

# ¿ De qué está hecho el Universo ?

De las partículas elementales a las supercuerdas

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# RESUMEN

**1. Solo entenderemos la composición del Universo si conocemos las partículas elementales que lo constituyen y las fuerzas que se ejercen entre ellas**

- Describiremos todas las partículas y las interacciones conocidas

**2. Después especularemos**

- ¿Hacen falta más partículas en nuestra lista?

**3. Higgs, Supersimetría, Supercuerdas, ...**

- ¿De qué está hecha la materia oscura?



The mess at the beginning of the 20th century:  
Heat, magnetism, electricity, light, X-rays, ultraviolet rays, ...

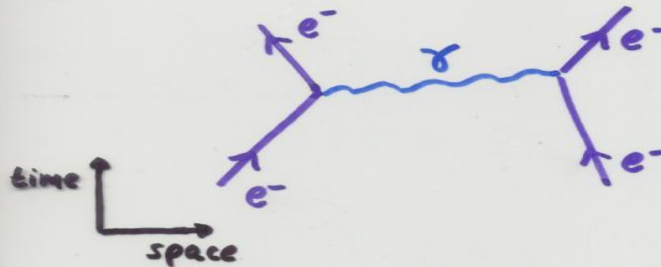
WAS SOLVED BY ONE THEORY, QUANTUM ELECTRODYNAMICS (1949)

QED

Feynman, Schwinger, Tomonaga,  
Nobel Prize in 1965

WITH THREE BASIC INGREDIENTS EXPLAINS THE INTERACTION OF  
LIGHT AND MATTER

QUANTUM MECHANICS  
SPECIAL RELATIVITY  
POINT-LIKE PARTICLES



e.g. THE FORCE OF REPULSION  
BETWEEN TWO ELECTRONS IS DUE  
TO THE TRANSFER OF PHOTONS  
BETWEEN THEM  
SO-CALLED "SCATTERING PROCESS"

IN THIS WAY, CLASSICAL ELECTROMAGNETISM (MAXWELL 1873) WAS "QUANTIZED"

ELECTROMAGNETIC FIELD → MESSENGER PARTICLE (PHOTON)

QED HAS BEEN THOROUGHLY TESTED AND

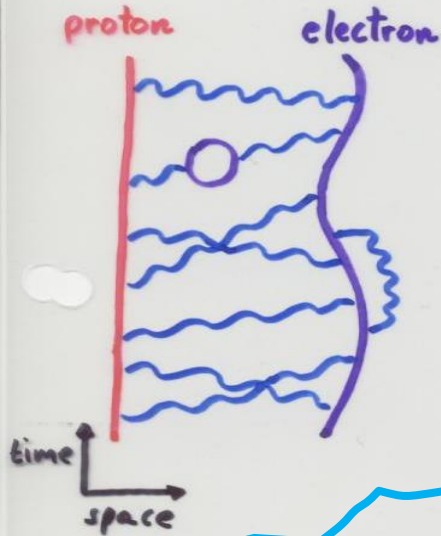
"AT THE PRESENT TIME I CAN PROUDLY SAY THAT THERE IS  
NO SIGNIFICANT DIFFERENCE BETWEEN EXPERIMENT AND THEORY"

FEYNMAN 1983

**MOST OF THE PHENOMENA**

IN THE WORLD CAN BE EXPLAINED BY  
**QED**

e.g. ALL THE ATOMS ARE MADE UP OF A CERTAIN NUMBER OF  
PROTONS EXCHANGING PHOTONS WITH ELECTRONS



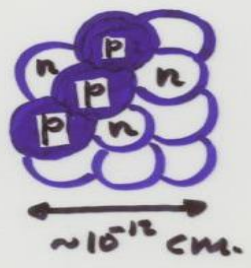
HYDROGEN ATOM: AN ELECTRON  
IS KEPT WITHIN A CERTAIN  
RANGE OF DISTANCE TO THE  
PROTON BY PHOTON EXCHANGES

Sin la QED no existirían los átomos

GASES, METALS, INSULATORS, CRYSTALS,  
SOFT THINGS, HARD THINGS, COLORED THINGS,  
TRANSPARENT THINGS, ...

BUT NOT ALL OF THEM

WHY PROTONS ARE HELD TOGETHER IN THE NUCLEUS DESPITE ELECTROMAGNETIC REPULSIONS?



SOLVED BY ONE THEORY, QUANTUM CHROMODYNAMICS (1973)

QCD

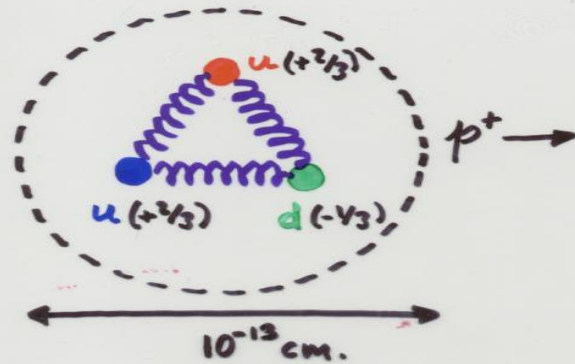
A NEW TYPE OF FORCE HOLDS THEM :

STRONG NUCLEAR INTERACTION

$d_s \gg d_{e.m.}$

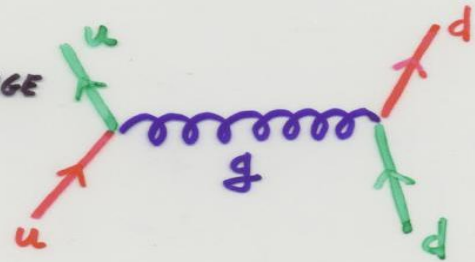
Sin la QCD no existirían los núcleos atómicos

e.g. INSIDE THE PROTON

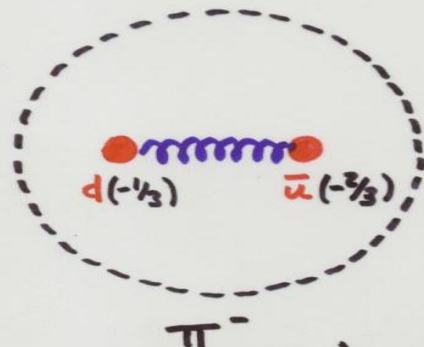
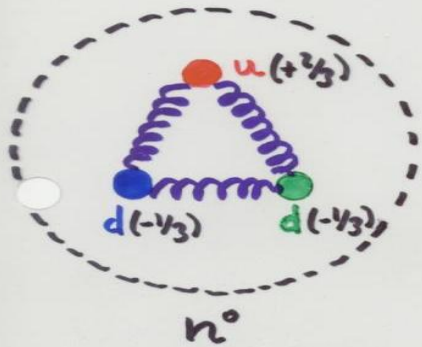


IS NOT AN ELEMENTARY PARTICLE

QUARKS ( $s = 1/2$ ) CARRY **COLOR** CHARGE AND ARE HELD TOGETHER EXCHANGING GLUONS ( $s = 1$ )



**ALL HADRONS** (HUNDREDS!) CAN BE EXPLAINED IN THIS WAY



KAON, LAMBDA, SIGMA, RHO, ...

