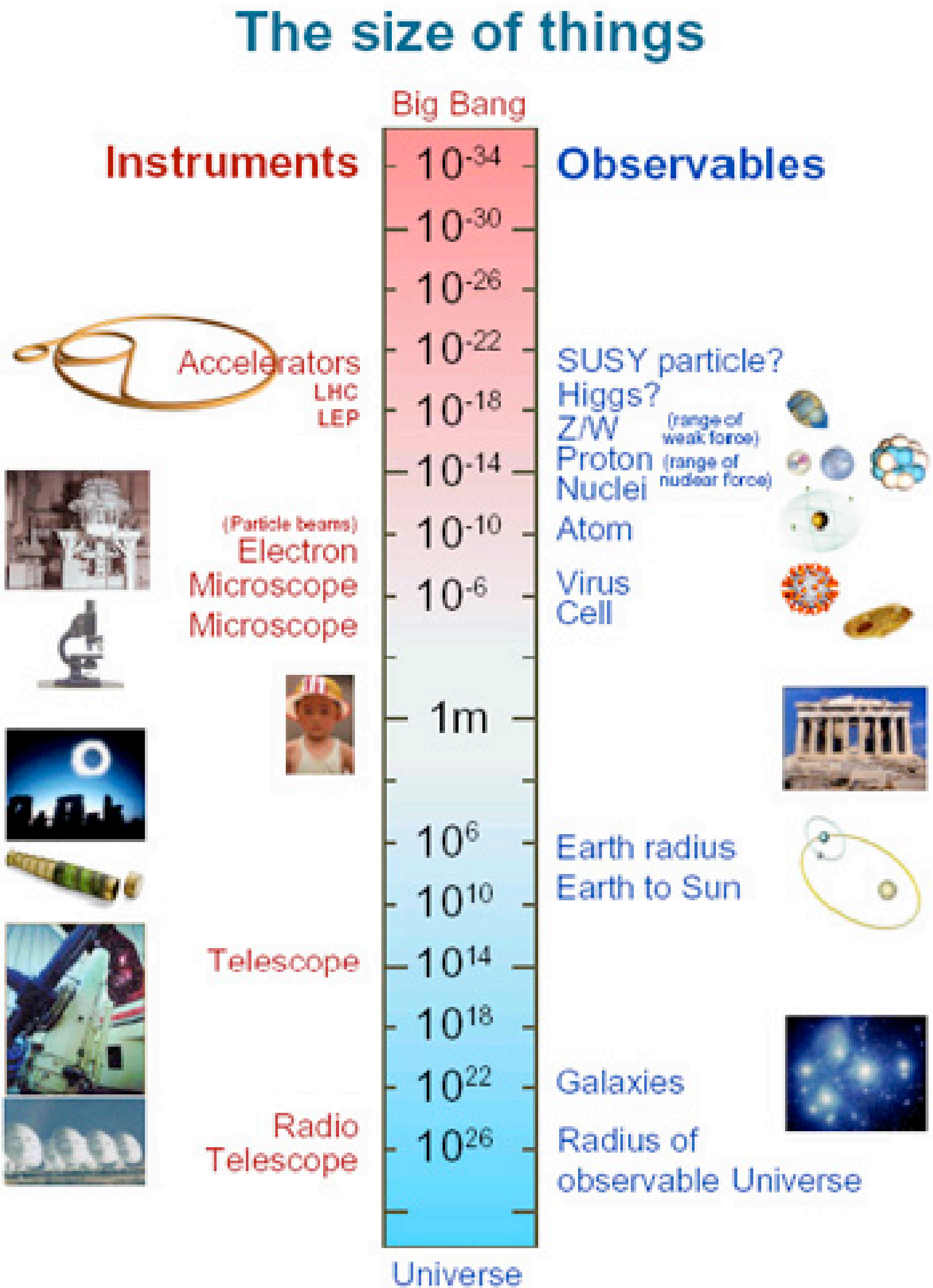
... para rellenar los huecos en el conocimiento de lo

ORDINARIO y de lo EXTRAORDINARIO





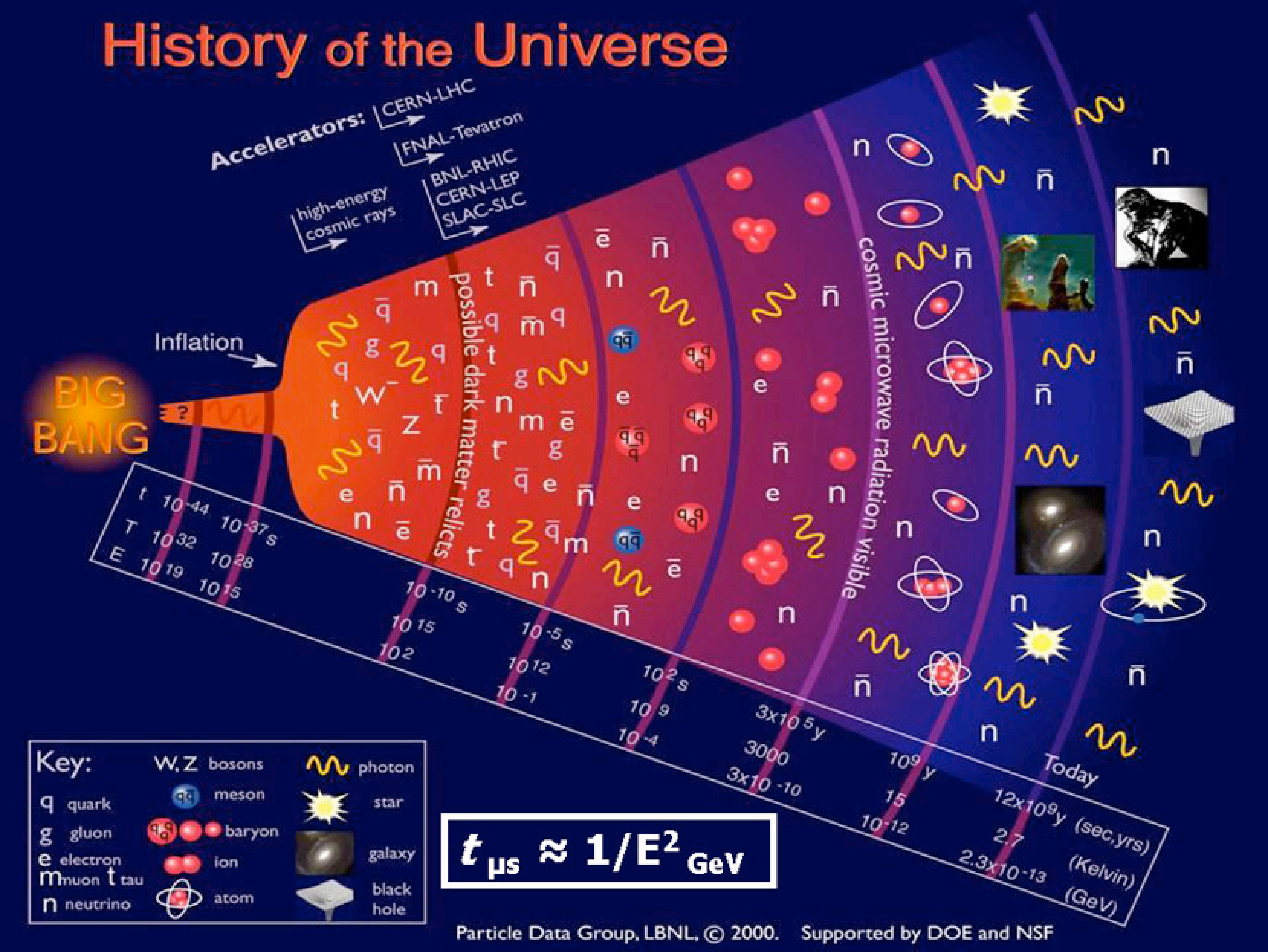
Estudio de los constituyentes últimos de la materia, de las fuerzas fundamentales a través de las cuales interaccionan y de las leyes de la Física que gobiernan la evolución del Universo.



$$\lambda = h / 2\pi p$$

- **p = 1 MeV (10^6 eV);**
  $\lambda \approx 10^{-13}$ m
- **p = 1 GeV (10^9 eV);**
  $\lambda \approx 10^{-16}$ m
- **p = 1 TeV (10^{12} eV);**
  $\lambda \approx 10^{-19}$ m
- **p = 10^5 TeV (10^{17} eV);**
  $\lambda \approx 10^{-24}$ m

Zeptometro = 10^{-21} m


History of the Universe
Acceleratores:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Today
t
T
E
10^{-44}
10^{-37} s
10^{32}
10^{28}
10^{19}
10^{15}
10^{-10} s
10^{15}
10^{2}
10^{-5} s
10^{12}
10^{-1}
10^{2} s
10^{9}
10^{-4}
$3x10^{5}$ y
3000
$3x10^{-10}$
10^{9} y
15
10^{-12}
$12x10^{9}$ y (sec,yrs)
2.7 (Kelvin)
$2.3x10^{-13}$ (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
$t_{\mu s} \approx 1/E^2_{GeV}$
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

TEORÍA CUÁNTICA DE CAMPOS RELATIVISTA BASADA EN EL GRUPO DE SIMETRÍA GAUGE :

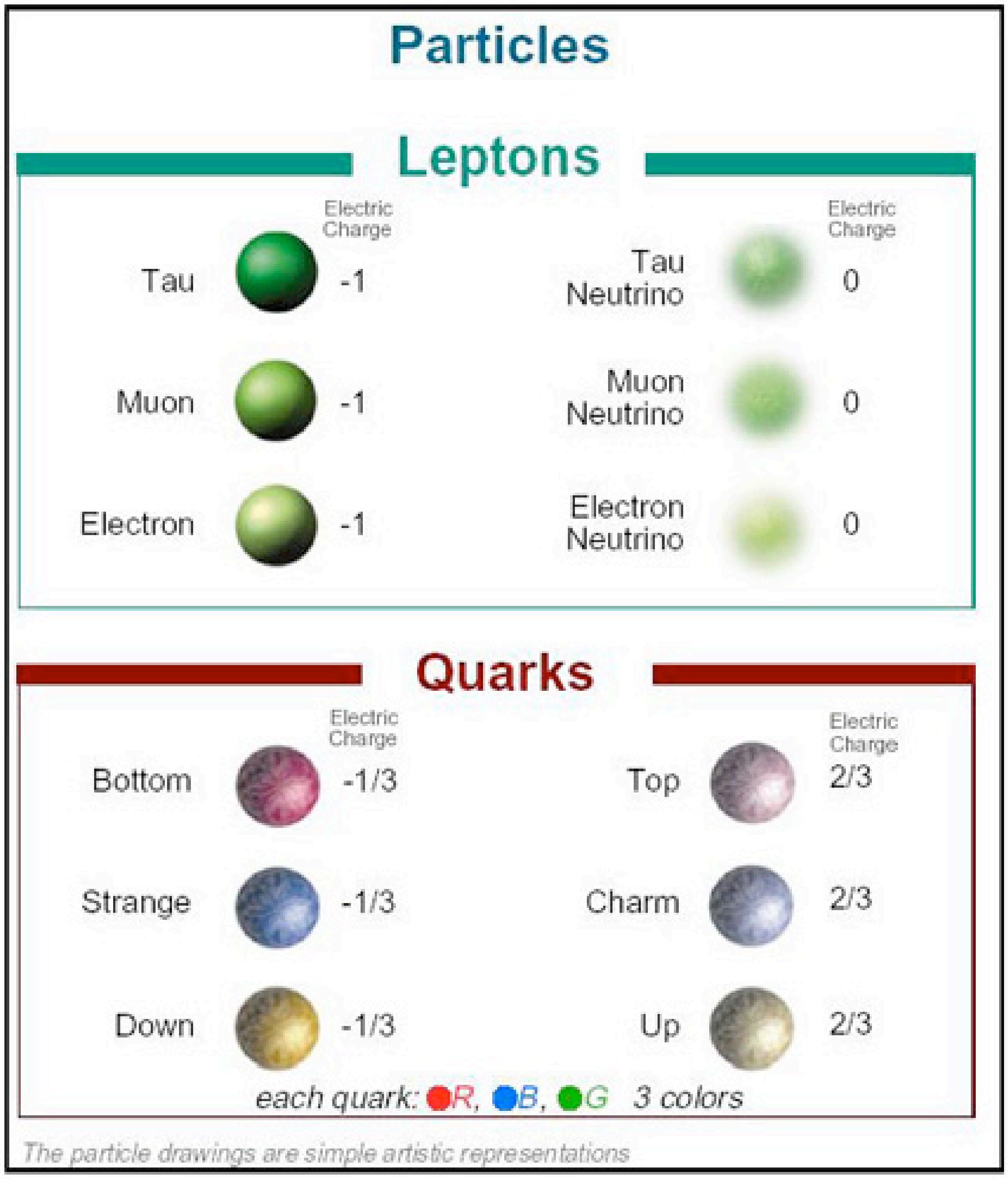
SU(3) X SU(2) X U(1)

SU(2) X U(1): MODELO ELECTRODÉBIL

SU(3): CROMODINÁMICA CUÁNTICA

MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

PARTÍCULAS DE MATERIA



LOS QUARKS Y LEPTONES TIENEN:

- **ESPÍN = ½ (FERMIONES)**
- **MASA ≠ 0**

FINNEGANS WAKE (*WORK IN PROGRESS*)

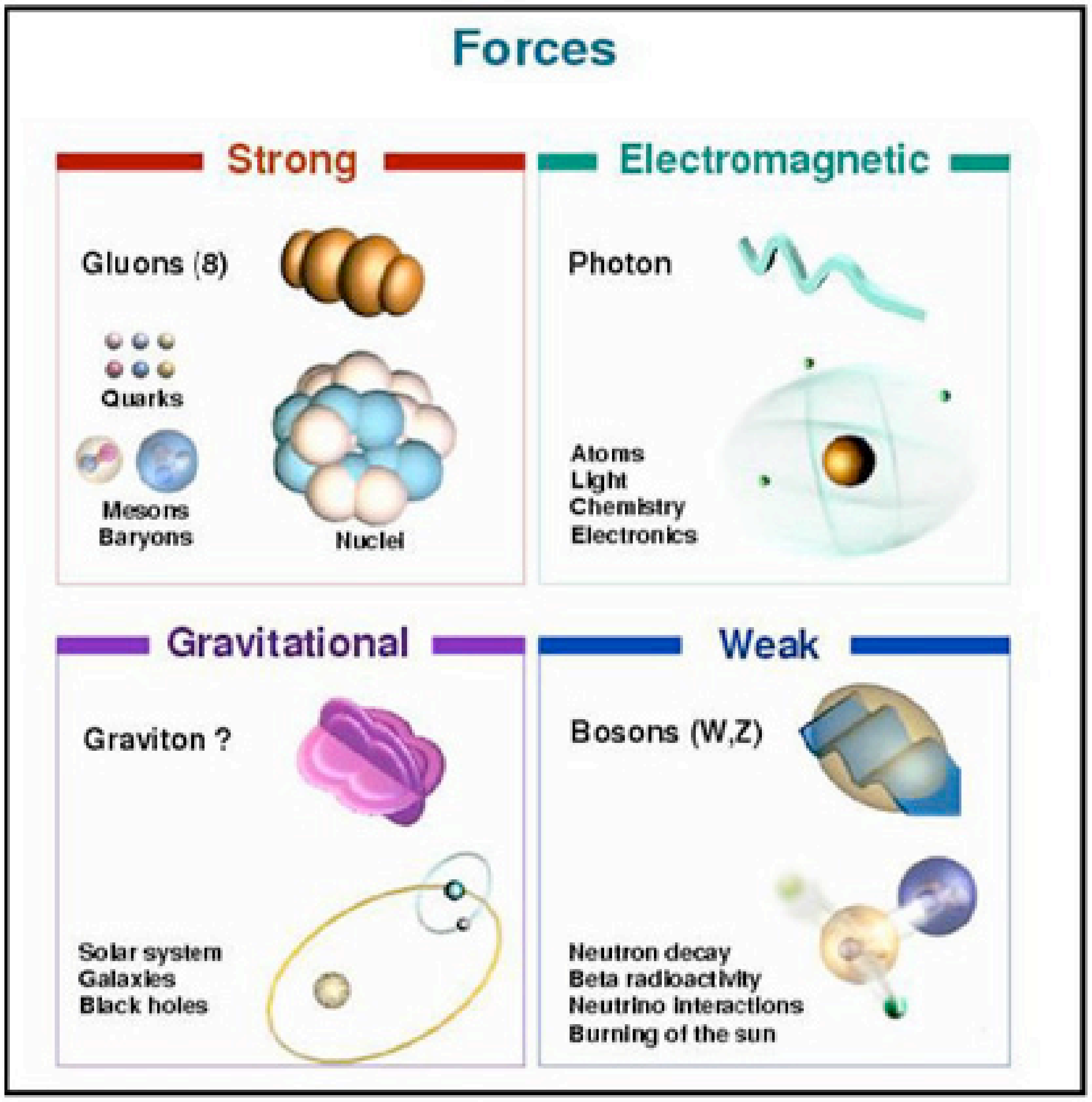
"Three Quarks for Muster Mark"

JAMES JOYCE
(1882–1941)

MURRAY GELL-MANN,
Premio Nobel Física 1969

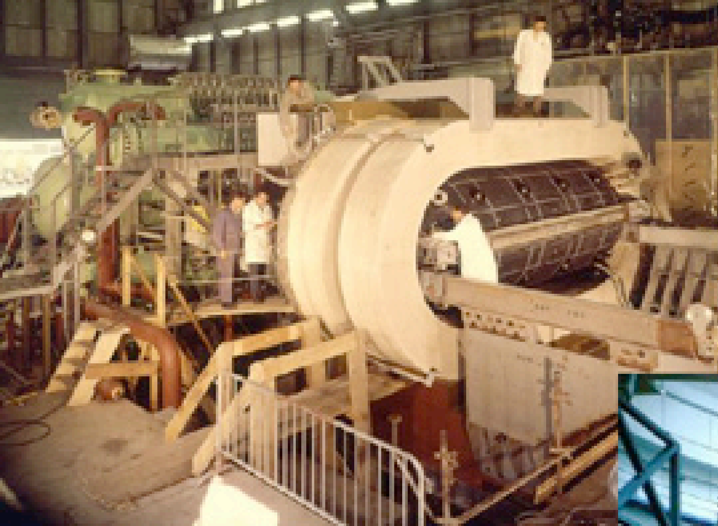
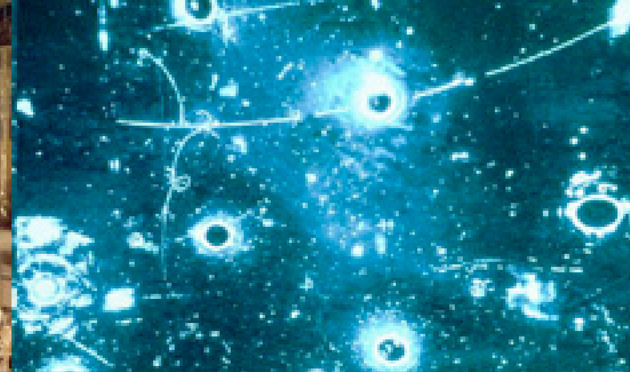
MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

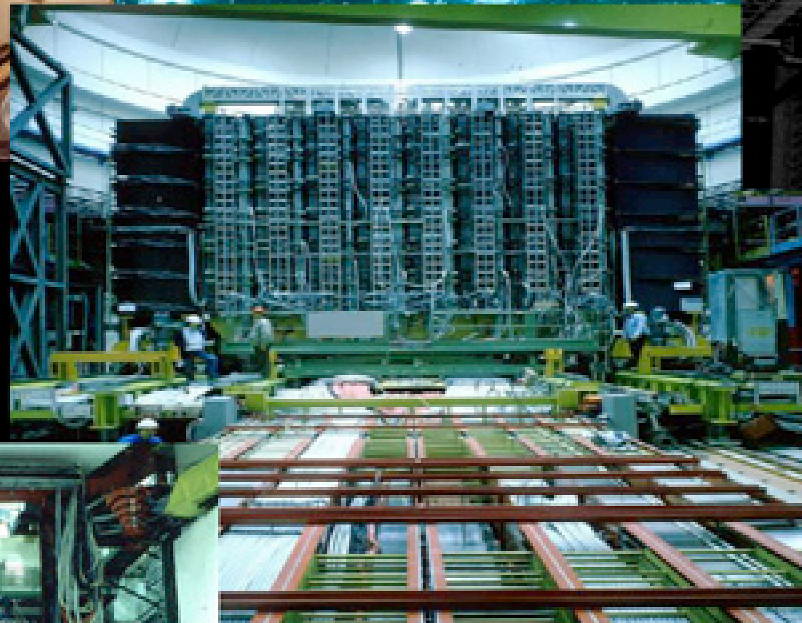
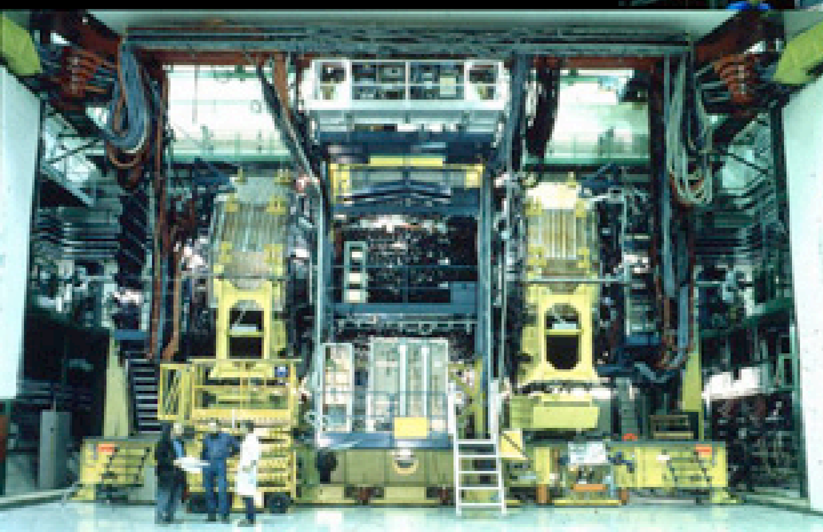
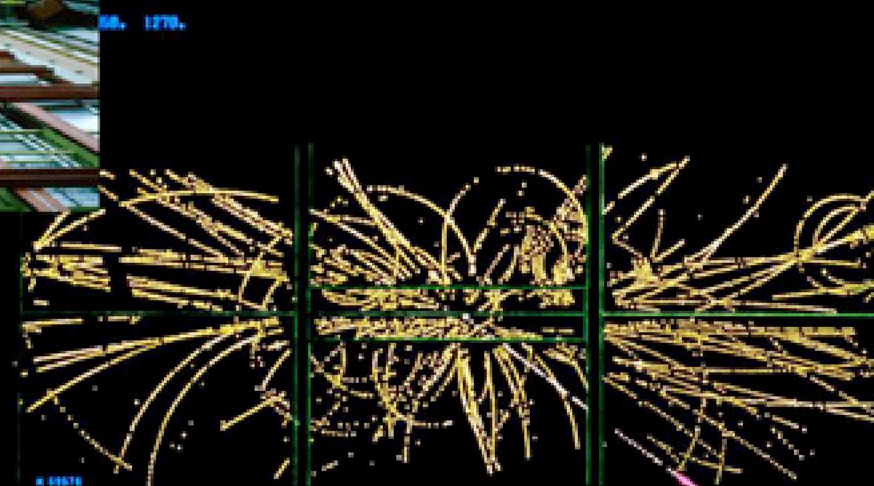
PARTÍCULAS DE FUERZA



LOS AGENTES PROPAGADORES DE LAS FUERZAS TIENEN:

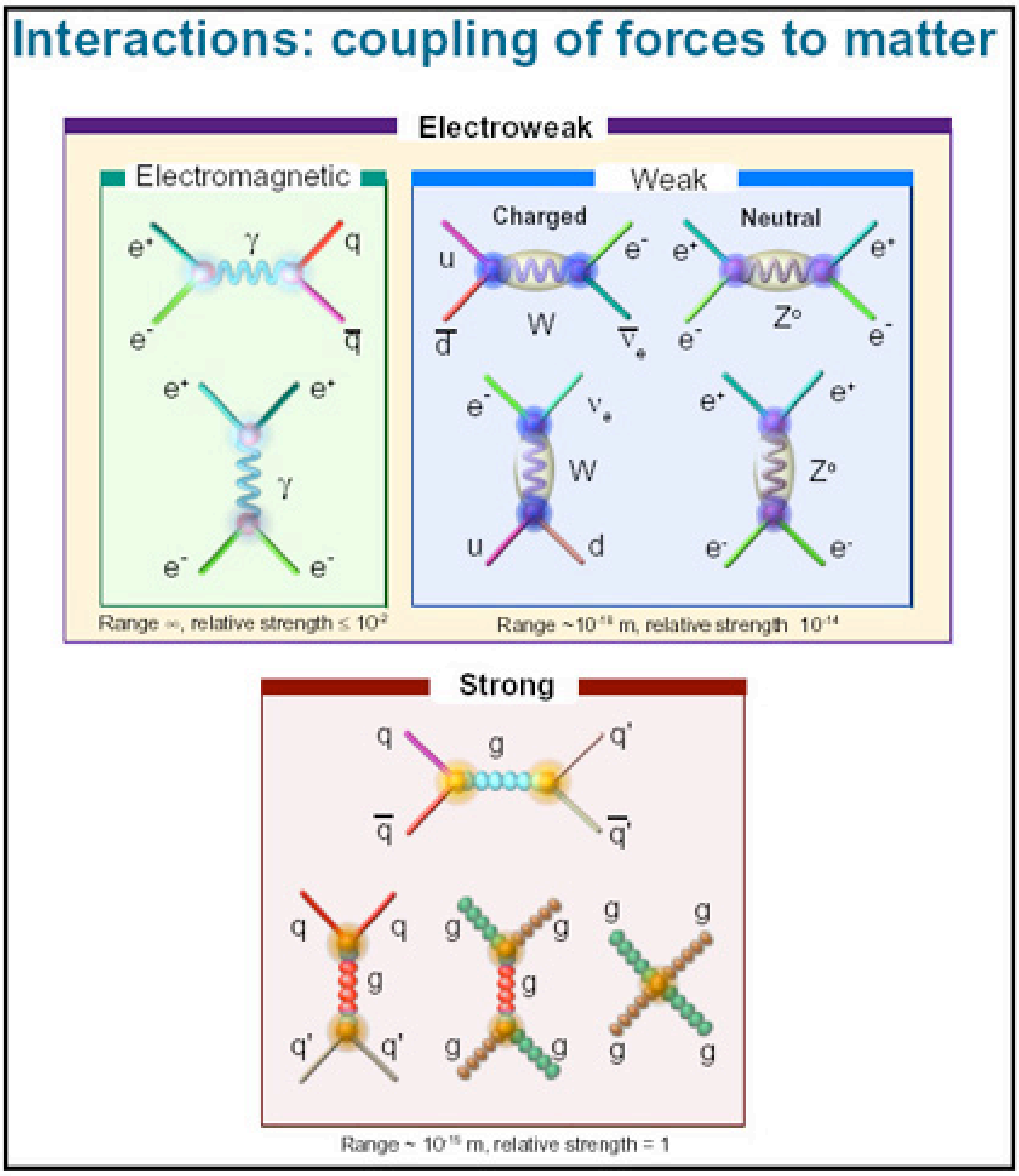
- **ESPÍN = 1-2 (BOSONES)**
- **MASA = 0 (γ), $\neq$0 ($W^{\pm}$, Z)**

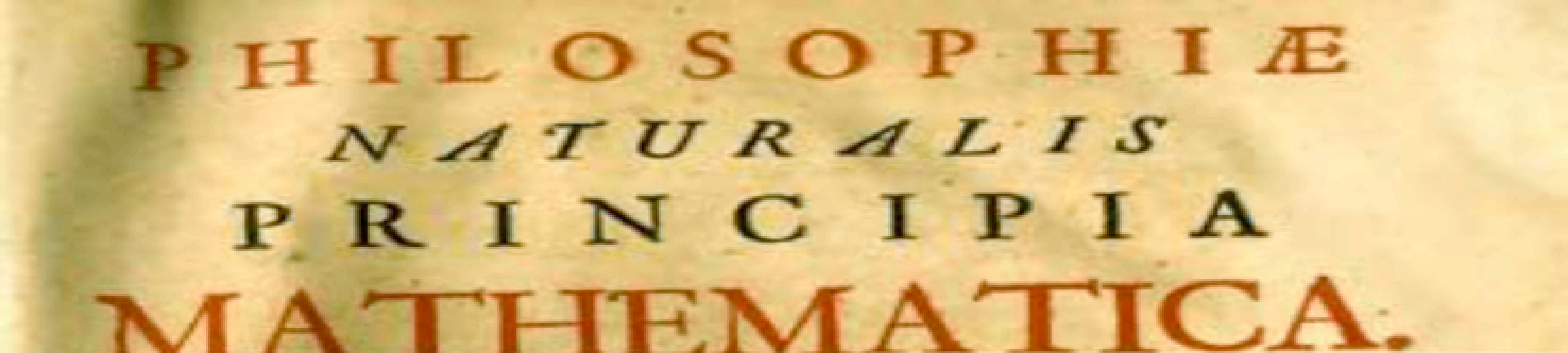



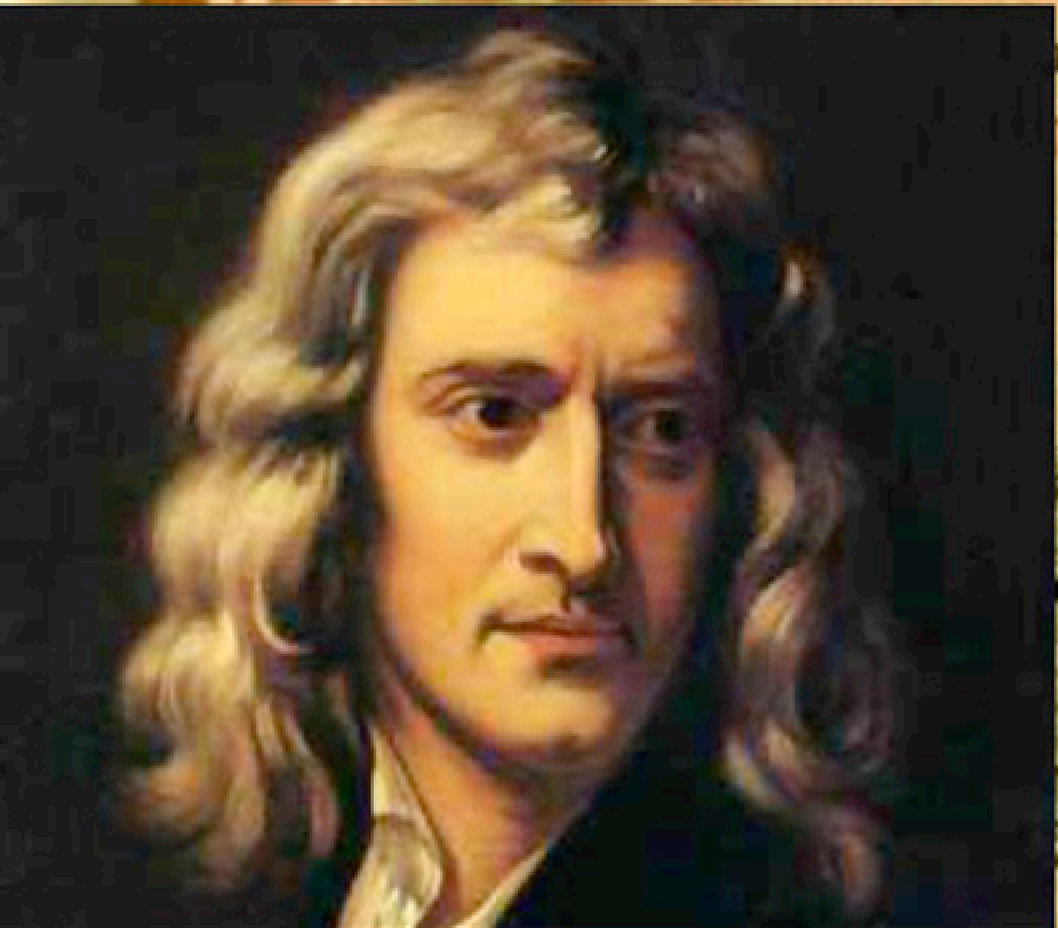




MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

INTERACCIONES: ACOPLAMIENTO PARTÍCULAS-FUERZAS

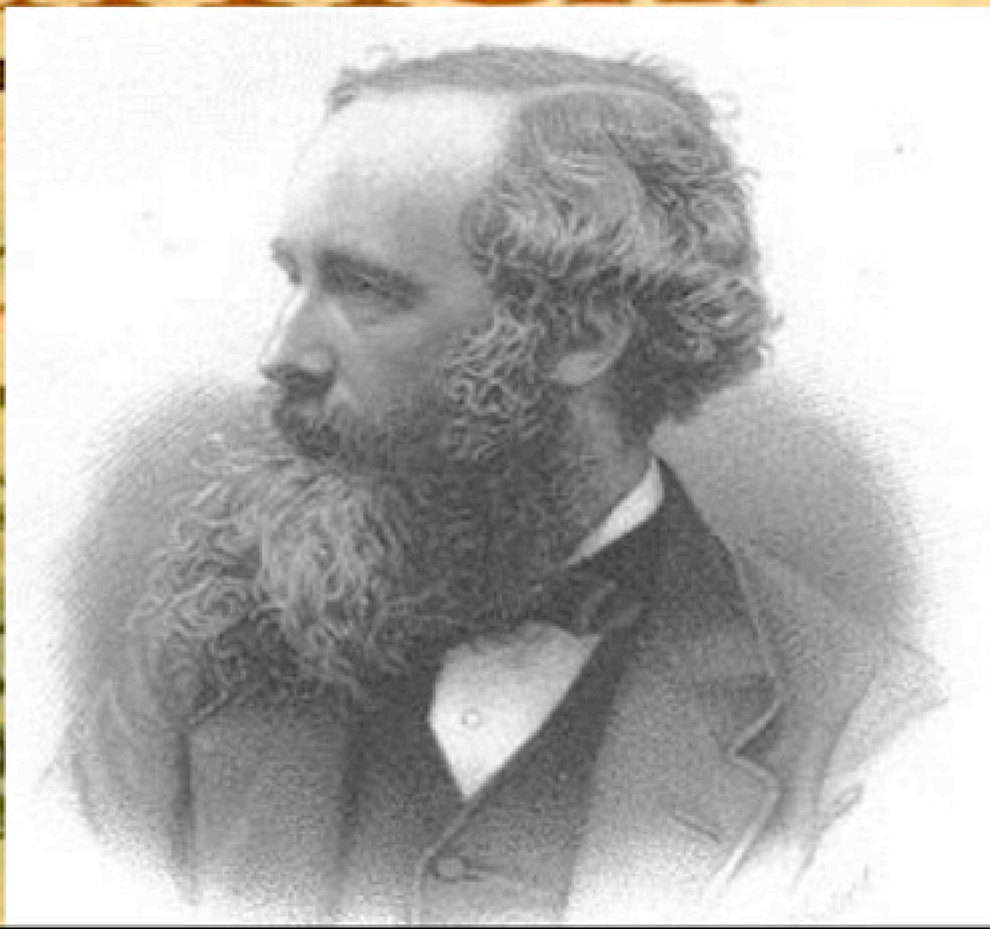






ISAAC NEWTON

1642–1727



JAMES CLERK MAXWELL

1831–1879

MODELO ELECTRODÉBIL

TEORÍA CUÁNTICA DE CAMPOS RELATIVISTA BASADA EN EL GRUPO DE SIMETRÍA *GAUGE* : SU(2) X U(1)

BOSONES *GAUGE* : W^{i}_{μ} , $i=1,2,3$; B_{μ}

CONSTANTES DE ACOPLAMIENTO *GAUGE*: *g, g'*

$\Theta_{W} \equiv \tan^{-1}(g'/g)$

TODOS LOS BOSONES *GAUGE* TIENEN MASA = 0

MODELO ELECTRODÉBIL

GENERACIÓN DE MASA:

CAMPO DE HIGGS $\phi \; (\phi^{+}, \phi^{-})$

$$e \equiv g \sin \theta_W$$

$$A \equiv B \cos + W^3 \sin \theta_W$$

$$W^{+} \equiv (W^1 - i W^2)/\sqrt{2}$$

$$W^{-} \equiv (W^1 + i W^2)/\sqrt{2}$$

$$Z \equiv -B \sin \theta_W + W^3 \cos \theta_W$$

EL MODELO ELECTRODÉBIL CON EL MECANISMO DE BROUT-ENGLERT-HIGGS PERMITE EXPLICAR LA DIFERENCIA DE MASA ENTRE

γ (m=0),

$W^{\pm}$ (m≈80 GeV), Z (m≈91GeV)

ROTURA ESPONTÁNEA DE LA SIMETRÍA ELECTRODÉBIL

YOICHIRO NAMBU
Tokyo, Japón, 1921
PREMIO NOBEL 2008

“ Por el descubrimiento del mecanismo de rotura espontánea de simetría en física subatómica ”

PHYSICAL REVIEW VOLUME 117, NUMBER 3 FEBRUARY 1, 1960

Quasi-Particles and Gauge Invariance in the Theory of Superconductivity*

YOICHIRO NAMBU
The Enrico Fermi Institute for Nuclear Studies and the Department of Physics, The University of Chicago, Chicago, Illinois
(Received July 23, 1959)

Ideas and techniques known in quantum electrodynamics have been applied to the Bardeen-Cooper-Schrieffer theory of superconductivity. In an approximation which corresponds to a generalization of the Hartree-Fock fields, one can write down an integral equation defining the self-energy of an electron in an electron gas with phonon and Coulomb interaction. The form of the equation implies the existence of a particular solution which does not follow from perturbation theory, and which leads to the energy gap equation and the quasi-particle picture analogous to Bogoliubov's.

The gauge invariance, to the first order in the external electromagnetic field, can be maintained in the quasi-particle picture by taking into account a certain class of corrections to the charge-current operator due to the phonon and Coulomb interaction. In fact, generalized forms of the Ward identity are obtained between certain vertex parts and the self-energy. The Meissner effect calculation is thus rendered strictly gauge invariant, but essentially keeping the BCS result unaltered for transverse fields.

It is shown also that the integral equation for vertex parts allows homogeneous solutions which describe collective excitations of quasi-particle pairs, and the nature and effects of such collective states are discussed.

PHYSICAL REVIEW VOLUME 122, NUMBER 1 APRIL 1, 1961

Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity. I*

Y. NAMBU AND G. JONA-LASINIO†
The Enrico Fermi Institute for Nuclear Studies and the Department of Physics, The University of Chicago, Chicago, Illinois
(Received October 27, 1960)

It is suggested that the nucleon mass arises largely as a self-energy of some primary fermion field through the same mechanism as the appearance of energy gap in the theory of superconductivity. The idea can be put into a mathematical formulation utilizing a generalized Hartree-Fock approximation which regards real nucleons as quasi-particle excitations. We consider a simplified model of nonlinear four-fermion interaction which allows a γ_5-gauge group. An interesting consequence of the symmetry is that there arise automatically pseudoscalar zero-mass bound states of nucleon-antinucleon pair which may be regarded as an idealized pion. In addition, massive bound states of nucleon number zero and two are predicted in a simple approximation.

The theory contains two parameters which can be explicitly related to observed nucleon mass and the pion-nucleon coupling constant. Some paradoxical aspects of the theory in connection with the γ_5 transformation are discussed in detail.

PHYSICAL REVIEW VOLUME 124, NUMBER 1 OCTOBER 1, 1961

Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity. II*

Y. NAMBU AND G. JONA-LASINIO†
Enrico Fermi Institute for Nuclear Studies and Department of Physics, University of Chicago, Chicago, Illinois
(Received May 10, 1961)

Continuing the program developed in a previous paper, a "superconductive" solution describing the proton-neutron doublet is obtained from a nonlinear spinor field Lagrangian. We find the pions of finite mass as nucleon-antinucleon bound states by introducing a small bare mass into the Lagrangian which otherwise possesses a certain type of the γ_5 invariance. In addition, heavier mesons and two-nucleon bound states are obtained in the same approximation. On the basis of numerical mass relations, it is suggested that the bare nucleon field is similar to the electron-neutrino field, and further speculations are made concerning the complete description of the baryons and leptons.

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

It is of interest to inquire whether gauge vector mesons acquire mass through interaction[1]; by a gauge vector meson we mean a Yang-Mills field[2] associated with the extension of a Lie group from global to local symmetry. The importance of this problem resides in the possibility that strong-interaction physics originates from massive gauge fields related to a system of conserved currents.[3] In this note, we shall show that in certain cases vector mesons do indeed acquire mass when the vacuum is degenerate with respect to a compact Lie group.

Theories with degenerate vacuum (broken symmetry) have been the subject of intensive study since their inception by Nambu.[4-6] A characteristic feature of such theories is the possible existence of zero-mass bosons which tend to restore the symmetry.[7,8] We shall show that it is precisely these singularities which maintain the gauge invariance of the theory, despite the fact that the vector meson acquires mass.

We shall first treat the case where the original fields are a set of bosons φ_A which transform as a basis for a representation of a compact Lie group. This example should be considered as a rather general phenomenological model. As such, we shall not study the particular mechanism by which the symmetry is broken but simply assume that such a mechanism exists. A calculation performed in lowest order perturbation theory indicates that those vector mesons which are coupled to currents that "rotate" the original vacuum are the ones which acquire mass [see Eq. (6)].

We shall then examine a particular model based on chirality invariance which may have a more fundamental significance. Here we begin with a chirality-invariant Lagrangian and introduce both vector and pseudovector gauge fields, thereby guaranteeing invariance under both local phase and local γ_5-phase transformations. In this model the gauge fields themselves may break the γ_5 invariance leading to a mass for the original Fermi field. We shall show in this case that the pseudovector field acquires mass.

In the last paragraph we sketch a simple argument which renders these results reasonable.

(1) Lest the simplicity of the argument be shrouded in a cloud of indices, we first consider a one-parameter Abelian group, representing, for example, the phase transformation of a charged boson; we then present the generalization to an arbitrary compact Lie group.

The interaction between the φ and the A_μ fields is

$$H_{\text{int}} = ieA_\mu \varphi^* \overleftrightarrow{\partial}_\mu \varphi - e^2 \varphi^* \varphi A_\mu A_\mu, \qquad (1)$$

where $\varphi = (\varphi_1 + i\varphi_2)/\sqrt{2}$. We shall break the symmetry by fixing $\langle\varphi\rangle \neq 0$ in the vacuum, with the phase chosen for convenience such that $\langle\varphi\rangle = \langle\varphi^*\rangle = \langle\varphi_1\rangle/\sqrt{2}$.

We shall assume that the application of the

Volume 13, Number 20 PHYSICAL REVIEW LETTERS 16 November 1964

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)

In all of the fairly numerous attempts to date to formulate a consistent field theory possessing a broken symmetry, Goldstone's remarkable theorem[1] has played an important role. This theorem, briefly stated, asserts that if there exists a conserved operator Q_i such that

$$[Q_i, A_j(x)] = \sum_k t_{ijk} A_k(x),$$

and if it is possible consistently to take $\sum_k t_{ijk} \langle 0|A_k|0\rangle \neq 0$, then $A_j(x)$ has a zero-mass particle in its spectrum. It has more recently been observed that the assumed Lorentz invariance essential to the proof[2] may allow one the hope of avoiding such massless particles through the introduction of vector gauge fields and the consequent breakdown of manifest covariance.[3] This, of course, represents a departure from the assumptions of the theorem, and a limitation on its applicability which in no way reflects on the general validity of the proof.

