

EL CERN CUMPLE 60 AÑOS



MANUEL AGUILAR BENITEZ DE LUGO
REAL ACADEMIA DE CIENCIAS



2014

ANIVERSARIOS

1954: CREACIÓN DEL CERN

1984: PREMIO NOBEL A RUBBIA, VAN DER MEER

1984: ESPAÑA RETORNA AL CERN

1964: “INVENCION” DE LOS QUARKS

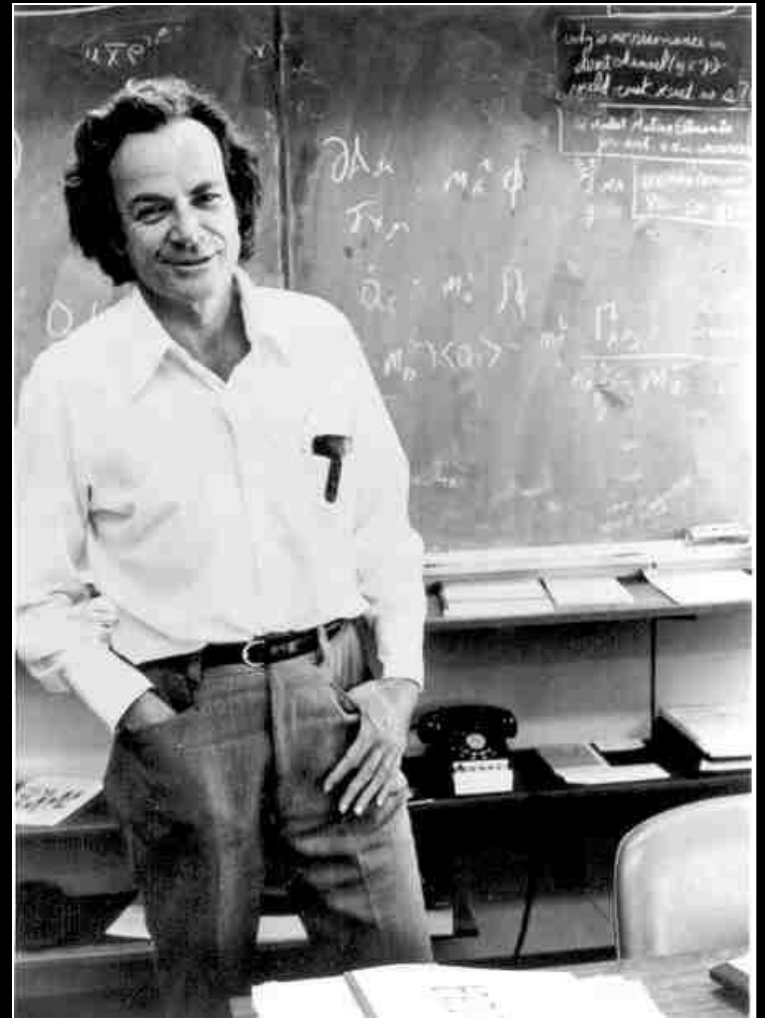
1964: VIOLACIÓN DE LA SIMETRÍA CP

1964: FORMULACIÓN DEL MECANISMO DE B-E-H

1974: DESCUBRIMIENTO DEL QUARK C

1964: DESCUBRIMIENTO DEL CMB

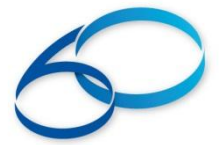
**THE AGE IN WHICH
WE LIVE IS THE AGE
IN WHICH WE ARE
DISCOVERING THE
FUNDAMENTAL LAWS
OF NATURE, AND
THAT DAY WILL
NEVER COME AGAIN**



R.P. FEYNMAN



CERN (1954–2014)



YEARS/ANS CERN



LHC

LEP

SPS

CERN
Préessin



CERN
Meyrin

FÍSICA DE PARTÍCULAS EN EL CERN

ESTUDIO DE LOS CONSTITUYENTES ÚLTIMOS DE LA MATERIA, DE LAS FUERZAS FUNDAMENTALES A TRAVÉS DE LAS QUE INTERACCIONAN Y DE LAS LEYES QUE RIGEN LA EVOLUCIÓN DEL UNIVERSO

- **HACER CRECER LAS FRONTERAS DEL CONOCIMIENTO**
- **AMPLIAR LAS FRONTERAS TECNOLÓGICAS**
- **EDUCAR A LOS CIENTÍFICOS E INGENIEROS DEL MAÑANA**
- **ACERCAR NACIONES A TRAVÉS DE LA CIENCIA**



"The effort to understand the universe is one of the very few things that lifts human life a little above the level of farce, and gives it some of the grace of tragedy."

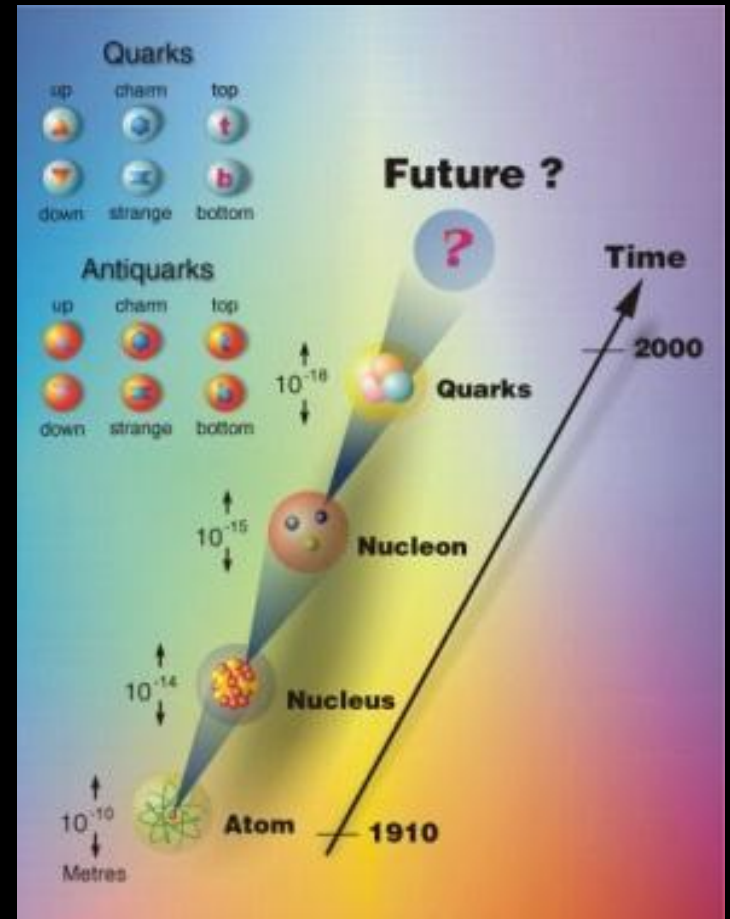
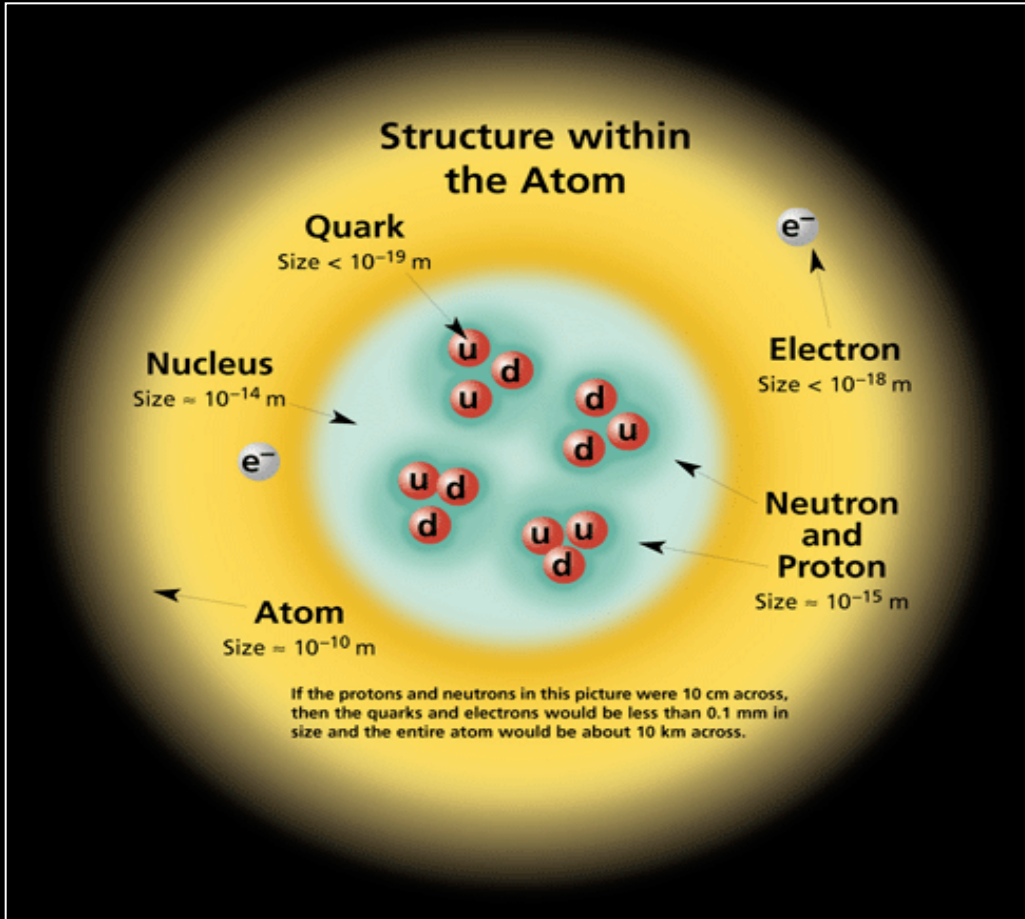
Steven Weinberg

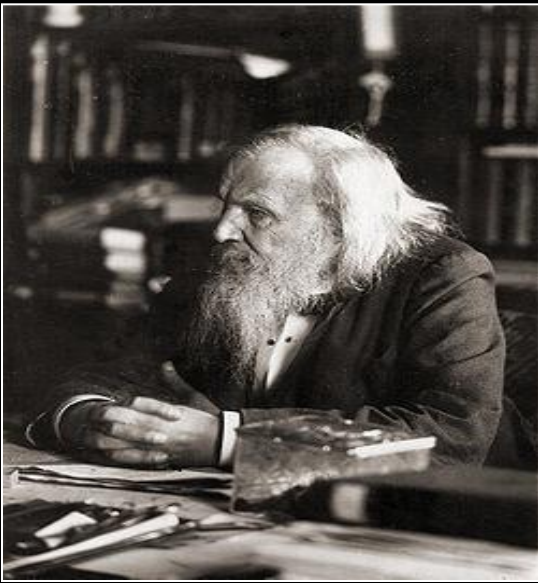
“EL esfuerzo para entender el Universo es una de las muy pocas cosas que eleva la vida humana un poco por encima del nivel de la farsa, y le da algo de la elegancia de una tragedia”

LA MATERIA TIENE ESTRUCTURA ATÓMICA

LA MATERIA NO LLENA TODO EL ESPACIO QUE OCUPA

ESTRUCTURA INTERNA DEL ÁTOMO





Reihen	Gruppe I. — R ⁰	Gruppe II. — R ⁰	Gruppe III. — R ⁰	Gruppe IV. RH ⁴ R ⁰	Gruppe V. RH ⁵ R ⁰	Gruppe VI. RH ⁶ R ⁰	Gruppe VII. RH R ⁰	Gruppe VIII. — R ⁰
1	II=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Po=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	

1871

D.I. MENDELEEV
(1834-1907)



Tableau périodique des éléments

Légende

- Electronegativité
- État de l'atome
- Nombre d'oxydation
- Densité (à 300 K)
- Température de fusion du corps pur [°C]
- Température d'ébullition du corps pur [°C]
- Non métallique
- Métal
- Yttrium
- Masses atomiques moyennes (si entre parenthèses, masse de l'isotope le plus stable)
- Symbole (solide, liquide, gaz), Éléments synthétiques en italique
- Numéro atomique

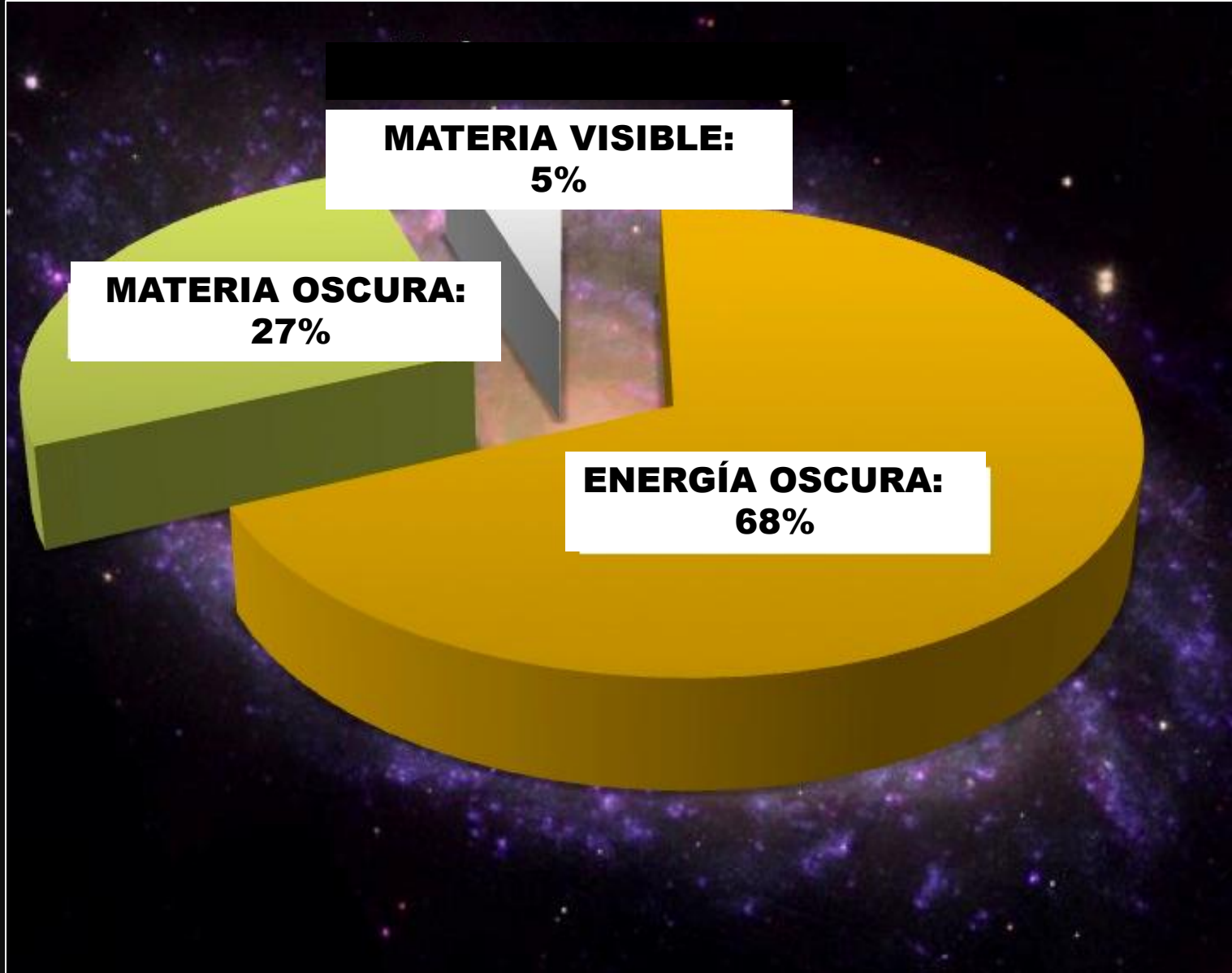
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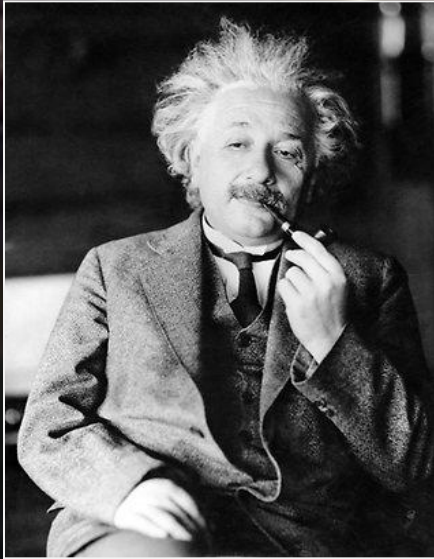
Tableau périodique des éléments modifié d'après l'Union internationale de chimie pure et appliquée (IUPAC) et le Comité de l'Union internationale de chimie pure et appliquée (IUPAC) 2016.

MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

		Three Generations of Matter (Fermions)			
		I	II	III	
mass→		3 MeV	1.24 GeV	172.5 GeV	0
charge→		$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin→		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name→		u up	c charm	t top	γ photon
	Quarks	6 MeV	95 MeV	4.2 GeV	0
		$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
		d down	s strange	b bottom	g gluon
	Leptons	<2 eV	<0.19 MeV	<18.2 MeV	90.2 GeV
		0	0	0	0
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
		ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z⁰ weak force
		0.511 MeV	106 MeV	1.78 GeV	80.4 GeV
		-1	-1	-1	±1
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
		e electron	μ muon	τ tau	W[±] weak force
					Bosons (Forces)

CONTENIDO MATERIA – ENERGÍA DEL UNIVERSO





**EL SUPREMO DESAFÍO DEL
FÍSICO ES LLEGAR A AQUELLAS LEYES
ELEMENTALES A PARTIR DE LAS CUALES
EL COSMOS PUEDE CONSTRUIRSE POR
PURA DEDUCCIÓN**

**MODELO ESTÁNDAR DE
FÍSICA DE PARTÍCULAS**

MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

LAS LEYES QUE GOBIERNAN LOS PROCESOS ENTRE PARTÍCULAS ELEMENTALES PUEDEN DERIVARSE EXIGIENDO QUE SEAN INVARIANTES BAJO LAS TRANSFORMACIONES DE UN DETERMINADO GRUPO DE SIMETRÍA

¿QUÉ GRUPO?

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$$

MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

UNA DE LAS CREACIONES CIENTÍFICAS MÁS EXTRAORDINARIAS DEL SIGLO XX

EJEMPLO PARADIGMÁTICO DE SÍNTESIS CIENTÍFICA

TEORÍA CONCEPTUALMENTE SIMPLE CONSTRUÍDA ESENCIALMENTE A PARTIR DE PRINCIPIOS DE SIMETRÍA

EXTRAORDINARIO PODER PREDICTIVO

- INVENCION & DESCUBRIMIENTO DE LOS QUARKS (1964)**
- DESCRIPCIÓN UNIFICADA DEL ELECTROMAGNETISMO Y LA FUERZA DÉBIL (1961-1967)**
- COMPRENSIÓN DE LA FUERZA FUERTE (1973)**

QUARKS



M. GELL-MANN



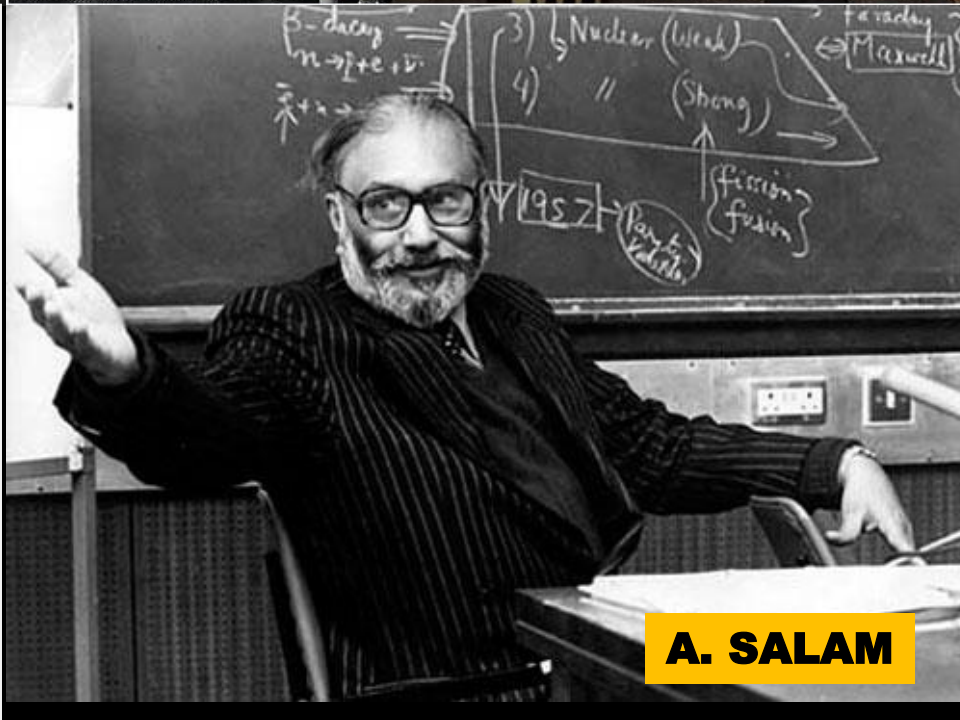
S. WEINBERG

S. GLASHOW

ACES



G. ZWEIG



A. SALAM

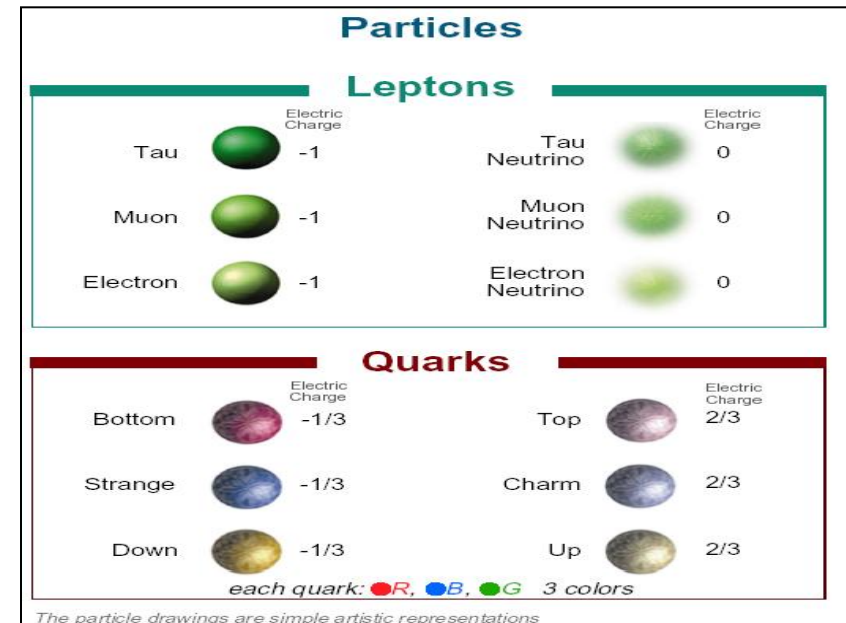
MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

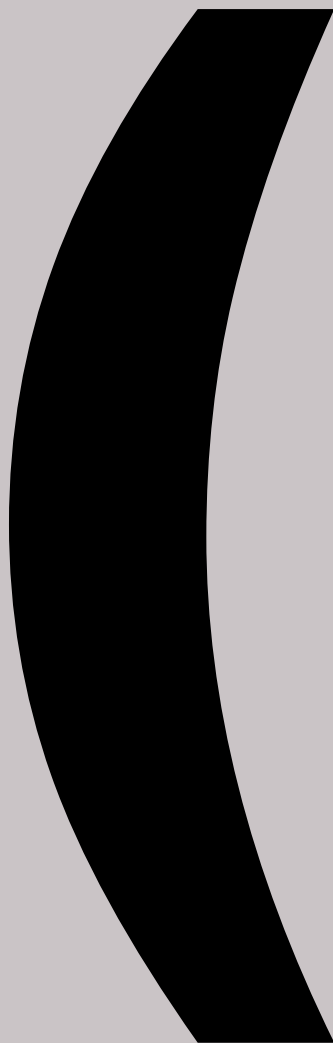
TODA LA MATERIA ORDINARIA EN EL UNIVERSO ESTÁ HECHA

DE QUARKS u , d

Y LEPTONES e , ν_e

¿POR QUÉ?





Materia & Antimateria

Dirac predijo en 1926 que para cada **PARTÍCULA** debería existir su correspondiente **ANTIPARTÍCULA**.

Las **ANTIPARTÍCULAS** tienen las mismas propiedades estáticas (masa, vida media, spin, ...) que las **PARTÍCULAS**, aunque algunas con signo opuesto (carga eléctrica, números cuánticos)

Descubiertas en los rayos cósmicos
Estudiadas en los aceleradores



P.A.M. DIRAC (1902-1984)
Teoría del electrón (1926)
Premio Nobel de Física 1933

"We must regard it rather as an accident that the Earth (and presumably the whole solar system) contains a preponderance of negative electrons and positive protons. It is quite possible that for some stars it is the other way about, these stars being built mainly of positrons and negative protons. The two kinds of stars would both show exactly the same spectra, and there would be no way of distinguishing them by the present astronomical methods"

V.L. FITCH

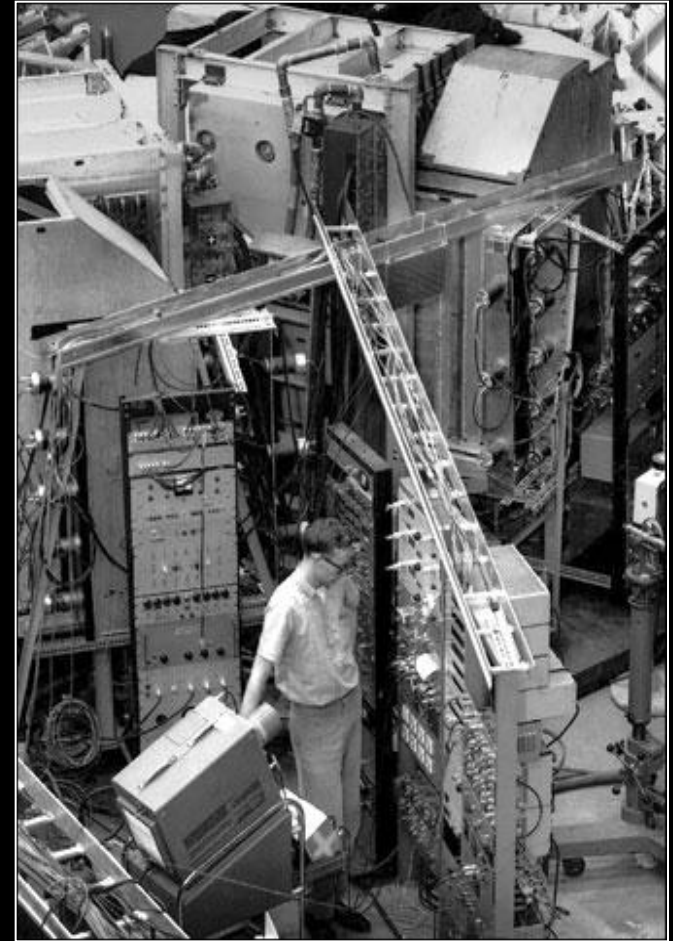
J.W. CRONIN

S.C.C. TING



C.N. YANG

I.I. RABI



**EXPERIMENTO BNL
VIOLACIÓN DE LA
SIMETRÍA CP (1964)**

LA HIPÓTESIS DEL BIG BANG ACERCA DEL ORIGEN DEL UNIVERSO IMPLICA IGUAL CANTIDAD DE MATERIA Y ANTIMATERIA EN EL UNIVERSO PRIMIGENIO



Search for the existence of anti Universe

Search for the origin of the Universe

¿QUÉ HA OCURRIDO CON LA ANTIMATERIA PRIMORDIAL?

Anti-Universe

Universe

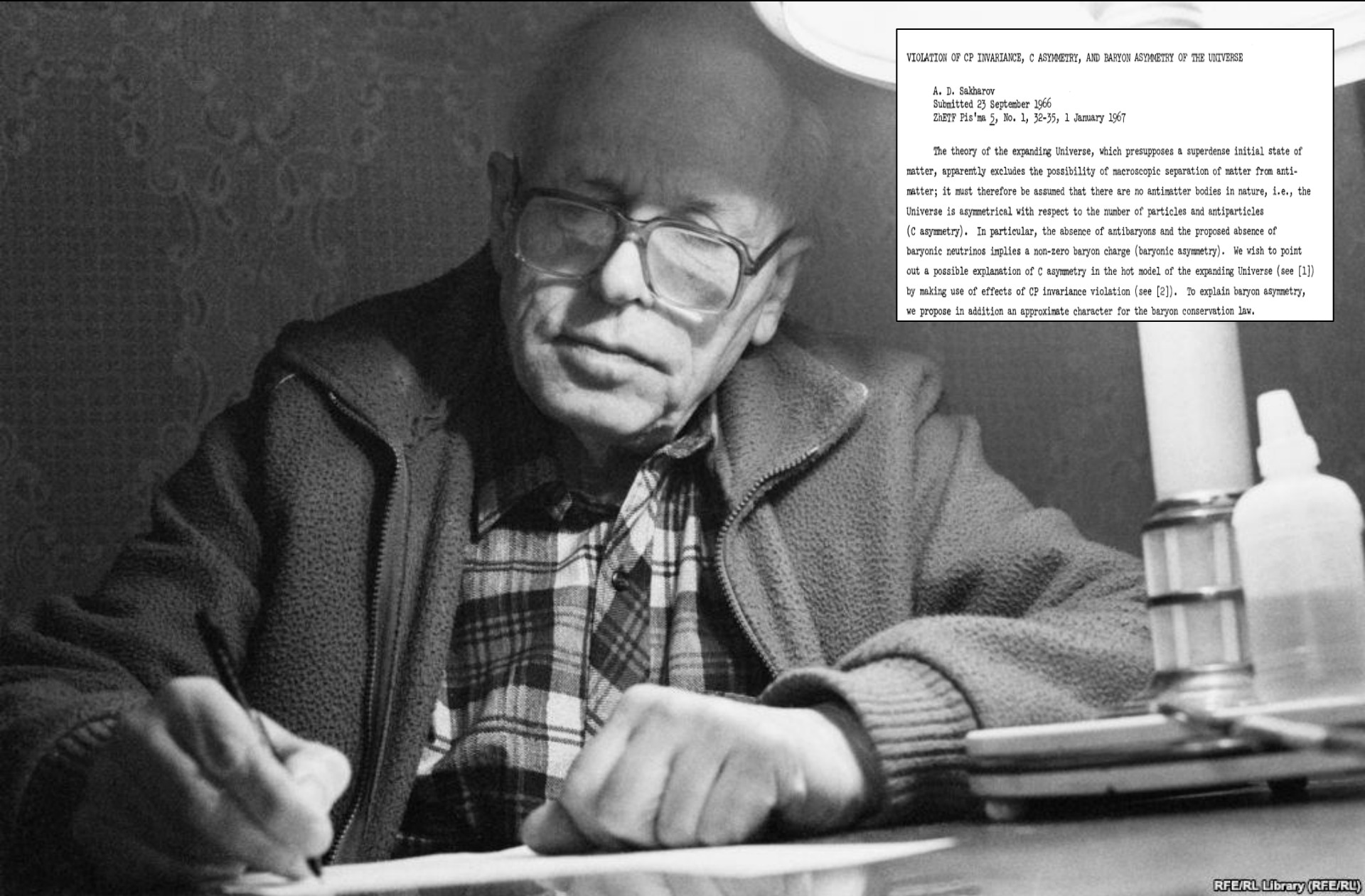
Materia & Antimateria

MATERIA \neq ANTIMATERIA
¿POR QUÉ?