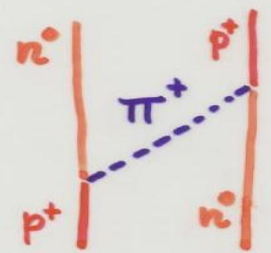
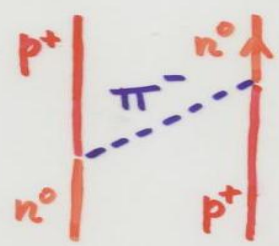
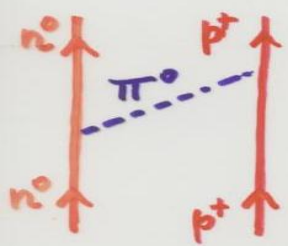
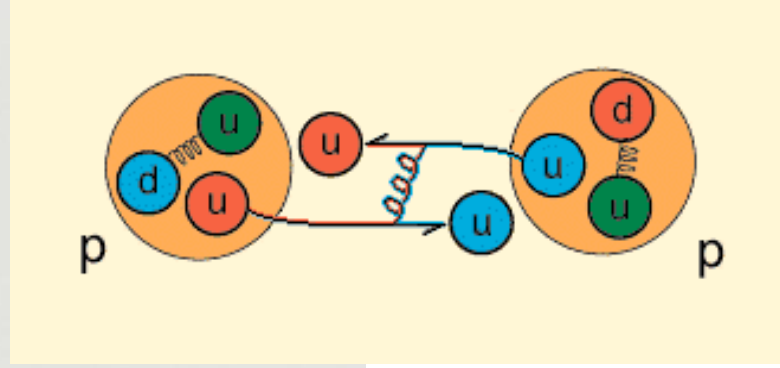
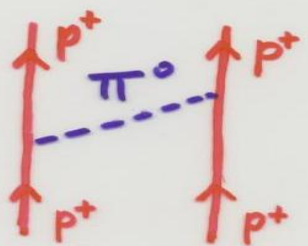
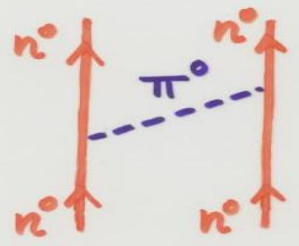
Gell-Mann, Nobel Prize in 1969

Zweig

Friedman, Kendall, Taylor Nobel Prize in 1990

Gross, Wilczek, Politzer, Nobel Prize in 2004

STRONG NUCLEAR INTERACTION BETWEEN NEUTRONS AND PROTONS IS A COMPLICATED MANIFESTATION OF THE MORE FUNDAMENTAL COLOUR FORCE ACTING BETWEEN THEIR CONSTITUENTS



$$m_{\pi} = 1/7 m_p$$

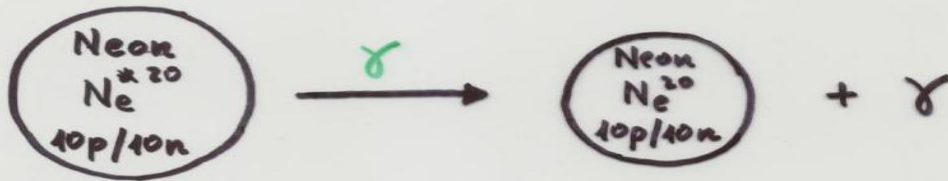
→ SHORT RANGE FORCE  
 $\sim 10^{-12}$  cm

**MOST OF THE** NUCLEAR PHENOMENA

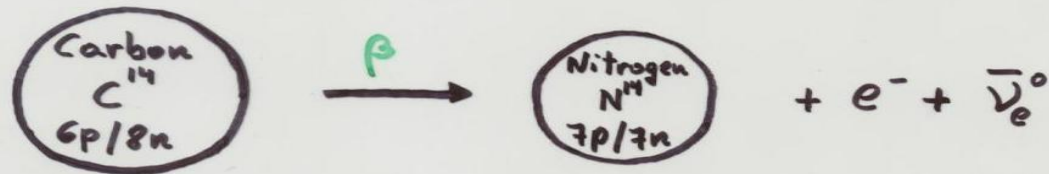
CAN BE EXPLAINED BY

QCD AND QED

e.g.  $\alpha$  AND  $\gamma$  RADIOACTIVE DECAY



BUT **NOT ALL** OF THEM



WHY  $\beta$  DECAY PROCESS DOES NOT SEPARATELY CONSERVE THE NUMBER OF PROTONS AND NEUTRONS?



SOLVED BY ONE THEORY (~60's)

# WEAK THEORY

A NEW TYPE OF FORCE IS RESPONSIBLE FOR THE DECAY:

WEAK NUCLEAR INTERACTION

$$d_w \ll d_{e.m.}$$

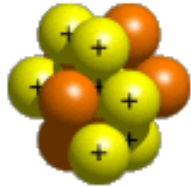
Carbon-14



6 protons  
8 neutrons



Nitrogen-14



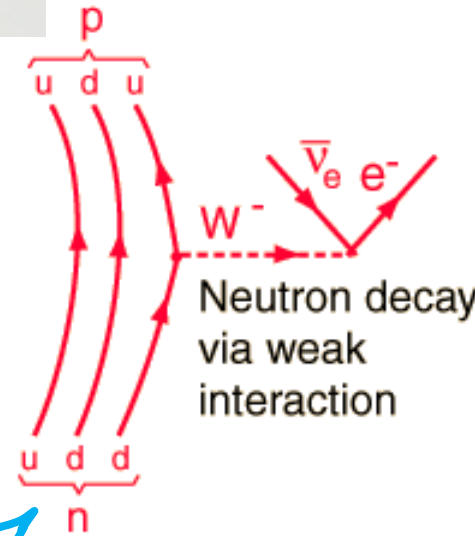
7 protons  
7 neutrons



Antineutrino

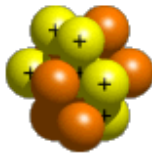


Electron



Sin la interacción débil no se producirían las reacciones de fusión nuclear en el Sol, sin las cuales no habría vida en la Tierra

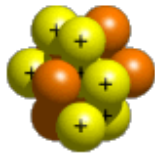
Carbon-14



6 protons  
8 neutrons



Nitrogen-14



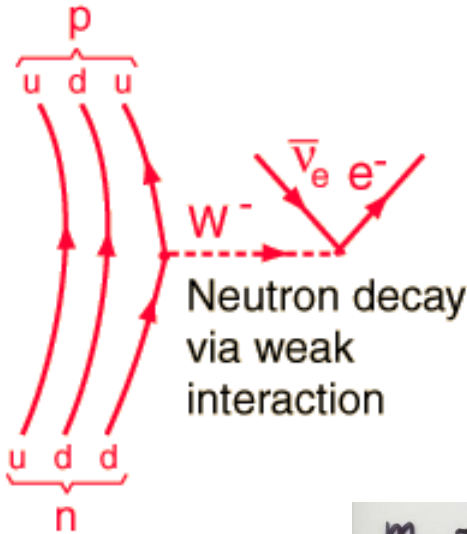
7 protons  
7 neutrons



La emisión de neutrinos está asociado a la desintegración beta.

Historicamente, parecía que este proceso no conservaba la energía y eso llevó a Pauli a postular en 1930 la existencia de una partícula nueva (el neutrino).

“Sólo” se tardó 25 años en descubrir el neutrino experimentalmente



la carga está relacionada con el estado de movimiento y no con el tipo de partícula (aquellas con espín antiparalelo a la dirección del movimiento poseen carga débil)

$m_W = 80000 \text{ MeV}$   
 $\approx m_{Rb \text{ atom}}$  → SHORT RANGE FORCE  
 $\sim 10^{-16} \text{ cm}$

QUARKS AND LEPTONS CARRY WEAK CHARGE AND INTERACT EXCHANGING  $W^+, W^-, Z^0$  ( $s=1$ )

Glashow, Weinberg, Salam, Nobel Prize in 1979

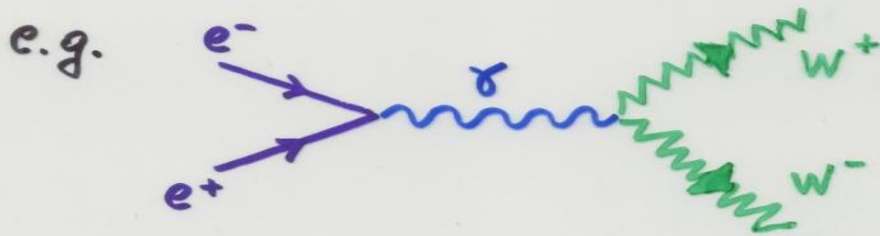
Rubia, Van der Meer, Nobel Prize in 1984

