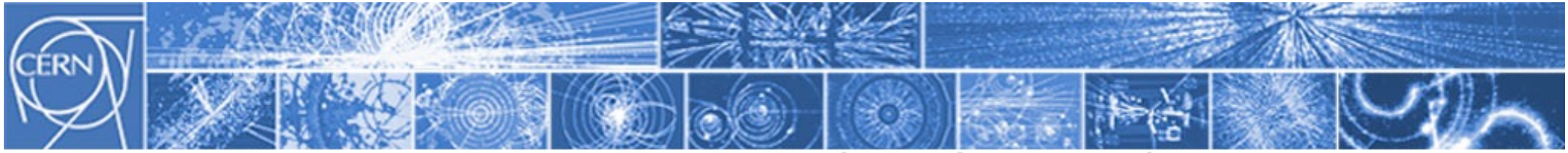


CERN

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?

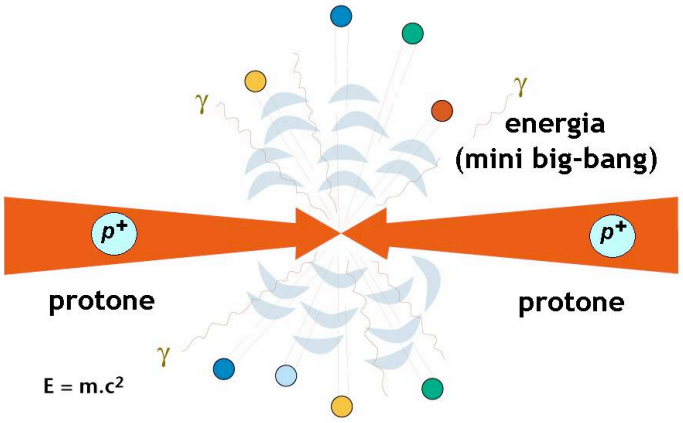
Accelerare le particelle elementari *(protoni, elettroni...)*

fino a energie elevatissime *(14 TeV)*

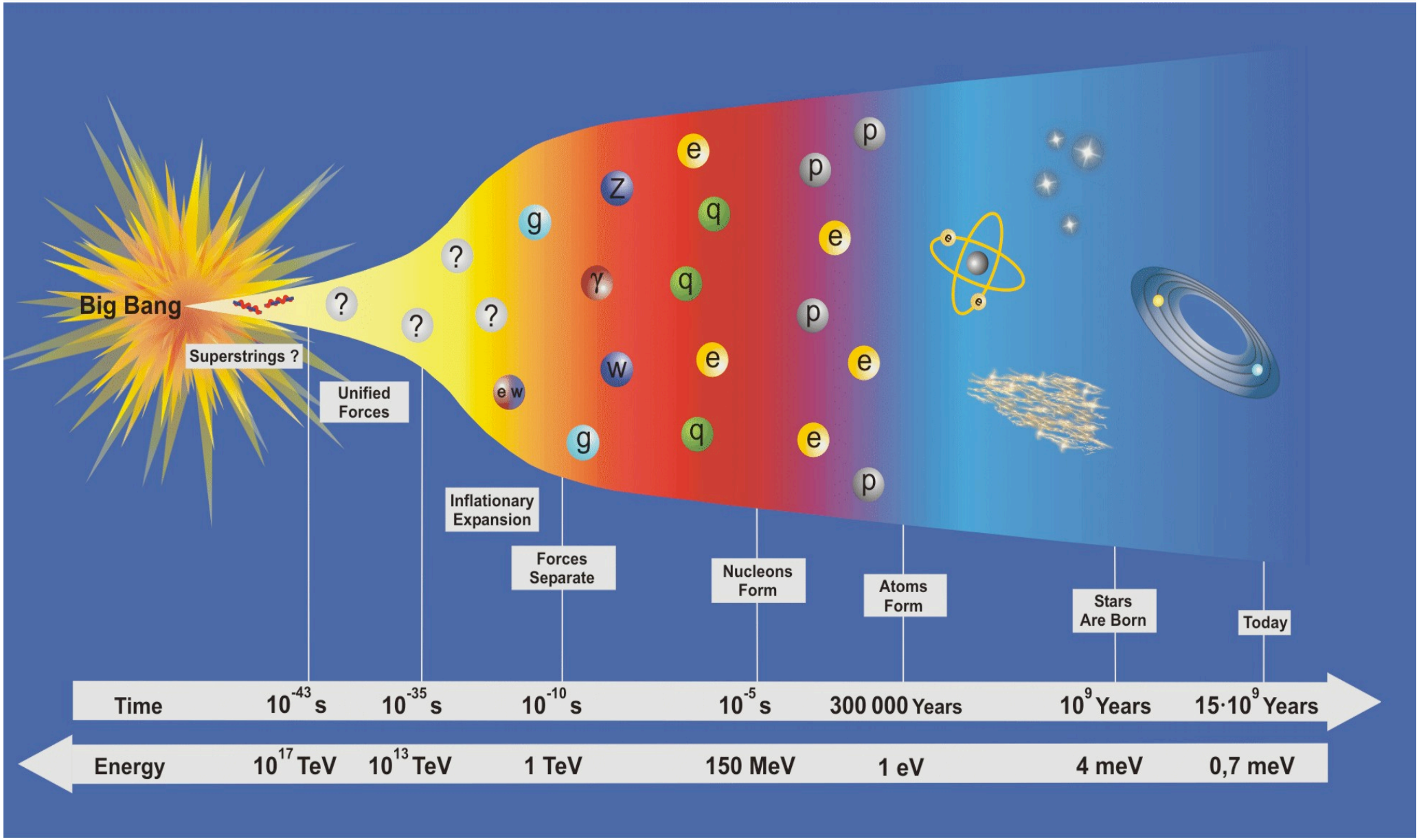
e portarle a collidere. $E=mc^2$

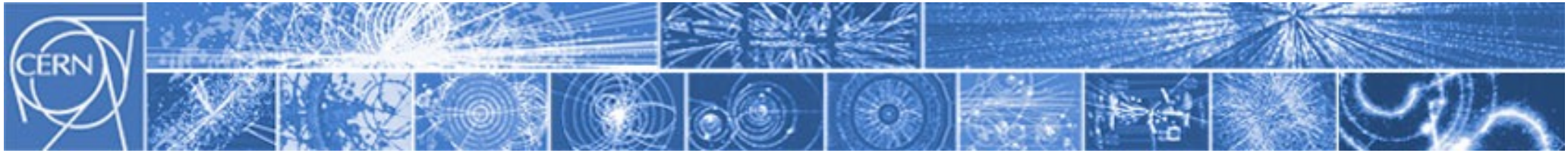
Analizzare accuratamente i prodotti

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)

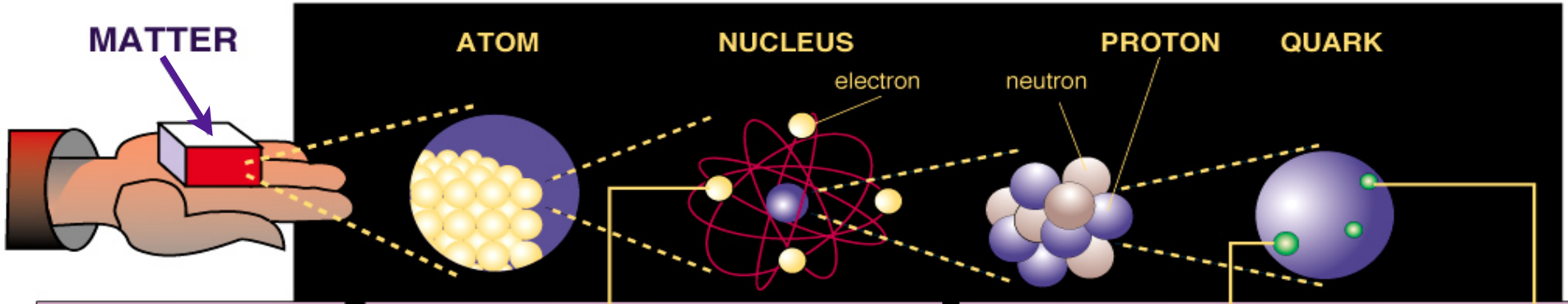
1970's teoria della QCD - interazioni nucleari forti
(Gross, Politzer, Wilczek)

1936 μ
1956 ν_e
1962 ν_μ
1974 τ
2000 ν_τ

1968 s quark
1974 c quark
1977 b quark
1995 t quark

2012 higgs

STANDARD MODEL



ALL ORDINARY MATTER BELONGS TO THIS GROUP.

FOR THE MOST PART, THESE PARTICLES EXISTED IN THE EARLY MOMENTS AFTER THE BIG BANG.

LEPTONS

electron Electric charge - 1 Responsible for electricity and chemical reactions	**electron neutrino** Electric charge 0 . rarely interacts with other matter.
muon A heavier relative of the electron.	**muon neutrino** Created with muons when some particles decay.
tau Heavier still.	**tau neutrino** recently observed

QUARKS

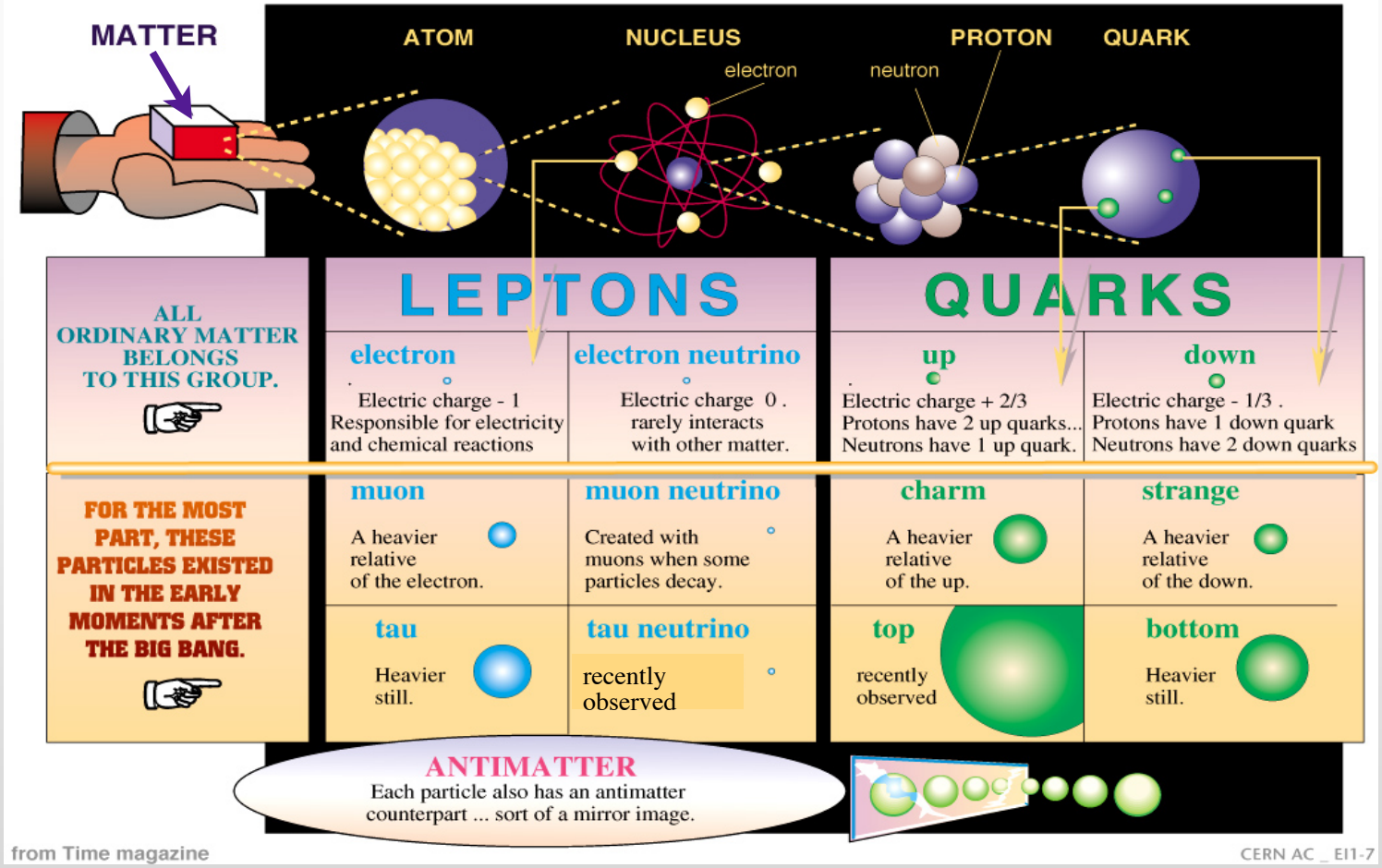
up Electric charge + 2/3 Protons have 2 up quarks... Neutrons have 1 up quark.	**down** Electric charge - 1/3 . Protons have 1 down quark Neutrons have 2 down quarks
charm A heavier relative of the up.	**strange** A heavier relative of the down.
top recently observed	**bottom** Heavier still.

ANTIMATTER
Each particle also has an antimatter counterpart ... sort of a mirror image.

