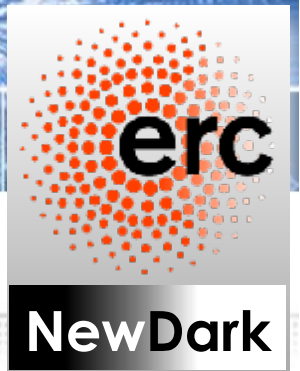


CERN

European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire



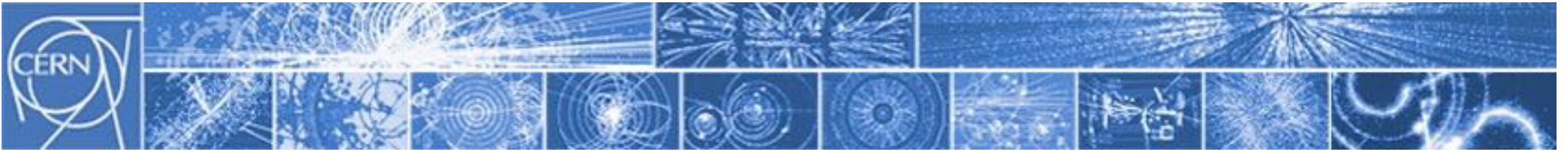
Fisica delle particelle oggi

Il Modello Standard and Beyond

- Bosone di Higgs
- SuperSimmetria
- Astroparticle & Materia Oscura

Marco CIRELLI [CNRS LPTHE Jussieu & Sorbonne]

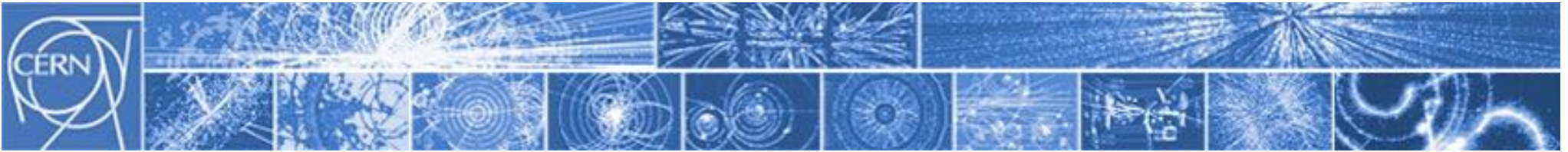
Mini-intro:
- livello variabile
- non storico
- about MC



Cosa si fa al CERN

Ricerca fondamentale in Fisica delle Particelle

- i costituenti elementari della materia
- le forze fondamentali che li governano
- l'origine, il contenuto e la struttura dell'Universo



Come risolvere questi problemi? o... Come si fanno le scoperte?

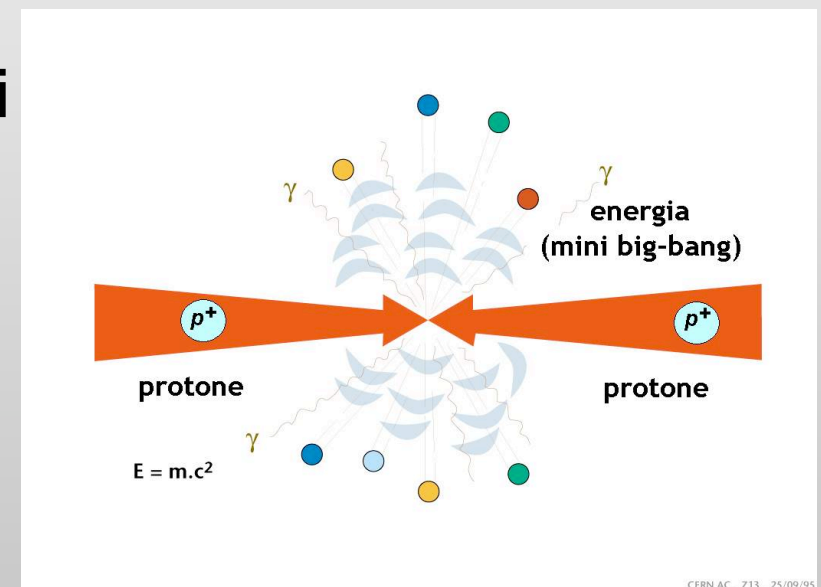
Accelerare le particelle elementari (*protoni, elettroni...*)

fino a energie elevatissime (*14 TeV*)

e portarle a collidere. $E=mc^2$

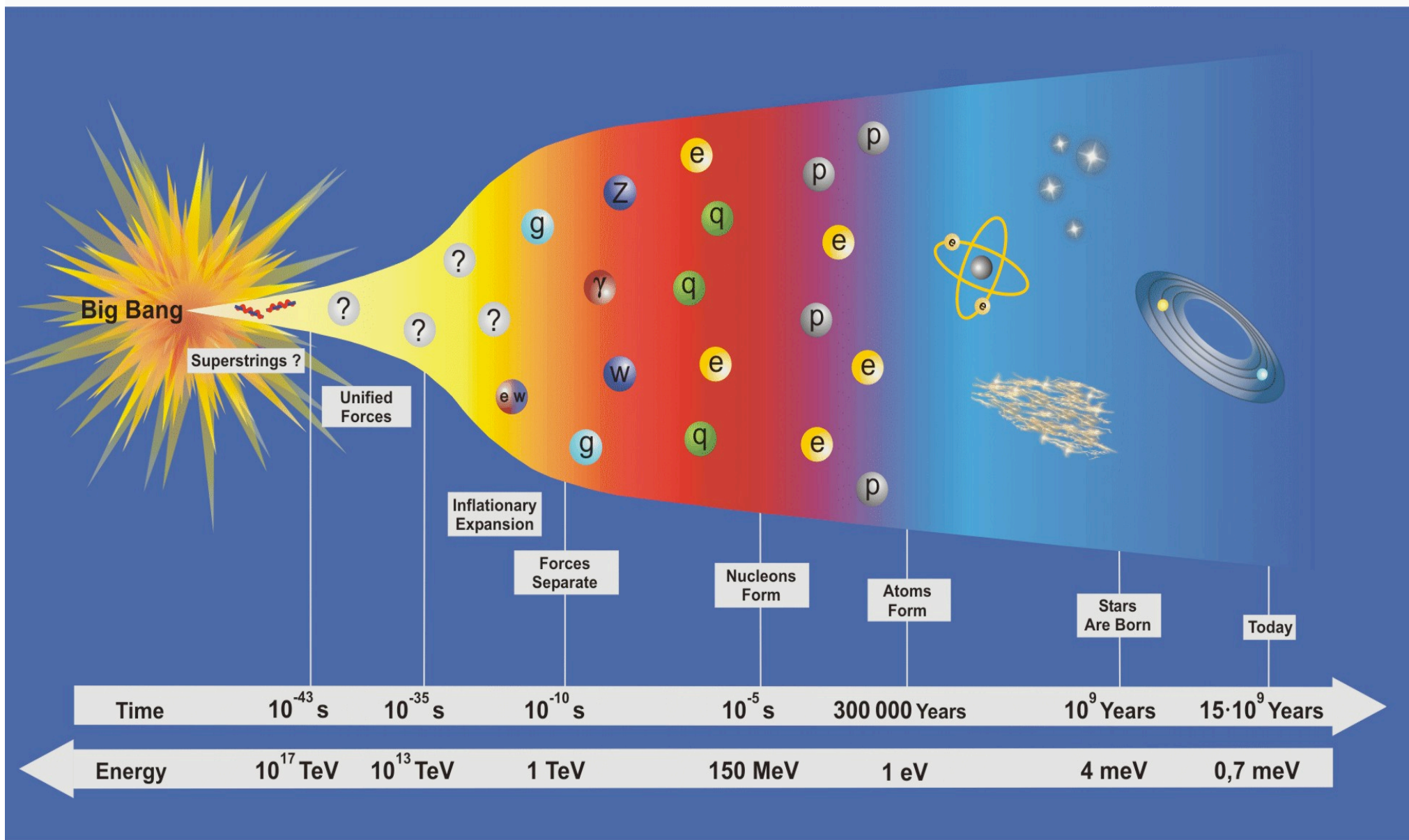
Analizzare accuratamente i prodotti

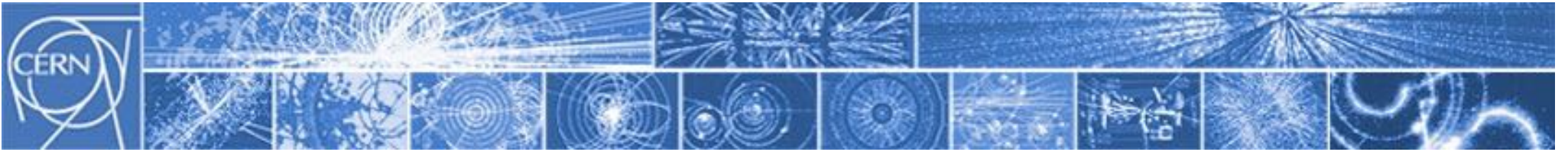
per scoprire nuove particelle,
nuove forze,
'nuova fisica'...