In this note we shall show, within the framework of a simple soluble field theory, that it is possible consistently to break a symmetry (in the sense that $\sum_k t_{ijk}\langle 0|A_k|0\rangle \neq 0$) without requiring that $A(x)$ excite a zero-mass particle. While this result might suggest a general procedure for the elimination of unwanted massless bosons, it will be seen that this has been accomplished by giving up the global conservation law usually

Volume 13, Number 16 PHYSICAL REVIEW LETTERS 19 October 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(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

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

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

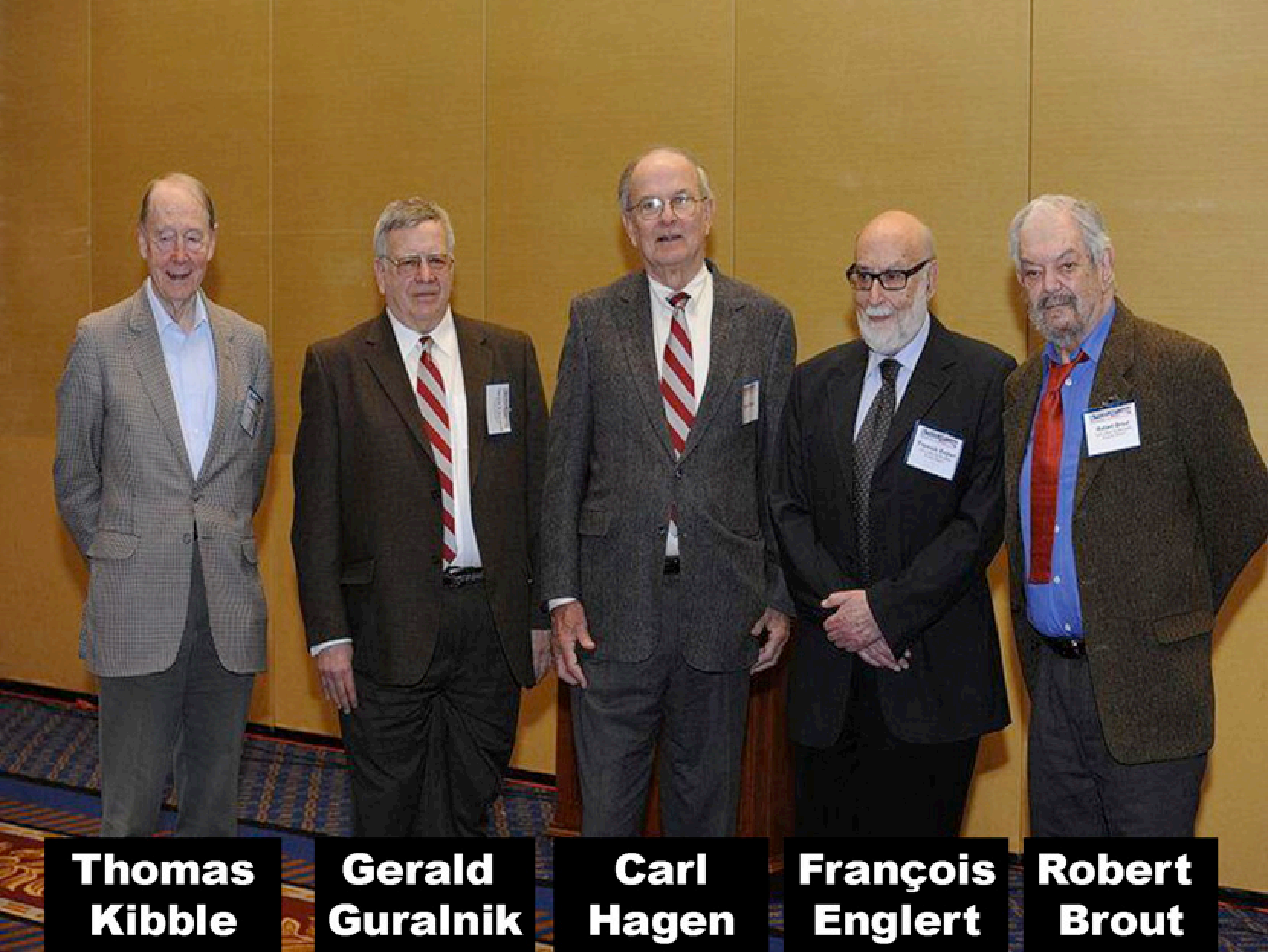
into the form

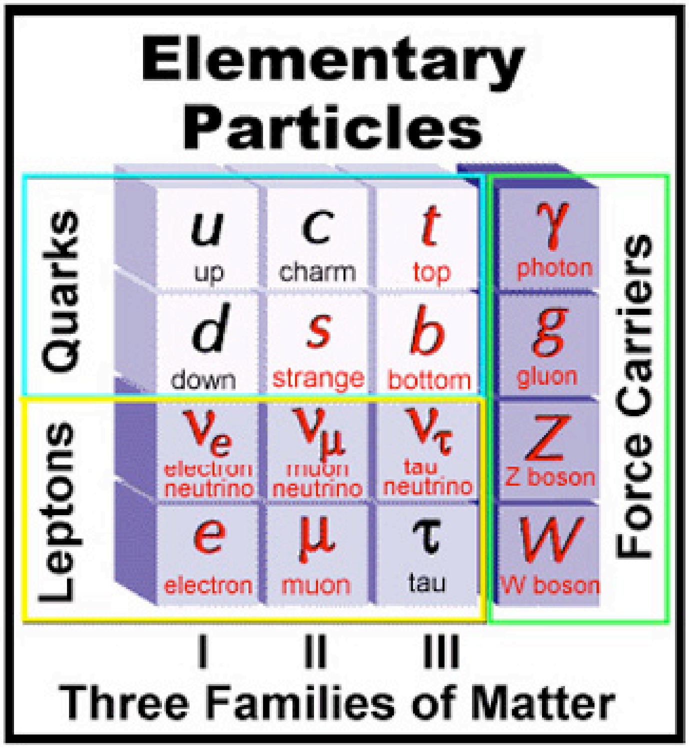
$$\partial_\mu B^\mu = 0, \quad \partial_\nu G^{\mu\nu} + e^2\varphi_0^2 B^\mu = 0. \qquad (4)$$

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

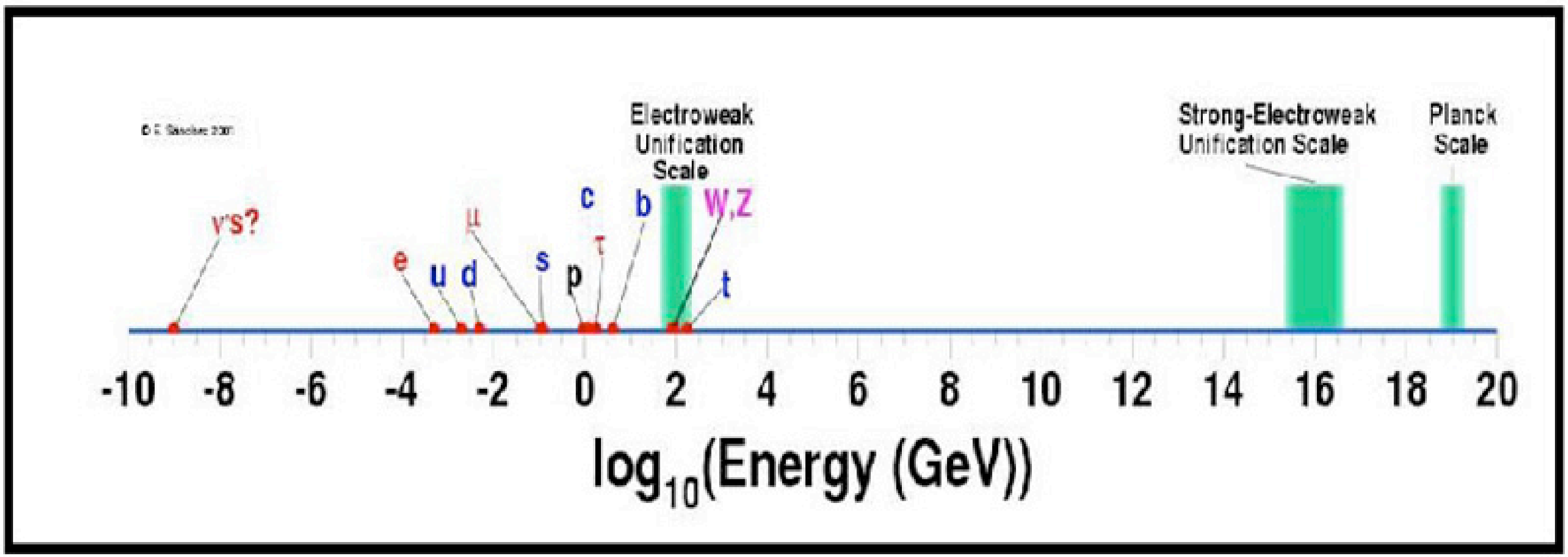
2008: Primer Higgs observado en CMS & ATLAS


Thomas Kibble
Gerald Guralnik
Carl Hagen
François Englert
Robert Brout



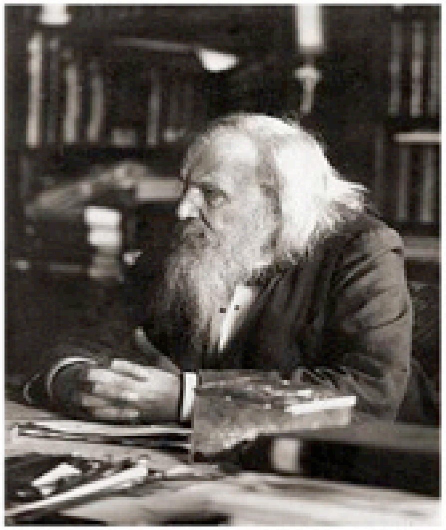
+ BOSÓN DE HIGGS ...

EL HUECO EN EL CONOCIMIENTO DE LO ORDINARO



DMITRI IVANOVICH MENDELEYEV

(1834-1907)



Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII	VII	VII	IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 106	107 107	108 108	109 109	110 110	111 111	112 112						

Naming conventions of new elements

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

“Si lo que he contado les parece claro y transparente, han debido intrepretar erroneamente lo que he dicho”

ALAN GREENSPAN

The Standard Model

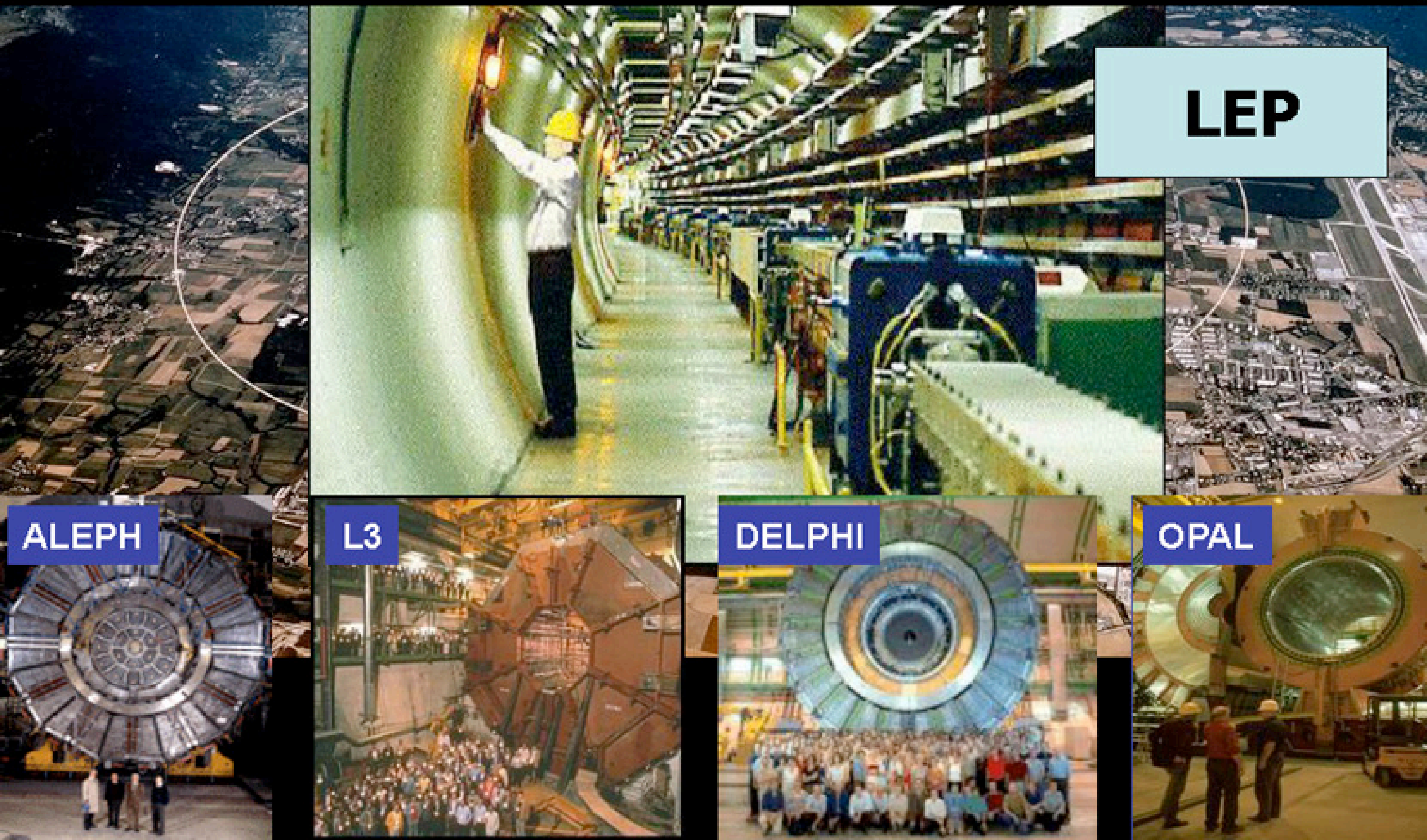
$$
\begin{gathered}
-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \\
\frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \\
\frac{1}{2}m_h^2 H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - M^2\phi^+\phi^- - \frac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\frac{2M^2}{g^2} + \\
\frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu\partial_\nu W^-_\mu - \\
W^-_\nu\partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu\partial_\nu W^-_\mu - \\
W^-_\mu\partial_\nu W^+_\mu) + A_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \\
\frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + \\
g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - \\
W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \\
\frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] - \\
gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - \\
W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \\
\phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + \\
igs_w MA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + \\
igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \\
\frac{1}{4}g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + \\
W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + \\
W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- - \\
g^1 s_w^2 A_\mu A_\mu\phi^+\phi^- - \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j - \\
\bar{d}^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_w A_\mu[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)] + \\
\frac{ig}{4c_w}Z^0_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\frac{4}{3}s_w^2 - \\
1 - \gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1 - \frac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt{2}}W^+_\mu[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + \\
(\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt{2}}W^-_\mu[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1 + \\
\gamma^5)u^\lambda_j)] + \frac{ig}{2\sqrt{2}}\frac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] - \\
\frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + \\
m_u^\lambda(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1 - \\
\gamma^5)u^\kappa_j] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m_d^\lambda}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \\
\frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \\
\frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \\
\partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \\
\partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \\
\partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] + \\
\frac{1-2c_w^2}{2c_w}igM[\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-] + \frac{1}{2c_w}igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \\
igMs_w[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]
\end{gathered}
$$

S. GLASHOW, S. WEINBERG, A. SALAM / PNF 1979

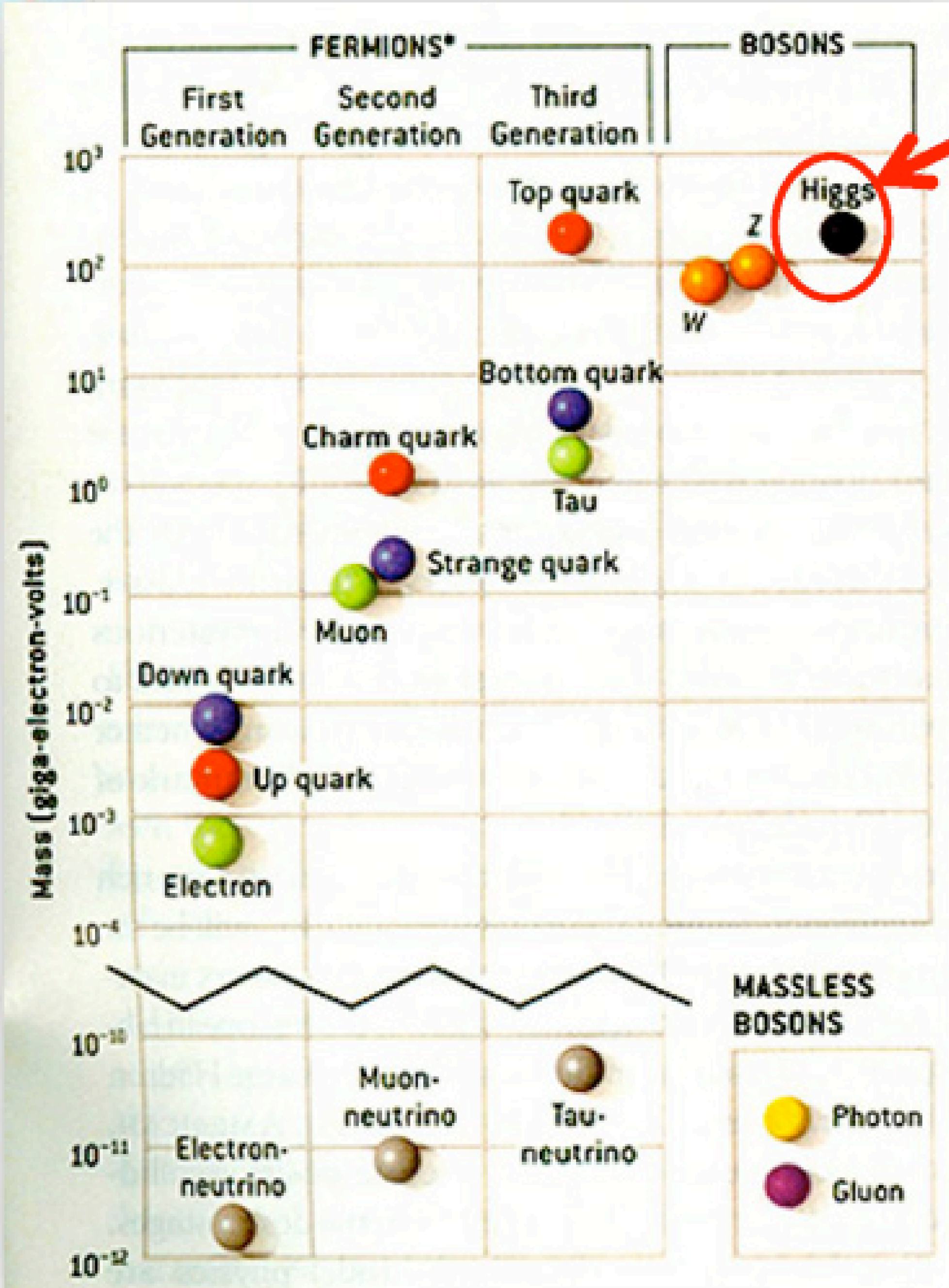
M. VELTMAN, G. 't HOOFT / PNF 1999

D.POLITZER, D. GROSS, F. WILCZEK / PNF 2004

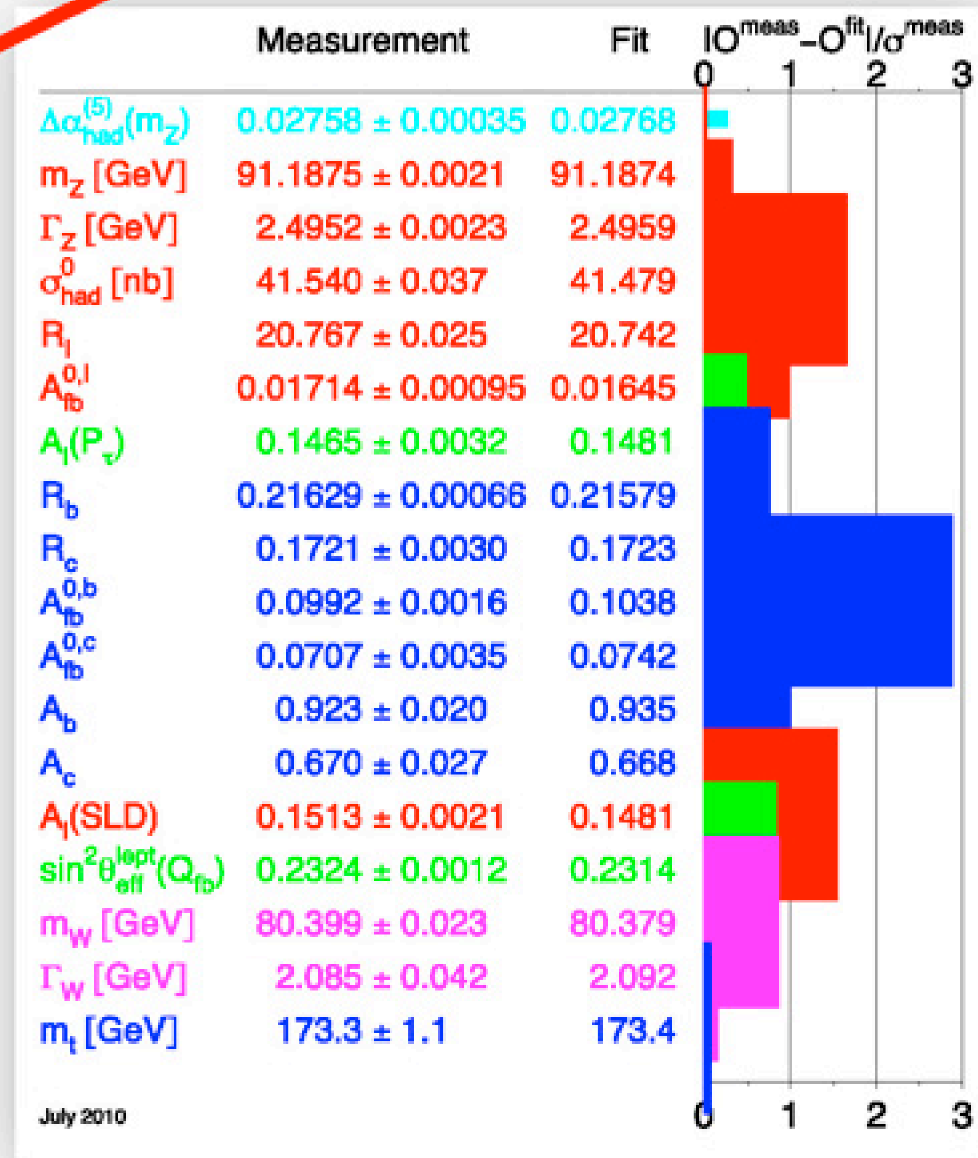
1989 — 2000
VALIDACIÓN DEL MODELO ESTÁNDAR



MODELO ESTÁNDAR

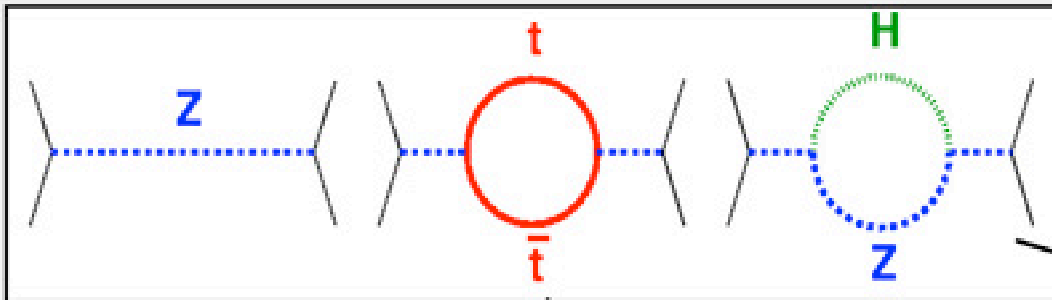


FALTA 1 PIEZA: EL HIGGS

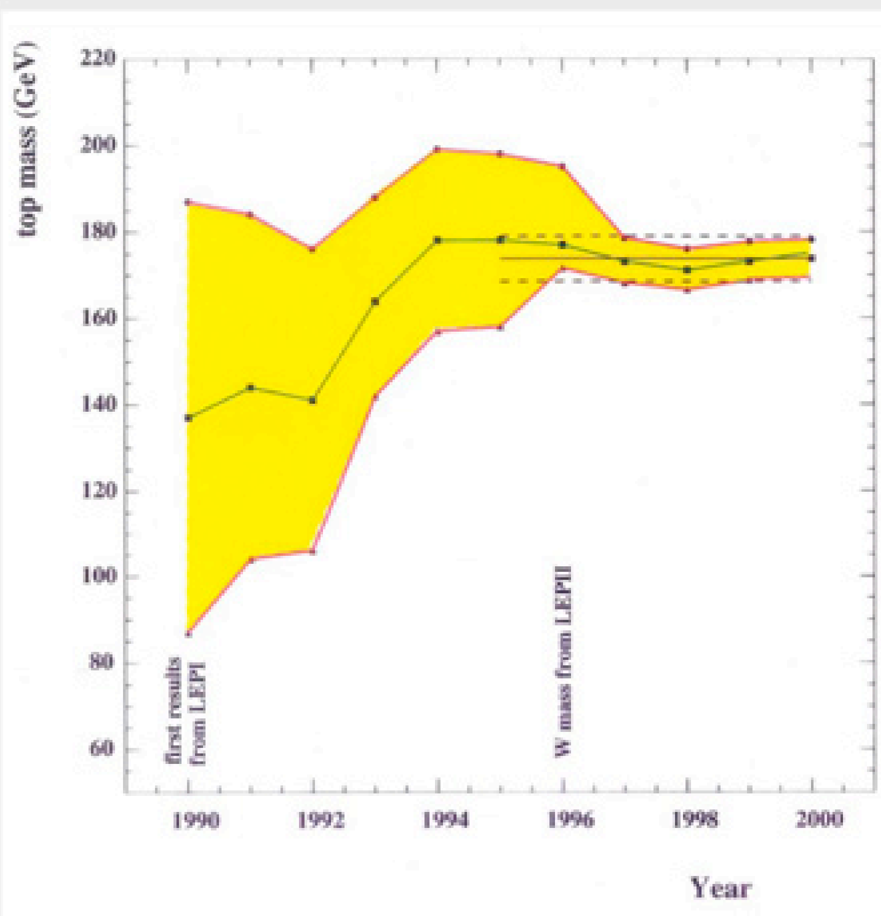


	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ_{had}^0 [nb]	41.540 ± 0.037	41.479	
R_l	20.767 ± 0.025	20.742	
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1723	
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038	
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.399 ± 0.023	80.379	
Γ_W [GeV]	2.085 ± 0.042	2.092	
m_t [GeV]	173.3 ± 1.1	173.4	

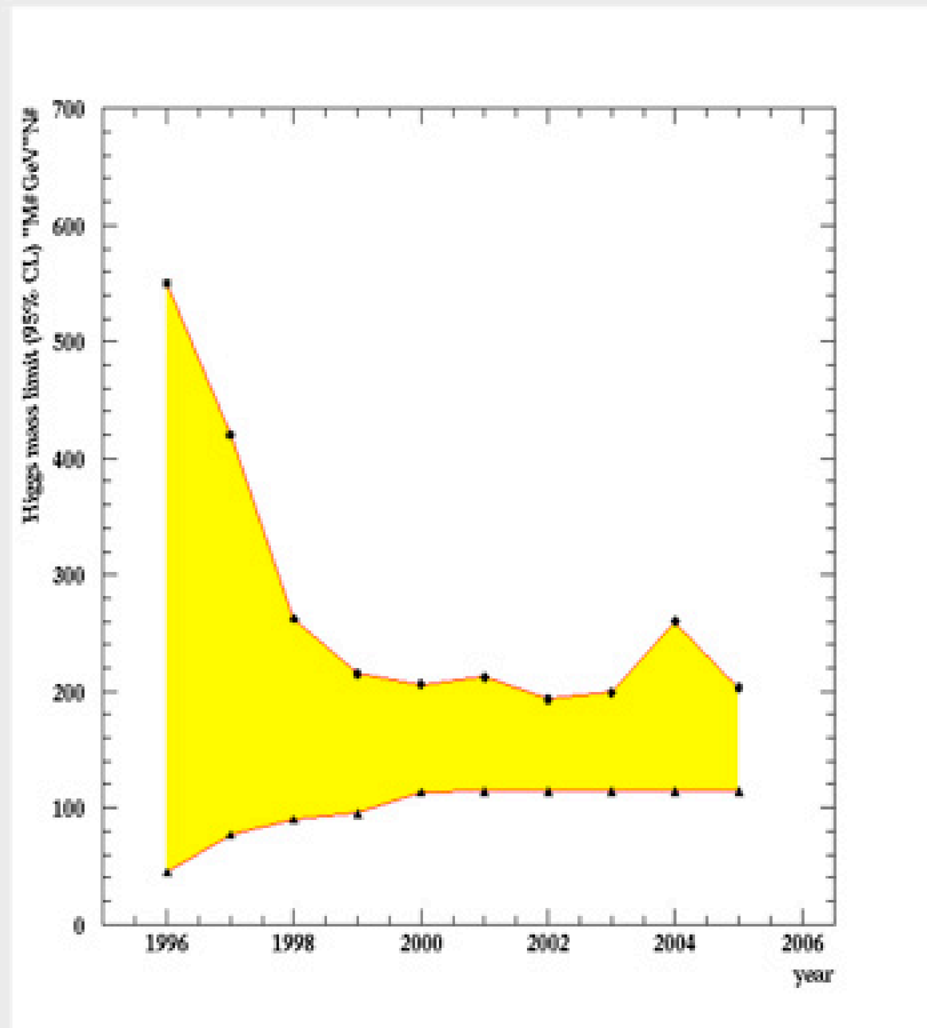
TEST DEL MODELO ESTÁNDAR A NIVEL DE LAS FLUCTUACIONES MECANO-CUÁNTICAS



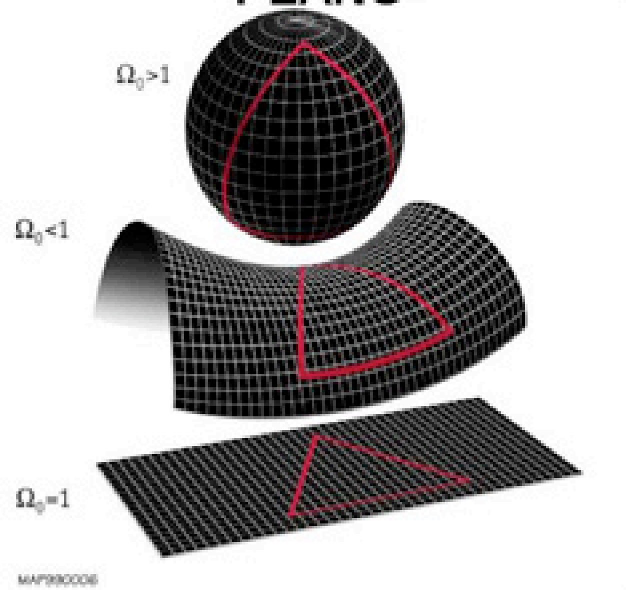
Determinación indirecta de la masa del quark top

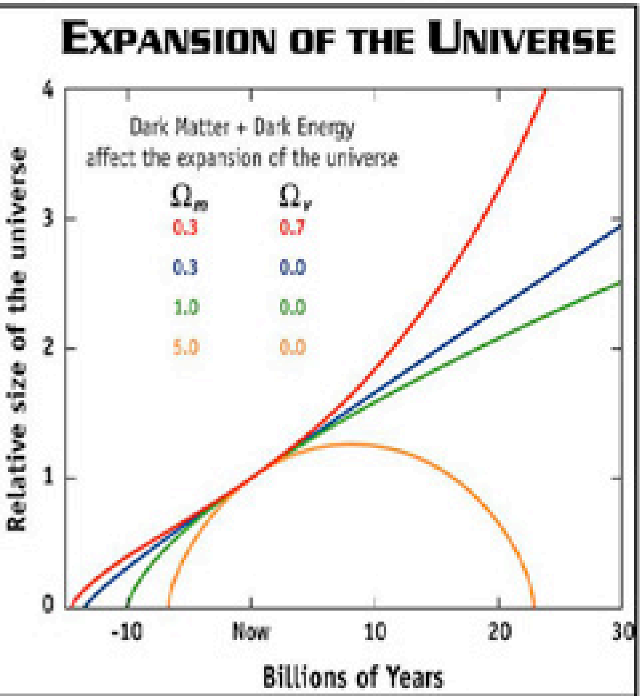


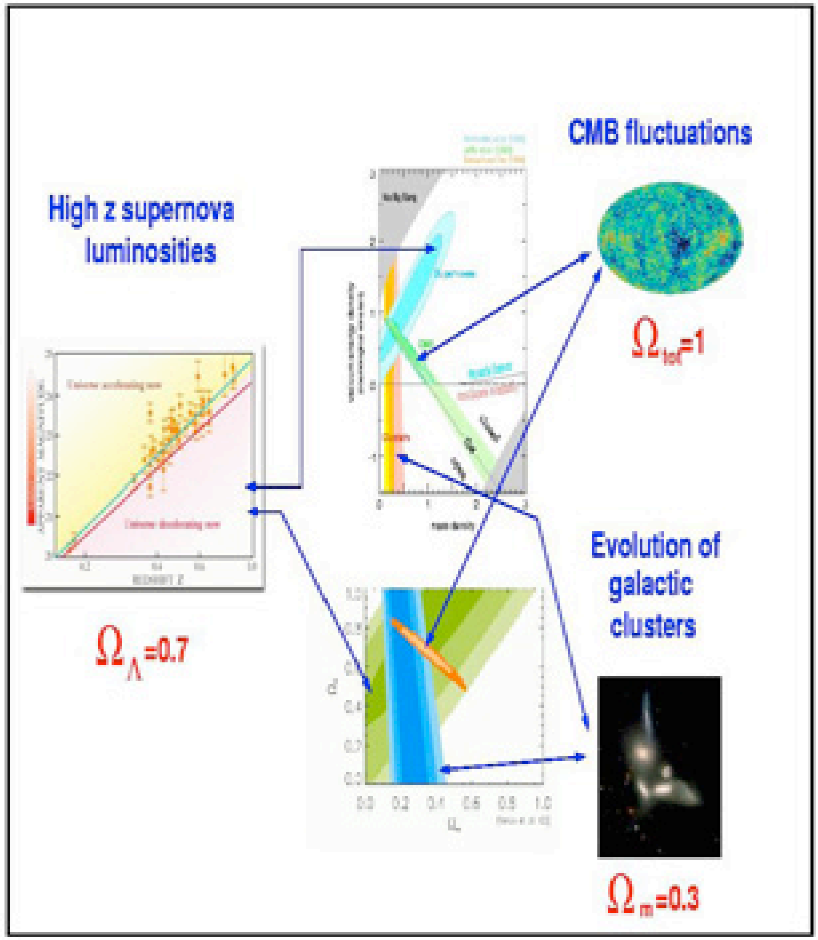
Predicción del intervalo de masa posible para el bosón de Higgs

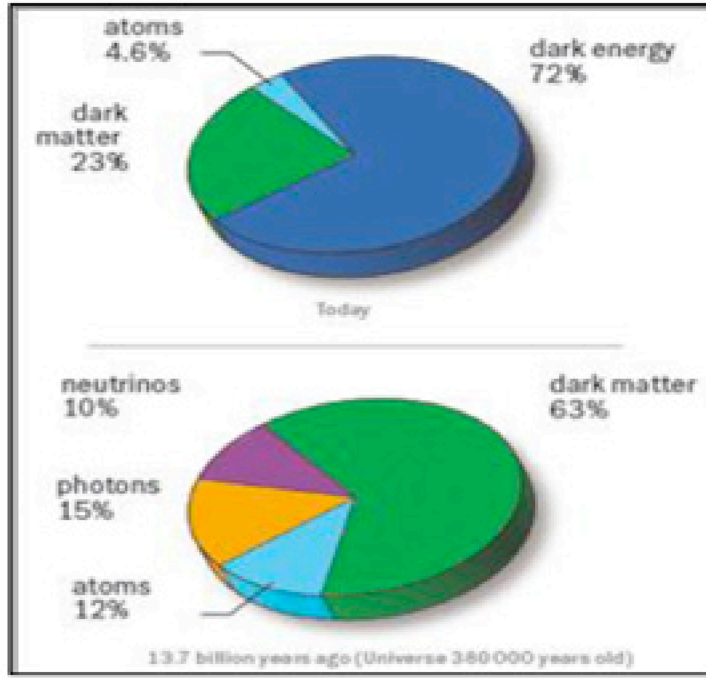


EL UNIVERSO ES PLANO





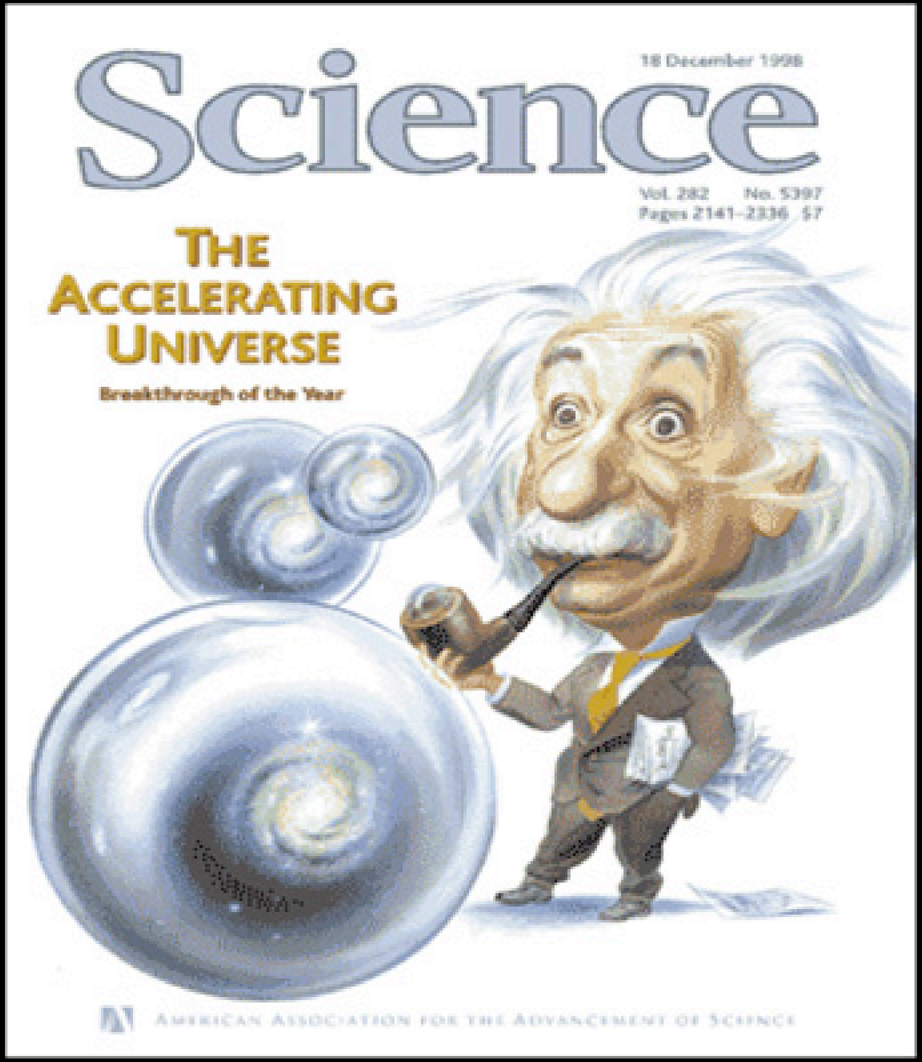




EL HUECO EN EL CONOCIMIENTO DE LO EXTRAORDINARO

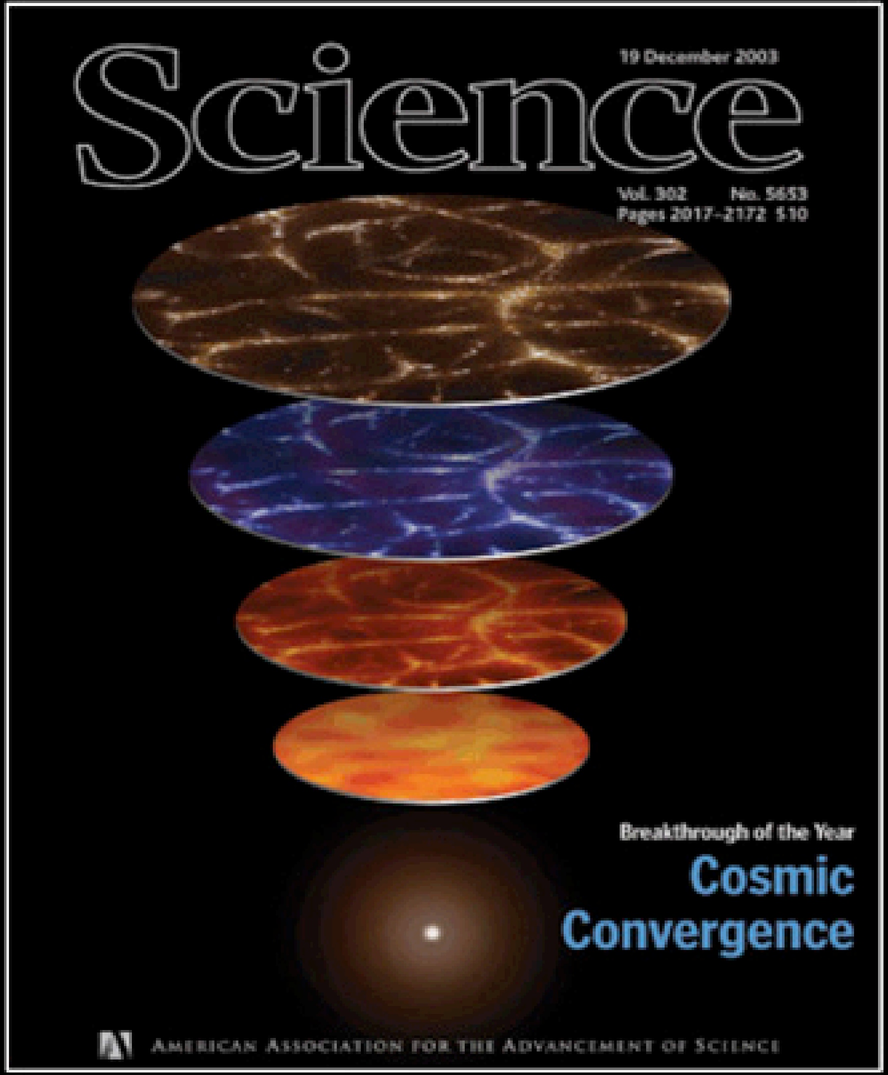
SCIENCE 1998: BREAKTROUGH OF THE YEAR

Descubrimiento de la energía oscura



SCIENCE 2003: BREAKTROUGH OF THE YEAR

Modelo estándar de la cosmología

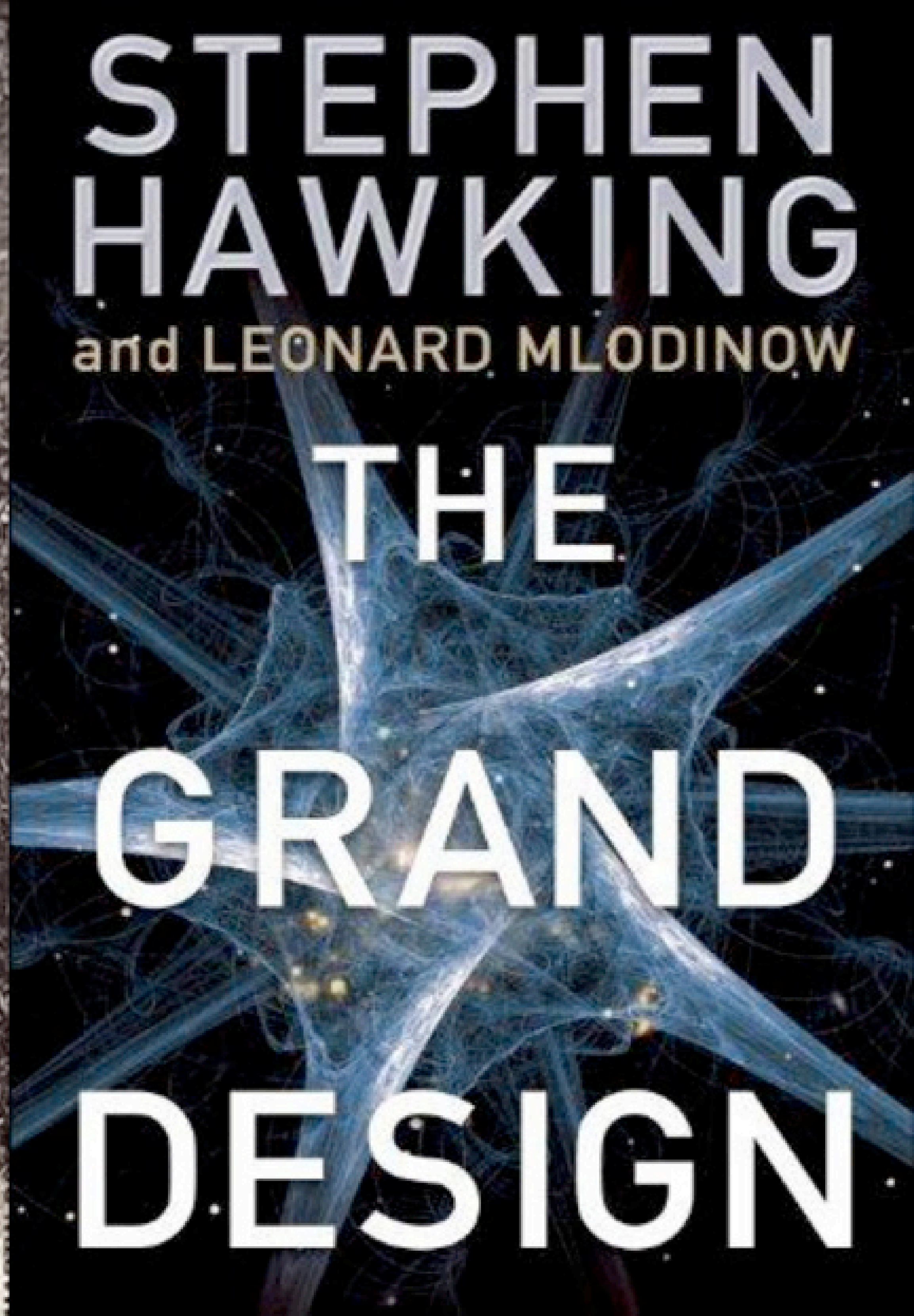


PREMIO NOBEL DE FÍSICA 2011

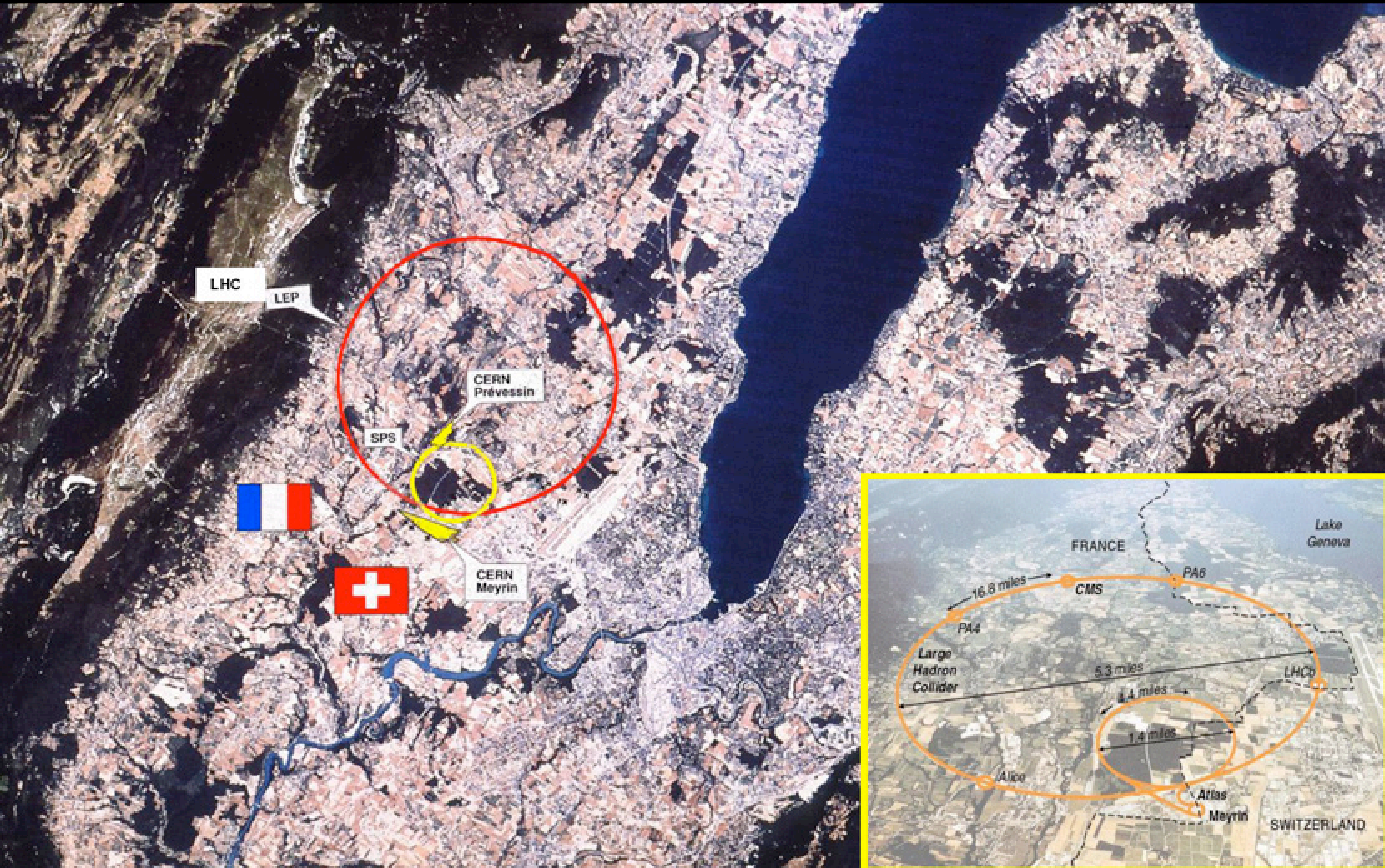
“POR EL DESCUBRIMIENTO DE LA EXPANSIÓN ACELERADA DEL UNIVERSO OBSERVANDO SUPERNOVAS DISTANTES”