When they meet, they annihilate

from Time magazine

STANDARD MODEL

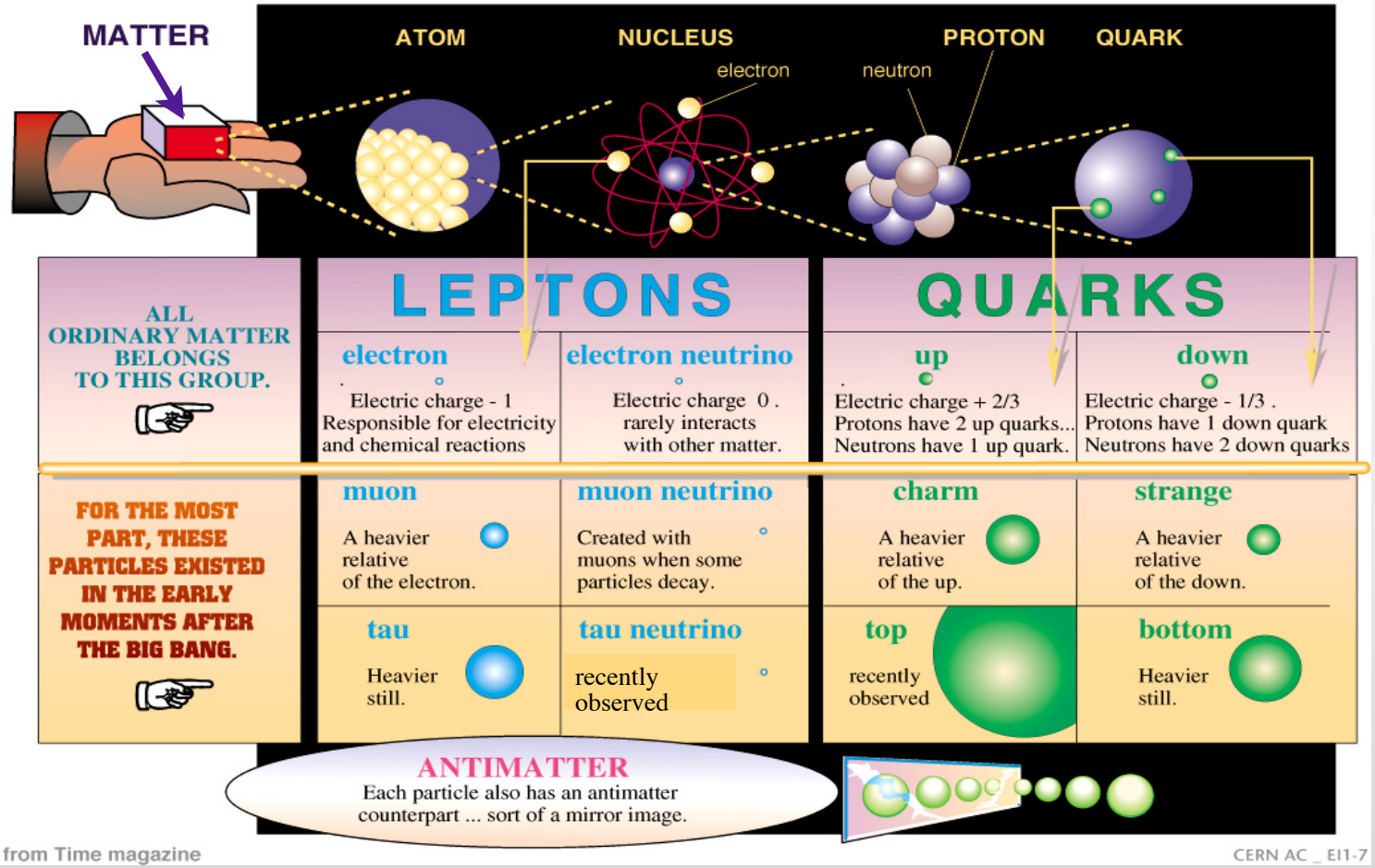


from Time magazine

CERN AC _ EI1-7

FORCES

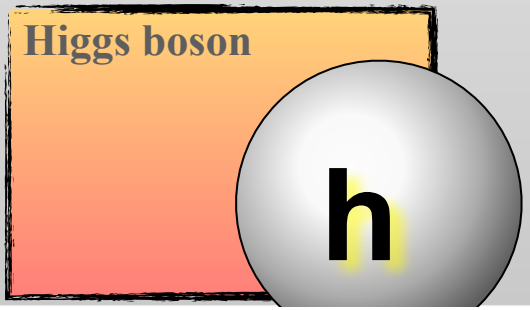
STANDARD MODEL



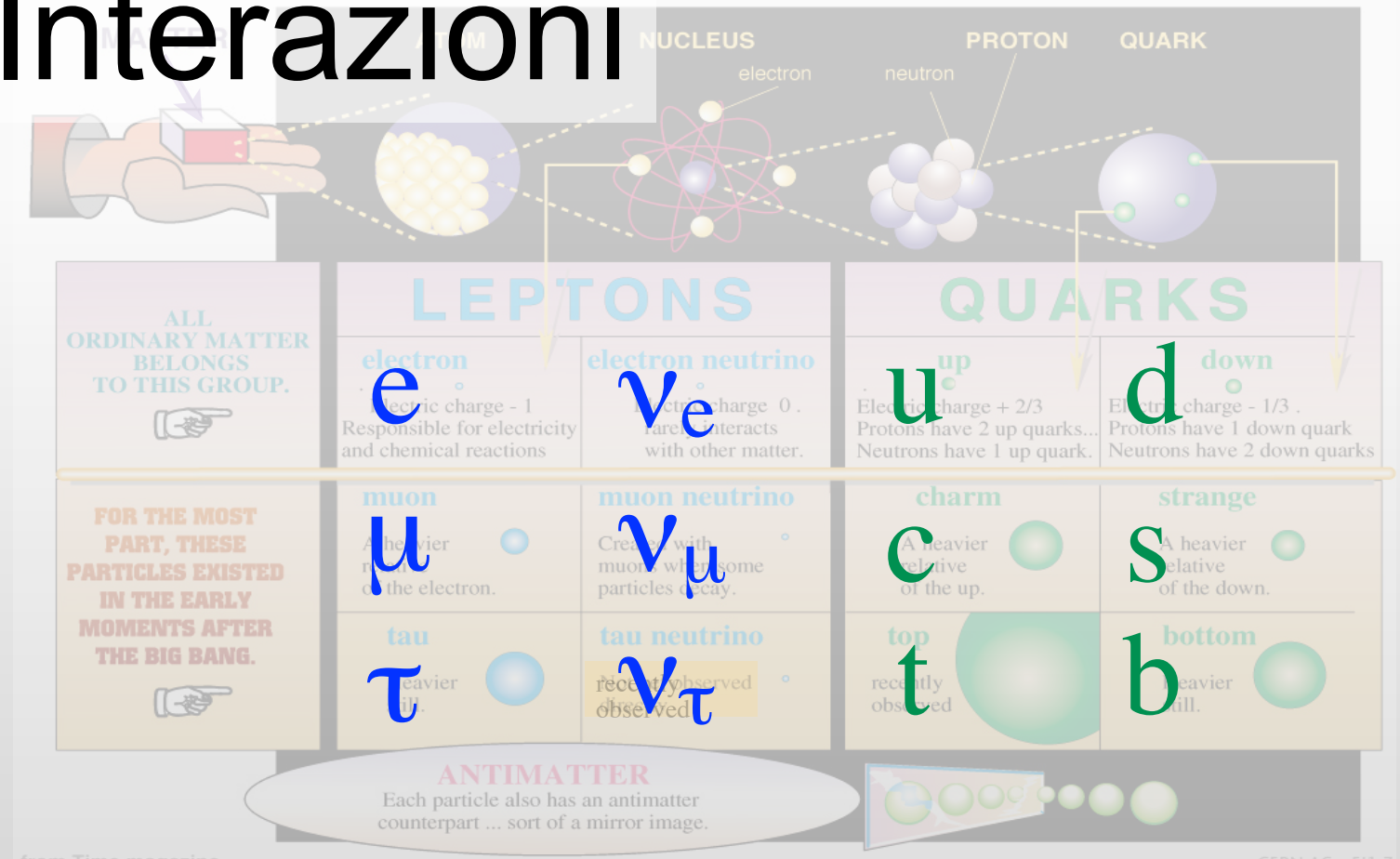
from Time magazine

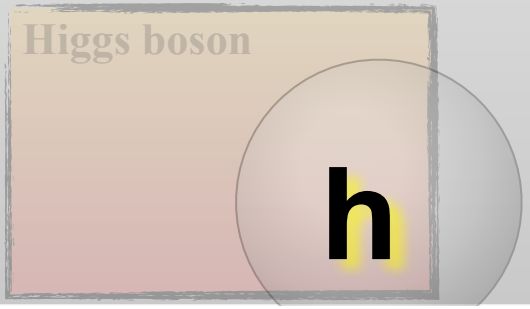
CERN AC _ EI1-7

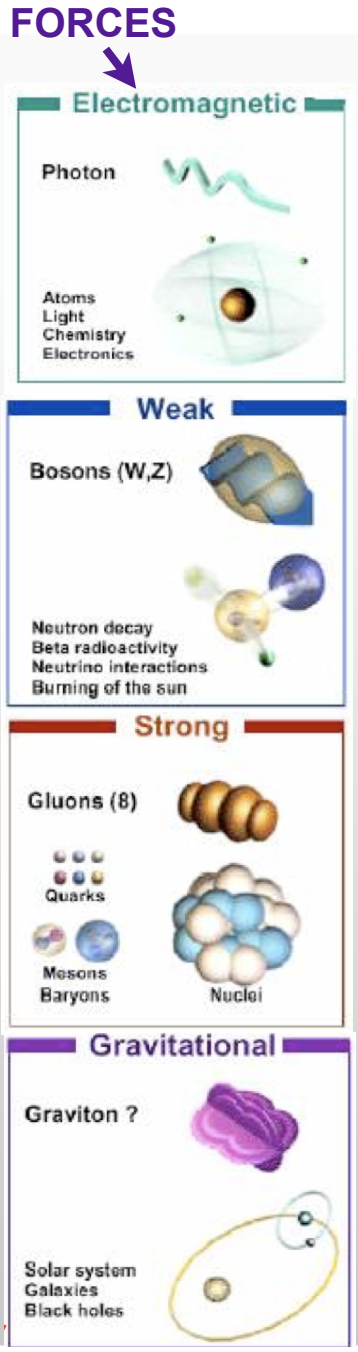
FORCES



Interazioni







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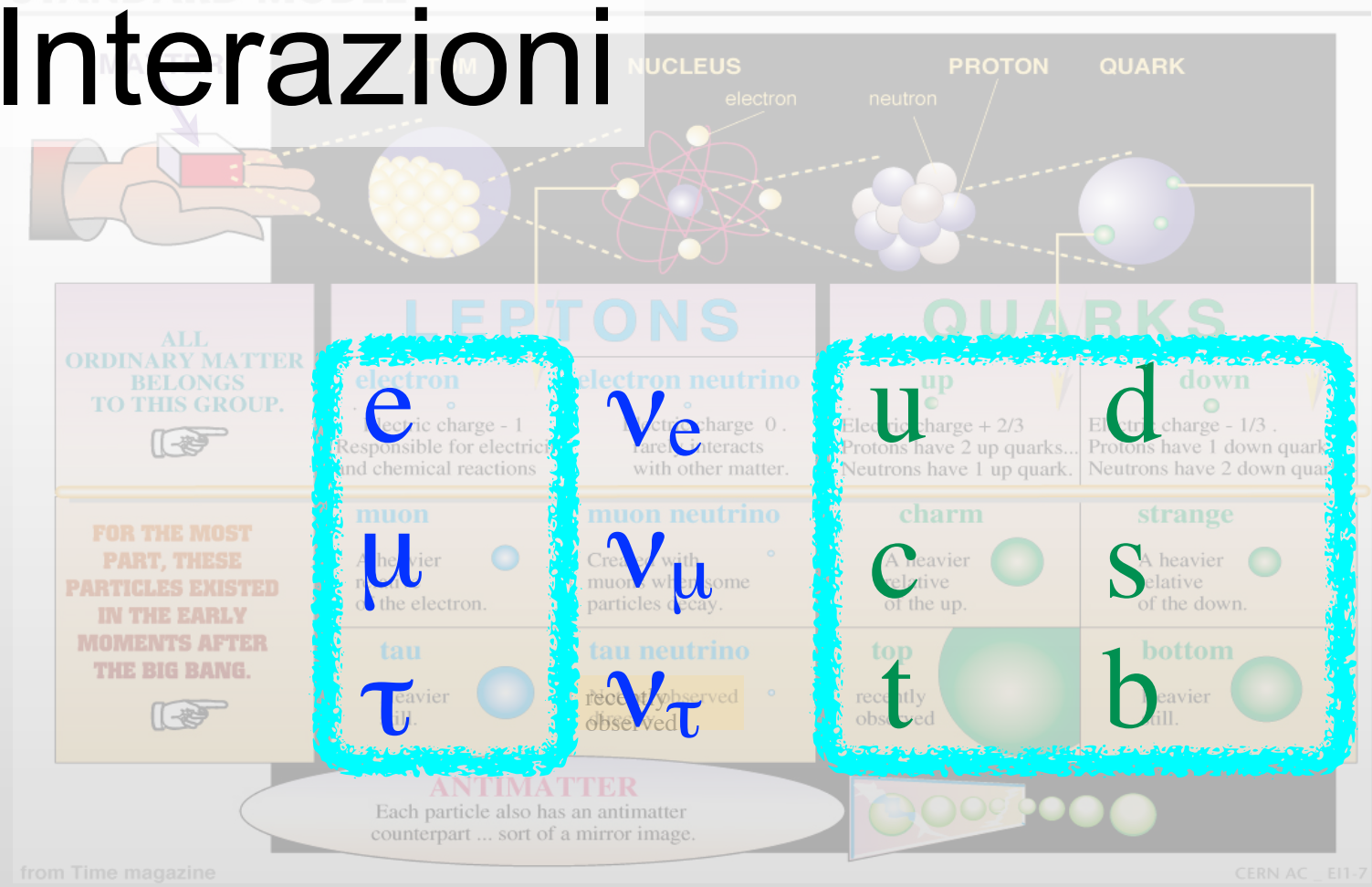
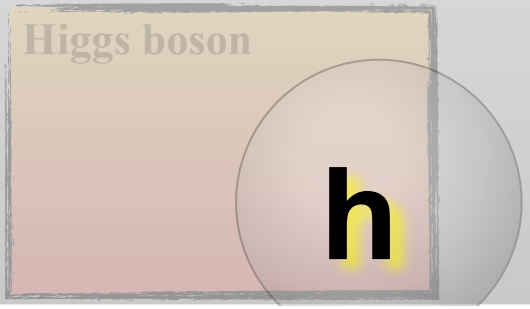
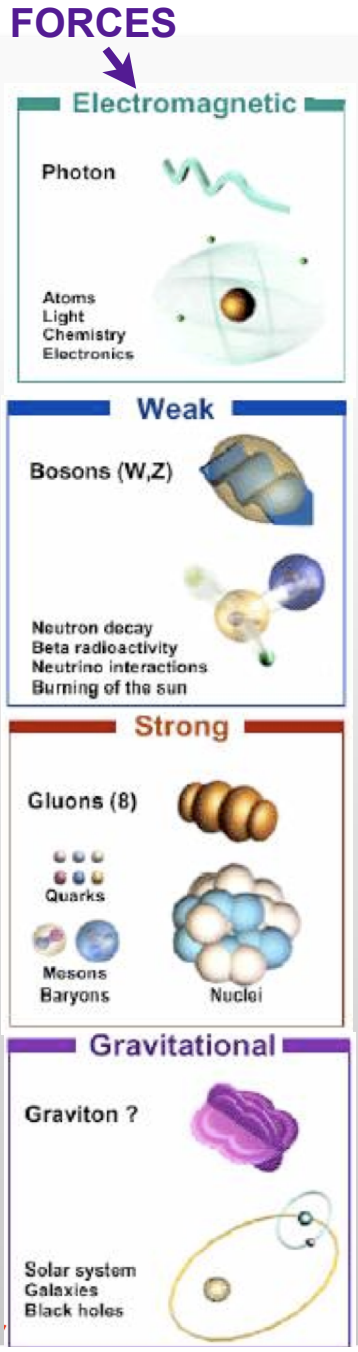