't Hooft, Veltman, Nobel Prize in 1999

CERN (GENEVE) HAS BUILT <sup>(1989)</sup> THE LARGEST PARTICLE ACCELERATOR  
 IN THE WORLD (LEP) CIRCUMFERENCE 27 km

CAPABLE OF ACCELERATING  $e^-$  AND  $e^+$  TO ENERGIES  
 $\sim 200000 \text{ MeV}$

$W^+$ ,  $W^-$ ,  $Z^0$  ARE CREATED

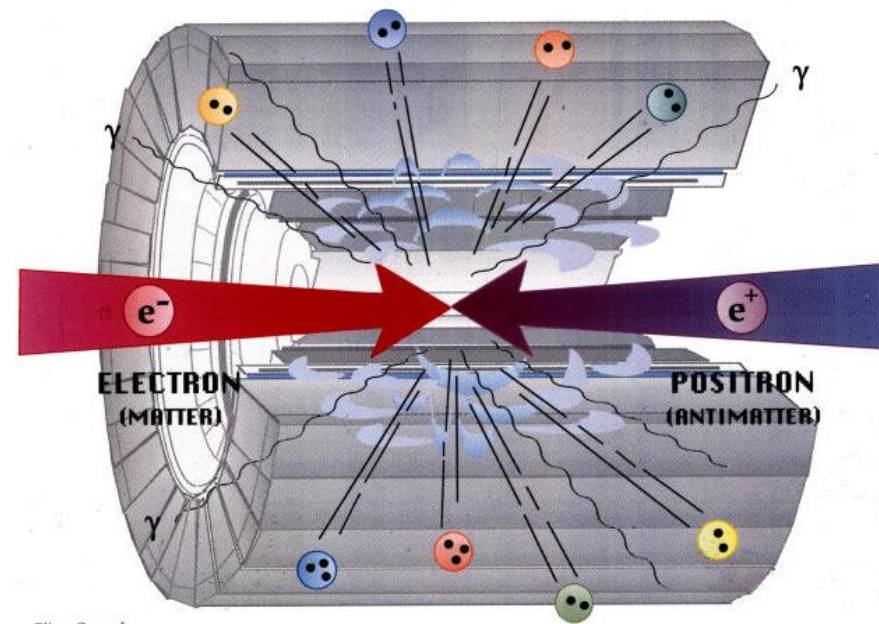
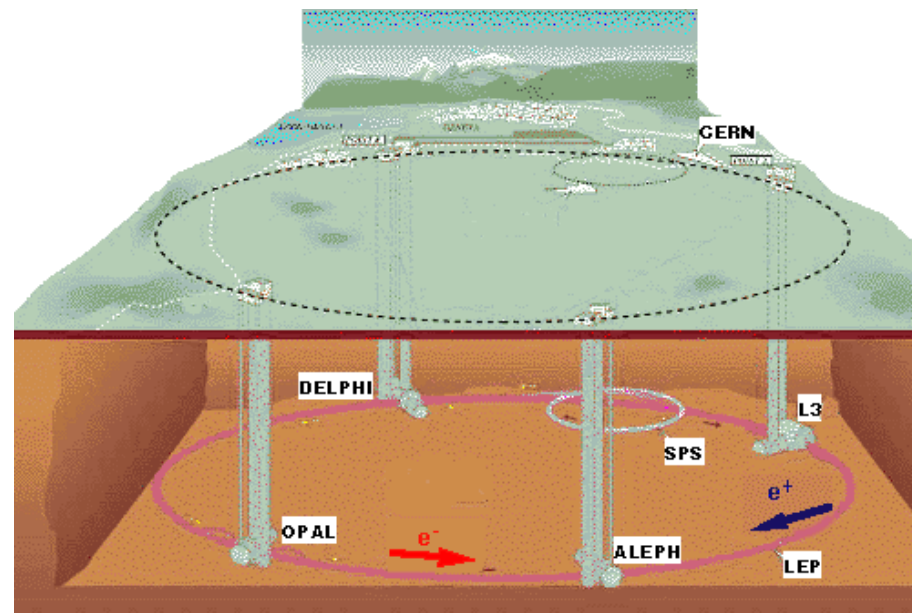
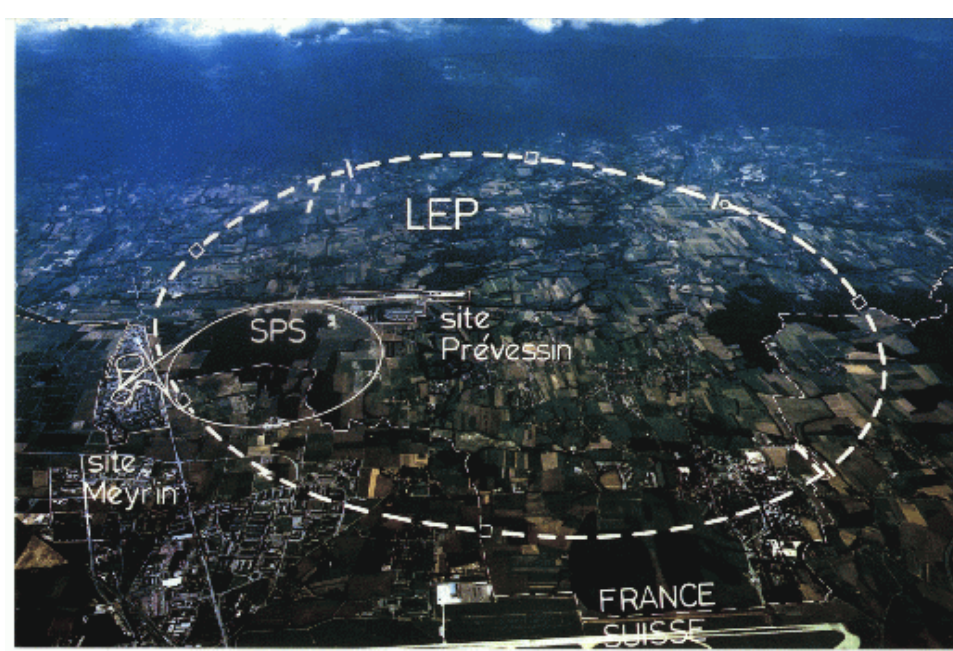


$$E_e = \frac{m_e c^2}{\sqrt{1 - \frac{v_e^2}{c^2}}} = \frac{0.5 \text{ MeV}}{\sqrt{1 - \frac{v_e^2}{c^2}}} = 100000 \text{ MeV} \approx m_W c^2$$

$v_e \approx c$

$\parallel$   
80000 MeV

THE PHYSICS THAT IS MET AT THESE <sup>HIGH</sup> ENERGIES IS THAT  
 WHICH PREVAILED WHEN OUR EXPANDING UNIVERSE WAS  
 $10^{-10} \text{ s. OLD}$



Eliane Onursal

# PARTICLE ZOO

e	— simbol
0.51	— mass (MeV)

spin  $\frac{1}{2}$  particles

u, d, s  
~5

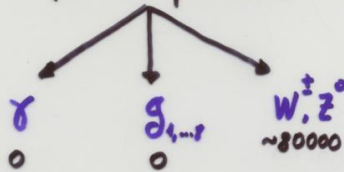
d, s, s  
~10

e  
~0.51

$\nu_e$

~0.00000001

spin 1 particles



# PARTICLE ZOO

$e$  — simbol  
 $as1$  — mass (MeV)

spin  $\frac{1}{2}$  particles

$U_{1,2,3}$   
 $\sim 5$   
 $d_{1,2,3}$   
 $\sim 10$   
 $e$   
 $\sim as1$

$\nu_e$   
 $\sim 0.00000001$

spin 1 particles



THE ONLY ELEMENTARY PARTICLES IN THE WORLD ARE

{	QUARKS	GLUONS
	ELECTRONS	PHOTONS
	NEUTRINOS	$W^\pm, Z^0$

DEMOCRITUS (440 B.C.) WAS RIGHT!

