L’interazione forte

Fabrizio Tavecchio
INAF-OAB

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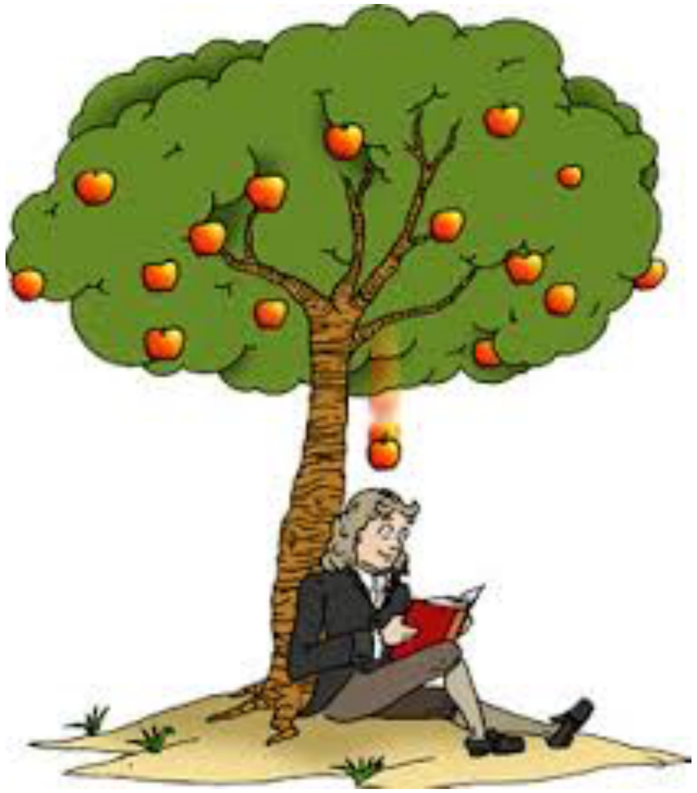
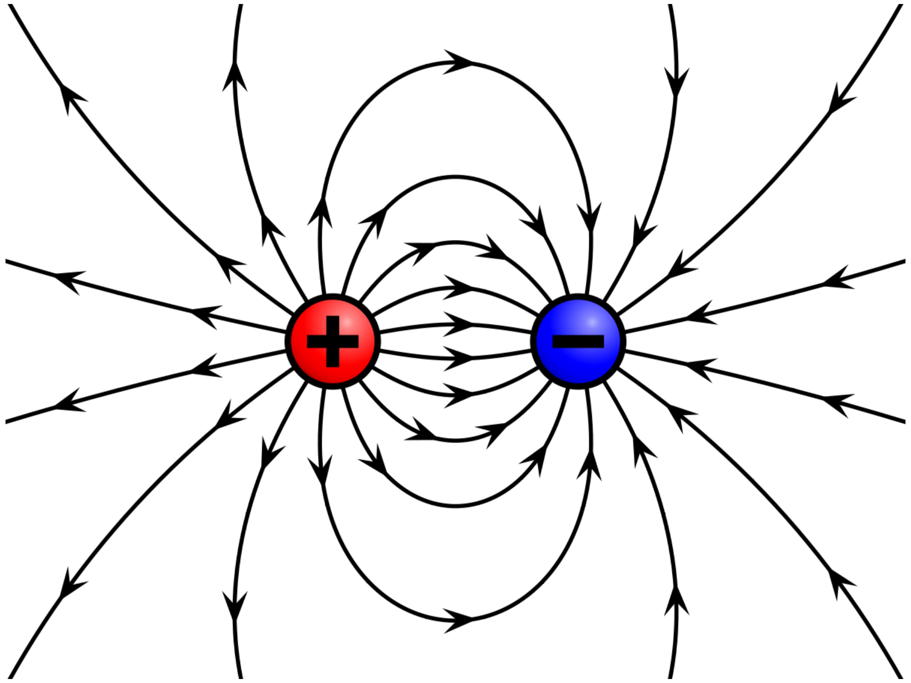
Corsi di astronomia all'Osservatorio Astronomico di Brera

«*I colori maturano la notte*» - Alda Merini

Interazioni (o forze)