Interazioni

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

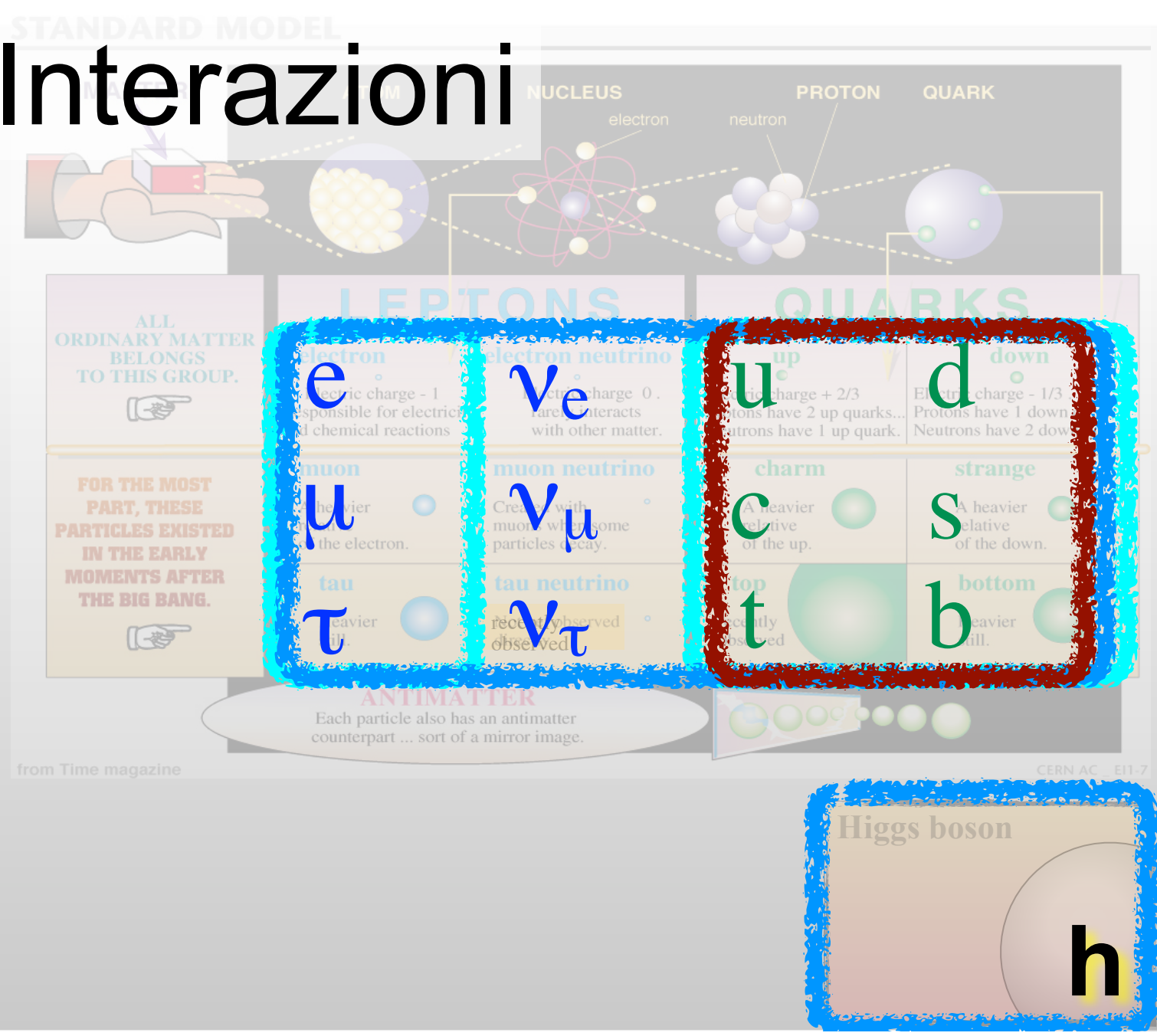
Nuclei

Gravitational

Graviton ?

Solar system
Galaxies
Black holes

Interazioni



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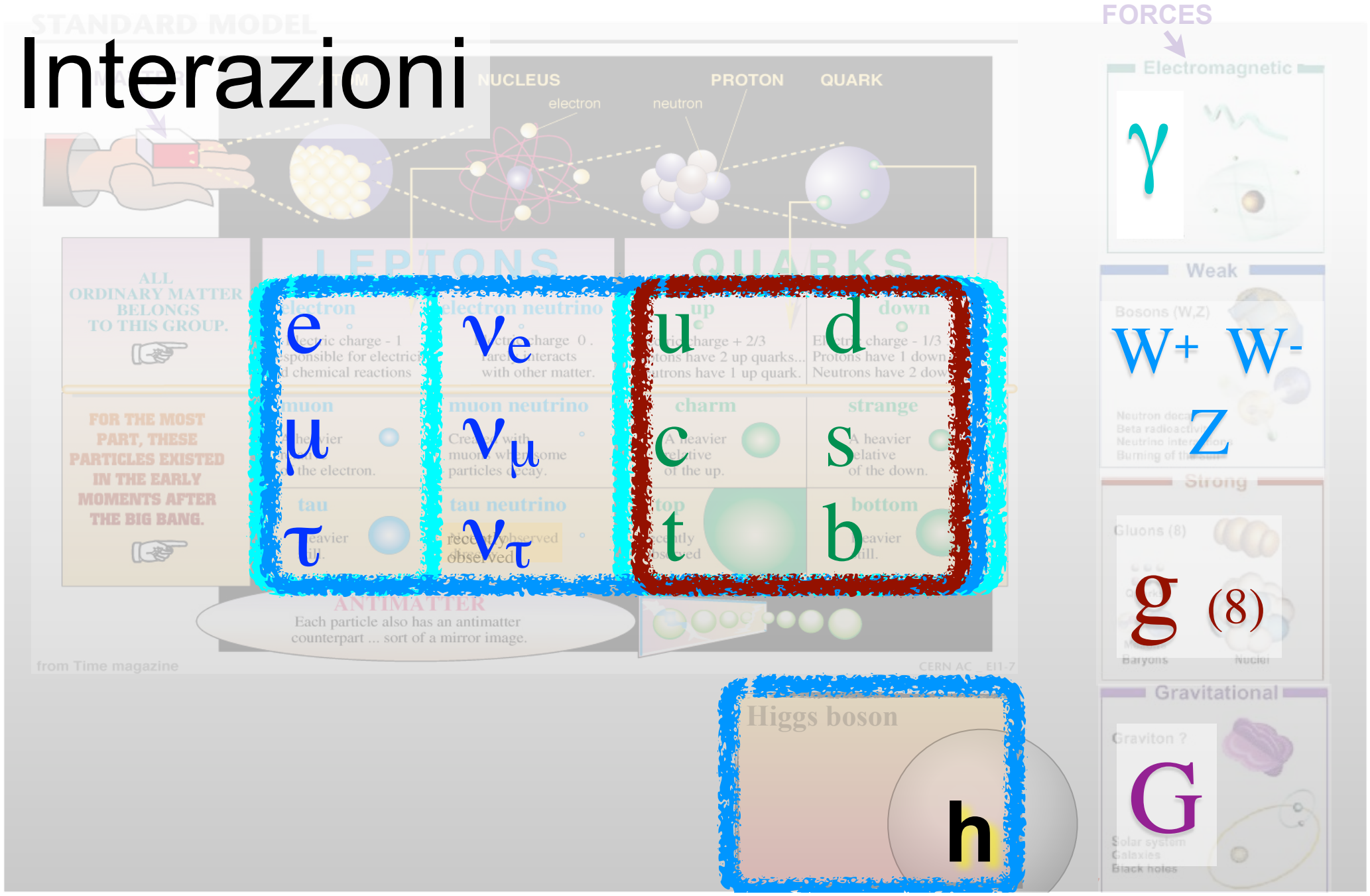
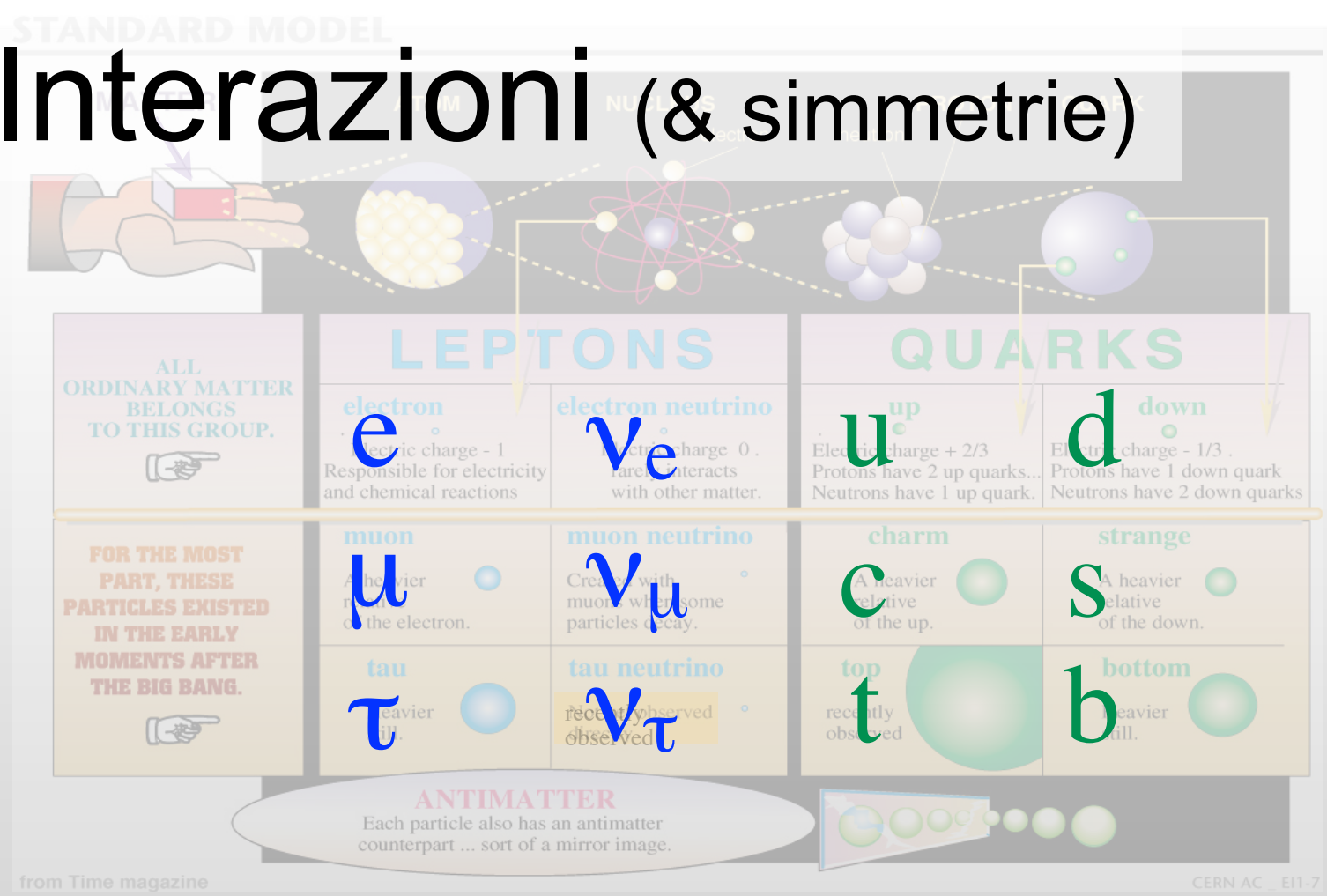
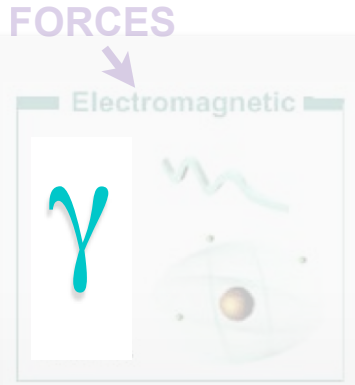
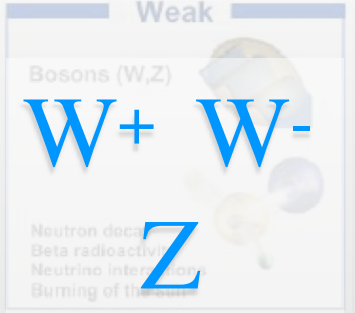


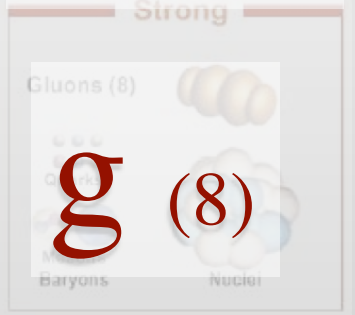
Interazioni

Interazioni (& simmetrie)

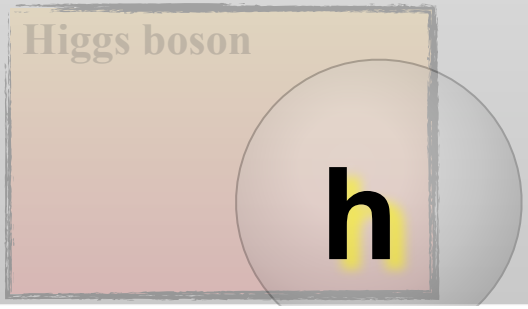








- $SU_c(3) \times SU_w(2) \times U_Y(1) \rightarrow SU_c(3) \times U_{em}(1)$



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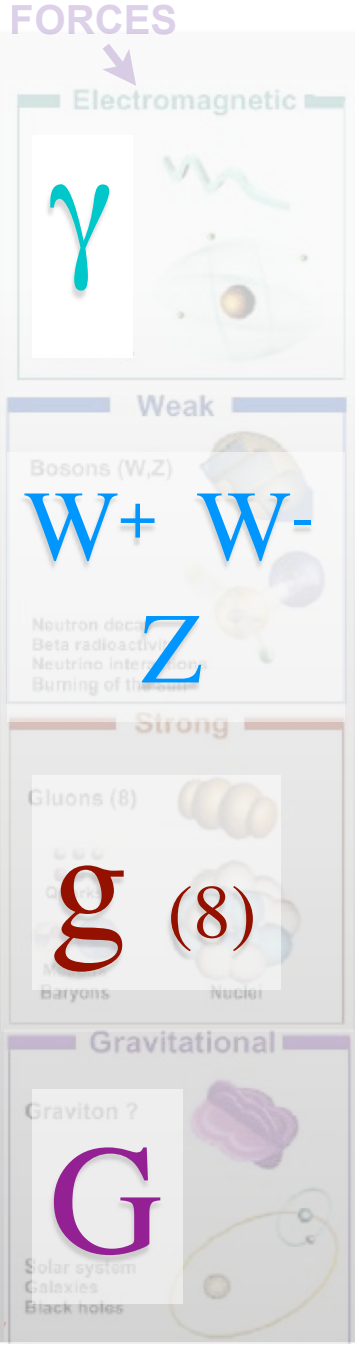

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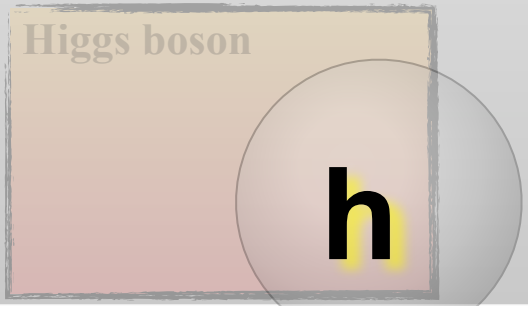

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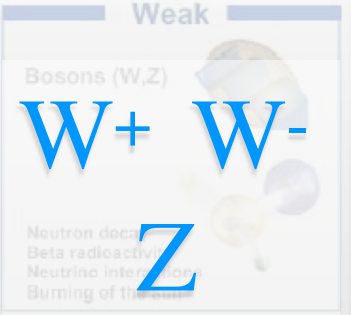

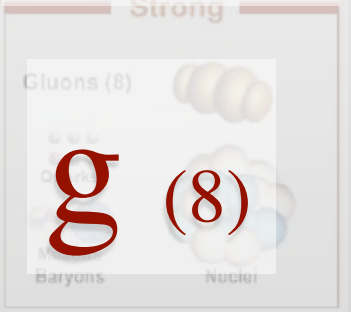

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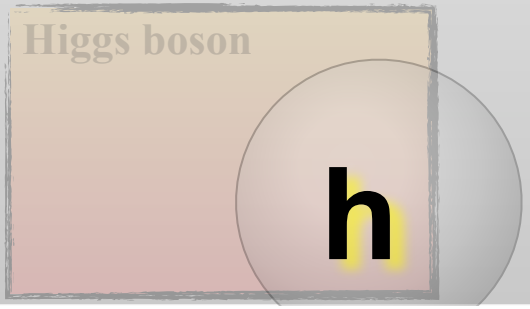