HASTA LA FECHA NO SE HA DETECTADO
ANTIMATERIA
EN LA RADIACIÓN CÓSMICA PRIMARIA

EL UNIVERSO PARECE ESTAR FORMADO
SÓLO DE MATERIA
¿POR QUÉ?

ANDREI SAKHAROV (1921–1989)



VIOLATION OF CP INVARIANCE, C ASYMMETRY, AND BARYON ASYMMETRY OF THE UNIVERSE

A. D. Sakharov

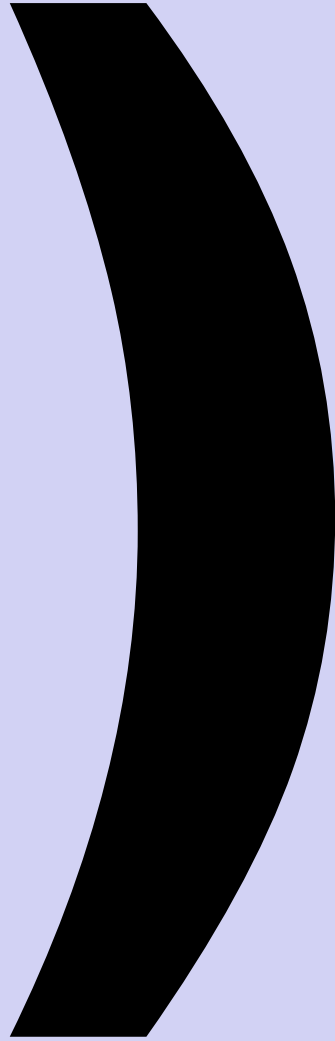
Submitted 23 September 1966

ZhETF Pis'ma 5, No. 1, 32-35, 1 January 1967

The theory of the expanding Universe, which presupposes a superdense initial state of matter, apparently excludes the possibility of macroscopic separation of matter from antimatter; it must therefore be assumed that there are no antimatter bodies in nature, i.e., the Universe is asymmetrical with respect to the number of particles and antiparticles (C asymmetry). In particular, the absence of antibaryons and the proposed absence of baryonic neutrinos implies a non-zero baryon charge (baryonic asymmetry). We wish to point out a possible explanation of C asymmetry in the hot model of the expanding Universe (see [1]) by making use of effects of CP invariance violation (see [2]). To explain baryon asymmetry, we propose in addition an approximate character for the baryon conservation law.

Hay ~ 100.000 millones de galaxias en el Universo,
cada una con ~ 100.000 millones de estrellas.
Keep searching, Stephen Hawking











MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS







TODA LA MATERIA ORDINARIA EN EL UNIVERSO ESTÁ HECHA

DE QUARKS u , d

Y LEPTONES e , ν_e

¿POR QUÉ?

Particles			
Leptons			
Tau		Electric Charge -1	
Muon		-1	
Electron		-1	
Tau Neutrino		0	Electric Charge
Muon Neutrino		0	
Electron Neutrino		0	

Quarks			
Bottom		Electric Charge -1/3	
Strange		-1/3	
Down		-1/3	
Top		2/3	Electric Charge
Charm		2/3	
Up		2/3	

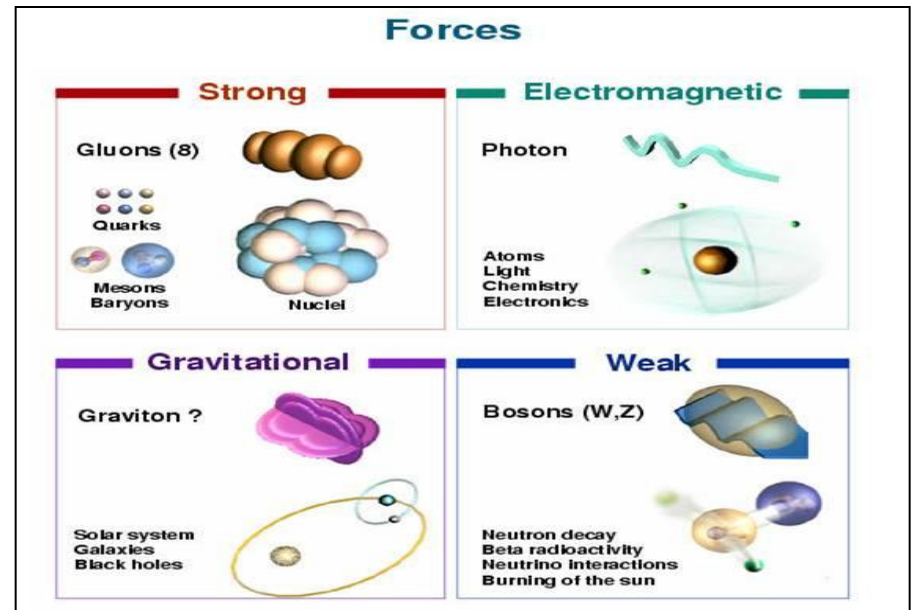
each quark: ●R, ●B, ●G 3 colors

The particle drawings are simple artistic representations

MECANISMO DE KOBAYASHI-MASKAWA (PNF 2008)
SE NECESITAN 3 GENERACIONES DE QUARKS Y LEPTONES
PARA EXPLICAR LA VIOLACIÓN DE CP EN EL MARCO DEL
MODELO ESTÁNDAR (1973)

MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

PARTÍCULAS DE FUERZA

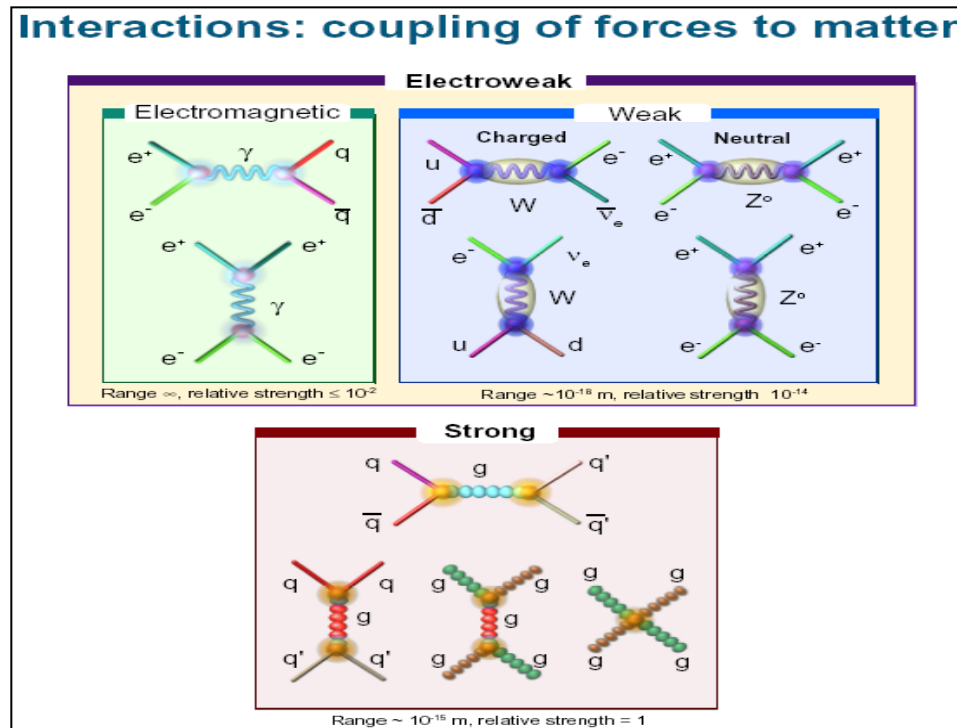


LOS MENSAJEROS DE LAS FUERZAS (PROPAGADORES) TIENEN:

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

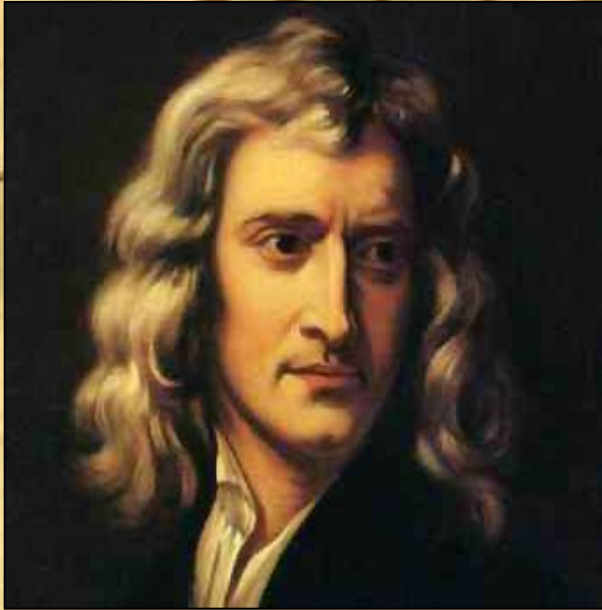
MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS

INTERACCIONES: ACOPLAMIENTO PARTÍCULAS-FUERZAS



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

AUCTORE



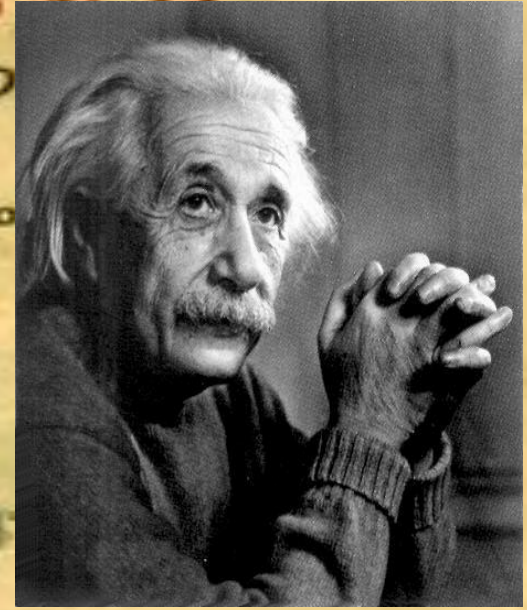
I. NEWTON

1642-1727



J.C. MAXWELL

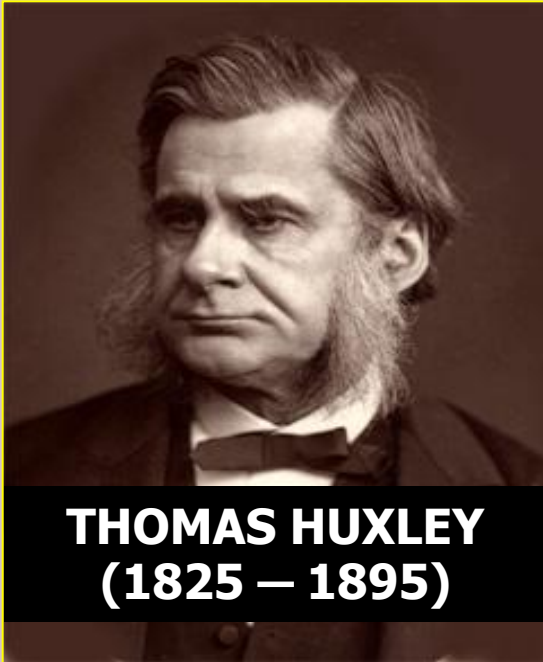
1831-1879



A. EINSTEIN

1879-1955

MODELO ESTÁNDAR DE FÍSICA DE PARTÍCULAS



THOMAS HUXLEY
(1825 – 1895)

“LA GRAN TRAGEDIA DE LA CIENCIA ES LA MUERTE DE UNA BELLA TEORÍA POR UN HECHO FEO”

**TODOS LOS BOSONES
GAUGE TIENEN MASA = 0**

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 (Received 26 June 1964)

It is of interest to inquire whether gauge vector mesons acquire mass through interaction; by a gauge vector meson we mean a Yang-Mills field¹ 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.² 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.³⁻⁵ A characteristic feature of such theories is the possible existence of zero-mass bosons which tend to restore the symmetry.^{6,7} 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 ψ_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) Least 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 ψ and the A_μ fields is

$$H_{int} = ieA_\mu \psi^\dagger \vec{\sigma} \psi - e^2 \psi^\dagger \psi A_\mu A_\mu, \quad (1)$$

where $\psi = (\psi_1 + i\psi_2)/\sqrt{2}$. We shall break the symmetry by fixing $\langle \psi \rangle \neq 0$ in the vacuum, with the phase chosen for convenience such that $\langle \psi \rangle = \langle \psi_1 \rangle / \sqrt{2}$.

We shall assume that the application of the

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In a recent note¹ 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 Anderson³ has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasma 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 Goldstone⁴ himself: Two real⁵ scalar fields ψ_1, ψ_2 and a real vector field A_μ interact through the Lagrangian density

$$L = -\frac{1}{2}(\partial_\mu \psi_1)^2 - \frac{1}{2}(\partial_\mu \psi_2)^2 - \frac{1}{2}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2 - \frac{1}{2}g^2(\psi_1^2 + \psi_2^2)^2 - \frac{1}{2}g^2\psi_1^2 A_\mu^2, \quad (1)$$

where

$$\begin{aligned} \nabla_\mu \psi_1 &= \partial_\mu \psi_1 - eA_\mu \psi_2 \\ \nabla_\mu \psi_2 &= \partial_\mu \psi_2 - eA_\mu \psi_1 \\ F_{\mu\nu} &= \partial_\mu A_\nu - \partial_\nu A_\mu \end{aligned}$$

e is a dimensionless coupling constant, and the metric is taken as $g_{\mu\nu} = \text{diag}(1, -1, -1, -1)$. L is invariant under simultaneous gauge transformations of the first kind on $\psi_1 + i\psi_2$ and of the second kind on A_μ . Let us suppose that $V(\psi_1^2 + \psi_2^2) > 0$; then spontaneous breakdown of U(1) symmetry occurs. Consider the equations [derived from (1)] by treating ψ_1, ψ_2, ψ_3 and A_μ as small quantities] governing the propagation of small oscillations

about the "vacuum" solution $\psi_1(x) = 0, \psi_2(x) = \psi_3$

$$\partial^\mu [\partial_\mu (\Delta\psi_1) - e\psi_3 \Delta A_\mu] = 0, \quad (2a)$$

$$\partial^\mu [-\partial_\mu (\psi_3 \Delta\psi_2) + (\Delta\psi_2) \psi_3] = 0, \quad (2b)$$

$$\partial^\mu [F_{\mu\nu} - e\psi_3 (\delta_{\mu\nu} \Delta\psi_1 - \partial_\nu \Delta\psi_1)] = 0. \quad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2e\psi_3/V''(\psi_3^2)^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu = A_\mu - (e\psi_3)^{-1} \partial_\mu (\Delta\psi_1),$$

$$G_{\mu\nu} = F_{\mu\nu} - e\psi_3 (\delta_{\mu\nu} \Delta\psi_1 - \partial_\nu \Delta\psi_1), \quad (3)$$

into the form

$$\partial^\mu B_\mu = 0, \quad \partial^\mu G_{\mu\nu} - e^2 \psi_3^2 B_\nu = 0. \quad (4)$$

Equation (4) describes vector waves whose quanta have (bare) mass $e\psi_3$. 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.⁶

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.⁷ 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.⁸ 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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 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 theorem¹ has played an important role. This theorem, briefly stated, asserts that if there exists a conserved operator Q_i such that

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

and if it is possible consistently to take $\sum_k f_{ijk} \times (0|A_k(0) \neq 0$, 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 proof² may allow one the hope of avoiding such massless particles through the in-

roduction 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 $\sum_k f_{ijk} (0|A_k(0) \neq 0$) 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



2008: Primer Higgs observado en CMS

1964



Thomas Kibble

Gerald Guralnik

Carl Hagen

François Englert

Robert Brout

EL MODELO ESTÁNDAR 1967



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

$$\begin{aligned}
 & -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \\
 & \frac{1}{2}ig_s^2 (\bar{q}_i^\mu \gamma^\mu q_j^\mu) g_\mu^a + G^a \partial^2 G^a + g_s f^{abc} \partial_\nu G^a G^b g_\nu^c - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - \\
 & M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2} M^2 Z_\mu^0 Z_\mu^0 - \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 \left[\frac{2M^2}{\phi^2} + \right. \\
 & \left. \frac{2M}{s} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{s^2} \alpha_h - ig_{cw} [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - Z_\nu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - \\
 & W_\nu^- \partial_\nu W_\mu^+)] - ig_{sw} [\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_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + \\
 & g^2 s_w^2 (A_\mu W_\mu^+ A_\nu W_\nu^- - A_\mu A_\nu W_\mu^+ W_\nu^-) + g^2 s_w c_w [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 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)^2 H^2] - \\
 & g M W_\mu^+ W_\nu^- H - \frac{1}{2}g \frac{M}{c_w^2} Z_\mu^0 Z_\nu^0 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_\mu^0 (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig_{cw} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \\
 & ig_{sw} M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
 & ig_{sw} 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_\mu^0 Z_\nu^0 [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_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z_\mu^0 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_\mu^0 A_\mu \phi^+ \phi^- - \\
 & g^1 s_w^2 A_\mu A_\nu \phi^+ \phi^- - e^\lambda (\gamma \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \\
 & \bar{d}_j^\lambda (\gamma \partial + m_d^\lambda) d_j^\lambda + ig_{sw} A_\mu [-(e^\lambda \gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)] + \\
 & \frac{ig}{4c_w} Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (e^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - \\
 & 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + \\
 & (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda k} d_k^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\lambda C_{\lambda k}^\dagger \gamma^\mu (1 + \\
 & \gamma^5) u_j^\lambda)] + \frac{ig}{2\sqrt{2}} \frac{m_\lambda^2}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \\
 & \frac{g}{2} \frac{m_\lambda^2}{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^\lambda (\bar{u}_j^\lambda C_{\lambda k} (1 - \gamma^5) d_k^\lambda) + \\
 & m_u^\lambda (\bar{u}_j^\lambda C_{\lambda k} (1 + \gamma^5) d_k^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^- [m_d^\lambda (\bar{d}_j^\lambda C_{\lambda k}^\dagger (1 + \gamma^5) u_j^\lambda) - m_u^\lambda (\bar{d}_j^\lambda C_{\lambda k}^\dagger (1 - \\
 & \gamma^5) u_j^\lambda)] - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \\
 & \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \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 + ig_{cw} W_\mu^+ (\partial_\mu X^0 X^- - \partial_\mu X^+ X^0) + ig_{sw} W_\mu^+ (\partial_\mu \bar{Y} X^- - \\
 & \partial_\mu \bar{X}^+ Y) + ig_{cw} W_\mu^- (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + ig_{sw} W_\mu^- (\partial_\mu \bar{X}^- Y - \\
 & \partial_\mu \bar{Y} X^+) + ig_{cw} Z_\mu^0 (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + ig_{sw} A_\mu (\partial_\mu \bar{X}^+ X^+ - \\
 & \partial_\mu \bar{X}^- X^-) - \frac{1}{2}g M [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w} \bar{X}^0 X^0 H] + \\
 & \frac{1-2c_w^2}{2c_w} ig M [\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \frac{1}{2c_w} ig M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\
 & ig M s_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \frac{1}{2}ig M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
 \end{aligned}$$



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



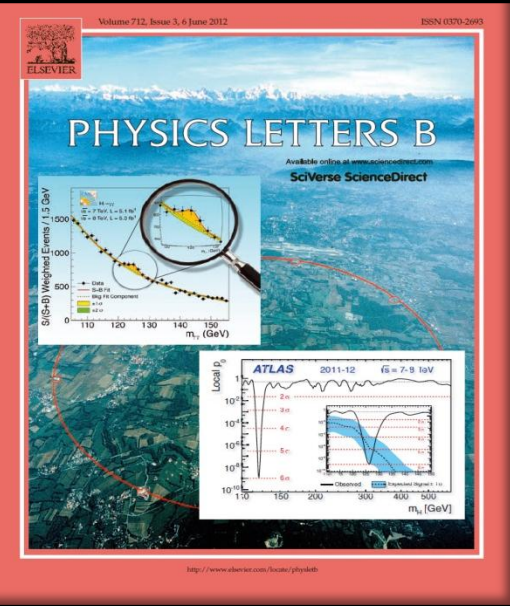
D. POLITZER, D. GROSS, F. WILCZEK / PNF 2004

CERN, 4 DE JULIO, 2012



- MVAs for photon ID and event classification
 - 1st mass distribution in 4 event classes based on a diphoton MVA output + 2 di-jet categories
 - Improvement in expected limit $\sim 15\%$ over cut-based analysis
- Cross-checked with an alternative background model extraction
 - Fit output of a 2nd MVA combining diphoton MVA and m_{jj} , using data in mass sidebands to construct the background model
- Also cross-checked with a cut based analysis
 - Simple and robust
 - Cut based photon ID and event classification
 - 1st data mass distribution in a $1\text{rapidity} \times 4$ shower shape η_4 categories with different signal over Background (SBR) + 2 di-jet categories
 - Published for 2013 data
 - Phys.Lett. B720 (2012) 409-425 arXiv:1204.1487







F. ENGLERT
ORSAY, JULIO 2012

P. HIGGS
OVIEDO, OCTUBRE 2013



BOSÓN B-E-H RELLENA EL HUECO EN EL CONOCIMIENTO DE LO ORDINARIO

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	-1	s strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	-1	b bottom	4.3	-1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of \hbar , which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58 \cdot 10^{-25}$ GeV s = $1.05 \cdot 10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is $1.60 \cdot 10^{-19}$ coulombs.

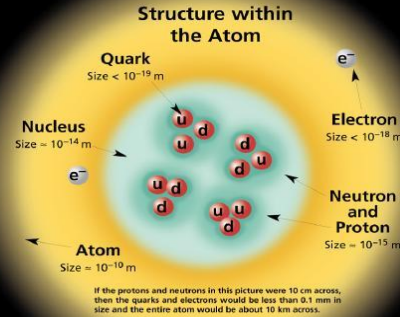
The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c² (remember $E = mc^2$), where 1 GeV = 10^9 eV = $1.60 \cdot 10^{-10}$ joule. The mass of the proton is 0.938 GeV/c² = $1.67 \cdot 10^{-27}$ kg.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge	Name	Mass GeV/c ²	Electric charge
γ photon	0	0	g gluon	0	0
W⁻	80.4	-1			
W⁺	80.4	+1			
Z⁰	91.187	0			

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and **W** and **Z** bosons have no strong interactions and hence no color charge.



Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq .

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
p	proton	uud	1	0.938	1/2
\bar{p}	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
n	neutron	udd	0	0.940	1/2
\bar{n}	anti-neutron	$\bar{u}\bar{d}\bar{d}$	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	-1	1.672	3/2

Property	Interaction	Gravitational	Weak	Electromagnetic	Strong	
			(Electroweak)		Fundamental	Residual
Acts on:		Mass - Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:		All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:		Graviton (not yet observed)	W⁺ W⁻ Z⁰	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at:	10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
	3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus		10^{-36}	10^{-7}	1	Not applicable to hadrons	20

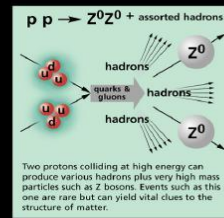
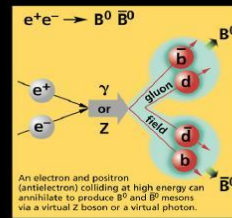
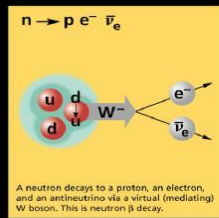
Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
π^+	pion	u\bar{d}	+1	0.140	0
K^-	kaon	s\bar{u}	-1	0.494	0
ρ^+	rho	u\bar{d}	+1	0.770	1
B^0	B-zero	d\bar{b}	0	5.279	0
η_c	eta-c	c\bar{c}	0	2.980	0

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or - charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0 , γ , and $\nu_e = \bar{\nu}_e$, but not $K^0 = \bar{K}^0$) are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are not exact and have no meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



The Particle Adventure

Visit the award-winning web feature *The Particle Adventure* at <http://ParticleAdventure.org>

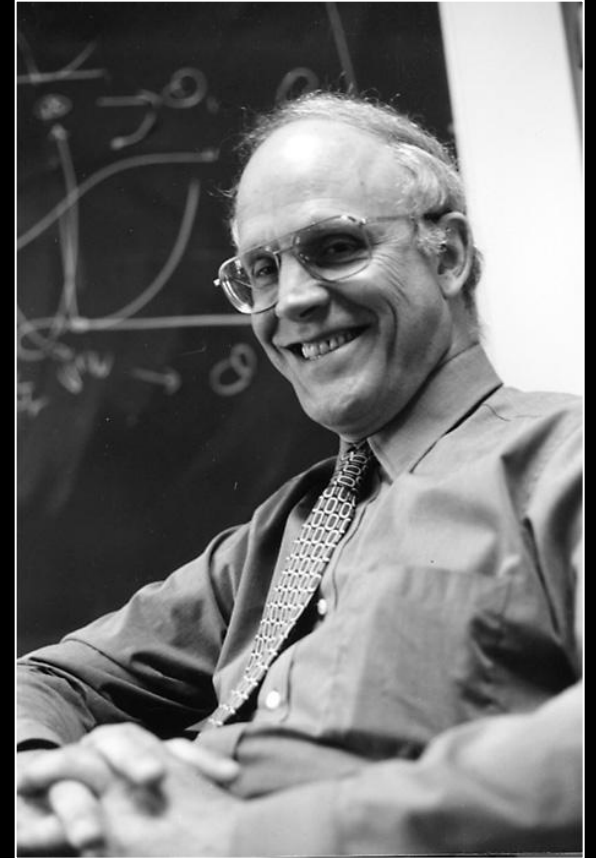
This chart has been made possible by the generous support of:

U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

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<http://CPEPweb.org>

**EL PRODUCTO
MÁS IMPORTANTE DE LA
INVESTIGACIÓN
ES LA IGNORANCIA**



D. GROSS

Quarks

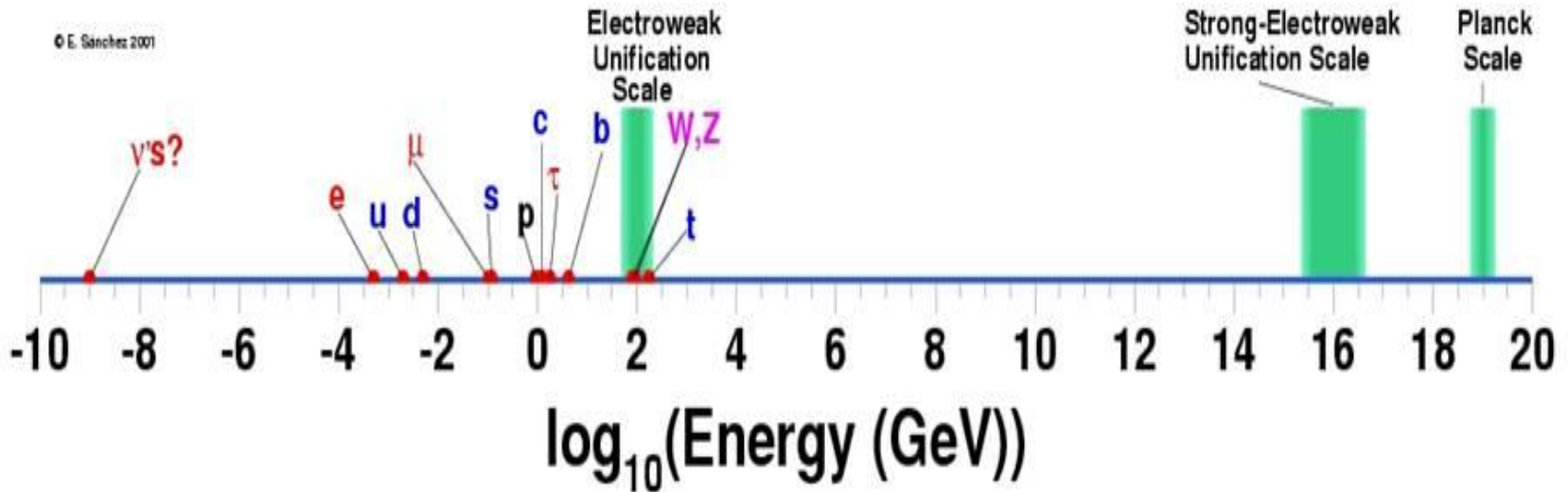


Forces



Leptons

- JERARQUÍA & NATURALIDAD
- NATURALEZA DE LOS NEUTRINOS
- PROBLEMA DEL SABOR
- MATERIA & ENERGÍA OSCURA
- BARIOGÉNESIS

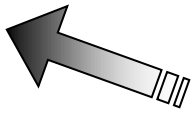




Englert, Higgs

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 Steinberger Schwartz Lederman Ting Rubbia van der Meer Fitch Cronin



Perl Schwinger Feynman Richter Gell-Mann Alvarez Taylor Yang Lee Hofstadter

Selected NP since 1957



Tomonaga Nambu Kobayashi Maskawa

successful for ever??