$$F = G\,\frac{m_1 m_2}{r^2}$$

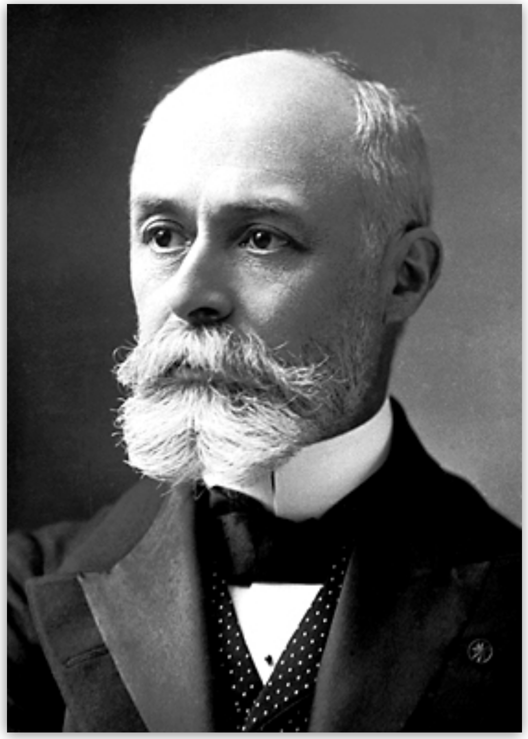


$$F = K\,\frac{q_1 q_2}{r^2}$$

Inizio '900

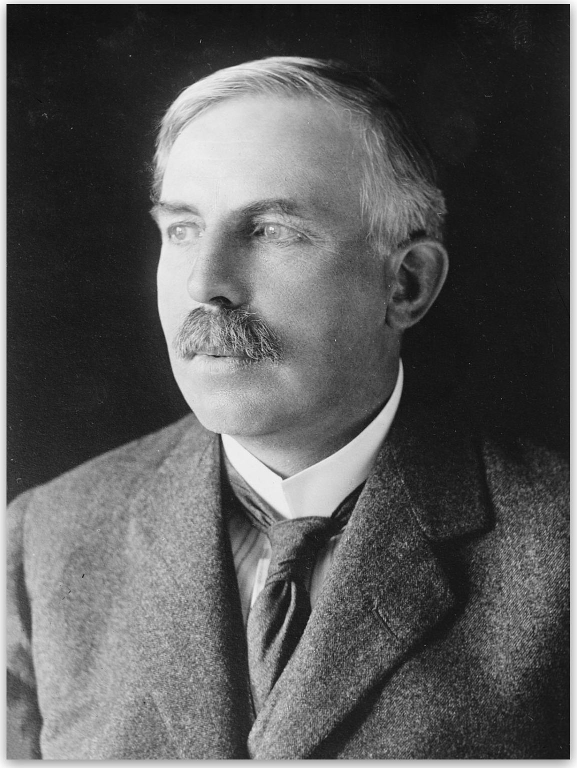
L’atomo e il nucleo atomico

Bequerel



Thomson

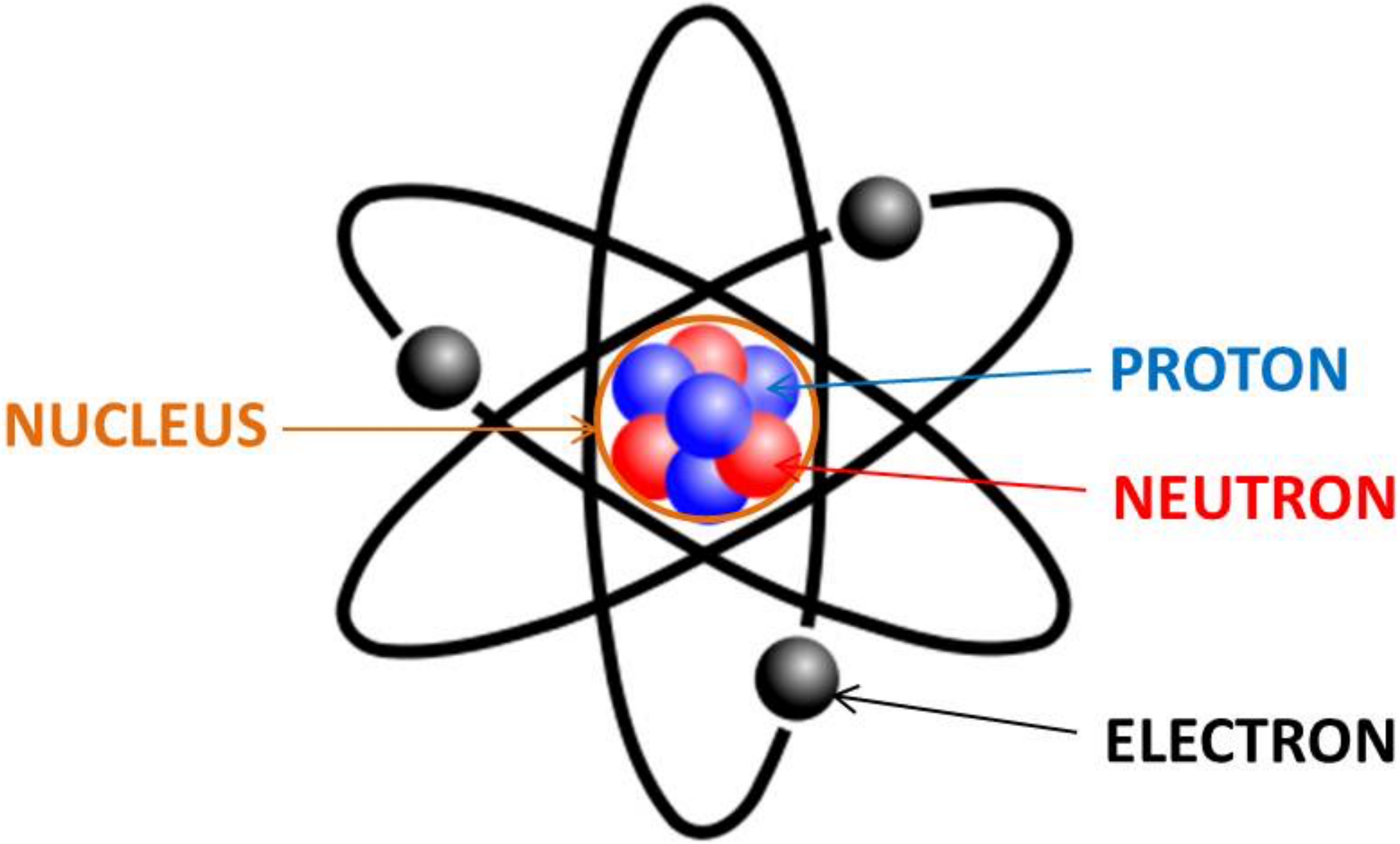
Rutherford



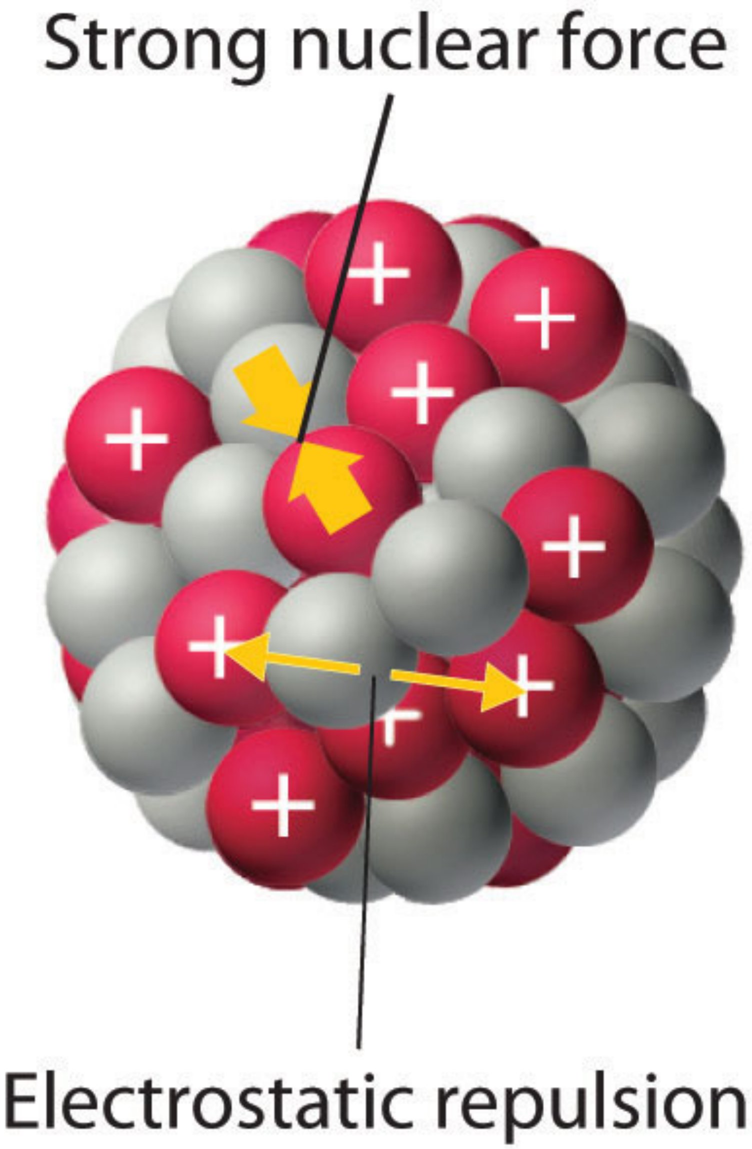
Chadwick

L'atomo

~1932


NUCLEUS
PROTON
NEUTRON
ELECTRON

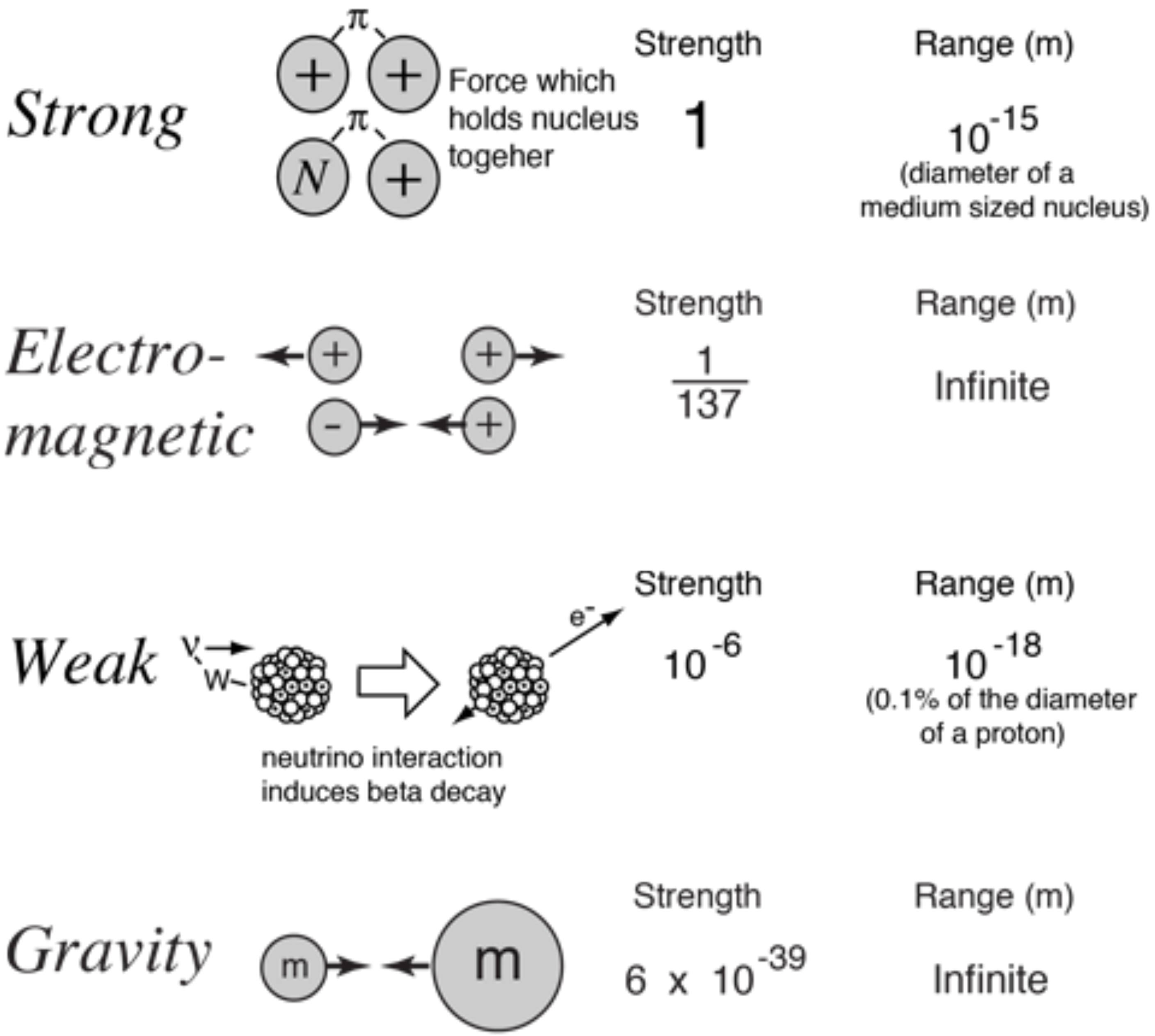
Il nucleo atomico


Strong nuclear force
+
Electrostatic repulsion

Una nuova interazione

L'esistenza di protoni e neutroni legati nei nuclei implica l'esistenza di una nuova interazione, definita FORTE

Perche’ forte?

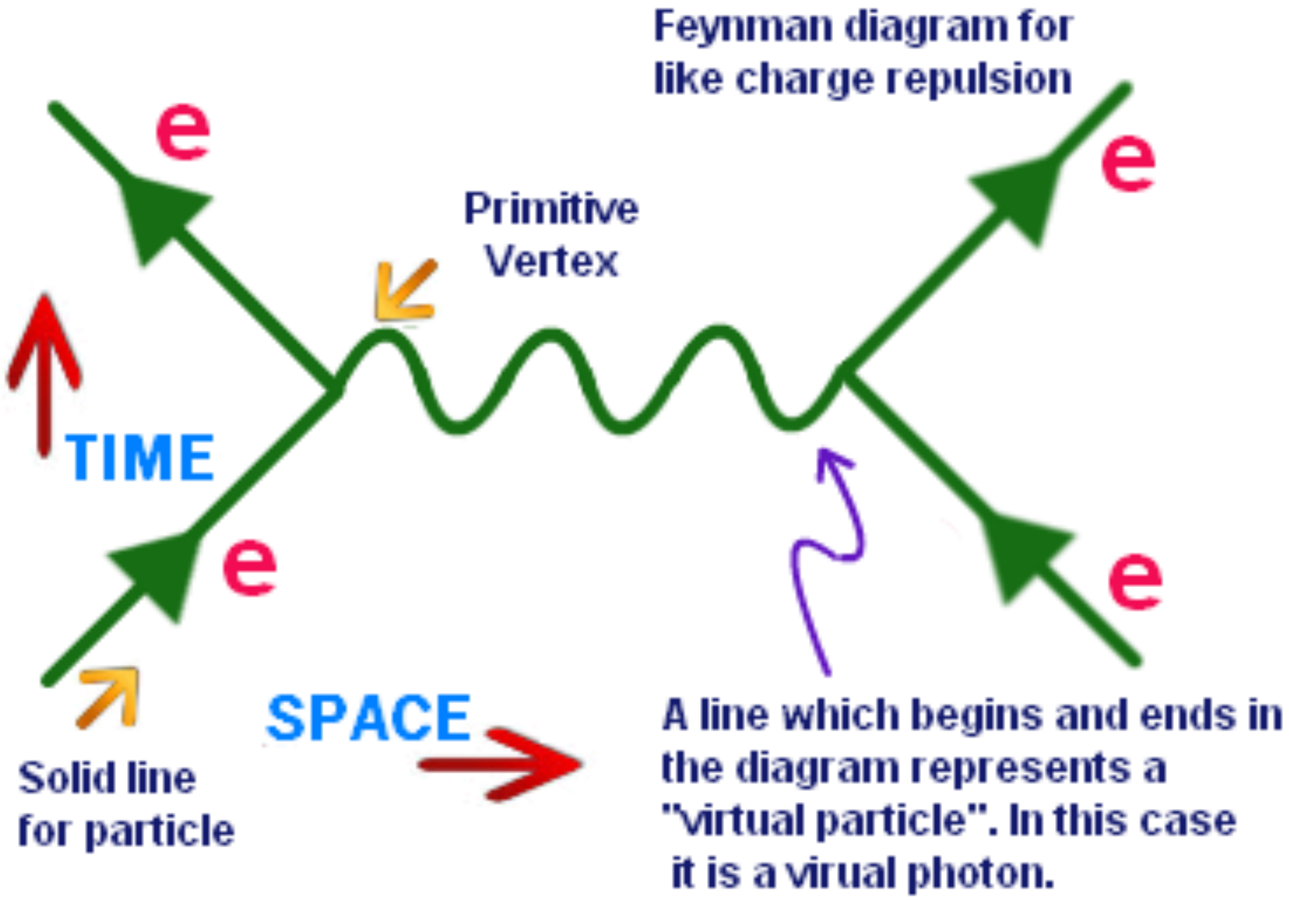


Force which holds nucleus togeher

neutrino interaction induces beta decay

	Strength	Range (m)
Strong	1	10^{-15} (diameter of a medium sized nucleus)
Electro-magnetic	$\frac{1}{137}$	Infinite
Weak	10^{-6}	10^{-18} (0.1% of the diameter of a proton)
Gravity	6×10^{-39}	Infinite

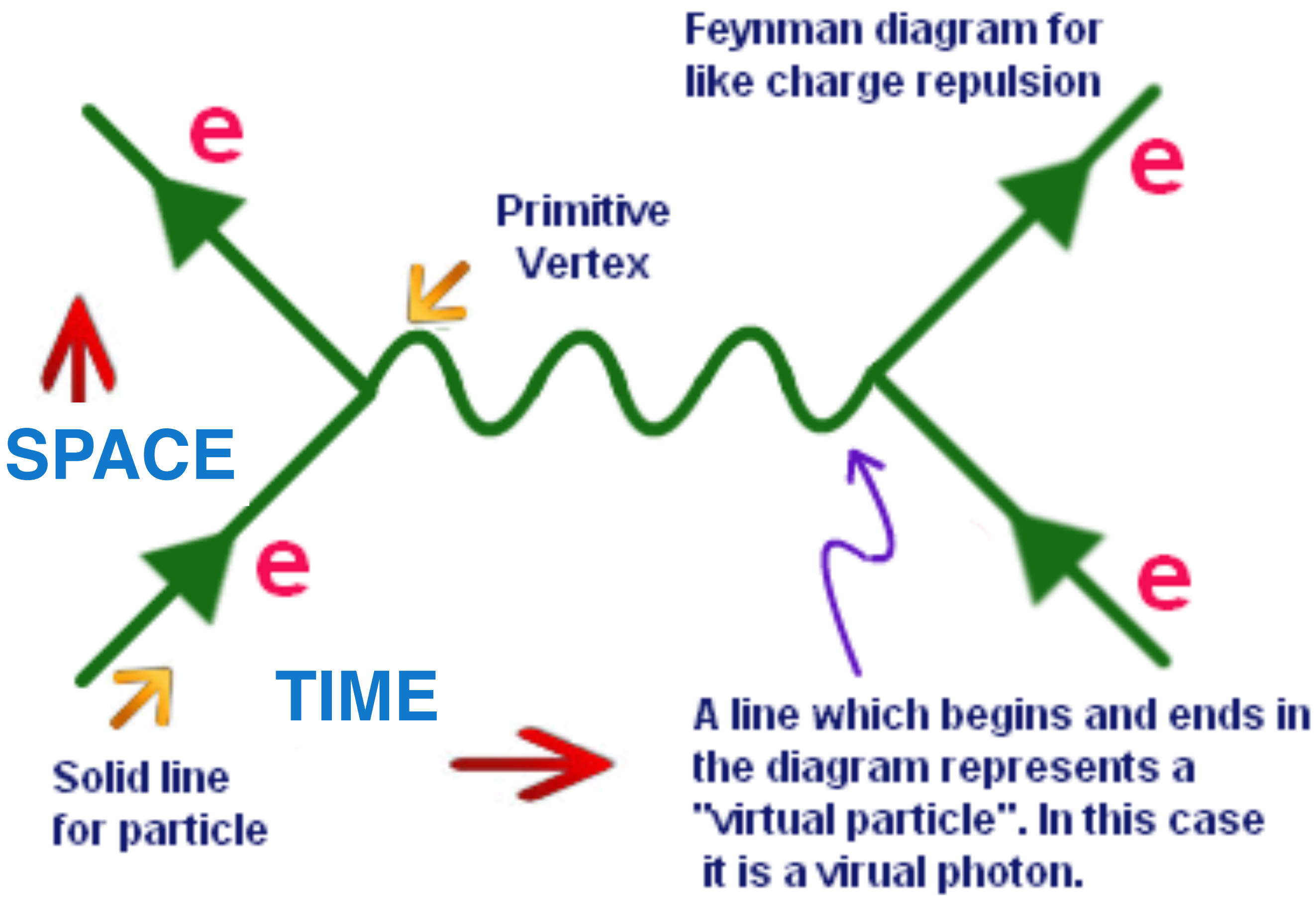
Interazioni


e
e
e
e
TIME
SPACE
Primitive Vertex
Solid line for particle

Feynman diagram for like charge repulsion

A line which begins and ends in the diagram represents a "virtual particle". In this case it is a virual photon.