THE MATTER IS MADE FROM ATOMS BUT

ATOMS ARE MADE FROM PROTONS, NEUTRONS, ELECTRONS  
 PROTONS AND NEUTRONS ARE MADE FROM QUARKS  
 AND ALL THESE PARTICLES ARE EXCHANGING  $\gamma, W^\pm, Z^0, g$

## THE PERIODIC TABLE

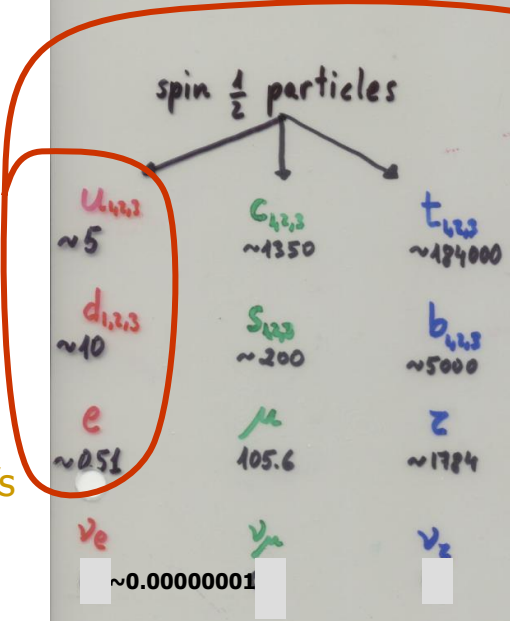
I A										18 VIIIA											
1 H										He											
2 IIA										13 IIIA		14 IVA		15 VA		16 VIA		17 VIIA		18 VIIIA	
Li Be										B C		N O		F Ne							
3 Na Mg		3 IIB		4 IVB		5 VB		6 VIB		7 VIIB		8 9 10 VIII		11 IB		12 IIB					
4 K Ca		Sc Ti		V Cr		Mn Fe		Co Ni		Cu Zn		Ga Ge		As Se		Br Kr					
5 Rb Sr		Y Zr		Nb Mo		Tc Ru		Rh Pd		Ag Cd		In Sn		Sb Te		I Xe					
6 Cs Ba		La Hf		Ta W		Re Os		Pt Au		Hg Tl		Pb Bi		Po At		Rn					
7 Fr Ra		Ac Rf		Db Sg		Bh Hs		Mt		Unlabeled		Unlabeled		Unlabeled		Unlabeled					
ALKALI METALS		ALKALI EARTH METALS								LANTHANIDES		ACTINIDES				HALOGENS		NOBLE GASES			
HAYDEN		HAYDEN		HAYDEN		HAYDEN		HAYDEN		HAYDEN		HAYDEN		HAYDEN		HAYDEN		HAYDEN			
SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS		SPECIALTY PRODUCTS			
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Mendeleiev, 1869

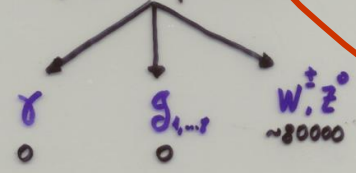
# PARTICLE ZOO

$e$  — simbol  
0.51 — mass (MeV)

## spin $\frac{1}{2}$ particles



## spin 1 particles



H  
~100000

THE ONLY ELEMENTARY PARTICLES IN THE WORLD ARE

- QUARKS
- ELECTRONS
- NEUTRINOS
- GLUONS
- PHOTONS
- W<sup>±</sup>, Z<sup>0</sup>

THAT'S NOT ALL! ALTHOUGH ORDINARY MATTER (INCLUDING US!) IS MADE FROM u, d, e WHEN HIGHER ENERGIES ARE USED IN THE EXPERIMENTS NEW (HIGHLY UNSTABLE) ELEMENTARY PARTICLES APPEAR  
**DEMOCRITUS (440 B.C.) WAS RIGHT!**

THE MATTER IS MADE FROM ATOMS **BUT**  
 ATOMS ARE MADE FROM PROTONS, NEUTRONS, ELECTRONS  
 PROTONS AND NEUTRONS ARE MADE FROM QUARKS  
 AND ALL THESE PARTICLES ARE EXCHANGING  $\gamma, W, Z, g$

**THE PERIODIC TABLE**

										18 VIIIa																																	
1 IA										13 IIIA		14 IVA		15 VA		16 VIA		17 VIIA		18 VIIIa																							
H 1.008 Hydrogen		2 IIA										B 10.81 Boron		C 12.01 Carbon		N 14.01 Nitrogen		O 16.00 Oxygen		F 19.00 Fluorine		Ne 20.18 Neon																					
3 Na 22.99 Sodium		4 Mg 24.31 Magnesium		5 IIIB		6 IVB		7 VB		8 VIB		9 VIIB		10 VIII		11 IB		12 IIB		Al 26.98 Aluminum		Si 28.09 Silicon		P 30.97 Phosphorus		S 32.07 Sulfur		Cl 35.45 Chlorine		Ar 39.95 Argon													
19 K 39.10 Potassium		20 Ca 40.08 Calcium		21 Sc 44.96 Scandium		22 Ti 47.88 Titanium		23 V 50.94 Vanadium		24 Cr 52.00 Chromium		25 Mn 54.94 Manganese		26 Fe 55.85 Iron		27 Co 58.93 Cobalt		28 Ni 58.69 Nickel		29 Cu 63.55 Copper		30 Zn 65.39 Zinc		31 Ga 69.72 Gallium		32 Ge 72.61 Germanium		33 As 74.92 Arsenic		34 Se 78.96 Selenium		35 Br 79.90 Bromine		36 Kr 83.80 Krypton									
37 Rb 85.47 Rubidium		38 Sr 87.62 Strontium		39 Y 88.91 Yttrium		40 Zr 91.22 Zirconium		41 Nb 92.91 Niobium		42 Mo 95.94 Molybdenum		43 Tc 98.91 Technetium		44 Ru 101.07 Ruthenium		45 Rh 102.91 Rhodium		46 Pd 106.42 Palladium		47 Ag 107.87 Silver		48 Cd 112.41 Cadmium		49 In 114.82 Indium		50 Sn 118.71 Tin		51 Sb 121.76 Antimony		52 Te 127.60 Tellurium		53 I 126.91 Iodine		54 Xe 131.29 Xenon									
55 Cs 89.90 Cesium		56 Ba 137.33 Barium		57 La 138.91 Lanthanum		58 Ce 140.12 Cerium		59 Pr 140.91 Praseodymium		60 Nd 144.24 Neodymium		61 Pm 144.91 Promethium		62 Sm 150.36 Samarium		63 Eu 151.97 Europium		64 Gd 157.25 Gadolinium		65 Tb 158.93 Terbium		66 Dy 162.50 Dysprosium		67 Ho 164.93 Holmium		68 Er 167.26 Erbium		69 Tm 168.93 Thulium		70 Yb 173.04 Ytterbium		71 Lu 174.97 Lutetium											
72 Hf 178.49 Hafnium		73 Ta 180.96 Tantalum		74 W 183.85 Tungsten		75 Re 186.21 Rhenium		76 Os 190.23 Osmium		77 Ir 192.22 Iridium		78 Pt 195.08 Platinum		79 Au 196.97 Gold		80 Hg 200.59 Mercury		81 Tl 204.38 Thallium		82 Pb 207.2 Lead		83 Bi 208.98 Bismuth		84 Po (209) Polonium		85 At (210) Astatine		86 Rn (222) Radon															
74 Rf 223.02 Rutherfordium		75 Ra 226.03 Radium		76 Ac 227.03 Actinium		77 Rf (261) Rutherfordium		78 Db (262) Dubnium		79 Sg (263) Seaborgium		80 Bh (264) Bohrium		81 Hs (265) Hassium		82 Mt (266) Meitnerium		Unassigned Nov. 1994		Unassigned Nov. 1994		Unassigned 1986		Unassigned 1999		Unassigned 1999		Unassigned 1999		Unassigned 1999													
ALKALI METALS		ALKALI EARTH METALS		LANTHANIDES																		ACTINIDES		HALOGENS																		NOBLE GASES	
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Mendeleiev, 1869