DIFICULTADES OBSERVACIONALES
• MASAS DE NEUTRINOS ≠ 0
• MATERIA OSCURA
• MATERIA VS ANTIMATERIA

“Preguntarse qué había antes del Big Bang es como preguntarse qué hay al norte del polo norte”



CERN (1954–)


LHC
LEP
CERN
Prévessin
SPS
CERN
Meyrin
FRANCE
Lake
Geneva
16.8 miles
CMS
PA6
PA4
Large
Hadron
Collider
5.3 miles
LHCb
4.4 miles
1.4 miles
Alice
Atlas
Meyrin
SWITZERLAND

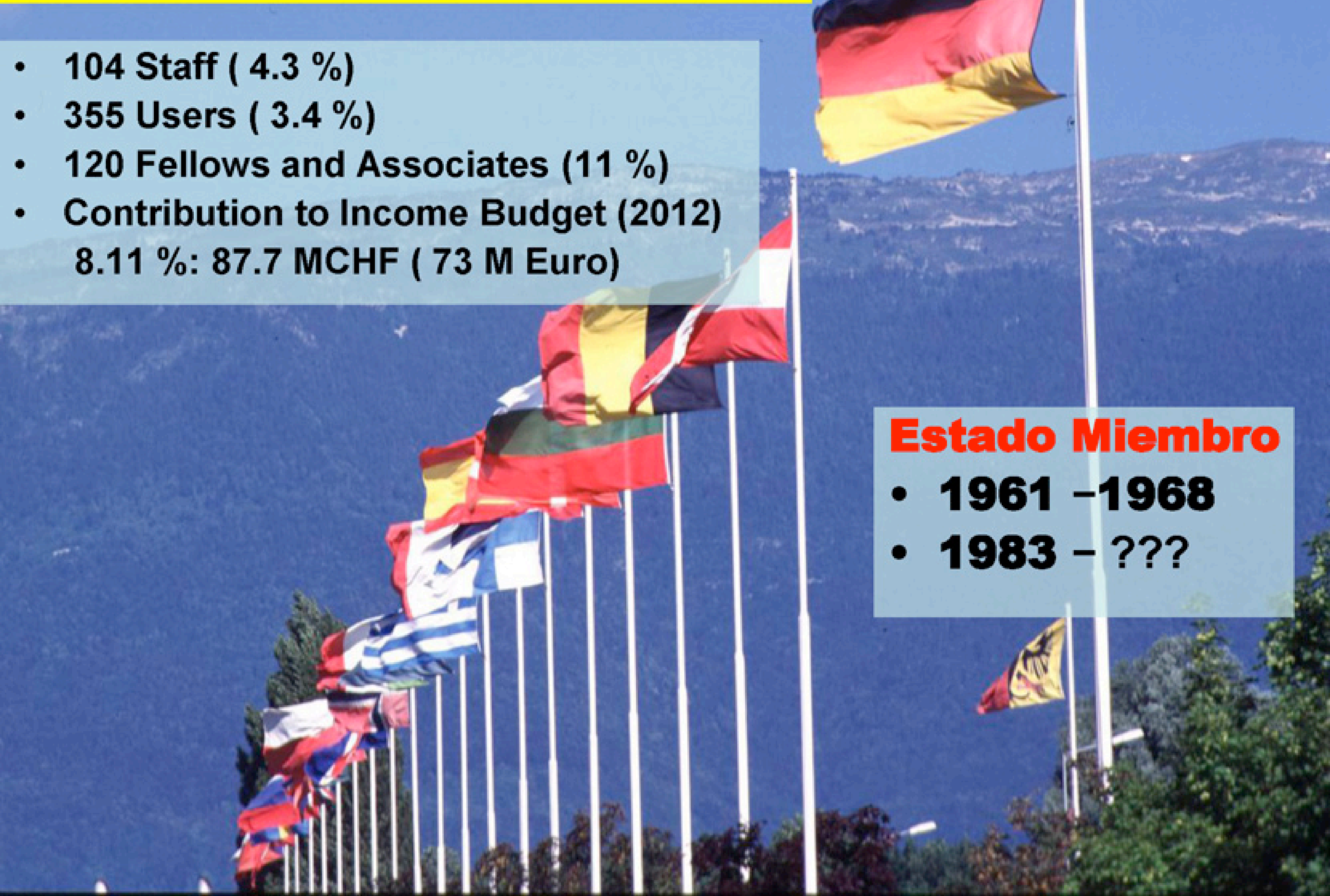
DATOS CERN

- **2424 Staff (31.12.2011)**
- **10388 Users**
- **1092 Fellows and Associates**
- **Budget (2012)**
  Expenses: 1288 MCHF (1073 M Euro)
  Income: 1223 MCHF (1019 M Euro)

- Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.
- Observers: India, Israel, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and Unesco

ESPAÑA @ CERN

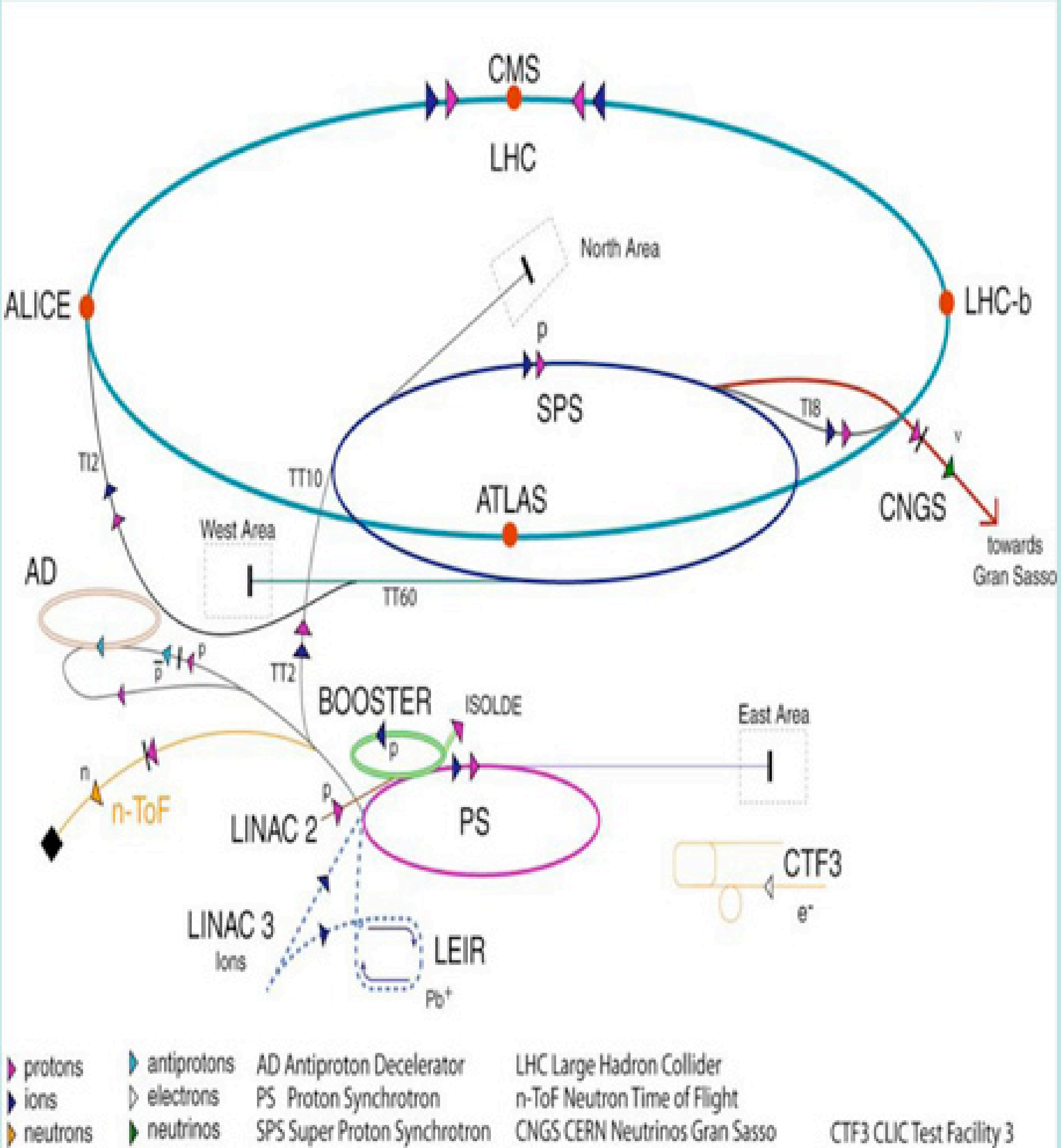
- 104 Staff (4.3 %)
- 355 Users (3.4 %)
- 120 Fellows and Associates (11 %)
- Contribution to Income Budget (2012)
  8.11 %: 87.7 MCHF (73 M Euro)



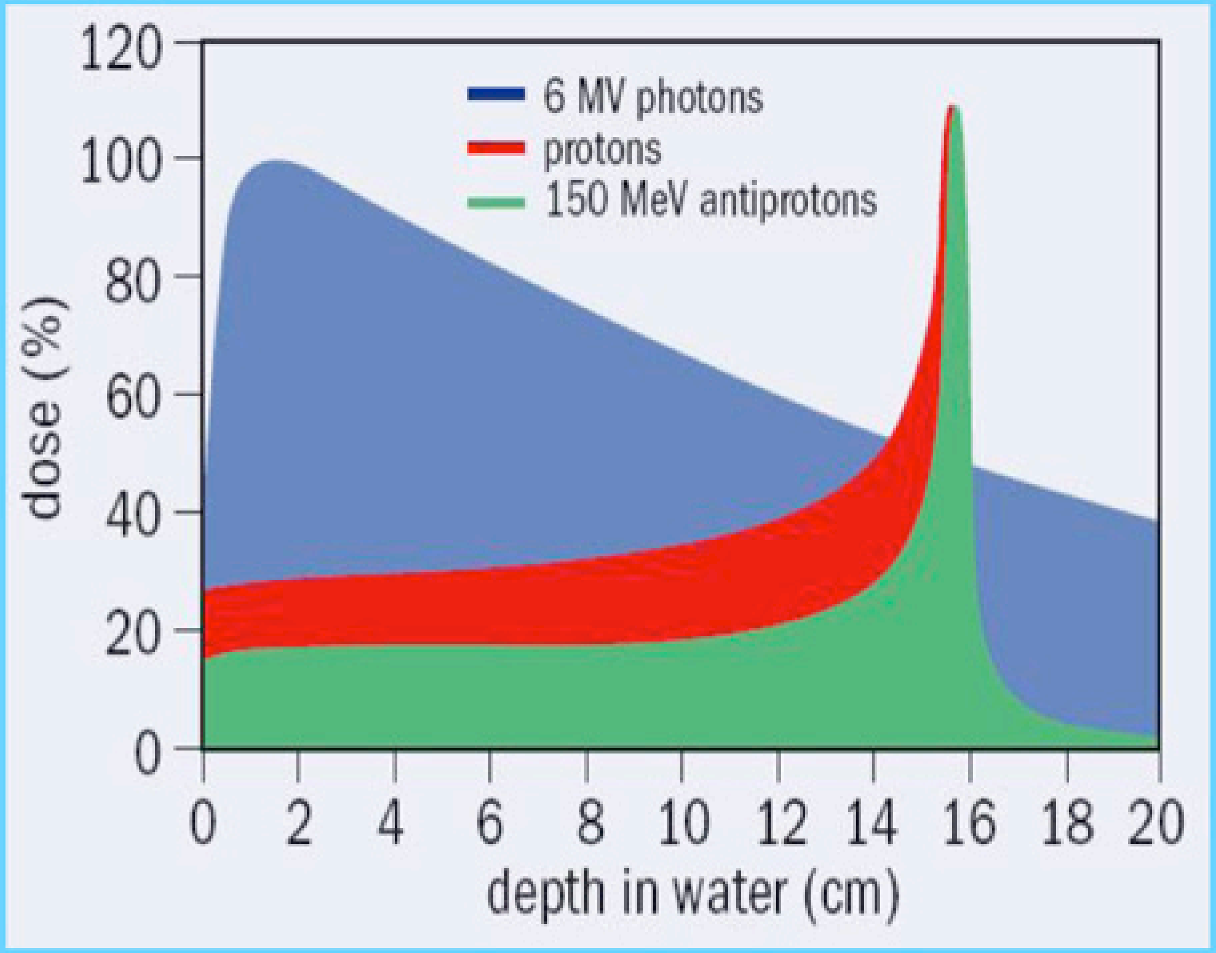
Estado Miembro

- 1961 –1968
- 1983 – ???

CERN: el Complejo de Aceleradores más Completo del Mundo

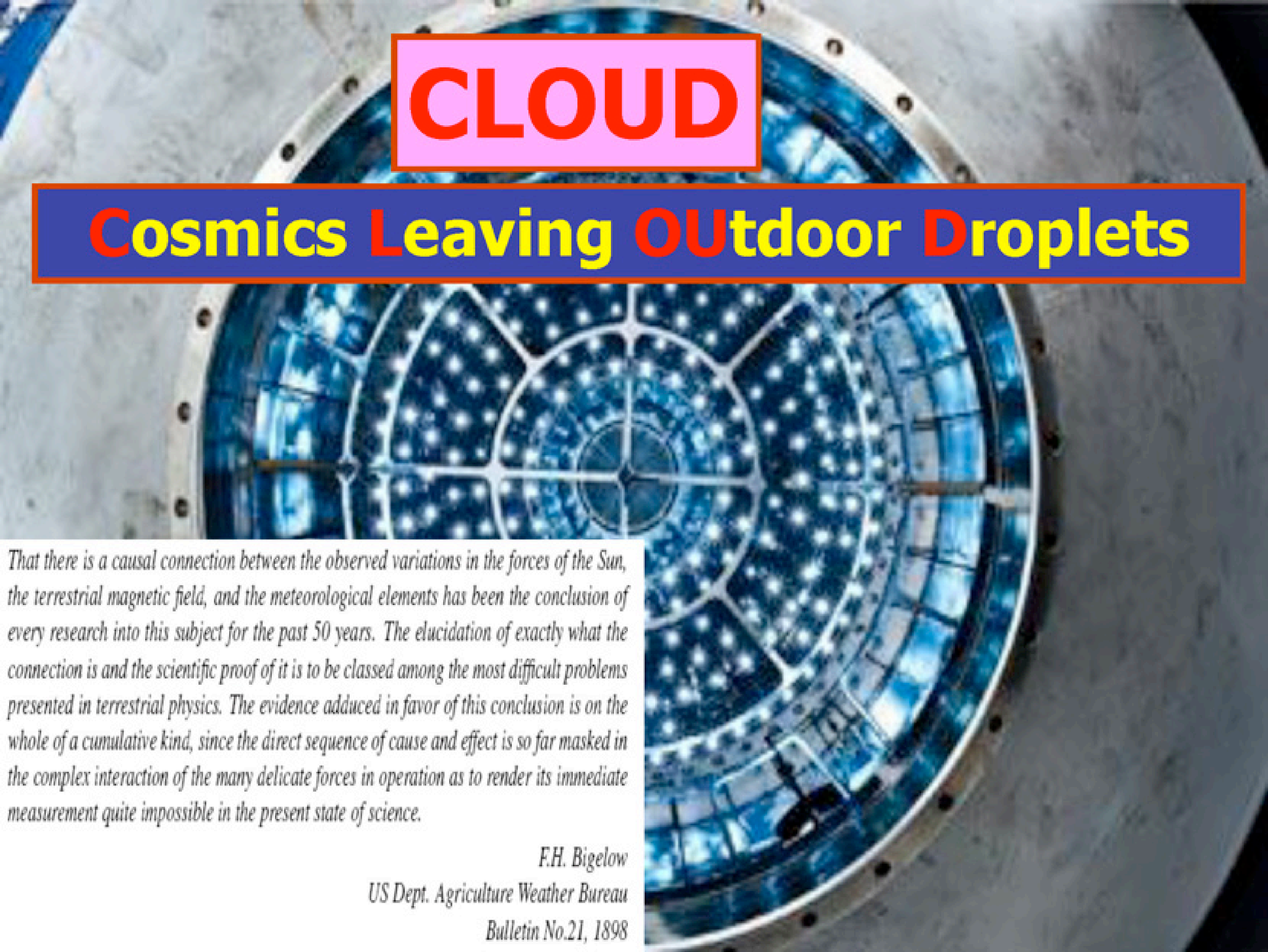


ANTIPROTON CELL EXPERIMENT
CERN ANTIPROTON DECELERATOR



CLOUD

Cosmics Leaving OUtdoor Droplets



That there is a causal connection between the observed variations in the forces of the Sun, the terrestrial magnetic field, and the meteorological elements has been the conclusion of every research into this subject for the past 50 years. The elucidation of exactly what the connection is and the scientific proof of it is to be classed among the most difficult problems presented in terrestrial physics. The evidence adduced in favor of this conclusion is on the whole of a cumulative kind, since the direct sequence of cause and effect is so far masked in the complex interaction of the many delicate forces in operation as to render its immediate measurement quite impossible in the present state of science.

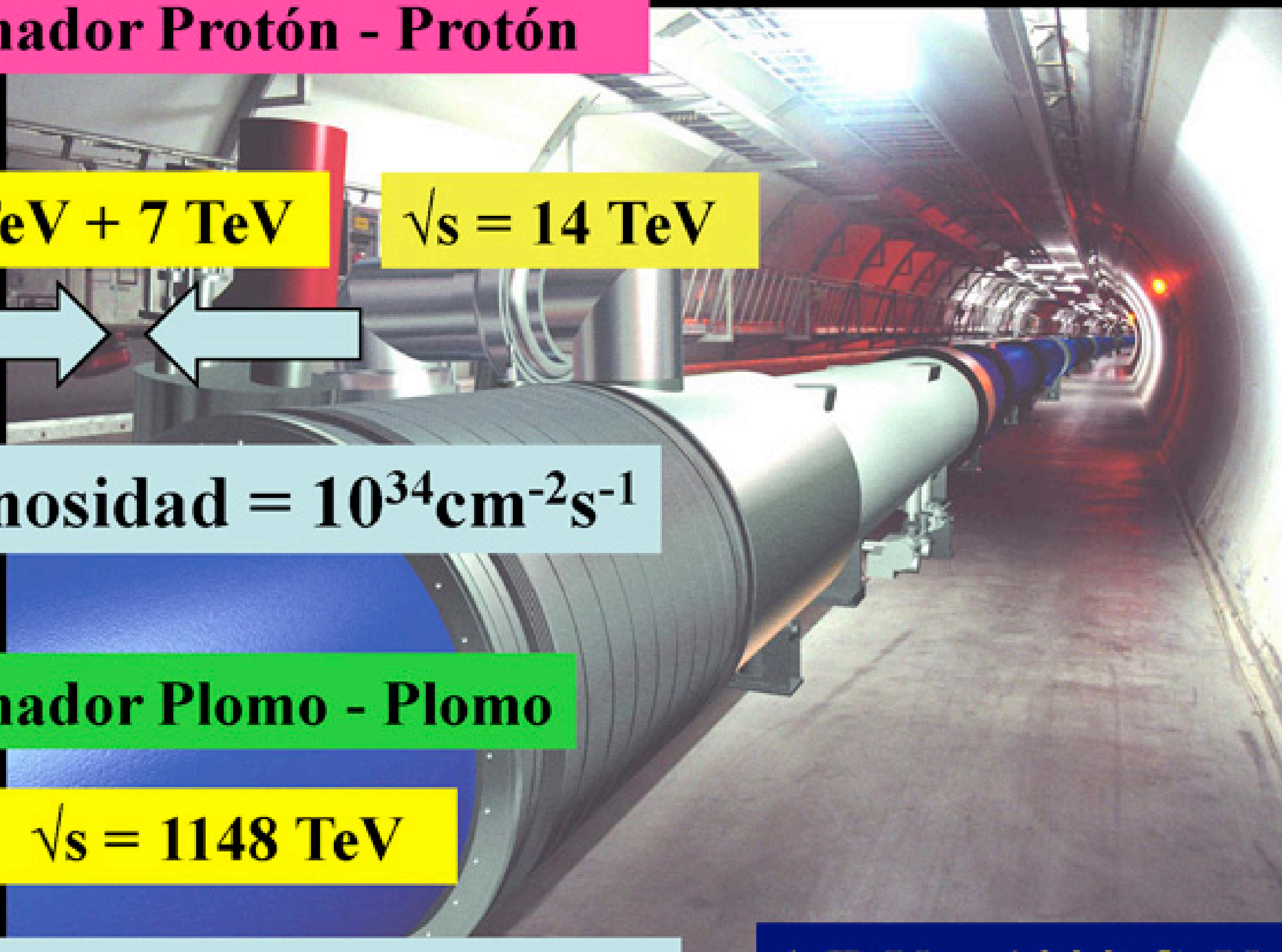
F.H. Bigelow
US Dept. Agriculture Weather Bureau
Bulletin No.21, 1898

LHC: UNA NUEVA ERA EN CIENCIA FUNDAMENTAL

El inicio del programa del LHC, uno de los mayores y verdaderamente globales proyectos científicos jamás realizados, representa un hito extraordinario en Física de Partículas Elementales.

Exploración de una nueva frontera de energía. Colisiones protón-protón e iones pesados a muy alta energía (E_{CM}= 7–14 TeV)

El Large Hadron Collider (LHC)



Colisionador Protón - Protón

7 TeV + 7 TeV

$\sqrt{s}$ = 14 TeV

Luminosidad = $10^{34} cm^{-2} s^{-1}$

Colisionador Plomo - Plomo

$\sqrt{s}$ = 1148 TeV

Luminosidad = $10^{28} cm^{-2} s^{-1}$

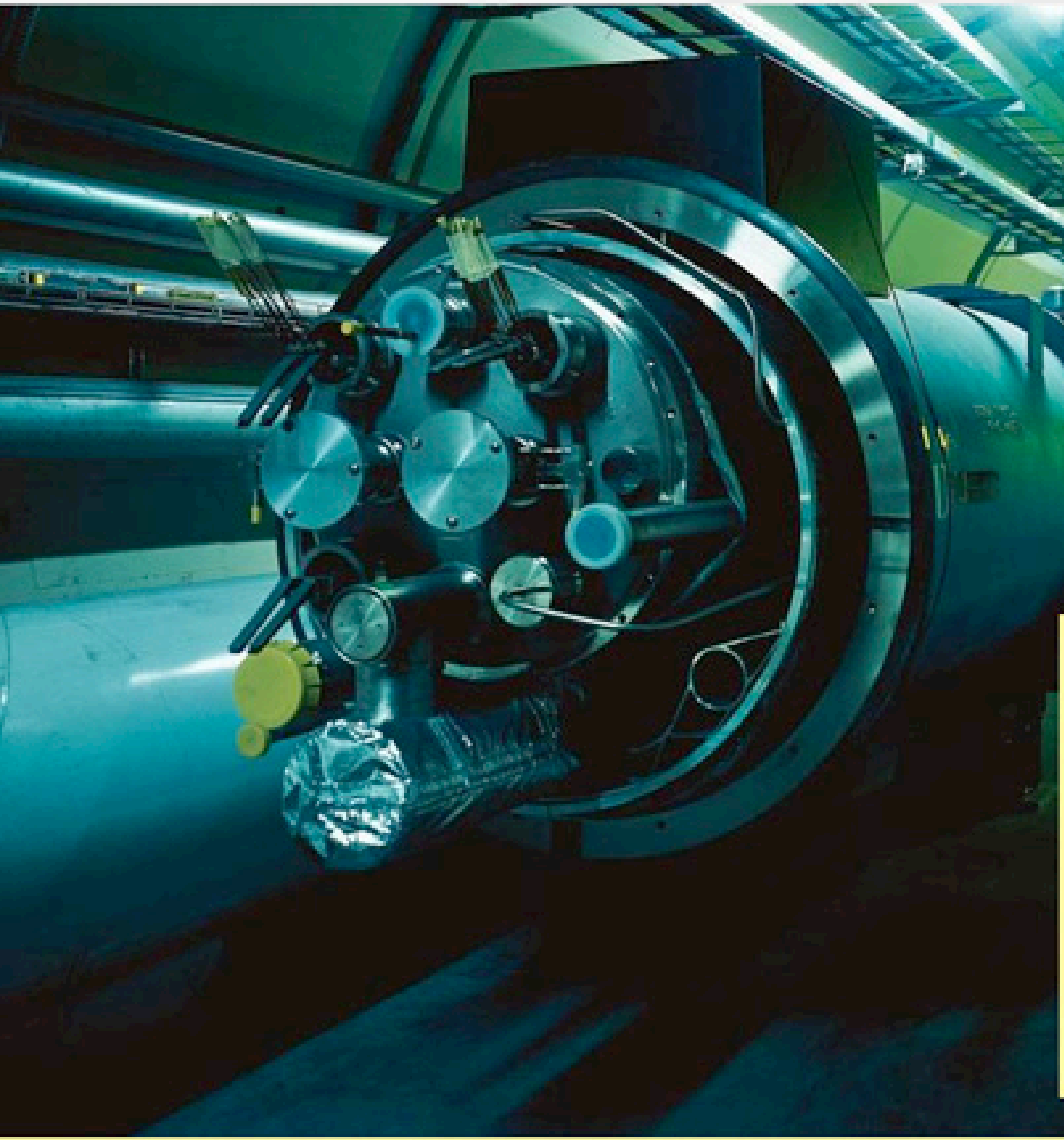
1 TeV = 1000 GeV
~ 1000 veces la masa del protón

¡¡ EL LHC !!

UNA ODISEA ZEPTOESPACIAL

LYN EVANS

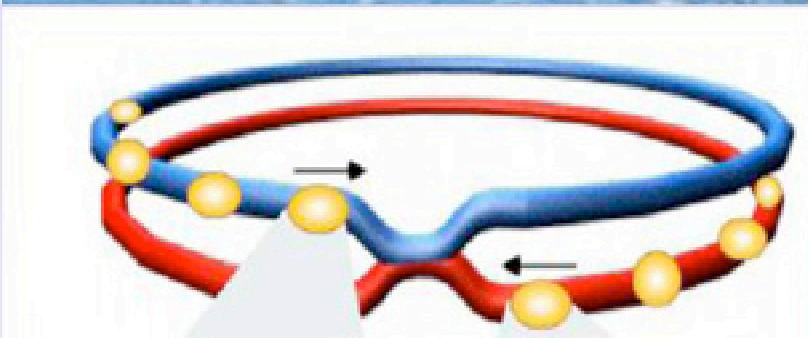
ROLF HEUER

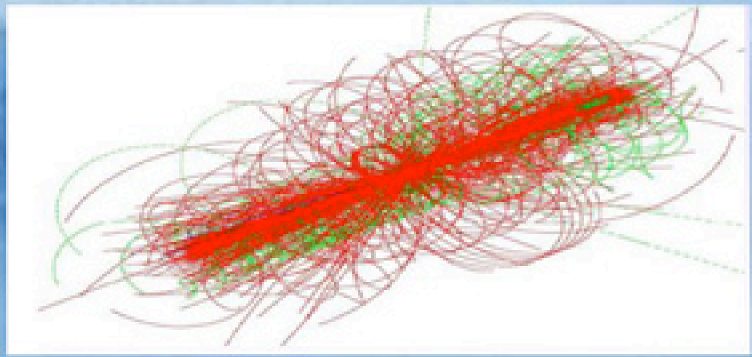


Objetivos Físicos Principales

- Origen de la Masa
- Naturaleza de la Materia Oscura
- Comprensión del Espacio –Tiempo
- Materia & Antimateria
- Plasma Primordial

El LHC determinará el Futuro de la Física de Altas Energías





LHC @ 14 TeV

2808 + 2808 paquetes de protones separados por 7.5 m
→ colisiones cada 25 ns, 40 MHz tasa de cruce

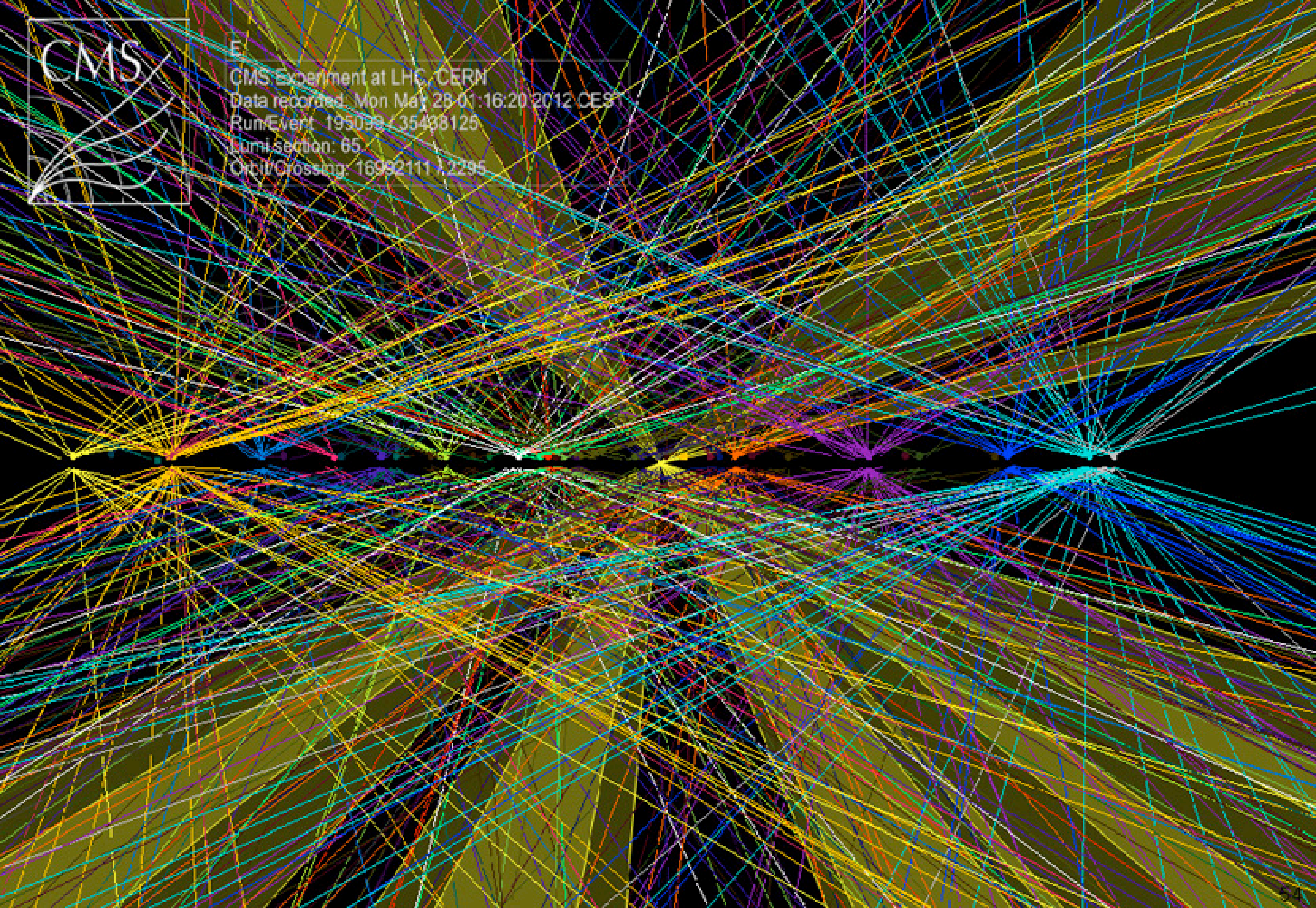
10^{11} protones por paquete

A 10^{34}cm^{2}/s ≈ 35 pp interacciones por cruce, *pile-up*

→ ≈ 10^{9} interacciones pp por segundo !!!

En cada colisión se producen ≈ 1600 partículas cargadas

ENORME DESAFÍO PARA LOS DETECTORES Y PARA LA ADQUISICIÓN Y ANÁLISIS DE DATOS


CMS
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295

LHC (algunos datos)

Parámetros (protones):

- Energía: 7 TeV
- Campo Magnético (dipolos): 8.3 T
- $2.8*10^{14}$ protones / haz
  (en 2808 paquetes)
- Corriente: 0.56 A
- Luminosidad: 10^{34} cm^2/s

Imanes Superconductores, Criogenia:

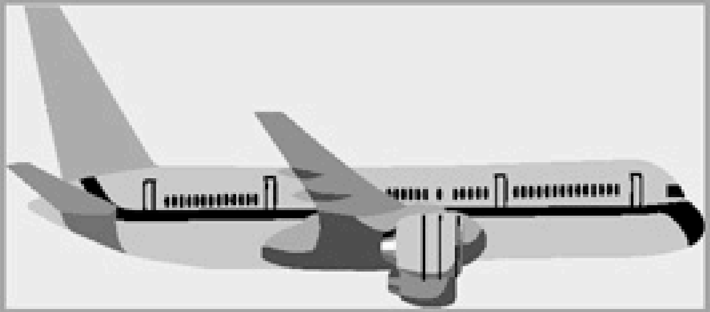
12 millones de litros de nitrógeno líquido se vaporizan durante la fase inicial de enfriamiento de las 31000 toneladas de masa fría; 700000 litros de of helio líquido se necesitan para mantener la masa fría a 2K.

Total: 11 GJ

Energía Almacenada:

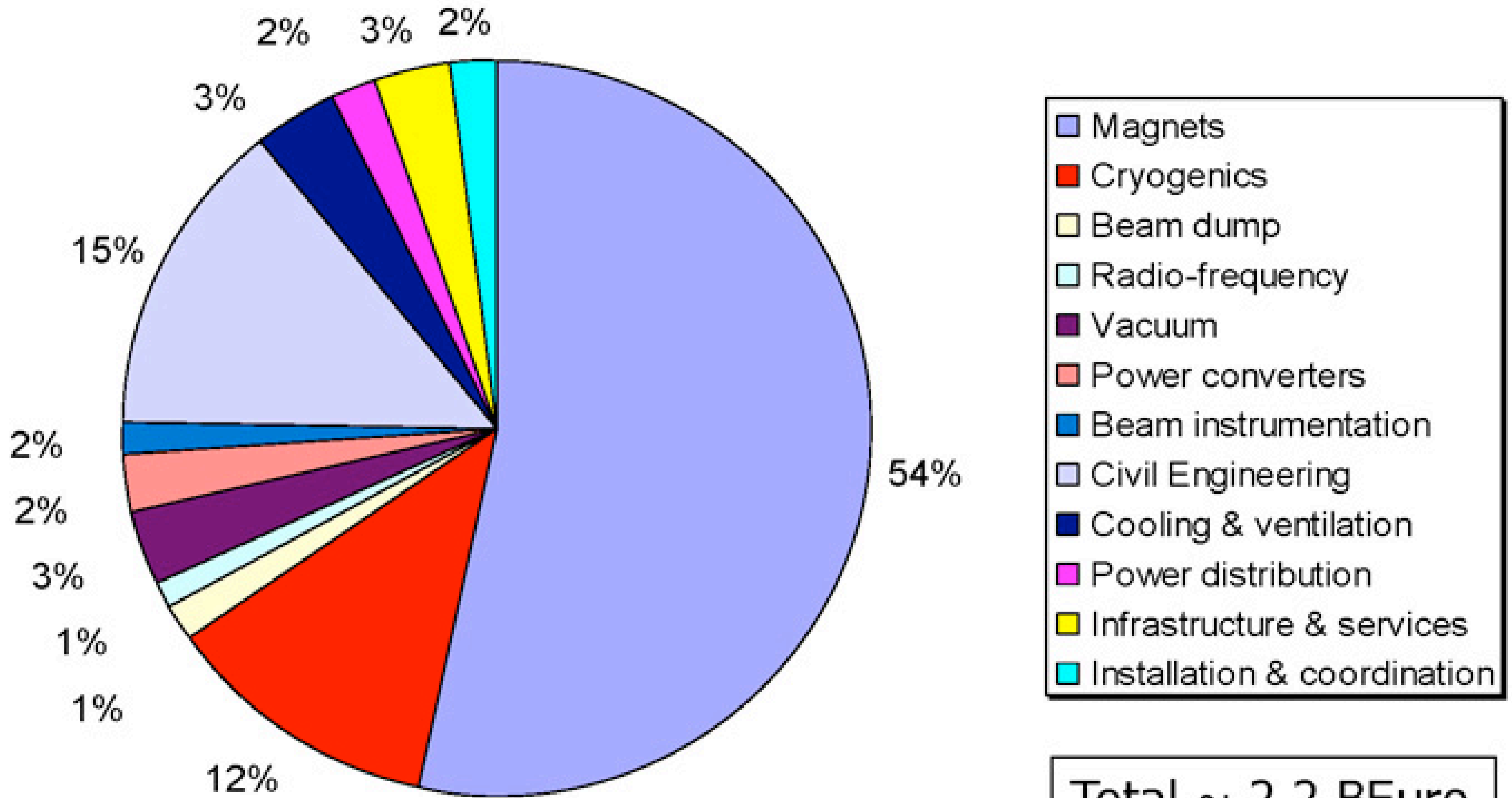
Energía en los dos haces: 0.7 GJ

Energía en los imanes: 10.4 GJ



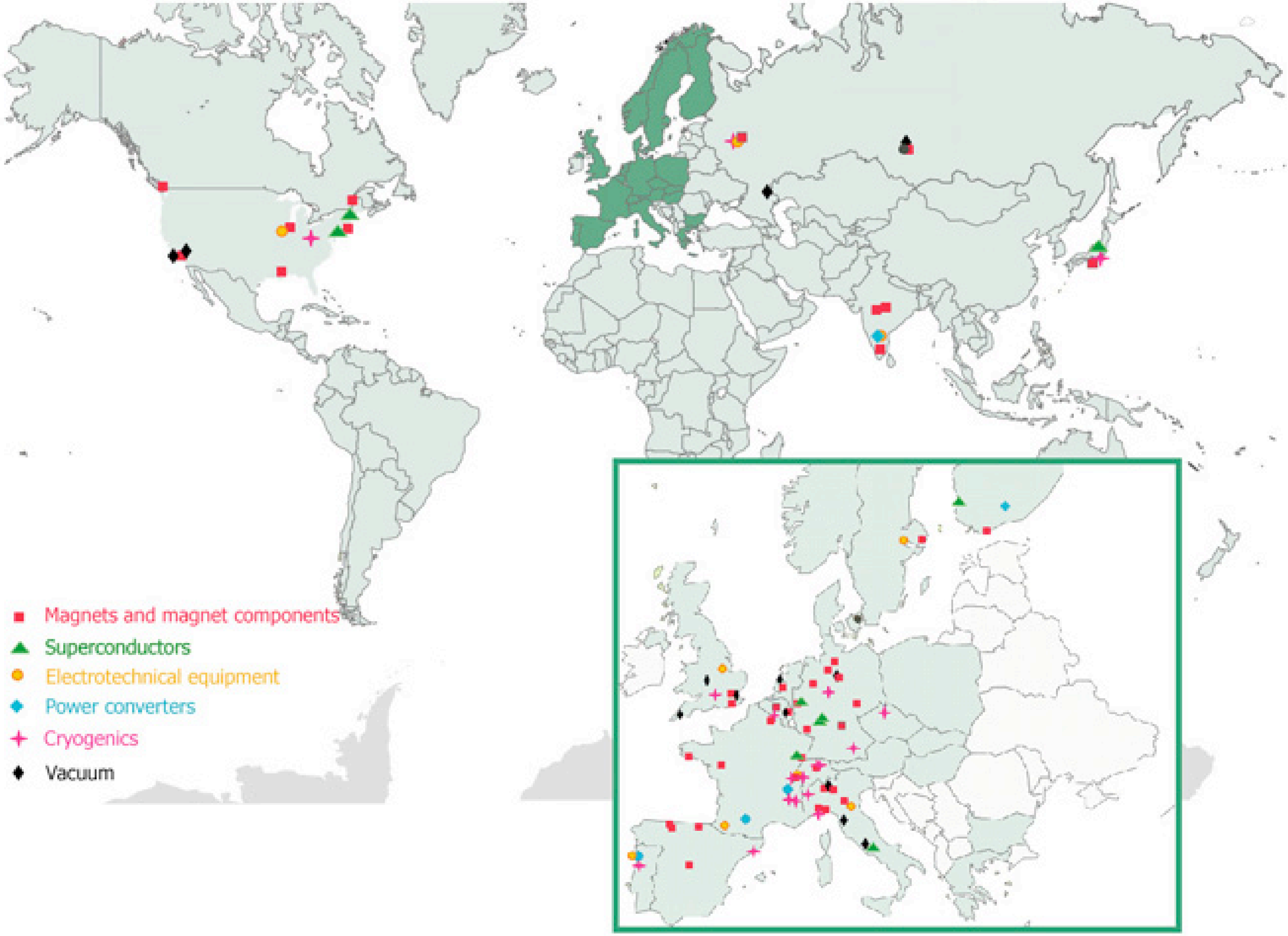
600 km/h

Estructura de Costes del acelerador LHC



Total ~ 2.2 BEuro

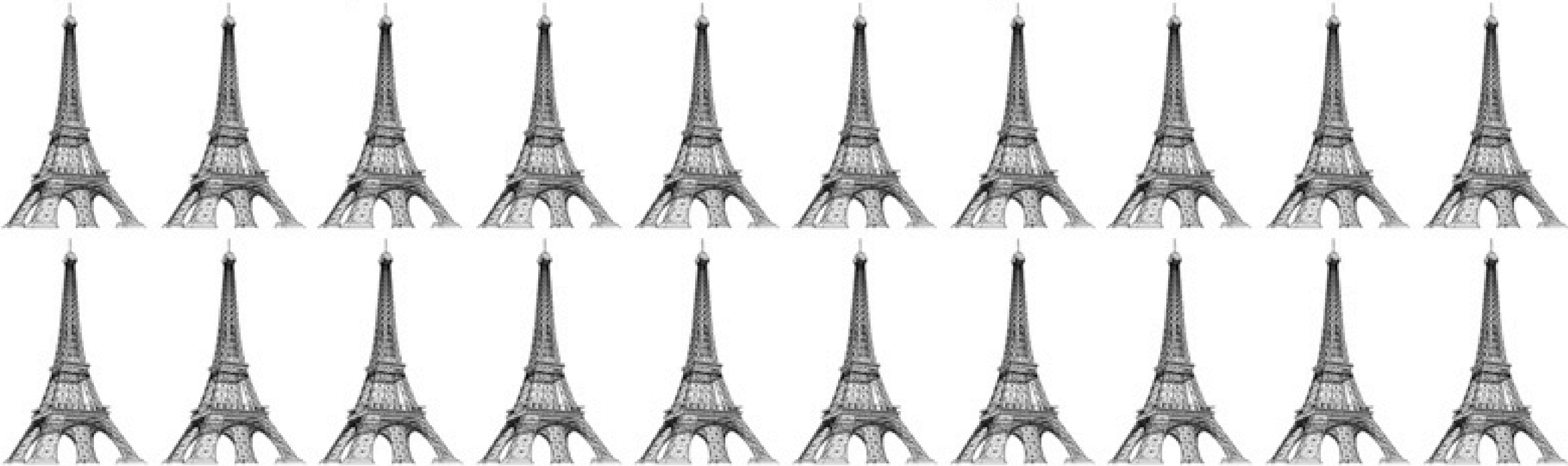
90 grandes contratos industriales



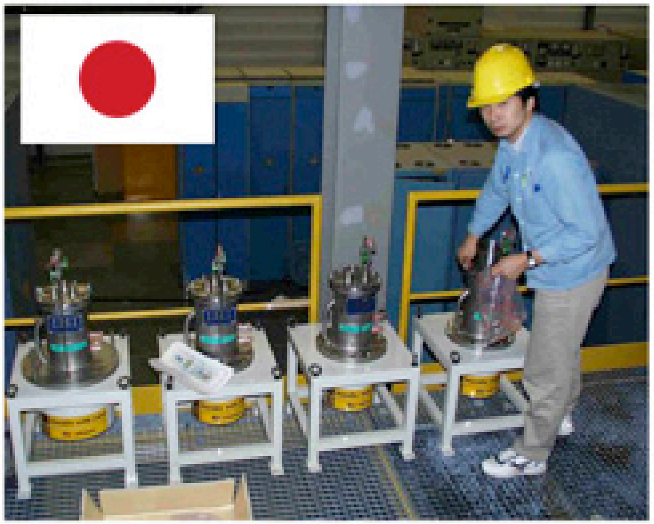
Logística de Suministro & Instalación
Calidad y cantidad en el momento y en el lugar adecuado

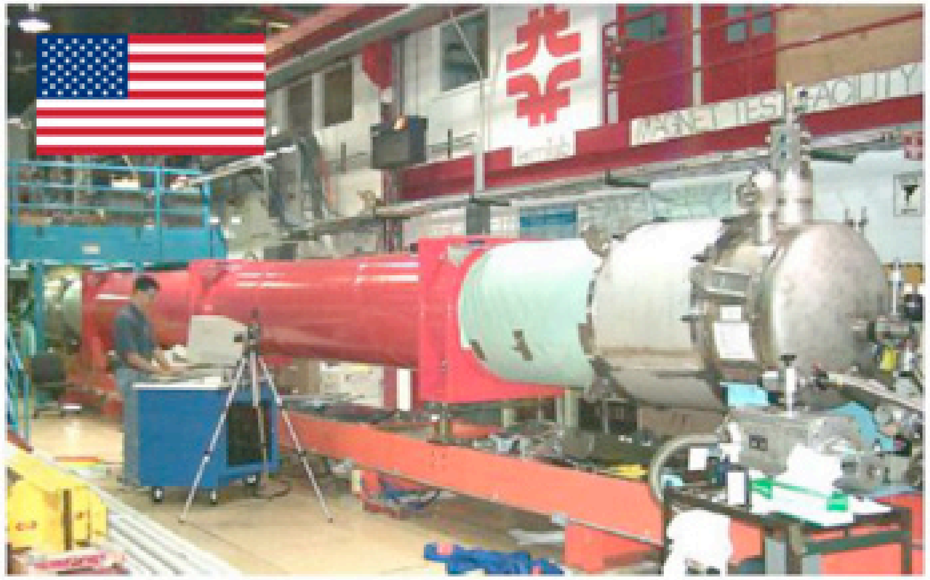
Instalados en el túnel del LHC: 50 000 t

Transportados a través de Europa: ~150 000 t



Un proyecto global en el espacio ...