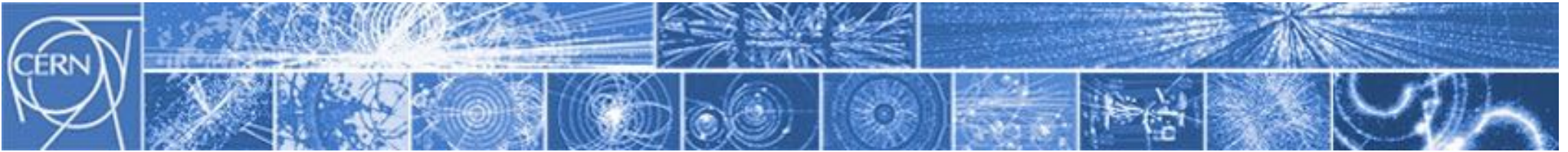
Ripercorrere all'indietro la storia dell'Universo





Modello Standard

(della fisica delle particelle elementari)



Il Modello Standard è la costruzione ('scoperta') fondamentale della fisica delle particelle, nella seconda metà del XX secolo.

XIX secolo elettromagnetismo

1932 teoria di Fermi del decadimento beta - interazioni deboli

1960's unificazione em-debole: teoria ElectroWeak
(Glashow, Weinberg, Salam)

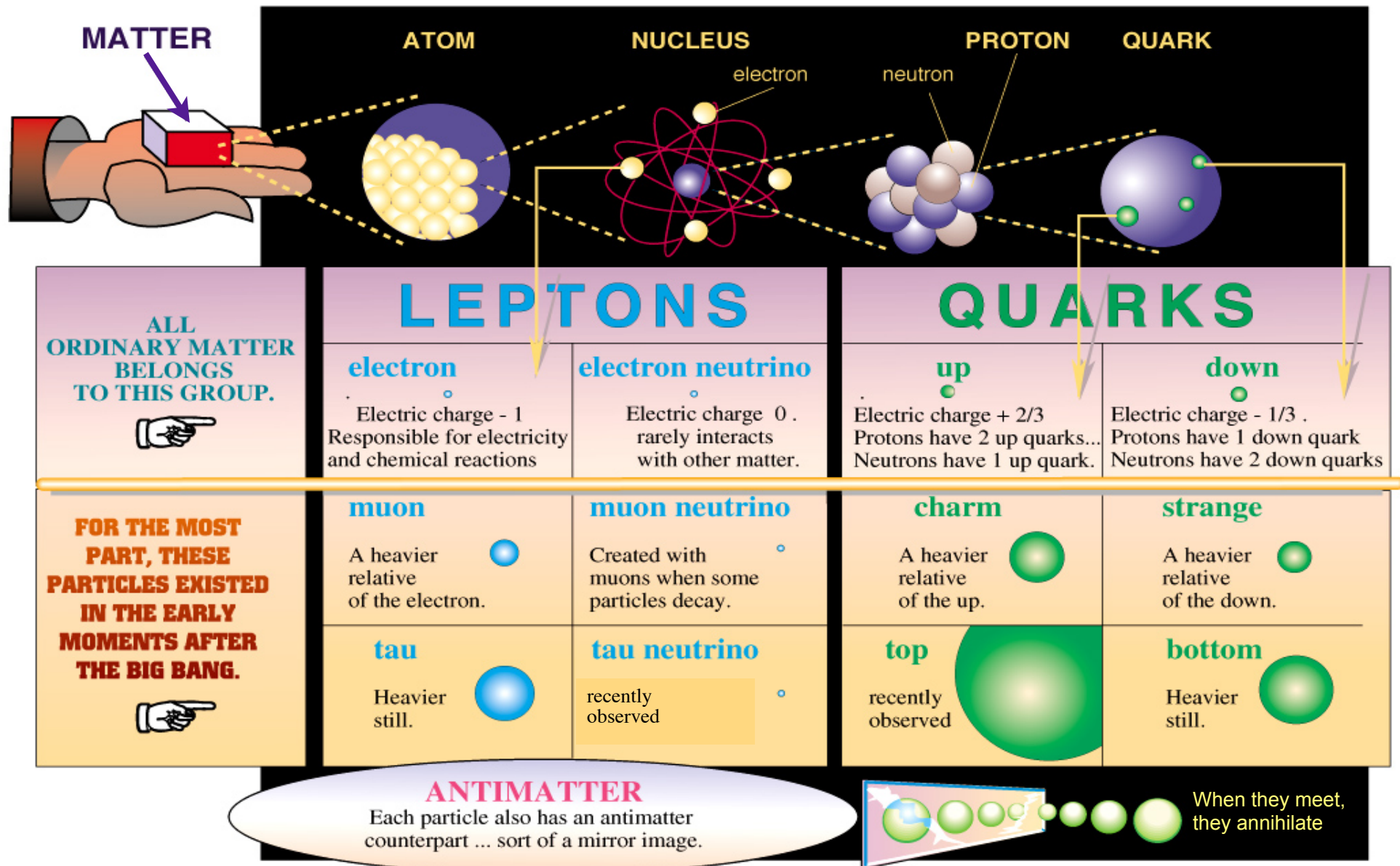
1981 scoperta bosoni W e Z (Rubbia)

1970's teoria della QCD - interazioni nucleari forti
(Gross, Politzer, Wilczek)

1936	μ	1968	s quark	2012	higgs
1956	ν_e	1974	c quark		
1962	ν_μ	1977	b quark		
1974	τ	1995	t quark		
2000	ν_τ				