And, in addition there should exist the so-called Higgs boson

Kobayashi, Maskawa,

predicted in 1972 the existence of 3 families

Nobel Prize in 2008

# PRESENT

THE SO-CALLED **STANDARD MODEL** OF ELEMENTARY PARTICLES

**QCD** + **WEAK THEORY** + **QED**

NOTICE THAT THEY ARE VERY SIMILAR TO QED

$$\begin{aligned} e^- &\longleftrightarrow \gamma \\ \gamma &\longleftrightarrow g, W^\pm, Z^0 \end{aligned}$$

WRITTEN IN A MORE ELEGANT WAY

$$\begin{aligned} &SU(3) \otimes SU(2) \otimes U(1) \\ &\downarrow \qquad \swarrow \searrow \\ &\begin{pmatrix} u_R \\ u_L \\ u_B \end{pmatrix} \quad \begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \end{aligned}$$

SAYS THAT THE STANDARD MODEL IS GAUGE INVARIANT (INTERNAL SYMMETRY)

e.g. **U(1)** INVARIANCE  $\rightarrow \mathcal{L}_{QED}$

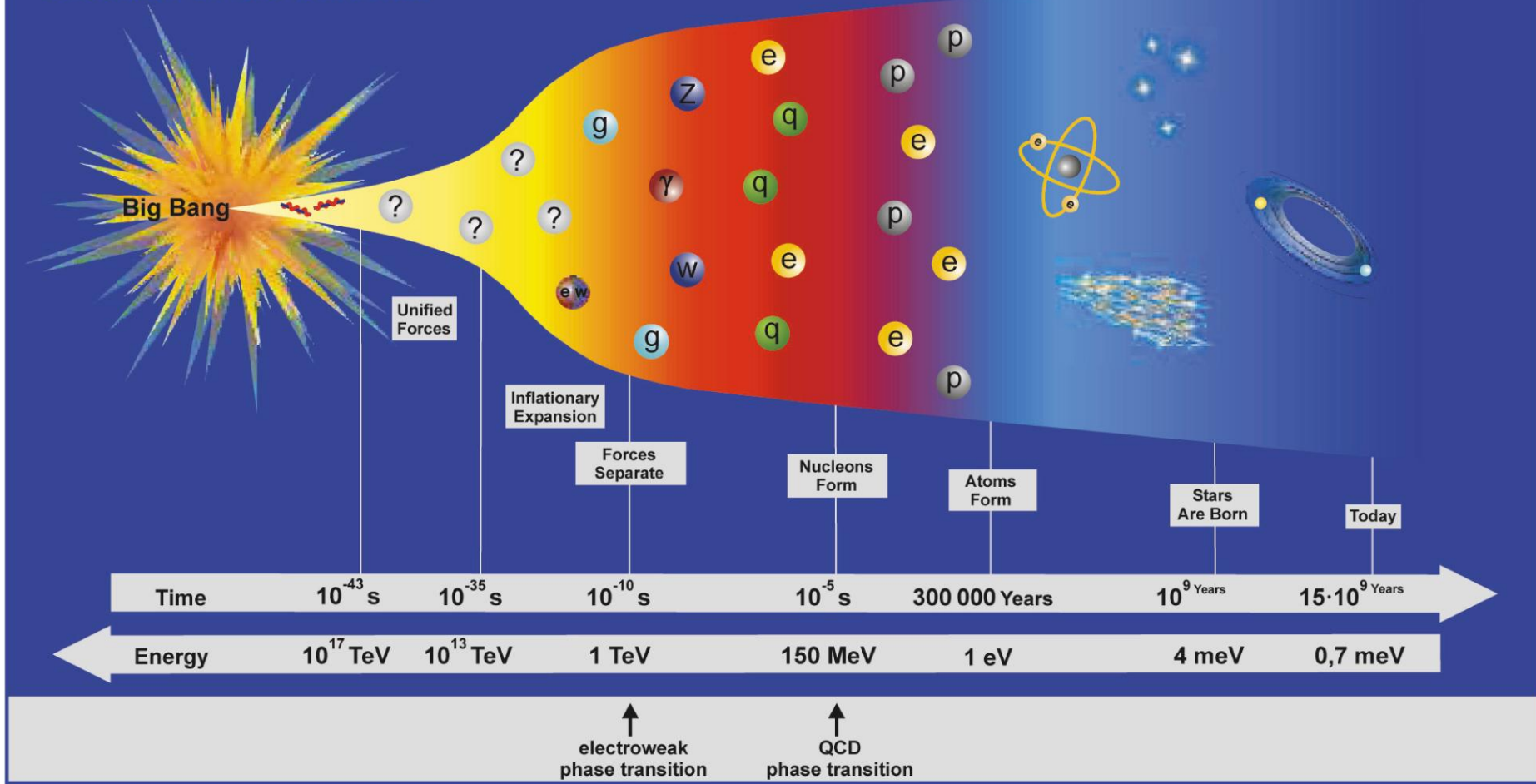
MUST BE INVARIANT UNDER  $\begin{cases} \psi_e(x) \rightarrow e^{-ief\omega} \psi_e(x) \\ A_\mu(x) \rightarrow A_\mu(x) + \partial_\mu f(x) \end{cases}$

"GAUGE SYMMETRY DICTATES THE FORM OF THE INTERACTION" YANG

WORKS **OUTSTANDINGLY WELL** IN PRACTICE



# Evolution of the Universe



Besides, the standard model provides the fundamentals of the early Universe cosmology

**SPECULATION:**

Do other particles exist still undetected ?

## History

Symmetries are crucial in physics

The laws of modern physics are invariant under certain symmetries:

- ❖ Lorentz transformations [special relativity]
- ❖ Local gauge transformations [ $SU(3)_C \times SU(2)_L \times U(1)_Y$ ]

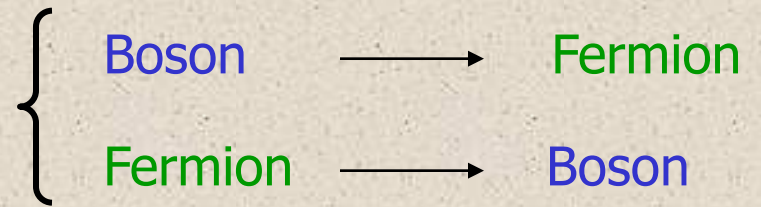
**Supersymmetry (SUSY)** was proposed in the early 1970's:

Golfand, Likhtman, 1971

Volkov, Akulov, 1972

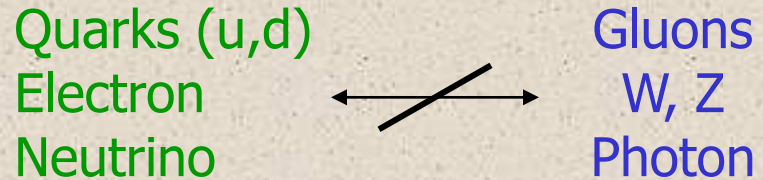
Wess, Zumino, 1974

❖ An invariance of the theory under interchange of fermions and bosons



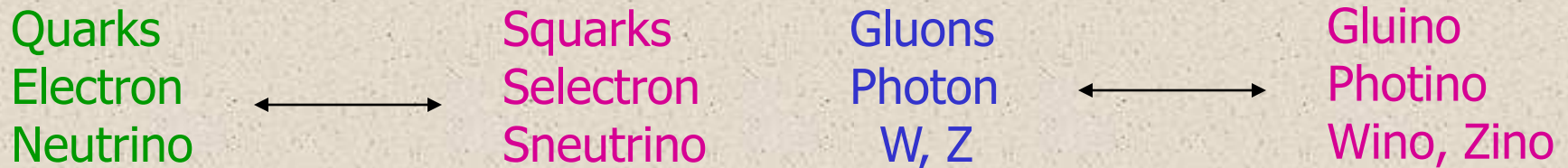
$$\mathcal{L}(\text{bosons}, \text{fermions}) \longrightarrow \mathcal{L}(\text{fermions}, \text{bosons}) = \mathcal{L}(\text{bosons}, \text{fermions})$$

