

L'interazione debole

Fabrizio Tavecchio
INAF-OAB

17 GENNAIO 2018



L'universo in fiore 2017-2018

Corsi di astronomia all'Osservatorio Astronomico di Brera

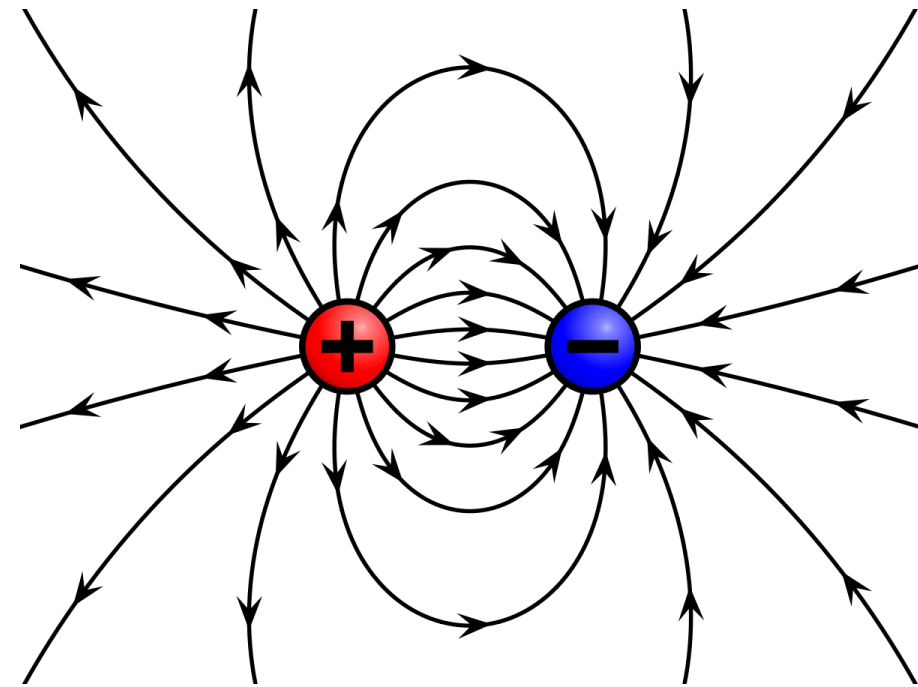
«I colori maturano la notte» - Alda Merini



Interazioni (o forze)