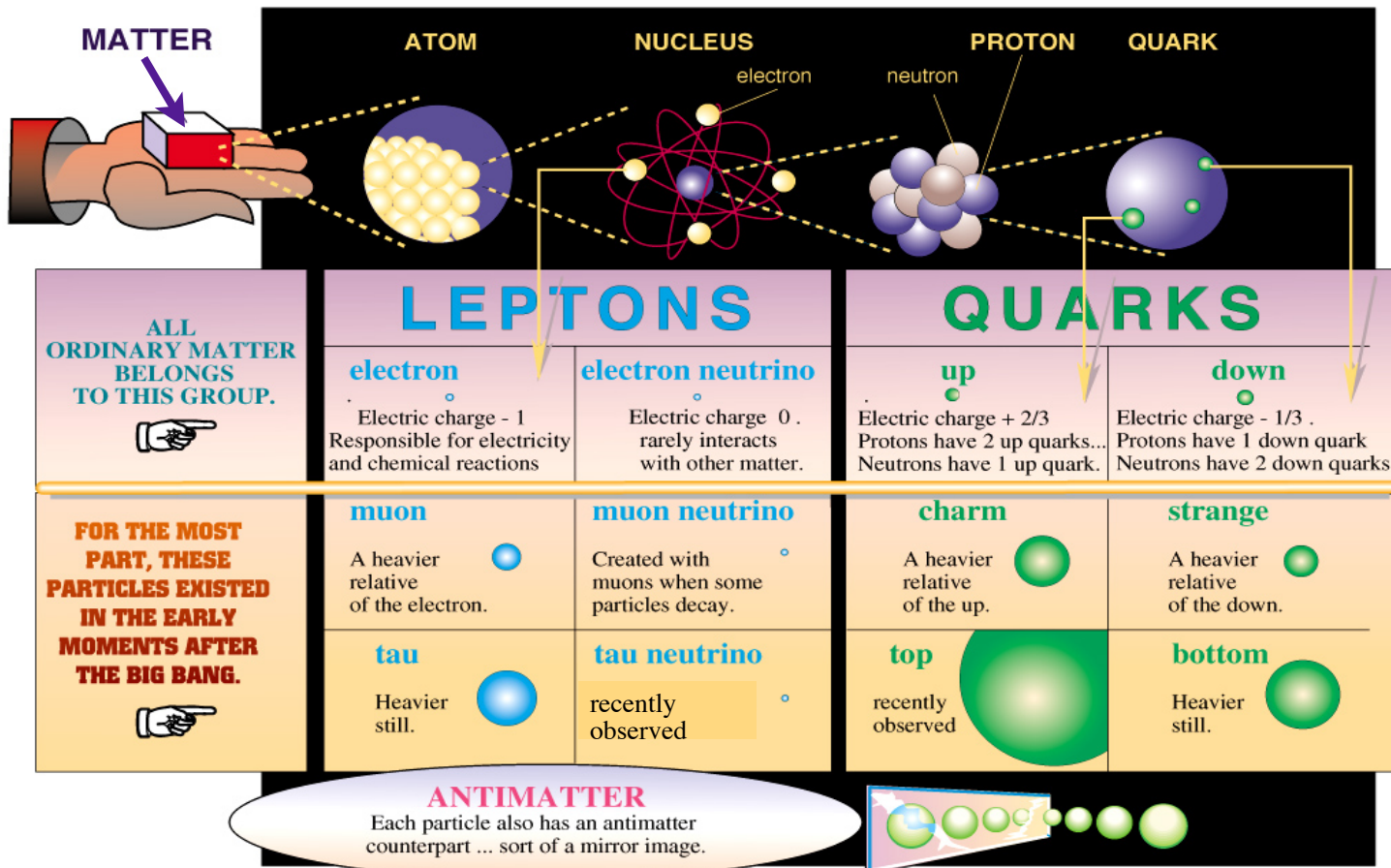
STANDARD MODEL





STANDARD MODEL

FORCES



Electromagnetic

Photon

Atoms
Light
Chemistry
Electronics

Weak

Bosons (W,Z)

Neutron decay
Beta radioactivity
Neutrino interactions
Burning of the sun

Strong

Gluons (8)

Quarks

Mesons

Baryons

Nuclei

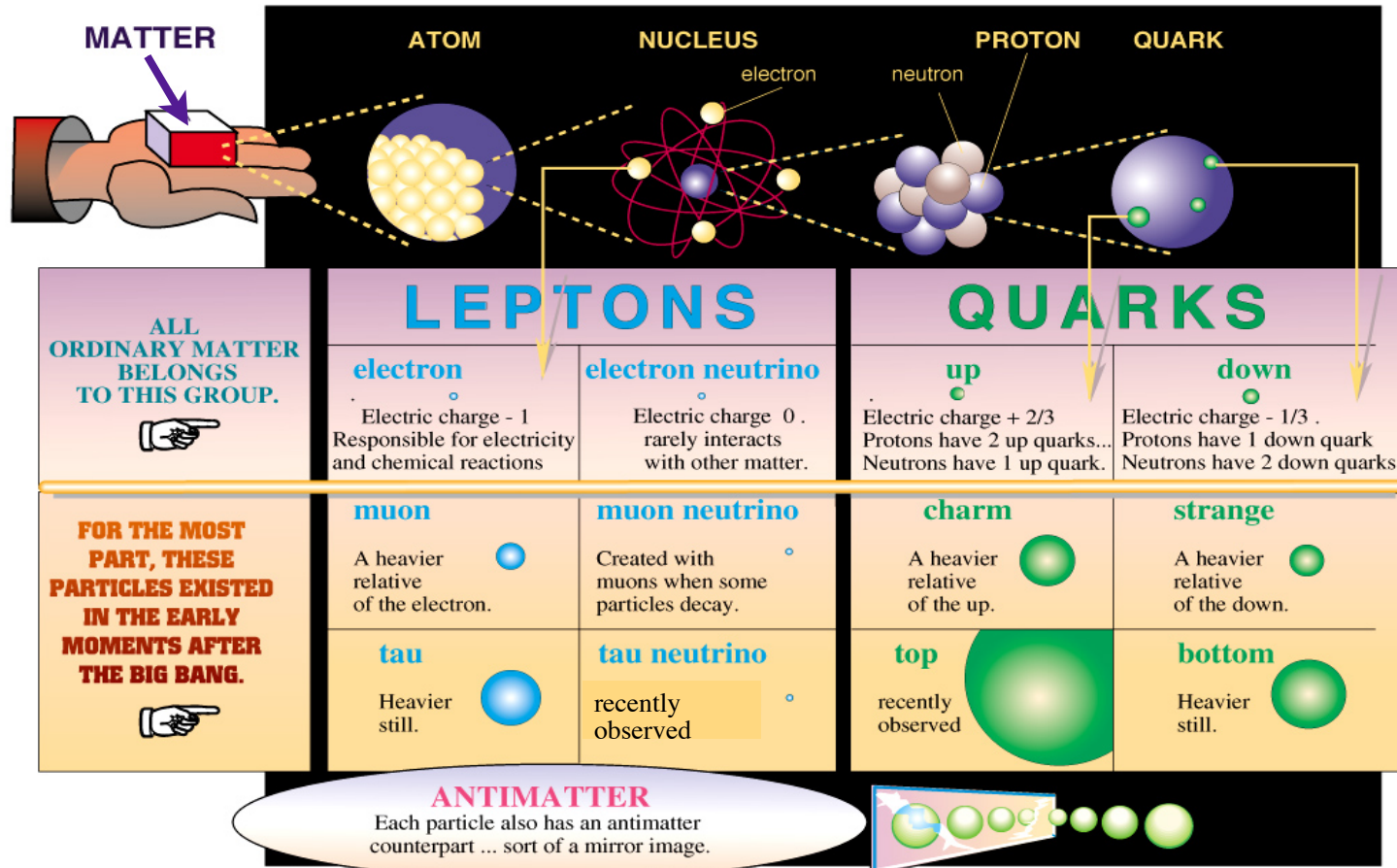
Gravitational

Graviton ?

Solar system
Galaxies
Black holes



STANDARD MODEL



from Time magazine

CERN AC _ E11-7

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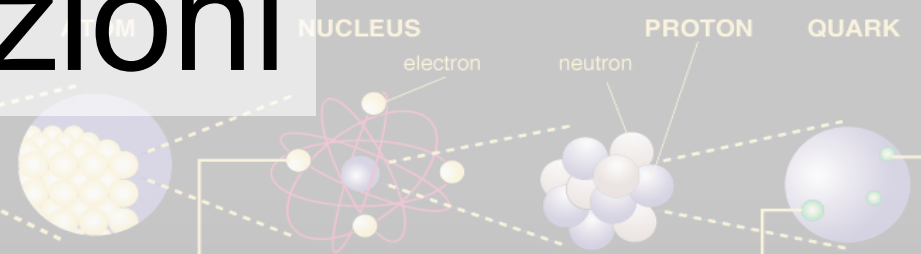
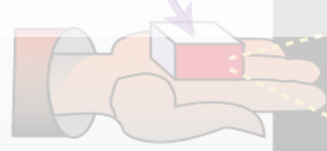
Higgs boson

h



STANDARD MODEL

Interazioni



<p>ALL ORDINARY MATTER BELONGS TO THIS GROUP.</p>	<h2>LEPTONS</h2>		<h2>QUARKS</h2>	
	<p>electron e Electric charge - 1 Responsible for electricity and chemical reactions</p>	<p>electron neutrino ν_e Electric charge 0 Rarely interacts with other matter.</p>	<p>up u Electric charge + 2/3 Protons have 2 up quarks... Neutrons have 1 up quark.</p>	<p>down d Electric charge - 1/3 Protons have 1 down quark Neutrons have 2 down quarks</p>
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	<p>tau τ heavier still.</p>	<p>tau neutrino ν_τ recently observed</p>	<p>top t recently observed</p>	<p>bottom b heavier still.</p>