But known bosons and fermions are not married up in this fashion



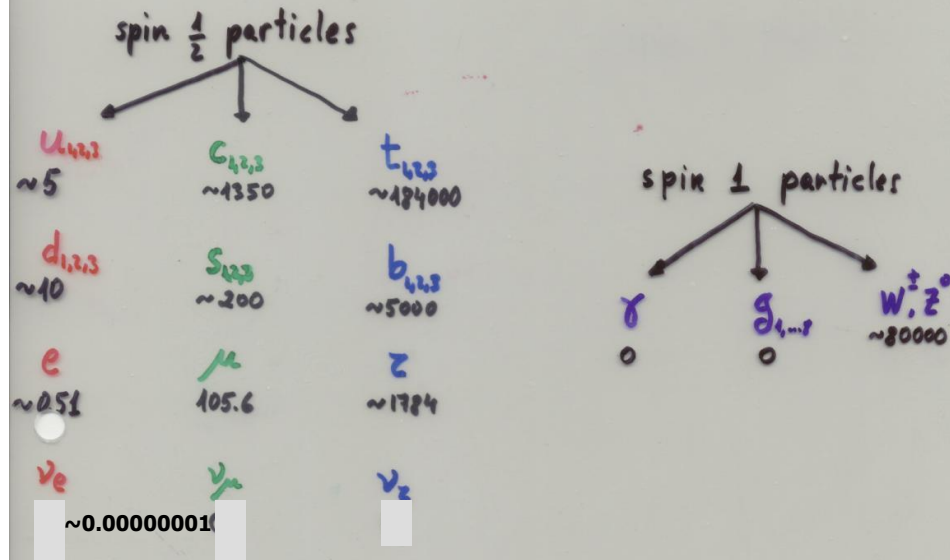
Instead, every known particle should have a (super) partner Fayet, 1976

The spectrum of elementary particles is doubled ! With masses  $\approx 1000 m_p$



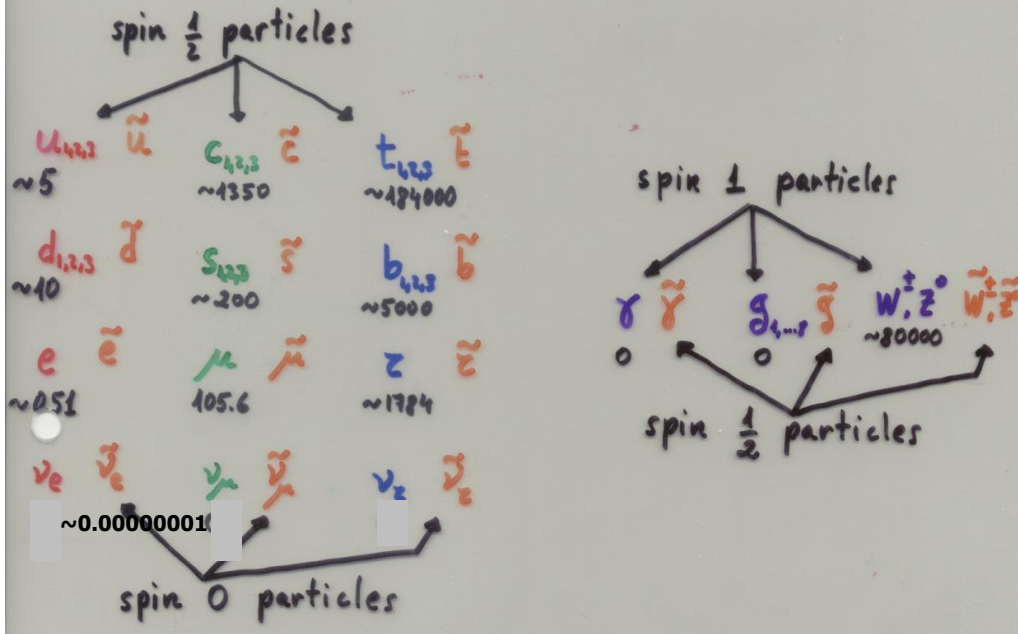
# PARTICLE ZOO

e — simbol  
0.51 — mass (MeV)



# PARTICLE ZOO

e — simbol  
0.51 — mass (MeV)



# CAN THESE SPECULATIONS BE TESTED

HIGGSES, SUSY PARTICLES, ...

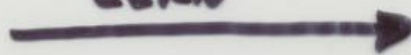
ONLY WITH MORE ENERGY SINCE

$$m_{\text{susy}} \sim 1000 m_p$$

LEP  
 $e^-e^+$

( $\sim 100 m_p$ )

CERN



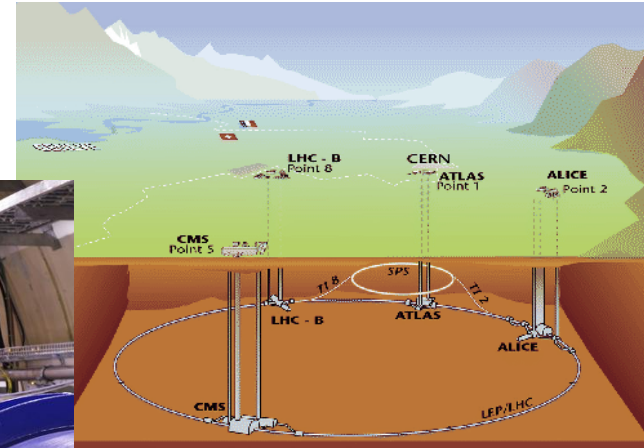
LHC  
 $p^+p^+$

( $\sim 1000 m_p$ )

LEP



LHC



**Cost of the LHC:  
4.000 million euros**



36 Nations, 160 Institutions, 2008 Scientists and Engineers (November 2003)

**TRIGGER & DATA ACQUISITION**

Austria, CERN, Finland, France, Greece, Hungary, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

**TRACKER**

Austria, Belgium, CERN, Finland, France, New Zealand, Germany, Italy, Japan\*, Switzerland, UK, USA

**CRYSTAL ECAL**

Belarus, CERN, China, Croatia, Cyprus, France, Ireland, Italy, Japan\*, Portugal, Russia, Serbia, Switzerland, UK, USA

**PRESHOWER**

Armenia, Belarus, CERN, Greece, India, Russia, Taipei, Uzbekistan

**RETURN YOKE**

Barrel: Czech Rep., Estonia, Germany, Greece, Russia  
Endcap: Japan\*, USA, Brazil

**SUPERCONDUCTING MAGNET**

All countries in CMS contribute to Magnet financing in particular:  
Finland, France, Italy, Japan\*, Korea, Switzerland, USA

**FEET**  
Pakistan  
China

**FORWARD CALORIMETER**  
Hungary, Iran, Russia, Turkey, USA

**HCAL**

Barrel: Bulgaria, India, Spain\*, USA  
Endcap: Belarus, Bulgaria, Russia, Ukraine  
HO: India

**MUON CHAMBERS**

Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,  
Endcap: Belarus, Bulgaria, China, Korea, Pakistan, Russia, USA