Supersymmetry
New particles at \approx TeV scale,
light Higgs
Unification of forces
Higgs mass stabilized
No new interactions

Extra Dimensions
New dimensions introduced
 $m_{\text{Gravity}} \approx m_{\text{elw}}$ Hierarchy problem solved
New particles at \approx TeV scale

PERSPECTIVAS

PREDECIR ES ALGO MUY DIFÍCIL, EN PARTICULAR ACERCA DEL FUTURO,

Niels Bohr

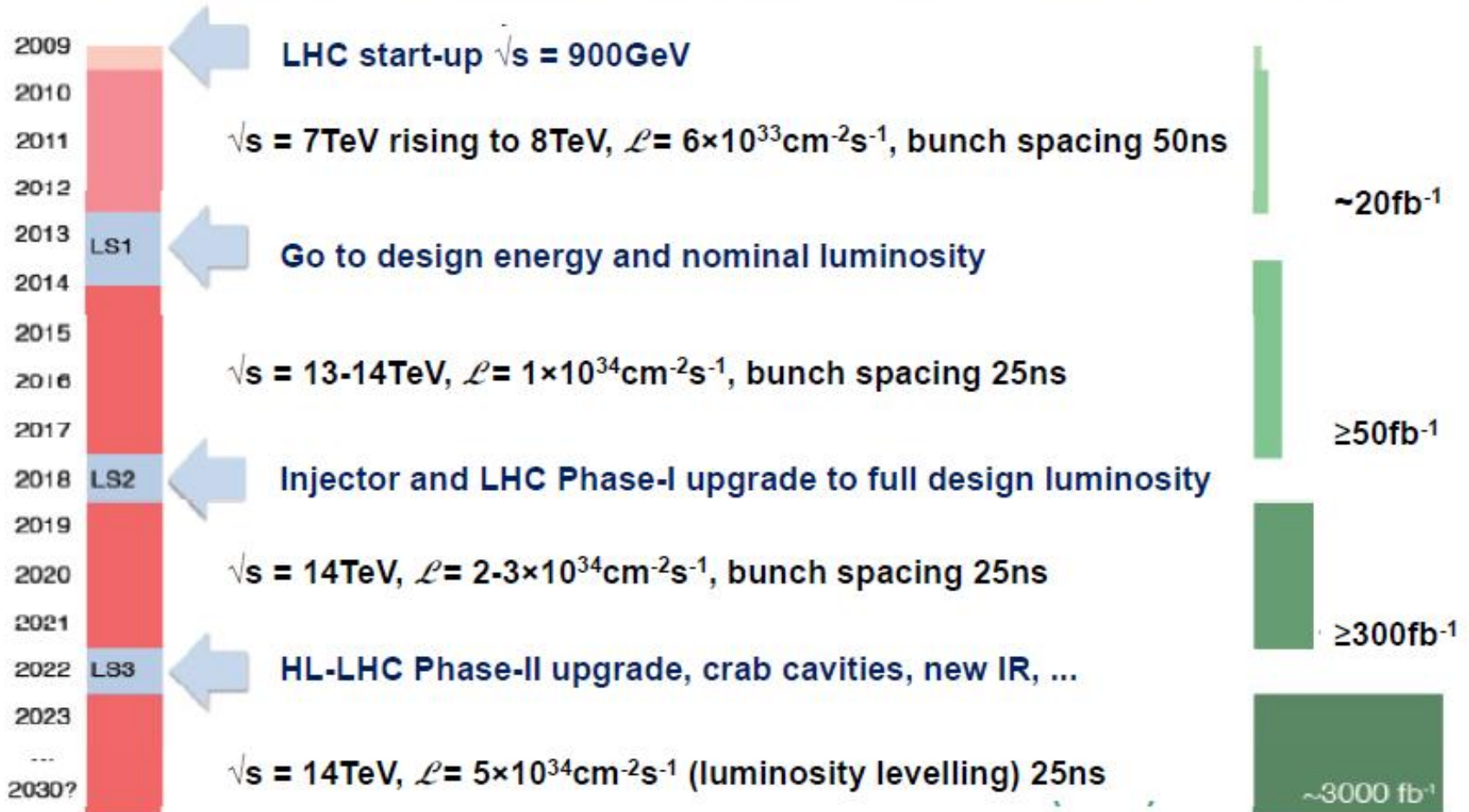
YA ES BASTANTE DURO CONOCER EL PASADO; SERÍA INSOPORTABLE CONOCER EL FUTURO,

William Somerset Maughan

THE
FUN
IS JUST
BEGINNING



LHC Schedule Assumptions



FUTUROS COLISIONADORES LINEALES

Legend

— CERN existing LHC

Potential underground siting :

●●●● CLIC 500 GeV

●●●● CLIC 1.5 TeV

●●●● CLIC 3 TeV

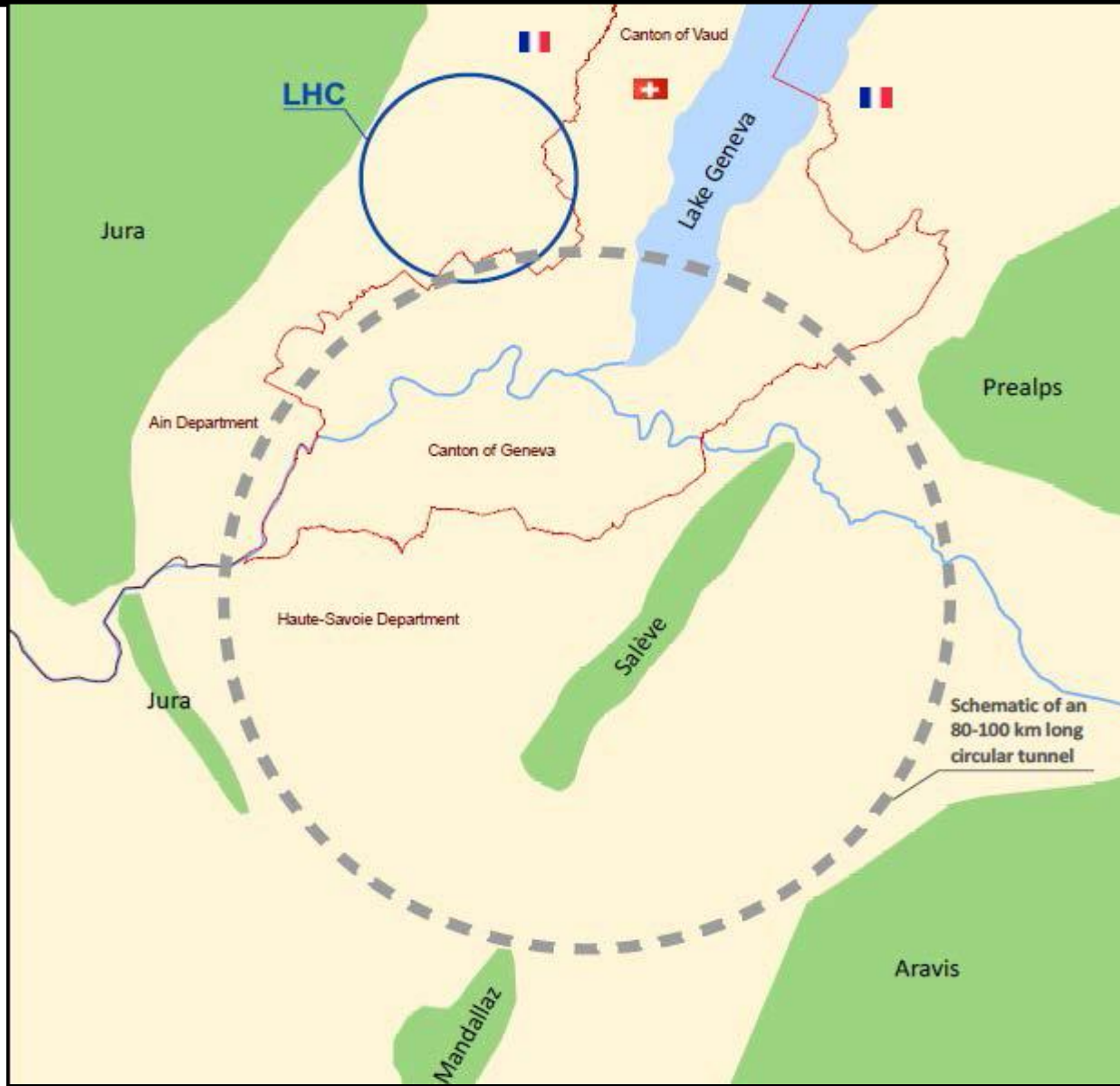
Jura Mountains

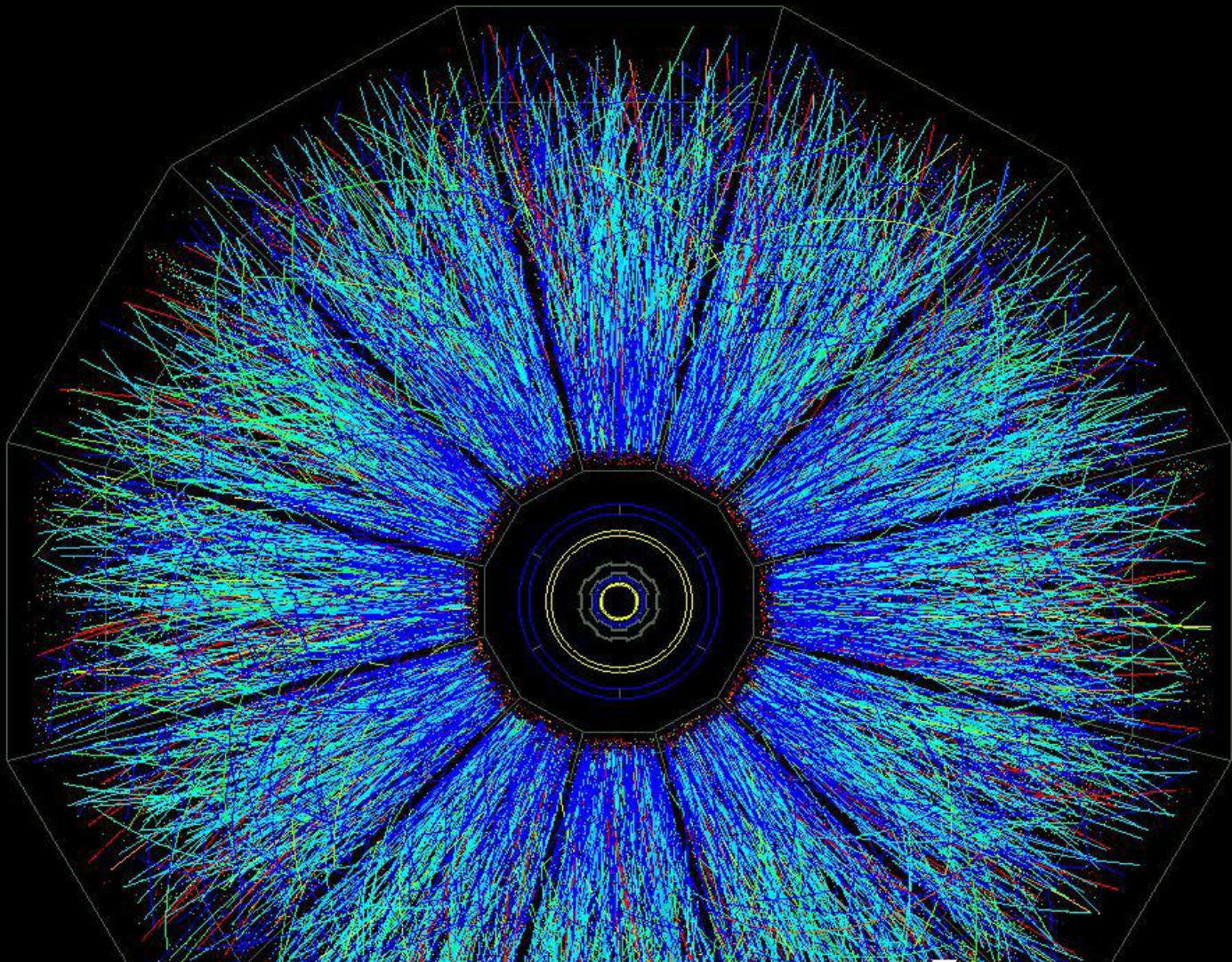
IP

Geneva

Lake Geneva

FUTUROS COLISIONADORES CIRCULARES





LA CONSTRUCCIÓN DEL MODELO ESTÁNDAR

CONSTRUCCIÓN EXPERIMENTAL DEL MODELO ESTÁNDAR

EN LA PRIMERA MITAD DEL SIGLO XX EL ESTUDIO DE LOS RAYOS CÓSMICOS, DESCUBIERTOS POR V.F. HESS EN 1912, FUE LA HERRAMIENTA BÁSICA PARA DESCUBRIR NUEVAS PARTÍCULAS

(e^+ , μ , π , K , K^0 , Λ , Σ , Ξ , ...)

EL DESCUBRIMIENTO DEL ANTIPROTÓN EN 1955, EN EL BEVATRON (LBL), MARCÓ UN PUNTO DE INFLEXIÓN EN LA FÍSICA EXPERIMENTAL DE ALTAS ENERGÍAS: **LOS ACELERADORES TOMARON EL RELEVO**, AUNQUE TODAVÍA HAY FASCINANTE CIENCIA QUE HACER CON LOS RAYOS CÓSMICOS (**NEUTRINOS, MATERIA OSCURA, MATERIA-ANTIMATERIA**)

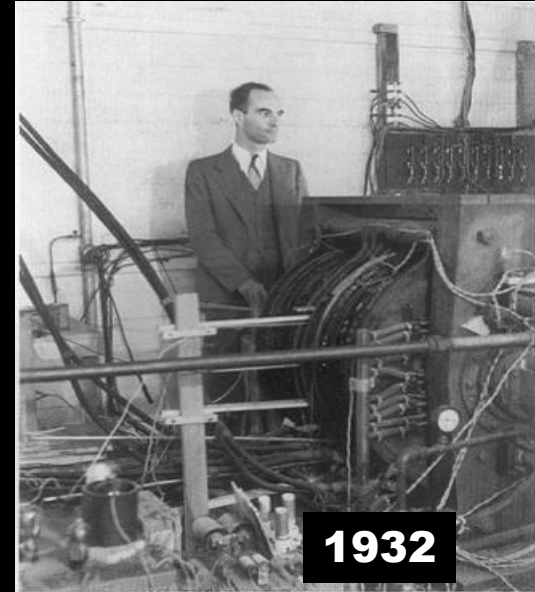
RAYOS CÓSMICOS



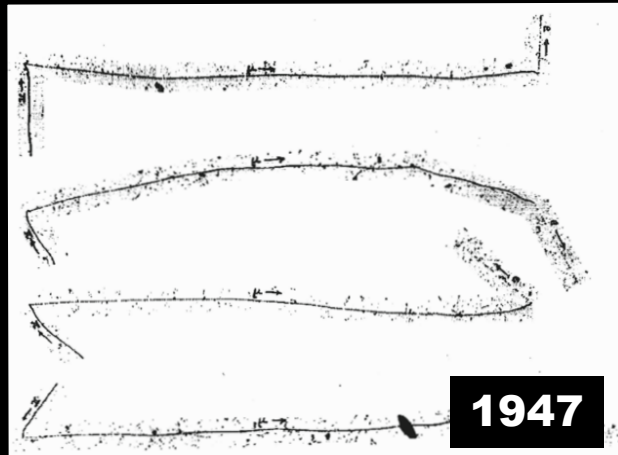
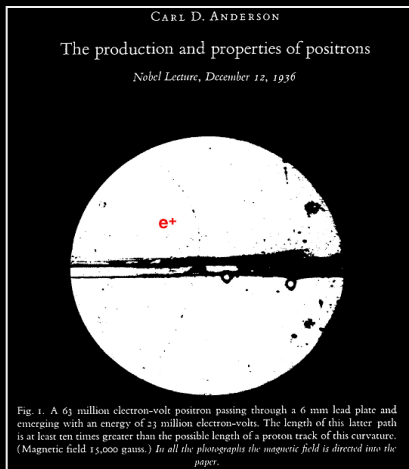
RAYOS CÓSMICOS



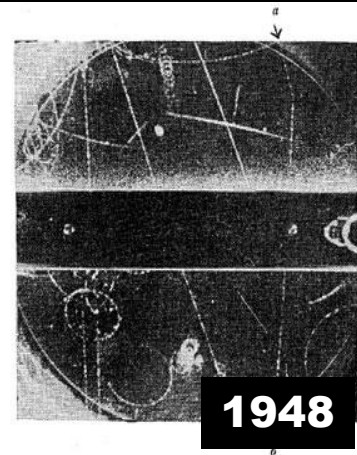
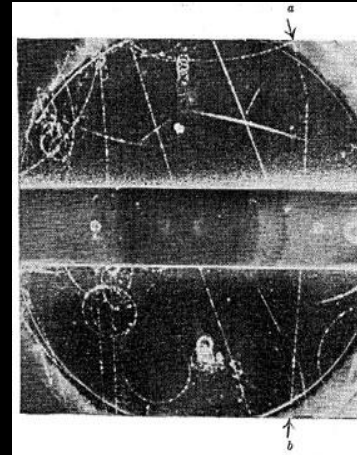
1912



1932



1947



1948

AIGUILLE DU MIDI, CHAMONIX



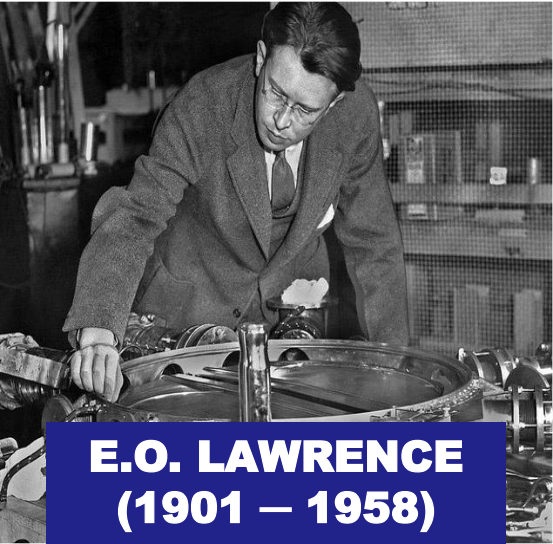
GRANDES OBSERVATORIOS

JUNGFRAU



PIC DU MIDI, BIGORRE





E.O. LAWRENCE
(1901 – 1958)



S. LIVINGSTONE
(1905 – 1986)

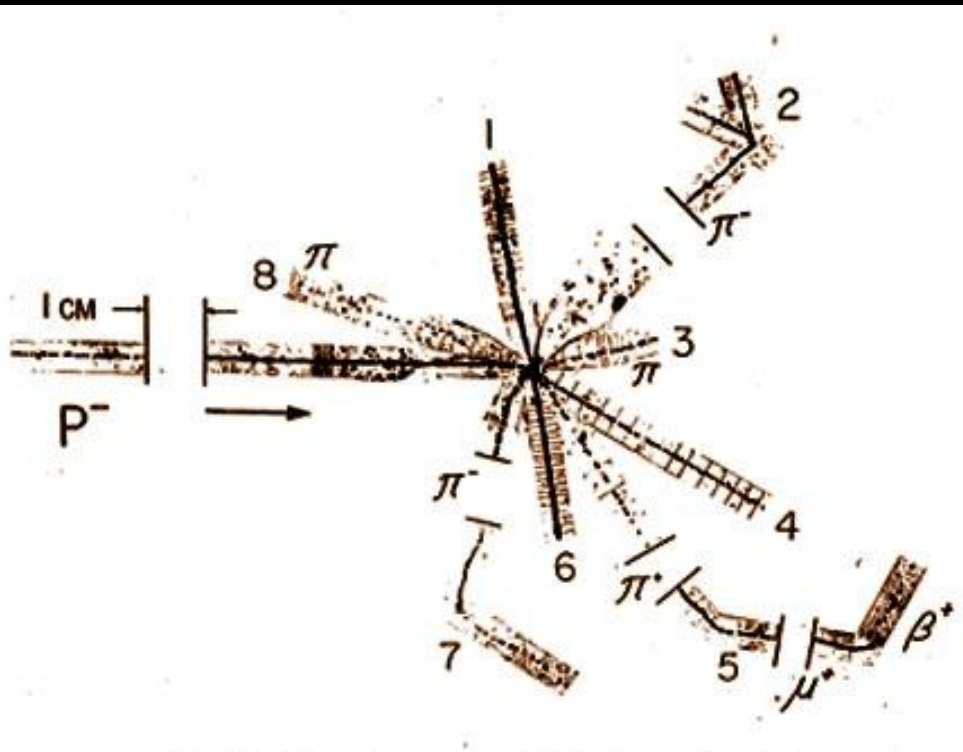




1955: DESCUBRIMIENTO DEL ANTIPROTÓN EN LBL

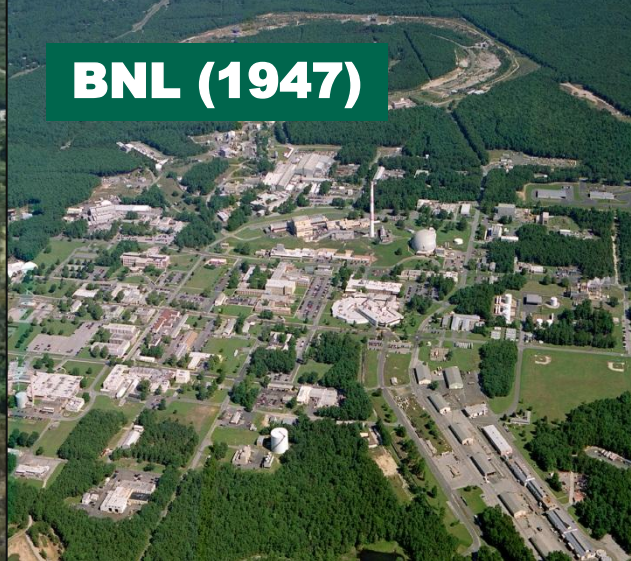


**E. SEGRÉ, C. WIEGAND, E.J. LOFGREN,
O. CHAMBERLAIN, T. YPSILANTIS**





LBL (1931)



BNL (1947)

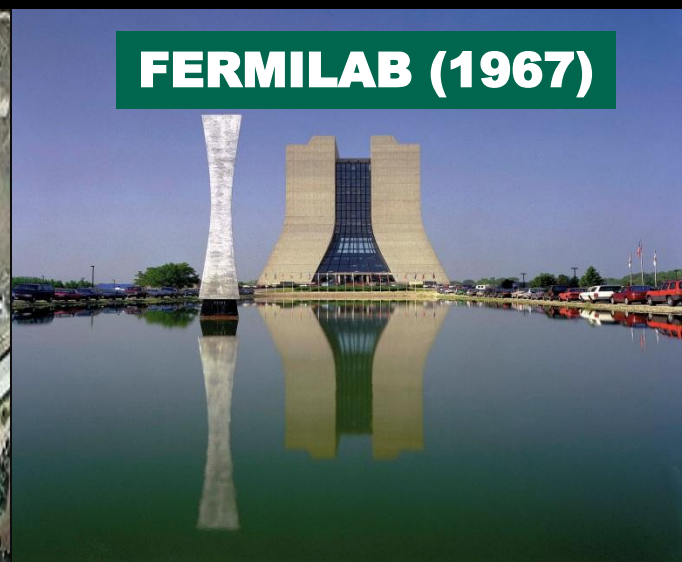


DESY (1959)

GRANDES LABORATORIOS



SLAC (1962)

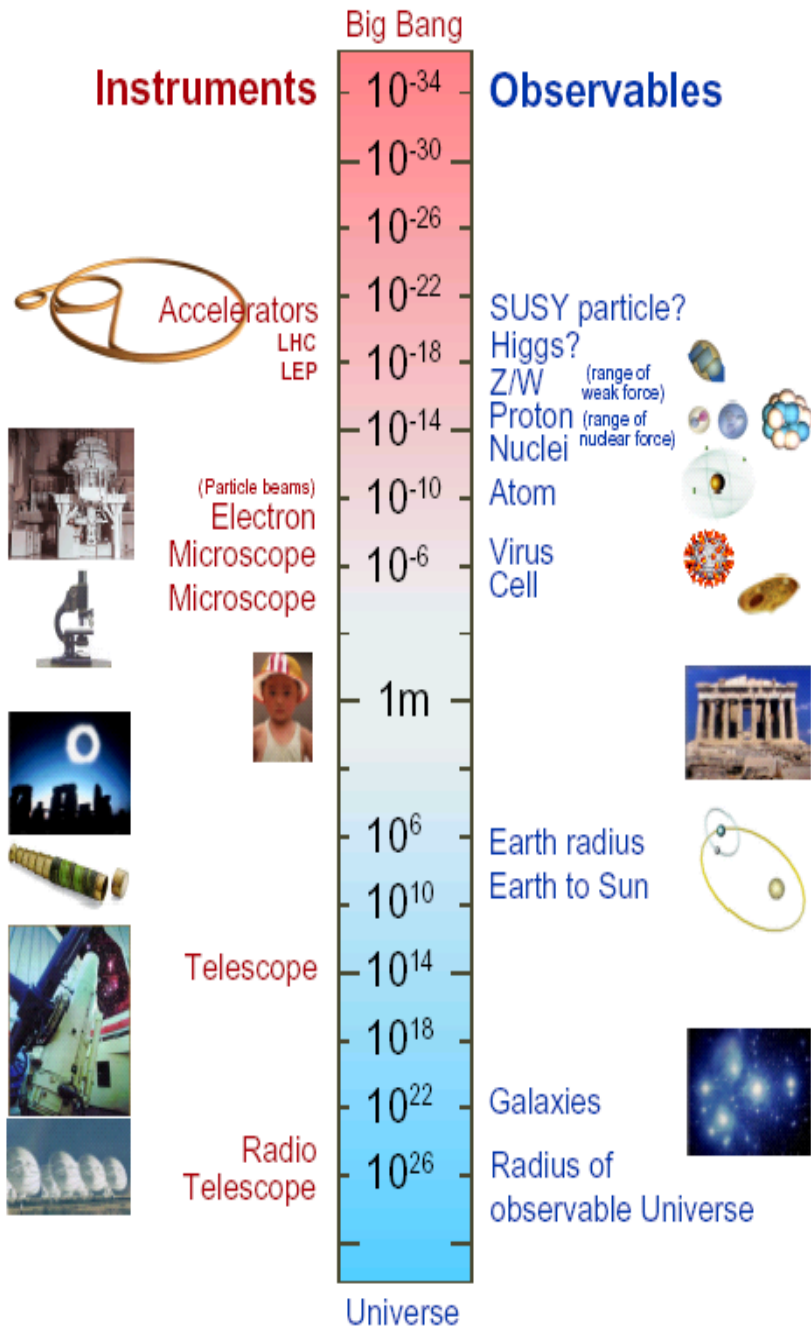


FERMILAB (1967)

The size of things

$$\lambda = h / p$$

$$h = 4,135667516 (91) \times 10^{-15} \text{ eV s}$$



- $p = 1 \text{ MeV}/c (10^6 \text{ eV}/c);$
 $\lambda \approx 10^{-12} \text{ m}$
- $p = 1 \text{ GeV}/c (10^9 \text{ eV}/c);$
 $\lambda \approx 10^{-15} \text{ m}$
- $p = 1 \text{ TeV}/c (10^{12} \text{ eV}/c);$
 $\lambda \approx 10^{-18} \text{ m}$
- $p = 10^5 \text{ TeV}/c (10^{17} \text{ eV}/c);$
 $\lambda \approx 10^{-23} \text{ m}$