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

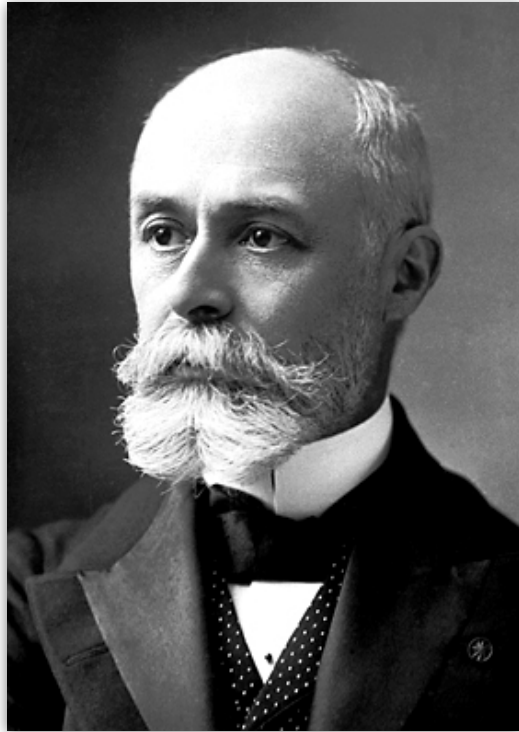


$$F = K \frac{q_1 q_2}{r^2}$$

inizio '900

L'atomo e il nucleo atomico

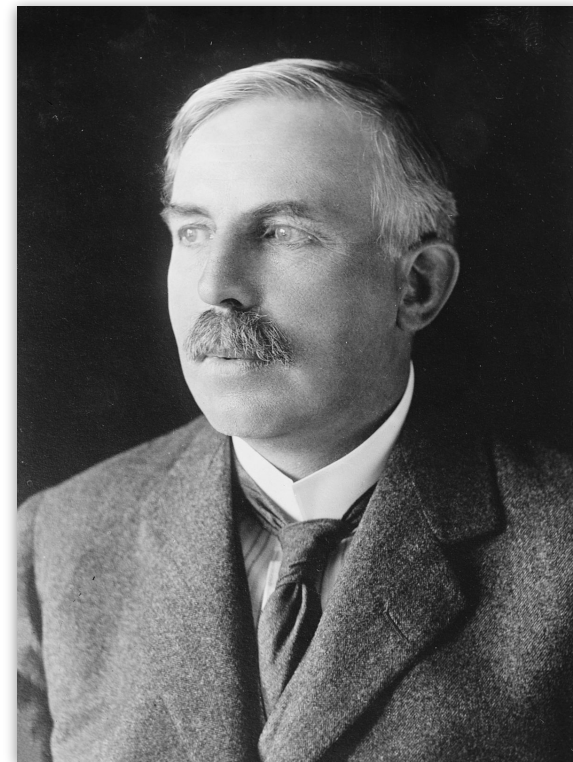
Bequerel



Thomson



Rutherford

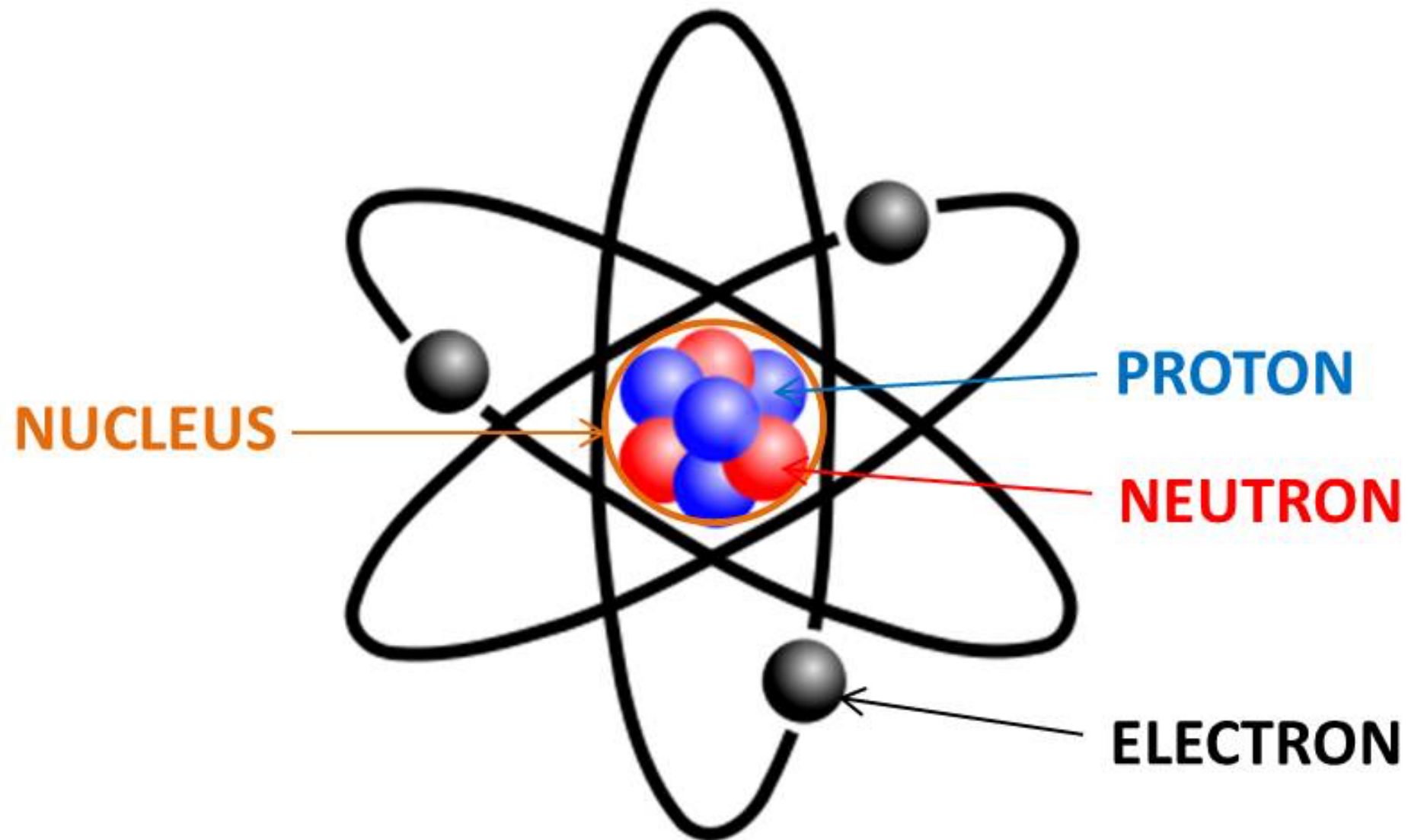


Chadwick

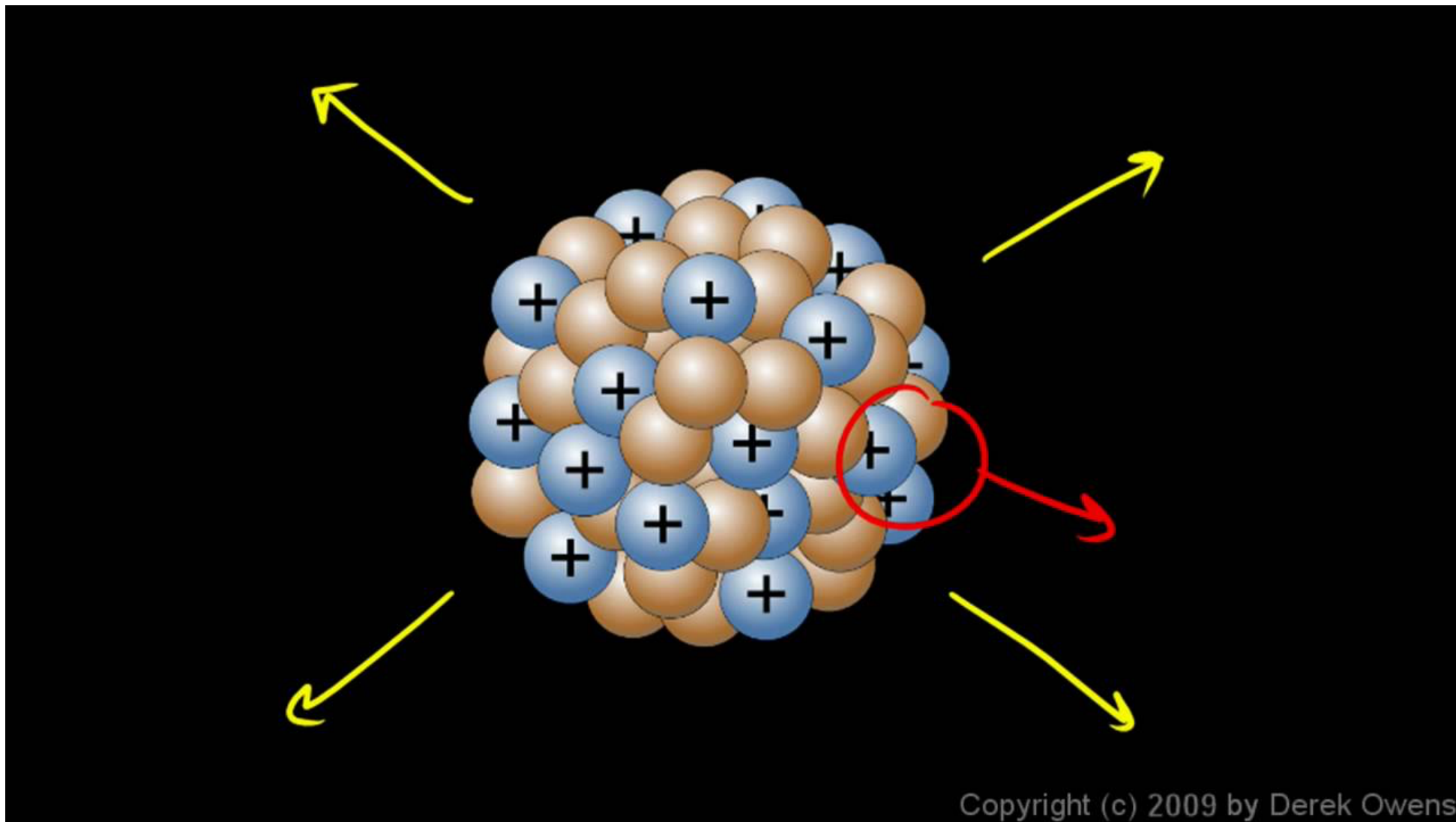


L'atomo

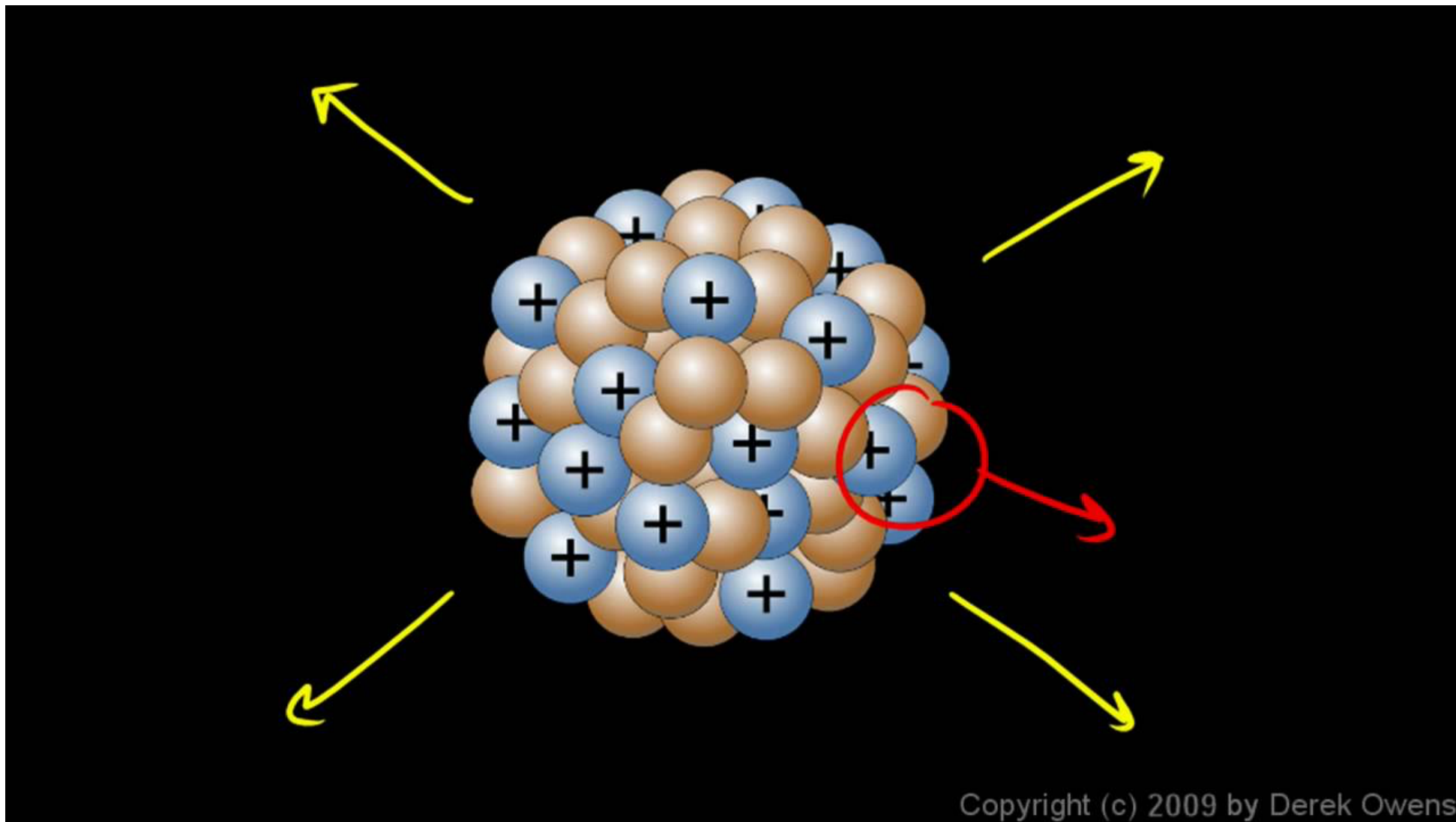
~1932



Il nucleo atomico



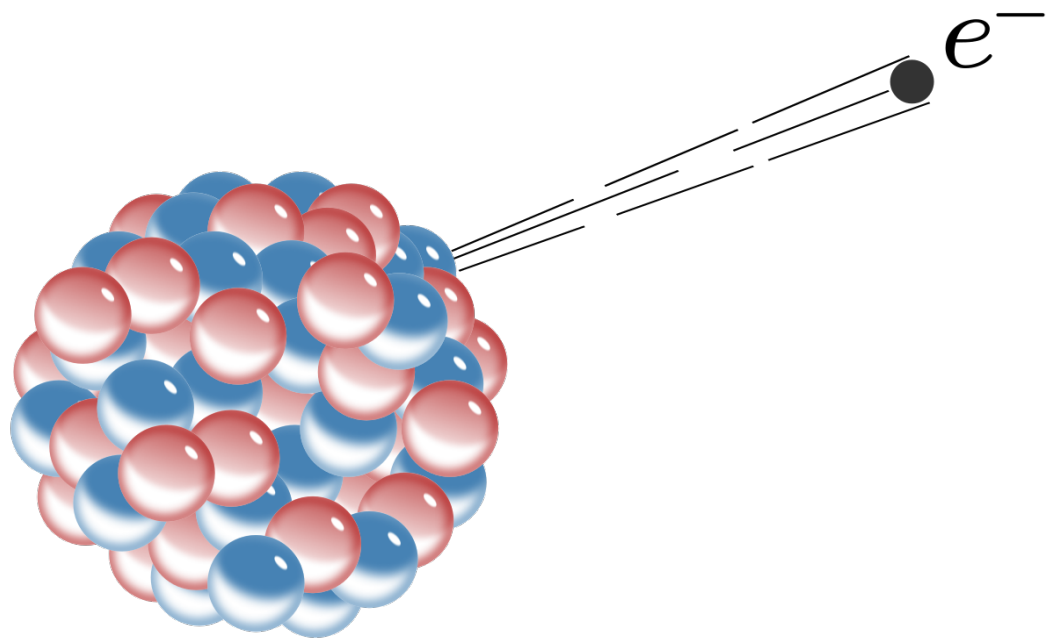
Il nucleo atomico



➡ *Interazione forte*

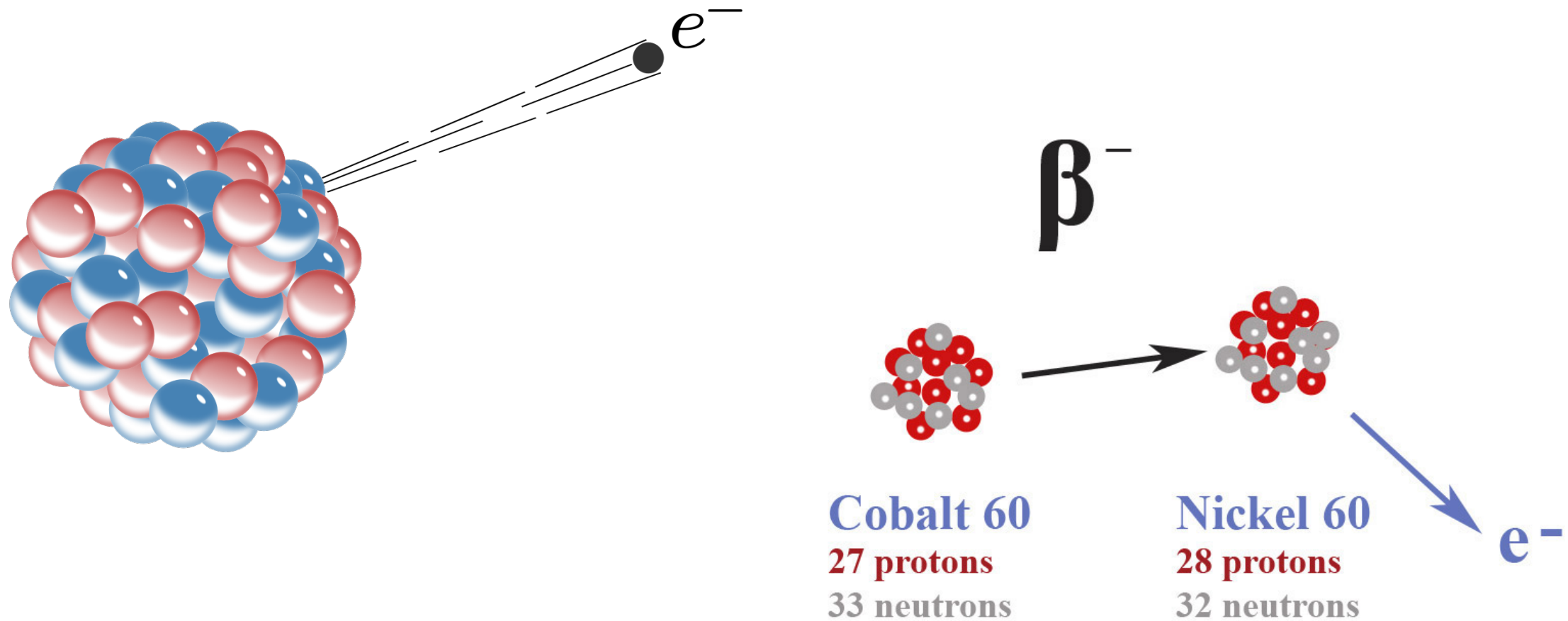
Decadimenti radioattivi

Decadimento beta



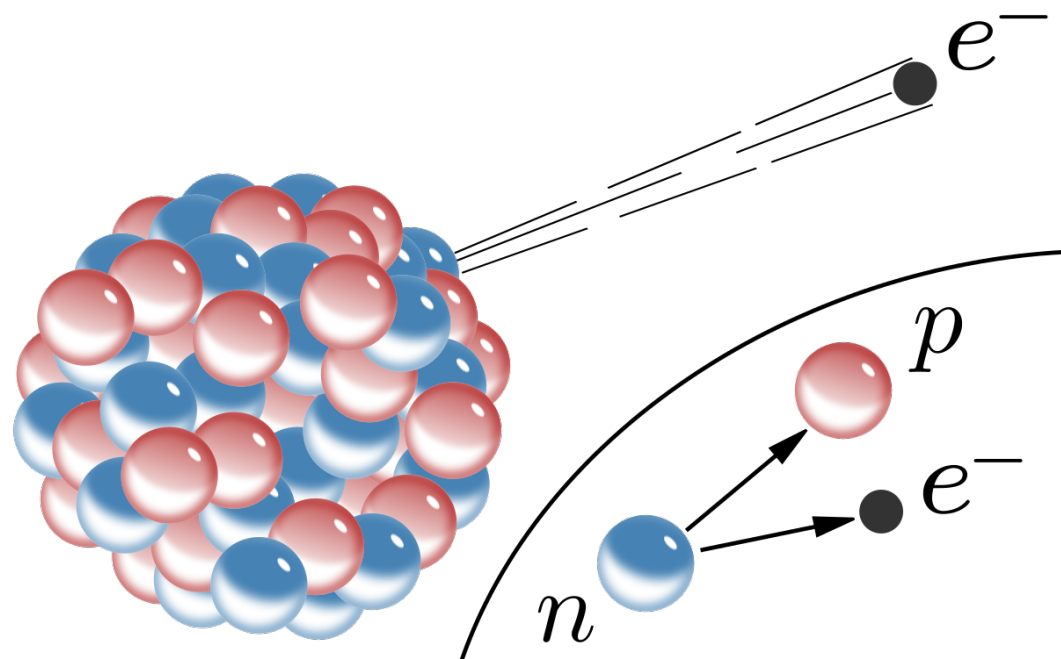
Decadimenti radioattivi

Decadimento beta



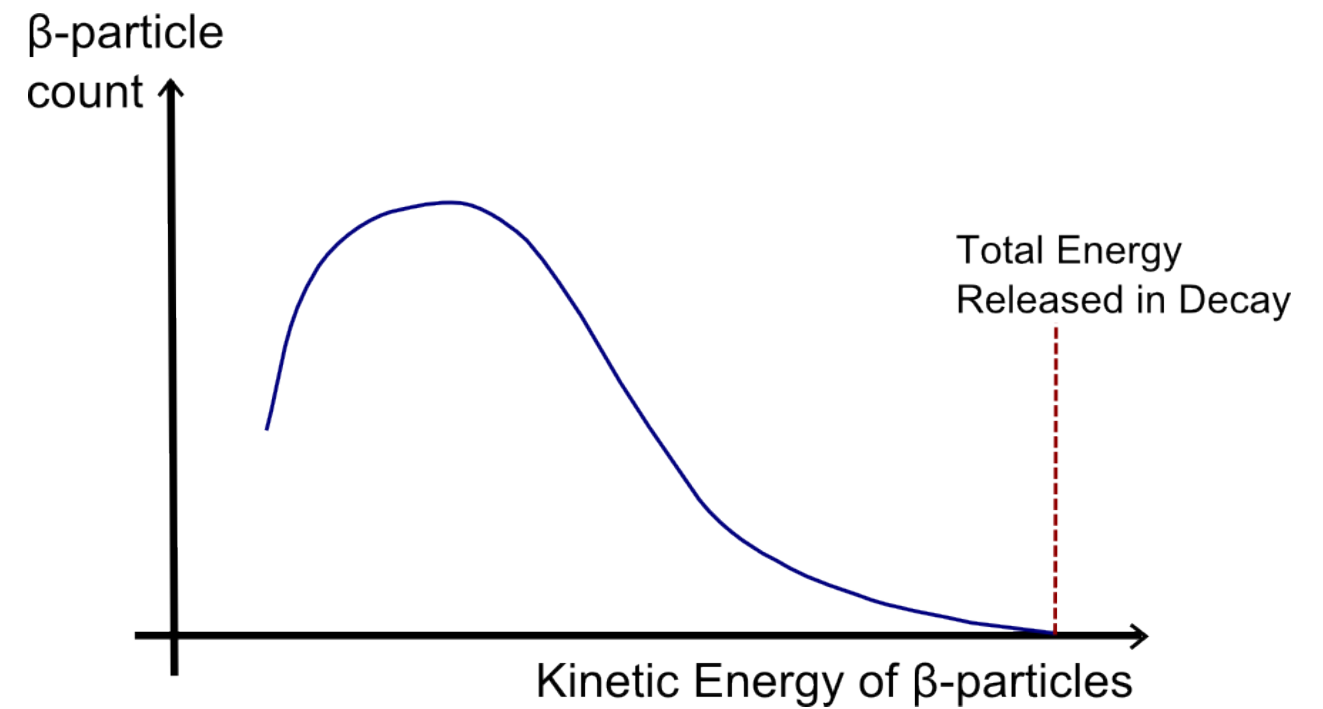
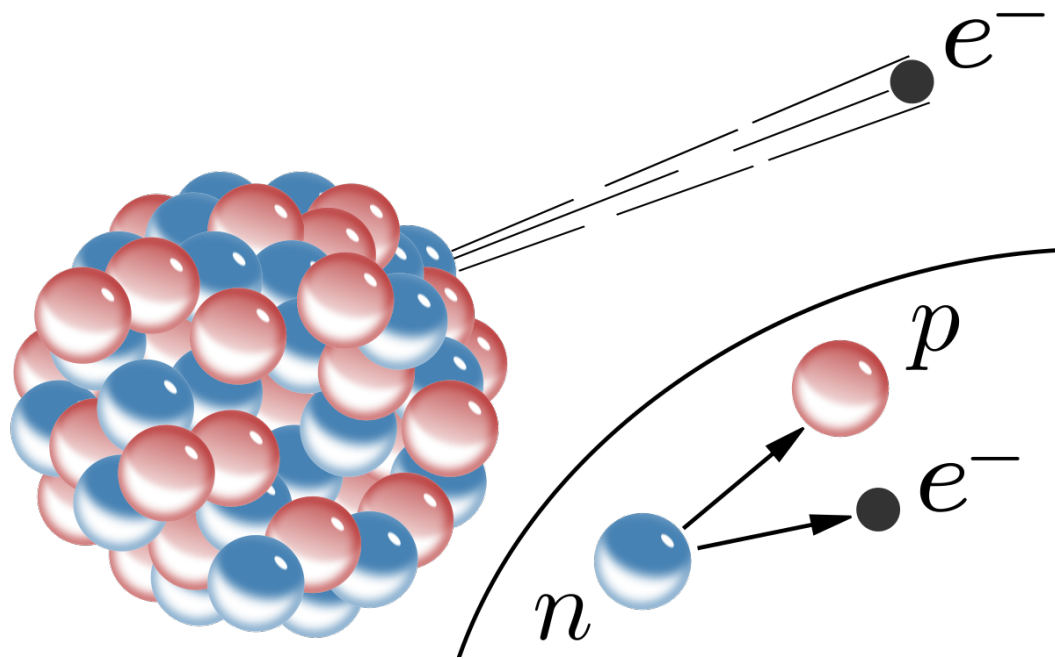
Decadimenti radioattivi