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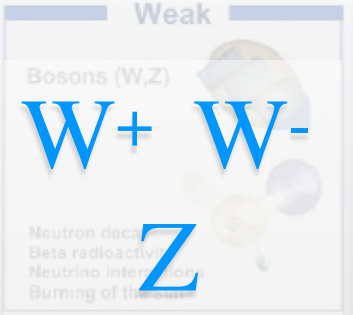
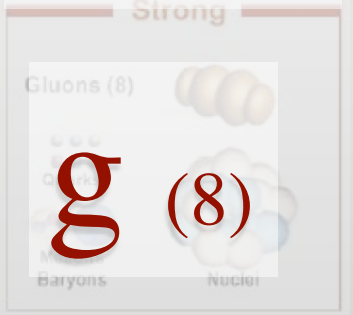
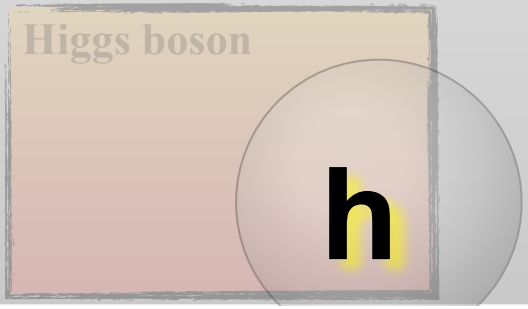




- $SU_c(3) \times SU_w(2) \times U_Y(1) \rightarrow SU_c(3) \times U_{em}(1)$
- colore e carica elettrica



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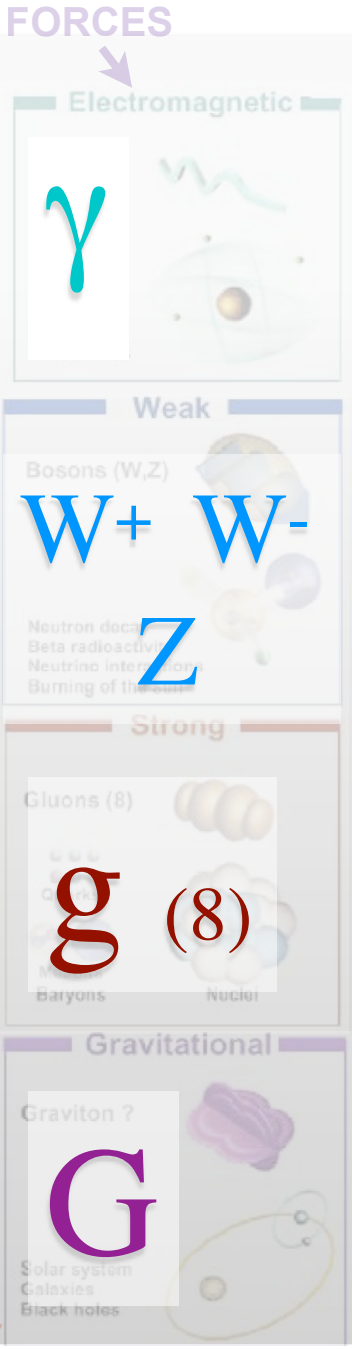
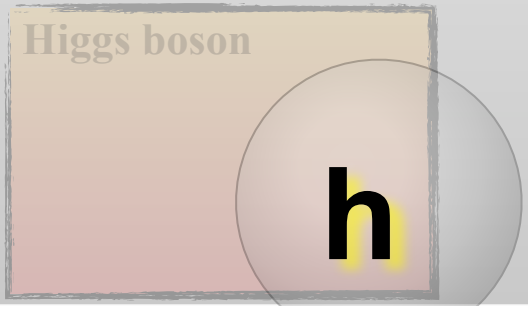


- $SU_c(3) \times SU_w(2) \times U_Y(1) \rightarrow SU_c(3) \times U_{em}(1)$
- colore e carica elettrica
- sapore barionico totale



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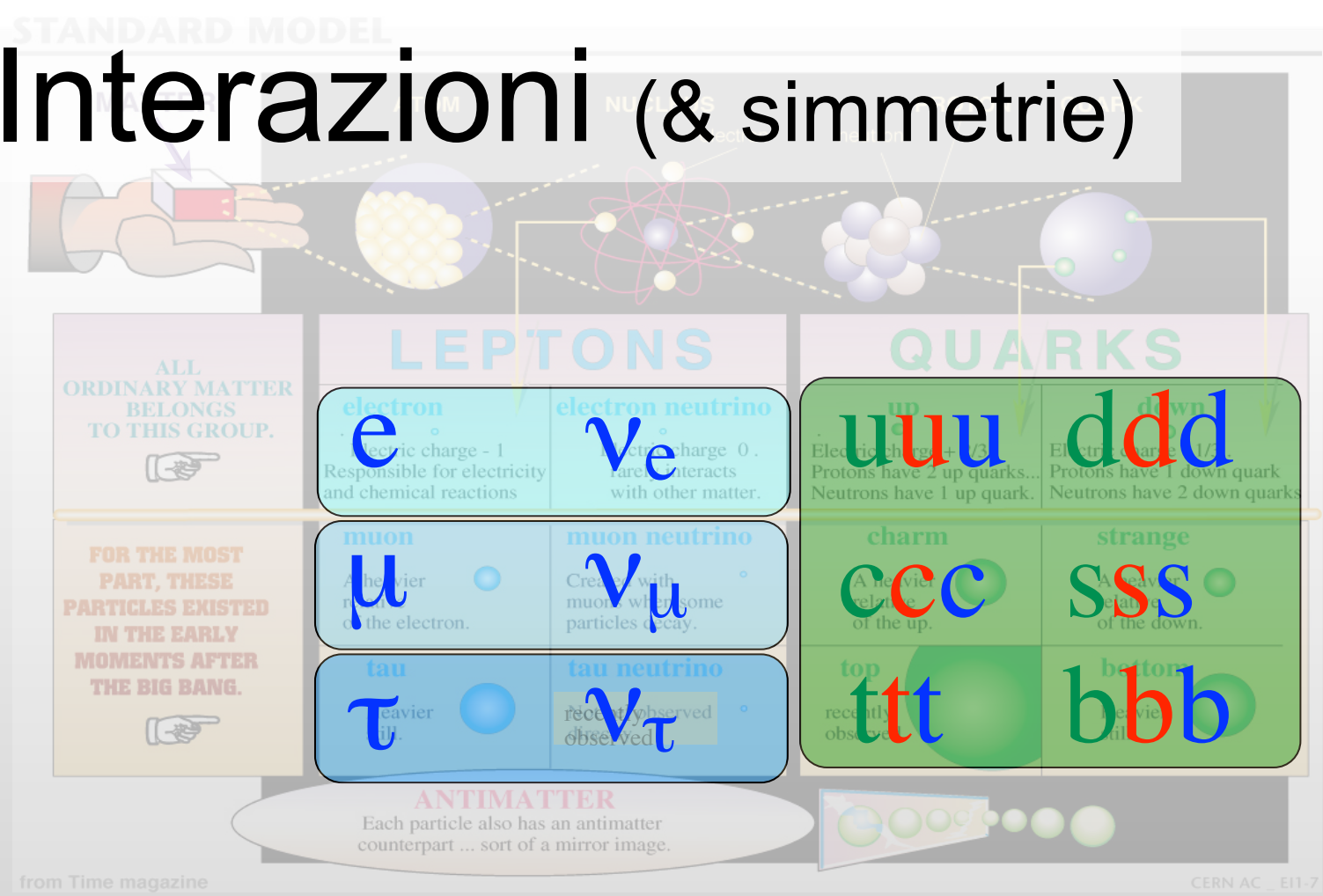
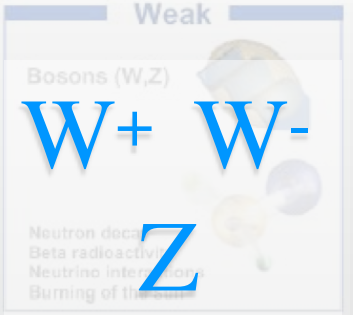
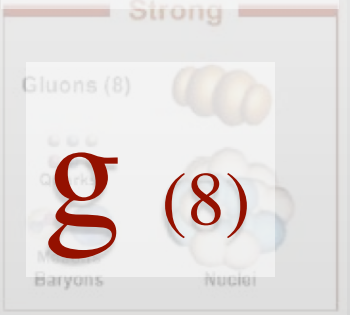
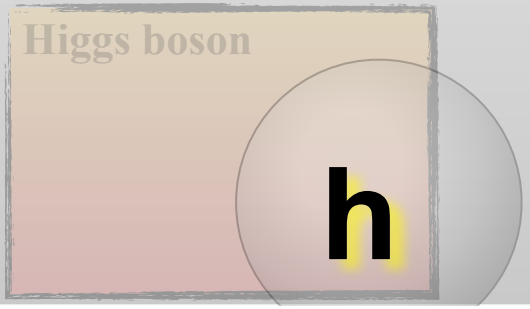






- $SU_c(3) \times SU_w(2) \times U_Y(1) \rightarrow SU_c(3) \times U_{em}(1)$
- colore e carica elettrica
- sapore barionico totale
- sapore leptonico individuale (ma: oscillazioni ν)



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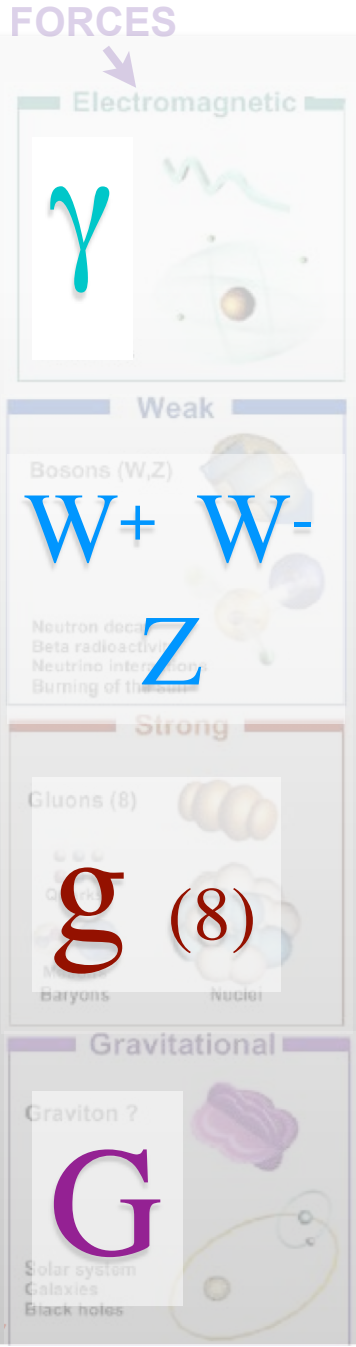
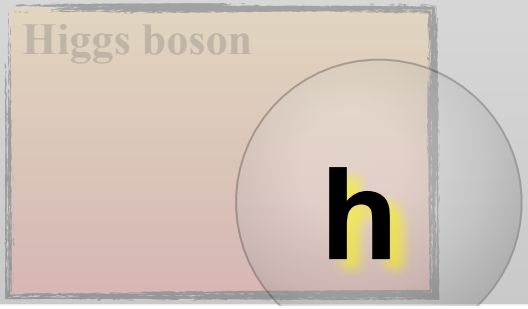
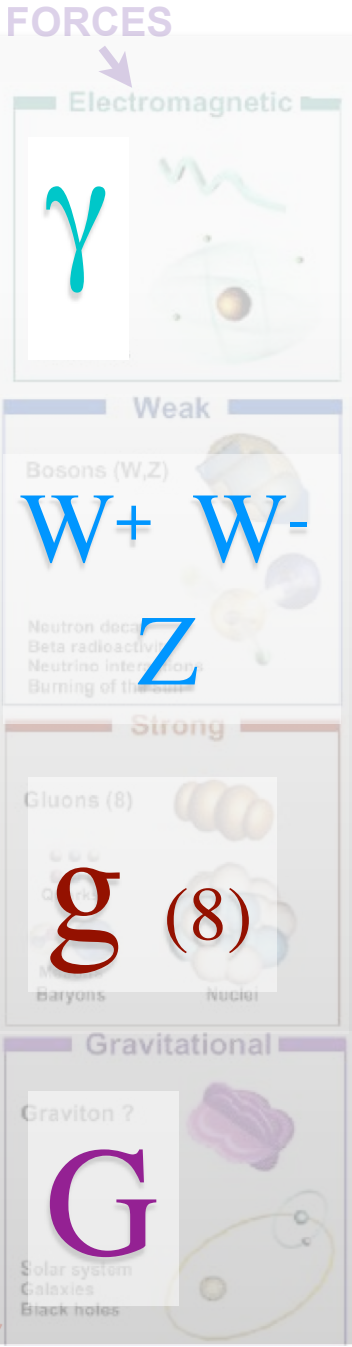


Adroni: stati composti di quarks



Interazioni (& simmetrie)



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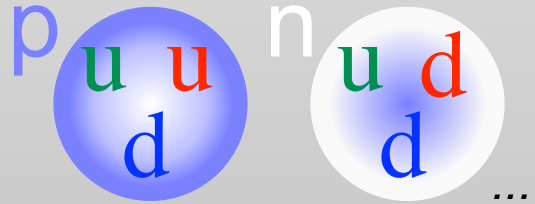
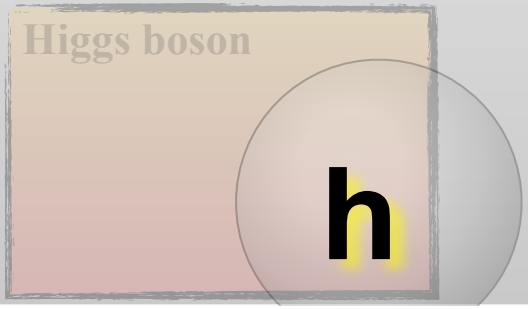


barioni ...