Interazioni


Feynman diagram for
like charge repulsion
e
e
e
e
Primitive
Vertex
SPACE
TIME
Solid line
for particle
A line which begins and ends in
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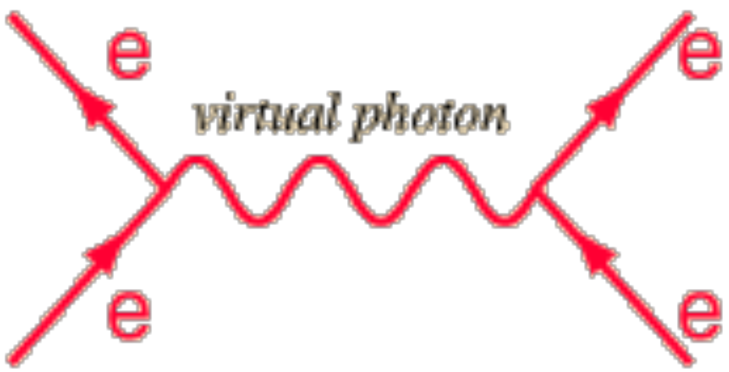
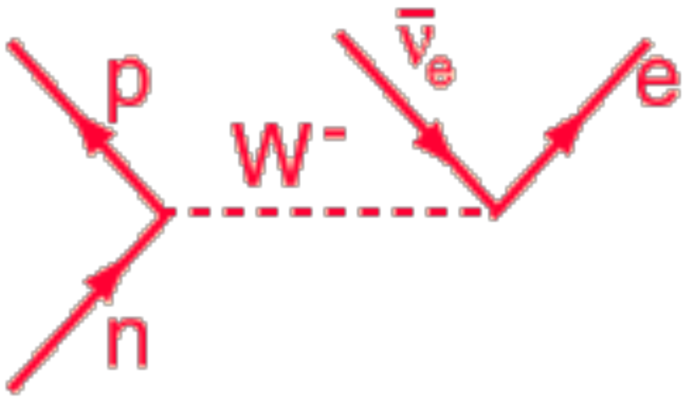
Interazioni

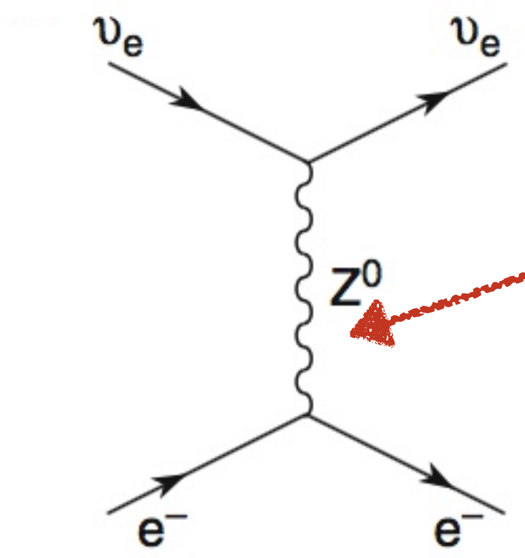

e
virtual photon
e
e
e

Electromagnetic


p
W⁻
$\bar{\nu}_e$
e
n

Weak

Mediatori



Particella "virtuale"

$$\Delta t \sim h/\Delta E$$

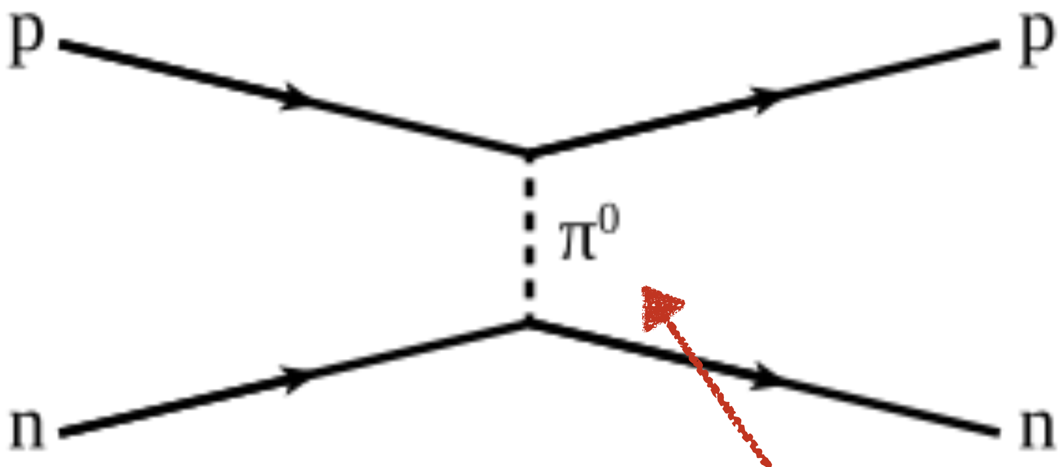
Principio di indeterminazione

$$\Delta t \sim h/Mc^2$$

Fotone M=0 —> raggio di azione infinito

Z0 M=100 GeV (100 volte il protone)

Mediatori



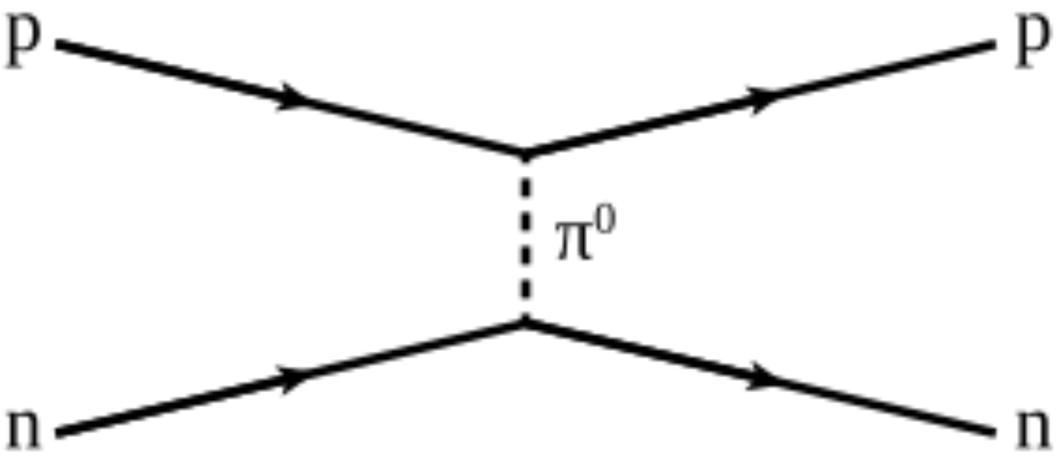
"mesone"

H. Yukawa

1935

Mediatori

1935



H. Yukawa

$$\Delta t \sim h/Mc^2$$

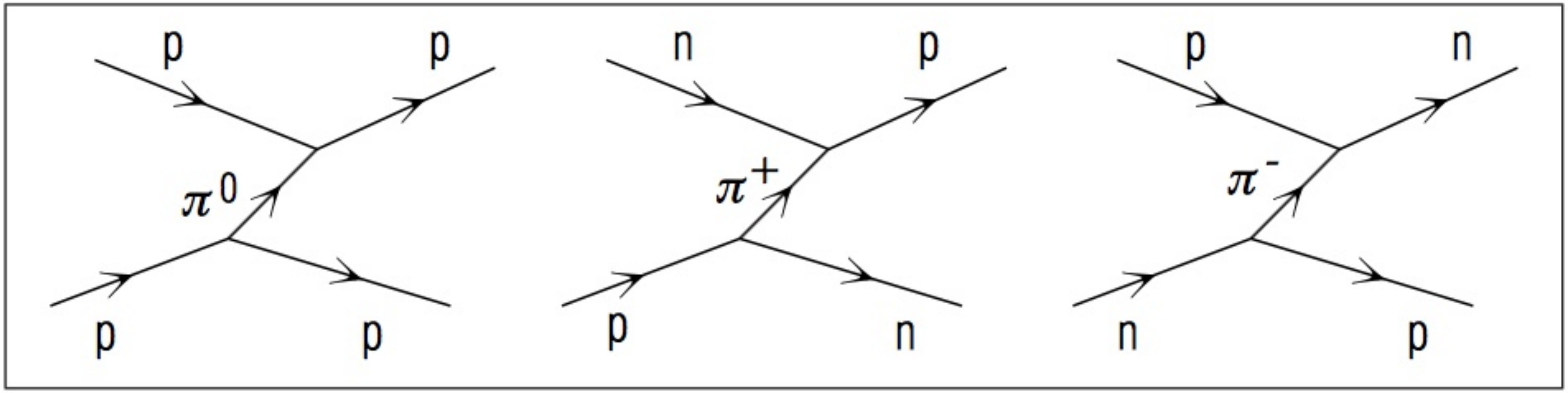
$$R \sim c\Delta t$$

R= distanza tra due protoni nel nucleo

$$Mc^2 \sim 200 \text{ MeV}$$

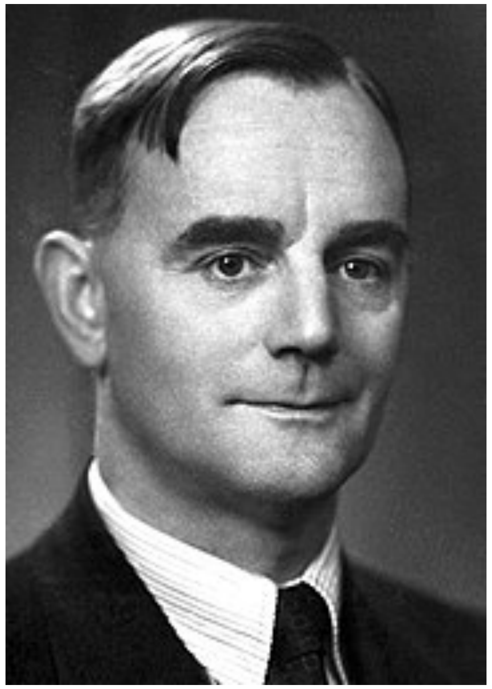
Mediatori

3 tipi di mesoni - pioni


p
p
π^0
p
p
n
p
π^+
p
n
p
n
π^-
n
p

PREDIZIONE: esistenza di 3 particelle con massa attorno a 100 MeV

Mediatori



C.F. Powell

G. Occhialini

C. Lattes

1947

Mediatori

Pion (π) comes to rest here, and then decays:

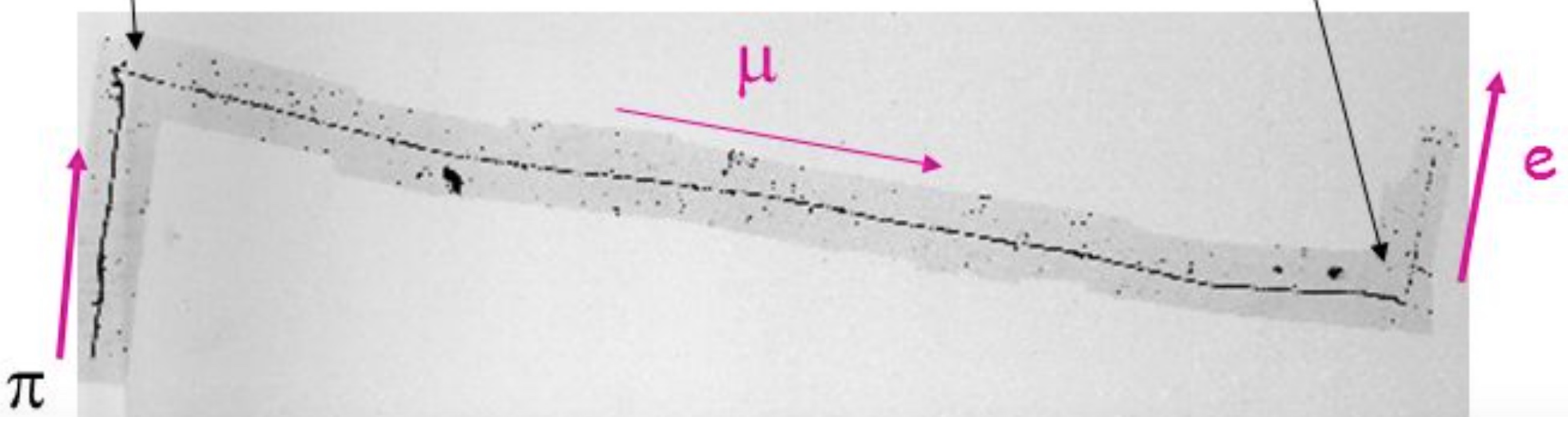
$\pi \rightarrow \mu + \nu$

Two neutrinos are also produces but escape undetected.

Muon (μ) comes to rest here, and then decays:

$\mu \rightarrow e + \nu + \nu$

Two more neutrinos are also produced but also escape undetected.

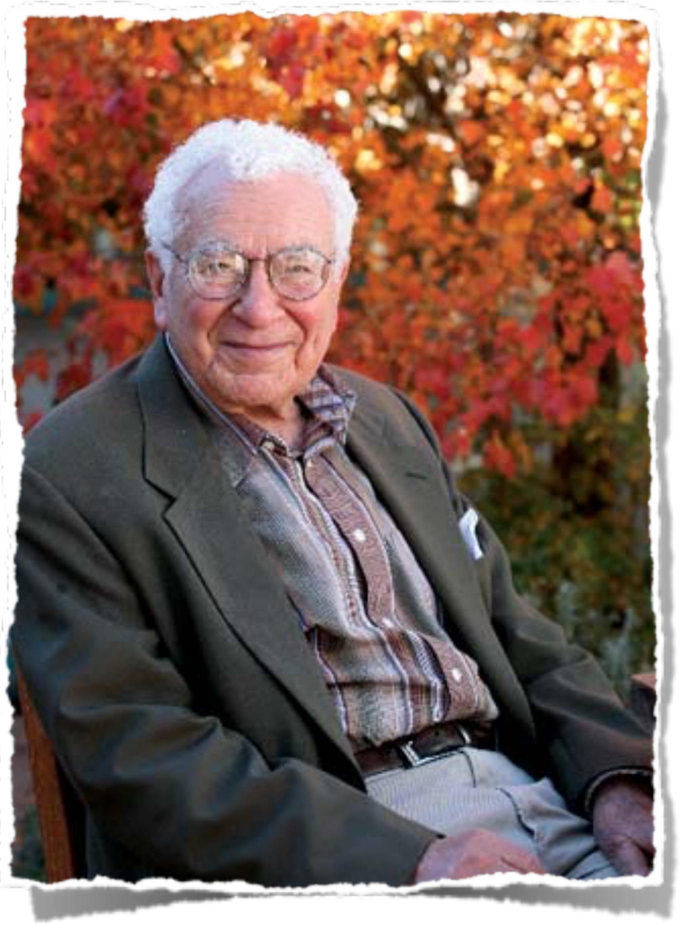


Elementari?