Zeptometro = 10⁻²¹ m

History of the Universe

Física pp en el LHC corresponde a condiciones en esta región, **0,1 ns**

BIG BANG

Inflation

possible dark matter relicts

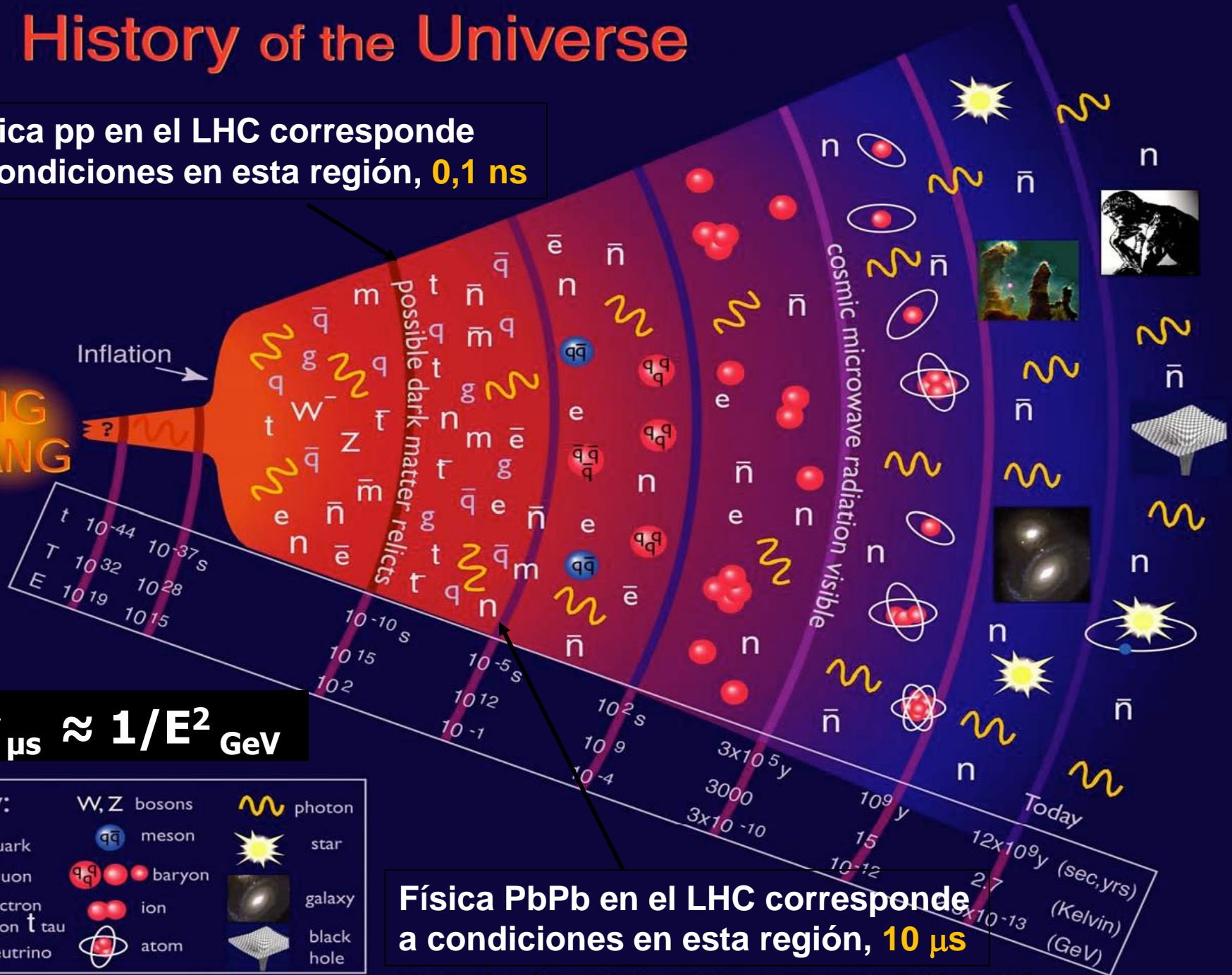
cosmic microwave radiation visible

$$t_{\mu s} \approx 1/E^2 \text{ GeV}$$

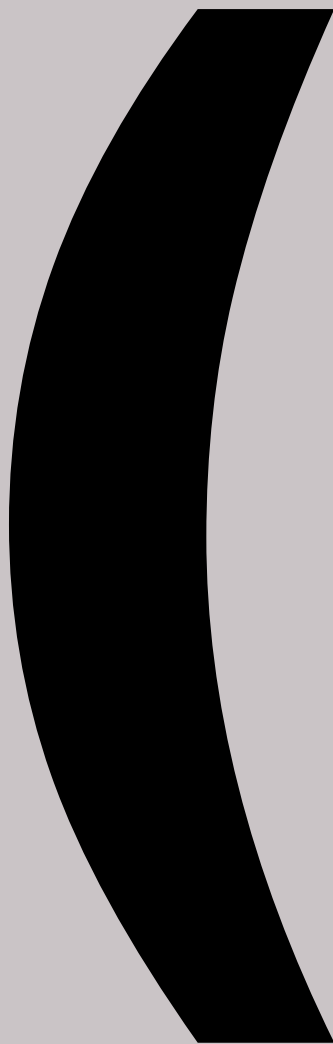
Key:

W, Z bosons	meson	photon
quark	baryon	star
gluon	ion	galaxy
electron	atom	black hole
muon		
tau		
neutrino		

Física PbPb en el LHC corresponde a condiciones en esta región, **10 μs**

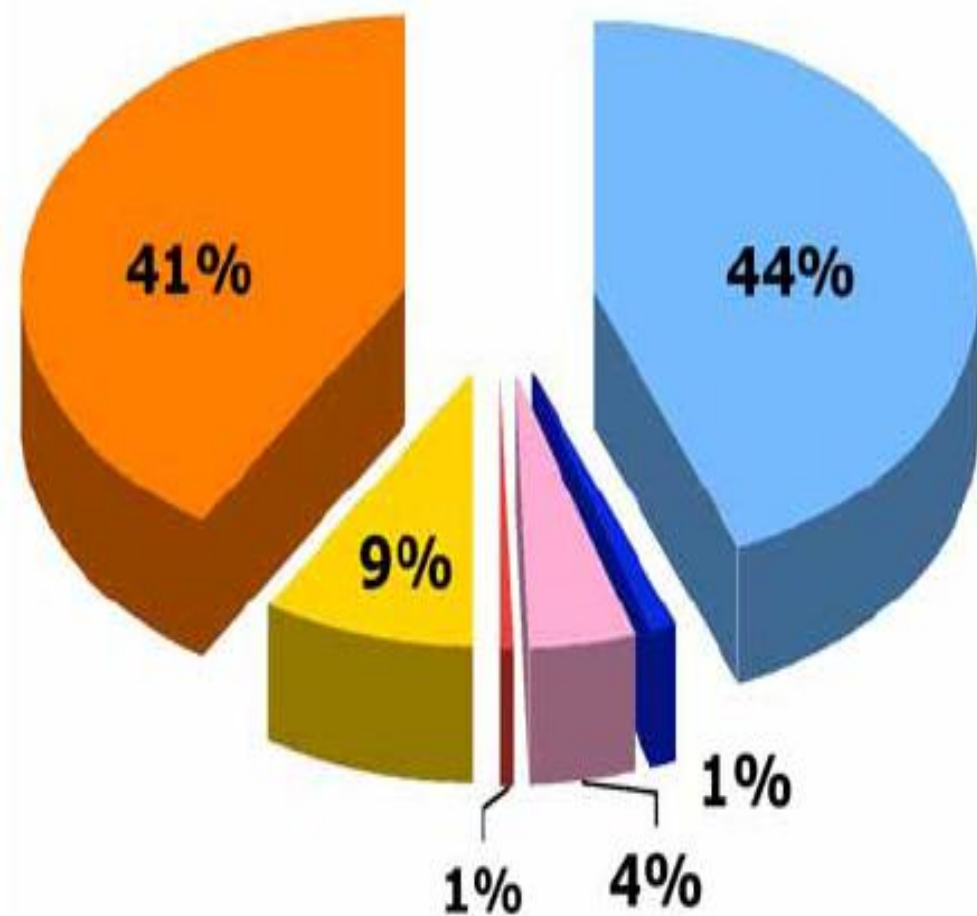


t	10^{-44}	10^{-37} s
T	10^{32}	10^{28}
E	10^{19}	10^{15}
	10^{-10} s	10^{-5} s
	10^{15}	10^{12}
	10^2	10^{-1}
	10^2 s	10^9
	10^{-4}	10^{-4}
	3×10^5 y	10^9 y
	3000	15
	3×10^{-10}	10^{-12}
		Today
		12×10^9 y (sec.yrs)
		2.7 (Kelvin)
		10^{-13} (GeV)



Number of accelerators worldwide

~ 26,000



■ Radiotherapy (>100.000 treatments/yr)*

■ Medical Radioisotopes

■ Research (incl. biomedical)

■ >1 GeV for research

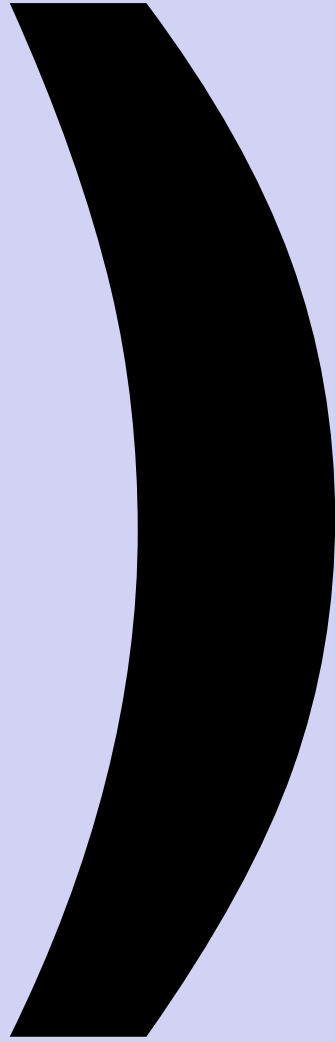
■ Industrial Processing and Research

■ Ion Implanters & Surface Modification

Annual growth is several percent

Sales >3.5 B\$/yr

Value of treated good > 50 B\$/yr **



OBSERVATORIOS SUBTERRÁNEOS

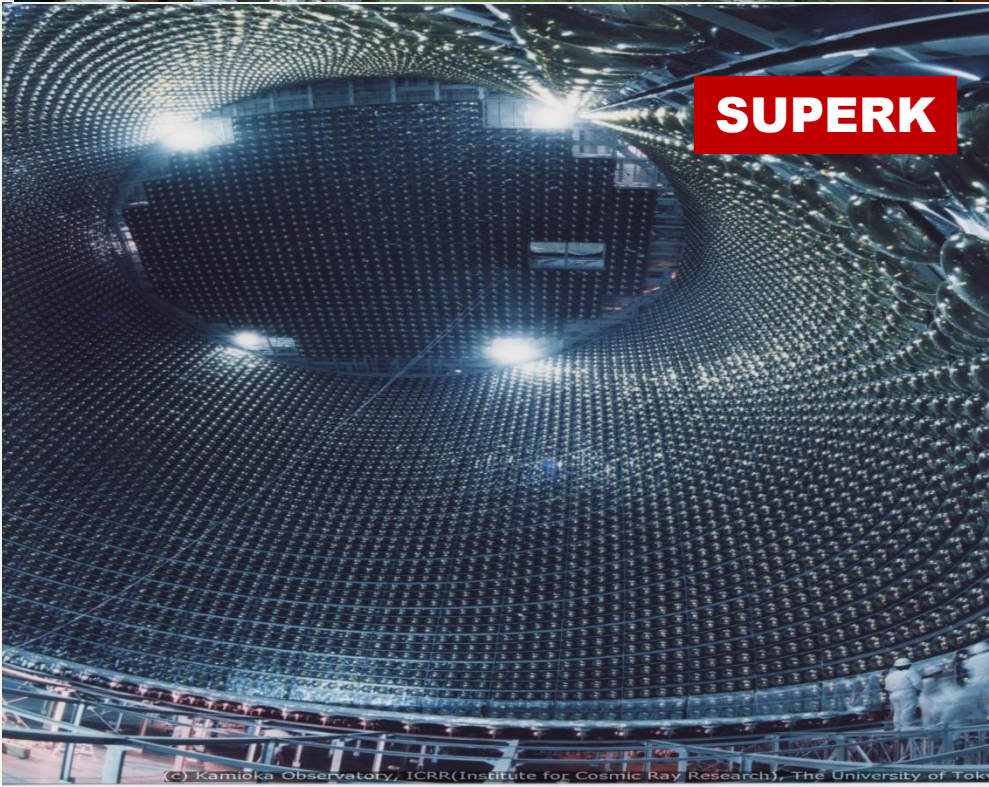
LNGS



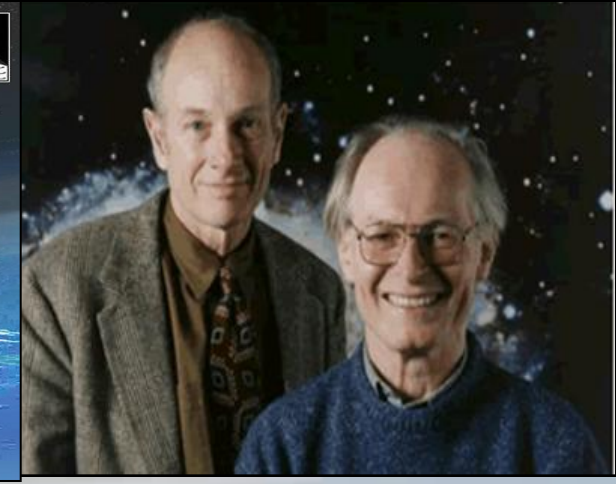
SNO



SUPERK

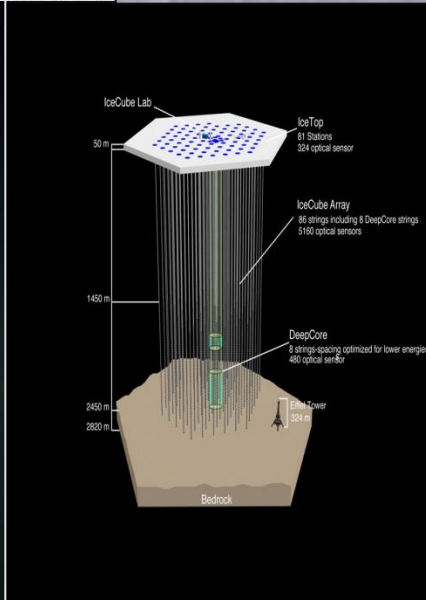


OBSERVATORIOS EN SUPERFICIE



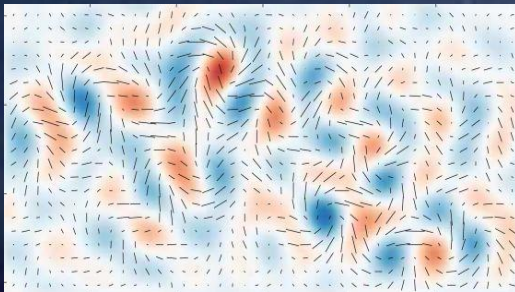
PIERRE AUGER OBSERVATORY

OBSERVATORIOS EN HIELO



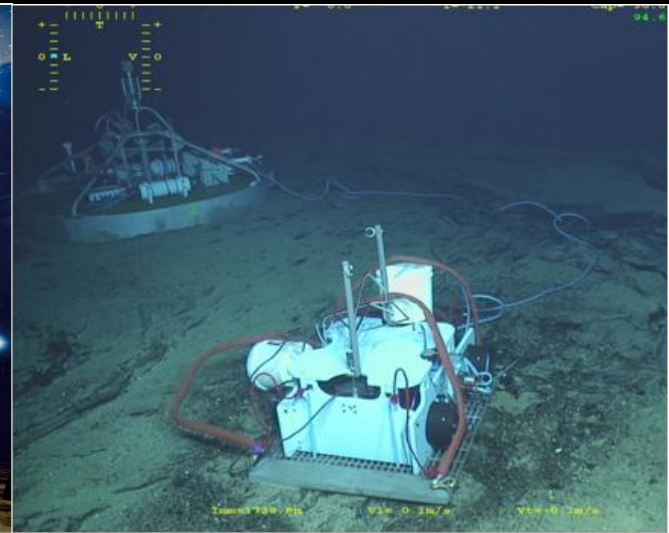
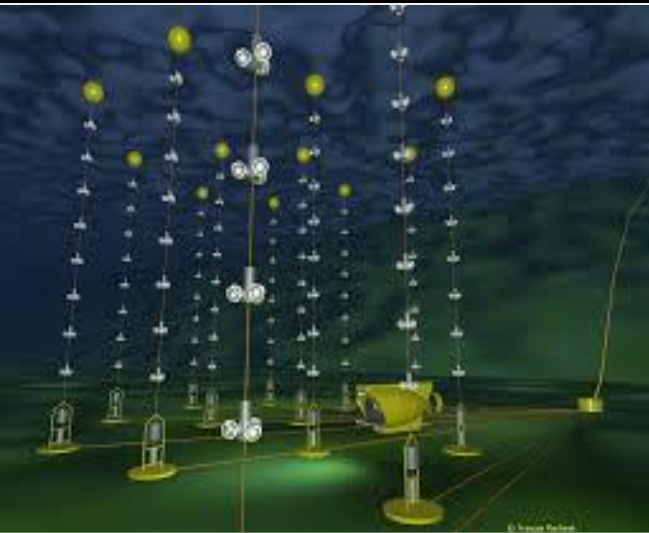
BICEP2 ---- BACKGROUND IMAGING COSMIC EXTRAGALACTIC POLARIZATION

MODO DE POLARIZACIÓN B DE LA RADIACIÓN CMB DEBIDA A LAS ONDAS GRAVITACIONALES GENERADAS POR LAS FLUCTUACIONES CUÁNTICAS PRODUCIDAS EN EL PROCESO INFLACIONARIO QUE TUVO LUGAR CUANDO EL UNIVERSO TENÍA $\sim 10^{-37}$ s, TEMPERATURA $\sim 10^{28}$ K, ENERGÍA $\sim 10^{15}$ GeV

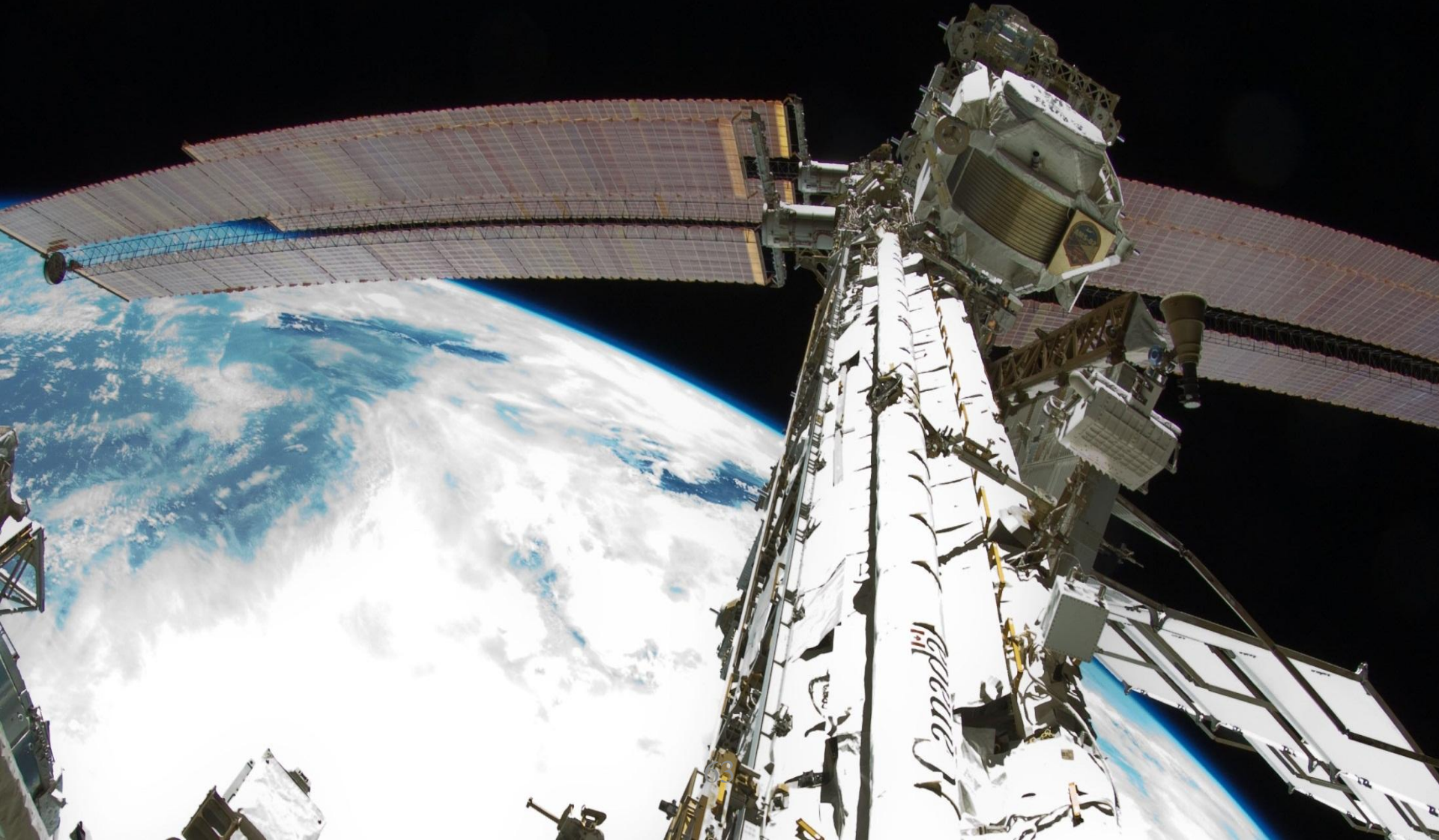


**TEORÍA DE LA INFLACIÓN CÓSMICA
ALAN GUTH, ANDREI LINDE, ALEXEI STAROBINSKY (~1980)**

OBSERVATORIOS EN AGUA



OBSERVATORIOS ESPACIALES





CERN (1954-2014)



YEARS/ANS CERN

1949
French physicist Léon de Broglie put forward the first official proposal for a European laboratory at a conference in Louvain in December.

1951
The first exchange of scientists with the first Institute for Nuclear Research at Dubna takes place, with three Soviet scientists arriving at CERN on 18 July.

1952
Under the auspices of UNESCO, the Council decides to set up a research institute - CERN - in France & neighboring states (Belgium, Luxembourg, the Swiss) under the name of the European Organization for Nuclear Research (O.N.R.).

1953
The countries participating in CERN sign, subject to ratification, by 12 future member states, at the annual session in Paris on 29 June-1 July. It stipulates that the research carried out must be purely scientific, not used for military applications, and that all results must be made public.

1954
In May on the site chosen near Geneva, the 29 September, the European Organization for Nuclear Research comes into being, after the countries it defined by a sufficient number of the 12 founding member states.

1955
First session. CERN's first director-general, Jean Dron, takes office on the site of Meyrin on 15 June. UNESCO gives observer status.

1959
The IAS starts up on 21 November. Asakia becomes a member state.

1961
Spain becomes a member state.

1962
First CERN School of Physics.

1965
With the signing on 13 September of agreements on the extension into French territory, CERN becomes the first international organization to open a frontier.

1967
A cooperation agreement between CERN and the USSR is signed in July, inviting European scientists to participate on the world's largest accelerator at the time, at the Institute for High Energy Physics at Serpukhov. CERN's director-general joins in the start-up celebrations.

1969
Spain leaves.

1970
1st Joint CERN-INSR Physics School.

1971
IP-21 starts. CERN's Intersecting Storage Rings (ISR) becomes the world's first proton collider, allowing a tenfold energy range. The experiments without nuclear particles from the US, and also groups from other non-member states, such as India.

1972
An agreement is signed with France to establish on 28 June, inaugurating a new CERN site at Frascati. Construction work soon begins for the Super Proton Synchrotron (SPS).

1973
One of the first contacts with scientists from the People's Republic of China takes place with a visit of its delegation from Peking to June.

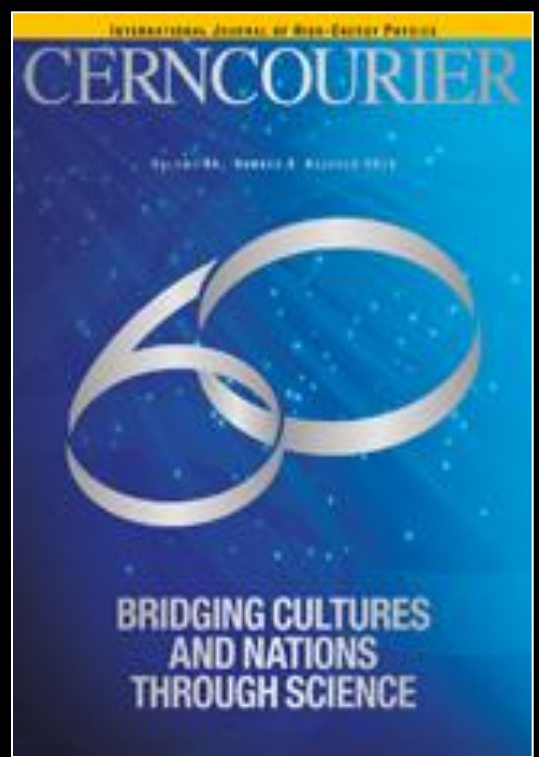
1976
The IAS is completed. After acceleration to 80 GeV in May, it reaches 900 GeV on 17 June.

1977
David techniques work on final preparations for the first post-CERN experiment, NA1, at the SPS.

1978
The ground-breaking ceremony for the 27th and largest tunnel (2.7 km) is held on 13 September. March of the tunnel to pass through French territory.

1979
Spain rejoins as a member state.

1981
The IAS is completed. 2000 tonnes (243 detector is ready when the SPS starts up as the world's first proton-antiproton collider in August. Led by Carlo Rubbia, the experiment sets a new record and attracts guests from the US to search for the W and Z bosons.



1985
The Union of Soviet Socialist Republics (USSR) applies for the 13th membership of the LEP begins in CERN, being accepted from both the USSR and China and membership established in France.

1986
Portugal becomes a member state.

1987
The home of the LEP experiments demands big collaborative efforts, with experiments involving more money resources. The superconducting coil of the SSC experiment at SLAC, designed from the 2.4m magnets near CERN, is ordered.

1988
The first collisions in August. LEP is inaugurated on 13 November in the presence of dignitaries from the 14 member states.

1989
The European Commission signs observer status.

1991
Finland and Poland become member states. USSR becomes an observer state. Israel becomes an observer state.

1992
Italy for LEP experiments go public for the first time at a meeting in Evian in March. The pre-collaborations include a cluster of six non-member states.

1993
The Czech Republic and Slovakia become member states. The Russian Federation becomes an observer state. The CERN-2000 school becomes the European School of High-Energy Physics.

1994
CERN's 40th anniversary year sees the first approval by Council for the construction of the LHC in the LEP tunnel.

1999
Hungary becomes a member state. Czechoslovakia becomes a member state.

1995
To mark the start of collaboration between Japan and CERN, the Japanese minister and CERN's director-general signed one year of a "Memorandum of Understanding" between the two countries. Japan becomes an observer state.

1996
The first "Power Top" set of beamline magnets from the US and Japan is received at CERN in April.

1997
An agreement between CERN and the US government signed in Washington and at the Council meeting in December marks the start of the significant partnership of the US to the LHC. US becomes an observer state.

1998
Researcher visits in the SPS West Area ends. The CERNUS agreement has just a significant contribution from Turkish projects.

1999
Bulgaria becomes a member state.

2000
CERN and the Centre National de la Recherche Scientifique de France initiate a new series of CERN-Les Rencontres de la Physique de la Haute-Energie. The first meeting held in Brazil in May.

2001
CERN and the Centre National de la Recherche Scientifique de France initiate a new series of CERN-Les Rencontres de la Physique de la Haute-Energie. The first meeting held in Brazil in May.

2002
India becomes an observer state.

2005
The first "Power Top" set of beamline magnets from the US and Japan is received at CERN in April.

2007
Completion of the superconducting LHC magnets, with the participation of teams from India, comes to a successful end.

2008
The inauguration of the LHC on 21 October is attended by CERN member states, including official delegations from CERN's member states, observer states, and non-member states.

2009
CERN and UNESCO hold the first digital history school in Africa, on the occasion in Rwanda.

2010
On 30 March the LHC produces the first proton-proton collisions at a new record energy of 7 TeV in the centre of mass.

2011
The 1st 2011 conference organized by physicists from around the world at the International Conference on High-Energy Physics in Wuhan, China, marks the 50th anniversary of the discovery of a Higgs boson by the ATLAS and CMS experiments at the LHC.

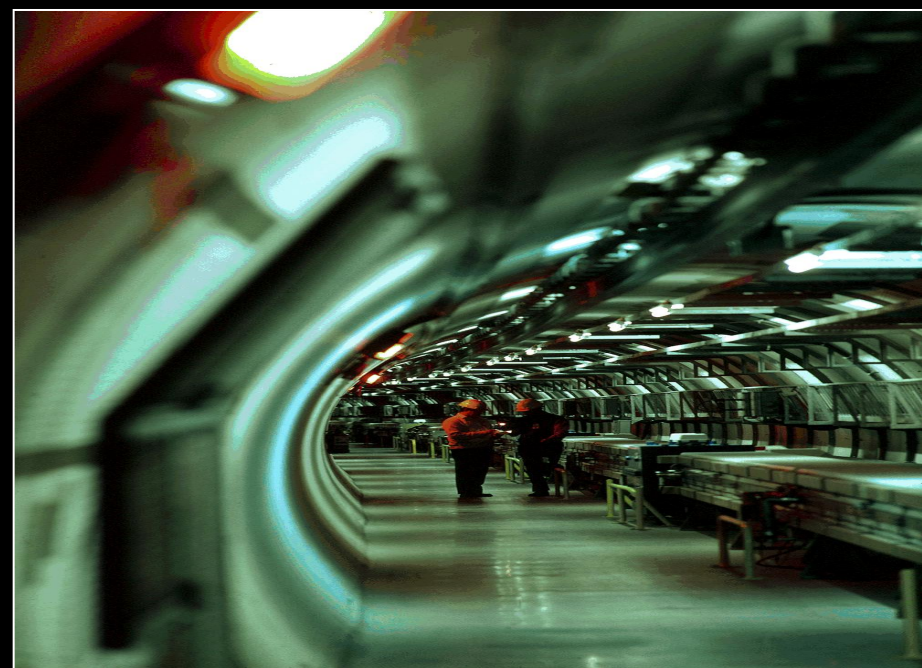
2012
The 1st 2012 conference organized by physicists from around the world at the International Conference on High-Energy Physics in Wuhan, China, marks the 50th anniversary of the discovery of a Higgs boson by the ATLAS and CMS experiments at the LHC.