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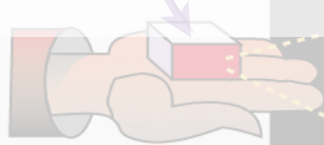
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Higgs boson

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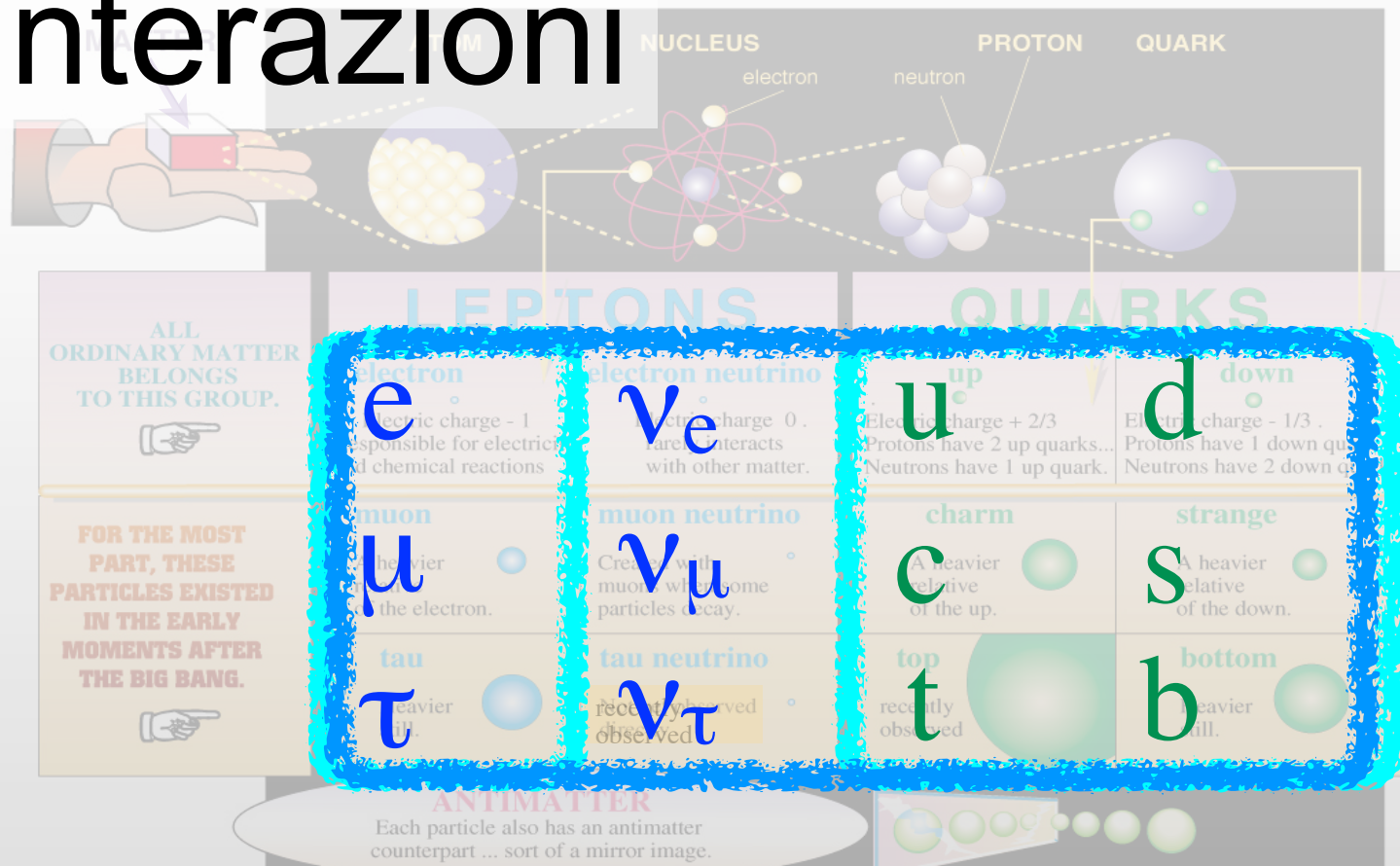
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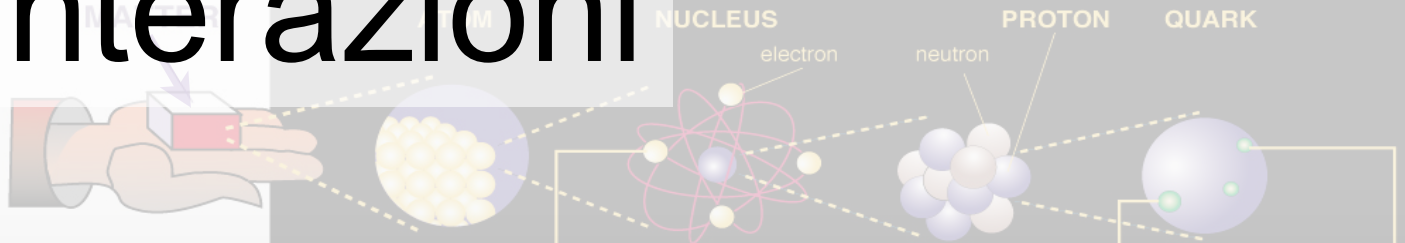
CERN AC E11-7



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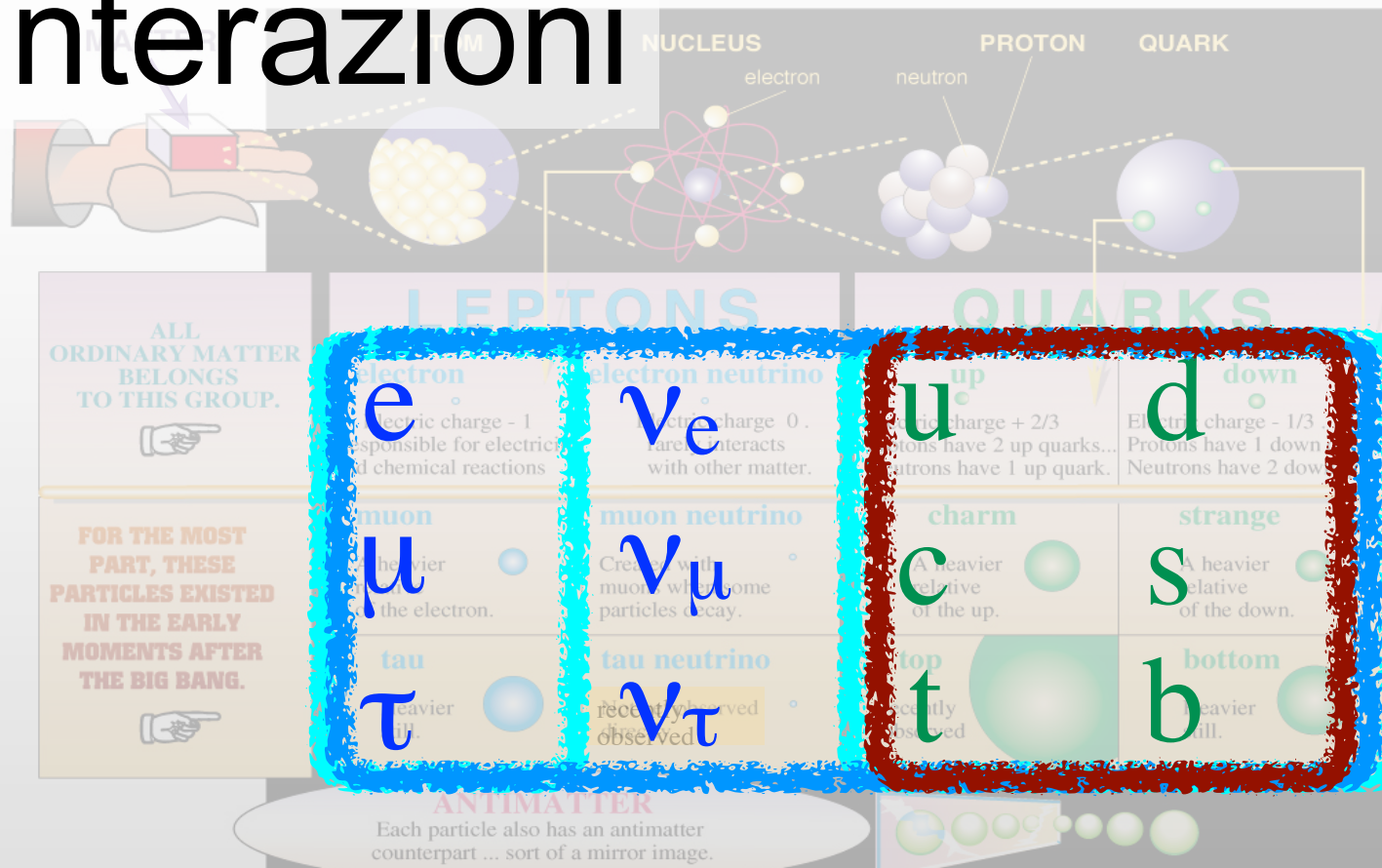
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Interazioni