—> Tra gli anni '50 e '60 nei nuovi acceleratori si scoprirono una pletora di nuove particelle

—> Attorno all'inizio degli anni '60 si comprese che protoni e neutroni non sono elementari.

I costituenti vennero chiamati quarks



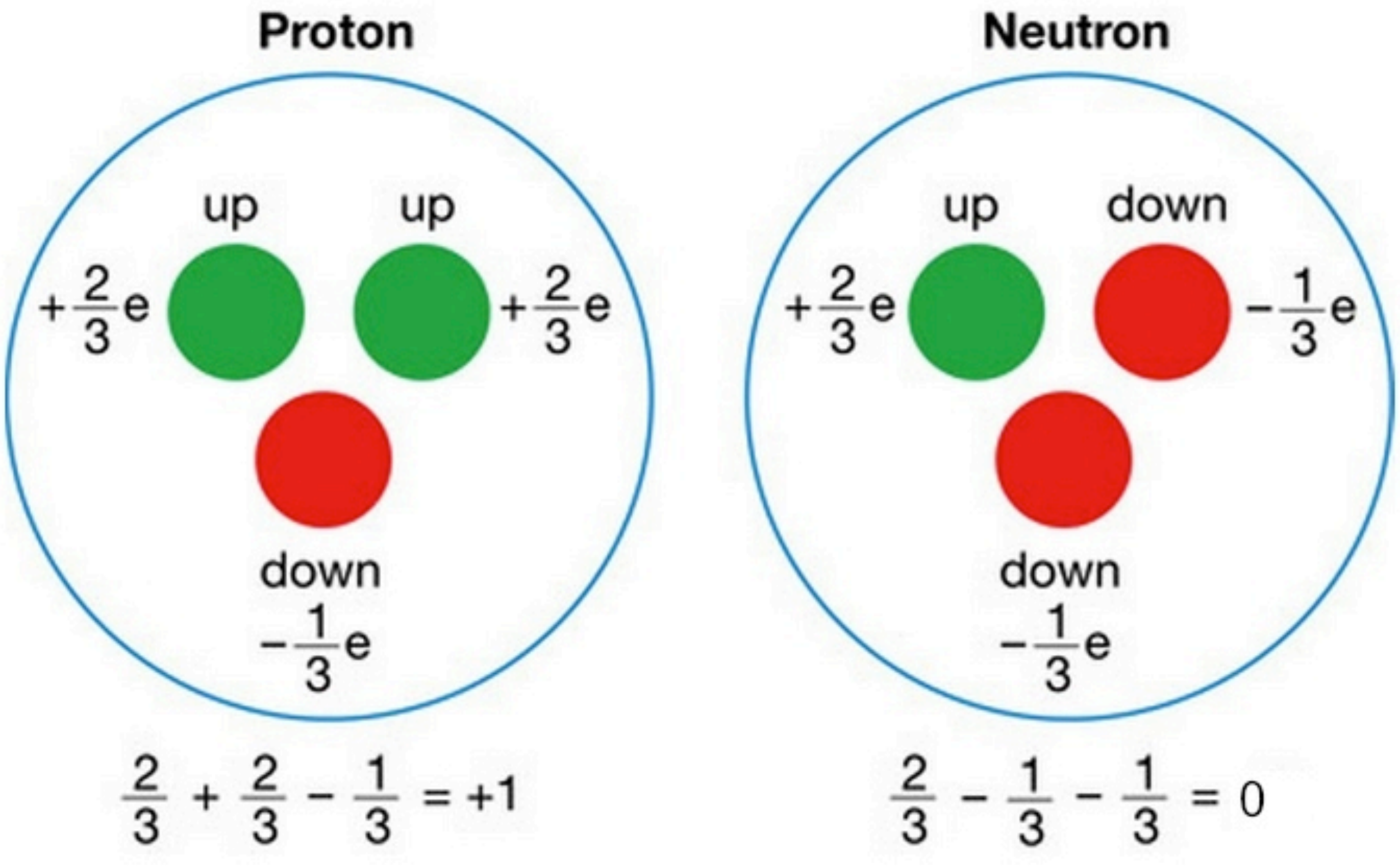
M. Gell-Mann

Quarks

🟢	**Up**	**2/3 e**
🔴	**Down**	**-1/3 e**

Cariche frazionarie!

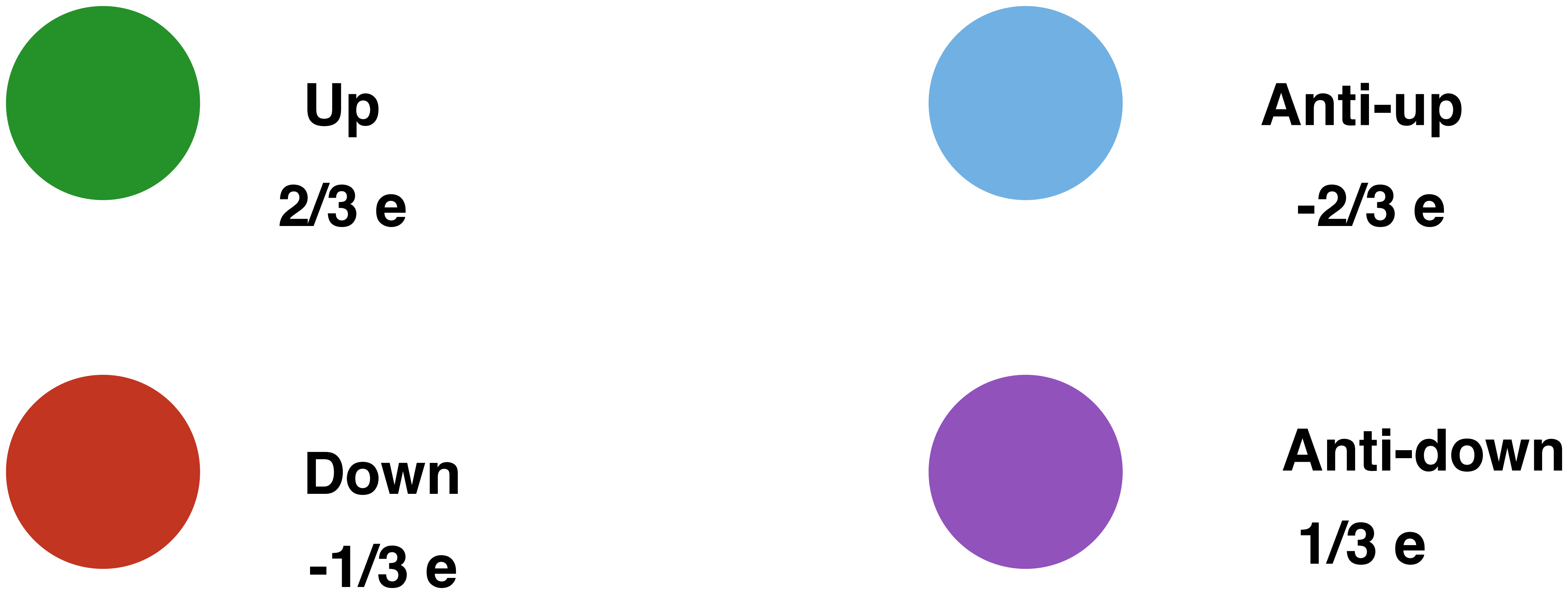
Quarks


Proton
up
up
$+\frac{2}{3}e$
$+\frac{2}{3}e$
down
$-\frac{1}{3}e$
Neutron
up
down
$+\frac{2}{3}e$
$-\frac{1}{3}e$
down
$-\frac{1}{3}e$

$$\frac{2}{3}+\frac{2}{3}-\frac{1}{3}=+1$$

$$\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$$

Quarks



Up

2/3 e

Anti-up

-2/3 e

Down

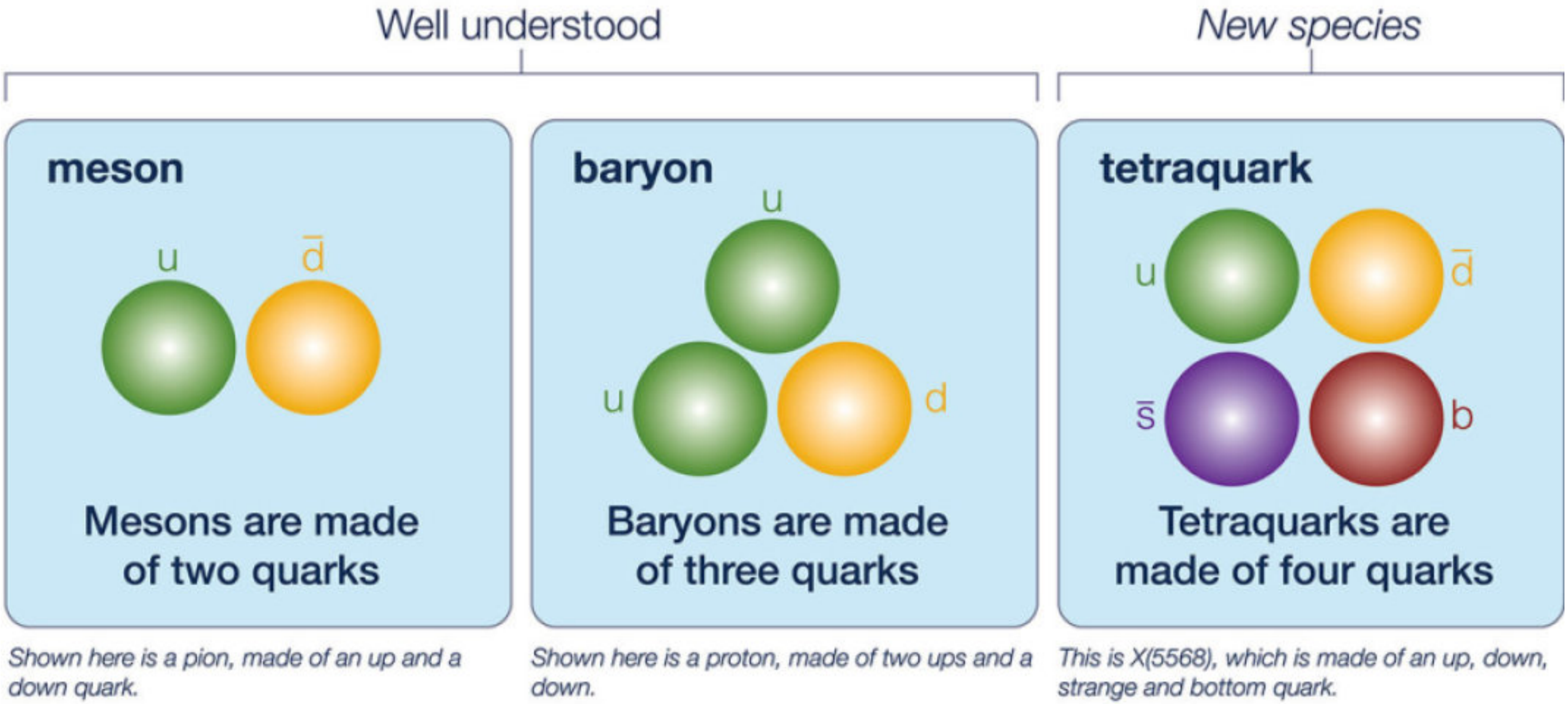
-1/3 e

Anti-down

1/3 e

Combinazioni di quarks

ADRONI



Well understood

New species

meson

Mesons are made of two quarks

Shown here is a pion, made of an up and a down quark.