... y en el tiempo

• Estudios preliminares conceptuales	1984
• Primeros modelos de imanes	1988
• Inicio de un programa estructurado de I&D	1990
• Aprobación por el Consejo del CERN	1994
• Industrialización de la producción en serie	1996-1999
• Inicio de los trabajos de ingeniería civil	1998
• Adjudicación de los grandes contratos	1998-2001
• Inicio de la instalación en el túnel	2003
• Instalación de los crioimanes en el túnel	2005-2007
• Prueba funcional del primer sector	2007
• Comisionado con haz	2008
• Operación para física	2009-2030

Table 1: LHC expenditure overview

[MCHF, rounded]		From 1995-2006 Accounts (in current prices) [i]			2007 Budget * (2007 prices) [ii]			2008 Outline (2007 prices) [iii]			Totals [iv]=[i]+[ii]+[iii]		
		Pers.	Mat.	Total	Pers.	Mat.	Total	Pers.	Mat.	Total	Pers.	Mat.	Total
a=i+ii	**LHC Machine and Experimental Areas (LHC M&A)**	**826,5**	**3 086,9**	**3 913,4**	**84,5**	**141,1**	**225,6**	**7,4**	**16,1**	**23,5**	**918,4**	**3 244,0**	**4 162,5**
i	Machine	766,4	2 719,9	3 486,2	78,7	140,0	218,7	7,4	16,1	23,5	852,5	2 876,0	3 728,5
ii	Experimental Areas	60,2	367,0	427,2	5,8	1,0	6,9			0,0	66,0	368,0	434,0
b	*LHC Machine & Areas in-kind contributions*		*430,0*	*430,0*		*1,9*	*1,9*			*0,0*		*431,9*	*431,9*
c=a+b	**TOTAL: LHC M&A with in-kind contributions**	**826,5**	**3 516,9**	**4 343,4**	**84,5**	**143,0**	**227,5**	**7,4**	**16,1**	**23,5**	**918,4**	**3 675,9**	**4 594,4**
d=sum (i-vi)	**Detectors including R&D**	**738,6**	**292,8**	**1 031,4**	**39,9**	**18,1**	**58,0**	**0,0**	**1,4**	**1,4**	**778,5**	**312,3**	**1 090,8**
i	ATLAS	267,5	123,0	390,5	12,5	6,6	19,1		0,0	0,0	280,0	129,6	409,6
ii	CMS	244,6	125,1	369,6	13,3	2,8	16,1		0,3	0,3	257,9	128,1	386,0
iii	ALICE	106,4	23,1	129,6	6,0	4,1	10,1		1,1	1,1	112,5	28,3	140,8
iv	LHCb	63,7	15,6	79,3	5,8	3,8	9,7		0,0	0,0	69,5	19,5	89,0
v	Totem	3,7	1,4	5,1	1,9	0,8	2,7		0,0	0,0	5,6	2,2	7,8
vi	Other Exp. & Common Projects	52,7	4,6	57,3	0,3	0,0	0,3		0,0	0,0	53,1	4,6	57,6
e=a+d	**TOTAL: Machine + Detectors without in-kind**	**1 565,1**	**3 379,7**	**4 944,8**	**124,4**	**159,1**	**283,5**	**7,4**	**17,5**	**24,9**	**1 697,0**	**3 556,3**	**5 253,3**
f	LHC Machine R&D	71,8	66,5	138,3			0,0				71,8	66,5	138,3
g	LHC Supplem. Infrastr. Operation		65,8	65,8		20,4	20,4				0,0	86,2	86,2
h	Infrastructure Consolidation for LHC		11,1	11,1			0,0				0,0	11,1	11,1
i=e+f+g+h	**TOTAL: Machine + Detectors + Infrastructure + R&D**	**1 637,0**	**3 523,1**	**5 160,1**	**124,4**	**179,5**	**303,9**	**7,4**	**17,5**	**24,9**	**1 768,8**	**3 720,1**	**5 488,9**
j	LHC Injectors (Project and Operation)	83,4	64,8	148,1	4,1	0,9	5,0	2,7	0,5	3,2	90,1	66,1	156,2
k	LHC Computing (Project and Operation)	57,2	49,3	106,5	18,6	14,6	33,1	17,5	30,2	47,7	93,2	94,0	187,3
l=i+j+k	**GRAND TOTAL: Machine + Detectors + Infrastructure + Injectors + Computing**	**1 777,5**	**3 637,1**	**5 414,7**	**147,0**	**195,0**	**342,0**	**27,6**	**48,1**	**75,7**	**1 952,2**	**3 880,2**	**5 832,4**
m	LHC Machine Test and operation	88,3	192,6	280,9	25,5	42,0	67,5	80,2	64,7	144,9	194,0	299,3	493,3
n	Detectors: Test and operation		153,8	153,8	42,3	18,6	60,9	74,9	13,4	88,4	117,3	185,8	303,1
o=l+m+n	**TOTAL LHC: Machine + Detectors + Infrastr. + Injectors + Computing + Operation**	**1 865,8**	**3 983,5**	**5 849,3**	**214,8**	**255,5**	**470,4**	**182,8**	**126,3**	**309,1**	**2 263,5**	**4 365,3**	**6 628,8**

* 2007 Budget increased by 21.35 MCHF for the LHC machine project costs.

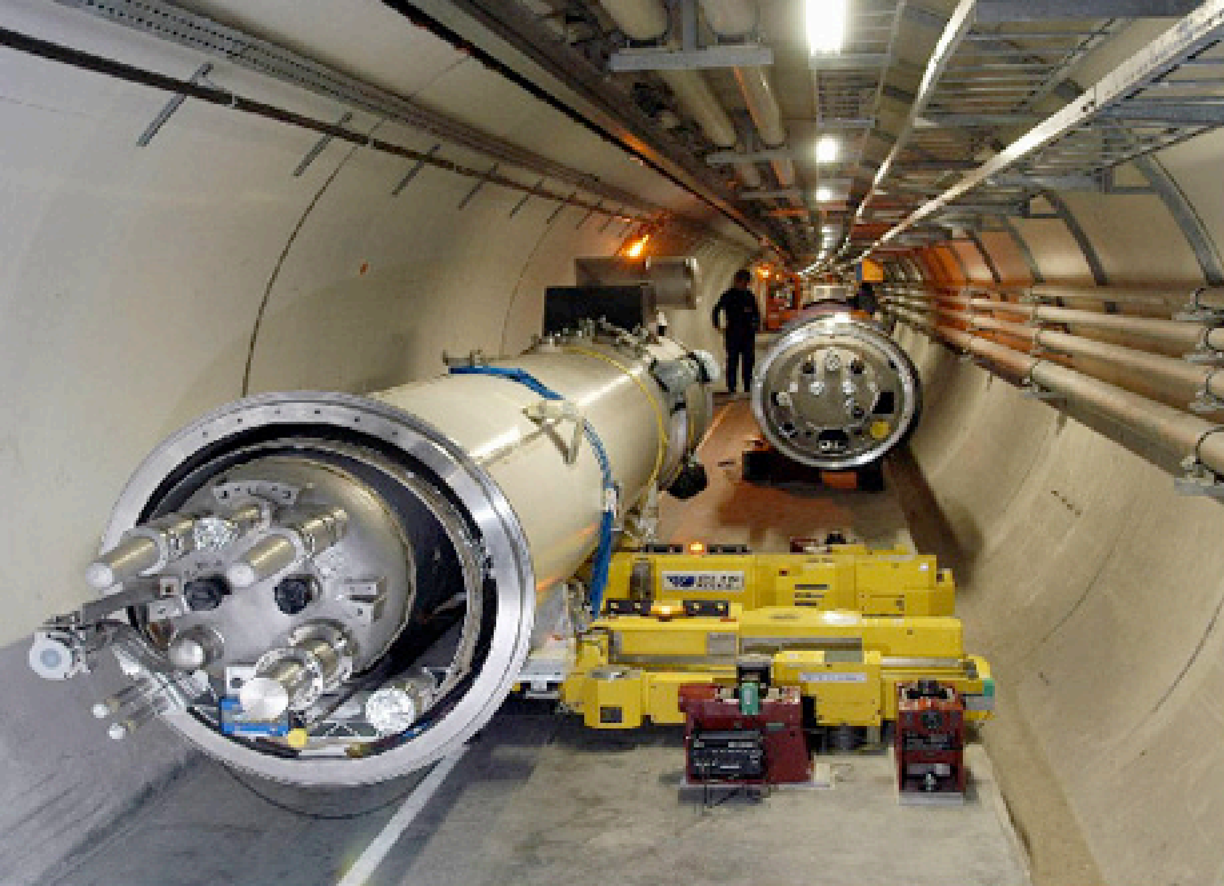
~6630 MCHF ≈ 4000 M€

Ensamblaje final de los crioimanes en el CERN

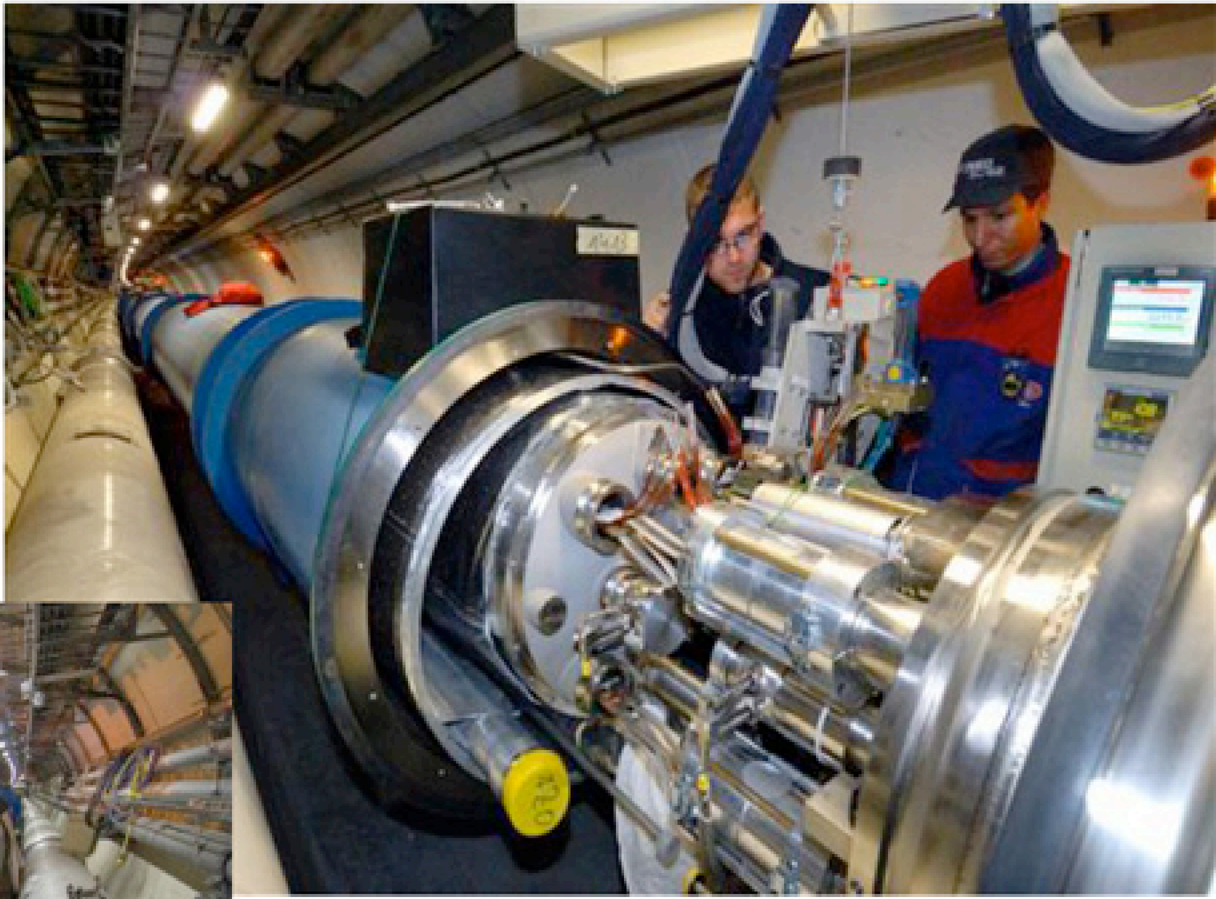
Pruebas criogénicas de imanes

Primer criodipolo: 7 Marzo 2005

Último criodipolo: 26 Abril 2007



Interconexiones en el túnel



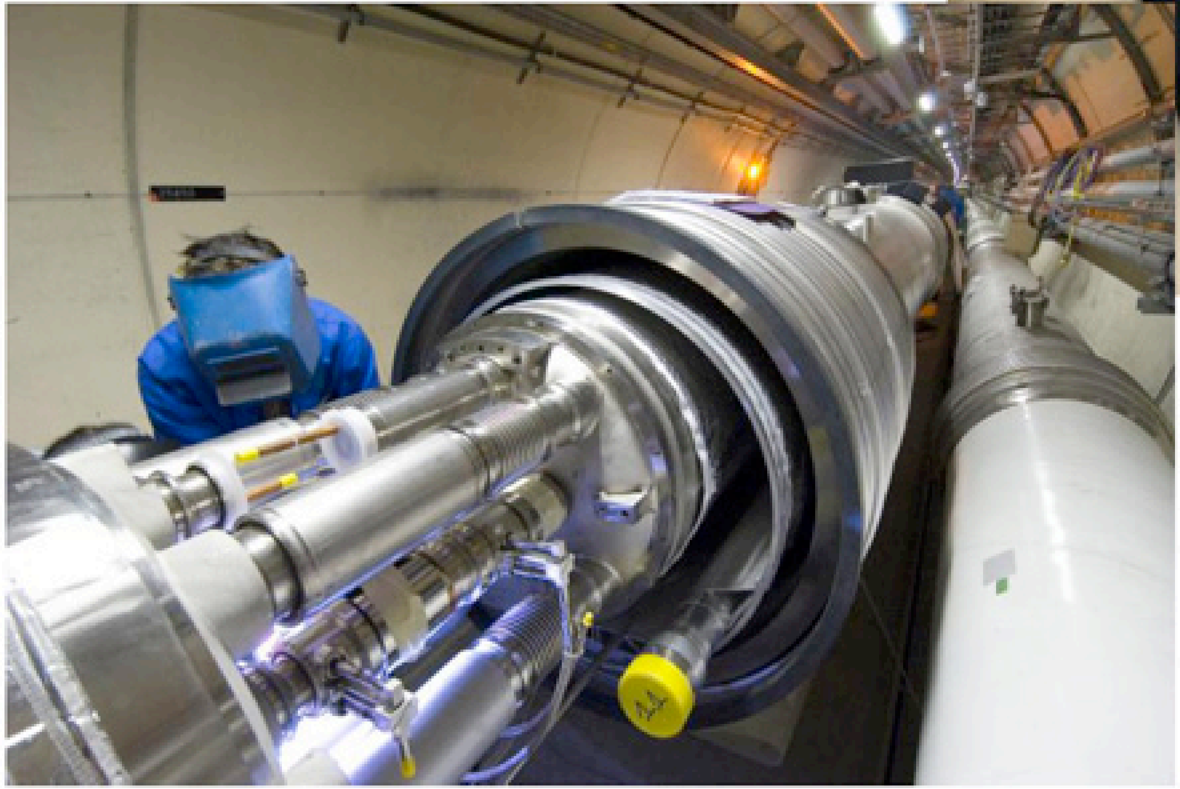
65’000 junturas eléctricas

Soldadura por inducción-térmica

Soldadura ultrasónica

Muy baja resistencia residual

Aislamiento eléctrico HV



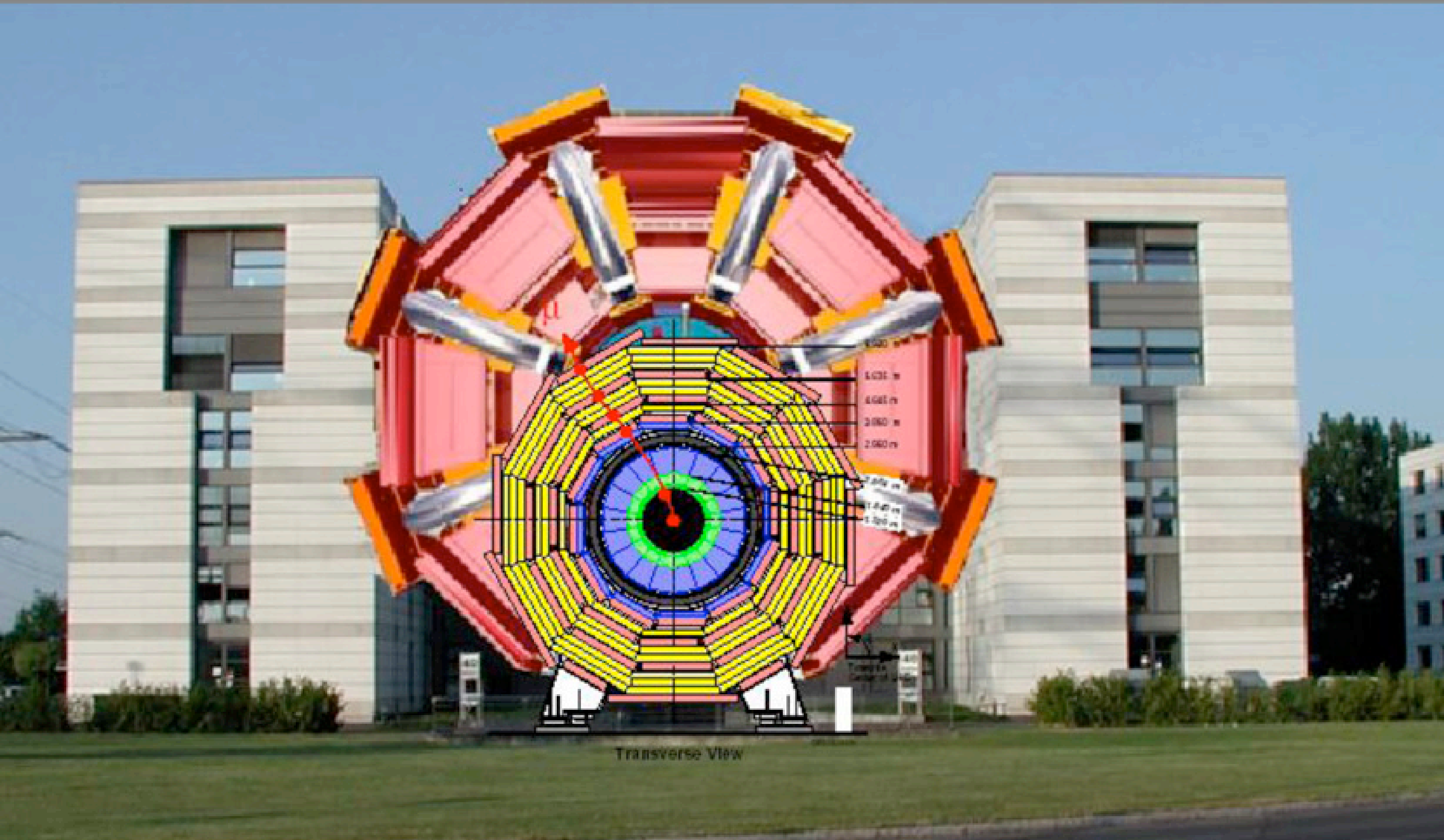
40’000 empalmes criogénicos

Soldadura orbital TIG

Calidad de soldadura

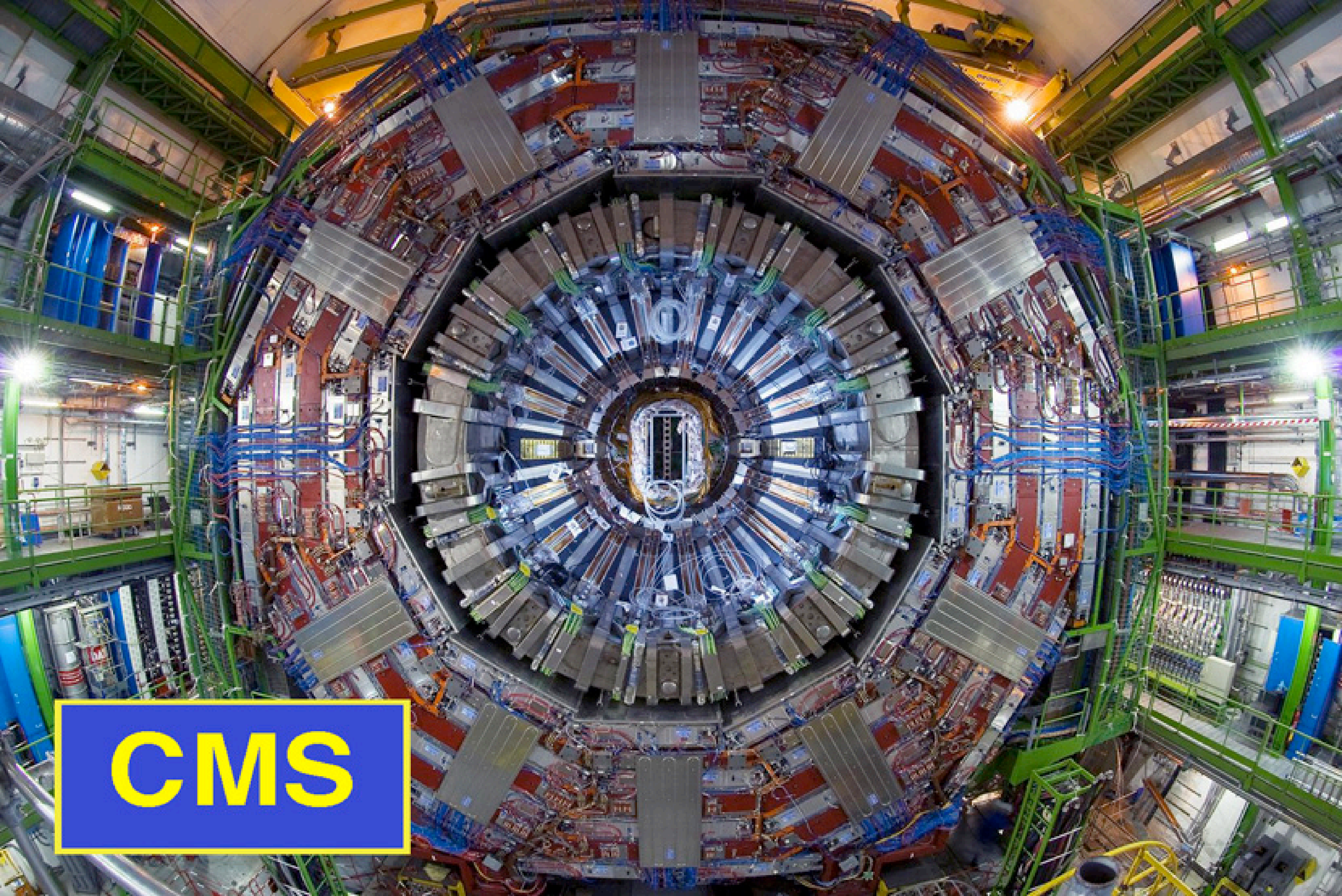
Estanqueidad fugas de Helio

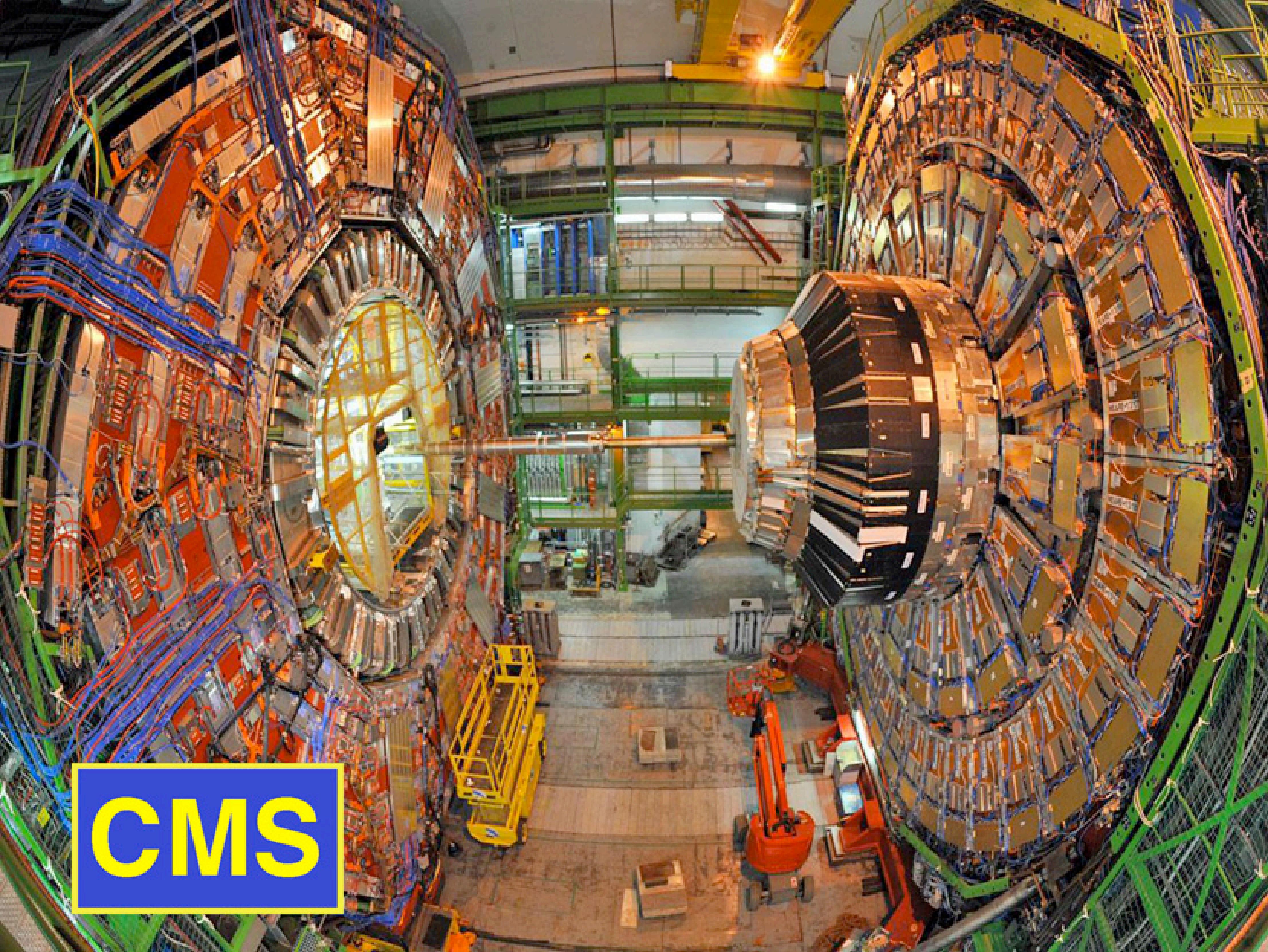
Los Experimentos del Large Hadron Collider

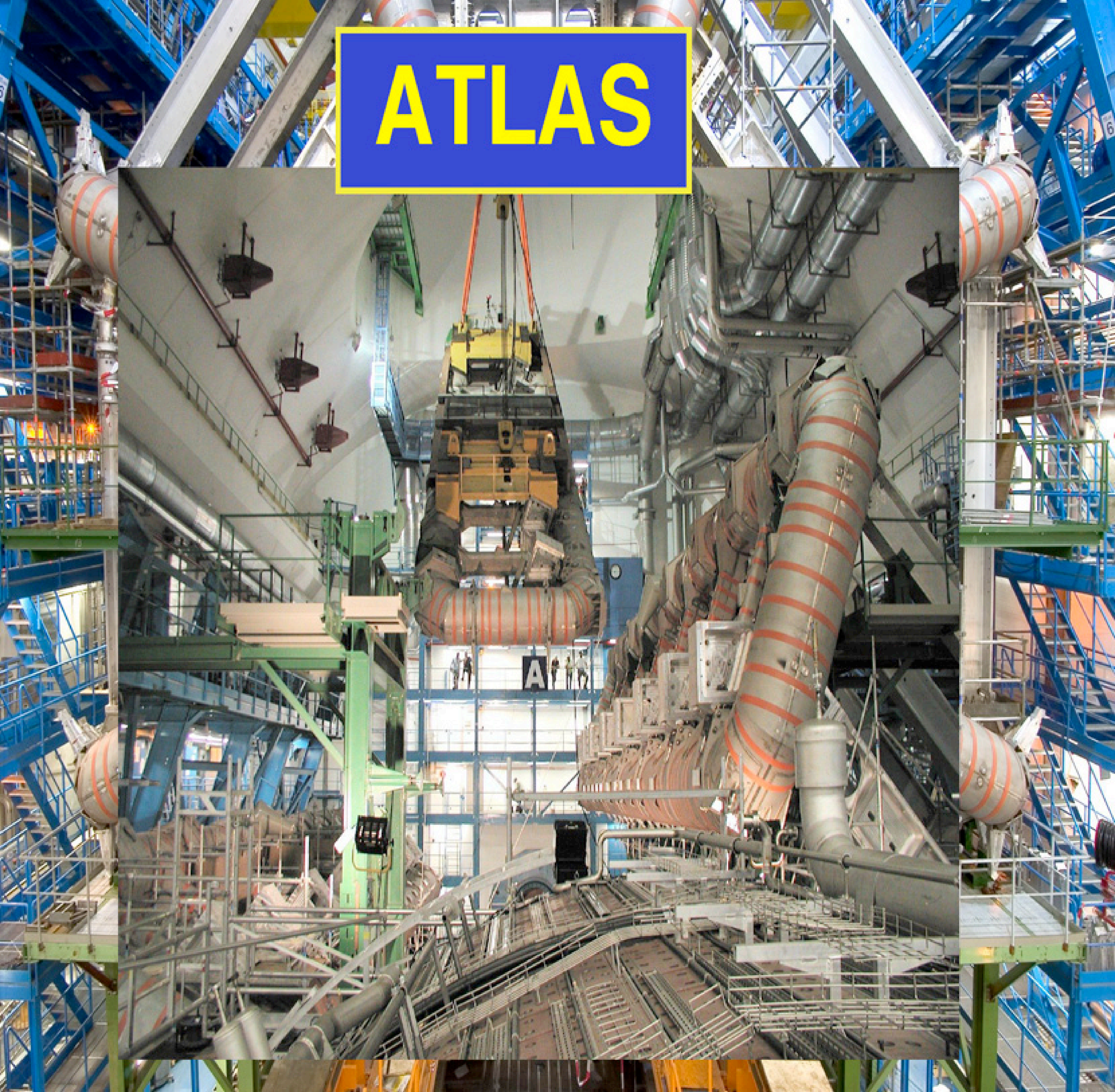

μ
Transverse View

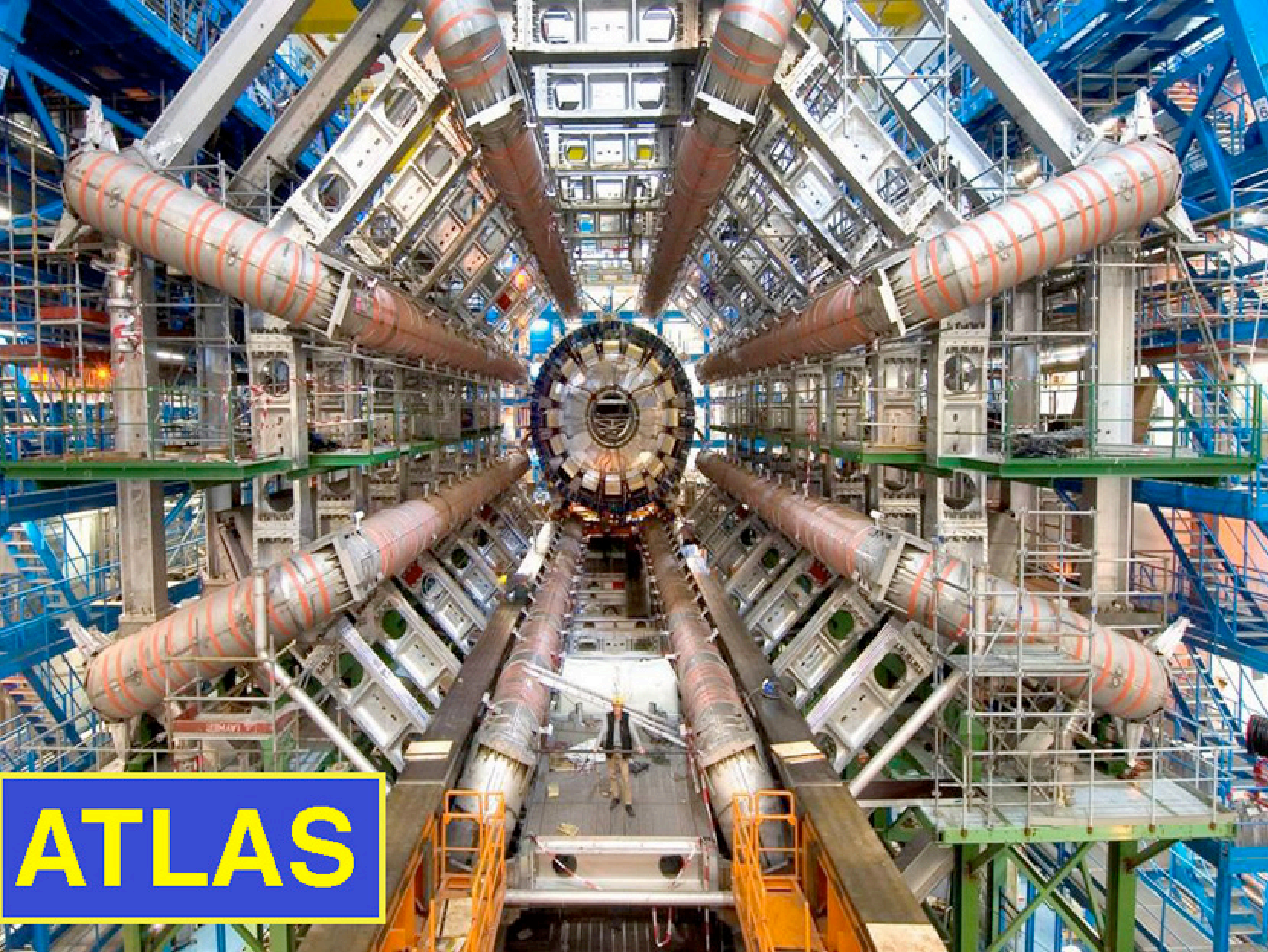
ESPAÑA EN ATLAS Y CMS

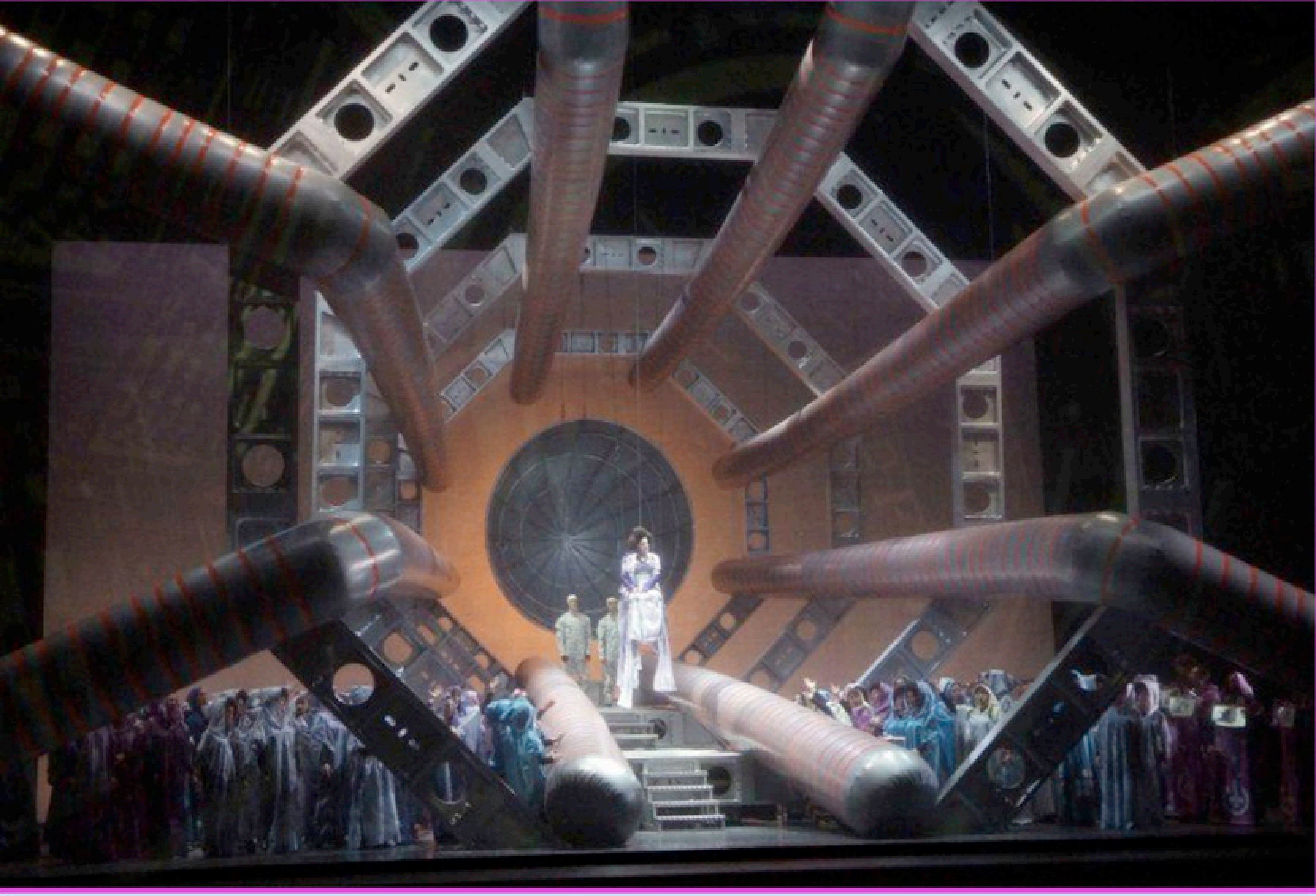

felguera
construcciones
mecánicas, s.a.
A16 A15 A14 A13
B15 B14 B13 B12
D7 D6


CMS

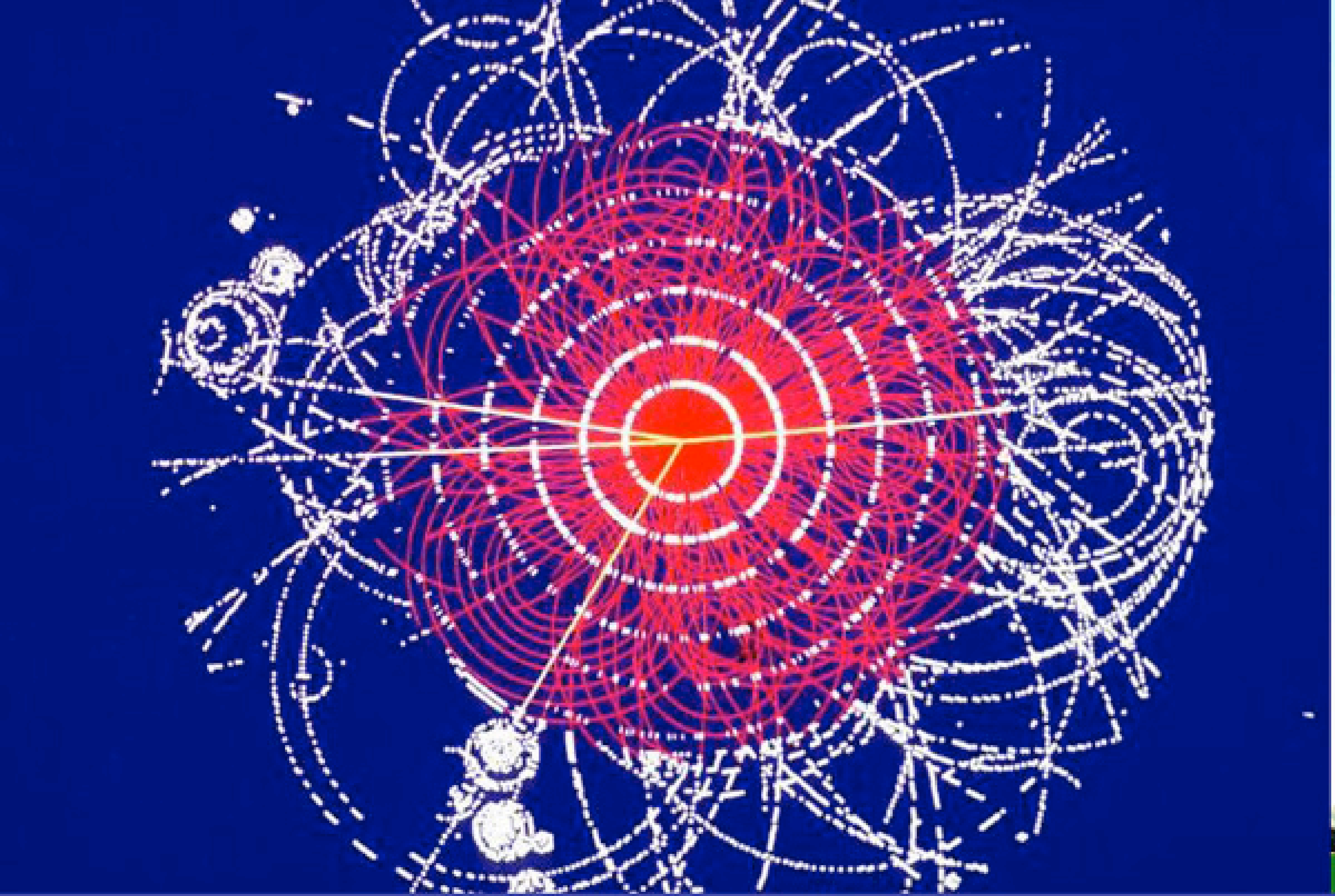

CMS

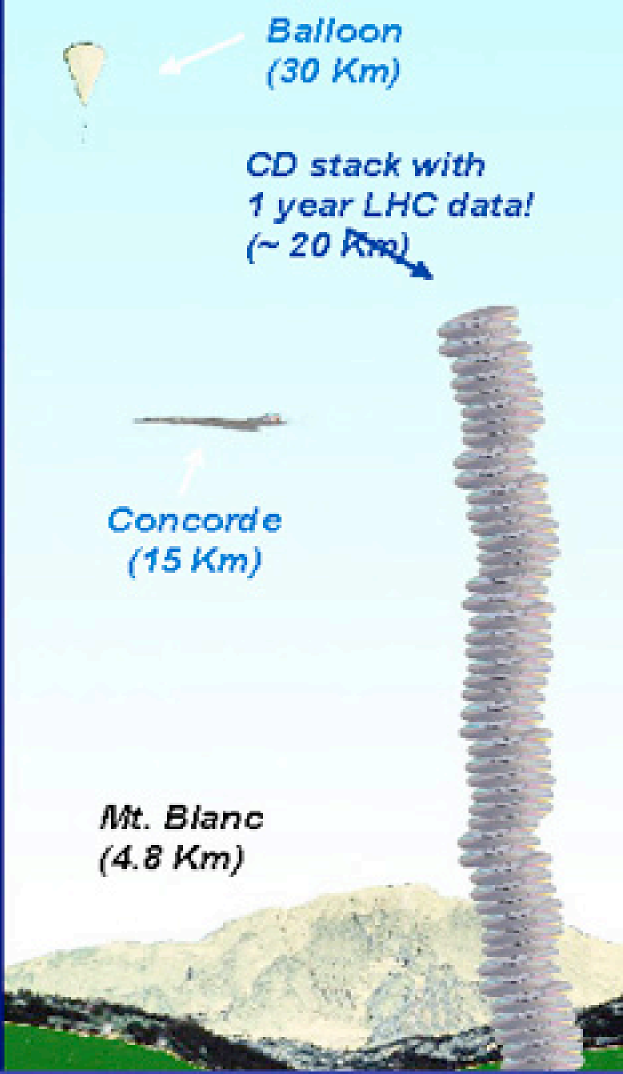

ATLAS


ATLAS



Hector Berlioz, “Les Troyens”, opera en cinco actos
Valencia, Palau de les Arts Reina Sofia, 31 Octobre–12 Noviembre 2009