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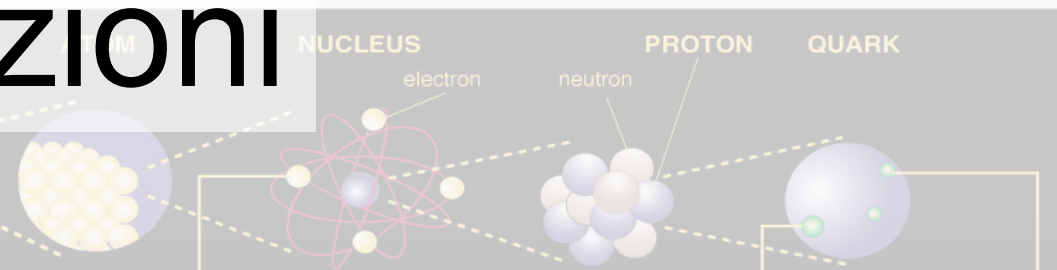
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from Time magazine

CERN AC E11-7



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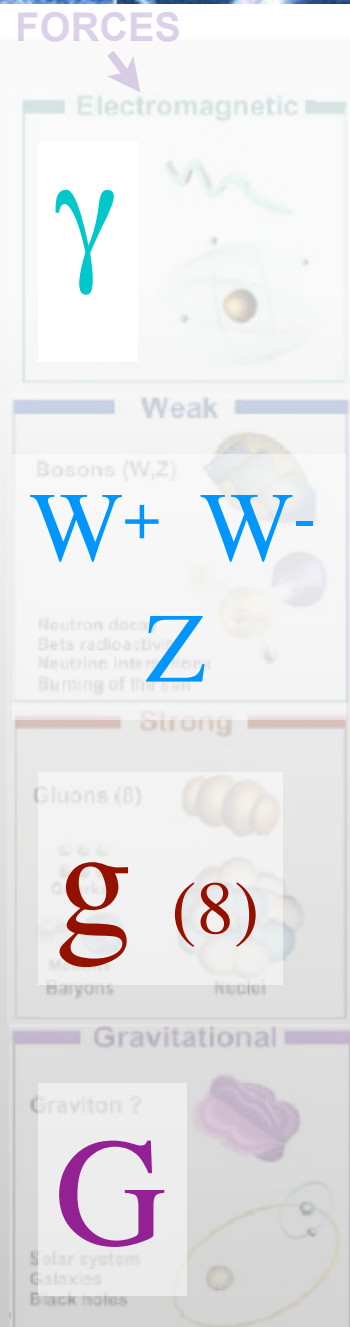
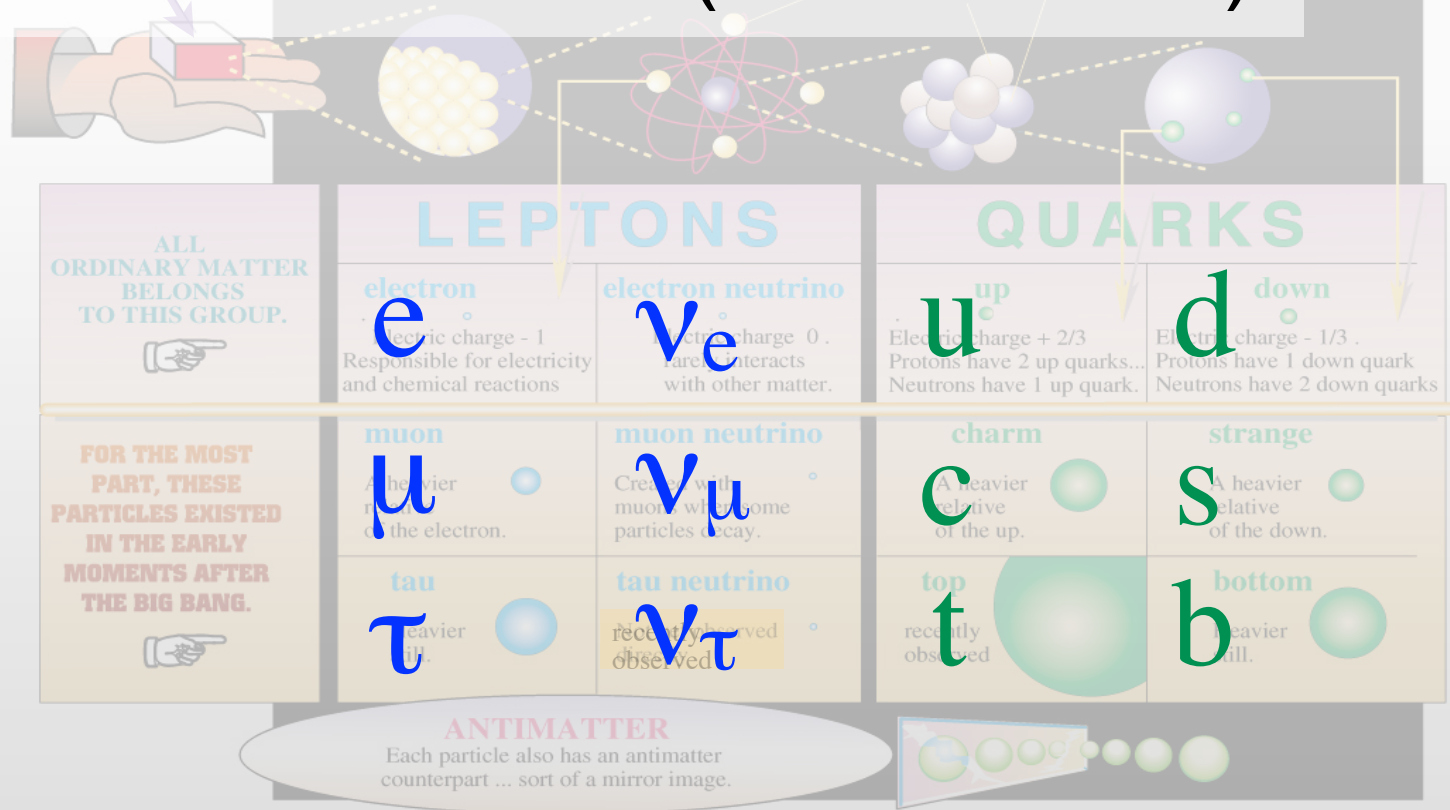
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STANDARD MODEL

Interazioni (& simmetrie)



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► $SU_c(3) \times SU_w(2) \times U_Y(1) \rightarrow SU_c(3) \times U_{em}(1)$

Higgs boson

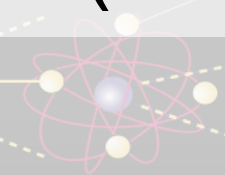
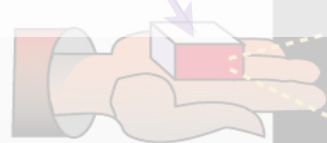
h

Solar system
Galaxies
Black holes



STANDARD MODEL

Interazioni (& simmetrie)



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	<p>tau</p> <p>τ</p> <p>heavier still.</p>	<p>tau neutrino</p> <p>ν_τ</p> <p>recently observed</p>	<p>top</p> <p>t</p> <p>recently observed</p>	<p>bottom</p> <p>b</p> <p>heavier still.</p>

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FORCES

Electromagnetic

γ

Weak

Bosons (W,Z)

W^+ W^-

Z

Strong

Gluons (8)

g (8)

Gravitational

Graviton ?