baryon

Baryons are made of three quarks

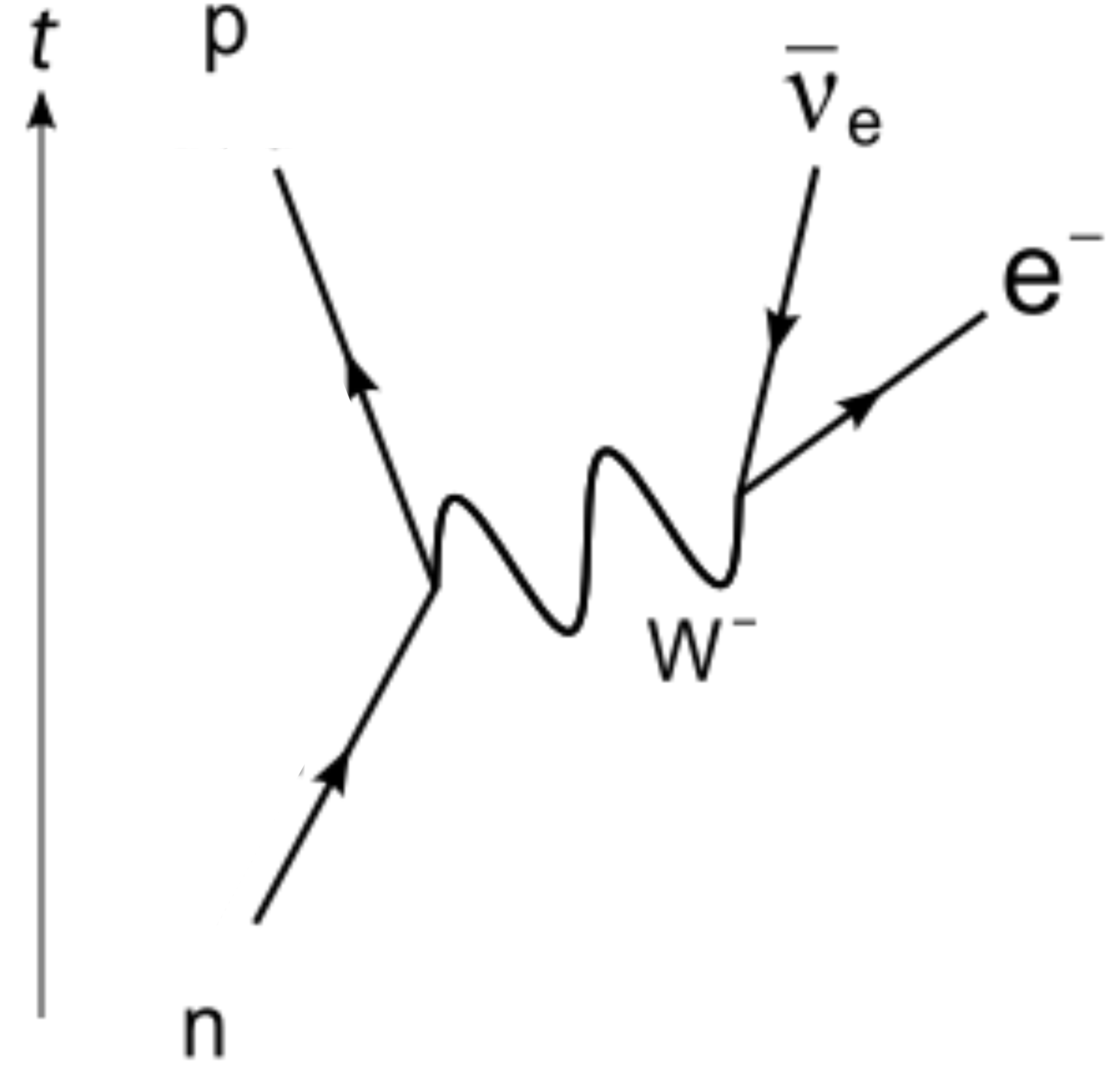
Shown here is a proton, made of two ups and a down.

tetraquark

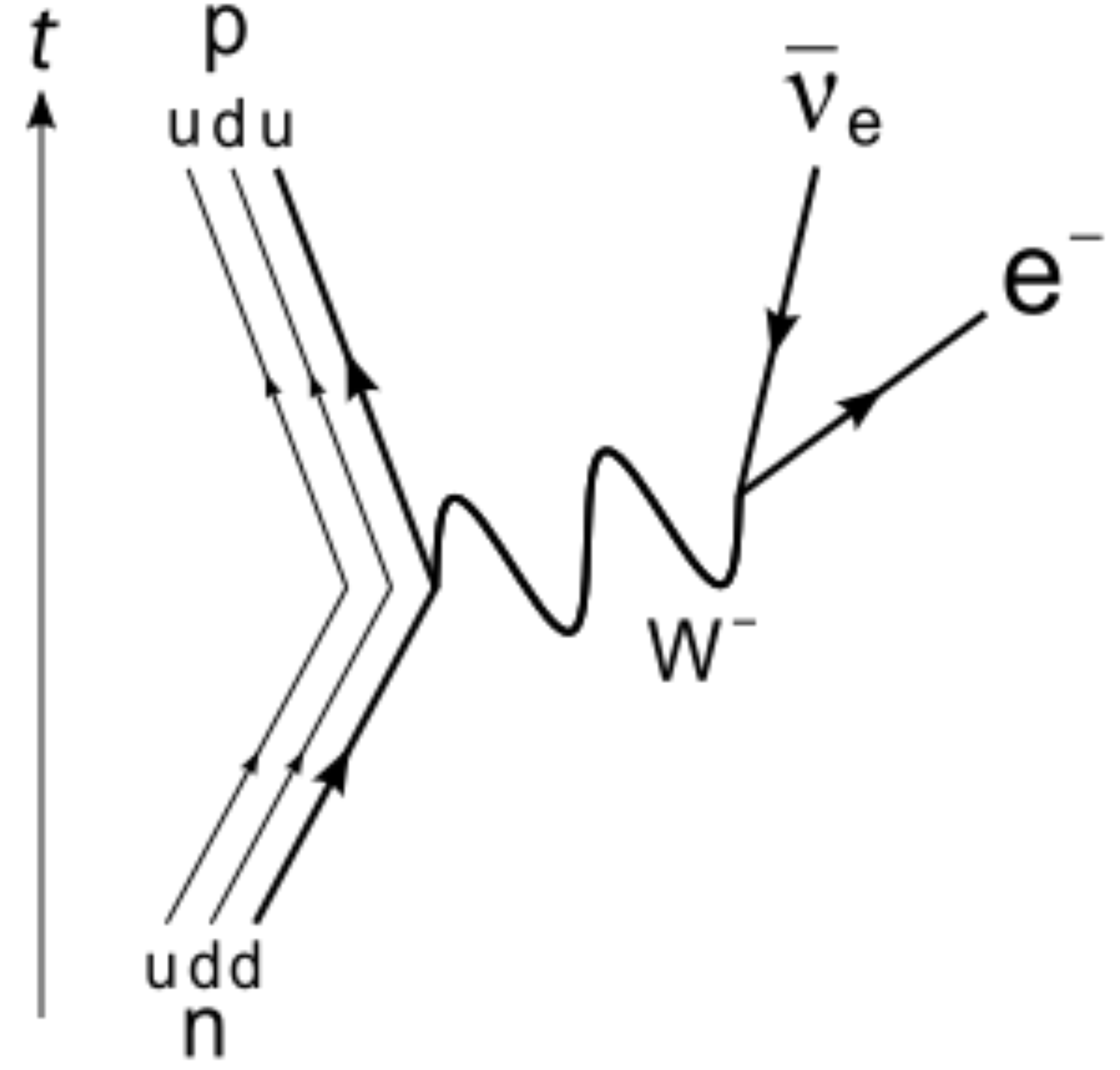
Tetraquarks are made of four quarks

This is X(5568), which is made of an up, down, strange and bottom quark.

Forza debole rivisitata


t
p
$\bar{\nu}_e$
e^-
W^-
n

Forza debole rivisitata


t
p
u d u
$\bar{\nu}_e$
e^-
W^-
u d d
n

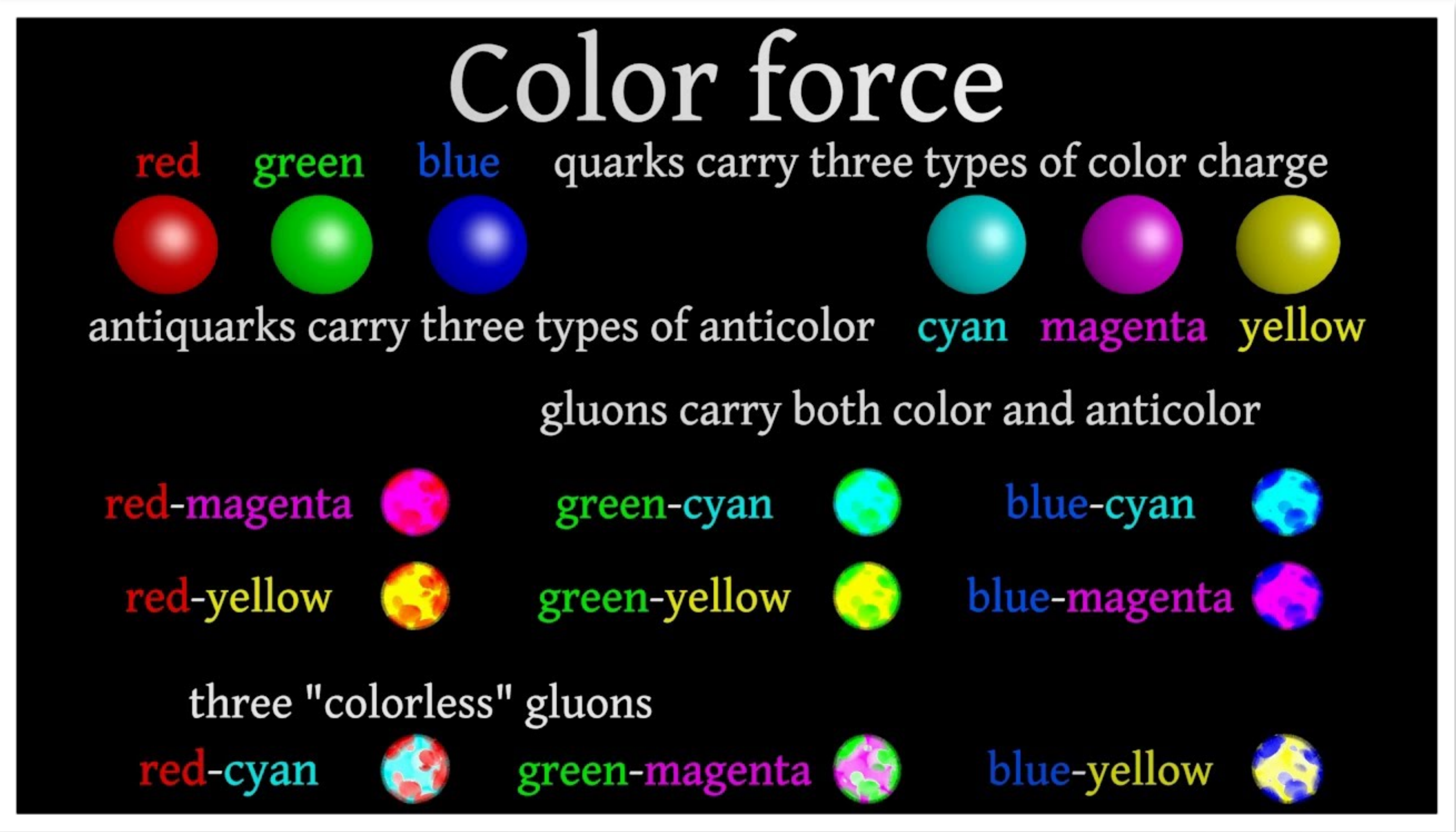
“Colore”

L’interazione forte agisce primariamente tra i quarks.

I mediatori sono stati denominati “gluoni”

L’interazione prende anche il nome di “forza di colore”

“Colore”