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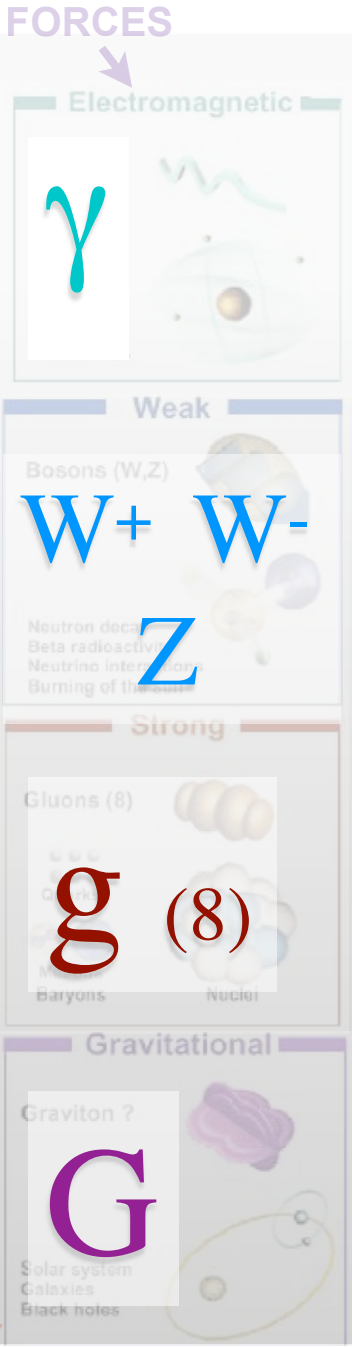

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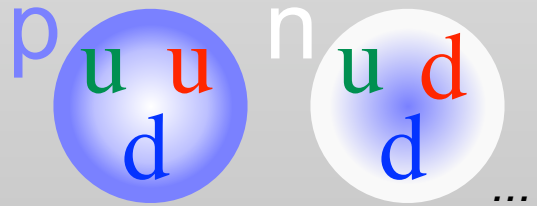
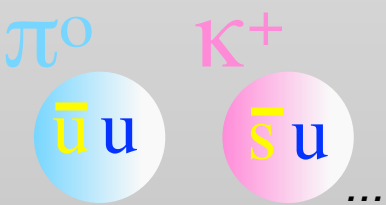
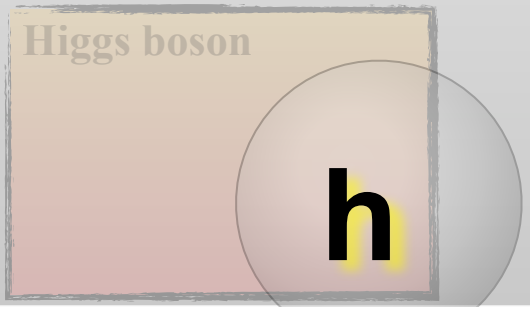


barioni



mesoni



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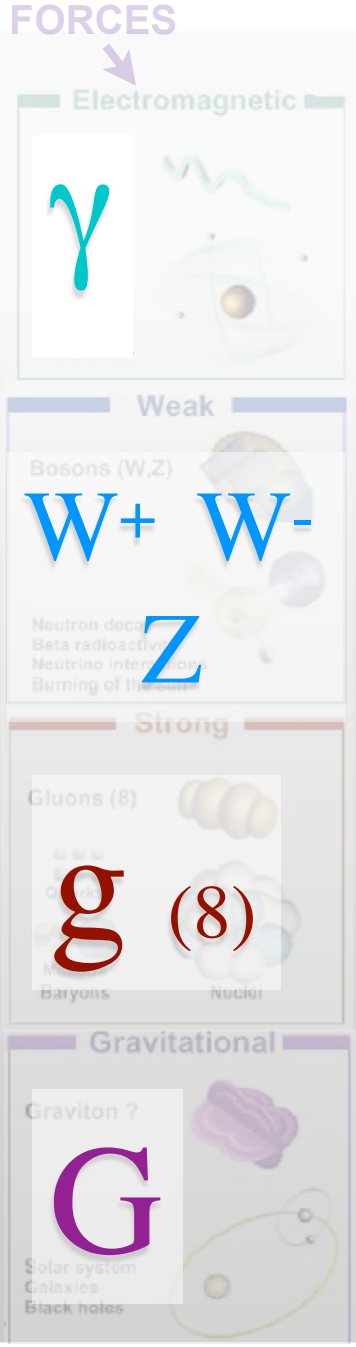

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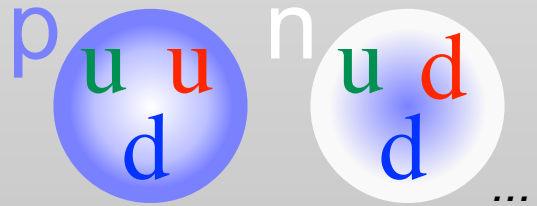
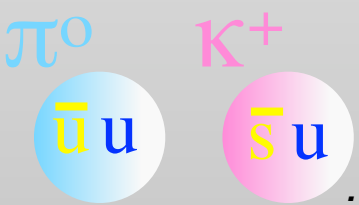
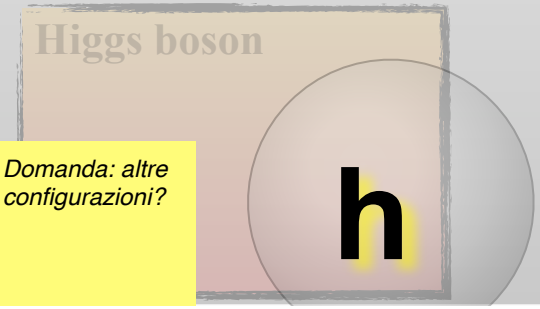


barioni ...

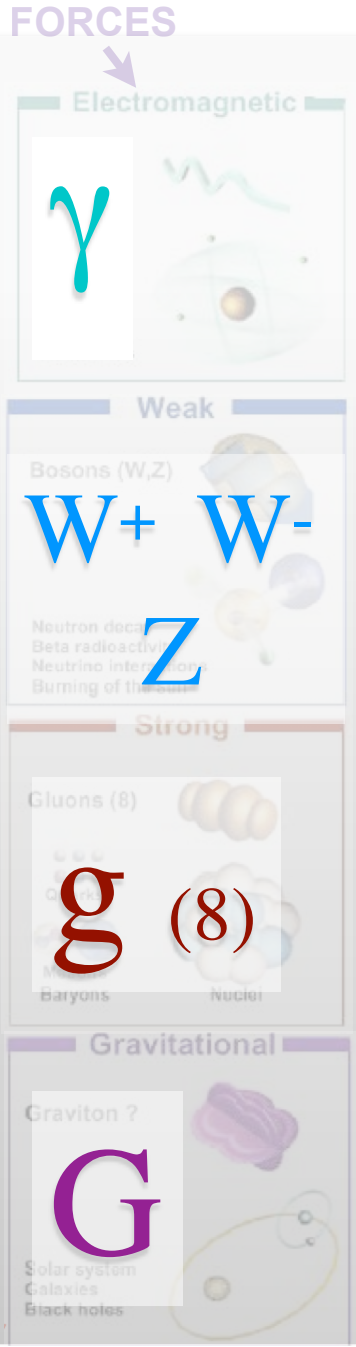


mesoni ...

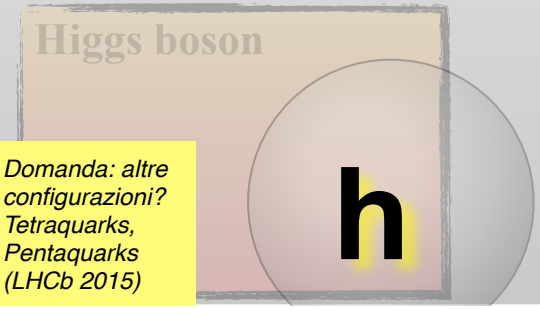


Domanda: altre configurazioni?

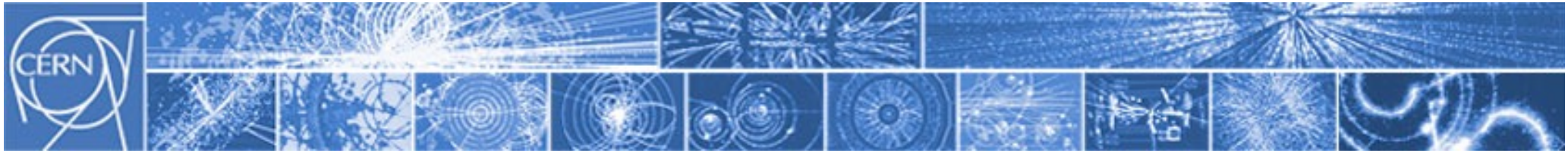
Interazioni (& simmetrie)



Adroni: stati composti di quarks

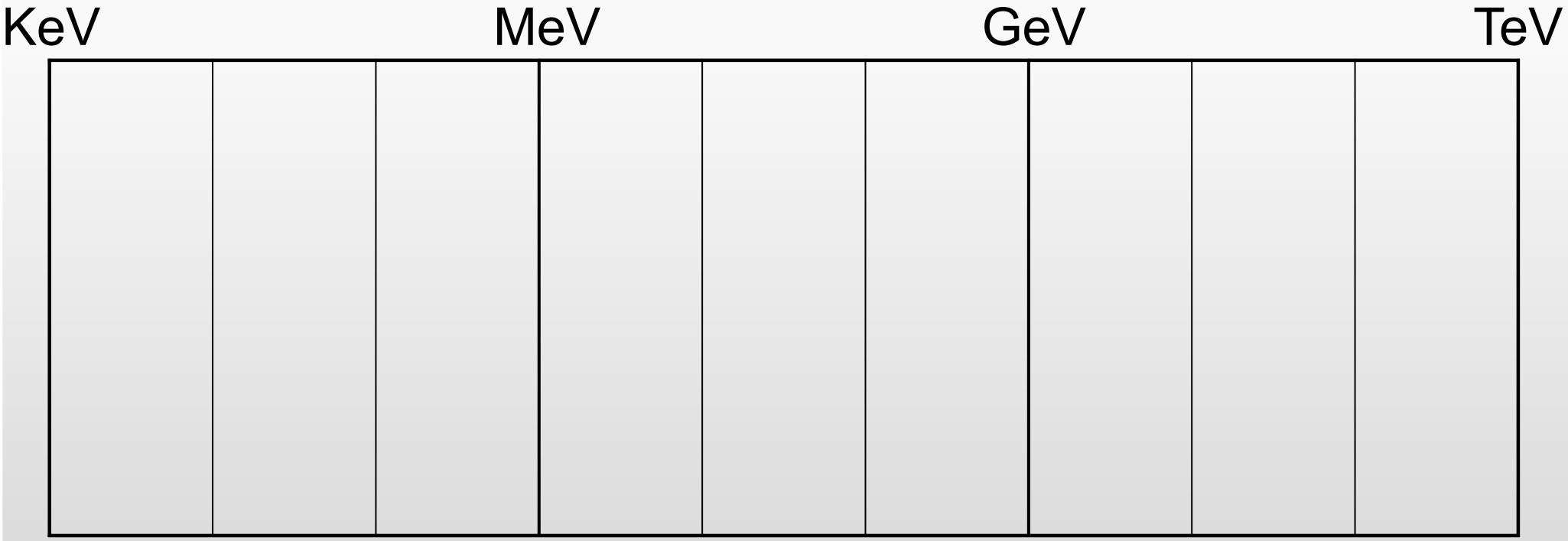


Domanda: altre configurazioni? Tetraquarks, Pentaquarks (LHCb 2015)