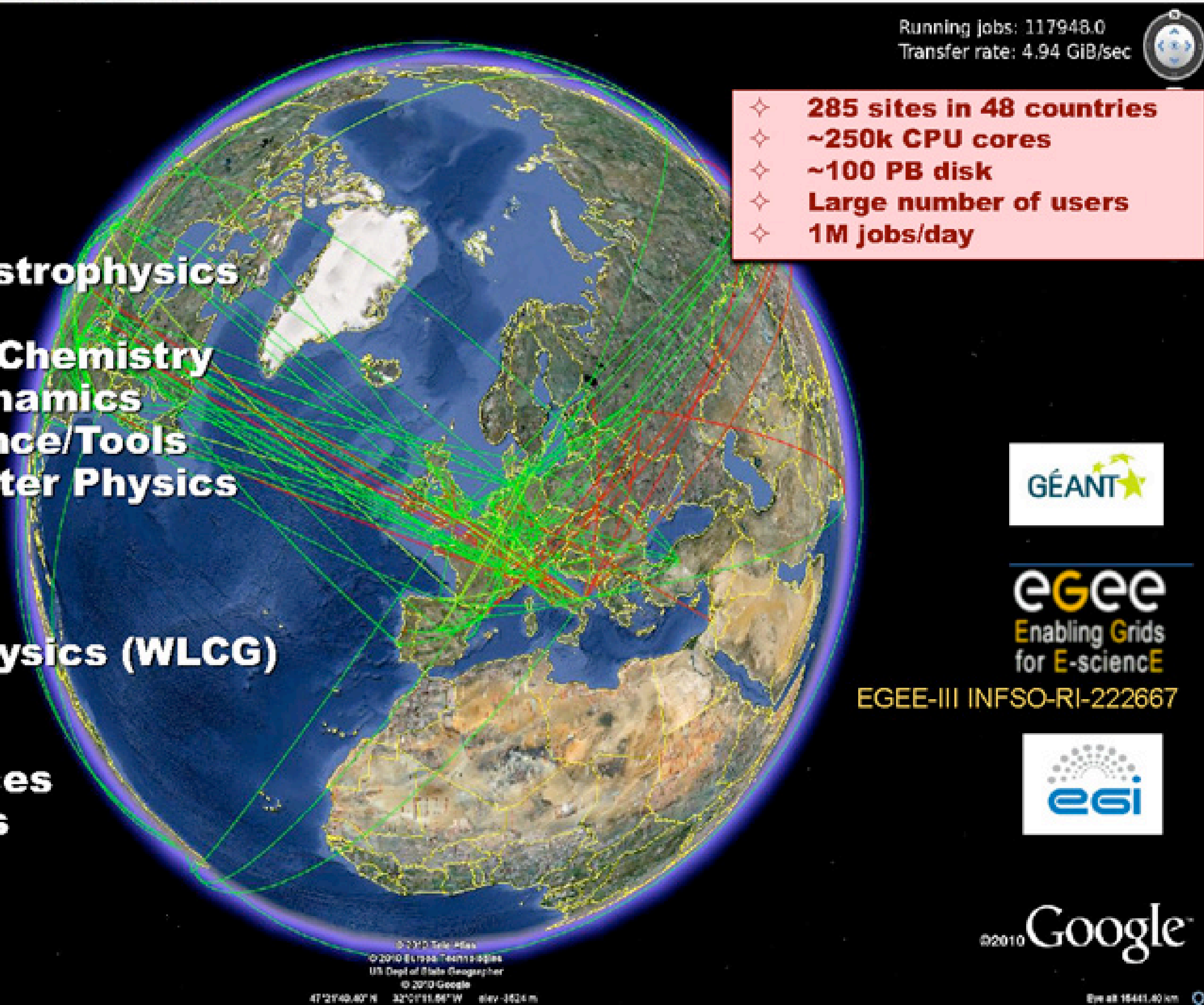




Los Experimentos producirán ~15 Millones de Gigabytes de datos cada año (~ 5 millones de DVDs!)

El analísis de los datos del LHC requiere una potencia de cálculo equivalente a ~100,000 procesadores PC de última generación

CERN y la Computación Grid



- 285 sites in 48 countries
- ~250k CPU cores
- ~100 PB disk
- Large number of users
- 1M jobs/day

Astronomy & Astrophysics
Civil Protection
Computational Chemistry
Comp. Fluid Dynamics
Computer Science/Tools
Condensed Matter Physics
Earth Sciences
Finance
Fusion
High Energy Physics (WLCG)
Humanities
Life Sciences
Material Sciences
Social Sciences

LCG

GÉANT

eGee
Enabling Grids for E-sciencE
EGEE-III INFSO-RI-222667

egi

PUERTO DE INFORMACIÓN CIENTÍFICA (PIC)

CIEMAT / UB-IFAE-DEI

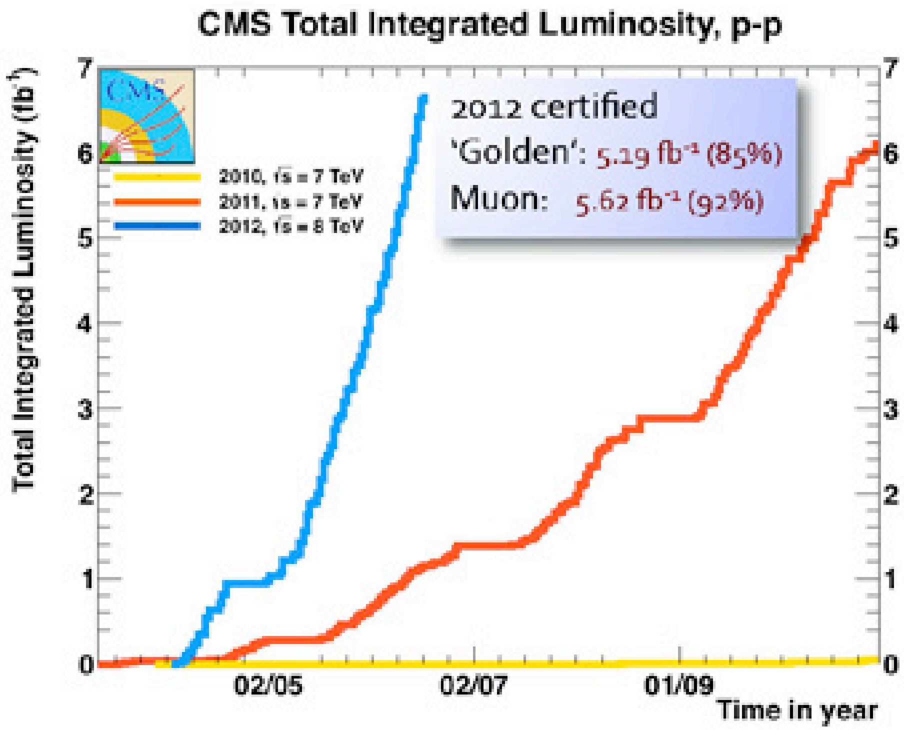
Análisis de datos del LHC

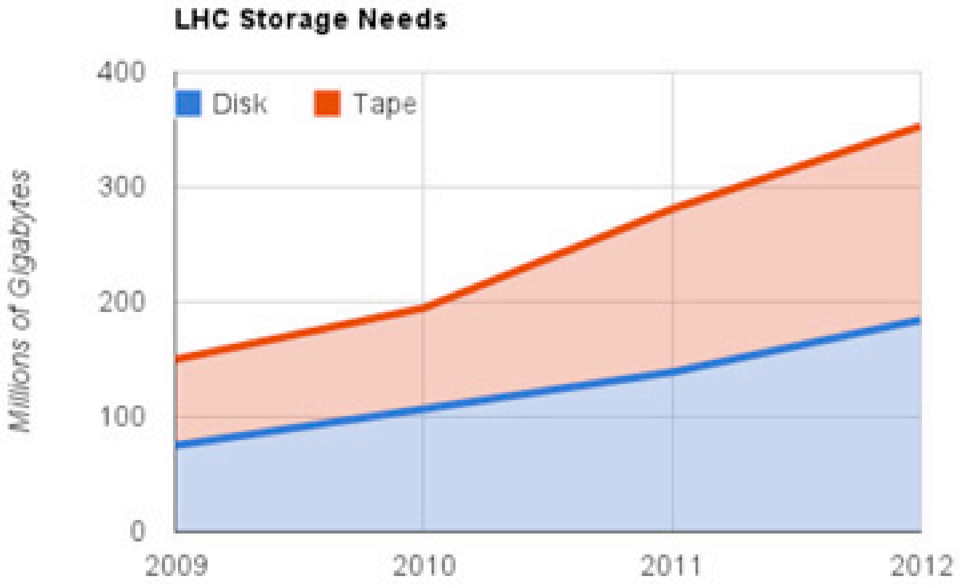
El LHC, pese a su extrema complejidad, ha funcionado perfectamente desde que se puso en marcha a finales de 2009.

Ha generado billones de colisiones protón-protón, que los detectores han registrado acumulando centenares de millones de Gigabytes de datos (centenares de Petabytes de datos).

1 Petabyte equivale a unos 13 años de video de alta definición. Se estima que toda la obra escrita desde el principio de la humanidad ocuparía 50 Petabytes. El volumen fabricado mundialmente de discos duros fue 20 Petabytes en 1995. 10.000 millones de fotos guardadas en Facebook ocuparían 1,5 Petabytes.

Fuente: http://www.smashingapps.com/2010/12/02/how-much-is-a-petabyte-graphic.html





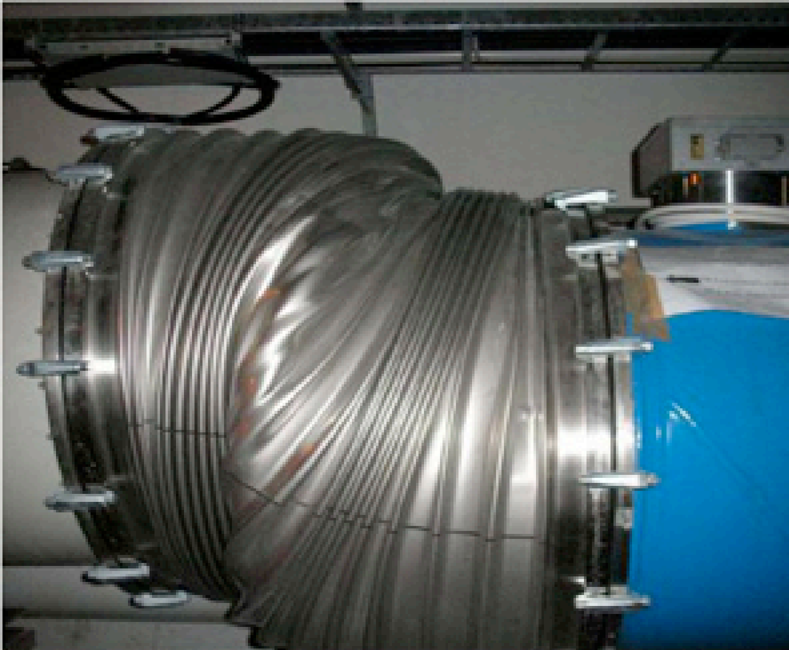
10/09/2008

¡¡ Funciona !!

El LHC se incorpora a la cultura popular

19/09/2008

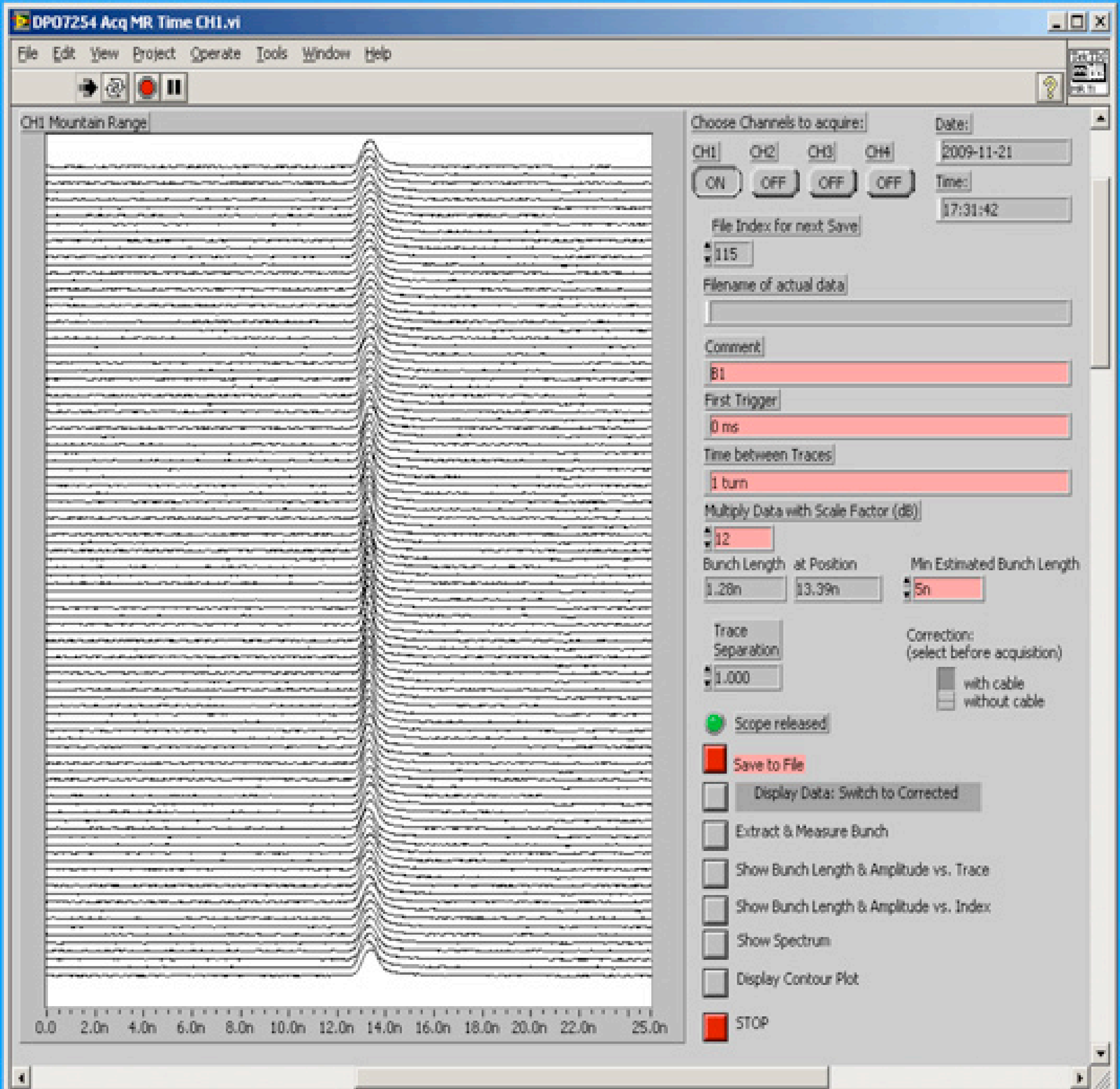
Incidente Importante



Desplazamientos de imanes

Daños colaterales

¡ NOVIEMBRE 2009 !

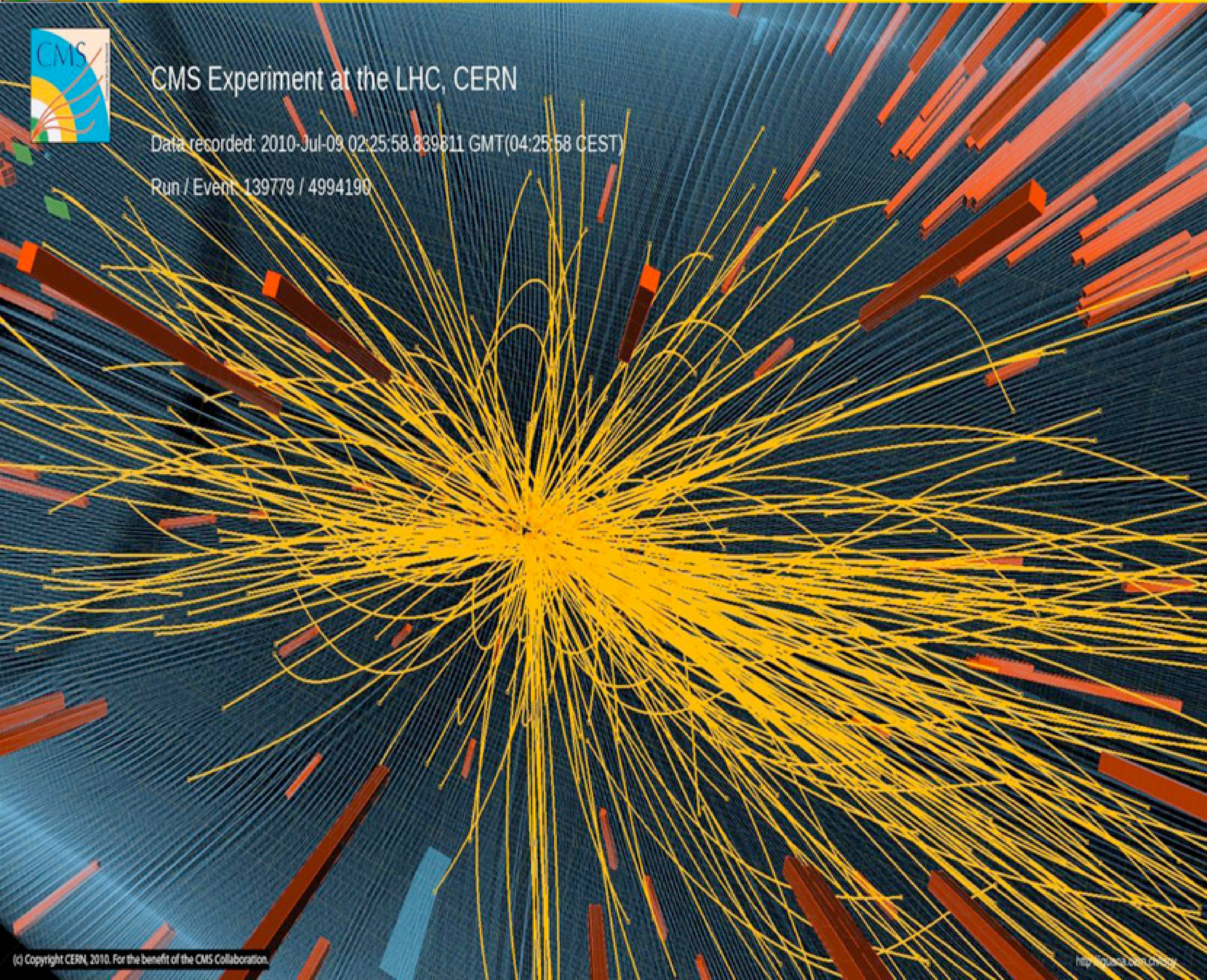


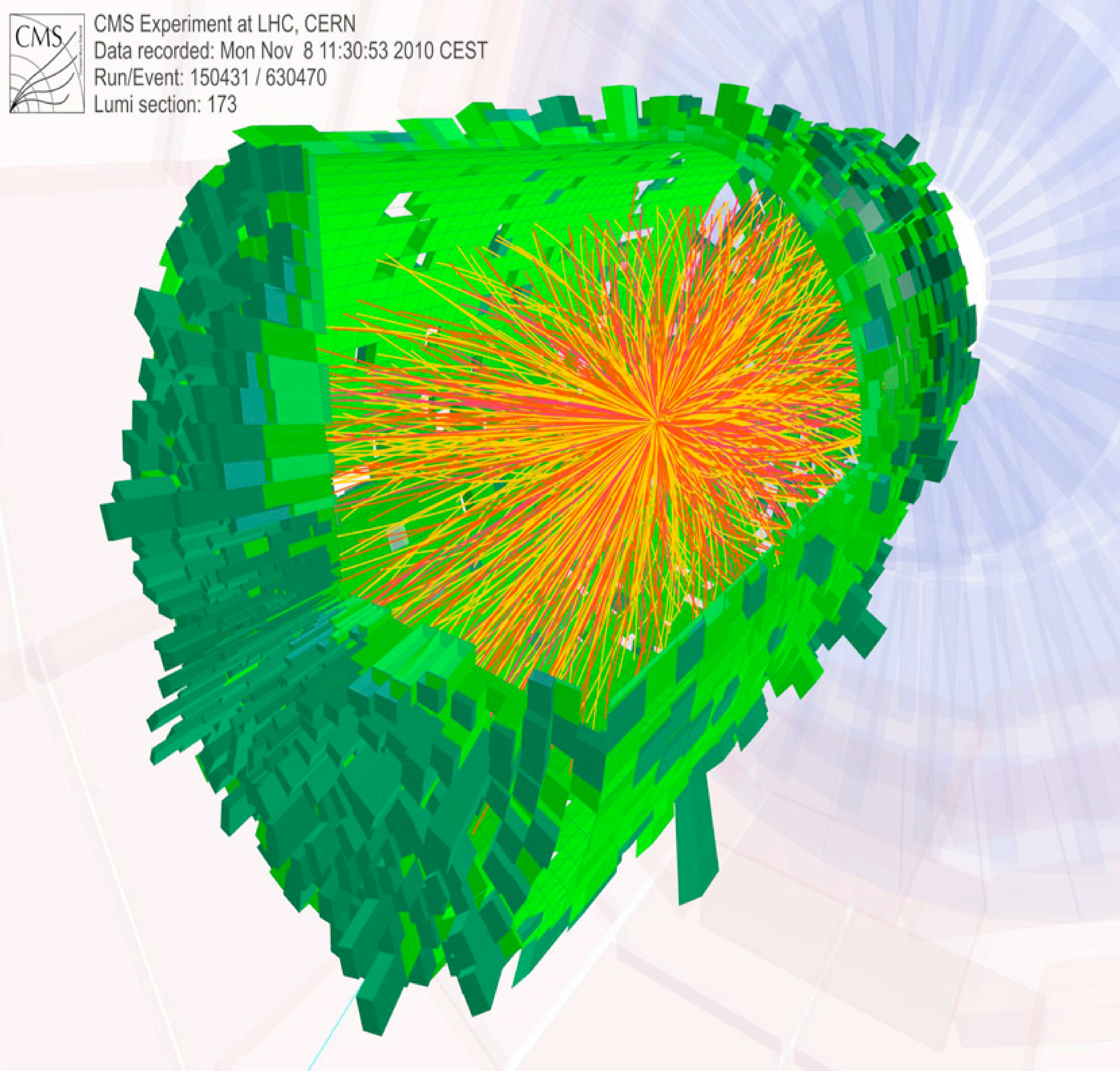
STEVE MYERS

HAZ CIRCULANDO Y ESTABLE

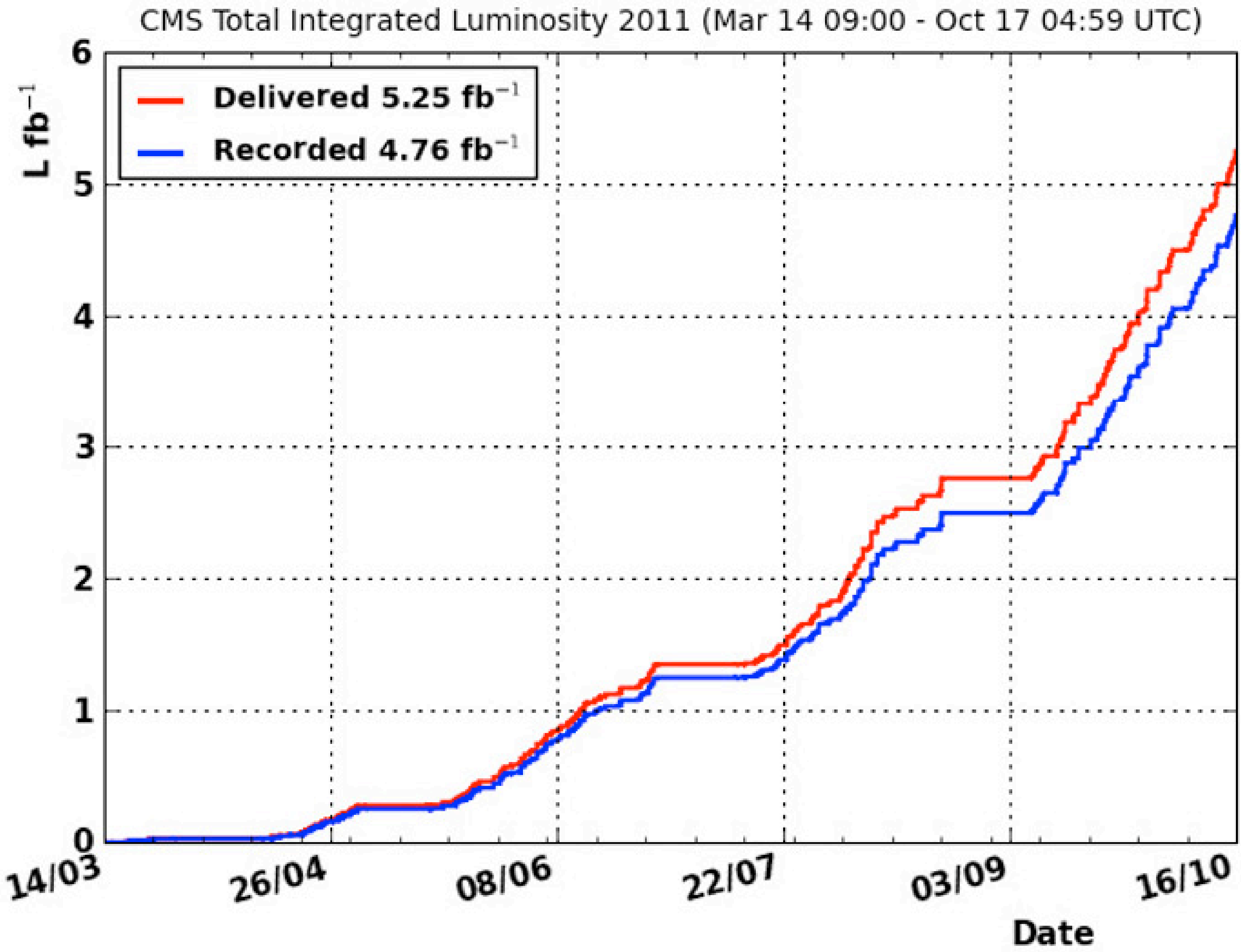
- magnets
- power supplies
- vacuum
- RF
- cryogenics
- all infrastructure
- optics
- injection

Long–Range Near–Side Angular Correlations in Proton–Proton Interactions at CMS




CMS
CMS Experiment at LHC, CERN
Data recorded: Mon Nov 8 11:30:53 2010 CEST
Run/Event: 150431 / 630470
Lumi section: 173

Luminosidad LHC: Suministrada & Registrada



Previsión para 2011 : 1 fb^{-1} Conseguido a finales de junio !!!

EPS 2011 (julio) : se presentan resultados con ~ 1 fb^{-1}

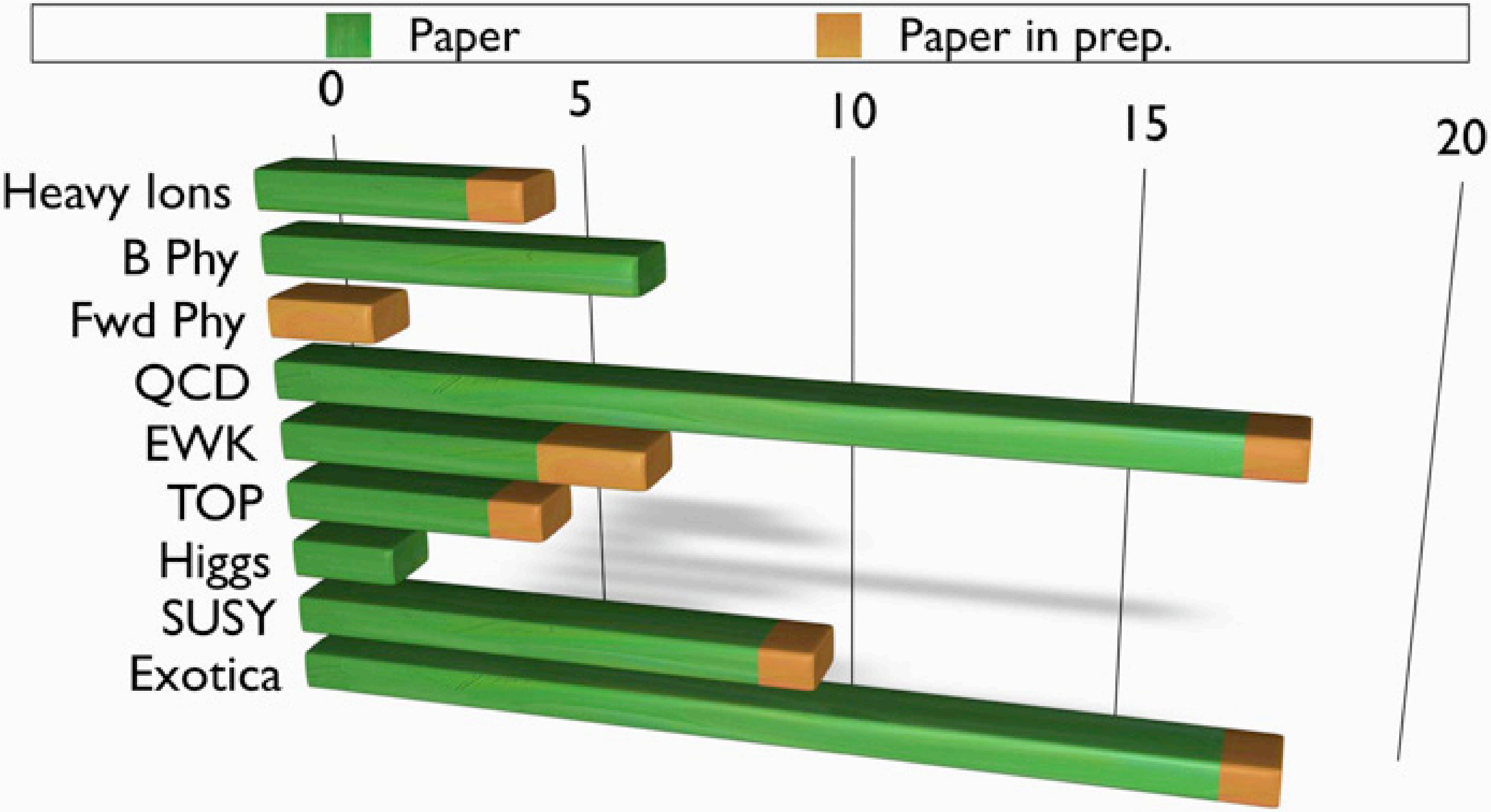
LP 2011 (agosto) : se presentan resultados con ~ 2 fb^{-1}

ICFA Seminar (septiembre) : se llega a 4 fb^{-1}

FINAL DEL PERIODO DE DATOS 2011 (octubre) : ~ 5 fb^{-1}


FASCINANTE
POTENCIAL
CIENTÍFICO

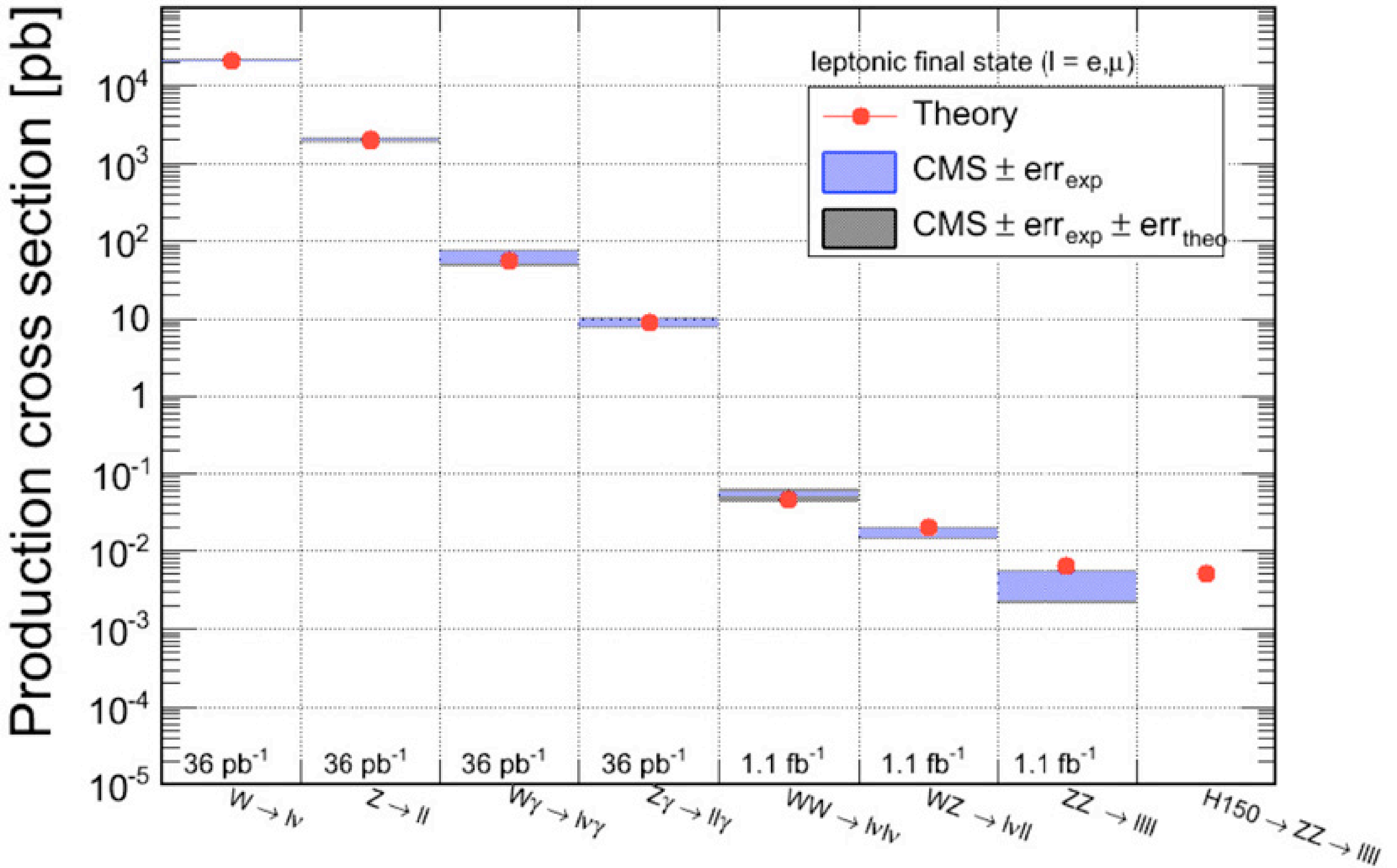
ARTÍCULOS PUBLICADOS POR CMS … HASTA JULIO 2011



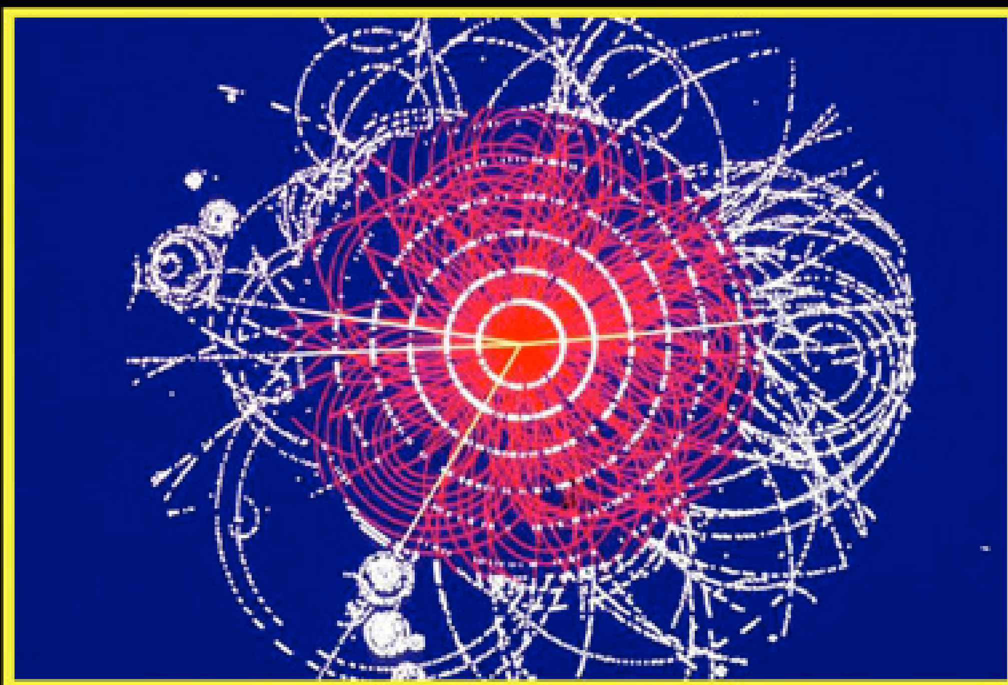
In total : **65** papers on physics analyses, submitted, accepted or published
9 papers close to submission

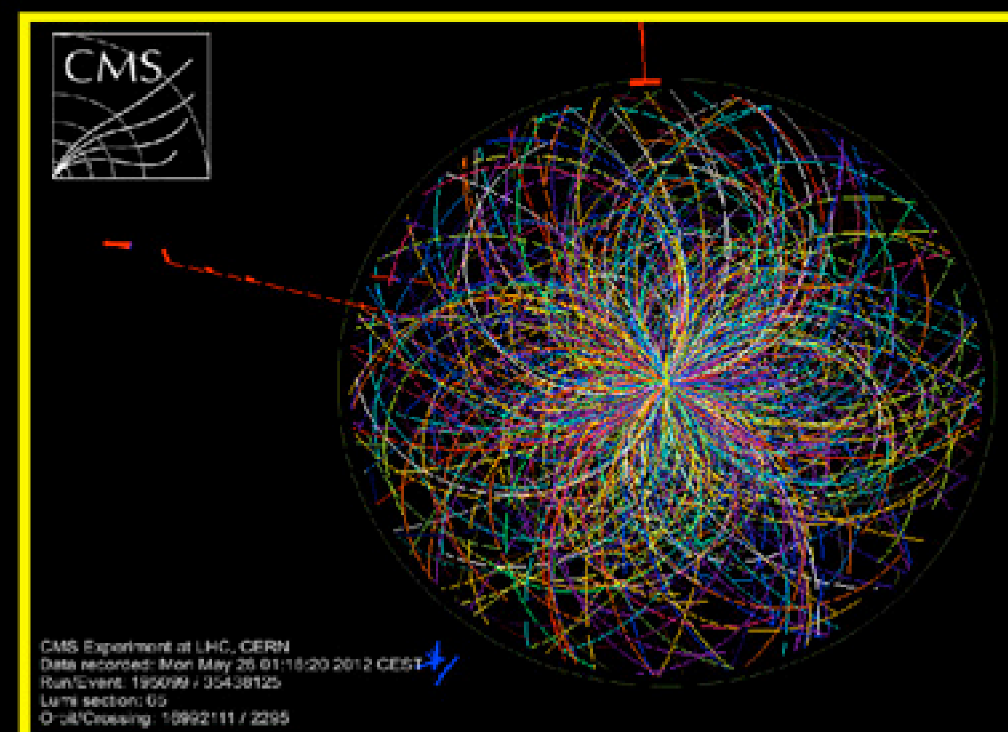
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Bosones & di-Bosones EWK

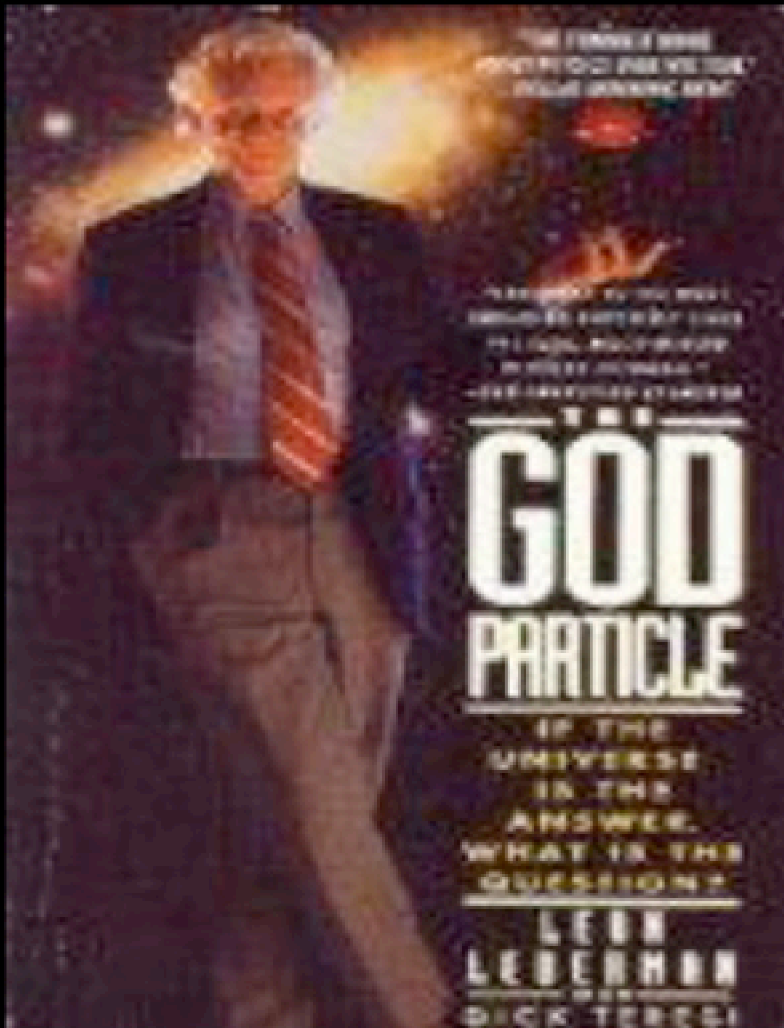


BÚSQUEDA DEL BOSÓN DE HIGGS, LA PARTÍCULA DIVINA





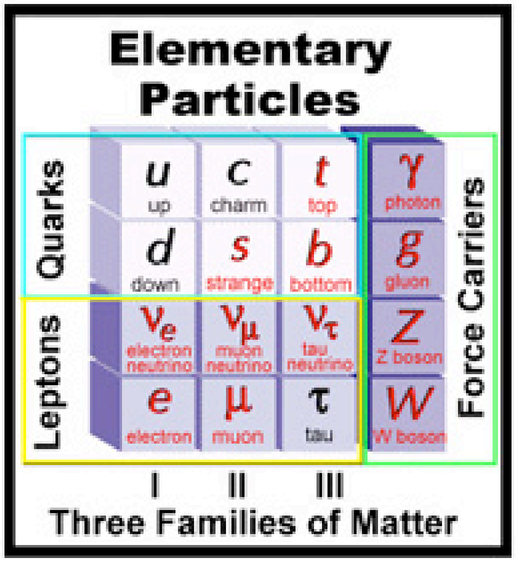
THE GOD PARTICLE



¿SI EL UNIVERSO
ES LA RESPUESTA,
CUÁL ES LA PREGUNTA?