Color force

red green blue quarks carry three types of color charge

antiquarks carry three types of anticolor cyan magenta yellow

gluons carry both color and anticolor

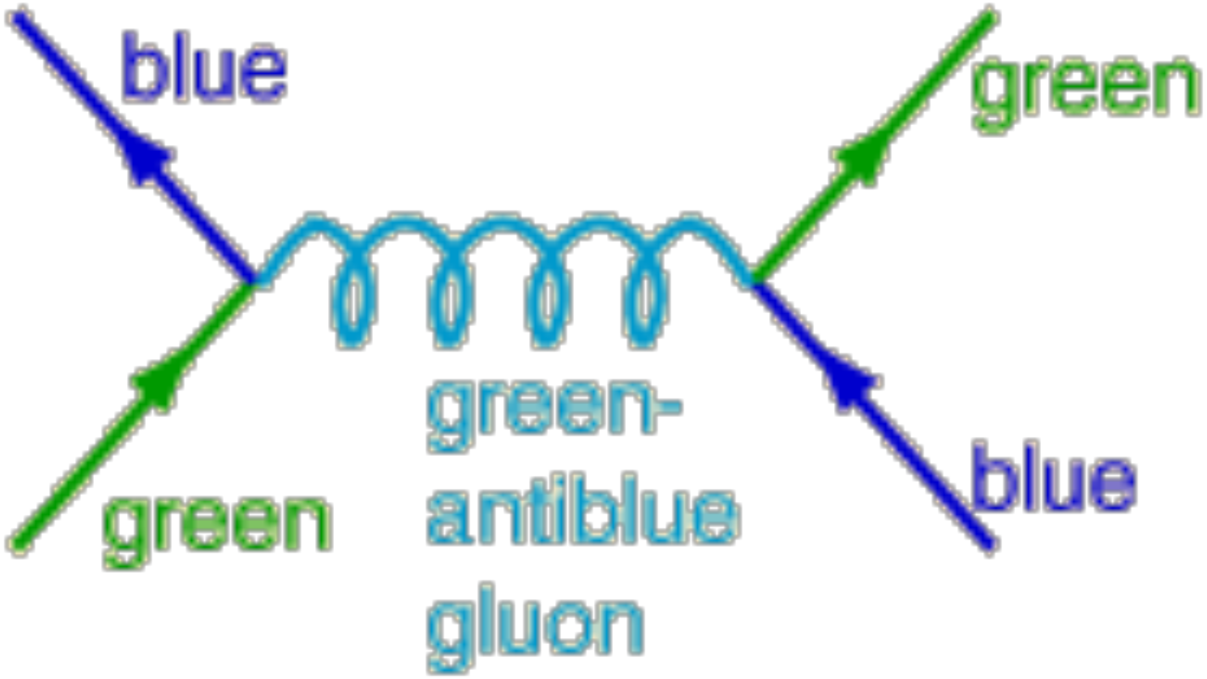
red-magenta green-cyan blue-cyan

red-yellow green-yellow blue-magenta

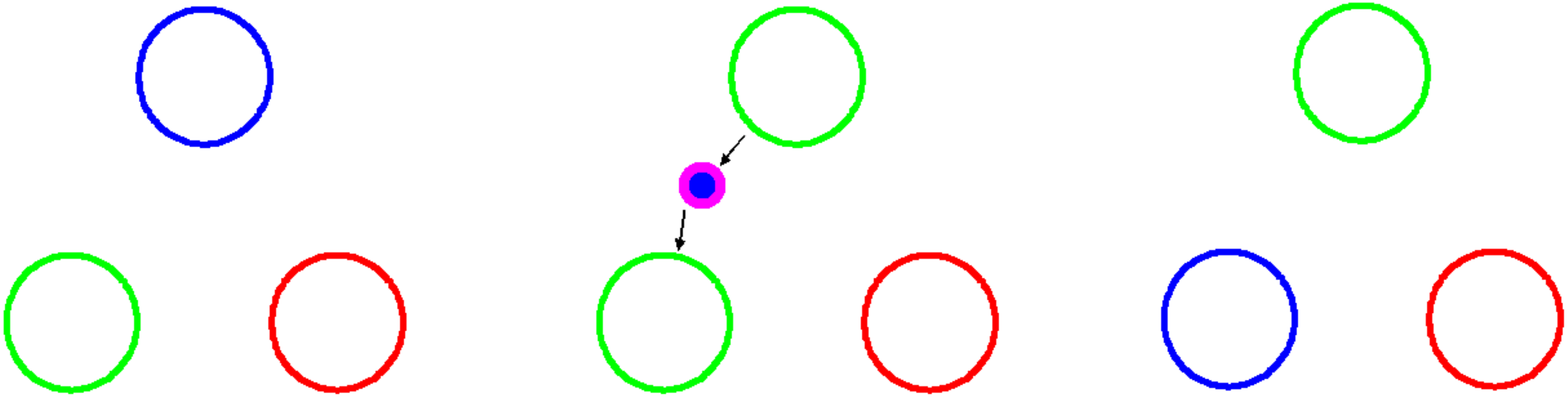
three "colorless" gluons

red-cyan green-magenta blue-yellow

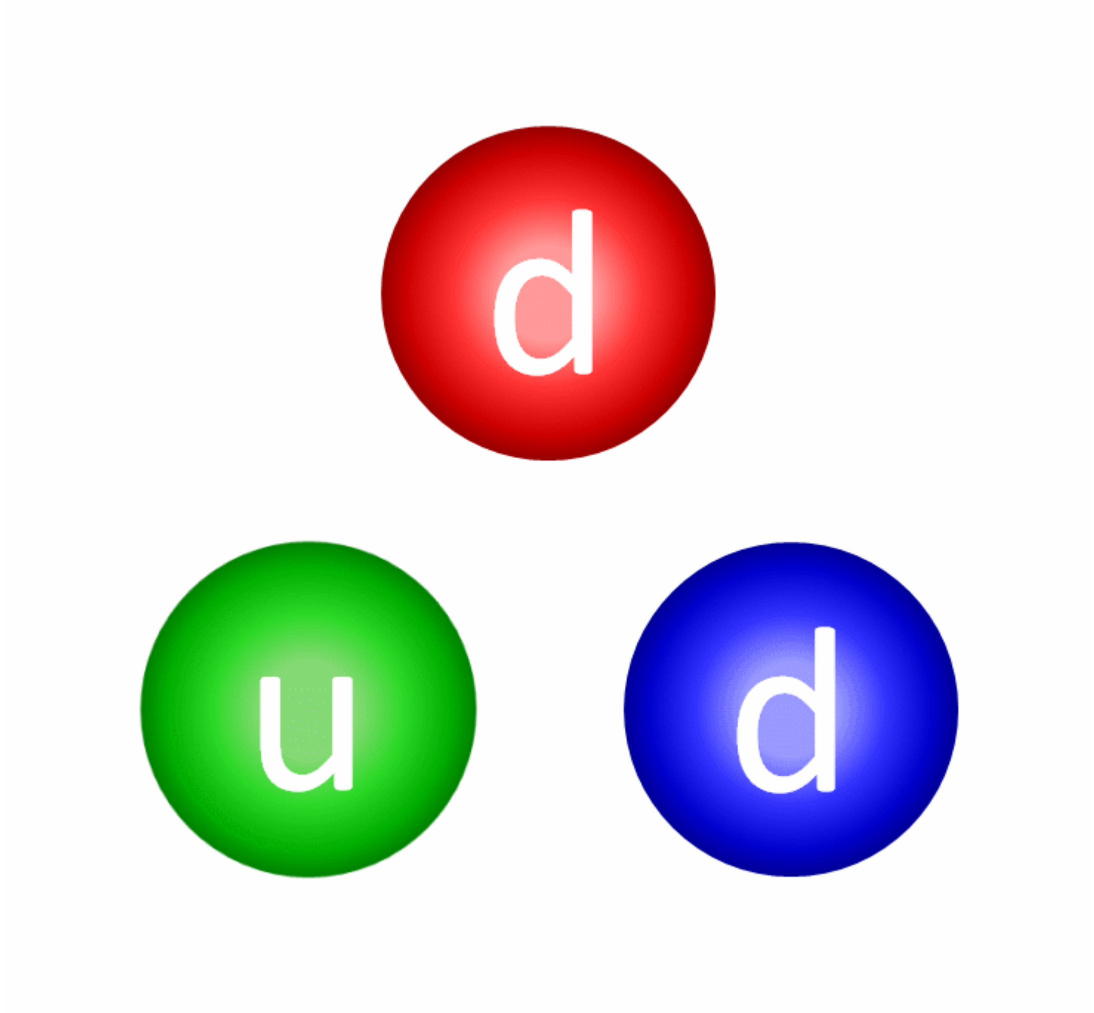
“Forza di colore”


blue
green
green-
antiblue
gluon
green
blue

“Forza di colore”



“Forza di colore”



Confinamento

Perchè non osserviamo quarks liberi?

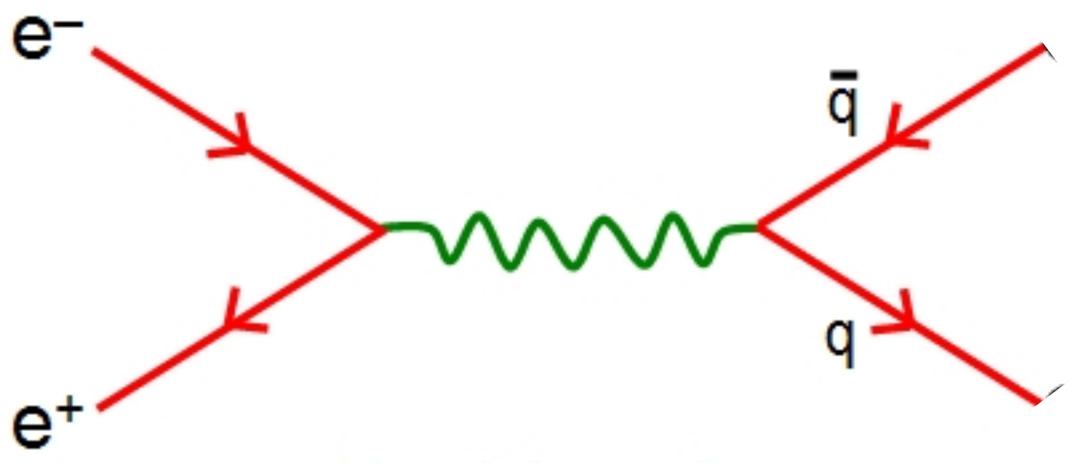
Confinamento

Perchè non osserviamo quarks liberi?

Ogni particella in natura deve essere senza colore (“bianca”)