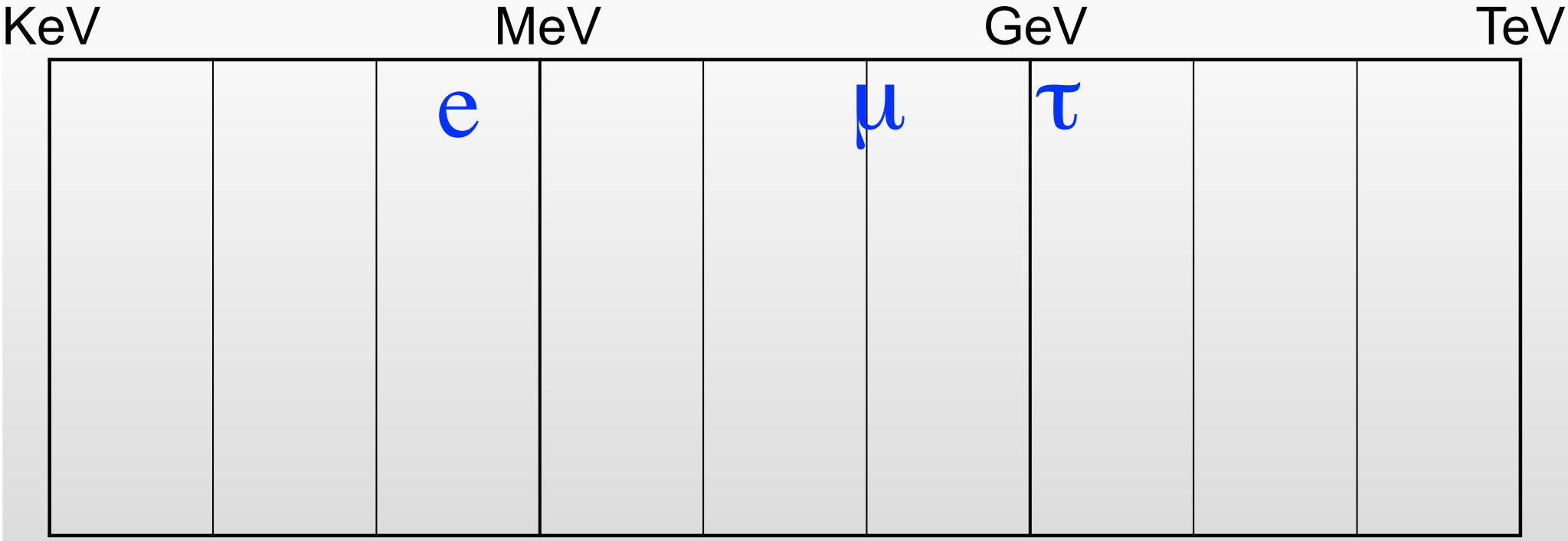


Masse

Masse

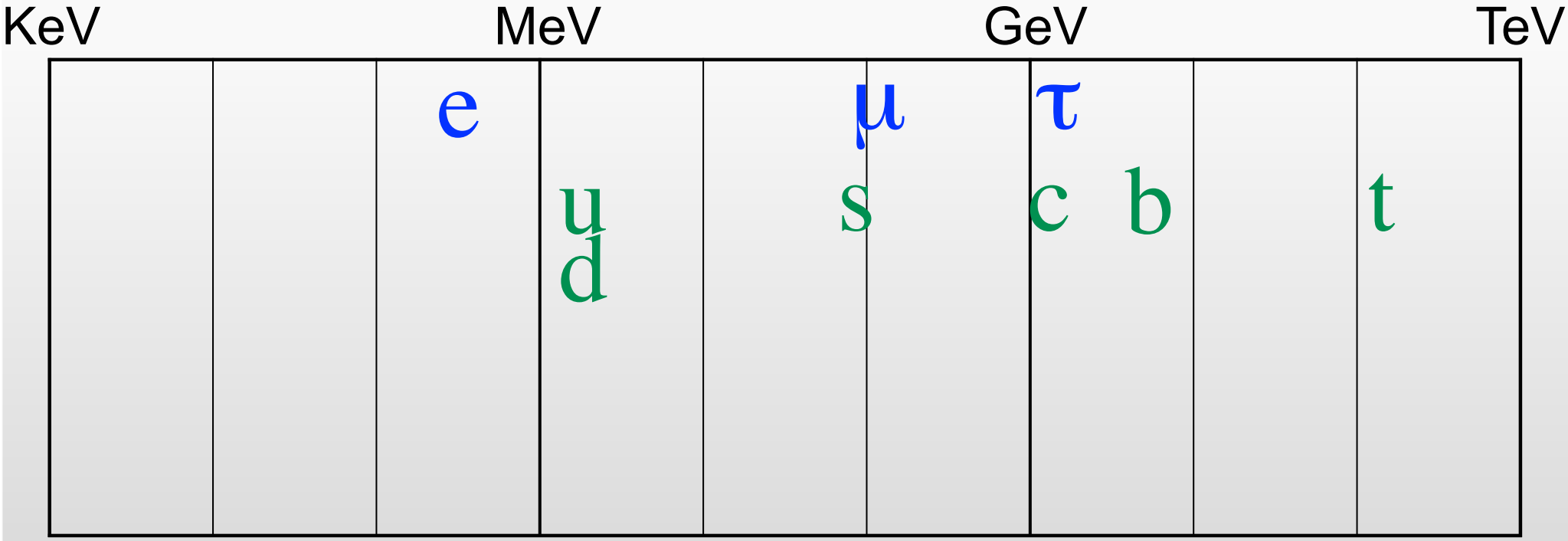


Masse



e 511 KeV
μ 105.7 MeV
τ 1.777 GeV

Masse

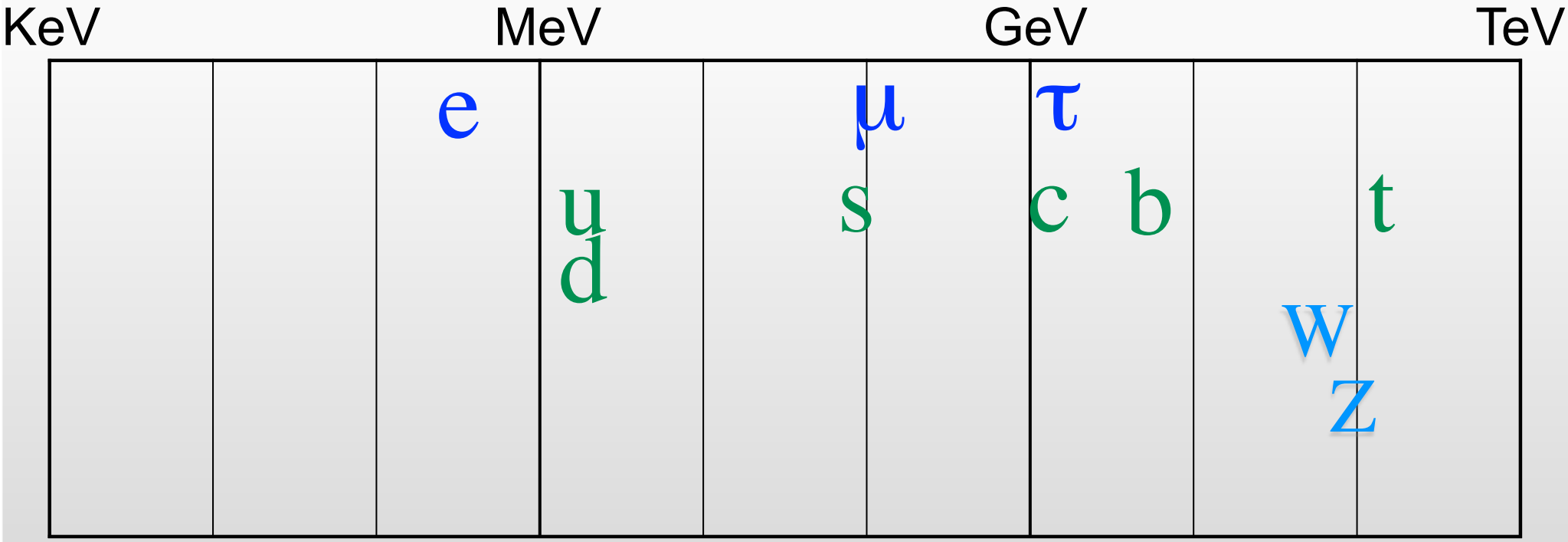


e 511 KeV
μ 105.7 MeV
τ 1.777 GeV

u ~2.3 MeV
d ~5 MeV
s ~95 MeV

c 1.27 GeV
b 4.2 GeV
t 173.2 GeV

Masse



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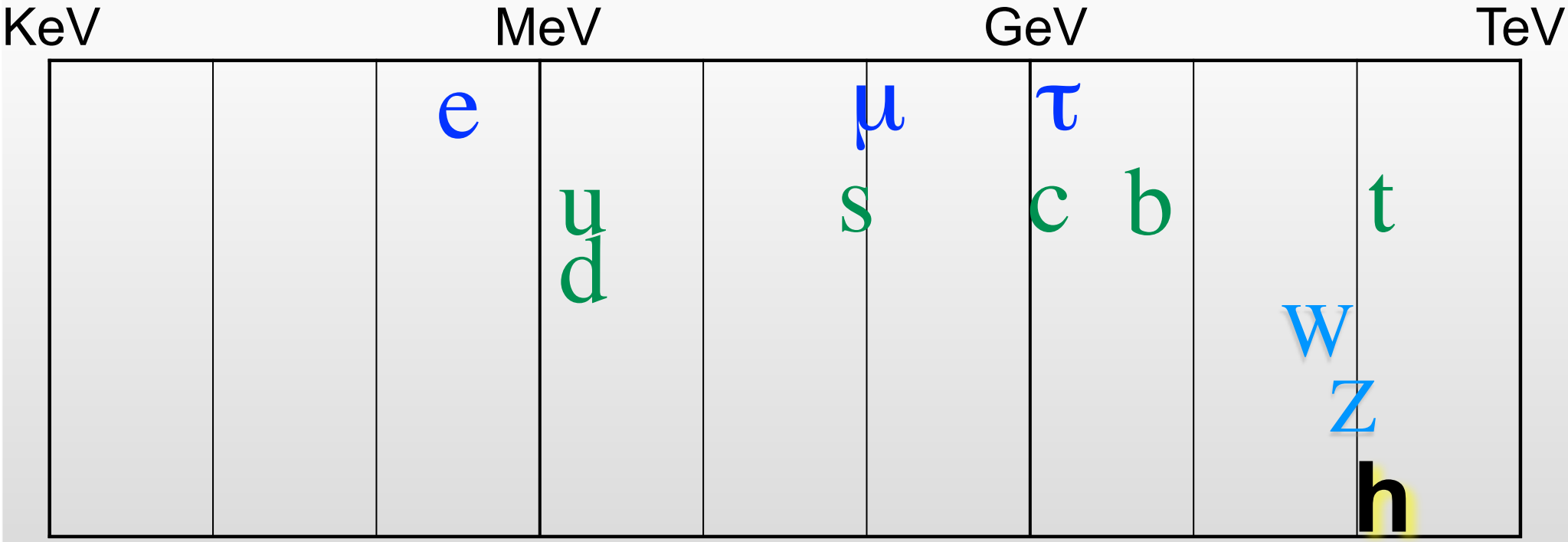
$W^{\pm}$ 80.385 GeV
Z 91.1876 GeV

Masse



e 511 KeV	u ~2.3 MeV	c 1.27 GeV	$W^{\pm}$ 80.385 GeV
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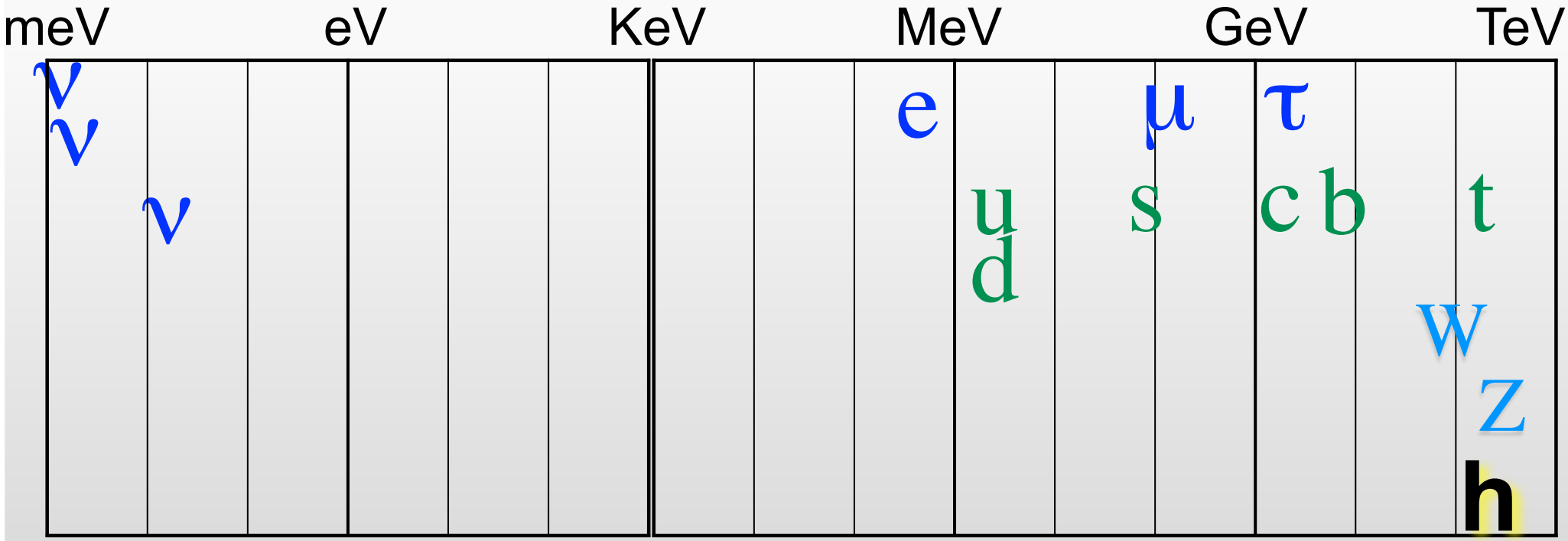
Masse



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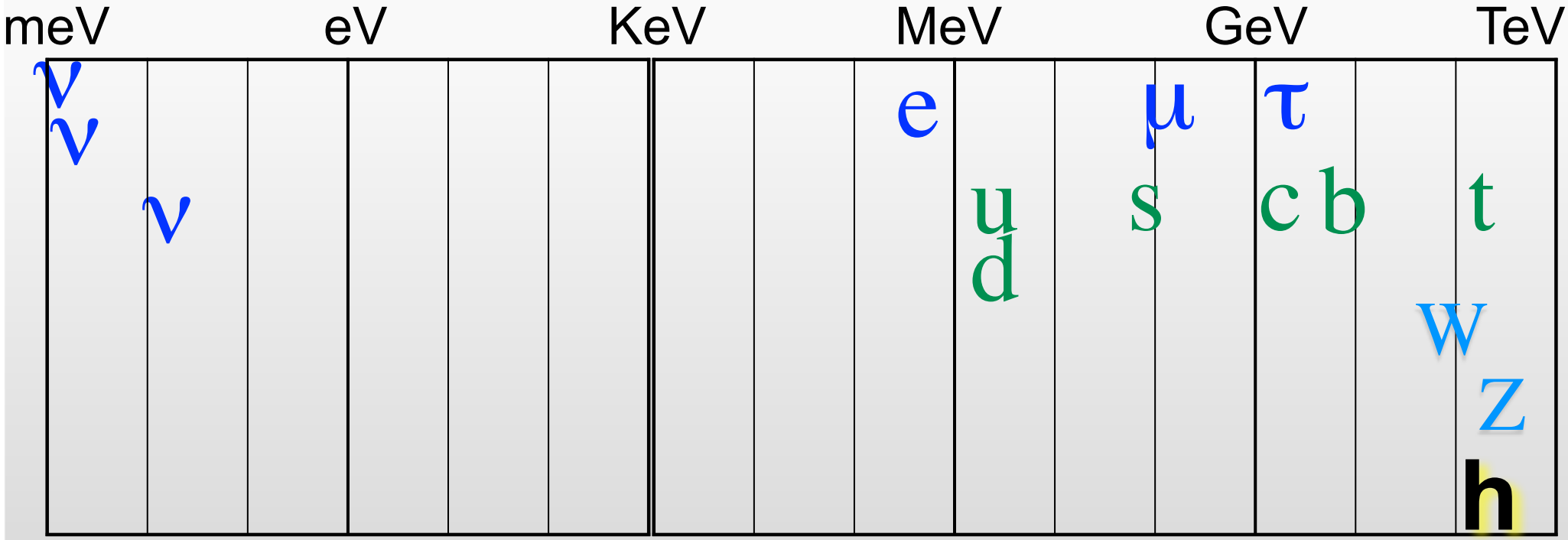
$9\ 10^{-3}\ \text{eV} \lesssim \nu_i \lesssim 0.2\ \text{eV}$

Masse

massa zero: γ g G

p ^{238}U



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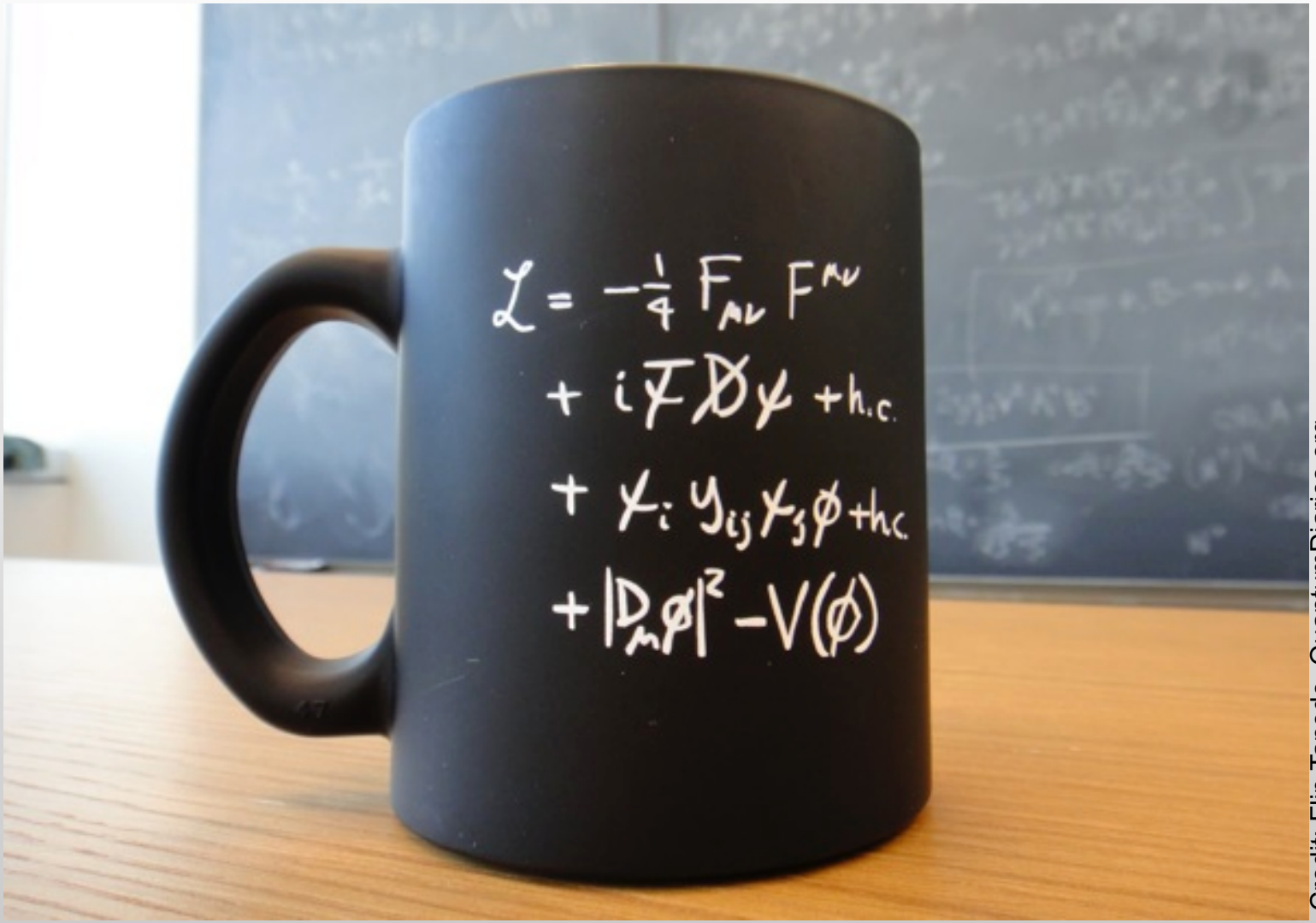
$9\ 10^{-3}$ eV $\lesssim \nu_i \lesssim$ 0.2 eV