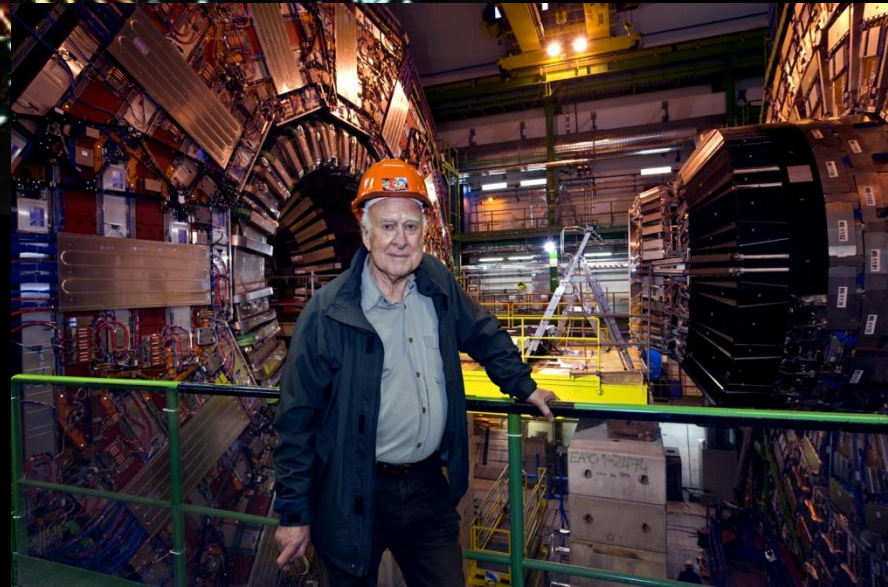
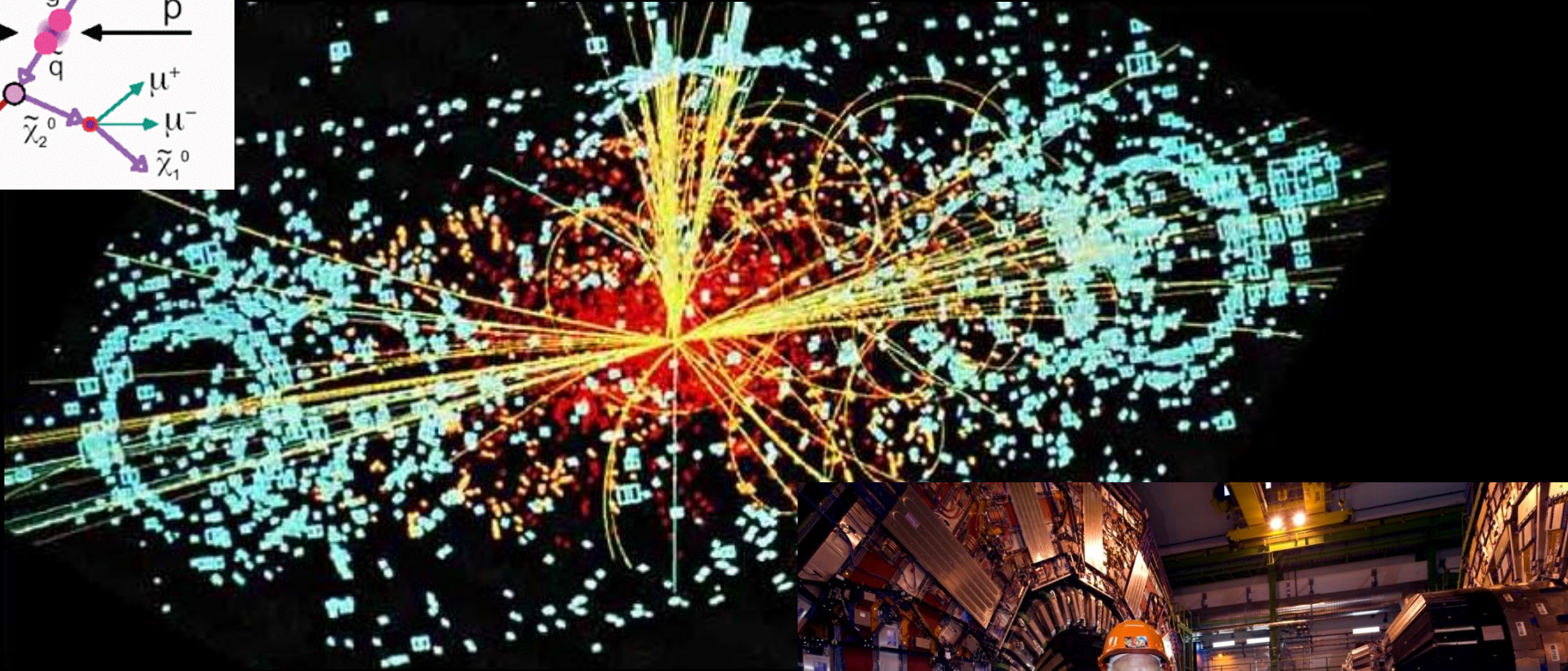
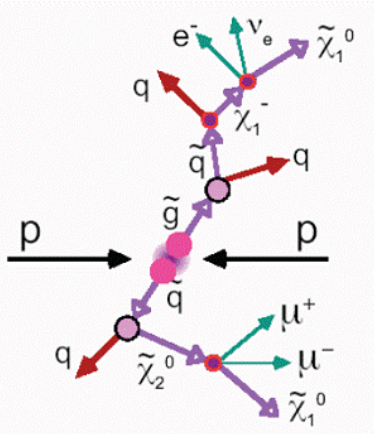
**Total weight** : 12500 T  
**Overall diameter** : 15.0 m  
**Overall length** : 21.5 m  
**Magnetic field** : 4 Tesla

\* Only through industrial contracts



Aunque cada haz tiene 300 billones de protones, solo se producen 60.000 colisiones

Pero como los protones dan 10.000 vueltas alrededor del LHC cada segundo, se producirán en total 600 millones de colisiones por segundo. ¡Y eso hay que analizarlo!



# One of the great enigmas still unsolved is the existence of dark matter

- Por ejemplo, usando simples argumentos gravitacionales , uno puede calcular la velocidad de rotación de estrellas aisladas o nubes de Hidrógeno en las partes externas de Galaxias

- Esa velocidad calculada usando la ley de Newton no coincide con la que miden los astrónomos.

$$\frac{v_{\text{rot}}^2}{r} = \frac{G M(r)}{r^2}$$

Salvo que asumamos que existe más materia que la luminosa.