G

Higgs boson

h

from Time magazine

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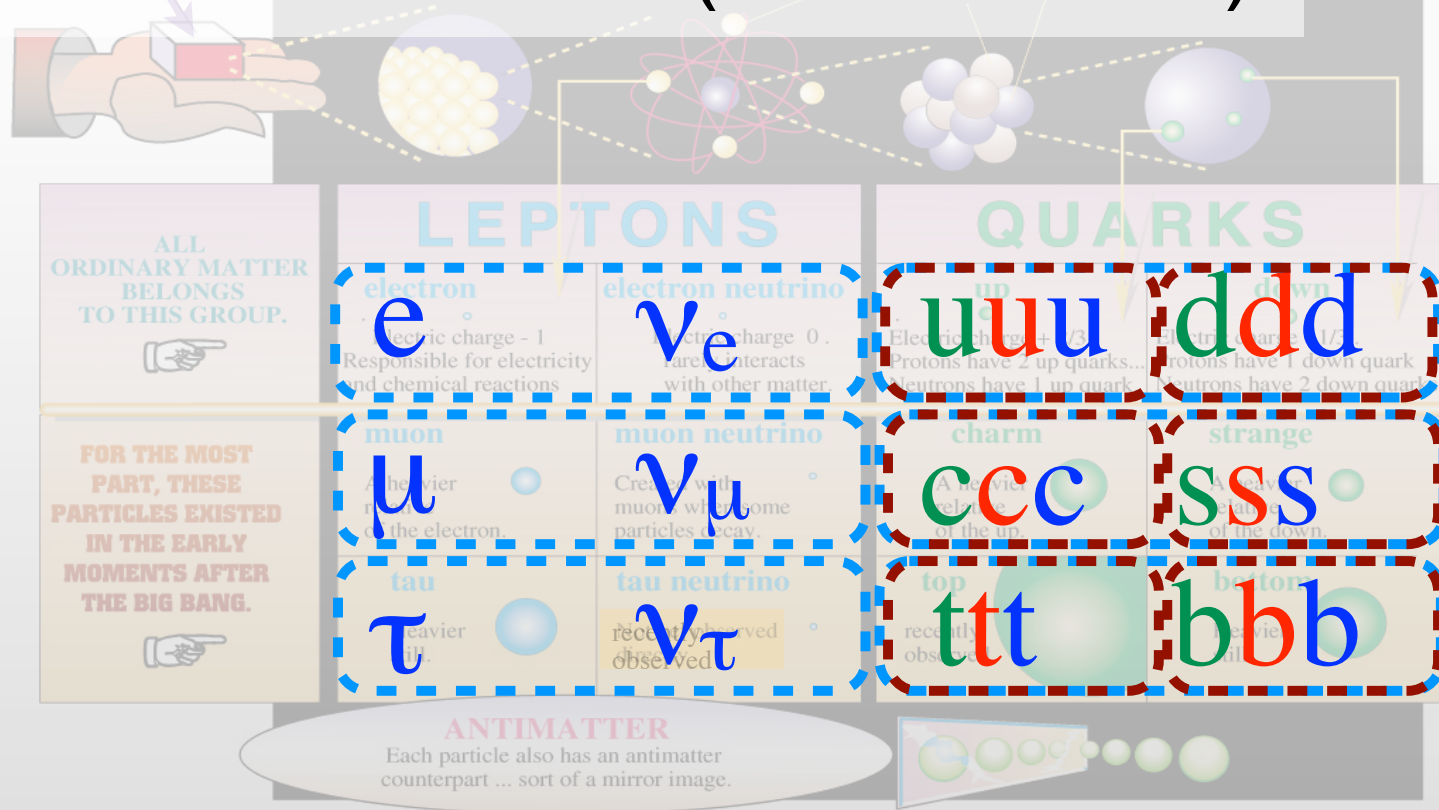
► $SU_c(3) \times SU_w(2) \times U_Y(1) \rightarrow SU_c(3) \times U_{em}(1)$



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from Time magazine

CERN AC...E11-7

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from Time magazine

CERN AC ... E11-7

- ▶ $SU_c(3) \times SU_w(2) \times U_Y(1) \rightarrow SU_c(3) \times U_{em}(1)$
- ▶ colore e carica elettrica