Lagrangiana del Modello Standard



Credit: Flip Tanedo, QuantumDiaries.org

Lagrangiana del Modello Standard

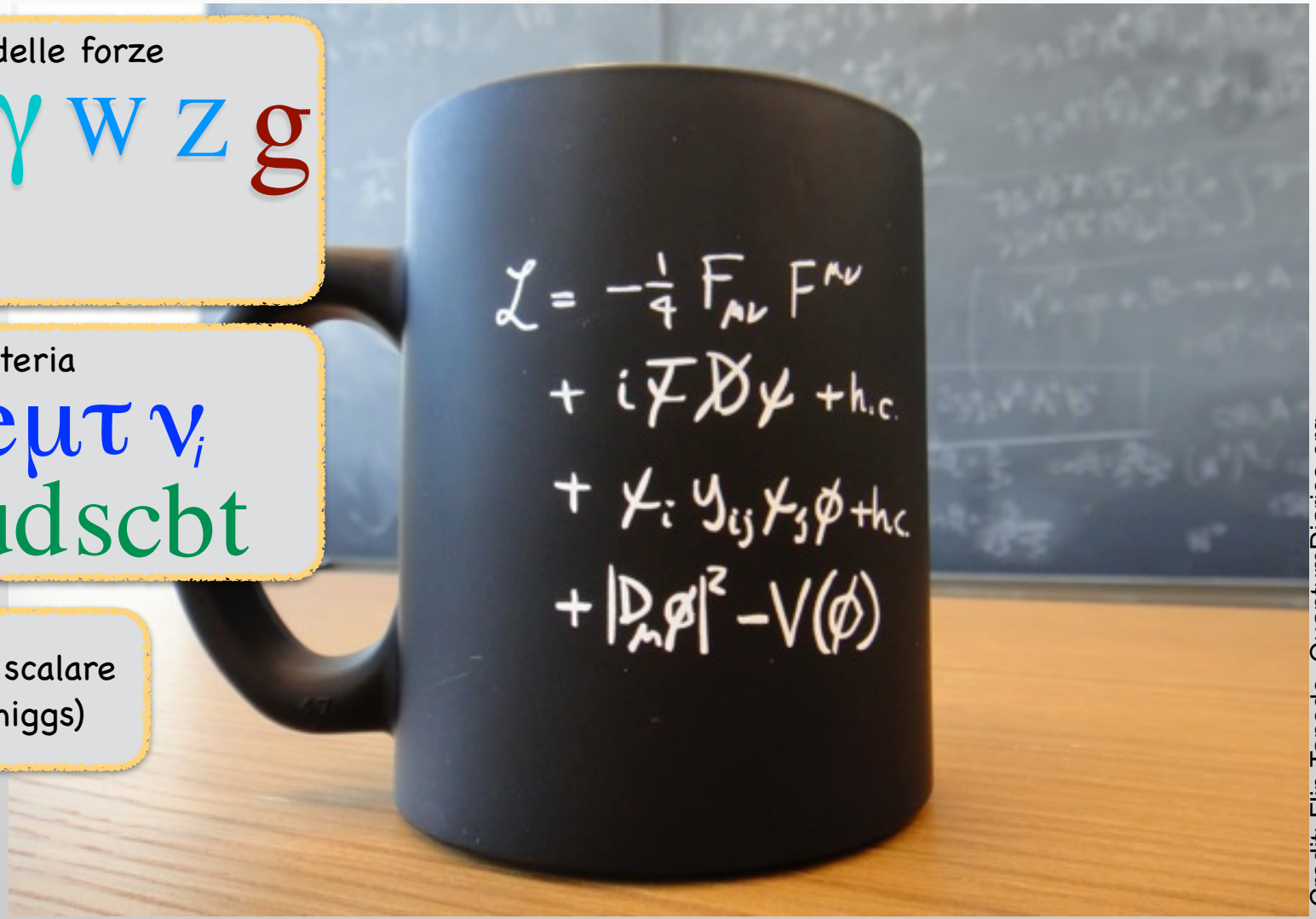
mediatori delle forze

$F_{\mu\nu}$ $\partial\!\!\!/$ → γ W Z g

campi di materia

ψ → e μ τ ν_i
u d s c b t

ϕ campo scalare (-> di higgs)



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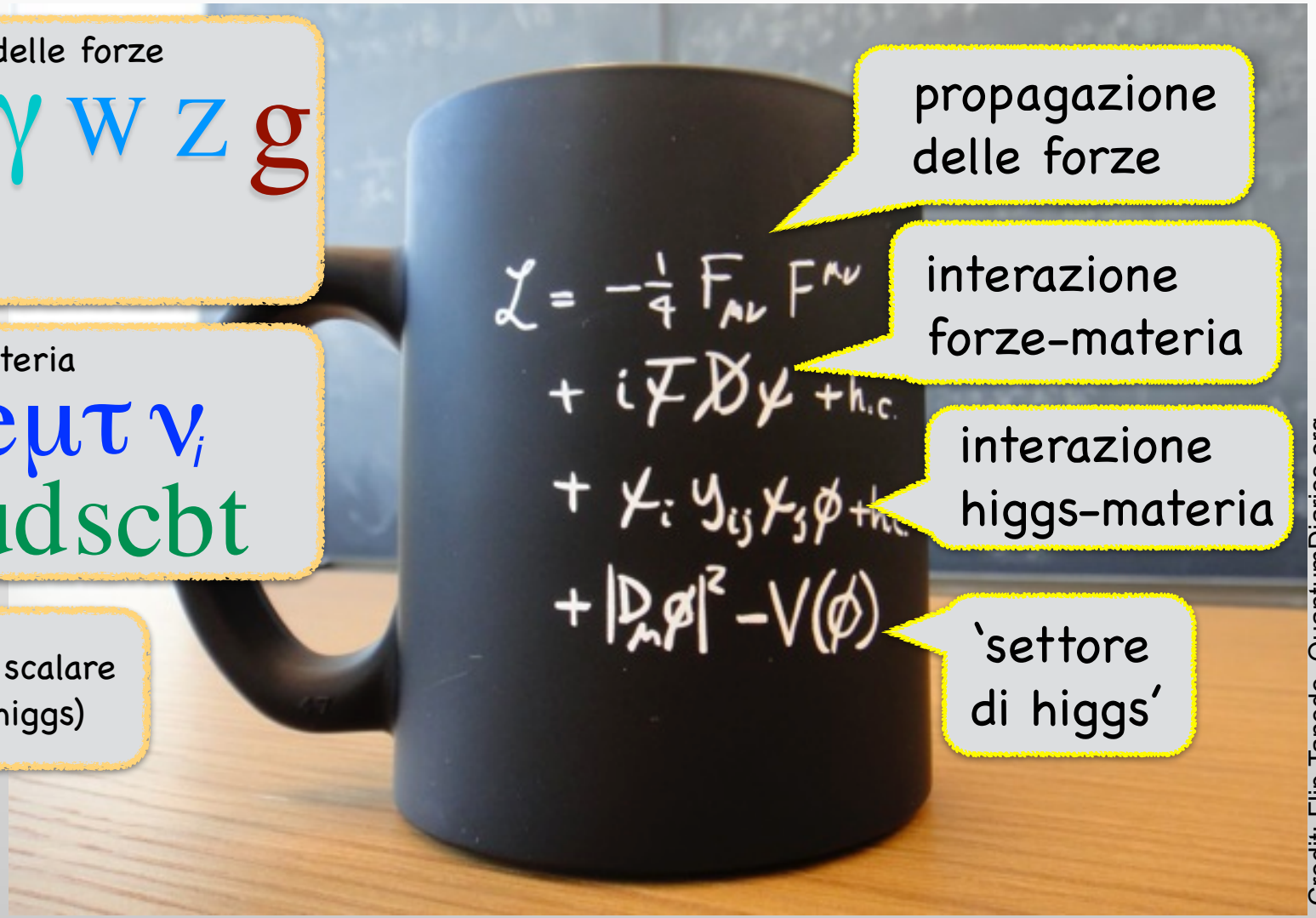
Lagrangiana del Modello Standard



mediatori delle forze

$F_{\mu\nu}$ → γ W Z g

$\not{D}$

propagazione delle forze

campi di materia

ψ → e μ τ ν_i u d s c b t

interazione forze-materia

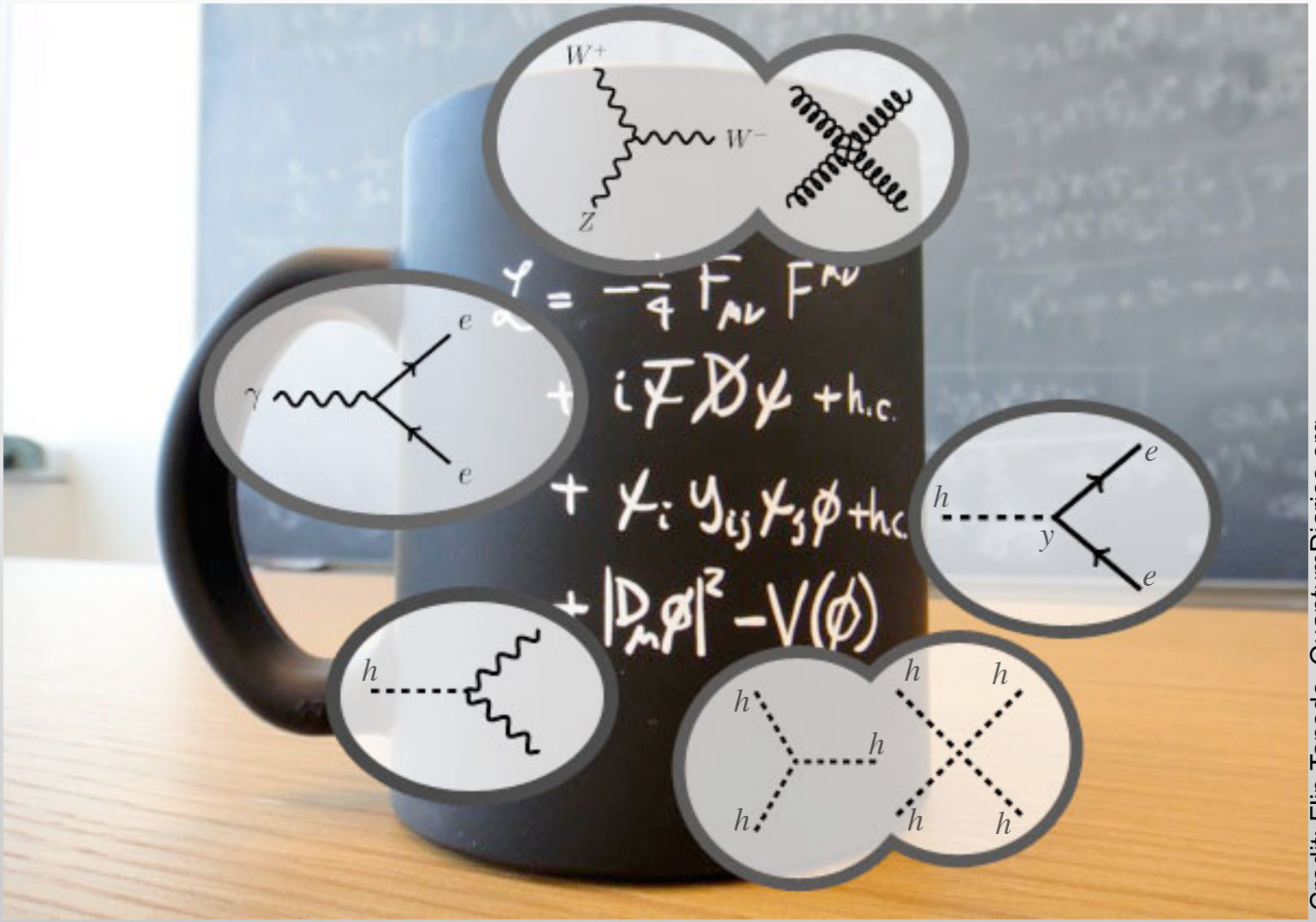
interazione higgs-materia

ϕ campo scalare (-> di higgs)

'settore di higgs'

Credit: Flip Tanedo, QuantumDiaries.org

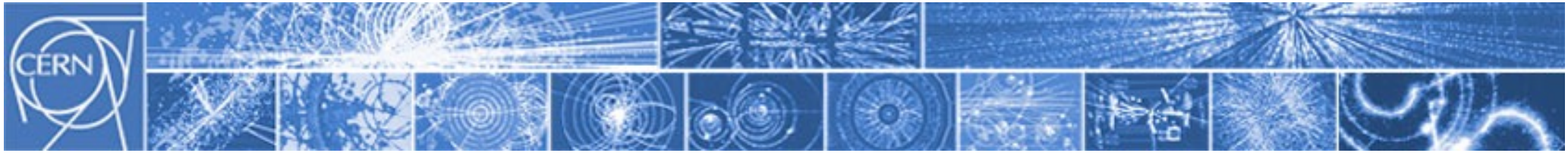
Lagrangiana del Modello Standard



Credit: Flip Tanedo, QuantumDiaries.org

presentazione per insegnanti:

J. Woithe, J. Wiener, F. Van der Veken, *Let's have a coffee with the Standard Model of particle physics!*, Phys. Educ. 52 (2017) 034001



I diagrammi di Feynman al lavoro

Esempio 1: collisione e^+e^-

(semirigoroso)

I diagrammi di Feynman al lavoro

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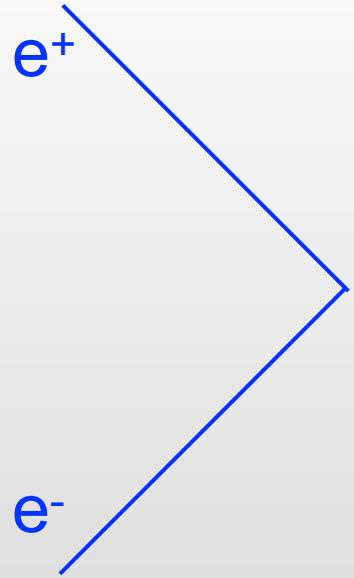
LEP
105 GeV