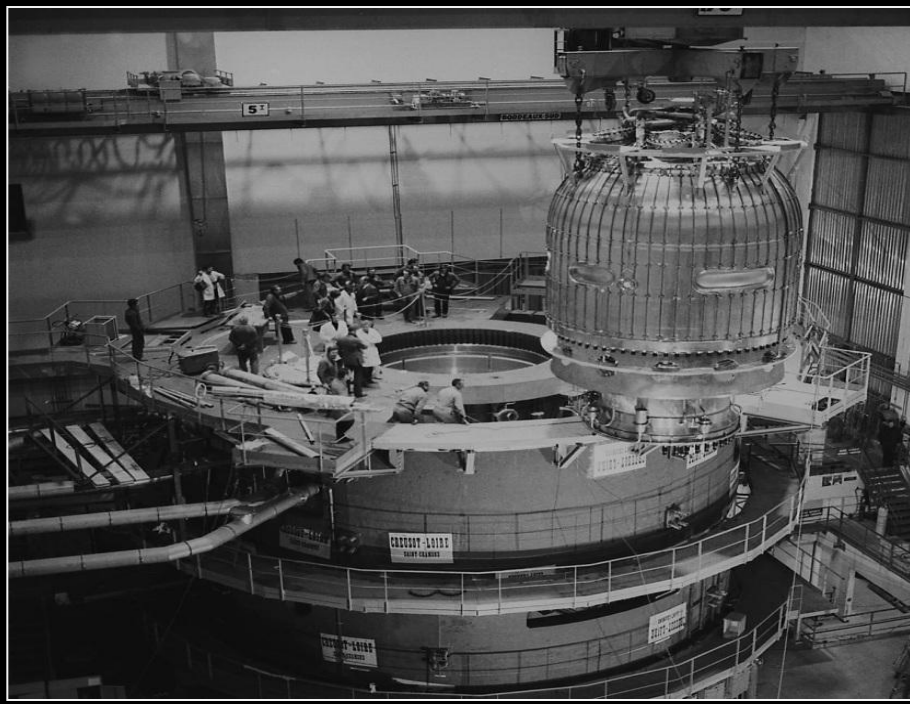
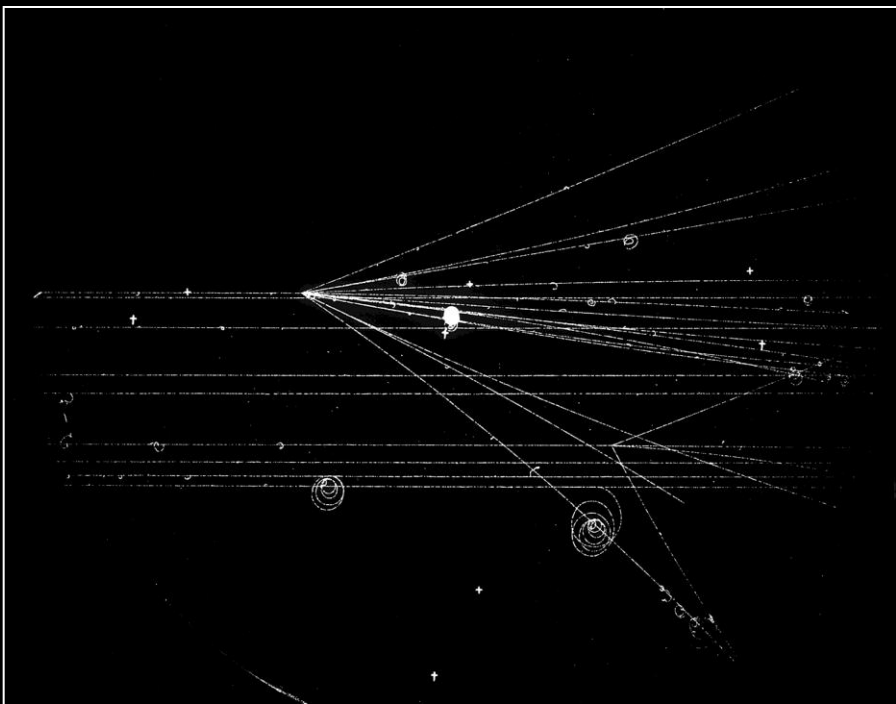
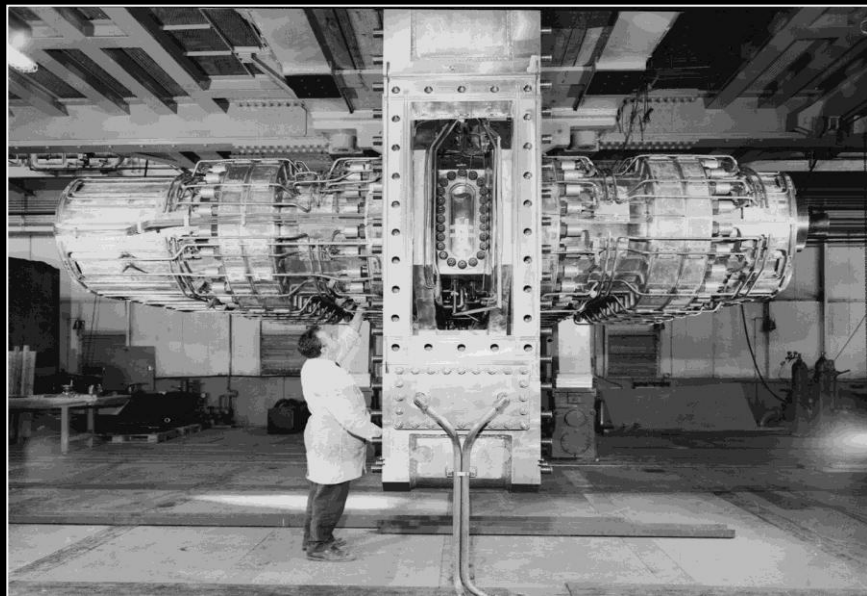
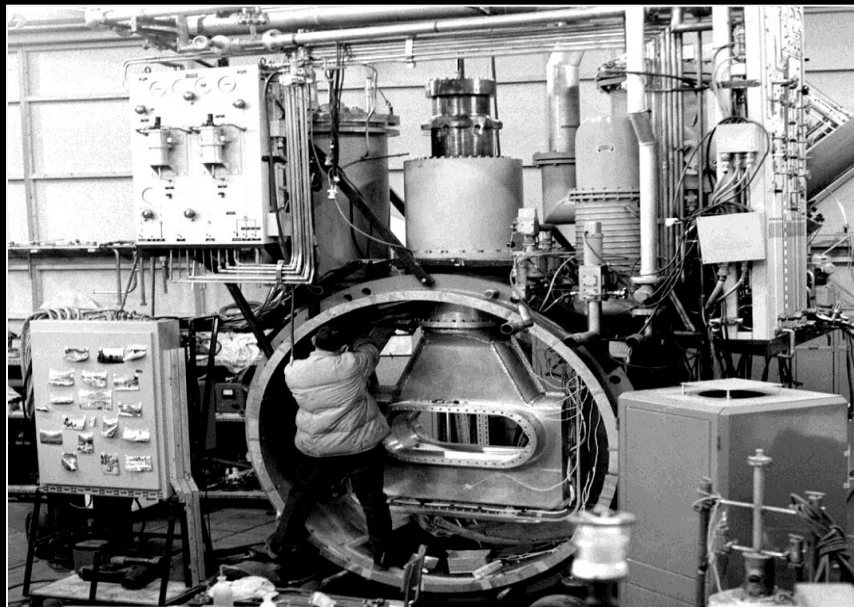
2013
Serbia becomes an associate member in the pre-stage to membership.

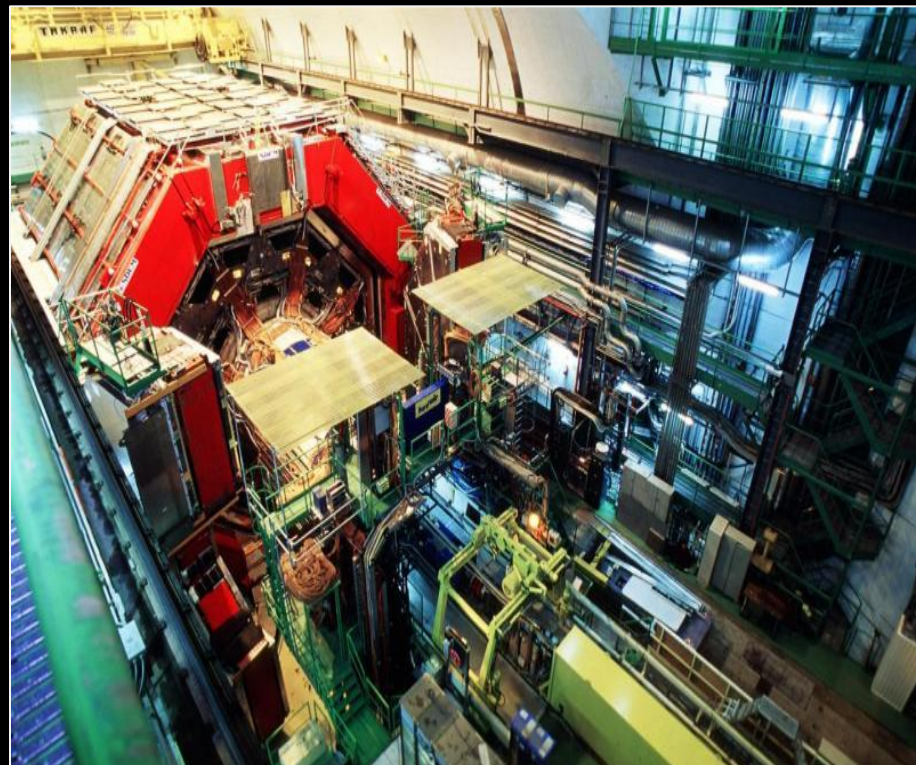
2014
CERN celebrates 60 years of science for science.

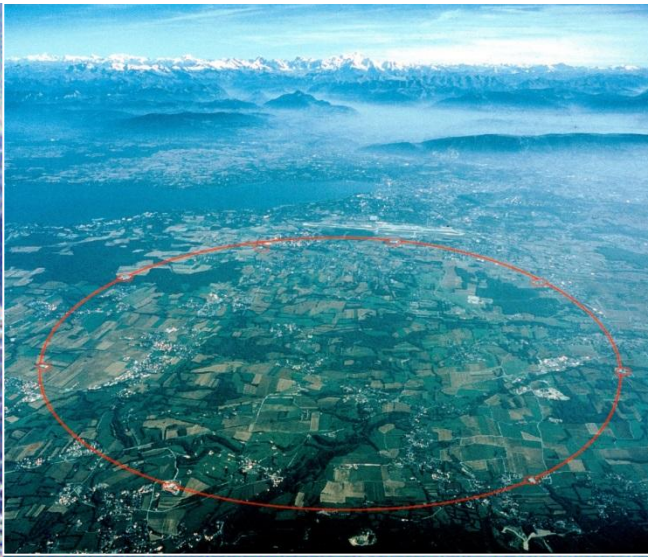
2014
Israel becomes a member state.











CERN (2014)








CERN



Les vingt et un Etats membres du CERN

Etats membres (date d'accession)

-  Allemagne (1953)
-  Autriche (1953)
-  Belgique (1953)
-  Bulgarie (1969)
-  Danemark (1953)
-  Espagne (1/1961-12/1969-1/1983)
-  Finlande (1991)
-  France (1953)
-  Grèce (1953)
-  Hongrie (1962)
-  Israël (2014)
-  Italie (1953)
-  Norvège (1953)
-  Pays-Bas (1953)
-  Pologne (1961)
-  Portugal (1966)
-  République slovaque (1993)
-  République tchèque (1993)
-  Royaume-Uni (1953)
-  Suède (1953)
-  Suisse (1953)





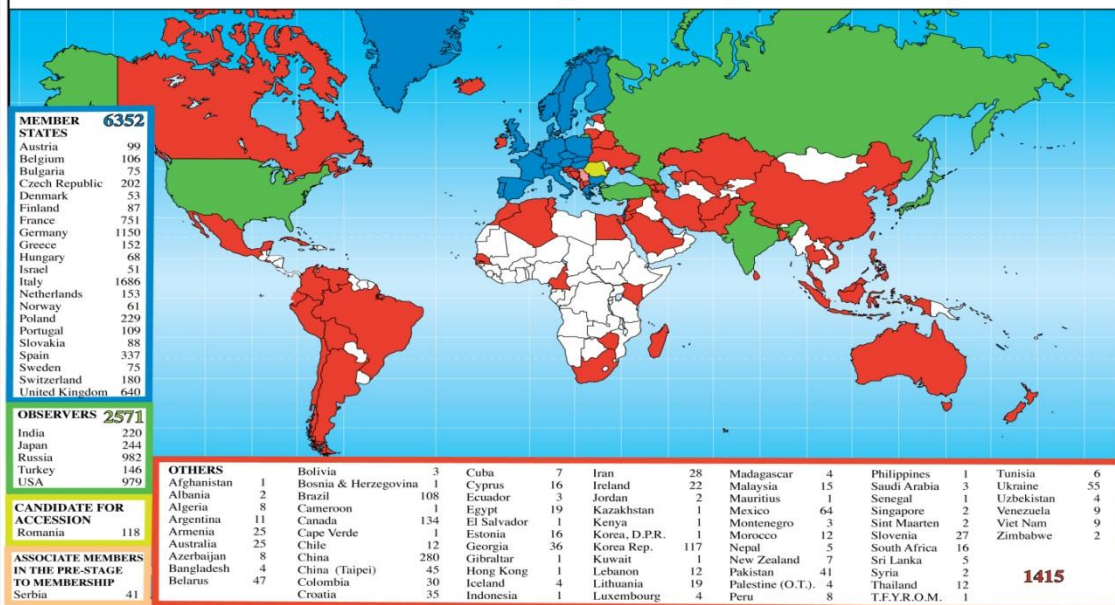
CERN

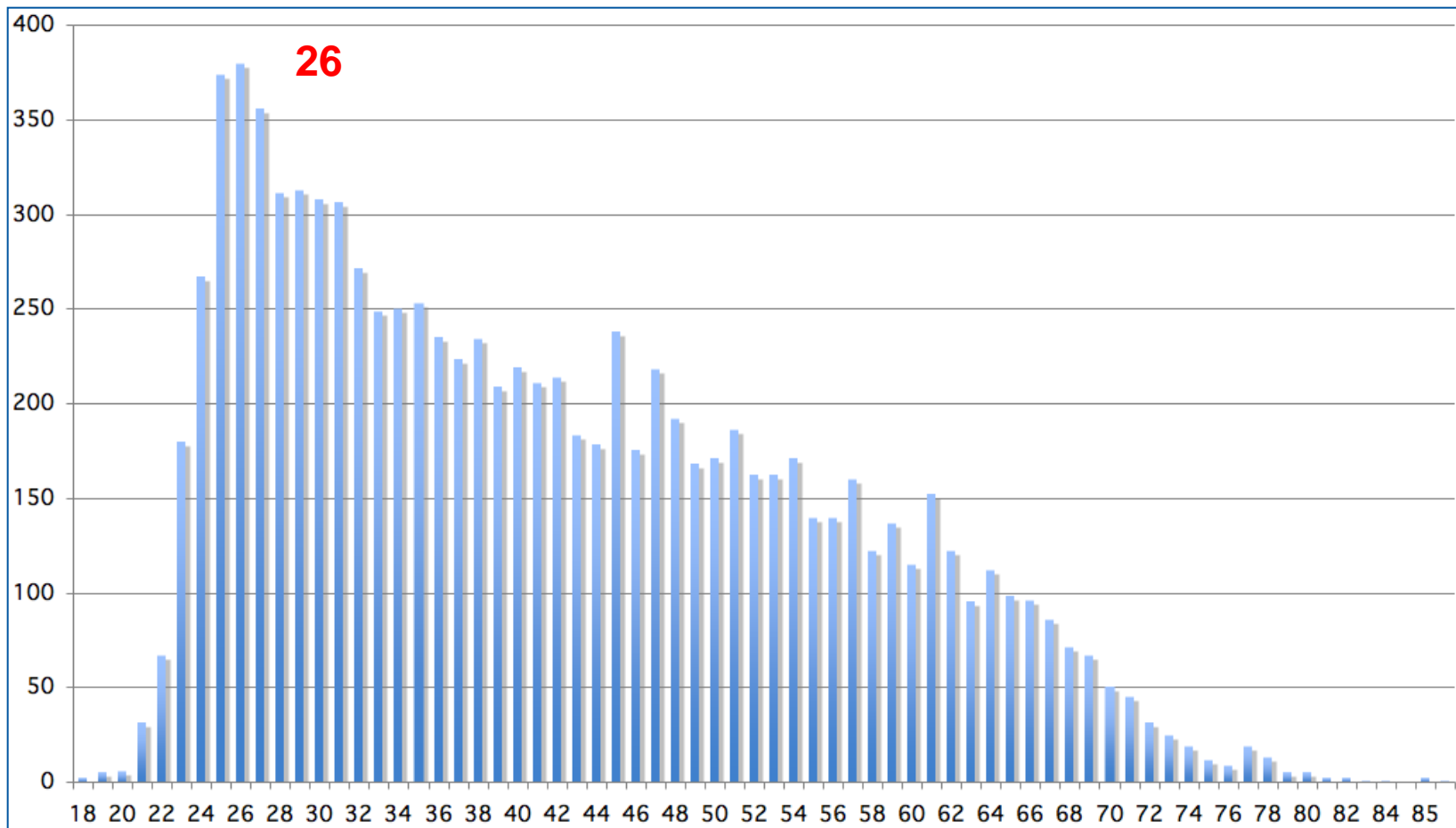


YEARS/ANS CERN

- **2513 Staff (31.12.2013)**
- **10611 Usuarios**
- **566 Becarios**
- **1180 Estudiantes & Asociados**
- **Contribuciones EM (2014):
1108,5 MCHF (~908,6 M Euros)**

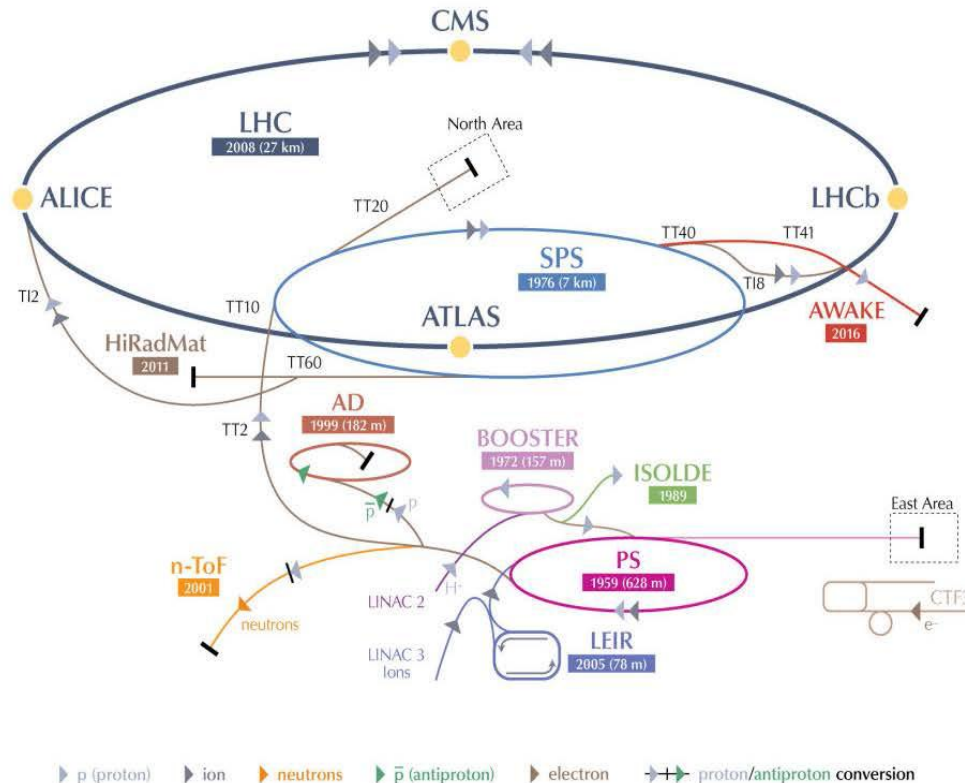
Distribution of All CERN Users by Nationality on 14 January 2014





YEARS/ANS CERN

CERN: EL COMPLEJO DE ACELERADORES MÁS COMPLETO DEL MUNDO



LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility AWAKE Advanced WAKEfield Experiment ISOLDE Isotope Separator OnLine Device

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

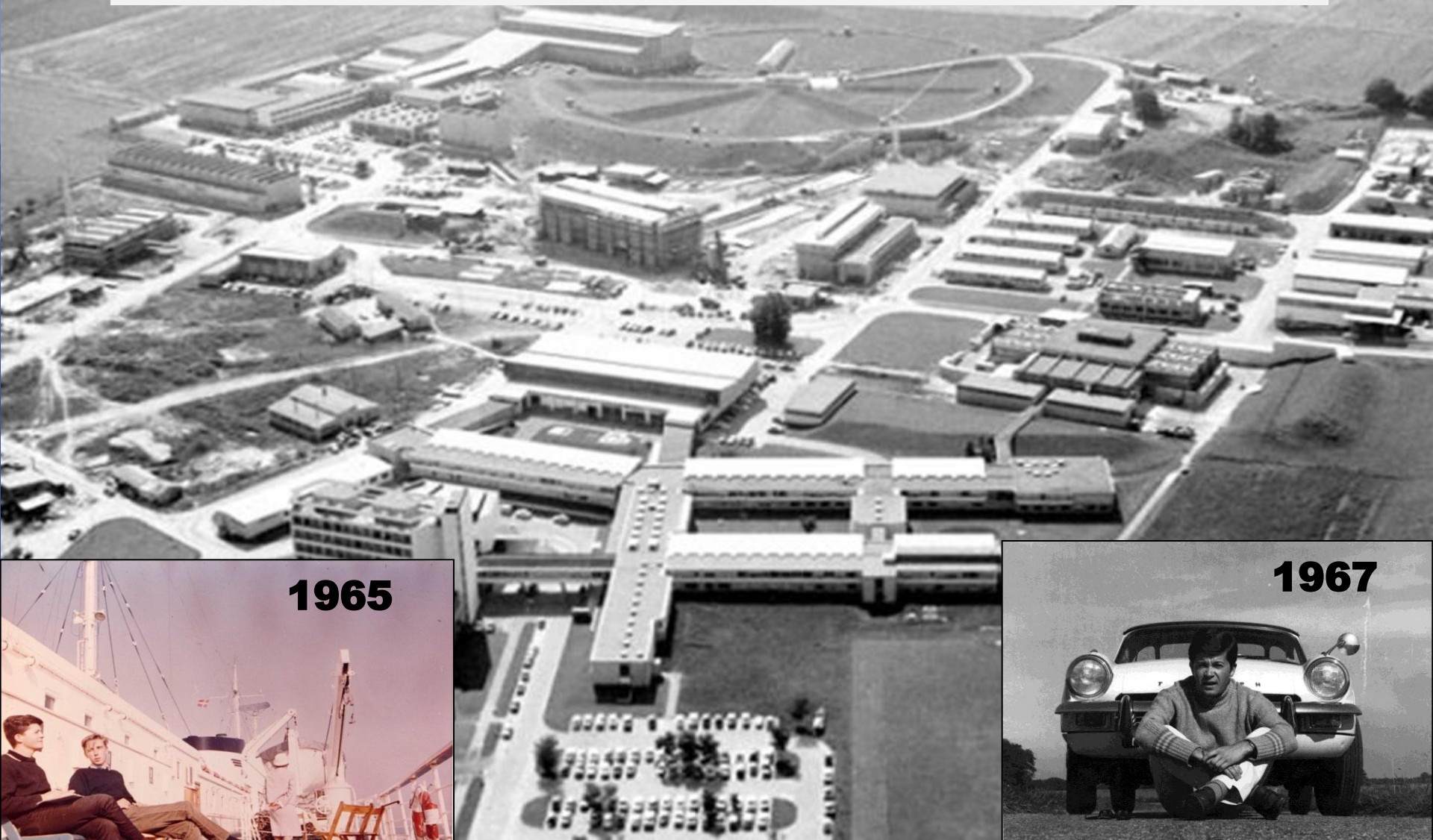




ESPAÑA & CERN



ESTADO MIEMBRO: 1961-1968; 1983-



1965



1967



ESPAÑA & CERN



NOVIEMBRE 1983



JUAN CARLOS I
REY DE ESPAÑA



CONCEDIDA por las Cortes Generales la autorización prevista en el artículo 94.1 de la Constitución y, por consiguiente, cumplidos los requisitos exigidos por la Legislación española, extendiendo el presente Instrumento de Adhesión de España al Convenio para la creación de una Organización Europea de Investigación Nuclear, hecho en París el uno de julio de 1953, para que, mediante su depósito y de conformidad con lo dispuesto en su Artículo XVII, España pase a ser Parte de dicho Convenio.

En fe de lo cual firmo el presente Instrumento, debidamente sellado y refrendado por el infrascrito Ministro de Asuntos Exteriores.

Dado en Madrid, a ...[19]83, de noviembre de mil novecientos ochenta y tres...

EL MINISTRO DE ASUNTOS EXTERIORES.

Fernando Urrutia



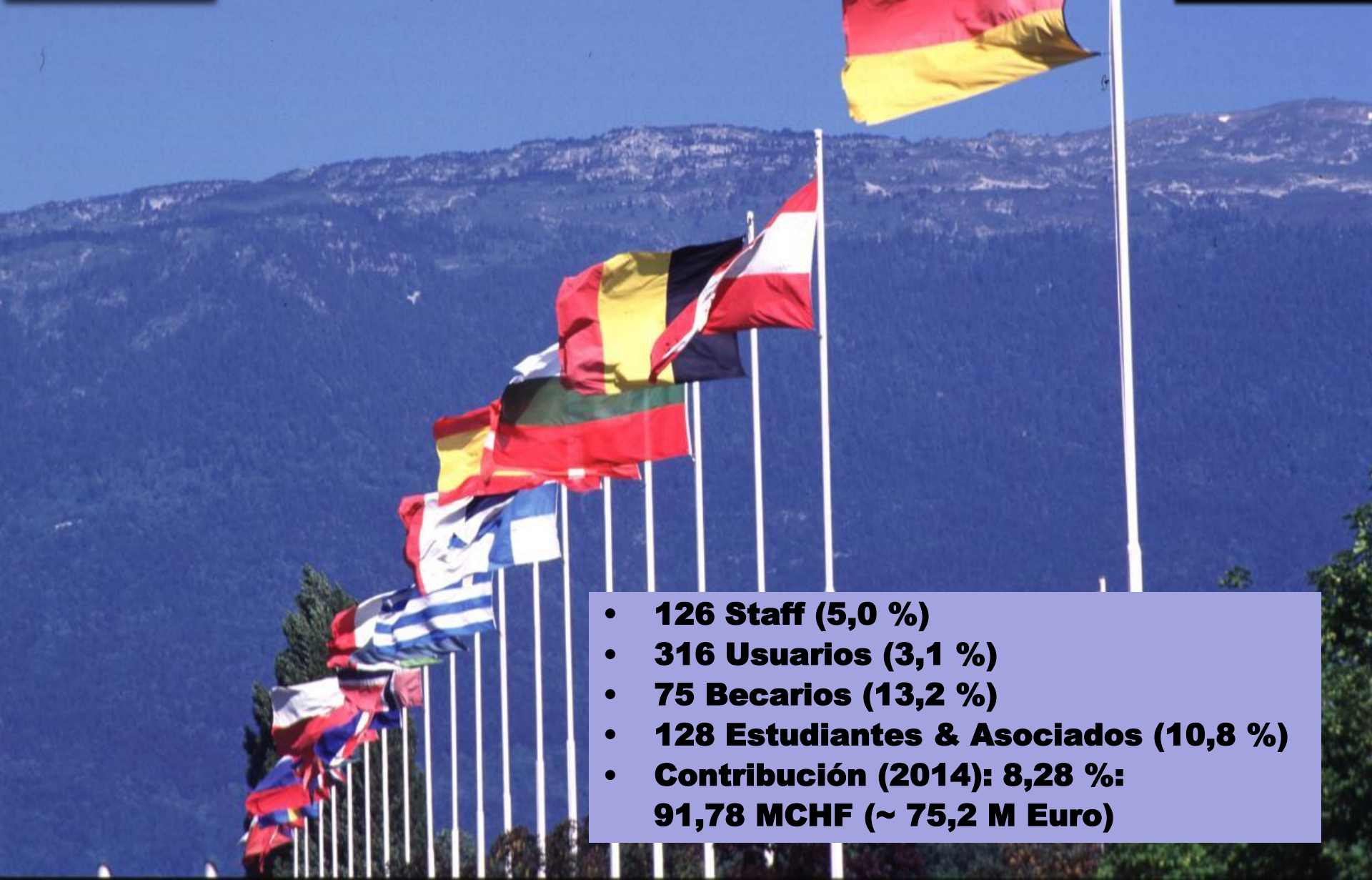
1984: CERN 30 ANIVERSARIO



2004: CERN 50 ANIVERSARIO



ESPAÑA & CERN



- **126 Staff (5,0 %)**
- **316 Usuarios (3,1 %)**
- **75 Becarios (13,2 %)**
- **128 Estudiantes & Asociados (10,8 %)**
- **Contribución (2014): 8,28 %:
91,78 MCHF (~ 75,2 M Euro)**