Zwicky, 1933

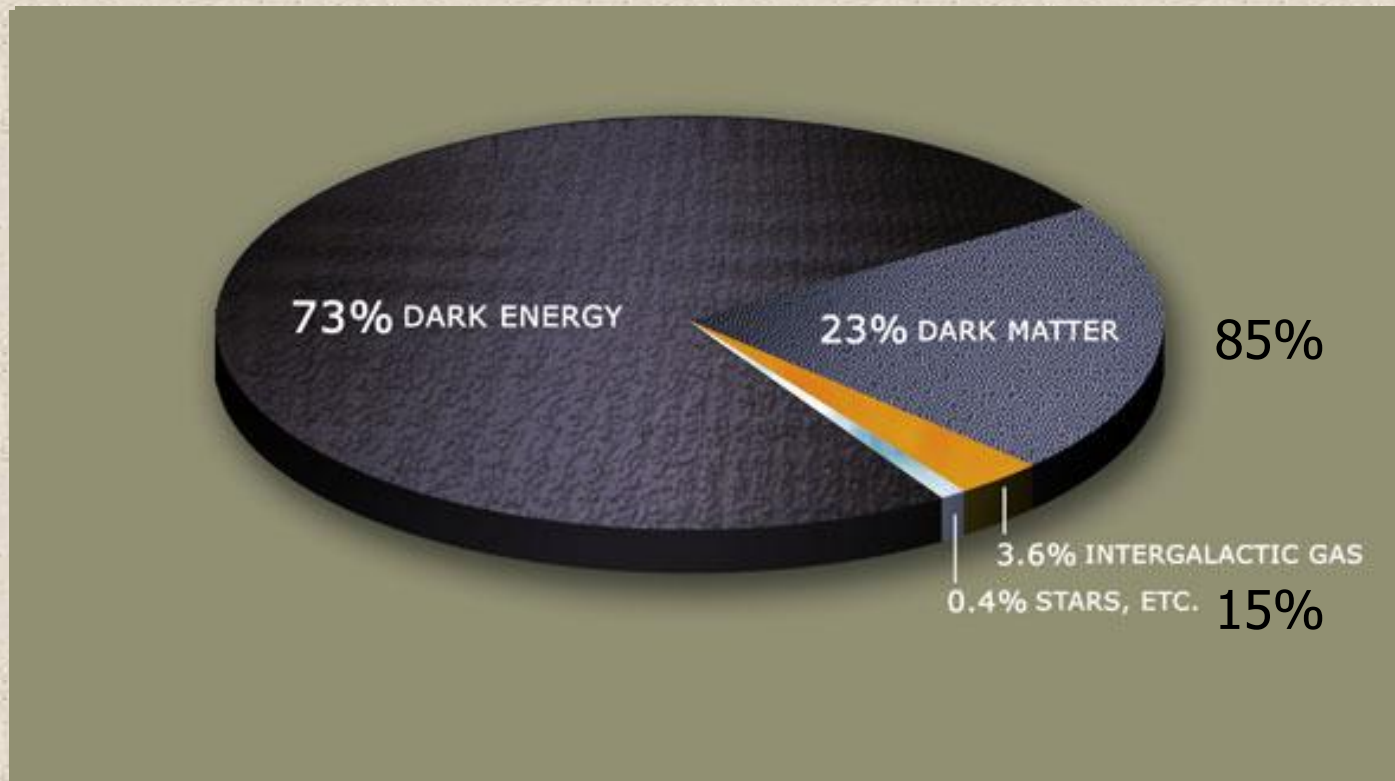


## Dark Matter

This hypothesis is not so odd if we remember that the existence of Neptune was suggested on the basis of the irregular motion of Uranus



✿ Actually, about 85% of the matter in the Universe is dark



We are not made of what most of the Universe is made of !

# ¿De qué está hecha la materia oscura?

Ninguna de las partículas del modelo estándar tiene las propiedades adecuadas para constituir la materia oscura;  
Ni los quarks, ni los electrones, ni los neutrinos, ...

Esta es una indicación contundente de que necesitamos ir

**Más allá del modelo estándar de la física de partículas**

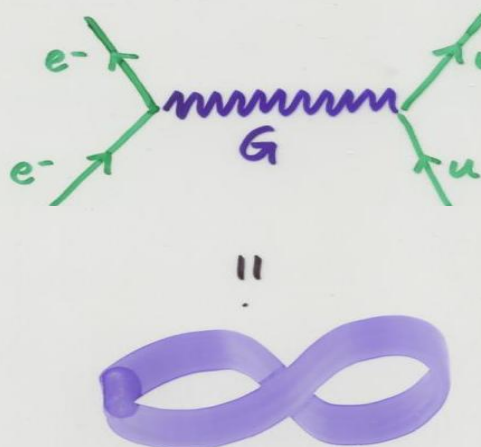
Y precisamente, algunas de las **partículas supersimétricas** tienen las propiedades adecuadas para constituir la materia oscura

Sin embargo, si queremos unificar la gravedad con las demás interacciones, tenemos que ir incluso **más allá de la supersimetría**

E.M. FORCE + STRONG FORCE + WEAK FORCE + GRAVITY  
CONTROL EVERYTHING (BULK MATTER, BIOLOGICAL, CHEMICAL AND NUCLEAR PHENOMENA)

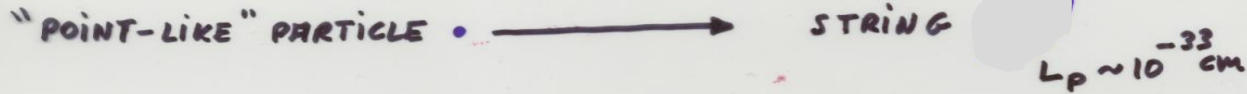
Sin la gravedad los seres humanos no se mantendrían sobre la Tierra, los planetas no girarían alrededor del Sol, las estrellas no formarían galaxias, las galaxias no formarían cúmulos de galaxias y, ..., el Universo no sería como lo conocemos.

GRAVITY IS EXTREMELY WEAK  
e.g. IN HYDROGEN ATOM  
 $\frac{F_G}{F_{e.m.}} \approx 10^{-40}$

HOWEVER WE WOULD LIKE TO QUANTIZE IT  
THE ANALOGUE OF THE PHOTON IS CALLED GRAVITON (S=2)  


# FUTURE?

## STRING THEORY



\* THE PARTICLES CORRESPOND TO THE DIFFERENT MODES OF VIBRATION OF THE STRING

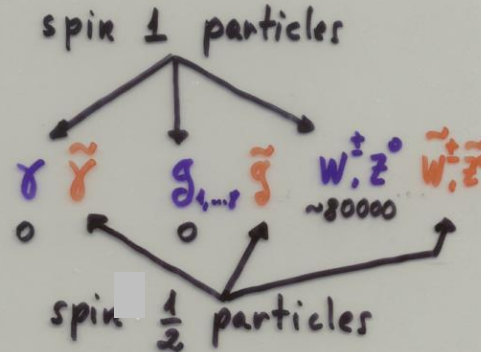
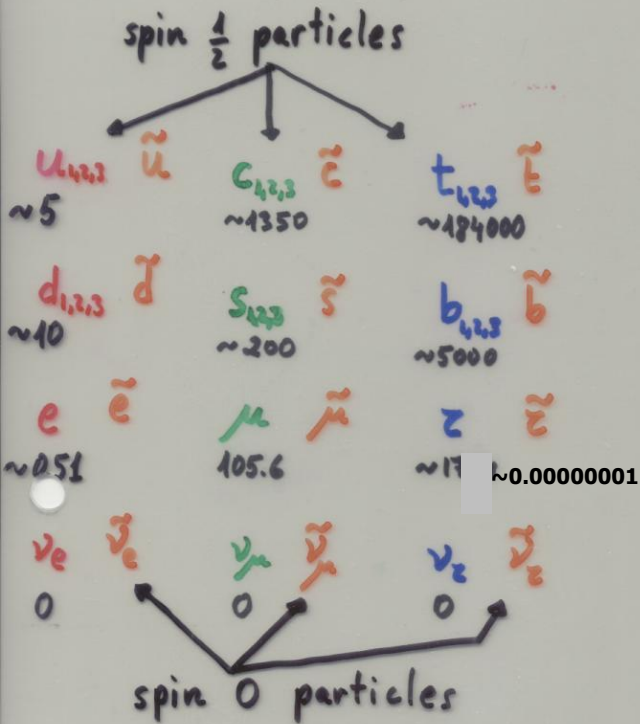
PRESENT ACCELERATORS CANNOT RESOLVE  $L < 10^{-16}$  cm  
THAT'S WHY THE POINT PARTICLE APPROXIMATION IS SO SUCCESSFUL

\* THE GRAVITON APPEARS IN THE SPECTRUM  $\hookrightarrow$   
UNIFIED THEORY OF GRAVITY AND STANDARD MODEL



# PARTICLE ZOO

e — simbol  
0.51 — mass (MeV)



Todo este zoo se unifica en un único objeto fundamental



# STRING THEORY

IS THE ONLY CANDIDATE TO BE

THE THEORY OF EVERYTHING

ANSWERING, WHY DOES THE UNIVERSE BEHAVE THE WAY  
IT DOES?

IS ONLY CONSISTENT IN  $D=10$  ( $9+1$ )

→ 6 DIMENSIONS MUST BE COMPACTIFIED IN A VERY

SMALL SPACE  
 $L_c \sim 10^{-33}$  cm

e.g.



# CONCLUSIONS

The standard model of particle physics “almost” answers the question:  
What is the Universe made of?

- ✚ However, one of the great enigmas still unsolved is the existence of **dark matter**
- ✚ Within the standard model there are no possible candidates, thus we need to assume the existence of **new particles**
- ✚ **Supersymmetry**, that predicts that every known particle should have a partner, has candidates for dark matter, which could be tested in the LHC
- ✚ Supersimetría no es suficiente para unificar la gravedad con las demás interacciones de la Naturaleza, pero quizá la teoría de **Supercuerdas** nos permita conseguir este objetivo

**THE END**