I diagrammi di Feynman al lavoro

Esempio 1: collisione e^+e^-

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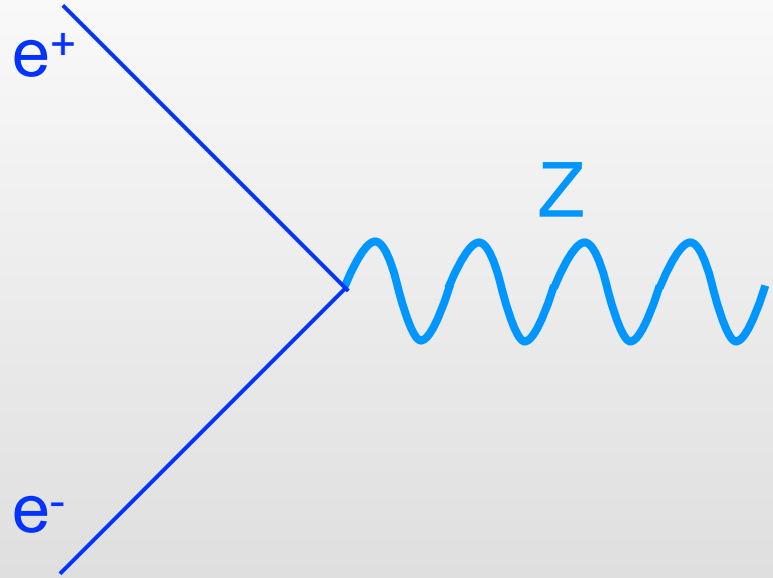

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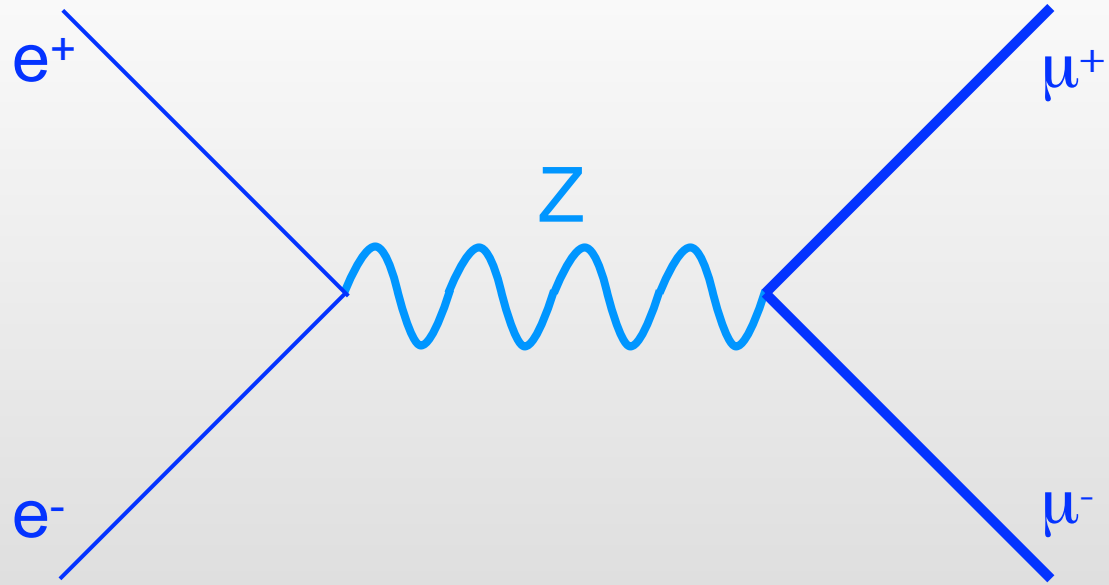

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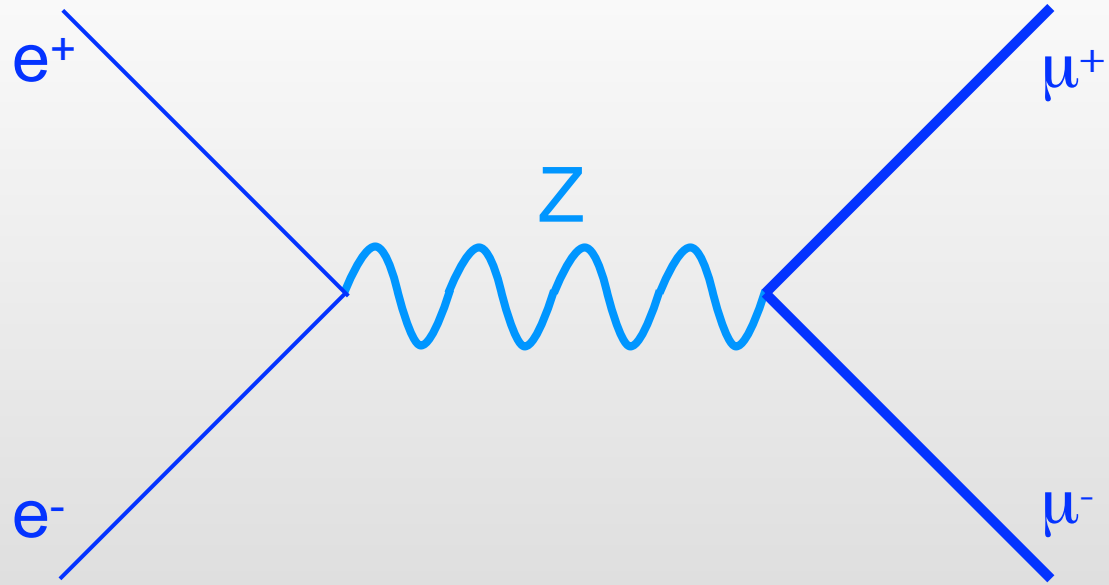

- ☑ *carica elettrica*
- ☑ *sapore leptonico indiv.*

I diagrammi di Feynman al lavoro

Esempio 1: collisione e^+e^-

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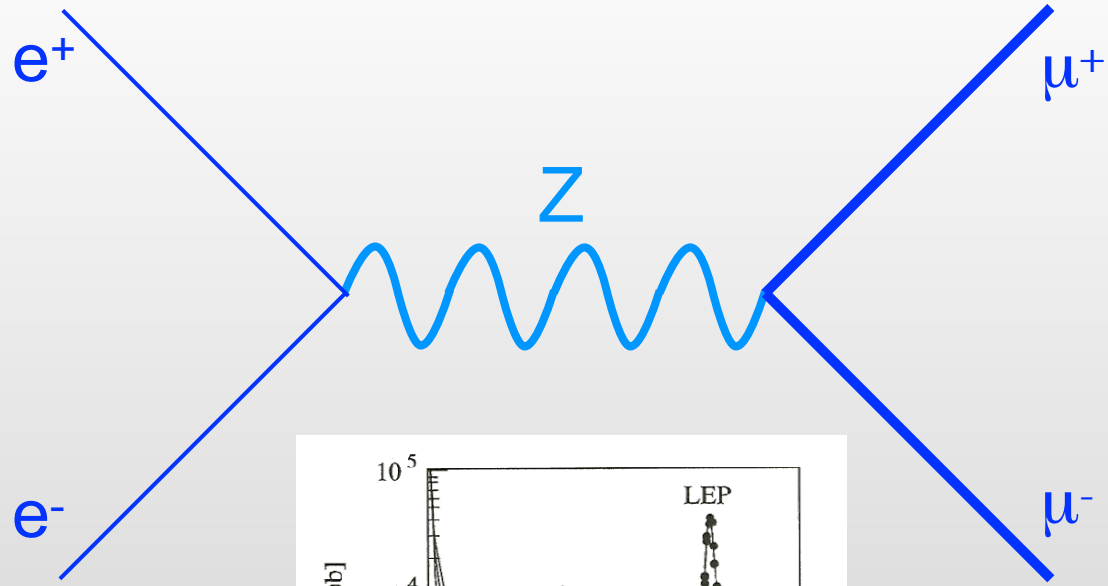
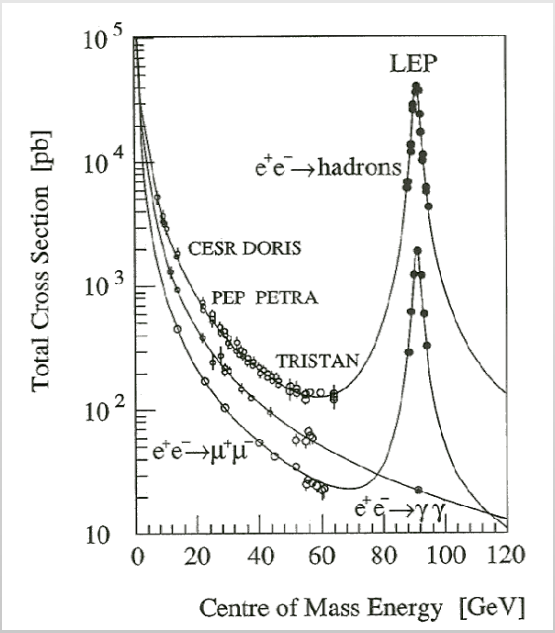


LEP
105 GeV

- ☑ *carica elettrica*
- ☑ *sapore leptonico indiv.*

La *risonanza* tradisce la produzione del *mediatore.*

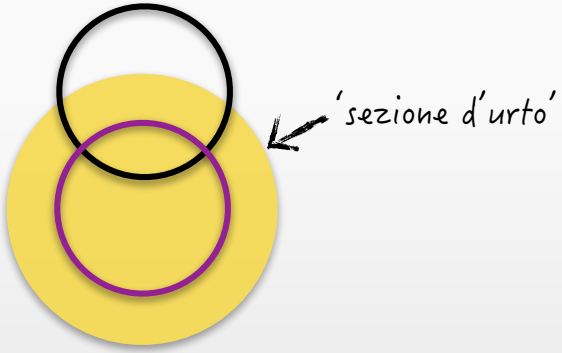
Magari scopriremo così un nuovo *mediatore*.

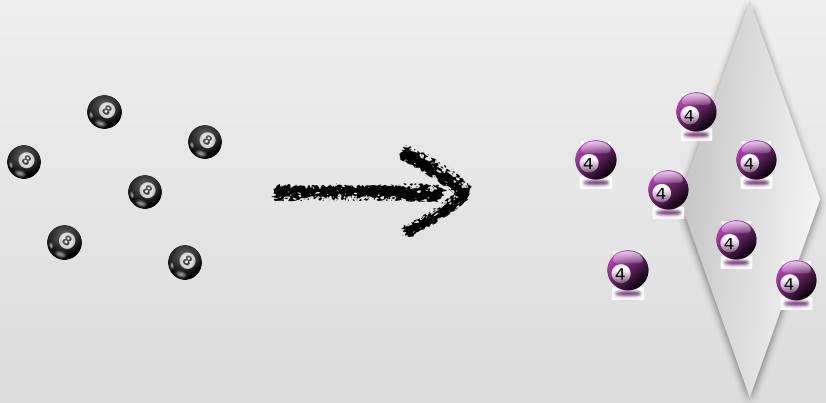


Domande per i più motivati:
perché la sezione d'urto $e^+e^-\to$hadrons è più grande di quella $e^+e^-\to\mu^+\mu^-$?
sai calcolare a priori il rapporto?
e perché quella $e^+e^-\to\gamma\gamma$ si comporta diversamente?

(*Parentesi*: sezione d'urto:

'Particelle' classiche:





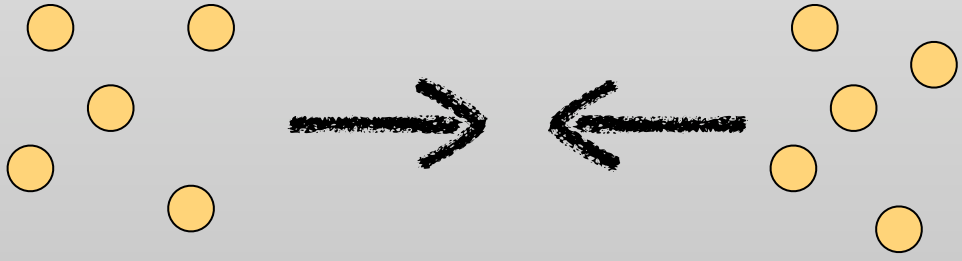
$$N \text{ urti per sec} = \Phi_{inc} \times N_{bers} \times \mathbf{S}$$

flusso incidente (particelle/s)

bersagli per area (particelle/cm^2)

superficie effettiva 1 bersaglio (cm^2)

Particelle quantistiche:



$$N \text{ eventi per sec} = \Phi_{inc} \times \rho_{bers} \times \boldsymbol{\sigma}$$

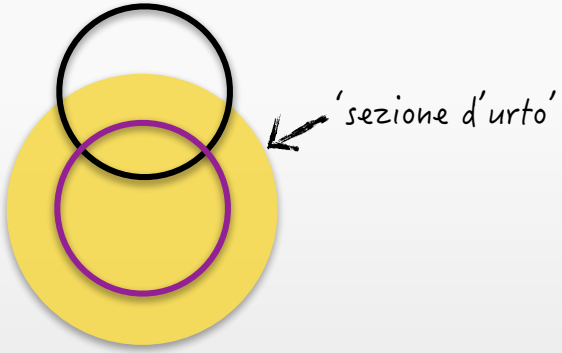
sezione d'urto

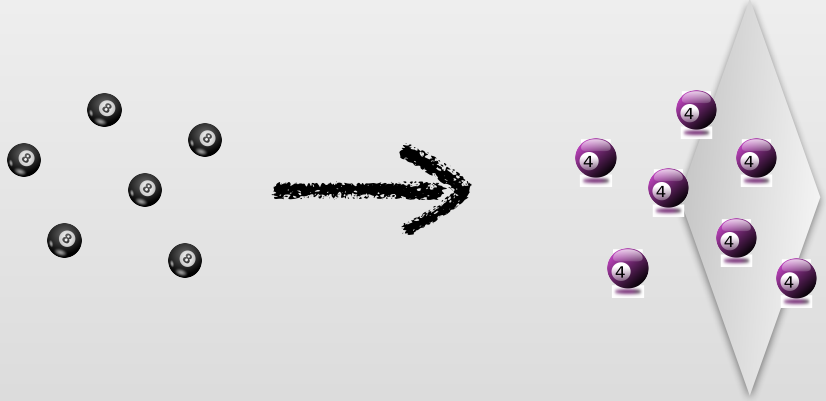
$$\boldsymbol{\sigma} = \frac{N/s}{\Phi_{inc}} \times \frac{1}{\rho_{bers}} = \text{probab} \times \frac{1}{\rho_{bers}}$$

)

(*Parentesi*: sezione d'urto:

'Particelle' classiche:





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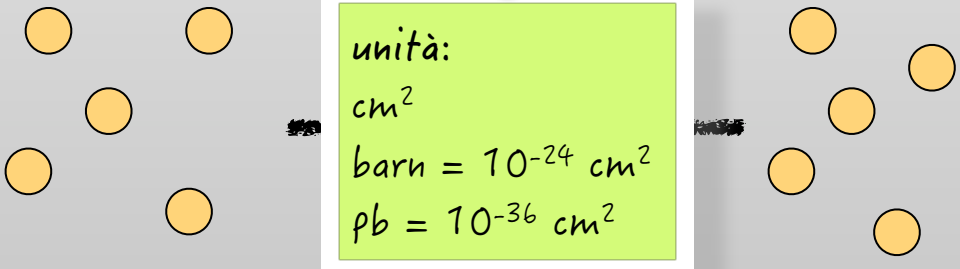

unità:
cm^2
barn = 10^{-24} cm^2
pb = 10^{-36} cm^2

$$N \text{ eventi per sec} = \Phi_{inc} \times \rho_{bers} \times \boldsymbol{\sigma}$$

sezione d'urto

$$\boldsymbol{\sigma} = \frac{N/s}{\Phi_{inc}} \times \frac{1}{\rho_{bers}} = \text{probab} \times \frac{1}{\rho_{bers}}$$

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