Decadimento beta



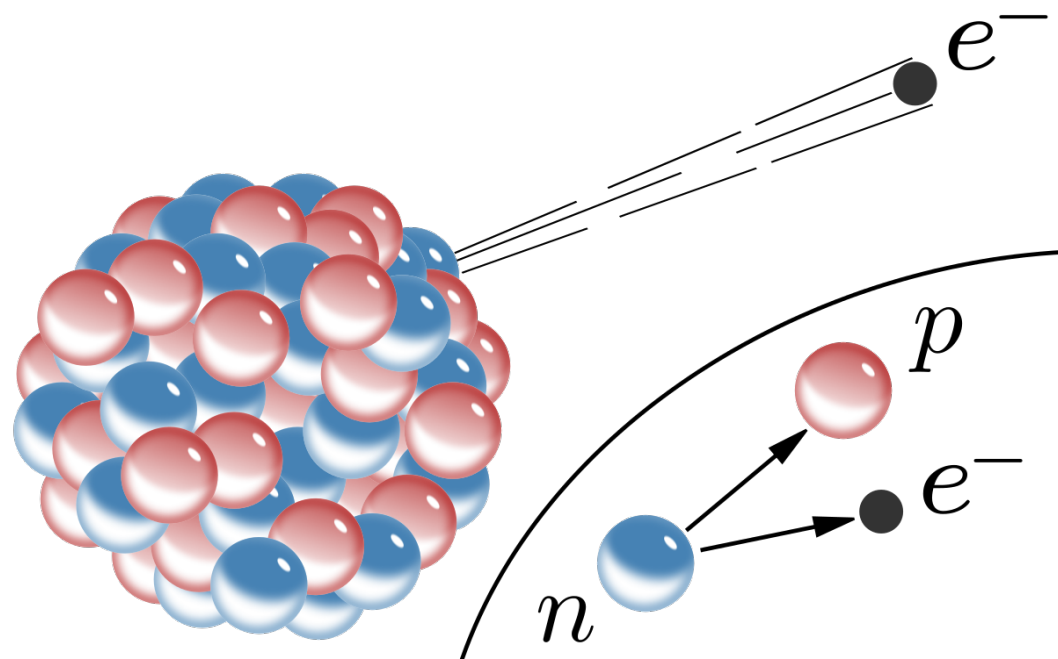
Decadimenti radioattivi

Decadimento beta

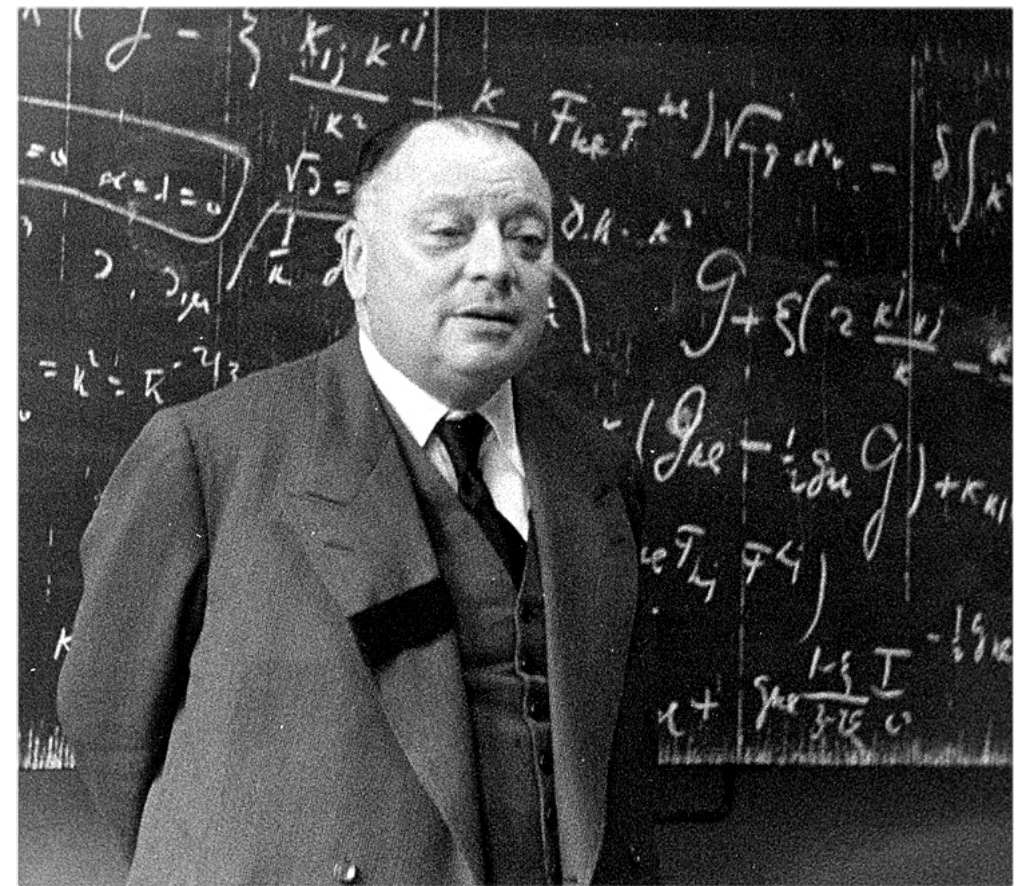


Decadimenti radioattivi

Decadimento beta



1930

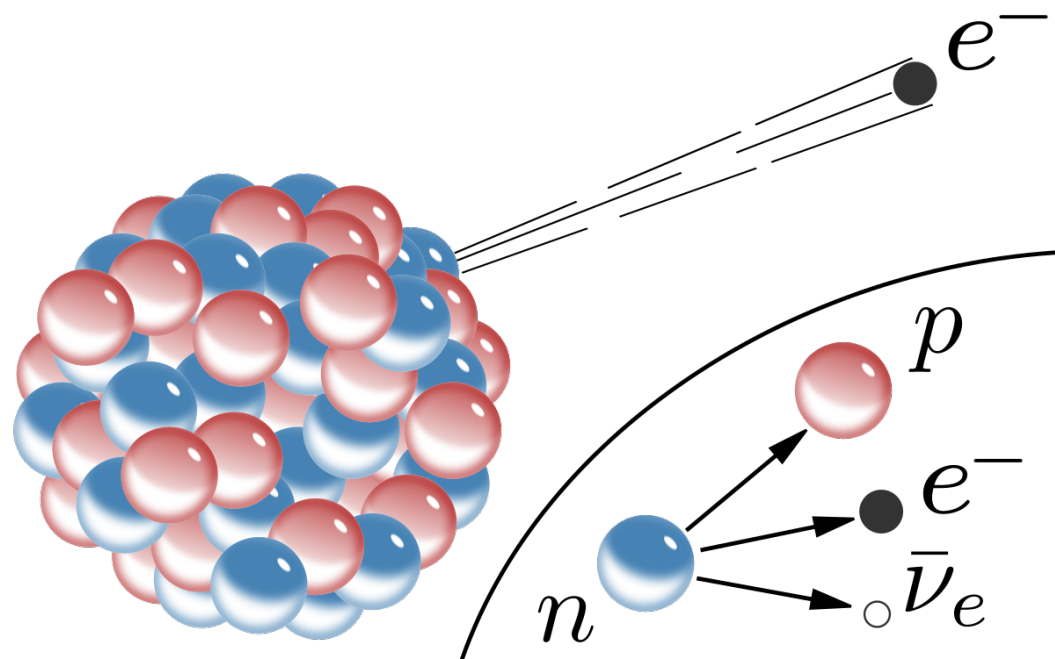


W. Pauli

Decadimenti radioattivi

Decadimento beta

Neutrino!



Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

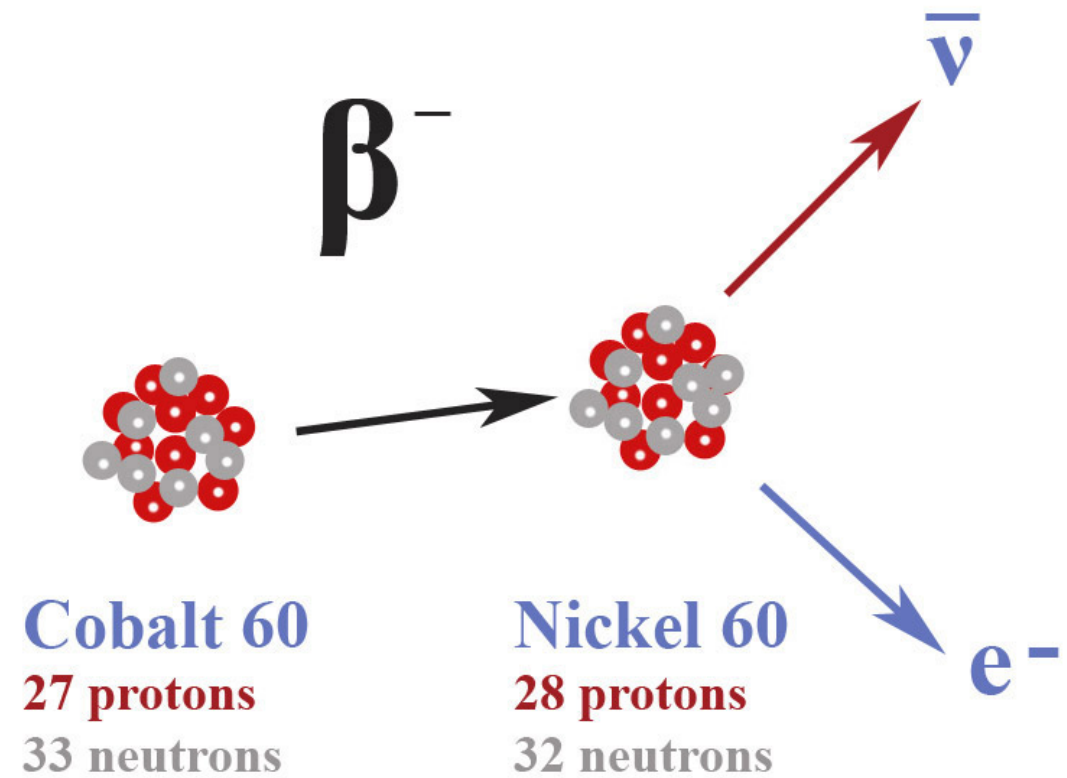
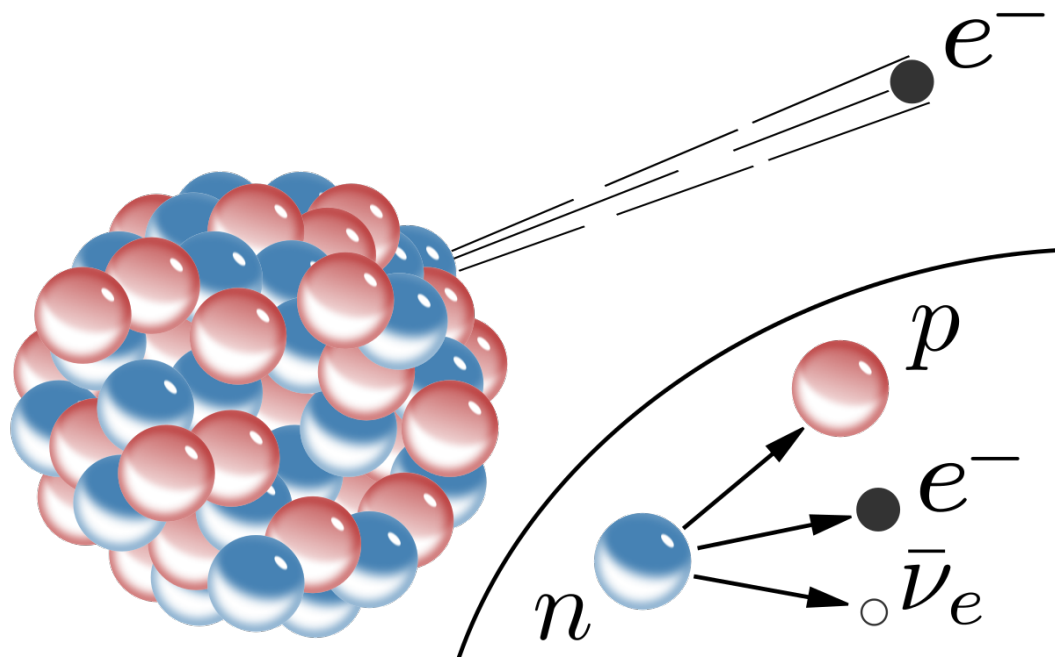
Zürich, 4. Dez. 1930
Oliviastrasse

Liebe Radioaktive Damen und Herren,

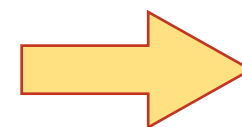
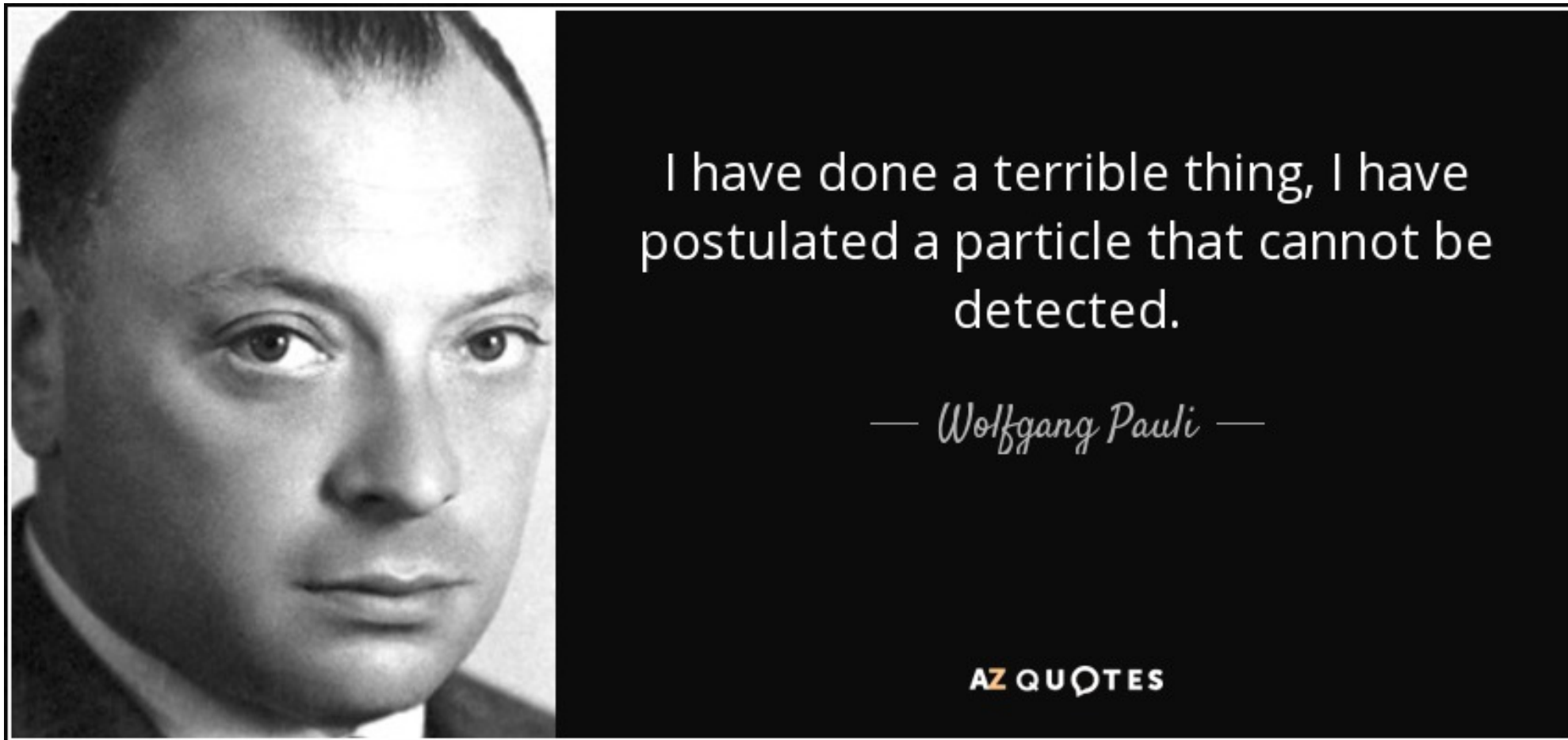
Wie der Ueberbringer dieser Zeilen, den ich herzlichst anzuheissen bitte, Ihnen das näher auseinanderzusetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin $1/2$ haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als $0,01$ Protonenmasse. Das kontinuierliche beta-Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Decadimenti radioattivi

Decadimento beta



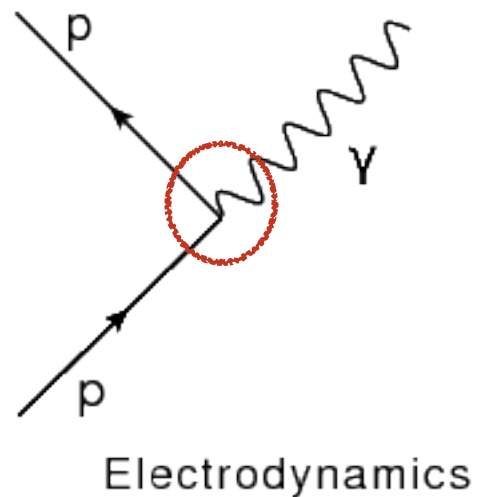
La particella fantasma



CORSO 2016-2017

Una nuova interazione

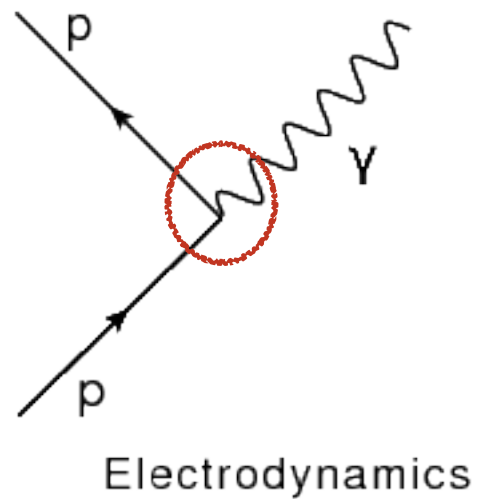
La comparsa di nuove particelle e' mediata, nella teoria quantistica dei campi, da una interazione tra le particelle stesse. Esempio classico la elettrodinamica quantistica.