LEON
LEDERMAN

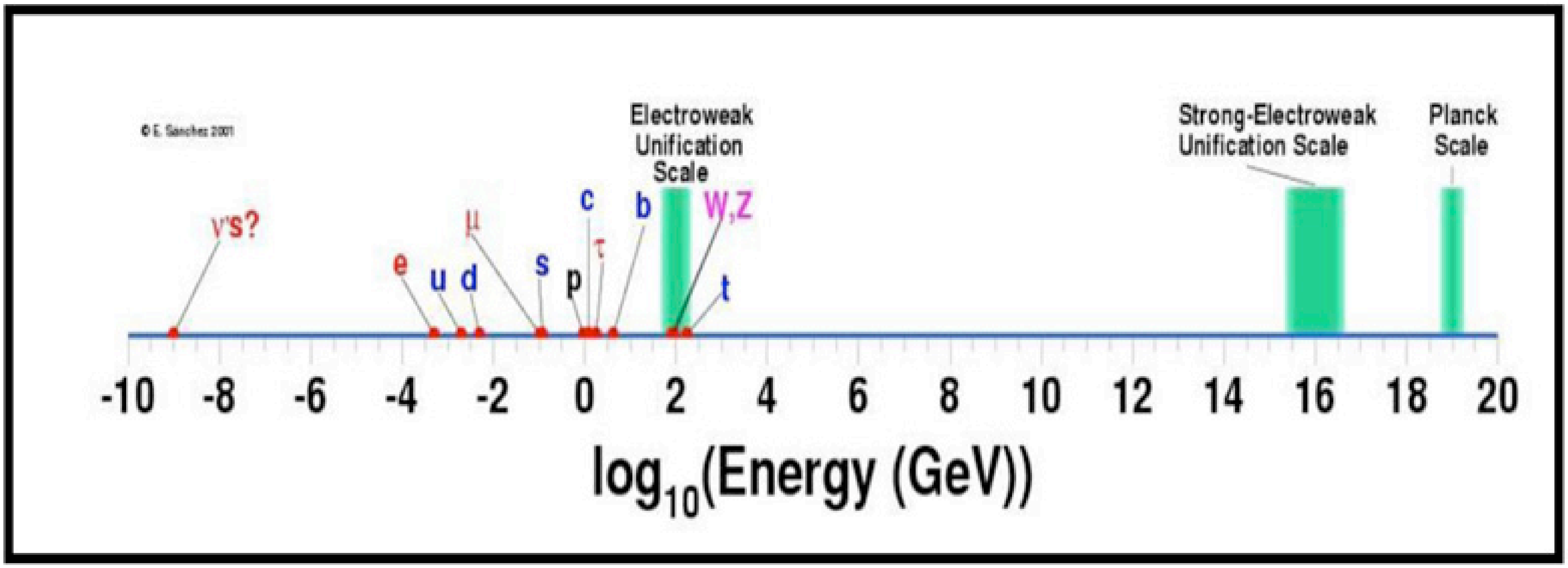
PETER HIGGS



BOSÓN DE HIGGS

EL HUECO EN EL CONOCIMIENTO DE LO ORDINARO

γ(m=0), $W^{\pm}$ (m≈80 GeV), Z (m≈91GeV)



- **JERARQUÍA**
- **NATURALIDAD**

¿QUÉ SABEMOS DEL BOSÓN DE HIGGS?

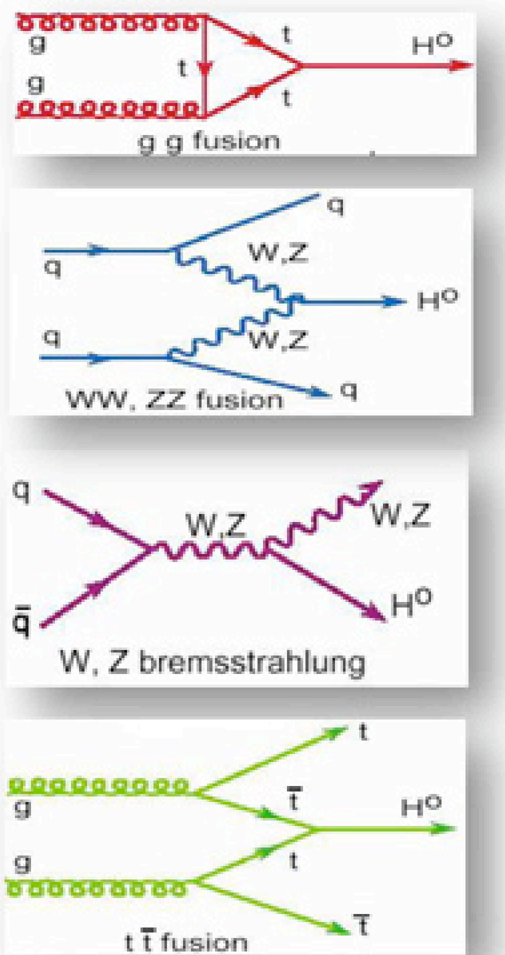
TODO ....
MENOS EL VALOR DE SU MASA m_H

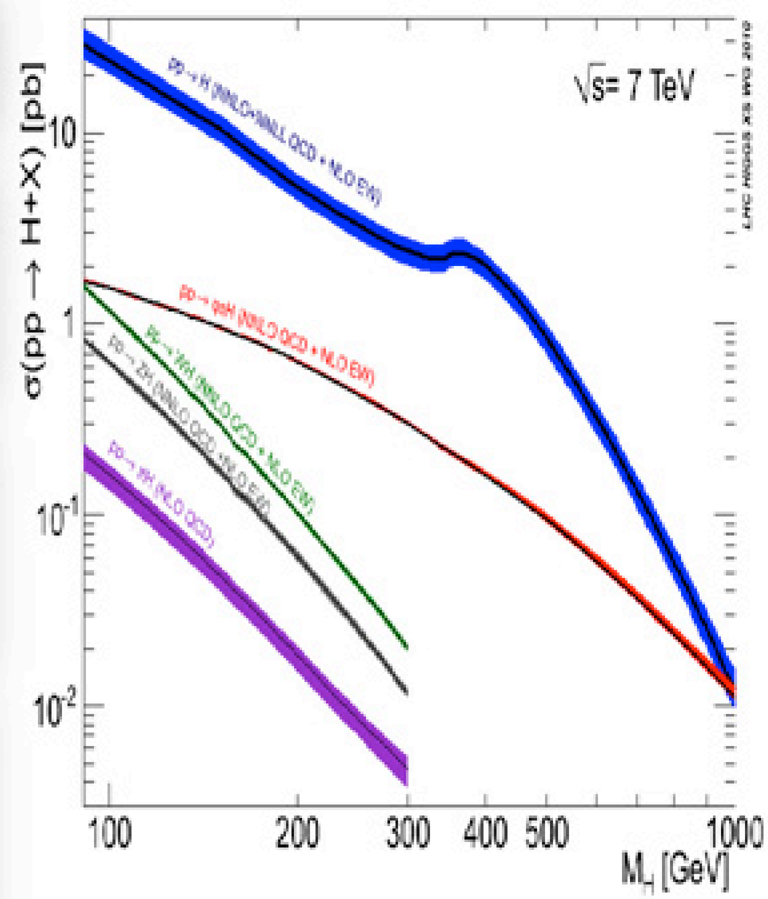
ESPÍN, PARIDAD, VIDA MEDIA, MODOS Y FRECUENCIAS DE DESINTEGRACIÓN, MECANISMOS DE PRODUCCIÓN, ETC

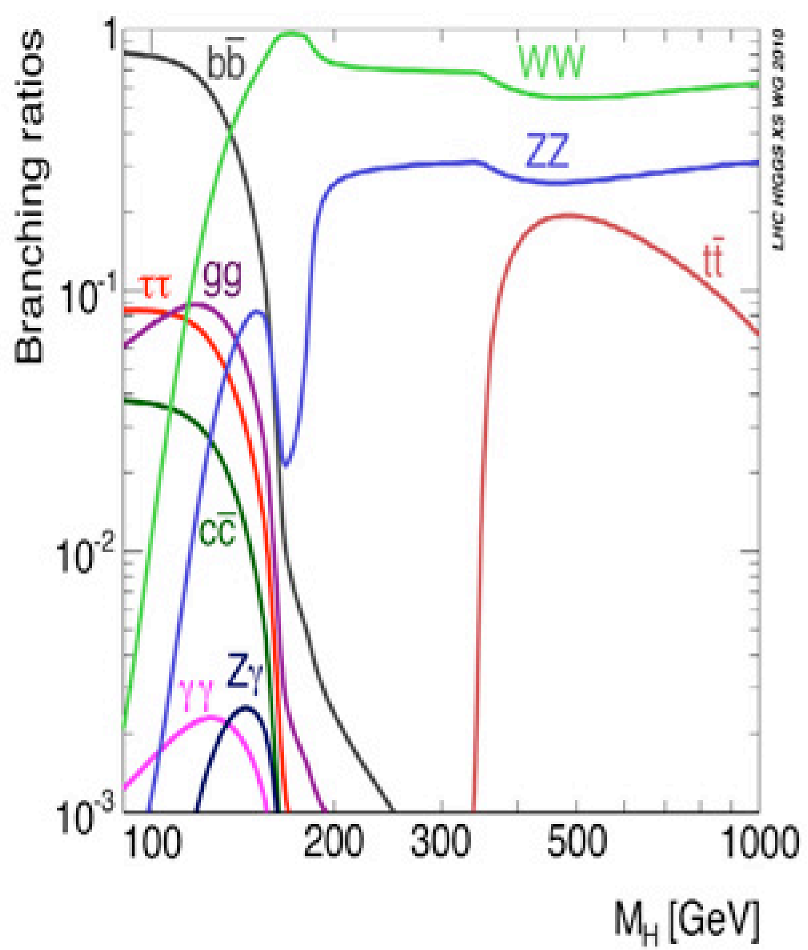
PRODUCCIÓN & DESINTEGRACIÓN

- **El bosón de Higgs, caso de existir, se produciría en el LHC en procesos de fusión de gluones, fusión de bosones vectoriales….**

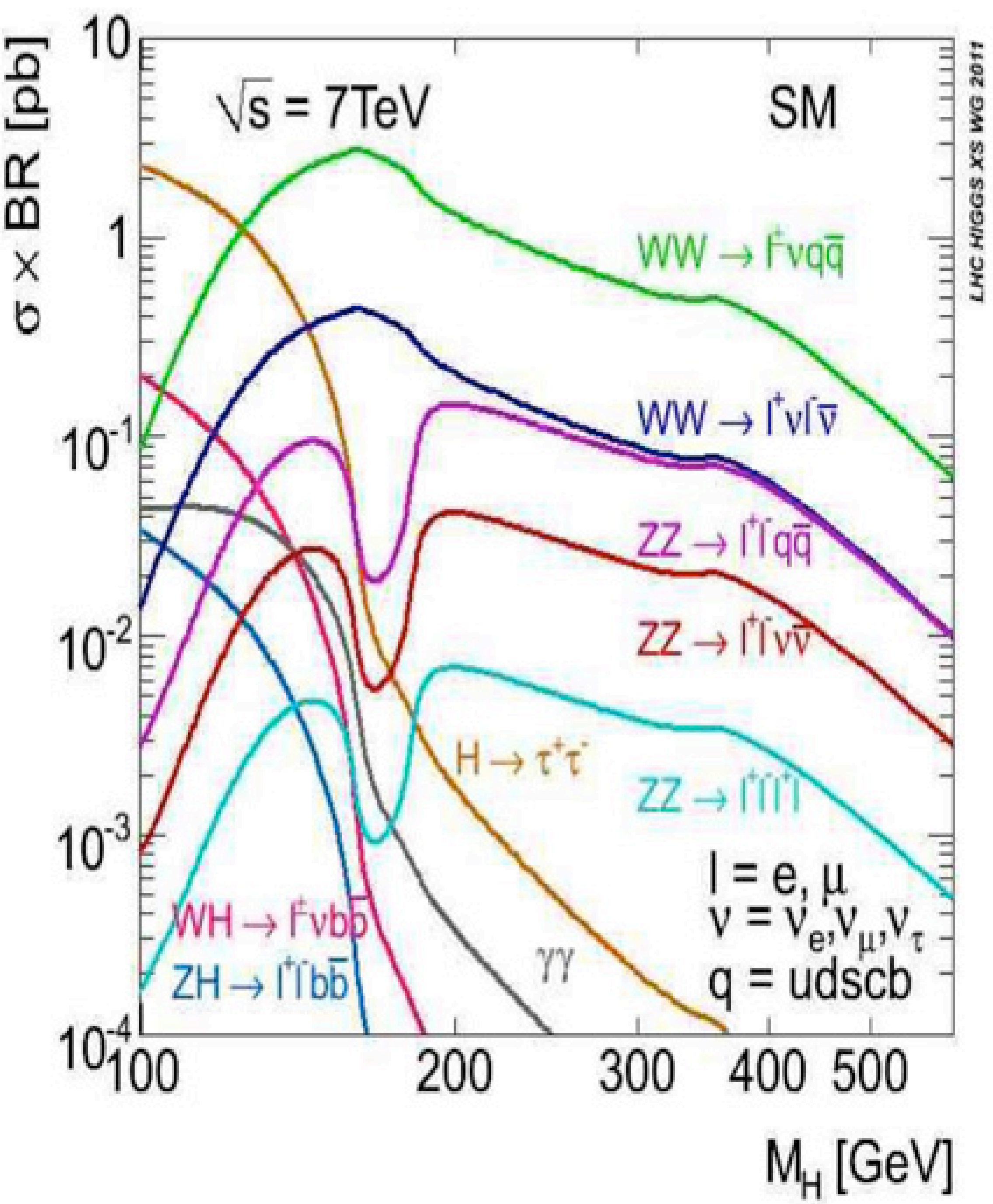
- **El bosón de Higgs se desintegraría en pares de fermiones o bosones. Los estados finales tendrían fotones de alto p_T, leptones y/o *jets*. Los ν's de alto p_T darían lugar a gran energía faltante E_T.**

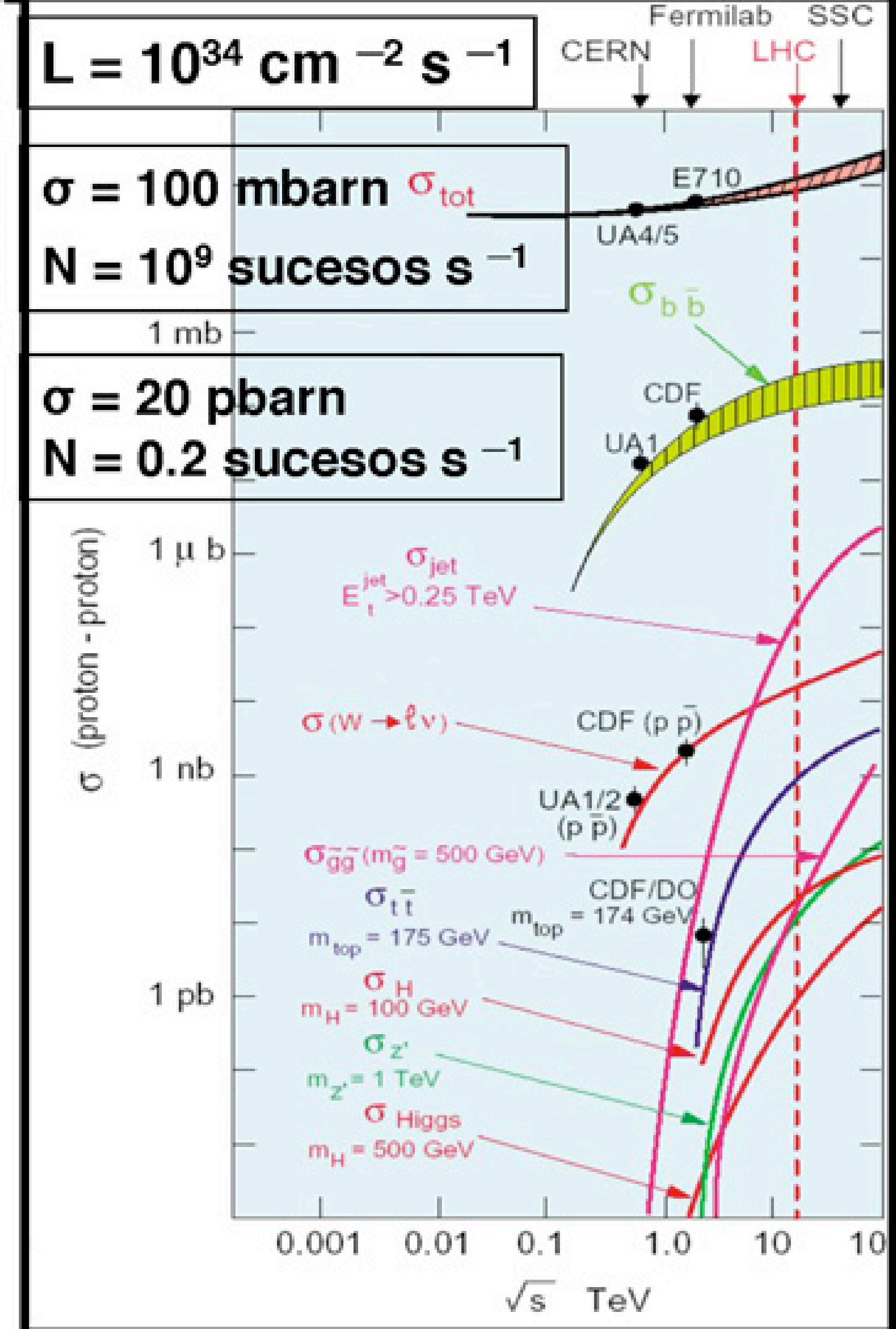






ESTADOS FINALES

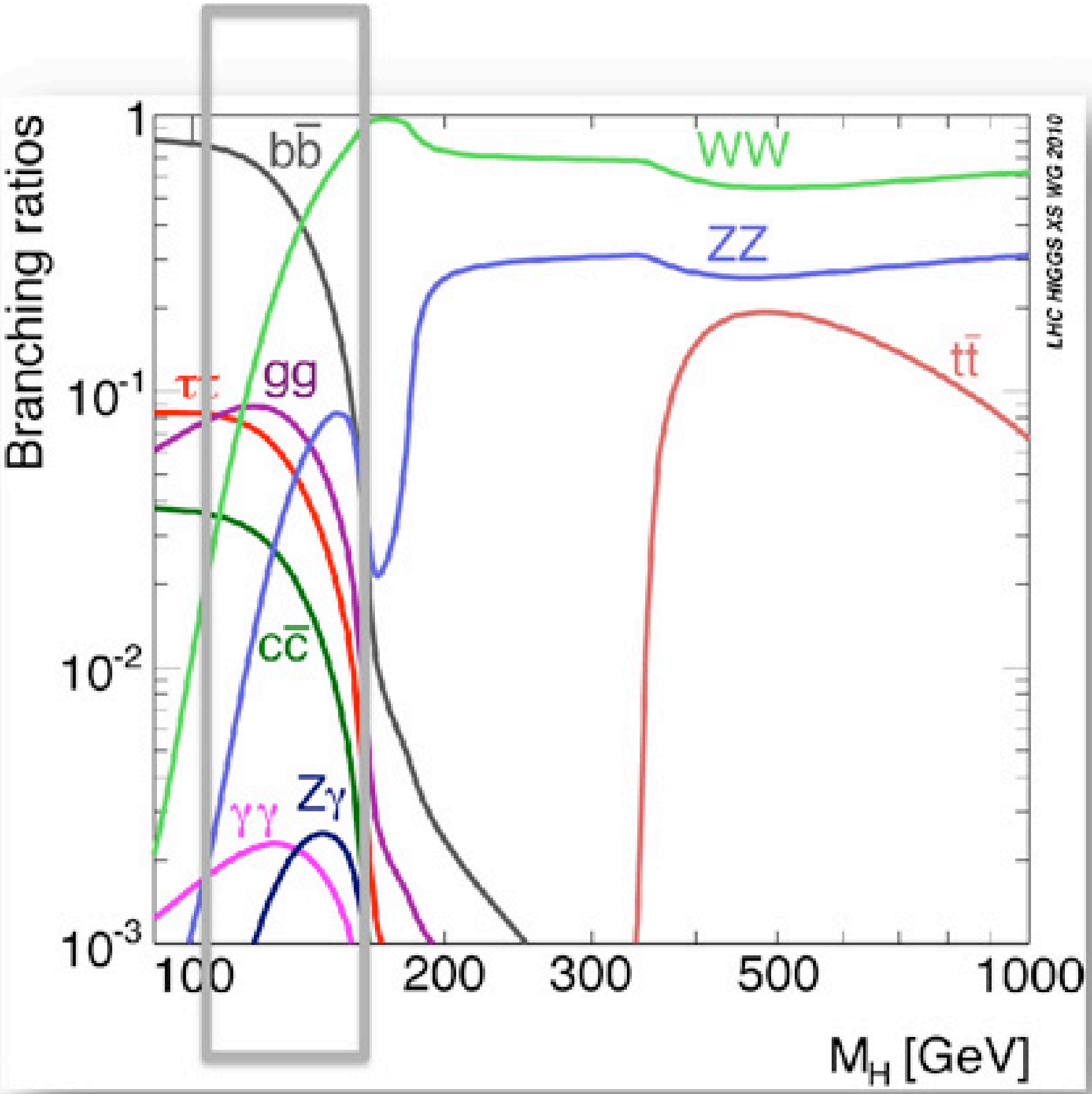




ESTADOS FINALES

5 MODOS UTILIZADOS

- **Alta masa : WW, ZZ**
- **Baja masa : bb, ττ, WW, ZZ, γγ**
- **Región de basa masa es muy difícil pero interesante:**
  Modos principales (bb, ττ) son difíciles a identificar con fondos enormes
- **Excelente resolución en masa (1%):**
  H→γγ and H→ZZ→4l

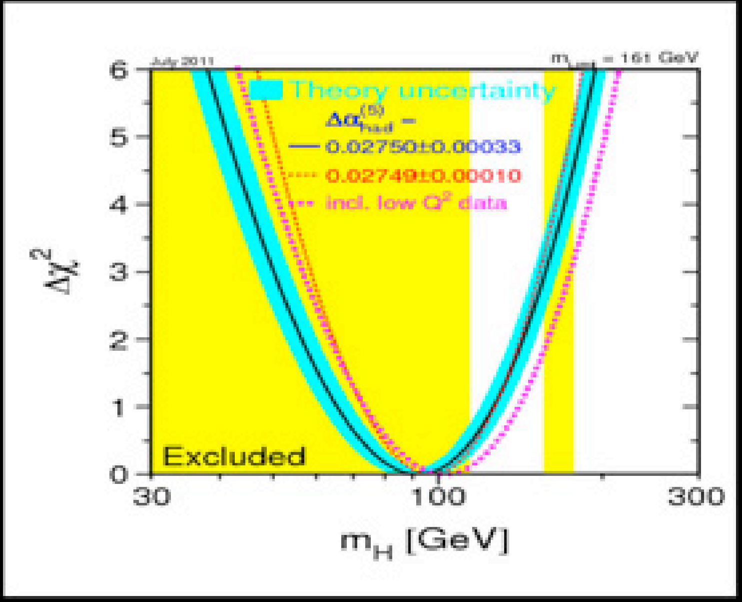


BÚSQUEDAS DEL BOSÓN DE HIGGS

Directa:

- **LEP**
  $e^+ e^- \rightarrow Z + H$

$m_H > 114.4$ GeV (95% CL)



Indirecta:

- **Medidas de alta precisión en LEP, Tevatrón**

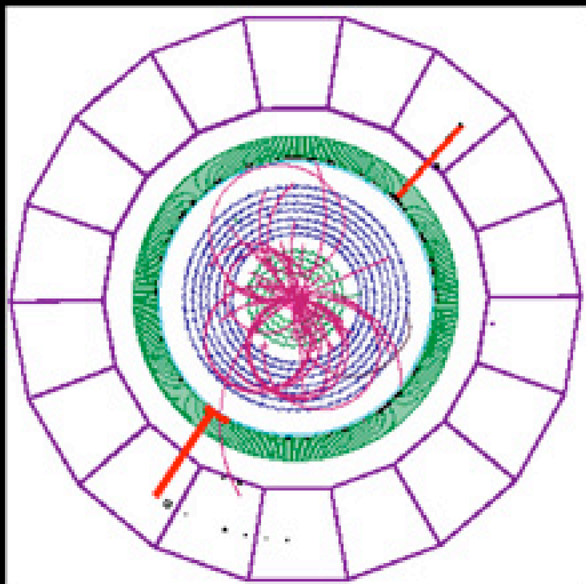
$m_H = 92^{+34}_{-26}$ GeV

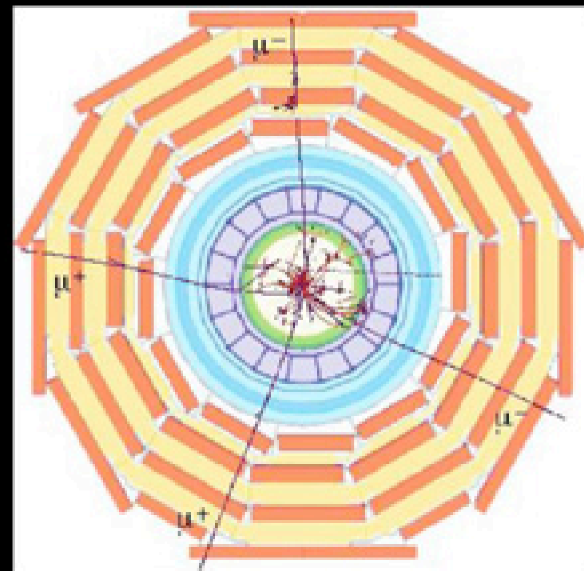
- **Límite superior a la masa del Bosón de Higgs:**

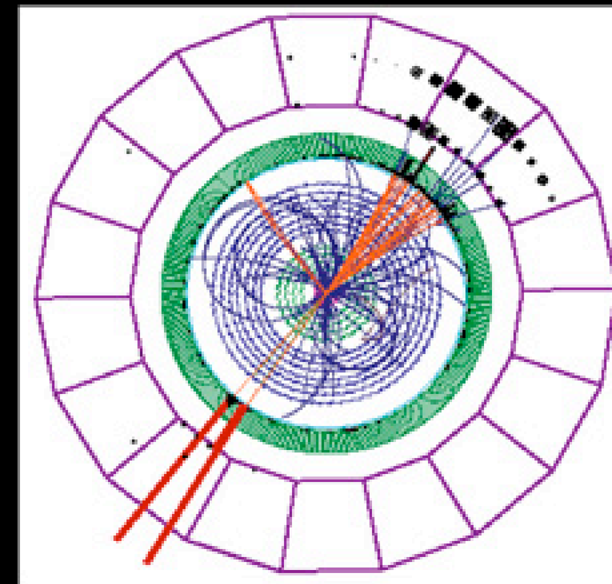
$m_H < 161$ GeV (95% CL)

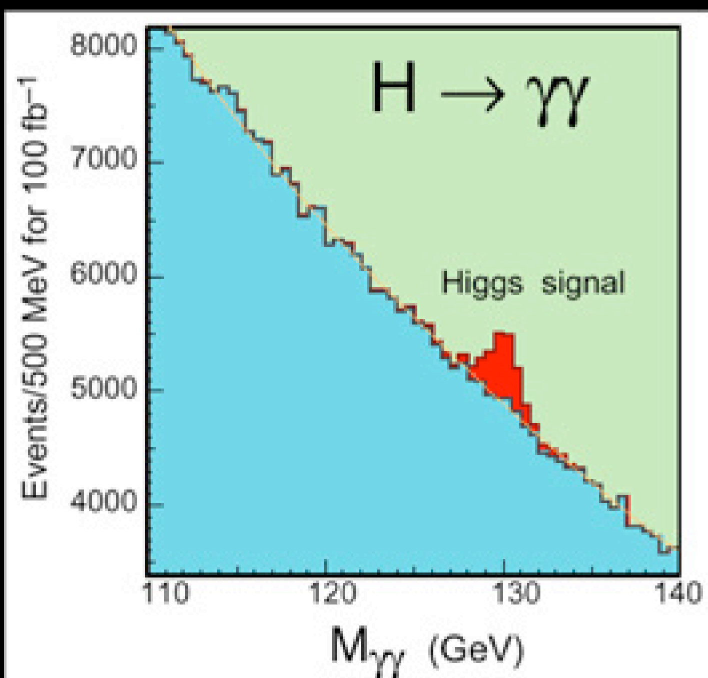
$114.4 \text{ GeV} < m_H < 161 \text{ GeV}$

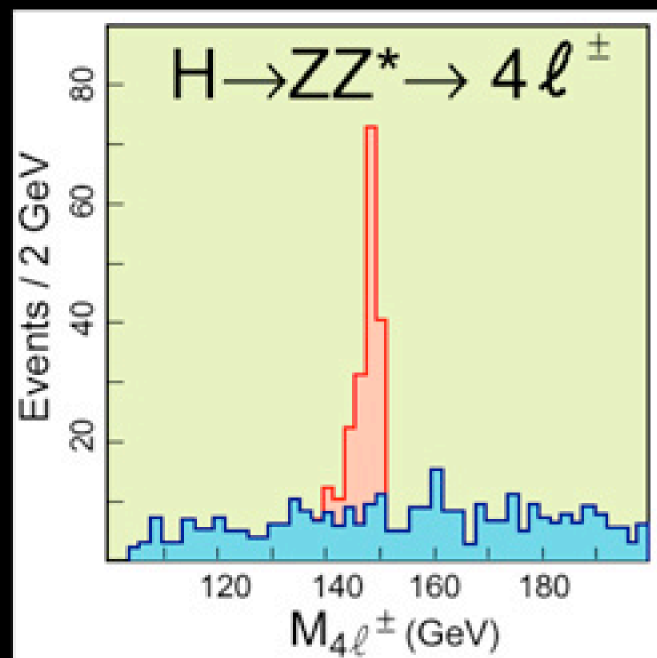
Búsqueda del Bosón de Higgs del Modelo Standard

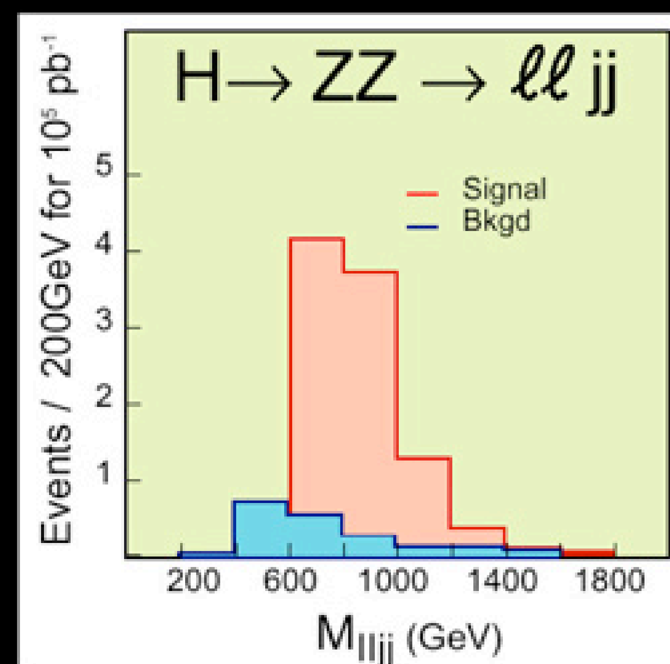




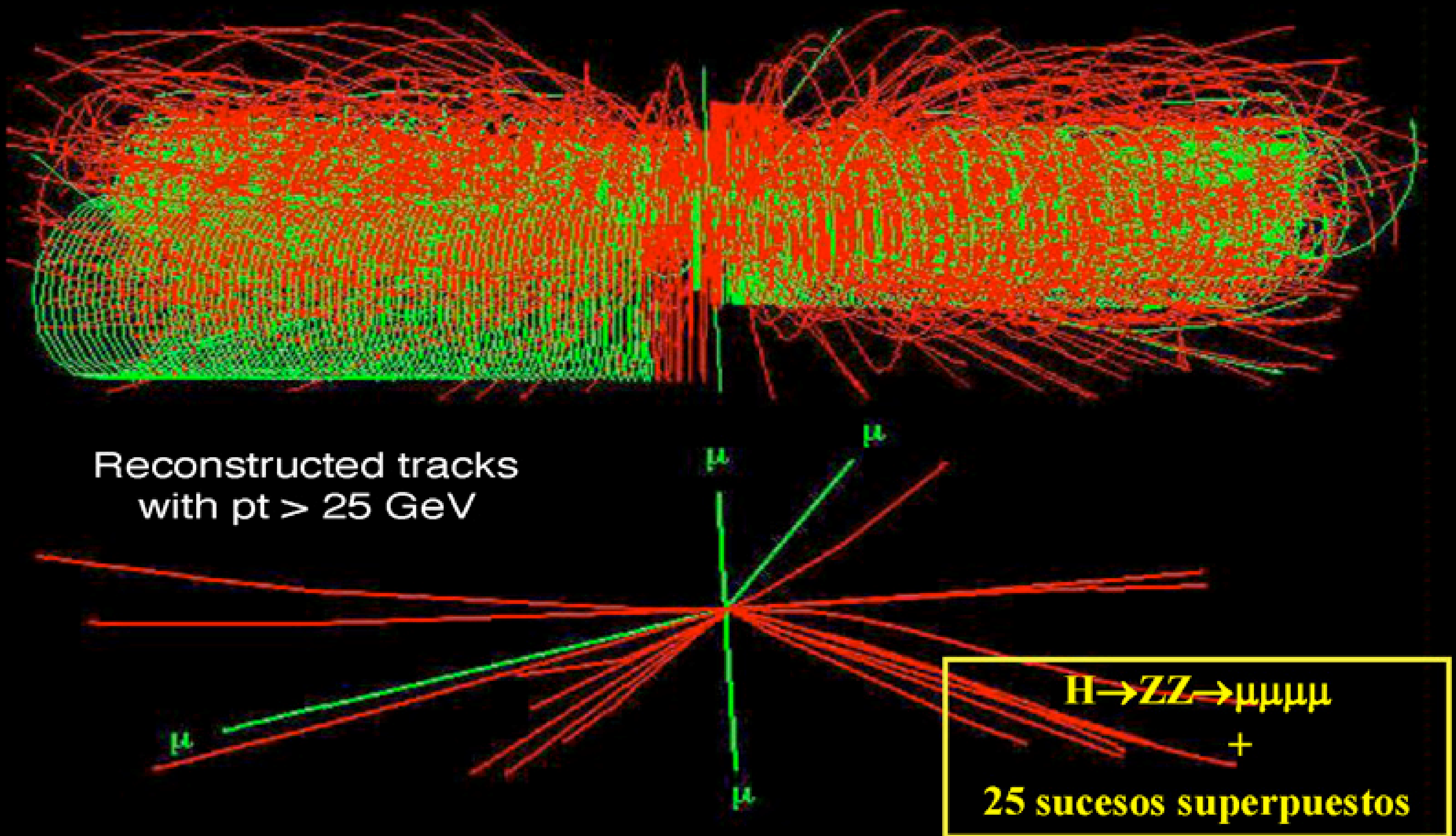


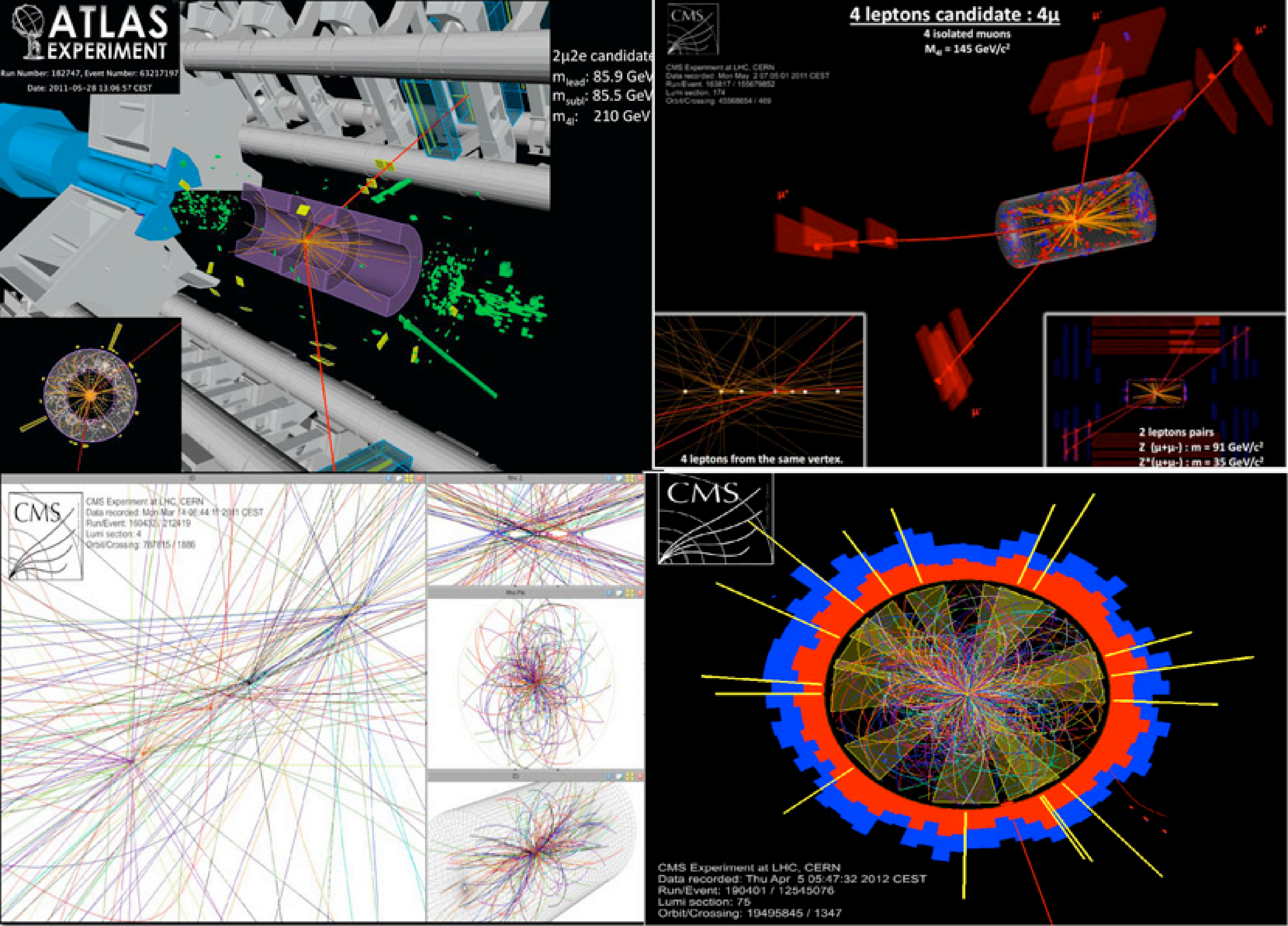


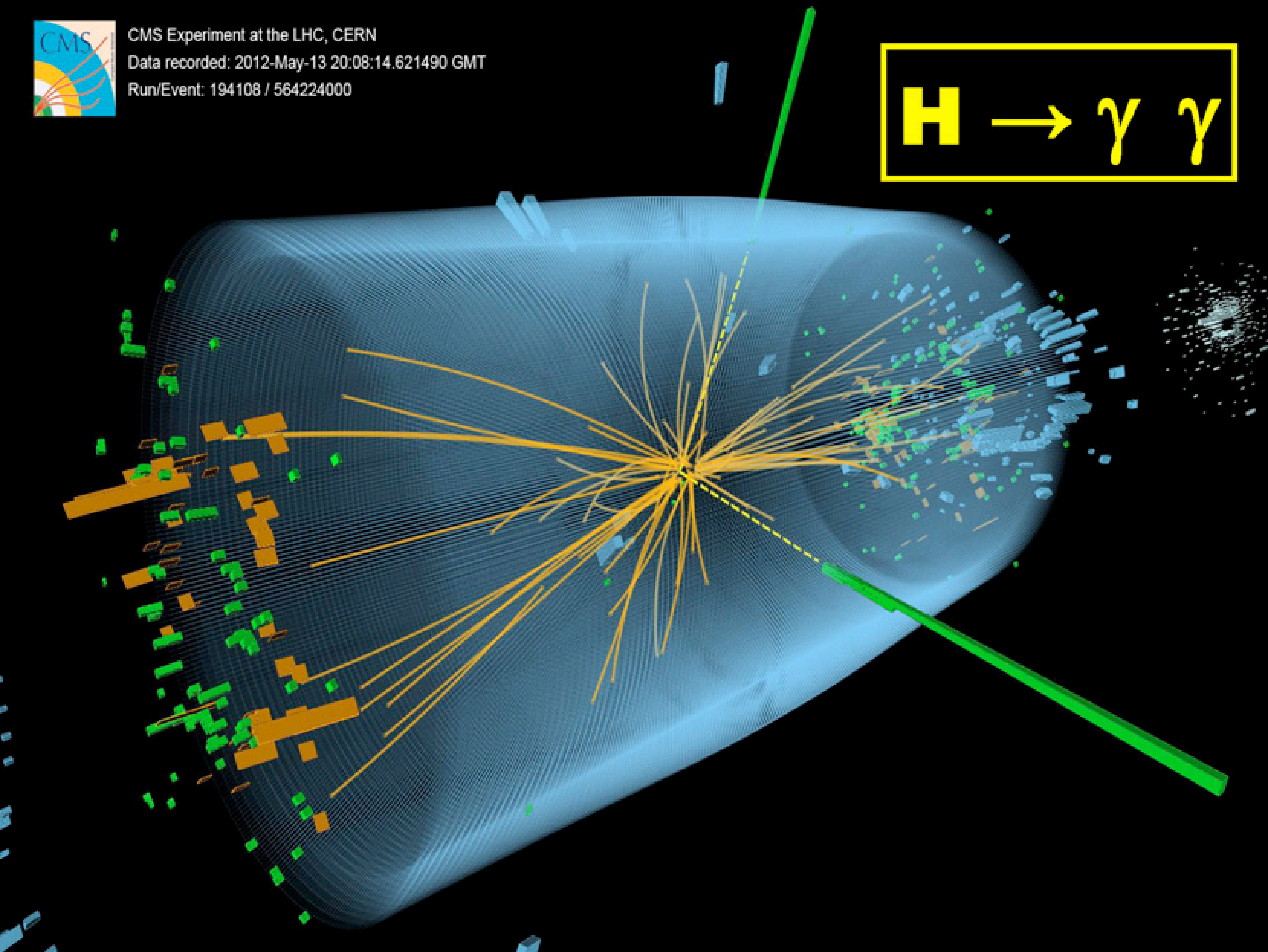




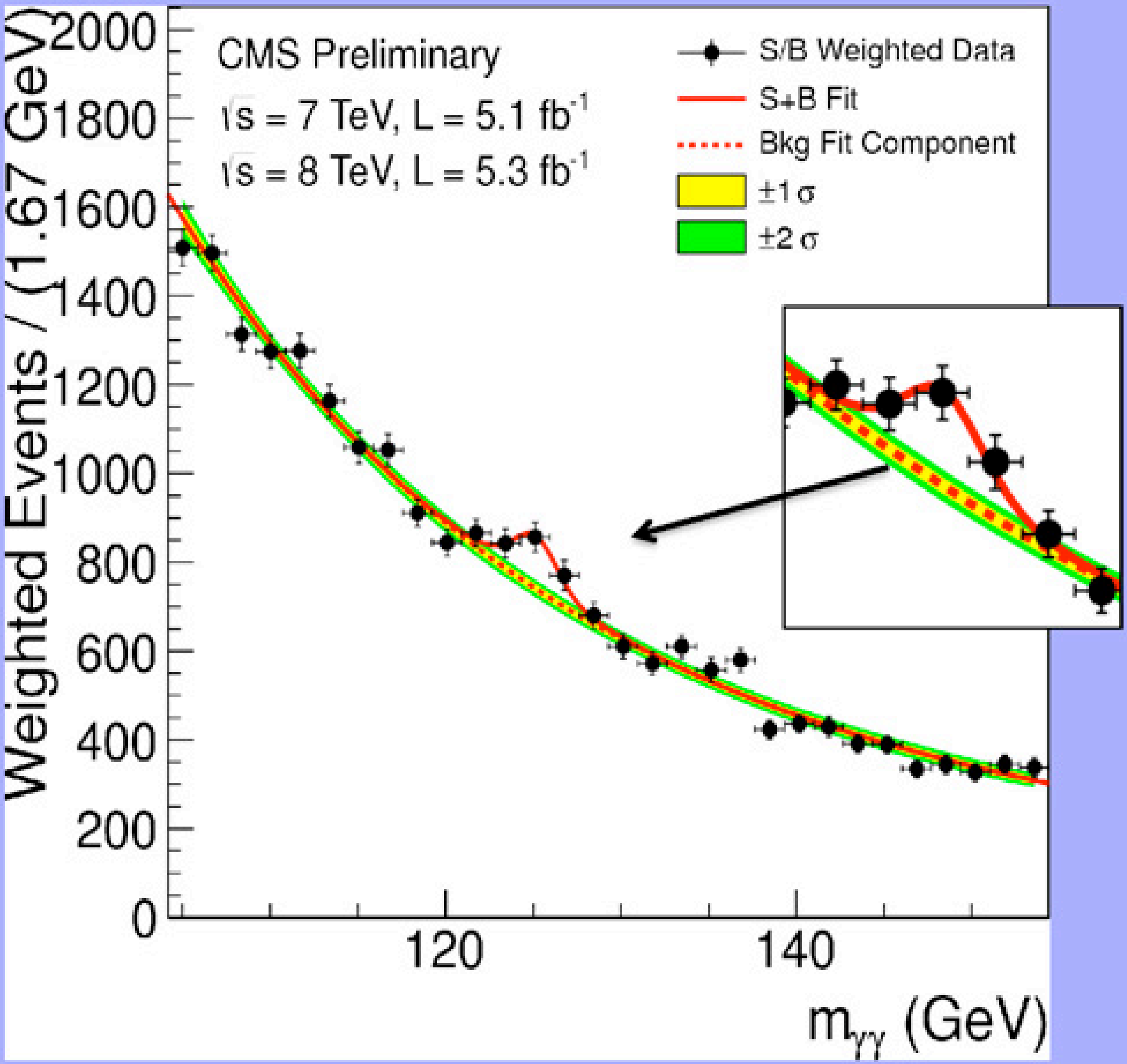
1 BOSÓN DE HIGGS / 10.000.000.000.000 INTERACCIONES