CONTRIBUCIÓN DEL CERN A LA CONSTRUCCIÓN DEL MODELO ESTÁNDAR

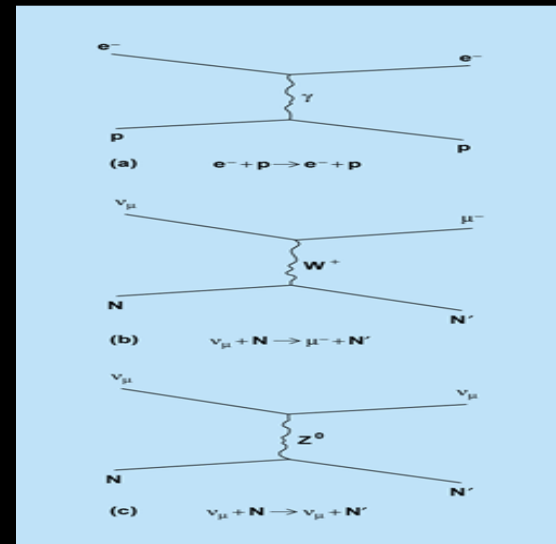
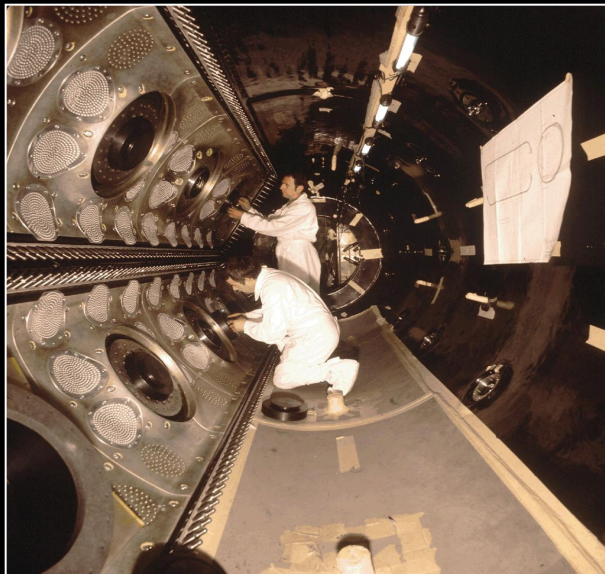
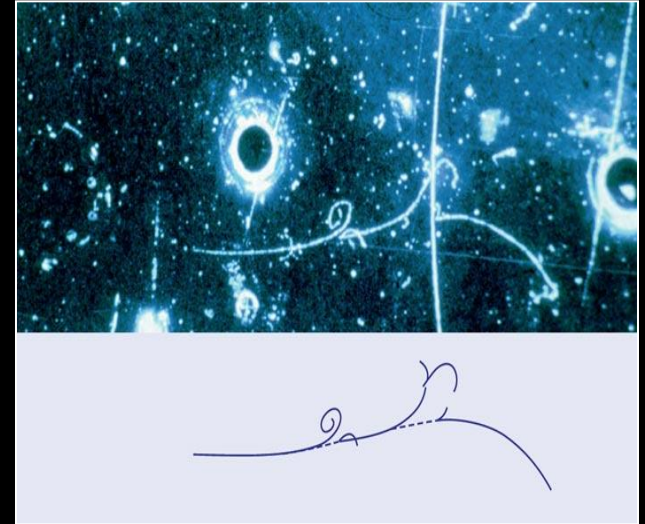
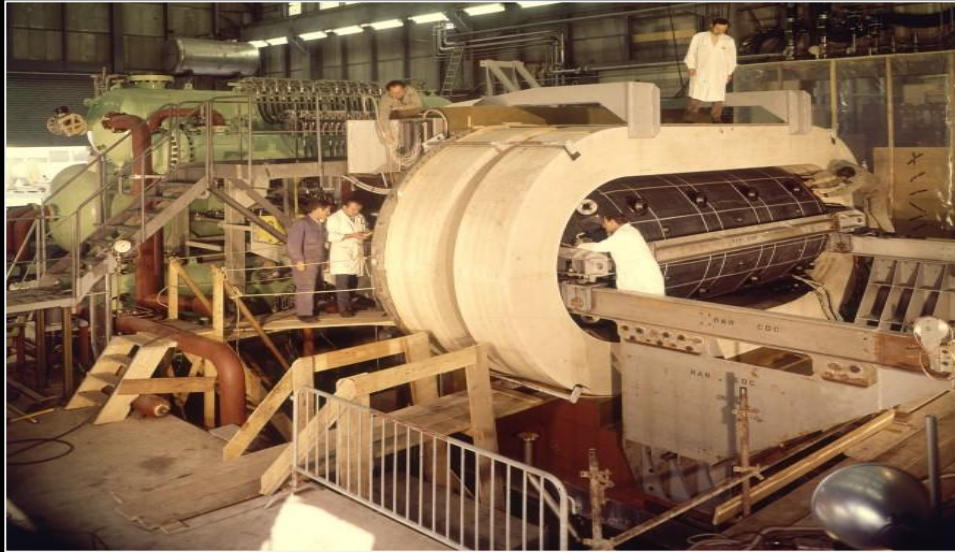
LOS AVANCES EN EL ACOPIO DE CONOCIMIENTO SE BASAN EN:

- **DESARROLLOS INSTRUMENTALES**
- **DESCUBRIMIENTO DE NUEVOS PROCESOS**
- **DESCUBRIMIENTO DE NUEVAS PARTÍCULAS**
- **VIOLACIÓN DE LEYES DE CONSERVACIÓN**
- **MEDIDAS DE PRECISIÓN**

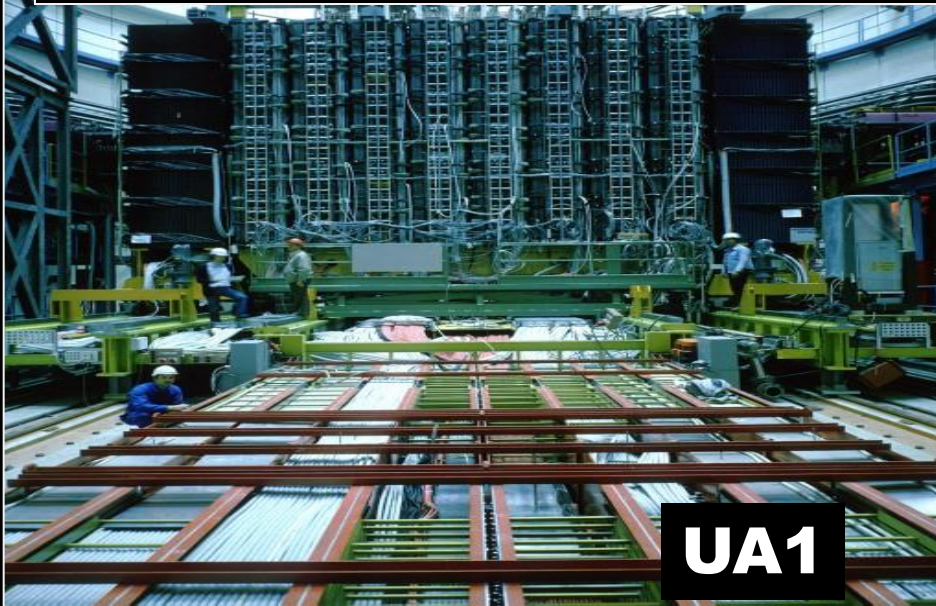
CONTRIBUCIONES DEL CERN

- **ESPECTROSCOPIA HADRÓNICA (1960-1980)**
- **INVENCION DEL "NEUTRINO HORN" (1961)**
- **INVENCION DE LAS CAMARAS MULTIHILOS (1967)**
- **INVENCION DEL ENFRIAMIENTO ESTOCÁSTICO (1971)**
- **DESCUBRIMIENTO DE LAS CORRIENTES NEUTRAS (1973)**
- **DISPERSION INELÁSTICA DE NEUTRINOS (1973-1985)**
- **DESCUBRIMIENTO DE LOS BOSONES W^{\pm} Y Z (1983)**
- **VIOLACION DE LA SIMETRIA CP (ϵ'/ϵ) (1985-2002)**
- **INVENCION DEL WORLD WIDE WEB (WWW) (1989)**
- **DETERMINACION DEL NUMERO DE NEUTRINOS (1992)**
- **DESCUBRIMIENTO DE LAS CORRECCIONES EW (1992)**
- **DESCUBRIMIENTO DEL BOSÓN DE HIGGS (2012)**

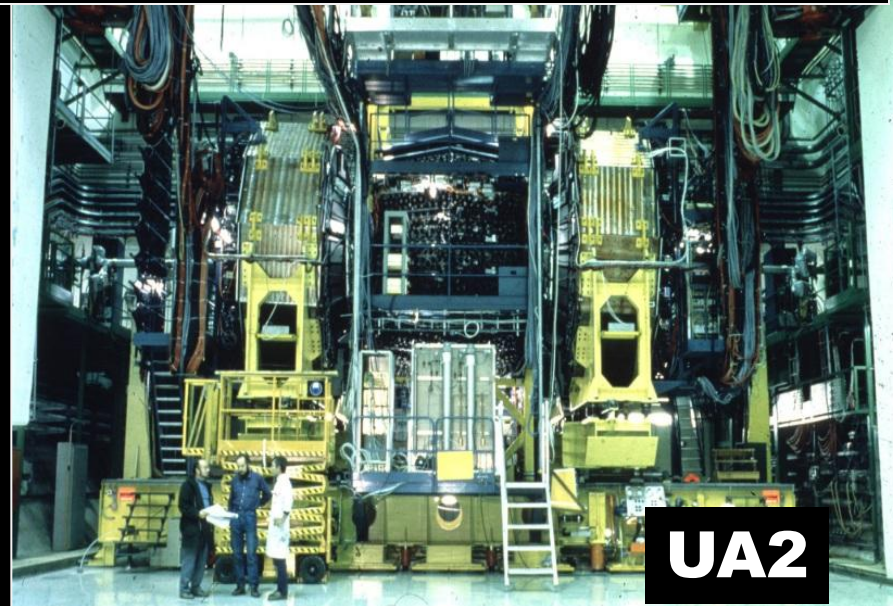
1973: DESCUBRIMIENTO DE LAS CORRIENTES NEUTRAS (GARGAMELLE)



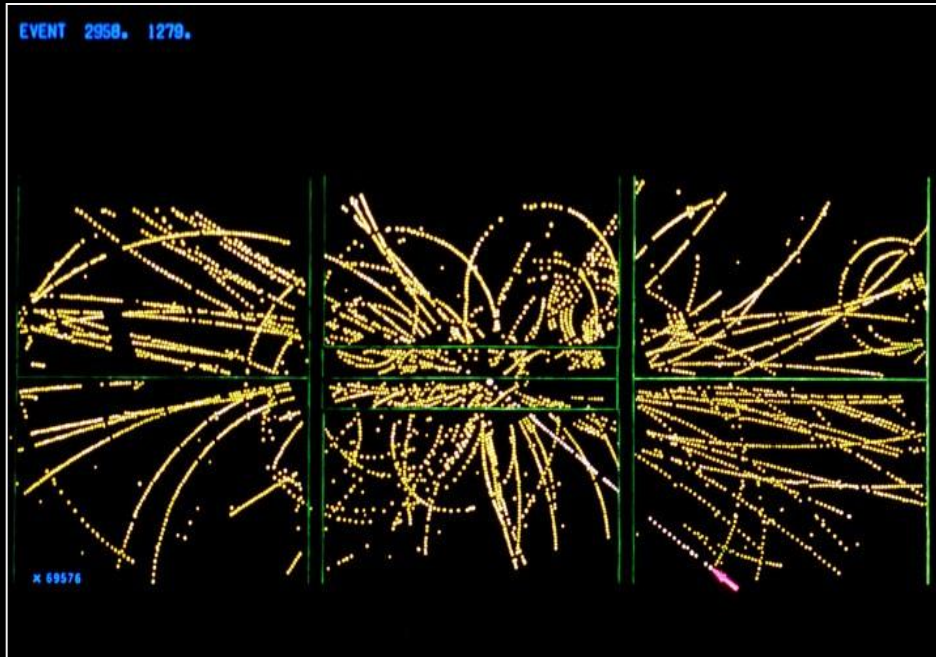
1983: DESCUBRIMIENTO DE LOS BOSONES W^\pm Y Z



UA1



UA2

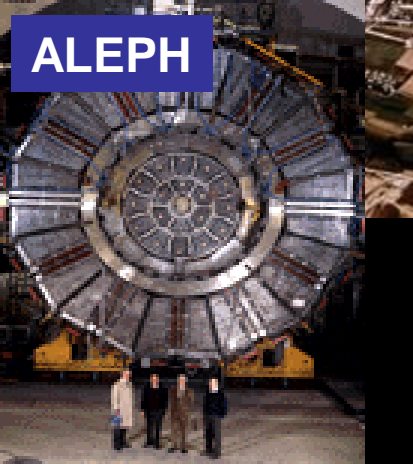


**C. RUBBIA, S. van DER MEER
PREMIOS NOBEL 1984**

1989 — 2000: VALIDACIÓN DEL MODELO ESTÁNDAR



LEP



ALEPH



L3

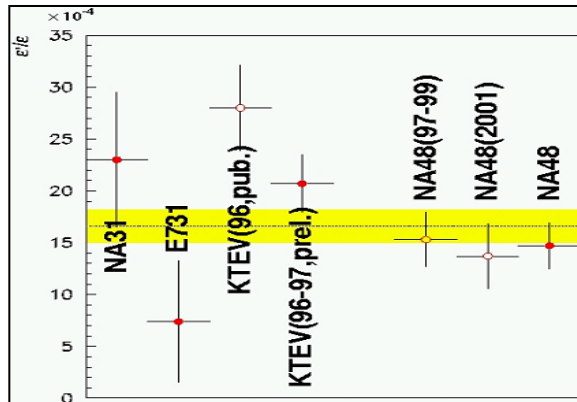
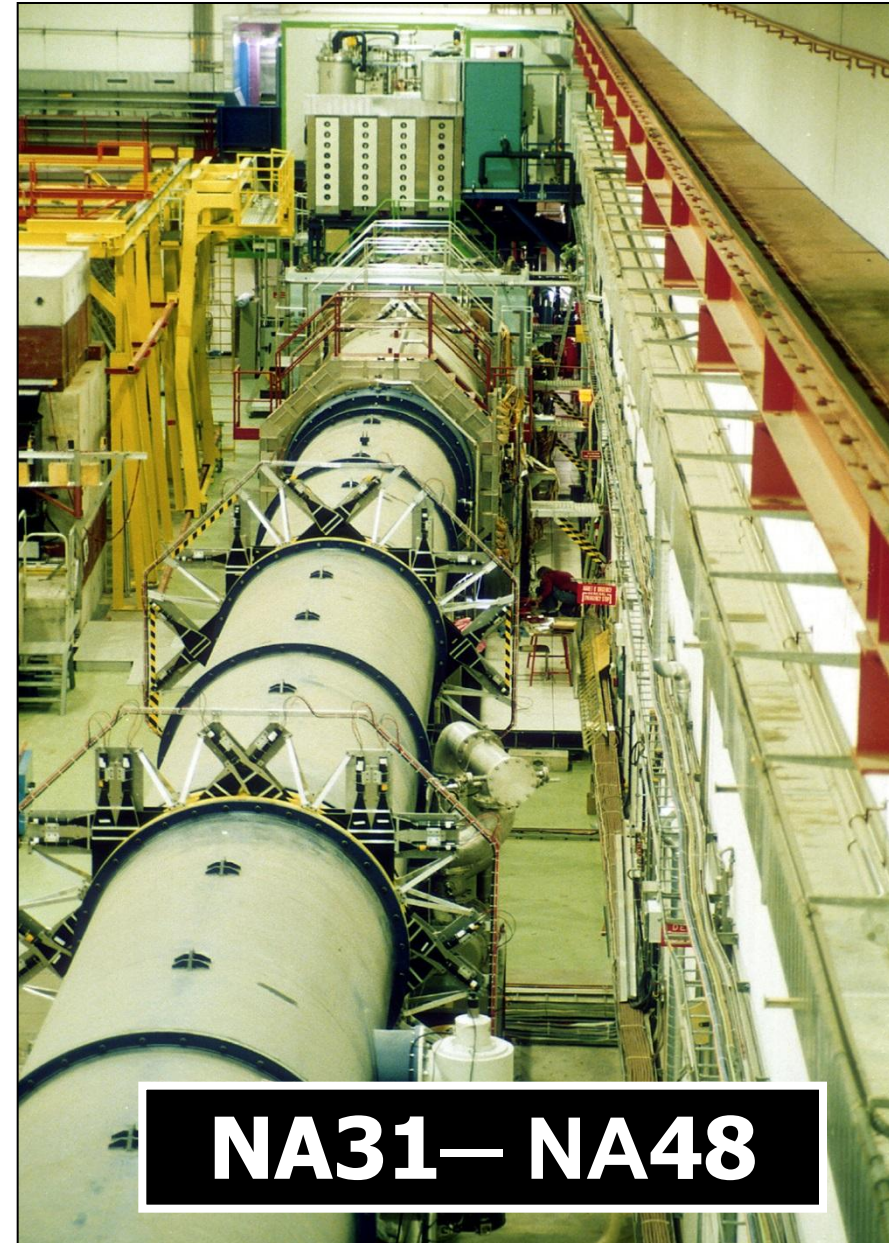
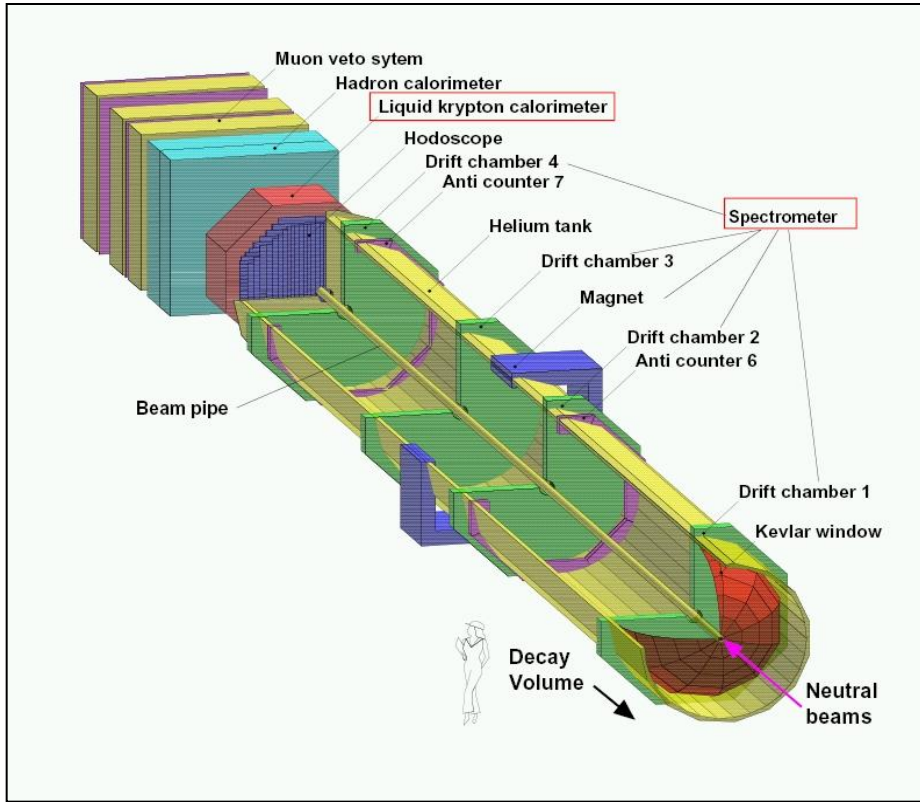


DELPHI

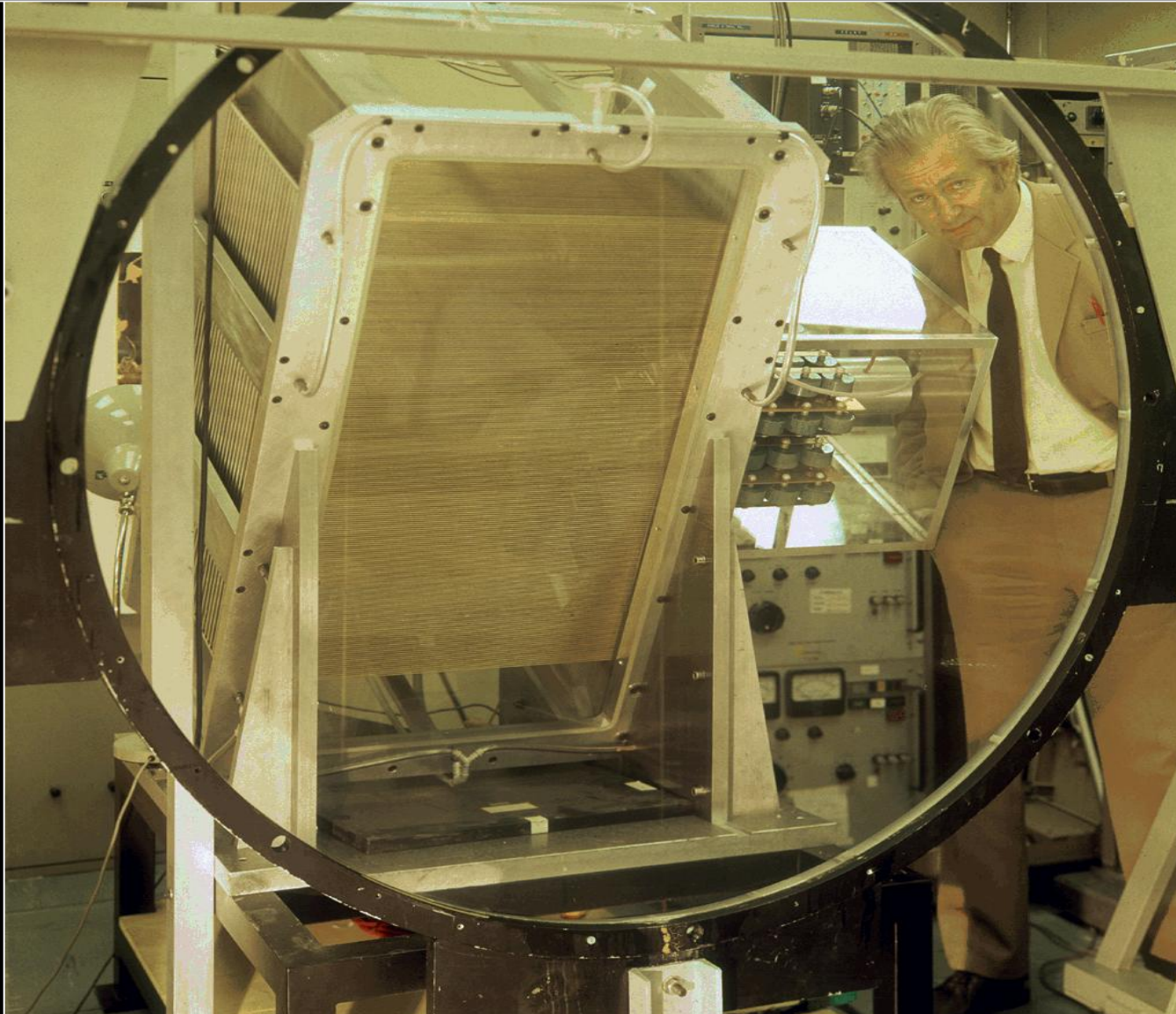


OPAL

1986 – 2001: MEDIDA DE ϵ' / ϵ



1967: INVENCION CÁMARA MULTIHILOS



G. CHARPAK (1924–2010), PREMIO NOBEL 1992

1989: INVENCIÓN DEL WWW

REWIREDSTATE

TIM BERNERS LEE

**DESCUBRIMIENTO
DEL BOSÓN B-E-H
EN EL LHC**

ii EL LHC !!

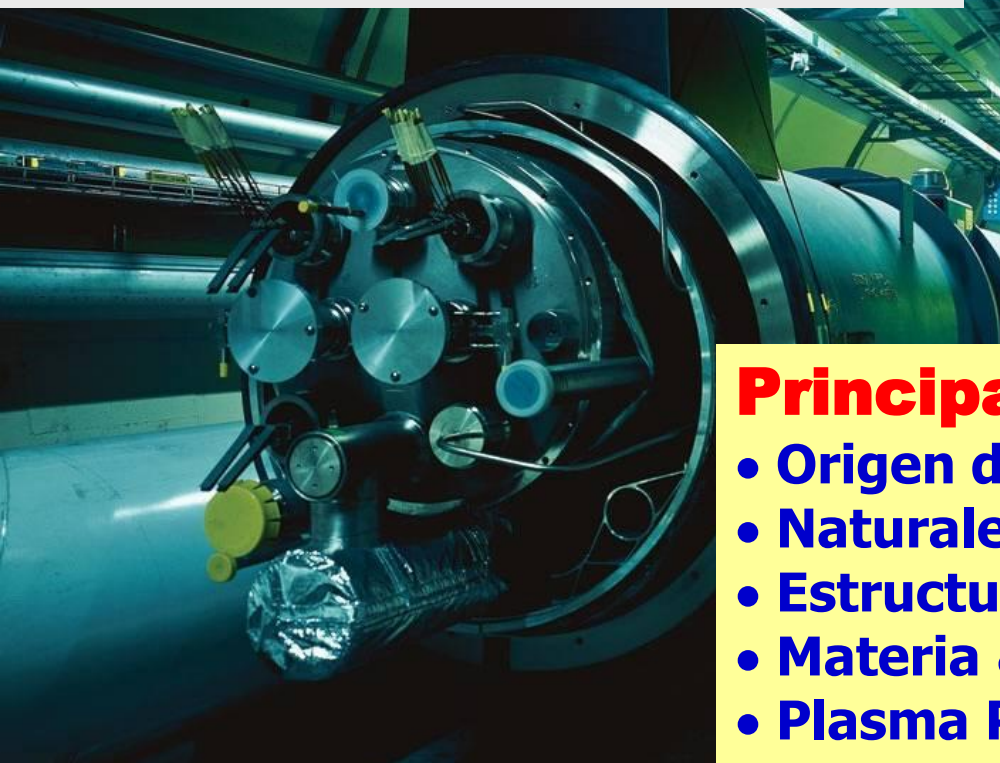
UNA ODISEA ZEPTOESPACIAL,
A Journey into the Physics of the LHC,
Gian Francesco Giudice



LYN EVANS



STEVE MYERS



ROLF HEUER

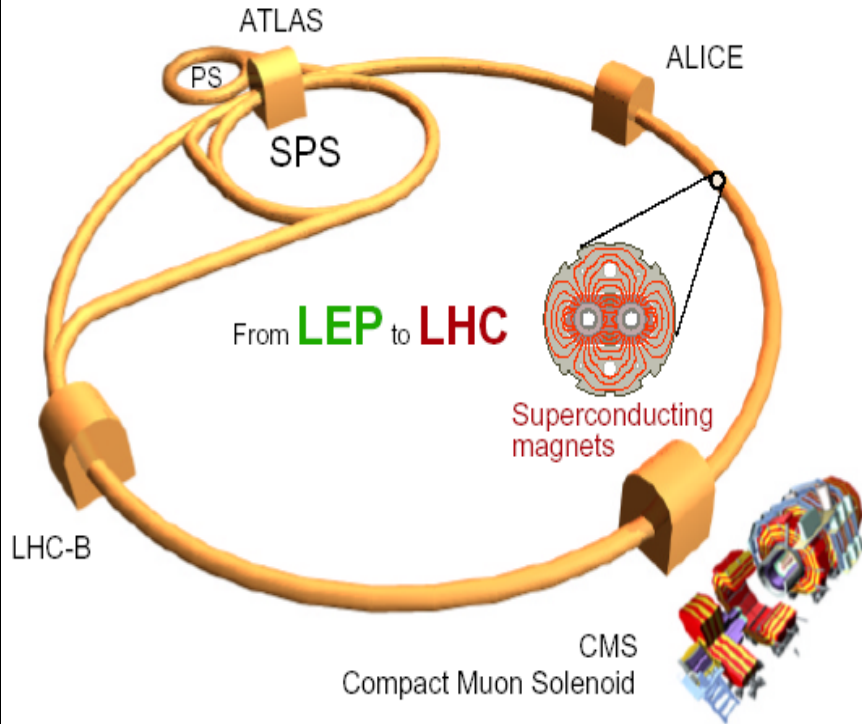


Principales Objetivos Científicos

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

EL LHC SEÑALARÁ EL FUTURO DE LA FÍSICA DE PARTÍCULAS

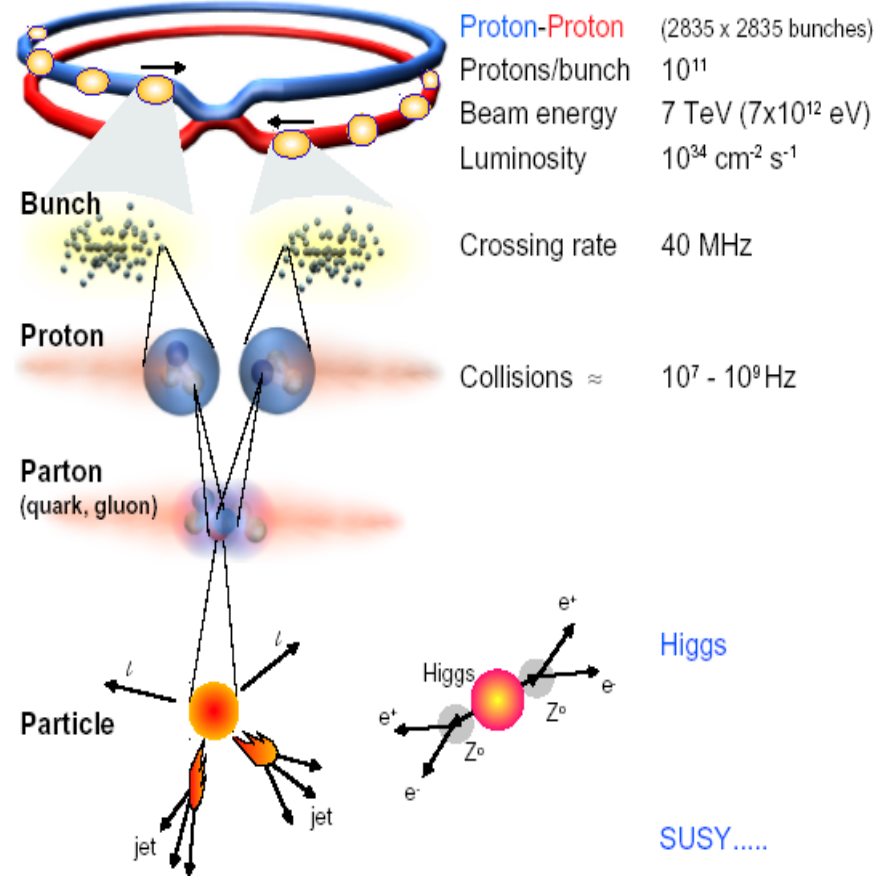
The Large Hadron Collider (LHC)



	Beams	Energy	Luminosity
LEP	e ⁺ e ⁻	200 GeV	10 ³² cm ⁻² s ⁻¹
LHC	p p	14 TeV	10 ³⁴
	Pb Pb	1312 TeV	10 ²⁷