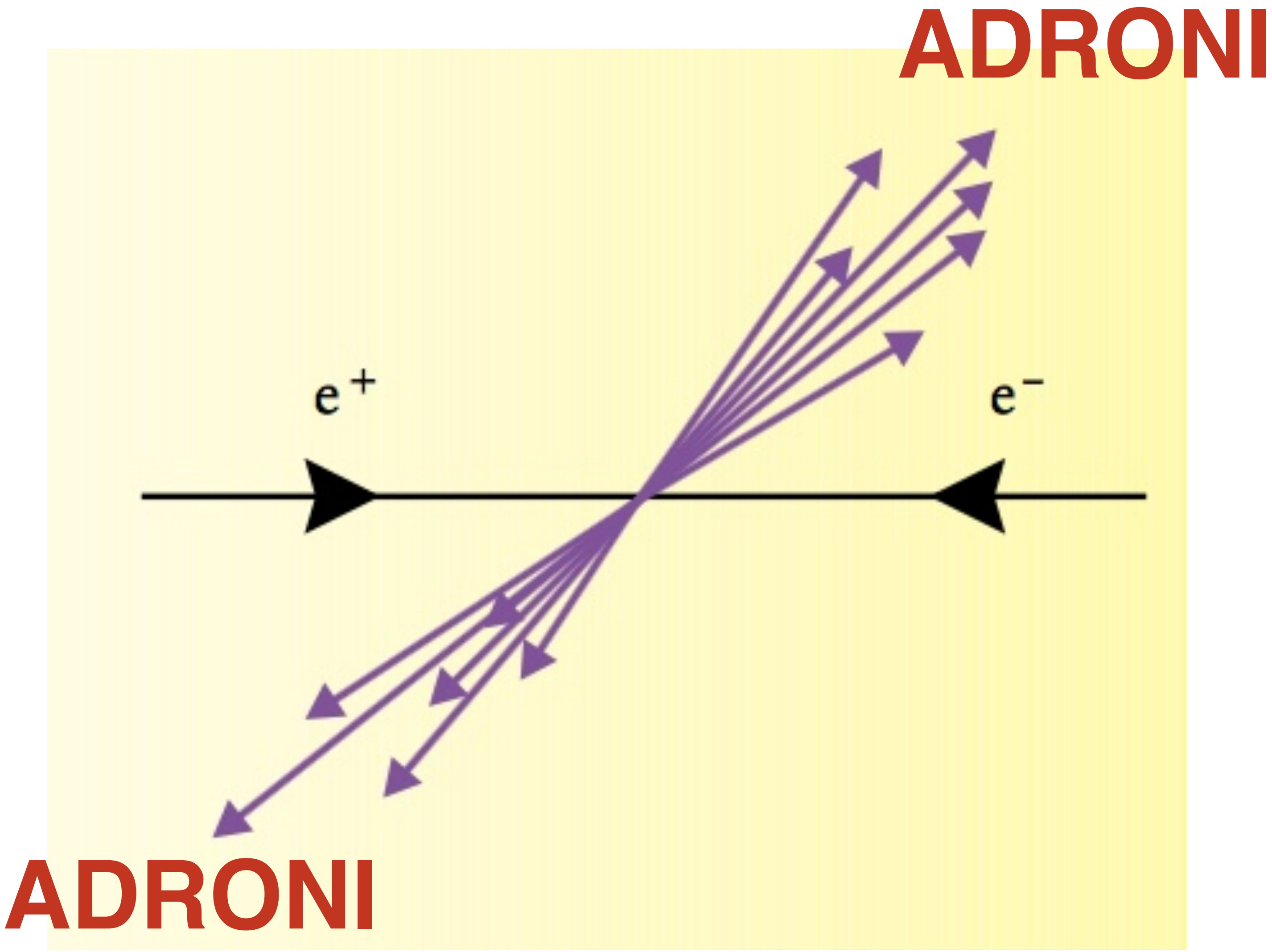
Confinamento

$e^+ + e^- \rightarrow q + \bar{q}$

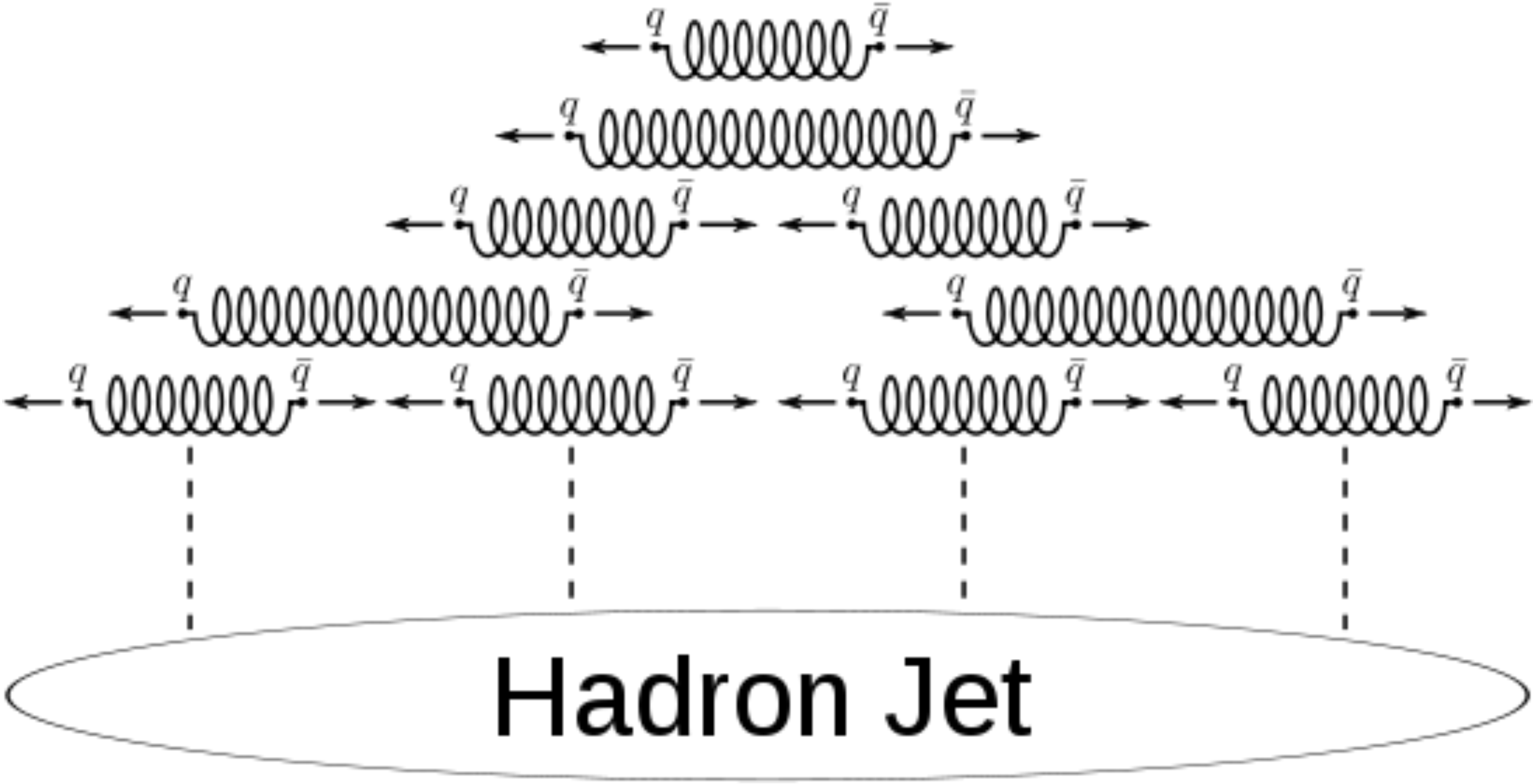


Two-jet event

Confinamento

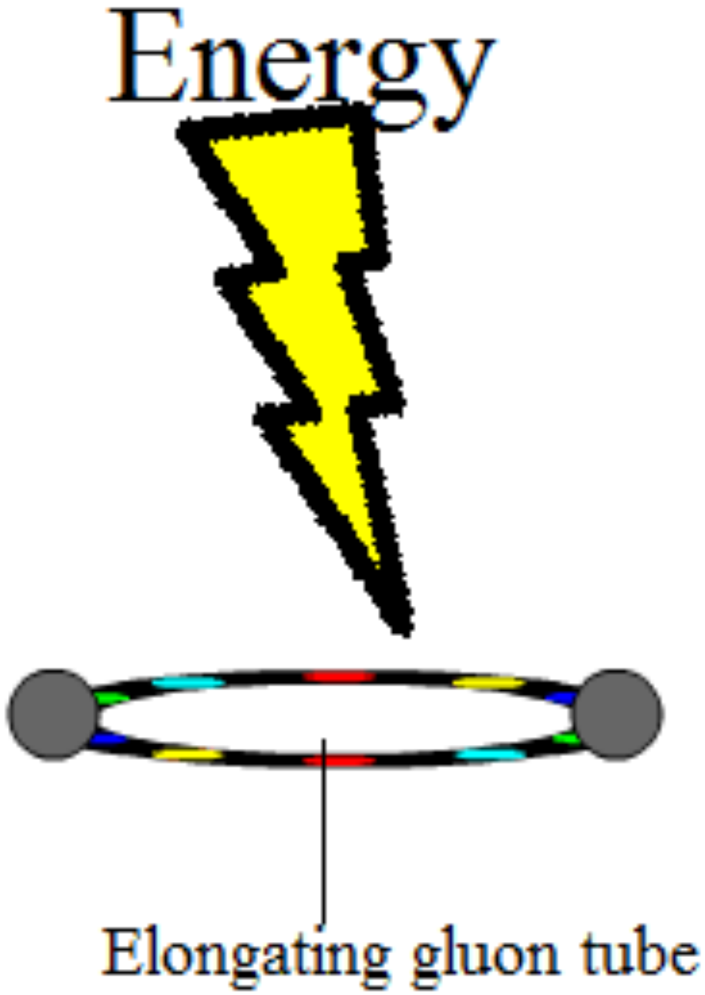

ADRONI
e⁺
e⁻
ADRONI

Confinamento



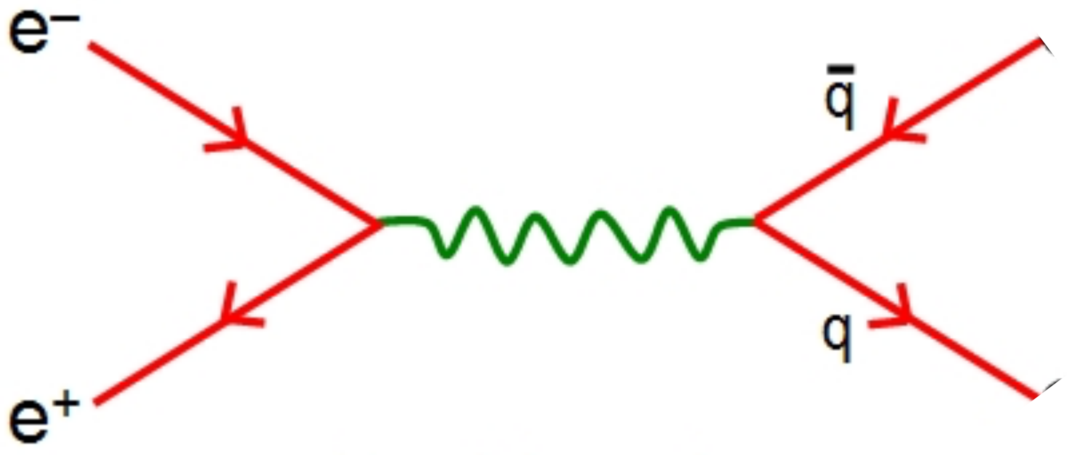
q
$\bar{q}$
Hadron Jet

Confinamento


Energy
Elongating gluon tube

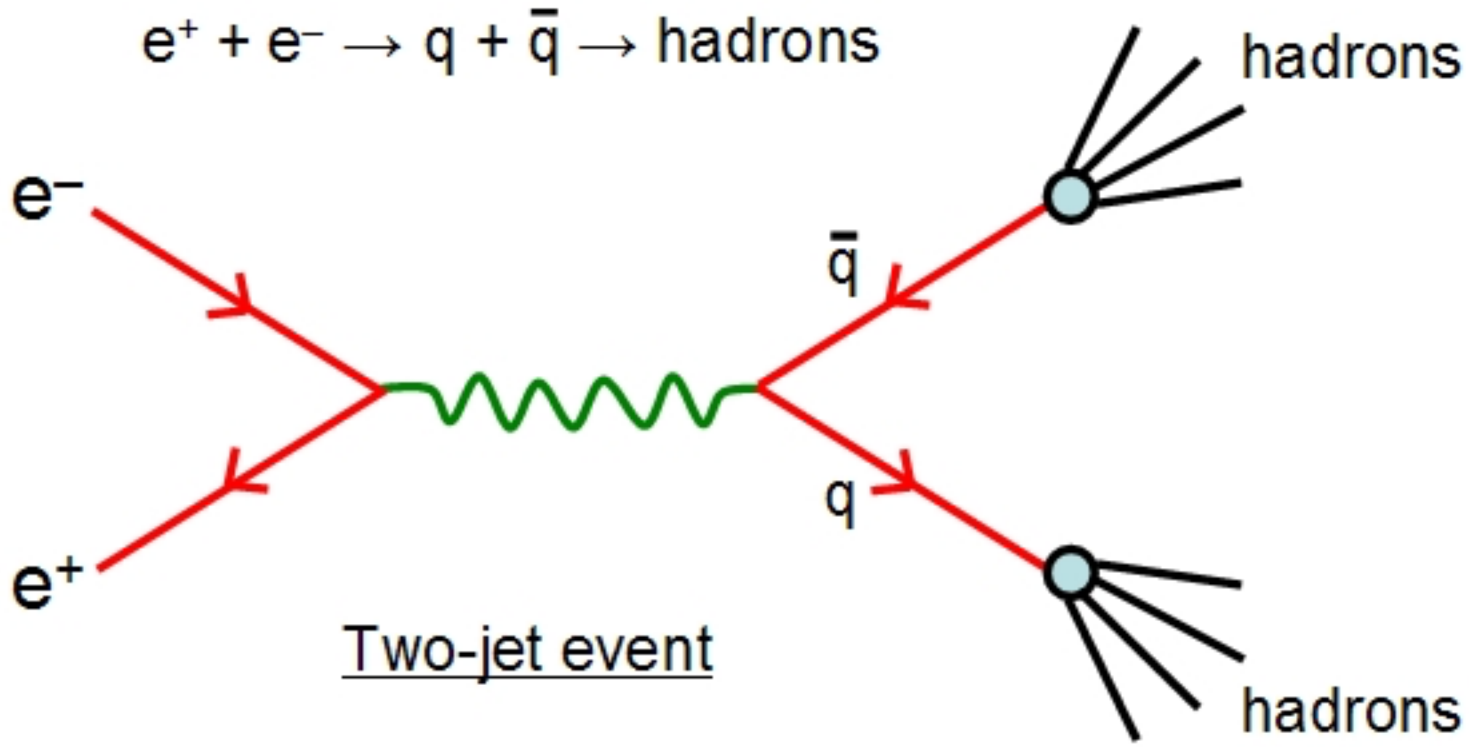
Confinamento

$e^+ + e^- \rightarrow q + \bar{q}$

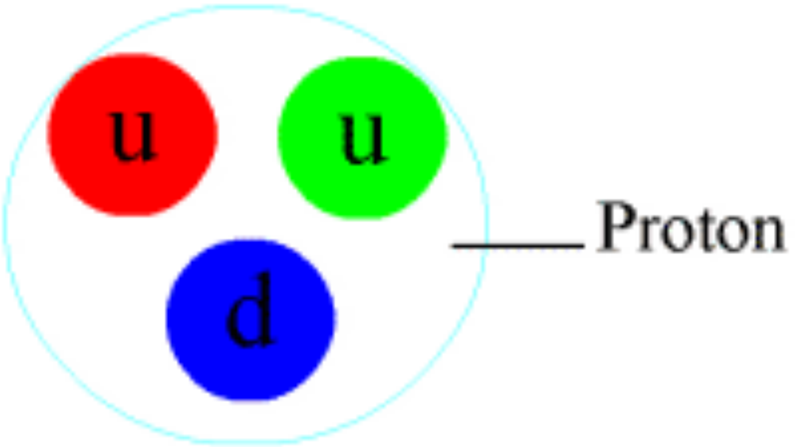


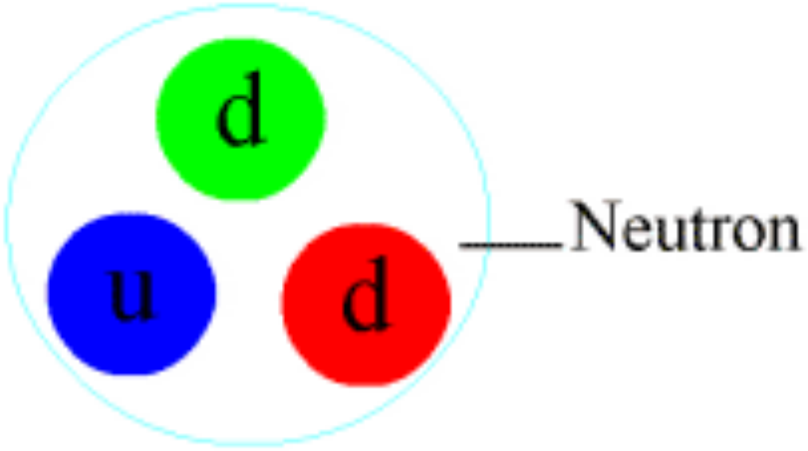
Two-jet event

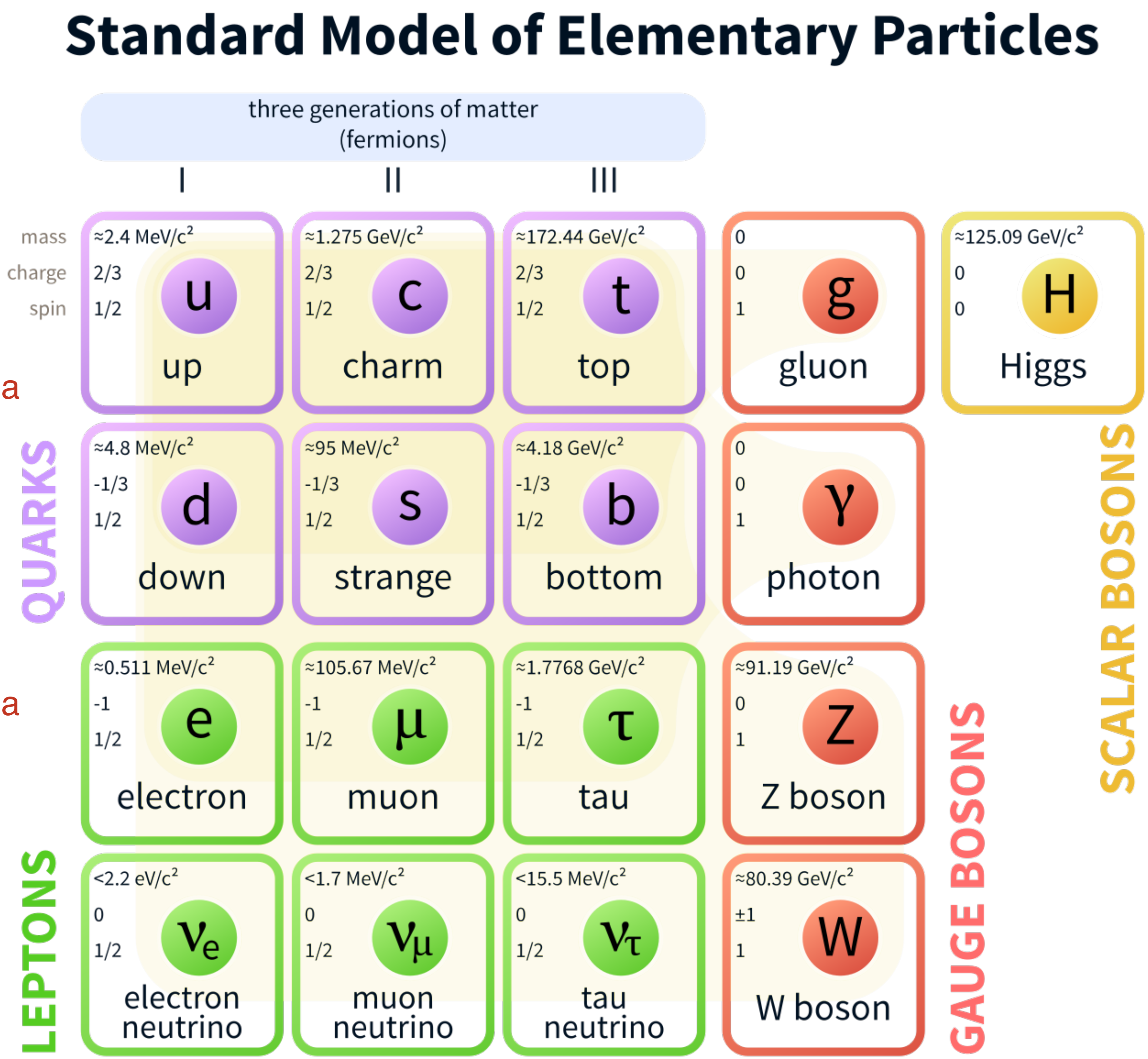
Confinamento


$e^+ + e^- \rightarrow q + \bar{q} \rightarrow$ hadrons
hadrons
e^-
$\bar{q}$
q
e^+
Two-jet event
hadrons

E I pioni?




d
u
d
Neutron


Standard Model of Elementary Particles
three generations of matter
(fermions)
I
II
III
mass
charge
spin
≈2.4 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈172.44 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈125.09 GeV/c²