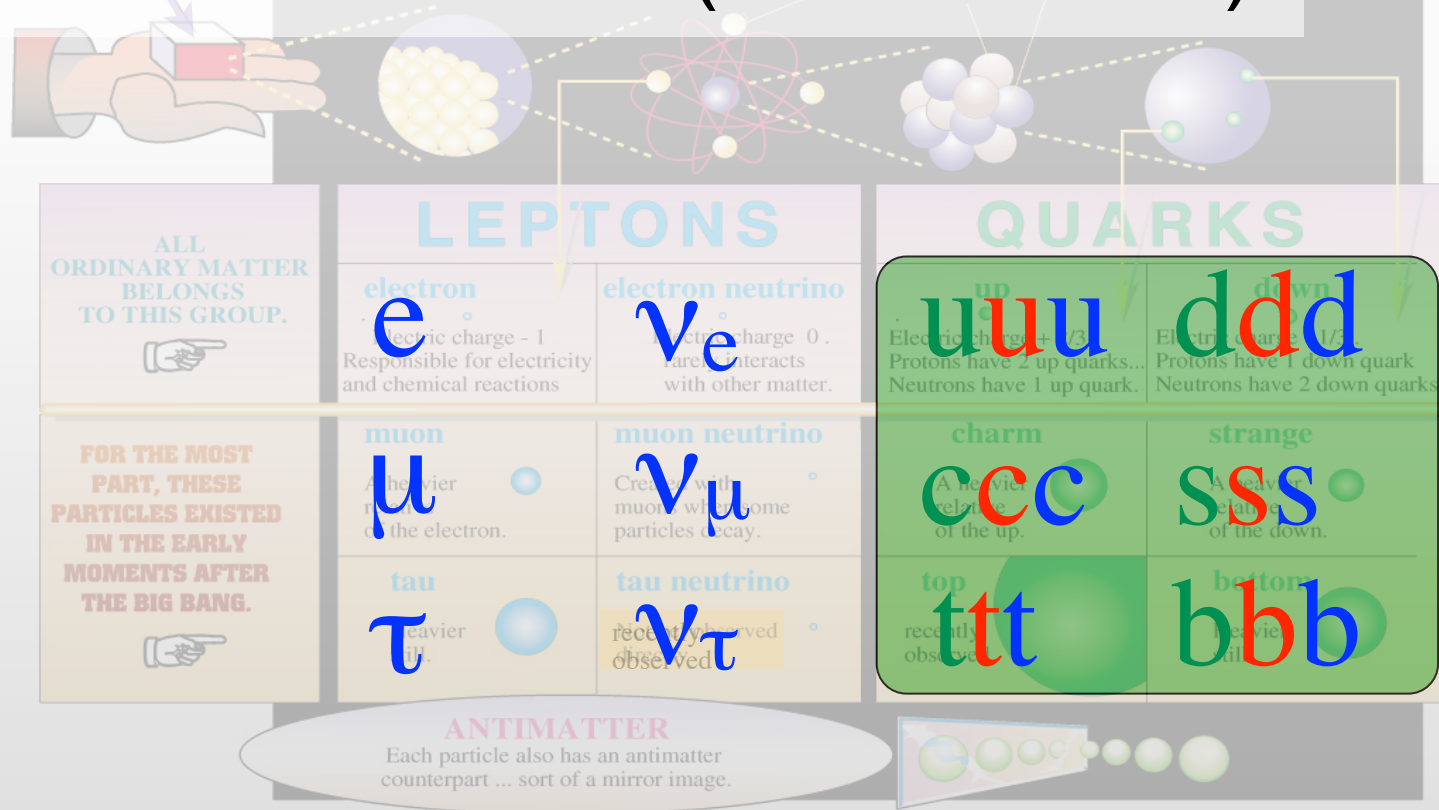
Higgs boson

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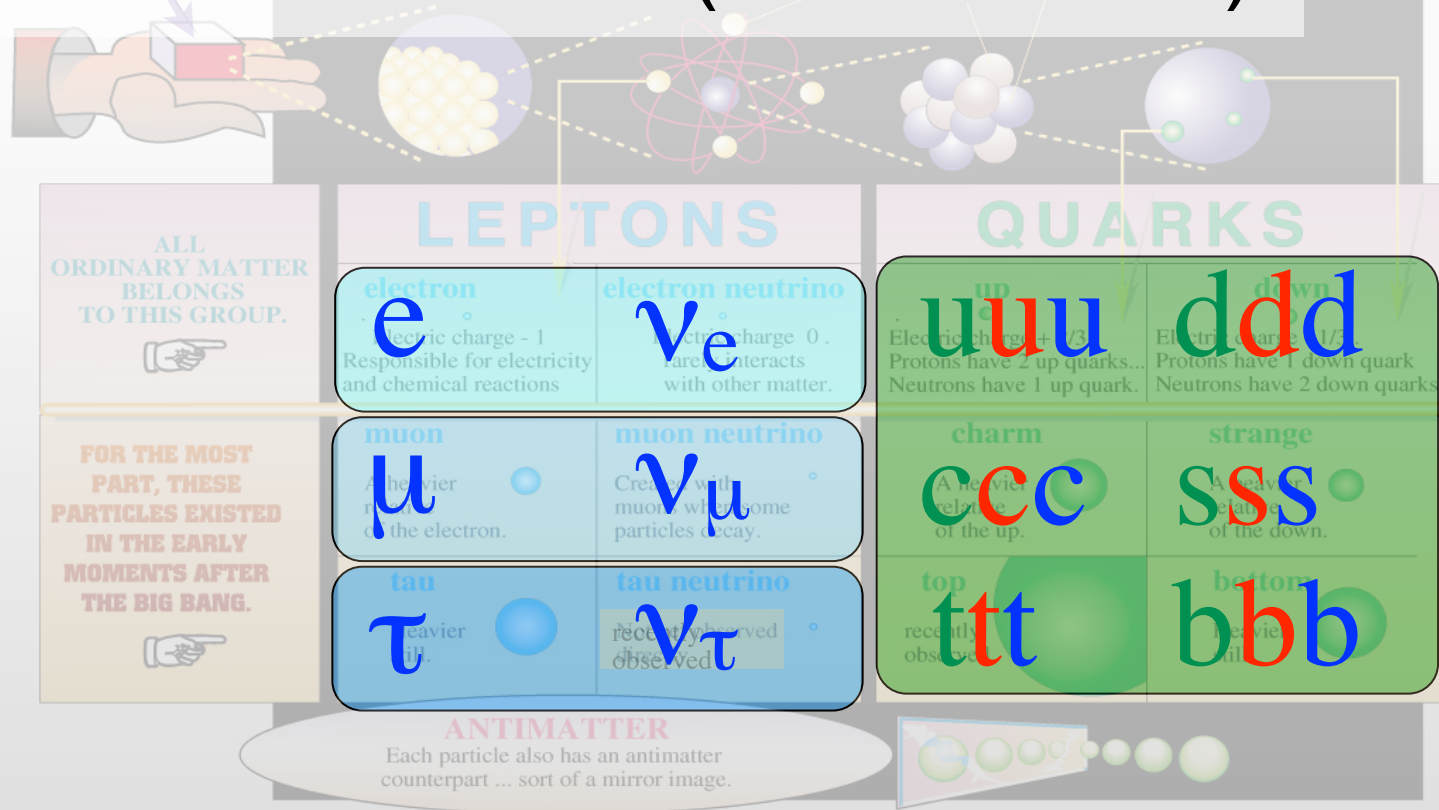
h

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CERN AC ... E11-7

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- ▶ colore e carica elettrica
- ▶ **sapore barionico totale**
- ▶ **sapore leptonico individuale** (ma: oscillazioni ν)



STANDARD MODEL

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CERN AC ... E11-7

Adroni: stati composti di quarks

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	<p>tau</p> <p>τ</p> <p>Heaviest lepton.</p>	<p>tau neutrino</p> <p>ν_τ</p> <p>Recently observed</p>	<p>top</p> <p>ttt</p> <p>Recently observed</p>	<p>bottom</p> <p>bbb</p> <p>Heaviest quark</p>
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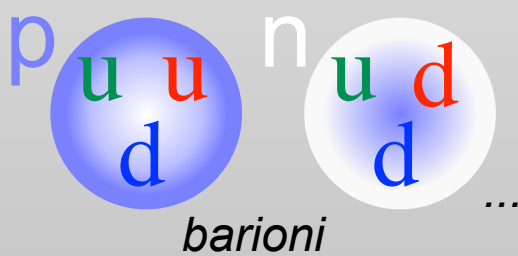
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	<p>electron e^- Electric charge - 1 Responsible for electricity and chemical reactions</p>	<p>electron neutrino ν_e Electric charge 0. Rare. Interacts with other matter.</p>	<p>up $u$$u$$u$ Electric charge 2/3 Protons have 2 up quarks... Neutrons have 1 up quark.</p>	<p>down $d$$d$$d$ Electric charge 1/3 Protons have 1 down quark Neutrons have 2 down quarks</p>
<p>FOR THE MOST PART, THESE PARTICLES EXISTED IN THE EARLY MOMENTS AFTER THE BIG BANG.</p>	<p>muon μ^- A heavier relative of the electron.</p>	<p>muon neutrino ν_μ Created with muon when some particles decay.</p>	<p>charm $c$$c$$c$ A heavier relative of the up.</p>	<p>strange $s$$s$$s$ A heavier relative of the down.</p>
	<p>tau τ^- Heavier still.</p>	<p>tau neutrino ν_τ Recently observed</p>	<p>top $t$$t$$t$ Recently observed</p>	<p>bottom $b$$b$$b$ Heavier still</p>
<p>ANTIMATTER Each particle also has an antimatter counterpart ... sort of a mirror image.</p>				

FORCES

Electromagnetic
 γ

Weak
Bosons (W,Z)
 W^+ W^-
 Z
Neutron decay
Beta radioactivity
Neutrino interaction
Burning of the sun

Strong
Gluons (8)
 g (8)
Baryons
Nuclei

Gravitational
Graviton ?
 G
Solar system
Galaxies
Black holes

from Time magazine

CERN AC ... E11-7

Adroni: stati composti di quarks

p u u d n u d d ...
barioni

π^0 \bar{u} u K^+ \bar{s} u ...
mesoni

Higgs boson

h



Interazioni (& simmetrie)

FORCES

<p>ALL ORDINARY MATTER BELONGS TO THIS GROUP.</p>	LEPTONS		QUARKS	
	<p>electron e^- Electric charge - 1 Responsible for electricity and chemical reactions</p>	<p>electron neutrino ν_e Electric charge 0. Rare. Interacts with other matter.</p>	<p>up $u$$u$$u$ Electric charge 2/3 Protons have 2 up quarks... Neutrons have 1 up quark.</p>	<p>down $d$$d$$d$ Electric charge 1/3 Protons have 1 down quark Neutrons have 2 down quarks</p>
<p>FOR THE MOST PART, THESE PARTICLES EXISTED IN THE EARLY MOMENTS AFTER THE BIG BANG.</p>	<p>muon μ^- A heavier relative of the electron.</p>	<p>muon neutrino ν_μ Created with muon when some particles decay.</p>	<p>charm $c$$c$$c$ A heavy relative of the up.</p>	<p>strange $s$$s$$s$ A heavy relative of the down.</p>
	<p>tau τ^- The heaviest of the leptons.</p>	<p>tau neutrino ν_τ Recently observed</p>	<p>top $t$$t$$t$ The heaviest of the quarks. Recently observed</p>	<p>bottom $b$$b$$b$ The second heaviest of the quarks. Recently observed</p>

ANTIMATTER
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Domanda: altre configurazioni?