Ogni interazione e' caratterizzata da un accoppiamento (che determina la "forza" dell'interazione)

Una nuova interazione

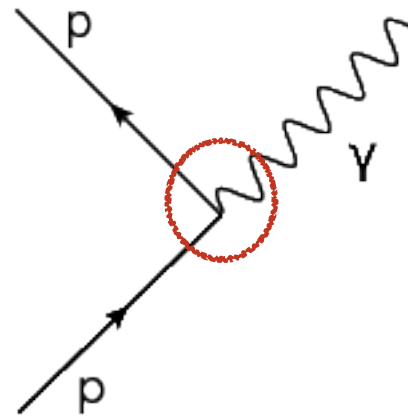
Analogia con la elettrodinamica quantistica (QED)



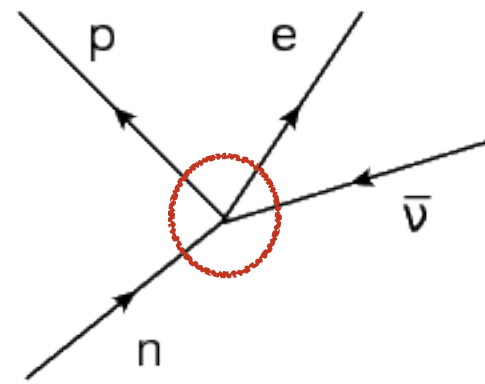
1933

Una nuova interazione

Analogia con la elettrodinamica quantistica (QED)



Electrodynamics



Weak interaction

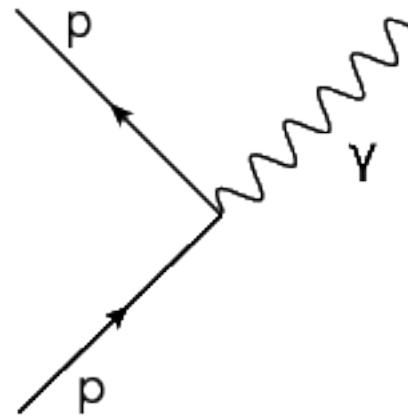
1933

L'accoppiamento della interazione debole risulta essere molto piccolo.

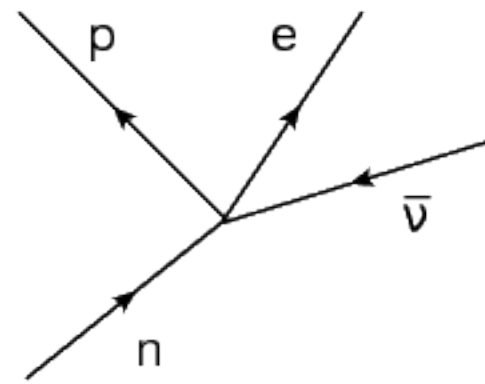
Per questo il neutrino, accoppiato SOLO attraverso la interazione debole, Interagisce molto debolmente.

Una nuova interazione

Analogia con la elettrodinamica quantistica (QED)



Electrodynamics

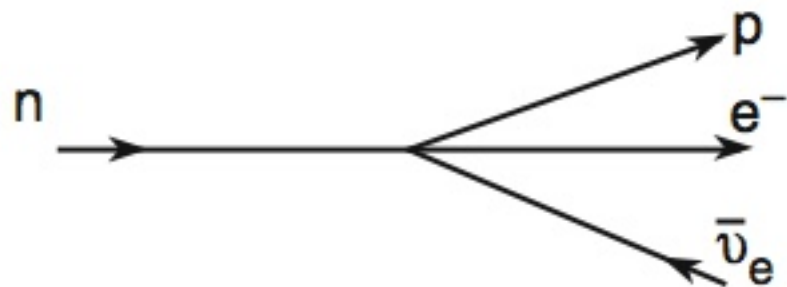


Weak interaction

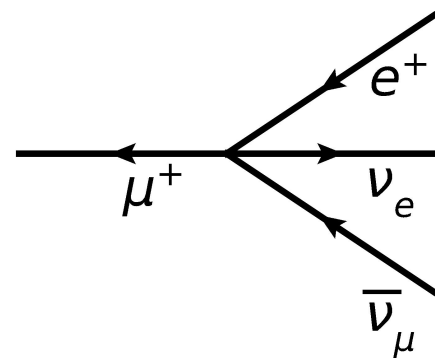
1933

Nature non pubblico l'articolo "because it contained speculations too remote from reality to be of interest to the reader"