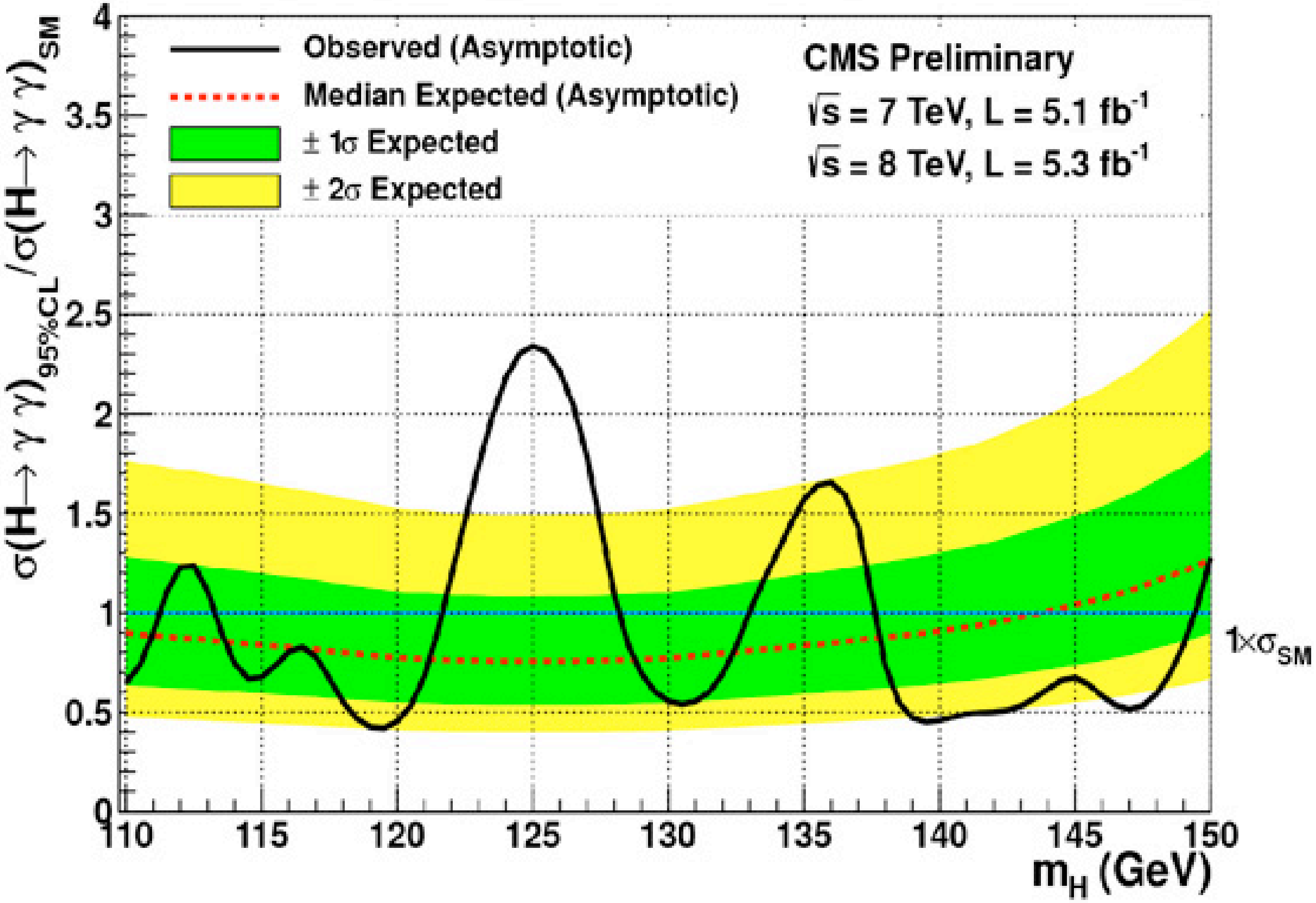

ATLAS EXPERIMENT
Run Number: 182747, Event Number: 63217197
Date: 2011-05-28 13:06:57 CEST
2μ2e candidate
m_lead: 85.9 GeV
m_subl: 85.5 GeV
m_4l: 210 GeV
CMS
4 leptons candidate : 4μ
4 isolated muons
M4l = 145 GeV/c²
4 leptons from the same vertex.
2 leptons pairs
Z (μ+μ-) : m = 91 GeV/c²
Z*(μ+μ-) : m = 35 GeV/c²
CMS
CMS Experiment at LHC, CERN
Lumi section: 4
CMS
CMS Experiment at LHC, CERN
Data recorded: Thu Apr 5 05:47:32 2012 CEST
Run/Event: 190401 / 12545076
Lumi section: 75
Orbit/Crossing: 19495845 / 1347


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H → γ γ

DISTRIBUCIÓN DE MASA EFECTIVA

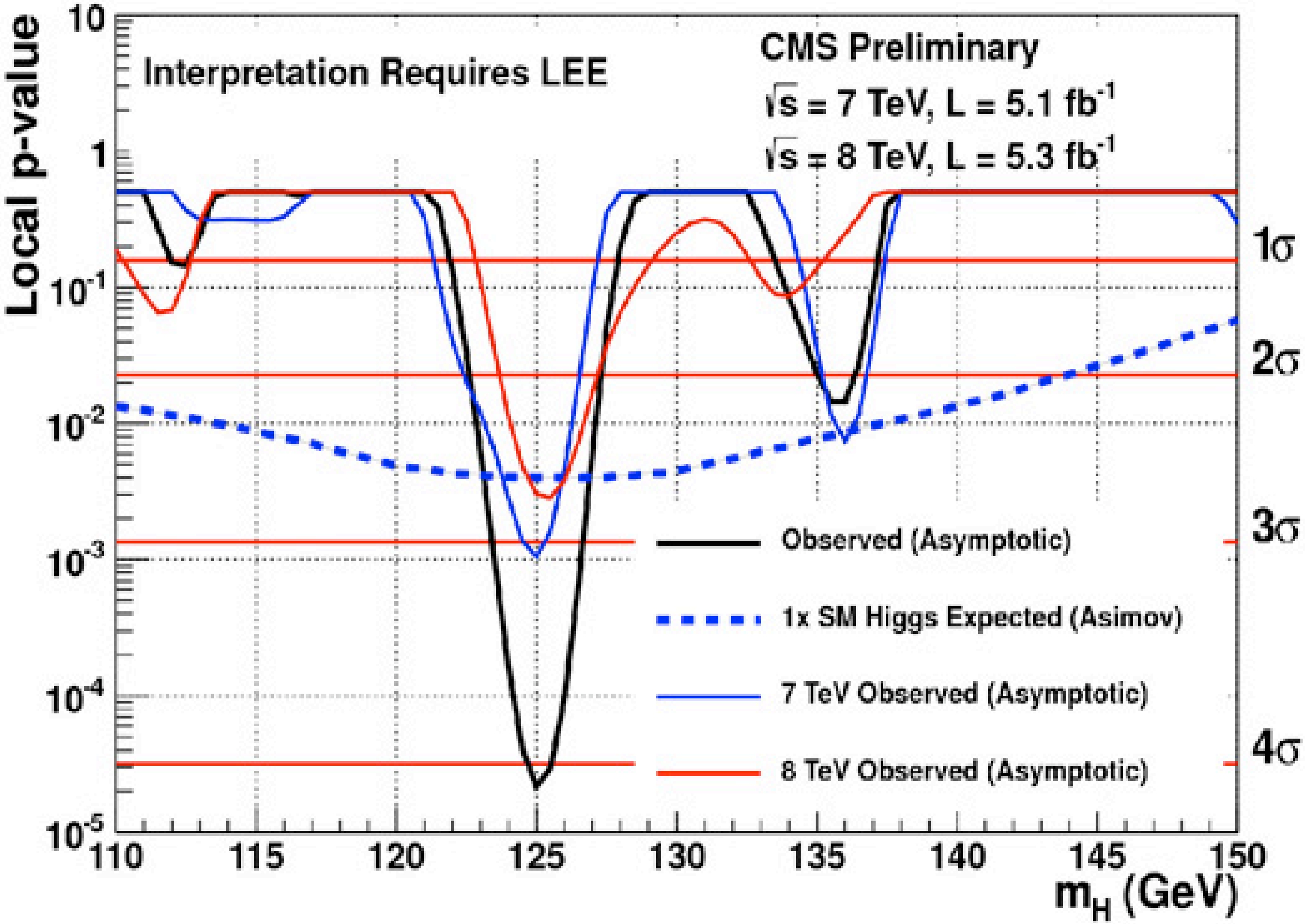


95% CL EXCLUSIÓN PARA HIGGS

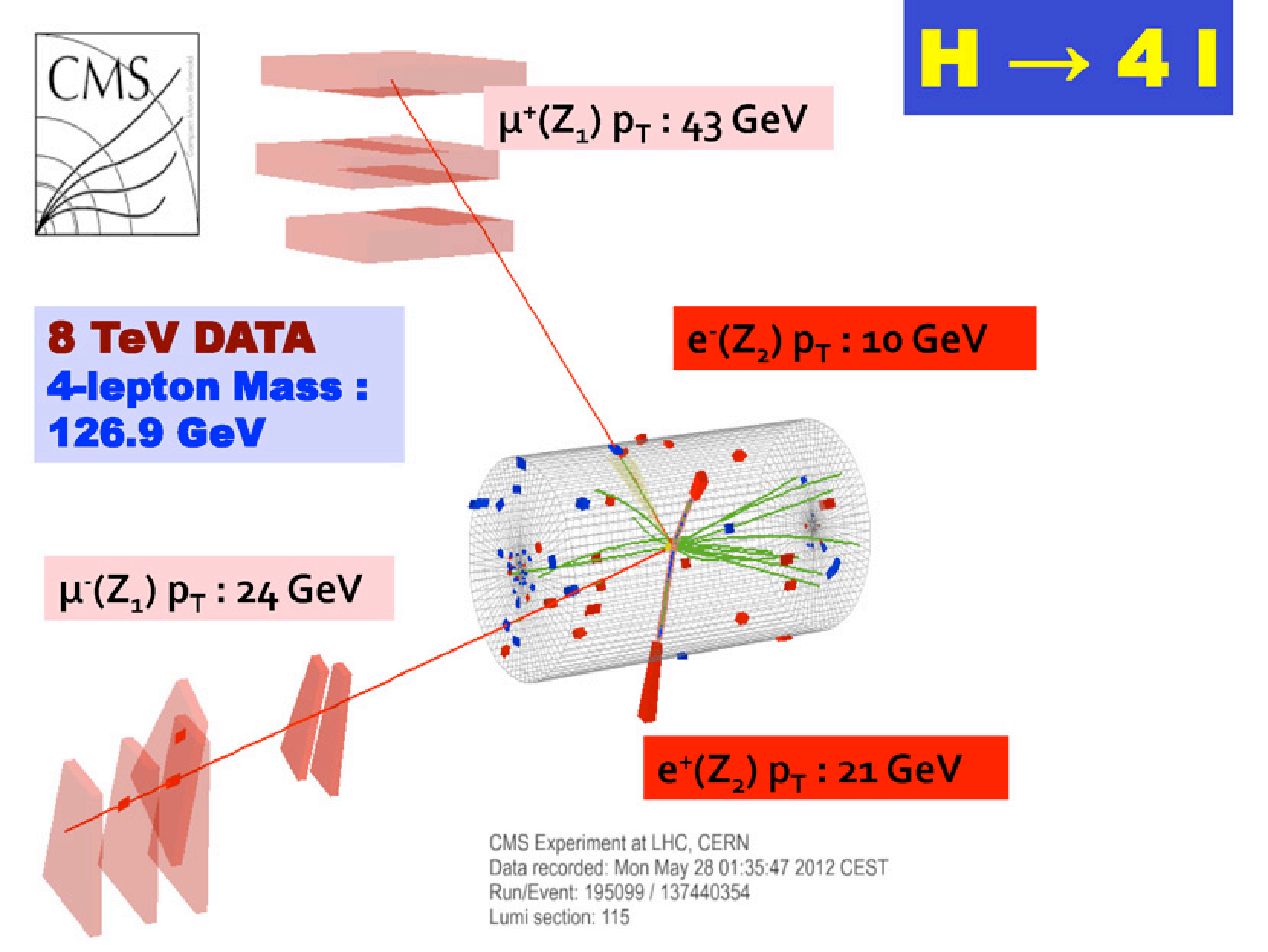


- **Esperada exclusión al 95% CL 0.76 veces el SM at 125 GeV**
- **Gran intervalo con la exclusión esperada por debajo del σ_{SM}**
- **Gran exceso a 125 GeV**

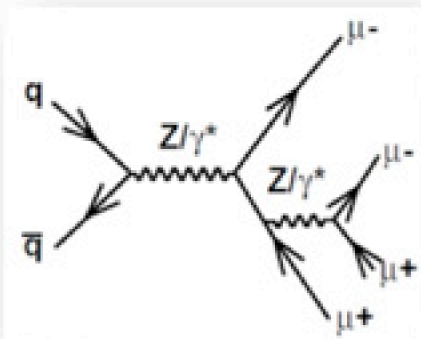
P-Values

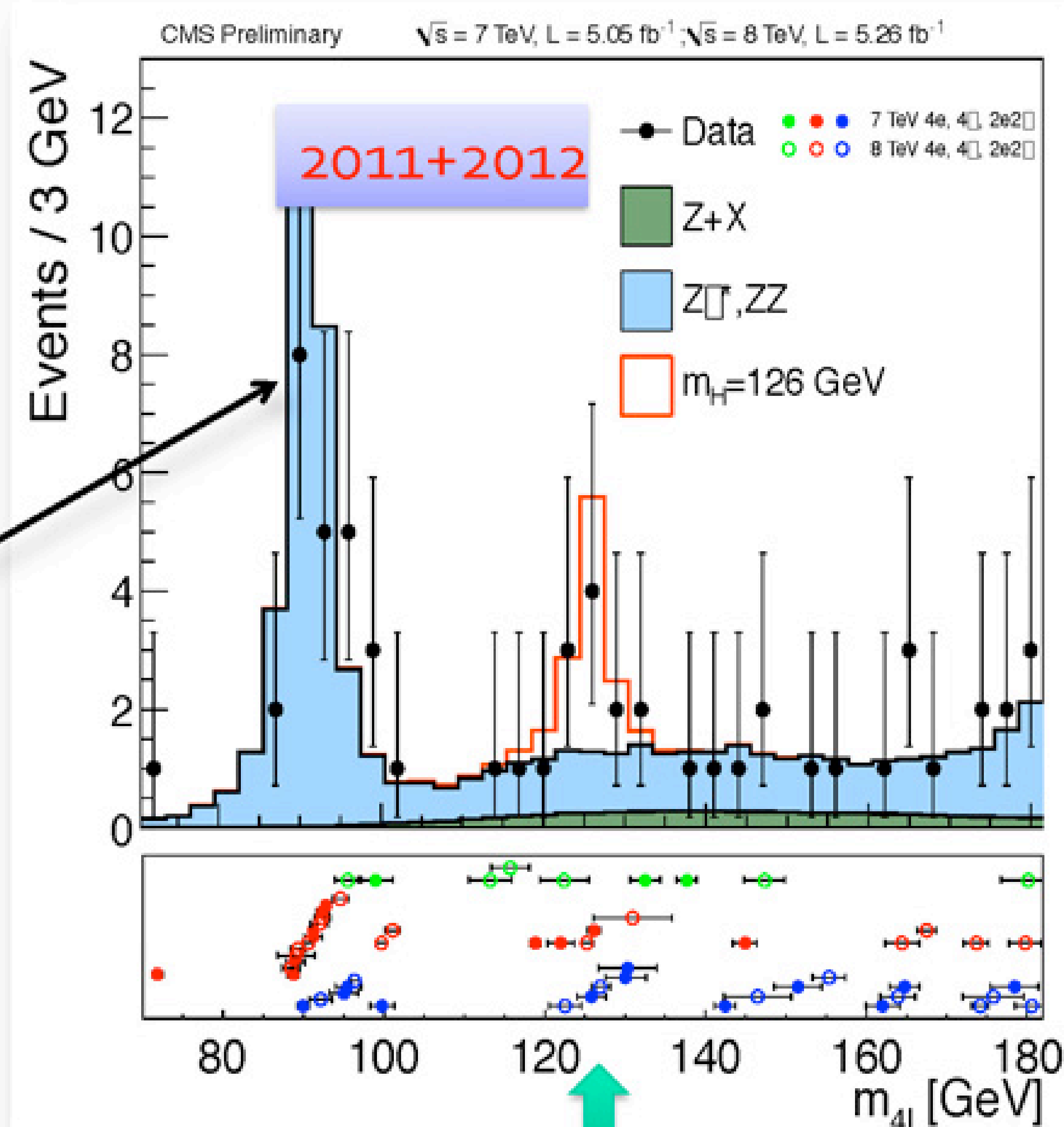


- **Mínimo p-value local a 125 GeV con significado local de 4.1 σ**
- **Exceso similar en 2011 y 2012**
- **Significado global en el intervalo explorado (110-150 GeV) 3.2 σ**


H → 4 l
CMS
μ+(Z1) pT : 43 GeV
8 TeV DATA
4-lepton Mass :
126.9 GeV
e-(Z2) pT : 10 GeV
μ-(Z1) pT : 24 GeV
e+(Z2) pT : 21 GeV
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:35:47 2012 CEST
Run/Event: 195099 / 137440354
Lumi section: 115

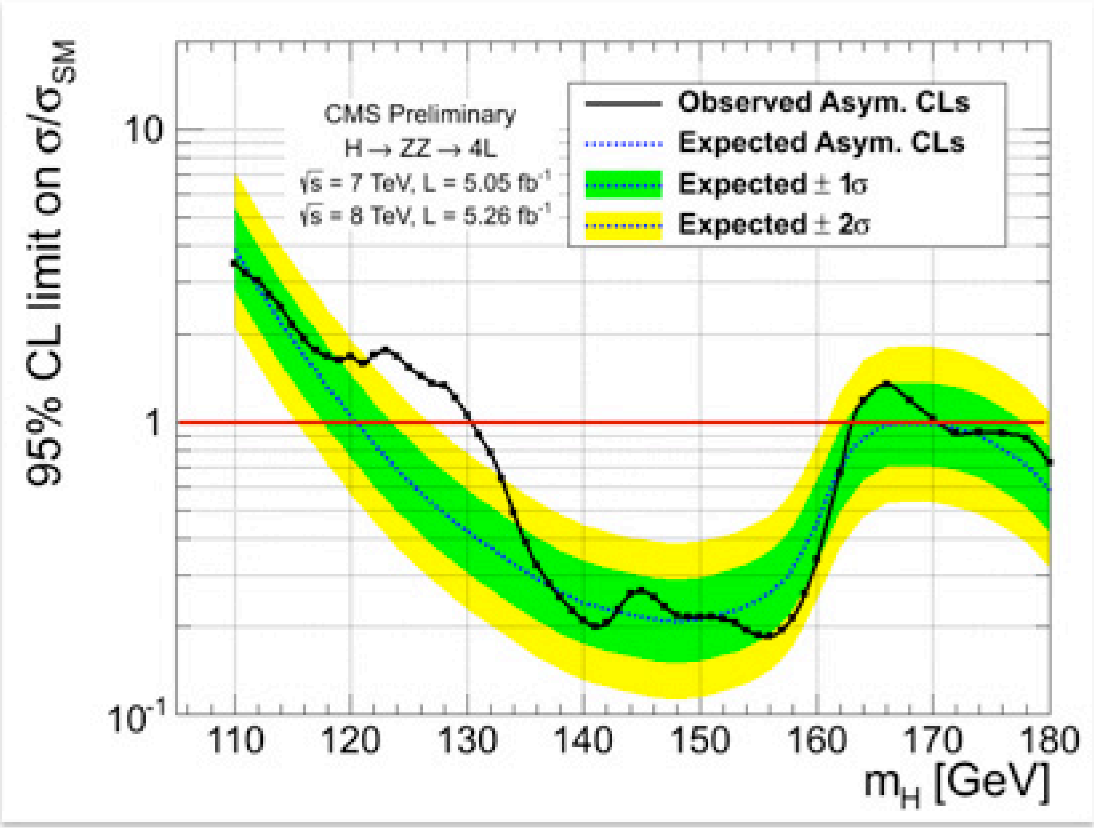
RESULTADOS: ESPECTRO m(4l)

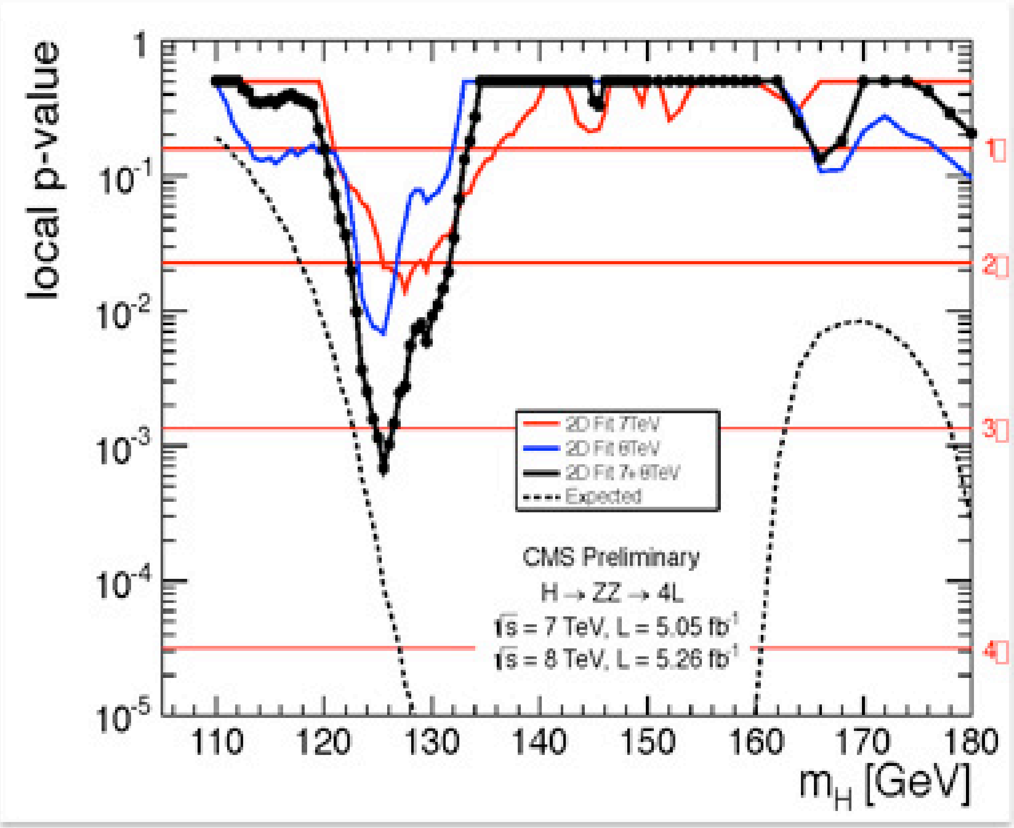




Errores suceso-a-suceso

LÍMITES, P-VALUES

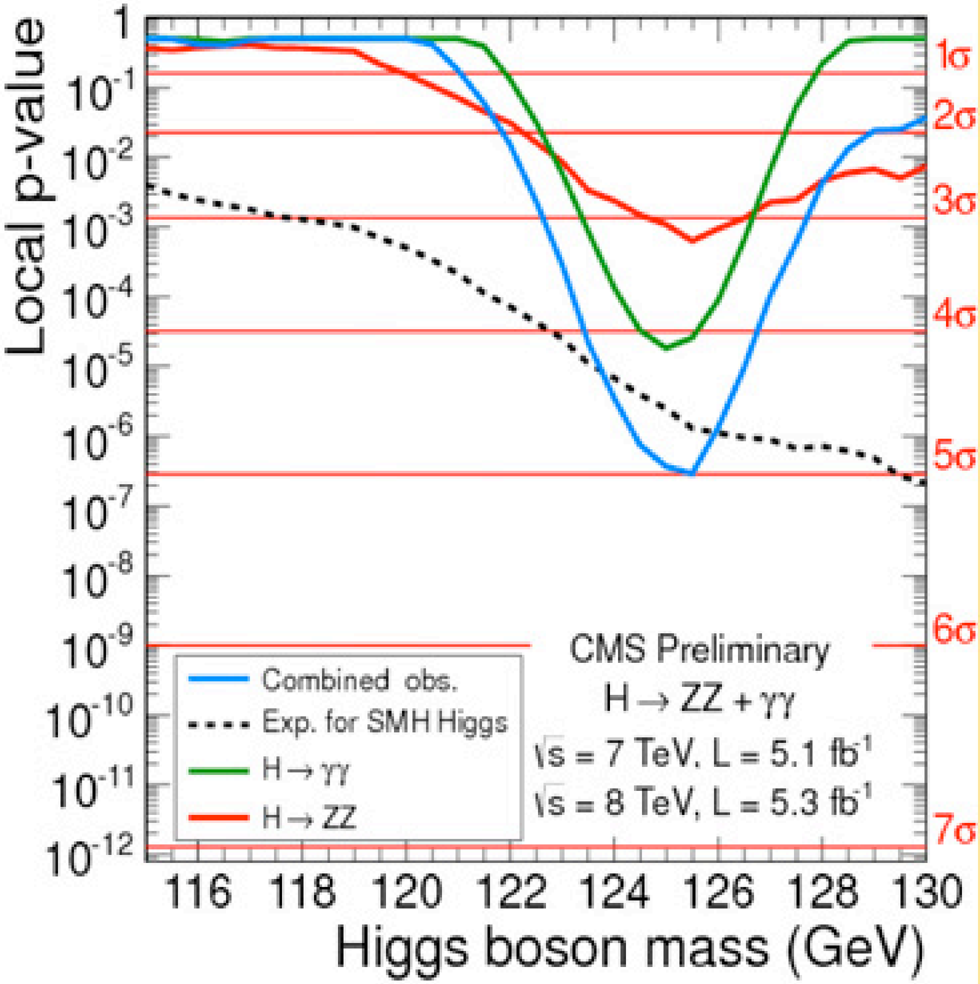




Exclusión esperada a 95% CL :
121-550 GeV
Exclusión observada a 95% CL :
131-162 GeV and 172-530 GeV

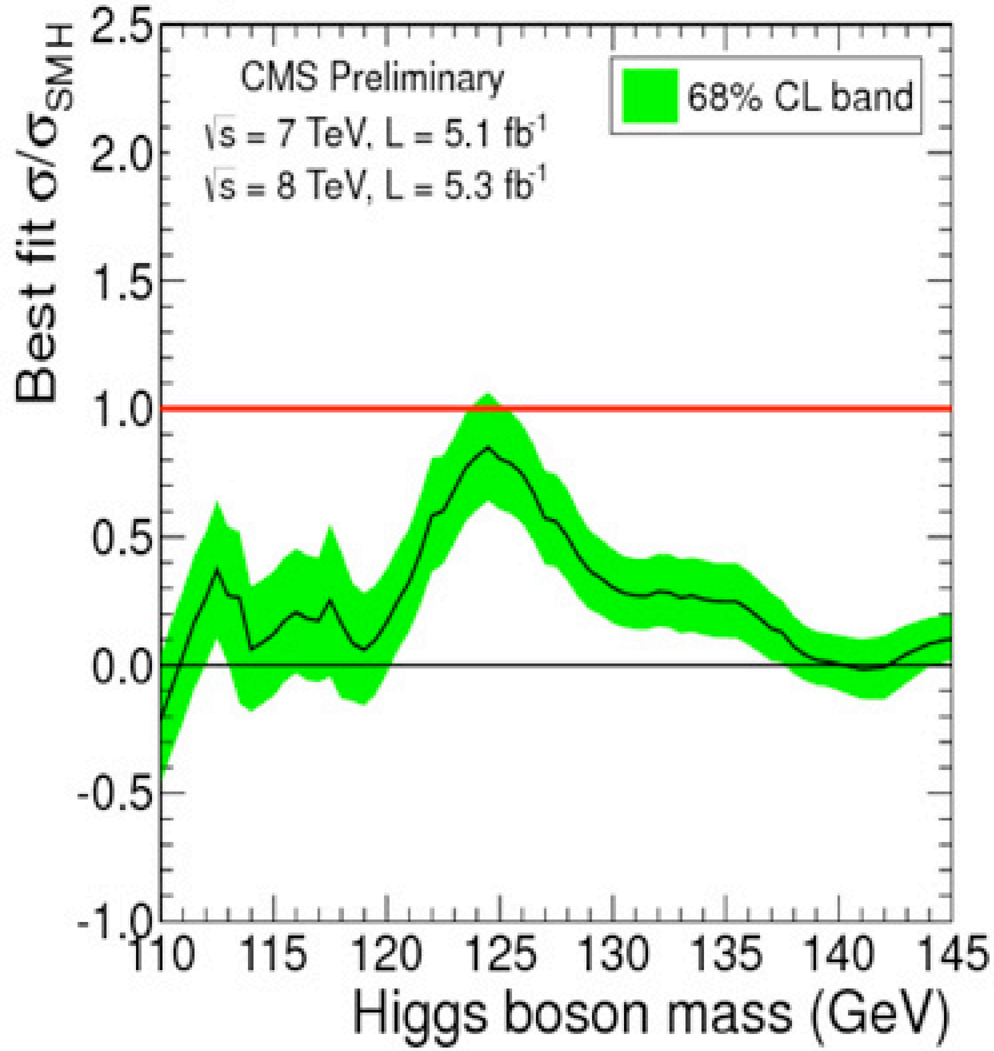
Significado esperado a 125.5 GeV :
3.8 σ
Significado observado a 125.5 GeV:
3.2 σ

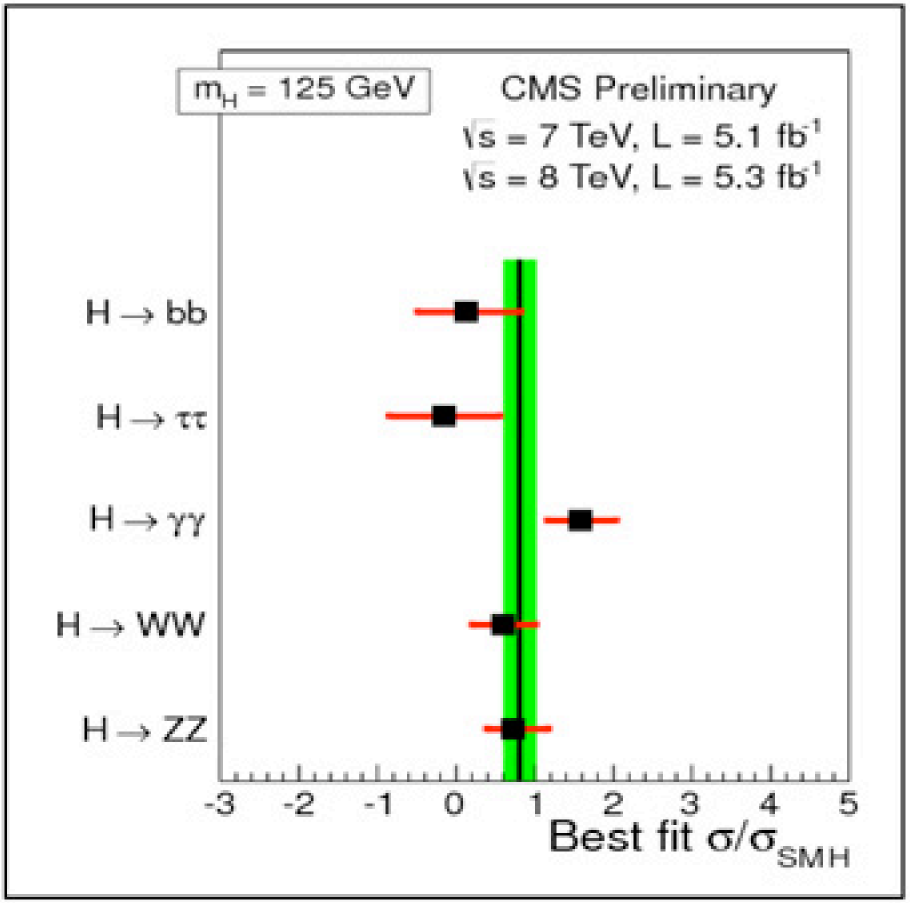
CARACTERIZACIÓN DEL EXCESO A ~125 GeV



- **Alta sensibilidad, canales con buena resolución en masa: γγ+4l**
  - **γγ: 4.1 σ exces**
  - **4 leptones: 3.2 σ exceso**
  - **Cerca de la misma masa 125 GeV**
- **Significado estadístico combinado:** **5.0 σ**
- **Significado estadístico esperado para un SM Higgs:** **4.7 σ**

COMPATIBILIDAD CON EL MODELO ESTÁNDAR



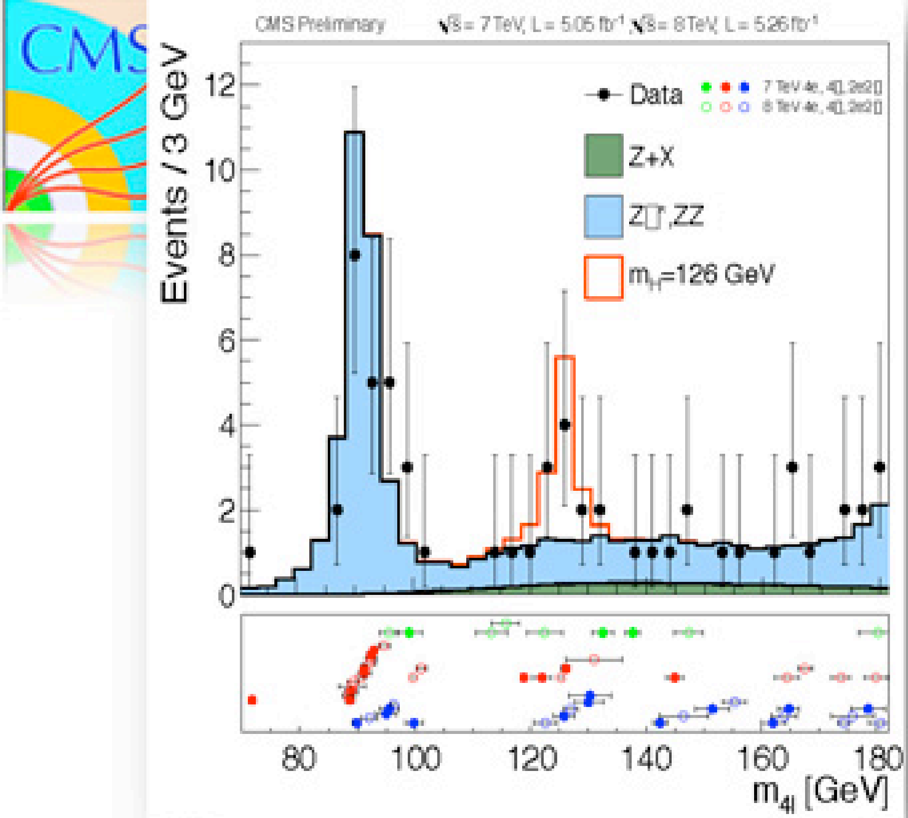


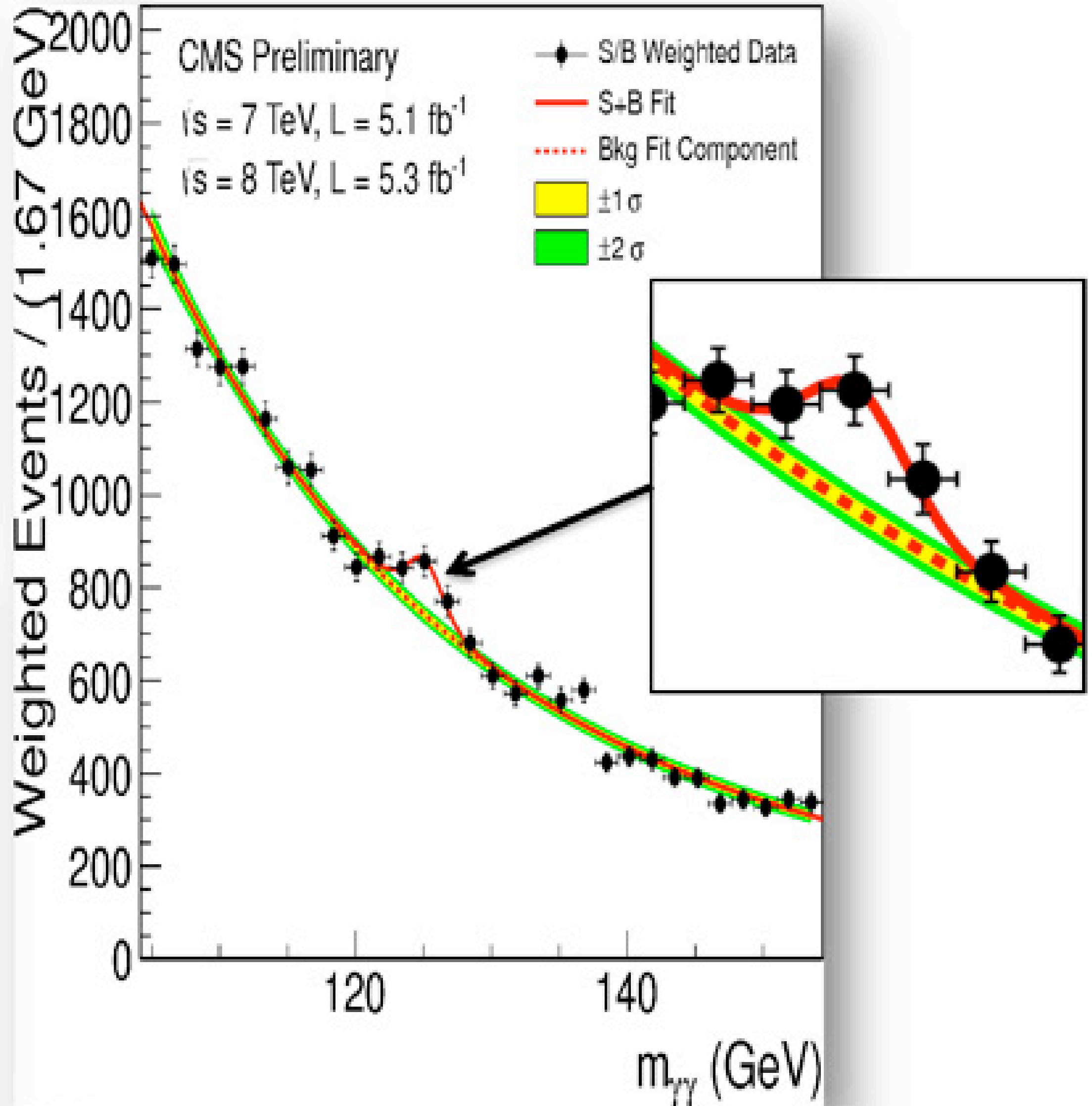
$\sigma/\sigma_{SM} = 0.80 \pm 0.22$

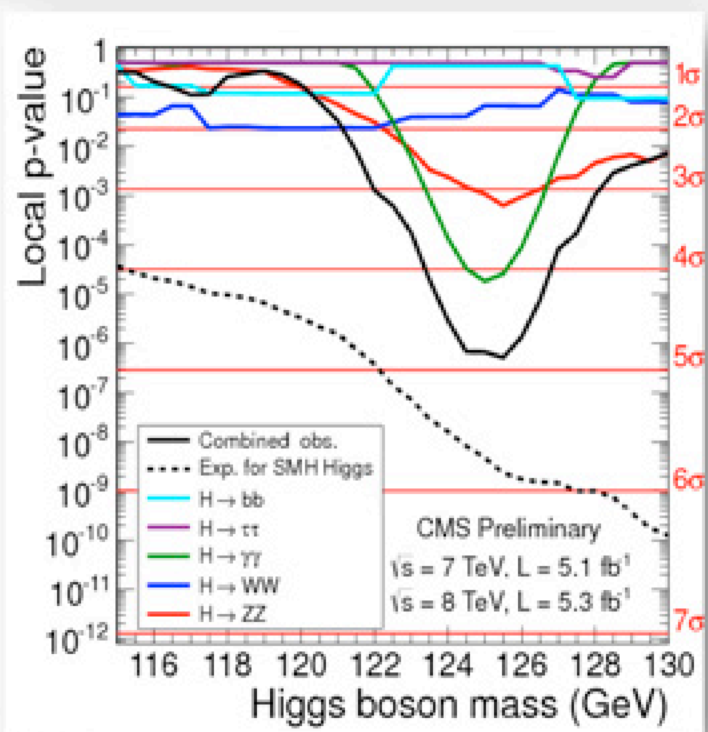
$R_{WW/ZZ} = 0.9^{+1.1}_{-0.6}$

CUSTODIAL SYMMETRY

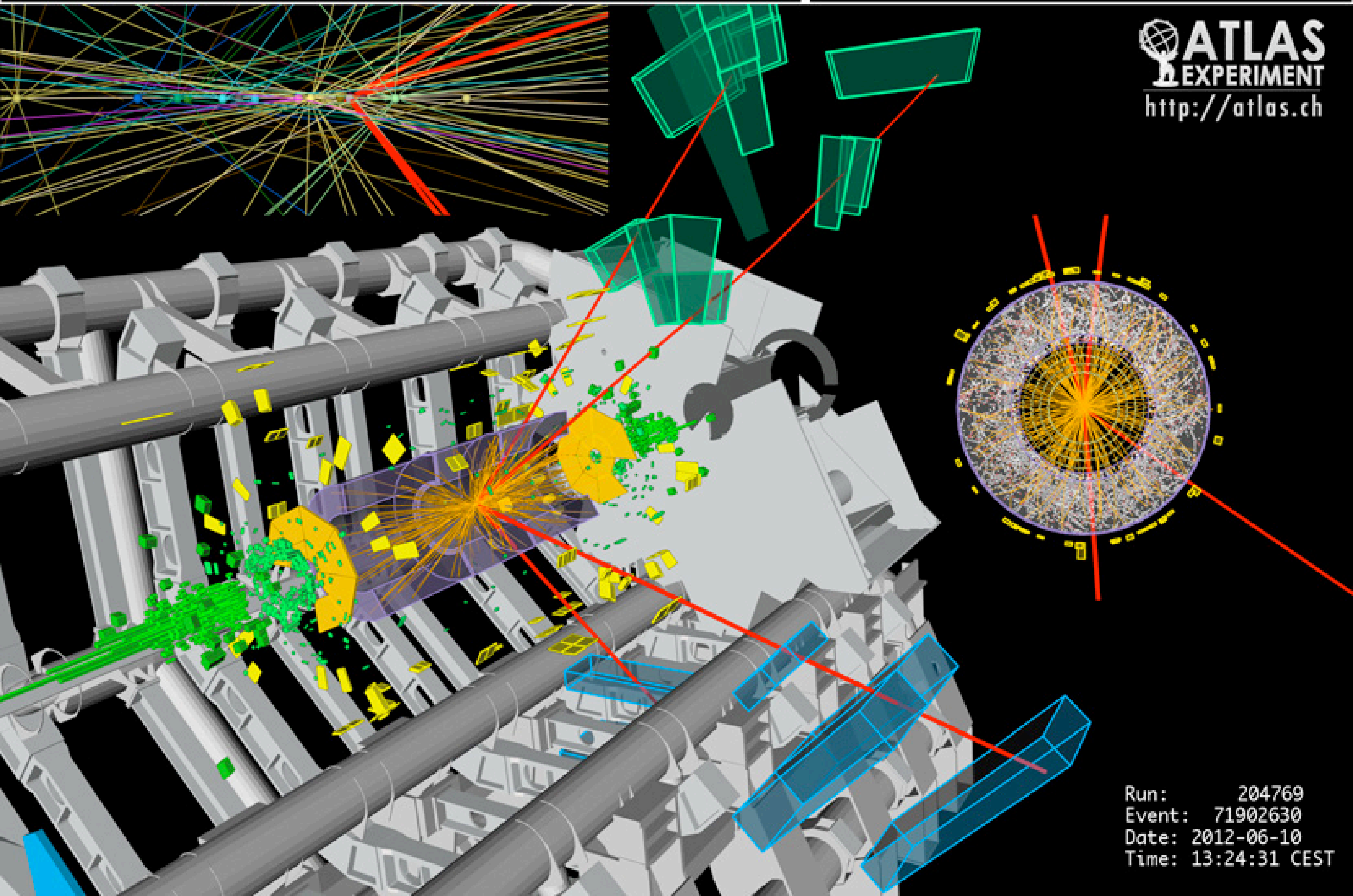
RESUMEN


CMS Preliminary
Events / 3 GeV
Data
Z+X
m_H=126 GeV
m_4l [GeV]
80 100 120 140 160 180