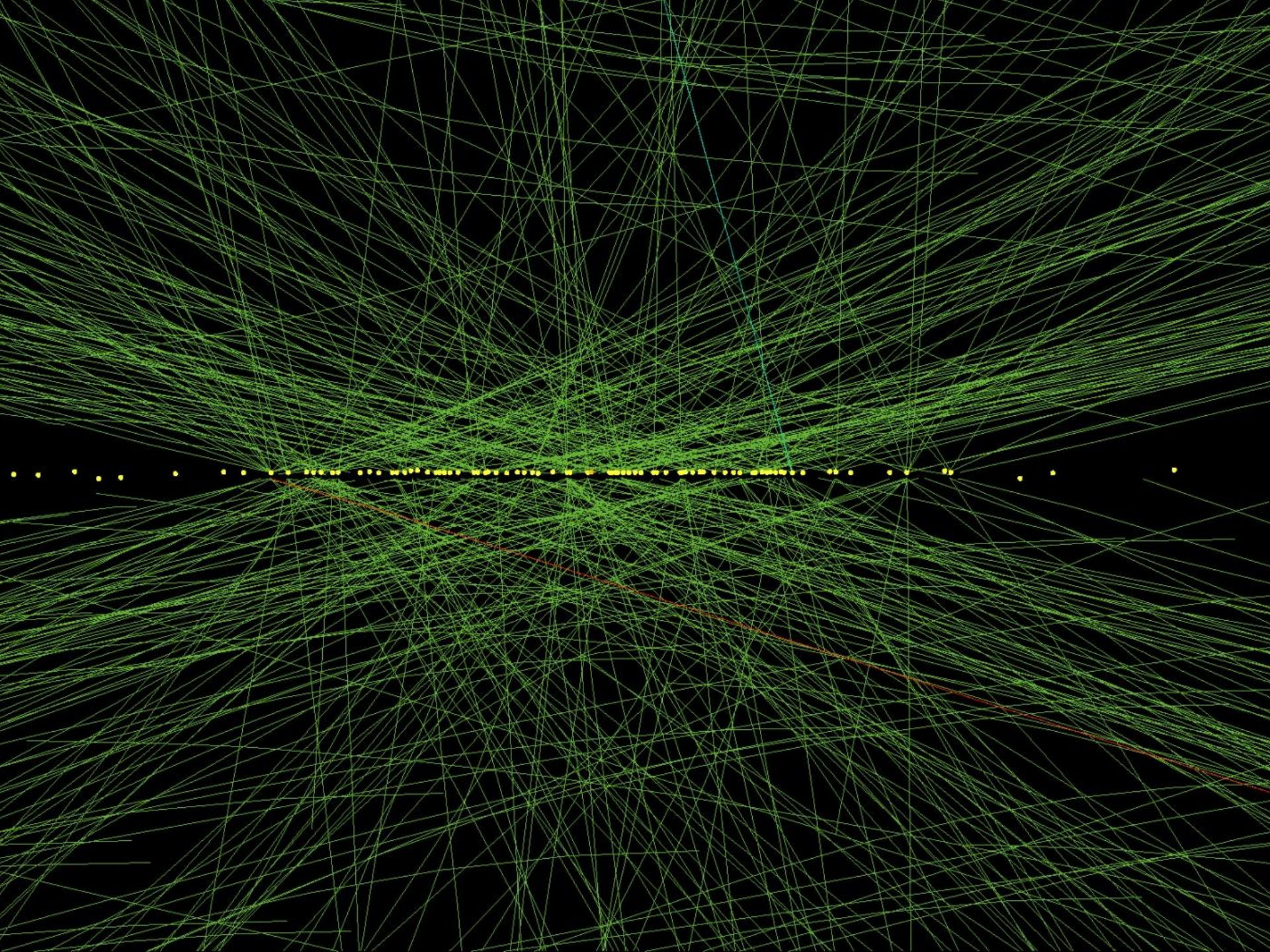
**SUPERCONDUCTIVIDAD,
CRIOGENIA**

Collisions at LHC

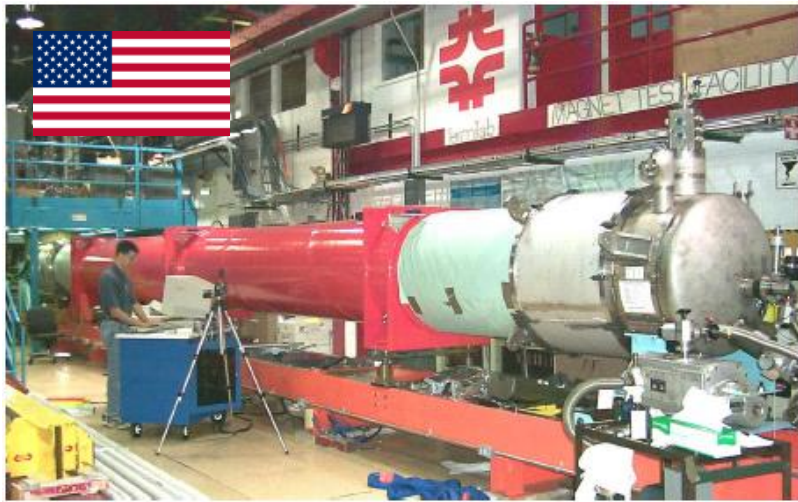


Selection of 1 in 10,000,000,000,000

**TECNOLOGÍAS DE ACELERADORES,
ELECTRÓNICA, DAQ, TRIGGER, ...**



UN PROYECTO GLOBAL EN EL ESPACIO



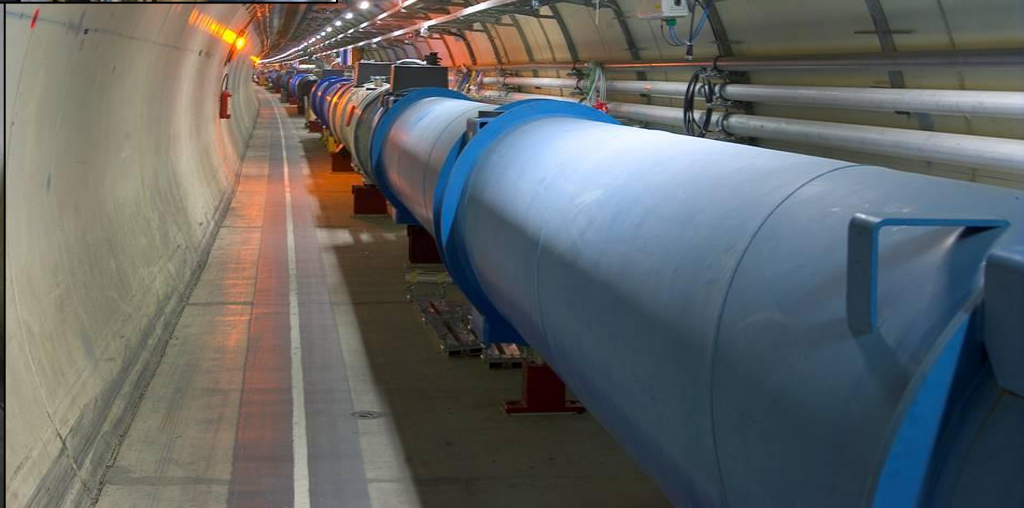
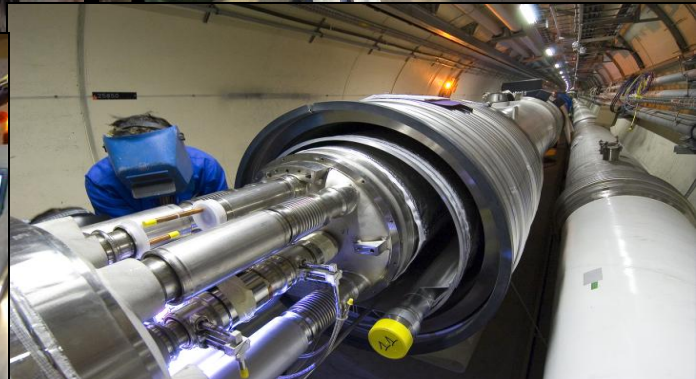
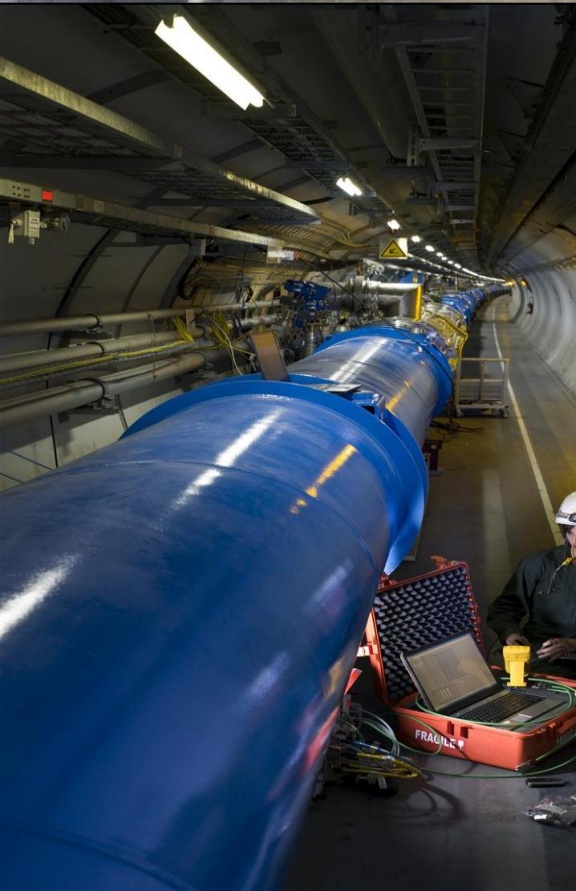
... Y EN EL TIEMPO

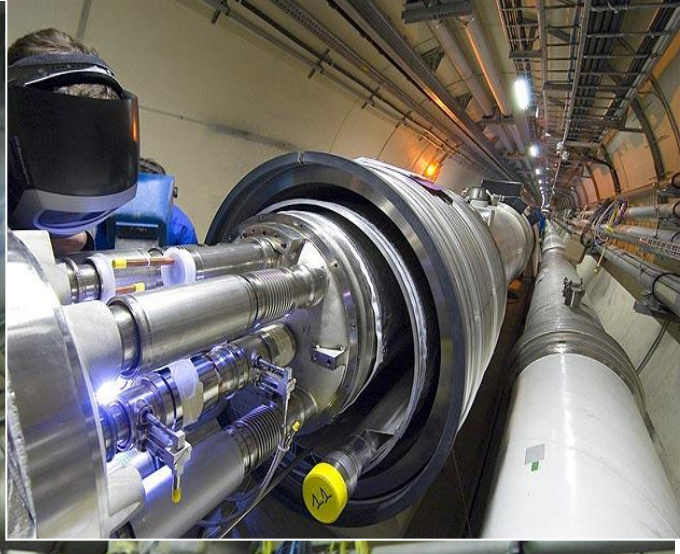
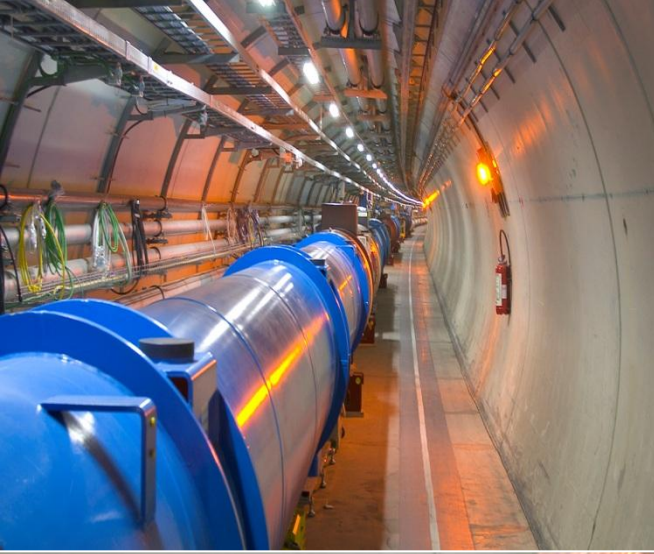
- **Estudios conceptuales preliminares** 1984
- **Primeros prototipos de imanes** 1988
- **Inicio de un programa estructurado de I&D** 1990
- **Aprobación del Consejo del CERN** 1994
- **Industrialización de la producción en serie** 1996-1999
- **Inicio de la ingeniería civil** 1998
- **Adjudicación de grandes contratos** 1998-2001
- **Inicio de la instalación en el tunel** 2003
- **Instalación de los crioimanes en el tunel** 2005-2007
- **Tests funcionales del primer sector** 2007
- **Comisionado del haz** 2008
- **Operación para Física** 2009-2030

... CON RECURSOS MULTIDISCIPLINARES

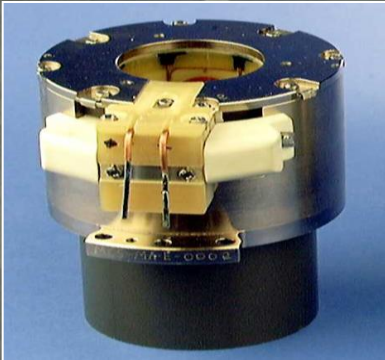
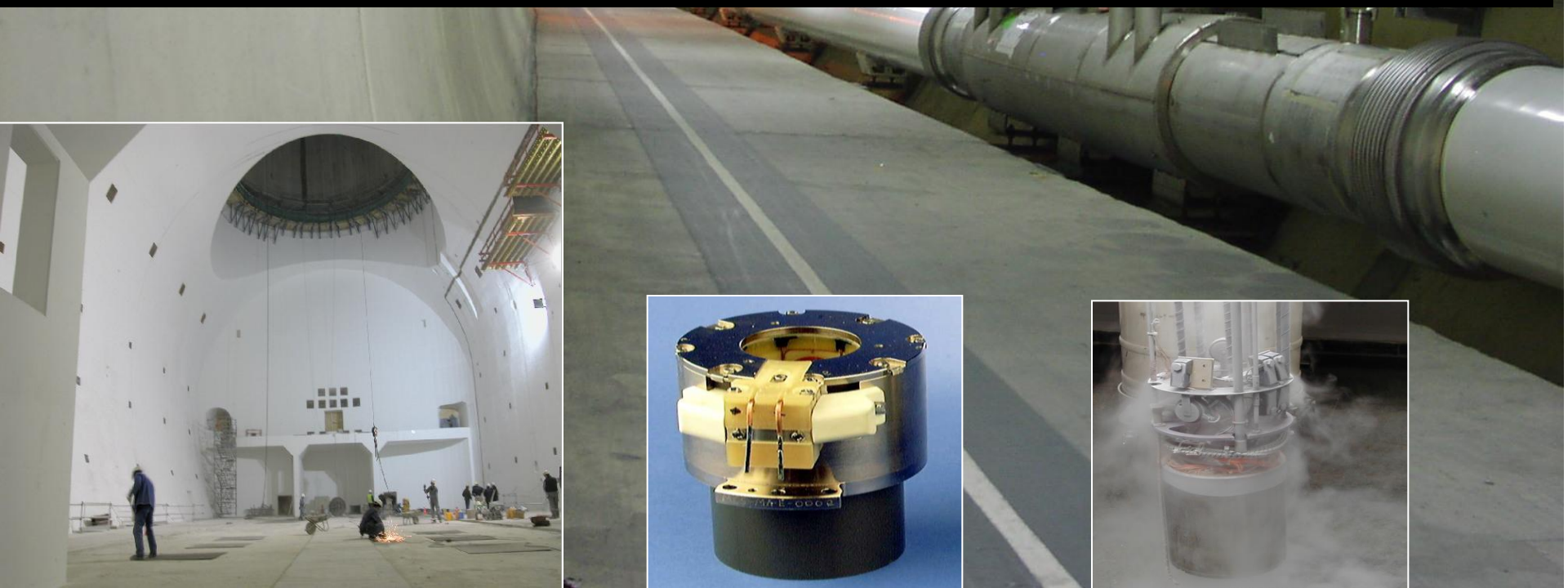








CONTRIBUCIÓN ESPAÑOLA AL LHC

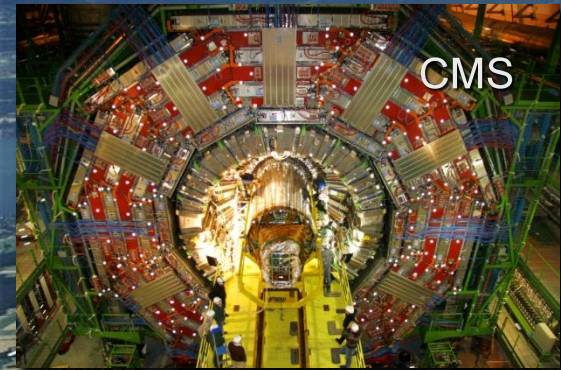




ESPECIALIZADO



PROPÓSITO GENERAL



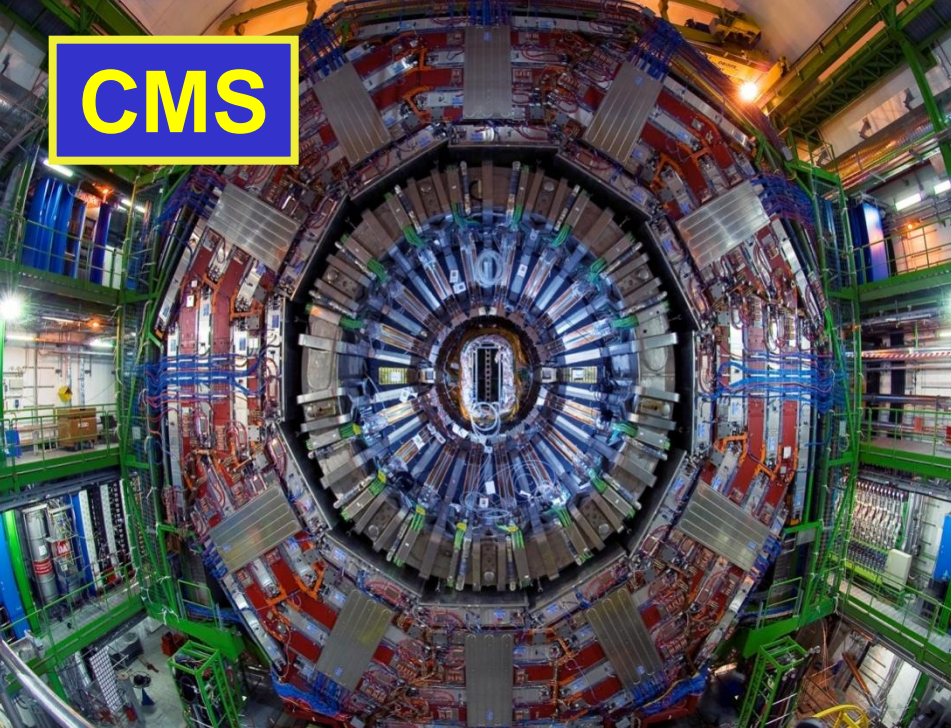
PROPÓSITO GENERAL



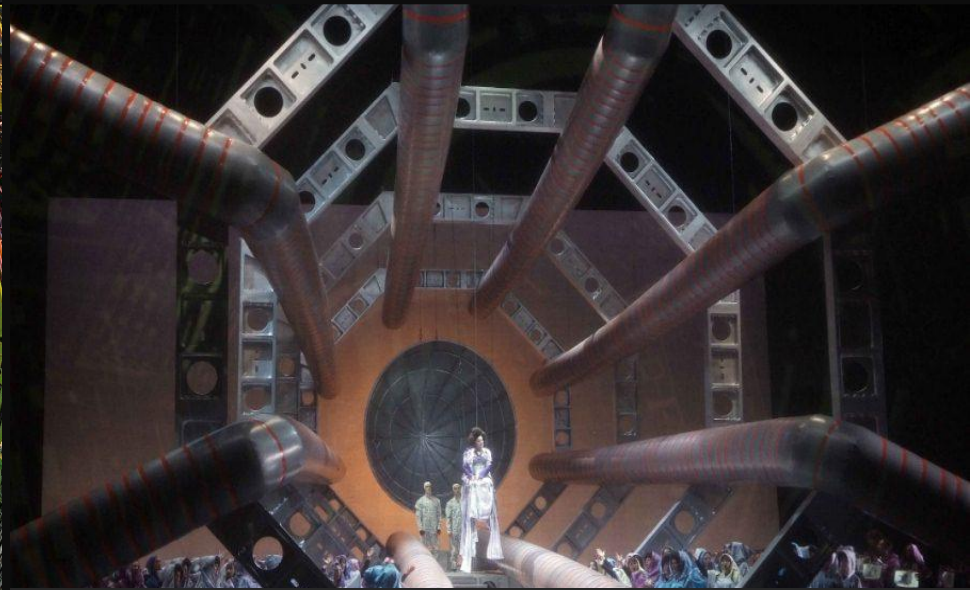
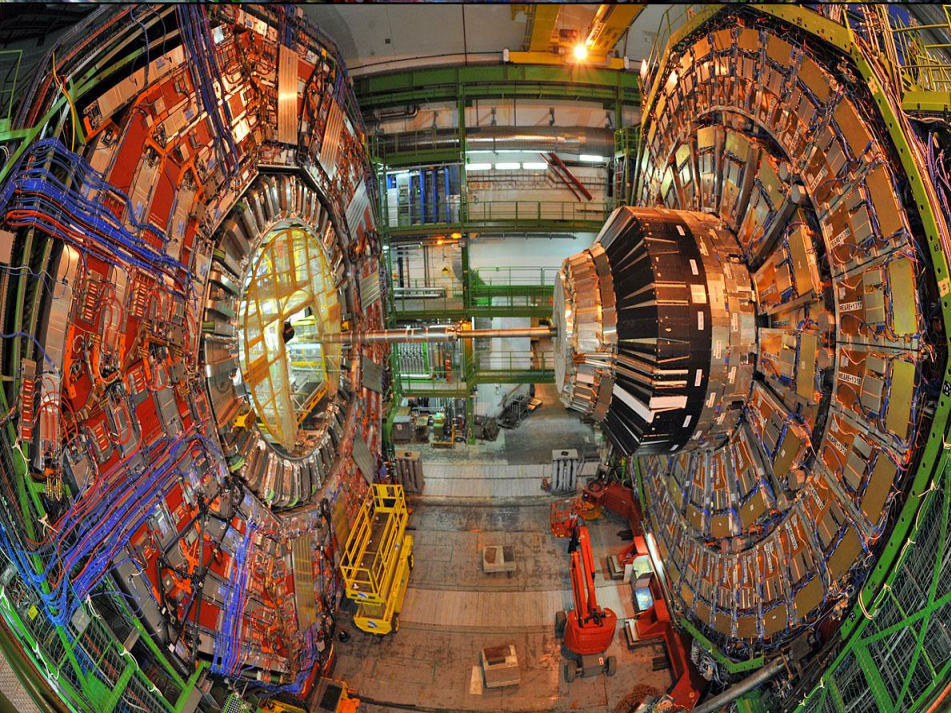
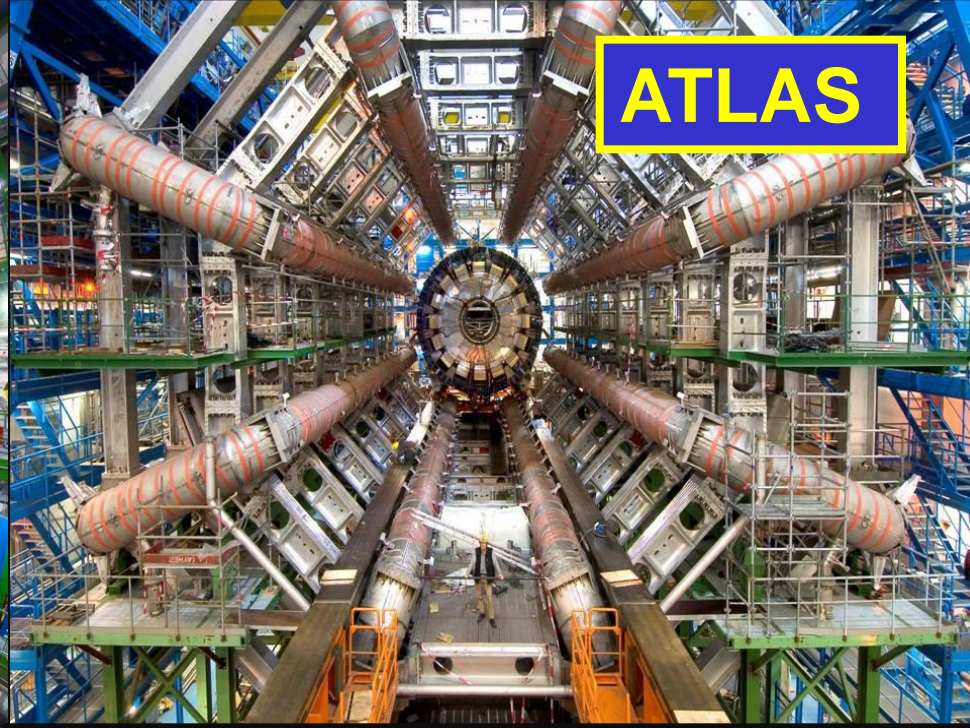
ESPECIALIZADO