Una nuova interazione

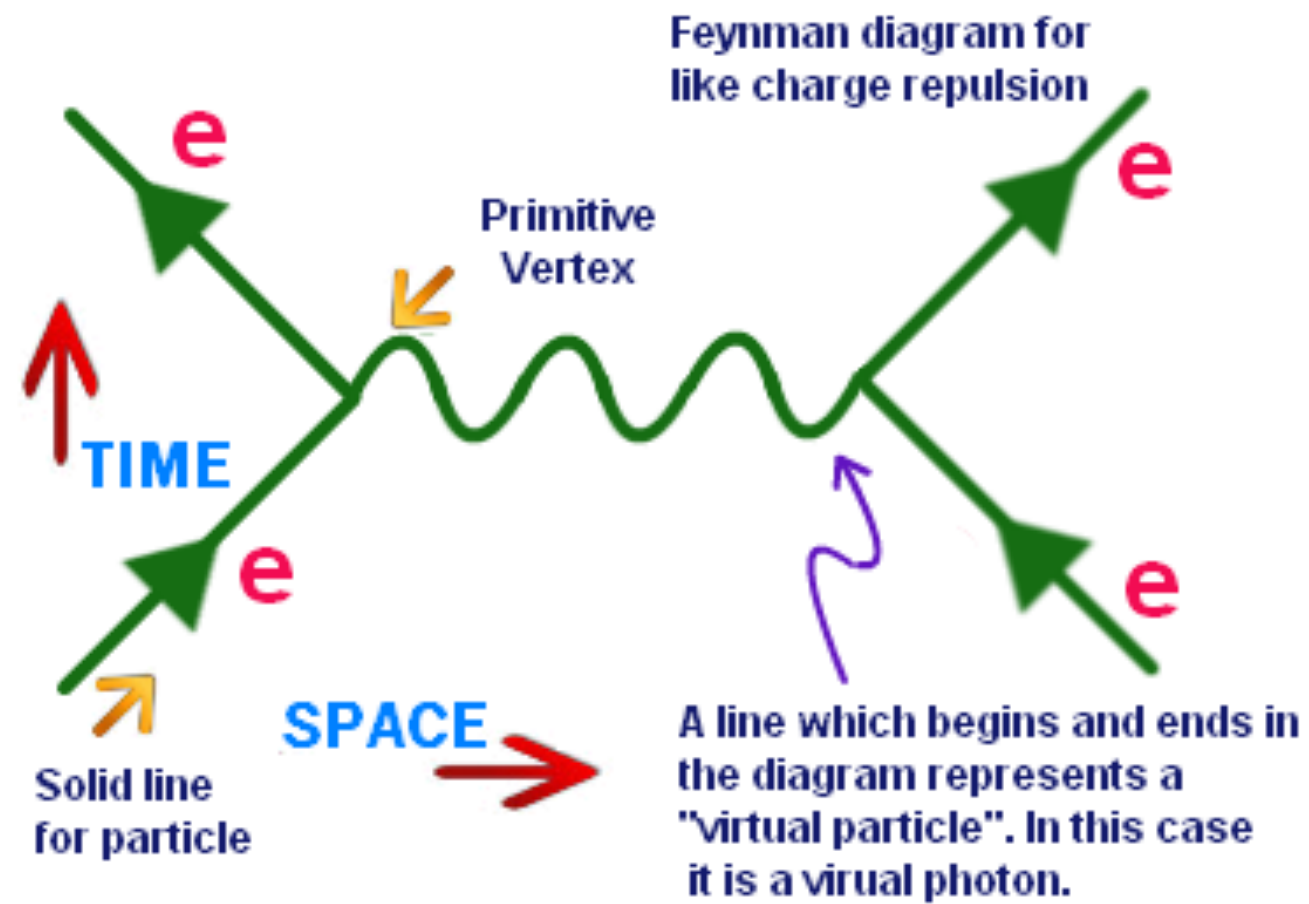


Decadimento del neutrone

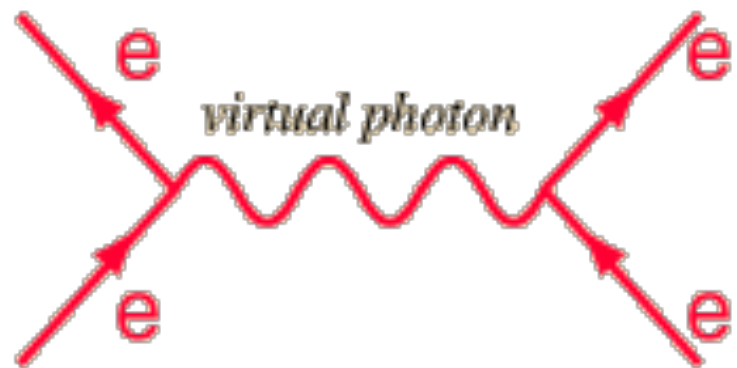


Decadimento del muone

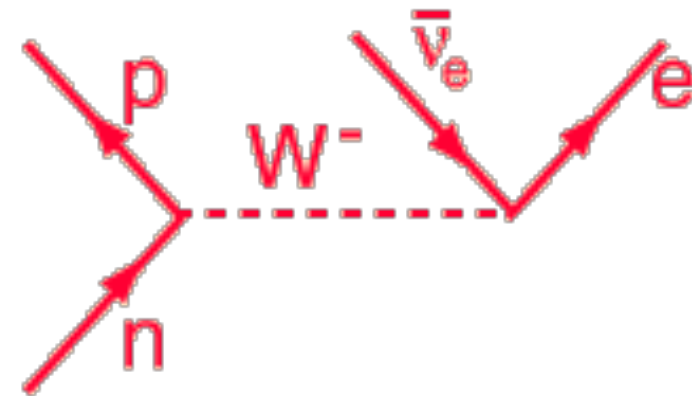
La visione moderna



La visione moderna

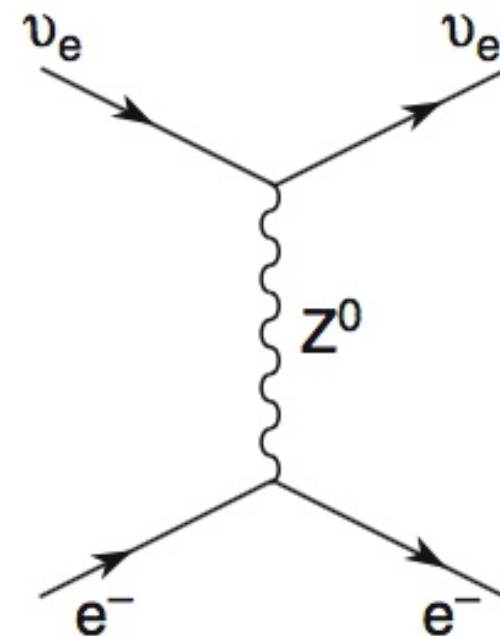


Electromagnetic



Weak

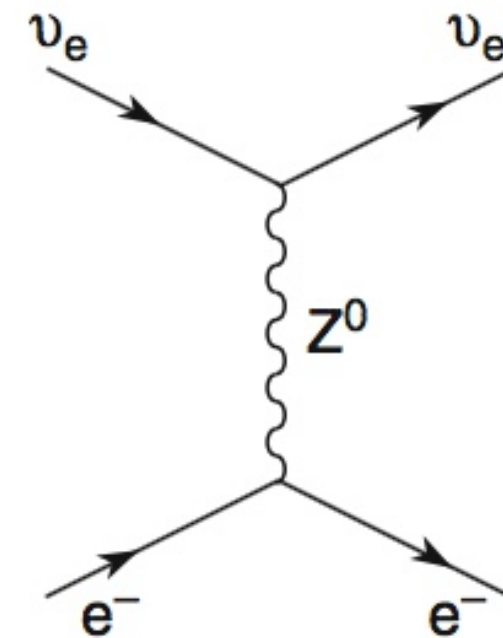
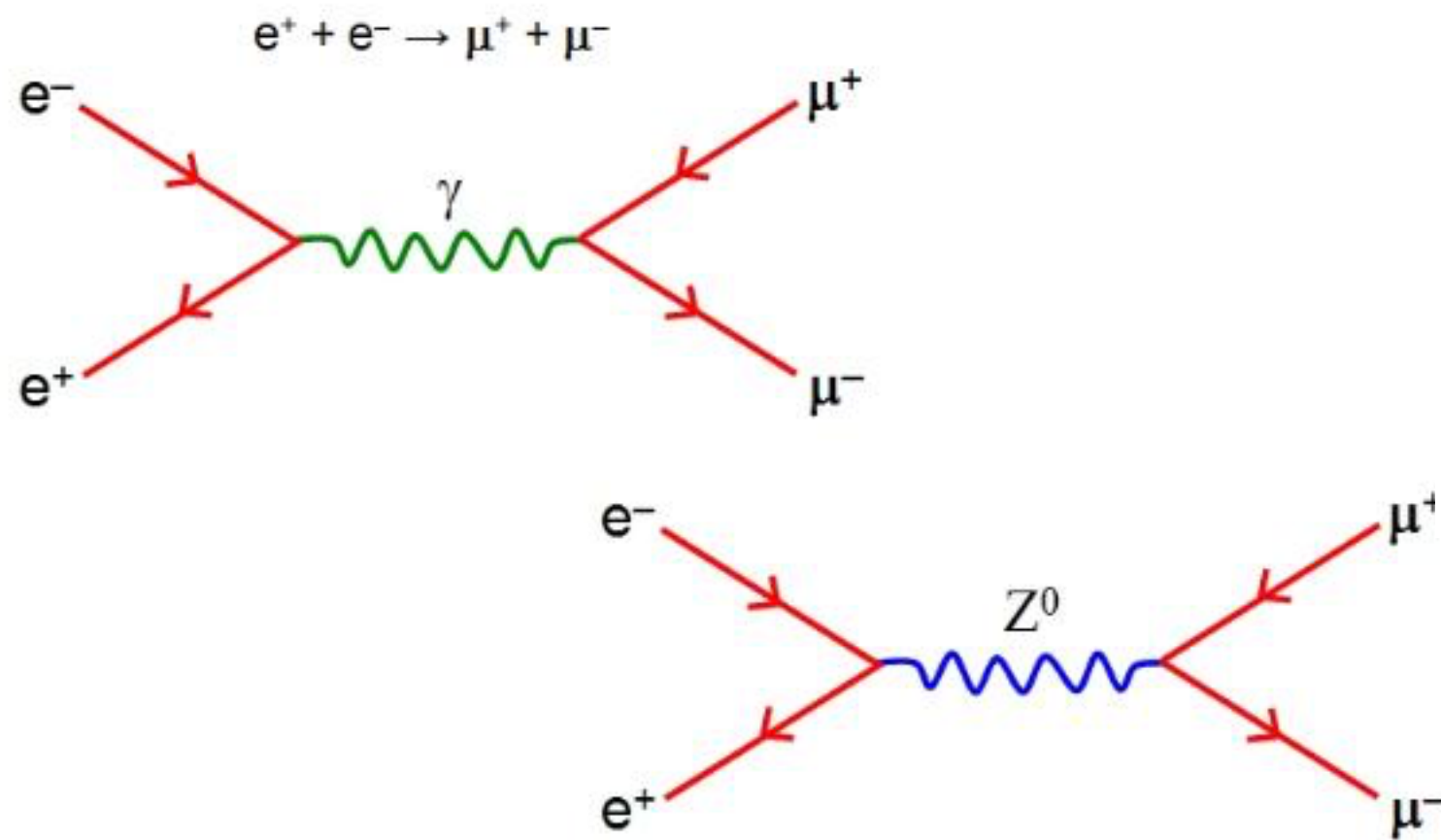
La visione moderna



La visione moderna

Neutral Current reactions

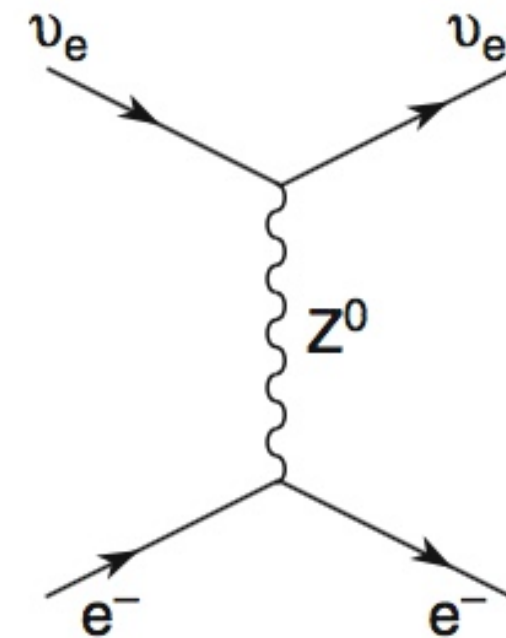
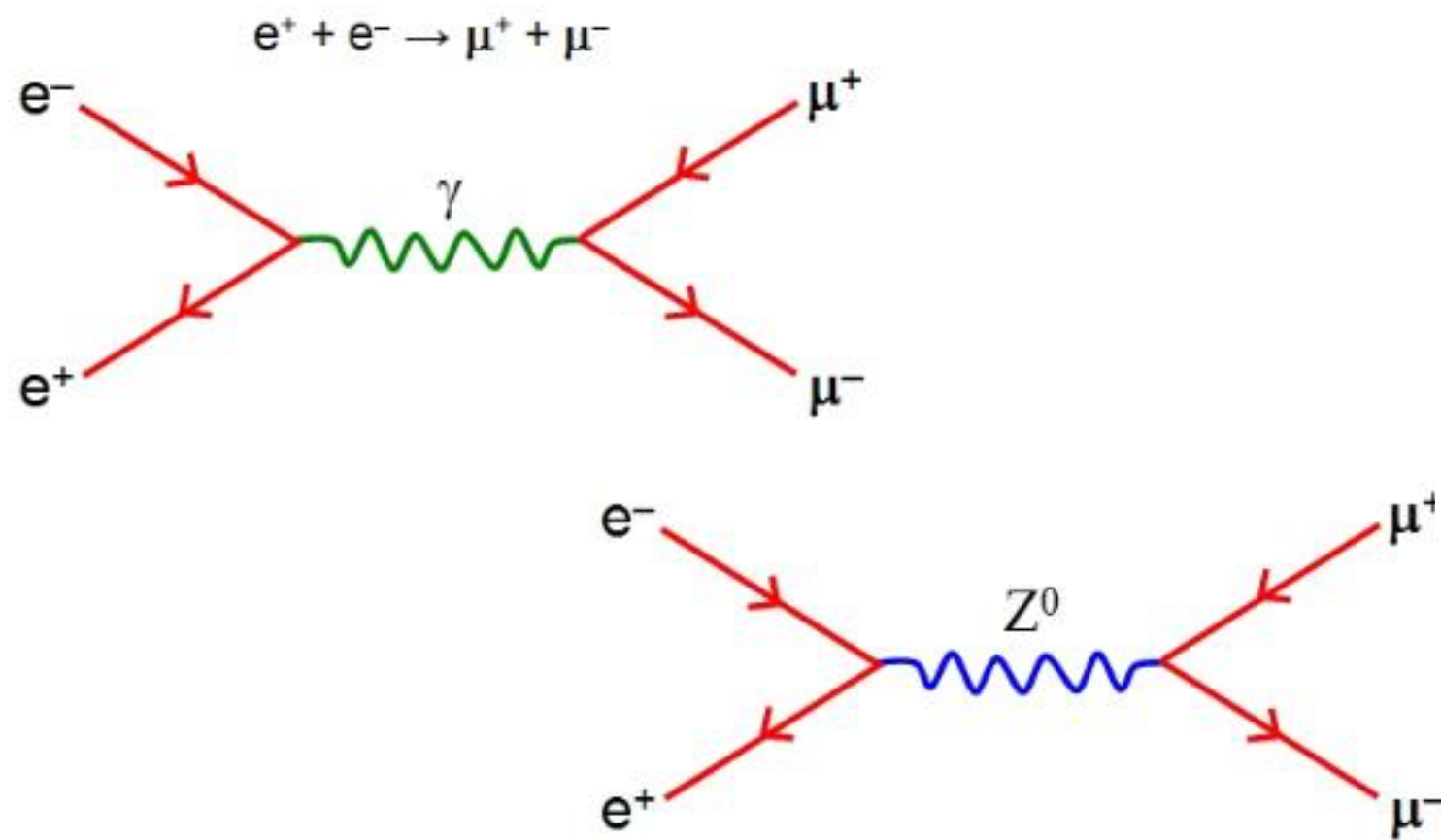
These are mediated by the Z^0 boson.



La visione moderna

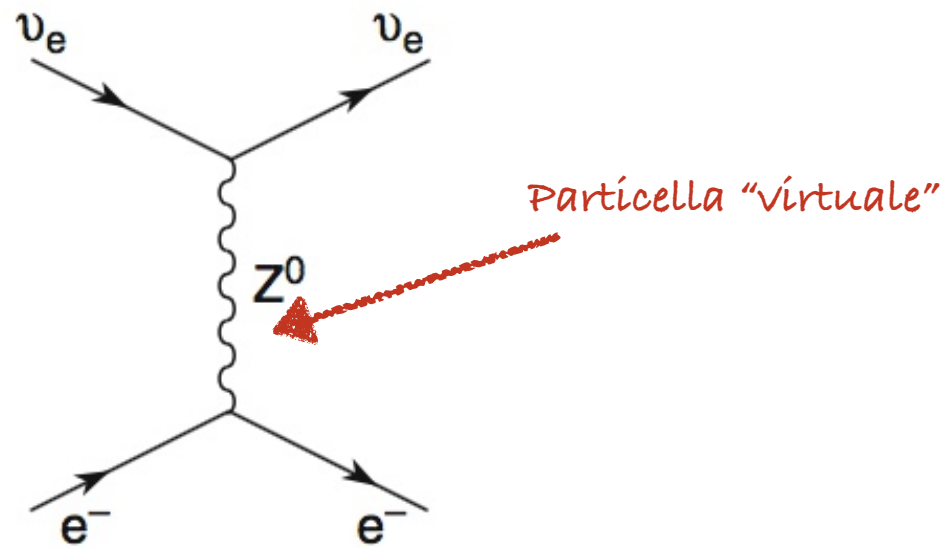
Neutral Current reactions

These are mediated by the Z^0 boson.



Perche' debole?

Mediatori



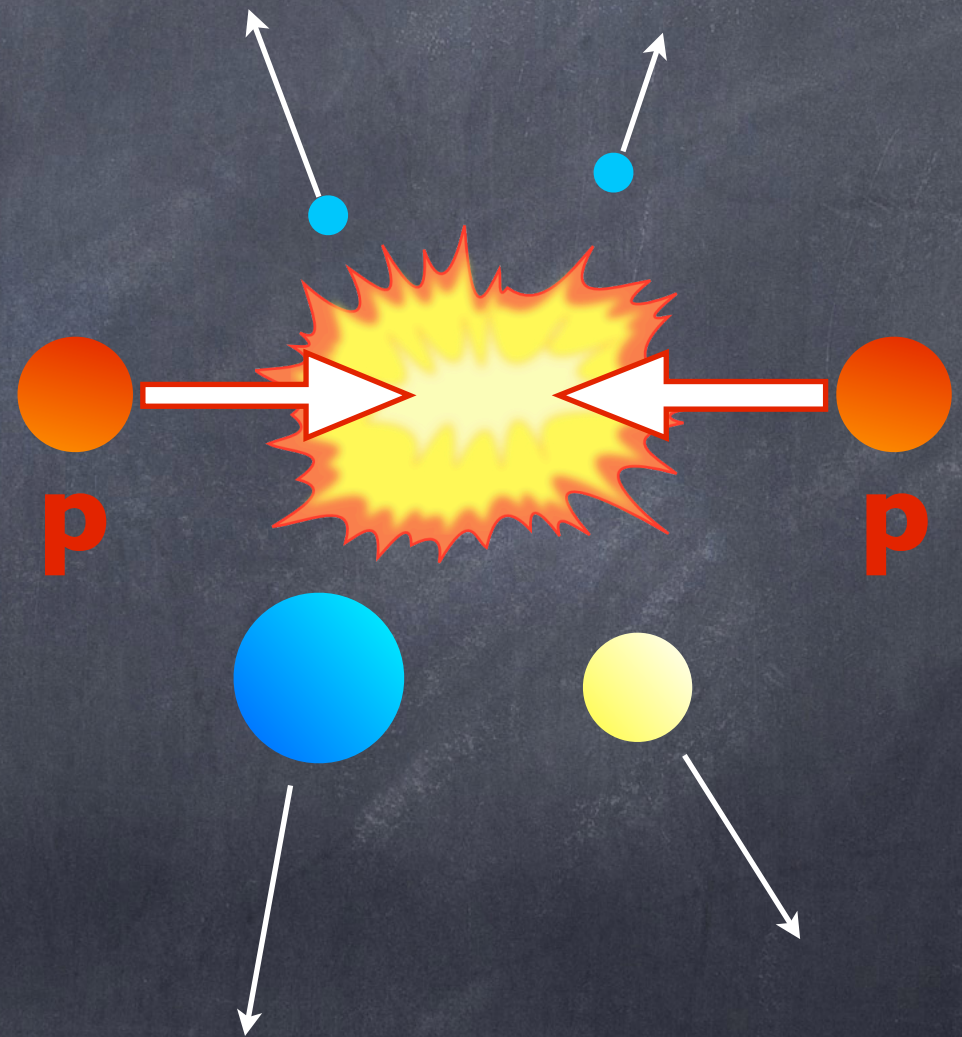
$$\Delta t \sim h / \Delta E$$

$$\Delta t \sim h / M c^2$$

Fotone $M=0 \rightarrow$ raggio di azione infinito

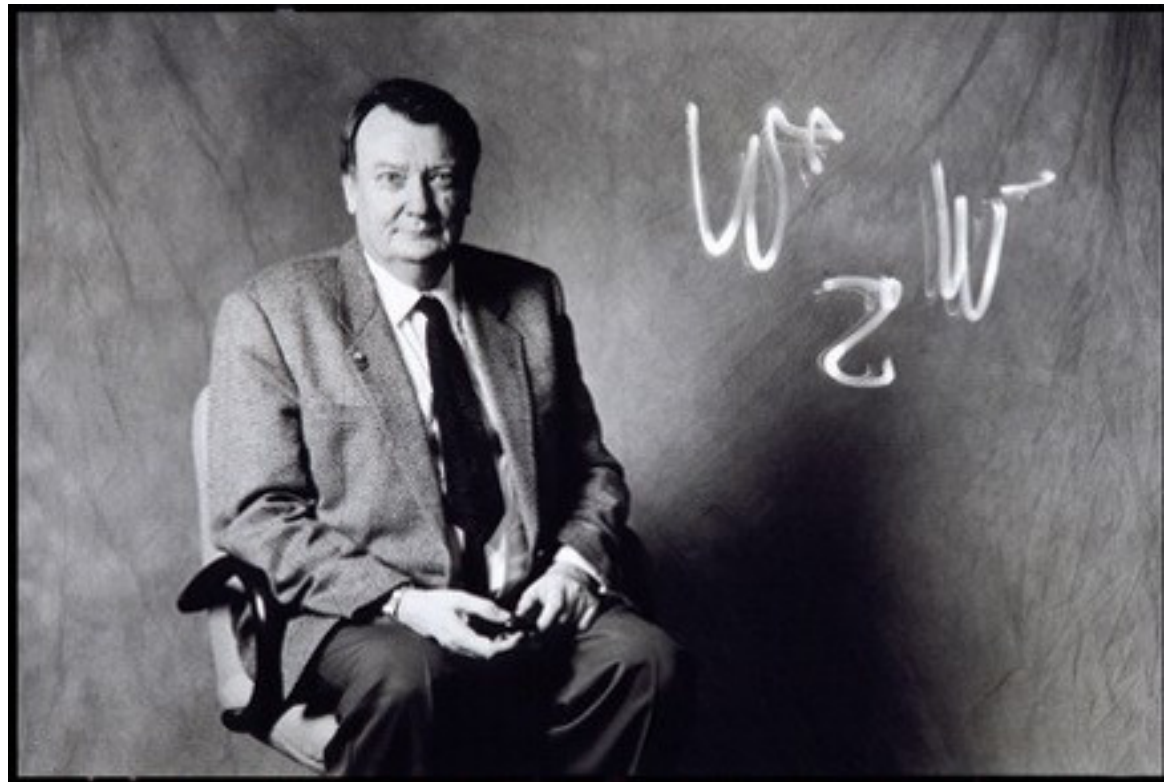
Z^0 $M=100 \text{ GeV}$ (100 volte il protone)