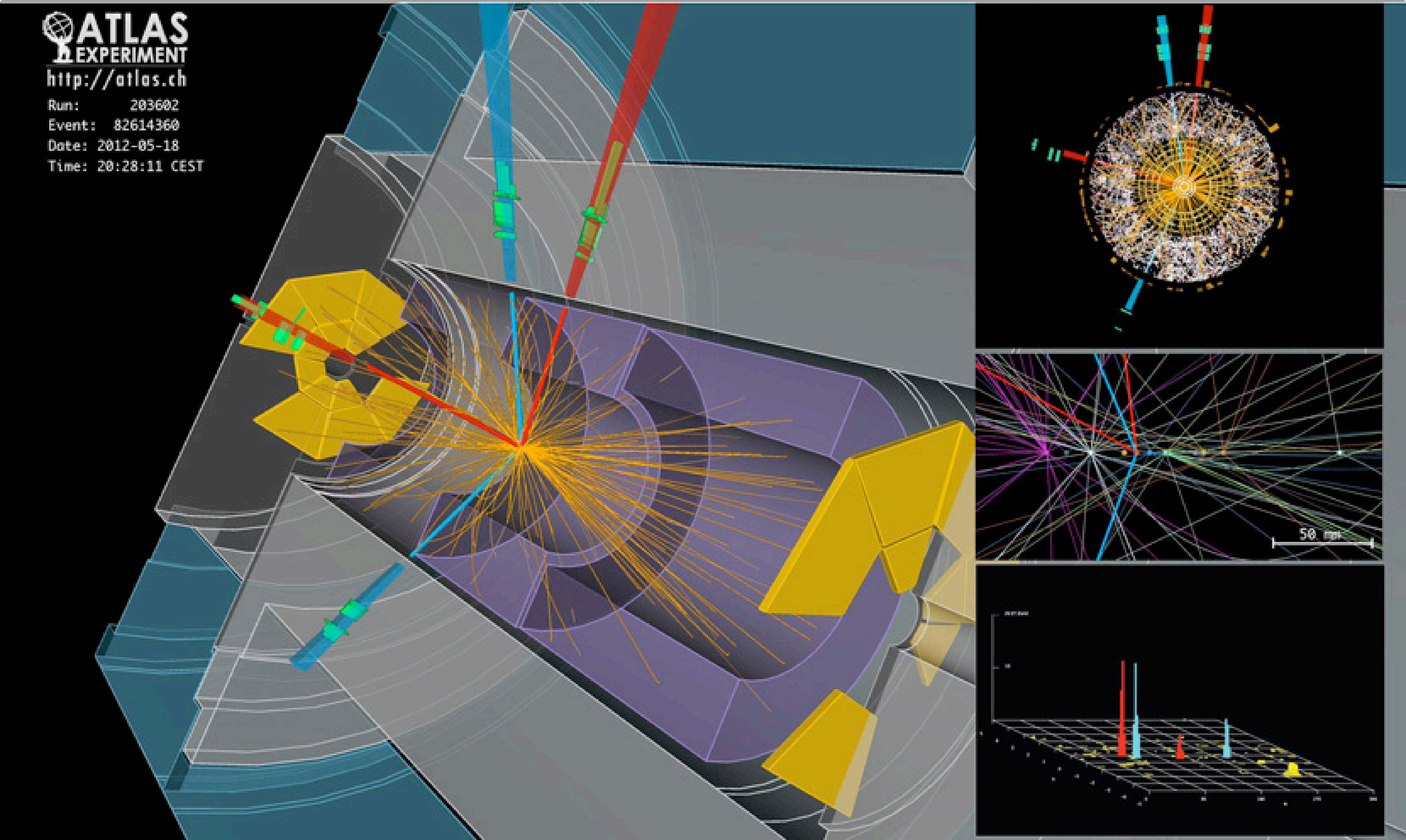

CMS Preliminary
√s = 7 TeV, L = 5.1 fb⁻¹
√s = 8 TeV, L = 5.3 fb⁻¹
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
m_γγ (GeV)
120 140

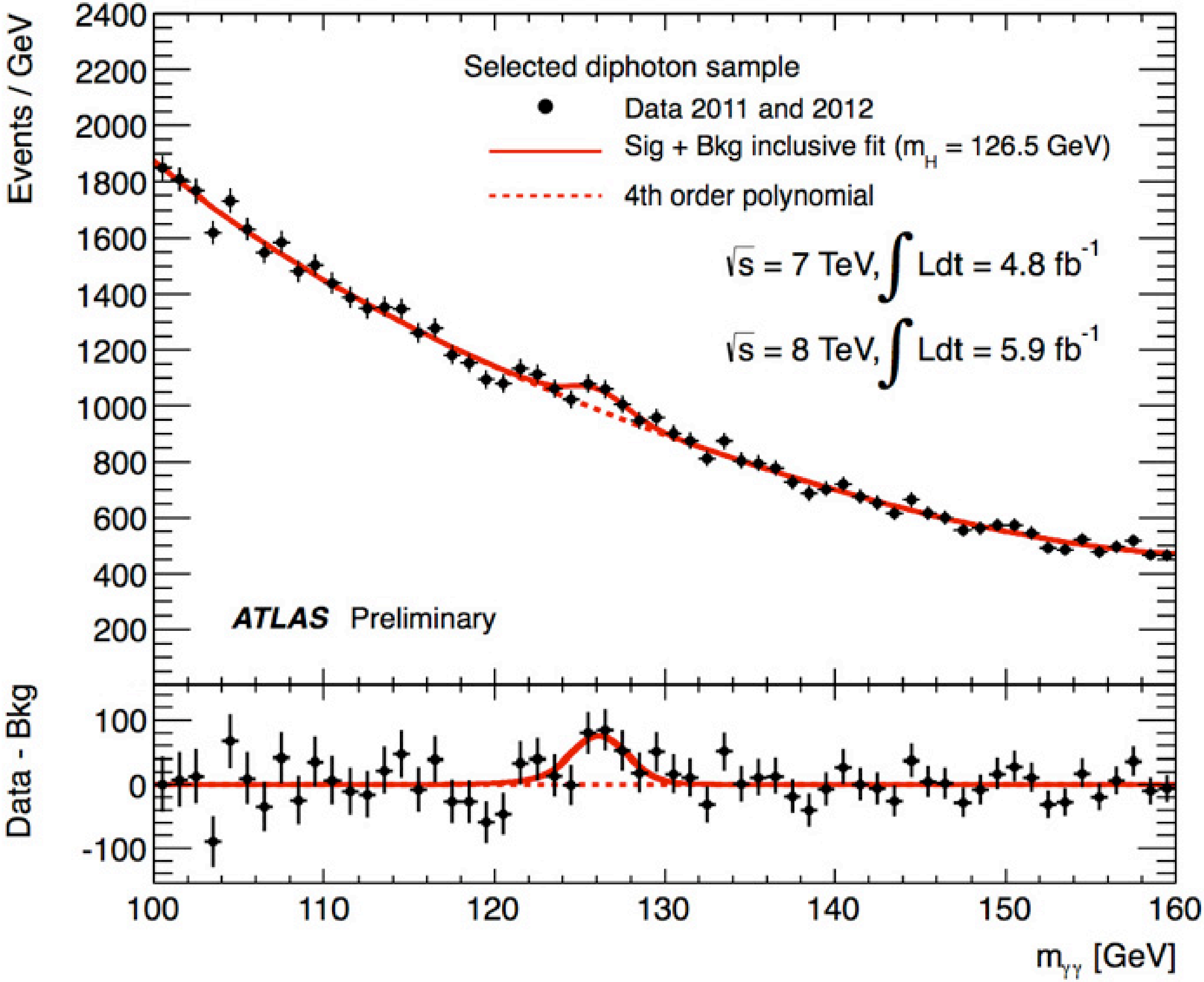

Local p-value
Higgs boson mass (GeV)
Combined obs.
Exp. for SMH Higgs
H → bb
H → ττ
H → γγ
H → WW
H → ZZ
CMS Preliminary
√s = 7 TeV, L = 5.1 fb⁻¹
√s = 8 TeV, L = 5.3 fb⁻¹
1σ
2σ
3σ
4σ
5σ
6σ
7σ
116 118 120 122 124 126 128 130

CANDIDATO 4μ, $m_{4\mu}$ = 125.1 GeV

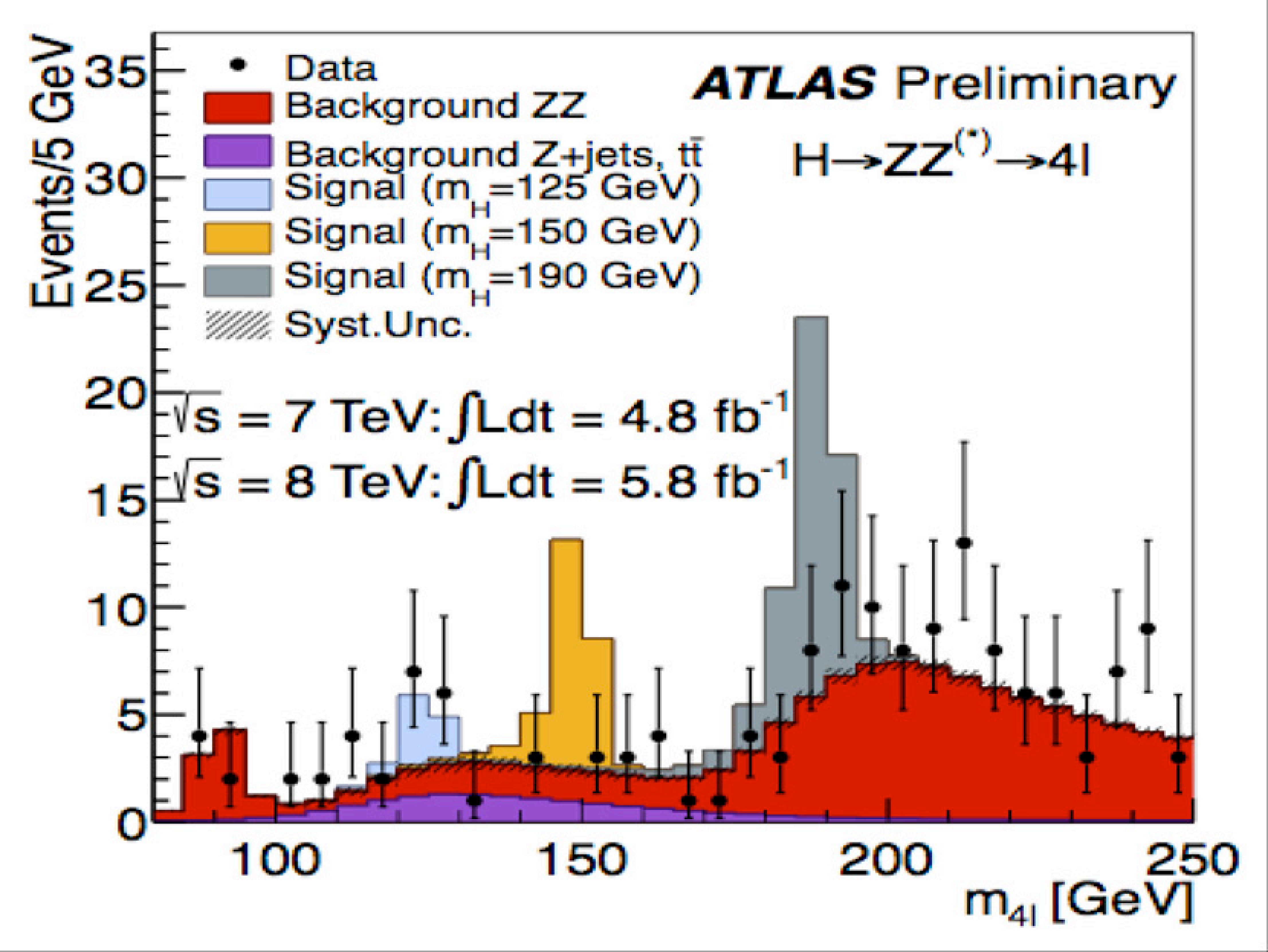


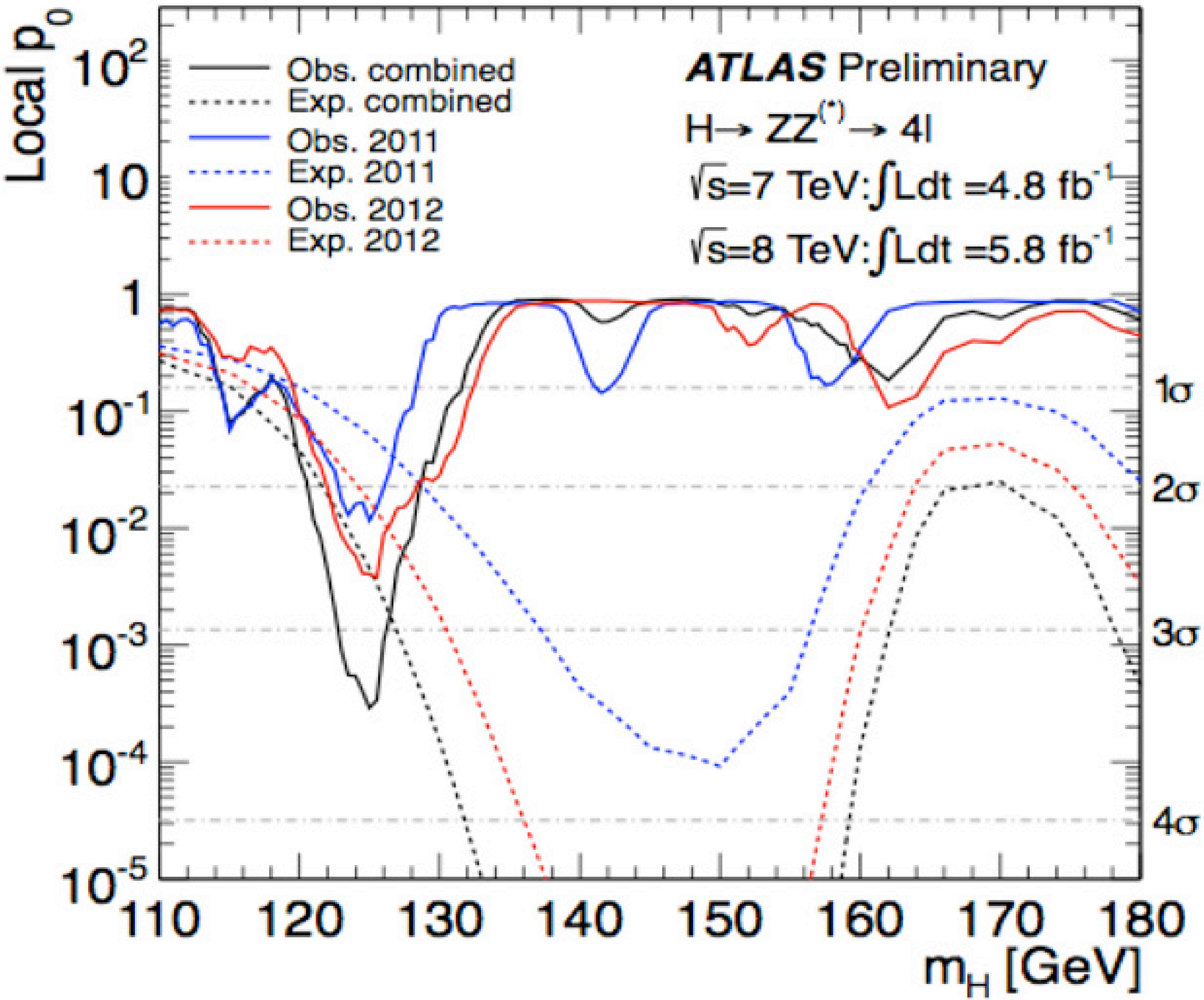
CANDIDATO 4e, m_{4e}= 124.6 GeV





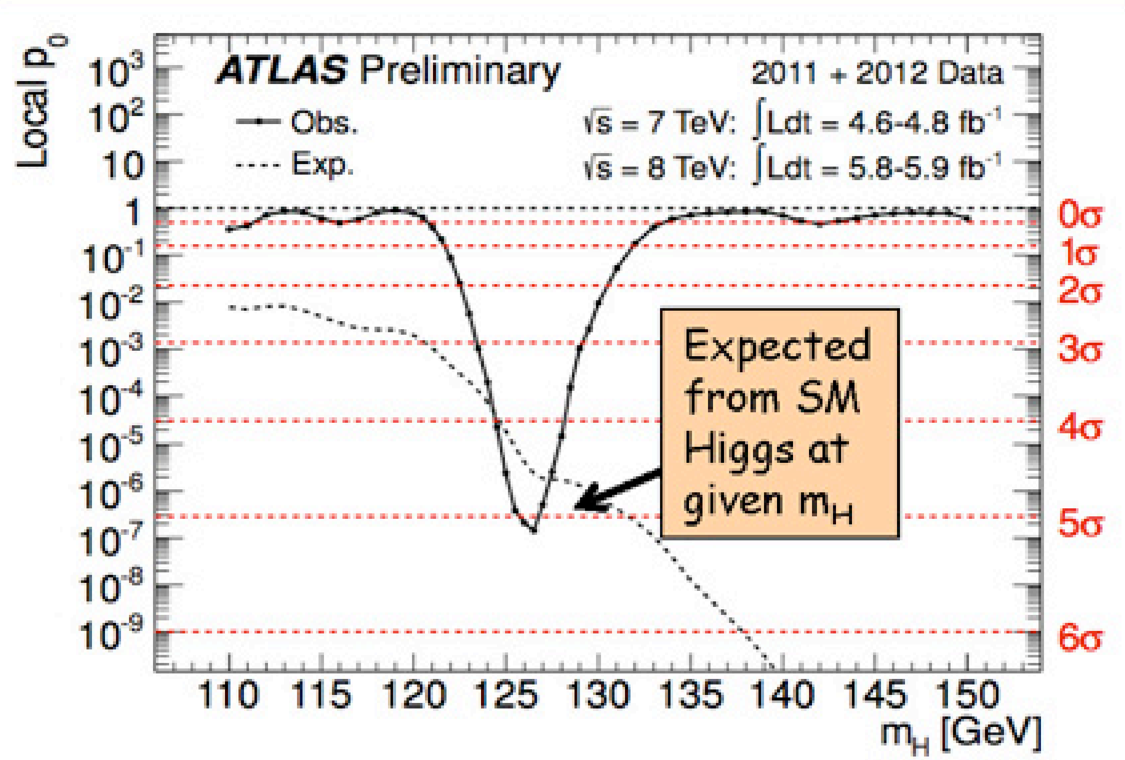
Events / GeV
Selected diphoton sample
Data 2011 and 2012
Sig + Bkg inclusive fit (m_H = 126.5 GeV)
4th order polynomial
$\sqrt{s}$ = 7 TeV, $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV, $\int Ldt$ = 5.9 fb^{-1}
ATLAS Preliminary
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
Data - Bkg
100
0
-100
100
110
120
130
140
150
160
$m_{\gamma\gamma}$ [GeV]

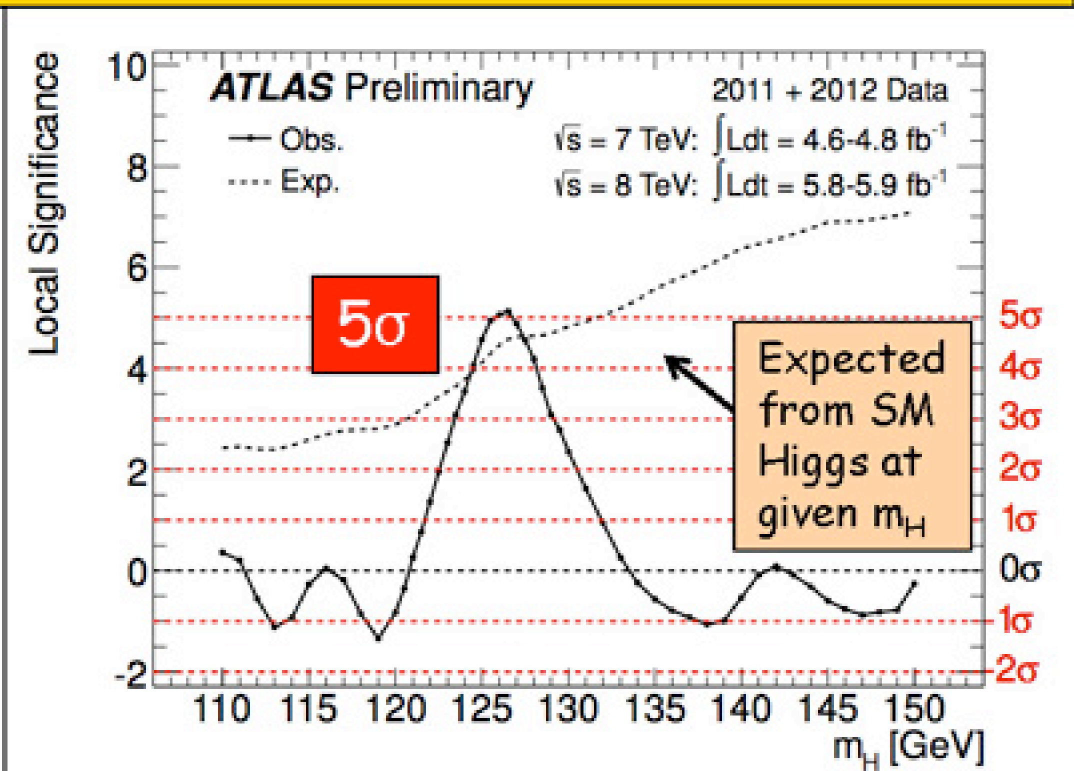

Events/5 GeV
Data
Background ZZ
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→4l
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
0
5
10
15
20
25
30
35
100
150
200
250
m4l [GeV]



Global 2011+2012 : 2.5σ

Combined results: the excess





Maximum excess observed at	m_H = 126.5 GeV
Local significance (including energy-scale systematics)	5.0 σ
Probability of background up-fluctuation	3×10^{-7}
Expected from SM Higgs m_H=126.5	4.6 σ

Global significance: 4.1-4.3 σ

CONCLUSIÓN

OBSERVACIÓN DE UN NUEVO BOSÓN

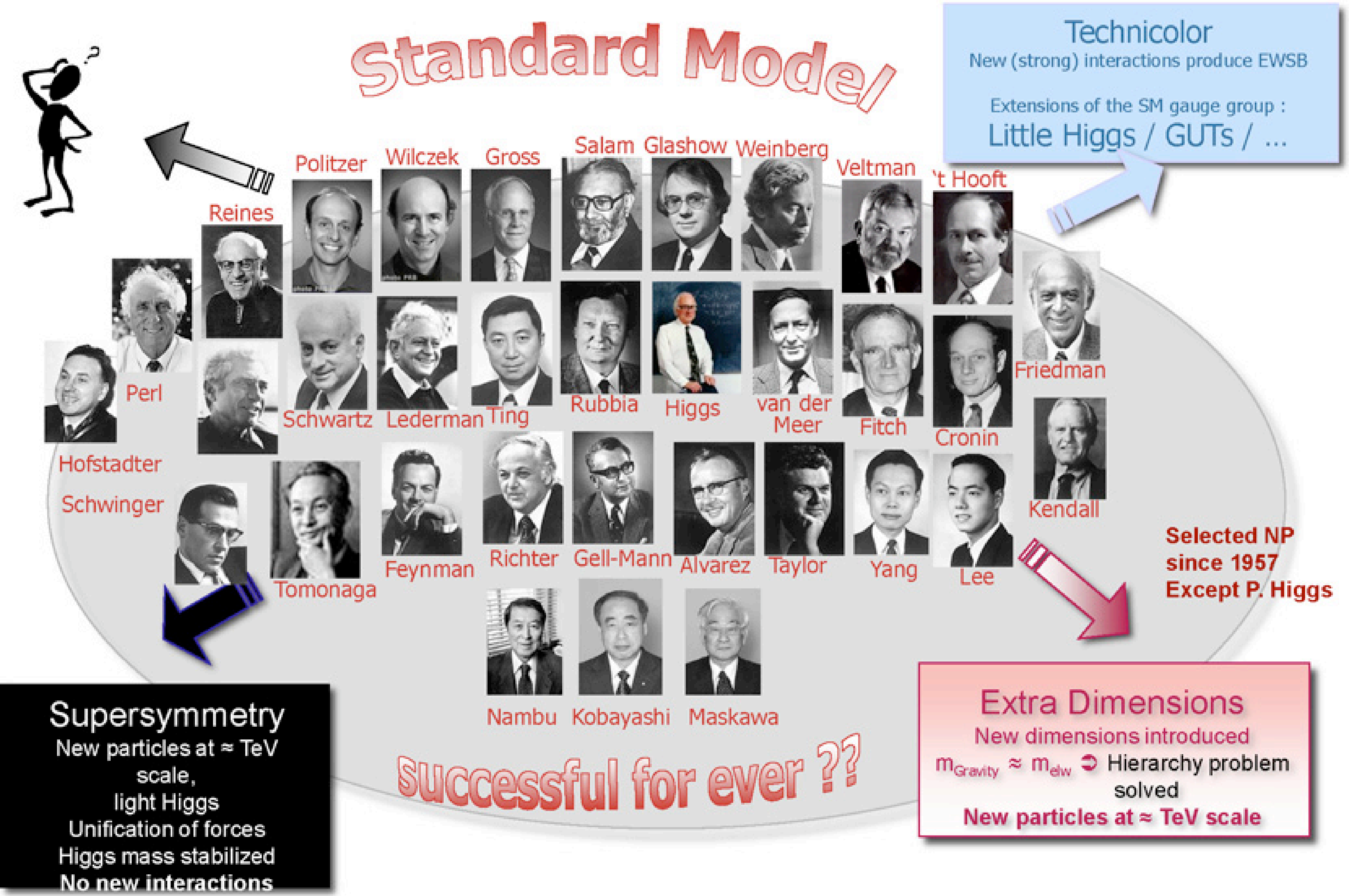
- **CMS:**

  m=125.3 ± 0.6 GeV, 4.9 σ

- **ATLAS:**

  m≈126.5, 4.3 σ


FÍSICOS TEÓRICOS
¿ QUÉ SERÁ ?
NUEVA PARTÍCULA DESCUBIERTA
FÍSICOS DE ATLAS & CMS
¡ HAY QUE SEGUIR ESTUDIÁNDOLA !



Standard Model
Technicolor
New (strong) interactions produce EWSB
Extensions of the SM gauge group :
Little Higgs / GUTs / ...
Politzer
Wilczek
Gross
Salam
Glashow
Weinberg
Veltman
't Hooft
Reines
Perl
Friedman
Hofstadter
Schwartz
Lederman
Ting
Rubbia
Higgs
van der Meer
Fitch
Cronin
Kendall
Schwinger
Tomonaga
Feynman
Richter
Gell-Mann
Alvarez
Taylor
Yang
Lee
Selected NP since 1957 Except P. Higgs
Nambu
Kobayashi
Maskawa
Supersymmetry
New particles at ≈ TeV scale,
light Higgs
Unification of forces
Higgs mass stabilized
No new interactions
Successful for ever ??
Extra Dimensions
New dimensions introduced
$m_{Gravity} \approx m_{elw}$ ➲ Hierarchy problem solved
New particles at ≈ TeV scale

MÁS ALLÁ DEL MODELO ESTÁNDAR...

A Cellar of New Ideas

'67	The Standard Model	a classic! aged to perfection
'77	Vin de Technicolor	better drink now
'70's	Supersymmetry: MSSM	mature, balanced, well developed - the Wino's choice
'90's	SUSY Beyond MSSM	svinters blend
'90's	CP Violating Higgs	all upfront, no finish lacks symmetry
'98	Extra Dimensions	bold, peppery, spicy uncertain terrior
'02	Little Higgs	complex structure
'03	Fat Higgs	young, still tannic needs to develop
'03	Higgsless	sleeper of the vintage what a surprise!
'04	Split Supersymmetry	finely-tuned
'05	Twin Higgs	double the taste

J. Hewett

MENSAJE RELEVANTE

LHC Y EL MODELO ESTÁNDAR

SI SE CONFIRMA QUE SE TRATA DEL BOSÓN DE HIGGS DEL MODELO ESTÁNDAR :

¡¡ DESCUBRIMIENTO !!

SI SE CONCLUYE QUE NO SE TRATA DEL BOSÓN DE HIGGS DEL MODELO ESTÁNDAR :

¡¡ DESCUBRIMIENTO !!

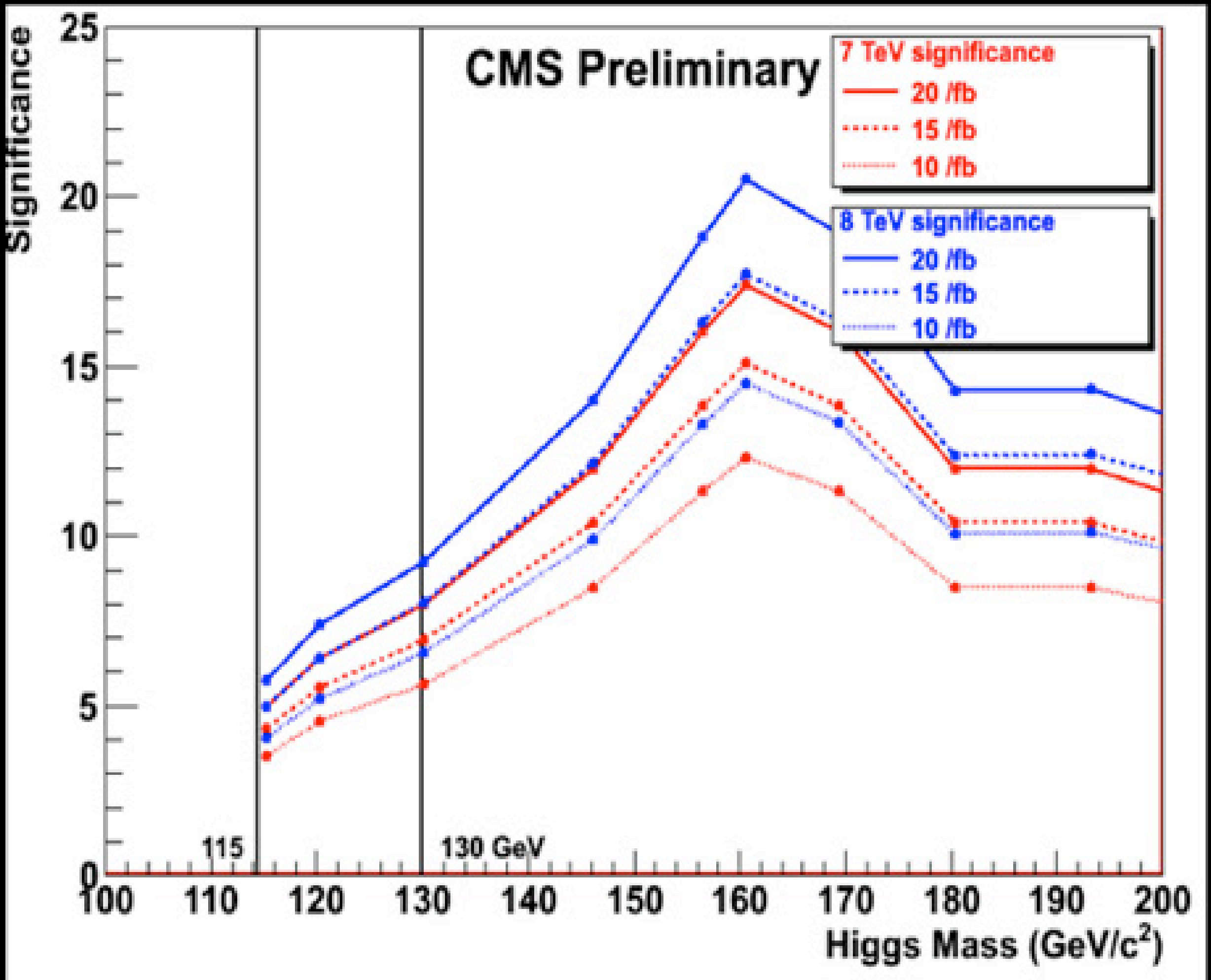
RECORDATORIO

LHC TIENE QUE CLARIFICAR EL MECANISMO DE LA ROTURA DE LA SIMETRÍA ELECTRODÉBIL

PERSPECTIVAS 2012

El CERN ha decidido prolongar la toma de datos 2-3 meses

A finales de 2012 se espera alcanzar los 25-30 fb^{-1}



EXPECTATIVAS

PREDECIR ES ALGO MUY DIFÍCIL, ESPECIALMENTE ACERCA DEL FUTURO,

Niels Bohr

ES YA MUY DURO CONOCER EL PASADO; SERÍA INTOLERABLE CONOCER EL FUTURO,

William Somerset Maughan

EXPECTATIVAS

- Esperar hasta principios de 2013 para confirmar que la partícula descubierta es el **Bosón de Brout-Englert-Higgs** del Modelo Estándar o se trata de algo diferente

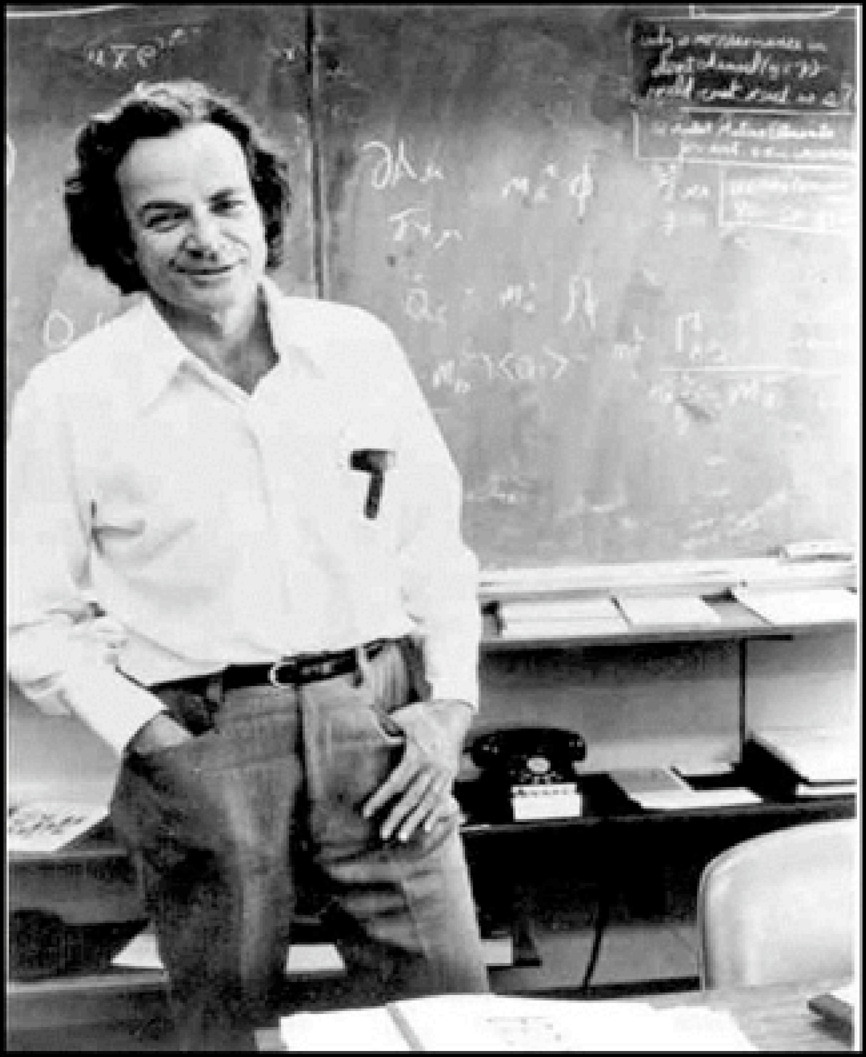
- Difícil predecir cuando aparecerán señales de física más allá del Modelo Estándar


EPÍLOGO

RICHARD FEYNMAN

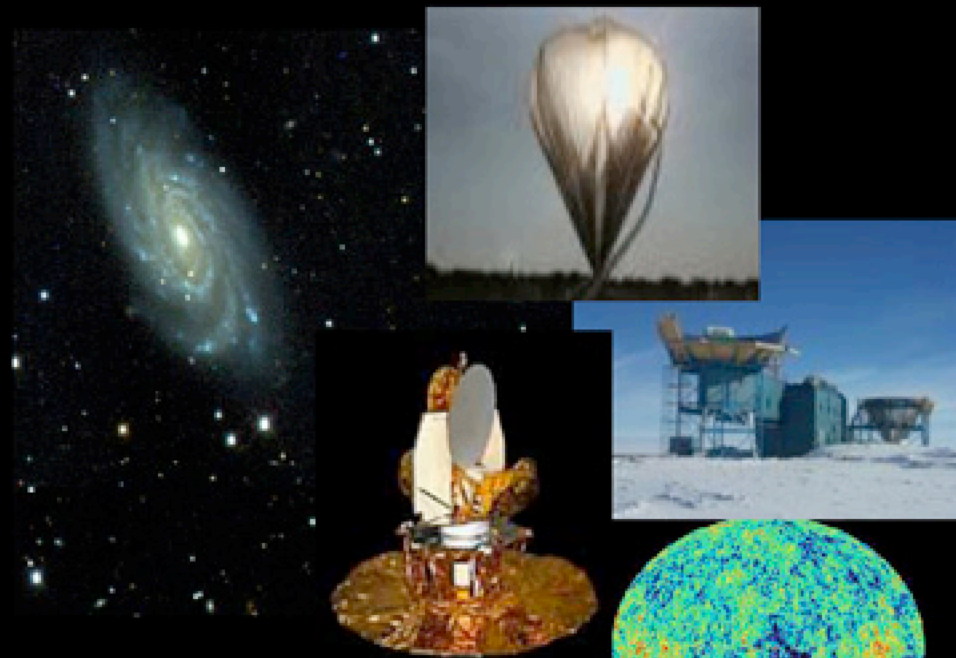
VIVIMOS EN UNA ÉPOCA EN LA QUE SE ESTÁN DESCUBRIENDO LAS LEYES FUNDAMENTALES DE LA NATURALEZA, Y ESA ÉPOCA ES

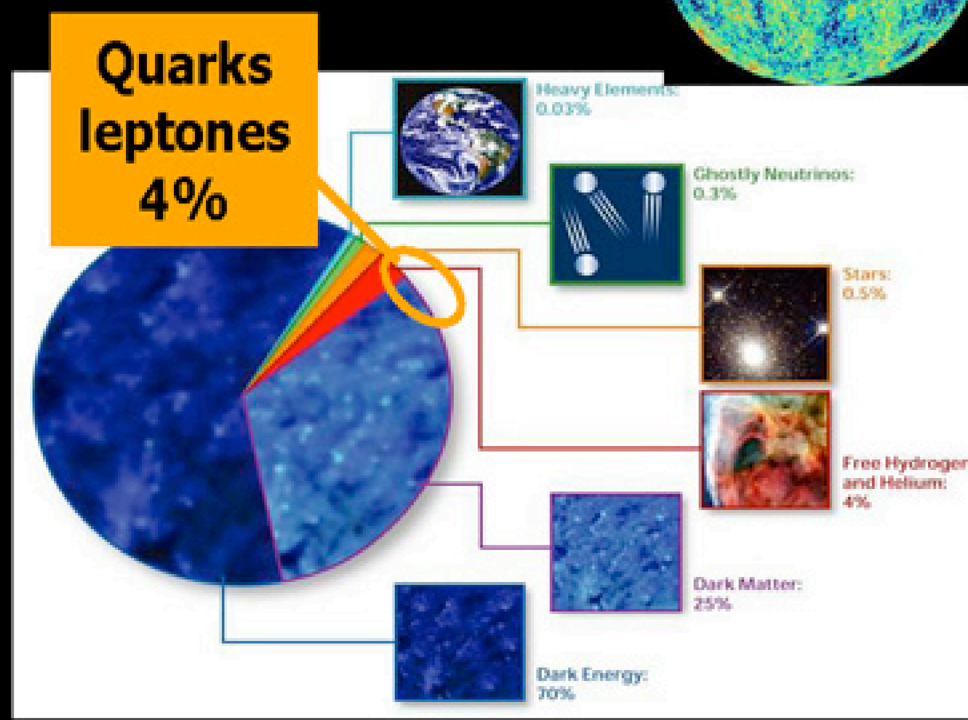
IRREPETIBLE



ACERCA DEL UNIVERSO …

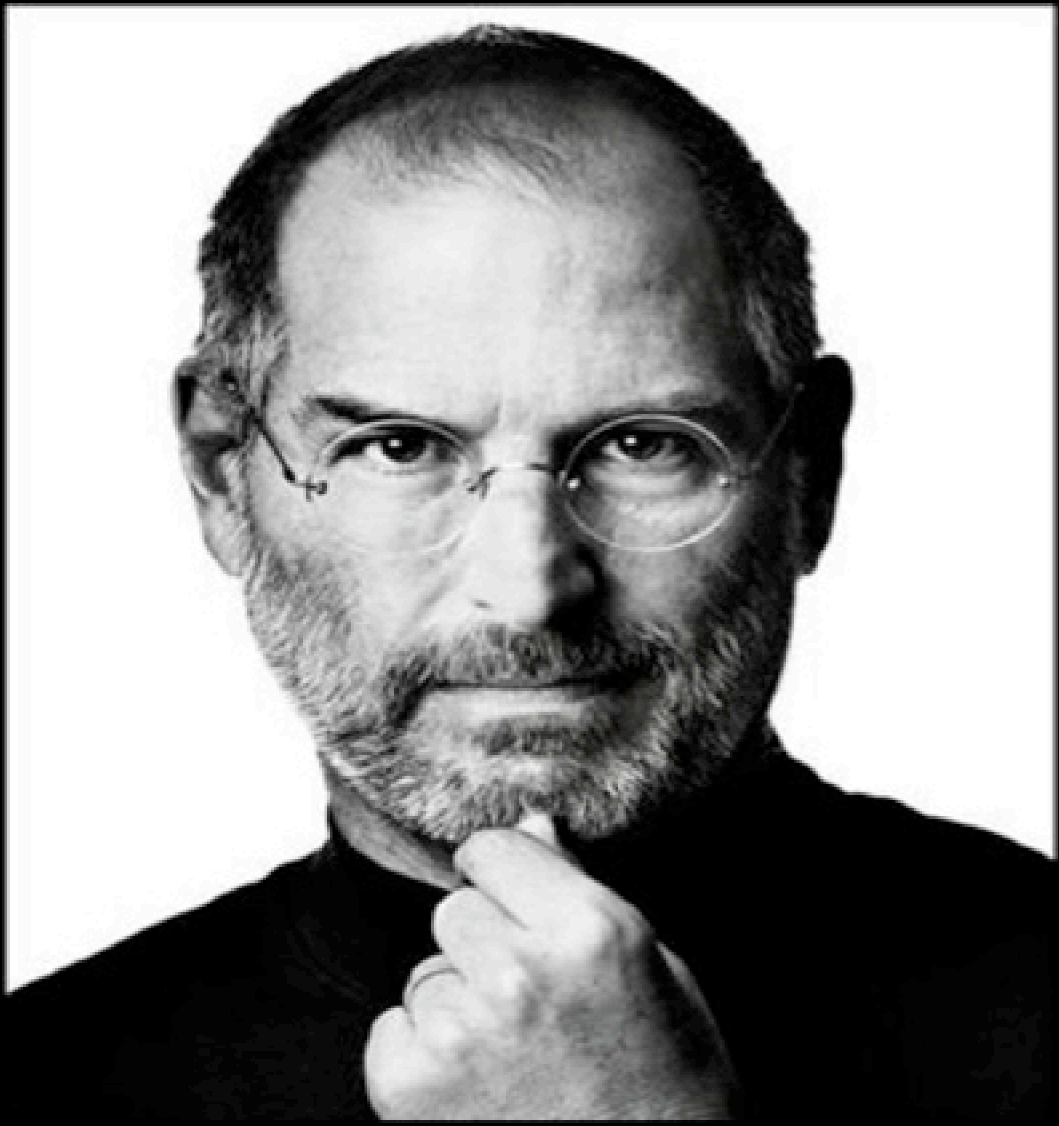
¡ NO SE CONOCE DE QUÉ ESTÁ HECHO EL 96% DEL UNIVERSO !






EL PRODUCTO MÁS IMPORTANTE DEL CONOCIMIENTO ES LA IGNORANCIA .....
DAVID J. GROSS
PREMIO NOBEL 2004
THE FUN IS JUST BEGINNING
¡ LA FIESTA HA EMPEZADO !

.... Y LA INNOVACIÓN !!



STEVE JOBS (1955–2011)


MUCHAS GRACIAS