Interazioni (& simmetrie)

FORCES

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	<p>tau τ^- Heaviest of the leptons.</p>	<p>tau neutrino ν_τ Recently observed</p>	<p>top $t$$t$$t$ Recently observed</p>	<p>bottom $b$$b$$b$ Heaviest of the quarks.</p>
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CERN AC ... E11-7

Adroni: stati composti di quarks

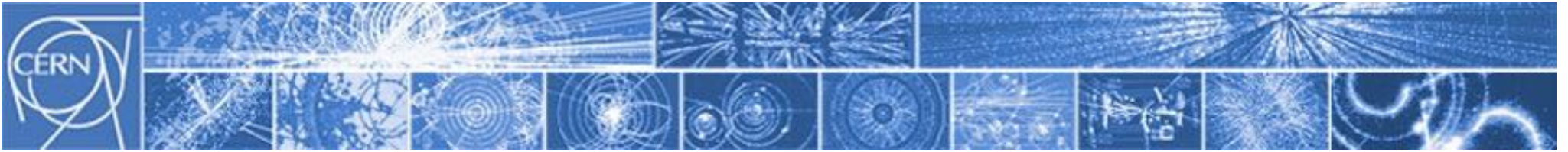
p u u d n u d d ...
barioni

π^0 \bar{u} u K^+ \bar{s} u ...
mesoni

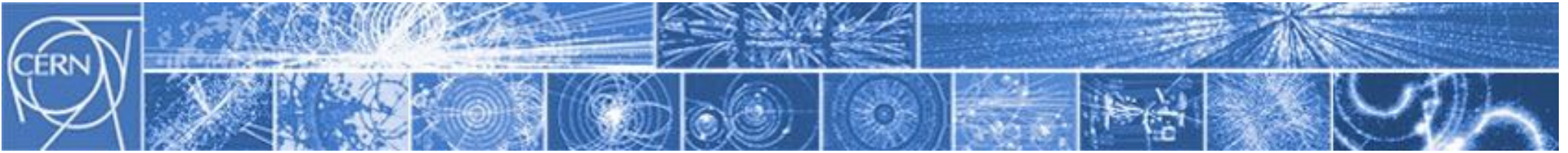
Higgs boson

h

Domanda: altre configurazioni?
Tetraquarks,
Pentaquarks
(LHCb 2015)



Masse



Masse

KeV

MeV

GeV

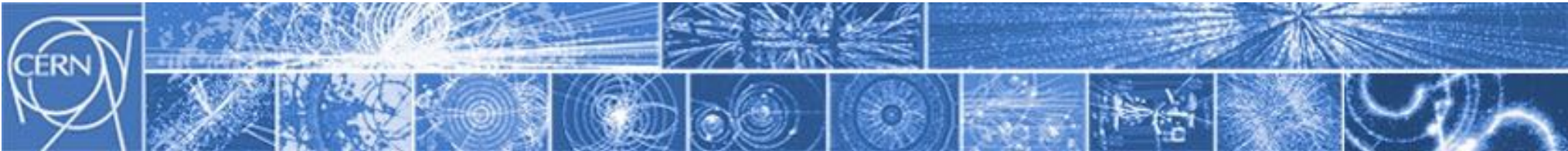
TeV

		e			μ	τ		
--	--	---	--	--	-------	--------	--	--

e 511 KeV

μ 105.7 MeV

τ 1.777 GeV



Masse

KeV

MeV

GeV

TeV

		e			μ	τ		
			u d		s	c b		t

e 511 KeV

μ 105.7 MeV

τ 1.777 GeV

u ~2.3 MeV

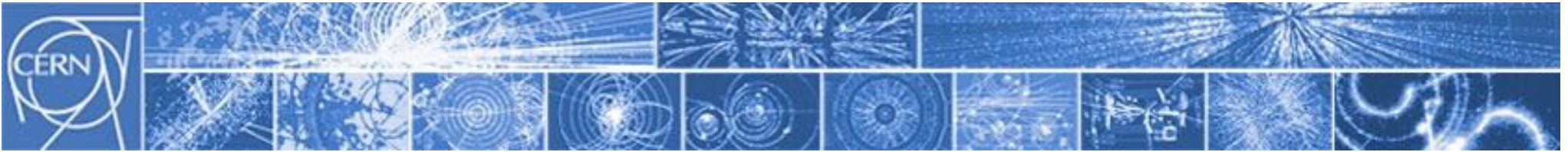
d ~5 MeV

s ~95 MeV

c 1.27 GeV

b 4.2 GeV

t 173.2 GeV



Masse

KeV

MeV

GeV

TeV

		e			μ	τ		
			u d		s	c	b	
								t
							W Z	

e 511 KeV

μ 105.7 MeV

τ 1.777 GeV

u ~2.3 MeV

d ~5 MeV

s ~95 MeV

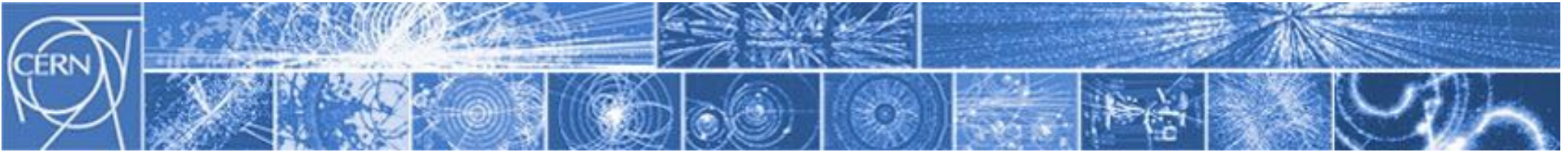
c 1.27 GeV

b 4.2 GeV

t 173.2 GeV

W[±] 80.385 GeV

Z 91.1876 GeV



Masse

KeV

MeV

GeV

TeV

		e			μ	τ		
			u d		s	c	b	
								t
							W Z	
								h

e 511 KeV

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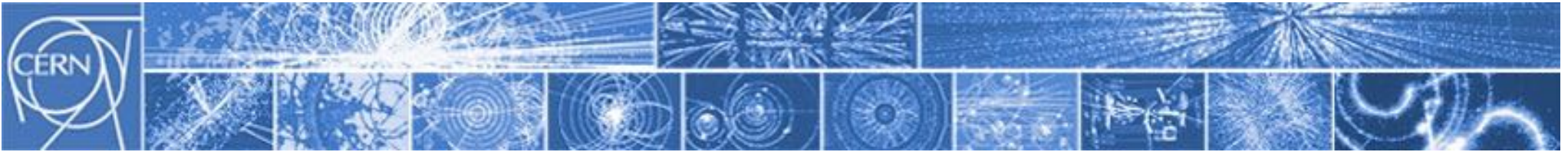
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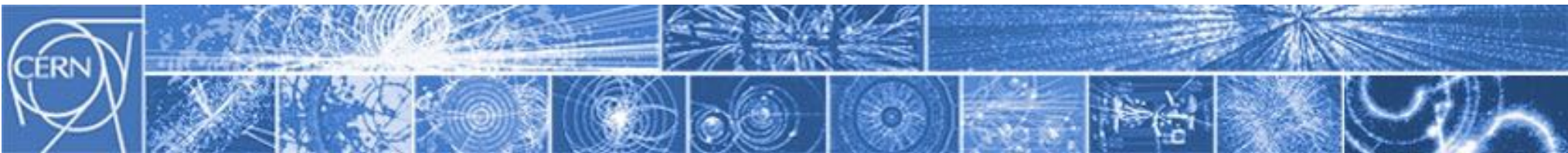


Masse

meV		eV		KeV		MeV		GeV		TeV	
ν	ν						e		μ	τ	
	ν						u	s	c	b	t
							d				W
											Z
											h

e 511 KeV	u ~2.3 MeV	c 1.27 GeV	W^\pm 80.385 GeV
μ 105.7 MeV	d ~5 MeV	b 4.2 GeV	Z 91.1876 GeV
τ 1.777 GeV	s ~95 MeV	t 173.2 GeV	h 125.7 GeV

$$9 \cdot 10^{-3} \text{ eV} \lesssim \nu_i \lesssim 0.2 \text{ eV}$$



Masse

massa zero: γ g G

meV		eV		KeV		MeV		GeV		TeV	
ν	ν						e		μ	τ	
	ν						u	s	c	b	t
							d				W
											Z
											h

e 511 KeV	u ~2.3 MeV	c 1.27 GeV	W^\pm 80.385 GeV
μ 105.7 MeV	d ~5 MeV	b 4.2 GeV	Z 91.1876 GeV
τ 1.777 GeV	s ~95 MeV	t 173.2 GeV	h 125.7 GeV

$$9 \cdot 10^{-3} \text{ eV} \lesssim \nu_i \lesssim 0.2 \text{ eV}$$