Produzione/distruzione di particelle



Mediatori

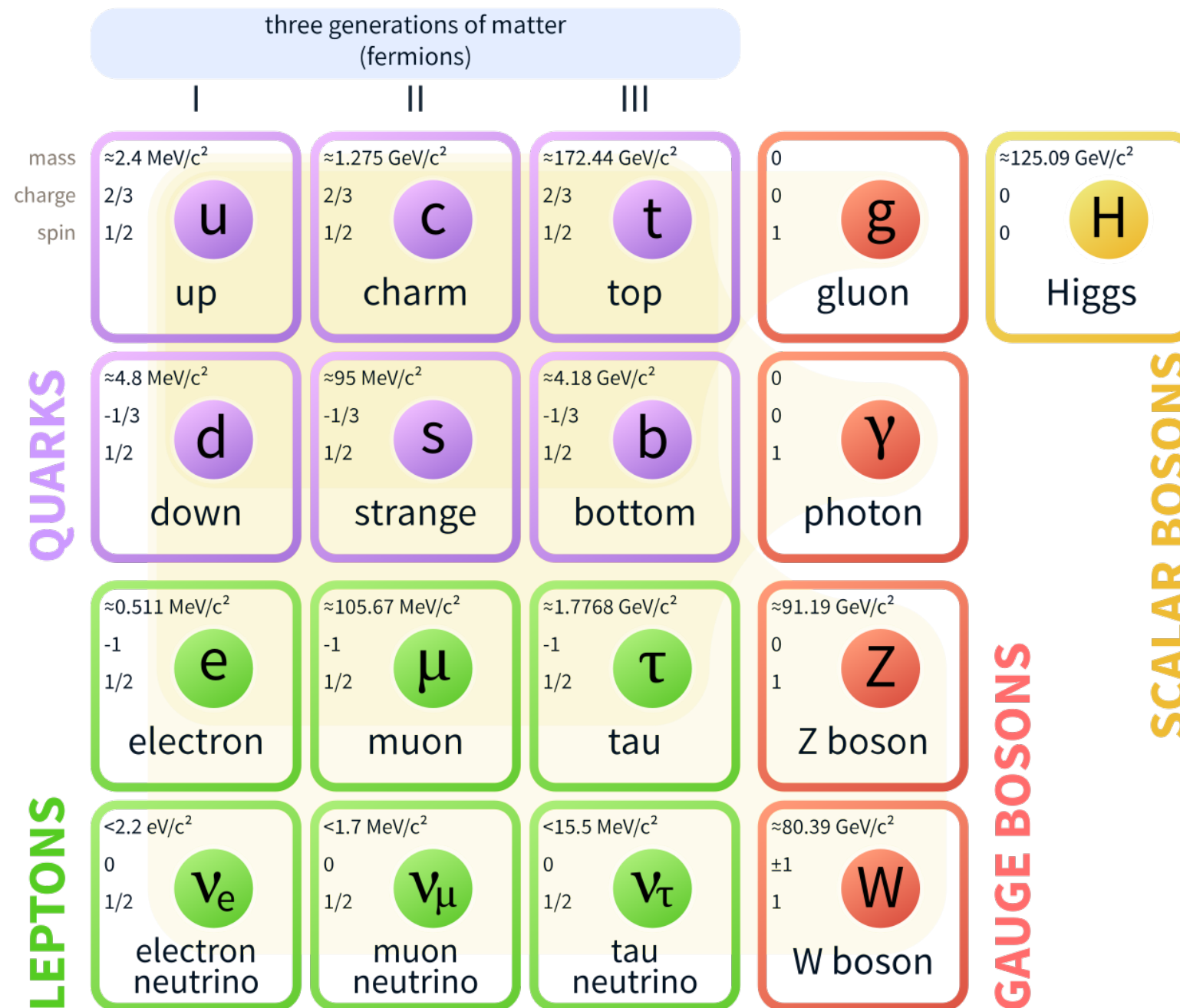
Super Proton Synchrotron (SPS)



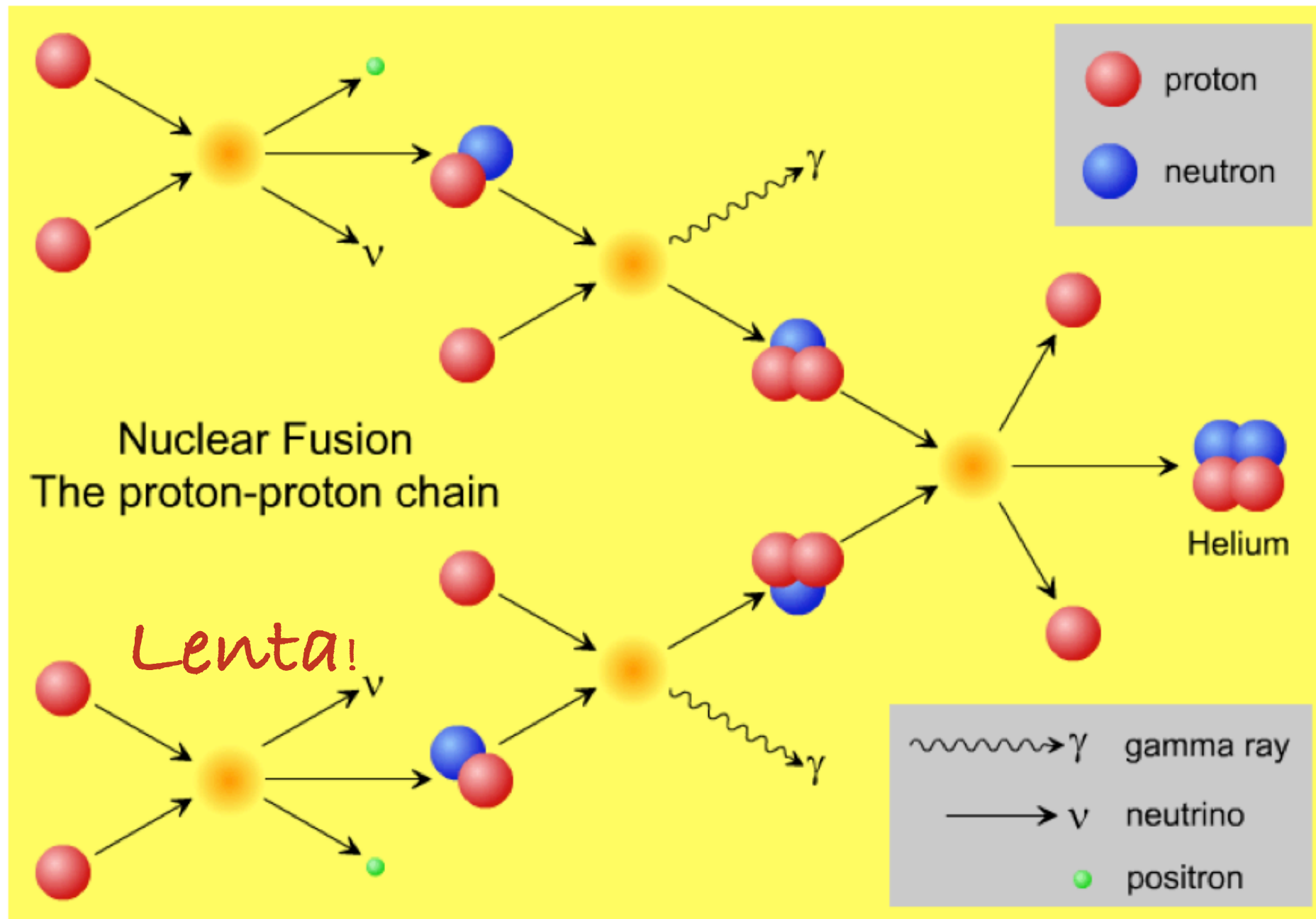
C. Rubbia

La visione moderna

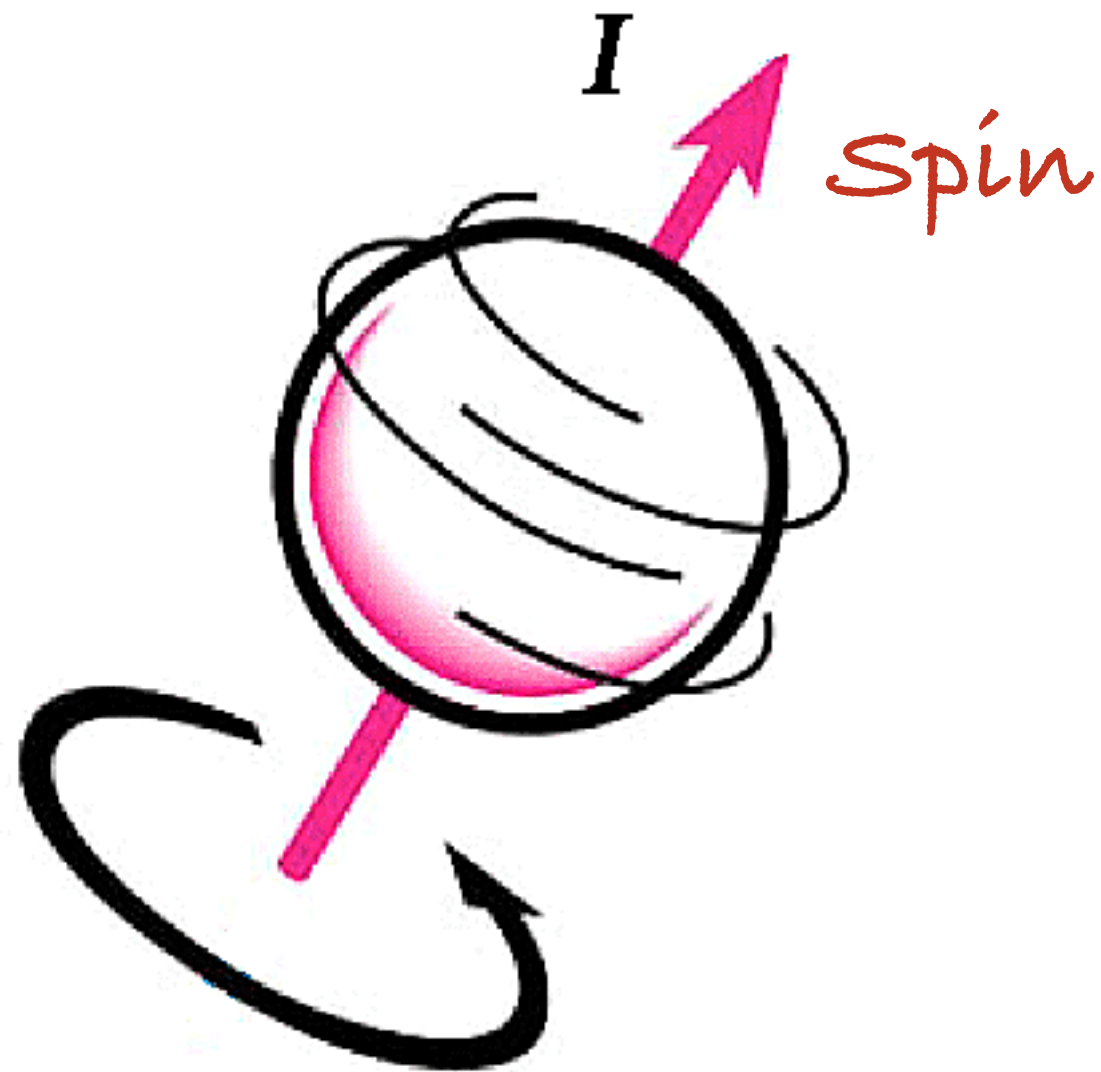
Standard Model of Elementary Particles



L'interazione debole in astrofisica

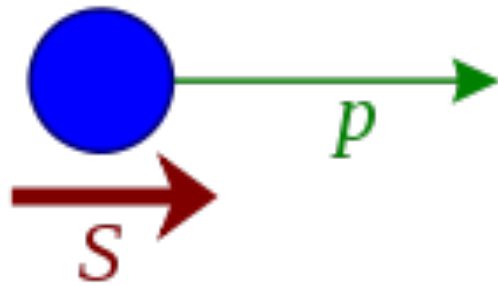


Trottole subatomiche

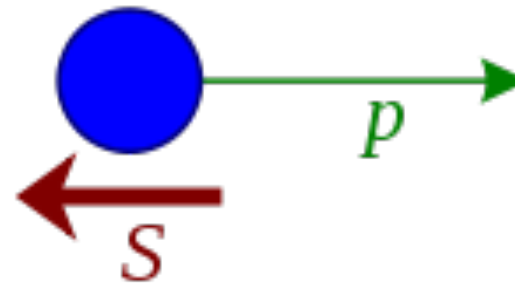


Trottole subatomiche

Right-handed:



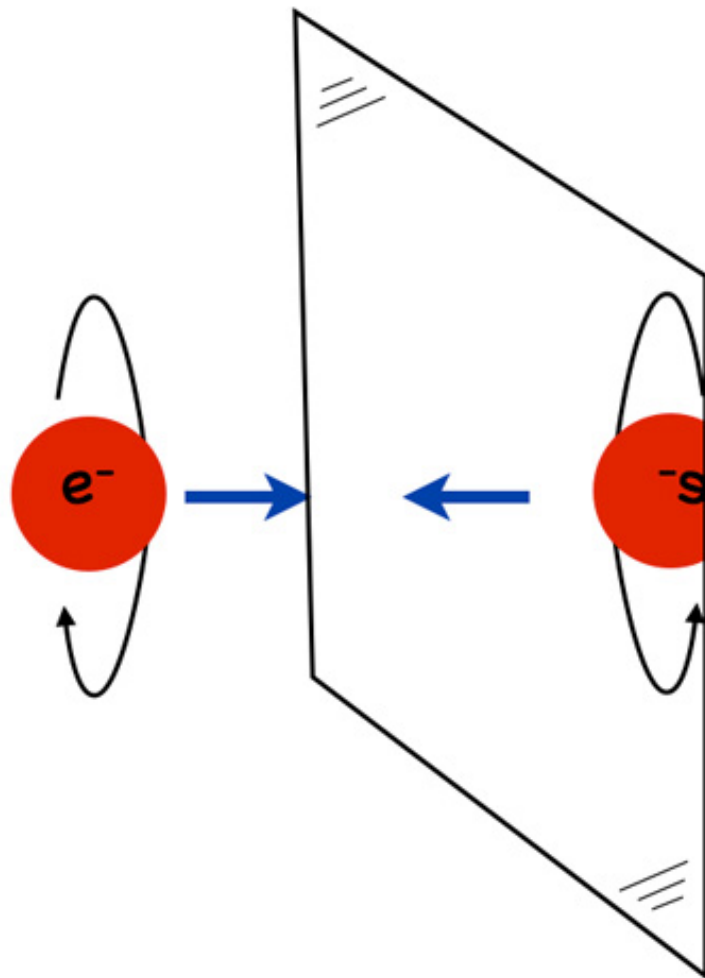
Left-handed:



Il mondo allo specchio



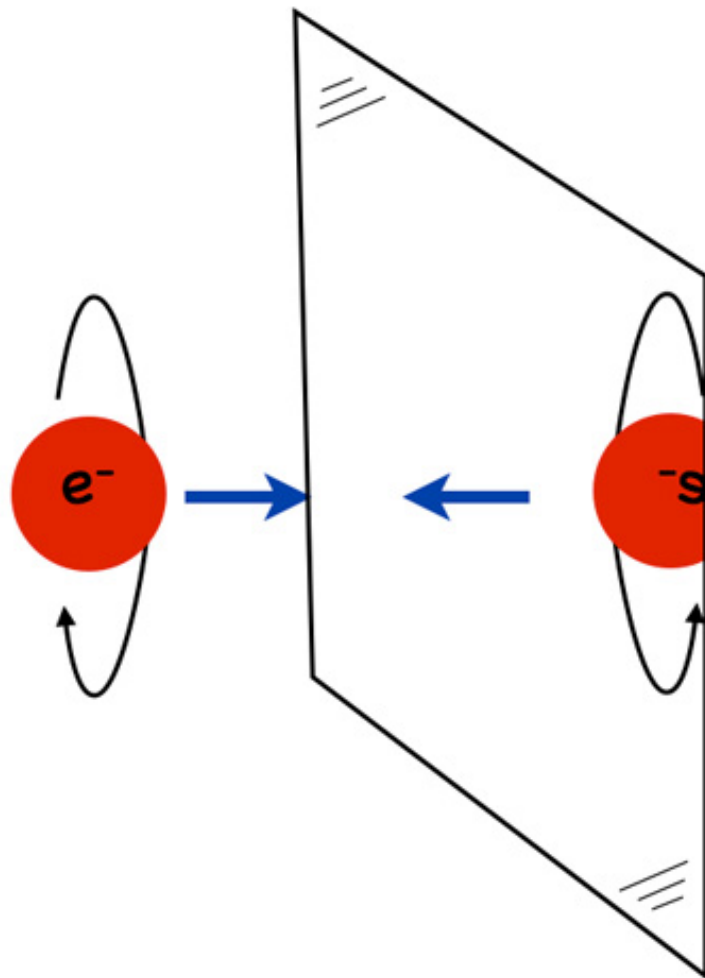
Simmetria di uno specchio (invarianza di parità')



Il mondo allo specchio



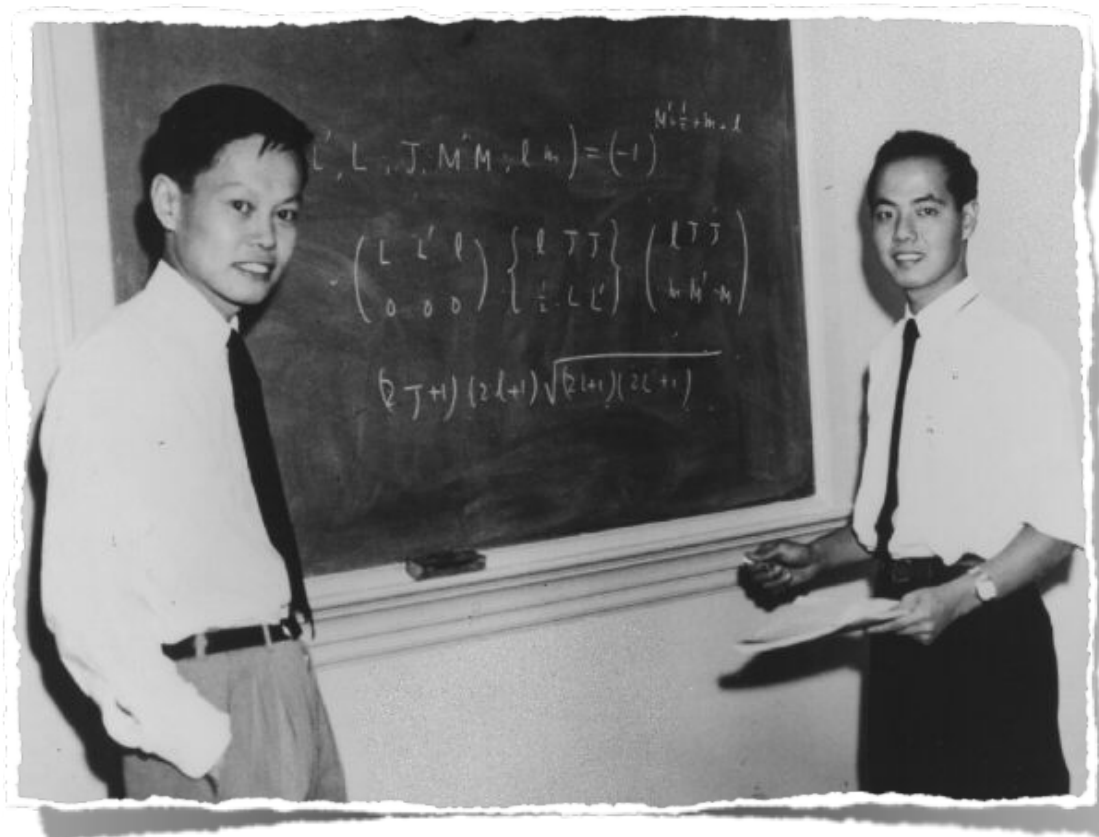
Simmetria di uno specchio (invarianza di parità')



Elettromagnetismo e gravita'
soddisfano questa simmetria

Le **leggi fisiche** che governano i fenomeni
elettromagnetici e *gravitazionali* nel mondo
“specchiato” sono uguali a quelle del mondo reale

Il mondo allo specchio



Lee e Yang

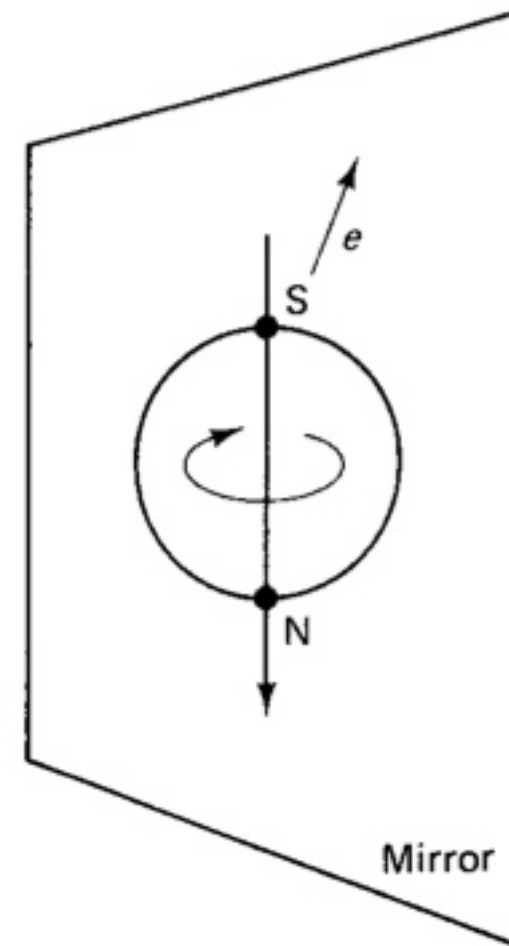
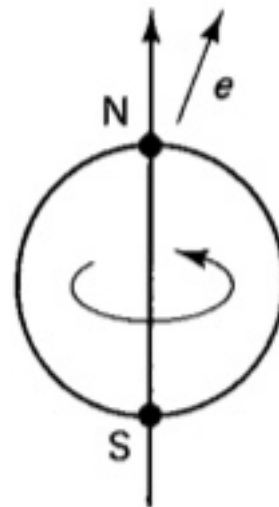
Le **leggi fisiche** che governano i fenomeni *elettromagnetici* e *gravitazionali* nel mondo “specchiato” sono uguali a quelle del mondo reale

E I fenomeni che coinvolgono la forza debole?

Lo specchio infranto



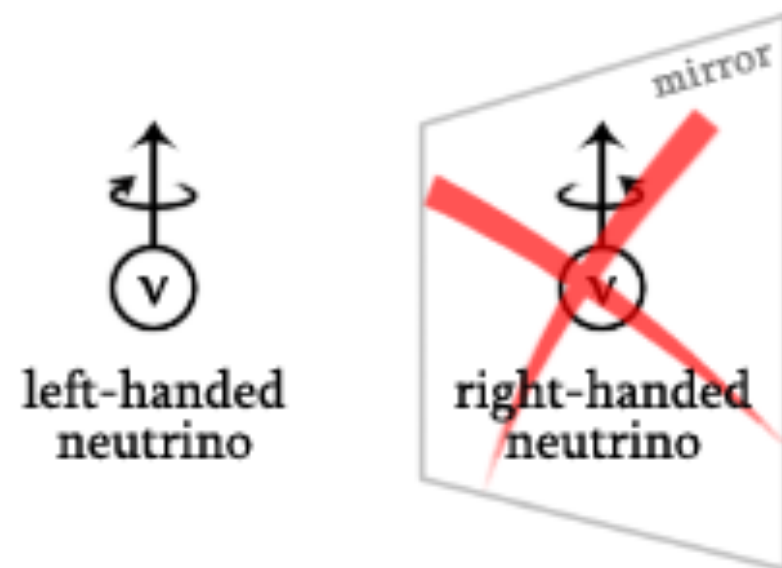
C.S. Wu



L'interazione debole non rispetta la parità!



Lo specchio infranto

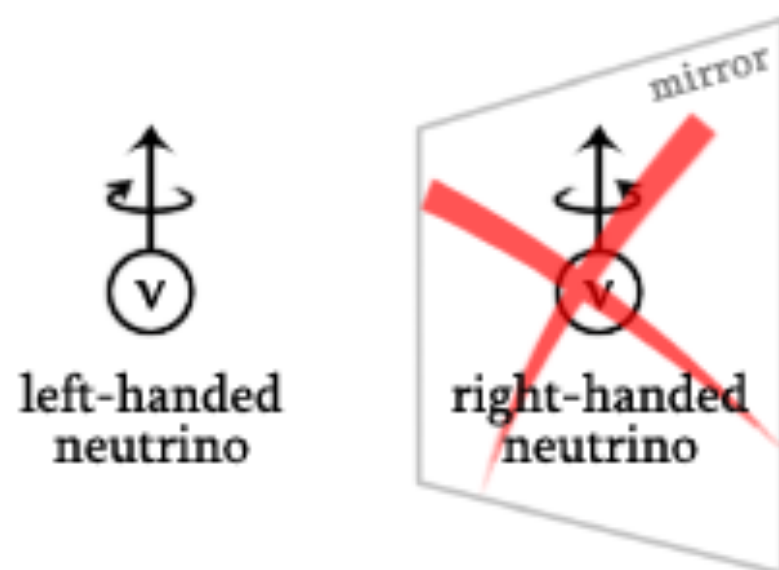


L'interazione debole e' **chirale**

Colpevole: il neutrino!

Solo neutrini sinistrorsi o antineutrini destrorsi interagiscono tramite l'interazione debole

Lo specchio infranto



L'interazione debole e' **chirale**

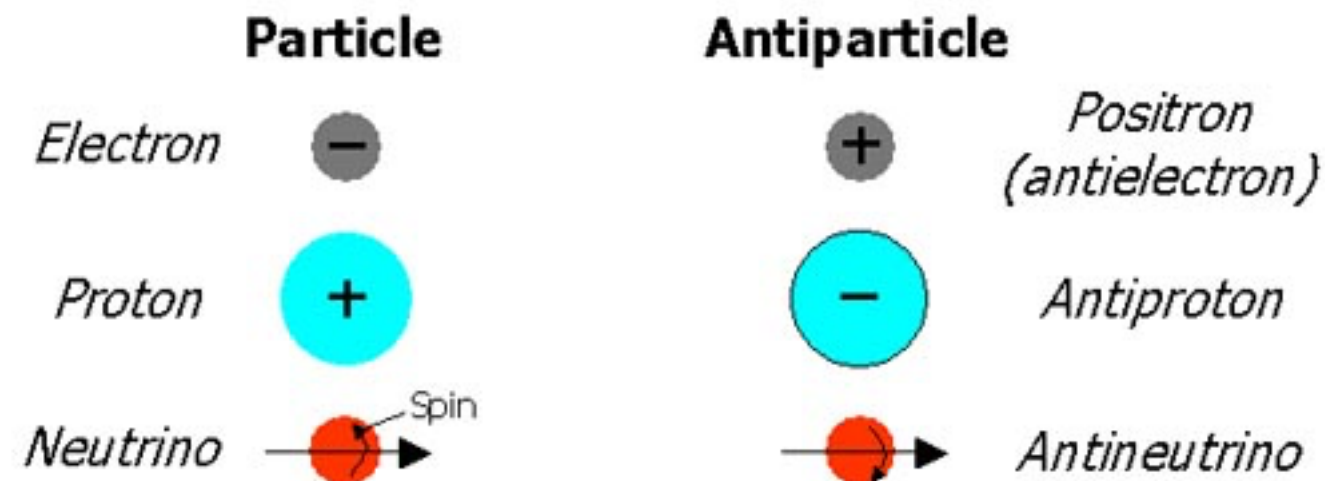
Solo neutrini sinistrorsi o antineutrini destrorsi interagiscono tramite l'interazione debole

➡ La simmetria C+P rimane però soddisfatta

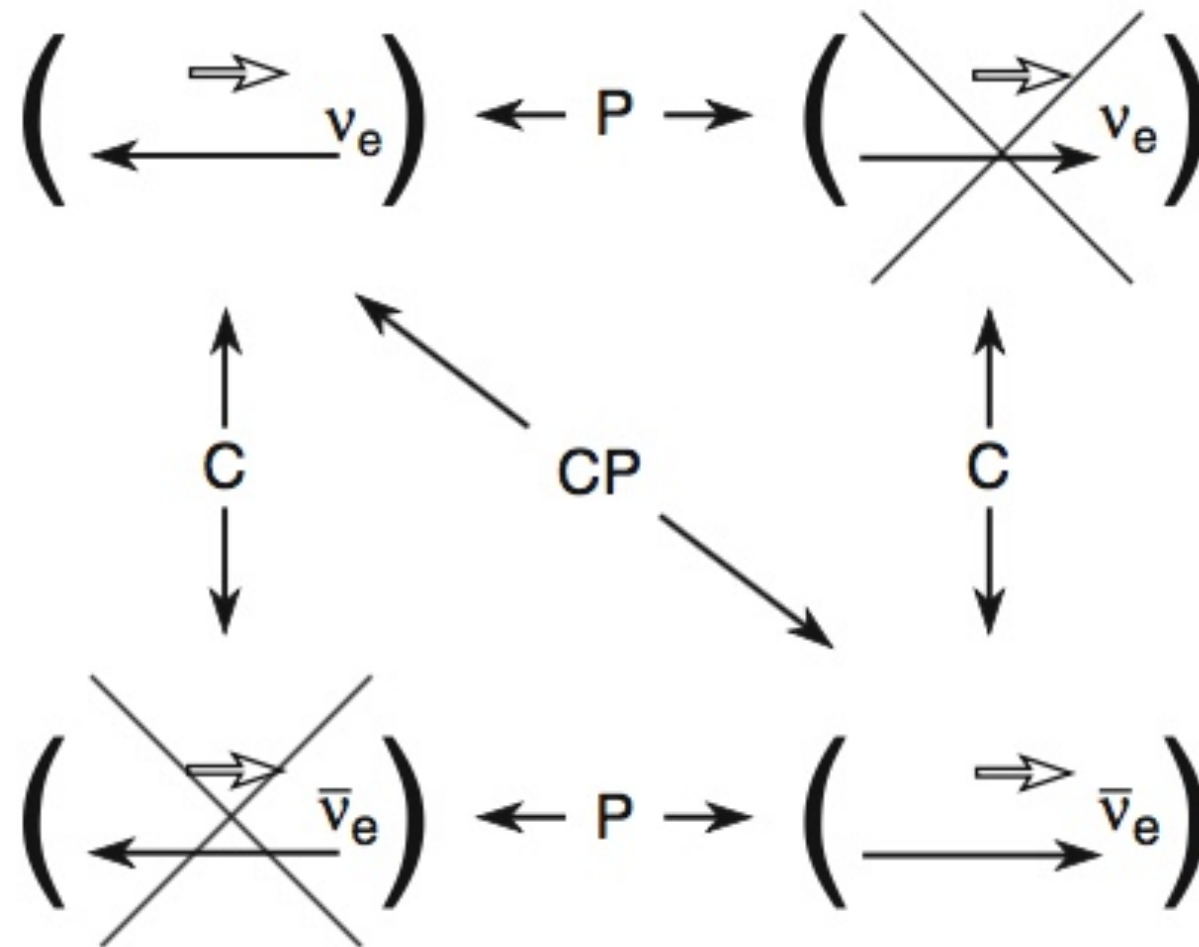
Simmetria C



Si ha sostituendo a tutte le particelle le relative antiparticelle
(per le particelle cariche significa cambiare il segno della carica)



Lo specchio riparato?