0
0
H
Higgs
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
≈0.511 MeV/c²
-1
1/2
e
electron
≈105.67 MeV/c²
-1
1/2
μ
muon
≈1.7768 GeV/c²
-1
1/2
τ
tau
≈91.19 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<1.7 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
≈80.39 GeV/c²
±1
1
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS
SCALAR BOSONS

Elettromagnetica
Debole
Forte

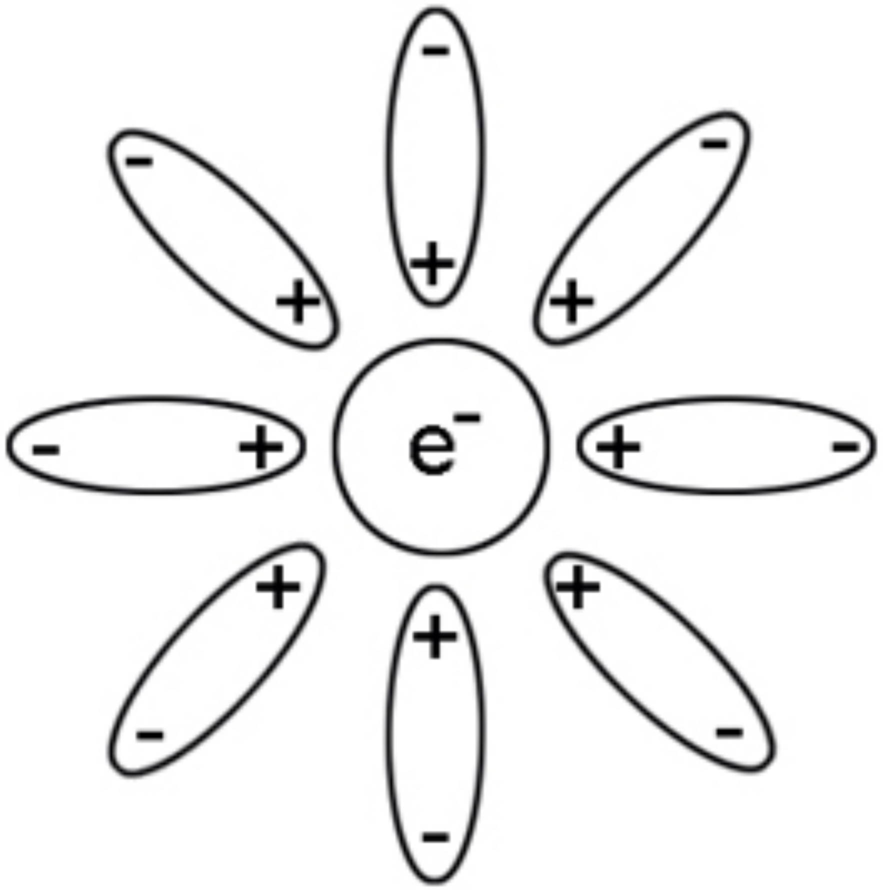
Elettromagnetica
Debole

Debole

Unificazione delle interazioni?

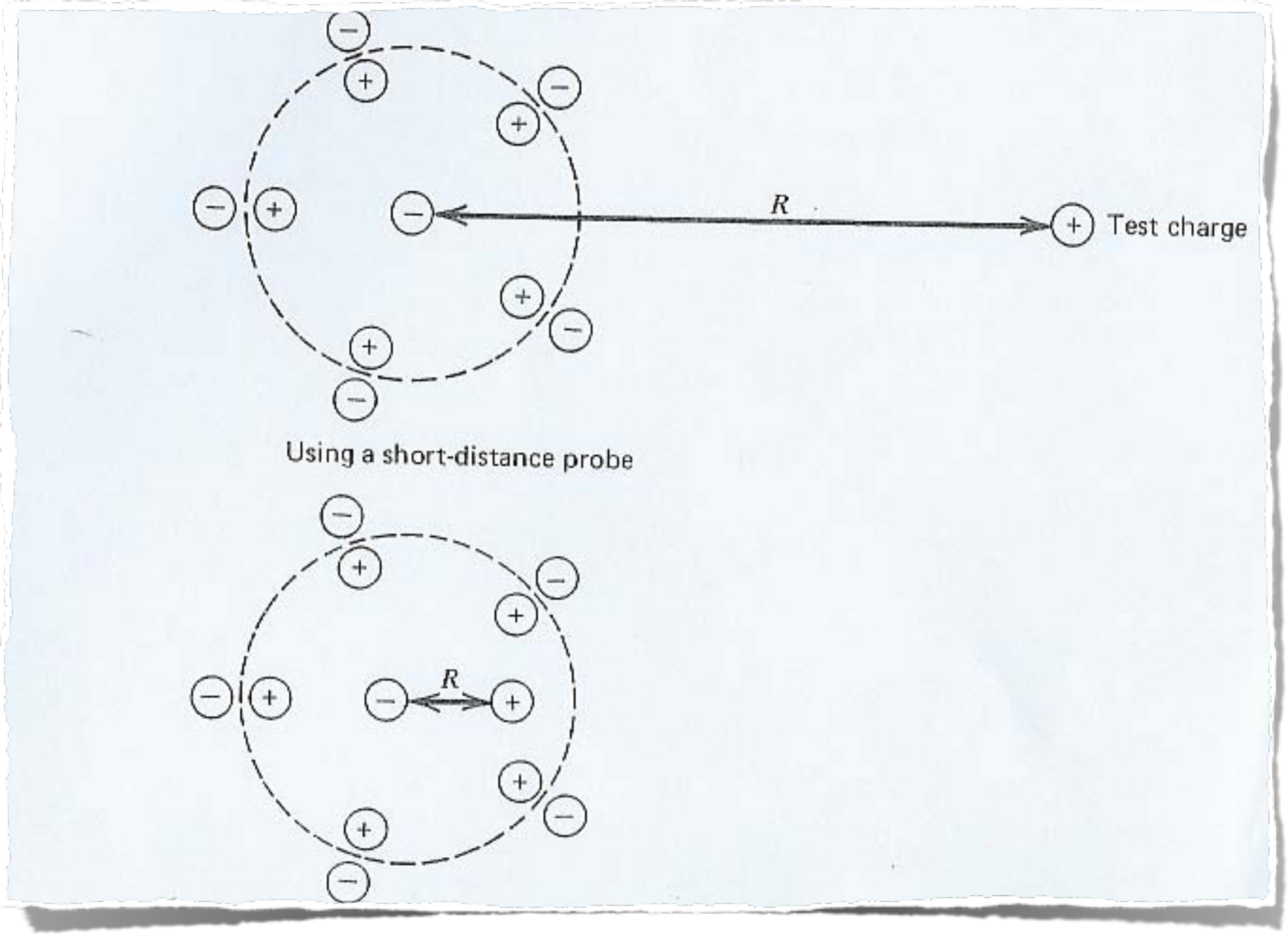
$$\Delta t \sim h/\Delta E$$

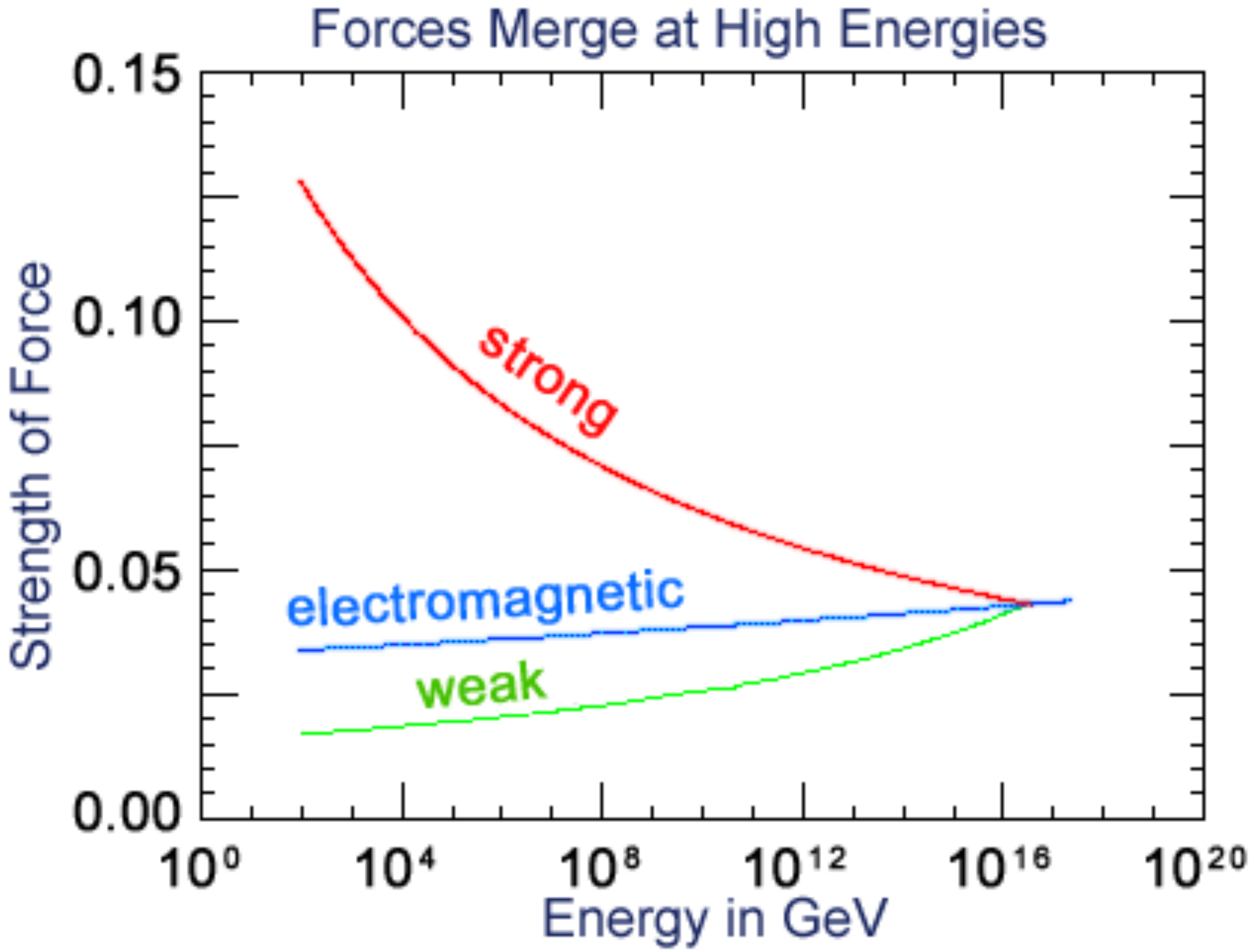
Riduzione della carica elettrica dovuta a coppie elettrone-positrone virtuali



Unificazione delle interazioni?

La riduzione "sentita" da una particella dipende però dalla sua energia


R
Test charge
Using a short-distance probe
R

Unificazione delle interazioni?