LOS EXPERIMENTOS EN EL LHC

CMS

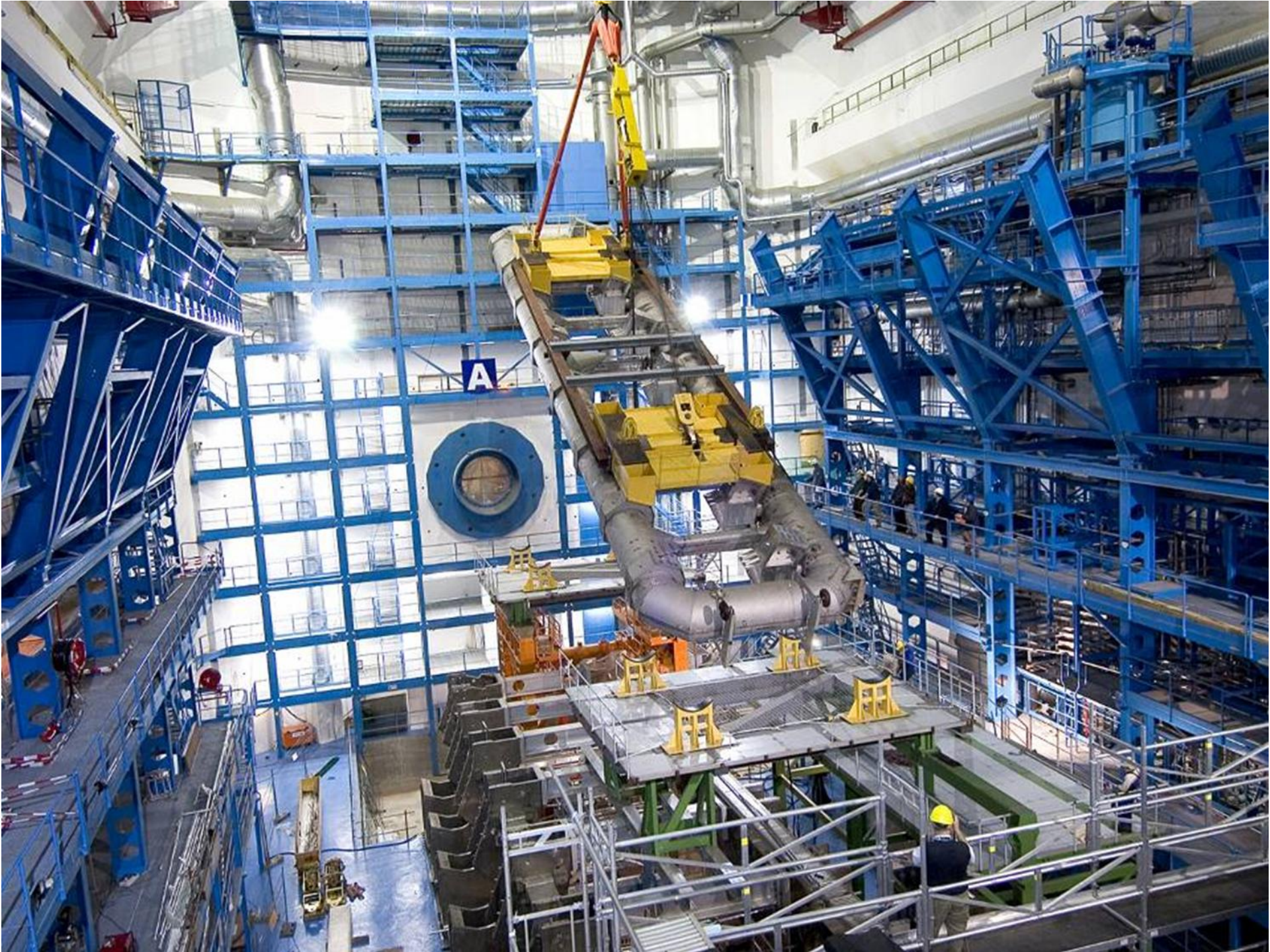


ATLAS



Hector Berlioz, "Les Troyens", Valencia, Palau de les Arts Reina Sofia, 2009



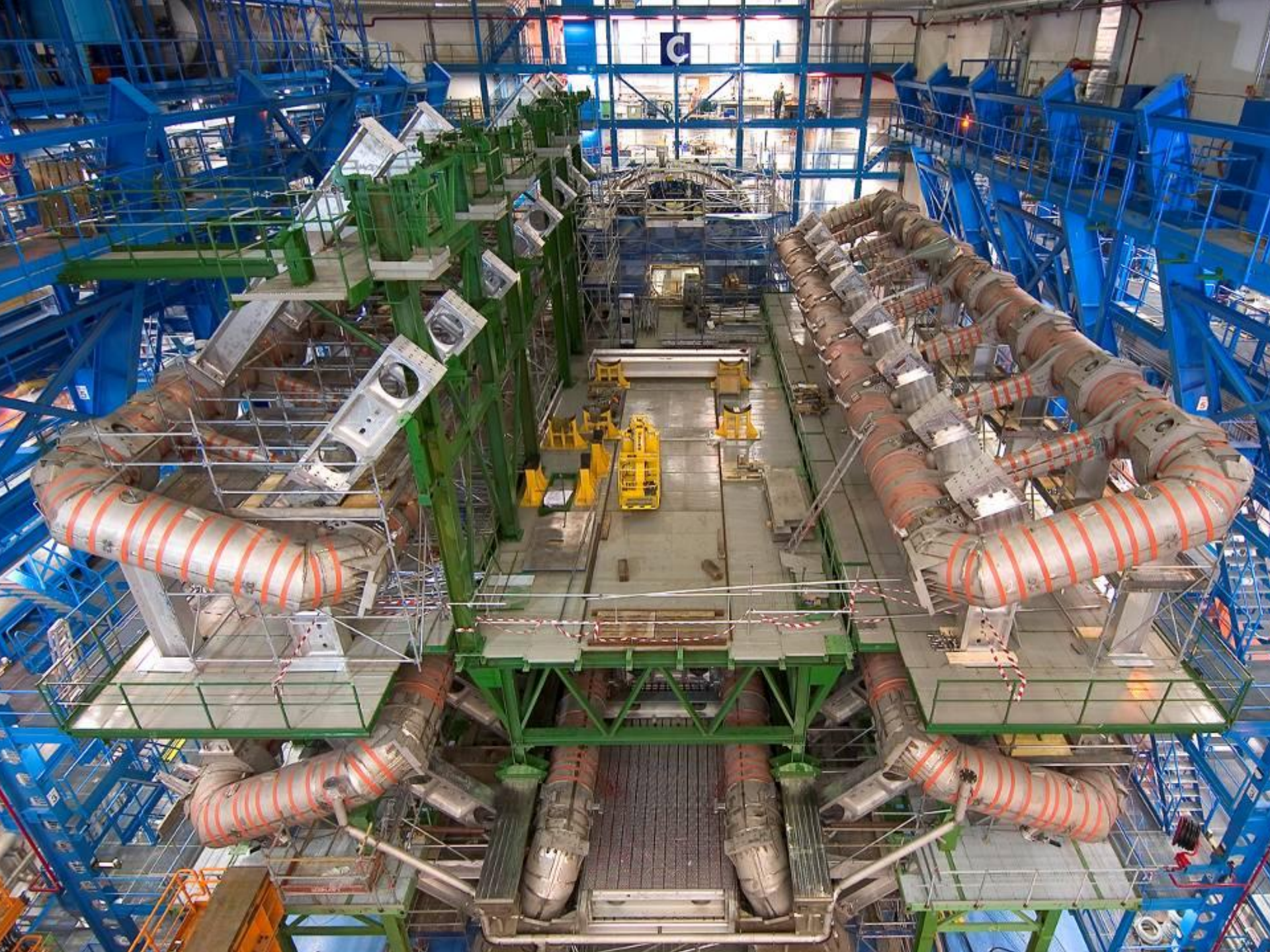




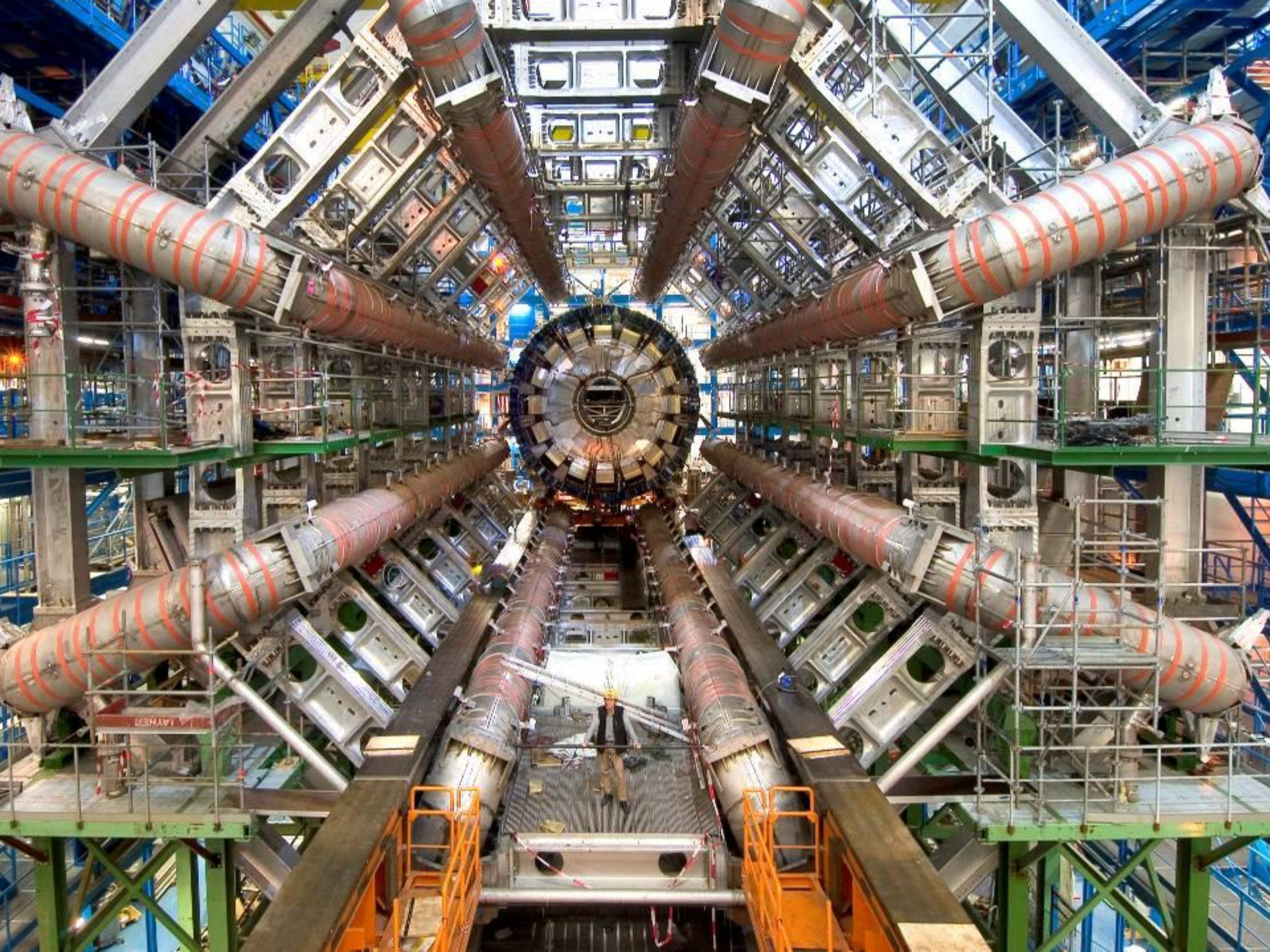










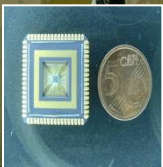
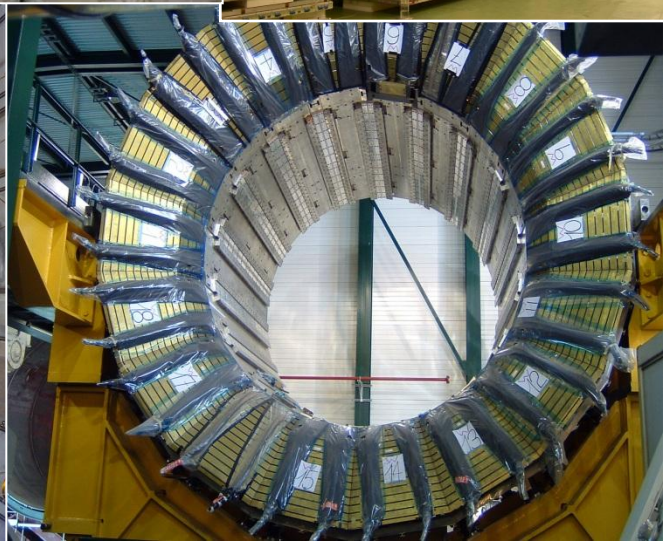
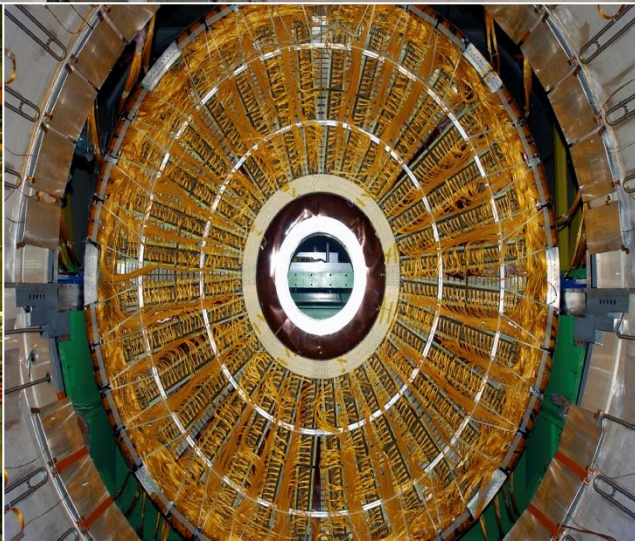
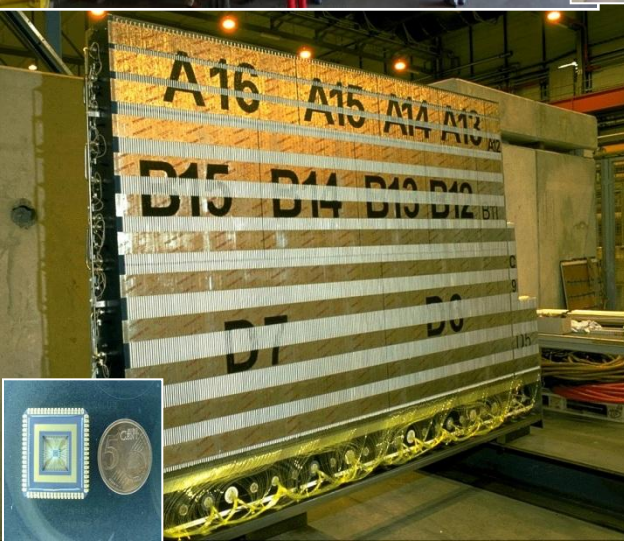




**40 PAÍSES, 193 INSTITUTOS
~ 3300 CIENTÍFICOS & INGENIEROS (~ 900 ESTUDIANTES)**



CONTRIBUCIÓN ESPAÑOLA A LOS DETECTORES DEL LHC





Juan José Rodríguez Romero

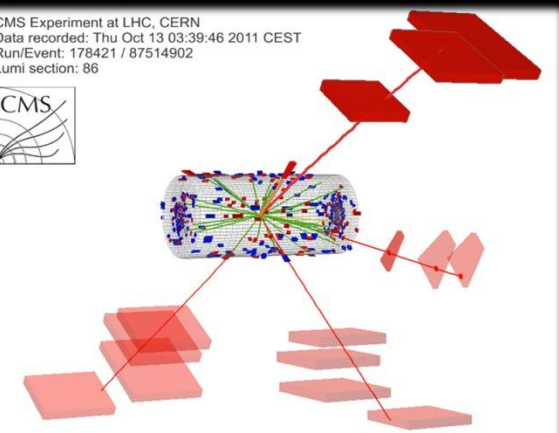


José Javier Navarrete Marn

Ciemat

Compact Muon Solenoid

CMS Experiment at LHC, CERN
Data recorded: Thu Oct 13 03:39:46 2011 CEST
Run/Event: 178421 / 87514902
Lumi section: 86



Juan José Martínez Morales



José Flix Molina



Gaspar López Rodríguez



Concepción Braña Pérez



Gonzalo Merino Arevalo



Javier Alberdi Primiña



Daniel Domínguez Vázquez



Carlos Blanco Ramos



Carlos Burgos Lázaro



José Alarcón Vega



María Cepeda Hermida



Nicanor Colino Arriero



Jesús Puerta Pelayo



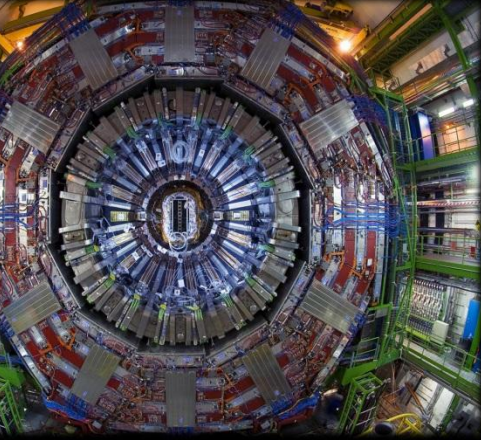
José Miguel Ahijado Muñoz



José Manuel Alarcón Vega



Carlos Vilameuva Muñoz



José Javier Chércoles Catalán



Manuel Corral Buena



Enrique Calvo Alamillo



María Chamizo Liatas



José Miguel Barcala Rivera



Juan Alcaraz Maestre



Mara Senghi Soares



Oscar González López



Silvia Goy López



Jesús Marín Muñoz



Pedro Ledrón de Guevara



Luis Galicia Saavedra



José Javier Chércoles Catalán



Juan Carlos Oller González



Juan José Rodríguez Vázquez



Juan Carlos Puras Sánchez



Pablo García Abia



Jesús Salicio Díez



José Luis Ramírez Pérez



José Caballero Bejar



Adrián Quintanro Omeda



Antonio Molinero Wela



Marcos Fernández García



Pedro Arce Dubois



Javier Yañez González



Javier Sastre Álvarez



Julián García Romero



Cristina Fernández Betoya



María Aldaya Martín



Carlo Battiana



Jorge Molina



José María Hernández Calama



Juan Pablo Fernández Ramos



M de la Cruz Fouz Iglesias



Luciano Romero Barajas



Ignacio Redondo Fernández



David Francia Ferrero



Luis Jesús Amigo Santiago



Marcos Cerrada Canales



Carlos Willmott Zappacosta



Álvaro Navarro Tobar



Francisco Martín Suárez



Antonio Ferrando García



Carmen Díez Pardo



M Isabel Josa Mutebarria



Celerino Yusta de Santos



Manuel Daniel Leal



Miguel Cárdenas Montes



Francisco García Alonso



M. Begoña De la Cruz Martínez



Antonio Delgado Peris



José Manuel Cela Ruiz



Equipo de la Unidad de Fabricación y Apoyo a I+D



Francisco Martín Suárez



Antonio Ferrando García



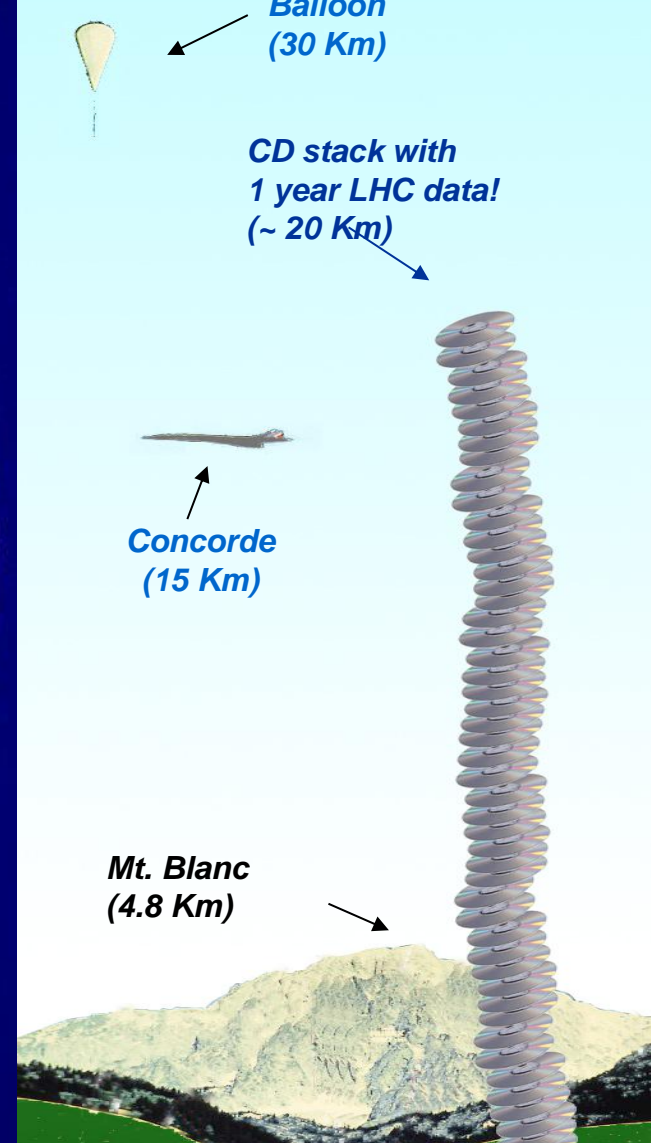
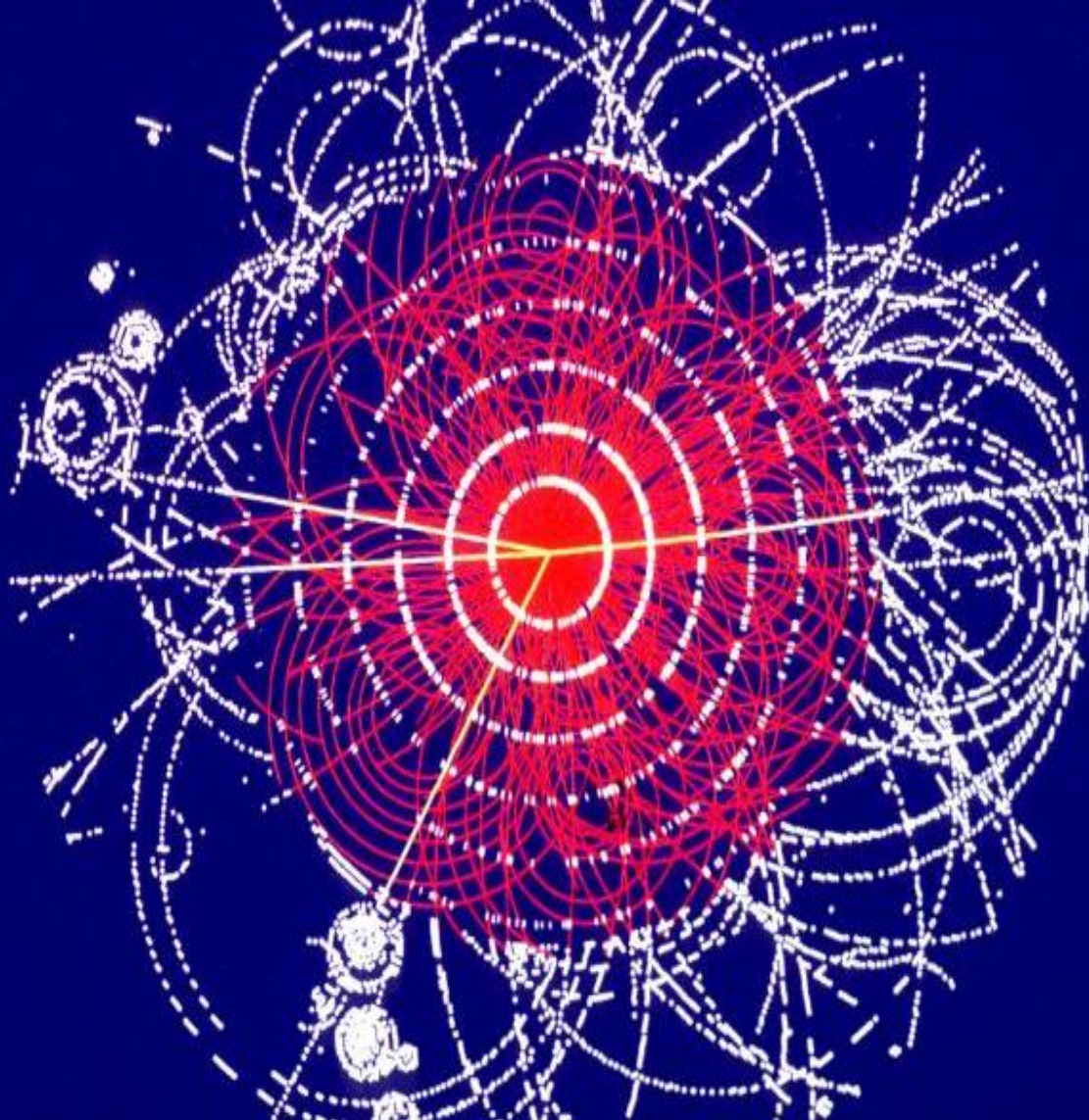
Carmen Díez Pardo



Antonio Luis Pardillo Porras



Antonio Luis Pardillo Porras



**ATLAS y CMS producirán ~15 millones de Gigabytes por año
(¡~5 millones DVDs!)**

**El análisis de los datos requerirá una potencia de cálculo
equivalente a ~100,000 procesadores PC de última generación**

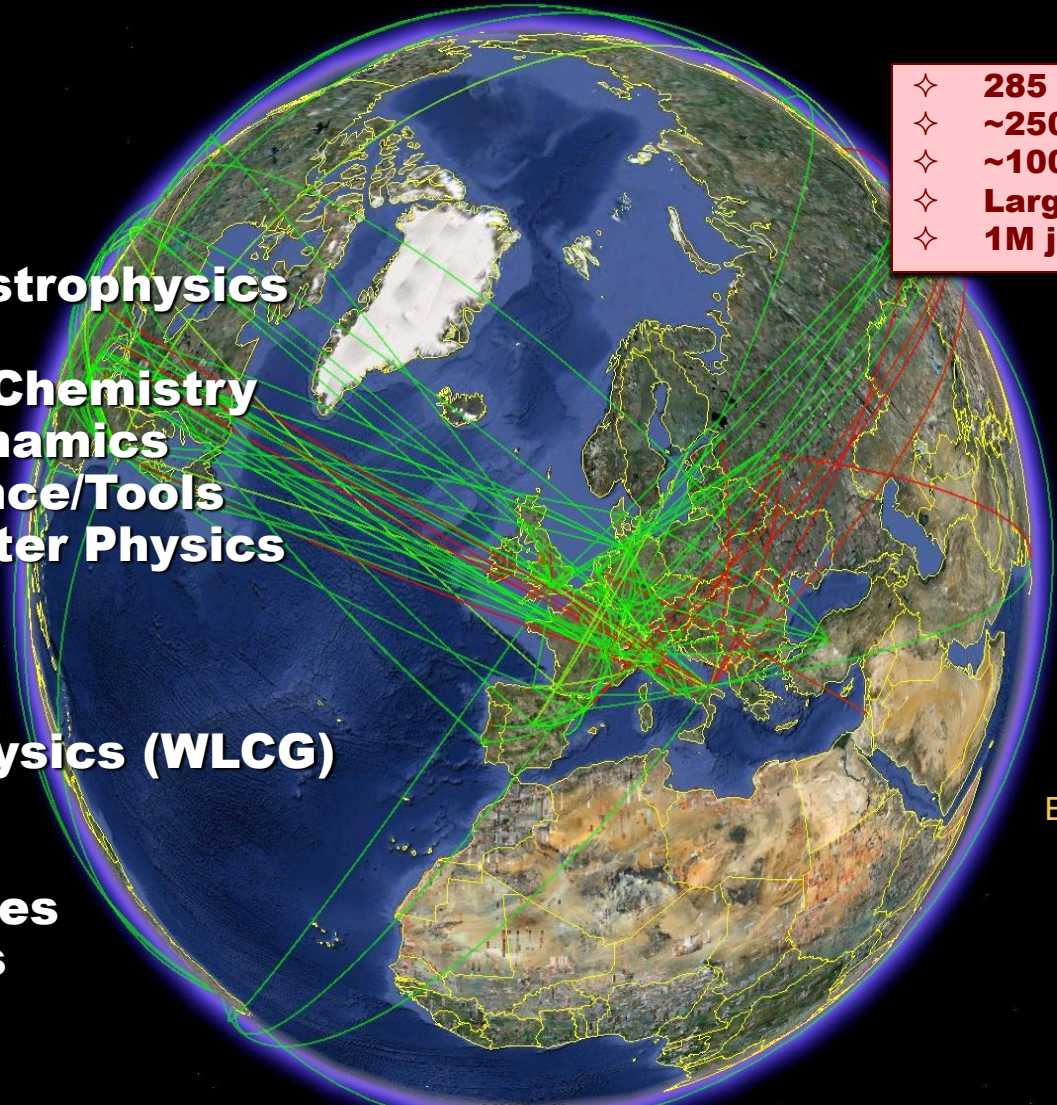
CERN & COMPUTACIÓN GRID

Oct 26, 2010 - 4:50:00 pm

Running jobs: 117948.0
Transfer rate: 4.94 GiB/sec



- ◇ **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**



EGEE-III INFISO-RI-222667



EL CERN COMO EDUCADOR

Visits

Accelerator School

Doctoral Student

Language Training

Exhibitions

Academic Training

Physics School

Communications Training

Apprentices

CERN-Latin America School

Technical Training

Computing School

Teachers programmes

Technical Student

Summer Student

Fellows

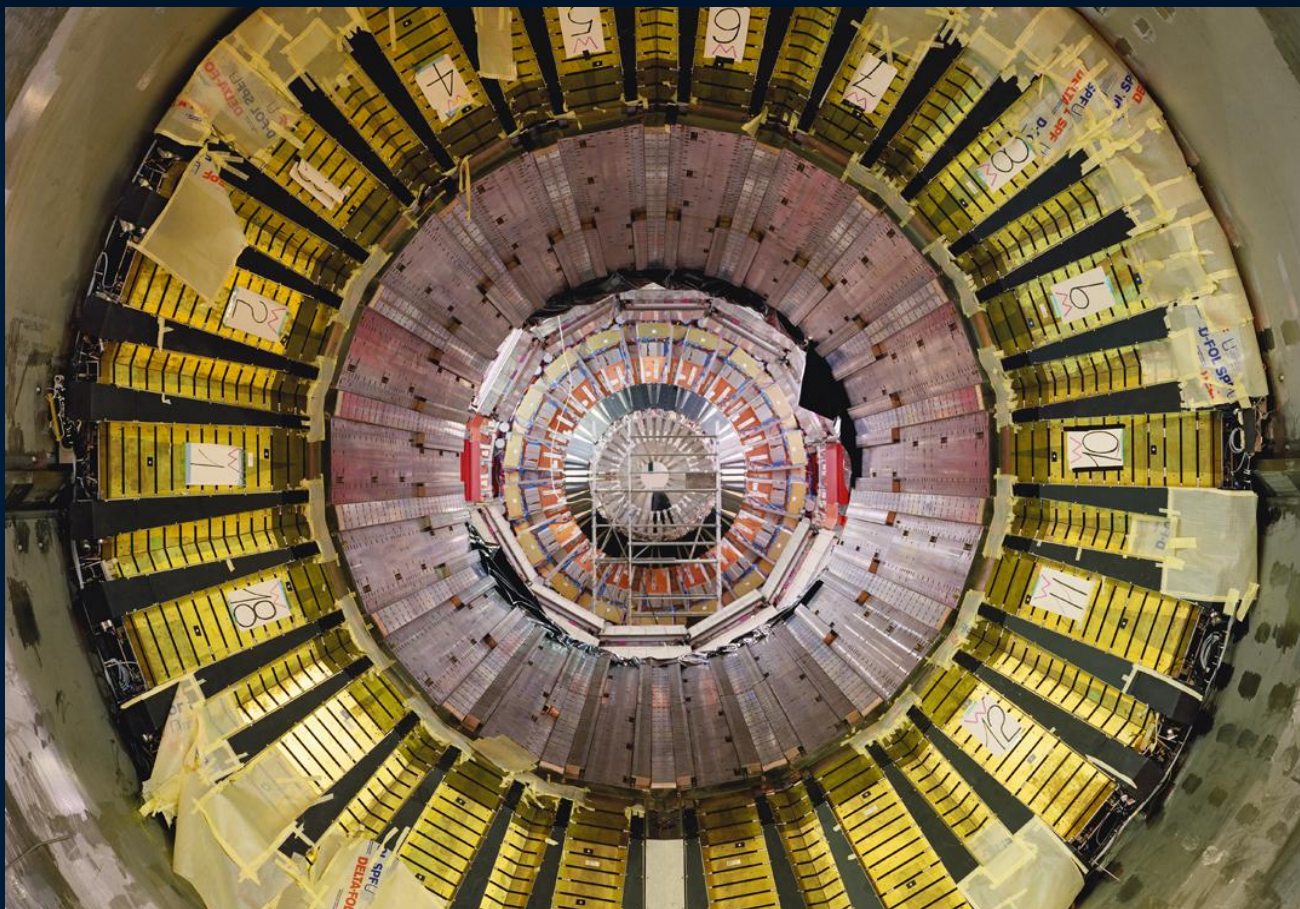
Management Training



**INNOVAR, DESCUBRIR,
PUBLICAR, COMPARTIR**



**... Y CONTRIBUIR A HACER UN MUNDO MÁS
INSTRUIDO, JUSTO Y SOLIDARIO**



***EL CONOCIMIENTO ES LIMITADO.
LA IMAGINACIÓN ABARCA TODO EL MUNDO...***

Albert Einstein



FELIZ ANIVERSARIO !!

... Y SUERTE !!





GRACIAS

MENSAJES RELEVANTES

- **COOPERACIÓN PACÍFICA EN LA FRONTERA DE LA CIENCIA CON INDEPENDENCIA DE DIFERENCIAS CULTURALES Y NACIONALES**
- **EL APOYO A LA INVESTIGACIÓN Y A LA INNOVACIÓN ES VITAL PARA ASEGURAR, EN UN ENTORNO GLOBAL COMPETITIVO, EL DESARROLLO SOSTENIBLE DE LA CIENCIA Y LA TECNOLOGÍA NECESARIAS PARA RESTABLECER EL CRECIMIENTO ECONÓMICO**
- **LA COOPERACIÓN Y LA COMPETICIÓN SON LOS CAMINOS HACIA EL ÉXITO**
- **EL ACCESO LIBRE Y EL COMPARTIR RESULTADOS PERMITE LA PARTICIPACIÓN Y EL DESARROLLO**
- **IMPLICAR Y COMPROMETER A LOS JÓVENES CON LA CIENCIA**
- **SUPERAR LA BRECHA ENTRE CIENCIA Y SOCIEDAD**