➡ La simmetria C+P rimane però soddisfatta

Lo specchio riparato?

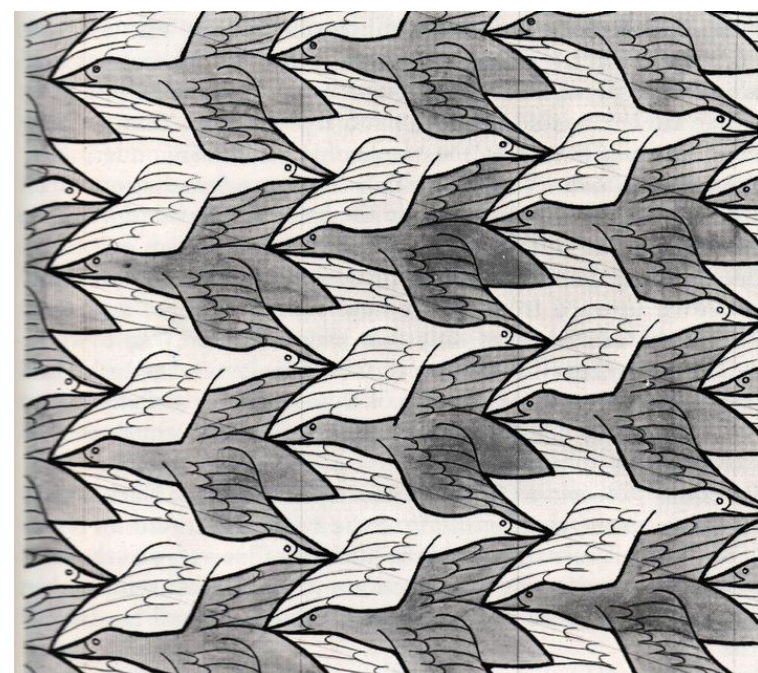
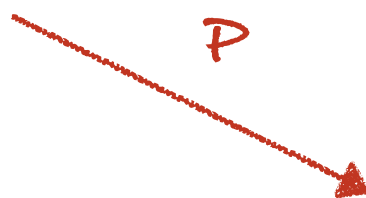


M. C. Escher

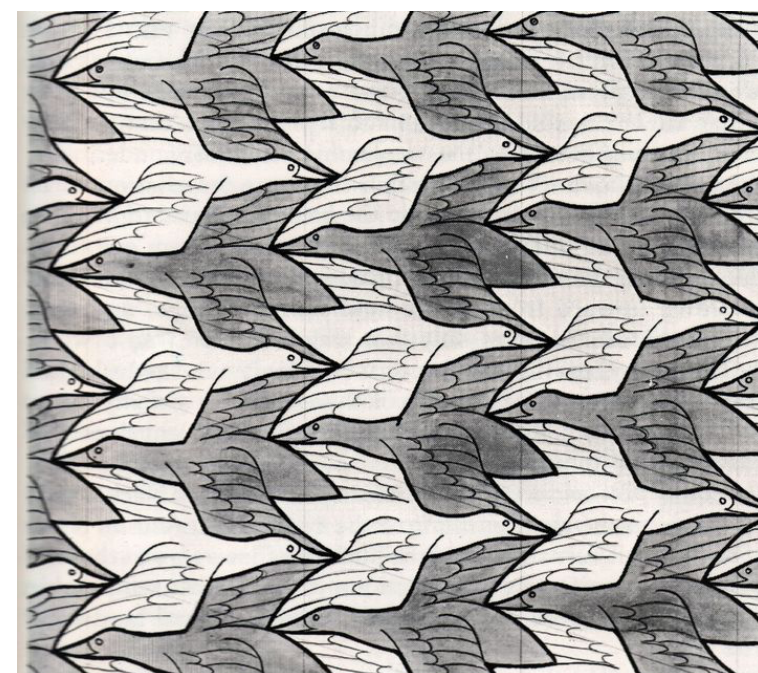
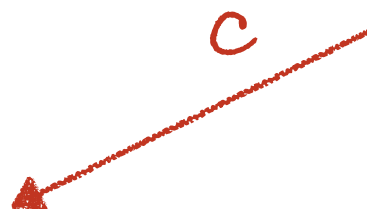
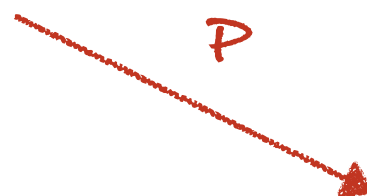
Lo specchio riparato?



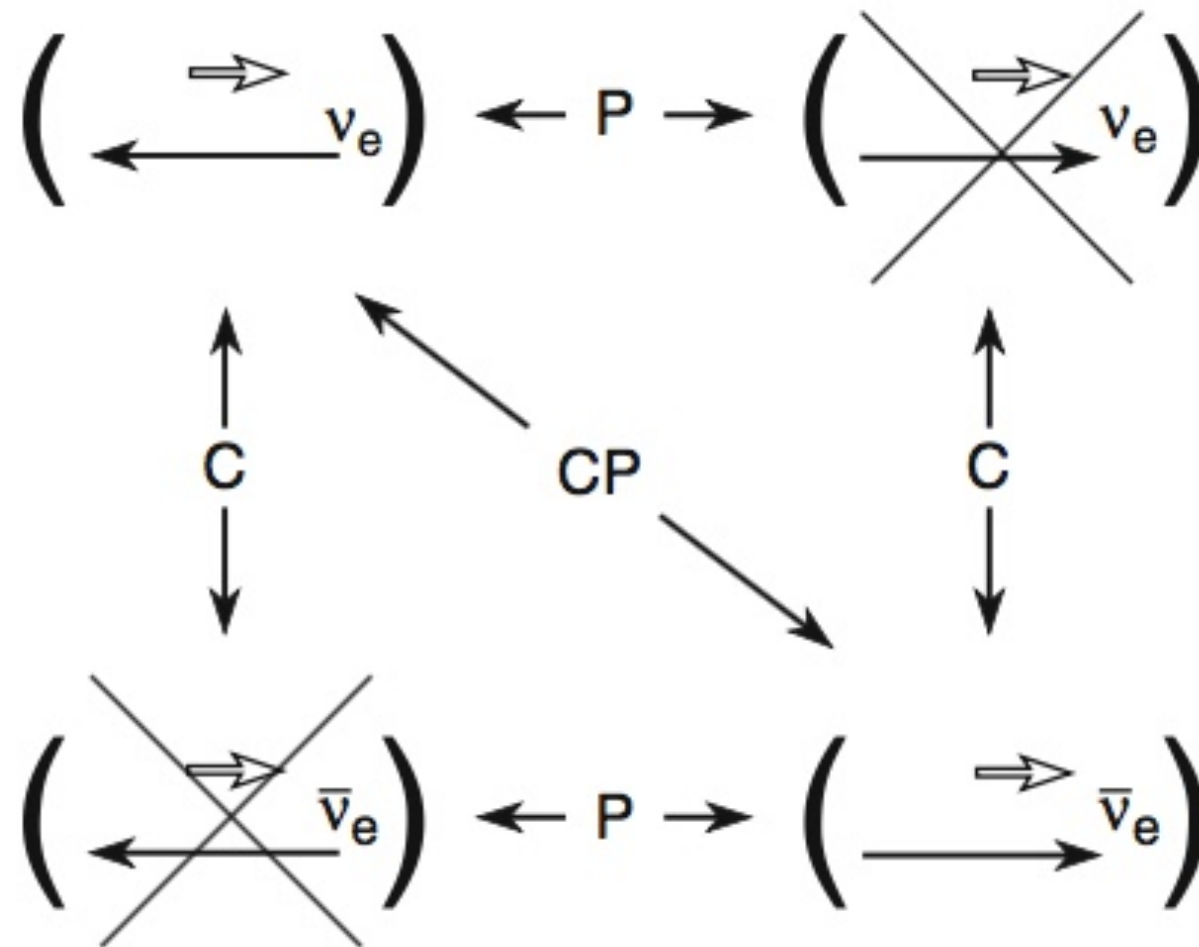
Lo specchio riparato?



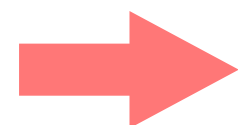
Lo specchio riparato?



Lo specchio riparato?



Davvero?

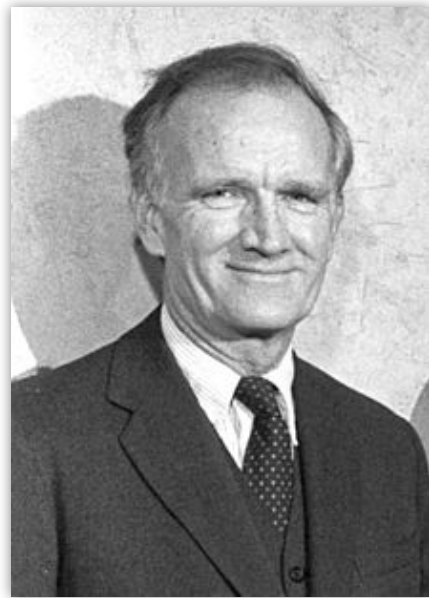


La simmetria C+P rimane però soddisfatta

La violazione di CP



J. Cronin



V. Fitch

1964

Un raro decadimento del “**mesone K**”
evidenzia una (debole) violazione di CP!

Oggi si studiano i decadimenti del **mesone B**

La violazione di CP



La natura “distingue” tra materia e anti-materia

Ragione per cui l’universo e’ composto
quasi esclusivamente da materia?

La violazione di CP



La natura “distingue” tra materia e anti-materia

Ragione per cui l’universo e’ composto quasi esclusivamente da materia?

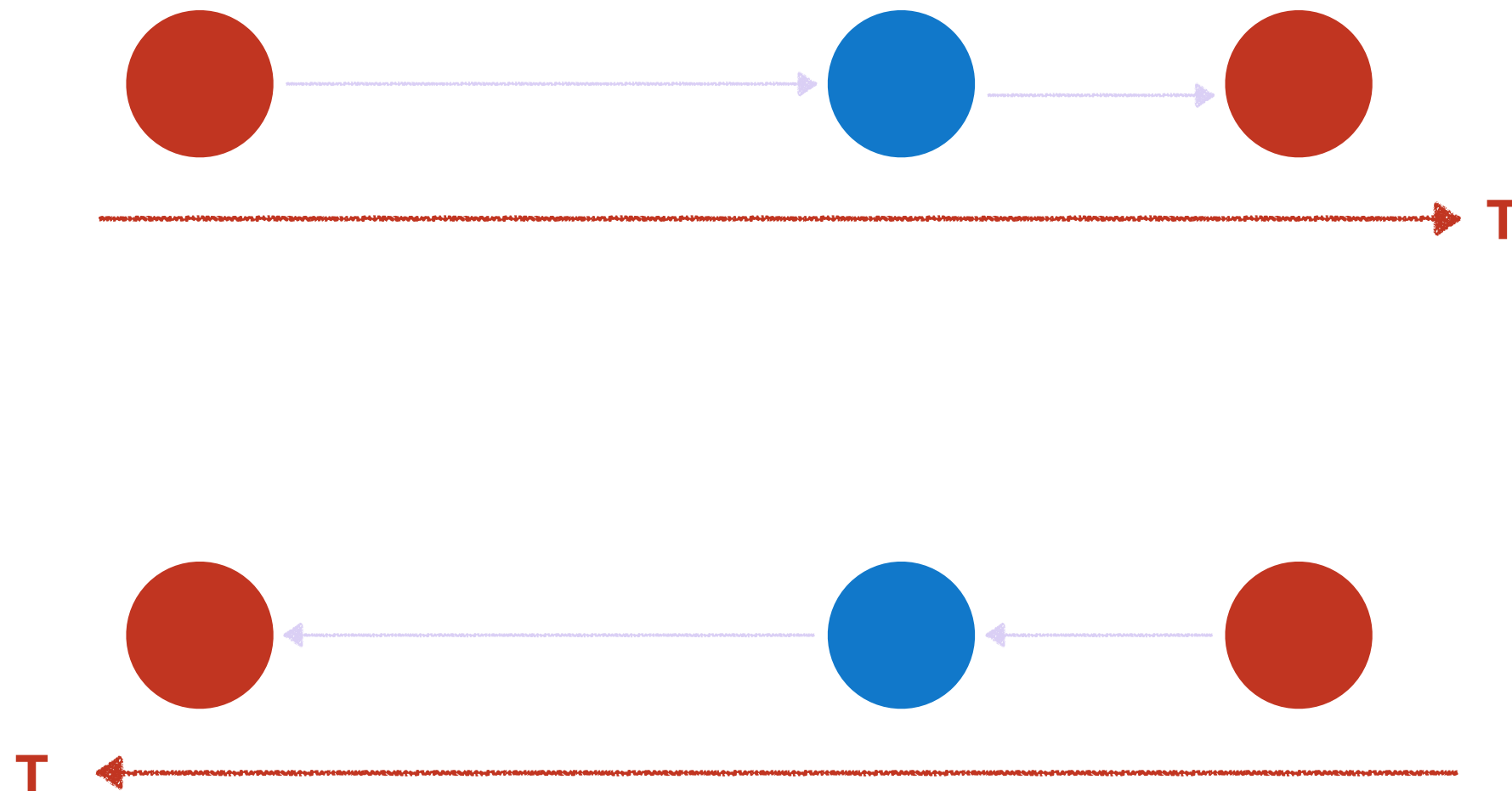
Violazione di CP significa necessariamente* che alcuni processi fisici “distinguono” la direzione del tempo (violazione di T)

*se valgono alcune assunzioni molto generali, in particolare la invarianza di Lorentz.

La violazione di CP



Violazione di CP significa necessariamente che alcuni processi fisici “distinguono” la direzione del tempo (violazione di T)



Il futuro ...